Heavy Flavor Physics in the RHIC-II Era

Physics at the Femtobarn-Scale

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Heavy Quark Workshop
LBL
November 1-3, 2007

RHIC-II
HEAVY FLAVOR

BROOKHAVEN
NATIONAL LABORATORY

What have we learned in the first six years at RHIC?

- Energy density (ε) over an order of magnitude above transition
- Collective excitations of the fluid observed
- Medium flows with very low viscosity ($\eta/s \sim 1\text{-}2 \times 1/4\pi$)
- Very large color fields in the medium ($\hat{q} >> 1$ GeV^2/fm)
- Matter equilibrates very rapidly $\tau < 1$ fm/c
- Final hadron distributions reflect underlying quark structure
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Strictly speaking:

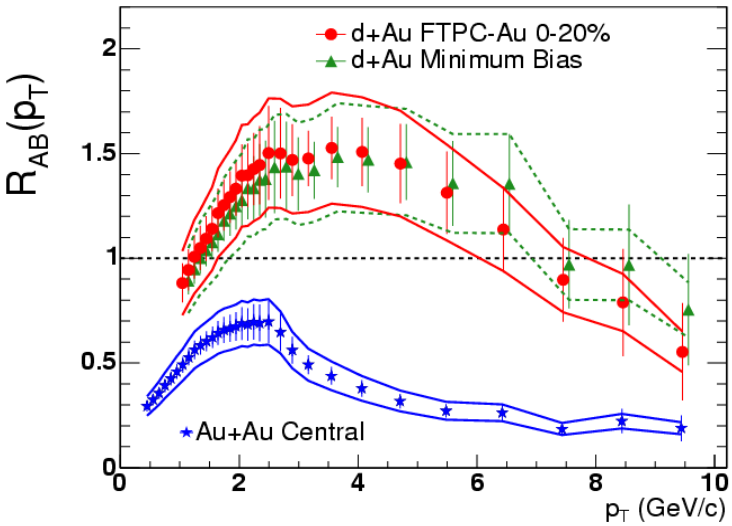
- All of the above is derived from the light quark sector
- None of the above findings is derived from heavy flavor probes

Why is that ?

... Do we need Heavy Flavor at all to learn about the QGP ?

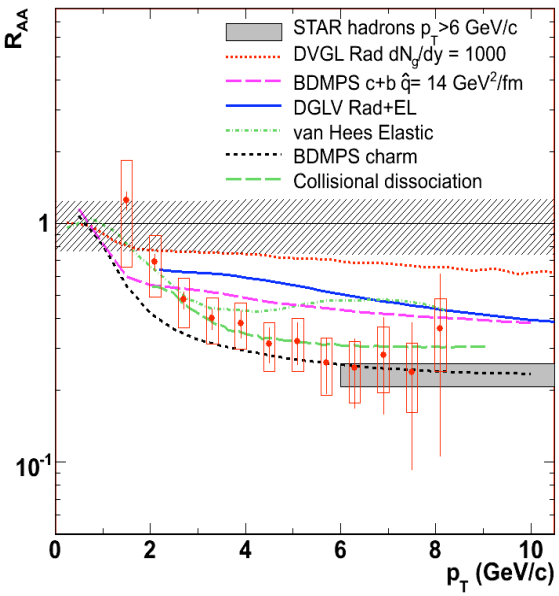
It's the Statistics Stupid ...

Light Hadrons



Inclusive Spectra

Heavy flavor



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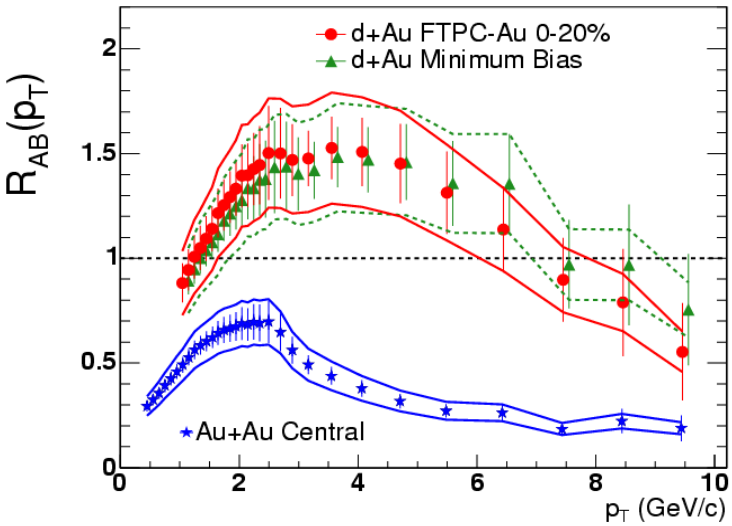

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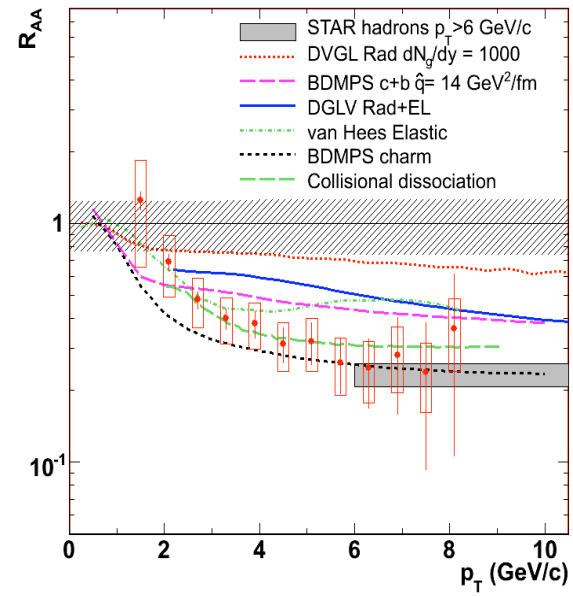
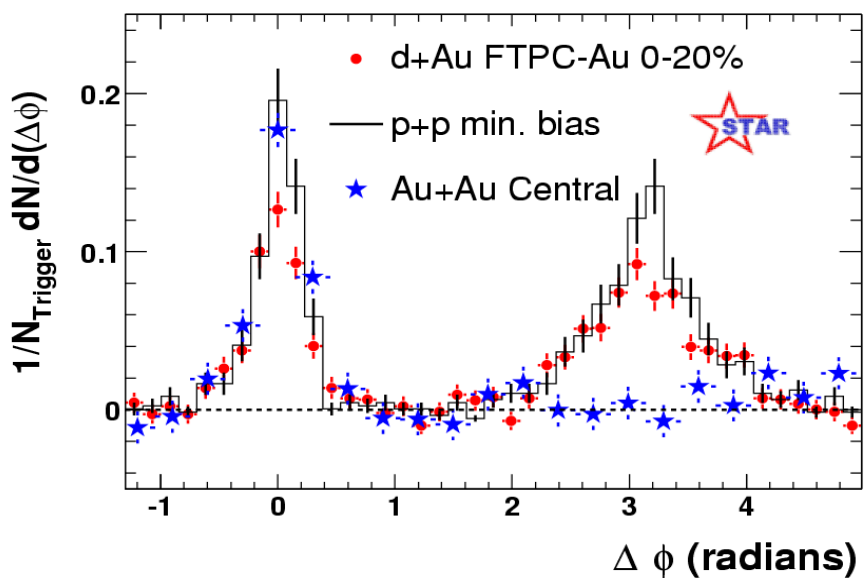
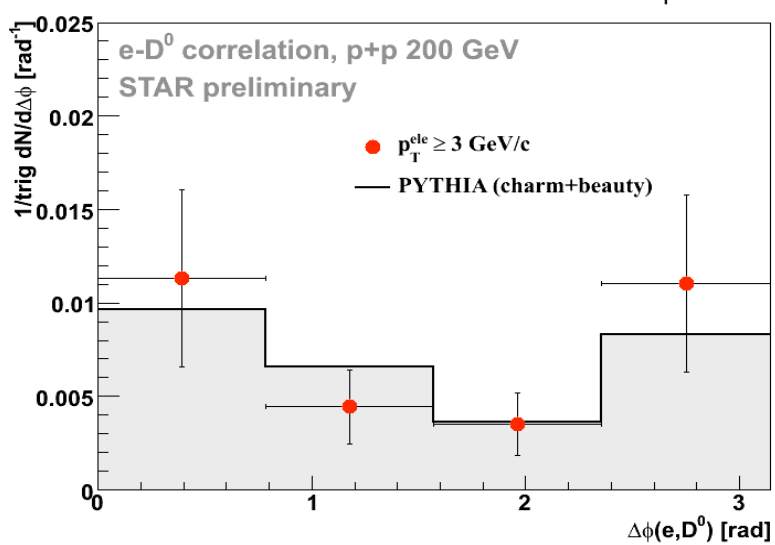
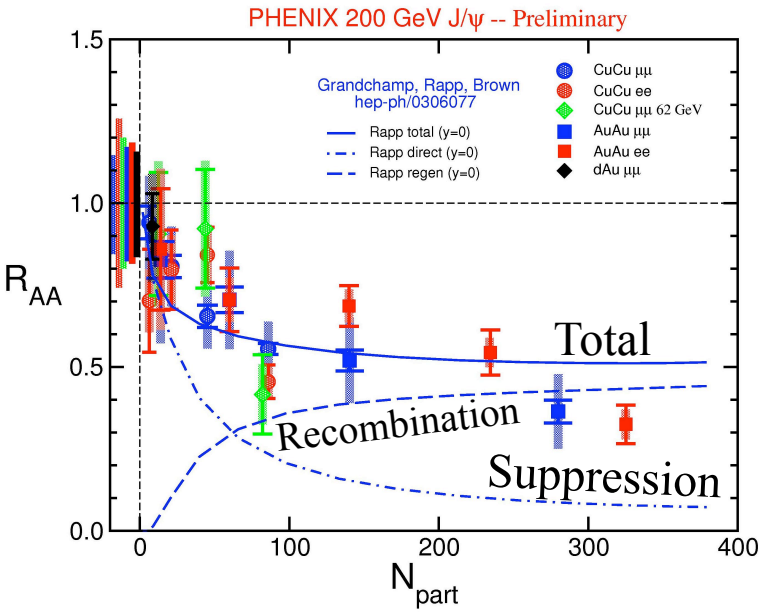


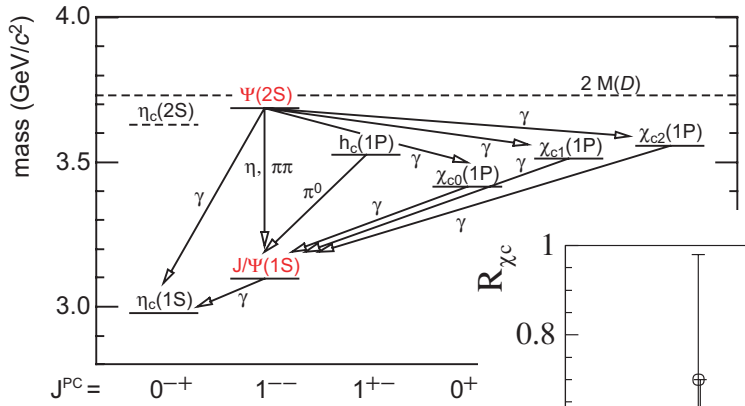
Correlations

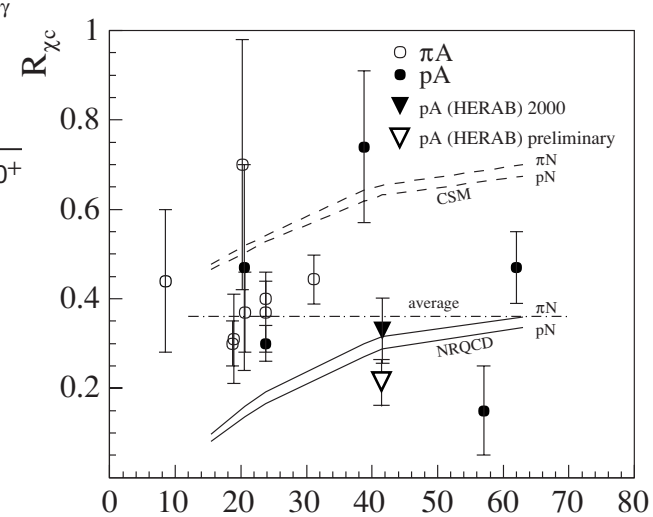




It's Not Being Able to Do Systematic Studies ...







Understanding of J/ψ Suppression/Production:

Feeddown ?

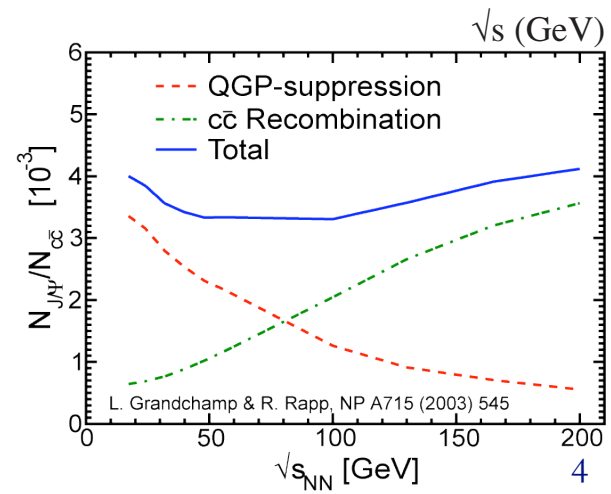
⇒ need to measure ψ' and χ_c

Recombination vs Suppression ?

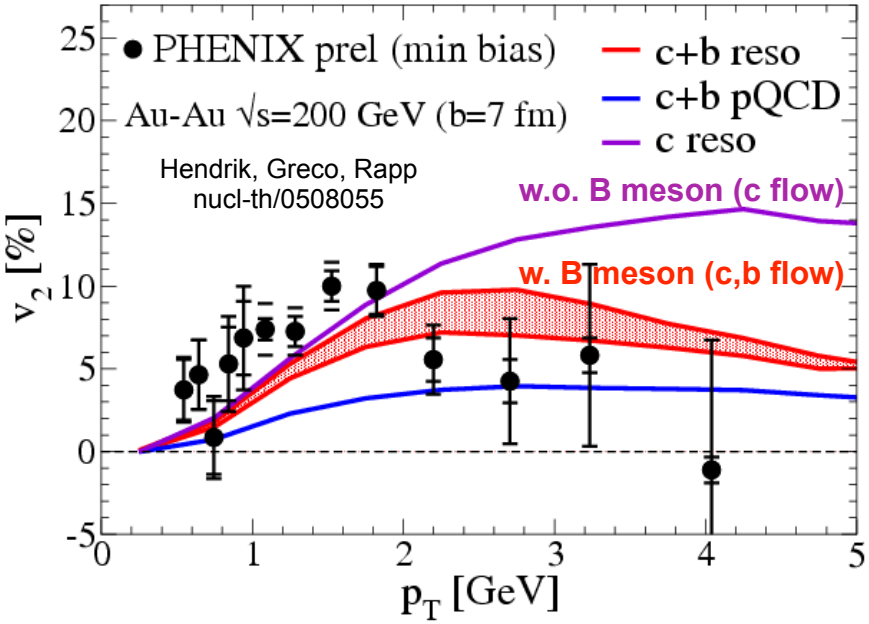
⇒ need energy scan with lots of luminosity

Effect of quenching?

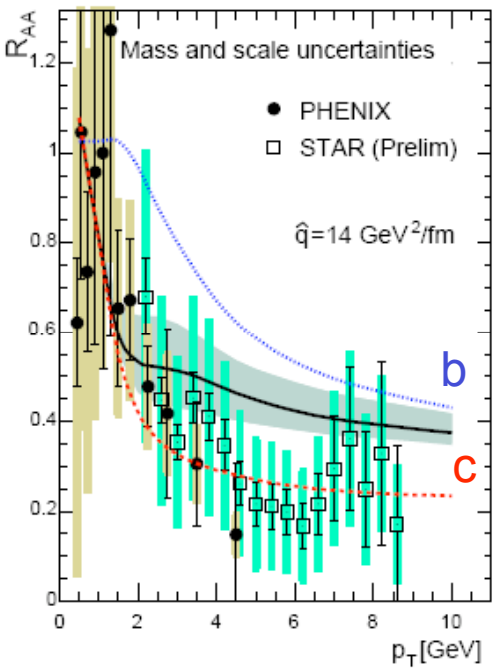
⇒ need J/ψ and ψ' at high-p_T

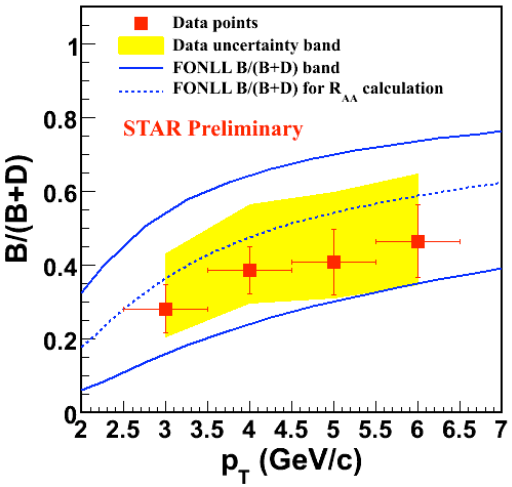


It's the Lack of PID ...



N. Armesto et al, nucl-ex/0511257





$e^{\pm}$ from semileptonic D/B decays:
poor man's way to measure charm and bottom
v_2 and R_{AA}: the mix of c/b matters (we still know little about that)

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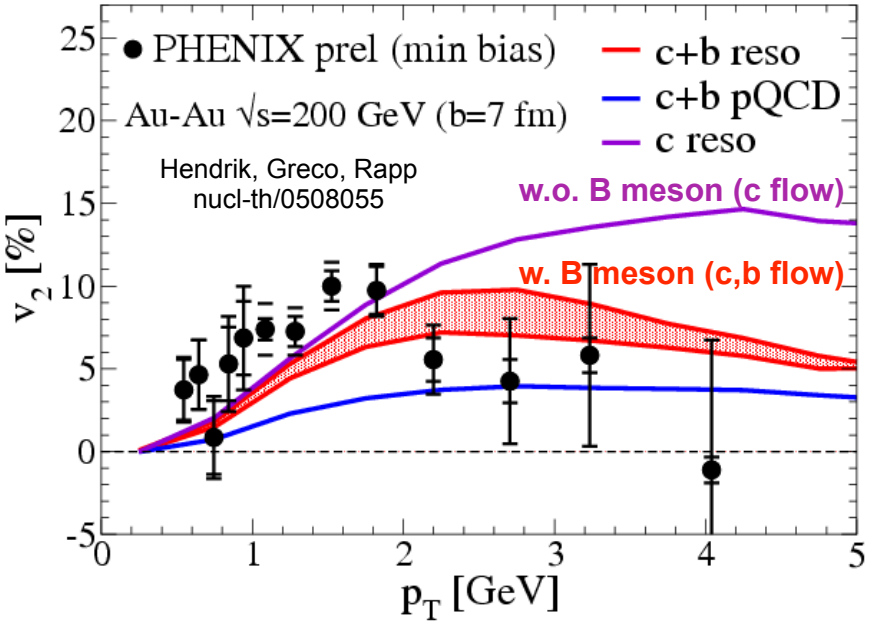

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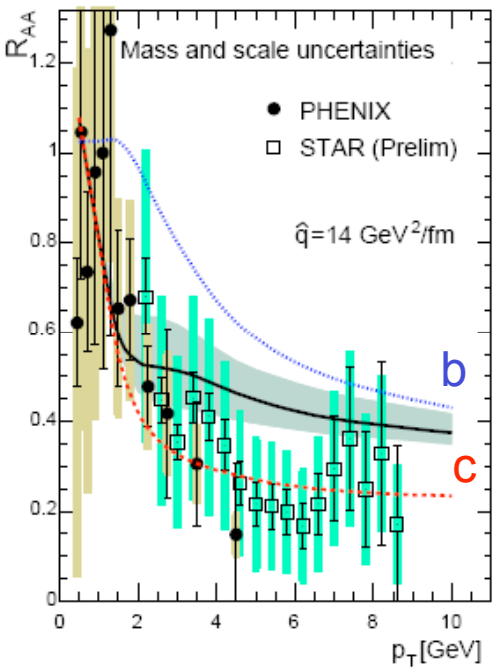

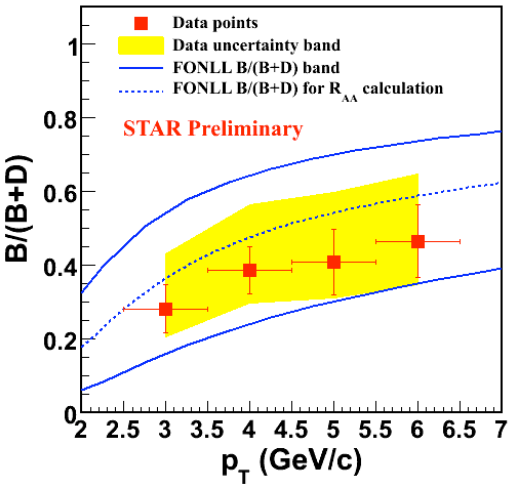

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poor man's way to measure charm and bottom
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⇒ need to disentangle contributions ⇒ need high statistics correlations studies
⇒ need to direct measurement through D (D → hadronic channels)
⇒ need to direct measurement of B (B → J/ψ + anything)
Requires high precision vertex detectors, high-p_T PID for K, π

Heavy Flavor Measurement at RHIC to Date

Open Charm

- D0 mesons (STAR)
  - d+Au, Au+Au (all 200 GeV)
  - hadronic channel: $D_0 \rightarrow K\,\pi$
  - $y \sim 0$, $p_T < 3$ GeV
  - problem: no vertexing ⇒ low S/B
  - low significance
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- Non-photonic leptons (PHENIX, STAR)
  - $D0 \rightarrow \ell + X$
  - $0.1 < pT < 10$ GeV/c
  - p+p, d+Au, Au+Au (all 200 GeV)
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  - μ at forward rapidities (PHENIX)
  - moderate to good statistics
  - problem: background, c/b content?

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Quarkonia

- $J/\psi \rightarrow e+e- / \mu+\mu-$ (PHENIX)
  - p+p, d+Au, Cu+Cu, Au+Au (all 200 GeV)
  - Cu+Cu (62 GeV)
- J/ψ' seen (analysis in progress)
- $\Upsilon \rightarrow e+e-$ (STAR)
  - total cross-section for $\Sigma\Upsilon$ in p+p (200 GeV)

General problem: luminosity, acceptance

Fundamental Science at RHIC in the Next Decade?

From Qualitative to Quantitative ...

- Quantitative determination of the Equation-of-State
- Experimental verification or null result on critical point
- Quantitative determination of viscosity (η/s).
- Quantitative determination of color field strength via $\hat{q}$.
- Experimental verification of deconfinement
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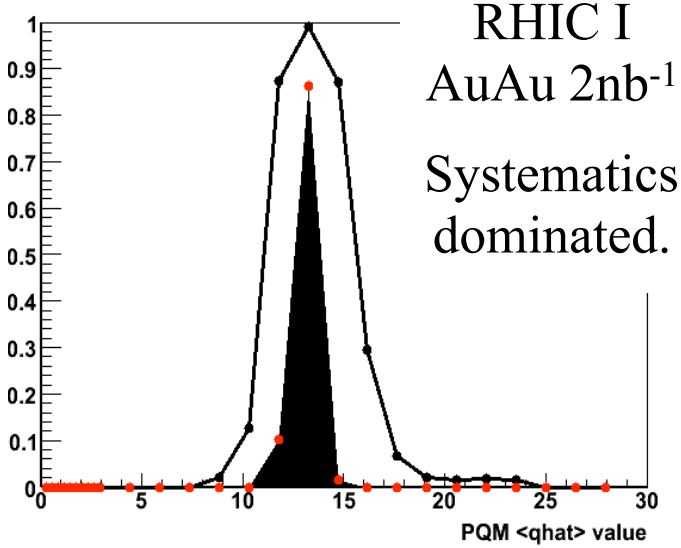
This is ultimately only possible

with Heavy Flavor Probes ...

Example: Determining Transport Coefficient $\hat{q}$



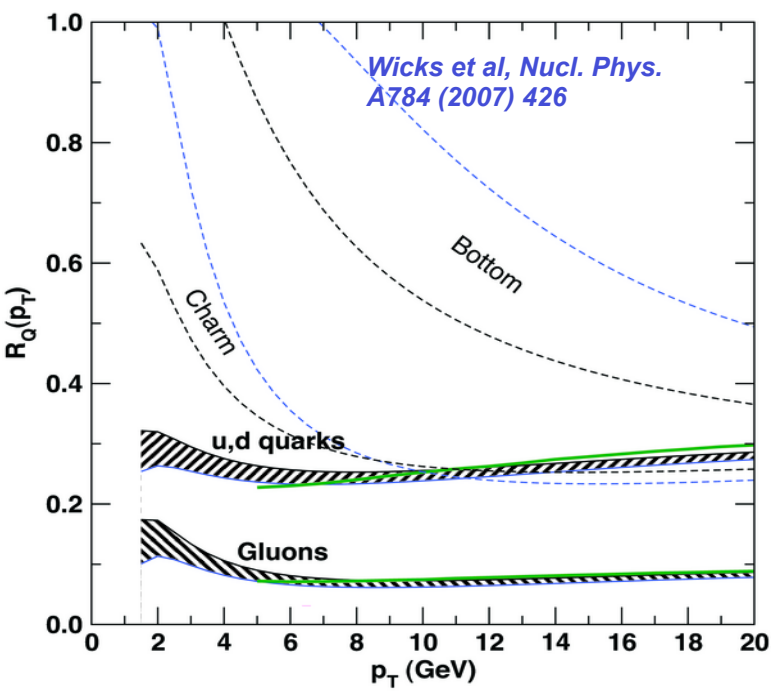
RHIC I
AuAu $2nb^{-1}$

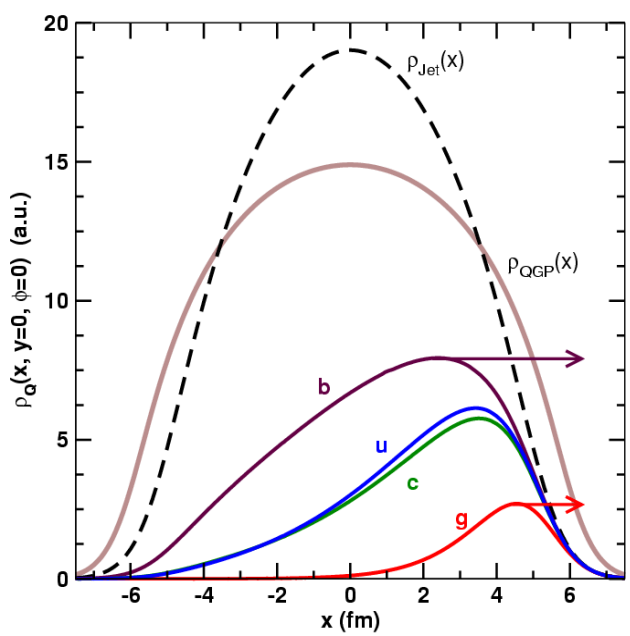
Systematics dominated.

- Problem: interaction with the medium so strong that information is lost: "black"
- $\hat{q}$ not well constraint:

$$6 \le \langle \hat{q} \rangle \le 24 \ \ \mathrm{GeV}^2/\mathrm{fm}$$
$$(\mathrm{Probability} > 10\%)$$

- Significant differences between predicted R_{AA}, depending on the probe





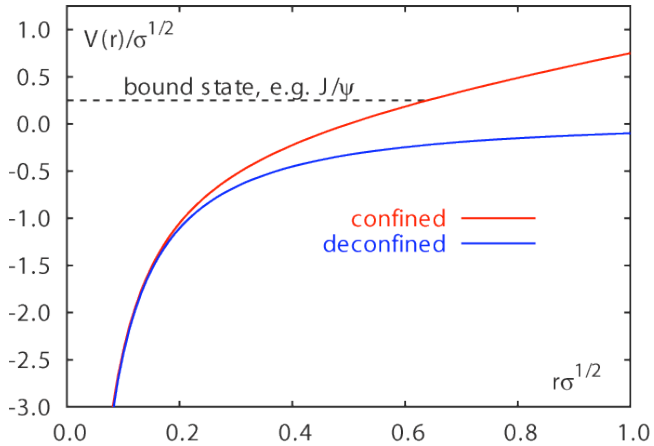
Dead Cone Effect:
Heavy Quarks look deeper

they are grey

Example: Deconfinement (I)

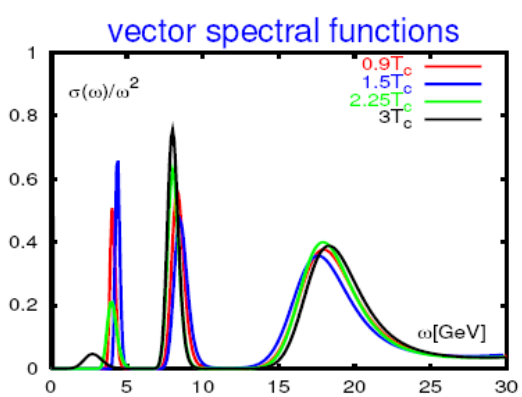
Charmonia: J/ψ, Ψ', χc Bottomonia: ϒ(1S), ϒ(2S), ϒ(3S)

- Key Idea: Melting in the plasma
  - Color screening of static potential between heavy quarks:
    - J/ψ suppression: Matsui and Satz, Phys. Lett. B 178 (1986) 416
  - Suppression of states is determined by TC and their binding energy



- Sequential disappearance of states:
  ⇒ Color screening ⇒ Deconfinement
  ⇒ QCD thermometer ⇒ Properties of QGP

This is the <u>only</u> clear (?) **signature of deconfinement** on the market



$$T_{diss}(\psi') \approx T_{diss}(\chi_c) < T_{diss}(\Upsilon(3S)) < T_{diss}(J/\psi)$$
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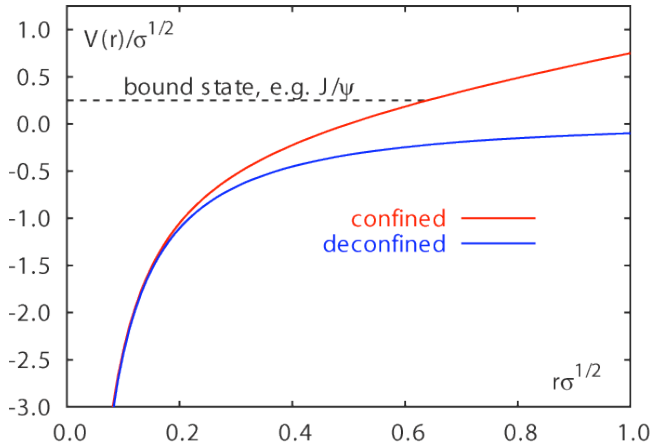

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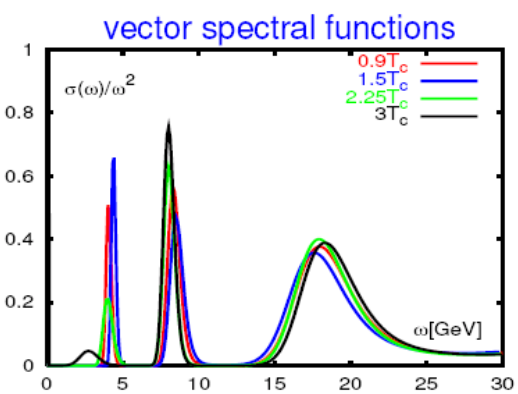

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F. Karsch:
Sequential suppression pattern is the smoking gun

Example: Deconfimenent (II)

Charmonia: J/ψ, Ψ', χ_c	Bottomonia: $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$
Measured: J/ψ (pp, AA) [PHENIX]	Measured: $\sigma(\Sigma\Upsilon$, pp only) [STAR]
Calculated on Lattice (interpretation)	No (reliable) lattice calculation (yet)
Largest cross-section of all charmonia	Small cross-section (truely rare probe)
Recombination: large	Recombination: none
Co-mover absorption	Co-mover absorption very small
S states can be easily separated	Separation of S states is challenge
Feeddown: χ_c (measurement possible)	Feeddown: χ_b (impossible?)
all Υ and Ψ', χ_c requires high luminosity; χ_c needs detector upgraded	

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My take: while certainly a **very compelling idea** we will only learn what we hope for by very systematic studies of all quarkonium states (J/ψ, ψ', χc, ϒ(1S), ϒ(3S), ϒ(3S) in various systems and energies over a large phase space.

⇒ one of the most difficult tasks in Heavy Ions

So where are we?

- With heavy flavor we only scratched the surface
  - Still, from what we saw we learned a lot and ...
  - several established ideas brought into question
    - e.g. radiative versus collisional e-loss

- but - deficits in detectors
  - need high precision vertexing
  - need forward coverage
    need improved PID

- need for higher luminosity

Glossary

- RHIC-II $\neq$ RHIC Detector Upgrades
  - but then one doesn't make sense without the other

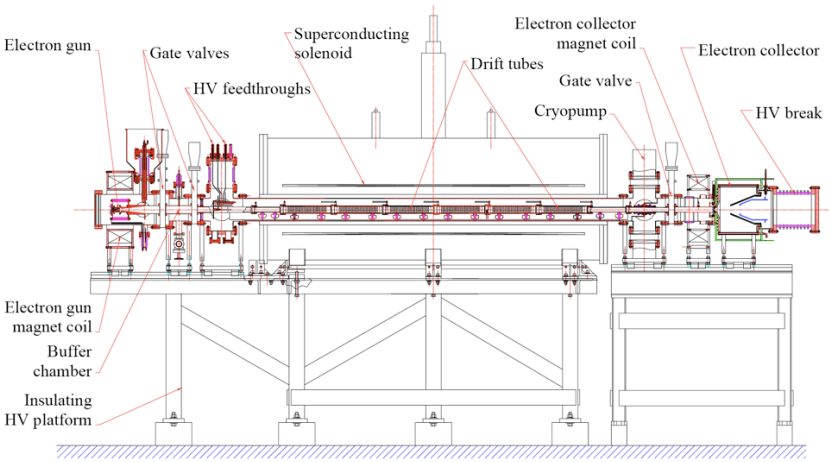
- RHIC Detectors
  - Current RHIC Detector Upgrades
    - Ongoing upgrades to PHENIX & STAR
  - RHIC Mid-Term Upgrades
    - Substantial Upgrades to RHIC Detectors (PHENIX & STAR)
      - Timescale: now – FY 2012

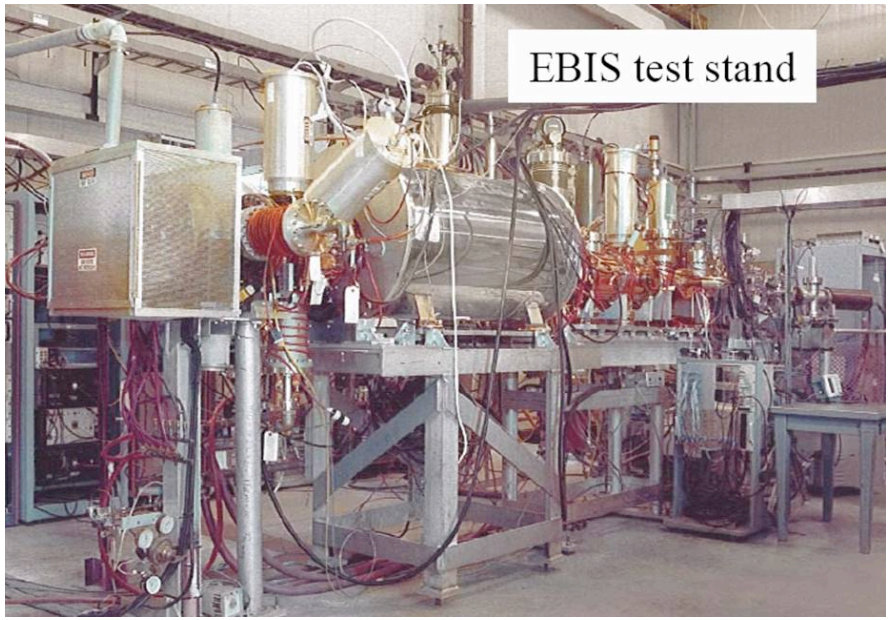
- RHIC-II
  - Cooling for RHIC $\Rightarrow$ Luminosity increase
    - electron cooling
    - stochastic cooling (new)
  - New heavy ion source EBIS allowing collisions up to U+U
  - Timescales:
    - EBIS: by FY 2009
    - e-cooling: by FY 2015
    - stochastic cooling: earlier ?

RHIC-II: EBIS Ion Source

New Ion Source:

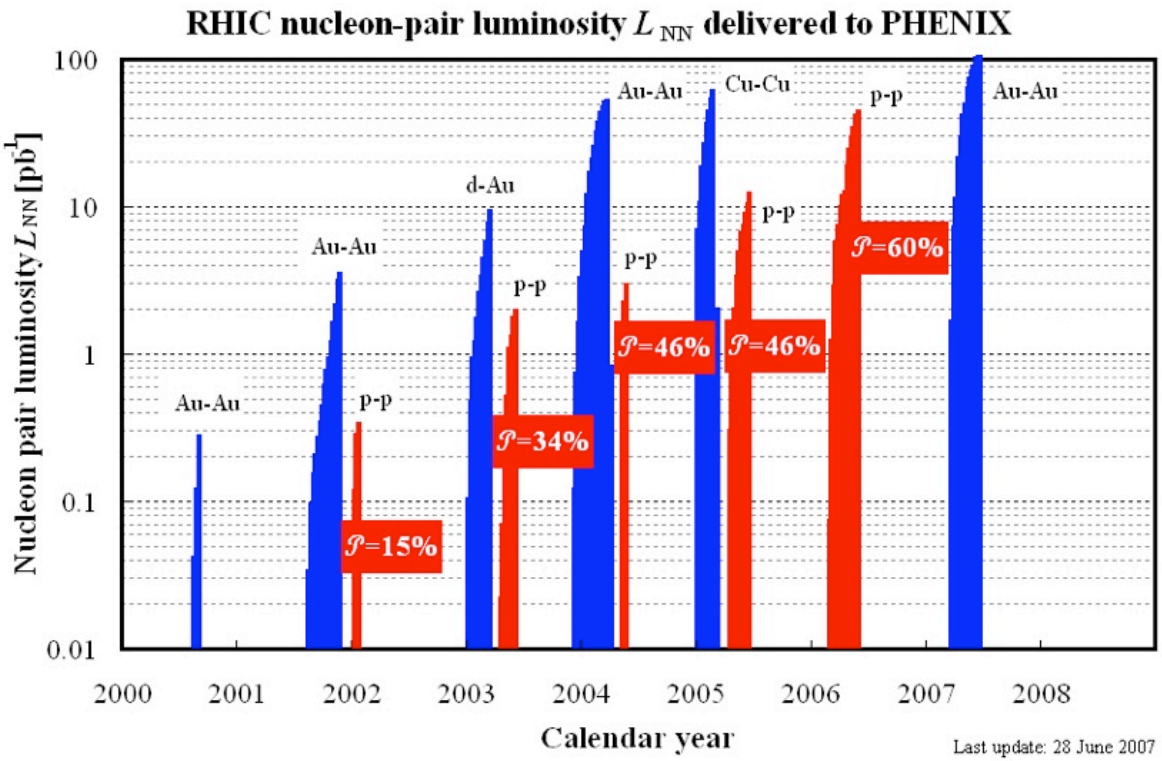
- New high brightness, high charge-state pulsed ion source
- Replaces 35 year old Tandem Van de Graafs
- Improved reliability, lower operations costs
- Enables new beams: noble gas ions, Uranium, polarized 3He
- Construction schedule: FY2006 –10





Impact on Heavy Flavor Program:
none but important for many other topics

RHIC-II: Luminosity Upgrade

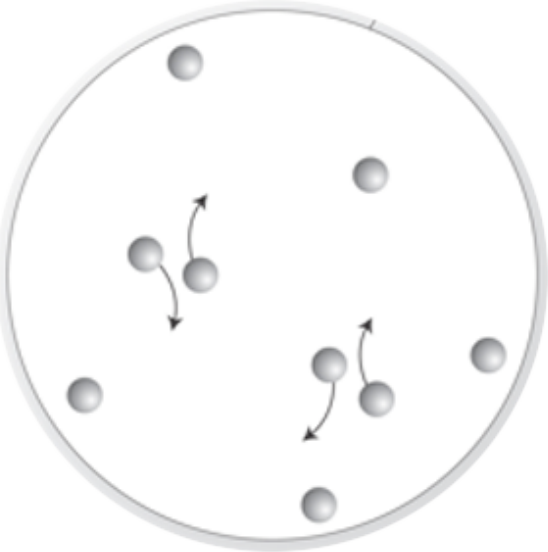


Luminosity Killer:
Beam blow-up from intra-beam scattering

Cooling ⇒
Reduce transverse and longitudinal emittance

	Design $\langle L \rangle_{store}$ ($cm^{-2}s^{-1}$)	Current $\langle L \rangle_{store}$ ($cm^{-2}s^{-1}$)
Au+Au	2×10^{26}	12×10^{26}
p+p	4×10^{30}	20×10^{30}

Note: LHC (Pb+Pb) ~ 2×10^{26} $cm^{-2}s^{-1}$



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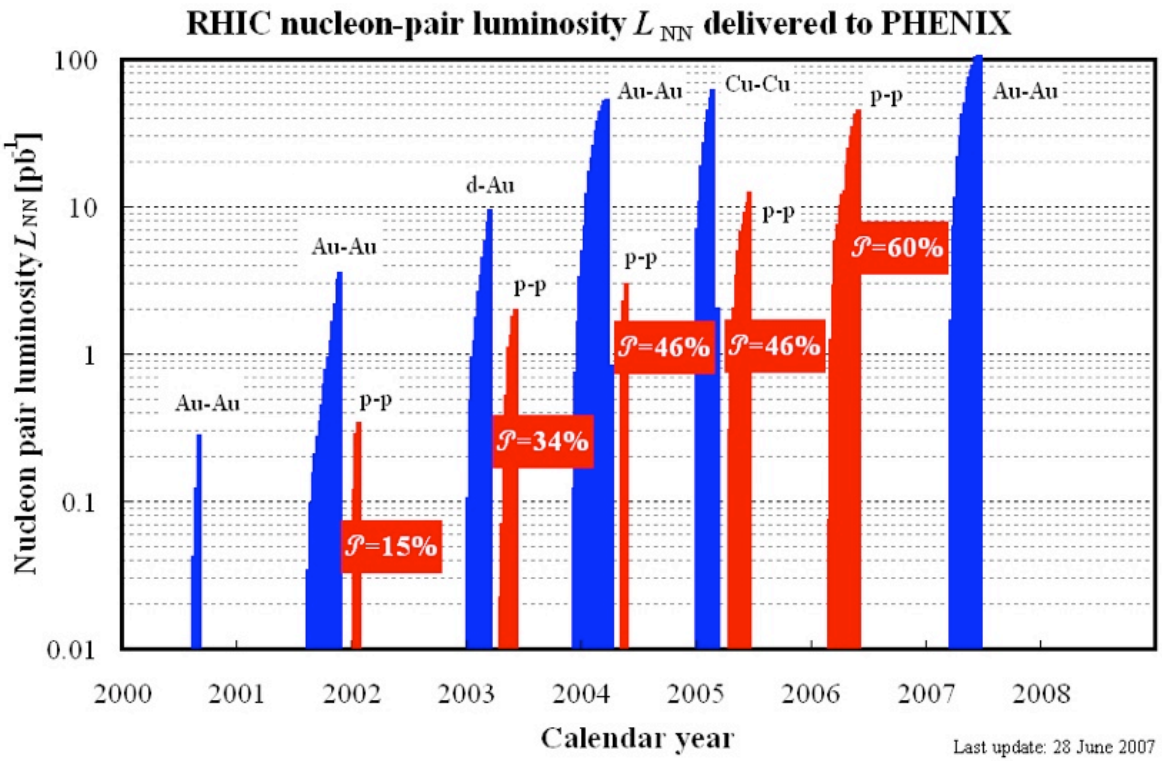

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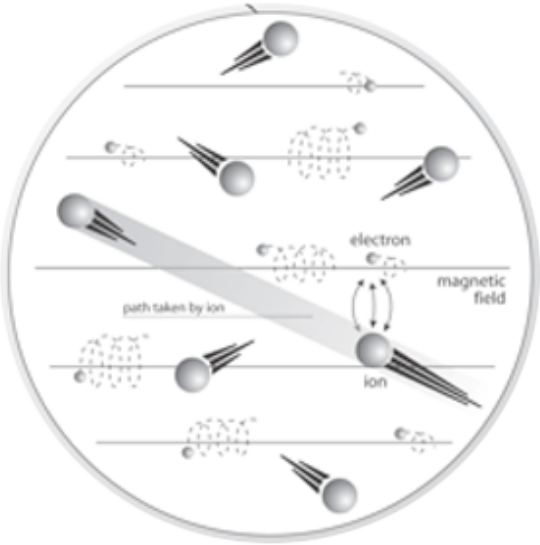
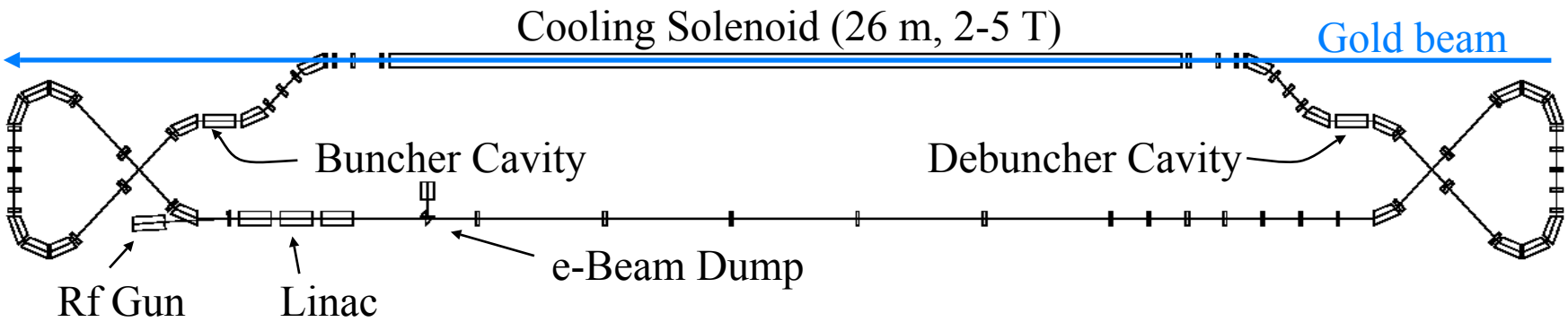
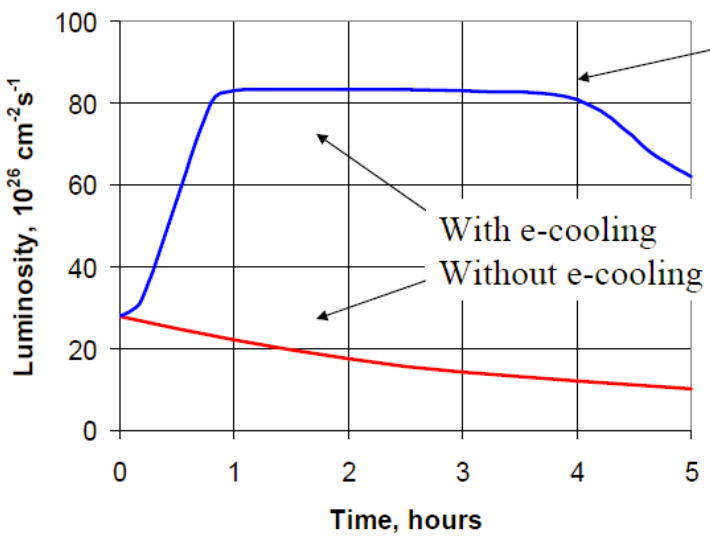


RHIC-II: Electron Cooling



Gold collisions (100 GeV/n x 100 GeV/n):	w/o e-cooling	with e-cooling
Ave. store luminosity [10^{26} cm^{-2} s^{-1}]	8 (12)	70
Pol. Proton Collision (250 GeV x 250 GeV):		
Ave. store luminosity [10^{32} cm^{-2} s^{-1}]	1.5	5.0



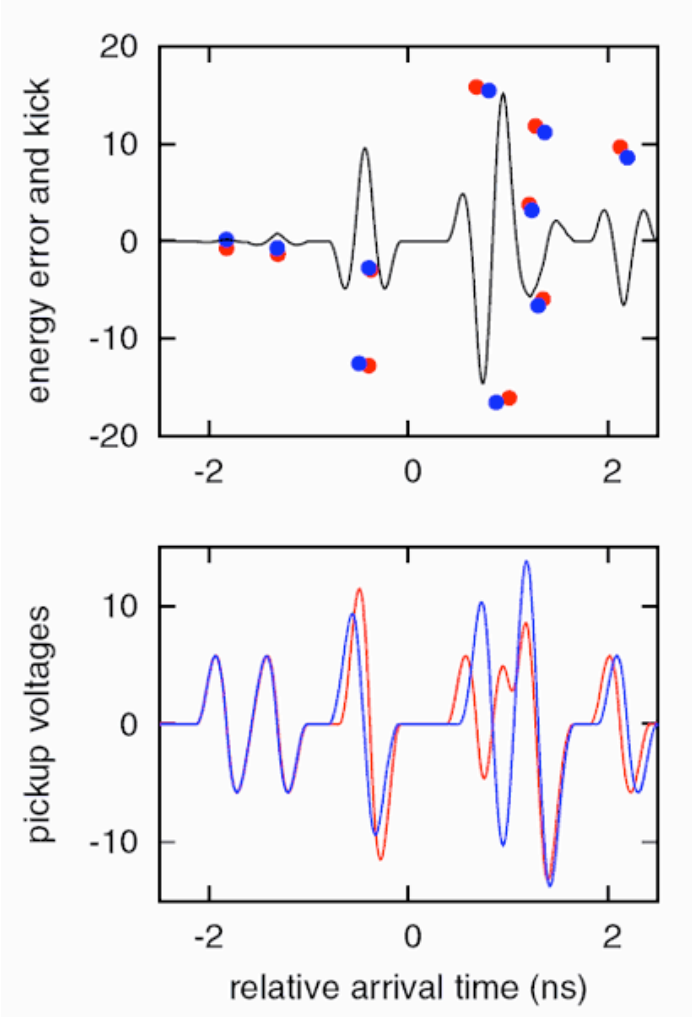
Electron cooling reduces the inter-beam Coulomb scattering and reduces the size of the beam at the IP

Because the collision "diamond" has σ = 20 cm at RHIC and σ = 10 cm at RHIC II, the gain in usable luminosity is larger than the ratio of delivered luminosity when going to RHIC II.

Luminosity leveling through continuously adjusted cooling

Store length limited to 4 hours by "burn-off"

RHIC-II: Stochastic Cooling



- Energy error: turn N
- Energy error: turn N+1

Change in arrival time ~ energy error
(more energy take longer around ☺)

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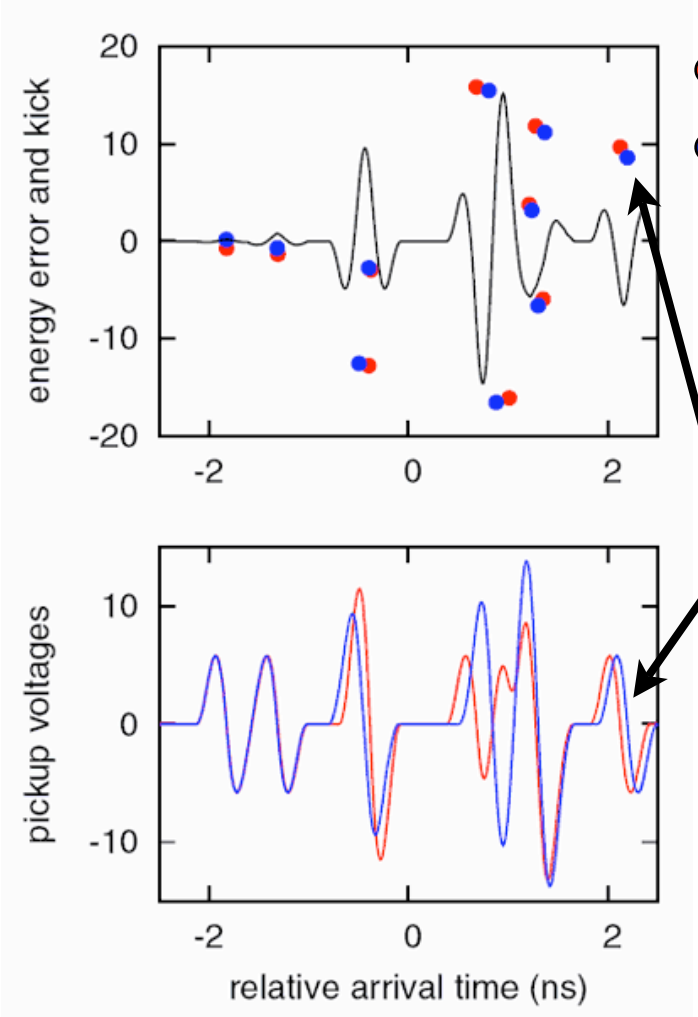

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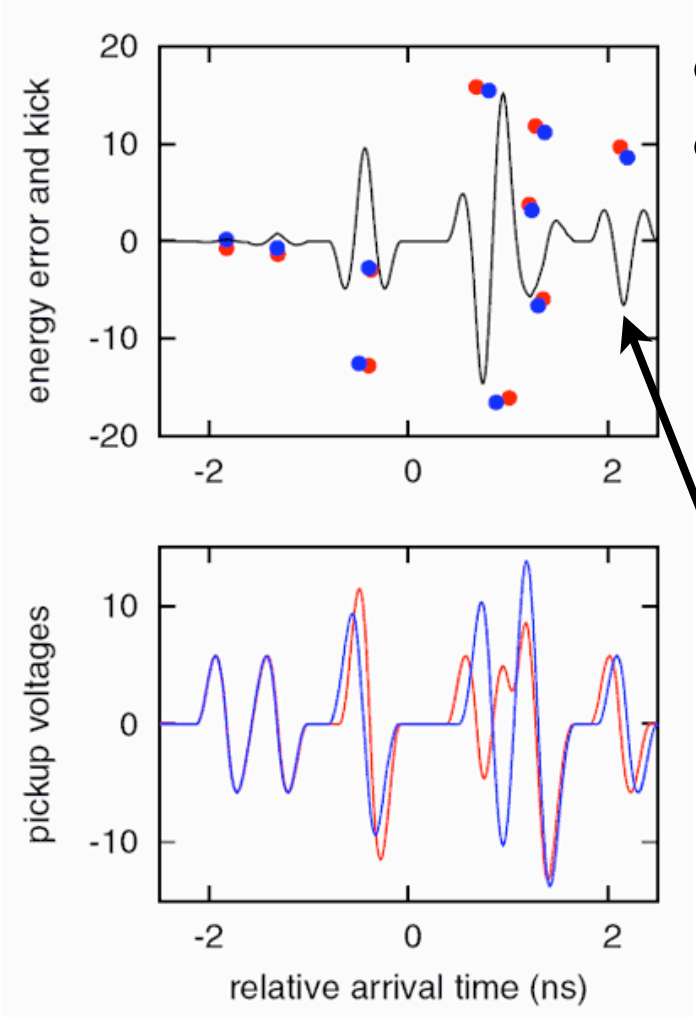
Stochastic Cooling:
measure relative arrival time for 2 turns

RHIC-II: Stochastic Cooling

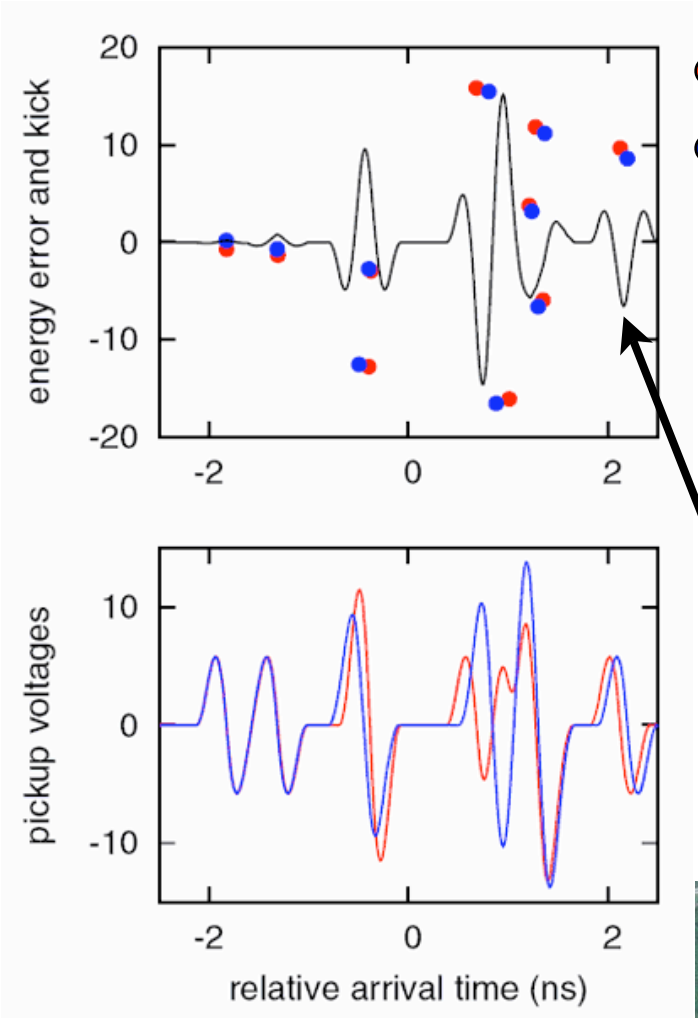


- Energy error: turn N
- Energy error: turn N+1

Change in arrival time ~ energy error
(more energy take longer around ☺)

Stochastic Cooling:
measure relative arrival time for 2 turns
required kick: red-blue
⇒ Reduction of energy spread

RHIC-II: Stochastic Cooling



- Energy error: turn N
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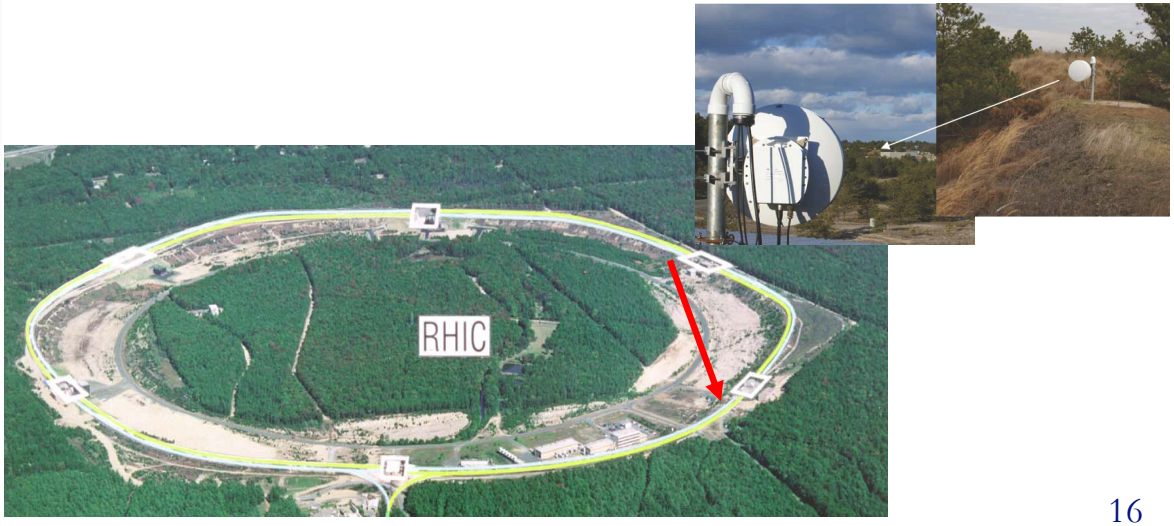


RHIC-II: Stochastic Cooling

Run 7 (2007):

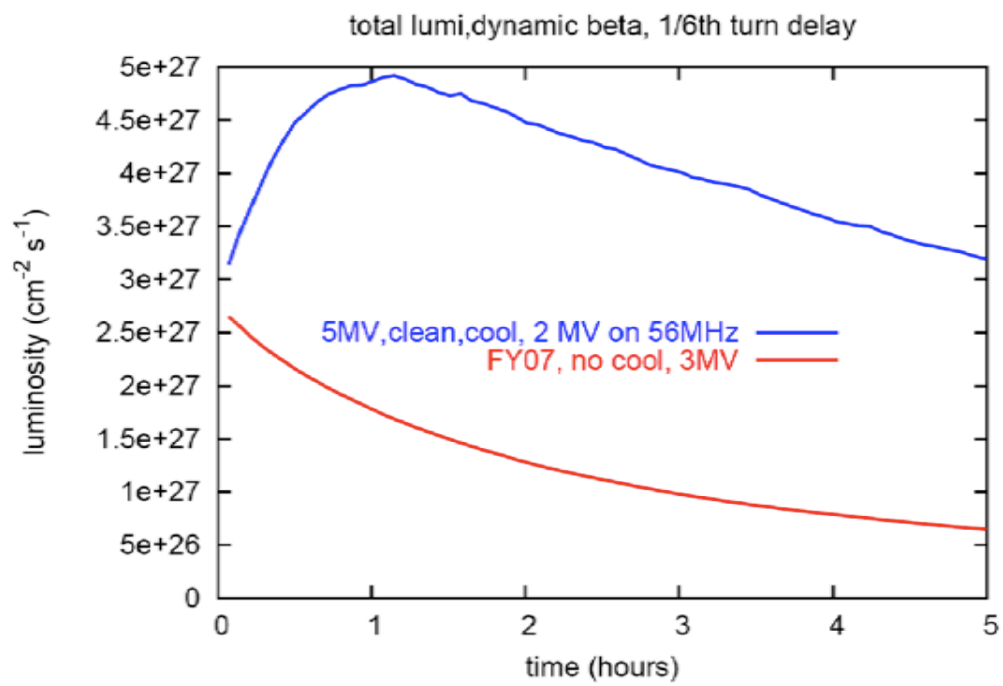
- Longitudinal bunched beam stochastic cooling
- Longitudinal stochastic cooling in blue ring under construction.
- Transverse stochastic cooling in RHIC at 100 GeV/n might be possible using the same approach.

Electron Cooling

- TPC: $95M (FY07$)
- Funding ... 2012-2015

Stochastic Cooling

- ~ $7M
- much earlier than above ...



L(e-cooling) ≈ 2-3 × L(stochastic-cooling)

Overview: Phenix Now and in the Future

Charged Particle Tracking:

- Drift Chamber
- Pad Chamber
- Time Expansion Chamber/TRD
- Cathode Strip Chambers(Mu Tracking)

Particle ID:

- Time of Flight
- Ring Imaging Cerenkov Counter
- TEC/TRD
- Muon ID (PDT's)

Calorimetry:

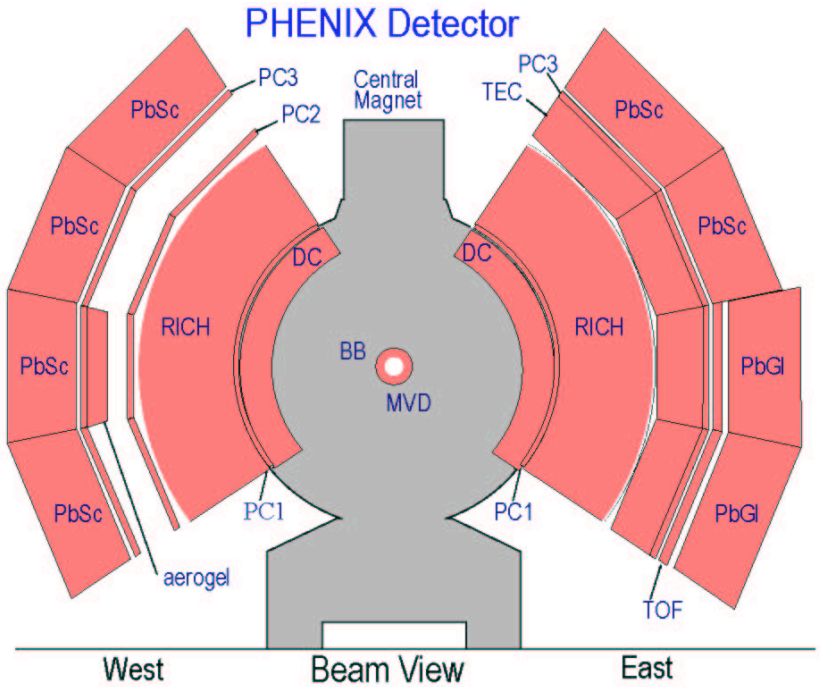
- Pb Scintillator
- Pb Glass

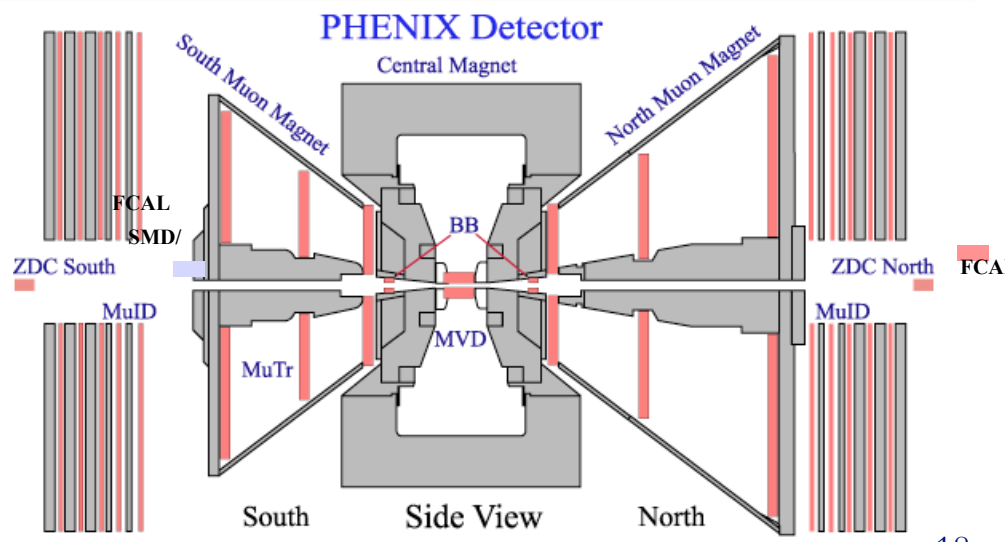
Event Characterization:

- Beam-Beam Counter
- Zero Degree Calorimeter/Shower Max Detector
- Forward Calorimeter

Data Acquisition:

- DAQ Upgrade





Overview: Phenix Now and in the Future

Charged Particle Tracking:

- Drift Chamber
- Pad Chamber
- Time Expansion Chamber/TRD
- Cathode Strip Chambers(Mu Tracking)
- **Forward Muon Trigger Detector**
- **Si Vertex Tracking Detector- Barrel (Pixel + Strips)**
- **Si Vertex Endcap (mini-strips)**

Particle ID:

- Time of Flight
- Ring Imaging Cerenkov Counter
- TEC/TRD
- Muon ID (PDT's)
- **Aerogel Cerenkov Counter**
- **Multi-Gap Resistive Plate Chamber ToF**
- **Hadron Blind Detector**

Calorimetry:

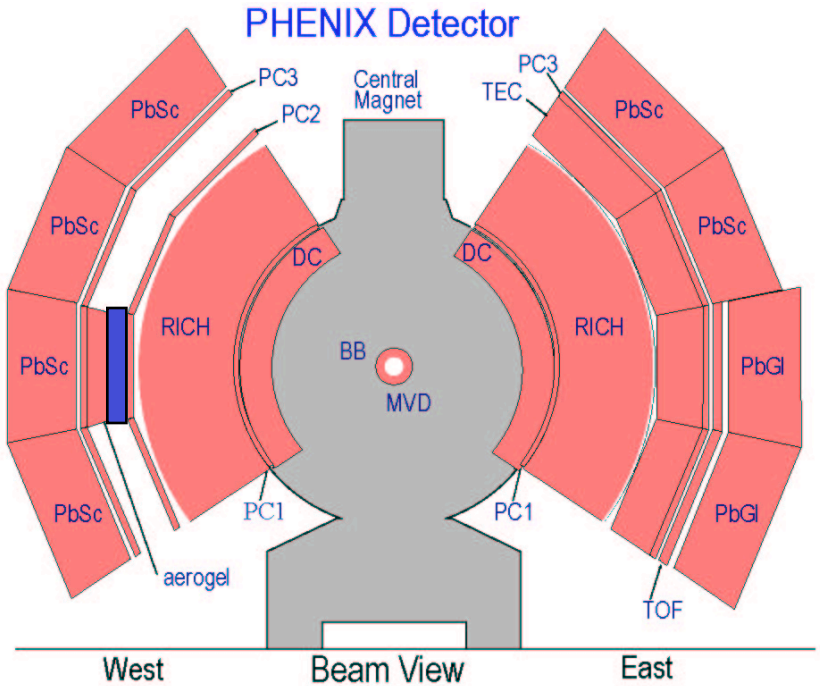
- Pb Scintillator
- Pb Glass
- **Nose Cone Calorimeter**
- **Muon Piston Calorimeter**

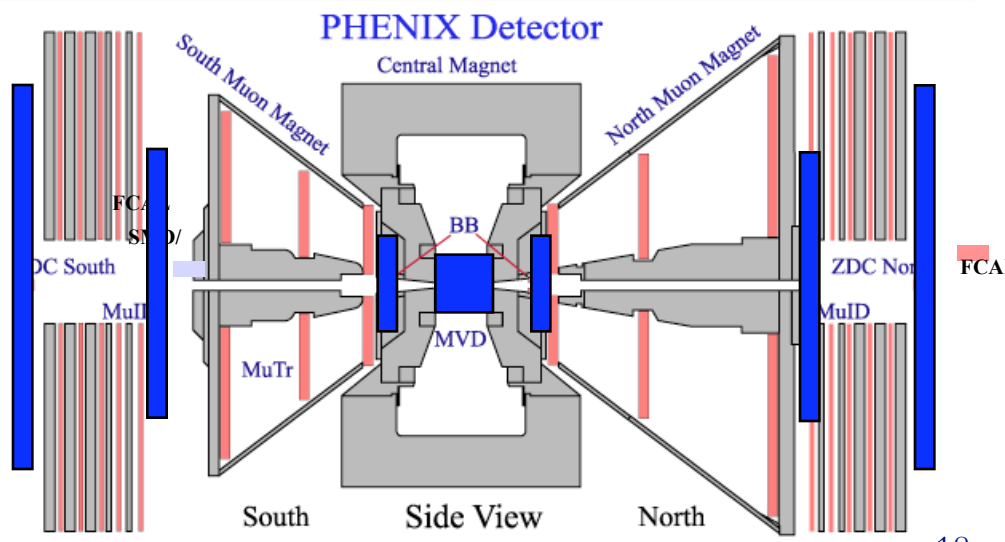
Event Characterization:

- Beam-Beam Counter
- Zero Degree Calorimeter/Shower Max Detector
- Forward Calorimeter
- **Reaction Plane Detector**

Data Acquisition:

- DAQ Upgrade



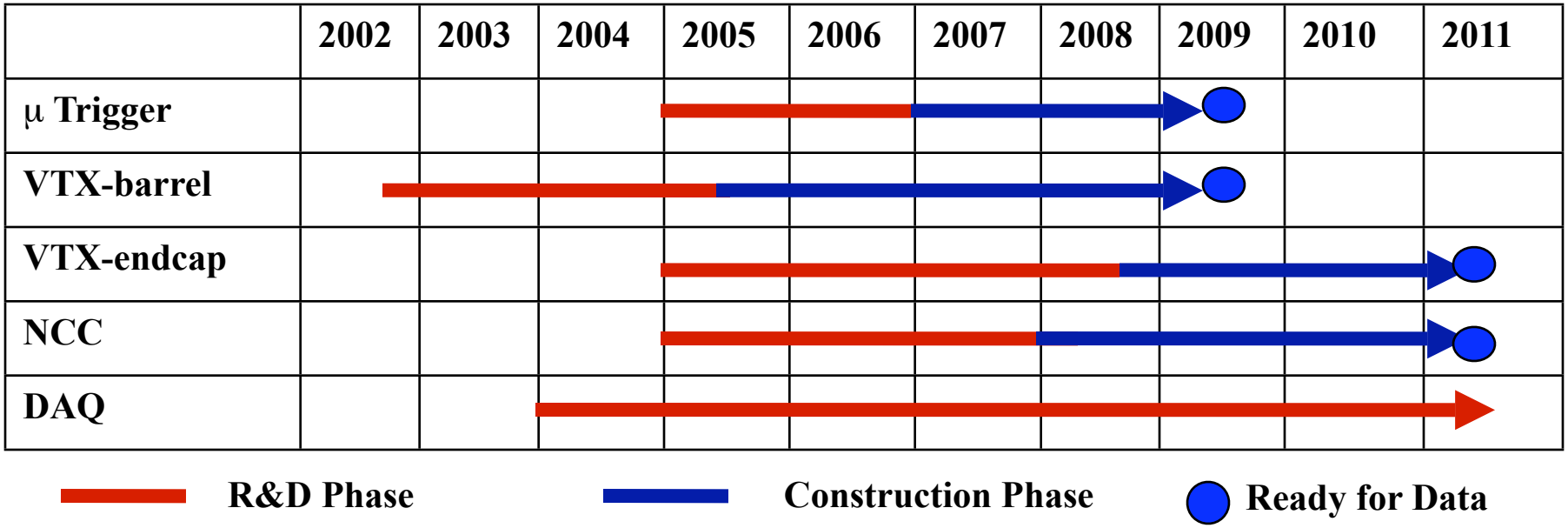


PHENIX Upgrades Physics Capabilities & Timeline

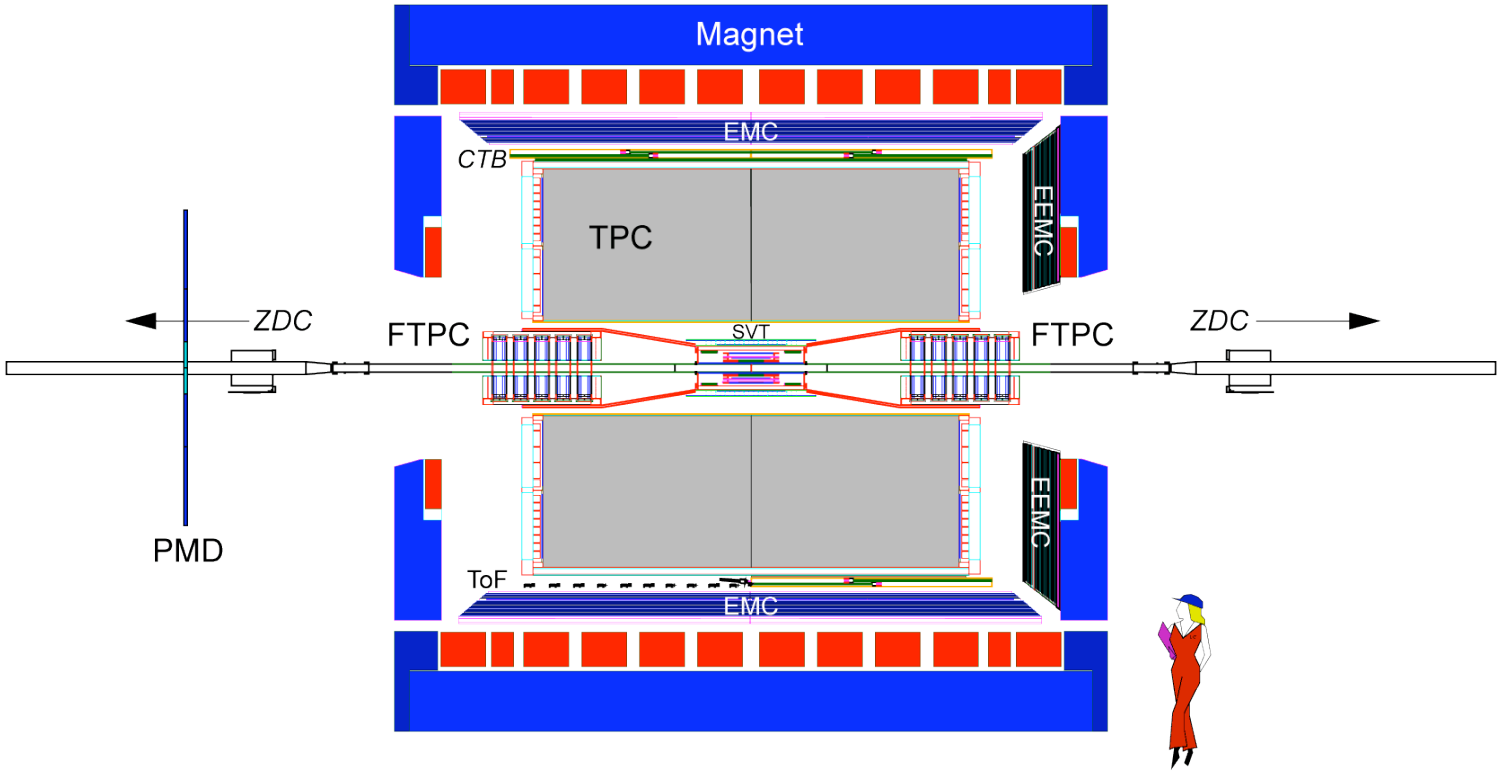
PHENIX Upgrades	High T QCD				Spin		Low x
	e+e-	heavy flavor	jet tomography	quarkonia	W	$\Delta G/G$	
hadron blind detector (HBD)	x						
vertex tracker (VTX)	x	x	o	o		x	o
μ trigger				o	x		
forward calorimeter (MPC)							x
forward Vertex tracker (FVTX)		x	o	o	o	o	o
forward calorimeter (NCC)			o	o	o	o	x
RHIC luminosity	o	o	x	x	o	o	o

x upgrade critical for success

o upgrade significantly enhancements program



Overview: STAR now and in the future



<u>Charged Particle Tracking:</u>

Main TPC

SSD + SVT

Forward TPC (FTPC)

<u>Particle ID:</u>

Time of Flight Patch (pToF)

<u>Calorimetry:</u>

Photon Mult. Detector (PMD)

Barrel EMC

Endcap EMC

<u>Event Characterization & Trigger:</u>

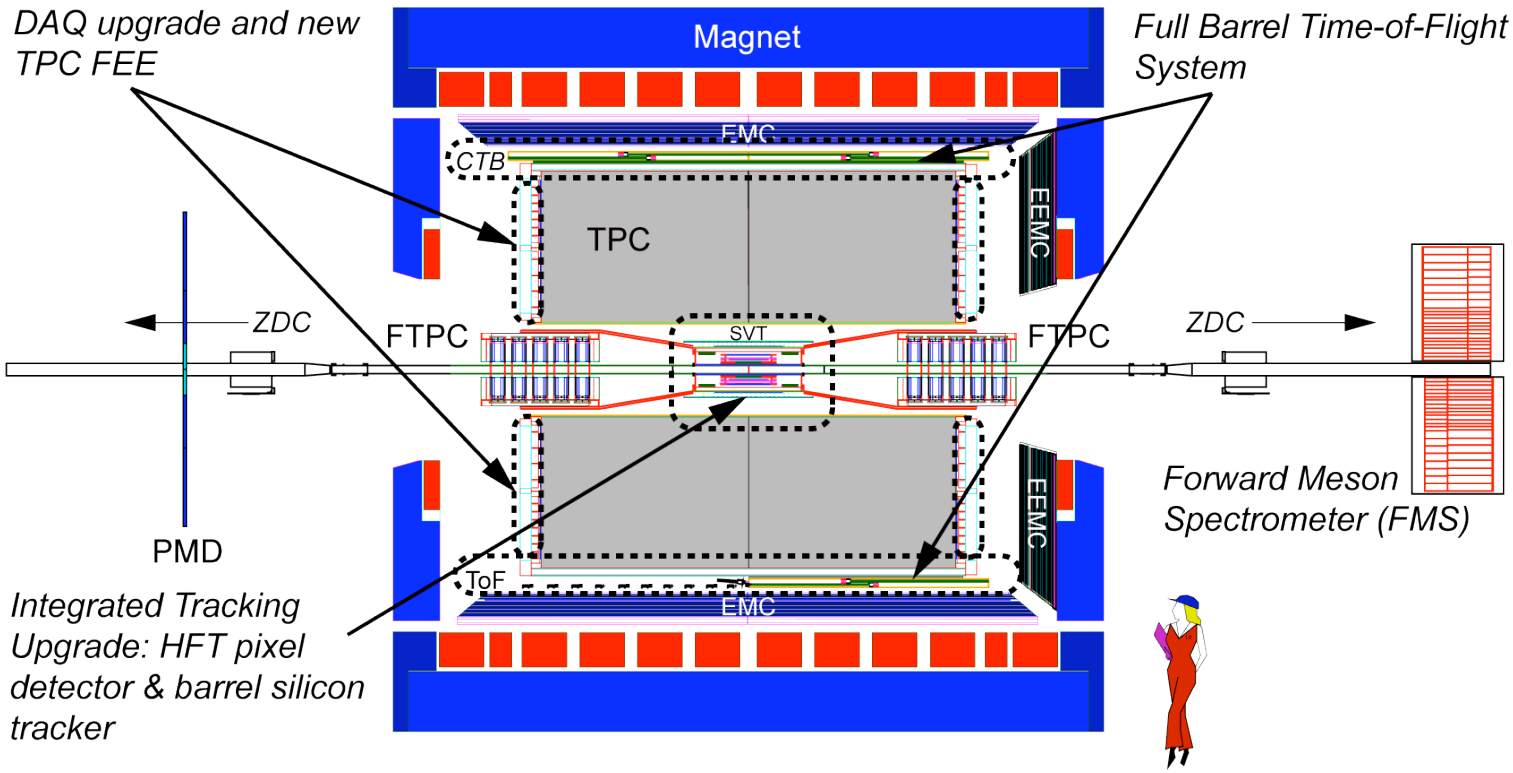
Central Trigger Barrel (CTB)

Beam-Beam Counter (BBC)

Zero Degree Calorimeter (ZDC)

Forward Pion Detectors (FPD)

Overview: STAR now and in the future



<u>Charged Particle Tracking:</u>

Main TPC

SSD + Intermediate Tracker + Active Pixel Detector = HFT

Forward TPC (FTPC)

Forward GEM Tracker

<u>Particle ID:</u>

Full Barrel ToF

Barrel μ Det. (CTB+MRPCs)

<u>Calorimetry:</u>

Photon Mult. Detector (PMD)

Barrel EMC

Endcap EMC

Forward Meson Spectrometer

<u>Event Characterization & Trigger:</u>

Central Trigger Barrel (CTB)

Beam-Beam Counter (BBC)

Zero Degree Calorimeter (ZDC)

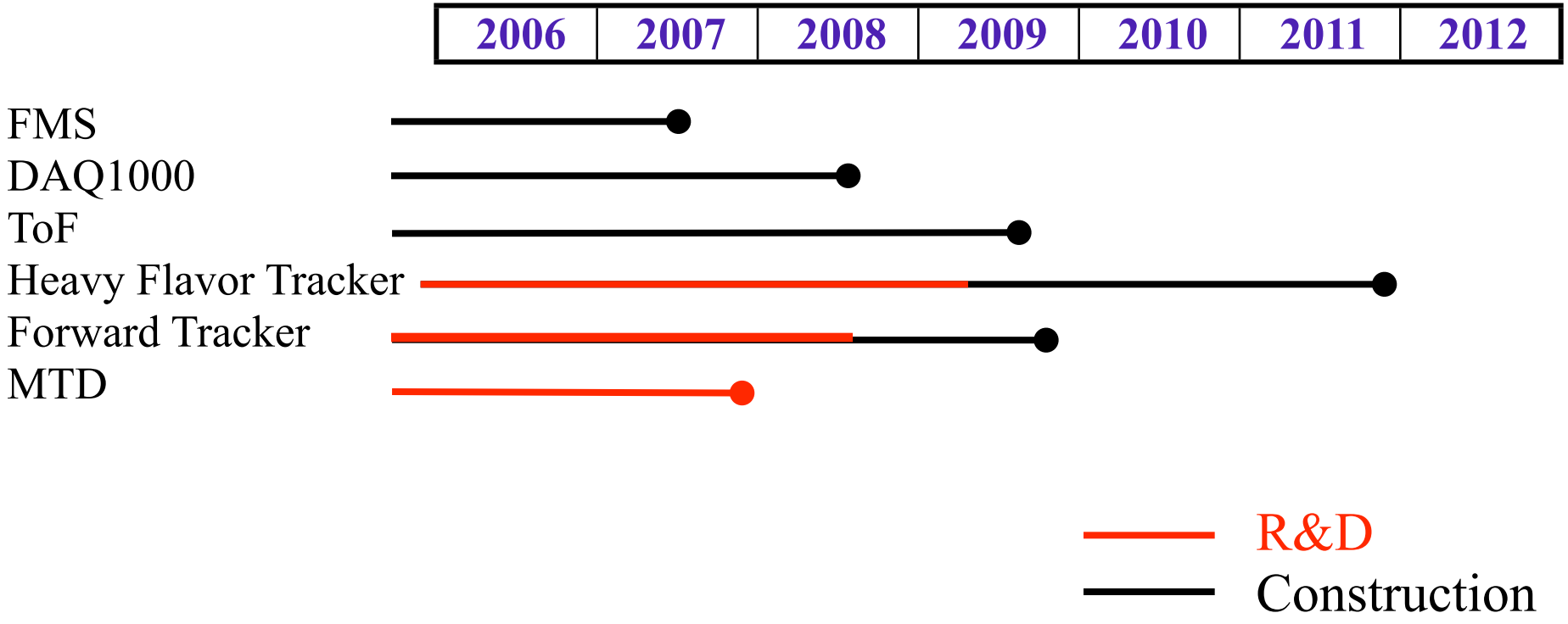
Forward Pion Detectors (FPD)

<u>Data Acquisition:</u>

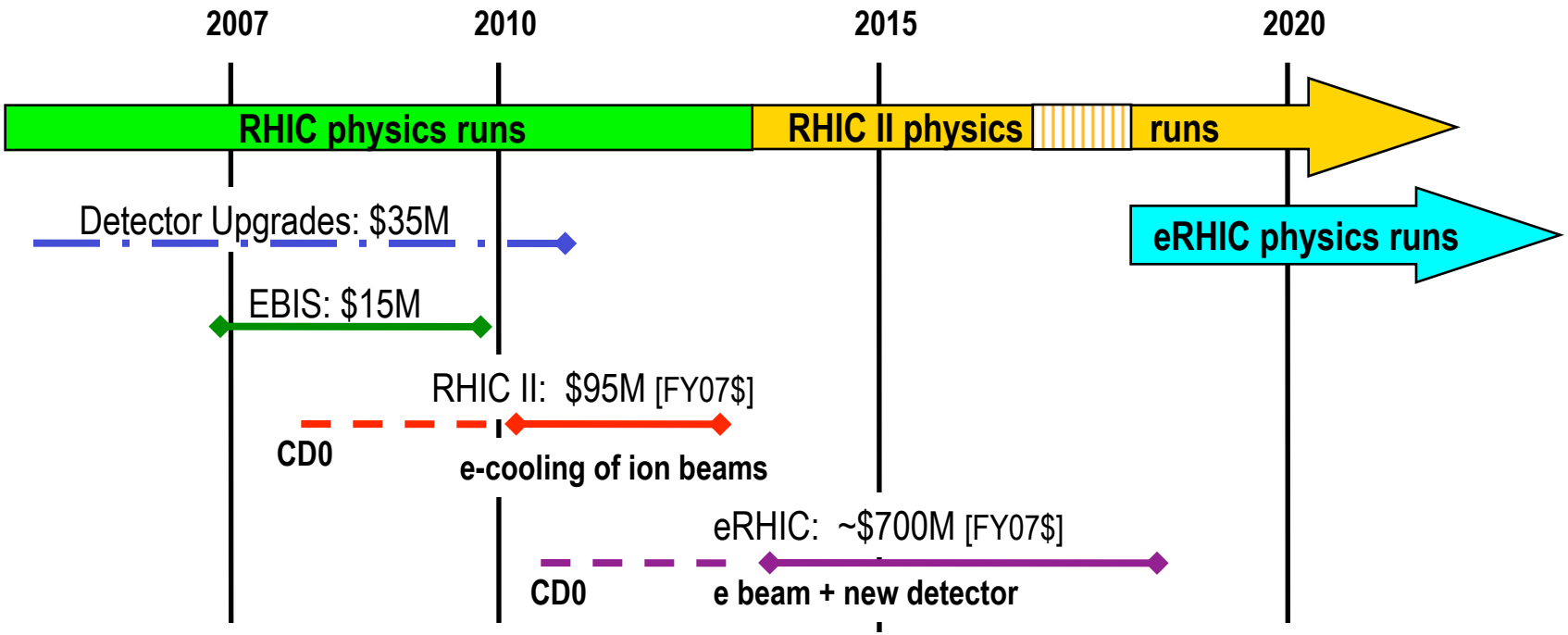
New TPC Readout Electronics

DAQ upgrade

STAR Upgrades Timelines



A Long Term Strategic View of RHIC



Legend:

- *R&D*
- *Construction*
- *Multiple small projects*

CD0: DOE Critical Decision, mission need

Source: S. Aronson

Remarks (TU):

- stochastic cooling
  - cheaper = earlier
- Note: additional $16M from NSF +Non-US+RHIC base

Heavy Flavor at RHIC-II

With detector upgrades (both PHENIX and STAR) and luminosity upgrade (one makes only sense with the other):

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- Charm via D mesons: R_{AA} and v_2

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With detector upgrades (both PHENIX and STAR) and luminosity upgrade (one makes only sense with the other):

- Charm via D mesons: R_{AA} and v_2
- Bottom via $B \rightarrow J/\psi$ from prompt J/ψ using displaced vertex

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- Bottom via electron/muons to high-p_T

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- J/ψ and ψ' R_{AA} to high p_T

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- Bottom via electron/muons to high-p_T
- J/ψ and ψ' R_{AA} to high p_T
- Measure $\chi_c \rightarrow J/\psi+\gamma$ R_{AA} and study feeddown into J/ψ

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With detector upgrades (both PHENIX and STAR) and luminosity upgrade (one makes only sense with the other):

- Charm via D mesons: R_{AA} and v_2
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- Measure $\chi_c \rightarrow J/\psi+\gamma$ R_{AA} and study feeddown into J/ψ
- $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$ R_{AA}

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- Measure $\chi_c \rightarrow J/\psi+\gamma$ R_{AA} and study feeddown into J/ψ
- $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$ R_{AA}
- J/ψ v_2 measurements versus p_T.

Heavy Flavor at RHIC-II

With detector upgrades (both PHENIX and STAR) and luminosity upgrade (one makes only sense with the other):

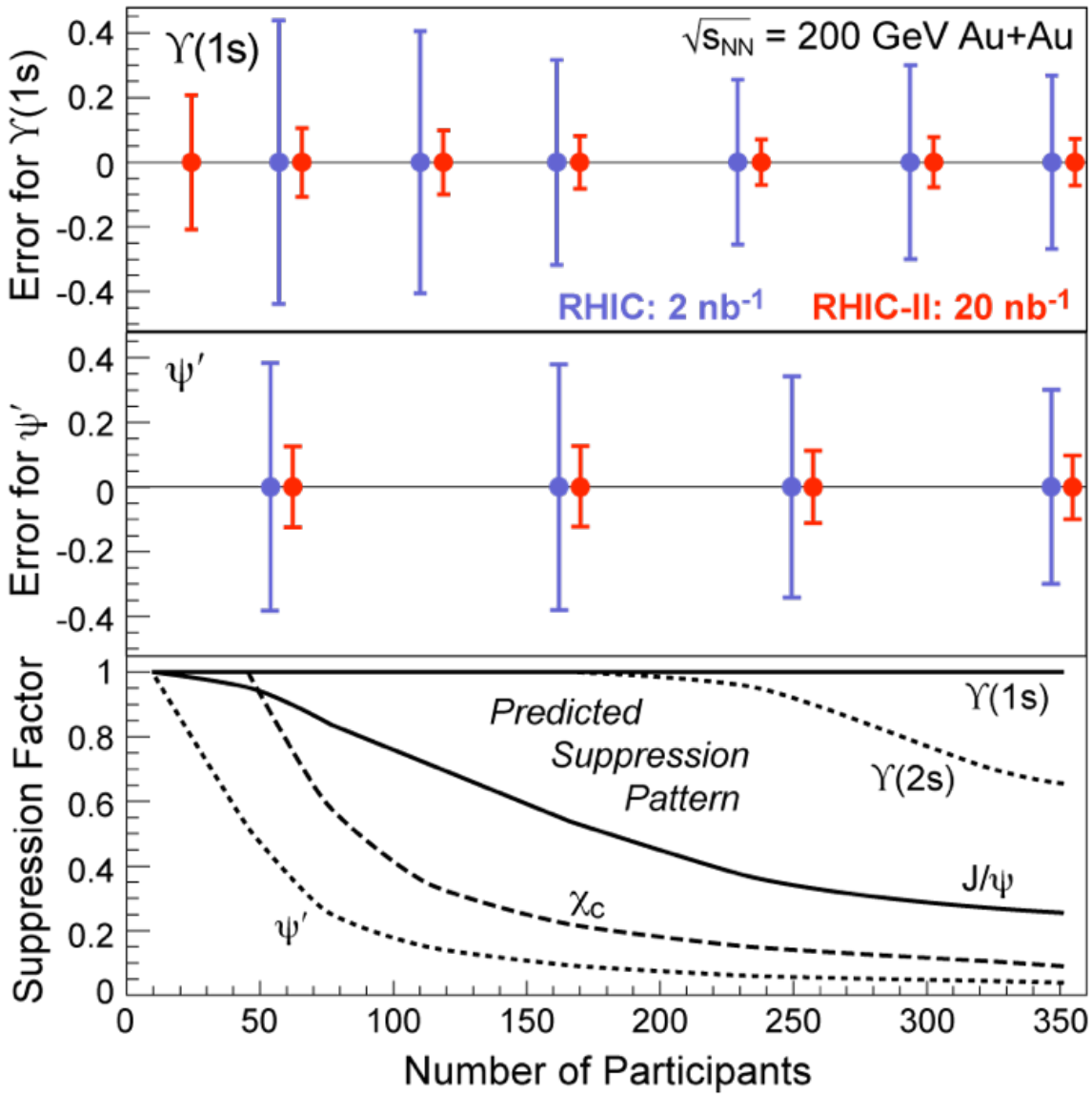
- Charm via D mesons: R_{AA} and v_2
- Bottom via $B \rightarrow J/\psi$ from prompt J/ψ using displaced vertex
- Bottom via electron/muons to high-p_T
- J/ψ and ψ' R_{AA} to high p_T
- Measure $\chi_c \rightarrow J/\psi+\gamma$ R_{AA} and study feeddown into J/ψ
- $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$ R_{AA}
- J/ψ v_2 measurements versus p_T.
- Open charm correlations with high statistics: e(from c)-h, e(from c)-D, D-h, D-h, e(from b)-h, ...

Heavy Flavor at RHIC-II

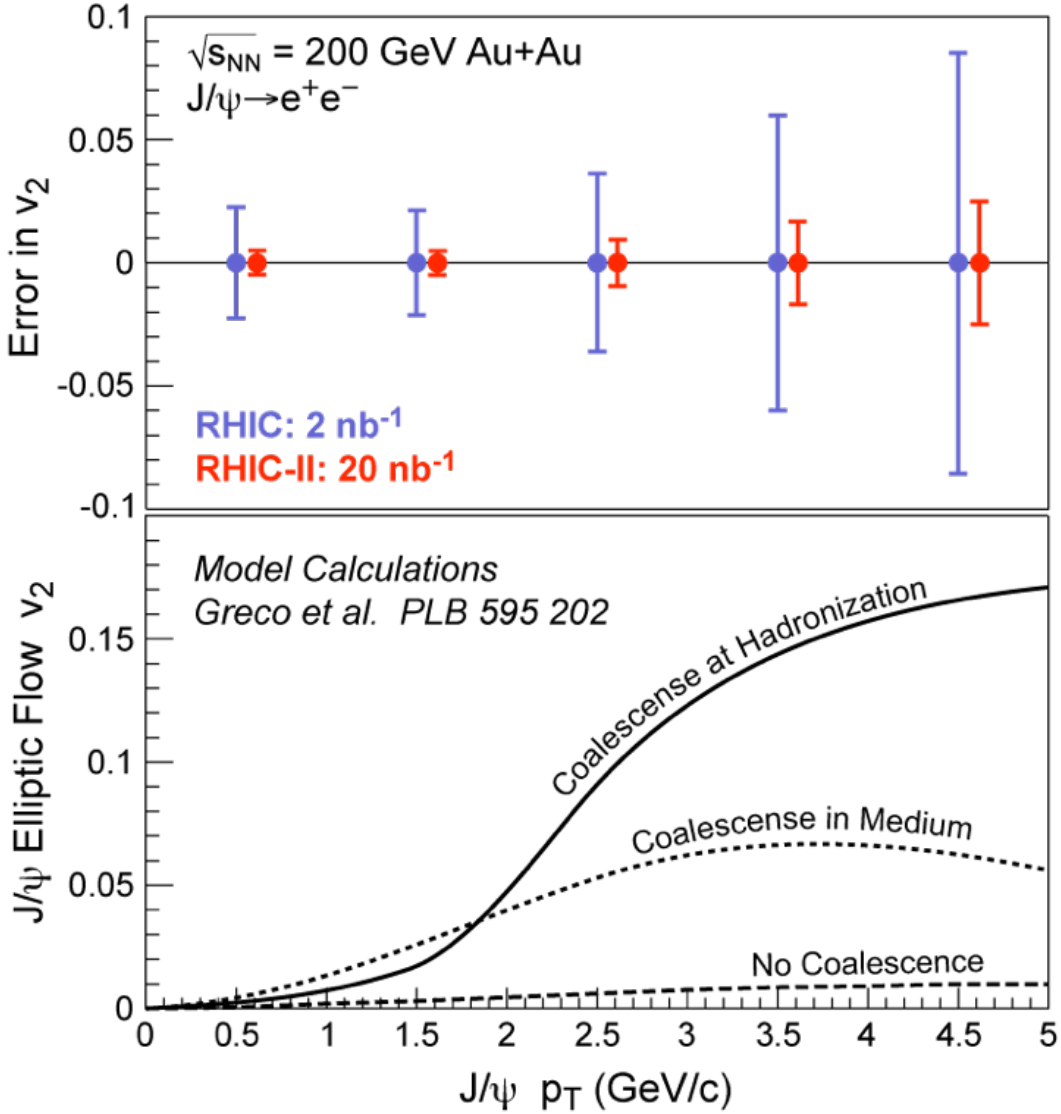
With detector upgrades (both PHENIX and STAR) and luminosity upgrade (one makes only sense with the other):

- Charm via D mesons: R_{AA} and v_2
- Bottom via $B \rightarrow J/\psi$ from prompt J/ψ using displaced vertex
- Bottom via electron/muons to high-p_T
- J/ψ and ψ' R_{AA} to high p_T
- Measure $\chi_c \rightarrow J/\psi+\gamma$ R_{AA} and study feeddown into J/ψ
- $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$ R_{AA}
- J/ψ v_2 measurements versus p_T.
- Open charm correlations with high statistics: e(from c)-h, e(from c)-D, D-h, D-h, e(from b)-h, ...
- Heavy Flavor measurements at low $\sqrt{s}$ (moderate p_T reach)

RHIC-II: Quarkonia



RHIC-II: J/ψ Elliptic Flow



RHIC II	LHC
Beams: **p to U** All combinations $\sqrt{s}$ = **5-200 GeV**	Beams: **p to Pb** p+p $\sqrt{s}$ = **14 TeV** p+Pb $\sqrt{s}$ = **8.8 TeV** Pb+Pb $\sqrt{s}$ = **5.5 TeV**
Central Au+Au: **$T \sim 2\ T_C$**	**Central Pb+Pb:** **$T \sim 4\ T_C$**
Detectors: PHENIX, STAR	**Detectors:** ALICE, ATLAS, CMS
24 weeks / year physics Average luminosity 7×10^{27} cm^{-2} s^{-1} **Integrated A_1A_2 $\int Ldt = \sim 1$ fb^{-1} (year)** **Au+Au lum/year: 20 nb^{-1}**	4 weeks / year physics Average luminosity 5×10^{26} cm^{-2} s^{-1} **Pb+Pb luminosity/year: 500 μb^{-1}**
$\int Ldt$ (RHIC)/ $\int Ldt$ LHC = **36** σ (J/ψ)LHC = σ (J/ψ)RHIC × **13** σ (Υ)LHC = σ (Υ)RHIC × **55**	
$N_{cc} \sim 10$ $N_{bb} \sim 0.05$ (central)	**$N_{cc} \sim 115$ $N_{bb} \sim 5$ (central)**

RHIC-II - Heavy Flavor Yields (Au+Au)

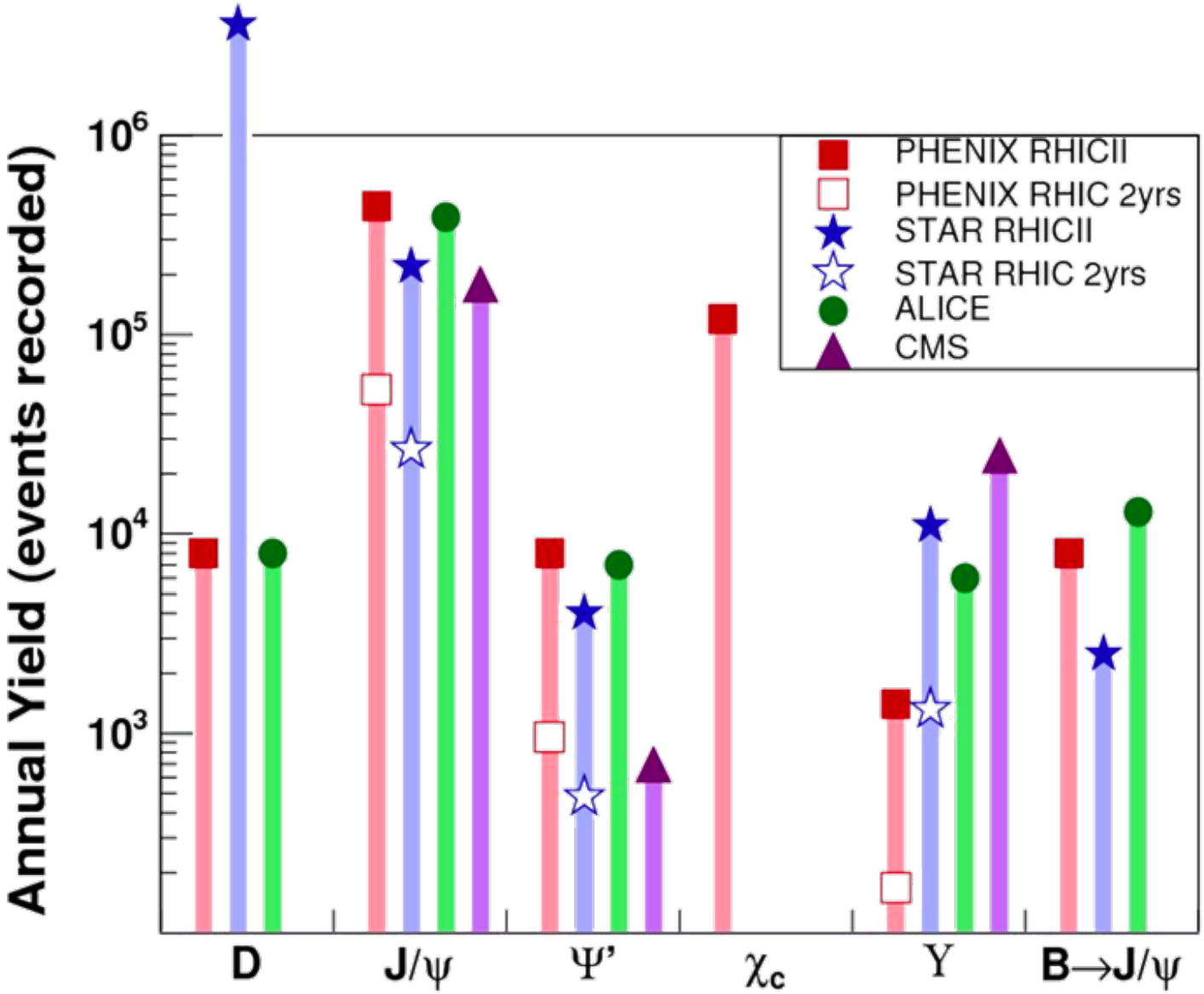
All numbers are first rough estimates (including trigger and reconstruction efficiencies) for 12 weeks physics run ($\int L_{eff}\, dt \sim 20\ nb^{-1}$)

Signal	RHIC Exp.	Obtained	RHIC-I (>2008)	RHIC-II	LHC / ALICE+
$J/\psi \rightarrow e^+e^-$	PHENIX	~800	3,300	45,000	9,500
$J/\psi \rightarrow \mu^+\mu^-$		~7000	29,000	395,000	740,000
$\Upsilon \rightarrow e^+e^-$	STAR	-	830	11,200	2,600
$\Upsilon \rightarrow \mu^+\mu^-$	PHENIX	-	80	1,040	8,400
$B \rightarrow J/\psi \rightarrow e^+e^-$	PHENIX	-	40	570	N/A
$B \rightarrow J/\psi \rightarrow \mu^+\mu^-$		-	420	5,700	N/A
$\chi_c \rightarrow e^+e^-\gamma$	PHENIX	-	220	2,900*	N/A
$\chi_c \rightarrow \mu^+\mu^-\gamma$		-	8,600	117,000*	N/A
$D \rightarrow K\pi$	STAR	$\sim 0.4\times10^6$ (S/B~1/600)	$\sim 1\times10^6$ (S/B ~ 1:600)	9×10^6** (S/B ~ 1:10)	?

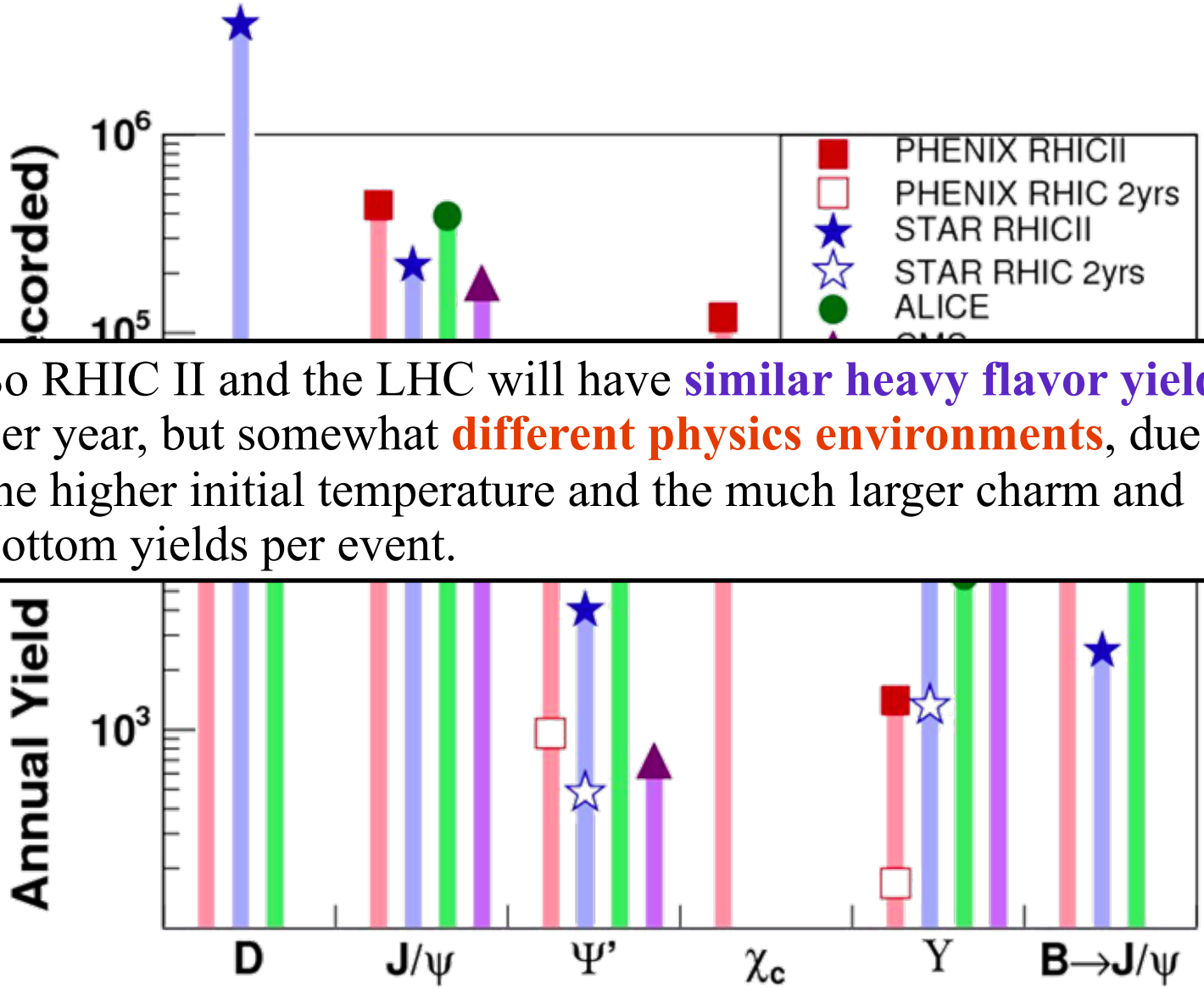
T. Frawley, TU, R. Vogt:
HF RHIC-II WG Writeup

* Large backgrounds, quality uncertain as yet
** Running at 500 Hz
+ 1 month (= year), P. Crochet, EPJdirect A1, a (2005) and private comm.

RHIC-II - Heavy Flavor Yields (Au+Au)

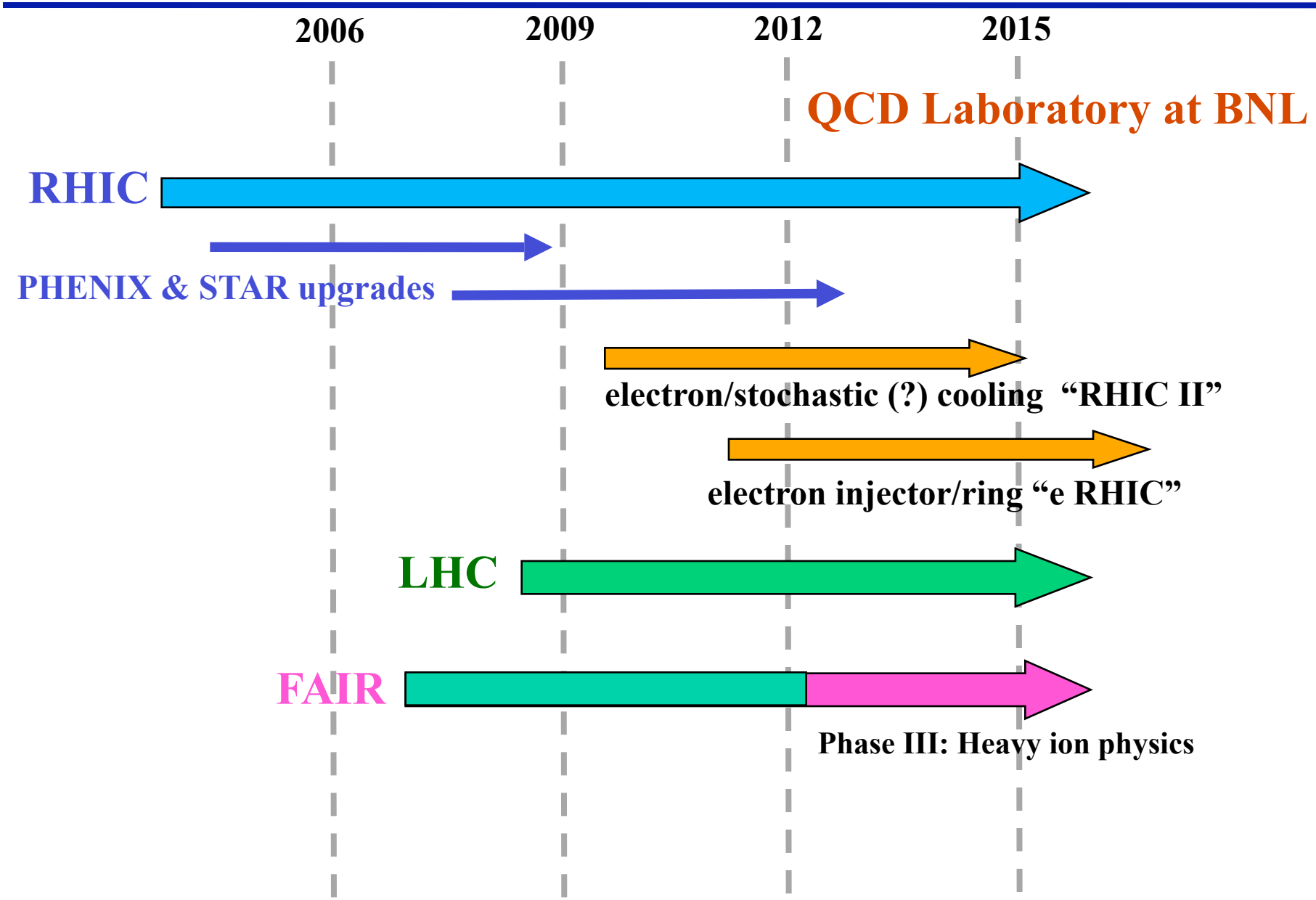


RHIC-II - Heavy Flavor Yields (Au+Au)



So RHIC II and the LHC will have **similar heavy flavor yields** per year, but somewhat **different physics environments**, due to the higher initial temperature and the much larger charm and bottom yields per event.

Long Term Timeline of Heavy Ion Facilities



Summary

RHIC II and the detector upgrades bring us dramatically expanded capabilities for heavy flavor physics

- Detector upgrades well underway (provided full funding)
- RHIC-II == cooling ?
  - e-cooling (2012 - 2015 and expensive)
  - stochastic cooling (earlier, less expensive, not as powerful as e-cooling)

Summary

RHIC II and the detector upgrades bring us dramatically expanded capabilities for heavy flavor physics

- Detector upgrades well underway (provided full funding)
- RHIC-II == cooling ?
  - e-cooling (2012 - 2015 and expensive)
  - stochastic cooling (earlier, less expensive, not as powerful as e-cooling)

✓ Mid-term future at RHIC is well defined and looks bright

⊙ The long term future is less well defined

- new upgrades/detectors ?
- eRHIC (when?)

Backup

Thanks Guys ...

Ernst Sichtermann

Glenda Fish

Hans Georg Ritter

Nu Xu

RHIC-II – Open Heavy Flavor

- With detector upgrades (both PHENIX and STAR):
  - Dramatically reduce backgrounds for all open charm, open beauty signals using displaced vertex measurement.
  - Separate $B \rightarrow J/\psi$ from prompt J/ψ using displaced vertex.

RHIC-II – Open Heavy Flavor

- With detector upgrades (both PHENIX and STAR):
  - Dramatically reduce backgrounds for all open charm, open beauty signals using displaced vertex measurement.
  - Separate $B \rightarrow J/\psi$ from prompt J/ψ using displaced vertex.

- And with the luminosity upgrade:
  - Extend open charm and beauty R_{AA} measurements to high p_T. What is the energy loss well above the thermalization region?
  - Measure D & semileptonic charm decay v_2 to high p_T. See the transition from thermalization to jet energy loss for charm.
  - Measure open charm correlations with open charm or hadrons.
  - Luminosity upgrade will also provide high enough luminosity to enable basic heavy flavor measurements at lower energies, where cross sections are smaller.

RHIC-II - Quarkonia

- With detector upgrades:
  - J/ψ from B decays with displaced vertex measurement (both).
  - Reduce $J/\psi \rightarrow \mu\mu$ background with forward μ trigger in PHENIX.
  - Improve mass resolution for charmonium and resolve Υ family.
  - See γ in forward calorimeter in front of muon arms (PHENIX) and in FMD in STAR

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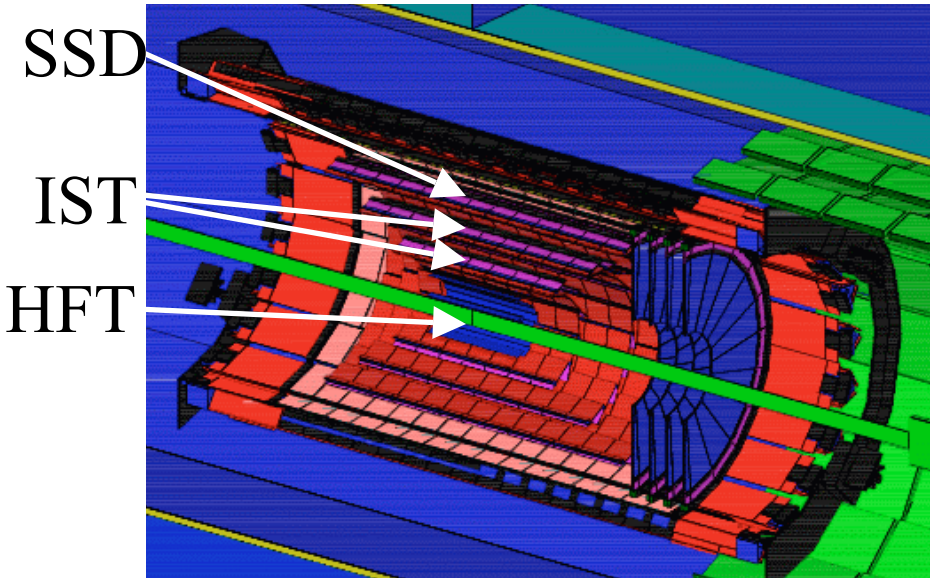
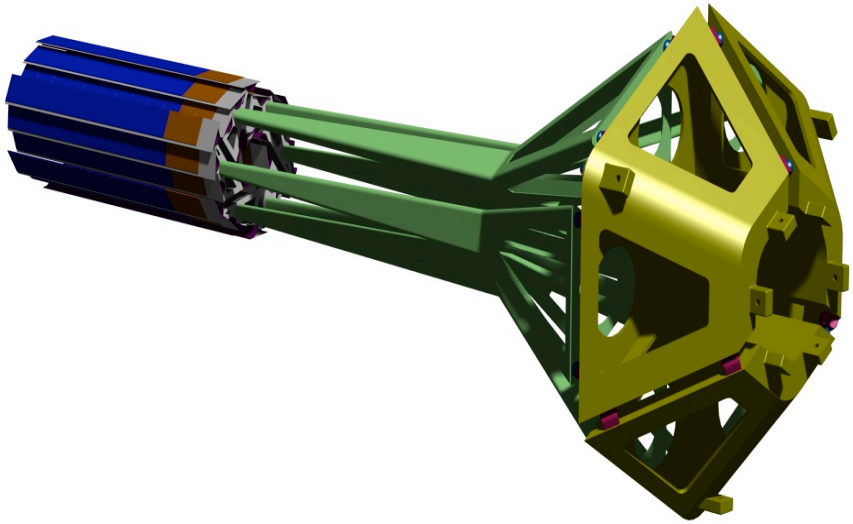
  - J/ψ from B decays with displaced vertex measurement (both).
  - Reduce $J/\psi \rightarrow \mu\mu$ background with forward μ trigger in PHENIX.
  - Improve mass resolution for charmonium and resolve Υ family.
  - See γ in forward calorimeter in front of muon arms (PHENIX) and in FMD in STAR
- And with the luminosity upgrade:
  - J/ψ R_{AA} to high p_T. Does J/ψ suppression go away at high p_T?
  - J/ψ v_2 measurements versus p_T. See evidence of charm recombination?
  - Υ R_{AA}. Which Upsilons are suppressed at RHIC?
  - Measure $\chi_c \rightarrow J/\psi+\gamma$ R_{AA}. Ratio to J/ψ?
  - Measure Ψ' R_{AA}. Ratio to J/ψ?
  - Measure $B \rightarrow J/\psi$ using displaced vertex - independent B yield measurement, also get background to prompt J/ψ measurement.
  - Low energy measurements of J/ψ rapidity and p_T distributions
    - Recombination vs. suppression changes as function of $\sqrt{s}$

New STAR Heavy Flavor Tracker: SSD + IST + PXL

Strategy:

- Keep existing Silicon Strip Det. (SSD)
- Remove current SVT (Silicon Drift)
  - Run 7 was last run
- Add intermediate layer (IST)
  - 2 layers of Si-strip detectors
- Add Active Pixel Layers (PXL):
  - 2 layers CMOS Active Pixel sensors
  - 50 μm thin Si to minimize MCS
  - Pixel dimension: 30 μm × 30 μm
  - Resolution: ~10 μm
  - Detector Chip active area: 19.2 mm × 19.2 mm
  - Detector Chip pixel array: 640 × 640
  - Inner barrel (6 ladders): r = 1.5 cm
  - Outer barrel (18 ladders): r = 5.0 cm
  - Ladder (w/Al cable) % X_0 = 0.28% (0.38%)
  - Beam Pipe Thickness: 0.5 mm or 0.14% X_0





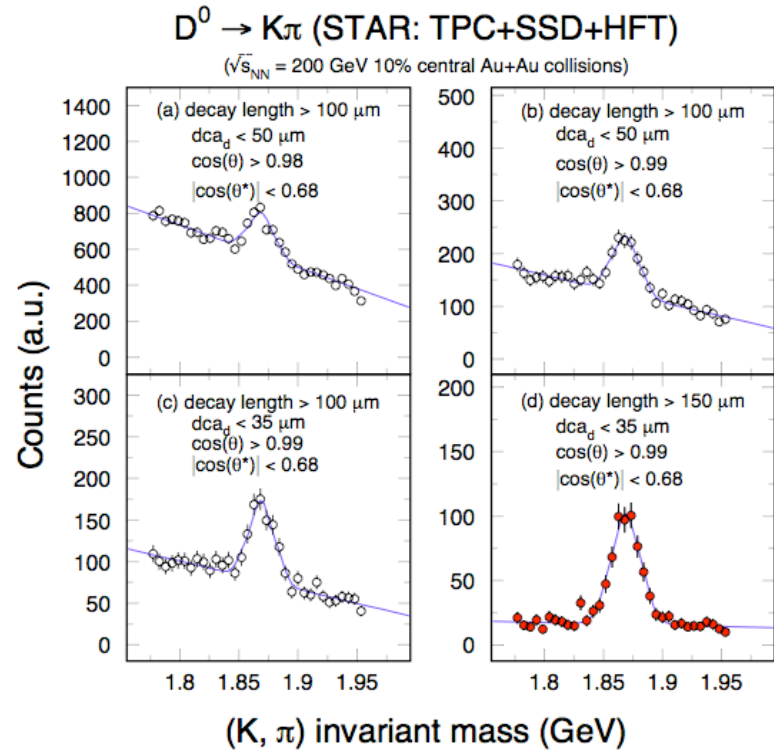
Status:

- ongoing R&D
- CD-0 in January

New STAR Inner Tracker System

Impact on Heavy Flavor Physics:

- Direct Topological reconstruction of Charm
  - Detect charm decays with small cτ, including $D^0 \rightarrow K\pi$
- New physics
  - Charm v_2 to test thermalization
  - Charm Energy Loss



Elliptic flow v_2 vs p_T at 10% error

p_T (GeV/c)	Δp_T (GeV/c)	# of Events q_c does flow	# of Events, q_c does not flow
0.6	0.2	260×10^6	525×10^6
1.0	0.5	70×10^6	140×10^6
2.0	0.5	53×10^6	125×10^6
3.0	1.0	105×10^6	175×10^6
5.0	1.0	210×10^6	440×10^6

Current data rate: 100×10^6 per run
DAQ1000: x10 rate

New STAR Inner Tracker System

Impact on Heavy Flavor Physics:

- Direct Topological reconstruction of Charm
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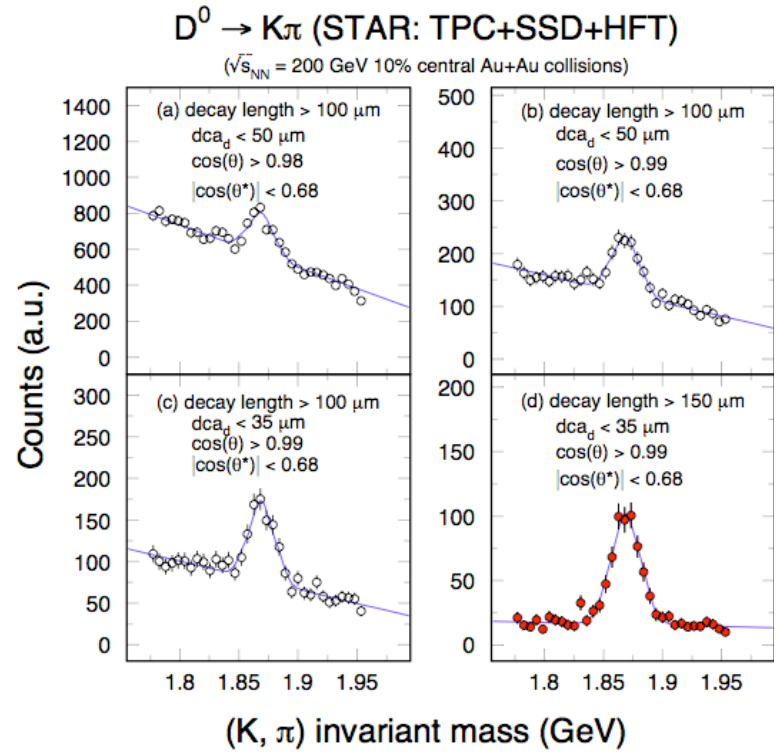


Spectra vs p_T at 10% error

p_T (GeV/c)	Δp_T (GeV/c)	# of Events, p+p	# of Events, 0-10% Au+Au
1.0	0.5	44×10^6	0.45×10^6
2.0	0.5	70×10^6	0.45×10^6
3.5	1.0	70×10^6	0.45×10^6
5.5	1.0	350×10^6	0.75×10^6
7.5	1.0	1200×10^6	3.5×10^6
10.5	1.5	7500×10^6	9×10^6

Current data rate: 100×10^6 per run
DAQ1000: x10 rate

Full Barrel Time-of-Flight Detector

Parameter:

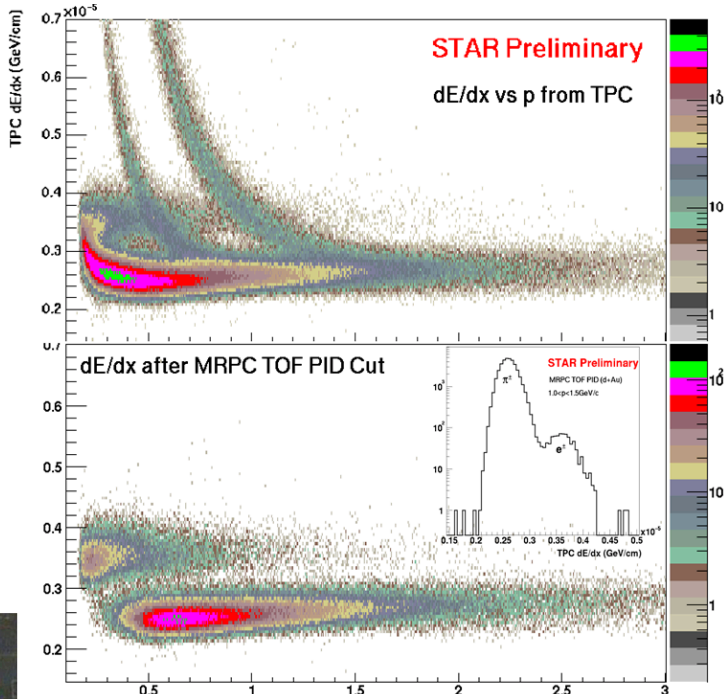
- State-of-art Multi-Gap Resistive Plate Chamber
- $-0.9<\eta<0.9$, $0<\phi<2\pi$
- 6 gap, 3x6 cm^2 pad, 23,000 channels

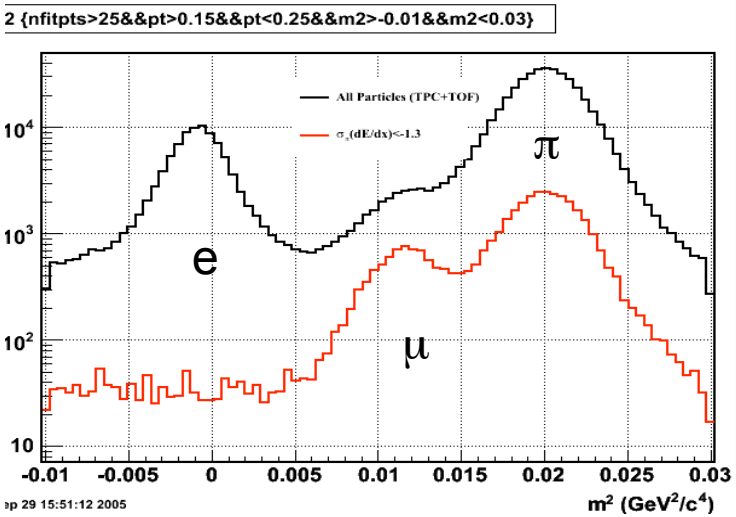
Status:

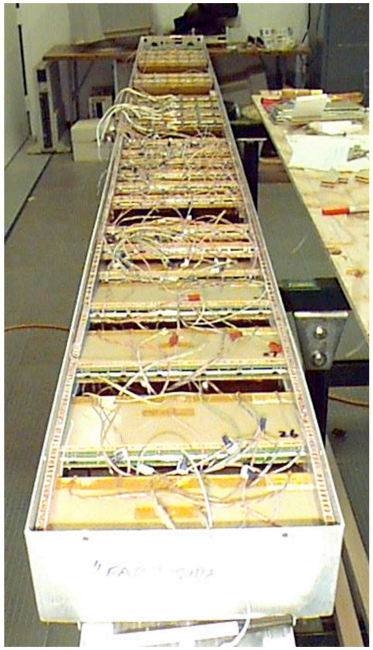
- Funded, under construction, completed in FY08

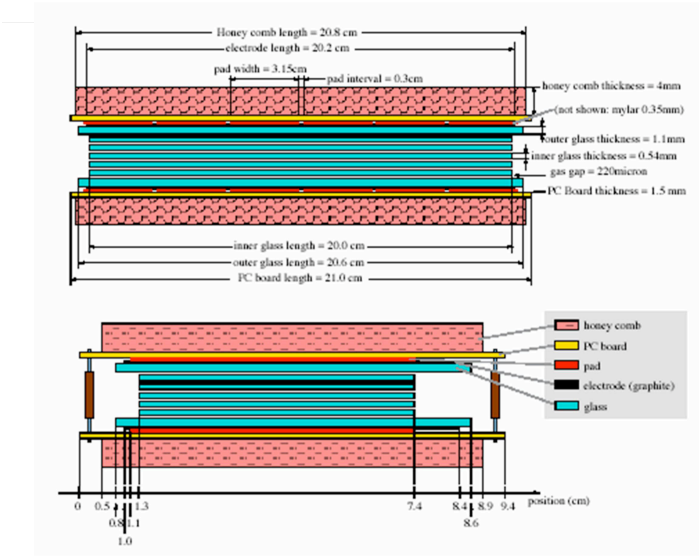
Impact on Heavy Flavor:

- Improved $D \rightarrow K\,\pi$ reconstruction
- Excellent Electron ID (J/ψ range $0.2<p<4$ GeV/c)
- J/ψ trigger in Au+Au
- low-pT μ ID (0.2 GeV/c)



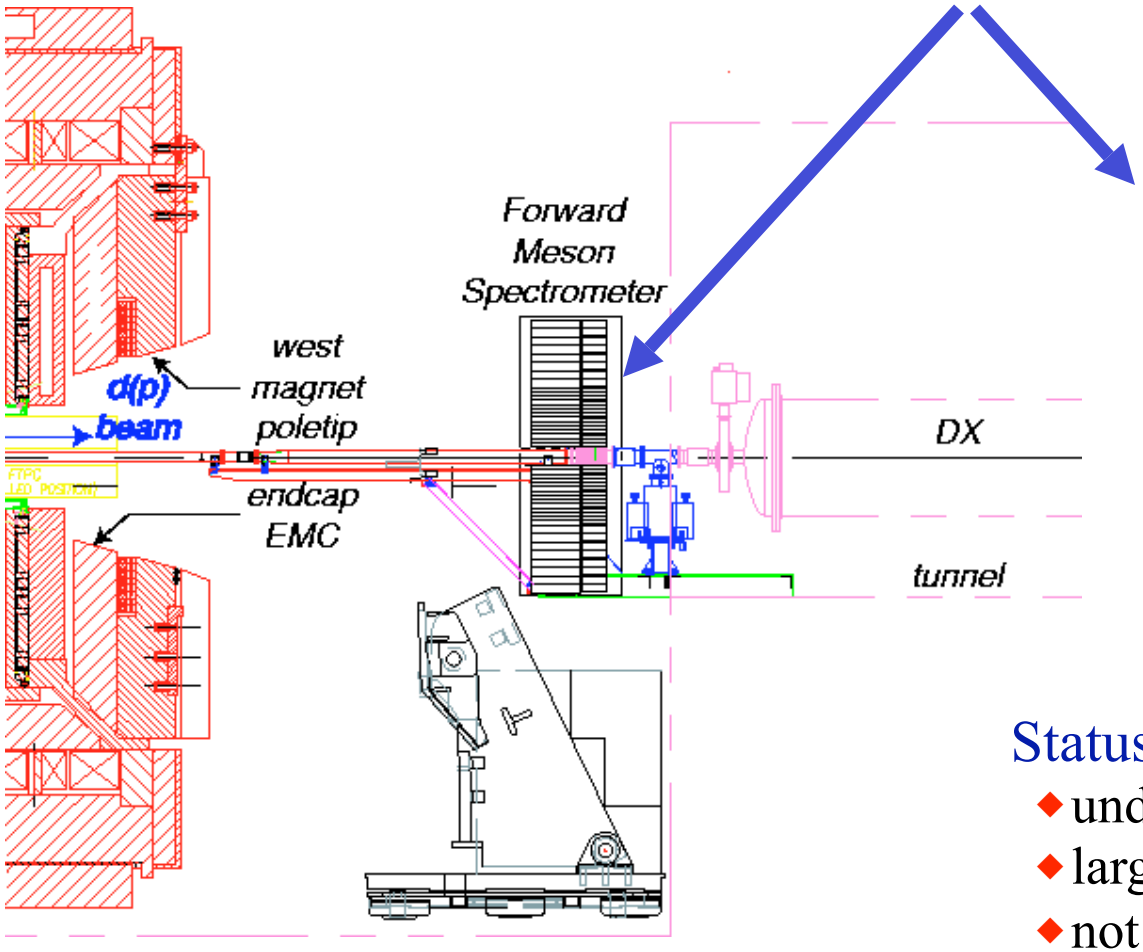




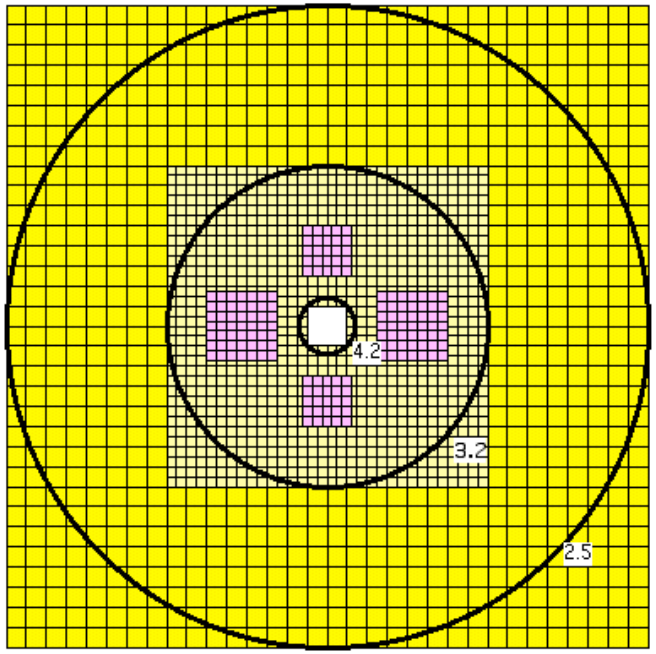


The Forward Meson Spectrometer

Side View of the East Pole Tip



End View of the PbGl Array



Status:

- under construction
- large fraction in place for next run
- not part of official mid-term plan

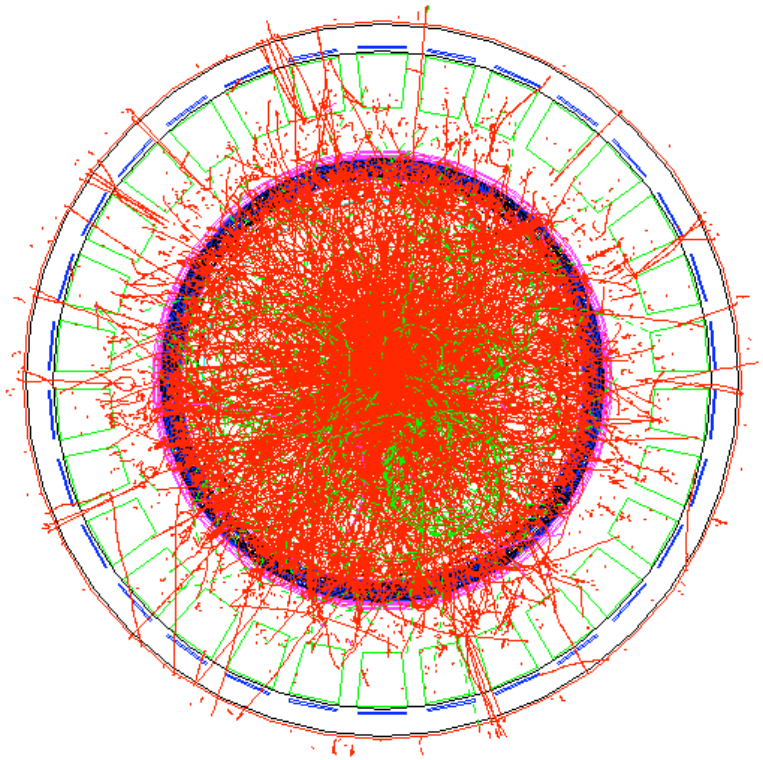
Impact on Heavy Flavor:

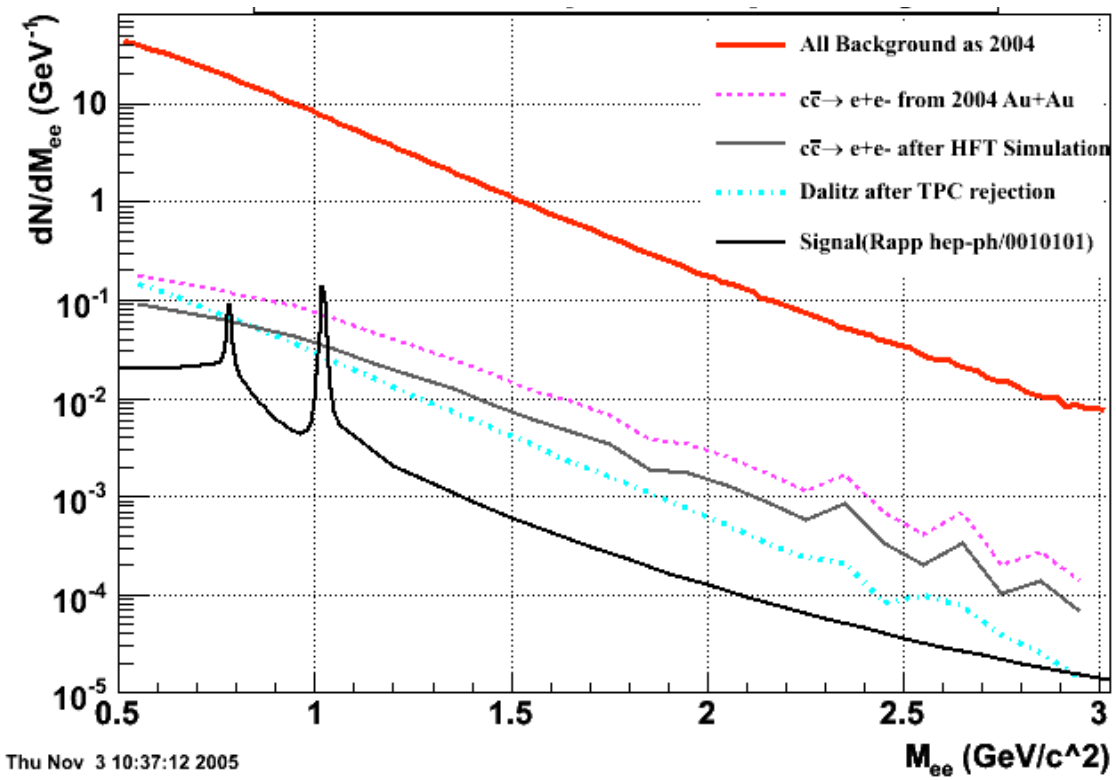
- J/ψ at $2.5 < \eta < 4.2$
- D mesons via $D^0 \rightarrow \bar{K}^0 \pi^0$

Parameters:

- ~ 2.4 m square PbGlass, ~ 1500 PMTs
- Granularity: 3.8 × 3.8 cm inner, 7.6 × 7.6 cm outer

Other STAR Initiative: Central Muon Detector

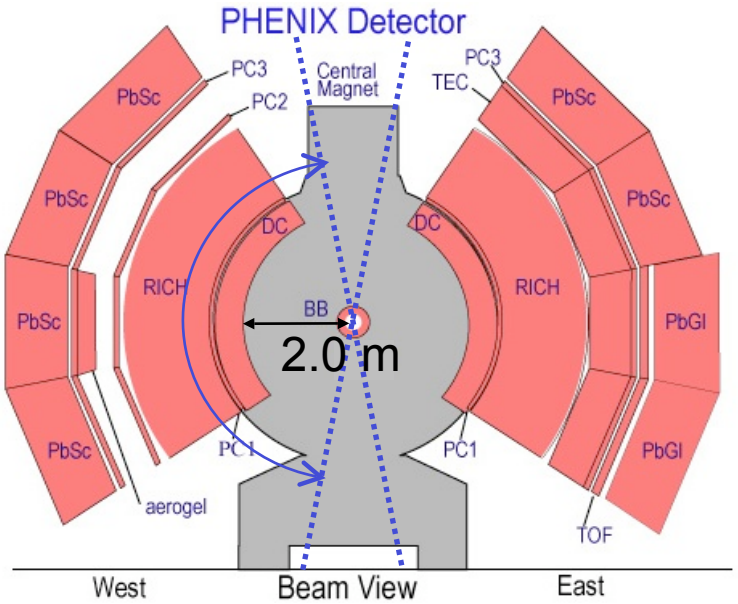




Muon Tracking Detector: use magnet steel as absorber, old CTB (scintillator slats) and new MRPC layers for detection

- Dileptons from intermediate mass up to quarkonia states
- Dielectrons using TOF for ID and HFT for background rejection

PHENIX - VTX Upgrade



Parameters:

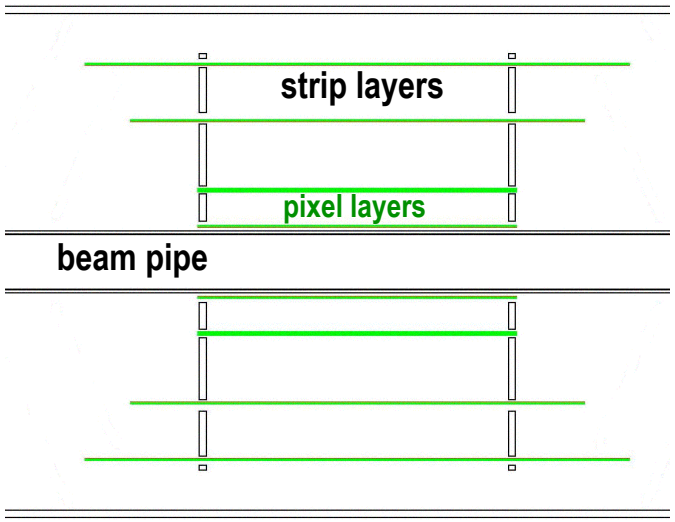
- Covers the acceptance of central arms
- $|\eta|<1.2$, $\sim 2\pi$, $\Delta z \sim \pm 10$ cm

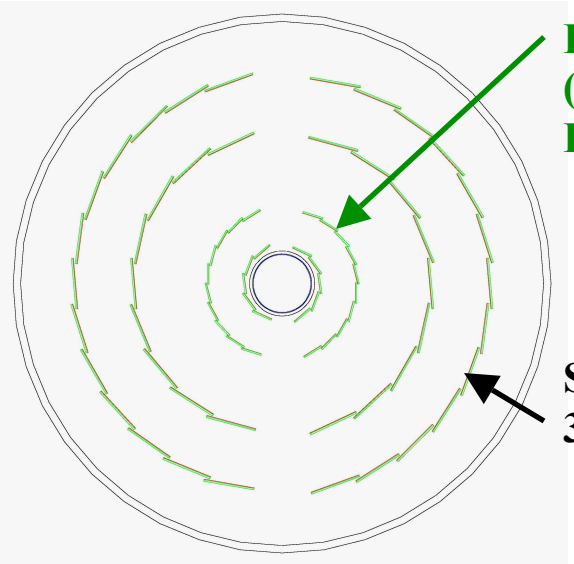
Impact on Heavy Flavor:

- D, B, non-photonic *e* physics

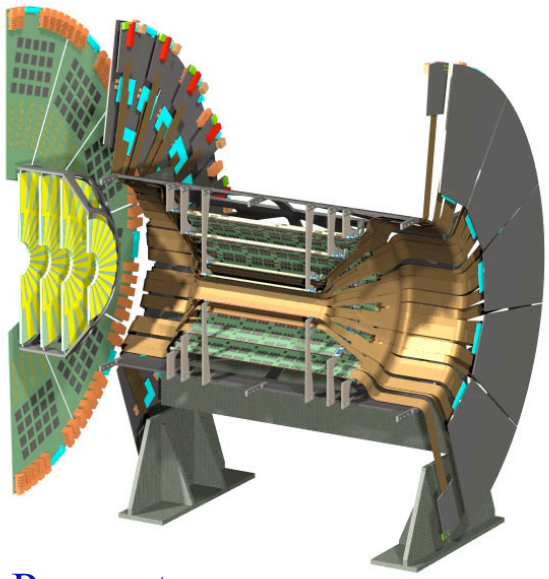
Status:

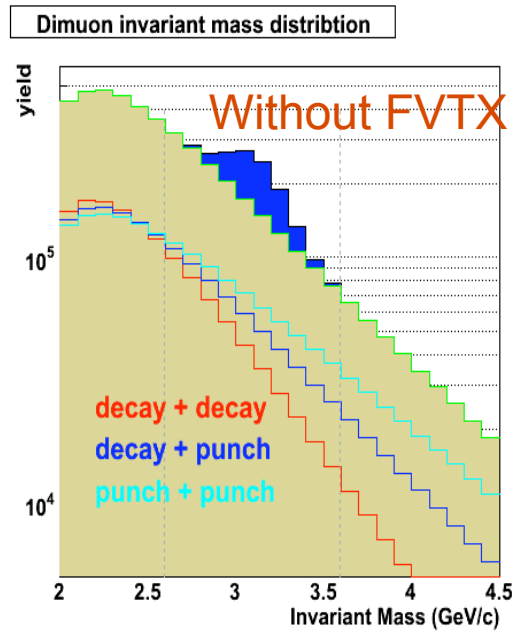
- Proposal submitted to DOE 2004:
  - ~$3M committed by RIKEN
  - Total Project Cost = $4.6M
  - In President's Budget for FY07

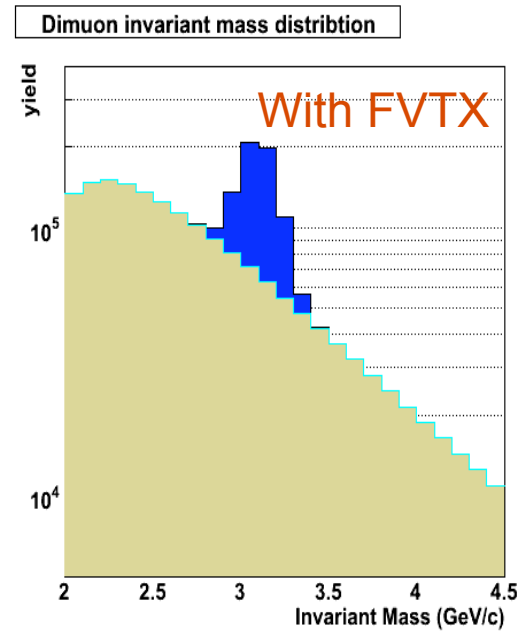




Forward Silicon Vertex







Parameters:

- 4 layers
- Vertical planes
- 75 μm radial pitch, 7.5° phi segmentation (2 – 13 mm)
- Maximize z and r extent to give good resolution and ≥3 hits/track as much as possible
- 2*600K channels
- z-vertex resolution ~ 130 mm

Status

- Submitted proposal to DOE for FY08 funding start

Impact on heavy flavor measurements:

- Secondary vertex ⇒ charm/bottom
- Allows B → J/ψ + X measurement
- Relatively free of background because prompt AND displaced B-decay vertex can be reconstructed
- Allows Drell-Yan measurements (separate DY from open charm)
- Improves/Enables Ψ' measurement

Nosecone Calorimeter (NCC)

Parameters

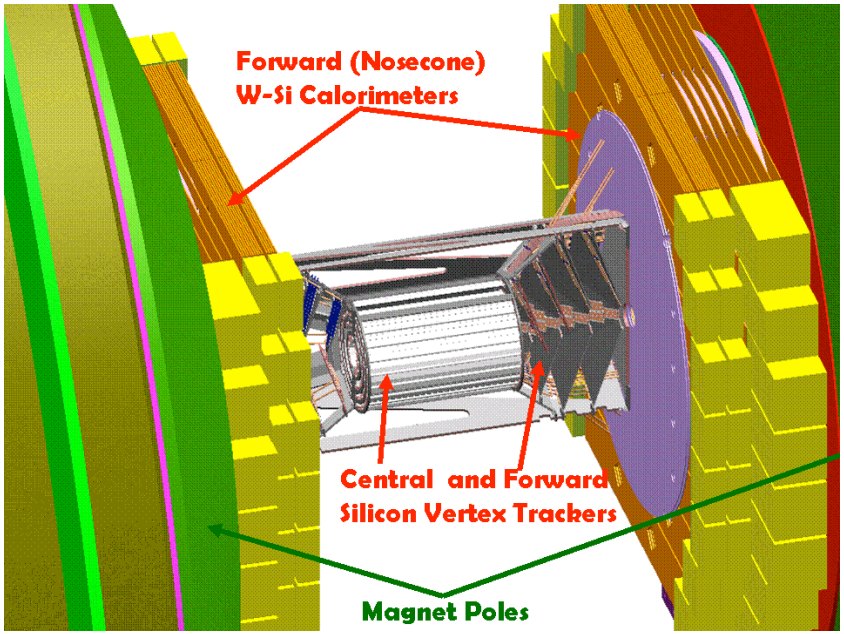
- Large acceptance calorimeter $0.9 < \eta < 3.0$
- 40 cm from collision vertex
- 20 cm depth
- EM calorimeter ~42 X/X_o
- hadronic section (1.6 λ/λ_0)
- Tungsten with Silicon readout

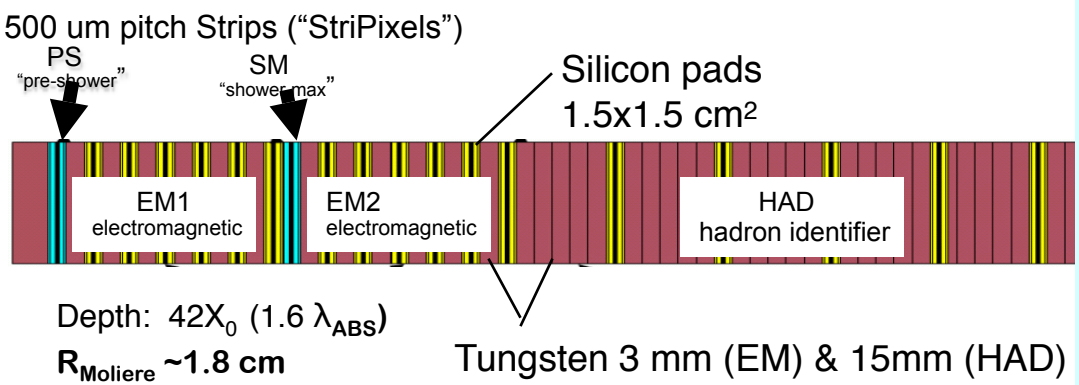
Impact on heavy flavor

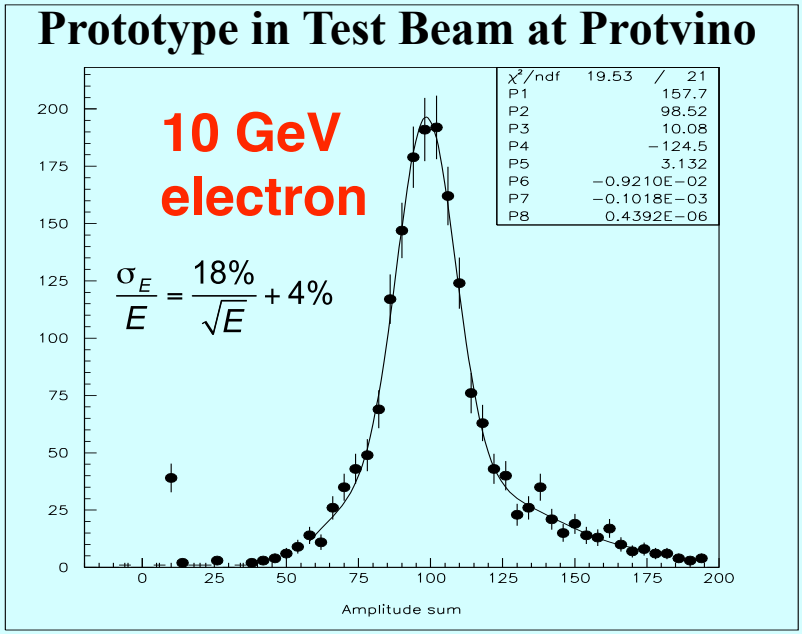
- $\chi_c \rightarrow J/\psi + \gamma$

Status

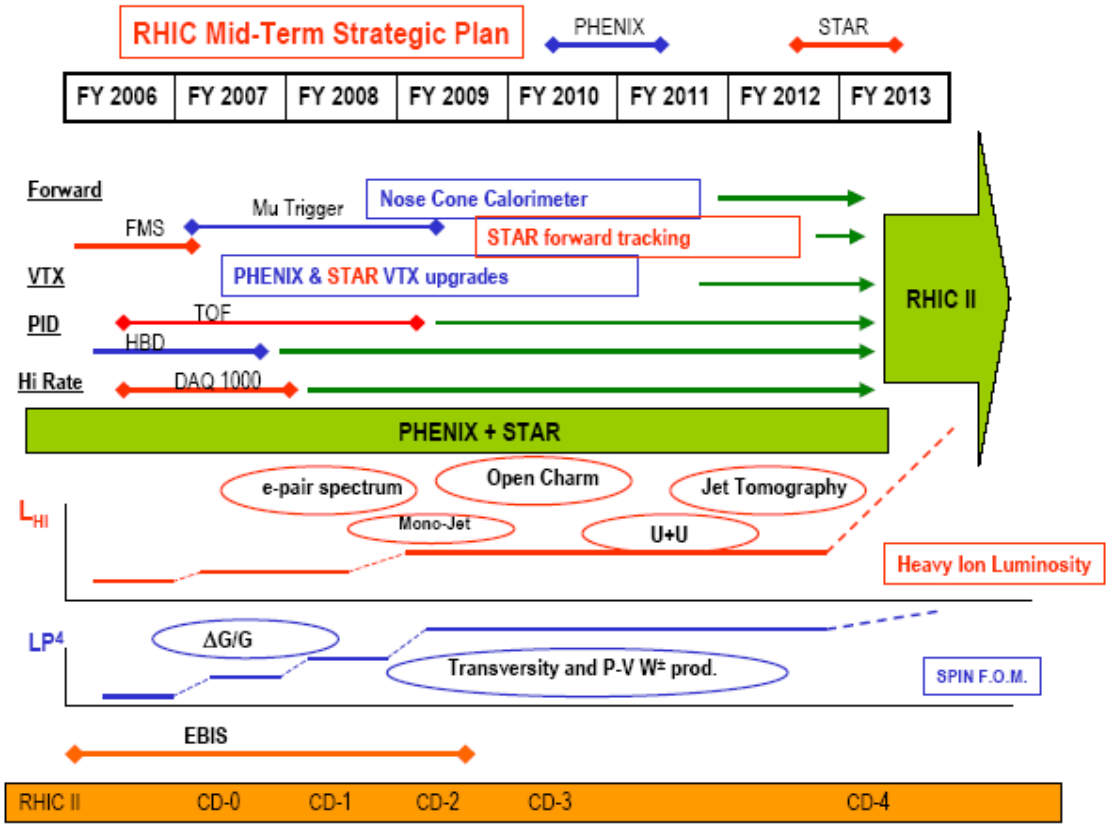
- Submitted to DOE for FY08 funding
- Construction FY08 – FY10







Mid-term Strategy for RHIC Facility



Detector upgrades relevant for heavy flavor:

- Particle identification → improved electron PID, improved PID range for charm decay daughters
- Displaced vertex detection → open charm and bottom
- Increased rate and acceptance → quarkonium & open heavy flavor yields
- Forward detectors → heavy flavor probing the CGC, increased x_F and y range, χ_c measurement

There are several upgrades that do not directly address heavy flavor that I will not discuss in the following. For more see:
http://www.bnl.gov/henp/docs/RHICplanning/RHIC_Mid-termplan_print.pdf

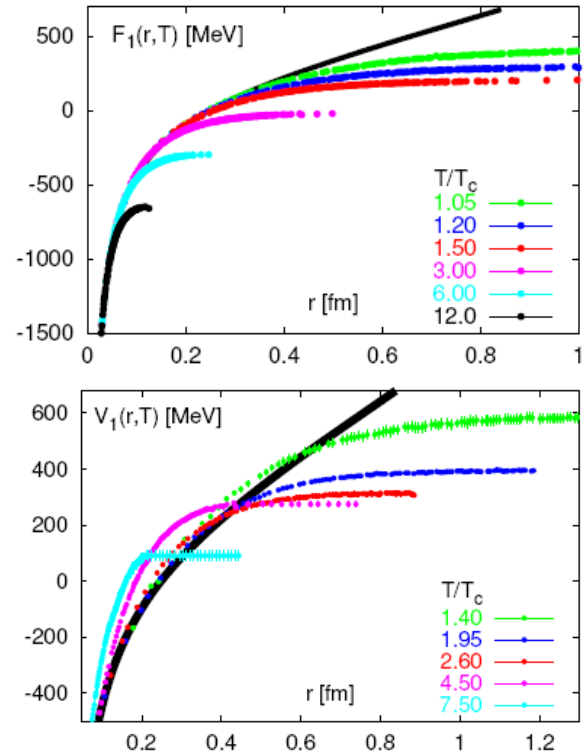
Quarkonia – Lattice QCD …

Recent developments:

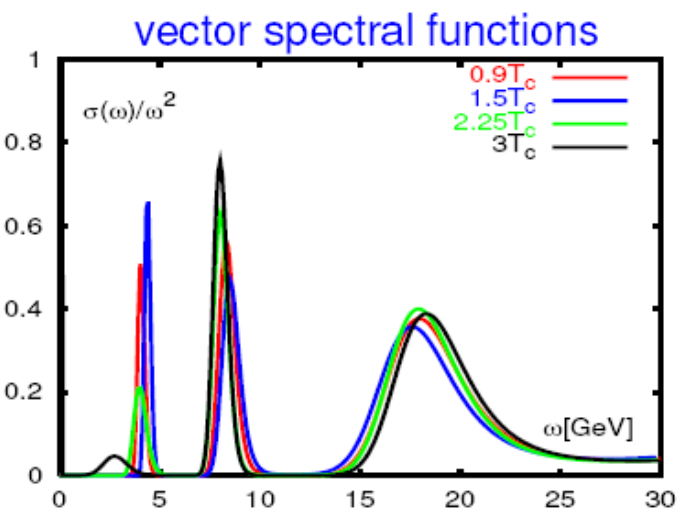
- Heavy Quark potential?
  - Singlet free energy: F_1 (entropy term?)
  - Singlet energy: V_1
- When do states really melt?
  - Neither F_1 nor V_1 are potentials, they are models!

  ⇒ spectral functions (results consistent with V_1)

  ⇒ J/ψ melts at 1.5-2.5 T_C



F. Karsch, RHIC-II Science Workshop



using F_1: S. Digal, P. Petreczky, H. Satz, Phys. Lett. B514 (2001) 57;

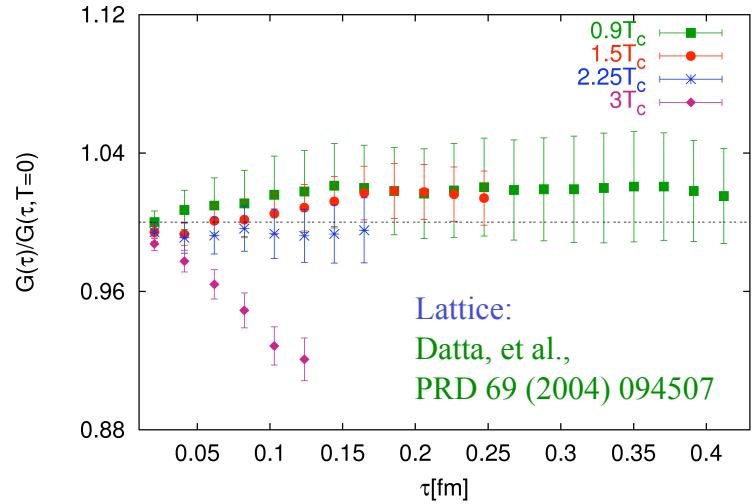
using V_1: C.-Y. Wong, hep-ph/0408020;

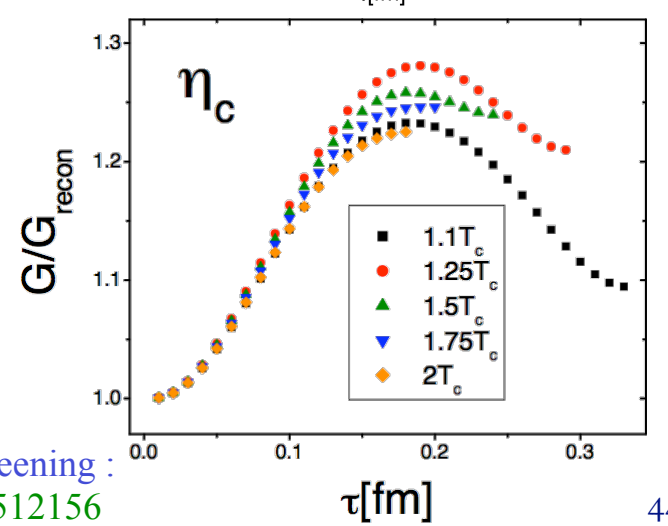
state	J/ψ	χ_c	ψ'	Υ	χ_b	Υ'	χ_b'	Υ''
E_s^i [GeV]	0.64	0.20	0.05	1.10	0.67	0.54	0.31	0.20
T_d/T_c	1.1	0.74	0.1 - 0.2	2.31	1.13	1.1	0.83	0.74
T_d/T_c	~ 2.0	~ 1.1	~ 1.1	~ 4.5	~ 2.0	~ 2.0	–	–

Just When You Think You Start to Understand …

Charmonia correlators: potentials vs. lattice *(Mócsy, Petereczky, hep-ph/0512156)*

- Lattice ⇒ reliable calculation of η_c and χ_c correlators
- Taking F,V as plain (Cornell) potentials ⇒ calculate correlators
- Temperature-dependence of η_c and χ_c lattice correlators is **not** explained with screened Cornell potential.
- Screening likely not responsible for quarkonia suppression
  - time scale of screening not small compared to time scale of heavy quark motion
- So why is it suppressed then in LQCD?
- Suppression from collisions with thermal gluons only?
  - $dN_{J/\psi}/dt = -N_g \langle \sigma_{dis} \rangle$
- Overall "idea" still sound?





Potential model with screening :
Á. Mócsy, P.P, hep-ph/0512156

So Let the Data Speak … but wait …

Need to sort out a *few* things before we can extract pure "suppression" mechanism

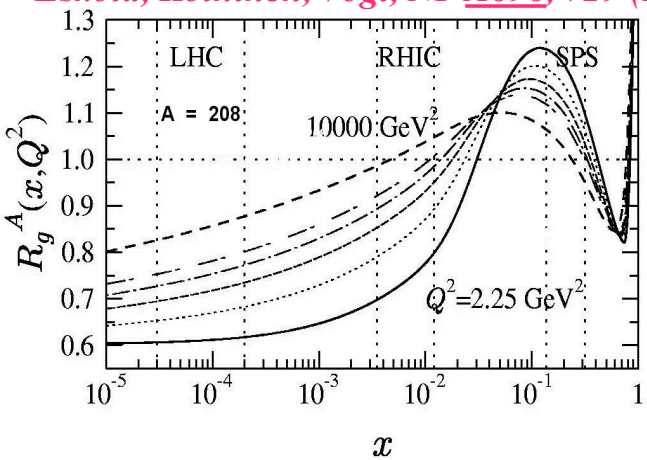
Modification of parton momentum distributions of nucleons embedded in nuclei

- shadowing – depletion of low-momentum partons (gluons)
- coherence & dynamical shadowing
- gluon saturation at small x – e.g. CGC model

Nuclear effects on parton "dynamics"

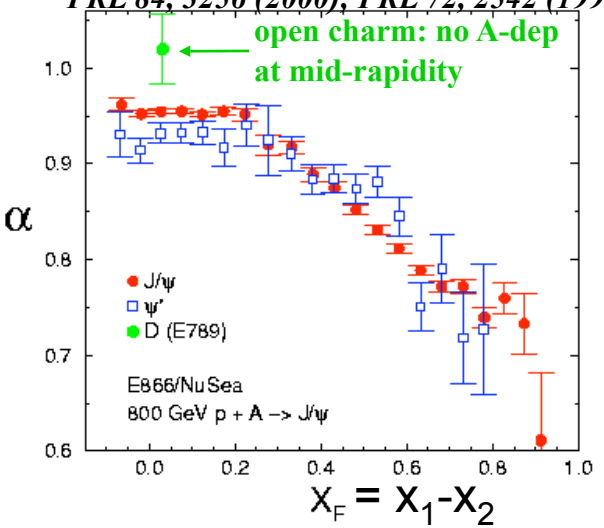
- absorption (or disassociation) of J/ψ by nucleons or co-movers
- energy loss of partons as they propagate through nuclei
- multiple scattering effects (Cronin effect) causing p_T broadening

Eskola, Kolhinen, Vogt, NP A696, 729 (2001)

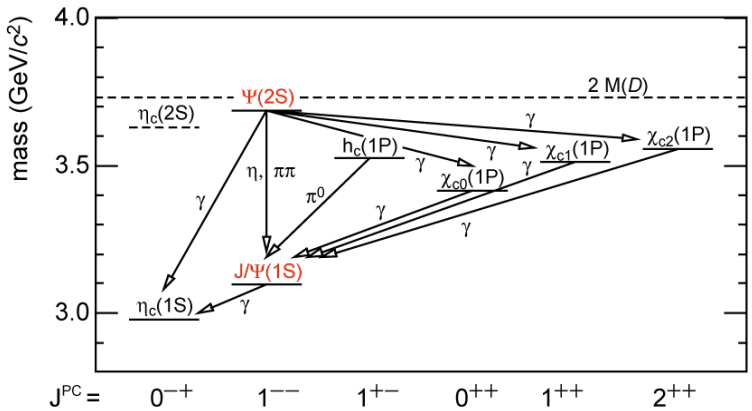


800 GeV p-A (FNAL) $\sigma_A = \sigma_p * A^\alpha$

PRL 84, 3256 (2000); PRL 72, 2542 (1994)

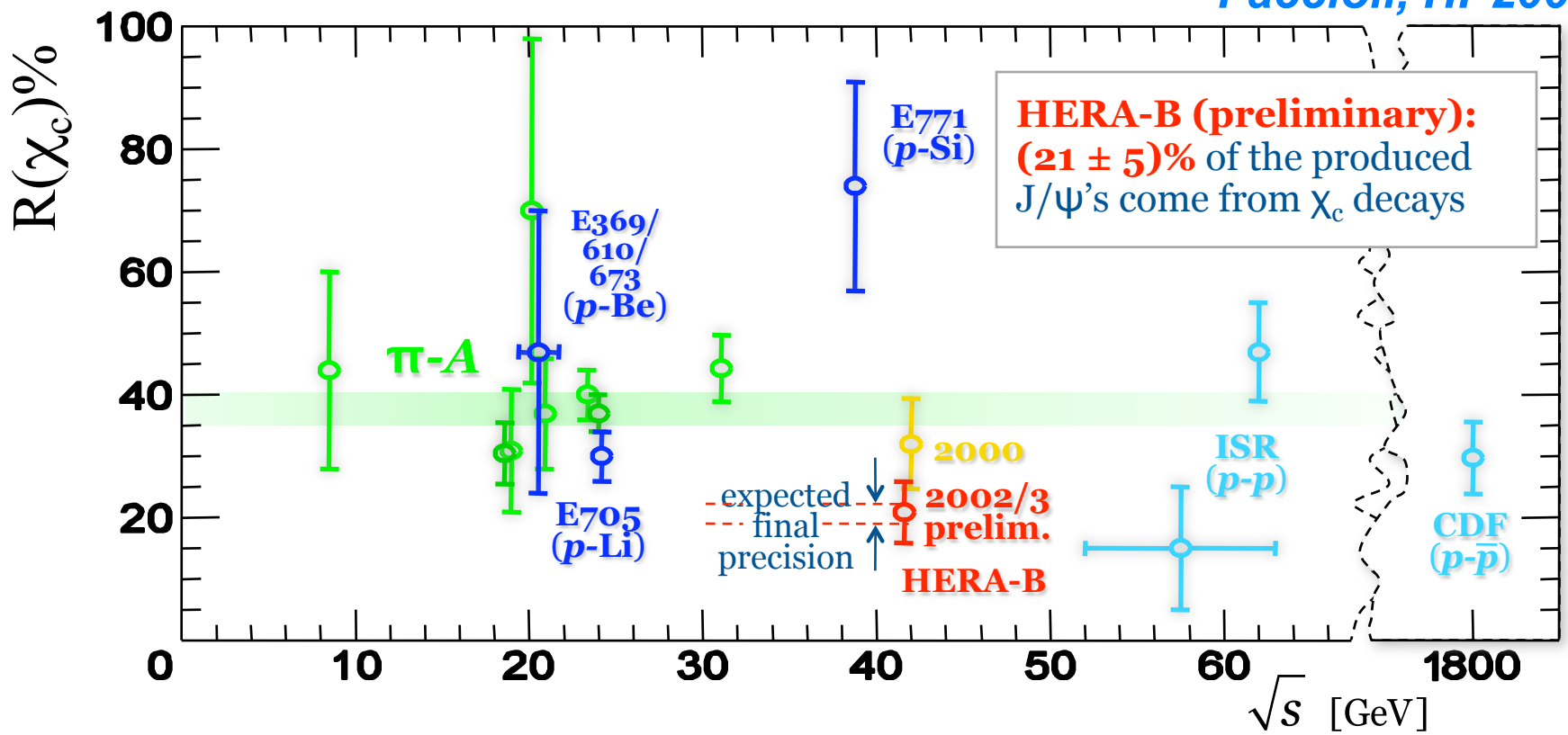


… and the list goes on …



- Feed down from χ_c and ψ':
  - Large from χ_c states
  - F. Karsch, D. Kharzeev, H. Satz, hep-ph/0512239 suggest SPS suppression due to feed-down?
  - Unknown at RHIC energies

Faccioli, HP2006



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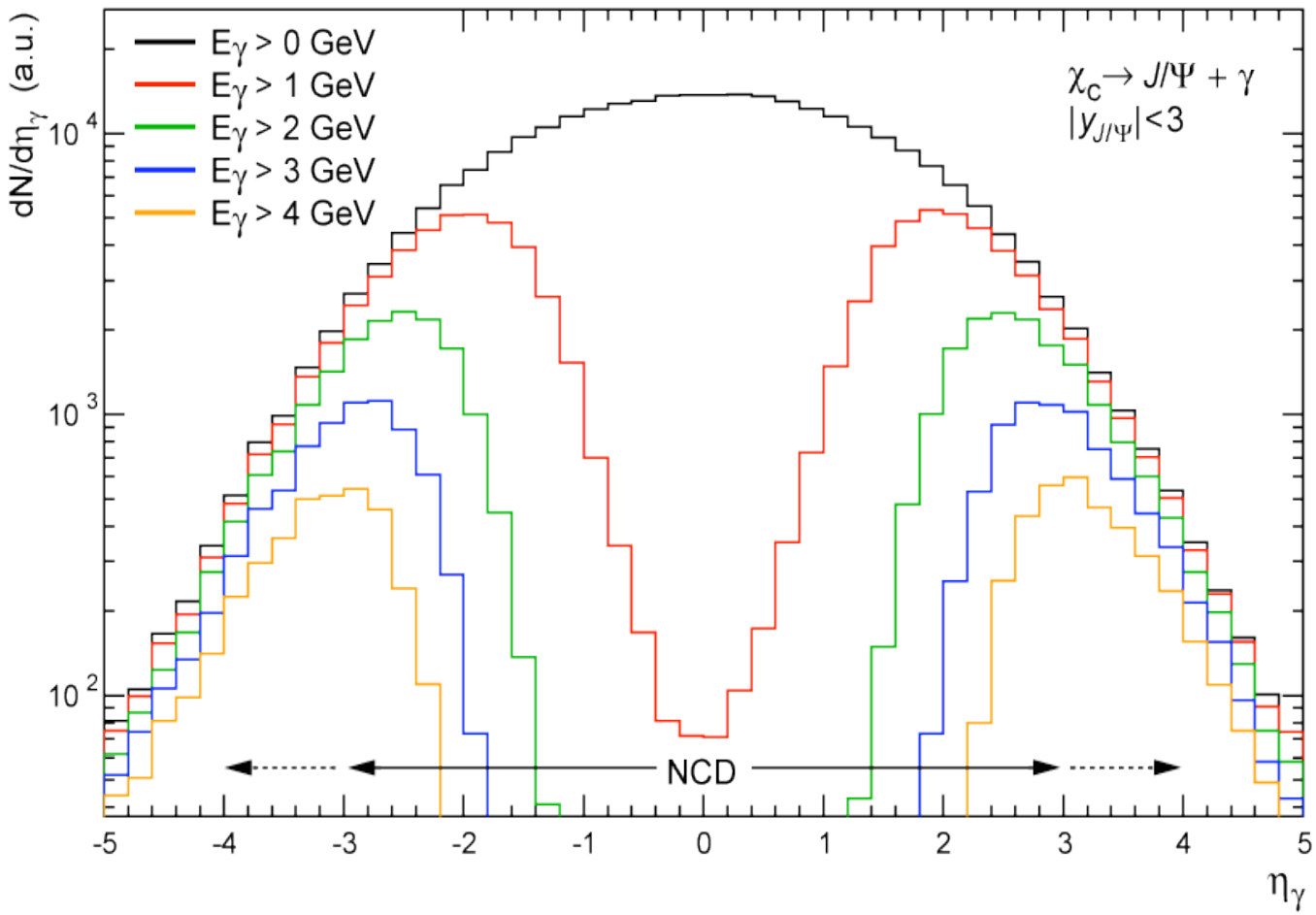
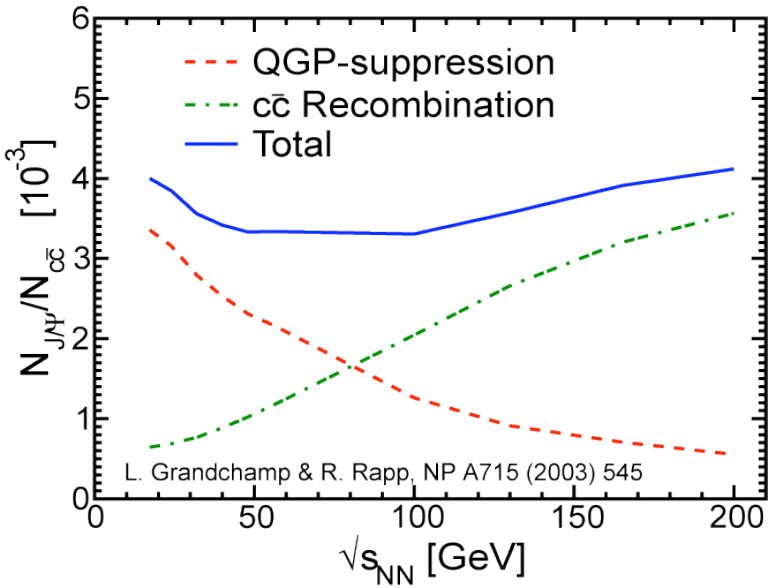


To measure χ_c decay & determine feed-down to J/ψ via $\chi_c \rightarrow J/\psi + \gamma$

- must have large forward acceptance for γ or
- accept large background (low S/B) at mid-rapidity

… and on

- Other sources of quarkonia production
  - Statistical coalescense (thermal production)
    - too small at RHIC – larger at LHC ?
  - Dynamic coalescence
    - coalescence: $\bar{c}+c \rightarrow J/\psi$
    - recombination: $J/\psi \rightarrow \bar{c}+c \rightarrow J/\psi$
    - $\Rightarrow$ narrower y and softer p_T distributions
- Comover absorption
  - $J/\psi + \pi\ (\rho) \rightarrow \bar{D}D$ (negligible for Υ !)



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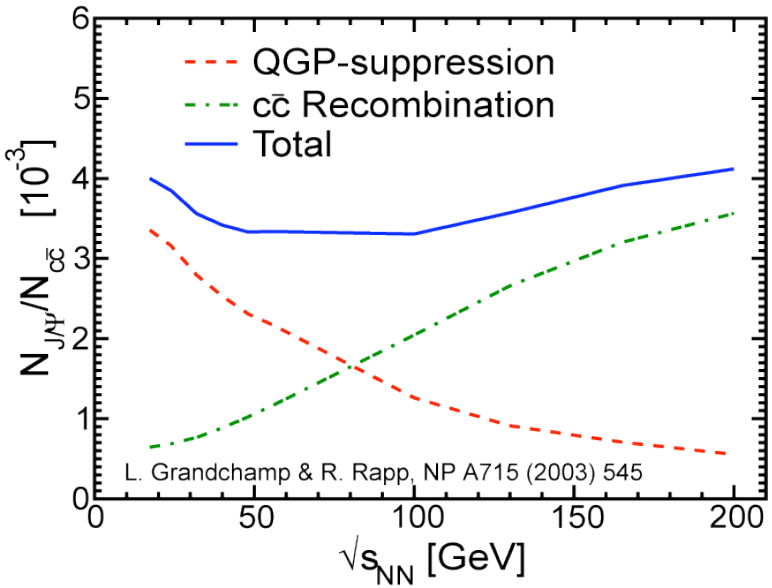
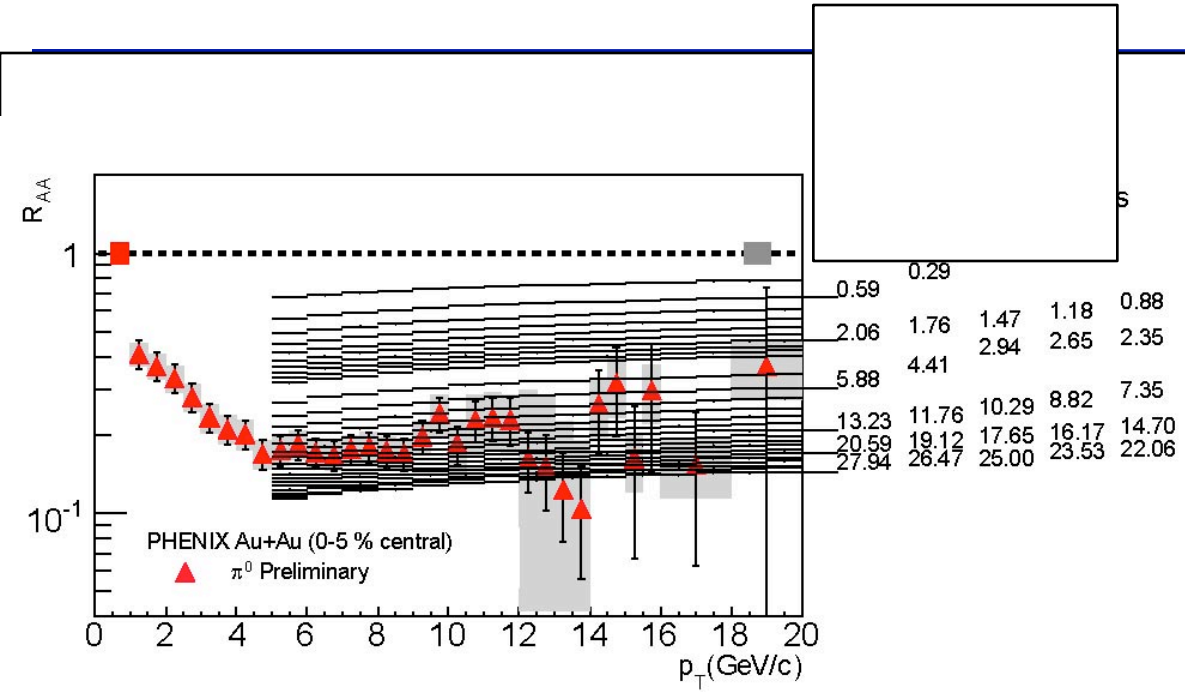
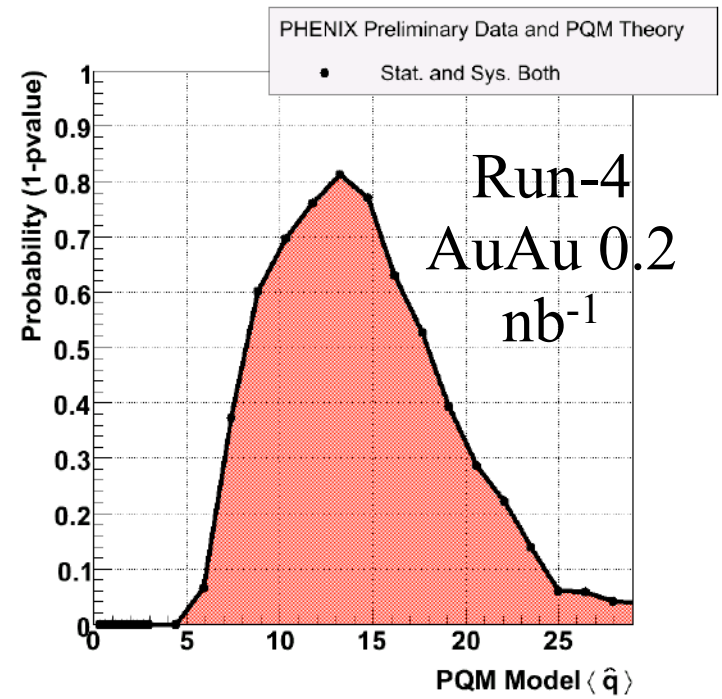


My take: while certainly a **very compelling idea** we will only learn what we hope for by very systematic studies of all quarkonium states (J/ψ, ψ', χc, $\Upsilon(1S)$, $\Upsilon(3S)$, $\Upsilon(3S)$ in various systems and energies over a large phase space.

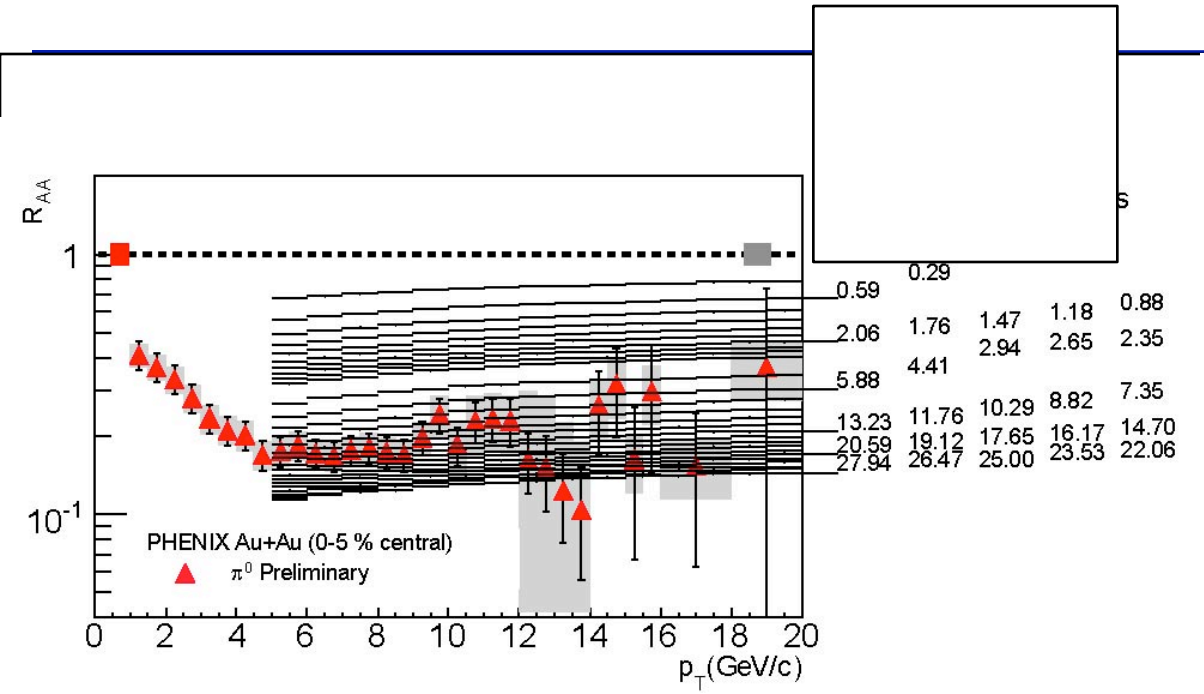
IMHO one of the most difficult tasks in Heavy Ions

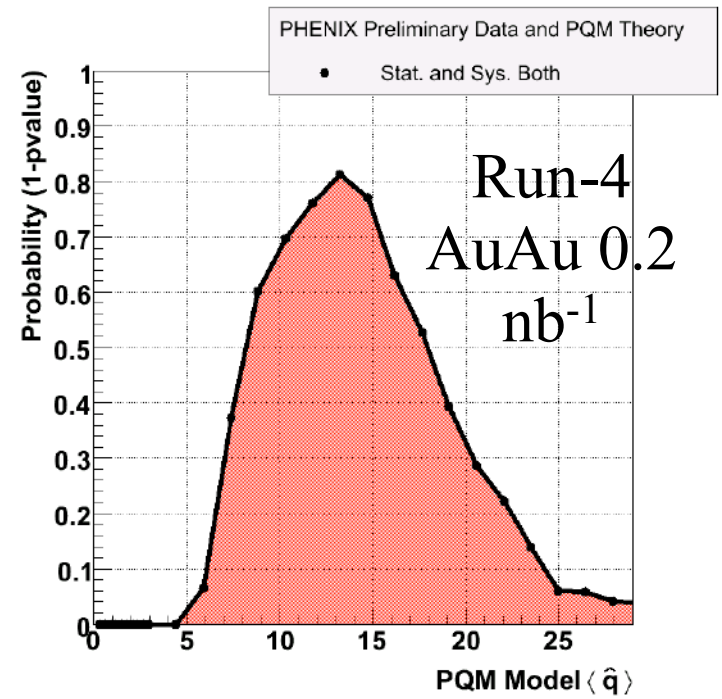




$$6 \le \langle \hat{q} \rangle \le 24 \ \ \mathrm{GeV}^2/\mathrm{fm}$$

(Probability > 10%)

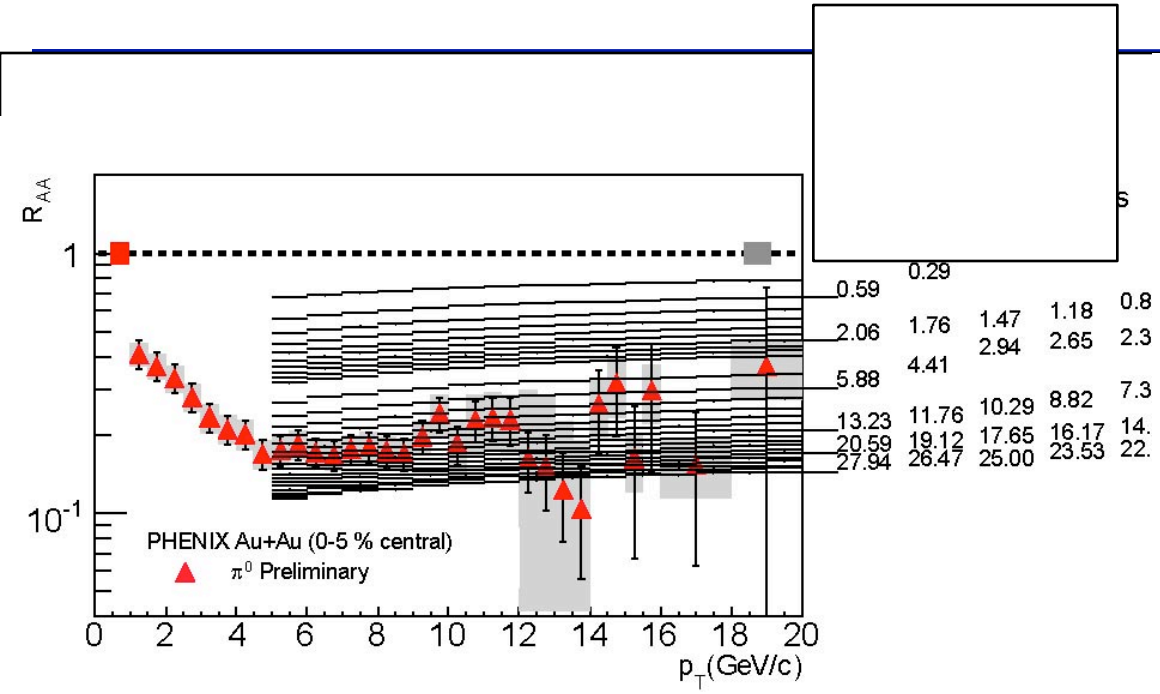


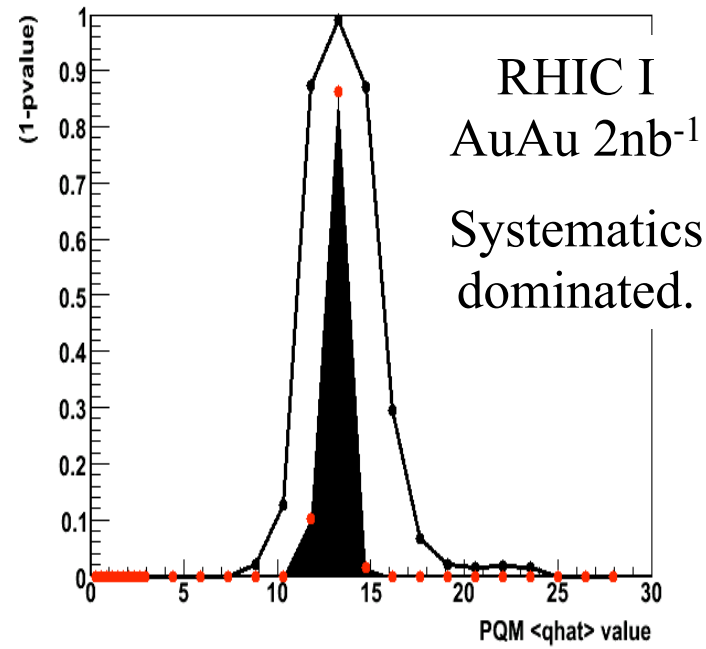


Physically $\hat{q}$ characterizes the $\langle p_T^2 \rangle$ transferred from the medium to a hard gluon per unit path length.

$$6 \le \langle \hat{q} \rangle \le 24 \ \ \mathrm{GeV}^2/\mathrm{fm}$$

(Probability > 10%)





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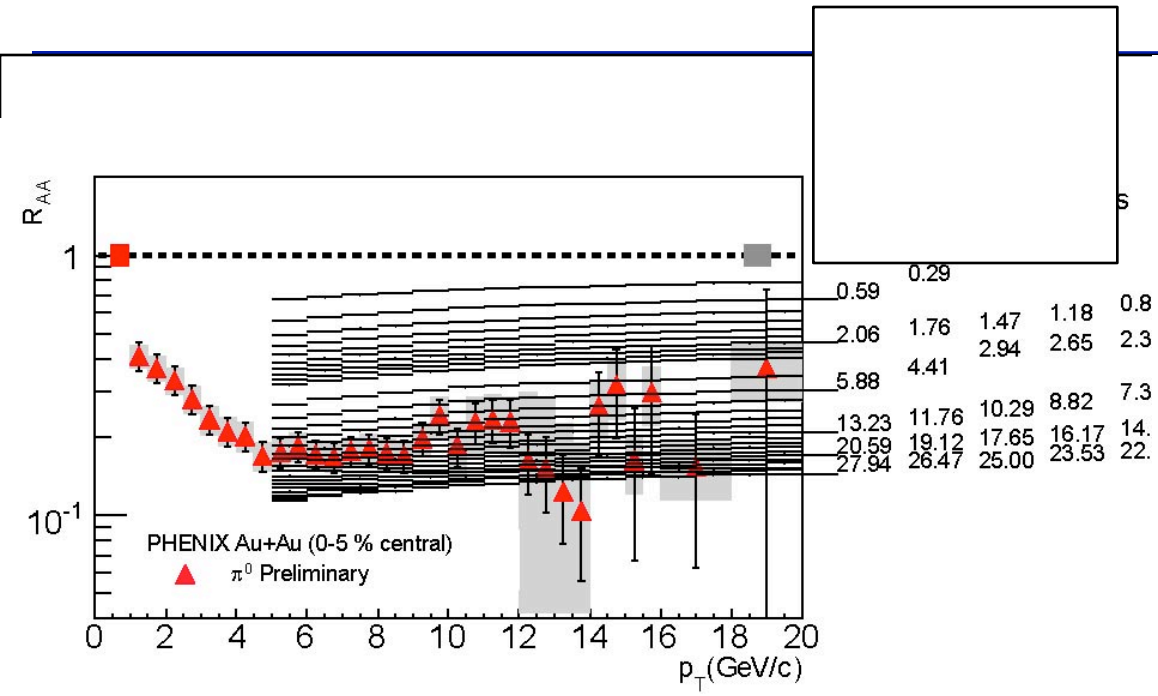

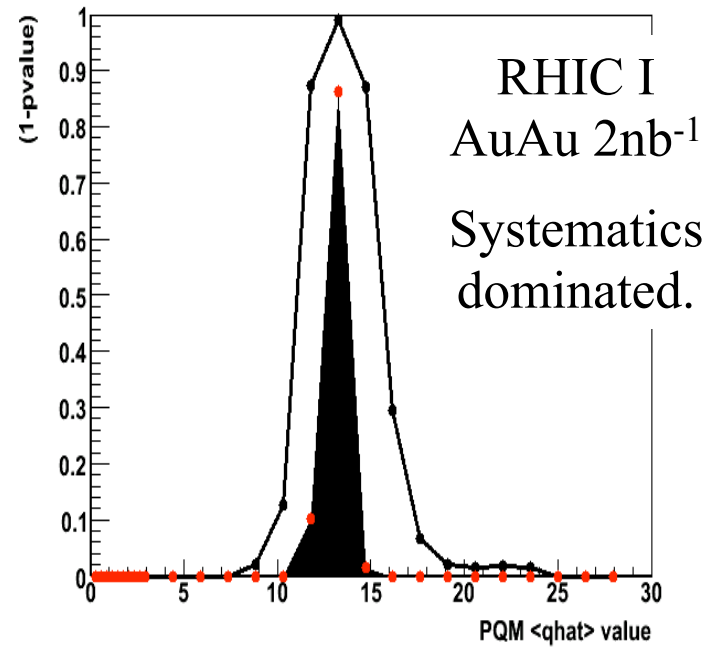

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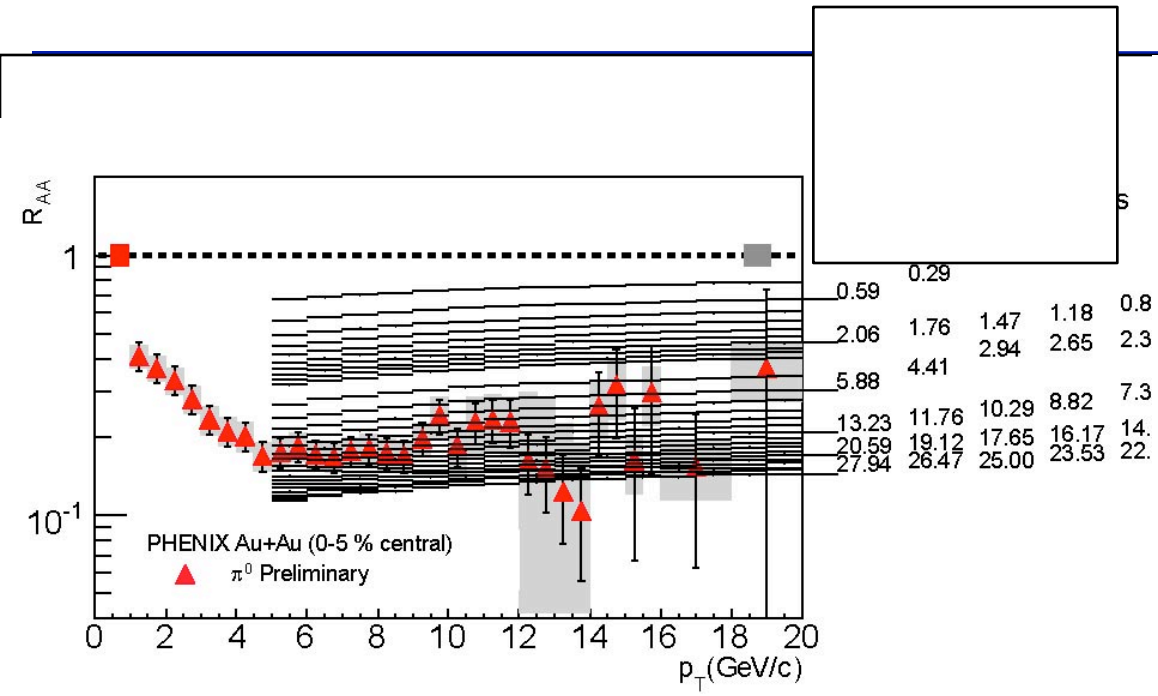
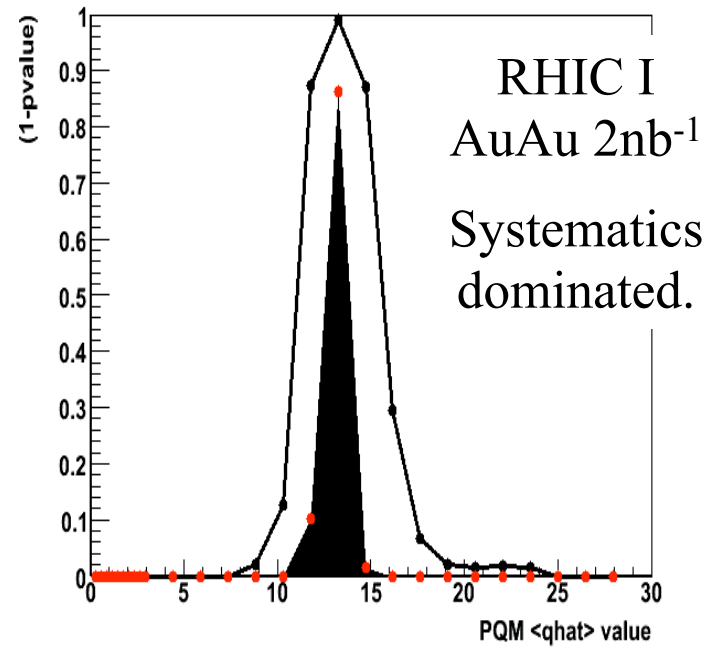
(Probability > 10%)

Detailed comparison with heavy quark probes is important.





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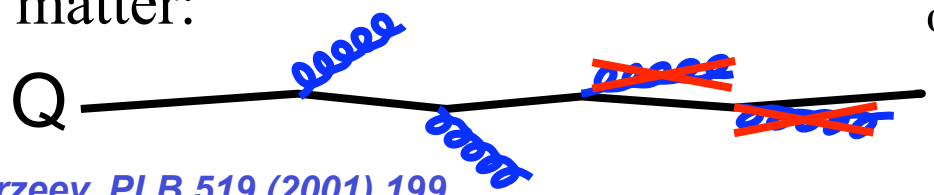
$$6 \le \langle \hat{q} \rangle \le 24 \ \ \mathrm{GeV}^2/\mathrm{fm}$$

(Probability > 10%)

Detailed comparison with heavy quark probes is important.
New detectors, higher luminosities and theoretical advances needed for precision transport coefficients.

High-p_T Heavy Quarks are Grey Probes

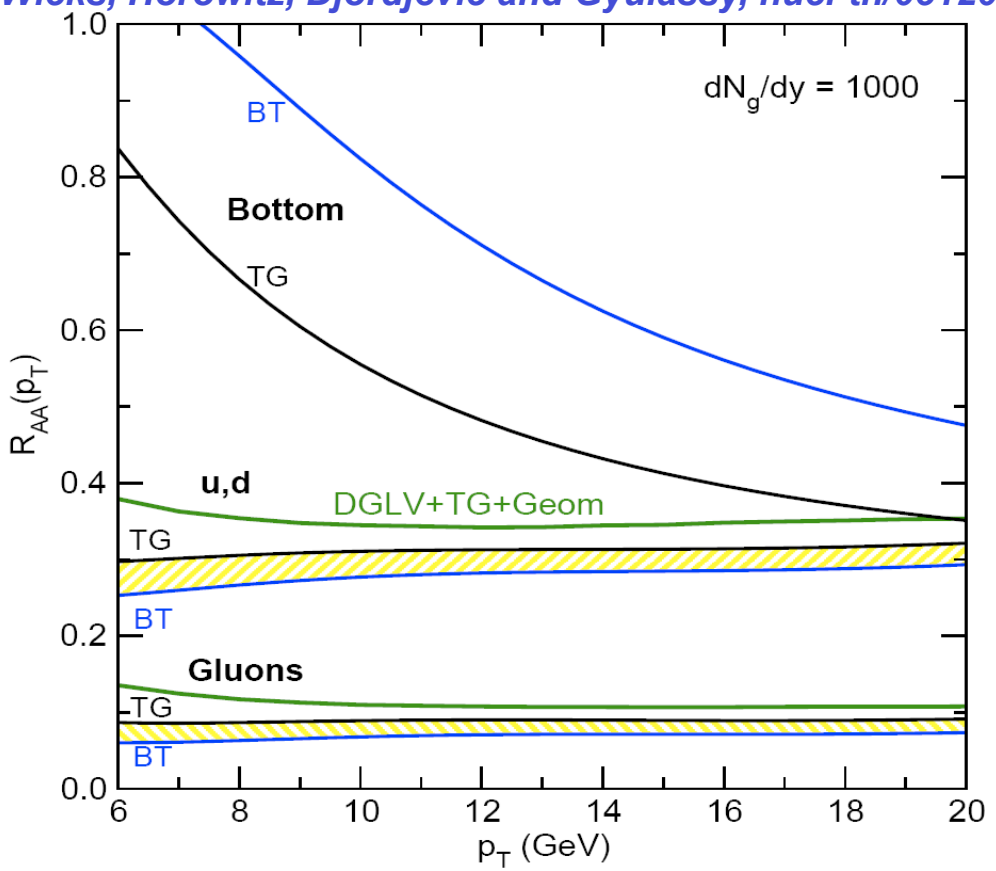
Dead cone effect implies lower heavy quark energy loss in matter:

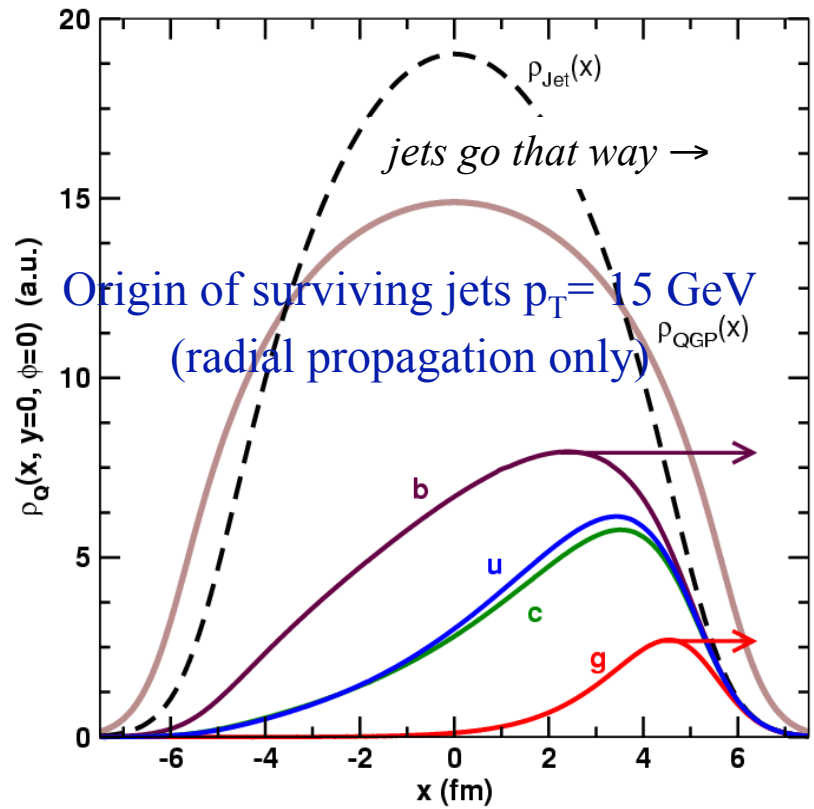


$$\omega \frac{dI}{d\omega}\bigg|_{HEAVY} = \frac{\omega \frac{dI}{d\omega}\bigg|_{LIGHT}}{\left(1+\left(\frac{m_Q}{E_Q}\right)^2 \frac{1}{\theta^2}\right)^2}$$

Dokshitzer and Kharzeev, PLB 519 (2001) 199.

Wicks, Horowitz, Djordjevic and Gyulassy, nucl-th/0512076



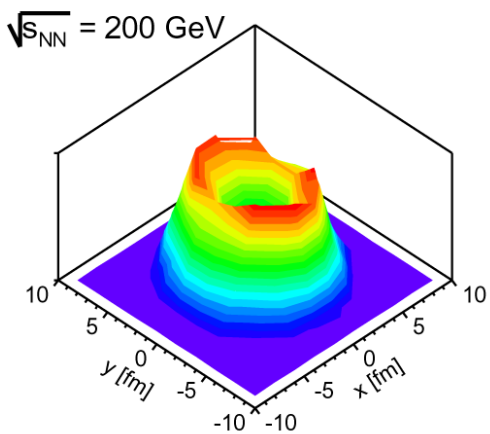


Origin of surviving jets p_T= 15 GeV
(radial propagation only)

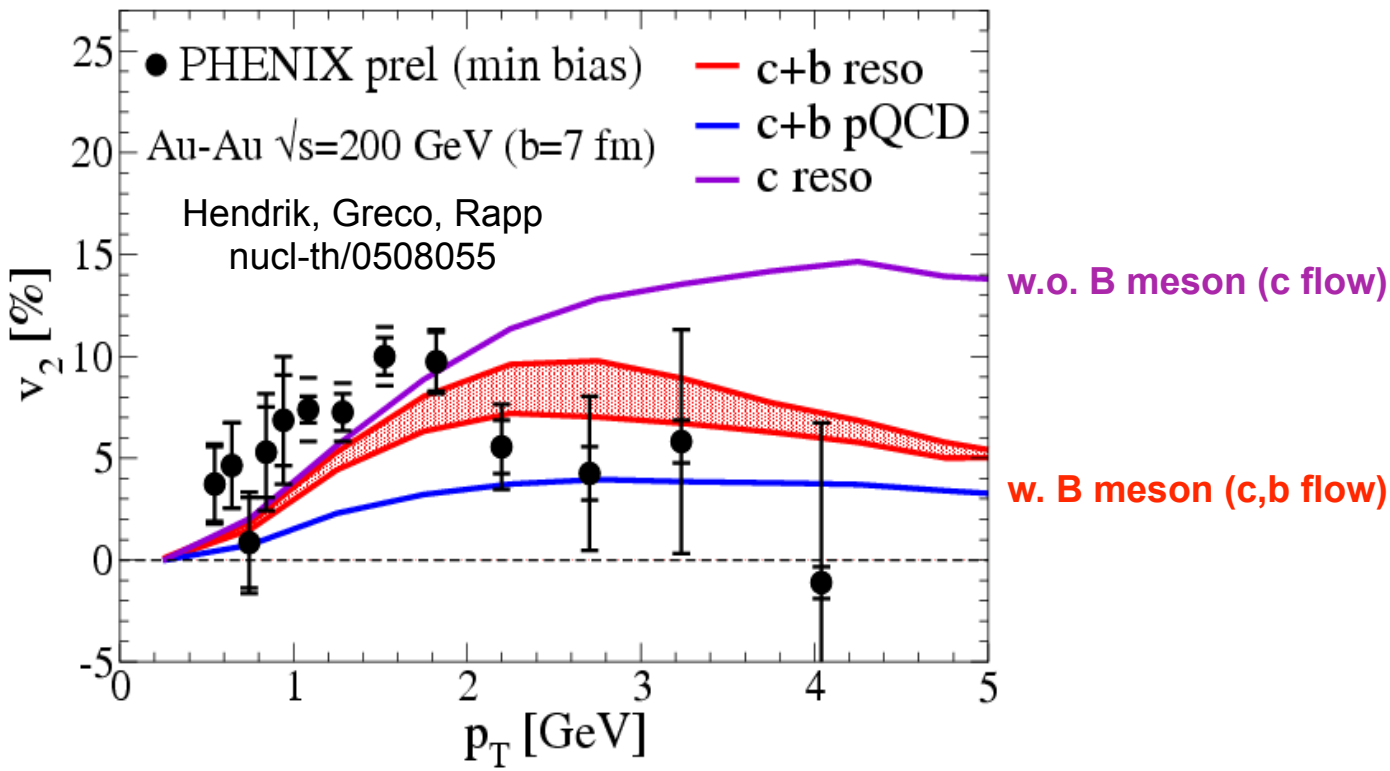
Grey Probes

- Problem: interaction with the medium so strong that information lost: "Black"
- Significant differences between predicted R_{AA}, depending on the probe

Experimental possibility: recover sensitivity to the properties of the medium by varying the probe



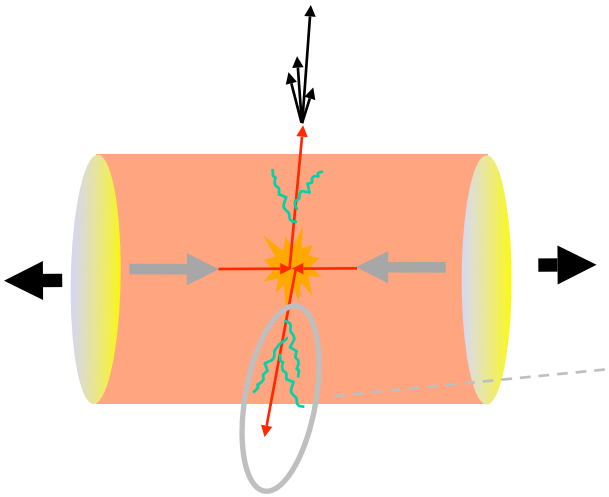
v_2 of Non-Photonic Electrons

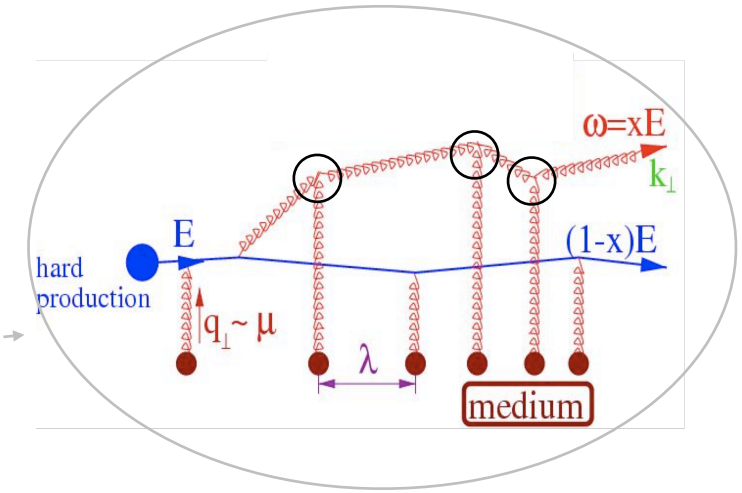


4. Large elliptic flow of non-photonic electrons for $p_T < 3$ GeV/c
   - Measurement still with large errors
   - Need ultimately D mesons for that

High-p_T Partons – Interacting with the Hot Matter

Baier, Schiff and Zakharov, AnnRevNuclPartSci 50, 37 (2000)





BDMPS approximation: multiple soft collisions in a medium of static color charges

Transport coefficient: $\hat{q} = \rho_{medium} \int d^2 q_\perp q_\perp^{\,2} \frac{d\sigma}{d^2 q_\perp} \equiv \frac{\mu^2}{\lambda}$

Total medium-induced energy loss:

$$\Delta E_{med} = \int^{L} dz \int^{\omega_C} d\omega\, \omega \frac{dI_{LPM}}{d\omega dz} \sim \alpha_S \sqrt{\hat{q}\omega_C}\, L \sim \alpha_S \hat{q} L^2$$

ΔE independent of parton energy (finite kinematics $\Delta E \sim \log(E)$)

$\Delta E \propto L^2$ due to interference effects (expanding medium $\Delta E \sim L$)

Towards the Quantitative : $\hat{q}$ and the Limitations of R_{AA}?

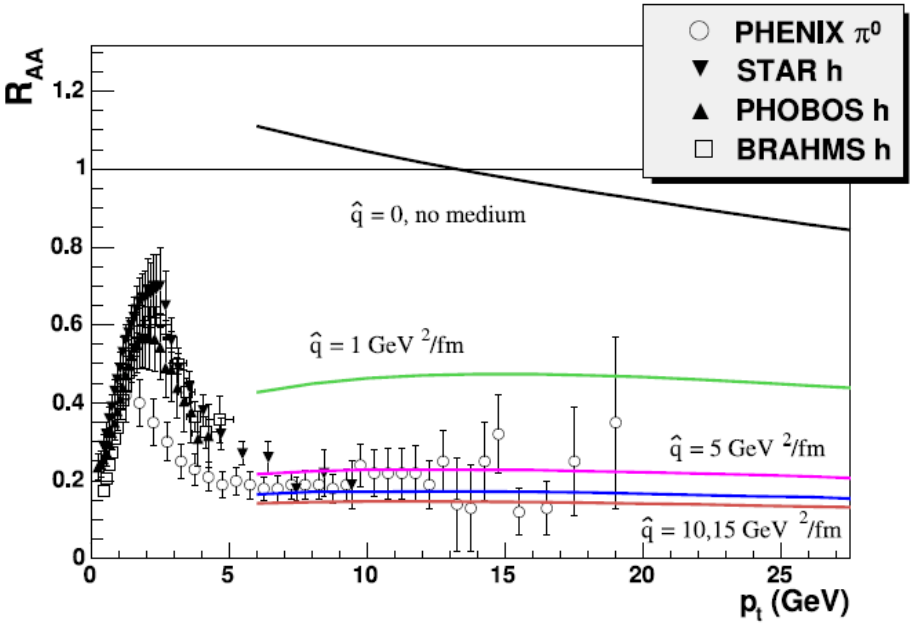
$\hat{q} = c\varepsilon^{\frac{3}{4}}$

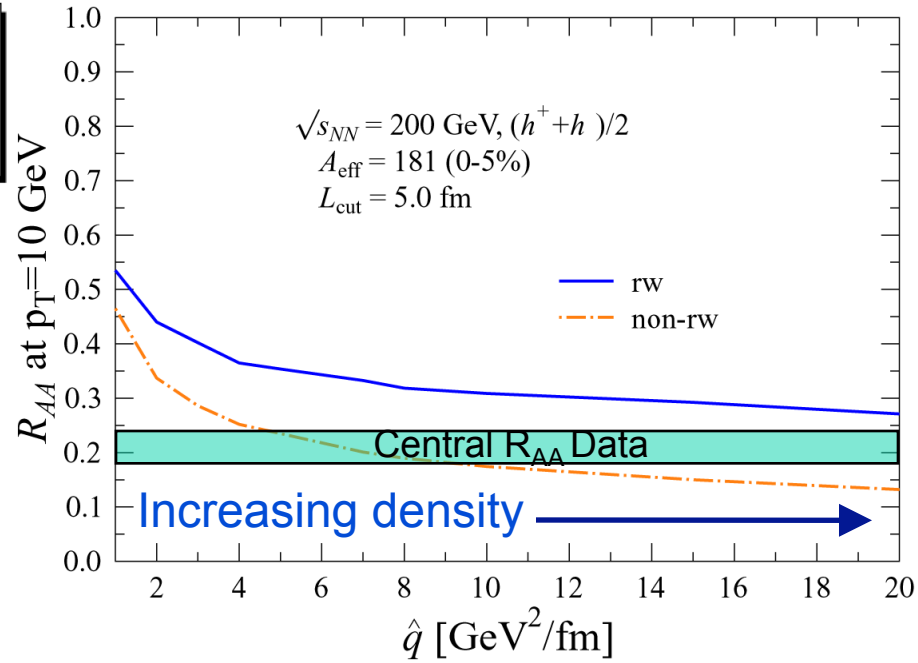
pQCD result: $c \sim 2$ (α_S? dof? …)
sQGP (multiplicities+hydro): $c \sim 10$

} Model uncertainties

$\hat{q}$ and modelling teaches us about energy density : $\mathring{a}(L, \hat{o})$

K.J. Eskola, H. Honkanken, C.A. Salgado, U.A. Wiedemann, Nucl. Phys. A747 (2005) 511

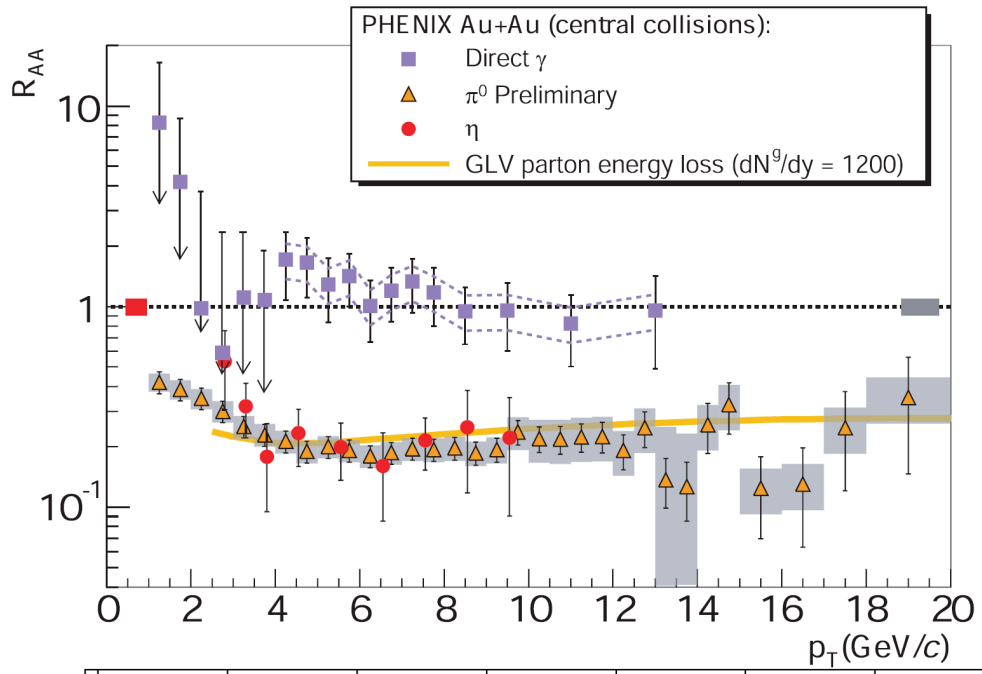


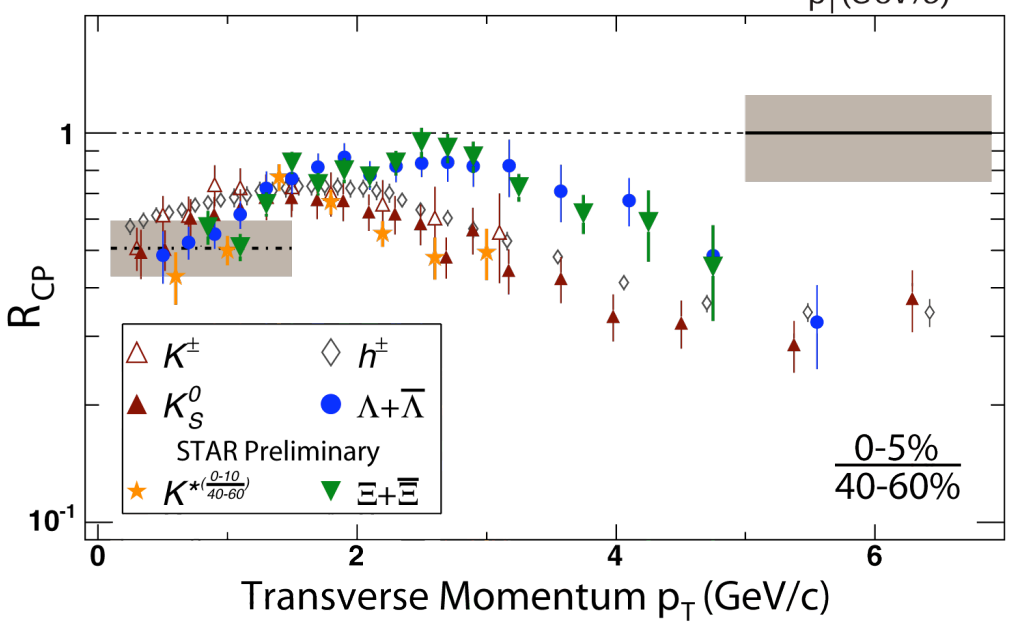


Surface bias effectively leads to saturation of R_{AA} with density

Challenge: Increase sensitivity to the density of the medium

High-p_T Suppression at RHIC





Observations at RHIC:

1. Hadrons are suppressed
2. Photons are not
3. Meson/baryon suppressed differently for $p_T < 5$ GeV/c due to recombination effects
4. For $p_T > 5$ GeV/c all the same and ~flat to 20 GeV/c
5. $\hat{q}$ not constraint sufficiently by R_{AA} ($5 < q < 12$ GeV^2/fm)

Better observables are need to probe deeper

Heavy Quarks at low p_T – elliptic flow

RHIC: Bulk of light quarks and gluons are (at least locally) thermalized

What's about charm?

- Naïve argument: need $M_q/T \sim 7$ times more collisions to thermalize

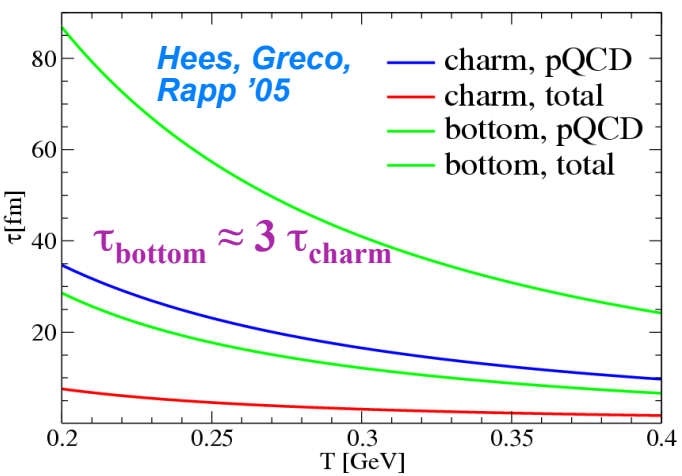
⇒Systematic study of charm v_2

- $v_2 \leftrightarrow$ re-scattering at early times
- v_2 at larger p_T related to R_{AA}
- pQCD suggest little to no flow - but then why should pQCD work in the bulk where α_s is large?

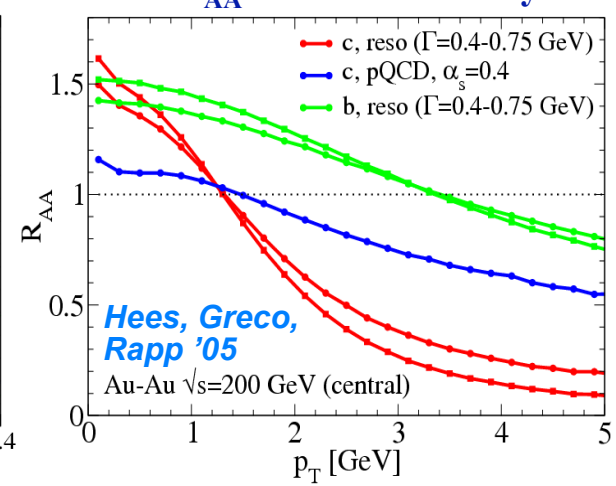
Many ideas around:

- Hees/Rapp: resonant heavy-light quark scattering
- Moore/Teany: diffusion coefficient in QGP in Langevin model

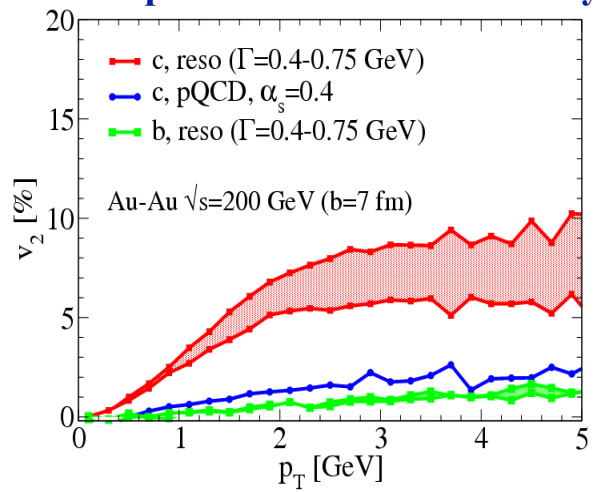
Thermalization Time in QGP



R_{AA} – e from D decay



Elliptic Flow – e from D decay



Heavy Quarks at low p_T – elliptic flow

RHIC: Bulk of light quarks and gluons are (at least locally) thermalized

Wha

⇒Sy

- v ght
- v
- p cient

t

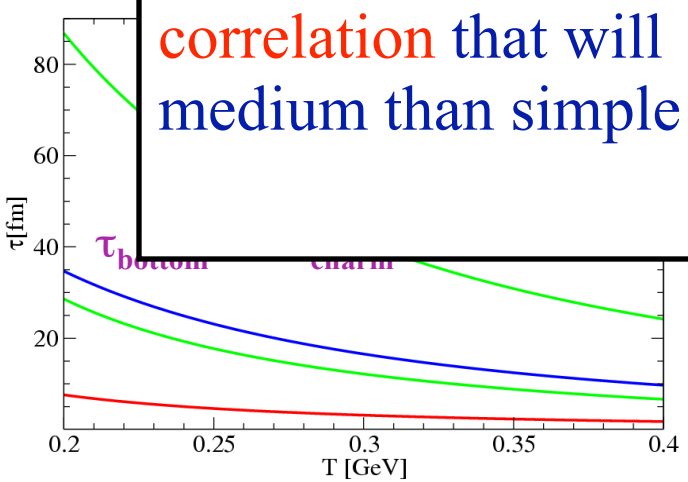
b

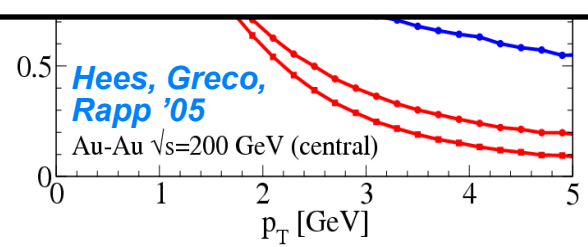
T m D decay

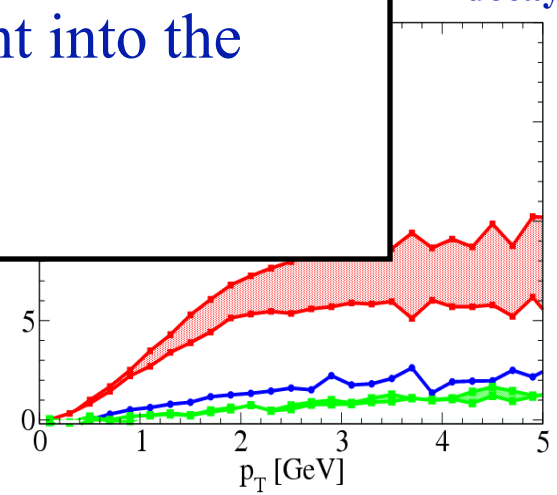
Need D (B) from low (v_2) to high-p_T (R_{AA}, R_{CP}) with good S/B and statistics.

Non-photonic electrons are a welcome proxy but are not sufficient and will not give us the final answer.

The final challenge are charm-charm and charm-hadron correlation that will allow for a deeper insight into the medium than simple R_{AA} or R_{CP} .

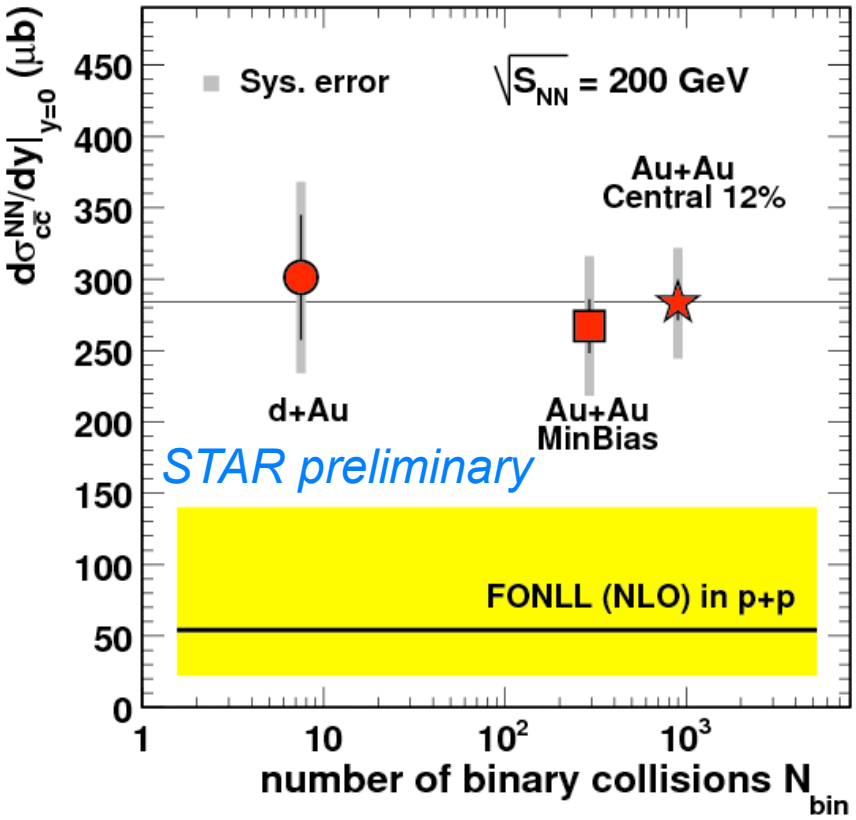


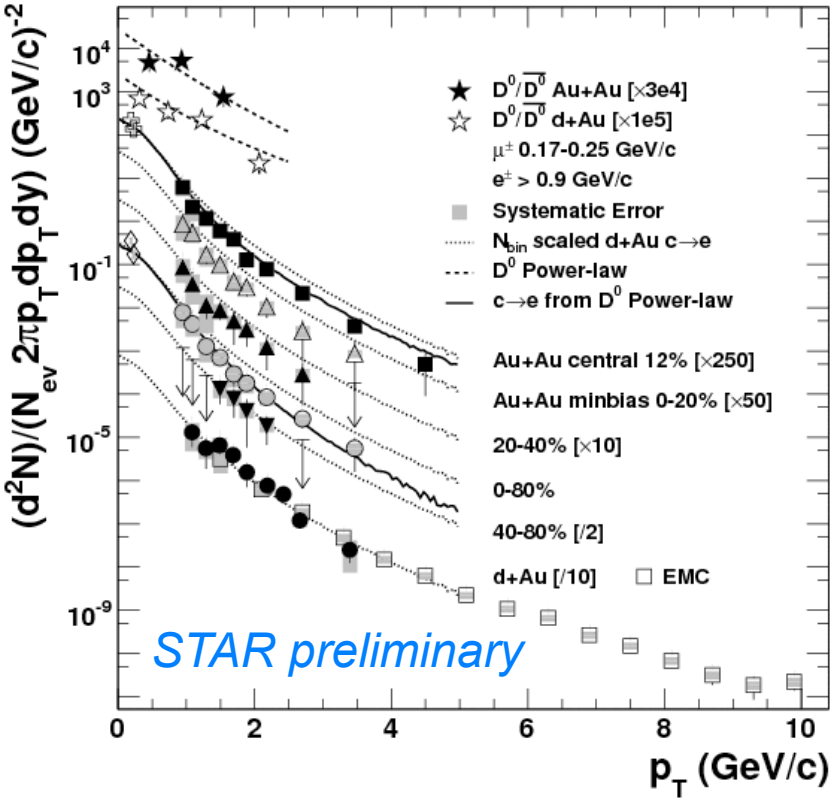




Brief Summary of Heavy Flavor at RHIC: σ_{cc}

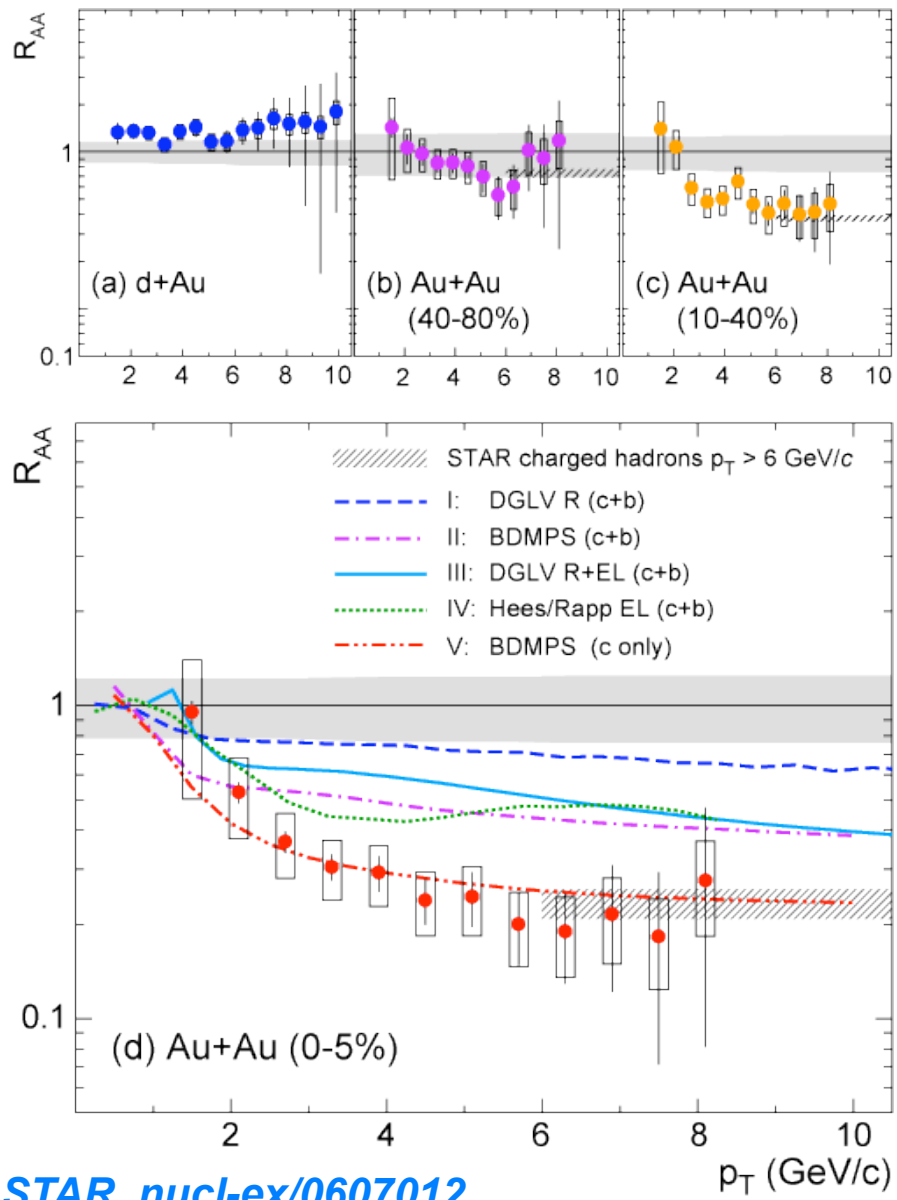
1. The cross-section is found to follow binary scaling, which is a signature of charm production in hard scattering.
2. The charm production cross-section is larger than expected from NLO calculations, $\sigma_{cc} \sim 1.3$ mb





σ derived from combined fit to *e*, μ, D^0 spectra in each system/centrality

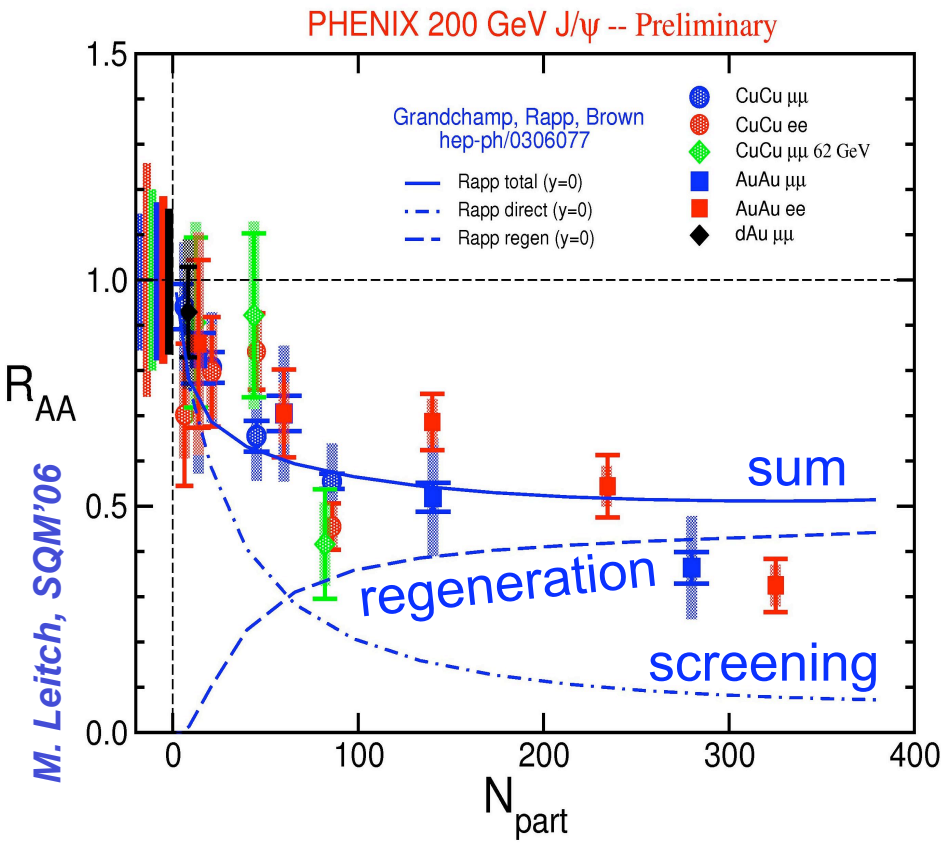
R_{AA} of Non-Photonic Electrons



STAR, nucl-ex/0607012

3. Measurement of non-photonic electrons from semileptonic D decays show substantial suppression in central Au+Au collisions comparable to that from light mesons
   - Models using radiative or radiative + collisional energy loss predict less suppression when bottom component is taken into account
   - models describe data when only charm is considered
   - Need to disentangle c and b contributions (e-h and e-K correlations?)
   - Need direct D meson spectra out to high-p_T

Charmonium at RHIC: Screening and Regeneration

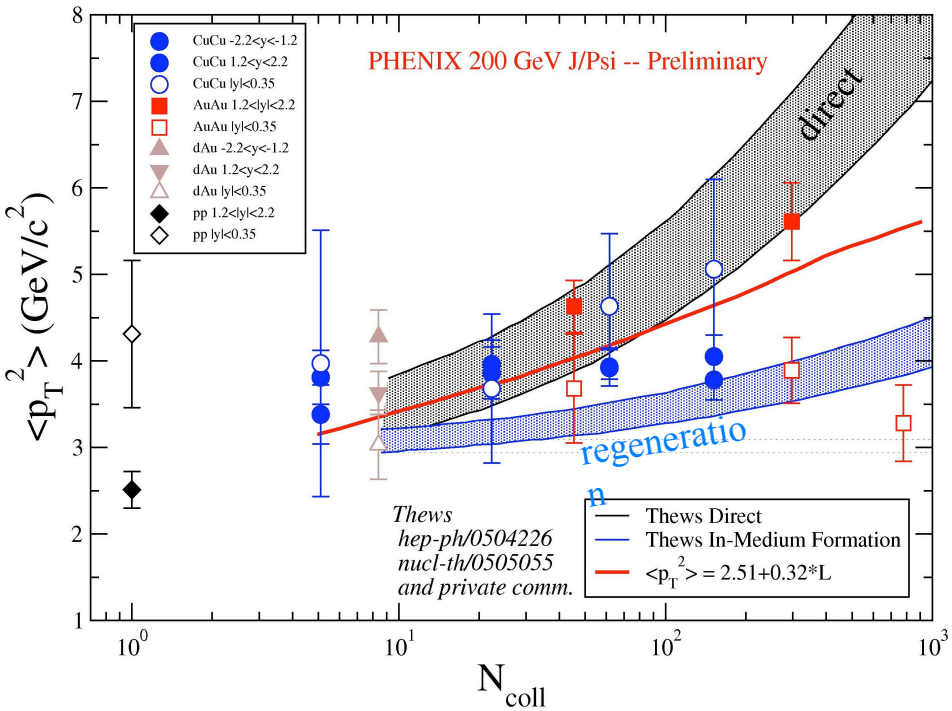


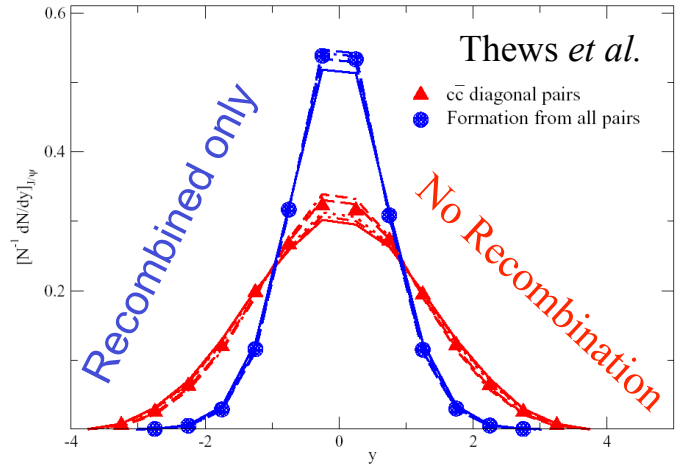
5. Models with regeneration, i.e., single charm quarks combining in the later stages to form J/ψ's – match the observed suppression better!

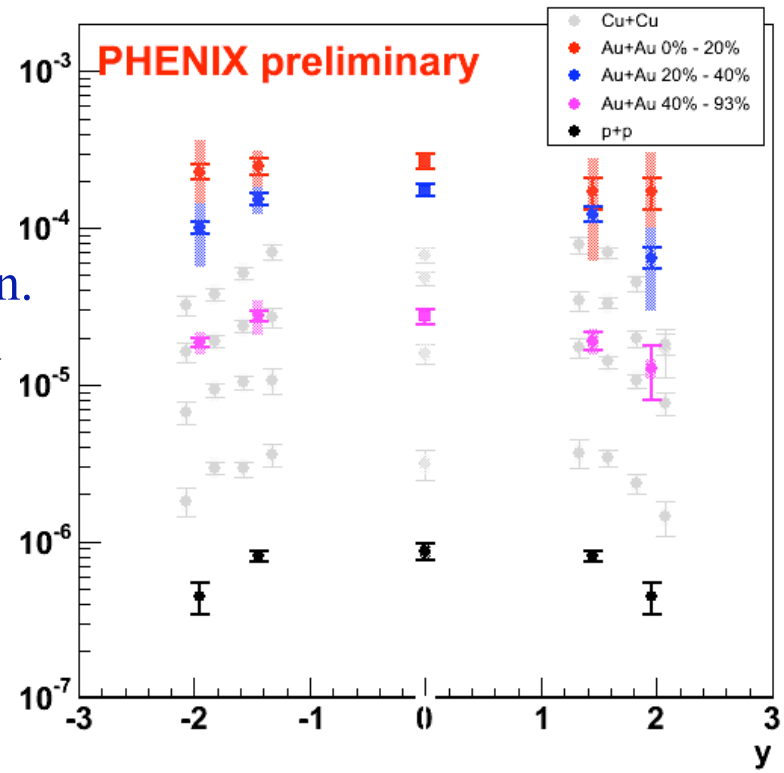
Most actual models have suppression + various regeneration mechanisms

- Rapp - PRL 92, 212301 (2004)
  - screening & in-medium production
- Thews - PRC73 (2006) 014904c
  - pQCD NLO charm + recombination
- Andronic - PLB57, 136 (2003)
  - statistical hadronization model with screening of primary J/ψ's + statistical recombination of thermalized $\bar{c}c$'s
- Kostyuk – PRC 68, 041902 (2003)
  - statistical coalescence + co-movers or QGP screening
- Bratkovskaya – PRC 69, 054903 (2004)
  - hadron-string dynamics transport
- Zhu - PLB607, 107 (2005)
  - J/ψ transport in QGP_co-movers, gluon breakup, hydro for QGP evolution no cold nuclear matter, no regeneration

Regeneration ⇒ Narrowing of y, Broadening of p_T?







- p_T broadening suggests "some" regeneration.
- Recombination predicts a narrower rapidity distribution with an increasing N_{part}.

6. Strange: Going from p+p to the most central Au+Au : no significant change seen in the shape of the rapidity distribution.

Mid-Term Improvements of RHIC

Tests during 2006:

RHIC can run at 4.6 GeV

Plan to retire the Tandem accelerators as the HI injector to RHIC

An EBIS source will take their place

All ions will be possible including U and polarized ^{3}He

Cost of operation will decrease

Operational in 2010

The Long Term Vision: *RHIC as a QCD Laboratory*

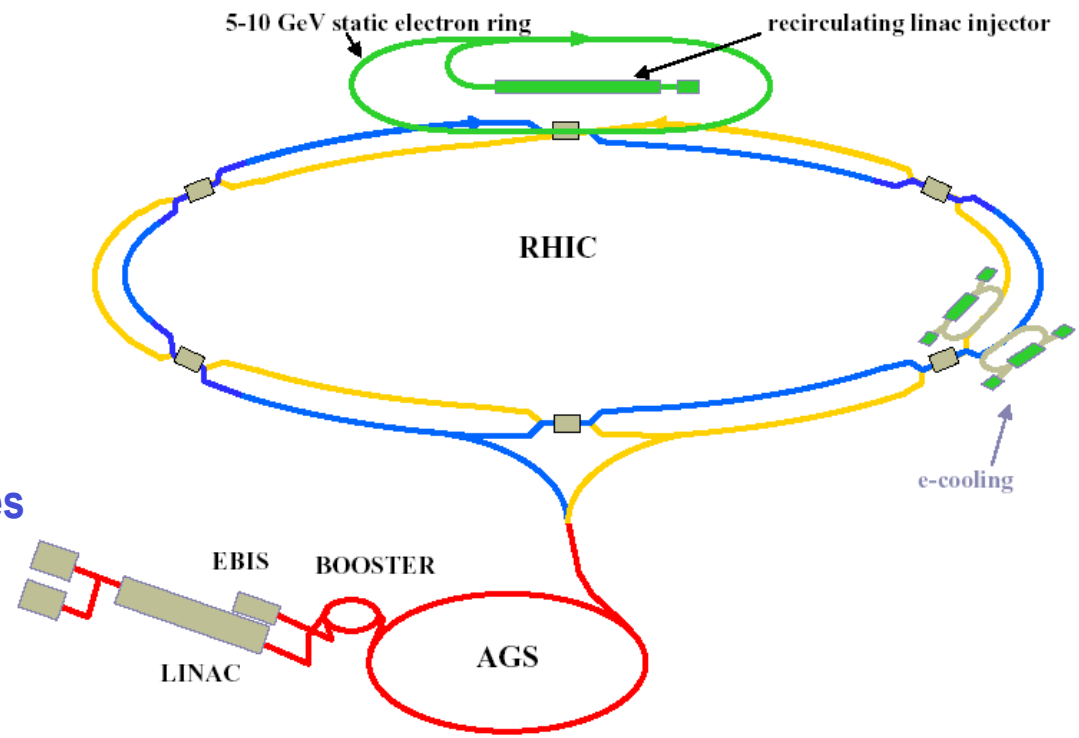
Evolve RHIC into a (the) QCD Laboratory

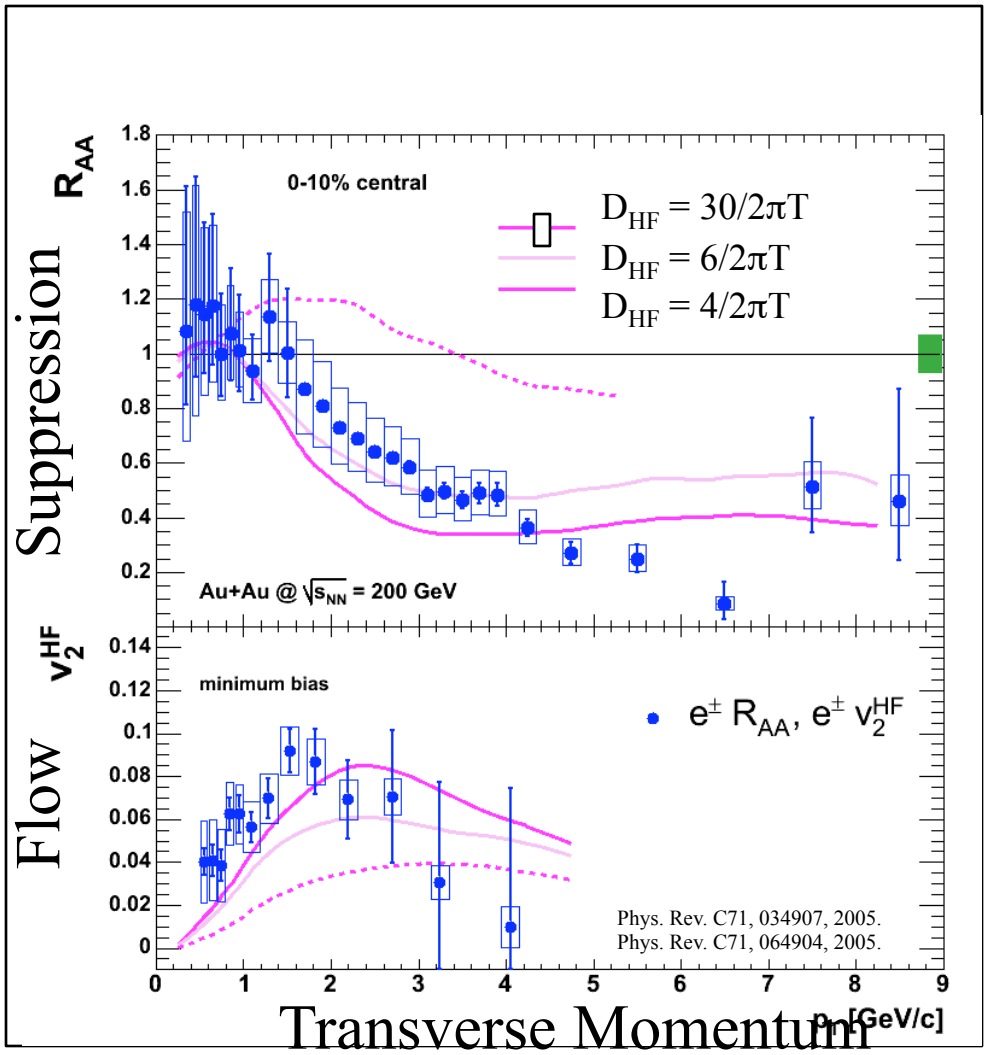
- Address the compelling questions in QCD revealed by the discoveries at RHIC
- Involve the RHI, Spin and DIS communities
- Issues:
  - EIC/JLab versus eRHIC/BNL
  - Strong push for RIA
  - New heavy ion detector or combined eRHIC/Heavy Ion apparatus?

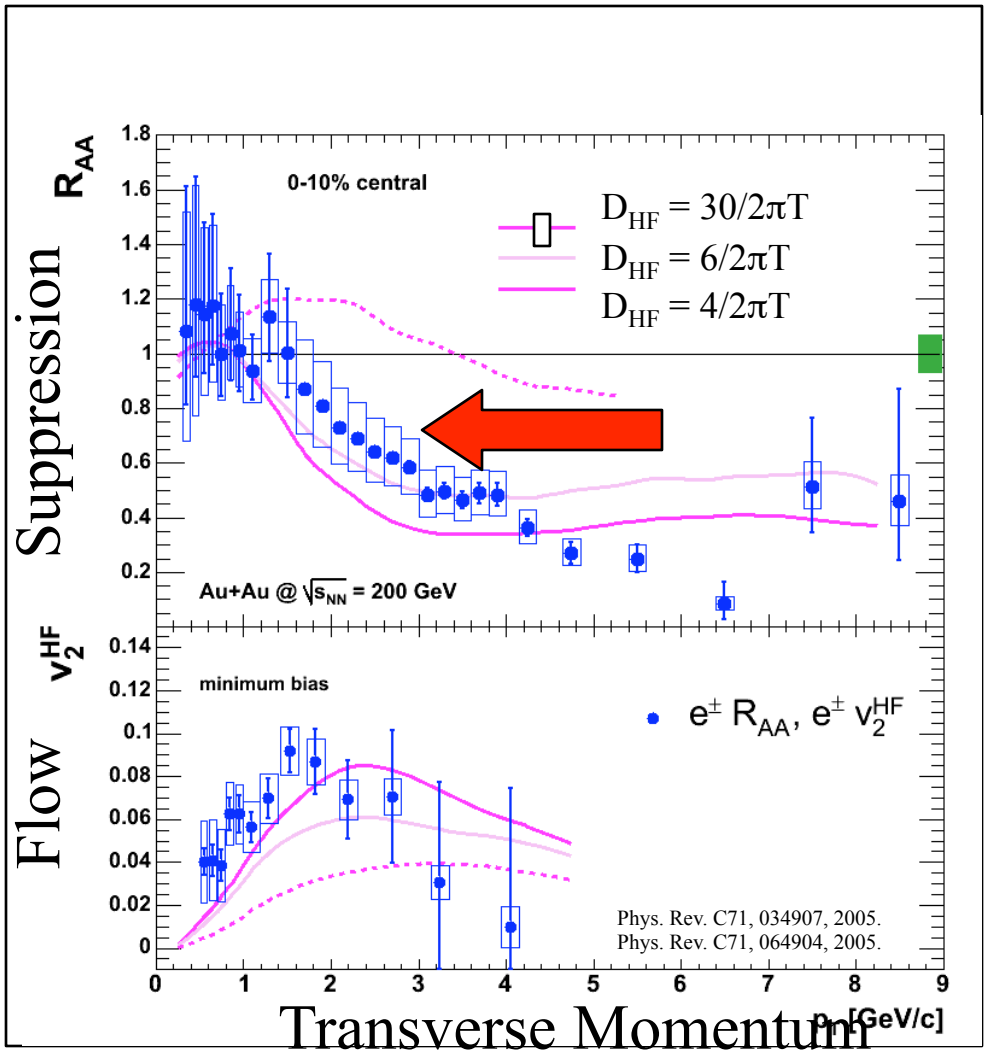
eRHIC: DIS at collider energies
e-A at 63 GeV/u
Polarized e-p at 100 GeV
L ~ 10^{33} cm^{-2} sec^{-1}

RHIC Spin: Strongly interacting probes

A-A: QGP physics at RHIC II luminosities




Suppression R_{AA}
0-10% central
$D_{HF} = 30/2\pi T$
$D_{HF} = 6/2\pi T$
$D_{HF} = 4/2\pi T$
Au+Au @ $\sqrt{s_{NN}}$ = 200 GeV
Flow v_2^{HF}
minimum bias
$e^{\pm}$ R_{AA}, $e^{\pm}$ v_2^{HF}
Phys. Rev. C71, 034907, 2005.
Phys. Rev. C71, 064904, 2005.
p_T [GeV/c]
Transverse Momentum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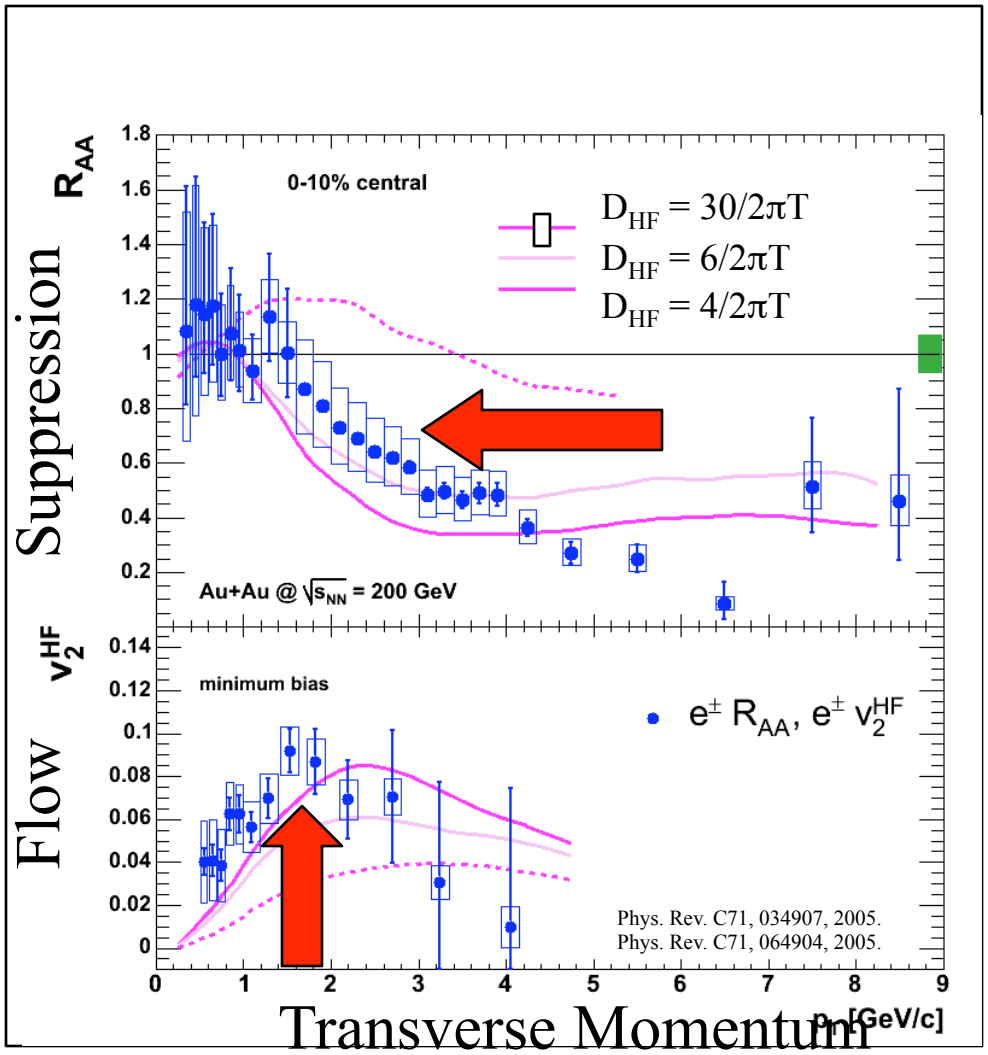
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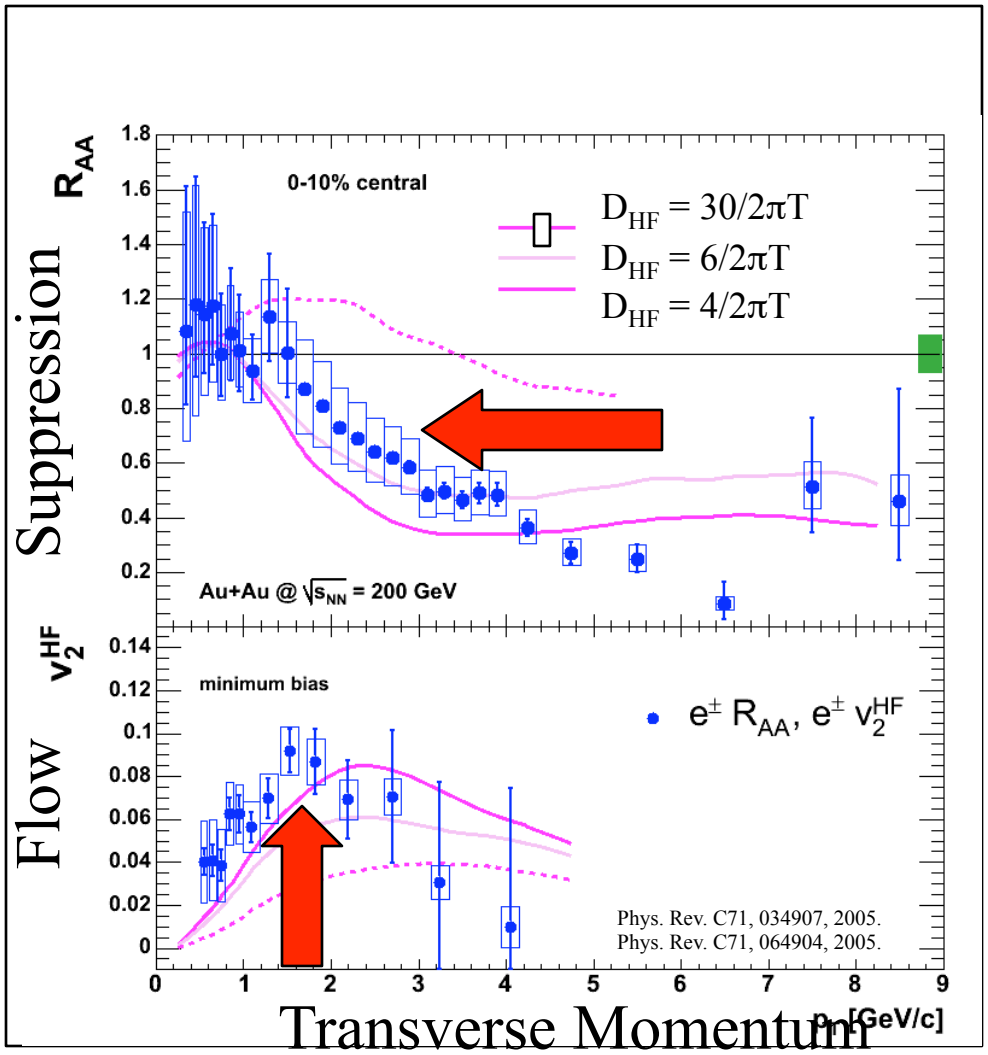
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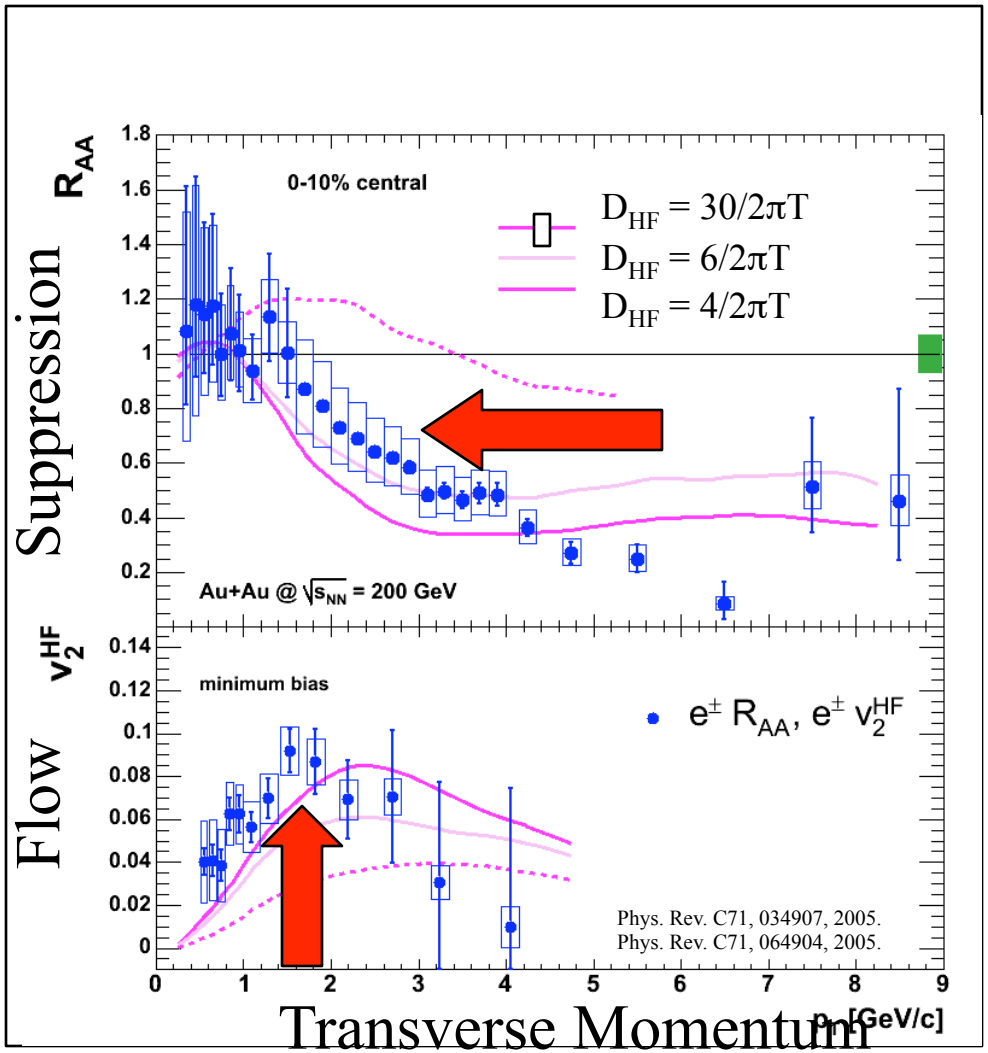
Phys. Rev. C71, 034907, 2005.
Phys. Rev. C71, 064904, 2005.
p_T [GeV/c]
Transverse Momentum

Theory comparisons imply η/s within a factor of two of the bound !



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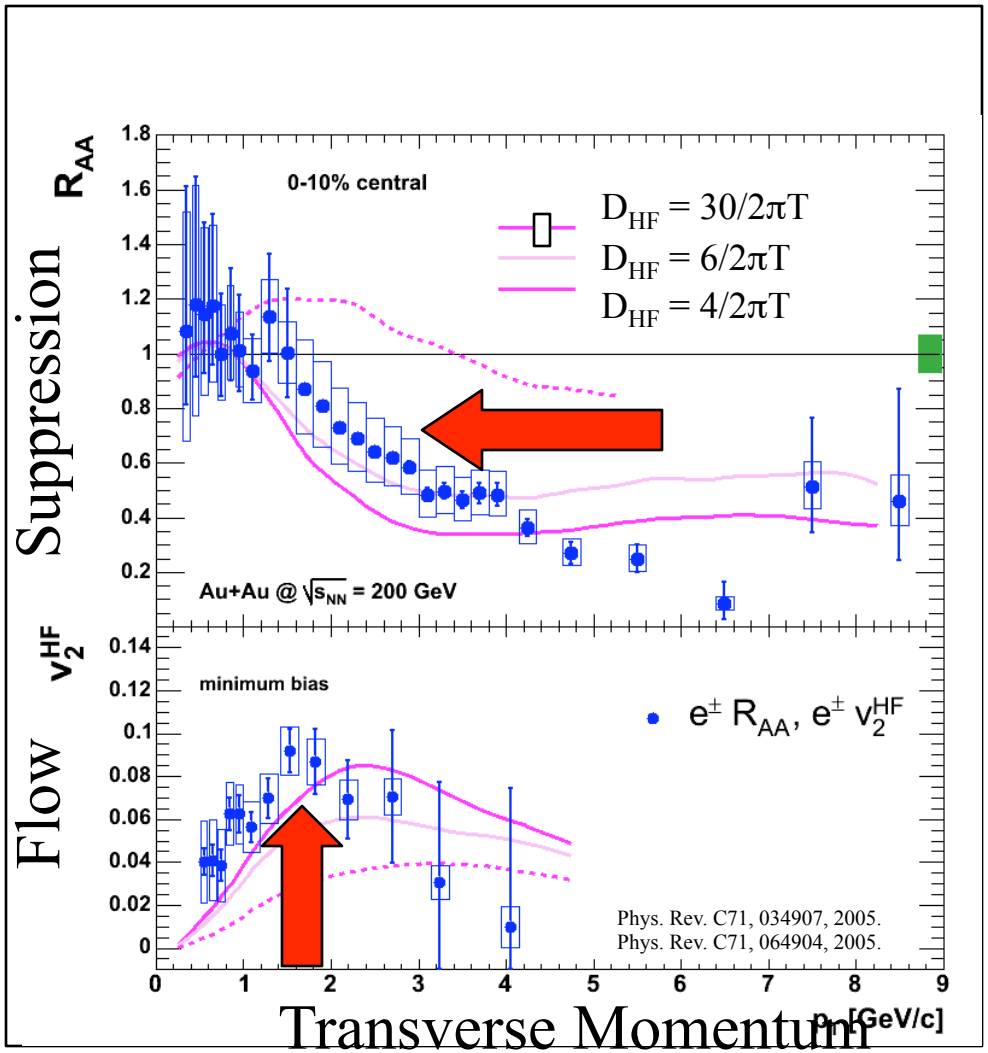
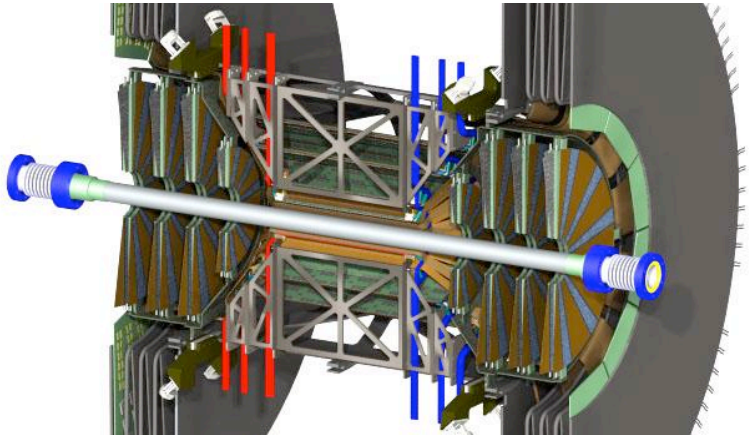
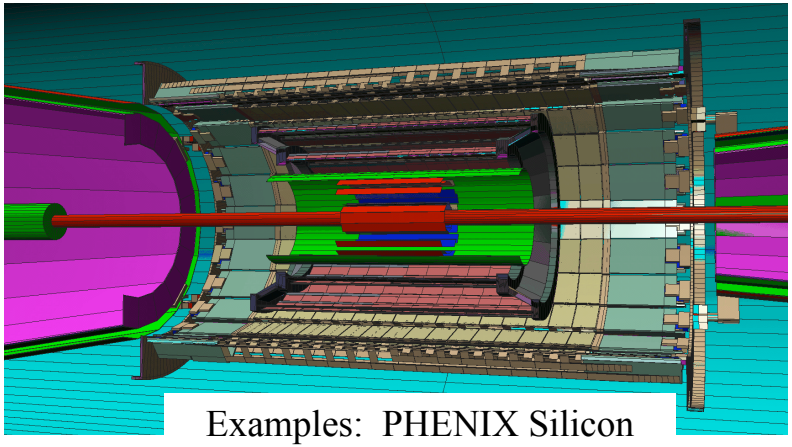


Displaced vertex measurements and luminosity will allow separation of charm and beauty, which is critical for fully constraining η/s.

Theory comparisons imply η/s within a factor of two of the bound !





Examples: PHENIX Silicon VTX and fVTX, STAR Heavy Flavor Tracker

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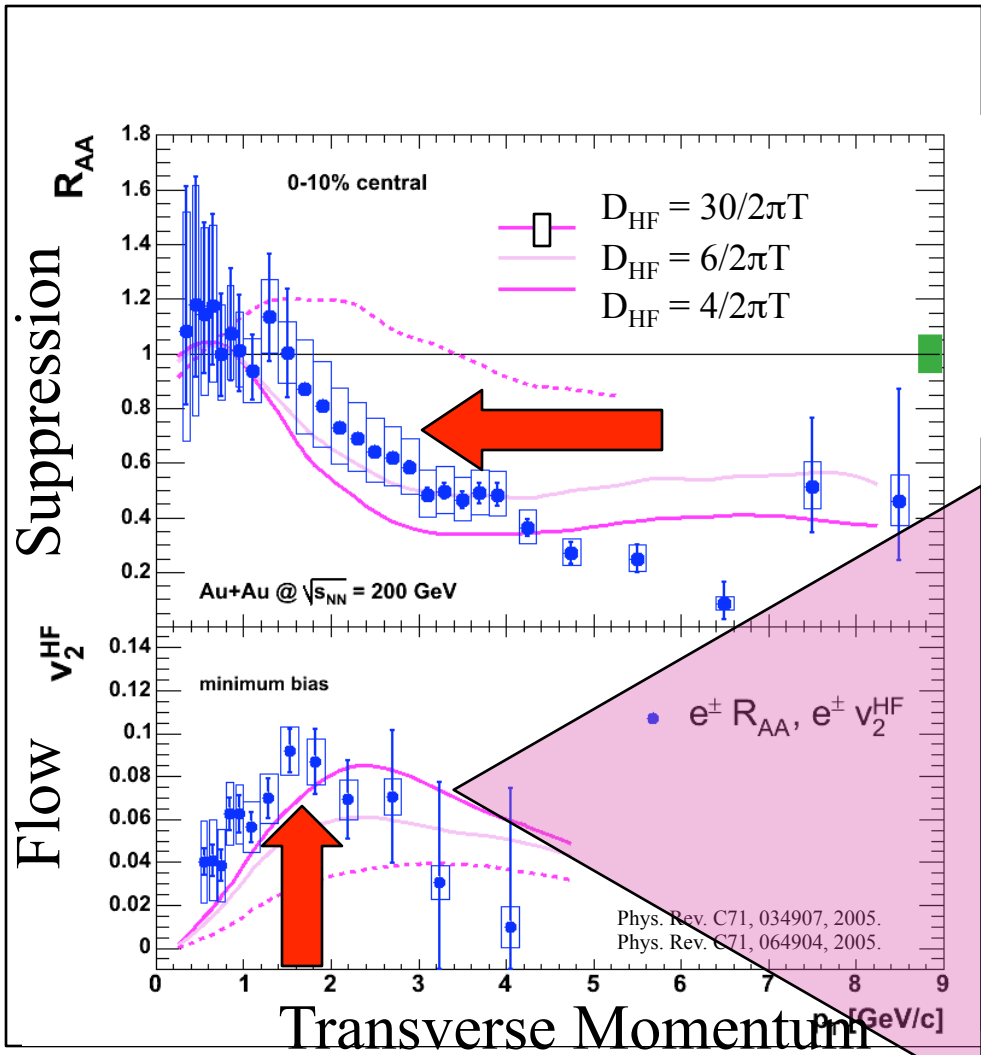
Theory comparisons imply η/s within a factor of two of the bound !



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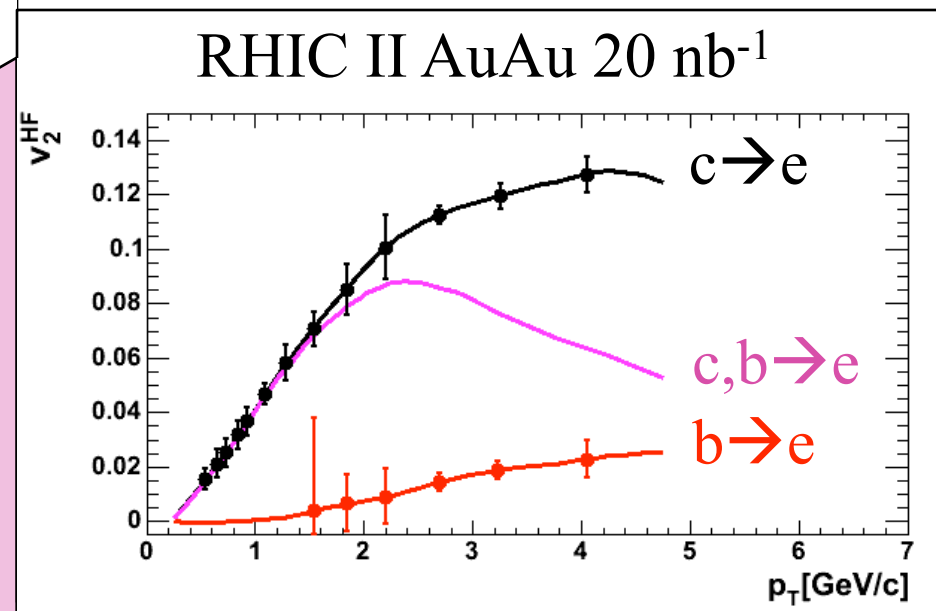
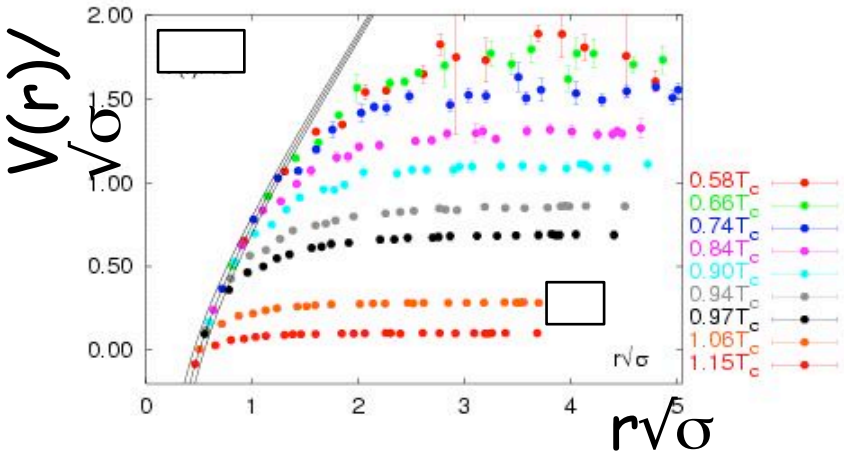
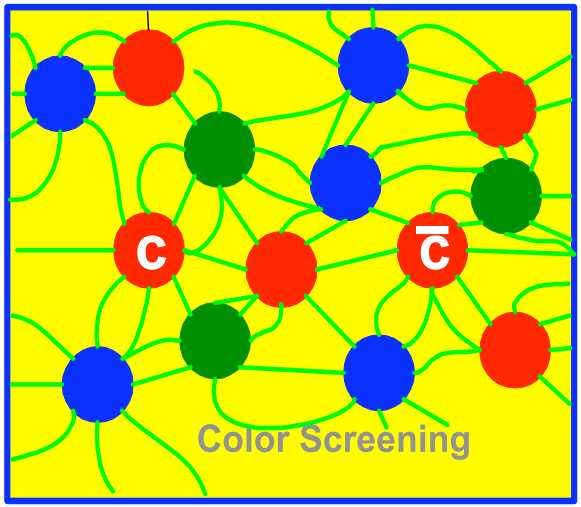
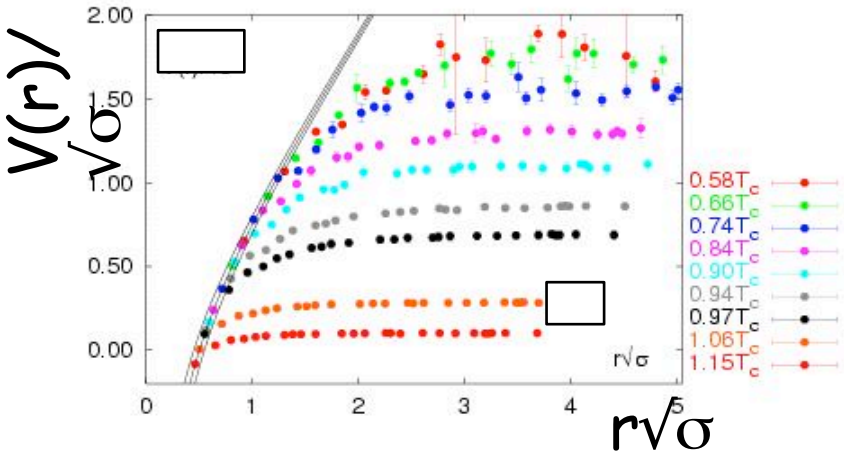


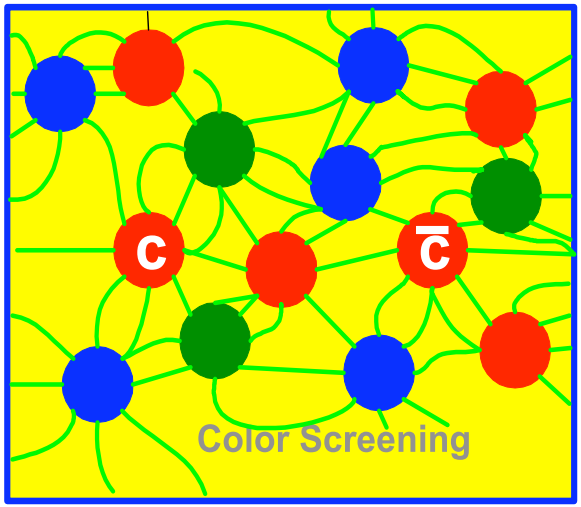
Lattice QCD calculation





Lattice QCD calculation





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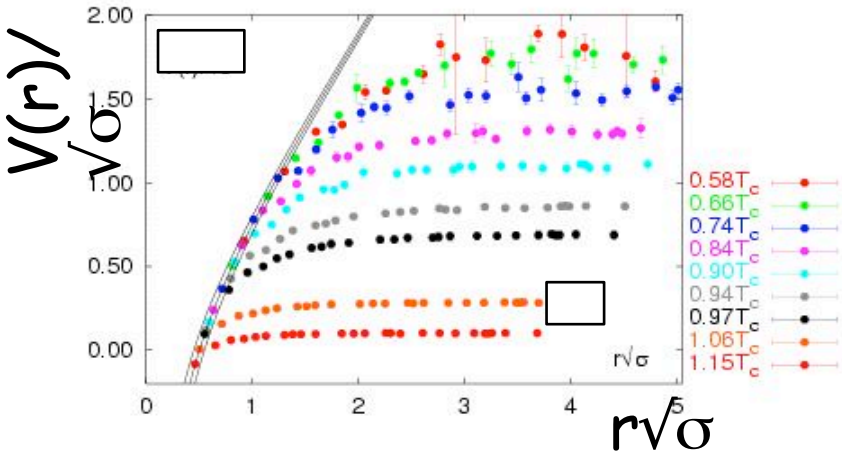
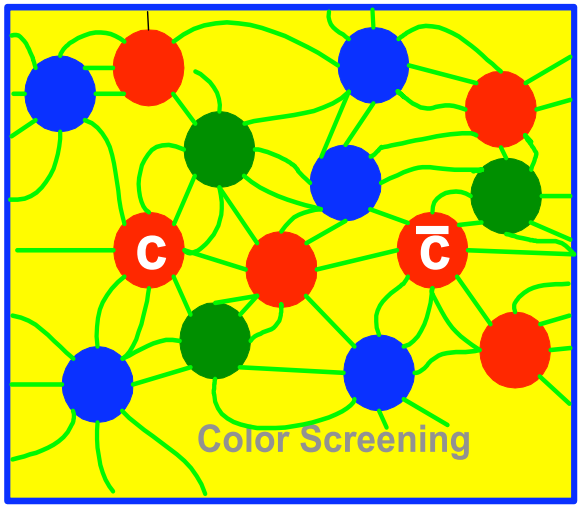
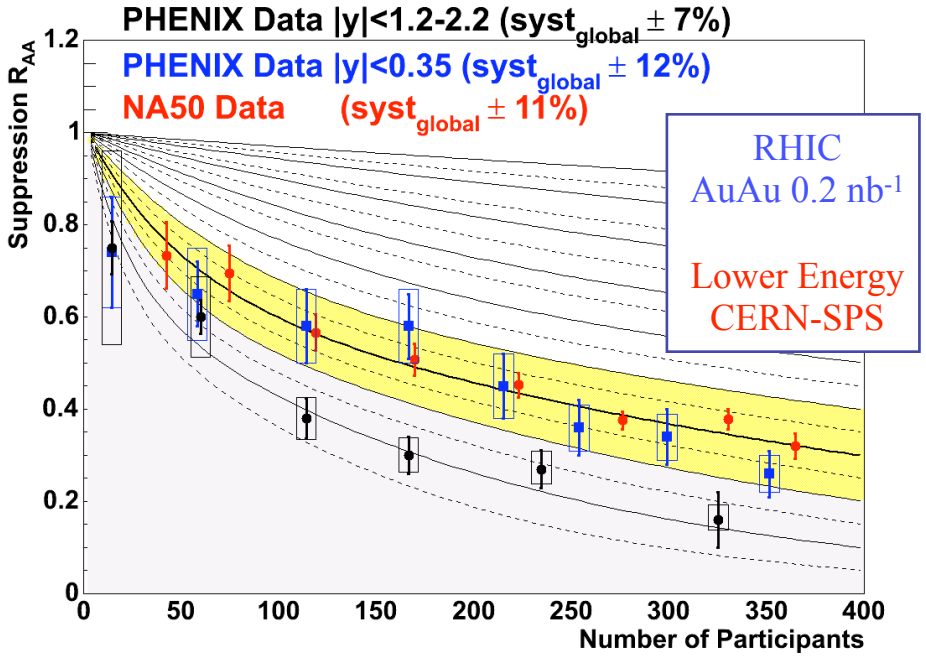
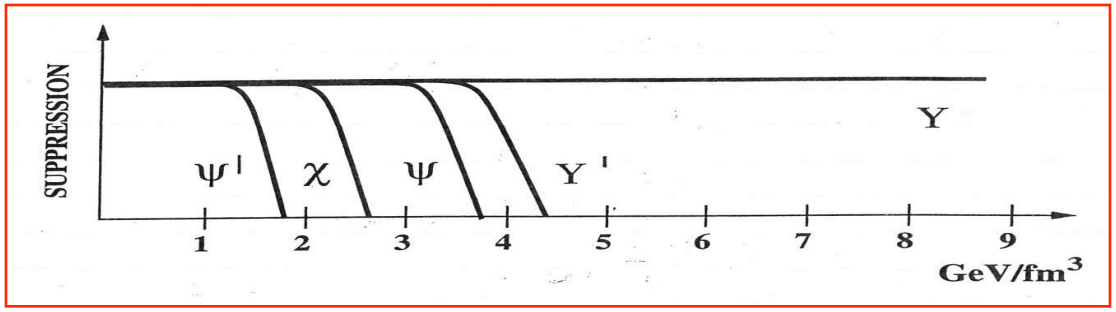
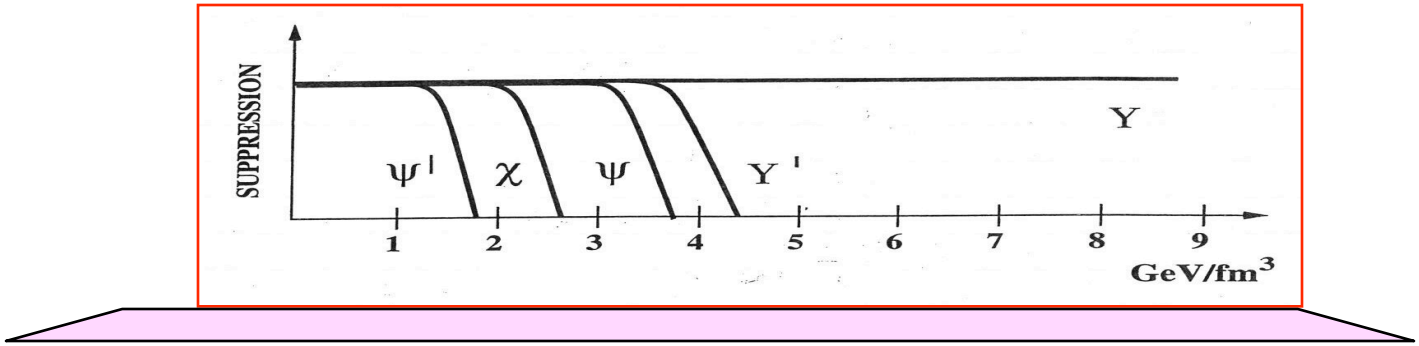




First J/ψ results from RHIC show remarkably similar suppression to that at lower energies (except at forward rapidity).




SUPPRESSION
ψ'
χ
ψ
Υ'
Υ
1
2
3
4
5
6
7
8
9
GeV/fm3

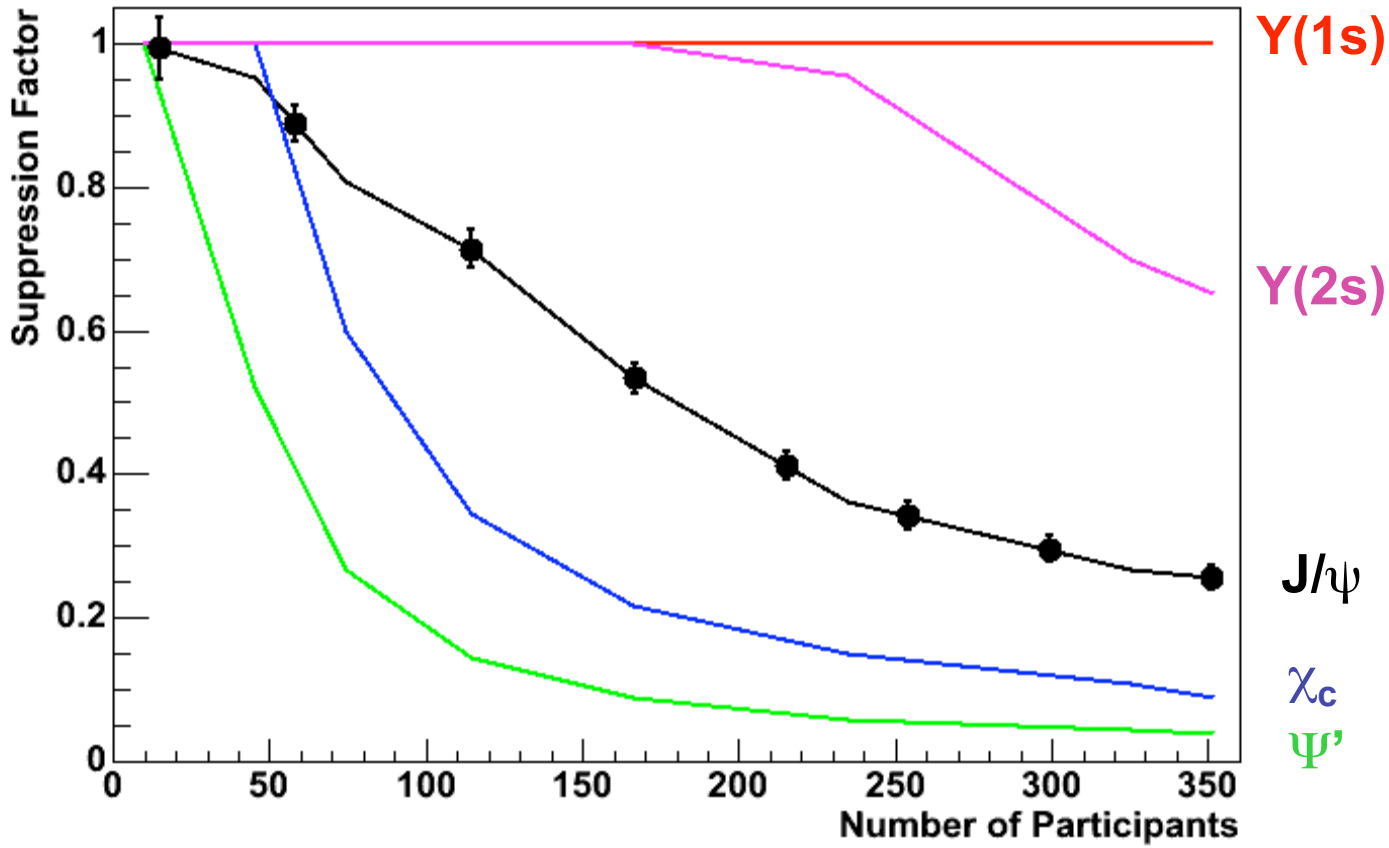


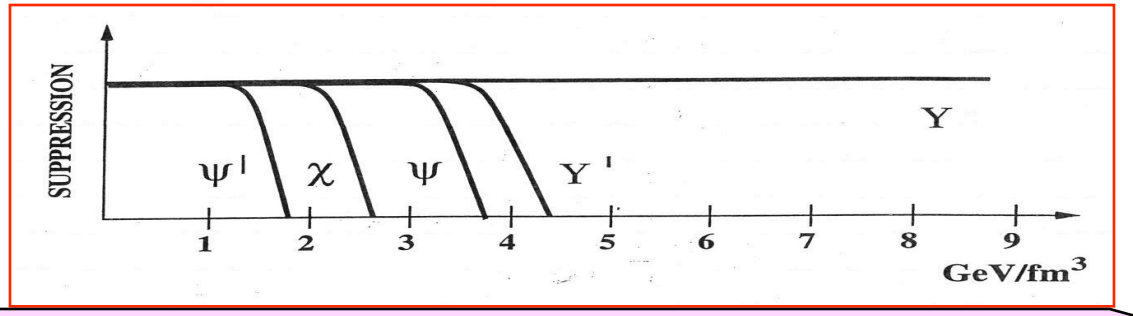
RHIC I

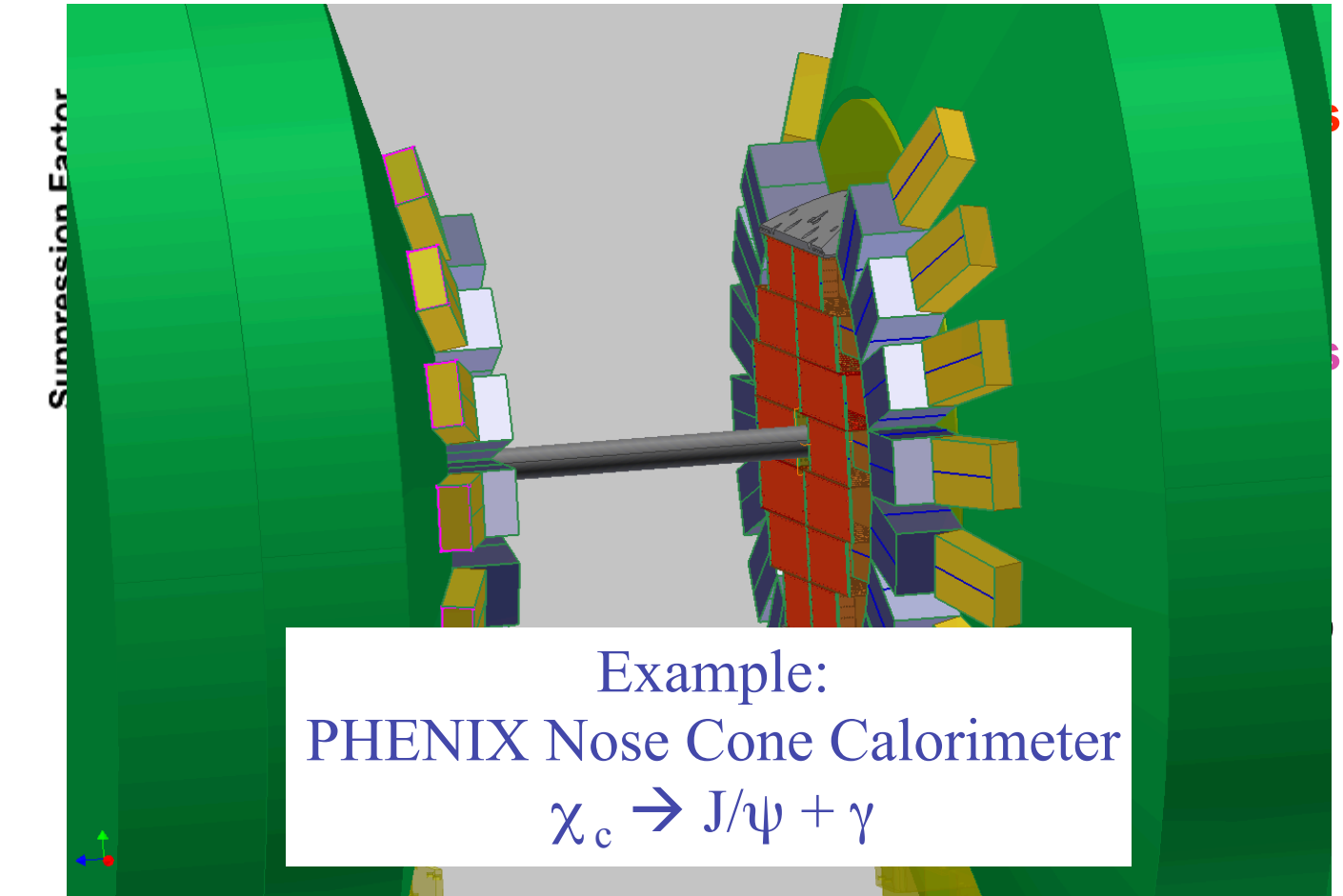
AuAu 0.2 nb^{-1}

No detector upgrades

No e-cooling







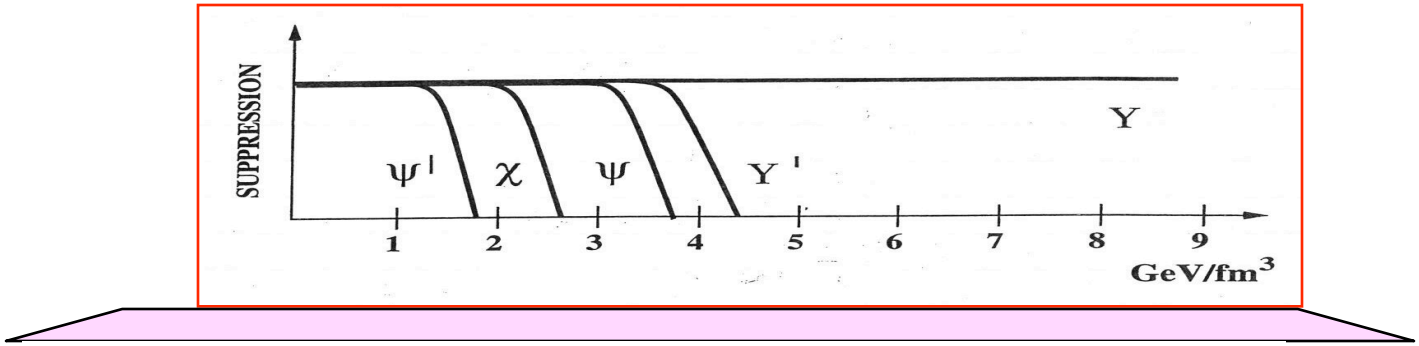
Example:
PHENIX Nose Cone Calorimeter
$\chi_c \rightarrow J/\psi + \gamma$

RHIC I

AuAu 0.2 nb^{-1}

No detector upgrades

No e-cooling

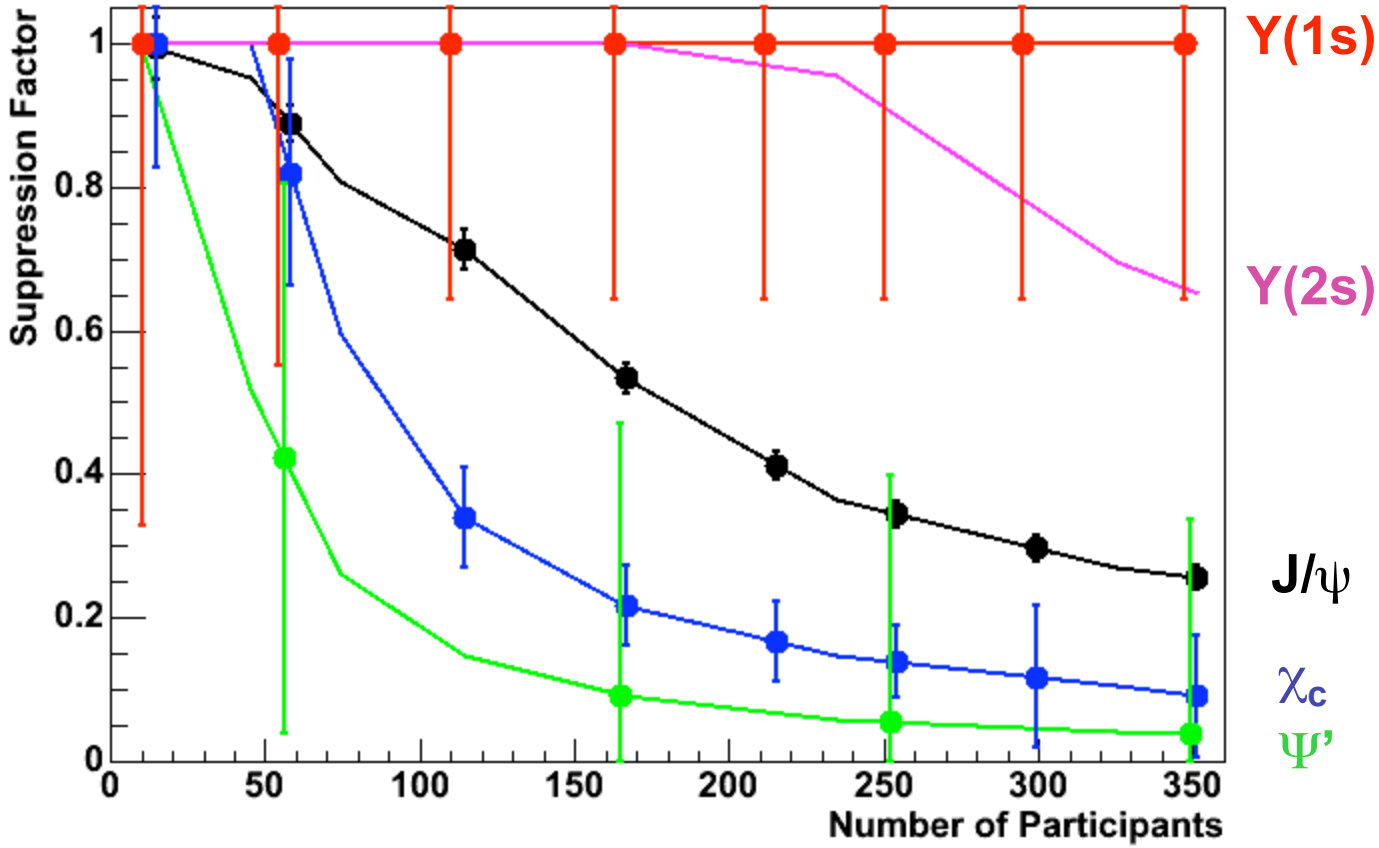


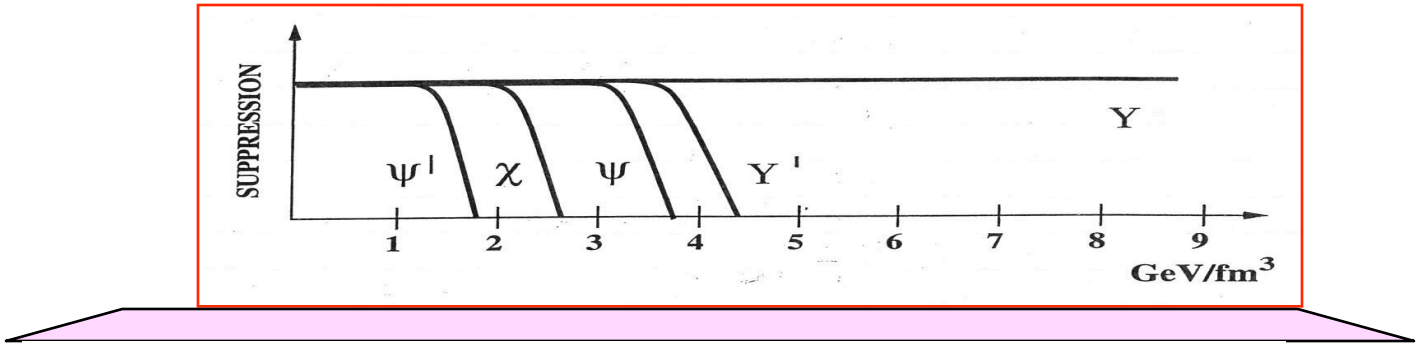
RHIC I ++

AuAu 2 nb^{-1}

Detector upgrades

No e-cooling



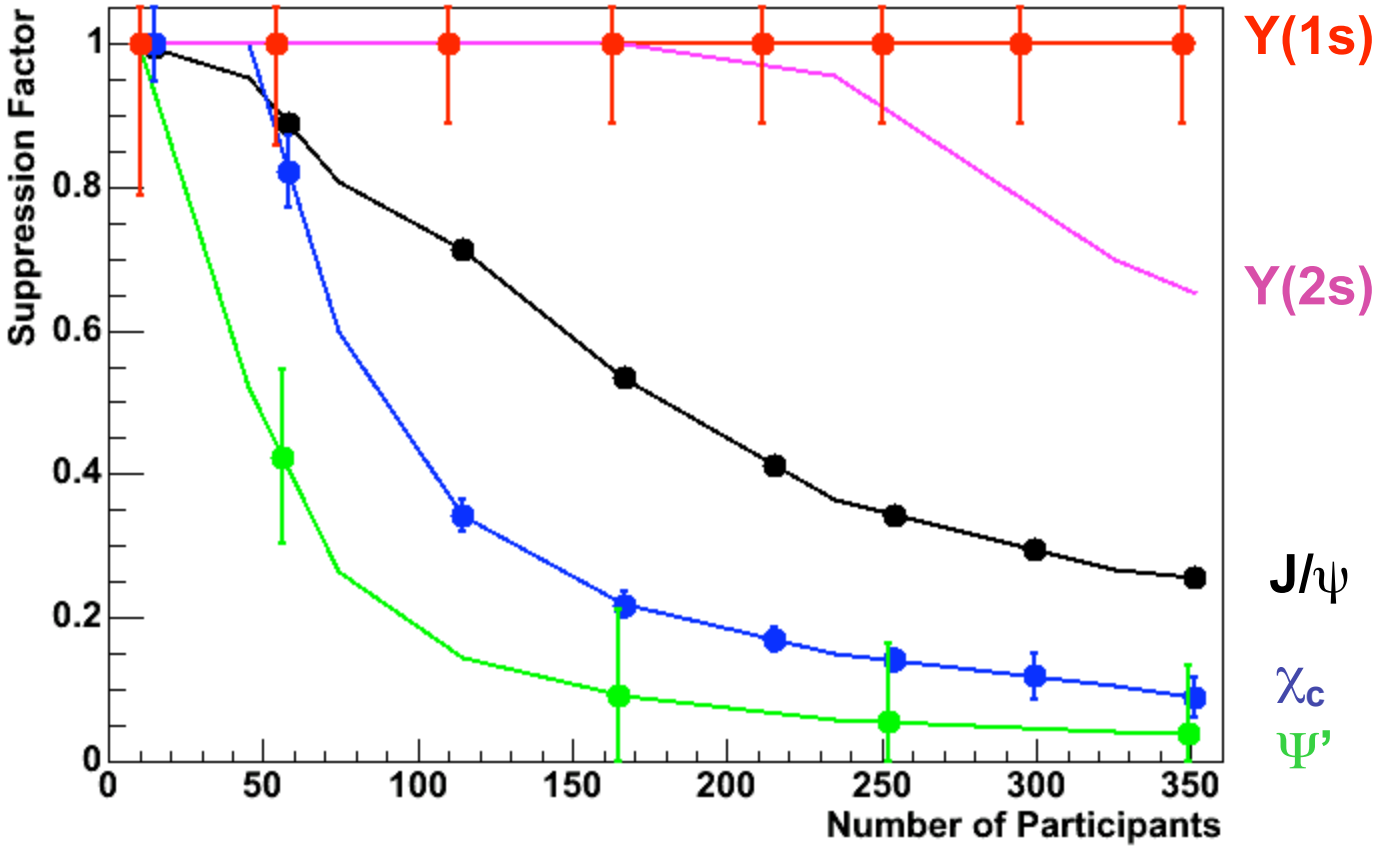


RHIC II

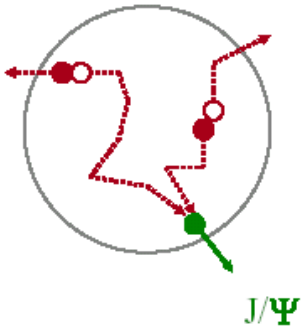
AuAu 20 nb^{-1}

Detector upgrades

With e-cooling



Many calculations include J/ψ formed via quark recombination which could drastically change the previous predictions.



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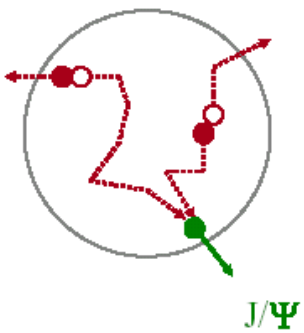

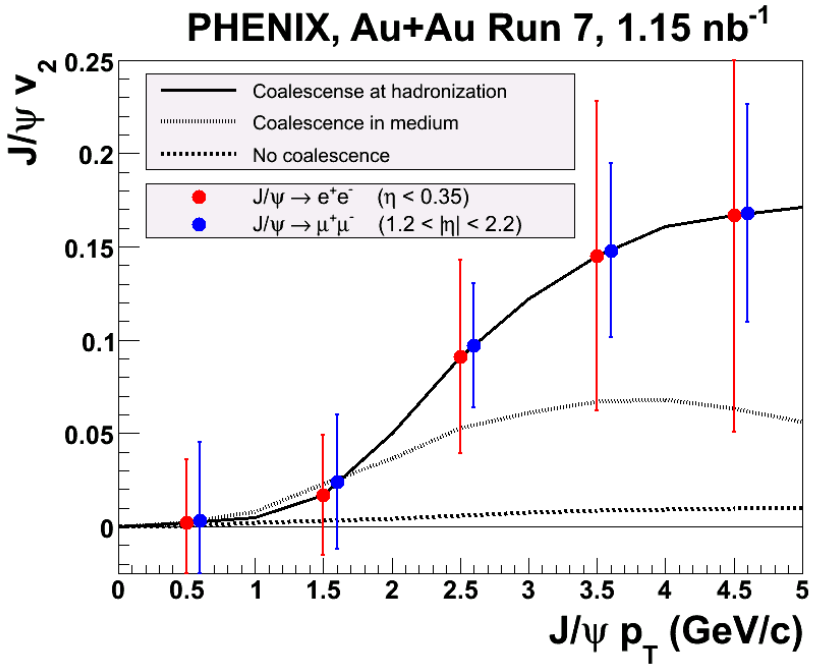

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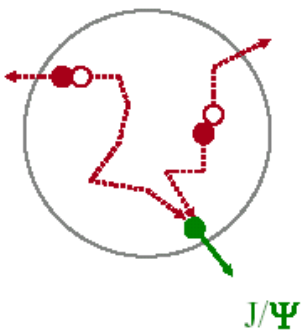
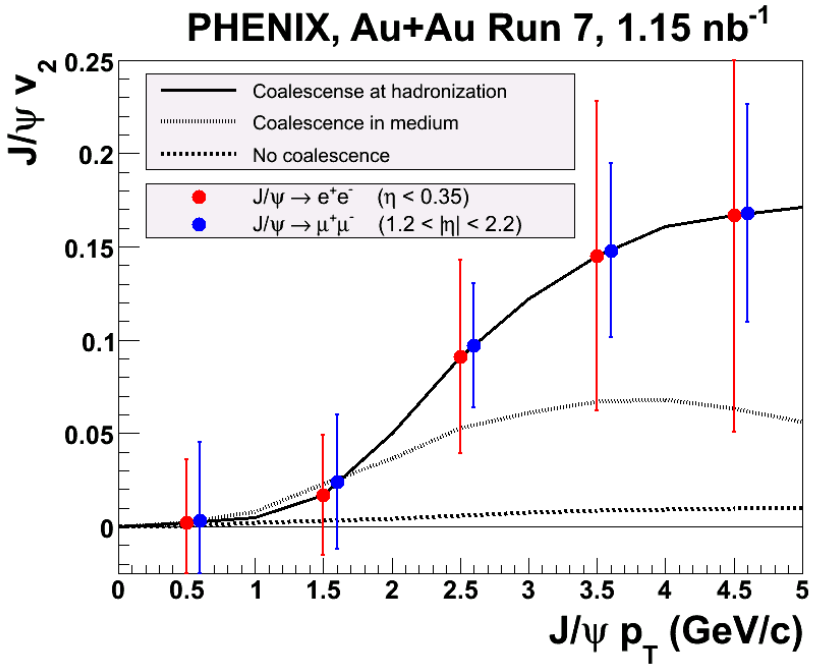
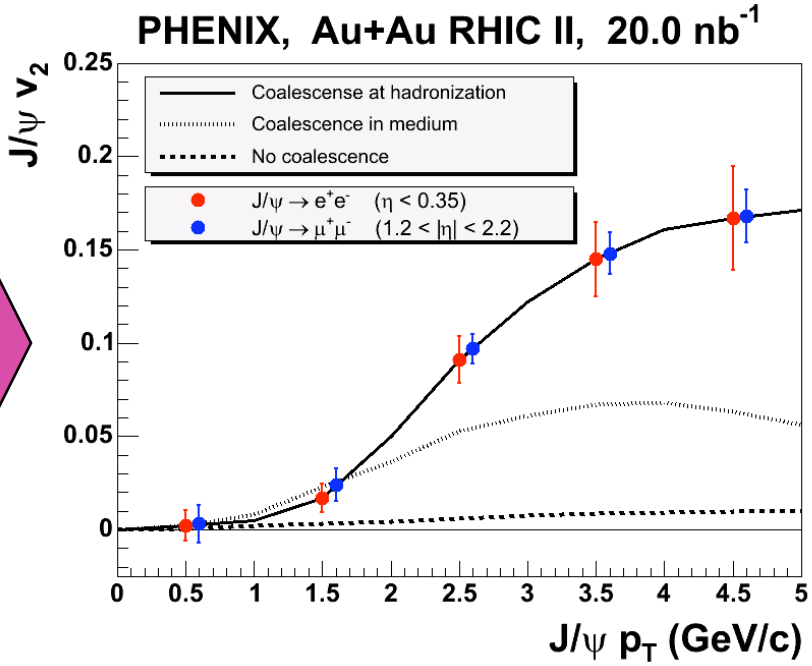
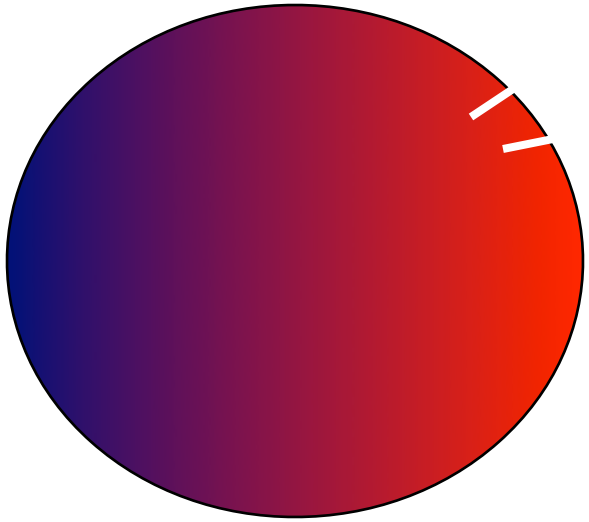
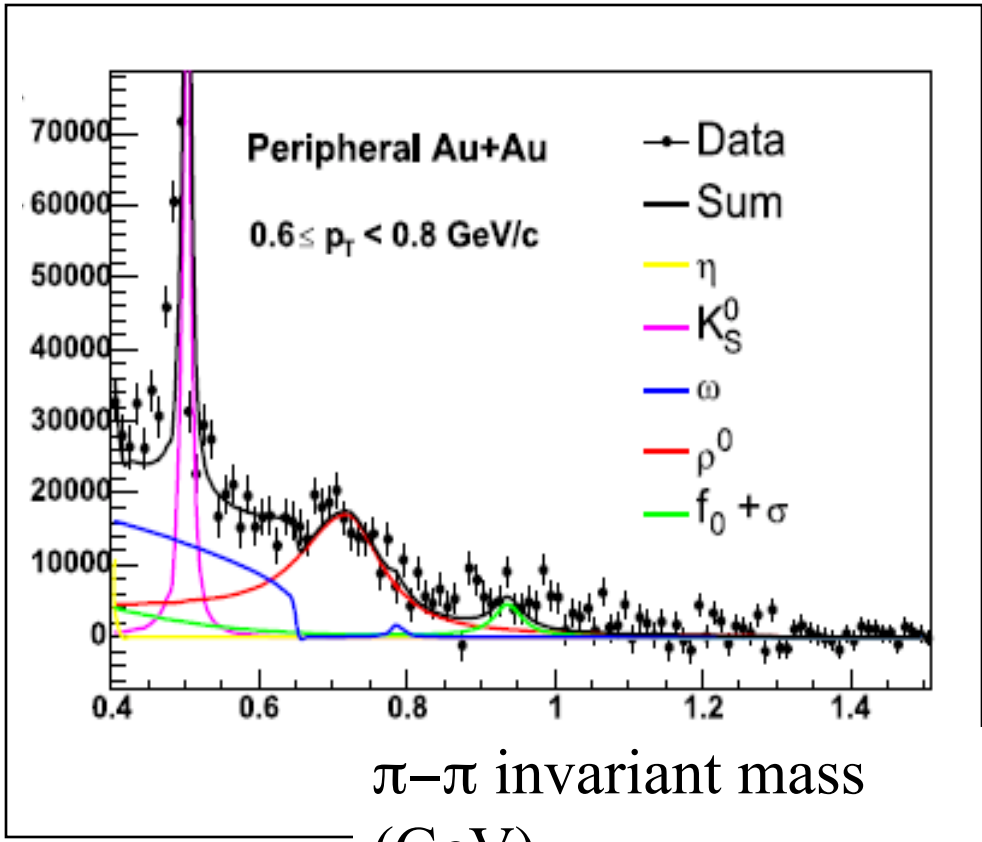


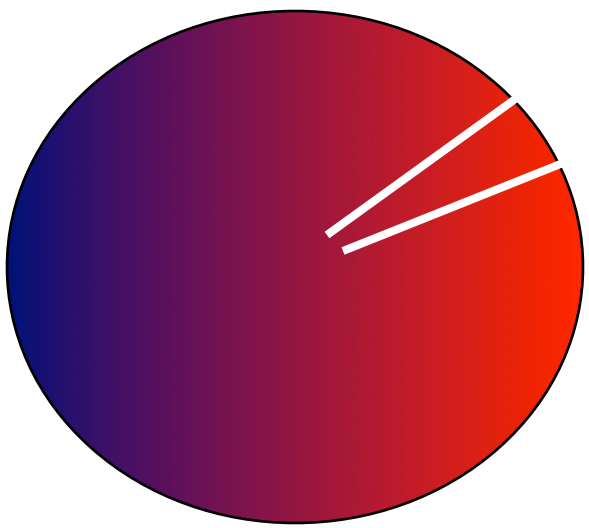


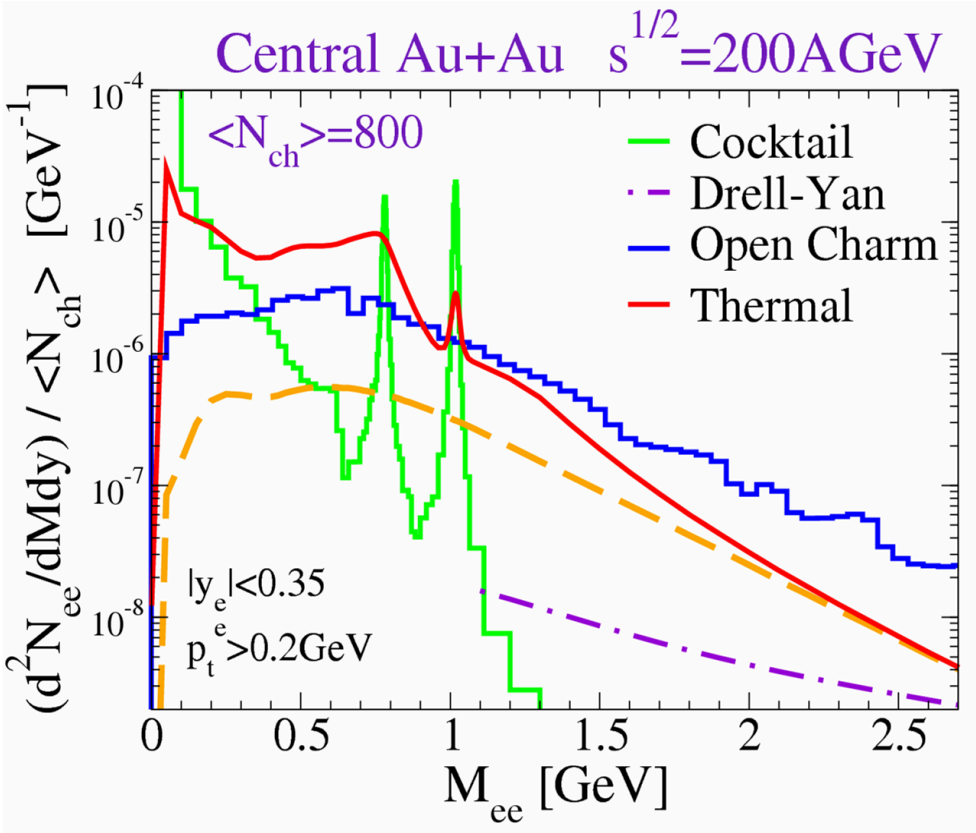


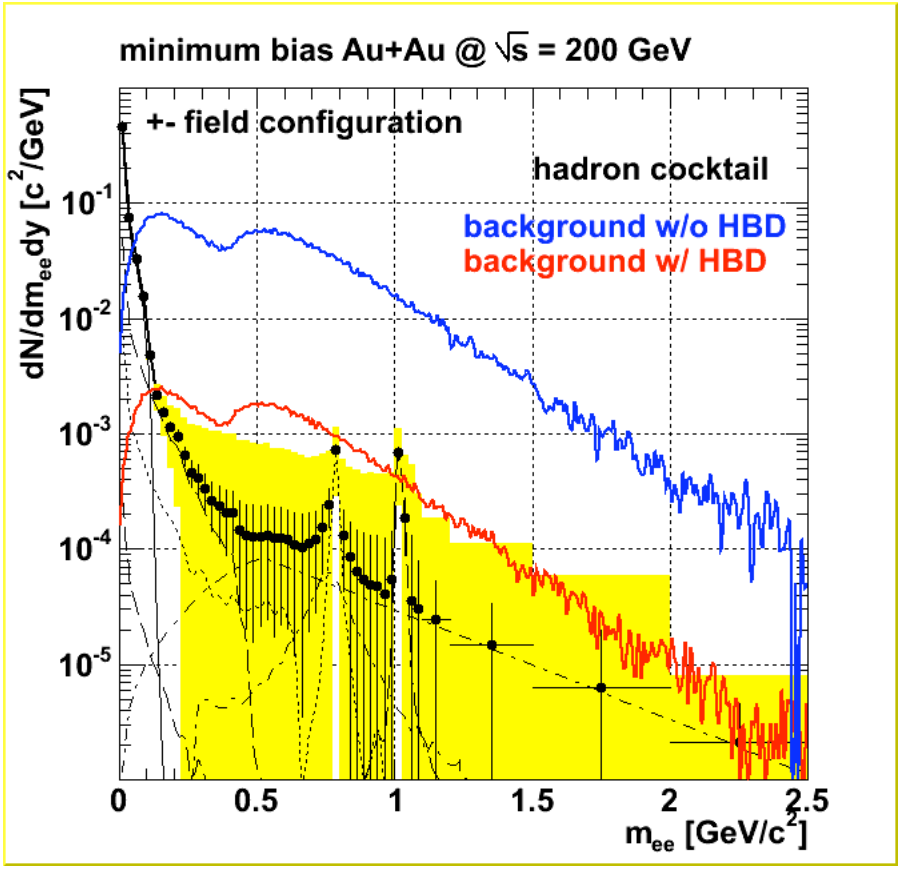


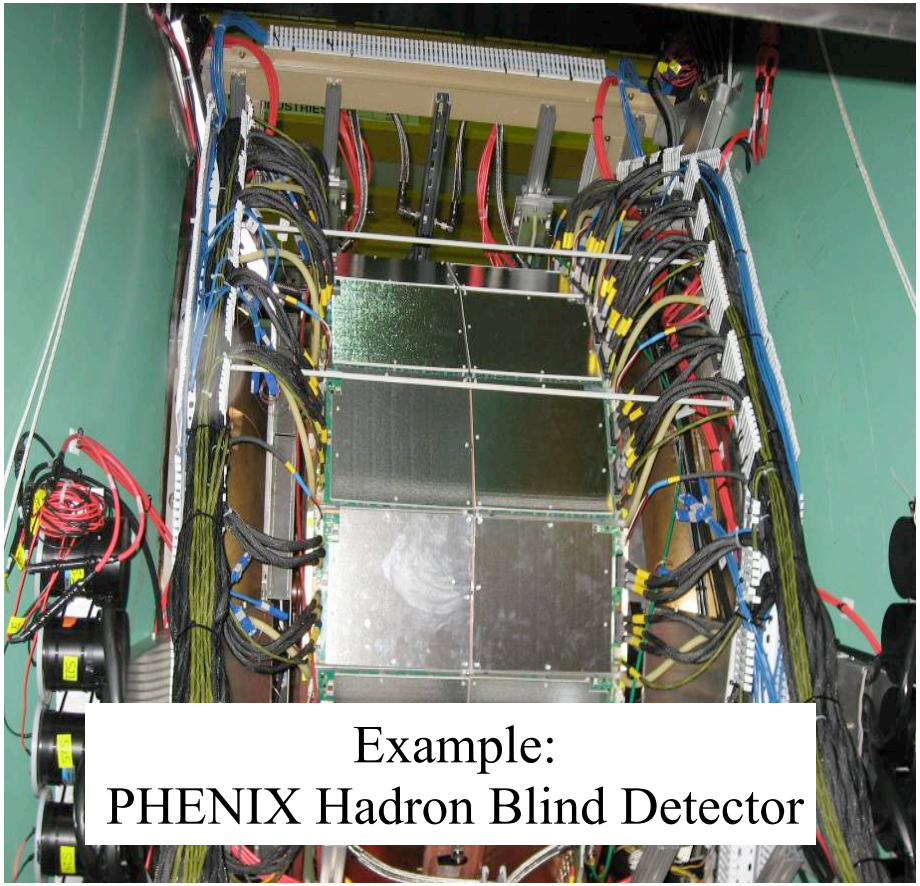


π–π invariant mass (GeV)

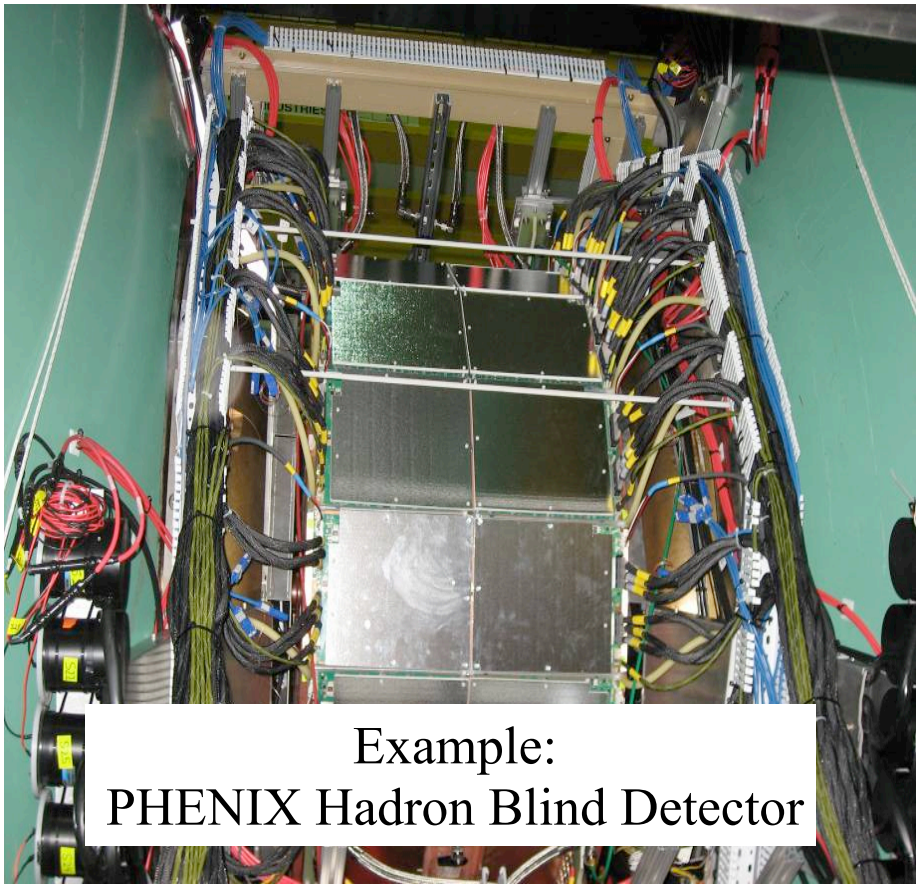



Central Au+Au s^1/2=200AGeV
<N_ch>=800
Cocktail
Drell-Yan
Open Charm
Thermal
|y_e|<0.35
p_t^e>0.2GeV
(d^2N_ee/dMdy) / <N_ch> [GeV^-1]
M_ee [GeV]
10^-4
10^-5
10^-6
10^-7
10^-8
0
0.5
1
1.5
2
2.5

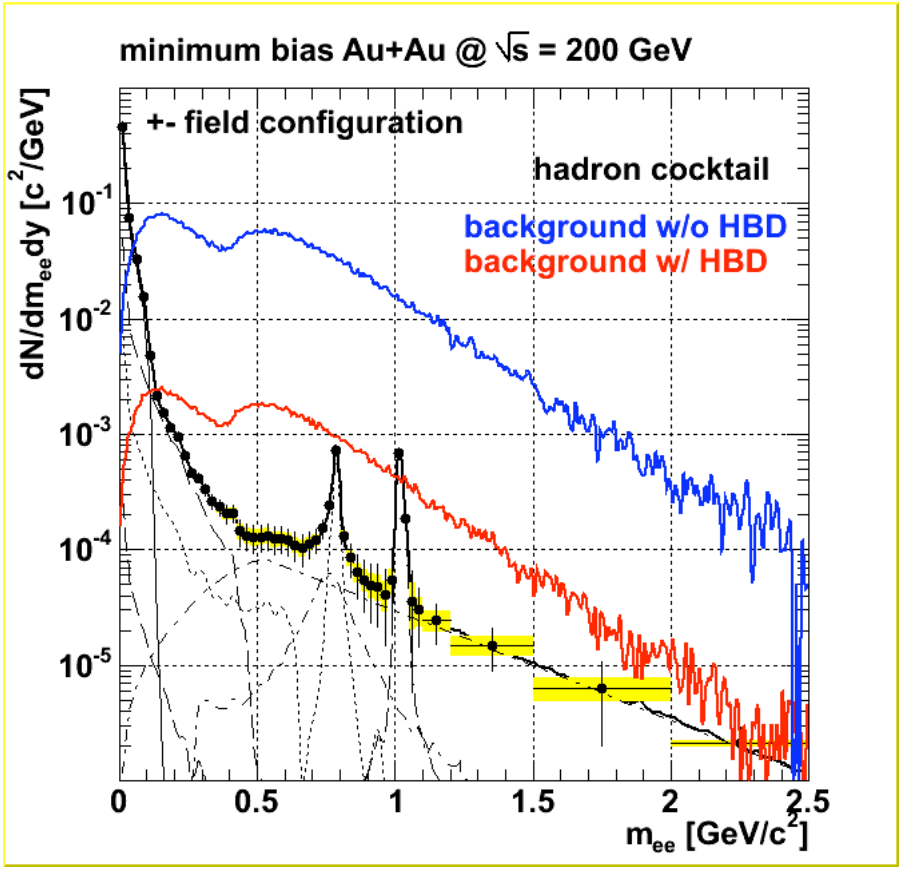

minimum bias Au+Au @ √s = 200 GeV
+- field configuration
hadron cocktail
background w/o HBD
background w/ HBD
dN/dm_ee dy [c^2/GeV]
10^-1
10^-2
10^-3
10^-4
10^-5
0
0.5
1
1.5
2
2.5
m_ee [GeV/c^2]



Example:
PHENIX Hadron Blind Detector



Example:
PHENIX Hadron Blind Detector

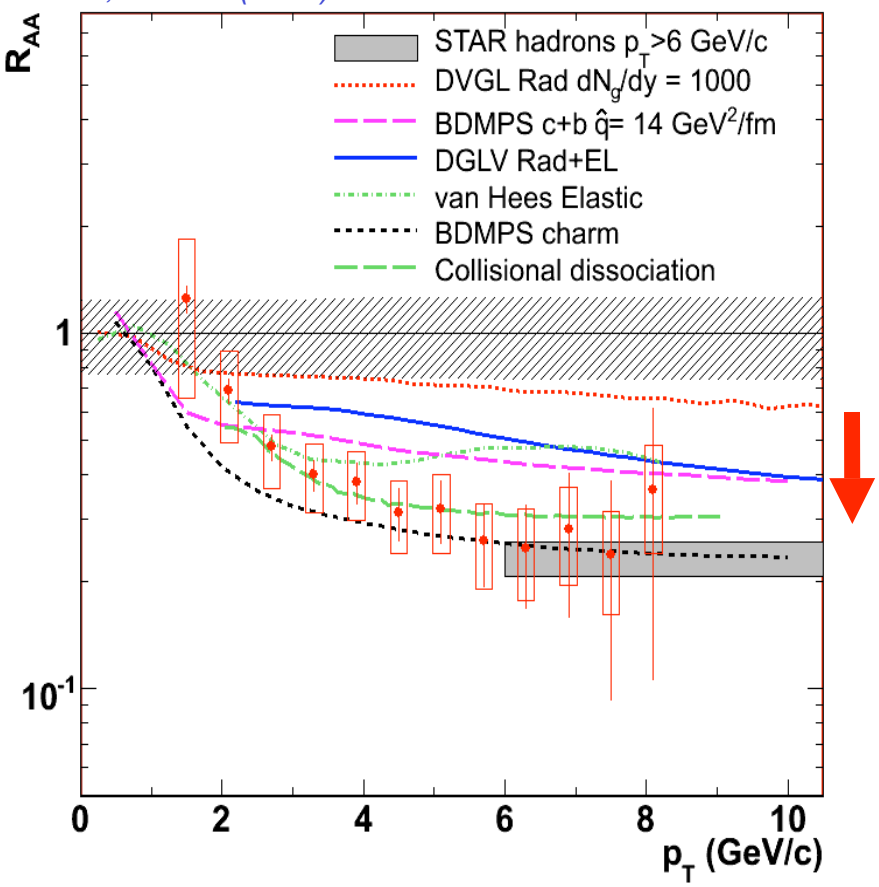


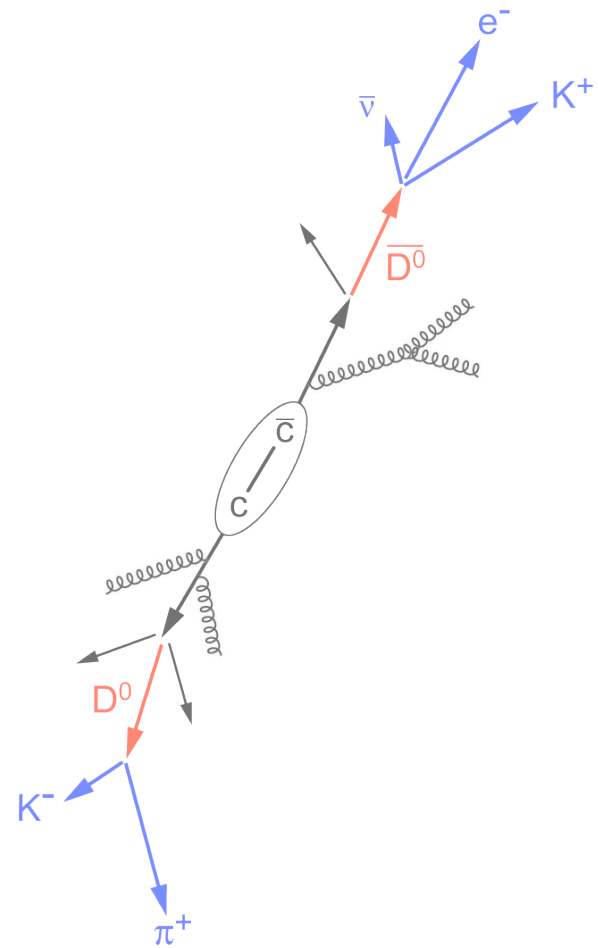
Upgrades	High T QCD				Spin		Low x
	e+e-	heavy flavor	jet tomography	quarkonia	W	ΔG/G	
PHENIX							
hadron blind detector (HBD)	X						
Vertex tracker (VTX and FVTX)	X	X	O	O		X	O
μ trigger				O	X		
forward calorimeter (NCC)			O	X	O		X
STAR							
time of flight (TOF)		O	X	O			
Heavy flavor tracker (HFT)		X	O	O			
tracking upgrade		O	O		X	O	
Forward calorimeter (FMS)						O	X
DAQ		O	X	X	O	O	O
RHIC luminosity	O	O	X	X	O	O	O

X upgrade critical for success
O upgrade significantly enhancements program

Suppression of Charm/Beauty

STAR, PRL 98 (2007) 192301



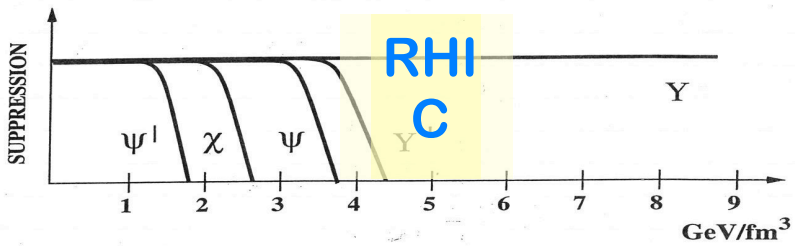


Unexpectedly strong suppression of non-photonic electrons a major issue

Uncertainties in B contribution: need to measure c and b separately

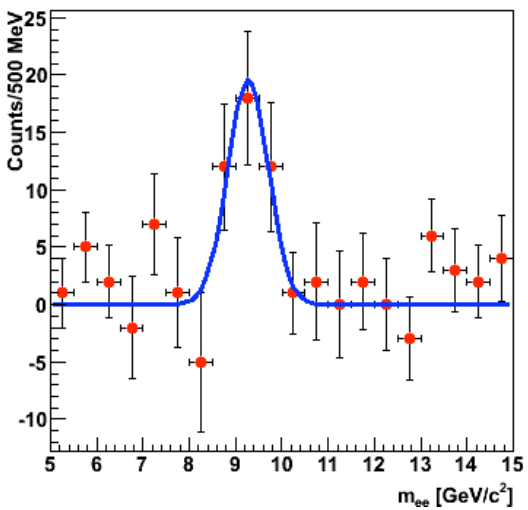
Precision measurements require upgraded detectors and RHIC II luminosity

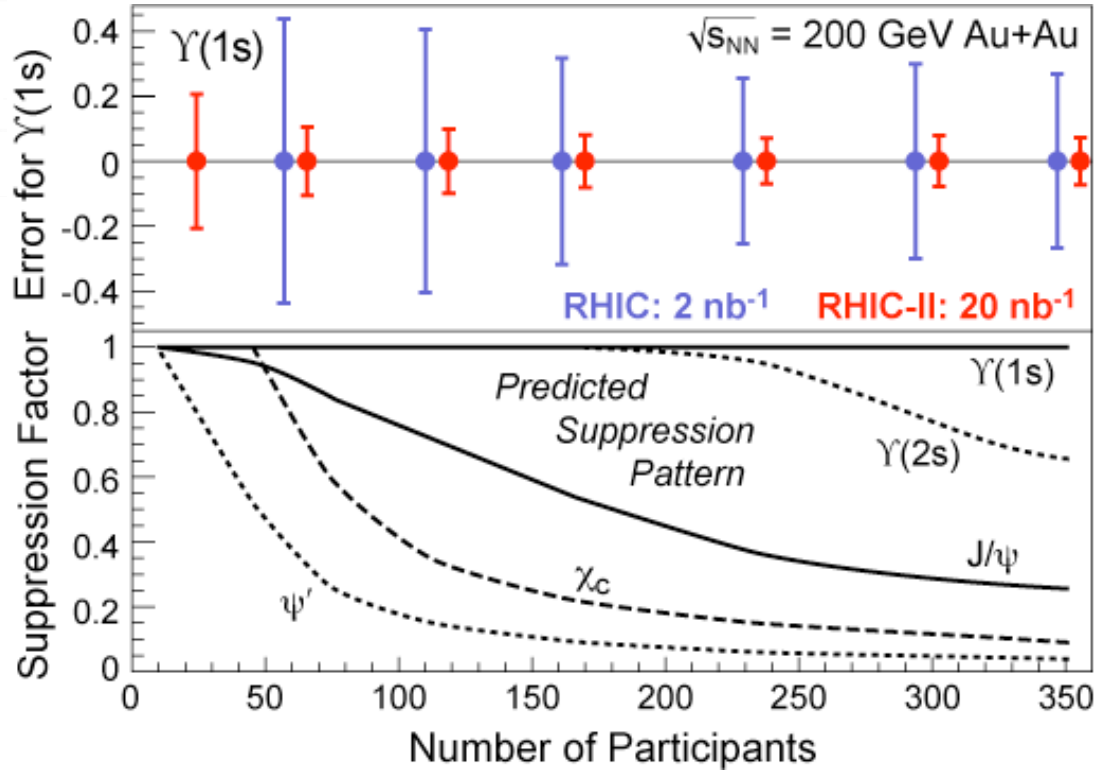
Quarkonium: Upsilon



Proof of principle measurement: run 6 p+p

Upsilon(1S+2S+3S)→e^+e^-

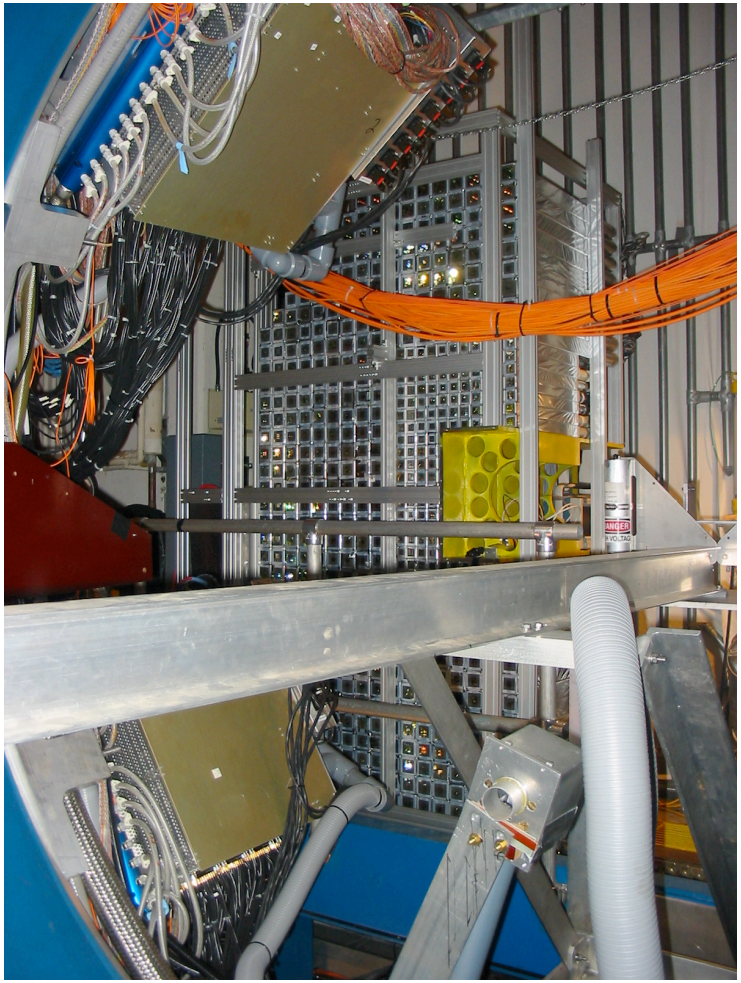




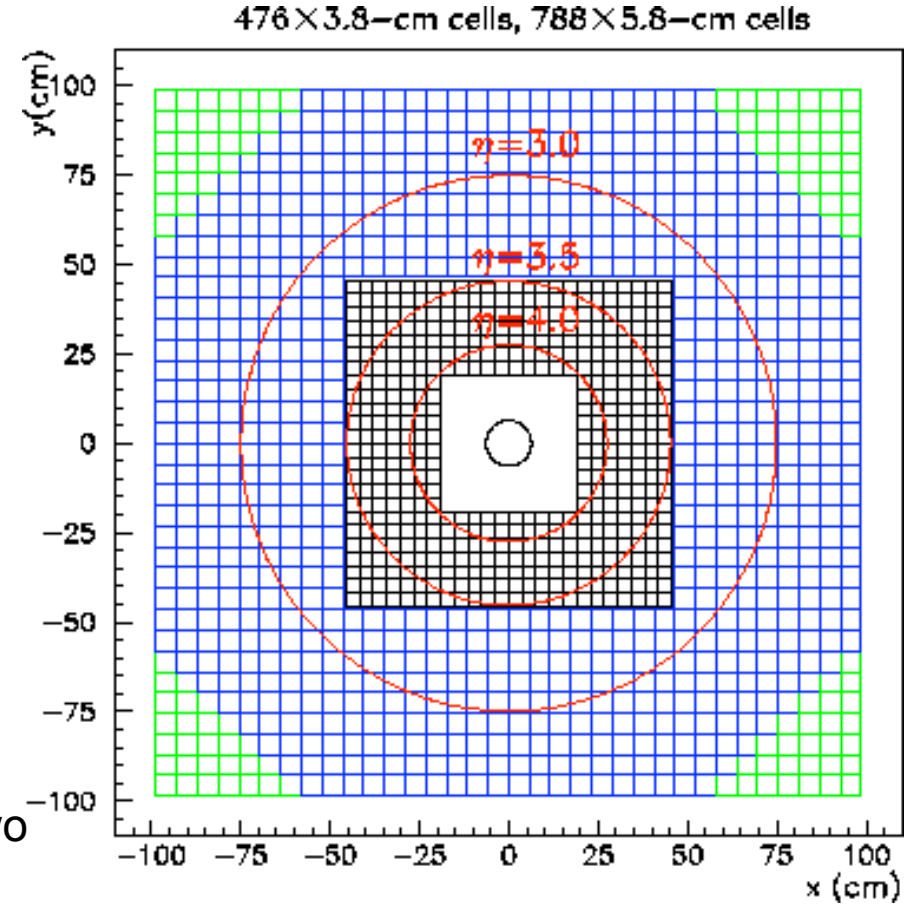
Sequential dissociation of quarkonia to measure energy density of plasma

Requires full luminosity of RHIC II for definitive measurements

STAR Forward Meson Spectrometer (FMS)

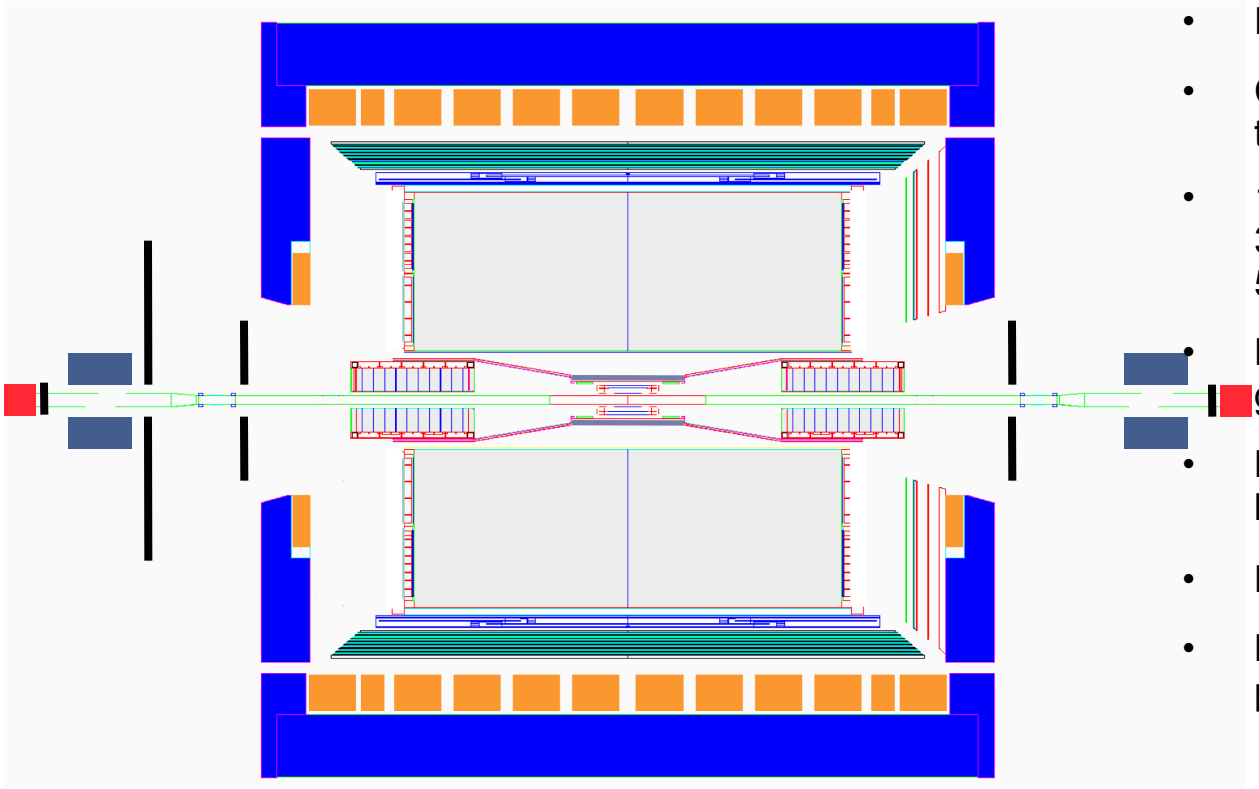


Schematic of the FMS as seen from the interaction point. The small-cell inner calorimeter has 476 detectors and the large cell outer calorimeter has 788 detectors.

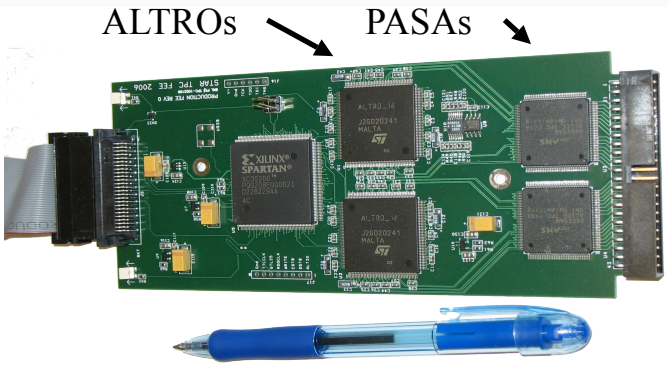


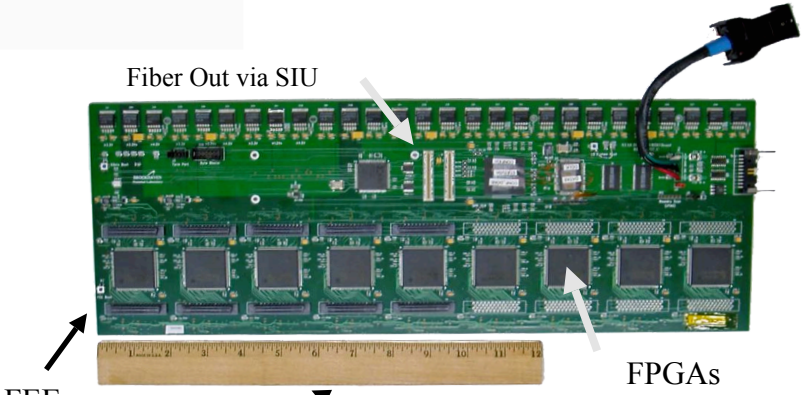
Detectors are stacked on the west platform in two movable halves. This view is of the south FMS half, as seen through the retracted west poletip.

TPC FEE and DAQ Upgrade – DAQ 1000

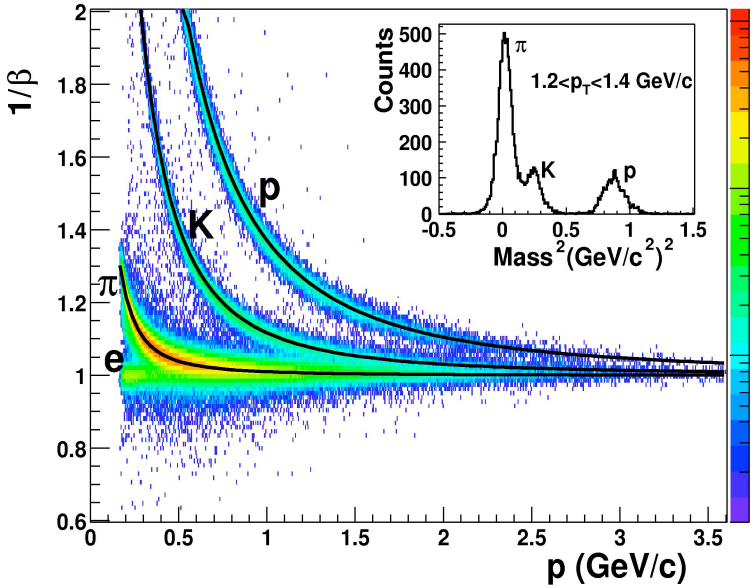


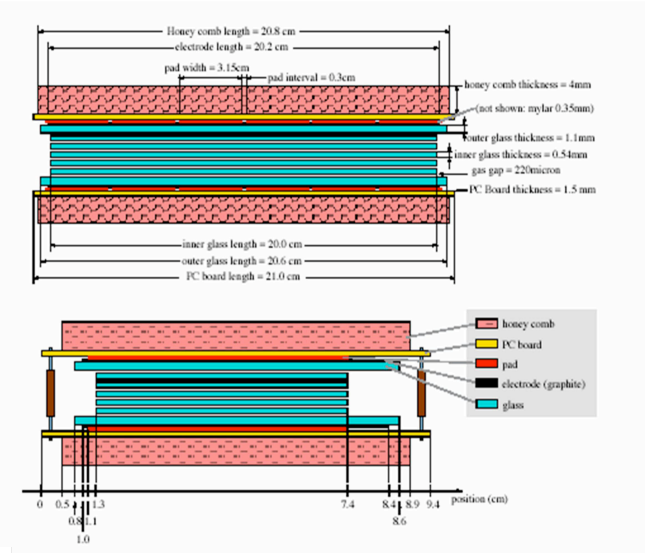
- Faster, smaller, better … (10x)
- Current TPC FEE and DAQ limited to 100 Hz
- 1 kHz central
  3 kHz minBias
  5 kHz future
- Replace TPC FEE with next generation CERN ALTRO, PASA
- Make the FEE smaller and creates less heat
- No dead time (well, almost …)
- More efficient for rare physics probes

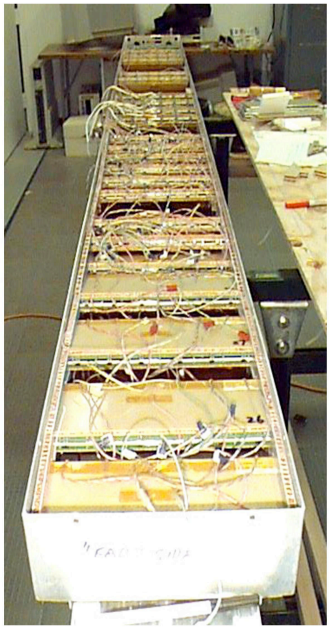


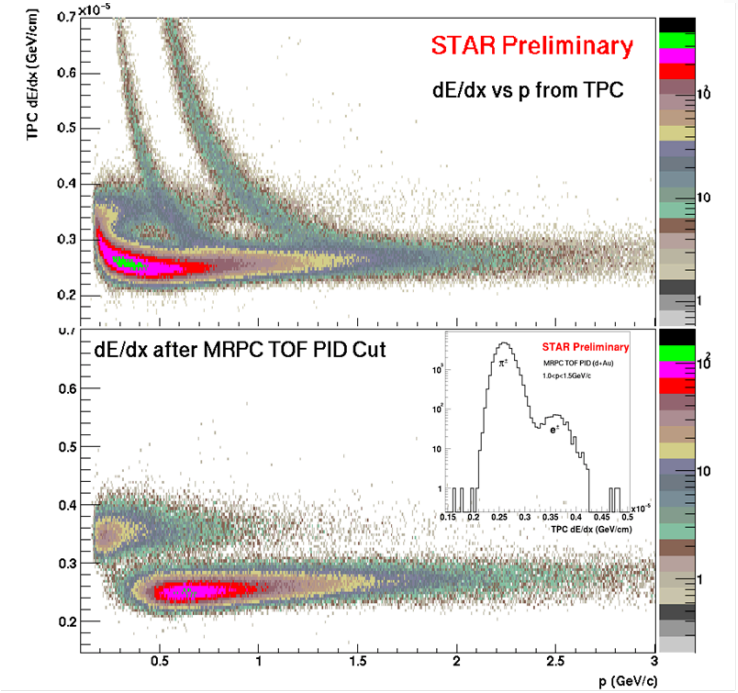


MRPC Time-of-Flight





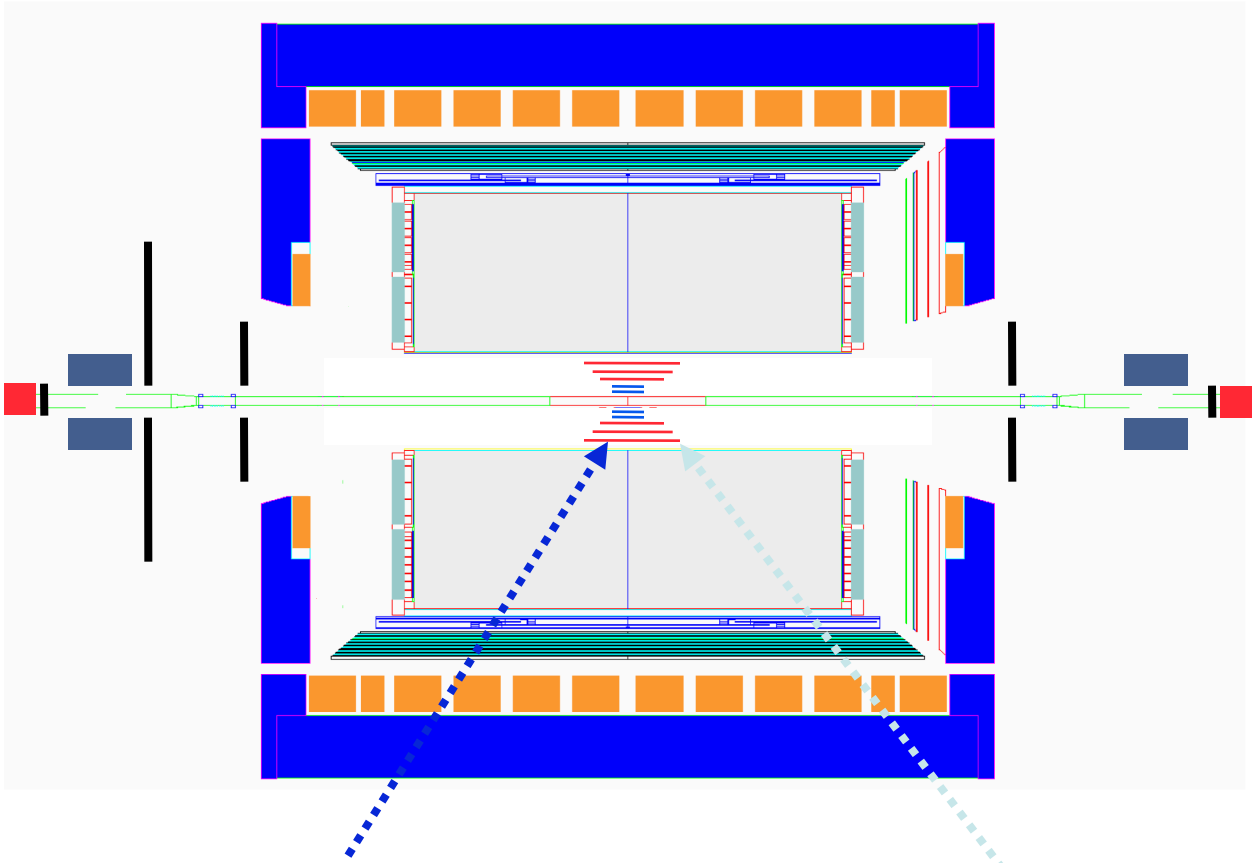




State-of-art Multi-gap Resistive Plate Chamber:
6 gap, 3x6cm^2 pad; 23,000 channels,
$-0.9<\eta<0.9$, $0<\phi<2\pi$, r=220cm

collaboration between the United States (DOE) and China (NNSFC, MoST, MoE) in high-energy particle physics detector research

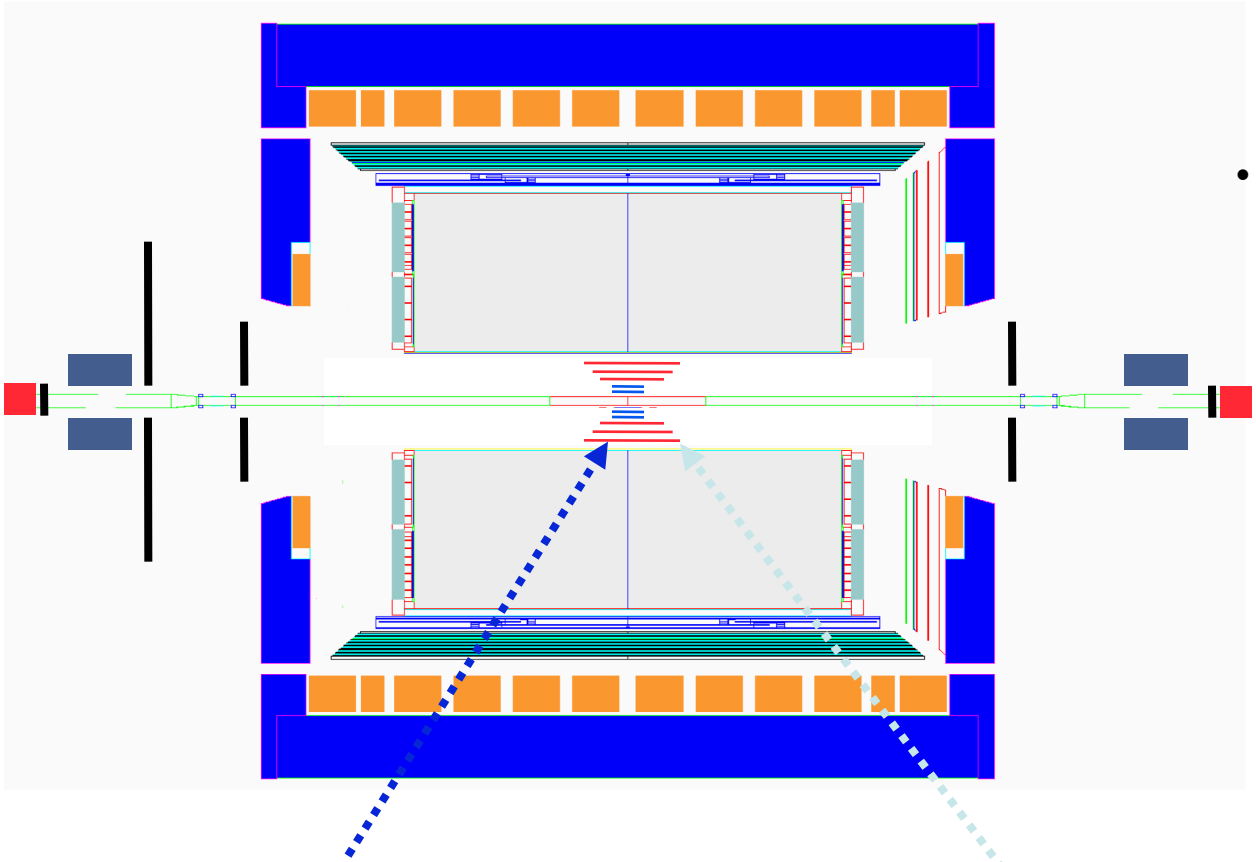
The Heavy Flavor Tracker



The PXL: 2 layers of Si at mid rapidity

Mid-rapidity Pointing Devices: IST + SSD

The Heavy Flavor Tracker

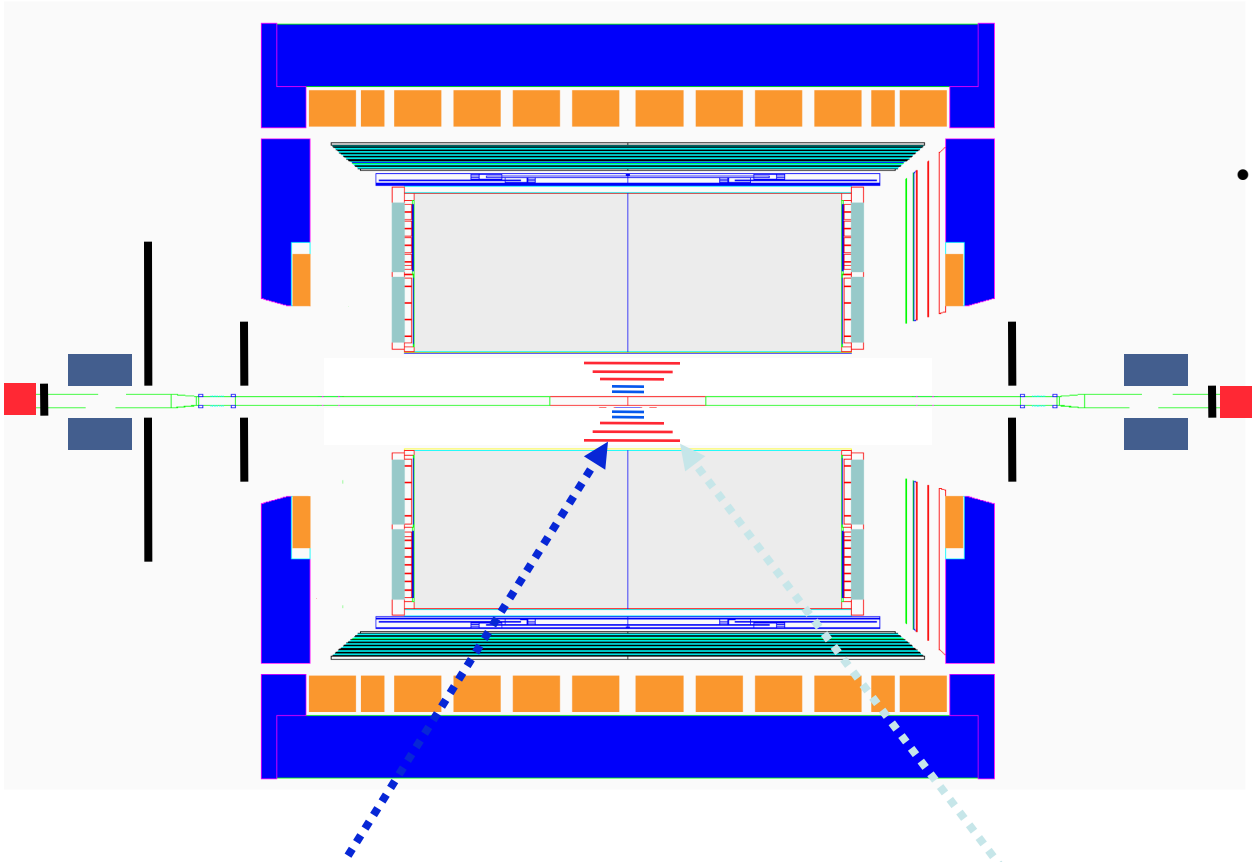


- The PXL is a new detector
  - 30 μm silicon pixels to yield 10 μm space point resolution
- Direct Topological reconstruction of Charm

The PXL: 2 layers of Si at mid rapidity

Mid-rapidity Pointing Devices: IST + SSD

The Heavy Flavor Tracker



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  - Detect charm decays with small cτ, including $D^0 \rightarrow K\,\pi$

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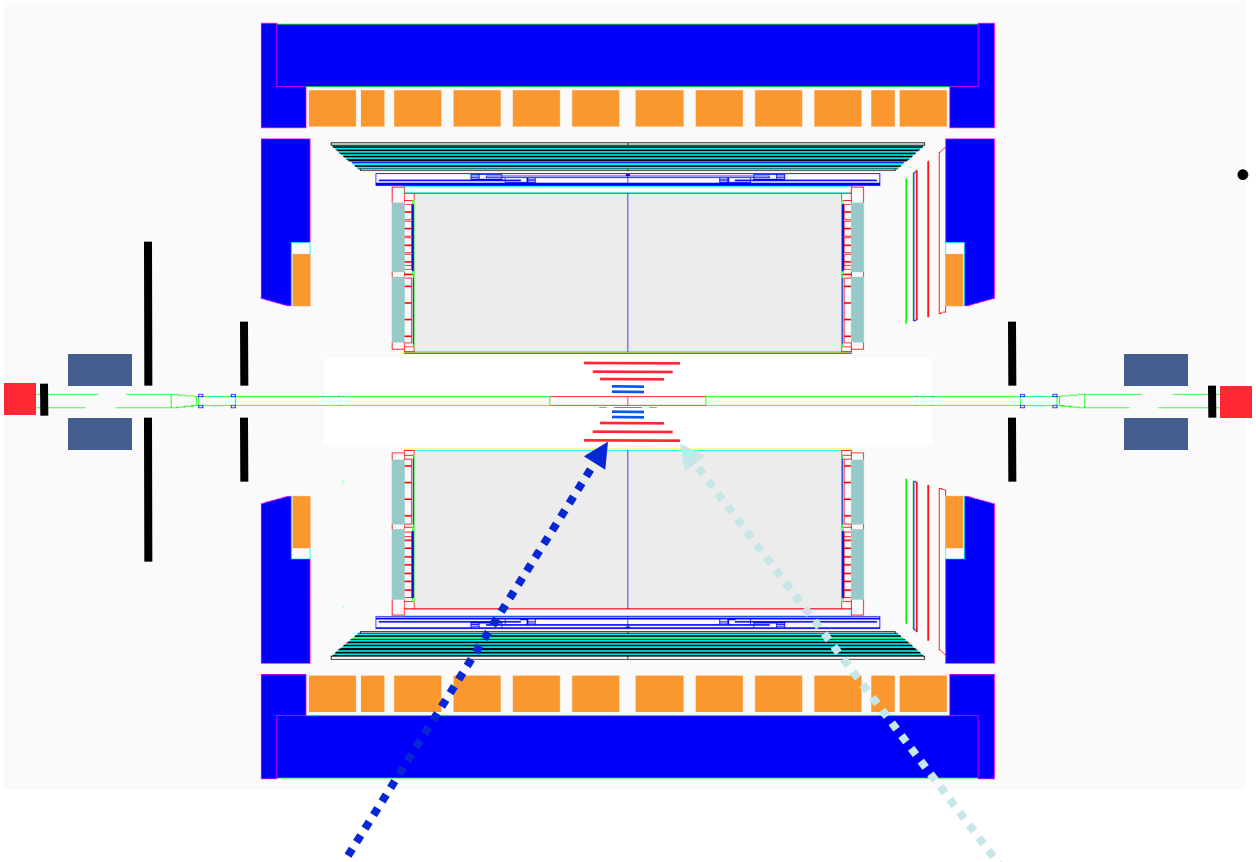

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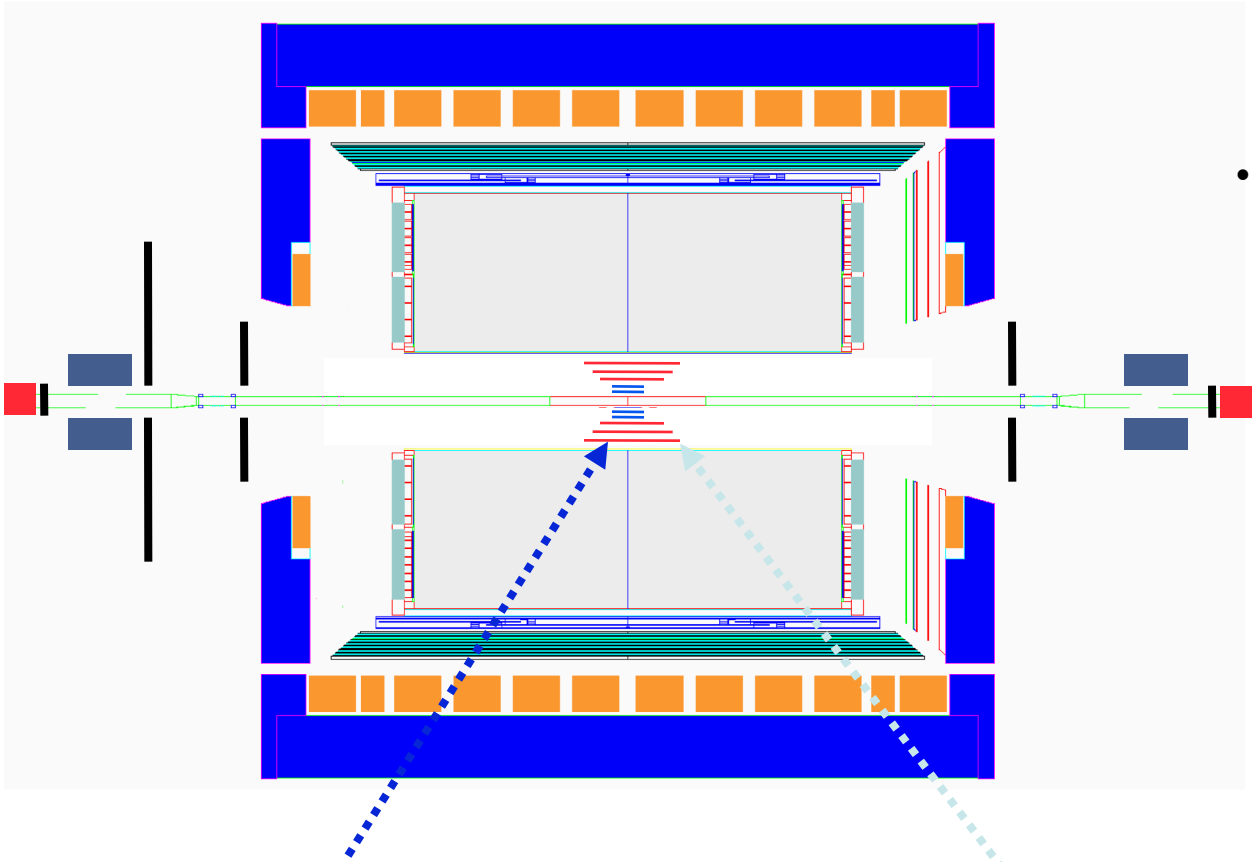
New physics

The Heavy Flavor Tracker



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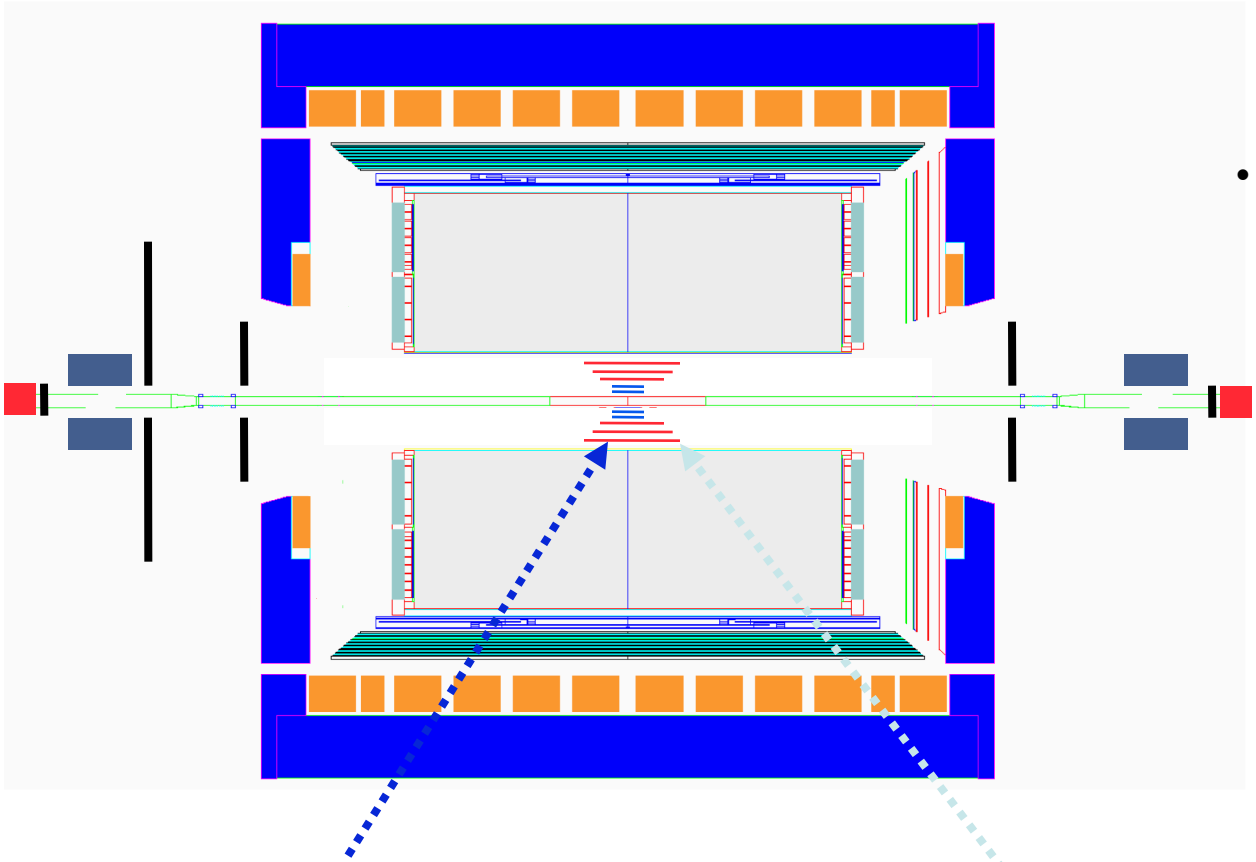
  - Detect charm decays with small cτ, including $D^0 \rightarrow K\,\pi$
- New physics
  - Charm collectivity and flow to test thermalization at RHIC

The Heavy Flavor Tracker



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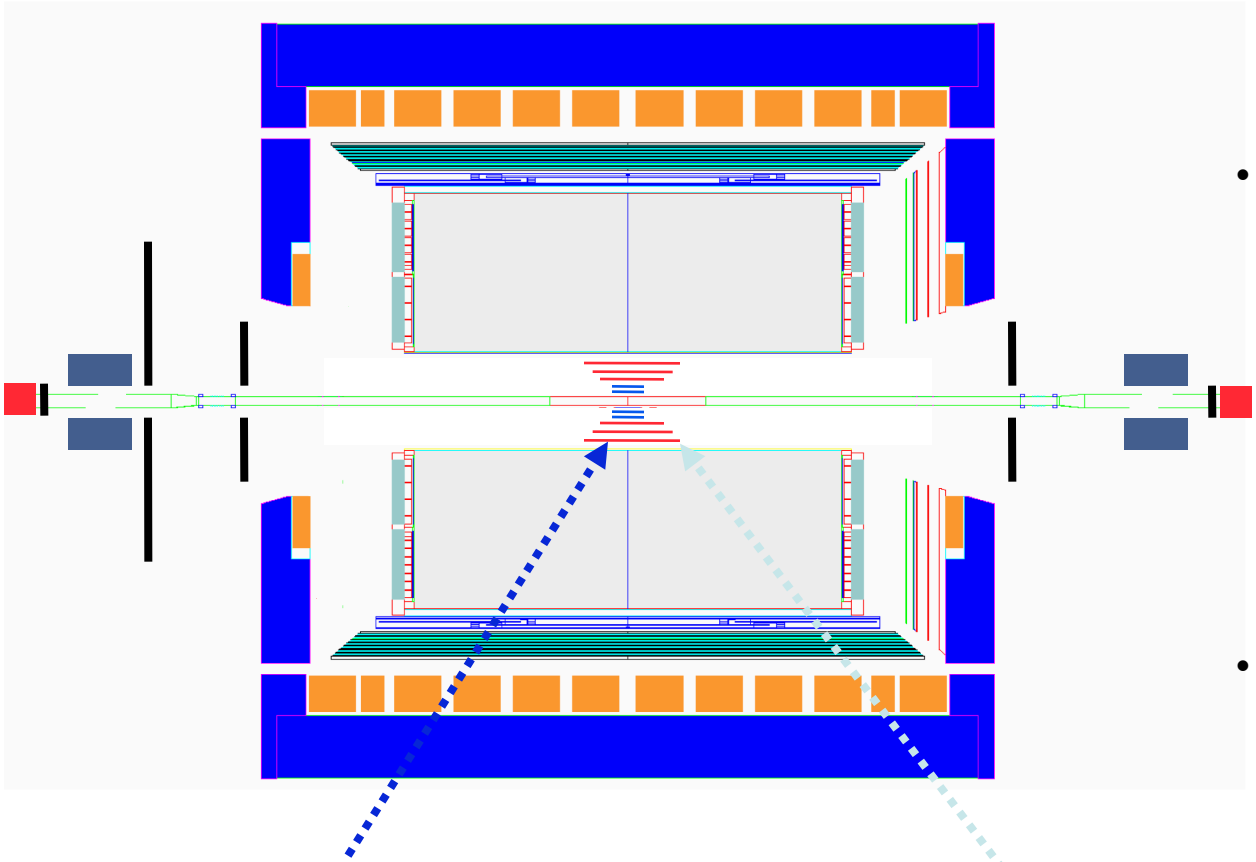
  - Charm collectivity and flow to test thermalization at RHIC
  - C & B Energy Loss to test pQCD in a hot and dense medium at RHIC

The Heavy Flavor Tracker



The PXL: 2 layers of Si at mid rapidity

Mid-rapidity Pointing Devices: IST + SSD

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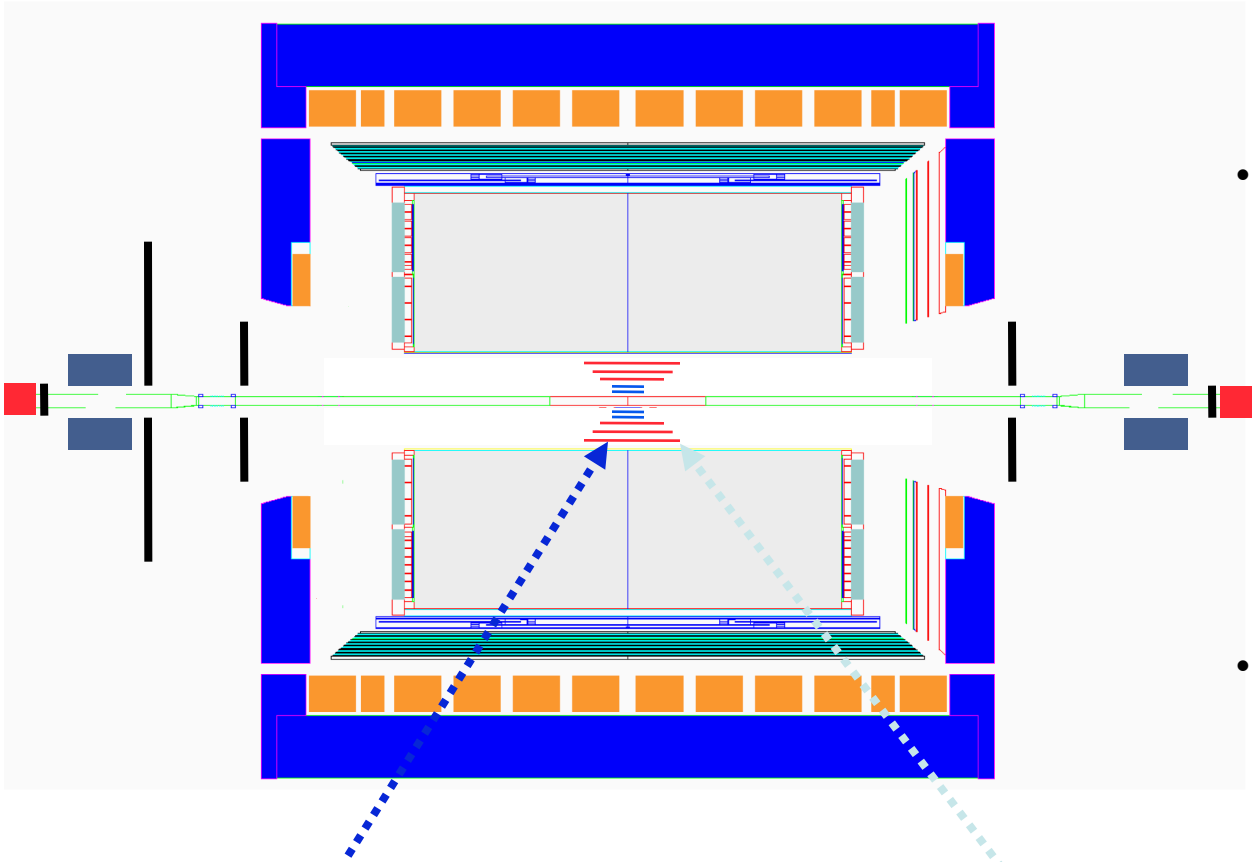
- Direct Topological reconstruction of Charm
  - Detect charm decays with small cτ, including $D^0 \rightarrow K\,\pi$
- New physics
  - Charm collectivity and flow to test thermalization at RHIC
  - C & B Energy Loss to test pQCD in a hot and dense medium at RHIC
- The proposed Tracking Upgrades include

The Heavy Flavor Tracker

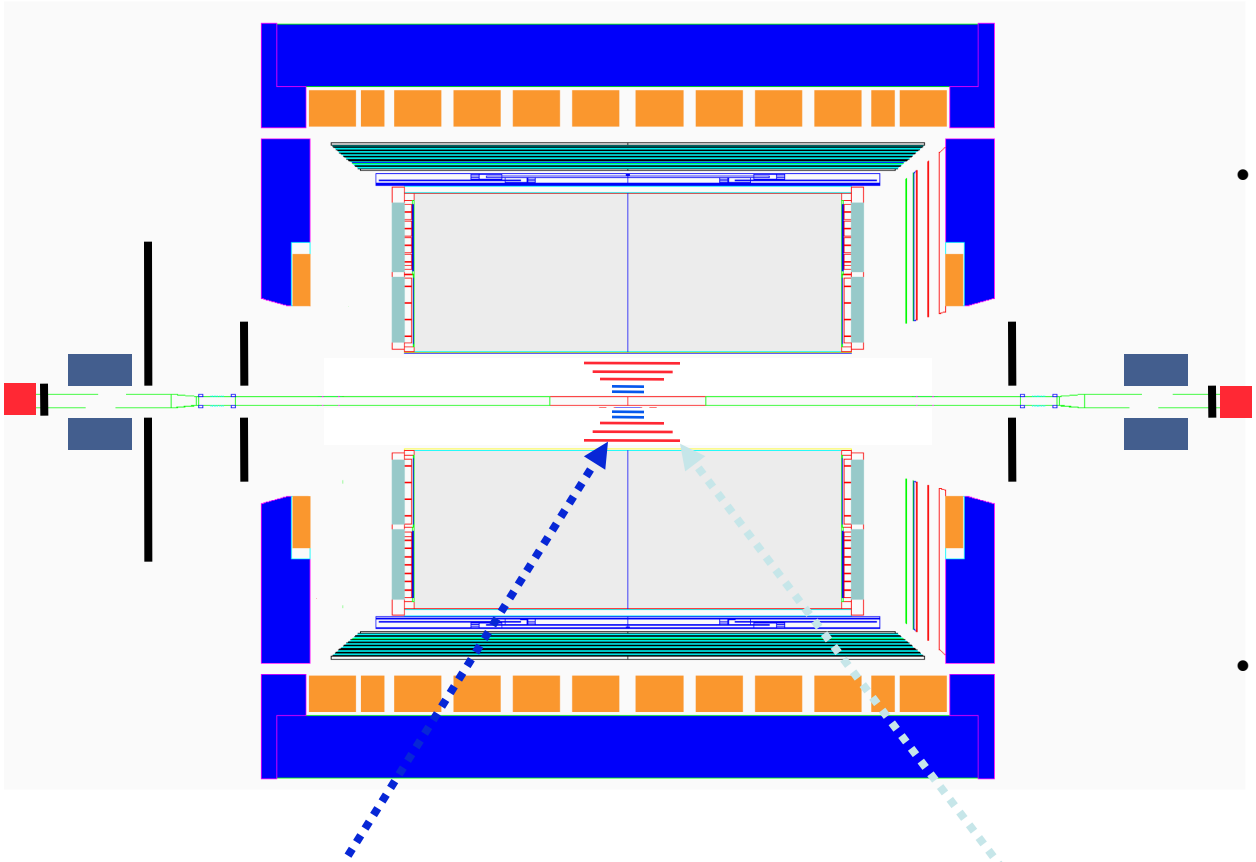


The PXL: 2 layers of Si at mid rapidity

Mid-rapidity Pointing Devices: IST + SSD

- The PXL is a new detector
  - 30 μm silicon pixels to yield 10 μm space point resolution
- Direct Topological reconstruction of Charm
  - Detect charm decays with small cτ, including $D^0 \rightarrow K\,\pi$
- New physics
  - Charm collectivity and flow to test thermalization at RHIC
  - C & B Energy Loss to test pQCD in a hot and dense medium at RHIC
- The proposed Tracking Upgrades include
  - PXL (2 layers)

The Heavy Flavor Tracker

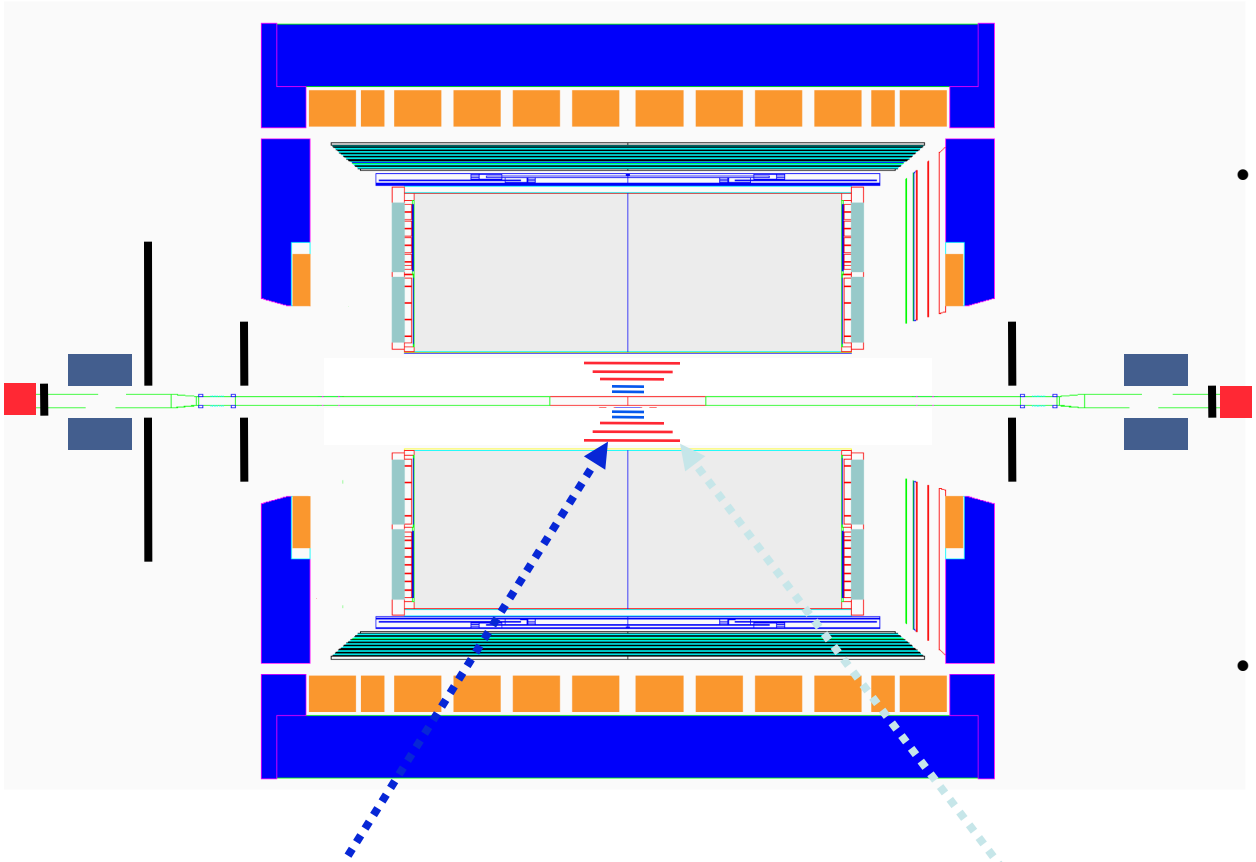


The PXL: 2 layers of Si at mid rapidity

Mid-rapidity Pointing Devices: IST + SSD

- The PXL is a new detector
  - 30 μm silicon pixels to yield 10 μm space point resolution
- Direct Topological reconstruction of Charm
  - Detect charm decays with small cτ, including $D^0 \rightarrow K\,\pi$
- New physics
  - Charm collectivity and flow to test thermalization at RHIC
  - C & B Energy Loss to test pQCD in a hot and dense medium at RHIC
- The proposed Tracking Upgrades include
  - PXL (2 layers)
  - IST (2 layers)

The Heavy Flavor Tracker = PXL + IST + SSD



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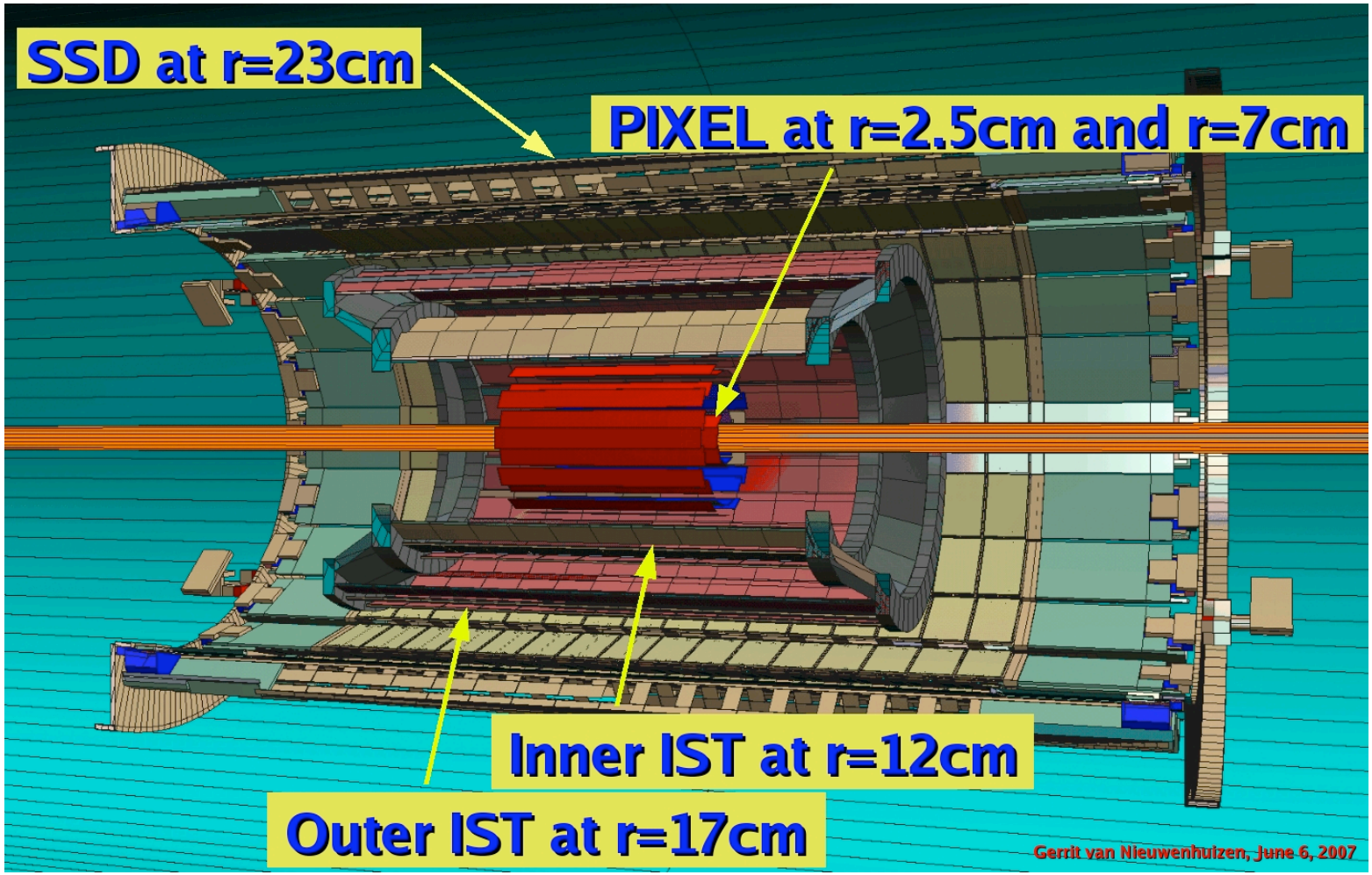
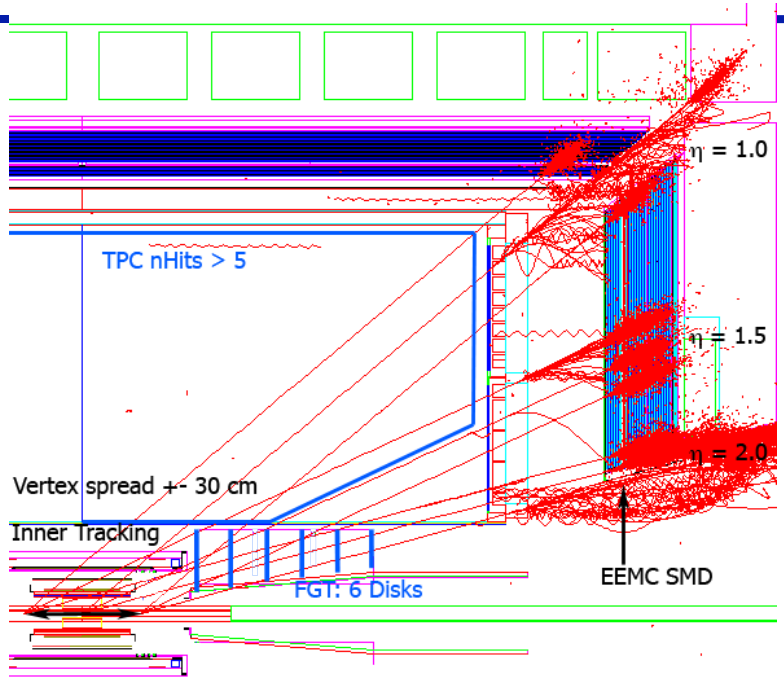
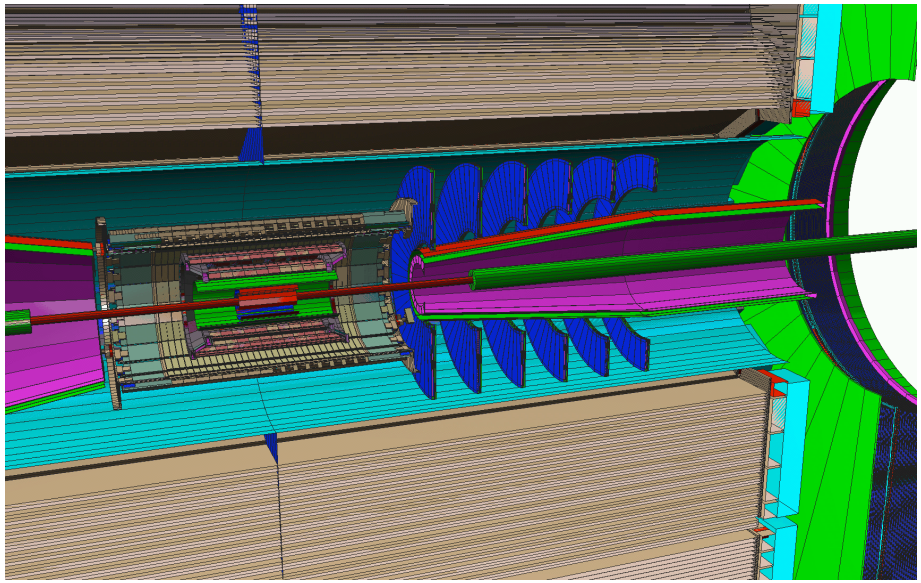
GEANT View of the Heavy Flavor Tracker

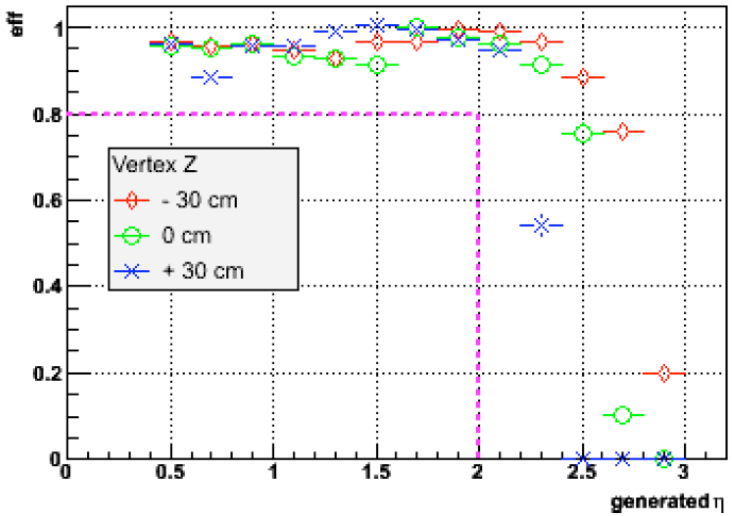


Forward GEM Tracker (FGT)





Probability to get the correct charge sign



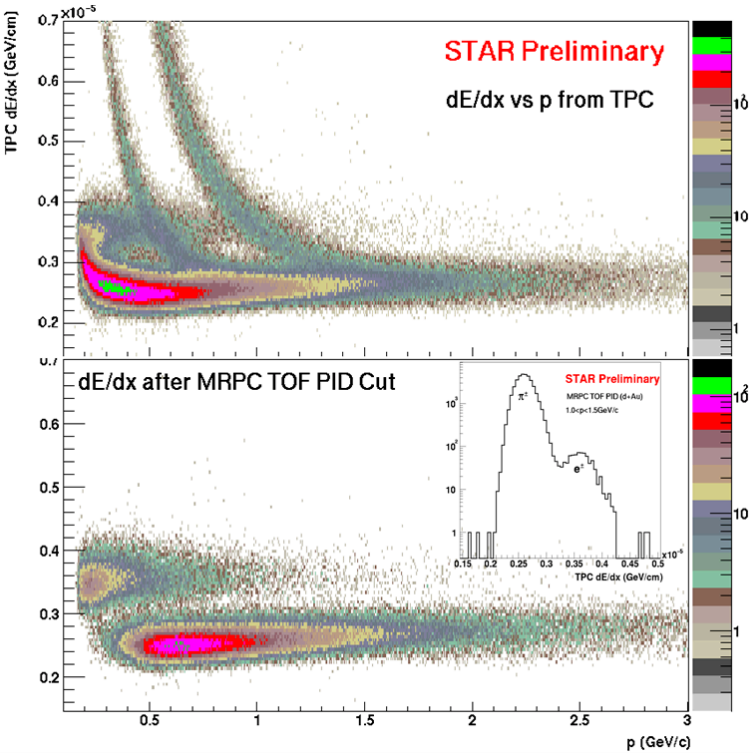
- 6 triple-GEM disks covering $1 < \eta < 2$

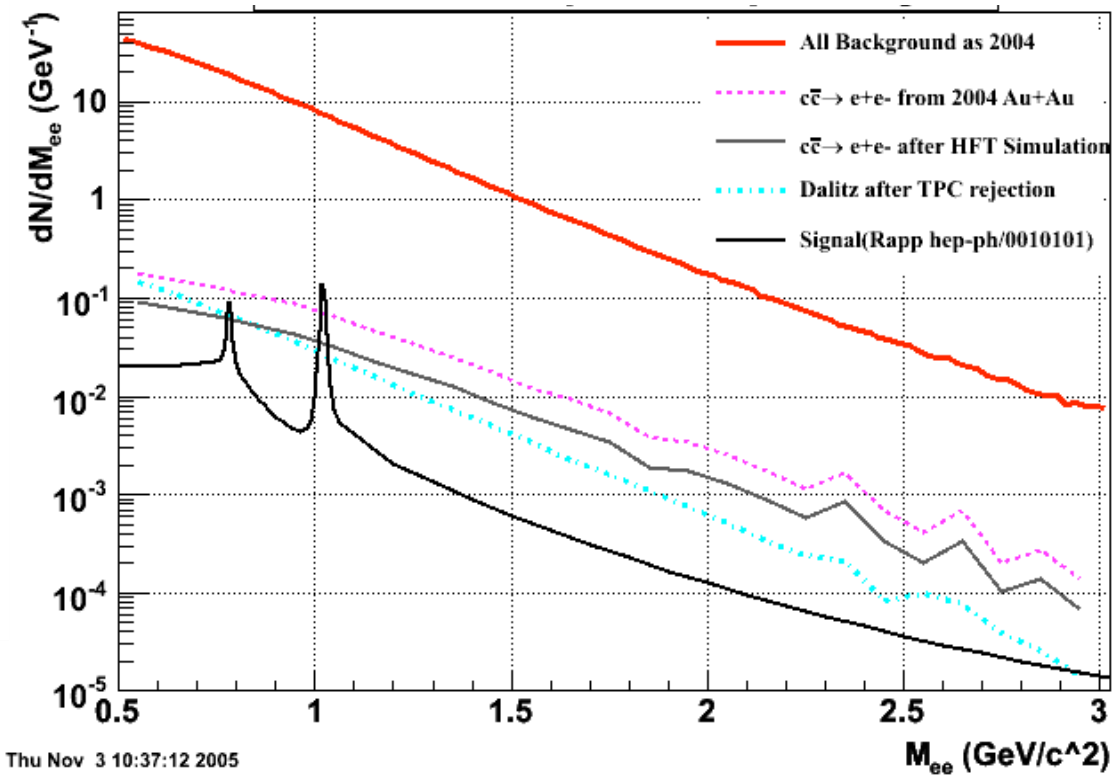
⇨outer radius ~ 40 cm

⇨inner radius varies with z position

- charge sign reconstruction

Upgraded TOF for dileptons

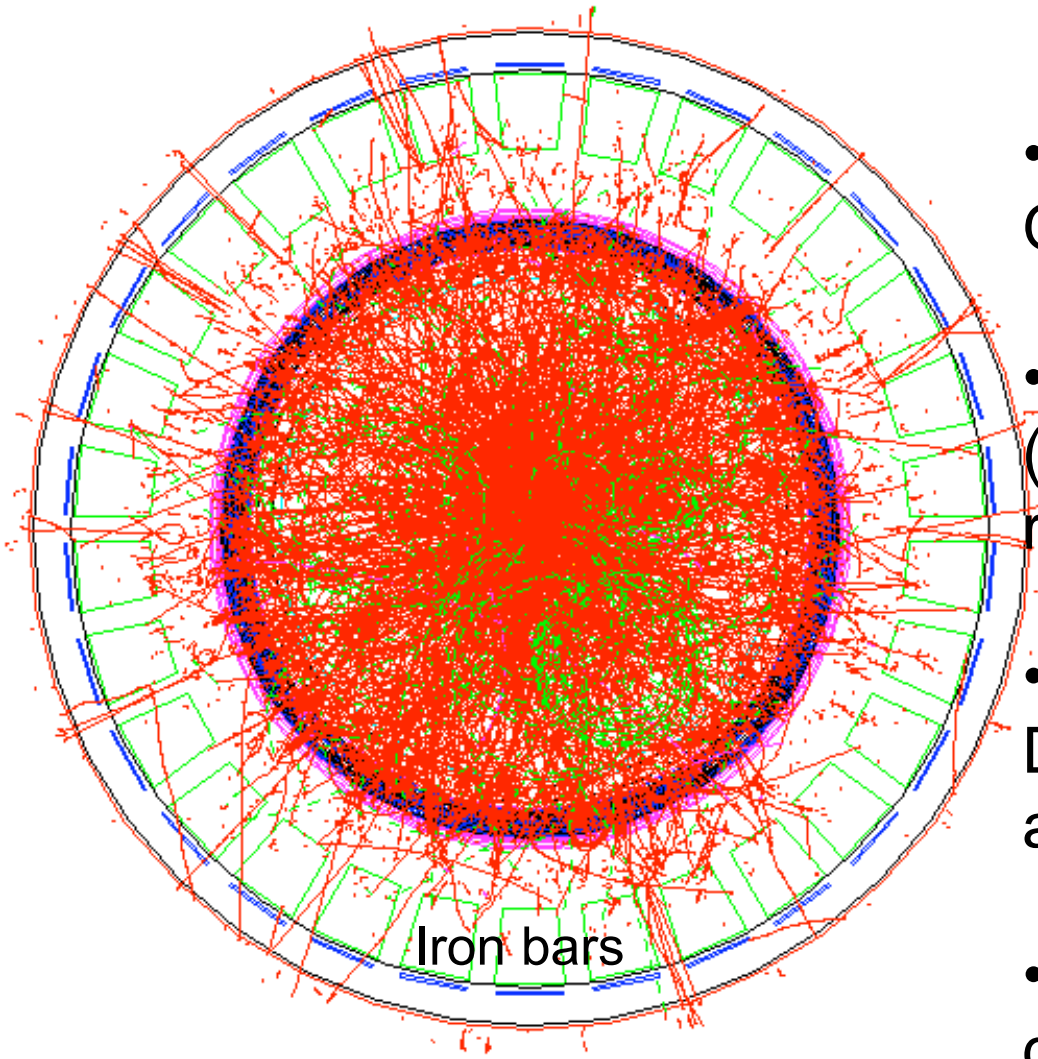




- Background: $\gamma \rightarrow e^+e^-$
- HFT discriminates background
- Need low mass detector
- Statistics comparable to NA60
- Charm background

Detectors	ω	ϕ
TPC+TOF	20K	6K

Muon Detector at Mid-rapidity



- Muon penetrates iron bars
  Other particles are stopped

- Good Time Resolution (60ps)
  rejects background (>100)

- 1 hit per 5 head-on Au+Au
  Dimuon trigger (>25) for J/Psi and Upsilon, etc.

- Large coverage:
  diameter of 8 meters

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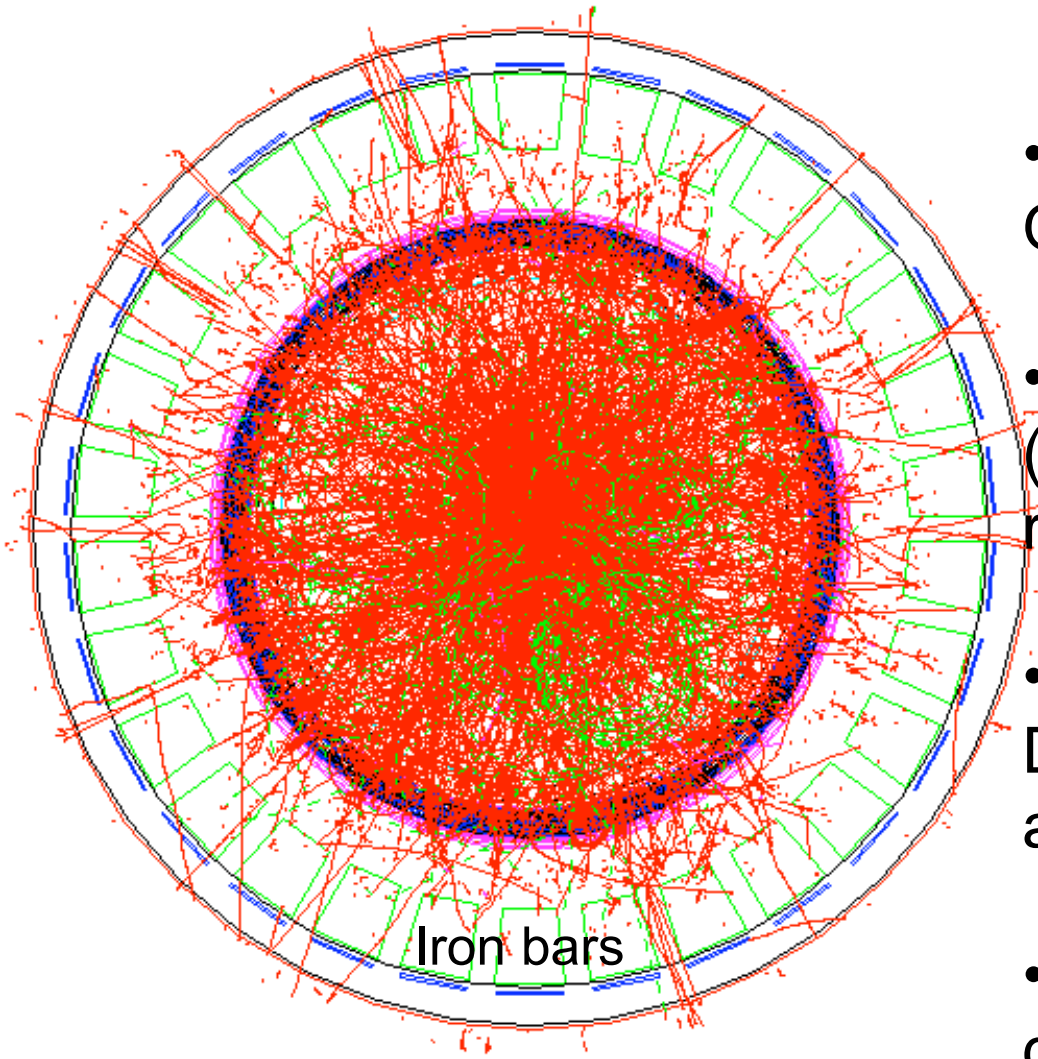

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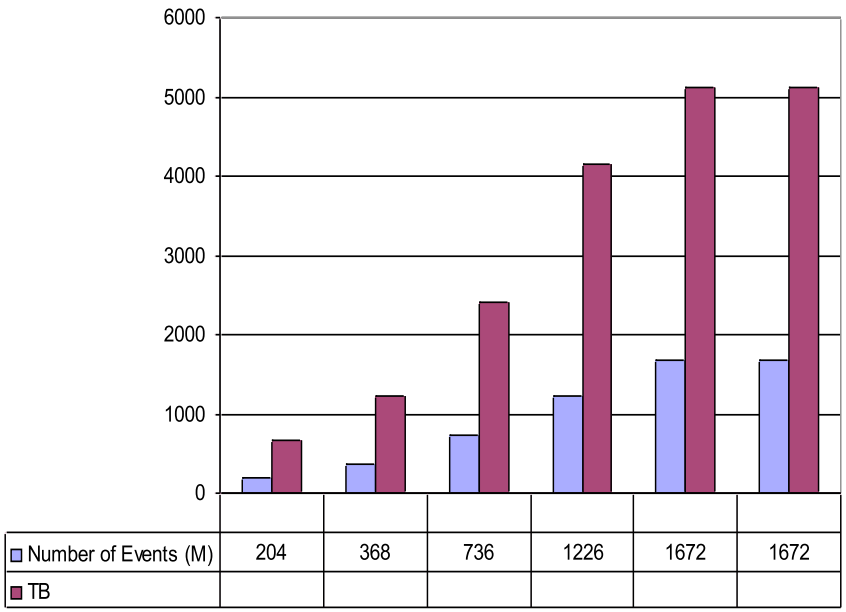
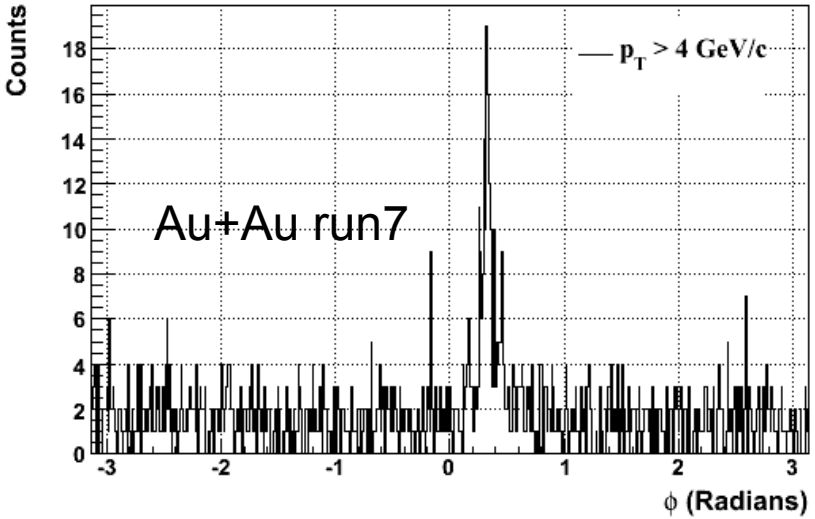
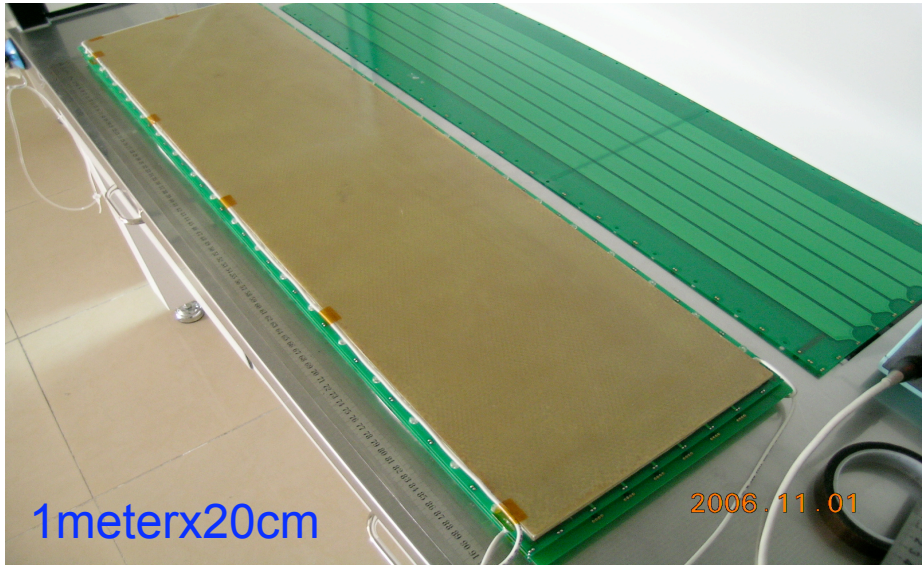
MRPC based MTD





Resolution: ~60ps (6x10^{-11}second)
Signal propagation velocity: ~60ps/cm
Spatial resolution: ~1cm
20x larger than the TOF modules



Prototype Install in RUN 7 (March-June, 2007)

But first - p_T reach for open and closed charm and beauty

Both STAR and PHENIX have heavy flavor semileptonic decay spectra from Run 4 Au+Au data. The STAR data appear to extend to ~ 7.5 GeV/c with good statistics. PHENIX has J/ψ spectra that extend beyond 5 GeV/c with good statistics.

RHIC II will produce about 2 orders of magnitude (x75) more integrated luminosity.

- According to FONLL calculations of p_T distributions for **D →e and B →e** by Ramona Vogt, this will extend the p_T reach by **~ 5 GeV/c**.

- The same calculations indicate that the p_T distributions for **D→Kπ** will be extended by **~ 5 GeV/c**.

- A simple extrapolation of the existing Run 4 PHENIX **J/ψ data** suggests that the p_T reach will increase by **~ 3 GeV/c.**

Quantitative estimates

In the next few slides I will show some quantitative estimates of the **heavy flavor signal yields** that we can expect at RHIC II, and I will also give a few examples of the corresponding yields for the LHC detectors. I will focus mostly on quarkonium measurements - these are generally the most statistics starved.

Assumptions for Au+Au at RHIC II:

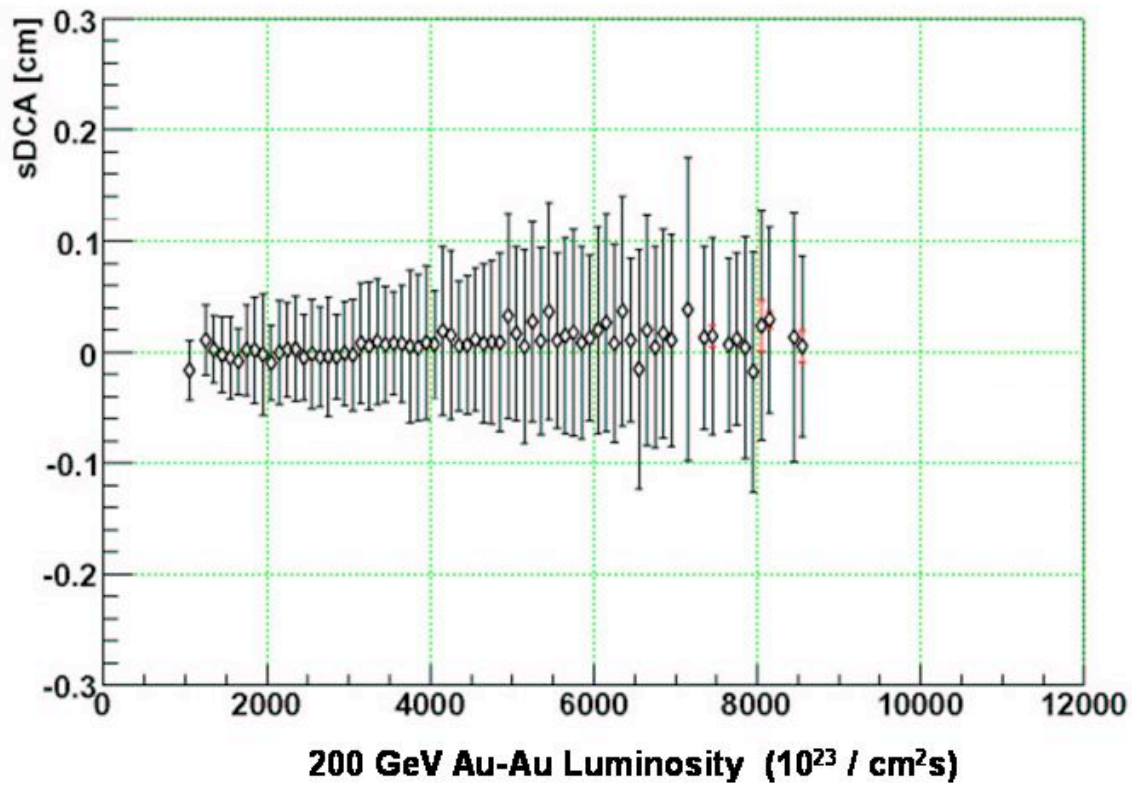
- J/ψ cross sections from PHENIX data.
- ϒ and open bottom cross sections from hep-ph/9502270 (agrees with PHENIX preliminary ϒ measurement)
- Pair reconstruction efficiency 40%
- Trigger efficiency ~ 80%
- PHENIX & STAR coll. vertex cut 80% (central bucket)*70% in ± 10 cm.
- Displaced vertex cut (open charm, bottom) 40% efficient.

LHC estimates provided by the LHC experiments.
(Mostly made with less conservative efficiencies than my RHIC II estimates)

The Question: STAR TPC at Higher Luminosities

Signed distance-of-closest approach (sDCA) measures deviation from event vertex for primary tracks due to distortions (say space charge effects).

Effect can be corrected "on average" but large spread event-by-event



FY09: peak luminosity 30×10^{26} $\Rightarrow$ we will know!

Inner Trackers: PXL+IST+SSD (distortion free): will help substantially

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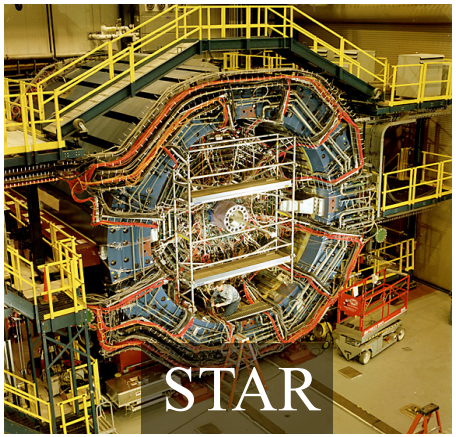
Requirements to achieve this goal:

- Detector and luminosity upgrades & commensurate progress in theory

RHIC Detector Upgrades & RHIC-II: Costs

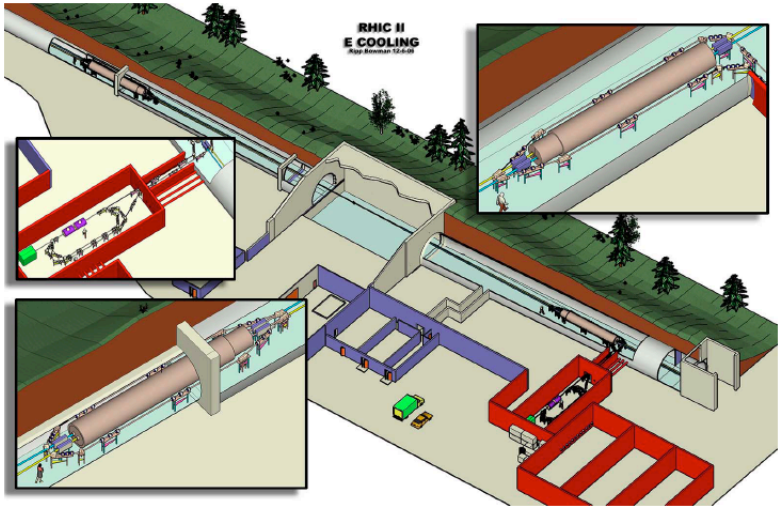


Forward Meson Spectrometer
DAQ/TPC Electronic
Time of Flight Barrel
Heavy Flavor Tracker
Barrel Silicon Tracker
Forward Tracker

Hadron Blind Detector
Muon Trigger
Silicon Vertex Barrel
Forward Silicon
Forward EMC

completed|ongoing|in preparations

Costs: DOE $35M; RHIC base $6M; NSF $2.2M; Non-US $9.5M
Total Cost: $51M



Electron cooling

- Increase Au+Au luminosity by factor 10 ⇒ RHIC II
- Ready for CD-0
- Technically driven schedule: construction could start ~2010

TPC: $95M (FY07$)

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3. We recommend a targeted program of experiments to investigate neutrino properties and fundamental symmetries. These experiments aim to discover the nature of the neutrino, yet unseen violations of time-reversal symmetry, and other key ingredients of the new standard model of fundamental interactions. Construction of a Deep Underground Science and Engineering Laboratory is vital to US leadership in core aspects of this initiative.

Recommendations (continued)

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4. The experiments at the Relativistic Heavy Ion Collider have discovered a new state of matter at extreme temperature and density—a quark-gluon plasma that exhibits unexpected, almost perfect liquid dynamical behavior. We recommend implementation of the RHIC II luminosity upgrade, together with detector improvements, to determine the properties of this new state of matter.

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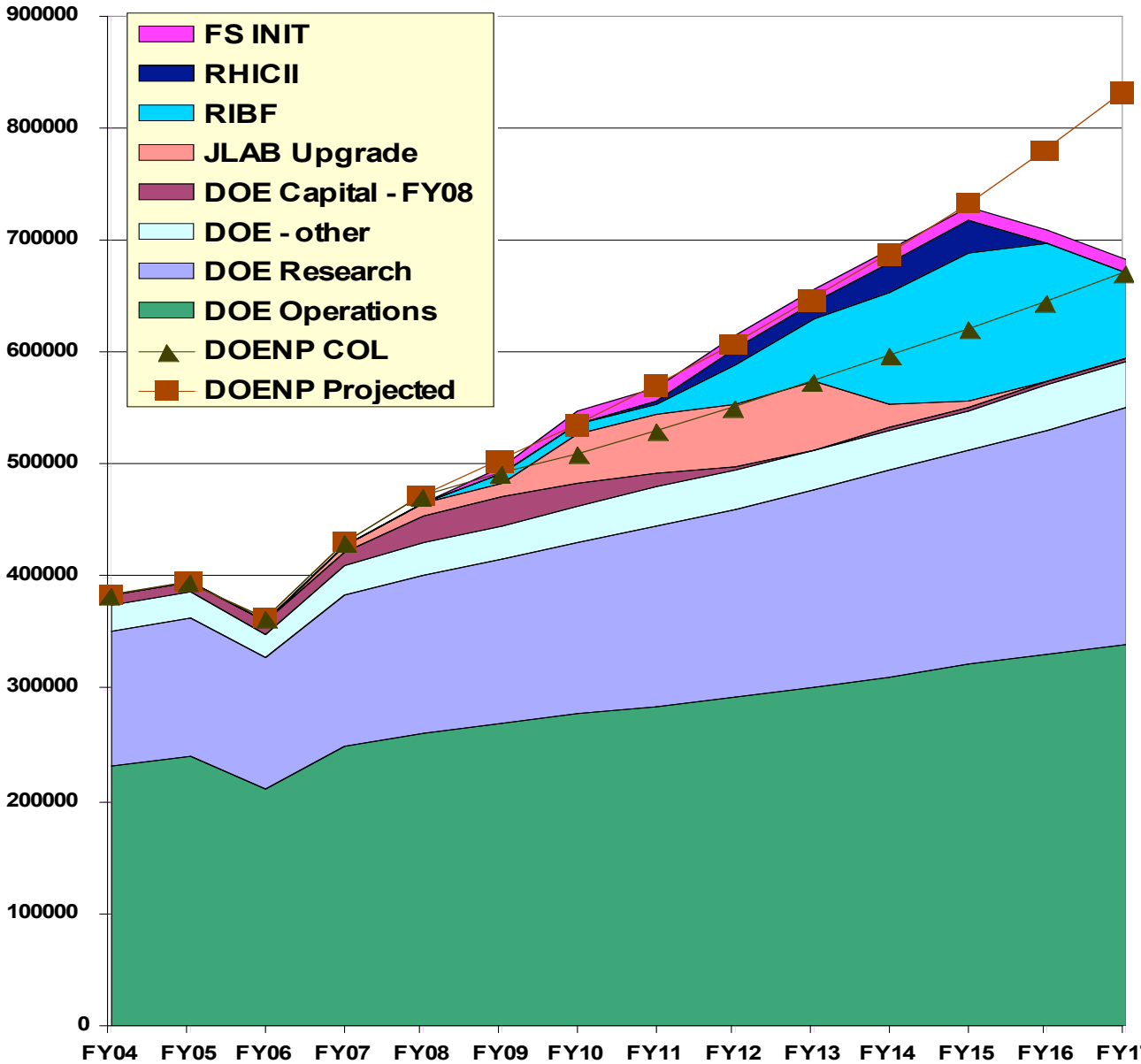
Note: Not a numbered recommendation

Recommendations & Budget



6.5% Scenario

Existence proof with reprogramming of Ops at JLAB and RHIC

Constant Effort Budget?

This would force NP to make hard choices on future much like 2005 ("Tribble") subcommittee faced

Discussion in LRP WG ongoing …

Outline

- What's the point in focusing on heavy flavor physics?
  - What can we learn?
  - What measurements do we need to make to make substantial progress?
- The status of heavy flavor measurements at RHIC
  - Charm cross-sections
  - Open charm production and its modification in matter
  - Quarkonia
- Near/Mid Term Future at RHIC
  - PHENIX & STAR upgrades and prospective measurements
- Long Term Future at RHIC
  - RHIC-II – upgrading the collider
  - RHIC-II and LHC (flavor vs. flavour): different, complementary, or more of the same?
  - The "QCD Lab"
- Conclusions