Low p_T e^+e^- pair production in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV and U+U collisions at $\sqrt{s_{NN}}$ = 193 GeV at STAR

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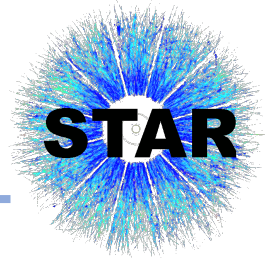
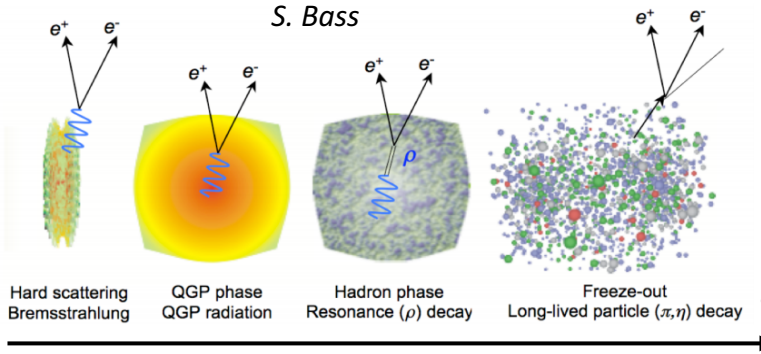
Outline

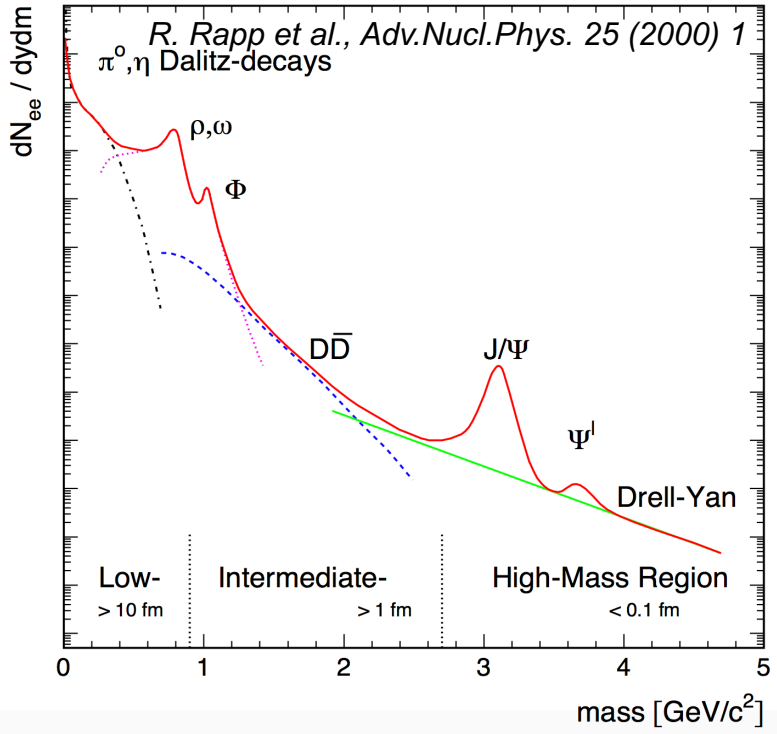


- Motivation
- The STAR experiment
- Electron identification
- Low p_T e^+e^- pair results in Au+Au and U+U collisions
- Isobaric collisions ($^{96}_{44}\mathrm{Ru}$ vs. $^{96}_{40}\mathrm{Zr}$)
- Summary

Dilepton - penetrating probe of hot medium



- Do not suffer strong interactions
- Bring direct information of the medium created in heavy ion collisions

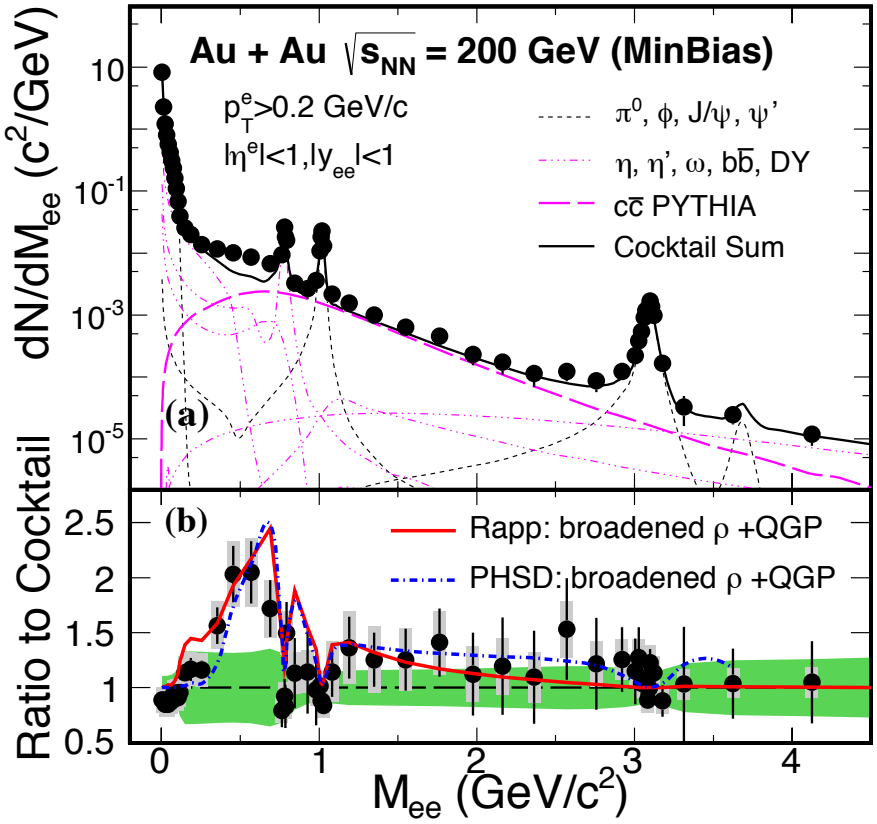


Different physics of interest

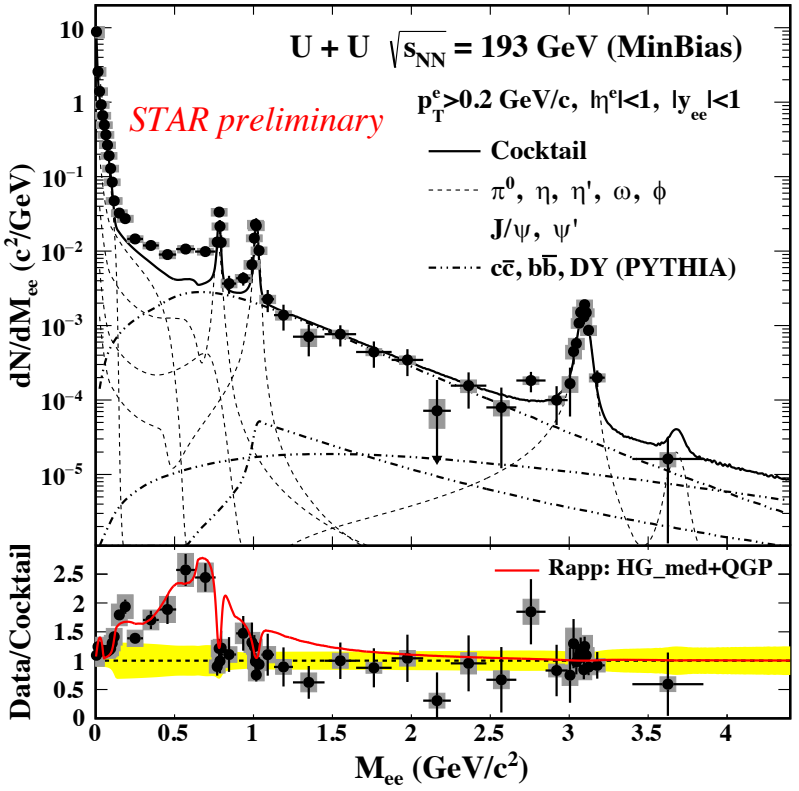
- **Low Mass Region (LMR)**
  - In-medium modifications of vector meson
- **Intermediate Mass Region (IMR)**
  - QGP thermal radiation
  - Semi-leptonic decays of $c\bar{c}$
- **High Mass Region (HMR)**
  - Drell-Yan process
  - Heavy quarkonia

p_T integrated invariant mass spectra in Au+Au@200GeV and U+U@193 GeV

Cocktail: contributions from known hadronic sources



STAR, Phys. Rev. Lett. 113 (2014) 022301

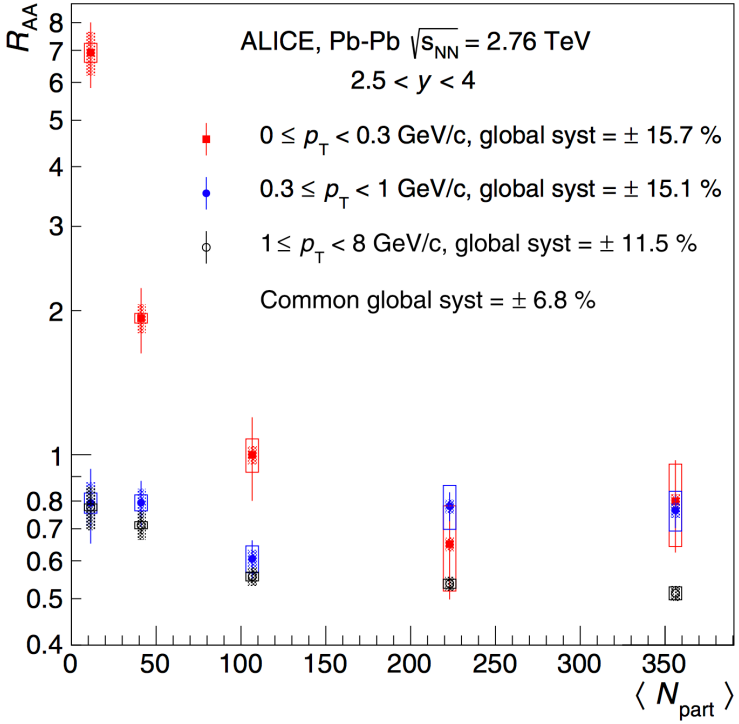


STAR, Nucl. Phys. A 956 (2016) 429

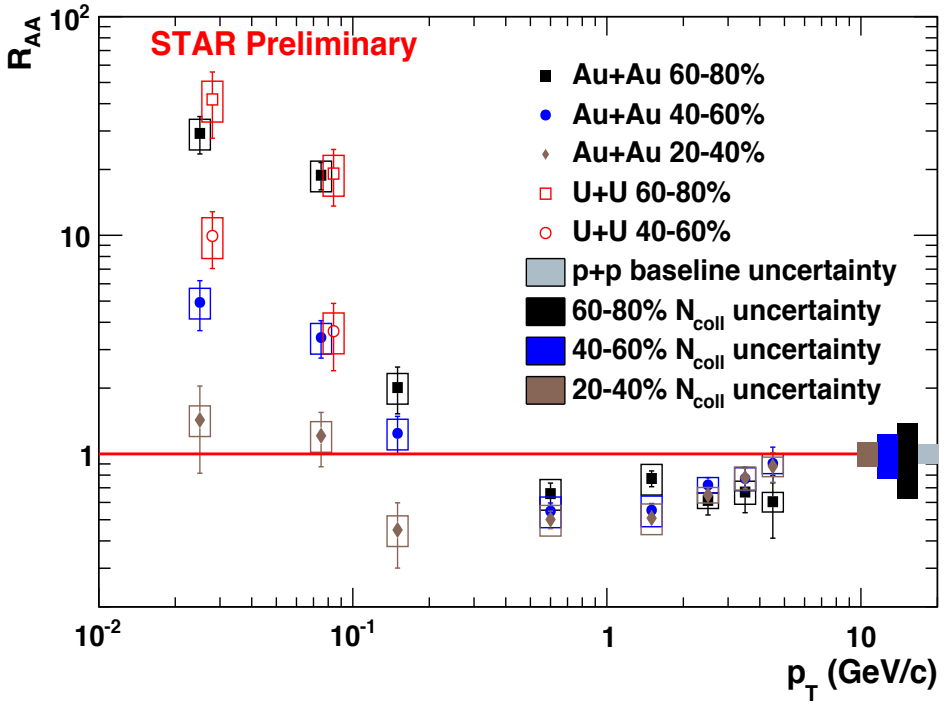
- Consistent with a theoretical calculation based on broadened **ρ** spectral function [*R. Rapp, Adv. High Energy Phys. 2013 (2013) 148253*]

Low p_T J/ψ enhancement in peripheral heavy-ion collisions

ALICE, Phys. Rev. Lett. 116 (2016) 222301



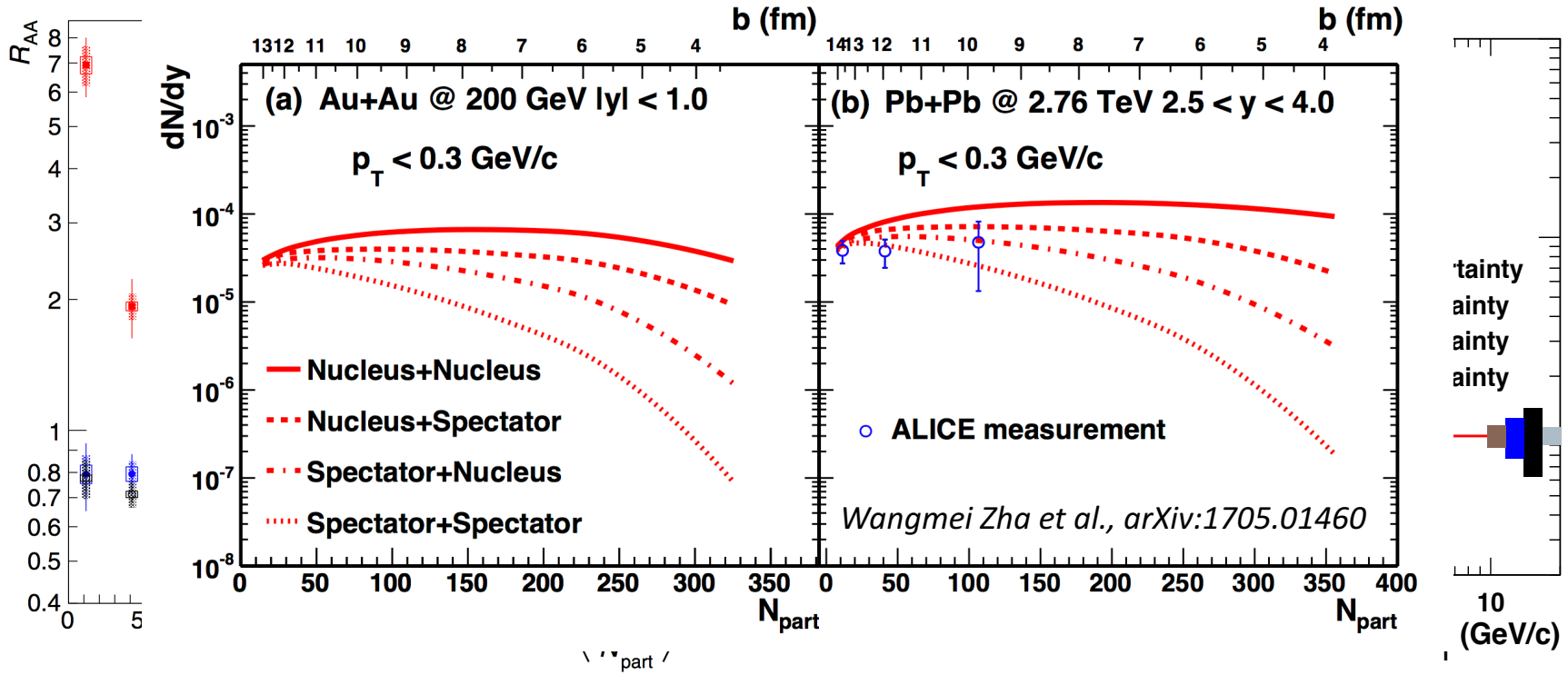
See Wangmei's Talk



- Significant enhancement at low p_T in peripheral collisions
  - Can not be explained by hadronic production accompanied with the cold and hot medium effects
  - Linked to coherent photoproduction? How to incorporate coherence conditions?

$$R_{AA} = \frac{\sigma_{pp}^{inel.}}{< N_{coll} >} \frac{d^2N_{AA}/(2\pi p_T dp_T dy)}{d^2\sigma_{pp}/(2\pi p_T dp_T dy)}$$

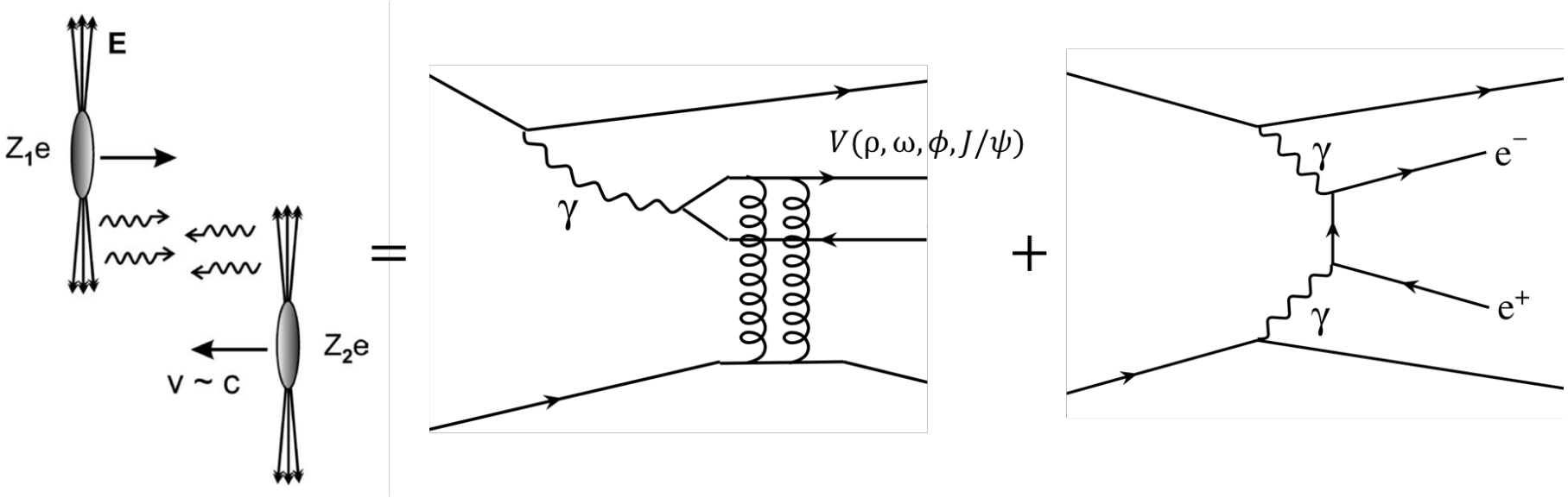
Low p_T J/ψ enhancement in peripheral heavy-ion collisions



- Significant enhancement at low p_T in peripheral collisions
  - Can not be explained by hadronic production accompanied with the cold and hot medium effects
  - Linked to coherent photoproduction? How to incorporate coherence conditions?
- Measure e^+e^- pair production in a wider invariant mass region at low p_T to understand the production mechanism

Photon interactions in Ultra-Peripheral Collisions (UPC)

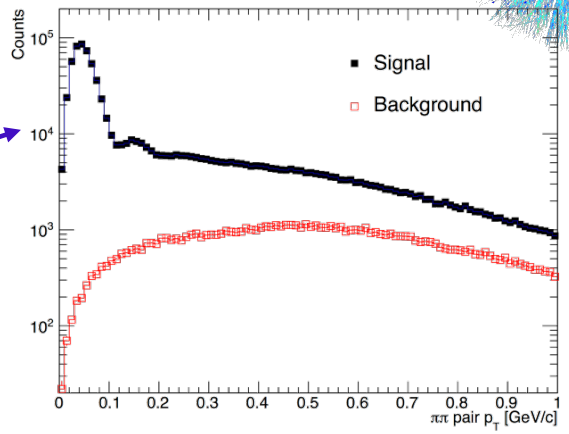
C. A. Bertulani et al., Ann. Rev. Nucl. Part. Sci. 55 (2005) 271
PHENIX, Phys. Lett. B 679 (2009) 321

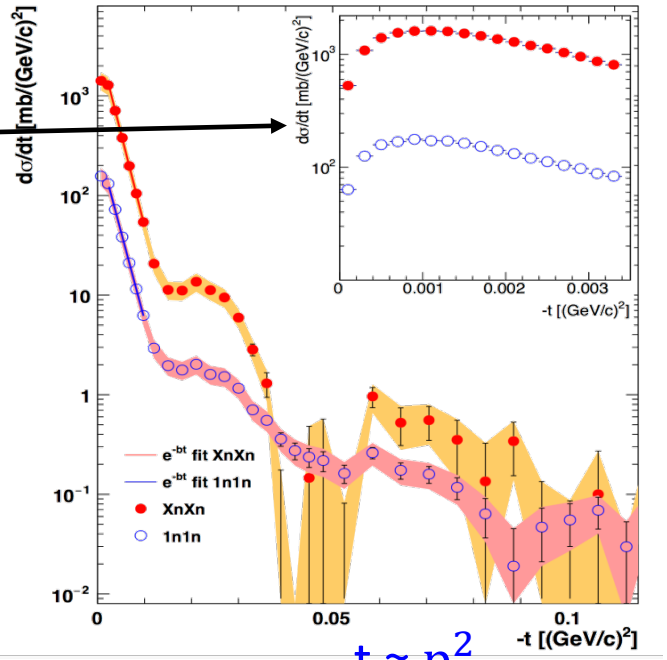


- Photon – photon interaction $\propto Z^4$
- Photon – nucleus interaction $\propto Z^2$
  - Coherent: photon interacts with the whole nucleus
  - Incoherent: photon interacts with nucleon or parton individually

Features of photon interactions in UPC

- Coherent photon – nucleus interaction
  - Both nucleus remain intact
  - Vector meson p_T is very low
  - Interference structure
    - ✓ Emitter and target are indistinguishable
    - ✓ Vector mesons have negative parity, thus opposite sign in amplitude
    - ✓ Destructive interference in $p_T << 1/b$



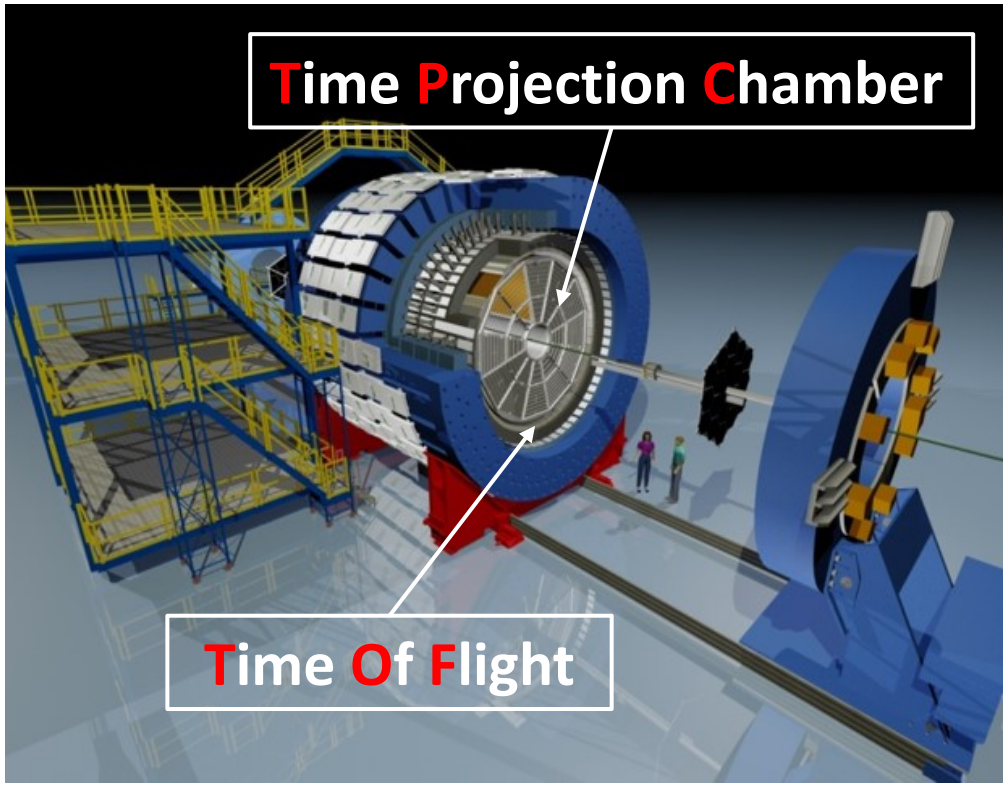


STAR, arxiv: 1702.07705

- Photon – photon interaction
  - Continuum
  - Pair p_T is very lower

$-t \approx p_T^2$

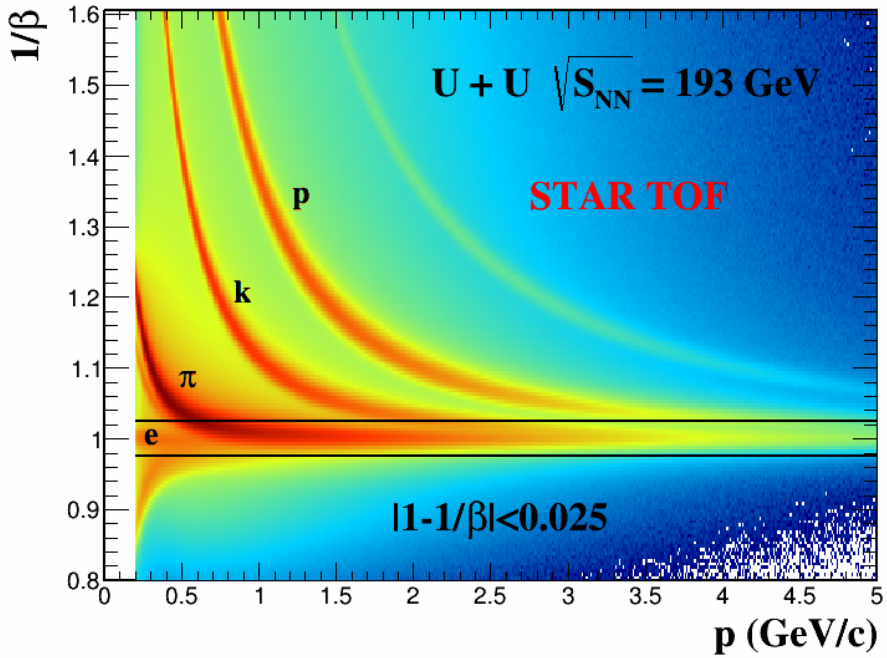
The STAR detector

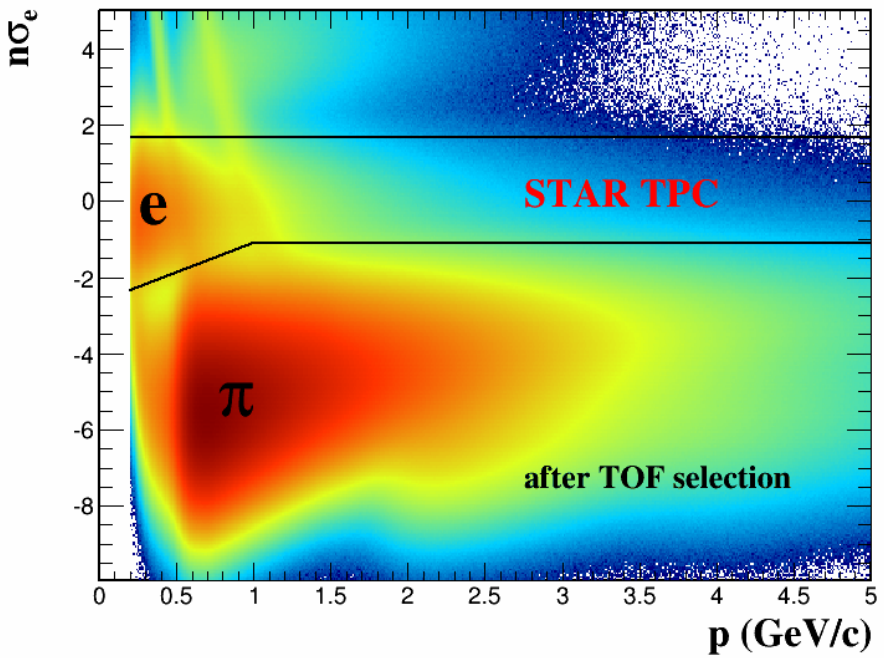


- Time Projection Chamber
  - $|\eta|<1$, $0<\phi<2\pi$
  - Main detector: tracking, momenta, and energy loss
- Time Of Flight
  - $|\eta|<0.9$, $0<\phi<2\pi$
  - Enables clean electron identification at $p < 3$ GeV/c

Electron identification

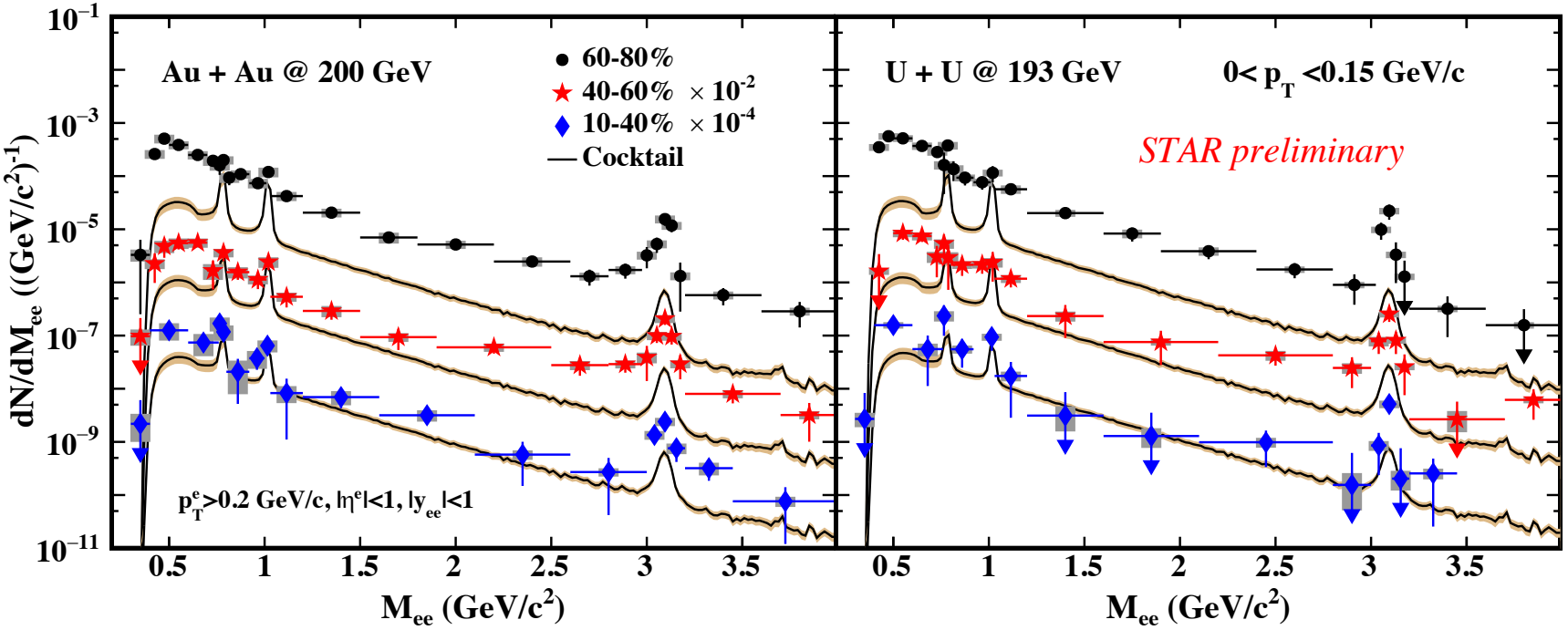
$$n\sigma_e = \frac{1}{R} log \frac{(dE/dx)_{measured}}{(dE/dx)_{electron}}$$





- The overall purity of electron, identified by combining of TPC and TOF, is ~95% in minimum bias Au+Au (U+U) collisions

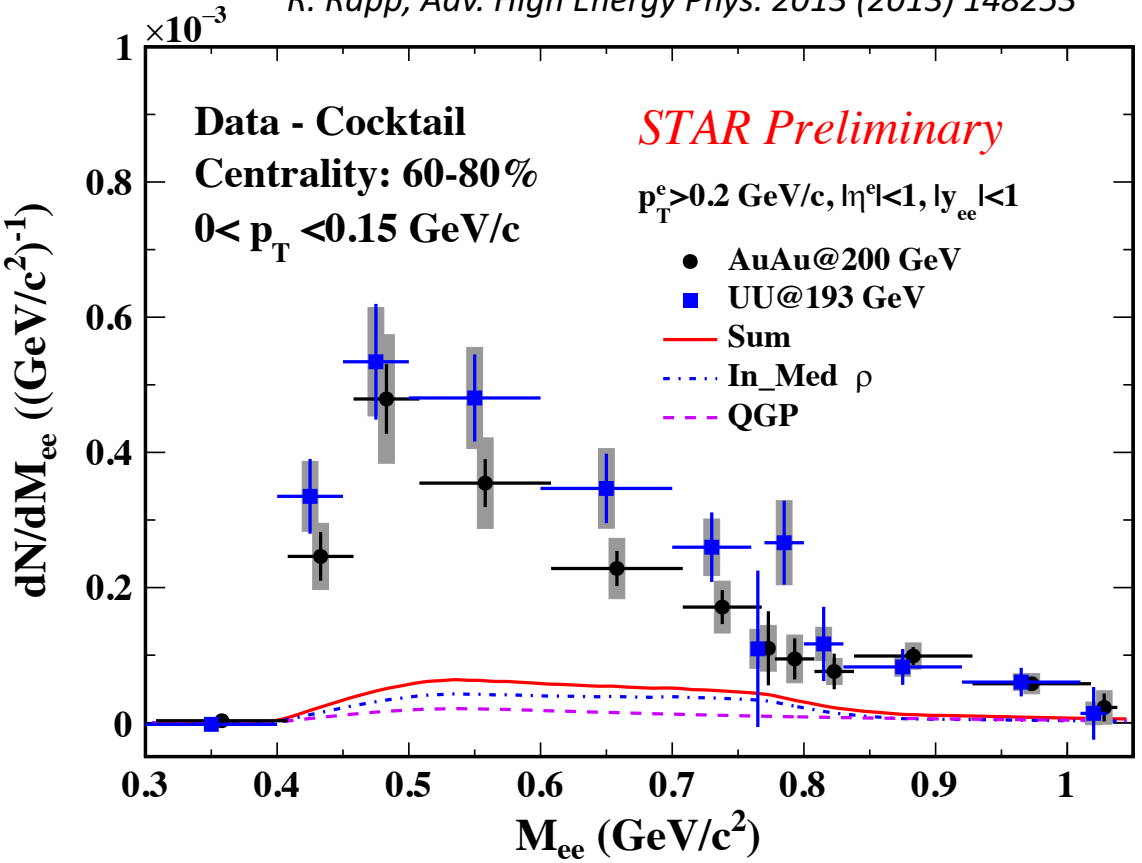
Centrality dependence of e^+e^- pair invariant mass spectra in $p_T < 0.15$ GeV/c



- Significant enhancement with respect to the cocktail in 60-80% central Au+Au and U+U collisions
- Enhancement factor (data/cocktail) decreases from peripheral to central collisions

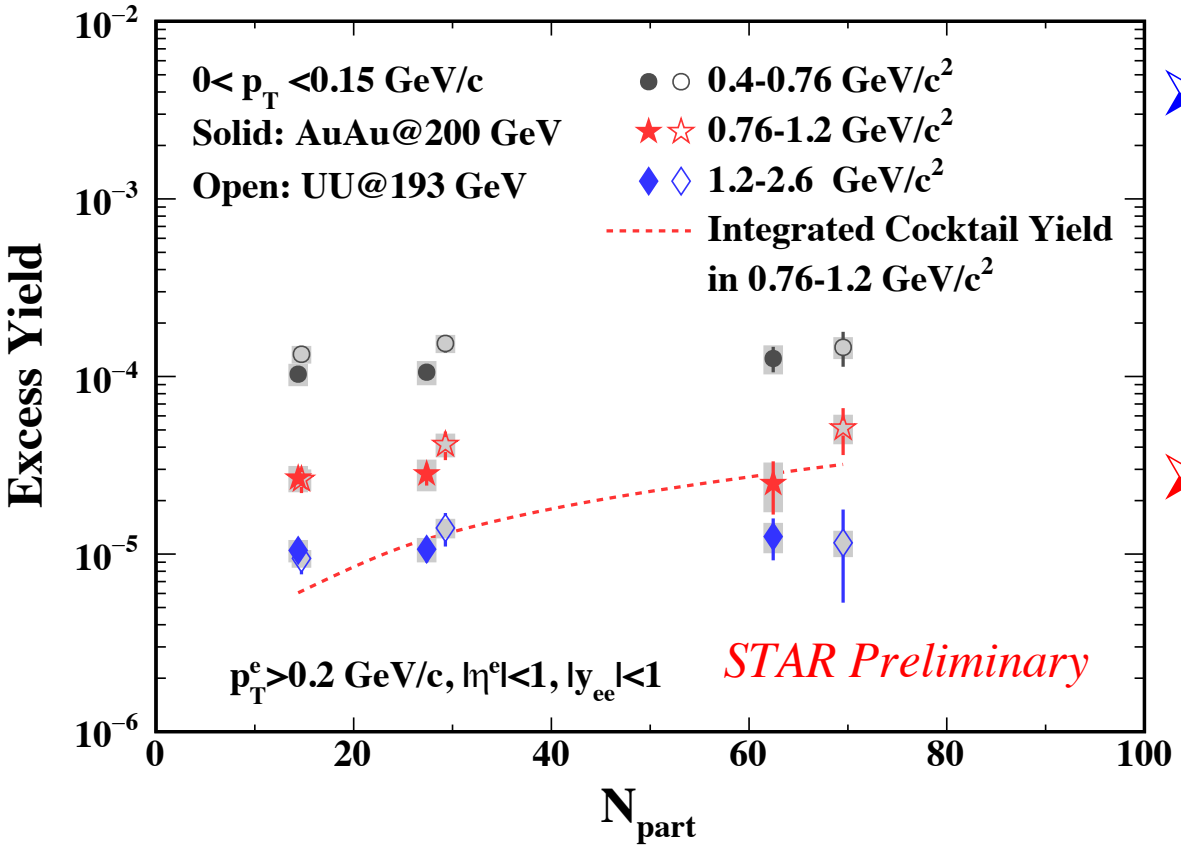
Enhancement spectra in $p_T < 0.15$ GeV/c

R. Rapp, Adv. High Energy Phys. 2013 (2013) 148253



- Can not be explained by broadened **ρ** model calculation
- Need additional source(s) to account for the significant enhancement

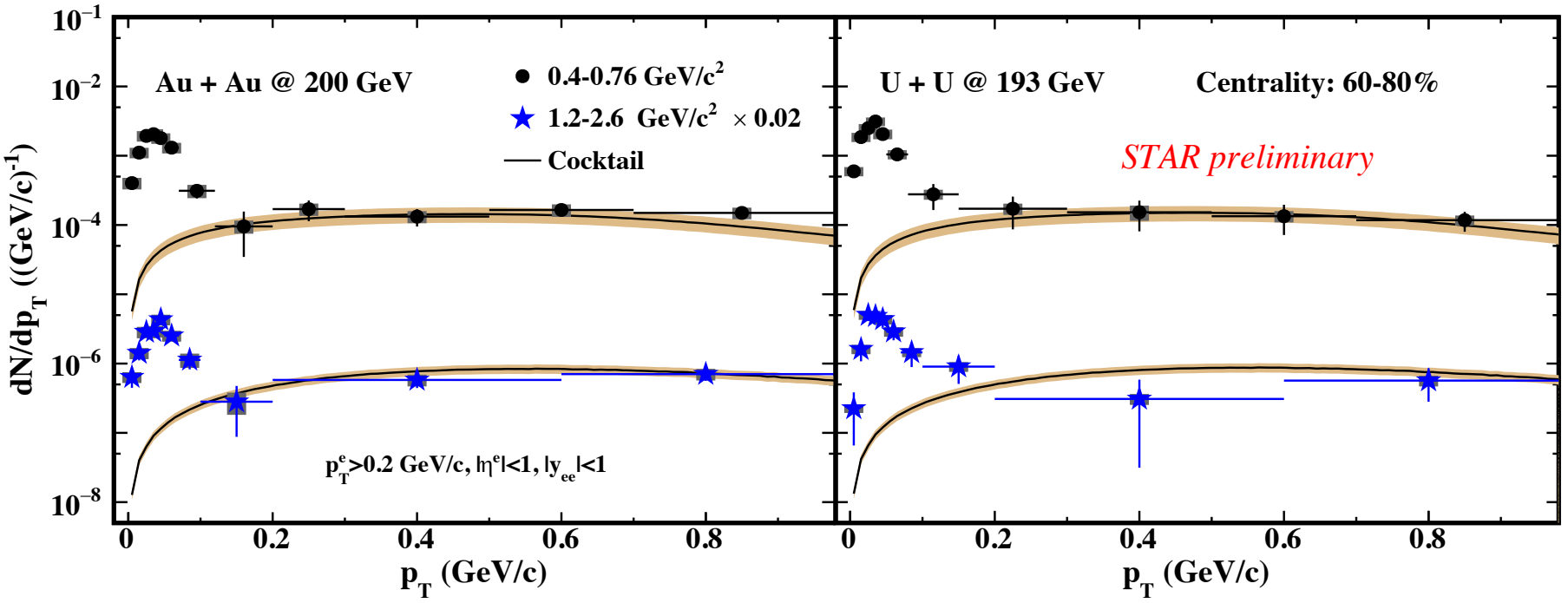
Centrality dependence of excess yield



- Excess yield (integrated yield of excess spectrum) has no obvious centrality dependence
- Hadronic production is expected to increase dramatically with N_{part}

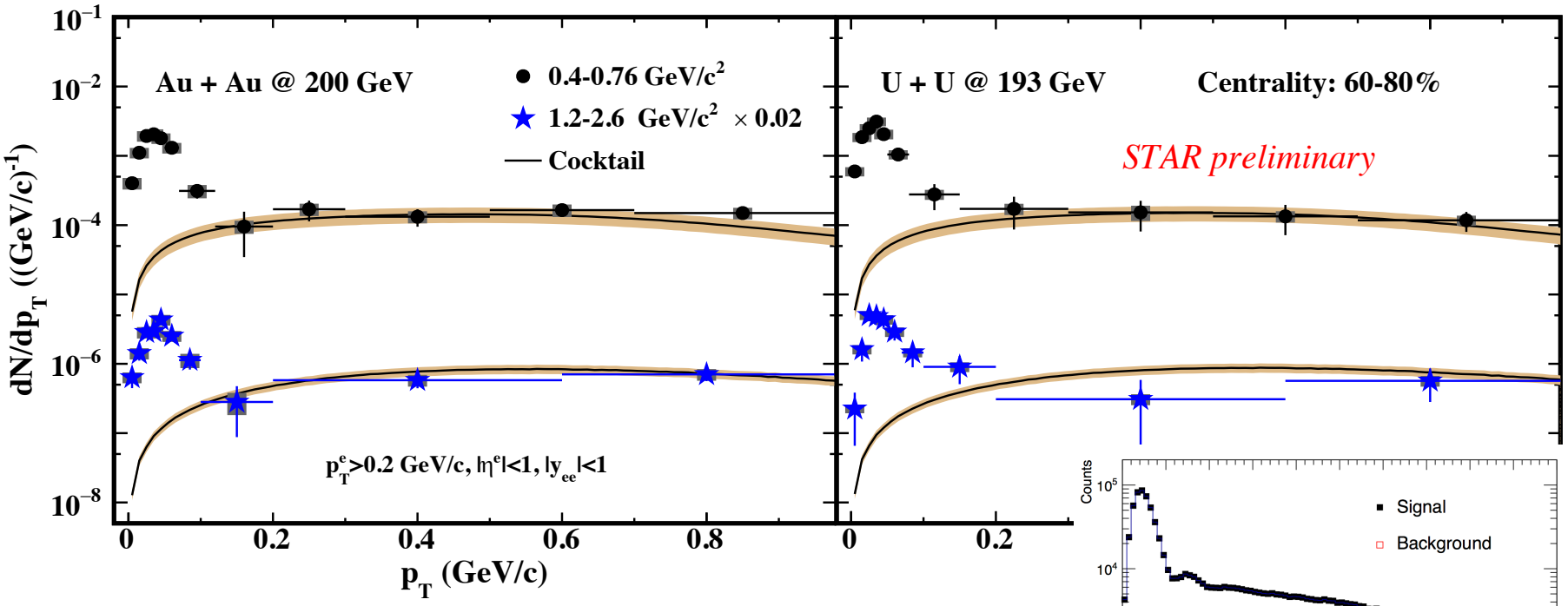
- Possible sources – photon interactions
  - Photon – photon interaction (continuum)
  - Coherent photon – nucleus interaction (vector mesons)

p_T spectra in 60-80% central collisions



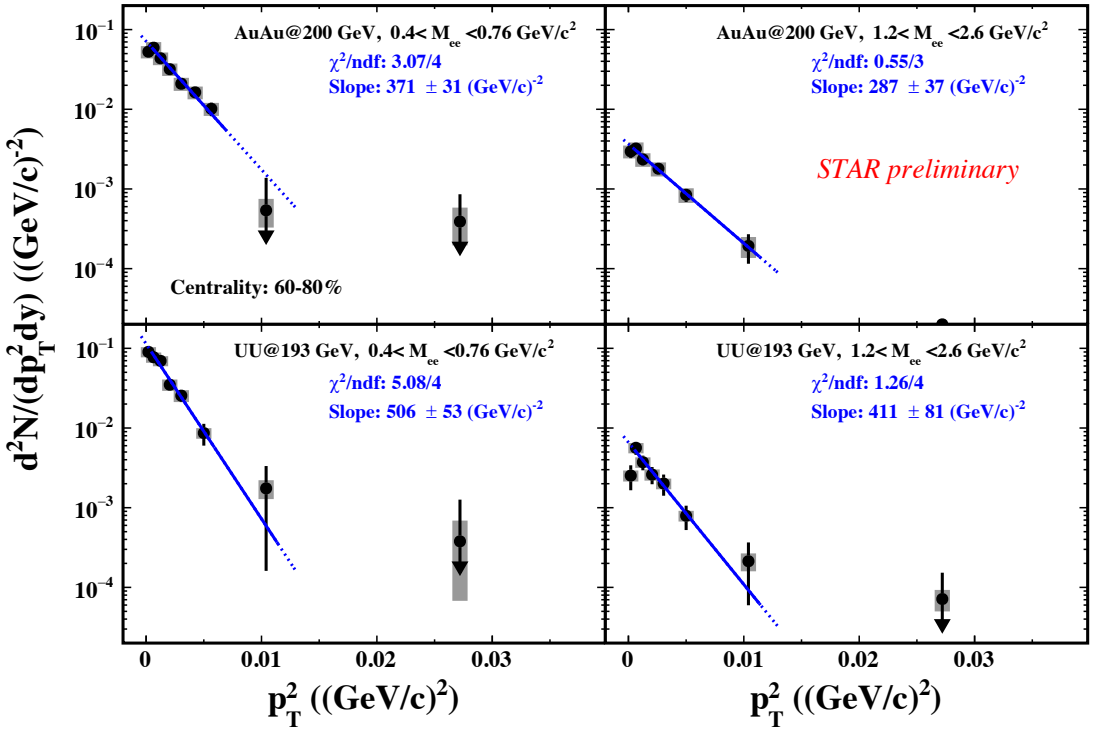
- Excess entirely happens in p_T < ~0.15 GeV/c
- Data are consistent with hadronic expectation when p_T > ~0.15 GeV/c

p_T spectra in 60-80% central collisions

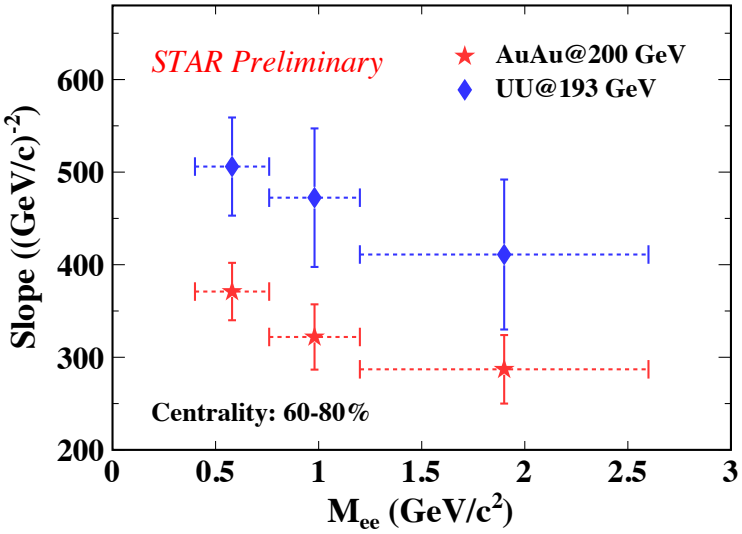


- Excess entirely happens in p_T < ~0.15 GeV/
- Data are consistent with hadronic expecta when p_T > ~0.15 GeV/c
- Similar p_T structure with coherent photoproduction in UPC

p_T^2 distributions in 60-80% central collisions



- Fit function: $A \times e^{-k*p_T^2}$
  - k is the slope parameter



- Slope has a mild invariant mass and collision species dependence
  - Au+Au vs. U+U: 2.2σ in 0.4-0.76 GeV/c^2, 1.8σ in 0.76-1.2 GeV/c^2, 1.4σ in 1.2-2.6 GeV/c^2
  - 0.4-0.76 vs. 1.2-2.6 GeV/c^2: 1.7σ in Au+Au collisions, 1.0σ in U+U collisions

Isobaric collisions at RHIC in 2018

- All aforementioned very low p_T e^+e^- measurements point to photon mediated interactions in violent hadronic A+A collisions.

- How to quantitatively disentangle the contributions from photon-photon, photon-nucleus processes?
  - Photon-photon interaction $\propto Z^4$
  - Photon-nuclear interaction $\propto Z^2$

- $^{96}_{44}\mathrm{Ru}$ vs. $^{96}_{40}\mathrm{Zr}$
  - Charge different by 10%, everything else almost the same
  - Z^4 difference: 46%; Z^2 difference: 21%;
  - 1.2 billion events for each particle species
  - Good opportunity to quantitatively disentangle photon interaction contributions for the observed low p_T e^+e^- excess

Summary

- A significant enhancement with respect to the hadronic cocktail is observed at very low p_T
  - Entirely happens in p_T < ~0.15 GeV/c
  - Can not be explained by QGP radiation and broadening of vector meson in-medium
  - Excess yield has no obvious centrality dependence
- p_T^2 distributions of STAR acceptance corrected excess yield in several mass differentials are measured in 60-80% central A+A collisions
  - The slope of p_T^2 distribution has mild invariant mass and collision species dependence
- The observed significant enhancement in hadronic A+A collisions is very likely mediated by photon interactions
  - Isobaric collisions may quantitatively disentangle the contributions from photon-photon and photon-nucleus processes.