Physics of Charmonium Production at RHIC

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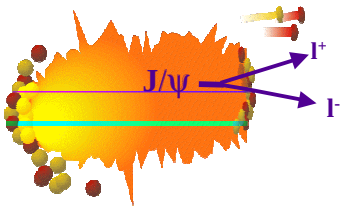
Outline

- **Experimental Capabilities to measure charmonium at RHIC**
  - PHENIX
  - STAR
- **Charmonium Production in heavy ion collisions**
  - Charmonium Suppression or Enhancement?
  - How we can disentangle various factors contributing to the production?



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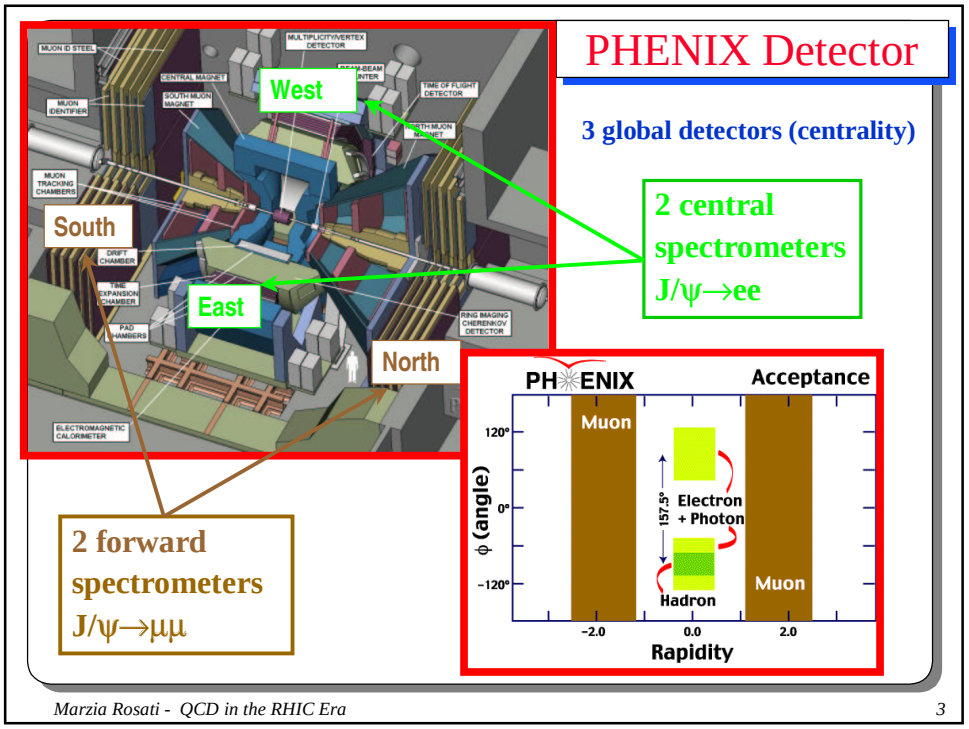
PHENIX Detector
3 global detectors (centrality)
West
East
South
North
2 central spectrometers
J/ψ→ee
2 forward spectrometers
J/ψ→μμ
PHENIX
Acceptance
Muon
Muon
Electron + Photon
Hadron
157.5°
120°
0°
−120°
φ (angle)
−2.0
0.0
2.0
Rapidity
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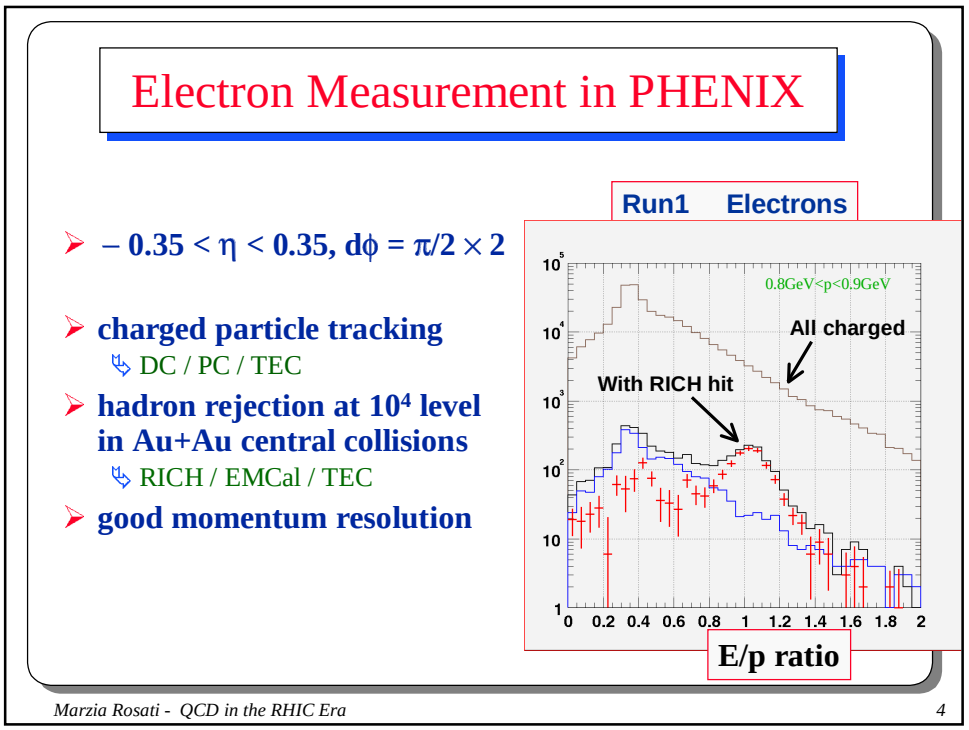
Electron Measurement in PHENIX
– 0.35 < η < 0.35, dϕ = π/2 × 2
charged particle tracking
DC / PC / TEC
hadron rejection at 10⁴ level in Au+Au central collisions
RICH / EMCal / TEC
good momentum resolution
Run1 Electrons
0.8GeV<p<0.9GeV
All charged
With RICH hit
E/p ratio
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Muon Measurement in PHENIX

- **$1.2 < \eta < 2.4$ (north), $1.2 < \eta < 2.2$ (south), full ϕ coverage**

PHENIX with 2 forward arms

- **tracking with 3 stations of chambers in magnetic field**
- **muon ID with 5 layers of steel absorber and Iarocci tubes**
  - low energy cutoff at 2 GeV/c

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PHENIX Measurement Capabilities

	central (electron) arms	forward (muon) arms
rapidity coverage	**$-0.35 < y < 0.35$**	**$1.2 < y < 2.4$ (north)** **$1.2 < y < 2.2$ (south)**
J/Ψ acceptance	**0.8 % of $B_{ee}\sigma$** **(4 % of $B_{ee}\sigma$ in $\|y\| < 0.5$)**	**4.3 % of $B_{\mu\mu}\sigma$ (per arm)**
ϒ acceptance	**1.7 % of $B_{ee}\sigma$** **(5 % of $B_{ee}\sigma$ in $\|y\| < 0.5$)**	**3.0 % of $B_{\mu\mu}\sigma$ (per arm)**
J/Ψ mass resolution	**20 MeV**	**105 MeV**
ϒ mass resolution	**160 MeV**	**180 MeV**

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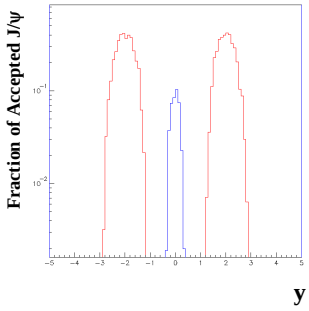
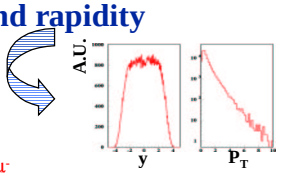
Detector Acceptance for J/ψ → dileptons

- **Acceptance is the percentage of J/ψ which have both leptons going through the detector**
- **Using the p-N cross section predictions as calculated at NLO for the transverse momentum and rapidity distribution**





For J/ψ →μ⁺μ⁻

$$\frac{N_{J/\psi}(accepted)}{N_{J/\psi}(total)} = 8.6\%$$

For J/ψ →e⁺e⁻

$$\frac{N_{J/\psi}(accepted)}{N_{J/\psi}(total)} = 0.75\%$$

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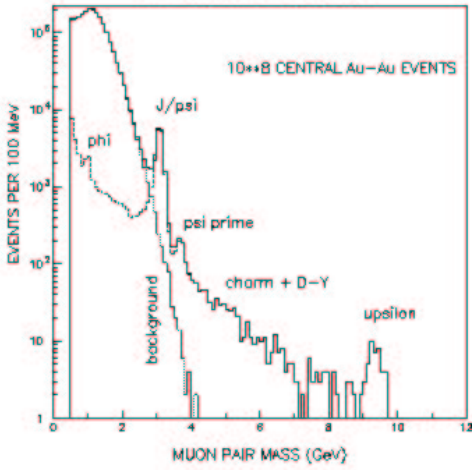
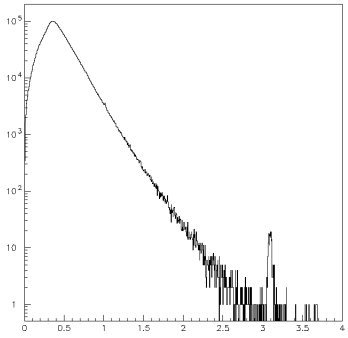
Simulated performance of PHENIX spectrometers





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Expected Quarkonium Statistics in PHENIX

- **In one year of RHIC running at full luminosity**
- **Assuming no anomalous suppression**

	PHENIX Muon North	PHENIX Muon South	PHENIX Electron
Y_{CM}	1.2 – 2.4	1.2 – 2.2	-0.35 – 0.35
J/Ψ	640k	610k	55k
Ψ'	11.5k	10.5k	900
ϒ	382	331	----

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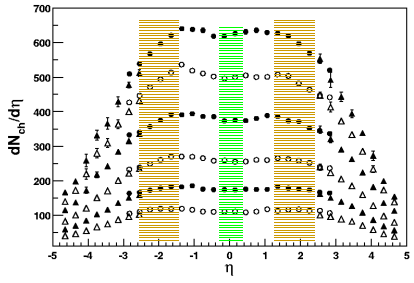
Charmonium in Central & Forward Arms

- **simultaneous access to regions with different energy densities**
  - rapidity density of produced particles as a measure
  - good test if suppression is a function of local energy density



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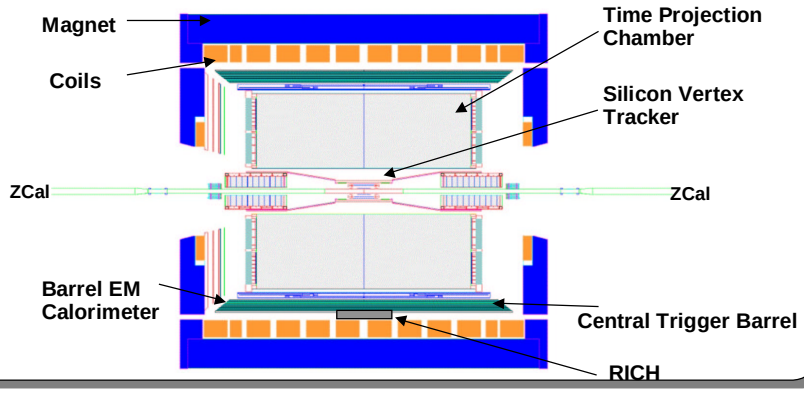
STAR Electron Measurement

- $-1 < \eta < 1$, $d\phi = 2\pi$
- **Particle Identification**
  - EMCAL, dE/dx in SVT and TPC



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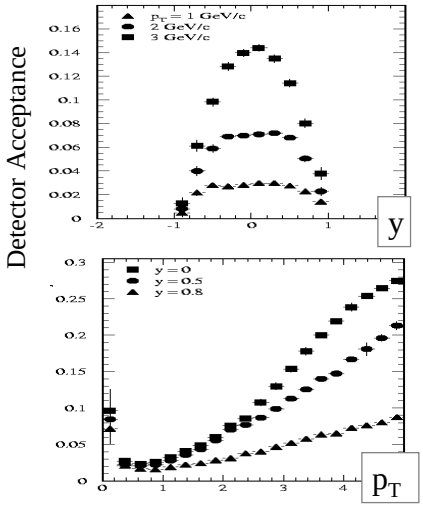
Charmonium Measurement in STAR

- **J/ψ is accepted if both electrons P>1.5GeV/c and fall into the EMC**
- **40K J/ψ for 1 year of running at full luminosity with signal/background=1:3**



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Charmonium Production in A+B Collisions

- **The cross section can be written as:**

$$d\sigma_{AB}(y, p_T) = A \cdot B \cdot d\sigma_{NN}(y, p_T) \cdot S(y, p_T)$$

Elementary nucleon-nucleon cross section

Suppression factor
•initial state (gluon shadowing)
•final state (ordinary nuclear absorption and medium effect)

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Do we understand the basic production mechanism?

- **The production mechanism of charmonium is not yet well understood.**
- **We need a good measurement of J/ψ cross section in p+p at RHIC.**
- **Data from RHIC can help to test QCD based models.**

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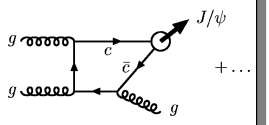
Charmonium Production in pp Collisions

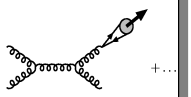
- **In the past few years new results in pp collisions have revealed the severe shortcoming of early charmonium production models.**

  Large discrepancy found in J/ψ, ψ‘ production at Tevatron in early ’90 (~ x 50) compared to leading ord Color Singlet model



- **The Non Relativistic Quantum Chromo Dynamics (NRQCD) formalism factorizes the short distance physics of the heavy quark creation and the long distance physics of bound state formation.**

  Within NRQCD, heavy quark pair can also be produced in a Color Octet state and radiate soft gluons at late times after quark pair has expanded to the charmonium size



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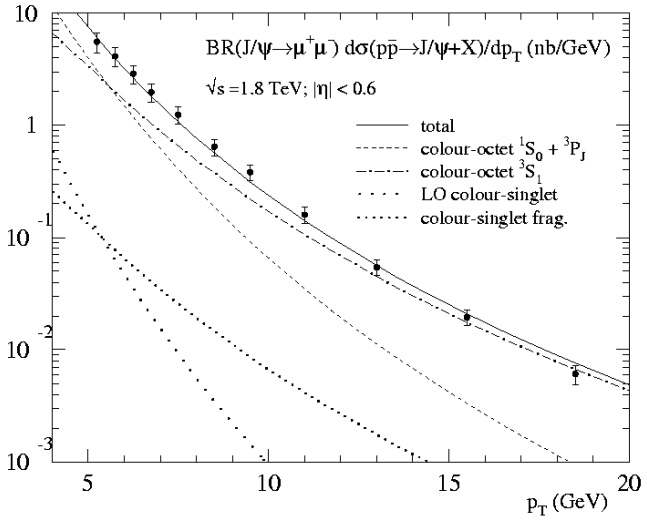
$p\bar{p} \rightarrow J/\psi + X$ at the Tevatron



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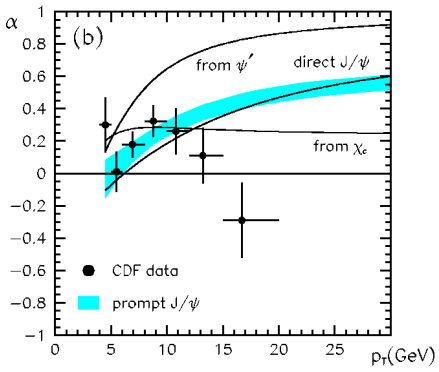
Ψ and Ψ' Polarization

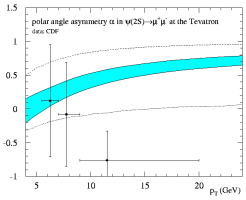
At large p_T (>>m_c) production is dominated by gluon fragmentation. Gluon is on shell and transverse:



$$\frac{d\Gamma}{d\cos\theta} = 1 + \alpha\cos^2\theta$$

For transverse polarization

α=1



Maybe different power counting needed in NRQCD? (Fleming)

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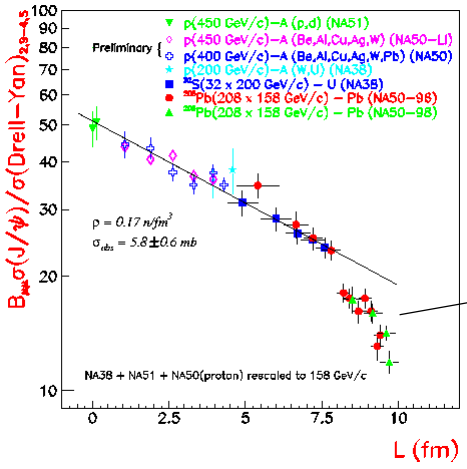
Charmonium Production in AB Collisions NA50 Measurement



Anomalous suppression

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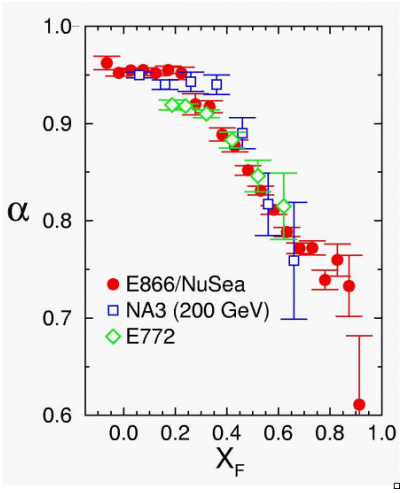
Charmonium Production in pA Collisions

- **Charmonium production and open charm in pA collisions will help disantangle the gluon shadowing, from the charmonium nuclear absorption and distringuish between**
  - cold nuclear matter
  - versus
  - hot (deconfined) nuclear matter



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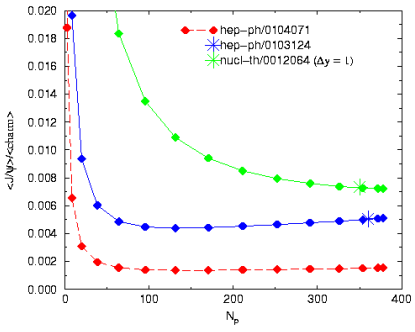
Charmonium enhancement?

- **Statistical hadronization coalescence models a nd dynamical models for formation in QGP predict J/ψ enhancement**
- **Measuring open charm will be an important control**



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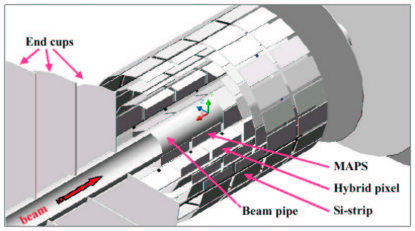
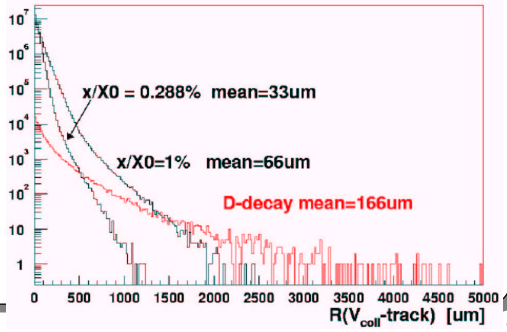
PHENIX Upgrade

- **Ultimately we want to detect open charm "directly" via displaced vertices**
- **Development of required Si tracking for PHENIX well underway**





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What to expect for Run 2?

- **170M events sampled (minbias + triggered)**
- **In the absence of anomalous suppression or additional thermal production at RHIC, and assuming**
- **$\sigma(pp \rightarrow J/\psi) = 3.3 \times 10^{-6}$ b we will reconstruct of order:**
  - ~100 $J/\psi \rightarrow ee$
  - ~500 $J/\psi \rightarrow \mu\mu$

Note: there is a large uncertainty (both in production and reconstruction) in this estimate

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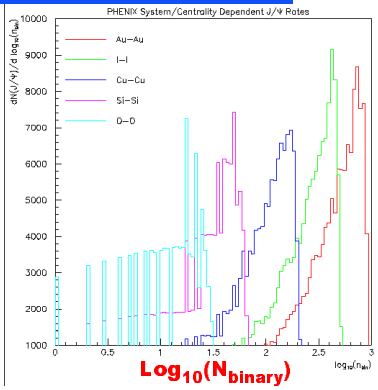
In the future

- **Full exploration of J/Ψ production versus "N_{binary}" ~ A(b)*A(b) via**
  - A long run with Au-Au
  - A series of shorter light ion runs
- **p-A or d-A running**



Species	Number of J/Ψ's (0.6 R.Y. - AuAu, 0.1 R.Y. - others)
OO	1.15E+05
SiSi	1.44E+05
CuCu	1.56E+05
II	1.73E+05
AuAu	1.79E+05

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Experimental Plan

- **To establish that the (to be observed) charmonium suppression/enhancement pattern results from QGP**
  - Study vs. p_T
  - Study vs. centrality
  - Study in lighter systems
  - Study vs. a *control* (a vector meson that should not be suppressed/enhanced, the Upsilon)

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How can theorists help?

- **Detailed predictions of the J/ψ suppression and enhancement**
  - Their rapidity dependencies
  - Their dN/dη dependencies
  - Their consequences on other observables
  - etc. etc.
- **Detailed calculation to estimate temperature will various quarkonium states i.e. if all J/ψ melt are we at T_c**

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Conclusions

- **PHENIX and STAR have the capability to measure charmonium production at RHIC**
  - wide rapidity coverage
  - high statistics
  - variety of beam combination
- **the future looks bright! Both theorists and experimentalists have a lot of work to do**

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