System size dependence of particle production and collectivity from the STAR experiment at RHIC

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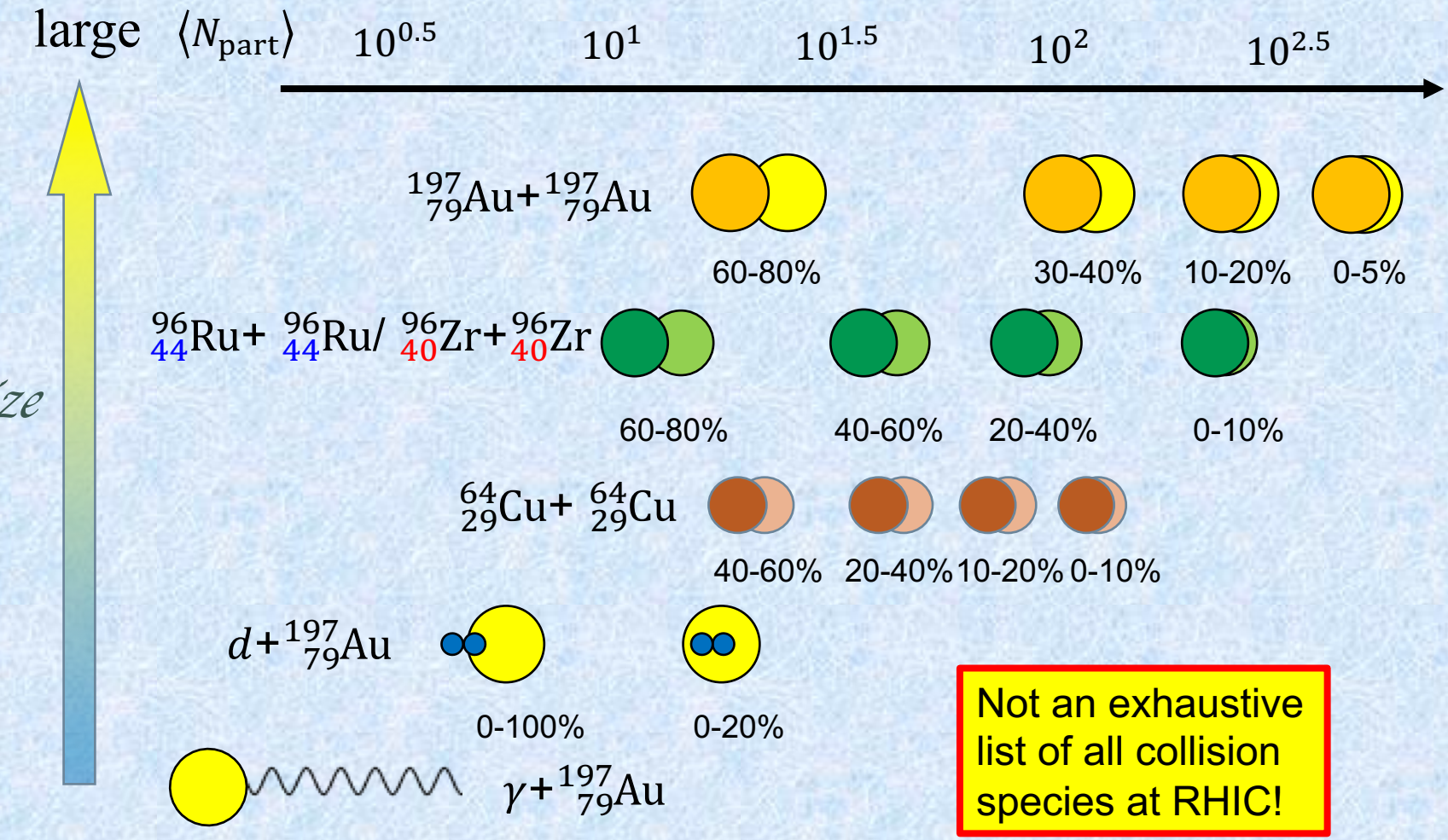
for the STAR collaboration

Quark Matter 2022, Krakow, Poland (hybrid)

In part supported by

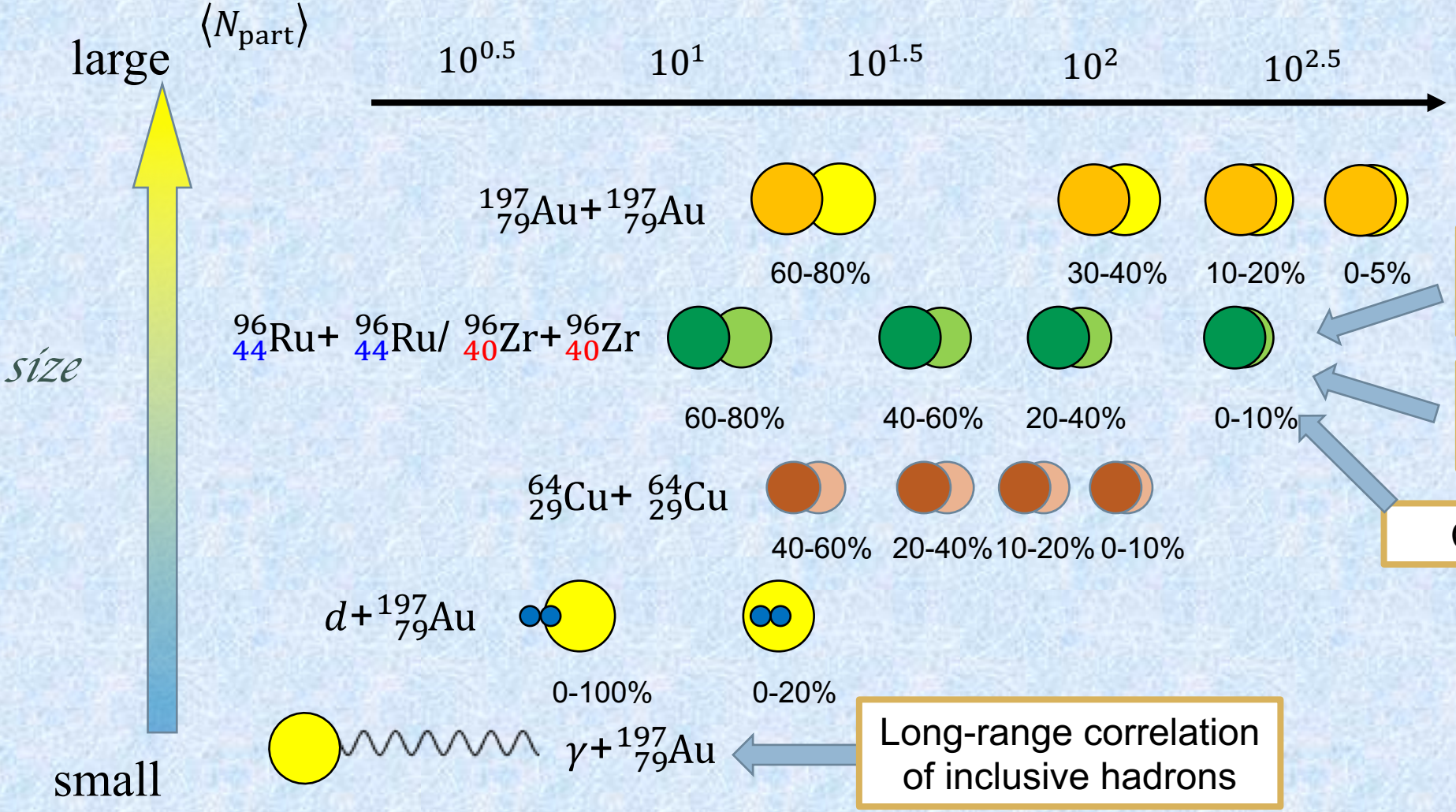
System Size Dependence of Medium Properties

- RHIC has provided us with a variety of collision systems
- For different collision systems, same N_{part} leads to different initial geometry
- What are the decisive factors of medium properties?

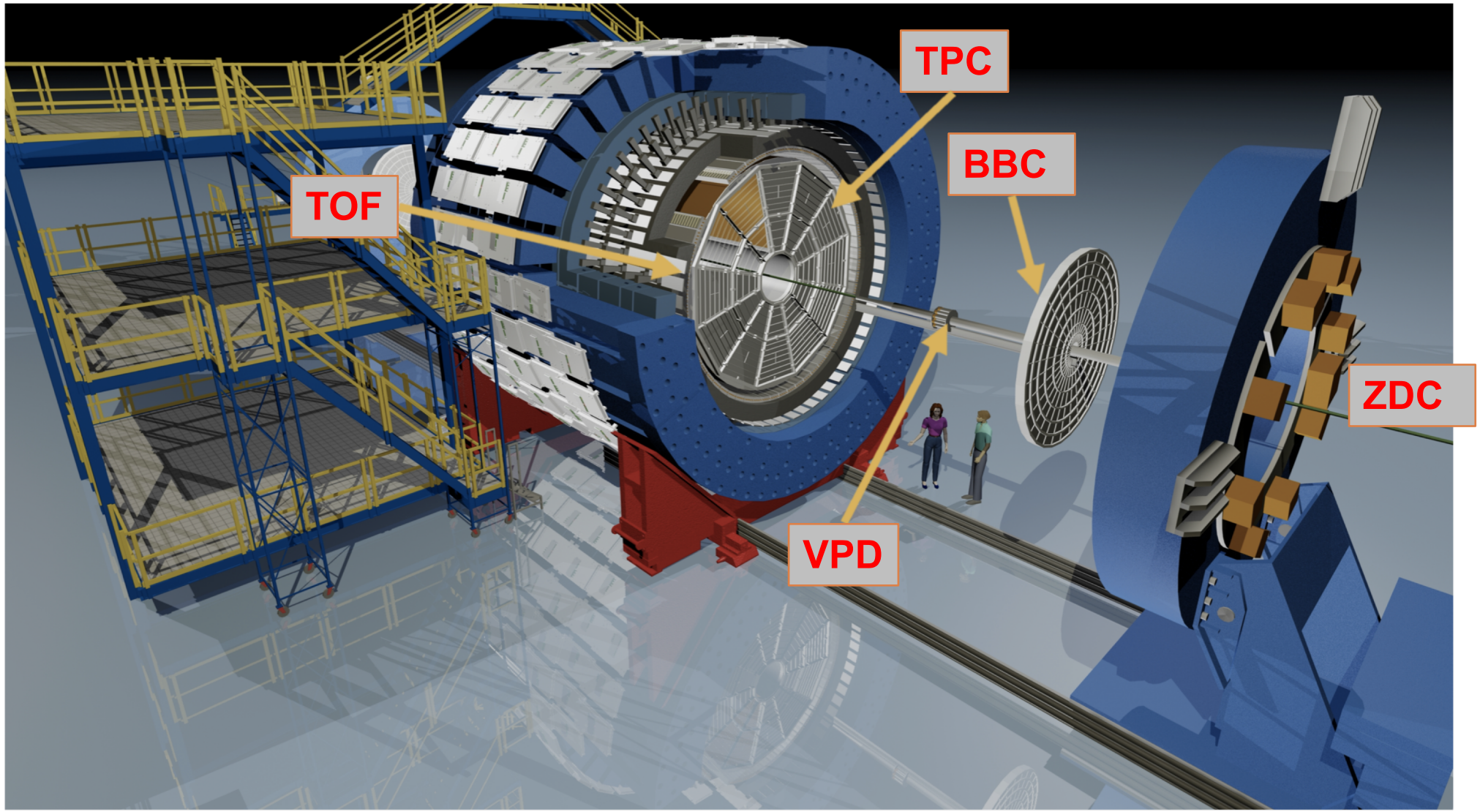


Not an exhaustive list of all collision species at RHIC!

System Size Dependence of Medium Properties



The STAR Detector



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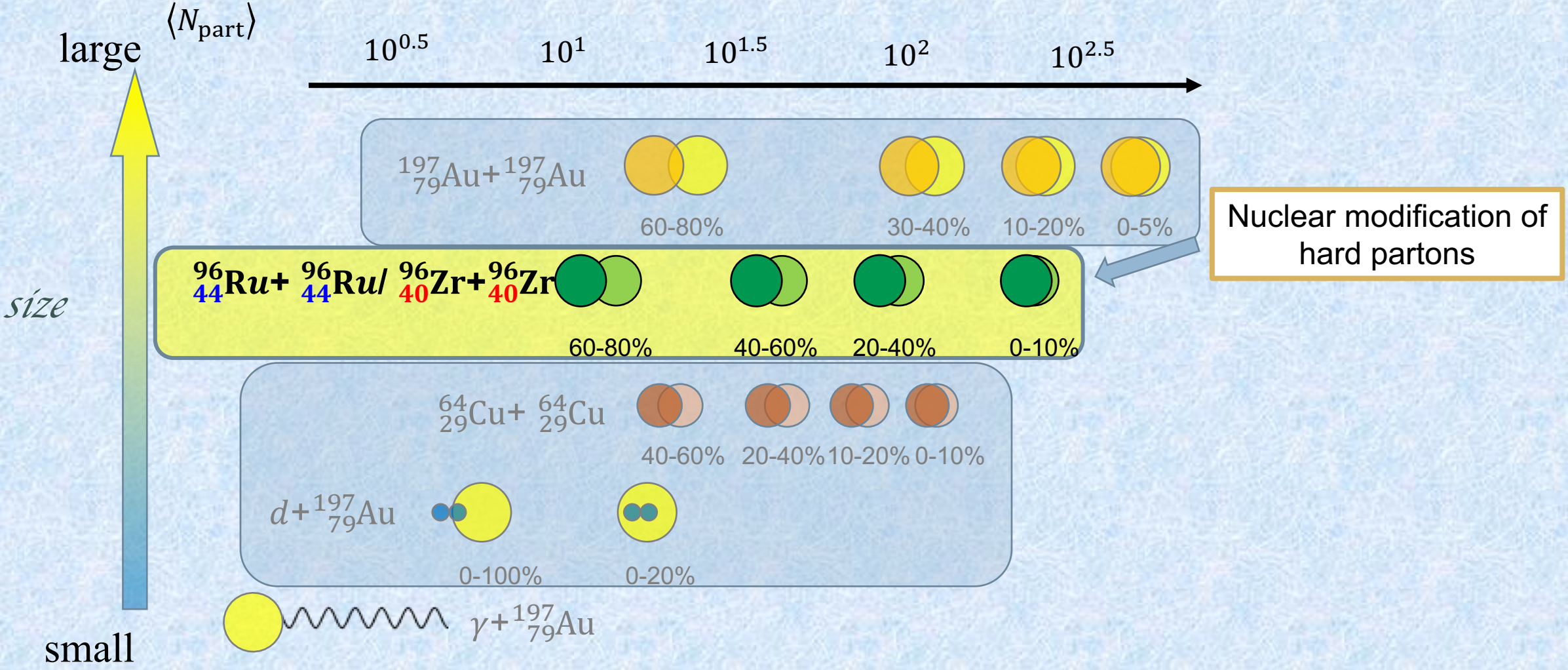
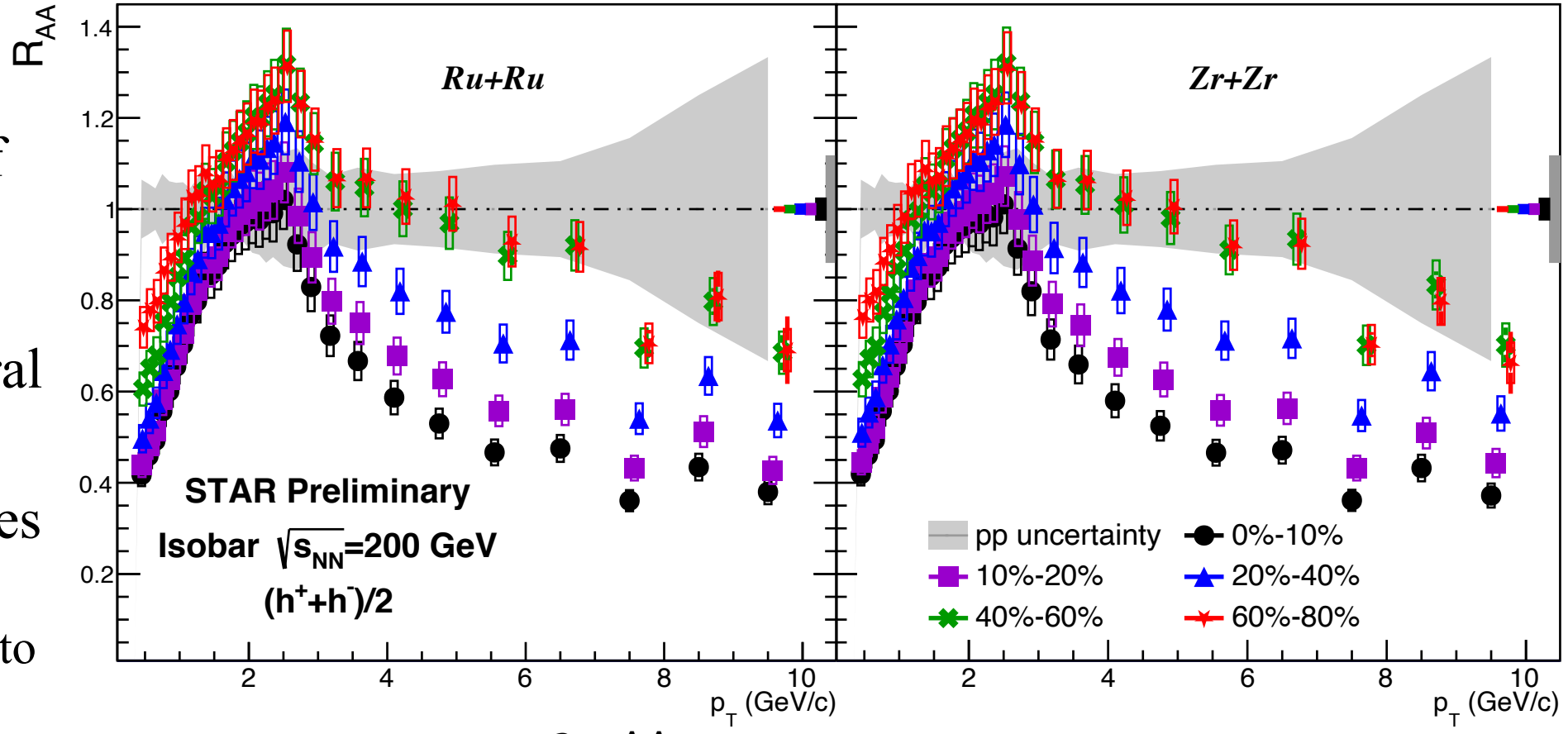


Nuclear modification of hard partons

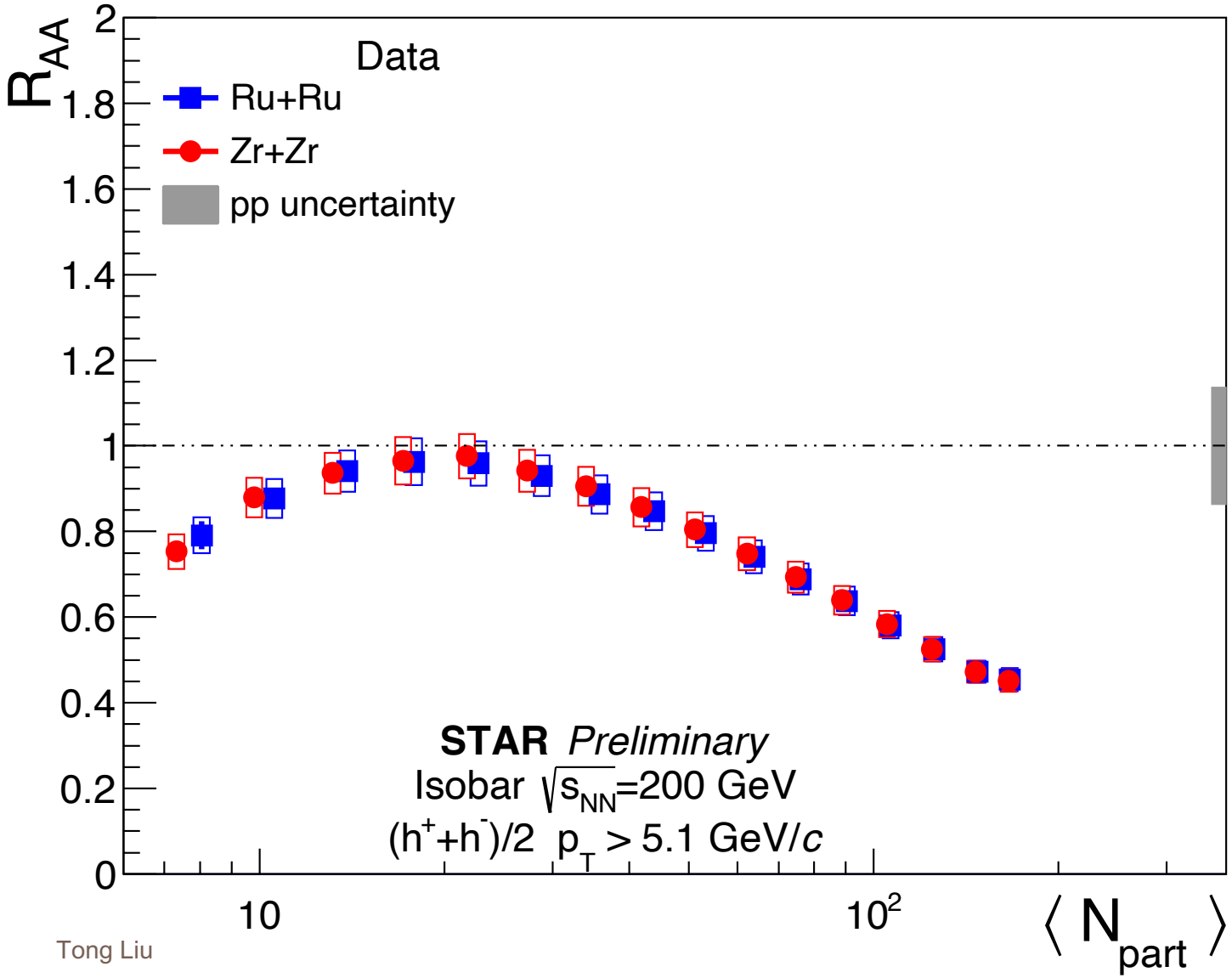
Medium Modification of Inclusive Hadrons in Isobar Collisions

- Ru+Ru & Zr+Zr show similar level of suppression
- Significant high-p_T suppression for central events
- Suppression decreases with centrality
  - 40-60% looks similar to 60-80%

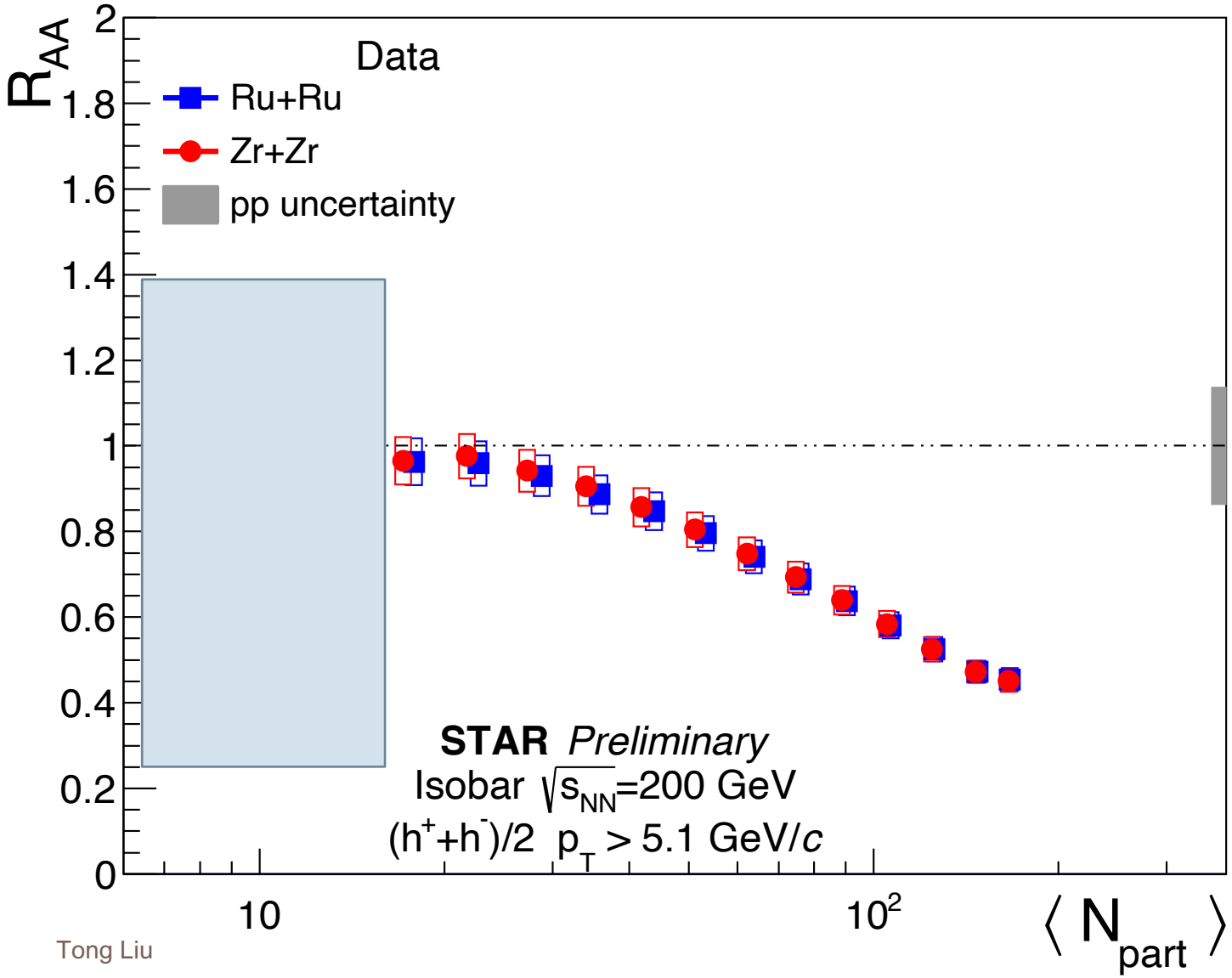


$$R_{\mathrm{AA}} = \frac{1}{N_{\mathrm{ev}}^{\mathrm{AA}}} \frac{d^2N^{\mathrm{AA}}/d\eta dp_{\mathrm{T}}}{T_{\mathrm{AA}} d^2\sigma^{\mathrm{NN}}/d\eta dp_{\mathrm{T}}}, T_{\mathrm{AA}} = \langle N_{\mathrm{coll}} \rangle / \sigma_{\mathrm{inel.}}^{\mathrm{NN}}$$

R_{AA} as a Function of N_{part}



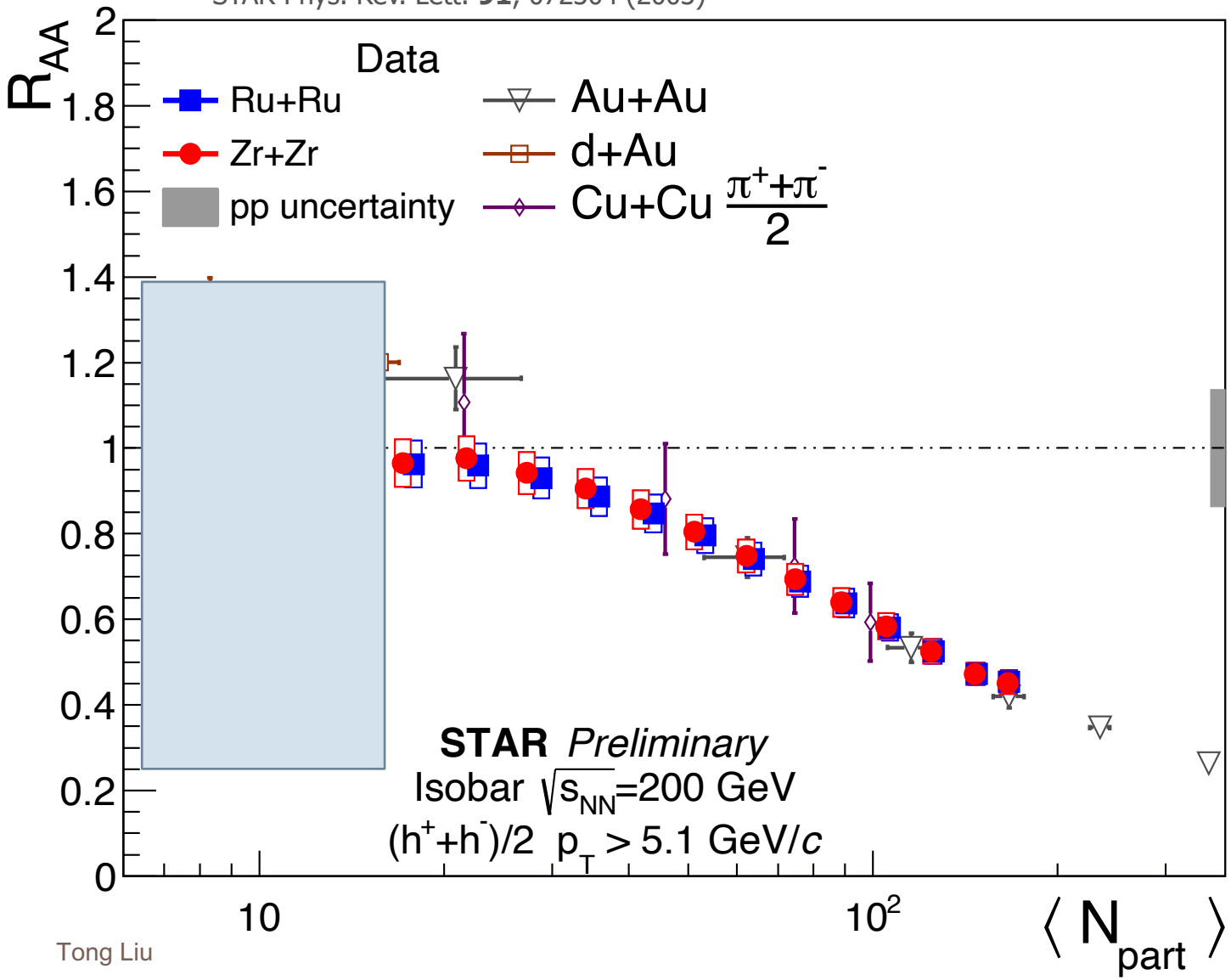
R_{AA} as a Function of N_{part}



- R_{AA} in 0-60% central events ($\langle N_{part} \rangle$ >20) decrease with $\langle N_{part} \rangle$

R_{AA} as a Function of N_{part}

STAR Phys. Rev. Lett. **91**, 172302 (2003) STAR Phys. Rev. C **81**, 054907 (2010)
STAR Phys. Rev. Lett. **91**, 072304 (2003)



- R_{AA} in 0-60% central events ($\langle N_{part} \rangle$ >20) decrease with $\langle N_{part} \rangle$
- **Same R_{AA} at same $\langle N_{part} \rangle$ regardless of system**

R_{AA} as a Function of N_{part}

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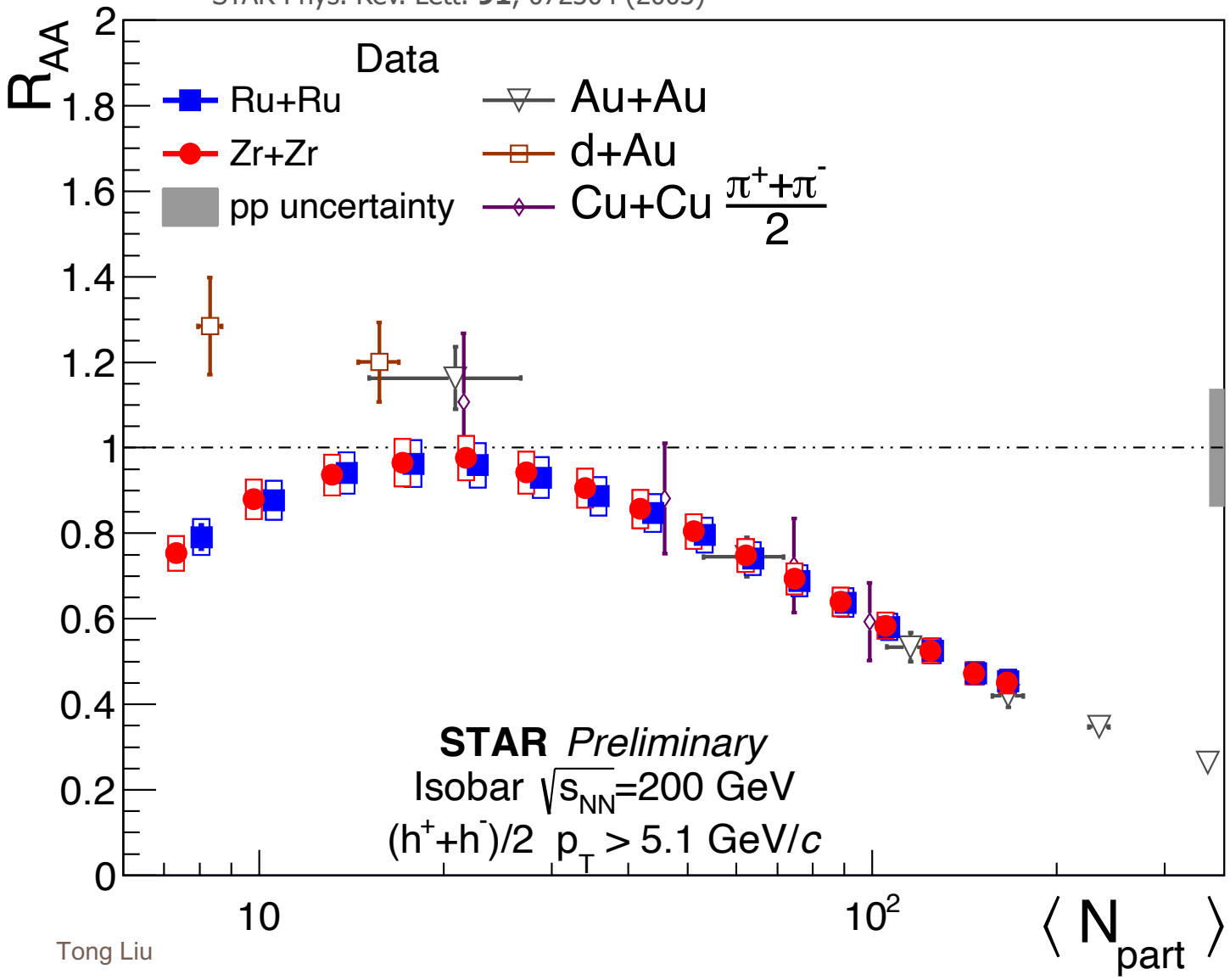

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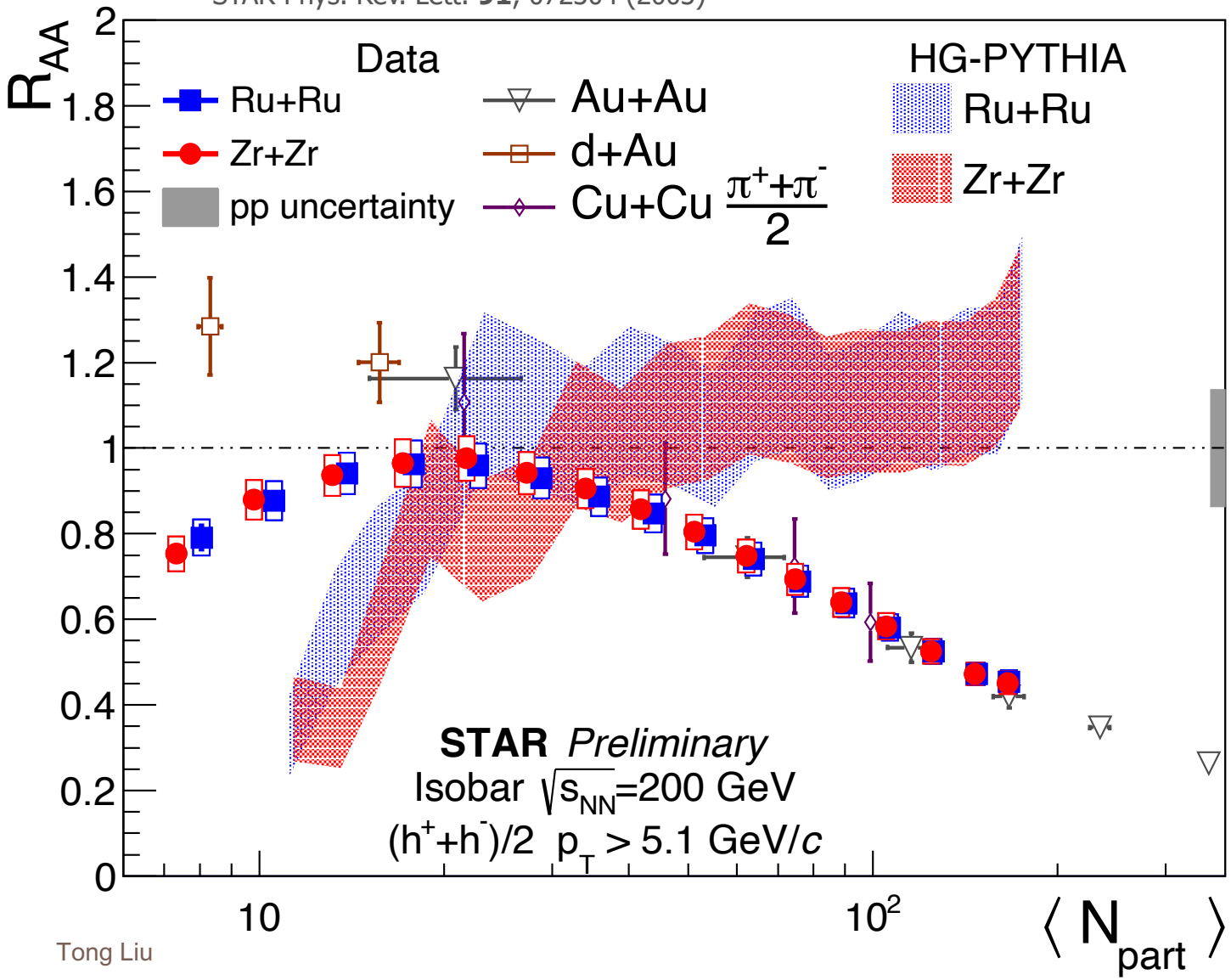
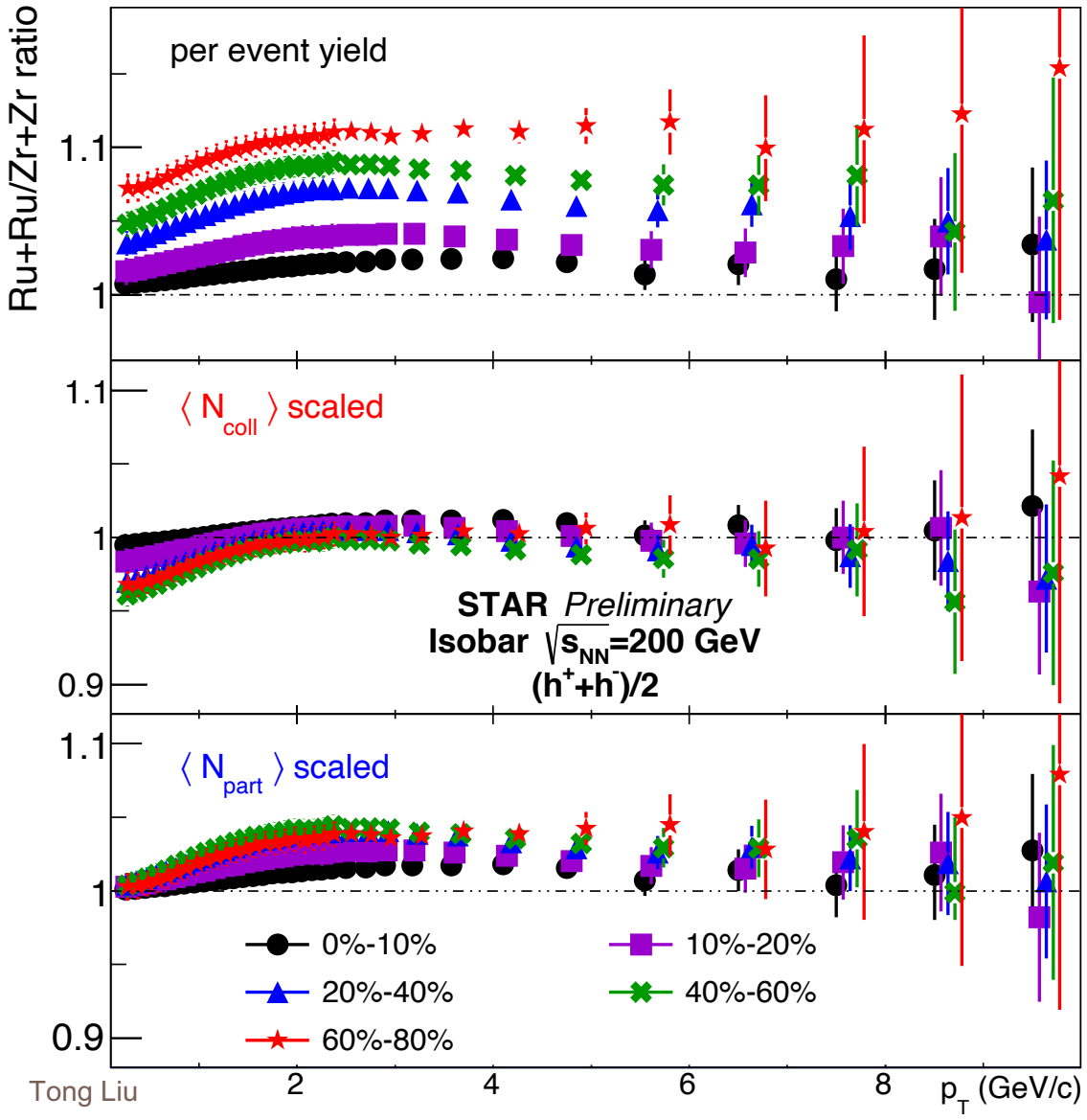


- R_{AA} in 0-60% central events ($\langle N_{part} \rangle$ >20) decrease with $\langle N_{part} \rangle$
- **Same R_{AA} at same $\langle N_{part} \rangle$ regardless of system**
- Deviation from trend starting at $\langle N_{part} \rangle \lesssim 20$
  - Event selection bias in peripheral events causes artificial suppression?
  - HG-PYTHIA[1] qualitatively gets trend but predicts steeper drop
  - Detailed studies ongoing

[1] Loizides & Morsch, Phys.Lett. B773 (2017) 408-411

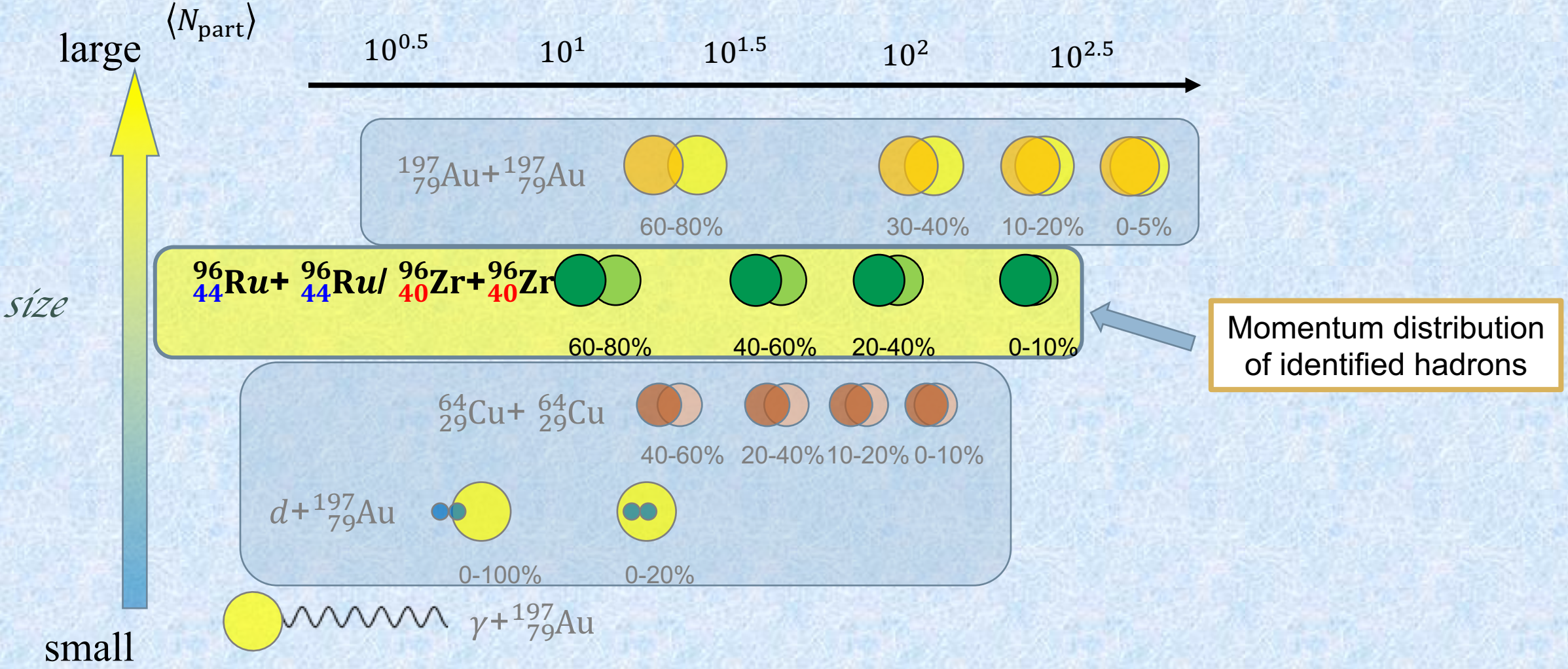
Ru+Ru/Zr+Zr Yield Ratio



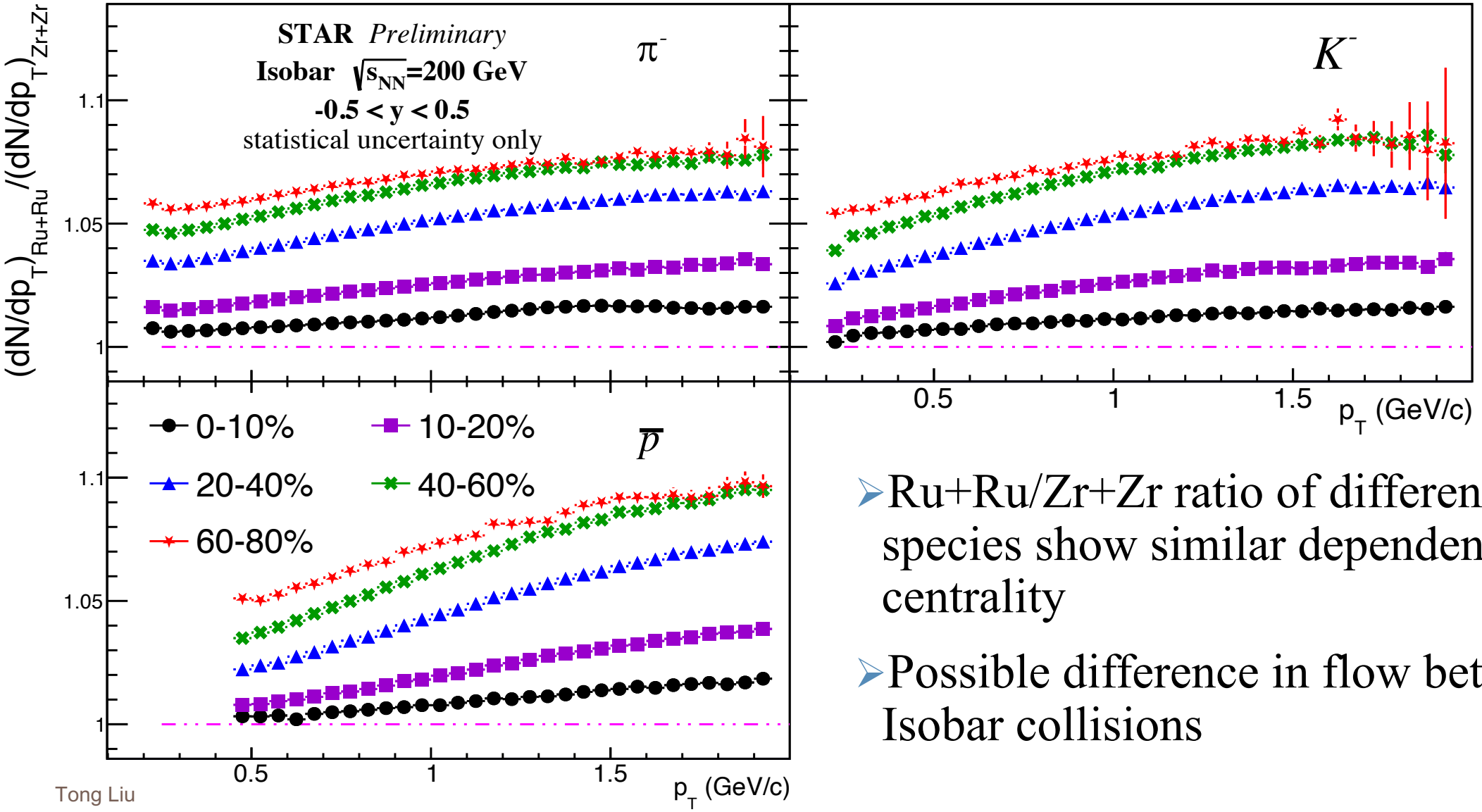
- For the same centrality percentage, Ru+Ru collisions have bigger N_{coll}
- Ru+Ru/Zr+Zr per-event yield ratio >1
  - strong resolution on system size difference
- N_{coll}-scaled ratio consistent with unity at high p_{T}
  - No significant difference on quenching
- N_{part}-scaled ratio beyond 1 at $p_{\mathrm{T}} > 0.5$ GeV/c
  - Consistent with unity at the lowest p_{T}
  - Rising with p_{T}: flow effect?

Refer to: Talk by Haojie Xu (Wed 9:00 AM T01) & Poster by Chunjian Zhang (Session 2 T14-2 #962)

System Size Dependence of Medium Properties



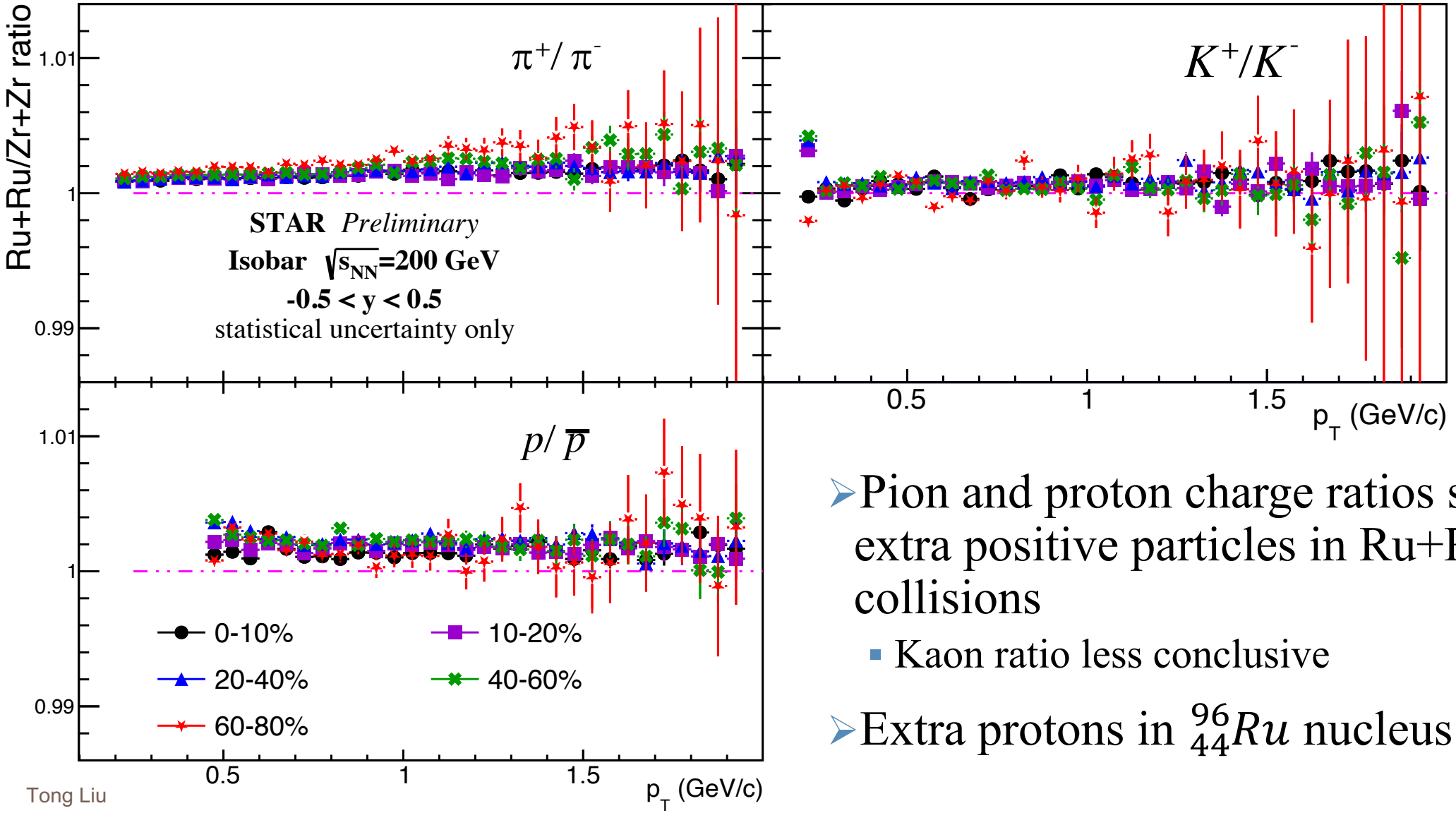
Identified Hadron Momentum Distribution in Isobar Collisions



Poster by Yang Li (Session 3 T16 #345)

- Ru+Ru/Zr+Zr ratio of different particle species show similar dependence on centrality
- Possible difference in flow between Isobar collisions

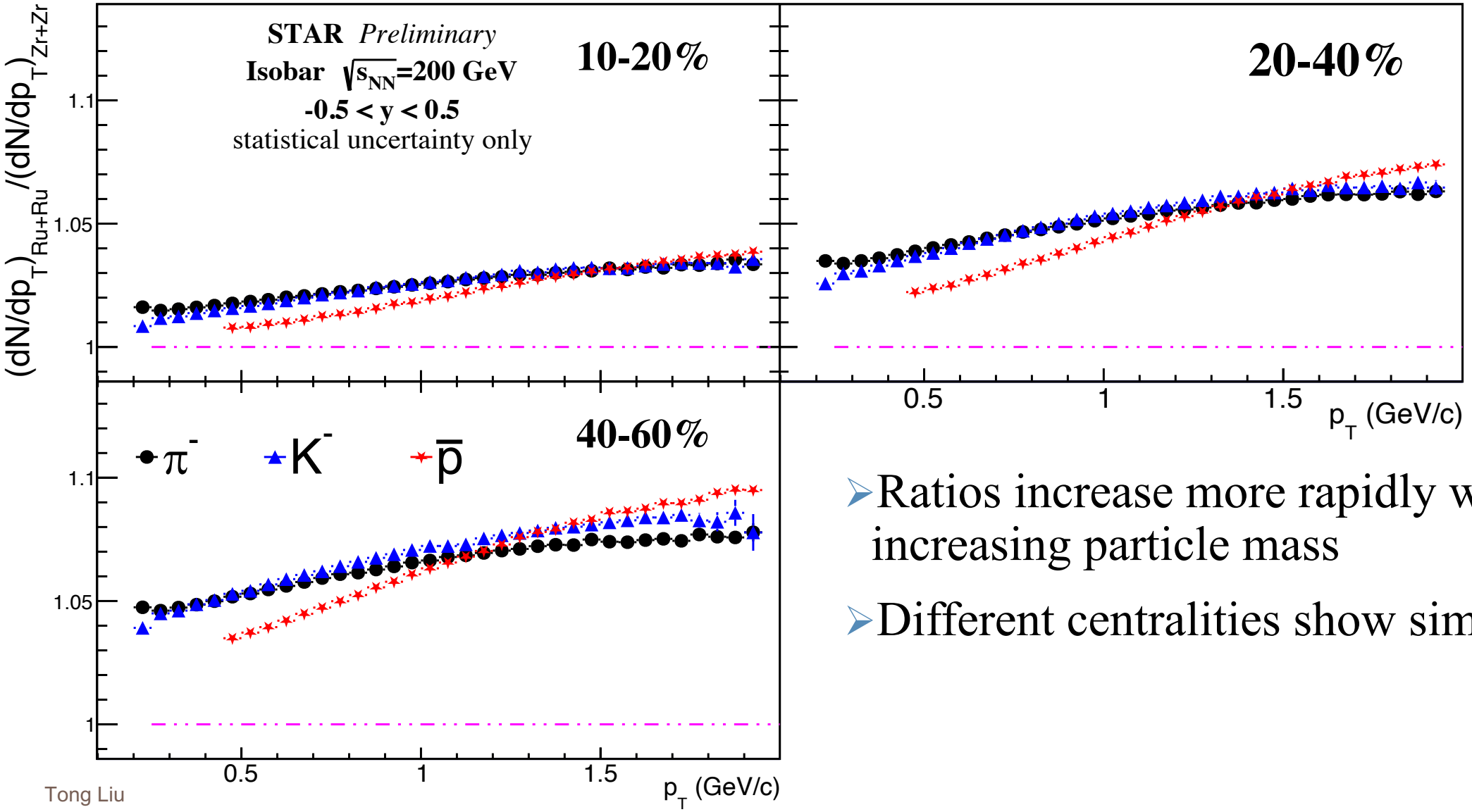
Charge Ratio: Effects of Extra Protons



Poster by Yang Li (Session 3 T16 #345)

- Pion and proton charge ratios show extra positive particles in Ru+Ru collisions
  - Kaon ratio less conclusive
- Extra protons in $^{96}_{44}Ru$ nucleus

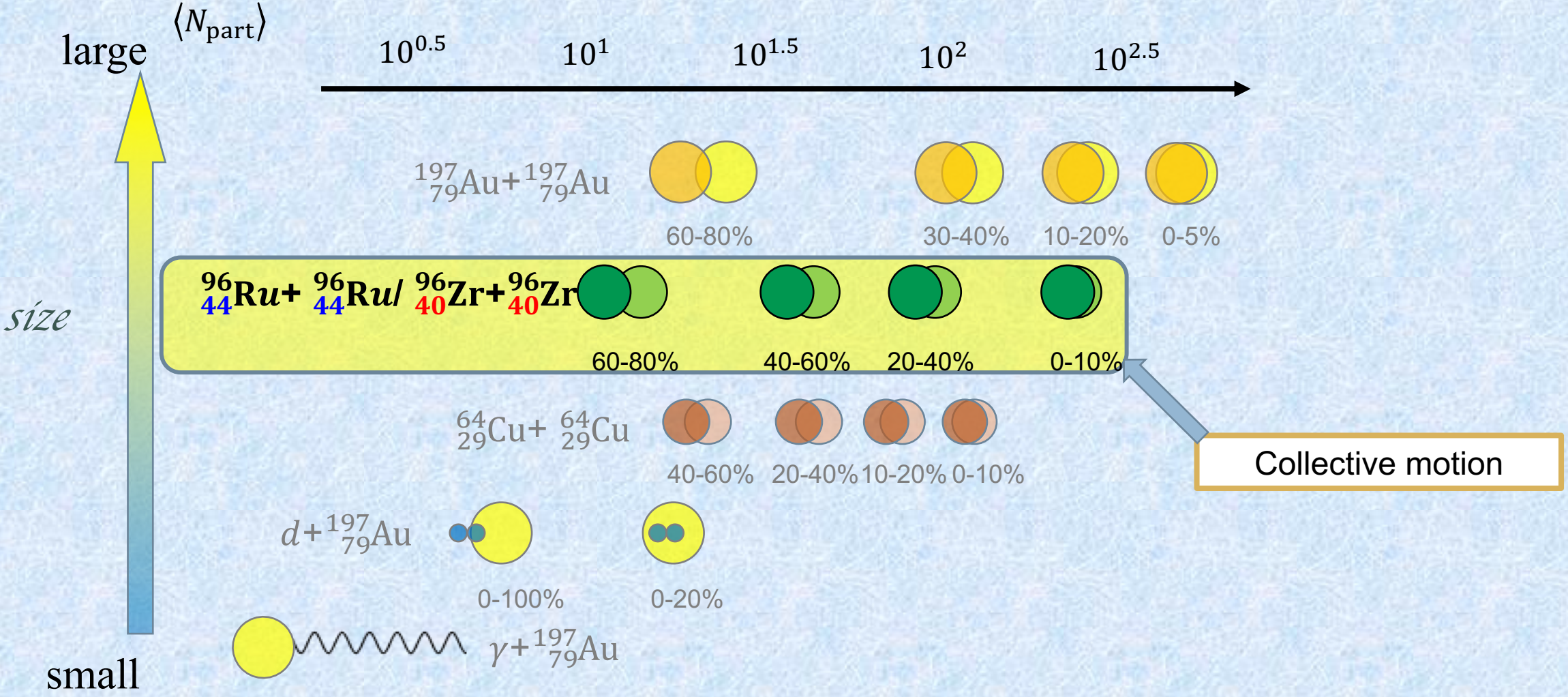
Difference Between Baryons and Mesons



Poster by Yang Li (Session 3 T16 #345)

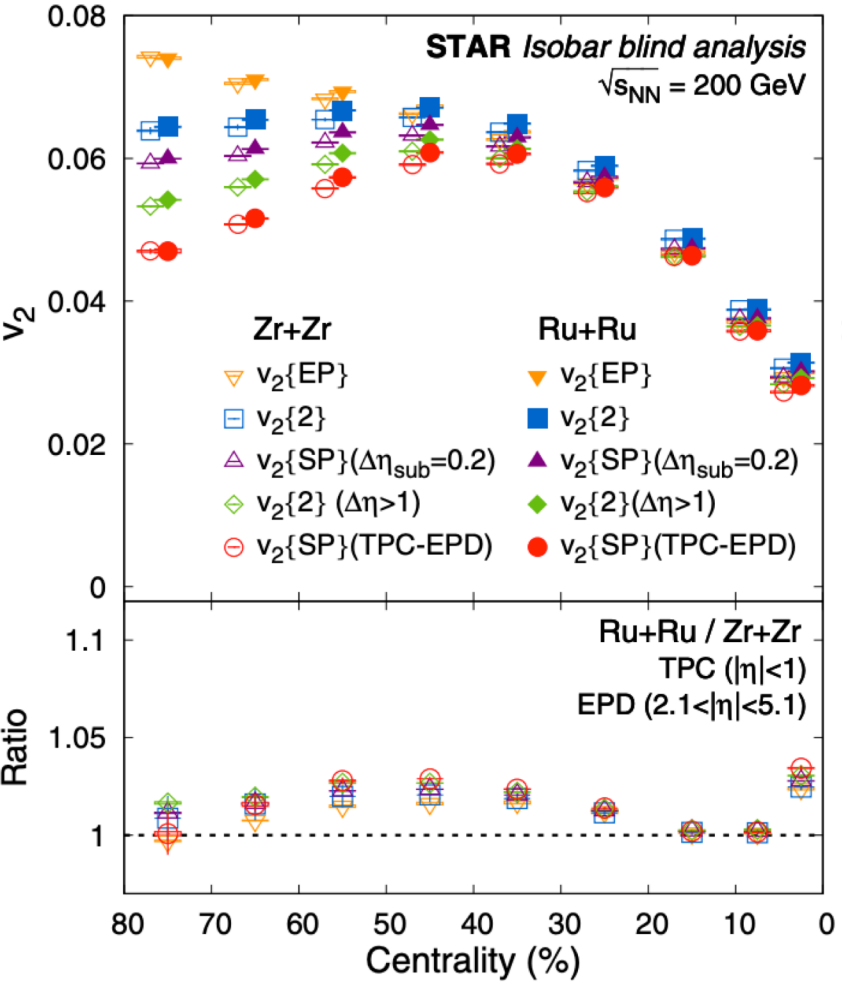
- Ratios increase more rapidly with increasing particle mass
- Different centralities show similar trends

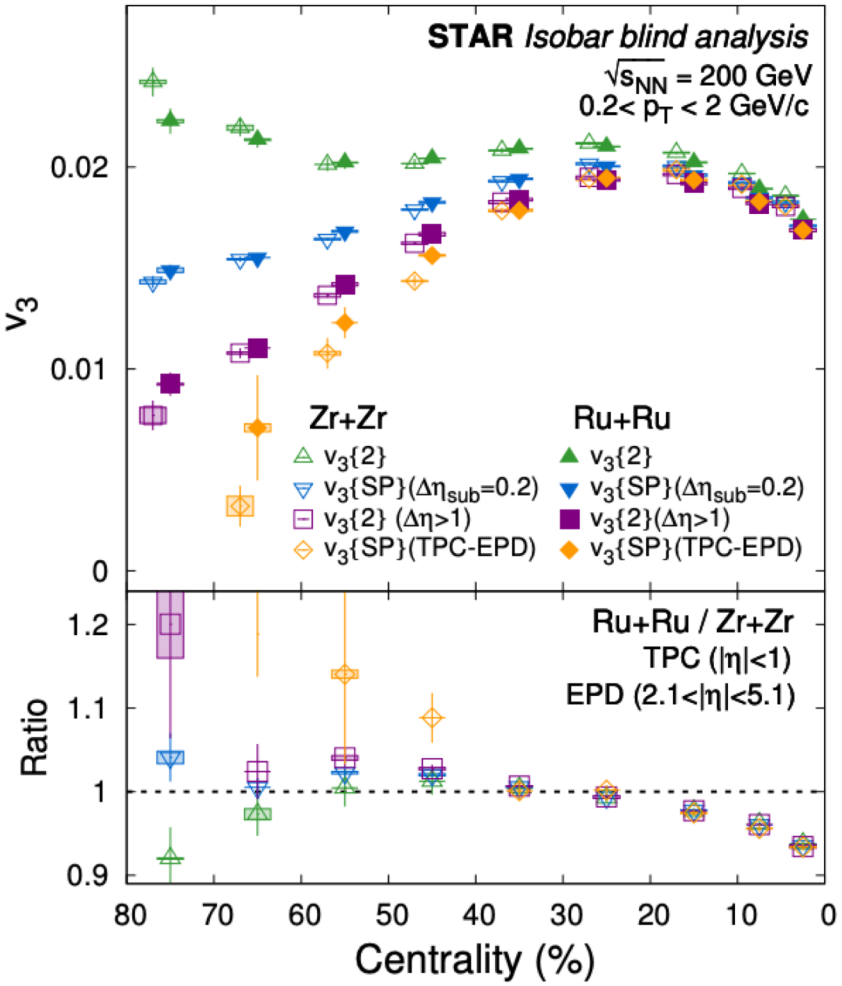
System Size Dependence of Medium Properties



Collectivity in Small & Medium Systems

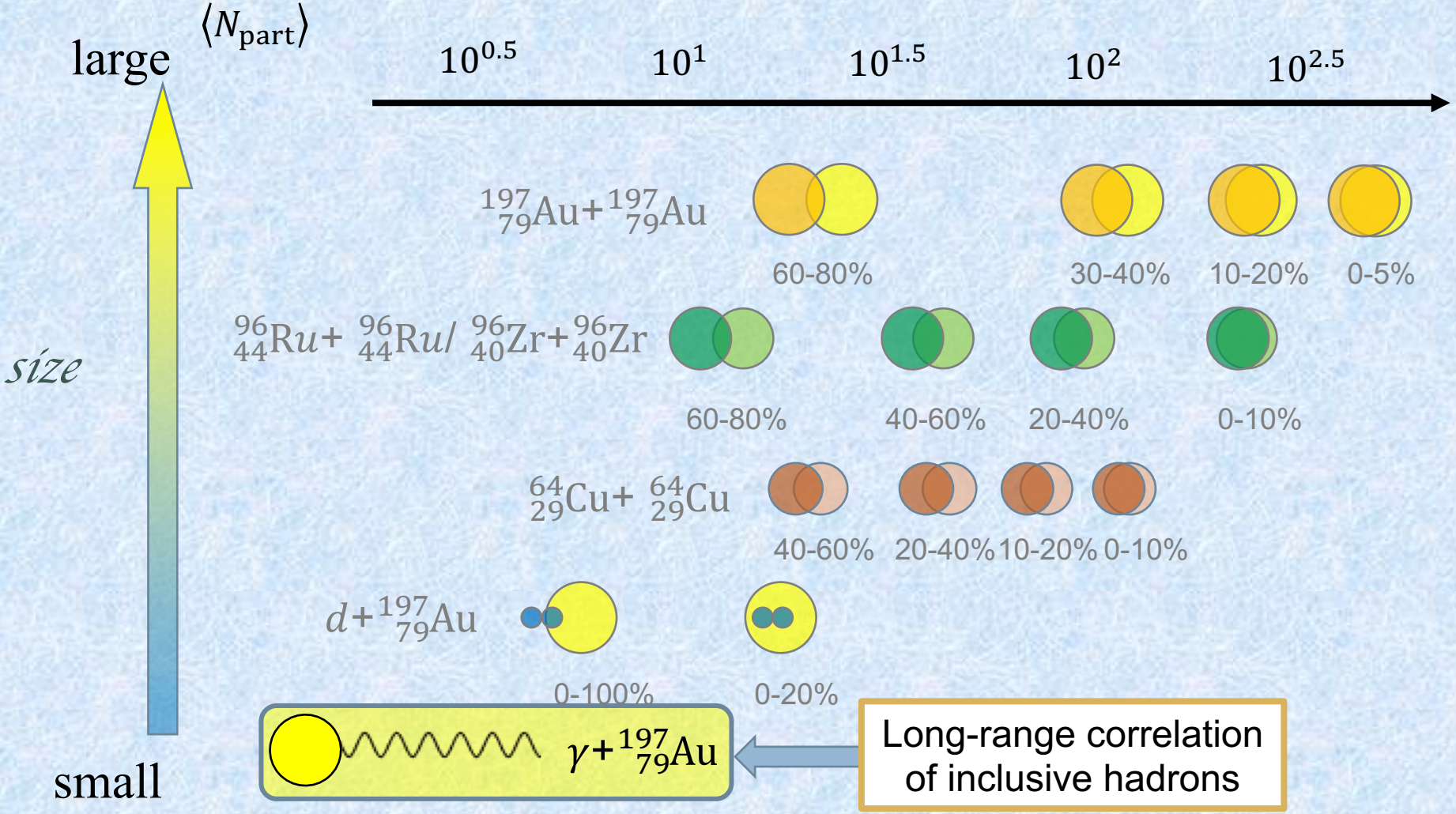
STAR, Phys. Rev. C, **105** 014901 (2022)



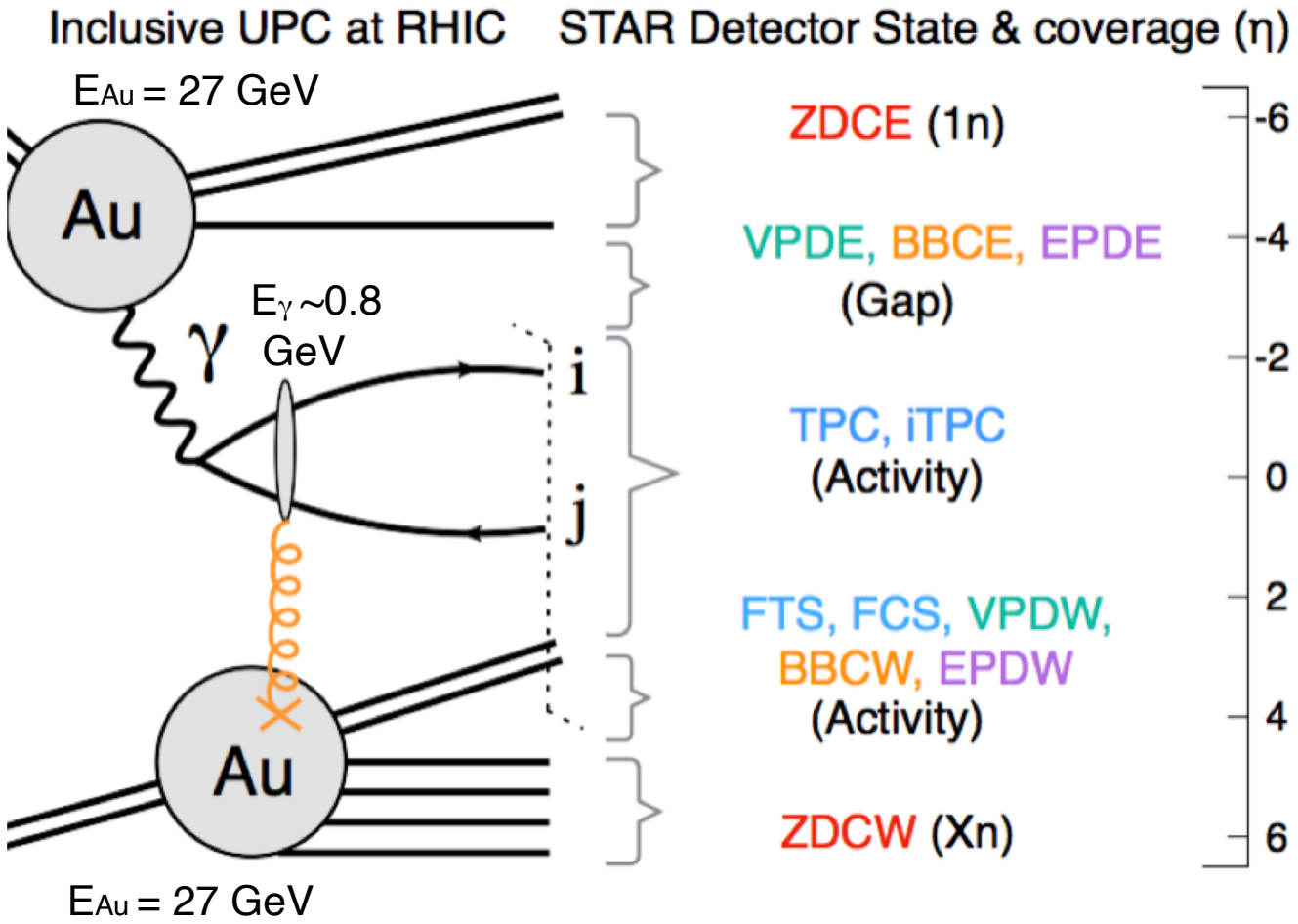


- Sizable v_2 & v_3 in isobar systems
- Different v_n for different methods
  - Same ratio for a fixed centrality bin
- Collectivity also seen in *p/d*+Au systems
- What does collectivity look like in even smaller system?

System Size Dependence of Medium Properties



Tagging Photonuclear Events in Heavy-Ion Collisions



Poster by Nicole Lewis(Session 2 T08 #551)

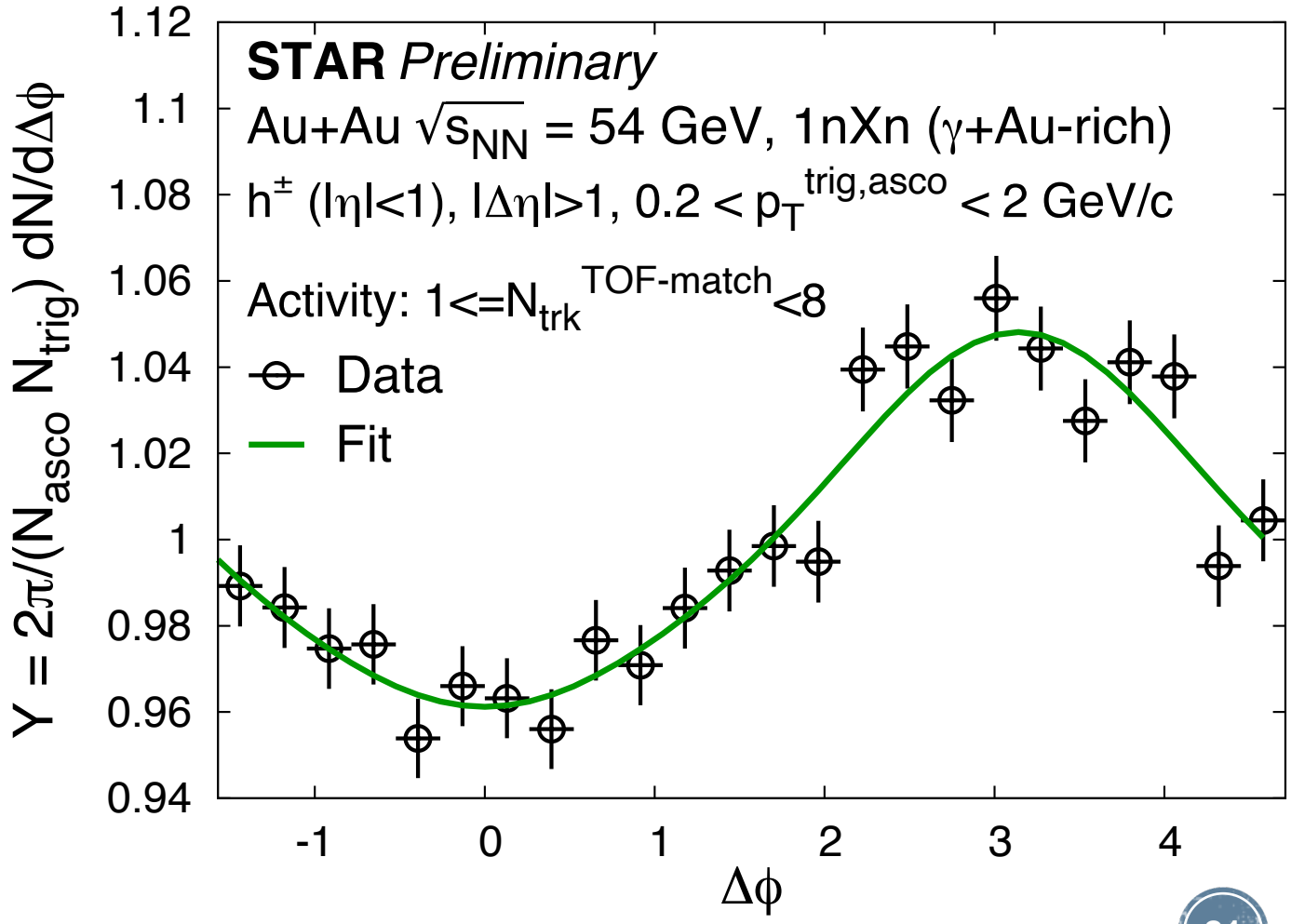
- Photo-nuclear collision: proxy for low-Q^2 DIS
- Experimental access: tagged heavy-ion events
- Take advantage of asymmetric nature in tagging
  - Forward particle production on nucleus-going side & absence on photon-going side
  - See backup slide for more details on tagging γ+Au events

Collectivity in Photonuclear Events?

- Di-hadron correlation: probe collectivity of system
- $Y(\Delta\phi, |\Delta\eta| > 1) = \frac{2\pi}{N_{\text{trig}} N_{\text{assoc}}} \frac{dN_{\text{pair}}}{d\Delta\phi}$

$= 1 + \sum_n 2v_n \cos(n\Delta\phi)$

- No near-side ridge within uncertainty: **No clear sign of collectivity**
- Higher activity γ+Au events under exploration
- Improved measurements with forward upgrade in 2023-25 with 200 GeV Au+Au collisions



Conclusions

- Medium suppression of high-p_T hadrons mainly determined by $\langle N_{part} \rangle$
- Selection bias observed in peripheral events
- Ru+Ru/Zr+Zr particle yield ratios show species dependence
- Charge ratio shows hint on isospin effect
- No significant collectivity in photonuclear collisions observed

Outlook

- Detailed study of selection bias in high-p_T particle yield
- More differential study on dependence of quenching: volume, path-length, etc.
- Detailed study of identified particle spectrum & ratio as a function of rapidity & centrality
- STAR forward upgrade: opportunities for γ+ A system

QUARK MATTER
KRAKÓW
2022

29TH INTERNATIONAL
CONFERENCE ON ULTRARELATIVISTIC
NUCLEUS - NUCLEUS COLLISIONS
APRIL 4-10, 2022
KRAKÓW, POLAND

Thank you!
Dziękuję Ci!

Backup

STAR Isobar Collisions

- Zr+Zr/Ru+Ru collision system
  - System size between large (Au+Au) and small (p/d+Au) system
- Run 18 Zr+Zr/Ru+Ru Collisions
  - Fine change in nuclear structure & system size: impact of difference in overlapping geometry
  - Large statistics:2B Zr+Zr & 1.8B Ru+Ru Minimum-biased Events
  - Highly controlled for detector uniformity across runs & luminosity condition
  - Minimized systematics

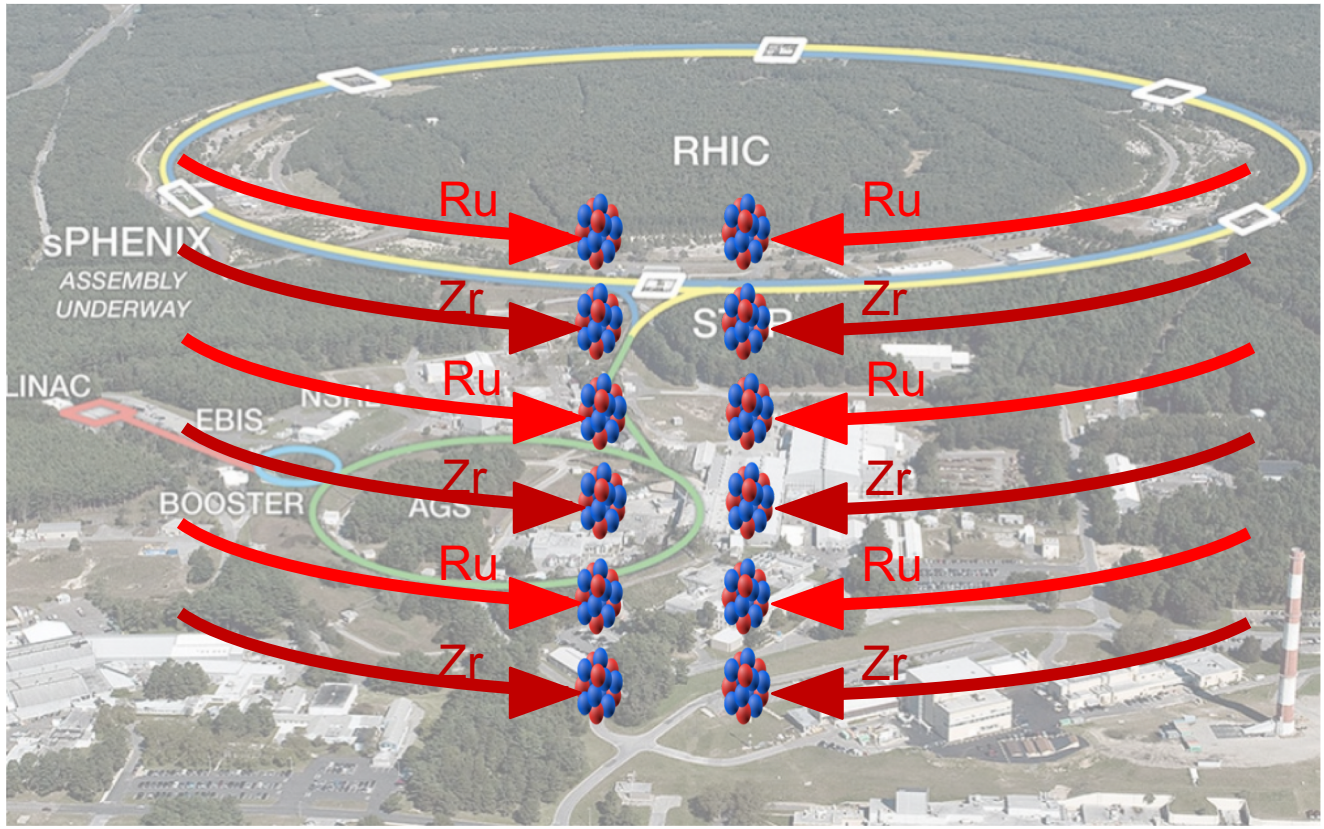
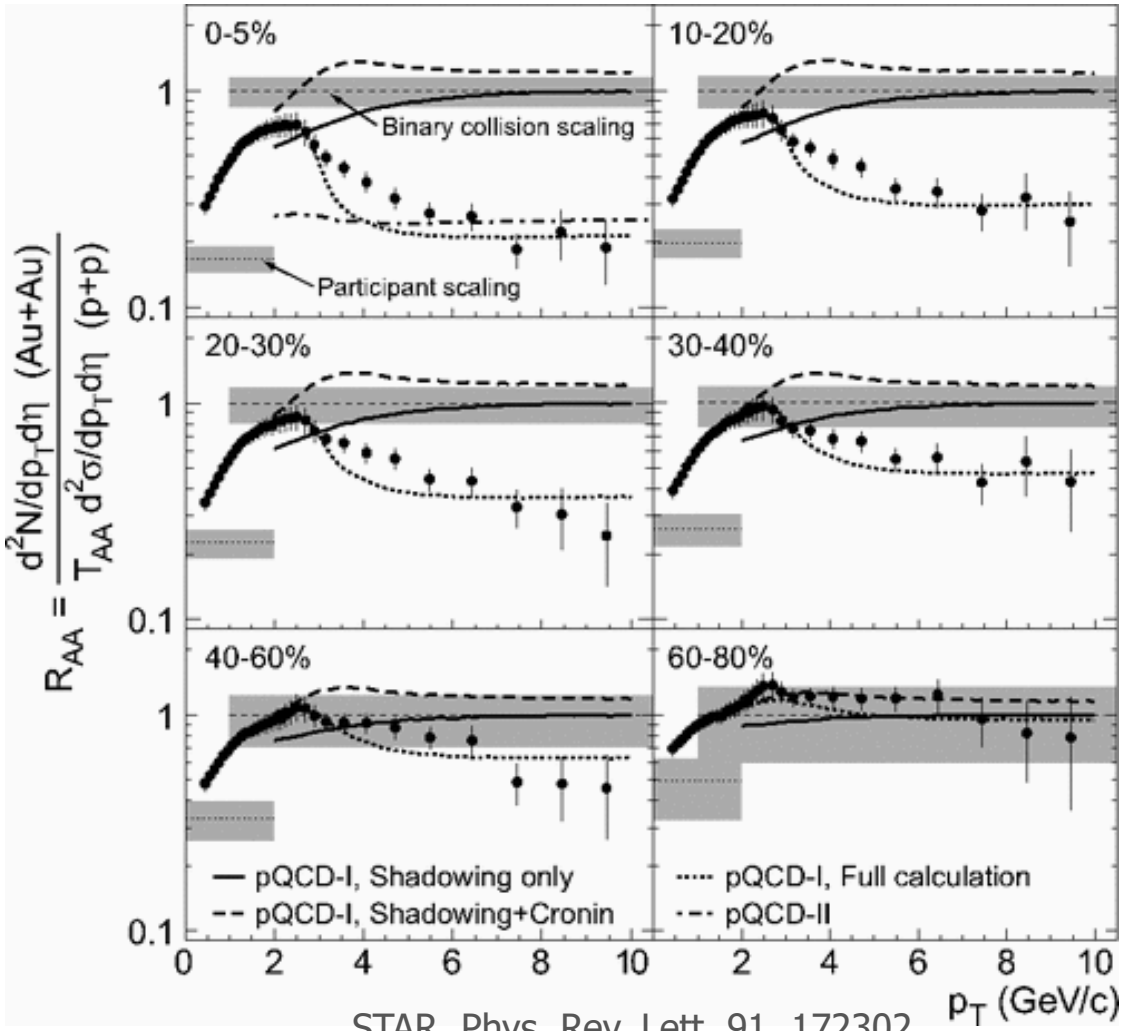


Photo Credit: https://en.wikipedia.org/wiki/Nucleon
https://www.interactions.org/press-release/start-22nd-run-relativistic-heavy-ion-collider-rhic

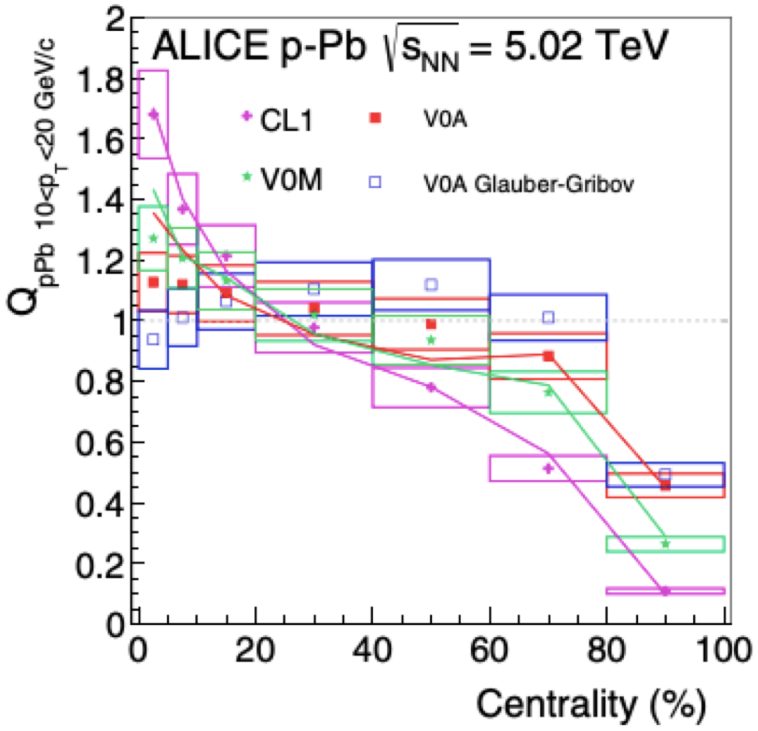
Hadron Yield at High Momentum & Medium Modification

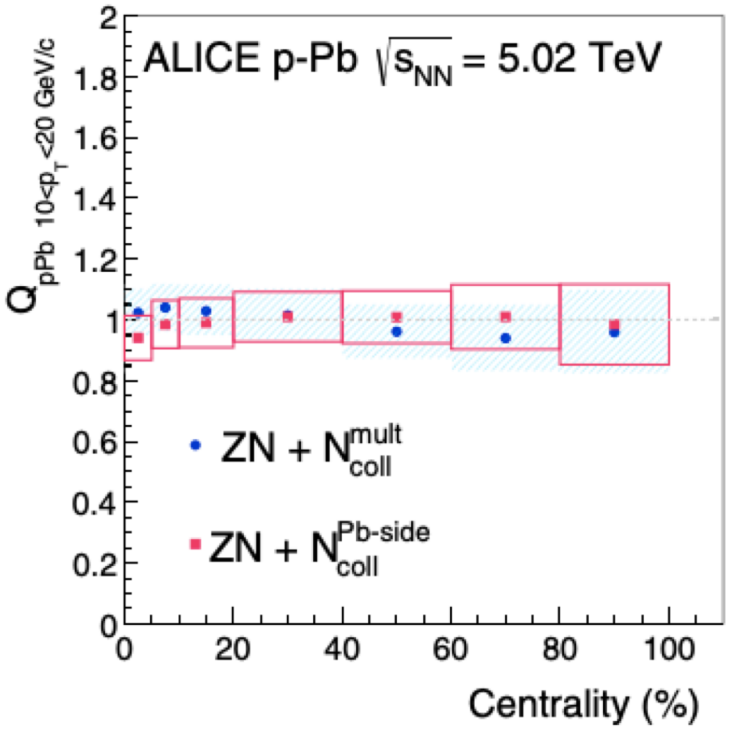
- Hard partons lose energy to QGP: Jet Quenching
- High p_T hadrons: proxy to hard partons
- Glauber model:
  - $\langle N_{part} \rangle$ scaling for lower- p_T
  - $\langle N_{coll} \rangle$ scaling for high- p_T
- Nuclear Modification factor R_{AA}: comparison to p+p collisions
- Combine with existing U+U, Au+Au, Cu+Cu & d+Au data
  - Continuous evolution with system size

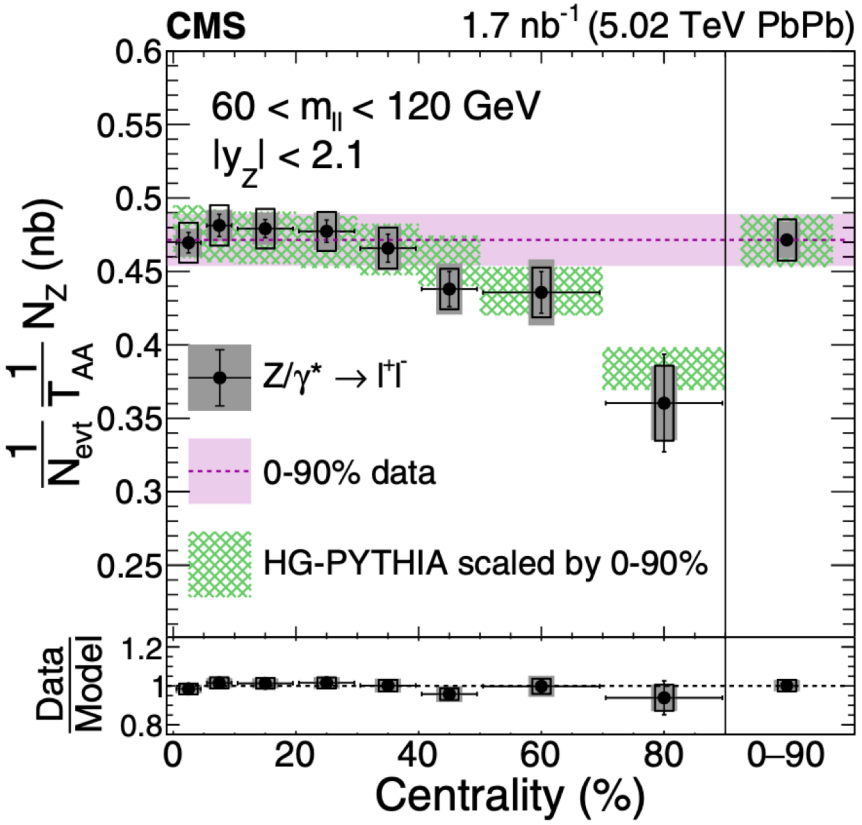


STAR, Phys. Rev. Lett. 91, 172302

Selection Bias on High-p_T Probes in Peripheral Events



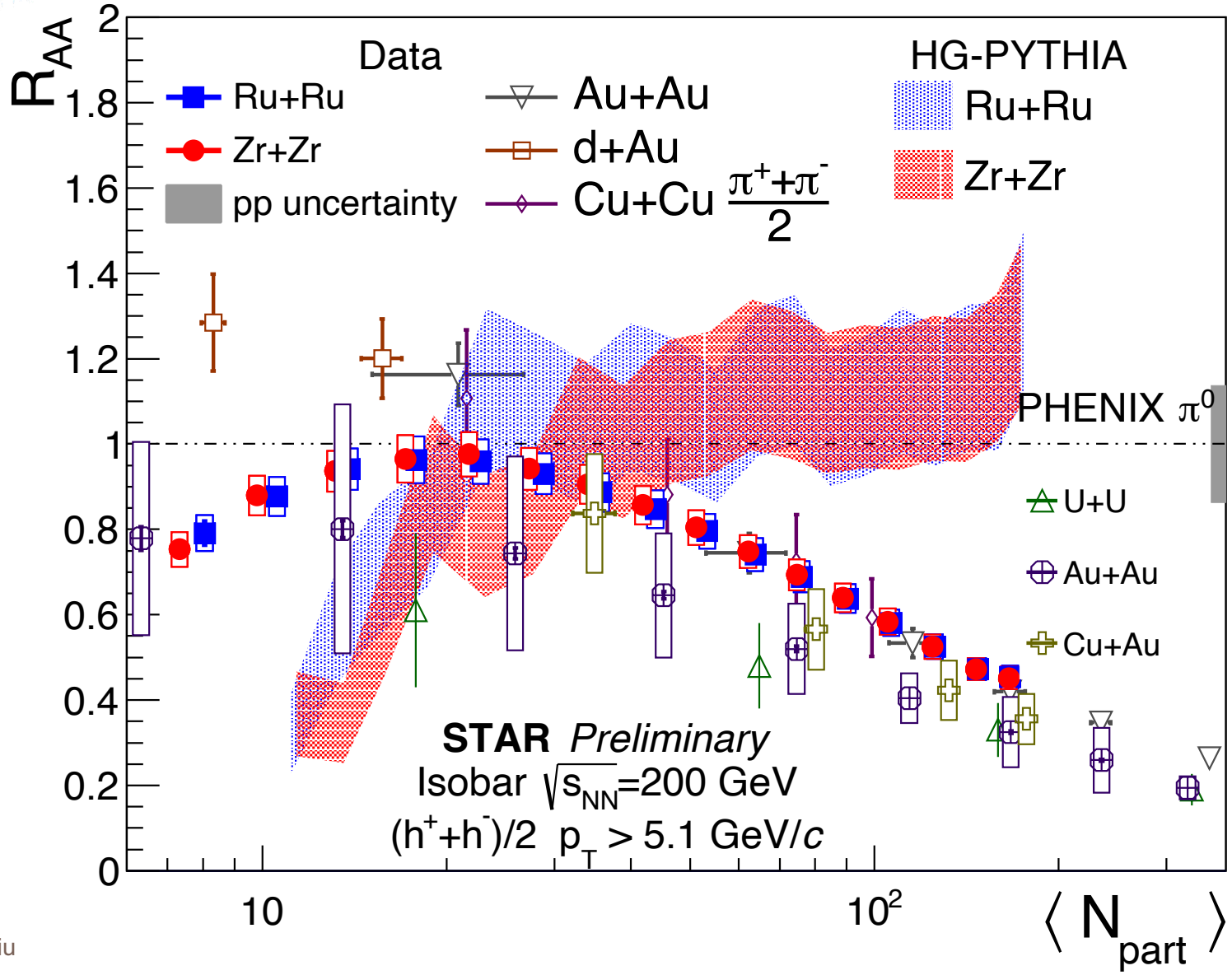




- ALICE show different selection biases on different centrality definitions
- CMS observed suppression in peripheral events for Z-boson yield

ALICE, Phys. Rev. C **91**, 064905 (2015)
CMS, Phys. Rev. Lett. **127**, 102002 (2021)

R_{AA} with PHENIX results

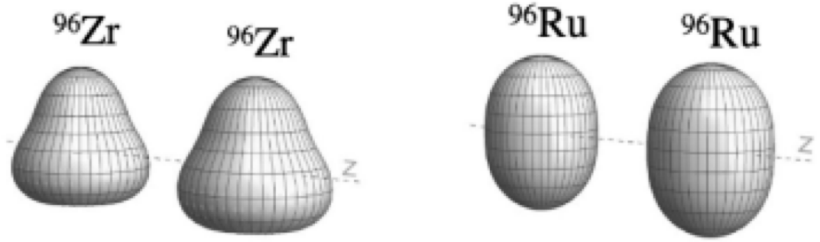


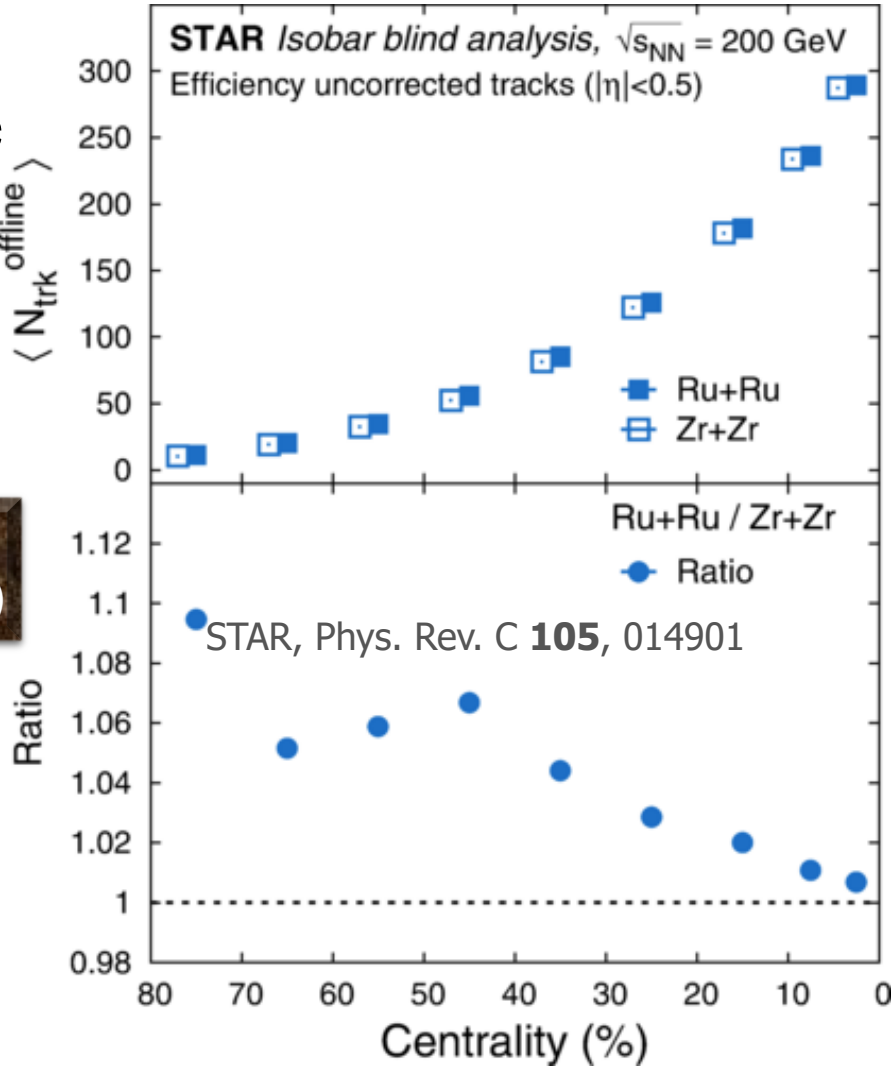
STAR Phys. Rev. Lett. **91**, 172302 (2003)
STAR Phys. Rev. Lett. **91**, 072304 (2003
STAR Phys. Rev. C **81**, 054907 (2010)
PHENIX Phys. Rev. C **102**, 064905 (2020)
PHENIX Phys. Rev. C **98**, 054903 (2018)
PHENIX Phys. Rev. Lett. **101**, 232301(2008)

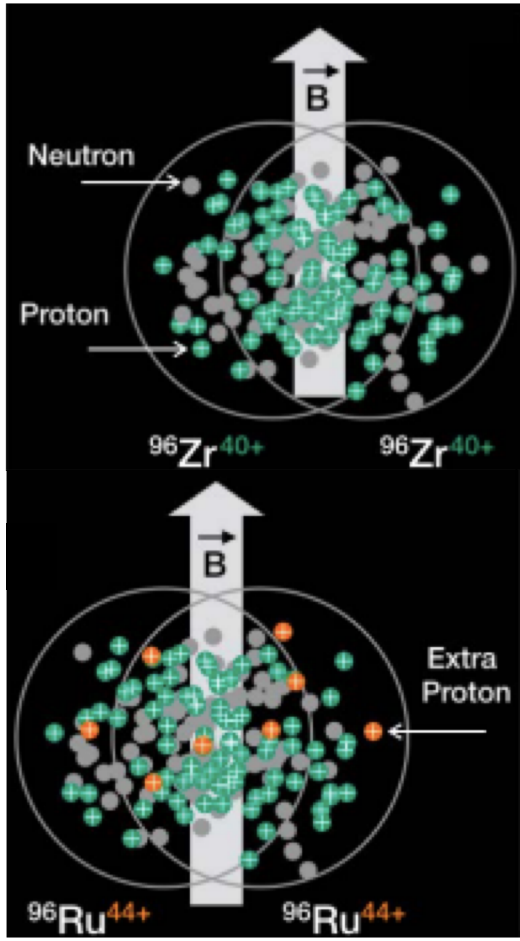
Identified Hadron Momentum Distribution in Isobar Collisions

- Different nuclear density function lead to different multiplicity in same centrality
- Difference in proton numbers also create net charge difference

Refer to: Talk by Haojie Xu (Wed 9:00 AM T01) & Poster by Chunjian Zhang (Session 2 T14-2 #962)







Selection of Photonuclear Events

- γ+ Au rich event selection:
  - Multiplicity: $1 < N_{\mathrm{trk}}^{\mathrm{TOF-Match}} \leq 8$
  - ZDC: 1n (γ-going) & Xn (nucleus-going)
  - VPD: $|v_z^{\mathrm{VPD}} - v_z^{\mathrm{TPC}}| > 10$cm, mismatch with TPC
  - BBC(γ-going)<200 & BBC(nucleus-going)>400