Υ production at the STAR experiment

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Outline

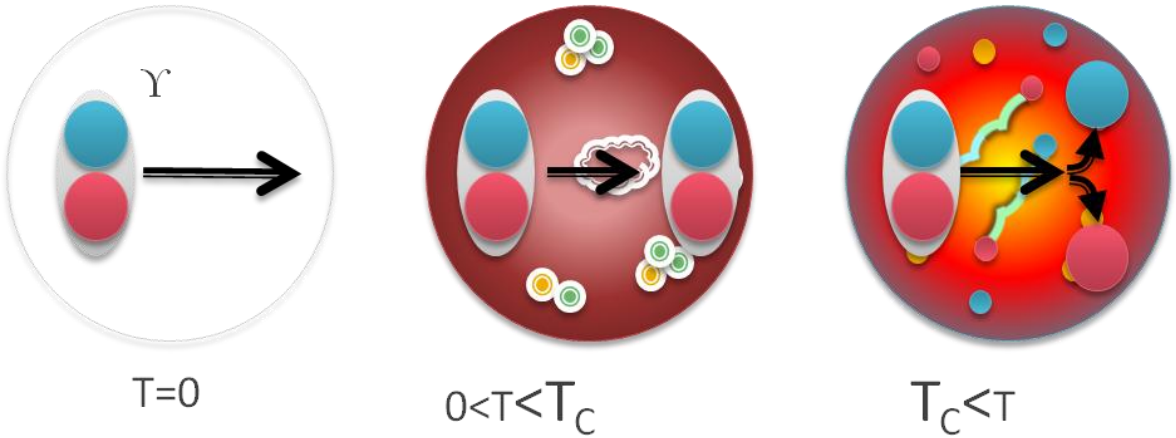
- Motivation: QGP and quarkonia
- The STAR experiment at RHIC
- Baseline: Υ production in p+p
- Cold nuclear effects: Υ production in d+Au
- Υ Nuclear Modification Factor in Au+Au
- Outlook
- Conclusions

Quarkonia as a probe of QGP

- Large masses of c, b quarks
  - created during initial stages of collision
  - calculable by pQCD

Quarkonia family:
c-$\bar{c}$: J/ψ, ψ′, χc …
b-$\bar{b}$: ϒ(1S), ϒ(2S), ϒ(3S) …

- Due to color screening of quark potential in QGP quarkonium dissociation is expected

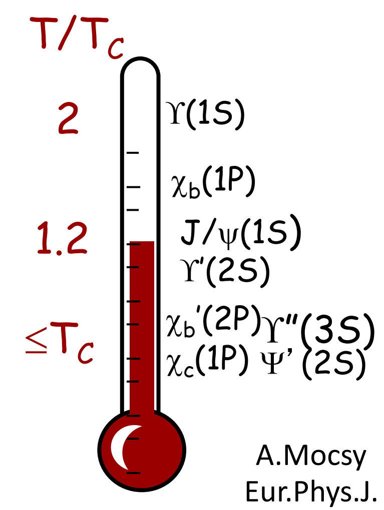


H. Satz, Nucl. Phys. A (783):249-260(2007)

Quarkonia as a probe of QGP

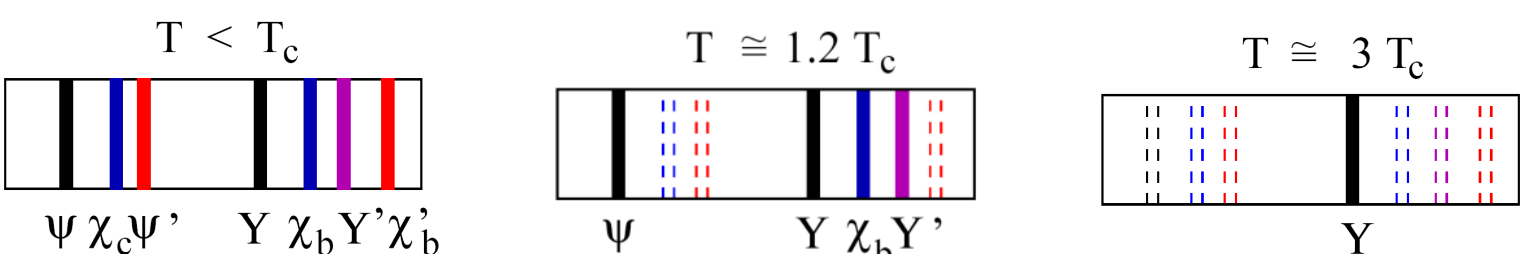
- Large masses of c, b quarks
  - created during initial stages of collision
  - calculable by pQCD
- Due to color screening of quark potential in QGP quarkonium dissociation is expected
- **Sequential suppression of different states is determined by medium temperature and their binding energy**
  - **QGP thermometer**

Quarkonia family:
c-$\bar{c}$: J/ψ, ψ′, χc ...
b-$\bar{b}$: ϒ(1S), ϒ(2S), ϒ(3S) ...



A.Mocsy Eur.Phys.J. C61:

$$T_{diss}(\psi') \approx T_{diss}(\chi_c) < T_{diss}(\Upsilon(3S)) < T_{diss}(J/\psi) \approx T_{diss}(\Upsilon(2S)) < T_{diss}(\Upsilon(1S))$$



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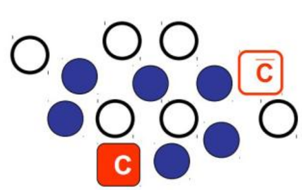
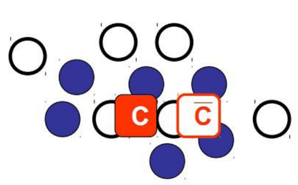
Other effects-complications

- Quarkonium production mechanism is not well understood.
  - Color-singlet vs. Color-octet?
- Observed yields are a mixture of direct production + feed down
  - E.g. $J/\psi \sim 0.6\ J/\psi$ (Direct) $+ \sim 0.3\ \chi_c + \sim 0.1\psi'$
- Suppression and enhancement in the “cold” nuclear medium
  - Nuclear absorption, Gluon shadowing, initial state energy loss, Cronin effect and gluon saturation.
- Hot/dense medium effects
  - Recombination from uncorrelated charm pairs.





Common approach - R_{AA}

- baseline - p+p: test of pQCD
- "normal" suppression - d+Au

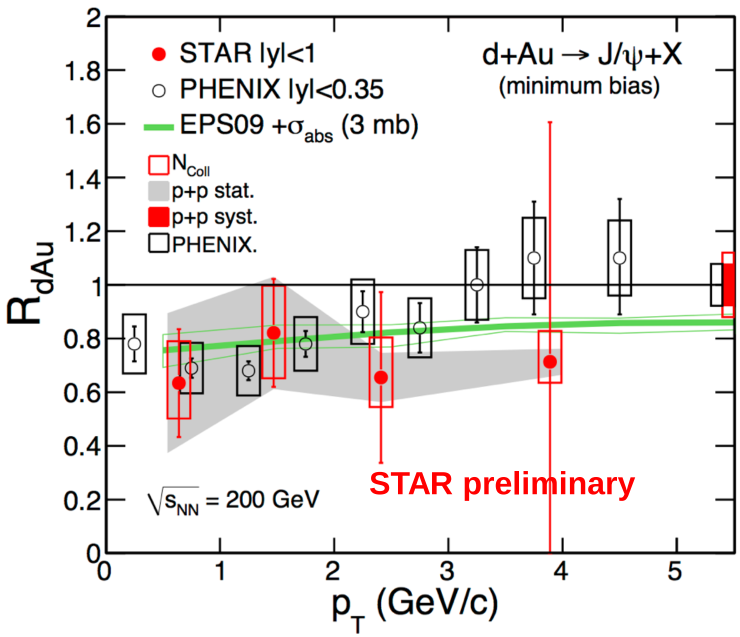
$$R_{dAu} = \frac{1}{\langle N_{coll} \rangle} \frac{dN/dy^{dAu}}{dN/dy^{pp}}$$

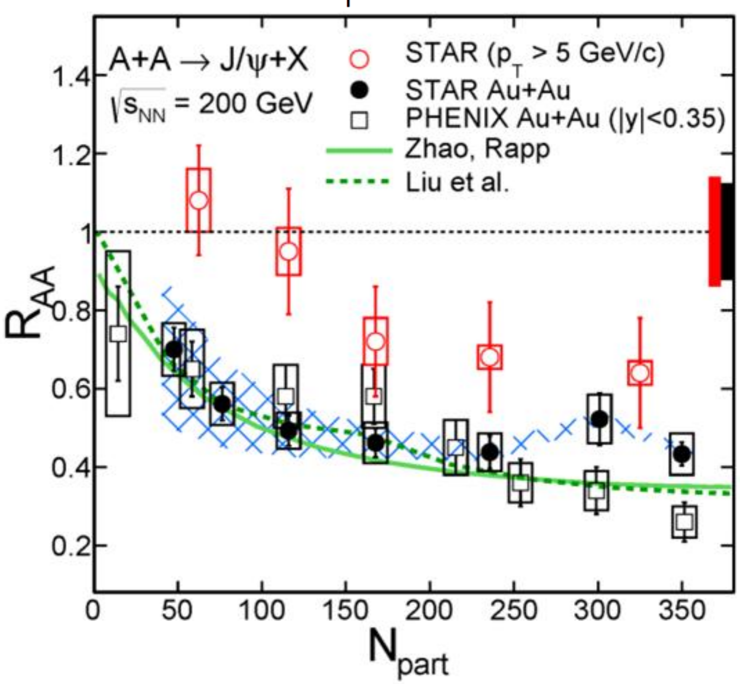
- "anomalous" suppression - Au+Au

$$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \frac{dN/dy^{AuAu}}{dN/dy^{pp}}$$

R_{AA} = 1 if no modification of the production in the medium.

Message from J/ψ at 200 GeV





- Cold nuclear effects important for interpreting Au+Au results.
- R_{dAu} consistent with model calculations
  - shadowing from EPS09 nPDF
  - nuclear absorption: $\sigma_{abs}^{J/\psi} = 2.8mb$
- J/ψ suppression increases with collision centrality and decreases with p_T
- Data agrees with models including color screening and regeneration
  - Liu et al., PLB 678:72 (2009)
  - Zhao et al., PRC 82,064905(2010)

STAR high-p T : Phys. Lett. B 722 (2013) 55
STAR low-p T : arxiv:1310.3563
PHENIX: Phys. Rev. Lett. 98 (2007) 232301

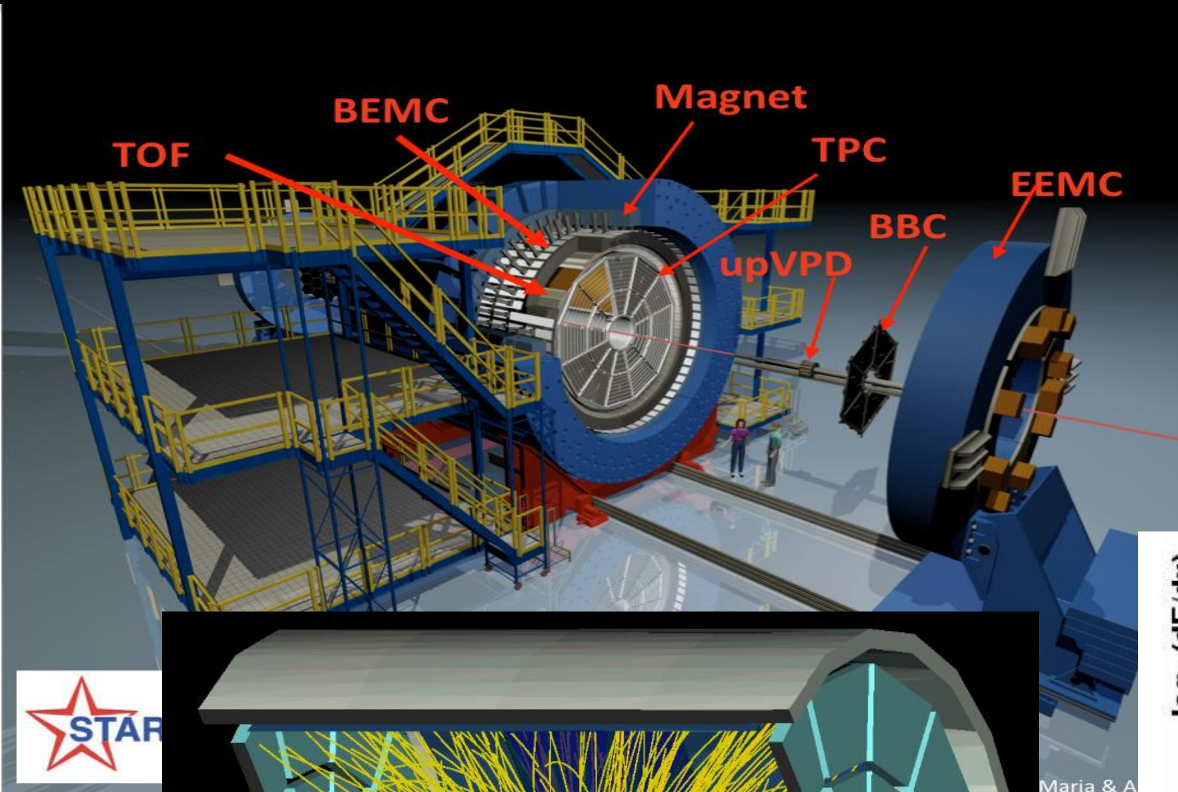
Upsilon measurements

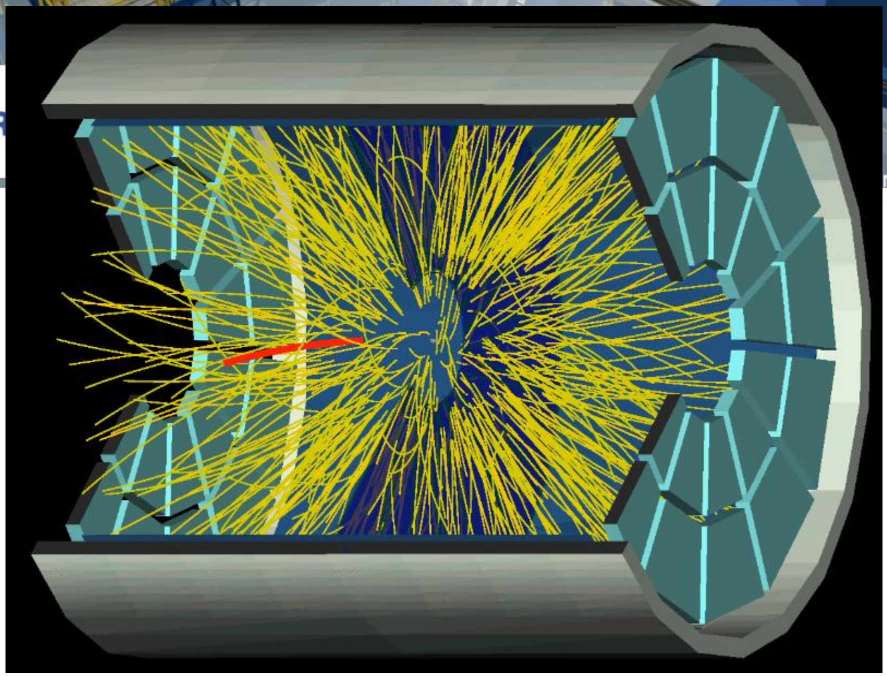
Υ-cleaner probe compared to J/ψ

- Less feed down
- Co-mover absorption $\longrightarrow$ negligible
  - Υ(1s): tightly bound, larger kinematic threshold.
  - Expect σ~ 0.2 mb, 5-10 times smaller than for J/ψ

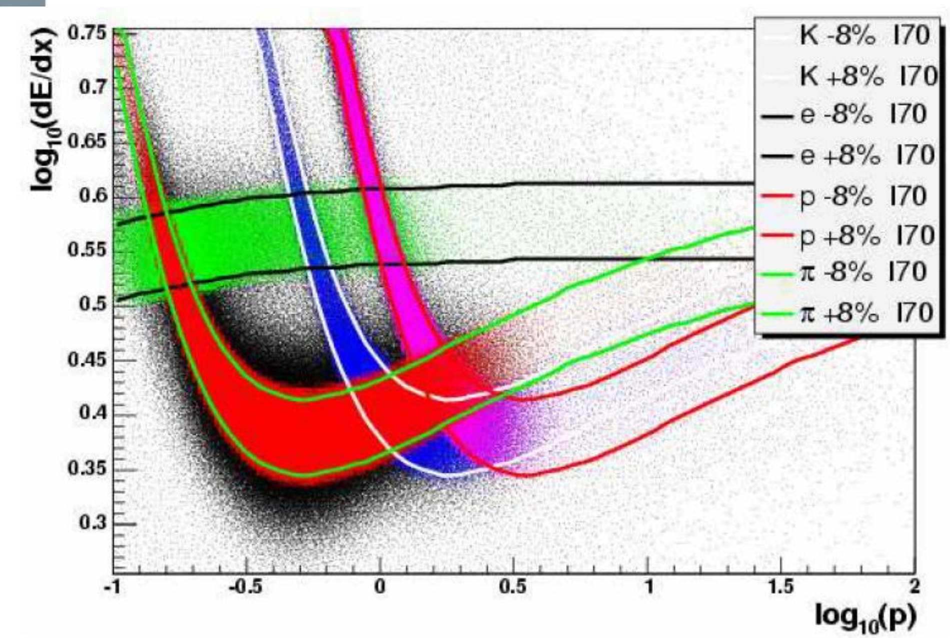
    Lin & Ko, PLB 503 (2001) 104
- Recombination $\longrightarrow$ negligible
  - at RHIC: σ_{cc} ~800μb >> σ_{bb} ~(1-2)μb
- Excited states: expect sequential suppression of Υ(1s), Υ(2s), Υ(2s) states
- Challenge: low rate, rare probe
  - Need large acceptance, efficient trigger
  - STAR upgrades

STAR experiment



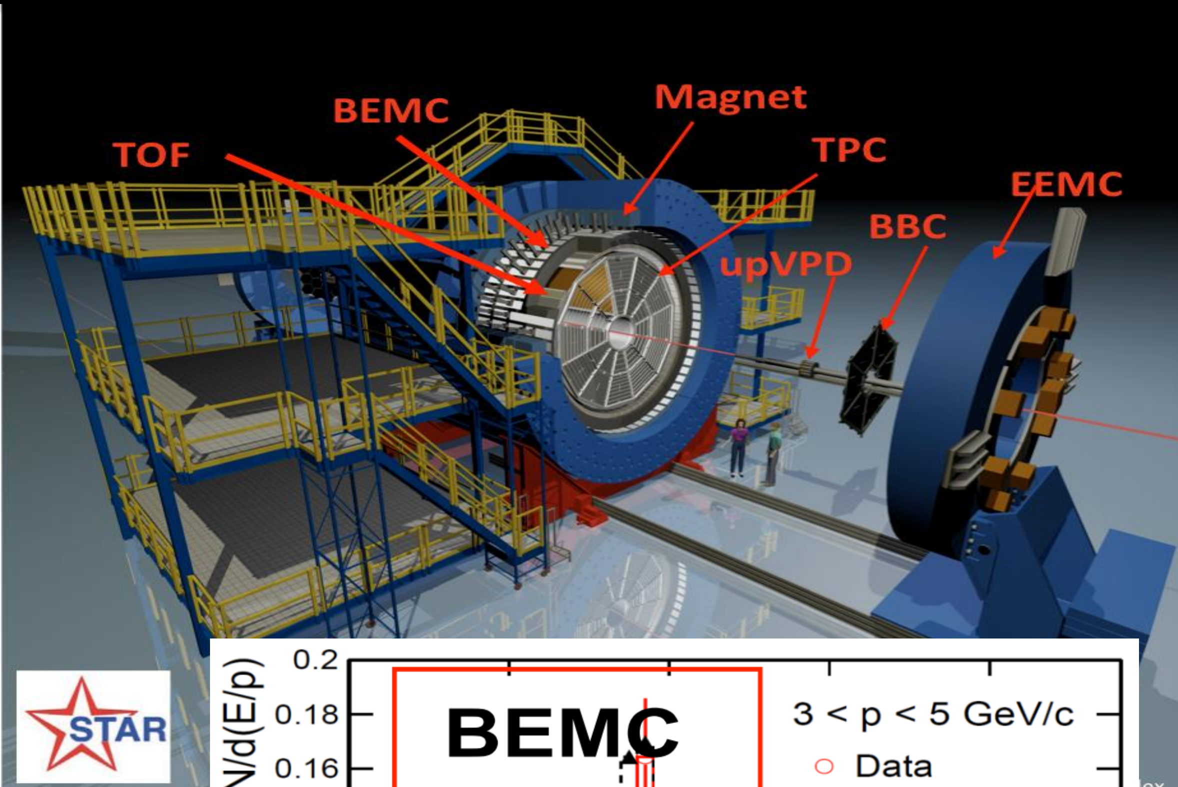


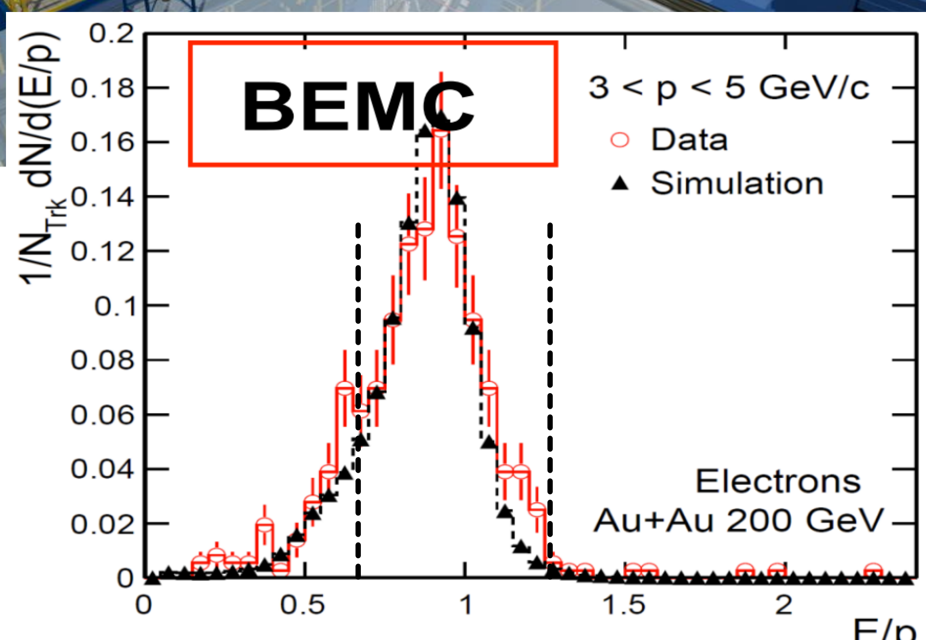
- Large acceptance electron ID
- **Time Projection Chamber (TPC):**
  - charged particle tracking, 2π coverage in $|\eta|<1.3$
  - dE/dx PID



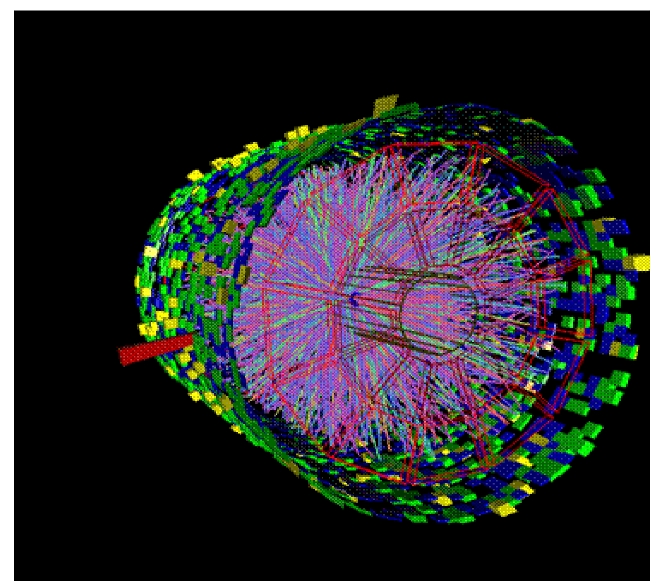
Nucl. Instrum. Meth. A **558** (2006) 419

STAR experiment

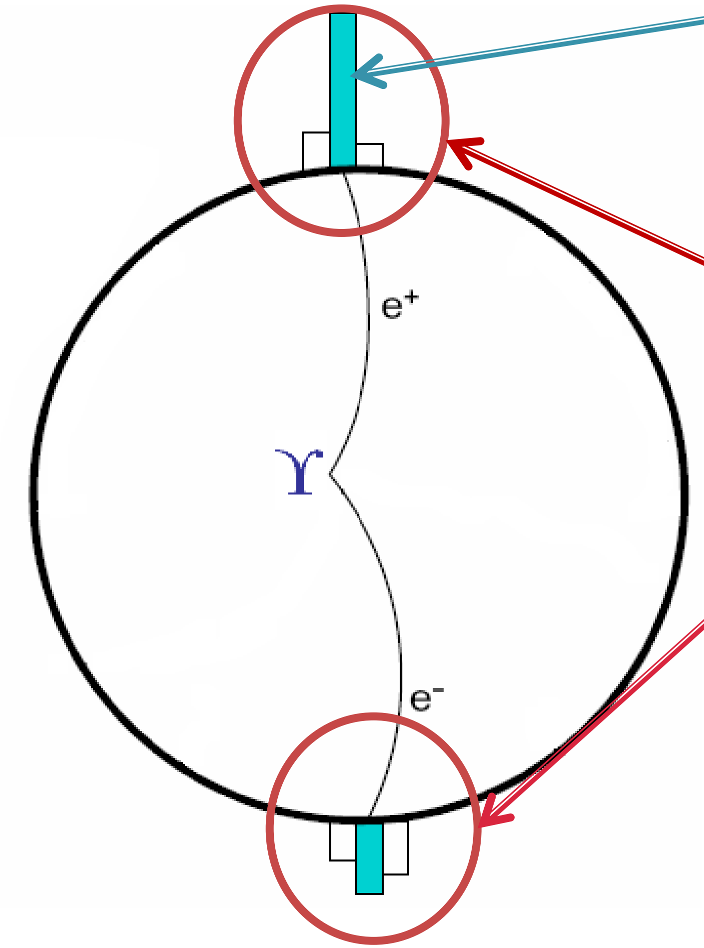




- Large acceptance electron ID
- **Time Projection Chamber (TPC):**
  - charged particle tracking, 2π coverage in $|\eta|<1.3$
  - dE/dx PID
- **EM Calorimeter**
  - 2π coverage in $|\eta|<1$
  - Electron ID via E/p ~ 1
  - Triggering capability



Triggering on Υ->e⁺e⁻ decays



- Level 0 Trigger (p+p,d+Au,Au+Au):
  - Hardware-based
  - Fires on at least one high tower
- Level 2 Trigger (p+p,d+Au):
  - Software-based
  - Calculates:
    - Cluster energies
    - Opening angle
    - Mass
  - Decision in ~5 ms for slow detectors to keep / abort data

High Rejection (~10^5 in p+p) allowed to sample full luminosity.

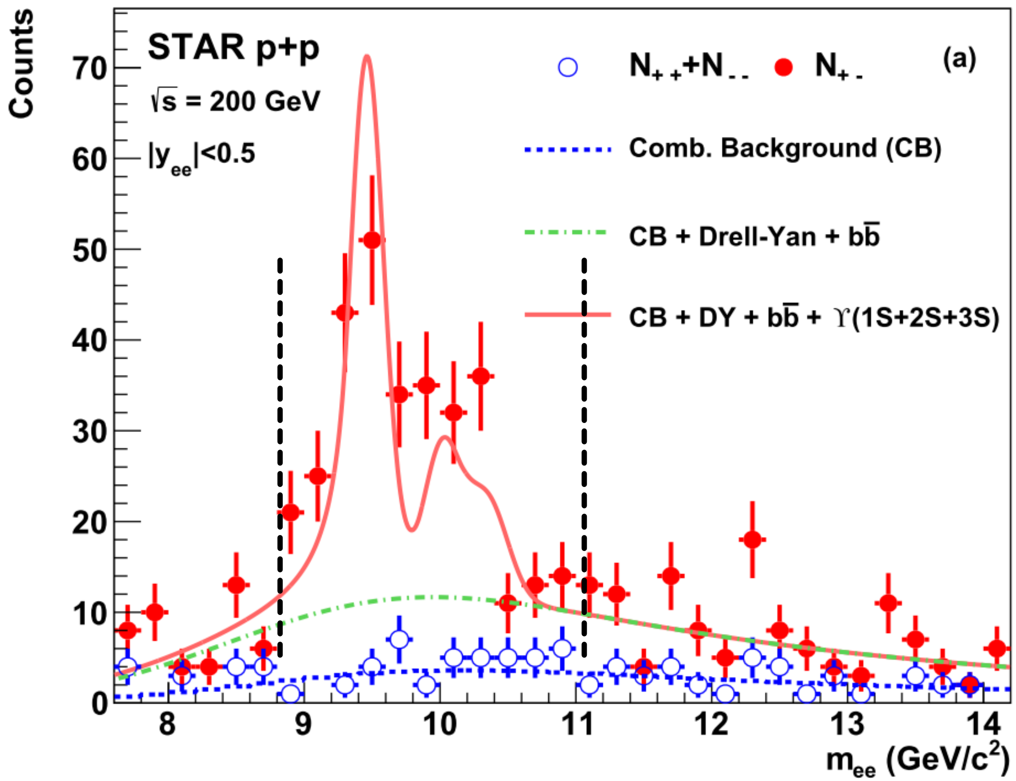
Υ in p+p 200 GeV from STAR

2009, $\int L\,dt = 20.0\ pb^{-1}$

arXiv:1312.3675

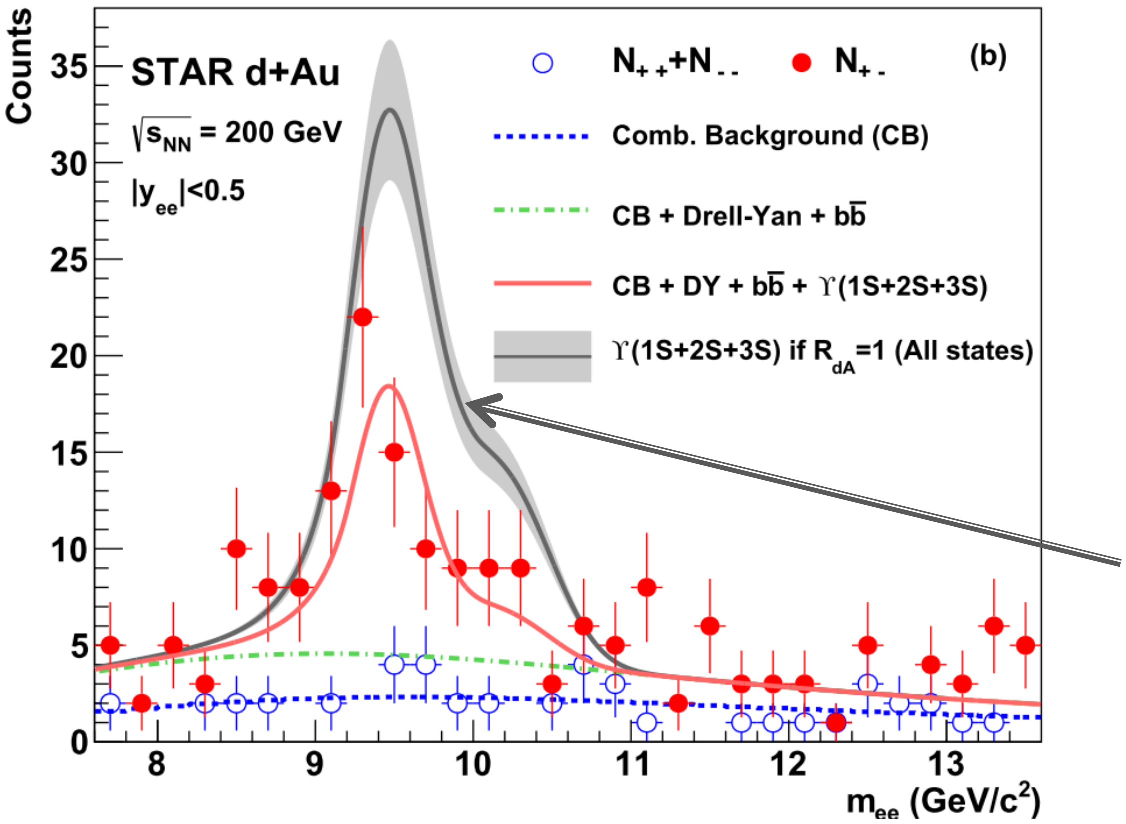
Signal extraction:

- Extracted signal for $\Upsilon(1S+2S+3S)$ and $\Upsilon(1s)$
- Two rapidity regions $|y|<0.5$, $0.5<|y|<1$
- Common fit to unlike and like-sign pairs
- Crystal-ball for Υ signals
  - momentum resolution + energy losses
- Background
  - Drell –Yan from NLO pQCD (R. Vogt)
  - $b\bar{b}$ - PYTHIA
- Fit used for background subtraction only



$$B_{ee} \times \left.\frac{d\sigma}{dy}^{\Upsilon(1S+2S+3S)}\right|_{|y|<1} = 85 \pm 9^{+18}_{-16}\,\mathrm{pb}$$

Υ in d+Au 200 GeV from STAR

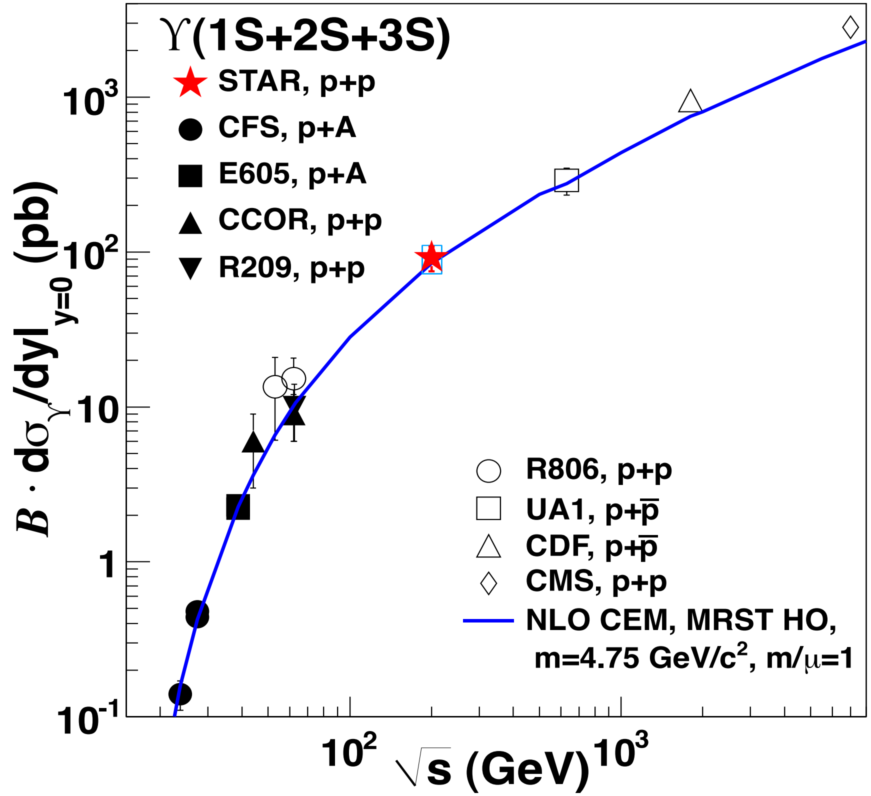


2008, $\int L\, dt = 28.2\ nb^{-1}$

- Separate yield extraction
  - For |y|<0.5 , -1<y<-0.5, 0.5<y< 1
  - For Υ(1s) and Υ(1S+2S+3S)
- Observed suppression with respect to binary-collision scaling

$$B_{ee} \times \left.\frac{d\sigma}{dy}^{\Upsilon(1S+2S+3S)}\right|_{|y|<1} = 22 \pm 3^{+4}_{-3}\,\mathrm{nb}$$

Comparison to NLO pQCD

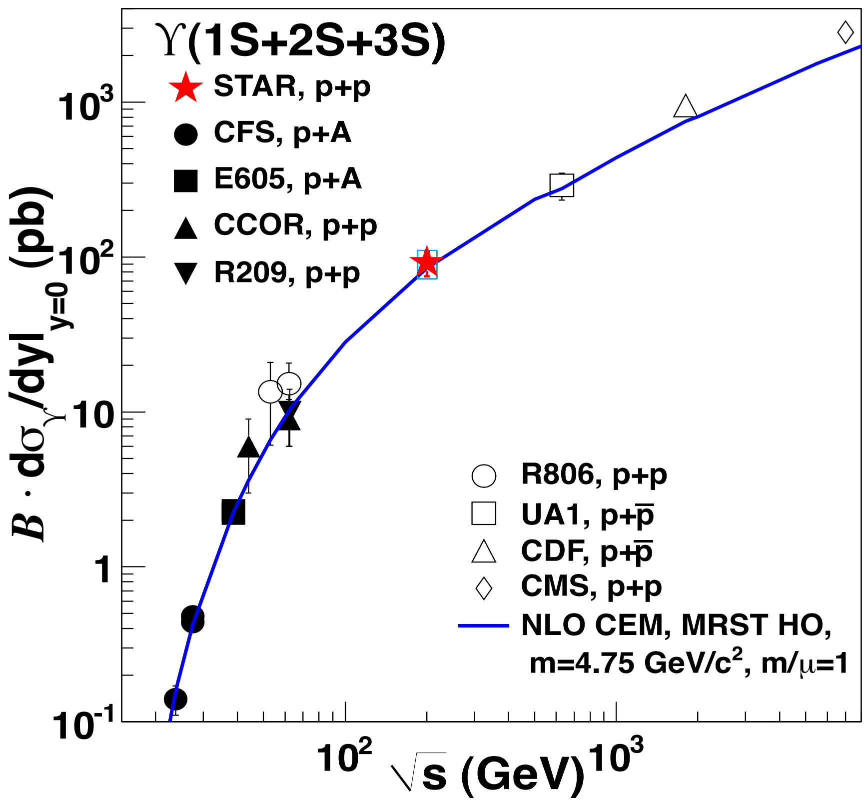


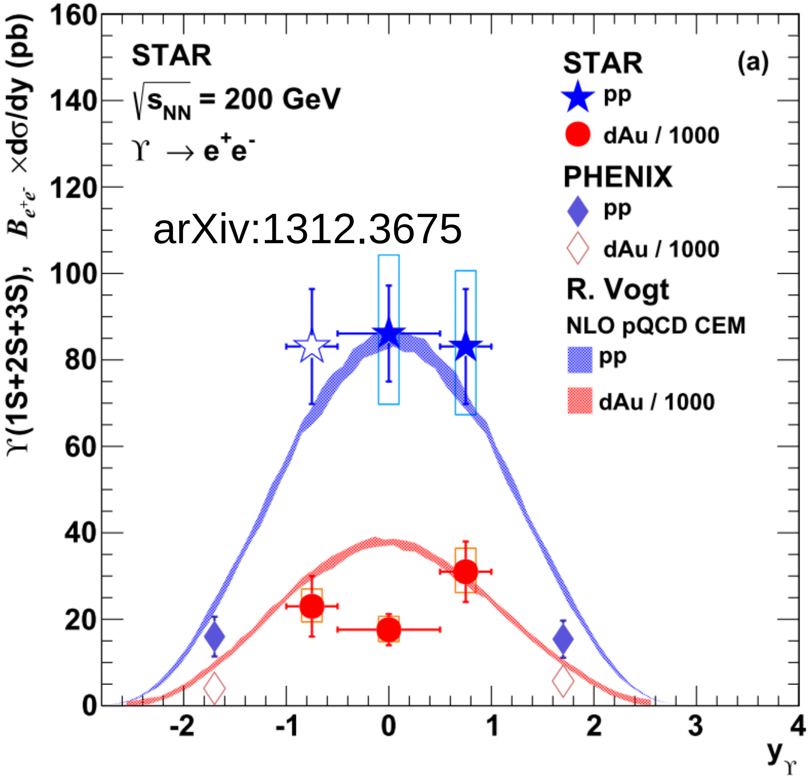
Υ(1S+2S+3S) $\rightarrow e^+e^-$ cross section:

- Agreement with world data trend

R. Vogt, Phys. Rep. 462125, 2008

Comparison to NLO pQCD



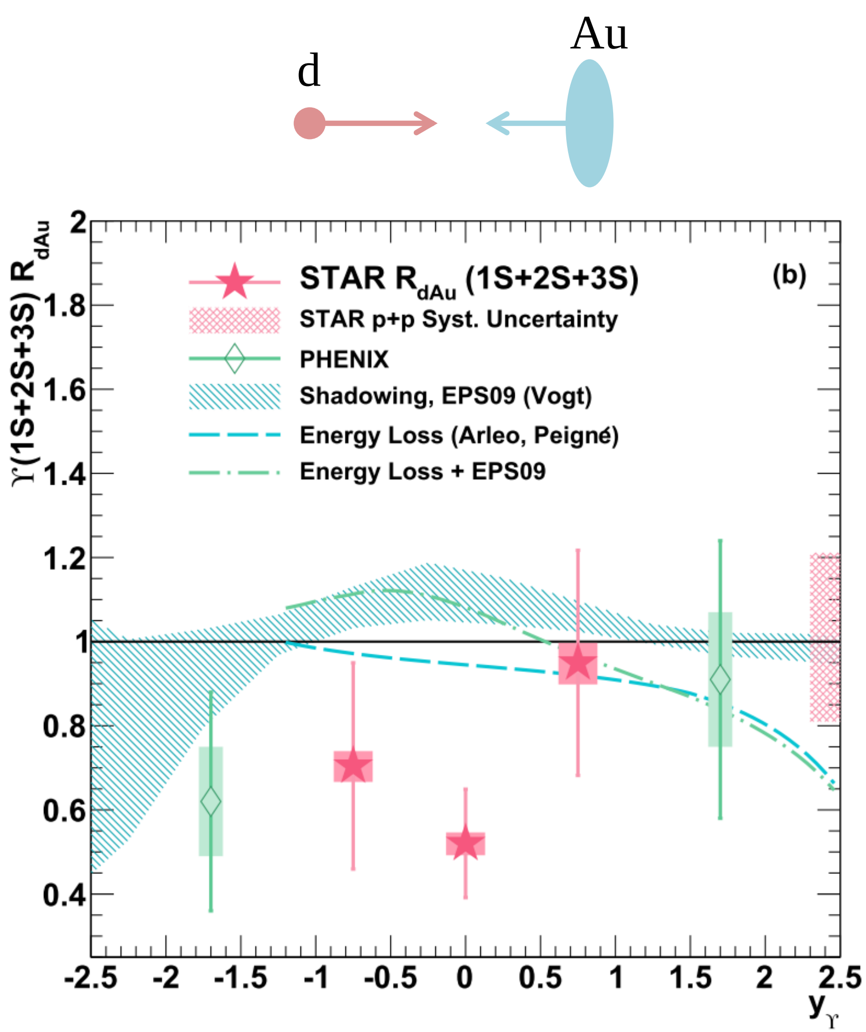


ϒ(1S+2S+3S) →e^+e^- cross section:

- Agreement with world data trend
- Consistent with pQCD Color Evaporation Model (CEM)
  - except for mid-rapidity d+Au
  - shadowing included for d+Au

R. Vogt, Phys. Rep. 462125, 2008

R_{dAu} and model comparison

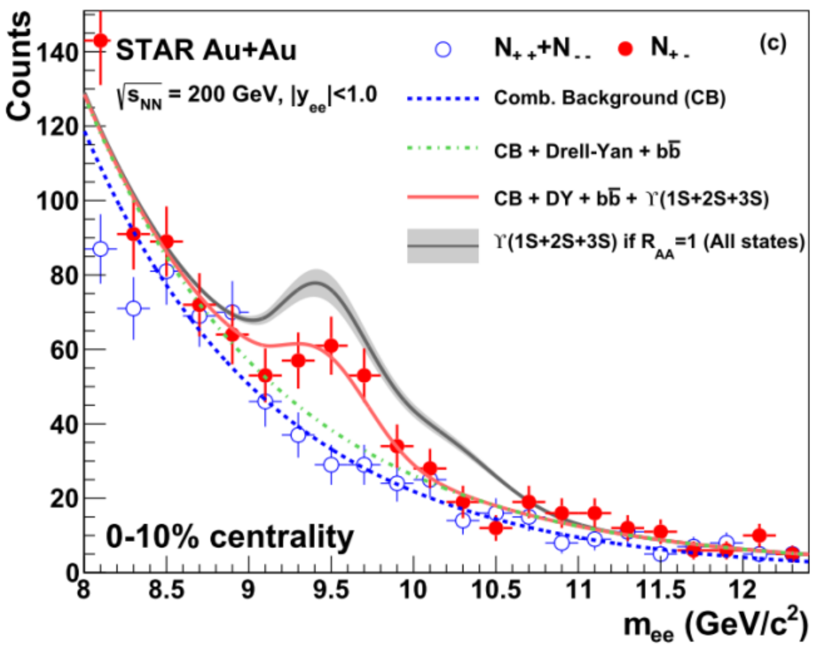


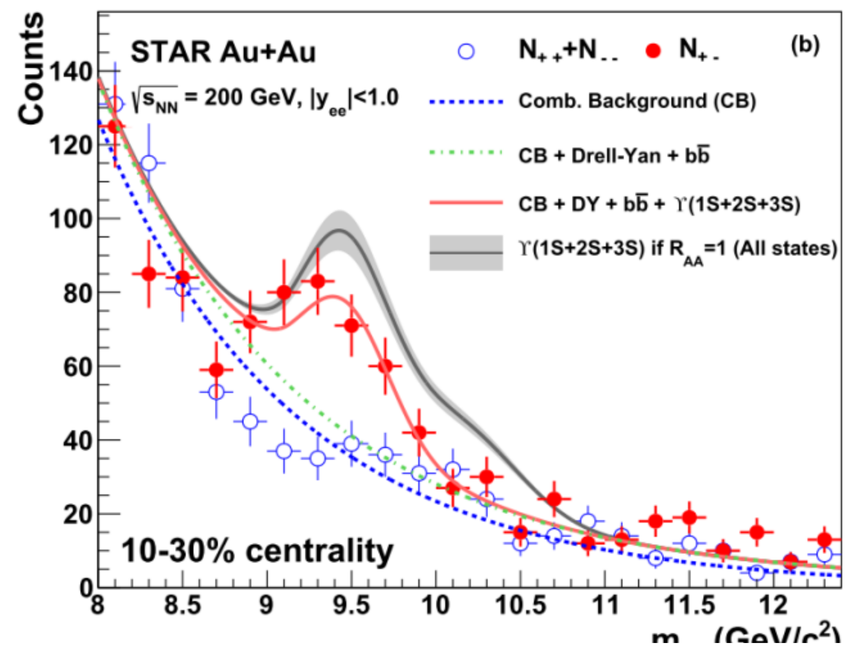
arXiv:1312.3675

Arleo F., Peigne , JHEP 1303 (2013) 122
arXiv:1212.0434

- Comparison to CEM calculations
  - Shadowing/Antishadowing of gluon nPDF
  - Initial parton energy loss
  - No absorption
- CNM effect
  - Models expect slight enhancement at mid-rapidity.
  - Data indicate suppression in CNM beyond these effects.

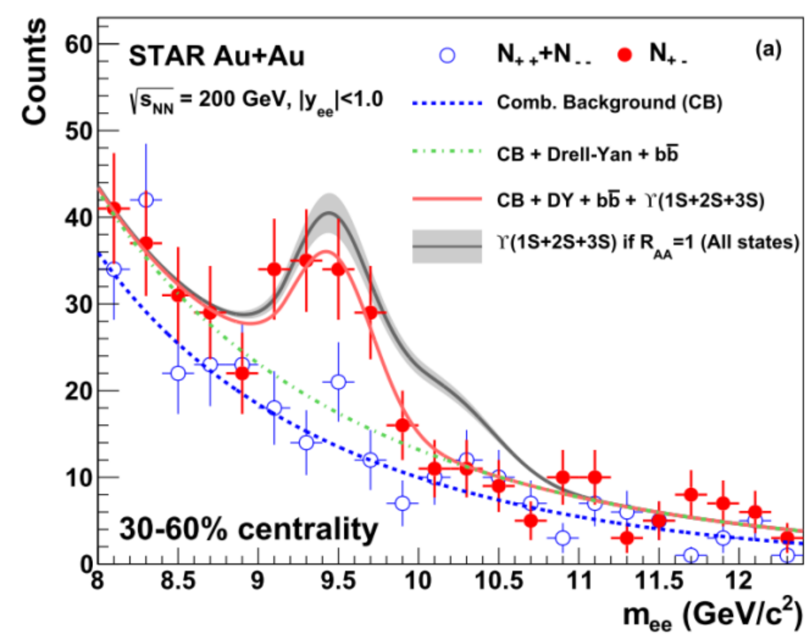
ϒ in Au+Au 200 GeV





2010, $\int L\, dt$ = 1.08 nb^{-1}

- Three centrality bins
- Separate yield extraction
  - For |y|<0.5 and |y|<1
  - For ϒ(1s) and ϒ(1S+2S+3S)
- Observed suppression compared to expectations from binary-collision scaling

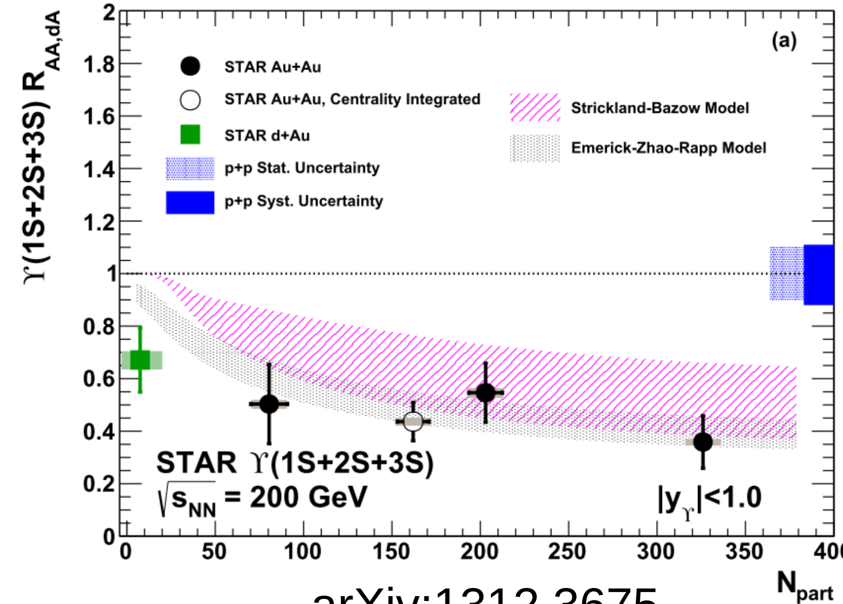


Au+Au 200 GeV: R_{AA}

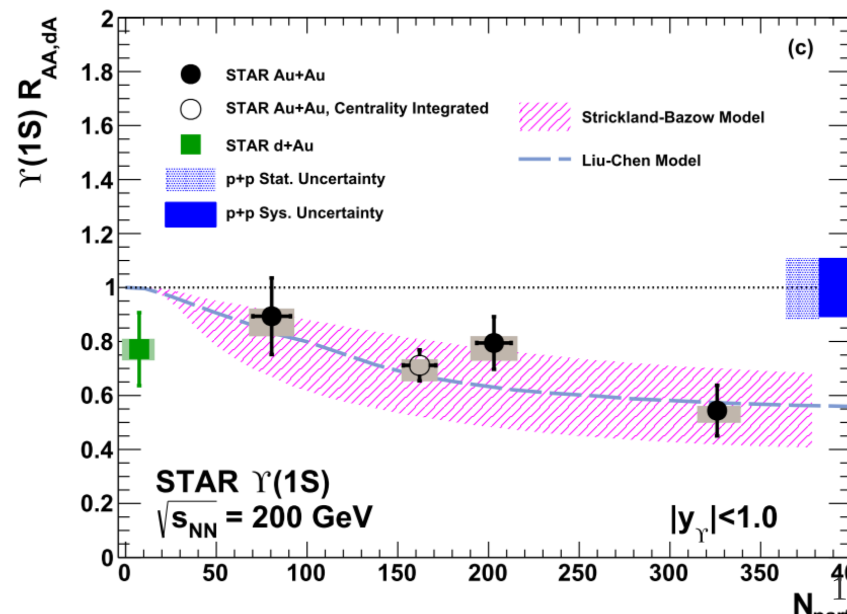
Suppression of Υ production in central Au+Au observed.

Comparison to dynamical models with feed down:

- Strickland et al., NP A 879 (2012) 25
  - anisotropic hydrodynamics
  - initial a T_o in the range of 428-442 MeV
  - No CNM effects
  - Results are consistent with complete 2S and 3S suppression
- Rapp et al., EPJ A 48 (2012) 72
  - Kinetic model
  - CNM effects – absorption σ=3mb.
  - T_o = 330 MeV
- Liu et al., Phys. Lett B 697 (2011) 32
  - Initial T_o = 340 MeV
  - Dissociation of higher states
  - No CNM effects



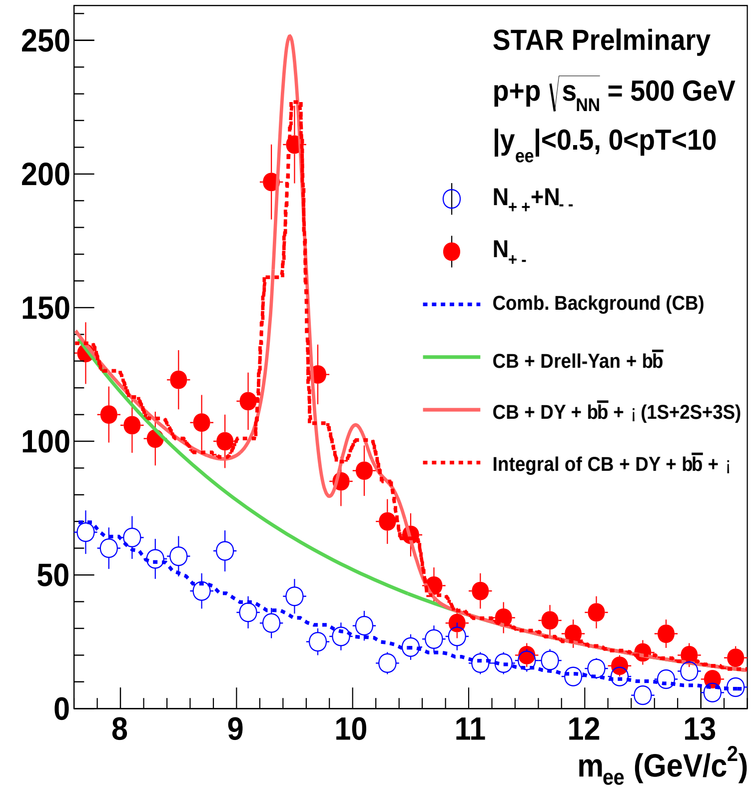
arXiv:1312.3675



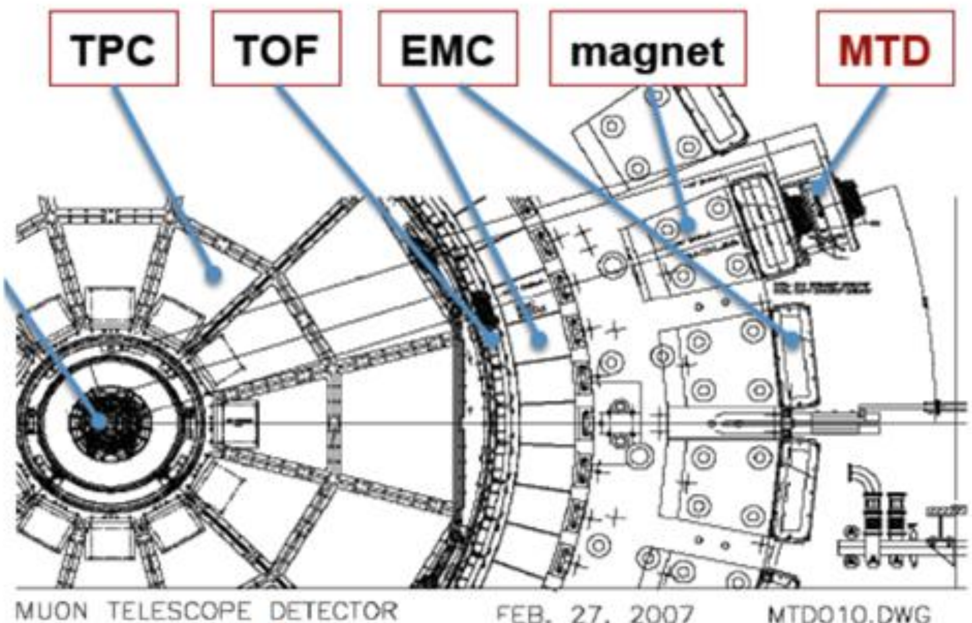
Outlook

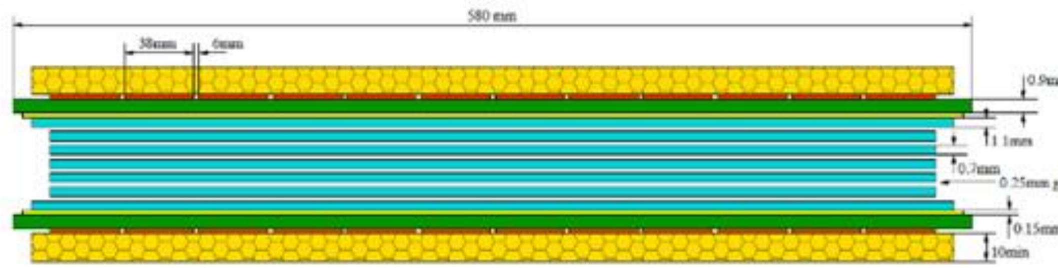
Ongoing analyses:

- Au+Au @ 200 GeV, 2011
  - same setup as in 2010
  - double the total luminosity ~ 2.8 nb^{-1}
- p+p @ 500 GeV, 2011
  - higher Upsilon cross section
  - approximately 22 pb^{-1} of data
- U+U @ 193 GeV, 2012
  - non-spherical nucleus
  - higher maximum initial density
- Υ – polarization and azimuthal hadron correlations
  - study production mechanism



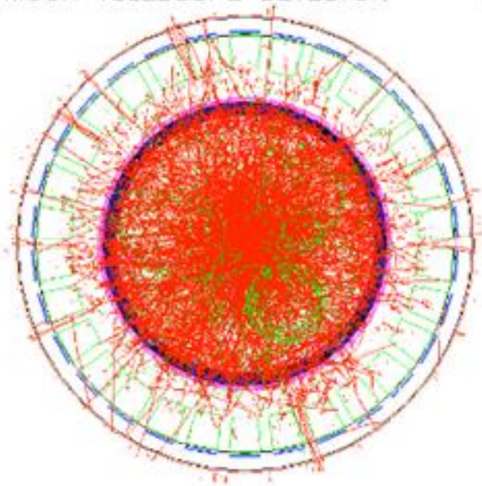
Outlook : Muon Telescope Detector





Multi-gap Resistive Plate Chamber (MRPC): gas detector, avalanche mode

A detector with long-MRPCs covers the whole iron bars and leave the gaps in-between uncovered. Acceptance: 45% at |η|<0.5

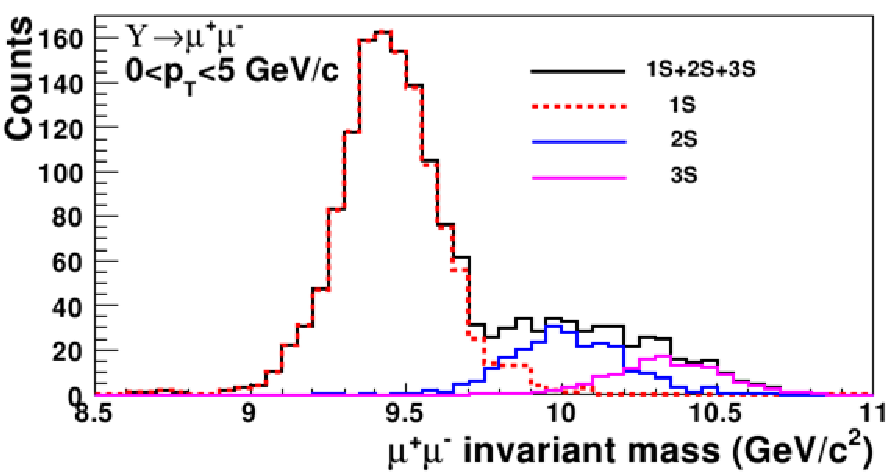


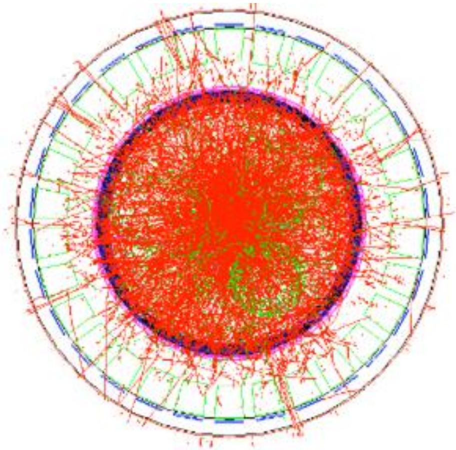
122 modules, 1464 readout strips, 2928 readout channels

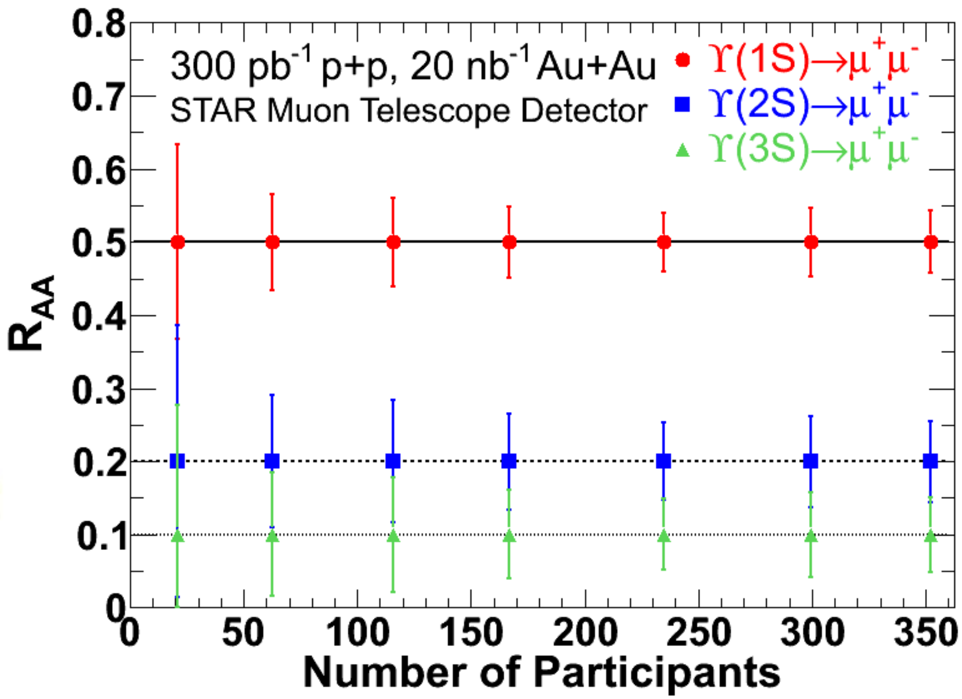
Long-MRPC detector technology, electronics same as used in STAR-TOF

Outlook : Υ via muon channel

- advantages over electrons:
  - no γ conversion
  - less Dalitz decay contribution
  - Less affected by radiative loses
- excellent mass resolution
  - separate different Upsilon states
- trigger capability
- full installation for 2014 physics run







Summary

- **Measured Upsilon production in p+p, d+Au, and Au+Au collisions at 200 GeV**
  - Extracted signal for $\Upsilon(1S+2S+3S)$ and $\Upsilon(1S)$ states
  - Rapidity dependence

arXiv:1312.3675

- **Upsilon in p+p and d+Au 200GeV**
  - Consistent with pQCD Color Evaporation Model.
  - Additional suppression from CNM effects needed for d+Au at mid-rapidity to fully reproduce Υ production
  - Increased statistics from run 9 have refined our p+p measurements
- **Upsilon in Au+Au 200GeV**
  - Increasing of Υ suppression with centrality.
  - Data consistent with models that contain bottomium melting in deconfined matter
  - Increased Au+Au statistics from run 11 will further decrease R_{AA} uncertainties
- **Muon Telescope Detector** upgrades.
  - Significant improvement of STAR quarkonium measurements