Leptons, Photons, and Heavy Quarks

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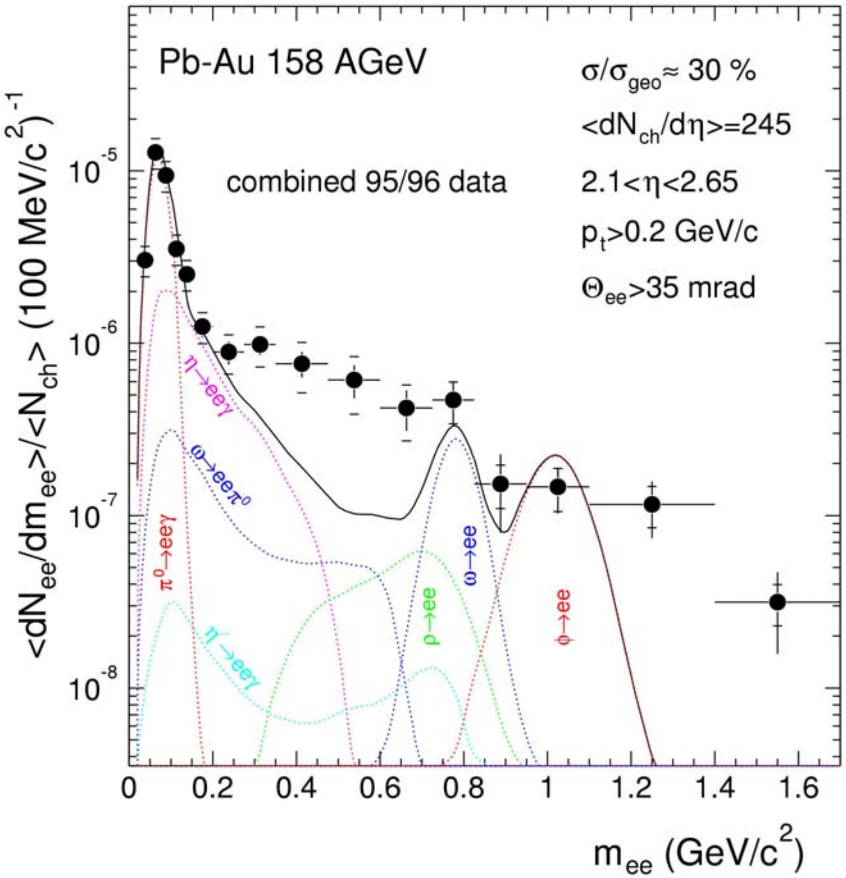
Quark Matter 2004, Oakland
January 11 - 17, 2004

Outline

- **Low and Intermediate-Mass Dileptons**
  - **open questions**
  - **pending answers**
- **Direct Photons**
  - **controlling jets**
- **Heavy Flavor**
  - **charmonia**
    - **news from SPS**
    - **preparing the case for RHIC**
  - **open charm at RHIC**
    - **reference and probe**
- **Summary**

SPS dilepton experiments: open questions

- low-mass dielectrons
  - excess established by NA45/CERES
  - vector mesons, i.e. ω, ϕ?
    - where are they?
    - medium modifications of yield, mass, width?



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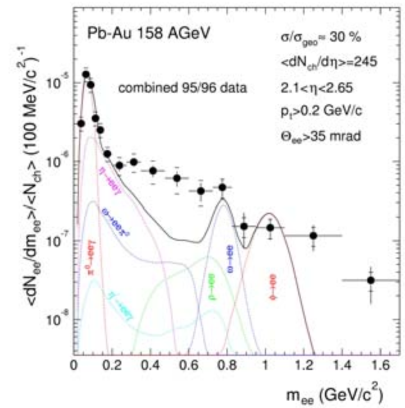
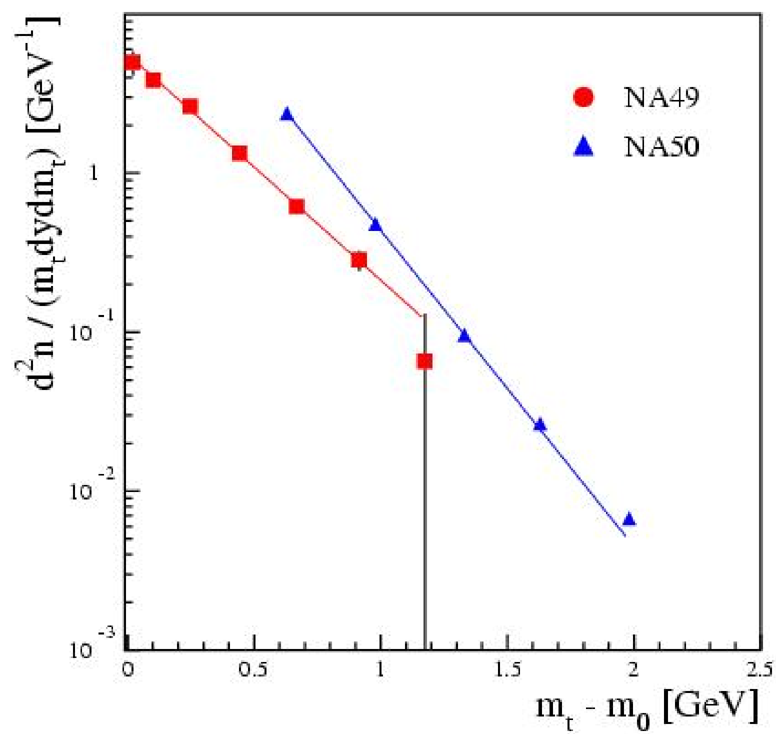


- the ϕ puzzle
  - discrepancy between NA49 ($\phi \rightarrow K^+K^-$) and NA50 ($\phi \rightarrow \mu^+\mu^-$)
  - physics (ϕ in-medium vs. ϕ at freeze-out)?



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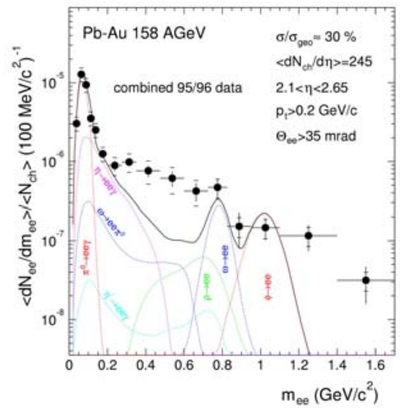

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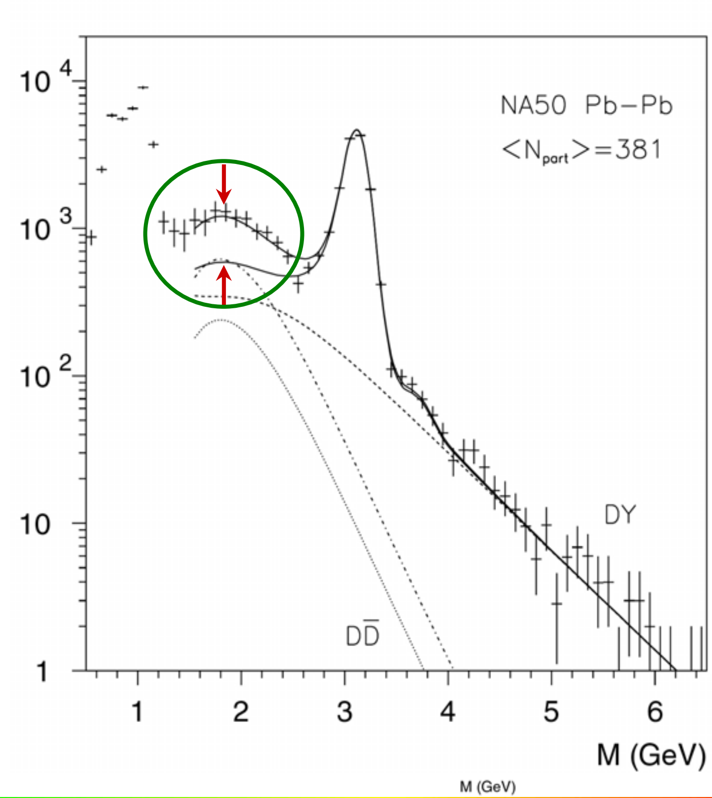
  - **dimuon excess observed at intermediate masses (NA50)**
    - **charm enhancement?**
    - **thermal dimuons?**



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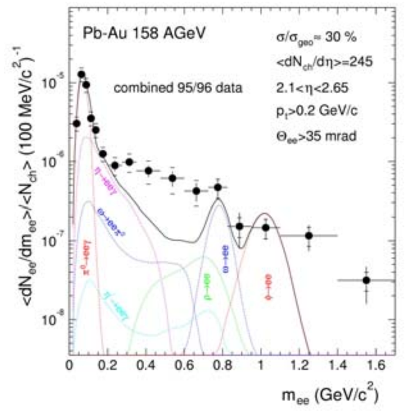

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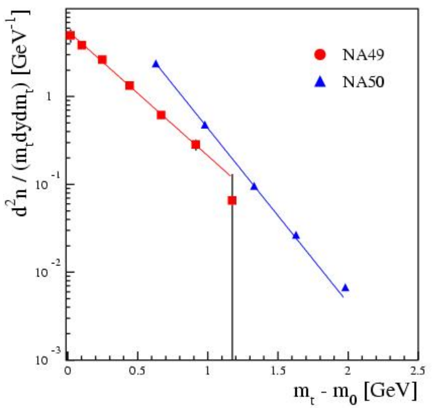

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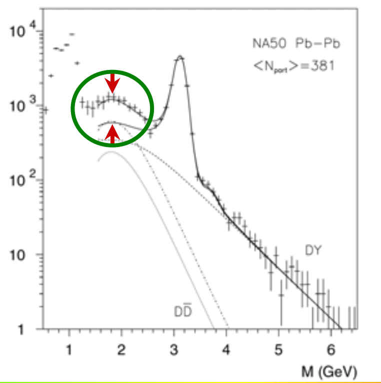
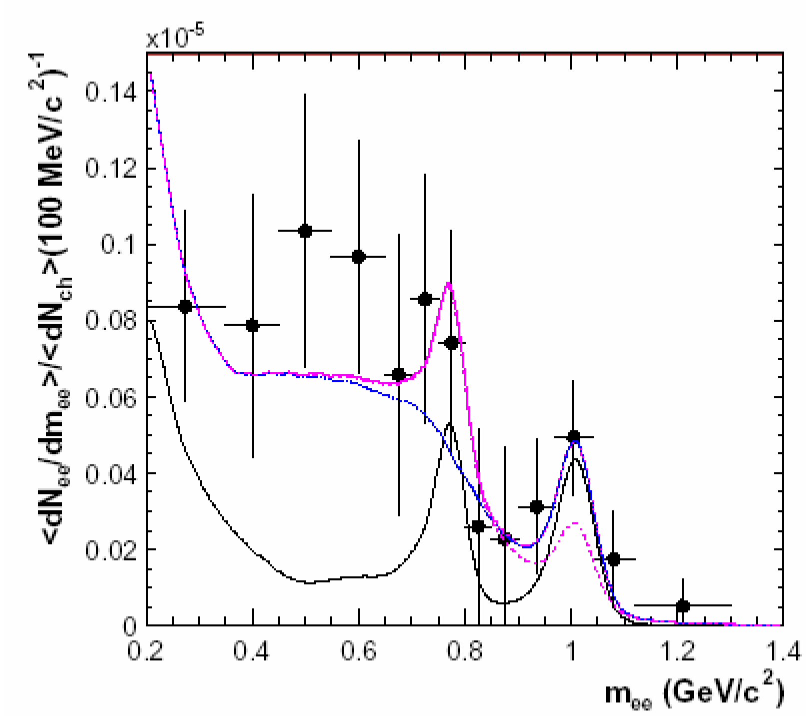


SPS dilepton experiments: answers?

NOT YET!

SPS dilepton experiments: perspectives!

- NA45/CERES (talks by A. Marin, A. Cherlin)
  - improved mass resolution (TPC)
  - possibility for $\phi \to e^+e^-$ and $\phi \to K^+K^-$ in one experiment
  - work in progress



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- NA60 (talks by P. Sonderegger, A. David)
  - DESIGNED to answer open questions!
    - high statistics due to selective trigger
    - good mass resolution (~20 MeV for ω,ϕ)
    - good phase-space coverage (down to zero p_T)
    - 50 μm secondary vertex resolution (prompt μ vs. μ from charm decays)

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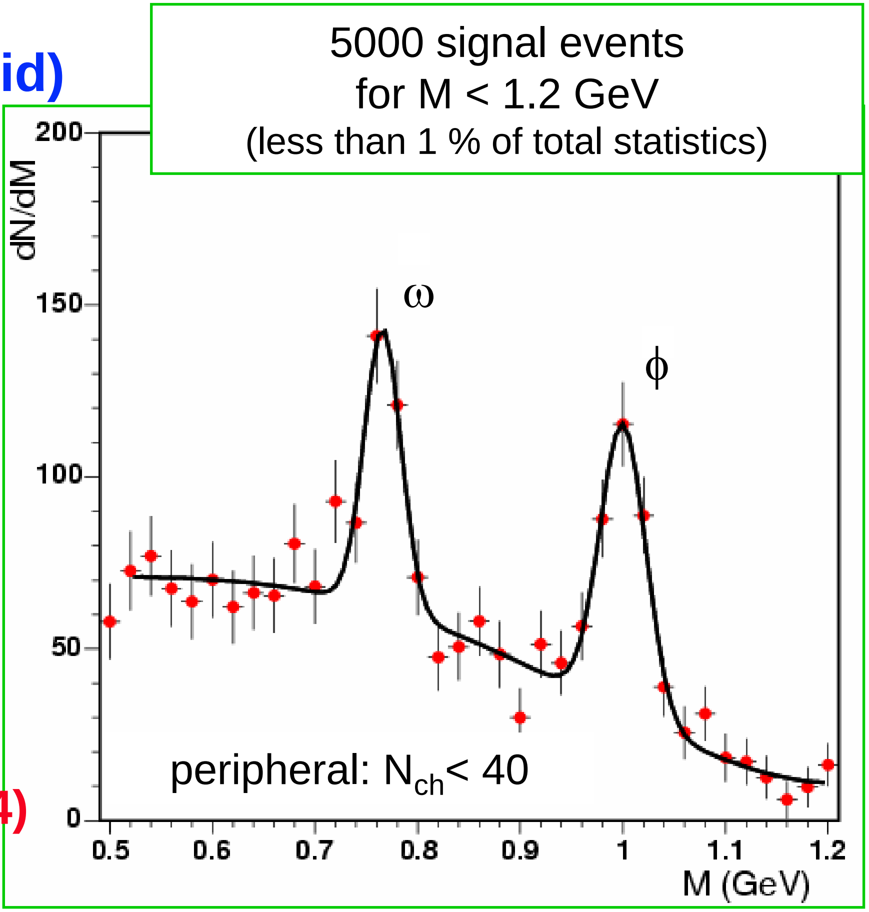
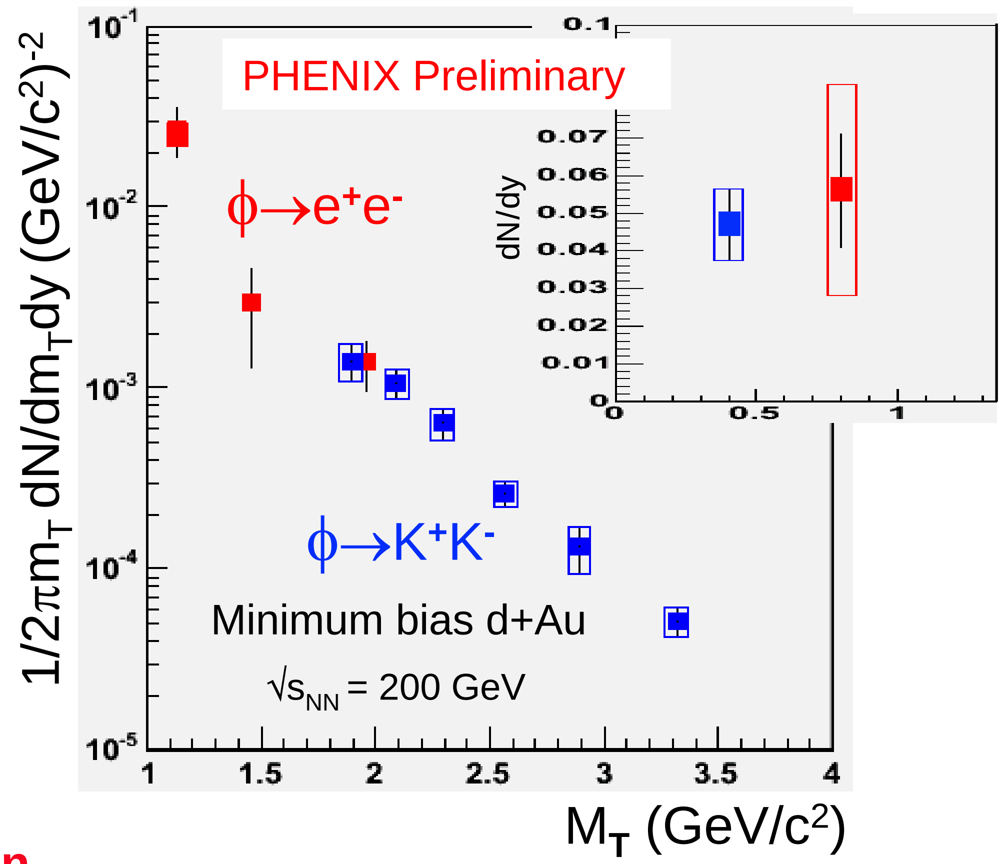
  - **Indium+Indium at 158 AGeV (2003)**
    - **$>10^6$ low-mass dimuons!**
    - **S/B: ½ - 1 (depending on centrality)**
    - **$>10^5$ $\phi \to \mu^+\mu^-$**
    - **$\phi \to K^+K^-$ feasible as well**
  - **proton reference run forthcoming (2004)**



Low-mass dileptons at RHIC

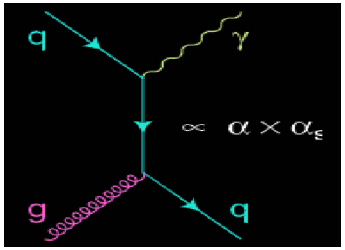
- PHENIX (talk by R. Seto): resonance measurements in leptonic and hadronic channels in ONE experiment
- look forward to results from large statistics Au+Au Run04 at RHIC
  - ρ, ω, ϕ
  - continuum (low and intermediate mass)
- RHIC upgrades (talk by A. Drees):
  - electron identification
    ⇒ Dalitz / Conversion rejection (poster by I. Ravinovich)
  - Silicon vertex spectrometers
    ⇒ resolve secondary vertices (heavy flavor physics)



- posters by C. Maguire, D. Pal, Y. Tsuchimoto

Virtual photons → real photons

- real photon sources in AA collisions
  - "trivial" ⇔ background
    - decays of light hadrons ($\pi^0 \to \gamma\gamma$)
    - dominant at low / intermediate p_T (few GeV/c)
  - "thermal" ⇔ black body radiation from hot medium
    - partonic and/or hadronic medium
    - expected at low p_T on top of huge background
  - "direct" ⇔ photons from initial state hard scattering
    - Compton scattering dominates, i.e. probe for gluon distribution
    - calculable in pQCD
    - no fragmentation of photon!
    - photon "shines through" hot and dense medium!



- direct photons "calibrate" hard scattering processes
  ⇒ IDEAL CONTROL EXPERIMENT FOR JET SUPPRESSION!
- how-to measure direct photons
  - subtraction of "background" photons (WA98 / PHENIX)
  - photon correlations
    (WA98 talk by
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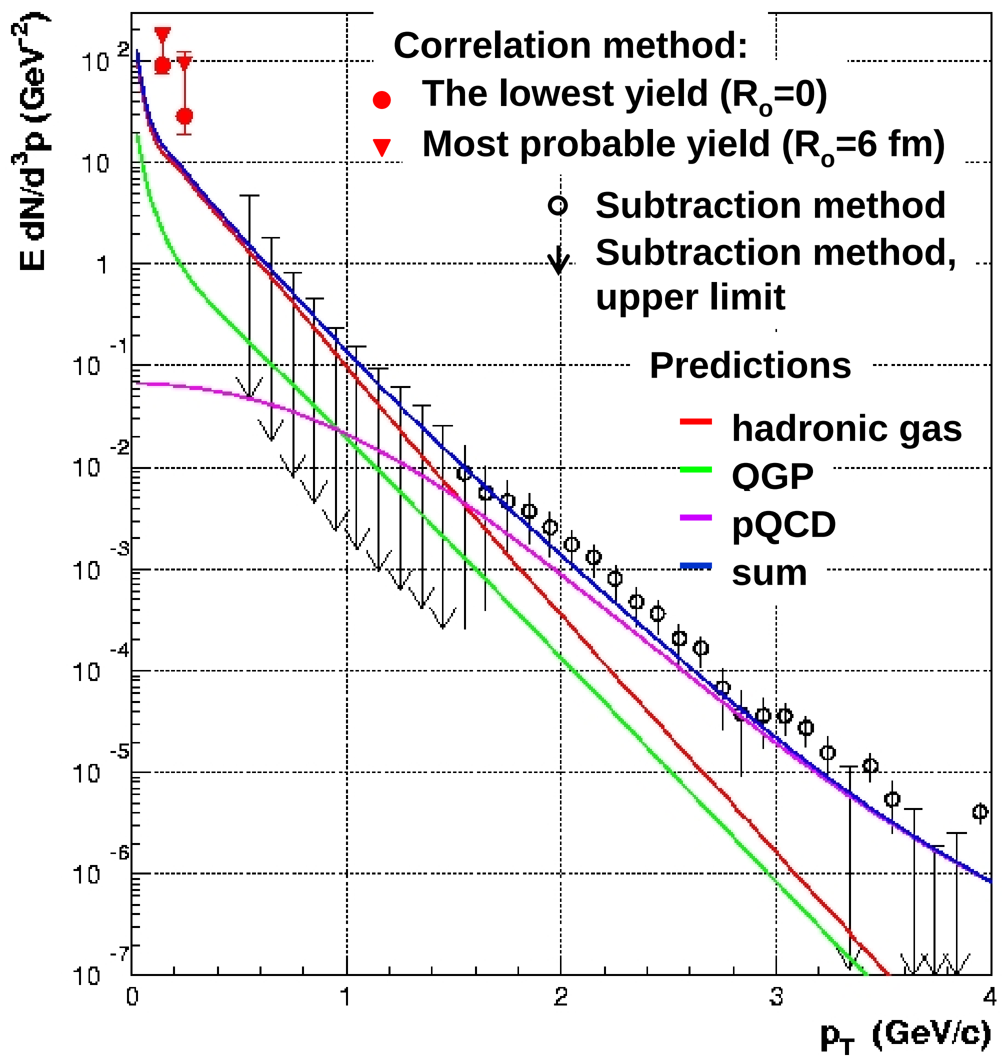

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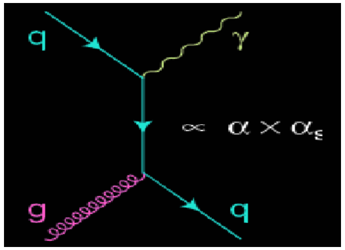

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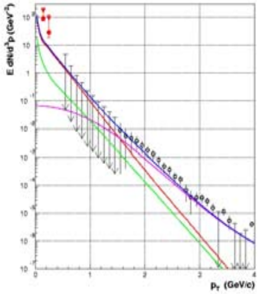
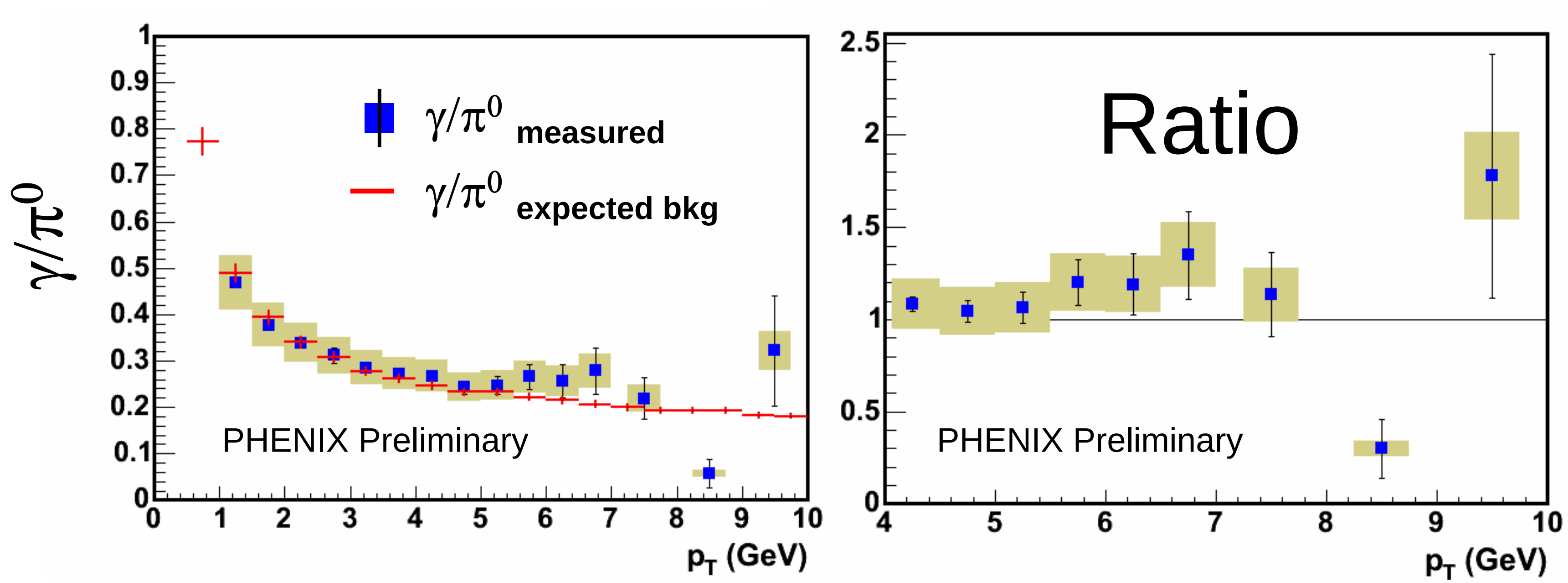


Direct photons from 200 GeV pp collisions



- **evaluation of excess above background: double ratio**
- $[\gamma/\pi]_{\text{measured}}$ / $[\gamma/\pi]_{\text{background}} \rightarrow \gamma_{\text{measured}}/\gamma_{\text{background}}$
- **(small) direct photon signal observed!**
  (PHENIX talk by J. Frantz,
  posters by G. David, K. Reygers, T. Sakaguchi)

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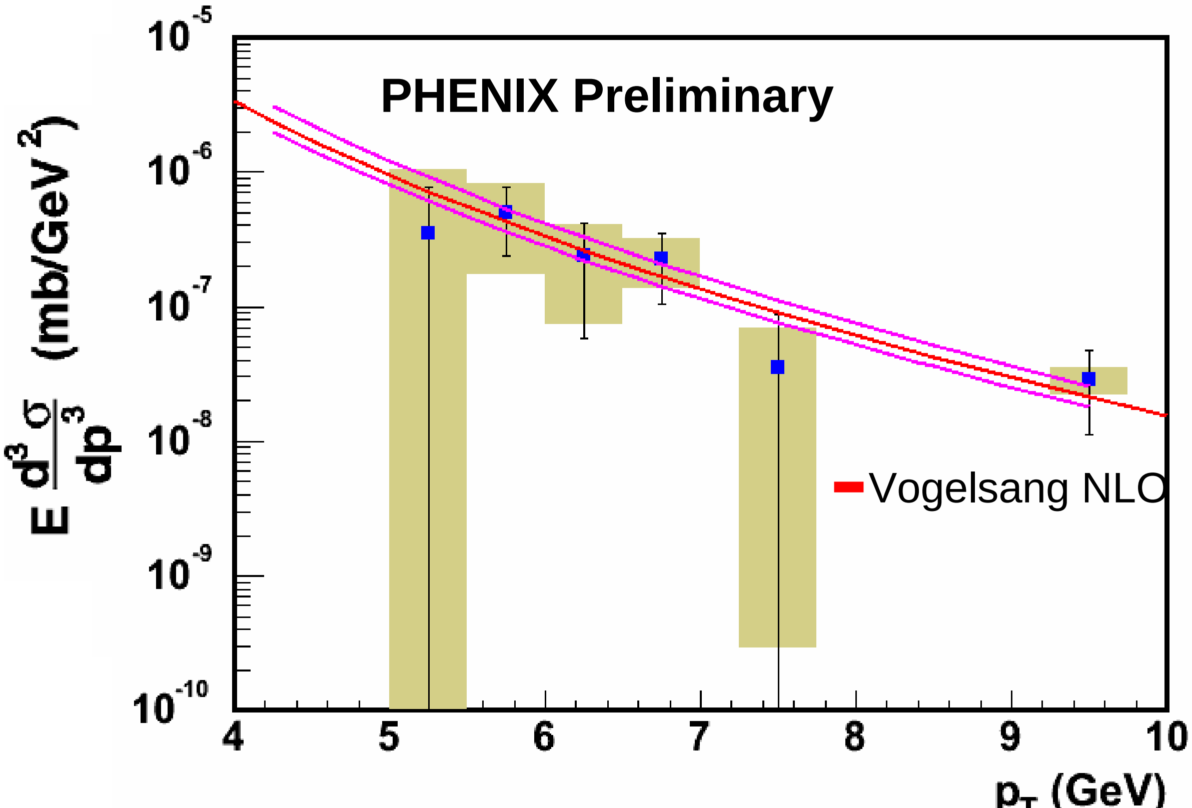

- **consistent with NLO pQCD calculation**
  (W. Vogelsang: JHEP 9903 (1999) 025 & priv. comm.)

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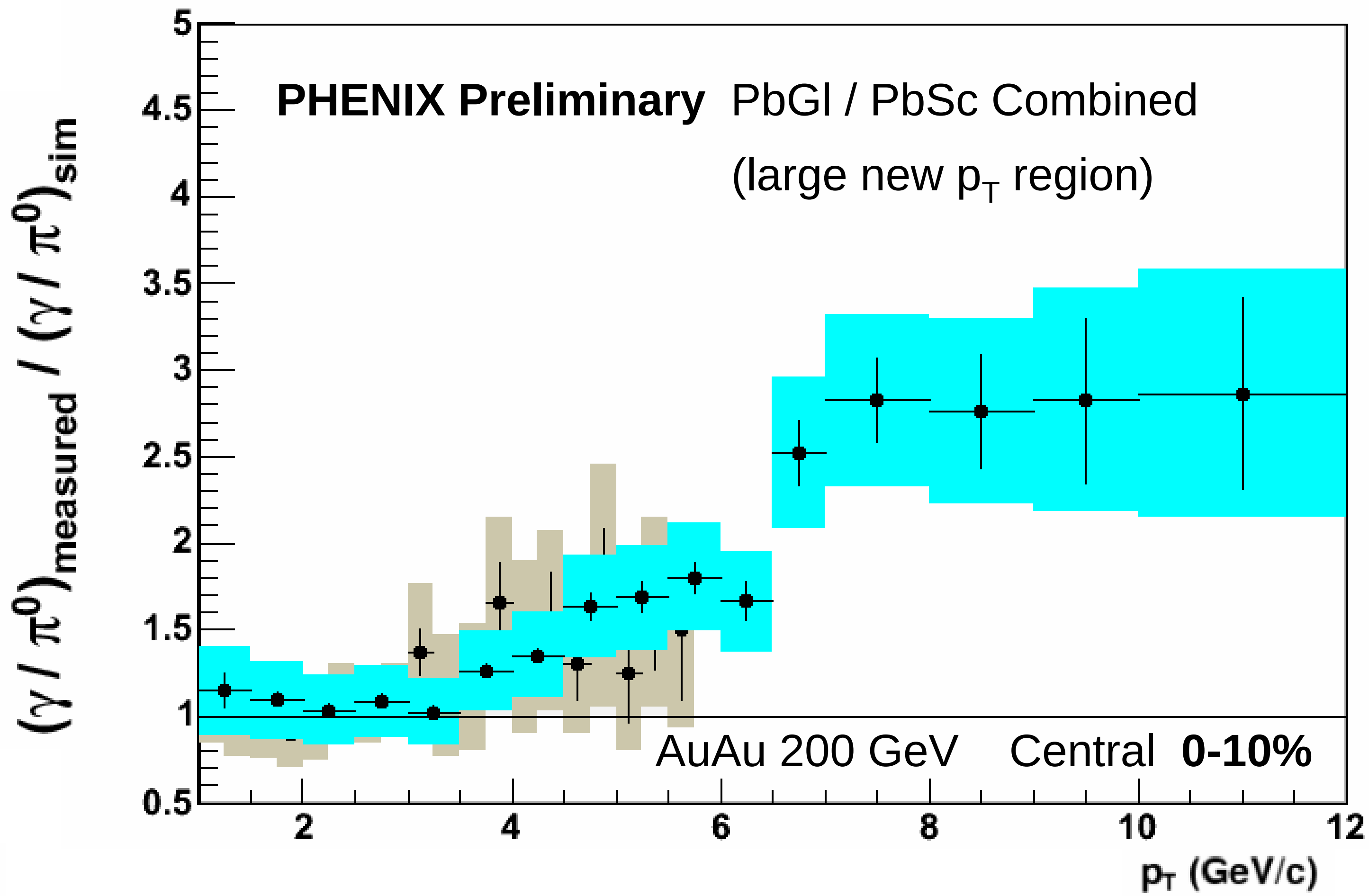
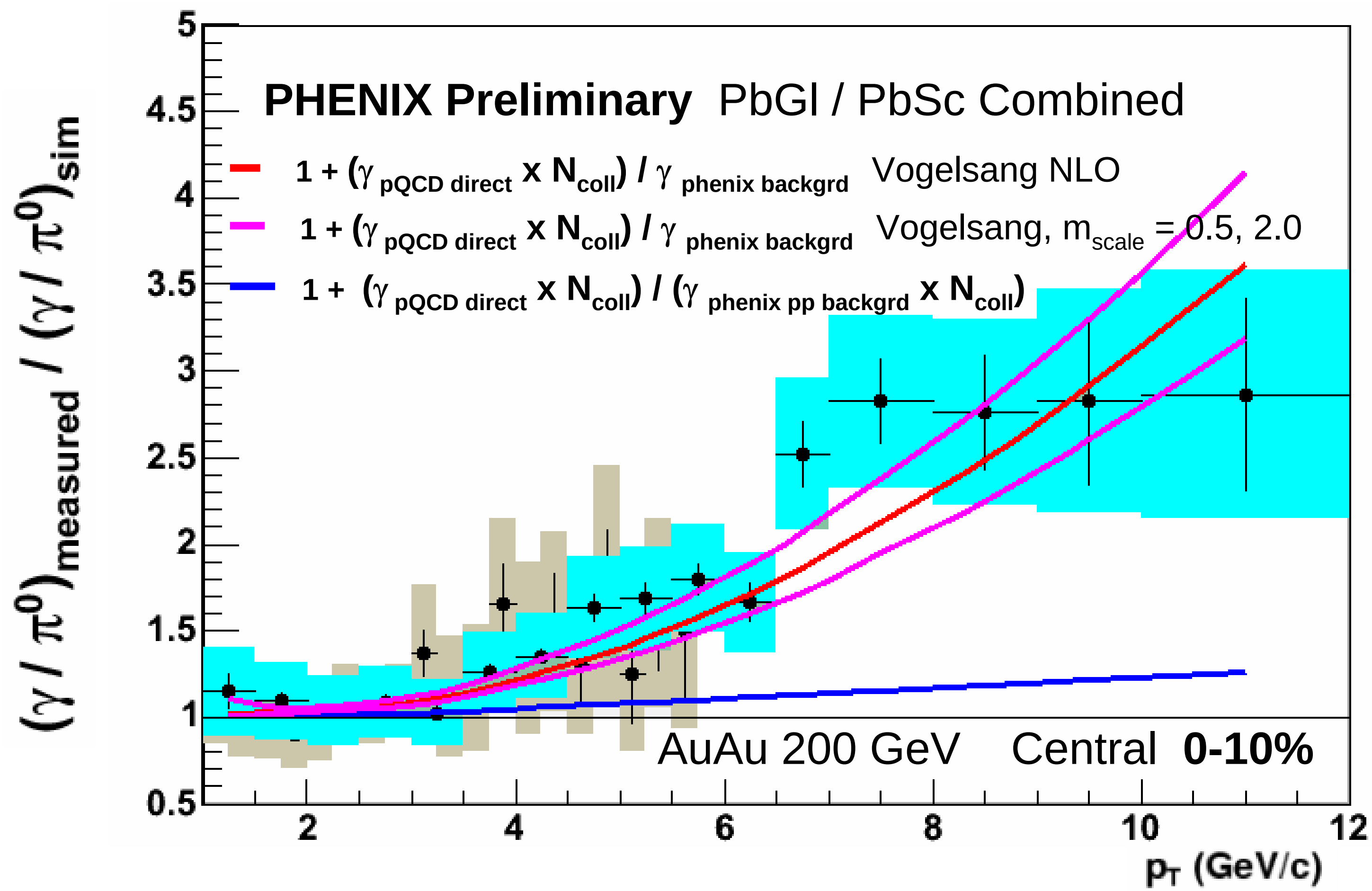
Direct photons from 200 GeV AuAu collisions

- **strong suppression of high p_T pions in central AuAu collisions**
  - **VERY significant background reduction!**

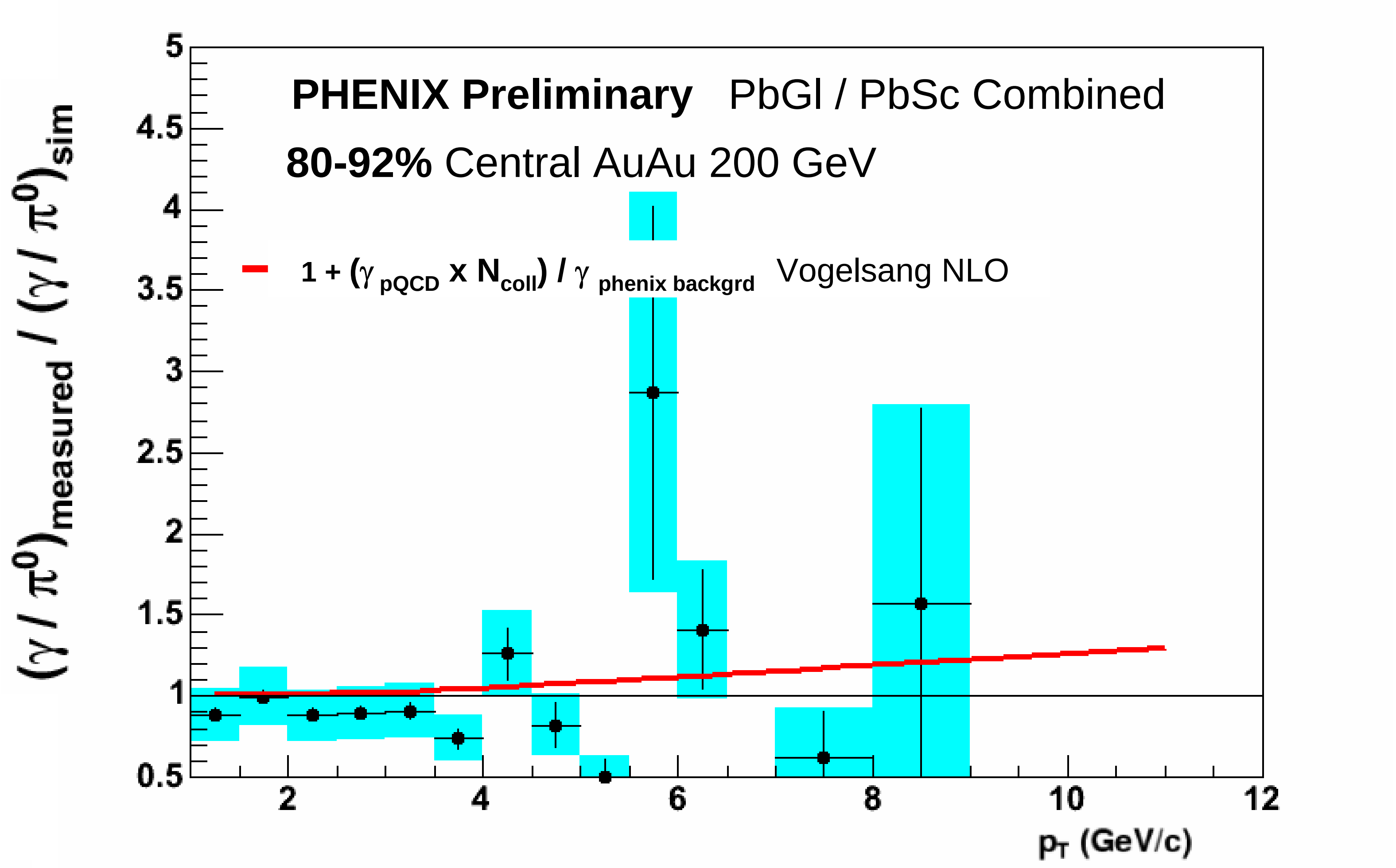


Comparison with NLO pQCD calculation



- **nice agreement with unsuppressed, binary scaled pp NLO pQCD calculation!**

Direct photons: centrality dependence



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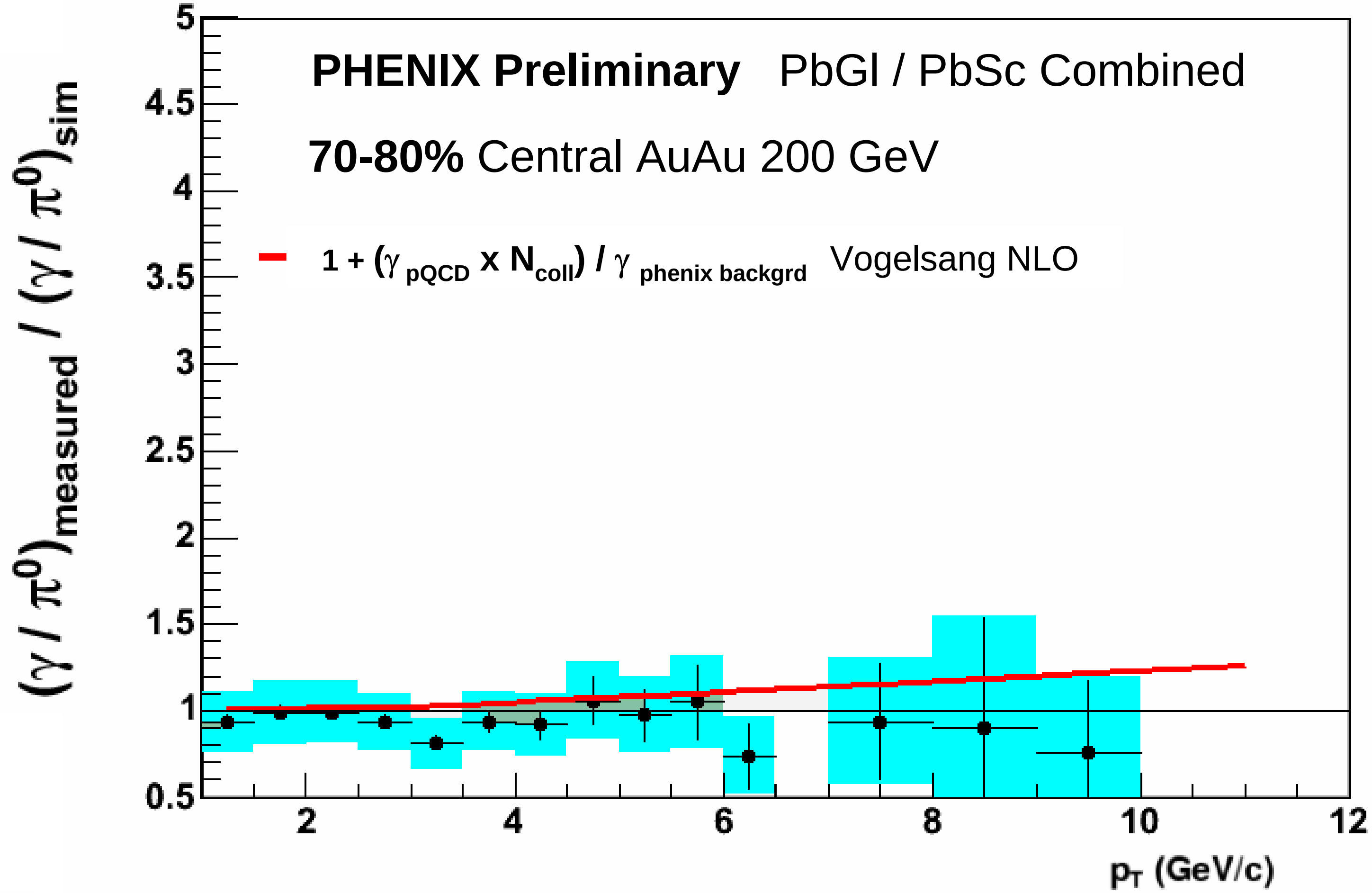

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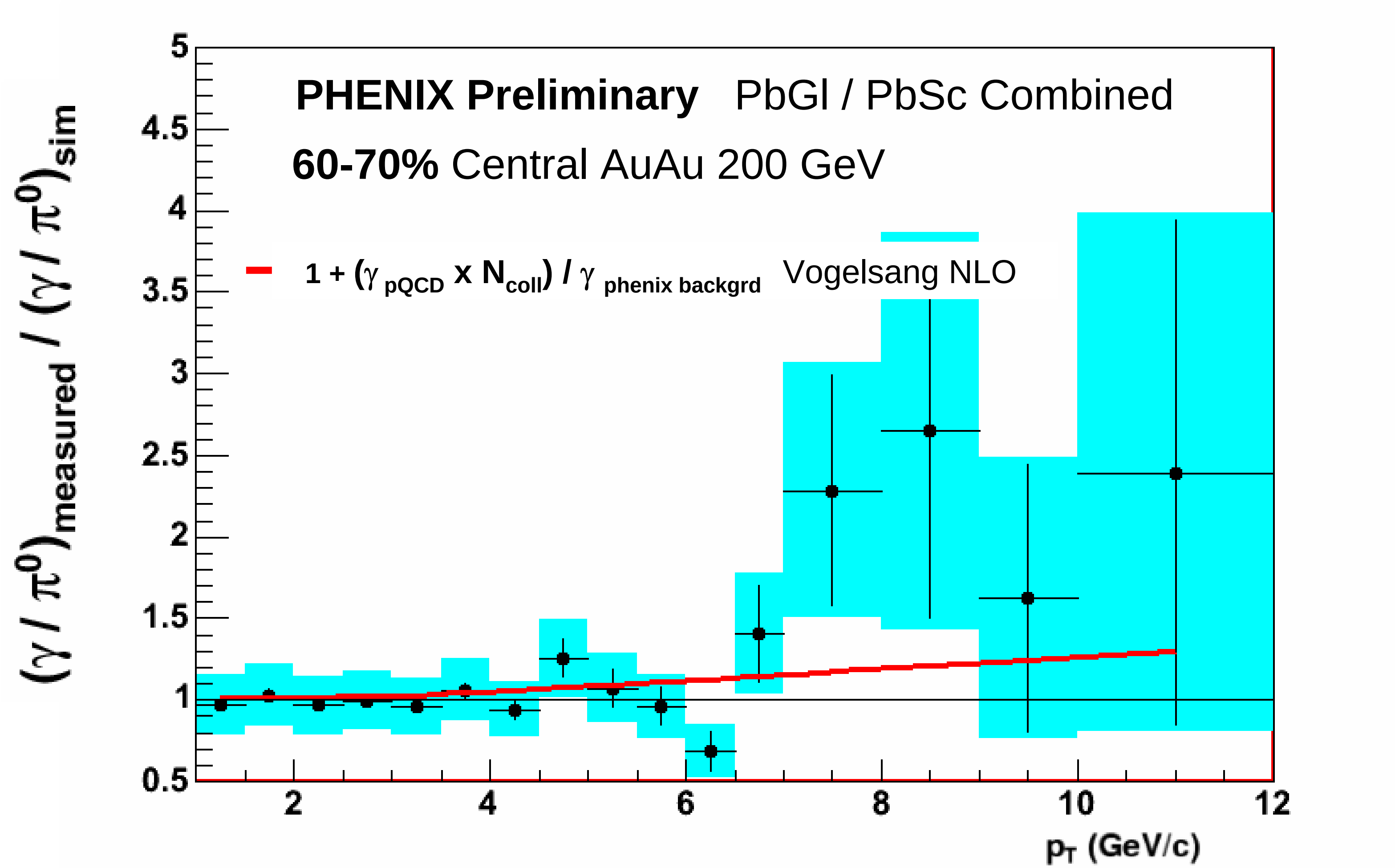

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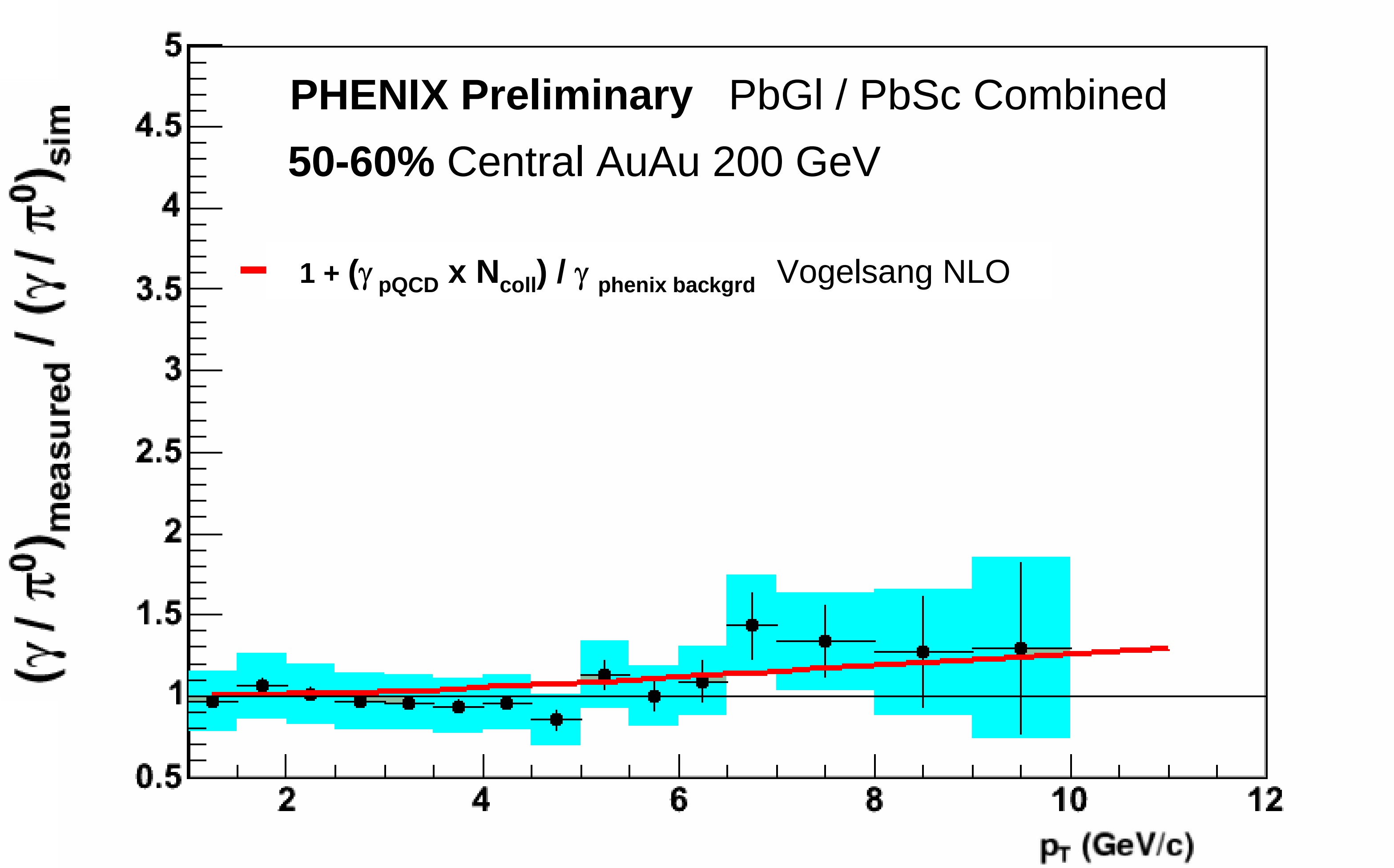

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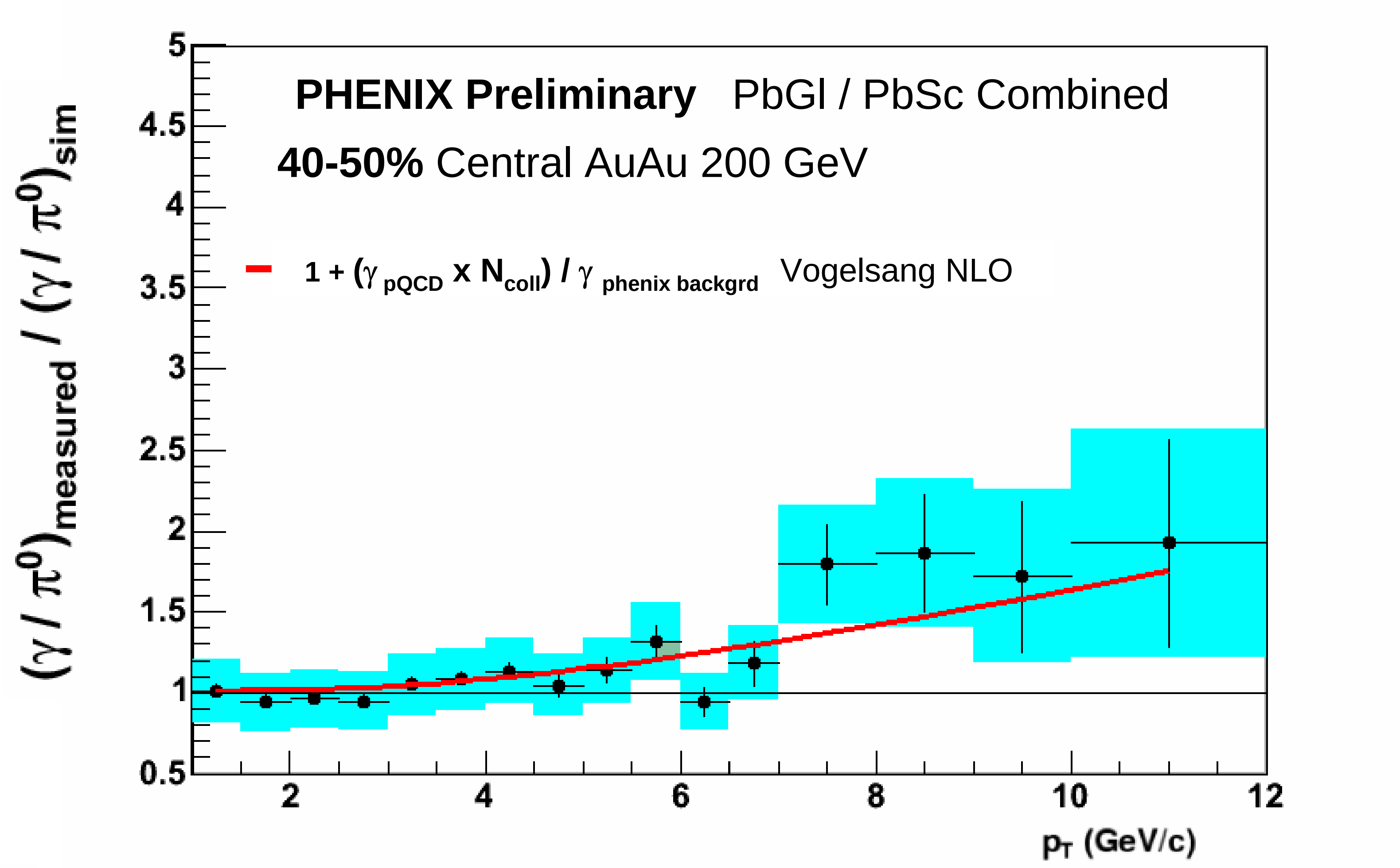

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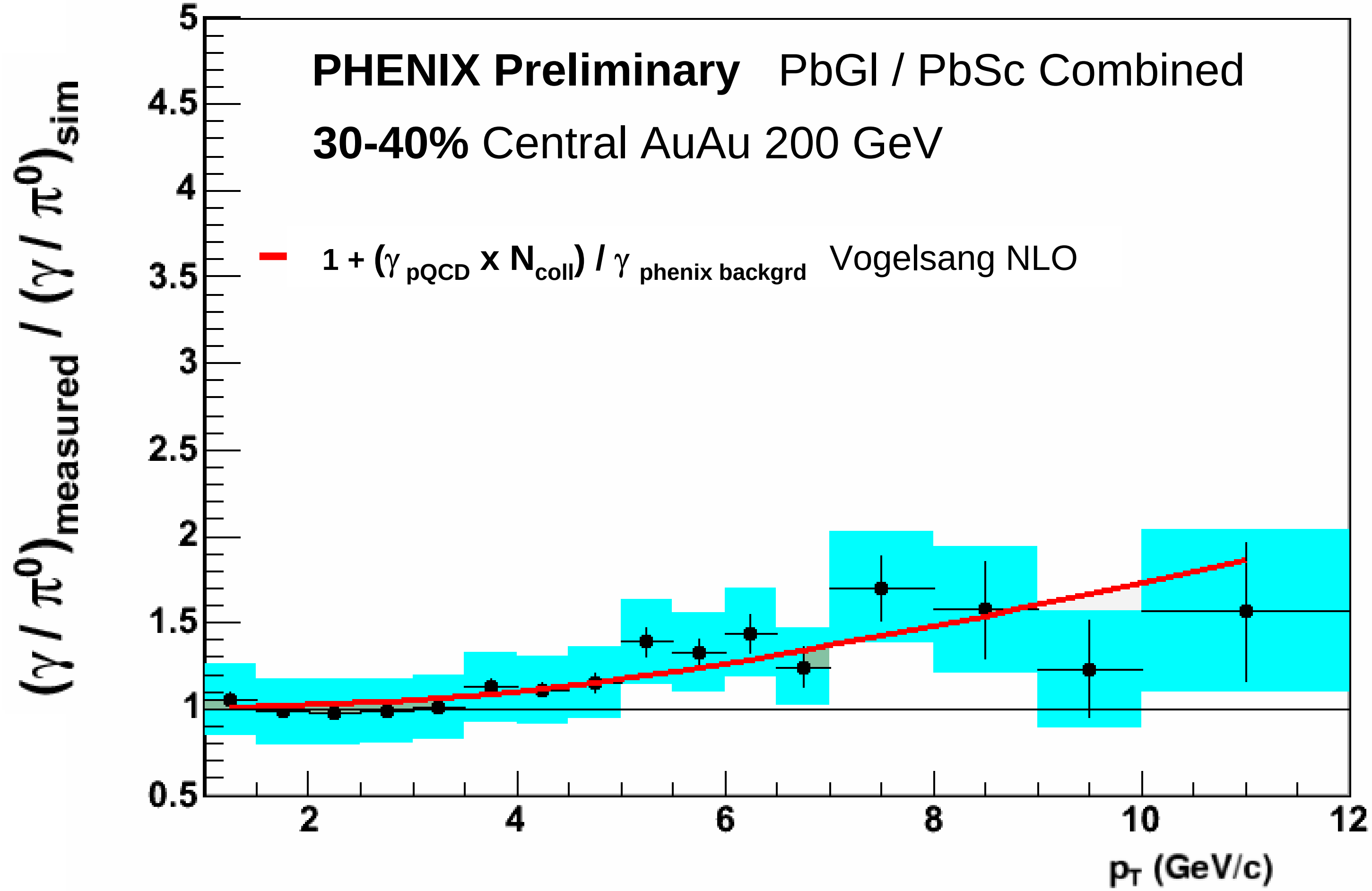

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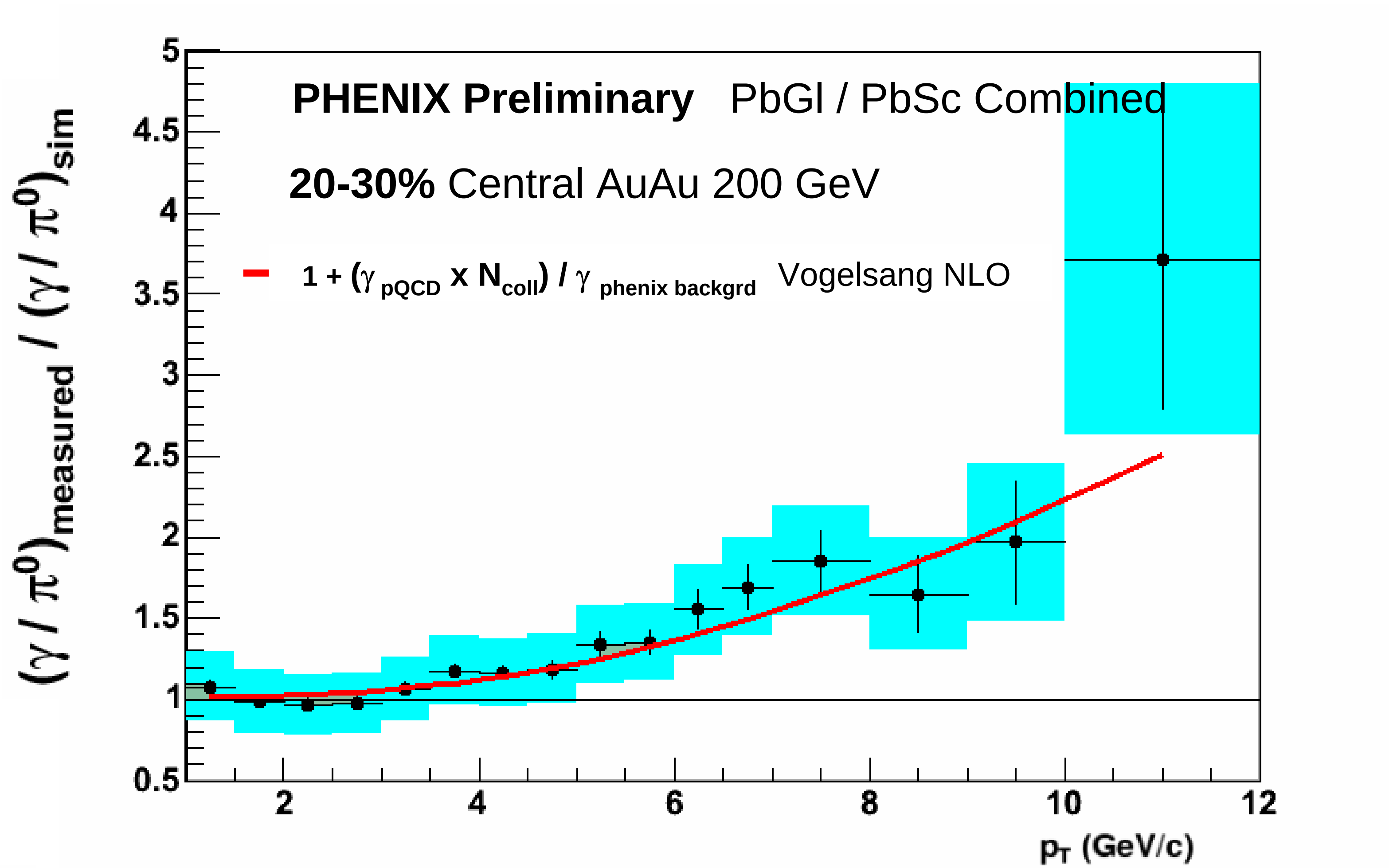

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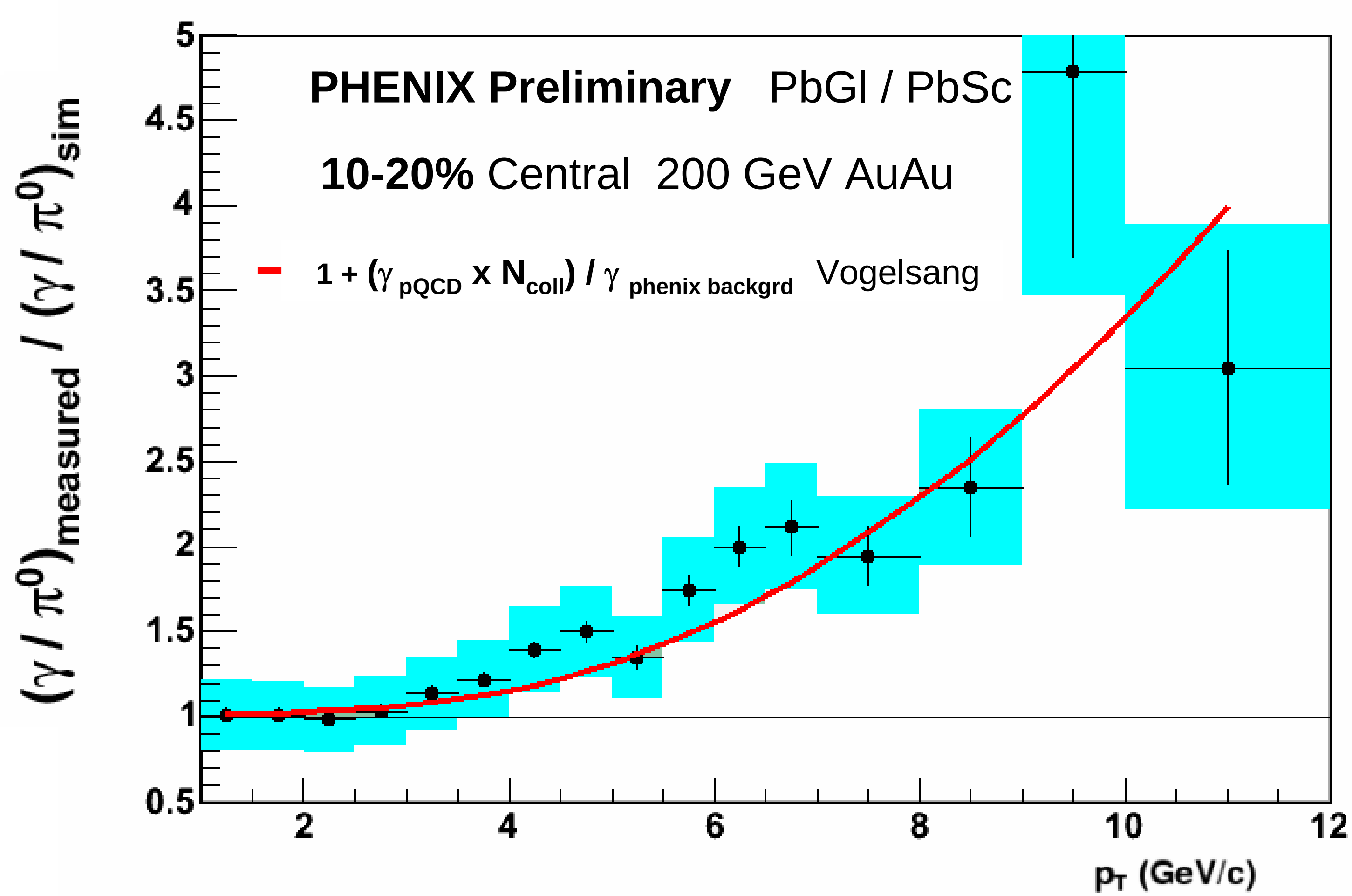
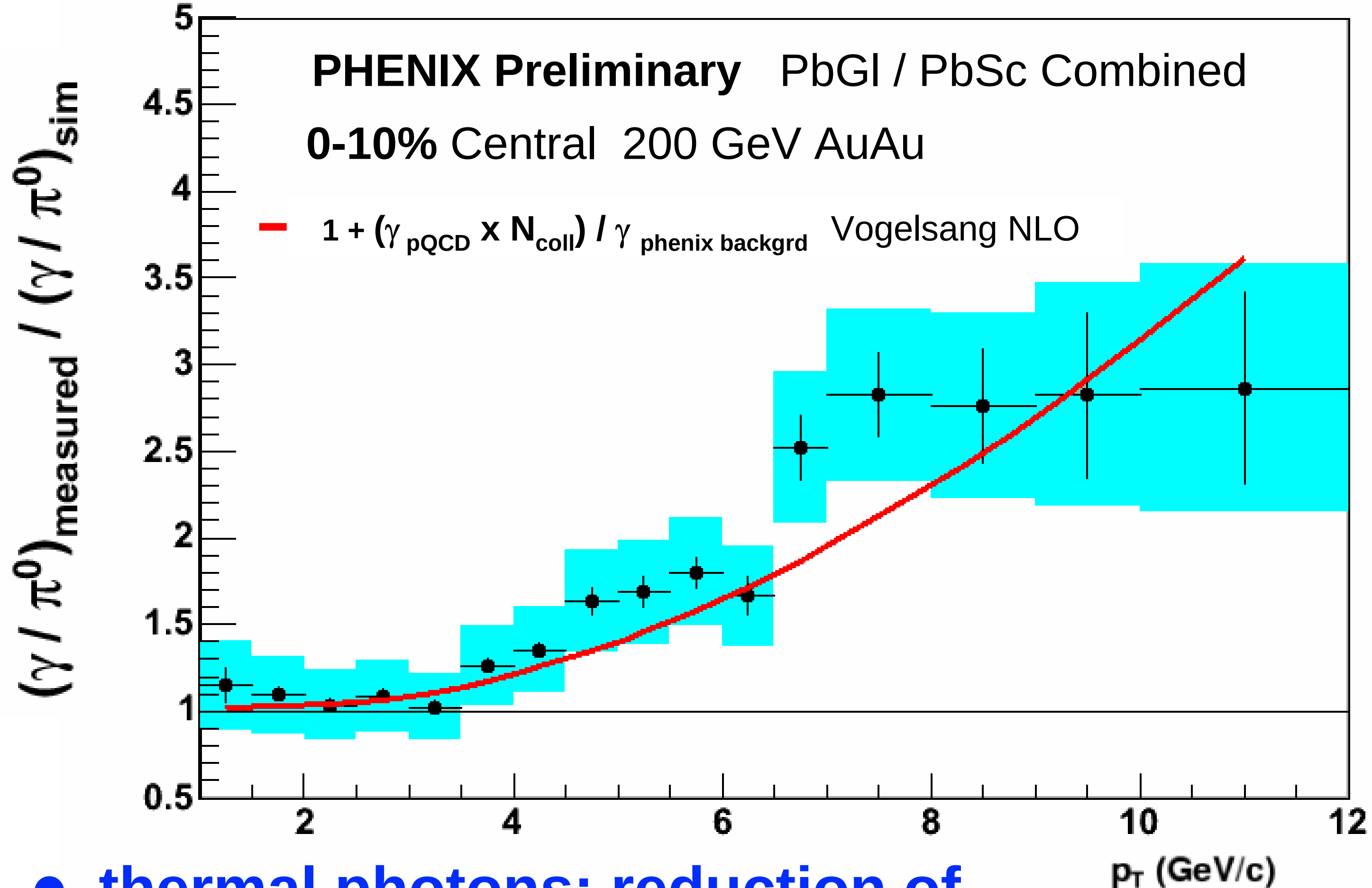


Direct photons: centrality dependence

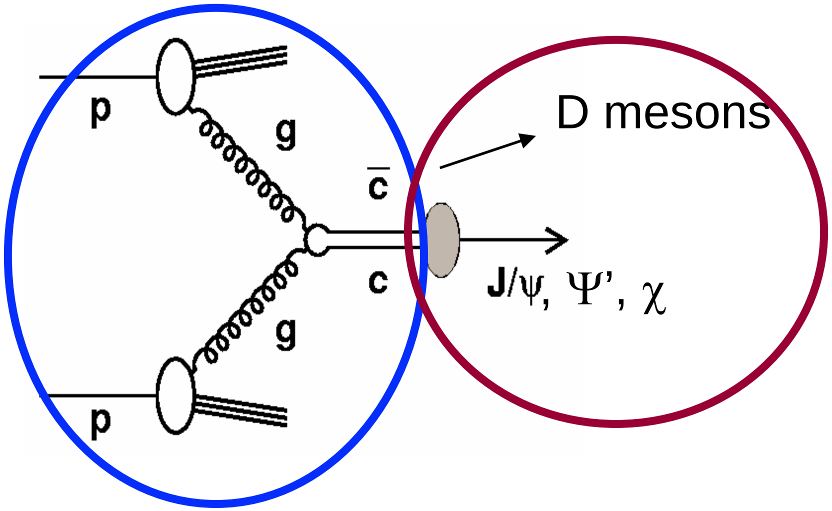
- direct photons are not inhibited by hot/dense medium and shine through consistent with pQCD!



- thermal photons: reduction of systematic uncertainties is essential!!

Another hard probe: heavy flavor production

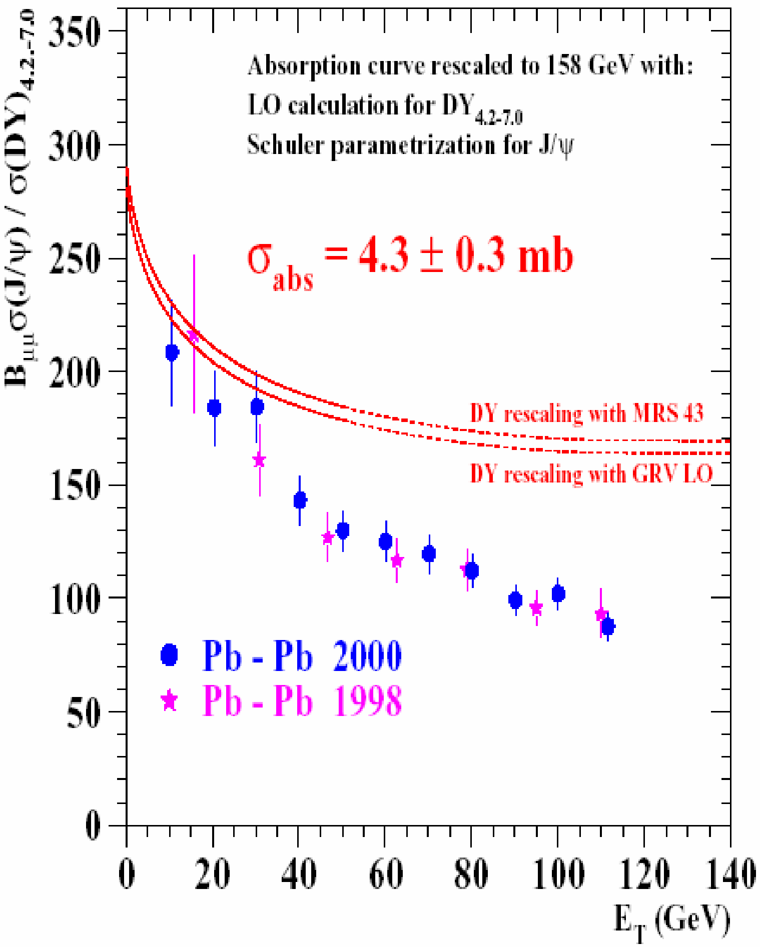
- a (very) complex playground
  - cc production in hard scattering
    - sensitive to PDF
  - propagation
  - hadronization
- medium modifications
  - modification of PDF in nuclei (shadowing, antishadowing)
  - multiple scattering $\Rightarrow p_T$ broadening
  - initial state parton energy loss
  - charmonia:
    - “normal” nuclear absorption
    - “anomalous” suppression (“Debye” screening)
    - enhancement via “coalescence”?
  - additional “thermal” production?
  - energy loss by induced gluon radiation? “Dead-cone effect”?
  - ….



- how to disentangle this?
- measure charmonium states and open charm
  - in pp, pA, AA collisions
  - in various kinematic regions
  - at various energies
    - news from SPS
    - news from RHIC

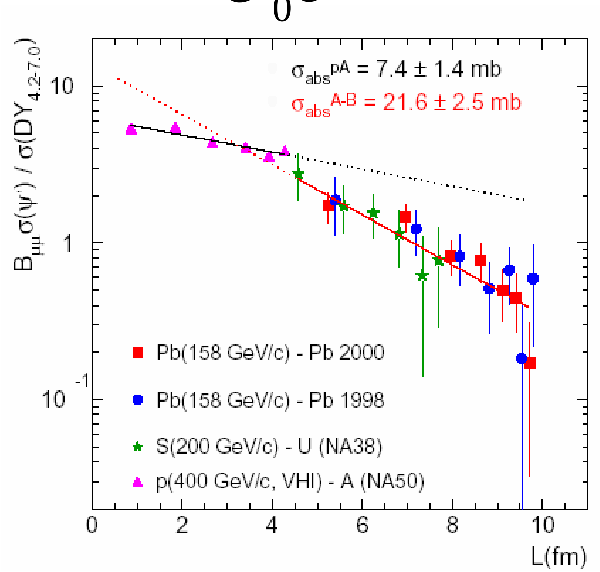
J/ψ suppression in PbPb at SPS

- updated analysis of J/ψ (and ψ’) absorption in cold nuclear matter (NA50 pA run at 400 GeV (2000) + combined fit of ALL data sets) (NA50 talk by G. Borges)
- $\sigma^{J/\Psi}_{abs} = 4.3 \pm 0.3$ mb
- J/ψ suppression with respect to this expected “normal” nuclear absorption (relative to Drell-Yan): a familiar pattern
- what is new?
  - ψ’ measurement
  - challenging because of
    - small dimuon cross section
    - small S/B
    - large suppression (weaker bound state than J/ψ)

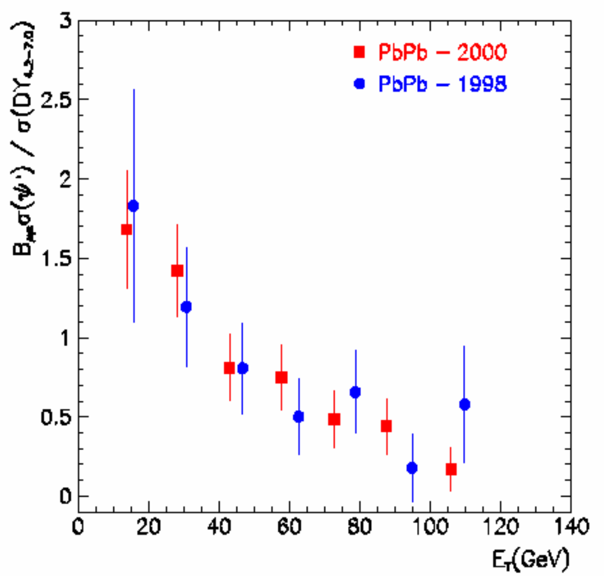


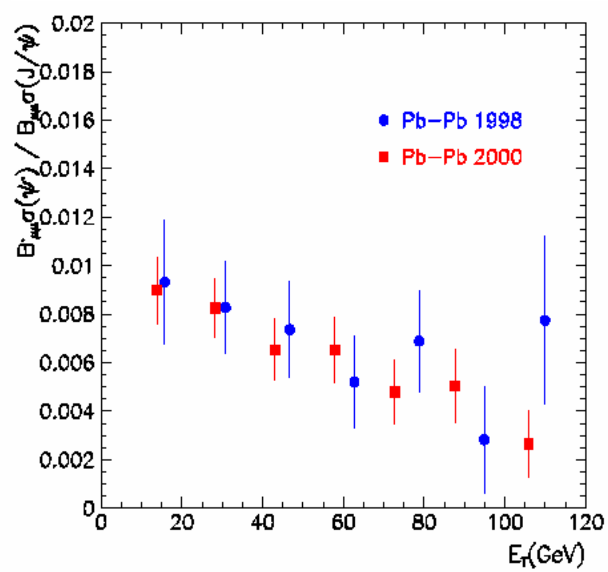
ψ' suppression at SPS

$$\sigma_0 e^{-<\rho L>\sigma_{abs}}$$



- NA50 talk by H. Santos
- ψ' absorption in pA is stronger than J/ψ absorption
- significantly stronger absorption in AA going from peripheral to central collisions
- no apparent difference in absorption pattern between SU and PbPb collisions
- ψ' suppression relative to Drell-Yan and J/ψ increases with centrality in PbPb collisions



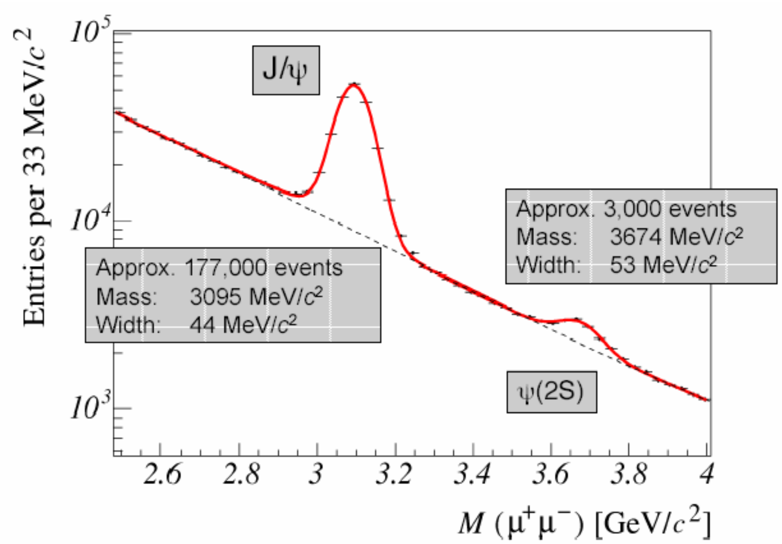


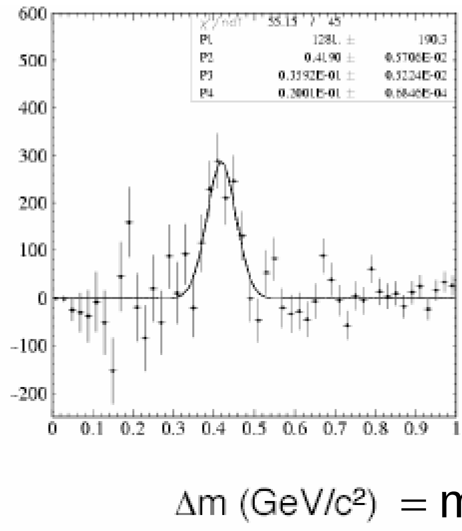
Open questions at SPS

- what fraction of J/ψ comes from χ_c feed down ($\chi_c \to J/\psi + \gamma$)?
- what is the nuclear dependence of χ_c production/absorption in pA?
- is open charm enhanced in AA?

will be answered by NA60

- χ_c measurement at HERA-B (huge statistics dilepton data sample from pA collisions at $\sqrt{s_{NN}}$ = 42 GeV)
(HERA-B talks by J. Spengler, A. Gorisek)





$= m_\chi - m_{J/\psi}$

$\chi_c/J/\psi = 0.21 \pm 0.05$ from 15 % of available statistics

J/ψ suppression / enhancement at RHIC?

- PHENIX: preparing the case

Year	Ions	$\sqrt{s_{NN}}$	Detectors	J/Ψ
2000	Au-Au	130 GeV	Central (electrons)	0
2001 2002	Au-Au p-p	200 GeV 200 GeV	Central + 1 muon arm	13 + 0 46 + 66
2002 2003	d-Au p-p	200 GeV 200 GeV	Central + 2 muon arms	300+800+600 100+300+120
2004	Au-Au	200 GeV	! ready !	~400+2x1600 ?

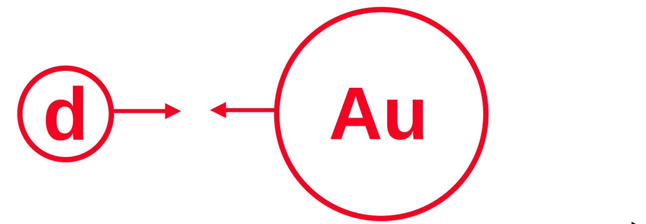
QM2002
first observation

QM2004
first sizeable pp & dAu samples

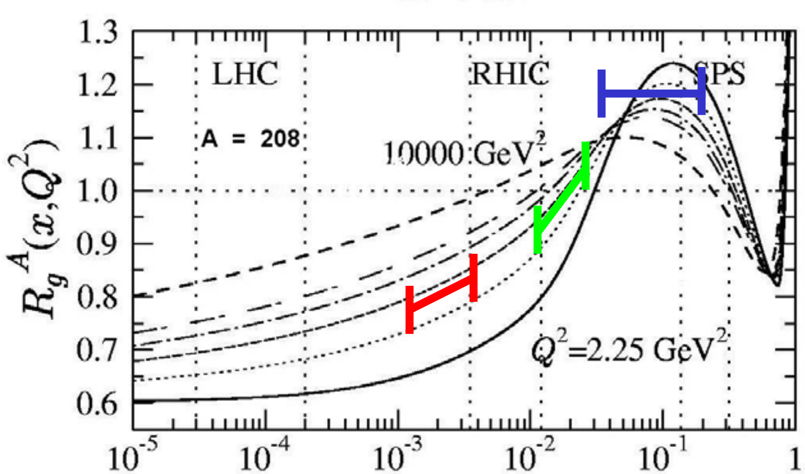
study J/ψ modifications in cold nuclear medium

J/ψ in dAu collisions at RHIC

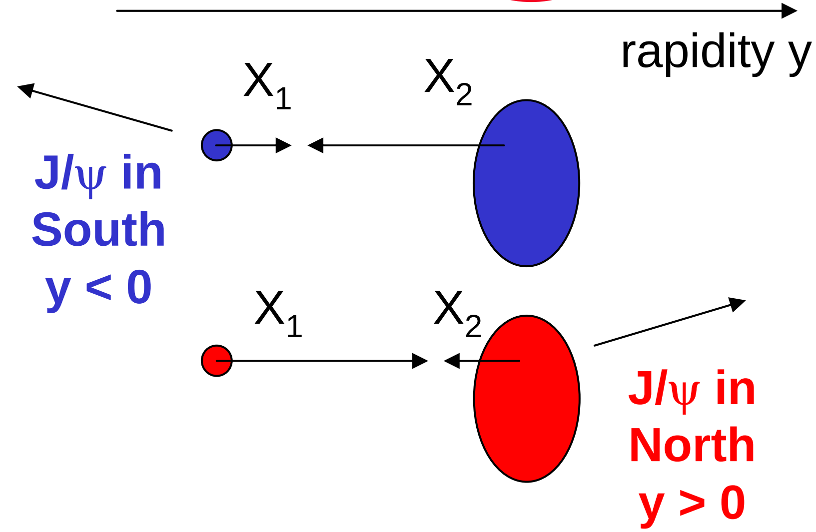
- **J/ψ produced by gluon fusion**
- **sensitivity to gluon pdf**
- **3 rapidity ranges in PHENIX probe different momentum fraction of Au partons**
  - **South (y < -1.2) : large X_2 (in gold)**
  - **Central (y ~ 0) : intermediate**
  - **North (y > 1.2) : small X_2 (in gold)**



Predicted Gluon Shadowing in d+Au

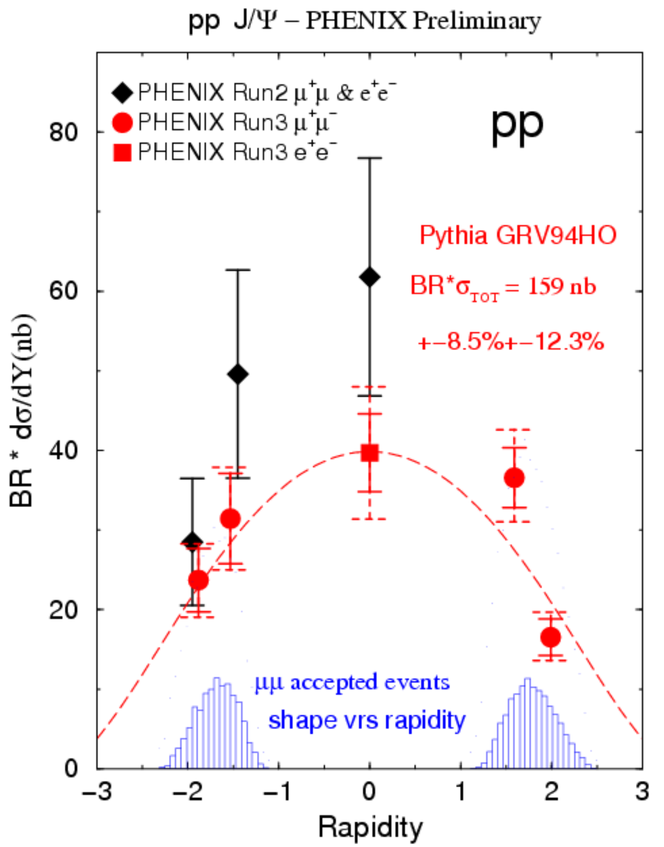


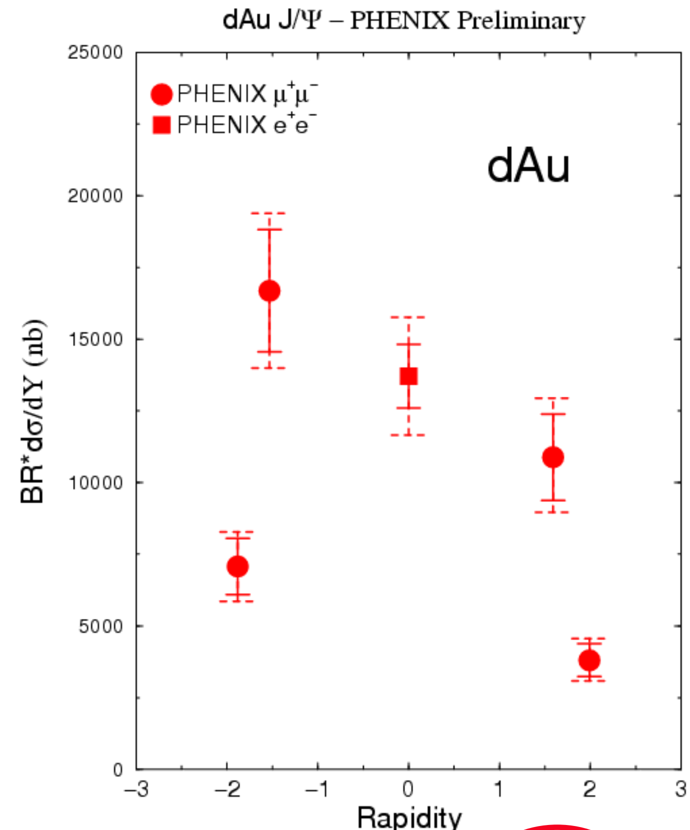
From Eskola, Kolhinen, Vogt
Nucl. Phys. A696 (2001) 729-746.



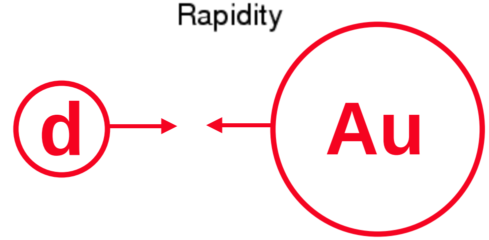
J/ψ in pp and dAu collisions at RHIC

- rapidity distributions: improved pp / first dAu measurements

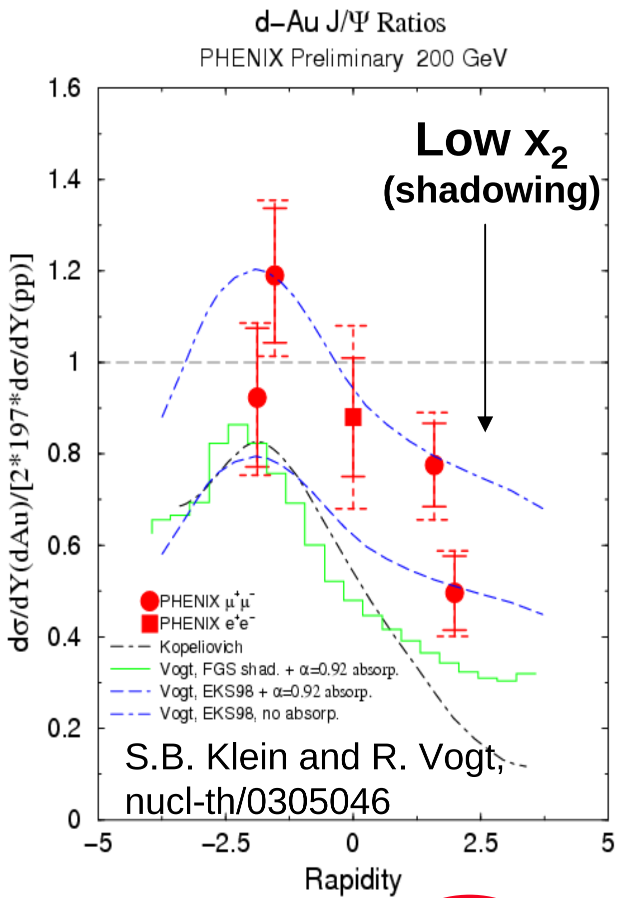


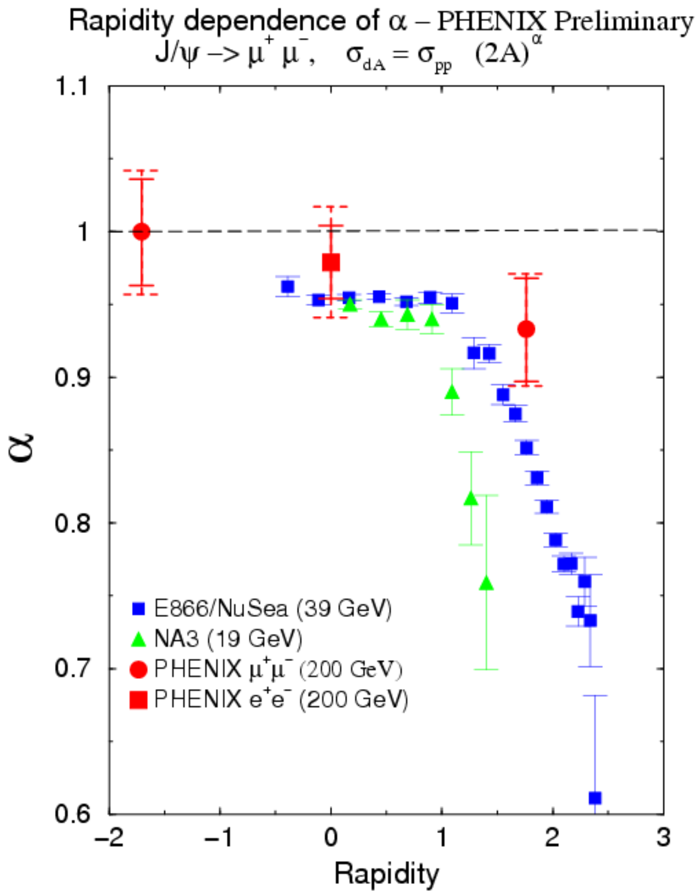


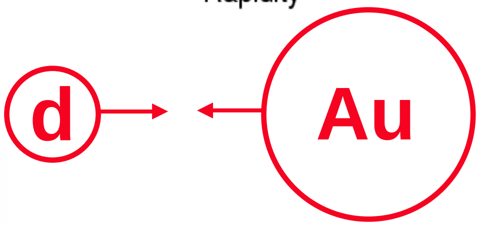
- PHENIX talk by R. G. de Cassagnac,
  posters: J.M. Burward-Hoy, S. Kametani,
  D. Kim, D. Silvermyr



J/ψ dAu/pp versus rapidity at RHIC

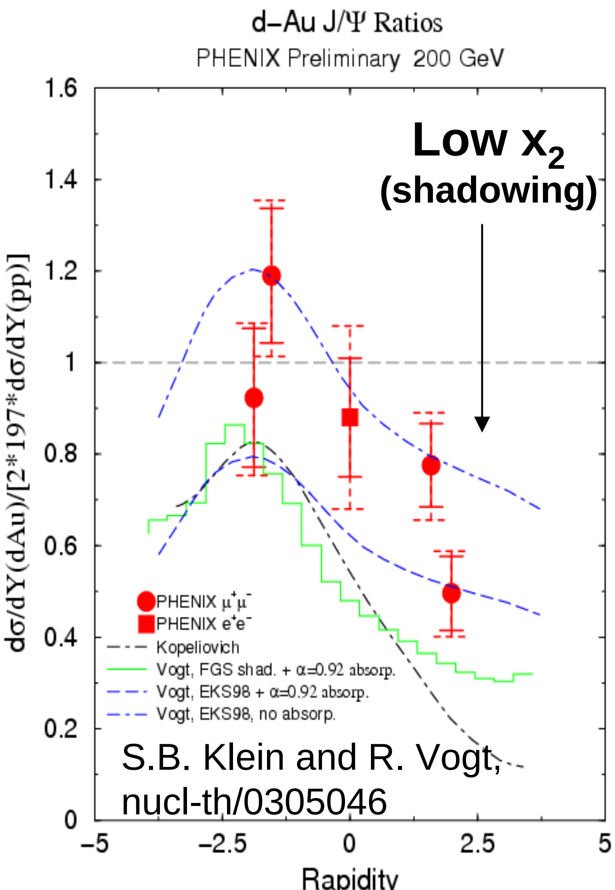


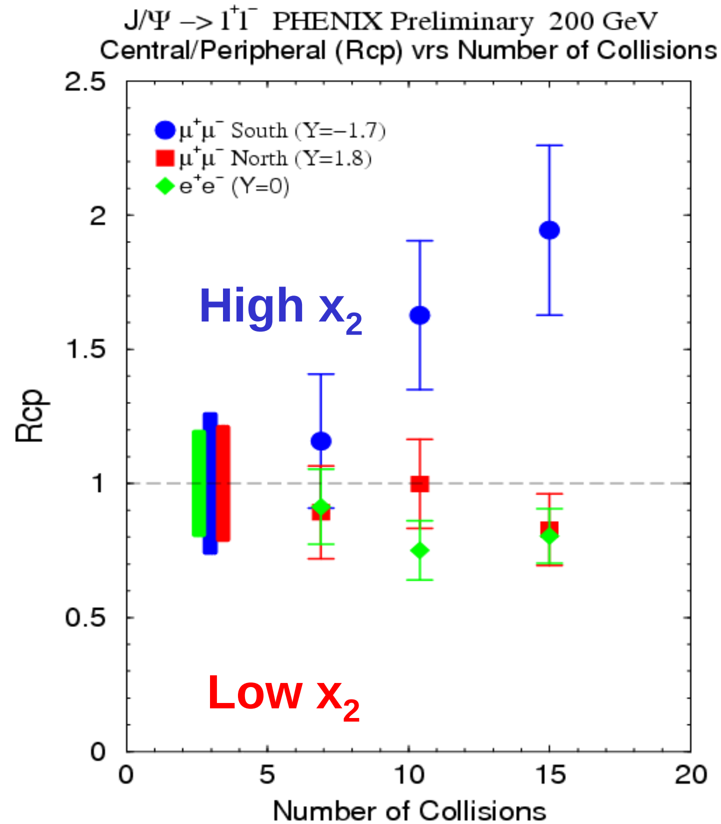


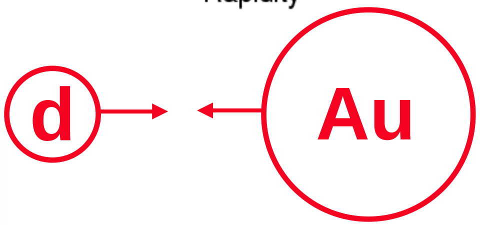


- indication for (weak) shadowing and absorption
- centrality dependence studied as well!
- more statistics desirable to disentangle nuclear effects (and distinguish models)

J/ψ dAu/pp versus rapidity at RHIC







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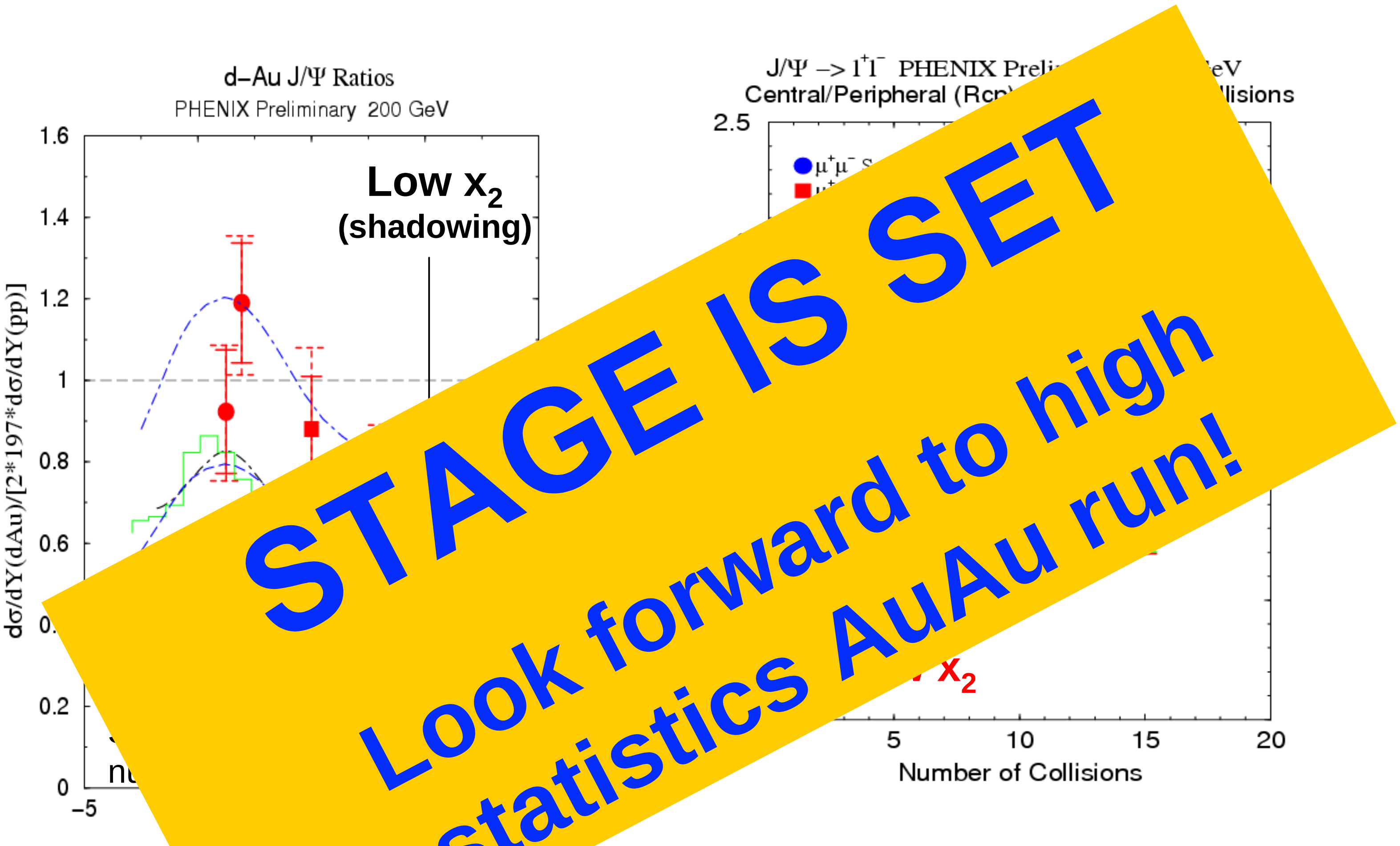

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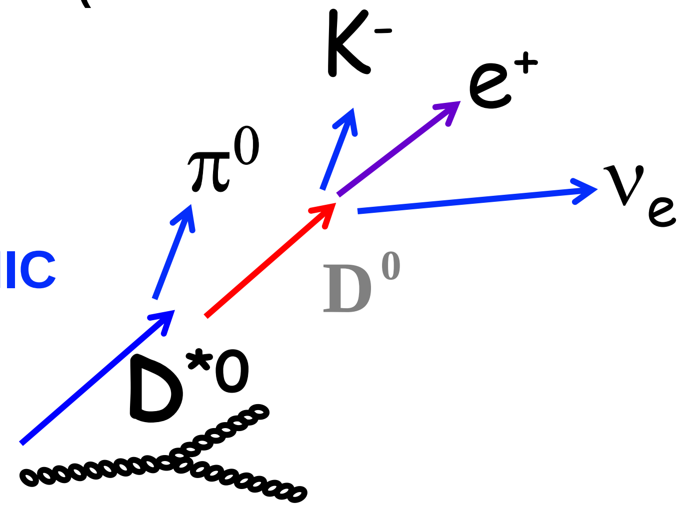
Open charm: reference and probe

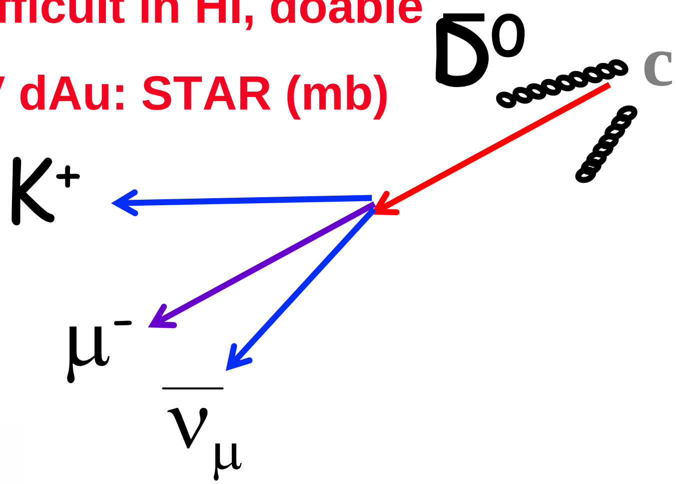
- physics motivation for open charm measurements
  - reference for J/ψ suppression / enhancement
  - production mainly via gluon fusion ⇒ interesting probe itself
    - sensitive to gluon structure function (and nuclear modification of this)
    - heavy quark energy loss
      - induced gluon radiation
      - “dead cone” effect
    - does charm flow?
- open charm measurements at RHIC



direct reconstruction

ideal, difficult in HI, doable

200 GeV dAu: STAR (mb)



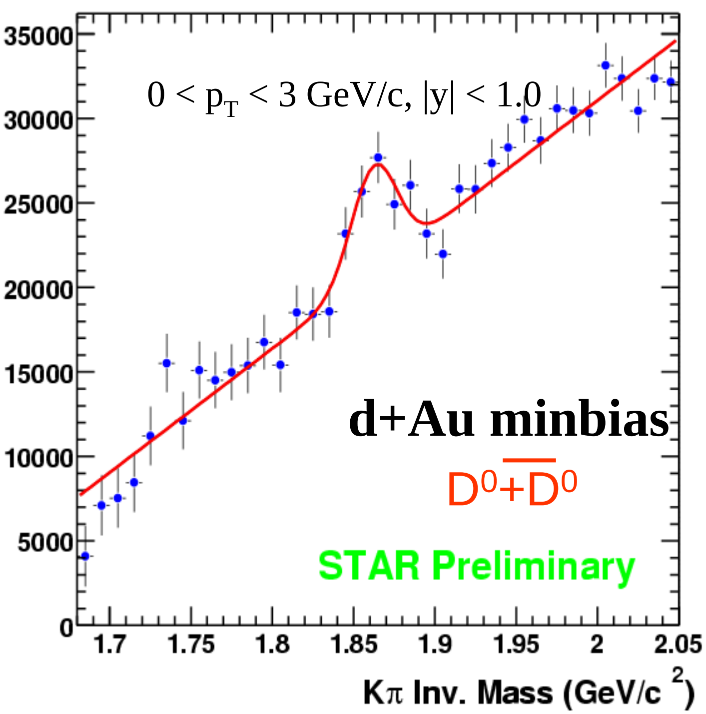
indirect measurements

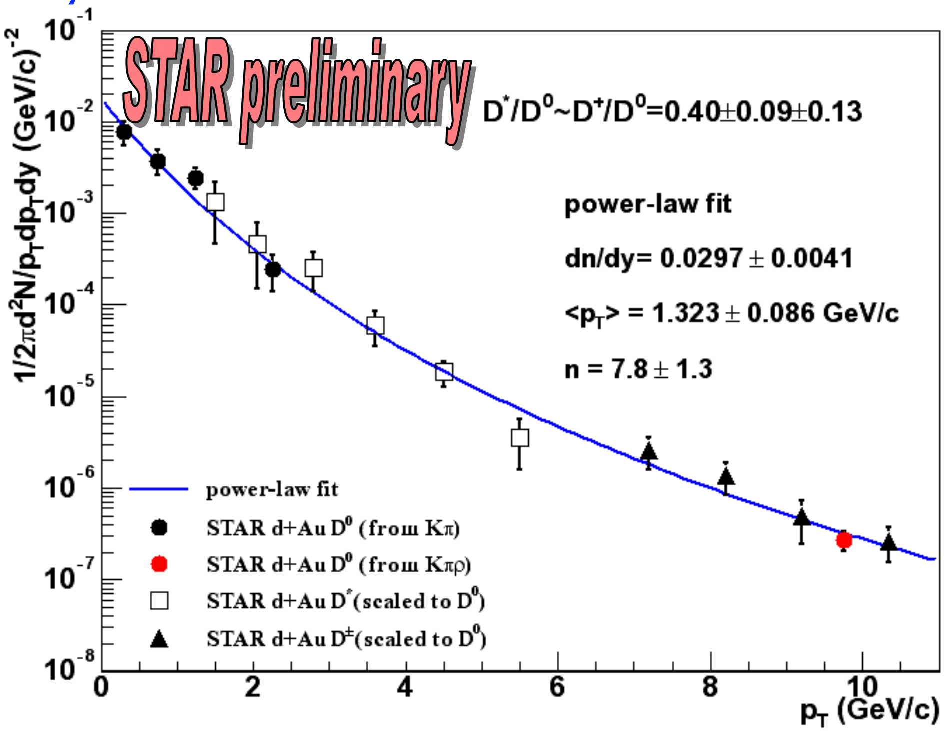
electrons from semileptonic decays

130 GeV AuAu: PHENIX (cent.)
200 GeV pp: PHENIX & STAR
200 GeV dAu: PHENIX (cent.) & STAR (mb)
200 GeV AuAu: PHENIX (cent)

First direct charm measurement (STAR)

- reconstruction of D mesons in minimum bias dAu collisions
  - D^0
  - $D^{\pm}$
  - D^*
- STAR talks by A. Tai, L. Ruan, A. Suaide

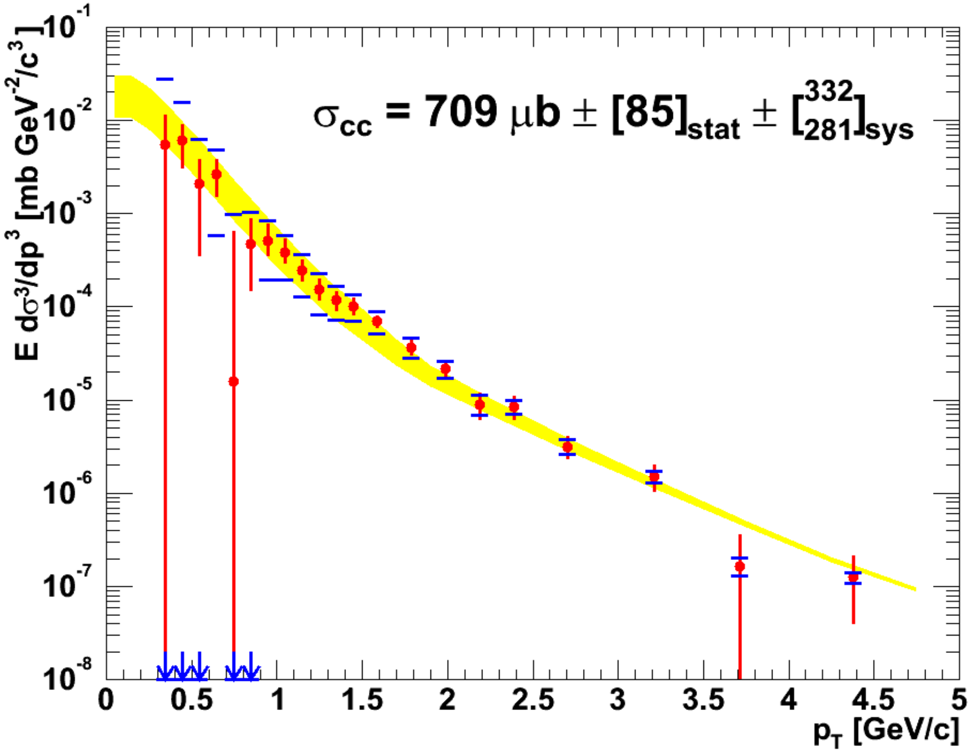


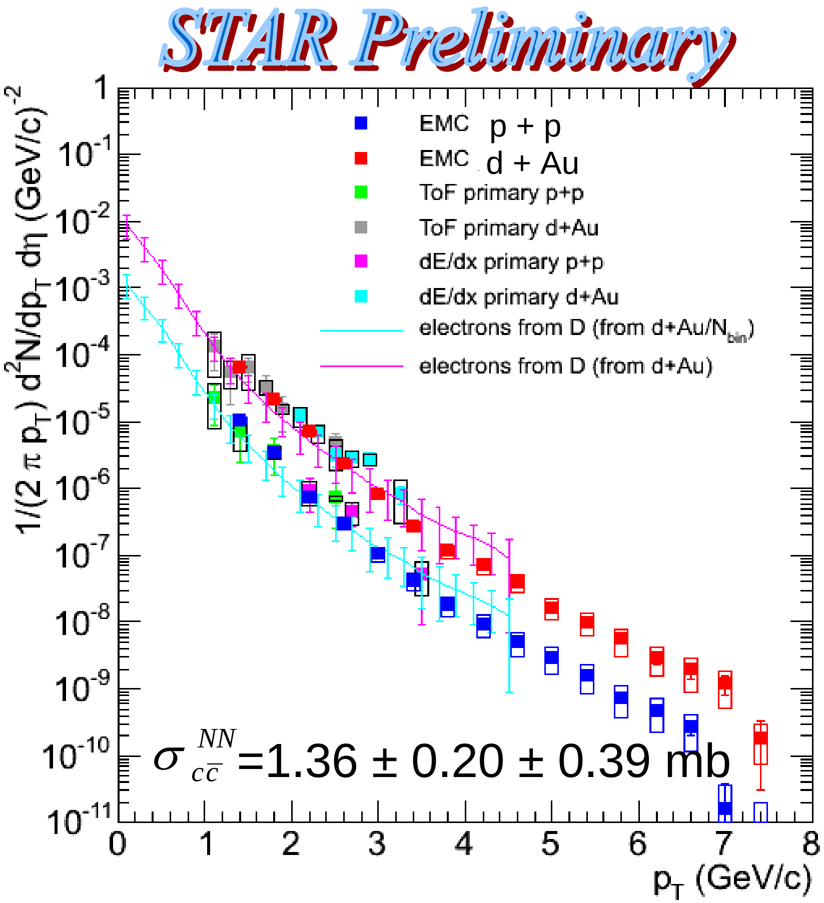


$\sigma^{NN}_{c\bar{c}}$ = 1.12 ± 0.20 ± 0.37 mb from D data
(1.36 ± 0.20 ± 0.39 mb with electrons)

Open charm in pp: the baseline

- two single electron measurements

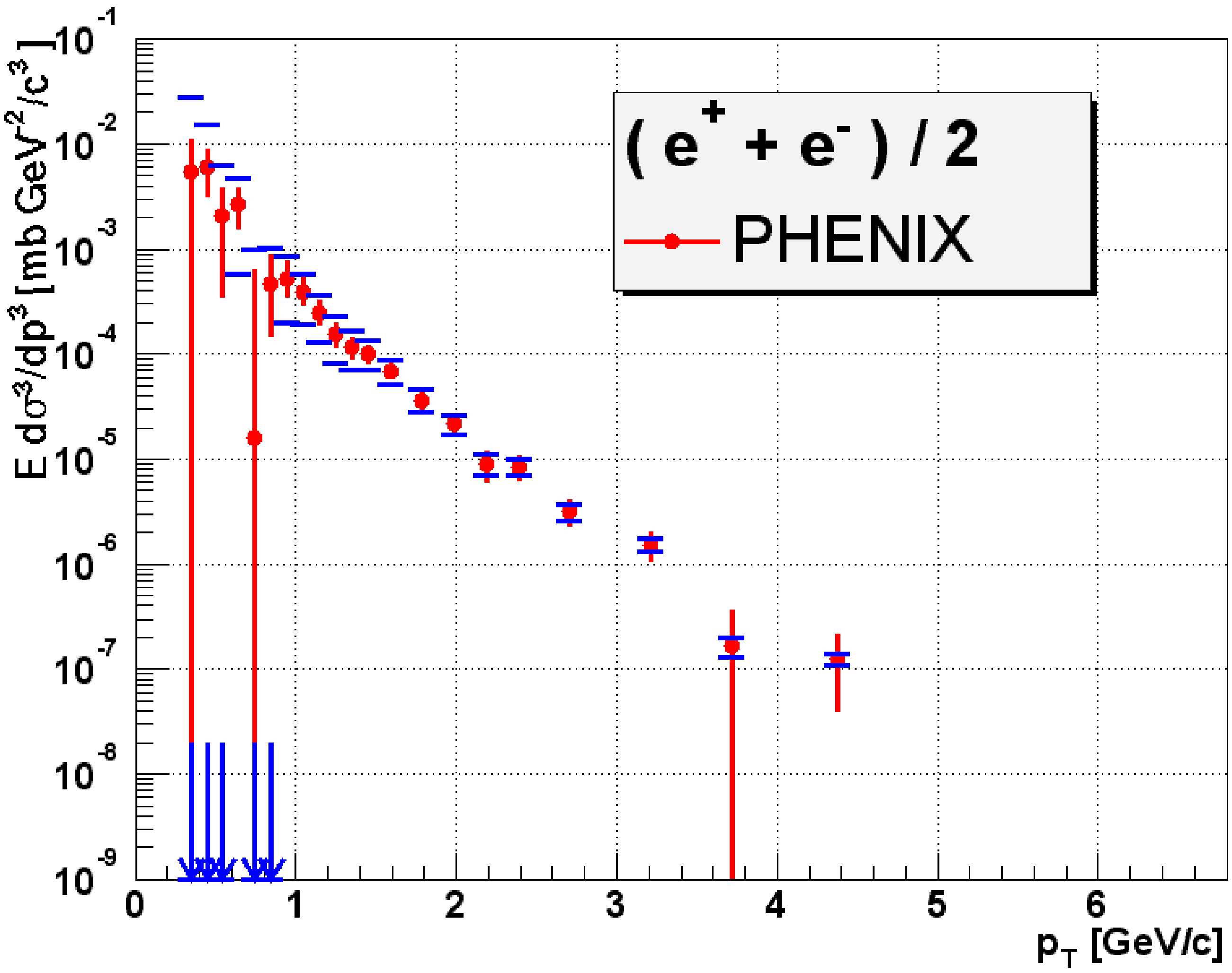




- three methods to subtract photonic background (PHENIX talk by S. Kelly)
- three methods to identify electrons (STAR talk by A. Suaide)

- charm cross sections (barely) agree!

Consistency between electron data sets



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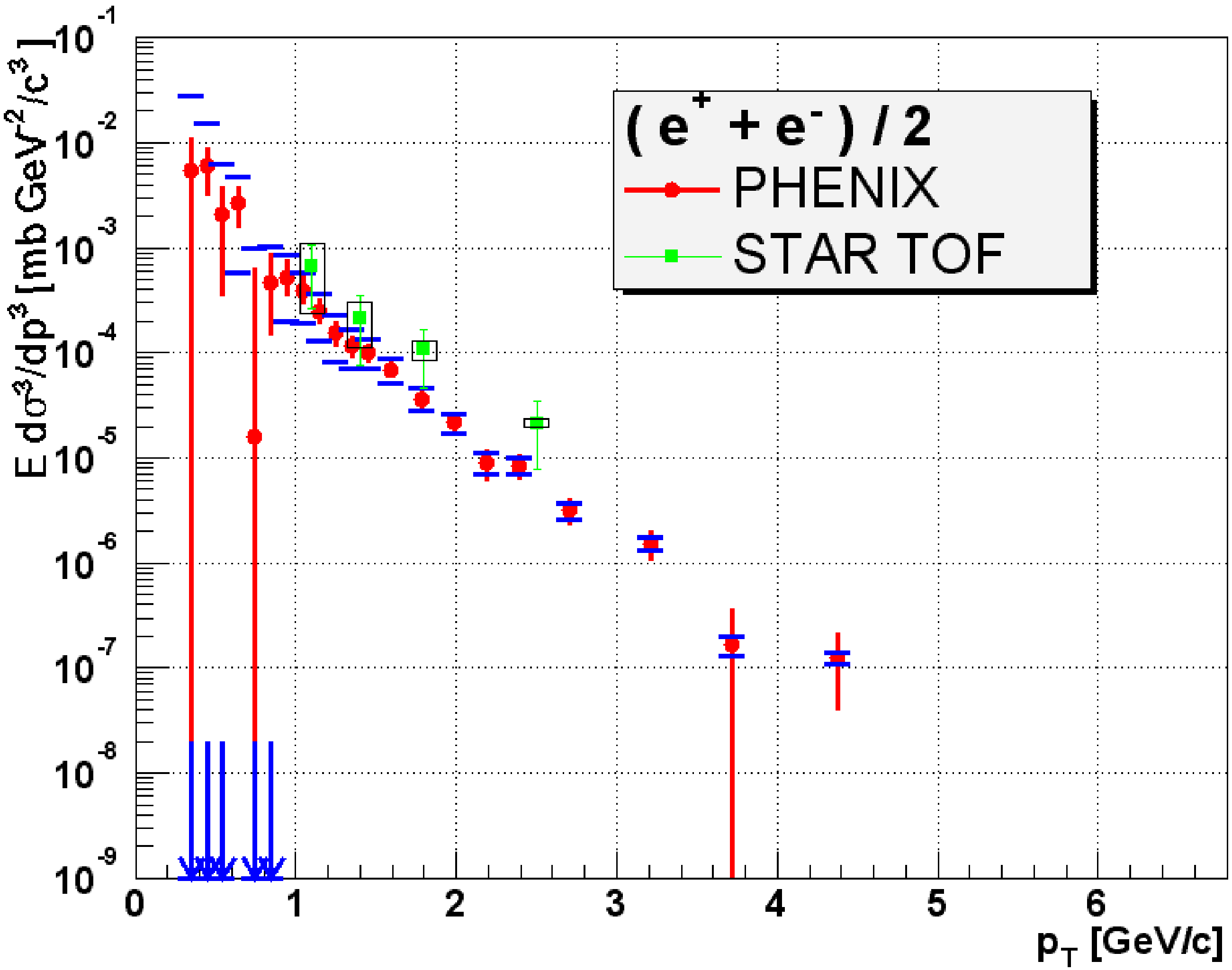

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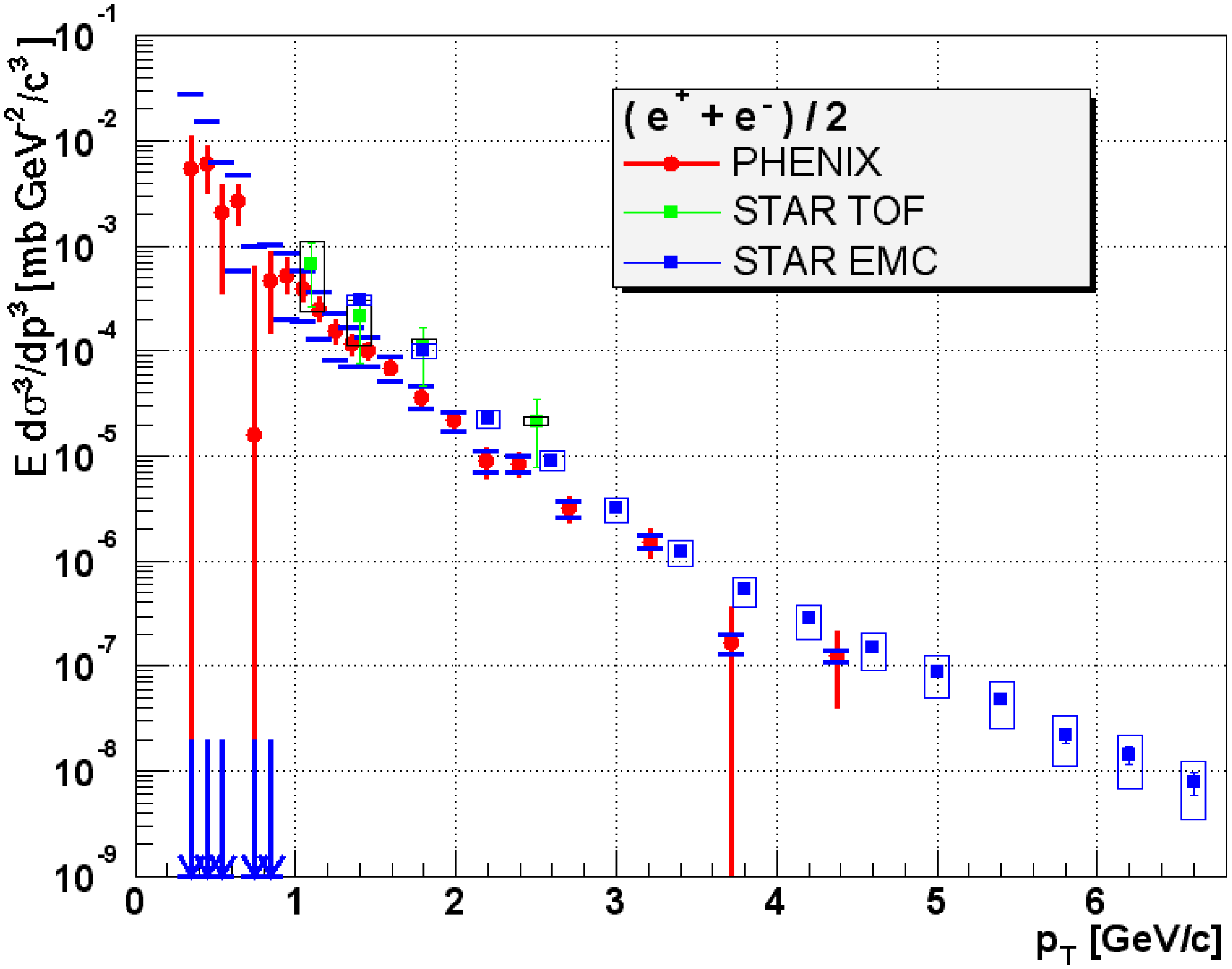

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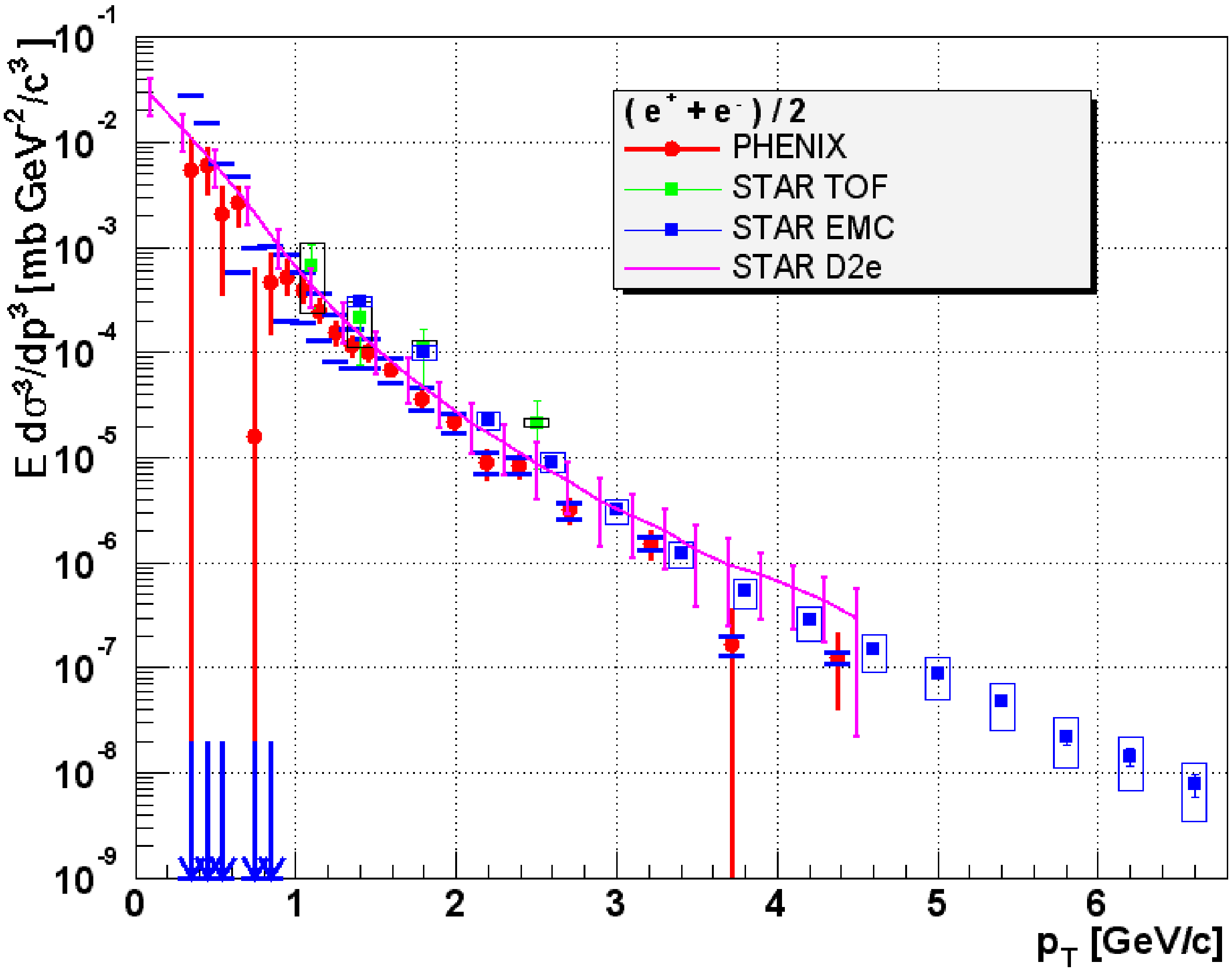

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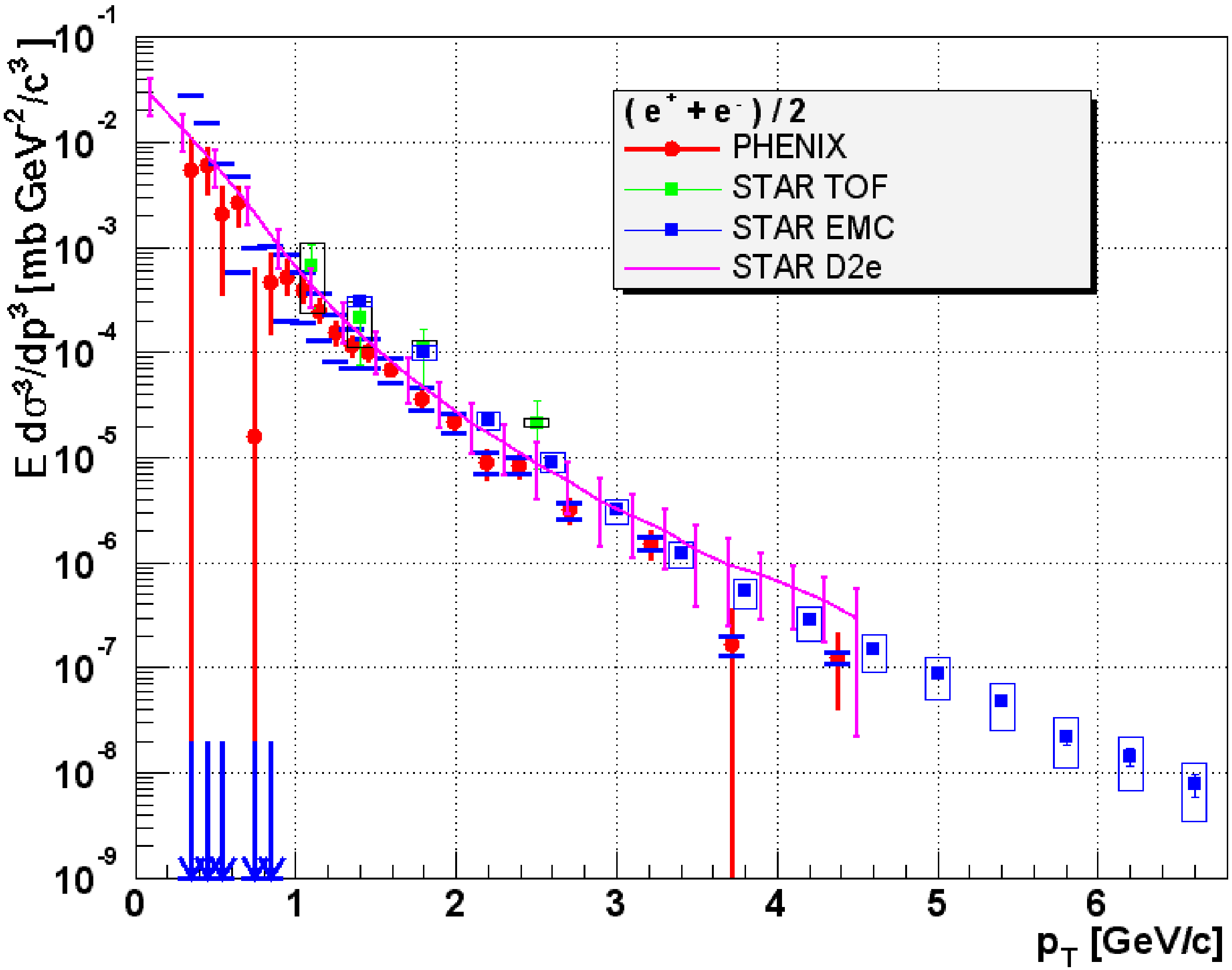
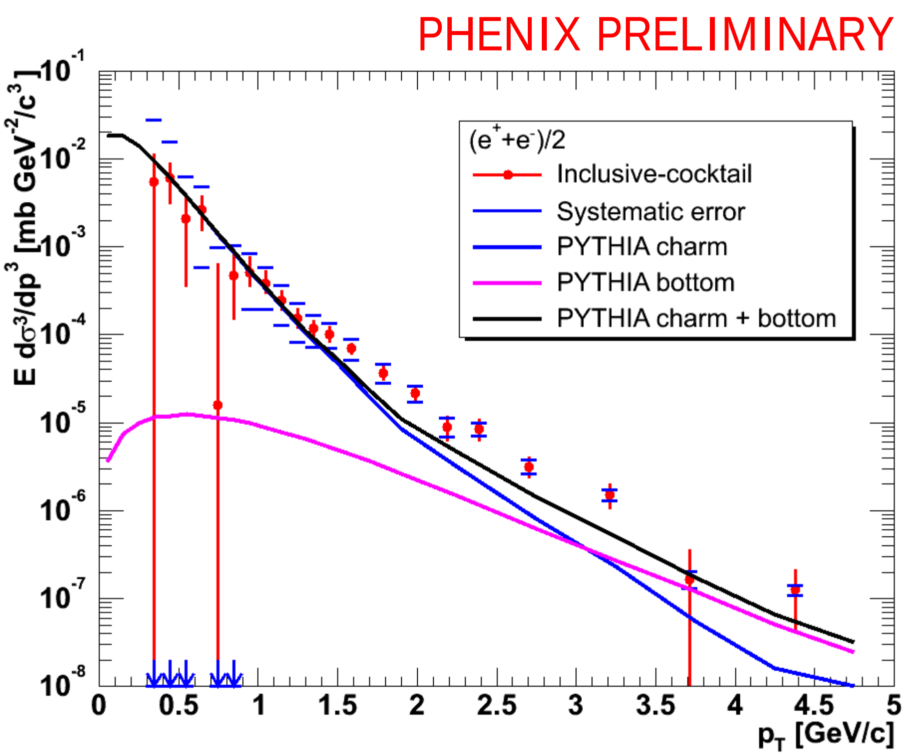
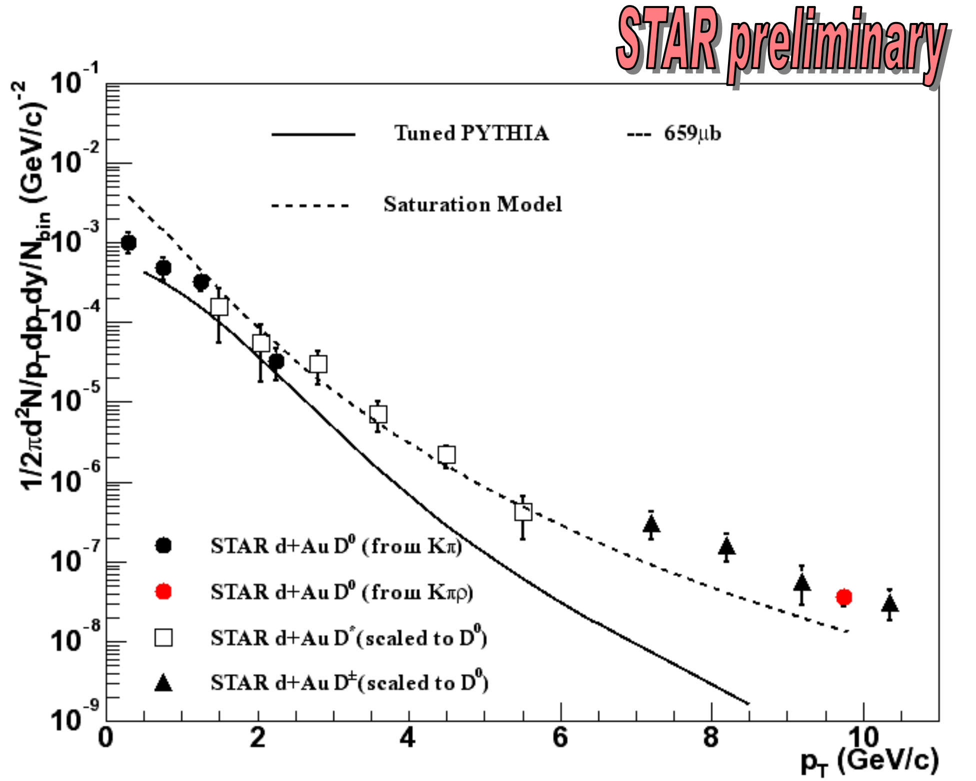


- STAR systematically (slightly) above PHENIX
- beware: error bars are meant to be taken seriously!

Does the PYTHIA extrapolation work?

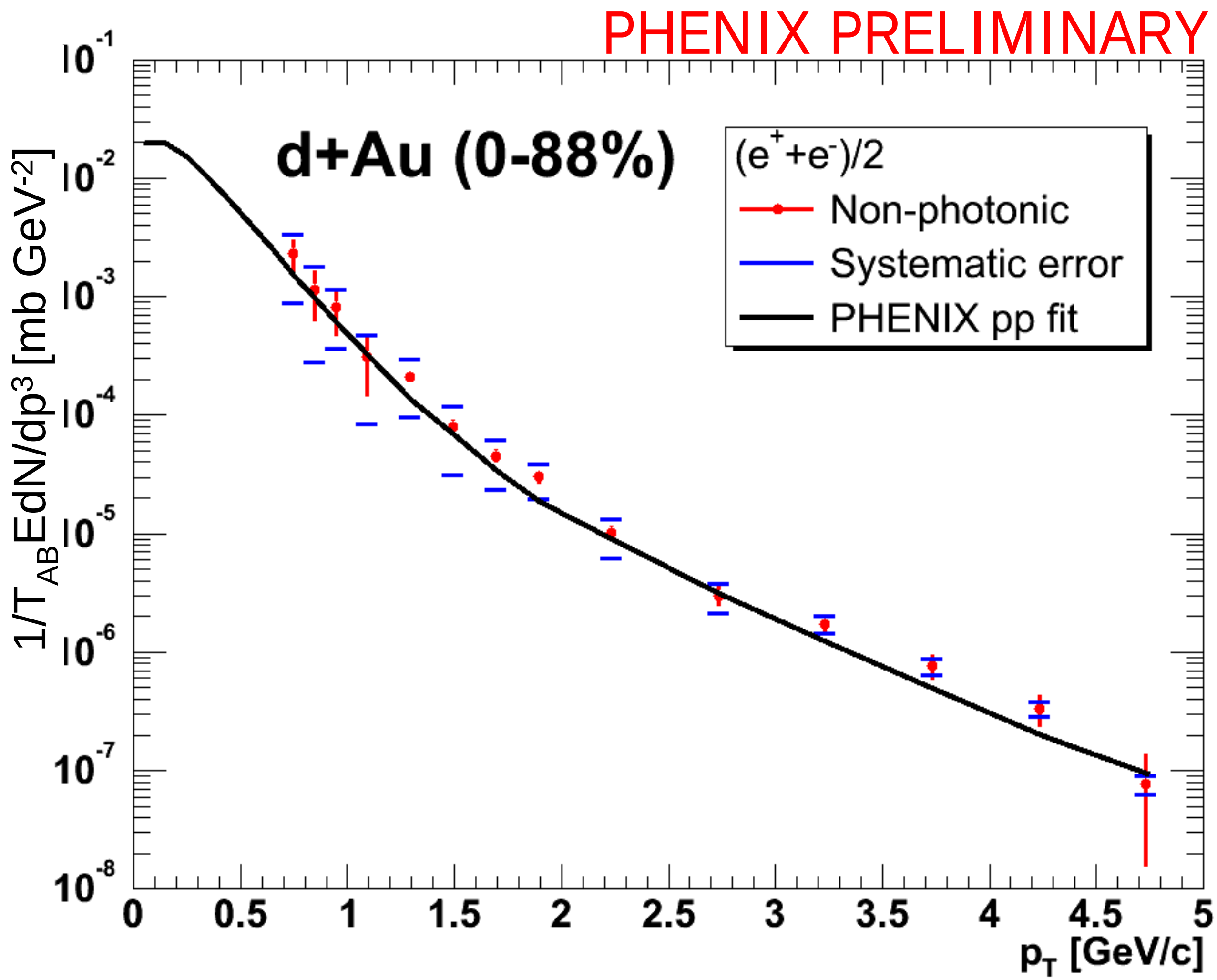
- PYTHIA tuned to available data ($\sqrt{s_{NN}}$ < 63 GeV) BEFORE RHIC results





- spectra are harder than PYTHIA extrapolation from low energies! (hard fragmentation function, charm quark recombination …?)
- PYTHIA can’t be used to extract bottom cross section!
- bottom measurement requires PRECICE D measurement first!

Centrality dependence in dAu (PHENIX)



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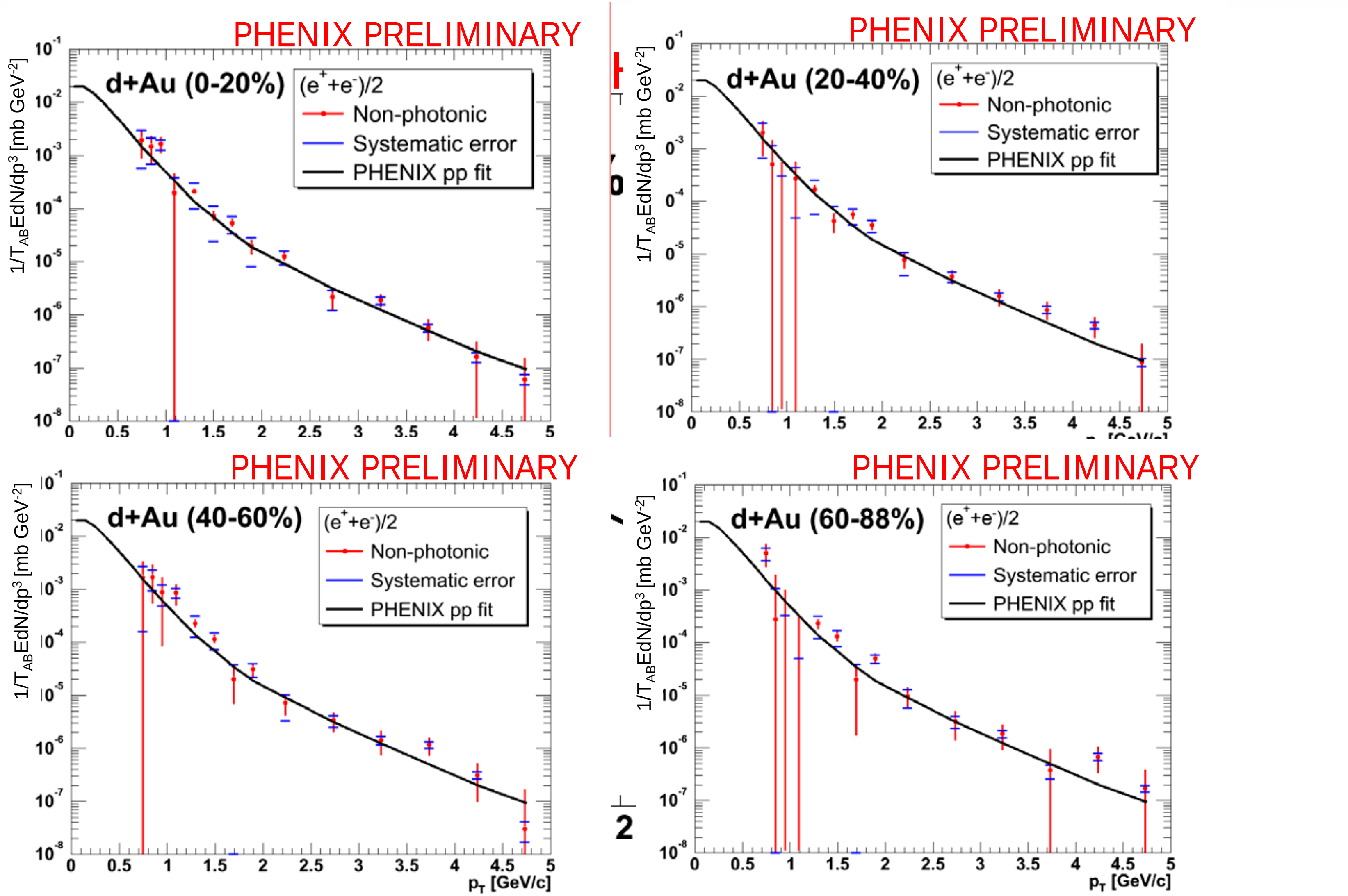

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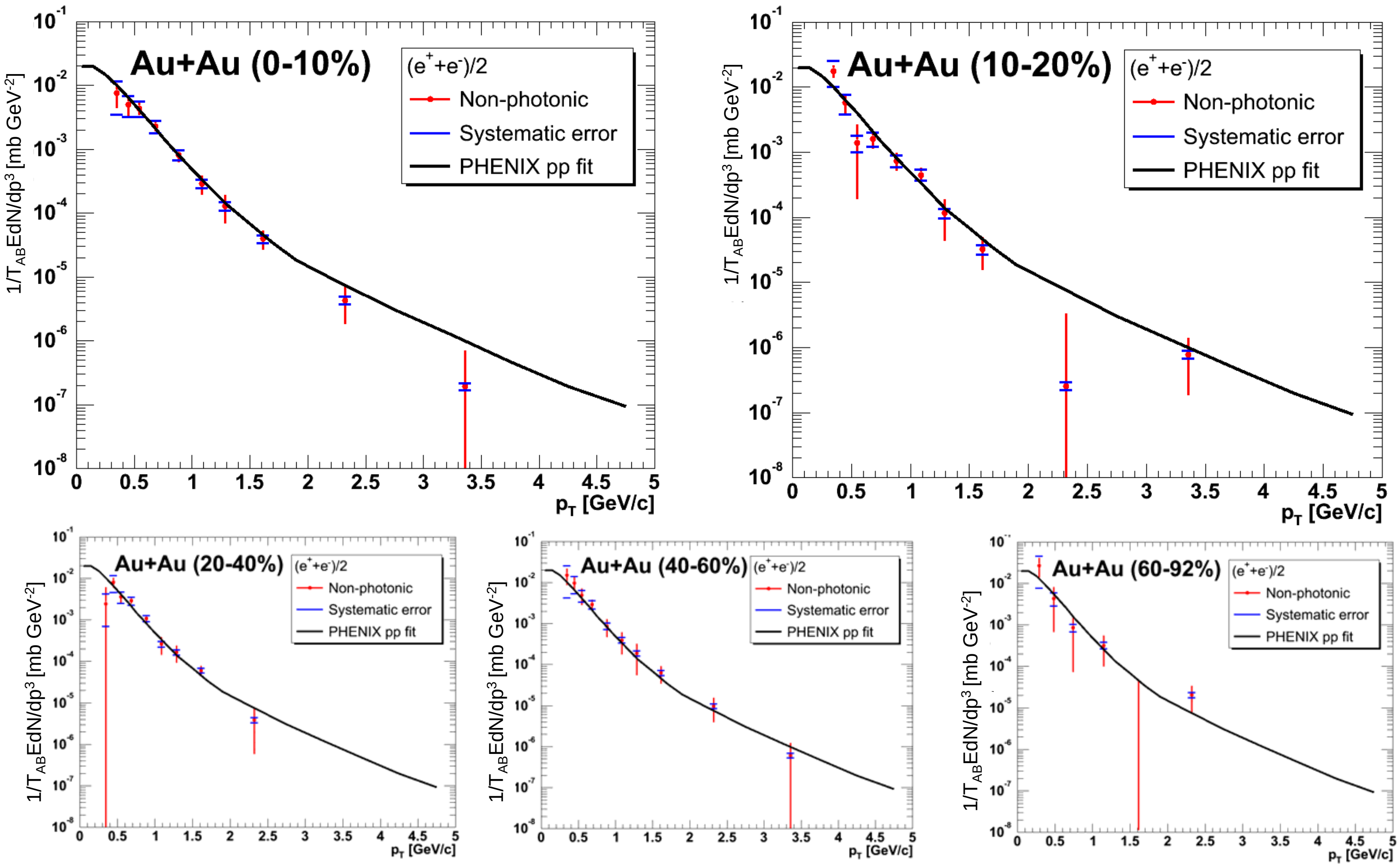
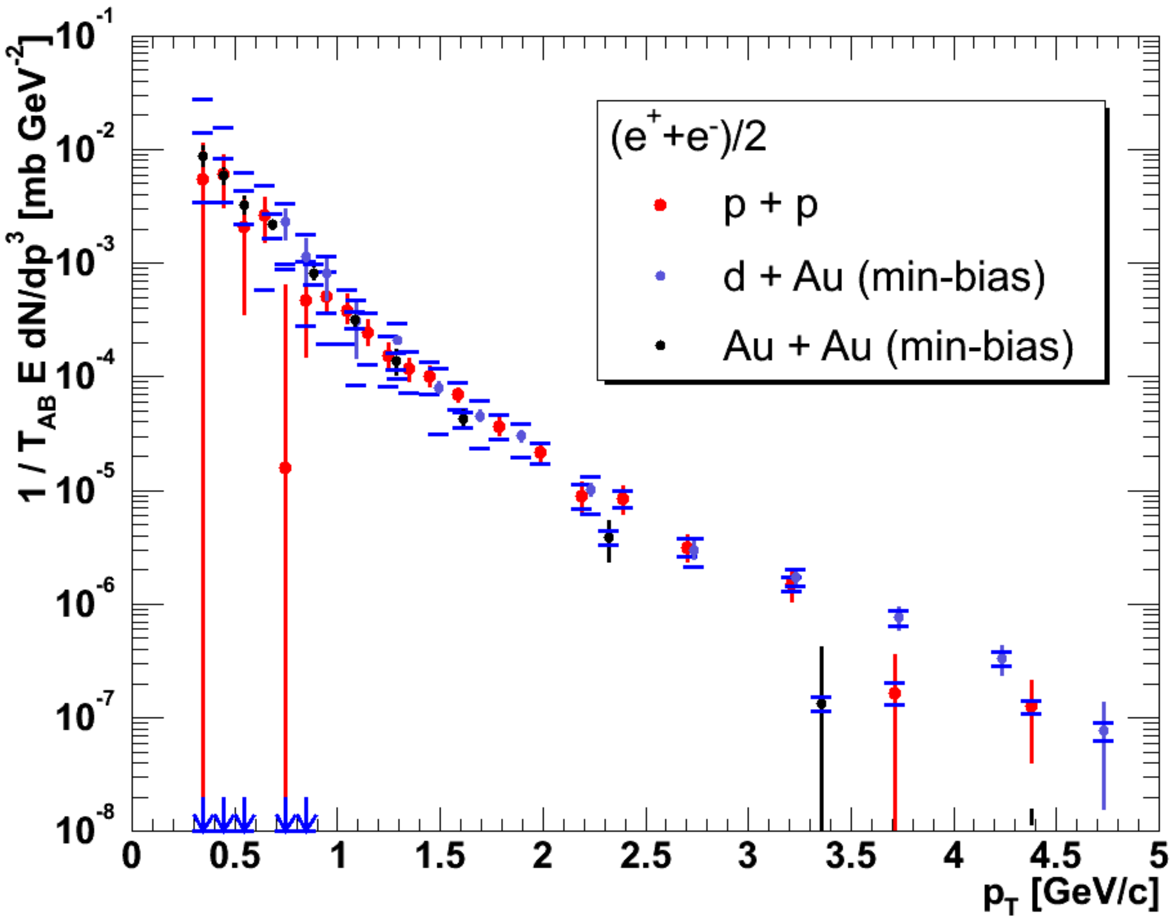


- **uncertainties too large for definite statements regarding (small) deviations from binary scaled pp results (poster: T. Hachiya)**

Binary collision scaling in AuAu (PHENIX)



- binary collision scaling of pp result works VERY WELL for non-photonic electrons in AuAu (PHENIX talk by S. Kelly)
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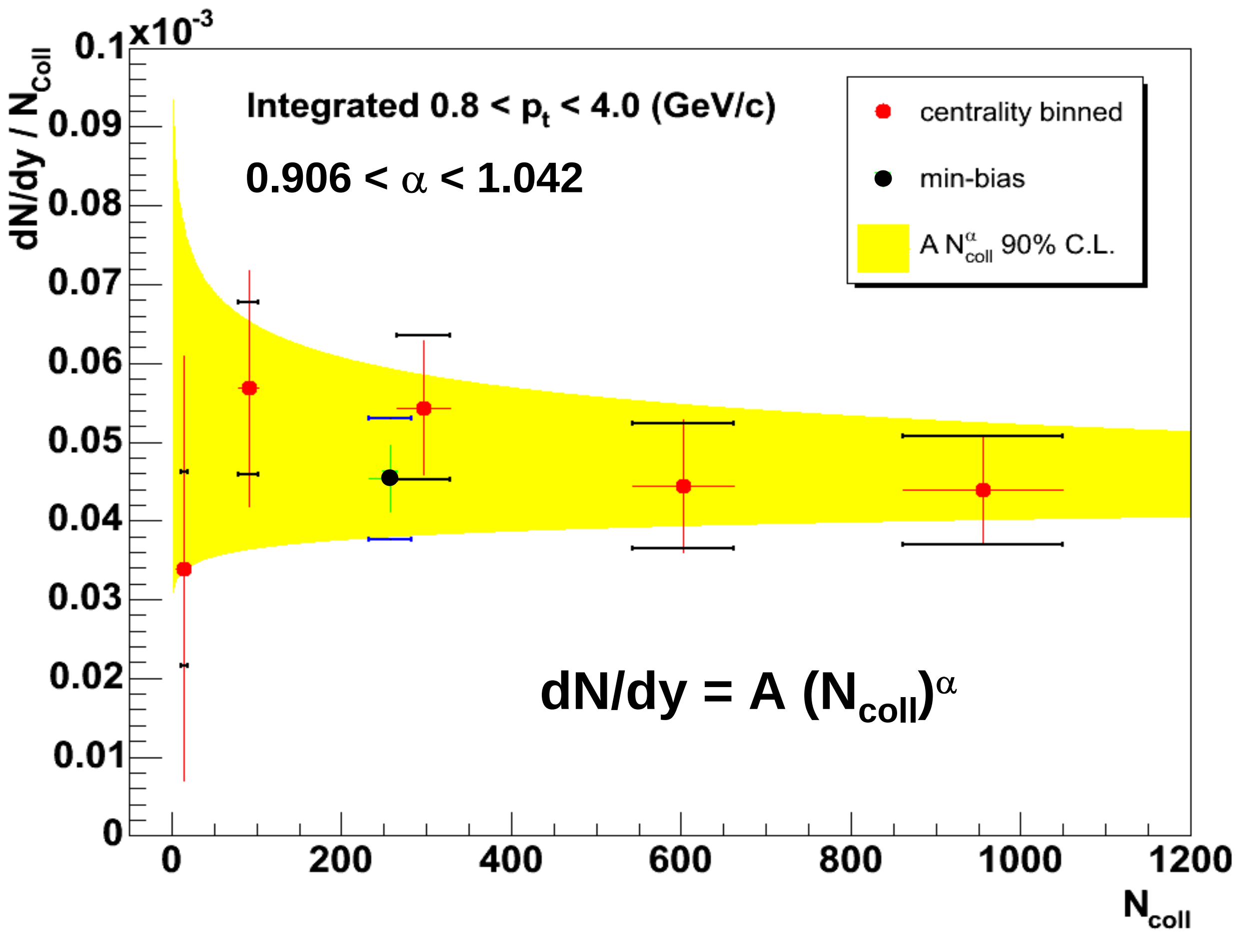

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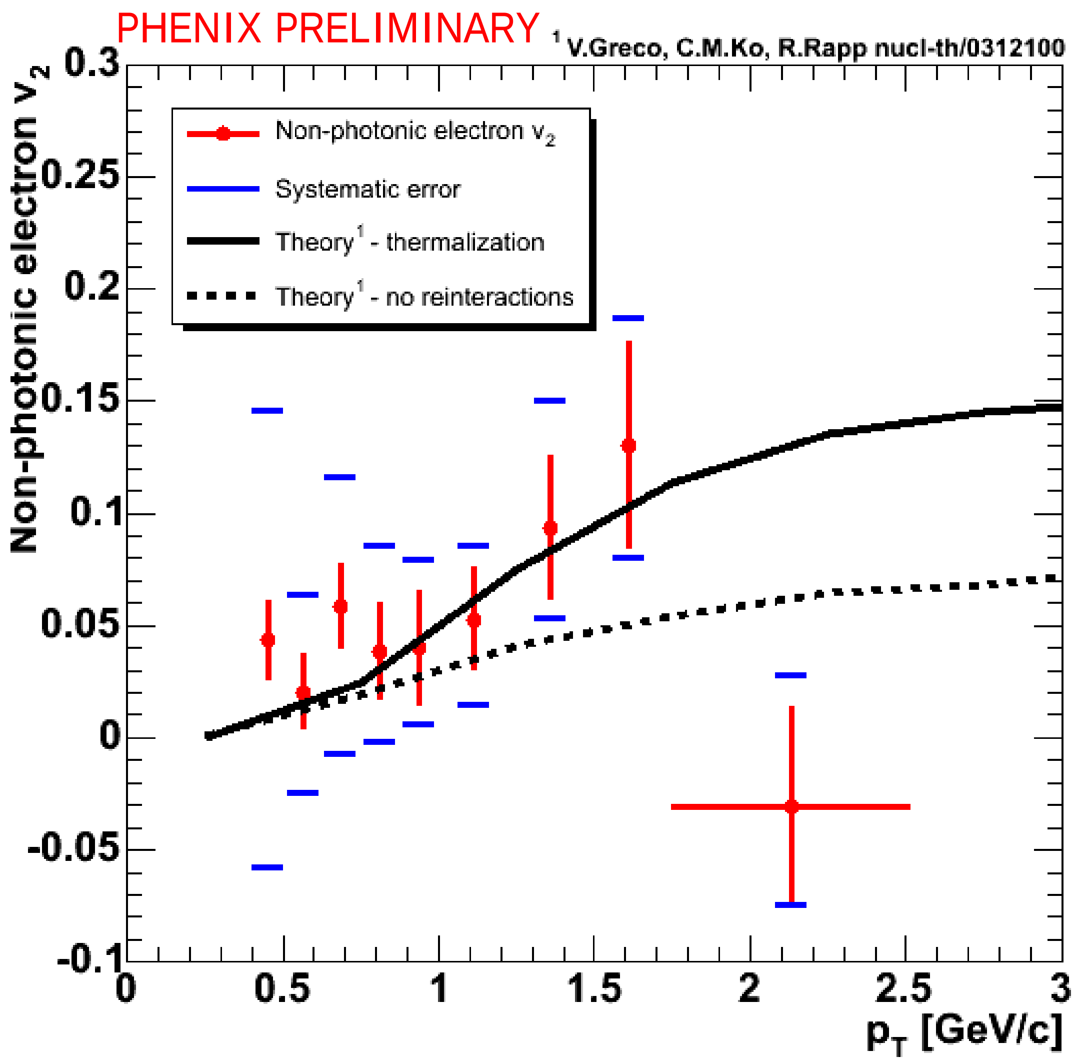
Does charm flow?



- is partonic flow realized?
- v2 of non-photonic electrons indicates non-zero charm flow in AuAu collisions
- uncertainties are large
- definite answer: AuAu RUN-04 at RHIC!

- PHENIX poster by S. Sakai

Summary

- low and intermediate-mass dileptons
  - looking forward to
    - solutions of SPS puzzles
    - data from RHIC
- direct photons as jet control measurement
  - pQCD at work
- charmonia
  - improvements at SPS
  - preparing the reference for RHIC
- open charm
  - a second player joined the game
- what next?
  - LUMINOSITY!!
  - back to work