UPC 2023 First international workshop on the physics of Ultra Peripheral Collisions

Dimuon production at low transverse momentum in peripheral Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV at STAR

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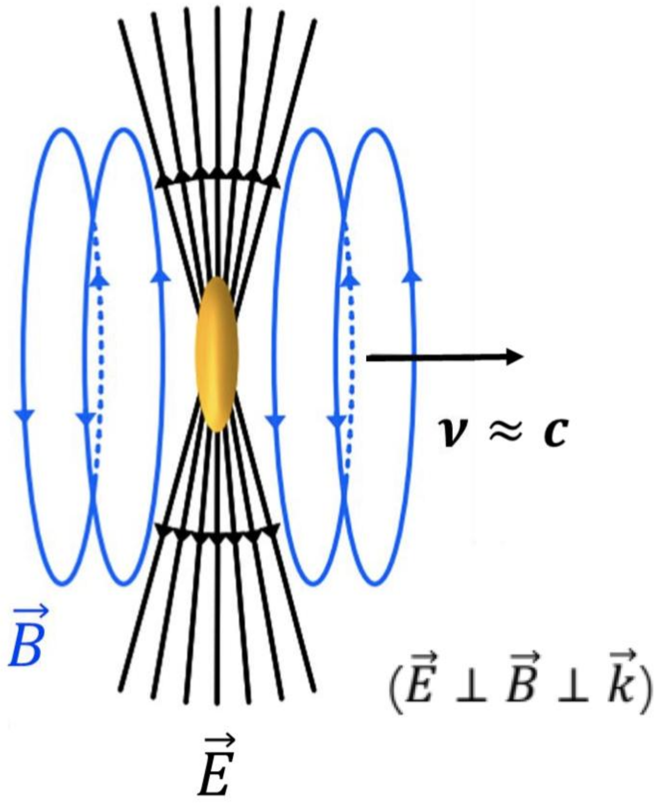
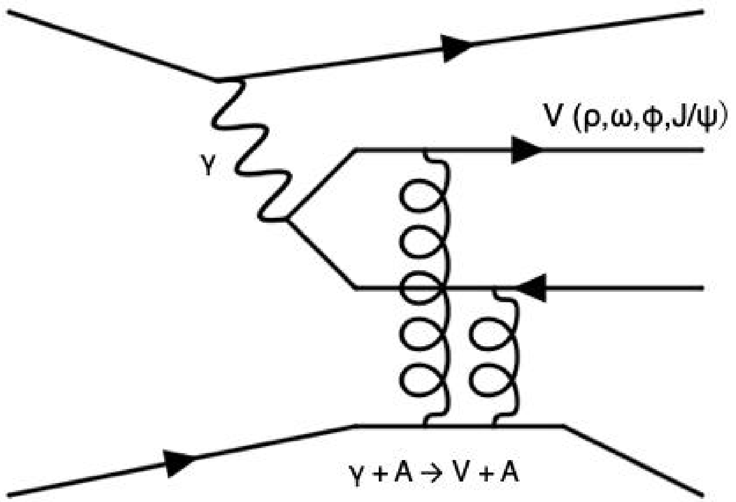
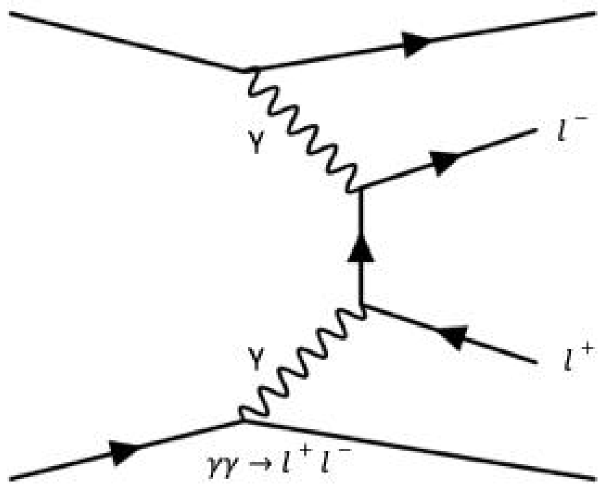
Photon-induced process







- Boosted nuclei generate intense electromagnetic fields
- Weizsacker-Williams equivalent photon approximation (EPA):
  - In a specific phase space, transverse EM fields can be quantized as a flux of quasi-real photons

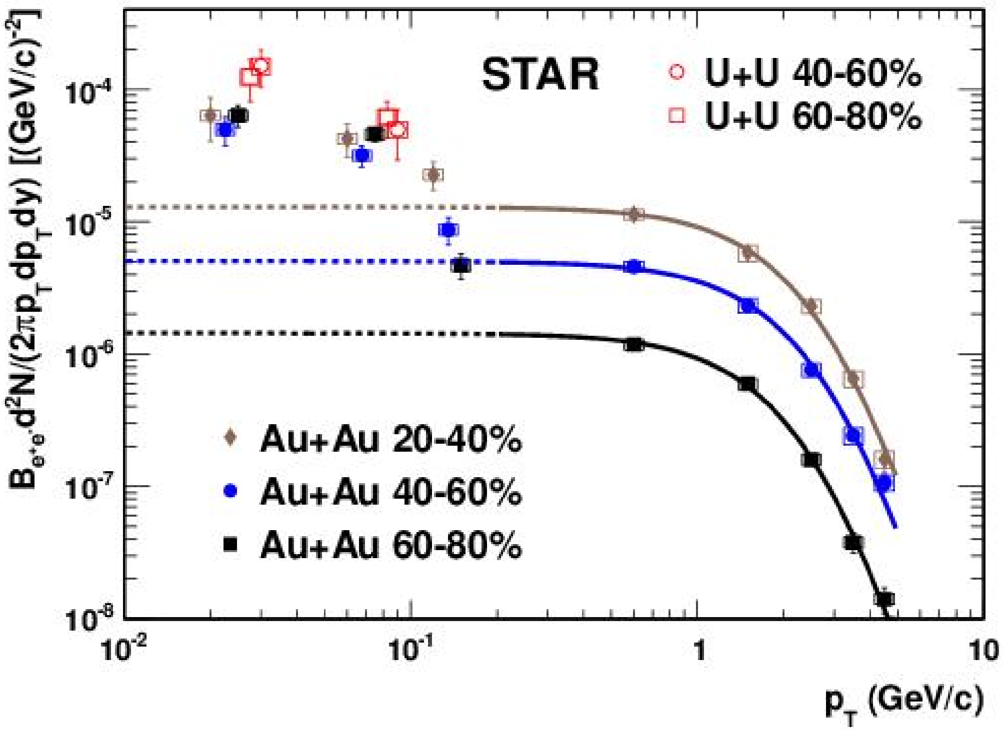
$$n \propto \vec{S} = \frac{1}{\mu_0}\vec{E} \times \vec{B} \approx |\vec{E}|^2 \approx |\vec{B}|^2$$

- Large quasi-real photon flux $\propto Z^2$

Photoproduction with nuclear overlap

$\gamma A \rightarrow J/\psi \rightarrow e^+e^-$

STAR: Phys. Rev. Lett. 123, 132302 (2019)



$\gamma\gamma \rightarrow e^+e^-$

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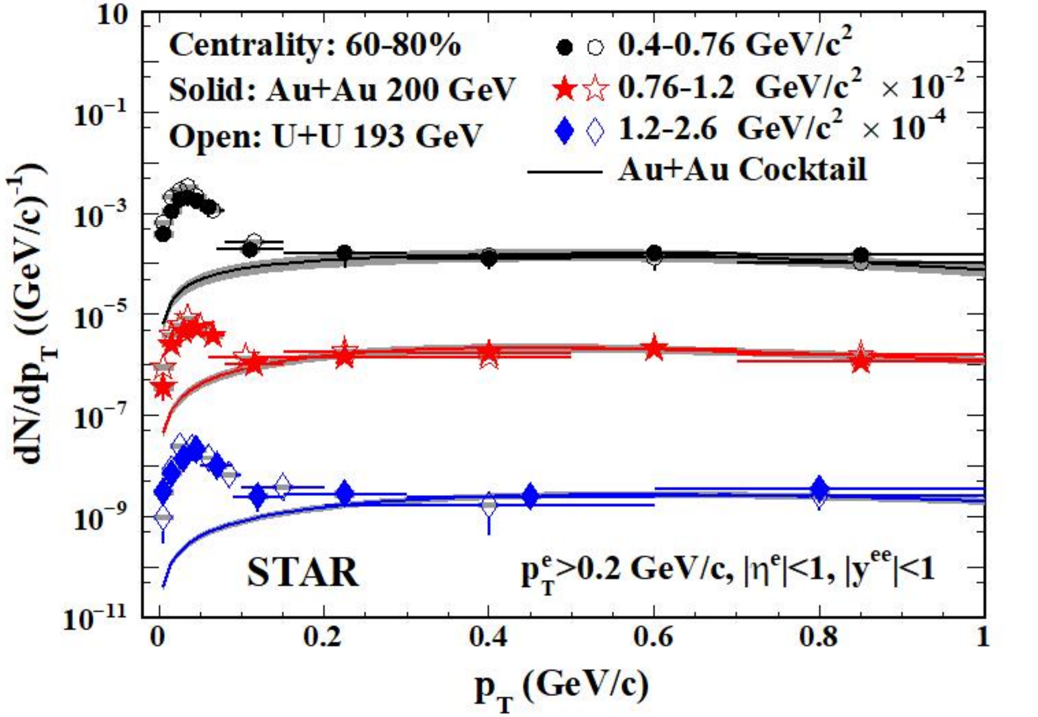
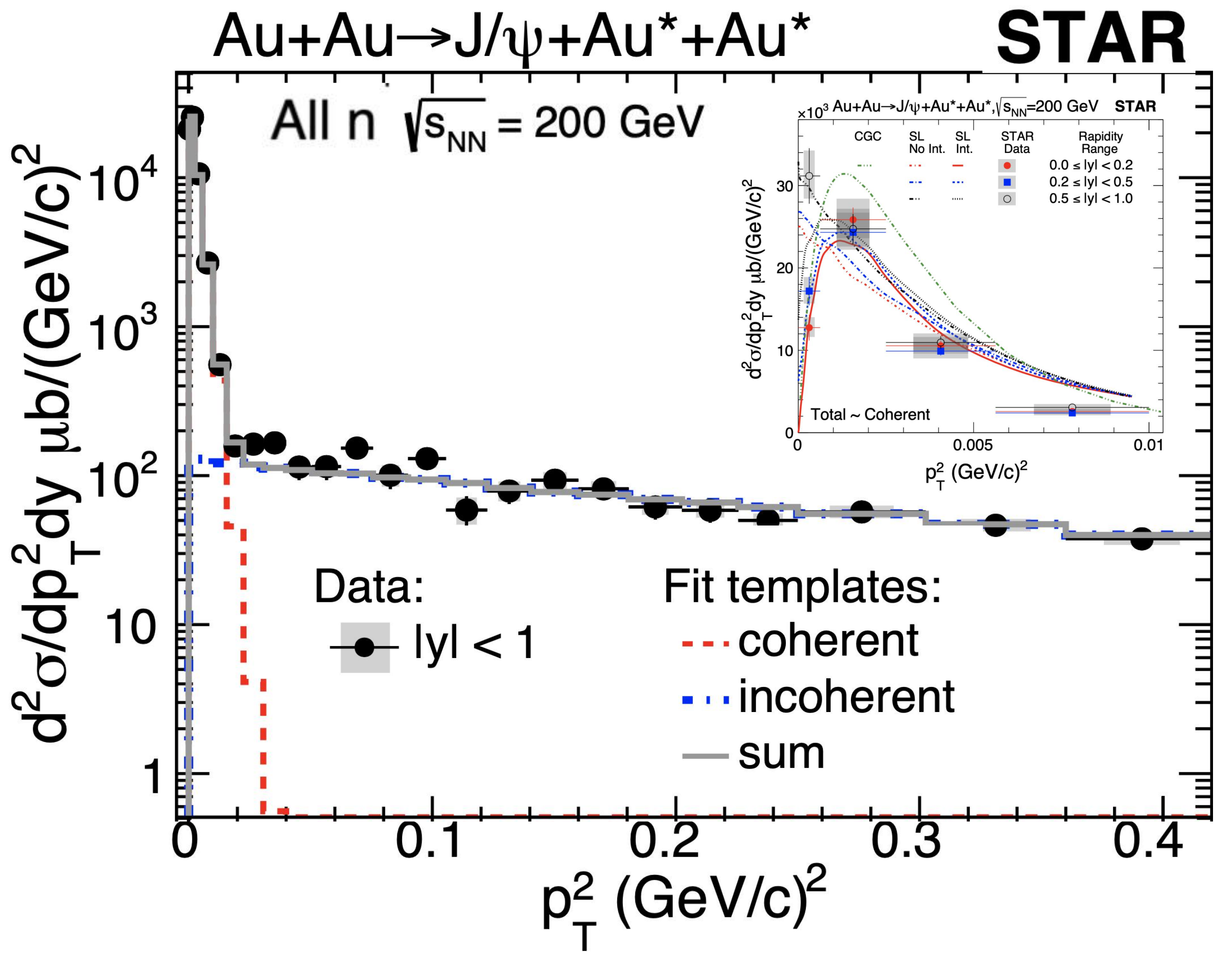


- Significant enhancements of J/ψ and dielectron pair production at very low p_T (below ~ 0.2 GeV/c)
- Evidence of coherent photon interactions in hadronic heavy–ion collisions

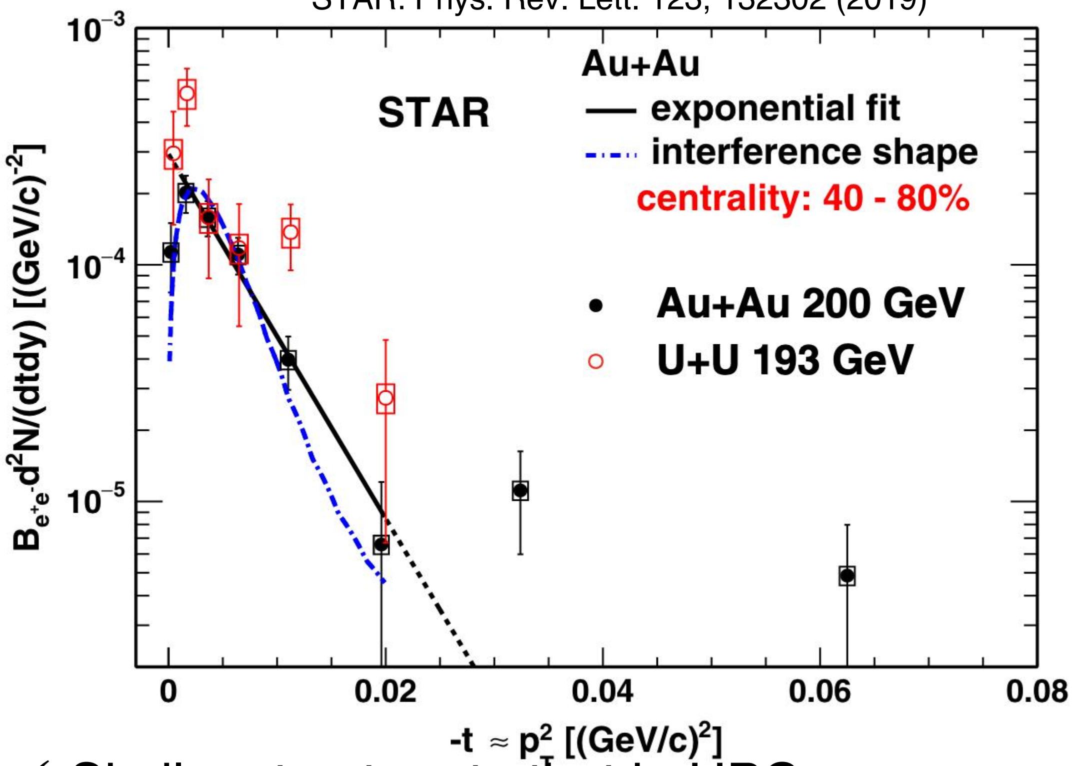
t spectra of photoproduced J/ψ



J/ψ as a function of the momentum transfer squared ($-t \approx p_T^2$) from STAR UPC measurements

STAR: arXiv:2311.13632 [nucl−ex]

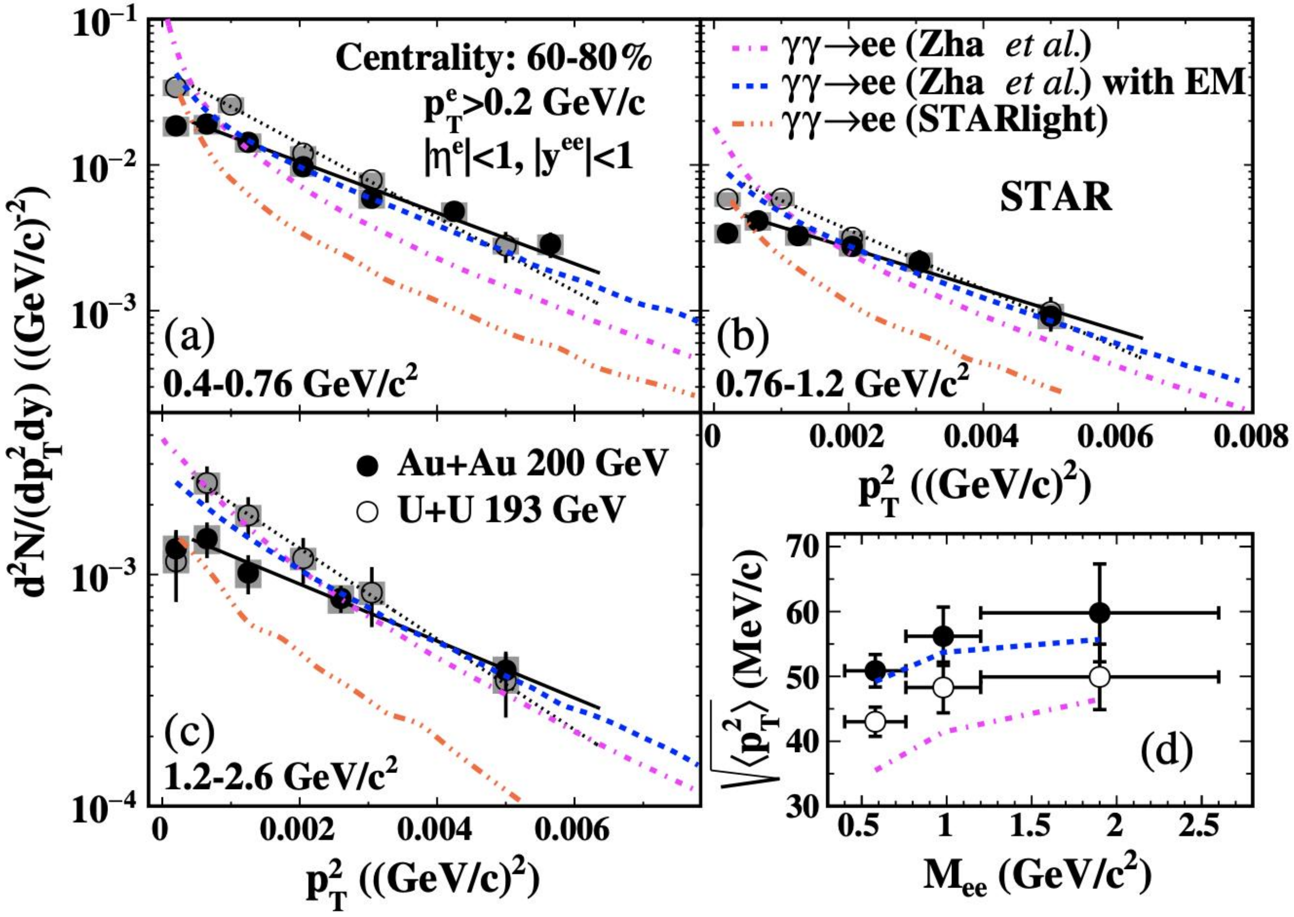
STAR: Phys. Rev. Lett. 123, 132302 (2019)



- ✓ Similar structure to that in UPC
- ✓ Indication of interference
- ✓ The slope from the exponential fit to Au+Au reflects the size and shape of nuclear target:
  - ➢ 177 ± 23 (GeV/c)$^{-2}$, consistent with that expected for an Au nucleus [199 (GeV/c)$^{-2}$] within uncertainties

Sensitivity to electromagnetic field trapped in QGP?

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



solid line : exponential fit to the Au+Au data

- p_T^2 spectra is measured in different dielectron mass regions
- Calculated p_T^2 spectra with EM effects can describe the data much better than the same model without 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

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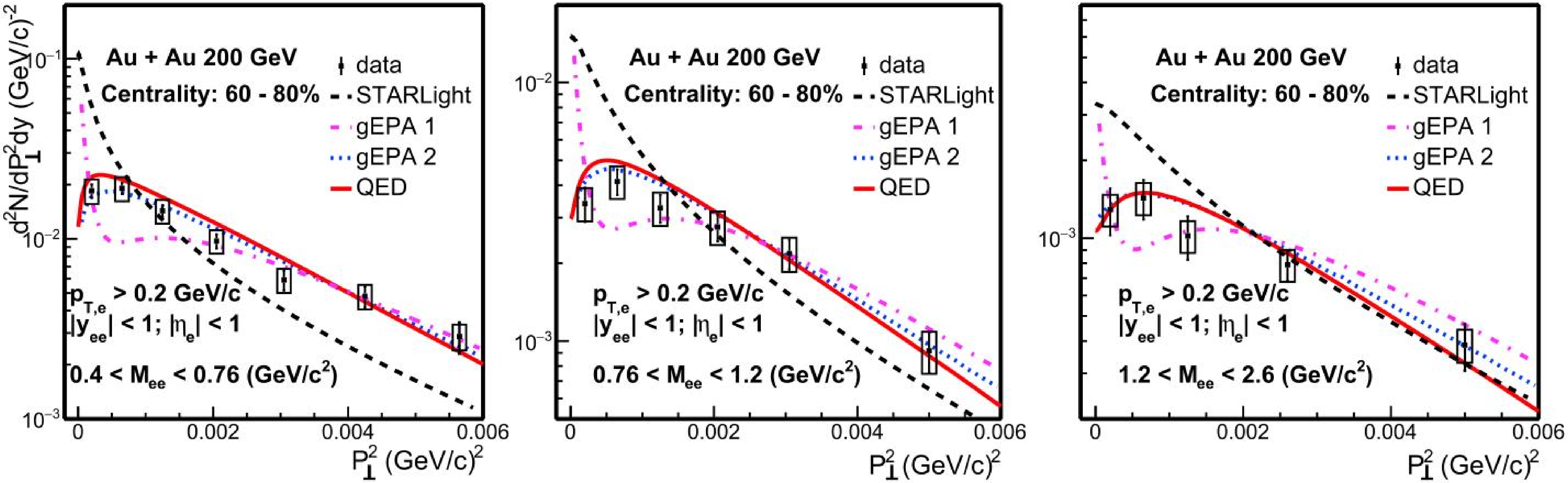

- The broadening originates predominantly from the initial electromagnetic field strength that varies significantly with impact parameter
- An additional small broadening may be due to final–state interaction

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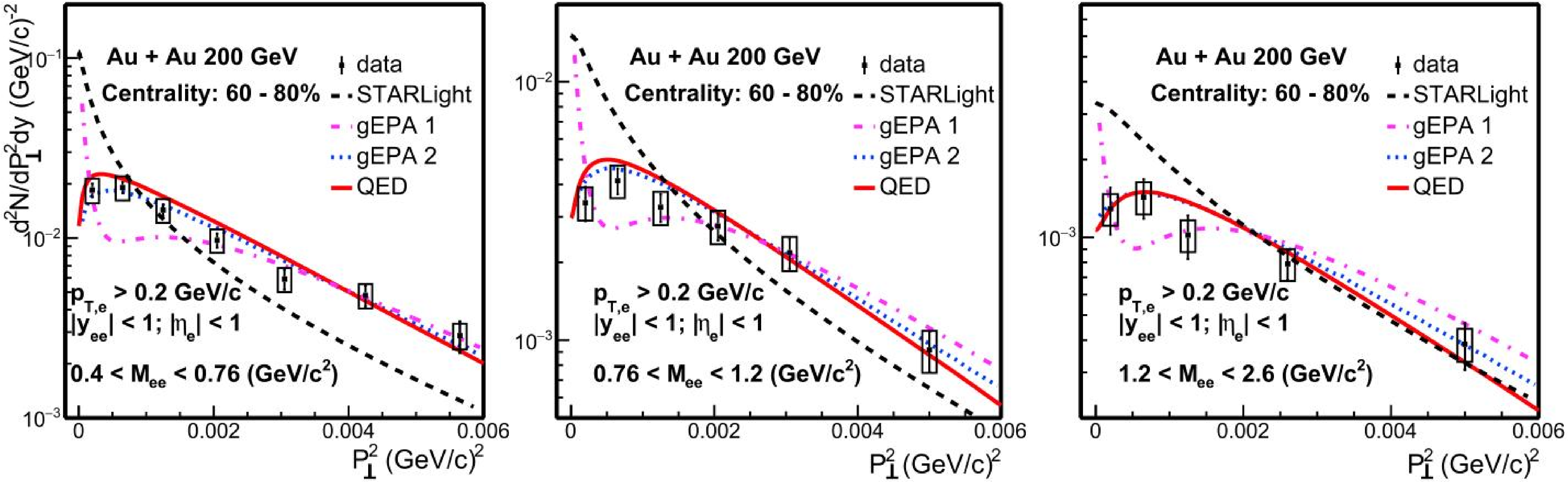
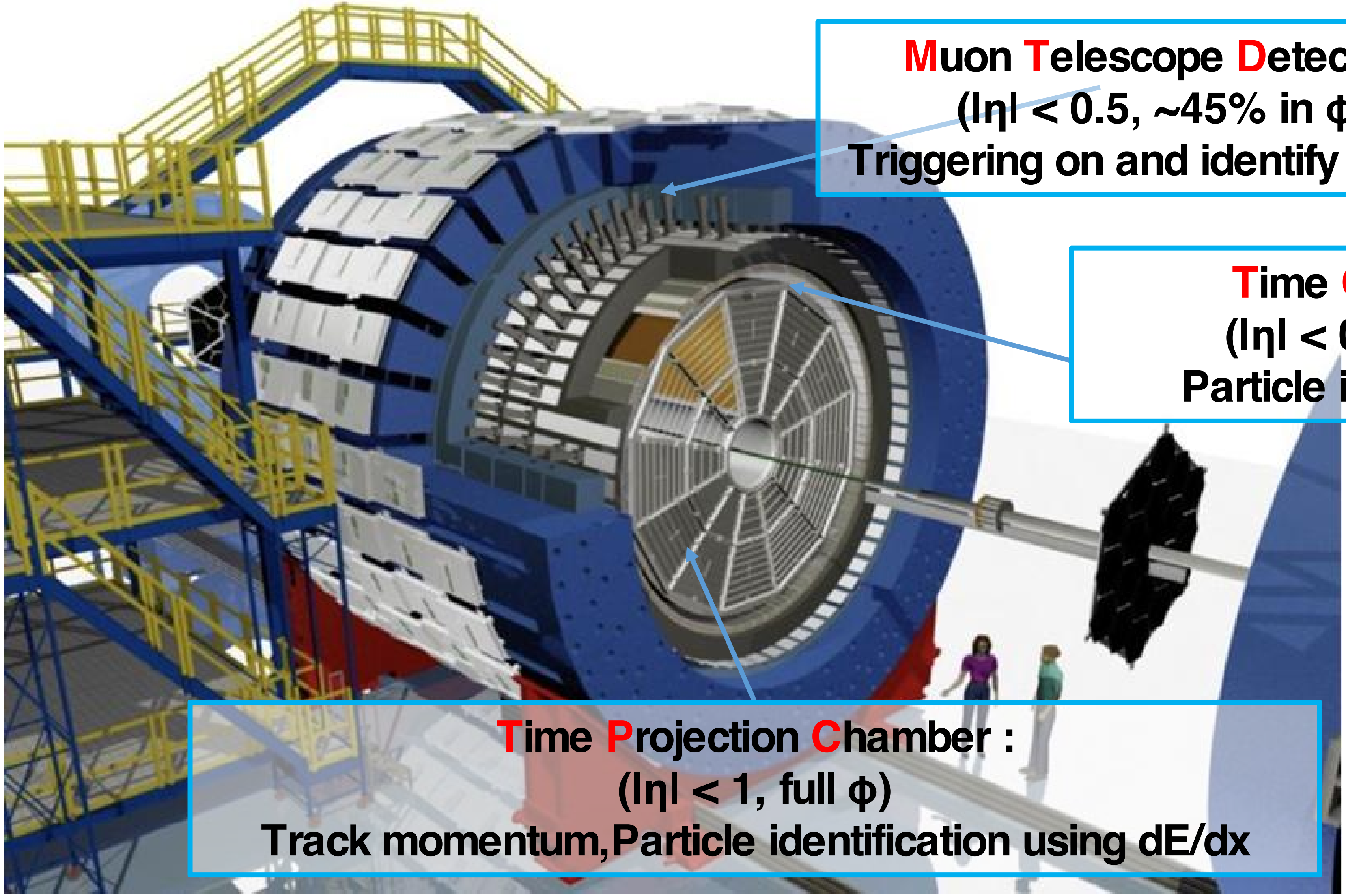


- Dimuon channel measurements are complementary to dielectron results and can help to further improve our understanding of photoproduction processes in peripheral heavy-ion collisions

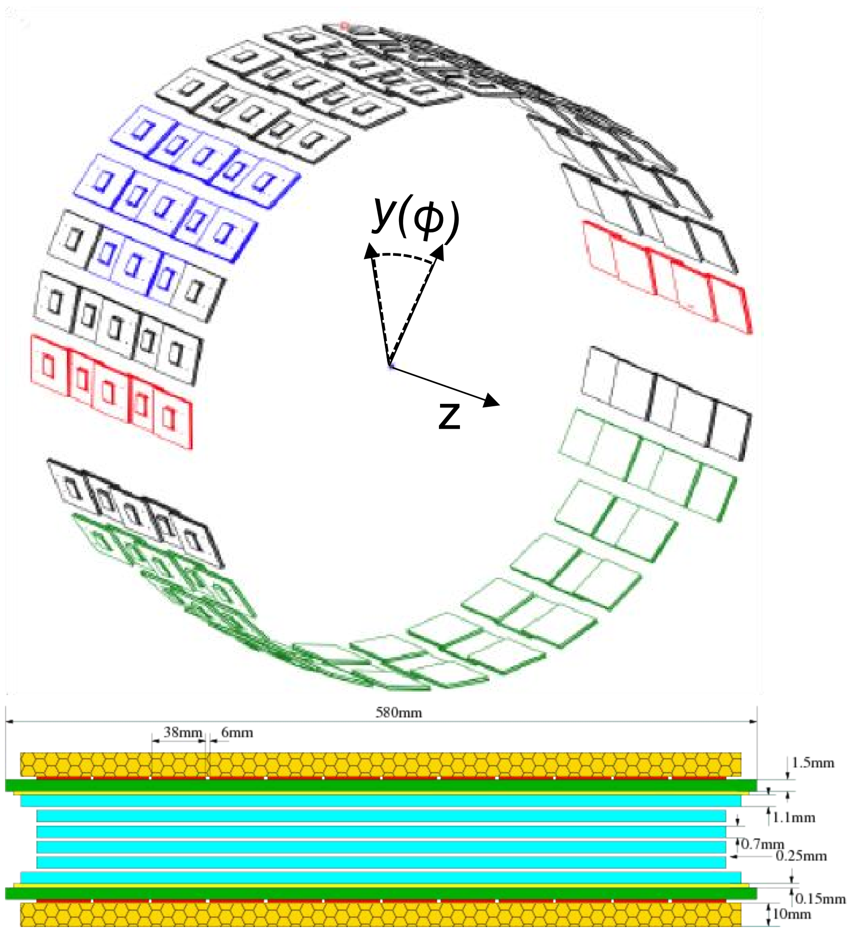
The Solenoidal Tracker At RHIC (STAR)



Data set:

- 2014 Au+Au 200 GeV
- Dimuon trigger (high mass)
  - ➢ sampled luminosity ~ 14.2 nb^{-1}
- Minimum bias (MB) trigger (low mass)

Muon PID in high momentum region



TPC:

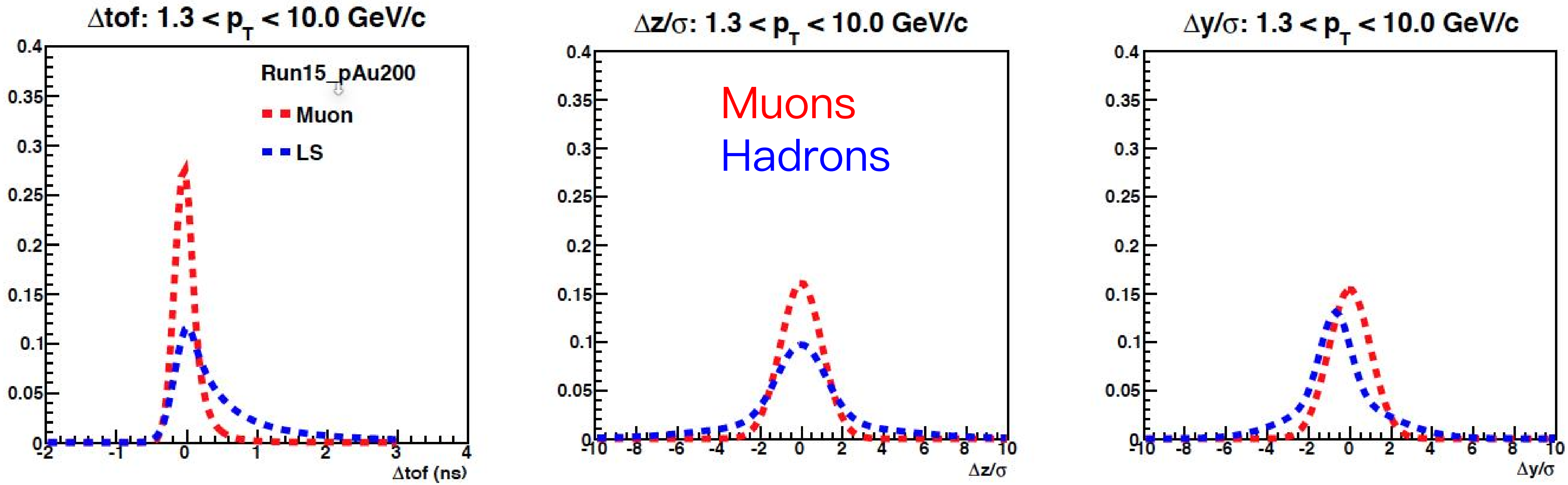
- dE/dx cut: muons are expected to lose about 0.5σ more energy compared to pions; $-1 < n\sigma_{\pi} < 3$

MTD system:

- Fully installed in 2014, behind the magnet (~ 5 interaction length)
- p_T threshold for MTD ~ 1.2 GeV/c

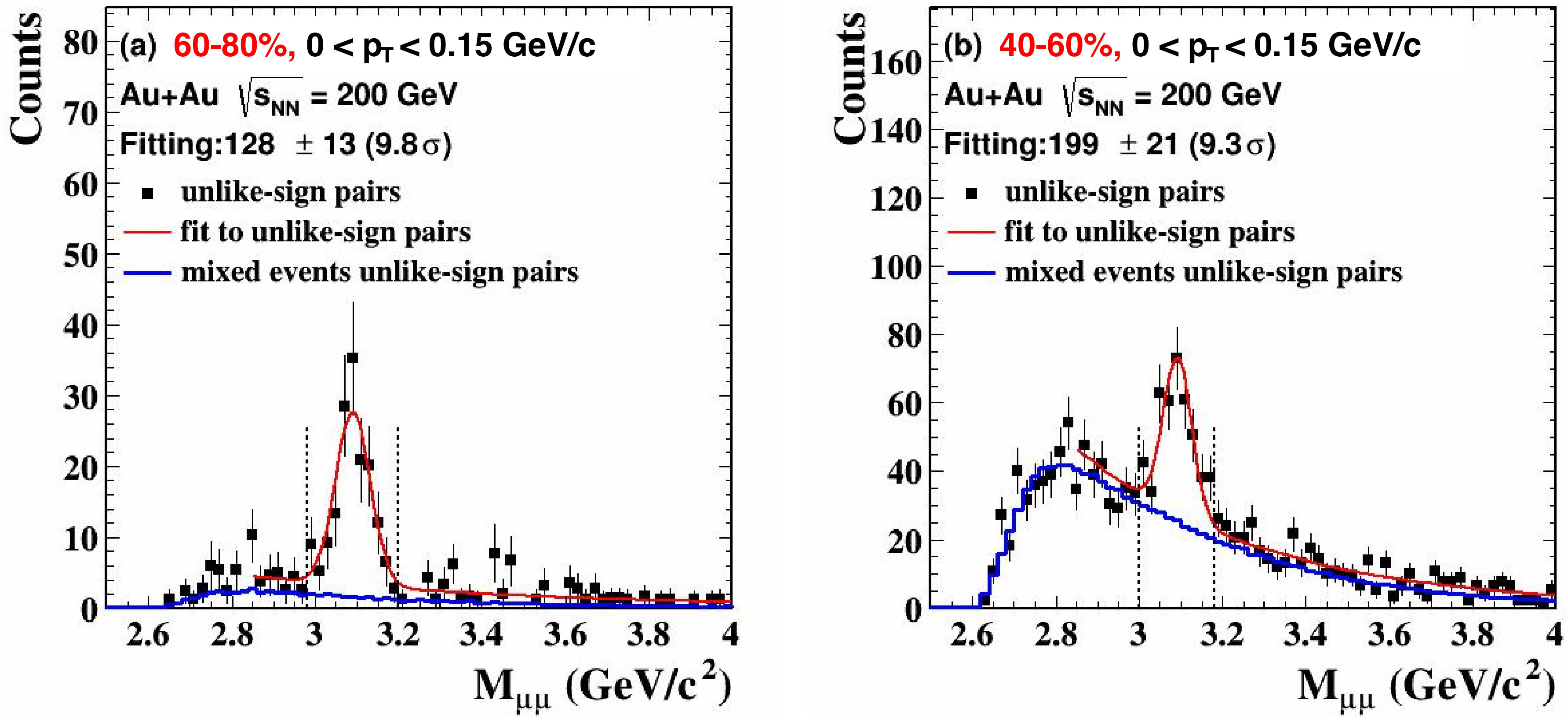
MTD system provides the capability of muon pair measurement in the high mass region

Position and timing information from MTD



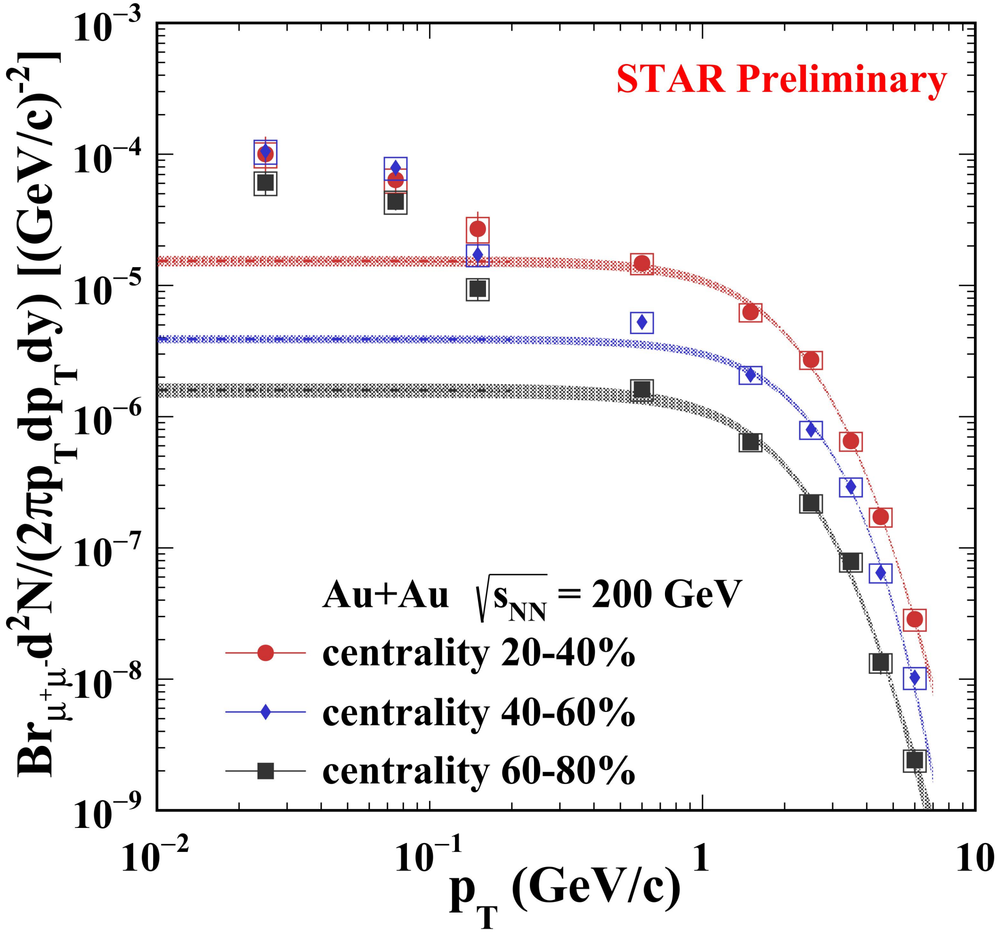
- Precise timing measurement (σ ~ 100 ps)
  - Arrival time: Δtof cut
- Intrinsic spatial resolution (~ 1 cm)
  - Hit position: Δy and Δz cuts

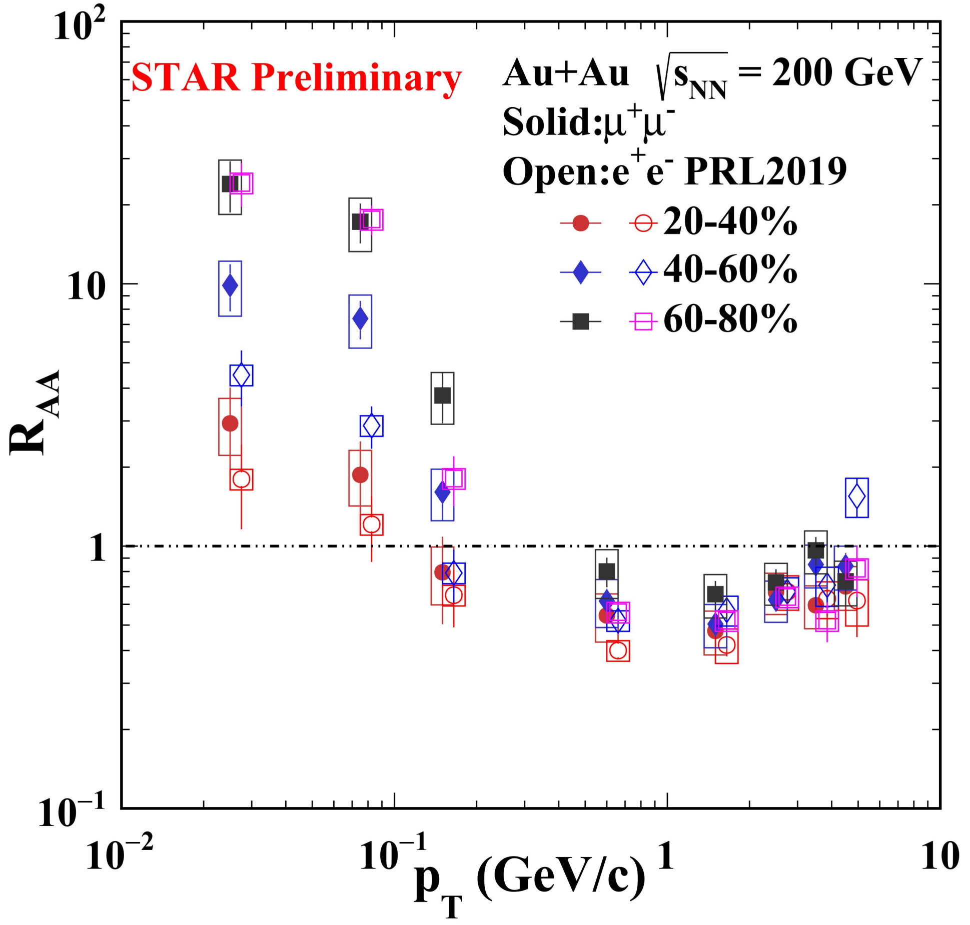
$J/\psi \rightarrow \mu^+\mu^-$ signal extraction



- Muon pair mass distributions for p_T < 0.15 GeV/c in 40-60% and 60-80% centralities
- The raw signal is obtained from the combined fit of signal, mixed event combinatorial background and residual background using the Maximum Likelihood (ML) method
- Focus on the J/ψ ($2.9 < M_{\mu\mu} < 3.2$ GeV/c^2) and high mass region ($M_{\mu\mu} > 3.2$ GeV/c^2, shown later)

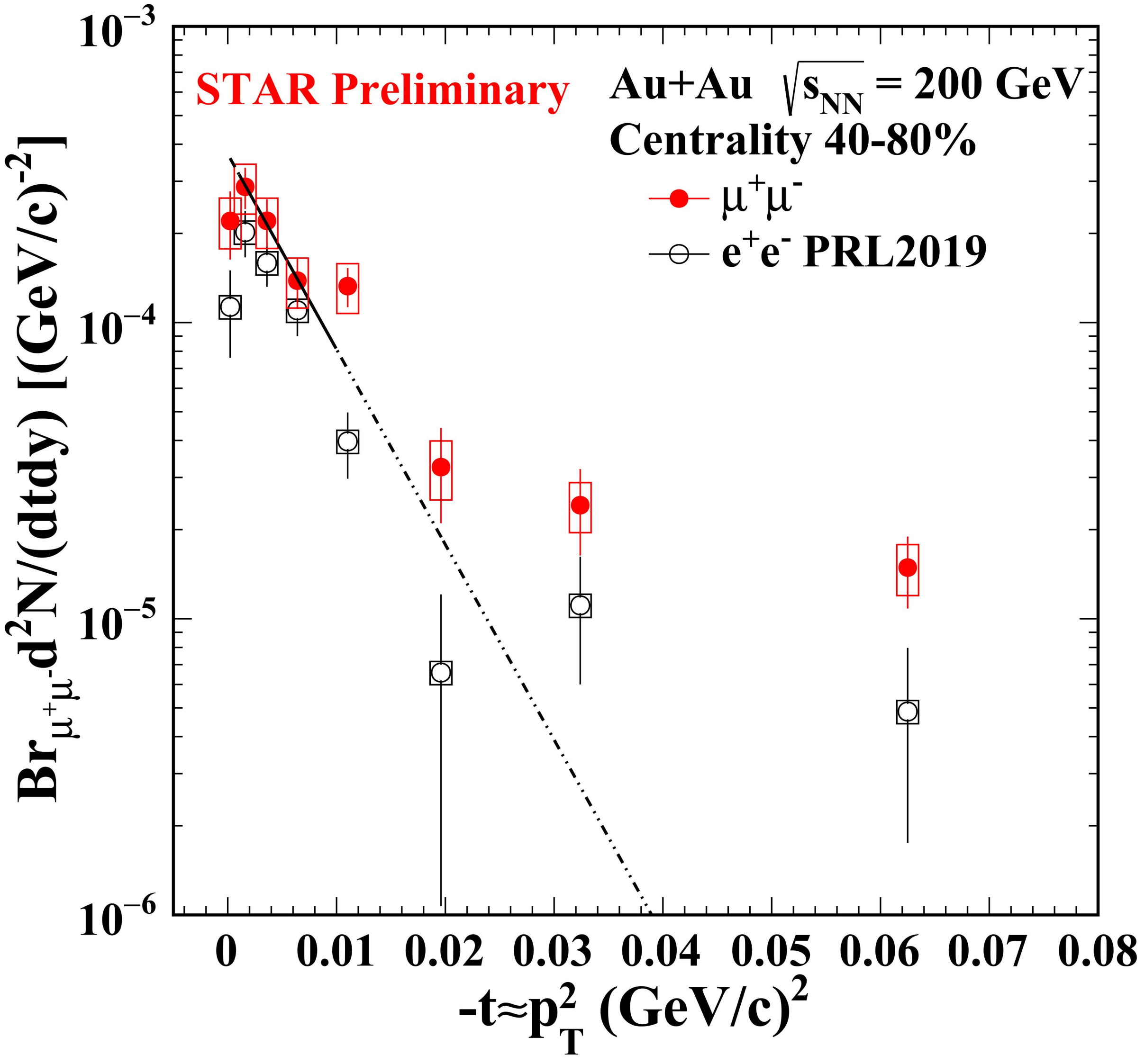
$J/\psi \to \mu^+\mu^-$ invariant yield and R_{AA}





- A large enhancement of the J/ψ yield at low p_T in peripheral collisions
- Consistent with dielectron channel results

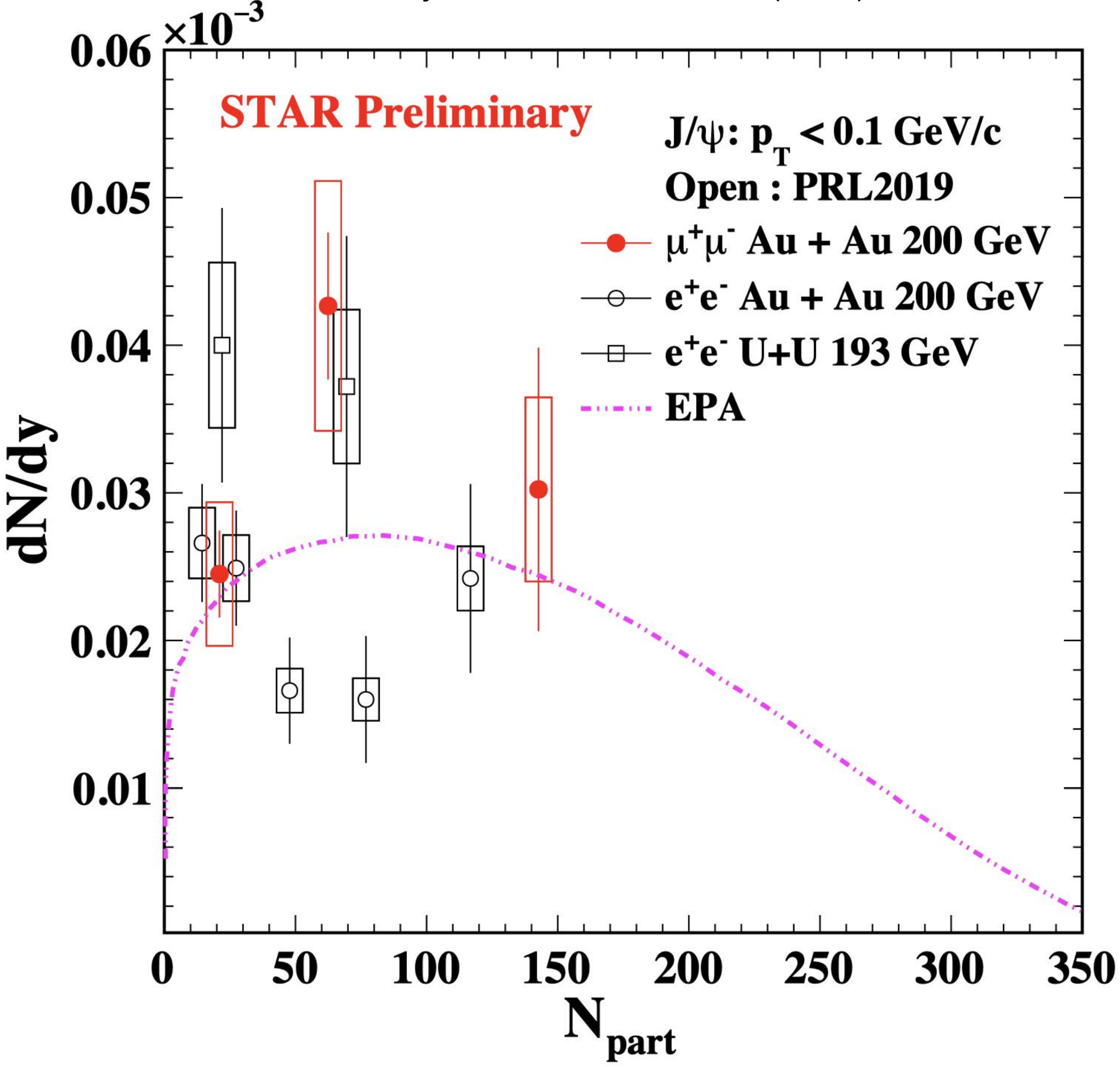
J/ψ→μ⁺μ⁻ t distribution



- The slope parameter is 153 ± 55 (GeV/c)$^{-2}$, consistent with the e^+e^- channel results, 177 ± 23 (GeV/c)$^{-2}$
- The first data point is significantly lower than the extrapolation of the exponential fit
  - Indication of interference

J/ψ→$\mu^+\mu^-$ excess yield

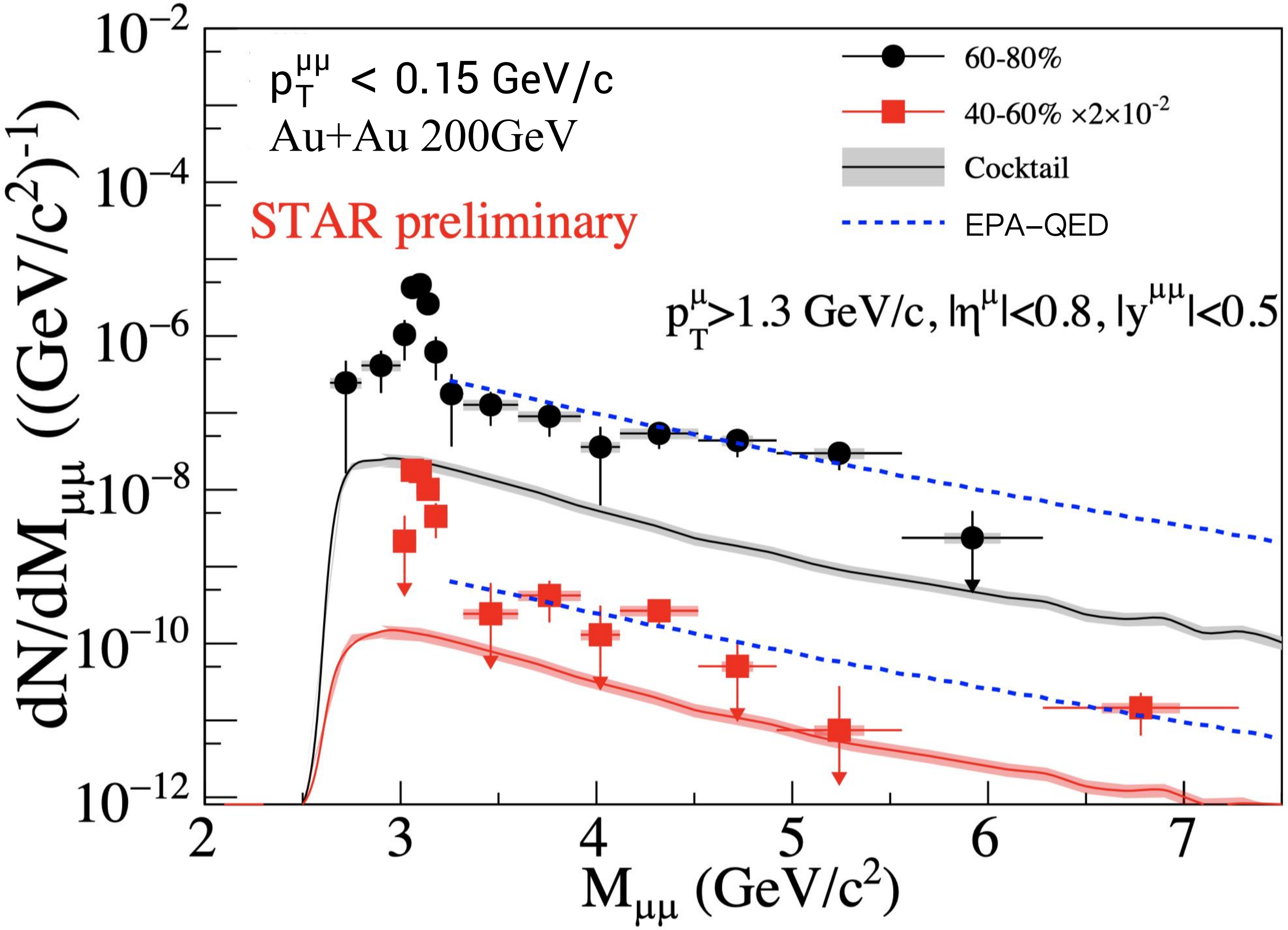
EPA : W. Zha et.al., Phys. Rev. C 99, 061901 (2019)



- No obvious centrality dependence of low p_T yields
- Excess yield consistent with equivalent photon approximation (EPA) calculation
  - In EPA calculation, the photon emitter is the whole nucleus and the Pomeron emitter is spectator nucleons

High mass $\mu^+\mu^-$: Invariant mass spectra

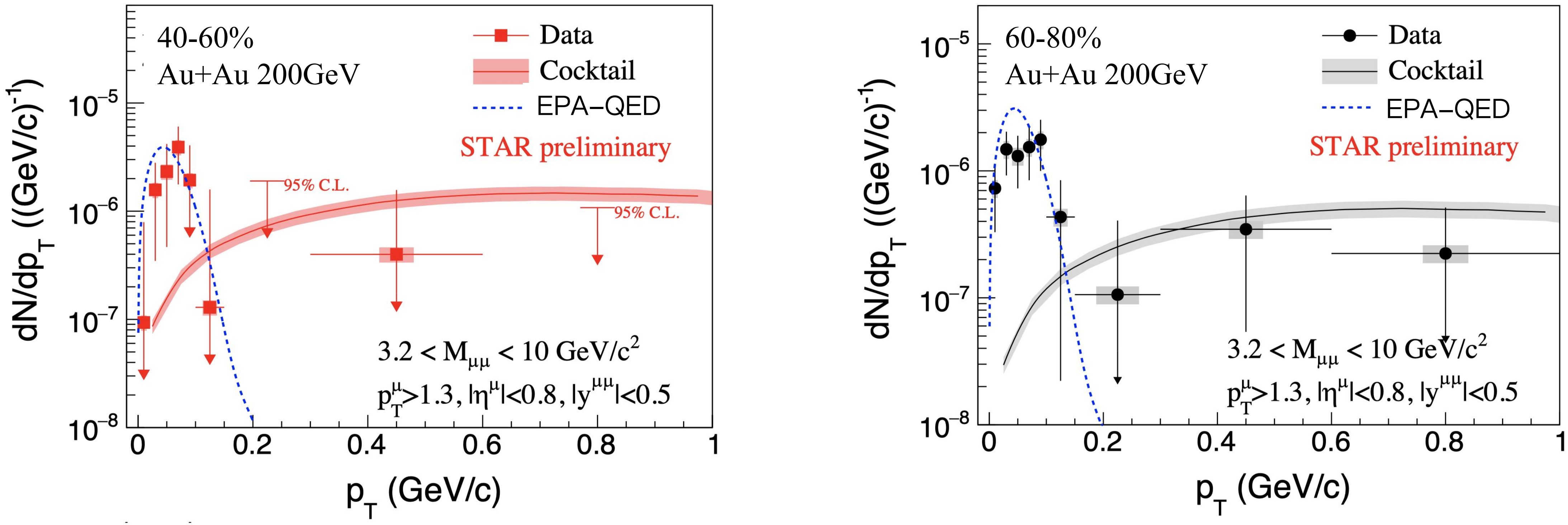
EPA -QED: W. Zha et al., Phys. Lett. B 800, 135089 (2020)



- Clear enhancement with respect to the cocktail in 40-60% and 60-80% centrality classes
  - Cocktail : simulation includes $c\overline{c}$, $b\overline{b}$, and Drell-Yan production
- Consistent with the theoretical calculation

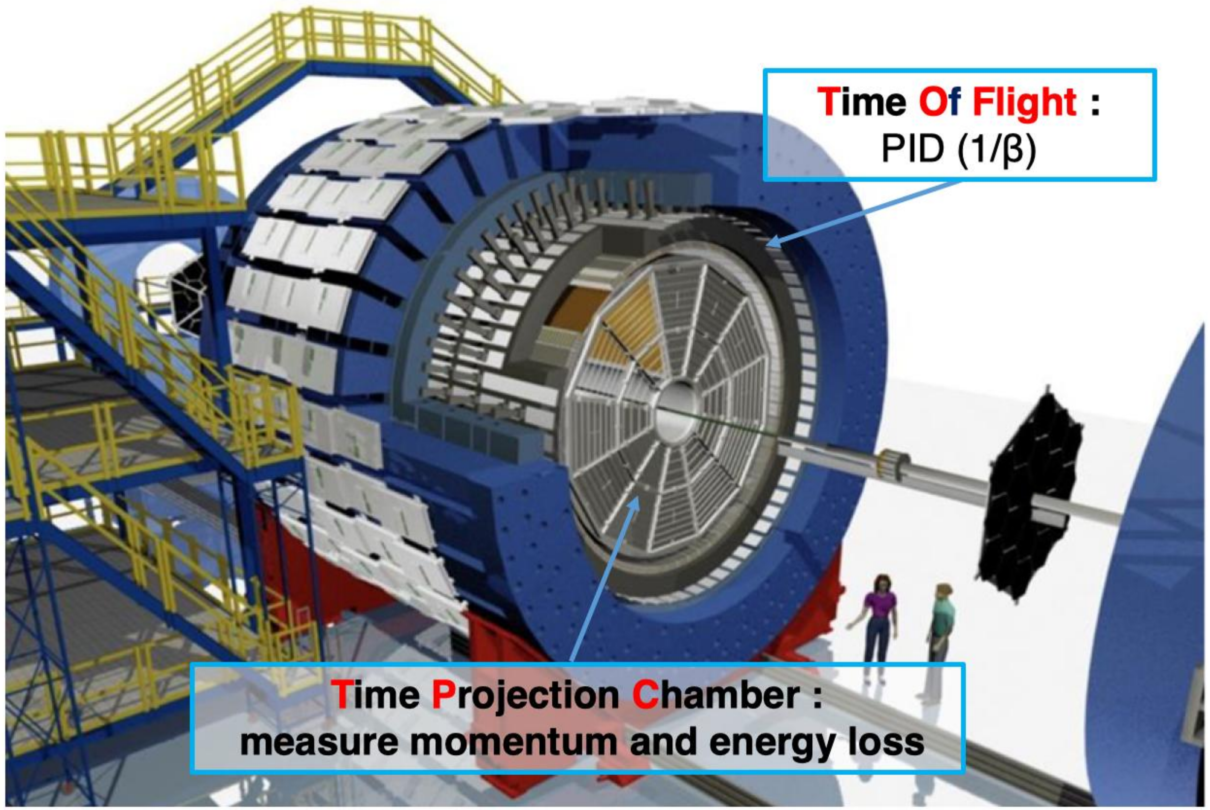
High mass $\mu^+\mu^-$: p_T distributions

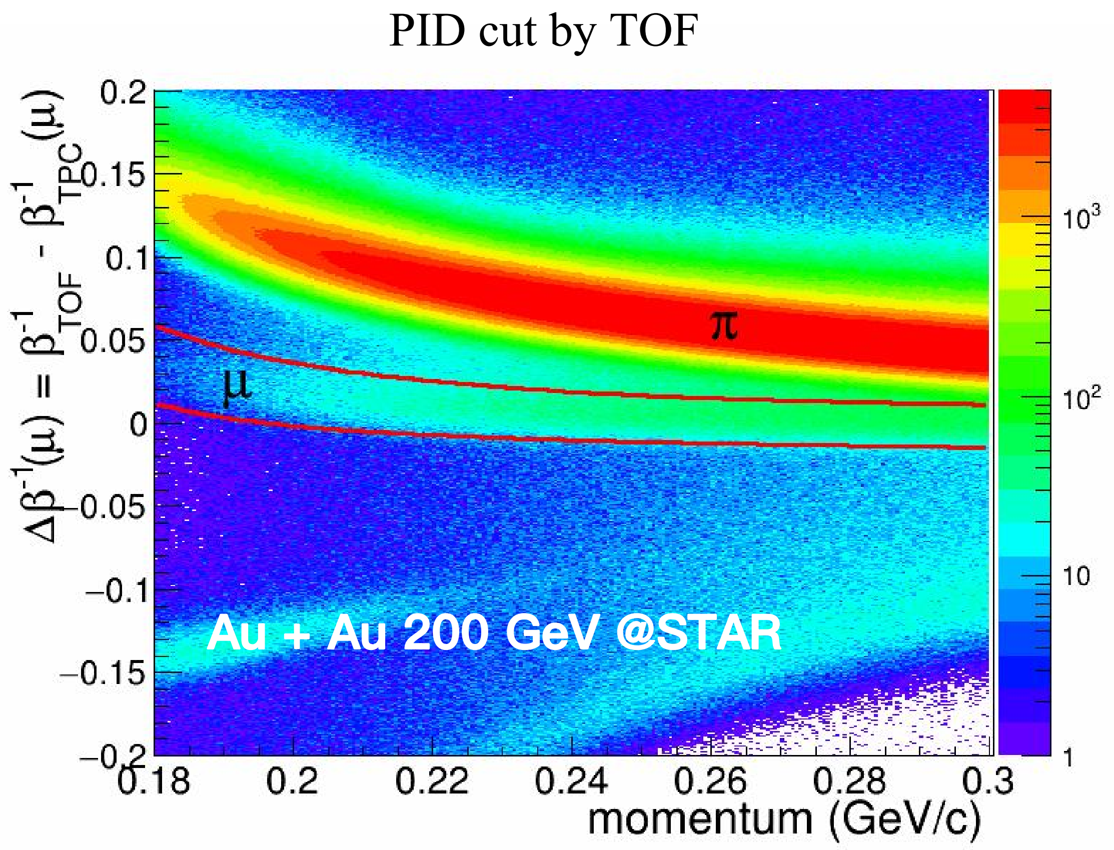
EPA -QED: W. Zha et al., Phys. Lett. B 800, 135089 (2020)



- Excesses concentrate below $p_T \sim 0.1$ GeV/c
- Data are consistent with hadronic expectation for $p_T > 0.1$ GeV/c
- EPA-QED calculations are compatible with data

Muon PID in low momentum region

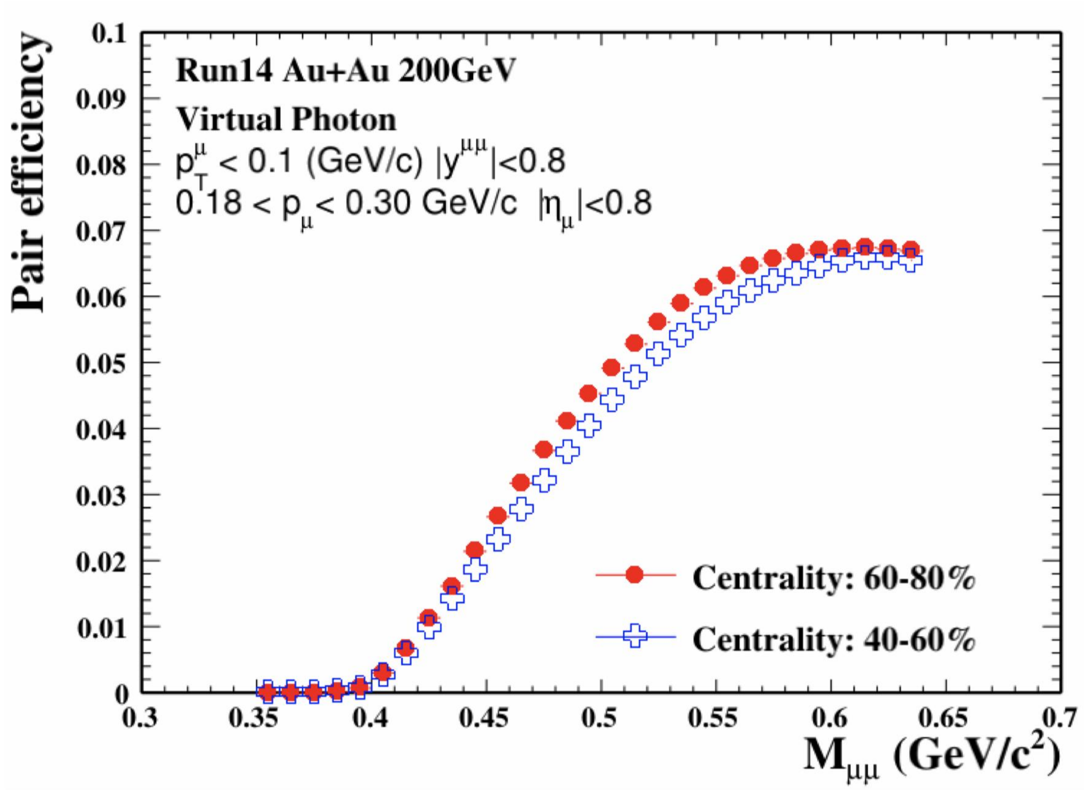


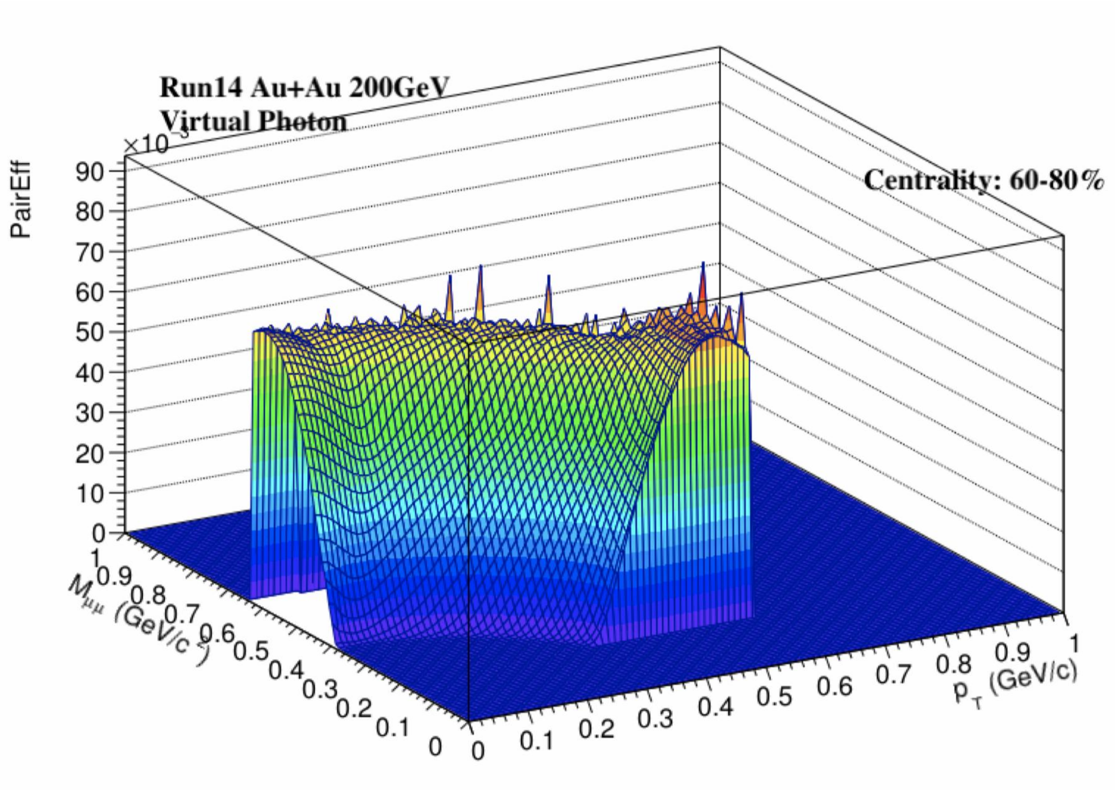


- TPC+TOF : dimuon measurement in low mass region

Efficiency estimation for μ⁺μ⁻ pairs

- Toy Monte Carlo approach.



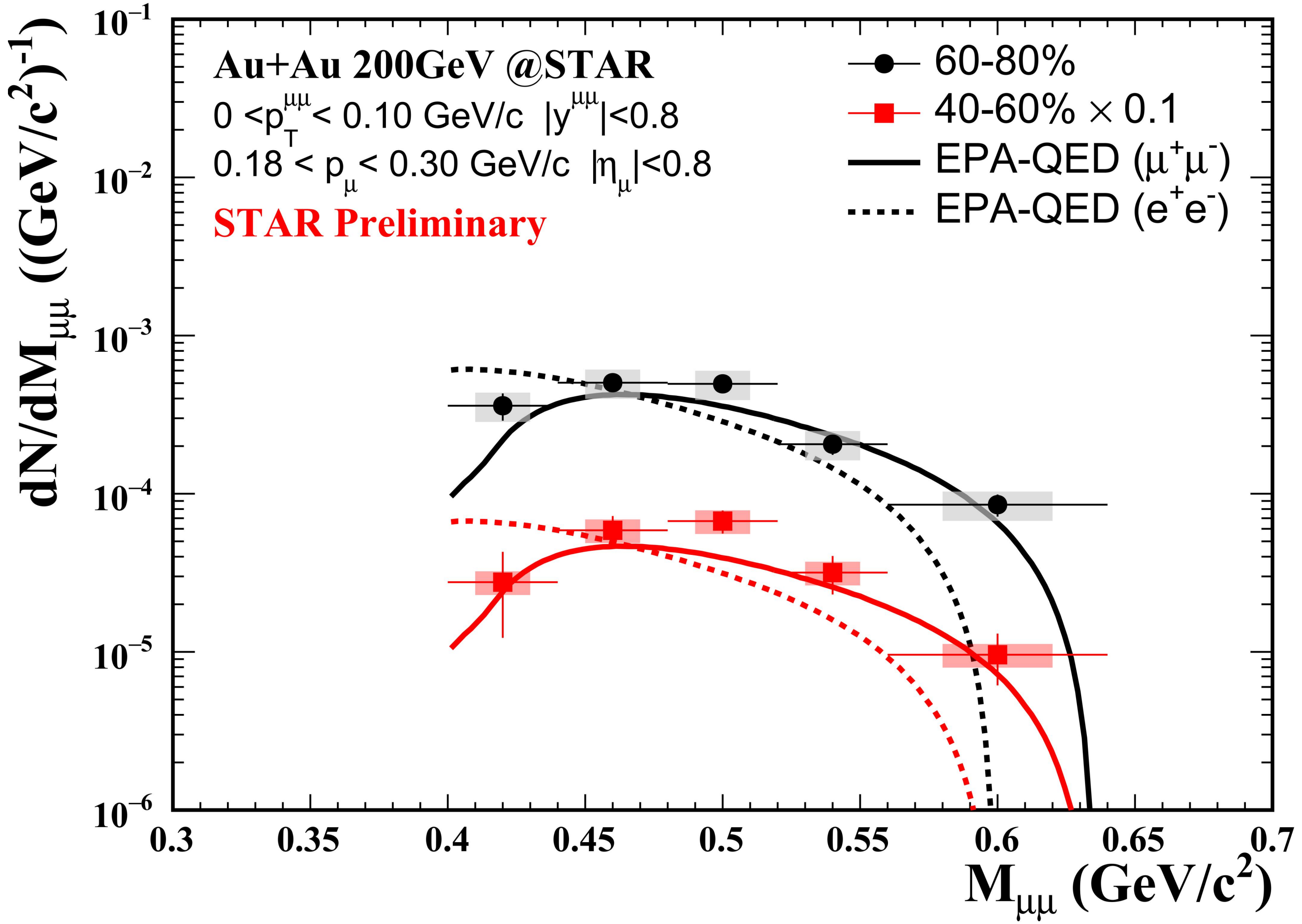


Default: input virtual photons decay into dimuon pairs isotropically

➢ Use theoretical calculation of $\gamma\gamma \longrightarrow \mu\mu$ as input to estimate systematic uncertainty

Low mass $\mu^+\mu^-$: Invariant mass spectra

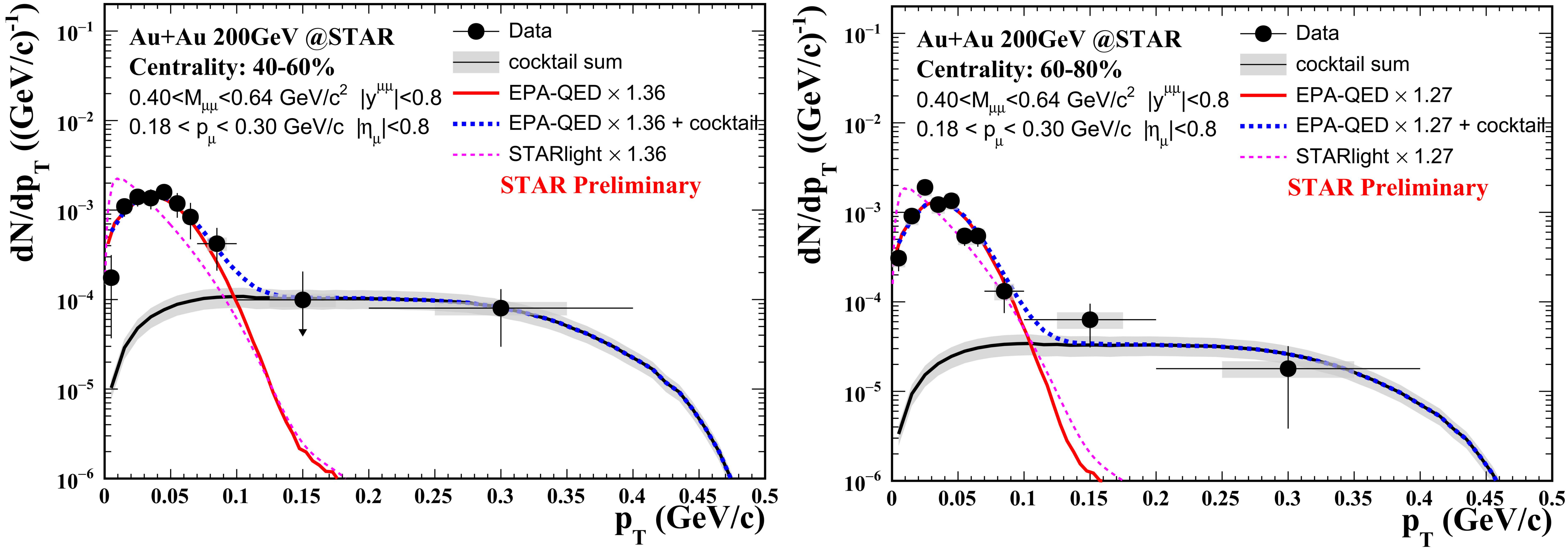
EPA -QED: W. Zha et al., Phys. Lett. B 800, 135089 (2020)



- Excess yields (Data - Cocktail) are extracted
- Consistent with the EPA-QED calculations in the two different centrality classes
  - Different shapes for e^+e^- and $\mu^+\mu^-$: mass difference of muons and electrons, resulting in the different acceptance in the narrow momentum range

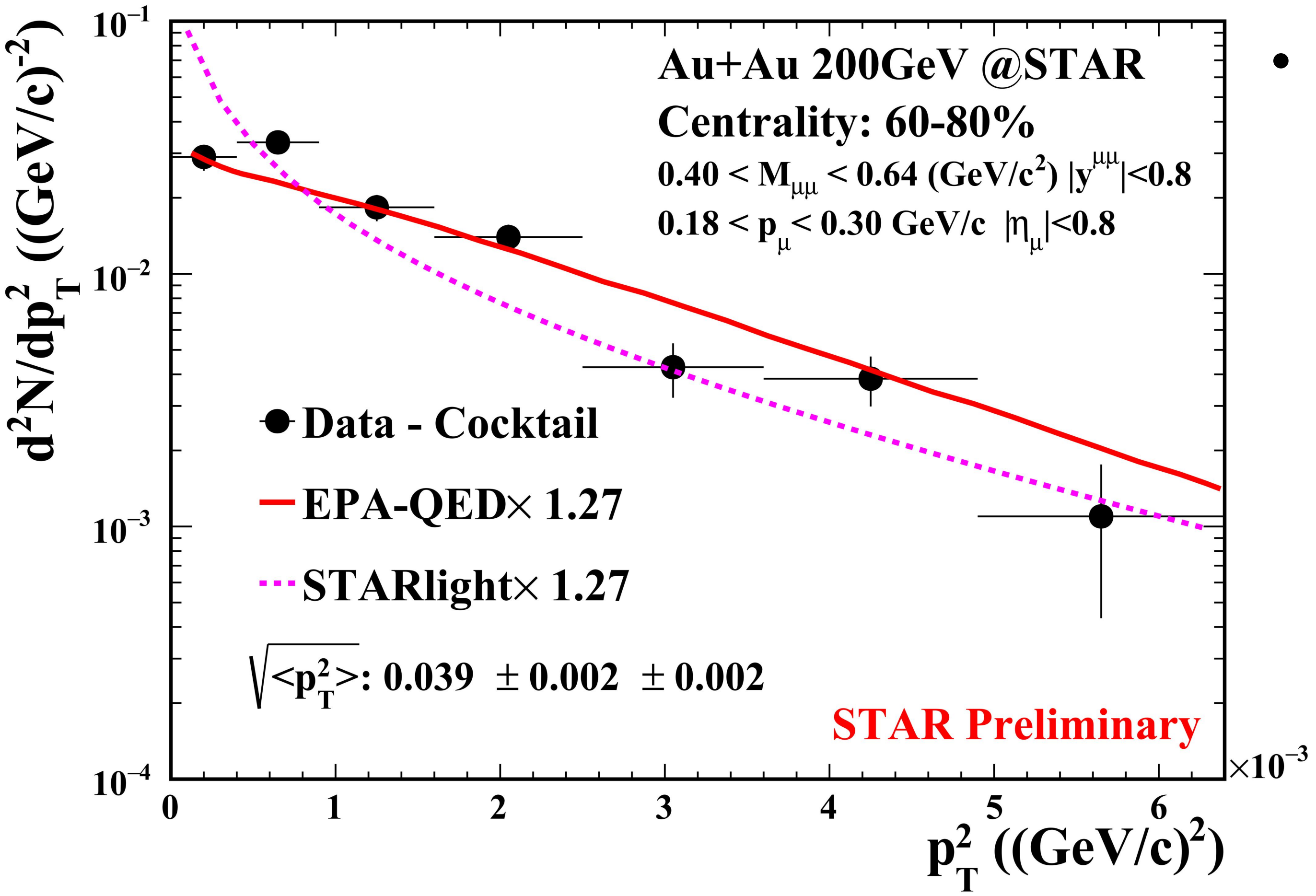
Low mass $\mu^+\mu^-$: p_T and t distributions

EPA -QED: W. Zha et al., Phys. Lett. B 800, 135089 (2020)



- Excesses concentrate below $p_T \approx 0.1$ GeV/c
- Data in favor of EPA-QED calculation over STARlight

Low mass $\mu^+\mu^-$: p_T and t distributions



- The $\sqrt{\langle p_T^2 \rangle}$ is consistent with the EPA-QED calculation over STARlight

	$\sqrt{\langle p_T^2 \rangle}$ (MeV/c)
measured	39.6 ± 2 ± 2
STARlight	33.6
EPA–QED	42.3

Summary

- First measurement of dimuon production in low and high mass range at very low p_T in peripheral Au+Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 200 GeV

- Significant J/ψ and $\mu^{+}\mu^{-}$ enhancements are observed

- The EPA-QED calculations can describe data, indicating the enhancements at very low p_T originate from photon-induced interactions.
  - Better precision is needed to pin down whether the effect of EM fields trapped in the QGP is present in these measurements

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Thank you !