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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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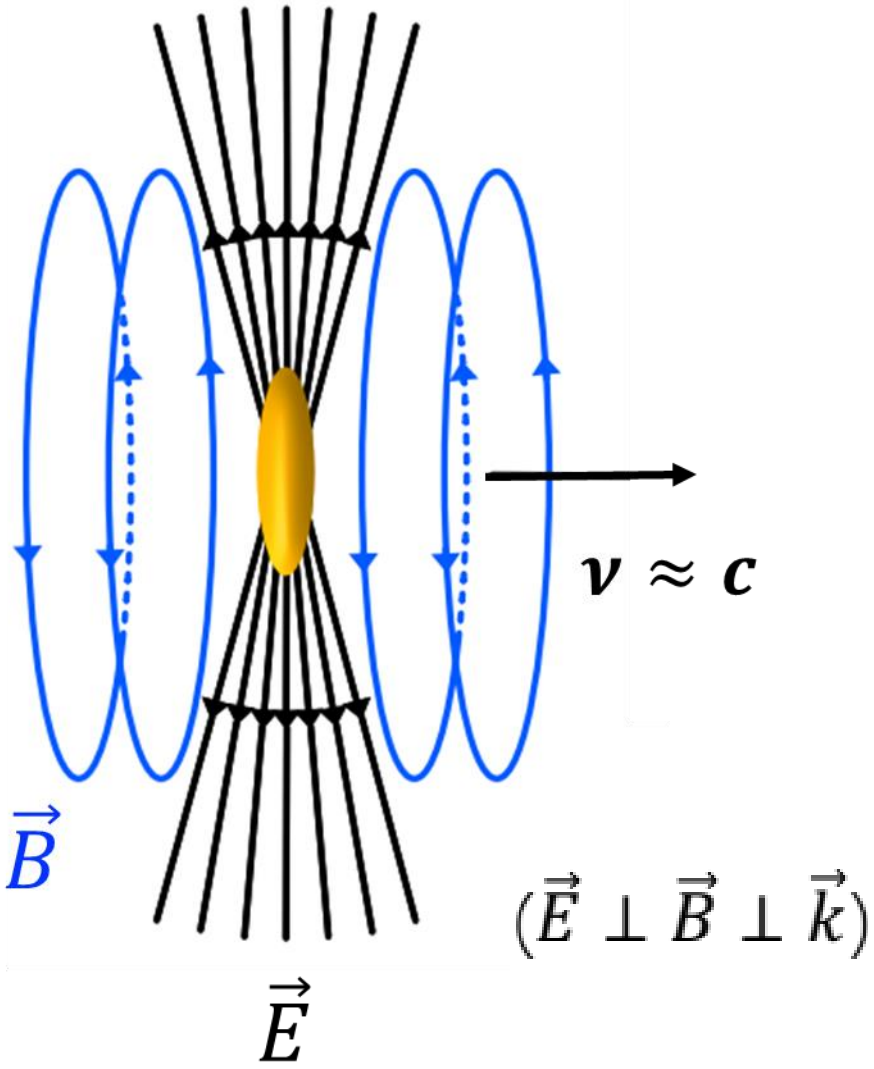
Outline

- 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

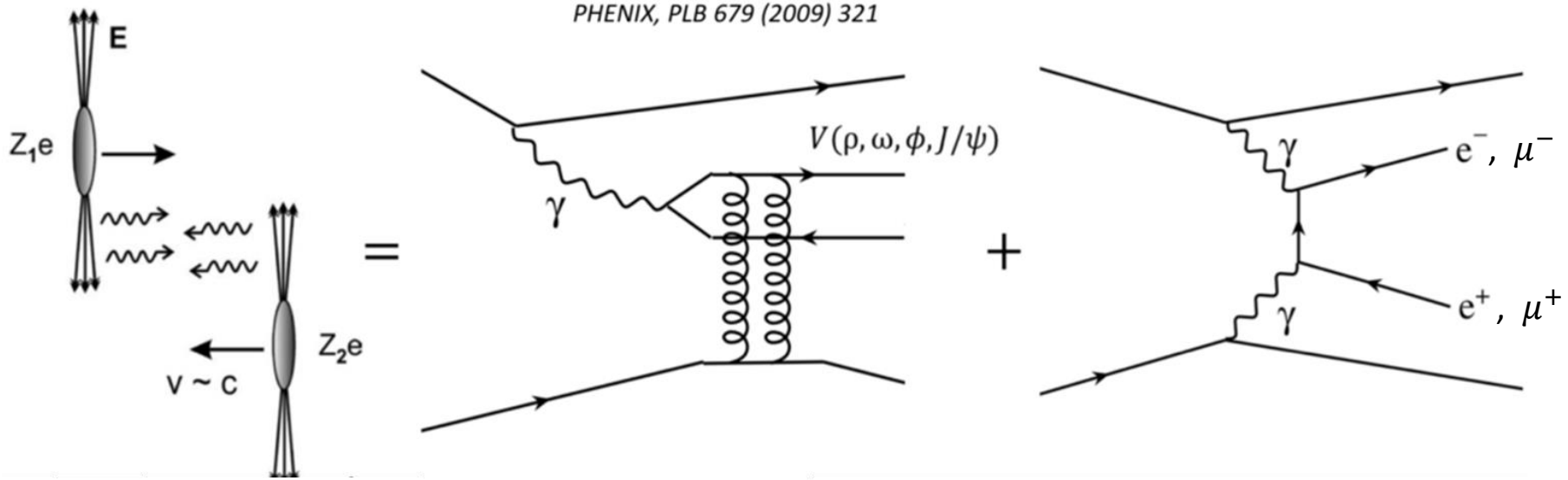
- Ultra-relativistic charged nuclei produce highly Lorentz contracted electromagnetic field.
- Weizsacker–Williams Equivalent Photon Approximation(EPA):
  - ✓ In a specific phase space, transverse EM fields can be quantized as a flux of quasi-real photons.

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

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

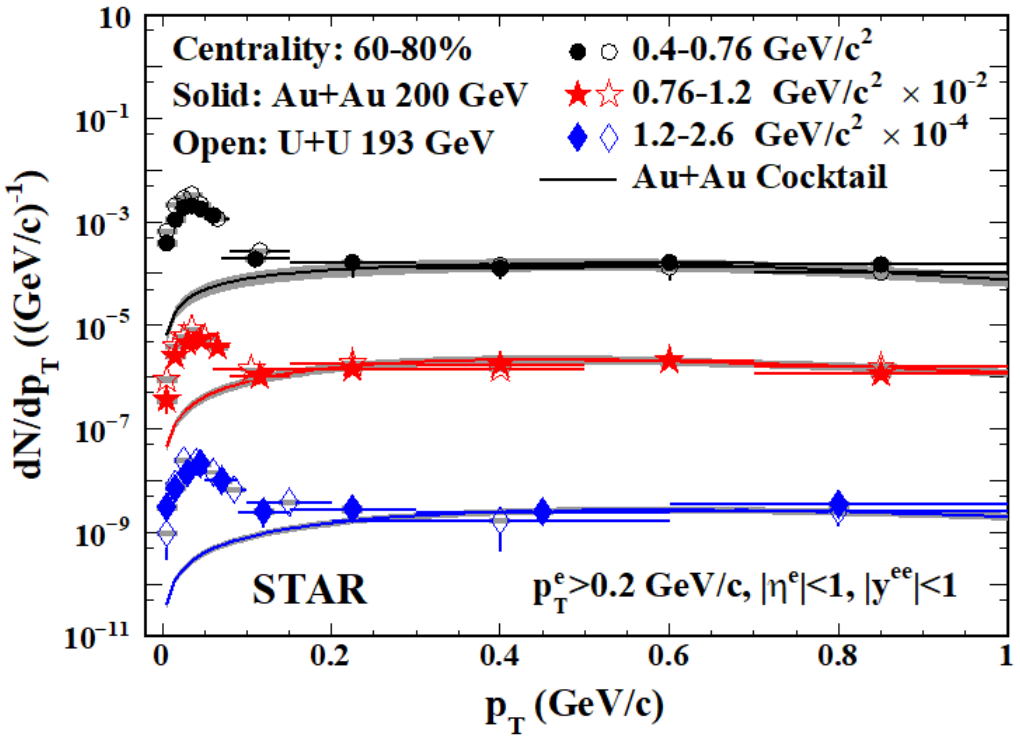
Di-leptons from photon interactions

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

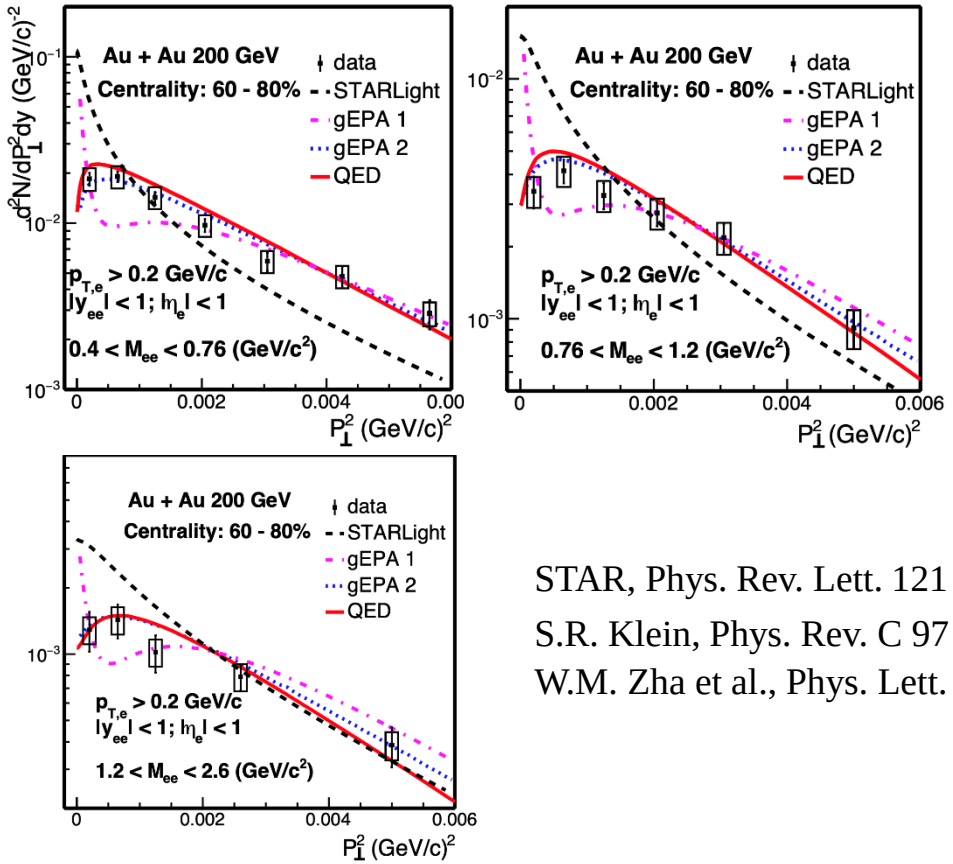


- Photon interactions
  - photon-photon interaction (dilepton...) $\propto Z^4$ —— distinctly peaked at low p_T
  - photon-nuclear interaction (vector mesons) $\propto Z^2$
    - ✓ Coherent: photon interacts with the whole nucleus
    - ✓ Incoherent: photon interacts with nucleon or parton individually
- 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



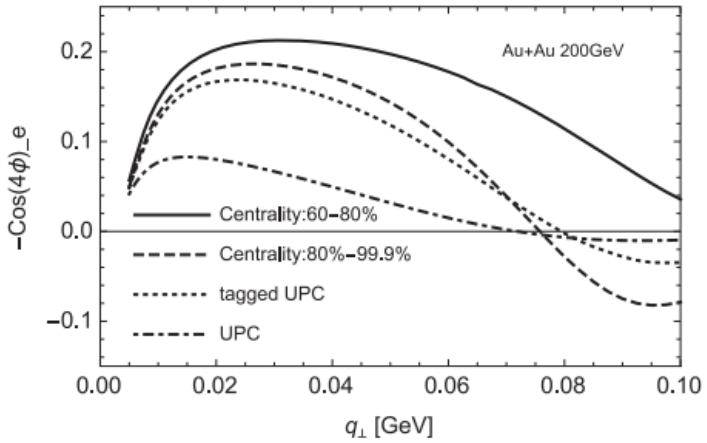
STAR, Phys. Rev. Lett. 121 (2018) 132301

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

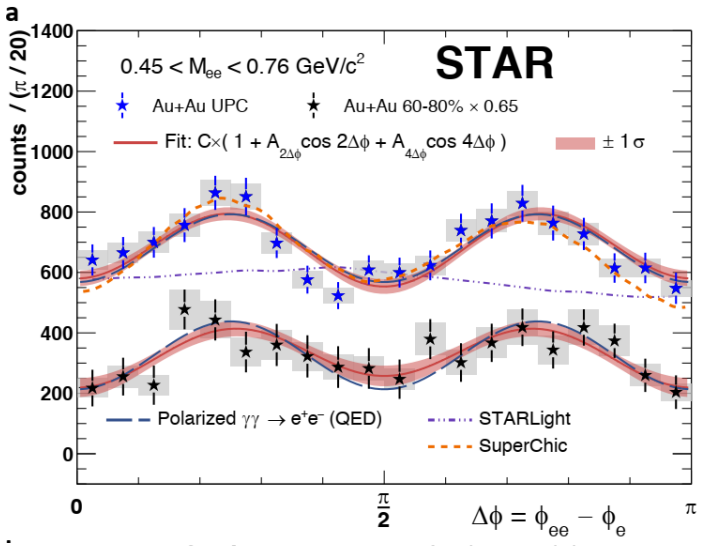
W.M. Zha et al., Phys. Lett. B 800 (2020) 135089

- 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



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

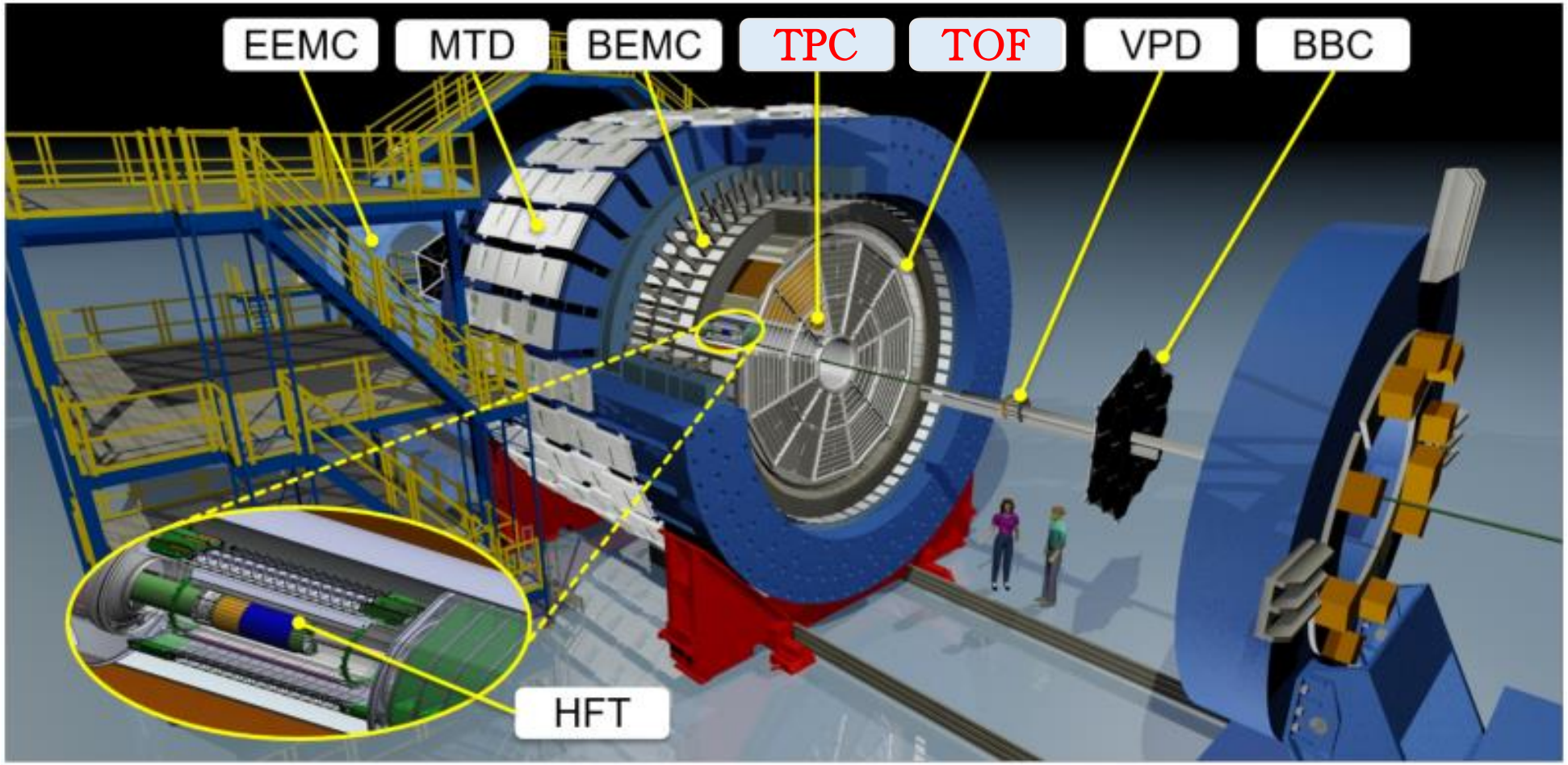


STAR, arXiv : 1910.12400

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.

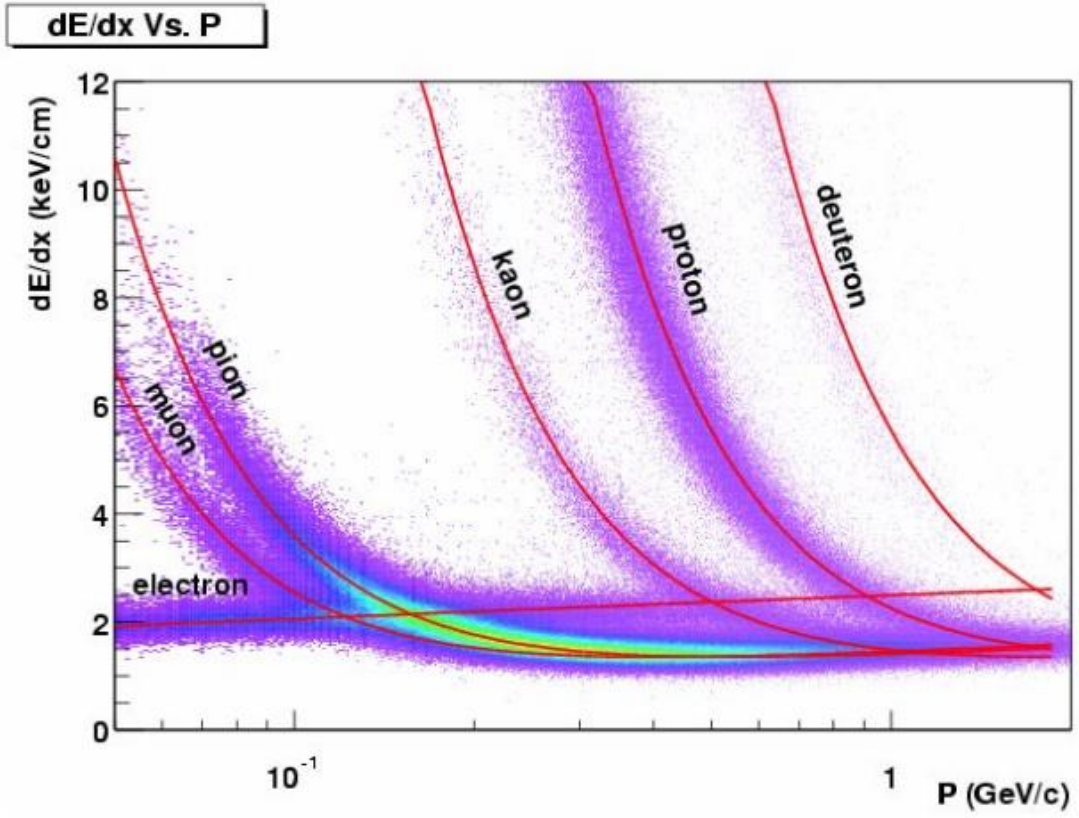
The Solenoidal Tracker At RHIC (STAR)



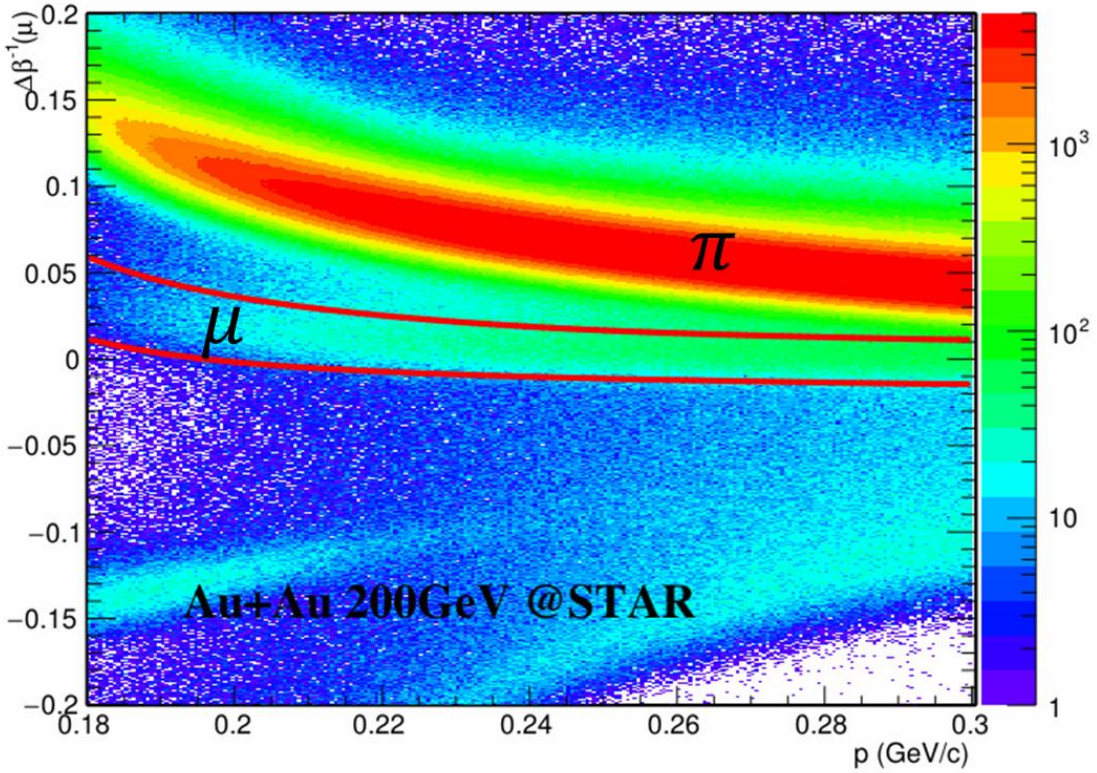
- Time Projection Chamber: tracking, momenta, and PID
- Time Of Flight: PID by velocity

Muon identification

PID@TPC



PID@TOF

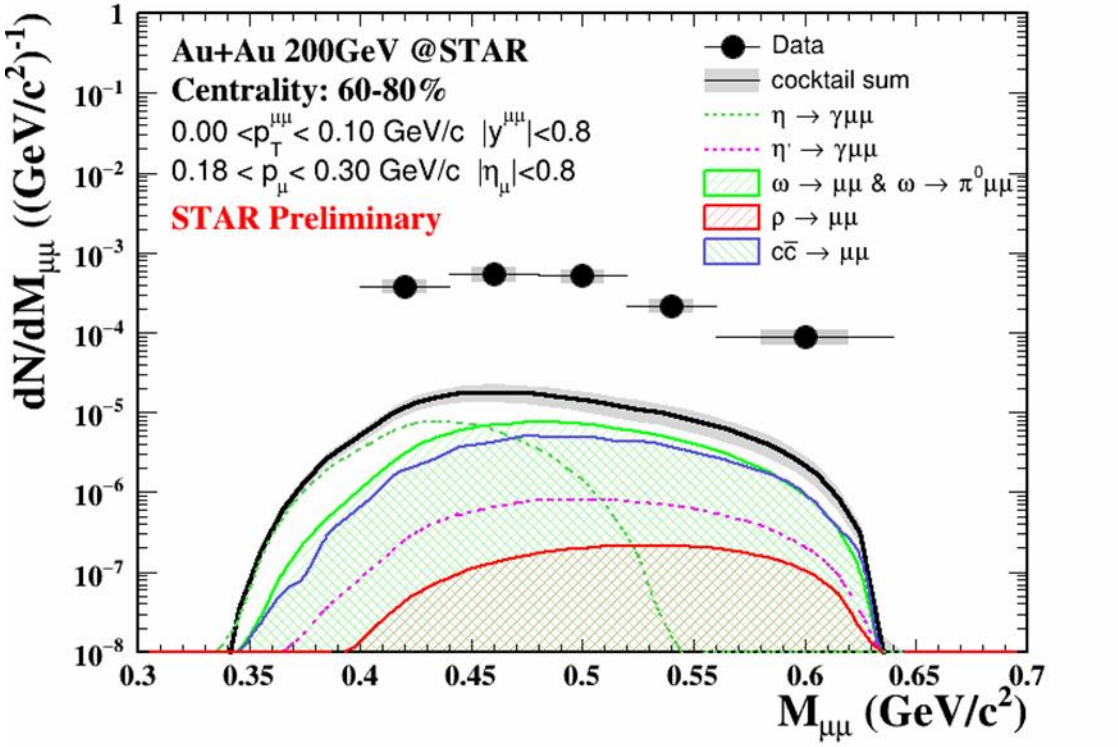


$$n\sigma_{\pi} = \frac{1}{R}\, log \frac{(dE/dx)_{measured}}{(dE/dx)_{pion}}$$

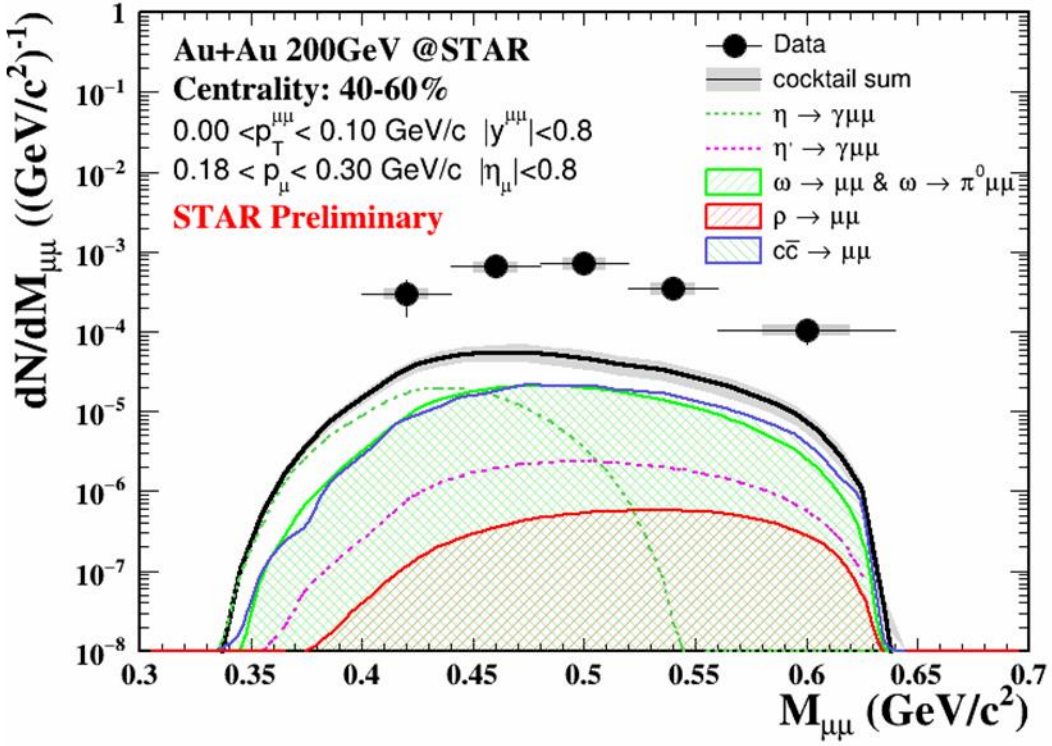
- Muons can be identified at low momentum by using TOF.

Invariant mass spectrum

Centrality:60-80%



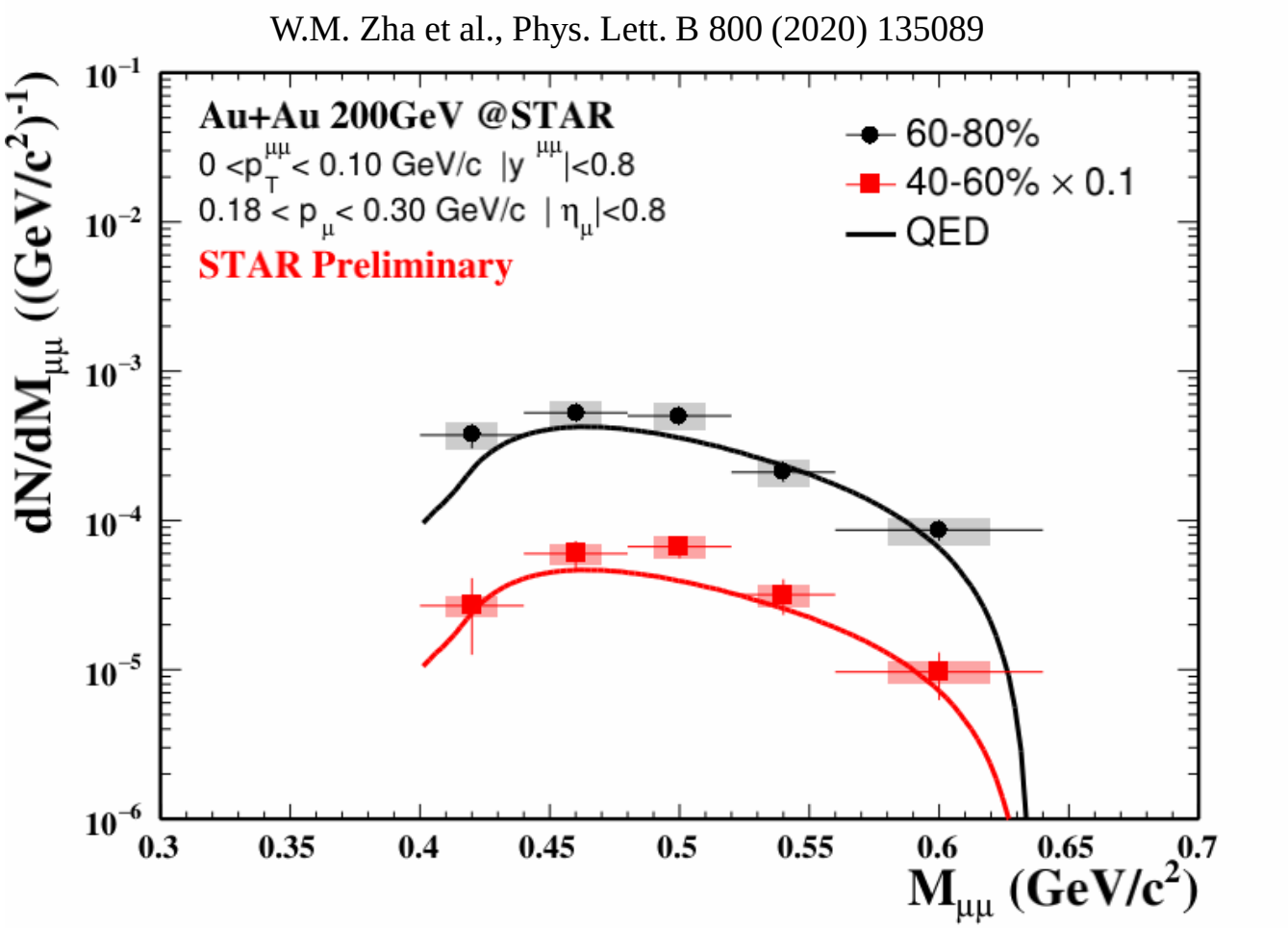
Centrality:40-60%



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

Invariant mass spectrum

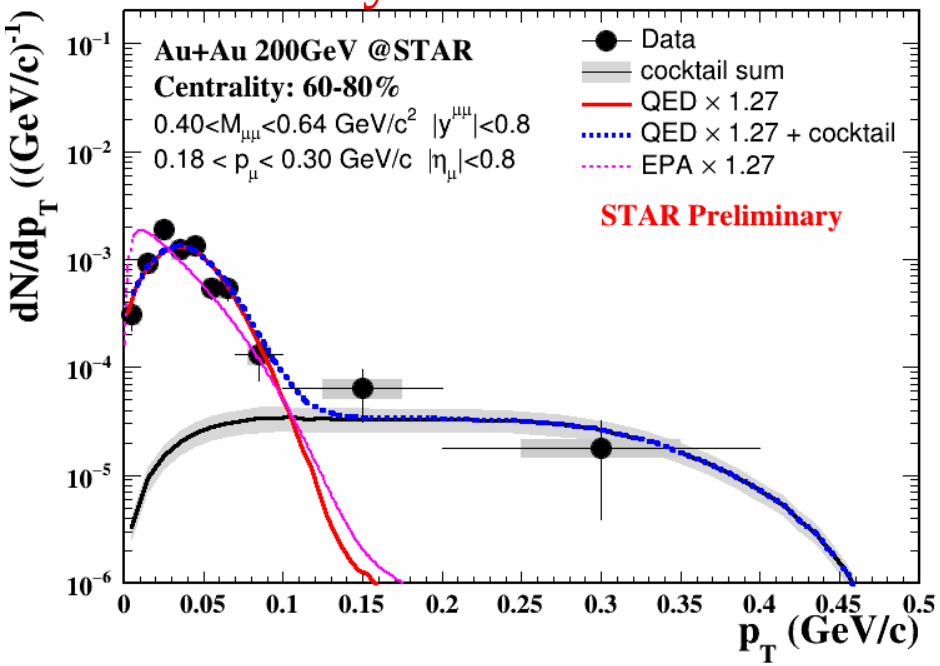
W.M. Zha et al., Phys. Lett. B 800 (2020) 135089



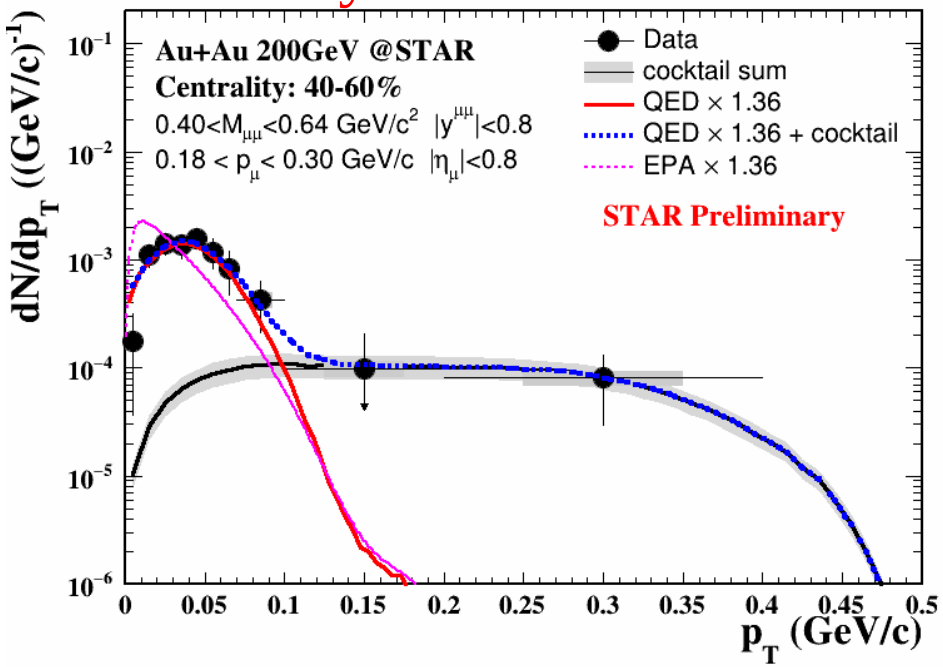
- Consistent with the theoretical calculations in different centrality.

p_T distributions

Centrality:60-80%



Centrality:40-60%

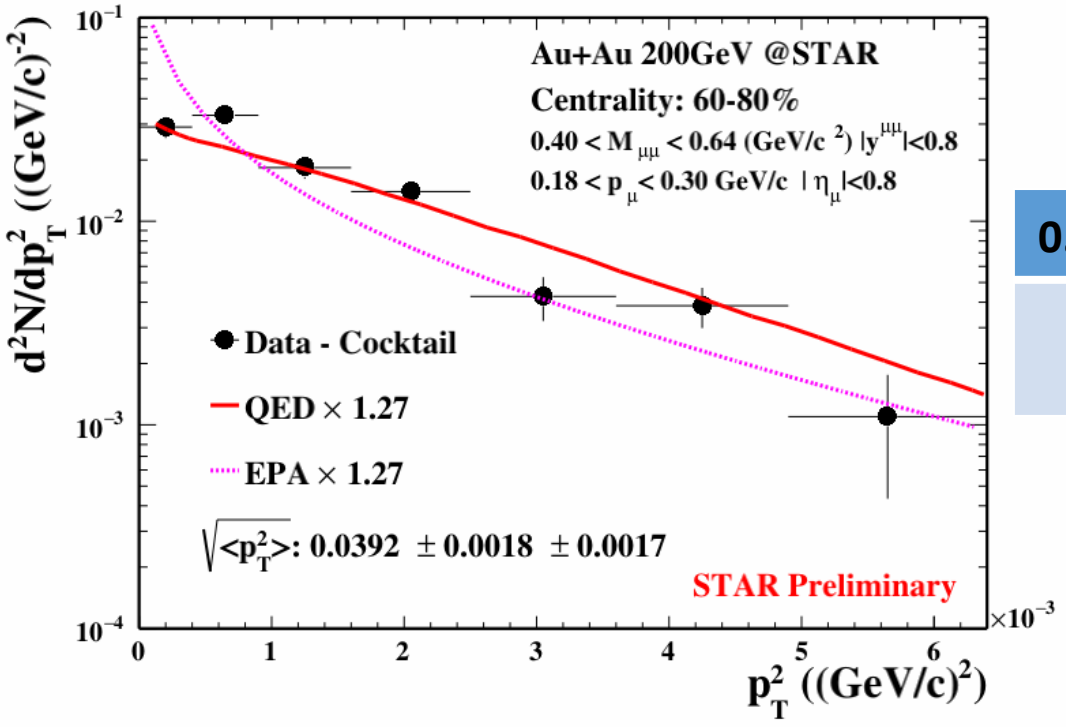


W.M. Zha et al., Phys. Lett. B 800 (2020) 135089

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

t distribution (60-80%)

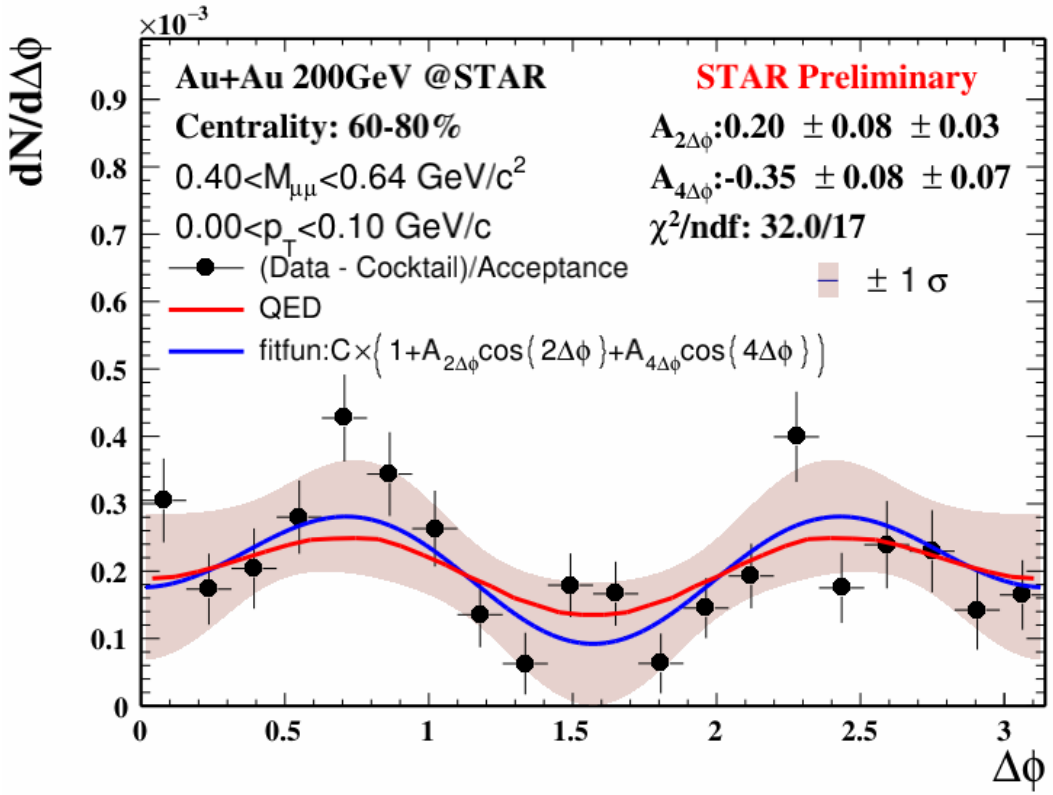
W.M. Zha et al., Phys. Lett. B 800 (2020) 135089



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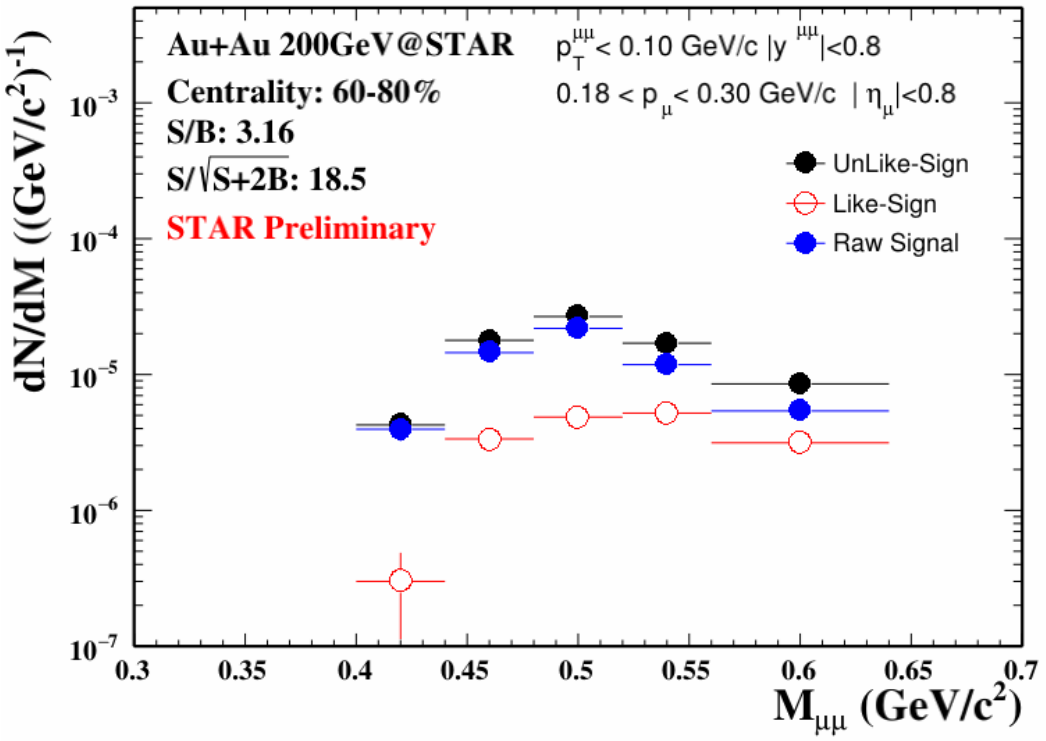
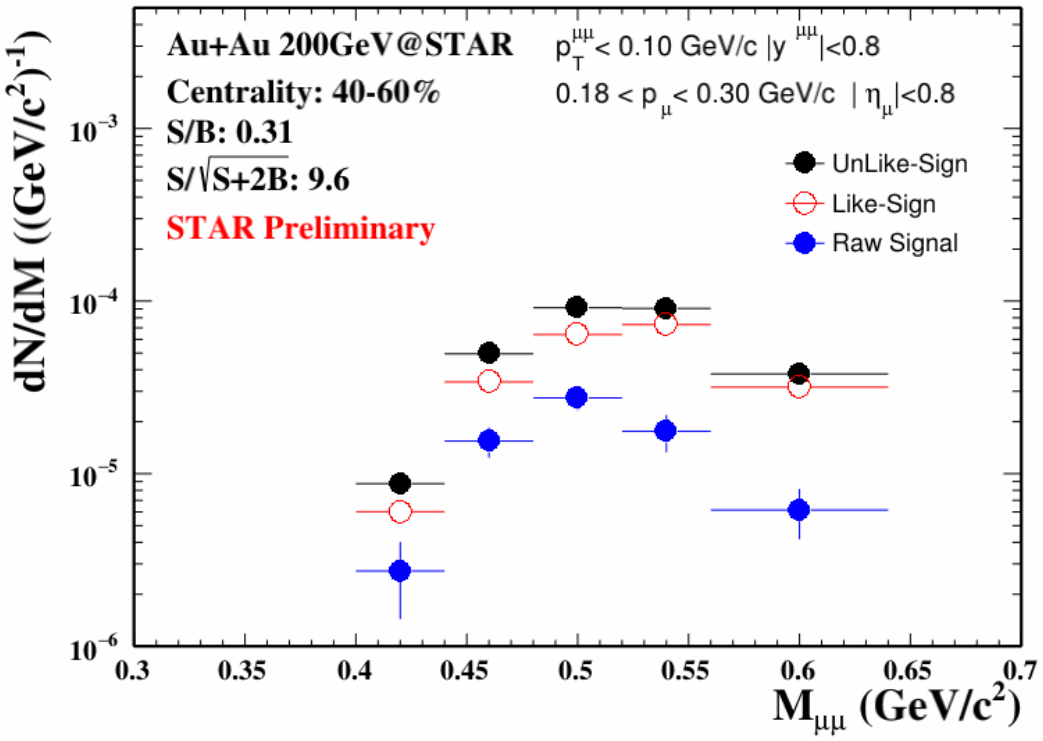
- A significant $\mu^+\mu^-$ enhancement w.r.t. cocktail is observed at very low p_T in peripheral Au + Au collisions at 200 GeV.
- The $\sqrt{< p_T^2 >}$ is consistent with the QED calculation.
- Observation of the 4th-order azimuthal angular modulation of $\mu^+\mu^-$ pair.
- First indication of the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

Thank you!

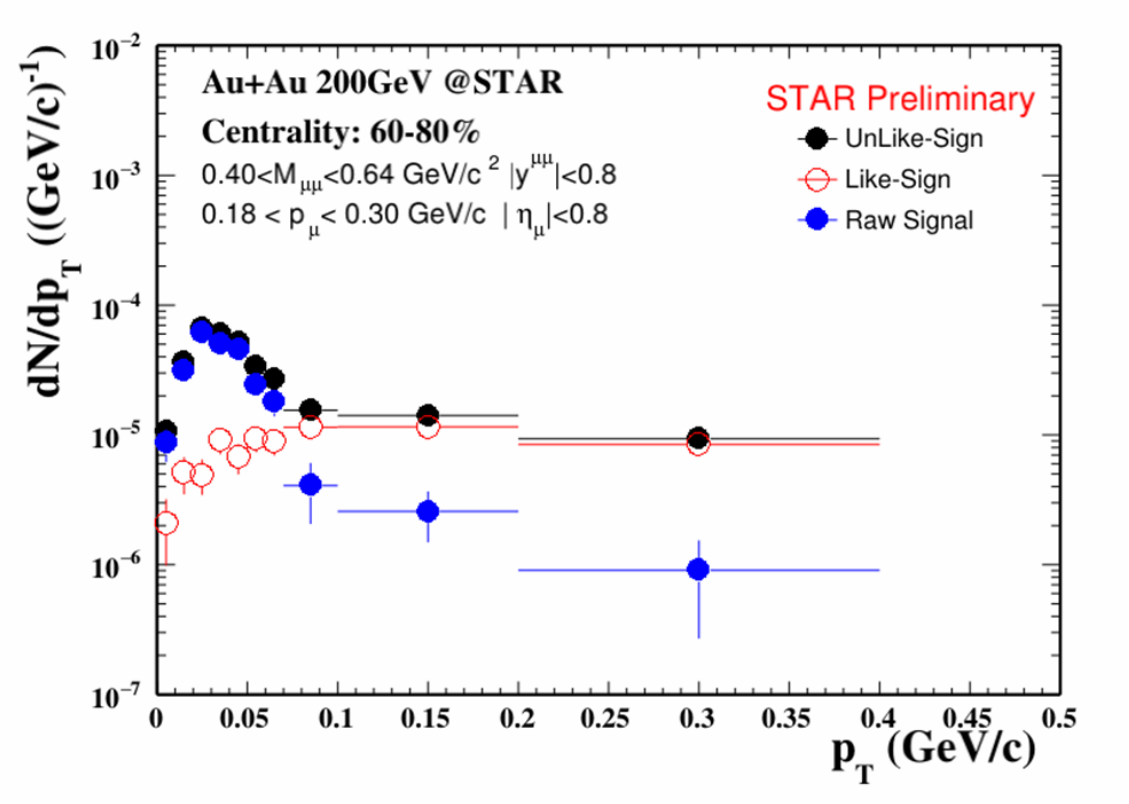
Back up

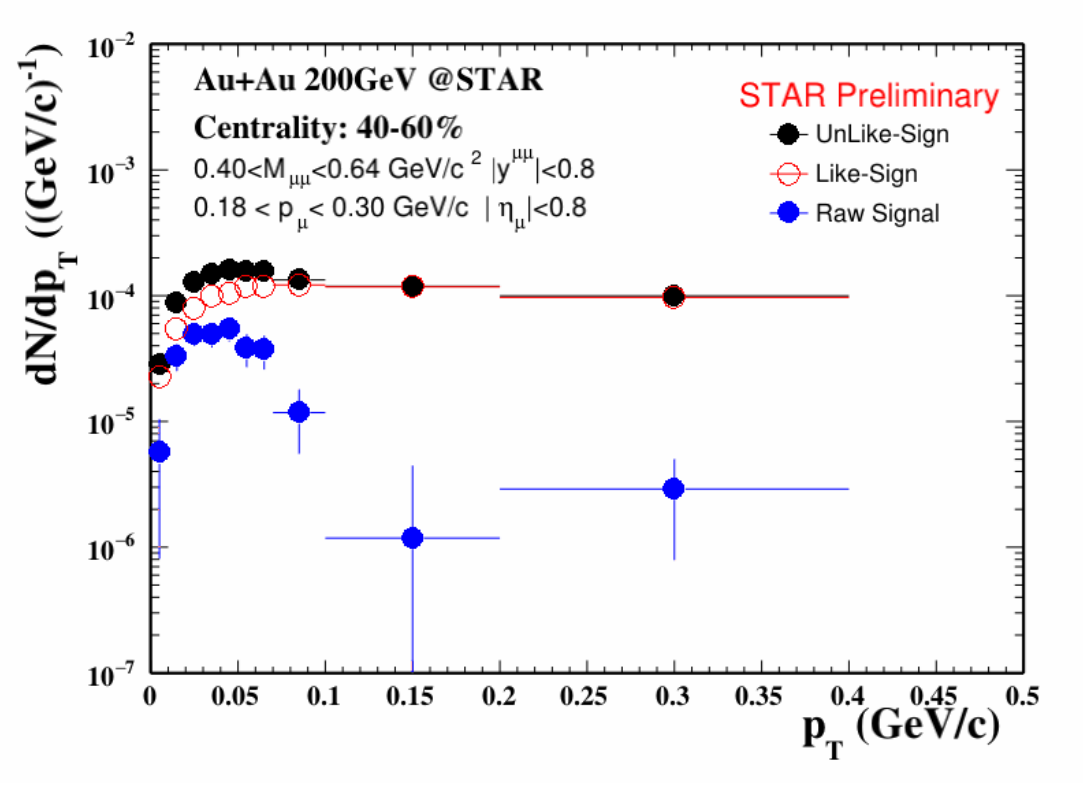
Raw signal extraction



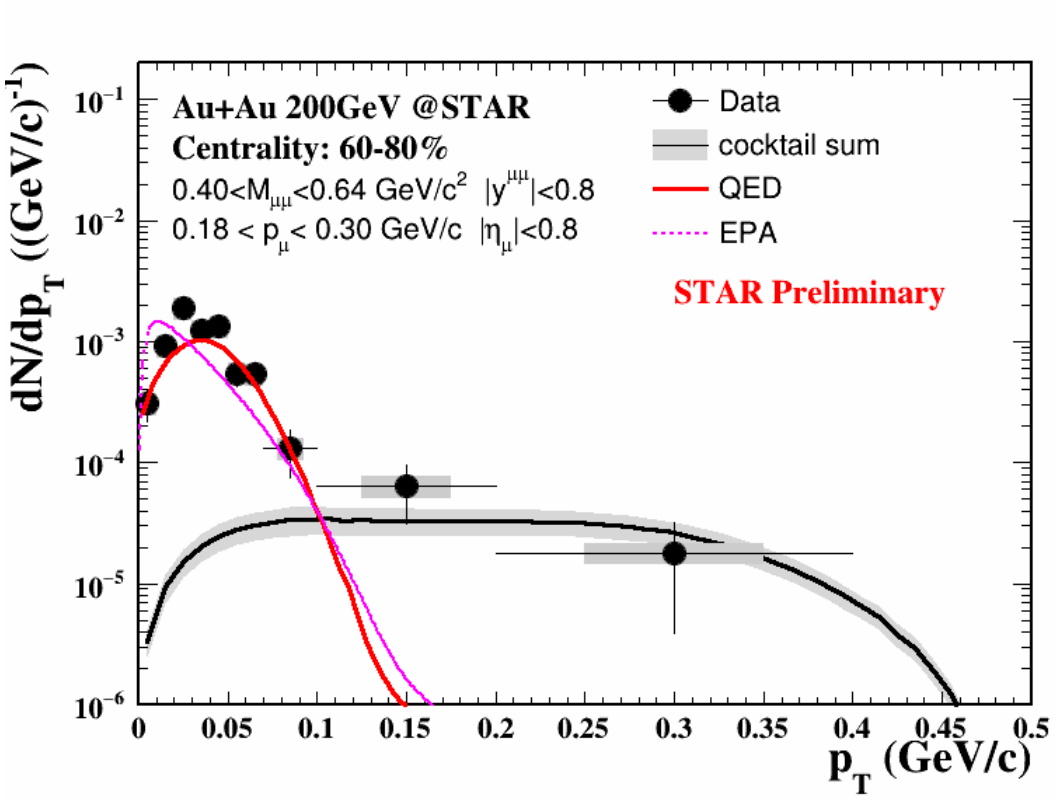


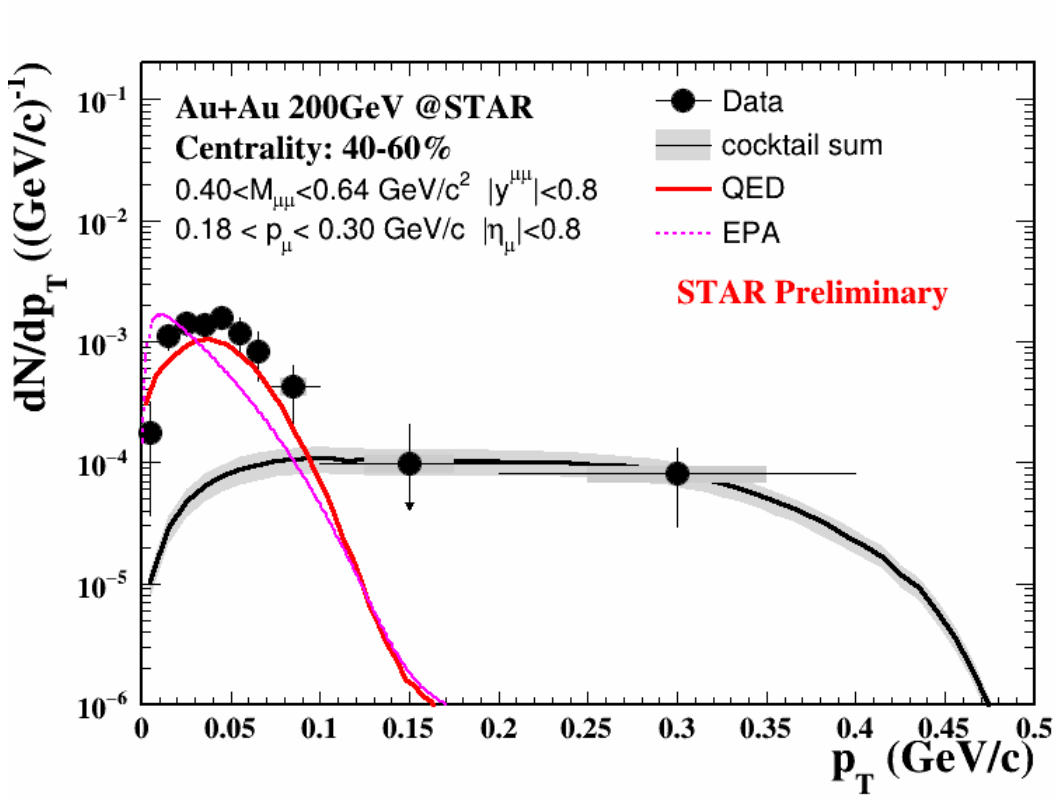
Raw signal extraction





Without scale





Without scale