Heavy quark and J/ψ production at RHIC/PHENIX

Outline

- Motivation
- PHENIX detector
- Open heavy quark measurements
- Heavy quarkonia measurements
- Summary

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Motivation – open heavy quark

- Open heavy quark measurement provides information of

Cold nuclear matter effect (p-p, d-Au)

(a) Cronin effect.

(b) (Anti-) shadowing.

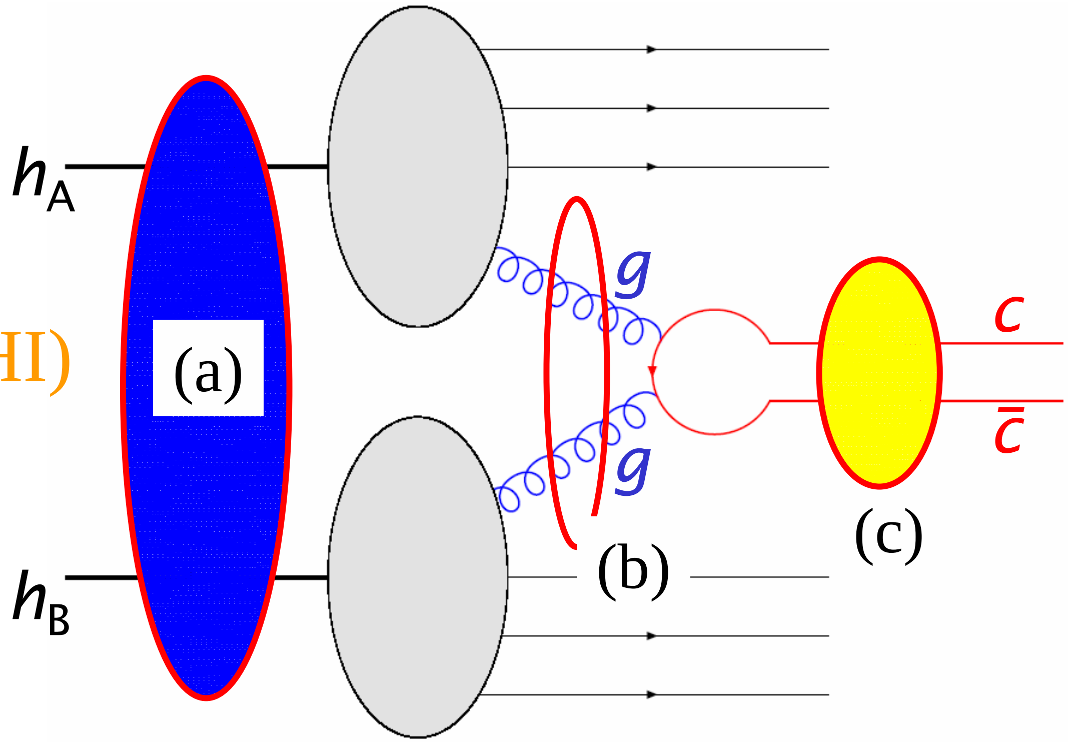
(c) Absorption.

Hot/dense matter effect (HI)

(c) Energy loss

Thermalization

Thermal production



Need systematic study for entanglement.

Motivation - Heavy quarkonia

- Heavy quarkonia measurement

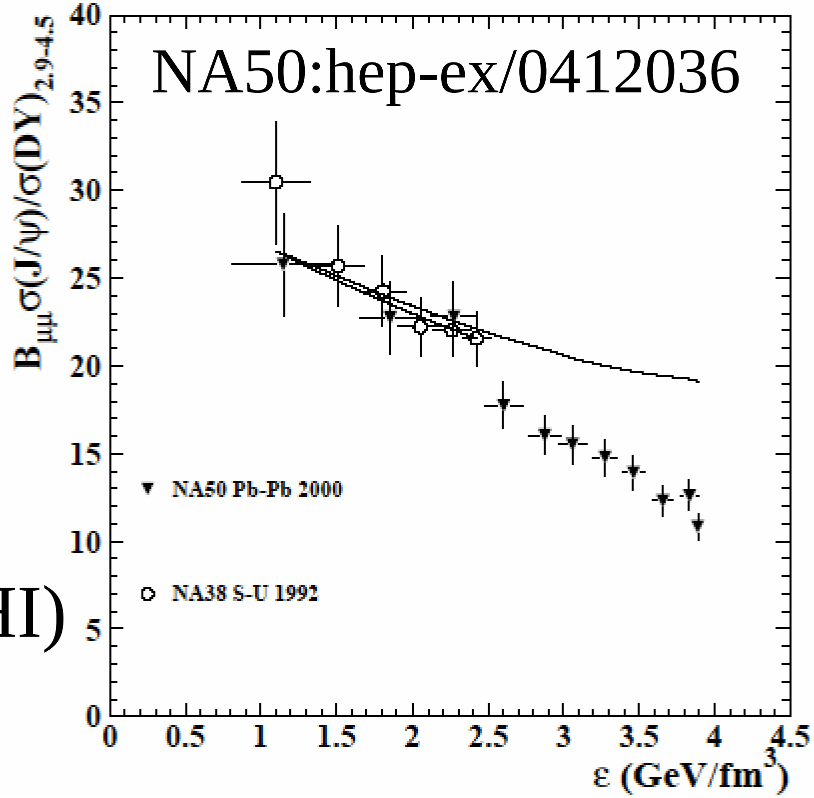
p-*p*, *d*-Au collisions

1. Production mechanism of quarkonia.

   Color octet/evaporation.
2. Other cold matter effect (*d*-Au).

Heavy ion collisions

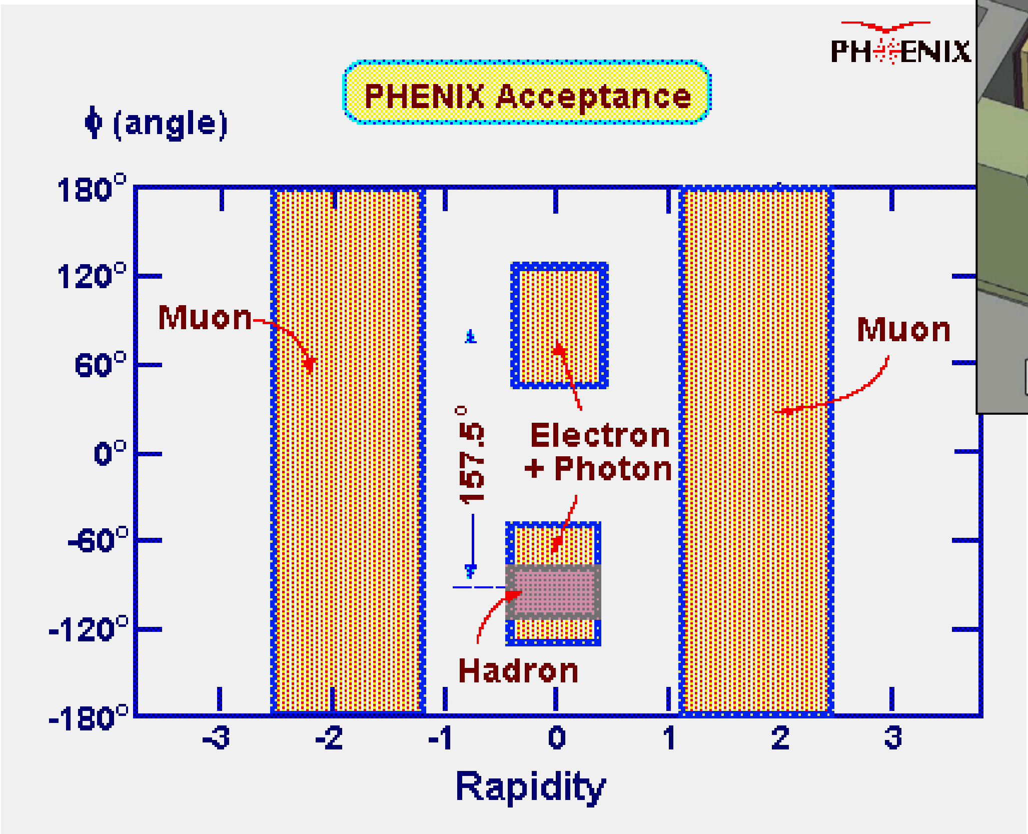
3. Quark deconfinement
4. Quark coalescence
5. Other hot/dense matter effect (HI)

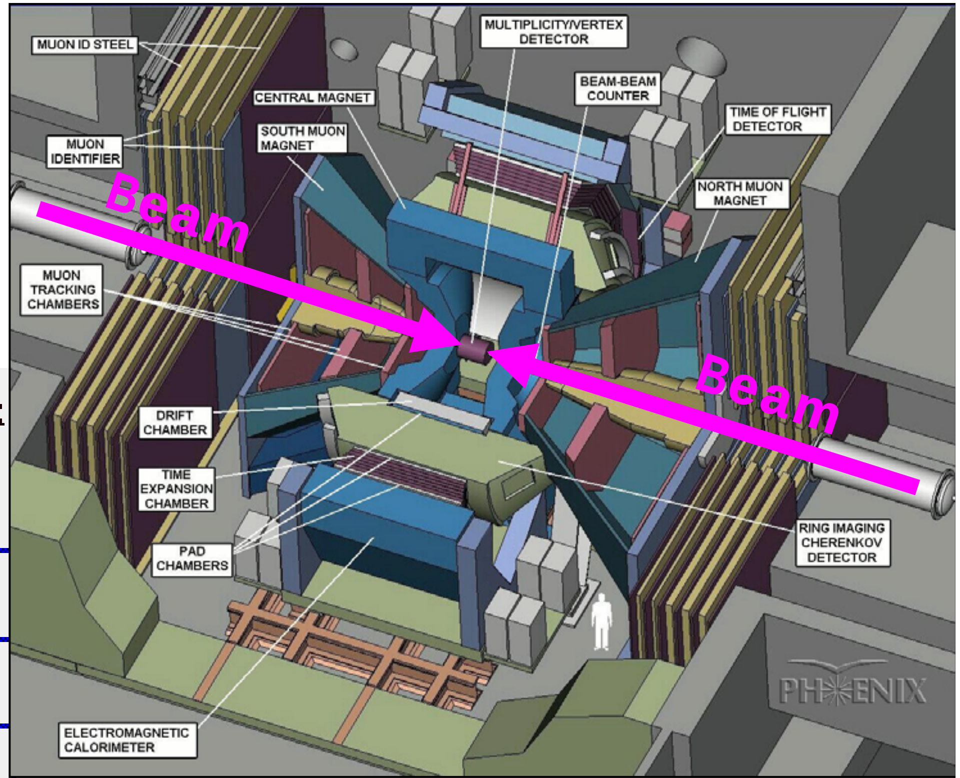


Need systematic study with open heavy quark measurement.

The PHENIX detector

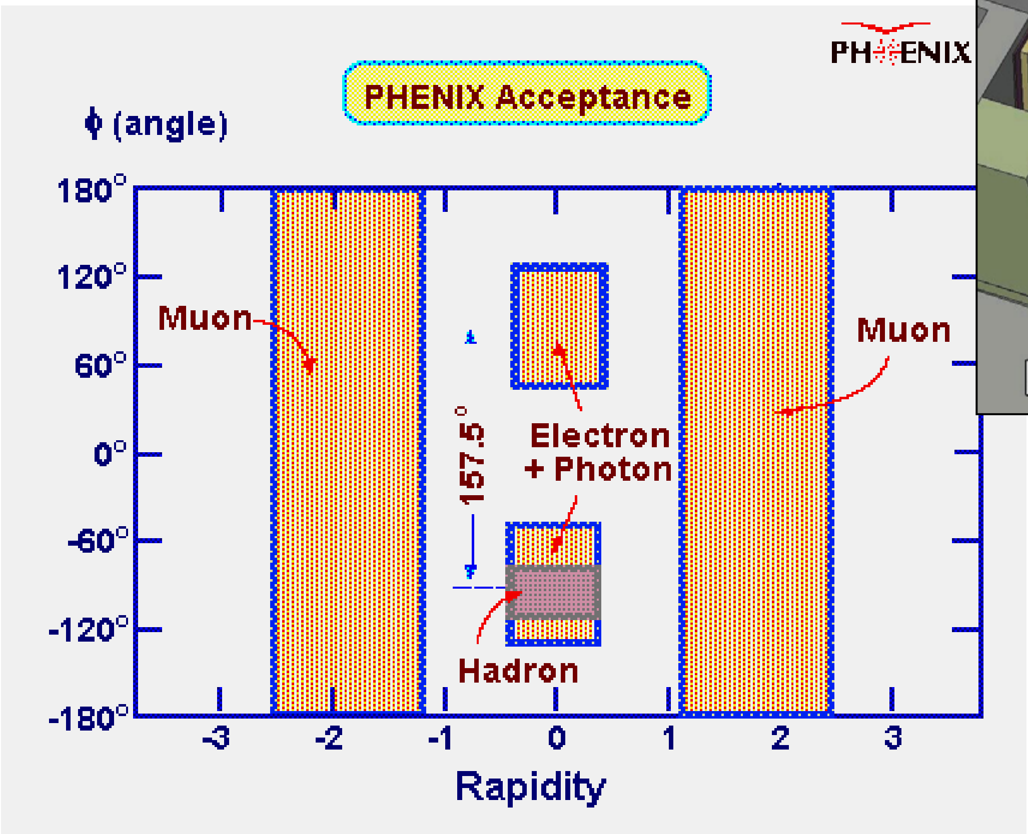
- A composite detector to measure **leptons, photons and hadrons**.

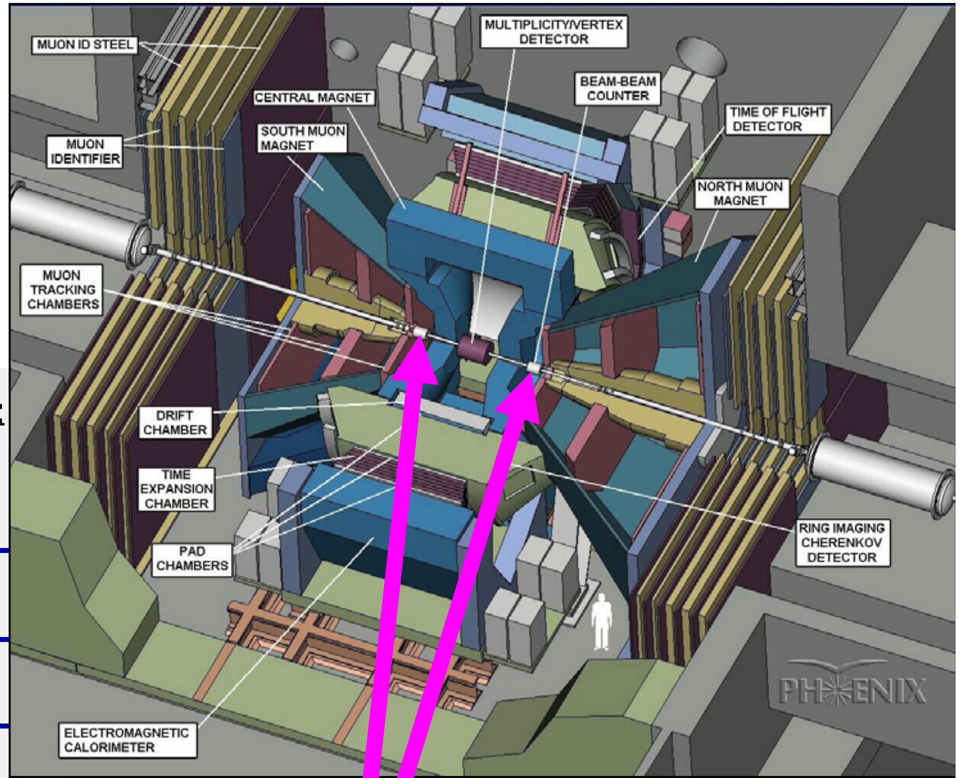




The PHENIX detector

- Event trigger is defined by beam-beam counters.





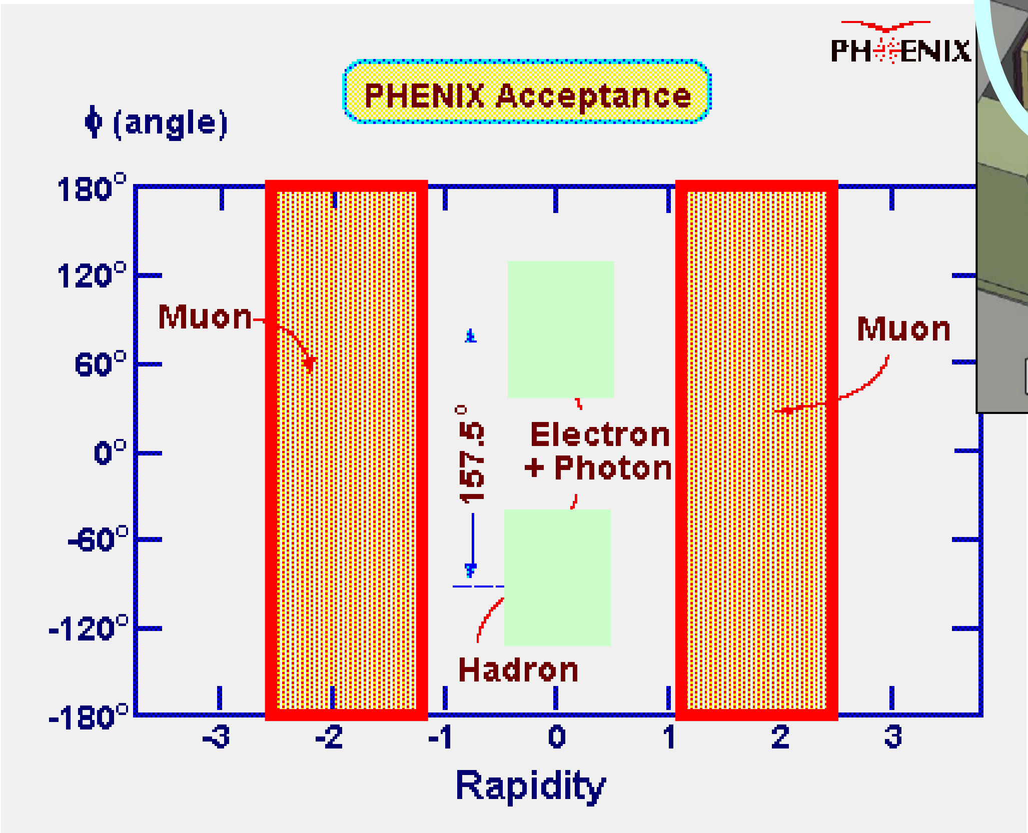
Beam-beam counters

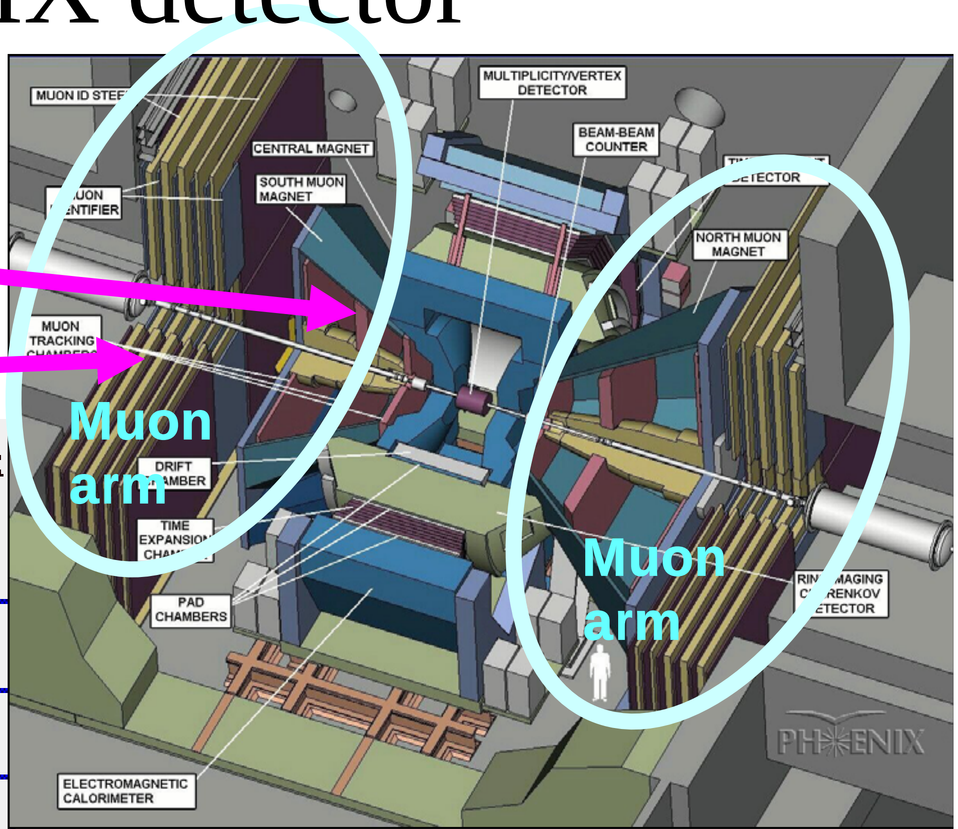
The PHENIX detector

- Muon arms

  tracking chambers

  Muon ID detectors





The PHENIX detector

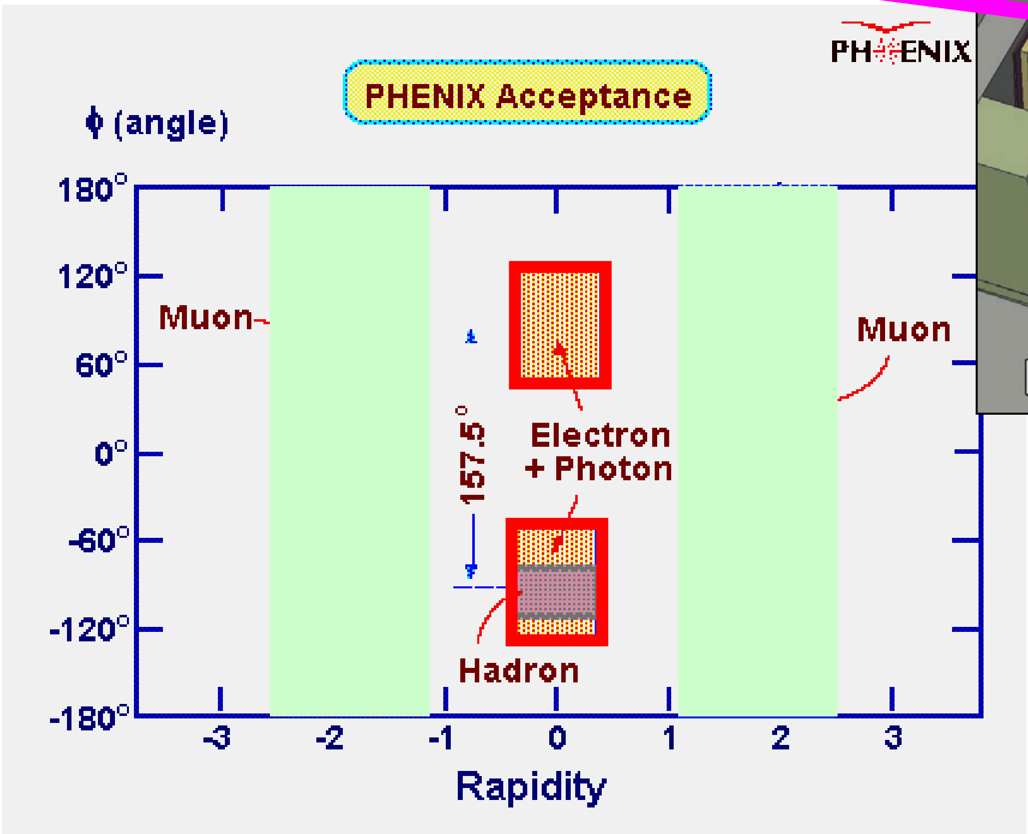
- Central arms

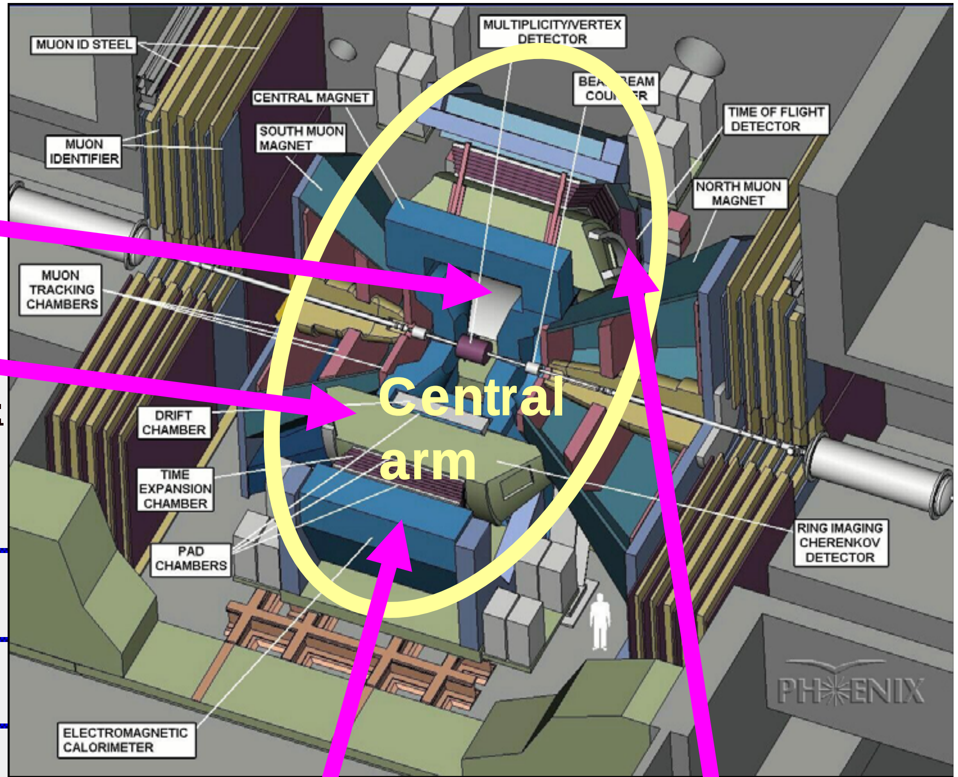
  Tracking chambers

  RICH counters

  EM calorimeters

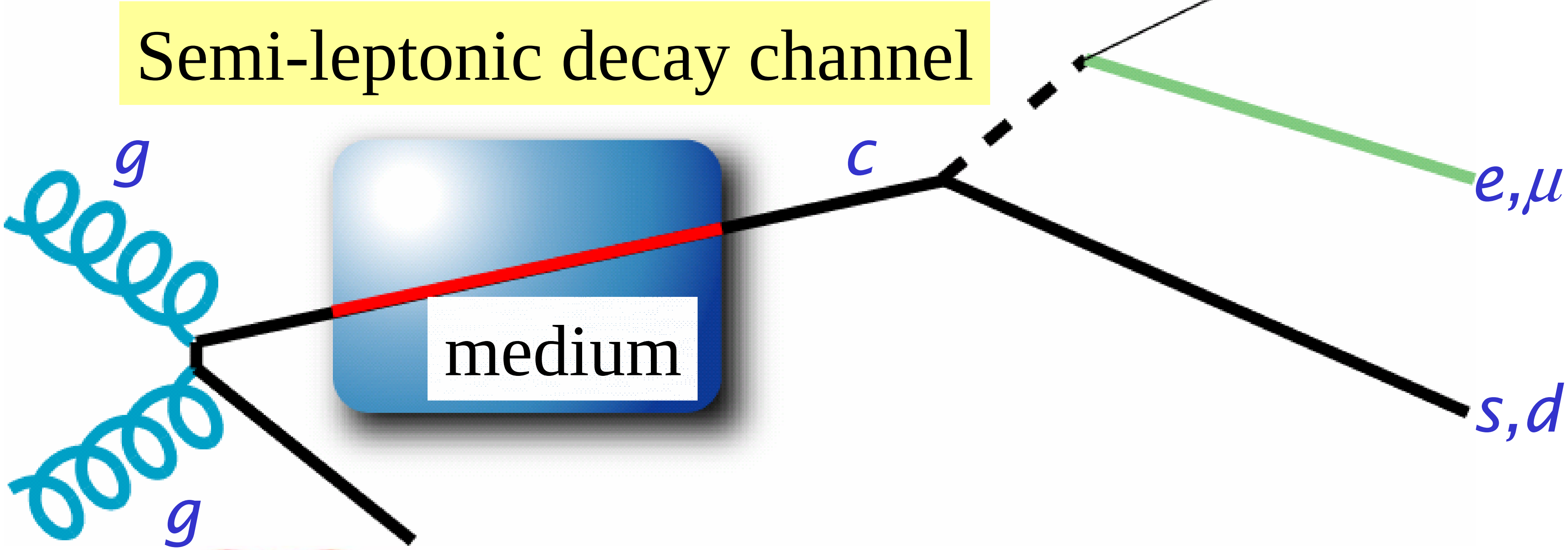
  TOF counters





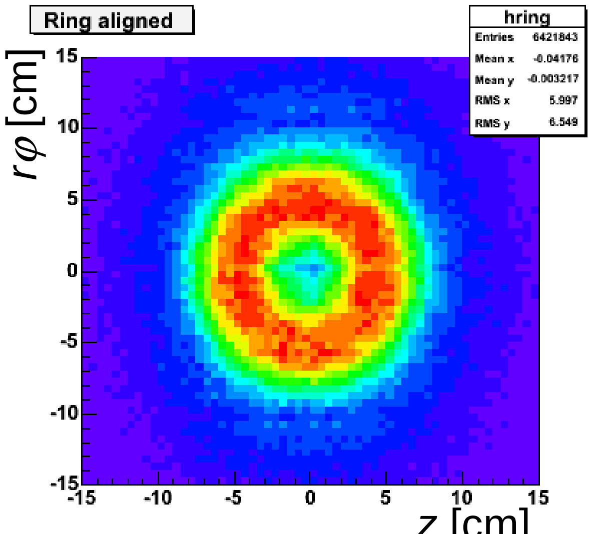
Open heavy quark measurement

- Today, open heavy quarks are measured by the semi-leptonic (electron) decay channel.
- In the future,
  - Hadronic decay → direct measurement of D mesons.
  - μ, e-μ → other kinematical regions.



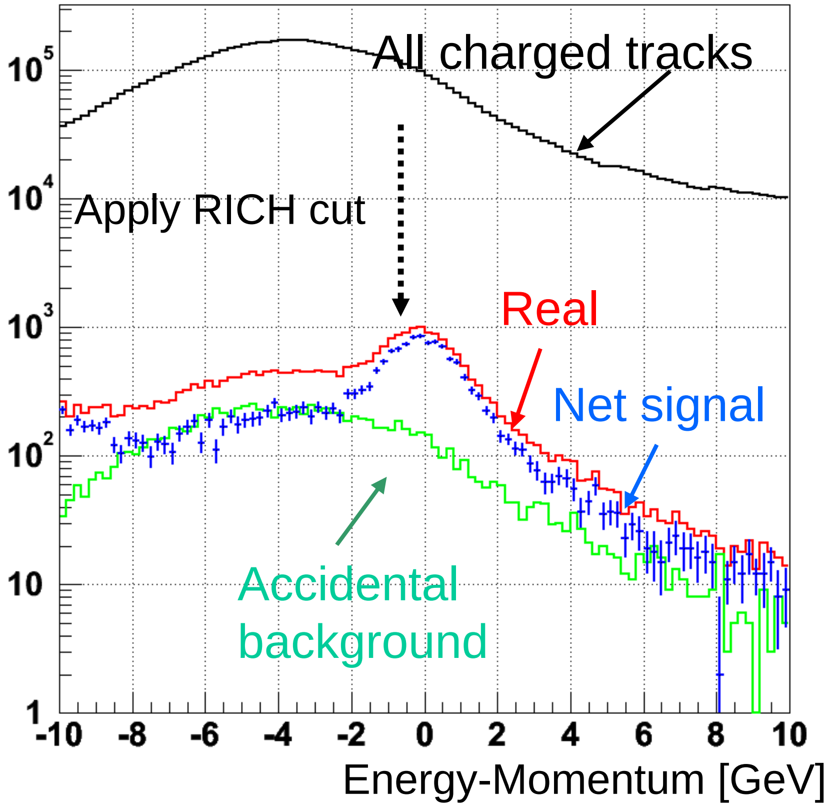
Electron ID

- Electrons are identified by RICH and EMCal *E*-*p* matching, position matching, shower shape cut.



RICH ring shape
(signal accumulated)

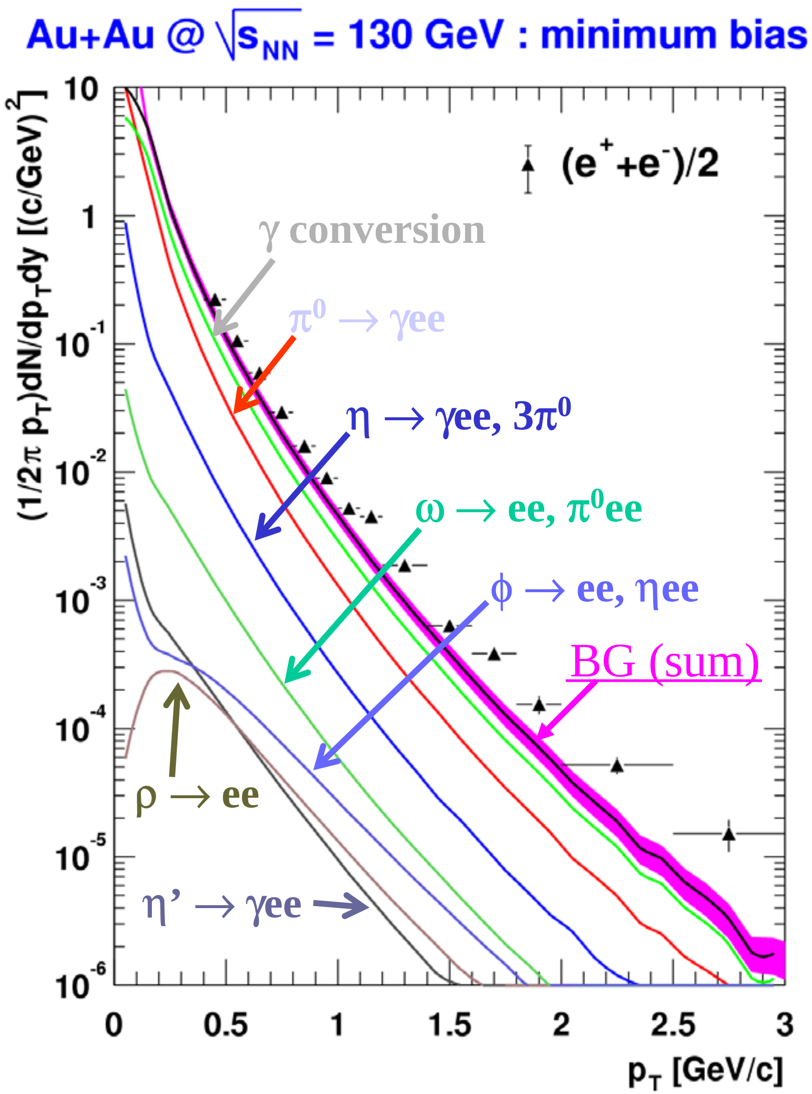
Au-Au data



Extraction method

- All physical backgrounds (BG) were evaluated by Monte-Carlo calculation using **real PHENIX data**.

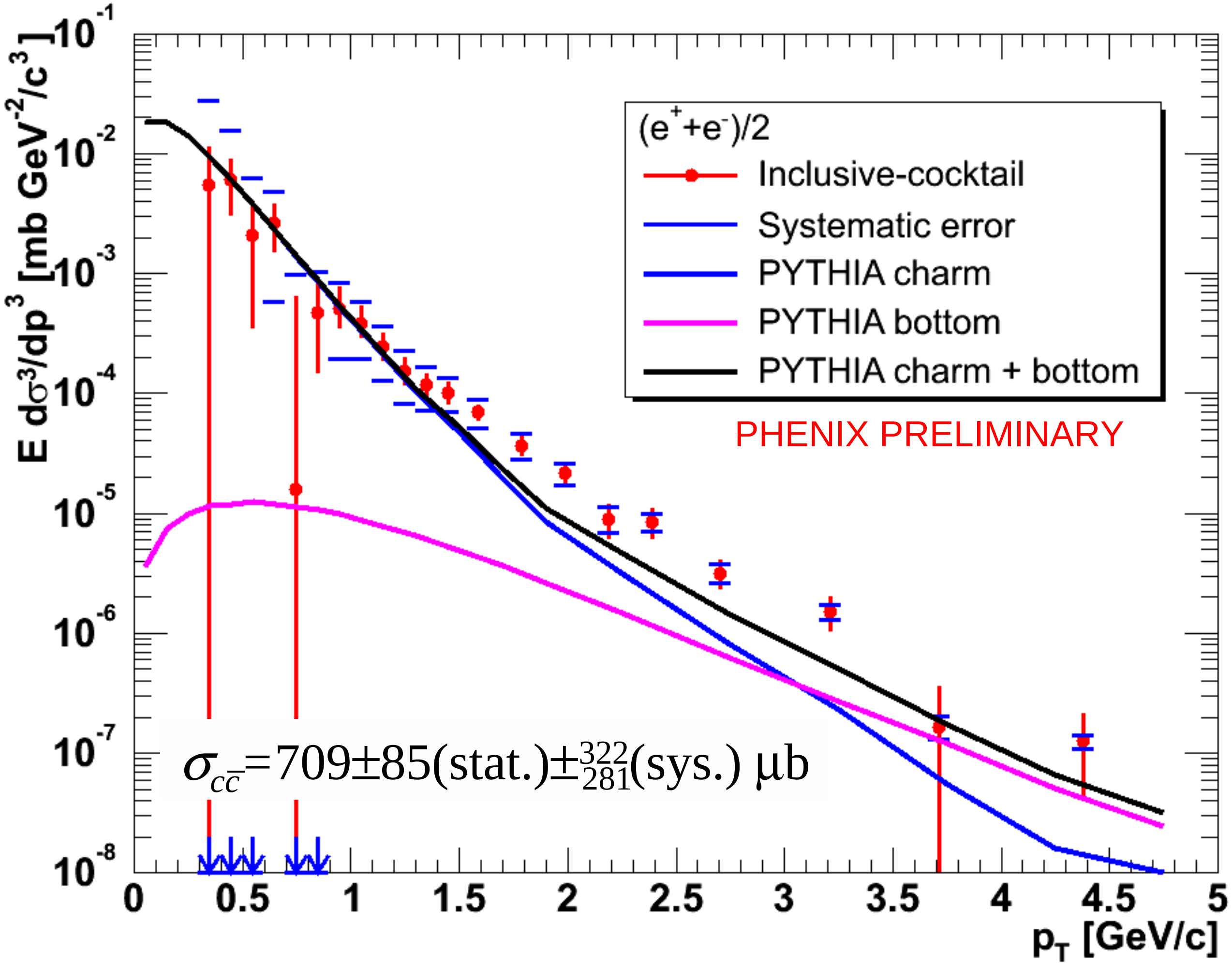
- Low p_T → Small S/N, Challenging
- **High p_T → Good S/N**



PHENIX: PRL 88(2002)192303

Result – p-p collisions at $\sqrt{s}$ =200 GeV

- Signal $e^{\pm}$ spectrum with PYTHIA calculation (tuned to lower energy data $\sqrt{s}$ <62 GeV).



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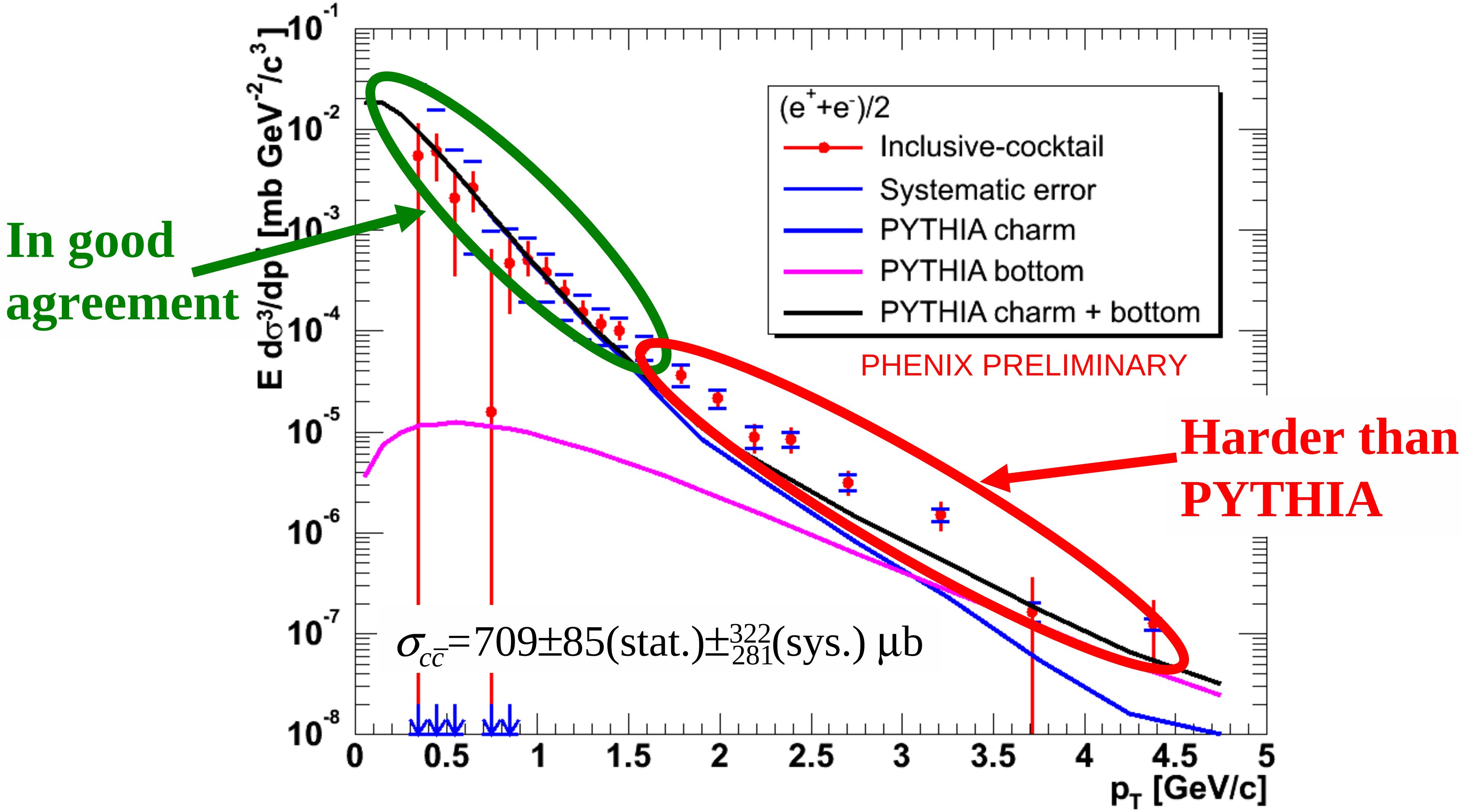
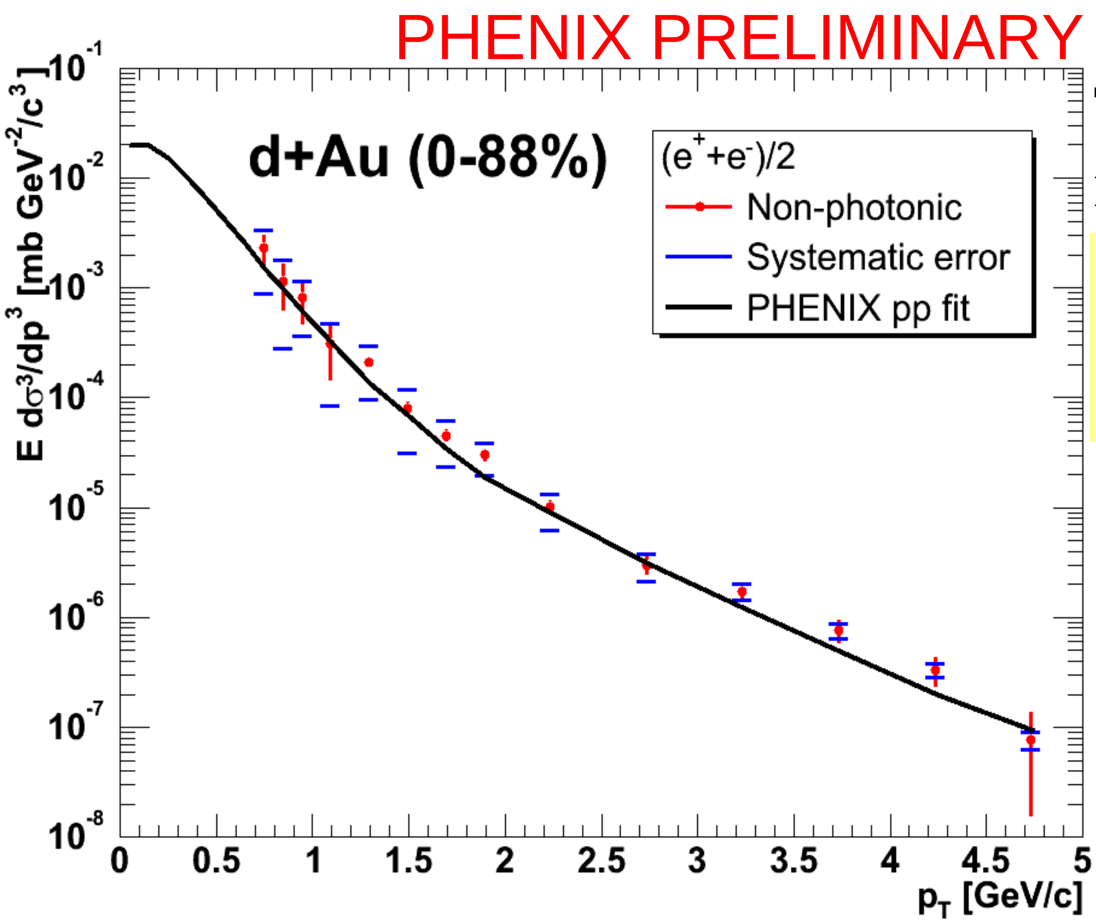


Result – d-Au collisions at $\sqrt{s}$ =200 GeV

- Spectra agree with p-p data after applying binary scaling.
- No significant cold nuclear medium effect in the uncertainty.



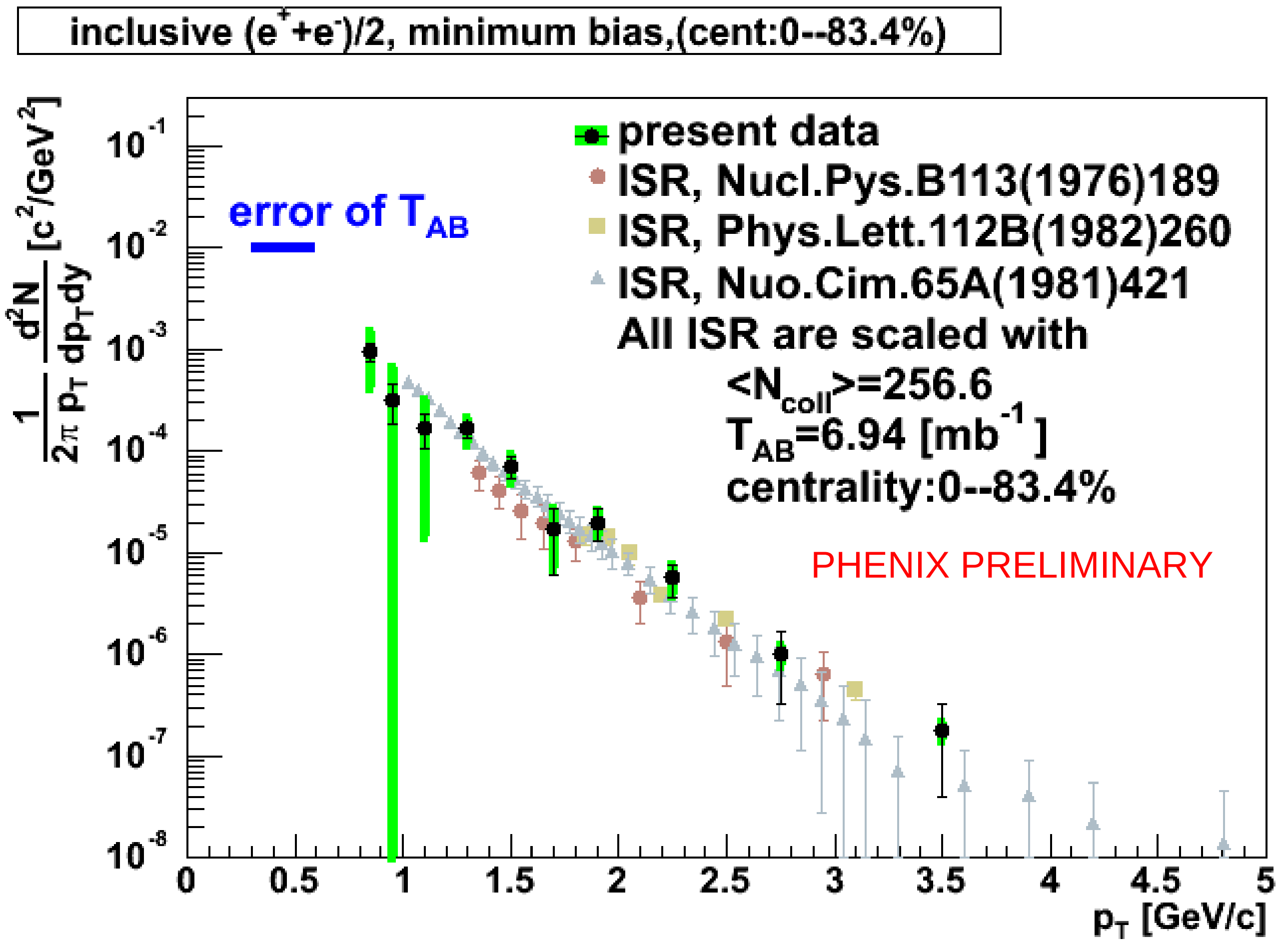
The d-Au data is scaled by number of binary collisions.

$$d\sigma = \frac{\sigma_{pp\ \mathrm{inel.}}}{\langle N_{\mathrm{binary}} \rangle} dN_{\mathrm{dAu}} = \frac{dN_{\mathrm{dAu}}}{T_{\mathrm{AB}}}$$

Non-photonic: electrons from heavy quarks (main part), light vector mesons and kaons (small fractions).

Result – Au-Au collisions at $\sqrt{s}$=62.4 GeV

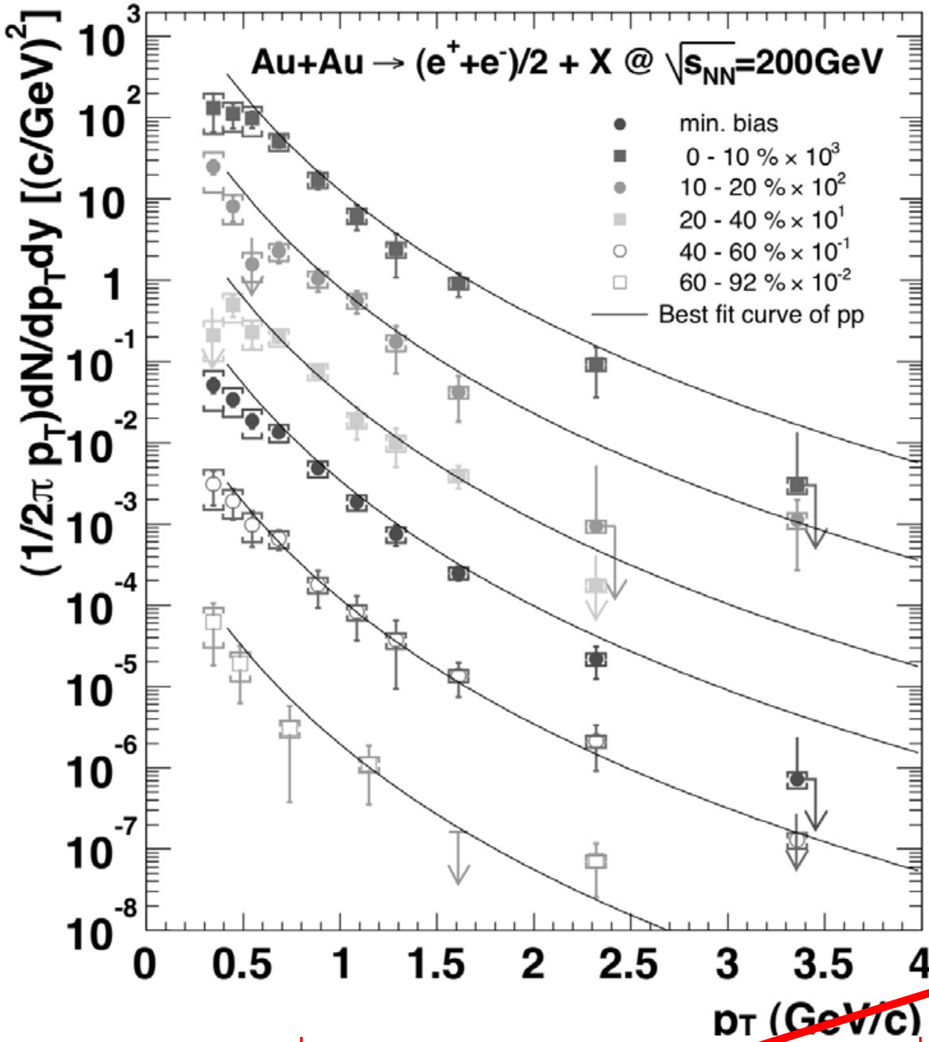
- Spectra agree with the ISR *p-p* data scaled by T_{AB} with uncertainty.



$$T_{AB} = \frac{\langle N_{\text{binary}} \rangle}{\sigma_{pp\ \text{inel.}}}$$

Result – Au-Au collisions at $\sqrt{s}$=200 GeV

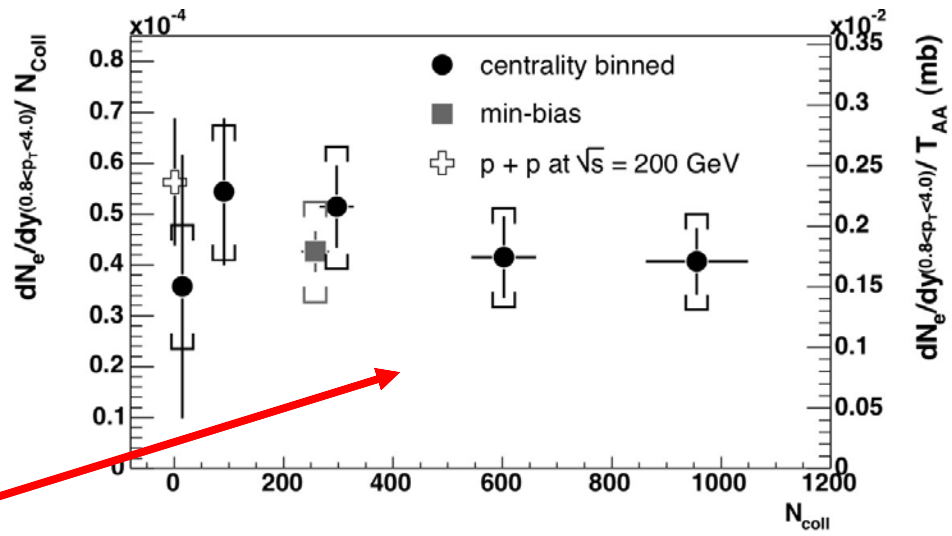
Differential CS nucl-ex/0409028



Integrate

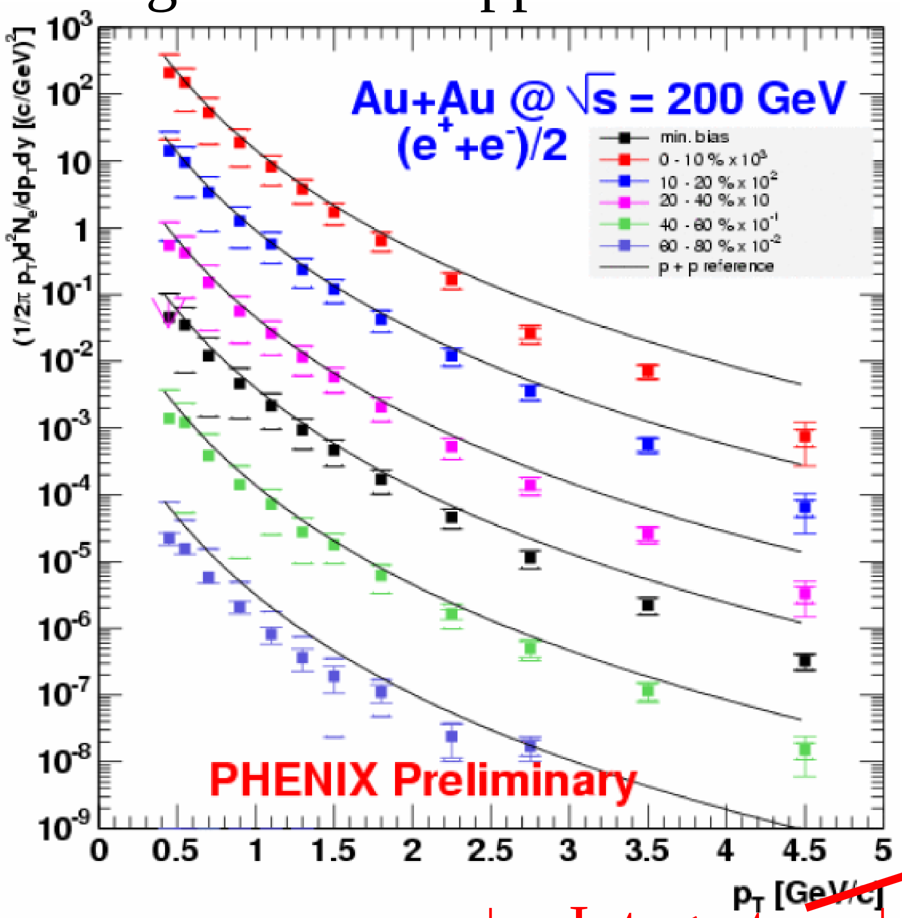
- Small statistics in high p_T.
- Integrated charm production cross section in Au-Au agree with *p*-*p* cross sections scaled by binary-collisions.

Integrated CS (0.8<p_T<4 GeV/*c*)



Result – Au-Au collisions at $\sqrt{s}$=200 GeV

- Result using full statistics.
- Single electrons in high p_T region seem suppressed.

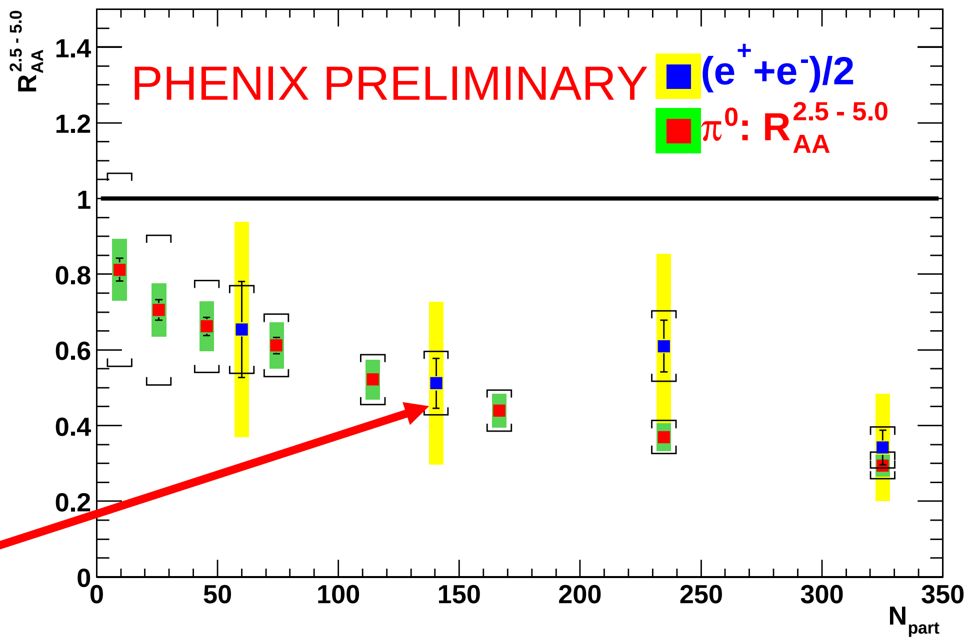


Integrate

- The nuclear modification factor (R_{AA}) have the same tendency with π^0.

$$R_{AA} = \frac{dN_{AA}}{T_{AB} d\sigma_{pp}}$$

R_{AA} of Integrated CS (2.5<pT<5.0 GeV/c).



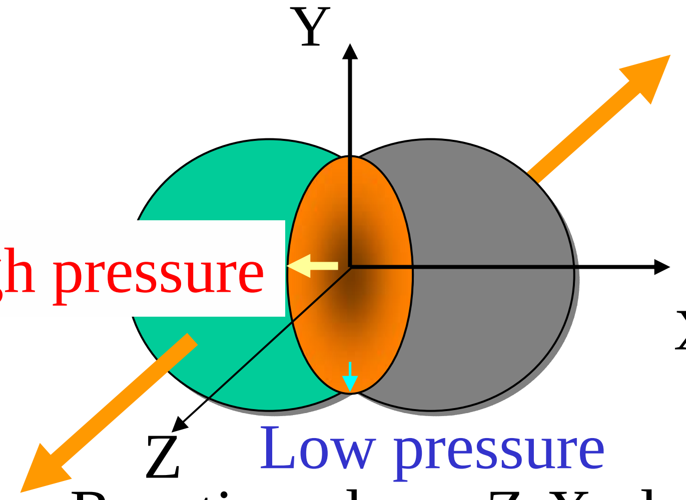
Single electron v_2 component

- The elliptic flow comes from pressure.

$$E\frac{d^3N}{d^3p}=\frac{d^2N}{2\pi p_T dp_T dy}\sum_{n=0}^{\infty}2v_n\cos\left(n\left(\varphi-\Psi_R\right)\right)$$

$v_2=\left\langle\cos 2\left(\varphi-\Psi_R\right)\right\rangle$ (Like ellipticity)

The Ψ_R is the angle between reaction plane and y=0.

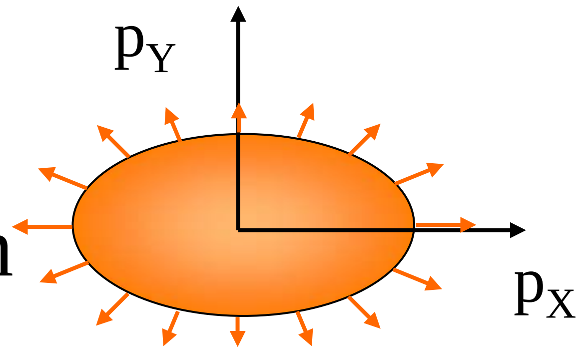


Reaction plane: Z-X plane

If heavy quarks are thermalized

→ Elliptic flow (or v2) of D meson

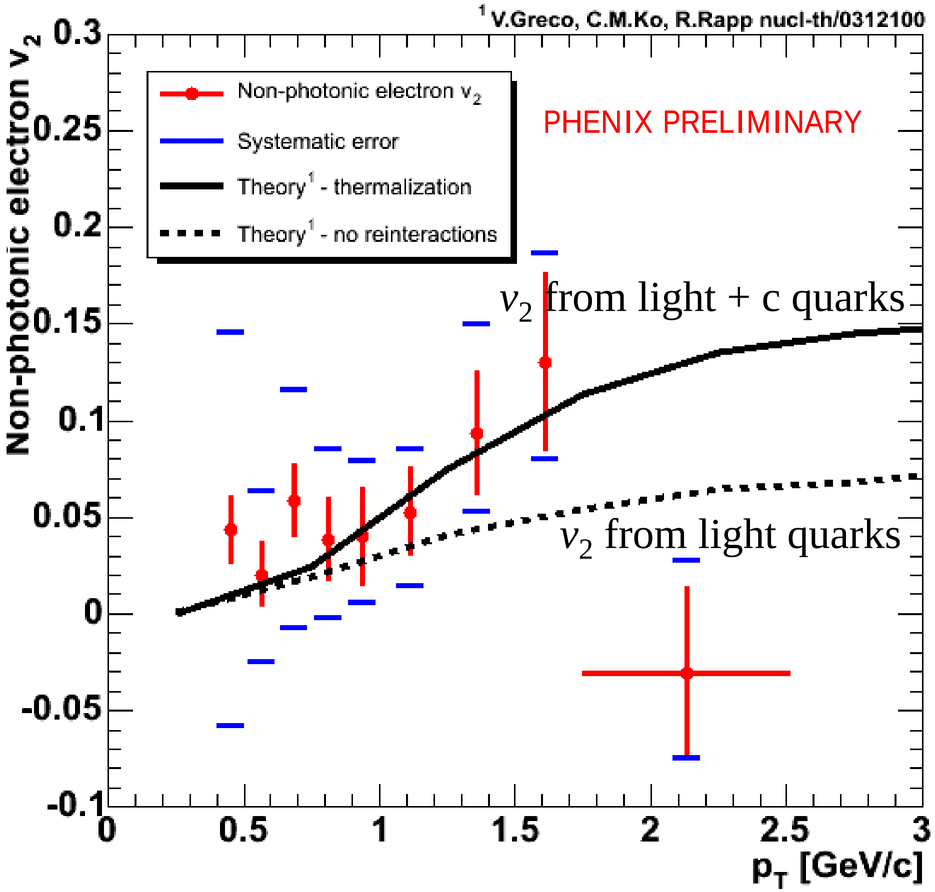
→ Single electron v2.



Flow

Result – Au-Au collisions at $\sqrt{s}$=200 GeV

- Non-photonic single electron flow (v_2 component) can come from both light and heavy quarks.
- To determine the charm flow, need more statistics.



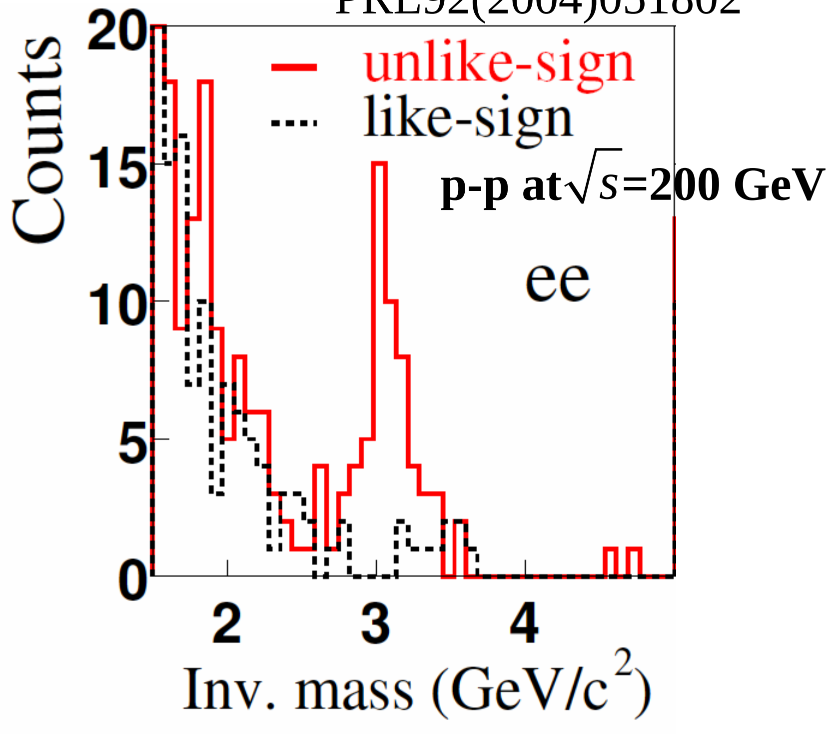
Summary – open charm measurement

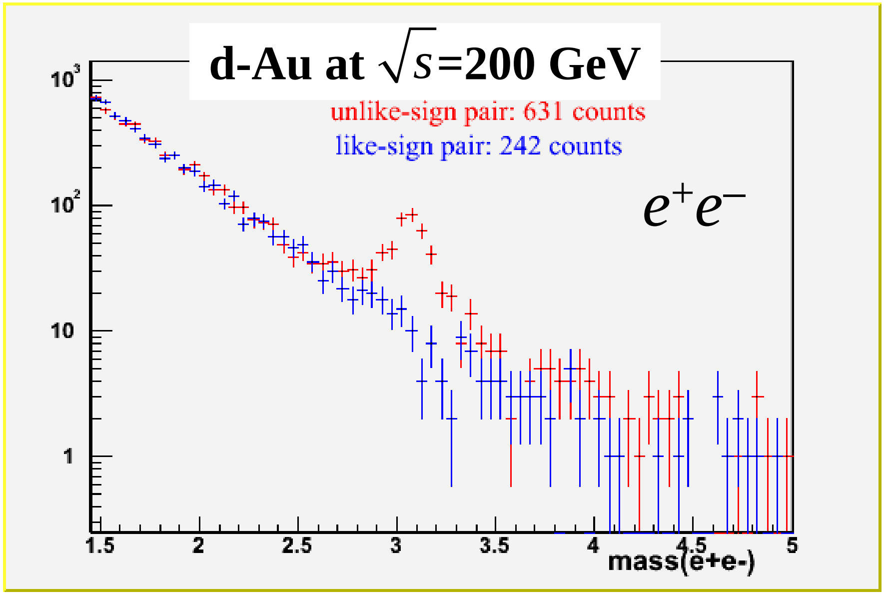
- The heavy quark production CS is harder in $1.5<p_T$ than PYTHIA tuned at the ISR data (*p*-*p* data).
- No significant cold matter effect is seen within the uncertainty (*d*-Au data).
- The integrated charm yield in the mid-rapidity is consistent with binary collision scaling (Au-Au data).
- In high p_T region (2.5 GeV or more), the charm yield is small compared to *p*-*p* data (Au-Au 200 GeV data).
- The charm flow (*v*2) measurement is on going. Need more statistics (Au-Au data).

J/ψ measurement

- $J/\psi \rightarrow e^+e^-$ at mid rapidity
- $J/\psi \rightarrow \mu^+\mu^-$ at forward and backward rapidity.

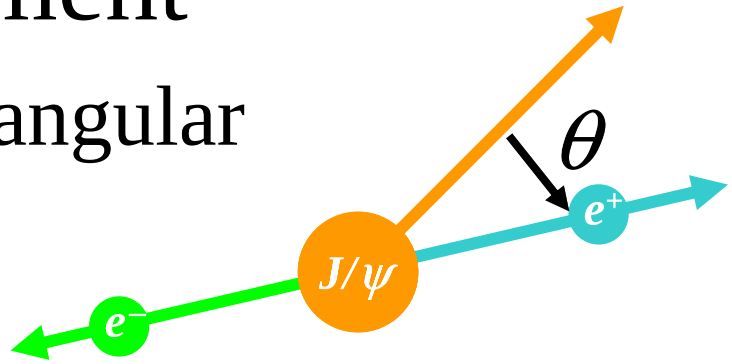
PRL92(2004)051802





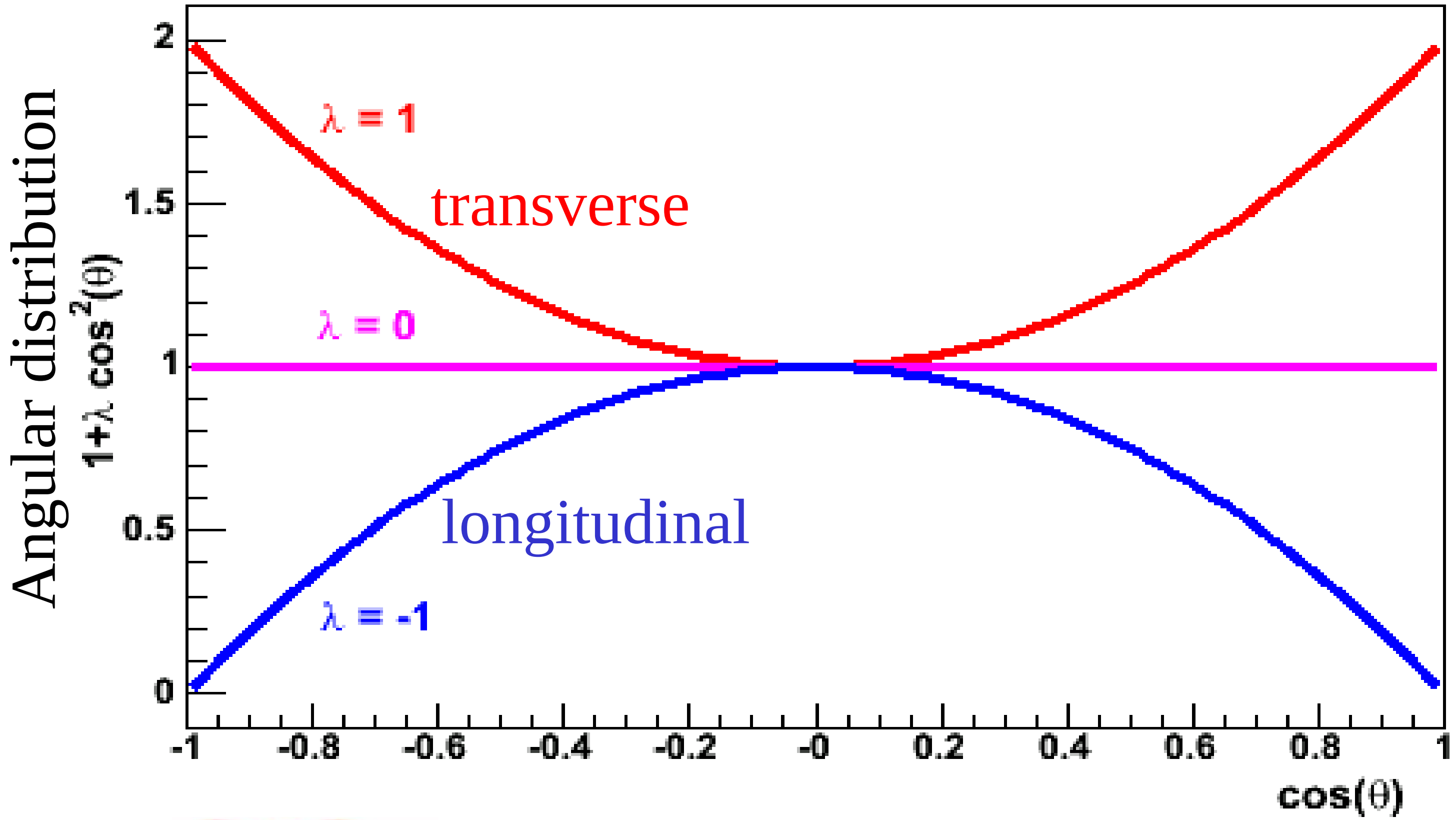
J/ψ spin alignment

- J/ψ spin alignment → positron angular distribution in J/ψ rest frame.



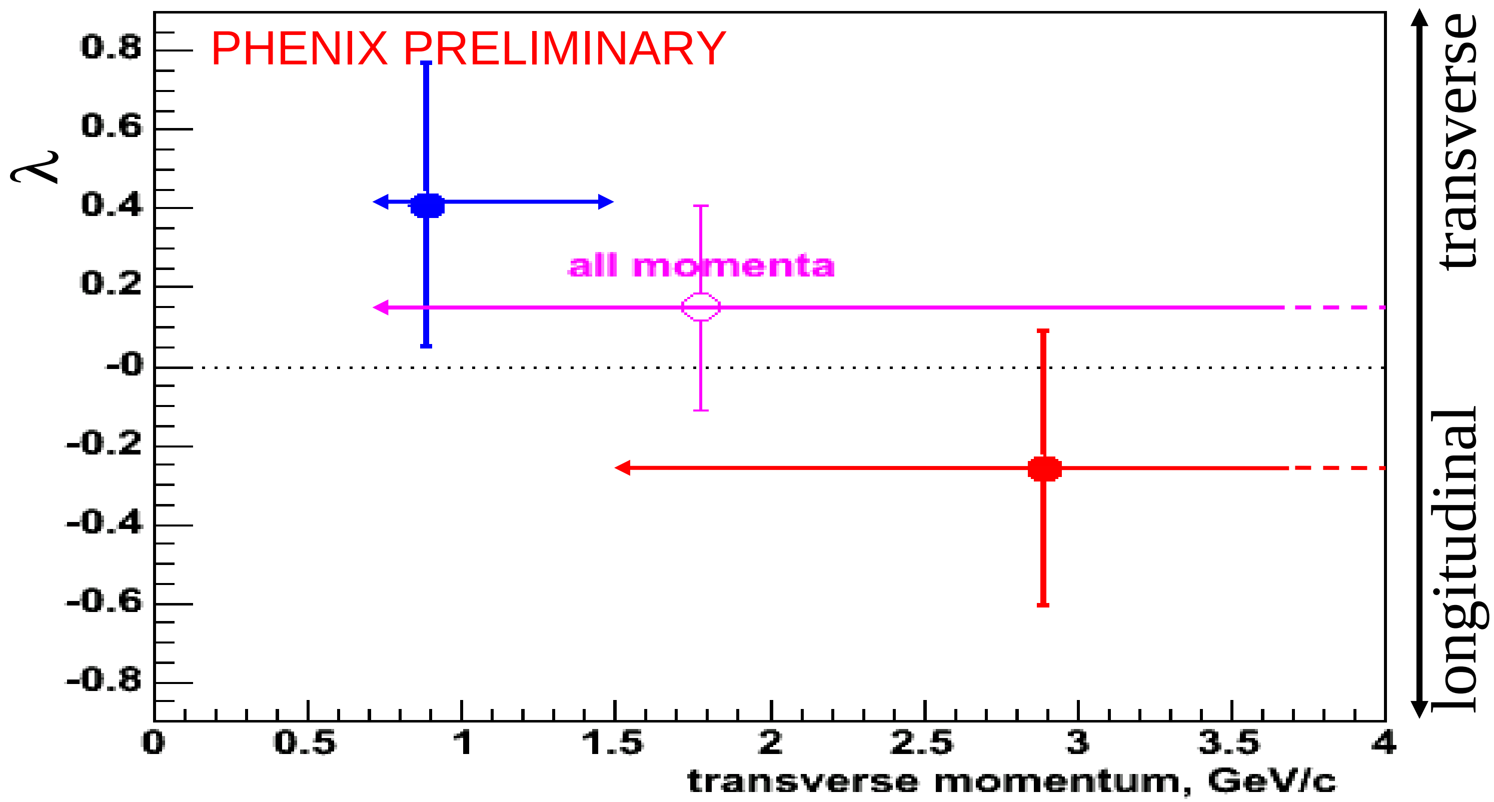
J/ψ rest frame

$1+\lambda\cos^2\theta$



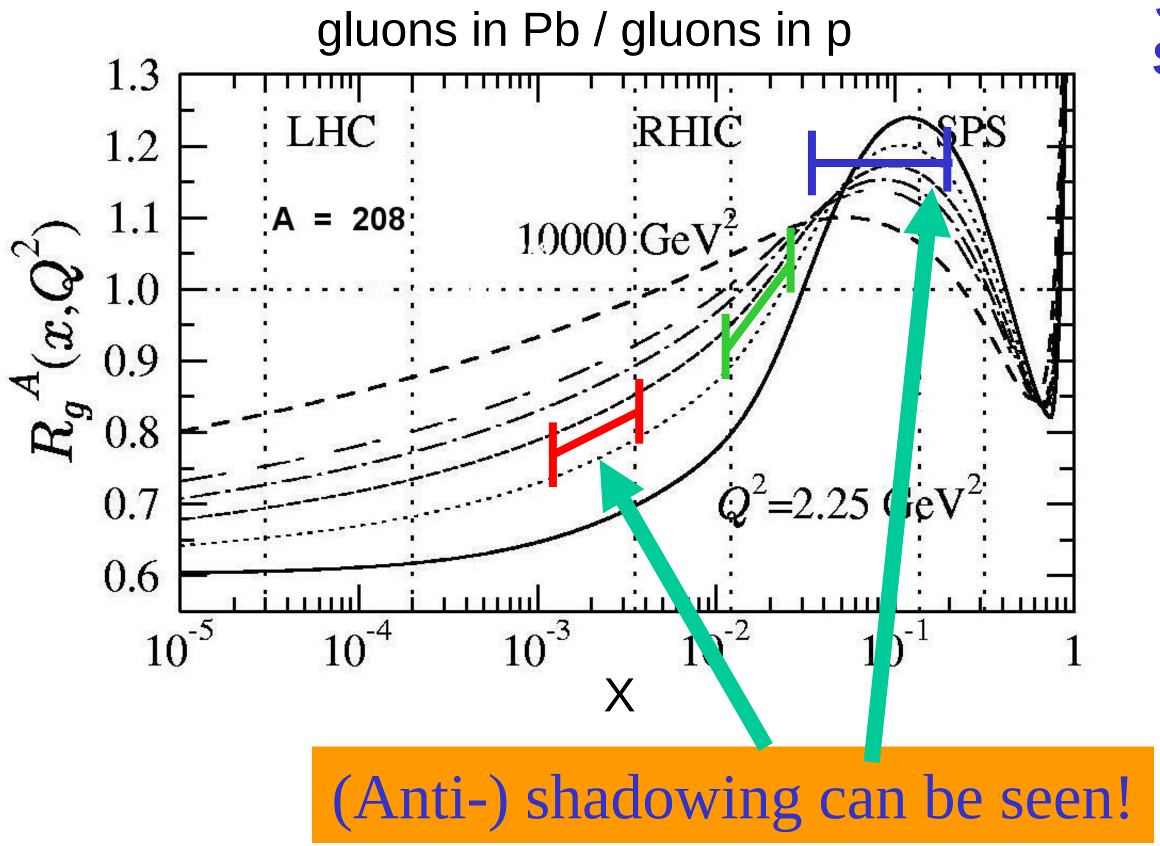
J/ψ spin alignment

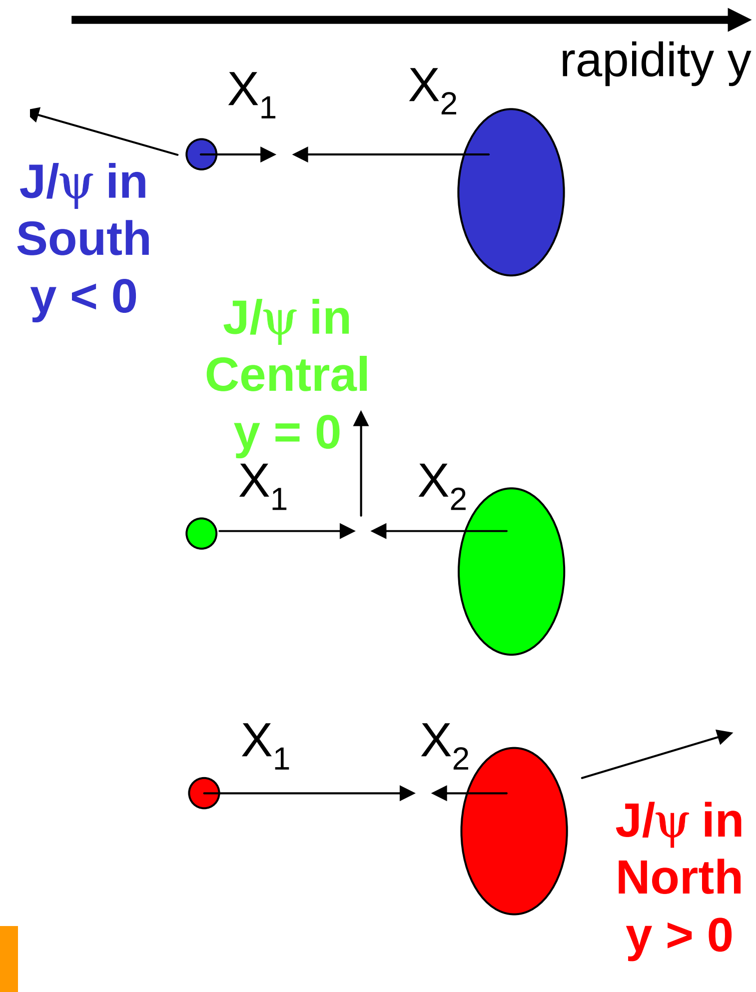
- Measured in *d*-Au 200 GeV data.
- Expected no or small alignment at low p_T.
- Need more data.



(Anti-) shadowing in d-Au collisions

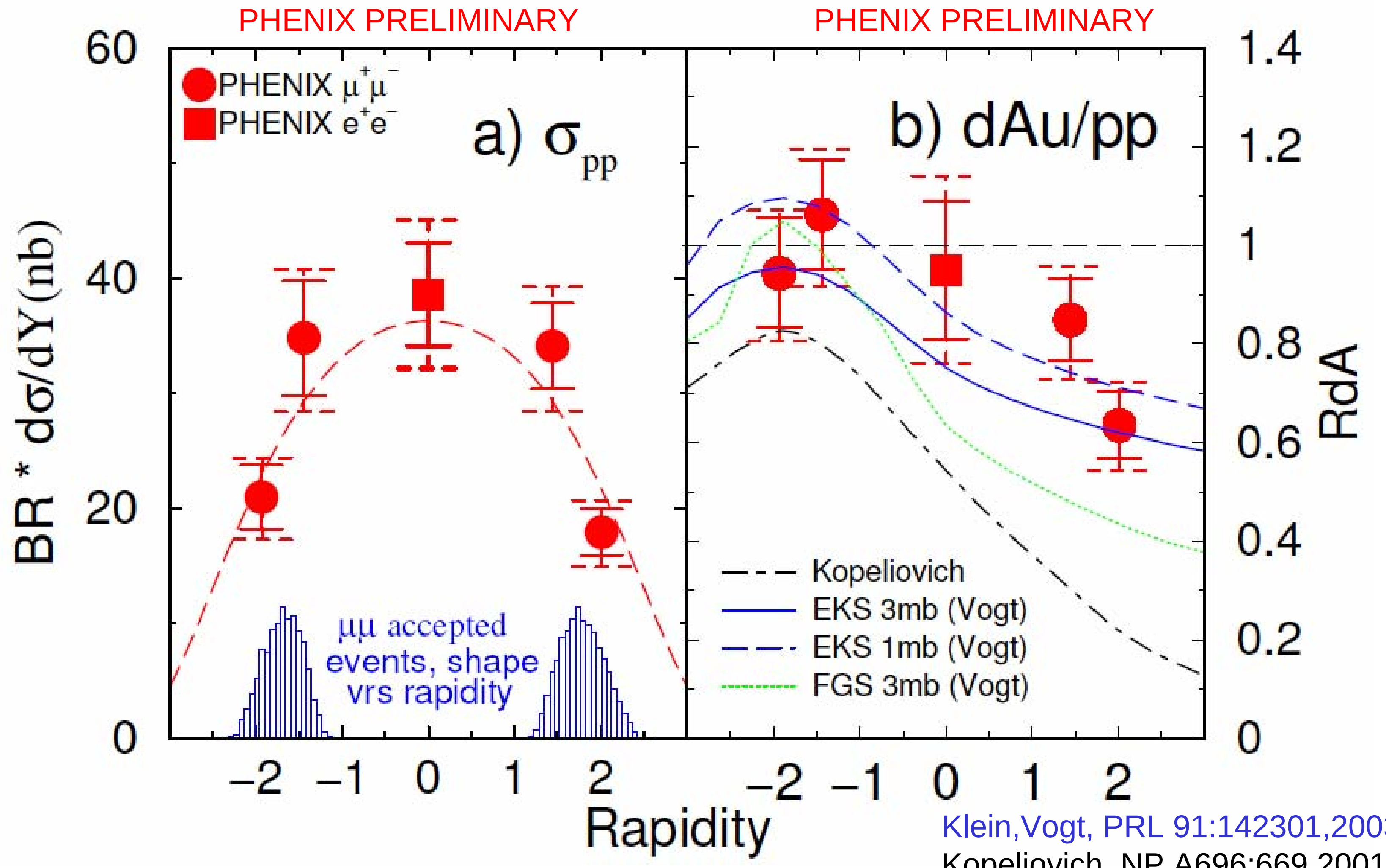
Example of predicted "gluon shadowing" in d+Au





Cross section and modification factor

- Weak shadowing?



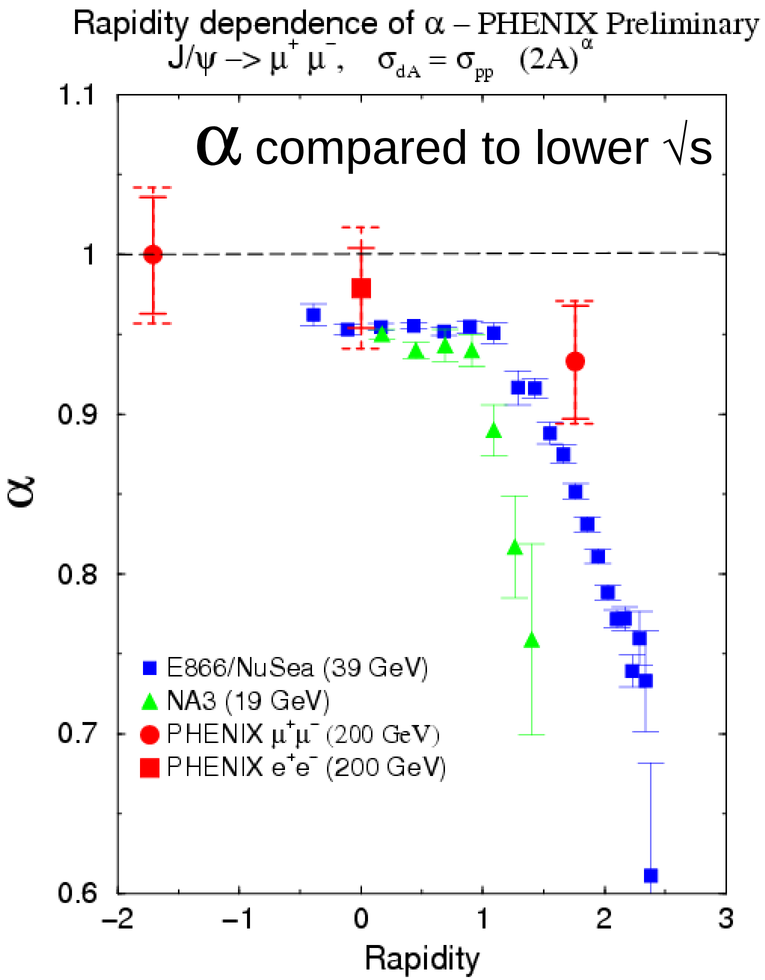
Klein,Vogt, PRL 91:142301,2003
Kopeliovich, NP A696:669,2001

Mass number dependence (*y*)

$$\sigma_{dA} = \sigma_{pp}(2\times197)^{\alpha}$$

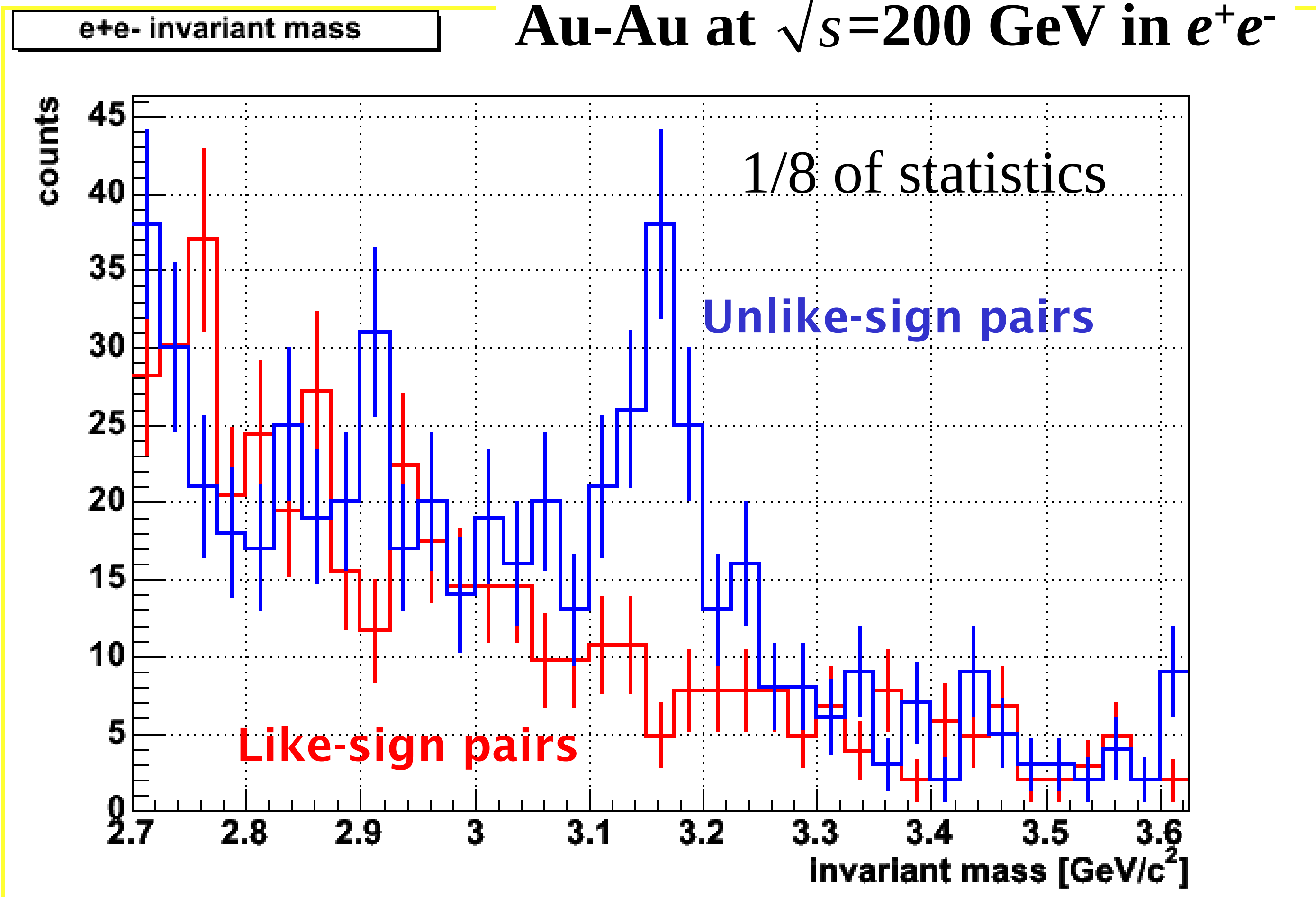
- Weaker absorption compared to lower $\sqrt{s}$?

- Absorption and shadowing are difficult to disentangle.



J/ψ measurement in Au-Au collisions

- The analysis for J/ψ is on going (2004 data).
- About 600 J/ψ are expected in e^+e^- data.



Summary – J/ψ measurement

- The J/ψ production cross sections were measured in *p*-*p*, *d*-Au and Au-Au collisions, and published.
- The J/ψ spin alignment was measured in *d*-Au collisions. No spin alignment was seen within the uncertainty.
- The J/ψ seems suppressed in *d* going direction in *d*-Au collisions. But, the entanglement between absorption and shadowing.
- For hot/dense matter effect, we are analyzing 2004 data.

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PHENIX

*12 Countries; 58 Institutions; 480 Participants**

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*as of January 2004