Prospects for heavy flavor measurements at RHIC II

Tony Frawley

Florida State University

Heavy flavor and quarkonium production workshop

RHIC/AGS User's Meeting

BNL, June 6, 2006

Advertisement:

See the RHIC II heavy flavor workshops report:

http://www.bnl.gov/physics/rhicIIscience/

"Heavy Flavor" link

What is RHIC II?

RHIC II is a **luminosity upgrade** to RHIC that will produce the following improvements in performance:

		---- Luminosity Delivered / week ---		
Species	**units**	**Obtained**	**RHIC 2008**	**RHIC II**
p+p	pb^{-1}	~6*	26	33
d+Au	nb^{-1}	4.5	--	62
Cu+Cu	nb^{-1}	2.4	--	25
Au+Au	mb^{-1}	160	327	2500

Note: Because the collision diamond has $\sigma = 20$ cm at RHIC and $\sigma = 10$ cm at RHIC II, the gain in **usable luminosity** is larger than the ratio of delivered luminosity when going to RHIC II.

There are also a number of planned detector upgrades for PHENIX and STAR that are crucial to the RHIC II physics program.

* Run 6, the last 5 weeks

Detector upgrades before RHIC II

PHENIX and STAR have extensive upgrade plans that will be completed in the mid near term - **about 5 years**.

These detector upgrades are crucial to the RHIC program both before and after the luminosity upgrade.

STAR:

- DAQ upgrade increases rate to 1 KHz, triggered data has ~ 0 dead time.
- Silicon tracking upgrade for heavy flavor, jet physics, spin physics.
- Barrel TOF for hadron PID, heavy flavor decay electron PID.
- EMCAL + TOF J/ψ trigger useful in Au+Au collisions.
- High p_T muon detector.

PHENIX:

- Silicon tracker for heavy flavor, jet physics, spin physics.
- Forward muon trigger for high rate pp + improved pattern recognition.
- Nose cone calorimeter for heavy flavor measurements.
- Aerogel + new MRP TOF detectors for hadron PID.
- Hadron-blind detector for light vector meson e^+e^- measurements.

Relationship to LHC

RHIC II luminosity will be available by ~ 2012.

The LHC heavy ion program will start to take data in 2008. By the time RHIC II is available, the LHC program should be up to speed.

So what do we need RHIC II for?

I will try to show how the two **facilities** compare in the next few slides, and I will discuss the complementarity of the heavy flavor **physics** programs later.

RHIC II

Beams: **p to U**
All combinations $\sqrt{s}$ = **22-200 GeV**

Central Au+Au: **$T \sim 2\ T_c$**

Detectors:
PHENIX STAR eRHIC detector?

12 weeks / year physics (split runs)
Average luminosity $7 * 10^{27}\ cm^{-2}\ s^{-1}$
Au+Au lum/year 18,000 mb^{-1}

$Lint_{RHIC}/Lint_{LHC}$ = **36**

$N_{cc} \sim 10$ $N_{bb} \sim 0.05$ (central)

LHC

Beams: **p to Pb**
p+p $\sqrt{s}$ = **14 TeV**
p+Pb $\sqrt{s}$ = **8.8 TeV**
Pb+Pb $\sqrt{s}$ = **5.5 TeV**

Central Pb+Pb: **$T \sim 3.5\ T_c$**

Detectors:
ALICE ATLAS CMS

4 weeks / year physics
Average luminosity $5 * 10^{26}\ cm^{-2}\ s^{-1}$
Pb+Pb luminosity/year 500 mb^{-1}
$\sigma\ (J/\psi)_{LHC} = \sigma\ (J/\psi)_{RHIC} * 13$
$\sigma\ (\Upsilon)_{LHC} = \sigma\ (\Upsilon)_{RHIC} * 55$

$N_{cc} \sim 115$ $N_{bb} \sim 5$ (central)

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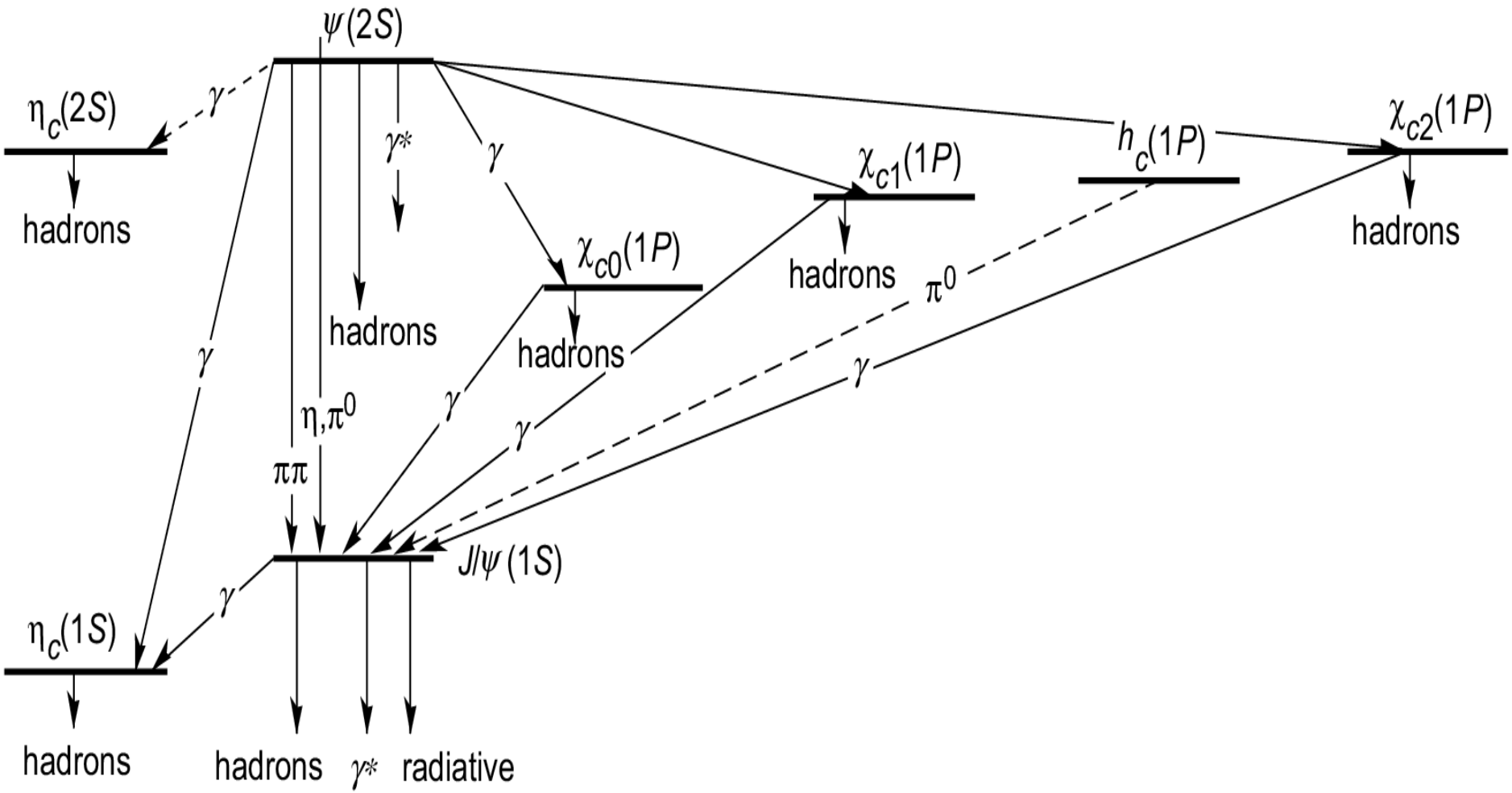
So RHIC II and the LHC will have **similar heavy flavor yields** per year, but somewhat **different physics environments**, due to the higher initial temperature and the much larger charm and bottom yields per event.

More later....

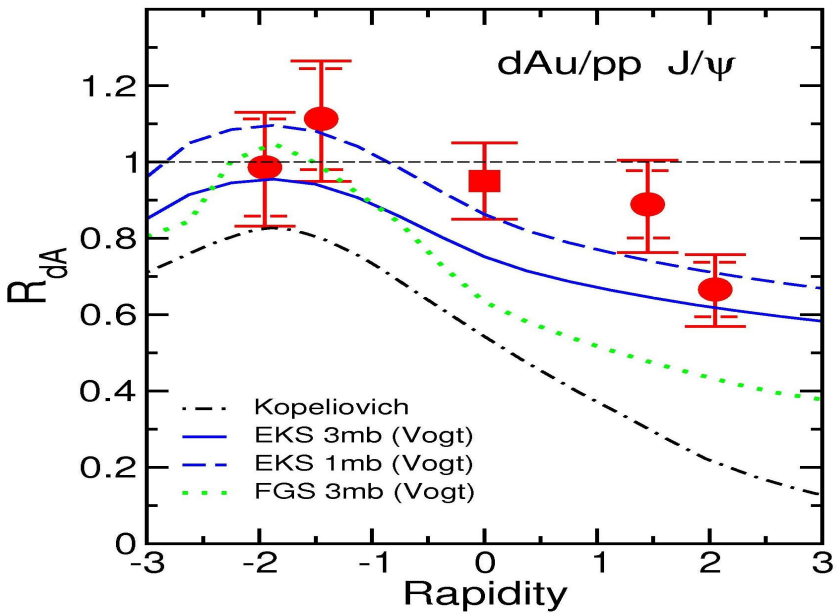
Charmonium

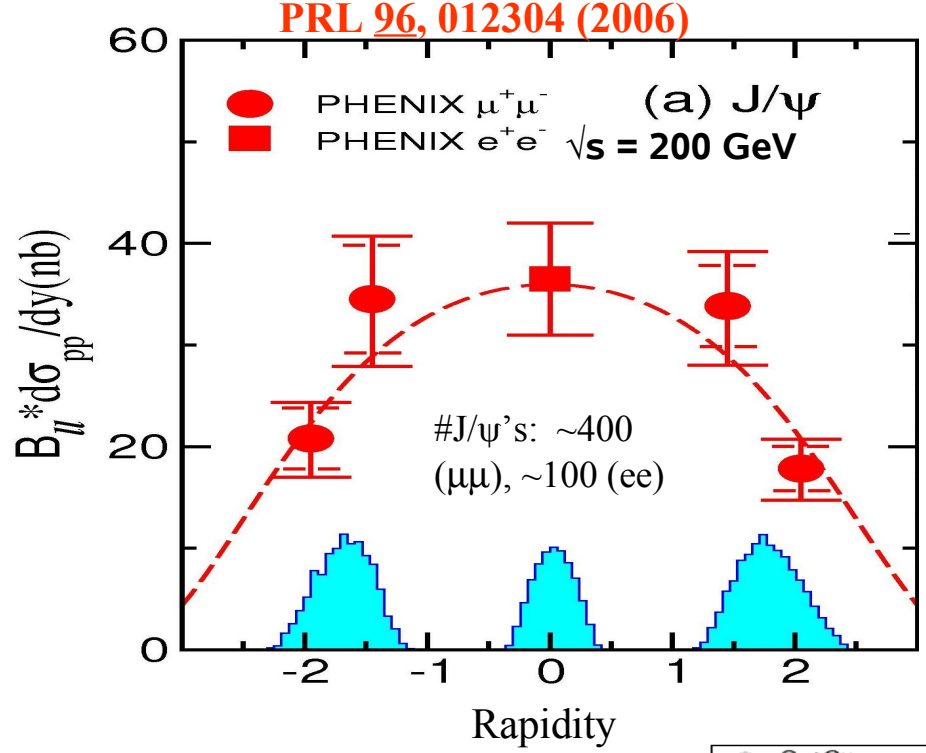


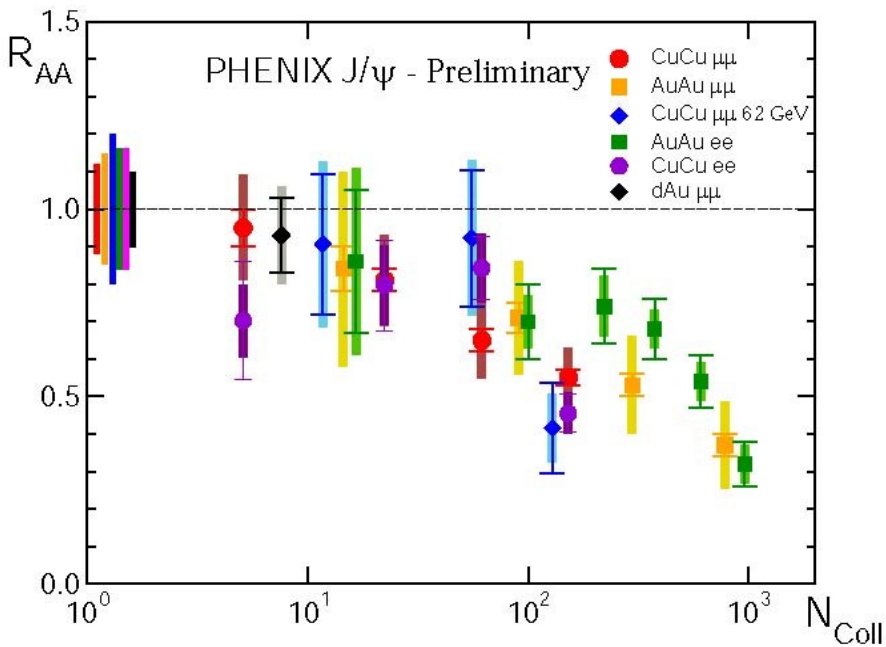
J^{PC} = 0^{-+} 1^{--} 0^{++} 1^{++} 1^{+-} 2^{++}

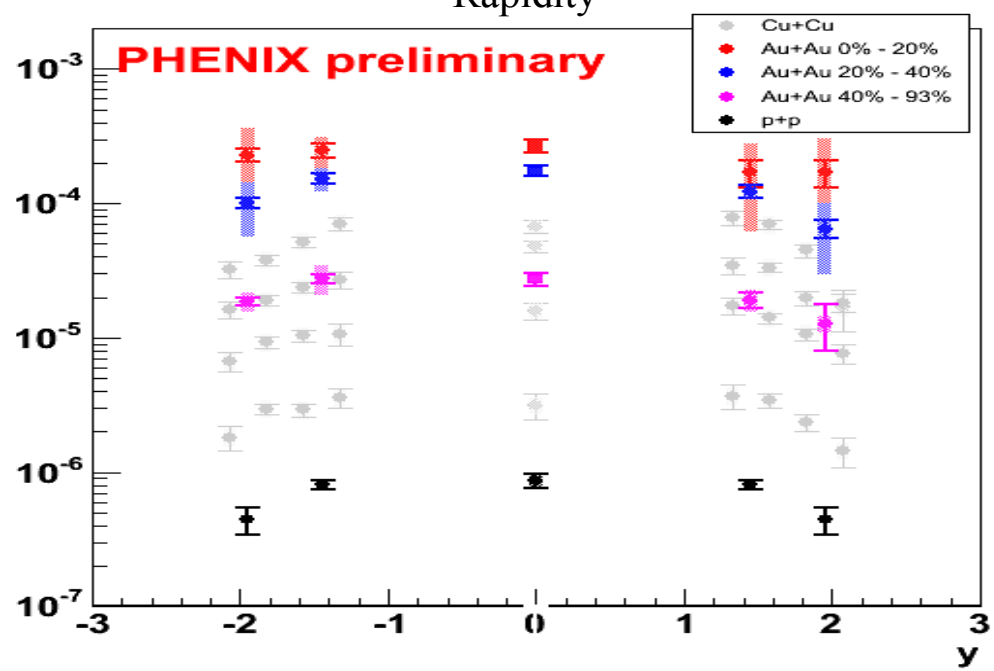
The J/ψ so far - PHENIX

PRL 96, 012304 (2006)



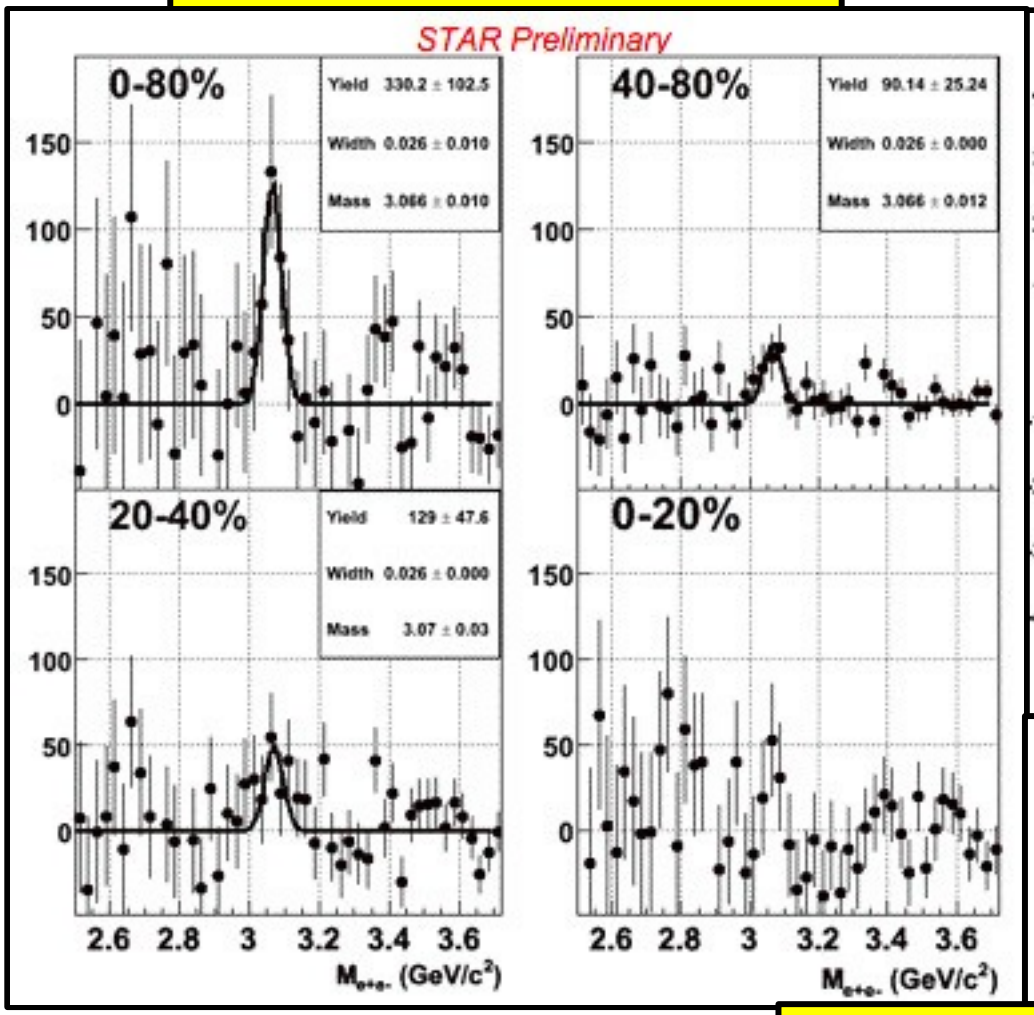




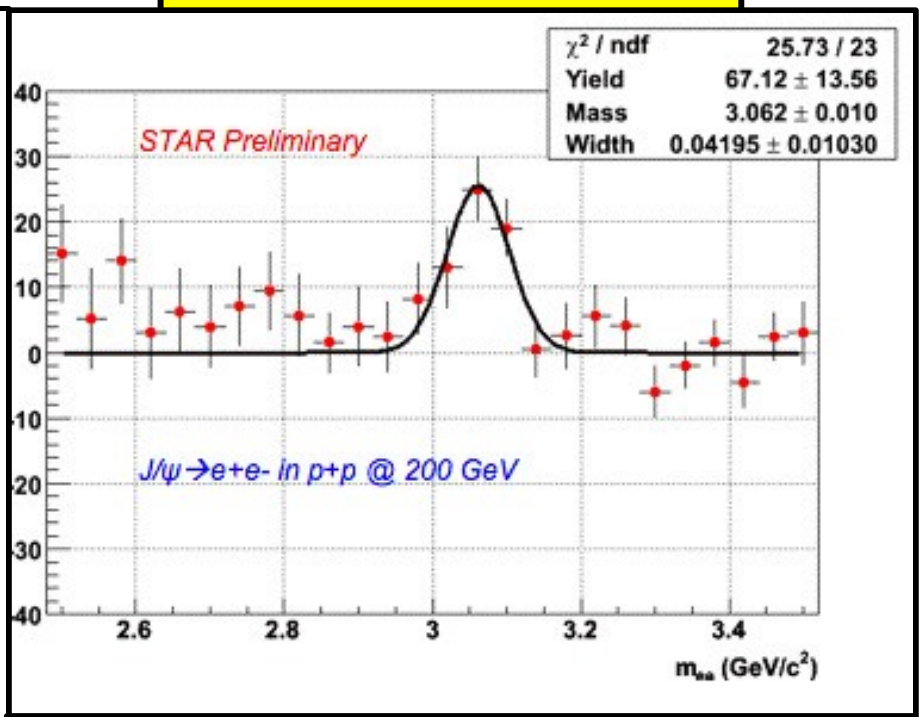


And STAR

Run 4: Au+Au, 200 GeV



Run 5: p+p, 200 GeV



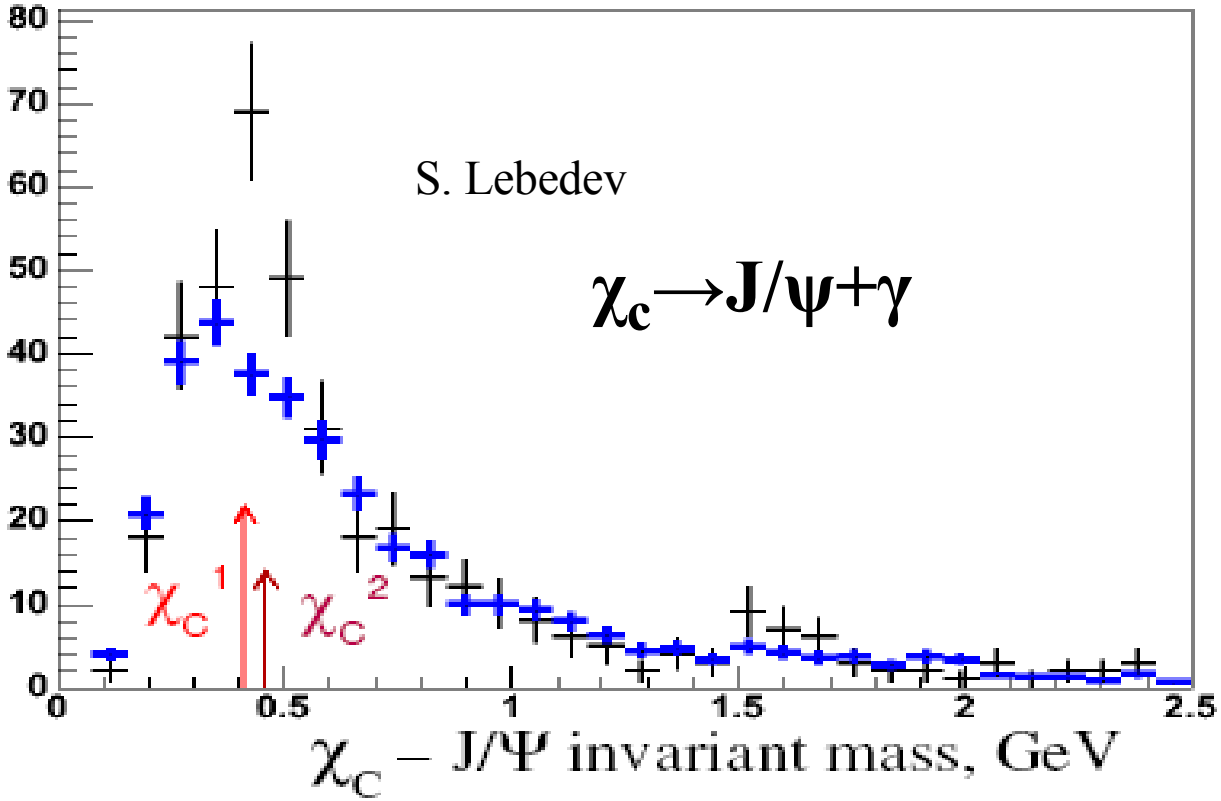
Future Prospects

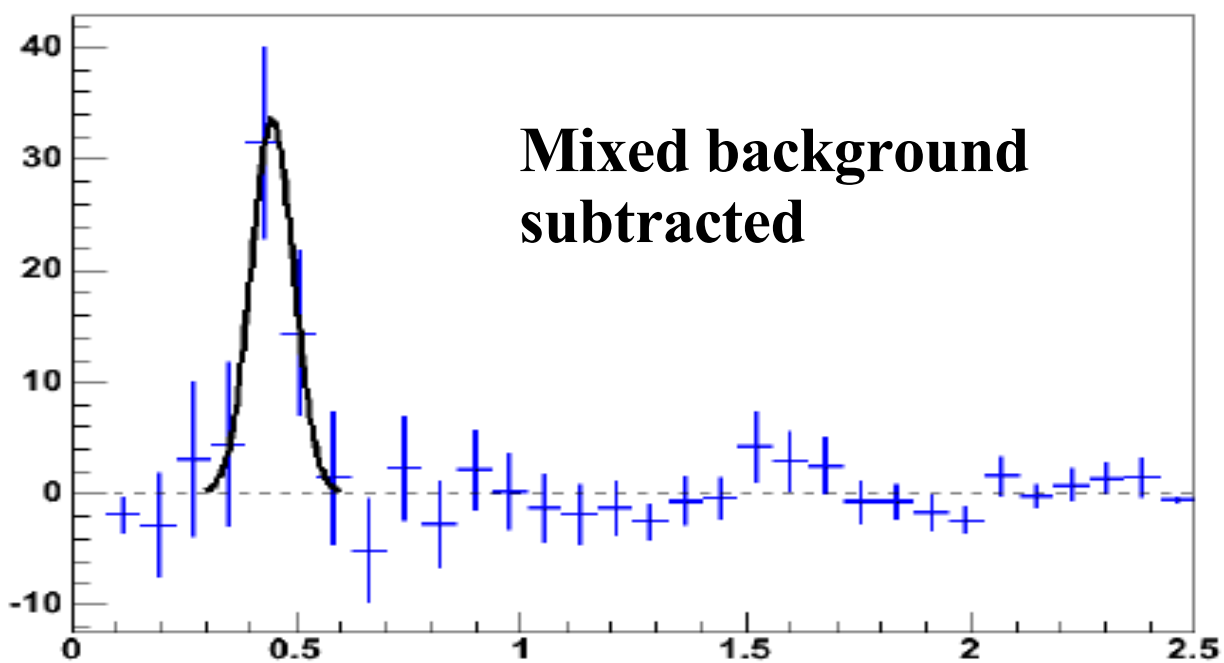
- New J/ψ trigger implemented for p+p collisions in PR06
- Barrel ToF and improved electron id
- Measurement versus centrality and p_T

J. Gonzalez, SQM 2006

(I stole this slide from Abby Bickley's talk yesterday)

The χ_c so far



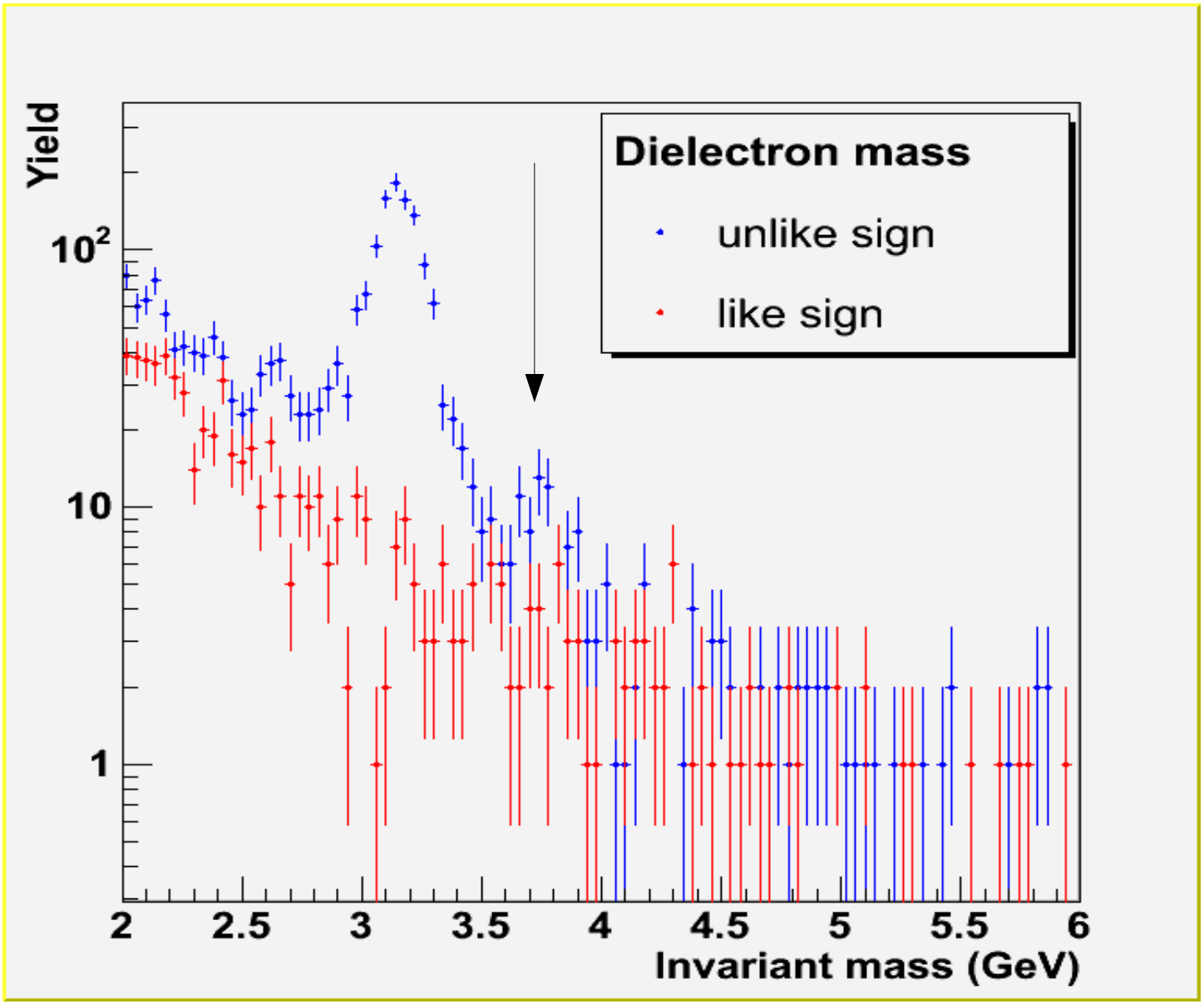


PHENIX

Run 5 pp with 3 pb^{-1}

Nice clean signal in pp. It will be considerably tougher for heavy ions!

The ψ' so far

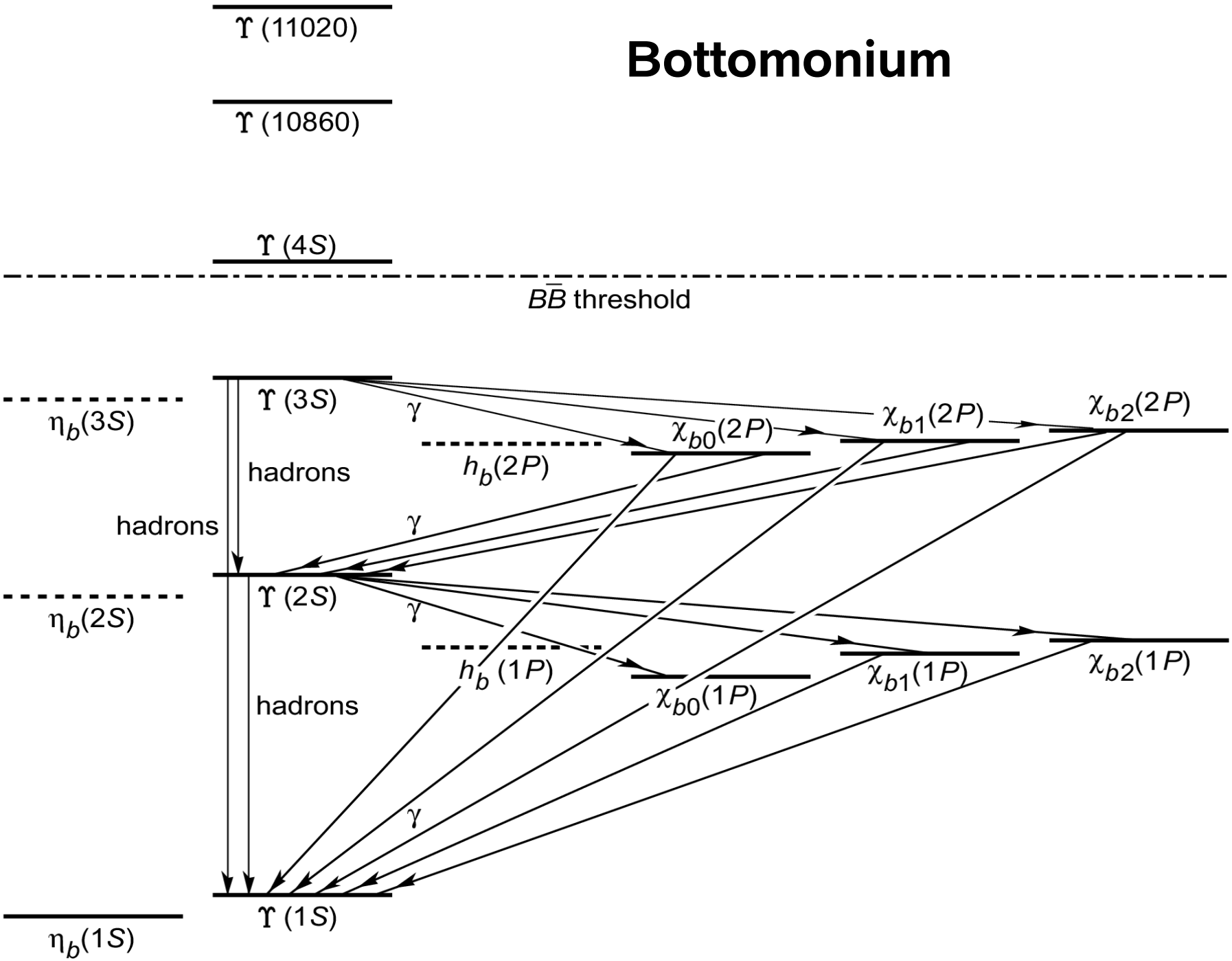


This is using most of the Run 6 luminosity. The resolution will improve significantly in the final analysis.

Even so, it will be a lot tougher for heavy ions.

PHENIX Run 6 200 GeV pp (level-2 filtered)

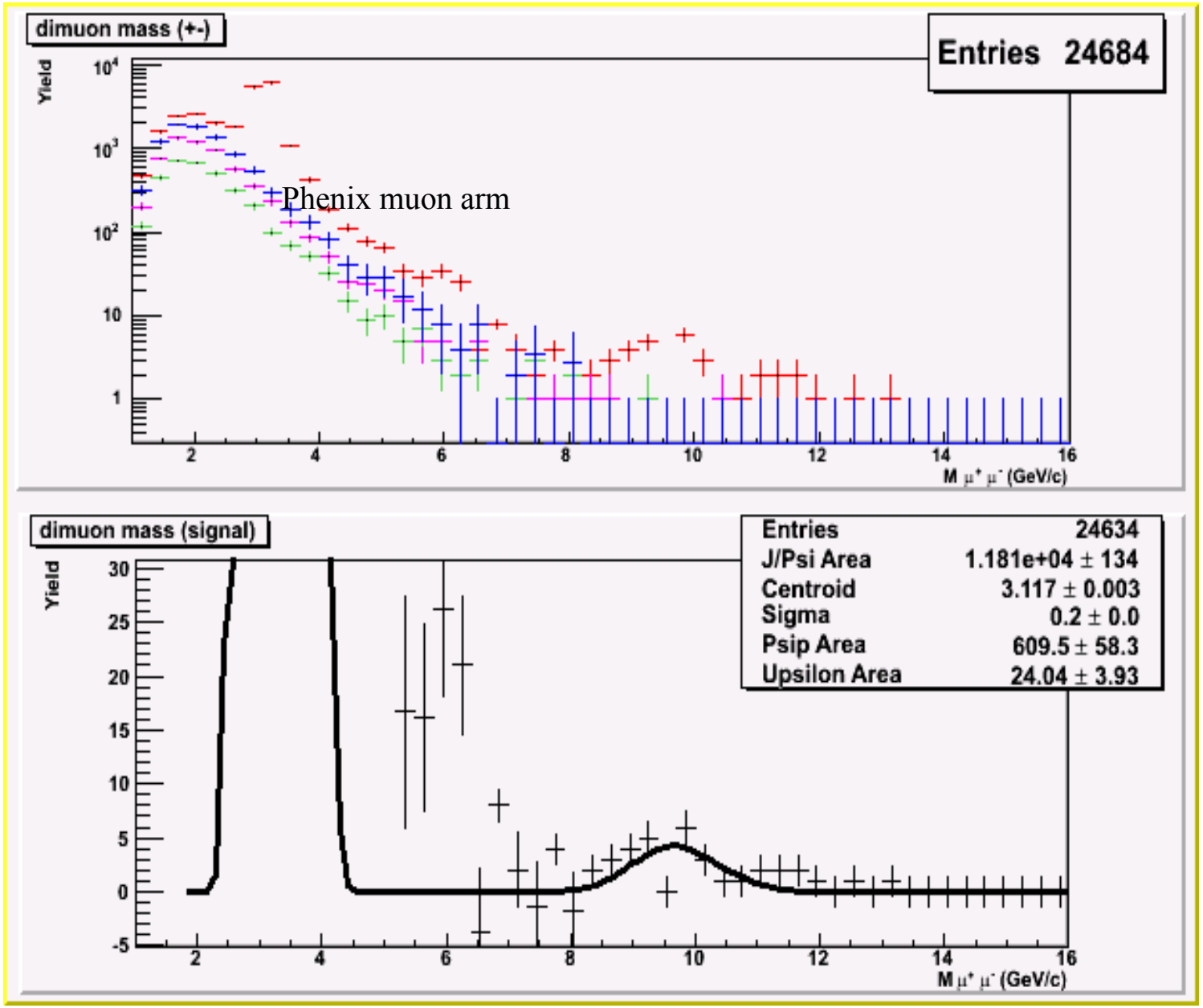
Bottomonium



$J^{PC} =$ 0^{-+} 1^{--} 1^{+-} 0^{++} 1^{++} 2^{++}

The Upsilon so far

PHENIX accumulated ~3 pb^{-1} in p-p collisions during Run 5.



The Y(1S,2S,3S) states are not resolved in the muon arms.

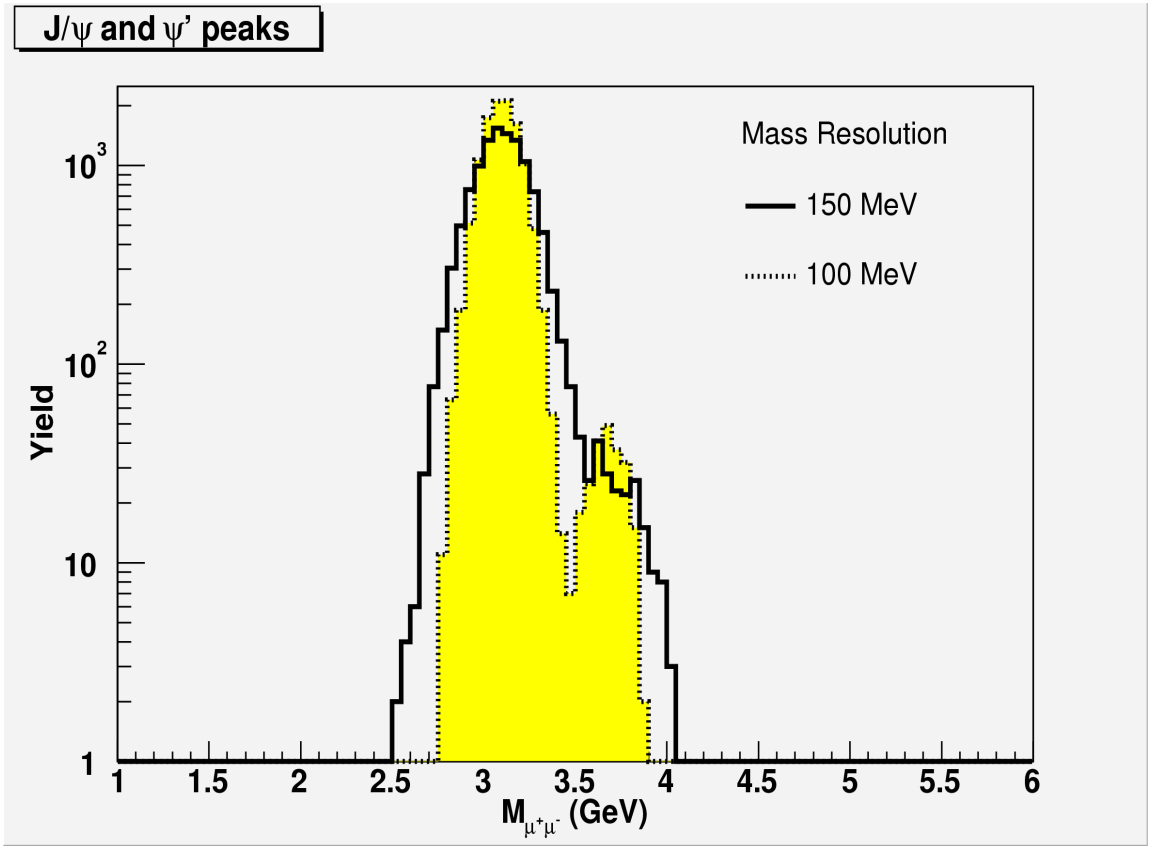
Charmonium and Bottomonium at RHIC II

With detector upgrades:

- J/ψ from B decays with displaced vertex measurement (PHENIX & STAR).
- Reduce J/ψ →μμ background with forward μ trigger in PHENIX.
- Improve mass resolution for charmonium and **resolve** Υ family (both).
- See γ in forward calorimeter in front of muon arms (PHENIX).

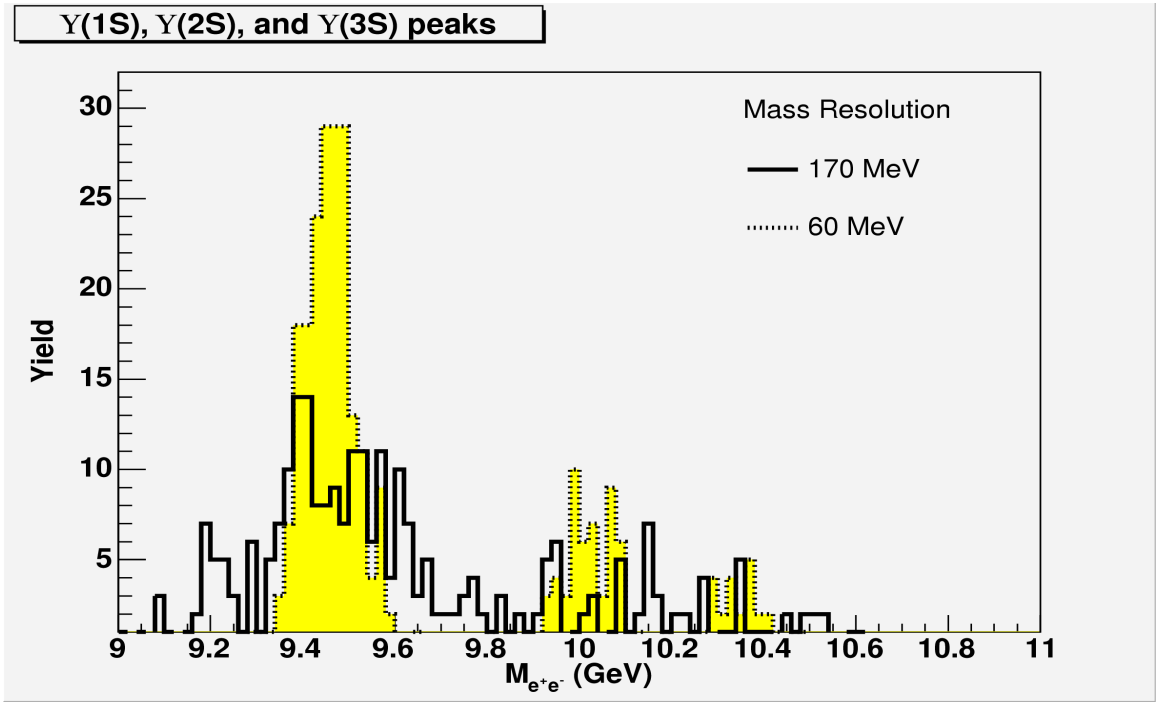
And with the luminosity upgrade:

- **J/ψ R_{AA} to high p_T**. Does J/ψ suppression go away at high p_T?
- **J/ψ v_2 measurements versus p_T**. See evidence of charm recombination?
- Υ **R_{AA}**. Which Upsilons are suppressed at RHIC?
- Measure $\chi_c \rightarrow$ **J/ψ+γ** **R_{AA}**. Ratio to J/ψ?
- Measure ψ' **R_{AA}**. Ratio to J/ψ?
- Measure **B → J/ψ** using displaced vertex - independent B yield measurement, also get background to prompt J/ψ measurement.



Future PHENIX

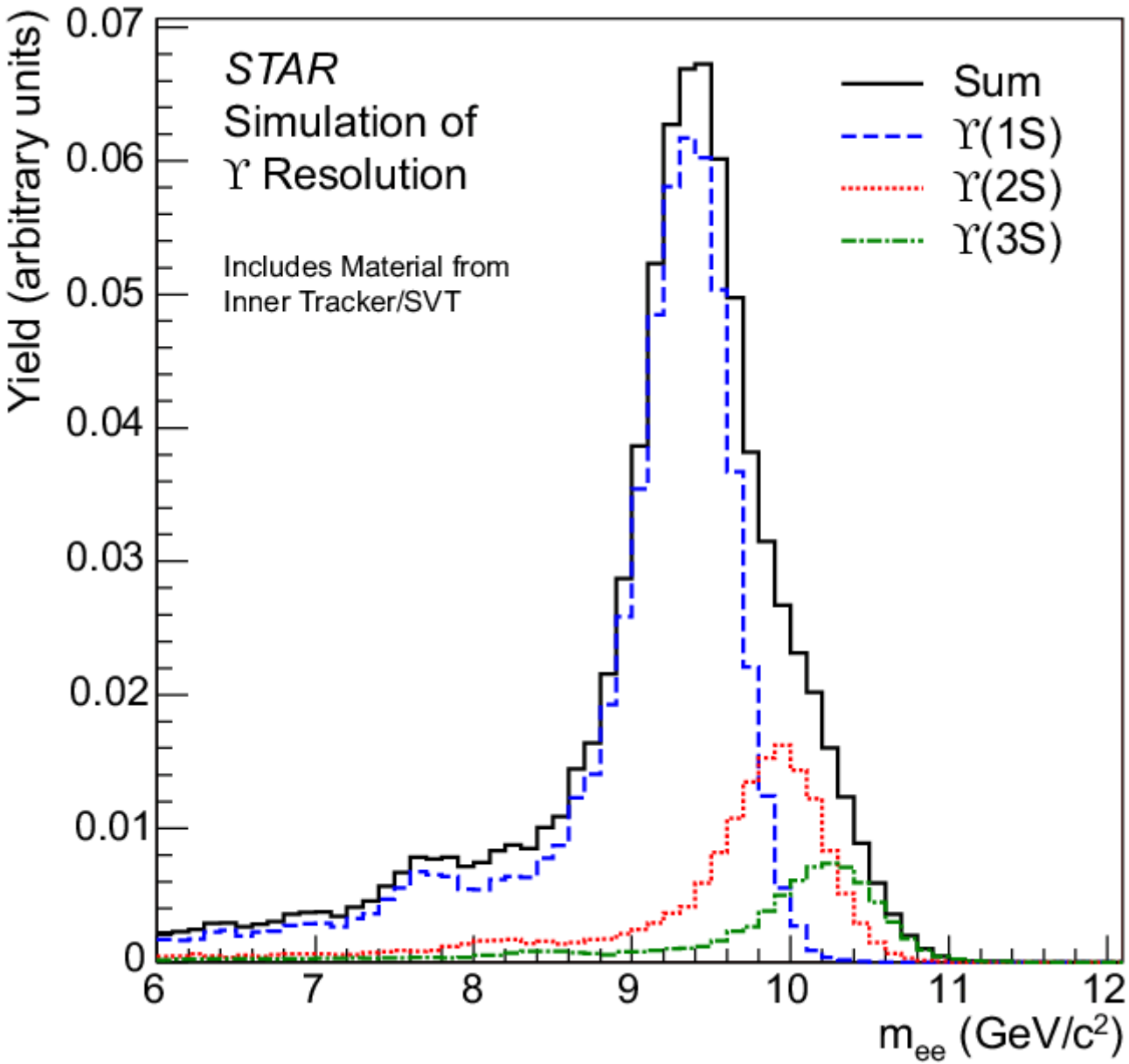
PHENIX J/ψ, ψ'→ $\mu^+\mu^-$
with Forward Si Vertex.



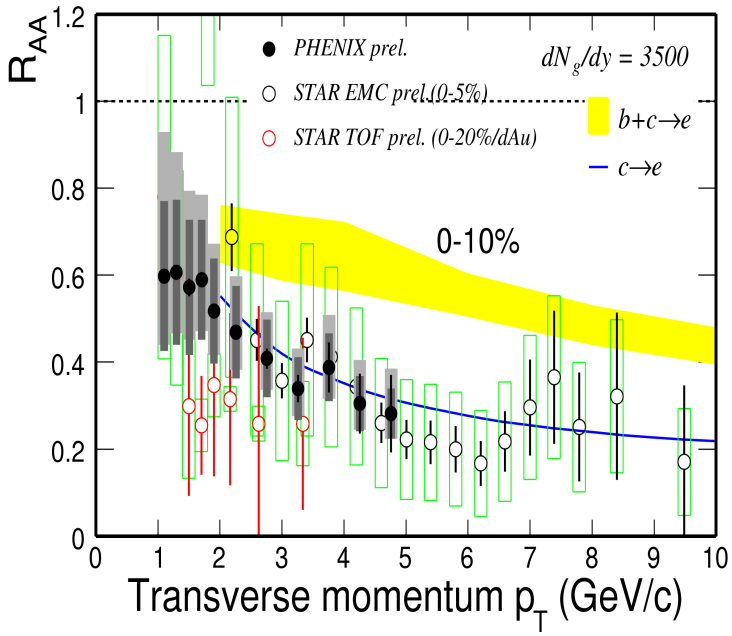
PHENIX Υ(1S,2S,3S)→ e^+e^-
central arm Si Vertex.

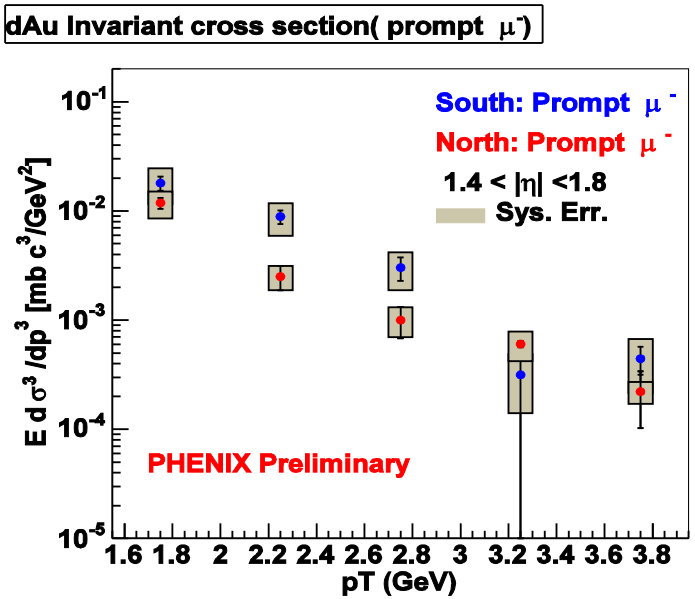
Future STAR

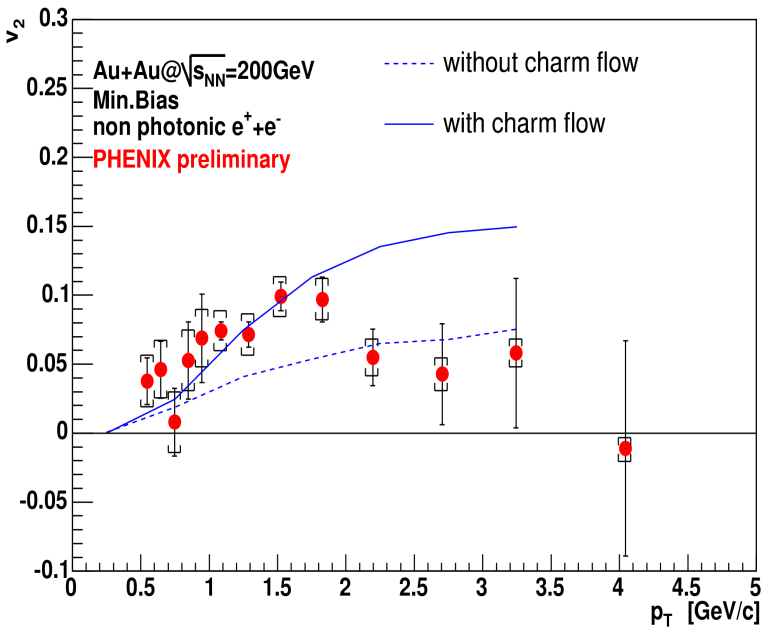
STAR needs to fit Υ(1S,2S,3S) peaks – **but** their yield is quite large.

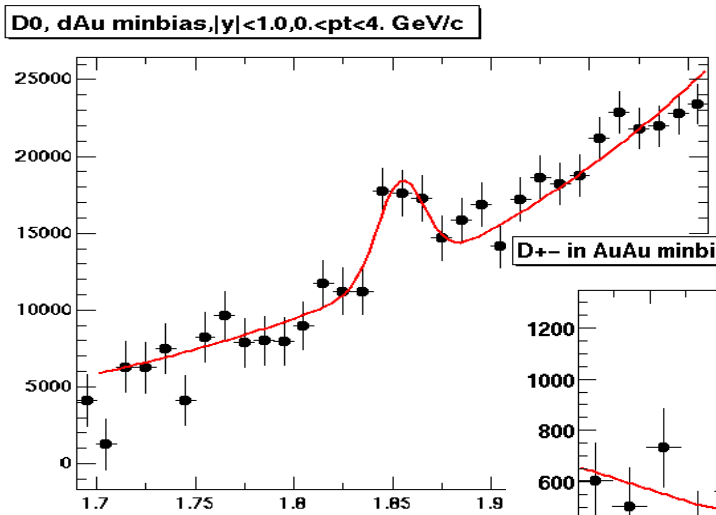


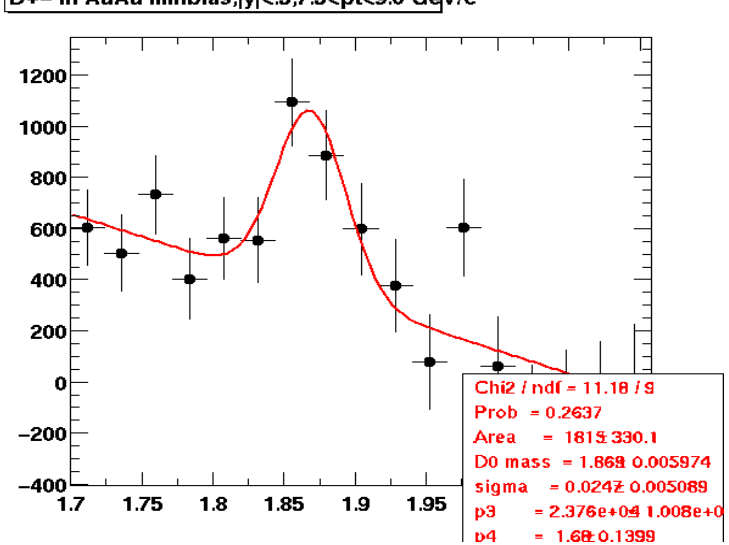
Open heavy flavor so far











Open Charm and beauty at RHIC II

With detector upgrades (both PHENIX and STAR):

- Dramatically reduce backgrounds for **all** (hadronic and semileptonic) open charm, open beauty signals using displaced vertex measurement.
- Separate open charm and beauty statistically using displaced vertex.
- Separate $B \rightarrow J/\psi$ from prompt J/ψ using displaced vertex.

And with the luminosity upgrade:

- Extend **open charm and beauty R_{AA}** measurements to high p_T. What is the energy loss well above the thermalization region?
- Measure semileptonic charm and beauty decay **v_2 to high p_T**. See the transition from thermalization to jet energy loss for charm.
- Measure **open charm correlations** with open charm or hadrons.

Quantitative estimates

In the next few slides I will show some quantitative estimates of the **heavy flavor signal yields** that we can expect at RHIC II, and I will also give a few examples of the corresponding yields for the LHC detectors. I will focus mostly on quarkonium measurements - these are generally the most statistics starved.

Assumptions for Au+Au at RHIC II:

- J/ψ cross sections from PHENIX data.
- Υ and open bottom cross sections from hep-ph/9502270 (agrees with PHENIX preliminary Υ measurement)
- Pair reconstruction efficiency 40%
- Trigger efficiency ~ 80%
- PHENIX & STAR coll. vertex cut 80% (central bucket)*70% in ± 10 cm.
- Displaced vertex cut (open charm, bottom) 40% efficient.

LHC estimates provided by the LHC experiments.
(Mostly made with less conservative efficiencies than my RHIC II estimates)

But first - p_T reach for open and closed charm and beauty

Both STAR and PHENIX have heavy flavor semileptonic decay spectra from Run 4 Au+Au data. The STAR data appear to extend to ~ 7.5 GeV/c with good statistics. PHENIX has J/ψ spectra that extend beyond 5 GeV/c with good statistics.

RHIC II will produce about 2 orders of magnitude (x75) more integrated luminosity.

- According to FONLL calculations of p_T distributions for **D →e and B →e** by Ramona Vogt, this will extend the p_T reach by **~ 5 GeV/c**.

- The same calculations indicate that the p_T distributions for **D→Kπ** will be extended by **~ 5 GeV/c**.

- A simple extrapolation of the existing Run 4 PHENIX **J/ψ data** suggests that the p_T reach will increase by **~ 3 GeV/c.**

Heavy flavor yields at RHIC II - PHENIX

200 GeV Au+Au for a 12 week physics run. Other species comparable.

Signal	|h|	Obtained	RHIC I (> 2008)	RHIC II
$J/\psi \rightarrow e^+e^-$	< 0.35	~ 800	3,300	45,000
$J/\psi \rightarrow \mu^+\mu^-$	1.2-2.4	~ 7000	29,000	395,000
$\psi' \rightarrow e^+e^-$	< 0.35		60	800
$\psi' \rightarrow \mu^+\mu^-$	1.2-2.4		520	7,100
$\chi_c \rightarrow e^+e^- \gamma$	< 0.35		220	2,900*
$\chi_c \rightarrow \mu^+\mu^- \gamma$	1.2-2.4		8,600	117,000*
$\Upsilon \rightarrow e^+e^-$	< 0.35		30	400
$\Upsilon \rightarrow \mu^+\mu^-$	1.2-2.4		80	1,040
$B \rightarrow J/\psi \rightarrow e^+e^-$	< 0.35		40	570
$B \rightarrow J/\psi \rightarrow \mu^+\mu^-$	1.2-2.4		420	5,700

* Large backgrounds, quality uncertain as yet.

Heavy flavor yields at RHIC II - STAR

200 GeV Au+Au for a 12 week physics run.

Signal	|h|	Obtained	RHIC I (> 2008)	RHIC II
$J/\psi \rightarrow e^+e^-$	< 1.0		16,200	220,000
$\psi' \rightarrow e^+e^-$	< 1.0		300	4,000
$\Upsilon \rightarrow e^+e^-$	< 1.0		830	11,200
$B \rightarrow J/\psi \rightarrow e^+e^-$	< 1.0		190	2,500
$D \rightarrow K\pi$	< 1.0		30,000*	30,000*

* From 100 Hz of minimum bias triggers (Thomas Ullrich).

Note: p+p yields are proportionately higher for J/ψ because trigger is more efficient in p+p than in Au+Au.

Heavy flavor yields at LHC - from the LHC experiments

200 GeV Pb+Pb for 1M seconds data taking (ie. 1 month), 500 μb^{-1}.

Signal	ALICE[1]	$\|\eta\|$	CMS[2]	$\|\eta\|$	ATLAS[3]	$\|\eta\|$
$J/\psi \rightarrow \mu^+\mu^-$	740,000	2.5-4	24,000	< 2.4	8K-100K	< 2.5
$J/\psi \rightarrow e^+e^-$	9,500[4]	< 0.9				
$\psi' \rightarrow \mu^+\mu^-$	14,000	2.5-4	440	< 2.4	140-1800	< 2.5
$\psi' \rightarrow e^+e^-$	190[4]	< 0.9				
$\Upsilon \rightarrow \mu^+\mu^-$	8,400	2.5-4	26,000	< 2.4	15,000	< 2.0
$\Upsilon \rightarrow e^+e^-$	2,600	< 0.9				
$D \rightarrow K\pi$	8,000	< 0.9				

1. Philippe Crochet, EPJdirect A1, 1 (2005), and private comm.
2. Bolek Wyslouch, PANIC LHC satellite workshop
3. Helio Takai, PANIC LHC satellite workshop
4. Minbias + central untriggered events - Philippe Crochet

Prompt J/ψ only

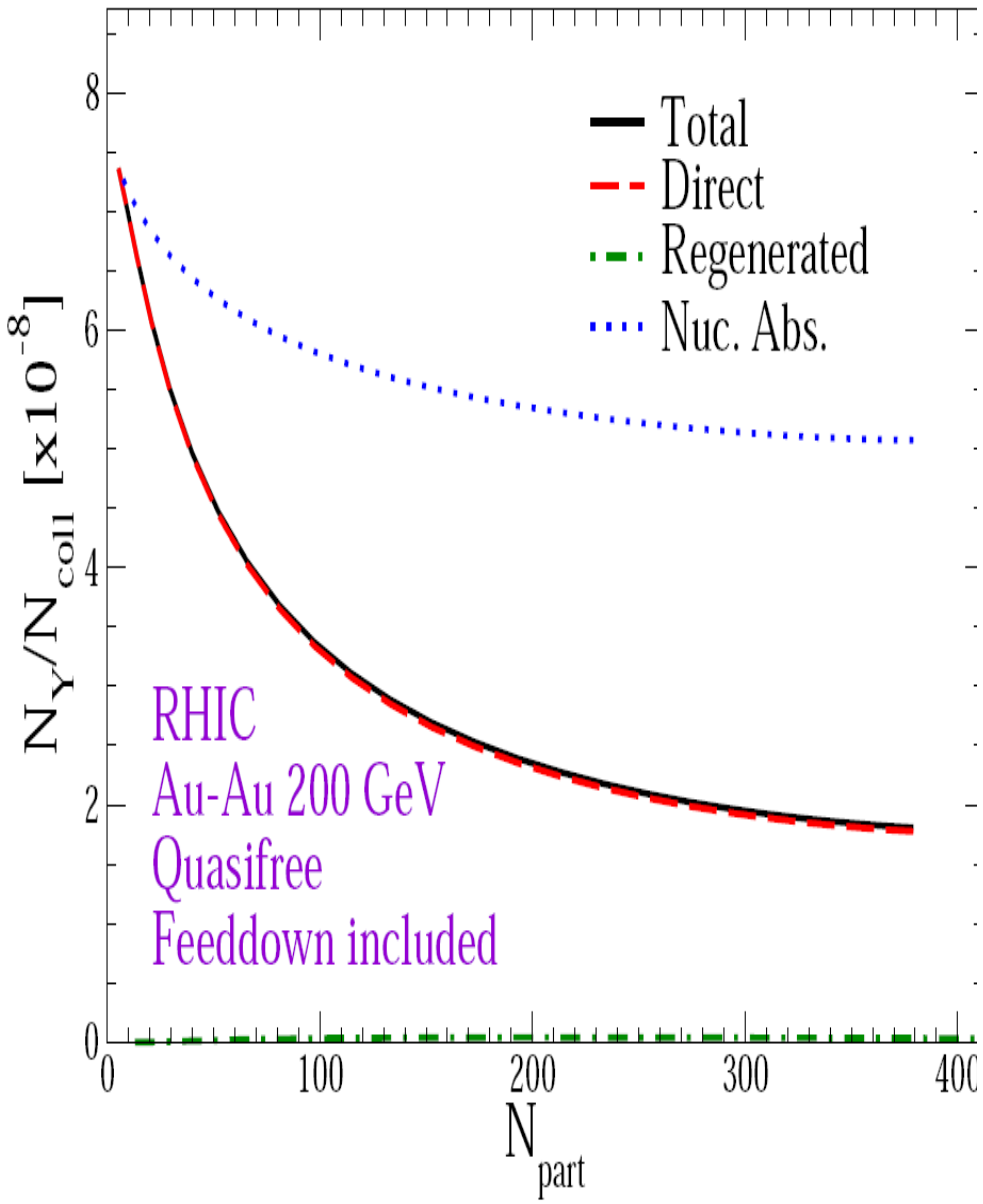
RHIC II / LHC complementarity

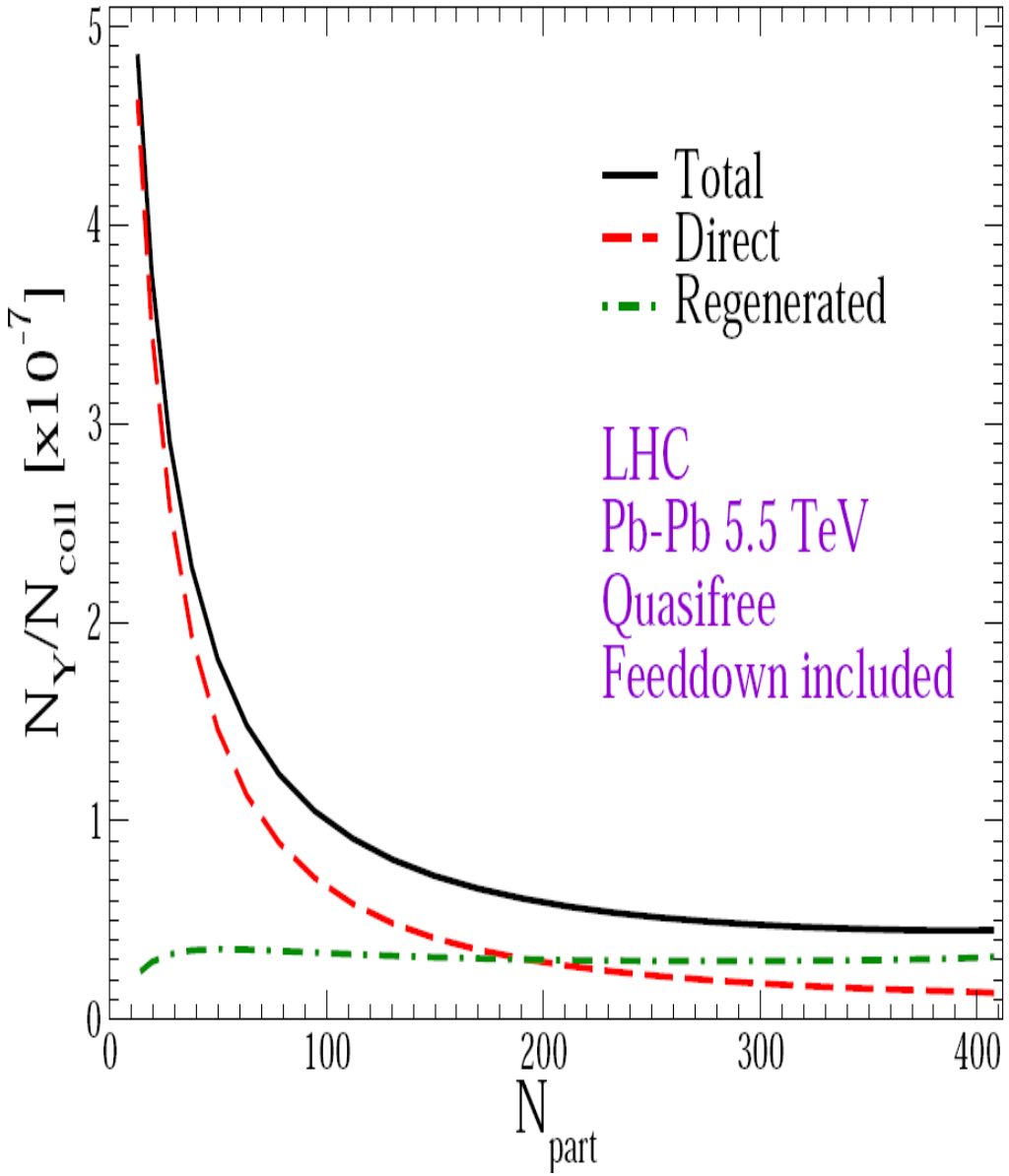
	RHIC II	LHC
HF yields	---------- similar ----------	
QGP temperature	$2T_c$	$4T_c$
QGP lifetime	~7 fm/c	~17 fm/c
N_{cc}	10	115
N_{bb}	0.05	5
J/ψ	bound	unbound
J/ψ form.[1]	suppr.+coalescence	coalescence
$\Upsilon(1S)$	bound	bound
$\Upsilon(1S)$ form.[2]	suppr.	suppr.+coalescence
Open b		easier (cross section ↑)
Open c		harder (b feed down ↑)

1. LHC data should help resolve ambiguity from suppr./coalescence at RHIC.
2. RHIC data should help resolve ambiguity from suppr./coalescence at LHC.

(See next slide)

Y(1S) at RHIC and LHC. From Grandchamp et al., hep-ph/0507314.
Coalescence is predicted to be unimportant at RHIC, dominant at LHC.



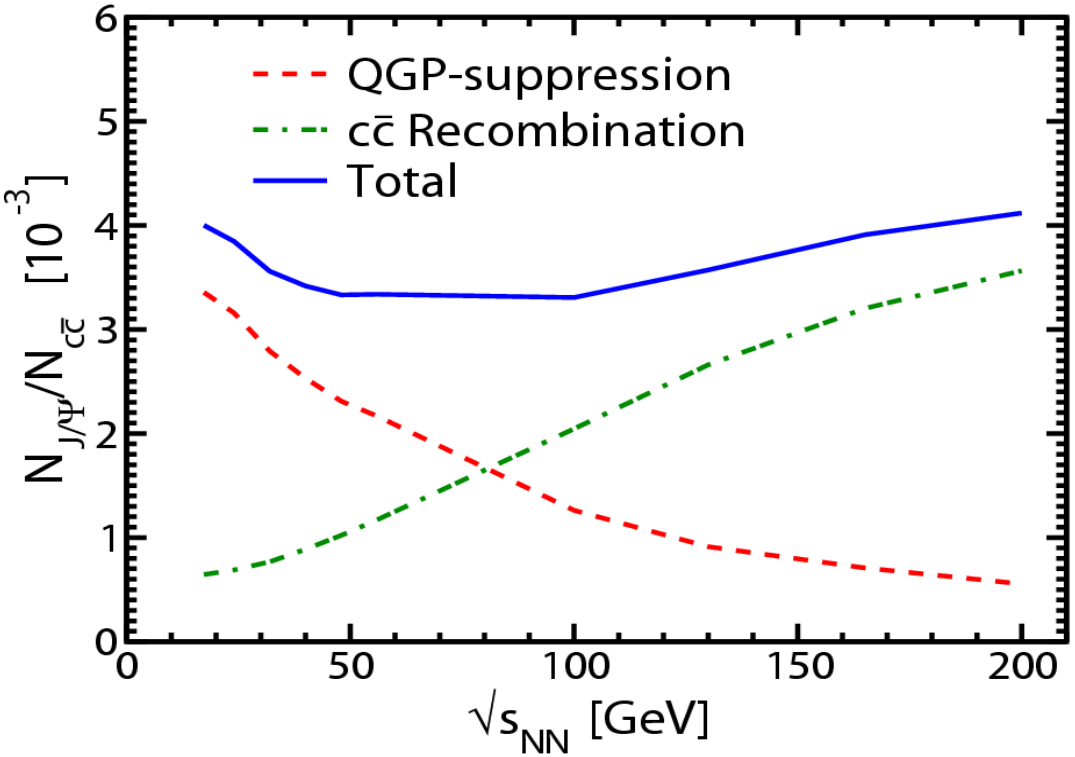


Low energy heavy flavor at RHIC II

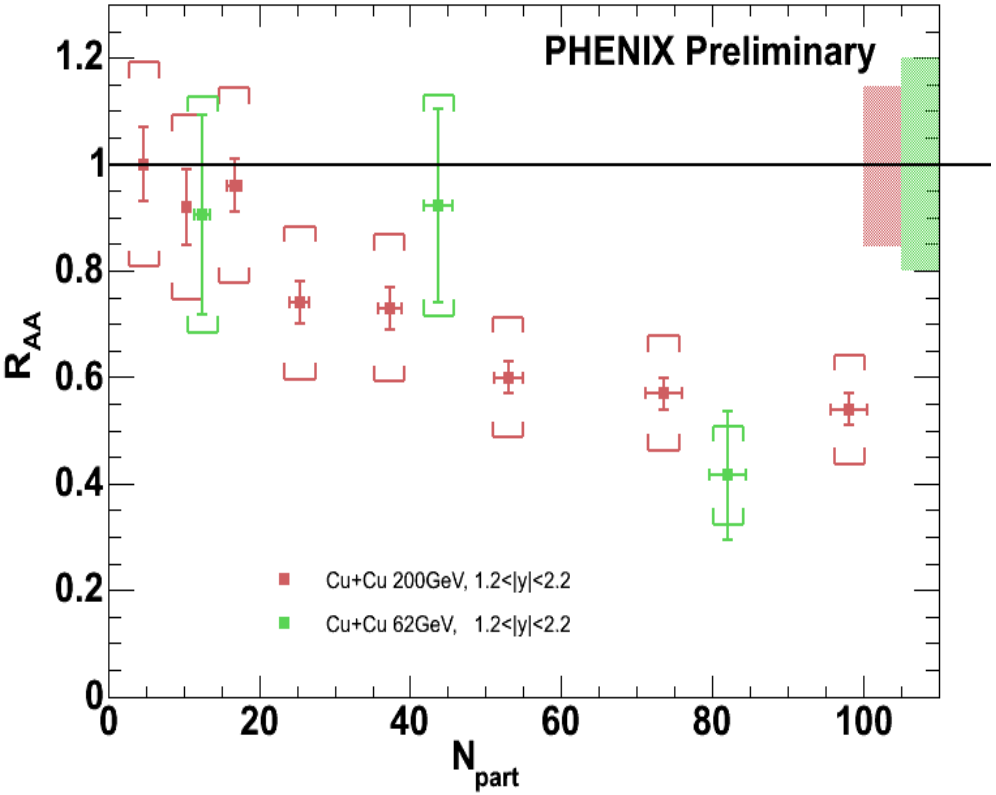
The RHIC II luminosity upgrade will also provide high enough luminosity to enable basic heavy flavor measurements at lower energies, where cross sections are smaller.

These measurements are likely to be focused on J/ψ and open charm, because the **excited** charmonium states and the Upsilon states would require **very** long runs at lower energies.

Low energy J/ψ at RHIC II



Coalescence model calculation of J/ψ yield in AuAu collisions vs collision energy by Grandchamp and Rapp, N.P. **A715**, 545 (2003). According to this model, **suppression dominates** at 62 GeV.



Measurements of J/ψ rapidity and p_T distributions should be feasible at RHIC II. Remember that we have seen a J/ψ signal in a short 62 GeV CuCu run.

Low energy open charm at RHIC II

Measurements of open charm at lower energy at RHIC II will allow us to see the effects of lower initial energy density on charm energy loss.

Open charm measurements at lower energy will benefit greatly from both the luminosity increase **and** the reduction in background provided by the displaced vertex measurement.

Conclusions

RHIC II and the detector upgrades bring us dramatically expanded capabilities for heavy flavor physics, including:

- Separated open charm and beauty, R_{AA} and v_2 measurements to high p_T. Clean measurements of heavy quark energy loss.
- J/ψ R_{AA} to high p_T. J/ψ v_2 versus p_T. J/ψ $\langle p_T^2 \rangle$ vs centrality. Precise J/ψ rapidity dependence. All are strong tests of production models.
- Excited charmonium: R_{AA} for $\chi_c \rightarrow J/\psi+\gamma$ and ψ'.
- Υ R_{AA}. Which Upsilons are suppressed at RHIC?
- $B \rightarrow J/\psi$. Independent B yield measurement, background to prompt J/ψ.
- Jets tagged with J/ψ, b, c, bb, cc - many clean handles on jet properties.

The RHIC II and LHC programs will complement each other by providing heavy flavor measurements of similar quality, but with rather different initial physics conditions (T_c, N_{cc}, N_{bb})