Quarkonium Measurements with PHENIX

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Bar Harbor, June 17th 2002

Overview of baseline PHENIX detector

Quarkonium measurements from RHIC I

PHENIX upgrades for RHIC II

Upsilon Spectroscopy with RHIC II luminosity

Charm and Bottom measurements with RHIC II

PHENIX Physics Capabilities

designed to measure rare probes:

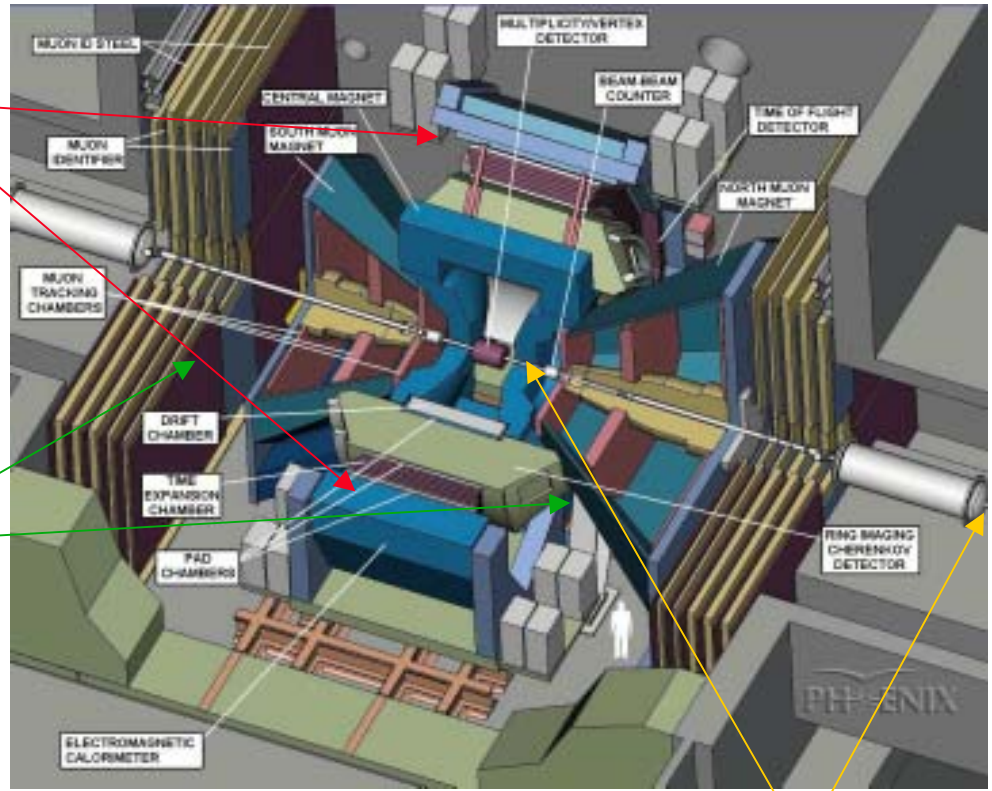
Au-Au & p-p spin

+ high rate capability & granularity
+ good mass resolution and particle ID
- limited acceptance

- **2 central arms:**

  electrons, photons, hadrons
  - **charmonium** $J/\psi, \psi' \rightarrow e^+e^-$
  - **vector meson** $\rho, \omega, \phi \rightarrow e^+e^-$
  - **high** p_T π^o, π^+, π^-
  - **direct photons**
  - **open charm**
  - **hadron physics**

- **2 muon arms:** **muons**
  - **"onium"** $J/\psi, \psi', \Upsilon \rightarrow \mu^+\mu^-$
  - **vector meson** $\phi \rightarrow \mu^+\mu^-$
  - **open charm**



- **combined central and muon arms:**

  charm production $DD \rightarrow e\mu$

- **global detectors**

  forward energy and multiplicity
  - **event characterization**

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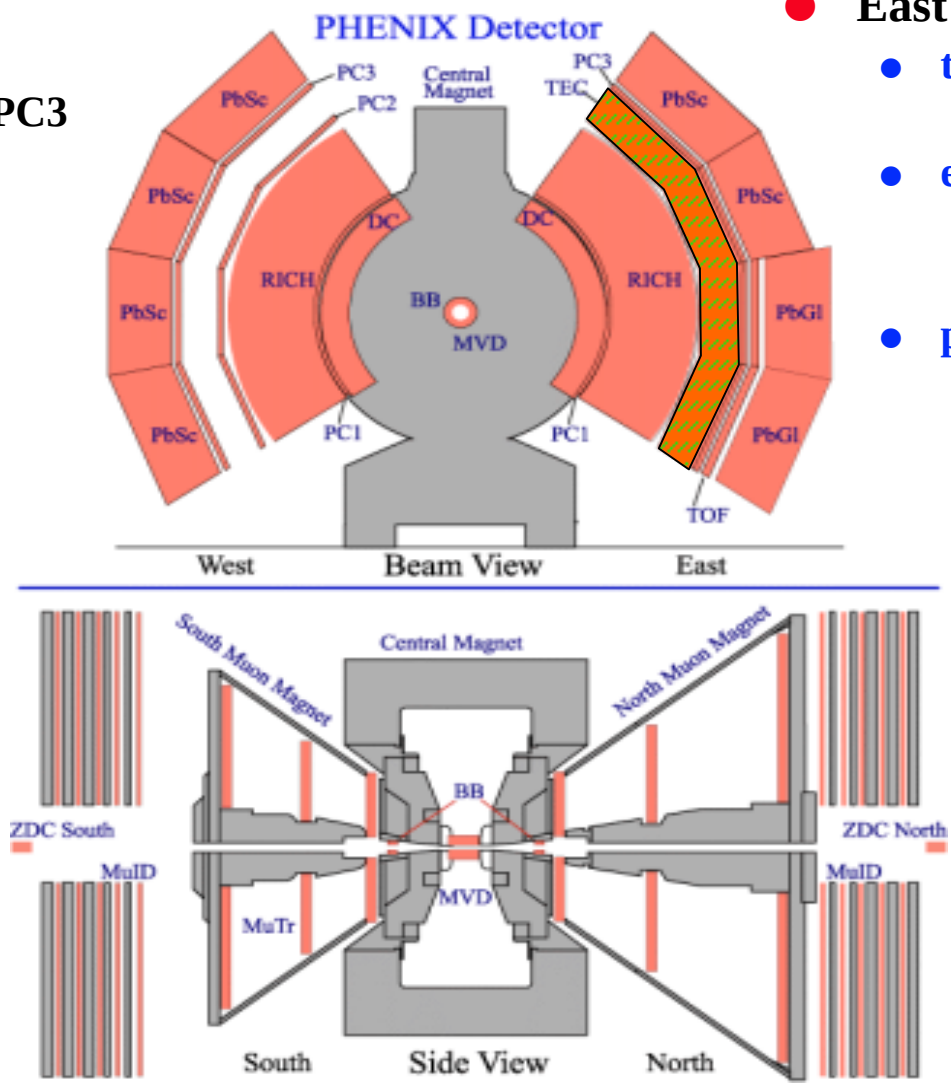
PHENIX Setup Completed in 2003

- **West Arm**
  - tracking:
    DC,PC1, PC2, PC3
  - electron ID:
    RICH,
    EMCal
  - photons:
    EMCal

- **South & North Arm**
  - tracking:
    MuTr
  - muon ID:
    MuID

- **Other Detectors**
  - Vertex
    & centrality:
    ZDC, BBC,
    MVD



- **East Arm**
  - tracking:
    DC, PC1, TEC, PC3
  - electron & hadron ID:
    RICH,TEC/TRD,
    TOF, EMC
  - photons:
    EMCal

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Acceptance, Cross Sections and Resolution

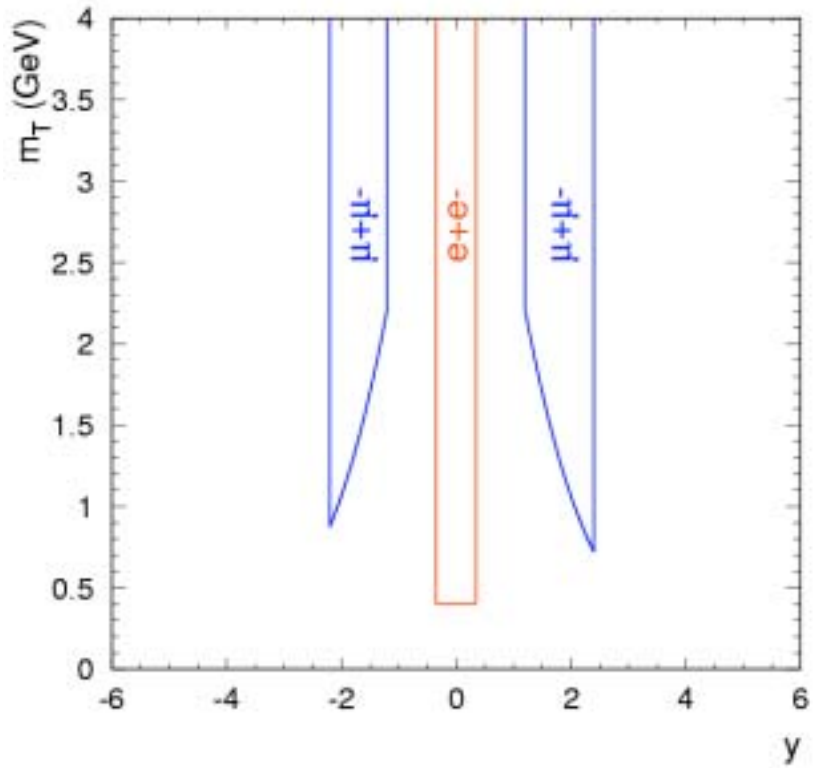
central arms: $J/\psi \rightarrow e^+e^-$

$p_t > 200$ MeV/c

$\Delta\phi = 2x\ \pi/2$

$-0.35 < \eta < 0.35$

central arm	acceptance (4π)	σ_{pp}	$B_{ee}\ \sigma_{pp}\ A^{1.92}$ a Au-Au	resolution σ_m
J/ψ	0.8%	3.3 μb	40 μb	20 MeV
Υ	1.7%	10 nb	110 nb	120 MeV



muon arms: $J/\psi,\ \psi',\ \Upsilon \rightarrow \mu^+\mu^-$

$p > 2$ GeV/c

$\Delta\phi = \pi$

$-1.2 < \eta < -2.2$

$1.2 < \eta < 2.4$

muon arms	acceptance (4π)	σ_{pp}	$B_{ee}\ \sigma_{pp}\ A^{1.92}$ a Au-Au	resolution σ_m
J/ψ	8.6%	3.3 μb	430 μb	110 MeV
Υ	6%	10 nb	380 nb	200 MeV

~ factor 10 larger acceptance for μμ

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Expected statistics for Au-Au RHIC I

- **One full Au-Au running season at design luminosity (run-3/run-4)**
  - **10 weeks running at 2 10^{26} cm^{-2} s^{-1} average luminosity**
  - **uptime 50% (RHIC) and 50% (PHENIX)**

recorded integrated luminosity: 300 μb^{-1}

- **all min.bias events are sampled with 2nd level trigger (bandwidth limit 8 kHz)**
- **additional losses for pessimistic estimate**
  - **trigger/reconstruction efficiency 50%**
  - **vertex position within ± 30cm 50%**

	μμ ideal	μμ reconstructed	ee ideal	ee reconstructed
J/ψ	125000	31000	12000	3000
ψ'	4600	1100	450	110
Υ	120	30	30	7

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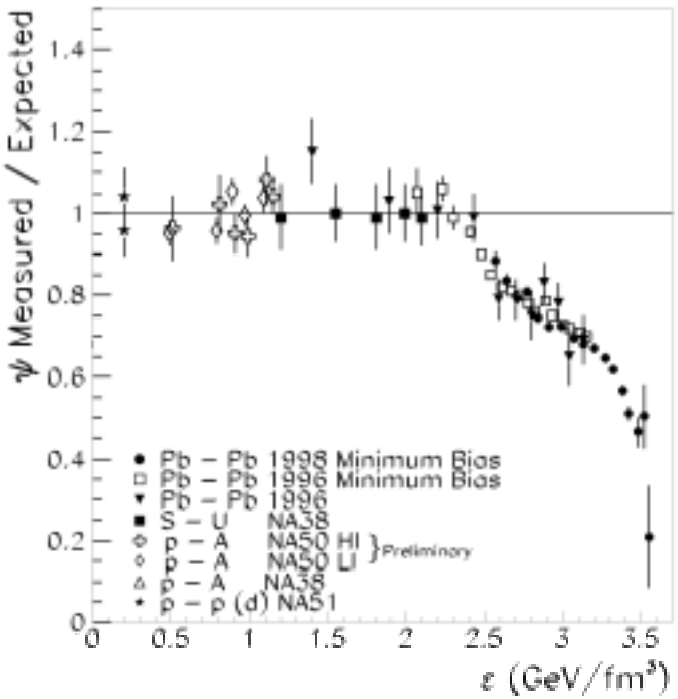
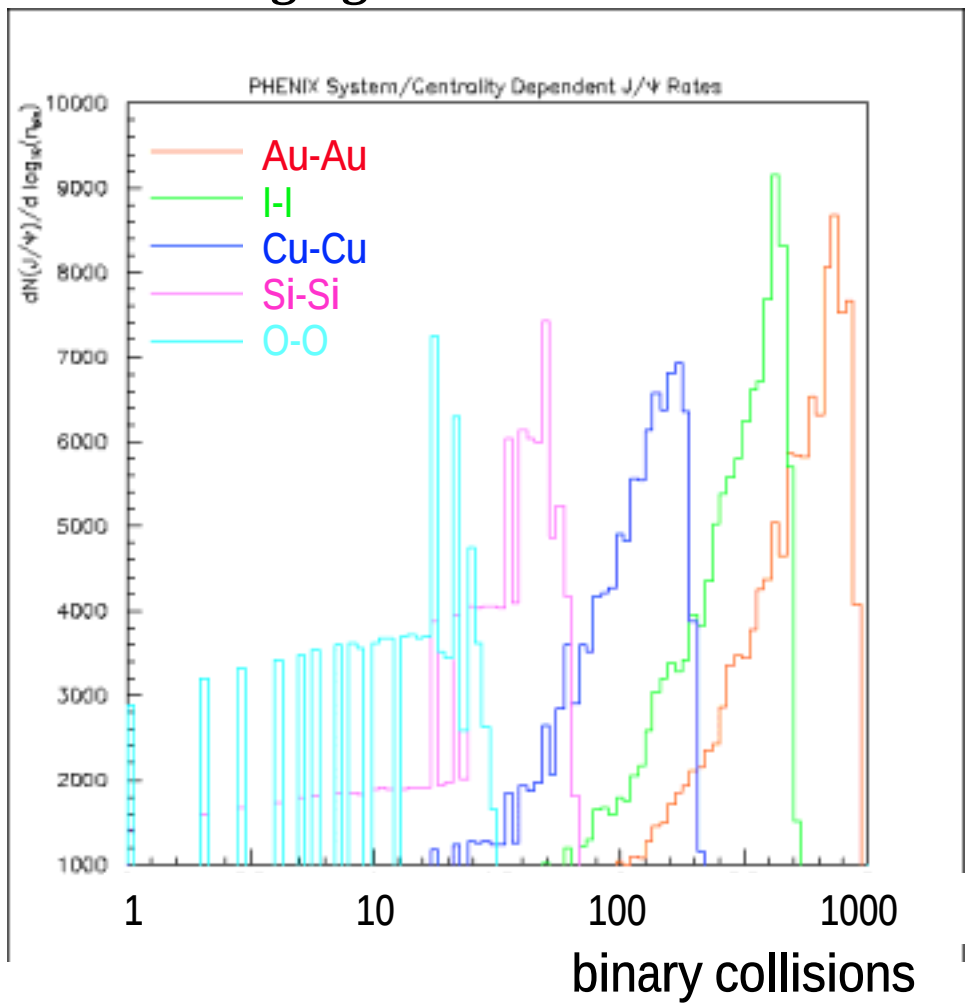
Species Scan

- Centrality or energy density dependence crucial observable
- Measurement of peripheral collisions challenging
- Cover range of small number of participants with lighter ions





PHENIX J/ψ and ψ' statistics from RHIC I

- **Running at full energy**
- **Au-Au 10 weeks (run3/run4)**
  - **J/ψ → μμ: 31000 J/ψ → ee: 3000**
  - **ψ' → μμ: 1100 ψ ' → ee: 110**
- **Species scan 2-3 weeks per species (run5/run6)**
  - **level 1 and level 2 triggers**
  - **equal statistics for J/ψ (ψ ') compared to Au-Au**
- **p-p and p-A comparison runs**

Species	A	luminosity (cm^{-2} s^{-1})	time (weeks)
Au-Au	197	$2\ 10^{26}$	10
I-I	127	$2.6\ 10^{27}$	2
Cu-Cu	63	$8.3\ 10^{27}$	2.5
Si-Si	28	$3.5\ 10^{28}$	2.5
O-O	16	$7.7\ 10^{28}$	3
p-p	1	$5.6\ 10^{30}$	6

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Electron reconstruction in PHENIX central arms

Track reconstruction: DC-PC1-PC3

- acceptance: $p_t > 200$ MeV/c
  $\Delta\phi = 2x\ \pi/2$
  $-0.35 < \eta < 0.35$

- resolution: $\sigma_p/p = 0.8\% \oplus 1\%\ p$ (reached)

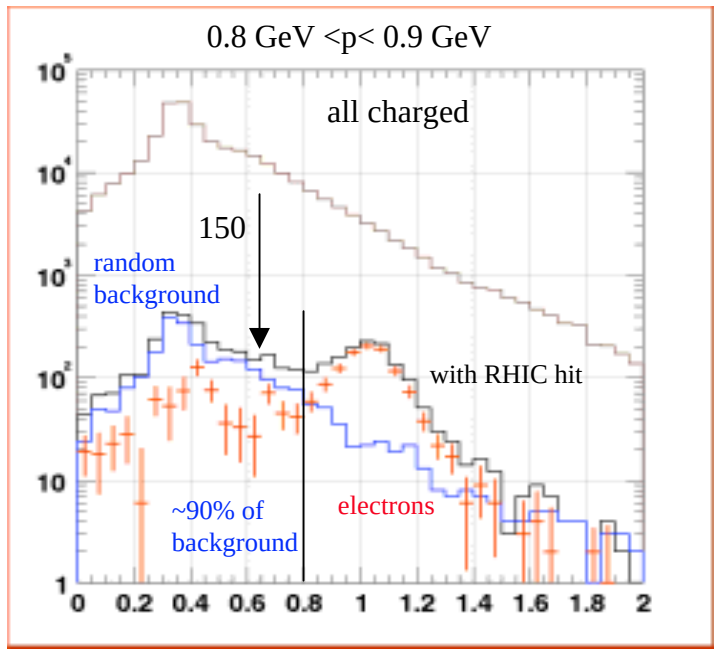
  $\sigma_p/p = 0.6\% \oplus 0.3\%\ p$ (design)

Electron identification:

- RICH
- EMCAL E-p matching
- subtracting remaining background

$e/\pi \sim 10^{-4}$

Au-Au data 2000



E/P ratio

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Run-2

- low luminosity
  - ~30 μb^{-1} Au-Au recorded
  - ~50 nb^{-1} p-p recorded
- commissioning of muon detectors
  - one of two muon arms
  - 2/3 active area in south muon
- commissioning muon and electron triggers
  - reduced performance

- expected J/ψ from run-2

  (note: large uncertainty in production and efficiencies
  + small S/B in Au-Au)

  - p-p $\rightarrow$ J/ψ $\rightarrow \mu\mu$ ~ 50-100
  - p-p $\rightarrow$ J/ψ $\rightarrow$ ee ~ 50-100

  - Au-Au $\rightarrow$ J/ψ $\rightarrow \mu\mu$ ~ 100-200
  - Au-Au $\rightarrow$ J/ψ $\rightarrow$ ee ~ 100-200

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PHENIX Beyond the Baseline

- **HI Physics program (pp-pA-AA)**
  - **Upsilon**
  - **lepton pair continuum (Drell-Yan)**
  - **heavy flavor (b-physics)**
  - **high p_T phenomena (>20 GeV and γ-jet)**

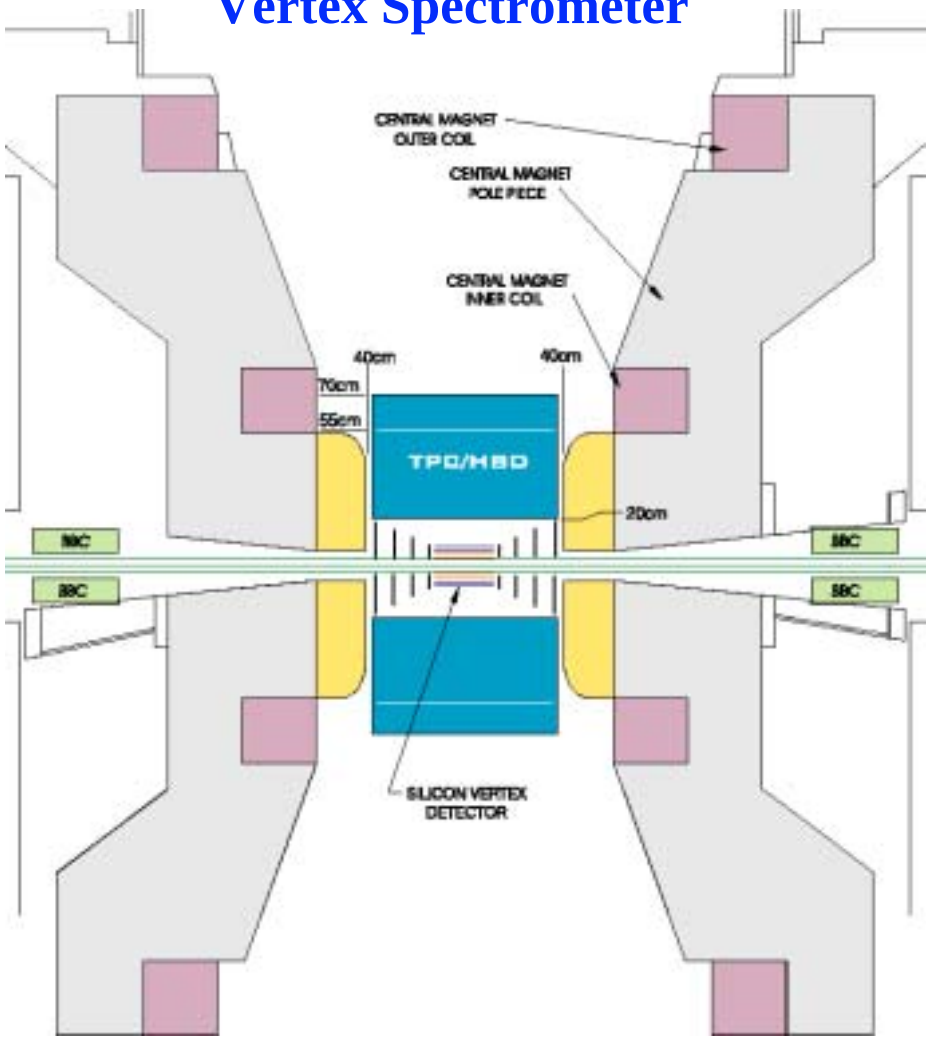
need RHIC II luminosity

- **Spin Physics**
  - **parton distribution functions**
  - **heavy flavor**
  - **W-Boson**
  - **transversity**

- **p-A Physics**
  - **parton structure of nuclei**
  - **diffractive processes**

PHENIX Detector Upgrades

Vertex Spectrometer



- **central vertex spectrometer**
  - flexible magnetic field
  - multi layer silicon vertex tracker
  - TPC/HBD
- **forward vertex tracking**
  - multiple layer silicon
- **enhanced particle ID**
  - TRD (east)
  - Aerogel/TOF (west)
- **enhanced muon trigger**
  - forward hodoscopes
  - forward calorimeter
  - station 1 anode readout
- **pA trigger detectors**
- **DAQ/trigger**

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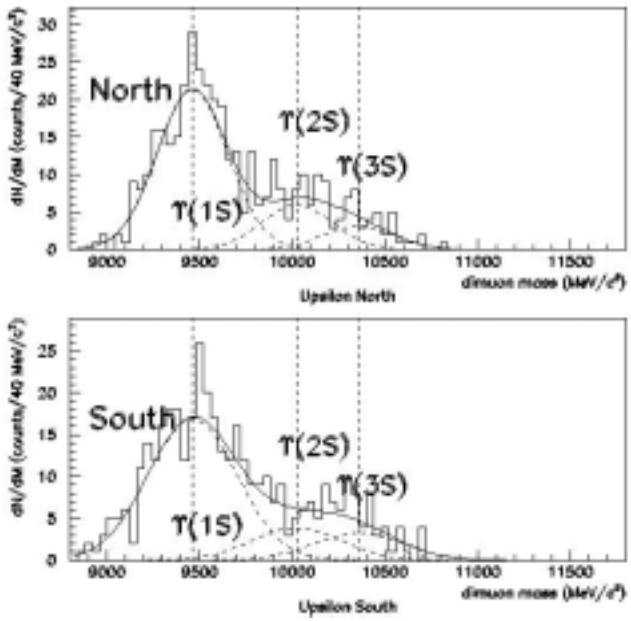
Upsilon Spectroscopy with RHIC II Luminosity

- **original PHENIX capability:**



Upsilon	mass (GeV)	Br(μμ) %	relative cross section	relative Br σ
Y(1S)	9.460	2.48	1	1
Y(2S)	10.023	1.31	0.36	.19
Y(3S)	10.355	1.81	0.25	.18

north muon arm: $\sigma_m \sim 190$ MeV

south muon arm $\sigma_m \sim 240$ MeV

37 week of Au-Au at 2 10^{26} $cm^{-2}s^{-1}$

total of ~ 400 Y decays

- **RHIC II performance:** — increase statistics by factor ~300
  - 10 week run at 2 10^{27} $cm^{-2}s^{-1}$ ⇒ 20 week run 8 10^{27} $cm^{-2}s^{-1}$
  - 50% loss due to vertex cut ⇒ no loss with longitudinal focussing
  - 25% RHIC/PHENIX uptime ⇒ 50% RHIC/PHENIX uptime

muon spectrometer:	Y→ μμ	30	⇒	9000	reconstructed
central spectrometer:	Y→ ee	7	⇒	2000	reconstructed

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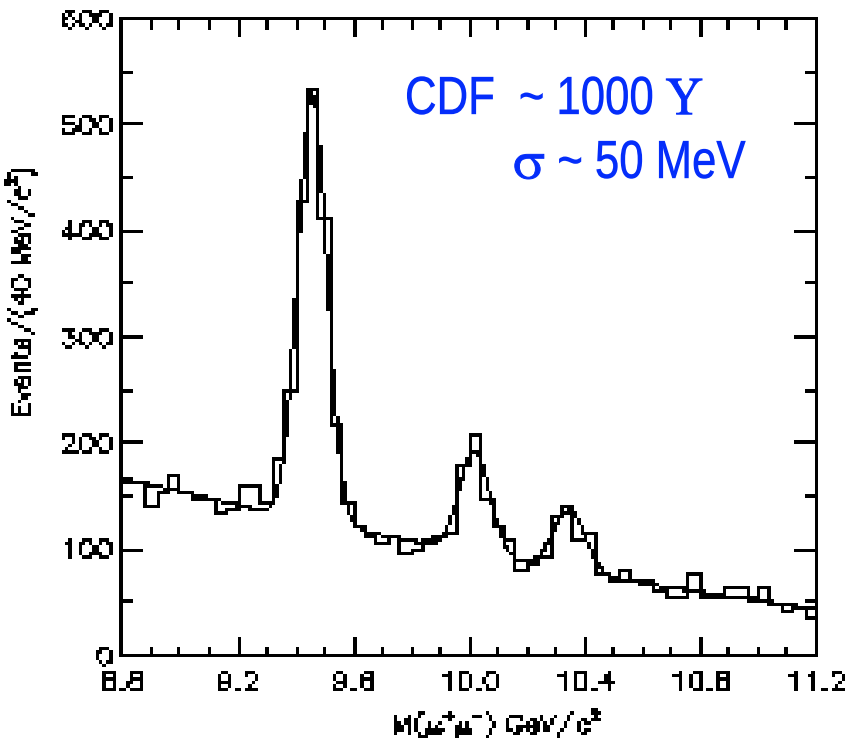
Axel Drees

Upsilon Spectroscopy with $\Upsilon \rightarrow e^+e^-$

- **Improve momentum resolution by factor ~4**
  - **increased magnetic field 0.73 Tm → 1.25 Tm**
  - **measure full angular deflection 40% → 100%**
- **Resolution of upsilon measurement limited by multiple scattering**
  - **8-16% X/X0 → σ_p/p ~ 0.9 - 1.4%**



Upsilon	mass (GeV)	yield
Y(1S)	9.460	2000
Y(2S)	10.023	380
Y(3S)	10.355	360

σ_m ~ 60 - 90 MeV:

$m_{Y(2S)} - m_{Y(1S)}$ = 563 MeV
6-9 σ separation

$m_{Y(3S)} - m_{Y(2S)}$ = 332 MeV
4-6 σ separation

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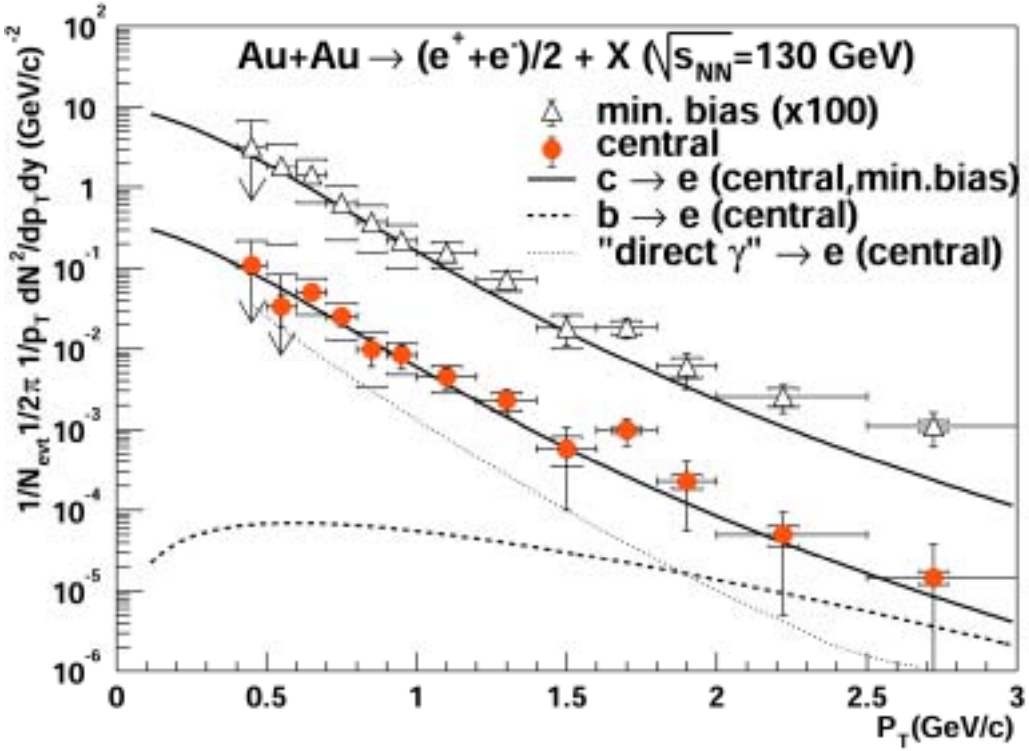
Charm and B Decays

open charm production from inclusive electrons

A high precision vertex detector will allow a clean separation of charm and bottom decays

	m GeV	cτ μm	→ eX %
D^0	1865	125	6.75
$D^\pm$	1869	317	17.2
B^0	5279	464	5.3
$B^\pm$	5279	496	5.2



Need secondary vertex resolution
~ 30 - 50 μm

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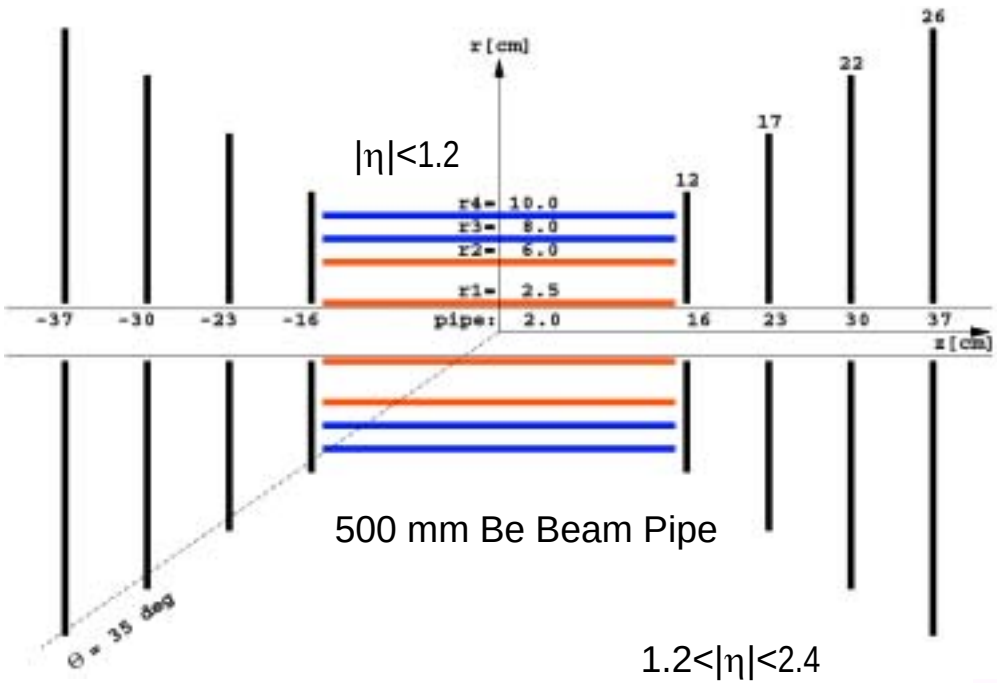
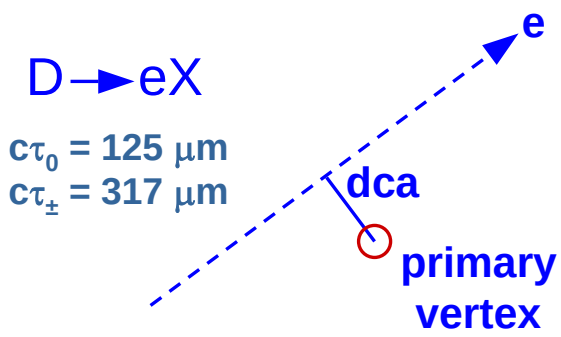
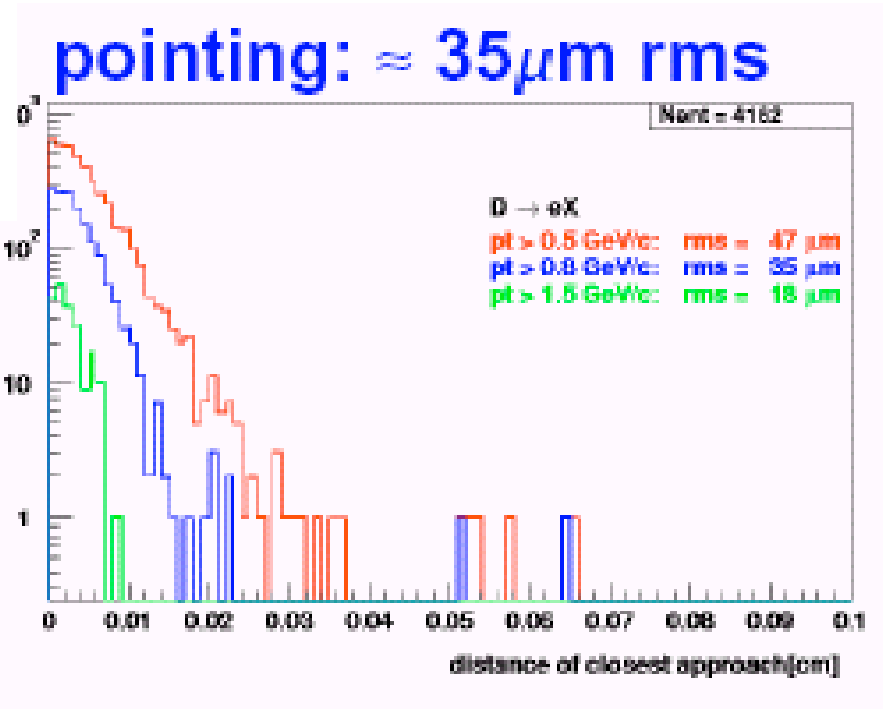
Proposed Silicon Tracker in PHENIX



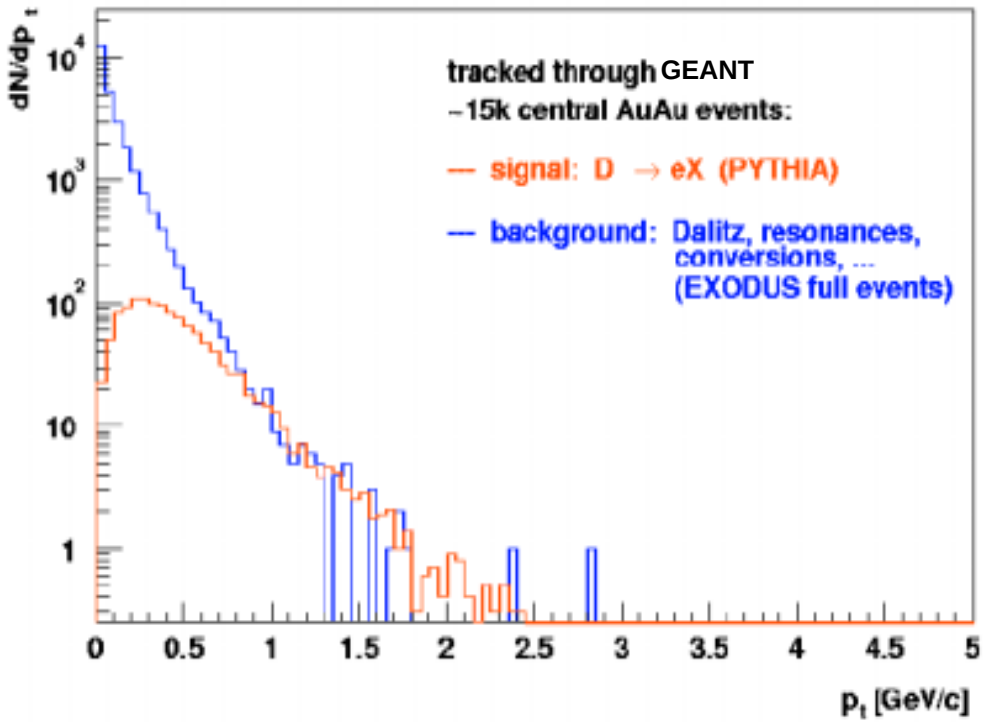


Pixel barrels (50 μm x 425 μm)
Strip barrels (80 μm x 3 cm)
Pixel disks (50 μm x 200 μm)

1.0% X_0 per layer



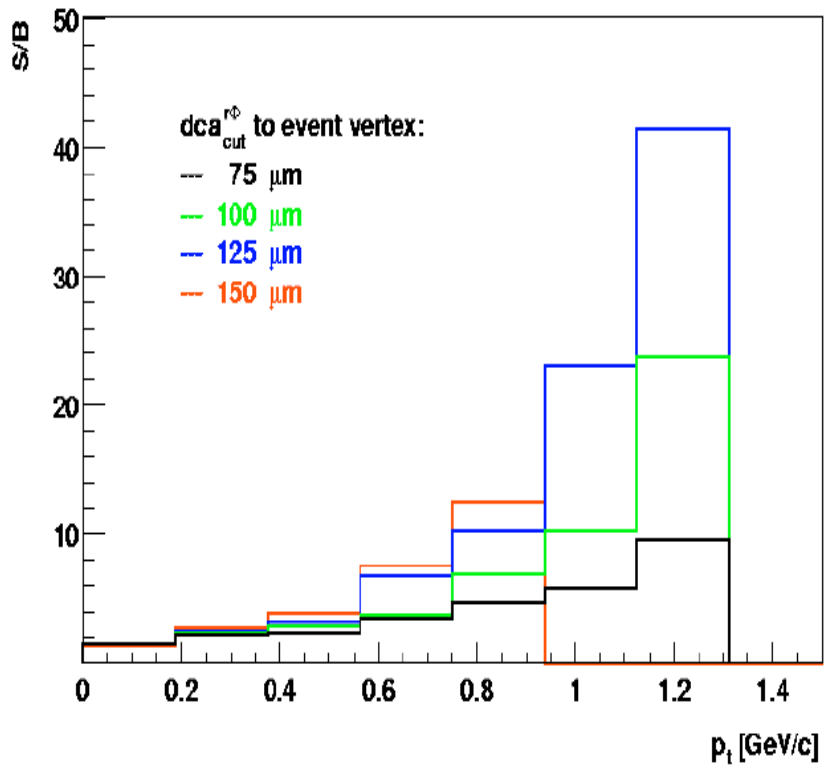
Signal/Background with DCA cut



Without cuts on displaced vertex

- **S/B ~ 1 for high-pt**
- **S/B ~ 0.1 p_T = 0.5 GeV/c**

S/B improves to > 10 for p_T > 1 GeV/c with DCA cut ~ 100 μm



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Summary

- **Integrated luminosity crucial for quarkonium measurements!**
- **PHENIX quarkonium capabilities for RHIC I**
  - **sufficient statistics for exploratory studies J/ψ and ψ'**
  - **comprehensive J/ψ and ψ' program**
    - **Au-Au**
    - **species scan**
    - **p-p and p-Au**
  - **given present run times data taking can be completed by run6 (2005/2006)**
  - **first upsilon measurement**
- **Luminosity increase with RHIC II**
  - **ultra high statistics measurement's for J/ψ and ψ'**
  - **upsilon measurements with sufficient statistics**
- **PHENIX detector upgrades + luminosity**
  - **precession measurement of open charm and bottom**
  - **upsilon spectroscopy**

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