Measurement of Υ in p+p collisions in the STAR experiment

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Hot Quarks 2014
September 21-28, 2014
Les Negras, Andalucia, Spain

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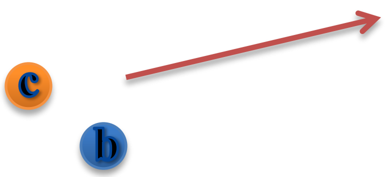
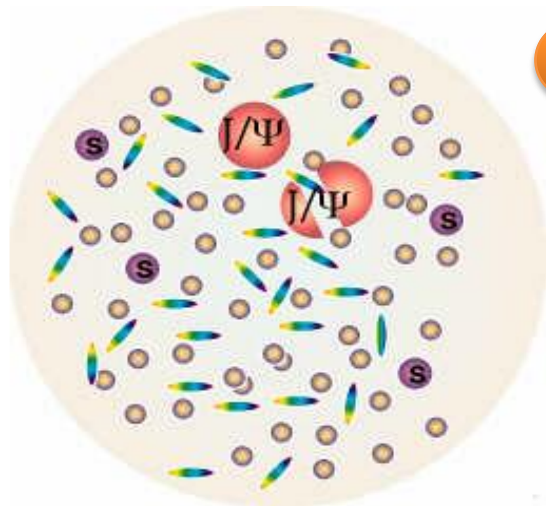
Outline

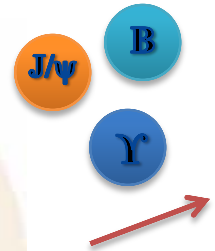
- Why Upsilon at RHIC?
- Experimental approach in STAR
- Measured yields and expected precision
- Efficiency studies
- Prospects for Upsilon measurements in STAR

Physics introduction

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



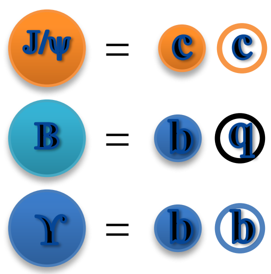




Hadrons containing heavy quarks can be observed and their modification in QGP measured.

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

Heavy quarks are „probes”, which interact with QGP

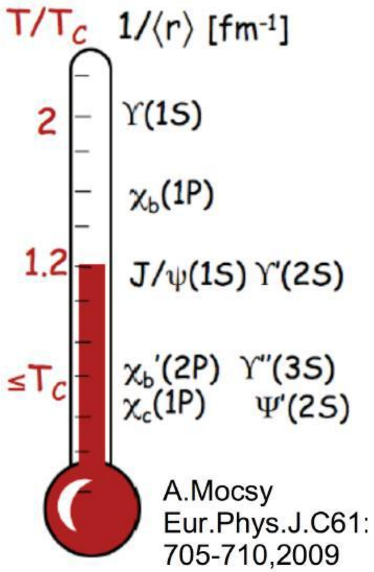


From this we can learn about QGP and interactions between quarks and gluons.

•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

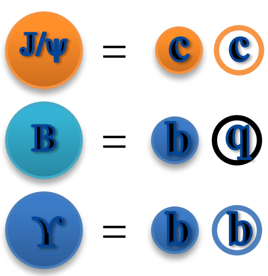


•Upsilons provide a cleaner probe than J/ψ, because of smaller regeneration and cold nuclear matter effects

•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.

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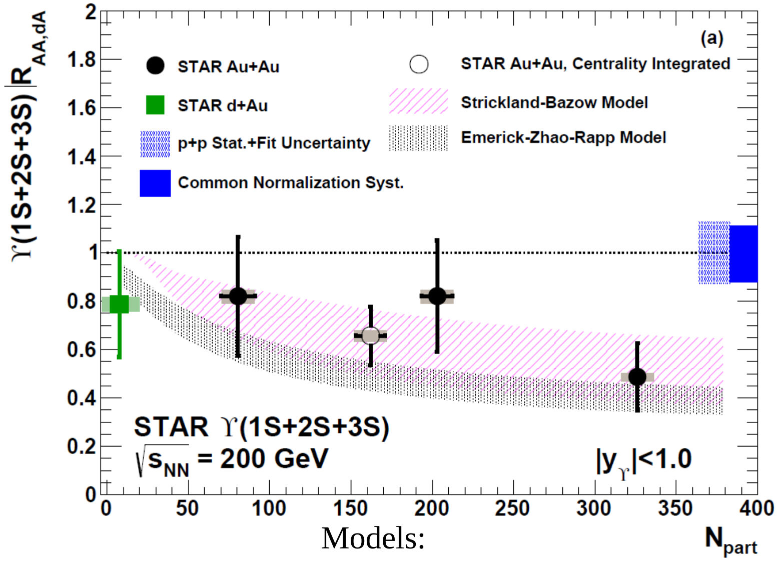
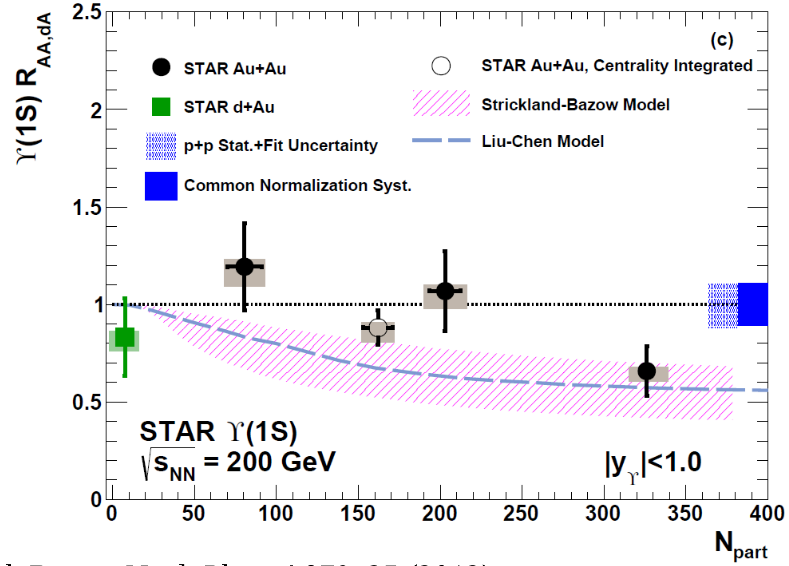




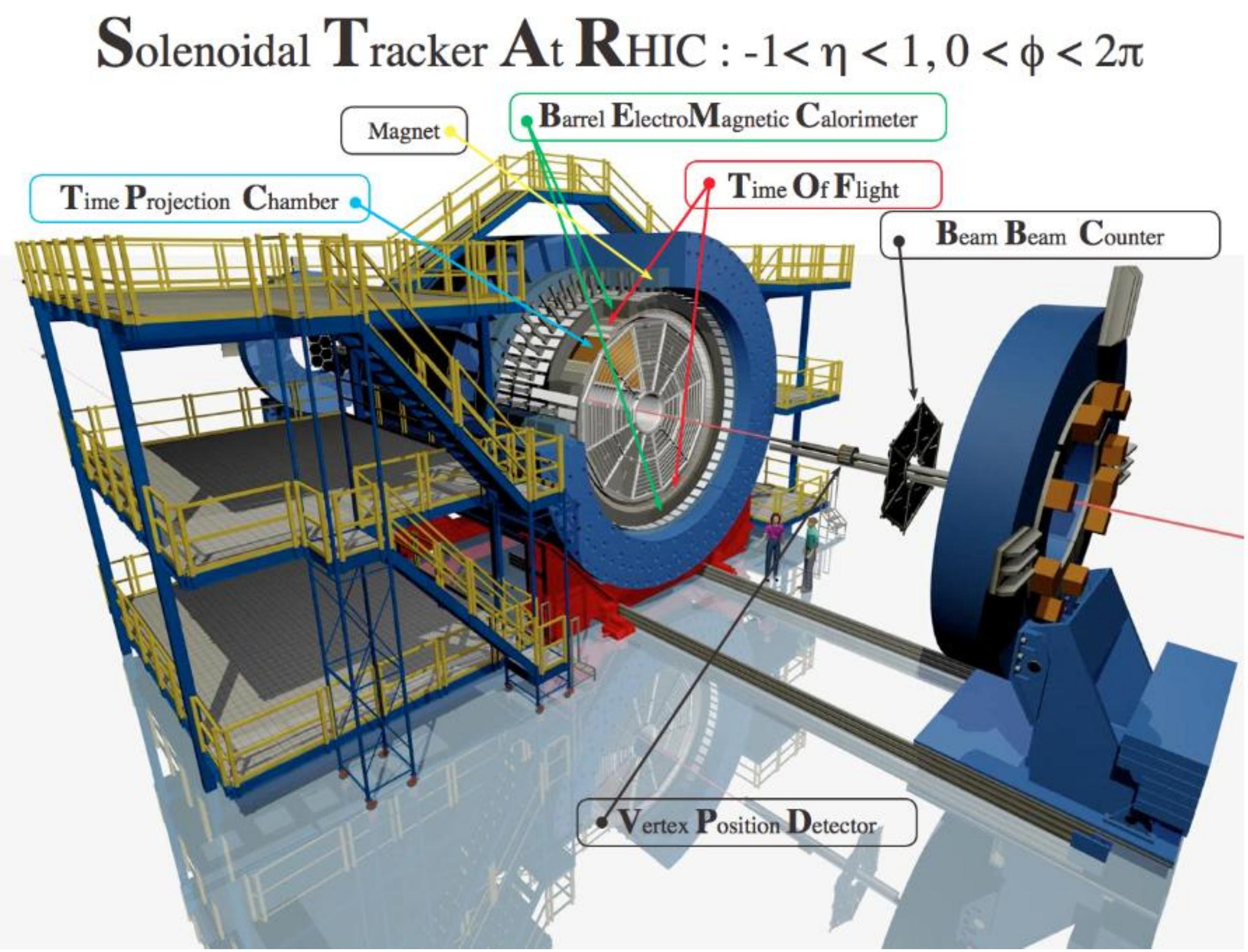
Models:
Hot and cold nuclear matter effects: Strickland, Bazov, Nucl. Phys. A879, 25 (2012)
Hot nuclear matter effects only: arXiv:1009.2585

•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)

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

STAR experiment



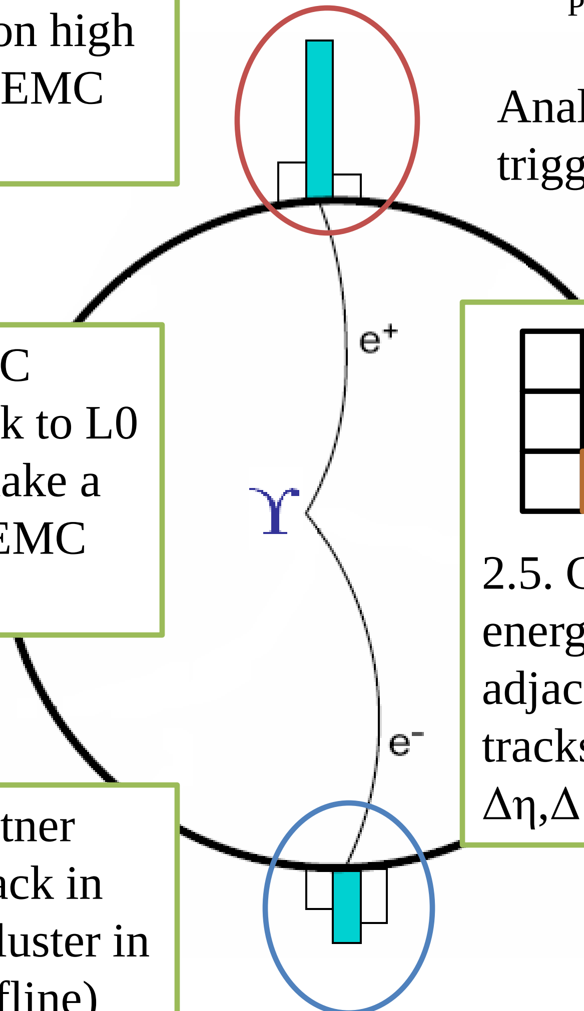
- TPC: Particle identification via dE/dx and tracking
- BEMC: Particle identification via E/p and online High Tower trigger

Experimental approach in STAR

$$\Upsilon \rightarrow e^{+}e^{-} \quad BR = 2.38 \pm 0.11\%$$

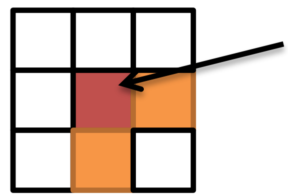
Phys. Rev. D**86, 010001 (2012)**

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)

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Offline analysis and particle identification

Track which fired the trigger:

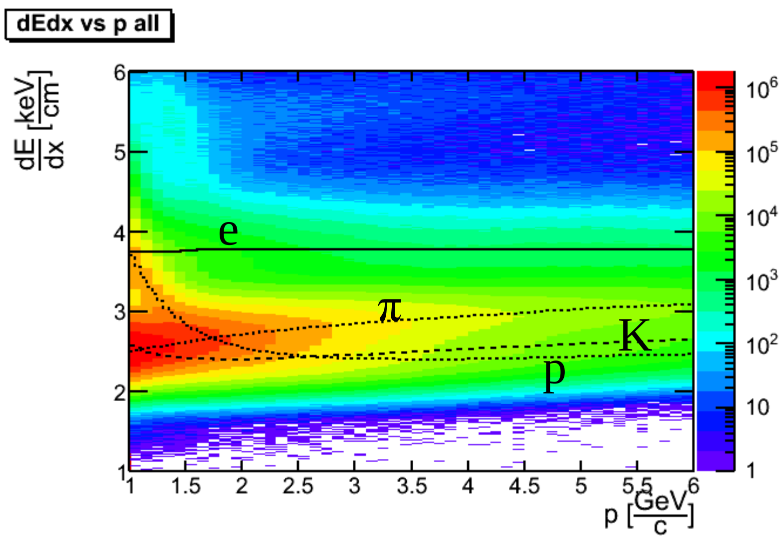
Match to L0 tower required

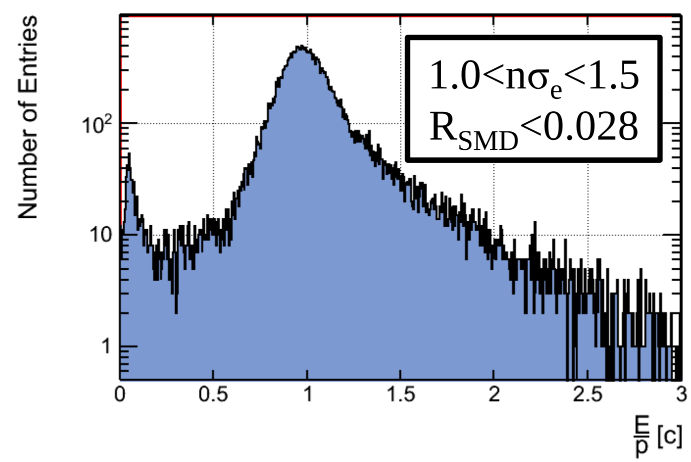
Partner track:

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

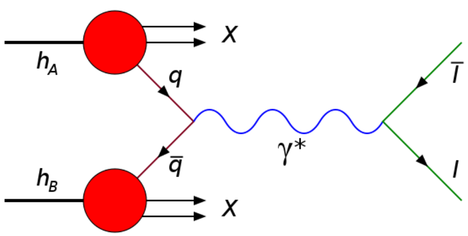
Invariant mass histogram of e+e- contains:

- Upsilon signal
- Combinatorial background

- described by like sign sum:

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

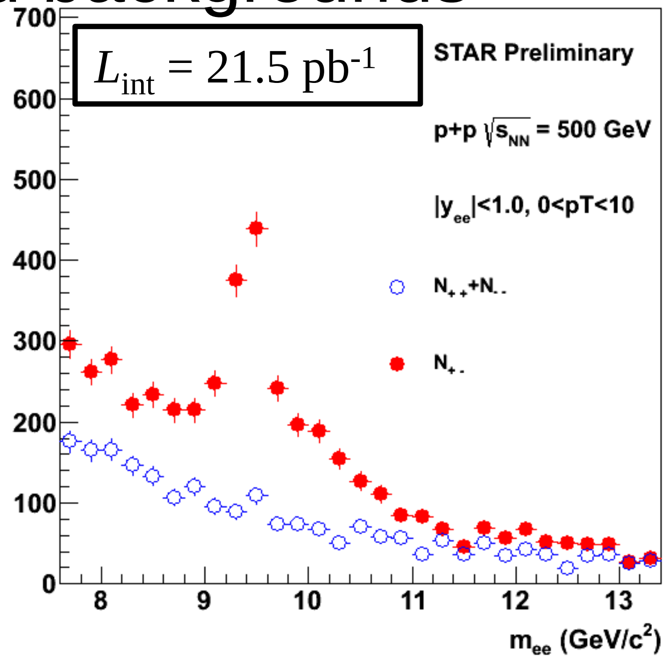
- Drell-Yan background: $q\bar{q} \rightarrow l\bar{l}$

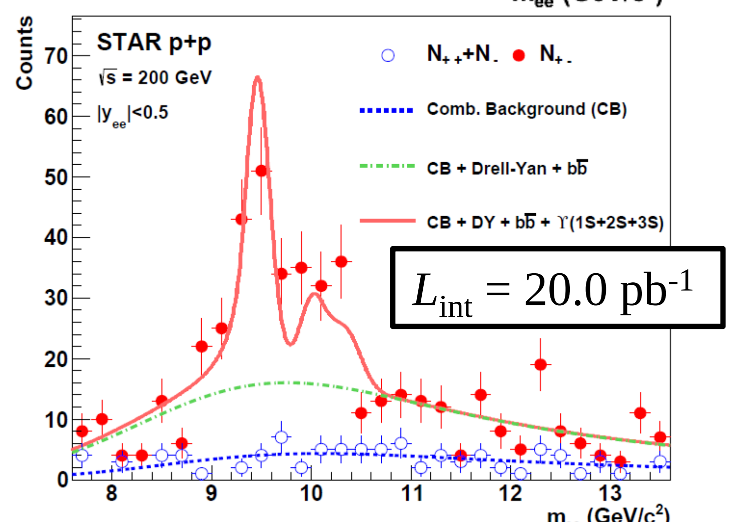


- b$\bar{\text{b}}$ background: $b\bar{b} \rightarrow e^+e^-$

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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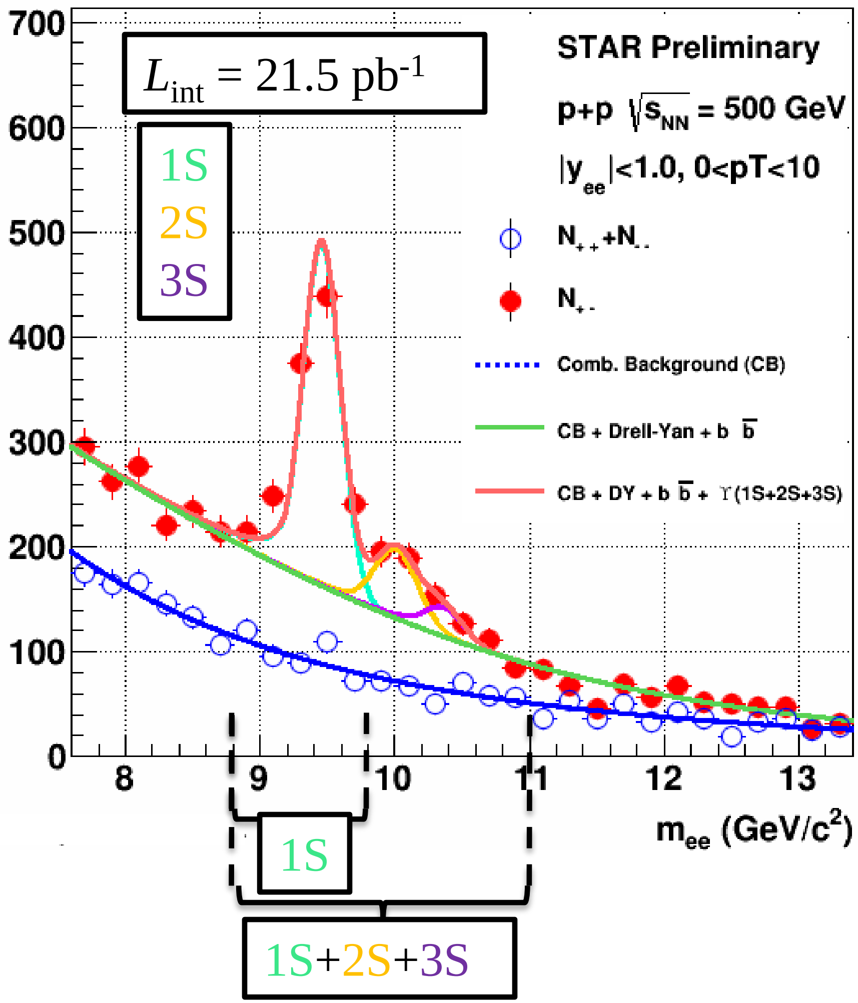
Upsilon signal



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

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

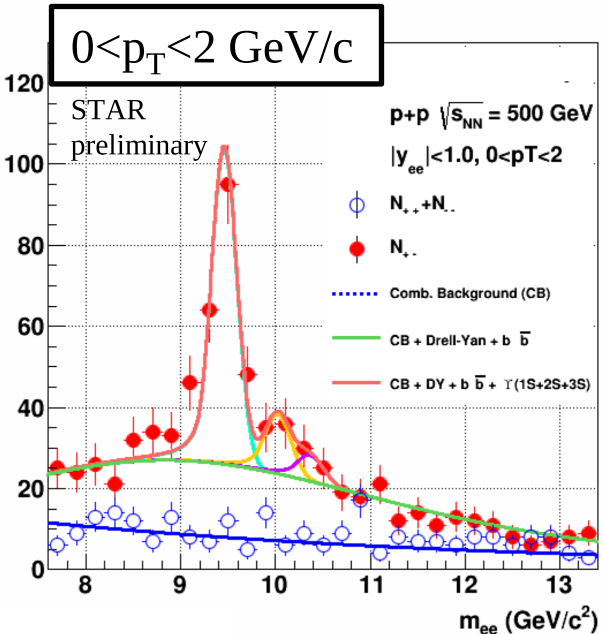
$$f_{CB} = N \cdot A \cdot \exp\left(\frac{-m}{B}\right) + N \cdot (1-A) \cdot \exp\left(\frac{-m}{C}\right)$$

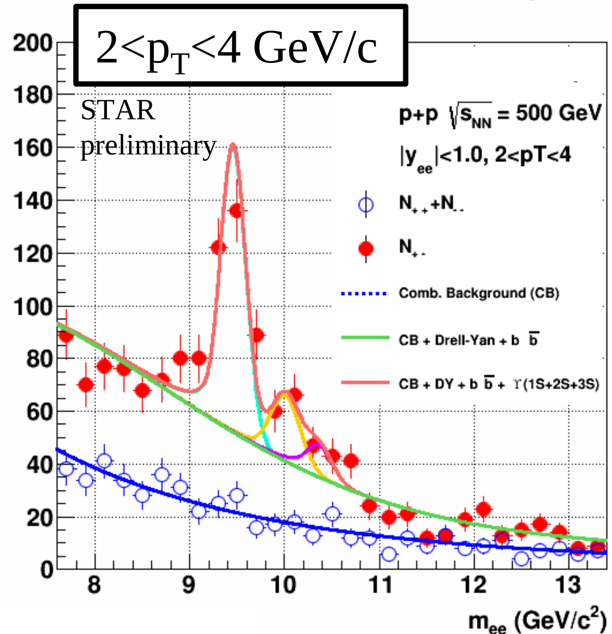
1S yield extracted in 8.8-9.8 GeV/c^2 range.
1S+2S+3S extracted in 8.8-11 GeV/c^2 range.

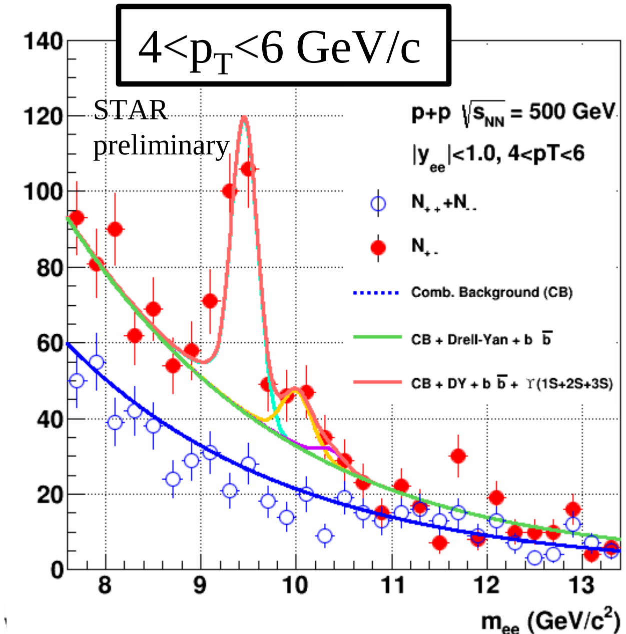
1S+2S+3S yield: 831 ± 45
1S yield: 653 ± 35

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

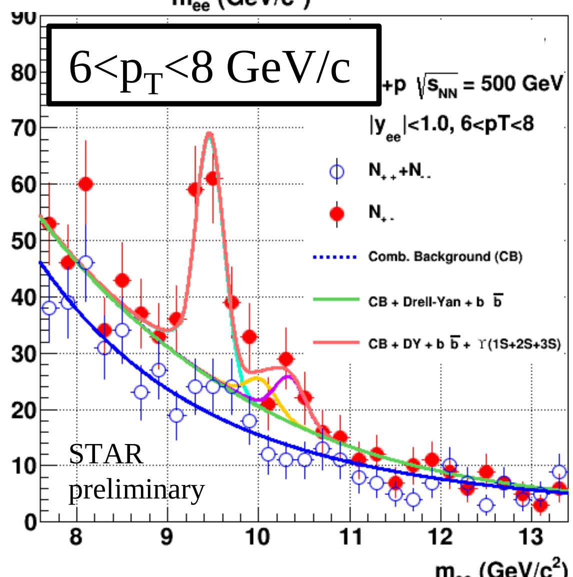
Upsilon signal – p_T bins

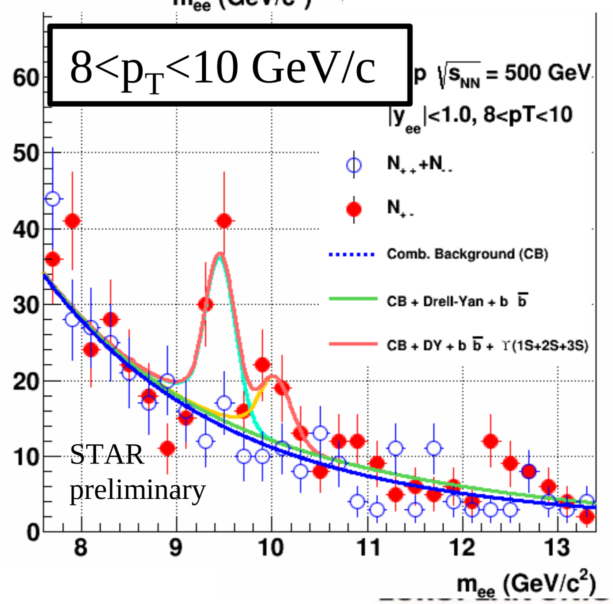






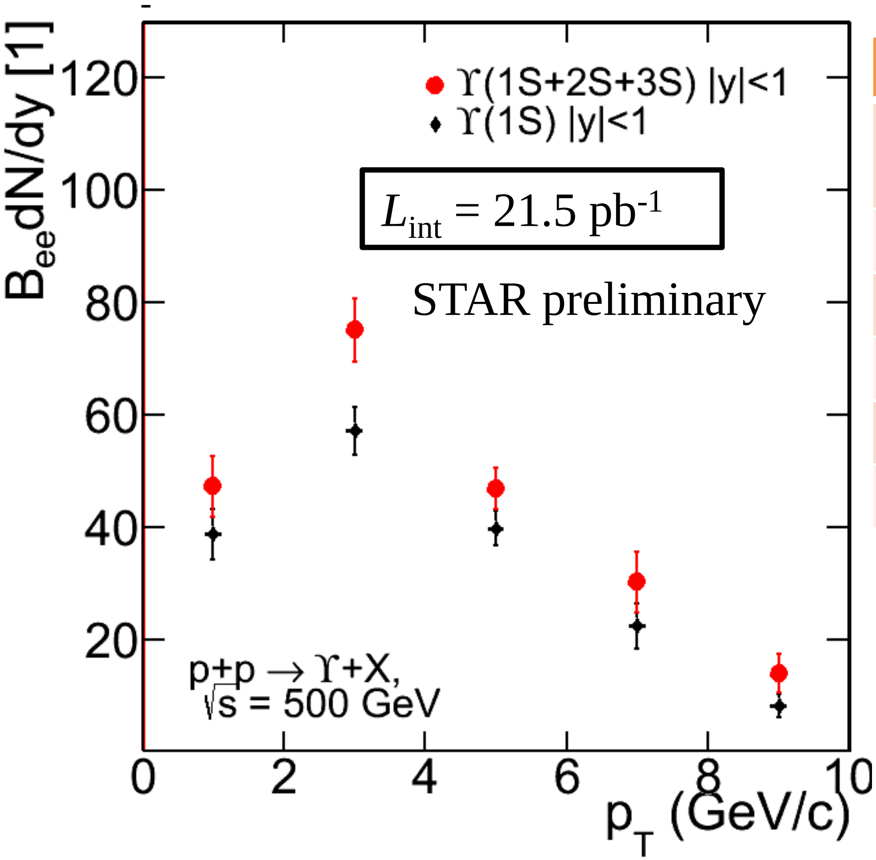
1S
2S
3S





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

Uncorrected p_T spectrum

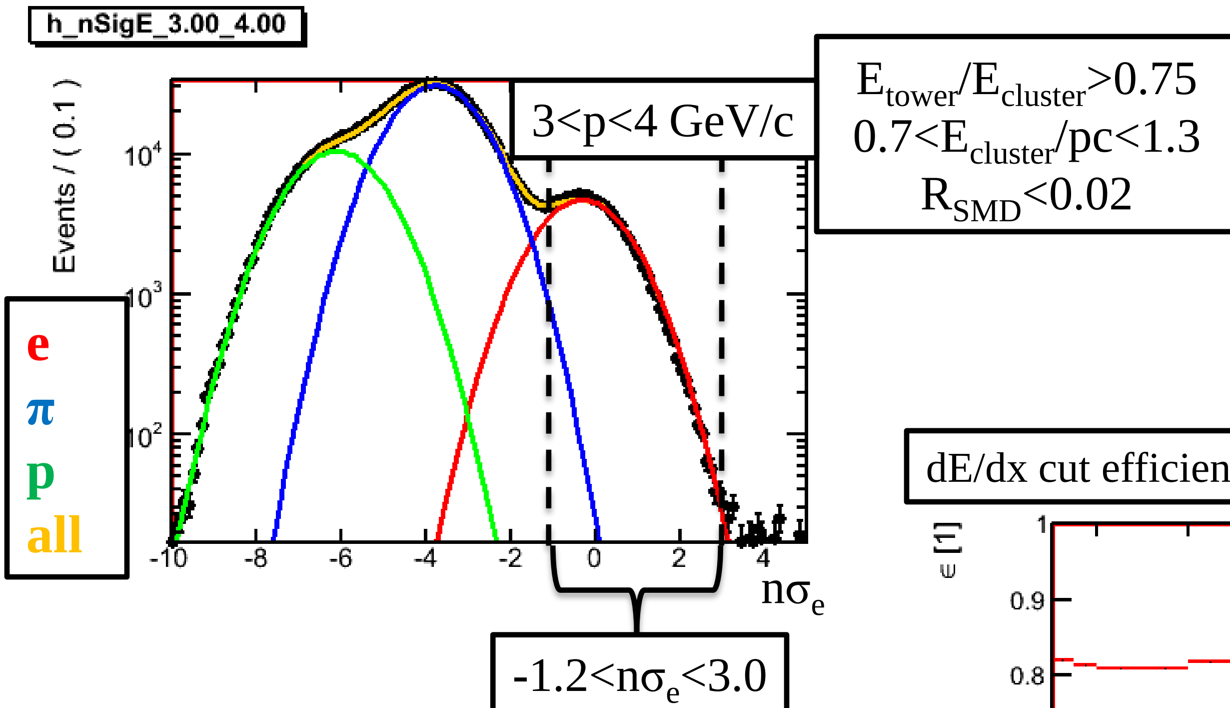


	1S+2S+3S		
p_T[GeV/c]	Yield	Uncertainty	Uncertainty %
0-2	189	22	12
2-4	301	23	8
4-6	188	15	8
6-8	121	22	19
8-10	56	15	27

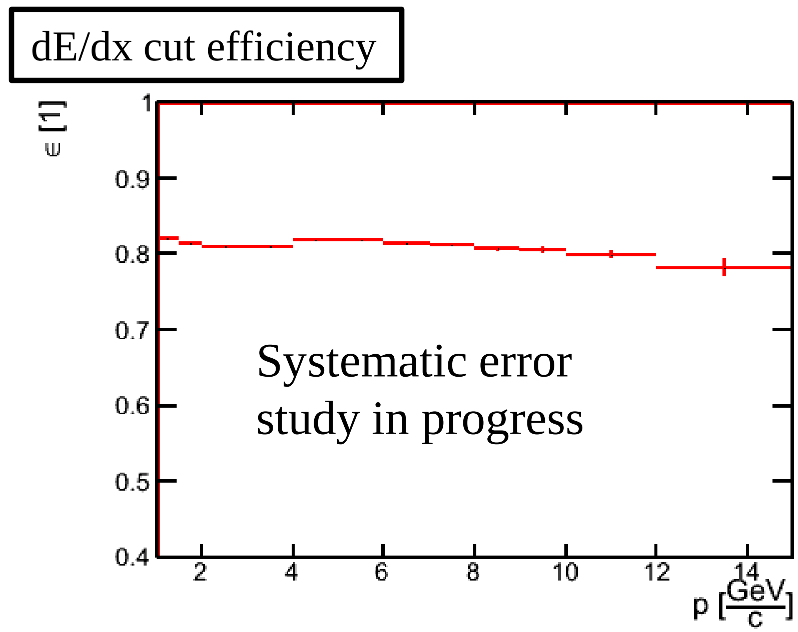
	1S		
p_T[GeV]	Yield	Uncertainty	Uncertainty %
0-2	155	18	12
2-4	229	18	8
4-6	159	13	9
6-8	90	16	18
8-10	32.9	8.4	26

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

dE/dx cut efficiency



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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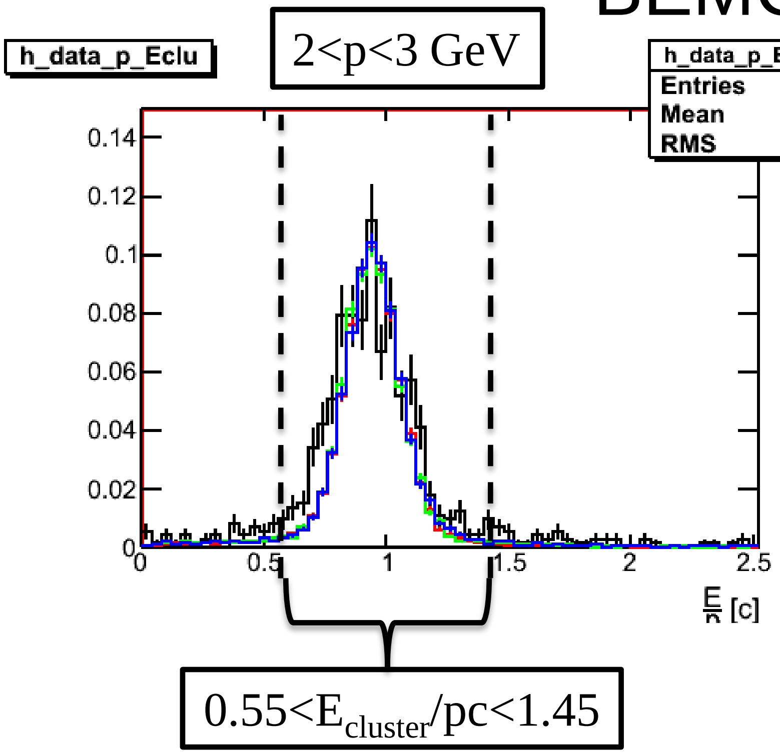
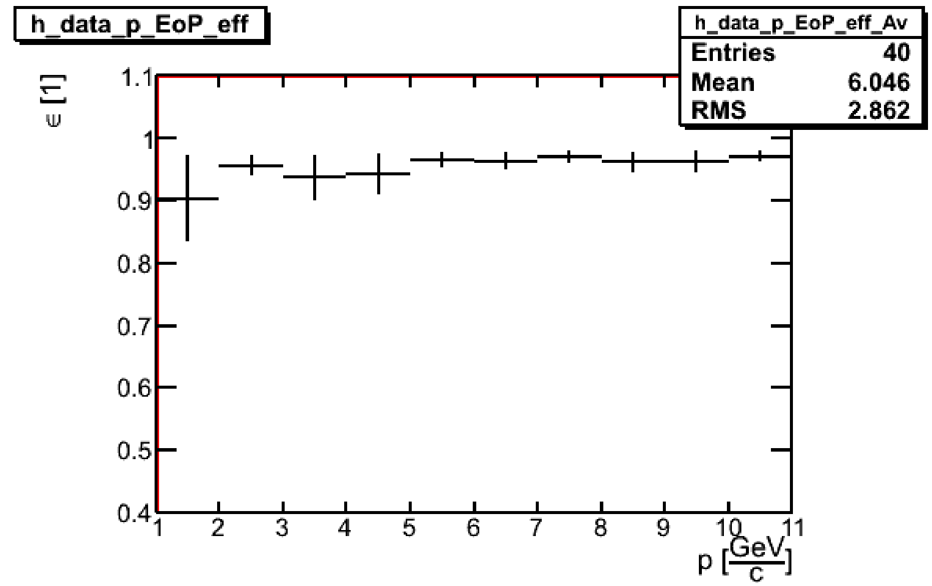
BEMC E/p efficiency

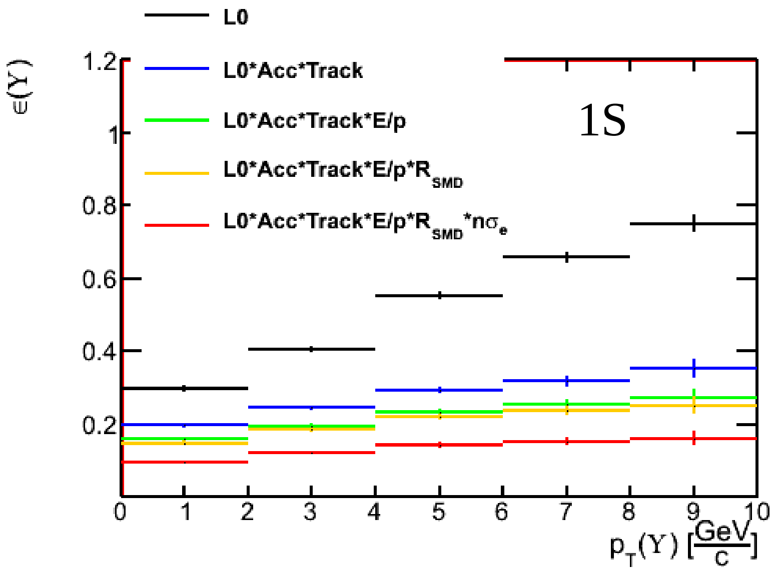


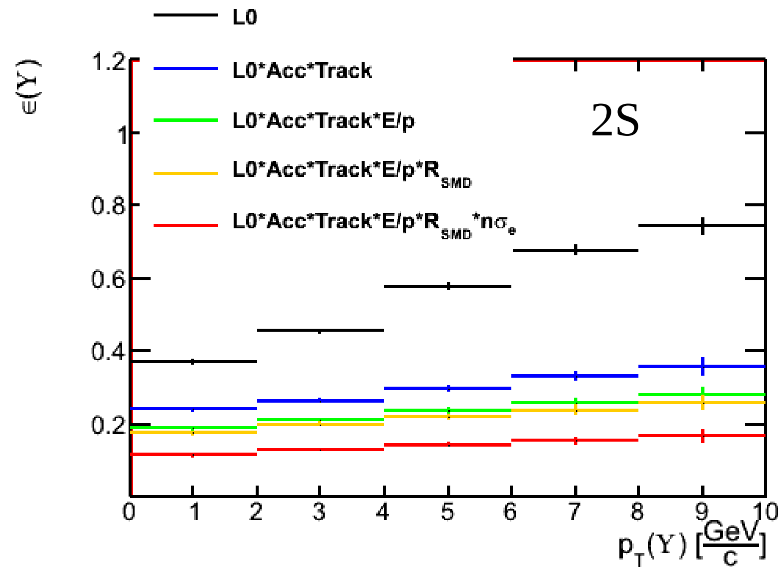


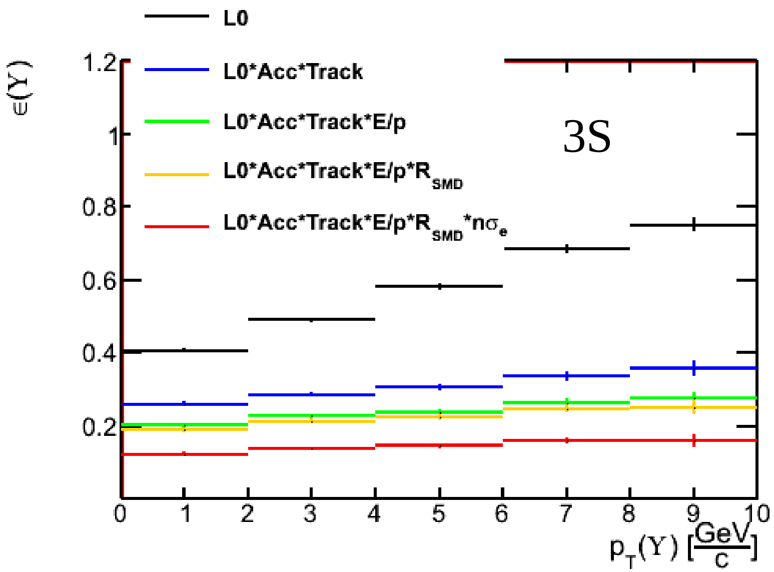
Compared E_{clu}/p distribution from MC simulation and data

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

Upsilon efficiencies from simulation



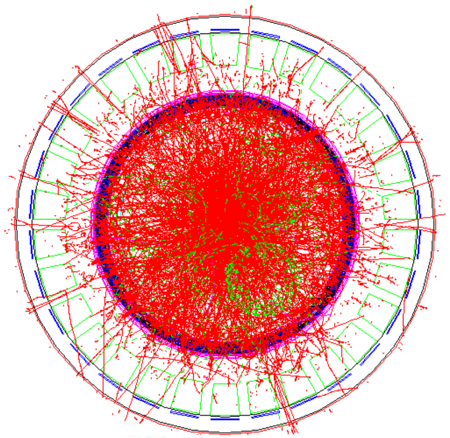


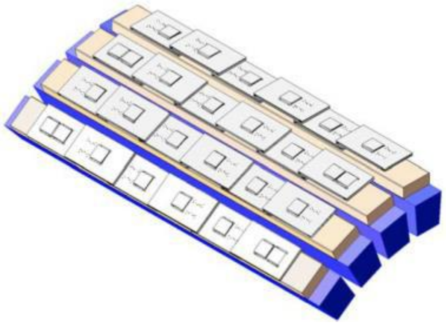


Upsilon reconstruction efficiency includes:
- L0 trigger efficiency
- Acceptance and tracking efficiency
- BEMC efficiencies
- dE/dx cut efficiency

Small differences between ϒ(1S), ϒ(2S) and ϒ(3S) (due to kinematics)

Muon Telescope Detector



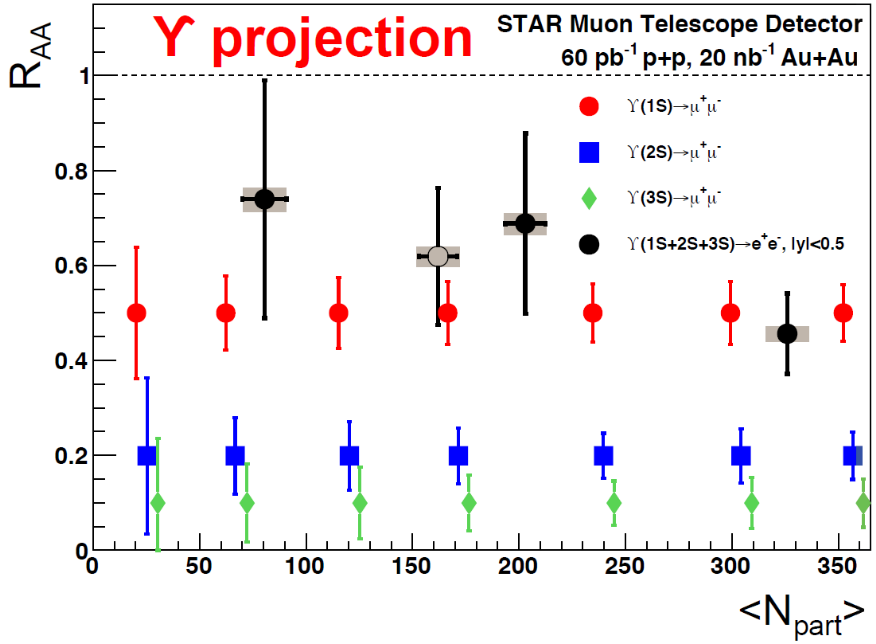


•Multi-gap Resistive Plate Chamber (MRPC) - gas detector outside STAR magnet

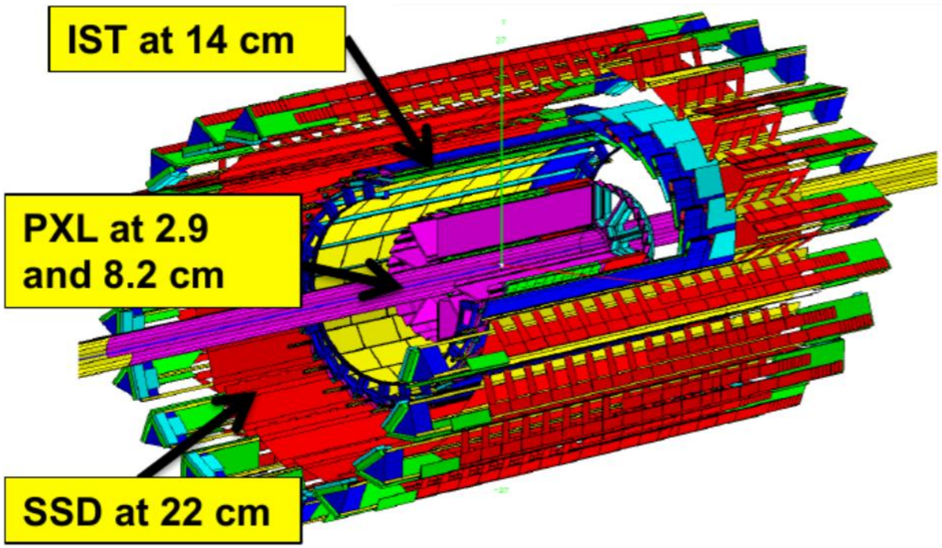
•Allows precision measurements of heavy quarkonia in dimuon channel (no γ conversions, less bremsstrahlung than e and less dalitz decays)

•Complete in 2014, sampled ~13.8 nb^{-1} in Au+Au data

Acceptance:
45% in φ
|η|<0.5



Heavy Flavor Tracker

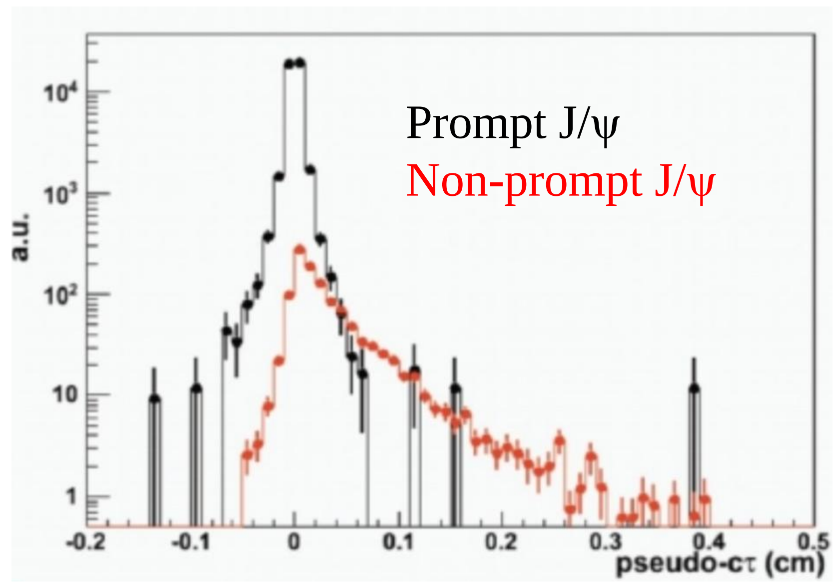


- State-of-the-art silicon tracker for heavy flavor studies
- Allows direct reconstruction of secondary vertices from D and B meson decays
- Fully installed in 2014, recorded ~1 billion Au+Au events

B measurement through non-prompt J/ψ:

$$B \to J/\psi + X \to e^+e^- + X$$

May provide direct $b\bar{b}$ cross section measurements



Summary

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

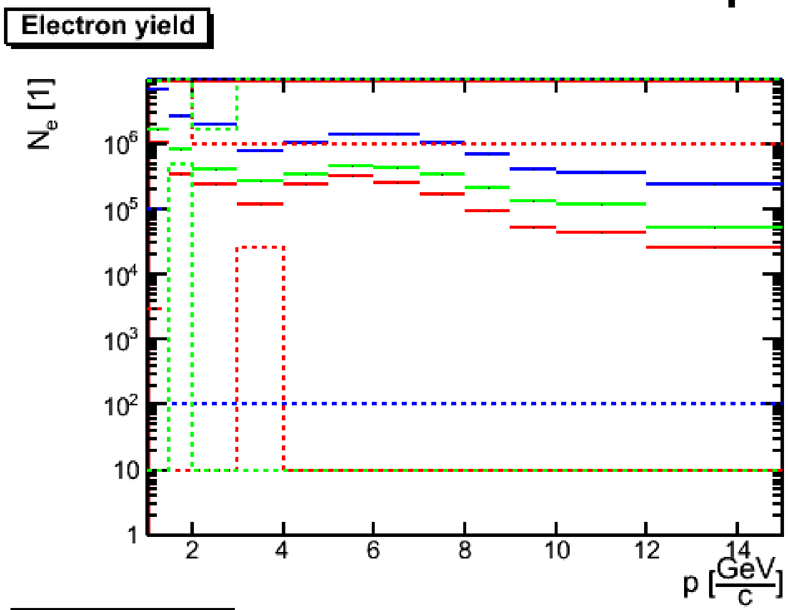
- Data can be divided into 5 p_T bins from 0-10 GeV/c

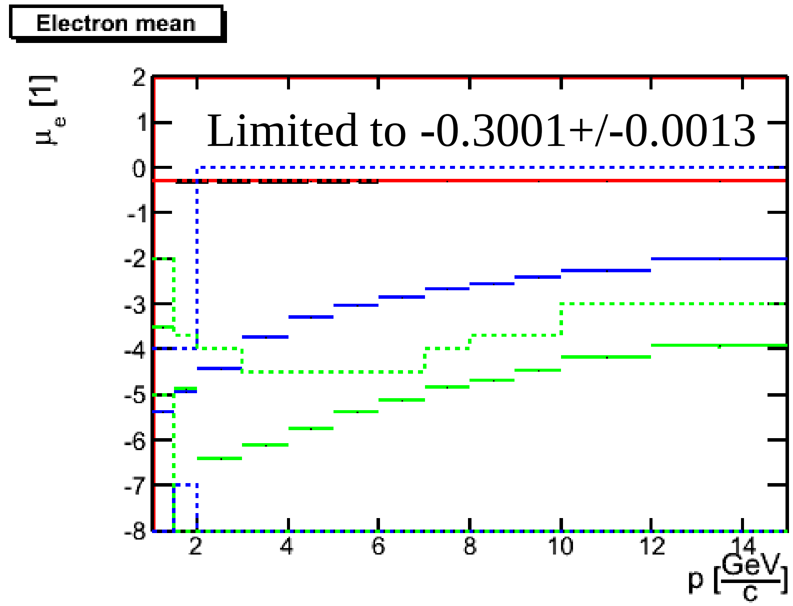
- With current data (L_{int} = 21.5 pb^{-1}), we can expect p_T spectrum for Upsilon 1S and combined states with statistical uncertainty< 20% for p_T up to 8 GeV/c

- Stay tuned for upcoming results!!

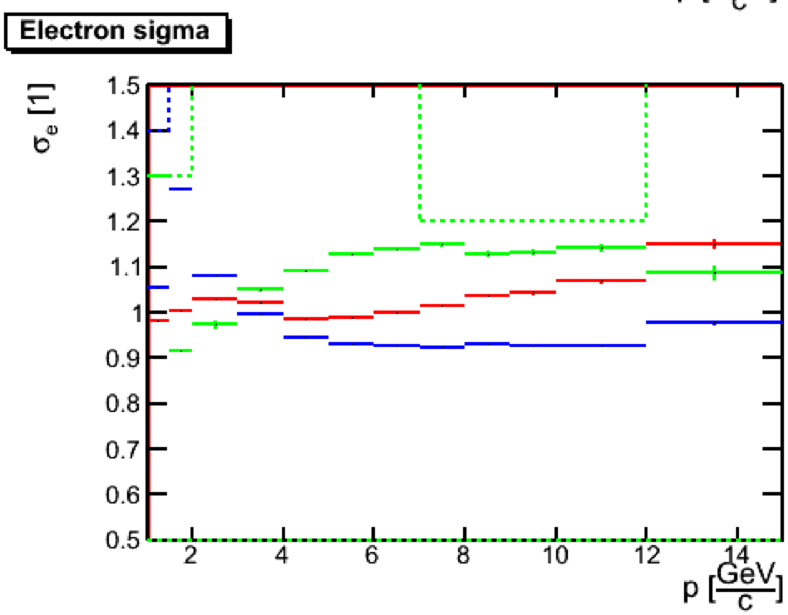
BACKUP

parameters





e
π
p
all

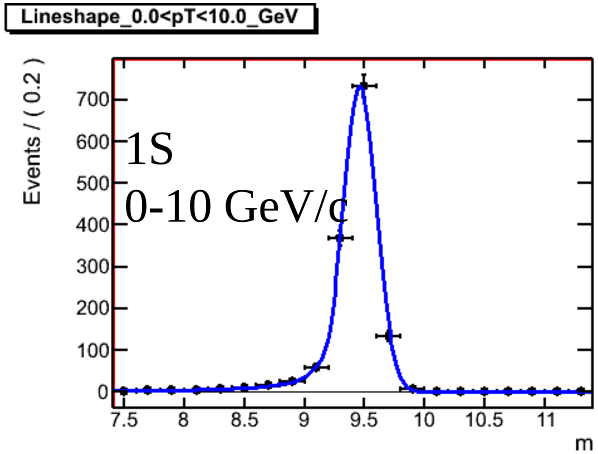


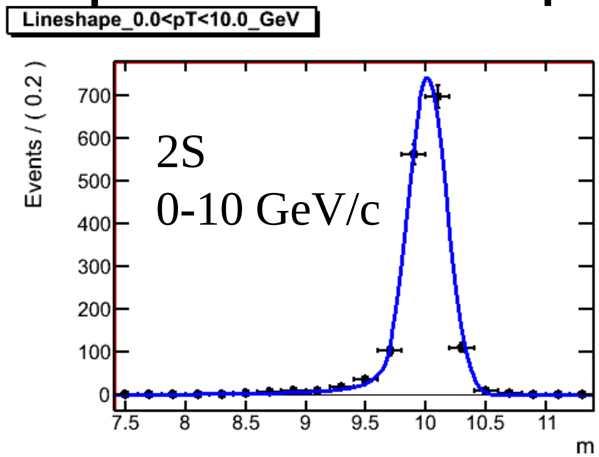
Smooth dependence => good

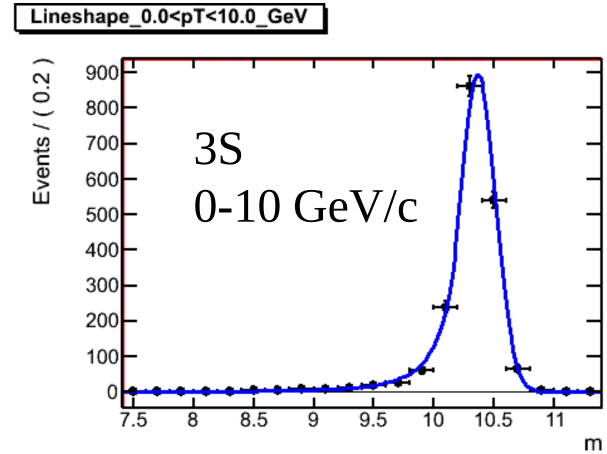
Set limit for electron mean based on straight line fit in 1.5-6 GeV: -0.3001+/-0.0013

Very little constraints (dotted lines)

Upsilon lineshapes







Crystall Ball function:

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

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

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

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

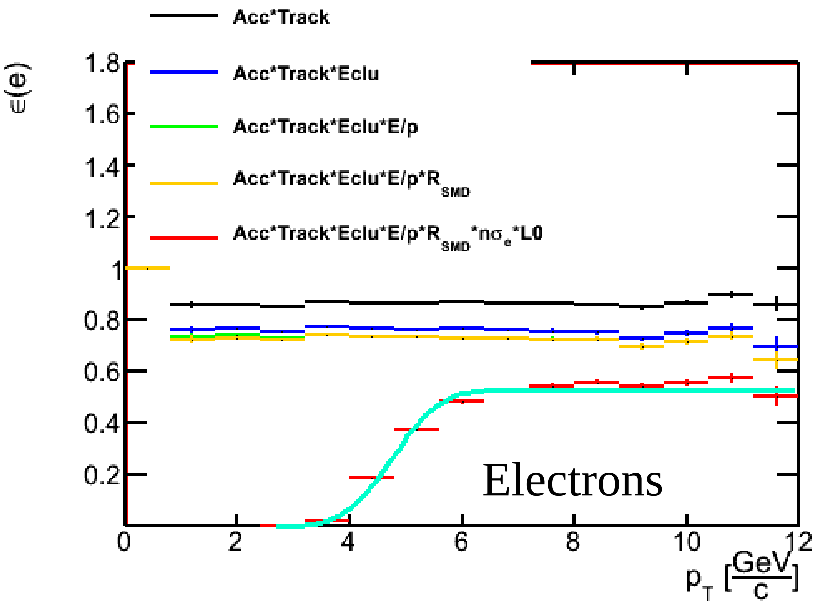
$$B=\frac{n}{|\alpha|}-|\alpha|$$

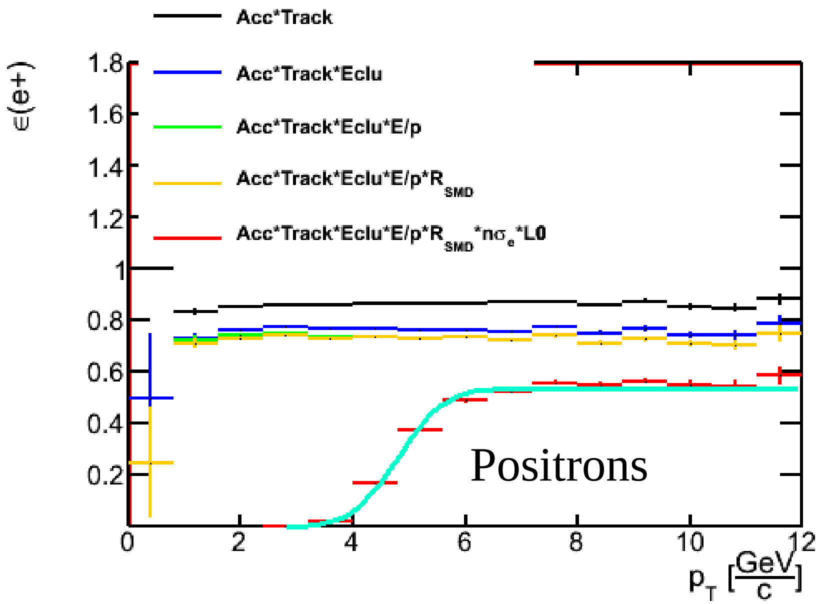
$$D=\sqrt{\frac{\pi}{2}}\cdot\left(1+erf\left(\frac{|\alpha|^2}{\sqrt{2}}\right)\right)$$

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

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

Electron efficiencies from simulation





Fit (teal):
A = 0.2662 +/- 0.0022
B = 4.752 +/- 0.018
C = 0.952 +/- 0.022

Fit function:

$$A \cdot Erf\left(\frac{p_T - B}{C} + 1\right)$$

Fit (teal):
A = 0.2687 +/- 0.0022
B = 4.798 +/- 0.018
C = 0.944 +/- 0.022