Υ measurements in p+p collisions at $\sqrt{s}$=500 GeV with the STAR experiment

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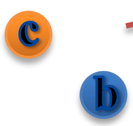
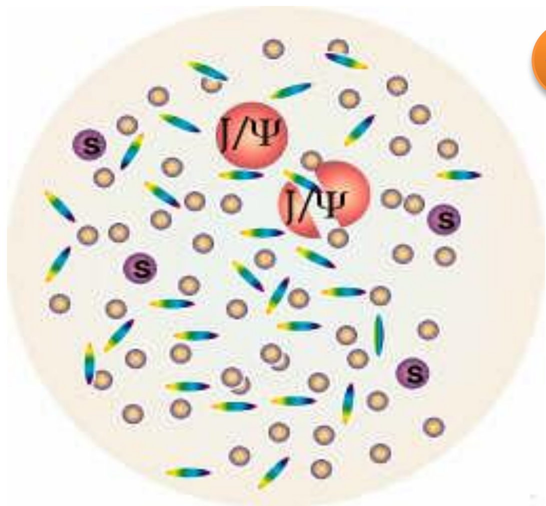
Outline

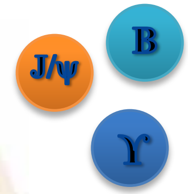
- Why Upsilon at RHIC?
- Experimental approach in STAR
- Measured yields and expected precision
- Efficiency studies
- Prospects for Upsilon measurements in STAR

Physics introduction

Heavy quarks (b,c) are produced in an early stage of the collision (before quark-gluon plasma (QGP) formation)

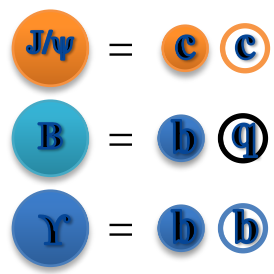






Hadrons containing heavy quarks can be observed and their modification in QGP measured.

Heavy quarks are „probes”, which interact with QGP



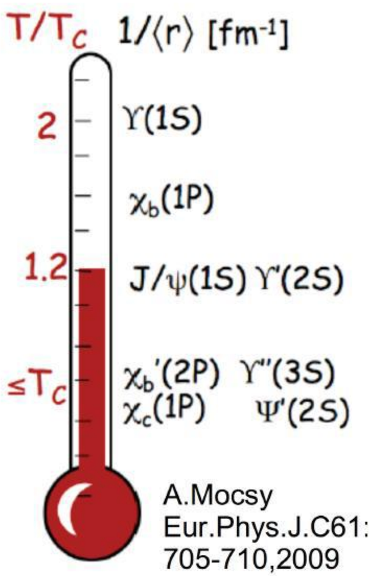
$$R_{AA} = \frac{1}{N_{coll}} \frac{(\text{invariant yield})_{AA}}{(\text{invariant yield})_{pp}}$$

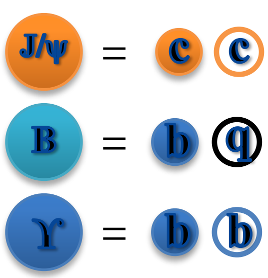
From this we can learn about QGP and interactions between quarks and gluons.

•Suppression of J/ψ in A+A is a signature of QGP formation.

T.Matsui and H.Satz 1986 Phys. Lett. B 178:416, 1986

Quarkonium suppression





•Upsilons provide a cleaner probe than J/ψ, because of smaller regeneration and cold nuclear matter effects

•Sequential suppression of more tightly bound states with increasing temperature – indirect QGP temperature measurement

Á. Mócsy, P. Petreczky, Phys. Rev. D77, 014501 (2008)

↓

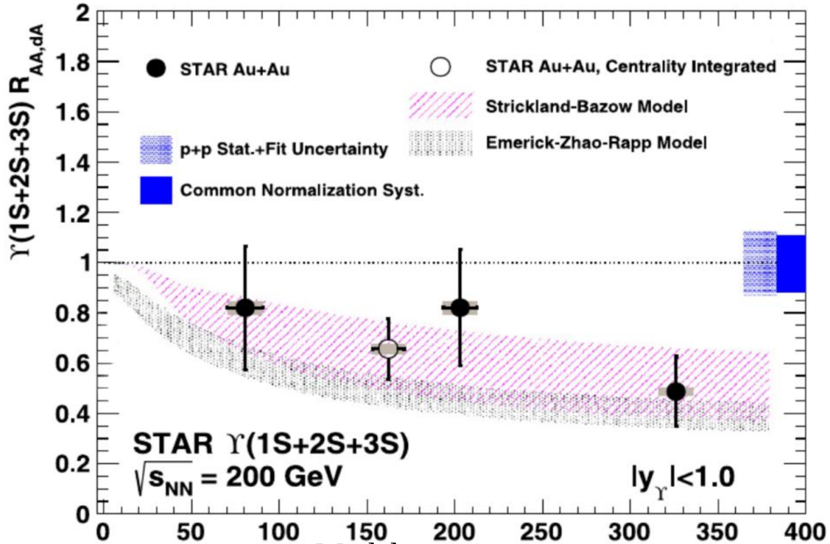
Requires measurements of suppression of different quarkonium states

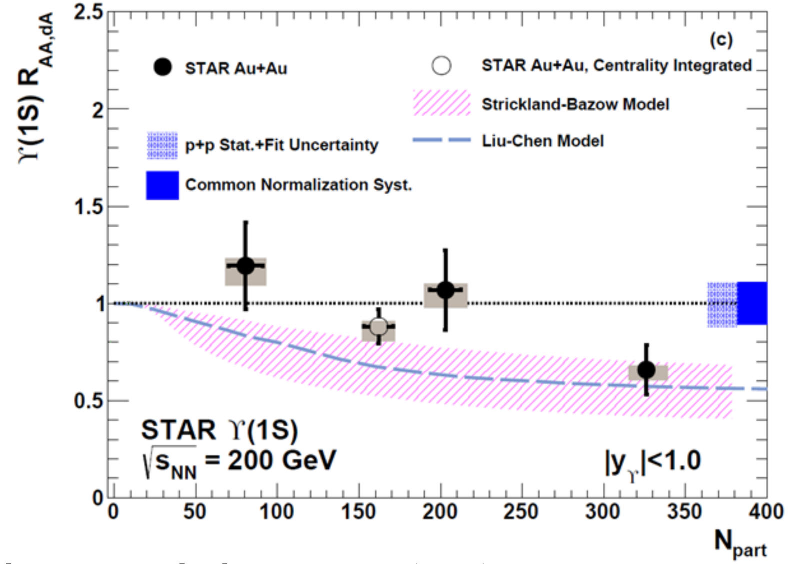
Why Upsilons at RHIC?

STAR measured R_{AA} for Upsilon 1S+2S+3S and 1S as a function of N_{part}.

•Shows significant suppression for integrated p_T.

Phys.Lett. B735 (2014) 127





Models:
Hot and cold nuclear matter effects: Strickland, Bazov, Nucl. Phys. A879, 25 (2012)
Hot nuclear matter effects only: arXiv:1009.2585

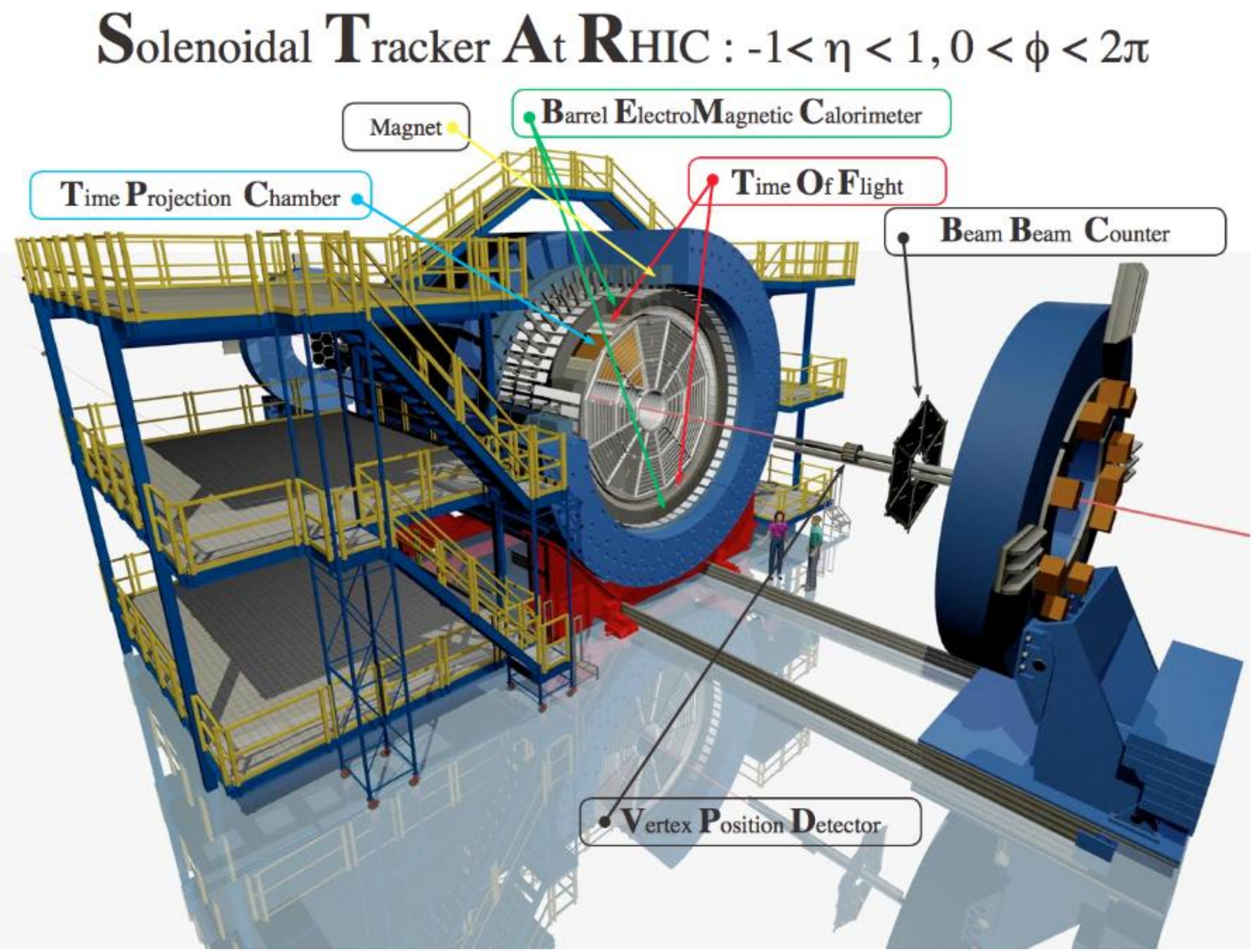
•We need p_T spectrum from p+p as a baseline for $R_{AA}(p_T)$ to study dynamical aspects of Upsilon interaction with QGP.

•STAR p+p 500 GeV provides much better statistical precision(larger $b\bar{b}$ cross section than at 200 GeV, and higher integrated luminosity)

•Will provide an opportunity to measure ratios of different states in production yields.

•May provide constraints for quarkonium production models

STAR experiment



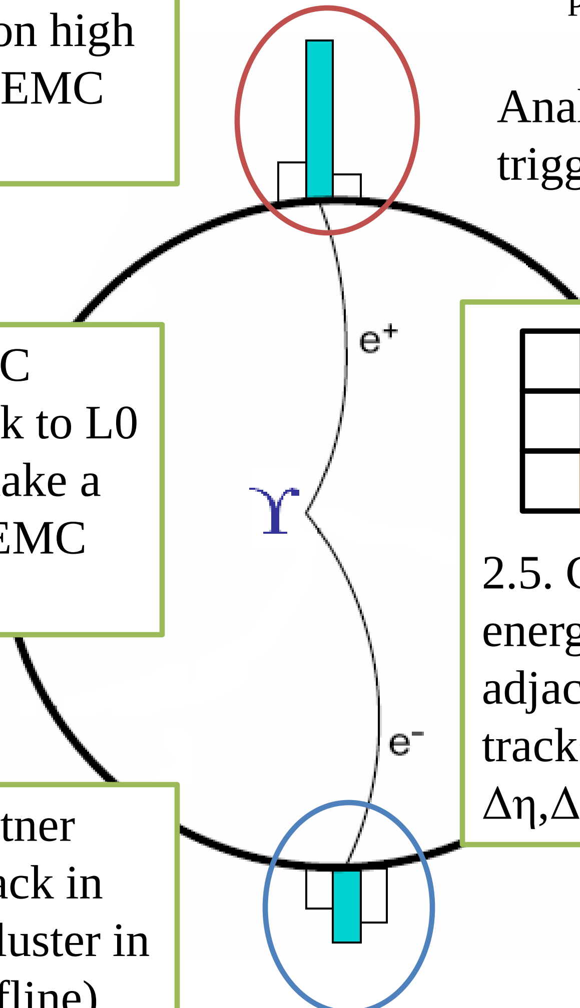
- TPC: Particle identification via dE/dx and tracking
- BEMC: Particle identification via E/p and shower shape, also provides online High Tower trigger

Experimental approach in STAR

$\Upsilon \to e^+e^- \quad BR = 2.38 \pm 0.11\%$

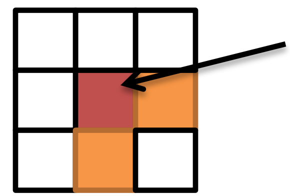
Phys. Rev. D**86, 010001 (2012)**

1. Trigger online on high energy tower in BEMC („L0 tower”)



Analyzed 160M p+p 500 GeV events triggered by High Tower trigger (L_{int} = 21.5 pb^{-1})

2. Match TPC electron track to L0 tower and make a cluster in BEMC (offline)



Tower pointed by a TPC track

2.5. Clusters are made by adding energy of 2 highest BEMC towers adjacent to the tower pointed in by TPC tracks:
$\Delta\eta, \Delta\varphi = \pm 1$ tower

3. Find partner electron track in TPC and cluster in BEMC (offline)

Offline analysis and particle identification

Track which fired the trigger:

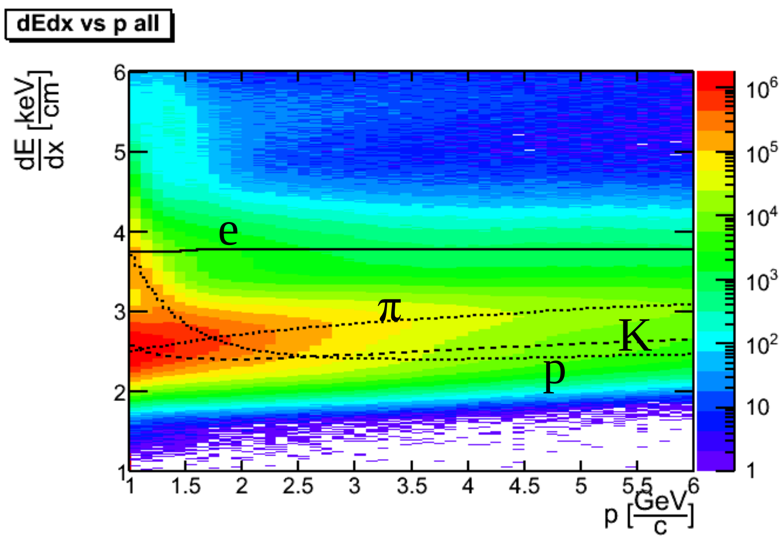
Match to L0 tower required

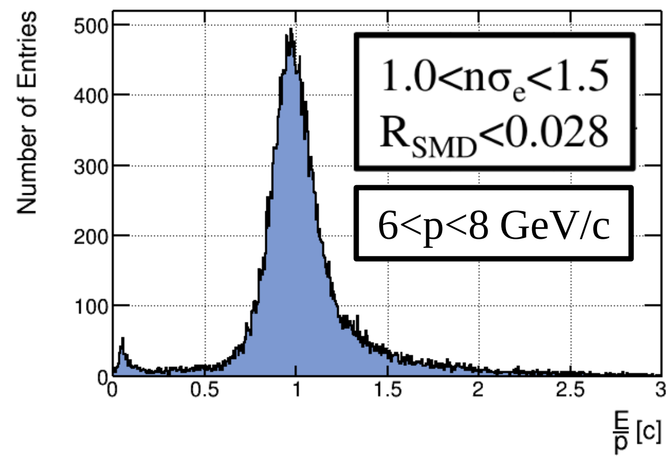
Partner track:

p>1 GeV/c

Both tracks:

$-1.2<n\sigma_e<3.0$
$E_{tower}/E_{cluster}>0.5$
$0.55<E_{cluster}/pc<1.45$
$R_{SMD}<0.028$





Normalized dE/dx: $n\sigma_e = \log\left(\frac{dE/dx_e}{dE/dx|_{Bichsel}}\right)/\sigma$

Distance between a track projection on BEMC SMD and center of a cluster: $R_{SMD} = \sqrt{\Delta\eta^2 + \Delta\phi^2}$

Upsilon signal and backgrounds

Invariant mass histogram of e+e- contains:

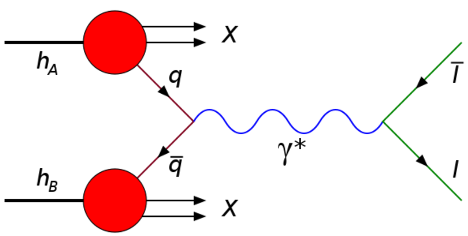
•Upsilon signal

•Combinatorial background

- described by like sign sum:

$$N_{e+e+} + N_{e-e-}$$

•Drell-Yan background: $q\bar{q} \rightarrow l\bar{l}$

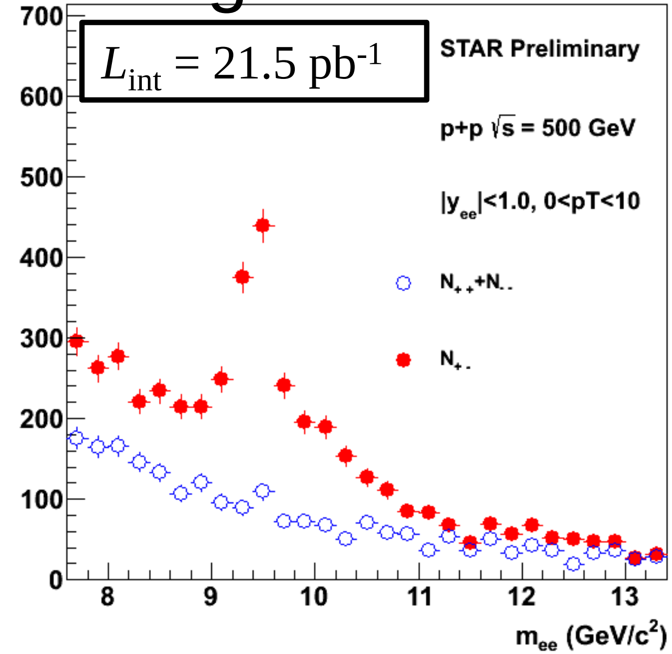


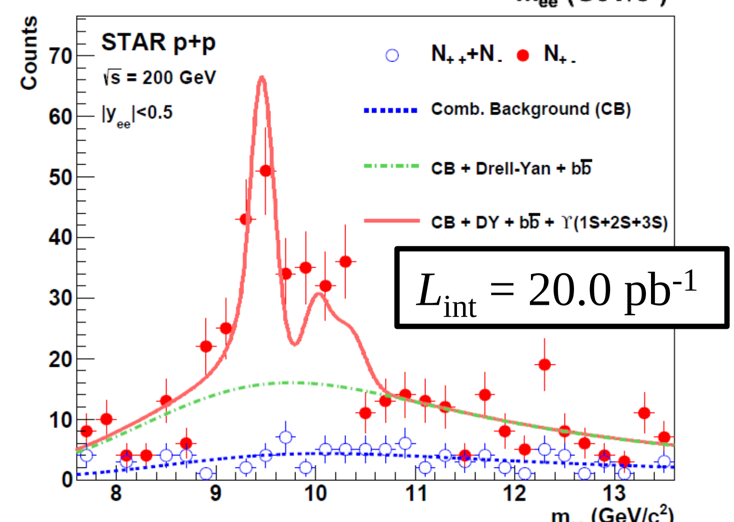
•bb̄ background: $b\bar{b} \rightarrow e^+e^-$

Signal extraction strategy:

•describe background by a function and do a simultaneous fit to signal and combinatorial background

•integrate counts in an Upsilon mass range and subtract background





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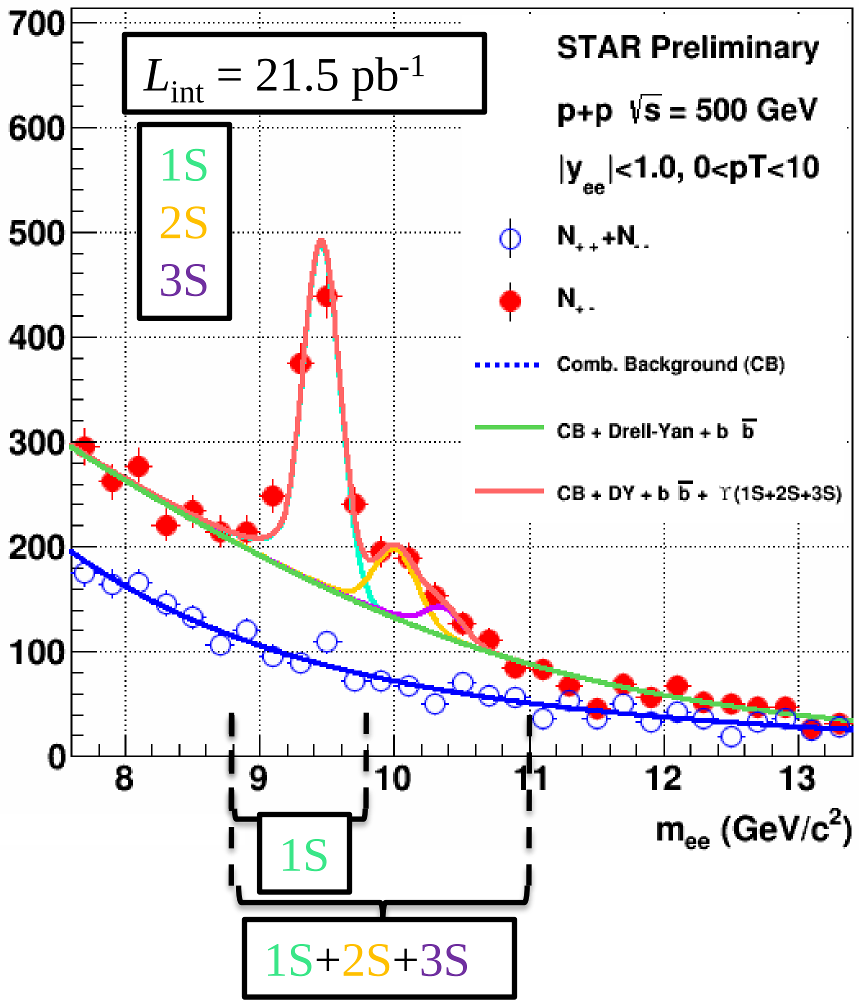
Upsilon signal



Signal calculated by integrating counts and subtracting backgrounds from fits:

$$N_{\Upsilon} = N_{e+e-} - N_{CB}^{Fit} - N_{DY}^{Fit} - N_{b\bar{b}}^{Fit}$$

Background fit functions:

$$f_{b\bar{b}} = N \frac{m^A}{\left(1+\frac{m}{B}\right)^C} \qquad f_{DY} = N \frac{1}{\left(1+\frac{m}{A}\right)^B}$$

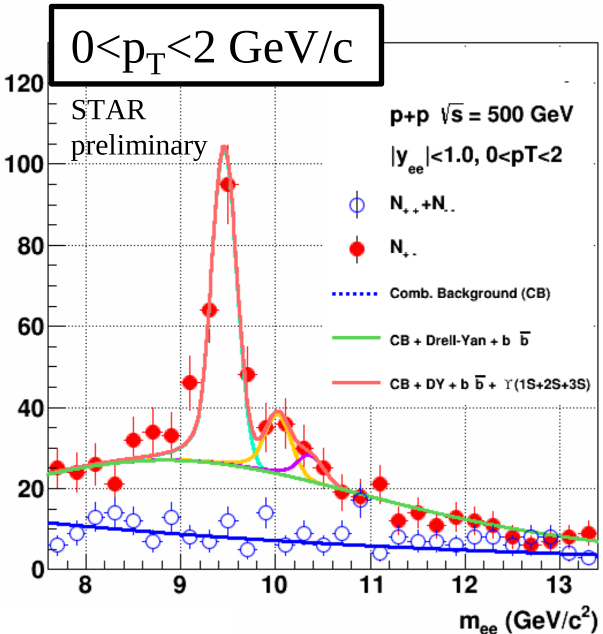
$$f_{CB} = N \cdot A \cdot \exp\left(\frac{-m}{B}\right) + N \cdot (1-A) \cdot \exp\left(\frac{-m}{C}\right)$$

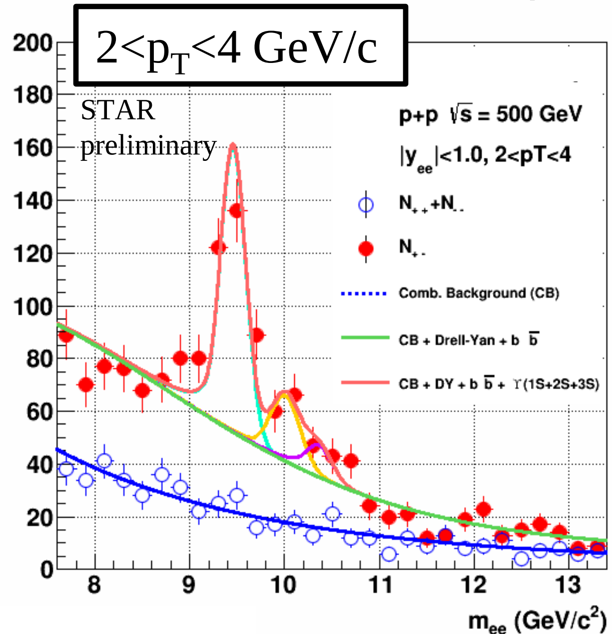
1S yield extracted in 8.8-9.8 GeV/c^2 range.
1S+2S+3S extracted in 8.8-11 GeV/c^2 range.

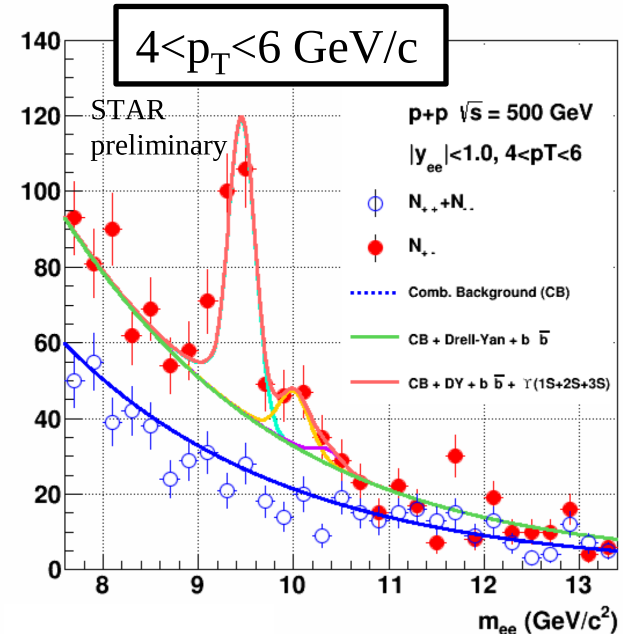
1S+2S+3S yield: 831 ± 45
1S yield: 653 ± 35

Statistical uncertainty ~5%
(~20% stat.+fit uncertainty for published p+p 200 GeV results)

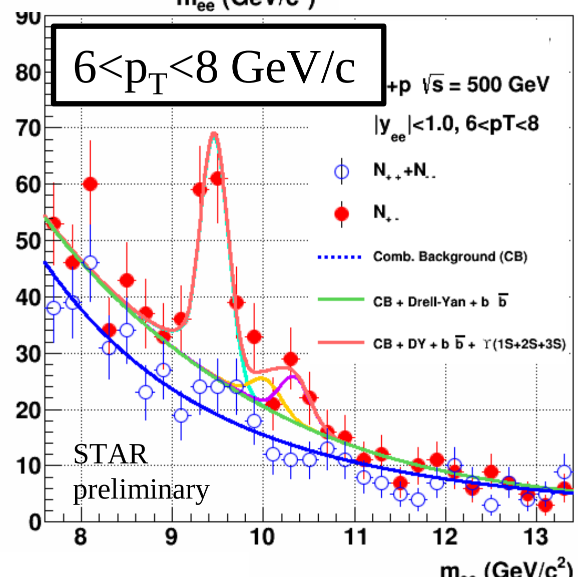
Upsilon signal – p_T bins

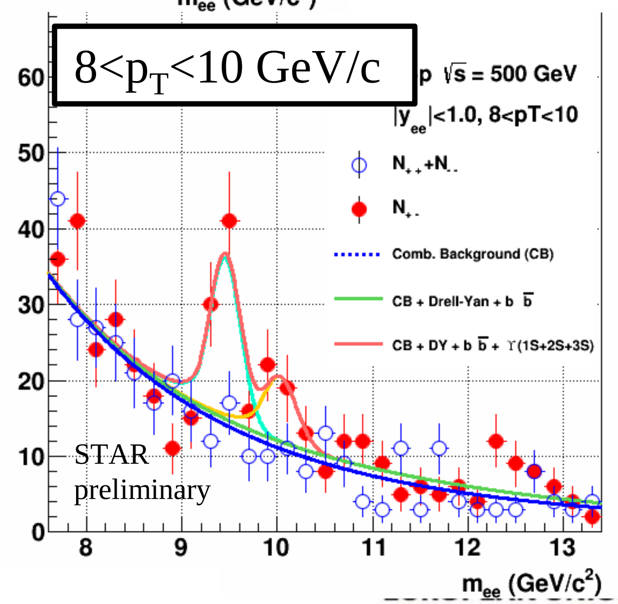






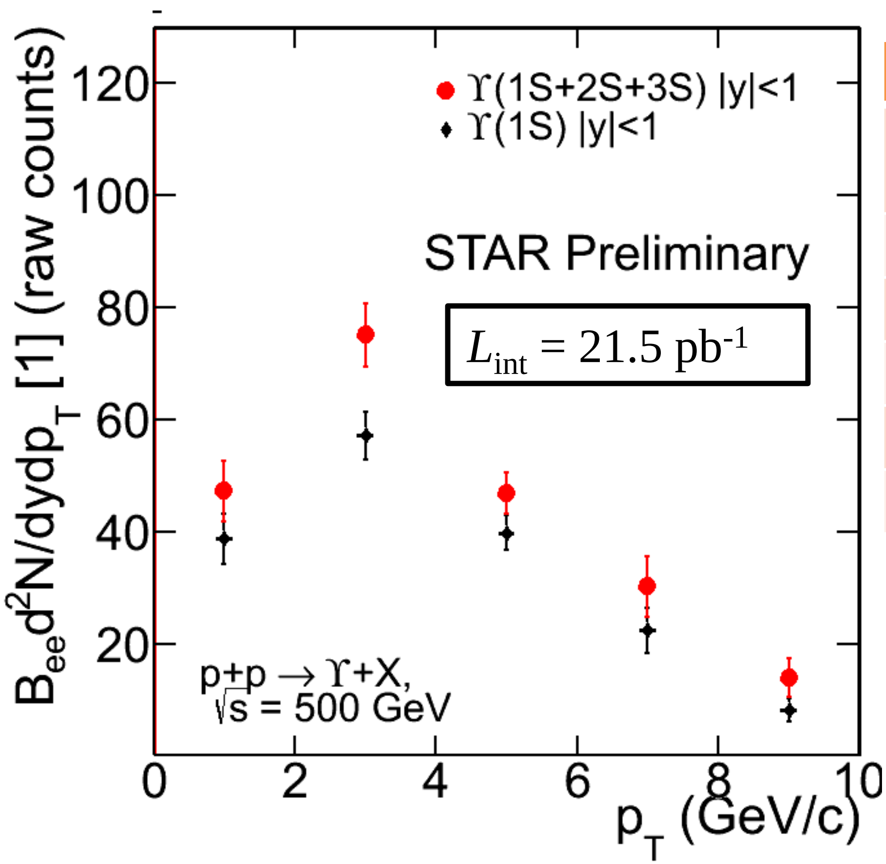
1S
2S
3S





Upsilon signal in 5 p_T bins up to 10 GeV/c!!

Uncorrected p_T spectrum

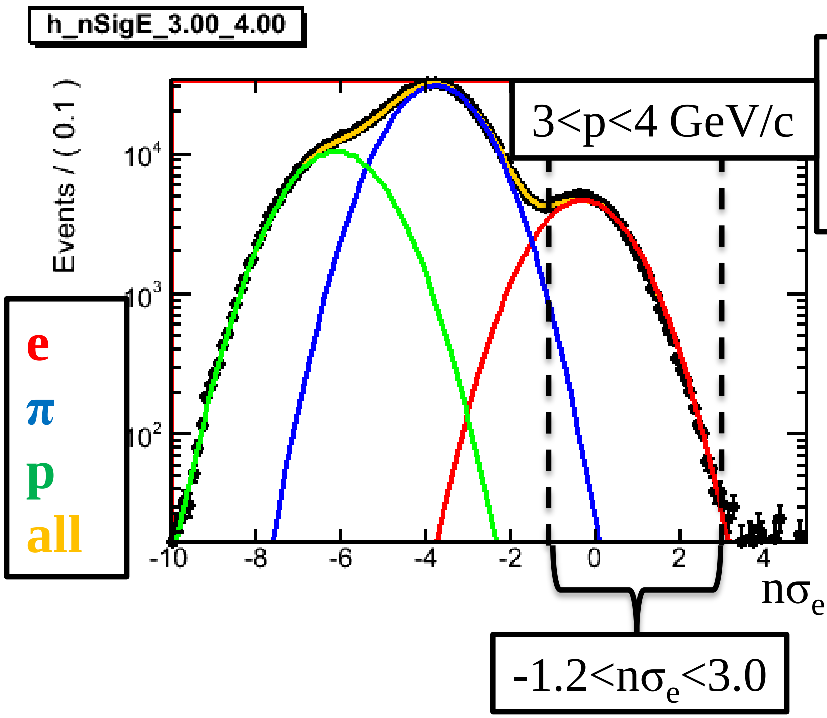


- Statistical uncertainty< 20% for p_T<8 GeV/c
- Even better than <10% for 2<p_T<6 GeV/c

	1S+2S+3S		
p_T[GeV/c]	**Yield**	**Uncertainty**	**Uncertainty %**
0-2	189	22	12
2-4	301	23	8
4-6	188	15	8
6-8	121	22	19
8-10	56	15	27

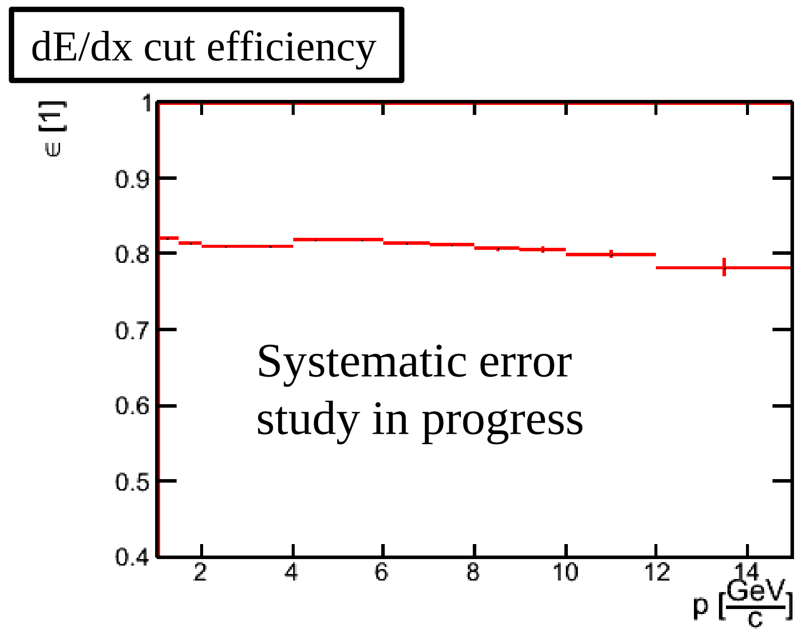
	1S		
p_T[GeV]	**Yield**	**Uncertainty**	**Uncertainty %**
0-2	155	18	12
2-4	229	18	8
4-6	159	13	9
6-8	90	16	18
8-10	32.9	8.4	26

dE/dx cut efficiency



$E_{tower}/E_{cluster}>0.75$
$0.7<E_{cluster}/pc<1.3$
$R_{SMD}<0.028$

Obtained a cleaner sample for dE/dx cut efficiency calculation and fitted multiple gaussians to $n\sigma_e$ distributions in momentum slices



Efficiency is a ratio of the integral of the electron gaussian within cut range to the total electron gaussian

Normalized dE/dx: $n\sigma_e = \log\left(\frac{dE/dx_e}{dE/dx|_{Bichsel}}\right)/\sigma$

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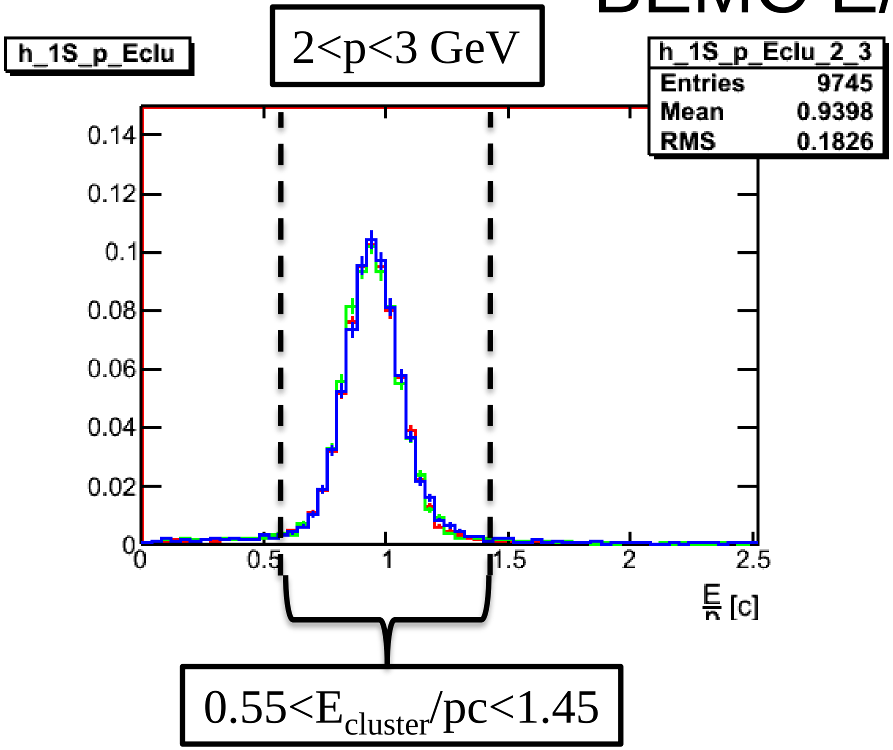
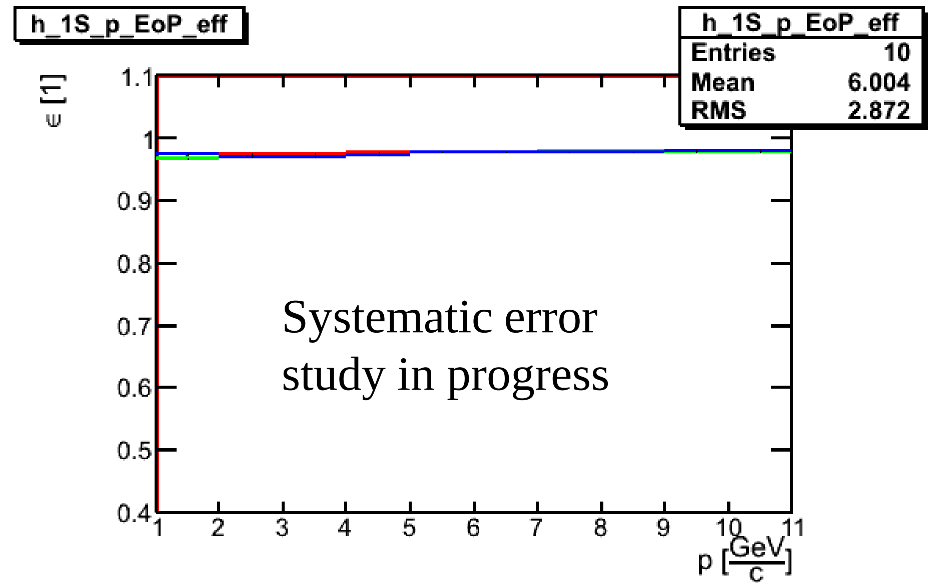
BEMC E/p efficiency

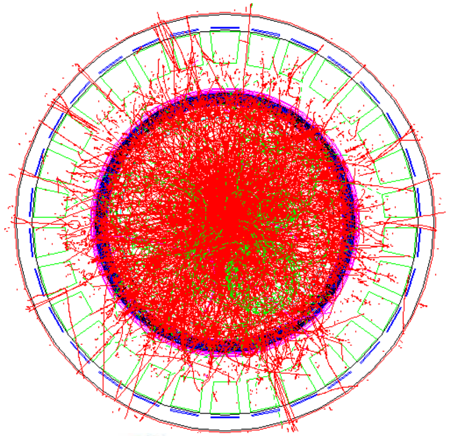




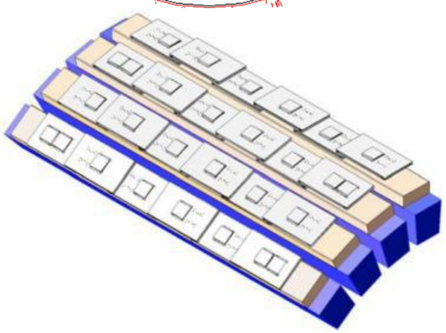
Compared E_{clu}/p distribution from MC simulation

MC simulation Υ(1S)
MC simulation Υ(2S)
MC simulation Υ(3S)

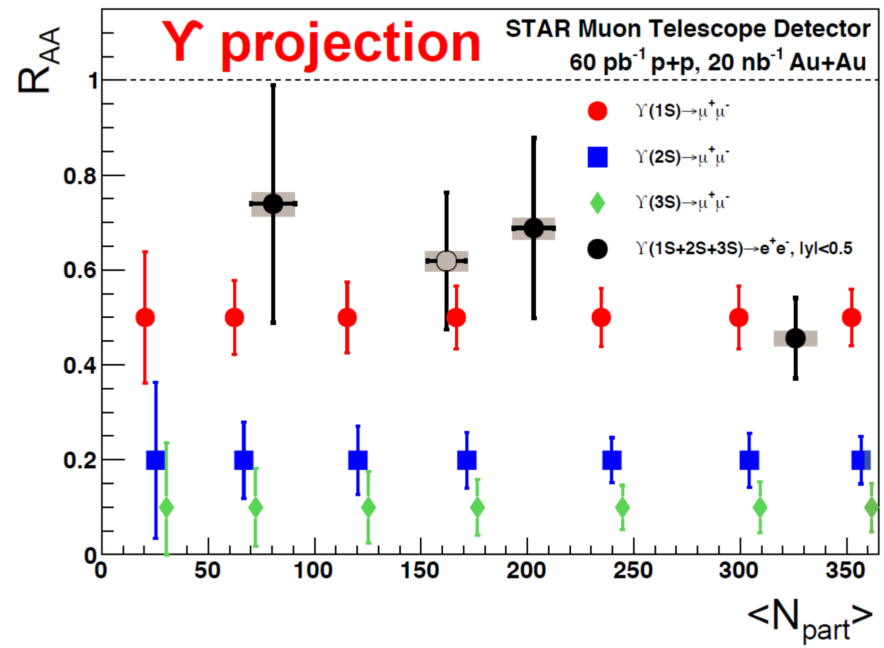
Muon Telescope Detector



- Multi-gap Resistive Plate Chamber (MRPC) - gas detector outside STAR magnet
- Allows precision measurements of heavy quarkonia in dimuon channel (no γ conversions, less bremsstrahlung than e and less dalitz decays)
- Complete in 2014, sampled ~13.8 nb^{-1} in Au+Au data



Acceptance:
45% in φ
|η|<0.5



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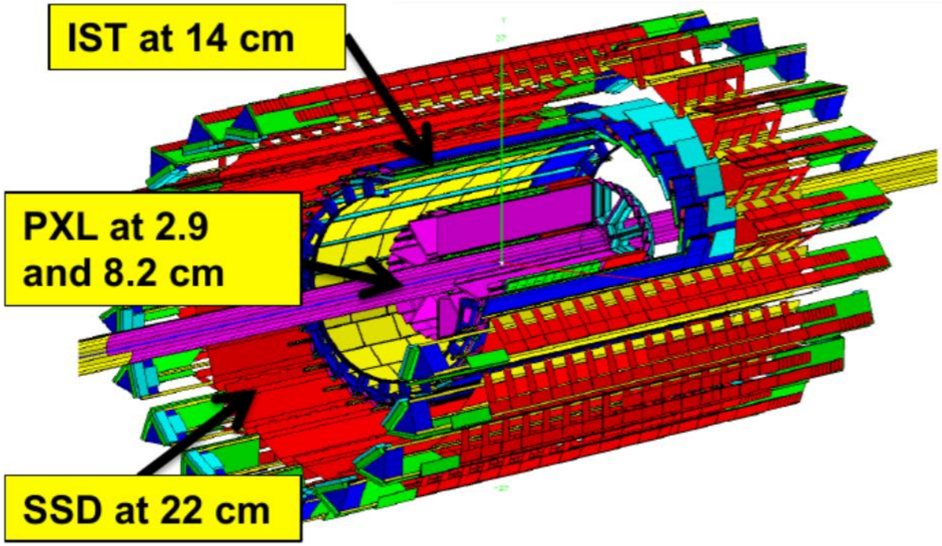
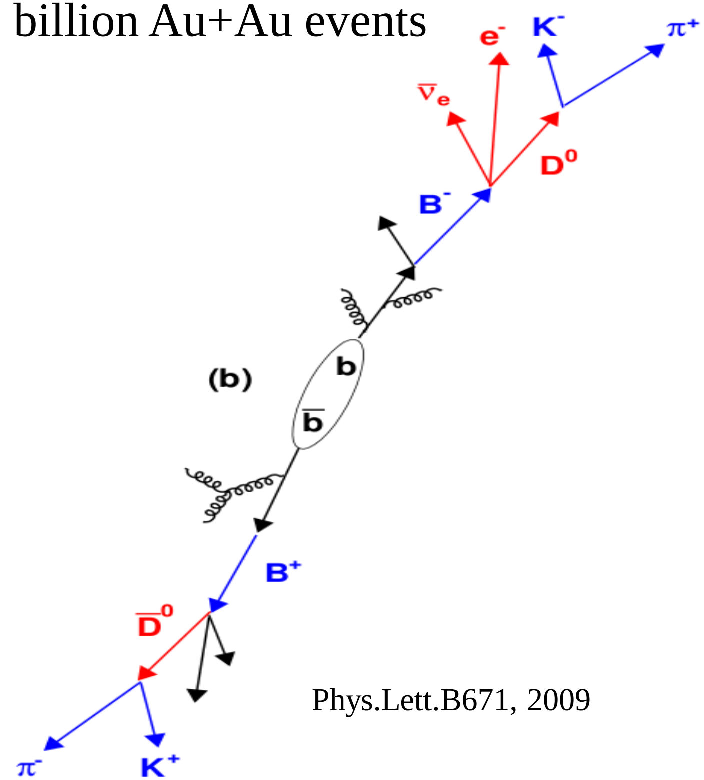
Heavy Flavor Tracker



- State-of-the-art silicon tracker for heavy flavor studies
- Allows direct reconstruction of secondary vertices from D and B meson decays
- Fully installed in 2014, recorded ~1 billion Au+Au events

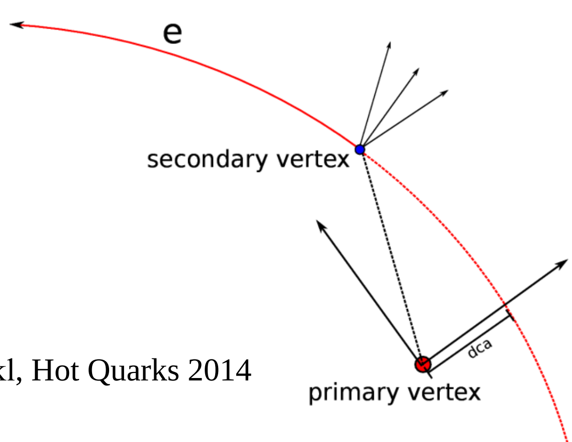


Phys.Lett.B671, 2009

May provide direct $b\bar{b}$ (background for Υ) cross section measurements through:

$$B \to e + X$$

$$b\bar{b} \to e^+e^-$$



M. Völkl, Hot Quarks 2014

Summary

•Upsilon measurement in p+p 500 GeV could provide a better statistical precision baseline for Au+Au 200 GeV after extrapolation

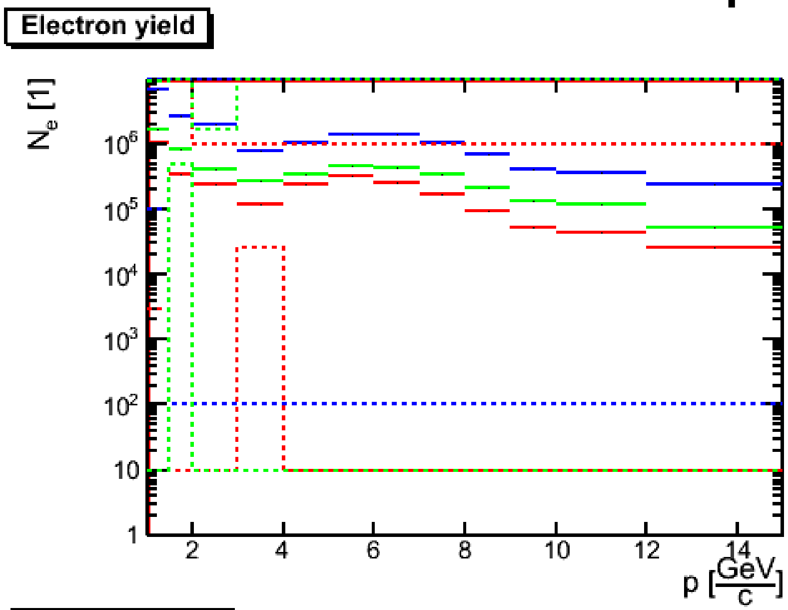
•Data can be divided into 5 p_T bins from 0-10 GeV/c

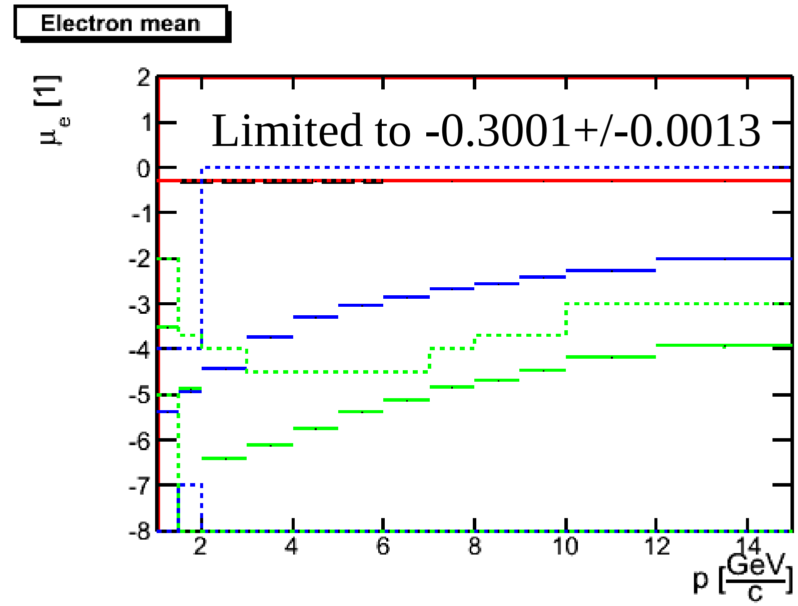
•With current data (L_{int} = 21.5 pb^{-1}), we can expect p_T spectrum for Upsilon 1S and combined states with statistical uncertainty< 20% for p_T up to 8 GeV/c

•Stay tuned for upcoming results!!

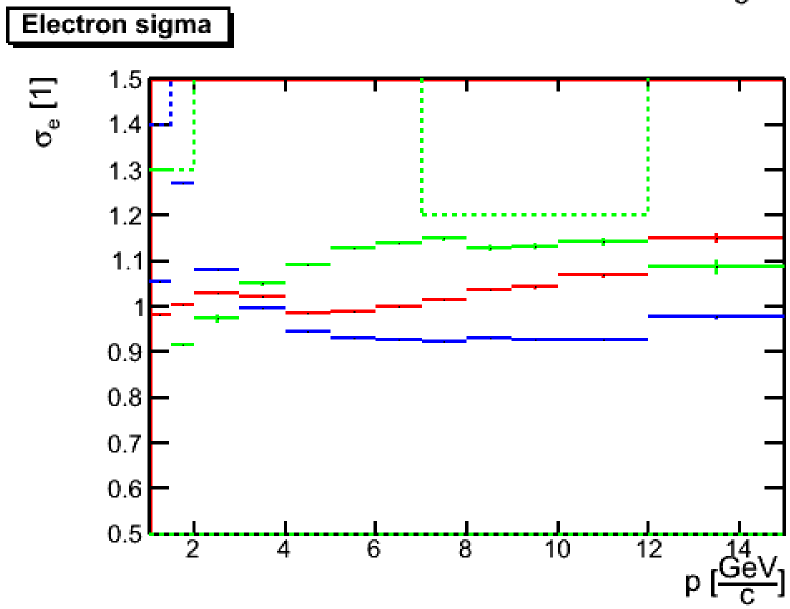
BACKUP

parameters





e
π
p
all

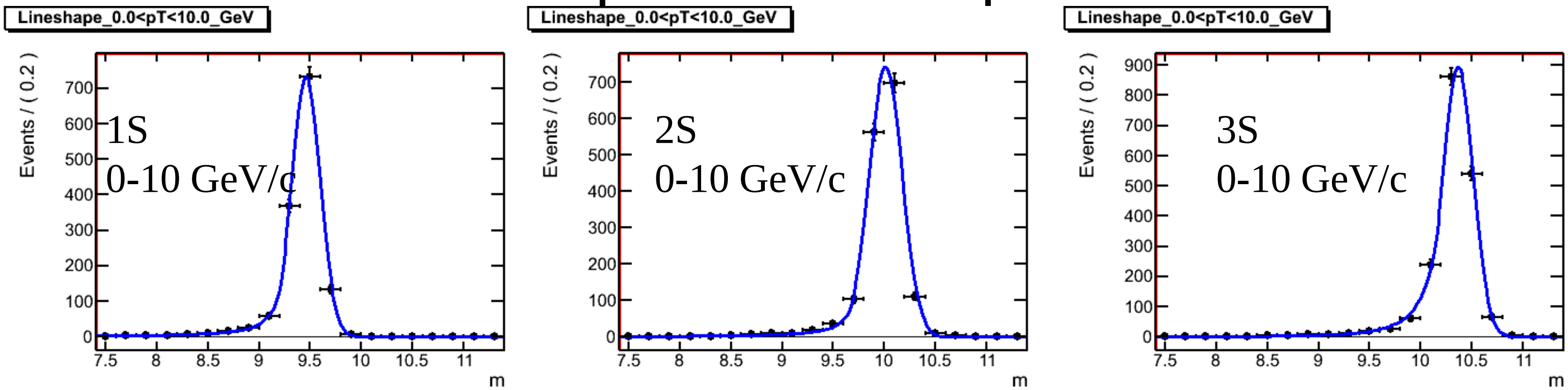


Smooth dependence => good

Set limit for electron mean based on straight line fit in 1.5-6 GeV: -0.3001+/-0.0013

Very little constraints (dotted lines)

Upsilon lineshapes



Crystall Ball function:

$$f(x;\alpha,n,\bar{x},\sigma)=N\begin{cases}\exp\left(-\frac{(x-\bar{x})^2}{2\sigma^2}\right), & \text{for } \frac{x-\bar{x}}{\sigma}>-\alpha\\ A\left(B-\frac{x-\bar{x}}{\sigma}\right)^{-n}, & \text{for } \frac{x-\bar{x}}{\sigma}\le-\alpha\end{cases}$$

Lineshapes from MC simulation include the reconstruction efficiency.

Fitted Crystal Ball functions to lineshapes

Made likelihood fits with RooFit in each p_T bin to take into account p_T dependence

$$A=\left(\frac{n}{|\alpha|}\right)^n\cdot\exp\left(-\frac{|\alpha|^2}{2}\right)$$

$$C=\frac{n}{|\alpha|}\cdot\frac{1}{n-1}\cdot\exp\left(-\frac{|\alpha|^2}{2}\right)$$

$$B=\frac{n}{|\alpha|}-|\alpha|$$

$$D=\sqrt{\frac{\pi}{2}}\cdot\left(1+erf\left(\frac{|\alpha|^2}{\sqrt{2}}\right)\right)$$

$$N=\frac{1}{\sigma(C+D)}$$

DESY F31-86-02(1986), Appendix E

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