Upsilon production in STAR

Pibero Djawotho for the STAR Collaboration
Texas A&M University

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Outline

I. Physics motivation
II. Experimental apparatus
   A. RHIC machine
   B. STAR detector
   C. STAR Υ trigger
III. Υ measurements
   A. p+p: baseline measurement
   B. d+Au: cold nuclear matter effects
   C. Υ-hadron correlations: production mechanism
IV. Conclusion and outlook for Au+Au

Physics motivation

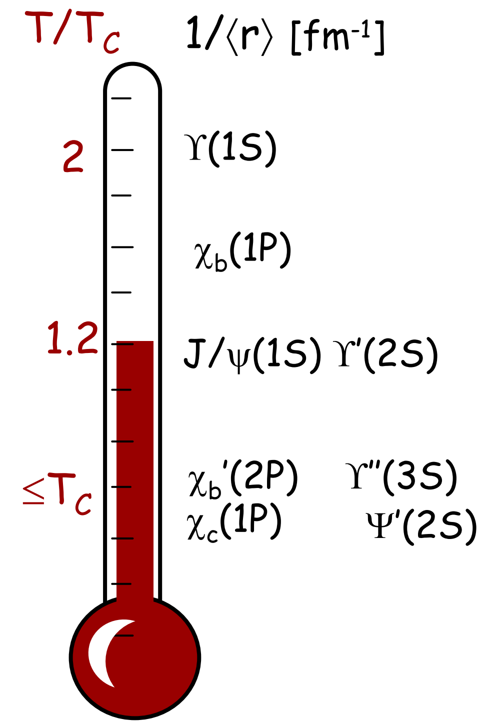
Sequential disappearance of states:

⇒Color screening ⇒ Deconfinement

Matsui T and Satz H, PLB 178 416 (1986)

⇒QCD thermometer ⇒ QGP Properties

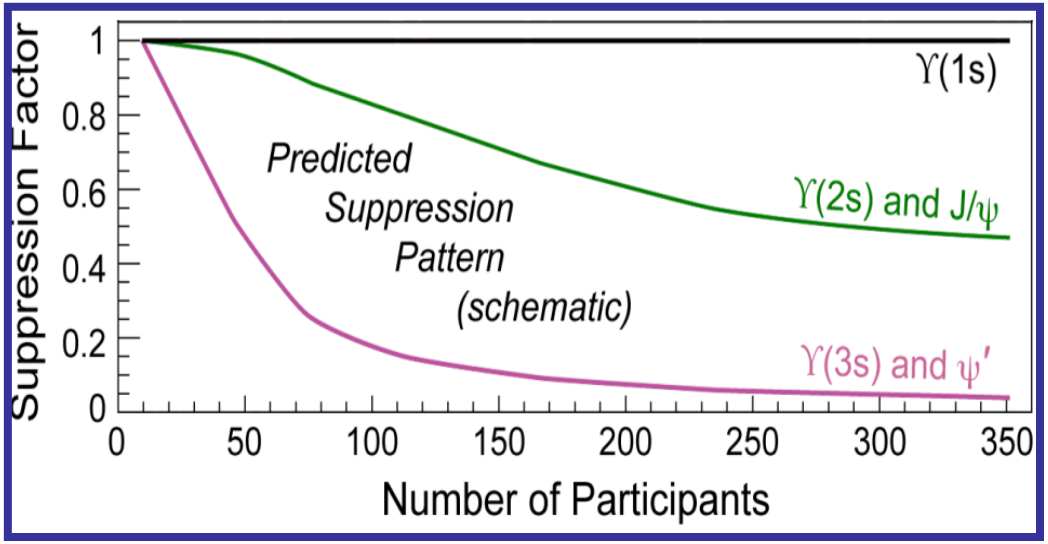
Mocsy A and Petreczky P, PRD 77 014501 (2008)



A .Mocsy, 417th WE-Heraeus-Seminar,2008

- Milestone measurements:
  1. Establish baseline in p+p and understand hadroproduction
  2. Study cold nuclear matter effects in d+Au
  3. Investigate QGP properties in Au+Au

Expectations at RHIC energies



- $\Upsilon(1S)$ does not melt
- $\Upsilon(2S)$ is likely to melt
- $\Upsilon(3S)$ will melt

Mocsy and Petreczky, PRL 99, 211602 (2007)

Υ Pros and Cons: Physics

Pros

- Small background at M_{ee}~10 GeV/c^2
- Co-mover absorption (reduces yield) is very small
  - Lin and Ko, PLB 503, 104 (2001)
- Recombination (enhances yield) negligible at RHIC ($\sigma_{bb} << \sigma_{cc}$)
  - Zhao and Rapp, PLB 664, 253 (2008)

Cons

- Extremely low rate
  - One Υ per 10^9 minimum bias p+p interactions

Υ Pros and Cons: Instrumental

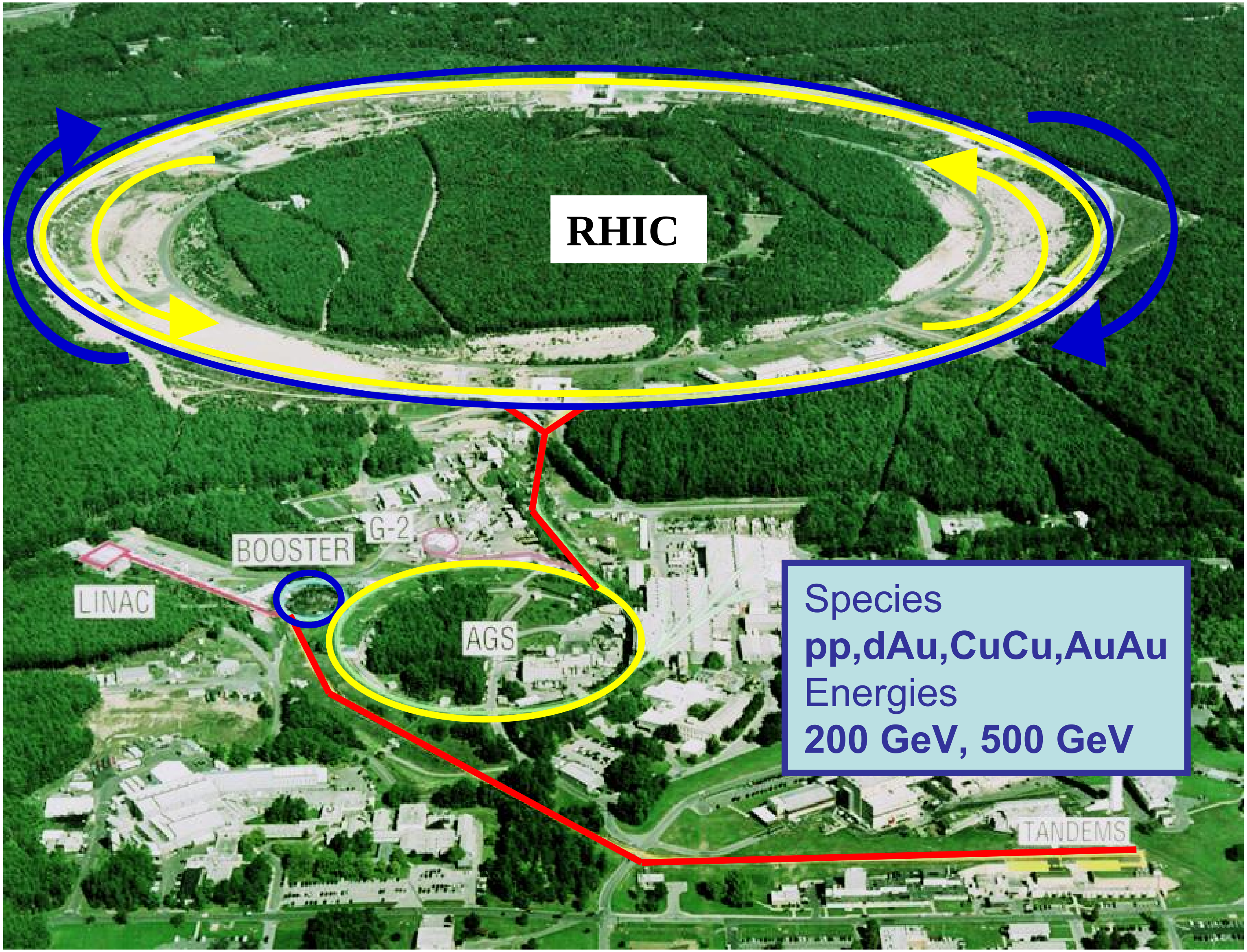
Pros

- Efficient trigger - works in p+p up to central Au+Au collisions
- Large acceptance at $|y|<0.5$ and $\Delta\varphi=2\pi$
- Large rejection factor $\sim10^5$ in p+p
- Sample full luminosity → no prescale

Cons

- Good resolution needed to separate all 3 Υ S-states

Relativistic Heavy Ion Collider (RHIC)



Species
pp,dAu,CuCu,AuAu
Energies
200 GeV, 500 GeV

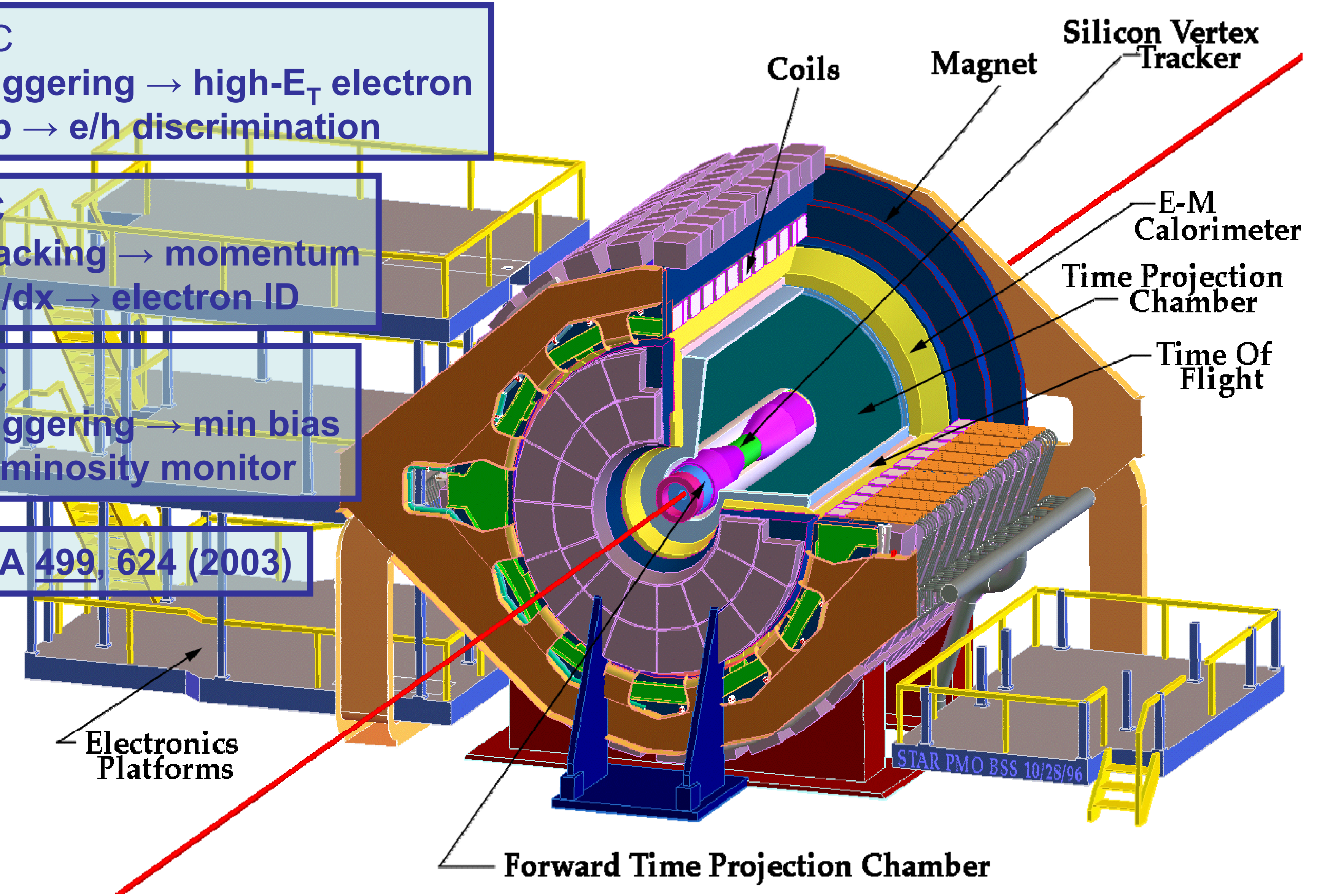
Solenoidal Tracker At RHIC (STAR)

EMC
- Triggering → high-E_T electron
- E/p → e/h discrimination

TPC
- Tracking → momentum
- dE/dx → electron ID

BBC
- Triggering → min bias
- Luminosity monitor

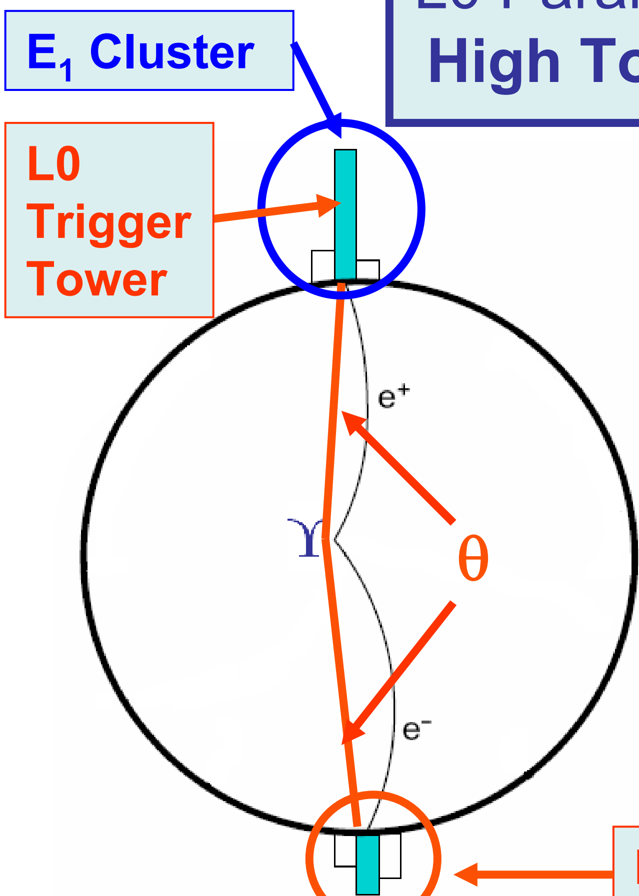
NIMA 499, 624 (2003)



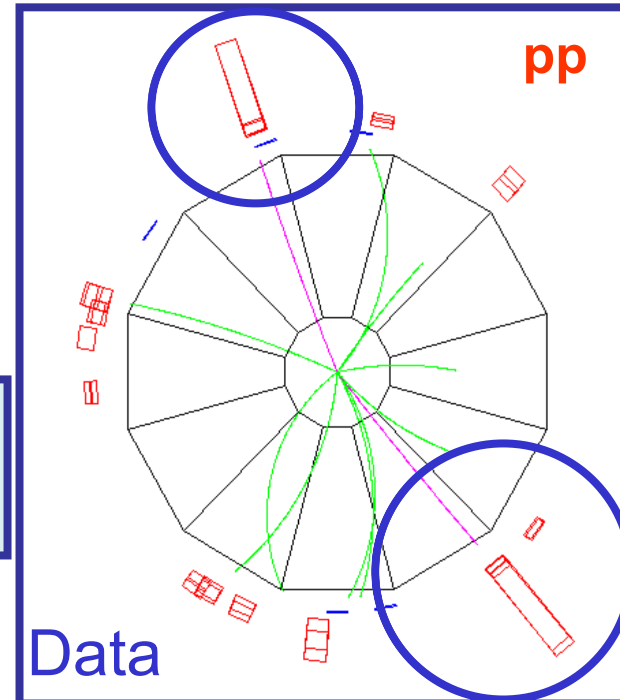
STAR ϒ Trigger

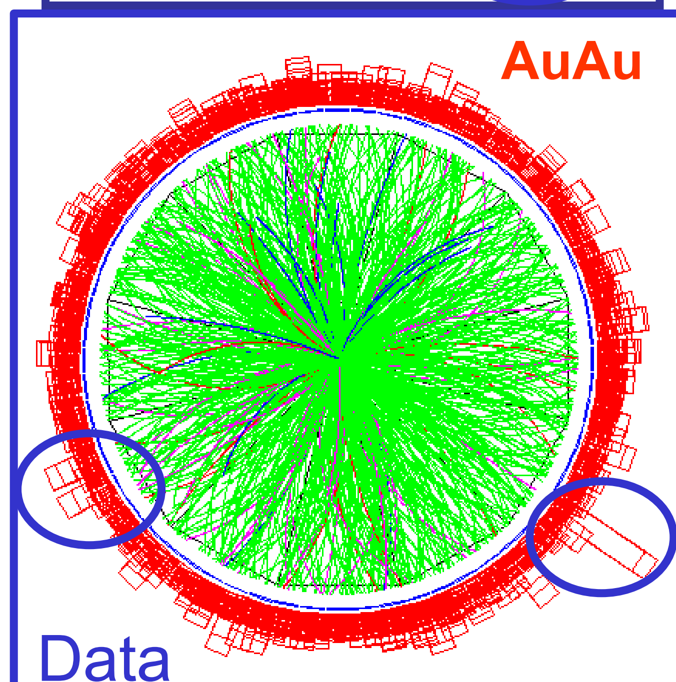
L0 Parameters (pp)
High Tower E_T > 3.5 GeV
Trigger Patch E_T > 4.3 GeV

L0 Parameters (dAu,AuAu)
High Tower E_T > 4.0 GeV



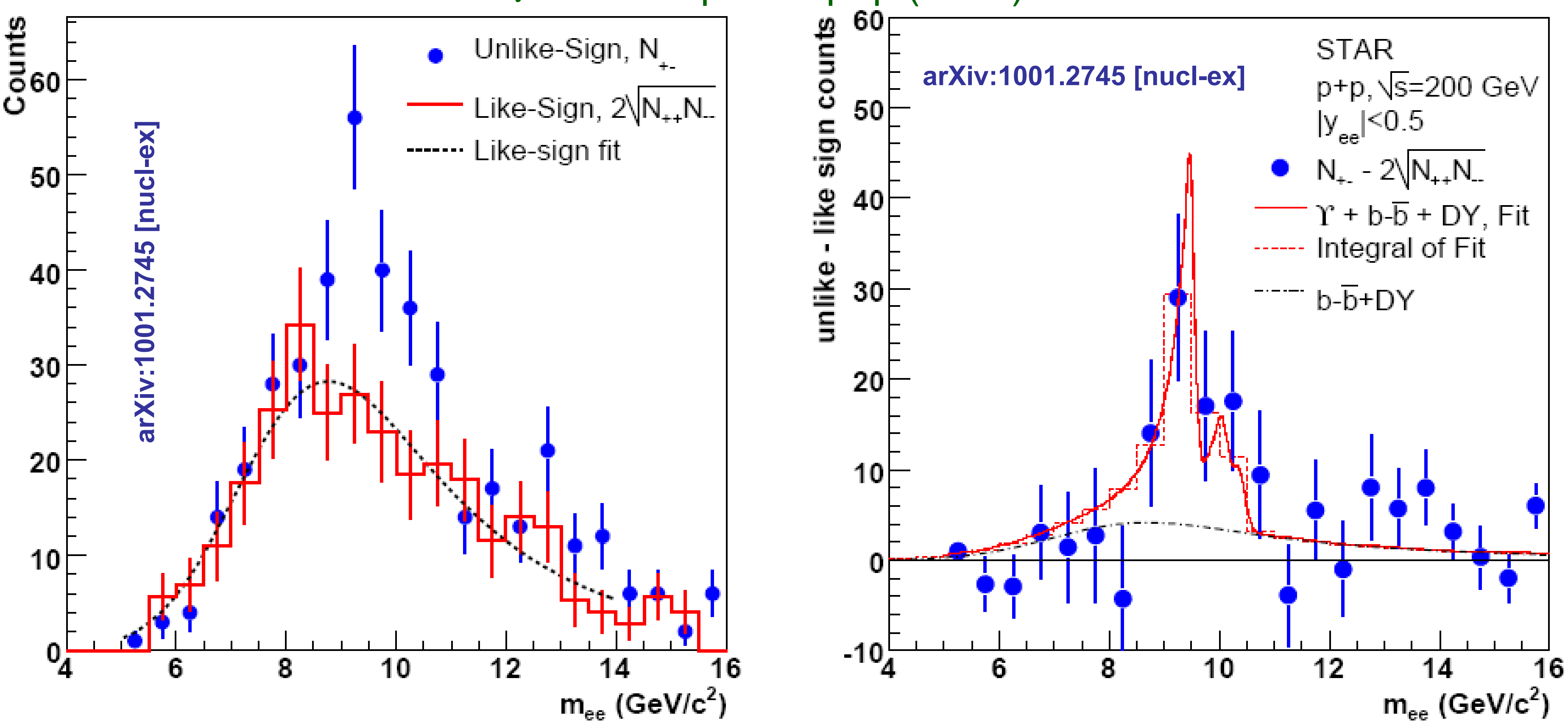
L2 Parameters
E_1 Cluster,
E_2 Cluster,
cos(θ),
Invariant Mass





$\Upsilon \rightarrow e^+e^-$ in p+p at $\sqrt{s}$=200 GeV

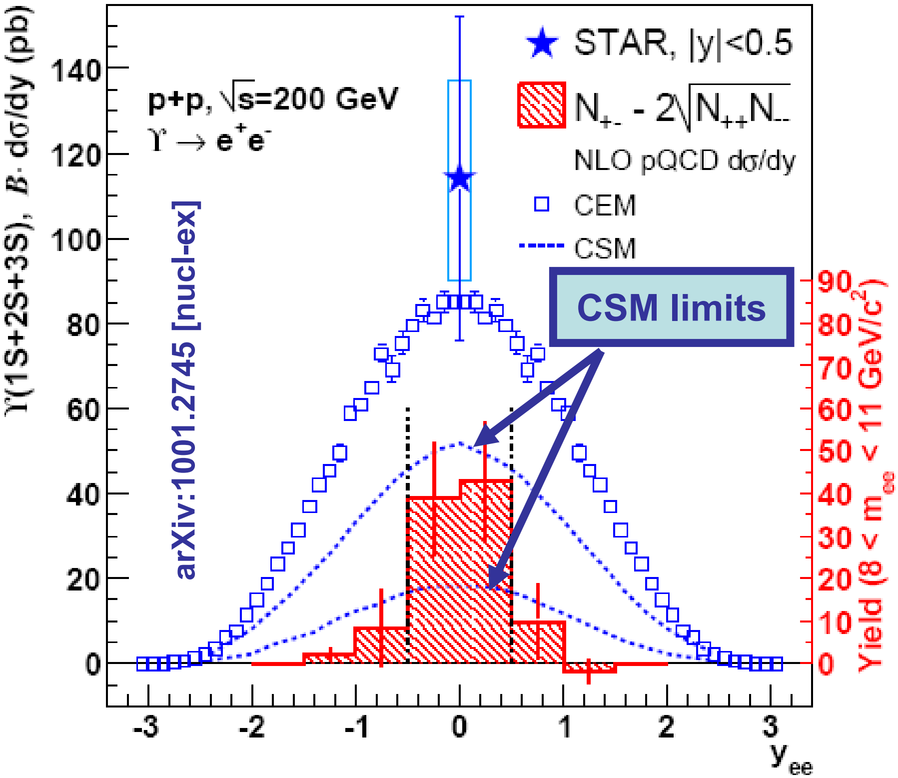
$\int \mathcal{L} dt$ = 7.9 pb^{-1} of p+p (2006)

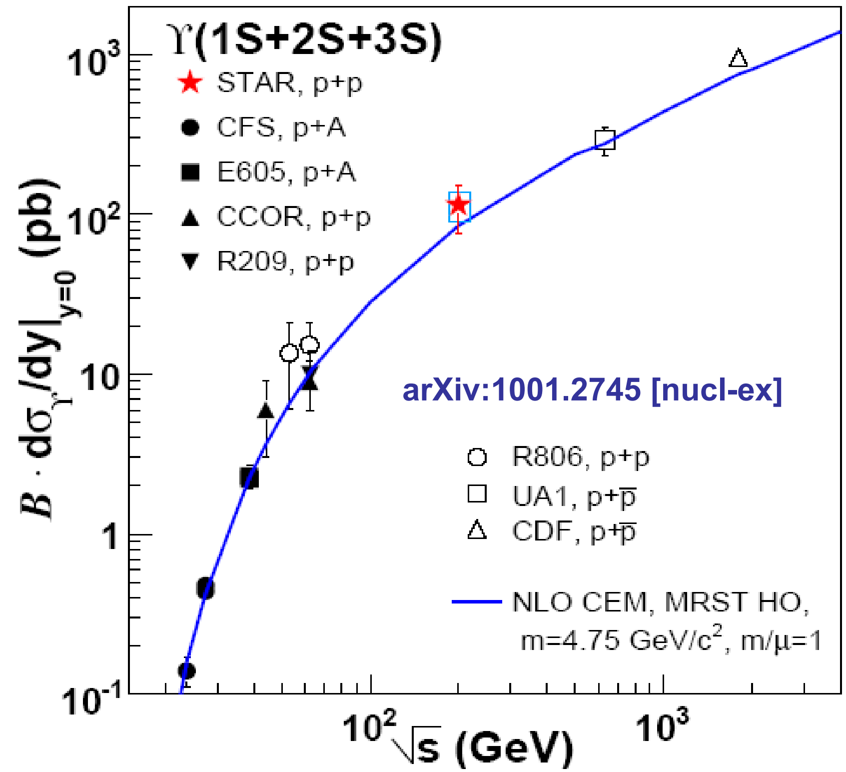


$$B_{ee} \times \left(\frac{d\sigma}{dy} \right)_{y=0}^{\Upsilon(1S+2S+3S)} = 114 \pm 38^{+23}_{-24} \text{ pb}$$

$$\left(\sigma_{DY} + \sigma_{b\bar{b}} \right)_{|y|<0.5,\, 8<m_{ee}<11\,\mathrm{GeV/c^2}} = 38 \pm 24 \text{ pb}$$

Comparison of STAR ϒ cross section in p+p at √s=200 GeV with theory and world data

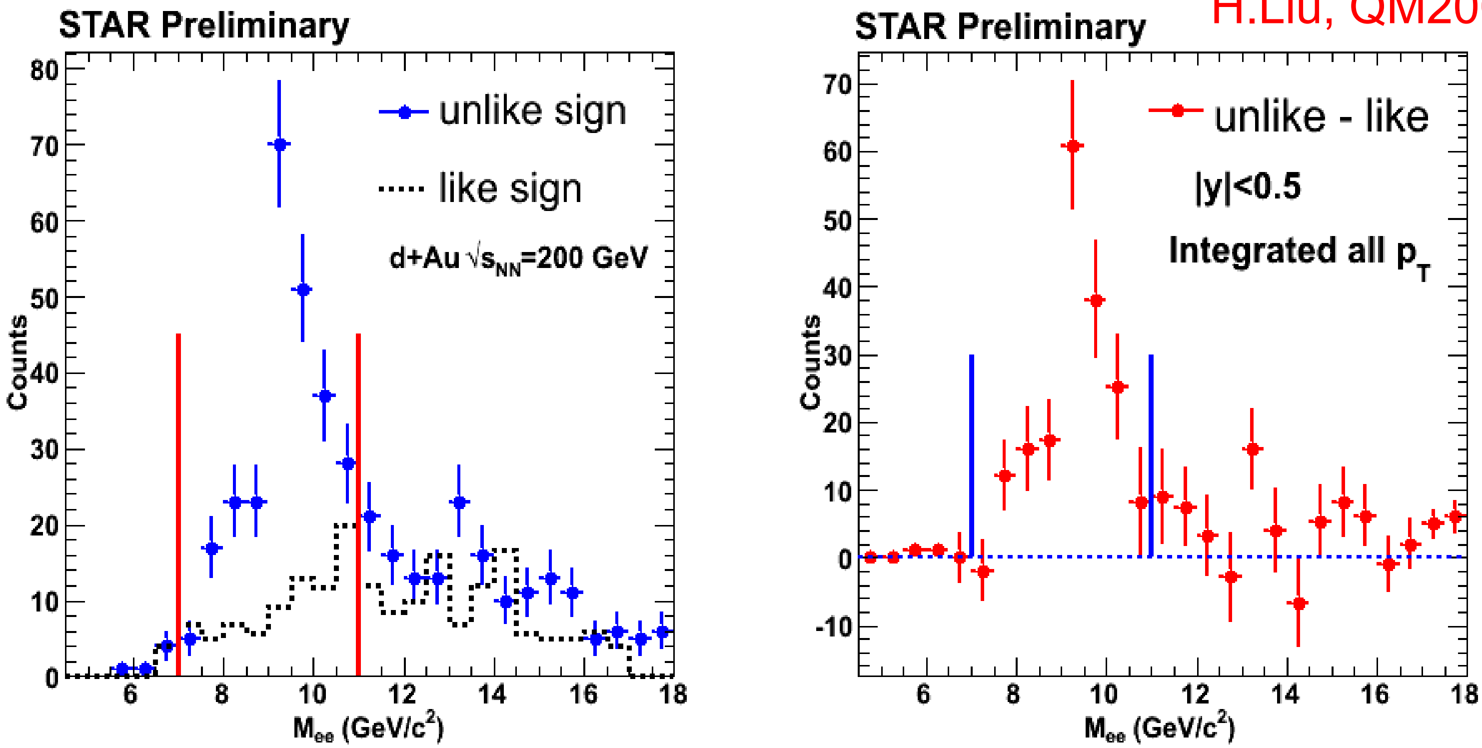




- STAR data agrees with Color Evaporation Model (CEM) at NLO
  - Phys. Rept. 462, 125 (2008)
- Color Singlet Model (CSM) underestimates STAR data by 2σ
  - PRD 81, 051502 (2010)
- STAR data consistent with world data trend

$\Upsilon \to e^+e^-$ in d+Au at $\sqrt{s_{NN}}$=200 GeV

H.Liu, QM2009



- No inner silicon detectors (SVT+SSD), reduced material (X_0) in 2008
- $\int \mathcal{L} dt = 32\ nb^{-1} \approx 12.5\ pb^{-1}$ (p+p equivalent)
- Signal+Background → unlike-sign electron pairs
- Background → like-sign electron pairs
- Raw Υ(1S+2S+3S) yield = 172±20(stat) extracted from M_{ee}=7-11 GeV/c^2
- Strong 8σ signal

Nucl.Phys. A830: 235c-238c (2009)

Nuclear Modification Factor

$$B_{ee} \times \left(\frac{d\sigma}{dy} \right)_{y=0}^{Y+Y'+Y''} = 35 \pm 4(\mathrm{stat}) \pm 5(\mathrm{syst})\,\mathrm{nb}$$

$$R_{dAu} = \frac{1}{N_{bin} \times \frac{\sigma_{dAu}}{\sigma_{pp}}} \times \frac{B_{ee} \times \left(\frac{d\sigma_{dAu}}{dy} \right)_{y=0}^{Y+Y'+Y''}}{B_{ee} \times \left(\frac{d\sigma_{pp}}{dy} \right)_{y=0}^{Y+Y'+Y''}}$$

$$\sigma_{pp} = 42\,\mathrm{mb} \quad \sigma_{dAu} = 2.2\,\mathrm{b}$$

$$N_{bin} = 7.5 \pm 0.4 \text{ for minimum bias d + Au}$$

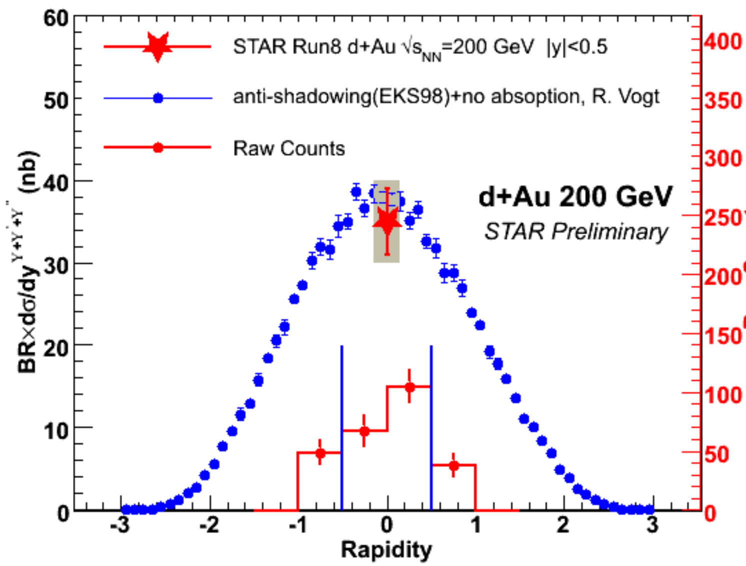
R_{dAu}=0.98±0.32(stat)±0.28(syst)

- Consistent with N_{bin} scaling
- Cold nuclear matter effects (shadowing) not large
- 2009 p+p data will help reduce uncertainty on R_{dAu} (improved statistics+reduced material)

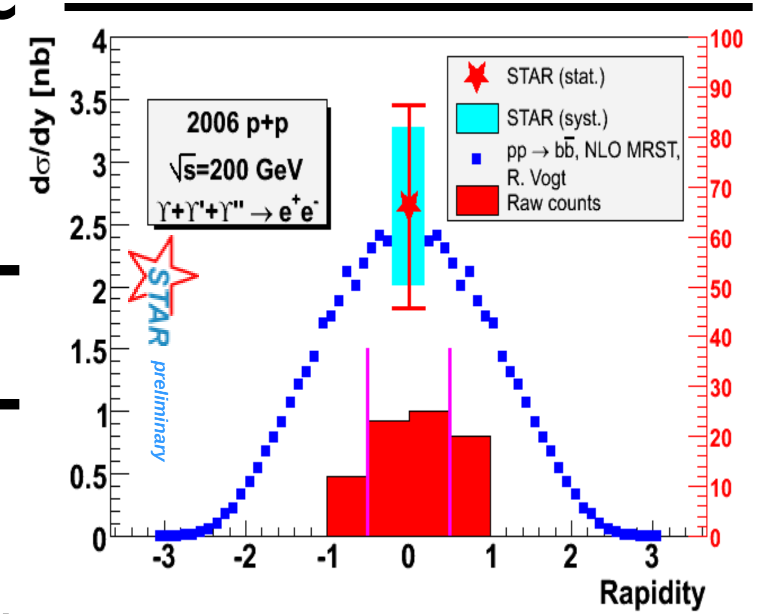
arXiv:0907.4538

R_{dAu} ~

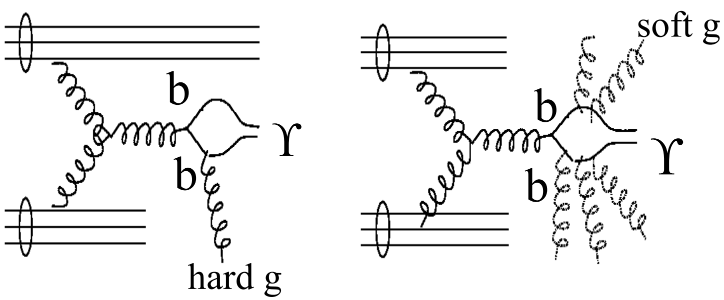
d+Au



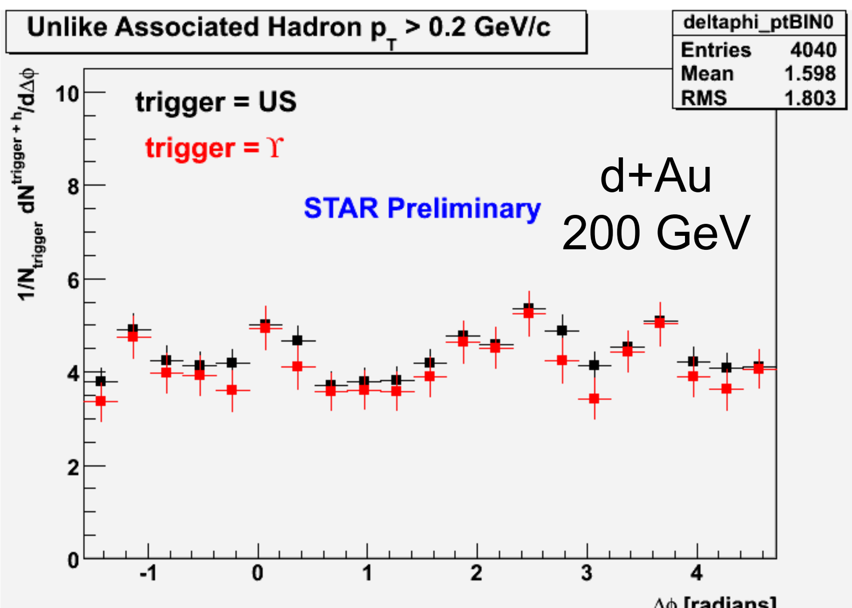
p+p



Υ-hadron correlations in d+Au at √s=200 GeV



M. Cervantes, APS2010



- Current models can't simultaneously reproduce quarkonia cross section, p_T spectrum, and polarization
  - CDF, PRL 99, 132001 (2007)
  - D0 Note 5089-CONF
  - Lansberg, arXiv:0811.4005v1 [hep-ph]
- Look for increase in hadronic activity on Δφ near-side peak as discriminator between CSM (Color Singlet Model) and COM (Color Octet Model)
  - Kraan, arXiv:0807.3123v1 [hep-ex]
- Significant underlying event contributions seen in d+Au collisions. p+p in the works!

Summary and outlook for Au+Au

- p+p at $\sqrt{s}$=200 GeV
  - ❑ $B_{ee}\times(d\sigma/dy)^{\Upsilon+\Upsilon'+\Upsilon''}_{y=0} = 114\pm38^{+23}_{-24}$ pb
  - ❑ $(\sigma_{DY}+\sigma_{bb})_{|y|<0.5,8<m<7\ GeV/c2} = 38\pm24$ pb
- d+Au at $\sqrt{s}$=200 GeV
  - ❑ $B_{ee}\times(d\sigma/dy)^{\Upsilon+\Upsilon'+\Upsilon''}_{y=0}$ = 35±4(stat)±5(syst) nb
  - ❑ R_{dAu} = 0.98±0.32(stat)±0.28(syst)
- Au+Au at $\sqrt{s}$=200 GeV
  - ❑ Cross section and R_{AA} coming soon!
- Higher integrated luminosity (20 pb^{-1}) from 2009 p+p
  - ❑ Low material
  - ❑ Reduced uncertainty for R_{dAu}
  - ❑ Possible separation of Υ states

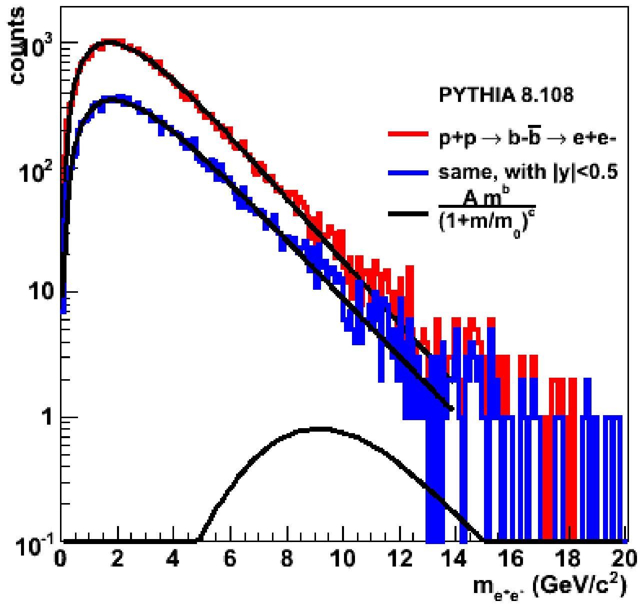
Backup Slides

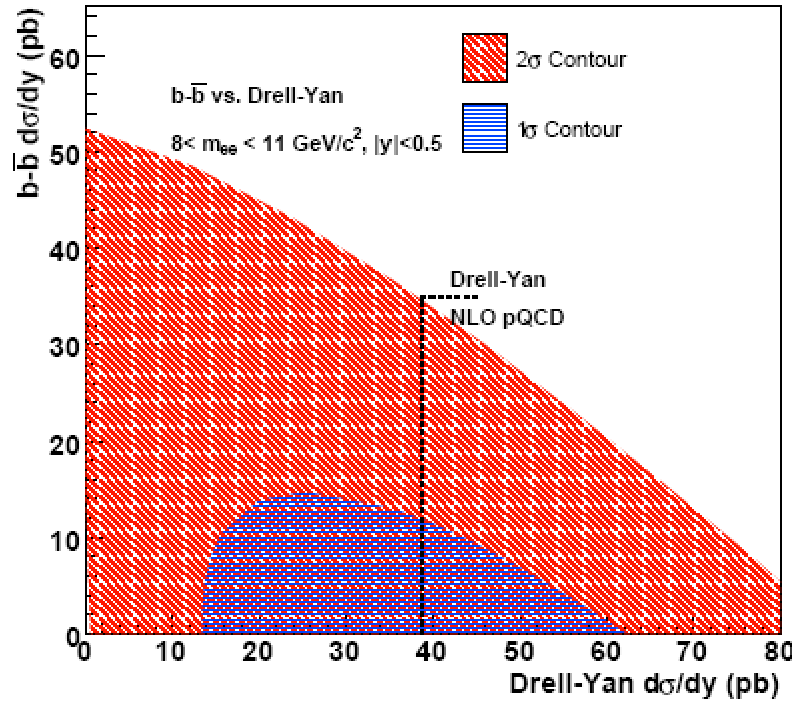
Systematic uncertainties for Υ in p+p

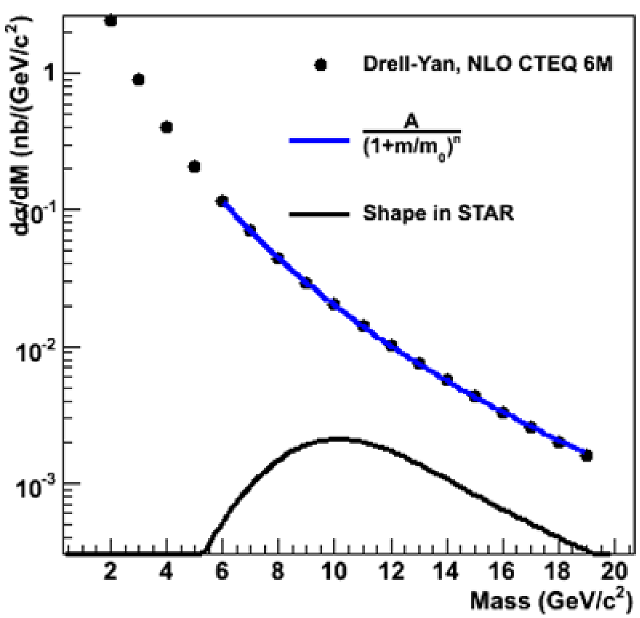
arXiv:1001.2745 [nucl-ex]

Quantity	Value	Syst. uncertainty on $d\sigma/dy$ (%)
$N_{+-} - 2\sqrt{N_{++}N_{--}}$	82.7	$^{+0}_{-9}$
$\mathcal{L}$	7.9 pb^{-1}	± 7
ϵ_{BBC}	0.87	± 9
ϵ_{geo}	0.57	$^{+3.0}_{-1.7}$
$\epsilon_{\mathrm{vertex}}$	0.96	± 1.0
ϵ_{L0}	0.43	$^{+7.5}_{-5.9}$
ϵ_{L2}	0.85	$^{+0.7}_{-0.2}$
ϵ_{TPC}	0.85^2	$2 \times \pm 5.8$
ϵ_{R}	0.93^2	$2 \times ^{+1.1}_{-0.2}$
$\epsilon_{dE/dx}$	0.84^2	$2 \times \pm 2.4$
$\epsilon_{E/p}$	0.93^2	$2 \times \pm 3.0$
Combined		$^{+22.8}_{-24.1}$

Drell-Yan and b-bbar contributions



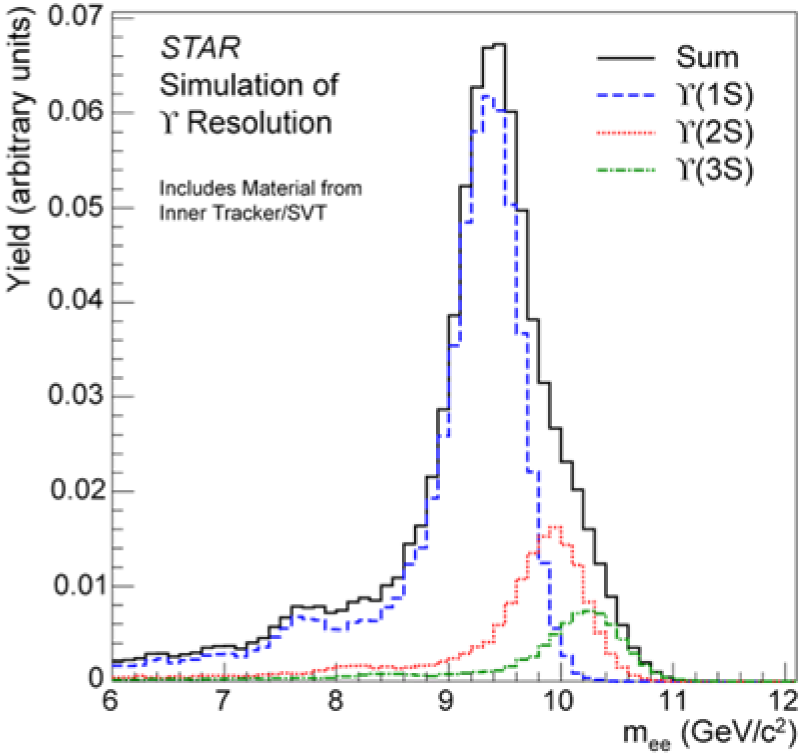




✓Obtaining the expected shape from $b\bar{b}$ simulation PHYTIA and Drell-Yan (NLO pQCD).

✓The continuum cross sections determined by a combined fit to bg. subtracted data.

STAR Υ Mass Resolution

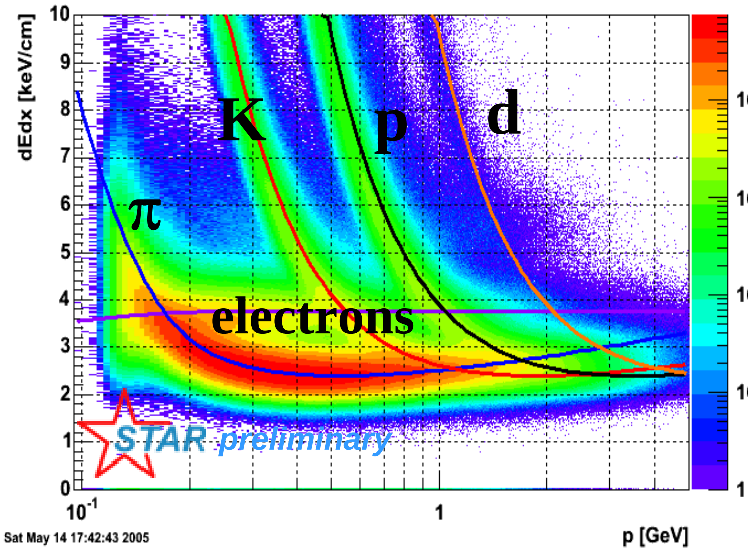


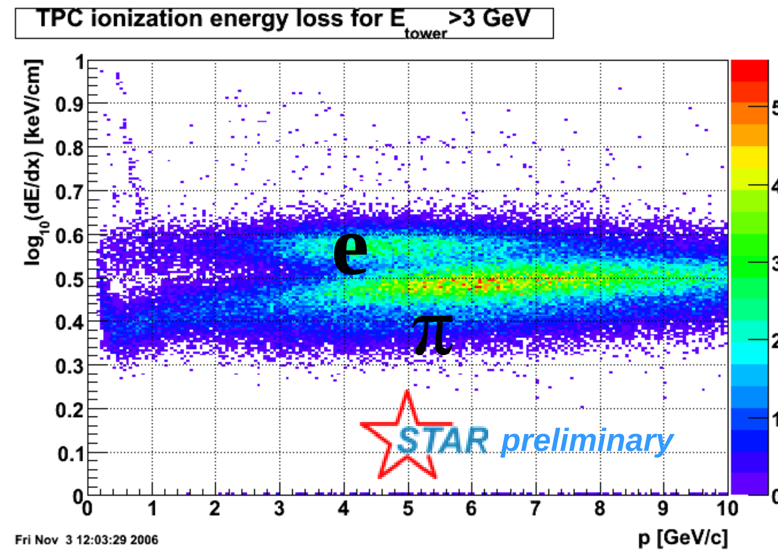
- STAR detector does not resolve individual states of the Υ
  - Finite p resolution
  - e-bremsstrahlung
- Yield is extracted from combined Υ+Υ′+Υ″ states
- FWHM ≈ 1 GeV/c^2

W.-M. Yao *et al*. (PDG), J. Phys. G **33**, 1 (2006);
R. Vogt *et al*., RHIC-II Heavy Flavor White Paper

State	Mass [GeV/c^2]	B_{ee} [%]	$(d\sigma/dy)_{y=0}$	$B_{ee}\times(d\sigma/dy)_{y=0}$
Υ	9.46030	2.38	2.6 nb	62 pb
Υ′	10.02326	1.91	0.87 nb	17 pb
Υ″	10.3552	2.18	0.53 nb	12 pb
Υ+Υ′+Υ″				91 pb

Υ Analysis: Electron ID with TPC and EMC





- Υ trigger enhances electrons
- Use TPC for charged tracks selection
- Use EMC for hadron rejection
- Electrons identified by dE/dx ionization energy loss in TPC
- Match TPC track to EMC tower and require 0.7<E/p<1.3