Probing Three-Body Baryonic Interactions via Femtoscopy Approach at STAR

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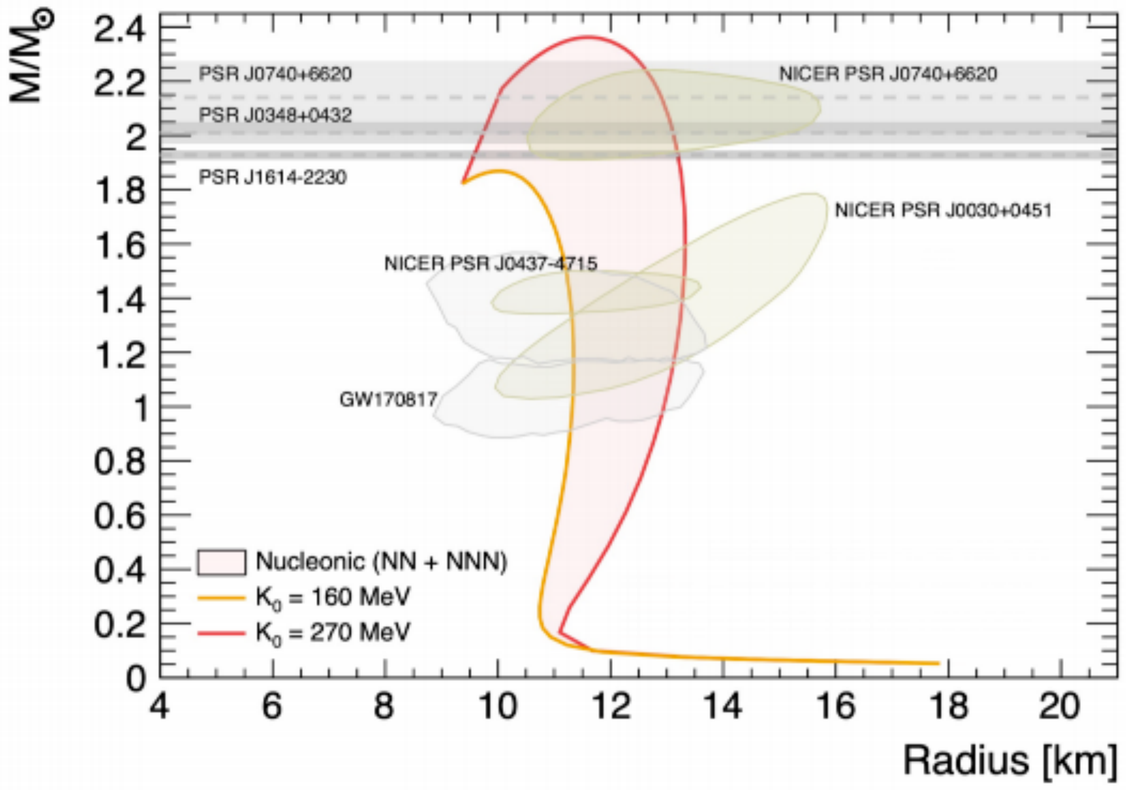
The 3rd International Workshop on Physics at High Baryon Density — Dalian, China — 2026.11.10-13

Outline

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2. Three-body Femtoscopy
3. STAR Detector
4. Analysis Details
5. Results
   (1) p-p-p correlation
   (2) p-p-Λ correlation
6. Summary and Outlook

Motivation

- **The nuclear force governs the equation of state at supra-saturation densities, crucial for neutron star stability ($> 2\rho_0$)**

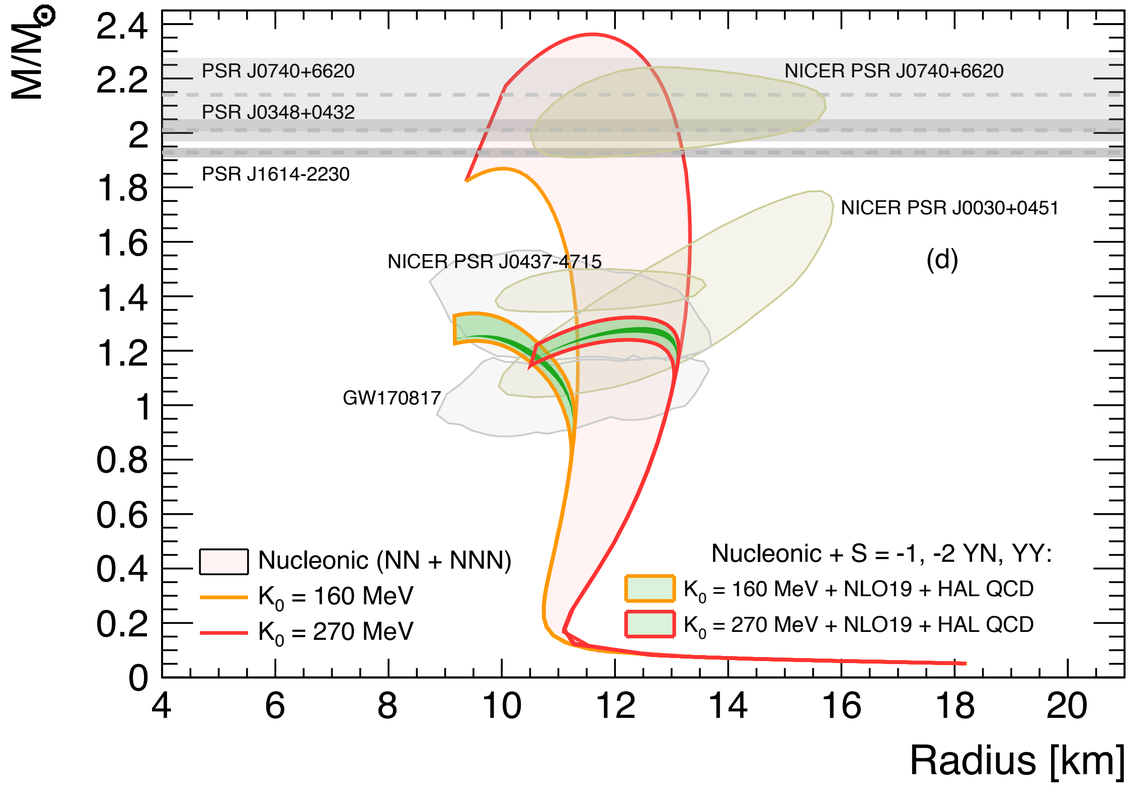


EPJ.A 61 (2025) 3, 59
Phys. Rev. C 110, 054004 (2024)
Phys. Rev. Lett. 114, 092301 (2015)

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- **The nuclear force governs the equation of state at supra-saturation densities, crucial for neutron star stability ($> 2\rho_0$)**

- **The appearance of hyperons softens the EoS, leading to the hyperon puzzle, which may require repulsive *YNN* three-body interactions**

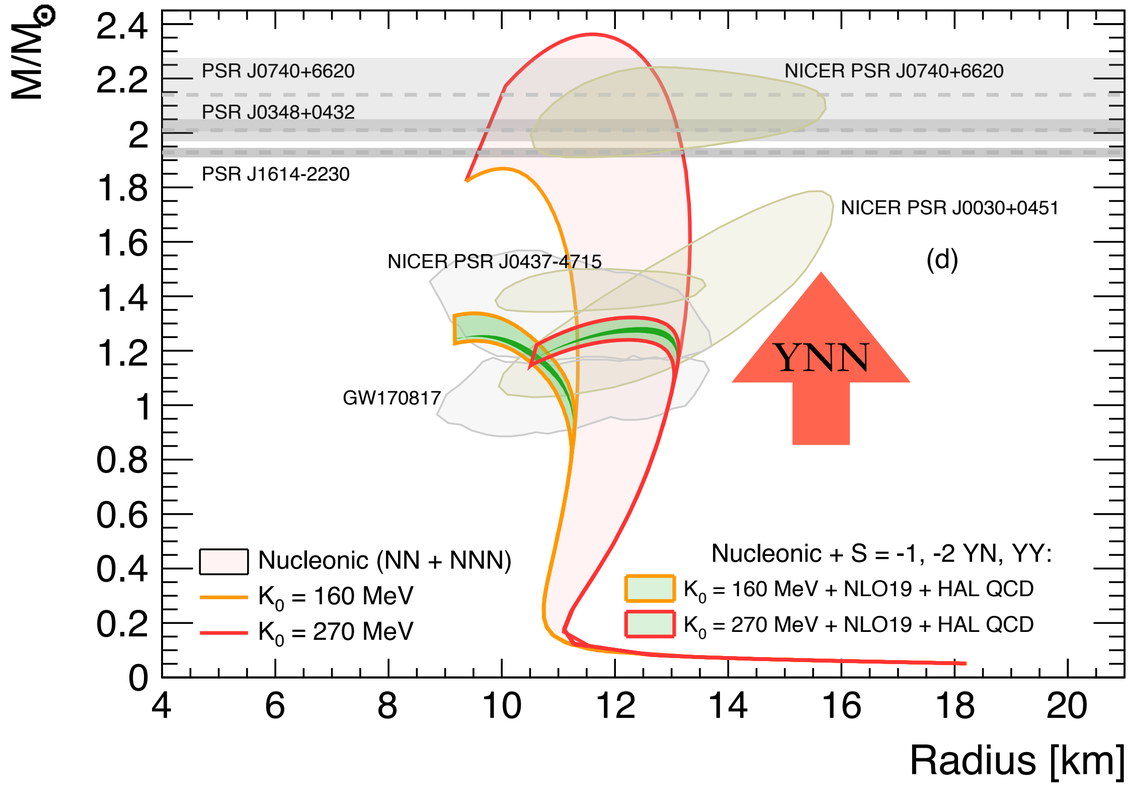


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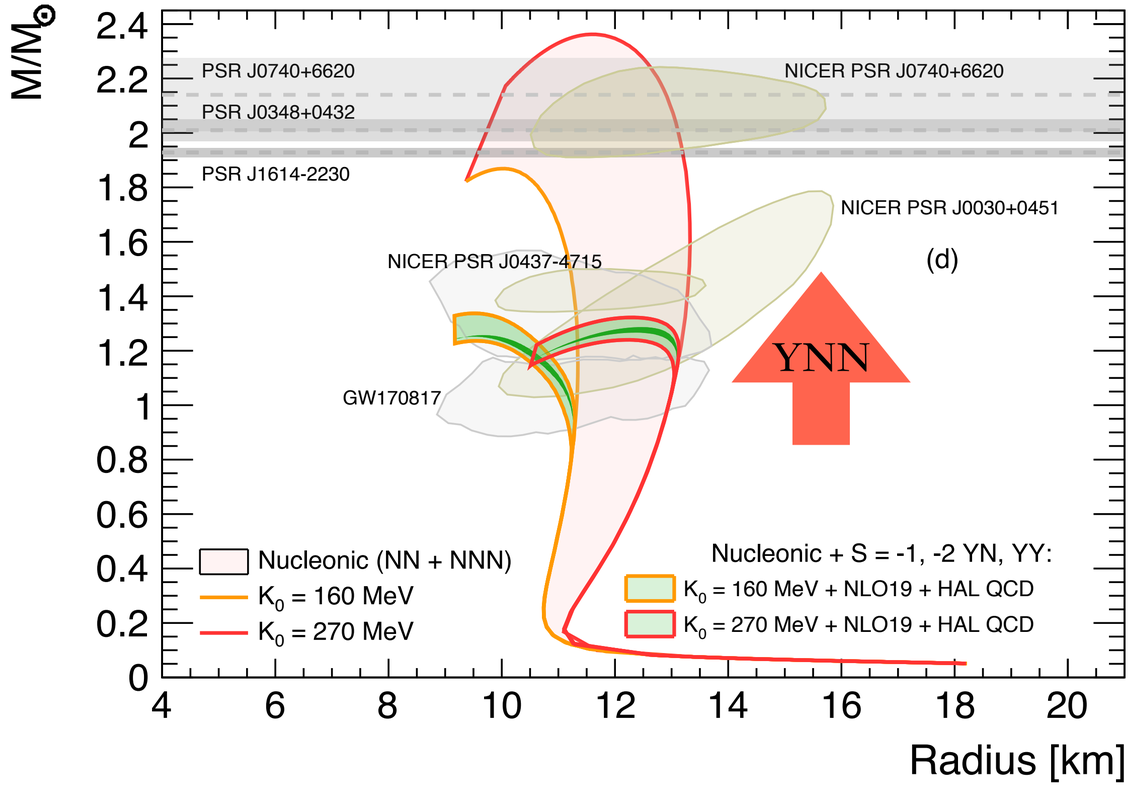
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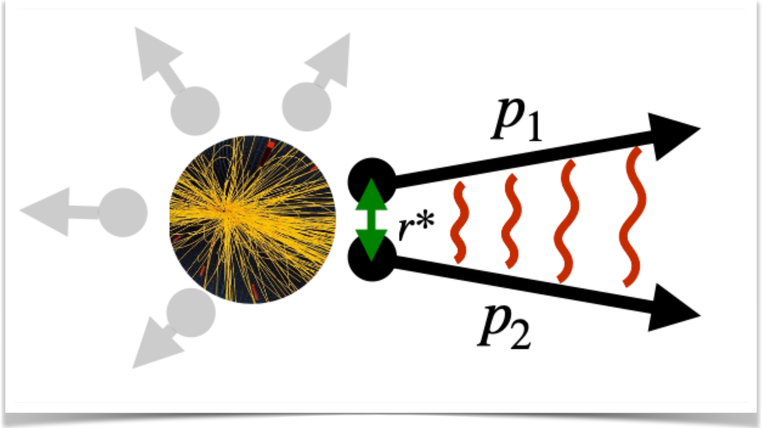
- The appearance of hyperons softens the EoS, leading to the hyperon puzzle, which may require repulsive *YNN* three-body interactions

- Experimental constraints on three-body interactions are very limited *(NNN, YNN)*
  - **Femtoscopy provides a unique opportunity to access few-body interactions at the femtometer scale in momentum space**



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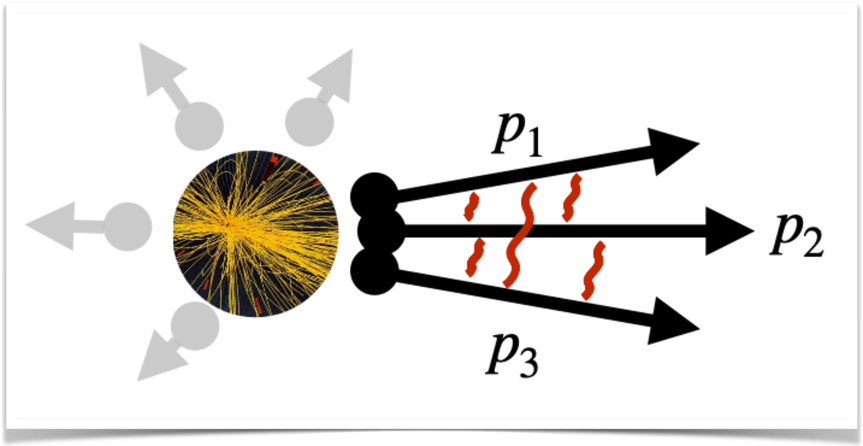
Methodology: Two-body Femtoscopy



- **Two-particle correlation:** $C(p_1, p_2) = \dfrac{P(p_1, p_2)}{P(p_1)P(p_2)}$

L. E. Marcucci et al., FP. 8, 69 (2020).
R. Del Grande et al. EPJC 82 (2022) 244
ALICE Coll., EPJ A 59, 145 (2023)
RDG et al. EPJC 82 (2022) 244
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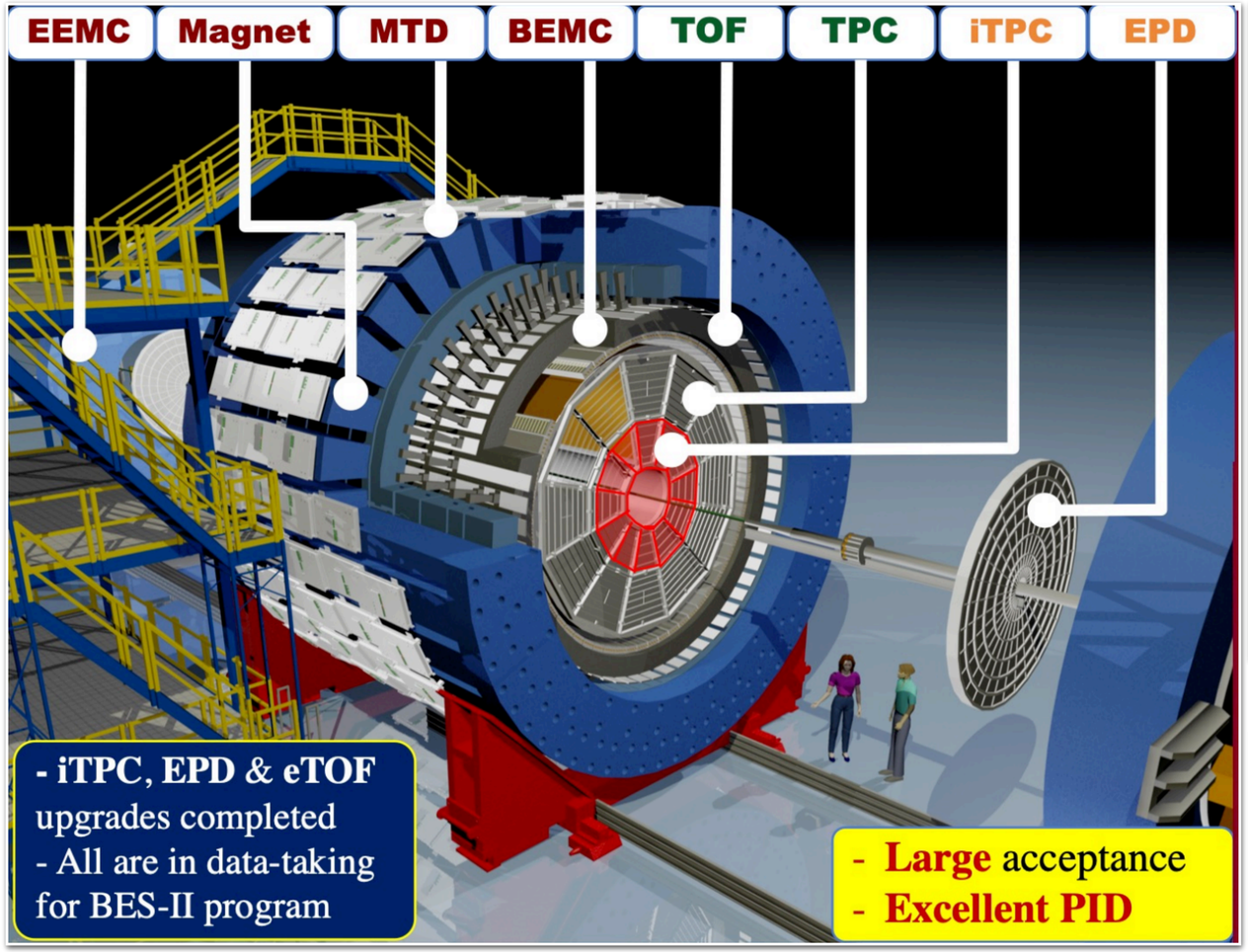
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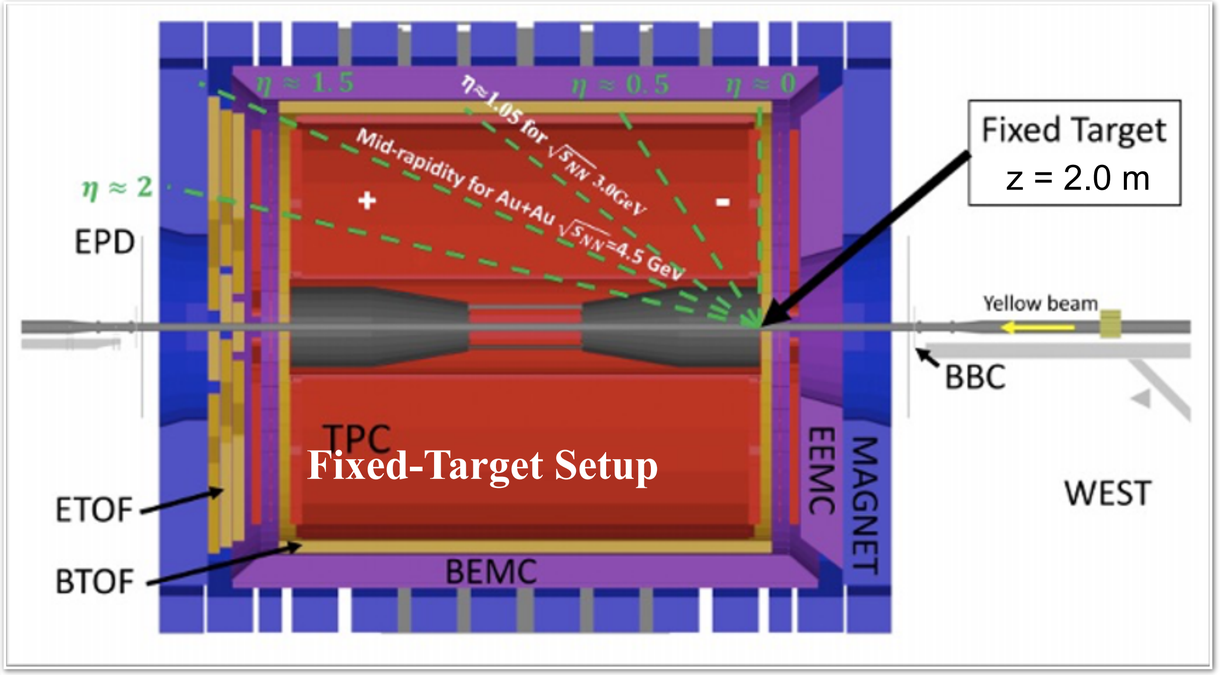


- ***Three-particle*** **correlation:** $C(p_1, p_2, p_3) = \dfrac{P(p_1, p_2, p_3)}{P(p_1)P(p_2)P(p_3)}$
- **Theory:**
  - $C(Q_3) = \int S(\rho, \rho_0)\ |\Psi(\rho, Q_3)|^2\ \rho^5 d\rho d\Omega_\rho$
    - $Q_3 = \sqrt{-q_{12}^2 - q_{23}^2 - q_{31}^2}$, **hypermomentum**
    - ρ_0: **hyper-radius between three particles in PRF**
    - $S(\rho, \rho_0)$: ***Three-body*** **source function,** ρ **is hyper-radius**
    - $|\Psi(\rho, Q_3)|^2$: ***Three-body*** **wave function**
- **Experimental observable:**
  - $C_{p_1,p_2,p_3} = C(Q_3) = N\dfrac{A_{same-event}(Q_3)}{B_{mixed-event}(Q_3)}$
- **Sensitive to:**
  - Quantum statistics, Coulomb and Strong interaction

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STAR Detector

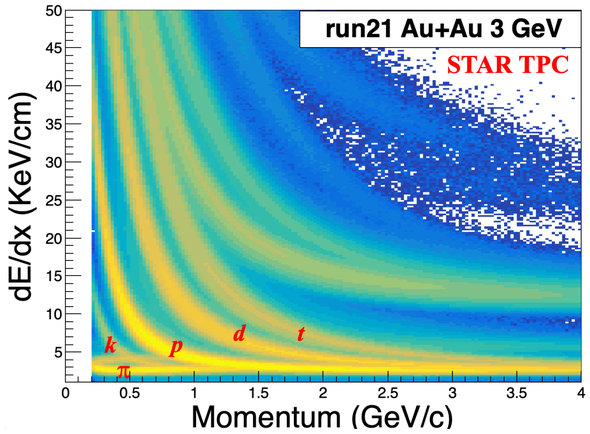


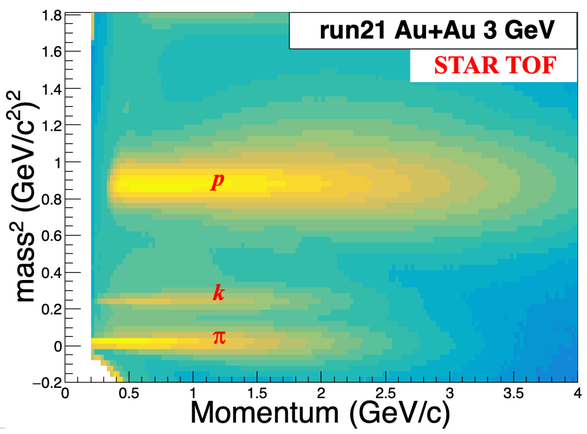


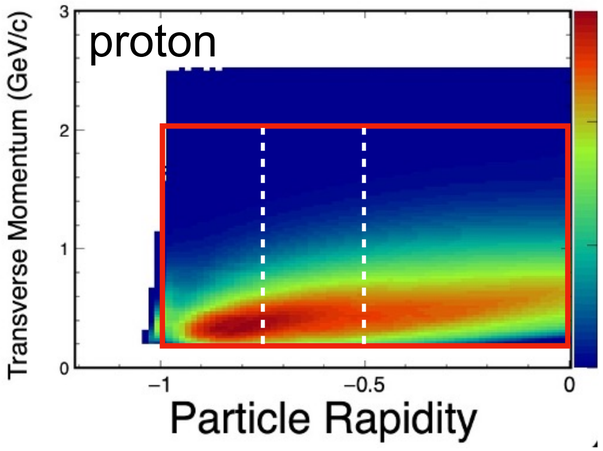
Center-of-Mass Energy	Collisions	Year	Mode	#Events
3 GeV	Au+Au	2021	FXT	2000 M

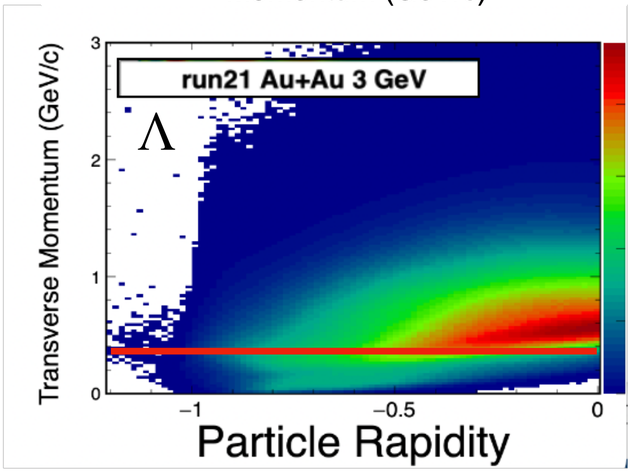
- Large acceptance with mid-rapidity coverage
- Excellent particle identification

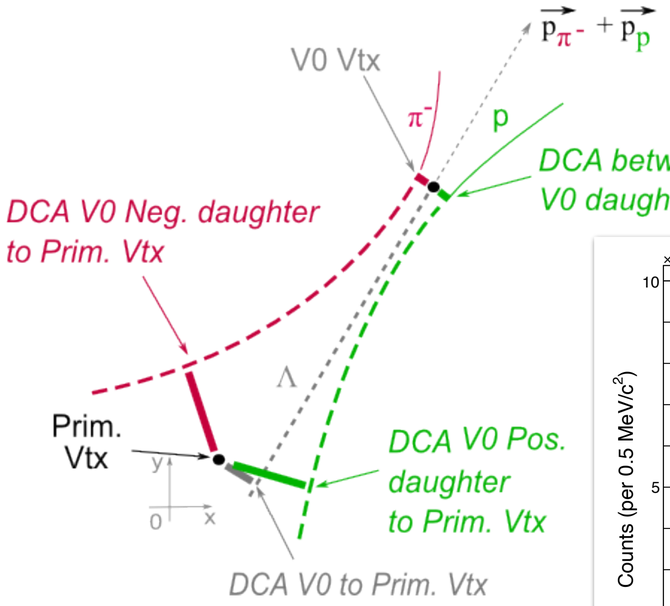
Particle Identification & Reconstruction

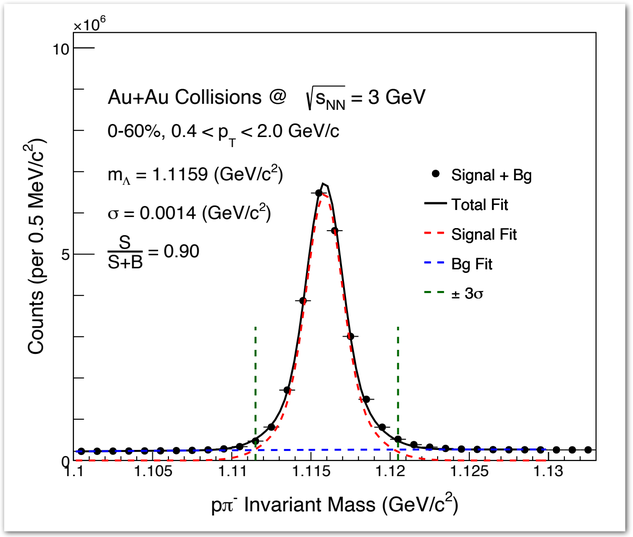












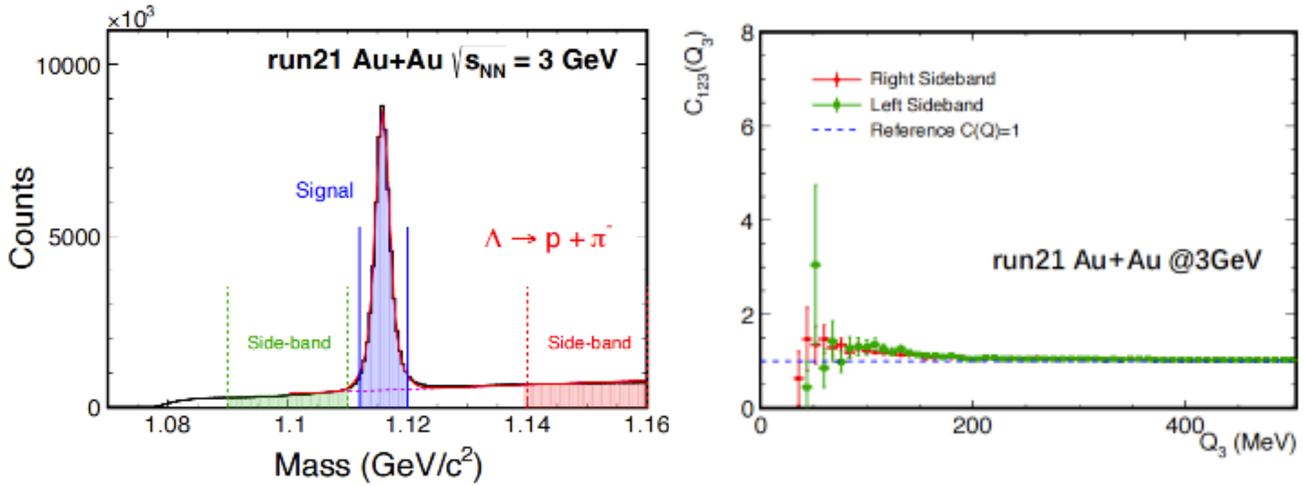
- **Proton PID:**
  - **Combination of TPC and TOF**
  - **Proton purity > 99%**
- **Λ reconstruction via $\Lambda \rightarrow p + \pi^-$ decay channel**
  - **KFParticle package used**
  - **Λ Purity ~ 87% (average)**

Analysis Details

$$C_{measured}(Q_3) = \lambda_{genuine} C_{genuine}(Q_3) + \lambda_{mis-id} C_{mis-id}(Q_3) + \lambda_{res} C_{res}(Q_3)$$

Background correction

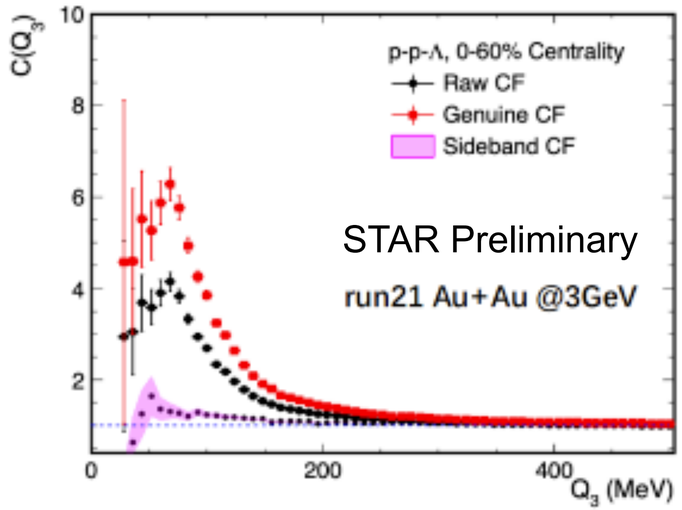
- **Mis-identification correlation $C_{mis-id}(Q_3)$: estimated via *side-band* method**



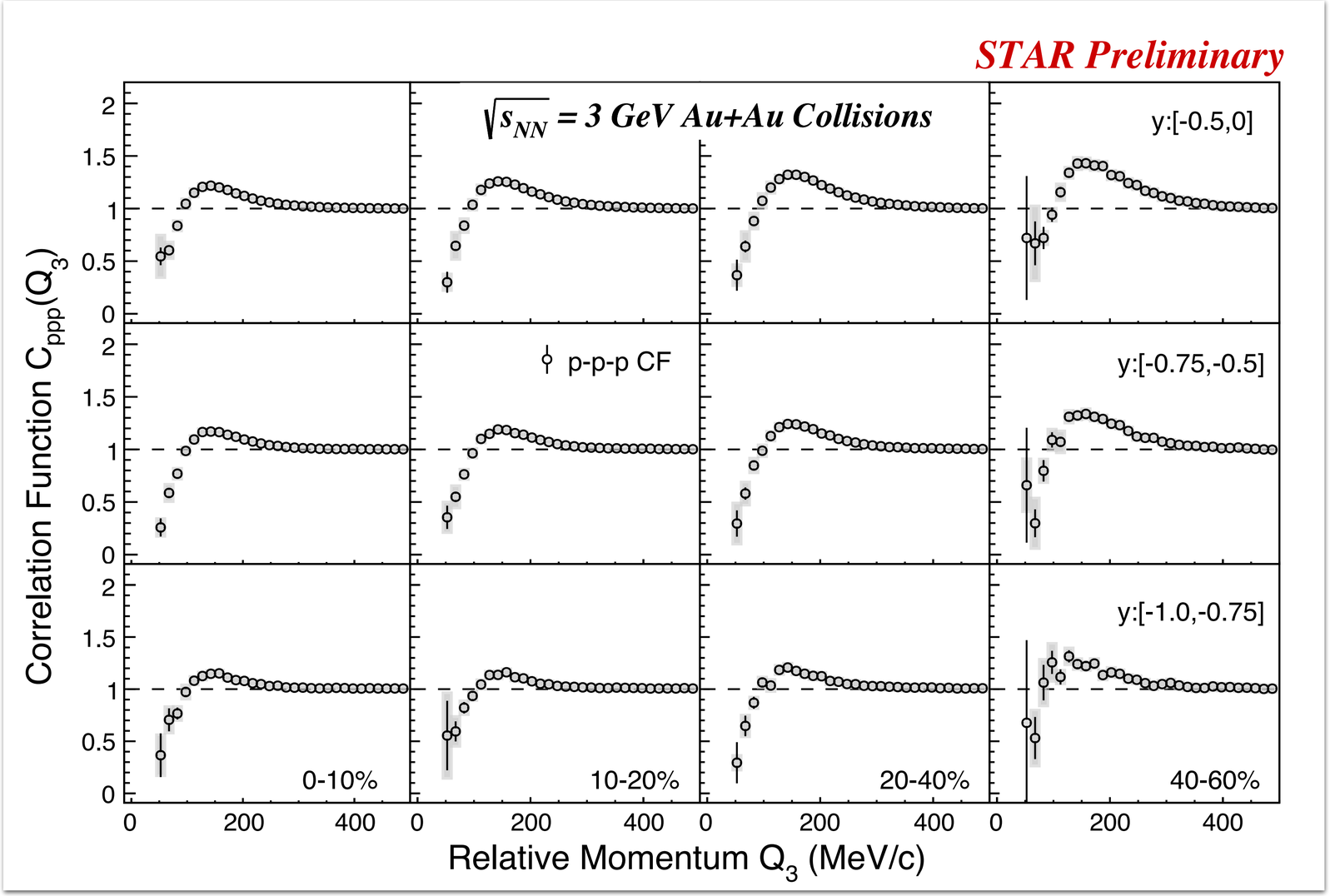
- **Residual correlation $C_{res}(Q_3)$**
  - **Main residual correlation comes from: $\Sigma^0 \to \Lambda + \gamma$**
  - **Assume flat correlation, due to no theory or experimental measurements**

Impurity fraction $\lambda_{gen}, \lambda_{mis-id}, \lambda_{res}$

- **Single particle purity:**
  - **Proton > 99%, Λ ~ 87 %**
- **Feed-down fraction:**
  - **Proton: < 2% (data-driven)**
  - **Λ: ~ 30% (Thermal model)**



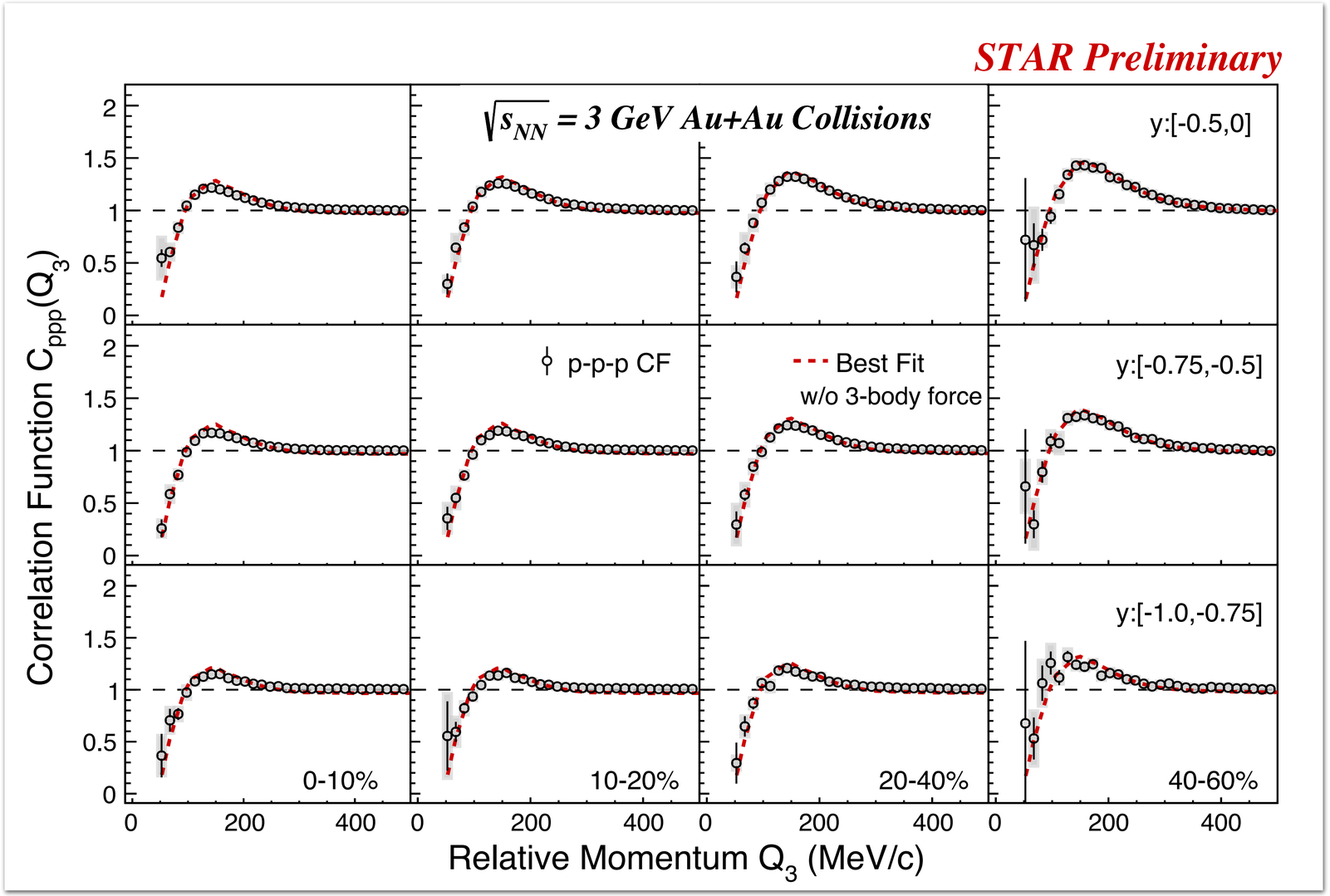
Results: p-p-p Correlation Function



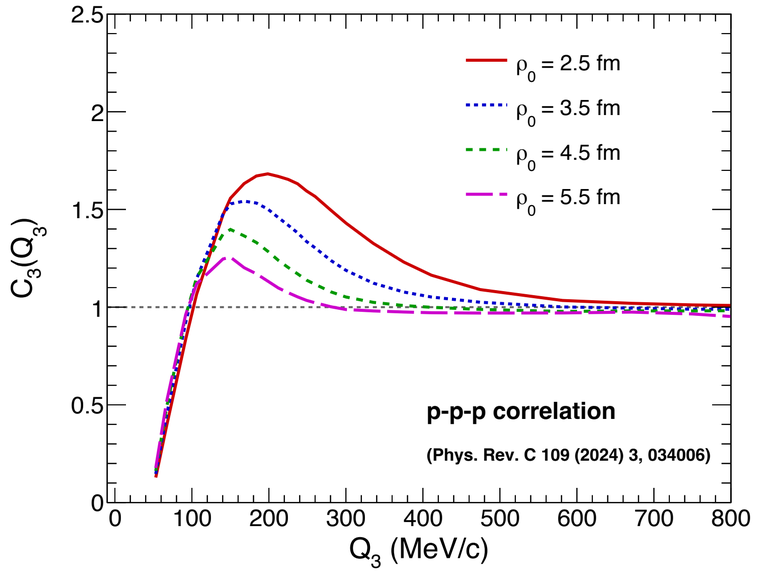
- ***First precise measurement*** **of p-p-p correlation function in Au+Au collisions at $\sqrt{s_{NN}}$ = 3 GeV, with 4 centrality and 3 rapidity classes**
  - **Centrality and rapidity dependence seen in data**

Phys.Rev.C 109 (2024) 3, 034006

Results: p-p-p Correlation Function



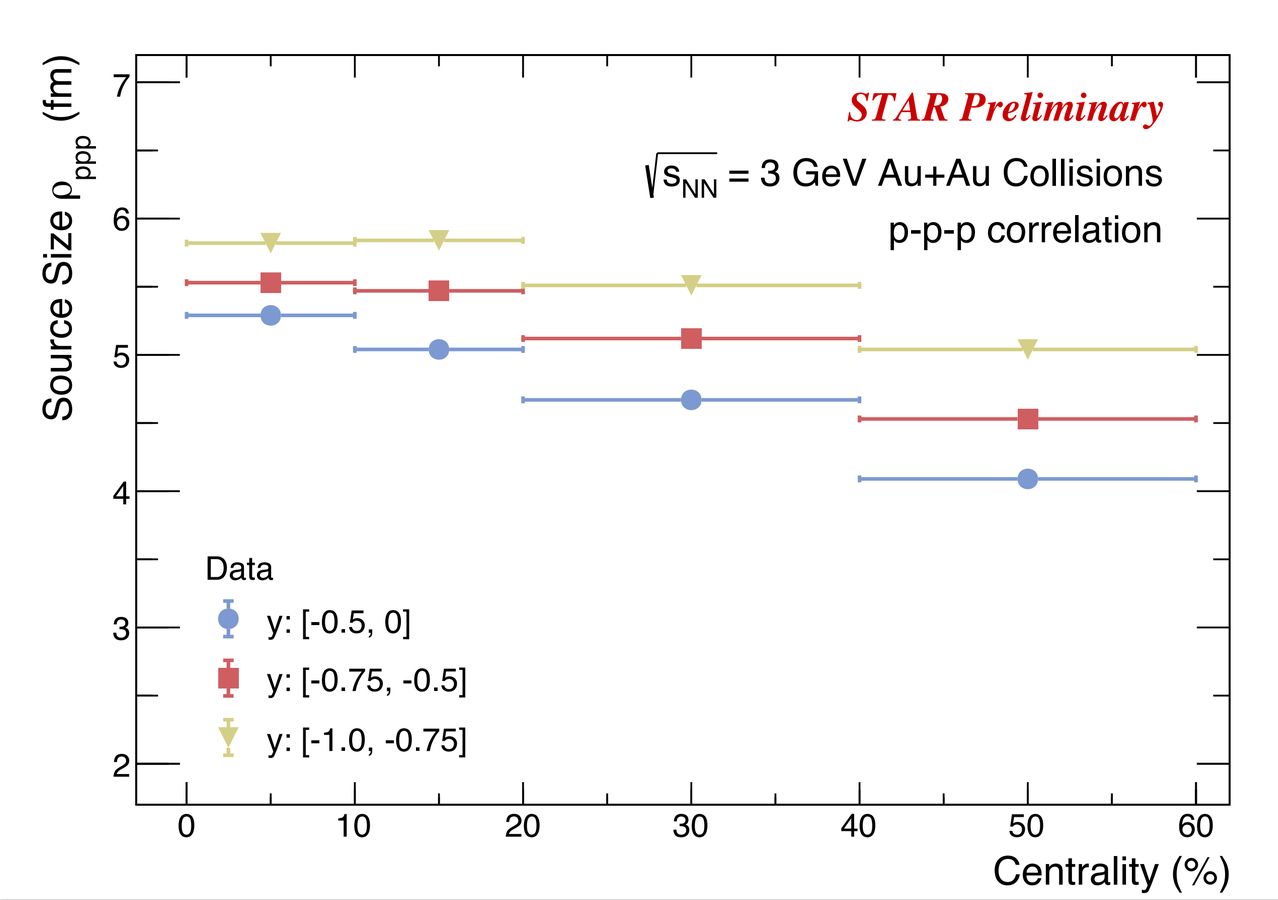
From theoretical calculation



- **The data are fitted with theoretical calculations incorporating:**
  - **Coulomb interaction**
  - **Quantum statistics**
  - ***Two-body* strong interaction**

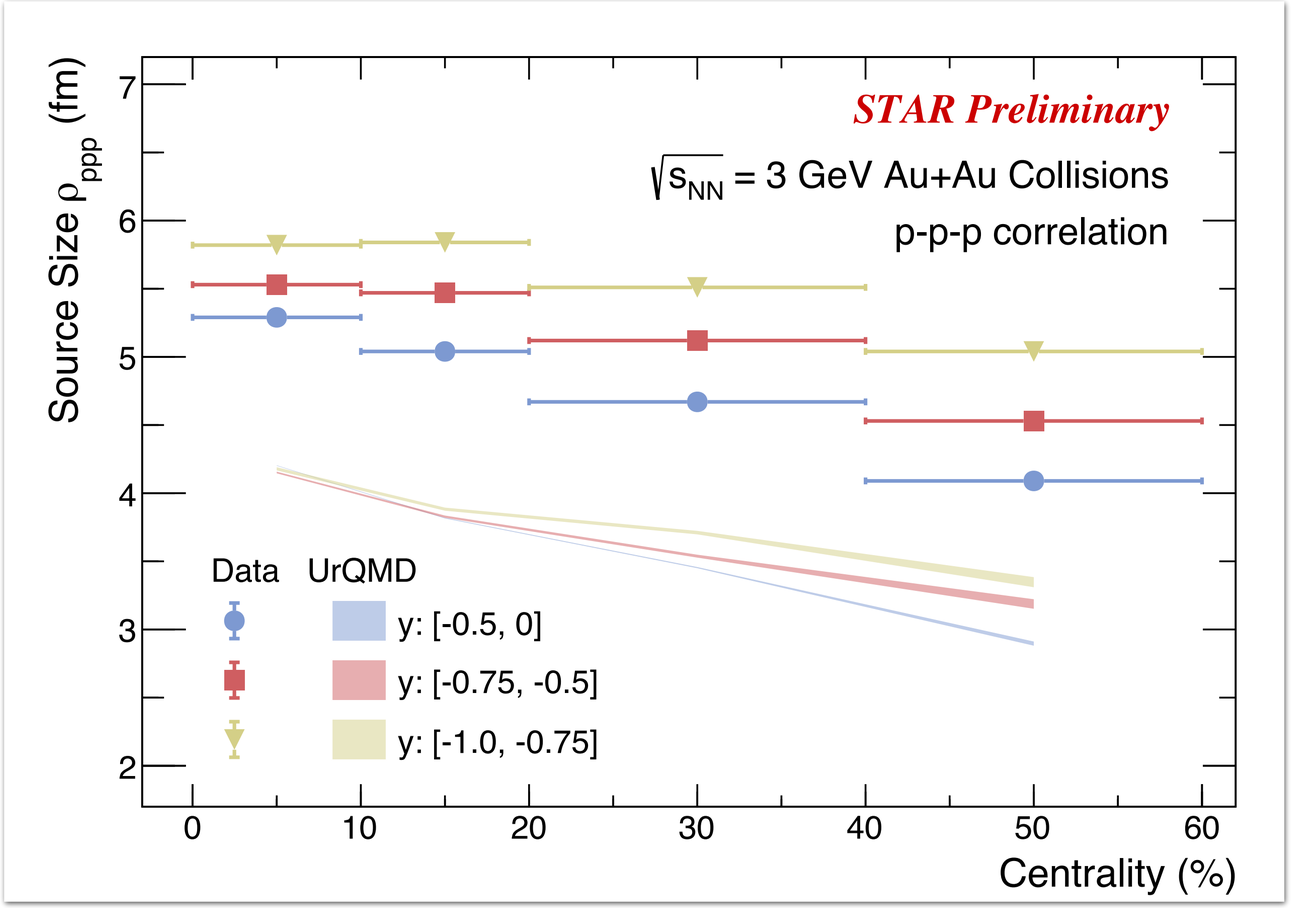
Phys.Rev.C 109 (2024) 3, 034006

Results: p-p-p Correlation Function



- **Extracted three-body source size (w/o 3-body force): ~ 4-6 fm**
  - $\rho_{central} > \rho_{peripheral}$**: consistent with a larger and expanding emission source in central collisions**
  - $\rho_{mid-y} < \rho_{tar-y}$**: related to different freeze-out dynamics**

Results: p-p-p Correlation Function

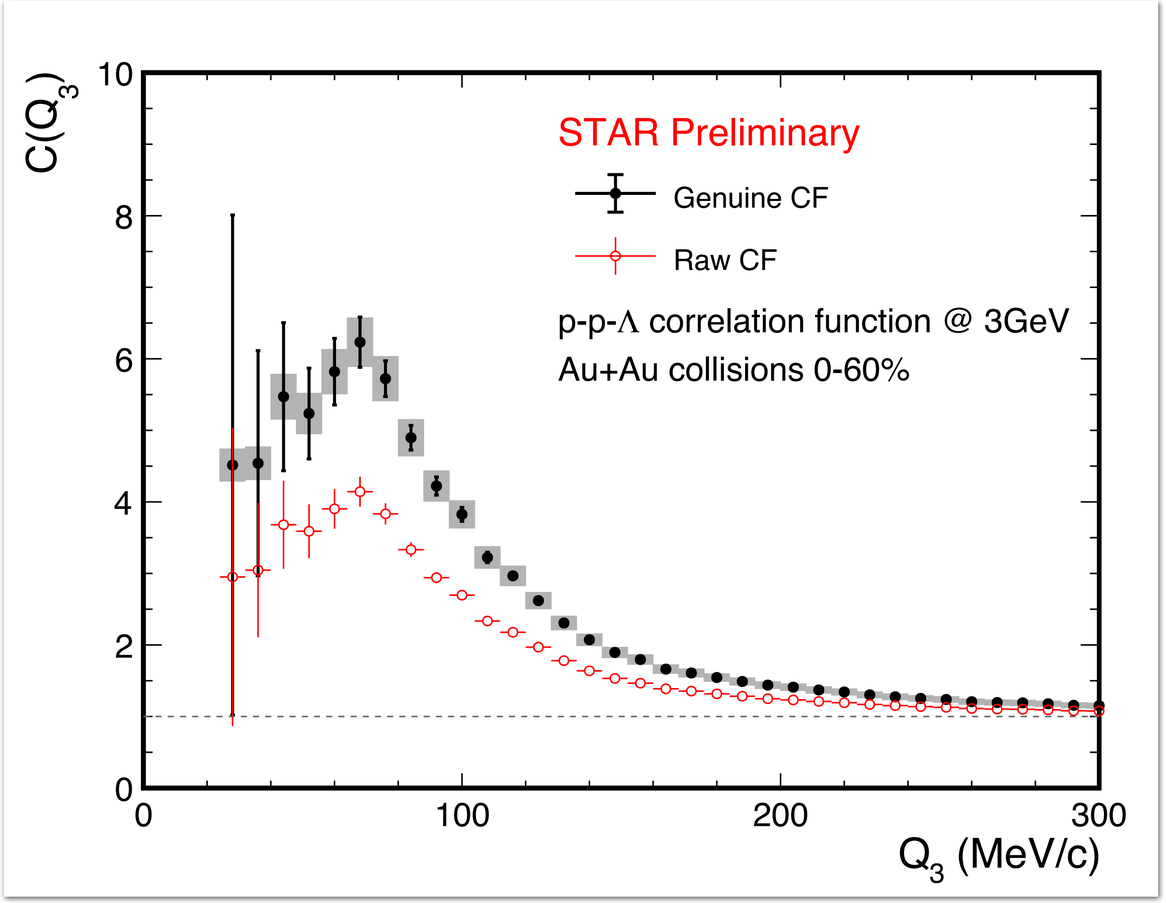


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  - $\rho_{mid-y} < \rho_{tar-y}$**: related to different freeze-out dynamics**

- **Simulated p-p-p source size with UrQMD model**
  - $x = r_1 - r_2;\ y = \sqrt{\frac{4}{3}}[r_3 - \frac{1}{2}(r_1 + r_2)];\ \rho = \sqrt{x^2 + y^2}$
  - $\rho_{data} > \rho_{UrQMD}$

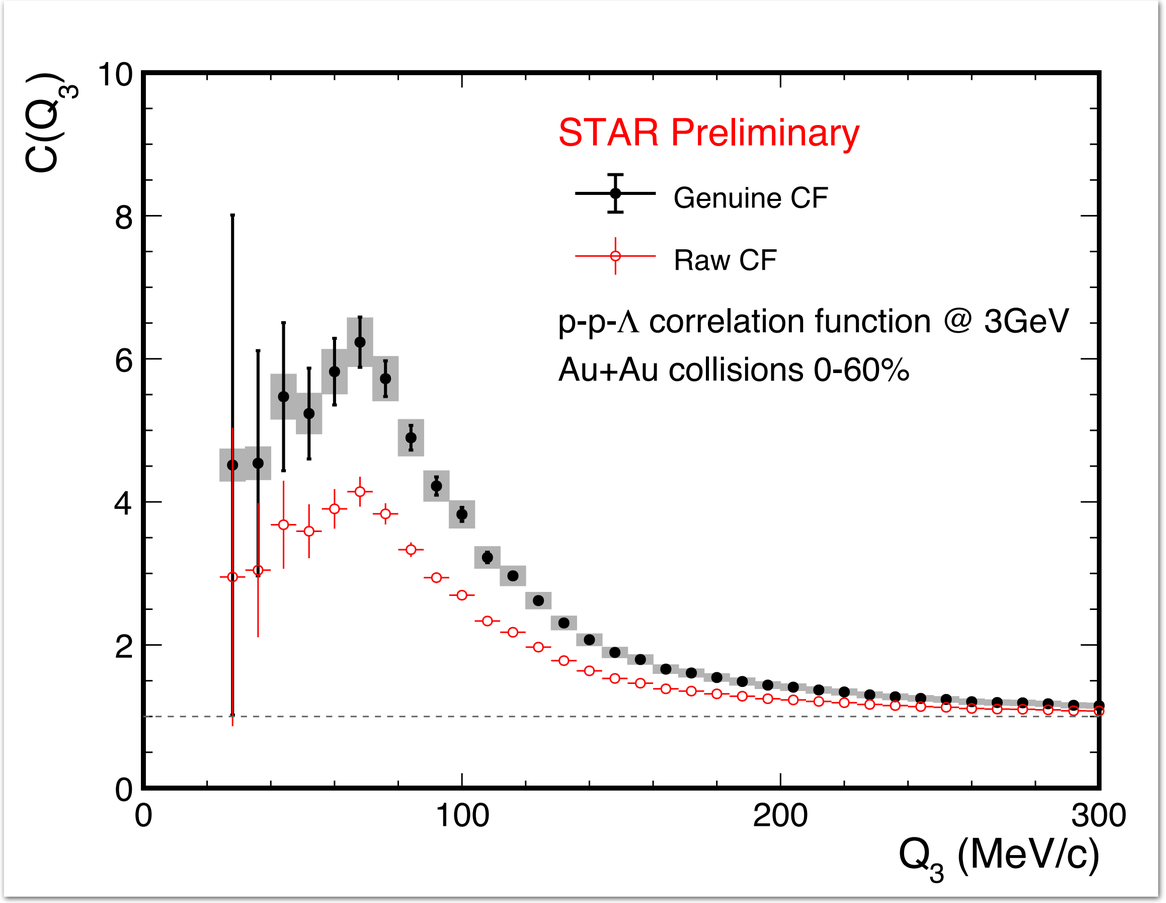
Phys. Rev. C 109, 034006 (2024)

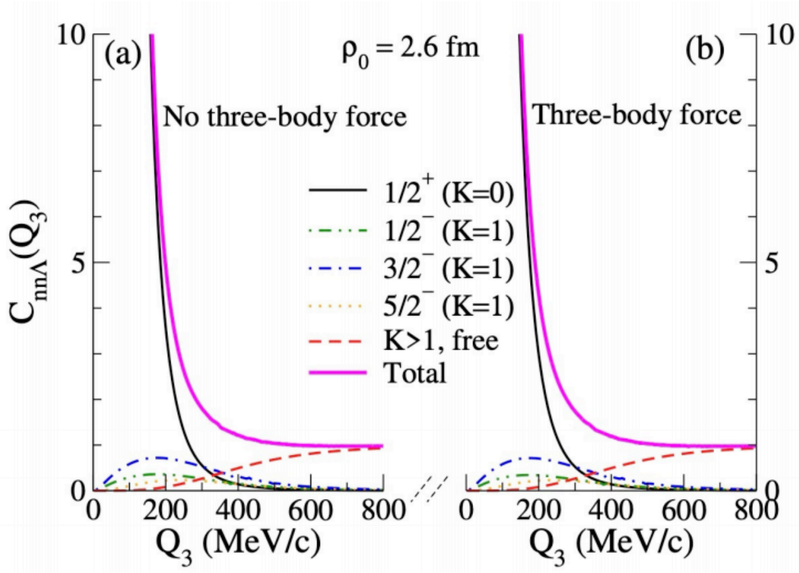
Results: p-p-Λ Correlation Function



- ***First precise measurement*** **of p-p-Λ correlation function in Au+Au collisions at $\sqrt{s_{NN}}$ = 3 GeV**
  - **Provide improved experimental coverage in the low-Q_3 region (Q_3 < 100 MeV/c)**

Results: p-p-Λ Correlation Function

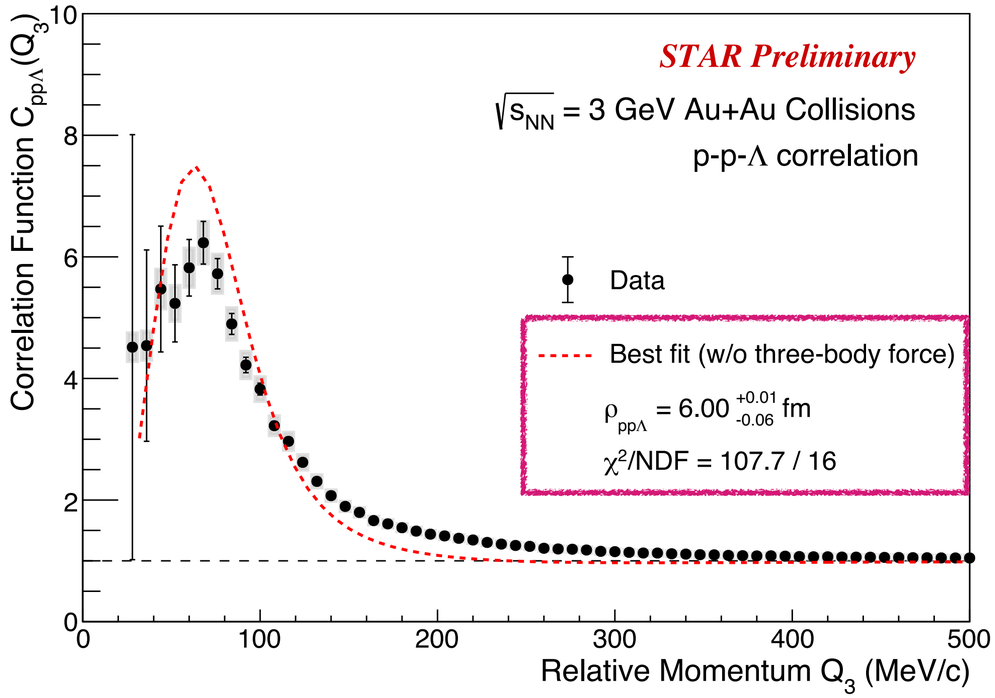


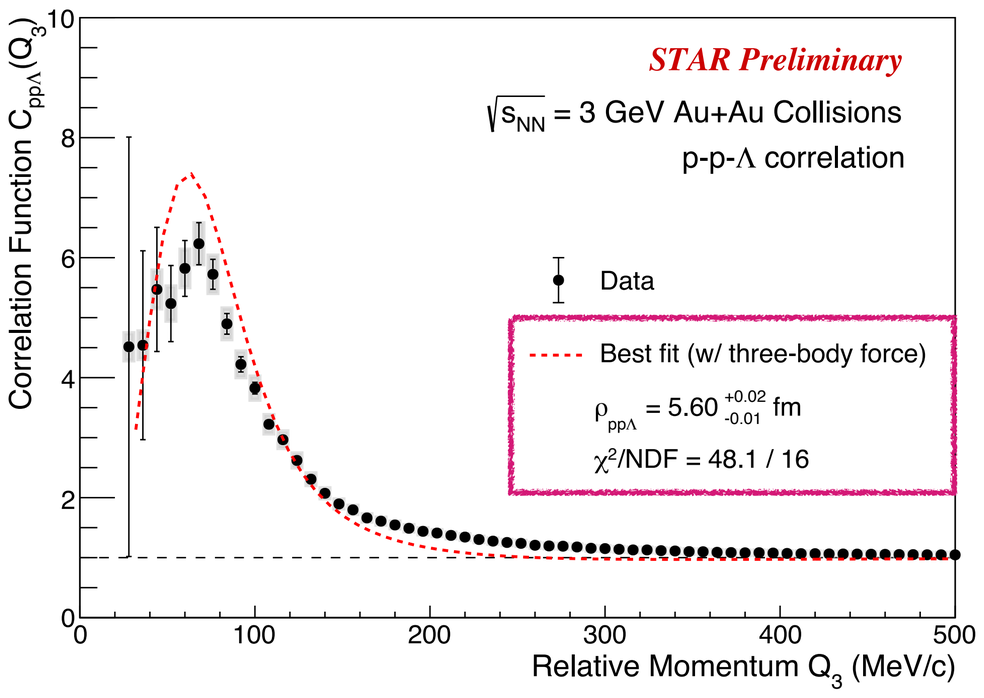


- Including the three-body force reduces the CF peak height by ~ **20%** compared to the case without the three-body force
- Low Q_3 dominated by the $\frac{1^+}{2}$ partial wave, at larger Q_3 region high J^π partial wave should be considered

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Results: p-p-Λ Correlation Function





- **Fit data with theoretical calculations w/o and w/ 3-body force, extracted source size:**
  - $\rho_{pp\Lambda}$ **= 6.00 ± 0.04 (stat.) ± 0.10 (sys.) fm (w/o 3-body force)**
  - $\rho_{pp\Lambda}$ **= 5.60 ± 0.02 (stat.) ± 0.08 (sys.) fm (w/ 3-body force)**

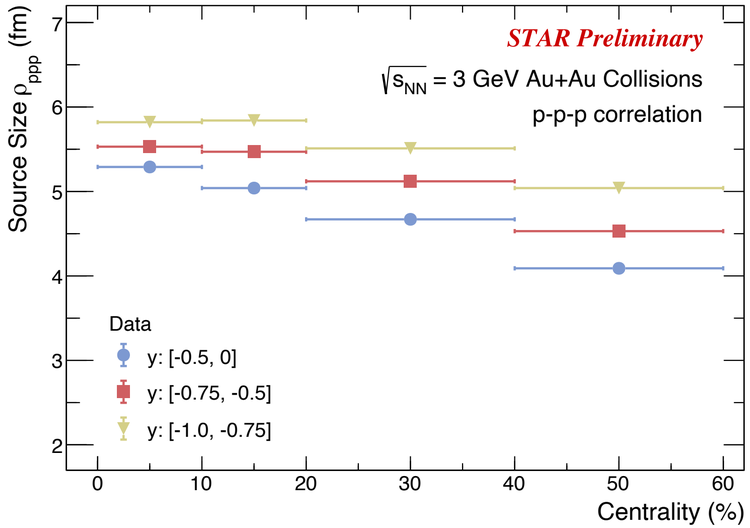
- **Simulated p-p-Λ pair source size in UrQMD model,** $\rho_{\mathrm{pp\Lambda}}^{UrQMD} \sim$ **3.90 fm**

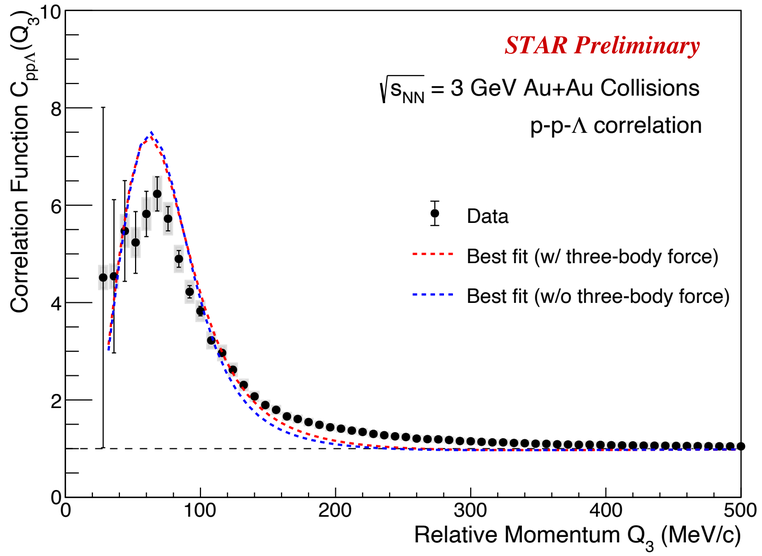
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Summary

- We present the first precise measurements of the p-p-p and p-p-Λ correlation function in Au+Au collisions at $\sqrt{s_{NN}}$ = 3 GeV
- Extracted source size ρ_0 with existing theoretical calculations:
  - p-p-p (w/o 3-body force): ρ_0 show centrality and rapidity dependence
  - p-p-Λ: $\rho_{pp\Lambda}$ = 6.00 ± 0.04 (stat.) ± 0.10 (sys.) fm (w/o 3-body force)

    $\rho_{pp\Lambda}$ = 5.60 ± 0.02 (stat.) ± 0.08 (sys.) fm (w/ 3-body force)
- Outlook:
  - Theoretical input to interpret the data and constrain 3-body force






Thank you for your attention!