A Complete Onium Program with R2D at RHIC II

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Outline

- Why is Onium so important?
- Recent results (QM 2005 and DNP)
- What are the current challenges?
- A new detector for RHIC-II
- Comparisons
  - Acceptance
  - Resolution
  - Rates
- Conclusions

Quarkonia

Charmonium States: J/ψ, ψ', χ_c

Bottomonium States: ϒ(1S), ϒ(2S), ϒ(3S)

- Key Idea: Sequential melting (plasma temperature)
  - J/ψ suppression, T. Matsui and H. Satz, *Phys. Lett. B* **178** (1986) 416
    - E. Shuriyak, *Phys. Lett. B* **78** (1797 !!) 150 (actually 1978)
  - Lattice QCD
  - F. Karsch, M.T. Mehr, and H. Satz, *Z. Phys. C* **37** (1988) 617
  - Dependent on binding strength

F. Karsch, RHIC-II Workshop, April 2005

- http://rhicii-science.bnl.gov/heavy/doc/April05Meeting/karsch-lattice.pdf

state	J/ψ	χ_c	ψ'	ϒ	χ_b	ϒ'	χ_b'	ϒ"
E_s^i [GeV]	0.64	0.20	0.05	1.10	0.67	0.54	0.31	0.20
T_d/T_c	1.1	0.74	0.1 - 0.2	2.31	1.13	1.1	0.83	0.74
T_d/T_c	~ 2.0	~ 1.1	~ 1.1	~ 4.5	~ 2.0	~ 2.0	–	–

using F_1: S. Digal, P. Petreczky, H. Satz, Phys. Lett. B514 (2001) 57;

using V_1: C.-Y. Wong, hep-ph/0408020;

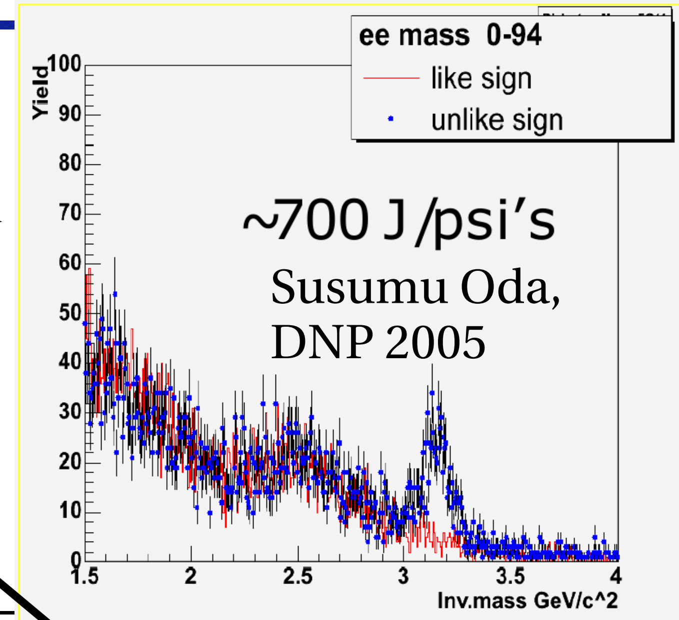
- Either way, the sequence is unchanged:
- Requires excellent mass resolution for ϒ states

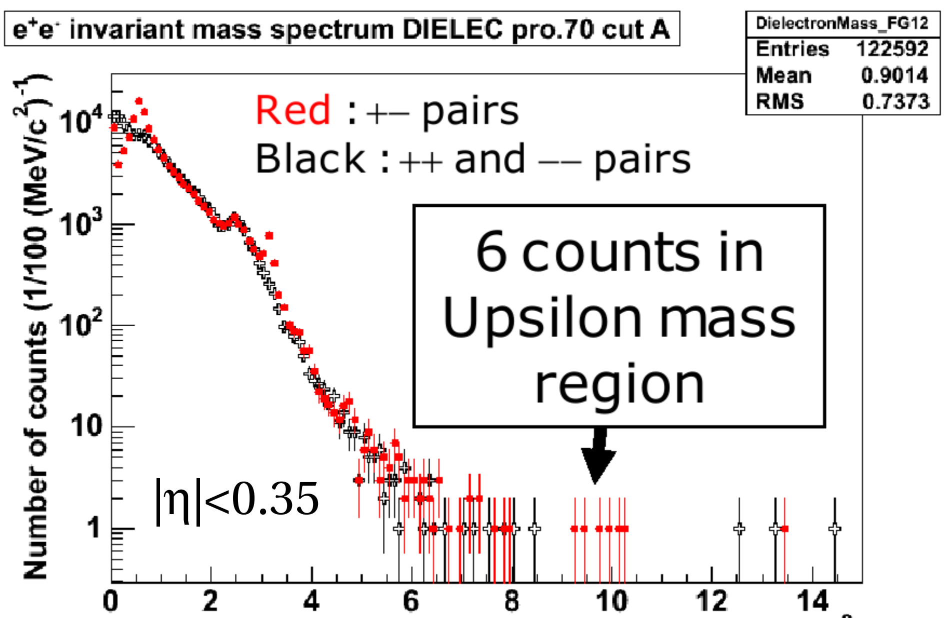
$T(\psi') < T(\Upsilon_{3S}) < T(J/\psi) \sim T(\Upsilon_{2S}) < T(\Upsilon_{1S})$

$T(\Upsilon_{3S}) < T_c$ $T(\Upsilon_{1S}) > T_c$

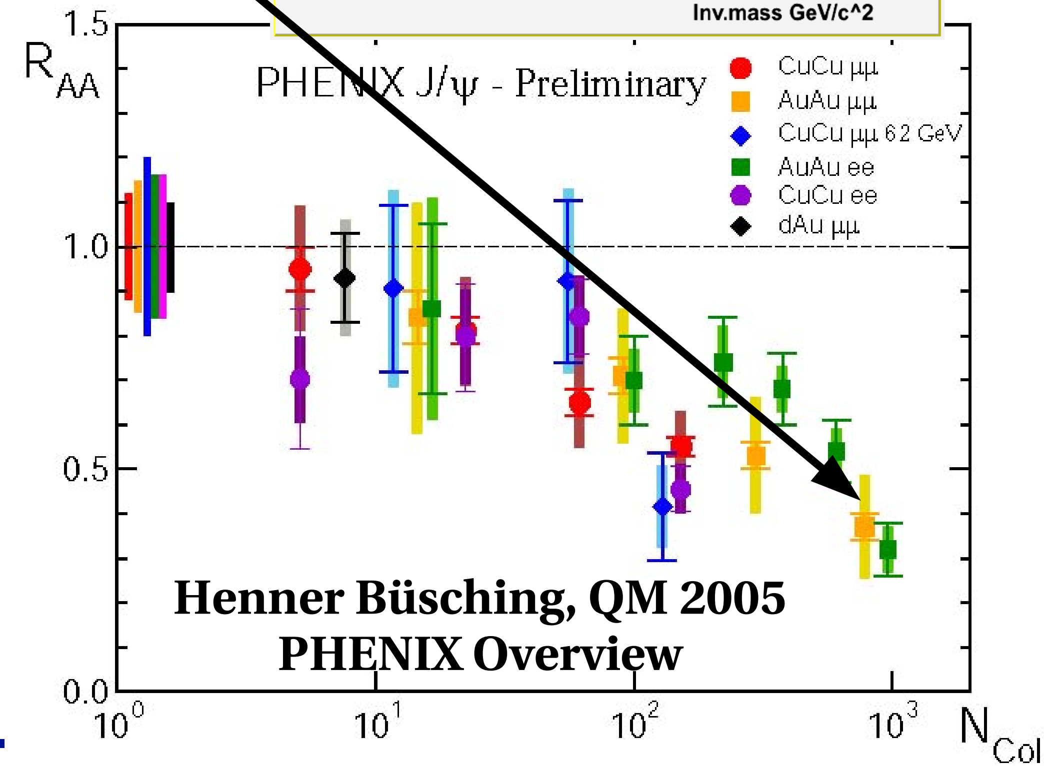
Results from QM 2005 and DNP

- Latest PHENIX results
  - ~6.4 billion Au+Au events
  - All centralities, all p_T ($|\eta|<0.35$, $\Delta\phi=\pi/2\times2$)
    - ~3000 J/ψ in muon arms
  - ~Factor 3 suppression in most central Au+Au
  - Essentially no Upsilon signal



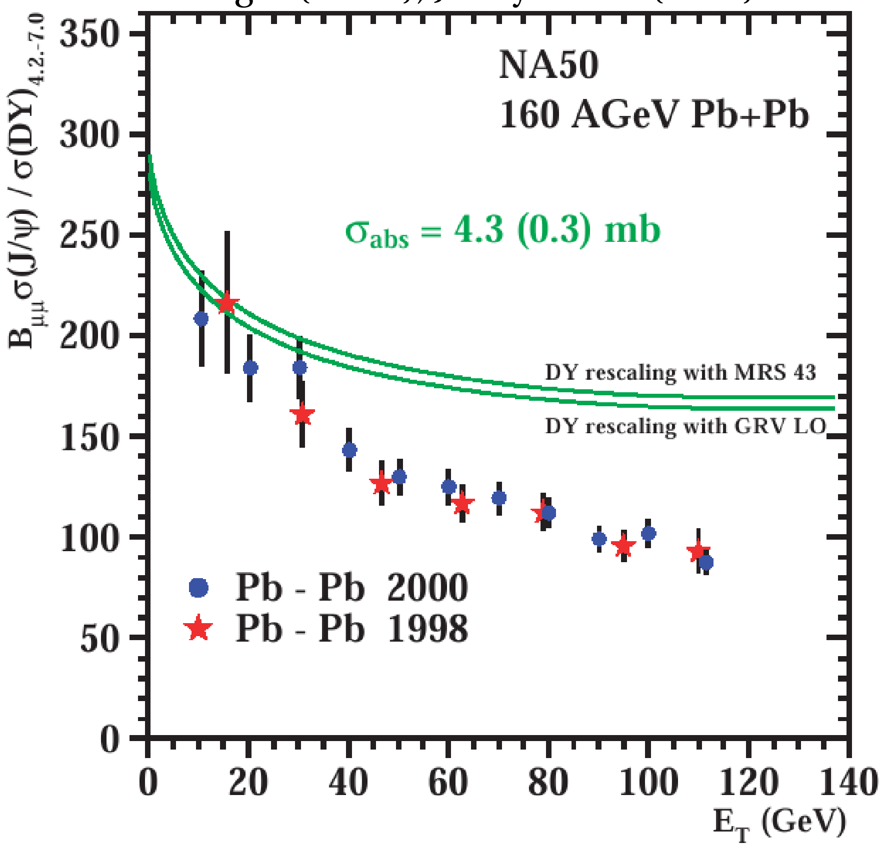


Susumu Oda, DNP 2005

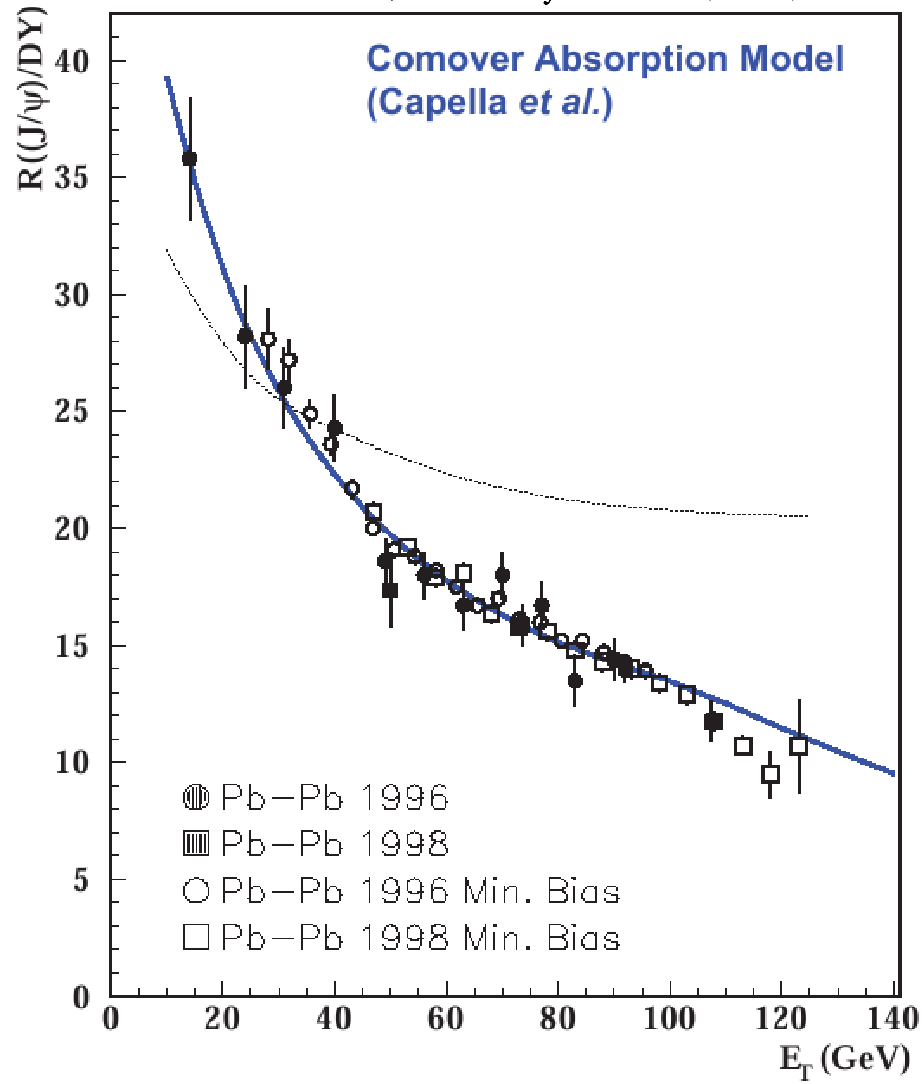


SPS Results

G. Borges (NA50), J. Phys. G **30** (2004) S1351



P.M. Dinh et al., Nuc. Phys. A **698** (2002) 579c

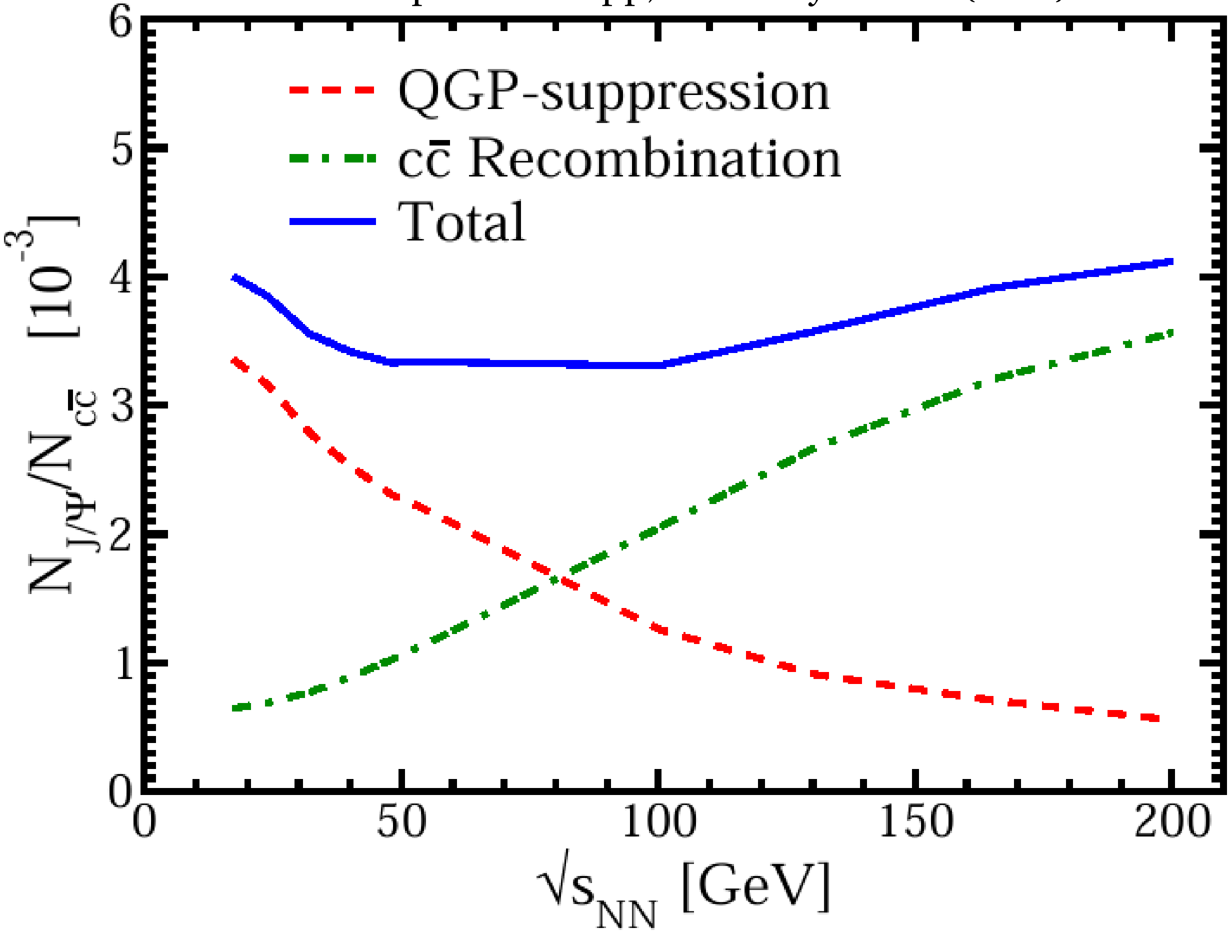


- High statistics
- Cold matter absorption
  - Still ~factor 2 suppression
- Co-mover absorption
  - Accounts for remaining suppression

Challenges

- J/ψ (quarkonia) requires understanding of:
  - Nuclear effects (shadowing and absorption)
  - Suppression vs. recombination

L. Grandchamp and R. Rapp, *Nucl. Phys. A* **715** (2003) 545-548



Challenges

- J/ψ (quarkonia) requires understanding of:
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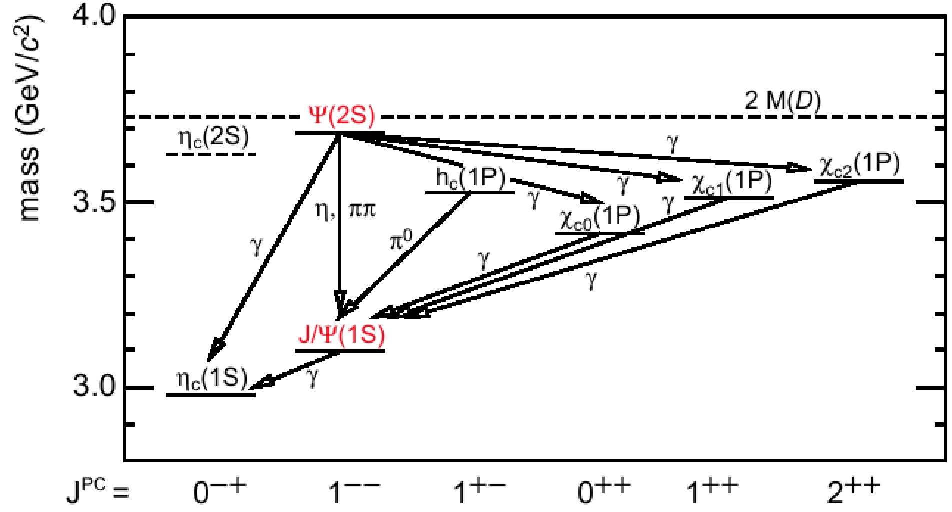
  - Open heavy flavor (consistency)
  - Feed-down ($\chi_c \rightarrow J/\psi + \gamma$)



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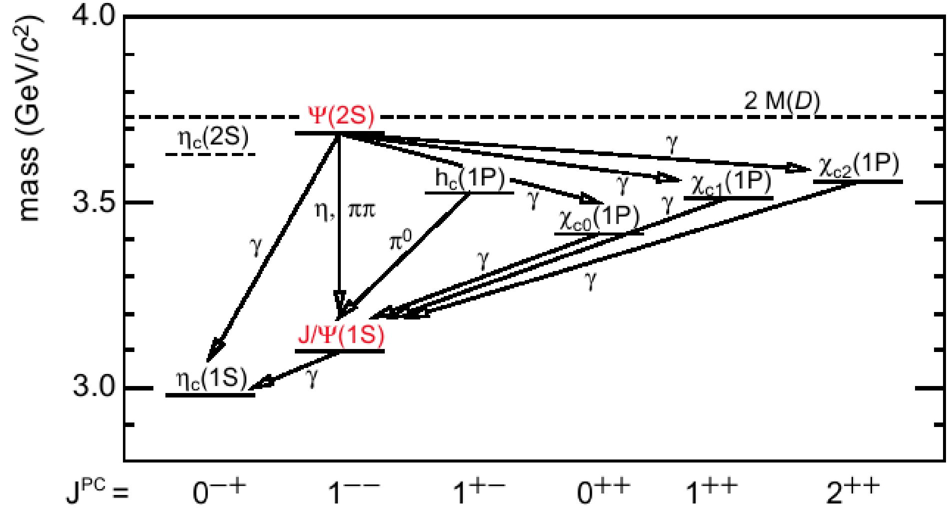
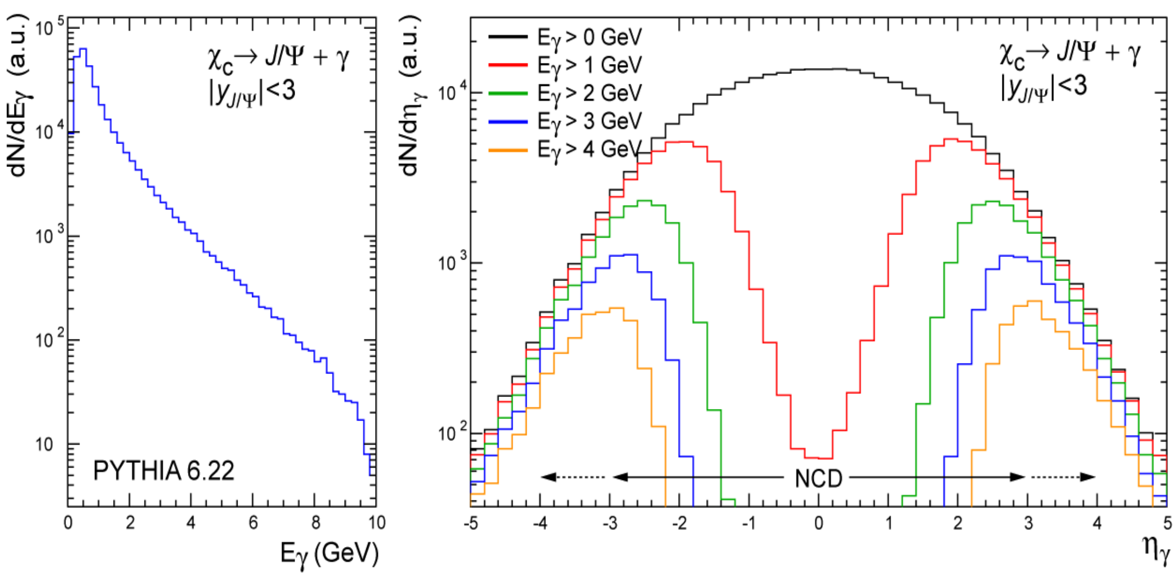


γ distribution for χ_c decay



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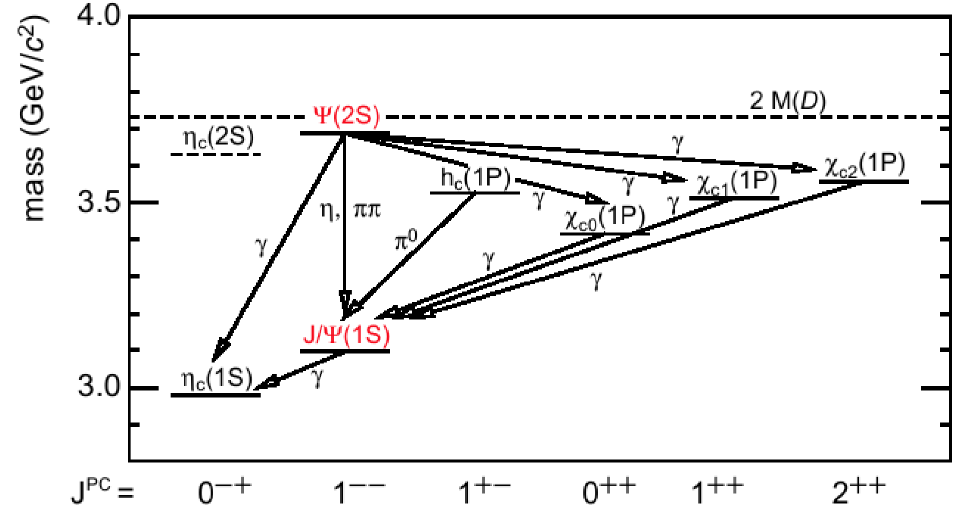
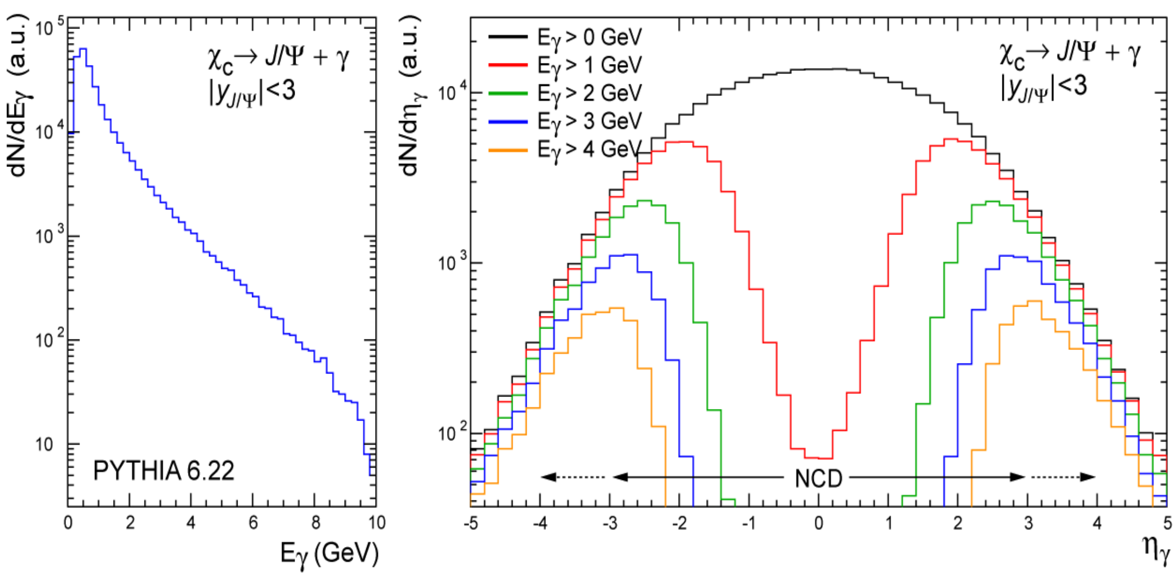
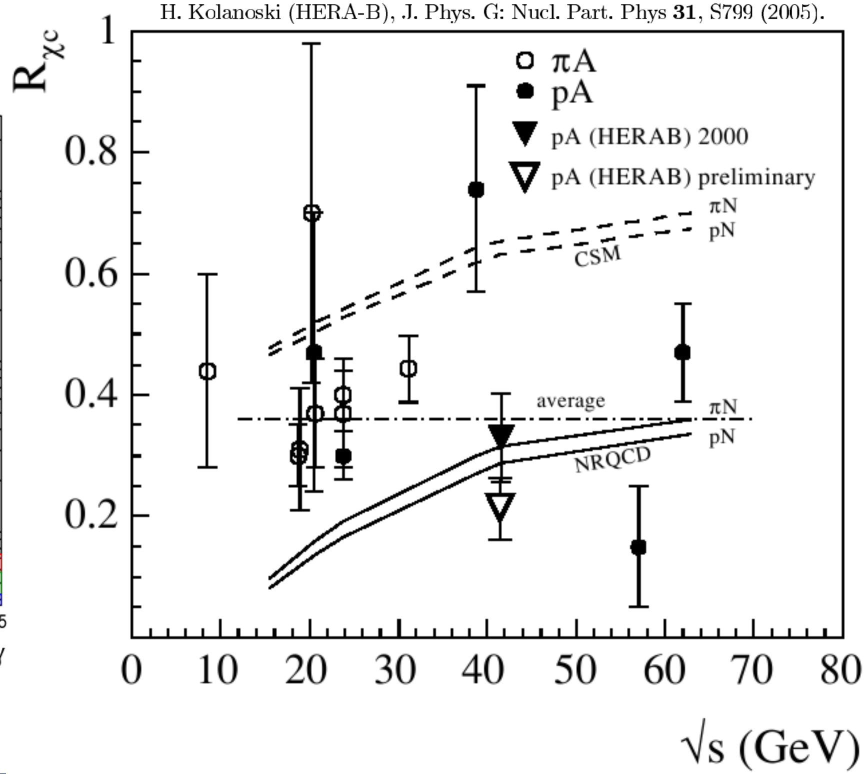
  - Open heavy flavor (consistency)
  - Feed-down ($\chi_c \rightarrow J/\psi + \gamma$)
  - Study systematics



H. Kolanoski (HERA-B), J. Phys. G: Nucl. Part. Phys **31**, S799 (2005).

γ distribution for χ_c decay



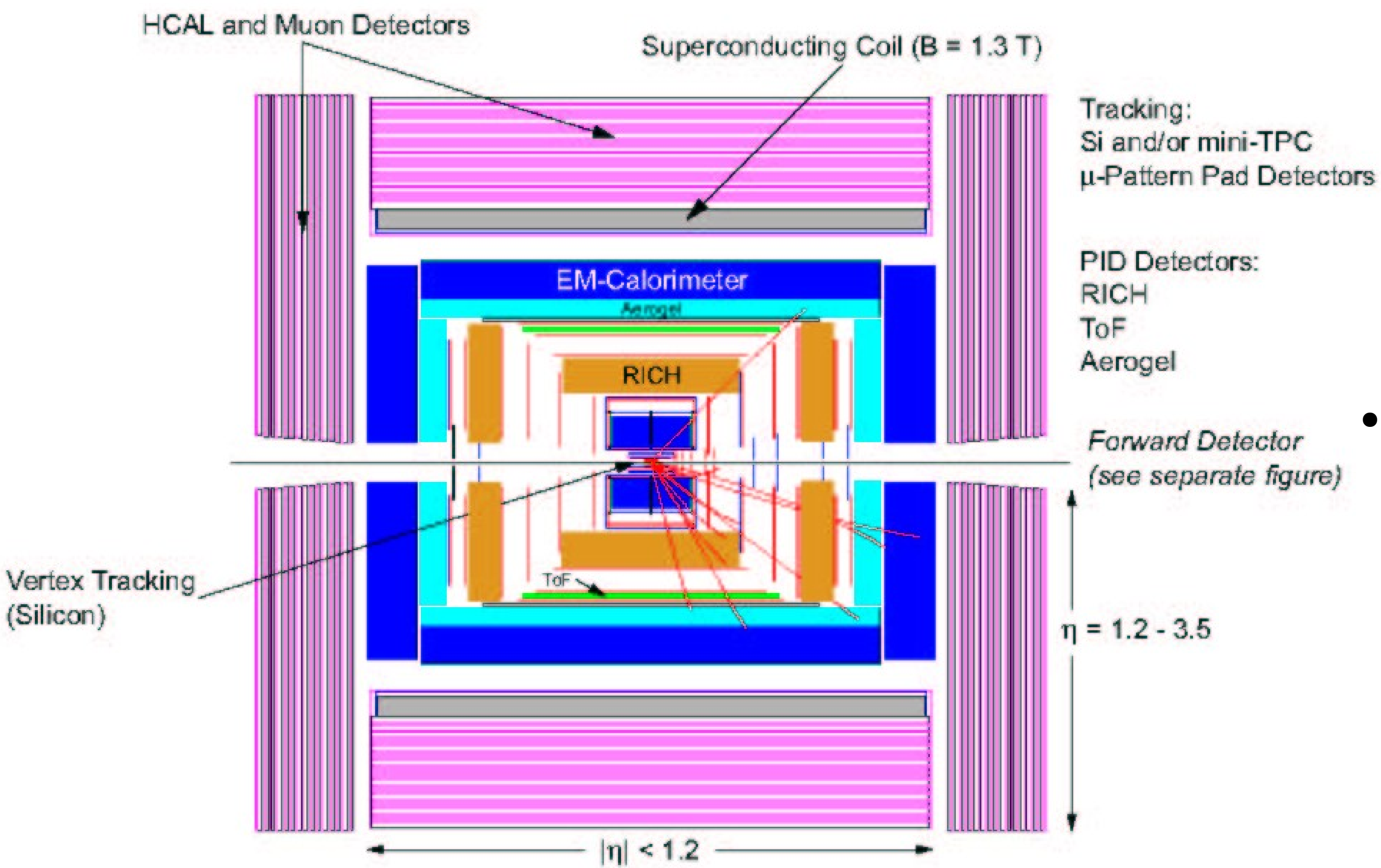


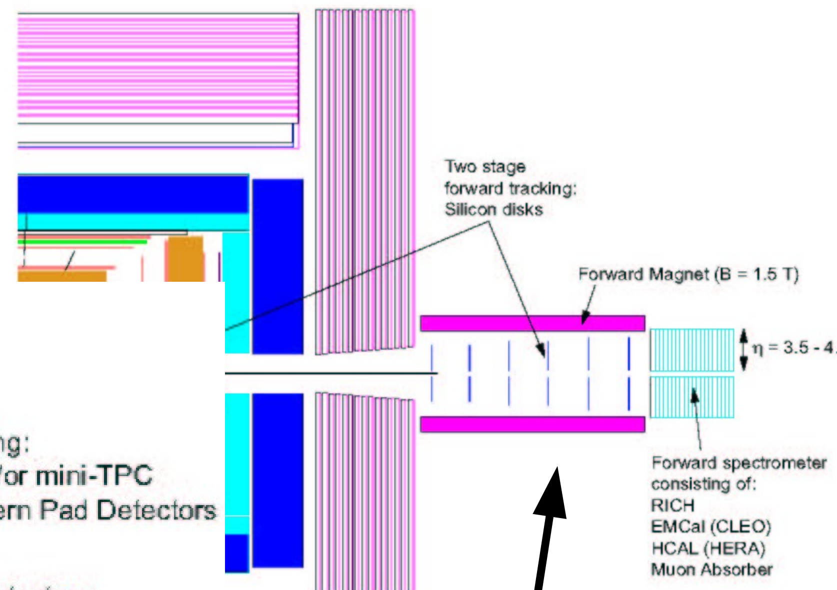
Requirements

Topic	Probes and Studies	Requirements
Baseline measurement	J/Ψ, Ψ', $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$ in AA, pA, and pp as a function of: • centrality • p_T • rapidity y • x_F • $\sqrt{s}$ • beam mass A	High rates and large acceptance to record sufficient statistics in available (limited) beam-time. High momentum resolution to resolve the Υ states.
Nuclear effects (shadowing, absorption)	Study pp and pA collisions: • Measure x_1, x_2, x_F dependence, measure A dependence (Cronin)	Large acceptance (incl. forward coverage) extending to large x_F and low x_{BJ}.
Distinguish suppression vs. recombination	• Charm production: $\sigma(p_T, y)$ • v_2 of J/Ψ • p_T dependence of suppression	High resolution vertex detectors (charm). Azimuthally symmetric detectors $(\Delta\phi = 2\pi)$ for correlation and elliptic flow measurements.
Contribution from feed-down	• Measure χ_c (challenge: soft γ at large η) at least in pA	Photon detection capabilities at mid- and forward-rapidities High rates, good energy and momentum resolution to enhance S/B ratio for the χ_c .
Quarkonium production	• Quarkonium polarization at least in pp and pA	Large acceptance to reach large $\cos\theta^*$

A Comprehensive RHIC II Detector

- RHIC II / *e*RHIC <u>will</u> require a new detector
  - High precision tracking in $|\eta|<3$, $\Delta\phi=2\pi$
  - Mass resolution for the 3 Υ states
  - μ ID *after* tracking detectors
  - $e^{\pm}$ ID using ECAL and PID

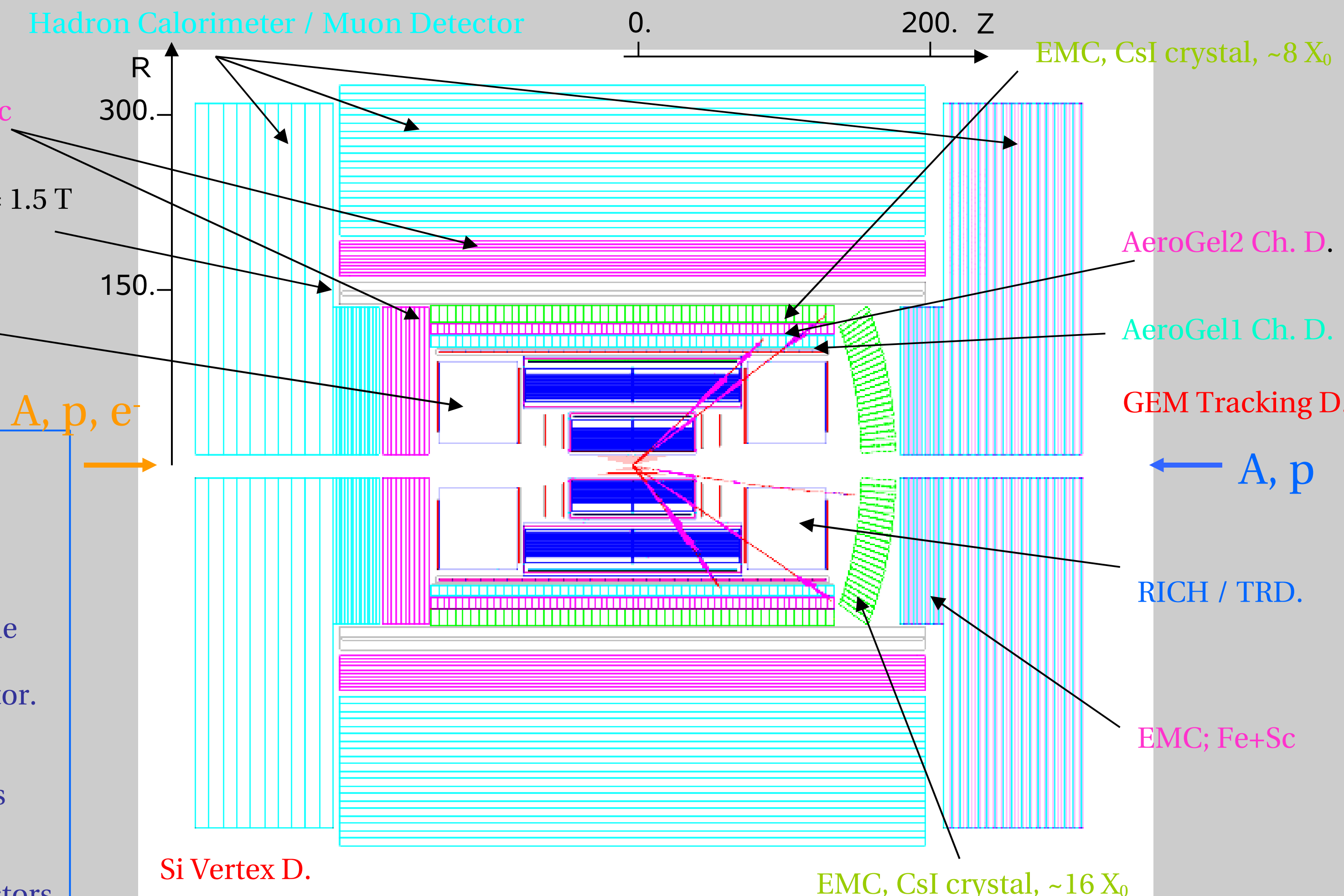




- Forward section
  - Tracking (silicon)
  - PID (RICH)
  - Had. and EM calorimetry
  - μ chamber
  - <u>Coverage from $3.5<|\eta|<4.8$</u>

“CDF/CLEO” setup for R2D/*e*RHIC

very preliminary, needs a lot of simulation and R&D to optimize and select



Barrel Tracking and PiD

Variant A:
Two TPC+Ch.D. systems.
Pad Detectors with CsI (UV converter) in the same gas volume to use TPC “working” gas as UV radiator.
First; C4H10 (C2H6) ?
Second: CF4
Maximum drift time ~10 μs
TPC readout: GEMs+pads

+ MicroPattern Gas Detectors

Variant B:
5-6 layers of Si strip Detectors
+ MicroPattern Gas Detectors
+ RICH gas Detector

End Cap Tracking and PiD

Si + MicroPattern Gas Detectors
+ RICH gas Detector
(or TRD in “e-side” , eRHIC)

ϒ Mass Resolution

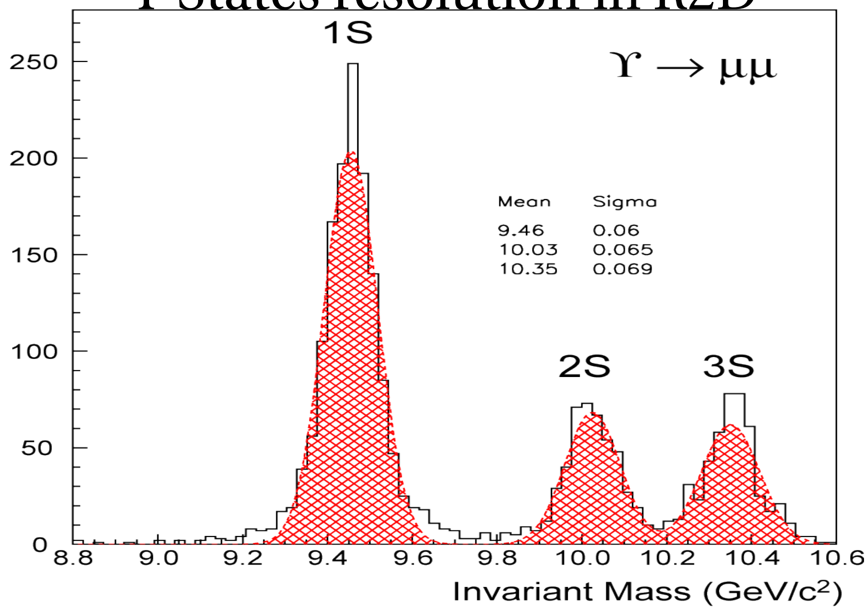
STAR (electron channel):
Δm = 340 MeV
- 170 MeV **with μ-vertex (HFT) upgrade**

PHENIX (electron channel):
Δm = 170 MeV
- 60 MeV **with VTX upgrade**

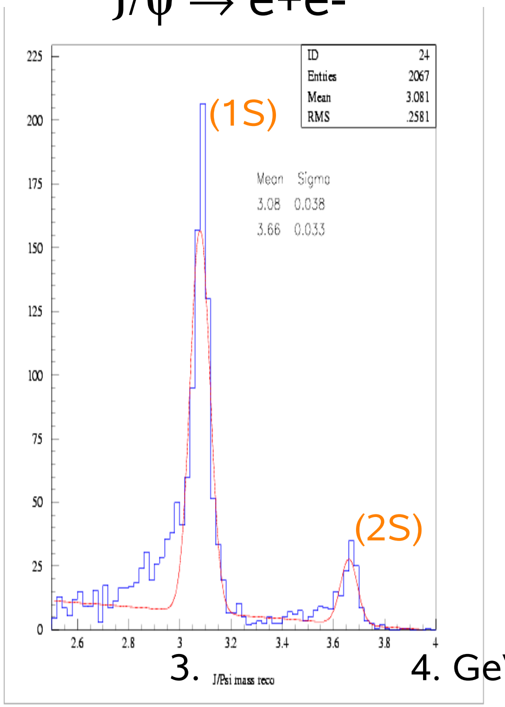
R2D can resolve:
- **Both J/ψ and ψ(2S)**
- **All three ϒ states (<u>both</u> dilepton channels)**
- Δm ~ 35 (for **J/ψ**) – 65 MeV (for ϒ)

One particle / event; no background

ϒ States resolution in R2D

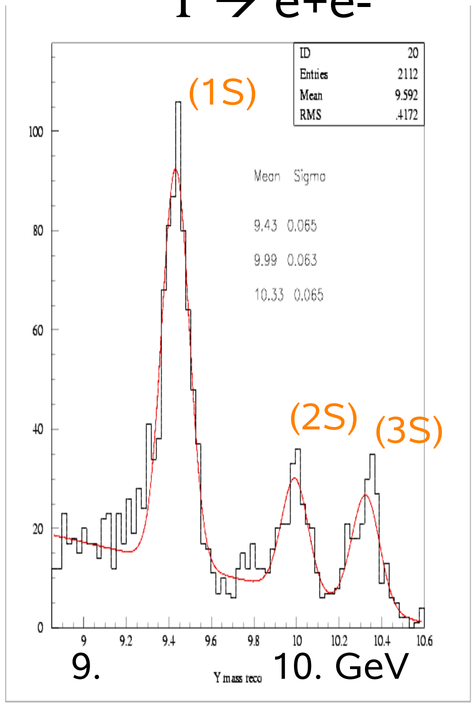


J/ψ → e+e-



Δm ~ 35 MeV

ϒ → e+e-



Δm ~ 65 MeV

Comparison

Thanks to T. Frawley, talk available at:

- http://rhicii-science.bnl.gov/heavy/doc/April05Meeting/frawley-lhc-rhich.pdf

Signal		PHENIX	STAR	ALICE	CMS	R2D
$J/\psi \rightarrow \mu\mu$ or ee	pp	525,000	1,600,000	135,900	17,219	10,200,000
	AA	440,000	8,000	208,600	26,400	8,580,000
$\psi \rightarrow \mu\mu$ or ee	pp	9,350	28,812	2,450	310	184,000
	AA	7,900	140	3,760	480	154,000
$\chi_c \rightarrow \mu\mu\gamma$ or $ee\gamma$	pp	142,000	?	?	?	1,560,000
	AA	120,000(?)	?	?	?	1,320,000
Υ (unresolved)	pp	740	8,300	1,350	3,010	35,200
	AA	1440	16,400	4,860	10,800	71,000
Υ(resolved)	pp	210	0	1,350	3,010	35,200
	AA	400	0	4,860	10,800	71,000
$B \rightarrow J/\psi \rightarrow \mu\mu$ or ee	pp	4,000	19,000	3,580	573	68,000
	AA	8,000	100	12,900	2,060	132,000

RHIC II *pp* is 12 weeks (238 pb^{-1}) @ 200 GeV

RHIC II AA is 12 weeks (18 nb^{-1}) @ 200 GeV

LHC *pp* is 1 month (3 pb^{-1}) @ 5.5 TeV

LHC AA is 1 month (500 μb^{-1}) @ 5.5 TeV

Conclusions

- Quarkonia can provide answers to many questions
  - Phase transition
  - Temperature of the plasma
- Quarkonia program requires RHIC-II luminosities
- Answers to many questions depend on new detector capabilites
  - Shadowing and absorption
  - Feed-down
  - Melting sequence
- R2D provides those capabilities
  - Large acceptance
  - PID capabilities to very high p_T
  - Excellent mass resolution
- R2D is crucial to the success of the RHIC-II / *e*RHIC program

The R2D Working Group

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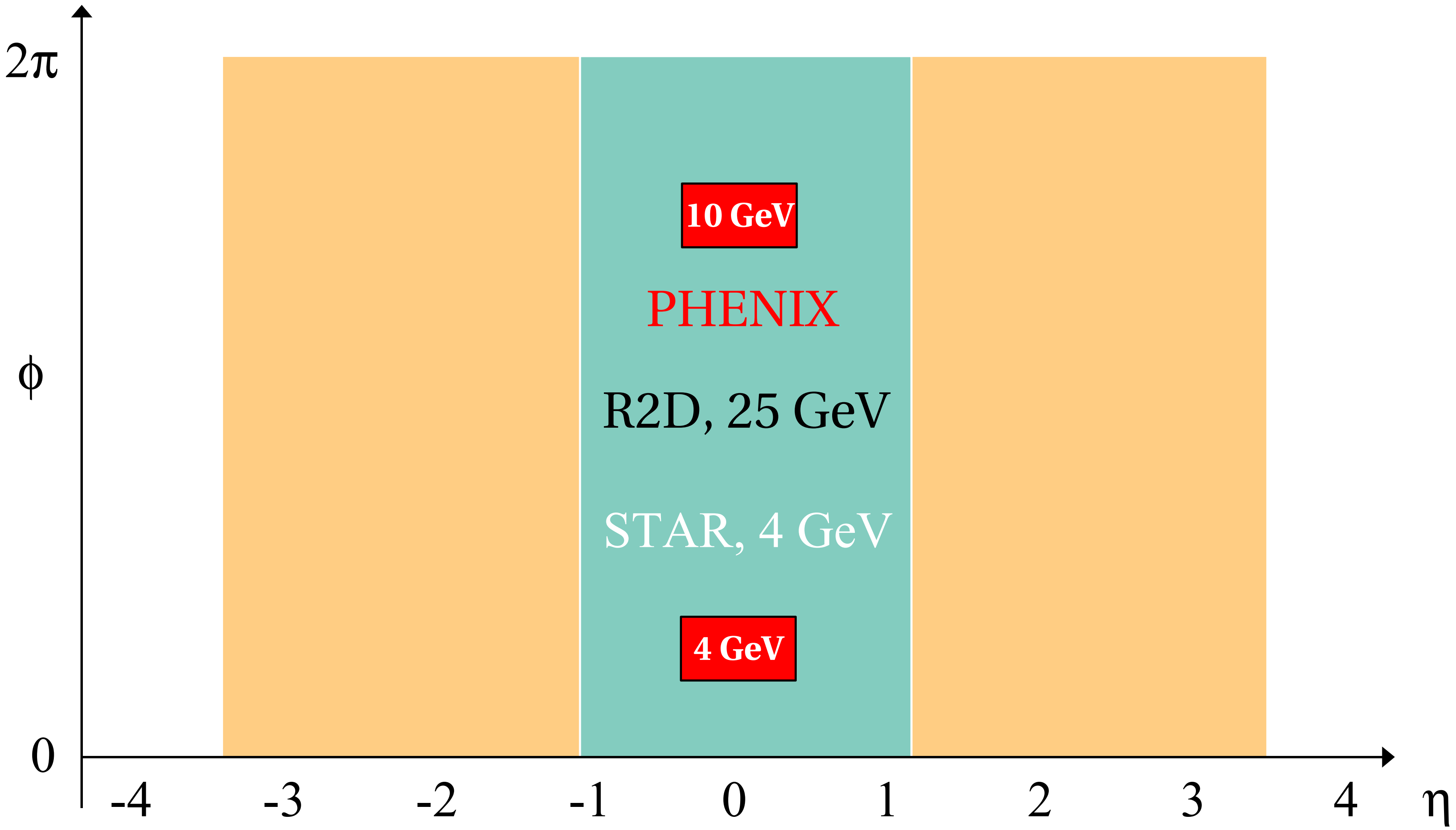
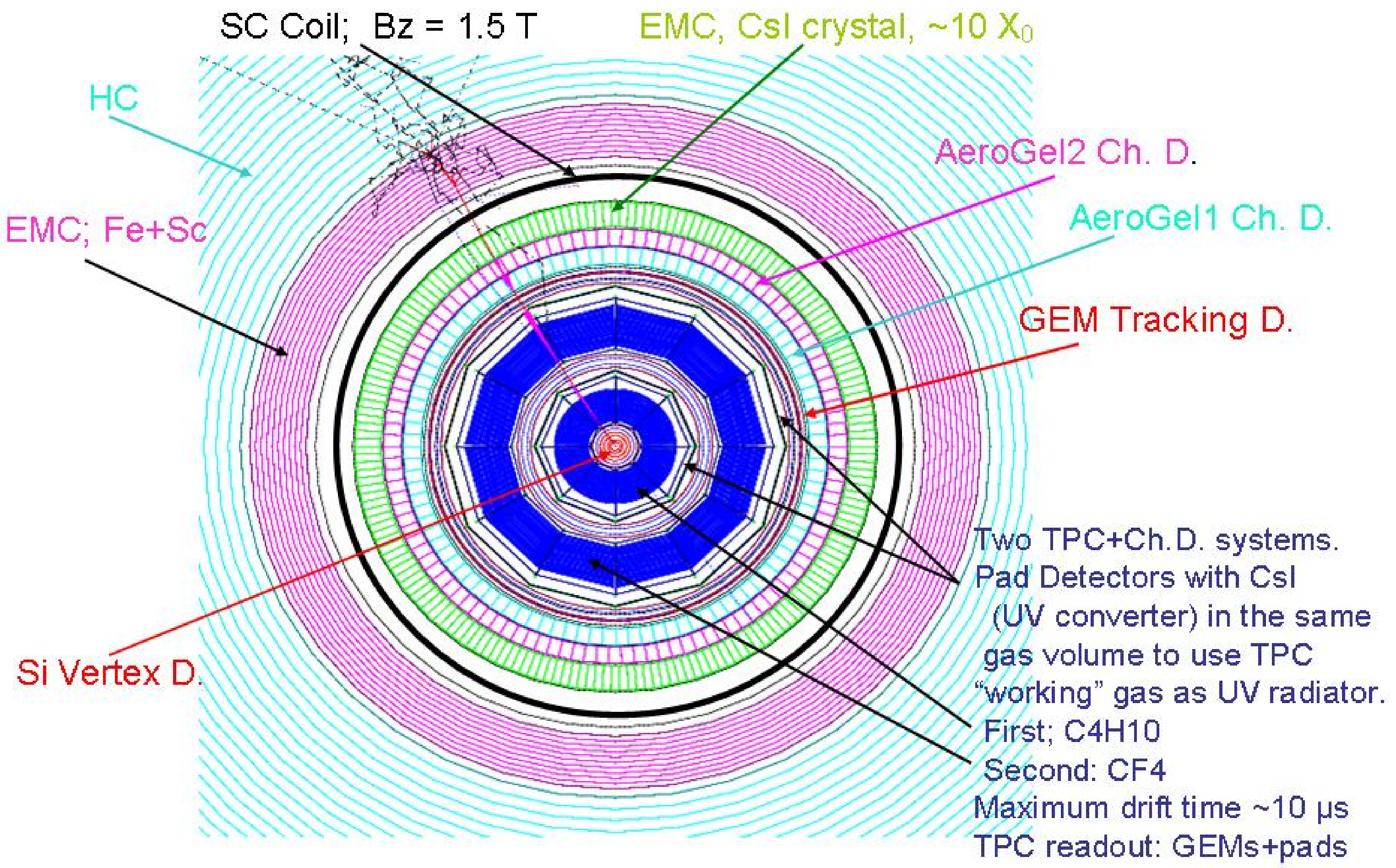
(EOI ~80 pages, submitted in August 2004,nucl-ex/0503002)

Backups

η and p_T PID Acceptance

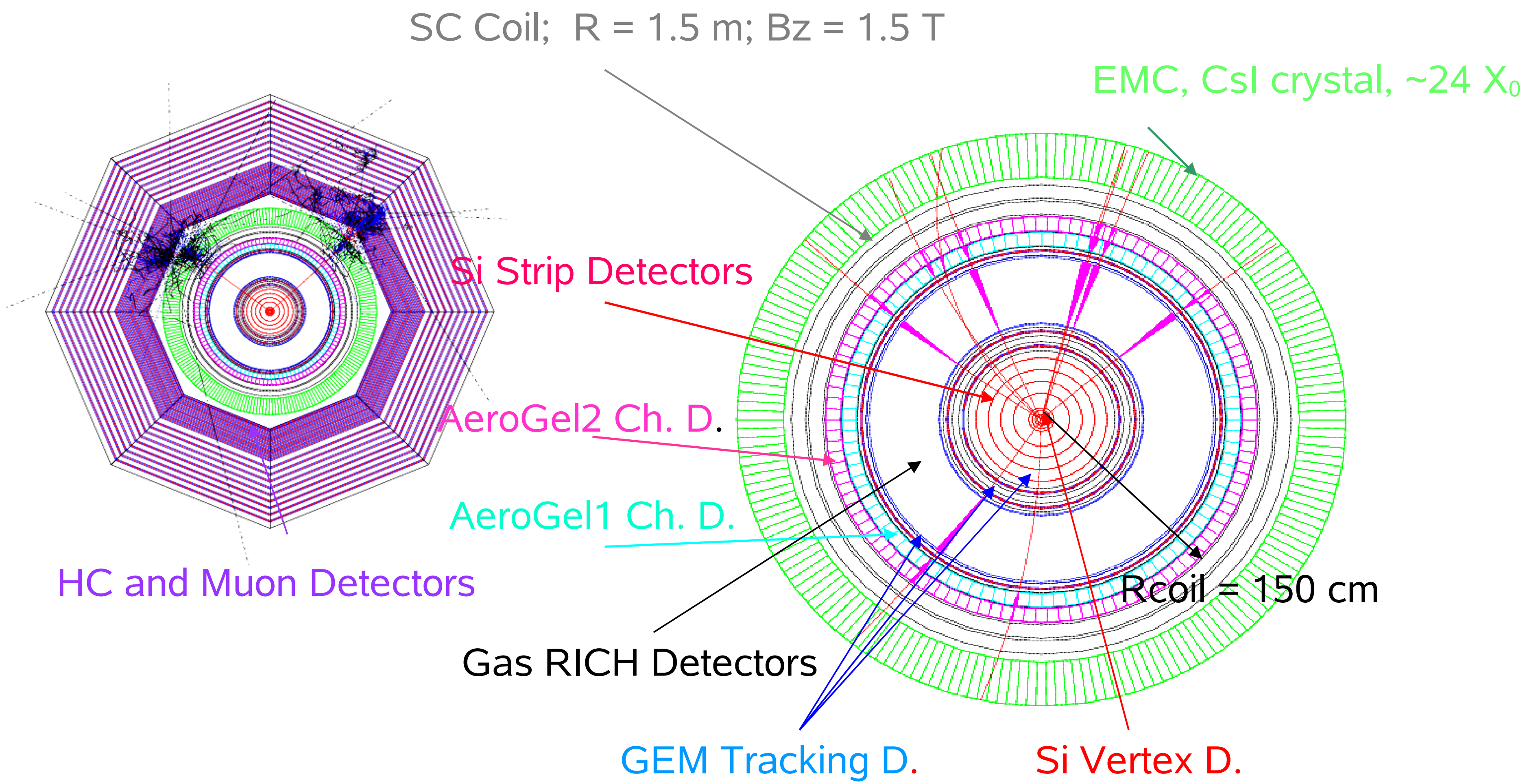


S(mall)-R2D Inner



S(mall)-R2D

CDF, CLEO and BABAR have same size magnets



CDF and D0

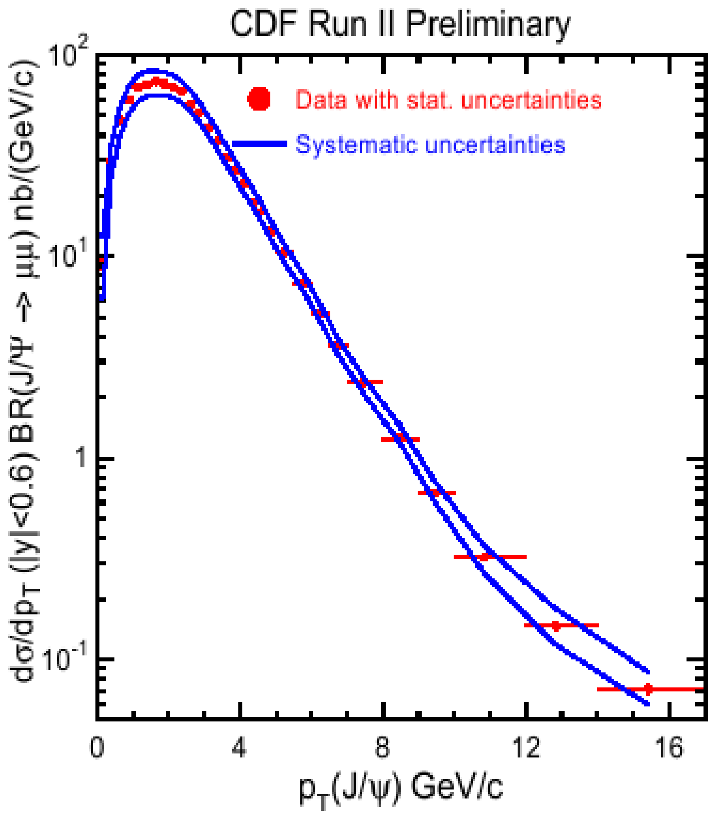


Figure 23: Preliminary p_T spectra of J/Ψ at $\sqrt{s}$ = 1.96 TeV from CDF[89] for $p_T = 0$ up to 18 GeV/c.

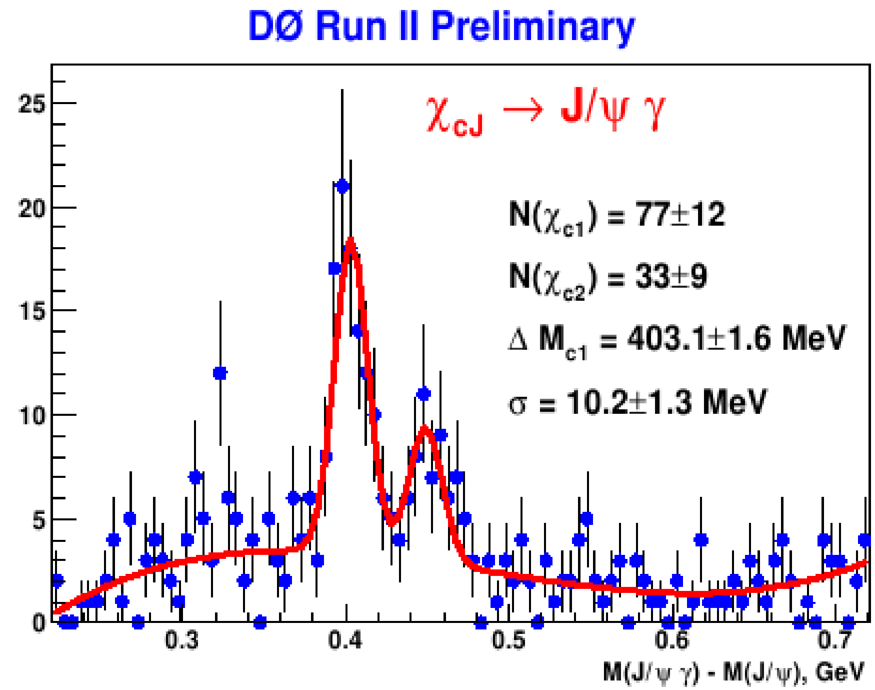
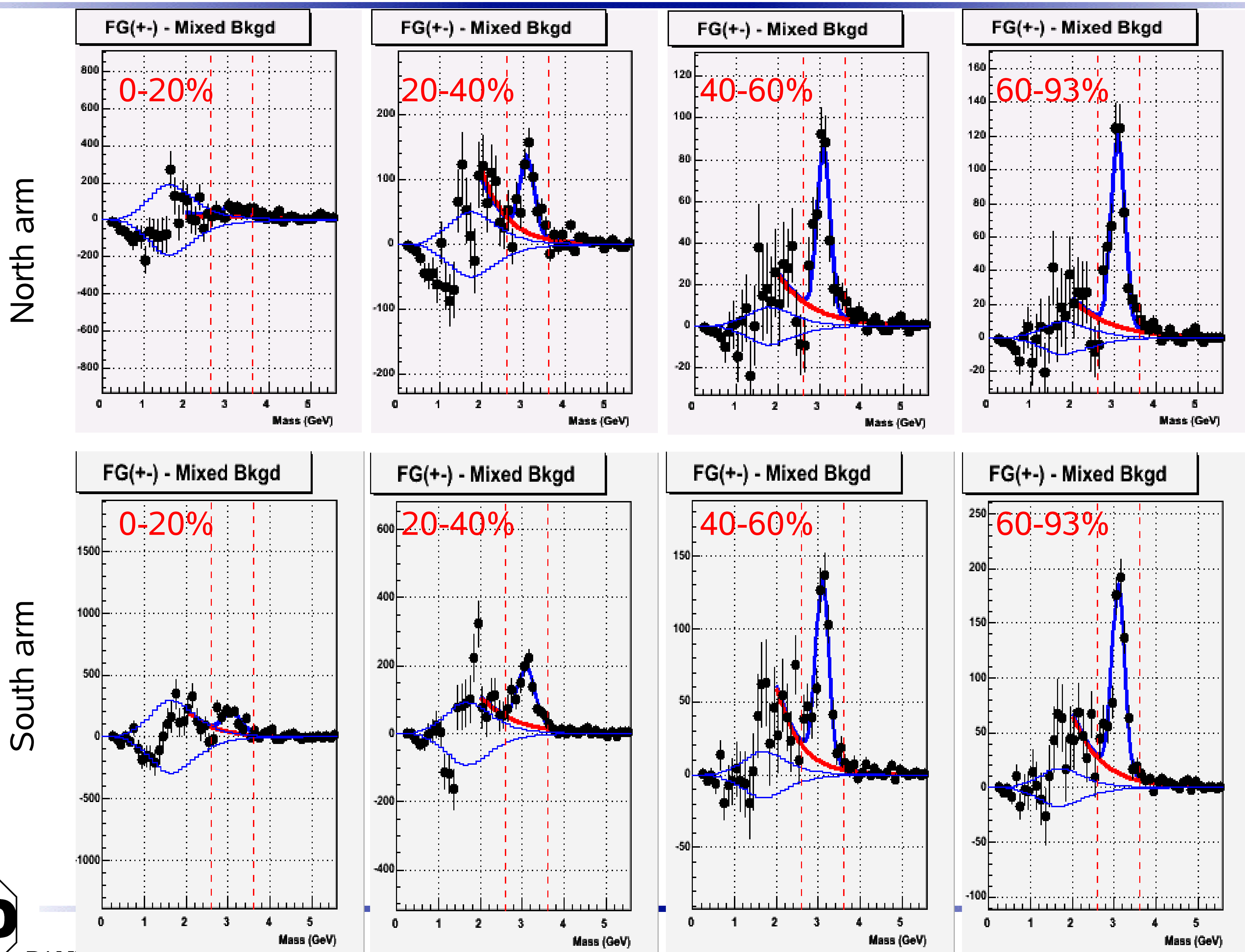
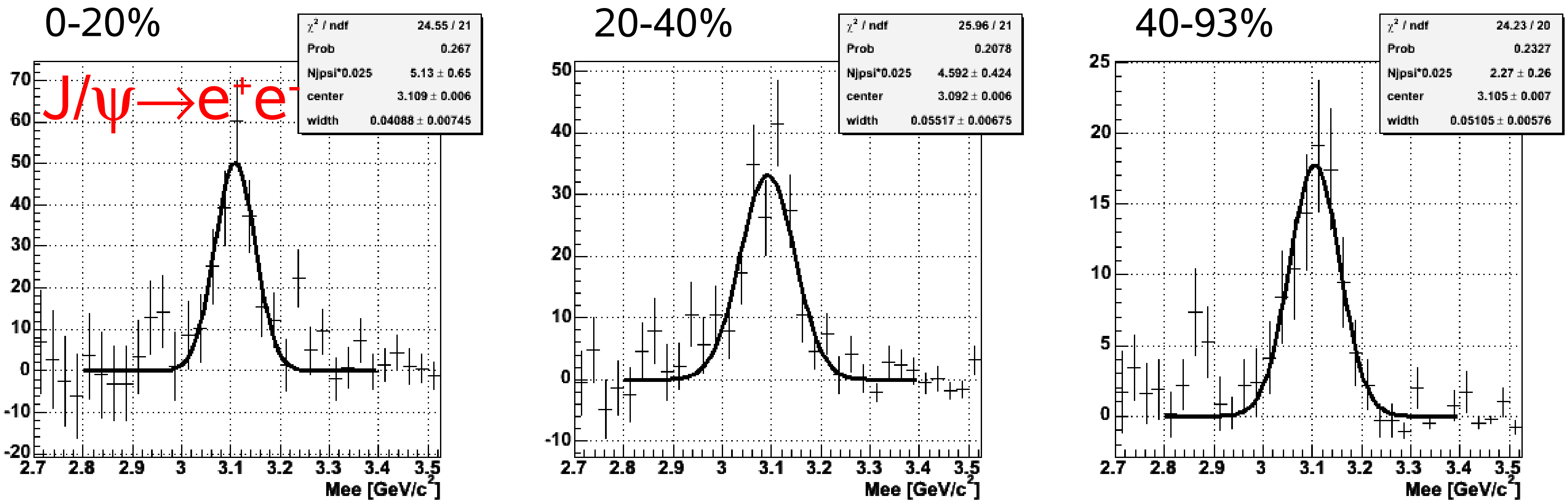


Figure 24: Invariant $J/\Psi\,\gamma$ mass spectrum as measured by D0[89] at $\sqrt{s}$ = 1.96 TeV. The peaks correspond to the two states χ_{c1} and χ_{c2}. Both are a large source of feed-down into J/Ψ but are extremely difficult to reconstruct.

PHENIX J/ψ->μ^++μ^-



PHENIX $J/\psi \rightarrow e^+ + e^-$



Planned Upgrades

Axel Drees, NSAC Meeting, April 2005:

- http://www.bnl.gov/henp/docs/nsac0405/Detector%20Strategy.pdf

Upgrades	High T QCD				Spin		Low x
PHENIX	e+e-	heavy flavor	jet tomography	quarkonia	W	ΔG/G	
hadron blind detector (HBD)	X						
Vertex tracker (VTX and FVTX)	X	X	O	O		X	O
μ trigger				O	X		
forward calorimeter (NCC)			O	O	O		X
STAR							
time of flight (TOF)		O	X	O			
Heavy flavor tracker (HFT)		X		X			
tracking upgrade		O			X	O	
Forward calorimeter (FMS)						O	X
DAQ		O	X	X	O	O	O
RHIC luminosity	O	O	X	X	O	O	O

X upgrade critical for success

O upgrade significantly enhancements program