Lepton and Charm Measurements in the First Two Years of RHIC: An Experimental Overview

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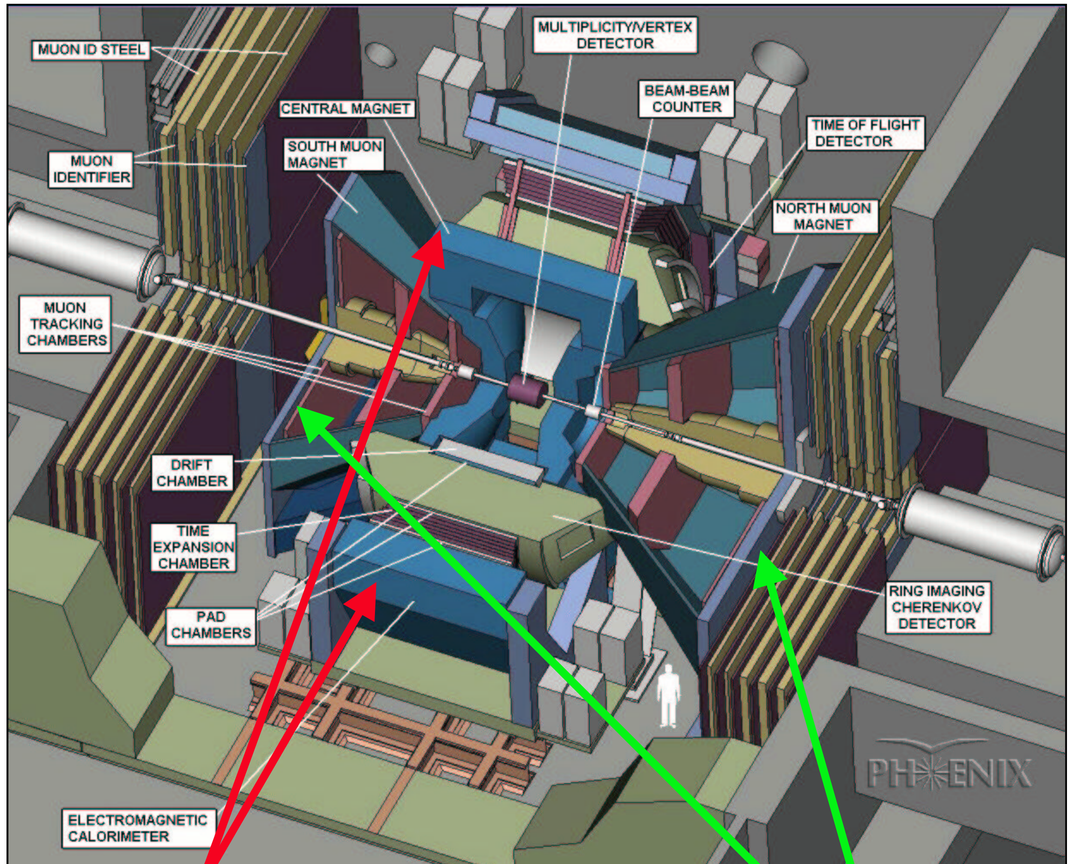
Outline

- lepton & charm measurements at RHIC ⇒ PHENIX
- PHENIX experiment: how to measure leptons
- Run-1: Au + Au @ $\sqrt{s_{NN}}$ = 130 GeV
  - single electrons from charm decays ($c \rightarrow D \rightarrow e + X$)
- Run-2: Au + Au and p+p @ $\sqrt{s_{NN}}$ = 200 GeV
  - single electrons refined
  - dielectron continuum
  - charmonium measurements
    - $J/\Psi \rightarrow e^+ e^-$ in p+p and Au+Au
    - $J/\Psi \rightarrow \mu^+ \mu^-$ in p+p
- summary and outlook

PHENIX experiment

- only RHIC experiment optimized for lepton measurements
- electrons: two central arms
- muons: two forward arms
- Run-1:
  - Au+Au at $\sqrt{s_{NN}}$ = 130 GeV
  - central arms partly instrumented
- Run-2:
  - Au+Au at $\sqrt{s_{NN}}$ = 200 GeV
  - p+p events at $\sqrt{s}$ = 200 GeV
  - central arms fully instrumented
  - one muon arm instrumented

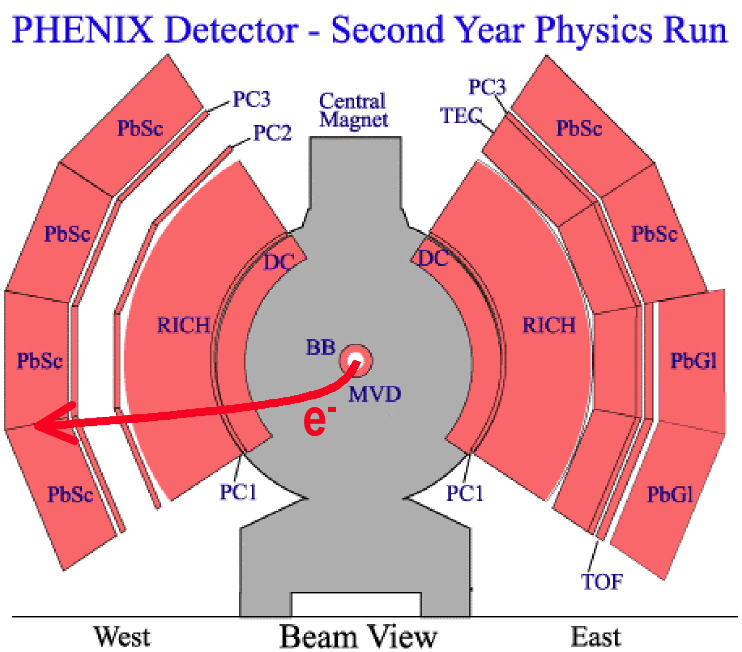


Two central electron/photon/hadron spectrometers

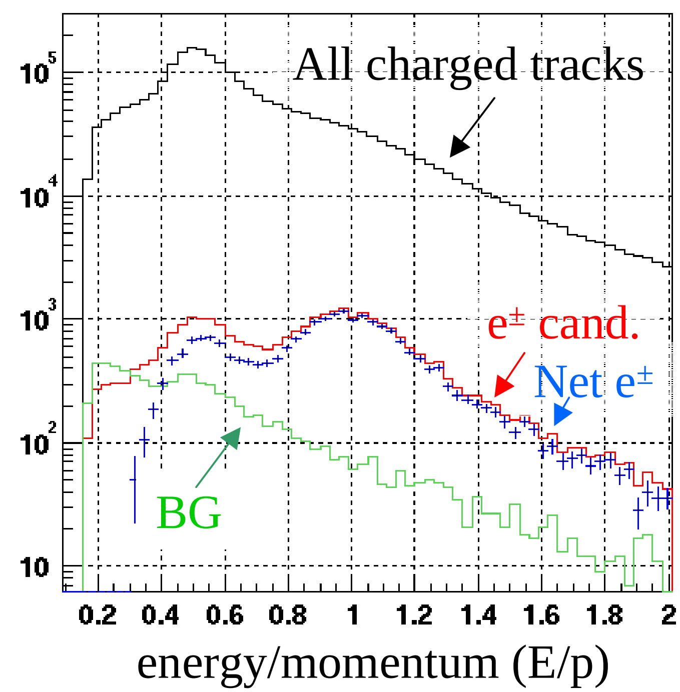
Two forward muon spectrometers

Electron measurement in PHENIX

- **high resolution tracking and momentum measurement**
  - **drift chamber and pad chambers**
  - **$|\eta| < 0.35$ and $p_T > 0.2$ GeV/c**
- **electron identification**
  - **ring imaging Cherenkov detectors and electromagnetic calorimeters**

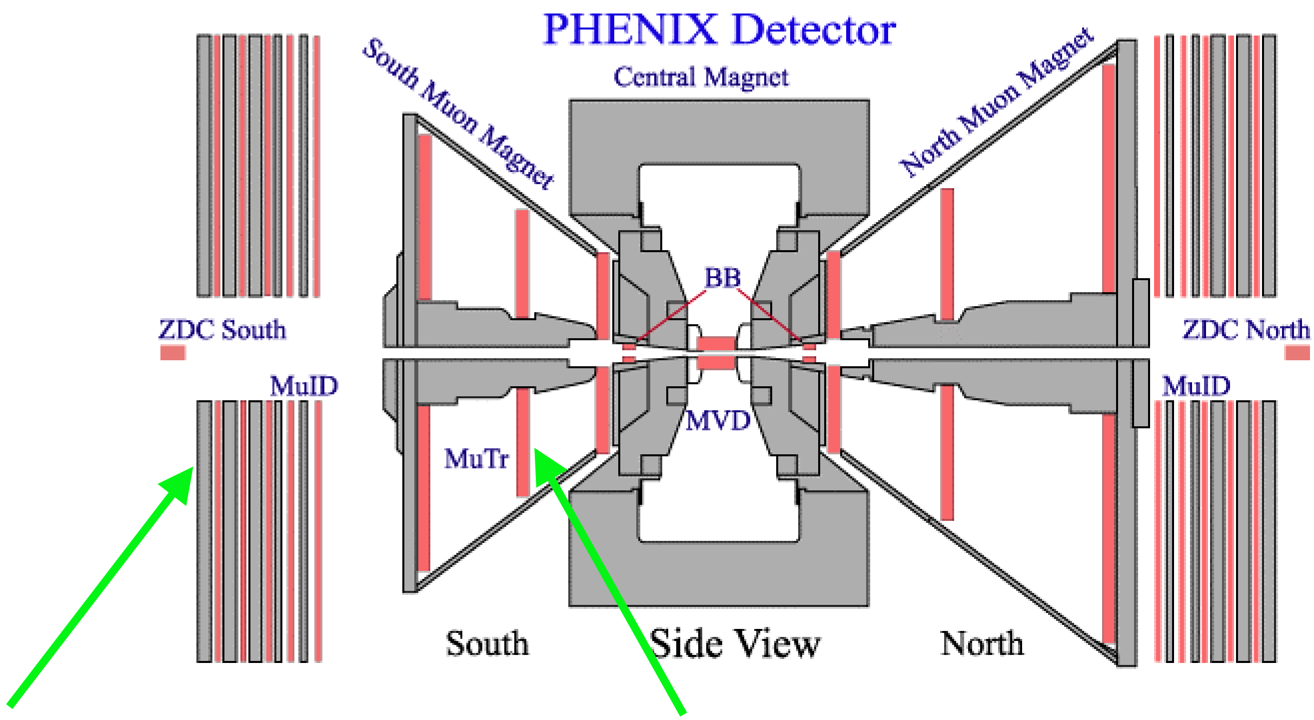


Run-1: half of one arm only



Muon measurement in PHENIX

- **muon identification, tracking, momentum measurement in south muon arm**
  - **forward muons: $1.2 < |\eta| < 2.2$**
  - **$p_{TOT} > 2.0$ GeV/c**



South muon identifier (MuID)

5 gaps per arm filled with planes of transversely oriented Iarocci tubes

South muon tracker (MuTR)

3 octagonal stations of cathode strip chambers per arm

Charm measurements: why are they important?

- charm production in heavy-ion collisions
  - production mainly via gg fusion in earliest stage of collision

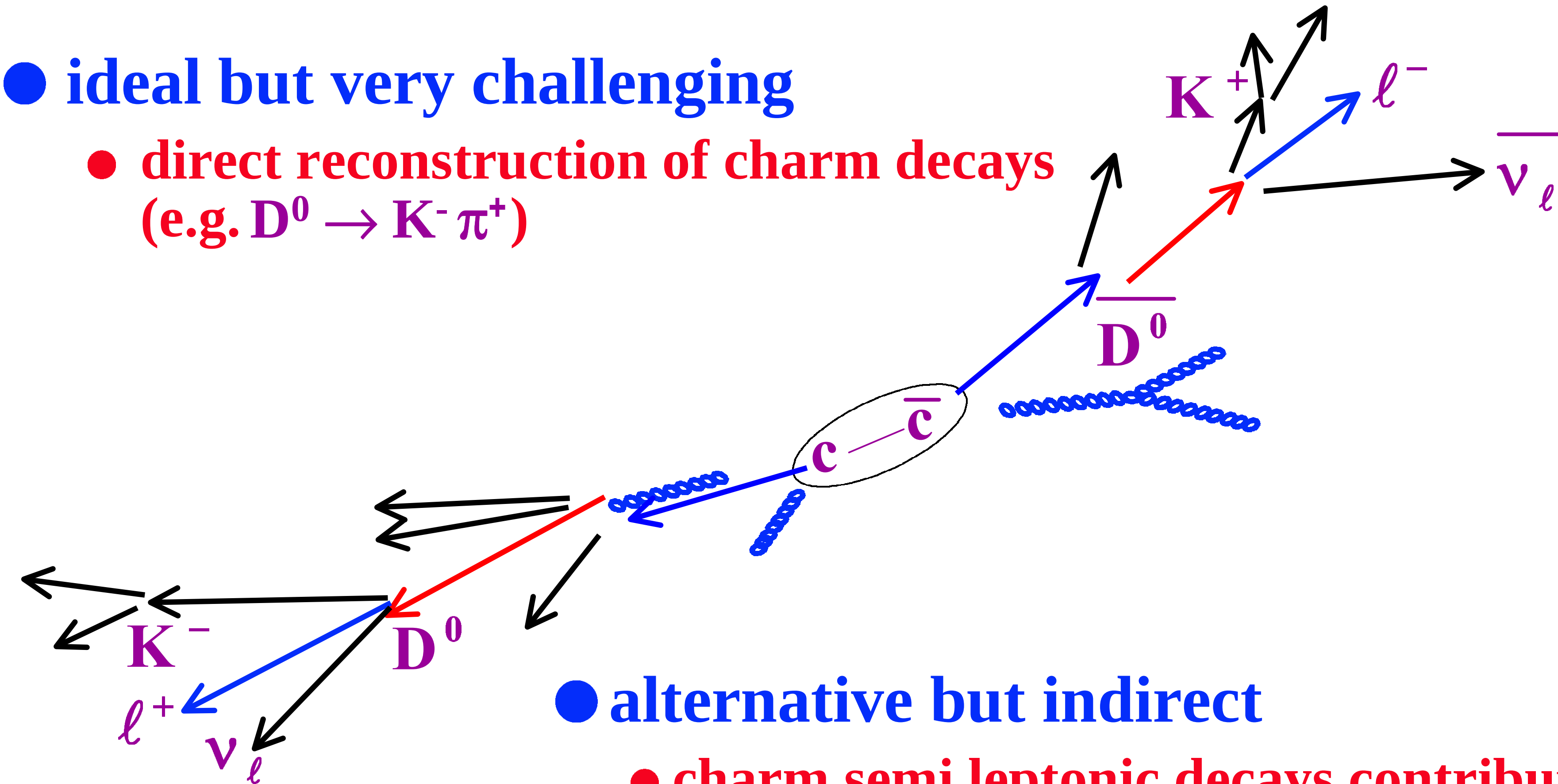
    ➡ **sensitive to initial gluon density**
  - additional thermal production at very high temperature

    ➡ **sensitive to initial temperature**
- propagation through dense (deconfined?) medium
  - energy loss by gluon radiation? $\rightarrow$ softening of D-meson spectra?

    ➡ **sensitive to state of nuclear medium**
- baseline measurement for charmonium suppression
- same arguments hold for bottom measurements
- NO data available from heavy-ion collisions (except quarkonia)

Charm measurements: why are they difficult?

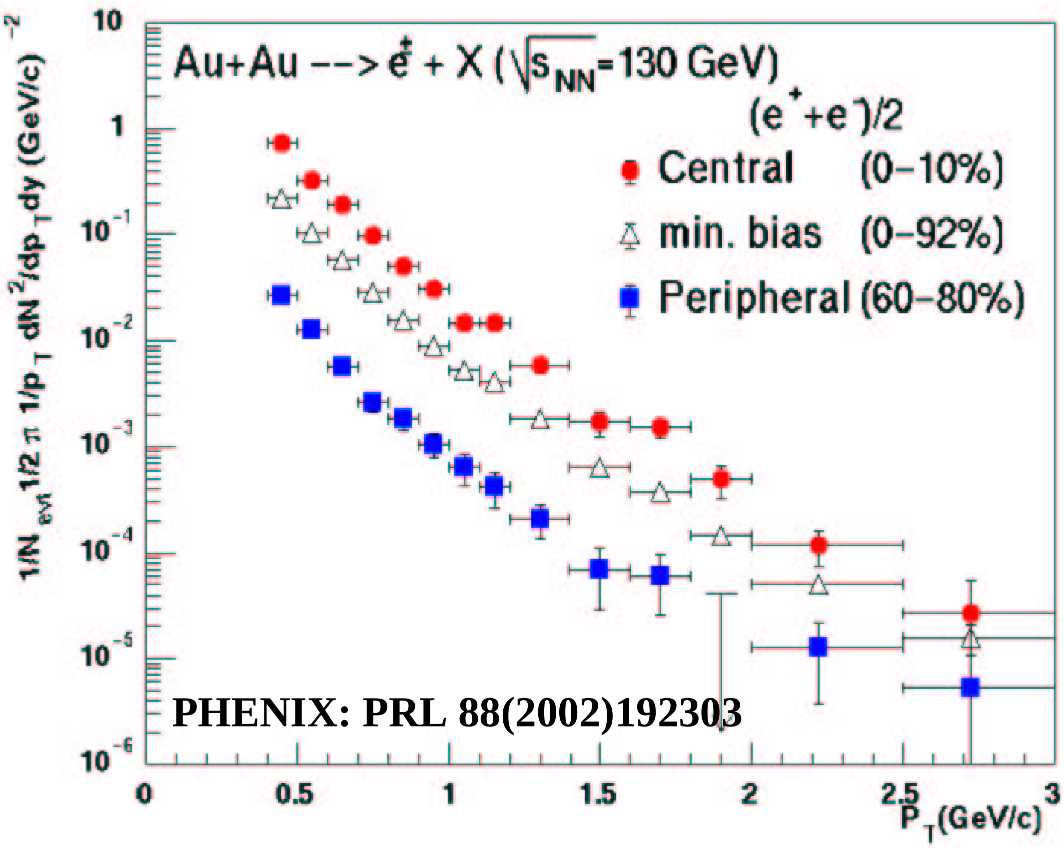
- ideal but very challenging
  - direct reconstruction of charm decays (e.g. $D^0 \rightarrow K^- \pi^+$)



- alternative but indirect
  - charm semi leptonic decays contribute to single lepton and lepton pair spectra
  - 1[st] approach at RHIC: analyze inclusive $e^\pm$ spectra

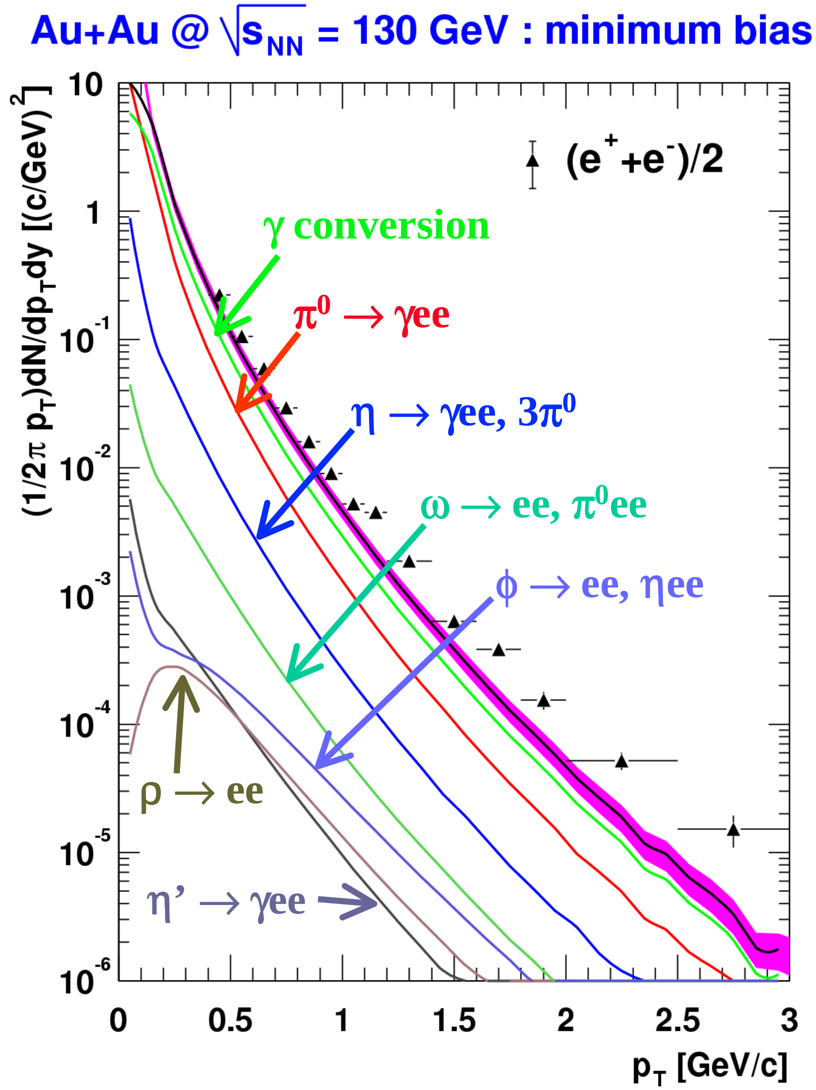
Inclusive $e^{\pm}$ spectra from Au+Au at 130 GeV

- how to extract the contribution from open charm decays?
- cocktail method
  - model known sources as precisely as possible
  - compare with data
- main sources contributing to the $e^{\pm}$ spectra
  - "photonic" sources
    - conversion of photons from hadron decays in material
    - Dalitz decays of light mesons (π^0, η, ω, η', ϕ)
  - "non-photonic" sources
    - semi leptonic decays of open charm (beauty)



Separation of non-photonic $e^{\pm}$: cocktail method

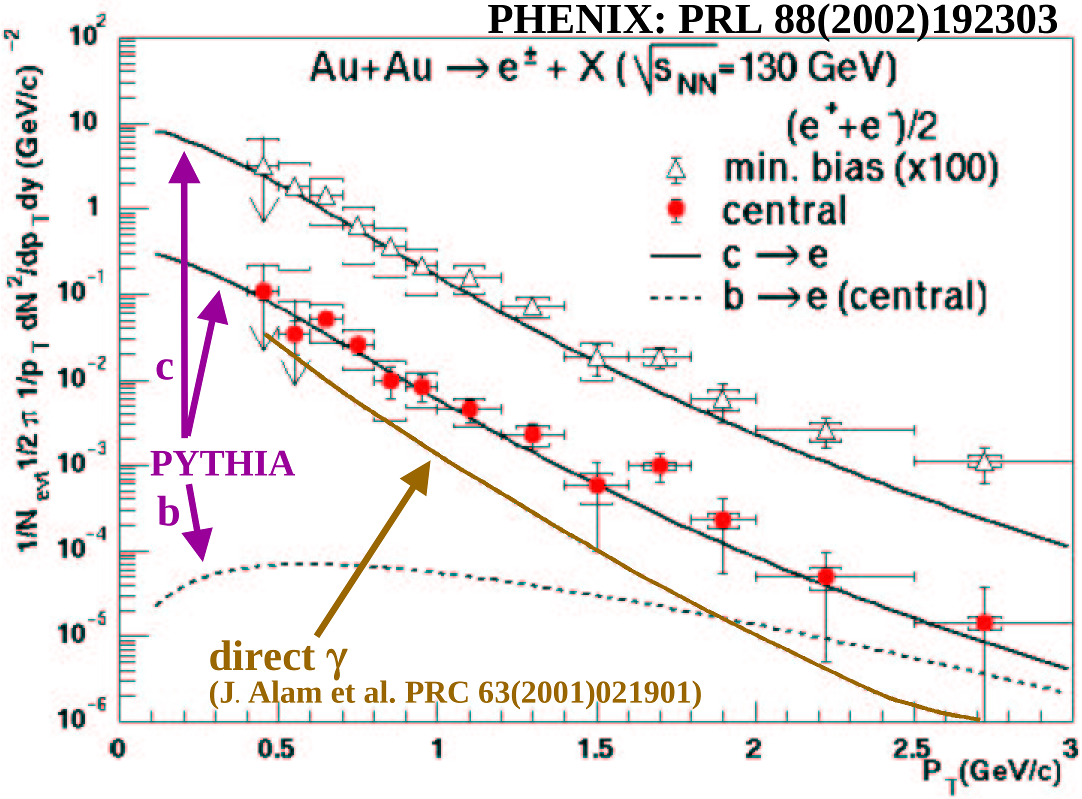
- **light hadron cocktail input:**
  - **π^0 (dominant source at low p_T)**
    - p_T spectra from PHENIX π^0, $\pi^{\pm}$ data
    - power law parameterization
  - **other hadrons**
    - m_T scaling: $p_t \rightarrow \sqrt{p_t^2 + m_h^2 - m_\pi^2}$
    - relative normalization to π at high p_T from other measurements at SPS, FNAL, ISR, RHIC
  - **photon conversions**
    - material known in acceptance
- **excess above cocktail**
  - **increasing with p_T**
  - **expected from charm decays**



Non-photonic $e^{\pm}$ spectra from Au-Au at 130 GeV

- compare excess $e^{\pm}$ spectra with PYTHIA calculation of semi leptonic charm decays ($c \rightarrow e + X$)
  - tuned to fit SPS, FNAL, ISR data ($\sqrt{s}$<63 GeV)
  - for pp at 130 GeV
    - –cross section $\sigma_{c\bar{c}} = 330\ \mu b$
  - scale to Au+Au using the number of binary collisions
- reasonable agreement between data and PYTHIA

PHENIX: PRL 88(2002)192303



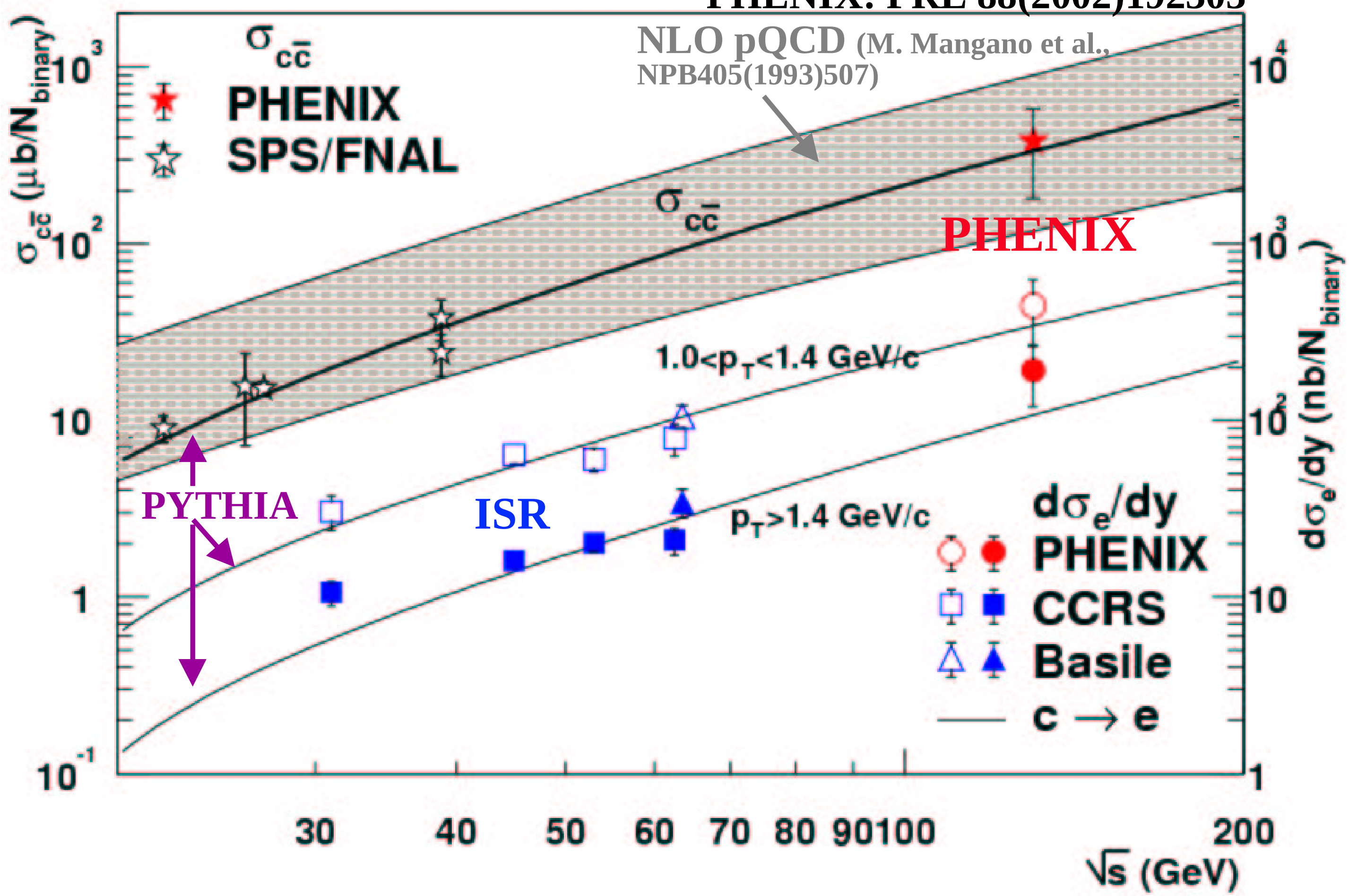
- corresponding charm cross section per binary collision from data
  - assumption: all $e^{\pm}$ are from charm decays
  - fitting PYTHIA to data for $p_T > 0.8$ GeV/c

$$\sigma_{c\bar{c}}^{0-10\%} = 380 \pm 60 \pm 200 \mu b \qquad \sigma_{c\bar{c}}^{0-92\%} = 420 \pm 33 \pm 250 \mu b$$

  - consistent with binary scaling (within large uncertainties)

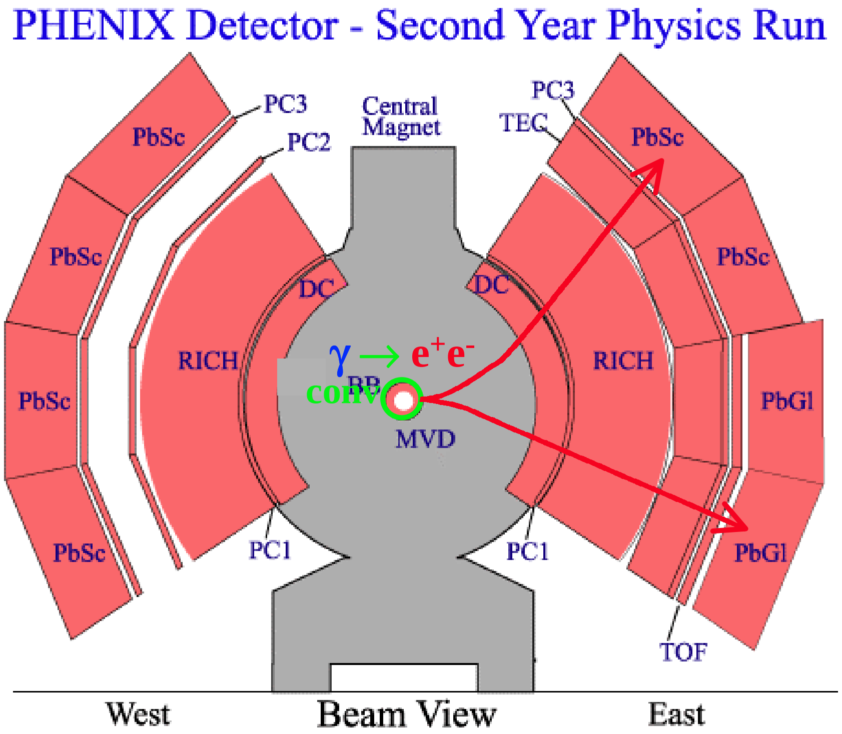
Energy dependence of charm production

PHENIX: PRL 88(2002)192303



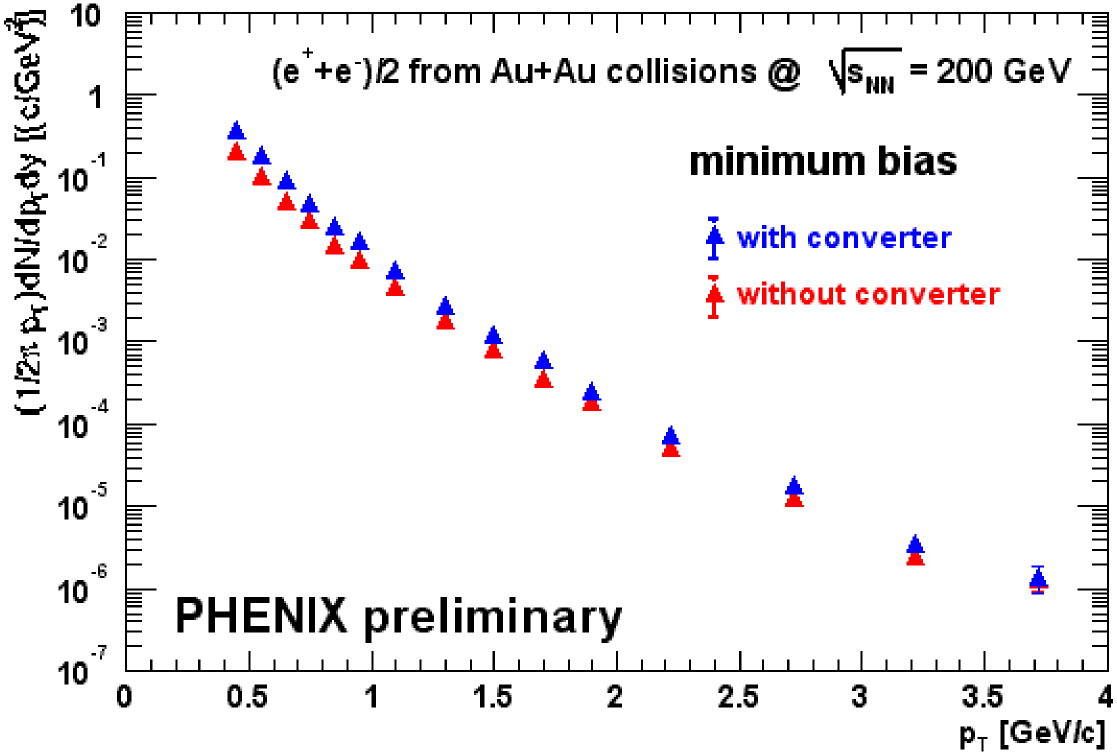
Photon converter in Run-2

- additional photon converter installed in parts of the 200 GeV run in PHENIX central arms
- 1.7 % X_0 brass close to beam line
- additional material increases the number of $e^{\pm}$ from photon conversions by a fixed factor
- ratio between Dalitz decays and photon conversions is fixed by relative branching ratios Dalitz/γγ, which is very similar for π^0 and η



- comparison of spectra with and without converter allows for complete separation of contributions from non-photonic and photonic sources
  - complementary to cocktail method
  - completely different systematics

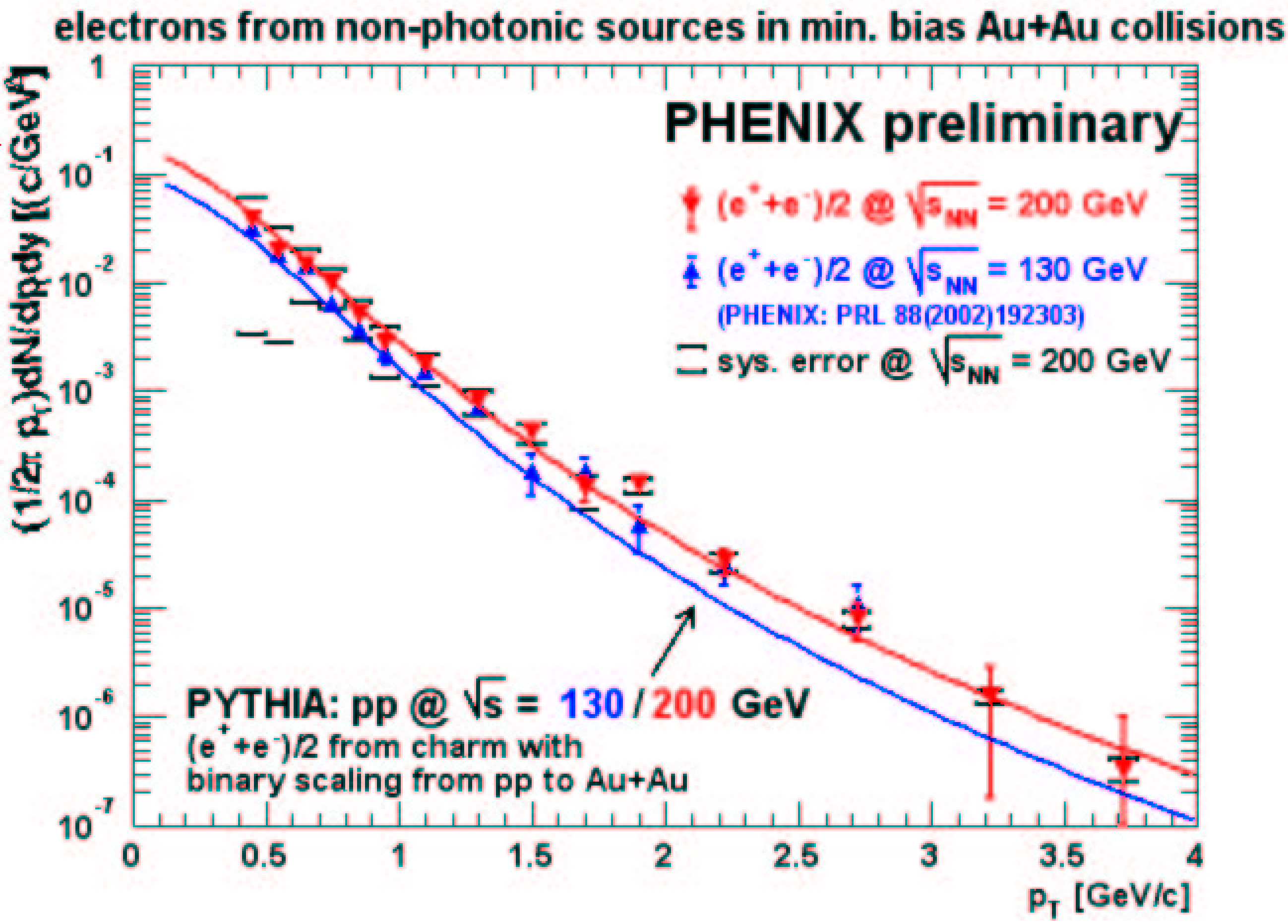
Converter method: proof of principle



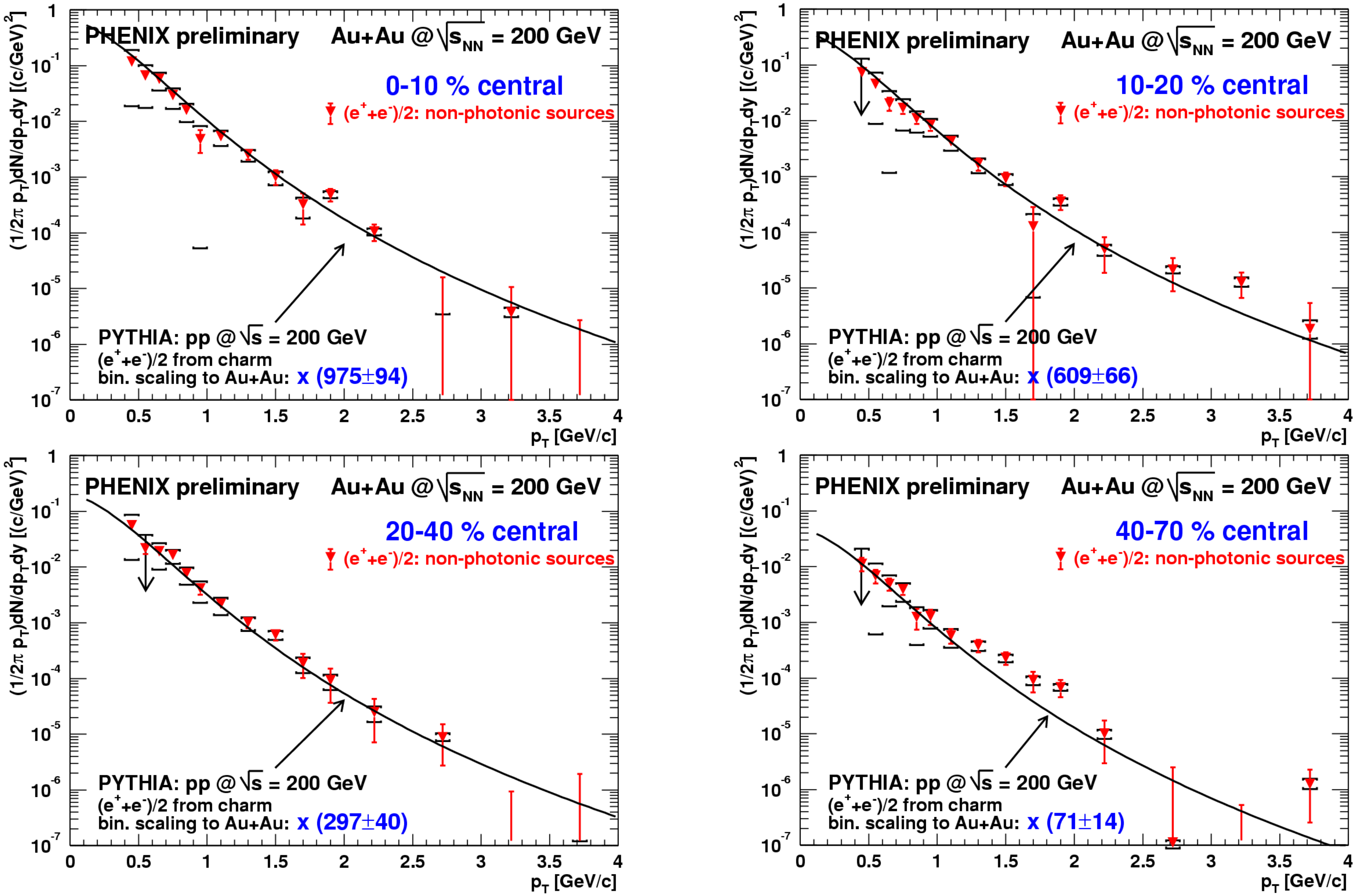
- $e^{\pm}$ spectra with converter: N^c
- $e^{\pm}$ spectra without converter: N
- if no contribution to $e^{\pm}$ from non-photonic sources $\rightarrow$ $N/N^c \approx$ const.
- but spectra approach each other with increasing p_T
  - indication for strong non-photonic source

Non-photonic $e^{\pm}$ spectra from Au-Au at 200 GeV

- non-photonic $e^{\pm}$ yield at 200 GeV
  - larger than at 130 GeV
  - consistent with PYTHIA, assuming binary scaling
  - PYTHIA for pp at 200 GeV: $\sigma_{c\bar{c}}$ = 650 μb
- spectral shape
  - consistent with PYTHIA prediction
- dominant uncertainties
  - at high p_T: statistical error in converter measurement
  - at low p_T: systematical error in material budget



Centrality dependence at 200 GeV



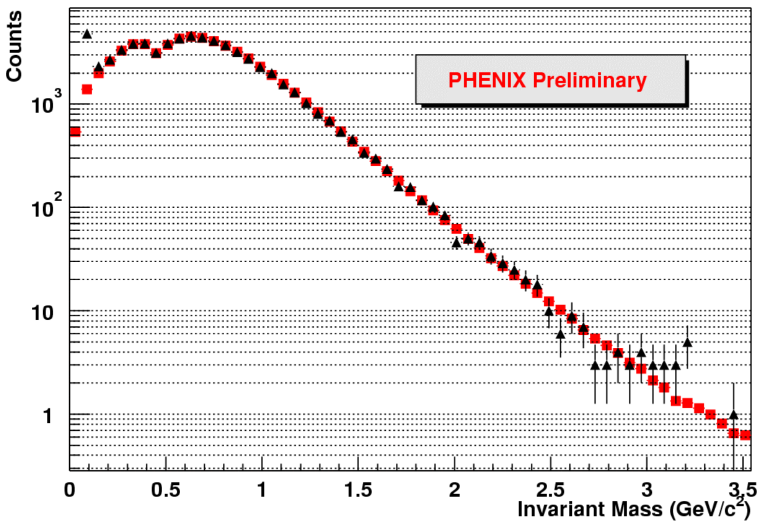
Observations from single $e^{\pm}$ data

- inclusive $e^{\pm}$ are consistent with binary scaling within the current statistical and systematical uncertainties
- a factor of ~3-4 suppression of high p_T hadrons is observed relative to binary scaling
  - no large effect observed in $e^{\pm}$ from charm decays
  - possibly less energy loss of charm quarks in medium due to "dead cone" effect (Y.L. Dokshitzer and D.E. Kharzeev, Phys. Lett. B519(2001)199)
- NA50 has inferred a factor of ~3 charm enhancement from dimuon measurements at SPS (NA50: Eur. Phys. J. C14(2000)443)
  - no large effect observed at RHIC
  - possible cross check: dileptons at RHIC
- next steps (work in progress):
  - charm in p+p as reference
  - complementary leptonic channels

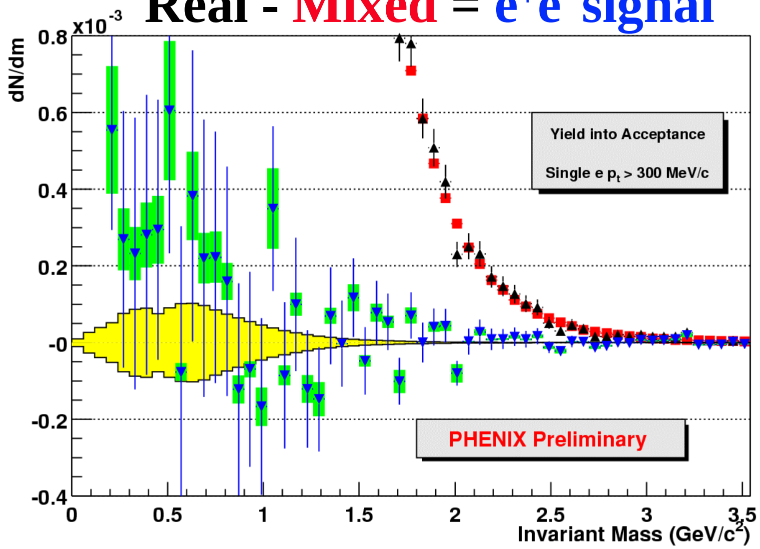
Dielectron continuum

- why is it interesting?
  - intermediate mass region (IMR): between the ϕ and the J/Ψ mass
    - may be dominated by charm decays at RHIC
    - another charm measurement with completely different systematics
  - low mass region (LMR): below the ϕ mass
    - dominated by light hadron decays
    - excess dielectron observed at SPS (NA45/CERES) and attributed to in-medium modifications of the ρ meson due to the restoration of approximate chiral symmetry
- and why it is so difficult to measure?
  - combinatorial background needs to be subtracted to extract small signal

Real and Mixed e^+e^- distributions

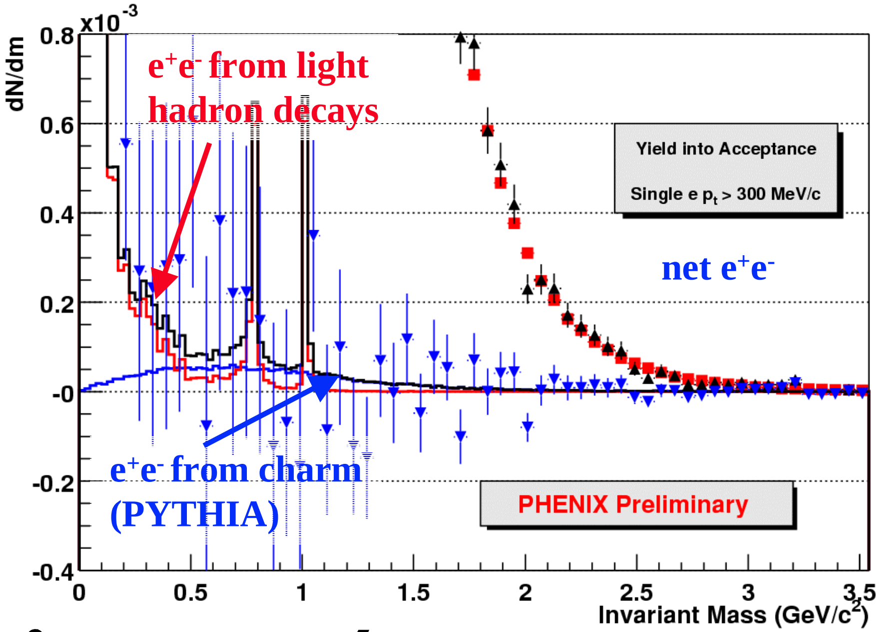


Real - Mixed = e^+e^- signal



Dielectron continuum: results

- comparison with cocktail including
  - light hadron decays using vacuum masses and branching fractions
  - charm decays from PYTHIA
- integrated yield in PHENIX expectated from cocktail
  - LMR (0.3 -1.0 GeV): ~9.2 x 10^{-5}
  - IMR (1.1 -2.5 GeV): ~1.5 x 10^{-5}
- PHENIX preliminary data



$$(N/N)_{M} = 4 \pm \ (\ )^{+2}_{-4}\ (\ ) \times 10^{-5}$$

$$(N/N)_{M} = 0.8 \pm 2.6\ (stat)^{+1.0}_{-0.8}\ (sys) \times 10^{-5}$$

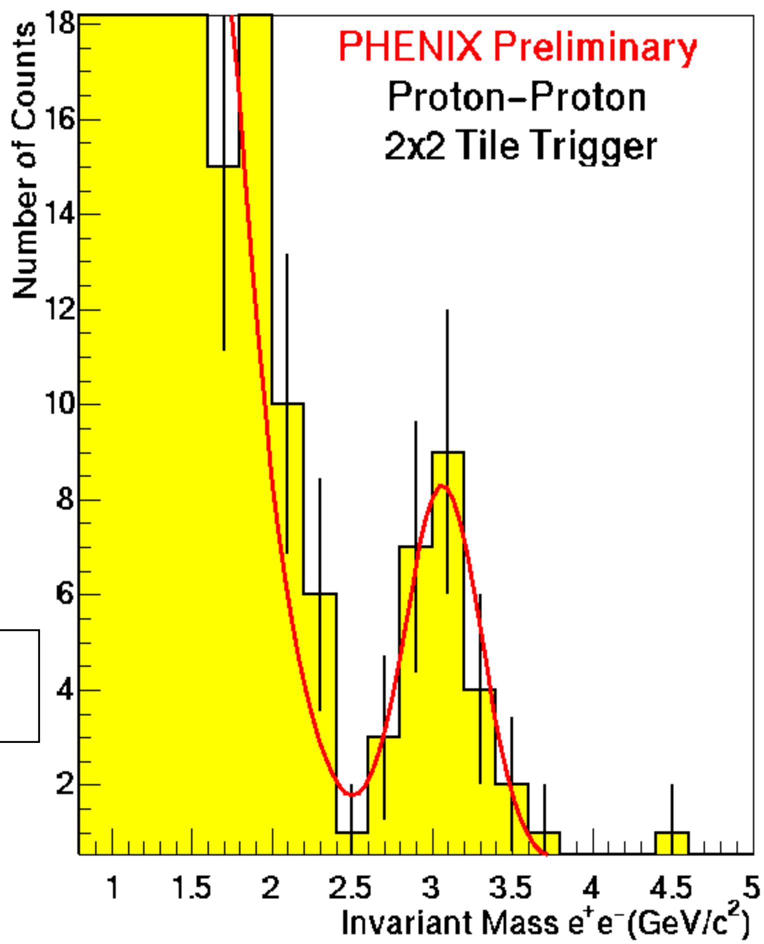
- reasonable agreement within huge uncertainties
- improvement requires future Au+Au run at RHIC design luminosity

J/Ψ physics

- why is it interesting?
  - possible signature of the deconfinement phase transition
  - J/Ψ yield in heavy ion collisions can be
    - suppressed, because of Debye screening of the attractive potential between c and $\bar{c}$ in the deconfined medium
    - enhanced, because of $c\bar{c}$ coalescence as the medium cools
- important to measure J/Ψ in Au+Au, p+p (Run-2), and d+Au (Run-3) to separate "normal" nuclear effects
- preliminary data from PHENIX
  - $J/\Psi \rightarrow e^+ e^-$ and $J/\Psi \rightarrow \mu^+\mu^-$ in p+p at $\sqrt{s}$ = 200 GeV
  - $J/\Psi \rightarrow e^+ e^-$ in Au+Au at $\sqrt{s_{NN}}$ = 200 GeV

$J/\Psi \rightarrow e^+e^-$ in p+p collisions at $\sqrt{s}$ = 200 GeV

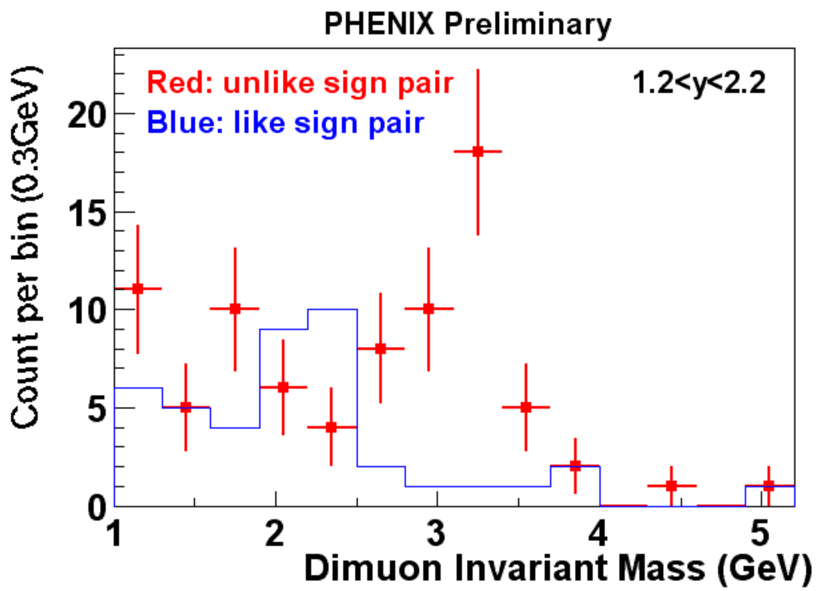
- ~ 1.0 billion pp collisions sampled with el.magn. calorimeter hardware trigger (single $e^{\pm}/\gamma$)
- represents about half of total p+p statistics

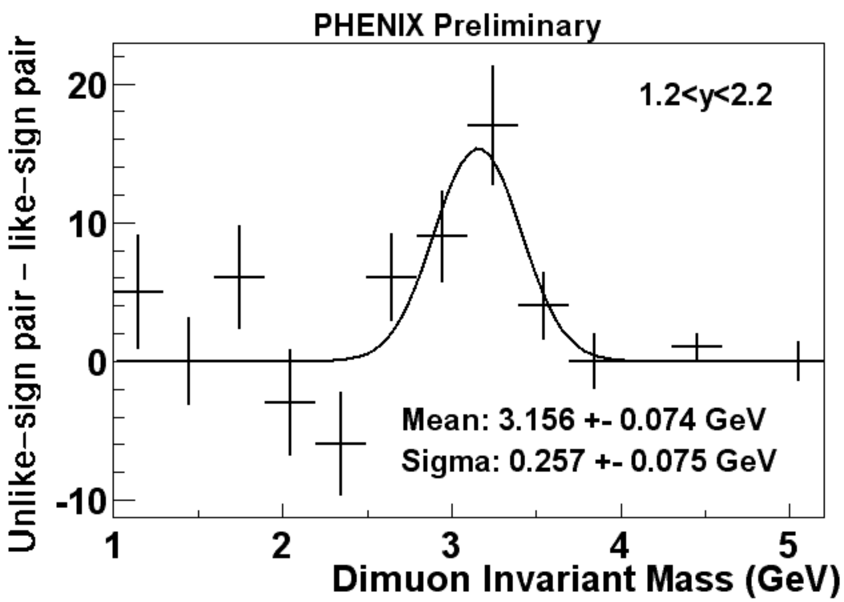


$N_{J/\psi}$ = 24 ± 6 (stat) ± 4 (sys)

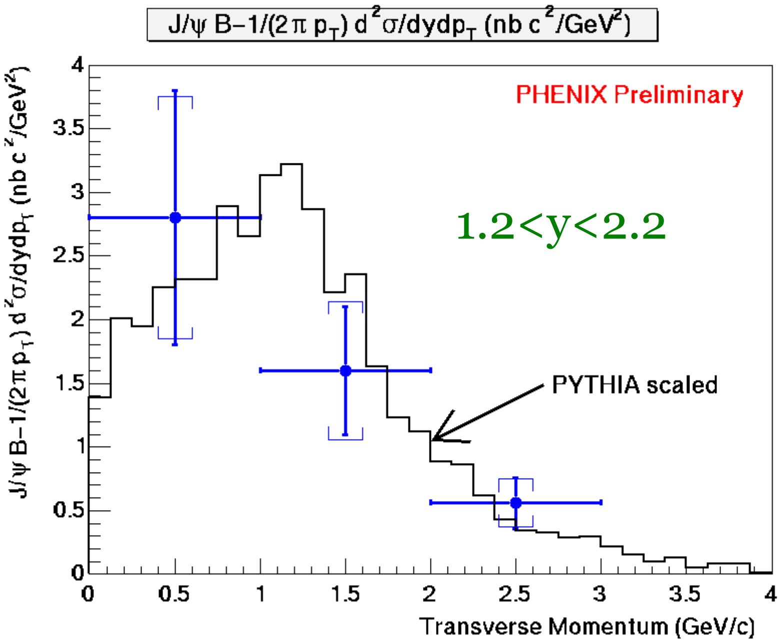
$J/\Psi \rightarrow \mu^+\mu^-$ in p+p collisions at $\sqrt{s}$ = 200 GeV

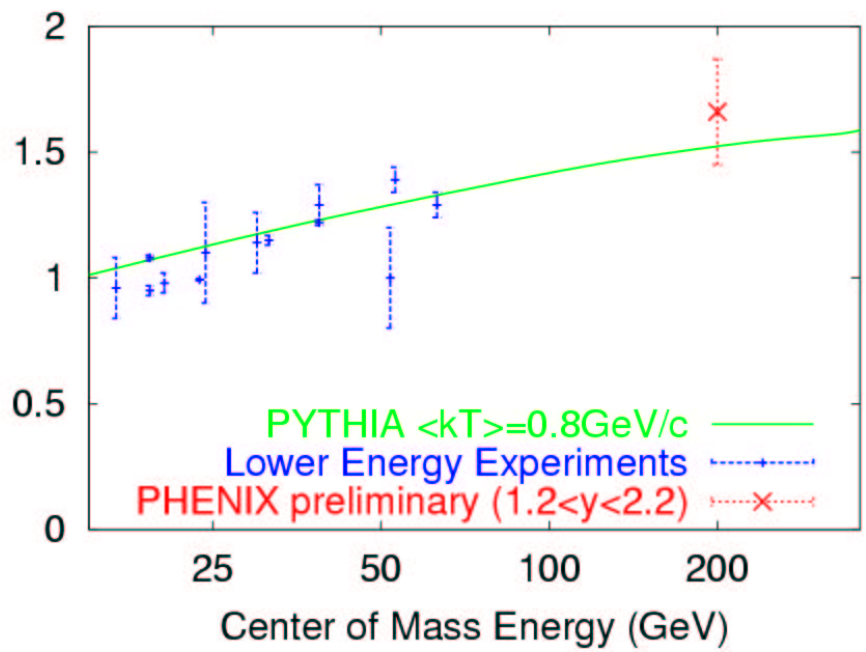
- ~1.7 billion pp collisions sampled with muon level-1 hardware trigger





J/Ψ p_T distribution in p+p collisions at $\sqrt{s}$ = 200 GeV

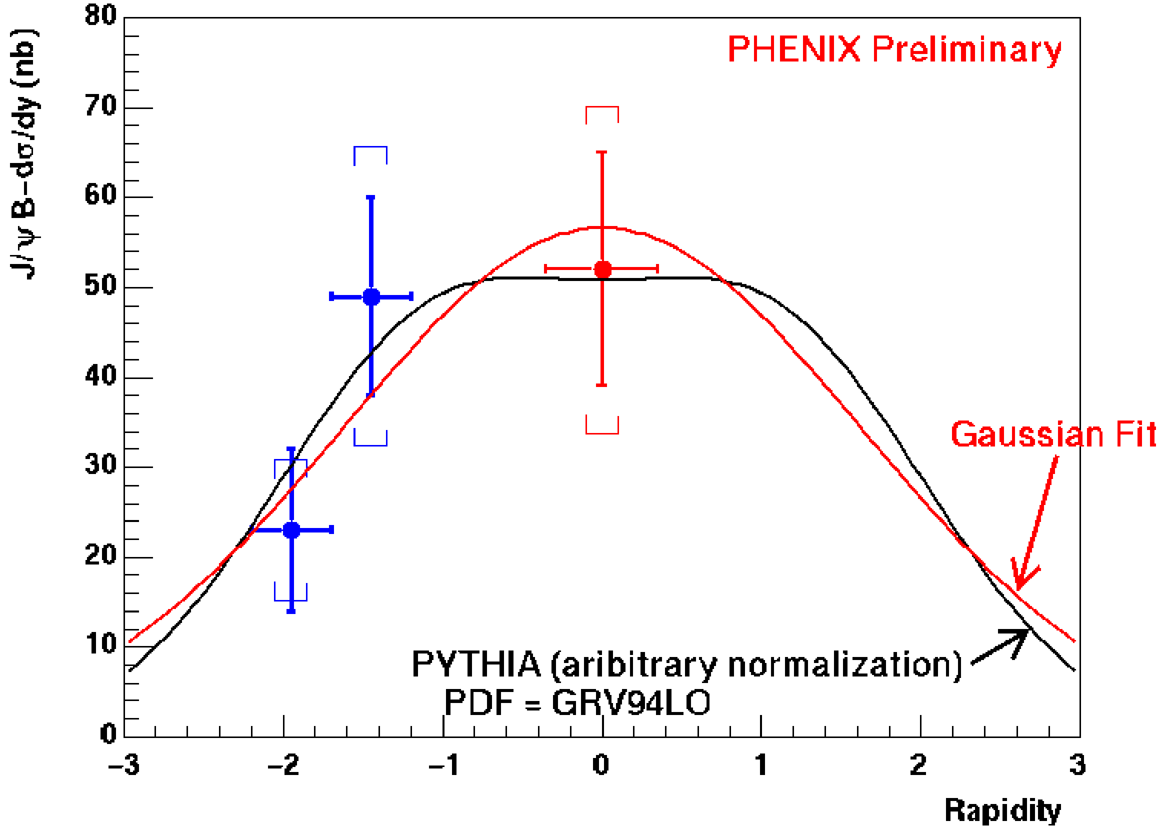




- shape of p_T distribution is consistent with a PYTHIA calculation
- average p_T
  - $\langle p_T \rangle_{y=1.7}$ = 1.66 ± 0.18 (stat.) ± 0.09 (syst.) GeV/c
  - slightly larger than measured at lower energies
  - consistent with a PYTHIA extrapolation to RHIC energy

J/Ψ rapidity distribution & integrated cross section

- **combination of muon measurement at forward rapidity and electron measurement at central rapidity**
  ⇒ rapidity distribution
- **integrated cross section consistent for**
  - **Gaussian fit**
  - **shape from PYTHIA**

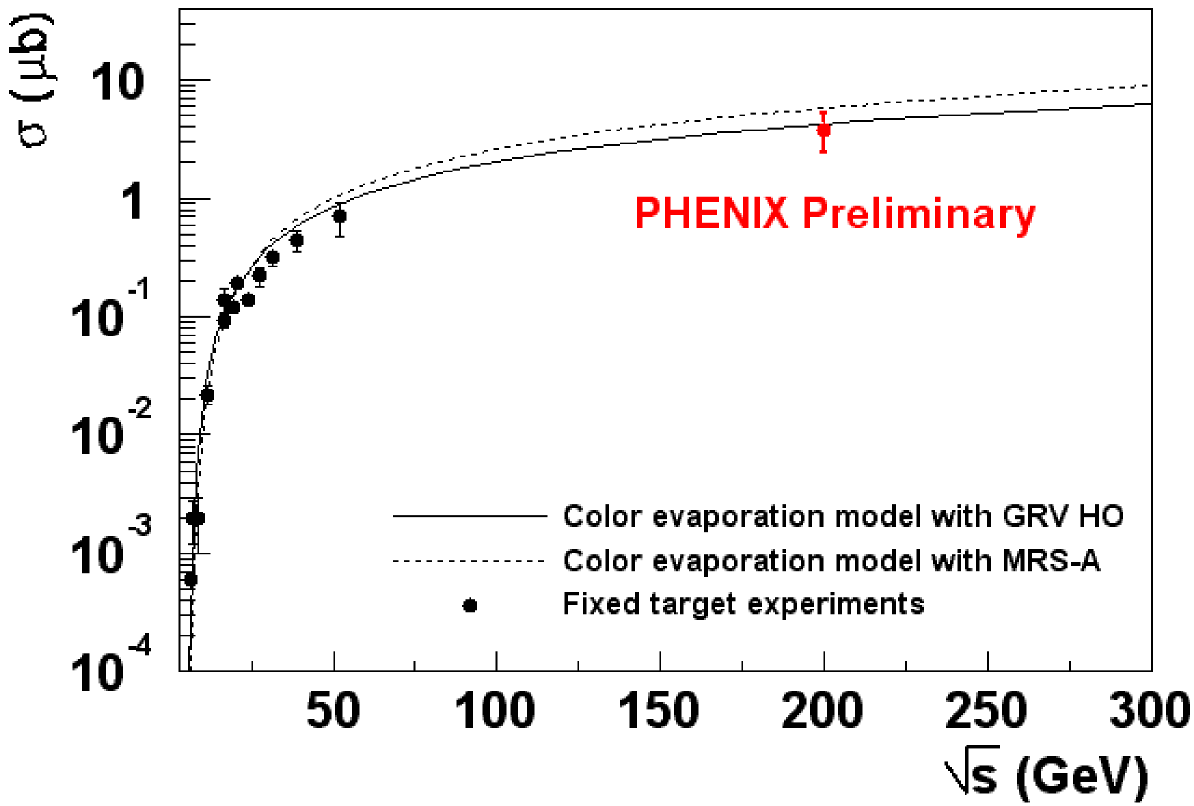


$$B\cdot\sigma(pp \to J/\psi + X) = 26 \pm 36\ (stat) \pm 79\ (sys)\ nb$$

$$\sigma(pp \to J/\psi + X) = 3.8 \pm 0.6(stat) \pm 1.3(sys)\ \mu b$$

√s dependence of J/Ψ production in p+p

- comparison with lower energy data and model predictions

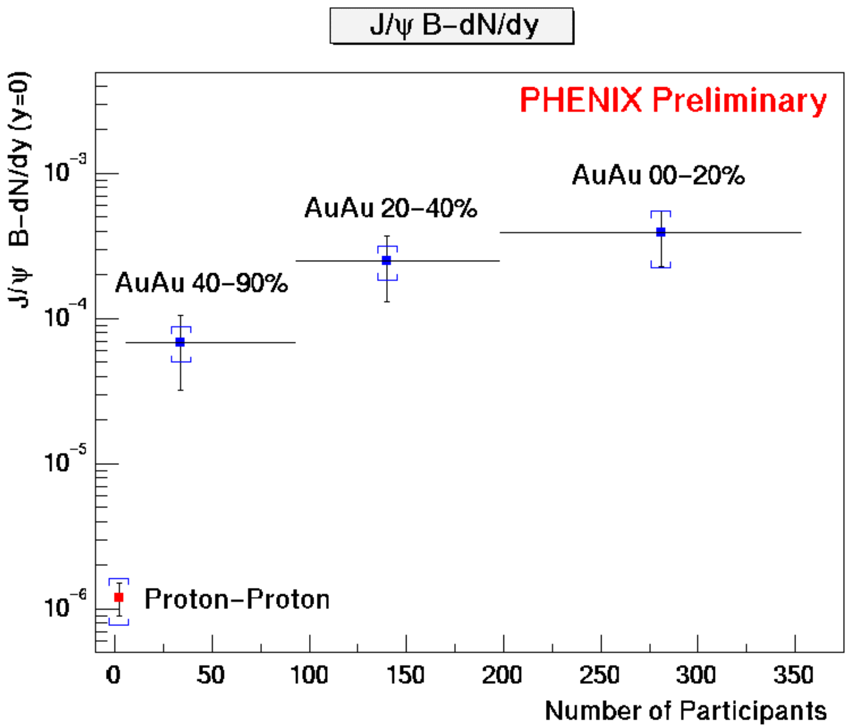


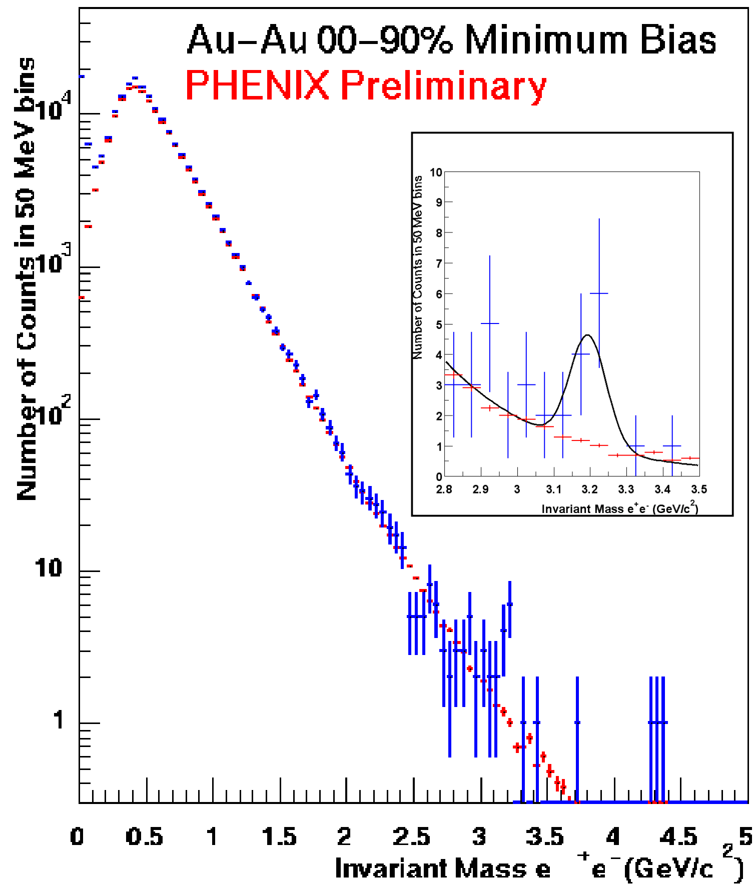
CEM predictions (J.F. Amundson et al.:Phys.Lett.B390:323-328,1997)

$J/\Psi \rightarrow e^+e^-$ in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV

- e^+e^- invariant mass analysis
- very limited statistics

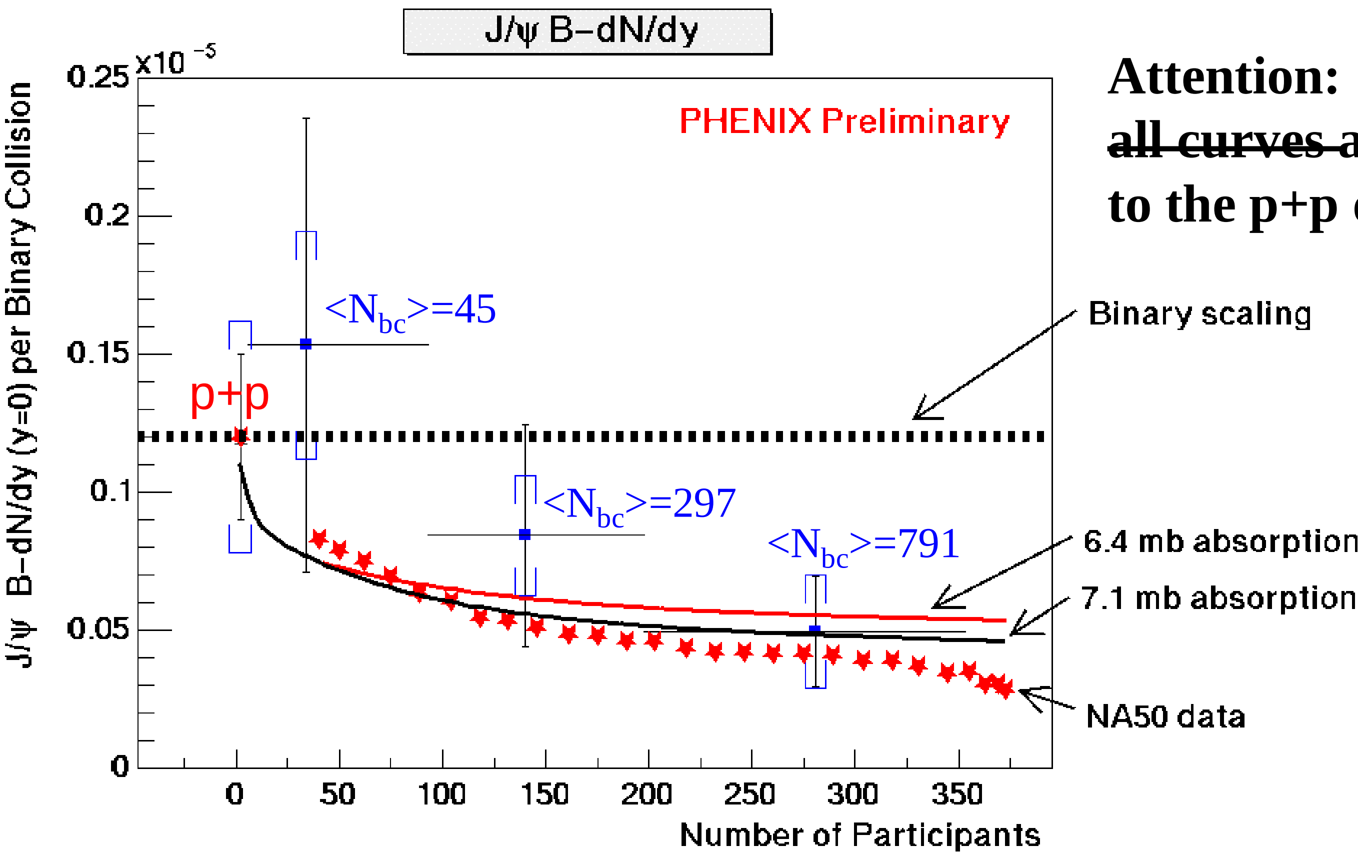
  N=10.8 ± 3.2 (stat) ± 3.8 (sys)
- split minimum bias sample into 3 centrality classes





Centrality dependence of J/Ψ yield

- J/Ψ B-dN/dy per binary collision compared to different models for J/Ψ absorption patterns
  - J/Ψ scale with the number of binary collisions
  - J/Ψ follow normal nuclear absorption with given absorption cross sections
  - J/Ψ follows same absorption pattern as observed by NA50 (Phys. Lett. B521(2002)195)



Attention:
~~all curves~~ are normalized to the p+p data point!

present accuracy

NO discrimination power between different scenarios

Summary and outlook

- **open charm @ RHIC**
  - single $e^{\pm}$: no direct charm measurement, but as close as it gets
  - Au+Au $\rightarrow$ cc: little room for large in-medium effects
  - p+p $\rightarrow$ cc: reference data are needed
- **dielectron continuum and J/Ψ @ RHIC**
  - capability to measure rare probes has been demonstrated
  - studies of continuum and J/Ψ suppression/enhancement pattern require more statistics to draw conclusions
  - long runs of p+p (Run-3), d+Au (Run-3), and Au+Au (Run-4) are needed at RHIC design luminosity