# $\Upsilon$ production in p+p, d+Au, Au+Au collisions at 200 GeV in STAR

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# Outline

- Motivations
- STAR detectors and the $\Upsilon$ trigger
- $\Upsilon$ measurements
  - p+p
  - d+Au
    - $R_{dA}$
  - Au+Au
- Summary

# Motivation

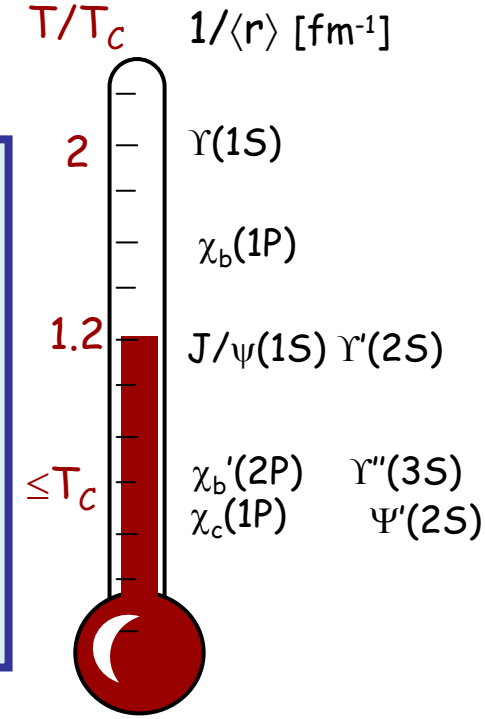
Sequential disappearance of states:

⇒Color screening ⇒ Deconfinement

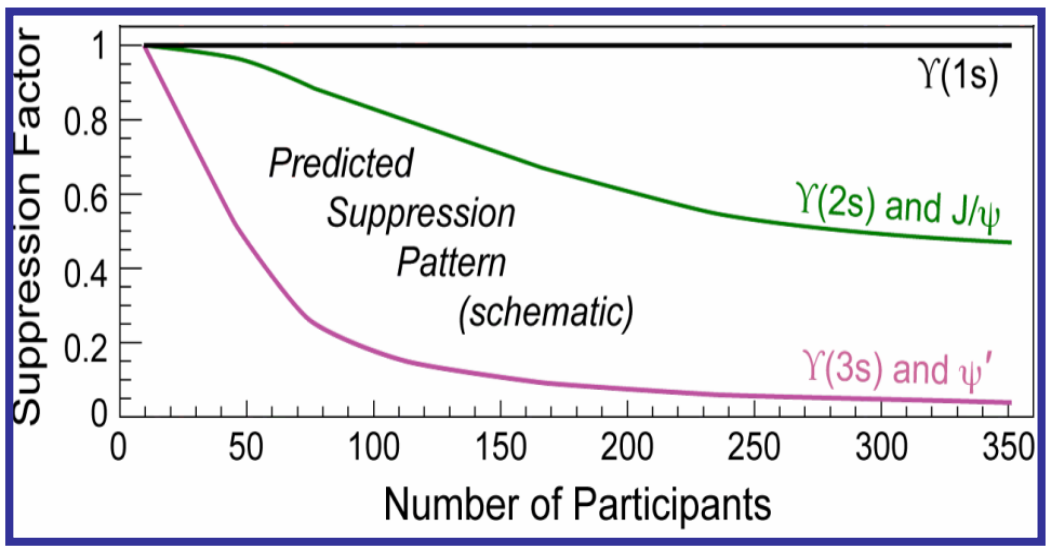
***Matsui T and Satz H 1986 Phys.Lett.B178:416,1986***

⇒QCD thermometer ⇒ QGP Properties

***A. Mocsy and P. Petreczky PRD 77 014501 (2008)***




***A .Mocsy, 417th WE-Heraeus-Seminar,2008***
***A. Mocsy and P.Petreczky, PRL 99, 211602 (2007)***




Expectation at 200 GeV

ϒ(1S) does not melt

ϒ(2S) is likely to melt

ϒ(3S) will melt

# Motivation – $\Upsilon$ Pros and Cons

## Pros

- Efficient trigger - works in p+p up to central A+A
- Large acceptance at $|y|<0.5$
- Small background at $M\sim10$ GeV/$c^2$
- Co-mover absorption is very small

  Z.W. Lin and C.M Ko PLB 503:104 (2001)

- Recombination negligible at RHIC ($\sigma_{b\bar{b}} << \sigma_{c\bar{c}}$)

## Cons

- extremely low rate
  - $10^{-9}$/minimum bias pp interaction
- Good resolution needed to separate 3 S-states

# STAR $\Upsilon$ Detectors

**BEMC**

$|\eta| < 1$

$0 < \phi < 2\pi$

electron ID : E/p

High-energy tower trigger

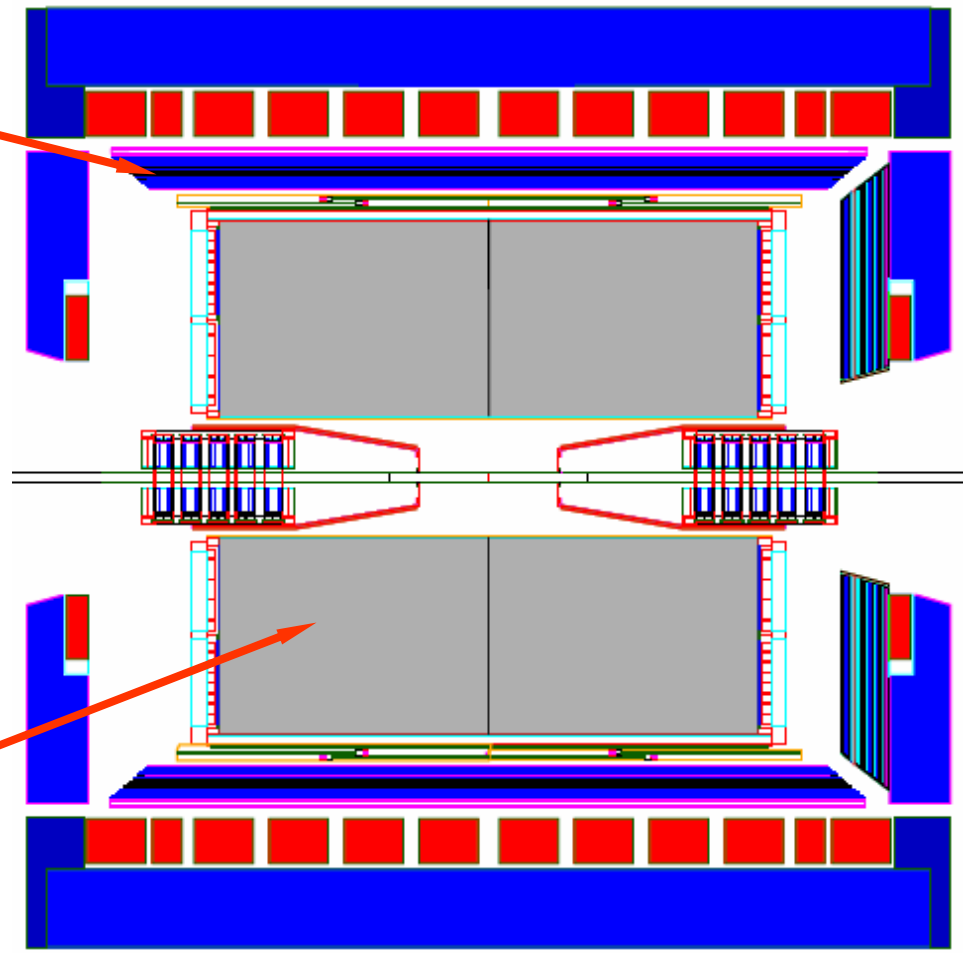
**TPC**

$|\eta| < 1$

$0 < \phi < 2\pi$

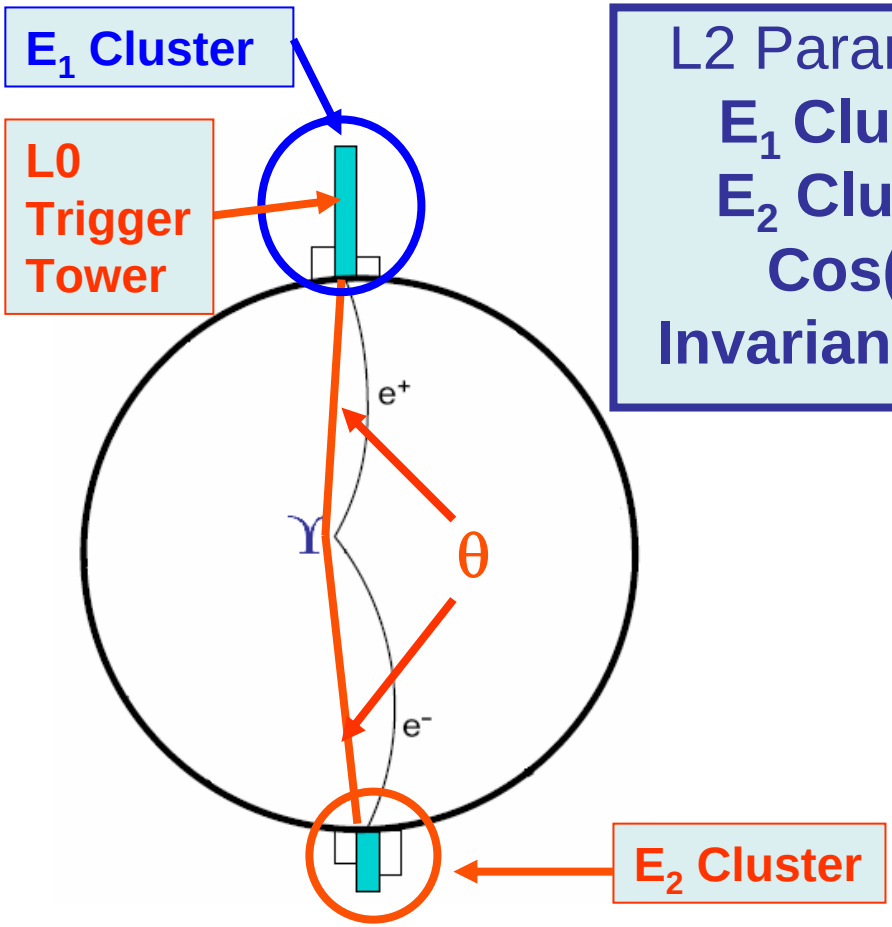
Tracking => momentum

electron ID: ionization energy loss

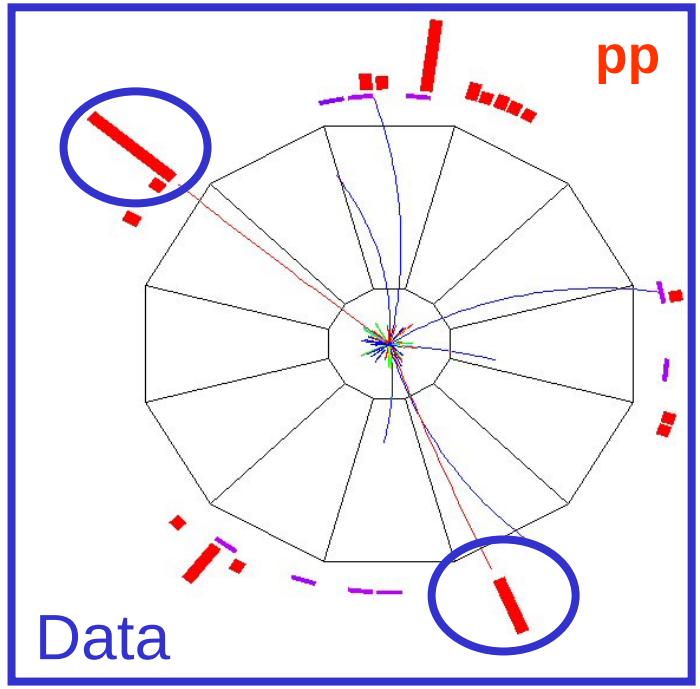


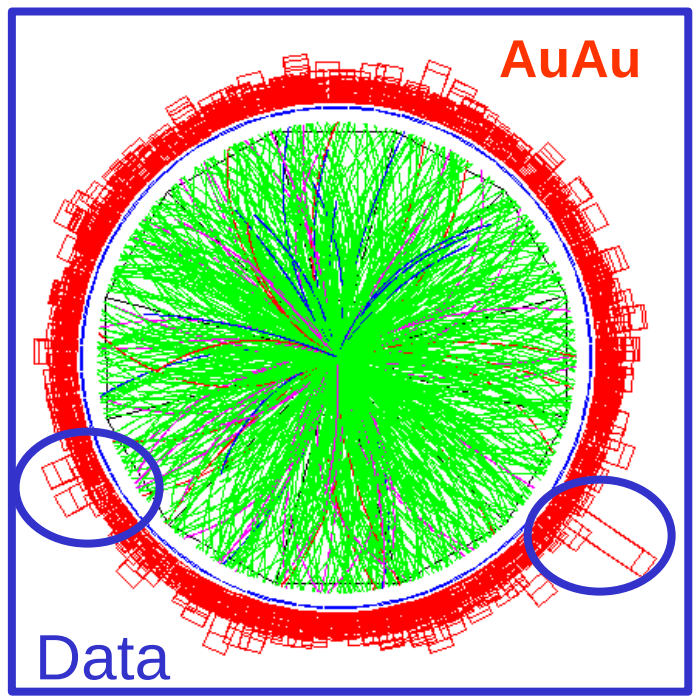
# STAR ϒ Trigger

L0 Parameters pp 2006 (dAu,AuAu)
**High Tower $E_T$** > 3.5 GeV (4.0 GeV)
**Trigger Patch $E_T$** > 4.3 GeV (NA)

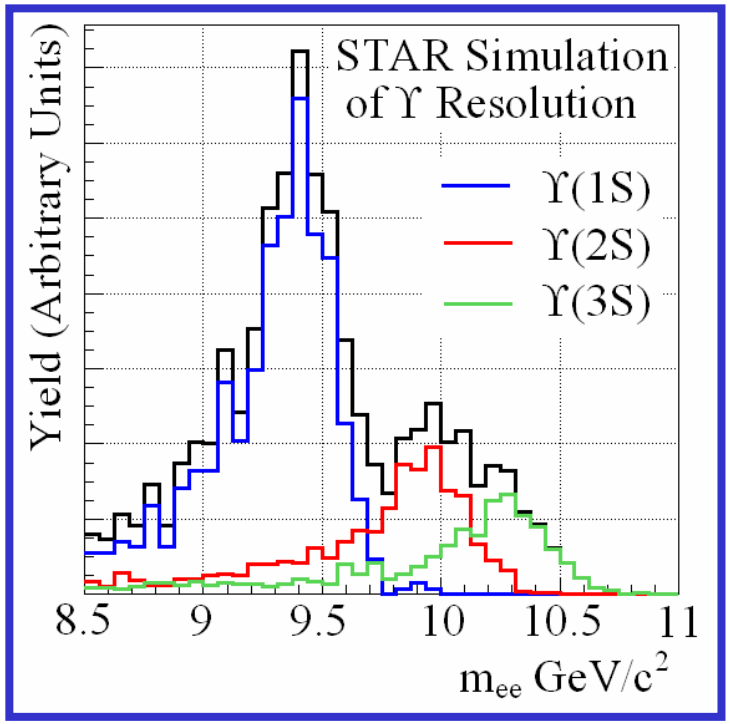



L2 Parameters
**$E_1$ Cluster,**
**$E_2$ Cluster,**
**Cos(θ),**
**Invariant Mass**

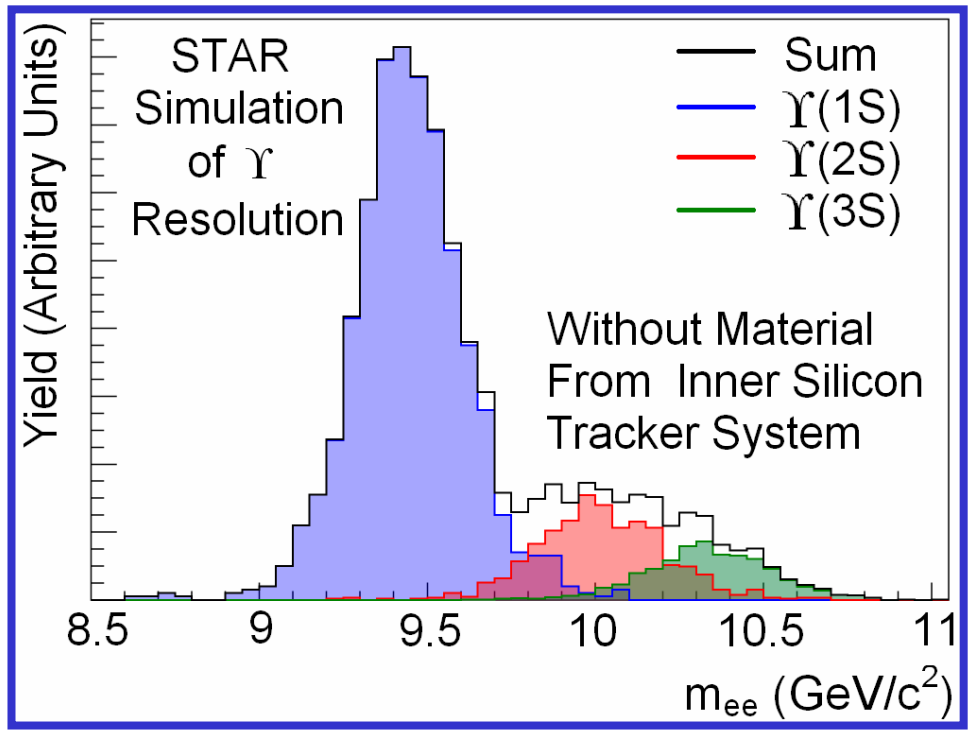


# Simulated ϒ Mass Resolution




with inner material
Run 6 (p+p)
Run 7 (Au+Au)



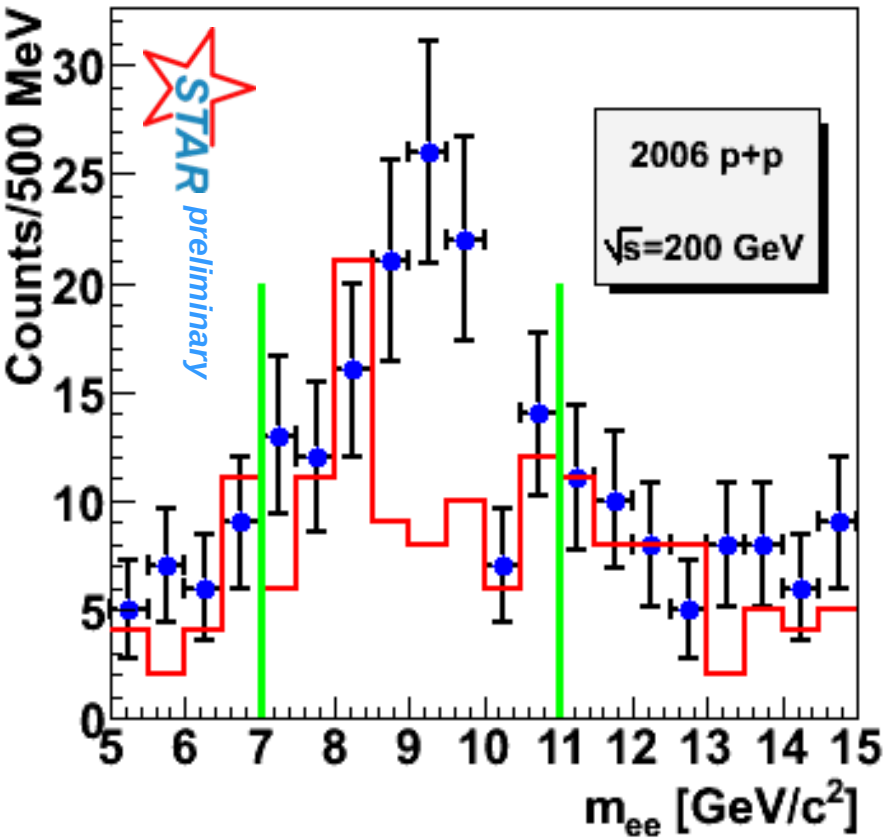

without inner material
Run 8 (d+Au)
Run 9 (p+p)
Improves 1S FWHM
from 0.42 to 0.32 GeV

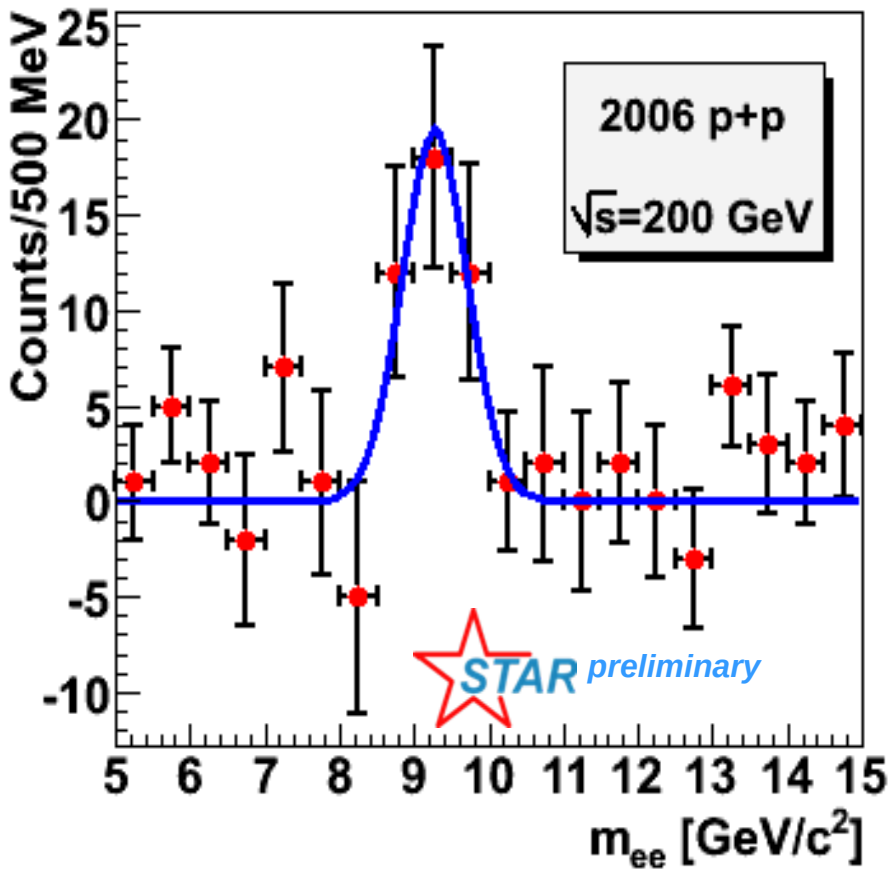
| Run | Integrated Lum. ($nb^{-1}$) |
|---|---|
| p+p (2006) | 8800* |
| Au+Au | 0.3 |
| d+Au | 32 |

*5200 used for QM 2006 analysis

# First Analysis $\Upsilon$ in p+p (2006)

QM 2006



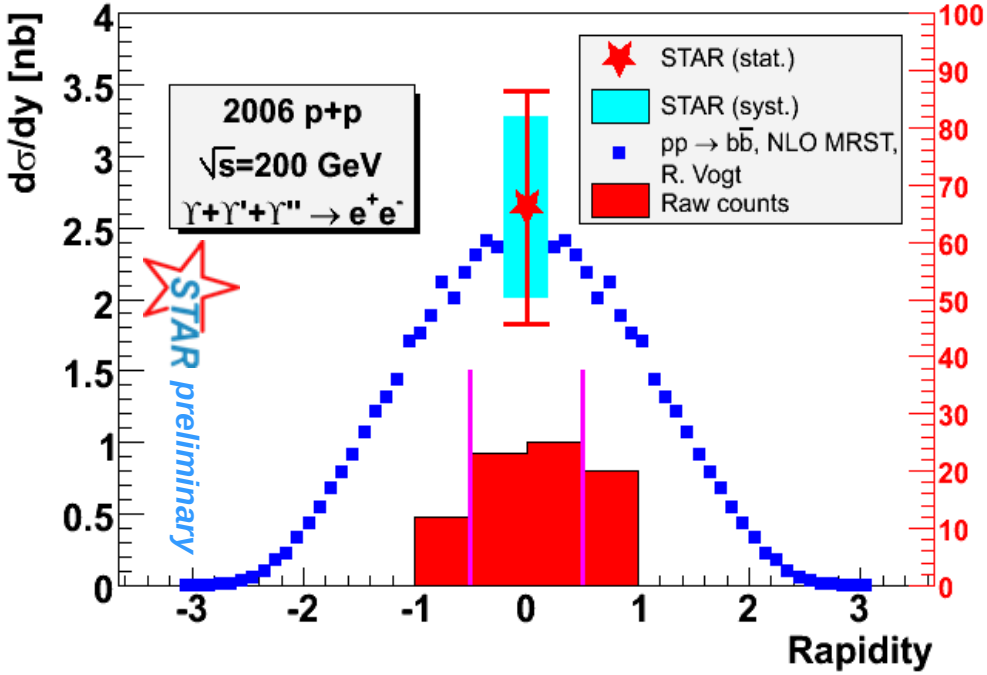

*J. Phys. G: Nucl. Part. Phys. 34(2007)S947*

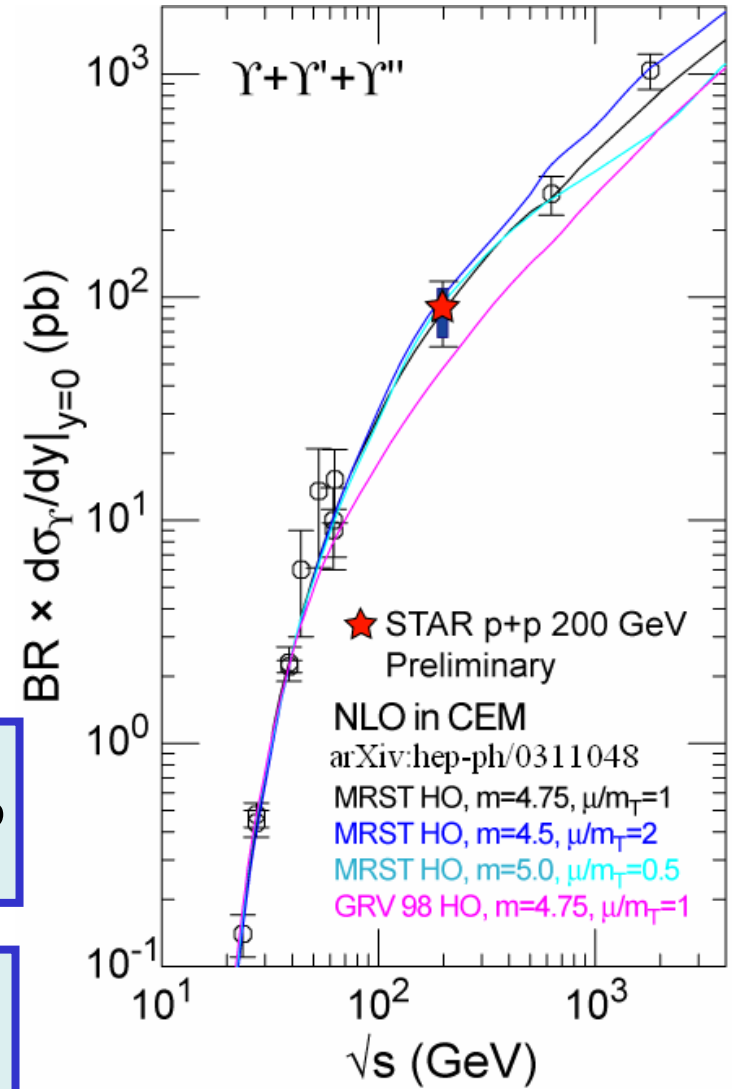
$$B_{ee} \times \left(\frac{d\sigma}{dy}\right)_{y=0}^{\Upsilon+\Upsilon'+\Upsilon''} = 91 \pm 28\,(\text{stat.}) \pm 22\,(\text{syst.})\ \text{pb}$$

$$BR_{ee} \times \left(\frac{d\sigma}{dy}\right)_{y=0} = \frac{N_{\Upsilon}}{dy \times \varepsilon_{\Upsilon} \times \int \mathcal{L}dt}$$

# STAR ϒ *vs.* theory and world data

*J. Phys. G: Nucl. Part. Phys. 34(2007)S947*



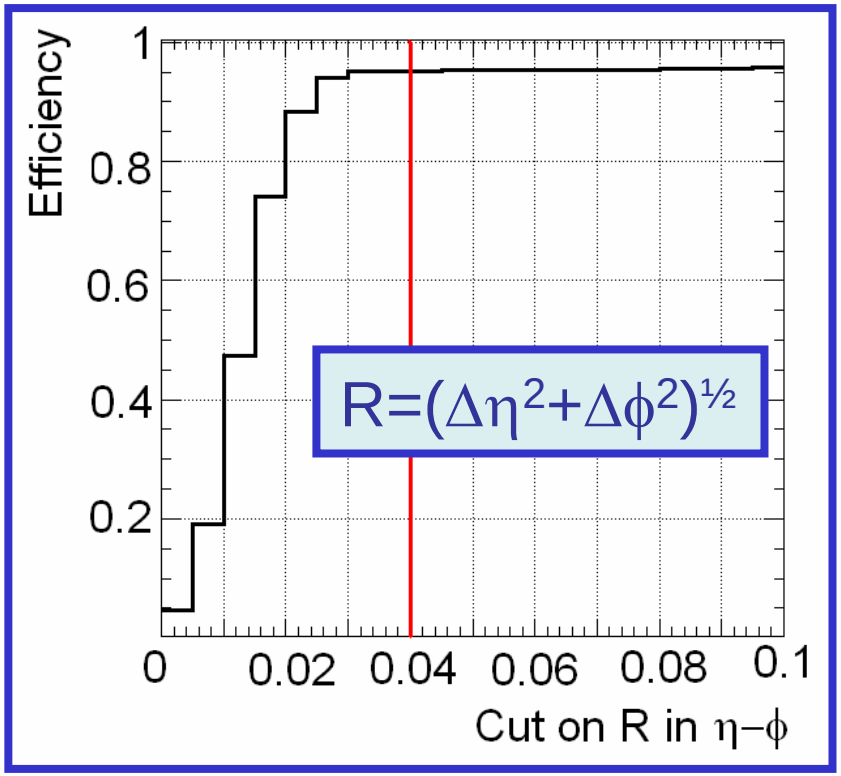

$$\mathbf{BR_{ee}} \times \left(\frac{d\sigma}{dy}\right)^{\Upsilon+\Upsilon'+\Upsilon''}_{y=0} = \mathbf{91 \pm 28(stat.) \pm 22(syst.)} \quad \mathbf{pb}$$

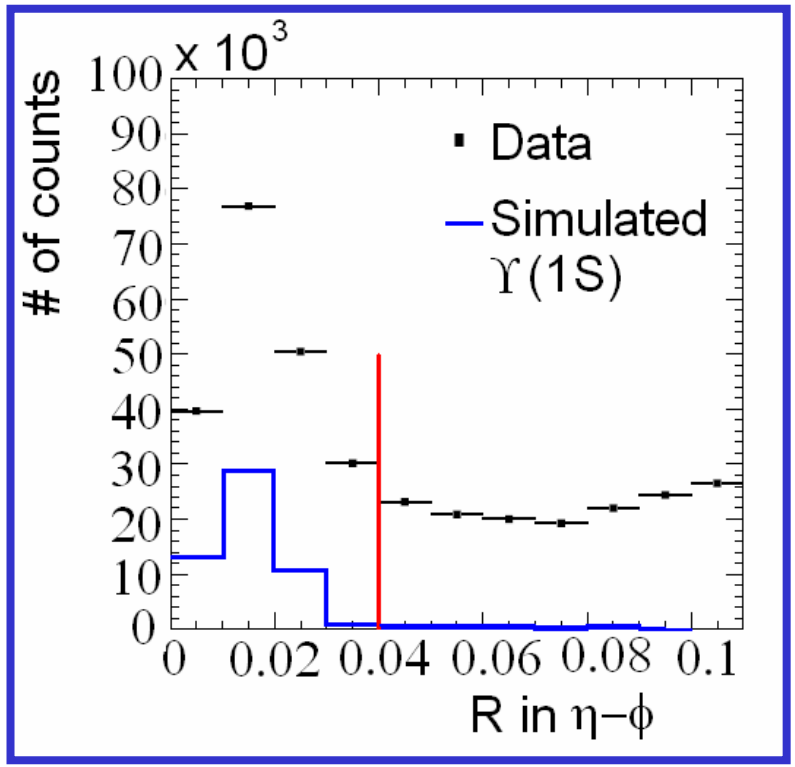
STAR 2006 √s=200 GeV p+p ϒ+ϒ′+ϒ″→$e^+e^-$ cross section consistent with pQCD and world data trend

# p+p $\Upsilon$ Analysis Improvements

- Included all available statistics
- Track to cluster matching
  - Removes random benefit
- Isolation cut
  - Removes additional jet background
- Estimate contribution from Drell-Yan and bb continuum
- Results are statistically consistent with QM 2006 result

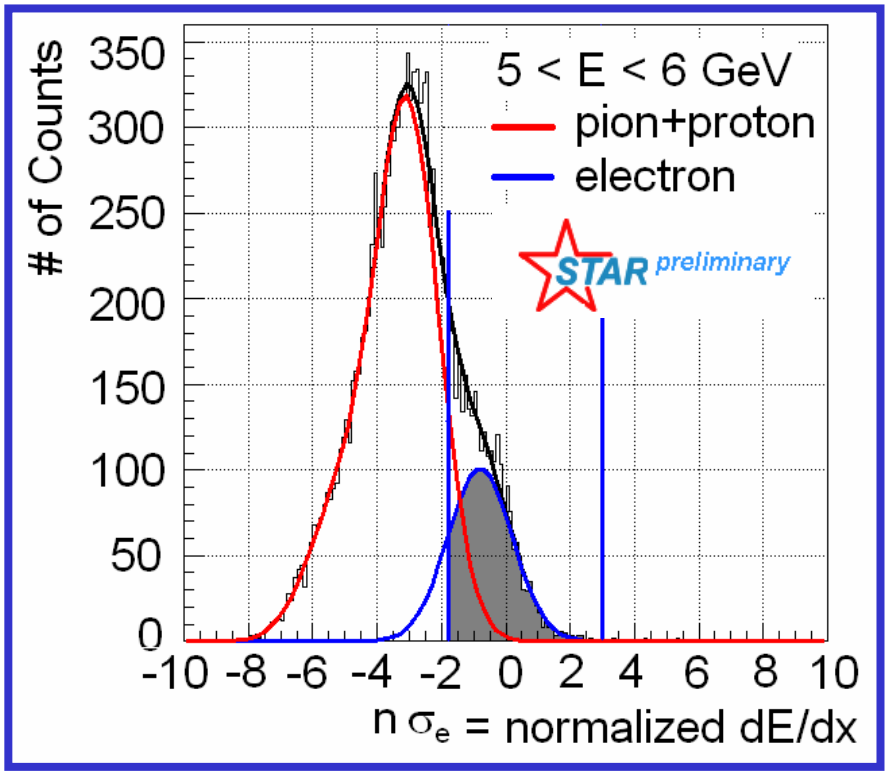
# Track to Cluster matching in p+p

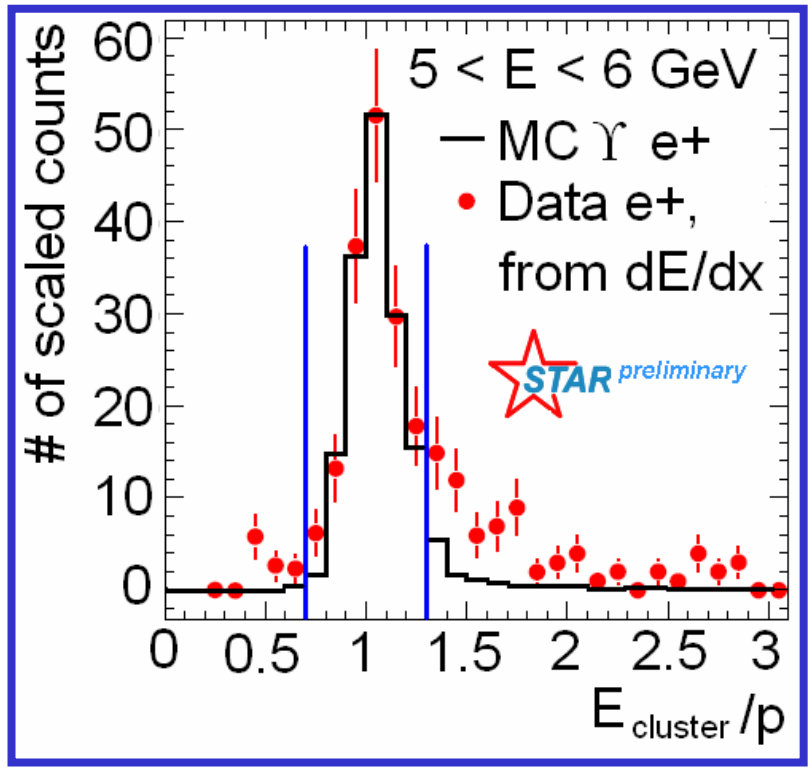



- ϒ candidates formed from tracks which extrapolate to triggered energy clusters
  - Must extrapolate within 0.04 in η-ϕ space
  - Removes background and false candidates
  - Improves S/B in p+p, d+Au and Au+Au

# Particle Identification

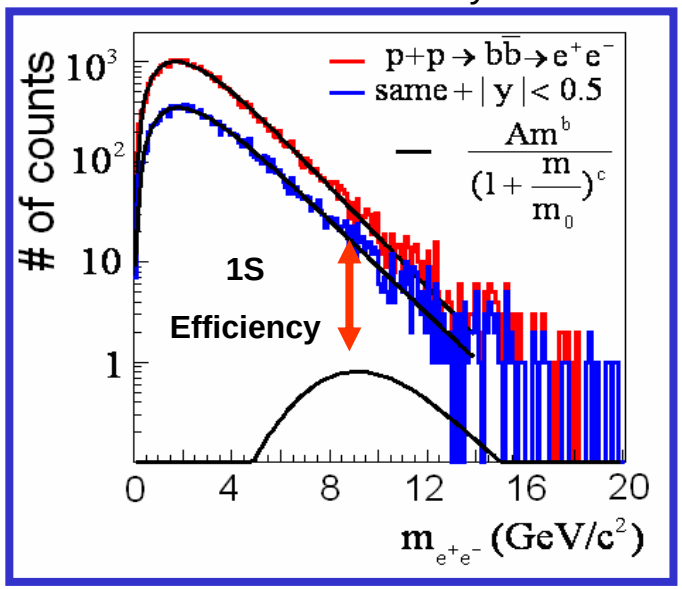


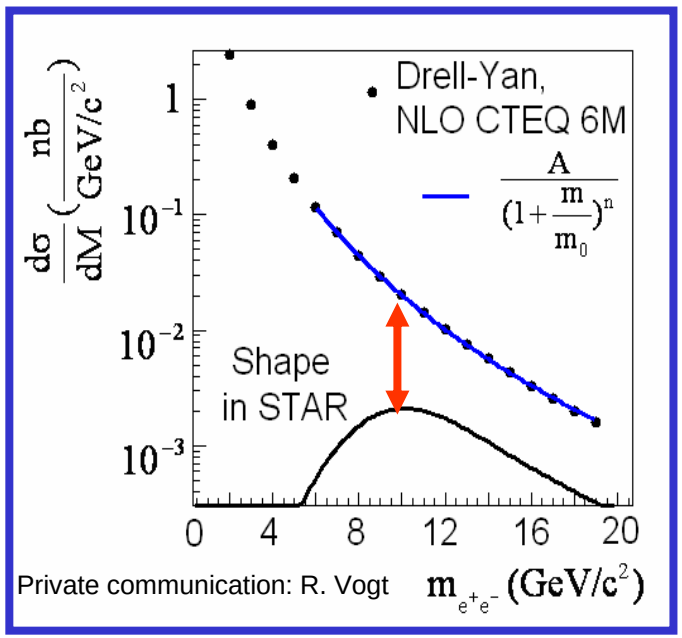




- Particle identification combines the TPC and BEMC
  - e+ or e- candidate tracks selected by dE/dx (TPC)
  - E/p removes pion contamination
    - E is the three tower cluster energy as measured in the BEMC
    - p is the momentum of the track as measured by the TPC

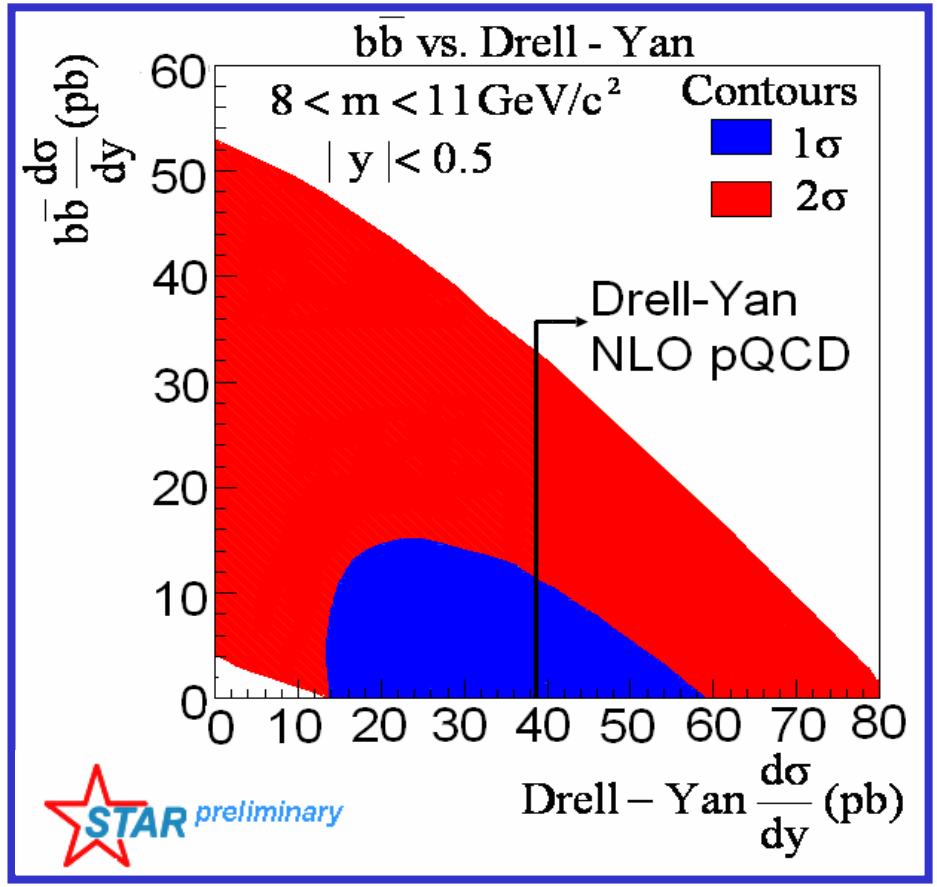
# $b\bar{b}$ and Drell-Yan contribution

PYTHIA 8.108 - Star Heavy Flavor Tune




Private communication: R. Vogt

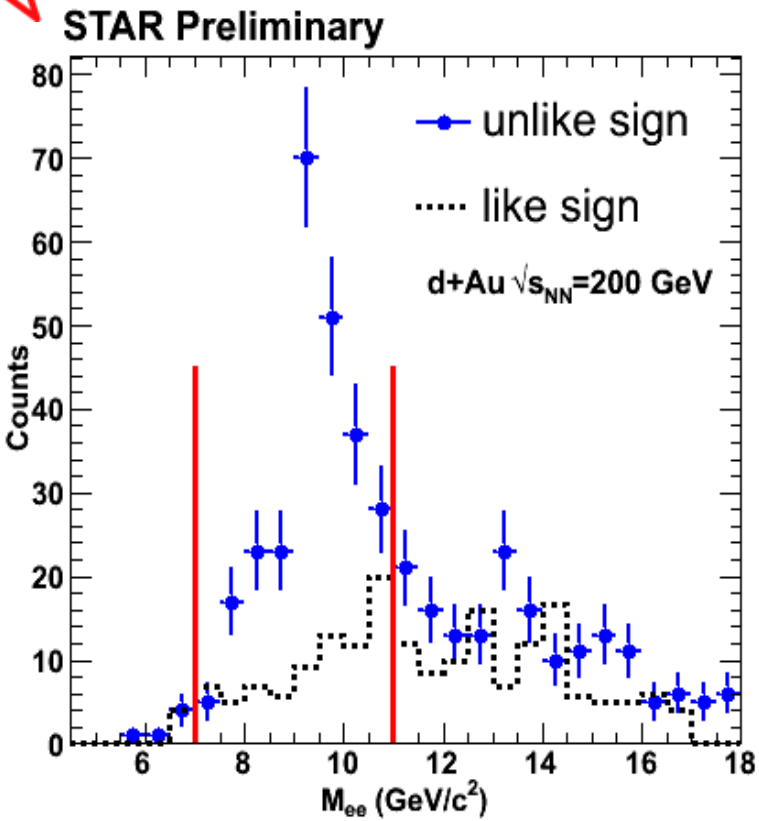


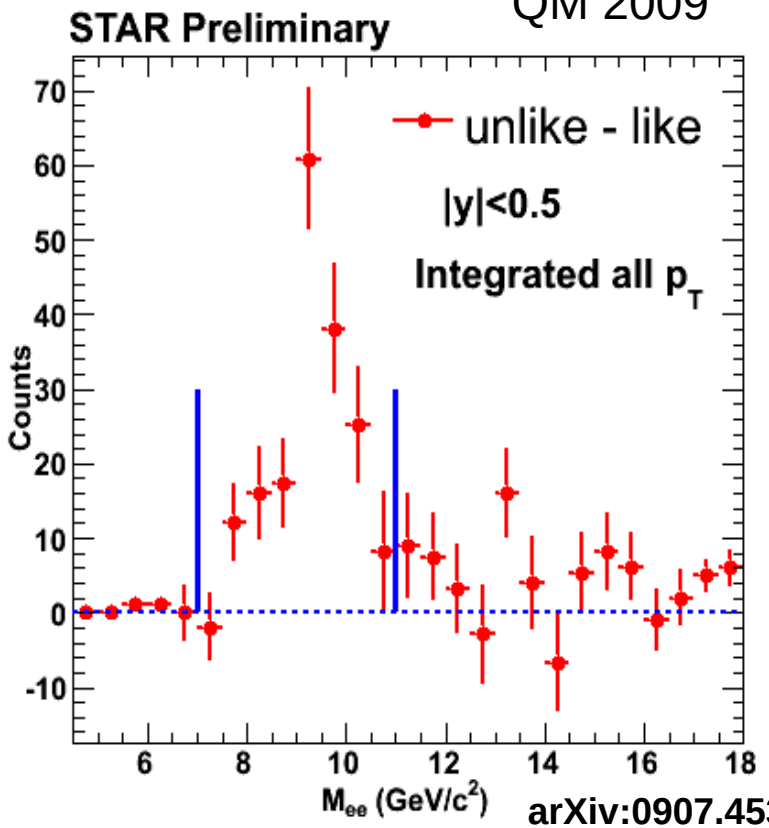

$b\bar{b}$ and Drell-Yan cross-sections determined by a combined fit to background subtracted data

Bottom cross section: 0 – 15 pb at 1σ
DY cross section: 36 ± 22 pb at 1σ

# ϒ in d+Au

QM 2009



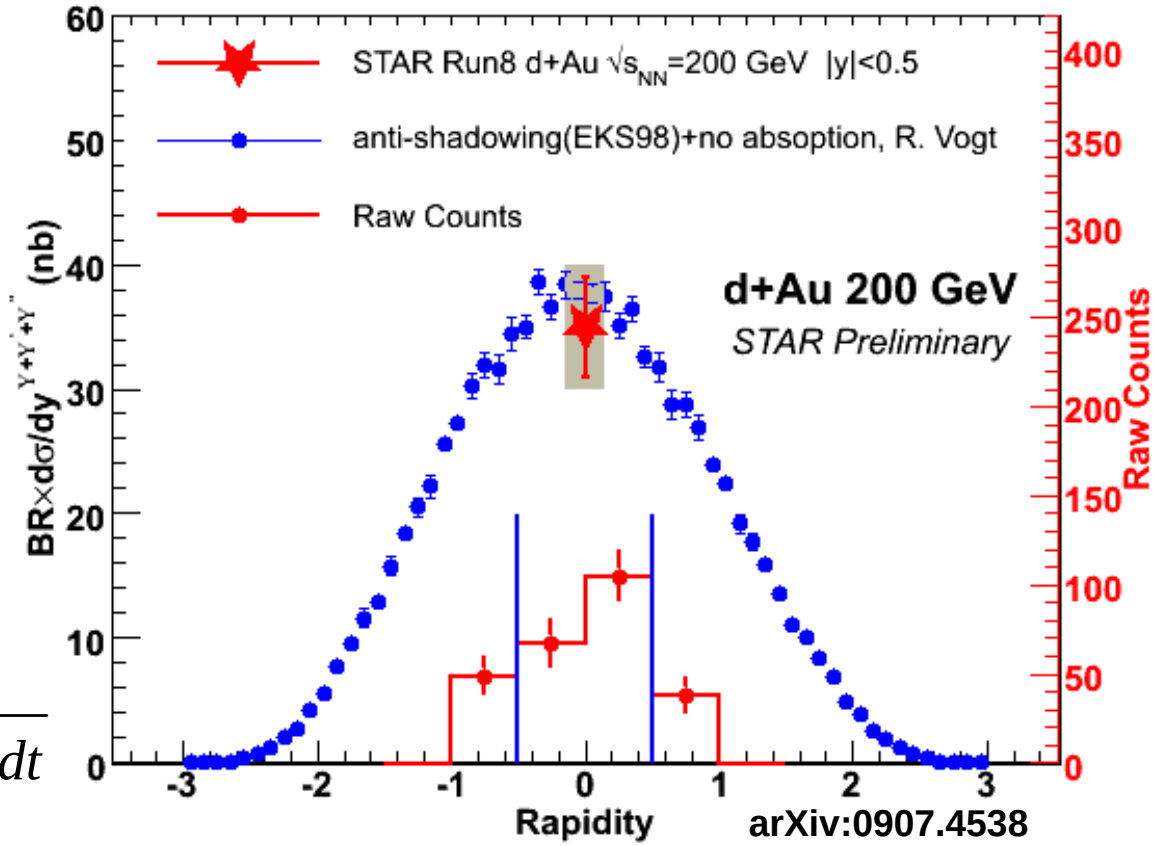




arXiv:0907.4538

- Signal + Background ⇒ unlike-sign electron pairs
- Background ⇒ like-sign electron pairs
- ϒ(1S+2S+3S) total yield: integrated from 7 to 11 GeV from background-subtracted $m_{ee}$ distribution
  - Raw Yield: 172 +/- 20 (stat.)
  - Strong signal (8σ significance)

# ϒ Cross section in d-Au at STAR

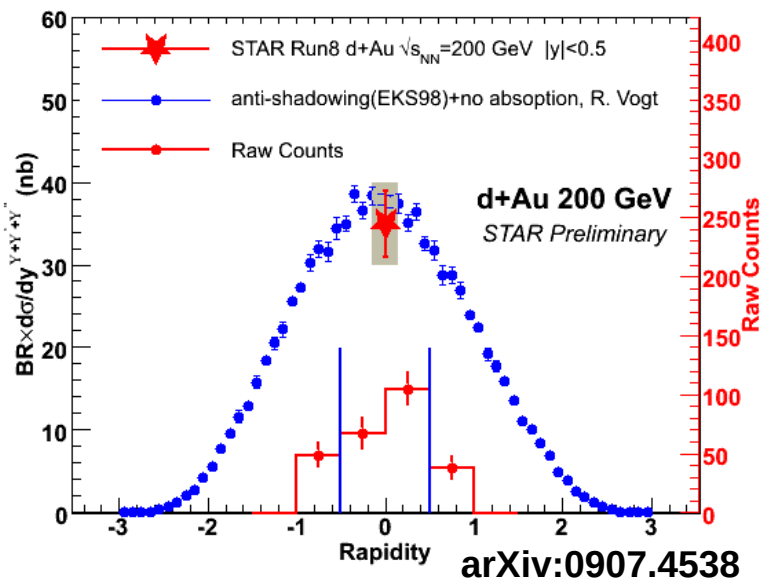
| | |
|---|---|
| $N_{\Upsilon}$ | 172 ± 20 |
| $\varepsilon_{\Upsilon}$ | 0.15 ± 0.02 |
| $\int \mathcal{L} dt$ | 33 $nb^{-1}$ |
| dy | 1.0 |

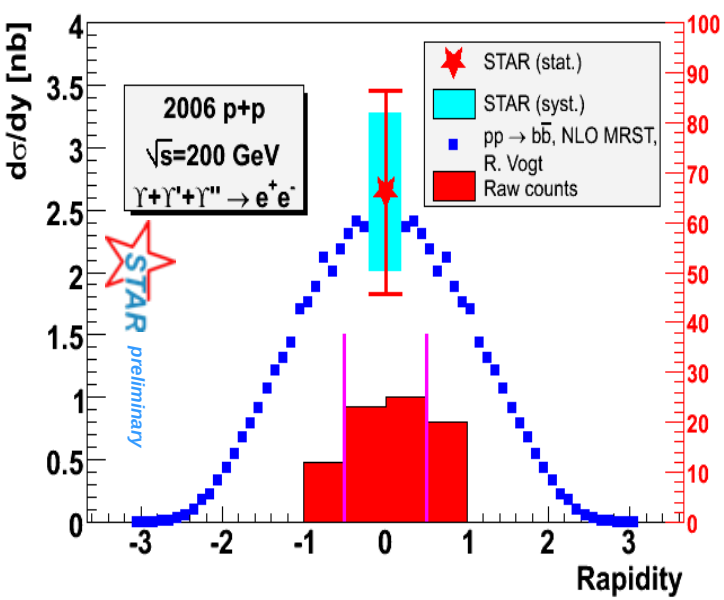



$$BR_{ee} \times \left(\frac{d\sigma}{dy}\right)_{y=0} = \frac{N_{\Upsilon}}{dy \times \varepsilon_{\Upsilon} \times \int \mathcal{L} dt}$$

$$B_{ee} \times \left(\frac{d\sigma}{dy}\right)_{y=0}^{\Upsilon+\Upsilon'+\Upsilon''} = 35 \pm 4(\text{stat.}) \pm 5(\text{sys.}) \quad \text{nb}$$

# Nuclear modification factor




*J. Phys. G: Nucl. Part. Phys. 34(2007)S947*

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

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

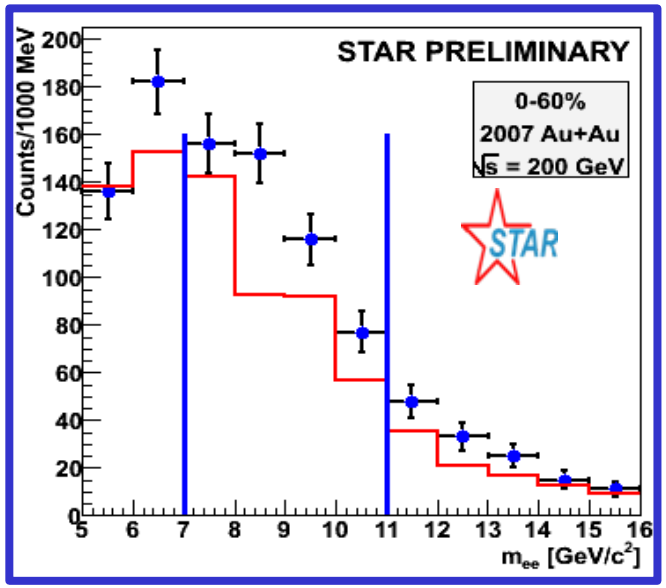
$N_{bin}$ = 7.5 ± 0.4 for Minbias dAu

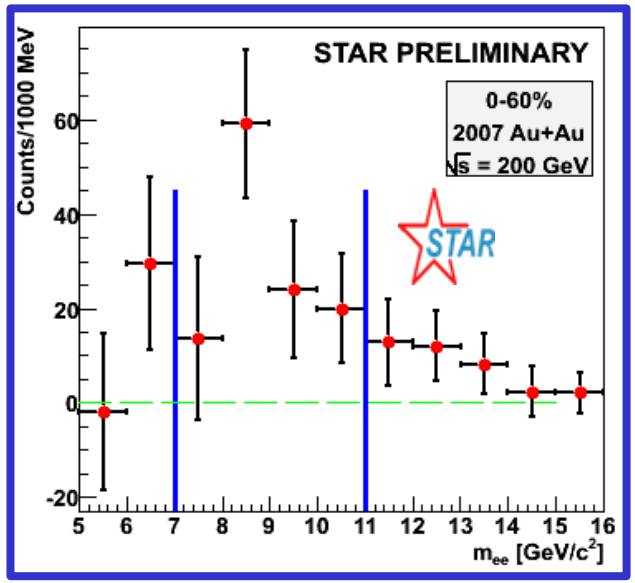
$$R_{dAu} = 0.98 \pm 0.32\ (\text{stat.}) \pm 0.28\ (\text{sys.})$$

Consistent with $N_{bin}$ scaling
Cold Nuclear Matter effects (Shadowing) are not large.

# $\Upsilon$ in Au+Au at $\sqrt{s}$ = 200 GeV

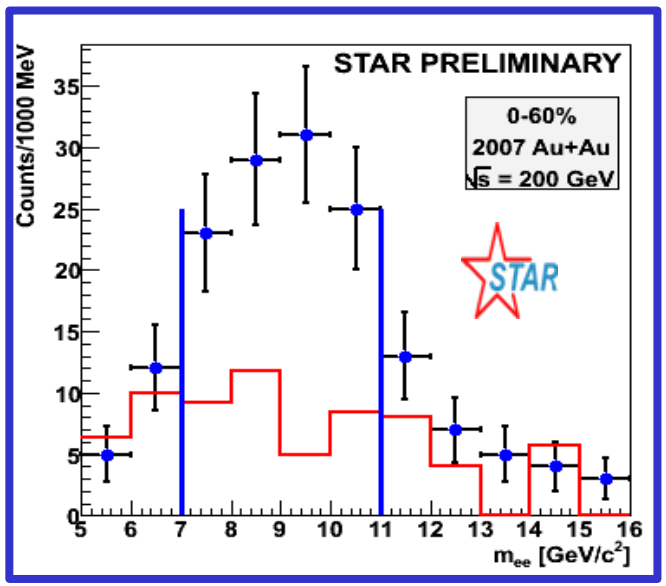
QM 2008

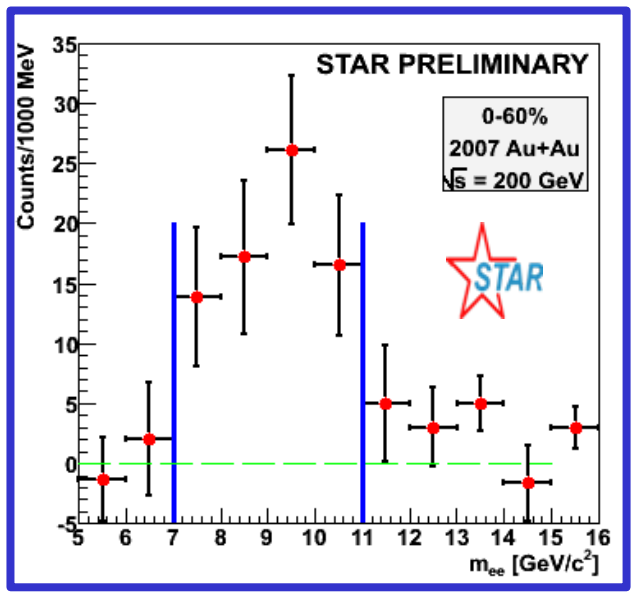



$R_{AA}$ < 1.3 at 90% CL

Used QM 2006 p+p analysis cuts



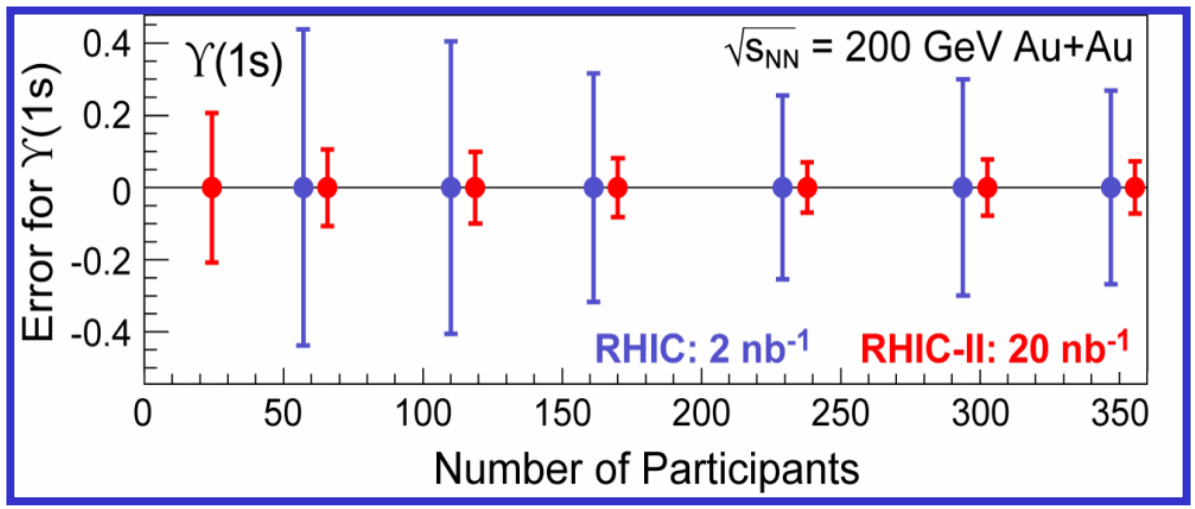

S/B can be improved

Inclusion of p+p analysis improvements in progress

*J. Phys. G: Nucl. Part. Phys. 35(2008)104153*

# Summary and Outlook

- $|y|<0.5$ preliminary meas. of $\Upsilon+\Upsilon'+\Upsilon''\rightarrow e^+e^-$ cross-section at $\sqrt{s}=200$ GeV
  - p+p - 6σ Signal Significance with
    $B_{ee}\times(d\sigma/dy)_{y=0}$= 91±28(stat)±22(sys) pb
  - d+Au - 8σ Signal Significance with
    $B_{ee}\times(d\sigma/dy)_{y=0}$= 35±4(stat)±5(sys) nb and
    $R_{dAu}$ =0.98±0.32(stat)±0.28(sys)
    Follows Binary Scaling (in 200 GeV dAu collisions)
  - Au+Au (central 0-60%) - 4σ Signal significance
    $R_{AA}$< 1.3 at 90% CL
- $\Upsilon$ meas. from additional 20 $pb^{-1}$ of p+p coming soon (9 $pb^{-1}$ previously)



# Back-up

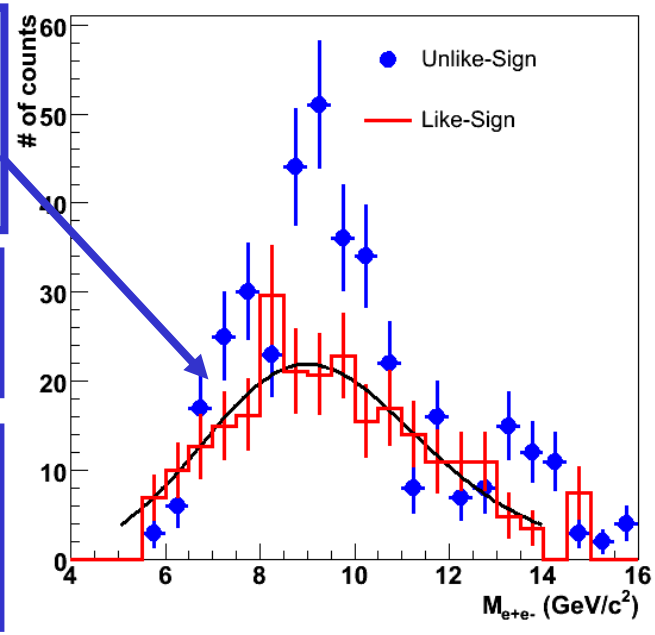
# $b\bar{b}$ contribution from PYTHIA 8 + Drell-Yan

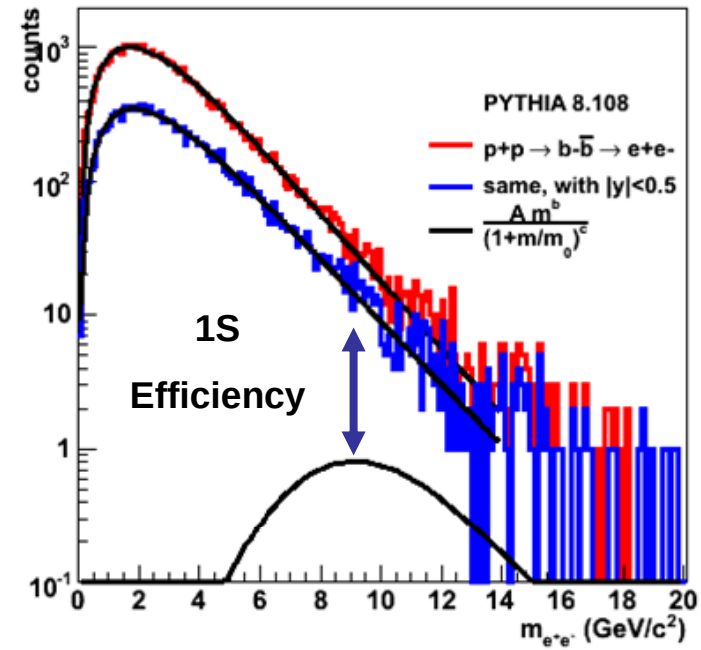
Like-sign background from data parameterizes trigger effects

$$\frac{erf\left(\frac{m - m_0}{\sigma} + 1\right)}{2}$$

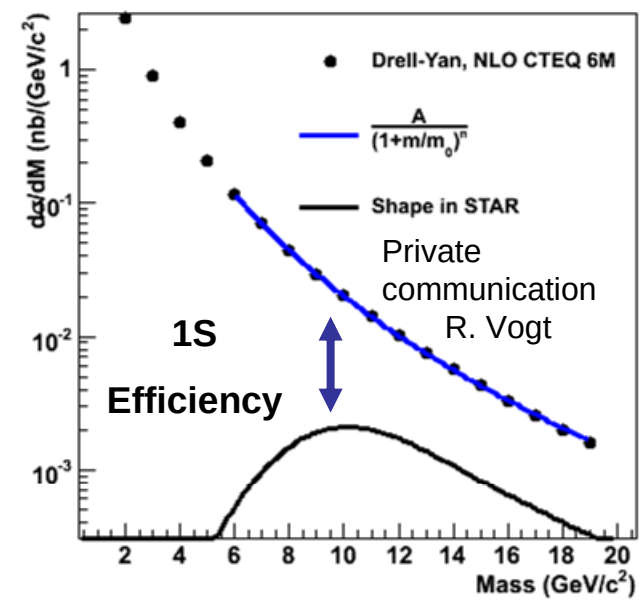
$m_0$ $\alpha$ trigger threshold = 8.1 +/- 0.7 GeV/c$^2$

$\sigma$ = width due to finite detector resolution = 1.8+/- 0.4 GeV/c$^2$




Exponentials from PYTHIA and Drell-Yan are multiplied by erf function to convolute background with detector effects

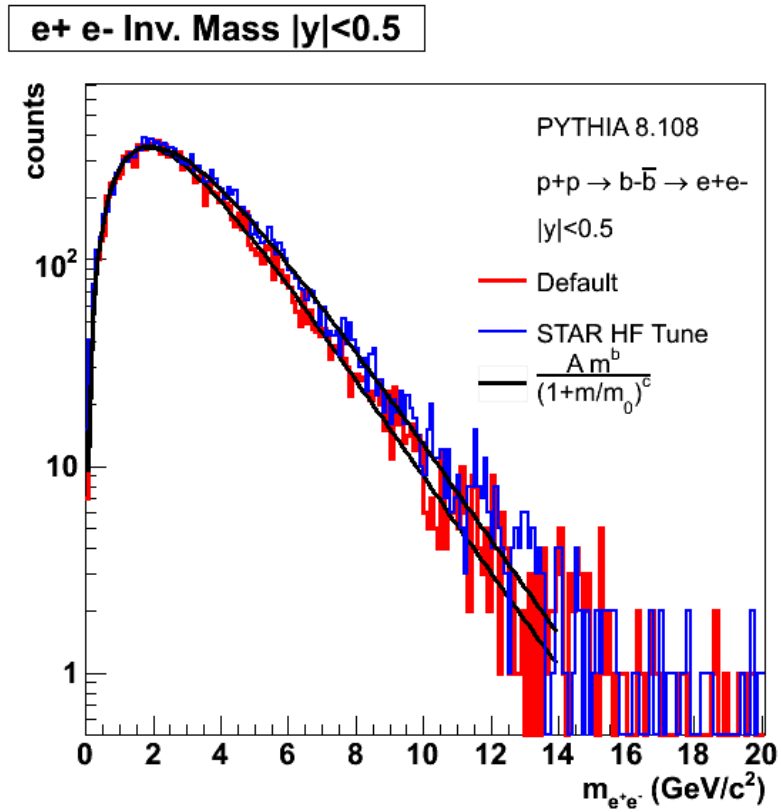



# $b\bar{b}$ counts in region 8 – 11 GeV/c$^2$ = 15

# Drell-Yan count in 8 – 11 GeV/c$^2$ = 25

# Updates: Using STAR HF Tune

- Pythia 8.108
- Changes from defaults
  - m=4.3 GeV/c2
    - 4.8 GeV/c2 Default
  - PDF : MRSTMCal.LHgrid
    - CTEQ5L default
  - Renormalization scale




From HF Tune:
- b-bbar cross section : 1.02 ub
- into e+e- : 7.7 nb
- into e+e-, 8<m<11 : 212 pb
- e+e-, 8<m<11, |y|<0.5: 47 pb

From Default Pythia 8:
- b-bbar cross section : 0.83 ub
- into e+e- : 6.5 nb
- into e+e-, 8<m<11 : 135 pb
- e+e-, 8<m<11, |y|<0.5: 24 pb