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Measurement of global spin alignment of vector meson at RHIC

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Introduction

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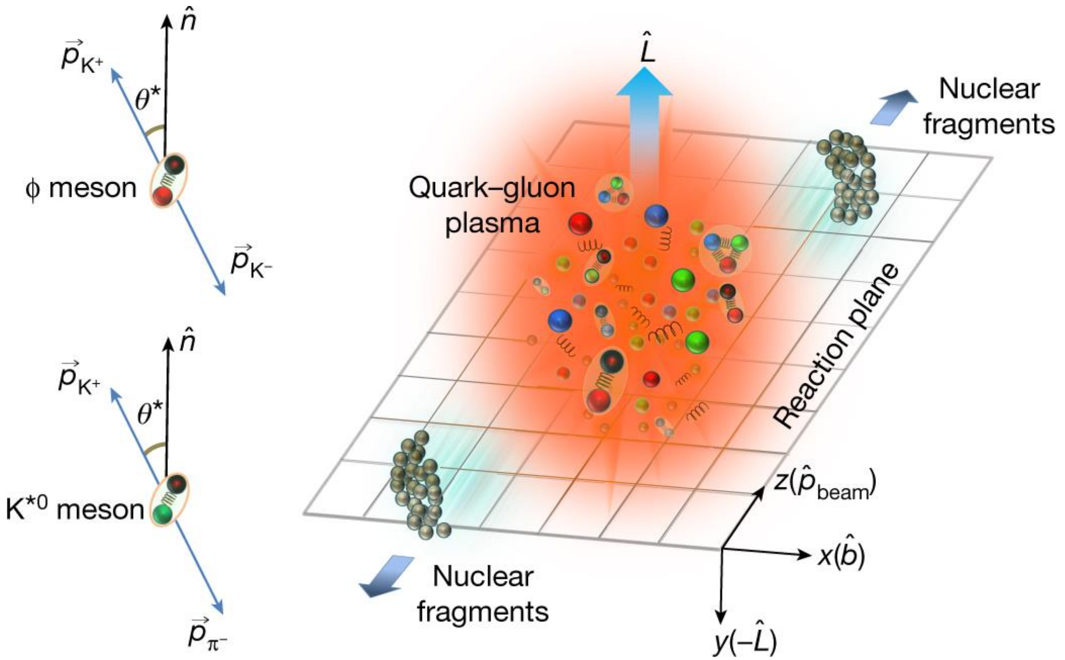
- A large orbital angular momentum (OAM) can be generated in noncentral relativistic heavy-ion collisions (HIC) $(10^5 - 10^7\hbar)$
- In the produced quark-gluon plasma (QGP) OAM can be partially transferred to the spin of quarks and anti-quarks (spin-orbit coupling)
- OAM can manifest itself in the form of fluid vorticity and polarized the particles

Introduction

- The incoming charged spectators can also induce a large but short field in HIC (10^{18} Gauss)
- In the produced QGP, the strong B-field can also polarize the spin of quarks and anti-quarks (intrinsic magnetic moment interaction)



Introduction

- The measurement of spin polarization can:

1. Offer insights into the initial OAM and B-field
2. Serve as an experimental probe to understand the response of QGP medium under these extreme initial conditions

- The measurement for Λ hyperons by STAR offered first experimental evidence of the presence of vorticity of the QGP medium
- The difference between Λ and $\bar{\Lambda}$ presents an opportunity to probe the initial B-field

Introduction

- Angular distribution of the decay daughter of the vector meson:

$$\frac{dN}{d\cos\theta^*} \propto (1-\rho_{00}) + (3\rho_{00}-1)\cos^2\theta^*$$

- ρ_{00} : the 00^{th} element of the spin density matrix
- θ^* : the angle between the polarization axis and momentum direction of the daughter particle in the rest frame of its parent
- Polarization axis: perpendicular to the reaction plane (OAM and B-field)

Introduction

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- The available physics mechanisms:

1. Hadronized the polarized quarks induced by vorticity ($\rho_{00} < \frac{1}{3}$)
2. The ρ_{00} induced by B-field ($\rho_{00} - \frac{1}{3} \sim 10^{-5}$)
3. The ρ_{00} induced by E-field ($\rho_{00} - \frac{1}{3} \sim 10^{-4}$)
4. The fragmentation of polarized quarks ($\rho_{00} - \frac{1}{3} \sim 10^{-5}$)
5. Local spin alignment, helicity polarization, turbulent color field ($\rho_{00} < \frac{1}{3}$)
6. Fluctuating strong force field of vector meson ($\rho_{00} - \frac{1}{3} \sim 10^{-1}$)

Introduction

- The neutral and charged vector mesons:

$$K^{*0} \to d\bar{s}\,, K^{*+} \to u\bar{s}$$

- The magnetic moments of their constituent quarks:

$$\mu_d \sim -0.97\mu_N\,, \mu_u \sim 1.85\mu_N$$

- The magnetic field driven contribution to the ρ_{00} of neutral and charged K^* is expect to be different

Analysis method

- ρ_{00} measurements of charged $K^{*\pm}$ along with neutral $K^{*0}(\overline{K^{*0}})$ vector meson
- Isobar collisions of ${}^{96}_{44}Ru + {}^{96}_{44}Ru$ and ${}^{96}_{40}Zr + {}^{96}_{40}Zr$ at $\sqrt{s_{NN}} = 200\ GeV$
- Reconstructed via:

1. $K^{*0}(\overline{K^{*0}}) \rightarrow \pi^{-} + K^{+}(\pi^{+} + K^{-})$
2. $K^{*+}(K^{*-}) \rightarrow \pi^{+} + K_S^0(\pi^{-} + K_S^0)$

- The minimum-bias (MB) event: a coincidence between the Vertex Position Detectors (VPD) located at $4.4 < |\eta| < 4.9$

Analysis method

- For analysis, the vertex position:

$$-35\ cm < V_{z,TPC} < 25\ cm\ , V_r < 5\ cm$$

- 1.8 billion good MB events for $Ru + Ru$ and $Zr + Zr$ collisions
- The collision centrality: the number of charged particles within $|\eta| < 0.5$ and using a Monte Carlo Glauber simulation
- The second order event plane ($\Psi_{2,TPC}$) : using the track inside TPC

Analysis method

- Identify the decay daughter of K^*: using the specific ionization energy loss in TPC gas volume and the velocity of particles measured by the TOF detector
- Select K_S^0 mesons: a weak decay topology
- Charged $K^{*\pm}$ reconstruction: K_S^0 candidates within $0.48 < M(\pi^+\pi^-) < 0.51\ GeV/c^2$
- The combinatorial background: a track rotation technique (one of the daughter track is rotated by $180°$ to break)

Analysis method

- Obtain the invariant mass signal: subtracting the combinatorial background
- K^* signal is fitted with a Breit-Wigner distribution and a second-order polynomial function to take care of residual background
- The detector acceptance and efficiency correction factors: a STAR detector simulation in GEANT3

Analysis method

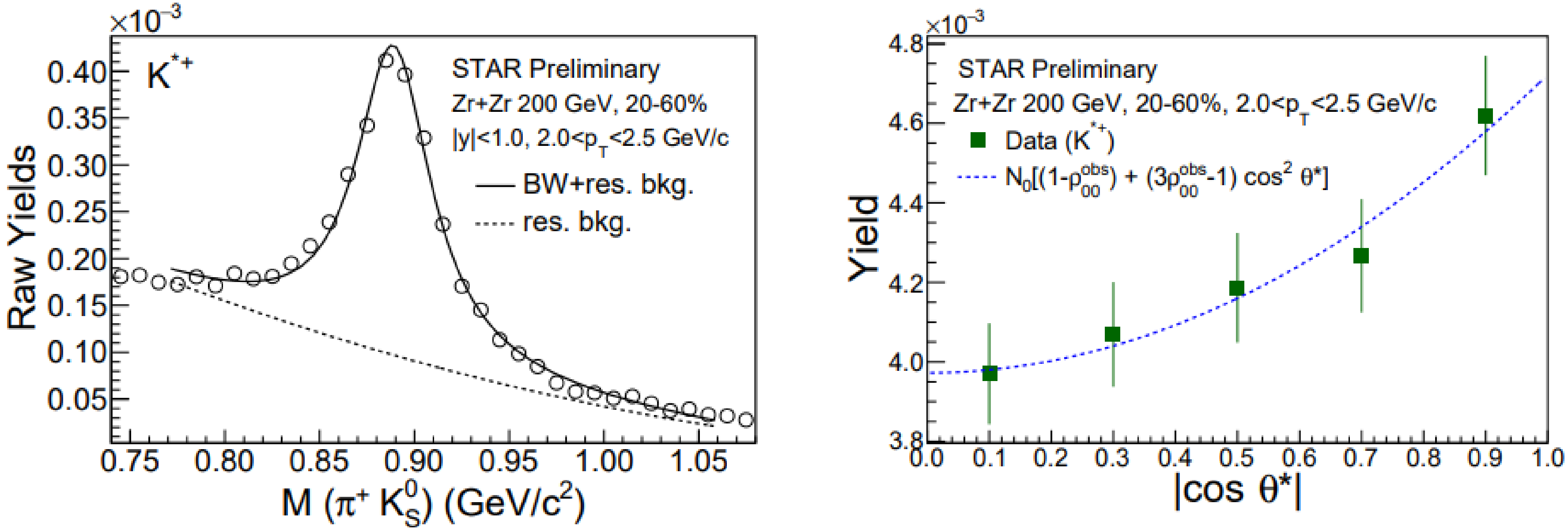
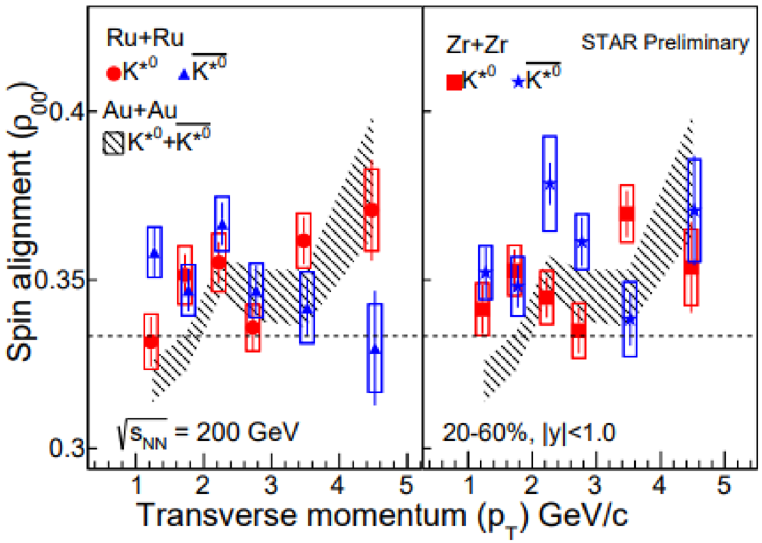
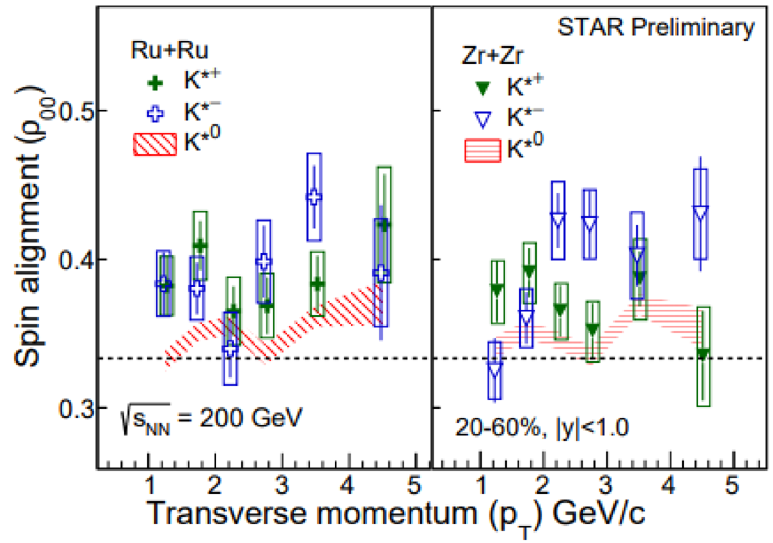


Fig. 1. Left: $K^{*+}(\rightarrow \pi^{+} + K^{0}_{S})$ invariant mass distribution for $2.0 < p_{\mathrm{T}} < 2.5$ GeV/c in 20-60% Zr+Zr collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV. Right: efficiency and acceptance corrected K^{*+} yield as a function of $|\cos\theta^{*}|$ in 200 GeV Zr+Zr collisions.

Results

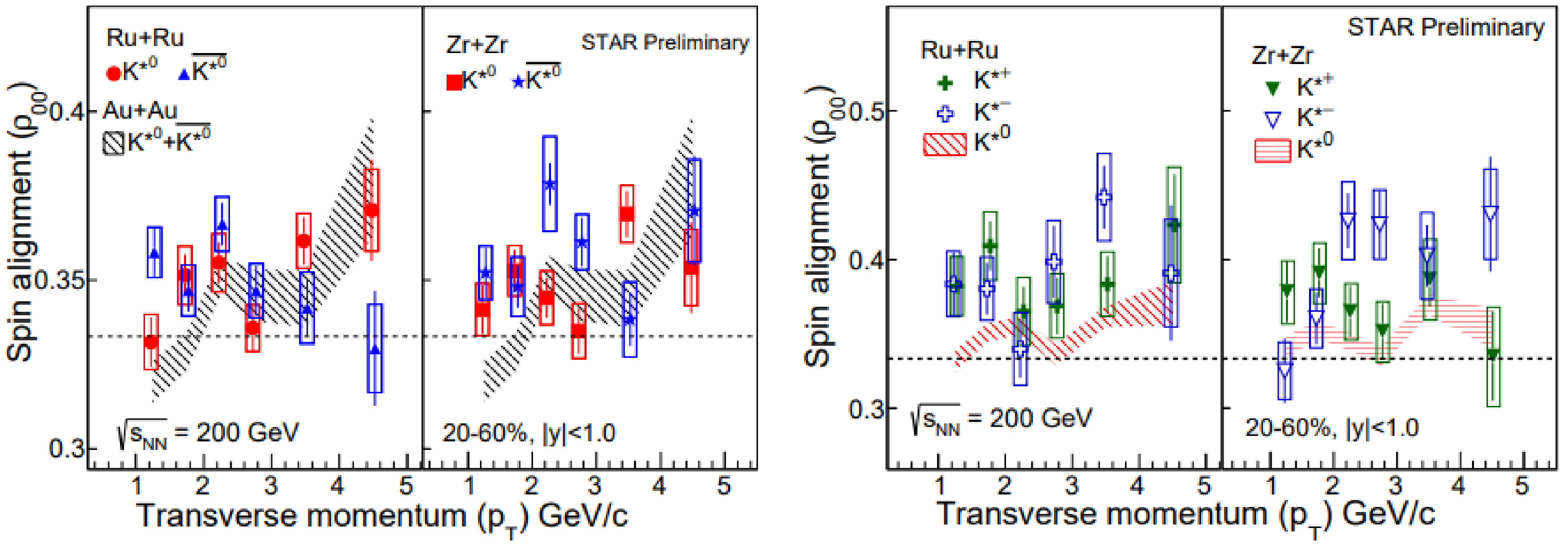
- ρ_{00} between the particle and anti-particle are consistent within errors
- ρ_{00} between isobar and $Au + Au$ collisions are consistent within uncertainties across the measured p_T region in mid-central collisions





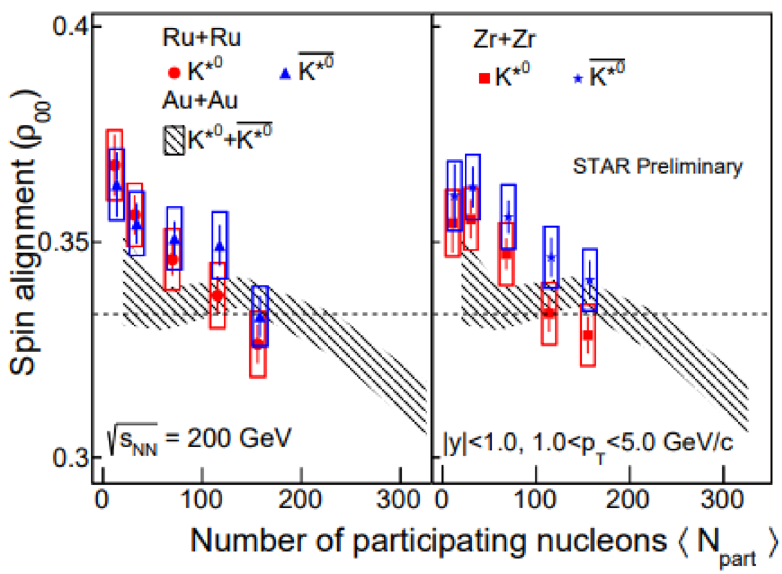
Results

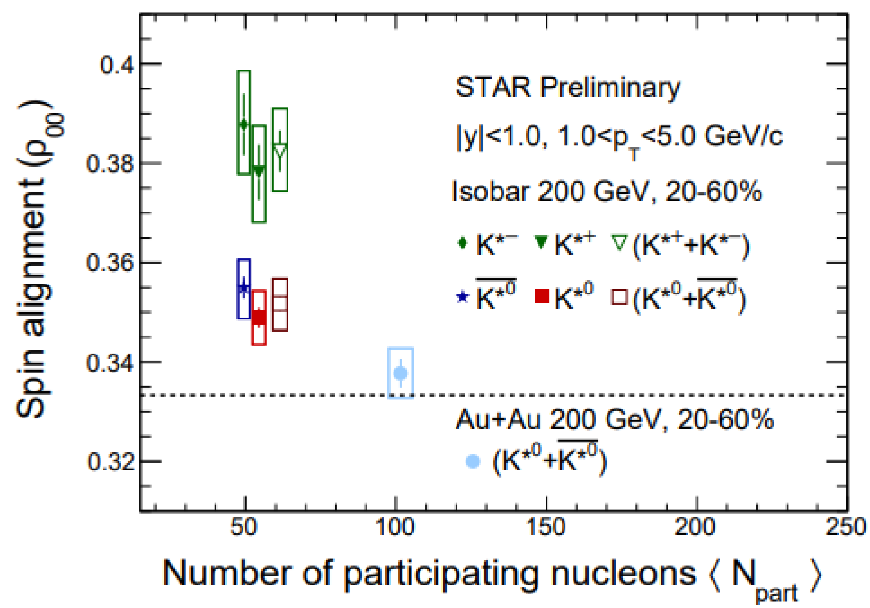
- ρ_{00} for charged $K^{*\pm}$ are systematically larger than the neutral K^{*0} across the measured p_T region



Results

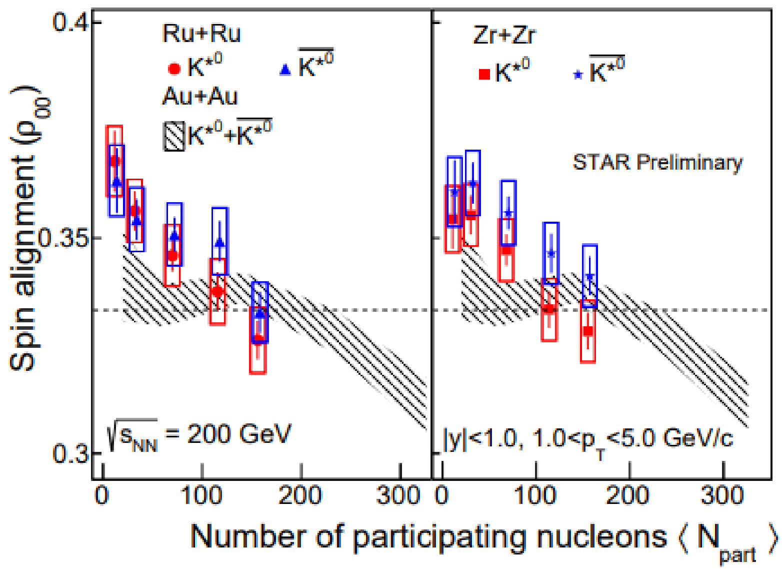
- K^{*0}: $\rho_{00} > \frac{1}{3}$ at small $\langle N_{part} \rangle$, $\rho_{00} < \frac{1}{3}$ at large $\langle N_{part} \rangle$
- ρ_{00} between small system isobar and large system $Au + Au$ are comparable within uncertainties

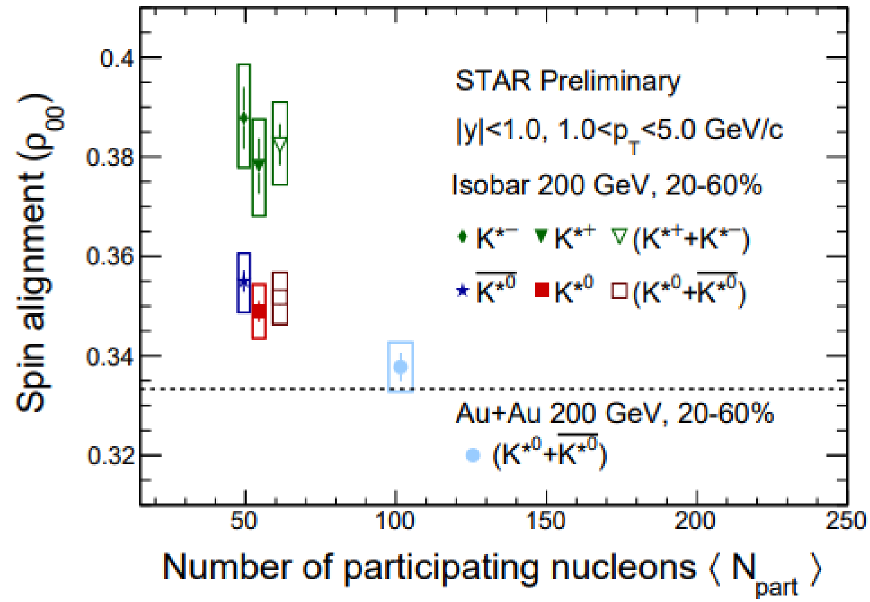




Results

- $K^{*\pm}$: $\rho_{00} > \frac{1}{3}$
- Charged species are about 3.9σ larger than the neutral ones
- Expectation: $K^{*0} > K^{*\pm}$ (B-field)





Summary and conclusion

- The measurements of ϕ and K^{*0} in $Au + Au$ collisions:
- $\phi \rightarrow$ a large positive deviation (fluctuating vector meson strong force field)
- $K^{*0} \rightarrow$ no obvious deviation (more theory inputs needed)
- Isobar collision data offer a new opportunity to extend the measurement for K^* with high precision

Summary and conclusion

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- Isobar collision data offer a new opportunity to extend the measurement for K^* with high precision
- $K^{*\pm}$ has non-zero spin alignment in HIC
- $K^{*\pm}$ is larger than K^{*0} for $20\% - 60\%$ isobar collisions
- The current large deviation of $K^{*\pm}$ and its ordering with K^{*0} (opposite to the expectation from B-field) → Theory inputs needed

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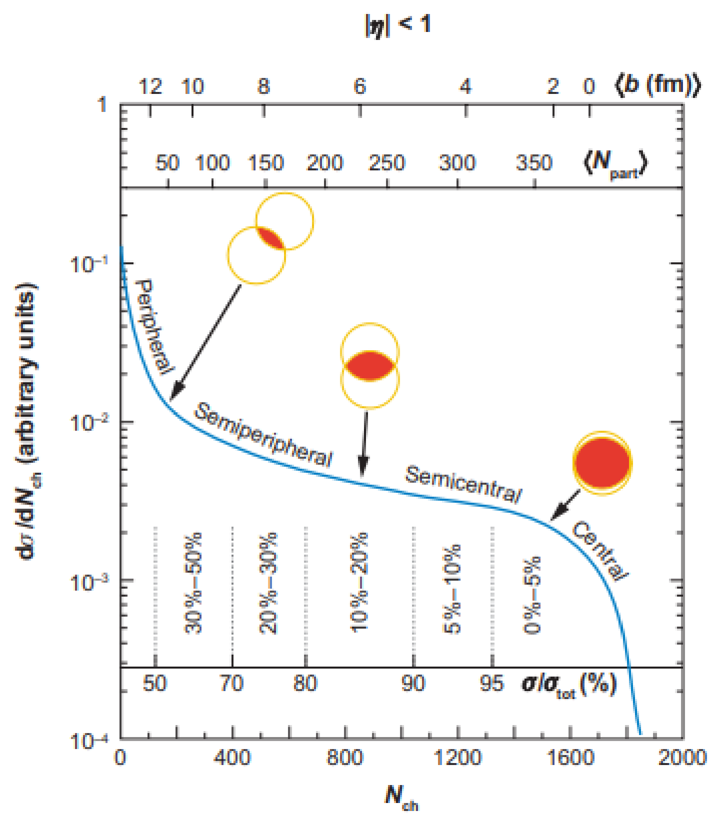
Back up

Back up

- Monte Carlo Glauber simulation:

$$\frac{dN_{ch}}{d\eta} \propto \left(N_{part} \leftrightarrow N_{coll}\right) \propto b \rightarrow Centrality$$



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Thank you