Low-p_T e^+e^- pair production in Au+Au collisions and exclusive J/ψ production in d+Au collisions at STAR

Xiaofeng Wang（王晓凤）

For the STAR Collaboration

Shandong University/Qufu Normal University

山东大学/曲阜师范大学

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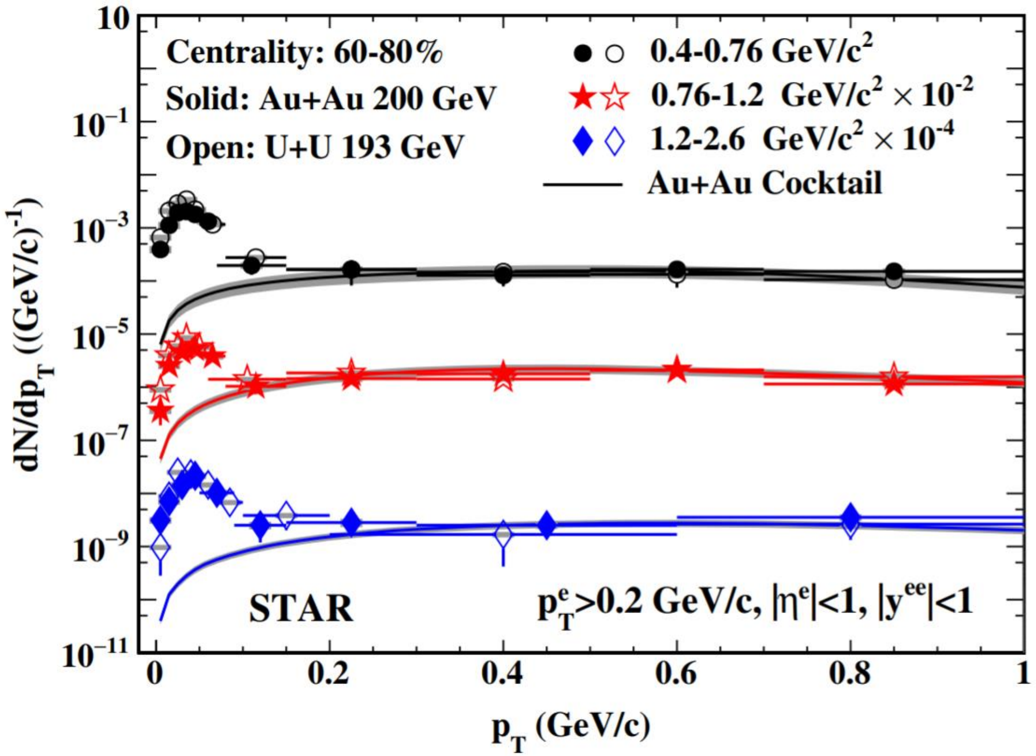
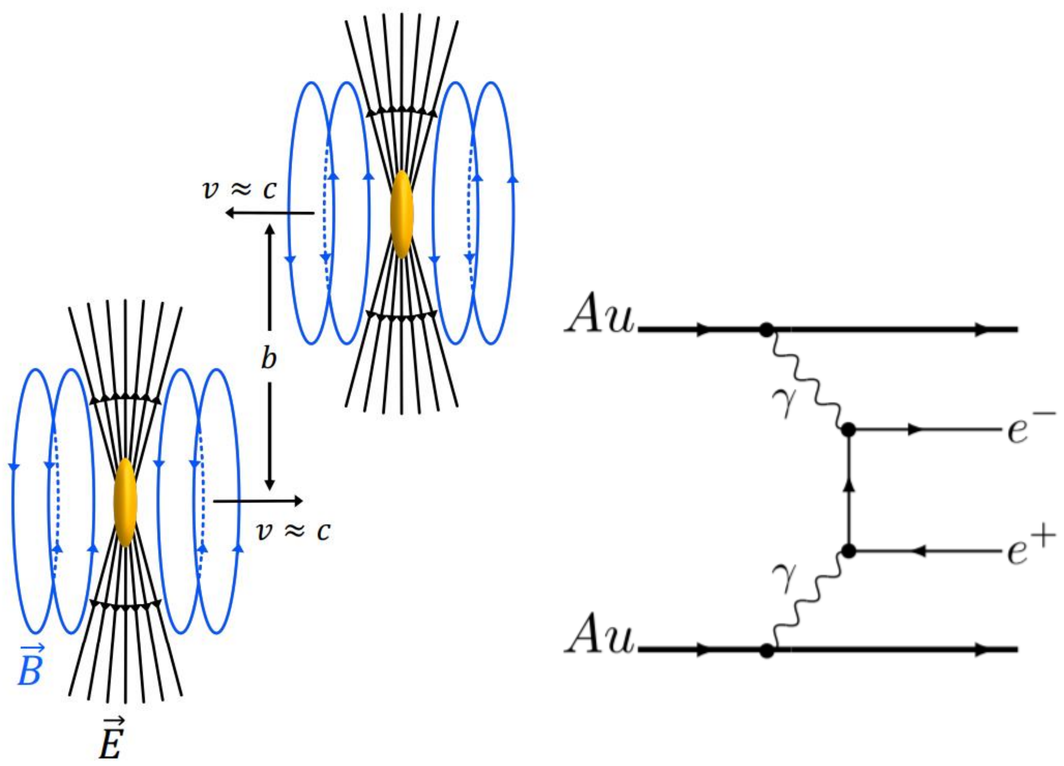
Di-electron from Photon Interactions

STAR, PRL 121,132301 (2018)



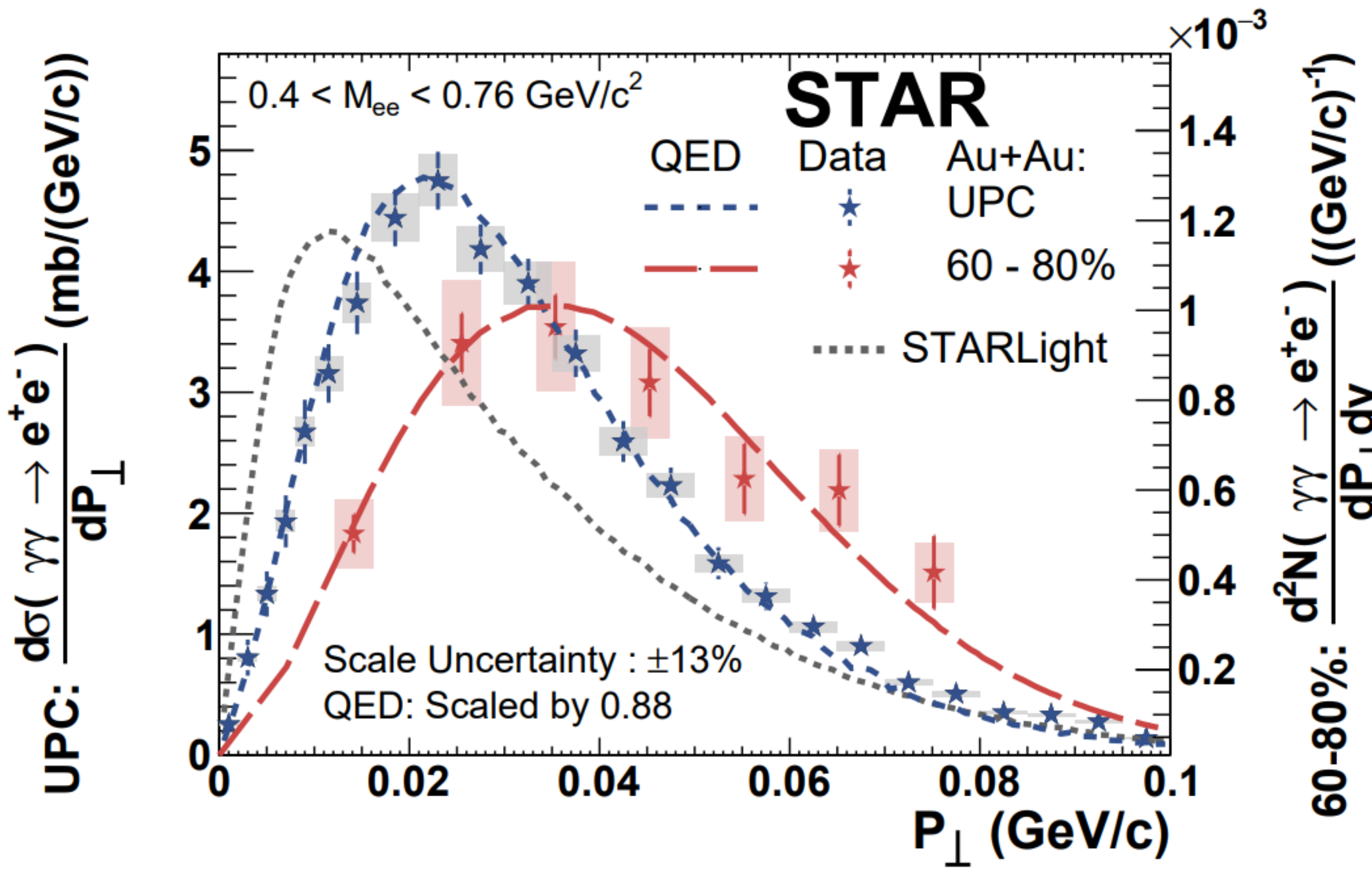


- The hadronic cocktail can describe the data for $p_T > 0.15$GeV/c in all three mass regions
- The observed excess is found to concentrate below $p_T \approx$ 0.15GeV/c

- Equivalent Photon Approximation (EPA):

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

$\gamma\gamma \rightarrow e^+e^-$: Ultra-Peripheral vs. Peripheral



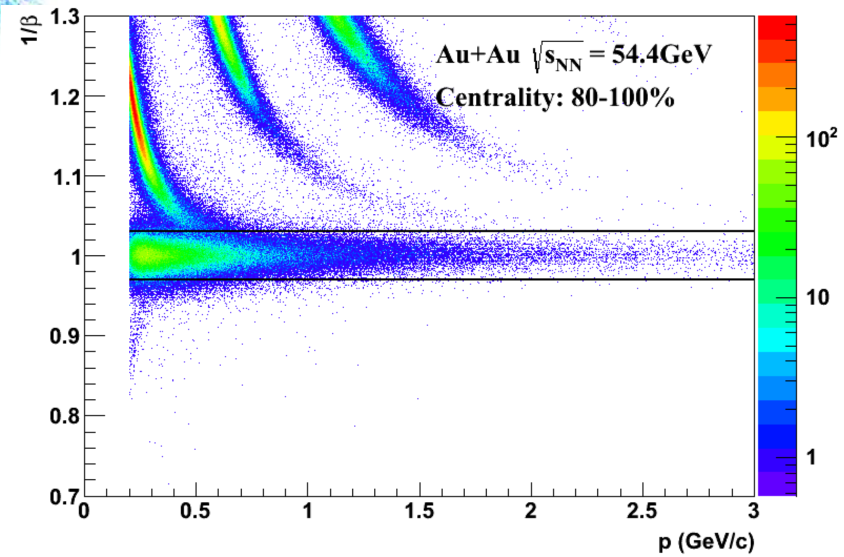
STAR, ArXiv : 1910.12400

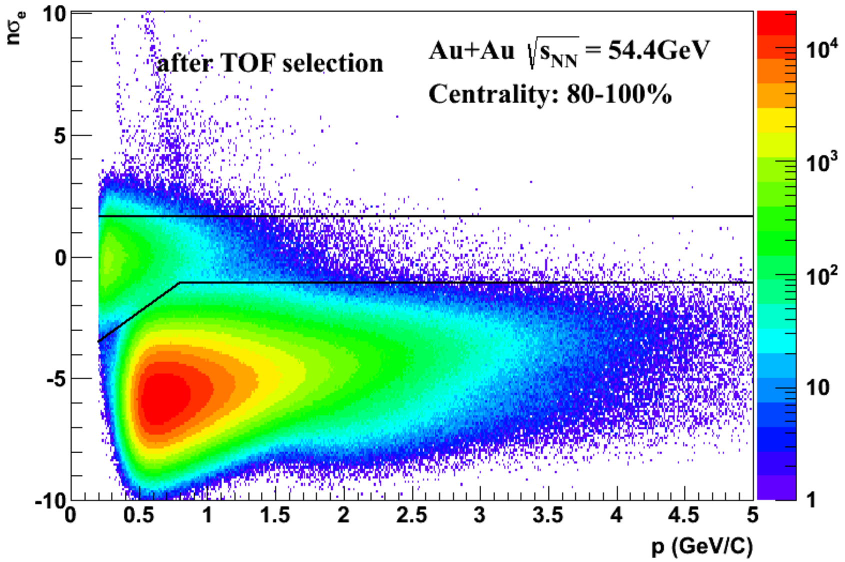
Characterize difference in spectra via $\sqrt{\langle P_\perp^2 \rangle}$

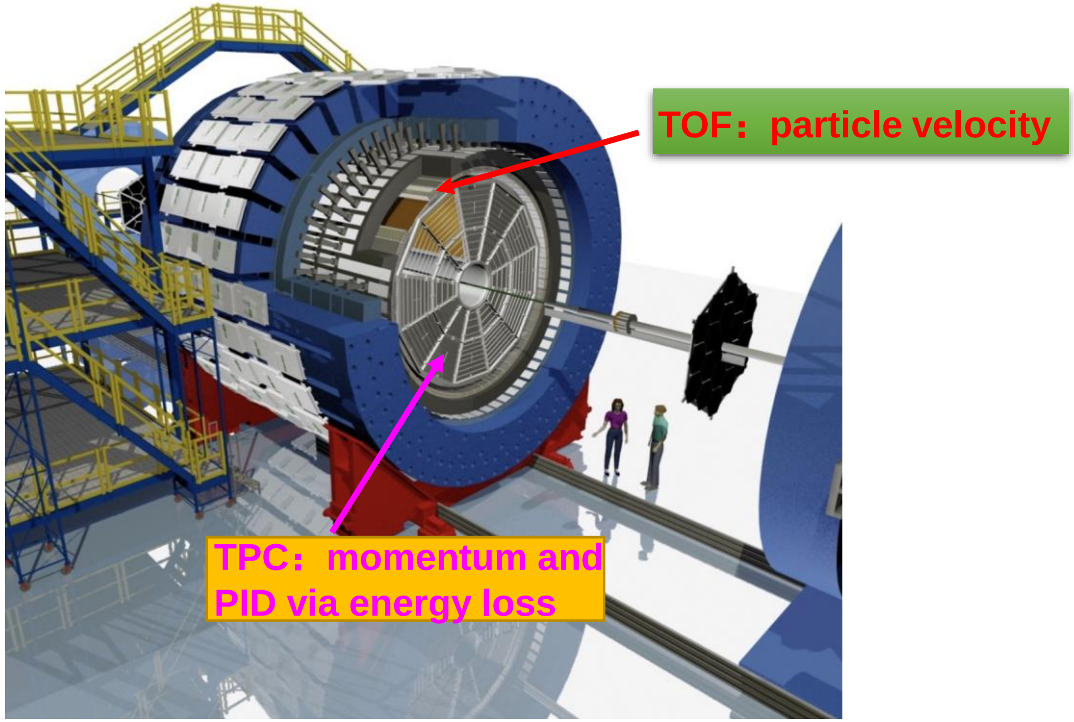
$\sqrt{\langle P_\perp^2 \rangle}$ (MeV/c)	UPC Au+Au	60-80% Au+Au
Measured	38.1 ± 0.9	50.9 ± 2.5
QED	37.6	48.5

- Leading order QED calculation of $\gamma\gamma \rightarrow e^+e^-$ describes both spectra ($\pm 1\sigma$)
- STAR observes $\mathbf{4.8\sigma}$ difference between UPC and 60-80% Au+Au collisions
- Proposed as a probe of trapped magnetic field or Coulomb scattering in QGP
- Di-electron measurement at the centrality of 80-100% can serve as a bridge between HIC and UPC $\gamma\gamma \rightarrow e^+e^-$ process

The Solenoid Tracker At RHIC (STAR)

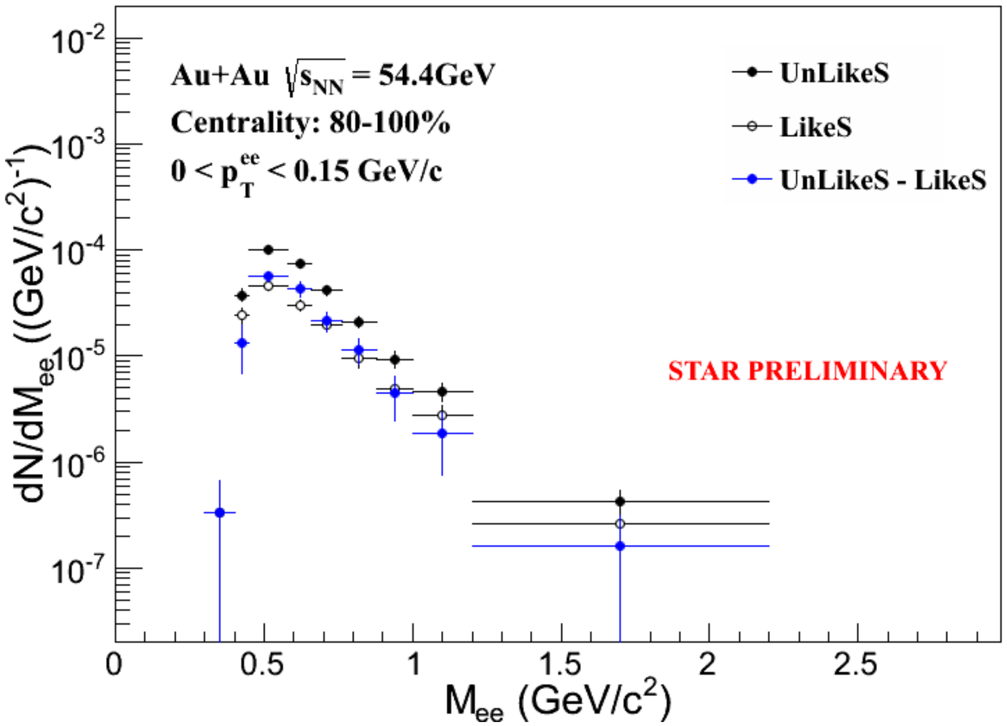


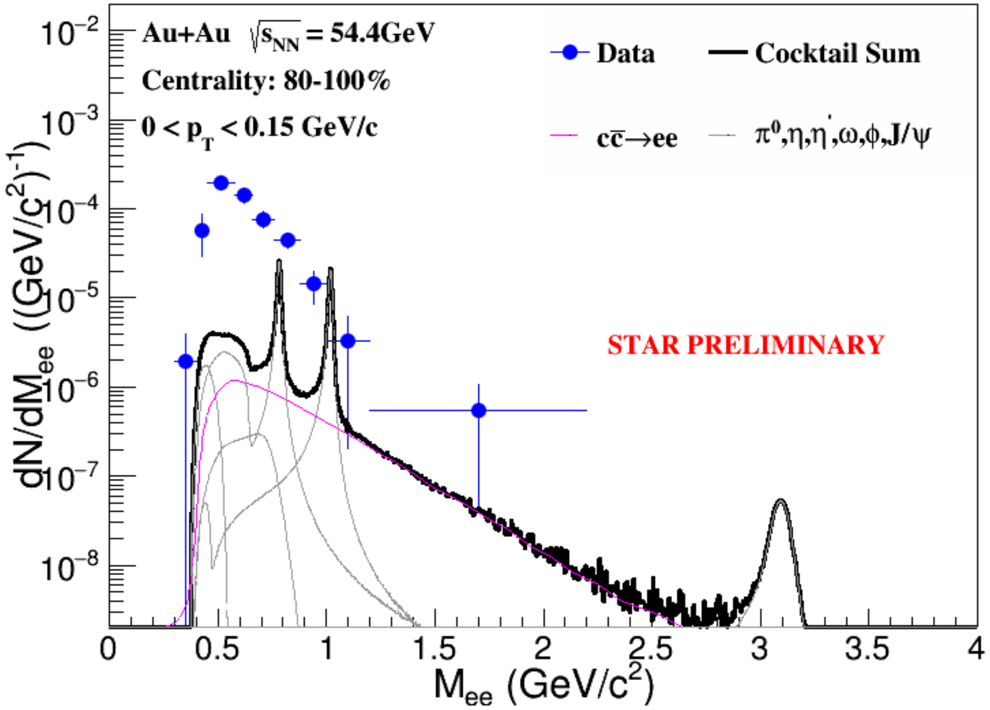




- Excellent electron identification capability with the information from TPC and TOF
- High electron purity (95% in $n\sigma_e$ non-overlapping area) sample with STAR PID

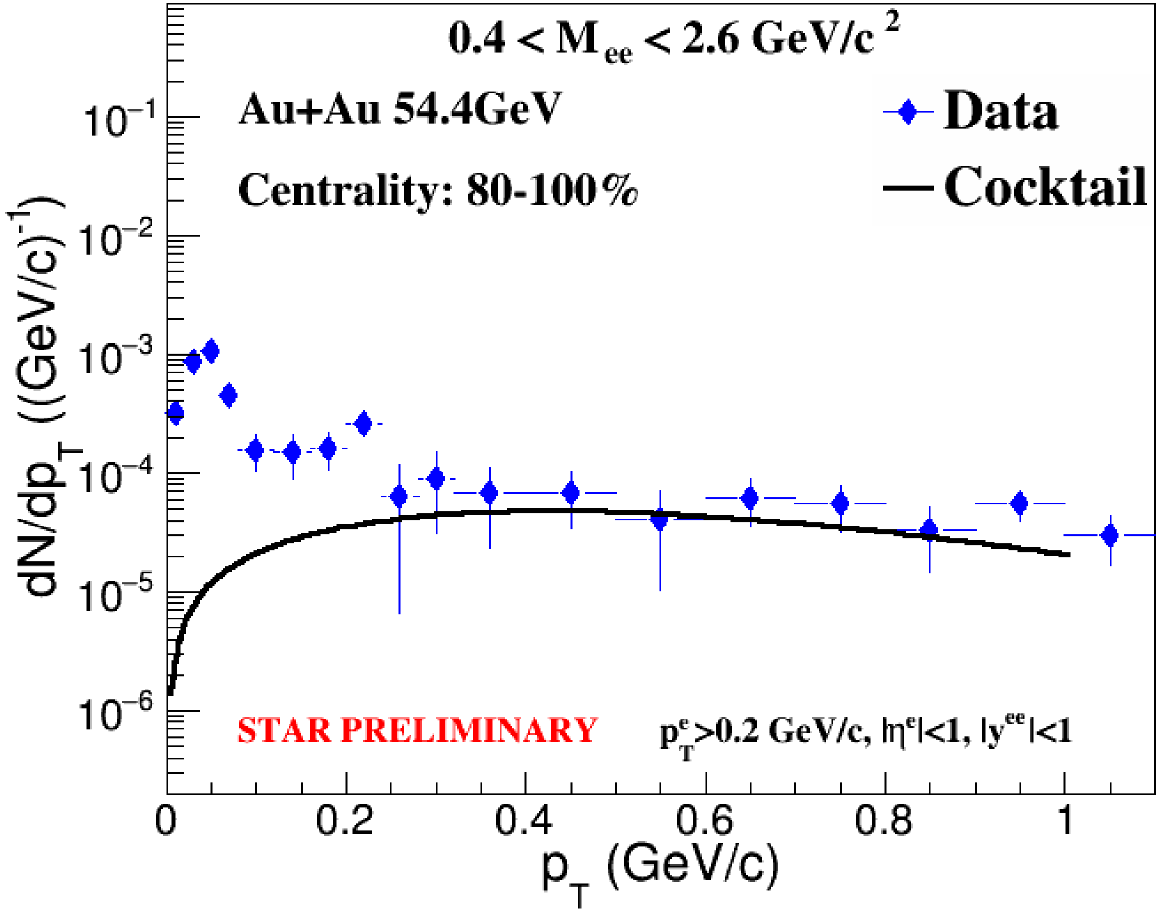
Mass Distribution in Low-p_T

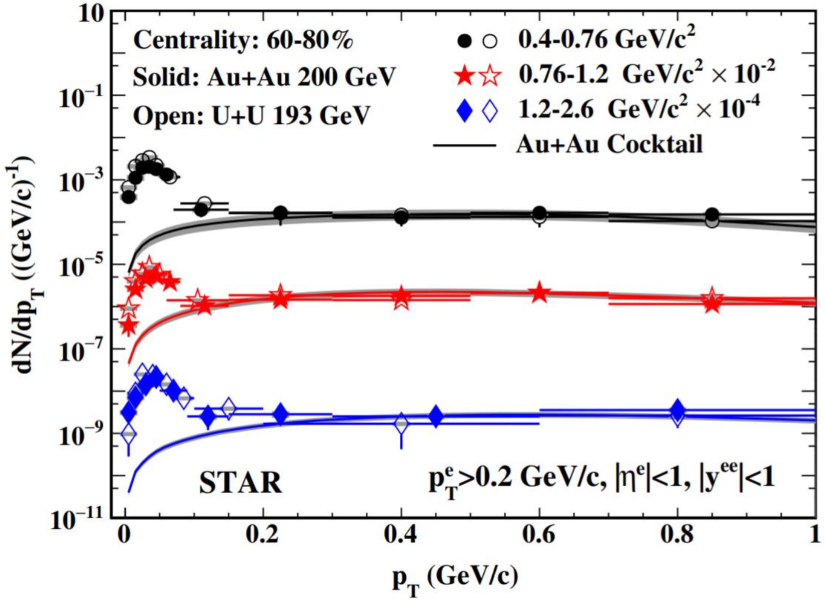




- First di-electron measurement at the centrality of 80-100% at STAR
- Significant enhanced di-electron yield compared to hadronic cocktail
- No vector meson is observed $\longrightarrow$ forbidden for real photons with helicity $\pm$ 1

p_T Distribution





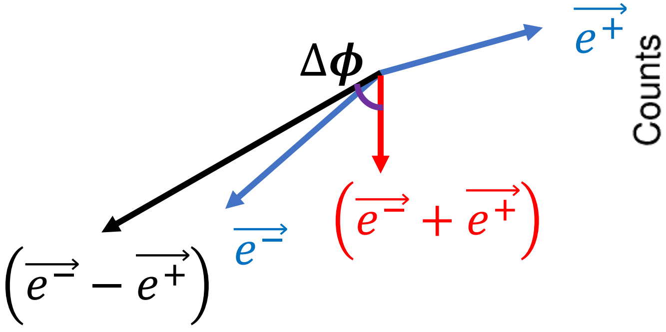
STAR, PRL 121,132301 (2018)

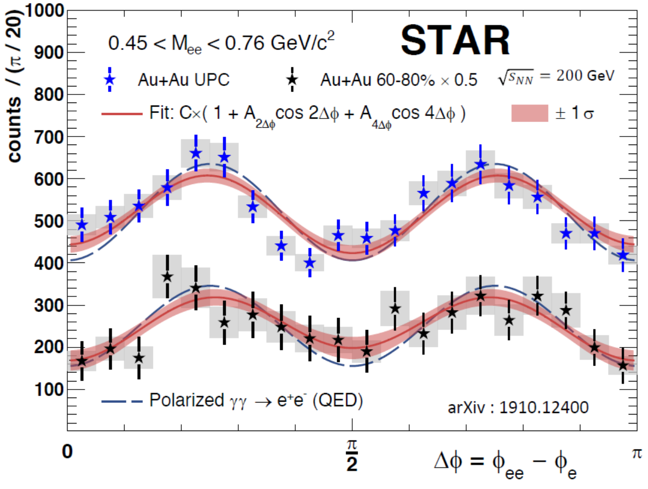
- Observed excess is concentrated below 0.2 GeV/c in 80-100% compared to the cocktail
- Similar p_T distribution of e^+e^- pairs to those of Au+Au at $\sqrt{s_{NN}} = 200$ GeV/c 60-80% centrality
  - ✓ Indication of $\gamma\gamma \rightarrow e^+e^-$ production

$\cos(4\Delta\phi)$ Modulations

- Lorentz contraction of EM fields → Quasi-real photons should be linearly polarized ($\vec{E} \perp \vec{B} \perp \vec{k}$)
- Recently realized, there are $\cos(4\Delta\phi)$ modulations in polarized $\gamma\gamma \rightarrow e^+e^-$ [1]

[1] C. Li, J. Zhou, Y.-j. Zhou, Phys. Lett. B 795, 576 (2019)





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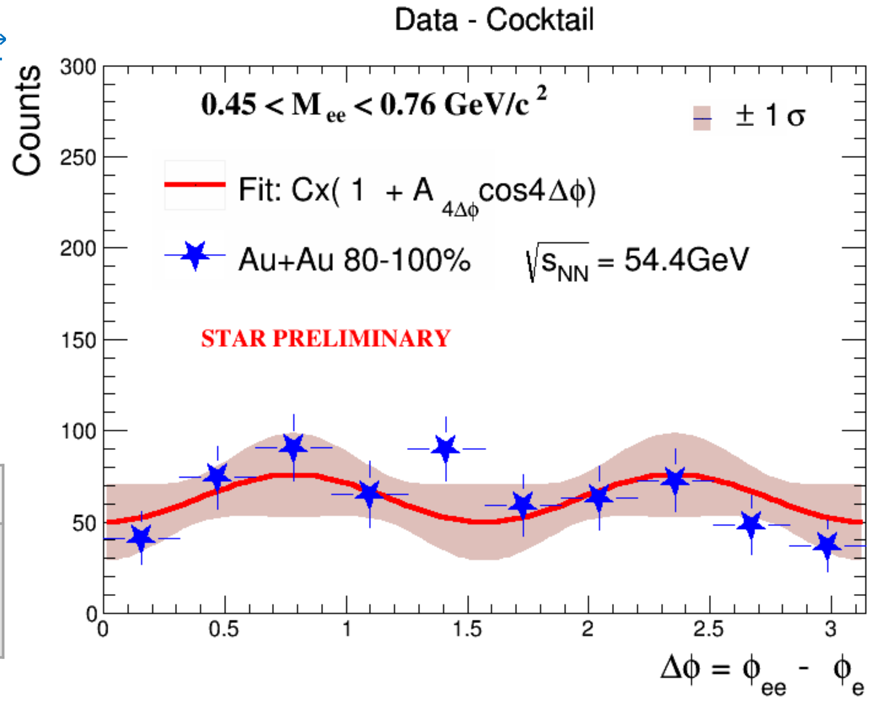
Quantity	Value	χ^2/ndf
C	62.5 ± 5.3	8.9/8
-$A_{4\Delta\phi}$(%)	20.8 ± 11.8	



- Indication of $\cos(4\Delta\phi)$ modulations in linearly polarized $\gamma\gamma \rightarrow e^+e^-$ process with a significance of 2σ (systematics needs to be studied)
  - ✓ More statistics is needed to confirm the trend

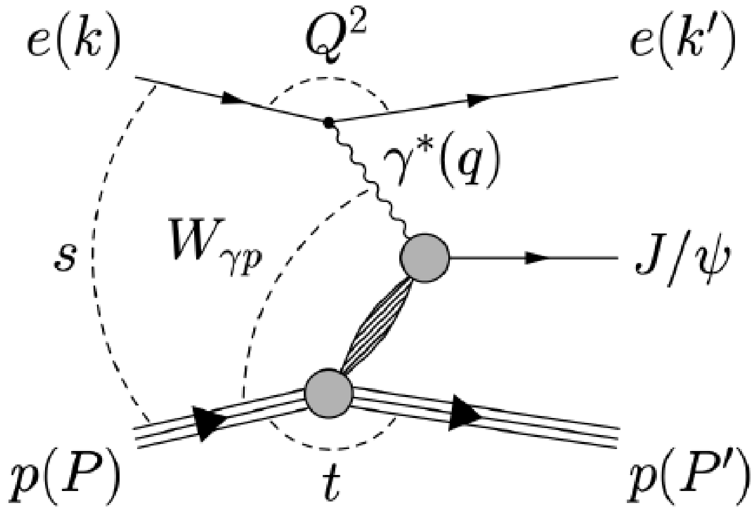
Photoproduction of J/ψ

- Cross section of J/ψ meson in photoproduction, with a **hard scale** imposed by its mass, is sensitive to the gluon density at the LO

$$\frac{d\sigma}{dt}(\gamma^* p \to \psi p) = \frac{\Gamma_{ee} M_\psi^3 \pi^3}{48\alpha} \frac{\alpha_s(\bar{Q}^2)^2}{\bar{Q}^8} \boxed{[xg(x,\bar{Q}^2)]^2} \left(1 + \frac{Q^2}{M_\psi^2}\right)$$

- It's a powerful probe to study the gluon density and its distributions inside nucleons and nucleus, physics applications:
  - ✓ Gluon spatial distributions
  - ✓ Gluon shadowing effects
  - ✓ …

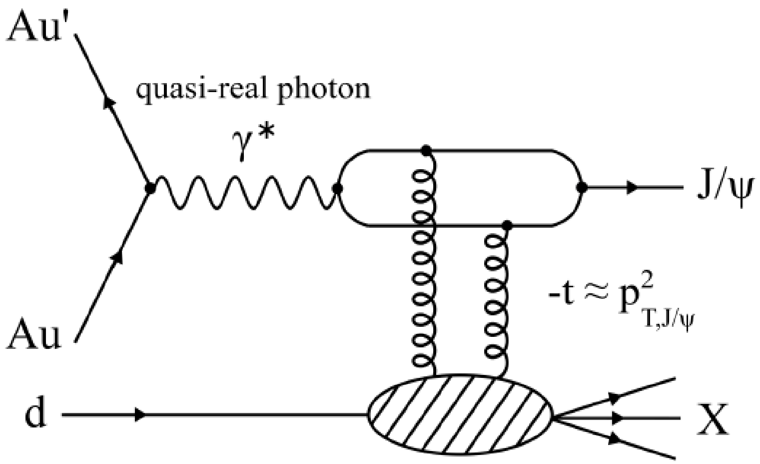
e+p=e'+J/psi+p'

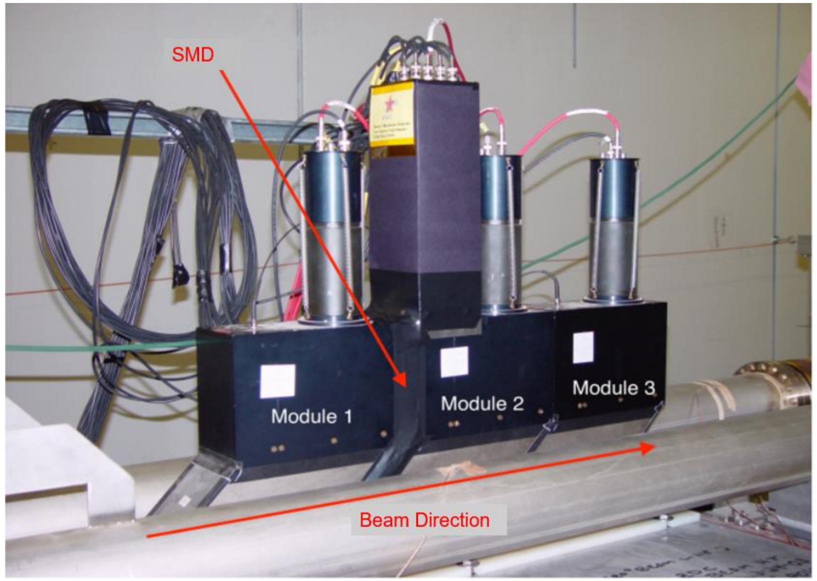


Photoproduction of J/ψ

- $J/\psi \rightarrow \mathrm{e}^{+}e^{-}$ pair are reconstructed using TPC for $|y| < 1.0$
- Zero Degree Calorimeter (ZDC) was used to detect neutrons from deuteron breakup, providing additional info about the physics process

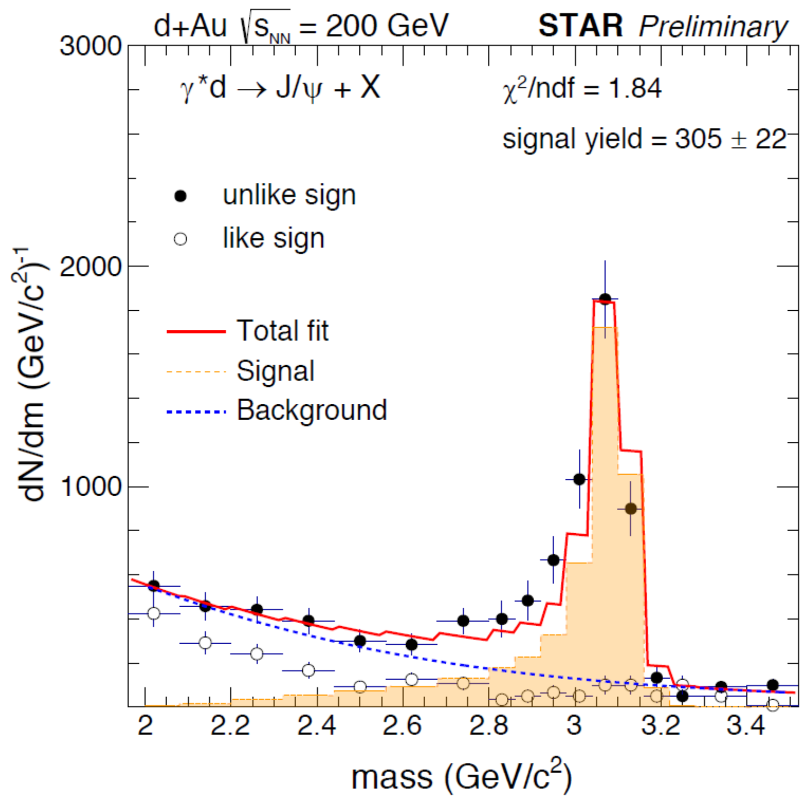
- Au + d → J/ψ + Au' +X
  - ✓ X = d' (coherent) or X = d', d' → p' + n' (coherent + Coulomb)
  - ✓ X = p' + n' (elastic nucleon)
  - ✓ X = p' + X or n' + X (nucleon dissoc.)

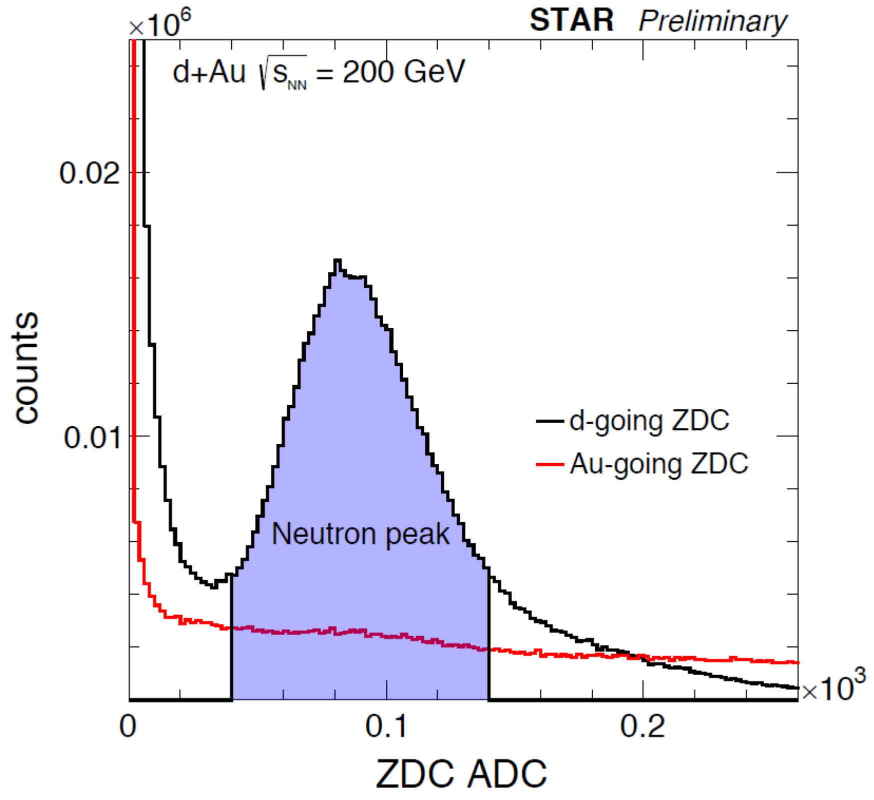




ZDC modules installed on RHIC-STAR experiment

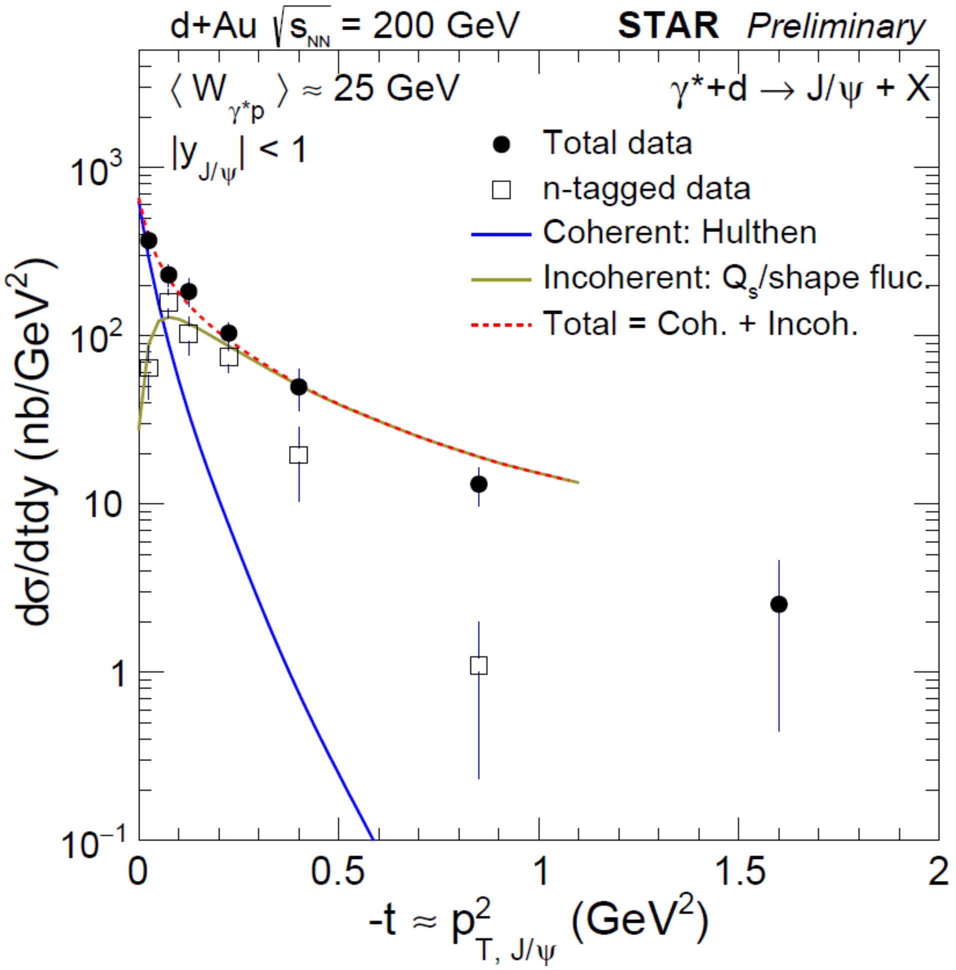
Photoproduction of J/ψ





- Clear signal, roughly 300 J/ψ are reconstructed
- The UPC trigger used in analysis is unbiased with respect to the ZDC
- Au-going side has no neutron, stay intact!

Photoproduction of J/ψ

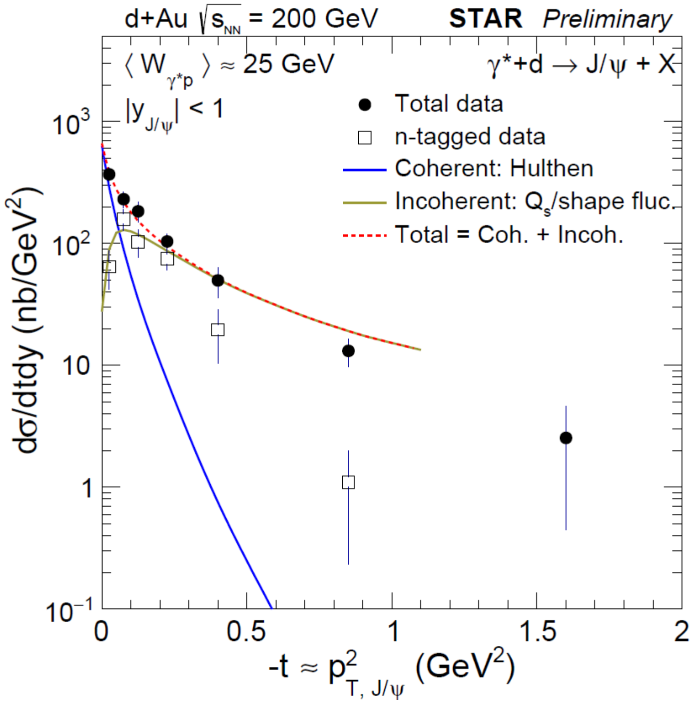


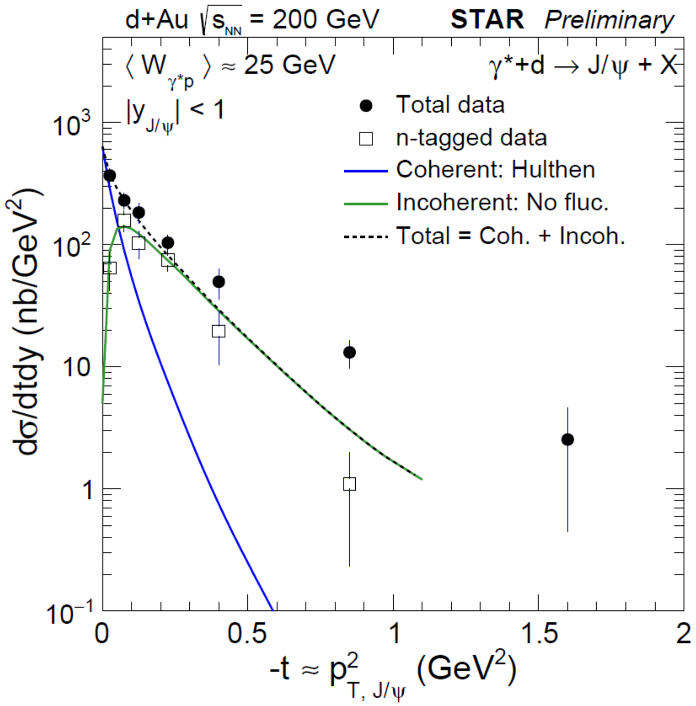
Coherent, Incoherent calculated by H. Mantysaari and B. Schenke, (https://arxiv.org/pdf/1910.03297.pdf)

- Total data – no selections on final-state of the deuteron breakups
- n-tagged data = total data $\oplus$ requirement of neutron at d-going ZDC
- The data is at $X_P \sim 0.01$ at STAR
  - X_P : longitudinal momentum fraction of the proton carried by the color-neutral "pomeron"

Photoproduction of J/ψ

With fluctuations





Coherent, Incoherent calculated by H. Mantysaari and B. Schenke, (https://arxiv.org/pdf/1910.03297.pdf)

Without fluctuations

- The data, despite large uncertainty,
  - Coherent: Hulthen and AV18 describes the data equally well. Expected to be dominant at low t
  - Incoherent: Qs/Shape fluctuation is found to describe the data better.
- ZDC n-tagged data: incoherent only at small t
- Separate coherent and incoherent process is extremely interesting but challenging, will be significantly improved at the EIC

Summary

- First di-electron measurement at the centrality of 80-100% at $\sqrt{s_{\mathrm{NN}}} = 54.4$ GeV at STAR
  - ✓ Indication of $\gamma\gamma \to e^+e^-$process
- Indication of $\cos(4\Delta\phi)$ modulations in linearly polarized $\gamma\gamma \to e^+e^-$ process, but more precise measurement is needed to improve the significance
- First measurement of J/ψ meson in photoproduction off deuteron in UPC
  - ✓ Data is well described by theoretical calculations using Hulthen/AV18 wave function for the coherent contribution along with incoherent contributions calculated using Qs/shape fluctuations
- Data with ZDC neutron tagging indicates incoherent contribution at low t

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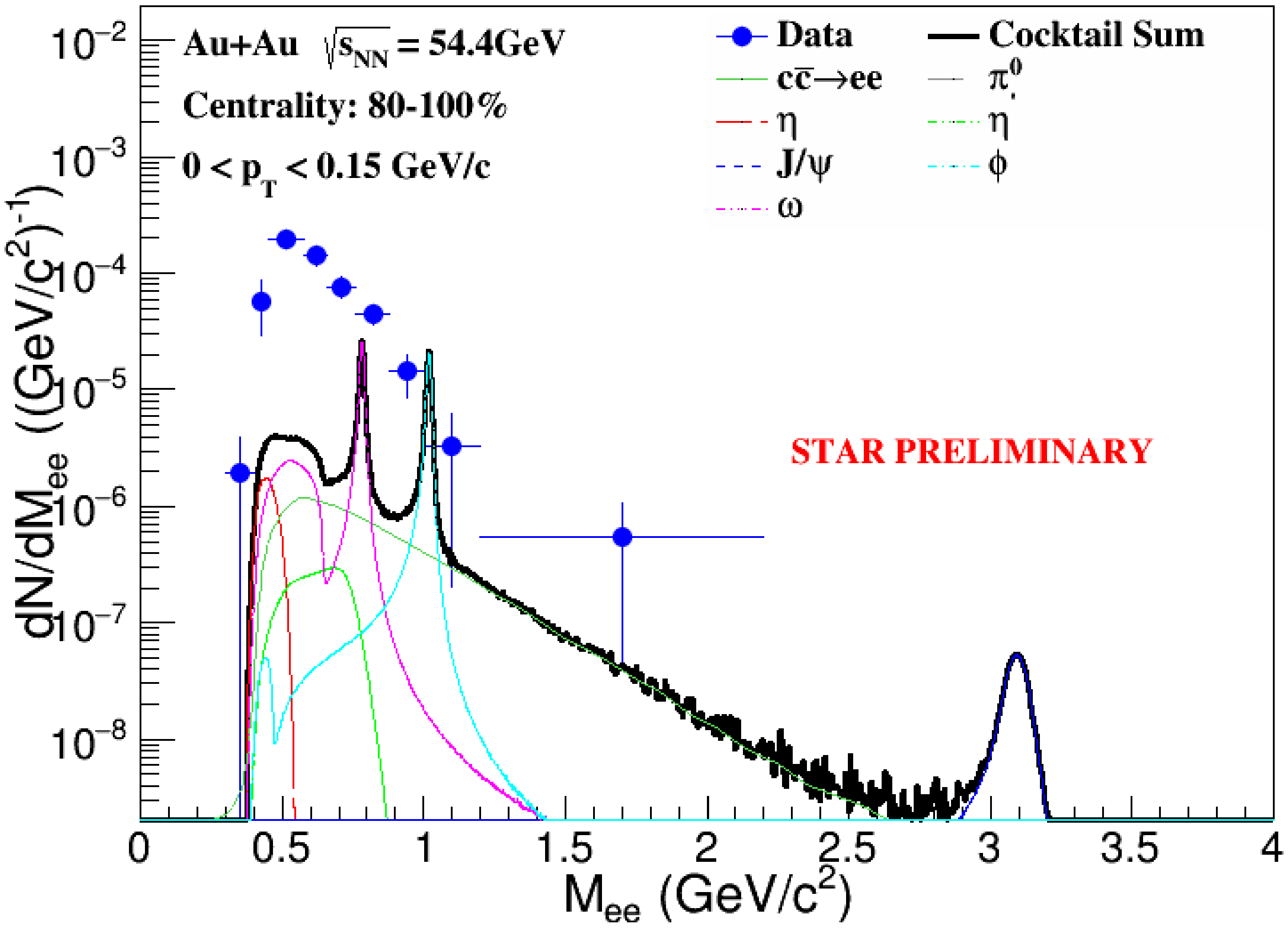
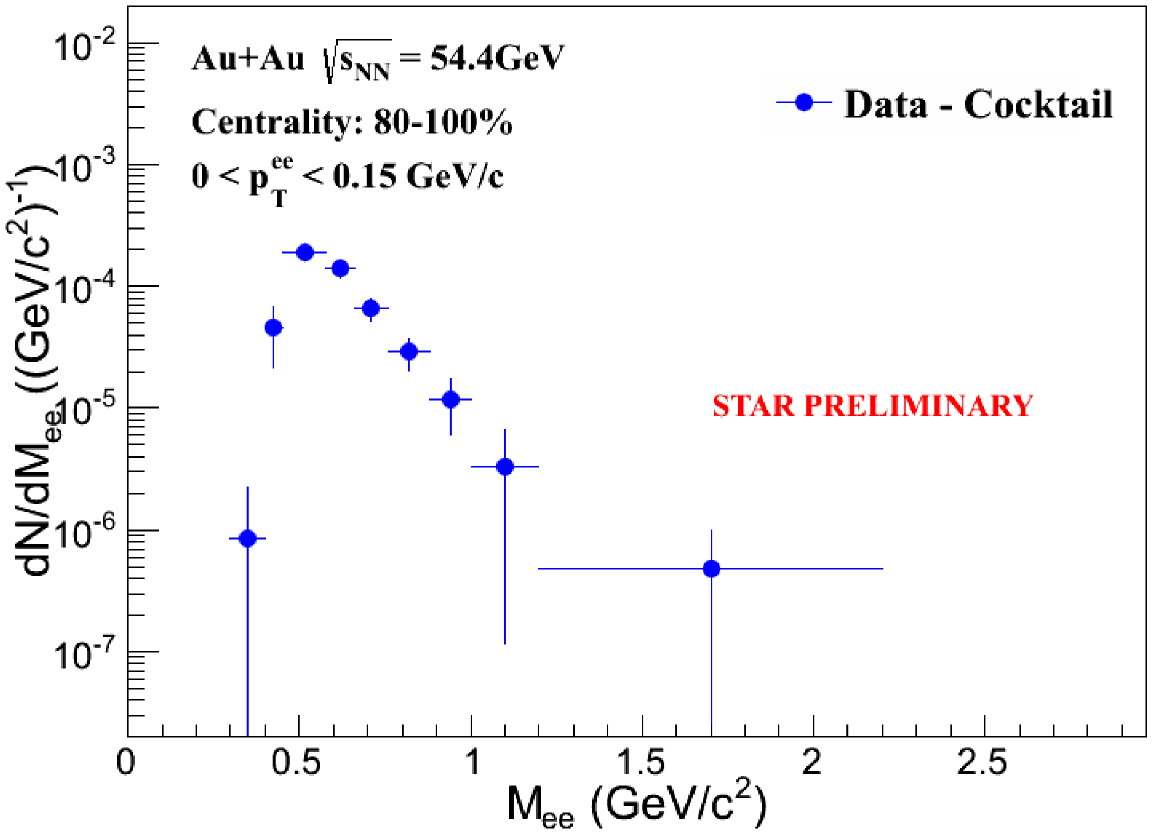
Thanks for Your Attention

Backup



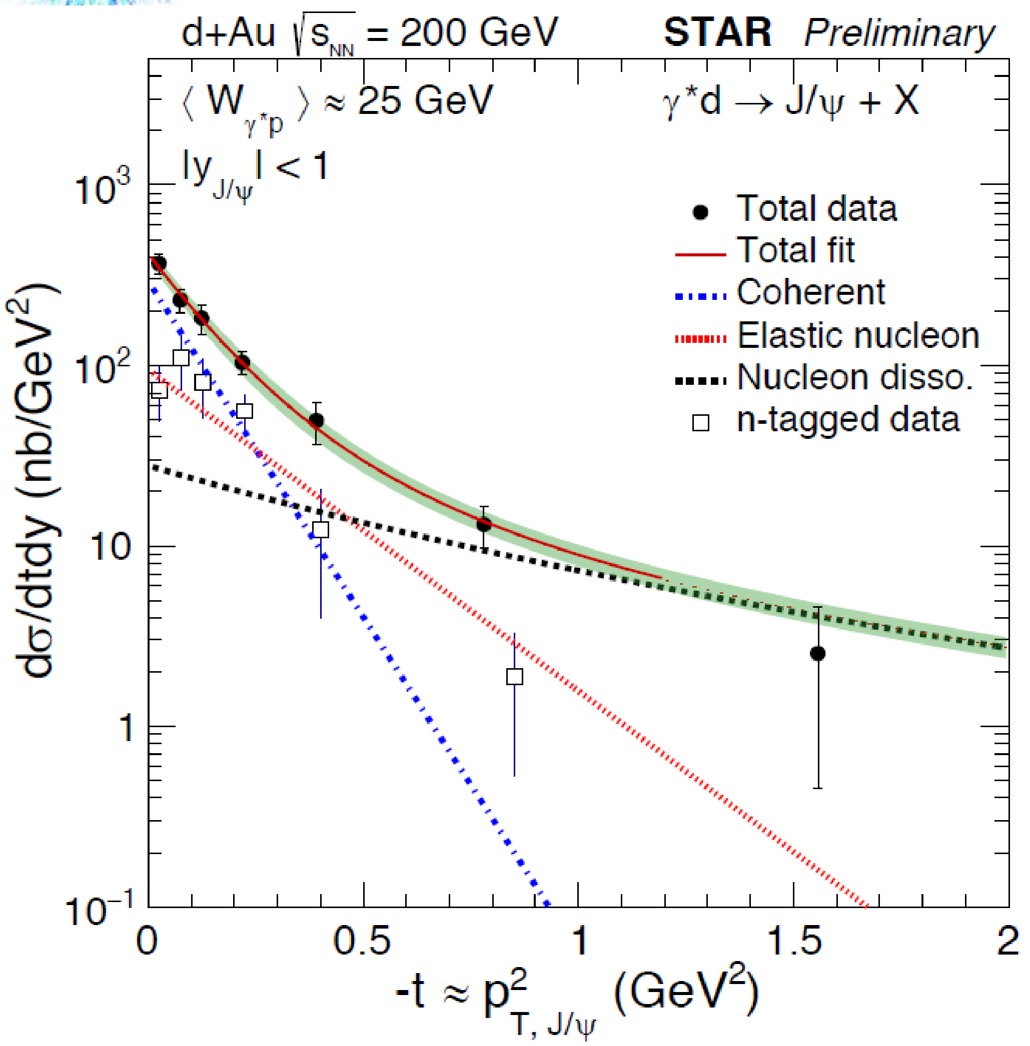
Au+Au $\sqrt{s_{NN}}$ = 54.4GeV
Centrality: 80-100%
0 < p_T < 0.15 GeV/c
Data
Cocktail Sum
$c\bar{c} \rightarrow ee$
π^0
η
η
J/ψ
φ
ω
STAR PRELIMINARY
dN/dM_{ee} $((GeV/c^2)^{-1})$
M_{ee} (GeV/c^2)

Mass Distribution in Low-p_T



- A smooth e^+e^- invariant mass distribution
- $\gamma\gamma \rightarrow e^+e^-$: no vector meson production $\Longrightarrow$ forbidden for real photons with helicity ±1(i.e. 0 is forbidden)

Photoproduction of J/ψ



Only statistical uncertainty is shown, green band is 1σ fit err

- Total data – no selections on final-state of the deuteron breakups, only J/ψ at mid-rapidity with no other activity
- n-tagged data = total data + requirement of neutron at d-going ZDC

- Total fit has three components:
  - ✓ Coherent contribution, assuming an exponential function
  - ✓ Elastic nucleon (H1 proton data as shape)
  - ✓ Nucleon dissociative (H1 proton data as shape)

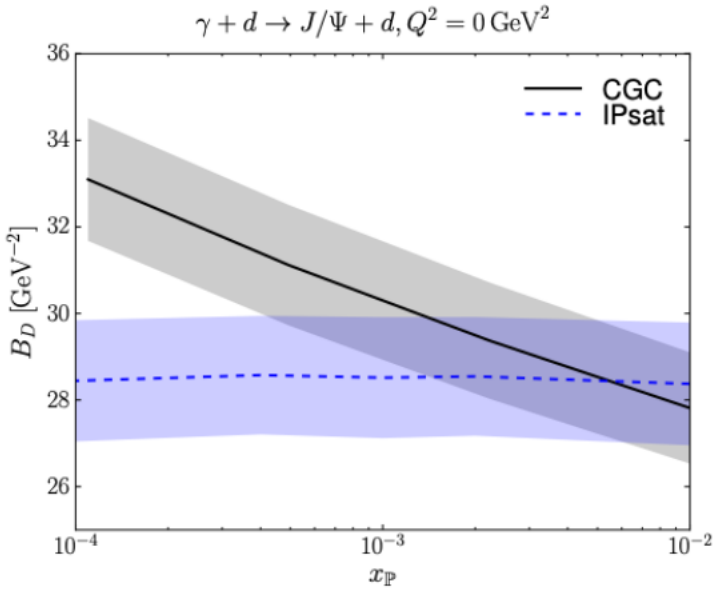
(**ref**. Eur.Phys.J.C73 (2013) 6, 2466)

What to look forward?

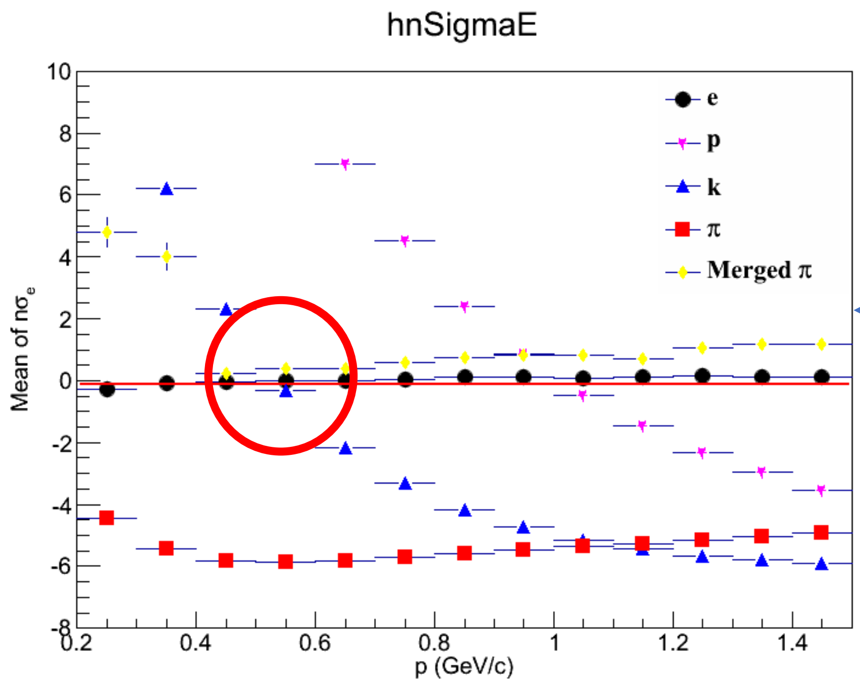
1. More statistics in this case *absolutely helps* (a lot), esp at low ***t***.

2. Higher energy || lower x || forward rapidity
→ sensitive to gluonic structure!

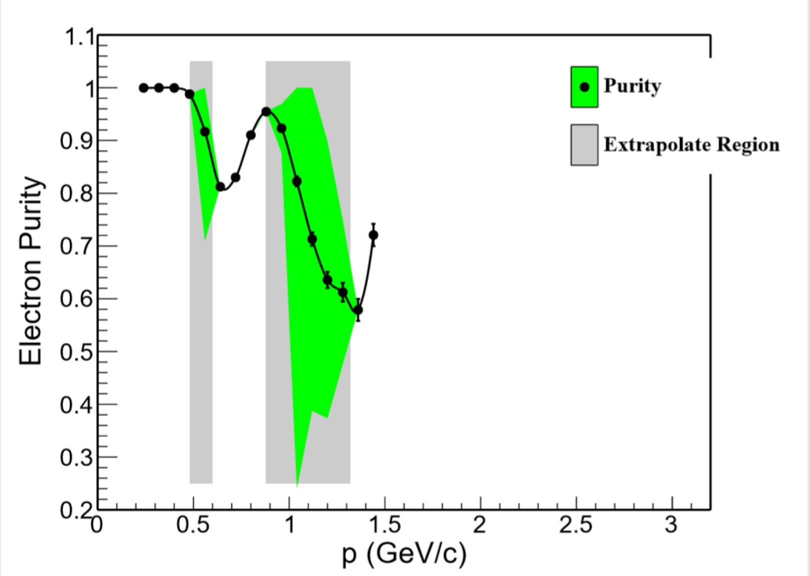
Coherent slope parameter



Low-x data should distinguish models!



- The left polt is, in every momentum bin, the pure hadron samples (π/K/p) mean $n\sigma_e$ distribution. We can found, for the electron mean $n\sigma_e$, it have overlap region with other hadron samples .for example, red circle is the electron and kaon $n\sigma_e$ overlap range.



◆In $n\sigma_e$ overlap range, it is hard to identify electron. So in this range, the electron purity is lower than non-overlap range.