中国物理学会高能物理分会

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

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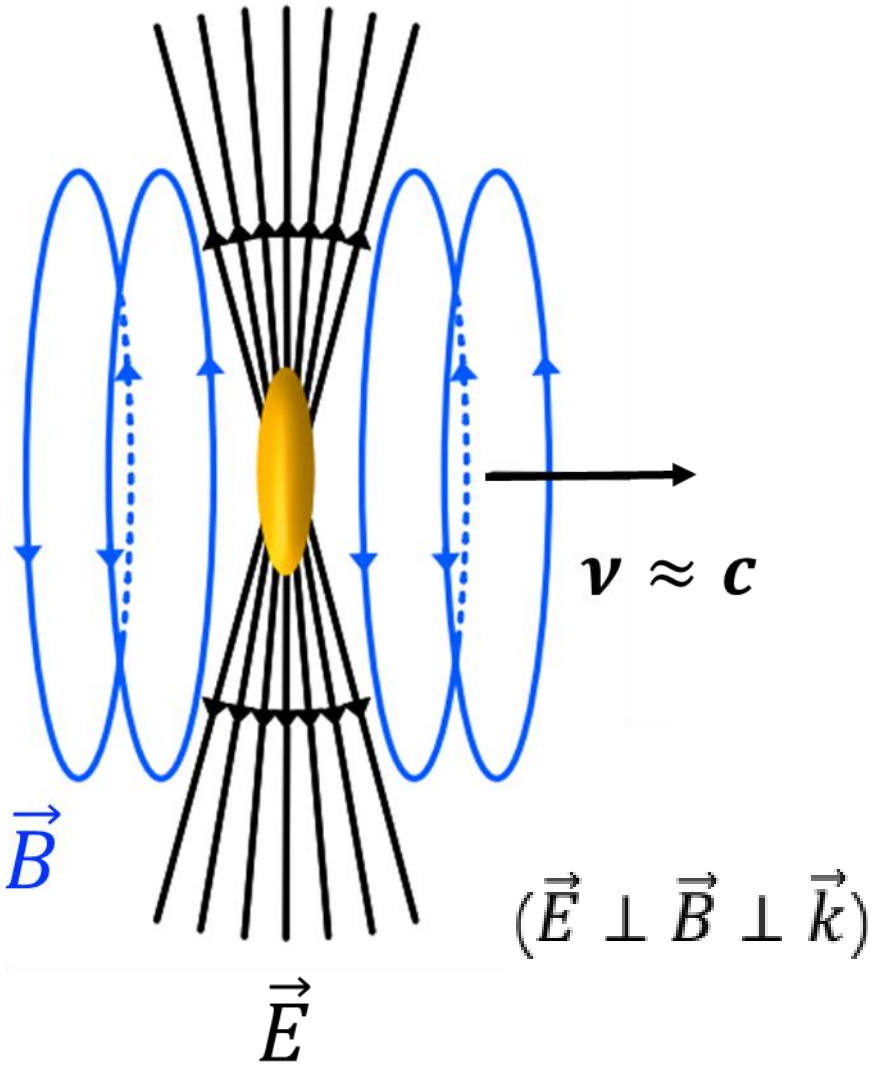
Outline

- Introduction and motivation
- Particle identification
- Preliminary results
  - Invariant mass spectrum
  - p_T distribution
  - t distribution
  - $\Delta\phi$ distribution
- Summary

Electromagnetic field in heavy-ion collisions



STAR, Daniel Brandenburg, QM2019

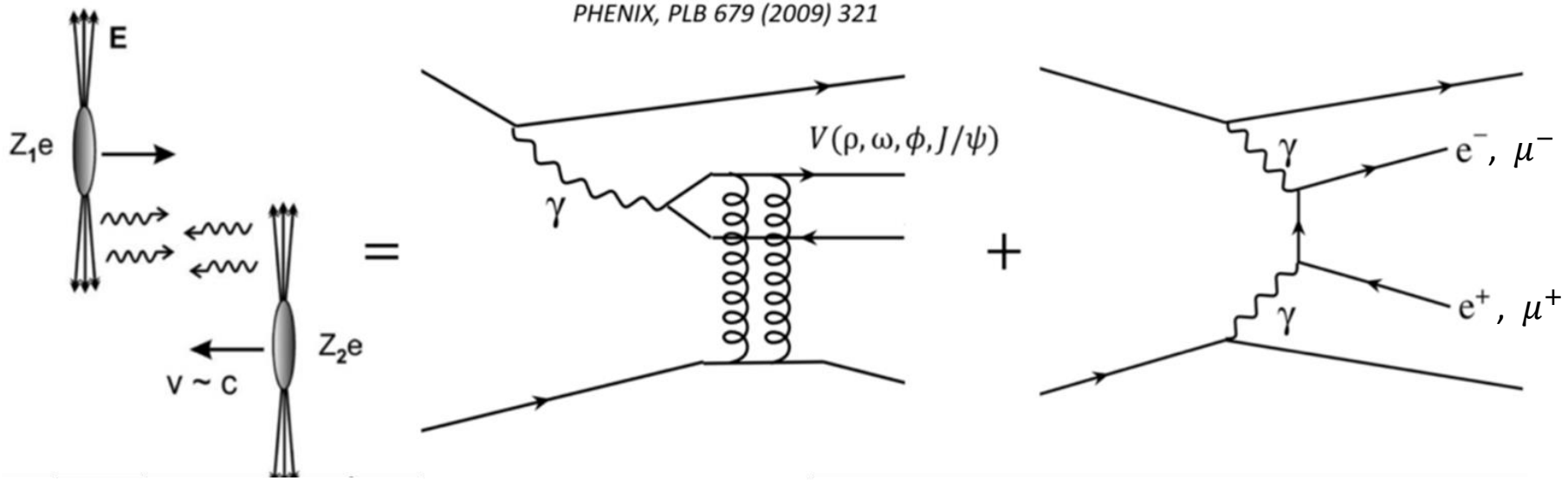
- Ultra-relativistic charged nuclei produce highly Lorentz contracted electromagnetic field.
- Weizsacker–Williams Equivalent Photon Approximation(EPA):
  - ✓ In a specific phase space, transverse EM fields can be quantized as a flux of quasi-real photons.

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

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

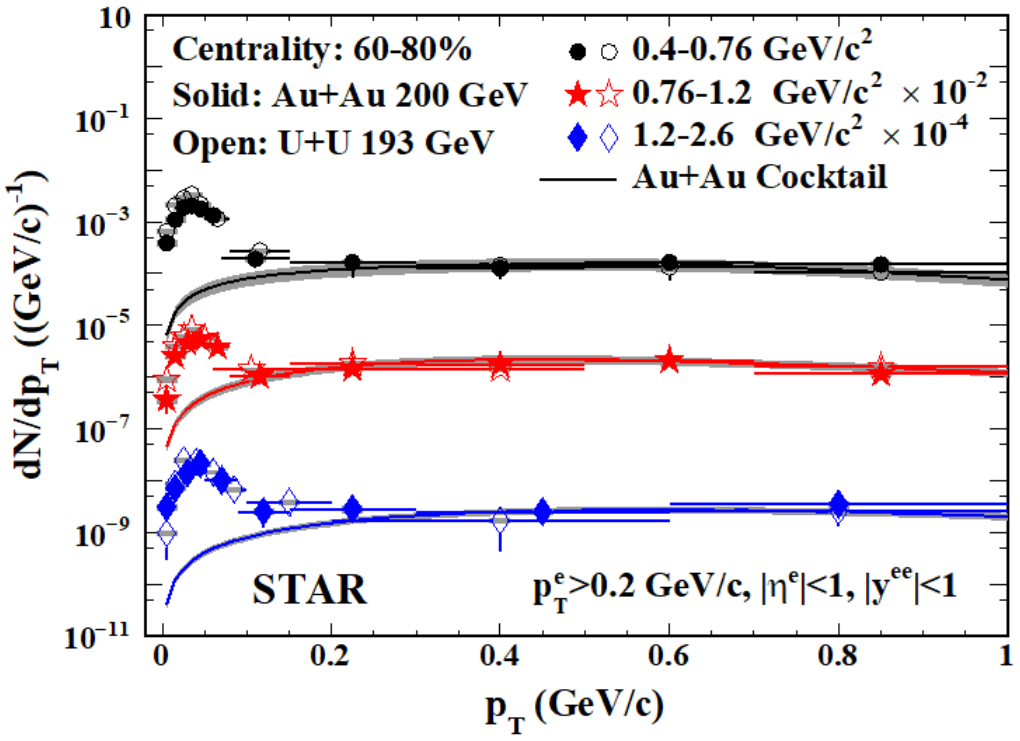
Di-leptons from photon interactions

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

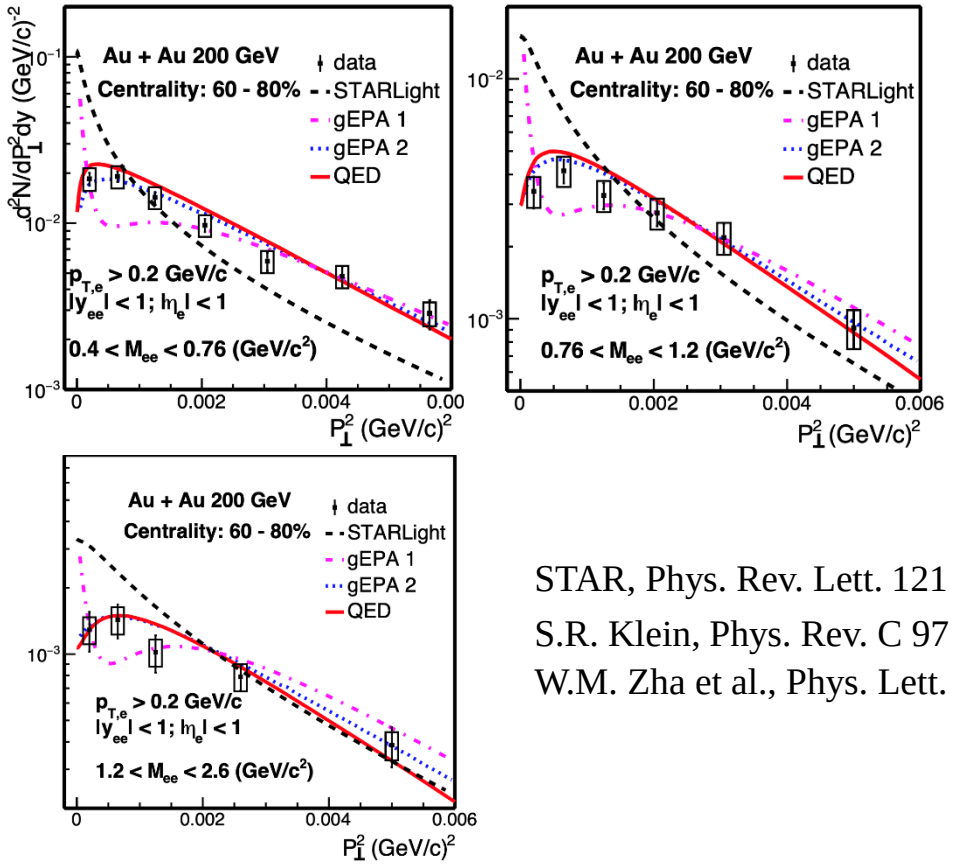


- Photon interactions
  - photon-photon interaction (dilepton...) $\propto Z^4$ —— distinctly peaked at low p_T
  - photon-nuclear interaction (vector mesons) $\propto Z^2$
    - ✓ Coherent: photon interacts with the whole nucleus
    - ✓ Incoherent: photon interacts with nucleon or parton individually
- Conventionally only studied in ultra-peripheral collisions (b>$2R_A$,UPCs) to keep coherence condition

Photon production with nuclear overlap



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



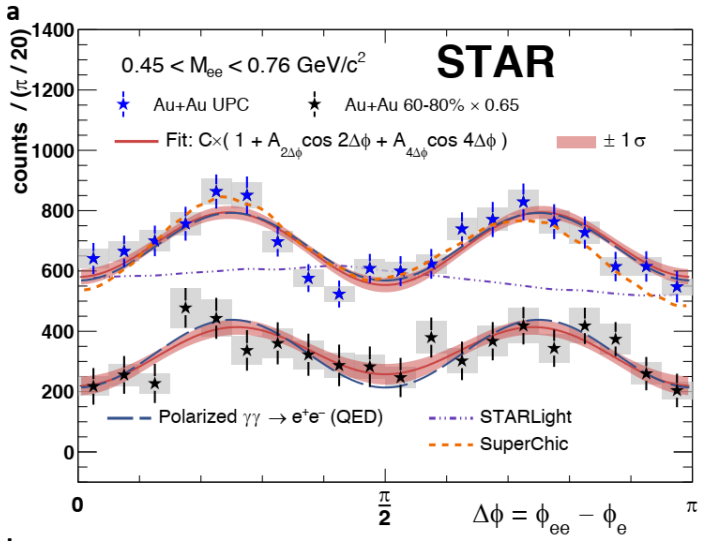
STAR, Phys. Rev. Lett. 121 (2018) 132301

S.R. Klein, Phys. Rev. C 97 (2018) 054903

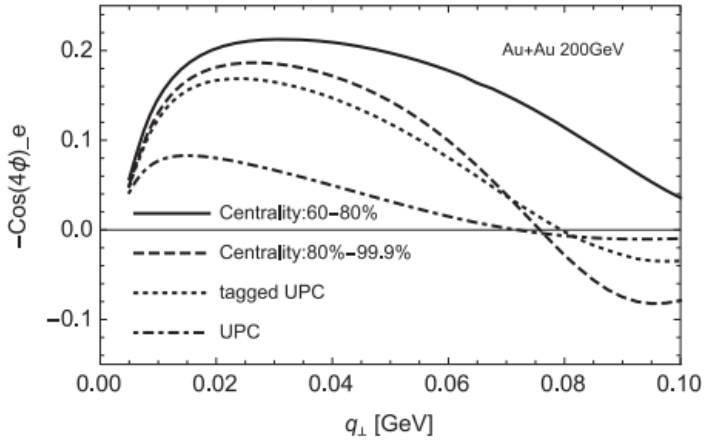
W.M. Zha et al., Phys. Lett. B 800 (2020) 135089

- Excess relative to the hadronic cocktail concentrates below p_T ~ 0.15 GeV/c.
  - Evidence of photon interactions in hadronic heavy ion collisions.
- p_T^2 spectra also were measured and compared with different model calculations.

Birefringence of the QED Vacuum



STAR, Phys. Rev. Lett. 127 (2021) 52302

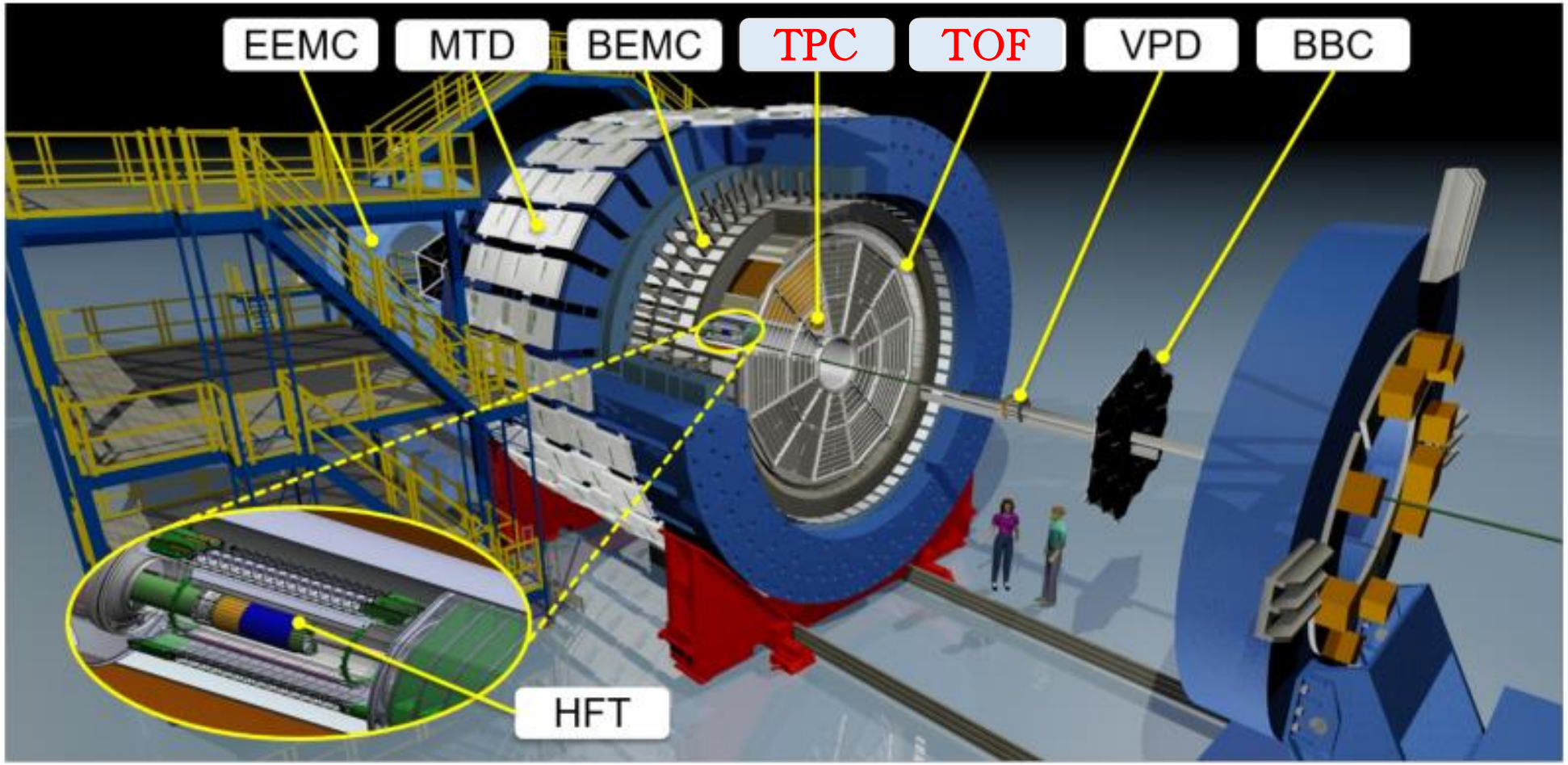


C.Li et al., Phys.Rev.D 101, 034015 (2020)

Recently realized, linearly polarized photon-photon collisions will lead to $\cos 4\Delta\phi$ and $\cos 2\Delta\phi$ angular distribution which is related to vacuum birefringence.

- 4th-order azimuthal angular modulation of e^+e^- pairs had been observed by the STAR Collaboration.
- $\cos 2\Delta\phi$ azimuthal asymmetry is proportional by $m^2/p_\perp^2$.
  - Only sizable for $\mu^+\mu^-$ pair production.

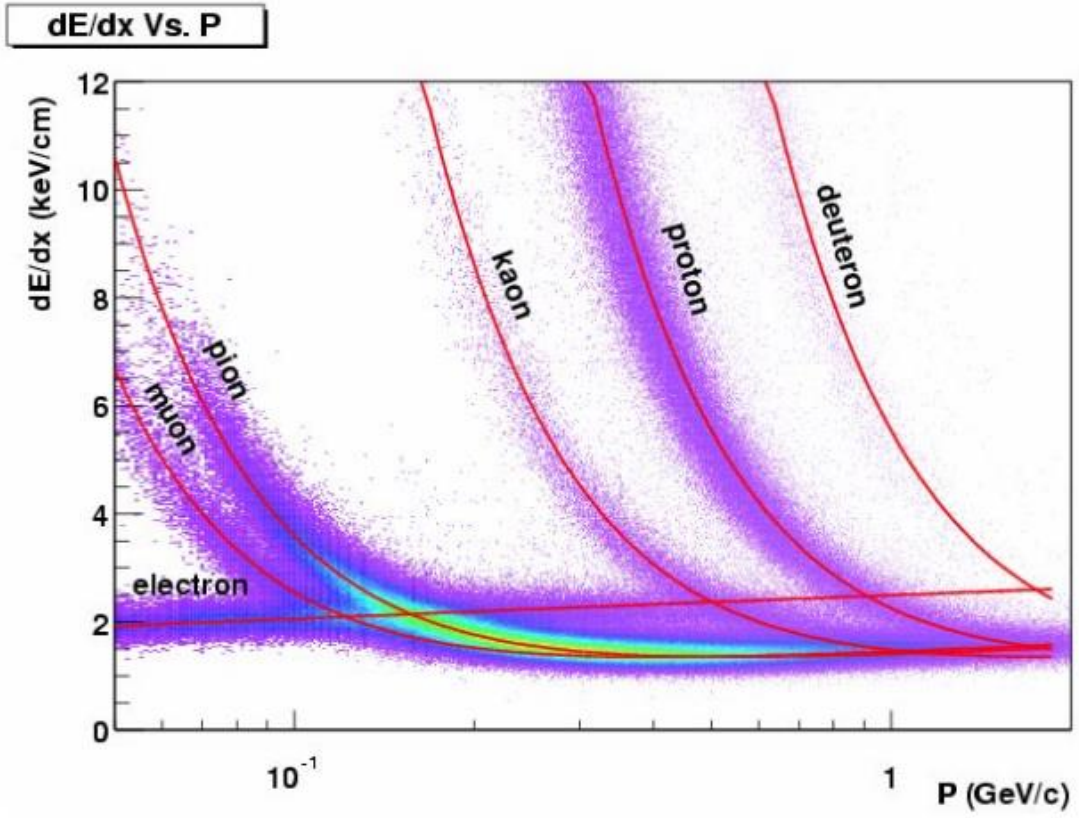
The Solenoidal Tracker At RHIC (STAR)



- Time Projection Chamber: tracking, momenta, and PID
- Time Of Flight: PID by velocity

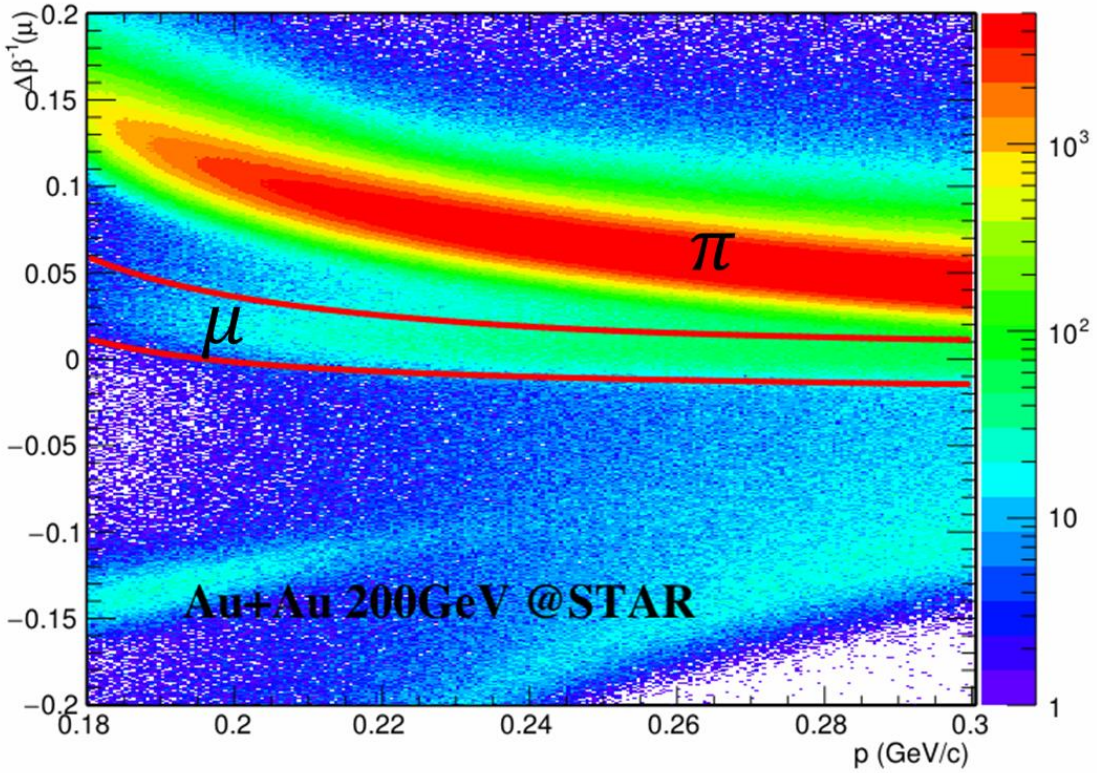
Muon identification

PID@TPC



$$n\sigma_{\pi} = \frac{1}{R}\, log \frac{(dE/dx)_{measured}}{(dE/dx)_{pion}}$$

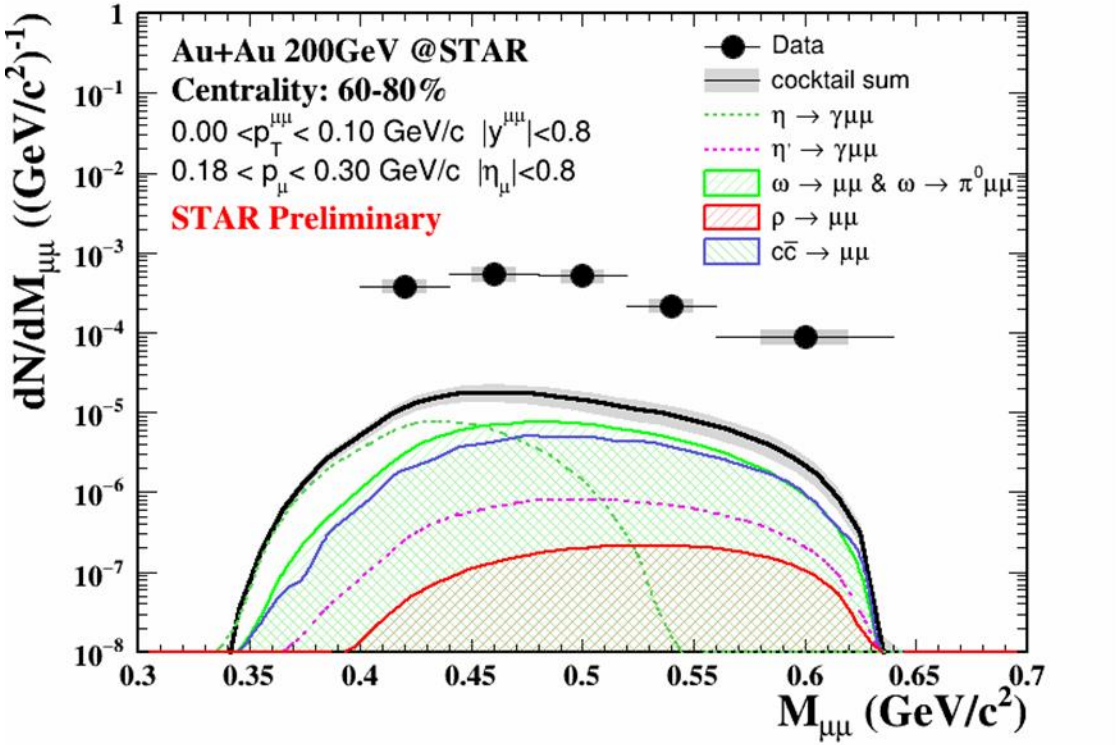
PID@TOF



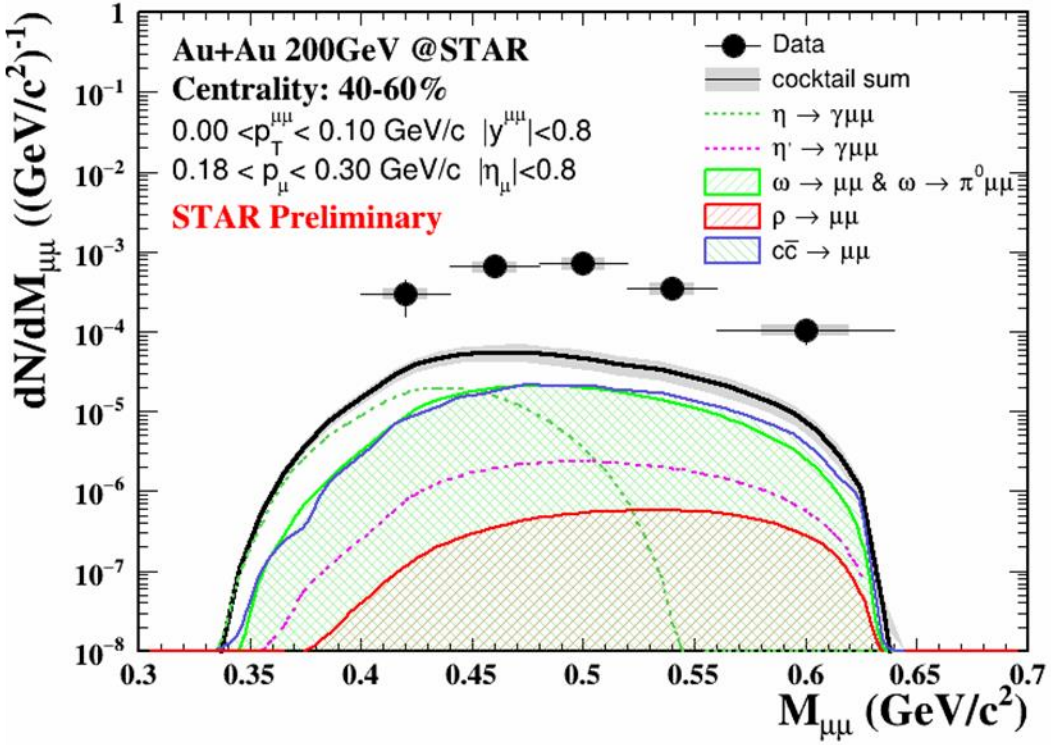
- Muons can be identified at low momentum by using TOF.

Invariant mass spectrum

Centrality:60-80%



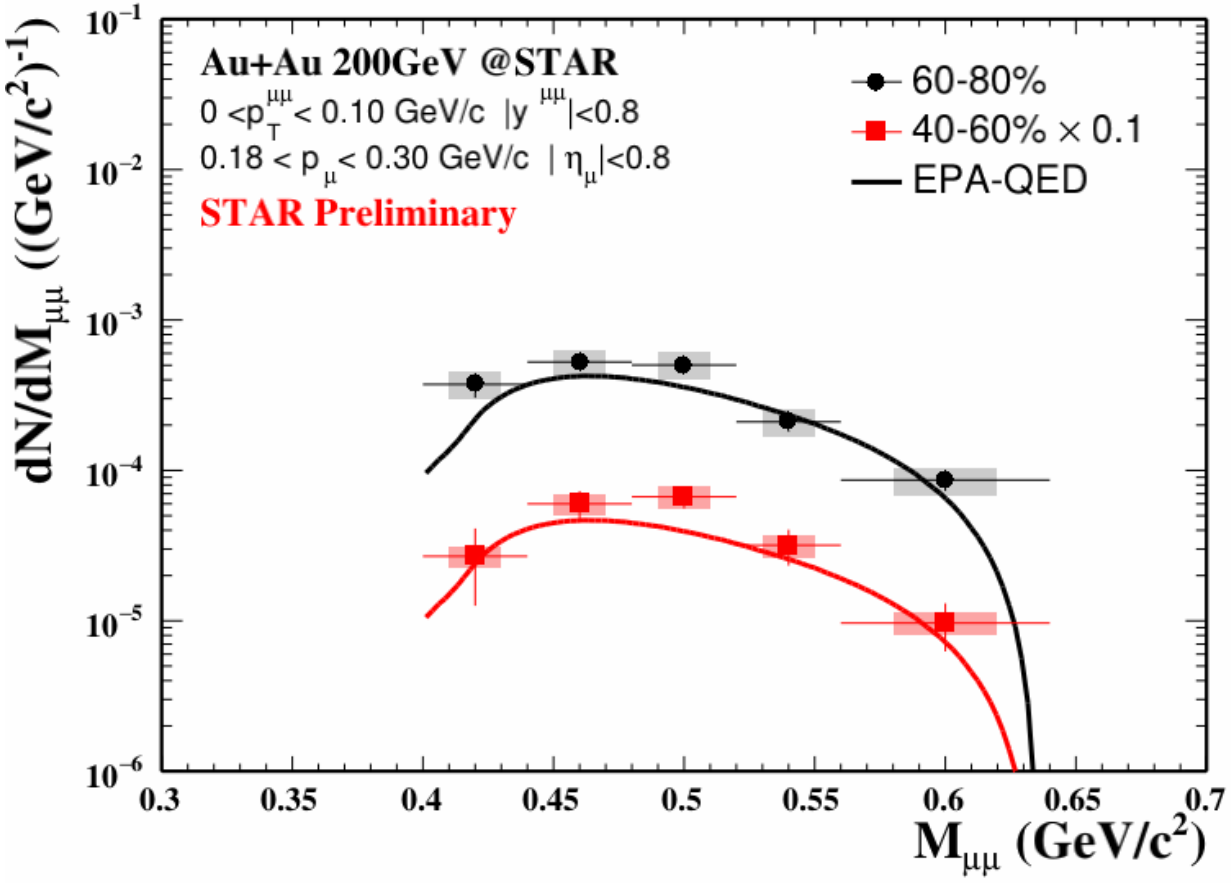
Centrality:40-60%



- A significant enhancement with respect to the cocktail.
- η, ω, and $c\bar{c}$ are the main sources of the cocktail.

Invariant mass spectrum

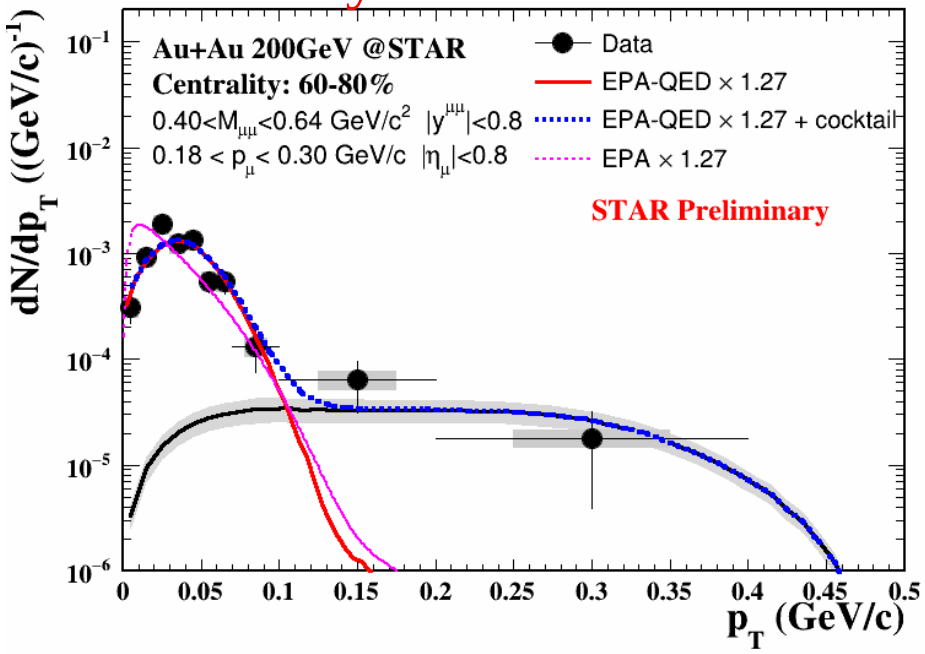
W.M. Zha et al., Phys. Lett. B 800 (2020) 135089



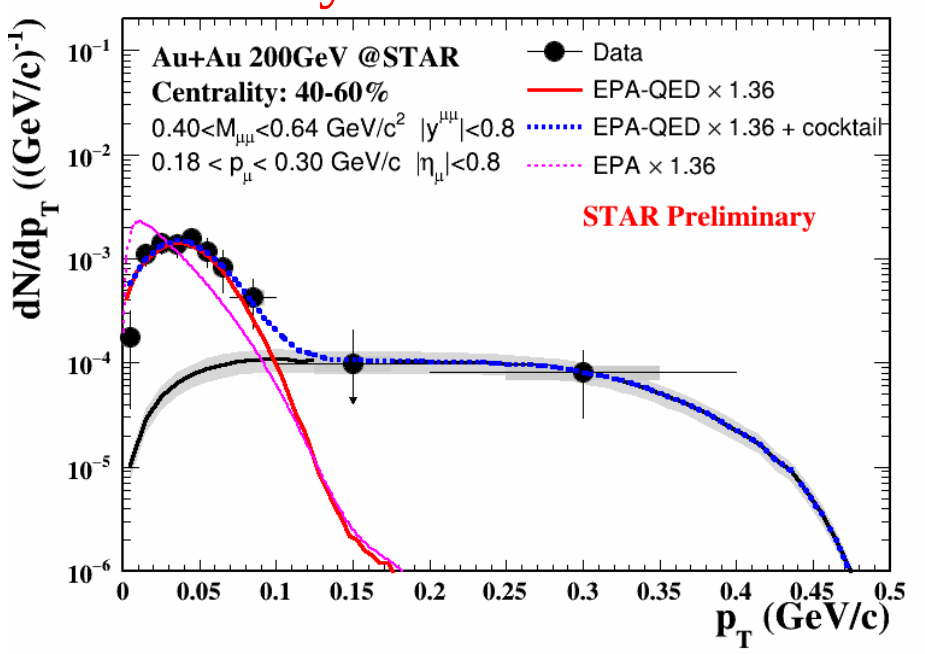
- Consistent with the theoretical calculations in different centrality.

p_T distributions

Centrality:60-80%



Centrality:40-60%

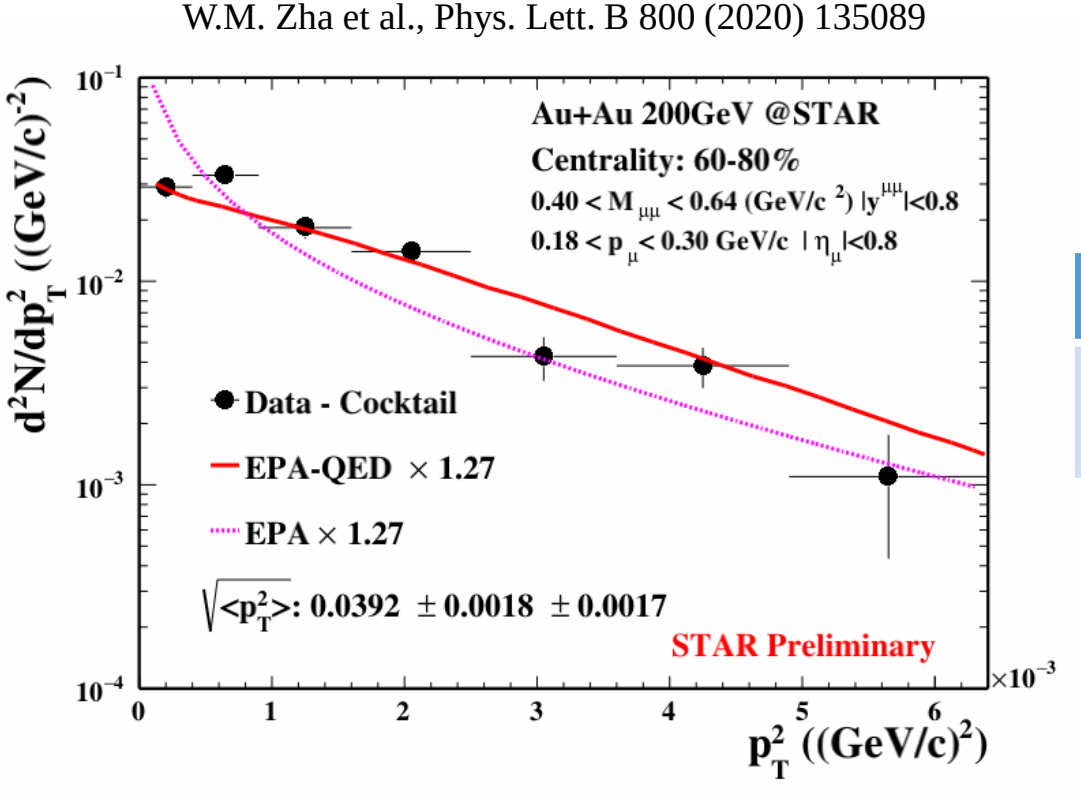


W.M. Zha et al., Phys. Lett. B 800 (2020) 135089

- Excesses concentrated below $p_T \approx 0.1$ GeV/c.
- Data are consistent with hadronic expectation when $p_T > 0.1$ GeV/c.
- EPA-QED calculation is compatible with data.

t distribution (60-80%)

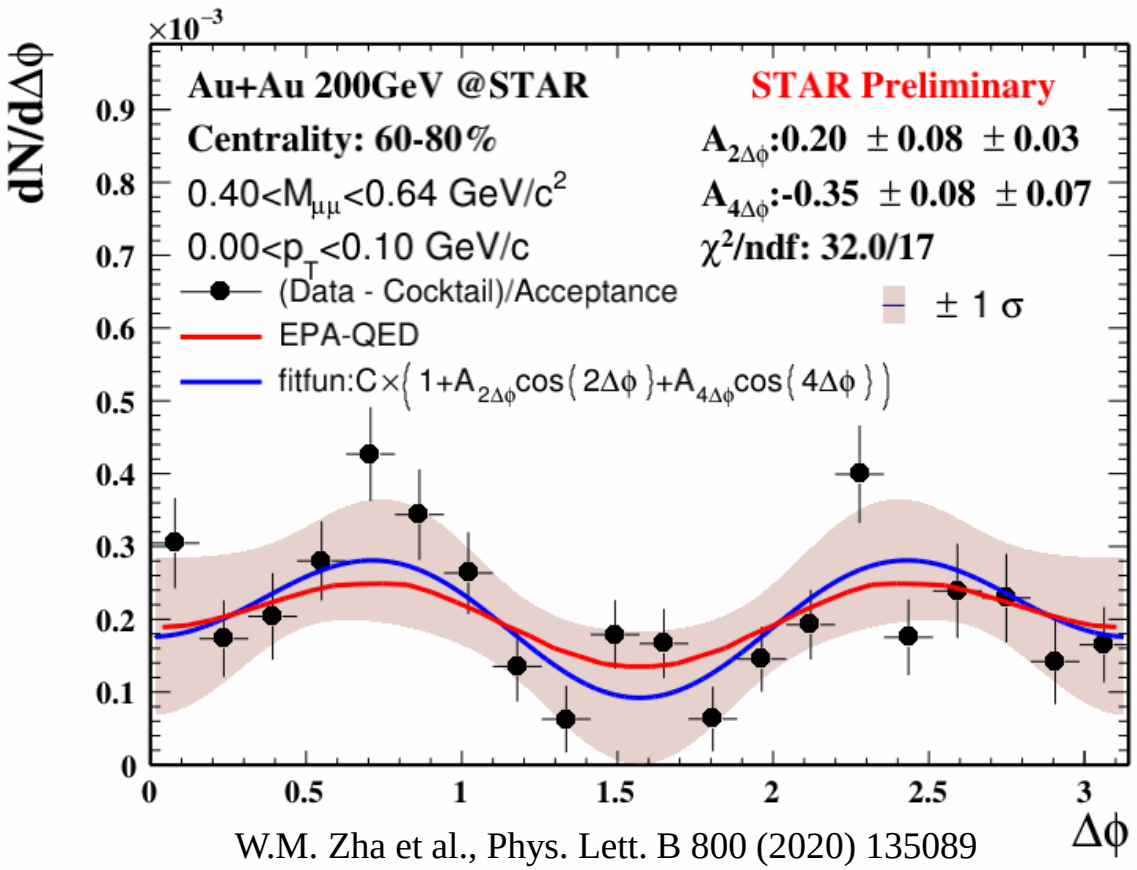
W.M. Zha et al., Phys. Lett. B 800 (2020) 135089



0.-0.0064 $((GeV/c)^2)$	Au + Au	QED	EPA
$\sqrt{< p_T^2 >}\ (MeV/c)$	$39.2 \pm 1.8 \pm 1.7$	42.3	33.6

- Employ $\sqrt{< p_T^2 >}$ (characterizes p_T broadening) to compare the data with model calculation.
- Consistent with the EPA-QED calculation.

$\Delta\phi$ distribution (60-80%)



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

	Measured	χ^2/ndf	QED
$\lvert A_{2\Delta\phi}\rvert$(%)	$20 \pm 8 \pm 3$	32/17	13
$\lvert A_{4\Delta\phi}\rvert$(%)	$35 \pm 8 \pm 7$		22

- Observation of the 4th-order azimuthal angular modulation of $\mu^+\mu^-$ pairs (3.3σ).
- First indication of the 2nd-order azimuthal angular modulation (2.3σ)!

Summary

- First measurement of photo-produced $\mu^+\mu^-$ pair production at very low p_T at STAR.
- A significant $\mu^+\mu^-$ enhancement w.r.t. cocktail is observed at very low p_T in peripheral Au + Au collisions at 200 GeV.
- The $\sqrt{< p_T^2 >}$ is consistent with the EPA-QED calculation.
- Observation of the 4th-order azimuthal angular modulation of $\mu^+\mu^-$ pair.
- First indication of the 2nd-order azimuthal angular modulation in $\gamma\gamma \to l^+l^-$!

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- Observation of the 4th-order azimuthal angular modulation of $\mu^+\mu^-$ pair.
- First indication of the 2nd-order azimuthal angular modulation in $\gamma\gamma \to l^+l^-$!

Thank you!