Event-by-Event AVFD Framework

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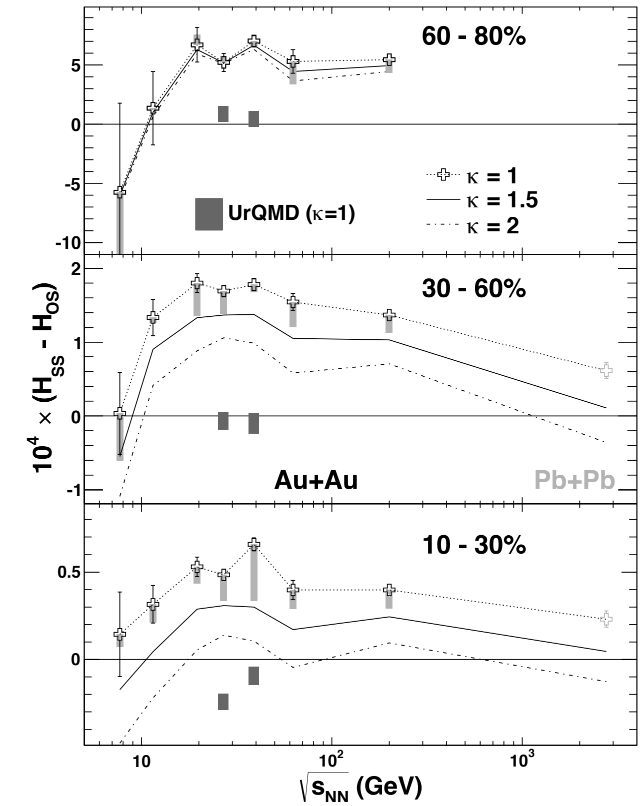
On behalf of the AVFD group

CME In Heavy-Ion Collisions



axial & vector charge density

Anomalous
-**V**iscous
Fluid
Dynamics

initial condition

+

driving force

B field

→ dynamical evolution → final particle distribution

Anomalous-Viscous Fluid Dynamics

$$D_\mu J_R{}^\mu = +\frac{N_c q^2}{4\pi^2} E_\mu B^\mu \qquad D_\mu J_L{}^\mu = -\frac{N_c q^2}{4\pi^2} E_\mu B^\mu$$

CME

$$J_R{}^\mu = n_R\, u^\mu + \nu_R{}^\mu + \frac{N_c q}{4\pi^2} \mu_R\, B^\mu$$

$$J_L{}^\mu = n_L\, u^\mu + \nu_L{}^\mu - \frac{N_c q}{4\pi^2} \mu_L\, B^\mu$$

Viscous Effect

$$\Delta^\mu{}_\nu\, \mathrm{d}\, \nu_{R,L}{}^\nu = -\frac{1}{\tau_{\mathrm{rlx}}}(\nu_{R,L}{}^\mu - \nu_{NS}{}^\mu)$$

$$\nu_{NS}{}^\mu = \frac{\sigma}{2} T \Delta^{\mu\nu} \partial_\nu \frac{\mu}{T} + \frac{\sigma}{2} q\, E^\mu$$

as the linear perturbation on top of
2+1D Hydro background

CME In Heavy-Ion Collisions

- B field ⊗ μ_5 ⇒ current ⇒ dipole (charge separation)

$$dN_{\pm}/d\phi \propto 1 + 2\, a_{1\pm} \sin(\phi - \psi_{RP}) + \ldots$$

CME In Heavy-Ion Collisions

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$$dN_{\pm}/d\phi \propto 1 + 2\, a_{1\pm} \sin(\phi - \psi_{RP}) + \ldots$$

- charge separation ⇒ charge dept. two-particle correlation

$$\gamma = \langle \cos(\Delta\phi_i + \Delta\phi_j) \rangle = \langle \cos\Delta\phi_i \cos\Delta\phi_j \rangle - \langle \sin\Delta\phi_i \sin\Delta\phi_j \rangle$$

$$\delta = \langle \cos(\Delta\phi_i - \Delta\phi_j) \rangle = \langle \cos\Delta\phi_i \cos\Delta\phi_j \rangle + \langle \sin\Delta\phi_i \sin\Delta\phi_j \rangle$$

$$\gamma = \kappa\, v_2\, F - H$$

$$\delta = F + H$$

F: Bulk Background

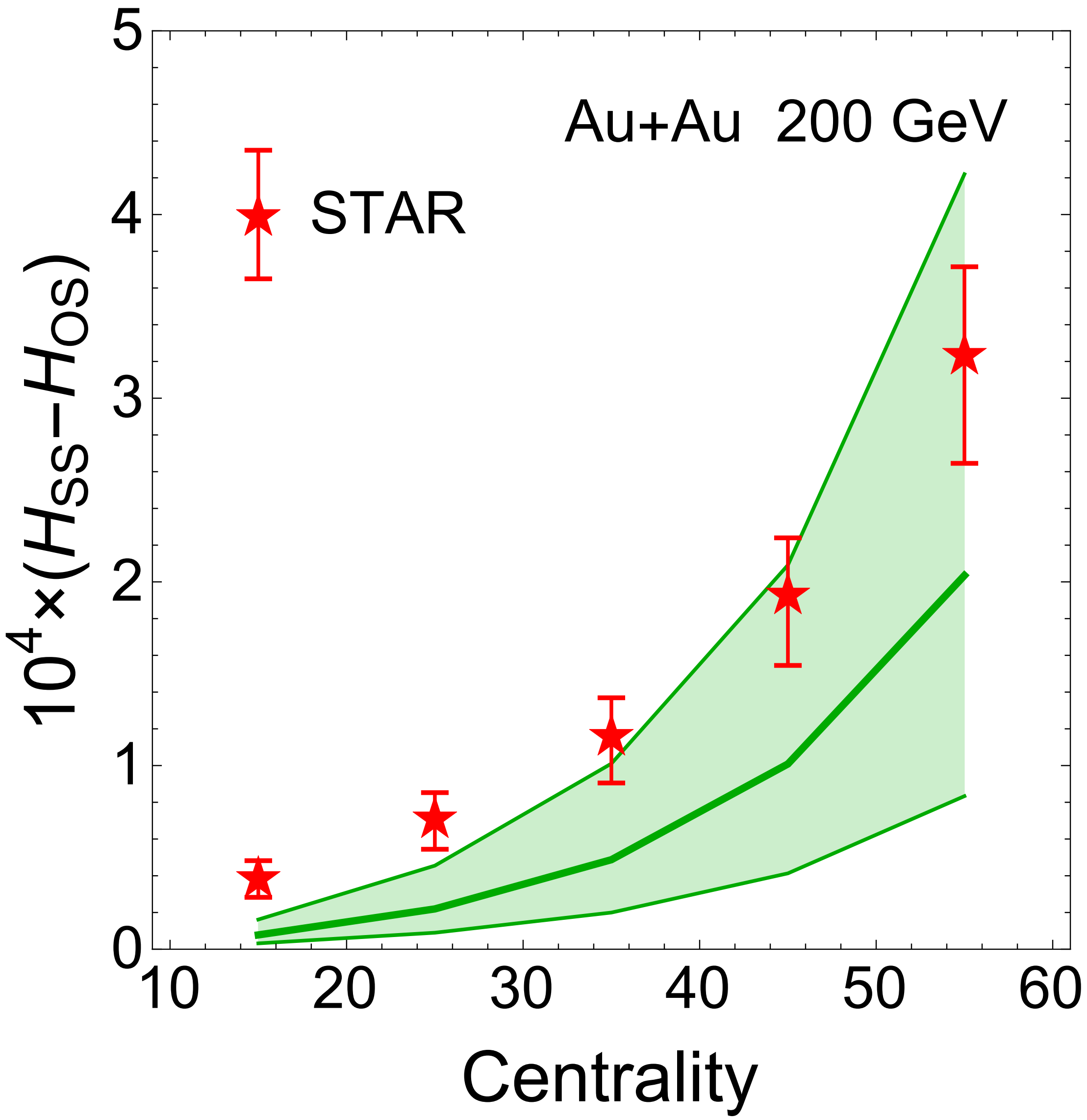
H: Possible Pure CME Signal = $(a_{1,CME})^2$

Anomalous-Viscous Fluid Dynamics Packages

1st generation: [1611.04586 & 1711.02496]

Smooth IC + Hydro + Cooper-Frye Dist. + Res. Decay

(Glauber) (VISH) (iS) (iS)



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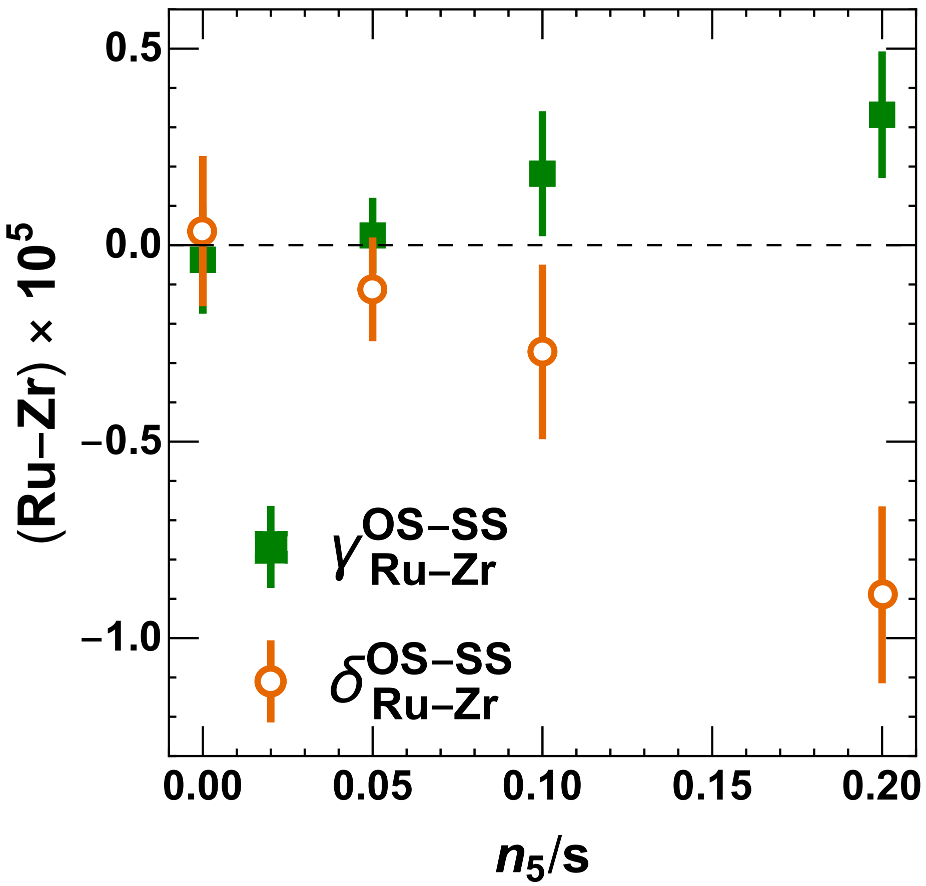
2nd generation: [1910.14010]

EbE IC + Hydro + grand-canonical sampler + Had. Cascade

(superMC) (VISH) (iSS w/ PLCC) (UrQMD)



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3rd generation:

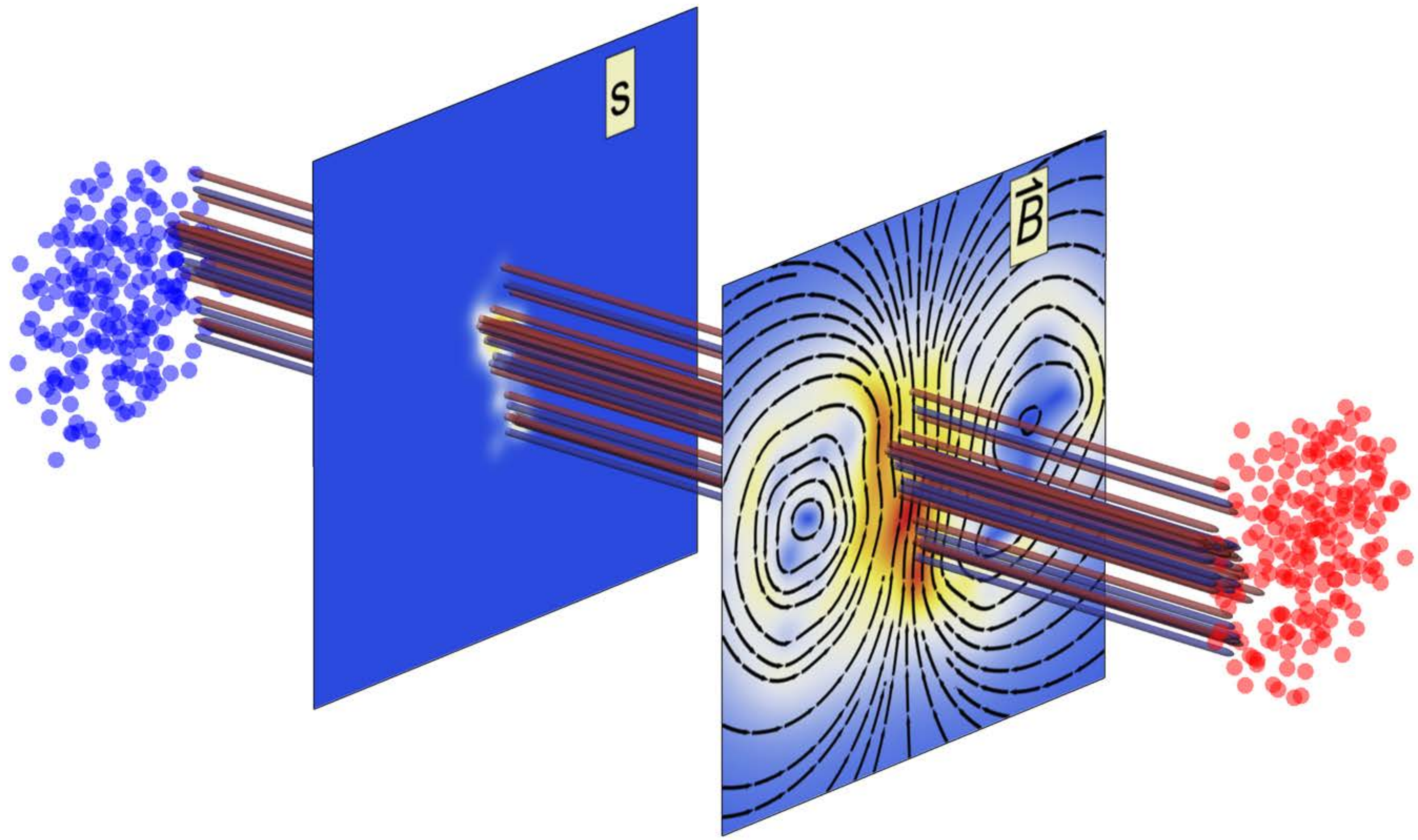
EbE IC + Hydro + micro-canonical sampler + Had. Cascade

(AVFD-IC) (MUSIC) (Oliinychenko-Koch) (smash)

Anomalous-Viscous Fluid Dynamics (3rd Gen.)

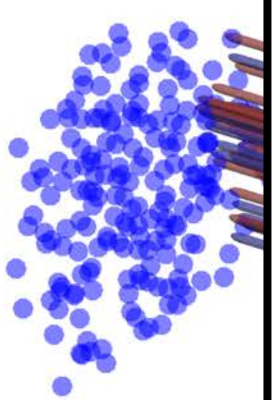
- MC-Glauber Generator
- New feature: able to test nucleon distribution

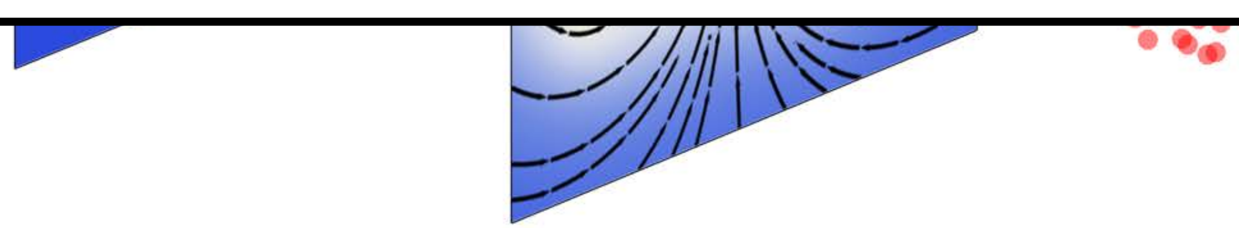
E-by-E IC of Bulk & B field



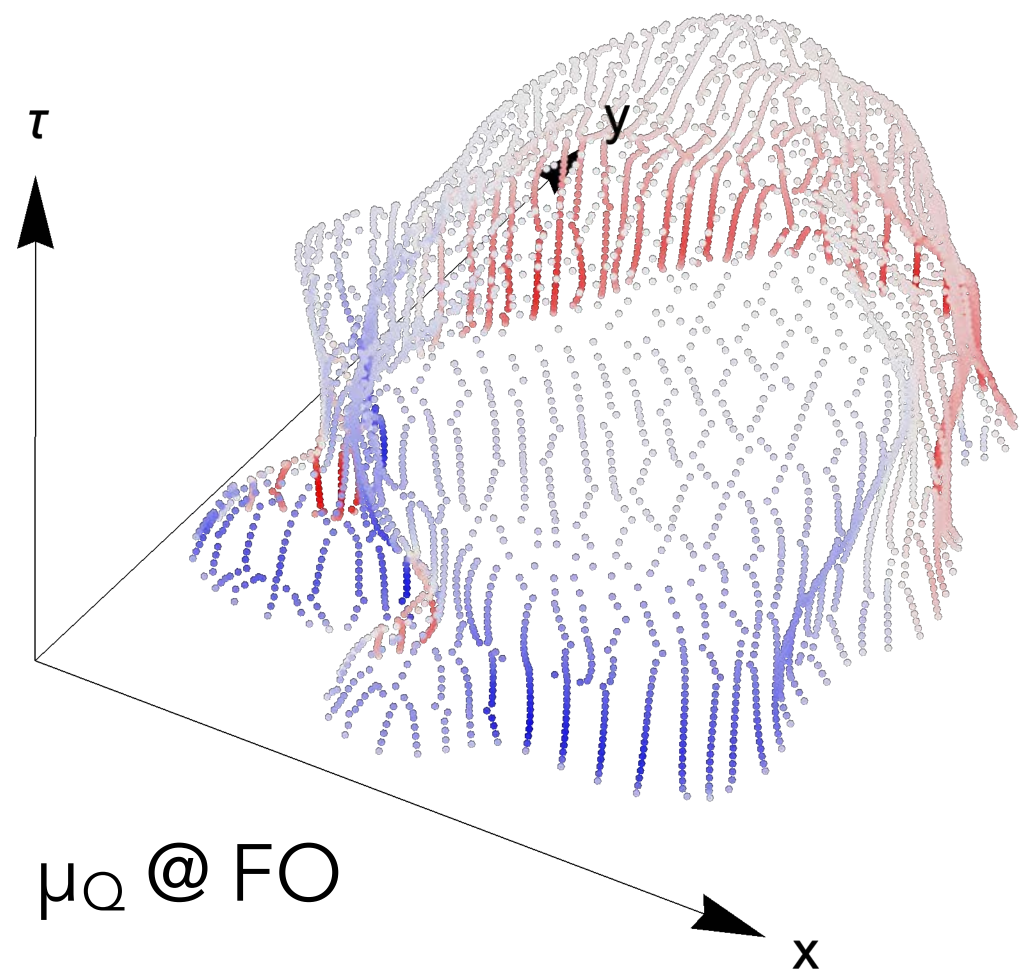
Anomalous-Viscous Fluid Dynamics (3rd Gen.)

E-by-E

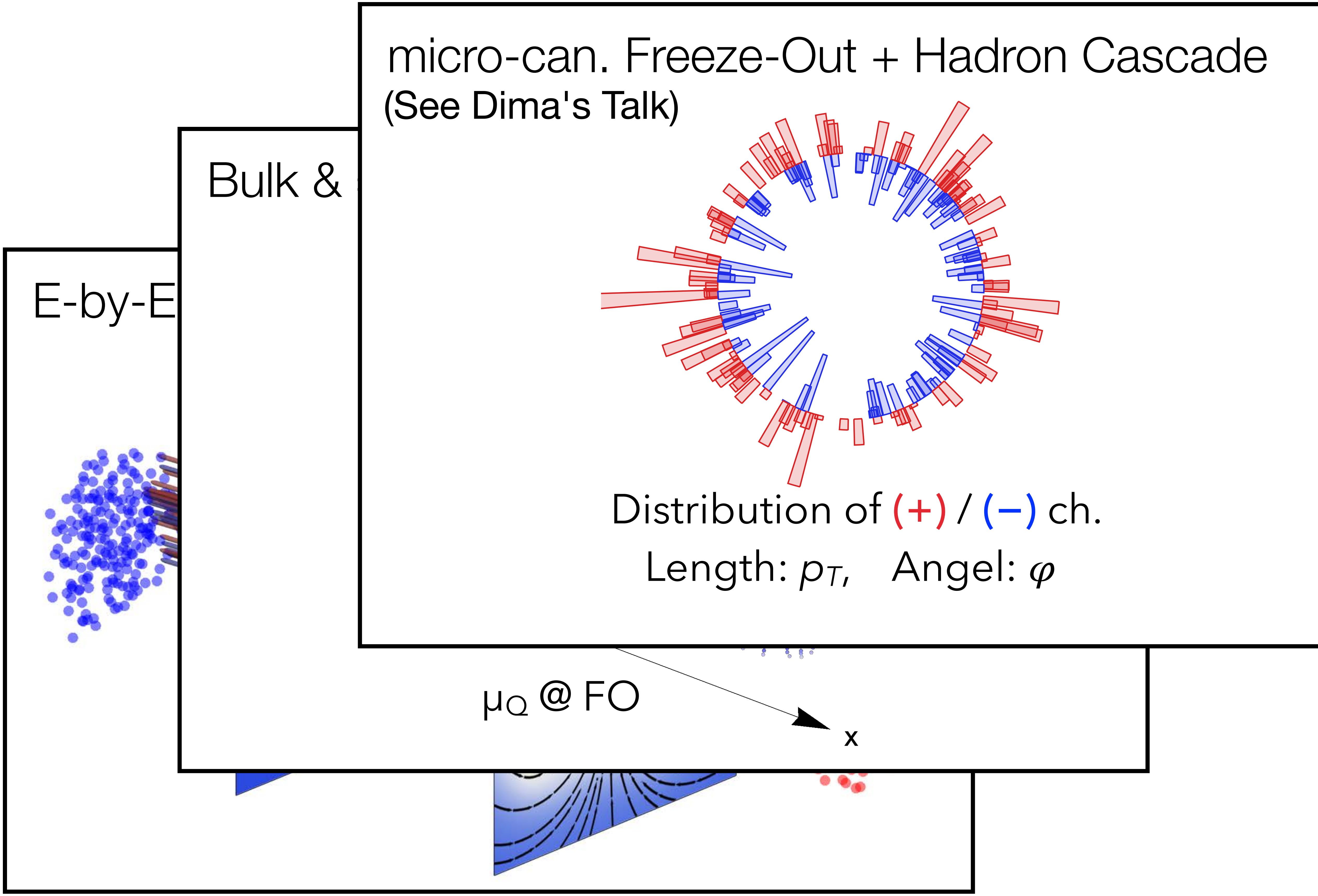




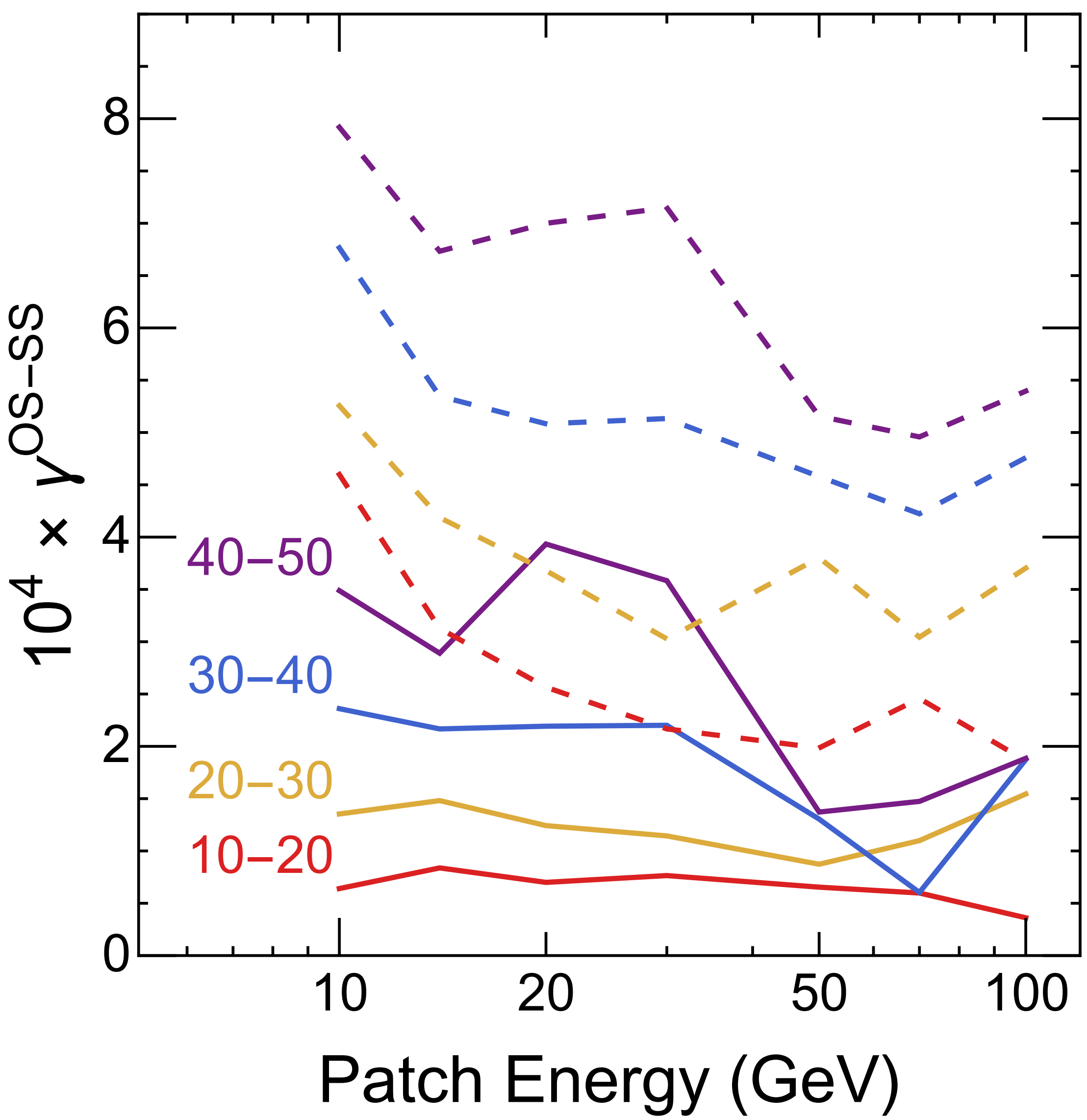
Bulk & => N, N5 evolution

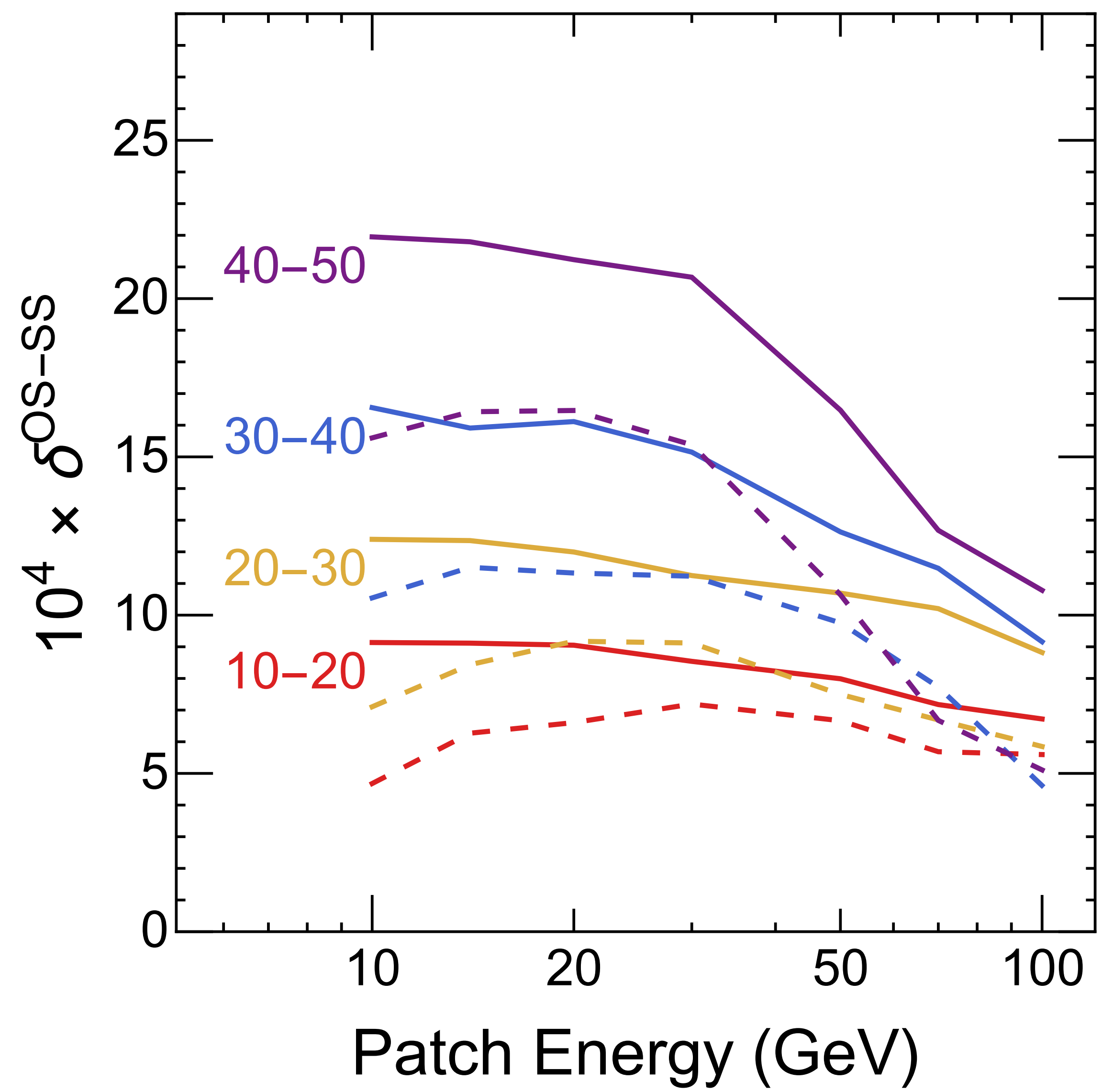


Anomalous-Viscous Fluid Dynamics (3rd Gen.)



Determining Patch Size in micro.-can. FO





solid: n_5=0, dash: n_5/s=0.2;
using smooth (event avg.) hydro
uncertainty band not shown;

sensitive to both signal and background

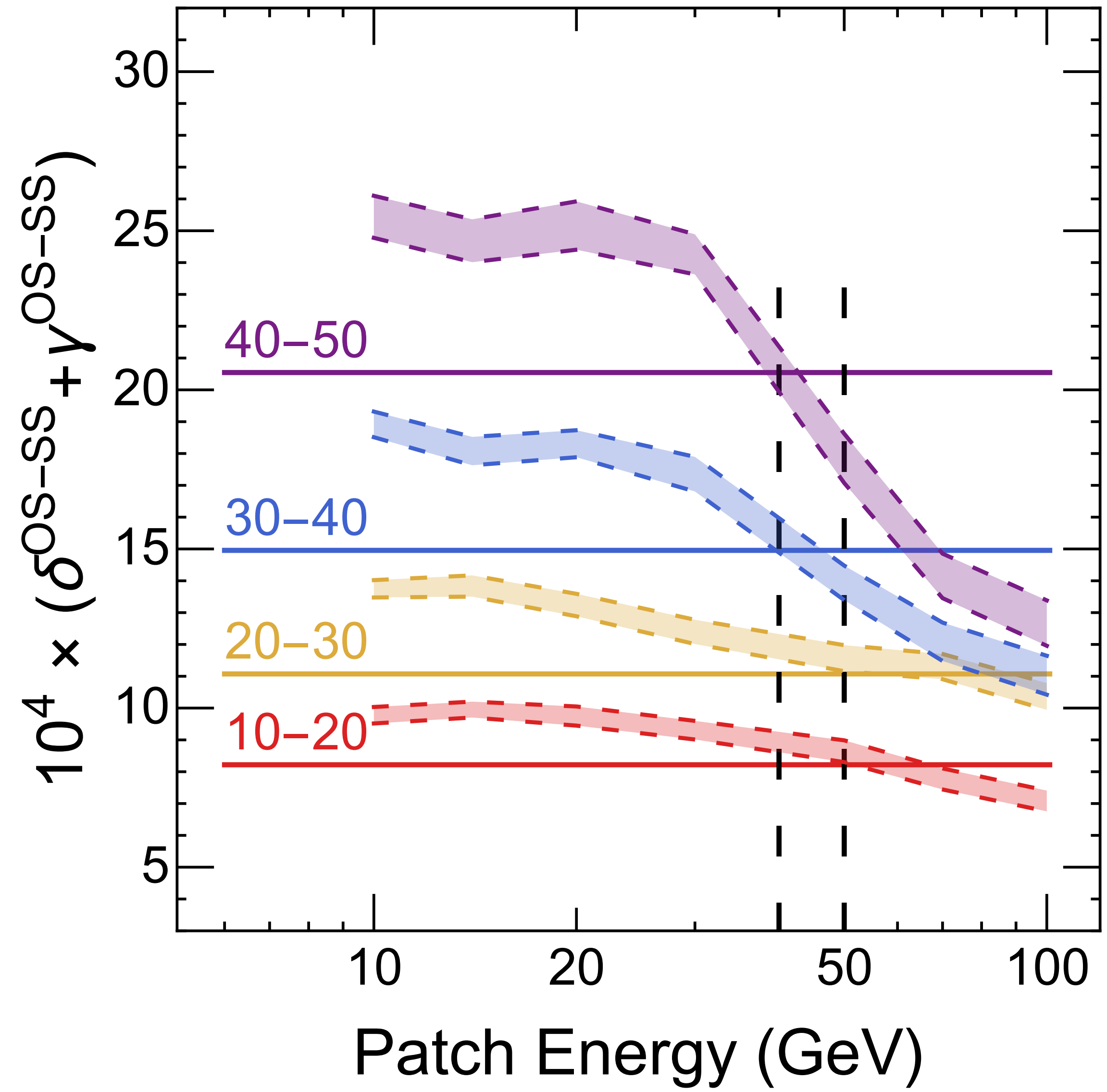
Determining Patch Size in micro.-can. FO

$$\gamma^{\mathrm{OS-SS}}\{\mathrm{RP}\} \sim \gamma^{\mathrm{OS-SS}}_{\mathrm{bkg}} + 2a^2_{1,\mathrm{CME}}$$

$$\delta^{\mathrm{OS-SS}} \sim \delta^{\mathrm{OS-SS}}_{\mathrm{bkg}} - 2a^2_{1,\mathrm{CME}}$$

$$\gamma^{\mathrm{OS-SS}}\{\mathrm{RP}\} + \delta^{\mathrm{OS-SS}}$$

shall be (mostly) background



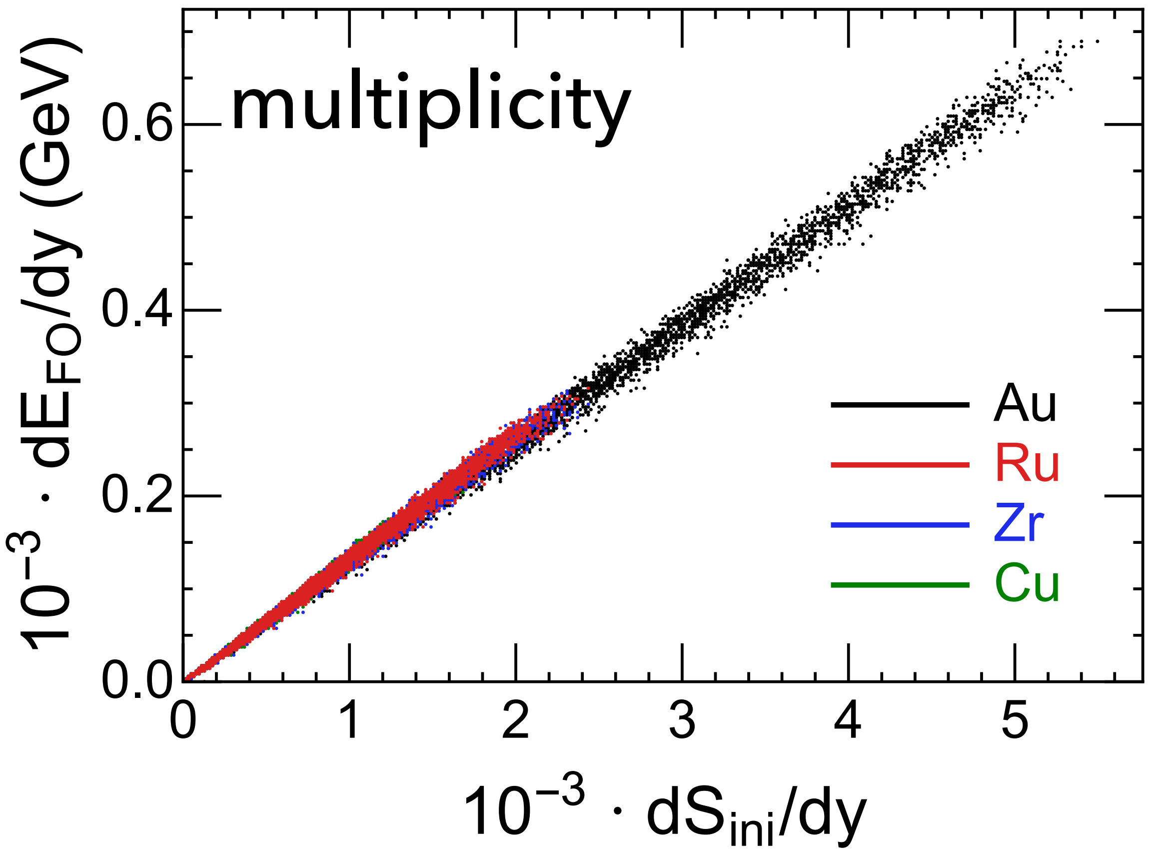
dashing band: simulation result

solid horizontal line: experiment,

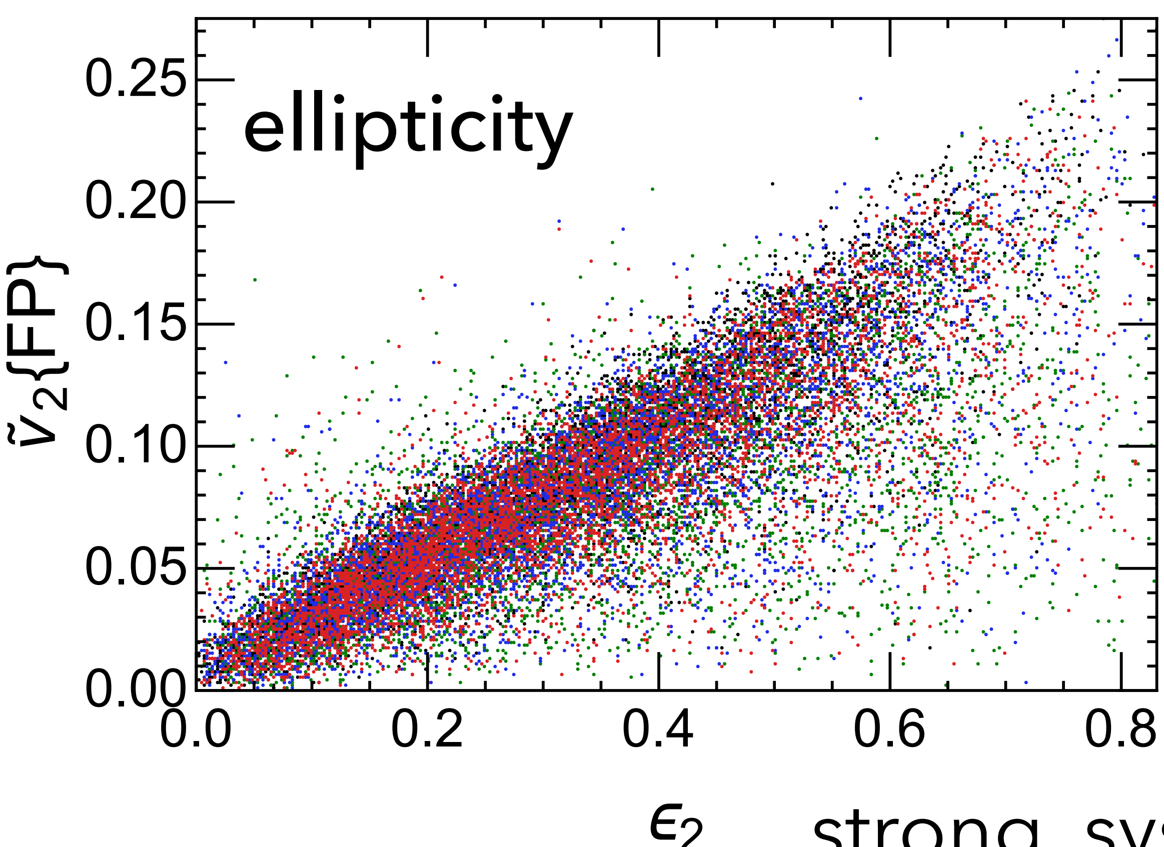
=> E_{patch} ~ 40 - 50 GeV;

"central value": E_{patch} = 45 GeV

Correlation between IC & Hydro

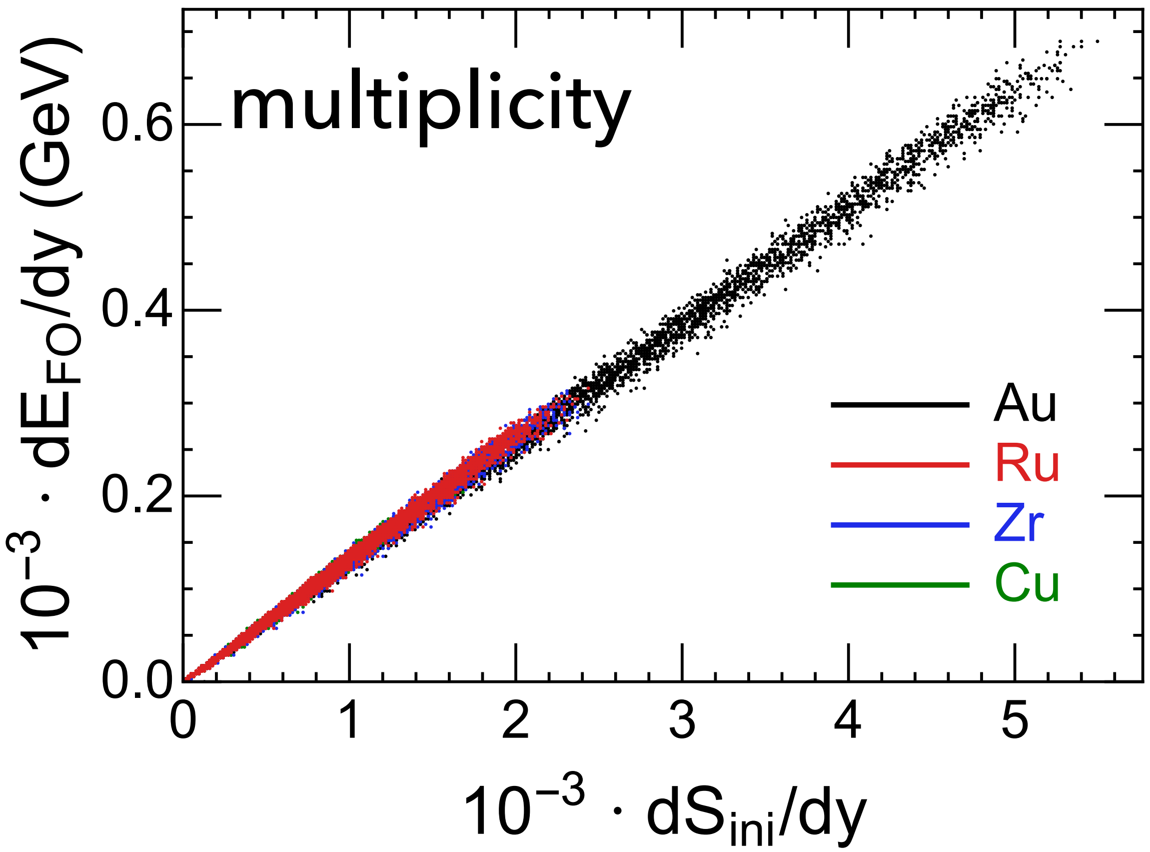


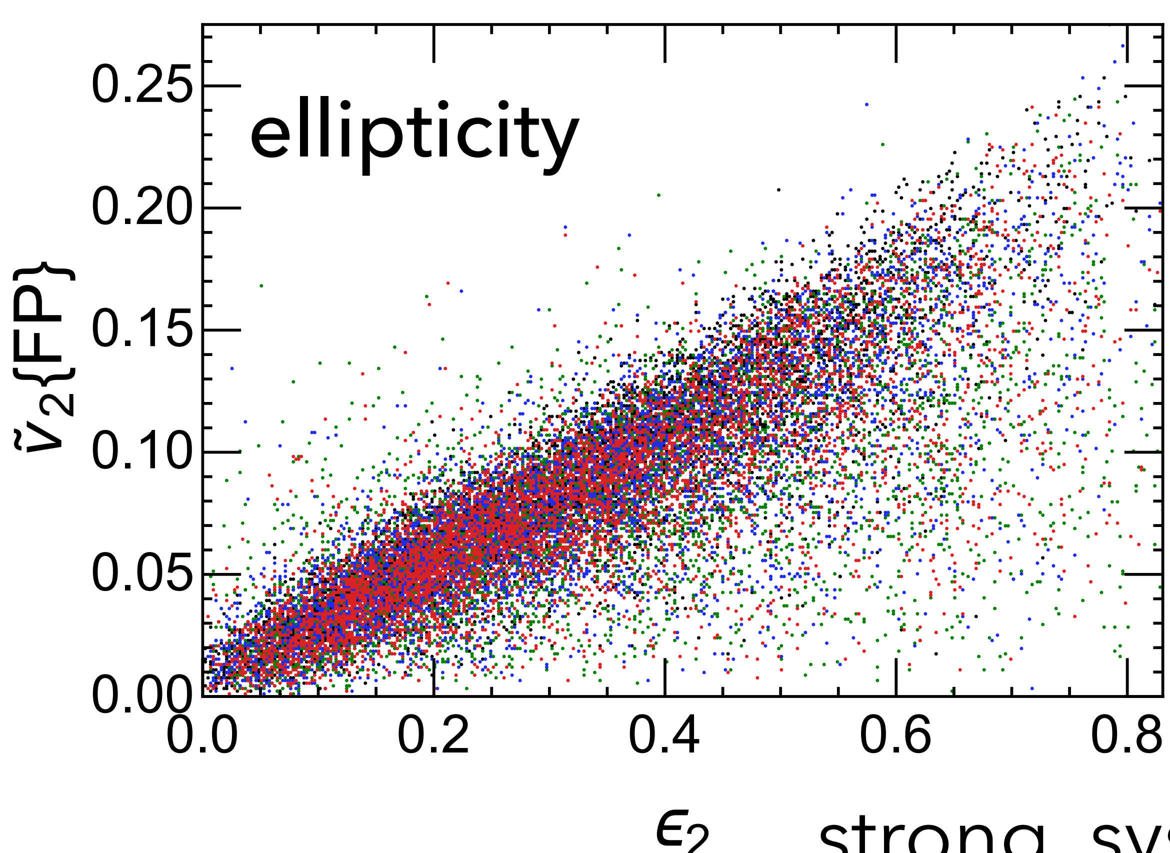
each point stands for one event



strong, sys. indept. correlation of mul. & ell.

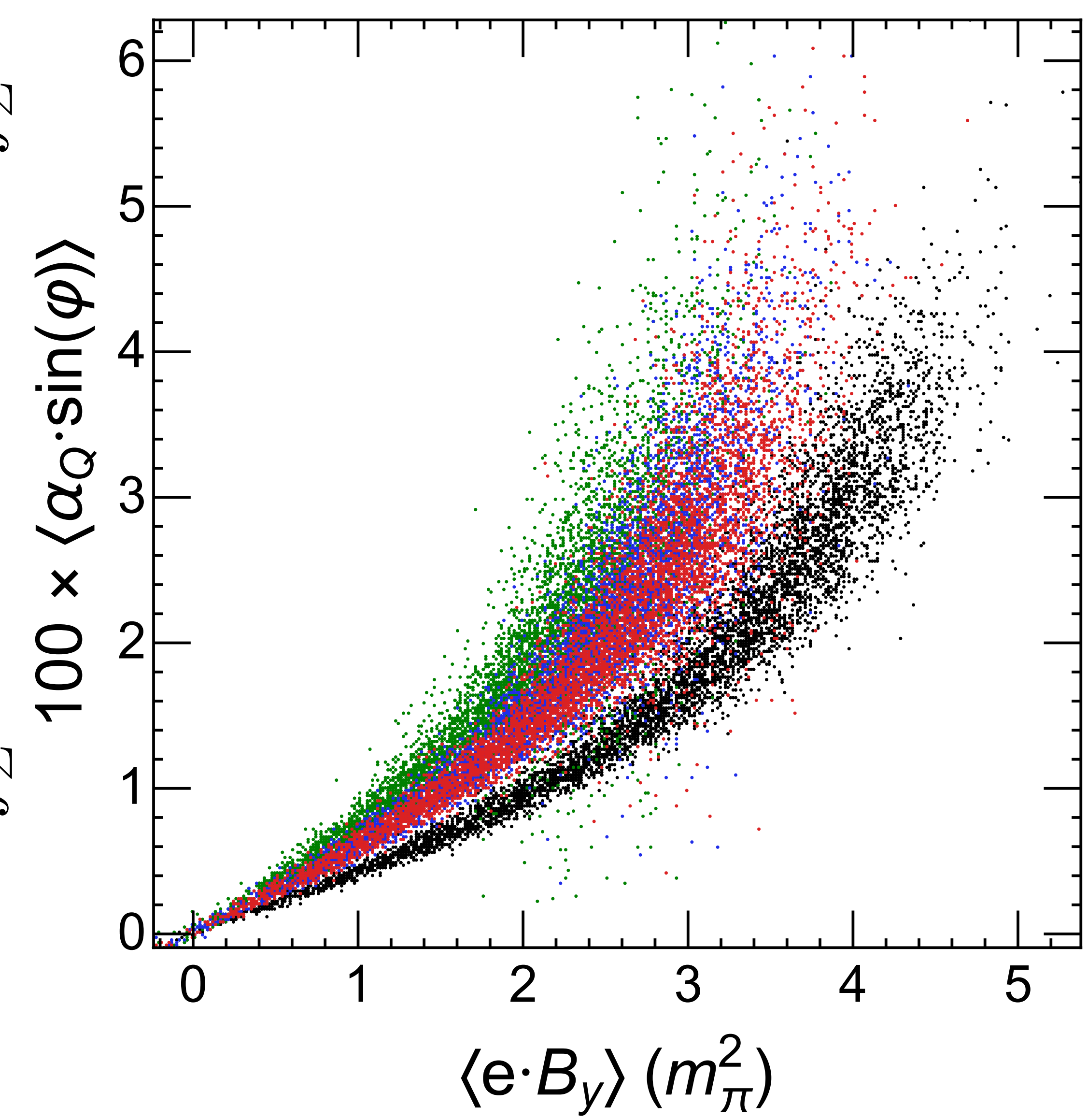
Correlation between IC & Hydro





$$\langle \alpha_Q \cdot \sin\varphi \rangle \equiv \left[\int_\Sigma u^\mu d\sigma_\mu \frac{\mu_Q}{T} \sin\varphi \right] \Big/ \left[\int_\Sigma u^\mu d\sigma_\mu \right]$$

each point stands for one event

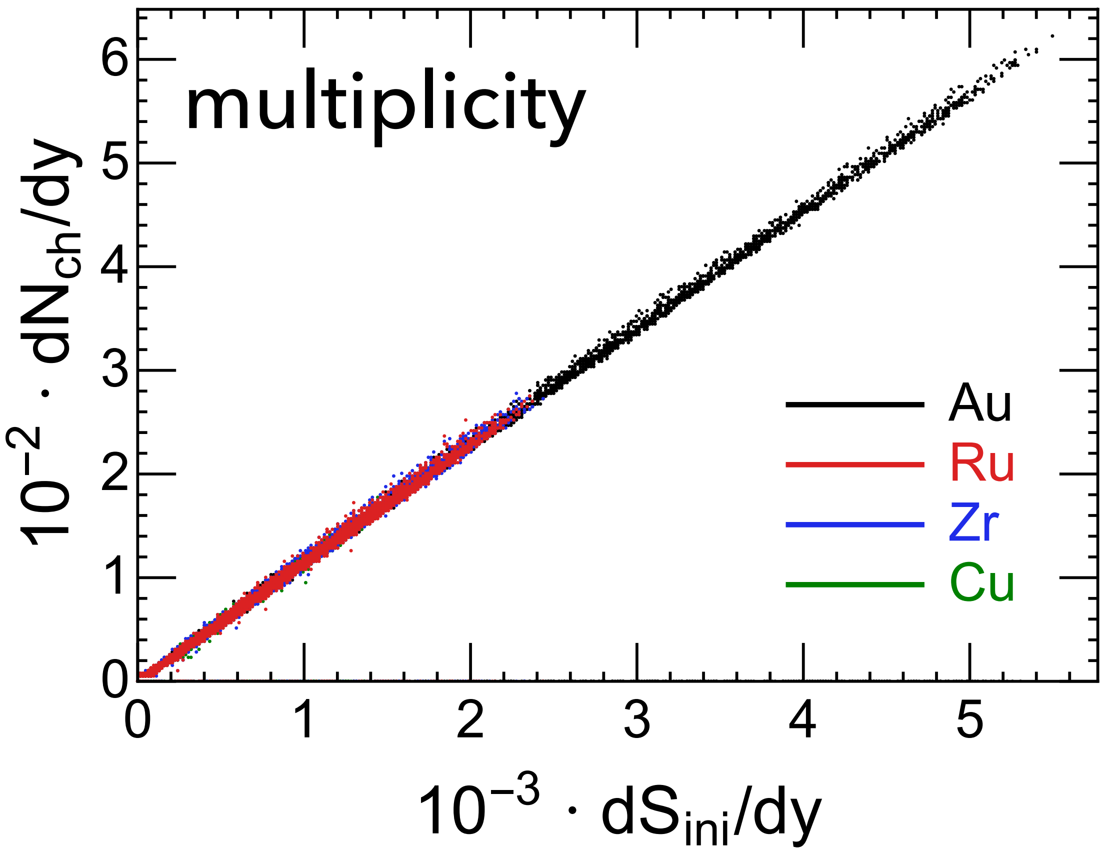


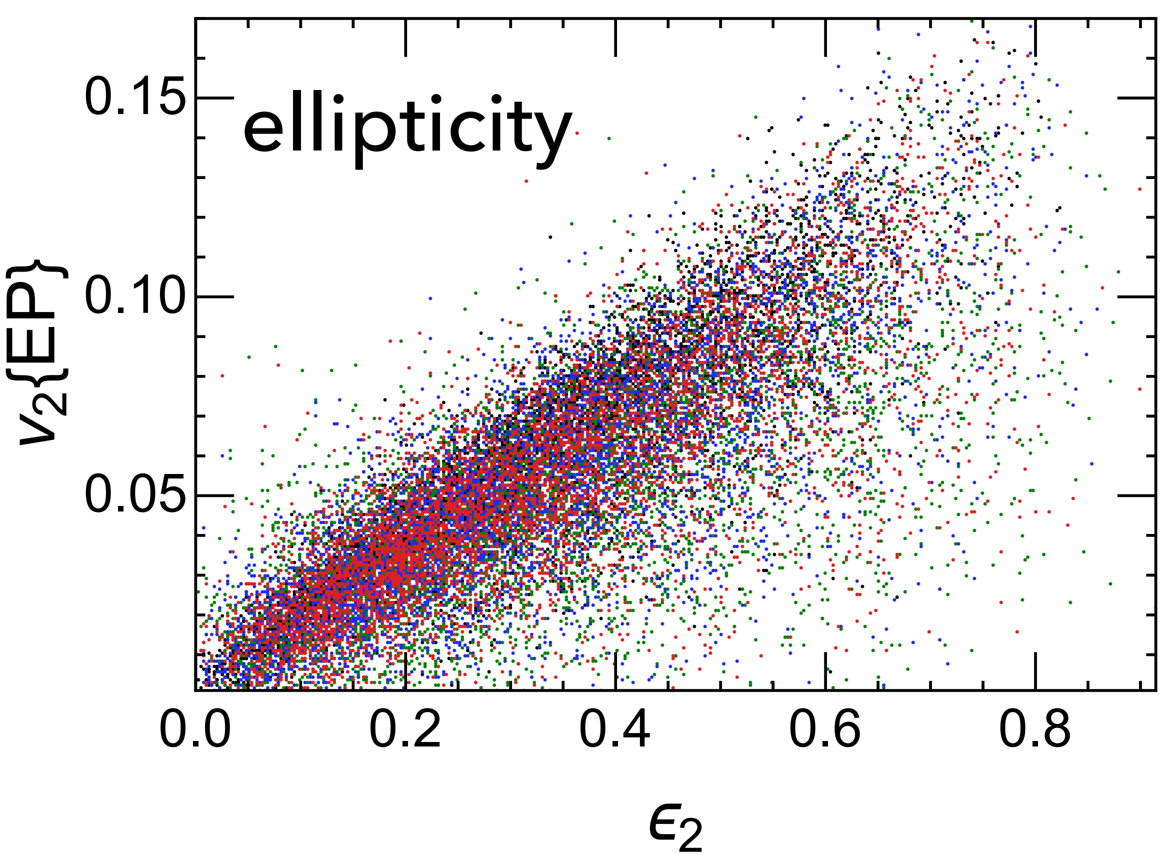
interesting correlation btw. B & dipole

strong, sys. indept. correlation of mul. & ell.

Correlation with Final Hadron dist.

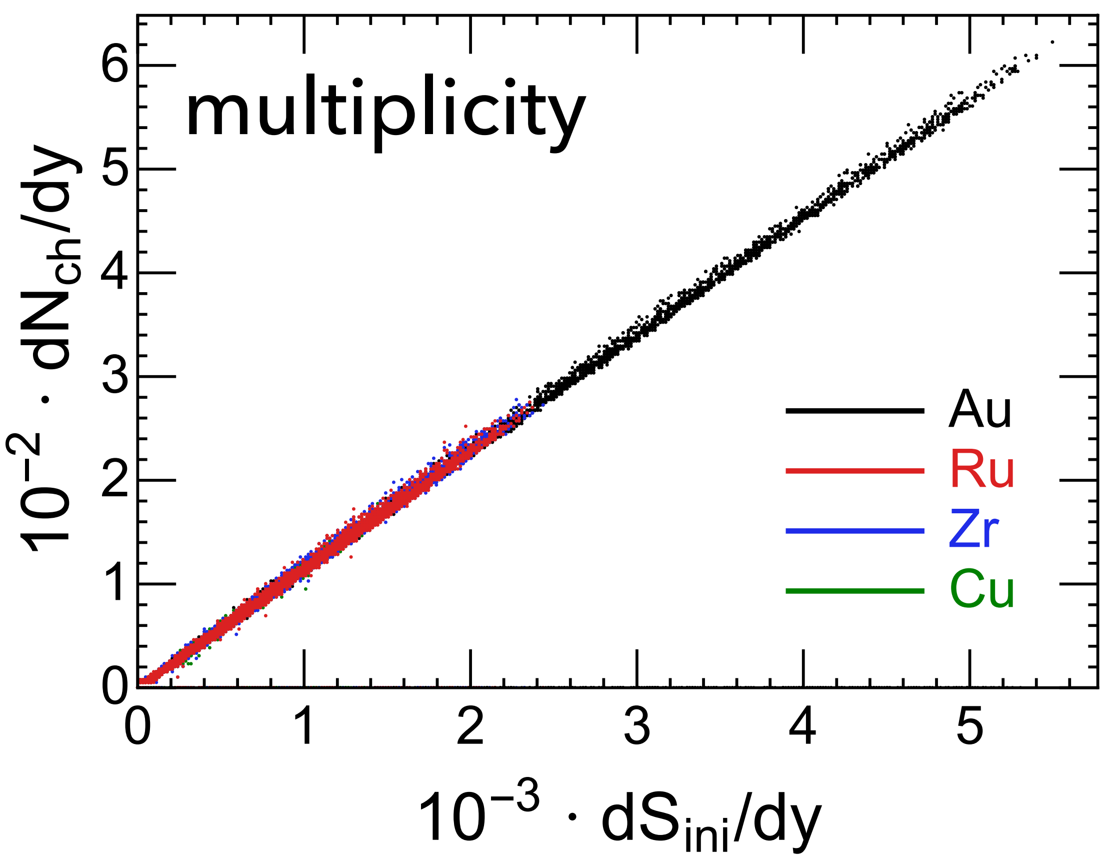
each point stands for one event

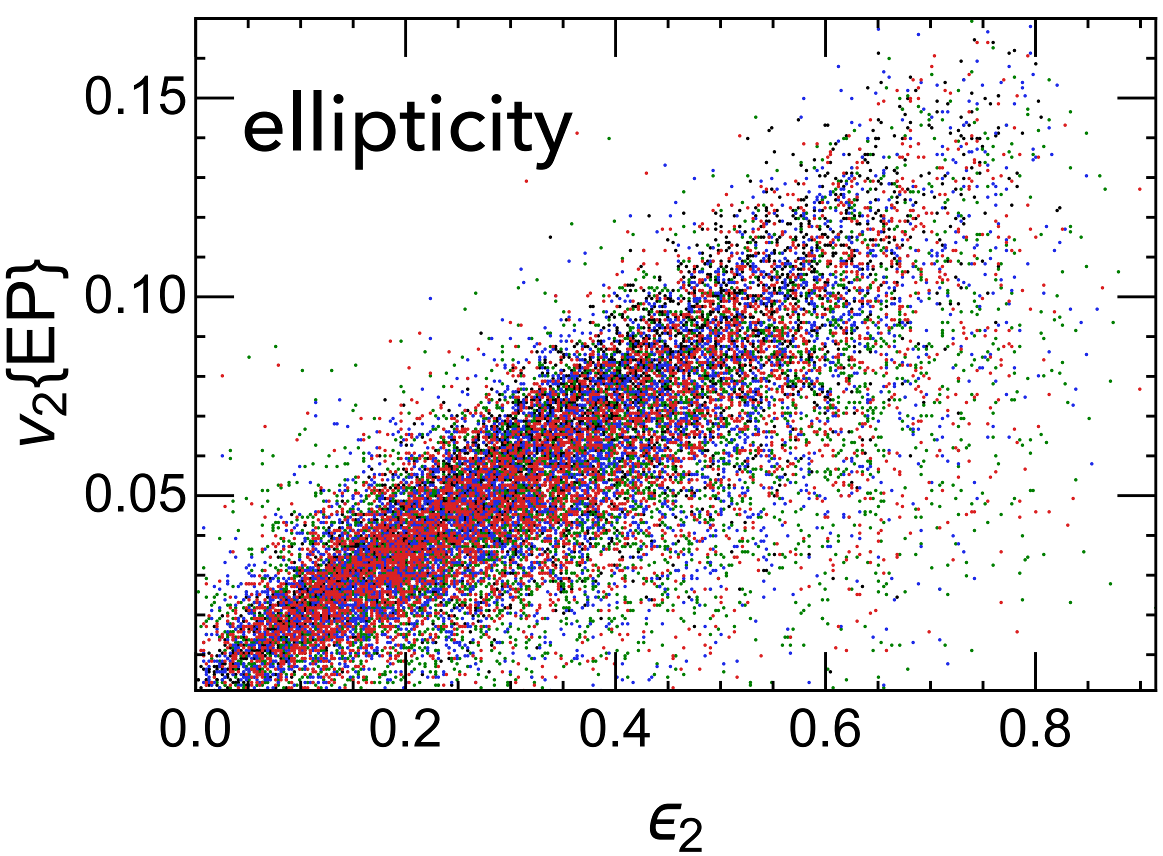


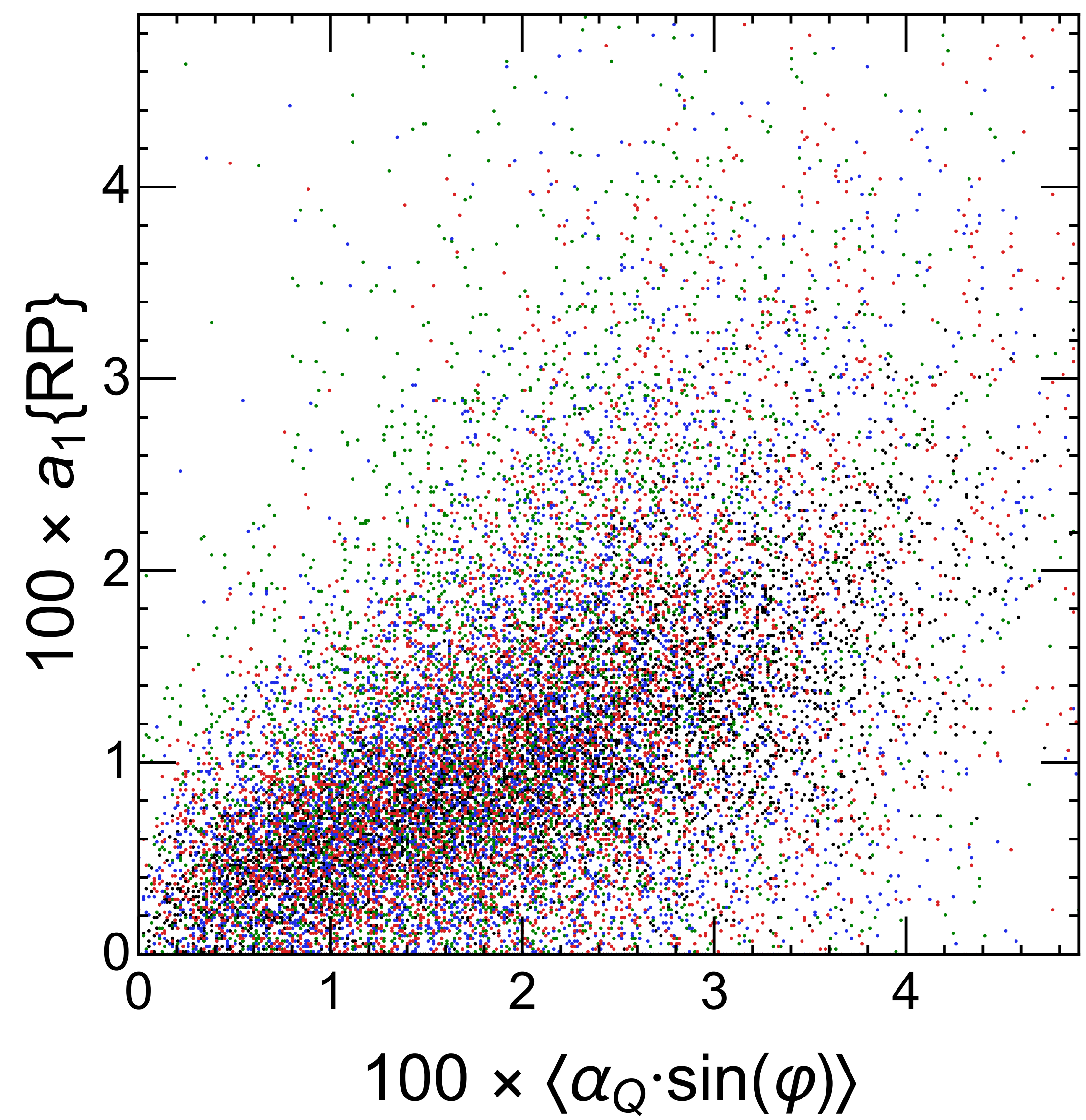


Correlation with Final Hadron dist.

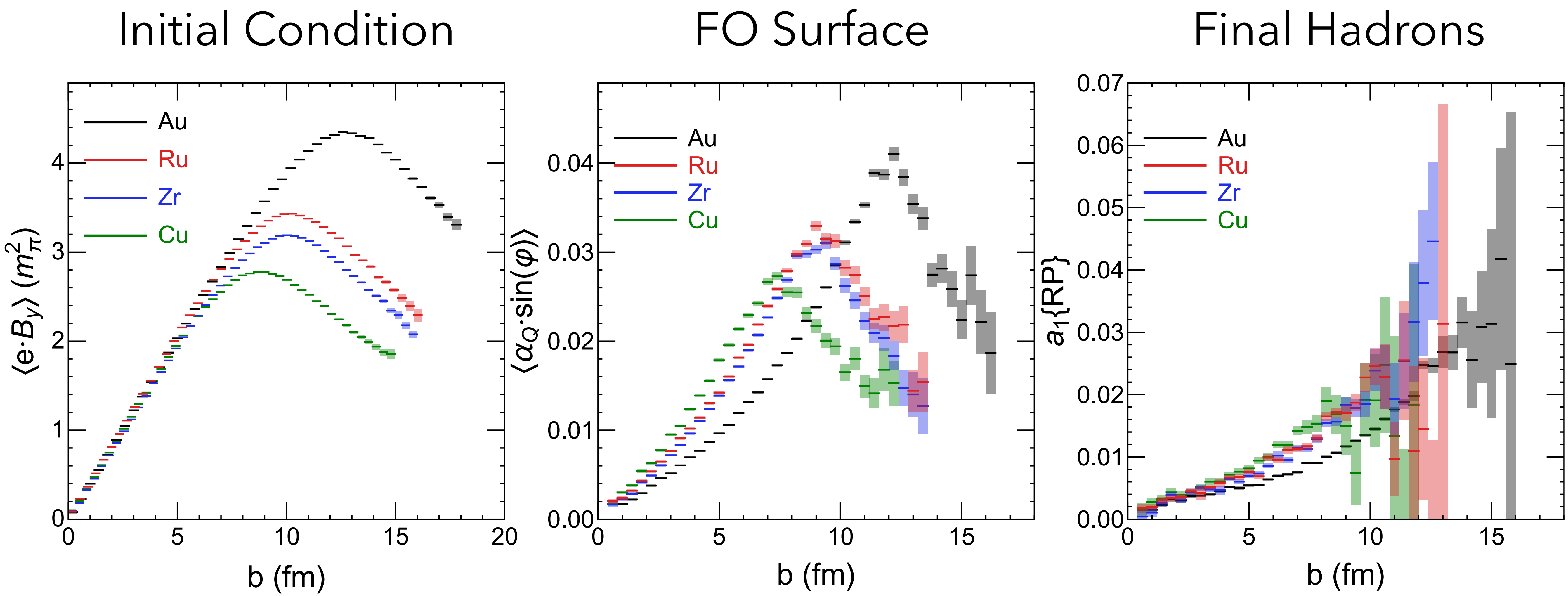
each point stands for one event







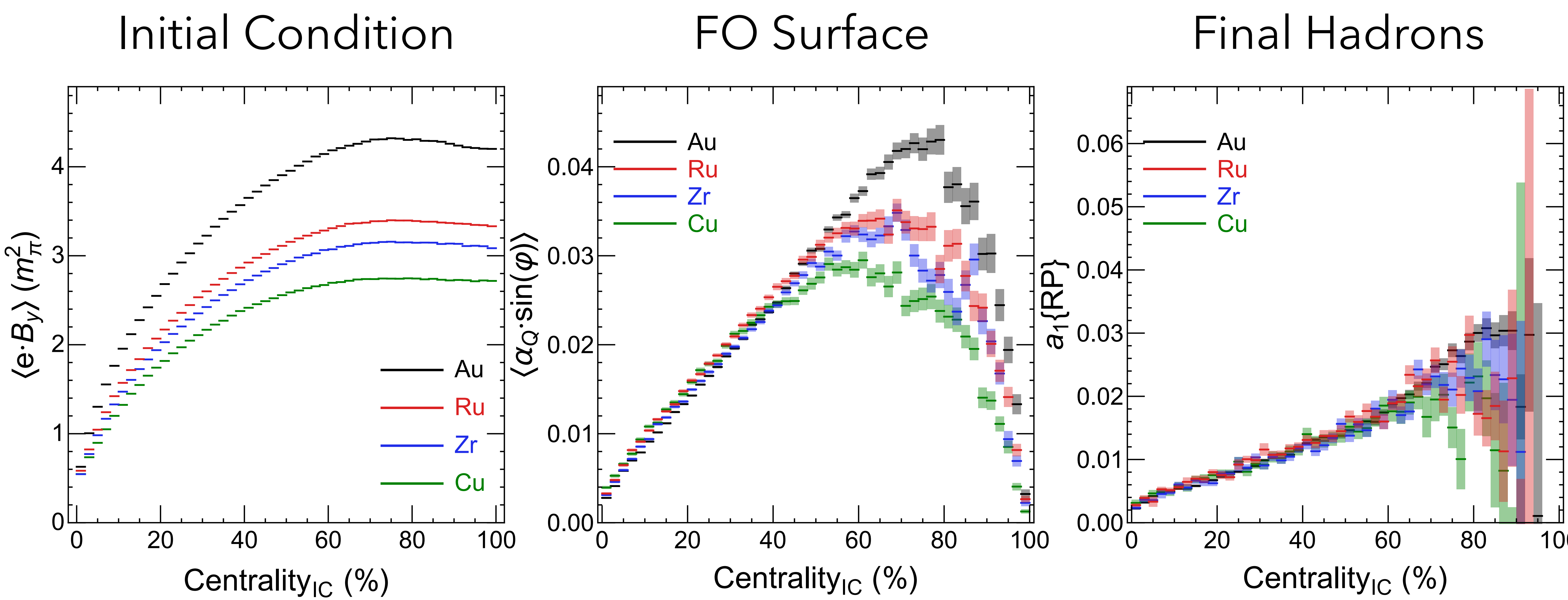
CME-related quantities vs. impact parameter



comparison between different systems:

B field ~ b (for central collisions)

CME-related quantities vs. centrality

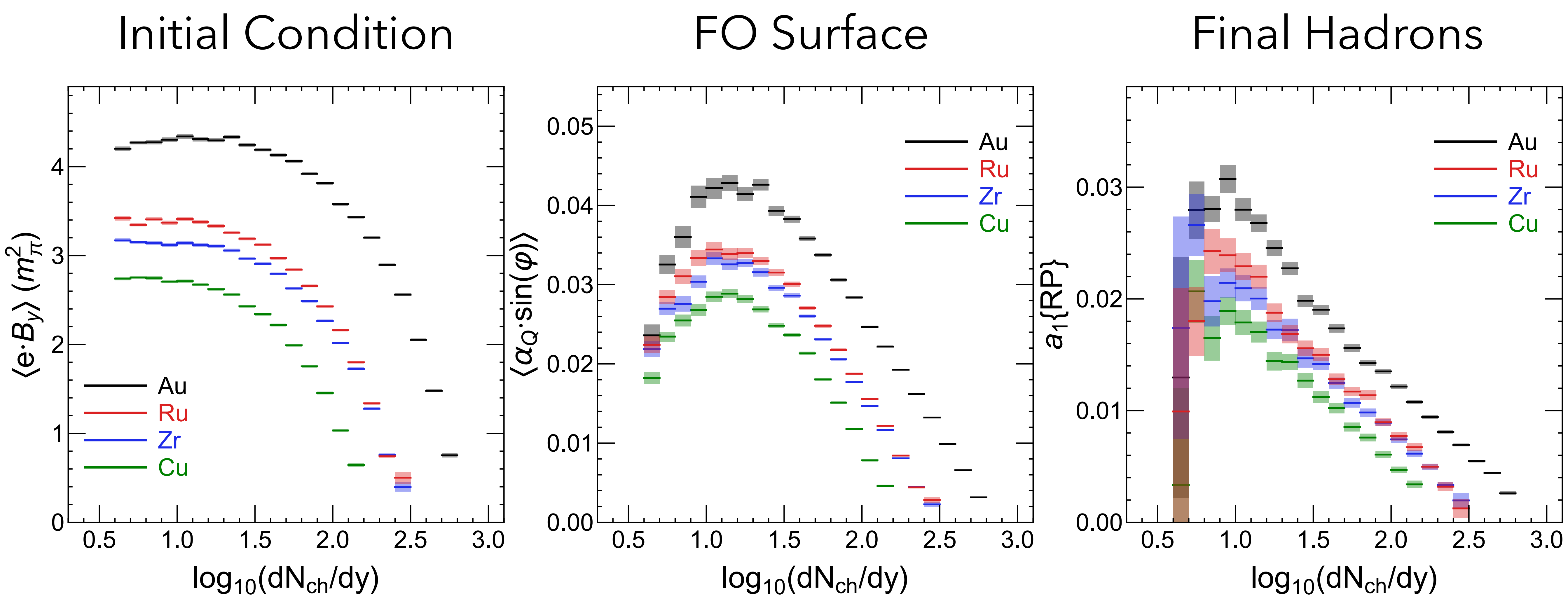


comparison between different systems:

B field ~ b (for central collisions)

charge dipole & separation ~ centrality (if the same n_5/s)

CME-related quantities vs. multiplicity



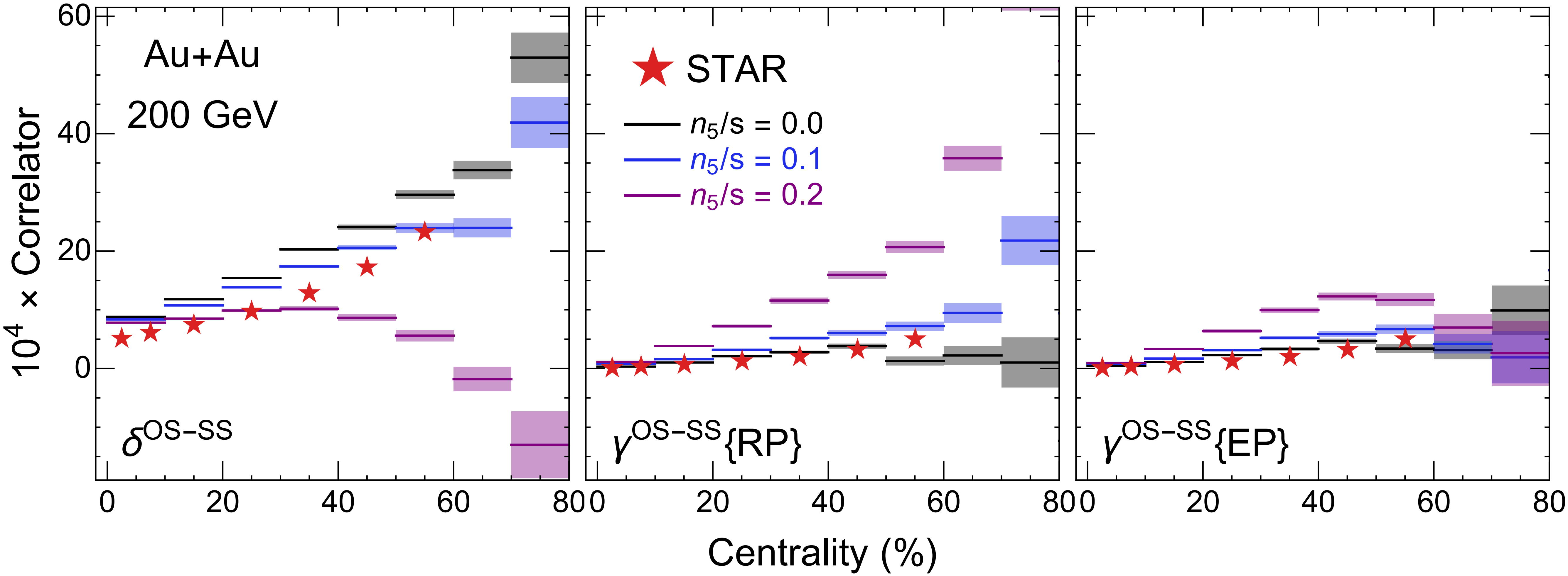
comparison between different systems:

B field ~ b (for central collisions)

charge dipole & separation ~ centrality (if the same n_5/s)

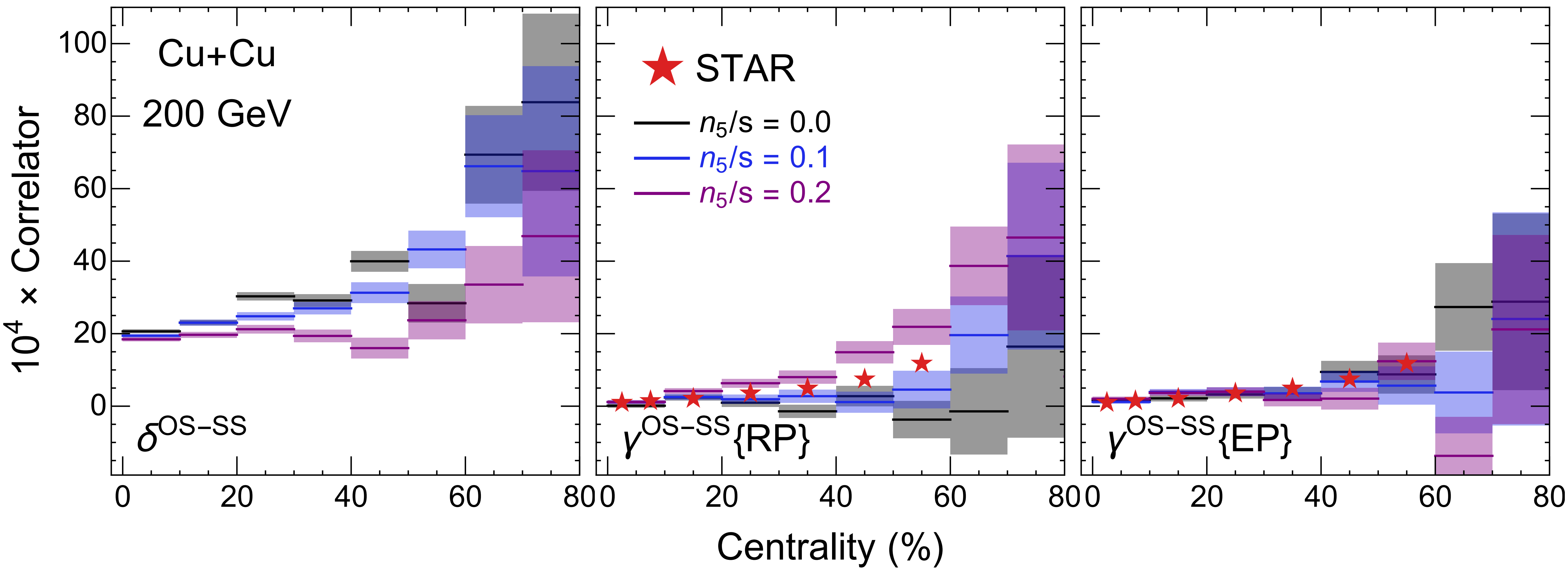
well separated if binned by multiplicity

CME correlators in Au+Au collisions



3×10^6 min-bias Au+Au events, for each n_5

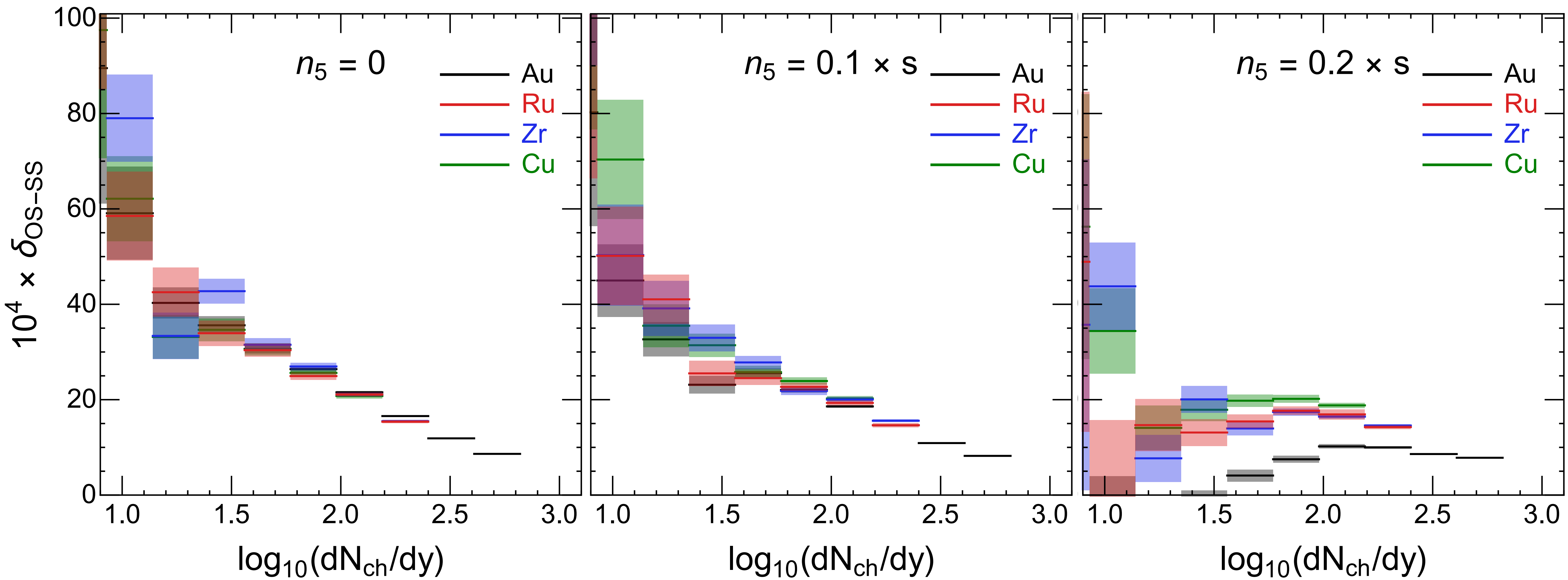
CME correlators in Cu+Cu collisions



10^6 min-bias Cu+Cu events, for each n_5

E_{patch} ~ 45 GeV looks promising to estimate the background,
Need further tunes & more investigations to test the sensitivity,...

delta-correlator in different systems

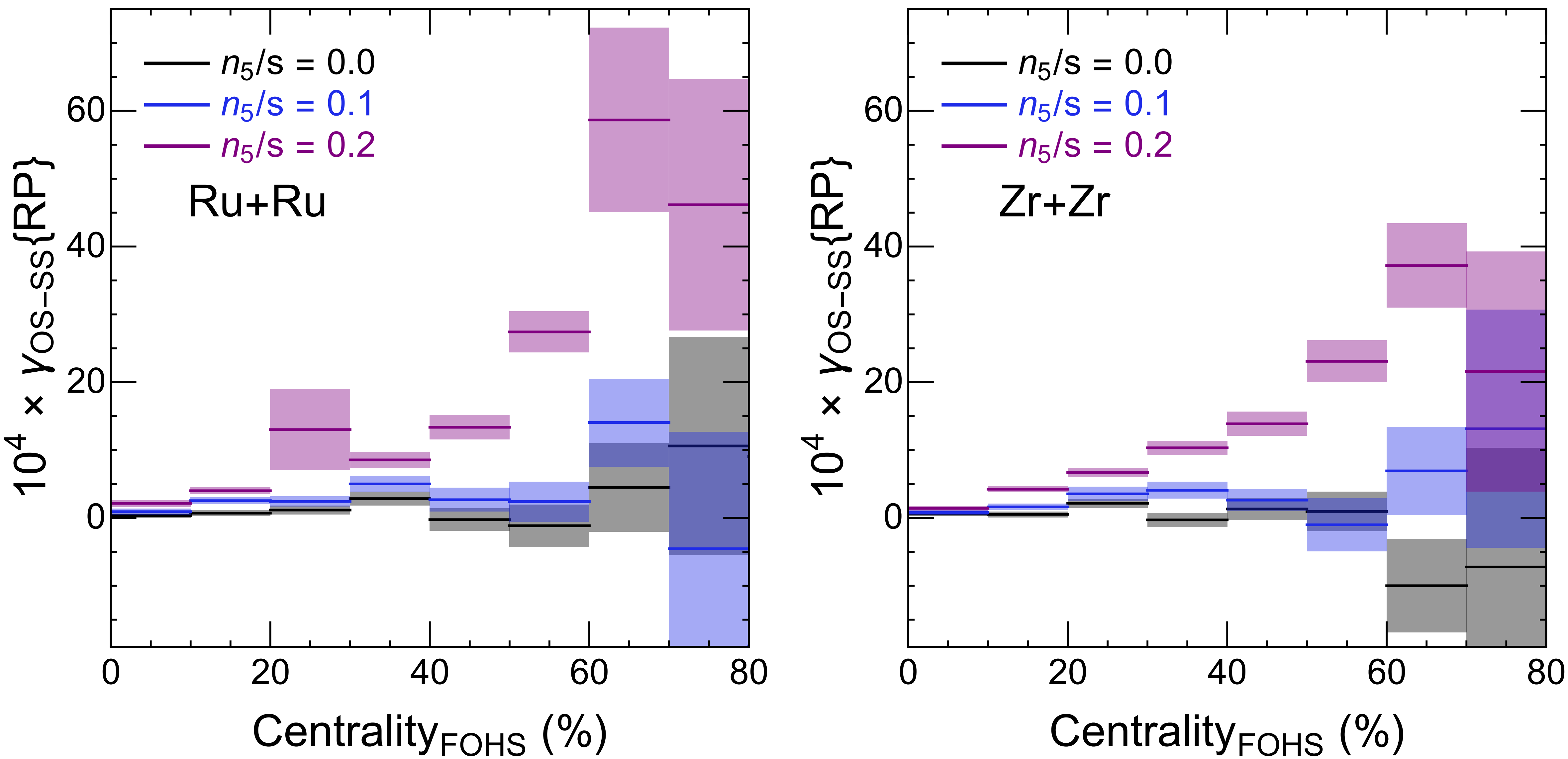


delta-correlator:

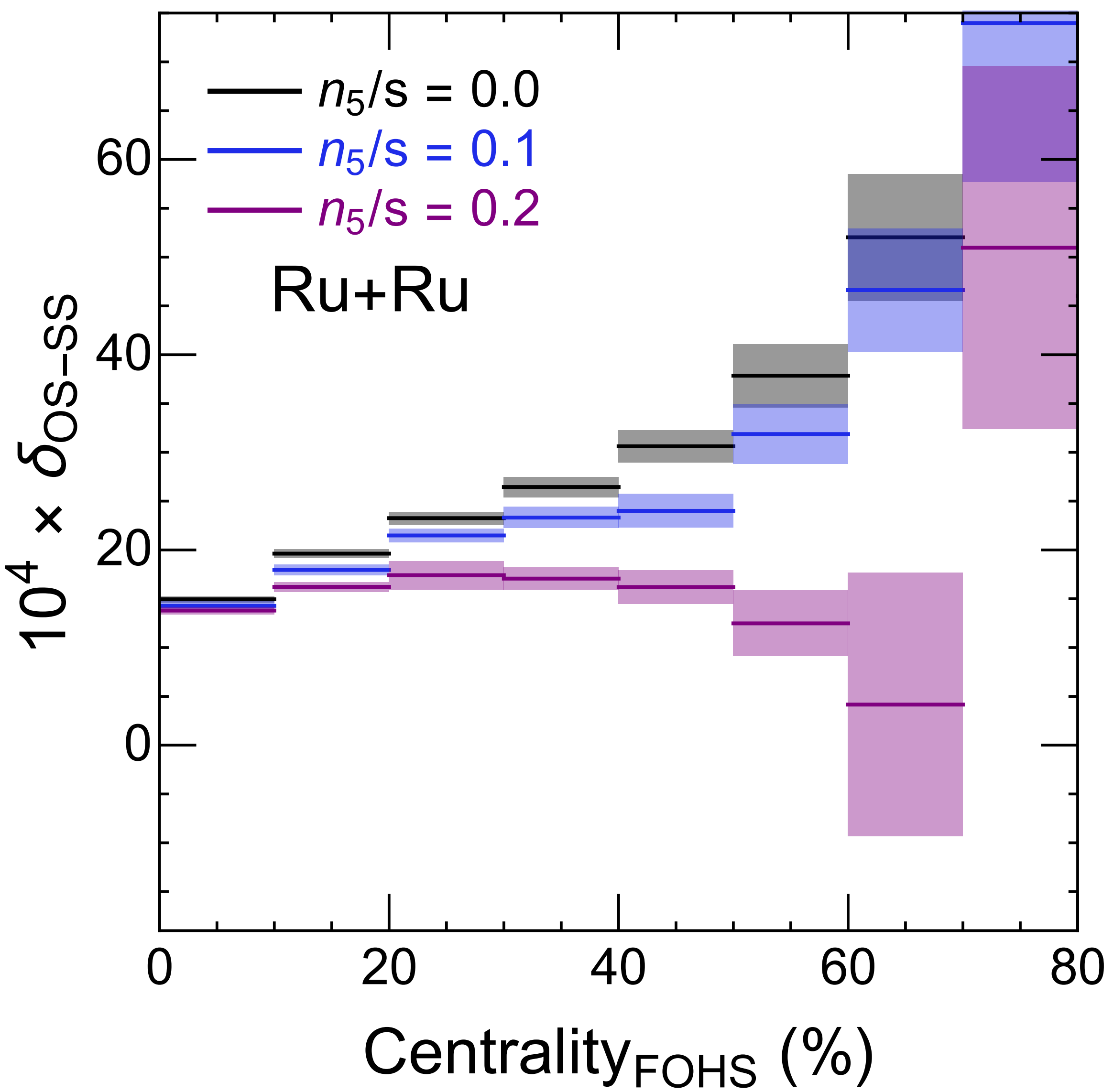
If only background: sys. indept. correlation with multiplicity

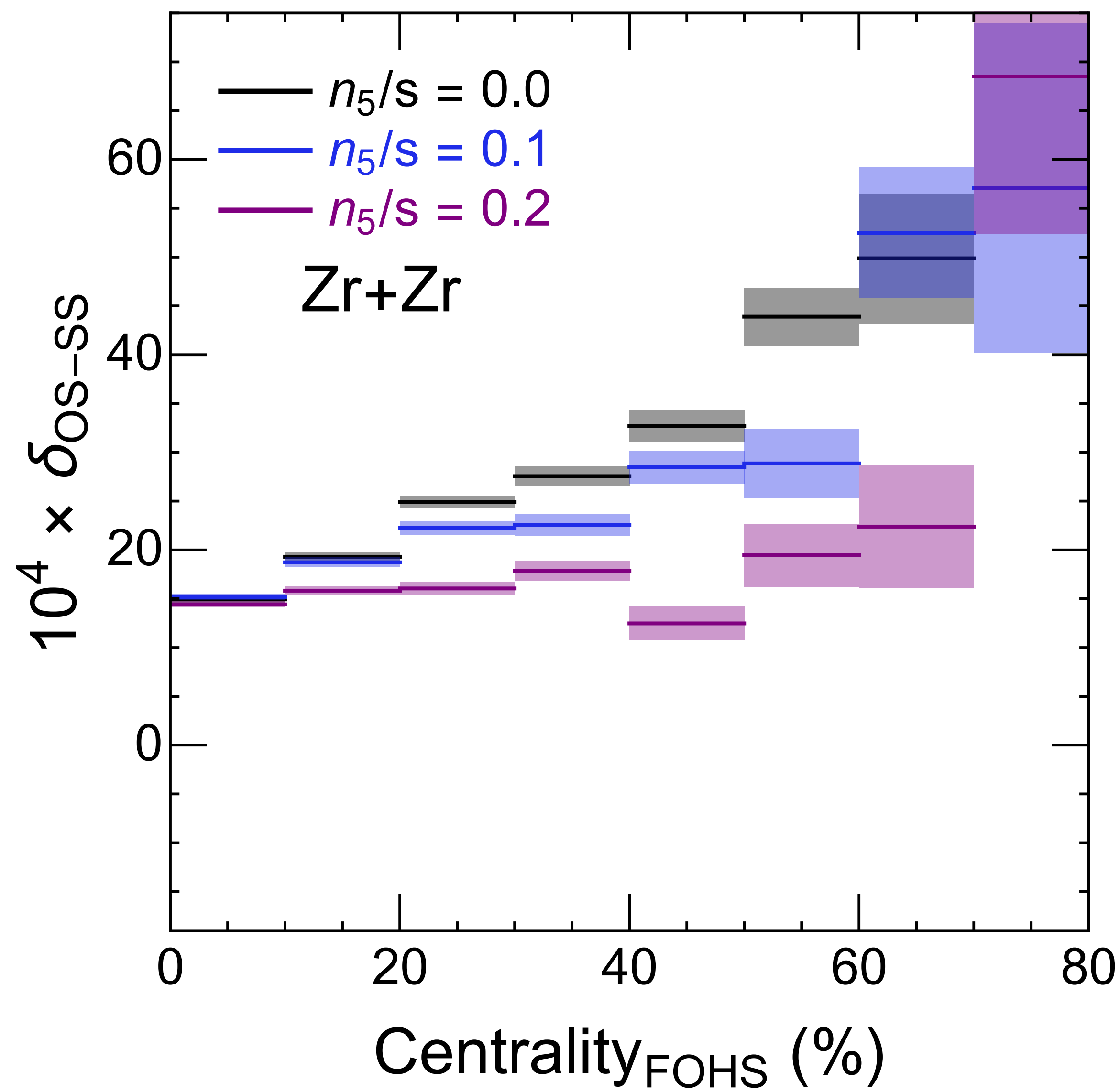
If large enough CME: well separated

CME correlators in isobaric collisions



CME correlators in isobaric collisions





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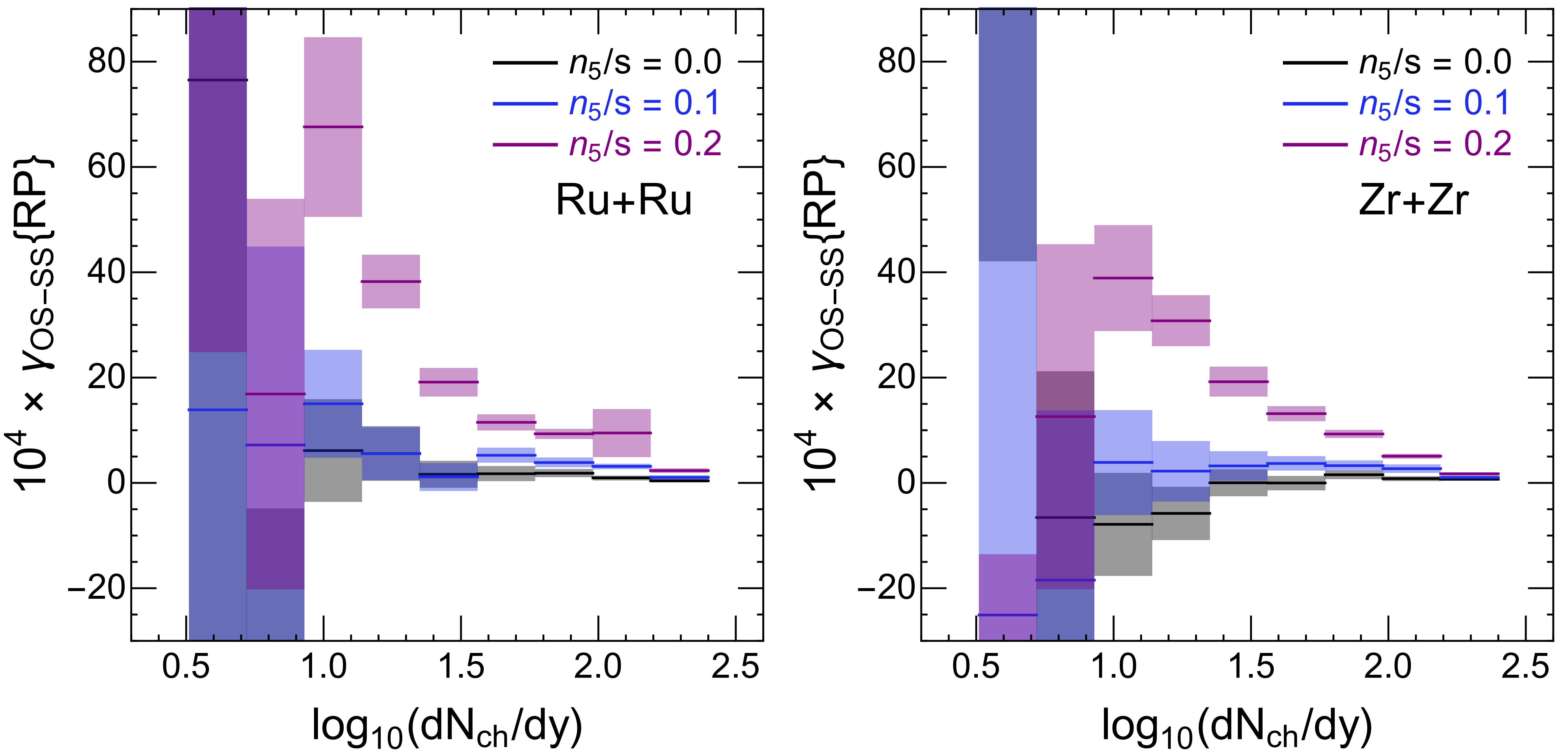

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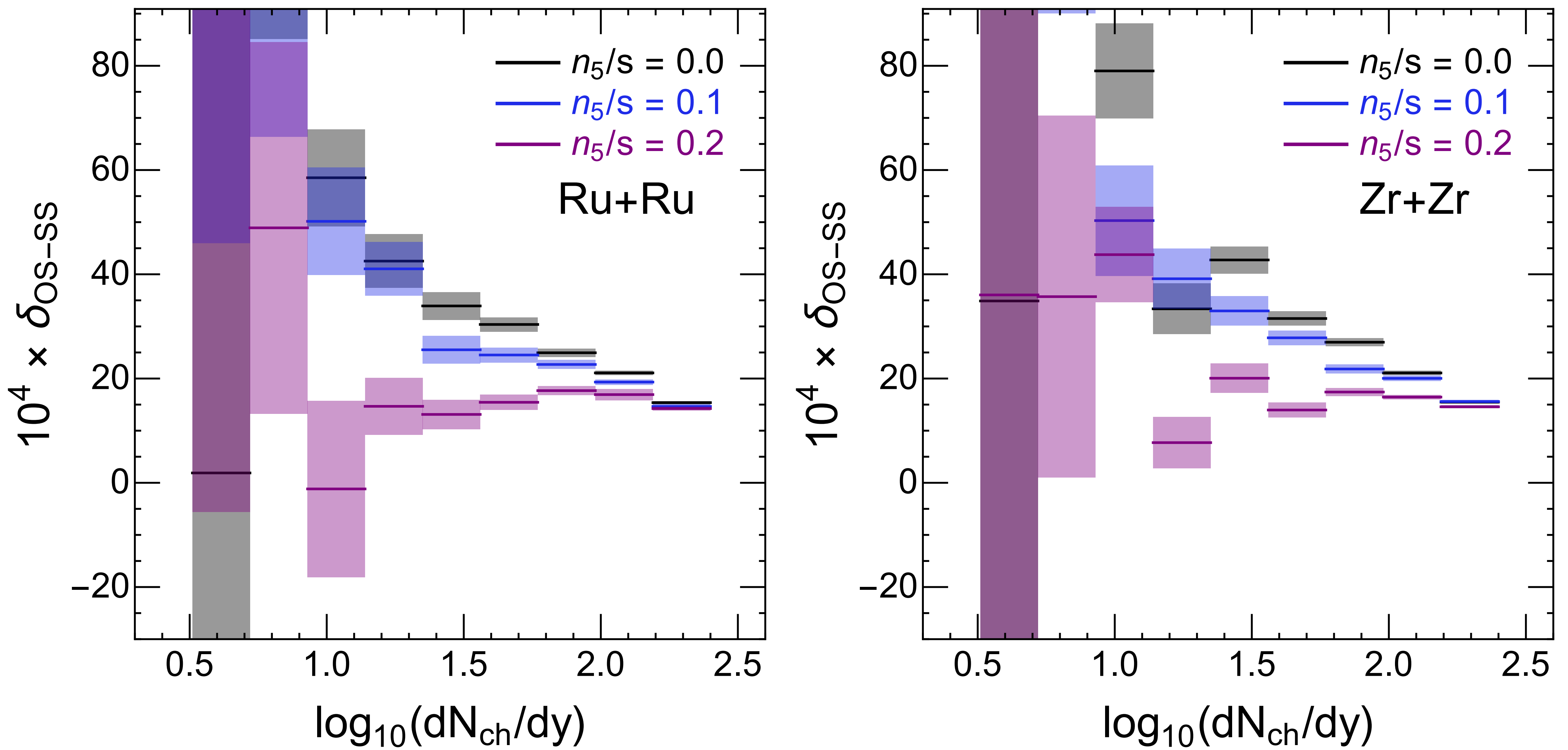


10^6 min-bias events for each system & n_5

Enough to show its sensitivity to CME,
but need more statistics to distinguish the isobar systems

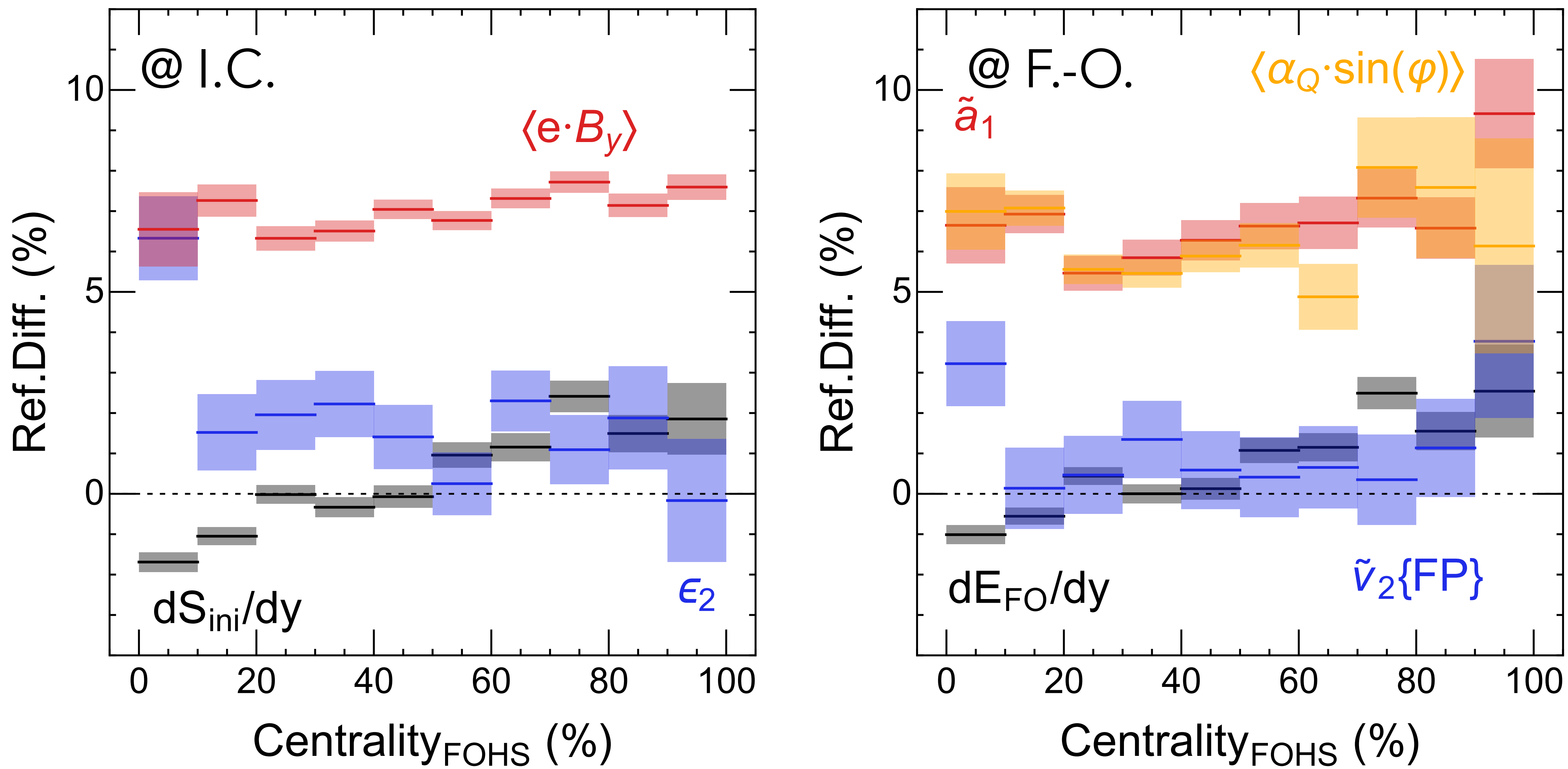
Question:

Are we on the right track?

Answer:

Let's take a look at the comparison of quantities that require less statistics.

other comparisons in isobaric collisions

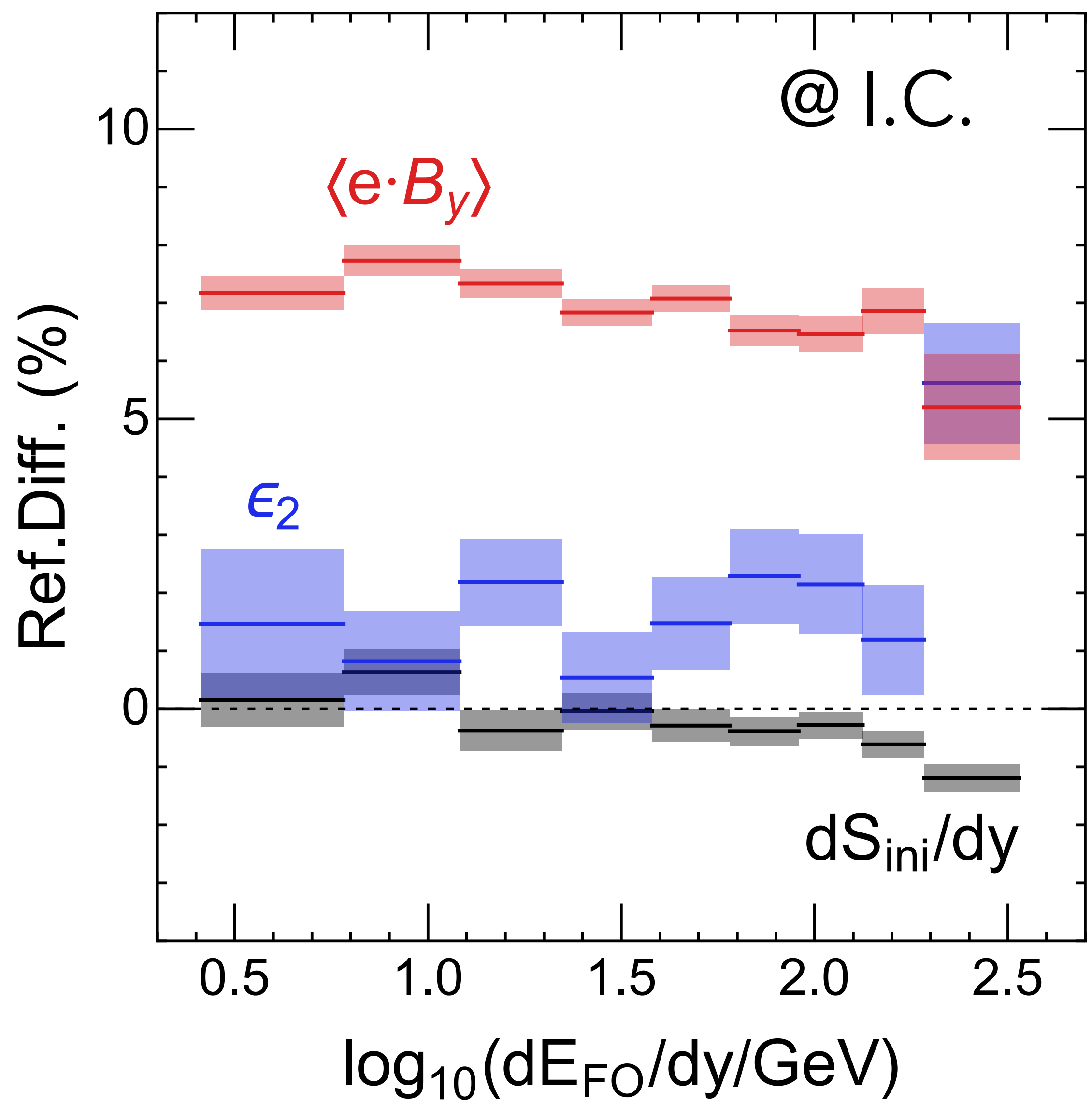


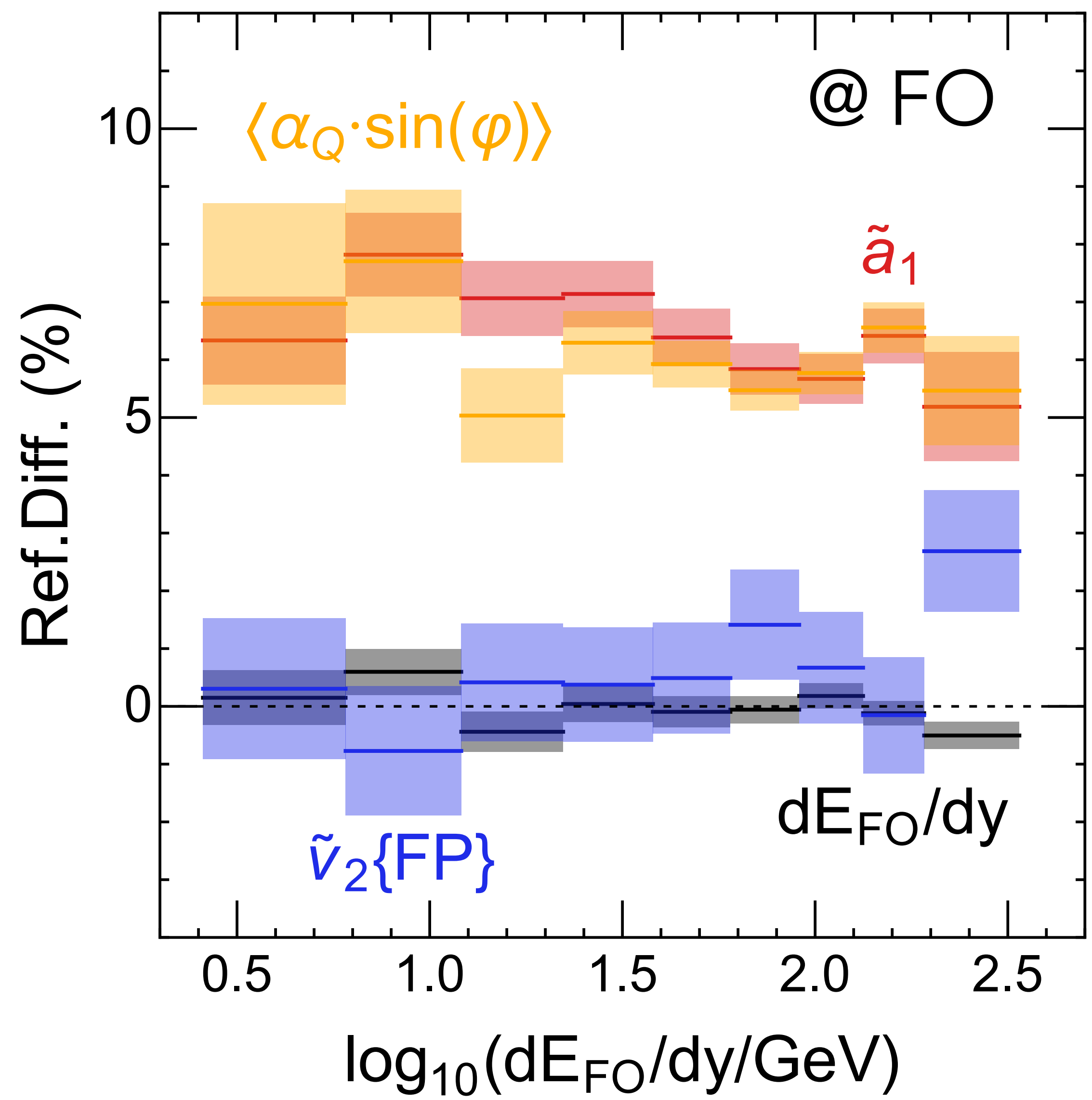
Red & Orange: CME-related quantities

Black & Blue: Bulk Background

Clear separation in B field strength & charge dipole

other comparisons in isobaric collisions





Red & Orange: CME-related quantities

Black & Blue: Bulk Background

Clear separation in B field strength & charge dipole

Multiplicity binning further eliminate possible difference in background

Summary & Outlook

The most updated EBE-AVFD package:

1) micro-canonical sampler implemented

2) look promising to describe both CME signal & non-CME background

To-Do:

1) More statistics

2) Further tune E_{patch}

3) Coupled with more realistic B field evolution (see Anping Huang's Talk)

THANK YOU!

BACKUP SLIDES

LCC implementation in the 2nd Gen.

take neutral systems ($\mu = 0$) as example

In the current particle sampler,
two ways to sample particles in a single FOHS cell:

(a) grand-canonical ensamble (both N_{net}, E fluctuate)
N_{pos} ~ Poisson Distribution with mean $\langle N \rangle = N_{thermal}$
N_{neg} ~ Poisson Distribution with mean $\langle N \rangle = N_{thermal}$
N_{pos} and N_{neg} are not necessarily the same

(b) canonical ensamble (N_{net} conserved, E fluctuates)
N_{pos} ~ Poisson Distribution with mean $\langle N \rangle = N_{thermal}$
$N_{neg} = N_{pos}$ B. Schenke, C. Shen, P. Tribedy, arXiv:1901.04378

LCC implementation in the 2nd Gen.

A hybrid approach?

c) for every cell, randomly choose (a) or (b), according to given acceptance probability P_{LCC} being a parameter $\in [0,1]$.

— P_{LCC} of the charged particles freeze-out ***in pairs***, from the ***same*** cell of hyper-surface;

— $1-P_{LCC}$ of the charged particles freeze-out ***independently***.

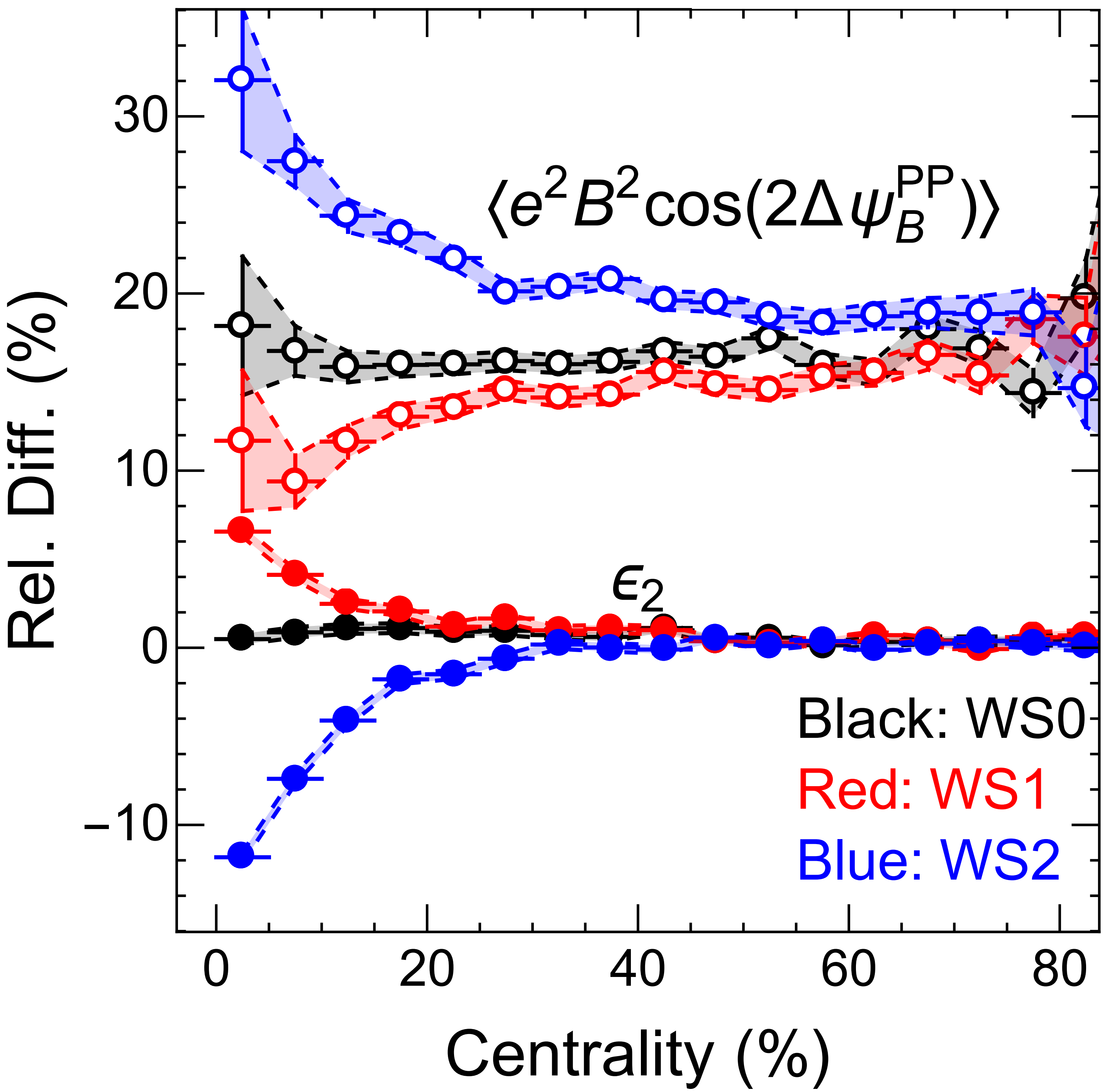
Non-CME Background

Different deformation schemes:

black - no deformation (both are spherical)

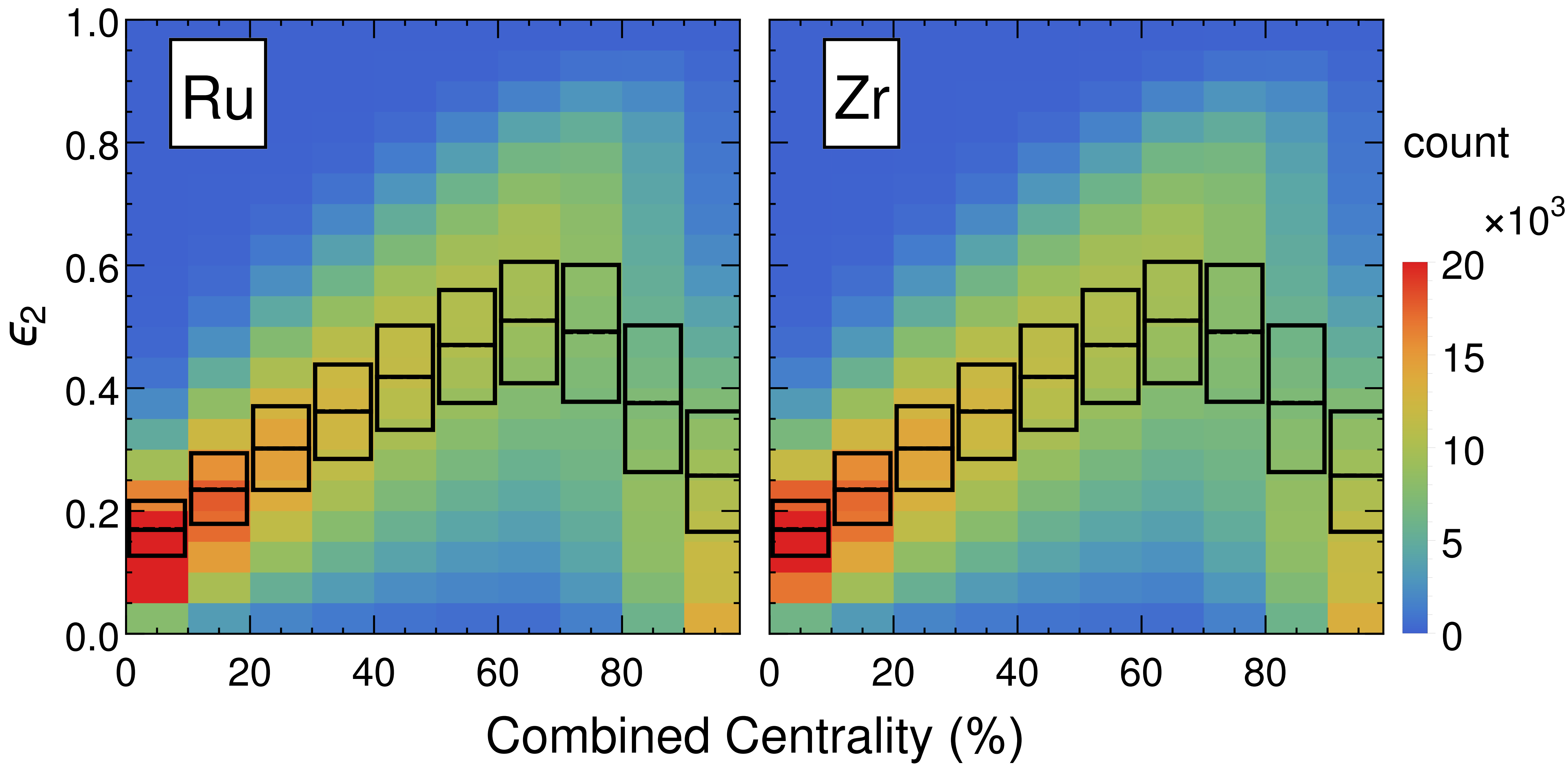
red - Ru is more deformed

blue - Zr is more deformed



Several percent relative difference in ellipticity

CME in IsoBar System



Joint cut of **Multiplicity⊗Eccentricity** ⇒ same background!