Overview of Quarkonium Results from STAR

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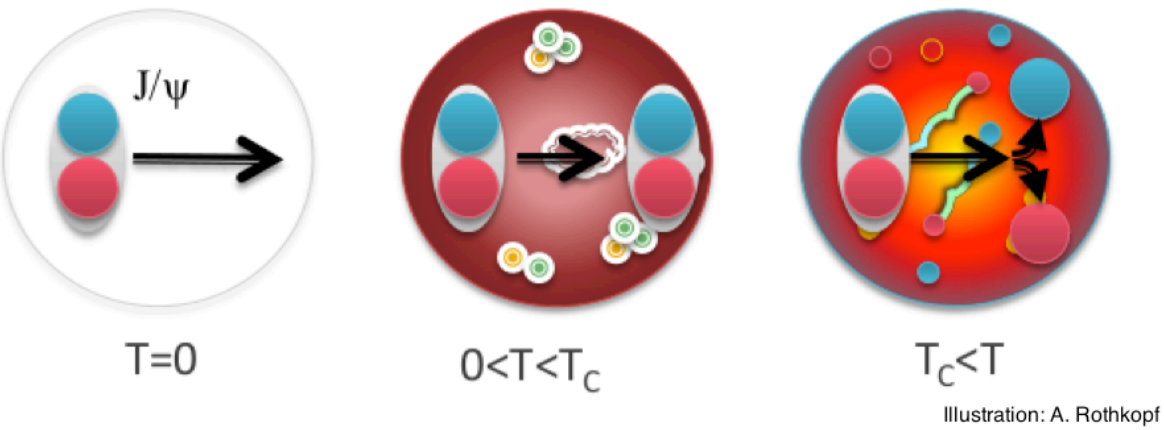
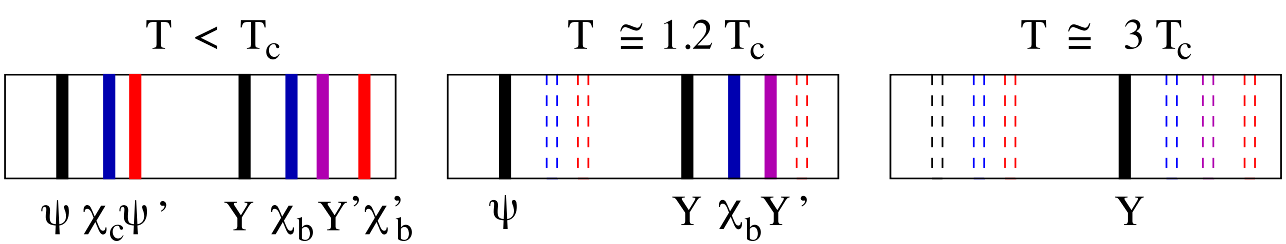
Why to Study Quarkonia

- ★ to learn about thermal properties of QGP
  - ★ Quarkonia are expected to dissociate due to Debye screening of heavy quark potential ($r_D \propto 1/T$) Phys.Lett. B178, 416



Charmonia ($c\bar{c}$):
J/Ψ, Ψ', χ_c

Bottomonia ($b\bar{b}$):
$\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$, χ_B



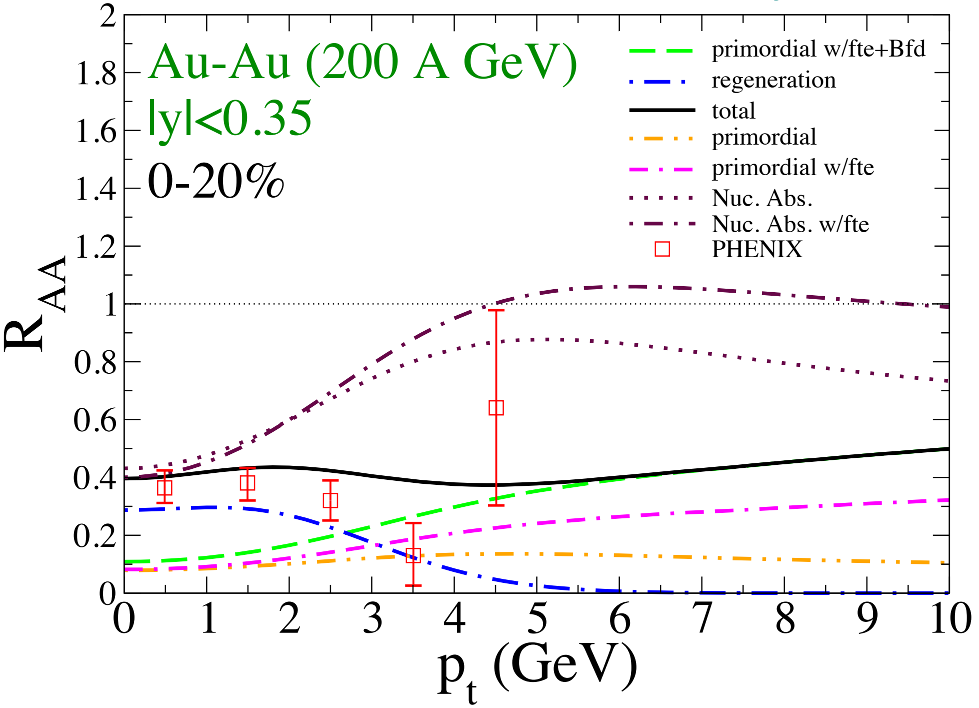
Phys. Rev. D77, 014501

- ★ pQCD test ($c\bar{c}$ production)

How to Study Quarkonia - Effects To Be Addressed

- Production mechanism in elementary collisions still unclear
- Feed-down:
  - prompt: Ψ(2S) and χ_c (40%)
  - non-prompt: B mesons (up to 25% at 12 GeV/c, Phys. Lett. B722, 55)
  - around 50% of ϒ(1S) comes from de-excitation Phys. Rev. Lett. 84, 2094
- Cold Nuclear Matter Effects (CNM Effects)
  - (anti-)shadowing, Cronin effect, nuclear absorption
- Hot Nuclear Matter Effects
  - regeneration

PRC 82, 064905
Nucl. Phys. A 774, 747



How to Study Quarkonia - Measurements at STAR

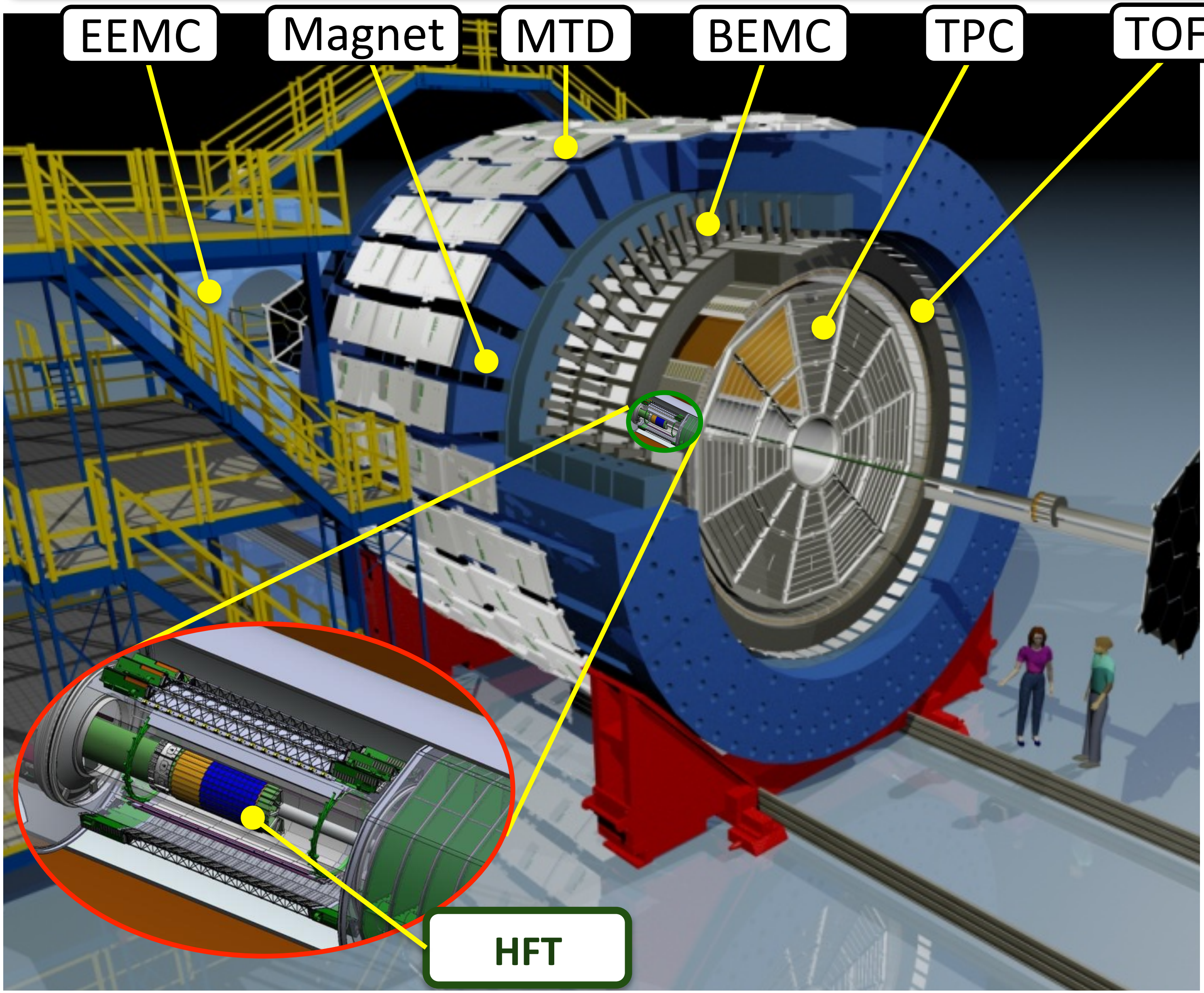
★ J/ψ measurements (J/ψ→e^+e^-, B.R. 6%)

- in d+Au: CNM effects
- in Au+Au, U+U: Hot nucl. matter effects, different energy densities
- at various energies (BES): changes relative contributions
- at high-p_T: regeneration and CNM effects suppressed

★ ϒ measurements (ϒ→e^+e^-, B.R. 2.4 %)

- ☺ regeneration predicted to be negligible at RHIC energies
- ☹ Low production cross sections at RHIC energies - requires specific triggering

The STAR Detector



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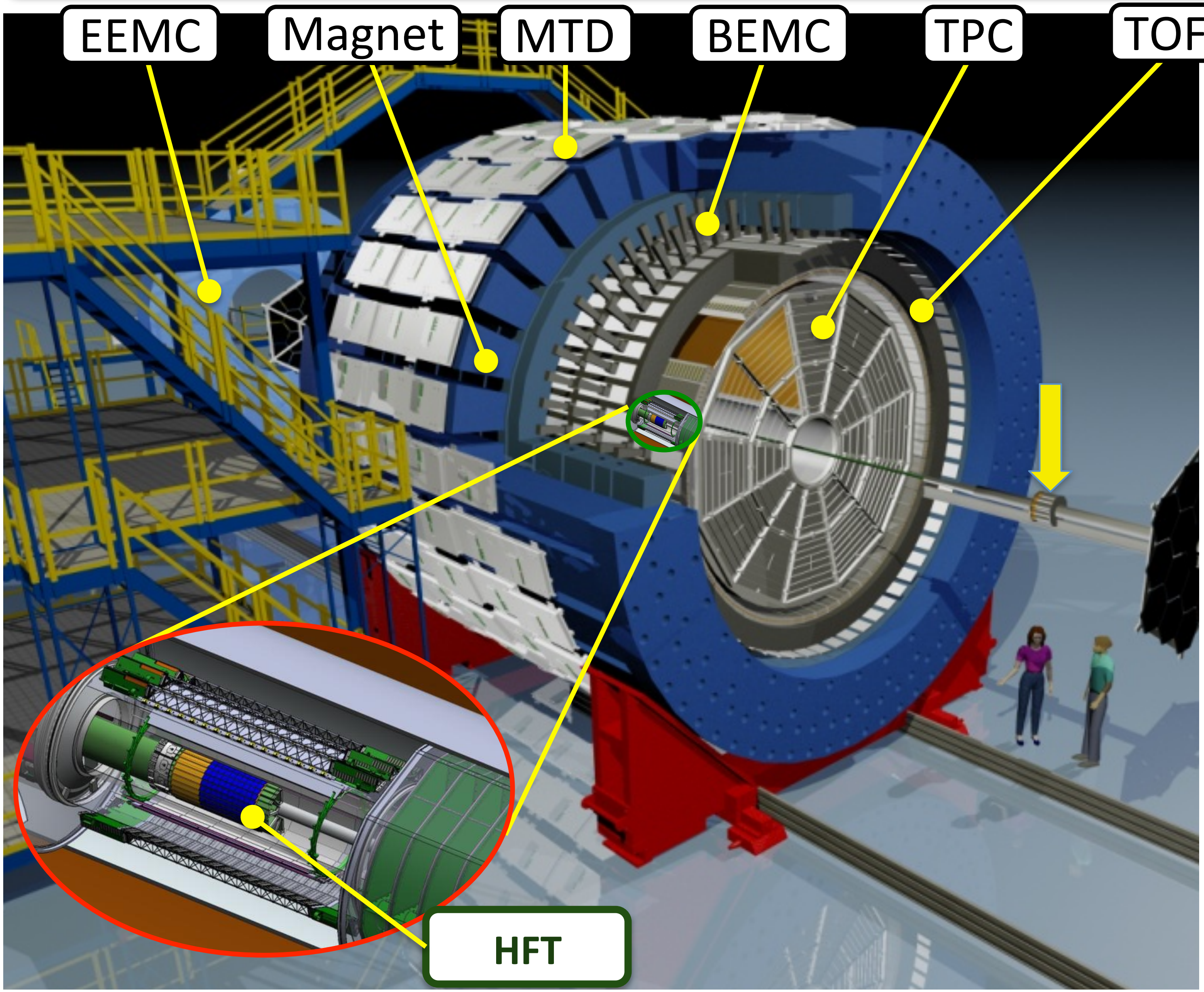
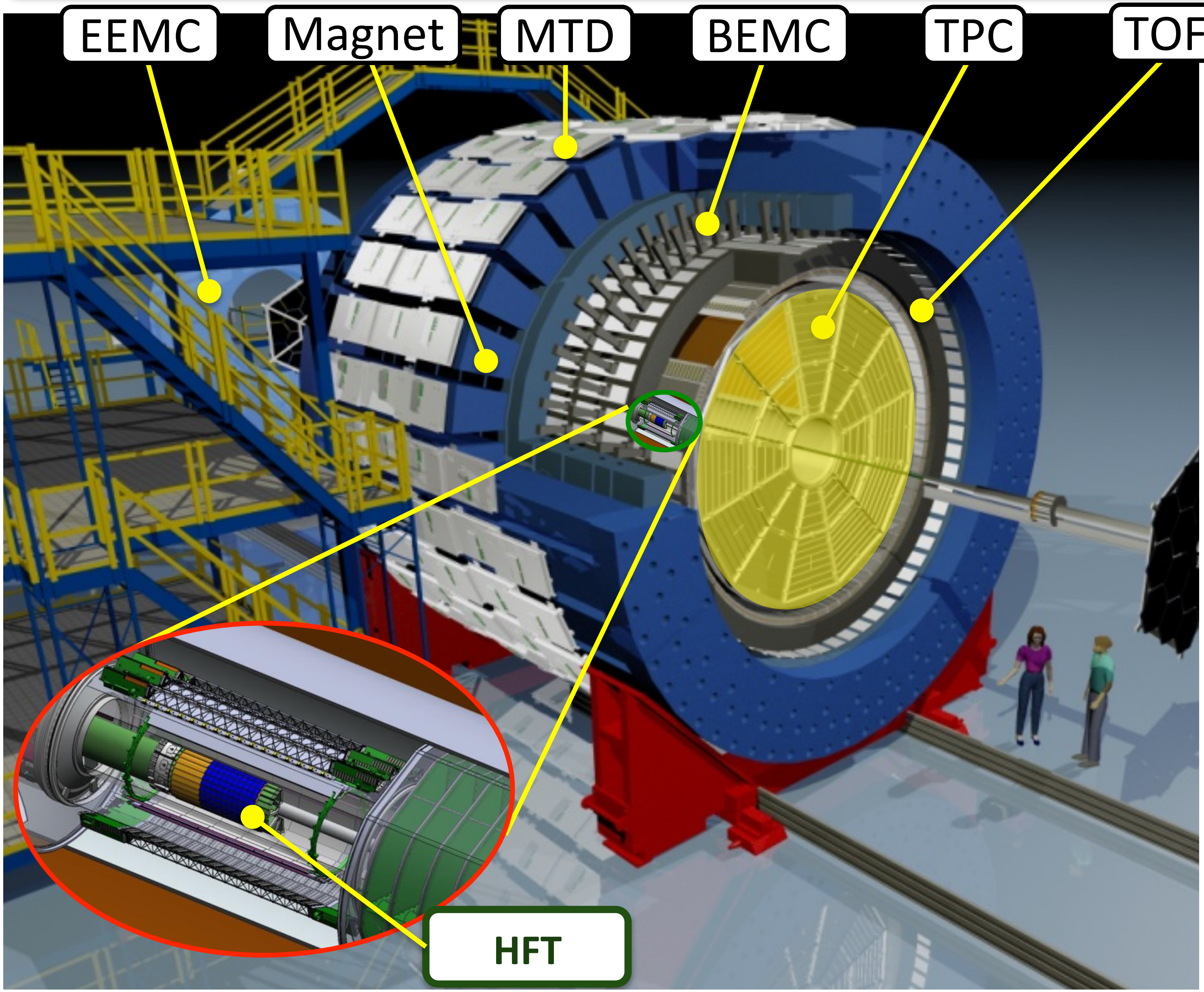


★ **VPD: minimum bias trigger**

The STAR Detector



- **VPD: minimum bias trigger**
- **TPC: particle identification, momentum**

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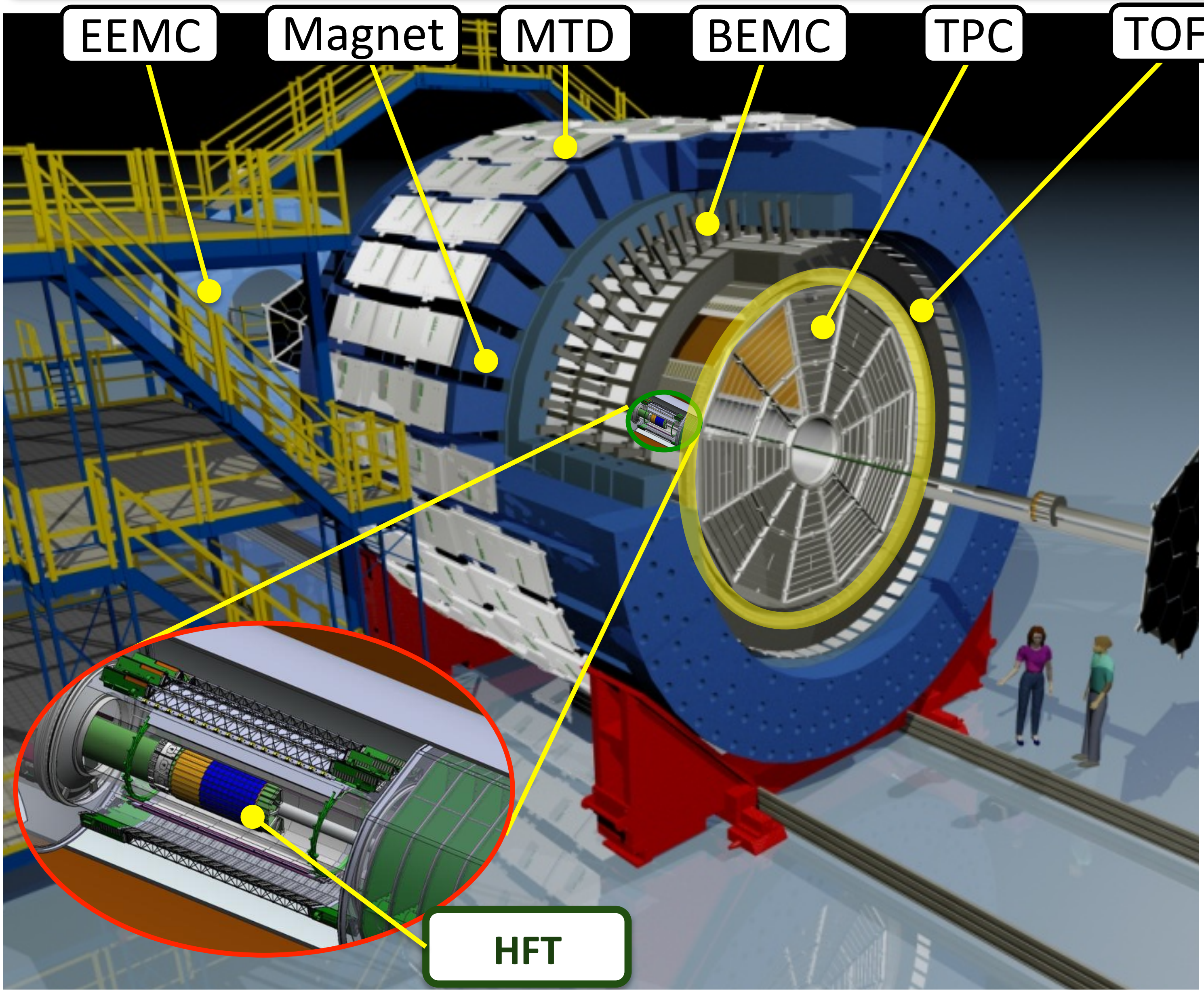

- **VPD: minimum bias trigger**
- **TPC: particle identification, momentum**
- **TOF: particle identification (time resolution 110 ps in p+p, 87 ps in Au+Au)**

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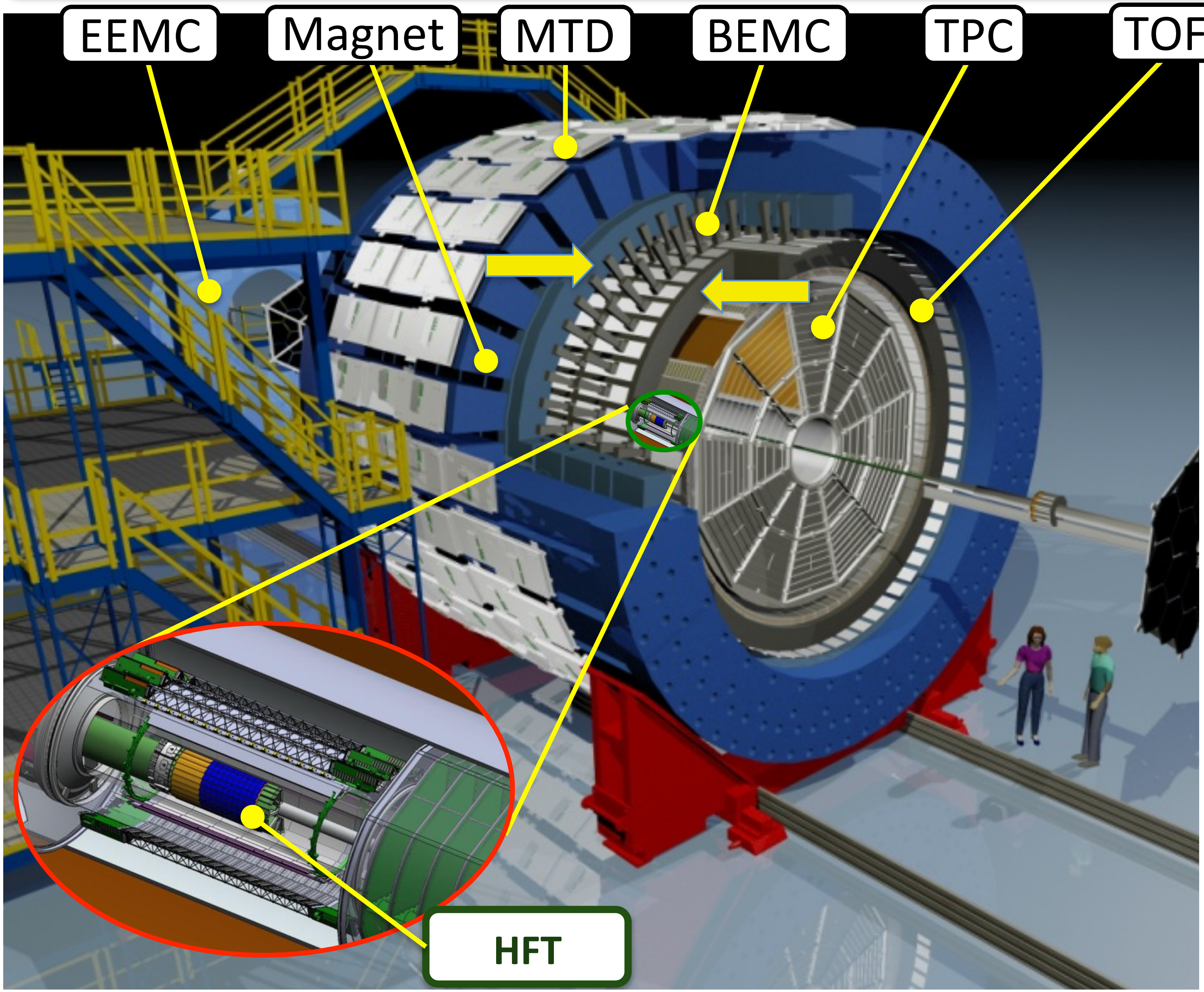

- VPD: minimum bias trigger
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- BEMC: high-energy trigger, electron identification
- MTD: muon identification

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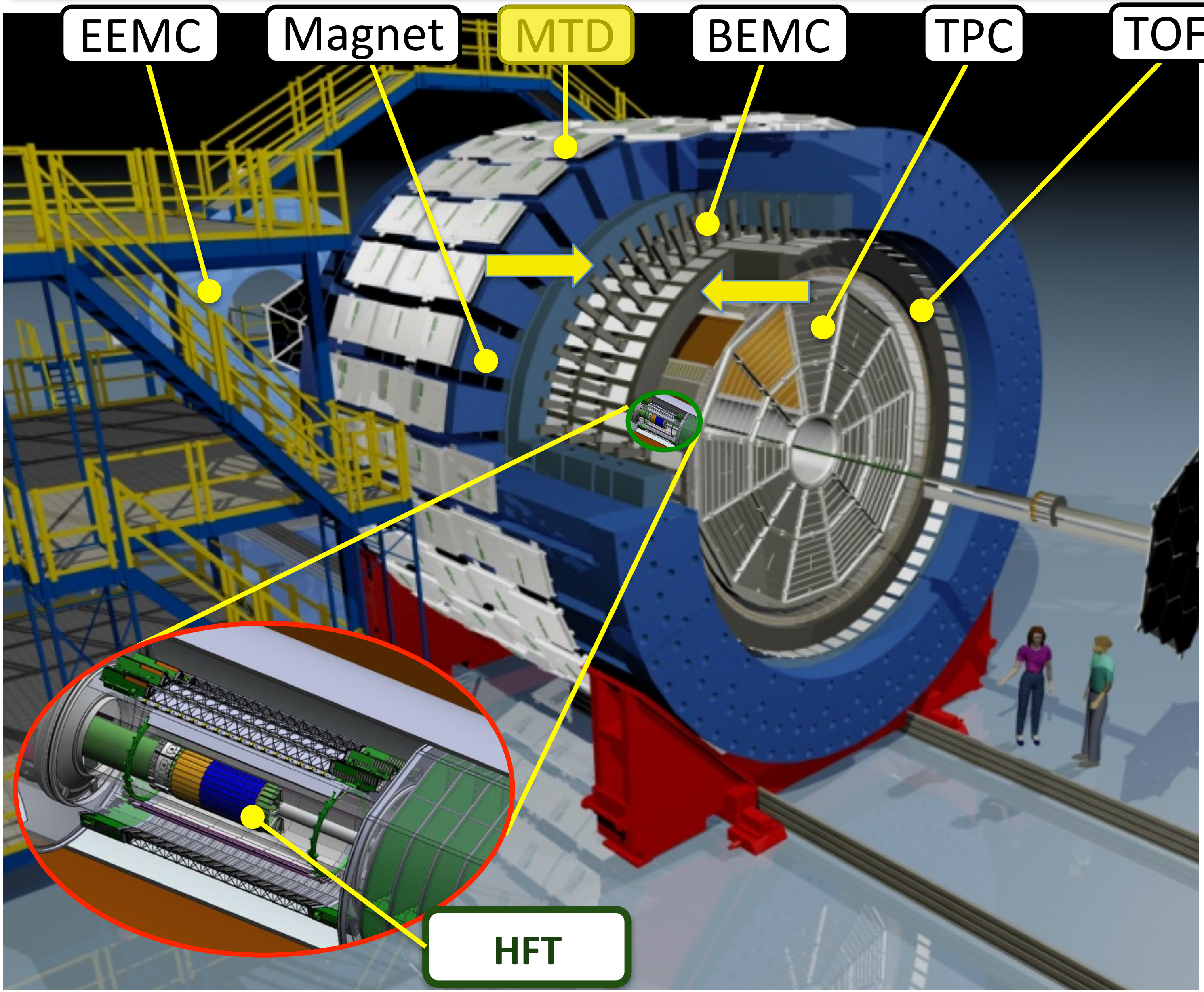

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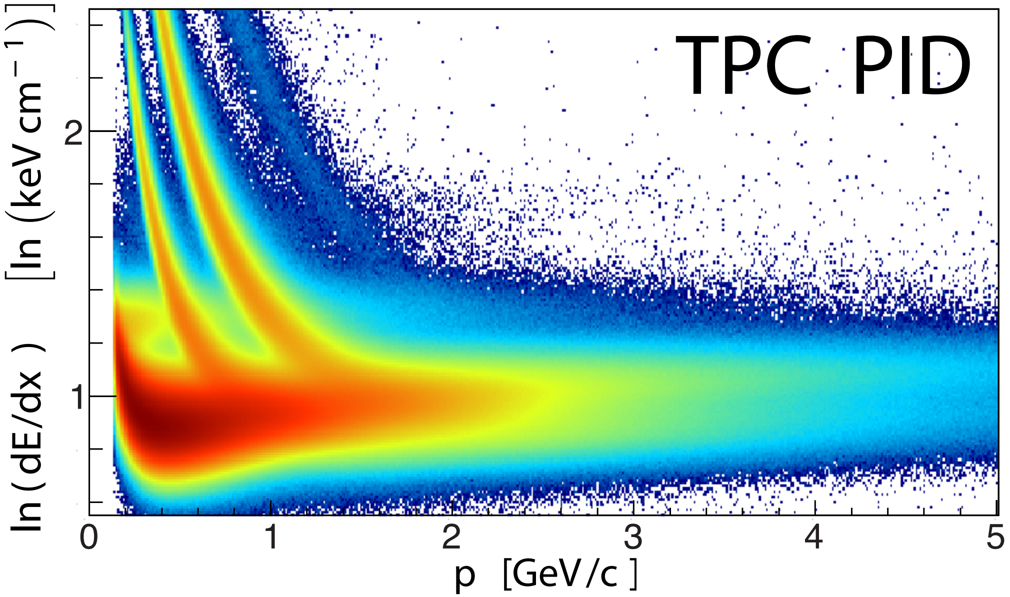
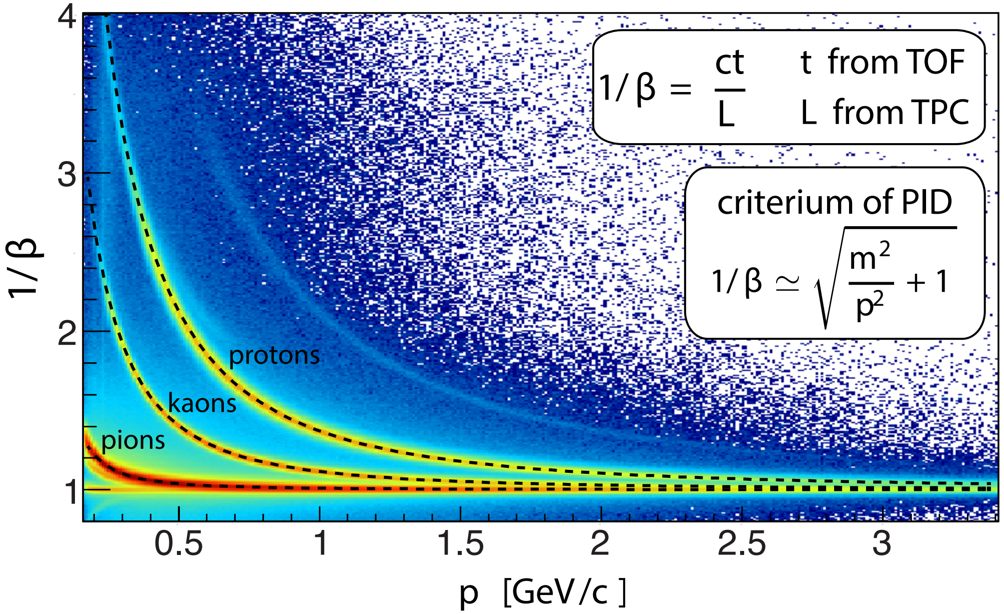
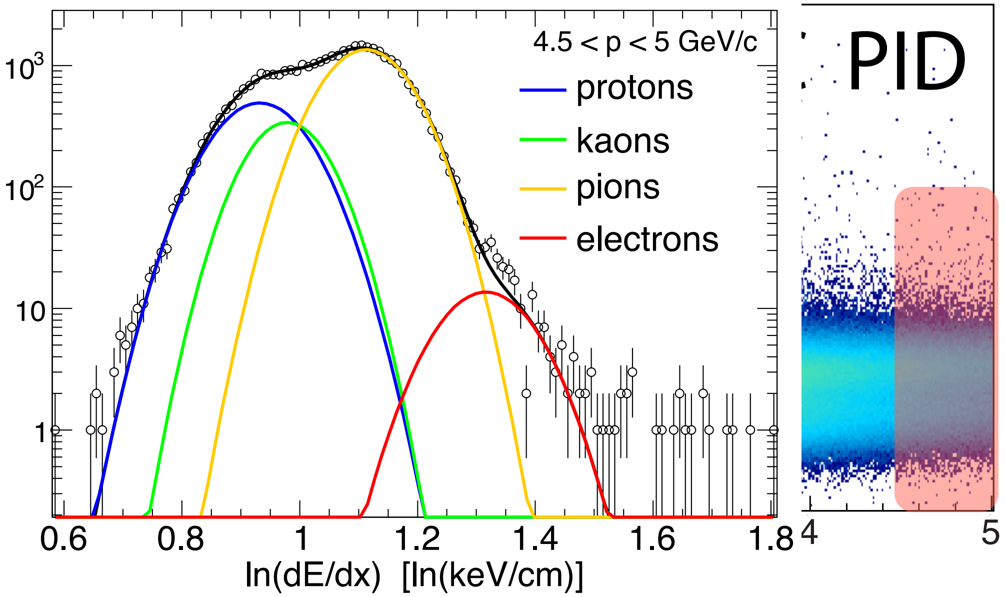
- ★ **MTD: muon identification**

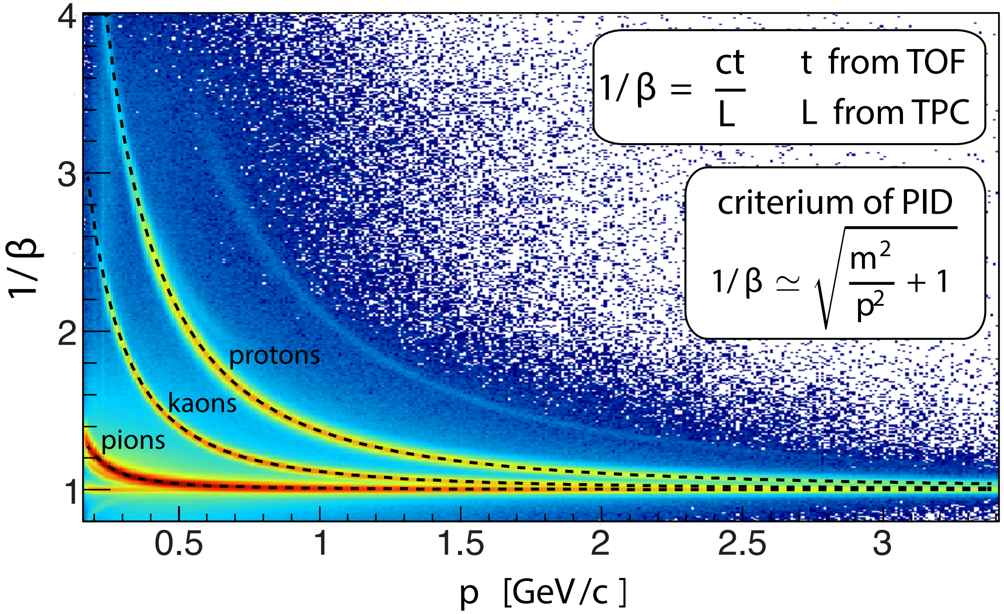
Electron Identification



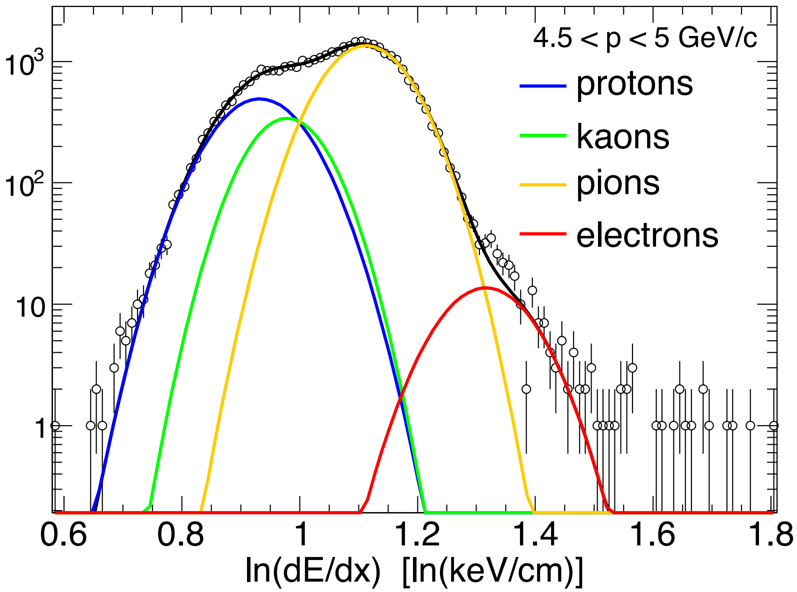


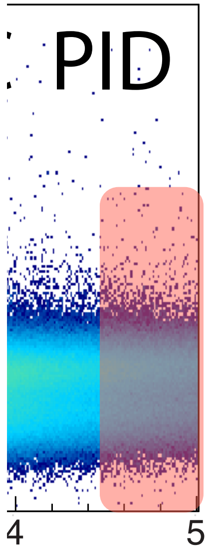
Electron Identification

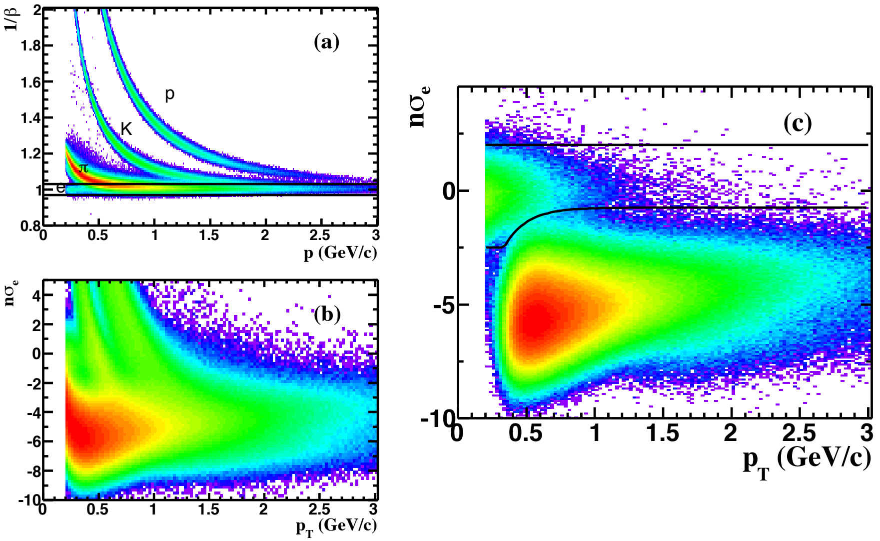


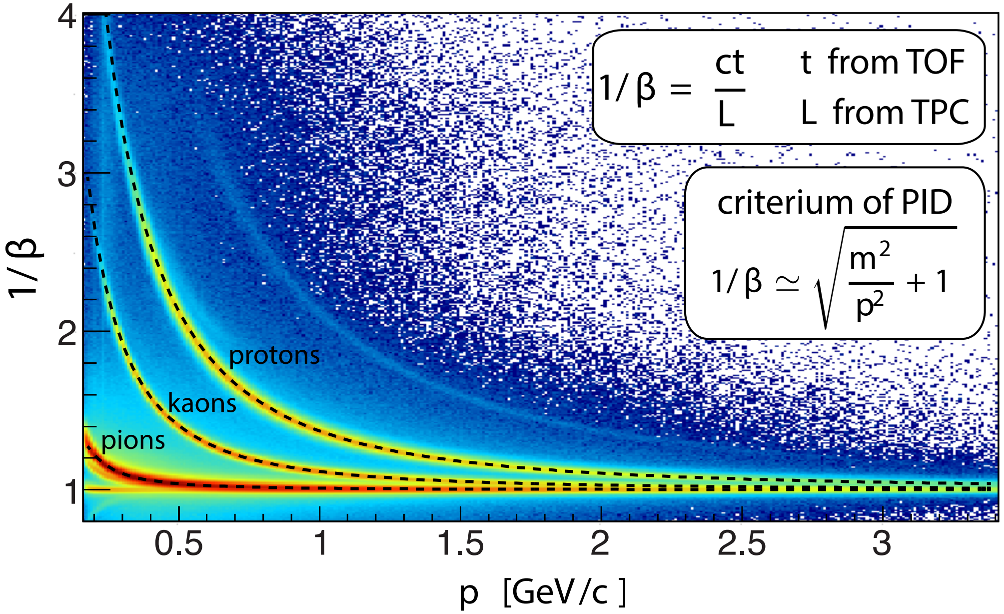


Electron Identification

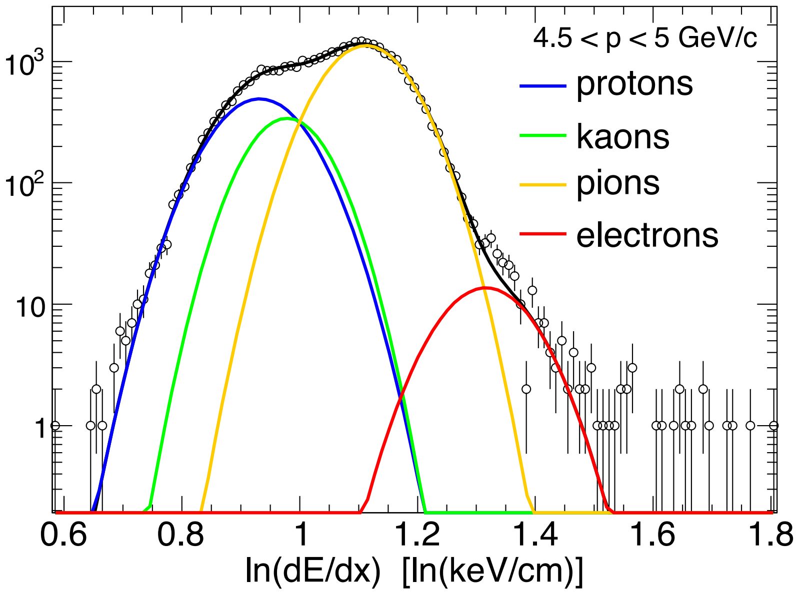


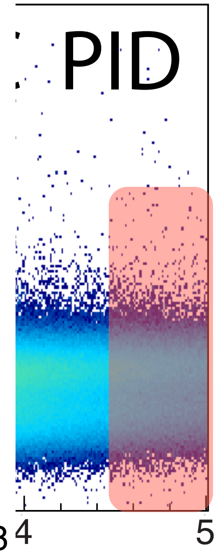


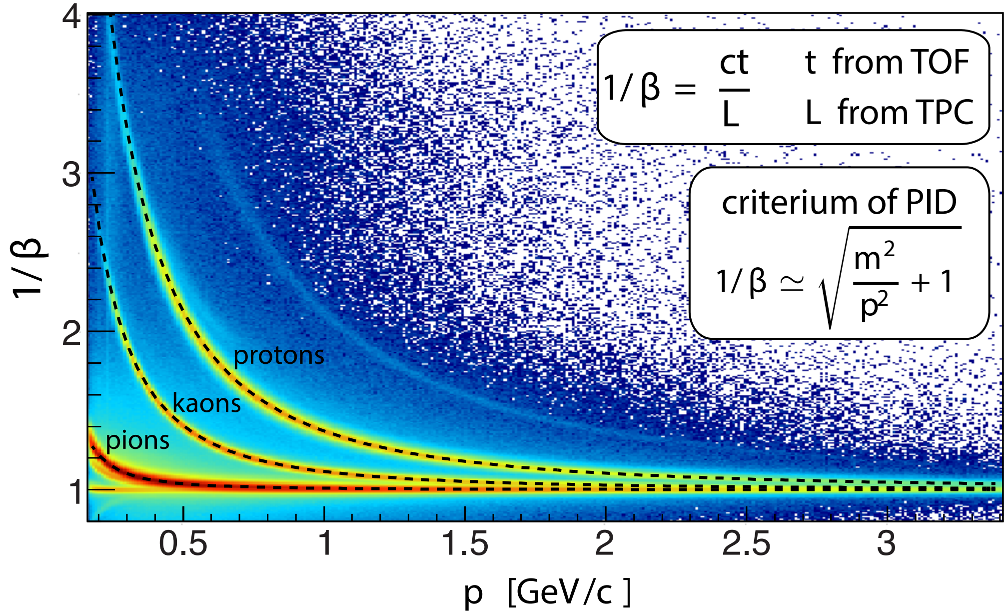


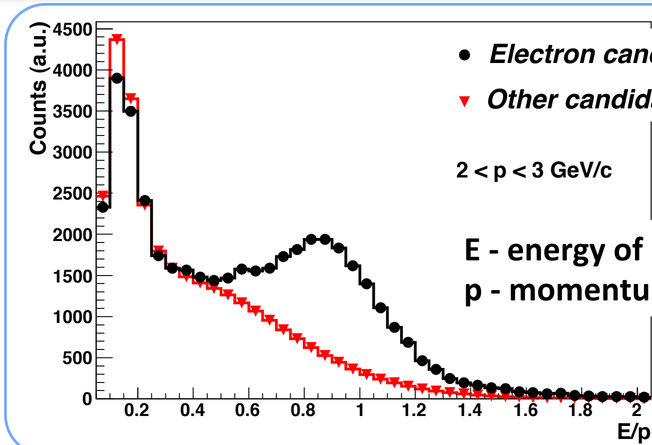


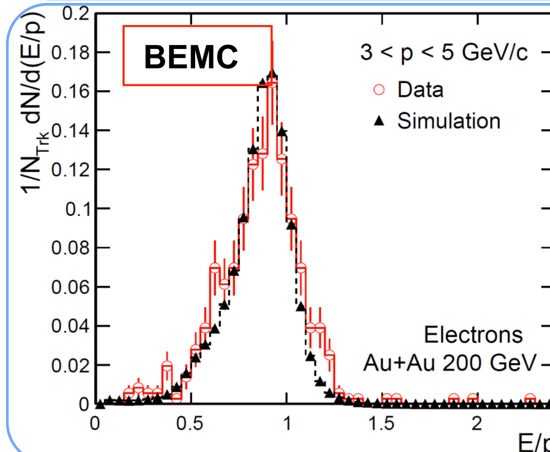
Electron Identification











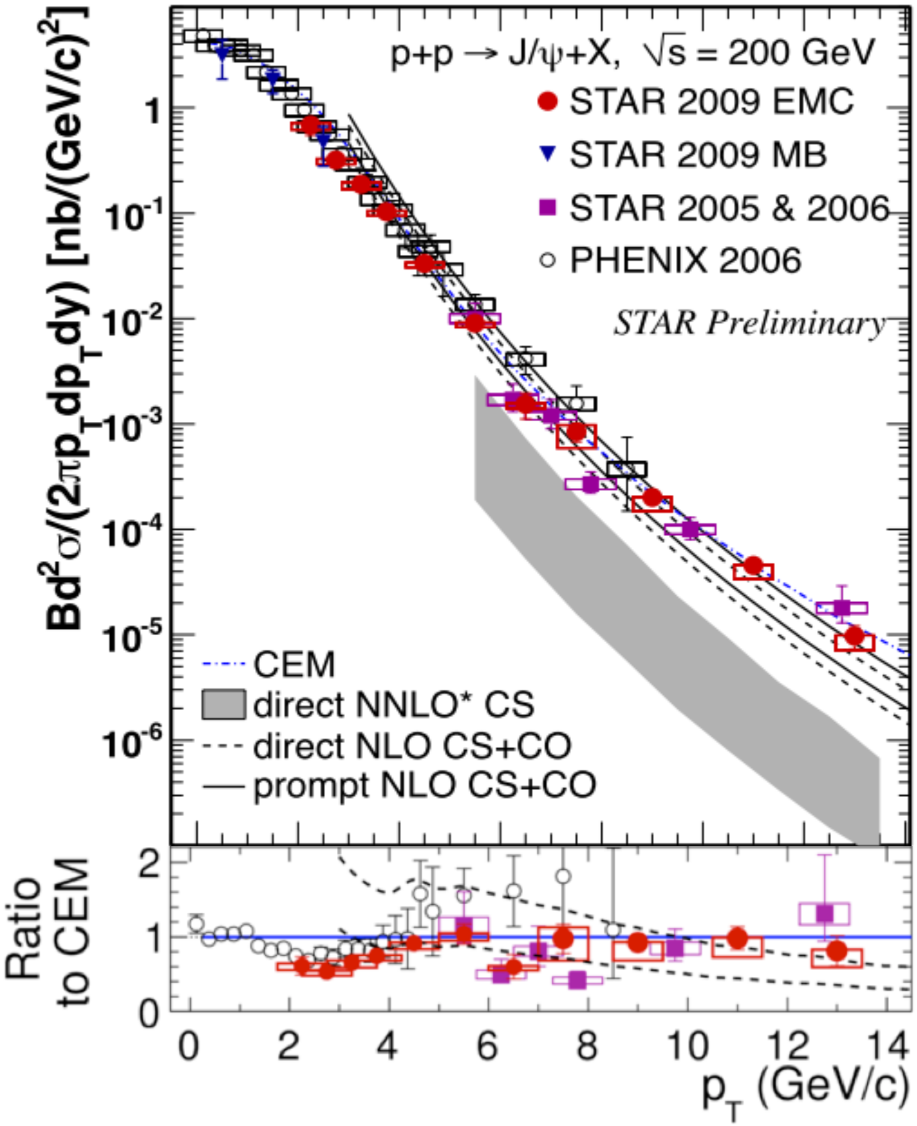
Photonic electron candidates

$M_{e^+e^-} < 0.24 \text{ GeV}/c^2$

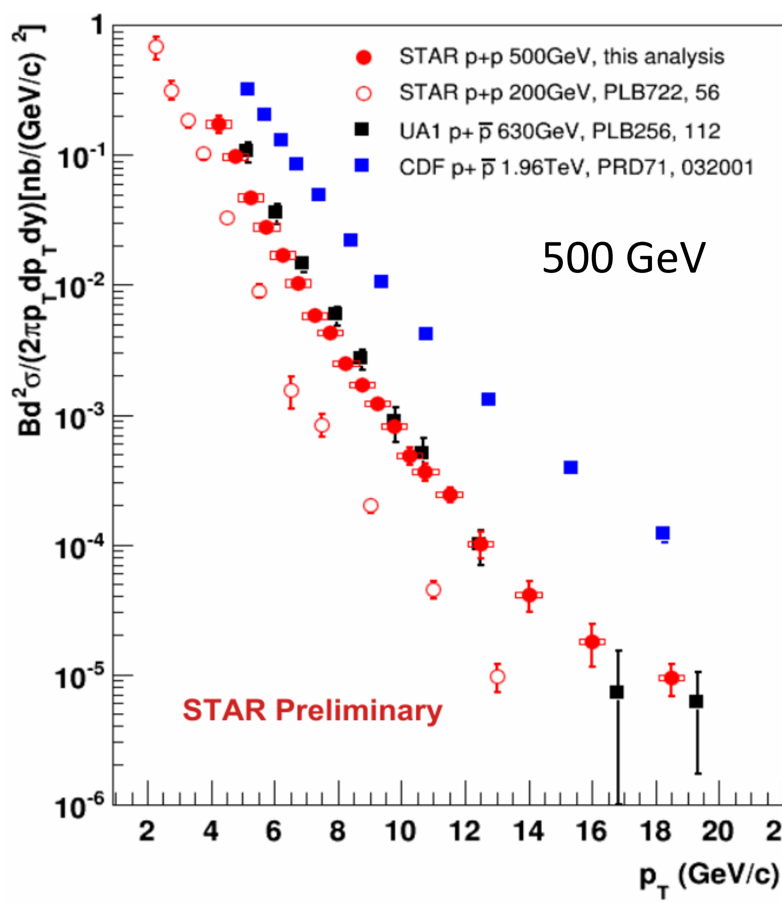
E - energy of BEMC cluster
p - momentum from TPC

electron/hadron separation with BEMC for p > 2 GeV/c

J/Ψ p_T spectra in p+p



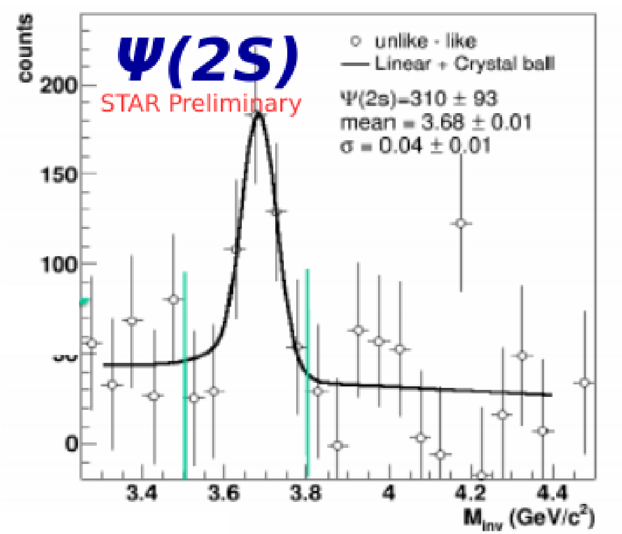
- prompt NLO CS+CO describes the data for p_T>4GeV/c
- direct NNLO*CS misses high-p_T part
- Prompt CEM over-predicts the data at p_T~3 GeV/c

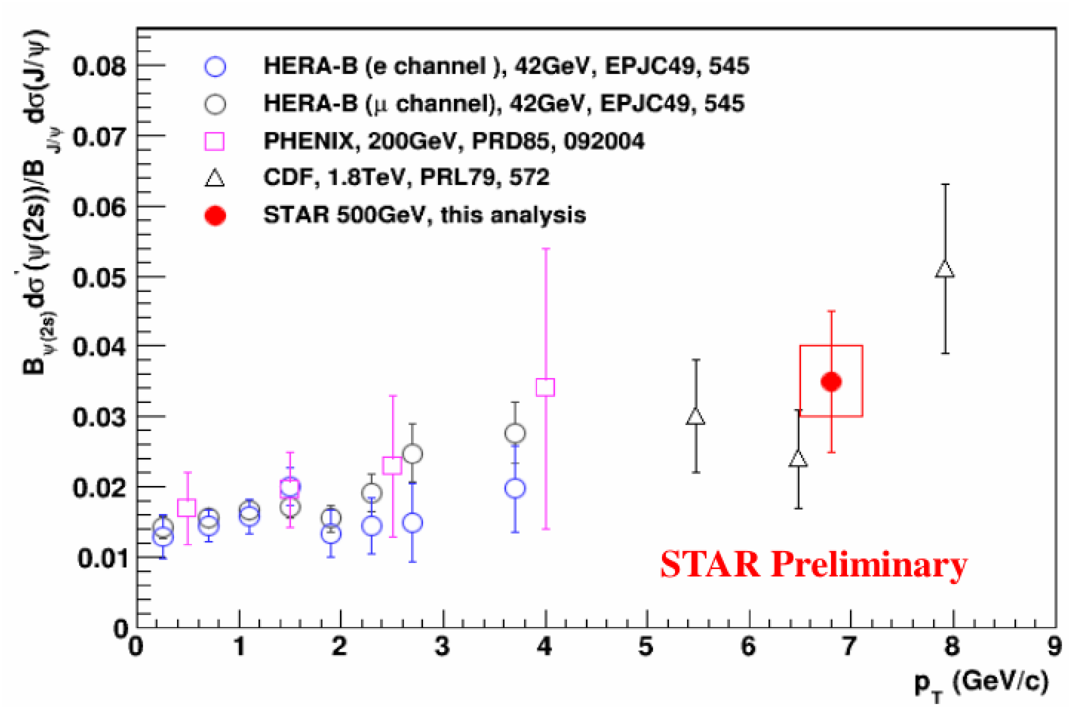


direct NNLO CS: P.Artoisenet et al., Phys. Rev. Lett. 101, 152001 (2008) and J.P.Lansberg private communication
NLO CS+CO: Y.-Q.Ma, K.Wang, and K.T.Chao, Phys. Rev. D 84, 51 114001 (2011) and priv. comm.
CEM: A.D. Frawley, T Ullrich, R. Vogt, Pys. Rept. 462 (2008) 125, and R.Vogt priv. comm.

Ψ(2S) at 500 GeV

Constrain ψ(2S) feed-down contribution to inclusive J/ψ production





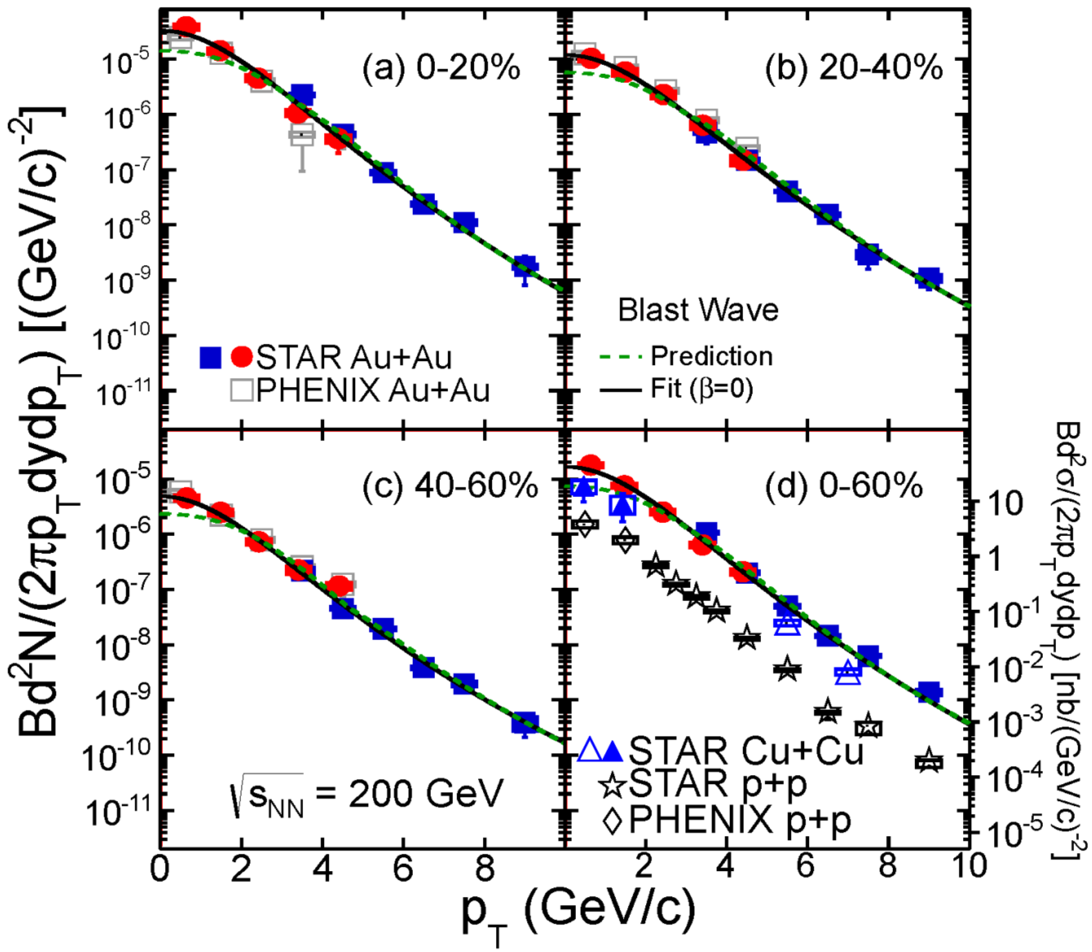
First measurement of (ψ(2S) / J/ψ) ratio in p+p at 500 GeV

Consistent with other experiments

No collision energy dependence observed

J/Ψ p_T spectra in Au+Au

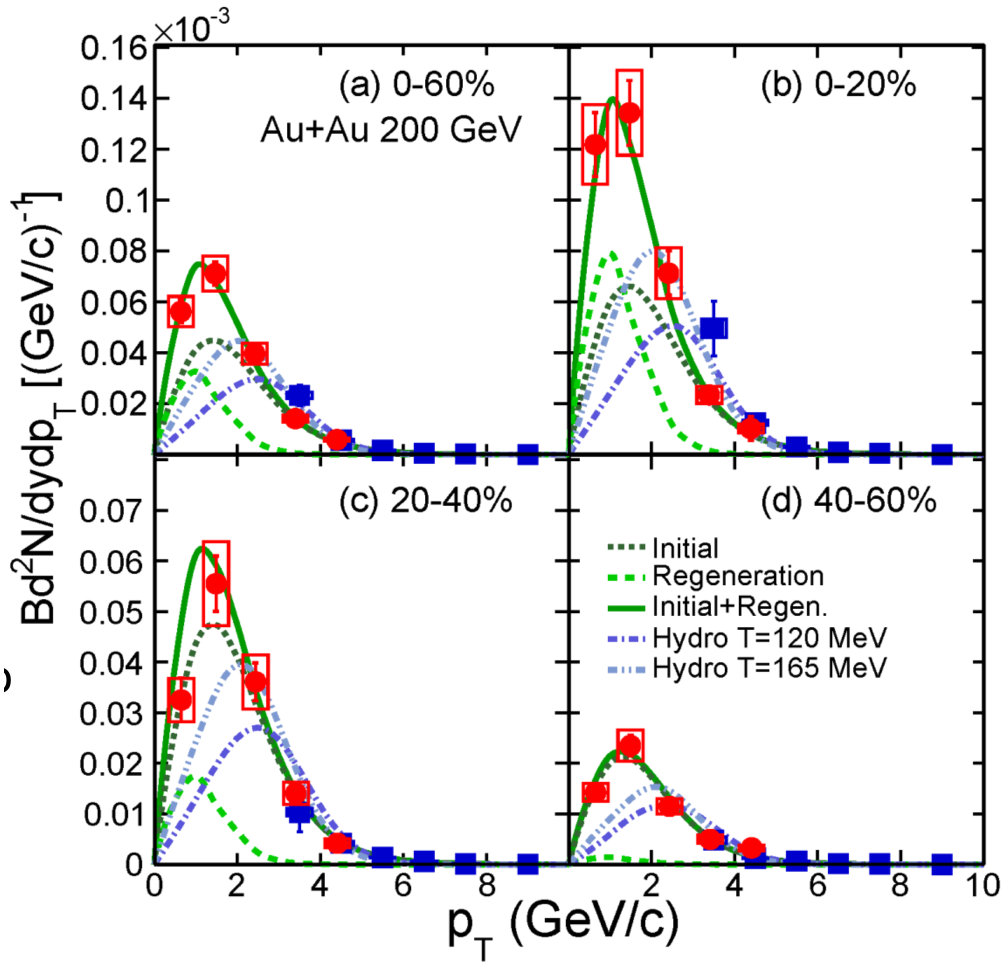
- ★ J/Ψ spectrum softer than Tsallis Blast-wave prediction



STAR low-p_T Au+Au, CuCu : arXiv:1310.3563
high-p_T Au+Au: Phys.Lett. B722, 55 (2013)
high-p_T Cu+Cu : Phys. Rev. C 80 (2009) 041902
PHENIX: Phys. Rev. Lett. 98 (2007) 232301
Tsallis B-W: Z.Tang et al., Chin.Phys.Lett. 30, 031201 (2013)

J/Ψ p_T spectra in Au+Au

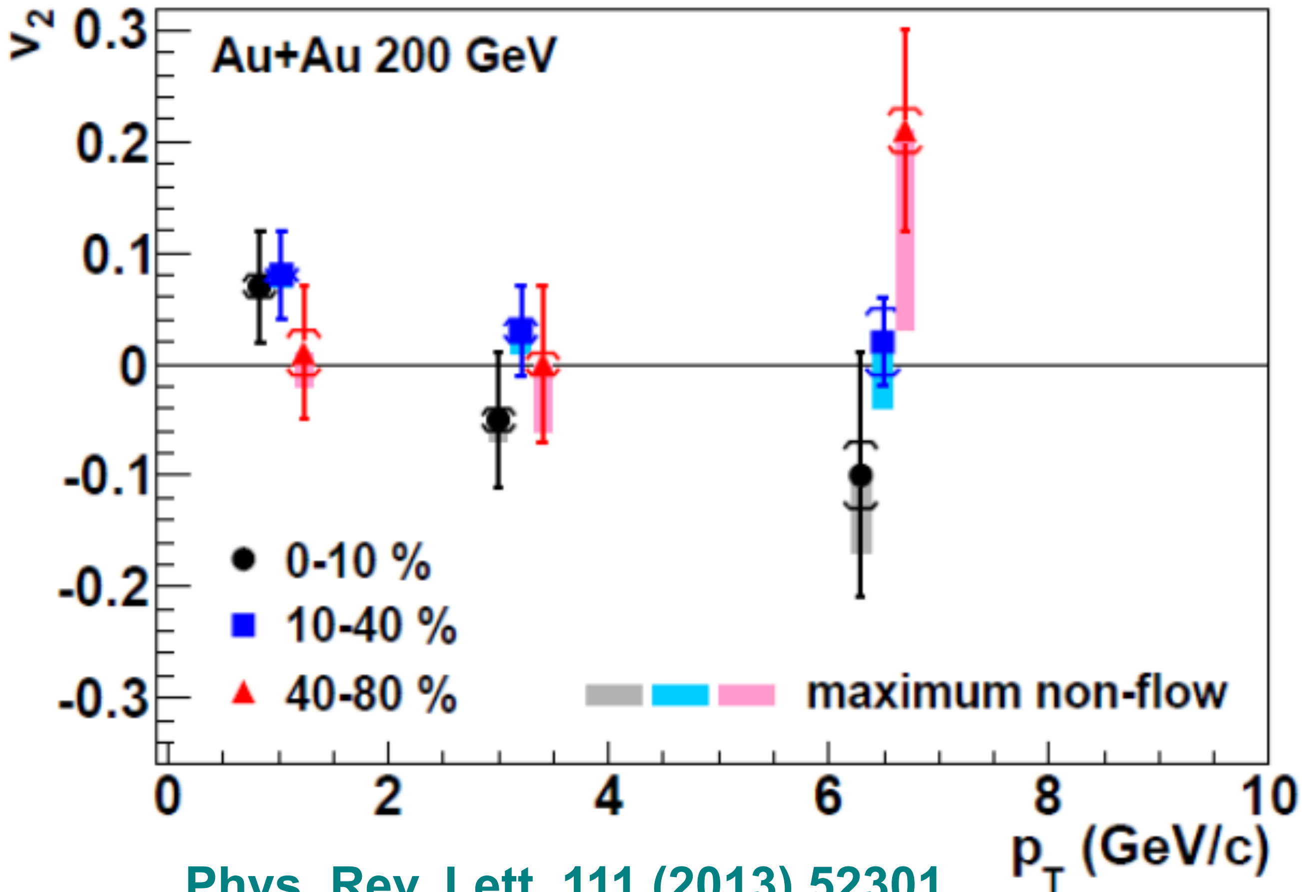
- J/Ψ spectrum softer than Tsallis Blast-wave prediction
- Hydro (viscous)
  - J/Ψ decouples at 120-165 MeV
  - fails at low p_T
- Initial+Regen (Y. Liu)
  - Includes J/Ψ supression due to color screening
  - Includes statistical regeneration
  - peripheral: initial production dominates
  - central: regeneration becomes more significant at low p_T



Y. Liu et al., Phys. Lett. B 678, 72 (2009)
U. W. Heinz and C. Shen (2011), private communication.

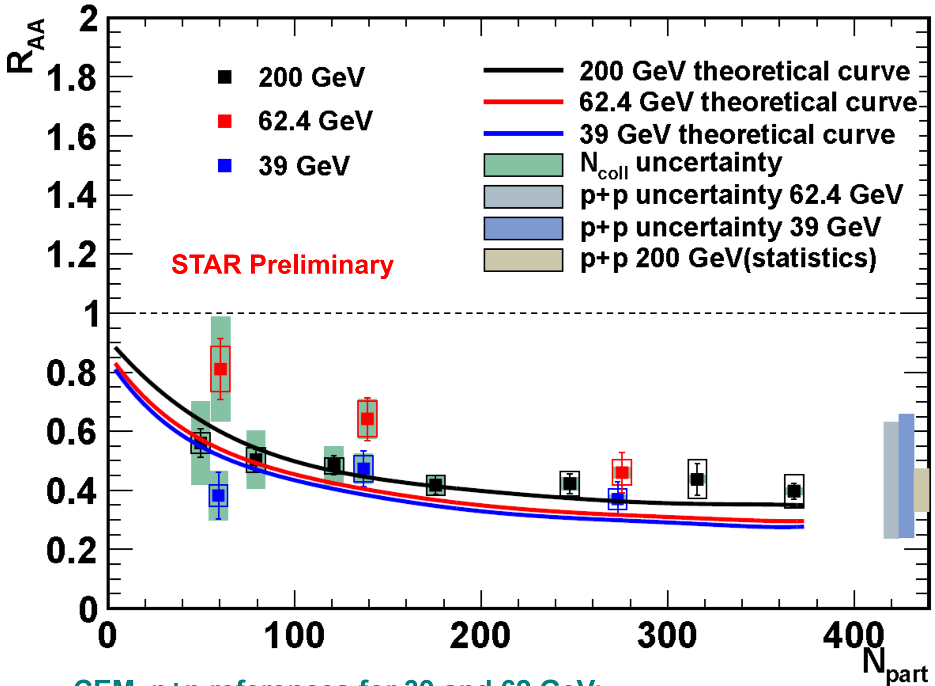
J/Ψ Azimuthal Anisotropy (v_2)

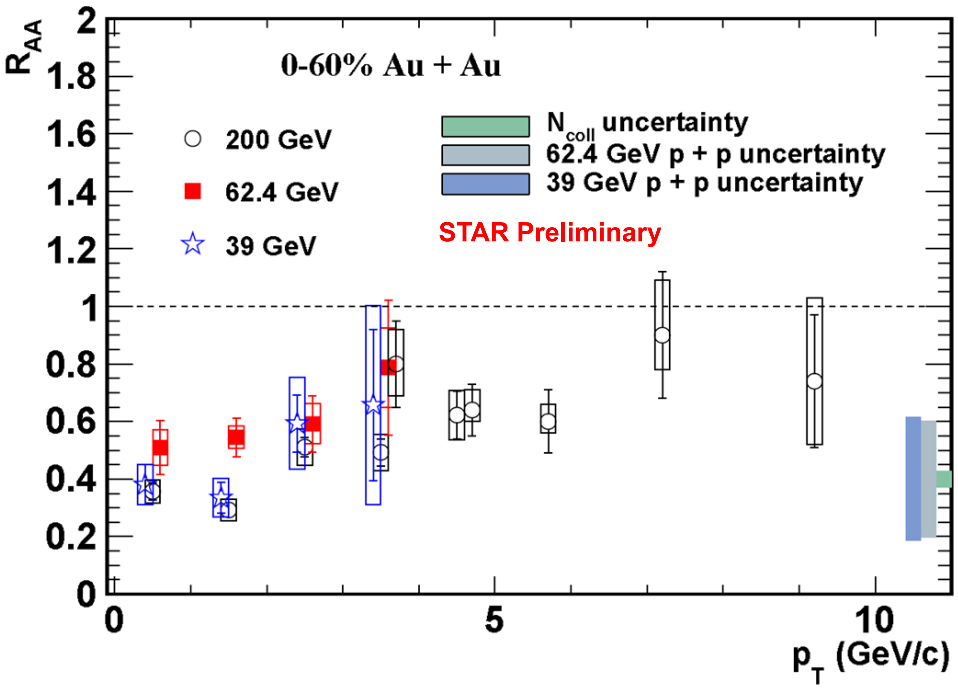
- consistent with non-flow for $p_T > 2$ GeV/c
  - unique among hadrons
  - regardless of centrality
  - thermalized charm quark coalescence does not dominate production



Phys. Rev. Lett. 111 (2013) 52301

J/Ψ R_{AA} in BES

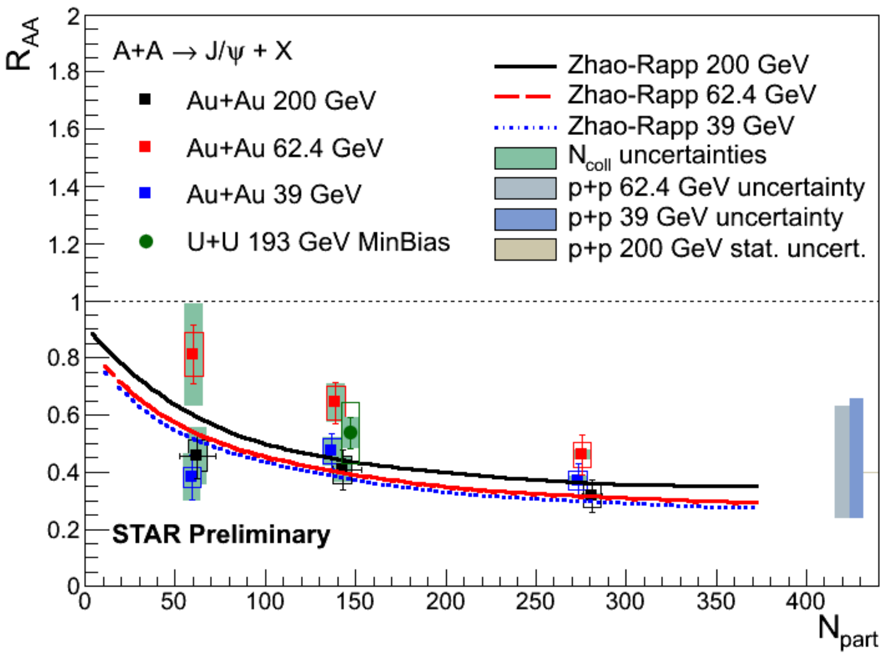


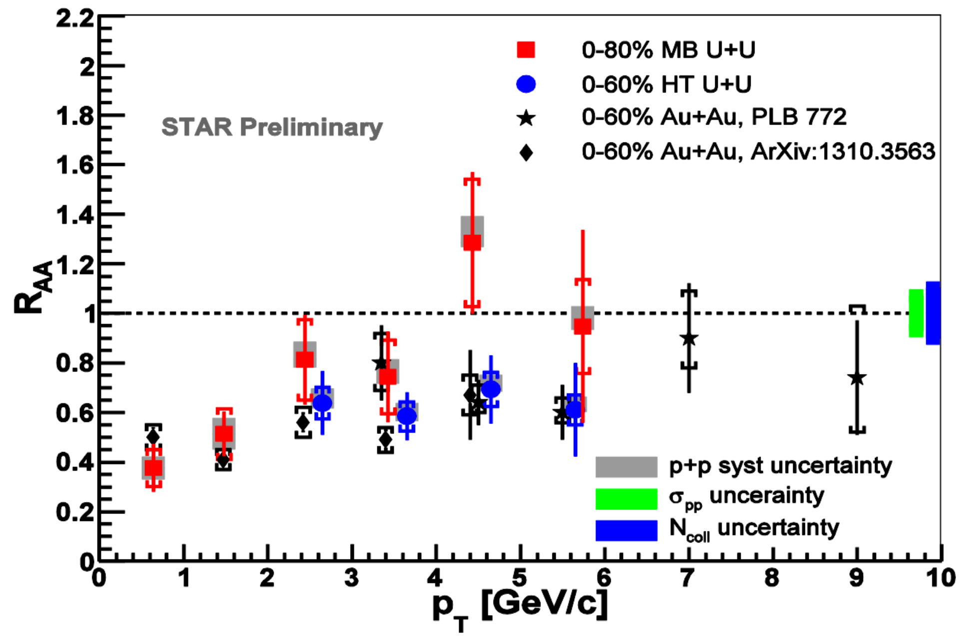


CEM p+p references for 39 and 62 GeV:
Nelson, Vogt et al., PRC87, 014908 (2013)
Theory: Zhao, Rapp, PRC82, 064905 (2010)

- Similar suppression in Au+Au at **200**, 62.4 and 39 GeV
- p+p reference was based on CEM calculationn

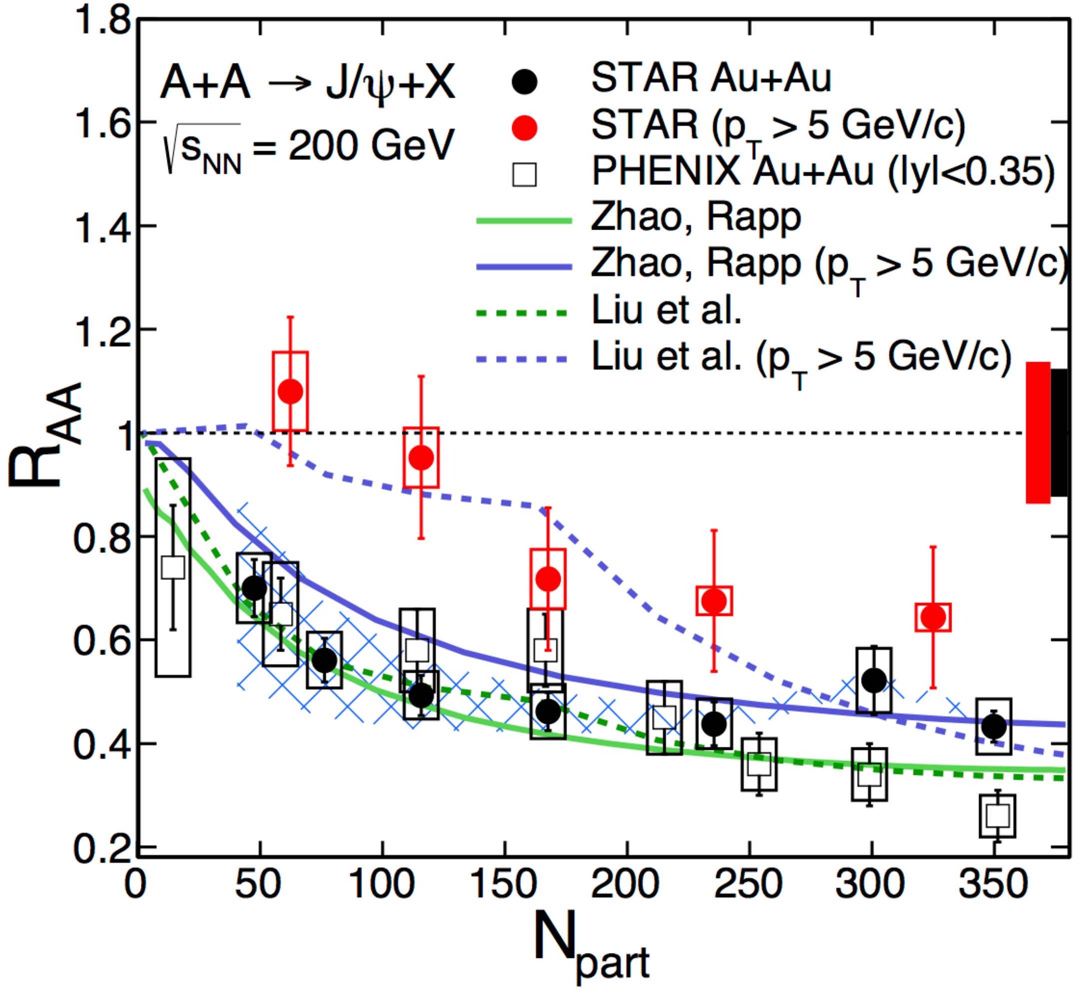
J/Ψ R_{AA} in U+U at 193 GeV





- ★ Similar to Au+Au
- ★ Similar trend in p_T
- ★ In U+U collisions, we reach higher N_{part} and energy density

High-p_T J/Ψ R_{AA} in Au+Au

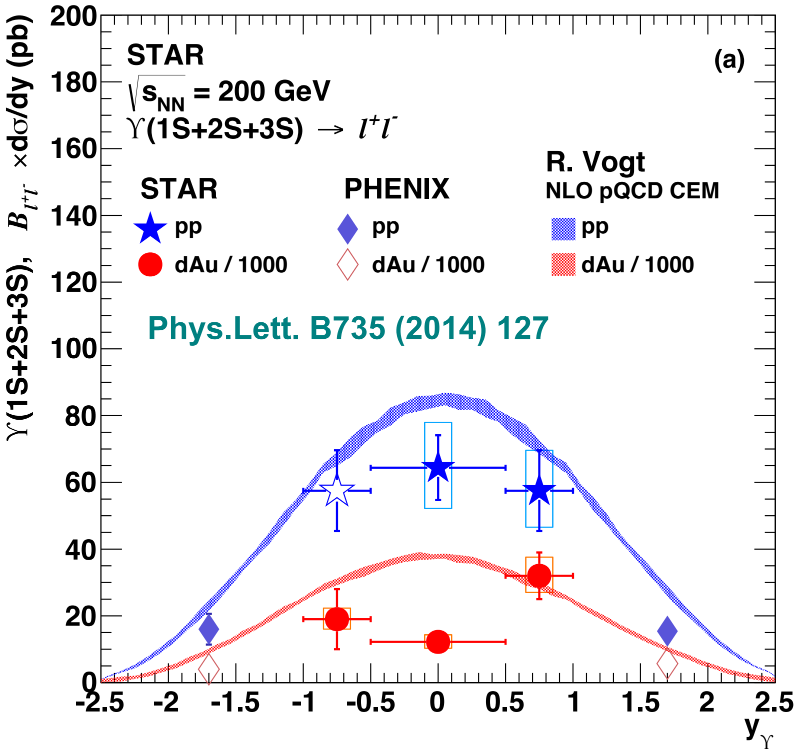


- ★ CNM effects negligible
- ★ Less regeneration
- ★ Suppression in central collisions

➡ **clear QGP effect**

STAR low-p_T : arXiv:1310.3563
STAR high-p_T : PLB722, 55 (2013)
Liu et al., PLB 678, 72 (2009)
Zhao and Rapp, PRC 82, 064905(2010), PLB 664, 253 (2008)
PHENIX Phys. Rev. Lett. 98, 232301 (2007)

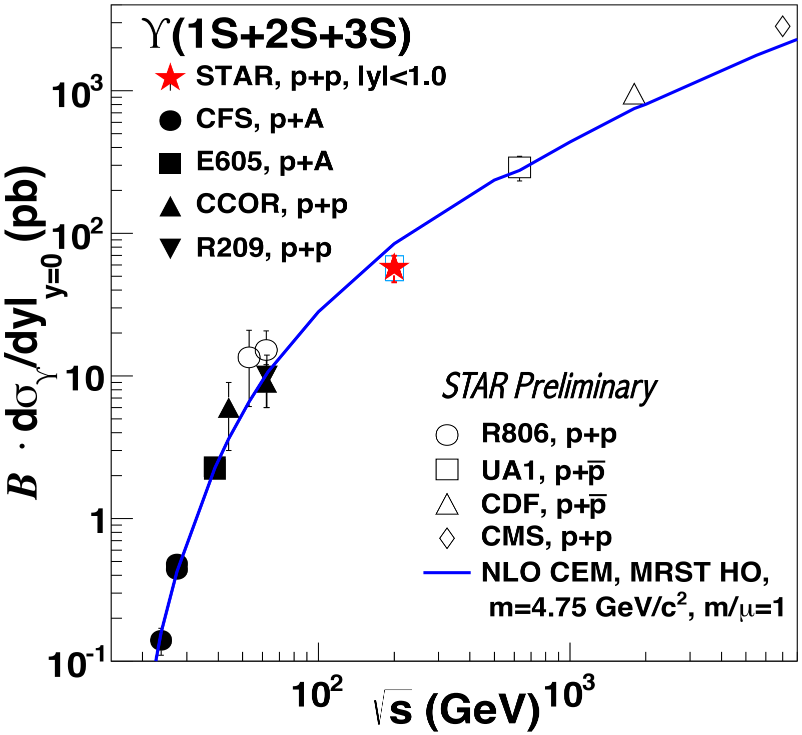
Υ in p+p - Baseline and pQCD Test



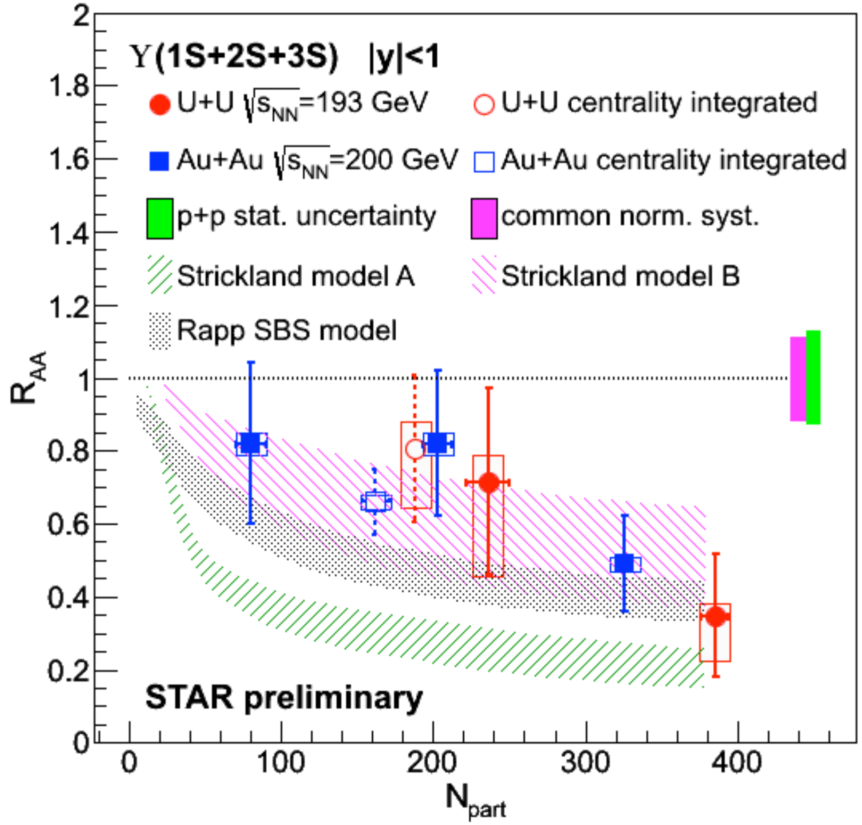
- p+p Υ cross section vs. y, compared to pQCD predictions

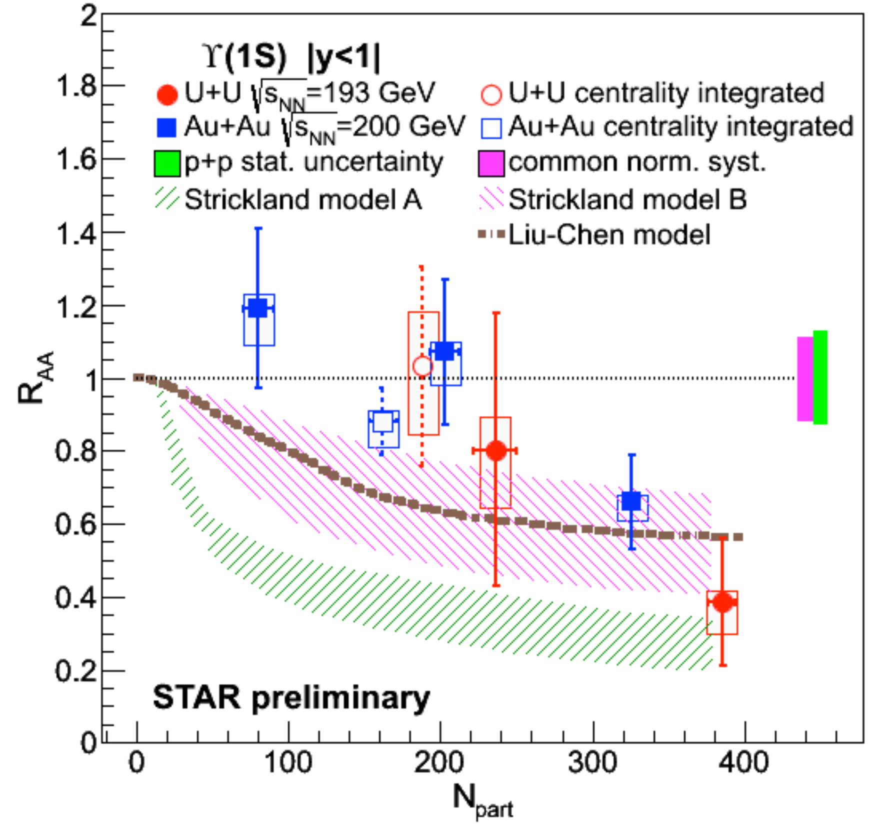
R. Vogt, Phys. Rep. 462125, 2008

- p+p Υ cross section, compared to world data trend



ϒ R_{AA} : ϒ(1S+2S+3S) and ϒ(1S) in Au+Au and U+U





Strickland, Bazov, Nucl.Phys.A 879, 25 (2012)

- No CNM effects, 428<T<443 MeV
- Potential model 'B' based on **heavy quark internal energy**
- Potential model 'A' based on heavy quark free energy (disfavored)

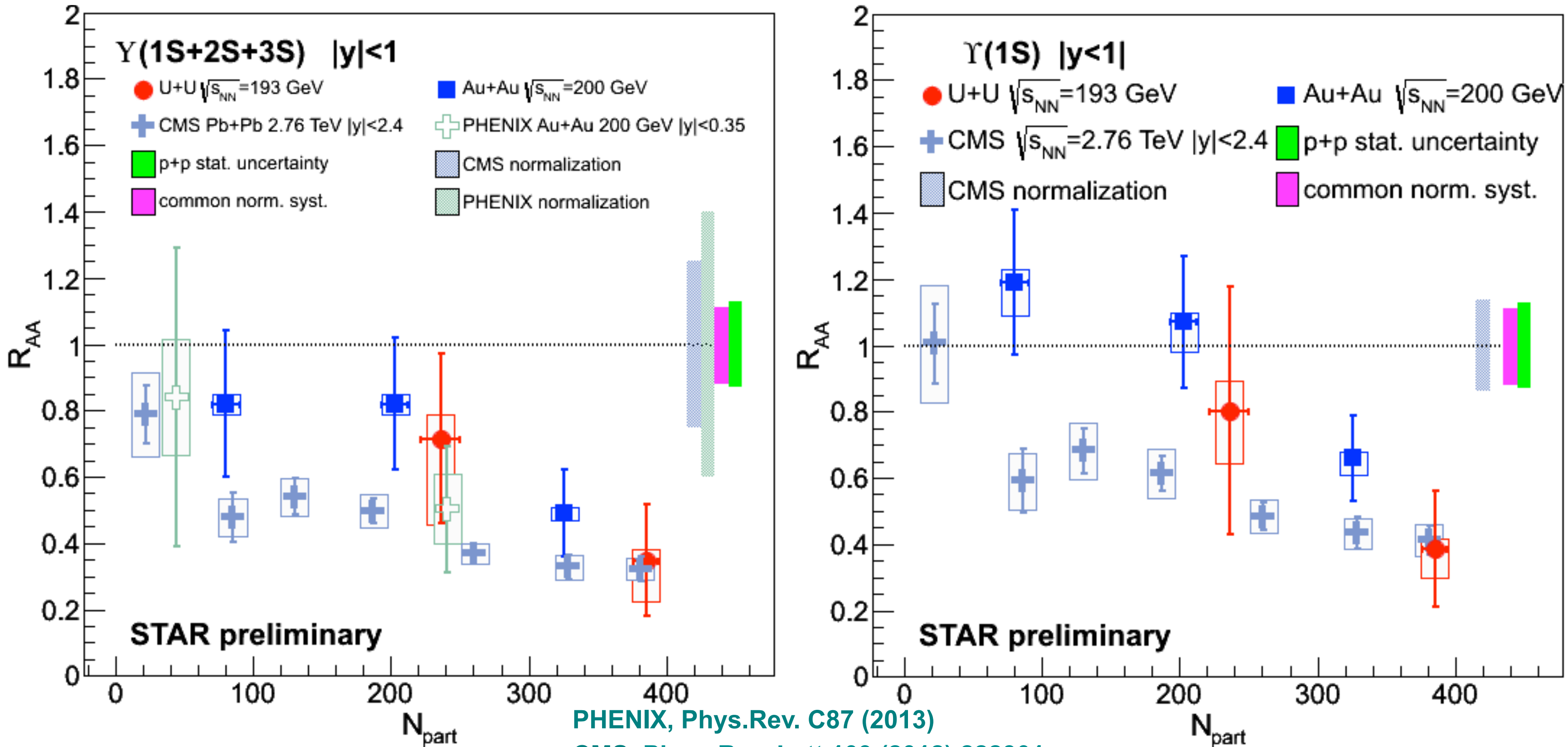
Liu, Chen, Xu, Zhuang, Phys.Lett.B 697, 32 (2011)

- Potential model, no CNM effects
- T=340 MeV, only excited states dissociate

Emerick, Zhao, Rapp, Eur.Phys.J A48, 72 (2012)

- **CNM effects** included
- Strong binding scenario

ϒ RAA : RHIC vs LHC

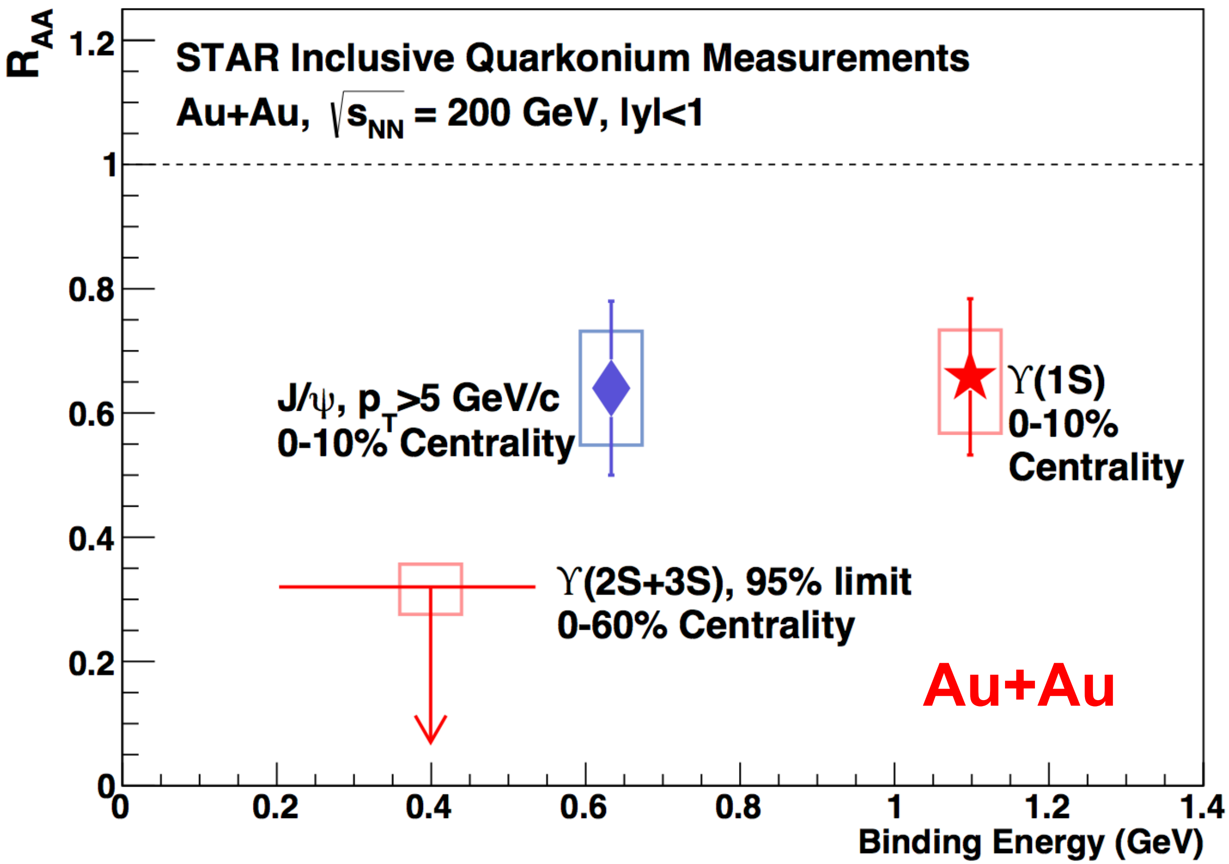


PHENIX, Phys.Rev. C87 (2013)
CMS, Phys. Rev. Lett 109 (2012) 222301

- ★ comparable at high N_{part}
- ★ N_{part} dependence appears weaker at LHC
- ➡ Is suppression driven by energy density?

Υ(2S+3S) R_{AA} in Au+Au

Phys.Lett. B735 (2014) 127

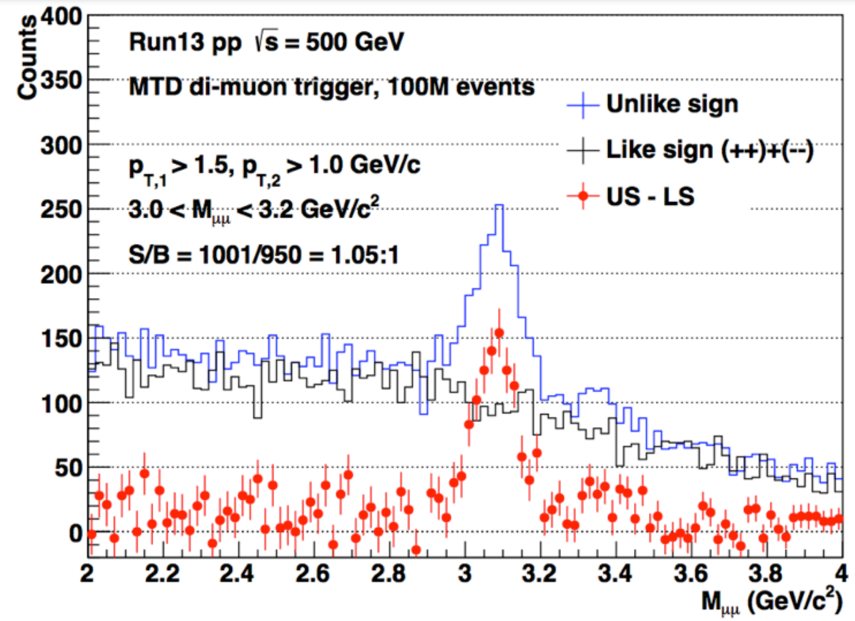


- ★ consistent with complete melting
- ★ Υ(1S) suppression similar to J/Ψ suppression

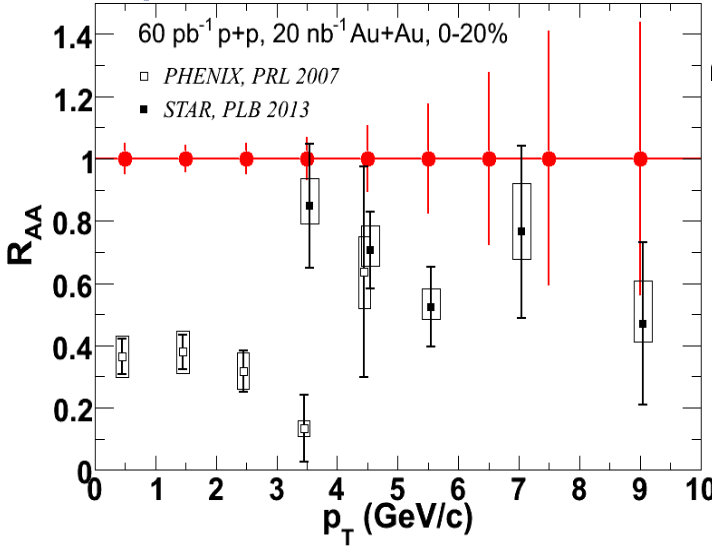
Υ suppression pattern supports sequential melting

Outlook: Muon Telescope Detector

- ★ No gamma conversion
- ★ Less Bremsstrahlung
  ⇒ better resolution
- ★ Less contribution from Dalitz decays
- ★ Trigger capability



J/ψ projected stat. errors



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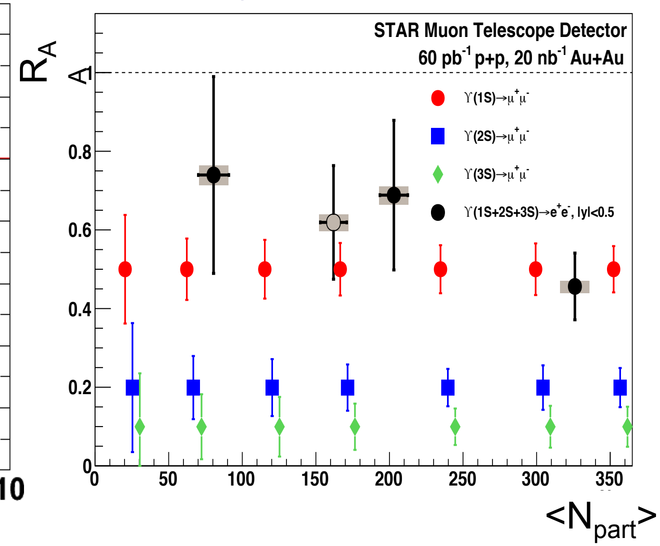

Summary

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- **J/ψ BES:** similar suppression in central 39, 62.4 and 200 GeV data
  ⇒attests *to the role of regeneration*
- **Collective behavior of J/ψ:** v_2 consistent with non-flow for $p_T > 2$GeV/c
- **Hot medium effects:**
  - Significant suppression of high-pT J/ψ and similar ϒ(1S) suppression in central Au+Au collisions
  - ϒ(2S) and ϒ(3S) suppression is stronger than ϒ(1S)
    ⇒ *clear signal of melting in a deconfined medium*
  - ϒ suppression in most central collisions similar to LHC
- **U+U measurements:** similar suppression patterns to Au+Au

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Stay tuned for new great results with MTD

Thank you