10th International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions

Low-p_T $\mu^+\mu^-$ production in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV at STAR

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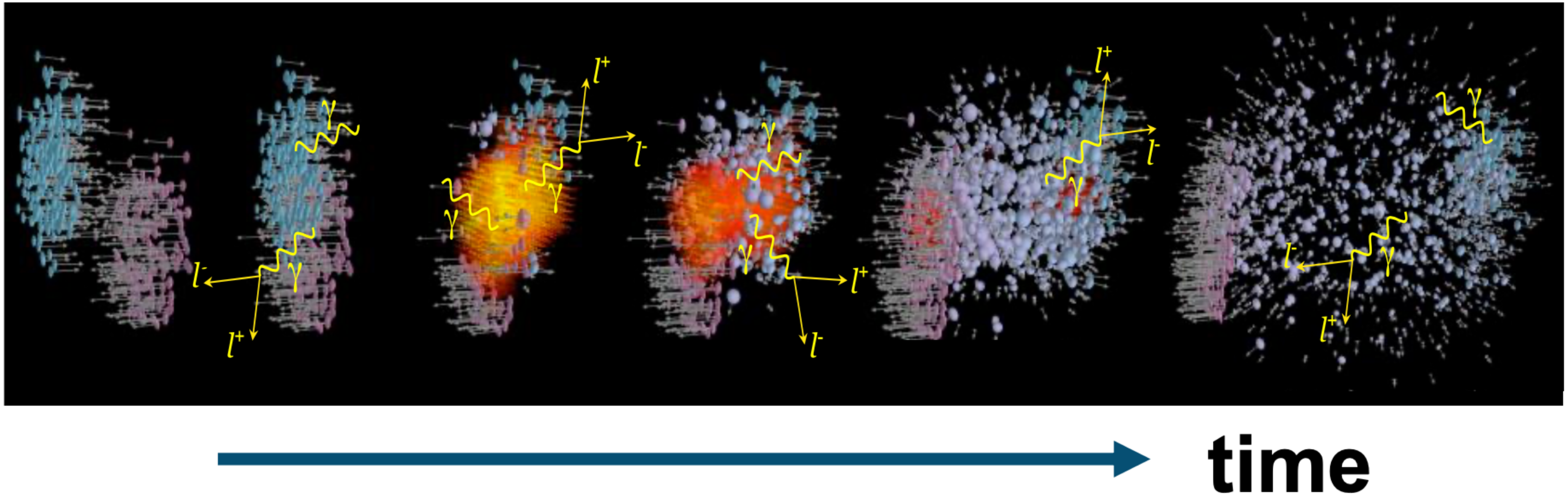
Dileptons – penetrating probe of QGP



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

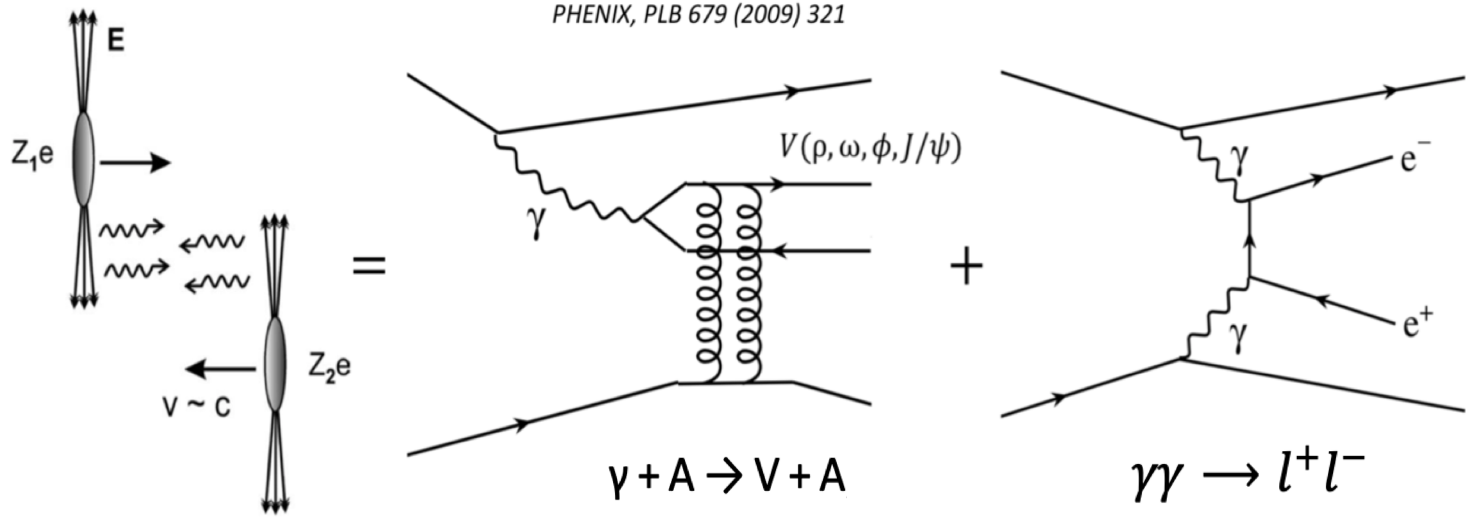
Dileptons from photon interactions

- Boosted nuclei have intense electromagnetic field ⇒ treated as quasi-real photons in the Weizsacker-Williams equivalent photon approximation
  - Photon flux increases with Z^2
  - Photoproduction is distinctly peaked at low p_T

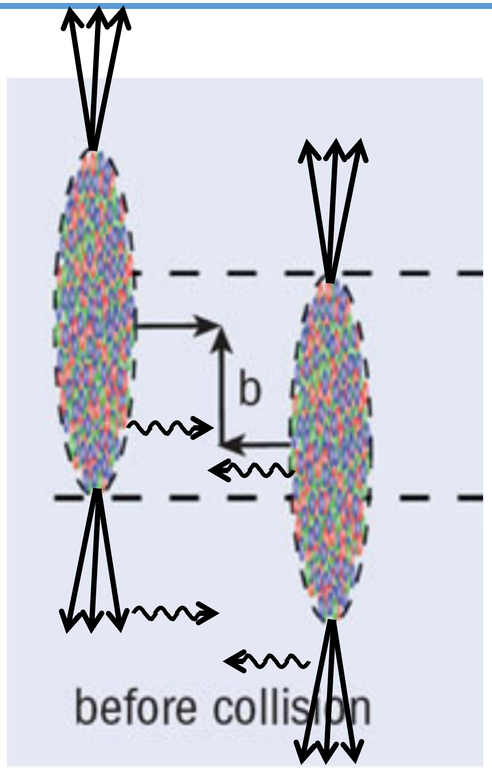
G. Breit and John A. Wheeler, Phys. Rev. 46 (1934) 1087

- Conventionally studied in ultraperipheral collisions (UPCs)

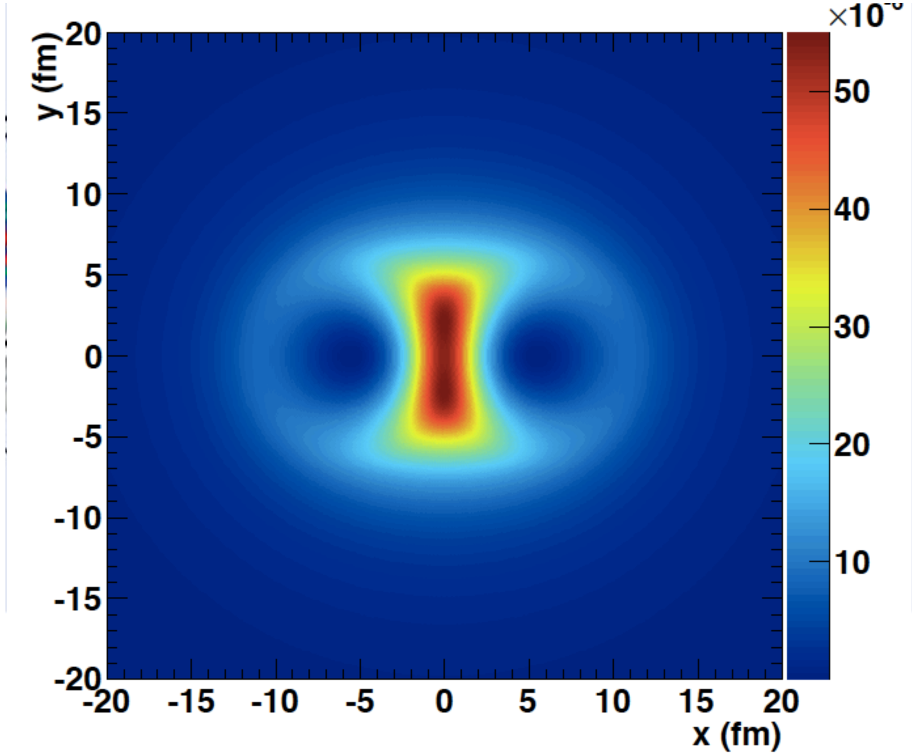
C. A. Bertulani et al., Ann. Rev. Nucl. Part. Sci. 55 (2005) 271
PHENIX, PLB 679 (2009) 321



Photons in hadronic heavy-ion collisions



Example of dilepton spatial distributions at z=0 in 50-60% Au+Au collisions

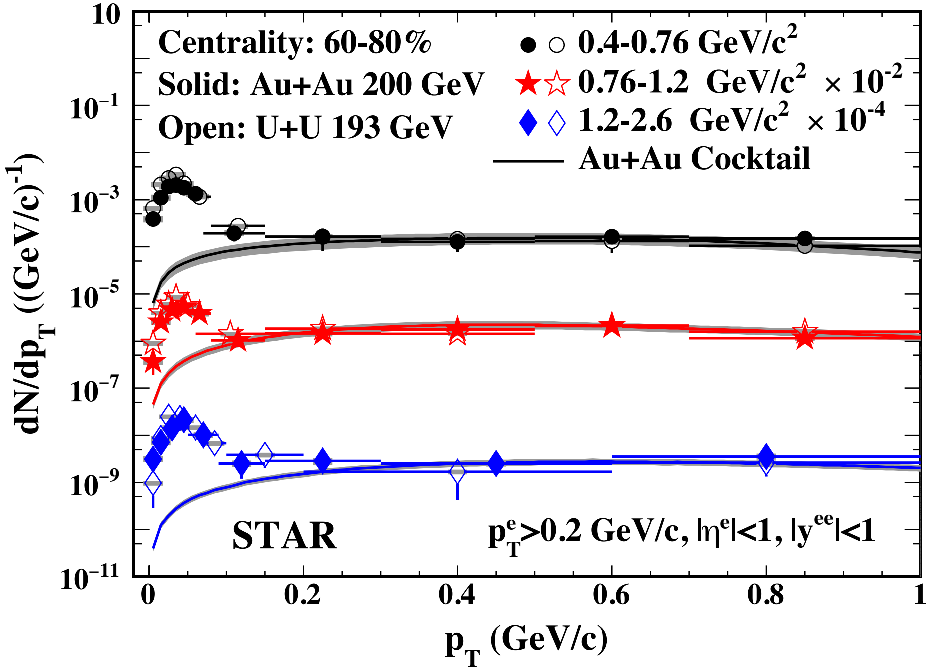


Based on W. M. Zha et al., Phys. Lett. B 781 (2018) 182

- Photons interact at the very beginning
- The dileptons can bring the information from the nuclear overlap region

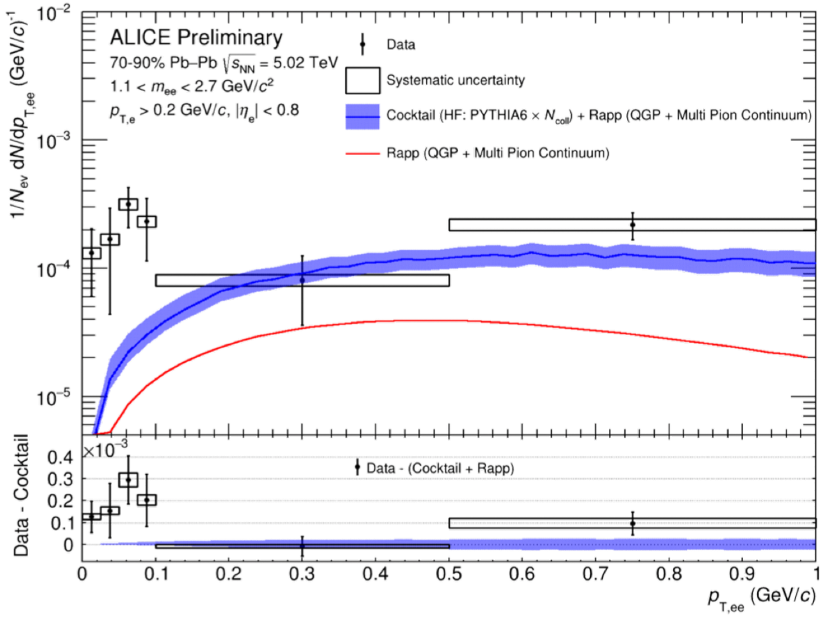
Photoproduction with nuclear overlap

STAR 60-80%



STAR, Phys. Rev. Lett. 121 (2018) 132301

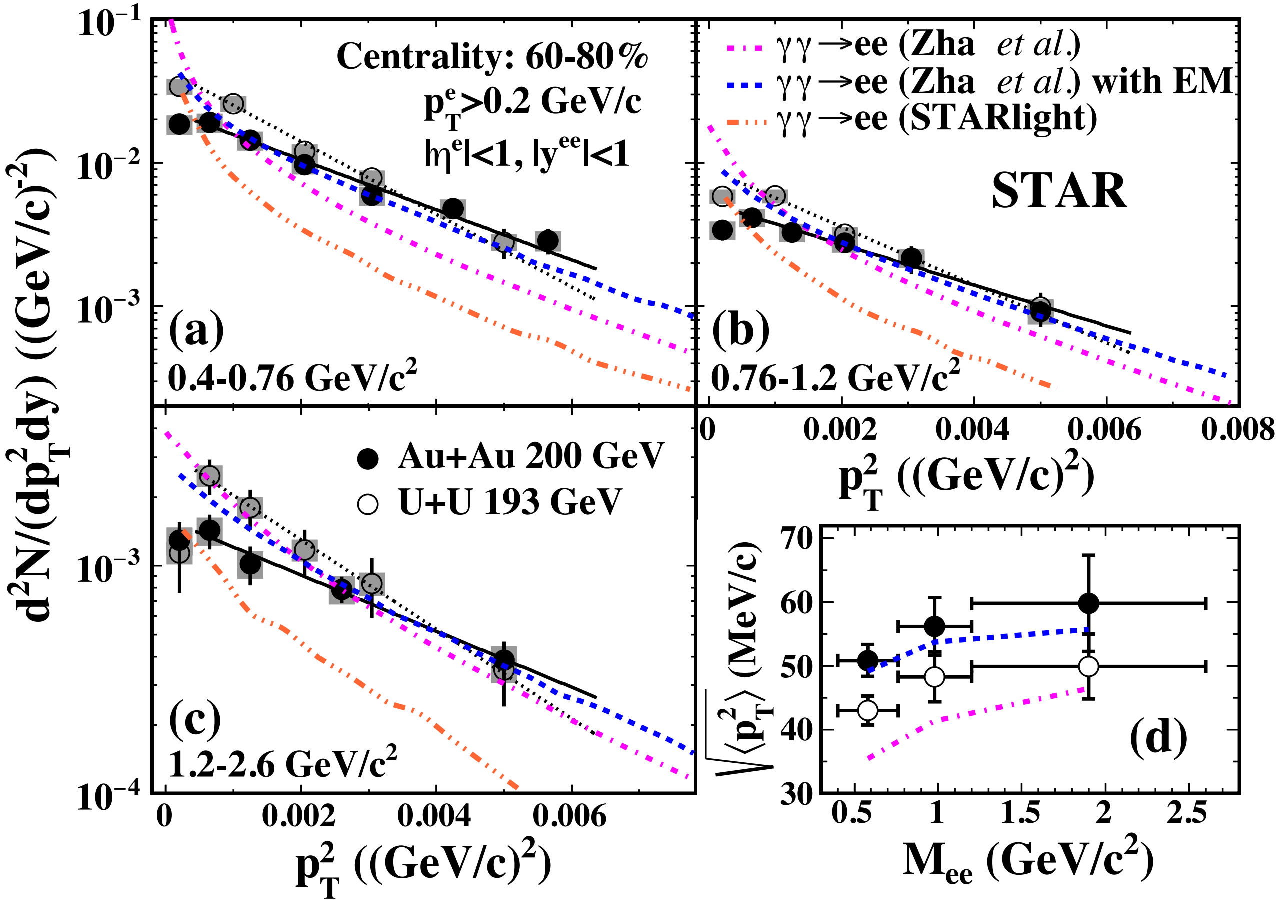
ALICE 70-90%



ALICE, S. Scheid, QM2019

- Excess e^+e^- pair p_T distribution concentrates below p_T ~ 0.15 GeV/c
  - Evidence of photon interactions in hadronic heavy ion collisions

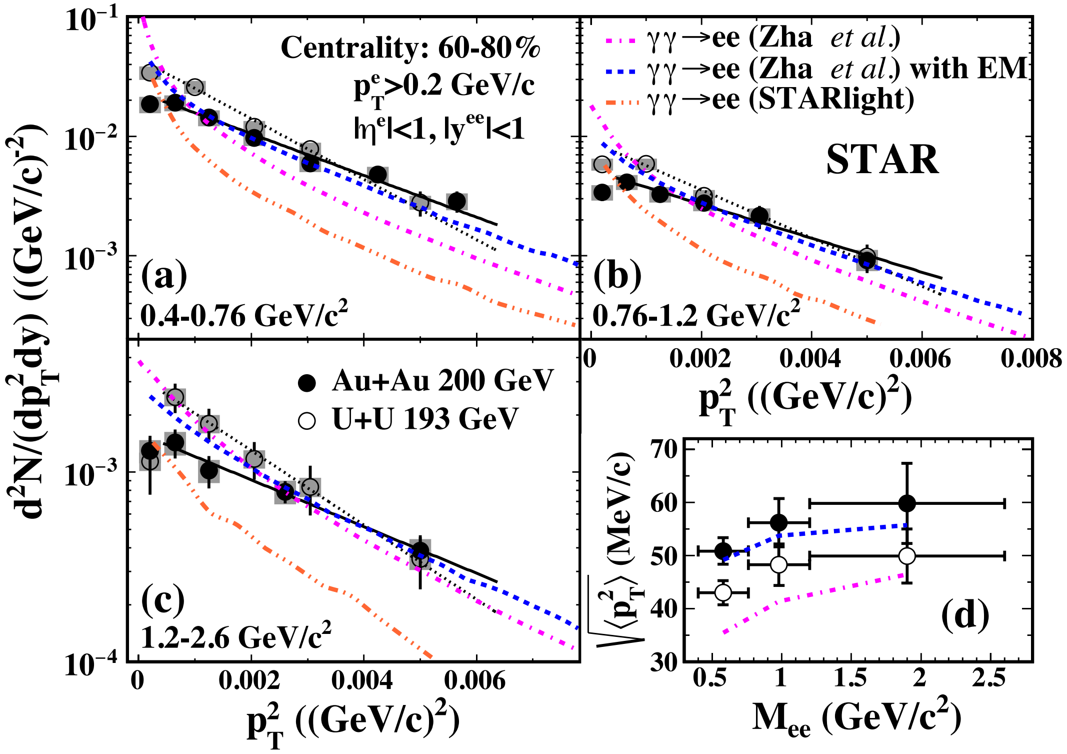
Sensitivity to electromagnetic field trapped in QGP?



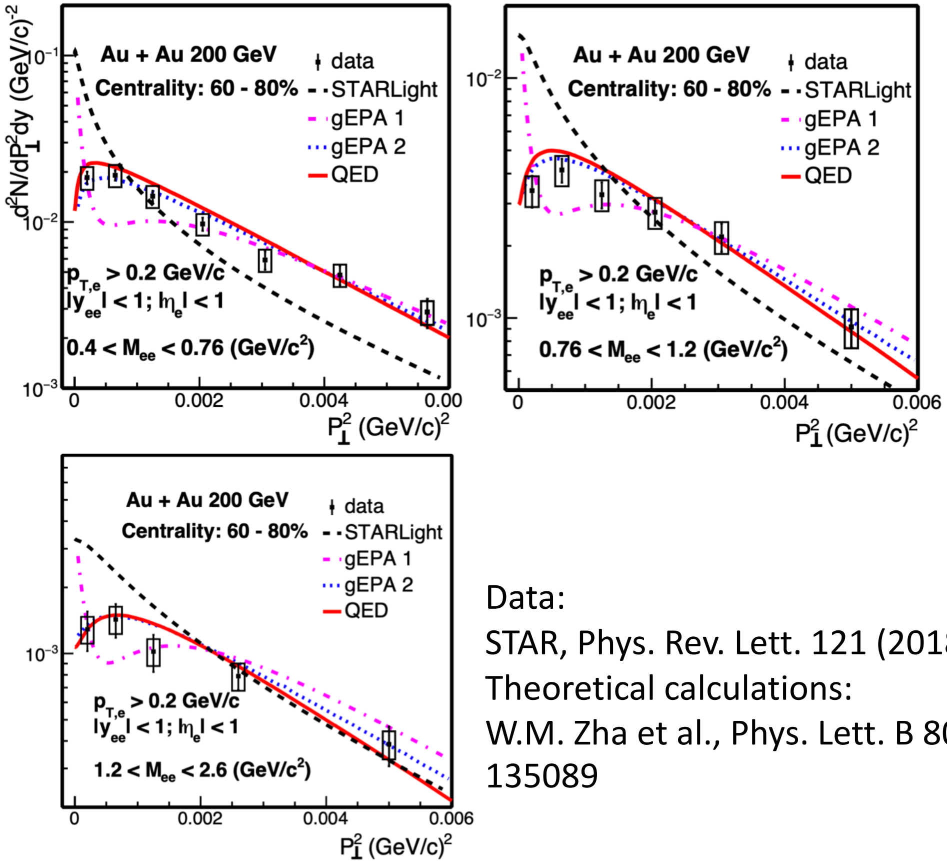
STAR, Phys. Rev. Lett. 121 (2018) 132301
STARlight, Phys. Rev. C 97 (2018) 054903
Zha et al. Phys. Lett. B 781 (2018) 182

- Calculated p_T^2 spectra with EM effects can describe the Au+Au data much better than the same model without incorporating EM effects
  - The level of p_T broadening may indicate the existence of strong magnetic field trapped in a conducting QGP?
  - Or due to the QED scattering between the lepton pair and the medium?
    - Spencer Klein et al., Phys. Rev. Lett. 122 (2019) 132301

Sensitivity to electromagnetic field trapped in QGP?



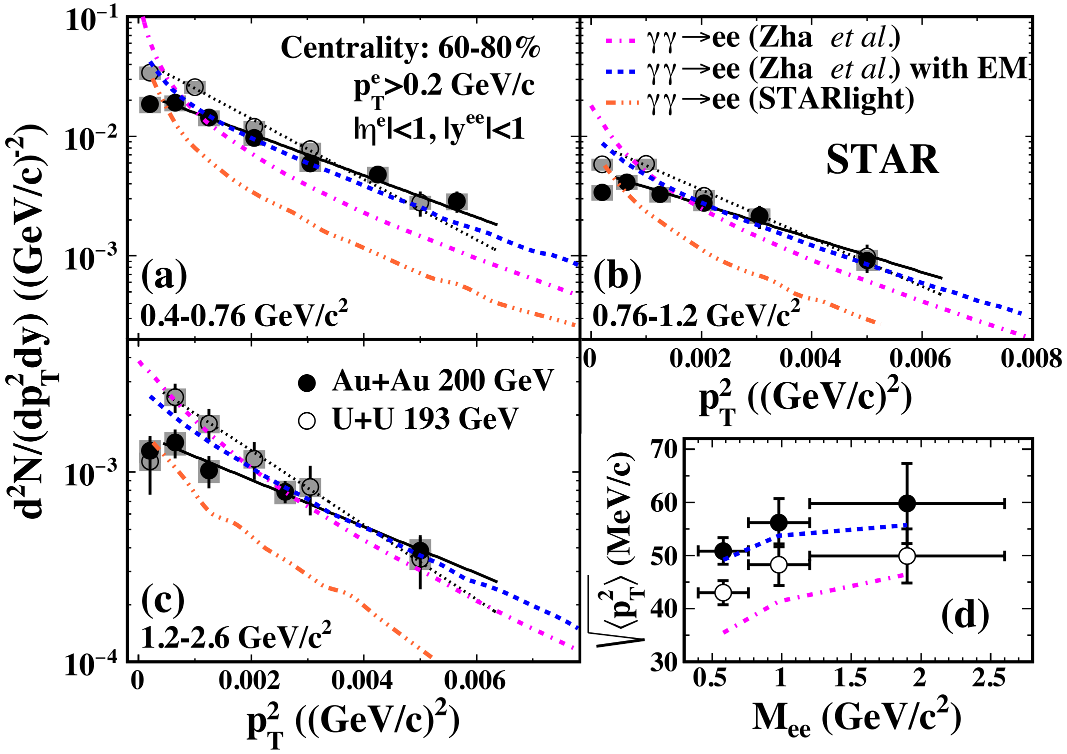
STAR, Phys. Rev. Lett. 121 (2018) 132301



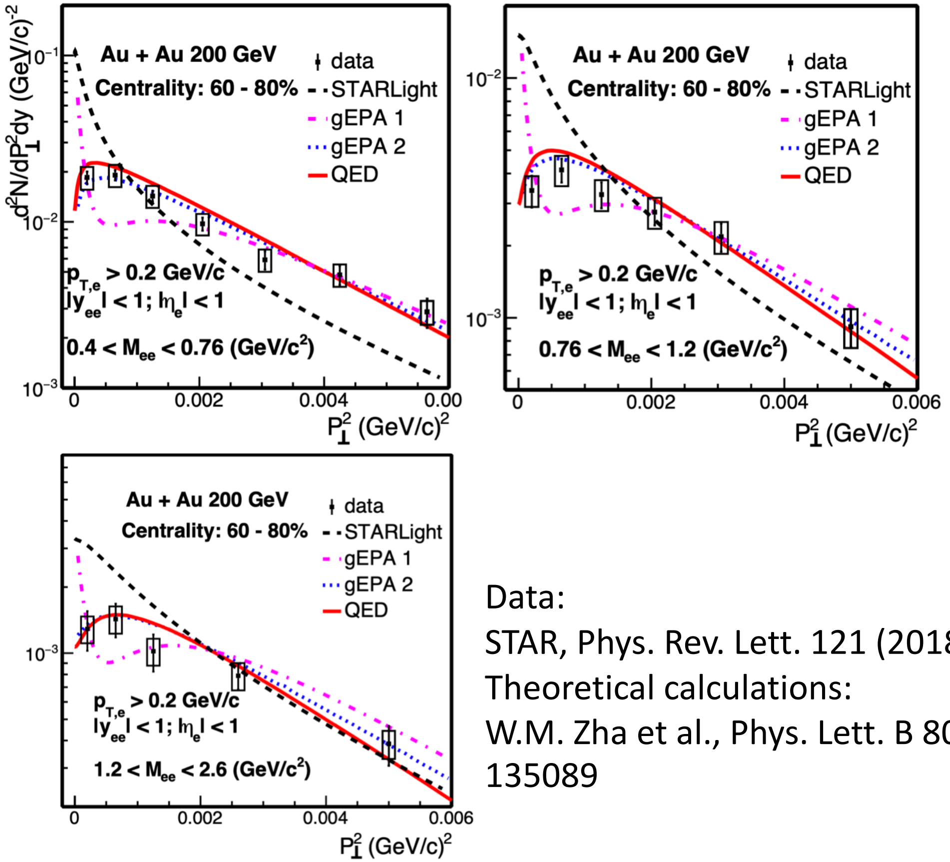
Data:
STAR, Phys. Rev. Lett. 121 (2018) 132301
Theoretical calculations:
W.M. Zha et al., Phys. Lett. B 800 (2020) 135089

- The broadening originates predominantly from the initial electromagnetic field strength that varies significantly with impact parameter
- An additional small broadening may be due to final-state interaction

Sensitivity to electromagnetic field trapped in QGP?



STAR, Phys. Rev. Lett. 121 (2018) 132301

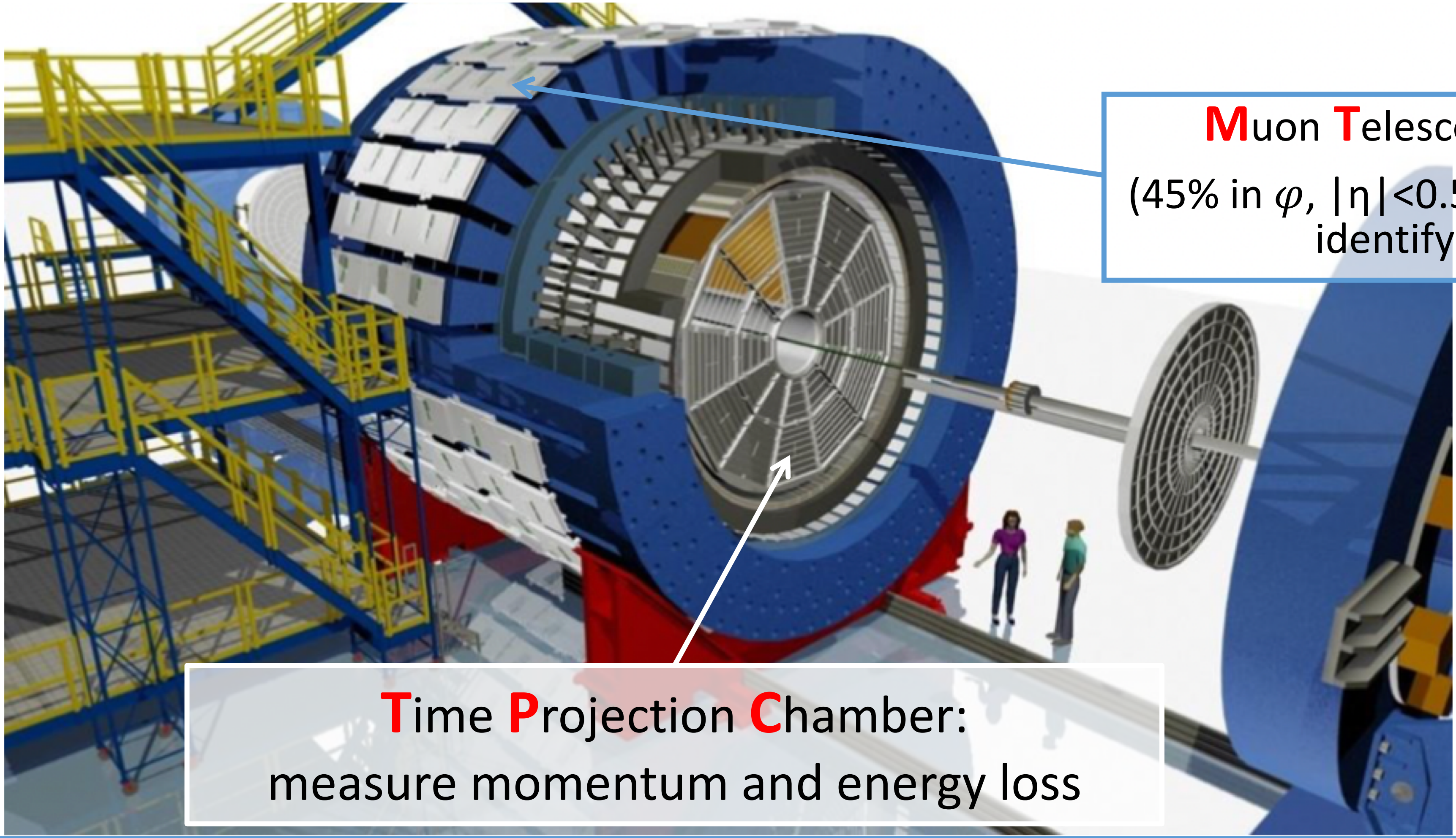


Data:
STAR, Phys. Rev. Lett. 121 (2018) 132301
Theoretical calculations:
W.M. Zha et al., Phys. Lett. B 800 (2020) 135089

- More studies are needed to understand the modification of coherent photoproduction with nuclear overlap
- Low-p_T muon pairs production measurements provide a complementary channel and will help to further improve our understanding of photon-induced processes

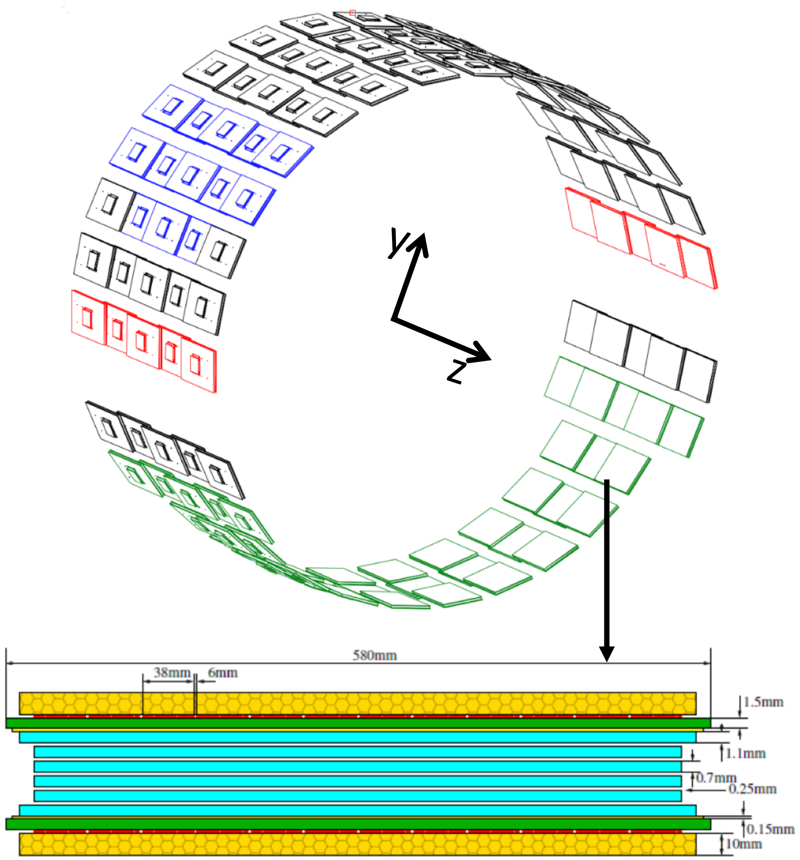
The Solenoid Tracker At RHIC (STAR)

- Mid-rapidity detector: $|\eta| < 1$, $0 < \varphi < 2\pi$



Muon PID with TPC+MTD

Data set: 2014 Au+Au 200 GeV, full luminosity ~ 14.2 nb^{-1}



End view of an LMRPC module for the full MTD

MTD system:

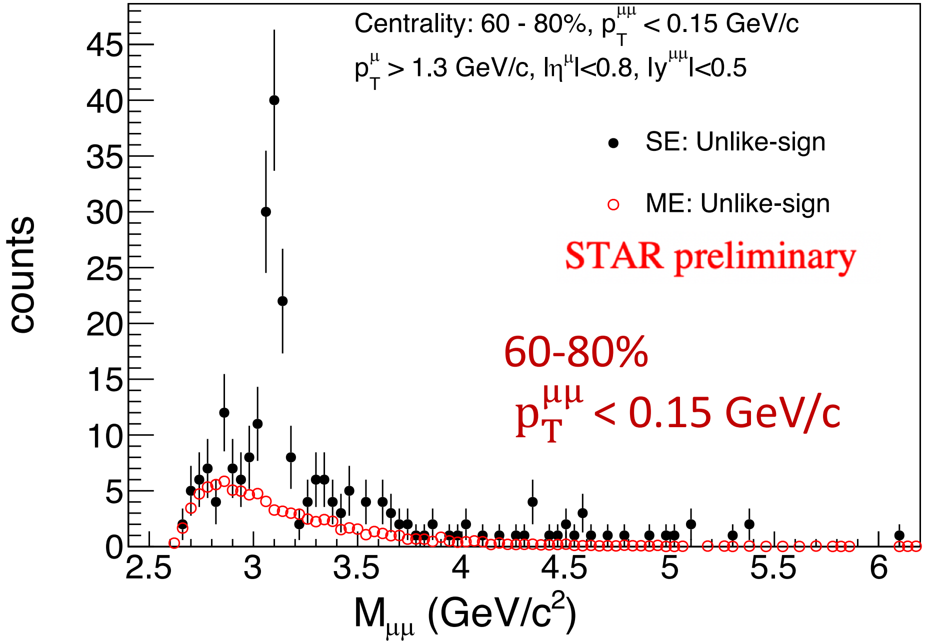
- fully installed in 2014, behind magnet backlegs (~ 5 interaction length)
  - p_T^{μ} > 1.3 GeV/c could hit MTD
  - Precise timing measurement (σ ~ 100 ps)
    - Arrive time: Δtof cut
  - Spatial resolution (~ 1 cm)
    - Hit position: Δy and Δz cut

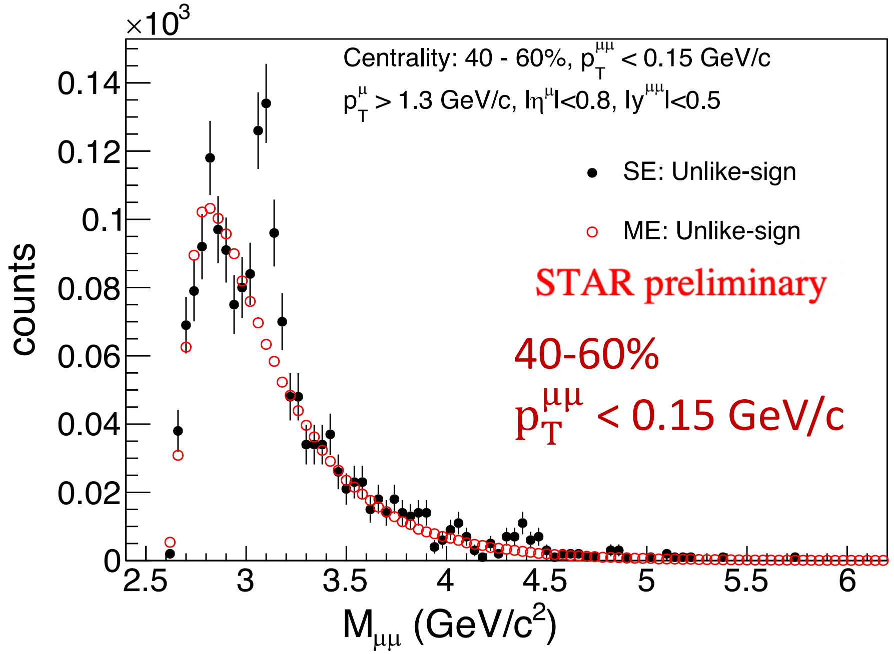
TPC:

- measure energy loss
  - dE/dx cut: muons are expected to lose about 0.5σ more energy compared to pions; $-1 < n\sigma_{\pi} < 3$ (2.5σ)

MTD system provides the possibility of muon pair measurement in the high mass region

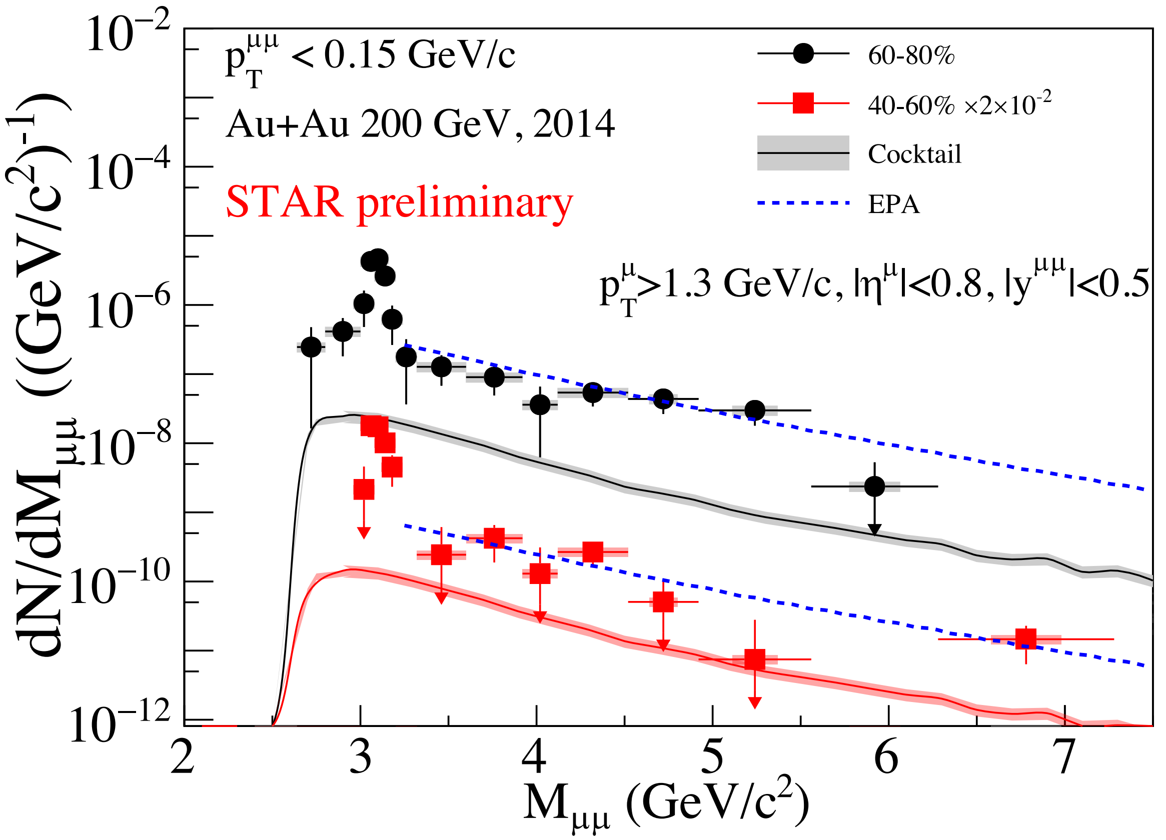
Signal Extraction





- The $\mu^+\mu^-$ invariant mass distribution for p_T < 0.15 GeV/c in peripheral collisions
  - The mixed-event technique is used to estimate the combinatorial background
  - Focused on the high mass region 3.2 < $M_{\mu\mu}$ <10 GeV/c^2

Invariant mass spectra in peripheral collisions



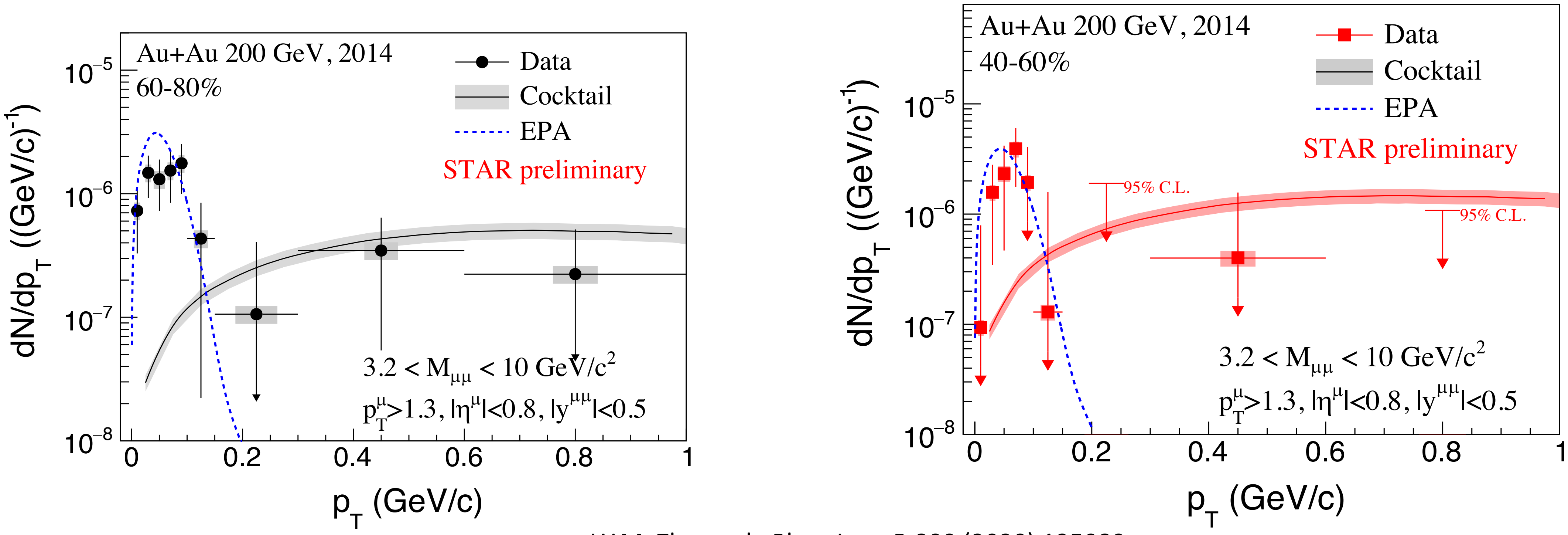
W.M. Zha et al., Phys. Lett. B 800 (2020) 135089

- Significant enhancement with respect to the cocktail in 60-80% centrality collisions
- Consistent with the theoretical calculation

Equivalent Photon Approximation (EPA) method

- Photon is treated as real
- Weizsacker–Williams method to estimate photon flux

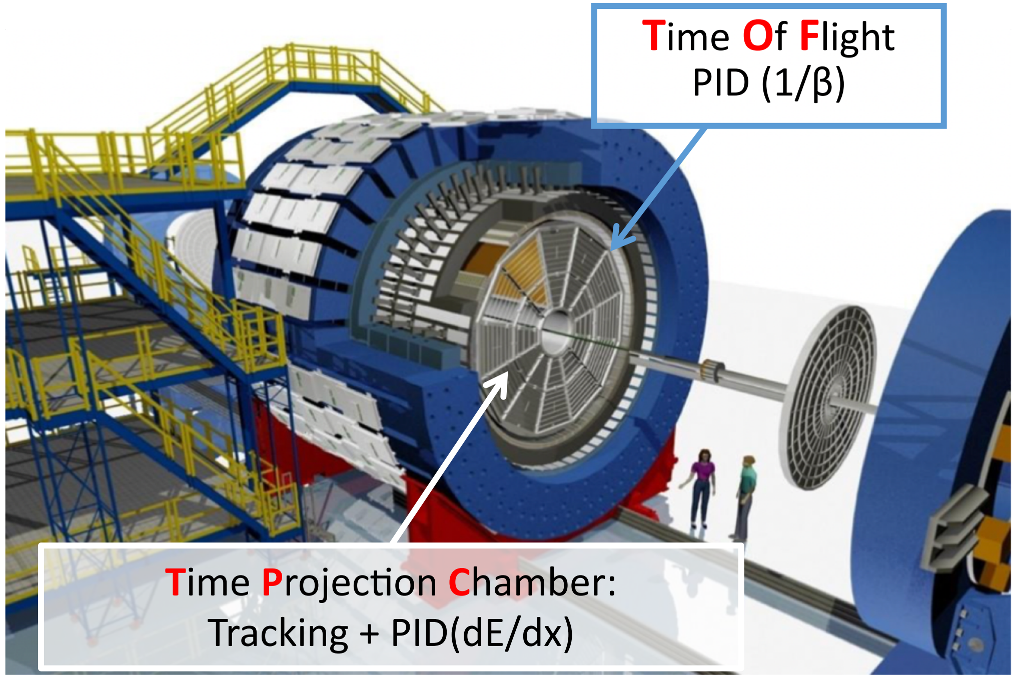
p_T distributions in peripheral collisions

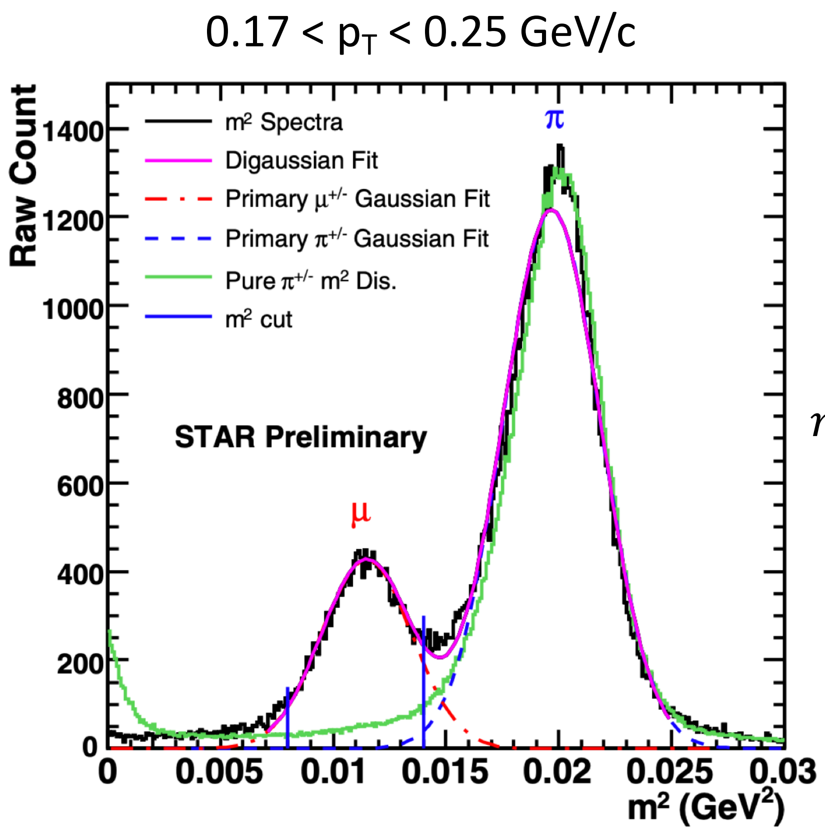


W.M. Zha et al., Phys. Lett. B 800 (2020) 135089

- Excesses concentrate below $p_T \approx 0.15$ GeV/c
- Data are consistent with hadronic expectation when $p_T > 0.15$ GeV/c
- Theoretical calculation is compatible with data

Dimuon in low mass region





$$m^2 = (p/(\beta\gamma))^2$$

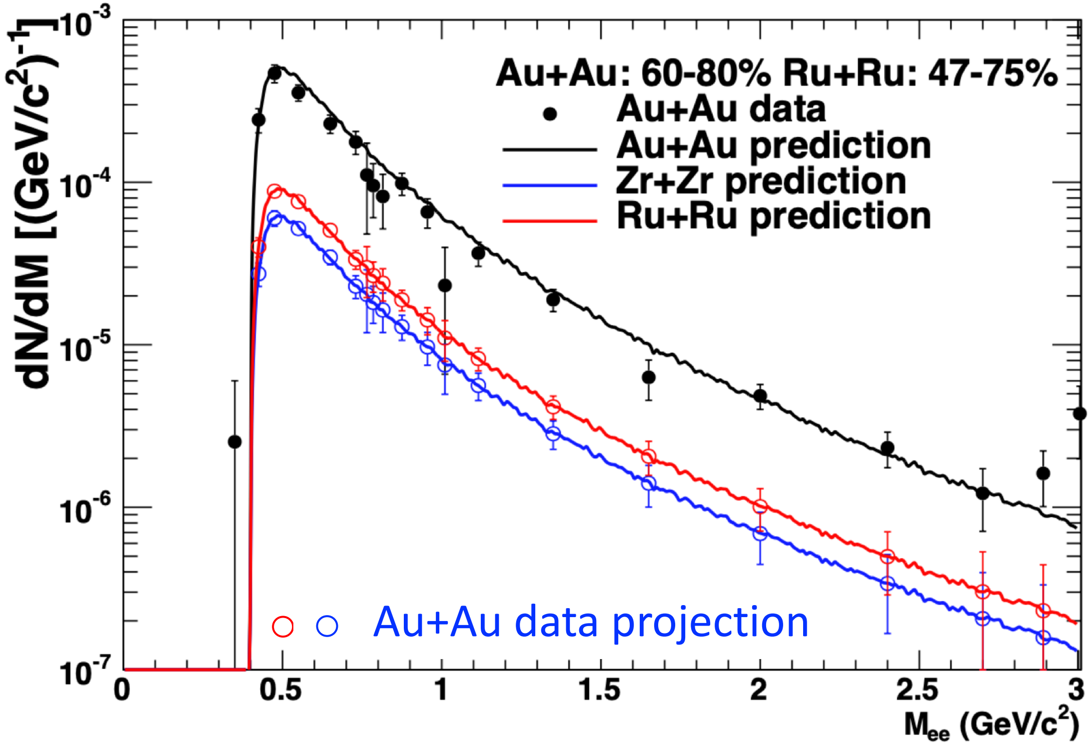
C. Zhong, J. Phys. G: Nucl. Part. Phys. 34 (2007) S741–S744

- TPC+TOF: dimuon measurement in low mass region ($0.4 < M_{\mu\mu} < 0.65$ GeV/c^2) is ongoing
  - Provide a complementary mass range
  - Help to further improve our understanding of photon induced processes

Isobaric collisions in 2018

- ${}^{96}_{44}\mathrm{Ru}$ vs. ${}^{96}_{40}\mathrm{Zr}$
  - Charge differs by 10%, everything else is almost the same
  - Huge statistics: 3.1B minimum-bias events for each

W.M. Zha et. al., PLB 789 (2019) 238-242



- 60-80% Au+Au vs. 47-75% Ru+Ru
  - Similar hadronic contribution
  - Different yields from two photon interactions
- Statistics
  - 60-80% Au+Au: ~180M
  - 47-75% Ru+Ru (Zr+Zr): ~840M
- Yield ratio in 0.4-0.76 GeV/c^2
  - Au : Ru : Zr ≈ 8.11 : 1.46 : 1
  - Difference between Ru+Ru and Zr+Zr: 3.7σ
  - Help to verify and constrain the possible trapped magnetic field

Summary

- A significant $\mu^+\mu^-$ enhancement w.r.t. cocktail is observed at very low p_T in peripheral Au+Au collisions at 200 GeV
  - Measured in high mass region $3.2 < M_{\mu\mu} < 10$ GeV/c^2
  - Excess entirely happens below $p_T \approx 0.15$ GeV/c
  - Compatible with the theoretical calculation
- Outlook
  - The low-p_T dimuon measurement in low mass region and using the isobaric data could further improve our understanding of photon induced processes

Thanks for your attention!