The effect of initial nuclear deformation on dielectron photoproduction in hadronic heavy-ion collisions

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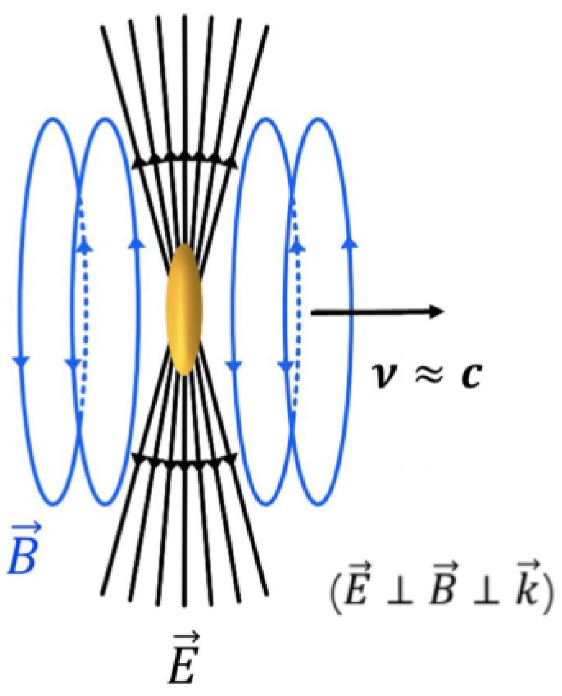
Outline

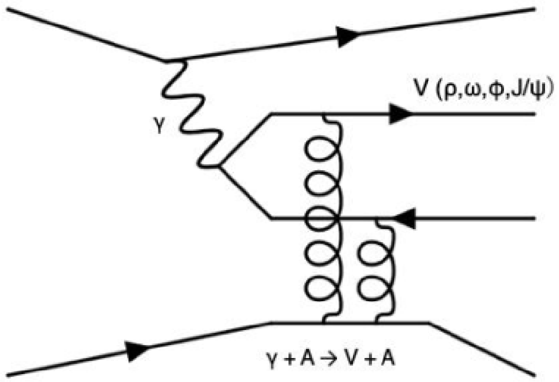
- Motivation and Introduction
- Initial nuclear deformation
- Dielectron photoproduction in deformed heavy-ion collisions
- Summary

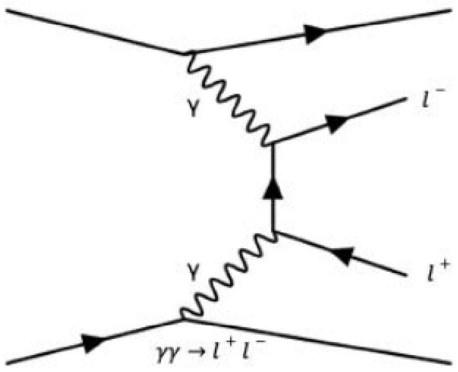
Photon-induced Process



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

$$|\vec{B}| \approx 10^{14}\text{-}10^{16}\mathrm{T}$$





- ➢ Ultra-relativistic charged nuclei produce highly Lorentz contracted EM field
- ➢ Weizsacker-Williams equivalent photon approximation (EPA):
  - ✓ Transverse EM fields are equivalent to a flux of quasi-real photons
  - ✓ Large quasi-real photon flux $\propto Z^2$
  - ✓ $p_{T,max} \sim \frac{\hbar c}{R}$, 30 MeV @ RHIC & LHC
- ➢ Photoproduction process:
  - ✓ Photon-nucleus interactions: Vector meson
  - ✓ Photon-photon interactions ($\propto Z^4$): dileptons

Dilepton Production in Peripheral Collisions

- Conventionally believed to be only exist in ultra-peripheral collisions ($b > 2R_A$, UPCs) to satisfy the coherence condition

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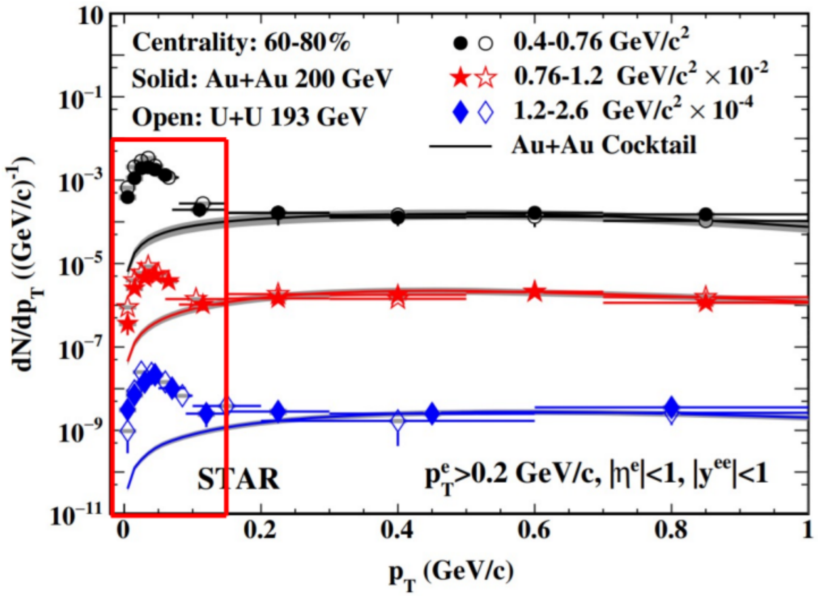
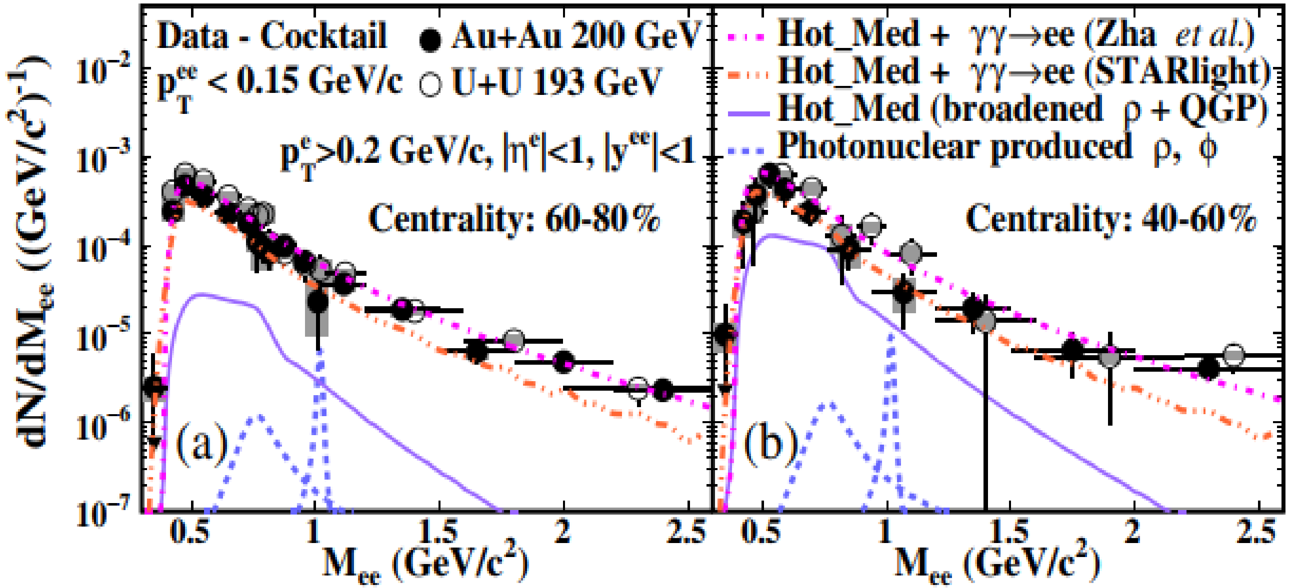
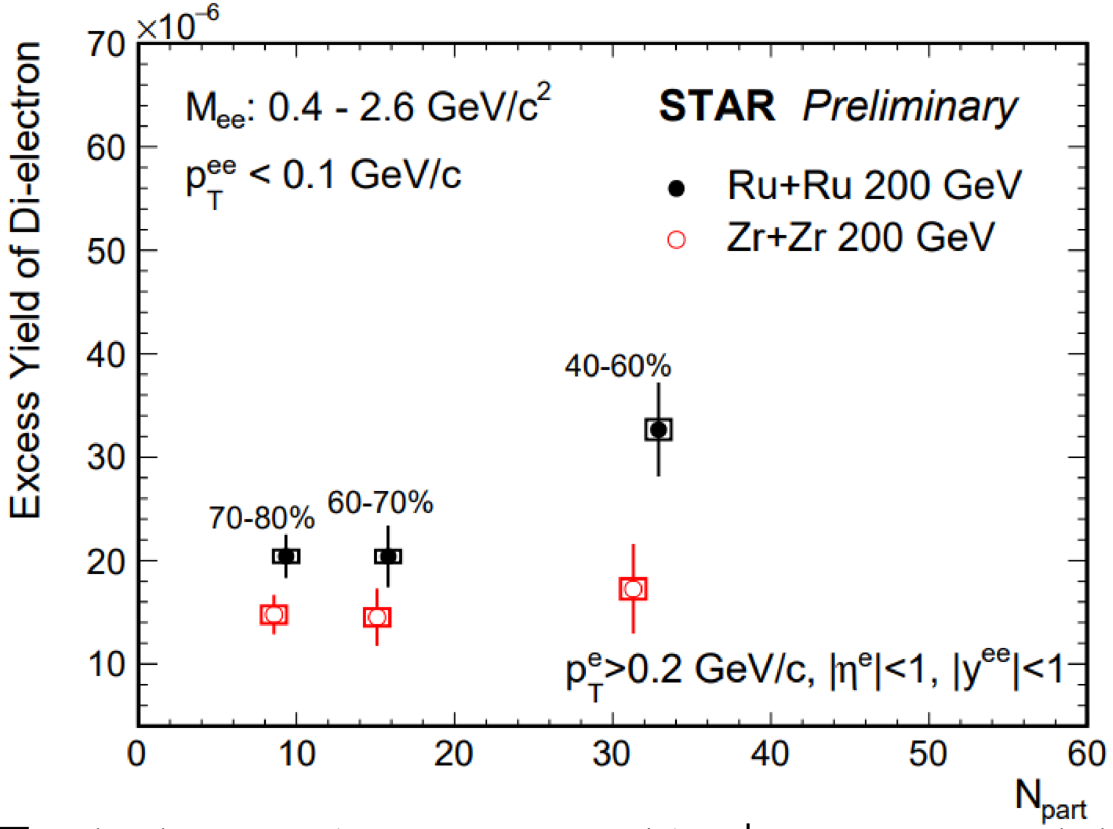


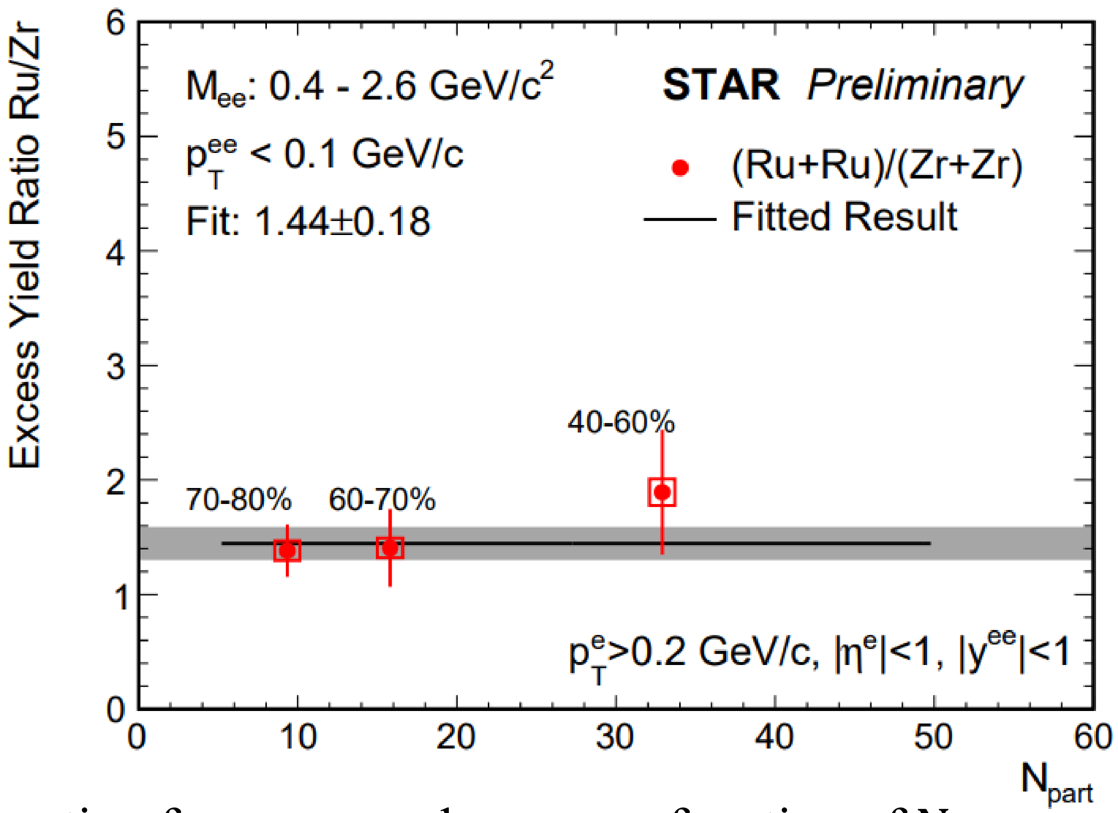


- Significant enhancements of e^+e^- production at very low p_T in peripheral collisions ($b < 2R_A$)
- Photon-photon interactions can explain the observed enhancements in spherical Au + Au collisions
- In hadronic U + U collisions: nuclear charge number vs. initial nuclear deformation

Photoproduction in Isobaric Collisions

- $^{96}_{44}Ru + ^{96}_{44}Ru$ and $^{96}_{40}Zr + ^{96}_{40}Zr$: the dependence of the observed excesses on nuclear charge number Z





- The low-p_T ($p_T < 0.1$ GeV/c) e^+e^- excess and the ratio of excess are shown as a function of N_{part}
- The excess yields in Ru+Ru collisions are systematically higher than those in Zr+Zr collisions
- A constant function is used to fit the ratio, which is close to $\left(\frac{44}{40}\right)^4$

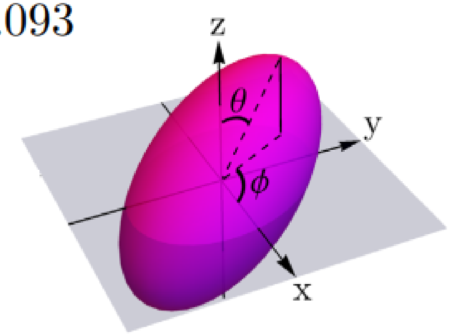
Initial Nuclear Deformation

- Nuclear charge density:

$$\rho_{sph}(r) = \frac{\rho_0}{1 + e^{(r-R_0)/a}} \qquad \rho(\vec{r}) = \frac{\rho_0}{1 + \exp[\frac{r - R_0[1+\beta_2 Y_2^0(\theta)+\beta_4 Y_4^0(\theta)]}{a}]}$$

Nucleus	R_0(fm)	a(fm)	β_2	β_4
$^{238}_{92}$U	6.8054	0.605	0.2863	0.093

- The shape: ellipsoid
  - ✓ rotational ellipsoid $\rho(\vec{r}) = \rho(r,\theta)$
  - ✓ a prolate spheroid when $\beta_2 > 0$

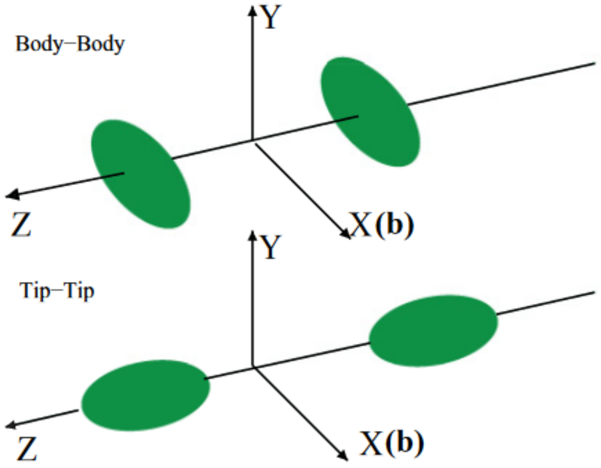


- The charge density of a deformed nucleus:

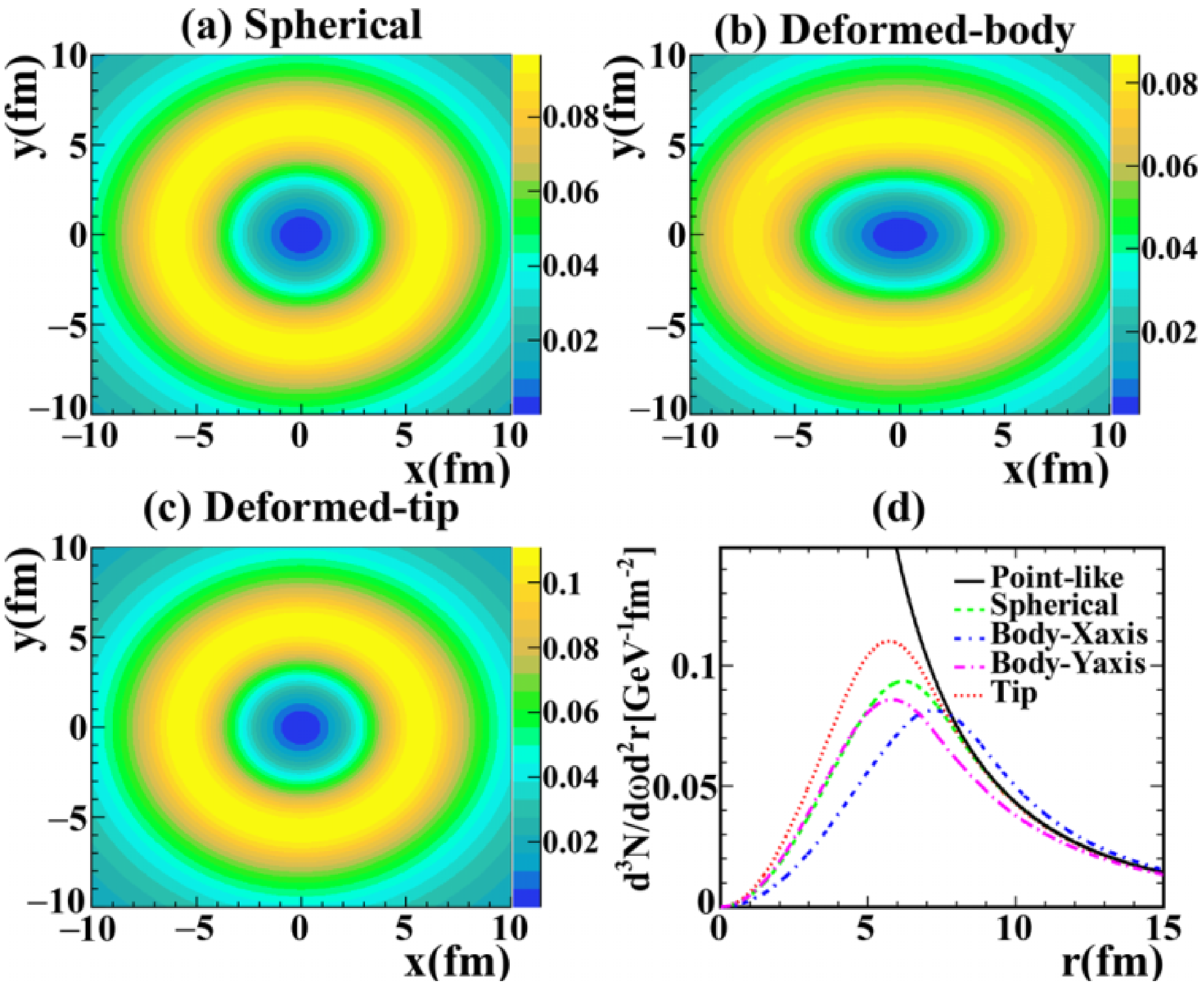
$$\rho_{\vec{v}}(\vec{r}) = \rho[R_z^{-1}(-\varphi_v)R_y^{-1}(\theta_v)R_z^{-1}(\varphi_v)\vec{r}]$$

  - ✓ the direction of the major axis: $\vec{v} = (\sin\theta_v\cos\varphi_v, \sin\theta_v\sin\varphi_v, \cos\theta_v)$
  - ✓ $\vec{v}$ is isotropic in the surface of the unit sphere

- Deformed heavy-ion collisions: two limiting cases
  - ✓ Body-body: $\vec{v_1} = \vec{v_2} = (\pm 1, 0, 0)$
  - ✓ Tip-Tip: $\vec{v_1} = \vec{v_2} = (0, 0, \pm 1)$



Equivalent Photon Flux



- The photon flux with energy ω = 1 GeV in U + U collisions at $\sqrt{s_{NN}}$ = 193 GeV

$$n(\omega, \vec{x_\perp}) = \frac{4Z^2\alpha}{\omega}\left|\int \frac{d^2\vec{q_\perp}}{(2\pi)^2}\vec{q_\perp}\frac{F(\vec{q})}{|\vec{q}|^2}e^{i\vec{x_\perp}\cdot\vec{q_\perp}}\right|^2$$

- The pattern from the body orientation exhibits an ellipse
  - ✓ the polar radius and equatorial radius of the prolate spheroid
- The differences are concentrated around R_0
  - ✓ Spherical
  - ✓ Deformed-body
  - ✓ Deformed-tip
  - ✓ Point-like

e^+e^- Pair Photoproduction

- The cross section of the e^+e^- pair produced by the two-photon process:

$$\sigma(AA \to AAe^+e^-) = \int d\omega_1 \int d\omega_2 n_1(\omega_1) n_2(\omega_2) \sigma(\gamma\gamma \to e^+e^-)$$

- The invariant mass M_{ee} and rapidity y of the e^+e^- pair:

$$M_{ee} = \sqrt{E^2 - p^2} = \sqrt{4\omega_1\omega_2} \qquad y = \frac{1}{2}\ln\frac{E+p_z}{E-p_z} = \frac{1}{2}\ln\frac{\omega_1}{\omega_2}$$

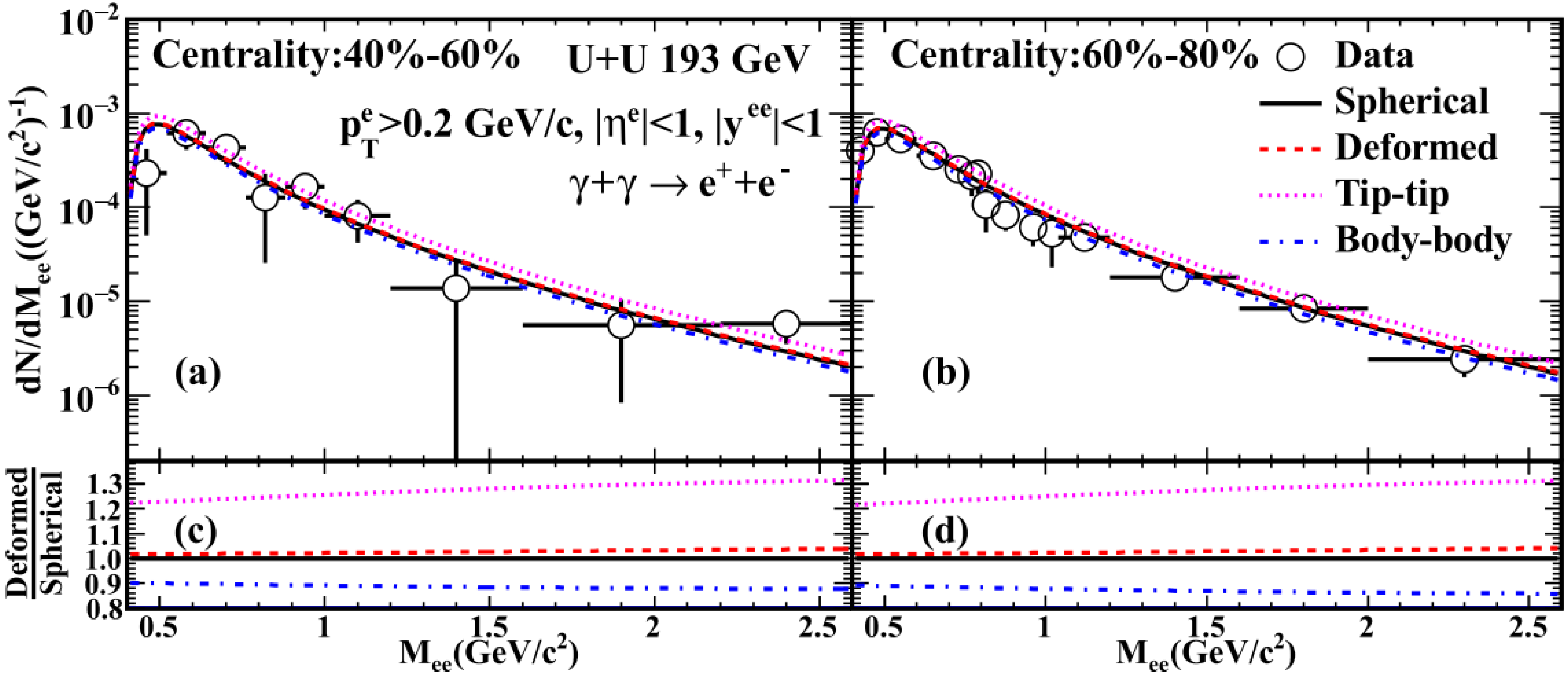
- Centrality definition to compare with experimental data:

  - ✓ the two-component approach $f N_{coll} + (1 - f) N_{part}$
  - ✓ set $f = 0$ for simplicity
  - ✓ the cumulative distribution function of N_{part}

$$c = \int_{N_{part}}^{\infty} dN'_{part} P(N'_{part})$$

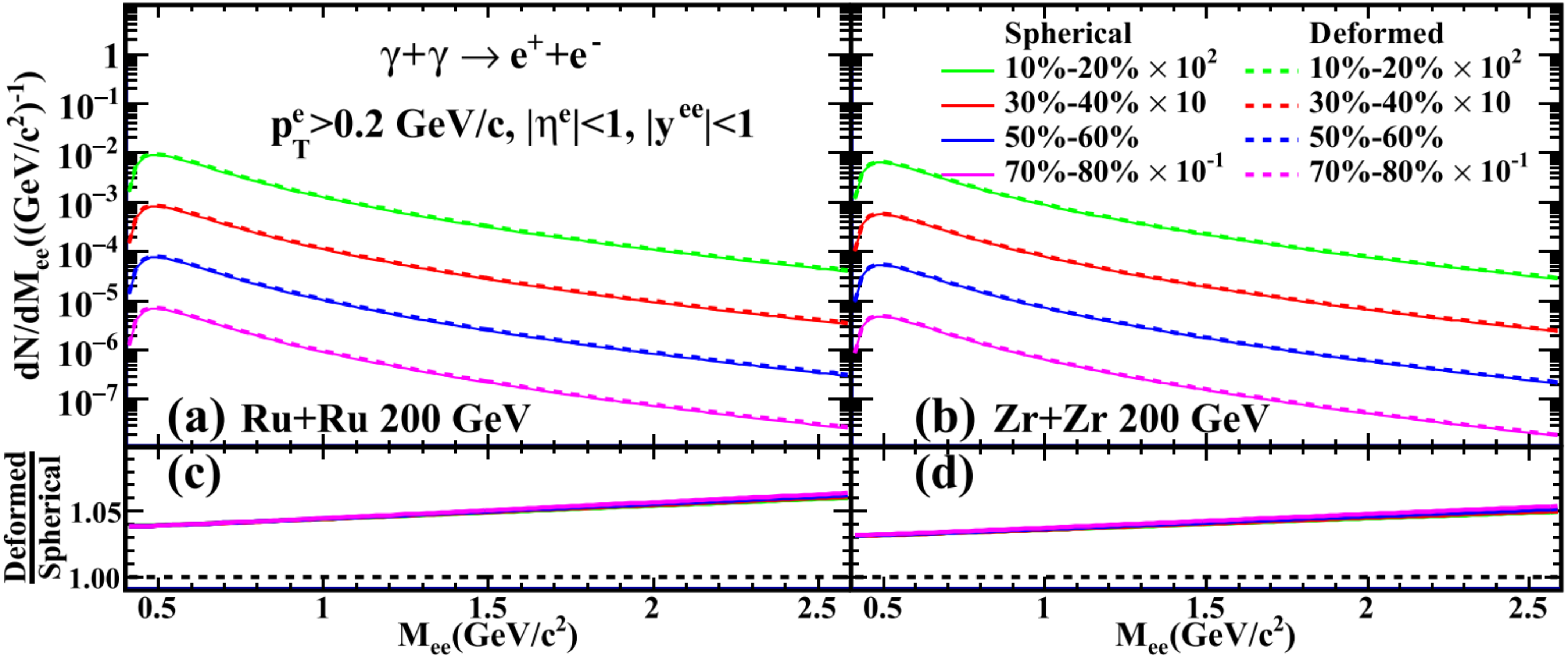
$$P(N_{part}) = \frac{\sum_{i=1}^{N} P_i(N_{part})}{N}$$

Impact of Initial Nuclear Deformation



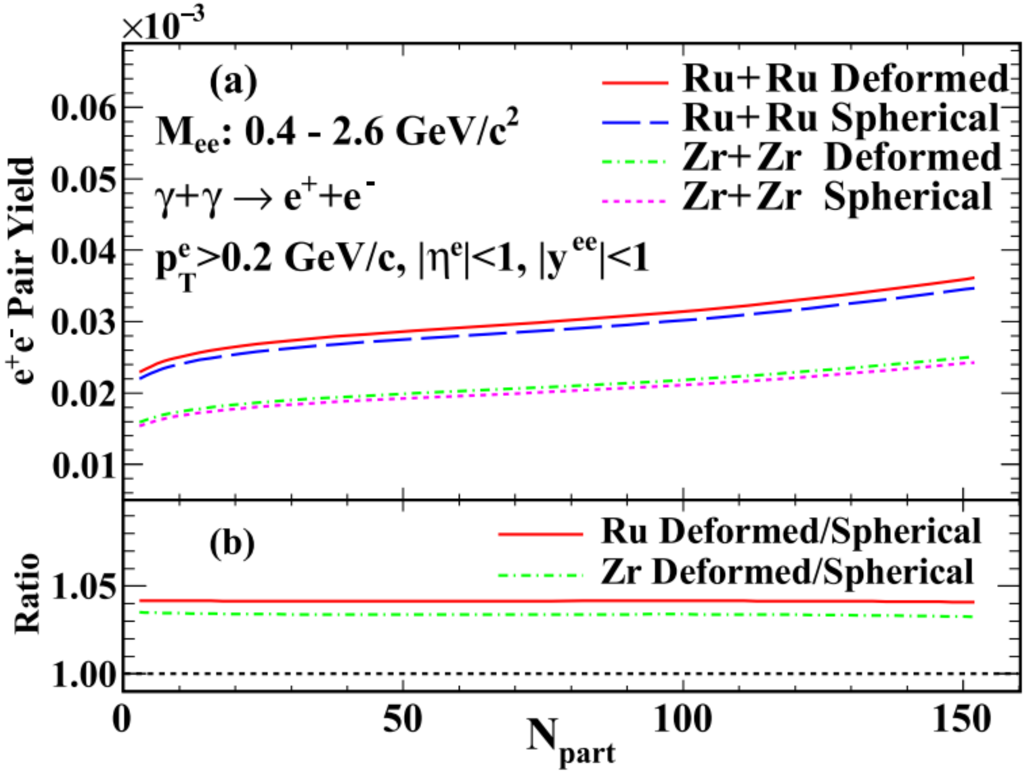
- Both the deformed and spherical configurations can describe the data well
- The difference becomes more significant as the invariant mass M_{ee} increases
- Tip-Tip: 25% higher Body-Body: 10% lower Deformed Average: 3% higher

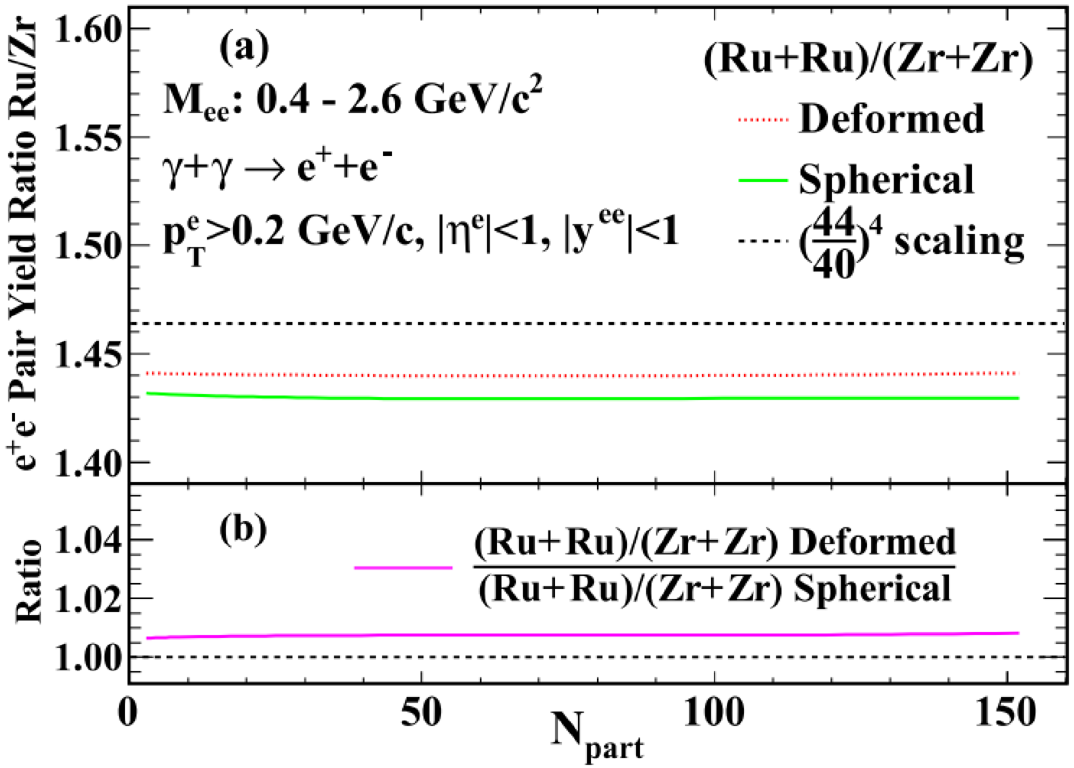
Isobaric Collisions



- 4% higher compared to the spherical case in Ru + Ru collisions, slightly smaller in Zr + Zr collisions
- The yields increase in more central collisions, the ratios do not seem to exhibit dependence on centrality

Centrality Dependence





- ➢ The impact of initial nuclear deformation on photoproduction does not have centrality dependence.
- ➢ The impact of initial nuclear deformation on the ratios of e^+e^- pair photoproduction between Ru + Ru and Zr + Zr collisions is negligible.

Summary

- Conduct calculations of e^+e^- pair photoproduction in hadronic heavy-ion collisions considering both spherical and deformed configurations

- In hadronic U + U collisions:
  - ✓ describe the experimental data well
  - ✓ significant differences in tip-tip and body-body collisions
  - ✓ approximately 3% differences between spherical and deformed configurations

- The impact of initial nuclear deformation on the ratios of e^+e^- pair photoproduction between Ru + Ru and Zr + Zr collisions is negligible (< 1%).

Thank You !