Faculty of Physics
WARSAW UNIVERSITY OF TECHNOLOGY

STAR

Femtoscopic measurements of two-kaon combinations in Au+Au collisions at the STAR experiment

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RESEARCH UNIVERSITY EXCELLENCE INITIATIVE

WUT

Femtoscopy - introduction

statistical | **model** | **experiment**

$$CF(\vec{q}) = \frac{P_{12}(\overrightarrow{p_1},\overrightarrow{p_2})}{P_1(\overrightarrow{p_1})P_2(\overrightarrow{p_2})} = \int d^3r\, S(\vec{q},\vec{r})|\Psi(\vec{q},\vec{r})|^2 = \frac{A(\vec{q})}{B(\vec{q})}$$

$\overrightarrow{p_1}, \overrightarrow{p_2}$ - single particle momentum

$S(\vec{q},\vec{r})$ – emission function
$\Psi(\vec{q},\vec{r})$ – pair wave function
$\vec{q} = |\overrightarrow{p_1} - \overrightarrow{p_2}|$ - relative momentum
$\vec{r}$ - relative distance between two particles

$A(\vec{q})$ - correlated
$B(\vec{q})$ - uncorrelated

Femtoscopy - introduction

statistical — model — experiment

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Kaon correlation functions are sensitive to:

$\mathbf{K^{\pm}K^{\pm}}$	$\mathbf{K^0_sK^0_s}$	$\mathbf{K^0_sK^{\pm}}$
Quantum Statistical effects (QS) Final State Interaction (FSI) - Coulomb interaction (COUL)	Quantum Statistical effects (QS) Final State Interaction (FSI) - strong interaction (SI)	Final State Interaction (FSI) - strong interaction (SI)

Femtoscopy - introduction

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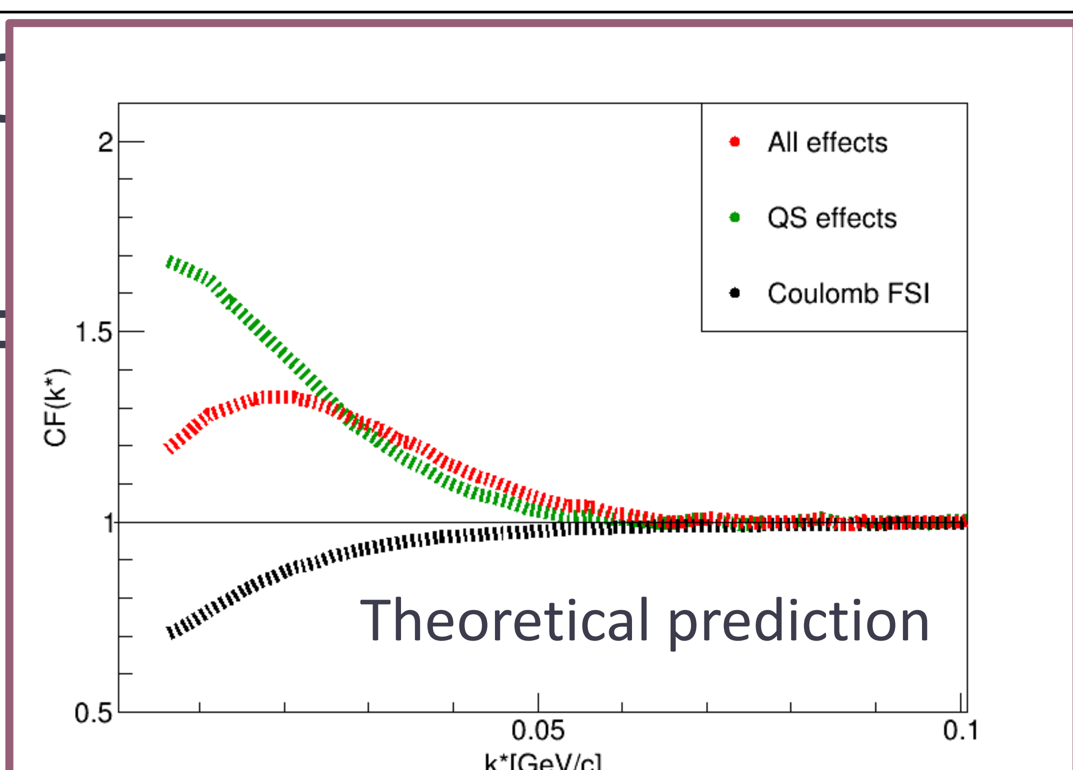
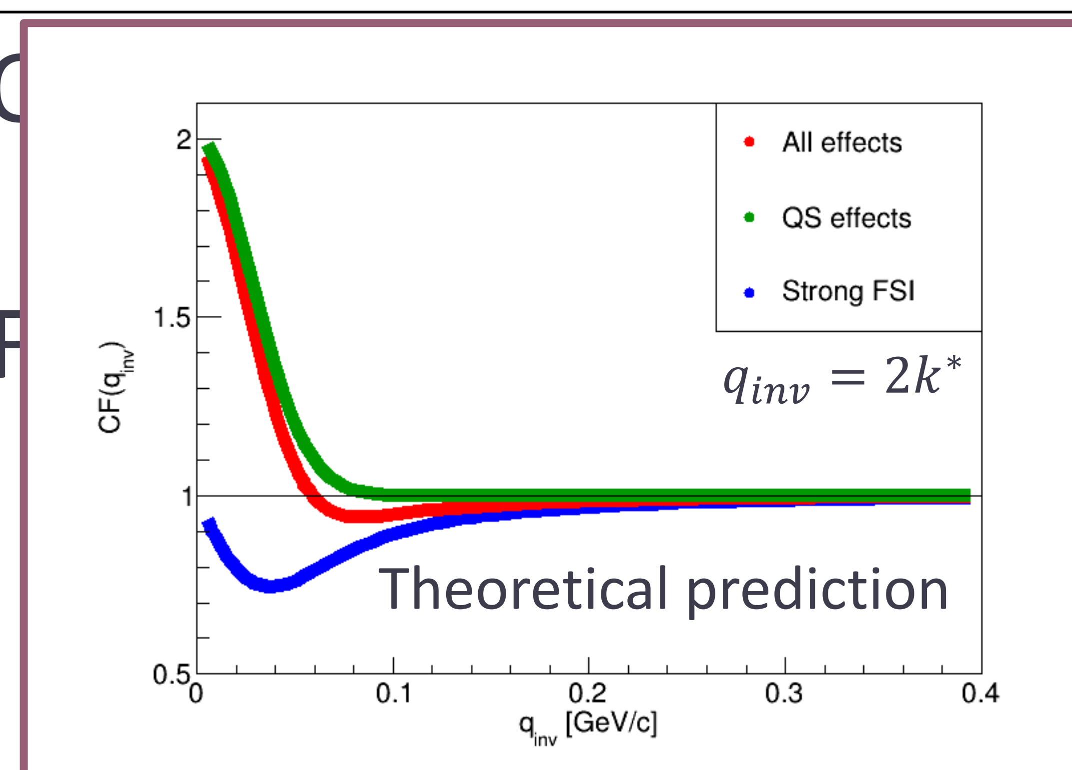
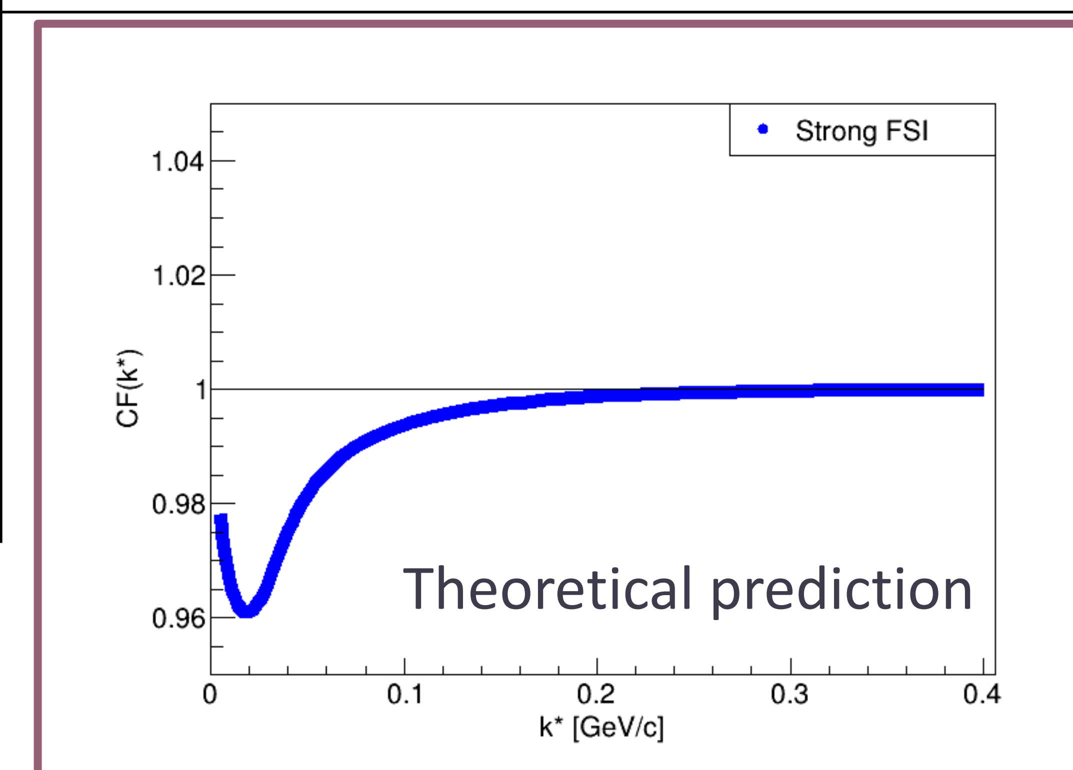


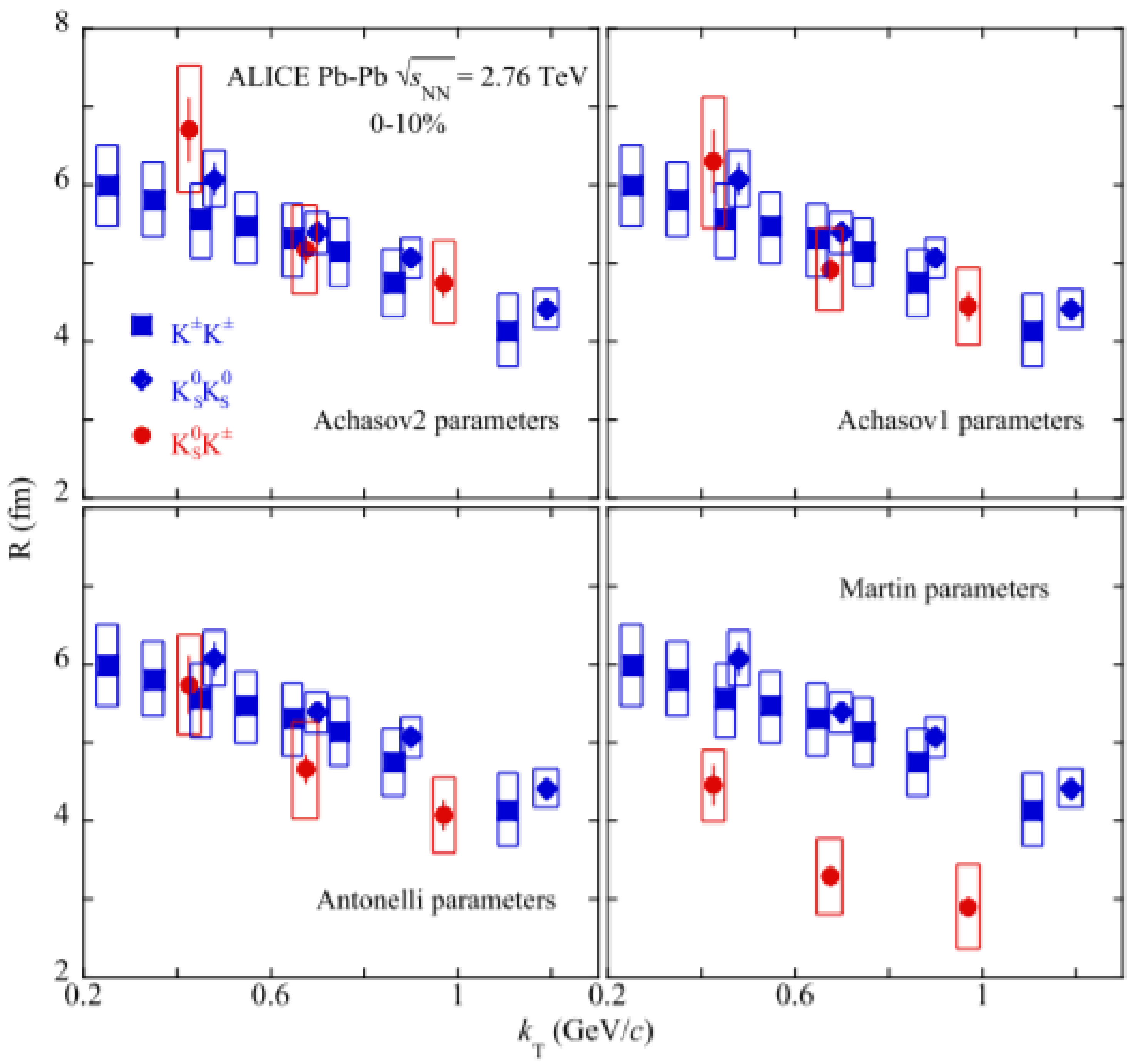




k^* - first particle momentum in PRF

Motivation

ALICE, Physics Letters B **774**(2017) 64



$$k_T = \frac{p_{T1} + p_{T2}}{2}$$

Kaons provide complementary information to pions:

- contain strange quarks (larger production of strange particles is one of the signatures of QGP)
- less affected by the feed-down from resonance decays
- smaller cross section on reaction with the hadronic matter

Very interesting:

- compare femtoscopic results for all possible kaon combination ($K^{\pm}K^{\pm}, K^0_S K^0_S, K^0_S K^{\pm}$)
- $K^0_S K^{\pm}$ - a_0 could be a 4-quark state (a tetraquark)

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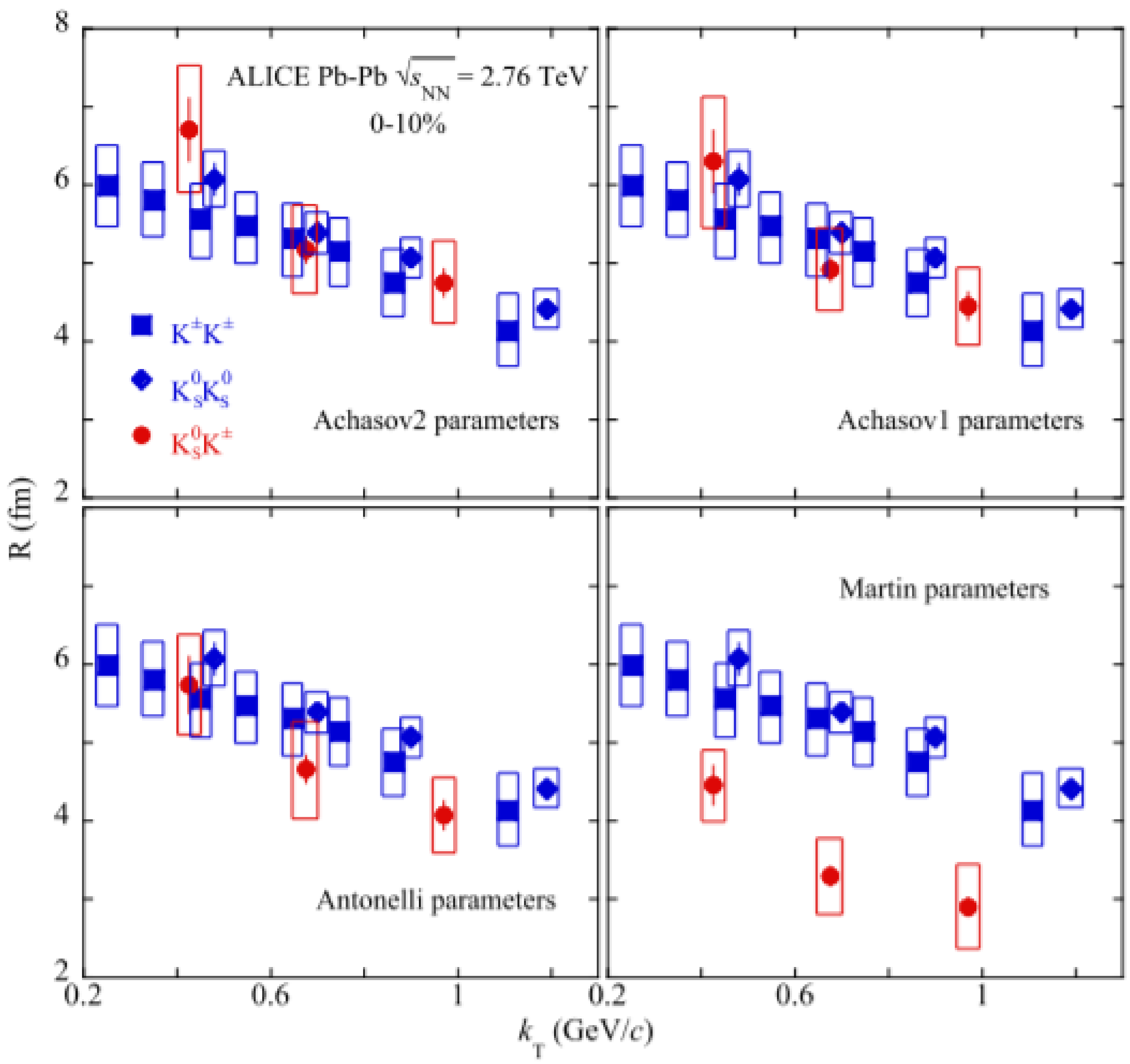

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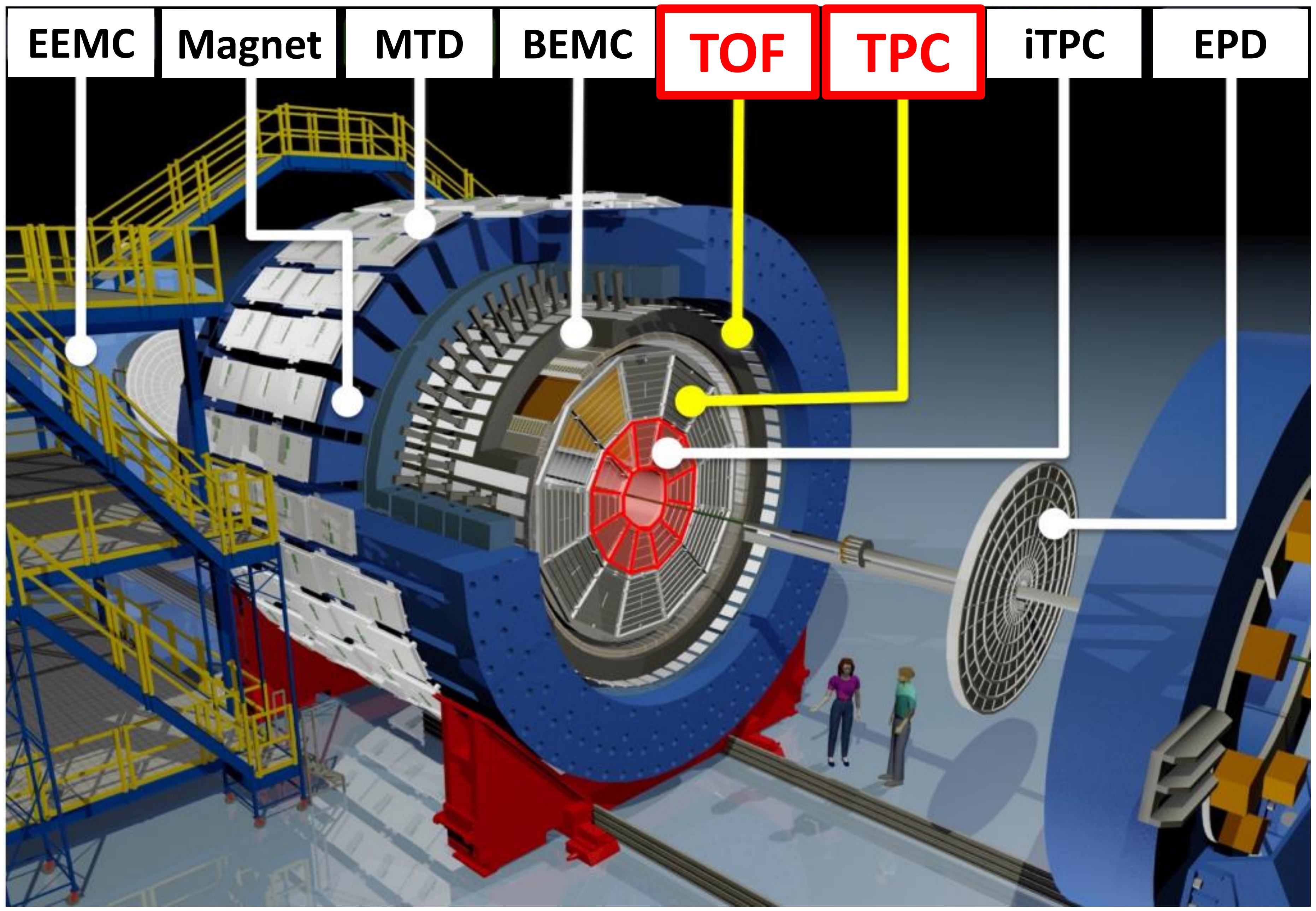
The STAR experiment



→ Exellent particle identification
→ Large, uniform acceptance at mid-rapidity

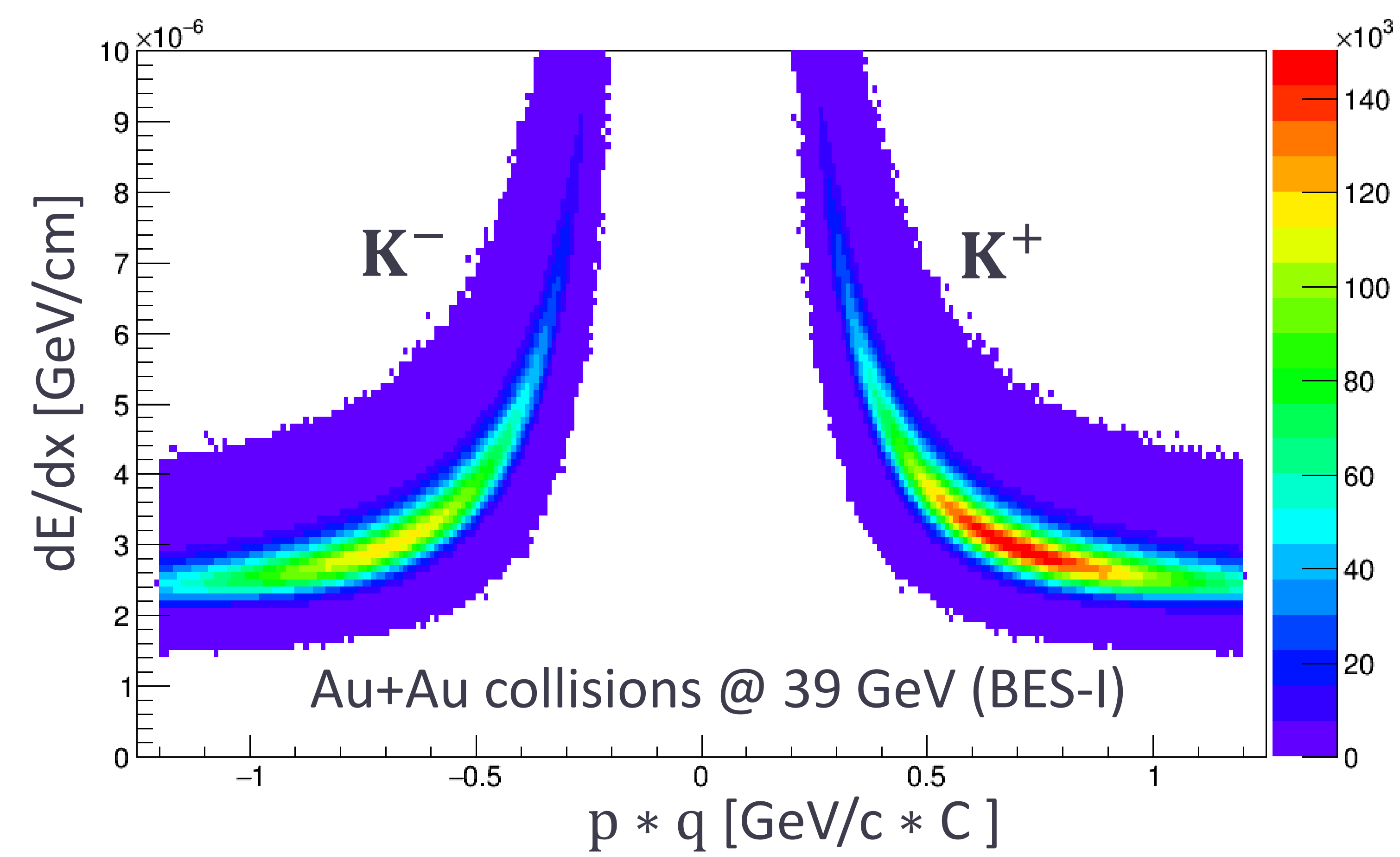
Time Projection Chamber
PID: dE/dx
Tracking
$0 < \phi < 2\pi$, $|\eta| < 1$

Time-Of-Flight
Time resolution < 80 ps
PID: m^2

Datasets

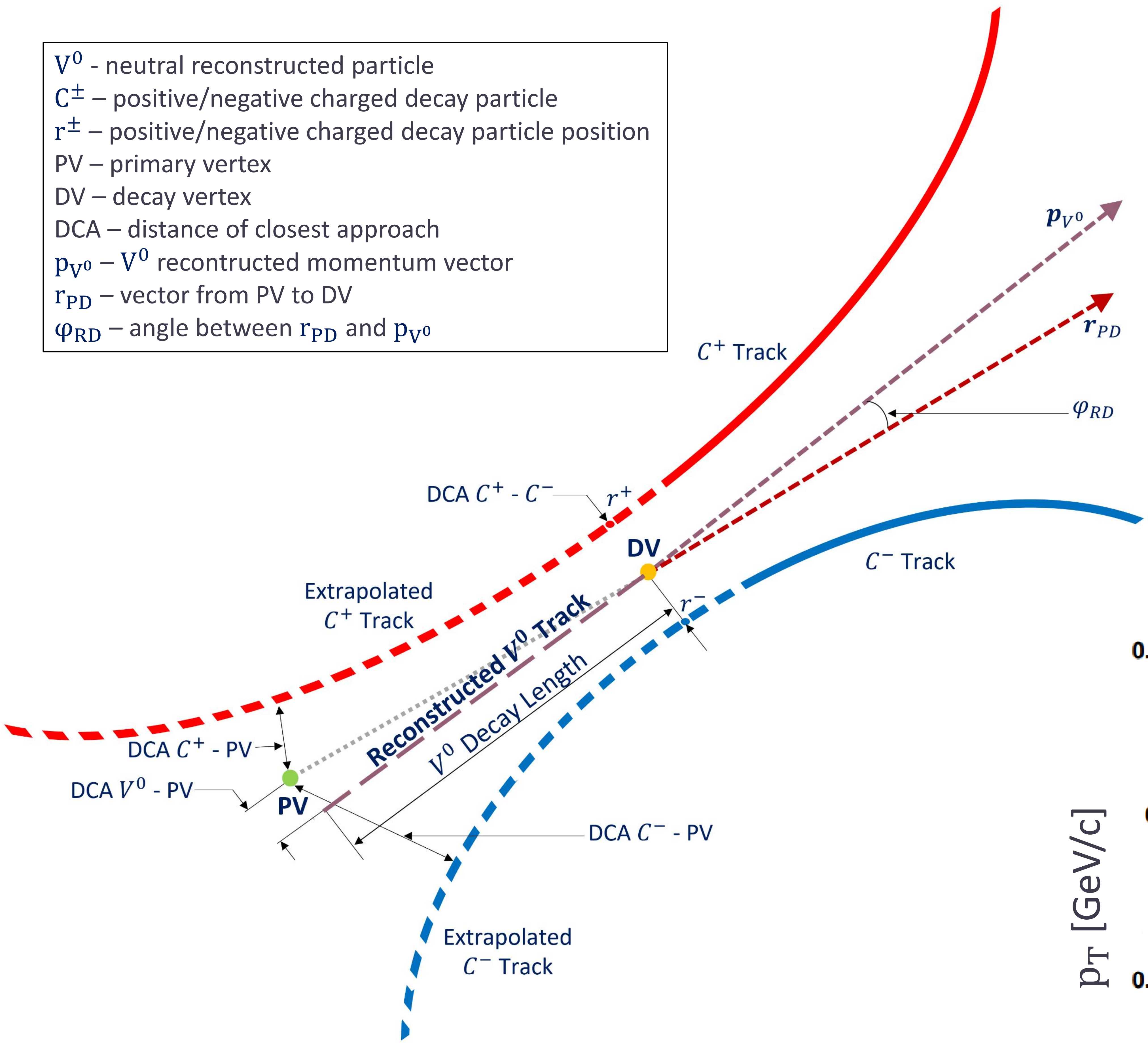
Energy $\sqrt{s_{NN}}$	Year	Mode	Statistics (M)
39 GeV	2010	Collider	~83
200 GeV	2010	Collider	~260

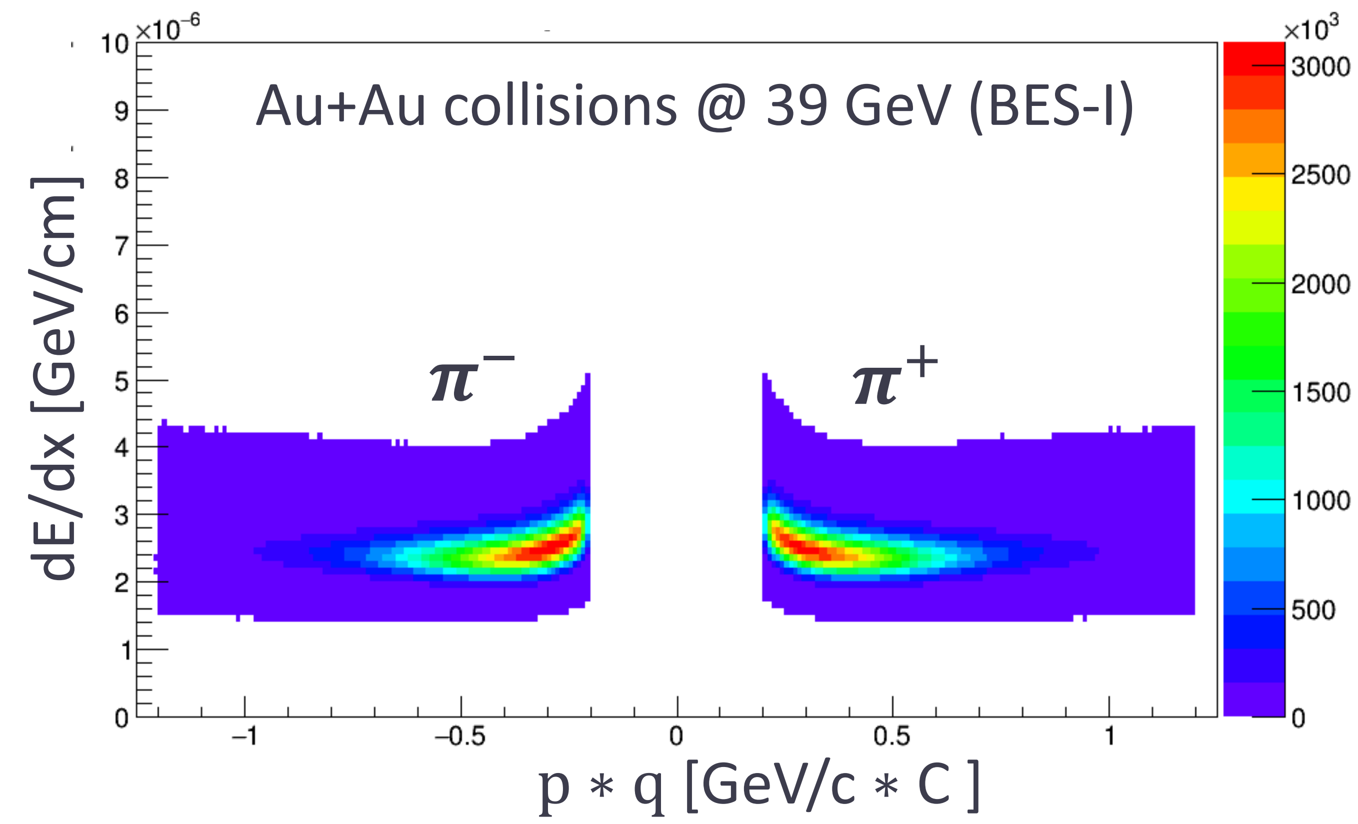
Au+Au collisions



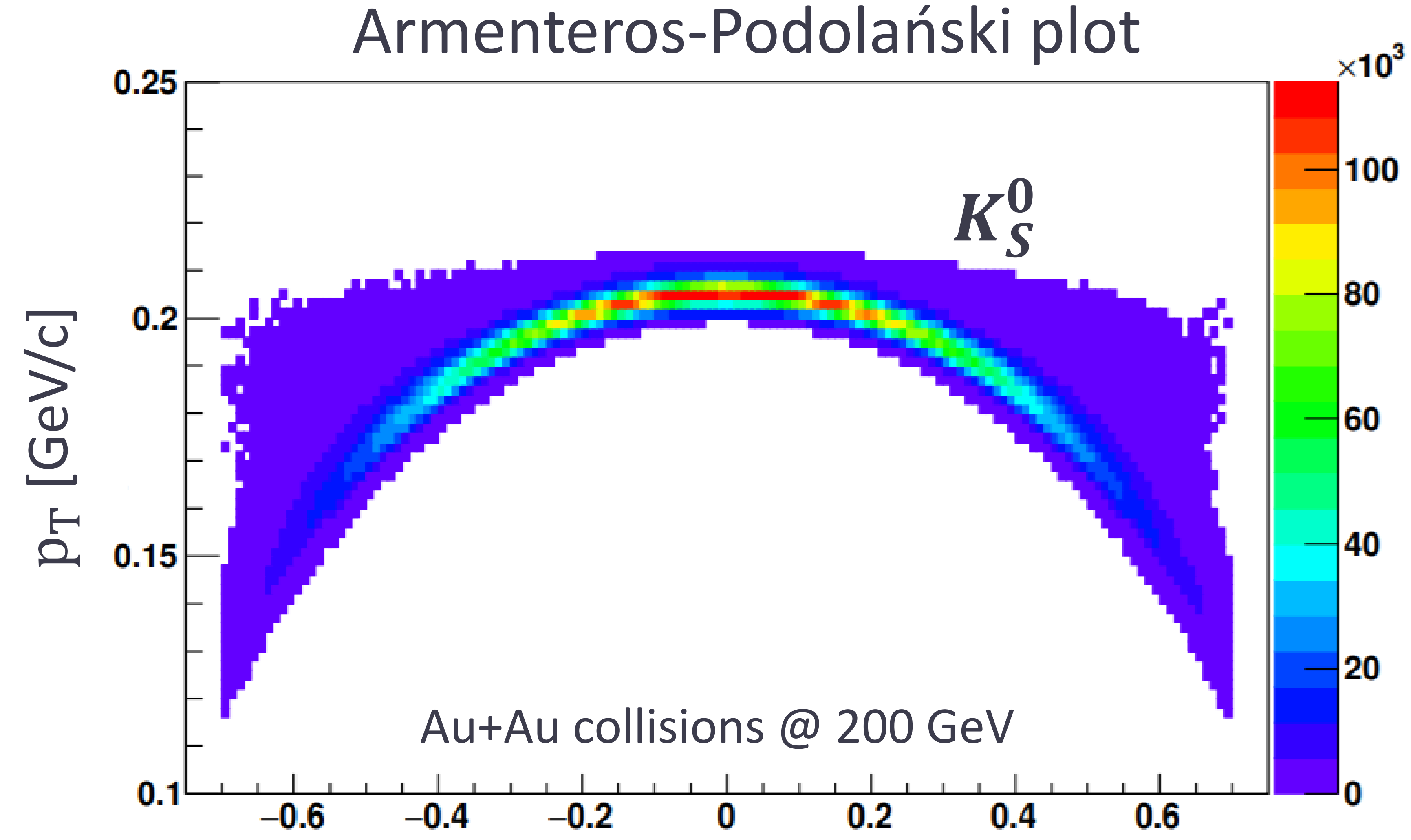
Neutral kaon reconstruction

V^0 - neutral reconstructed particle
$C^{\pm}$ – positive/negative charged decay particle
$r^{\pm}$ – positive/negative charged decay particle position
PV – primary vertex
DV – decay vertex
DCA – distance of closest approach
p_{V^0} – V^0 recontructed momentum vector
r_{PD} – vector from PV to DV
φ_{RD} – angle between r_{PD} and p_{V^0}





Armenteros-Podolański plot



$$\alpha = \frac{p_l^+ - p_l^-}{p_l^+ + p_l^-}$$

$K_S^0 \rightarrow \pi^+\pi^-$ (69.20±0.05)%

$K_S^0 \rightarrow \pi^0\pi^0$ (30.69±0.05)%

Parametrization - $K_s^0 K_s^0$

Gaussian density distribution (includes only **QS effects**): $CF(q_{inv}) = 1 + \lambda e^{[-R_{inv}^2 q_{inv}^2]}$

λ - the correlation strength, R_{inv} - the size of the particle-emitting source.

Lednicky & Lyuboshitz model includes **strong FSI**: [Sov.J.Nucl.Phys. 35, 770 (1982)]

$$CF(q_{inv}) = 1 + \lambda\left(e^{[-R_{inv}^2 q_{inv}^2]} + \frac{1}{2}\left[\left|\frac{f(k^*)}{R_{inv}}\right|^2 + \frac{4\Re f(k^*)}{\sqrt{\pi}R_{inv}} F_1(q_{inv}R_{inv}) - \frac{2\Im f(k^*)}{\sqrt{\pi}R_{inv}} F_2(q_{inv}R_{inv})\right]\right)$$

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QS effect — **strong FSI through the $f_0(980)$ and $a_0(980)$ resonances**

$$F_1(z) = \int_0^z dx \frac{e^{x^2} - x^2}{z}, \quad F_2(z) = \frac{1 - e^{x^2}}{z}$$

$$f(k^*) = \frac{1}{2}[f_0(k^*) + f_1(k^*)], \quad f_I(k^*) = \frac{\gamma_r}{m_r - s - i\gamma_r k^* - i\gamma_r' k_r'}, \quad s = 4(m_K^2 + k^{*2})$$

Parametrization - $K_s^0K_s^0$

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QS effect (first term) — **strong FSI through the $f_0(980)$ and $a_0(980)$ resonances** (bracketed term)

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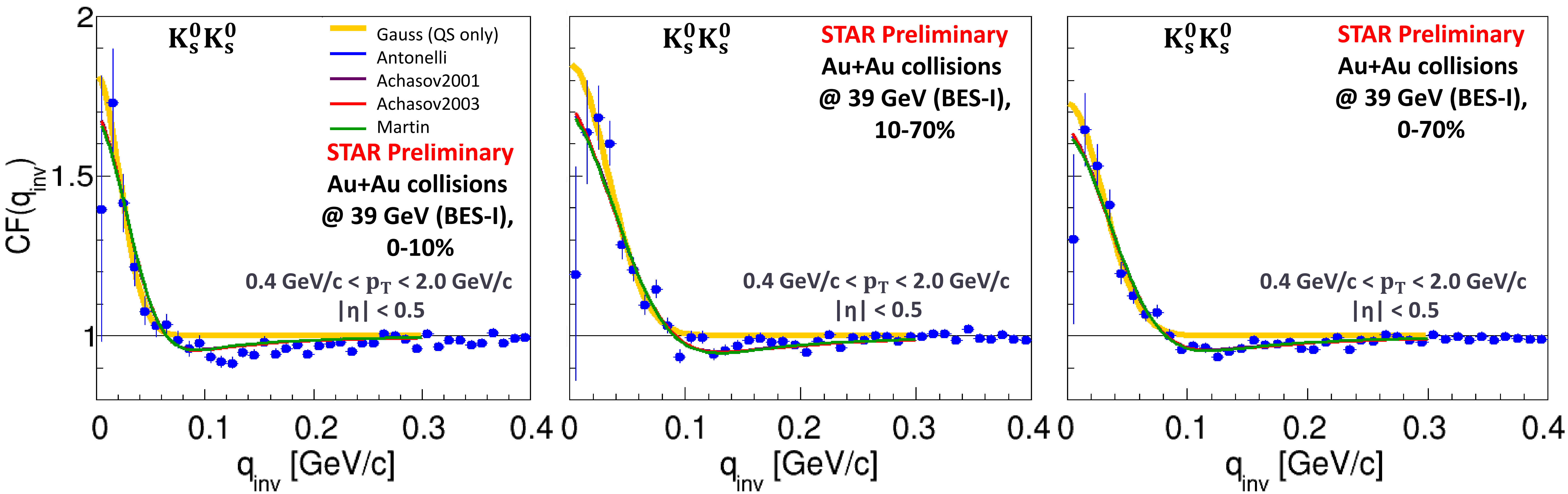
	$m_{f_0}\left[\frac{GeV}{c^2}\right]$	$\gamma_{f_0 K\bar{K}}$	$\gamma_{f_0\pi\pi}$	$m_{a_0}\left[\frac{GeV}{c^2}\right]$	$\gamma_{a_0 K\bar{K}}$	$\gamma_{a_0\pi\pi}$
Antonelli [1]	0.973	2.763	0.5283	0.985	0.4038	0.3711
Achasov2001 [2]	0.996	1.305	0.2684	0.992	0.5555	0.4401
Achasov2003 [3]	0.996	1.305	0.2684	1.003	0.8365	0.4580
Martin [4]	0.978	0.792	0.1990	0.974	0.3330	0.2220

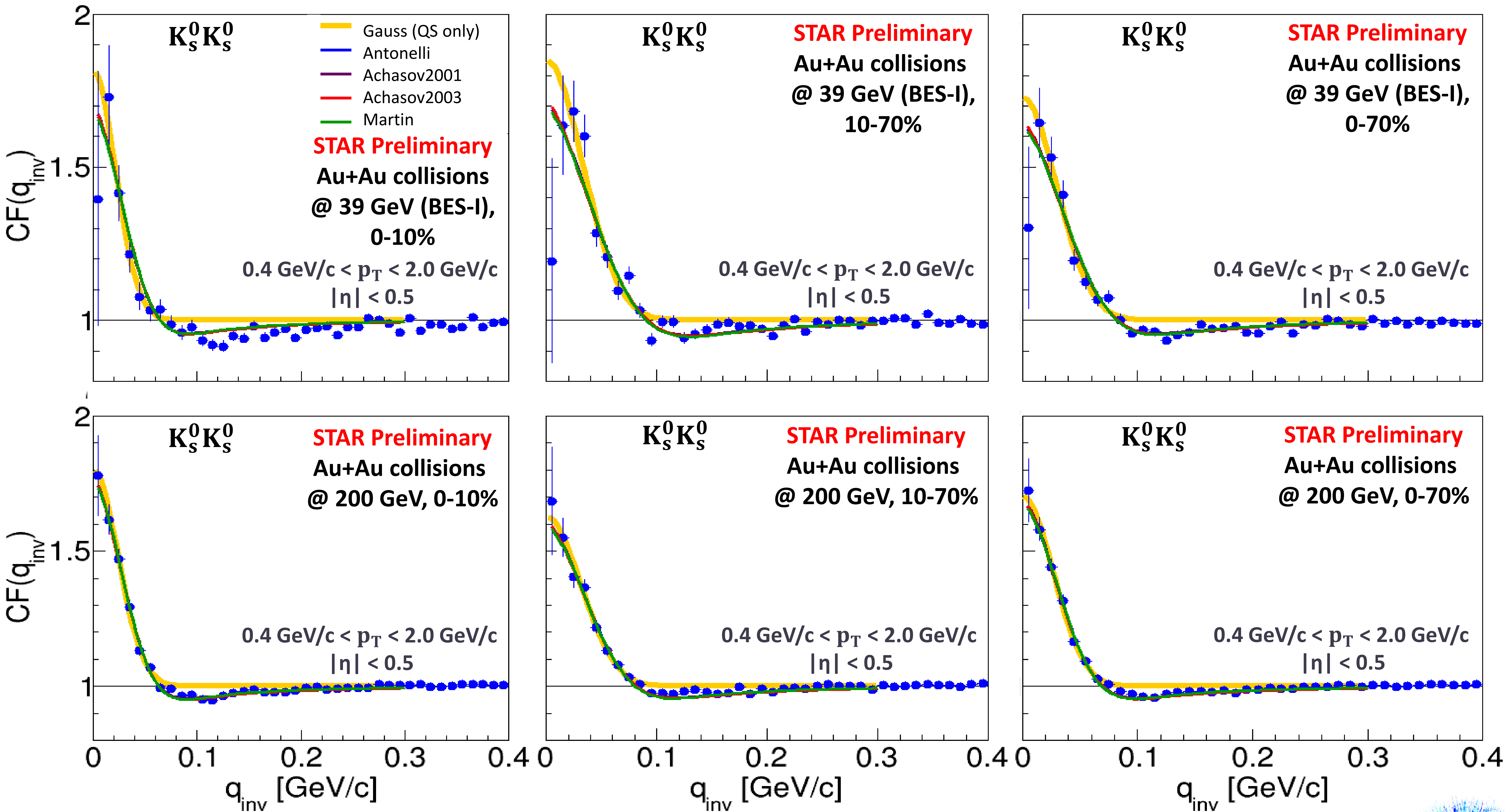
[1] eConf C020620, THAT06 (2002), [2] Phys. Rev. D 63, 094007 (2001)
[3] Phys. Rev. D 68, 014006 (2003), [4] Nucl. Phys. B 121, 514–530 (1977)

$K^0_s K^0_s$ femtoscopy at 39 GeV & 200 GeV



$q_{inv} = \sqrt{(\vec{p_1} - \vec{p_2})^2 - (E_1 - E_2)^2}$

$K_s^0K_s^0$ femtoscopy at 39 GeV & 200 GeV



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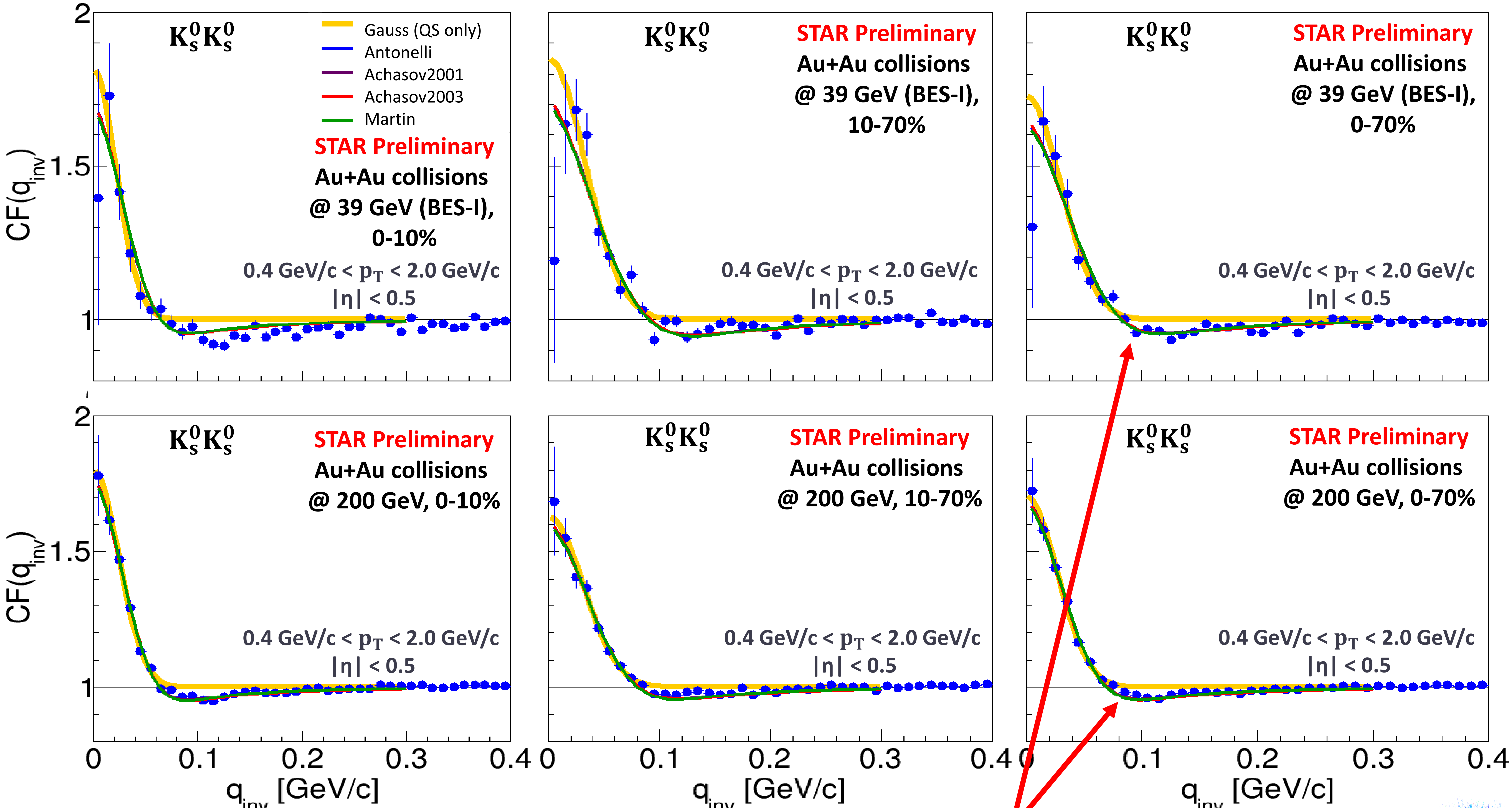

FSI is needed to reproduce the dip structure

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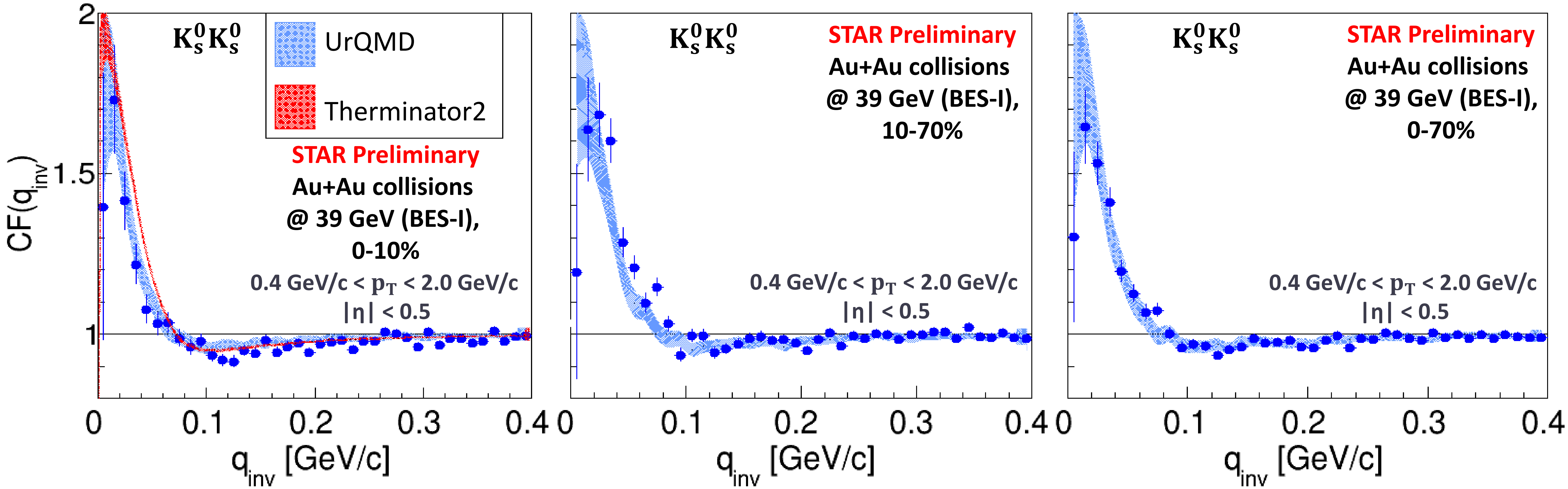
$K_s^0 K_s^0$ femtoscopy at 39 GeV & 200 GeV



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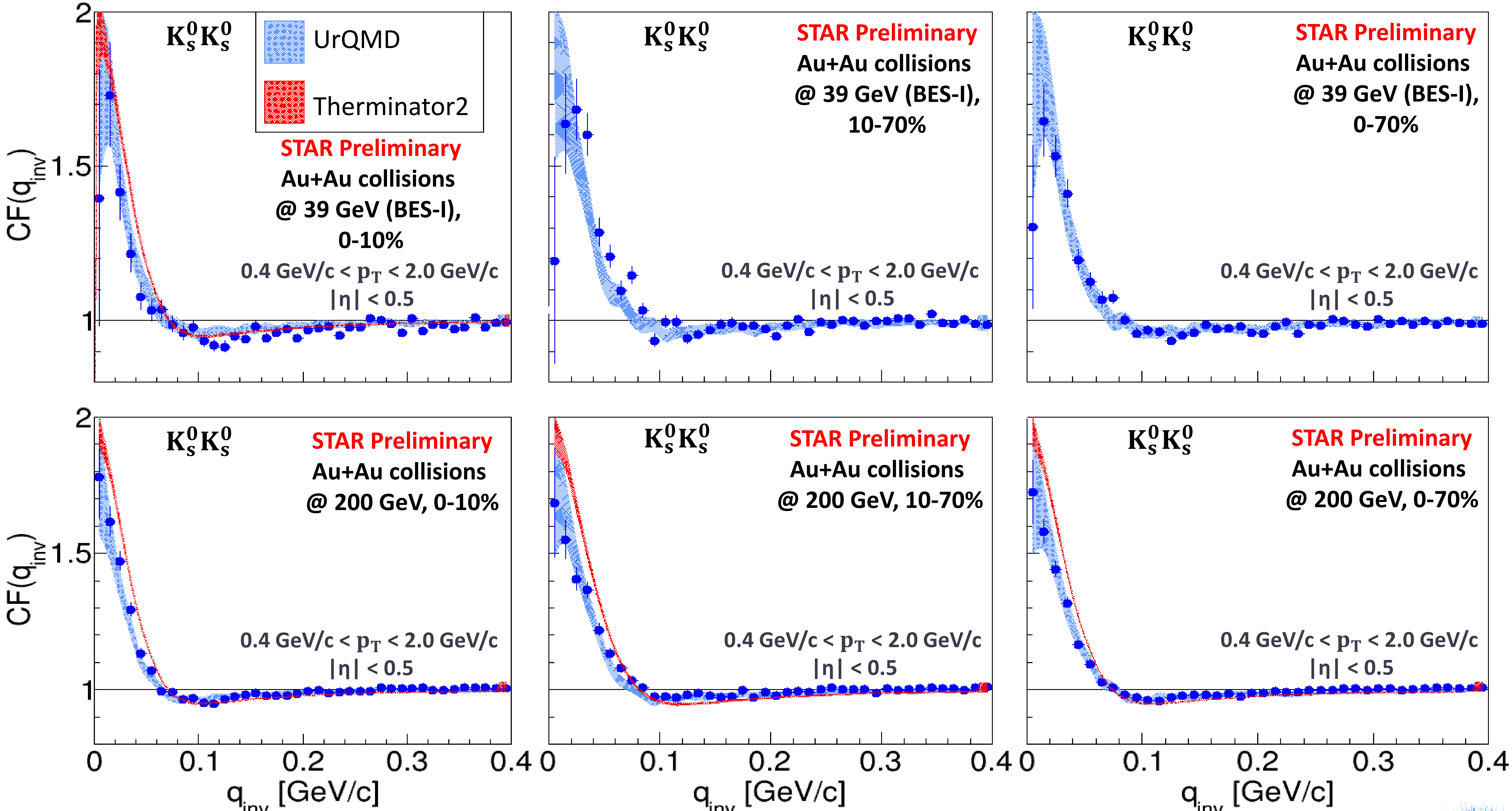

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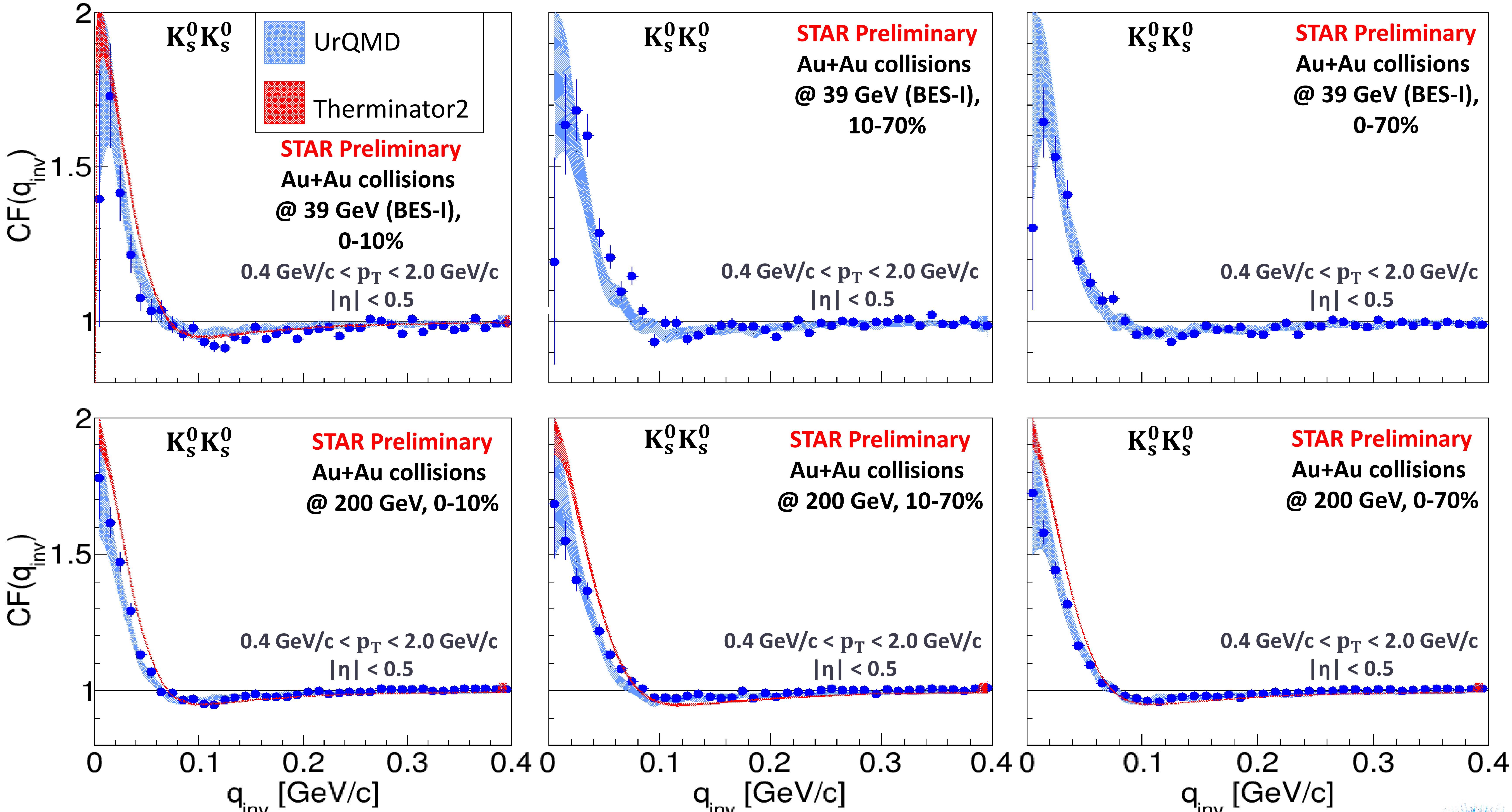
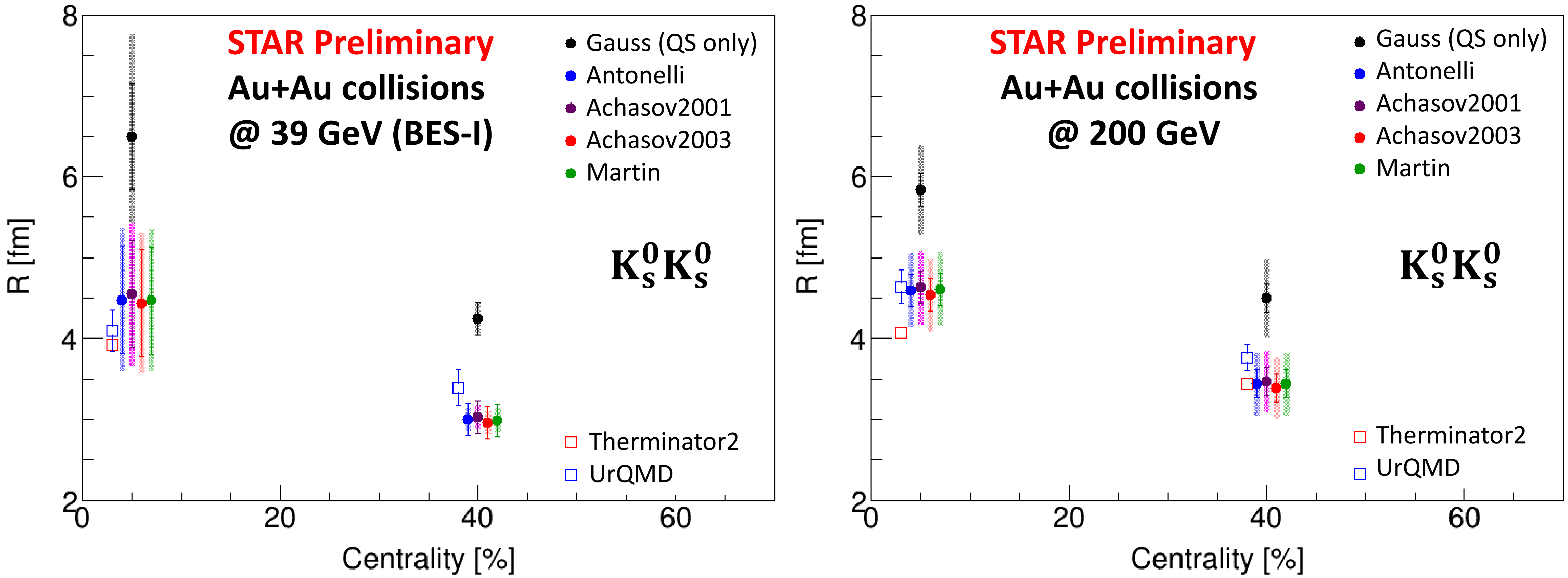


Good agreement of the experimental points with the models

$q_{inv} = \sqrt{(\vec{p_1} - \vec{p_2})^2 - (E_1 - E_2)^2}$

$K_s^0 K_s^0$ femtoscopy – centrality dependence

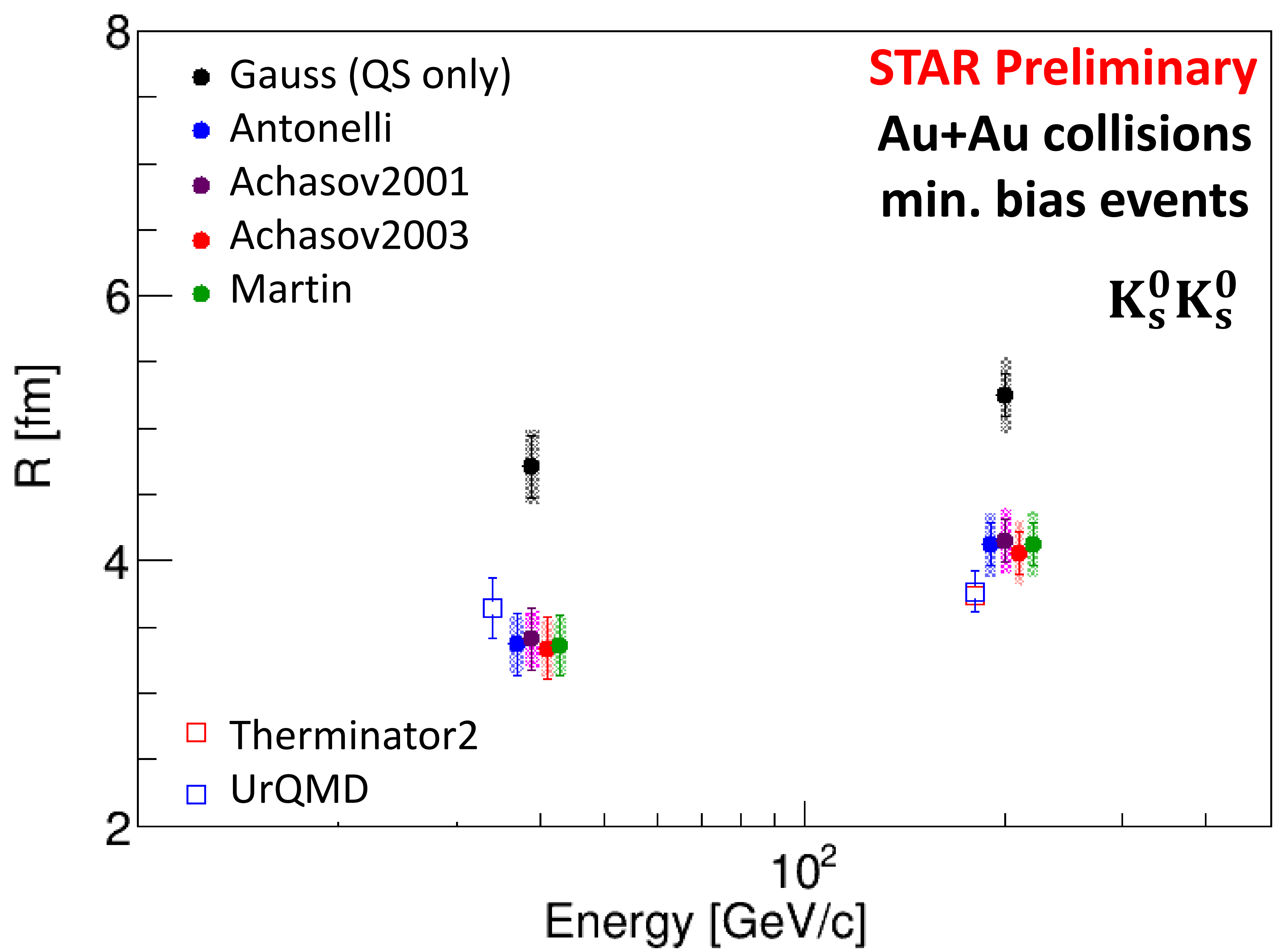


- Visible centrality dependence

$$R_{0-10\%} > R_{10-70\%}$$

- Only Gaussian assumption leads to larger R, showing importance to include SI

$K_s^0 K_s^0$ femtoscopy – energy dependence



- Visible energy dependence for both parametrization $R_{200\ GeV} > R_{39\ GeV}$
- Source sizes from models and FSI parametrizations consistent within the range of uncertainty

Parametrization - $K_s^0 K^{\pm}$

Lednicky & Lyuboshitz model includes strong FSI: [Sov.J.Nucl.Phys. 35, 770 (1982)]

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strong FSI through the a_0(980) resonance

$$F_1(z) = \int_0^z dx \frac{e^{x^2}-x^2}{z}, \quad F_2(z) = \frac{1-e^{x^2}}{z}$$

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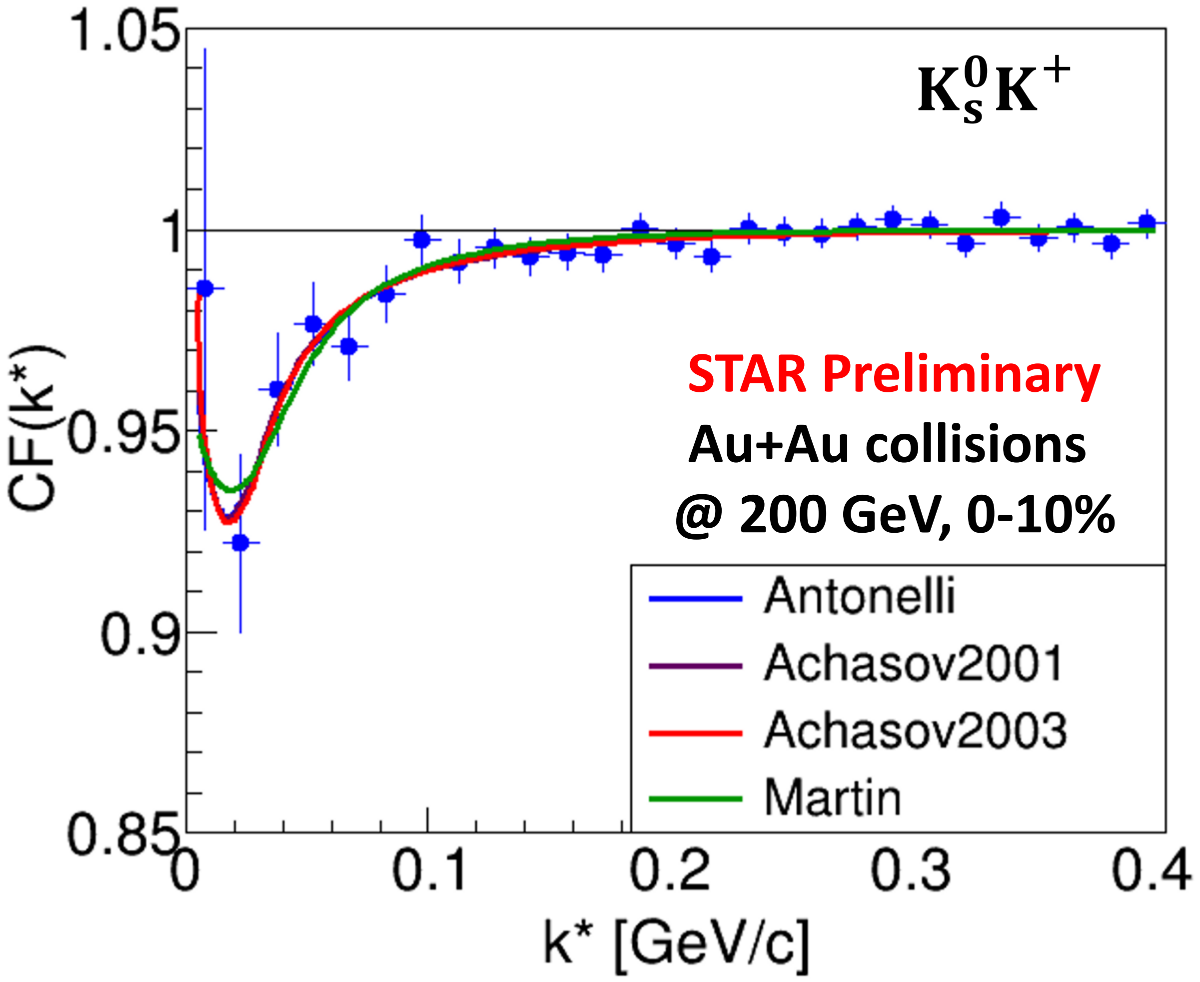
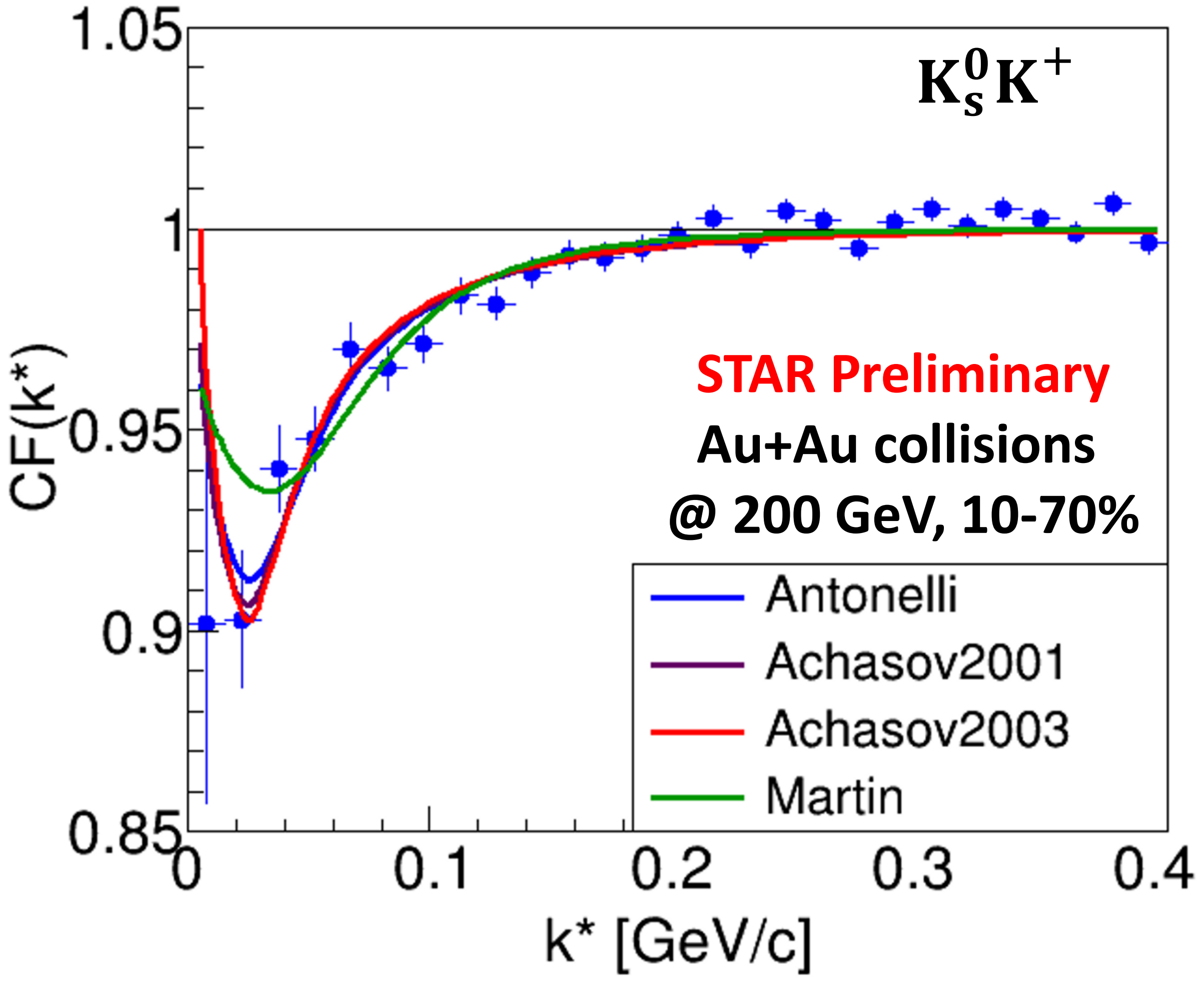
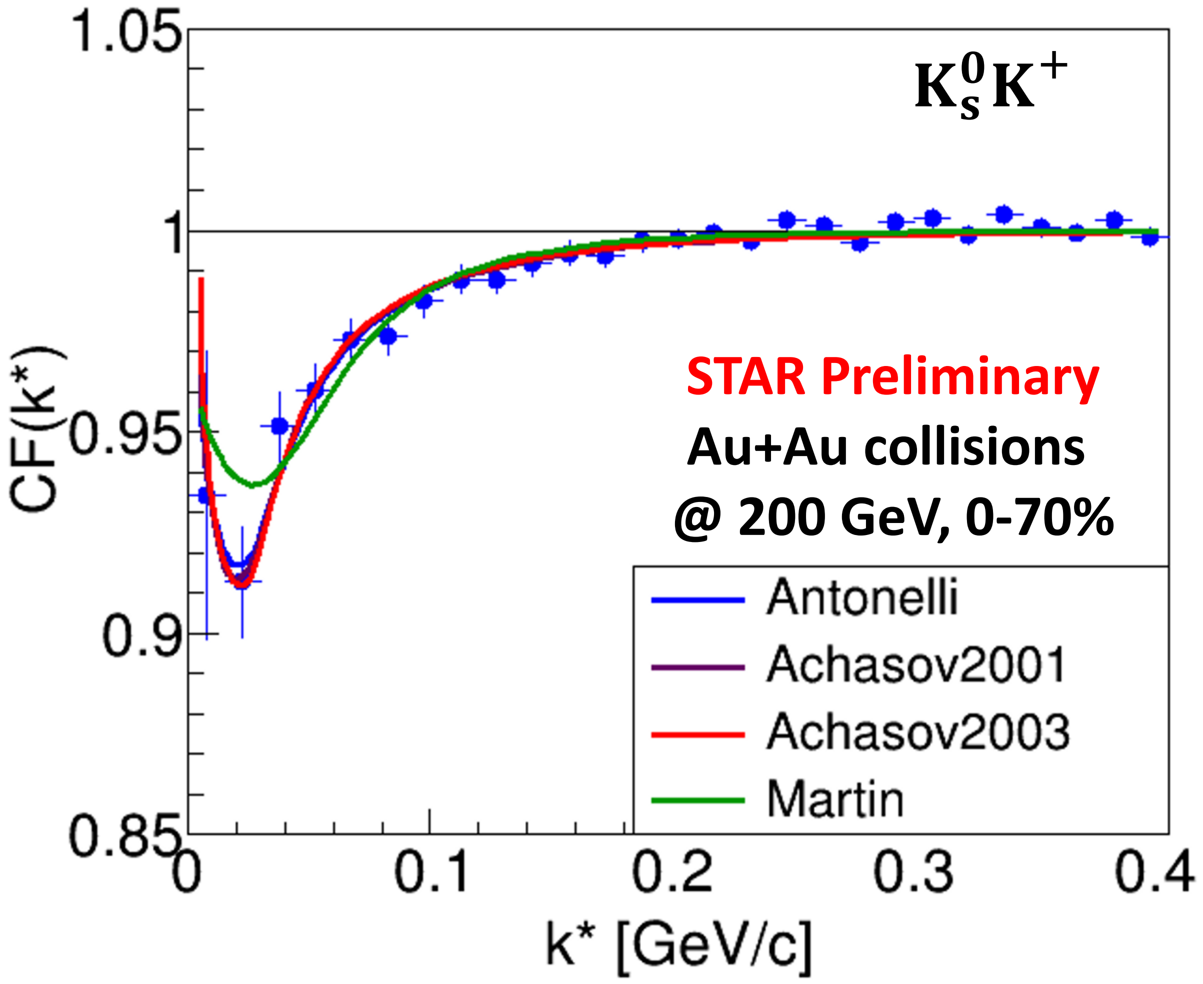
$K_s^0 K^+$ femtoscopy at 200 GeV

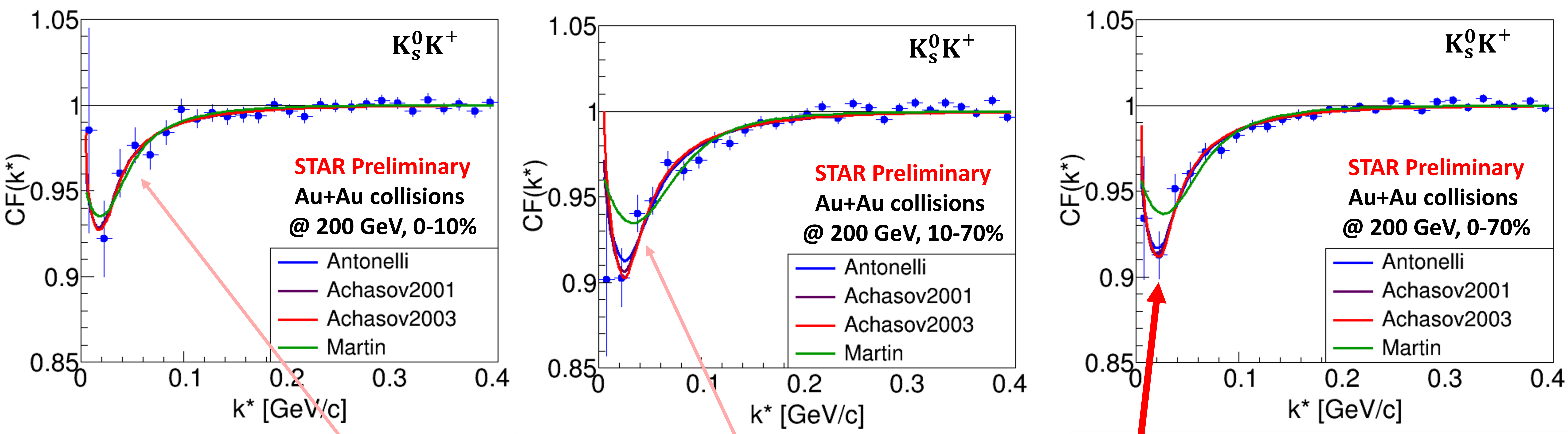






$k^* = |\vec{p_1}| = |\vec{p_2}|$

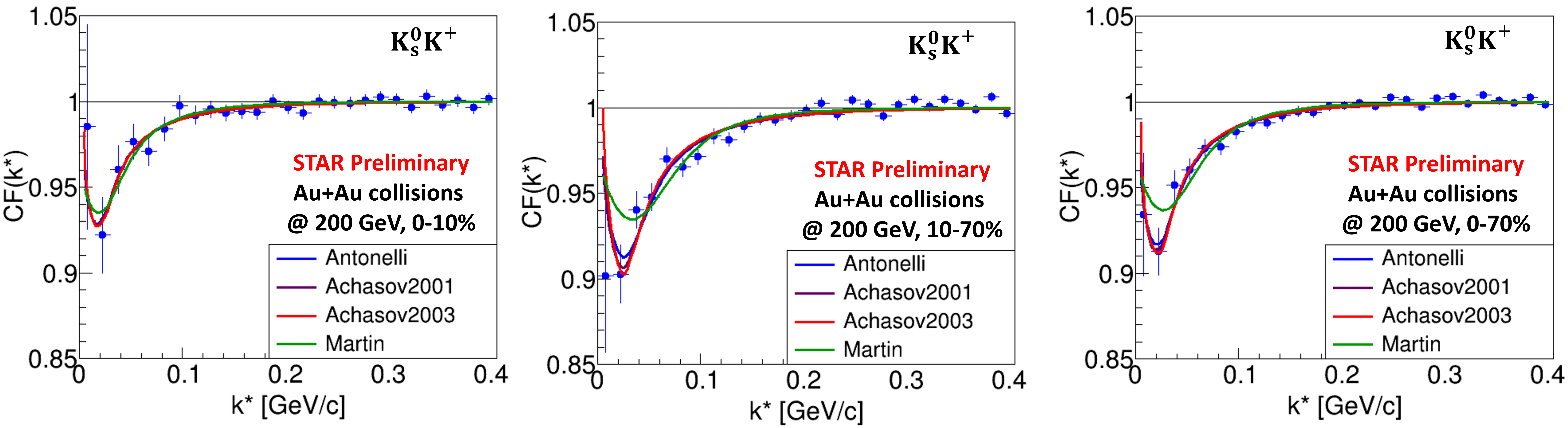
$K_s^0K^+$ femtoscopy at 200 GeV



The a_0 FSI parametrization gives an excellent representation of the signal region of the data

$k^* = |\vec{p_1}| = |\vec{p_2}|$

$K_s^0 K^+$ femtoscopy at 200 GeV



χ^2/NDF

	0-10%	10-70%	0-70%
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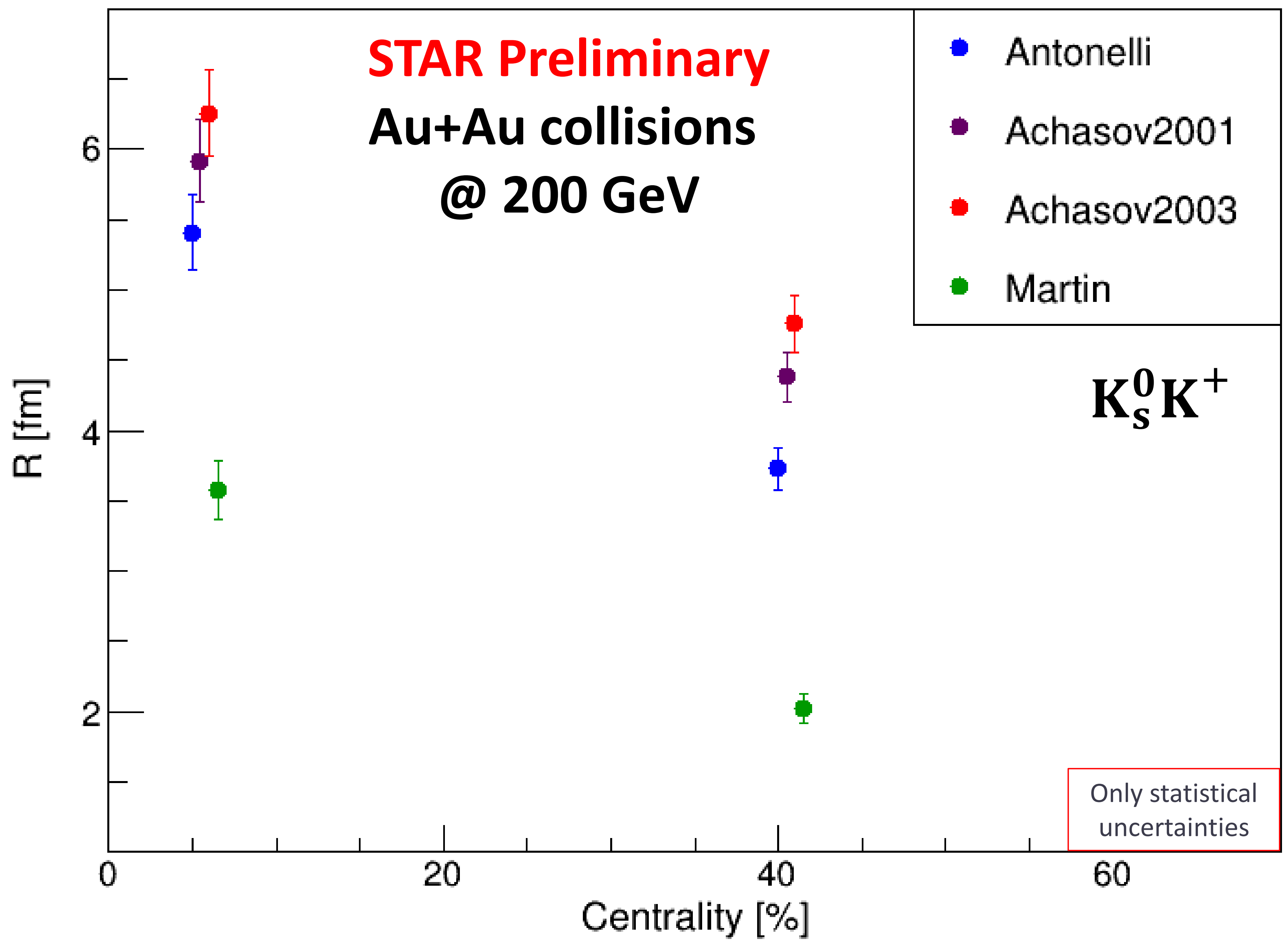
$K_s^0 K^+$ femtoscopy – centrality dependence

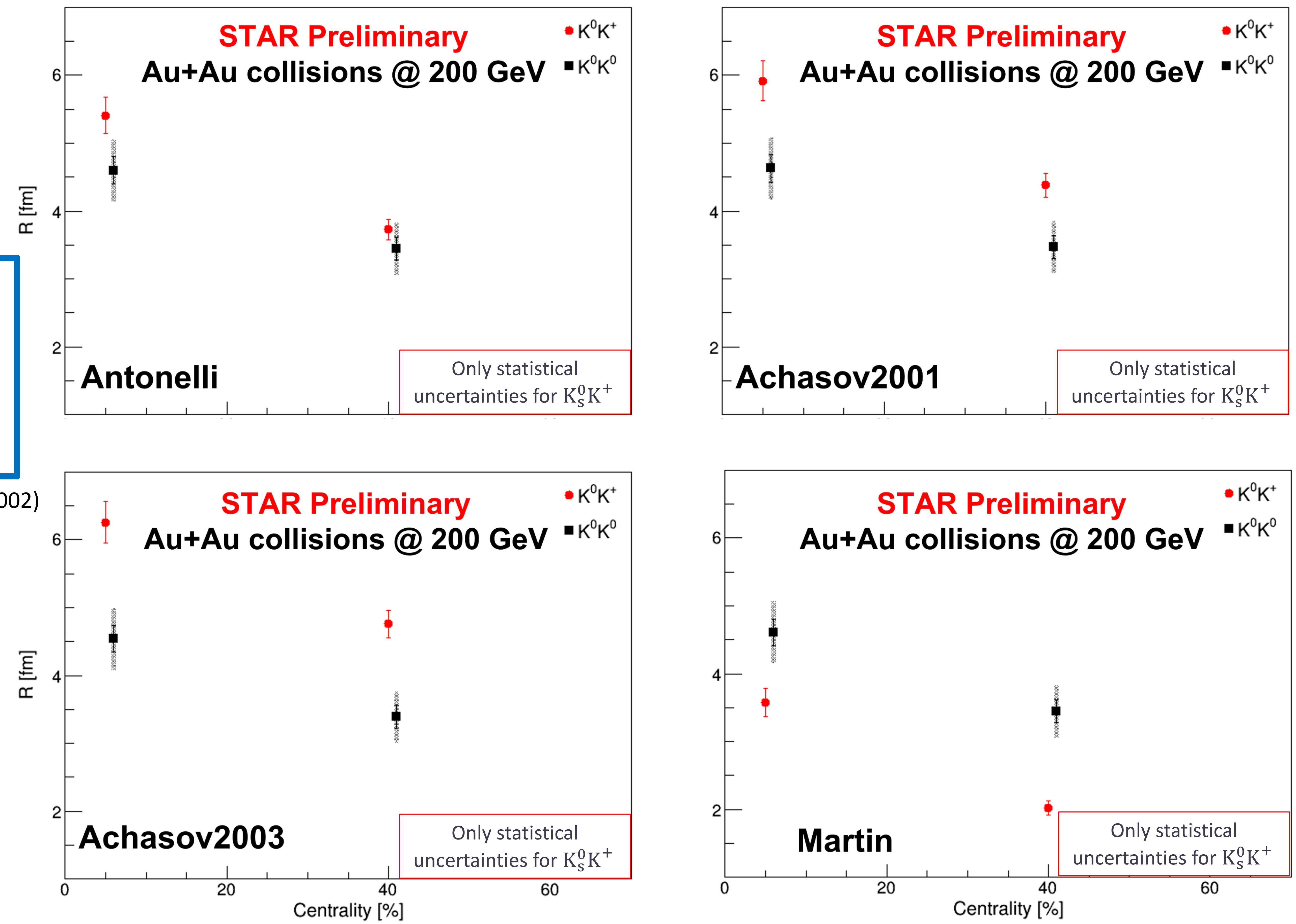


- Visible centrality dependence $R_{0-10\%} > R_{10-70\%}$
- **Achasov2003** pametrization (the larger a_0 mass) gives the larger size of the souce

Comparison - $K_s^0 K_s^0$ and $K_s^0 K^+$ - 200 GeV

Antonelli favors a_0 resonance as a tetraquark

eConf C020620, THAT06 (2002)



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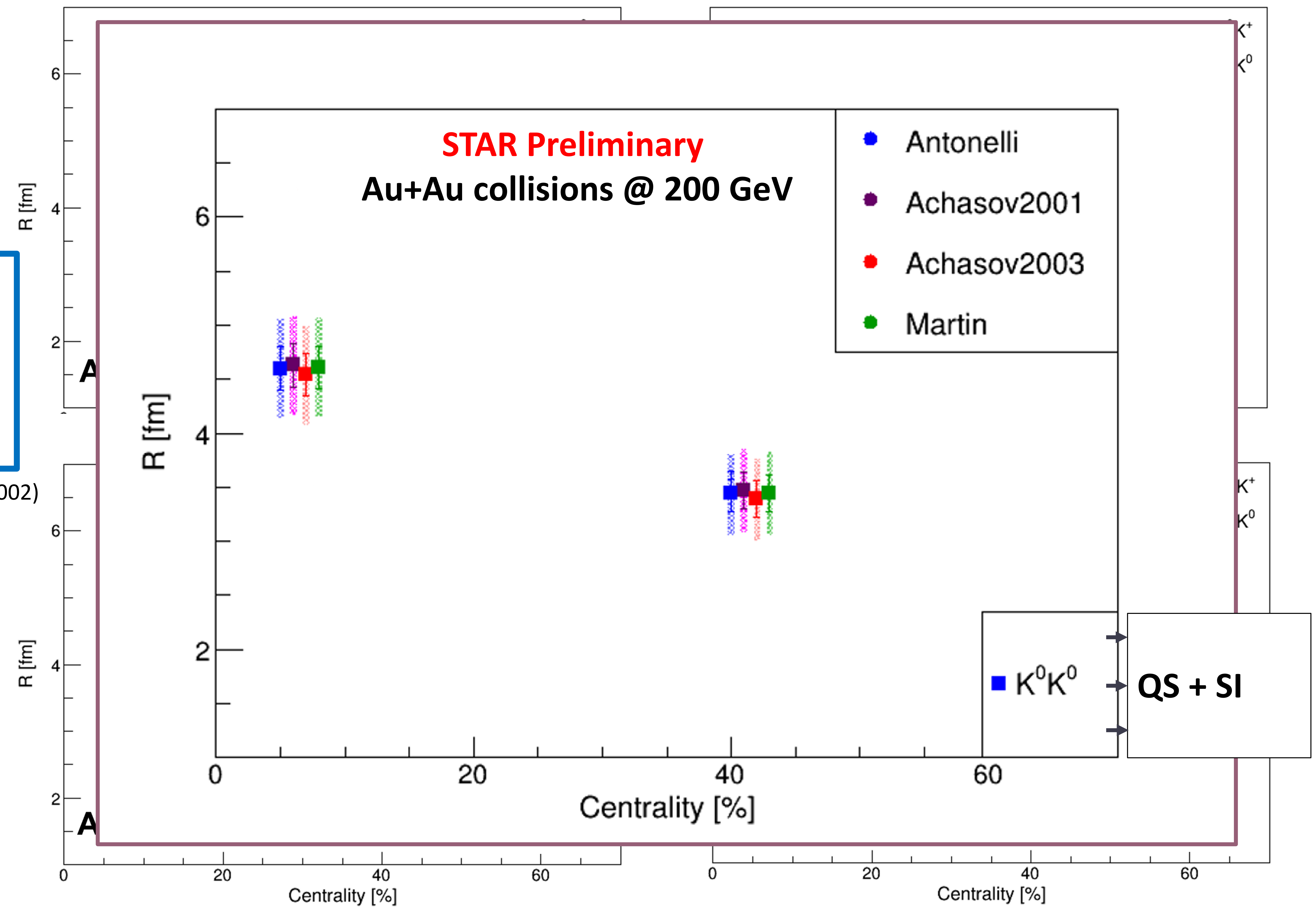

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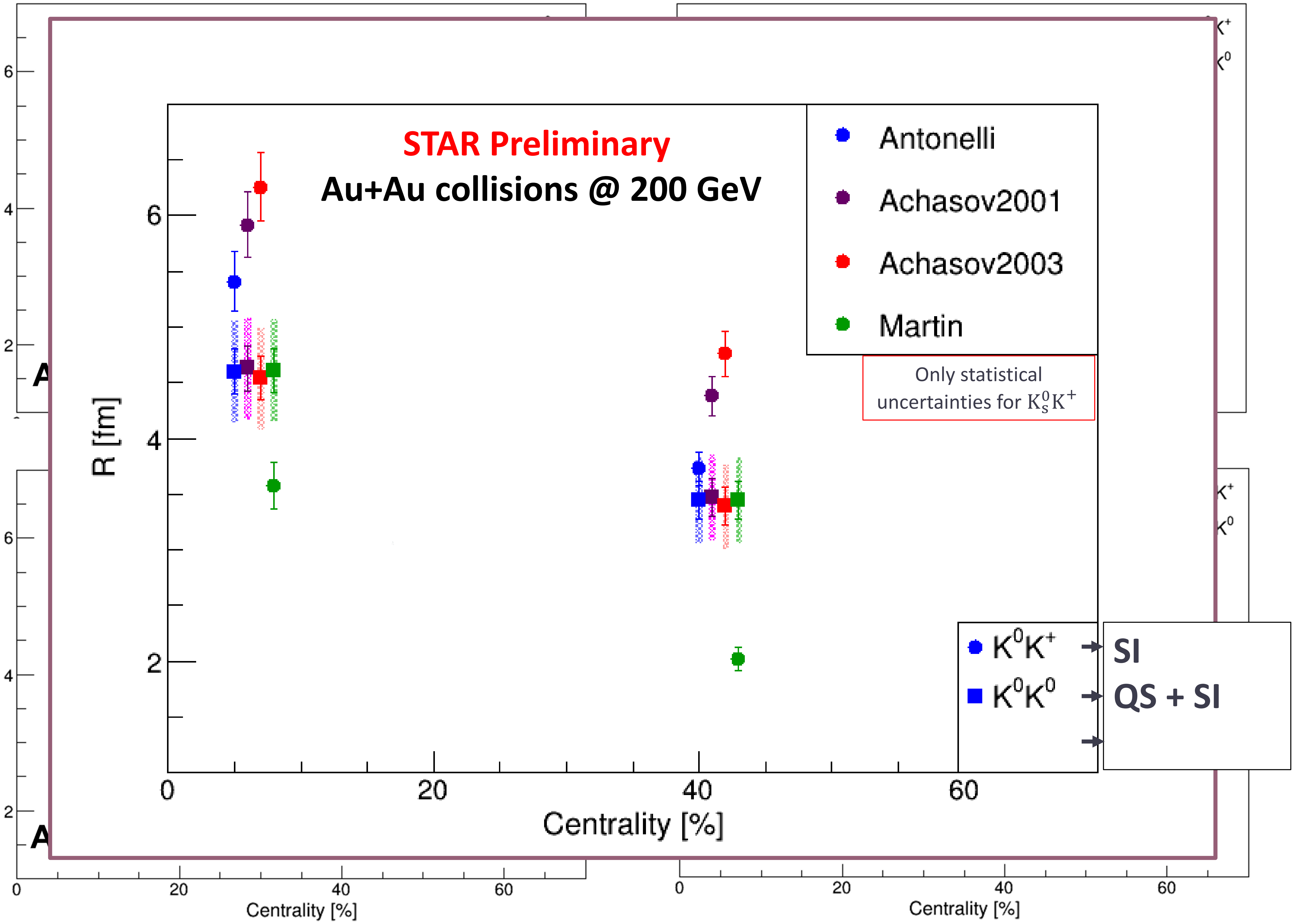

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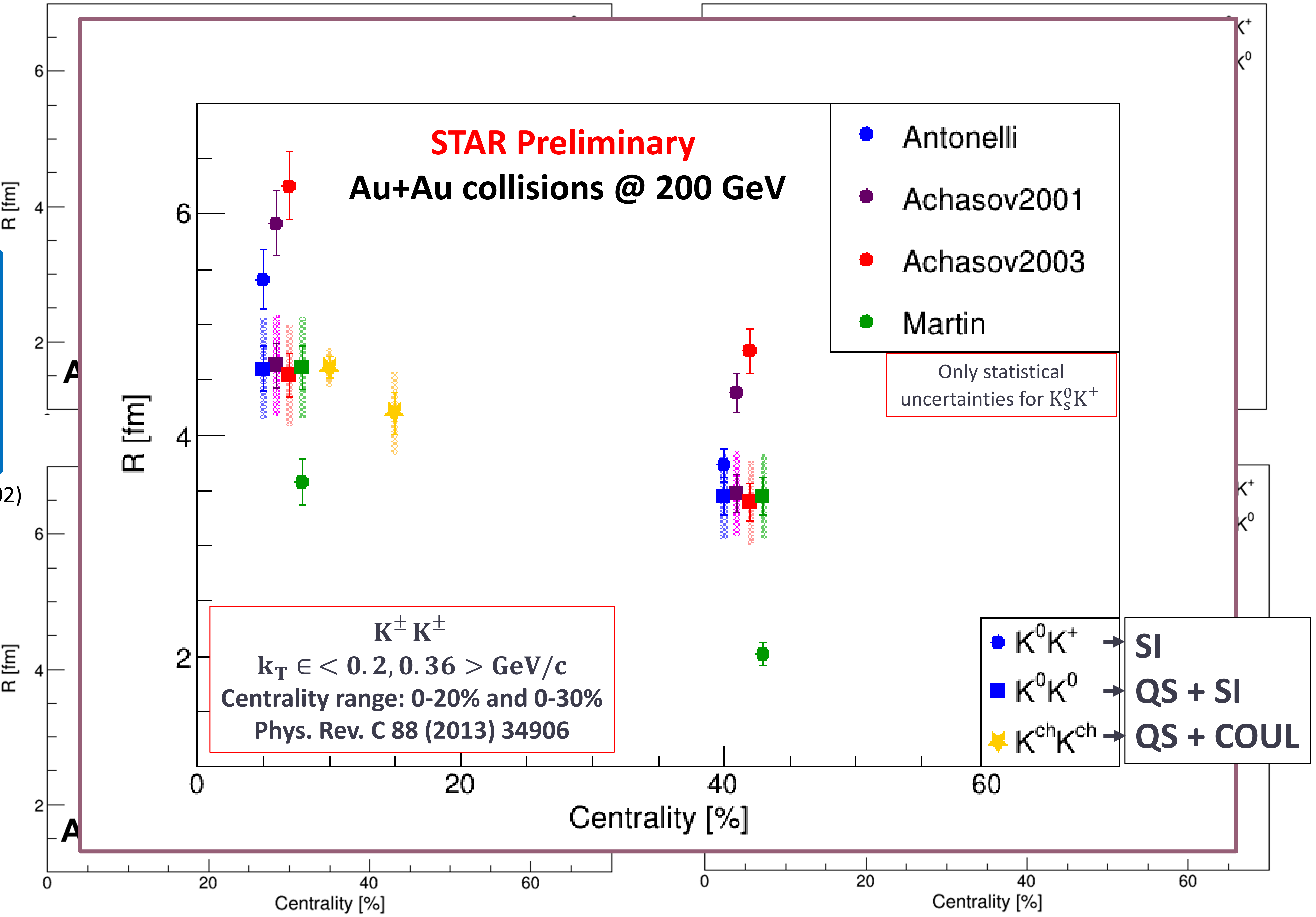

$$R_{K^{\pm}K^{\pm}} = \sqrt{\frac{R_{out}^2 + R_{side}^2 + R_{long}^2}{3}}$$

Summary

$K_s^0 K_s^0$ femtoscopy

- The strong final-state interaction has a significant effect on the $K_s^0 K_s^0$ correlation due to the near-threshold $f_0(980)$ and $a_0(980)$ resonances
- The radii of the source depend on centrality and increase with increasing collision energy
- Extracted source radii are comparable to these from models

$K_s^0 K^+$ femtoscopy

- The $a_0(980)$ FSI parametrization gives very good representation of the shape of the signal region in CF
- The parametrization with the larger $a_0(980)$ mass and decay coupling gives larger size of the source
- Comprarison with $K_s^0 K_s^0$
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Summary

$K_s^0K_s^0$ femtoscopy

- The strong final-state interaction has a significant effect on the $K_s^0K_s^0$ correlation due to the near-threshold $f_0(980)$ and $a_0(980)$ resonances
- The radii of the source depend on centrality and increase with increasing collision energy
- Extracted source radii are comparable to these from models

$K_s^0K^+$ femtoscopy

- The $a_0(980)$ FSI parametrization gives very good representation of the shape of the signal region in CF
- The parametrization with the larger $a_0(980)$ mass and decay coupling gives larger size of the source
- Comprarison with $K_s^0K_s^0$
  - Antonelli parametrization favors $a_0(980)$ resonance as a tetraquark

Compatibility of source sizes for $K_s^0K_s^0$, $K_s^0K^+$ and $K^{\pm}K^{\pm}$ pairs in the case of Antonelli

STAR

Summary

$K^0_S K^0_S$ femtoscopy

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$K^0_S K^+$ fem

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Outlook

High statistic BES-II data give the ability to analyze neutral kaon femtoscopy for energies $\sqrt{s_{NN}}$ < 20 GeV

Compatibility of source sizes for $K^0_S K^0_S$, $K^0_S K^+$ and $K^{\pm} K^{\pm}$ pairs in the case of Antonelli

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Thank you for your attention!!