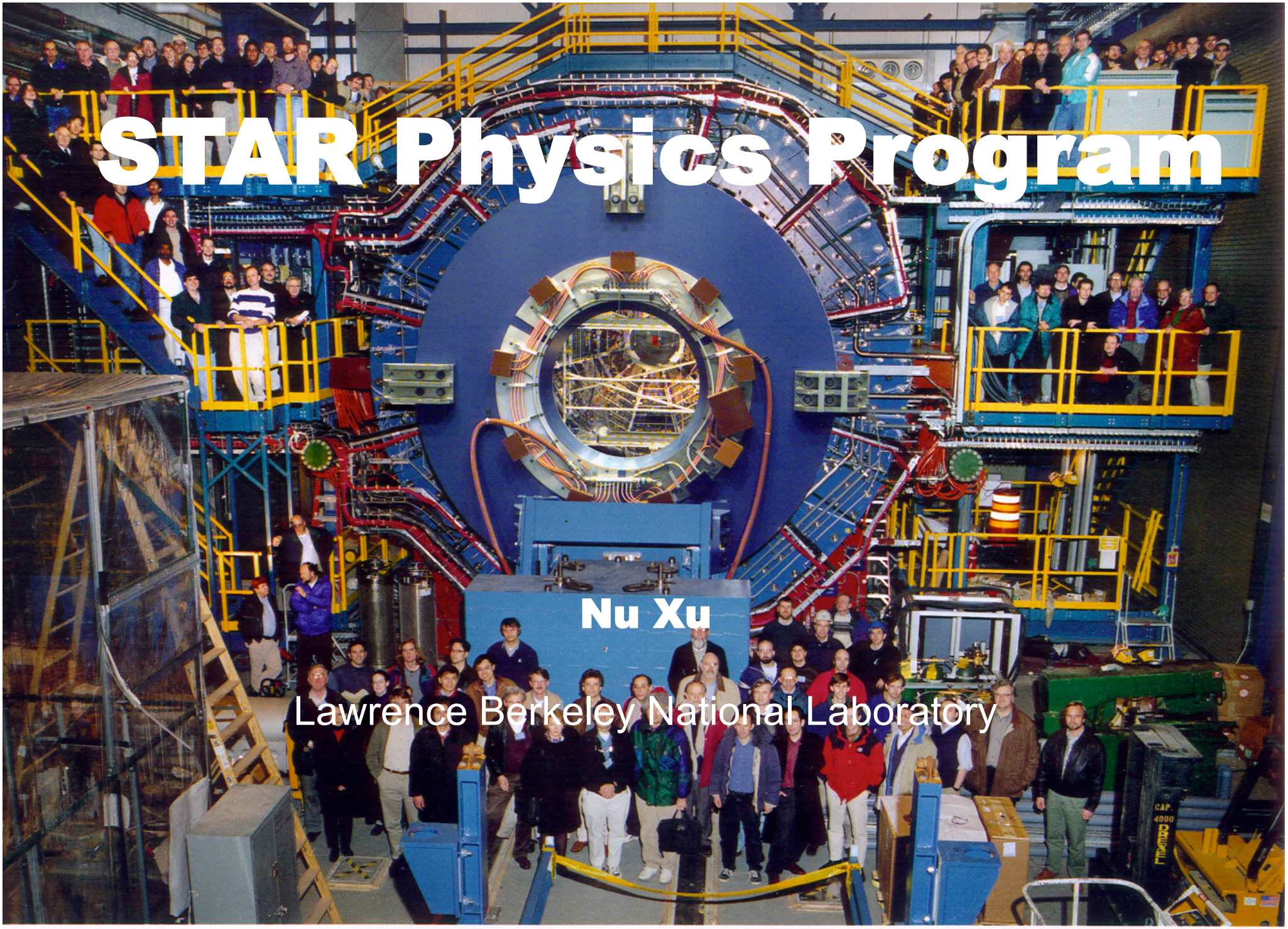
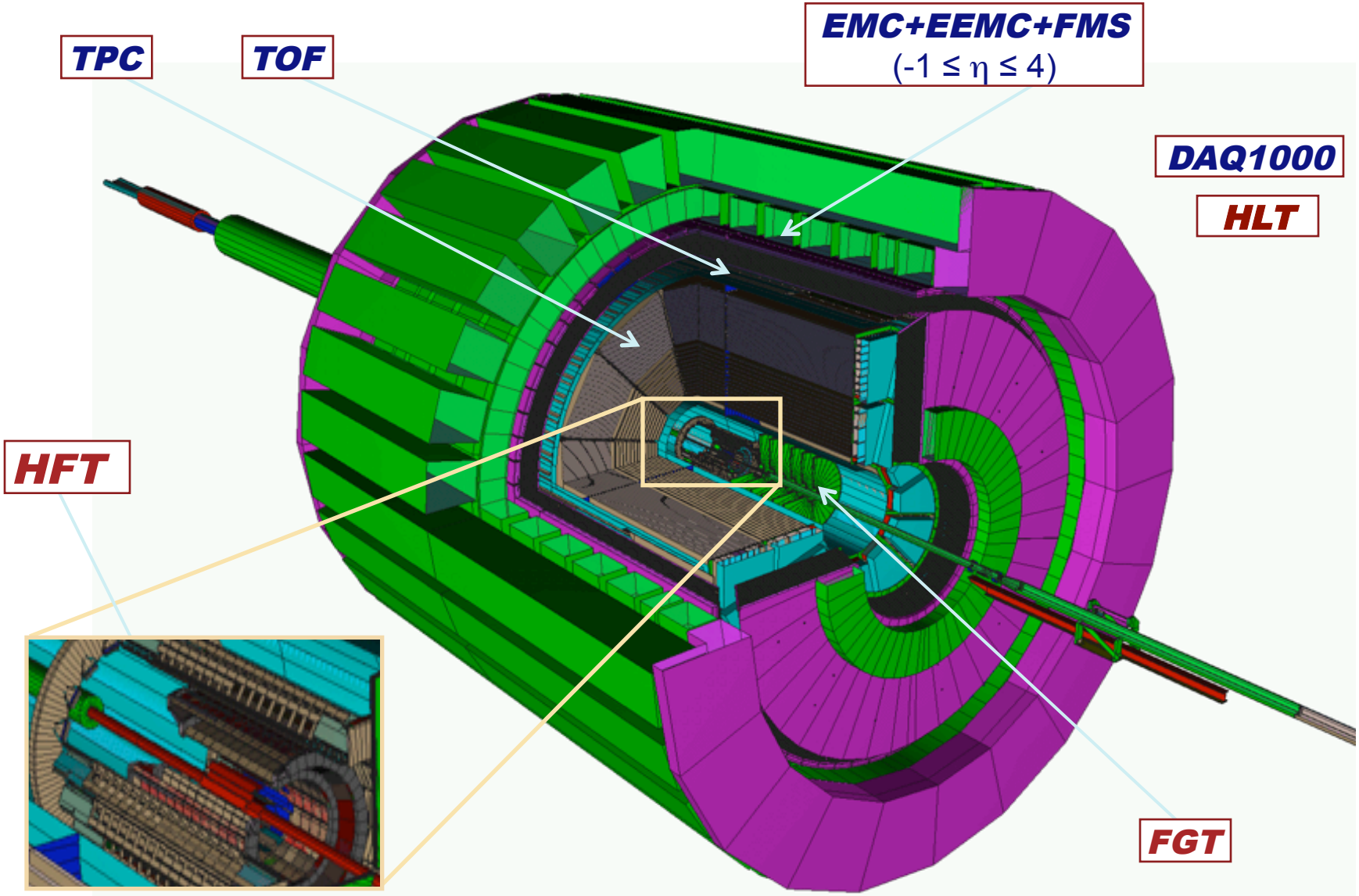
STAR Physics Program



Nu Xu

Lawrence Berkeley National Laboratory

STAR Detectors: *Full 2π particle identification!*



STAR Physics Focus

Structure of Nucleon

Structure of Cold Nuclear Matter

Structure of the Hot Matter

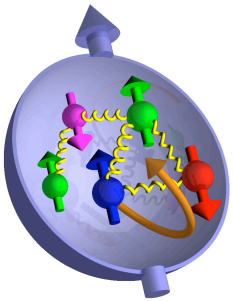
QCD

Outline

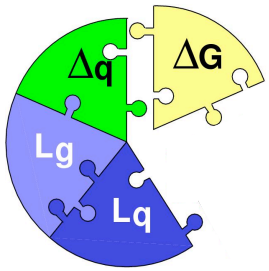
1) Spin program

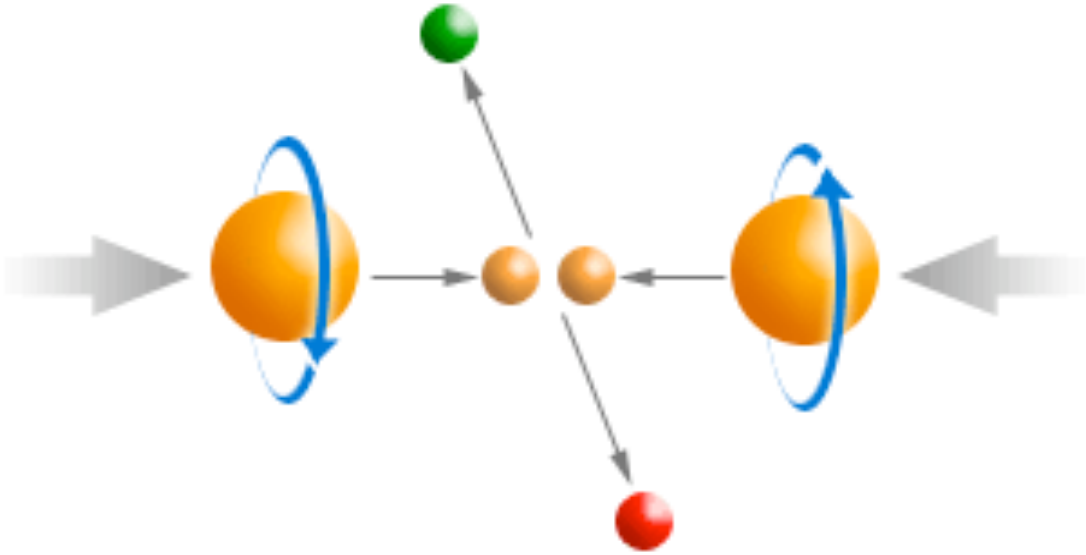
2) Heavy-Ion program

3) Future programs



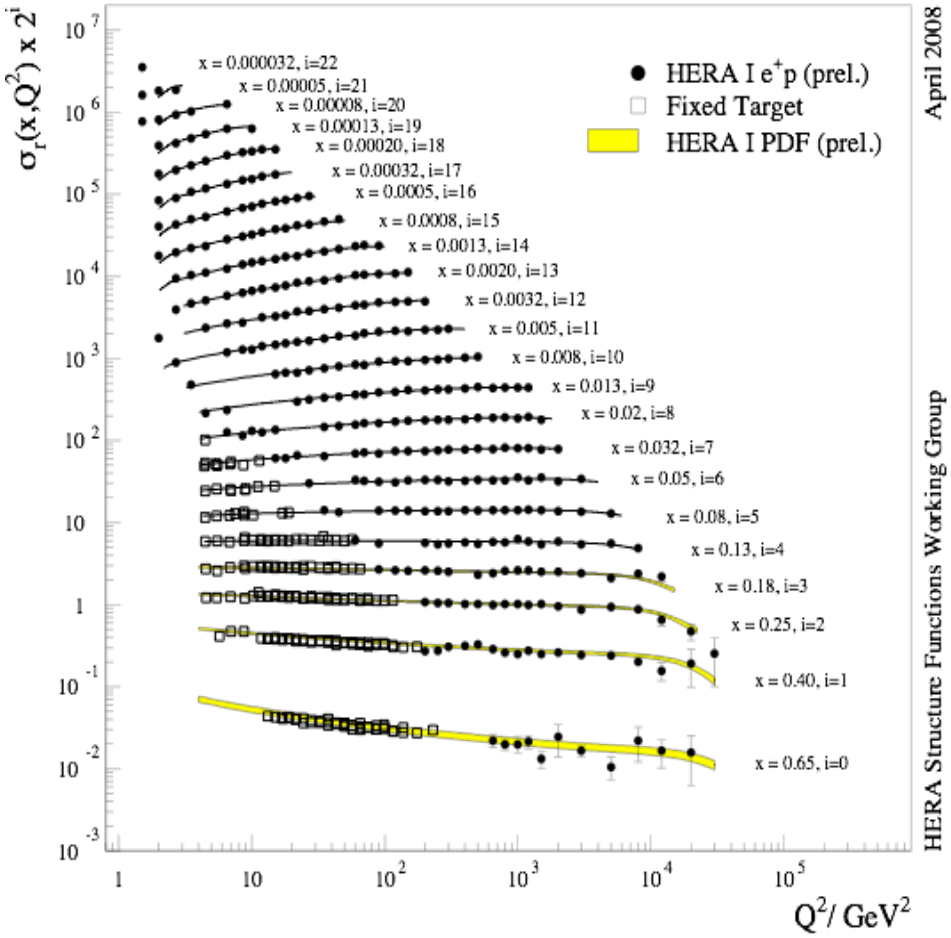
Proton Spin Physics

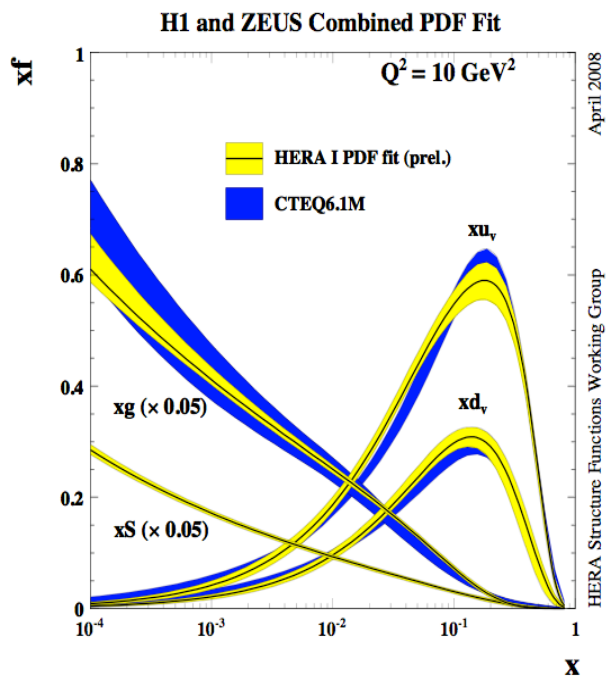




Nucleon Structure Function

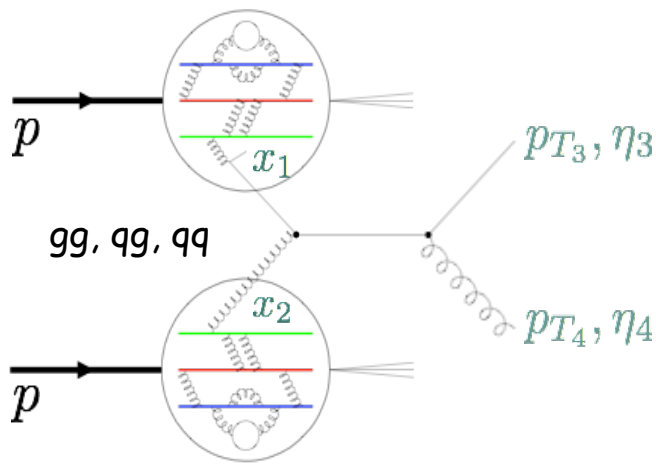
Precision measurements (e.g. F_2) ⇒ ***Precision on q/g structures***

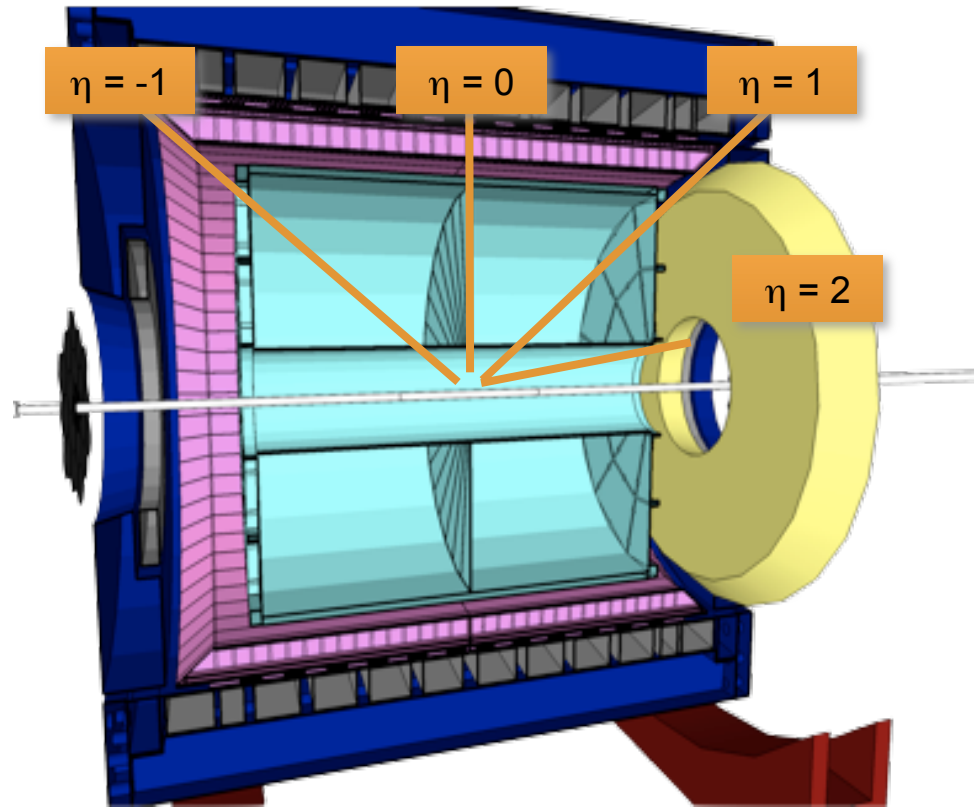




f(g) >> f(q) at small x!
Rich QCD phenomena.

Polarized *p*+*p* Program at RHIC





STAR: Large acceptance for correlation measurements

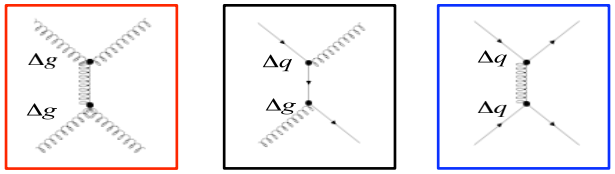
di-jets/hadron and γ-jet

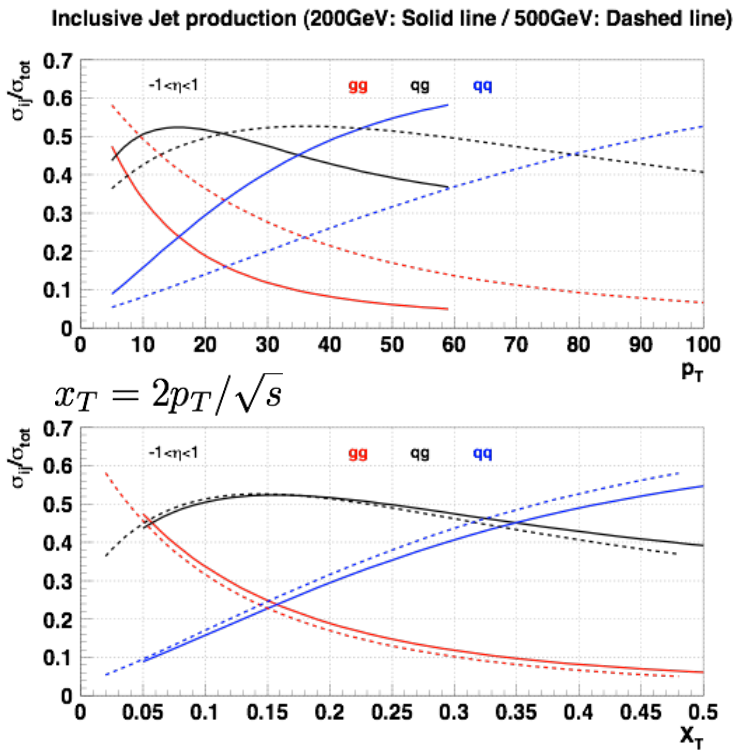
$$x_{1(2)} = \frac{1}{\sqrt{s}}\left[p_{T_3} e^{\eta_3(-\eta_3)} + p_{T_4} e^{\eta_4(-\eta_4)}\right]$$

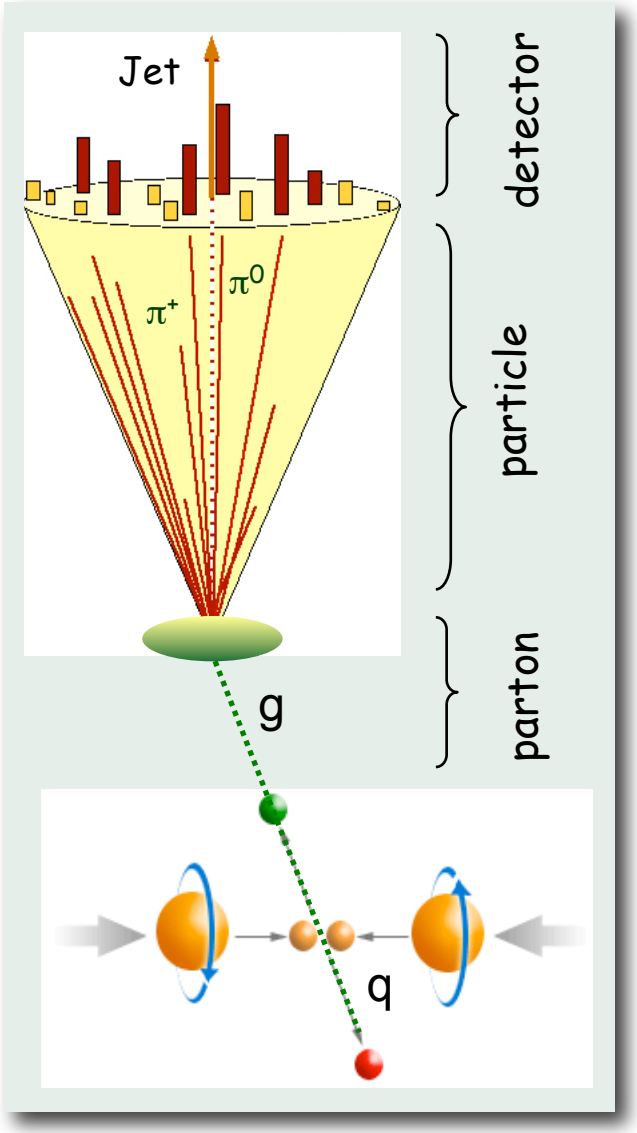
$$M = \sqrt{x_1 x_2 s} \qquad \eta_3 + \eta_4 = \ln\frac{x_1}{x_2} \qquad \cos\theta^* = \tanh\left(\frac{\eta_3 - \eta_4}{2}\right)$$

Δg Measurements at RHIC

Partonic Processes







Status on Δg Measurements at RHIC

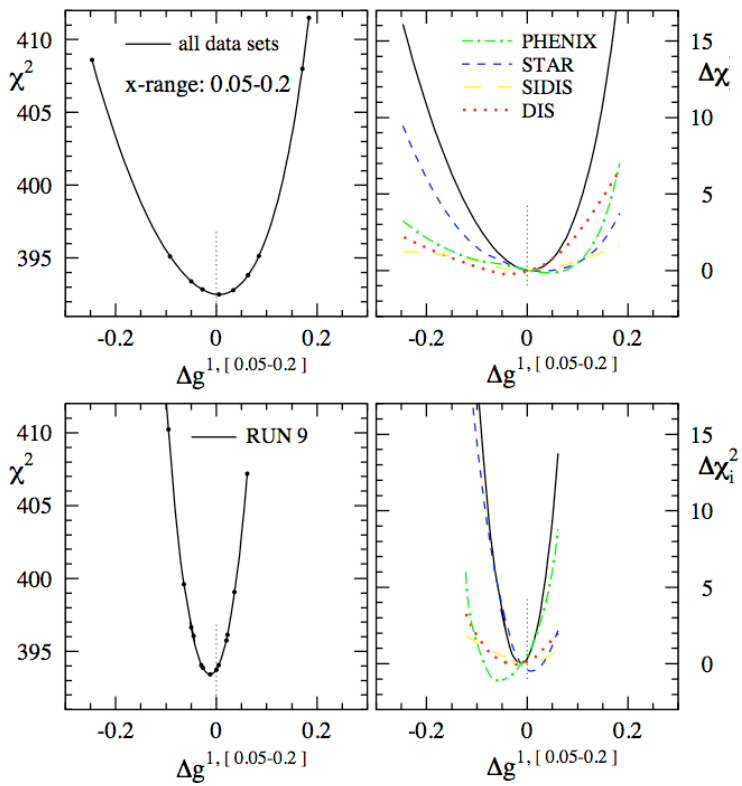
Run9: STAR bottom line is to collect **FoM: 6.5 pb^{-1}** (Run9: 2.3 pb^{-1})

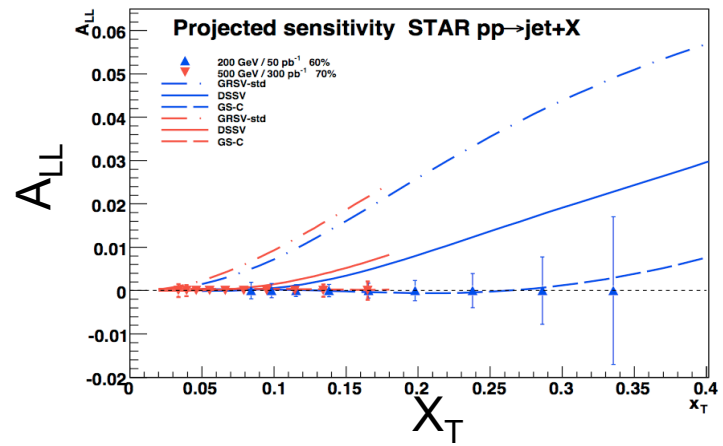
inclusive jet, di-jets, γ-jet… analysis

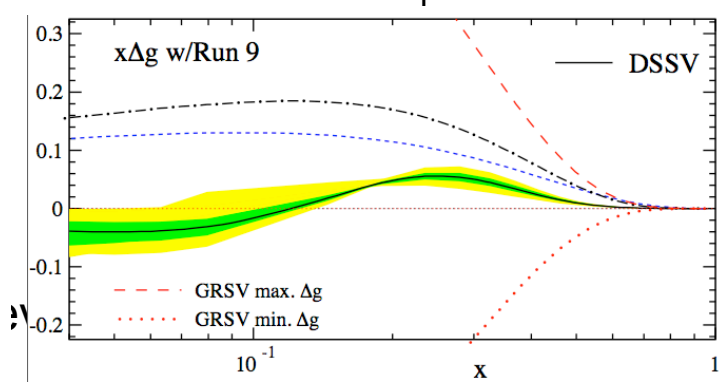
STAR: internal review of the *strategy* for spin physics in light of Run9 data. (Sichtermann, Sowinski, Surrow)

Run6

Run9 plan





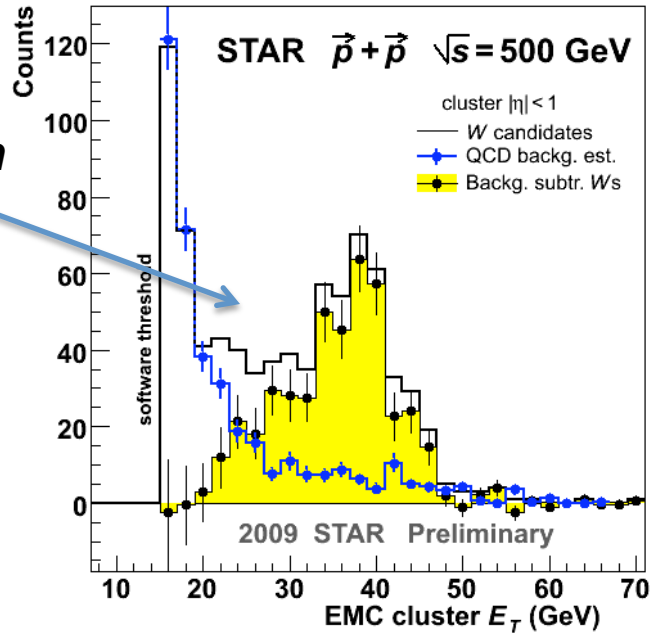


de Florian et al, arXiv: 0804.0422

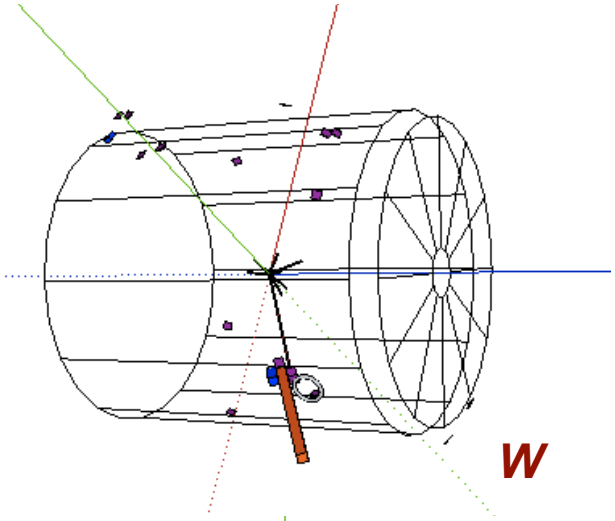
500 GeV p+p collisions

W

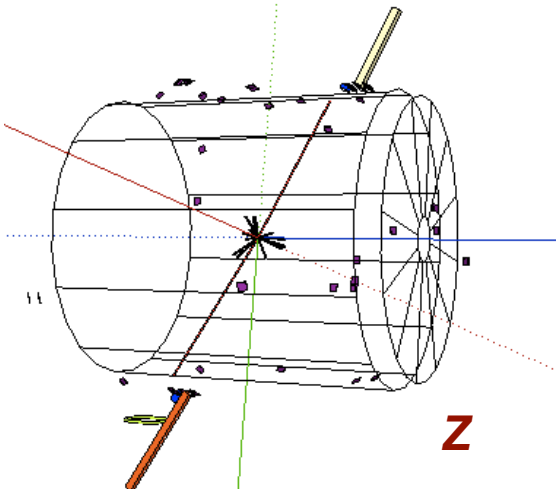
jacobian



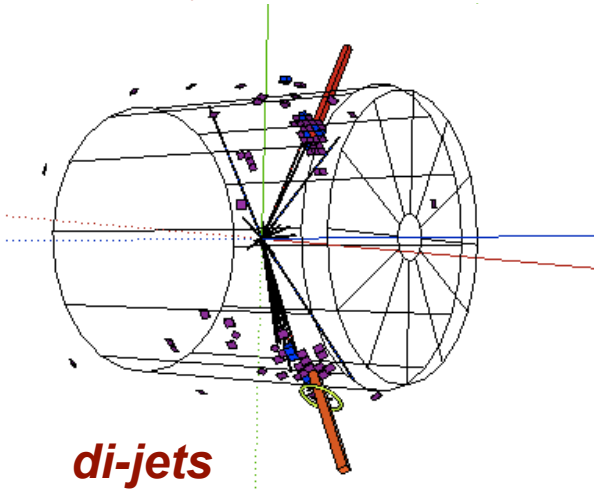
STAR Preliminary



W

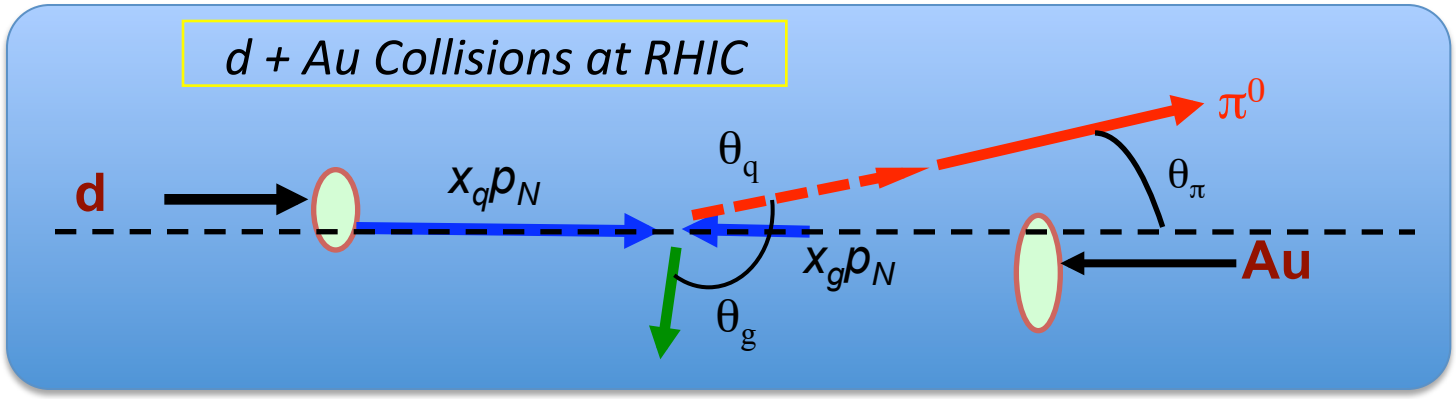


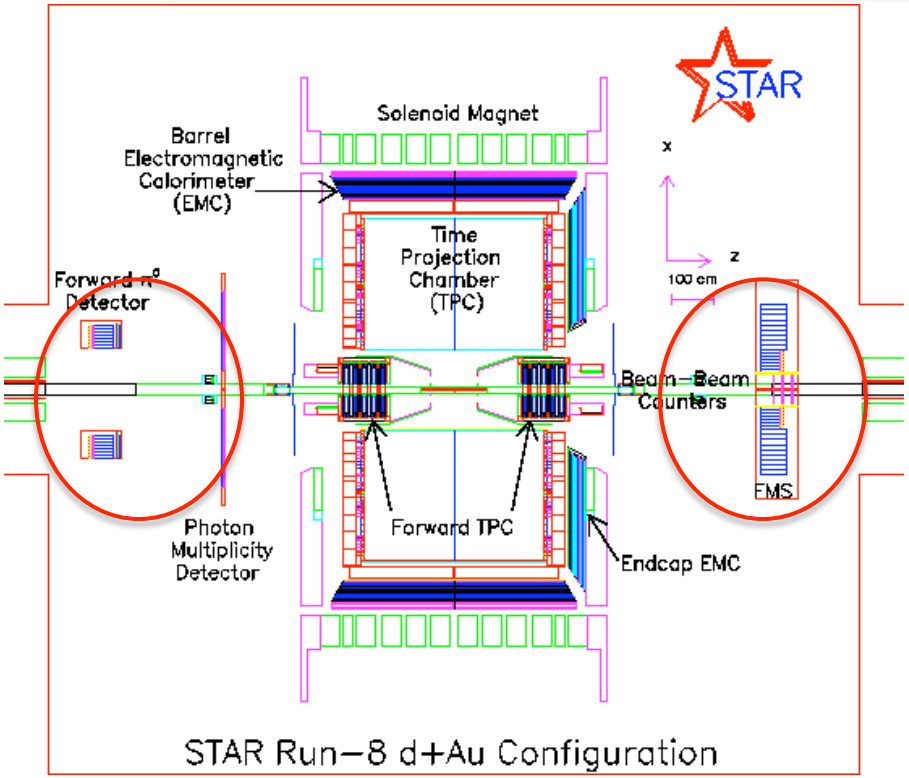
Z



di-jets

Forward Small-x QCD Physics





(1) <u>200 GeV *d+Au*:</u>

- forward small-x, scattering of asymmetric partonic collisions
- high-x valence q: $0.25 < x_q < 0.7$, large polarization
- low-x g: $0.001 < x_g < 0.1$

➔ Color Glass Condensate: parton structure function. Theory: $x_g \sim 10^{-4}$

(2) <u>200/500 GeV *p+p*:</u>

➔ Transverse spin phenomena: Siver or Collins effects

Fundamental QCD issues!

High-Energy Nuclear Collisions

sQGP and the QCD Phase Diagram

In 200 GeV Au+Au collisions at RHIC, strongly interacting matter formed:

- **Jet energy loss: R_{AA}**
- **Strong collectivity: v_0, v_1, v_2**
- **Hadronization via coalescence: n_q-scaling**

Questions:

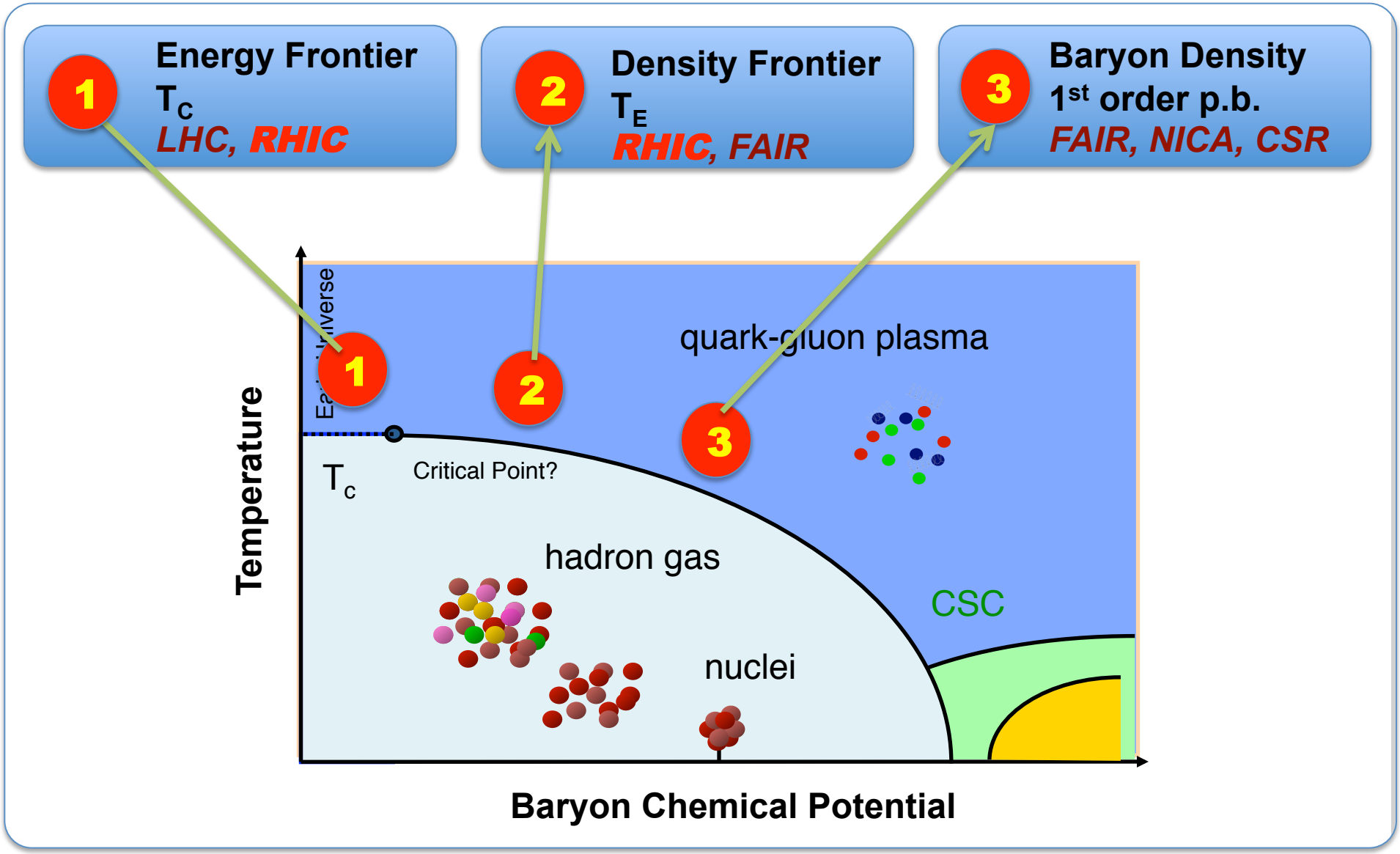
Is thermalization reached at RHIC?

- **Systematic analysis with dN/dp_T and dv_2/dp_T results…**
- ***Heavy quark and di-lepton measurements***

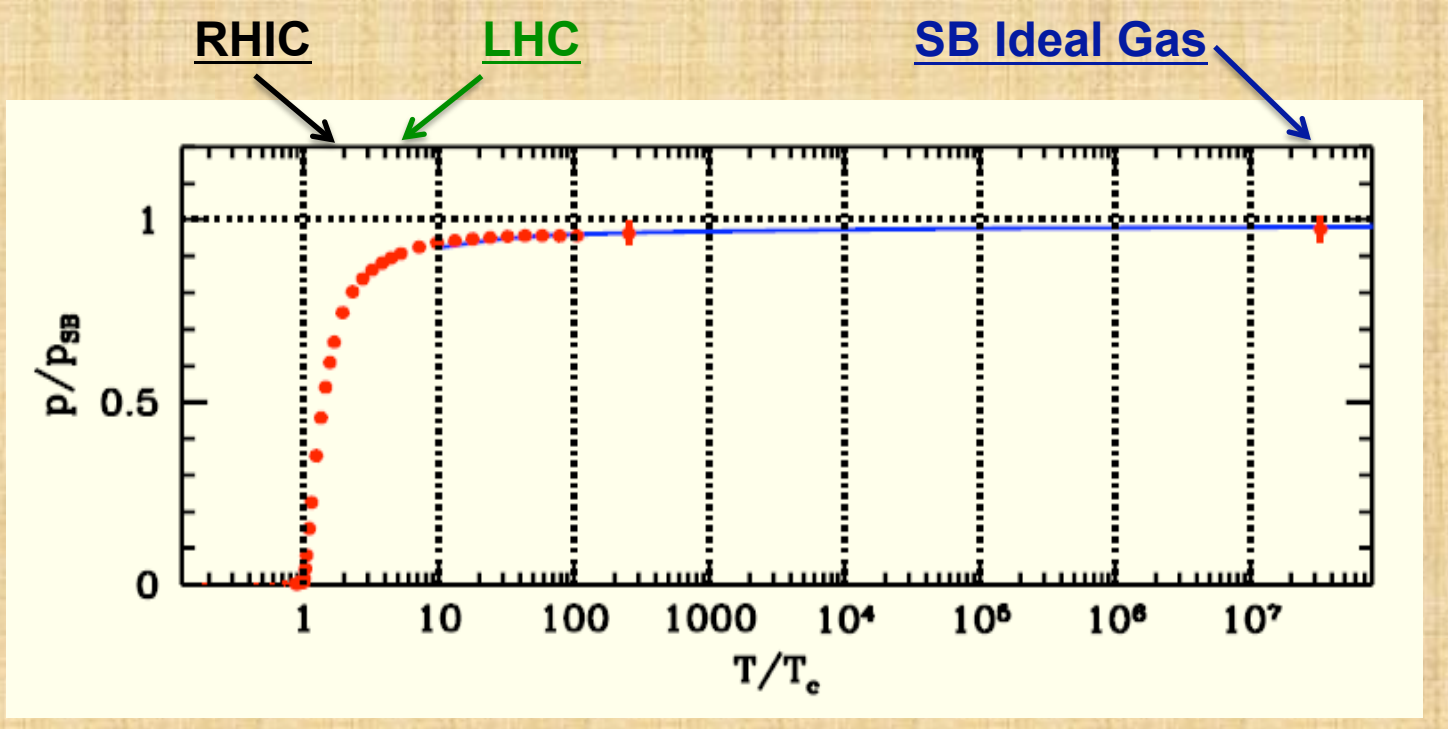
When (at which energy) does this transition happen?
What does the QCD phase diagram look like?

- ***RHIC beam energy scan***

High-Energy Nuclear Collisions



QCD Thermodynamics

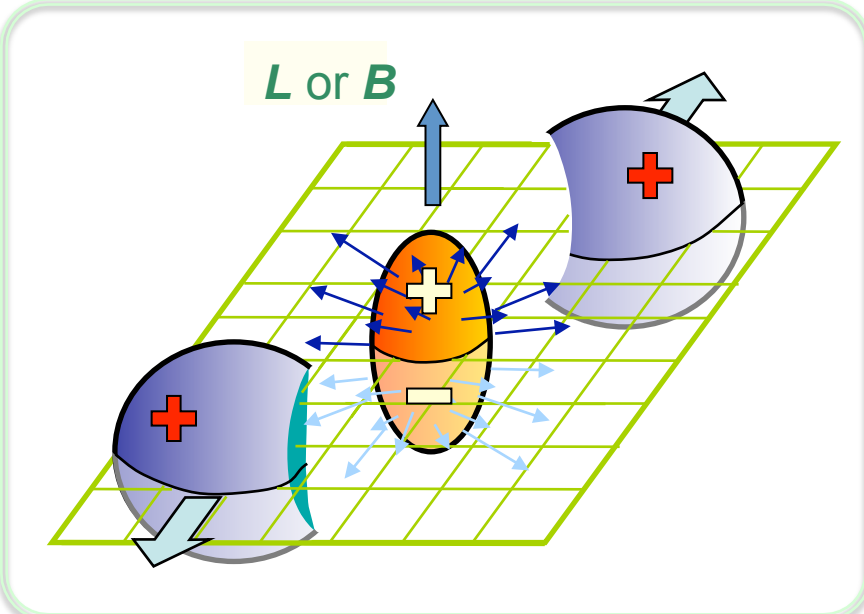


1) At $\mu_B = 0$: cross over, $150 < T_c < 200$ MeV
2) The SB ideal gas limit: $T/T_c \sim 10^7$
3) T_{ini} (LHC) ~ 2-3*T_{ini} (RHIC)
4) Thermodynamic evolutions are similar for RHIC and LHC

Zoltan Fodor, Lattice 2007

Search for Local Parity Violation

in High Energy Nuclear Collisions

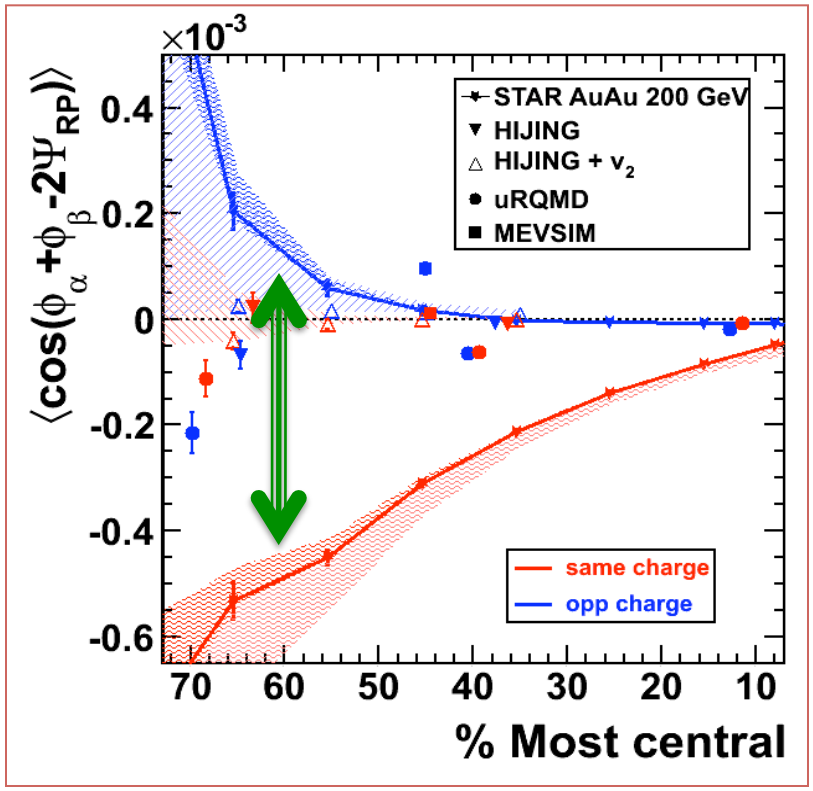


$$\left\langle \cos\left(\phi_\alpha + \phi_\beta - 2\Psi_{RP}\right)\right\rangle$$

Parity even observable

Voloshin, PR C62, 044901(00).

STAR; arXiv: 0909.1739 (PRL); 0909.1717 (PRC).



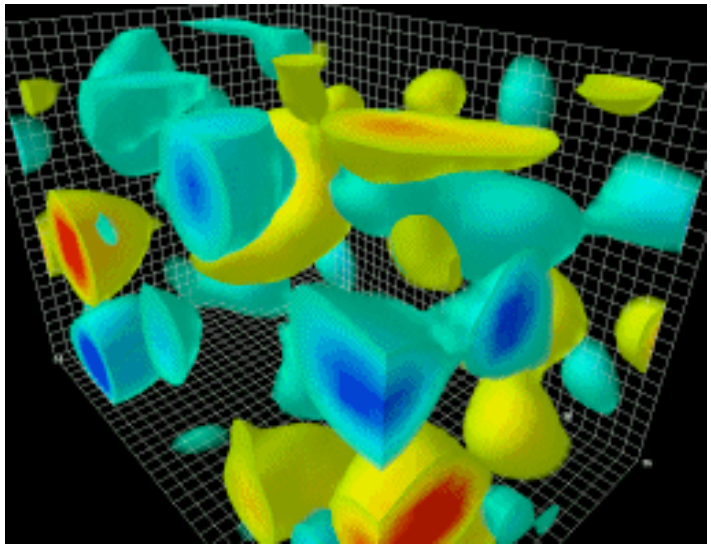
The separation between the same-charge and opposite-charge correlations.

- **Strong external EM field**
- ***De-confinement* and *Chiral symmetry restoration***

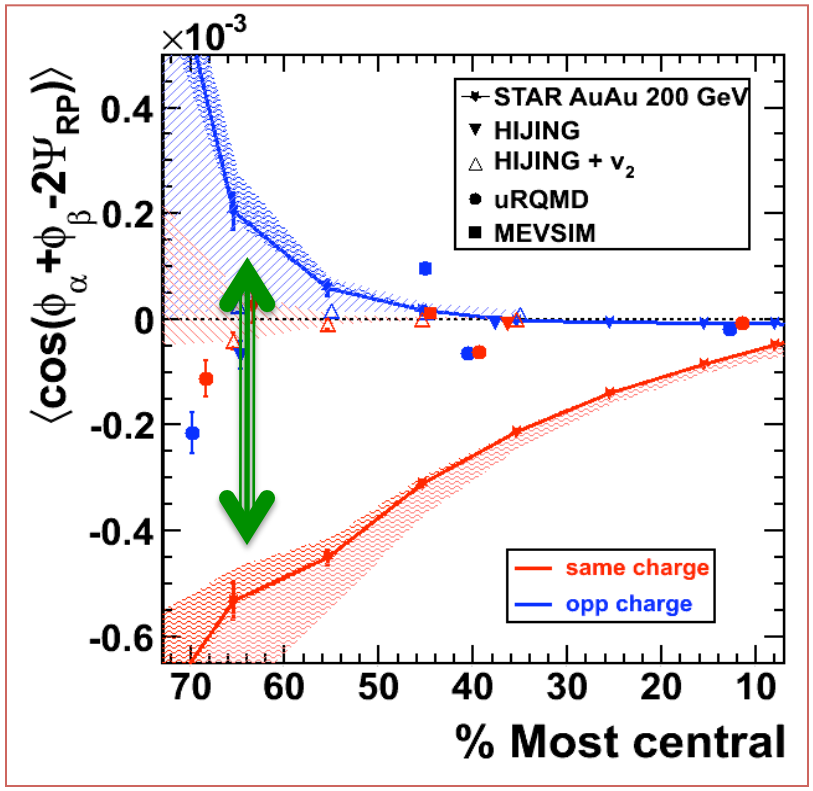
Search for Local Parity Violation

in High Energy Nuclear Collisions

Animation by *Derek Leinweber*



Topological transitions have never been observed *directly* (e.g. at the level of quarks in DIS). An observation of the *spontaneous strong* parity violation would be a clear proof for the existence of such physics.

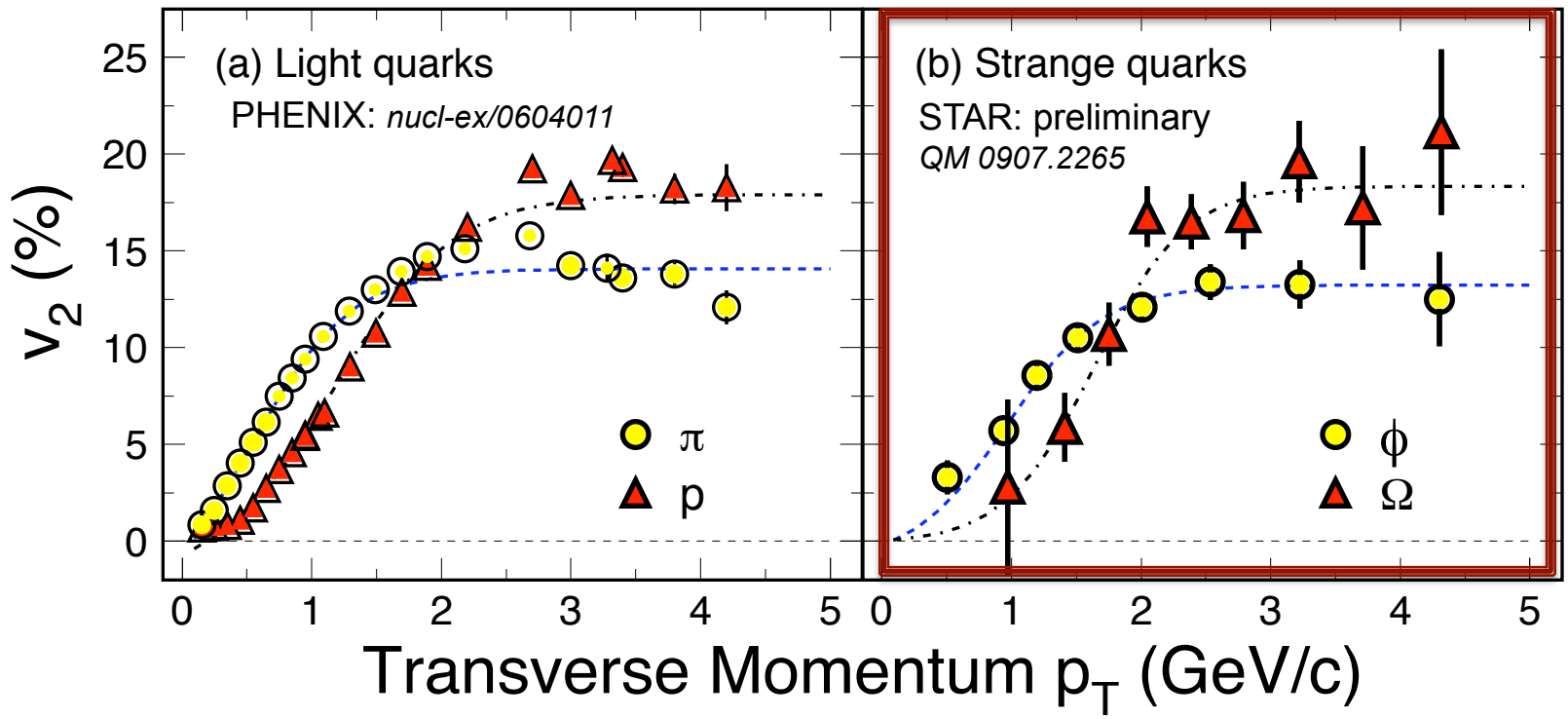


Chiral Magnetic Effect:

Kharzeev, PL B633 260 (2006).
Kharzeev, Zhitnitsky, NP A797 67(07).
Kharzeev, McLerran, Warringa, NP A803 227(08).
Fukushima, Kharzeev, Warringa, PR D78, 074033(08).

Partonic Collectivity at RHIC

$\sqrt{s_{NN}}$ = 200 GeV ^{197}Au+^{197}Au Collisions at RHIC

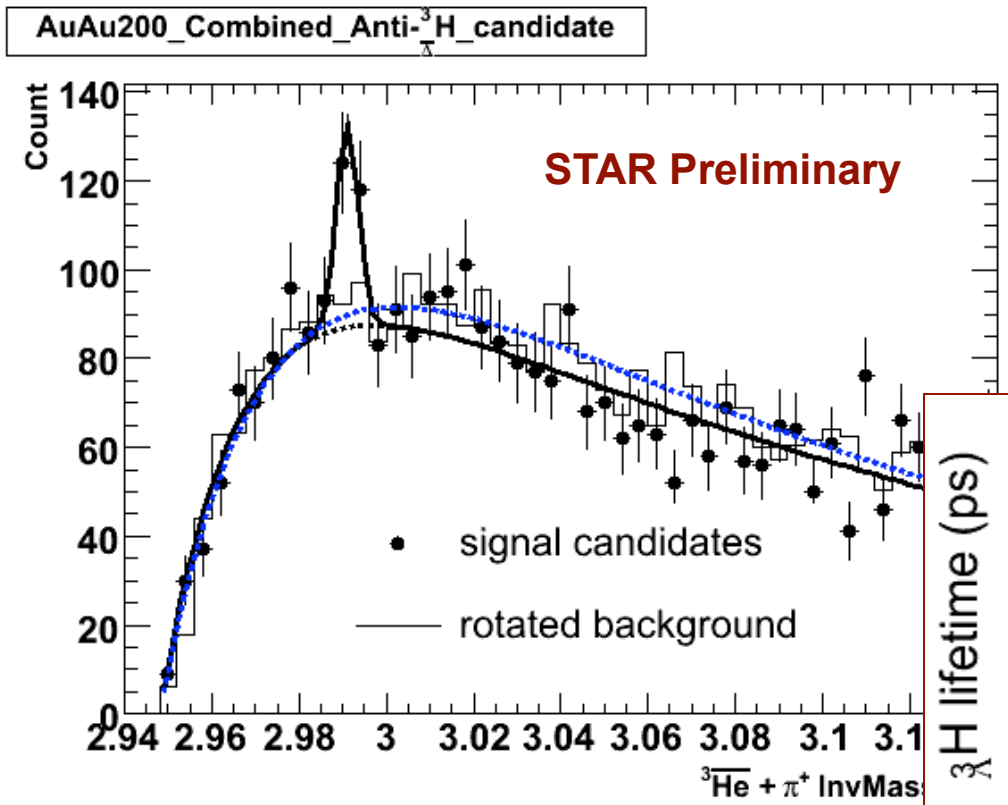


Low p_T (≤ 2 GeV/c): hydrodynamic mass ordering
High p_T (> 2 GeV/c): ***number of quarks ordering***

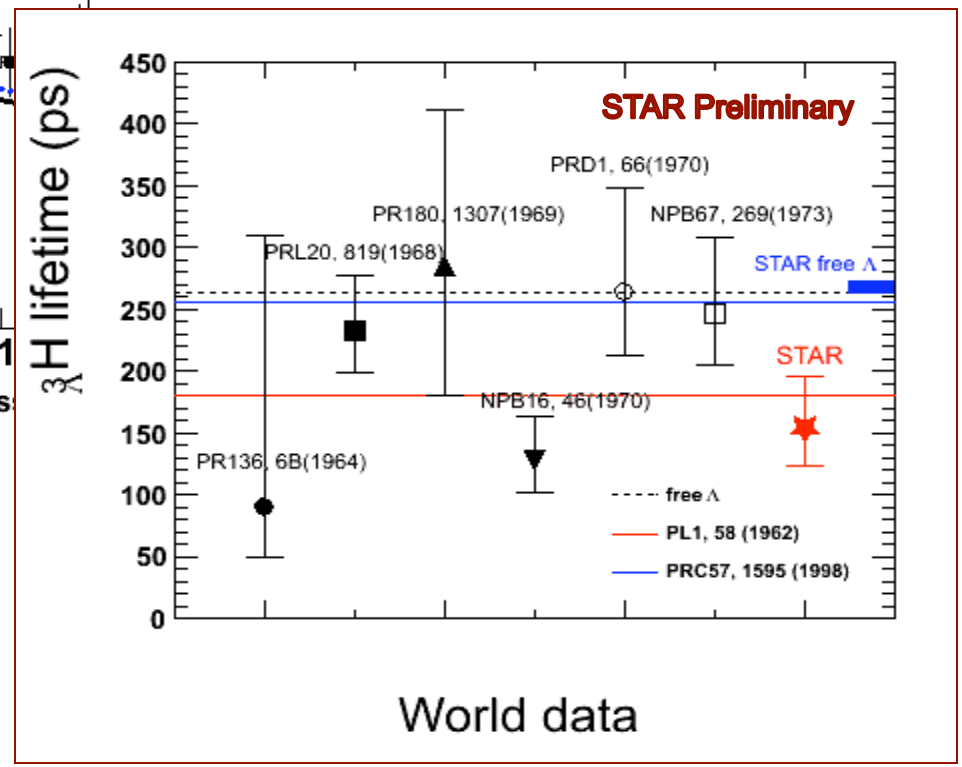
=> Collectivity developed at partonic stage!

=> Step forward for understanding the EOS at RHIC

First Observation of $^{3}_{\bar{\Lambda}}\overline{H} \rightarrow {}^{3}\overline{He} + \pi^{+}$



200 GeV Au+Au collisions at RHIC

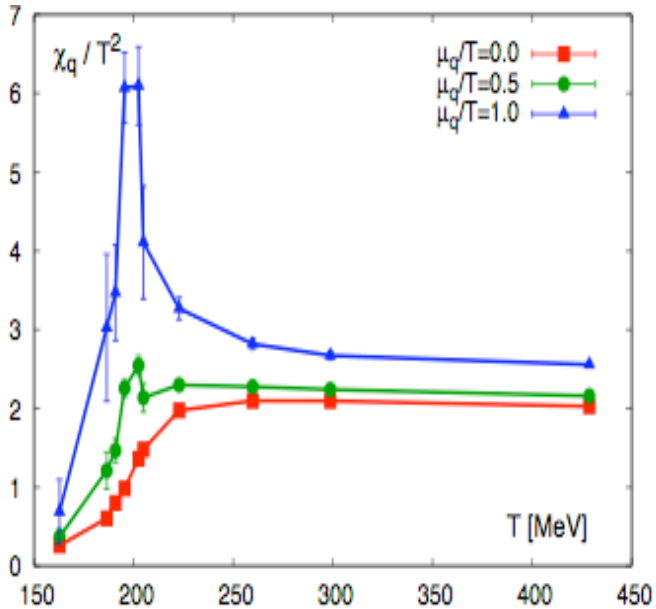


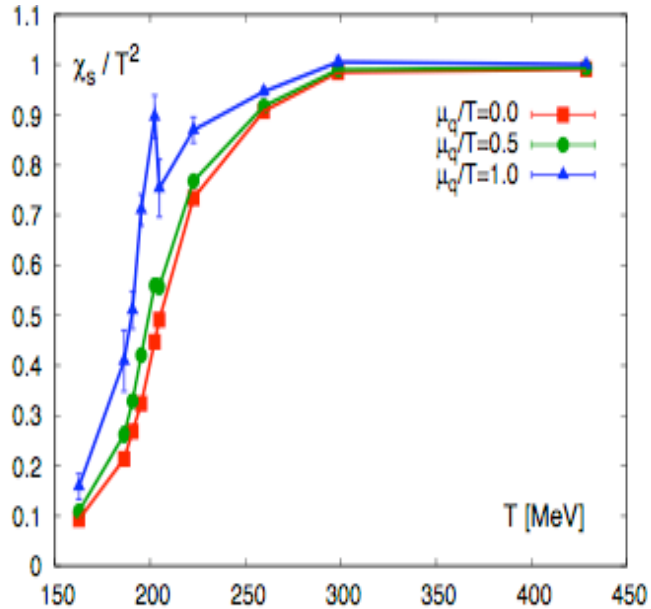
World data

First observation of
an anti-hypernucleus

To be submitted to ***Science*** magazine

Observables for QCD Critical Point





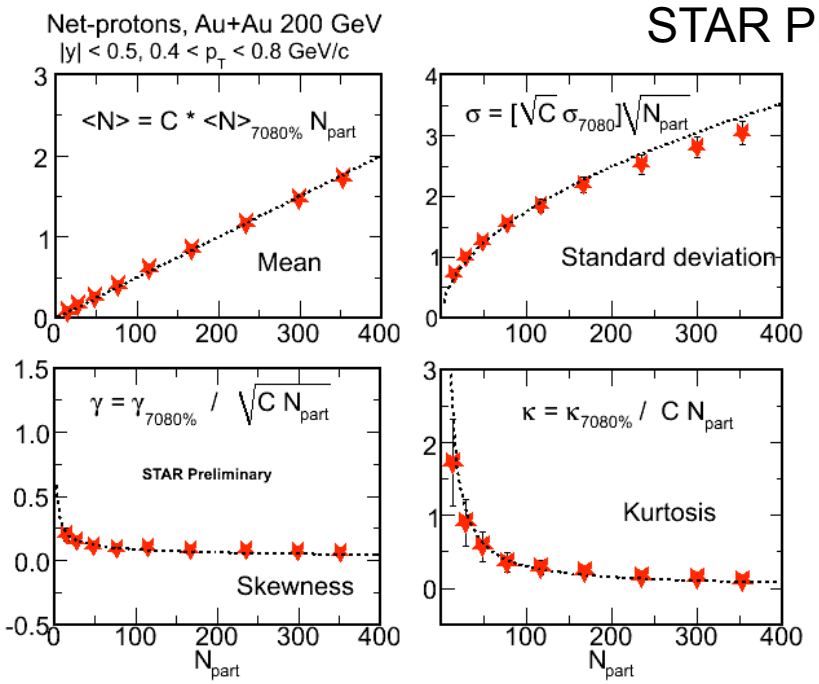
Event by Event:

1) The net-proton Kurtosis $K_p(E)$
2) Two proton correlation functions $C_2(E)$
3) Ratio of the d/p
4) Ratio of K/p

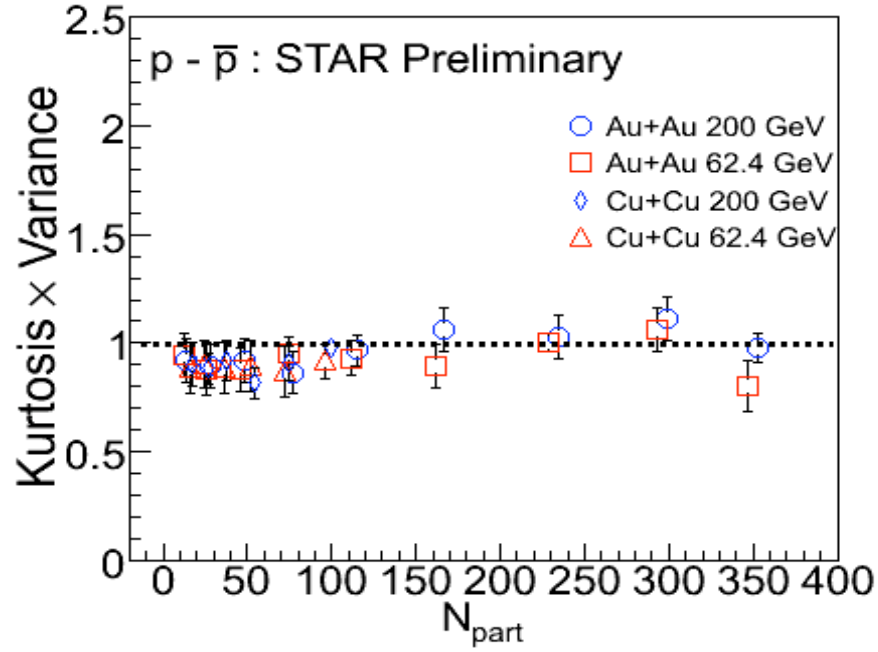
$$K_p = \frac{\langle N_p^4 \rangle - 3\langle N_p^2 \rangle^2}{\langle N_p^2 \rangle}$$

M. Cheng et al., PRD79, 074505(09);arXiv:0811.1006
*F. Karsch, INT, 08; M. A. Stephanov, PRL**102**, 032301(09)*

High Moment Analysis (BES)



STAR Preliminary, QM09



1) High moments are more sensitive to critical point related fluctuation.

2) The 4th moment, Kurtosis, is directly related to the corresponding thermodynamic quantity: susceptibility for conserved quantum numbers such as Baryon number, charge, strangeness…

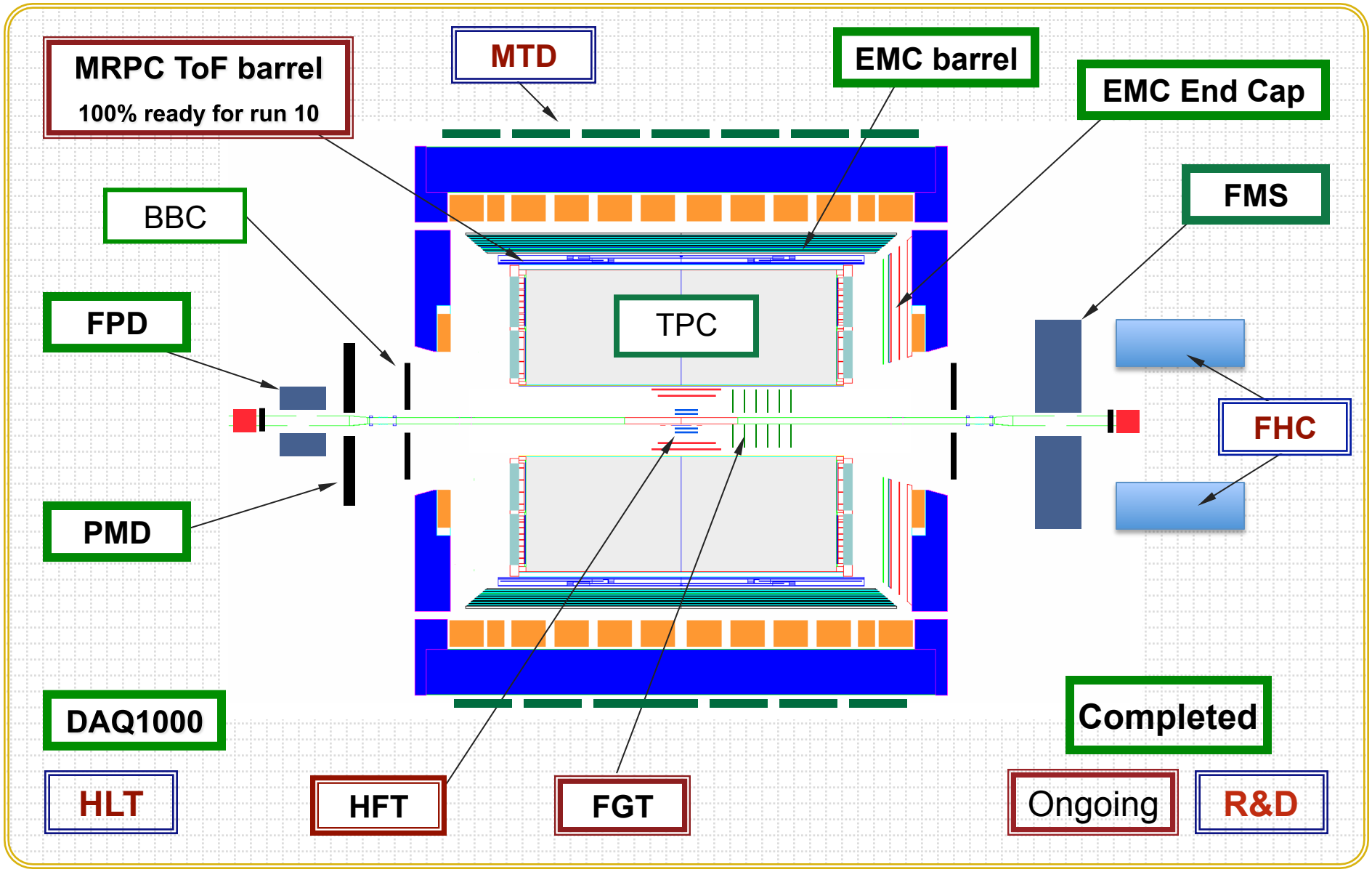
Run10 Physics Programs

RHIC cool down early Dec.

STAR shift starts Dec. 15th

Beam Energy (GeV)	25 cryo-week	30 cryo-week	20 cryo-week CR	Physics
200	10	10	10	Thermalization J/Ψ v_2, m_{ee}
62.4	4	4	5	
39	1	1.5		BES programs, T_E, *phase boundary*
27	2	4.5		
18	0	1.5		
11.5	2	2.5	**2.5**	
7.7	1	1	**2.5**	

STAR Detector

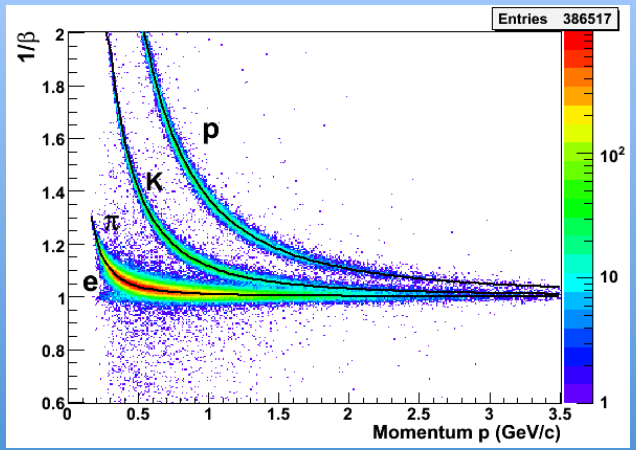


STAR: Physics with ToF (2010)

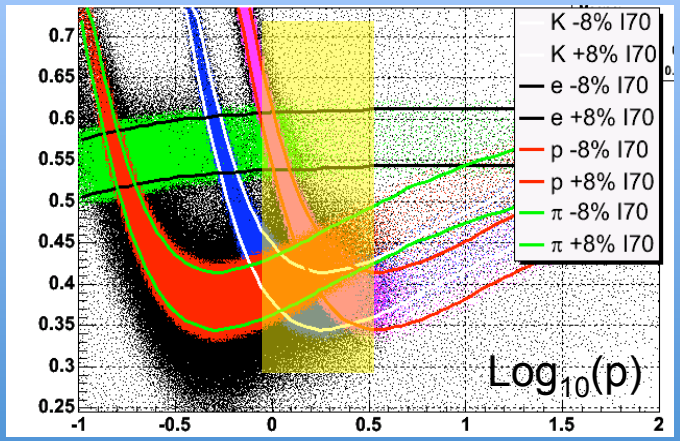
1) Significant improve PID. With TPC, PID will be been extended to p_T ~ 15 GeV/c
2) Correlations with PID hadrons; resonances (up to Ω); trigger with high p_T hadrons …
3) Beam energy scan program: event-by-event K/π analysis and net-p Kurtosis
4) 2π electron and di-electron analysis; heavy flavor program

…

STAR TOF

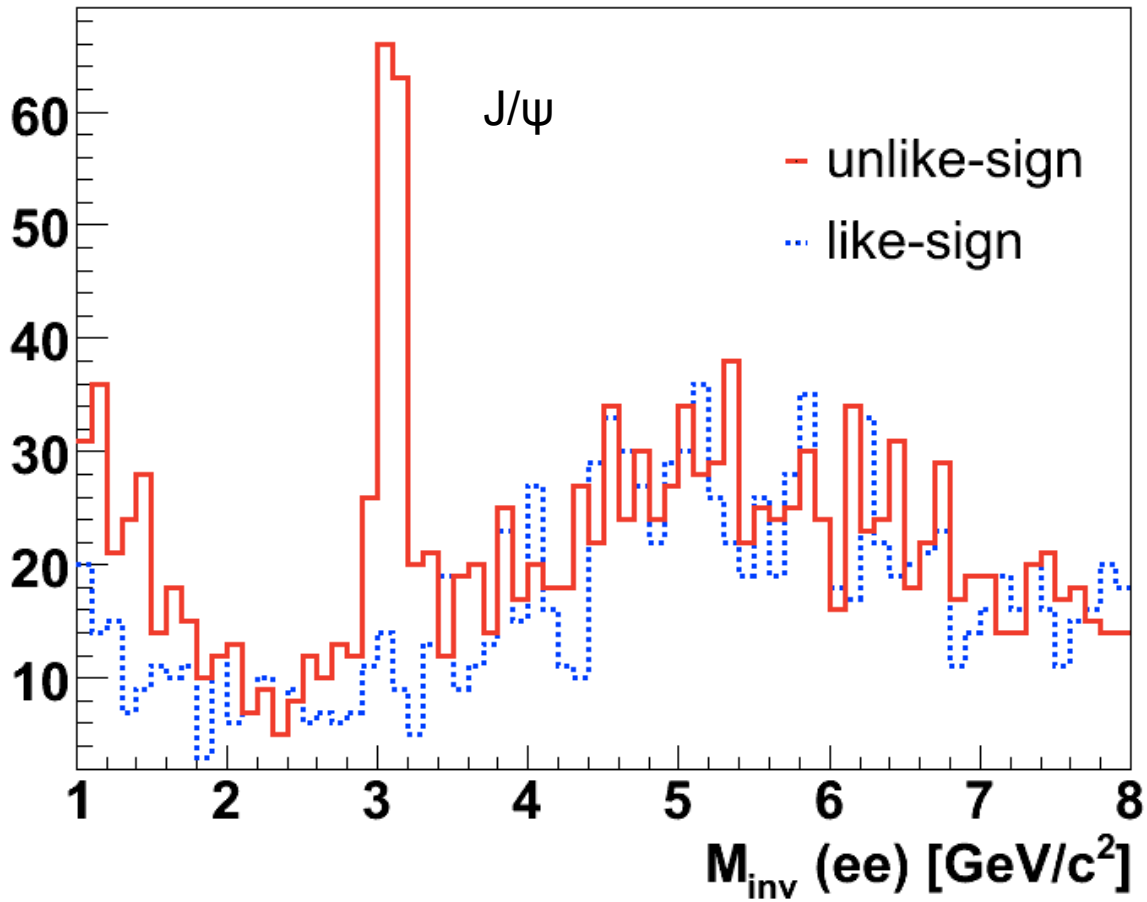


STAR TPC+TOF



STAR High Level Trigger

Run9 p+p 200 GeV, May 19 - 25



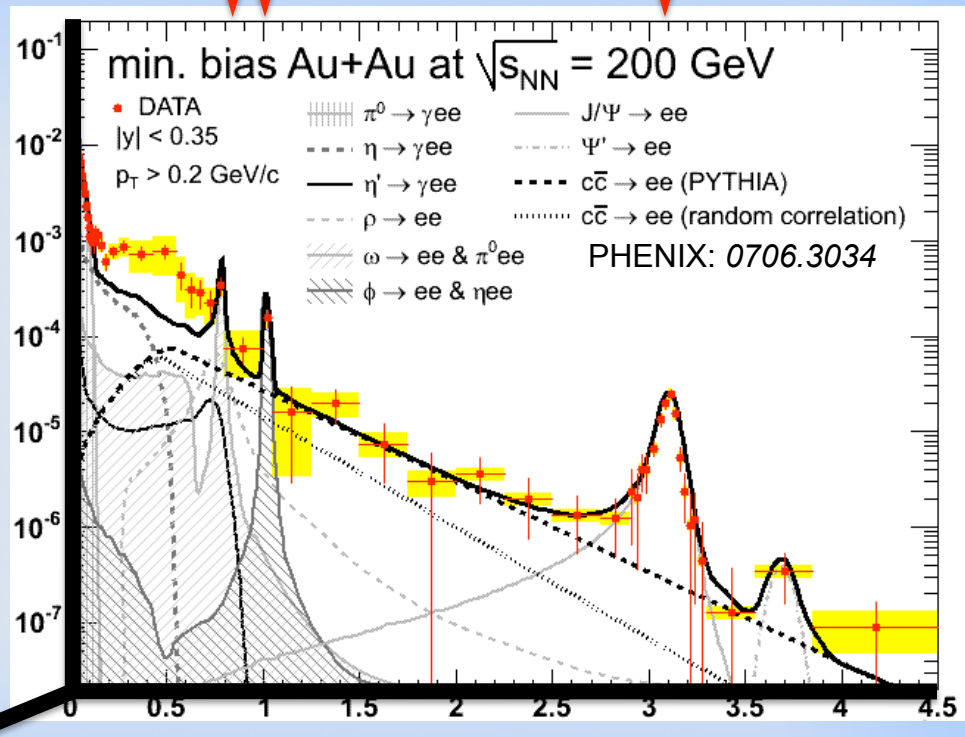
1) Fast filtering for quick data analysis. Run10: try J/ψ v_2
2) Online QA

The di-Lepton Program at STAR

(1) σ, m

(2) v_2

(3) R_{AA}



p_T (GeV/c)

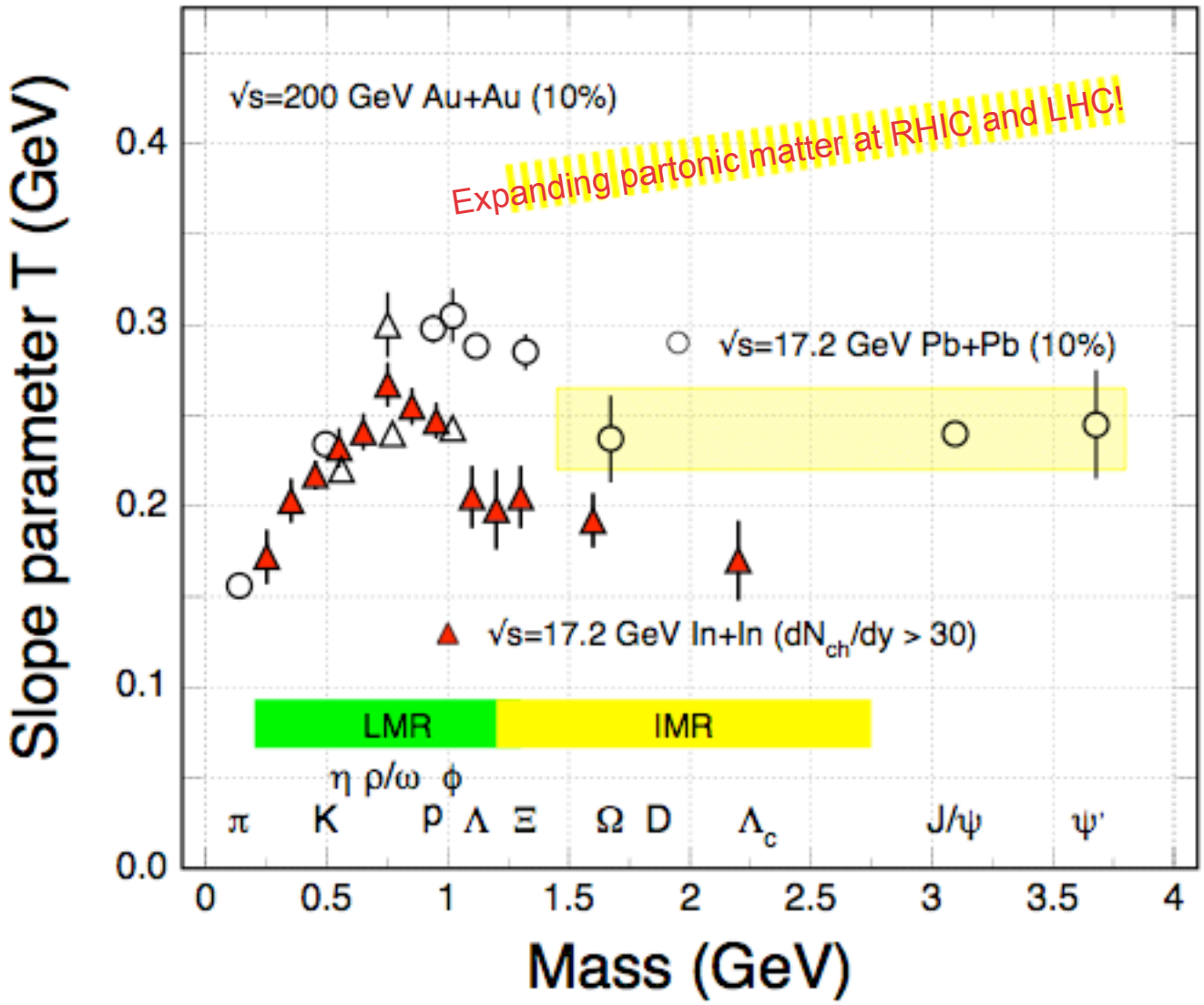
m_{ee} (GeV)

✓ **Chiral Symmetry Restoration**

✓ **Direct Radiation from The Hot/Dense Medium**

*** ToF Crucial for the physics.**

Direct Radiation



Di-leptons allow us to measure the direct radiation from the matter with partonic degrees of freedom, no hadronization!

- Low mass region:
  $\rho, \omega, \phi \Rightarrow e^-e^+$
  $m_{inv} \Rightarrow e^-e^+$

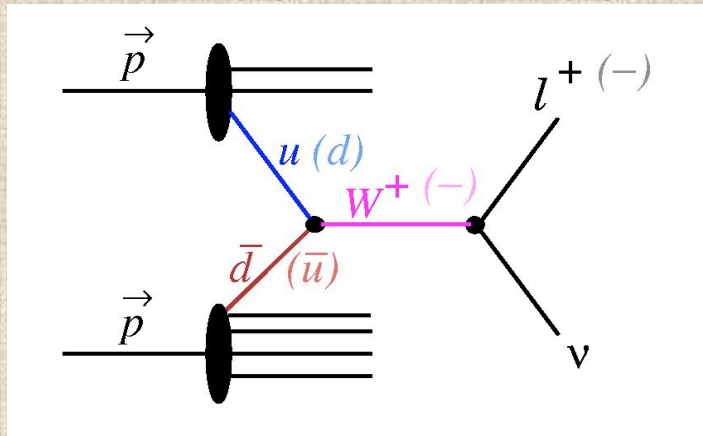
  medium effect
  Chiral symmetry

- High mass region:
  $J/\psi \Rightarrow e^-e^+$
  $m_{inv} \Rightarrow e^-e^+$

  Direct radiation

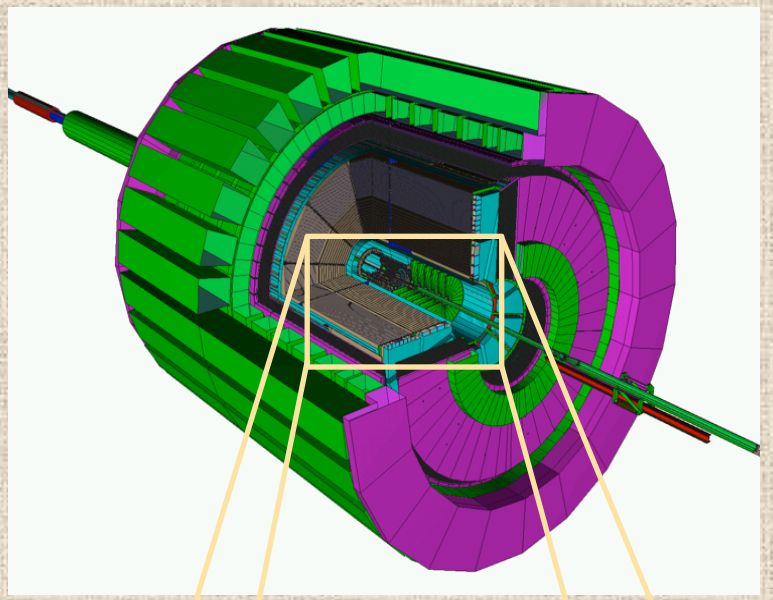
STAR: The *Sea-Quark* Program (2011)

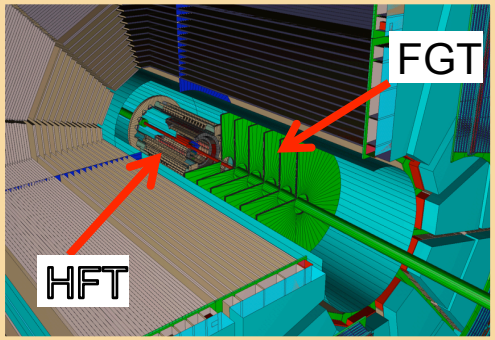
500 GeV p+p collisions



$$u + \bar{d} \rightarrow W^+ \rightarrow e^+ + \nu$$

$$\bar{u} + d \rightarrow W^- \rightarrow e^- + \bar{\nu}$$



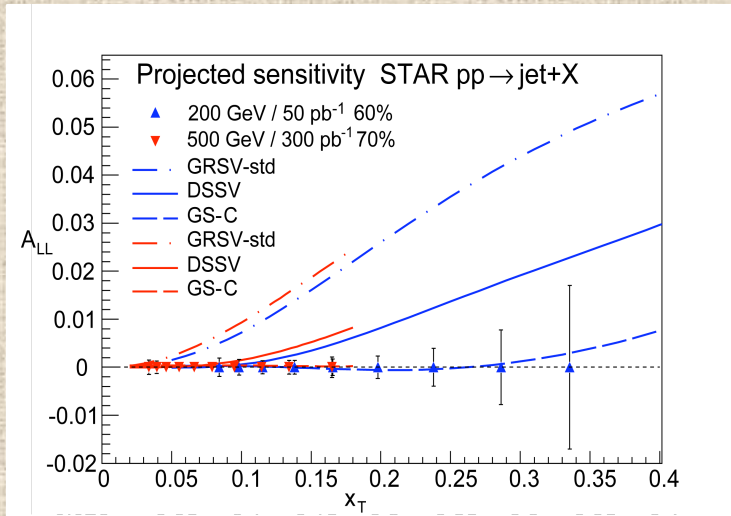


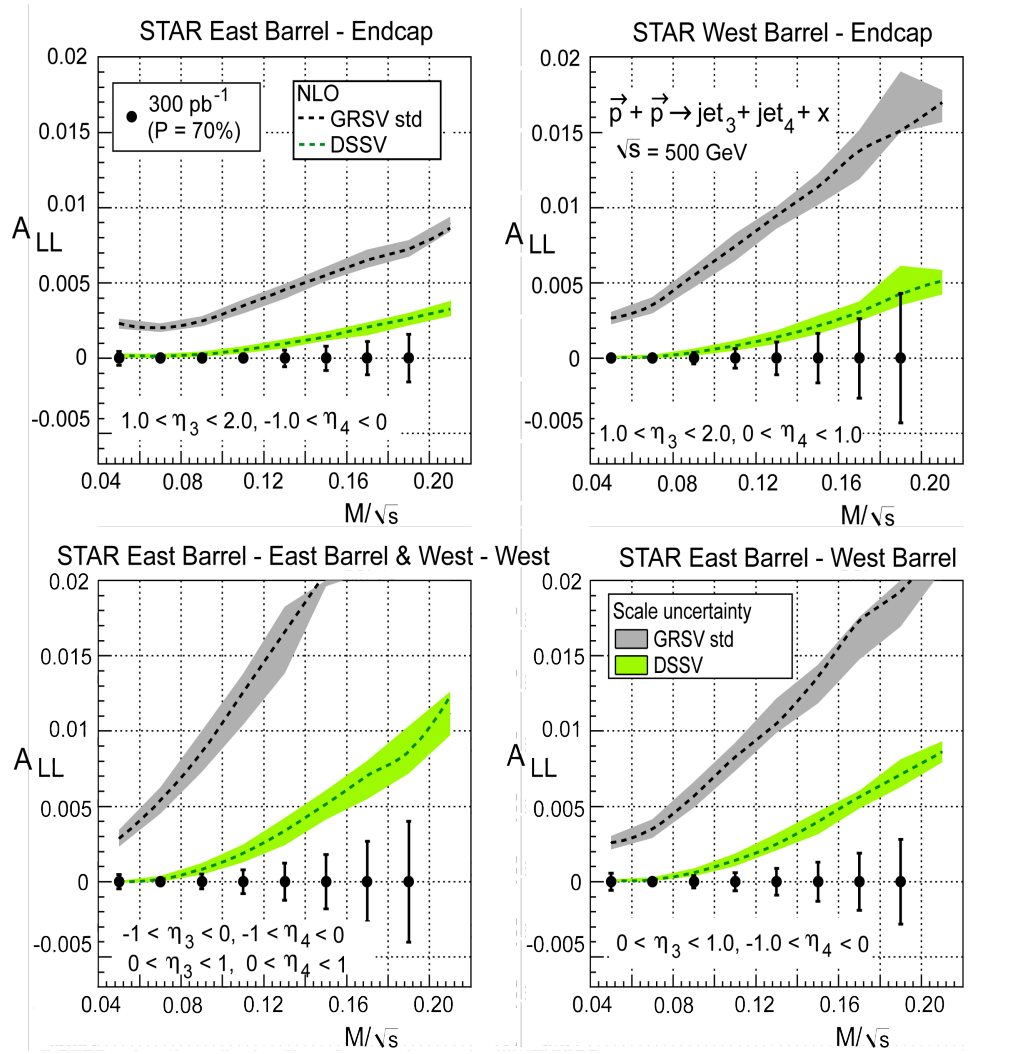
Forward GEM Tracker: FGT

1) Charge sign identification for high momentum electrons from W± decay (Energy determined with EEMC)

2) Triple-GEM technology, Summer 2011 for Run12

STAR: 500GeV Low-x Program



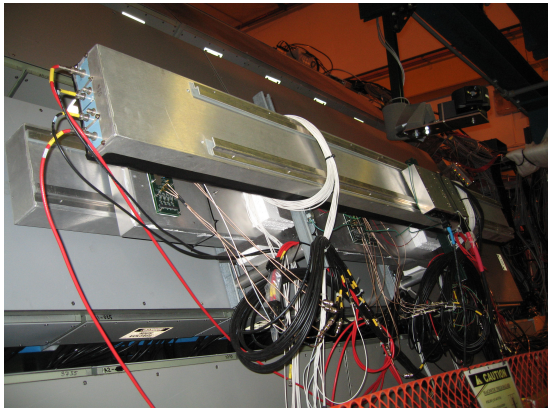


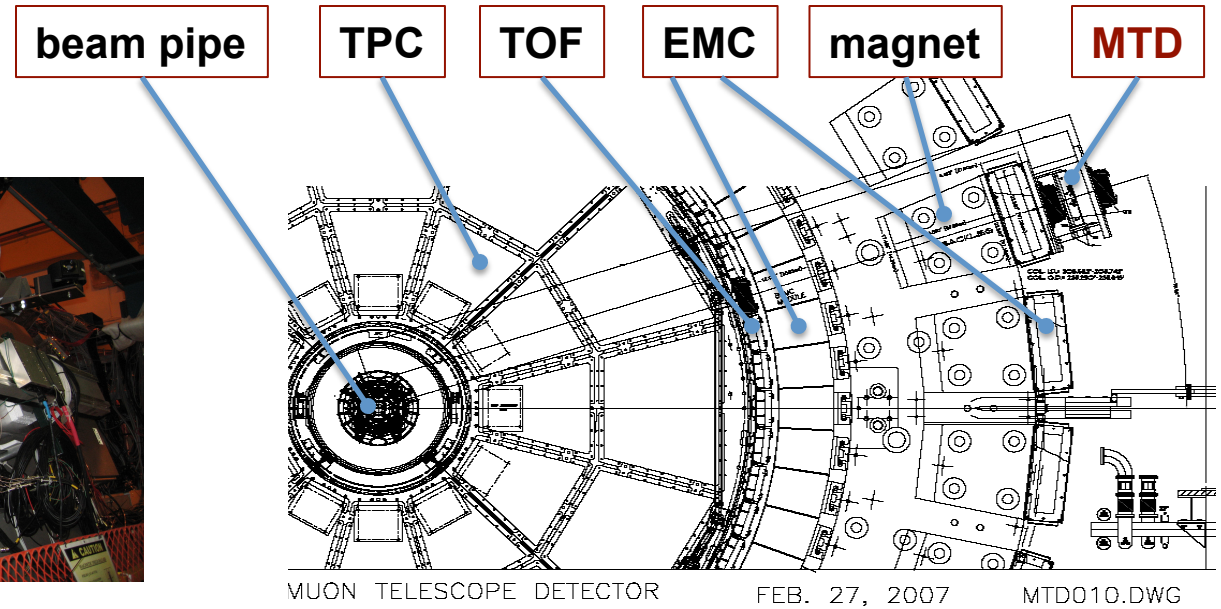
1) High precision at $\sqrt{s}$ = 500 GeV at small x, ~ 300pb^{-1}

2) Inclusive Jets

3) di-jet

STAR: Muon Telescope Detector (2012)

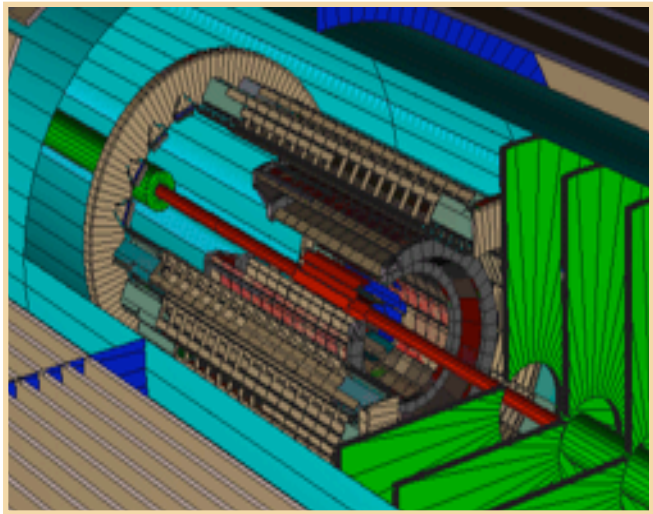


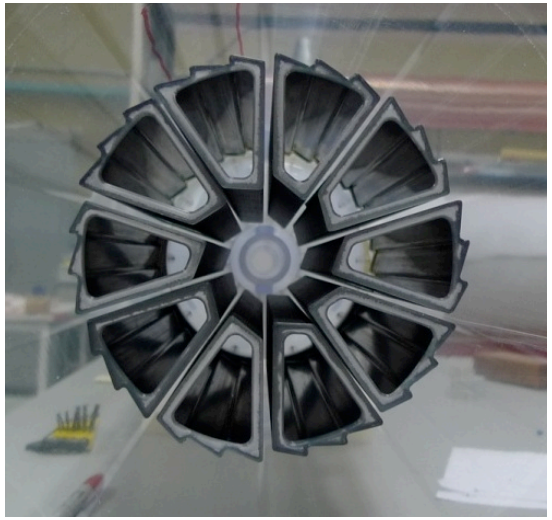


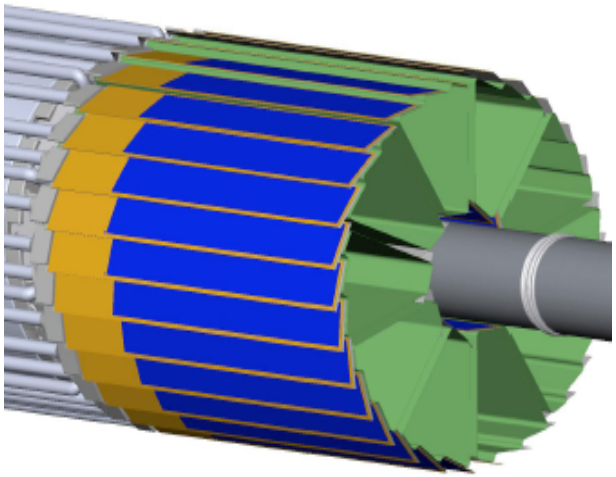
Muon Telescope Detector at STAR:

1) MRPC technology; μ_ε ~ 45%; cover ~60% azimuthally and |y| < 0.25
2) TPC+TOF+MTD: muon/hadron enhancement factor ~ $10^{2\text{-}3}$
3) For trigger and heavy quarkonium measurements
4) China-STAR collaboration: a proposal will be ready in mid-Sept.

STAR Heavy Flavor Tracker (2014)





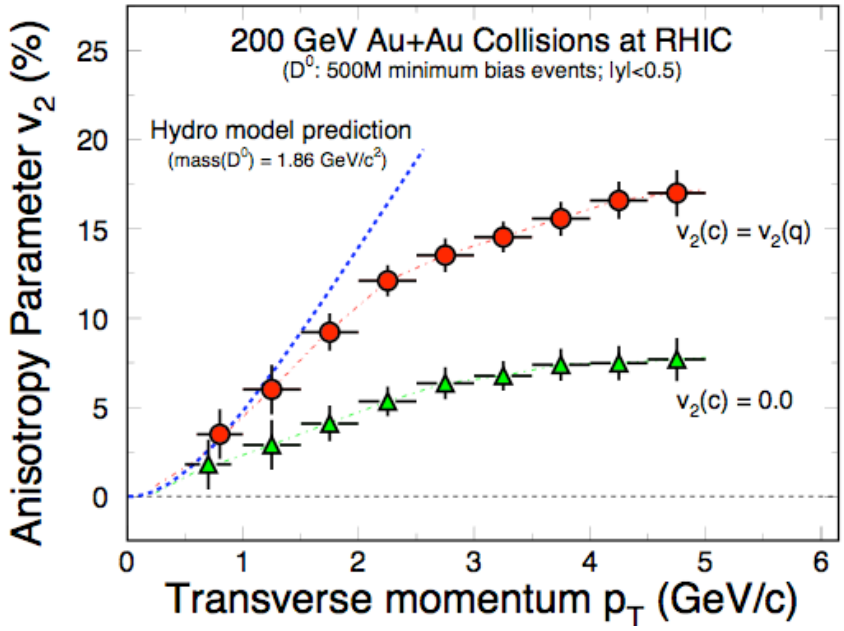


HFT: 2012-2014

1) Two-layer thin CMOS pixels; one-layer strips; SSD
2) First layer at 2.5 cm from beam pipe, 2pi coverage
3) Resolution~20μm

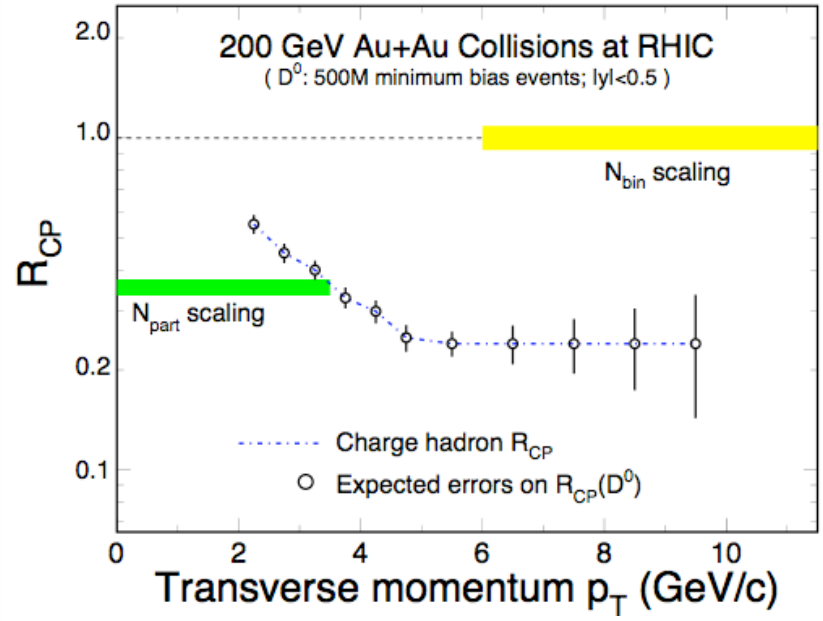
➔ Measure down to low p_T ~ 0.5 GeV/c for open charm hadrons

HFT: Charm Hadron v_2 and R_{AA}



- 200 GeV Au+Au m.b. collisions (500M events).
- Charm hadron collectivity ⇨ drag/diffusion constants ⇨

Medium properties!



- 200 GeV Au+Au m.b. collisions (|y|<0.5 500M events)
- Charm hadron R_{AA} ⇨

- Energy loss mechanism!
- QCD in dense medium!

STAR QCD physics program for the next decade:

Spin Physics:

- 200 GeV: ***Δg*** inclusive and di-jets, γ-jet
- 500 GeV: ***sea quark*** helicity distributions
- 200/500 GeV: transverse spin phenomena

Heavy Ion Physics:

- Thermalization at 200 GeV; m_{ee}
- QCD phase boundary and critical point
- In medium properties(?)

Low-x Physics:

- Study gluon-rich phenomena at RHIC
- Color glass condensate