Dilepton production in p+p, Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV and U+U collisions at $\sqrt{s_{NN}} = 193$ GeV

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RICE UNIVERSITY
FOR THE STAR COLLABORATION

In This Talk

Part I

- Very low p_T e^+e^- invariant mass spectra in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV and U+U collisions at $\sqrt{s_{NN}} = 193$ GeV

See Shuai Yang's Poster : Poster ID 340

Part II

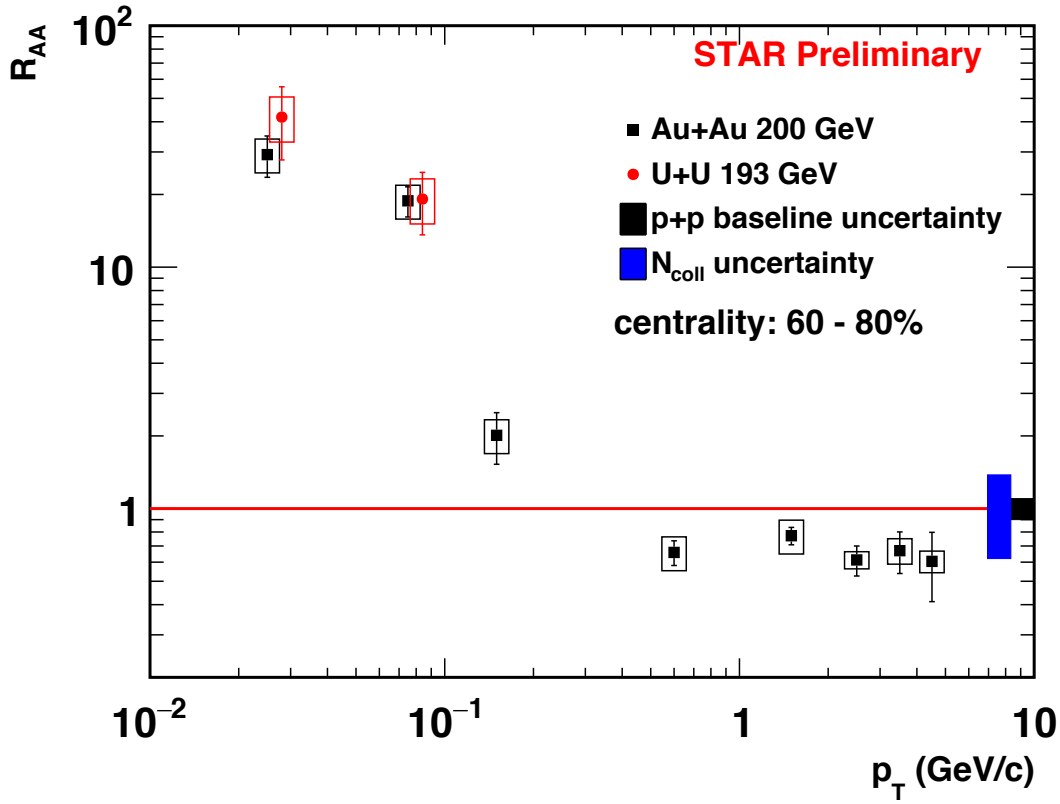
- First look at $\mu^+\mu^-$ invariant mass spectra with the Muon Telescope Detector at STAR in p+p collisions at $\sqrt{s} = 200$ GeV and peripheral Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

Motivation: Low p_T J/ψ Enhancement

- → STAR and ALICE have observed significant excess production of J/ψ in peripheral A+A collisions at low p_T (p_T < 300 MeV/c)
- → Cannot be described by hadronic production modified by medium / cold nuclear matter effects
- → May be due to coherent photoproduction?
- → Observed in collisions with impact parameter b < 2 R

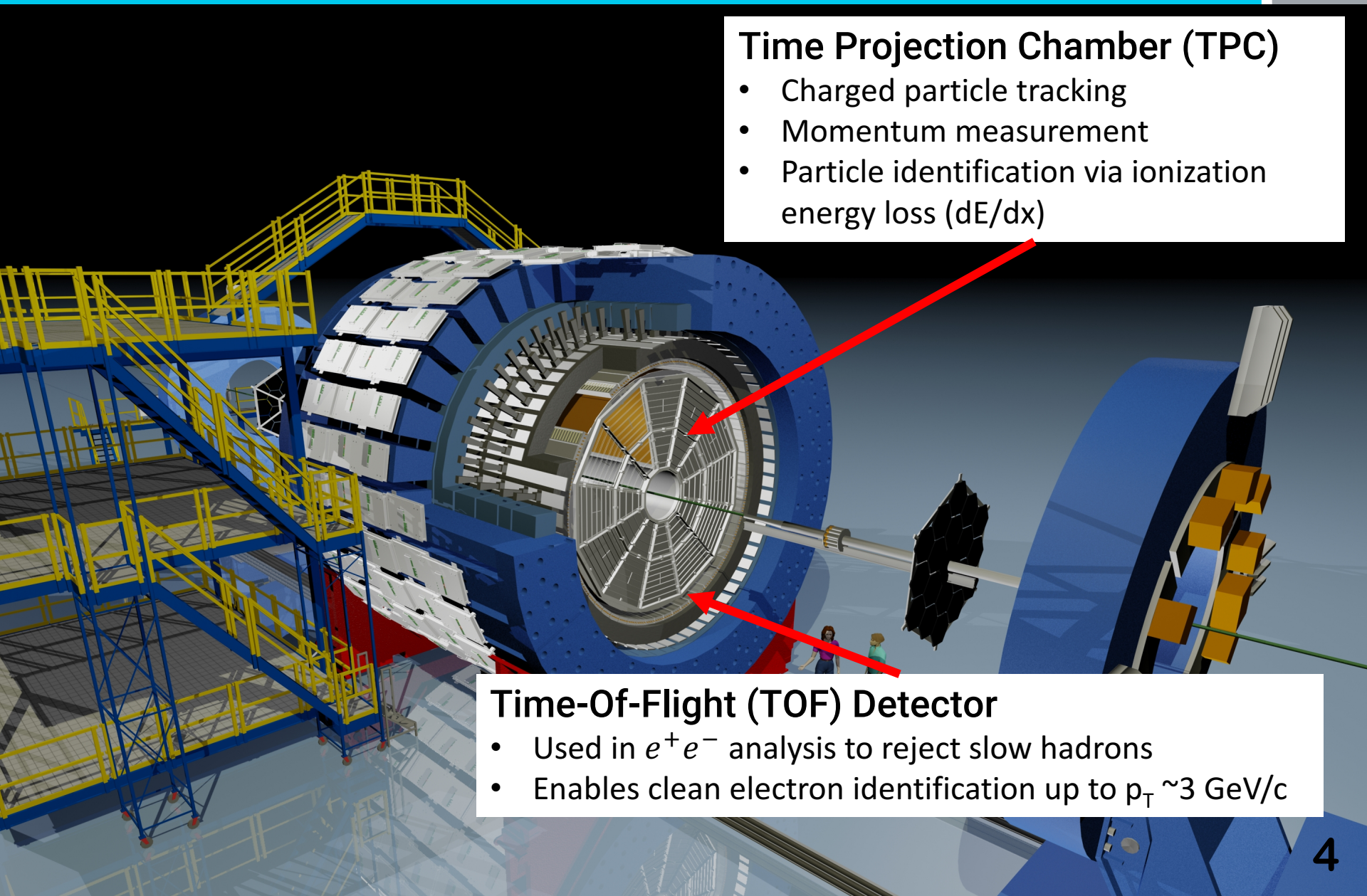
Motivation to measure e^+e^- pair production over a wider invariant mass range

J/ψ R_{AA} in Au+Au and U+U Collisions via $J/\psi \rightarrow e^+e^-$



See Wangmei Zha's poster
Poster ID 258

STAR Detector



Time Projection Chamber (TPC)

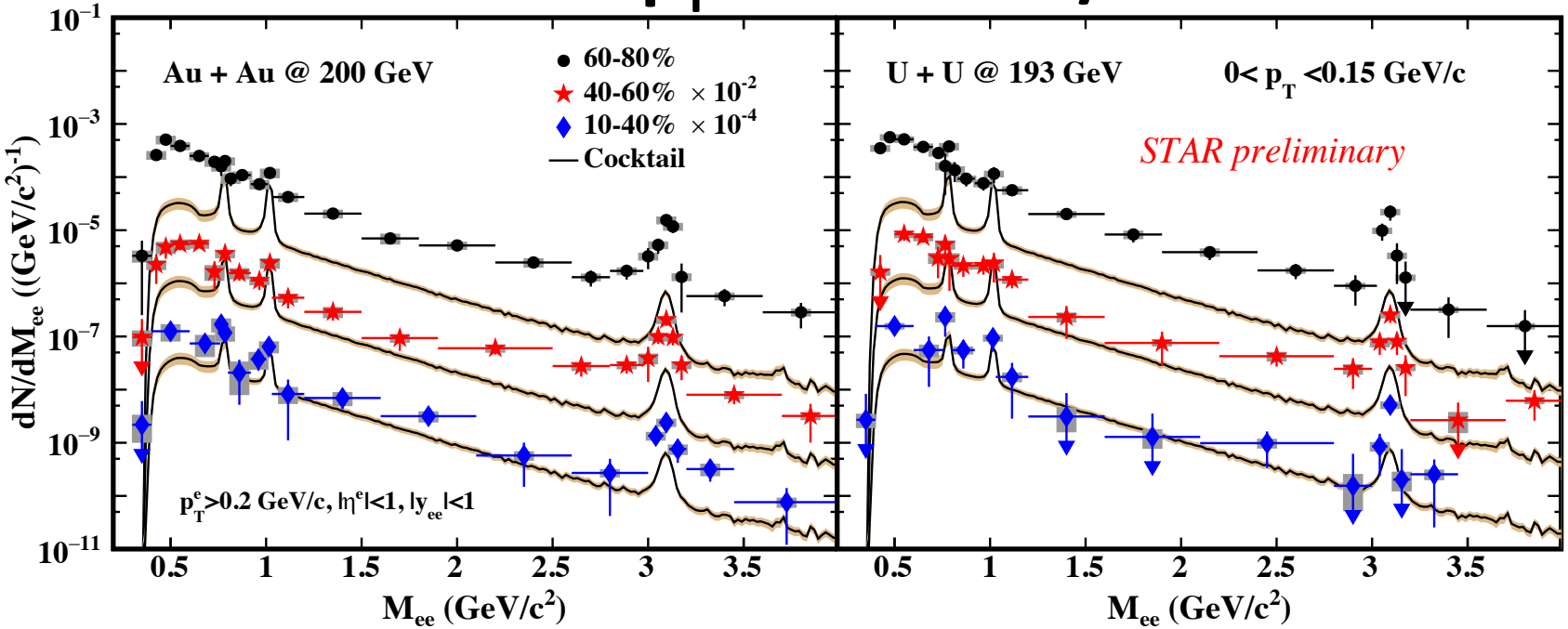
- Charged particle tracking
- Momentum measurement
- Particle identification via ionization energy loss (dE/dx)

Time-Of-Flight (TOF) Detector

- Used in e^+e^- analysis to reject slow hadrons
- Enables clean electron identification up to p_T ~3 GeV/c

STAR e^+e^- in Au+Au & U+U

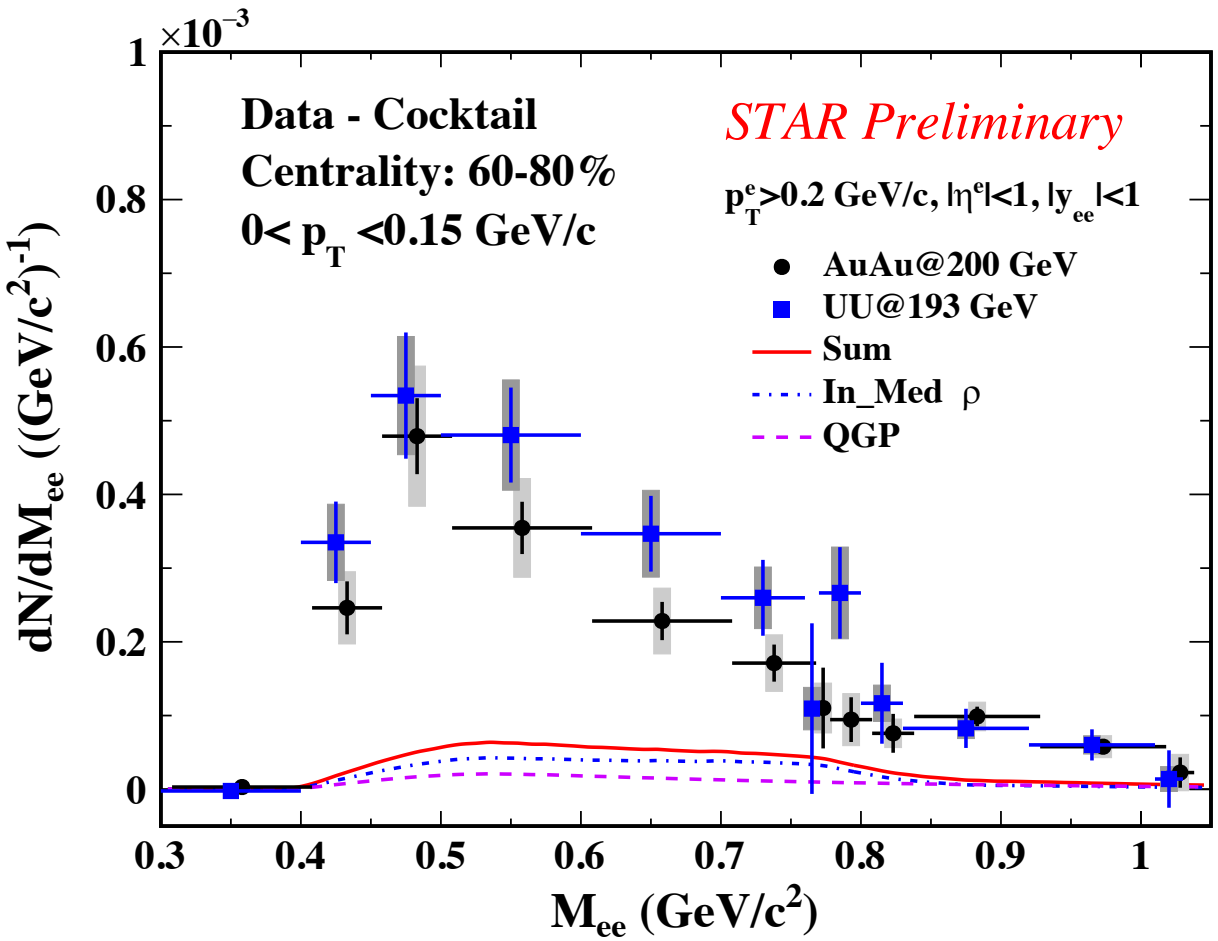
$0 < p_T < 0.15$ GeV/c



→ Significant excess in 60-80% central Au+Au and U+U collisions for $M_{ee} < 4$ GeV/c^2

→ Excess becomes less significant in more central collisions

STAR e^+e^- in Au+Au & U+U

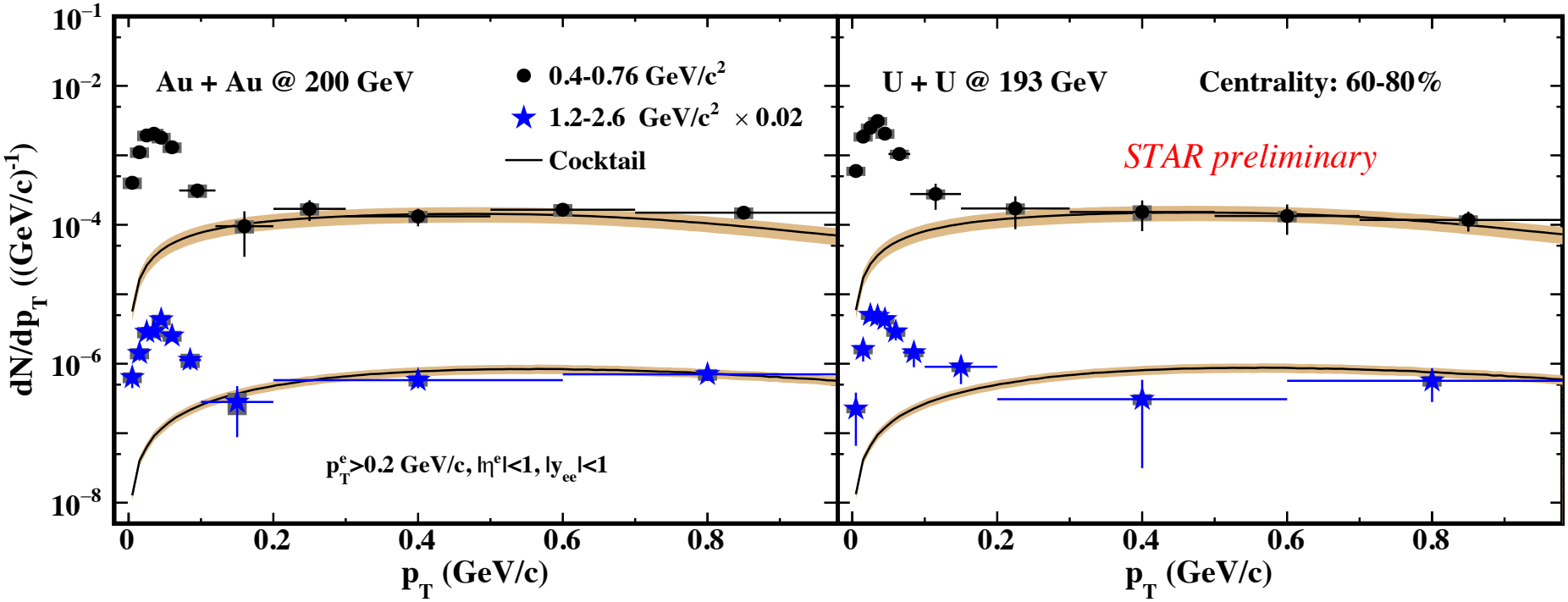


→ Excess is consistent in Au+Au and U+U

→ Excess cannot be explained by hadronic contributions modified by medium

→ **Can this excess be explained by coherent photoproduction?**

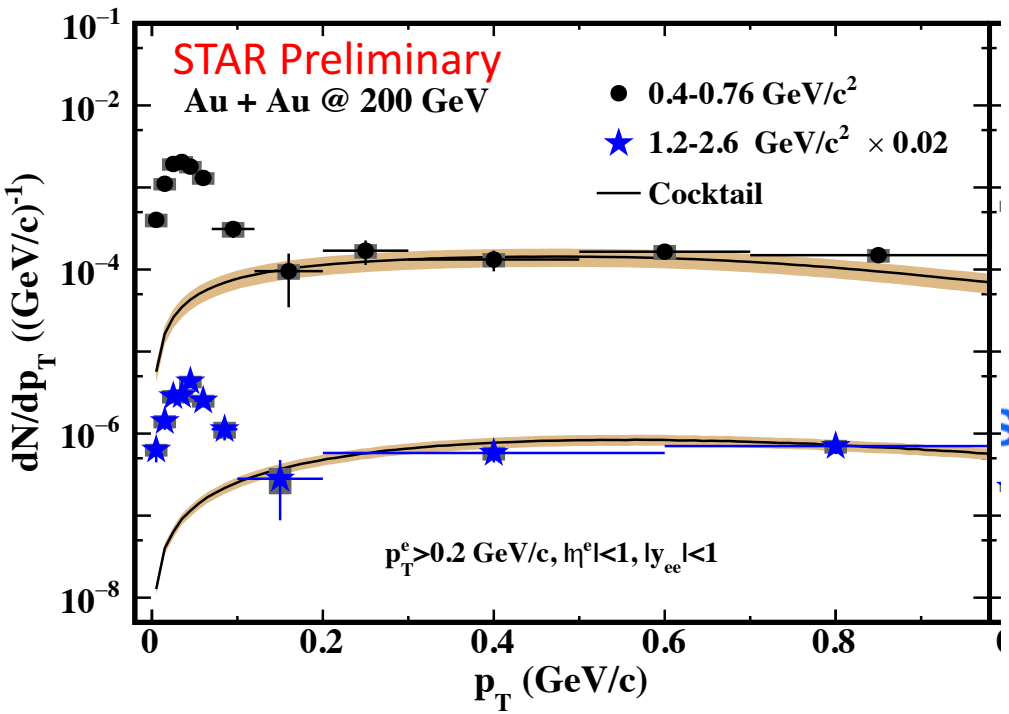
STAR e^+e^- in Au+Au & U+U

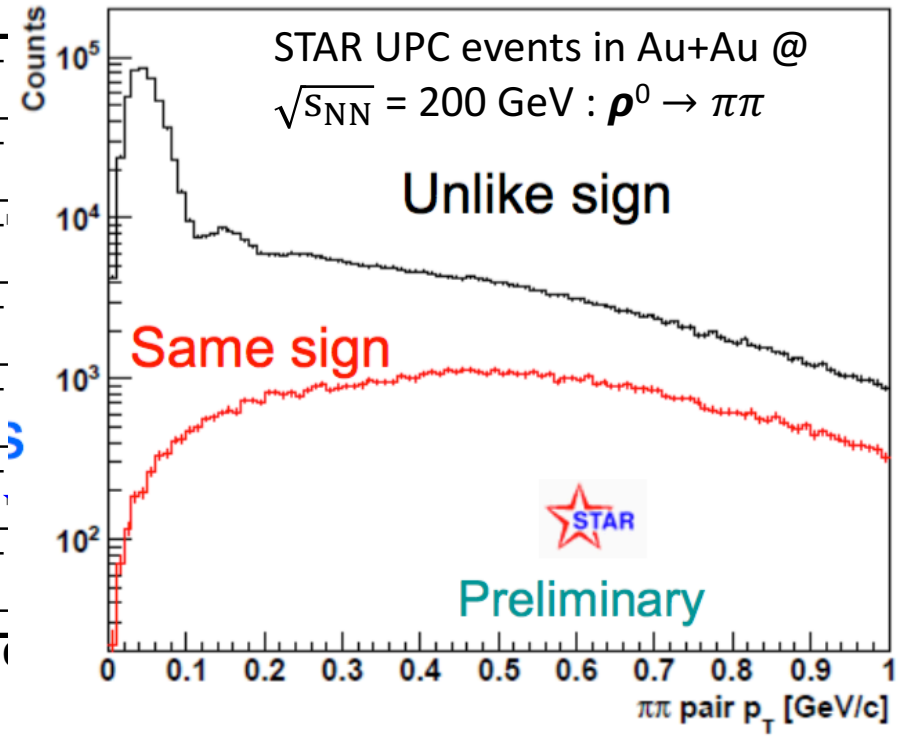


→ Good agreement with hadronic cocktail contributions for $p_T > 0.2$ GeV/c

→ Excess is found entirely below $p_T < 0.2$ GeV/c

STAR e^+e^- in Au+Au & U+U





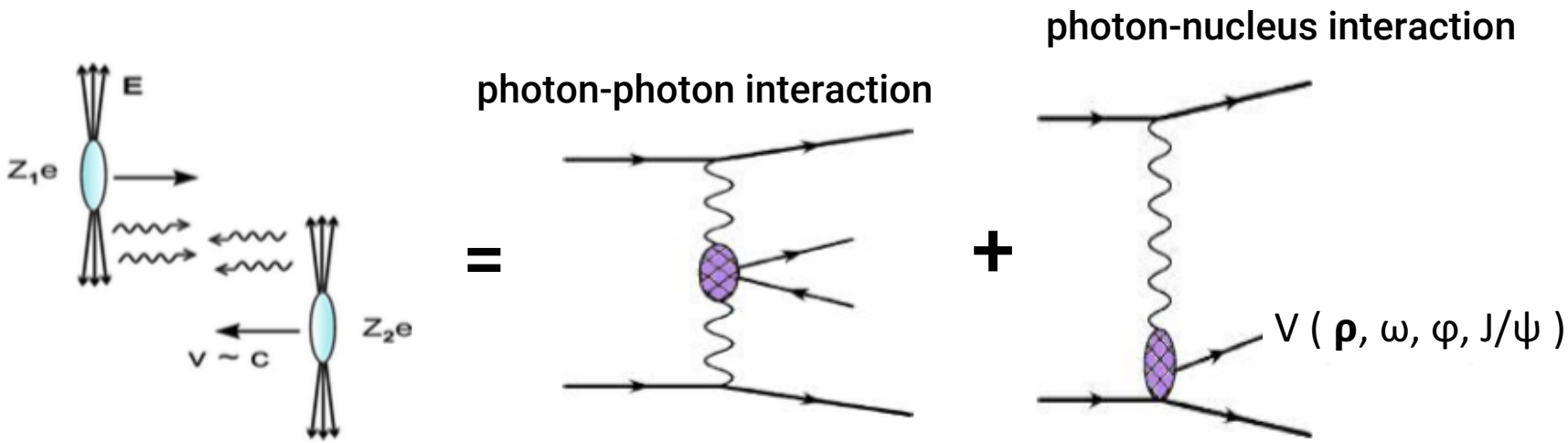
→ Low p_T shape very similar to that from coherent photoproduction in Ultra Peripheral Collisions

→ **Can this excess in e^+e^- be explained by coherent photoproduction?**

Photon Interactions in A+A Collisions

→**What is coherent photoproduction?**

Photoproduction in Ultra Peripheral Collisions (UPC)



C. Bertulani, S. Klein, J. Nystrand Ann. Rev. Nucl. Part. Sci.55:271(2005)

Coherent:

→Emitted photon/pomeron interacts with the nucleus as a whole

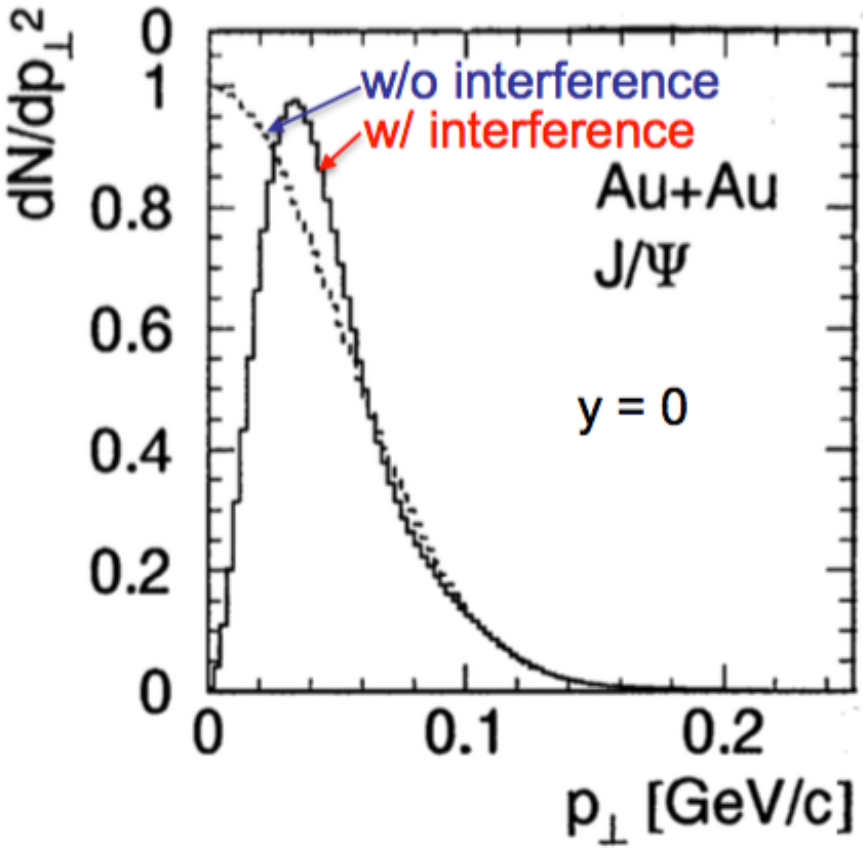
→Strong coupling ($Z\alpha_{EM}$ ~ 0.6) results in large cross sections

→Photon wavelength $\lambda = h/p > R_A$

→$p_T < h/R_A$ ~ 30 MeV/c for heavy ions

Photon Interactions in A+A Collisions

- We can gain insight into the production mechanism through the $t = p_T^2$ distribution due to interference effects



S. Klein and J. Nystrand, PRL **84** 2330 (2000)

Coherent photon-nucleus interaction:

→ Photon can be emitted from A_1 or A_2 , ie. two indistinguishable processes

→ For a vector meson, the amplitudes from each process have opposite signs

→ Results in strong destructive interference at very low p_T

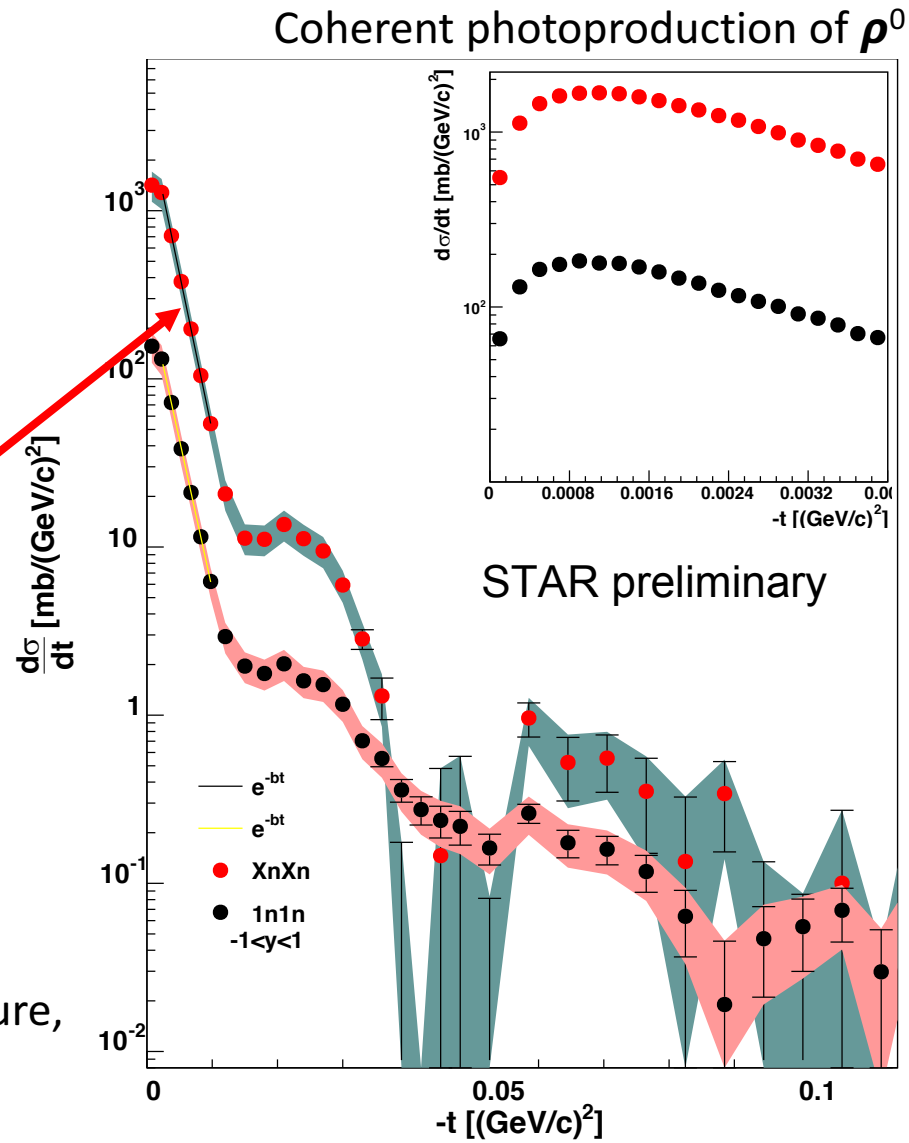
- Experimentally distinguish by looking at dN/dp_T^2 distribution at very low p_T

Coherent Photoproduction in UPCs

- What does this look like in the UPC case?
- Coherent production characterized by large slope parameter for small |t|

  SLOPE = 426 ± 2 (GeV/c)$^{-2}$

- Interference visible as downturn for very low values of |t|



See Spencer Klein's Talk
Ultra-peripheral collisions and hadronic structure, 10 Feb 2017, 18:00

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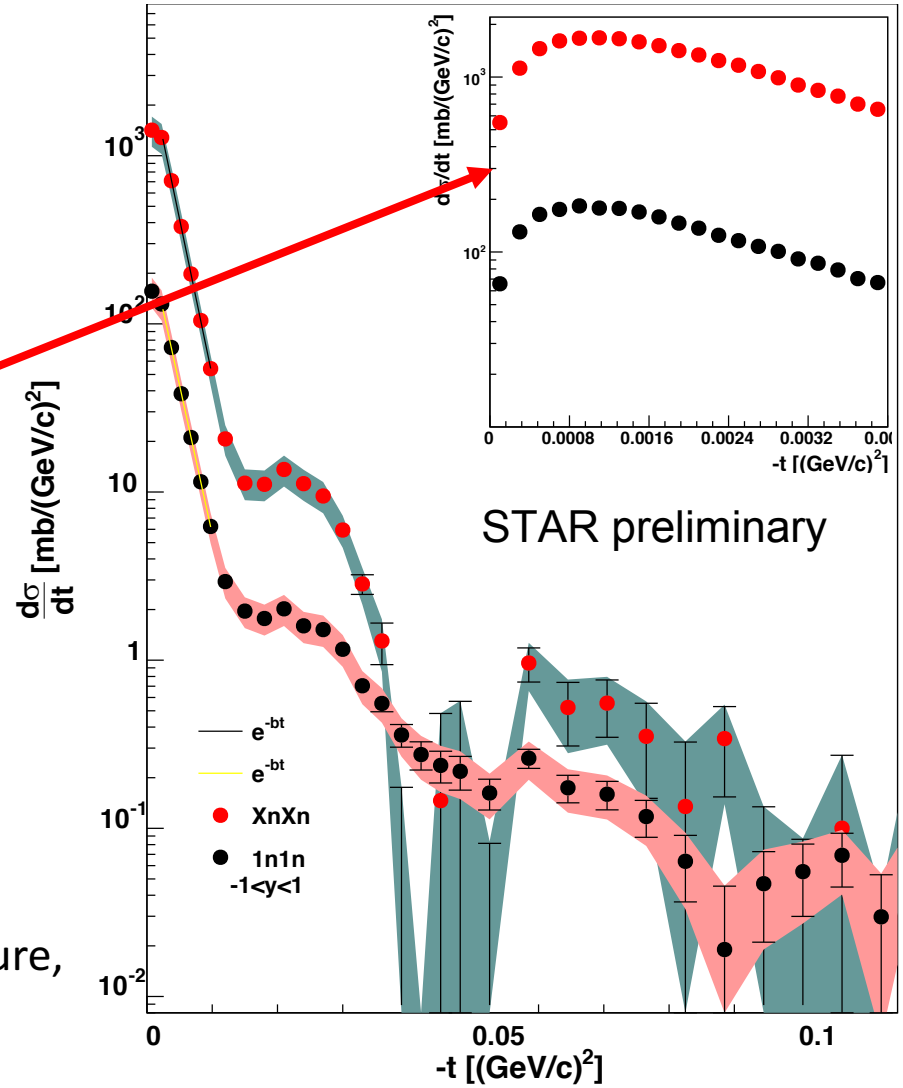
Coherent photoproduction of ρ^0



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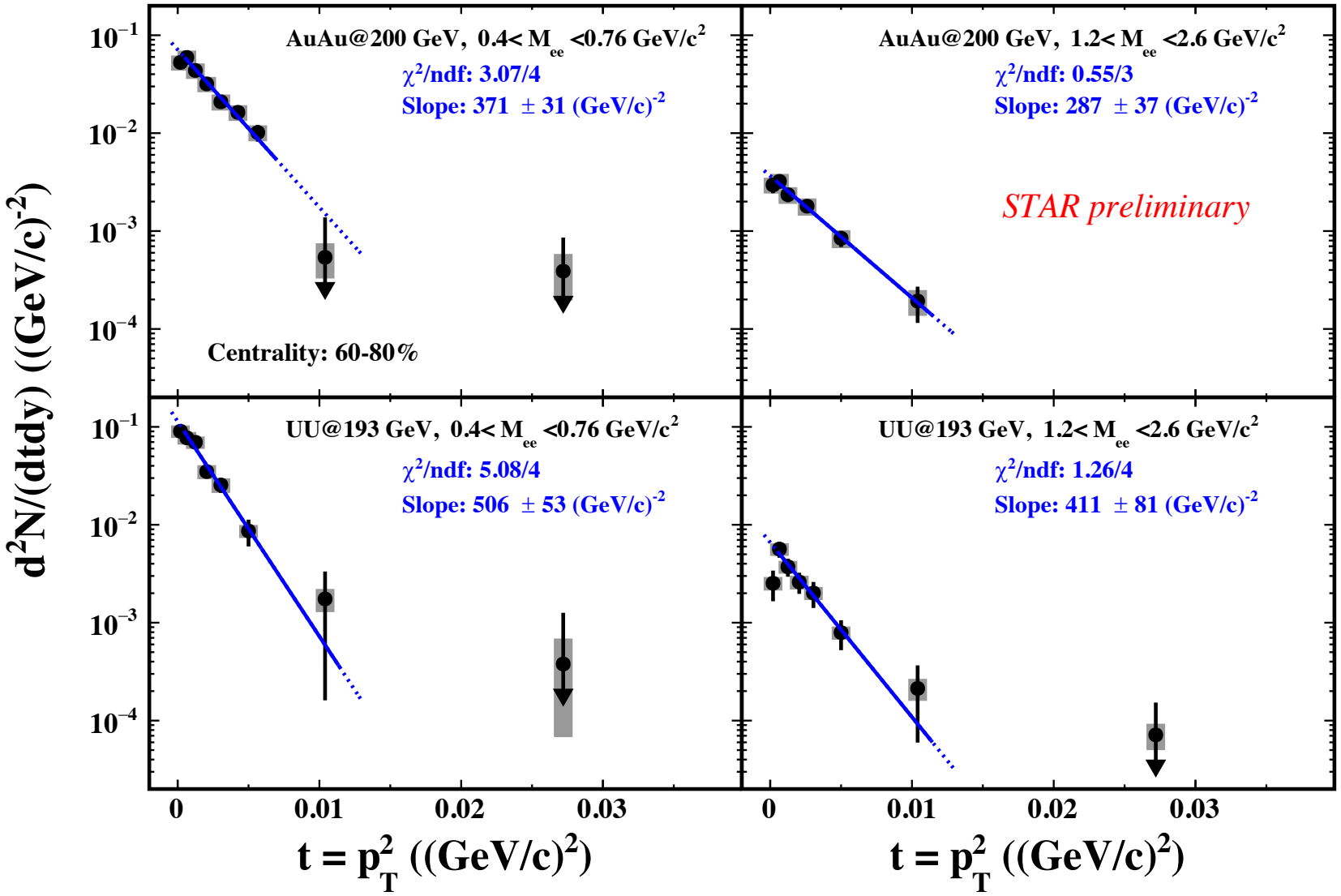
Photon Interactions in 60-80% A+A?



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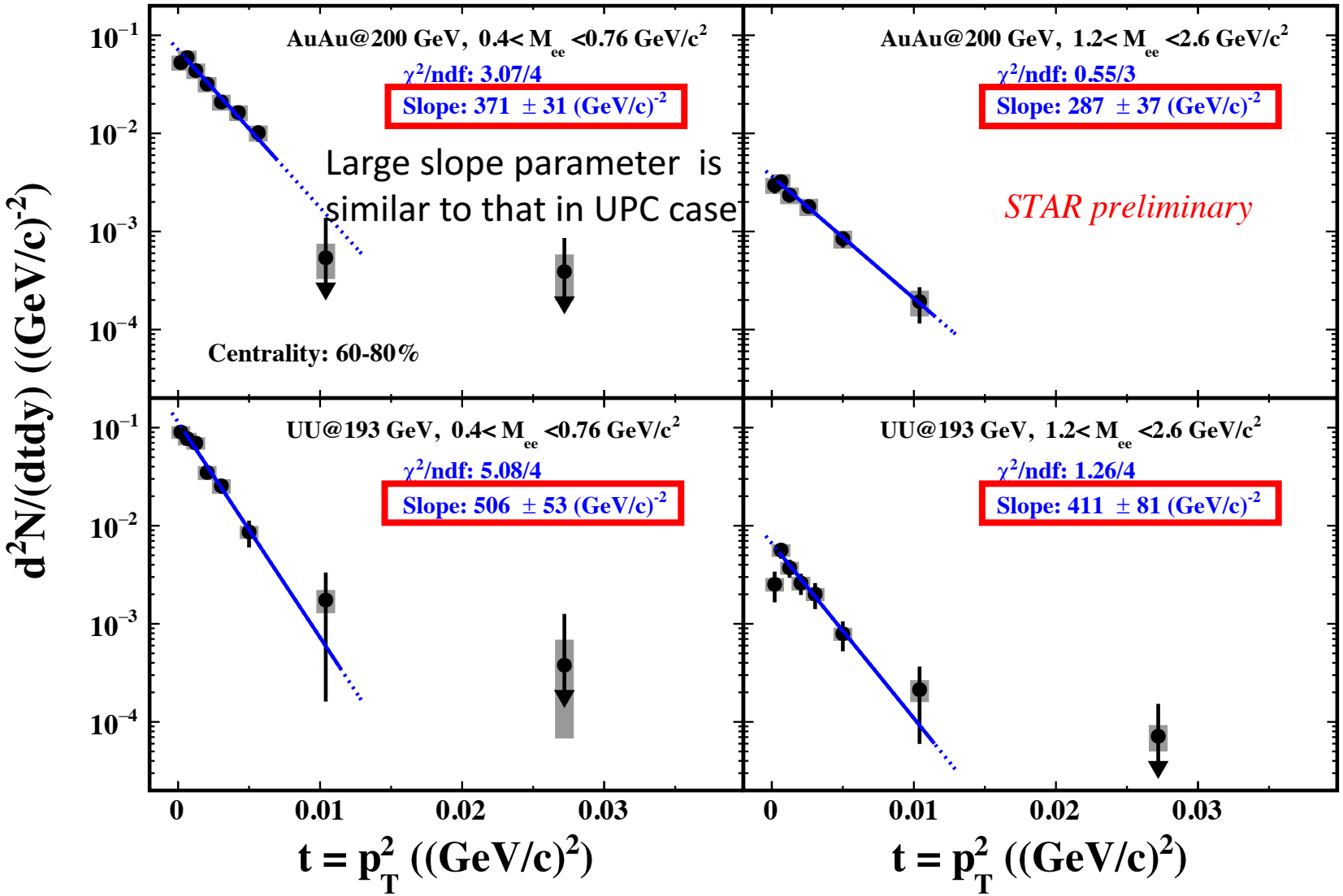

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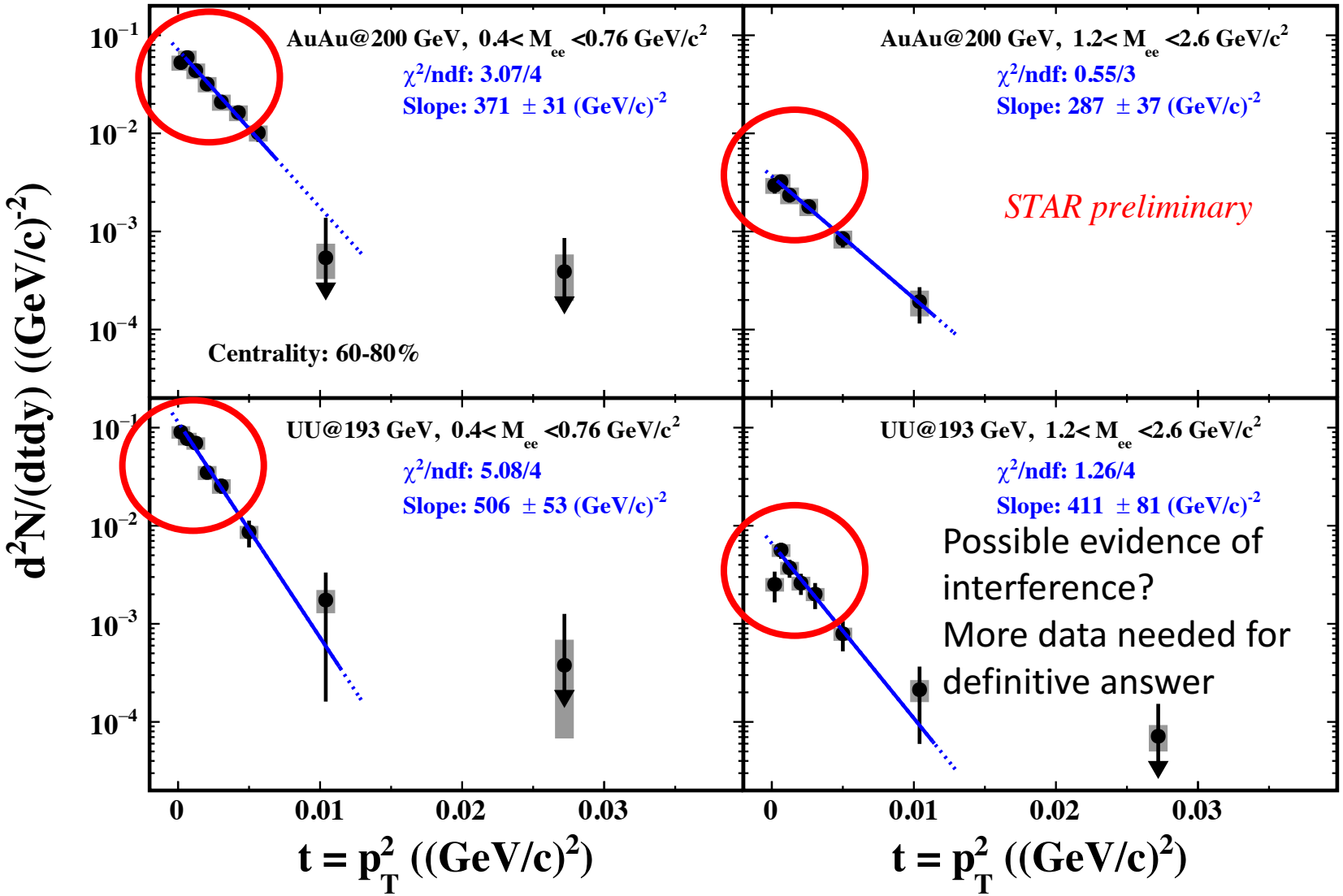

Novel Probe of the Medium?

→ Vector meson ($\boldsymbol{\rho}^0$, J/ψ) is coherently produced with very low p_T

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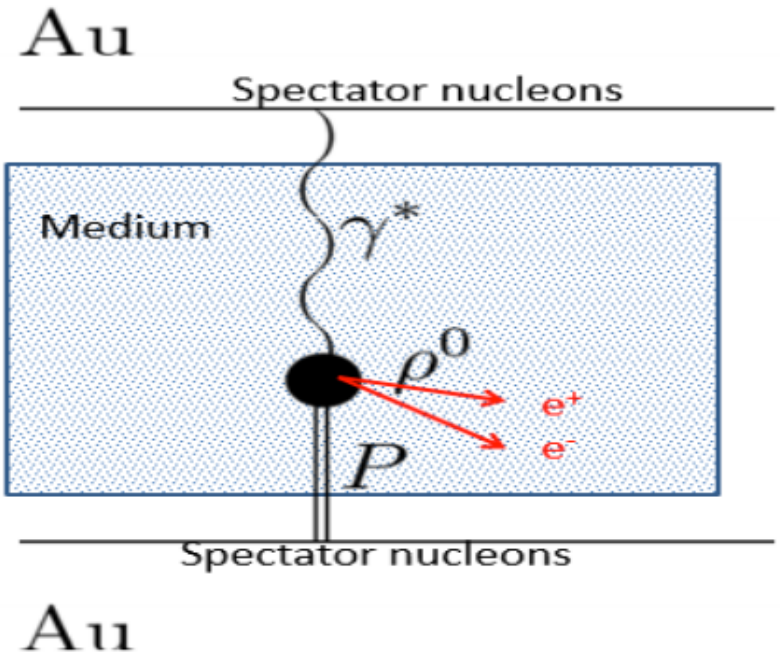
Novel Probe of the Medium?

- → Vector meson ($\boldsymbol{\rho}^0$, J/ψ) is coherently produced with very low p_T
- → Medium is produced by strong interaction
- → Meson has very low p_T → it remains in the medium until it decays to an l^+l^- pair
- → Since leptons are unaffected by the strong force, they carry information to the final state
- → Provide a clean probe of medium



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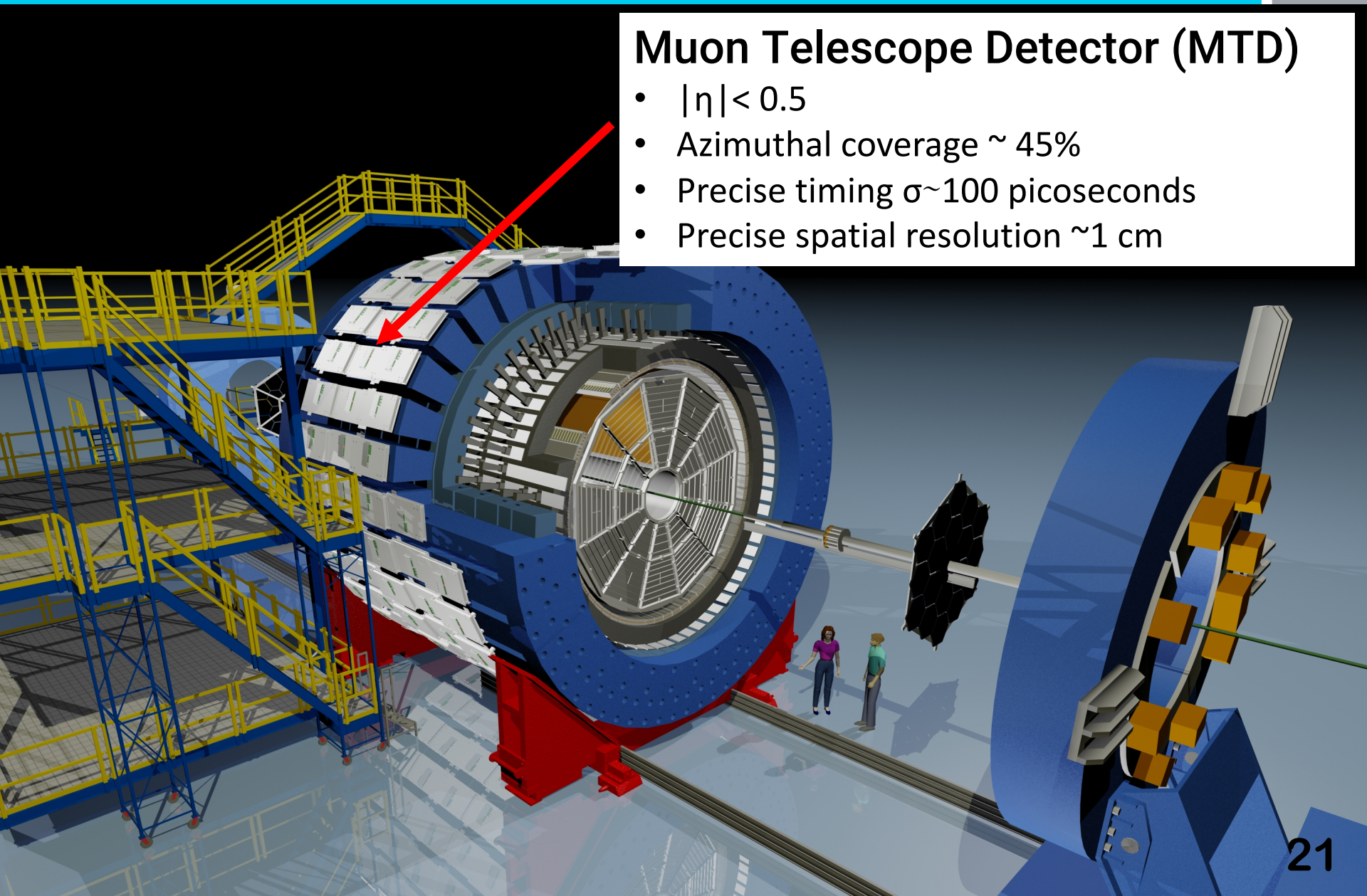
- First look at $\mu^+\mu^-$ invariant mass spectra with the Muon Telescope Detector at STAR in p+p collisions at $\sqrt{s} = 200$ GeV and Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

STAR Detector



Muon Telescope Detector (MTD)

- $|\eta| < 0.5$
- Azimuthal coverage ~ 45%
- Precise timing σ~100 picoseconds
- Precise spatial resolution ~1 cm

Motivation for STAR $\mu^+\mu^-$

- STAR's Muon Telescope Detector allows for new studies of the dimuon continuum at RHIC energies with STAR.

Species	Energy (GeV)	~Sampled Luminosity
p+p (63% MTD)	500	28 pb^{-1}
p+p	**200**	**122 pb^{-1}**
p+Au	200	409 nb^{-1}
d+Au	200	94 nb^{-1}
Au+Au 2014	**200**	**14 nb^{-1}**
Au+Au 2016	200	13 nb^{-1}

Why measure $\mu^+\mu^-$ in central heavy ion collisions?

→Low mass excess is sensitive to the lifetime of the medium

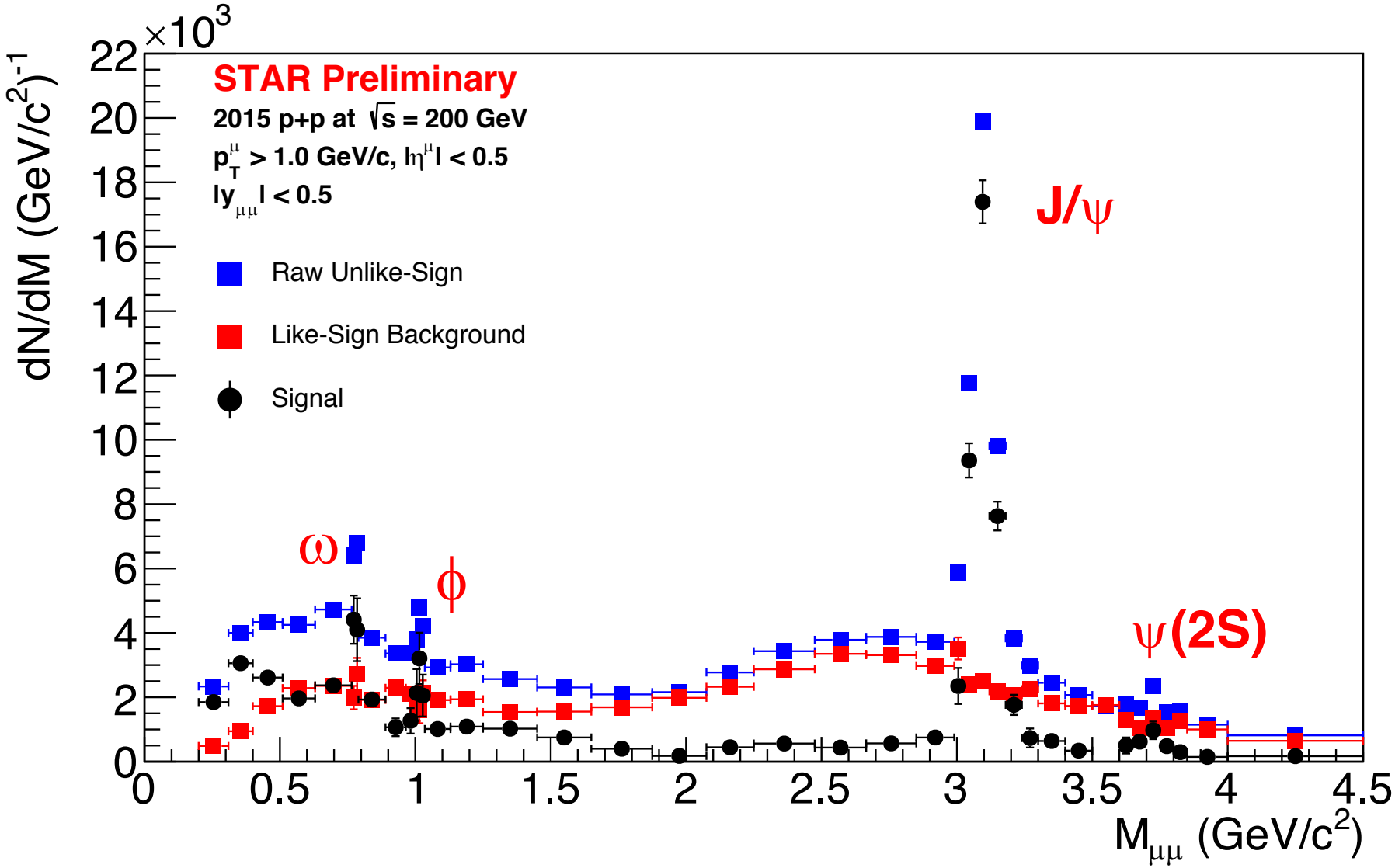
→Rho meson broadening may be a probe of chiral symmetry restoration

→Intermediate mass region is sensitive to QGP thermal radiation.

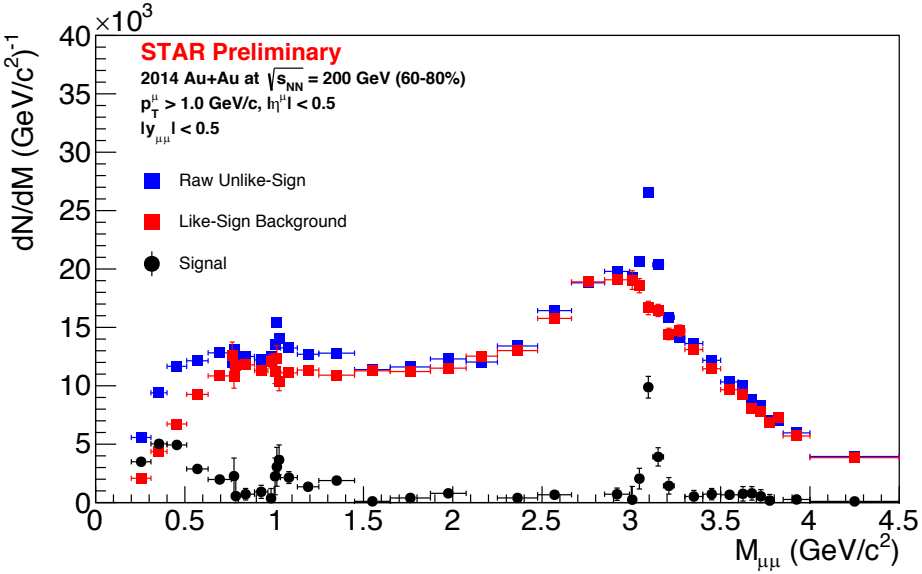
Measurements of $\mu^+\mu^-$ in p+p collisions :

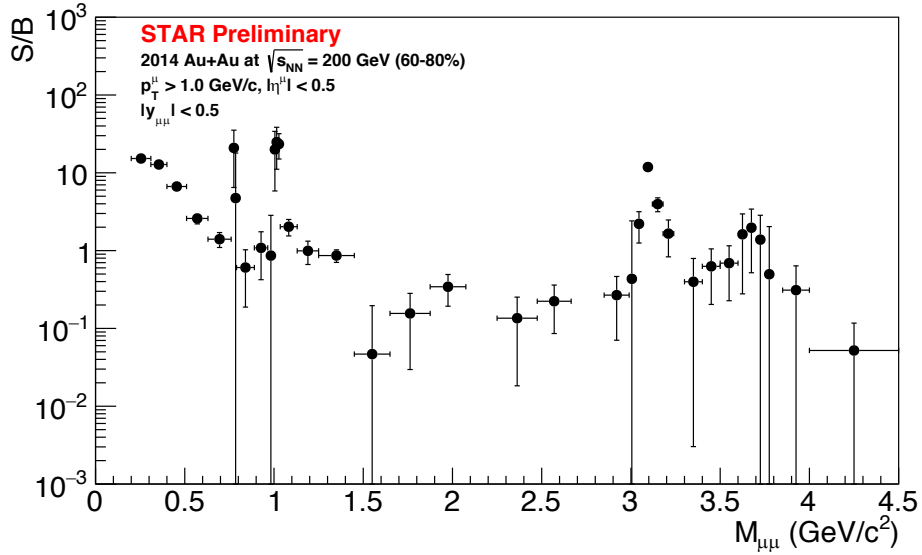
→Baseline for Au+Au measurements

$\mu^+\mu^-$ in Run15 p+p @ $\sqrt{s}$ = 200 GeV



$\mu^+\mu^-$ in Run14 Au+Au @ $\sqrt{s_{NN}}$ = 200 GeV





Data Triggered by dedicated Dimuon Trigger

In 60-80% Au+Au :

→Clear ϕ and J/ψ peaks

→S/B > ~1/10
(~1/100 to 1/250 in e^+e^-)

Significantly more data in semi-central and central collisions

→**Expect exciting new $\mu^+\mu^-$ results from STAR**

Summary

Low p_T e^+e^- measurements in Au+Au and U+U

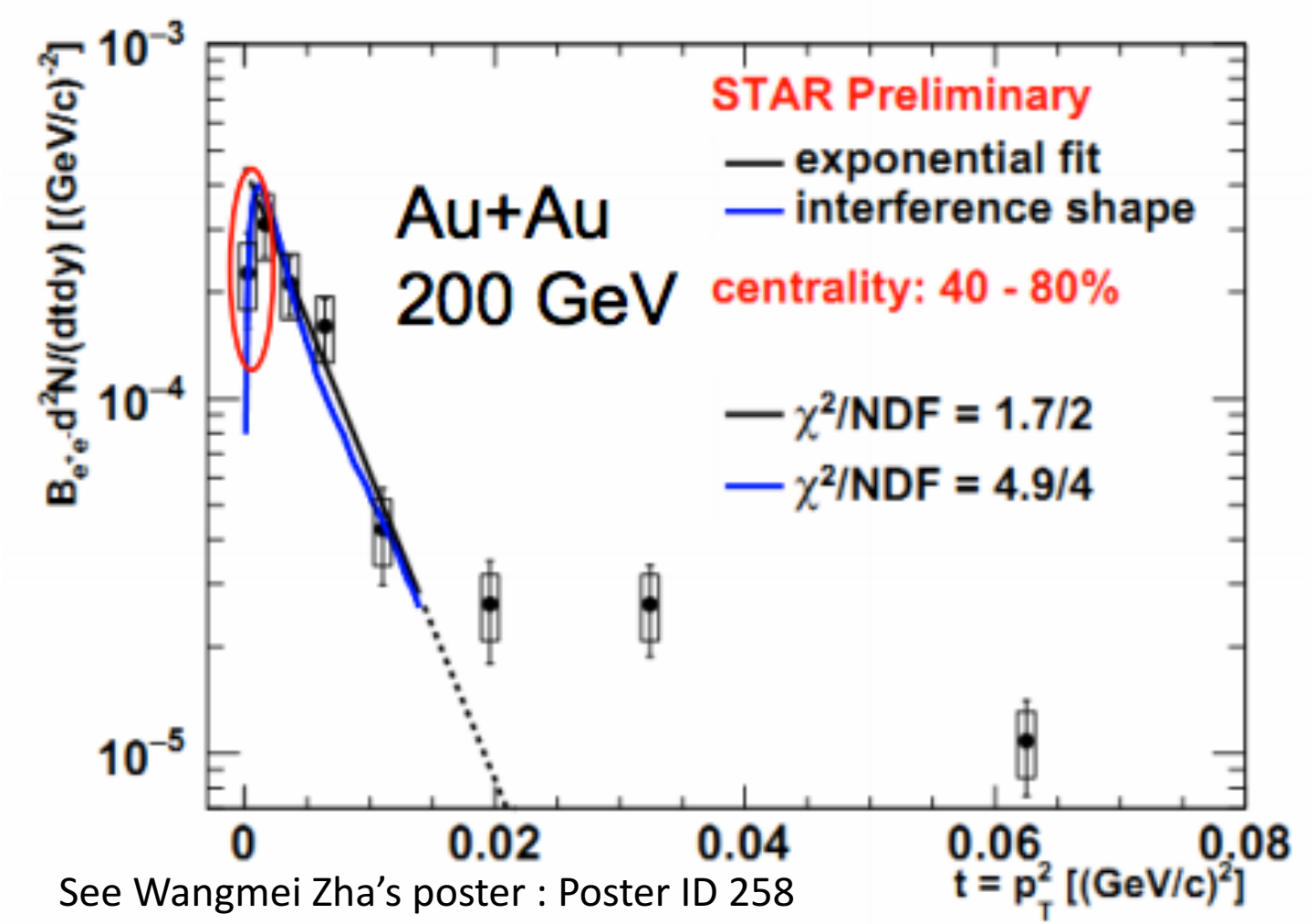
- Significant excess yield with respect to hadronic sources observed across wide invariant mass range (M_{ee}<4 GeV/c^2)
- Shape and slope of t distribution show evidence of interference
- Large slope parameter is evidence for UPC-like coherent photoproduction mechanism
- Future studies will help clarify production mechanism
- May provide a novel probe of the medium

First look at $\mu^+\mu^-$ invariant mass spectra from the Muon Telescope Detector at STAR

- New measurements possible at STAR with MTD
- Clear ω, ϕ, J/ψ, ψ(2S) signal in p+p collisions @ $\sqrt{s}$ = 200 GeV
- Expect exciting new $\mu^+\mu^-$ results from STAR

Thank you

J/ψ dN/dt distribution for Au+Au @ $\sqrt{s_{NN}}$ = 200 GeV (40-80%)



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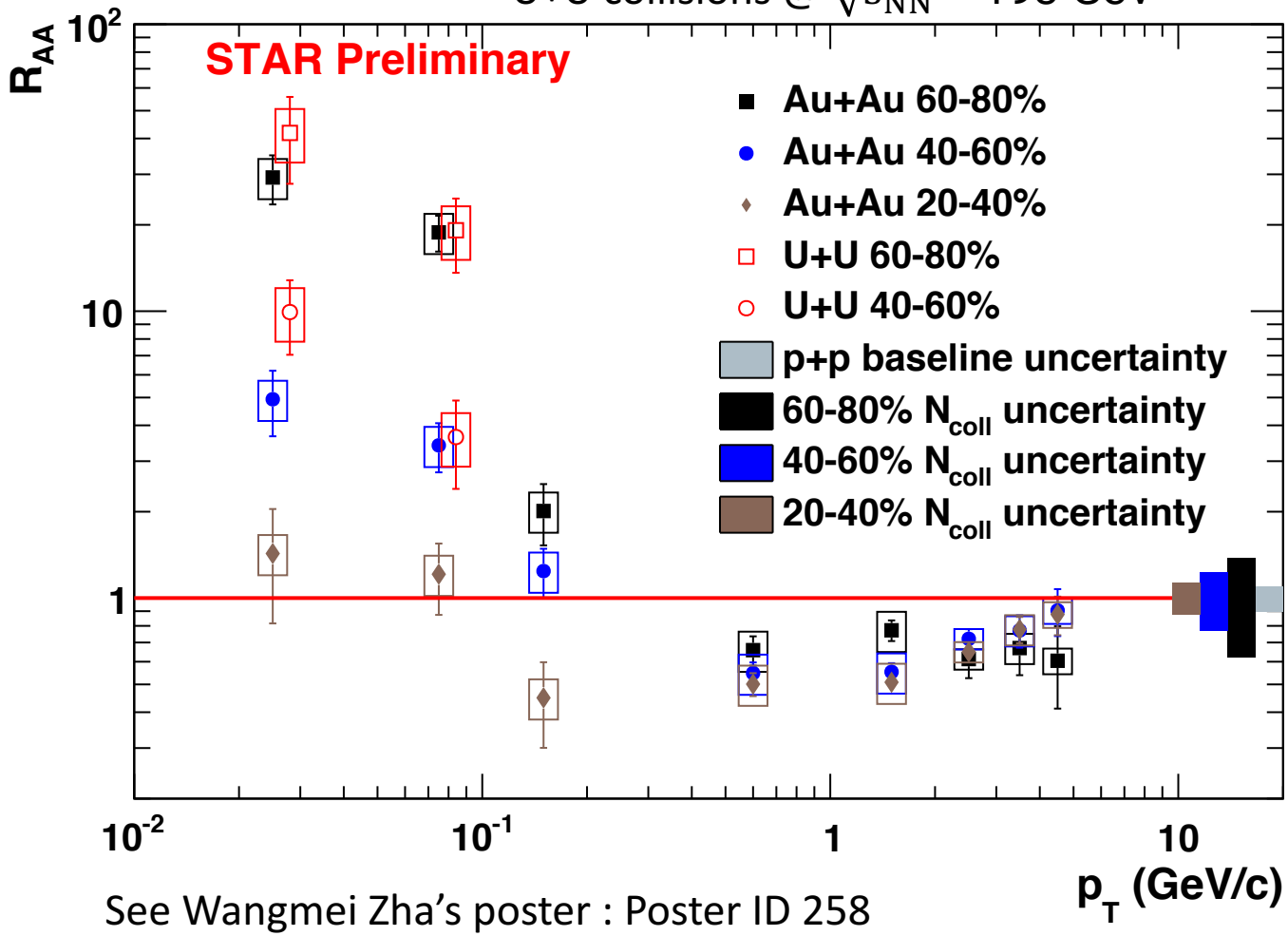

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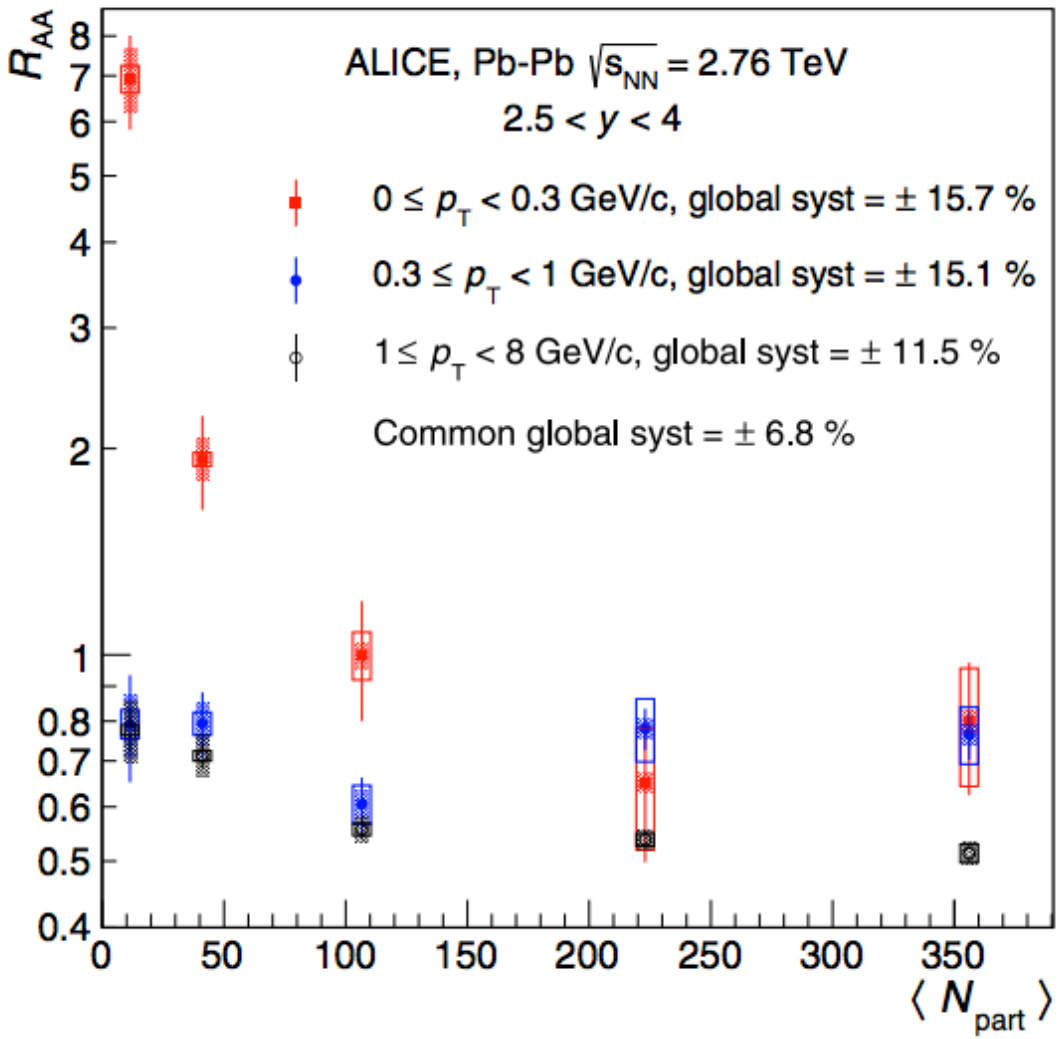

PRL**116**, 222301 (2016)