Photon-induced lepton pairs production in Au+Au collisions at 200GeV at STAR

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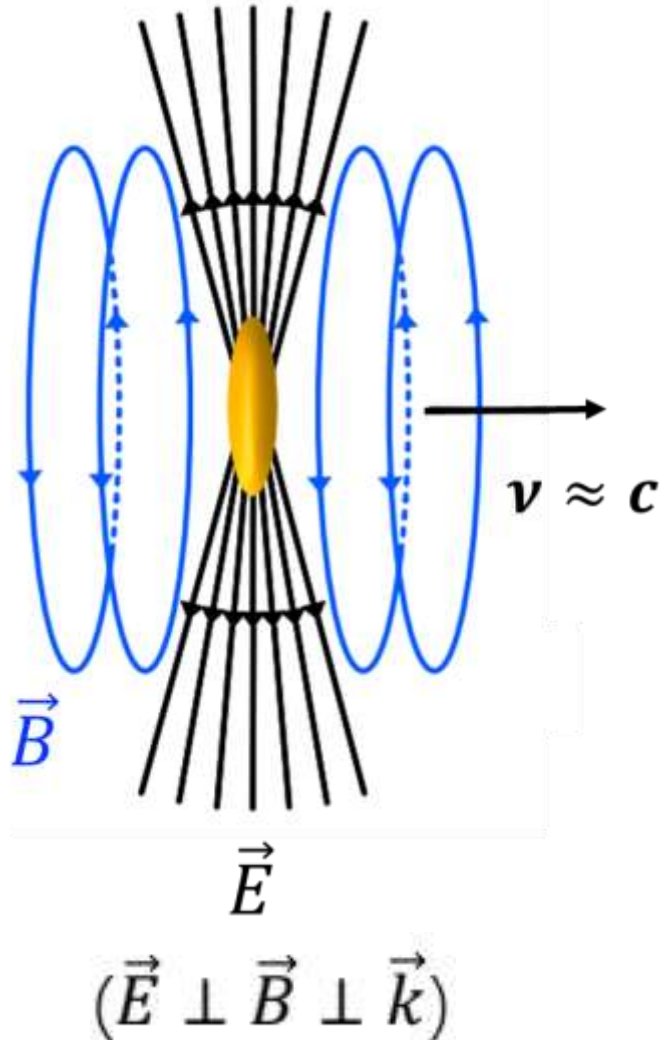
UPC physics 2023

Outline

- Introduction

- Low p_T e^+e^- pair production at STAR

- Low p_T $\mu^+\mu^-$ pair production at STAR

- Summary

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- ## Introduction

- Low p_T $e^+ e^-$ pair production at STAR

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Ultra-strong EM fields in heavy-ion collisions

$\vec{B}$

$v \approx c$

$\vec{E}$

$(\vec{E} \perp \vec{B} \perp \vec{k})$

➢ Ultra-relativistic charged nuclei produce highly Lorentz contracted electromagnetic field.

✓ The strongest electromagnetic fields ($\sim 10^{14}$ Tesla) in the known universe.

➢ Weizsacker–Williams Equivalent Photon Approximation(EPA):

✓ In a specific phase space, transverse EM fields can be quantized as a flux of quasi-real photons.

$$n \propto \vec{S} = \frac{1}{\mu_0} \vec{E} \times \vec{B} \approx |\vec{E}|^2 \approx |\vec{B}|^2$$
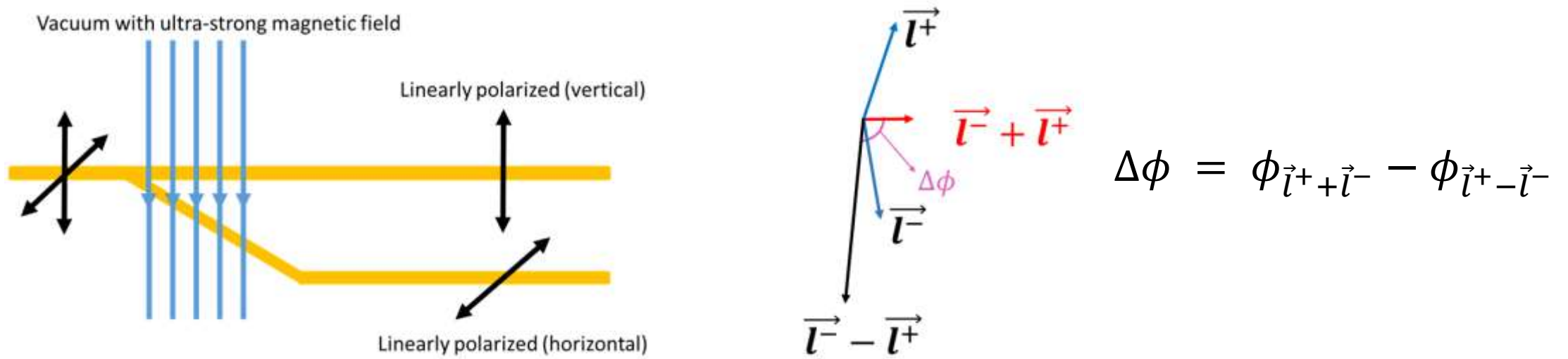
➢ Large quasi-real photon flux $\propto Z^2$

Photon induced Di-lepton pairs

$\vec{E} \perp \vec{B} \perp \vec{v}$
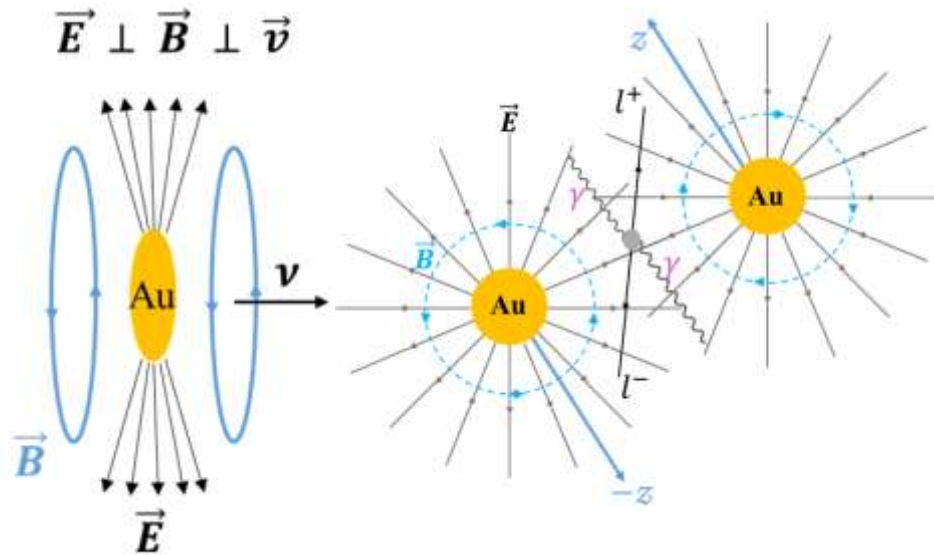
➢ Photon-photon interaction $\propto Z^4$
➢ Converting photons into dilepton

✓ Distinctly peaked at very low p_T .
✓ Could be used to test the strong initial electromagnetic fields.
✓ Could be studied in Ultra-Peripheral Collisions and peripheral collisions

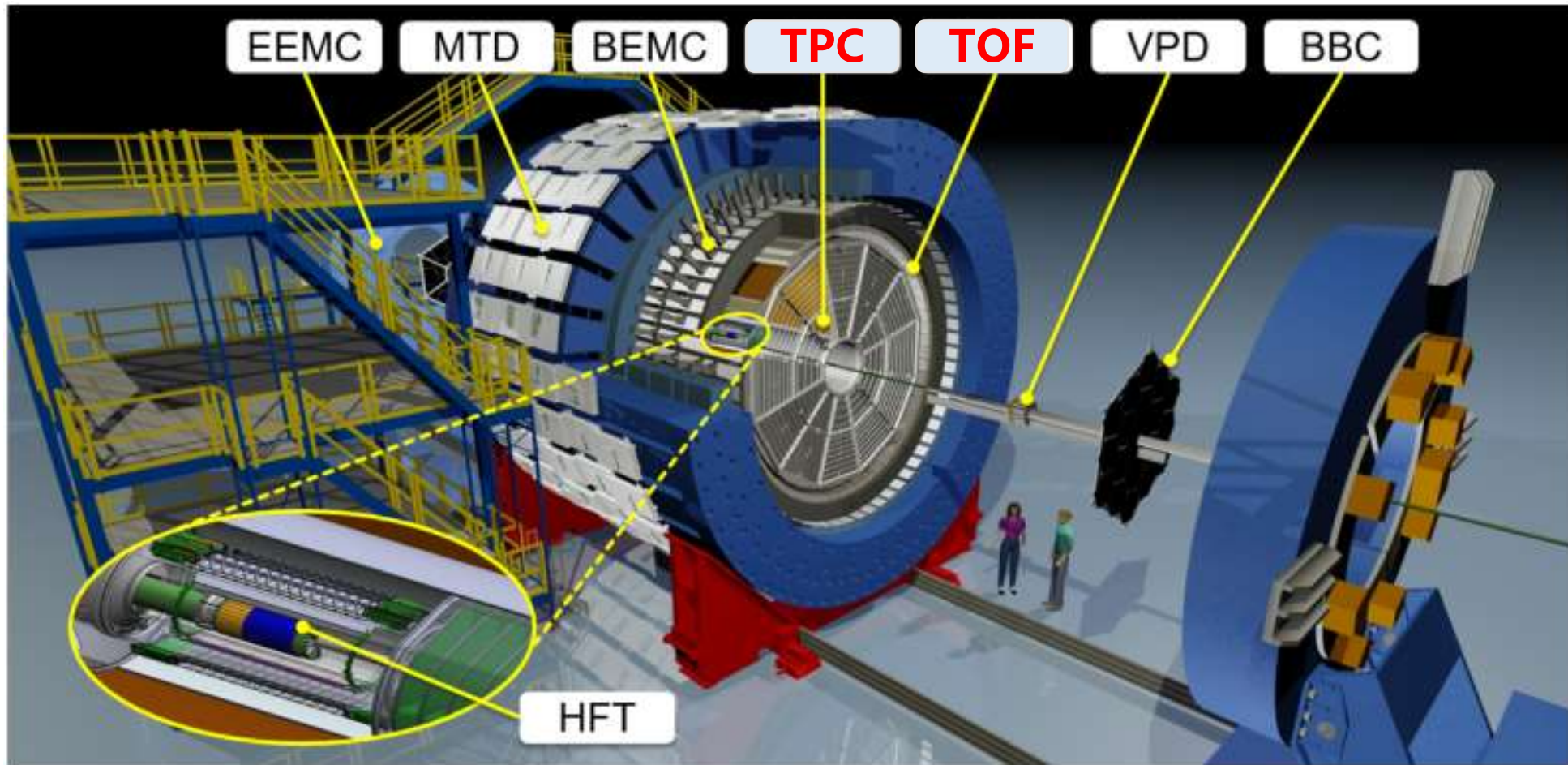# Birefringence of the QED Vacuum

$$\Delta\phi = \phi_{\vec{l}^+ + \vec{l}^-} - \phi_{\vec{l}^+ - \vec{l}^-}$$

Linearly polarized photon-photon collisions will lead to $\Delta\phi$ modulation which is related to vacuum birefringence.

- $\cos 4\Delta\phi$ azimuthal angular modulation could be studied in e^+e^- and $\mu^+\mu^-$ production

- $\cos 2\Delta\phi$ azimuthal asymmetry is proportional by $m^2/p_\perp^2$.
  - ☐ Only sizable for $\mu^+\mu^-$ pair production.

The Solenoidal Tracker At RHIC (STAR)

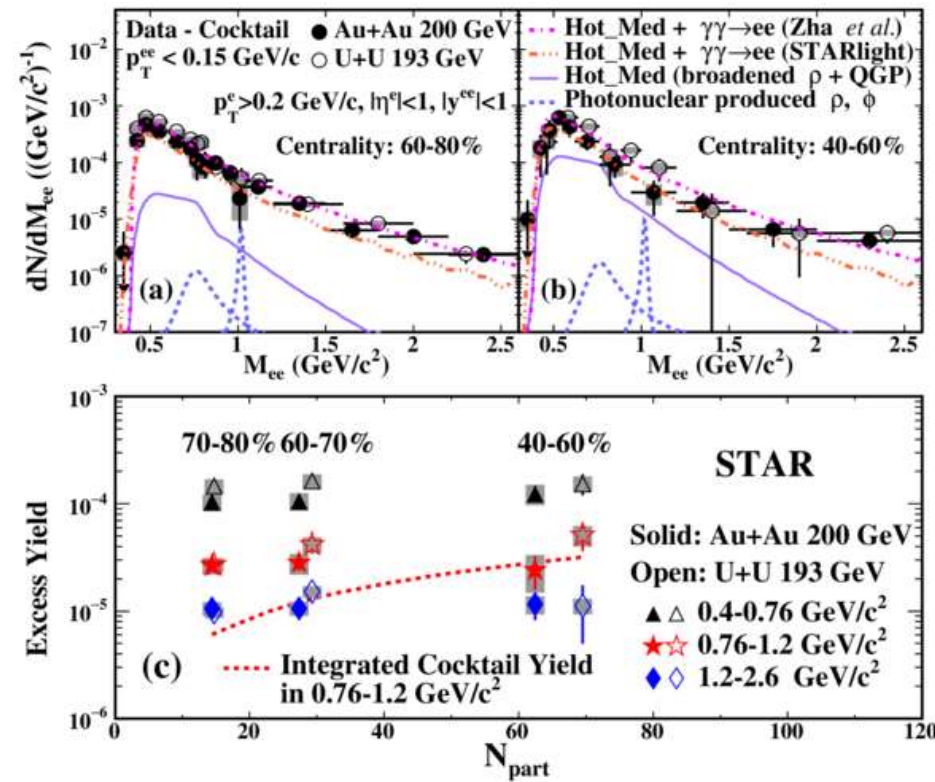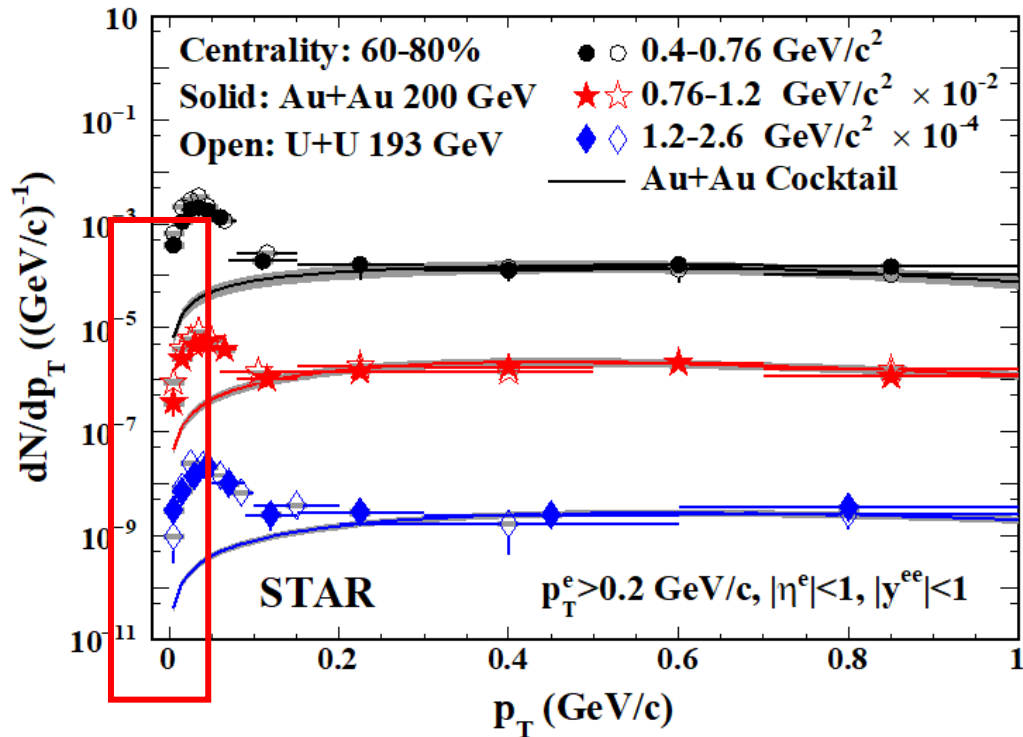➢ **T**ime **P**rojection **C**hamber:
tracking, momenta, and PID

➢ **T**ime **O**f **F**light:
PID by velocity

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Low $p_T \, e^+ e^-$ pair production

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

- Excess of dielectron production concentrates below $p_T \sim 0.15$ GeV/c
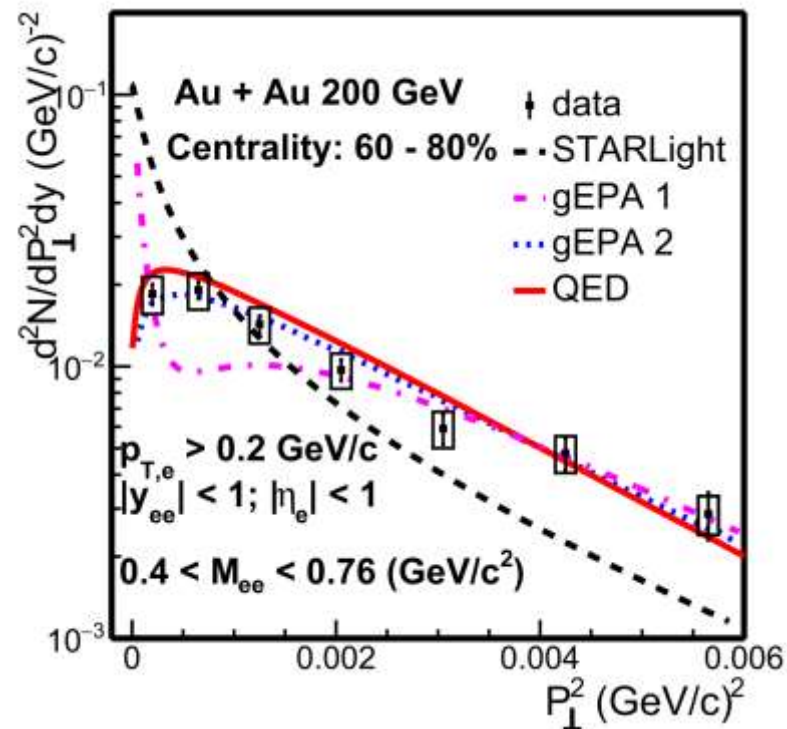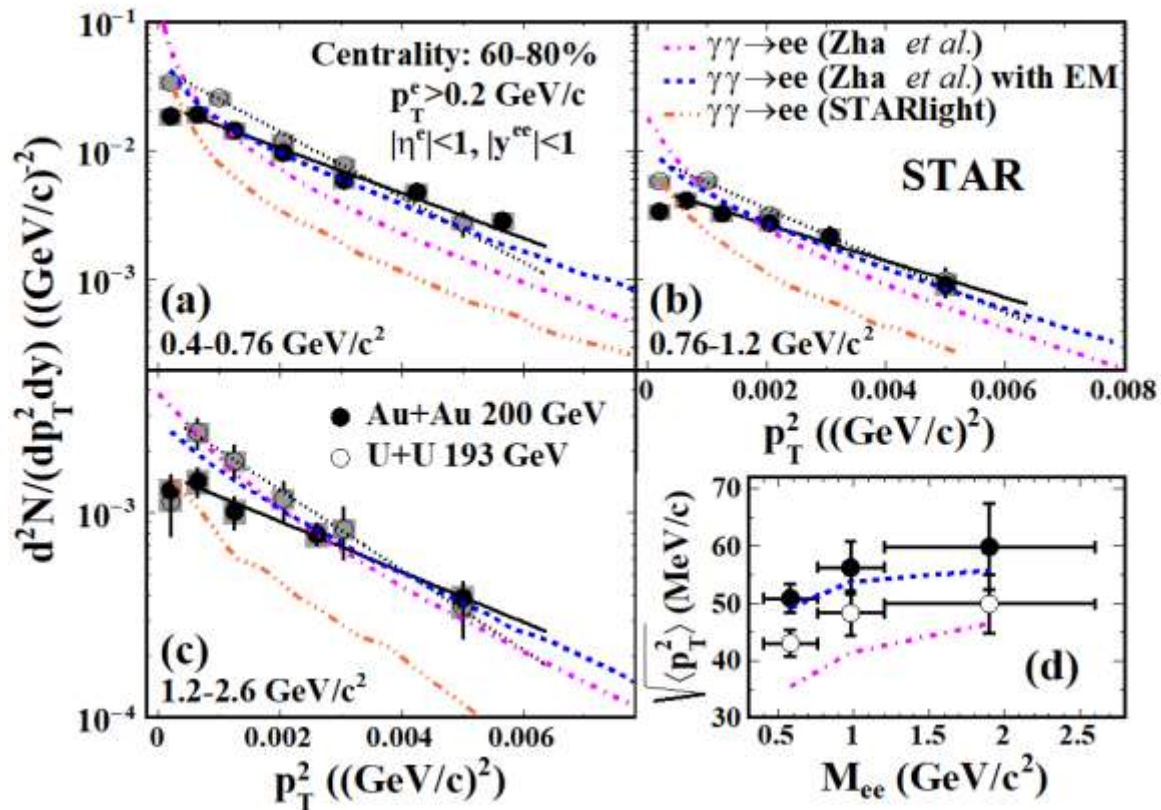- Features of photon-phonton interaction.

- excess yields exhibit weak dependence on centrality
- The excess is dominated by photon-photon interactions
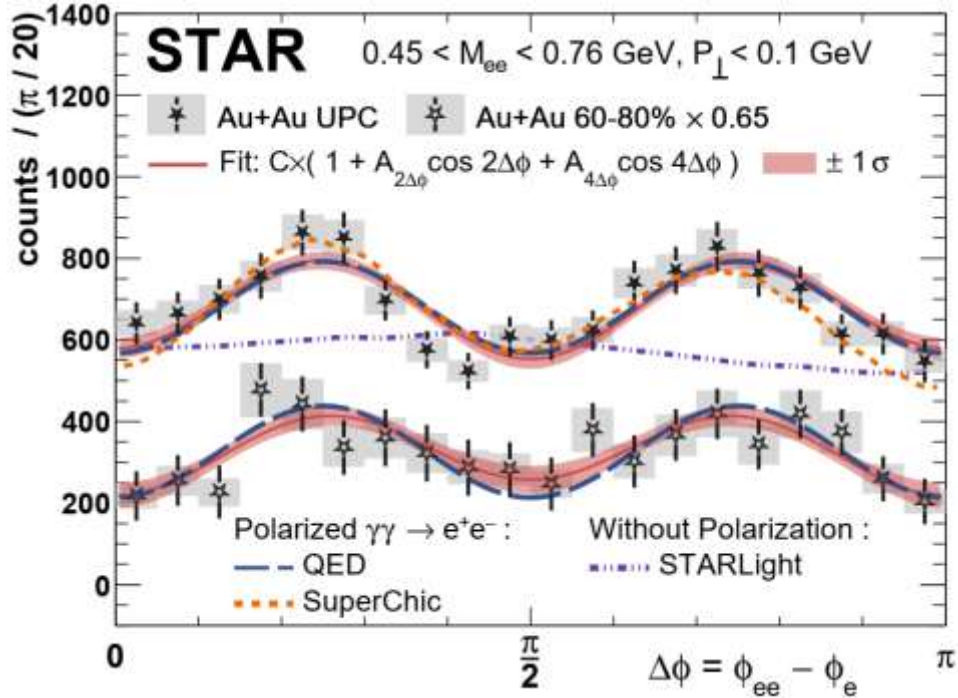
p_T^2 Spectrum

p_T Spectrum

➤ Consistent with the QED calculation

Impact parameter dependence of initial photon p_T

➤ Need more precise measurement!

$\Delta\phi$ modulation

STAR, Phys. Rev. Lett. 127 (2021) 052302

	Ultra-Peripheral				Peripheral	
	Measured	QED	SC	SL	Measured	QED
$\|A_{4\Delta\phi}\|$ (%)	16.8 ± 2.5	16.5	19	0	27 ± 6	34.5
$\|A_{2\Delta\phi}\|$ (%)	2.0 ± 2.4	0	5	5	6 ± 6	0

➤ First measurement of $\Delta\phi$ distribution for e^+e^- pairs produced in photonphoton collisions.

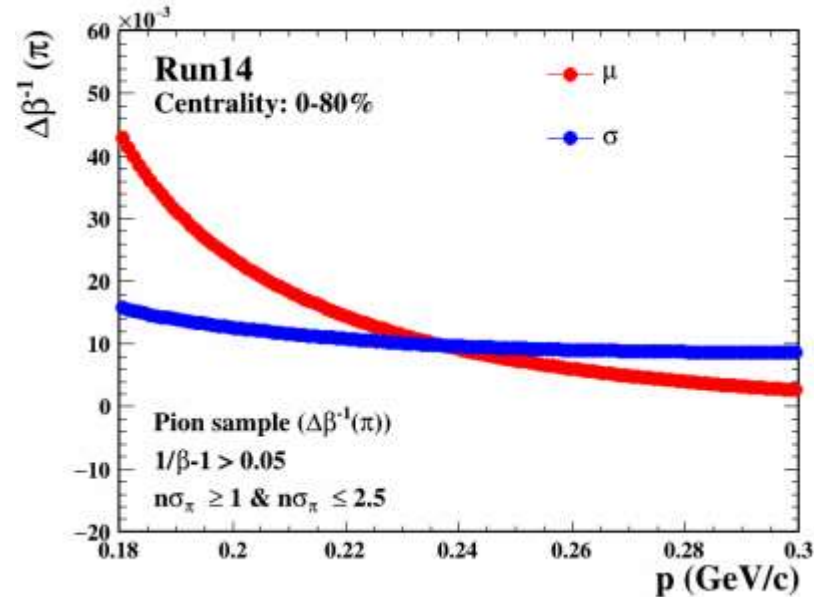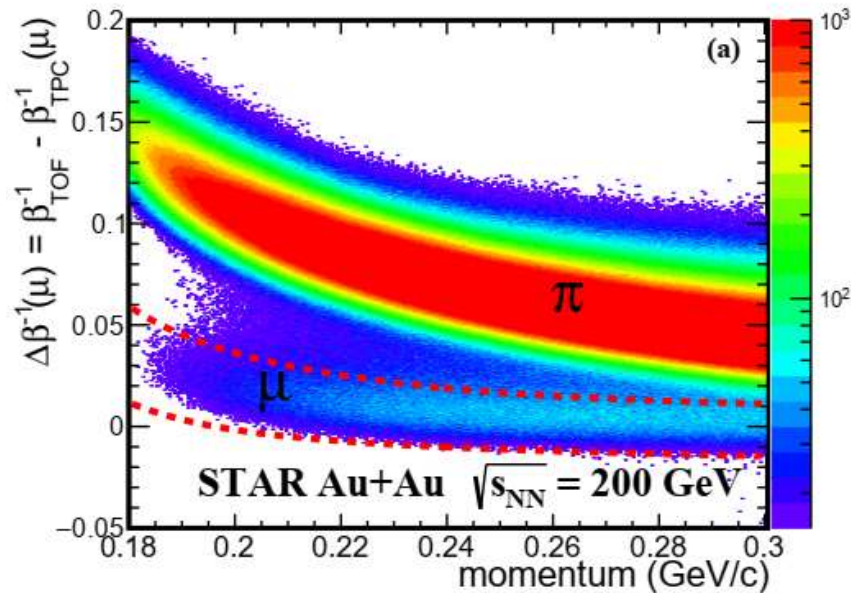➤ 4th-order azimuthal angular modulation of e^+e^- pairs had been observed

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Muon identification

$$\Delta\beta^{-1}(X) = \frac{1}{\beta_{tof}} - \frac{1}{\beta_{tpc(X)}} \qquad \beta_{tpc(X)} = \frac{p}{\sqrt{m_\mu^2 + p^2}}$$

Assumption: $\left[\frac{1}{\beta_{tof}} - \frac{1}{\beta_{tpc(\mu)}}\right]_{puremuon} = \left[\frac{1}{\beta_{tof}} - \frac{1}{\beta_{tpc(\pi)}}\right]_{purepion}$
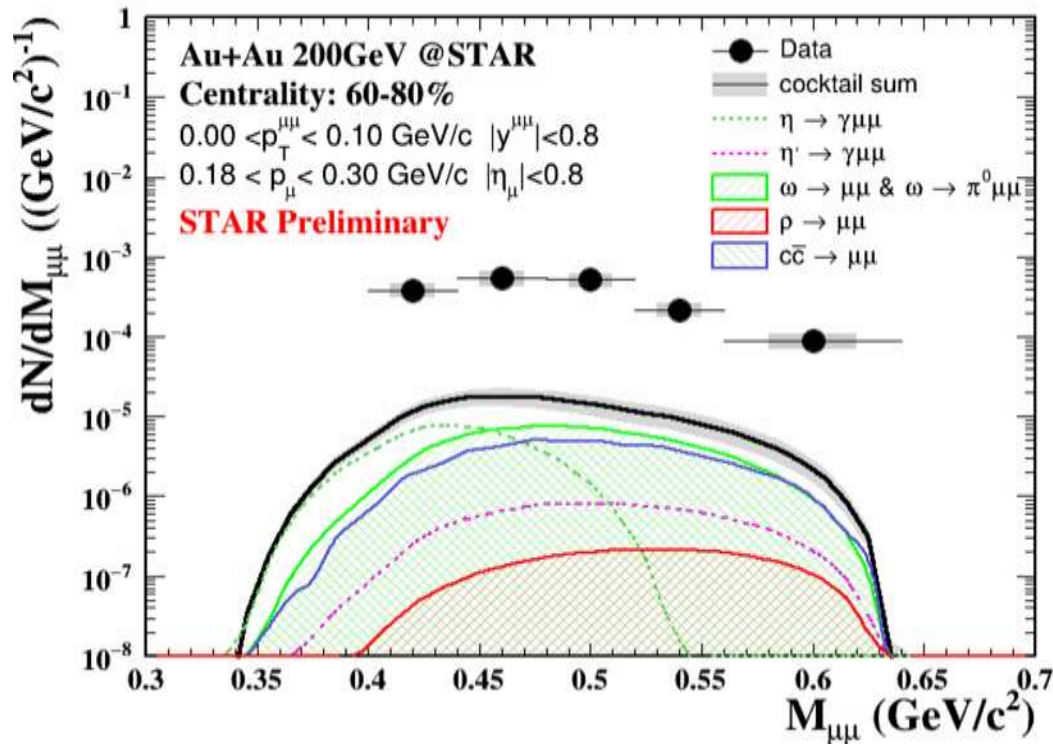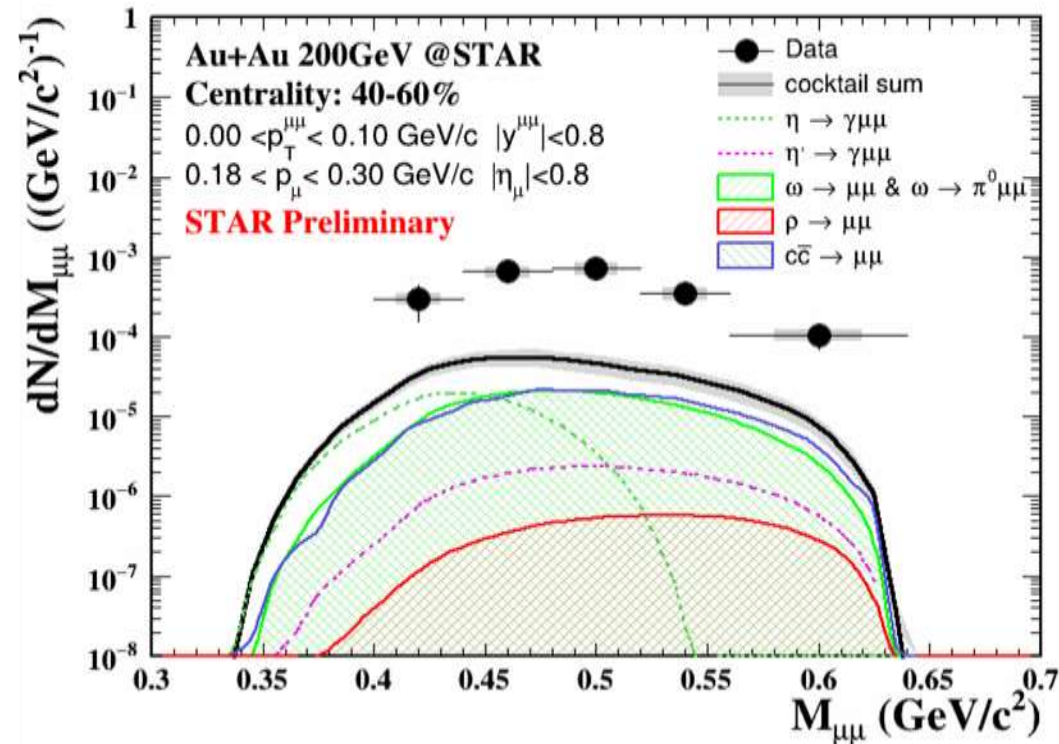

$$(\mu - 2\sigma, \mu + \sigma)$$

☐ Muon can be identified at low momentum using TOF.
✓ Two clear bands for π and μ can be observed at low momentum.
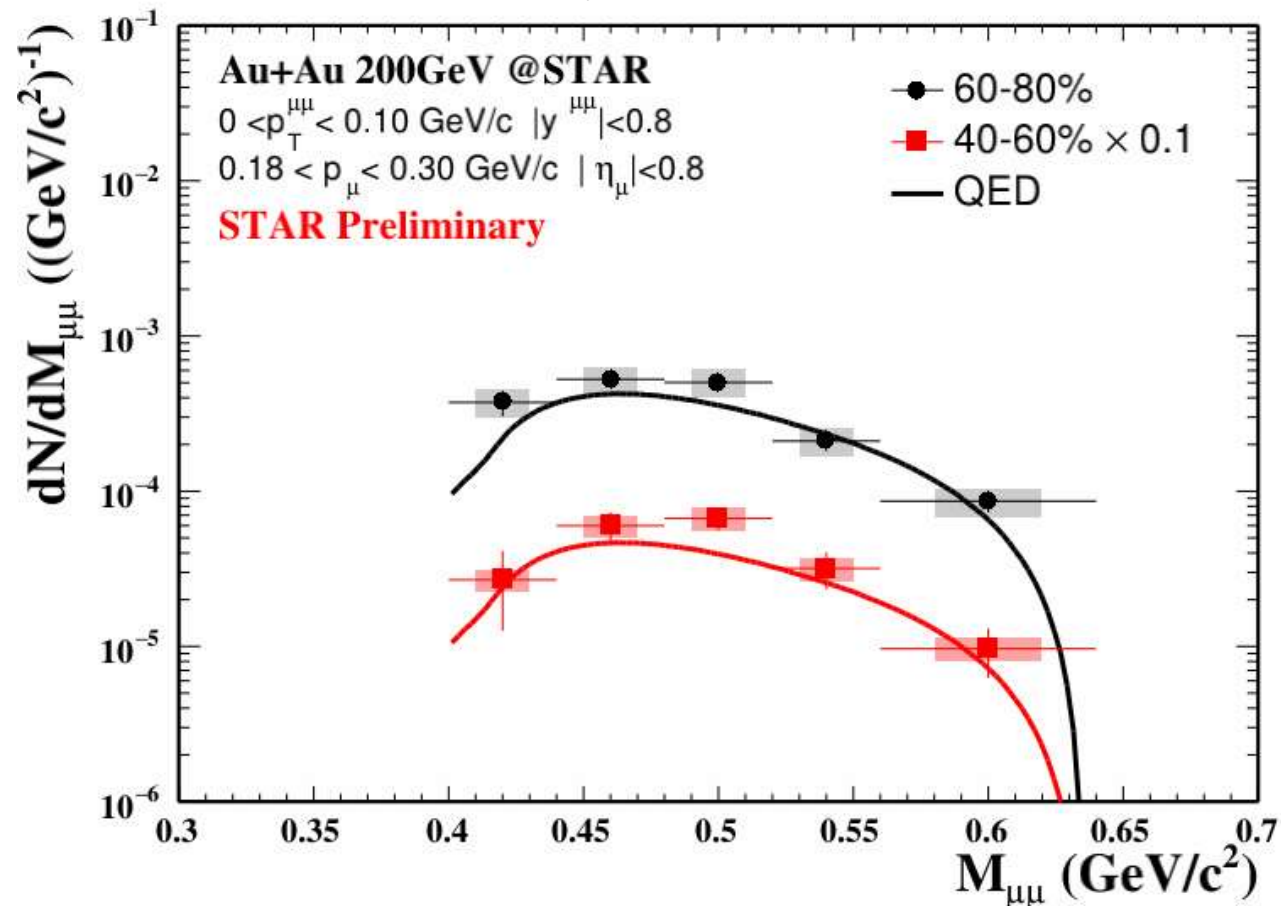
Invariant mass spectrum

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.
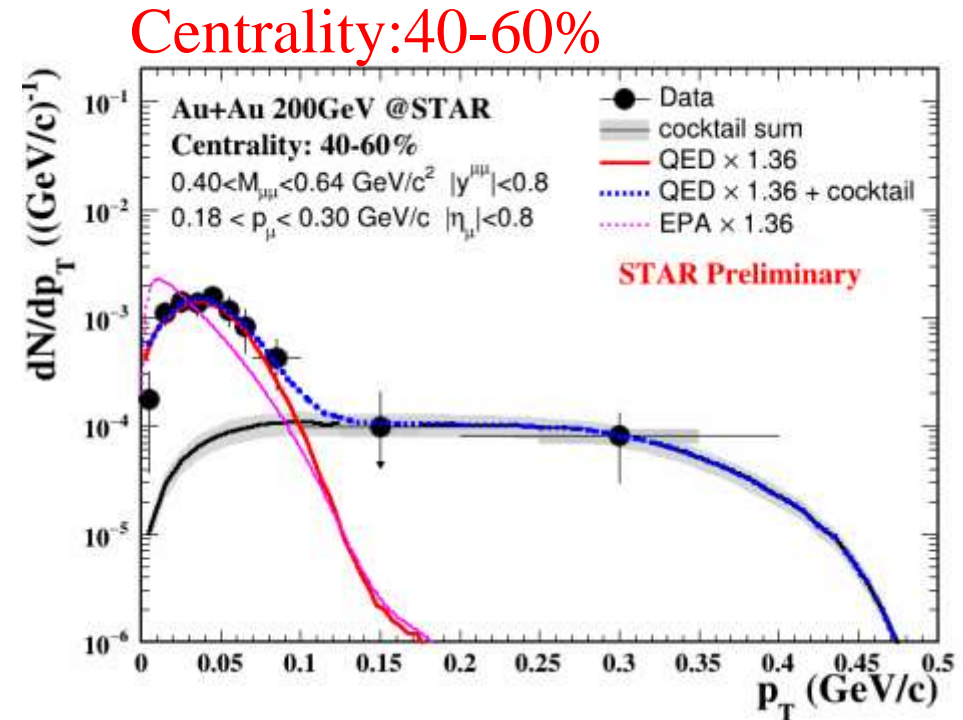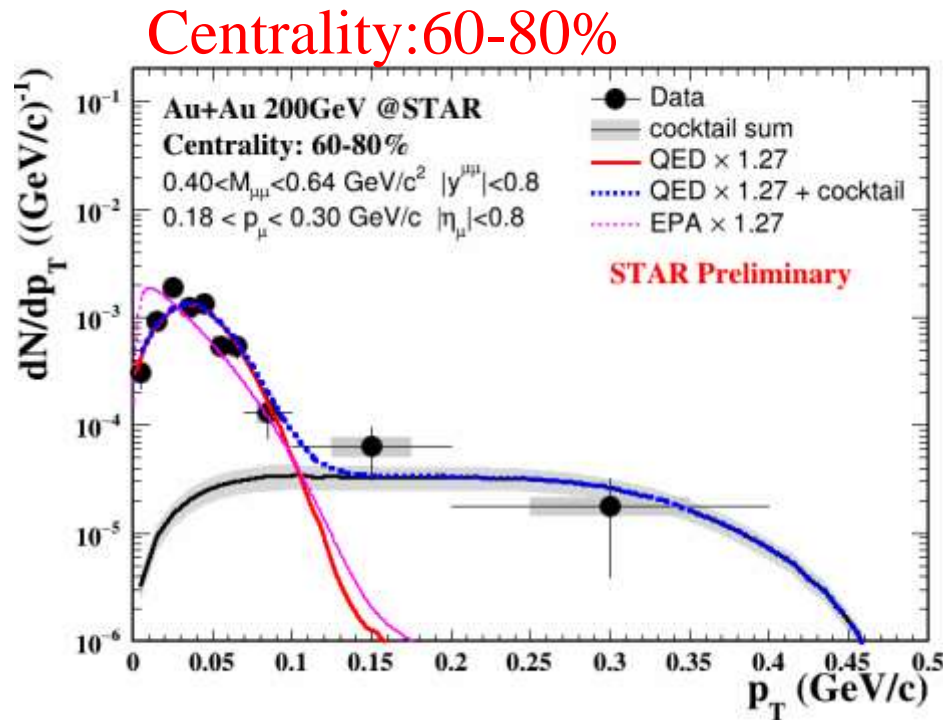
Invariant mass spectrum

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

● Consistent with the theoretical calculations in different centrality.

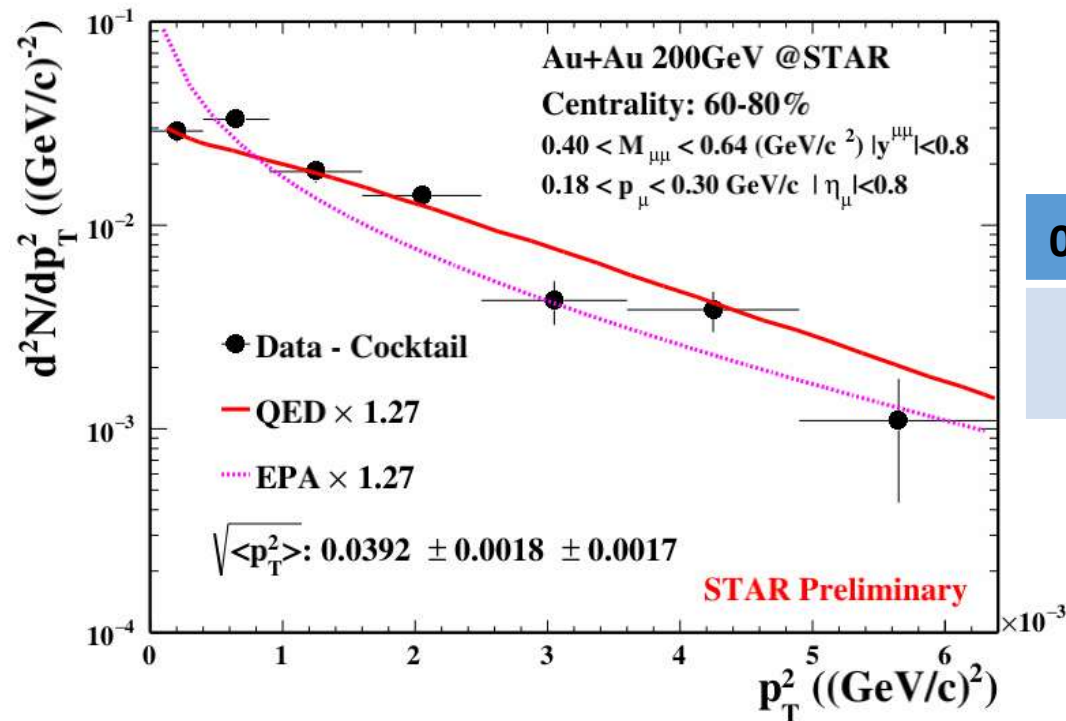# p_T distributions

Centrality:60-80%

Centrality:40-60%

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

- Excesses concentrated below $p_T \approx 0.1\text{GeV/c}$.

- Data are consistent with hadronic expectation when $p_T > 0.1$ GeV/c.

- QED calculation is compatible with data.

p_T^2 distribution

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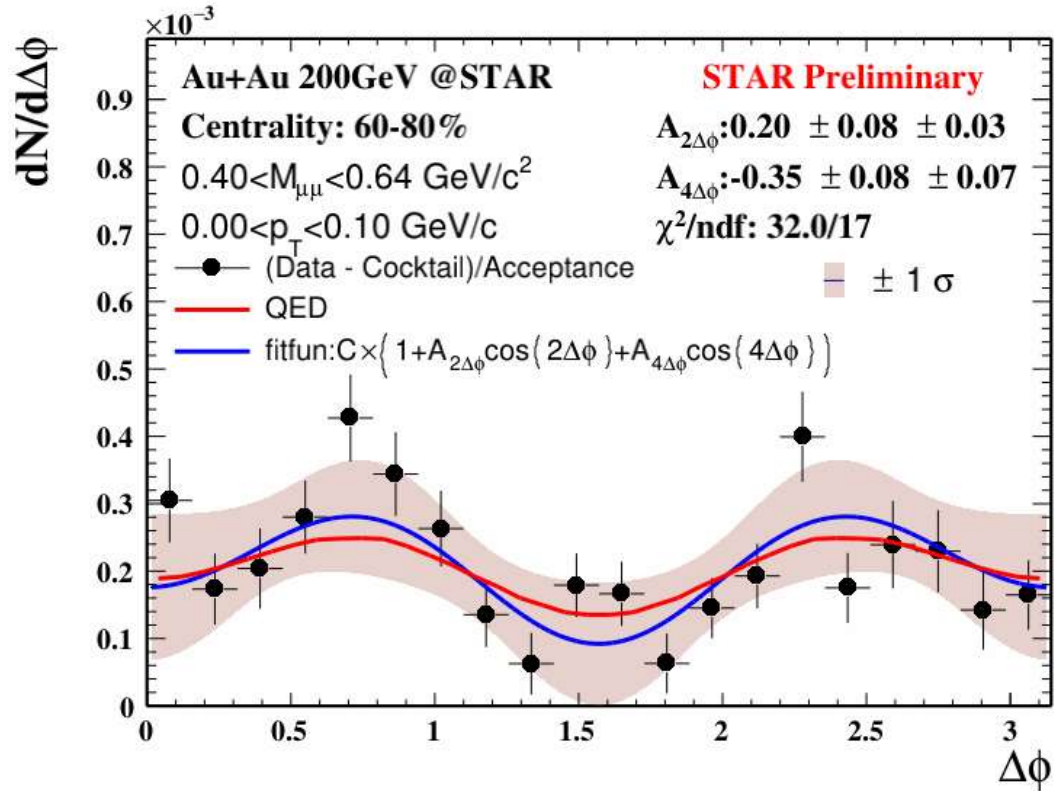
W.M. Zha et al., Phys. Lett. B 800 (2020) 135089

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

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➢ Measurements of photo-induced di-lepton pairs in heavy-ion collisions at STAR have been discussed

 ☐ A significant e^+e^- and $\mu^+\mu^-$ enhancement w.r.t. cocktail is observed at very low p_T

 ☐ The p_T and t distributions are consistent with the EPA-QED calculation

➢ Azimuthal angular modulations have been observed in e^+e^- and $\mu^+\mu^-$ production

 ☐ Hints of the 2-nd order angular modulation in dimuon channel

Outlook

✓ Measurements in UPC isobaric collisions

✓ Run 23 and 25 20 times the statistics than present data

Thank you !