Upsilon meson analysis at the STAR experiment

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Research project
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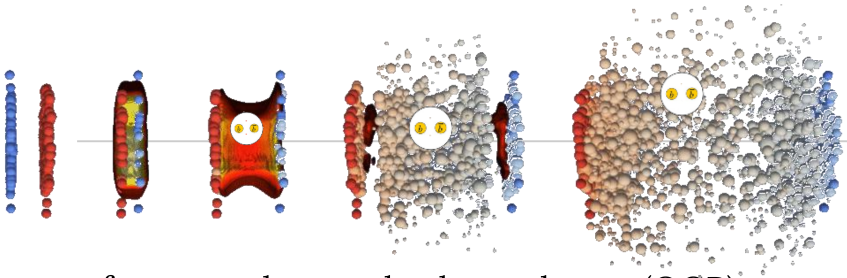
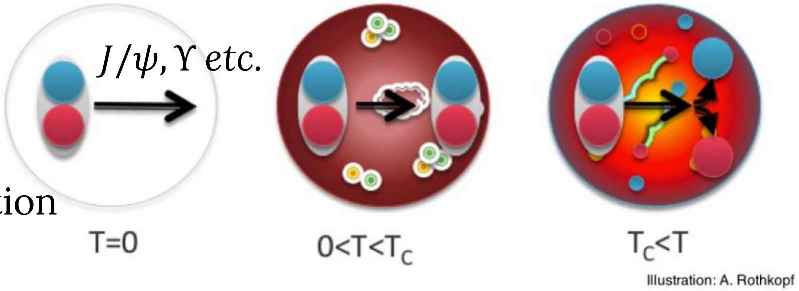
Introduction and outline



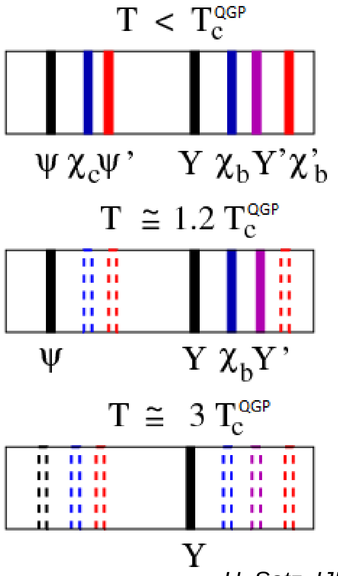
- Heavy-ion collisions are used to study a novel state of matter, the quark-gluon plasma (QGP)
- Measurements of quarkonia (e.g. Υ) serve as an excellent probe of the QGP and its temperature

1. **Heavy quarkonia as a QGP probe**
2. **The STAR experiment**
3. **Analysis of $\Upsilon \rightarrow e^{+}e^{-}$ in Au+Au collisions**
4. **Summary and outlook**

Heavy quarkonia in QGP



- $J/\psi, \Upsilon$ etc. are good candidates to probe QGP
  - $c\bar{c}$, $b\bar{b}$ pairs created mostly before the QGP formation
  - Production cross-section in p+p collisions can be calculated based on pQCD
- Dissociation by colour screening *T. Matsui, H. Satz, PLB 178 (1986) 416*
  - Quarkonium expected to *dissociate* when its radius exceeds the Debye radius: $r_{\text{Debye}} \propto 1/T$
- Sequential melting *A. Mocsy, EPJ C61 (2009) 705*
  - Dissociation depends on the quarkonium binding energy
  - Different states expected to melt at different temperatures
  - QGP *thermometer*



H. Satz, IJMPA 28 (2013)

Other effects also play a role

- Other phenomena complicate the measured quarkonium suppression
- Statistical recombination
  - Coalescence of deconfined quarks at QGP phase boundary

I. Das, QM2015, https://indico.cern.ch/event/355454/contributions/838966/

	RHIC 200 GeV	LHC 2.76 TeV
$\#c\bar{c}$ / event	13	115
$\#b\bar{b}$ / event	0.1	3

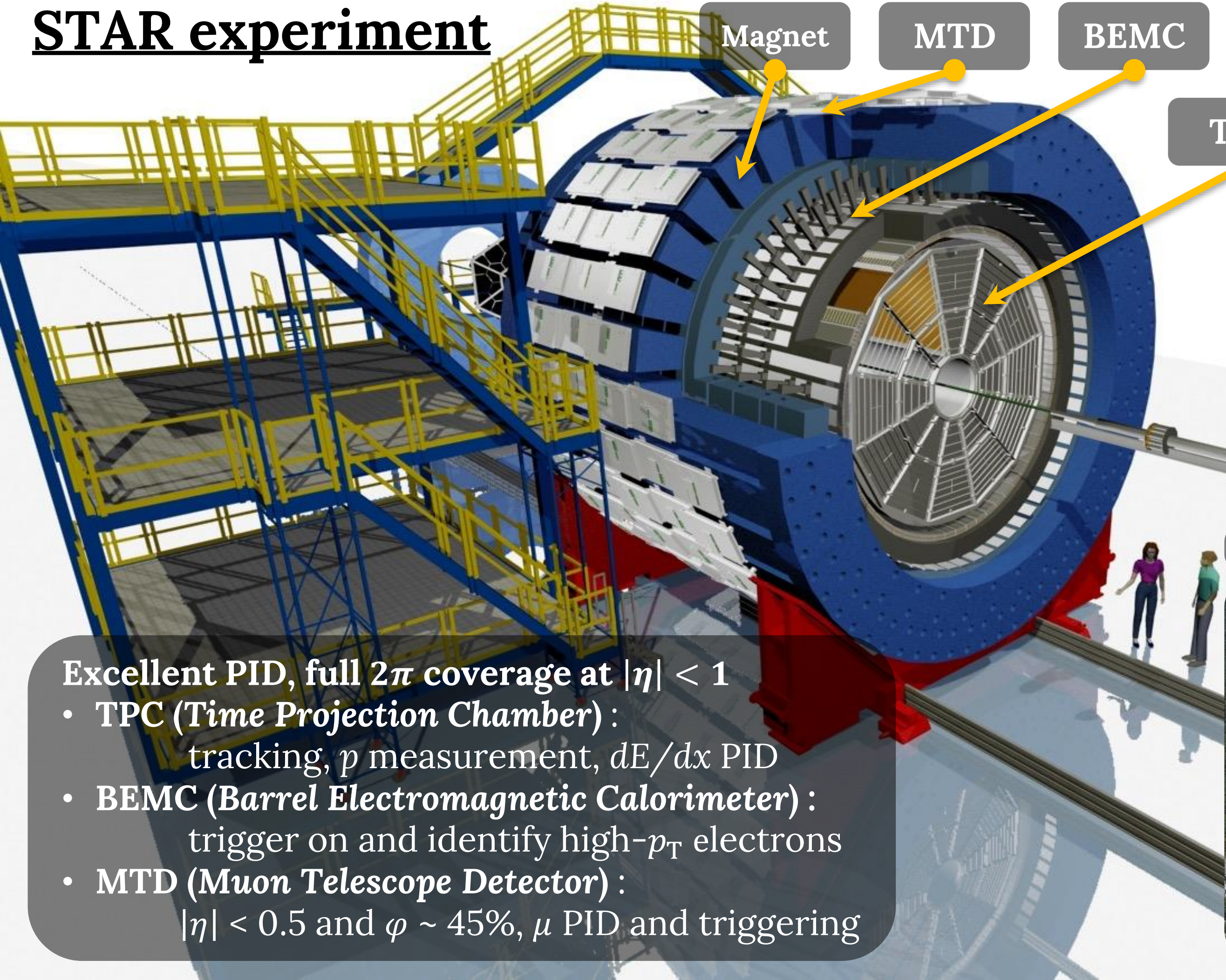
- Cold nuclear matter (CNM) effects
  - Initial state: shadowing, energy loss
  - Final state: inelastic interactions with hadrons
    → nuclear break-up
    → co-mover absorption
  - Can be studied in p+A collisions
- Feed-down

For $\Upsilon's$ at RHIC $\sqrt{s_{\mathrm{NN}}} = 200$ GeV :

- no recombination *A. Emerick, X. Zhao, R. Rapp, EPJ A48 (2012) 72*
- less co-mover absorption *Z. Lin, C. Ko, PLB 503 (2001) 104*

→ ***cleaner probe!***

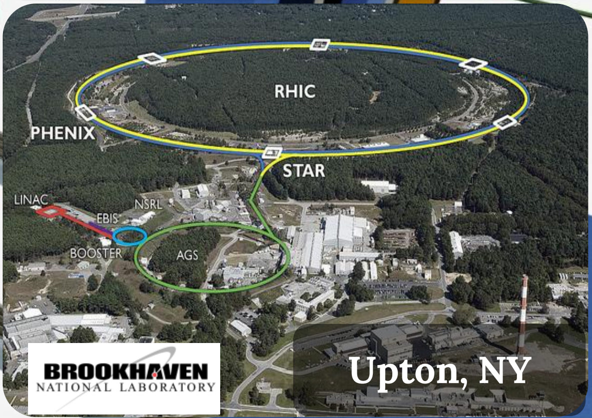
STAR experiment



Excellent PID, full 2π coverage at $|\eta| < 1$

- **TPC (*Time Projection Chamber*)** :
  tracking, p measurement, dE/dx PID
- **BEMC (*Barrel Electromagnetic Calorimeter*)** :
  trigger on and identify high-p_T electrons
- **MTD (*Muon Telescope Detector*)** :
  $|\eta| < 0.5$ and φ ~ 45%, μ PID and triggering

RHIC (*Relativistic Heavy Ion Collider*)

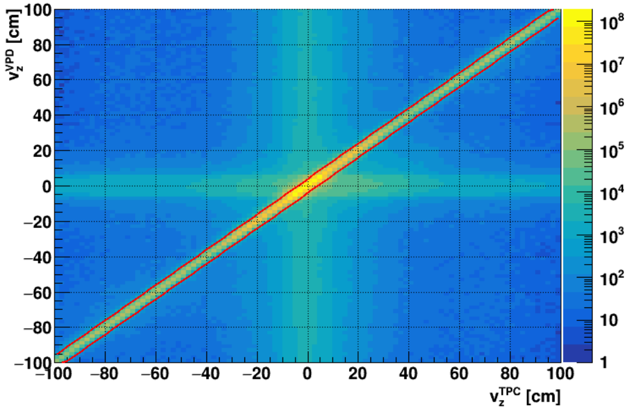


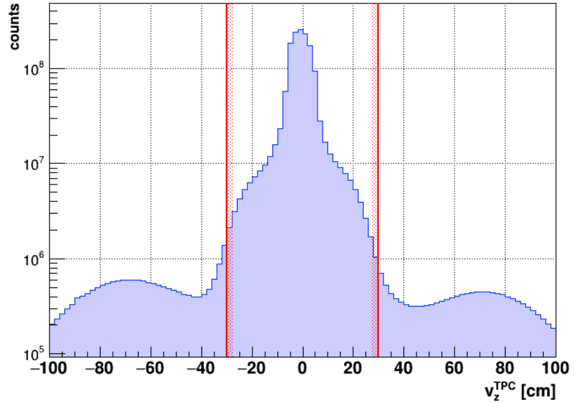
Data and event selection

- Au+Au collisions $\sqrt{s_{\mathrm{NN}}} = 200$ GeV from 2014
- 118.9 M high-tower–triggered events with BEMC (corresponds to integrated luminosity ~4.1 nb $^{-1}$)

- Event cuts:
  - $|v_z^{TPC} - v_z^{VPD}| < 4$ cm
  - $|v_z^{TPC}| < 30$ cm

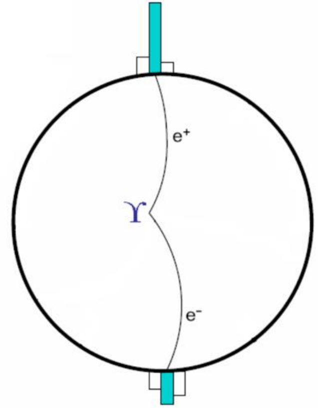
- + Monte Carlo dataset with embedded Υ's :
  - 900 K events with full GEANT-simulated detector response





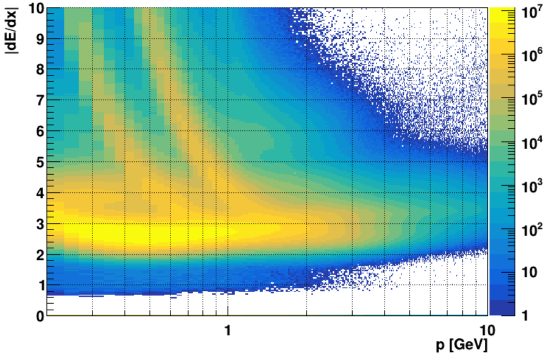
Υ reconstruction at STAR

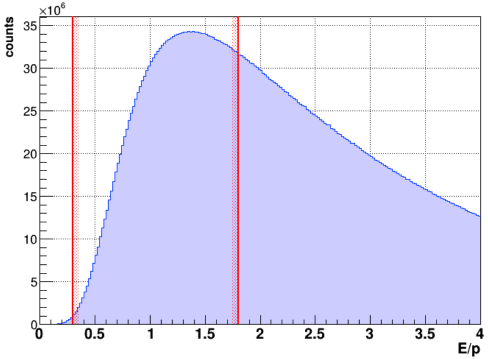
- Reconstructed from the di-electron decay channel



1. Trigger on hard electrons
2. Find electron tracks in TPC
3. Match tracks with BEMC-clusters
4. Further PID
5. Make Υ's from e^+e^- pairs

+ reconstruction efficiencies (in progress)

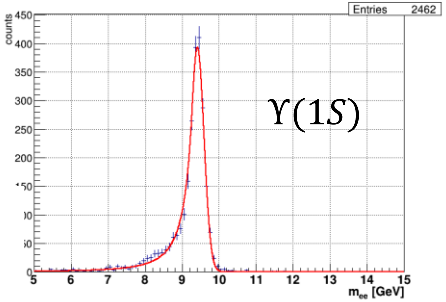


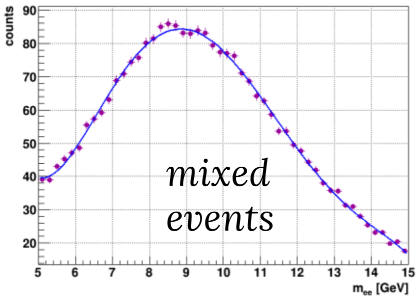


- TPC:
  - tracking, momentum measurement
  - PID with energy loss dE/dx
- BEMC:
  - energy deposit in clusters
  - PID with E/p, cluster shape

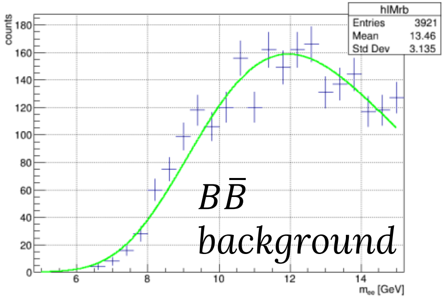
Signal extraction

- Limited statistics + contributions from background complicate the Υ yield extraction
- Signal shape:
  - $\Upsilon(1S), \Upsilon(2S), \Upsilon(3S)$ peaks fitted from embedding
  - Crystal-Ball function

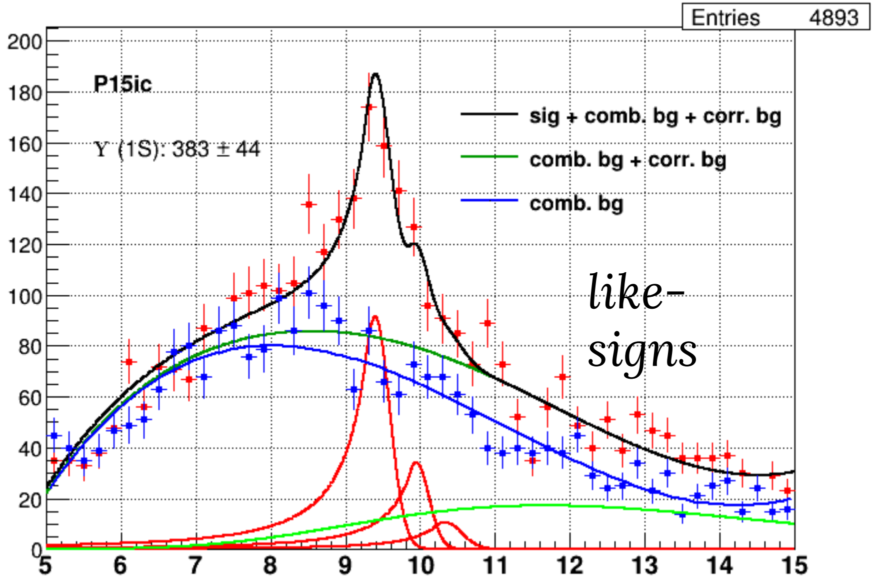


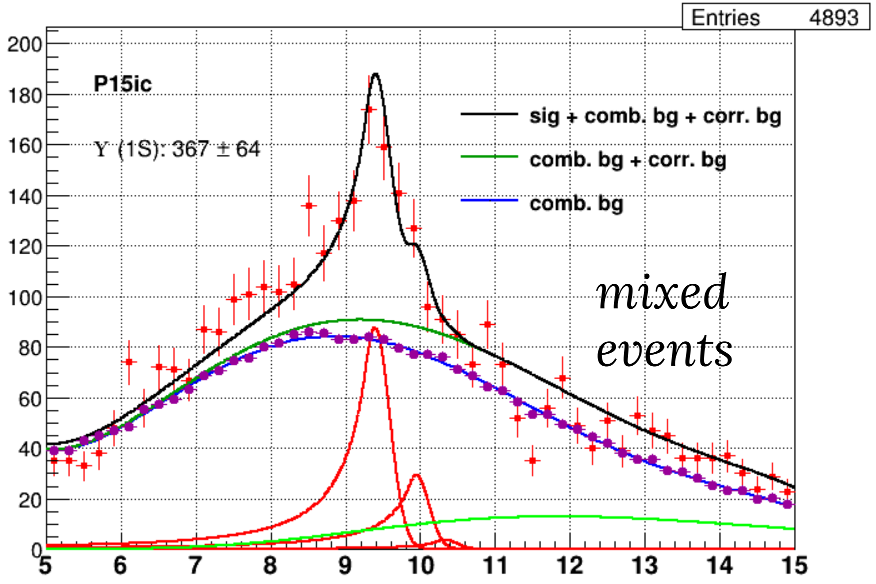


- Combinatorial background
  - Like-sign: sum of e^+e^+ and e^-e^- spectra
  - Event-mixing: e^+e^- from different events
- Physical background:
  - Drell-Yan, $B\bar{B}$ semi-leptonic decays
  - Monte Carlo simulations (Pythia, Herwig)



Mass spectrum





- Di-electron invariant mass spectrum with ϒ signal
- Composite fit including the signal peaks, combinatorial & physical background

Summary

- Υ successfully reconstructed from Au+Au data of $\sqrt{s_{\mathrm{NN}}} = 200$ GeV from 2014 via the di-electron decay channel
- Some reconstruction efficiencies were studied
- Signal extraction from the mass spectra was done by carefully analysing the major contributions in Monte Carlo simulations

Outlook

- Improve the fit result by e.g. including the Drell-Yan background
- Finish the determination of the total reconstruction efficiency
- Construct the nuclear modification factor R_{AA} as a function of N_{part} and p_T

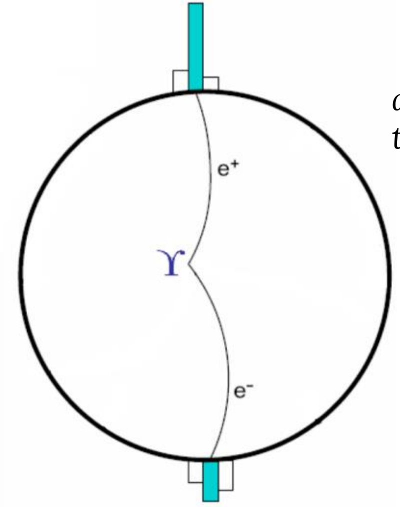
Thank you for your attention!

Back-up slides

Cuts used in the analysis

PID:

- TPC cuts
  - Primary tracks
  - nHitsFit >= 25
  - nHitsDedx >= 10
  - nHitsRatio >= 0.52
  - DCA < 1.5 cm
  - -1.5 < $n\sigma_{electron}$ < 3
- EMC cuts
  - 0.3 < E/p < 1.8 (cluster)
  - |zDist| < 5
  - |phiDist| < 0.05
- Kinematics
  - |eta| < 1
  - Low electron: pMomentum > 3.5 GeV
  - Leading electron: pMomentum > 4.5 GeV
- Pair cuts
  - Pair_Pt < 10 GeV
  - |Pair_y| < 1



at least 1 electron fired the trigger

both have BEMC clusters

Event selection:

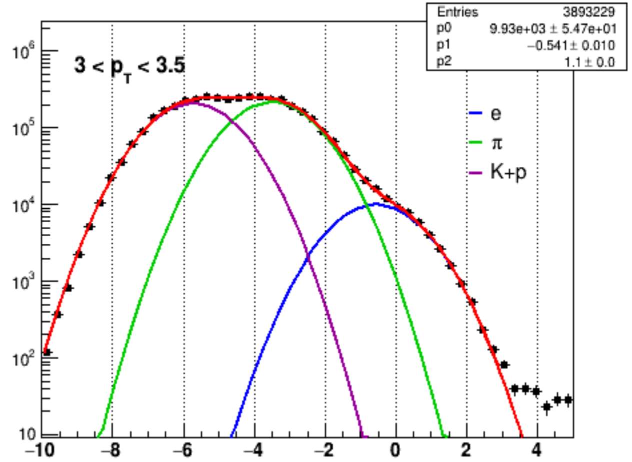
- |vzTPC| < 30
- |vzDiff| < 4
- isTrigger(450202) || isTrigger(450212)

$n\sigma^e$_cut efficiency

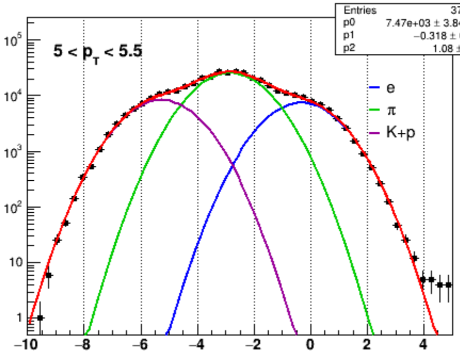
- Important part of total reconstruction efficiency

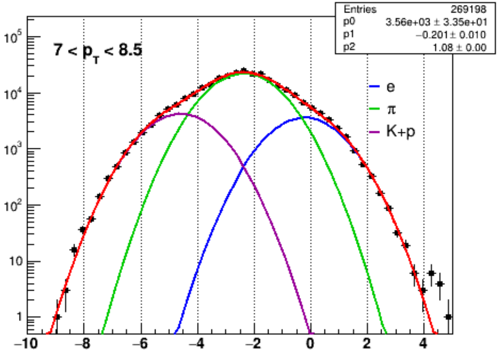
1) studied with identified single electrons:

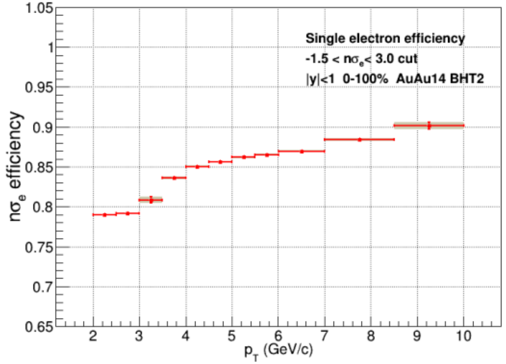
   → too many pions! results not too stable



Need to study with photonic $m_{ee} < 100$ MeV electrons:

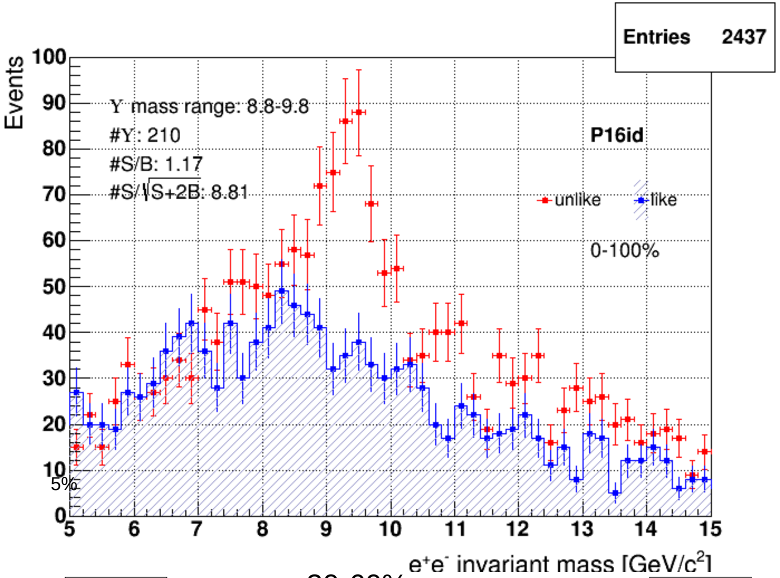




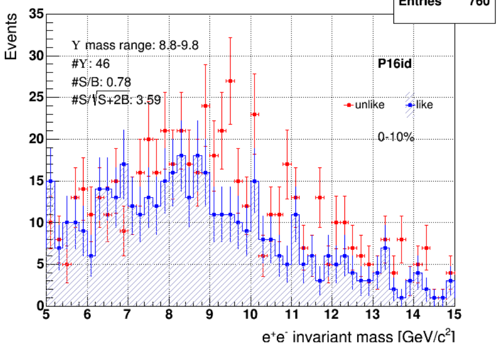


Invariant mass spectra

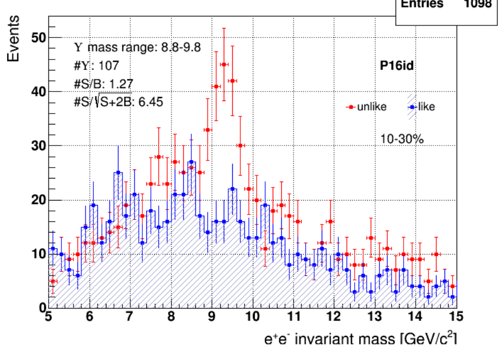
- $m_{ee}^2 = (E_{(1)} + E_{(2)})^2 - (\boldsymbol{p}_{(1)} + \boldsymbol{p}_{(2)})^2$
- divided in 3 centrality intervals



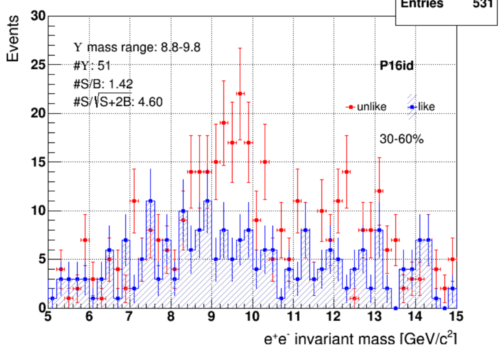
0-10%



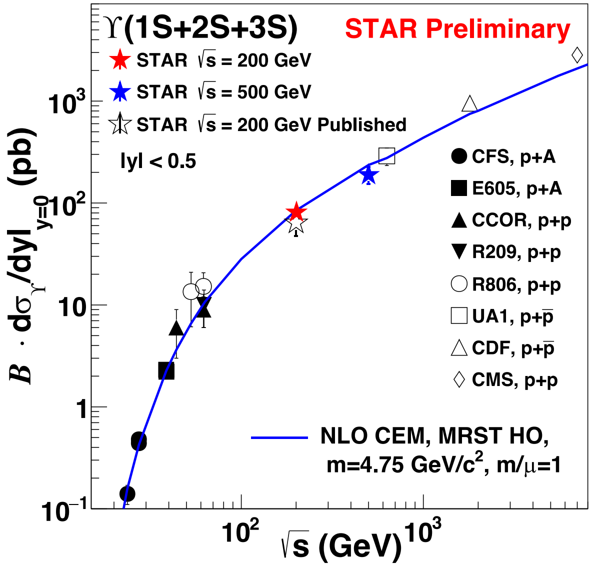
10-30%

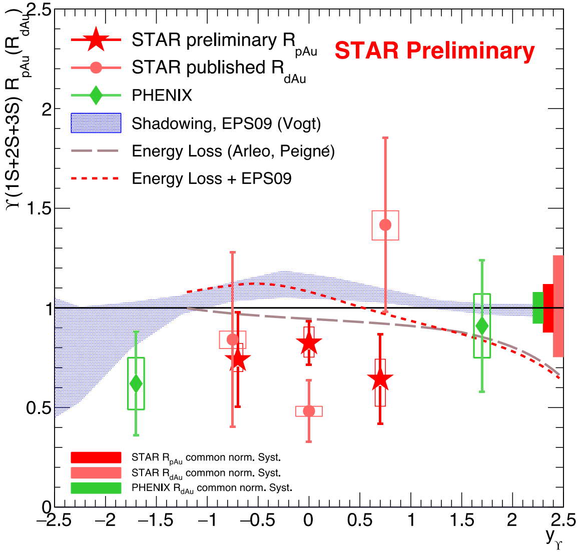


30-60%



Results from p+p and p+Au collisions





- **p+p** : precise baseline for comparison with Au+Au collisions

  → improved precision: $\sigma = 64 \pm 10\,(\text{stat.}) \pm 14\,(\text{syst.})\ \text{pb} \rightarrow 81 \pm 5\,(\text{stat.}) \pm 8\,(\text{syst.})\ \text{pb}$

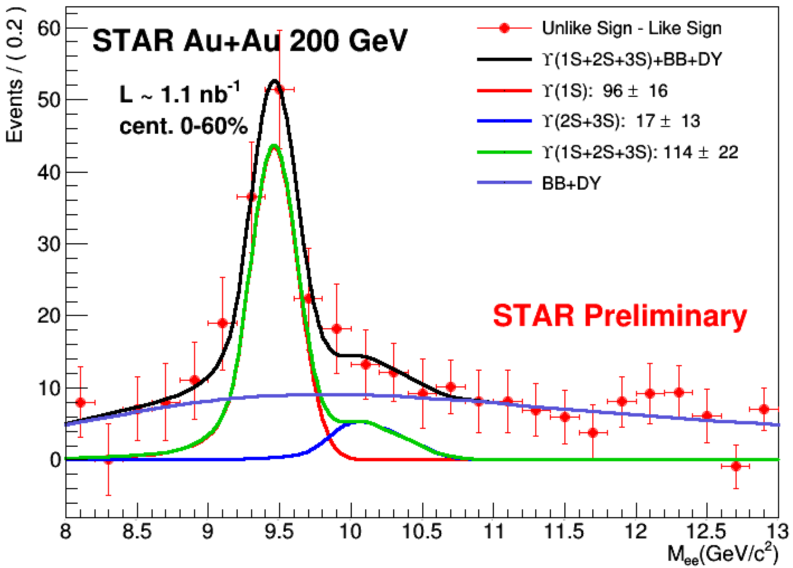
  → consistent with the Colour Evaporation Model (CEM) prediction

  A.Frawley, T.Ullrich, R.Vogt, PR 462 (2008) 125

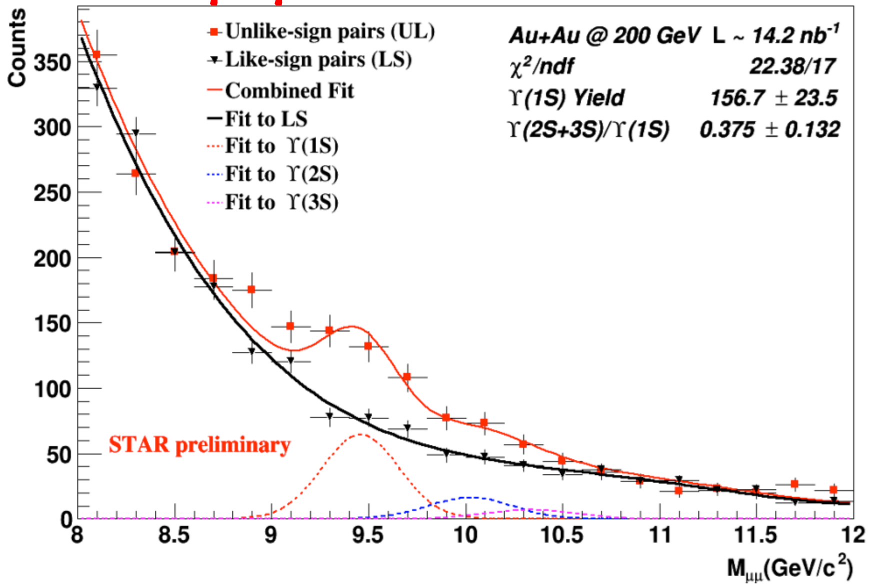
- **p+Au** : quantification of CNM effects with $R_{\text{pAu}} = 0.82 \pm 0.10\,(\text{stat.})\ ^{-0.07}_{+0.08}\,(\text{syst.}) \pm 0.10\,(\text{global})$

Signal in Au+Au collisions

$\Upsilon \rightarrow e^+e^-$ *2011 data*



$\Upsilon \rightarrow \mu^+\mu^-$ *2014 data*



- Background sources:

  → combinatorial background (estimated as $N_{l^+l^+} + N_{l^-l^-}$)

  → Drell-Yan di-leptons, $B\bar{B}$ semi-leptonic decays

Results from Au+Au collisions

- Nuclear modification factor

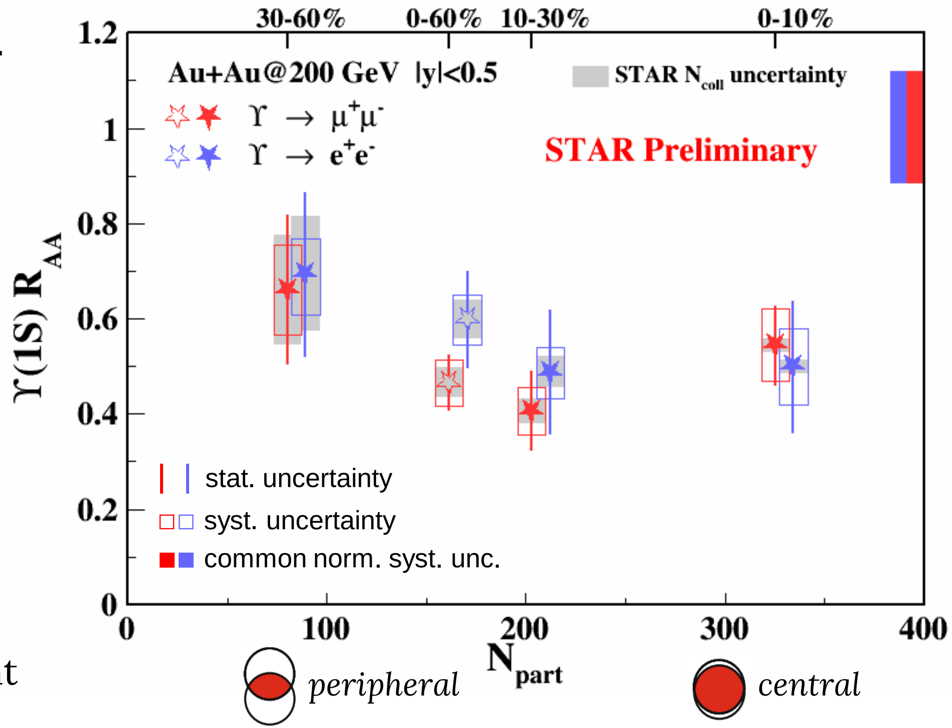
  $R_{\mathrm{AA}} = \frac{\sigma_{\mathrm{inel}}}{\langle N_{\mathrm{coll}} \rangle} \frac{\mathrm{d}^2 N_{\mathrm{AA}}/dp_{\mathrm{T}}dy}{\mathrm{d}^2\sigma_{\mathrm{pp}}/dp_{\mathrm{T}}dy}$ as a function of

  mean number of participants N_{part}

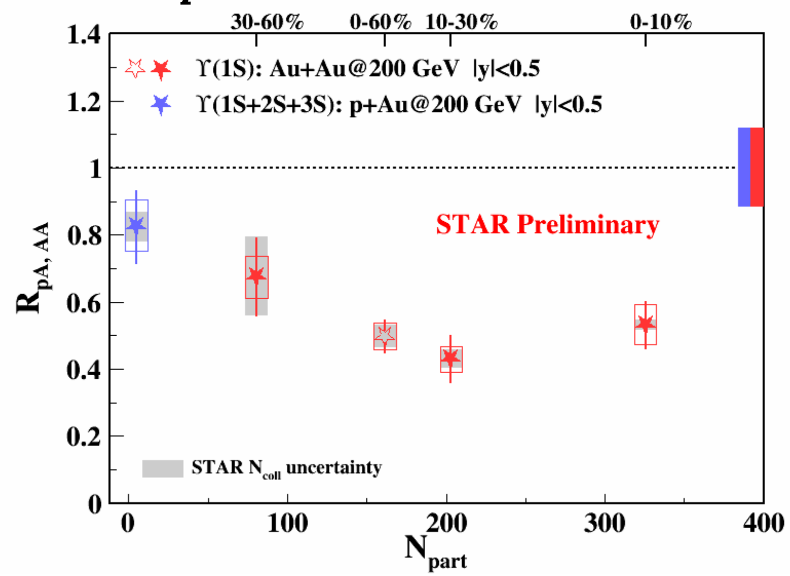
- ☆ is a combination of ★ results

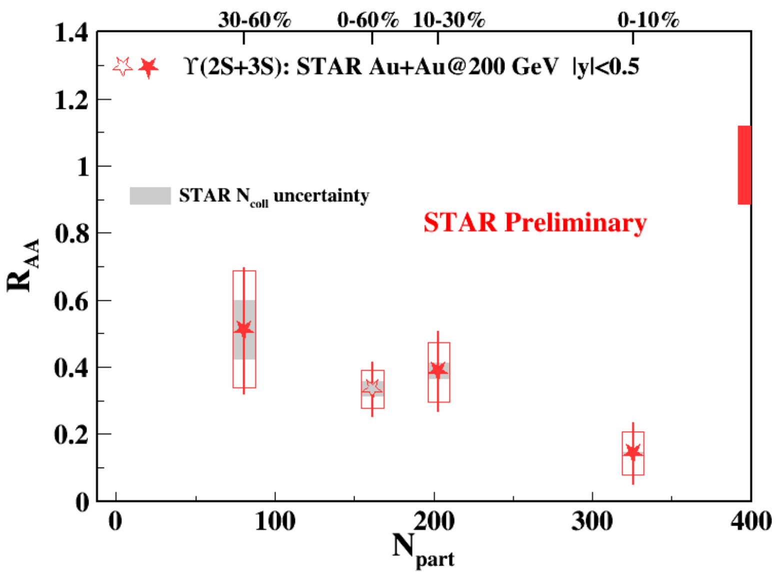
- **Di-muon** and **di-electron** results consistent with each other within the uncertainties

  → ***results combined for increased statistical precision***



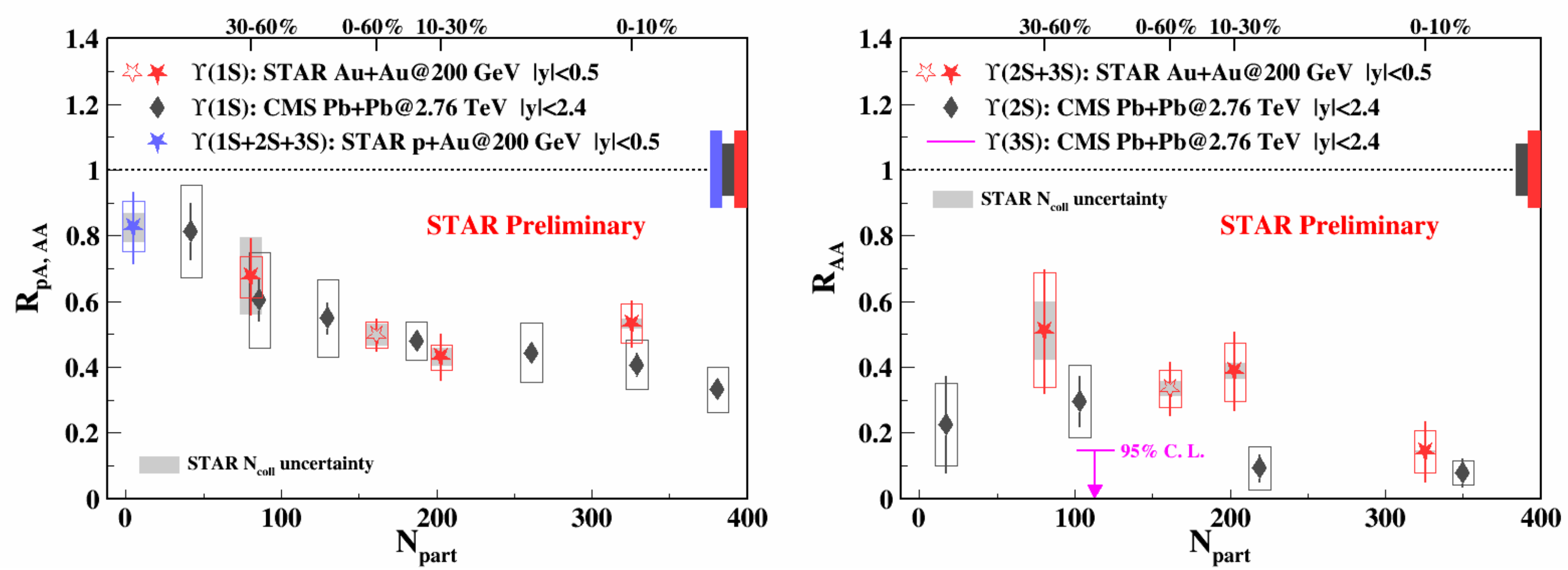
R_{AA} vs. N_{part} at RHIC





- $\Upsilon(2S), \Upsilon(3S)$ states ***more suppressed*** than $\Upsilon(1S)$ in central collisions

Compare RHIC with LHC

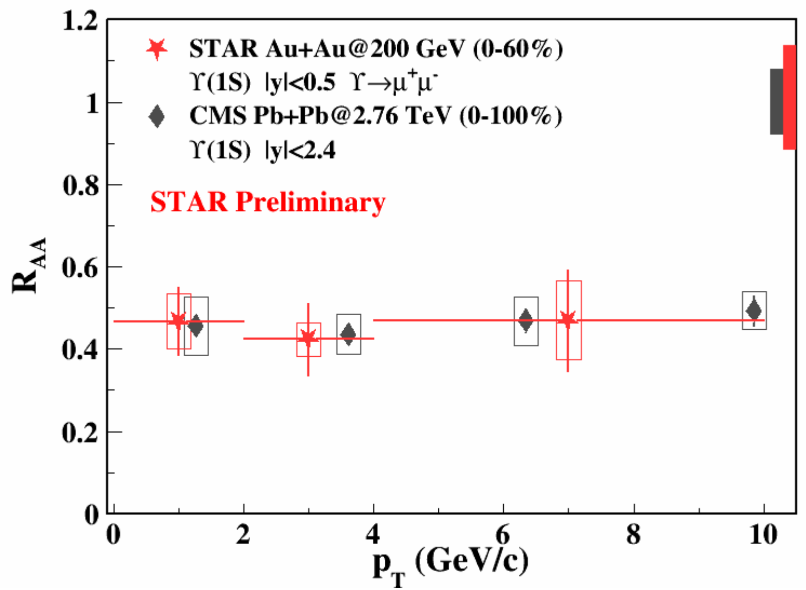


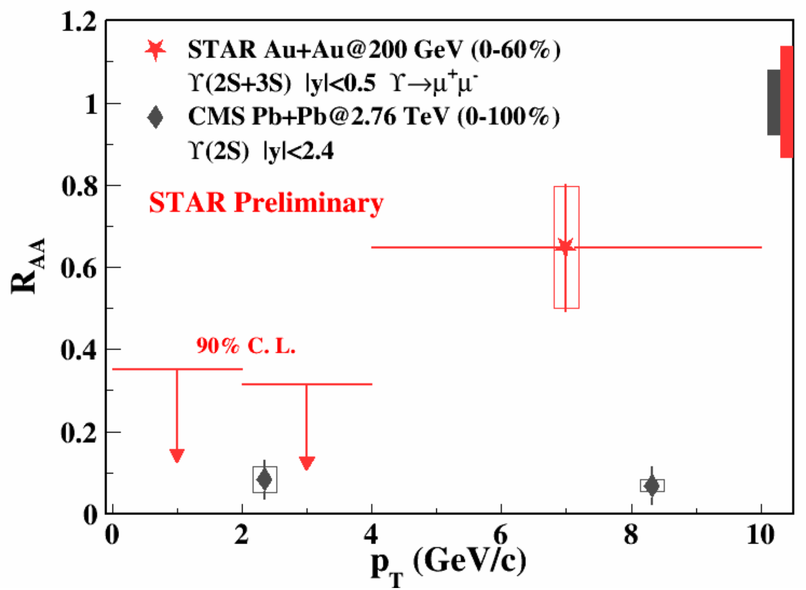
- $\Upsilon(2S), \Upsilon(3S)$ states ***more suppressed*** than $\Upsilon(1S)$ in central collisions
- Comparison with LHC: *CMS, PRL 109 (2012)*

  → solid consistency for $\Upsilon(1S)$

  → hint of ***less suppression*** for $\Upsilon(2S), \Upsilon(3S)$ at RHIC than at LHC

Suppression vs p_T





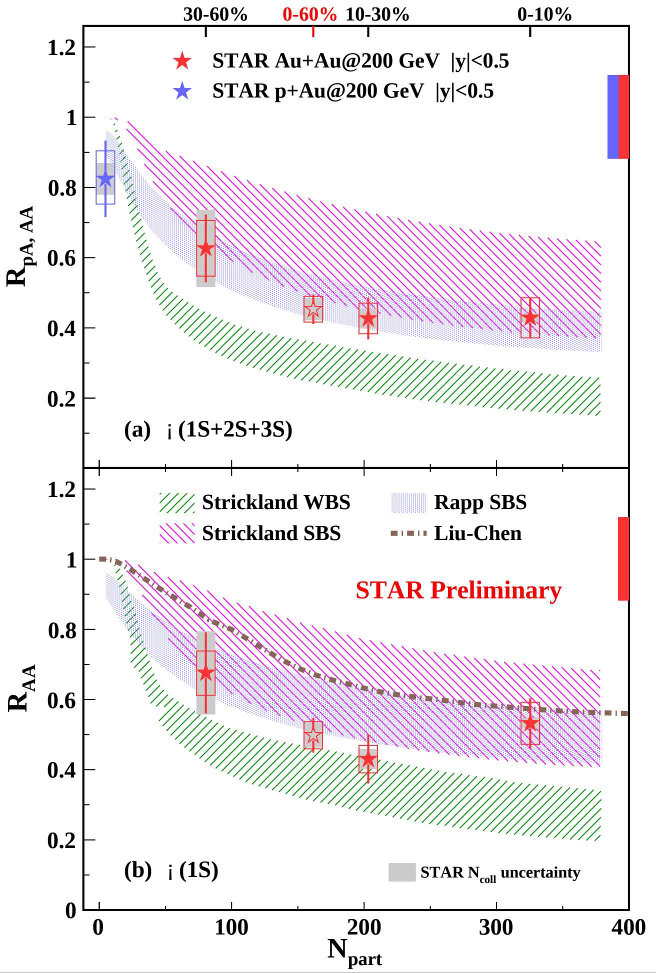
***RHIC** vs. LHC*

- Consistent for $\Upsilon(1S)$
- Signs of ***less suppression*** at high-p_T for $\Upsilon(2S), \Upsilon(3S)$

Comparison with models

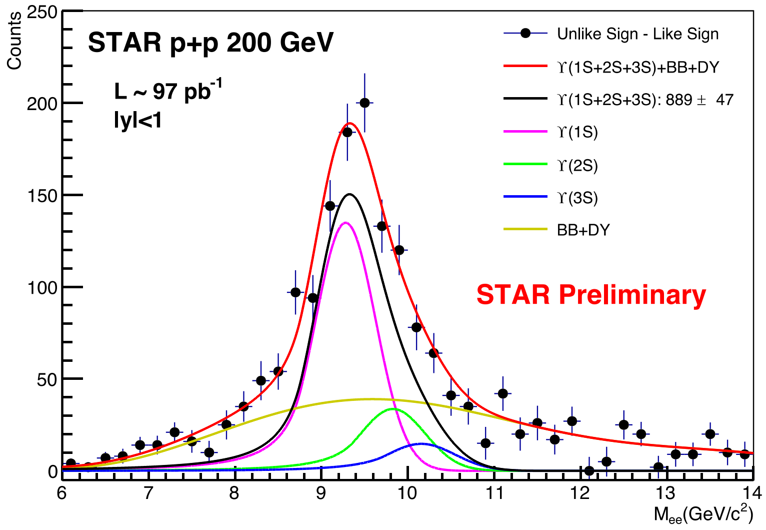
- Strickland, Bazov : *NPA 879 (2012) 25*
  - No CNM, no regeneration
  - SBS (Strongly Binding Scenario): fast dissociation–potential based on internal energy
  - WBS (Weakly Binding Scenario): slow dissociation–potential based on free energy
- Liu, Chen, Xu, Zhang : *PLB 697 (2011) 32*
  - No CNM
  - Dissociation only for excited states, suppression of ground state due to feed-down
- Emerick, Zhao, Rapp : *EPJ A48 (2012) 72*
  - Includes CNM, SBS case

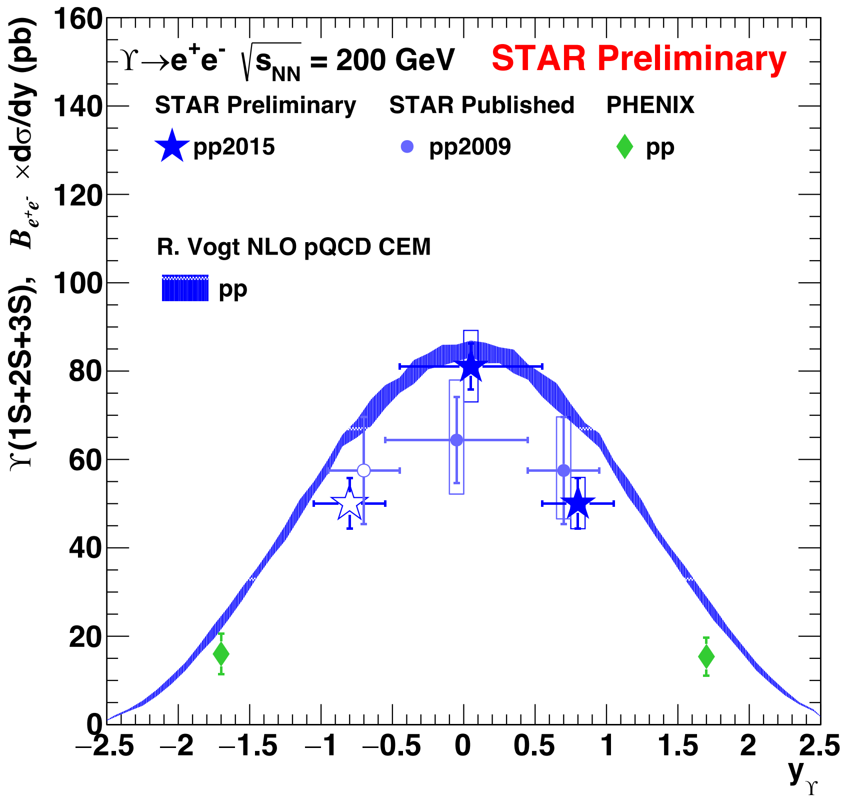
→ SBS models favoured by the data



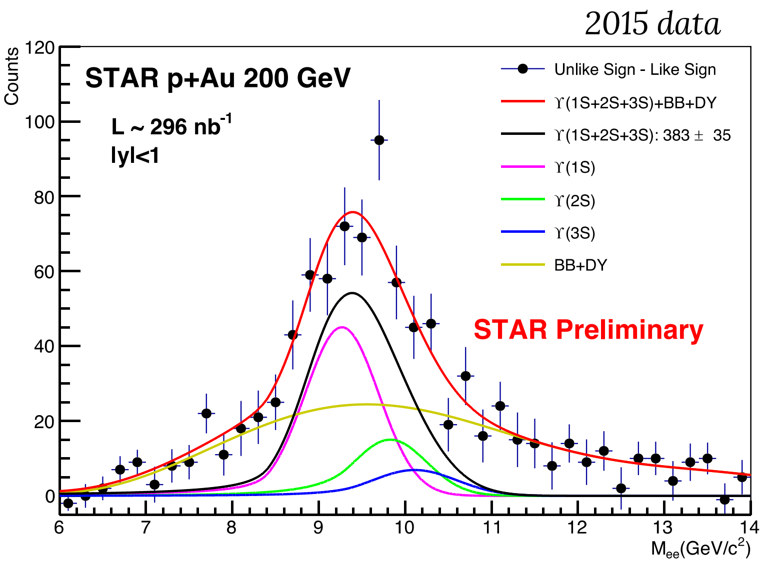
Results from p+p

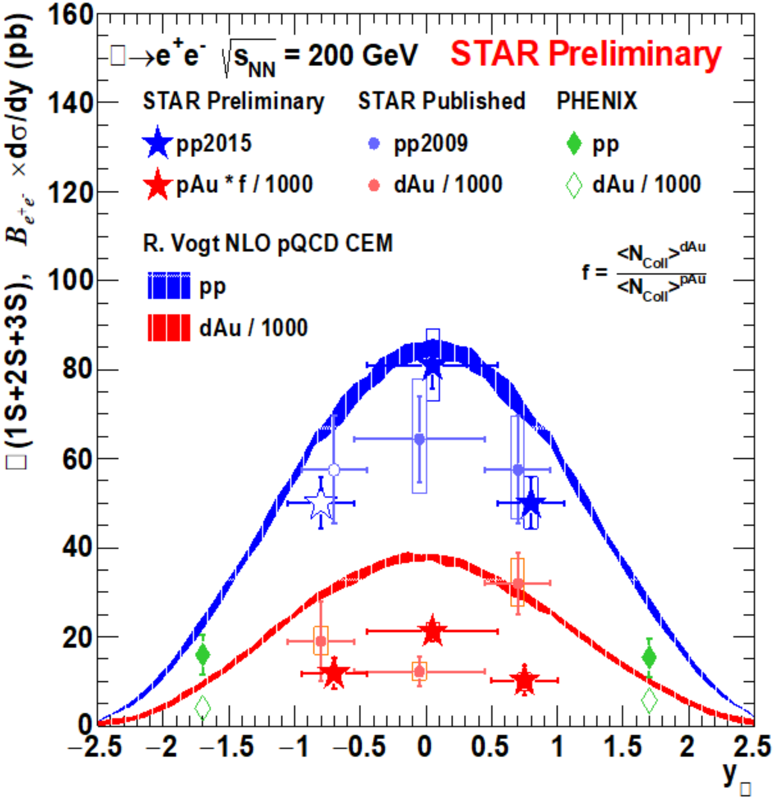
2015 data





Results from p+Au





Excited-to-ground-state ratio