J/ψ photoproduction in ultra-peripheral collisions

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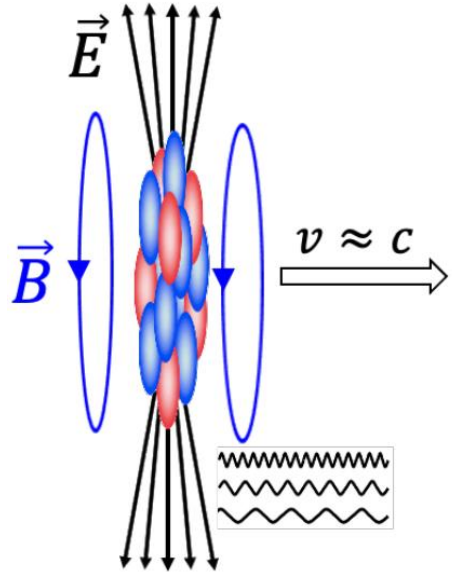
Outline

- UPC introduction : γ + A collider
- Motivation : Gluon structure with coherent J/ψ
  - Cross-section of coherent J/ψ in Au +Au collision at STAR.
  - Photon energy ambiguity.
- Data processing
  - Signal reconstruction with different rapidity and neutron multiplicity
  - Efficiency extraction.
- Summary



Equivalent Photon Approximation

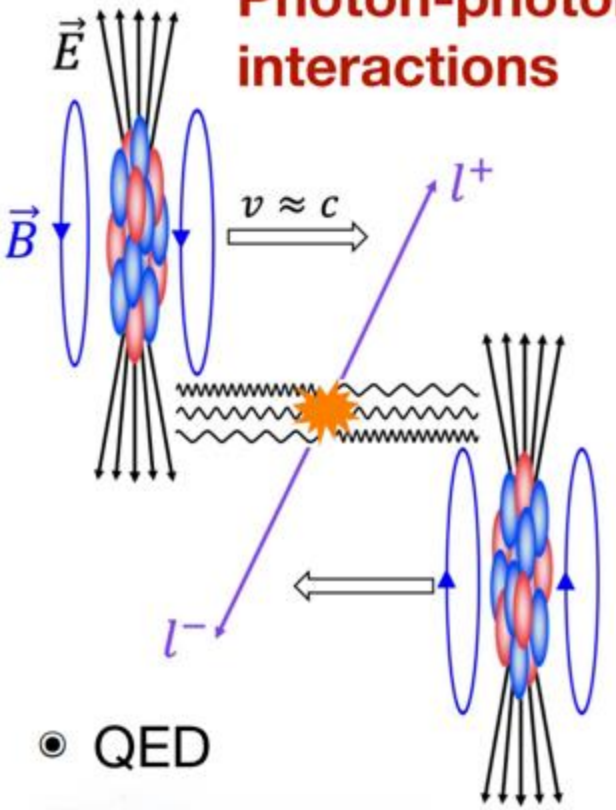
- Proposed in 1924 by Fermi (1901-1954)
  - On the theory of collisions between atoms and elastically charged particles
- Extended EPA method to relativistic particles by Williams&Weiszsacker
- Photon Flux ∝ Z^2

Photon kinematics

maximum energy $E_{\gamma,max}$~$\gamma(\hbar c/R)$	**80 GeV in Pb+Pb@LHC** **3 GeV in Au+Au@RHIC**
typical p_T (& virtuality) p_{Tmax} ~ $\hbar c/R$	**O(30) MeV @ RHIC & LHC**
Coherent strengths (rates) scale as **Z^2**: nuclei >> protons	Flux of photons on other nucleus ~ **Z^2**, flux of photons on photons ~ **Z^4 (45M!)**

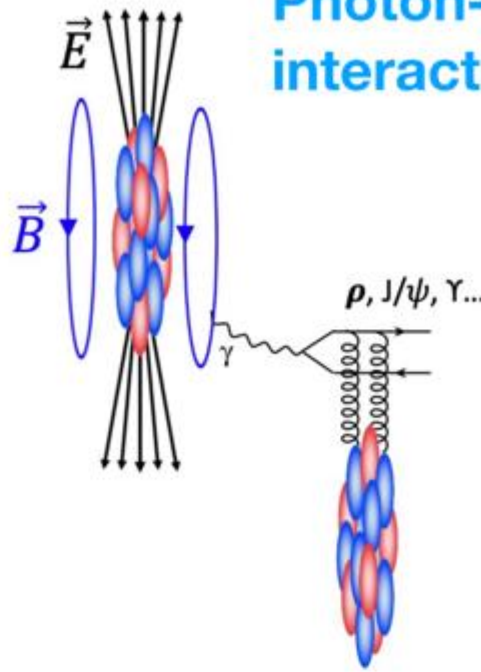
Photo-induced interaction

Photon-photon interactions



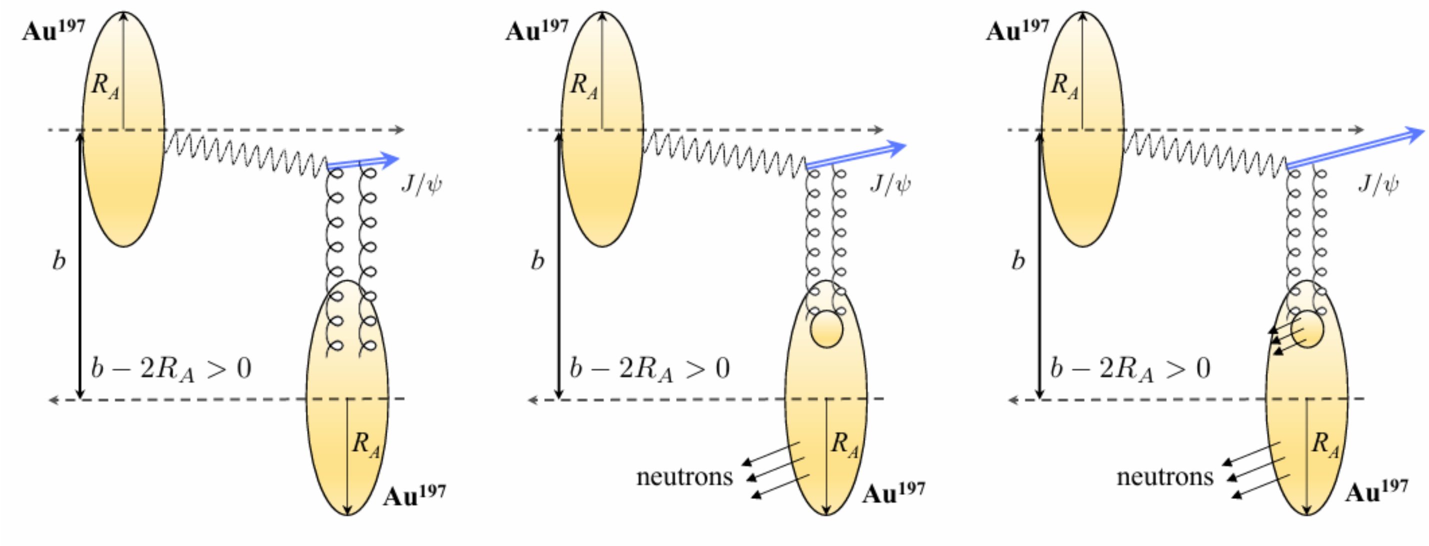
- QED

Photon-nuclear interactions



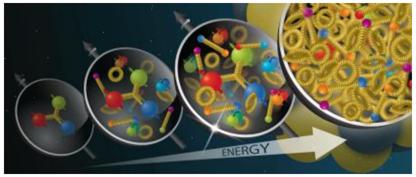
- Little "EIC"

A clean probe for gluon structure

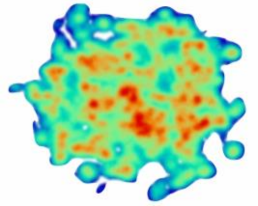


Coherent : nuclear keeps intact

Incoherent : nuclear breaks up

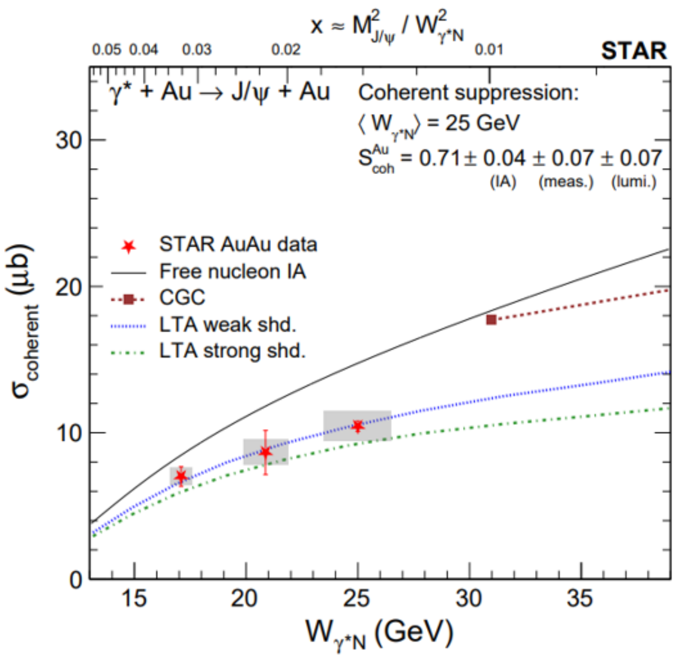


- Coherent: average gluon distribution in nucleus.
- Incoherent: sub-nucleon fluctuation.

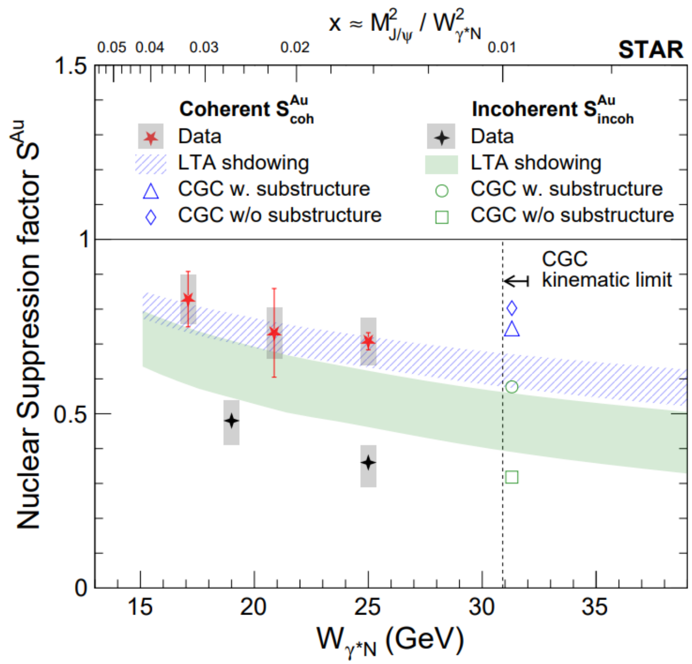


Motivation

M. I. Abdulhamid *et al.* (STAR Collaboration)
Phys. Rev. C **110**, 014911 – Published 31 July 2024



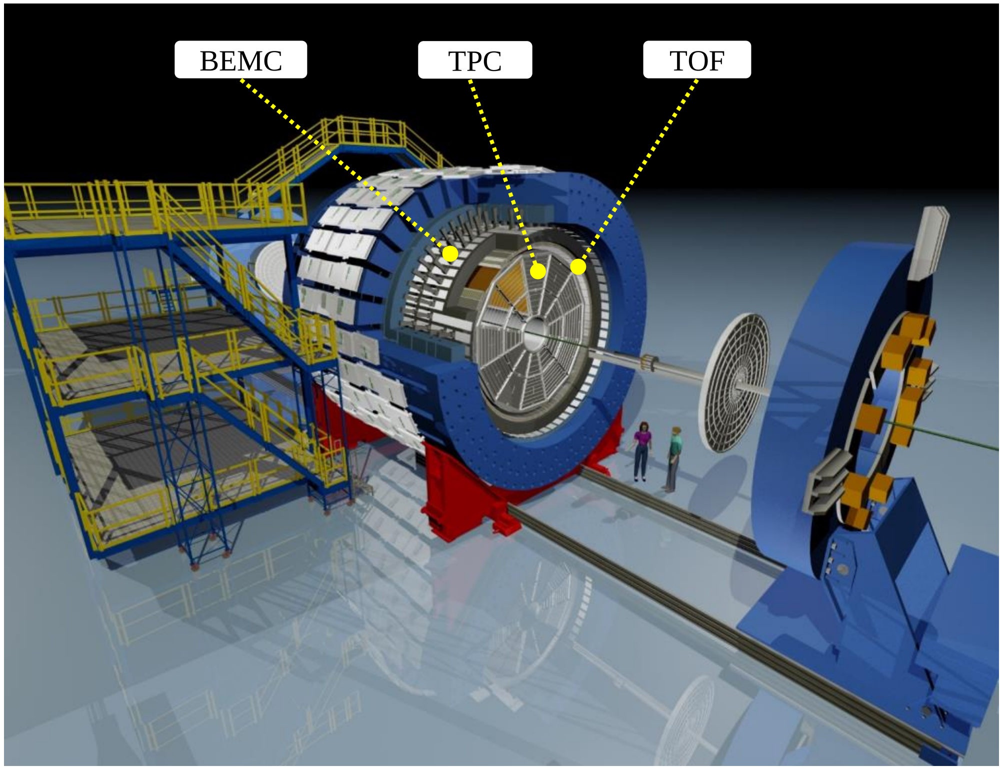
M. I. Abdulhamid *et al.* (STAR Collaboration)
Phys. Rev. Lett. **133**, 052301 – Published 31 July 2024



Advantage of the isobaric($^{96}_{44}Ru$, $^{96}_{40}Zr$)collision: smaller collision system.

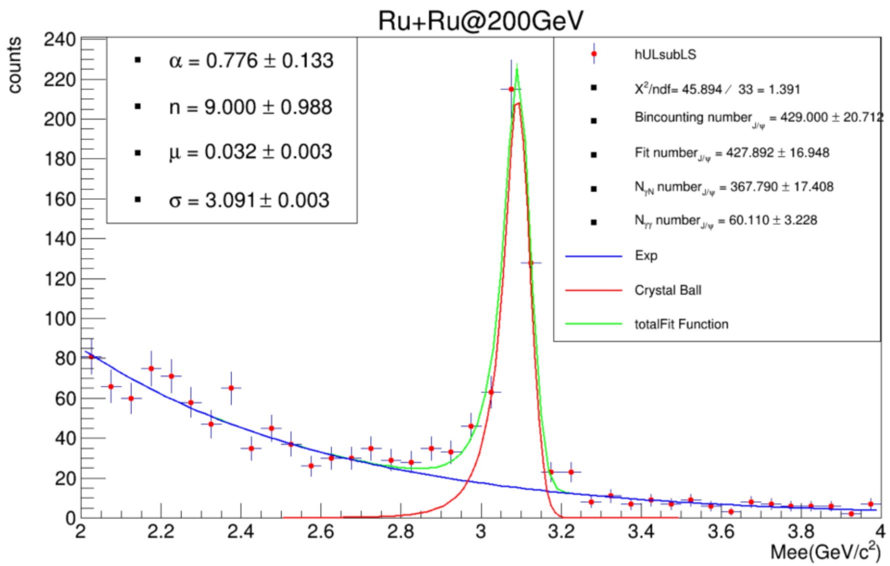
- Coherent J/ψ production measurement in UPC isobaric collisions will provide a direct way to study gluon structure dependence of collision system.

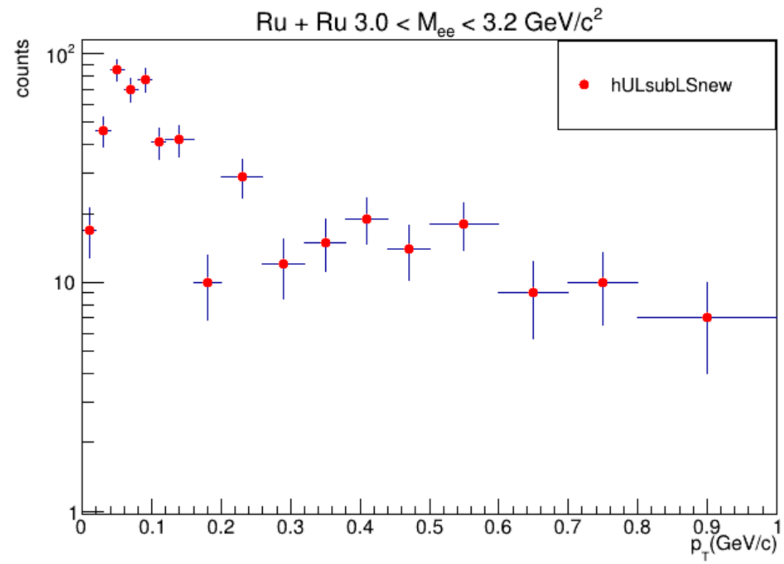
STAR detector



- **Time Projection Chamber**
  - Tracking reconstruction
  - Momentum and energy loss
  - Acceptance: $|\eta| < 1.5; 0 \leq \varphi < 2\pi$
- **Time Of Flight Detector**
  - Time of flight
  - Particle identification
  - Acceptance: $|\eta| < 1; 0 \leq \varphi < 2\pi$
- **Barrel ElectroMagnetic Calorimeter**
  - $e^{\pm}$ trigger
  - Particle identification with deposited energy
  - Acceptance: $|\eta| < 1; 0 \leq \varphi < 2\pi$

Signal extraction @ RuRu





Fit function:

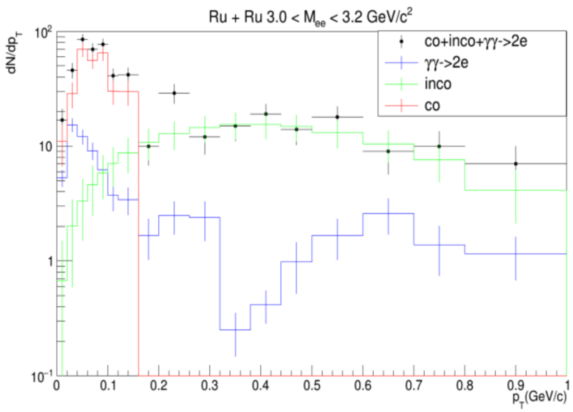
Crystal ball (signal) + Exponential (Background)

Include: Coherent + Incoherent + $QED\gamma\gamma \rightarrow e^{+}e^{-}$ + $\psi(2S)$feeddown

What we need!

Not considered in the report

p_T spectrum with different rapidity

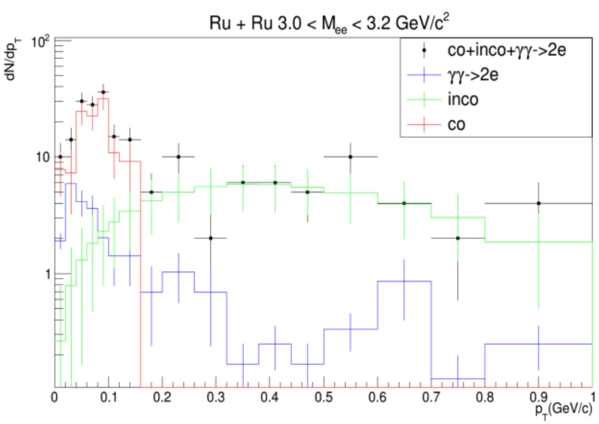


$|y| < 1$

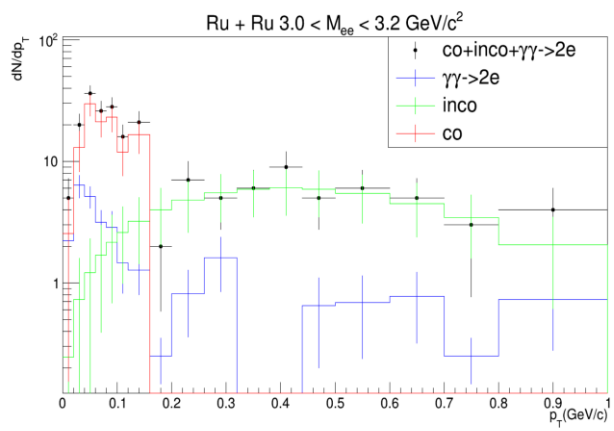
$\gamma\gamma$: Obtained through the template of the background mass region.

Inco: $\frac{d\sigma}{dp_T} = c_1 * p_T\left(1 + \left(\frac{c_2}{n}\right)\left|p_T^2\right|\right)^{-n}$ Eur. Phys. J. C (2013) 73:2466 DOI 10.1140/epjc/s10052-013-2466-y

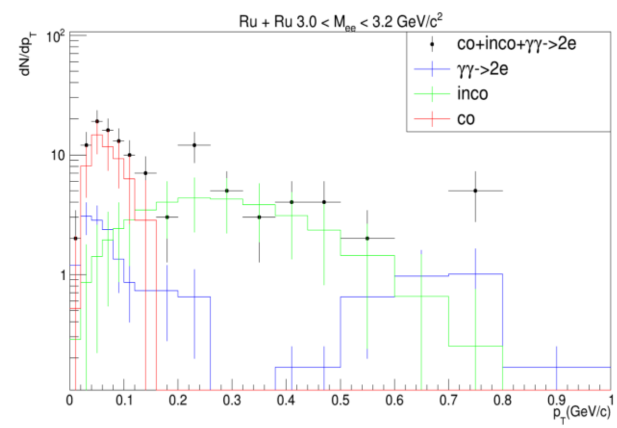
Coh: Obtained by subtracting the $\gamma\gamma$ and Inco.



$0 \le |y| < 0.2$



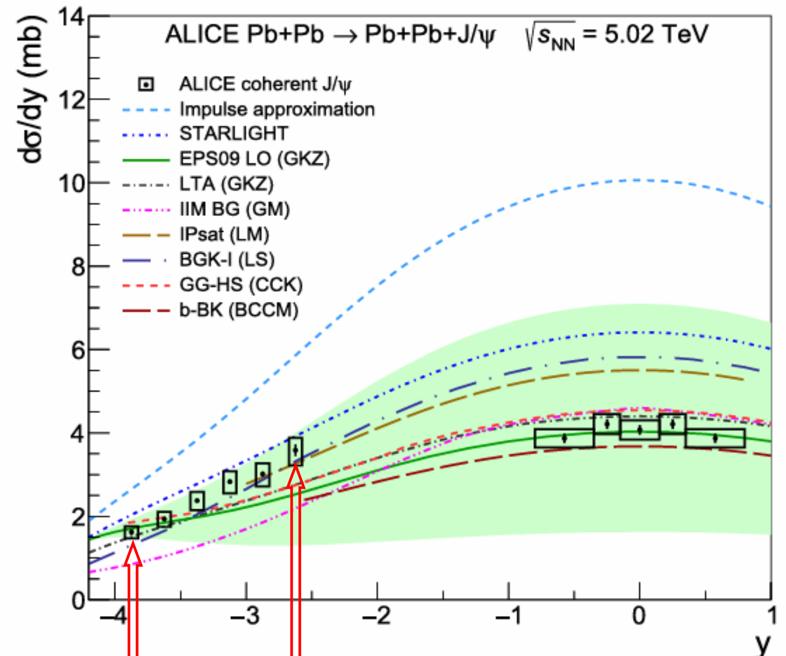
$0.2 \le |y| < 0.5$



$0.5 \le |y| < 1.0$

"Photon energy ambiguity" in AA

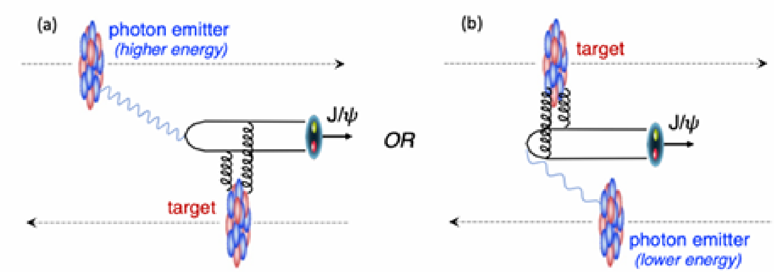
ALICE, PLB 798 (2019) 134926
ALICE, EPJC 81 (2021) 712



~60% large x

~95% large x

- Two-way ambiguity in A+A UPC



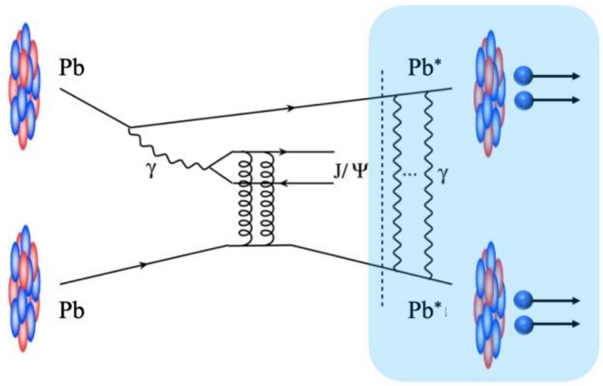
$$x = \frac{M_{J/\psi}}{2E_{beam}} e^{-y} \qquad x = \frac{M_{J/\psi}}{2E_{beam}} e^{+y}$$

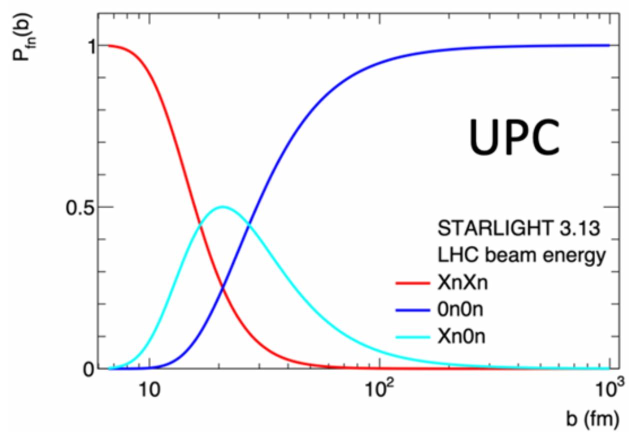
$$\frac{d\sigma_{AA \to AA' J/\psi}}{dy} = N_{\gamma/A}(\omega_1) \cdot \sigma_{\gamma A \to J/\psi A'(\omega_1)} + N_{\gamma/A}(\omega_2) \cdot \sigma_{\gamma A \to J/\psi A'(\omega_2)}$$

➢ obtain the proportion of the J/ψ cross-section produced by high-momentum photons and low-momentum gluons (or vice versa).

How to disentangle small x and large x

Another process





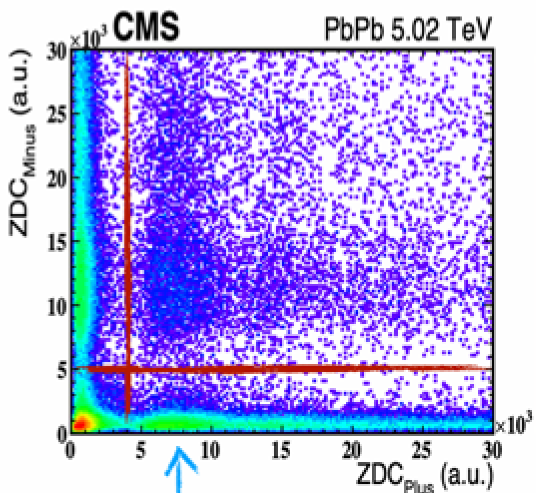
$$N(k) = \int d^2N(k,,b)P_{0had}(b)P_1(b)P_2(b)\,,P_i(b) \propto 1/b^2$$

- Nuclei may exchange soft photon(s) caused the nuclear dissociation. It's occurrence probability is related to the distance from the nucleus.
- Neutron multiplicity(N) can help to describe the impact parameter(b).
- The photon flux is also related to the distance from the nucleus

A solution to the "Photon energy ambiguity"

Guzey *et al.*, EPJC 74 (2014) 2942

CMS, PRL 127 (2021) 122001



Single neutron peak

Experimental measurements

Photon flux from theory

$$\frac{d\sigma^{0n0n}_{AA\to AA'J/\psi}}{dy} = N^{0n0n}_{\gamma/A}(\omega_1)\cdot\sigma_{\gamma A\to J/\psi A'(\omega_1)} + N^{0n0n}_{\gamma/A}(\omega_2)\cdot\sigma_{\gamma A\to J/\psi A'(\omega_2)}$$

$$\frac{d\sigma^{0nXn}_{AA\to AA'J/\psi}}{dy} = N^{0nXn}_{\gamma/A}(\omega_1)\cdot\sigma_{\gamma A\to J/\psi A'(\omega_1)} + N^{0nXn}_{\gamma/A}(\omega_2)\cdot\sigma_{\gamma A\to J/\psi A'(\omega_2)}$$

$$\frac{d\sigma^{XnXn}_{AA\to AA'J/\psi}}{dy} = N^{XnXn}_{\gamma/A}(\omega_1)\cdot\sigma_{\gamma A\to J/\psi A'(\omega_1)} + N^{XnXn}_{\gamma/A}(\omega_2)\cdot\sigma_{\gamma A\to J/\psi A'(\omega_2)}$$

What we need!

- Measuring the cross-section with different neutron multiplicity(0N0N,0NXN, XNXN) can help to solve this question.

$\frac{d\sigma}{dy}$ with different neutron multiplicity @AuAu

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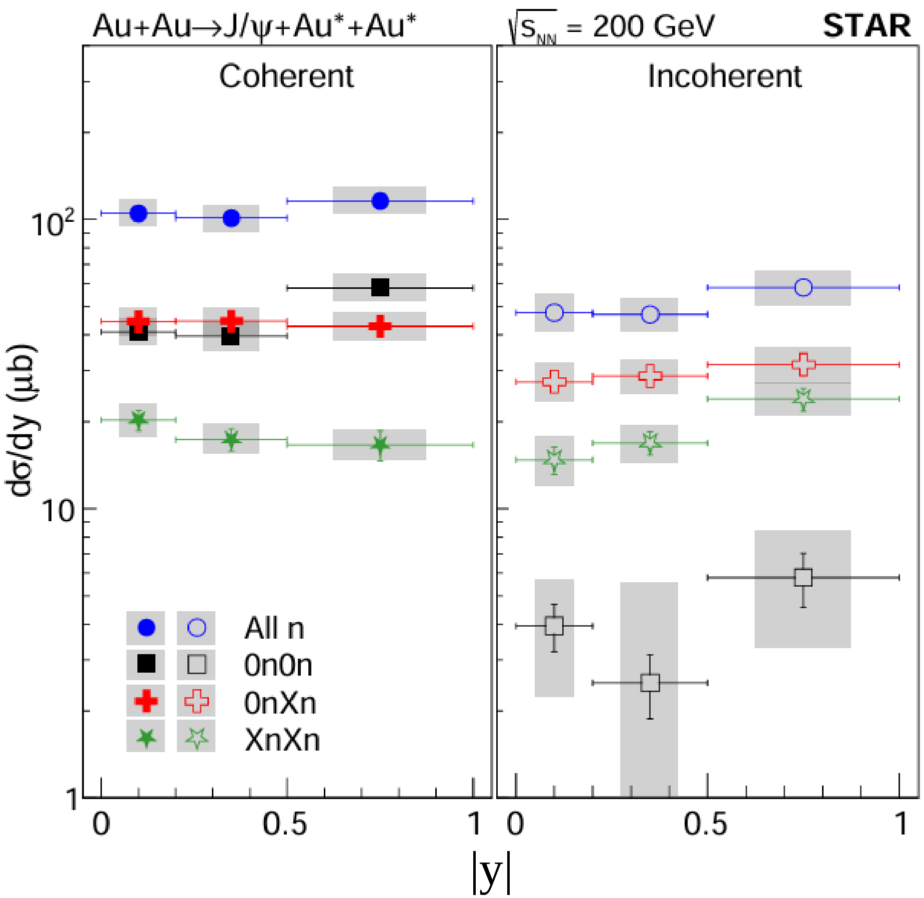
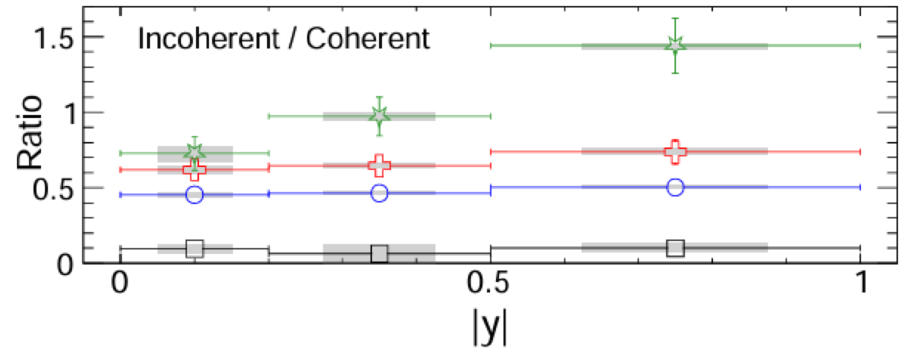
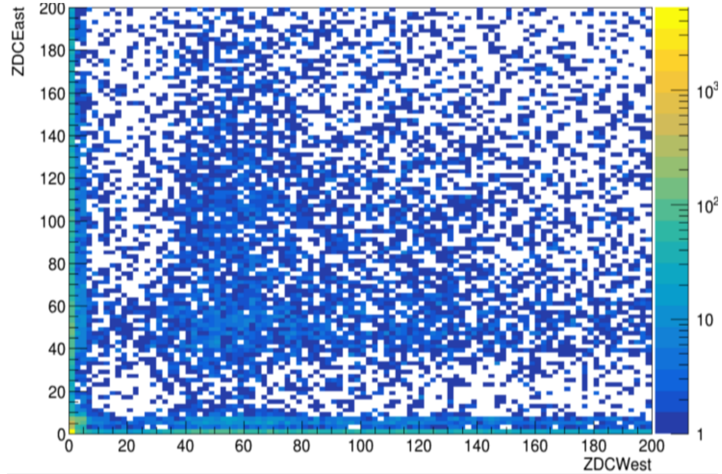
Phys. Rev. Lett. **133**, 052301 – Published 31 July 2024

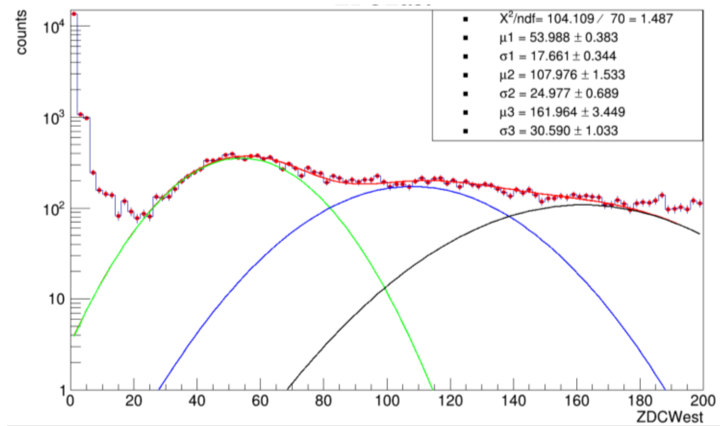




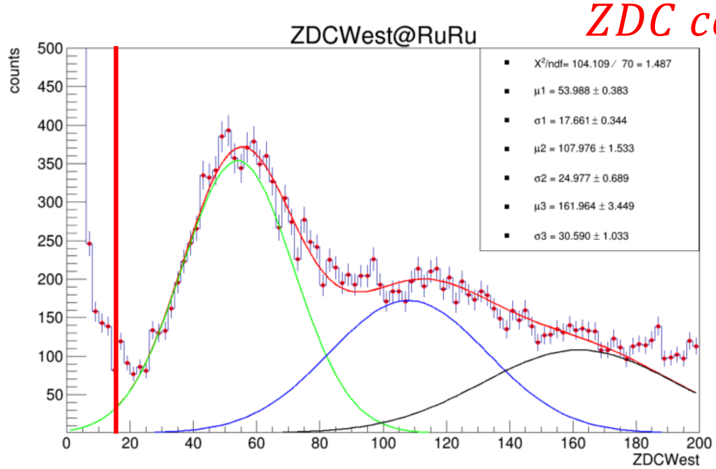
- Cross-sections as function as rapidity with different neutron multiplicity and the ratio of incoherent compared to coherent in Au + Au collision was measured to help solve the “Photon energy ambiguity”.

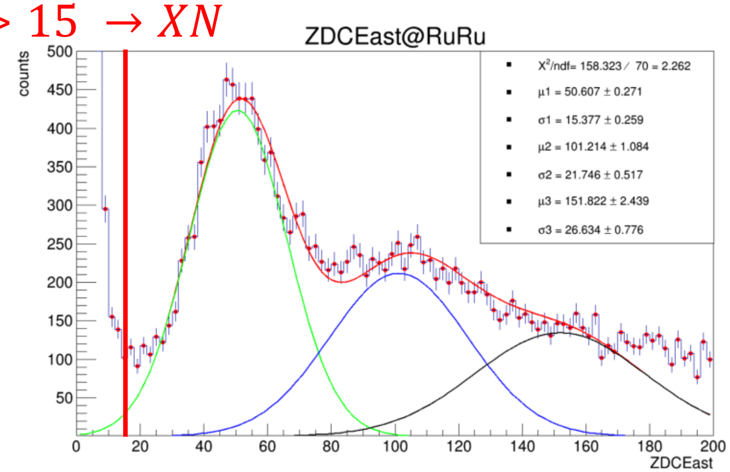
ZDC XN Find @ RuRu





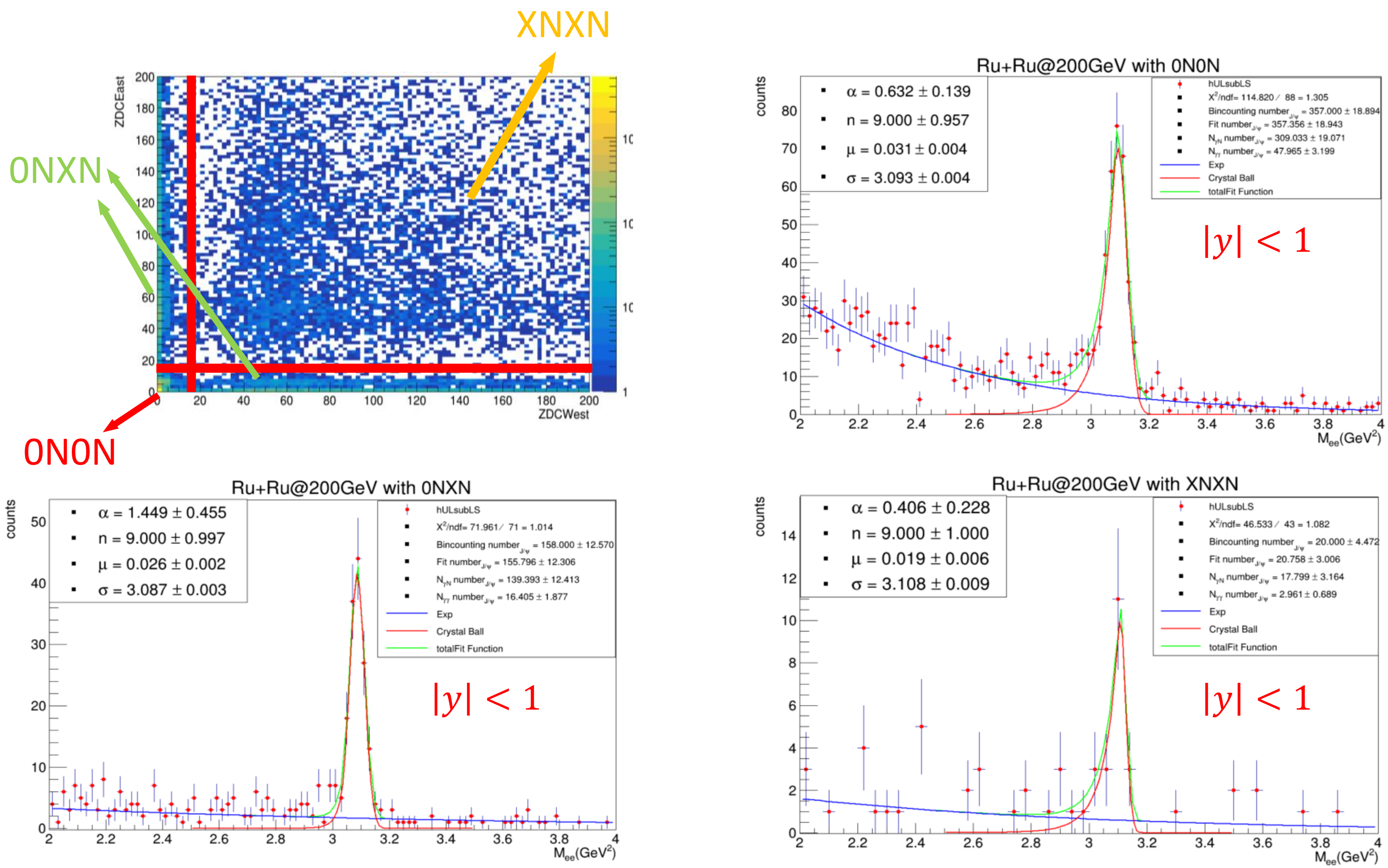
$ZDC\ counts\ > 15\ \rightarrow XN$





- We chose a neutron multiplicity of 15 as the boundary between 0N and XN.

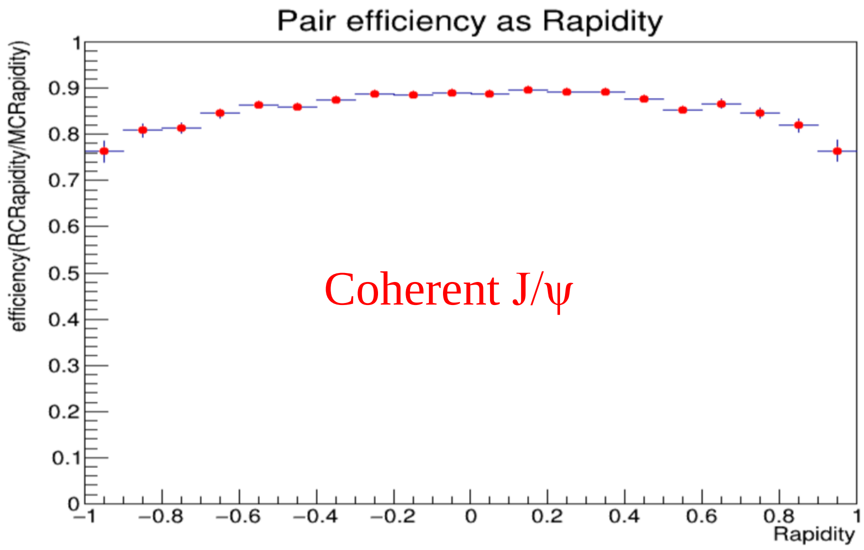
Raw *Mee* spectrum with different N

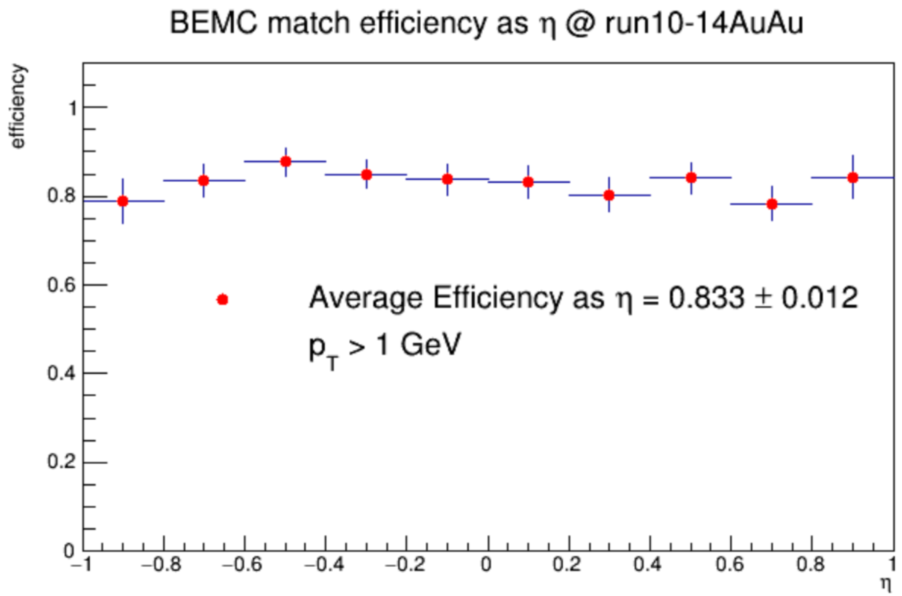


➢ Because of the low statistics, we may just focus on the $|y| < 1$ in XNXN cross-section.

TPC and BEMC efficiency correction

Method: Monte Carlo | Data-driven





- Using the MC (without embedding the daq files) to get the TPC reconstruction Efficiency(left).
- Using the data-driven to extract the BEMC-tracking match efficiency(right).

Summary and outlook

Summary:

- Raw M_{ee} spectrum, and raw p_T spectrum with different rapidity in the isobar system has been measured, also the distribution with different neutron multiplicity was measured.
- Using the MC to extract the TPC reconstruction efficiency, and the data-driven to extract the BEMC-tracking match efficiency.

Outlook:

- Efficiency.
  - BEMC trigger eff.
  - EID efficiency.
- $\frac{d\sigma}{dy}$ distribution.
  - $\frac{d\sigma}{dy}$ with different neutron multiplicity.

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Thanks!

Back up

Event selection and track cut

Collision	Year of data taken	Production Tag	Number of Events	Size (GB) of MuDst	Number of MuDst files
zrzr200	2018	P22ia	78285198	22604	8838
ruru200	2018	P22ia	78282272	22604	8837

Data set:

Run18 RuRu / ZrZr @200GeV

Trigger :

UPC_Jpsi

Trigger ID:

600701 600711

Trigger Requirements:

$1 \leq TofMult \leq 6$

BEMC back to back

BBC veto

Event Selection

- |Vz | < 100 cm
- $\leq$ 6 BEMC cluster (event activity cut)
- BEMC back to back cluster

Track quality cut

- nHitFit $\geq$ 15
- nHitdedx $\geq$ 11
- $|\eta| < 1$
- Match BEMC cluster

PID cut:

- One pair formed by 2 primary tracks from same vertex
- Tracks opening angle at BEMC is $\Delta\phi_{BEMC}$ > 2.618 (BEMC back to back cluster)
- $\chi^2_{ee} = nSigmae_1^2 + nSigmae_1^2 < 10$
- $\chi^2_{ee} < \chi^2_{\pi\pi}$

TPC reconstruction efficiency

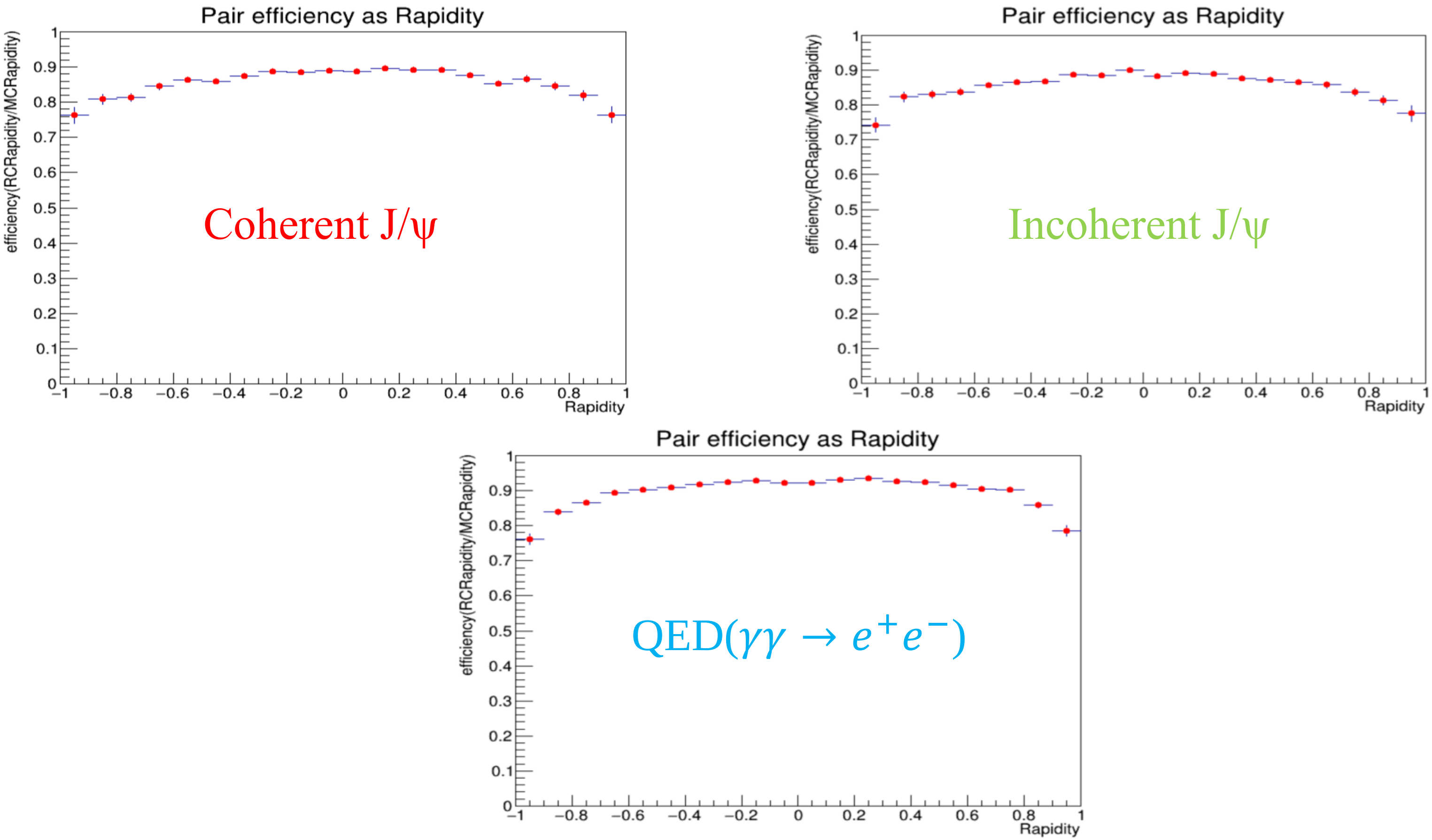
Track quality cut:

- $nHitsFit > 15$
- $nHitdEdx > 11$
- $|\eta|<1$
- Match BEMC Cluster(in BEMC match eff)

$$\varepsilon_{TPC} = \frac{N_{RC_{J/\psi}}(nHitsFit>15 \&\& nHitdEdx>11 \&\& |\eta|<1)}{N_{MC_{J/\psi}}(|\eta|<1)}$$

➢ Not include the vertex finder efficiency.

TPC reconstruction efficiency



Notice:

- We use the MC (without embedding the daq files) to get the TPC reconstruction Efficiency.
- Consider the vertex finder efficiency with the embedding.

BEMC-tracking match efficiency

Method: $data - driven$

Dataset:

- 10,11,14 AuAu200GeV "UPC_main" :
  $2 \leq tofmult \leq 6$, ZDC E/W N ≥ 1 , BBC E/W no signal

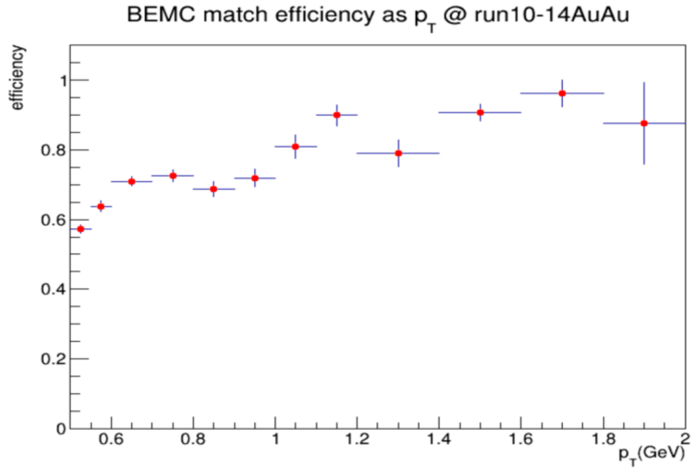
no BEMC bias

Selections:

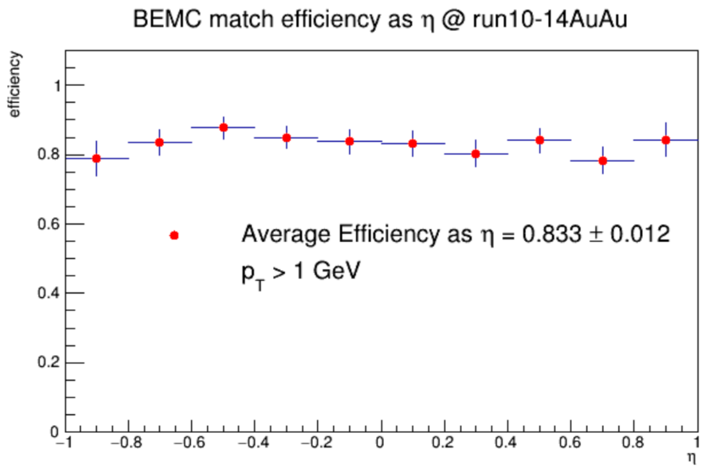
- Common: $nHitFit \geq 15$, $nHitdEdx \geq 11$, $|V_z| < 100cm$.
  $\chi^2_{ee} = nsigemae_1^2 + nsigemae_2^2 < 10$ && $\chi^2_{ee} < \chi^2_{\pi\pi}$,
  $ddtof\ cut$: $|ddtof| < 0.4ns$, vertex exactly 2 tracks TOF matched.

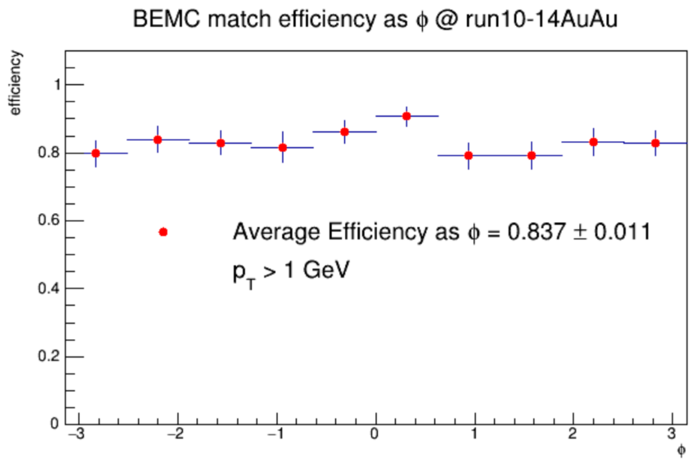
Raw BEMC match eff: $\varepsilon_{BEMC} = \frac{N(TOF+BEMC)}{N(TOF)}$

BEMC match efficiency in p_T, η, φ projections



- The BEMC match efficiency has the p_T-track dependence(or m_{ee} dependence).





- Raw BEMC-Track match efficiency of $p_T > 1$ GeV electron candidates By dataset without BEMC bias.
- Obtain the average efficiency using unequal precision measurements.