Warsaw University of Technology

Baryon-baryon correlations at the STAR experiment

Hanna Zbroszczyk for the STAR Collaboration

Faculty of Physics, Warsaw University of Technology

STAR

WPCF2018

Workshop on Particle Correlations and Femtoscopy, Kraków, 22nd May 2018

Outline

I) Introduction

- RHIC, STAR, femtoscopy

- Results from lower energy domain

II) Baryon-baryon correlations in STAR (heavy-ion collisions)

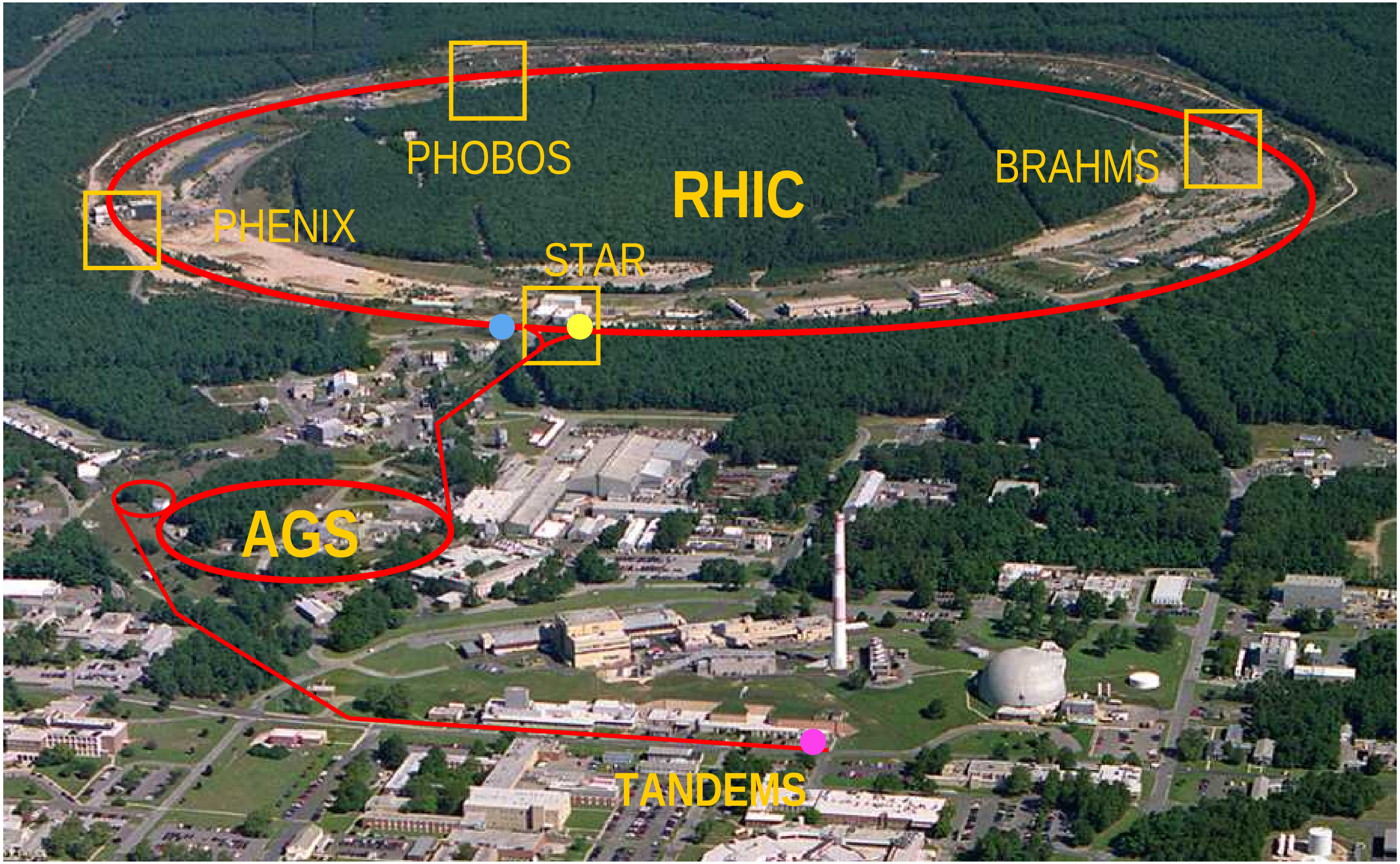
  - (anti)proton femtoscopy: @ 200 GeV, BES

  - strange baryon femtoscopy: p-Λ, Λ-Λ

III) Conclusions and summary

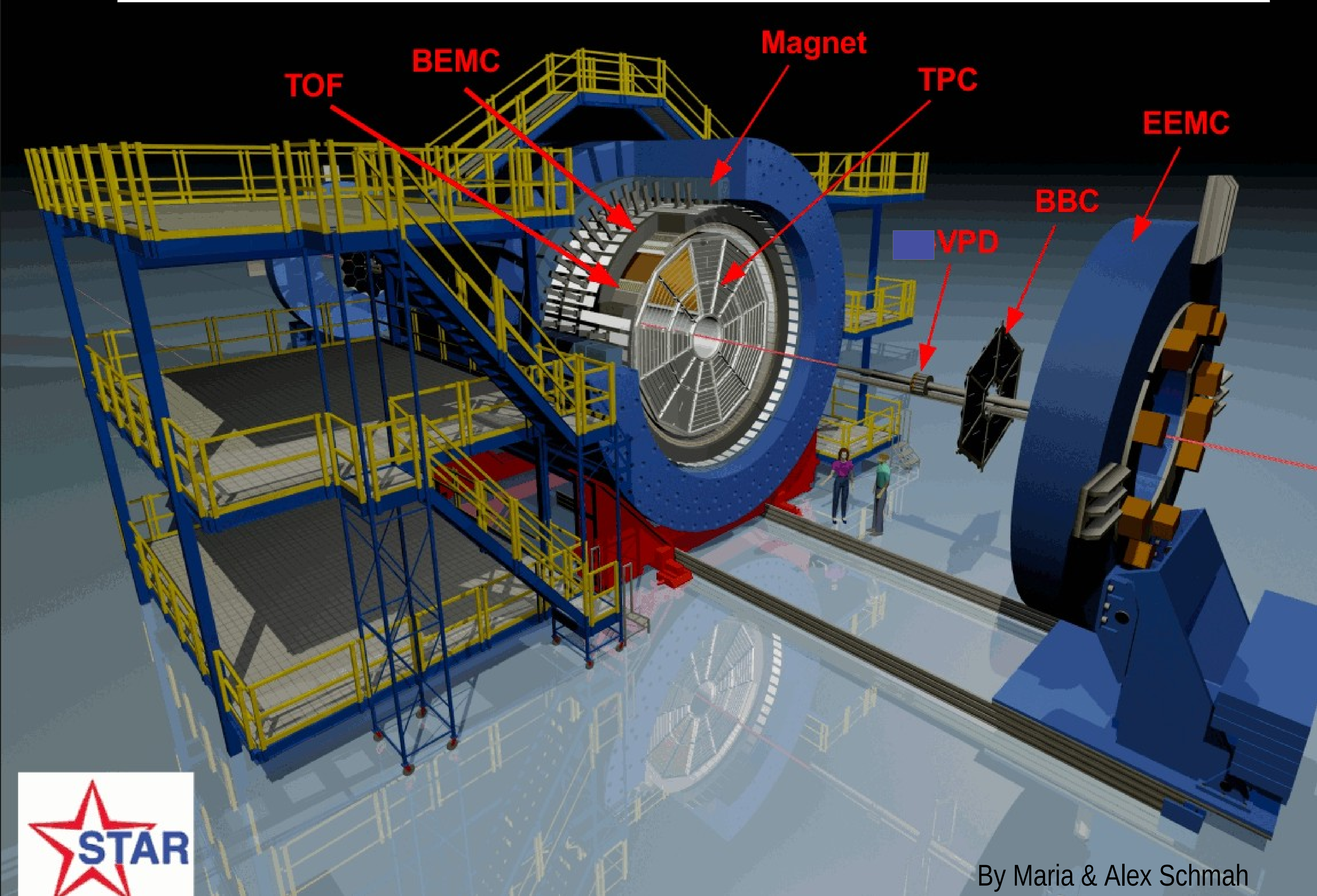
Introduction

Relativistic Heavy Ion Collider (RHIC)
Brookhaven National Laboratory (BNL), New York



- 2 concentric rings of 1740 superconducting magnets
- 3.8 km circumference

The Solenoidal Tracker At RHIC



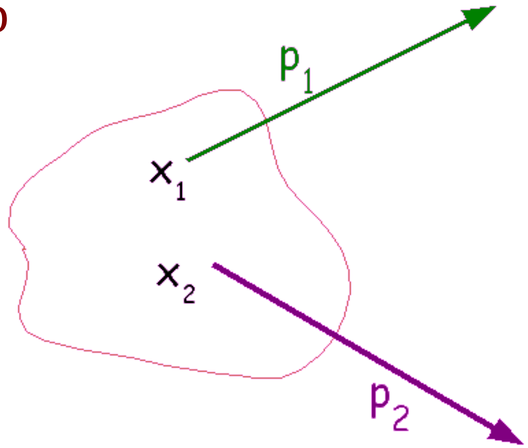
By Maria & Alex Schmah

Few Words About Femtoscopy

Single- and two- particle distributions

$$P_1(p) = E\frac{dN}{d^3p} = \int d^4x\, S(x,p)$$

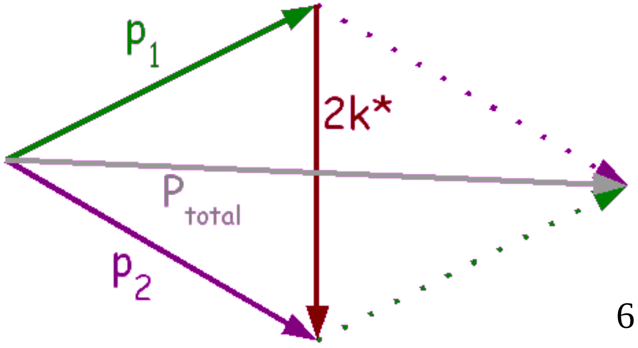
S(x,p) – emission function: the distribution of source density probability of finding particle with x and p



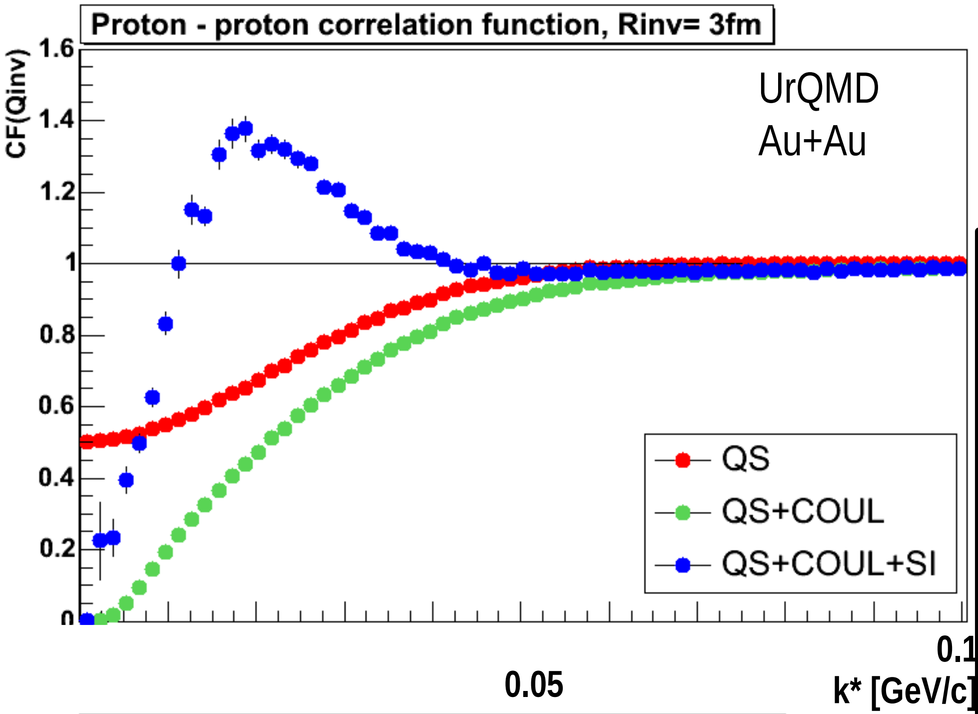
$$P_2(p_1,p_2) = E_1E_2\frac{dN}{d^3p_1d^3p_2} = \int d^4x_1 S(x_1,p_1)\, d^4x_2 S(x_2,p_2)\, \Phi(x_2,p_2|x_1,p_1)$$

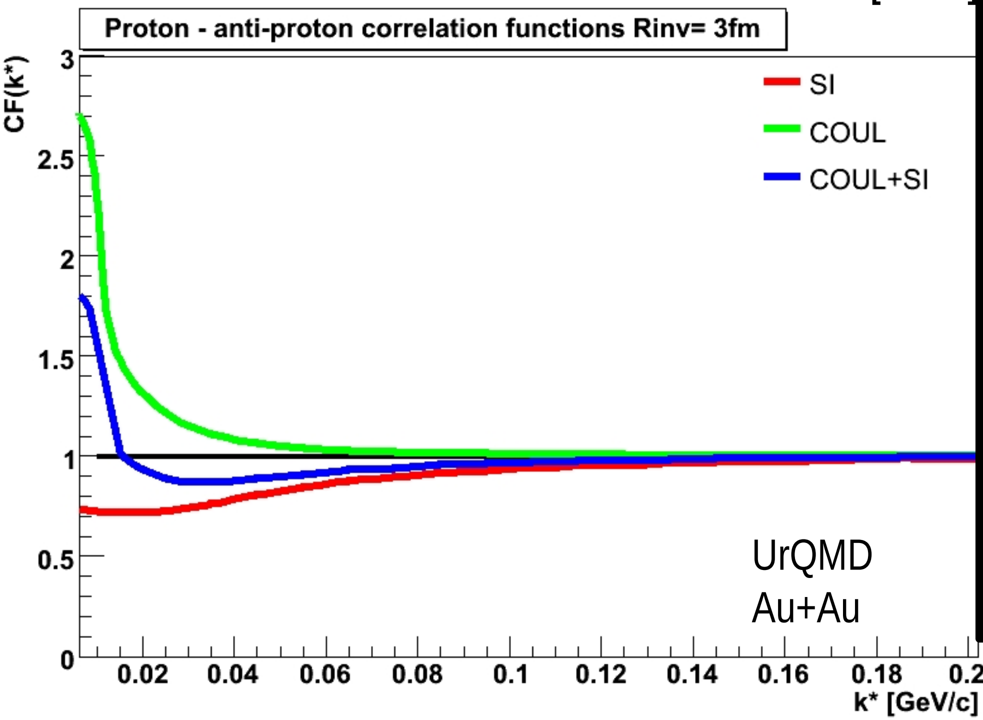
The correlation function

$$C(p_1,p_2) = \frac{P_2(p_1,p_2)}{P_1(p_1)P_1(p_2)}$$



Proton- (Anti)proton correlations





Identical baryon- baryon

- Quantum Statistics- **QS**

- Final State Interactions- **FSI**
  - **Coulomb**
  - **Strong**

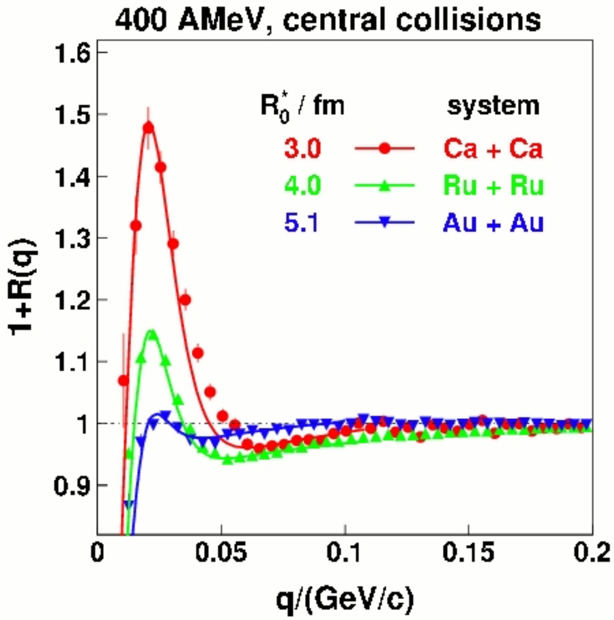
Non-identical baryon- (anti)baryon

- Final State Interactions- **FSI**
  - **Coulomb**
  - **Strong**

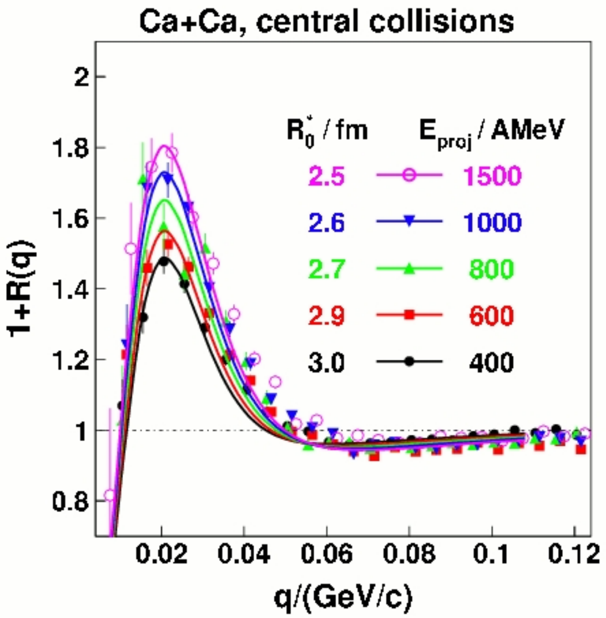
Results

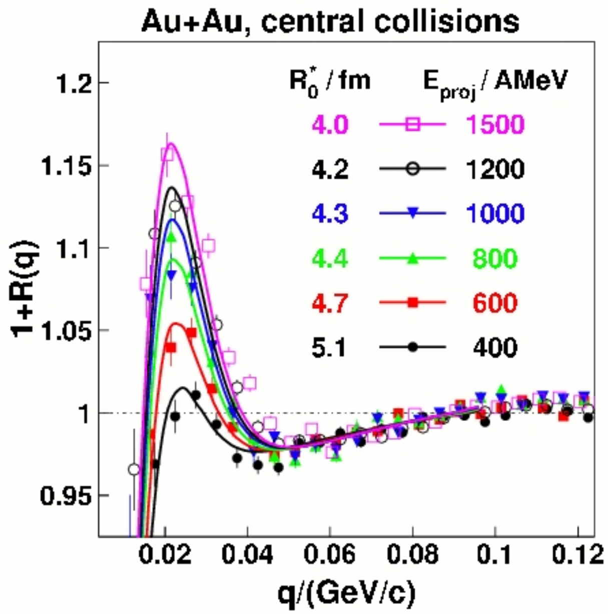
Results of p-p Correlations From Lower Energies

SIS → AGS/SPS → RHIC



Proton-proton correlations have been measured for many years

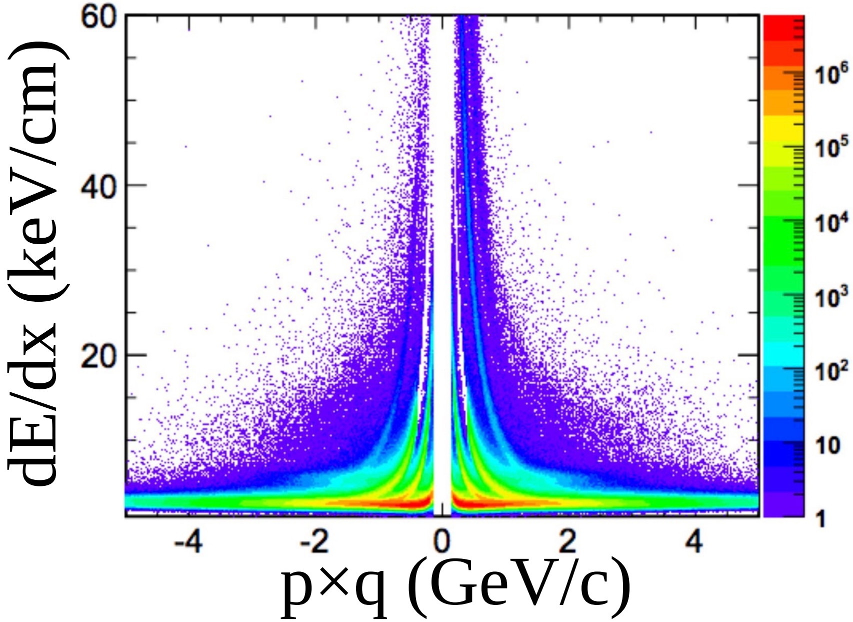


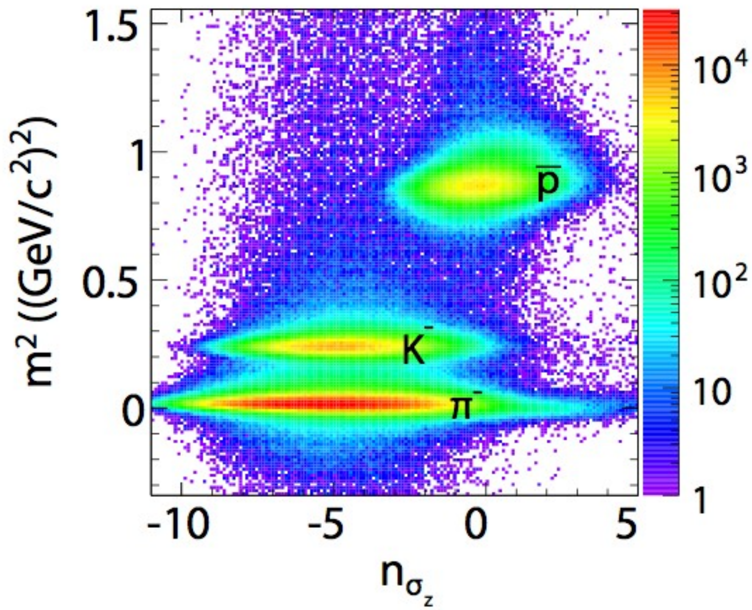


R. Kotte, et al. (FOPI collaboration)

Eur.J.Phys.A23: 271-278,2005

Particle Identification in STAR





m^2 vs $n\sigma_z$: Negative Charge

→ TPC and TOF for the particle identification.

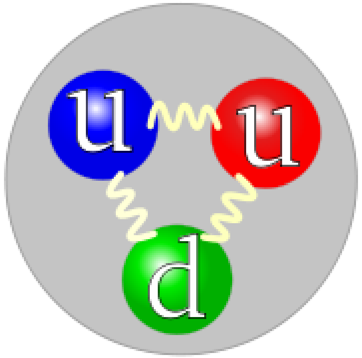
→ Cuts lead to very high efficiency (over 99%)

Proton Femtoscopy @200 GeV

So far, the knowledge on nuclear force was derived from studies made on **nucleon or / and nuclei**.

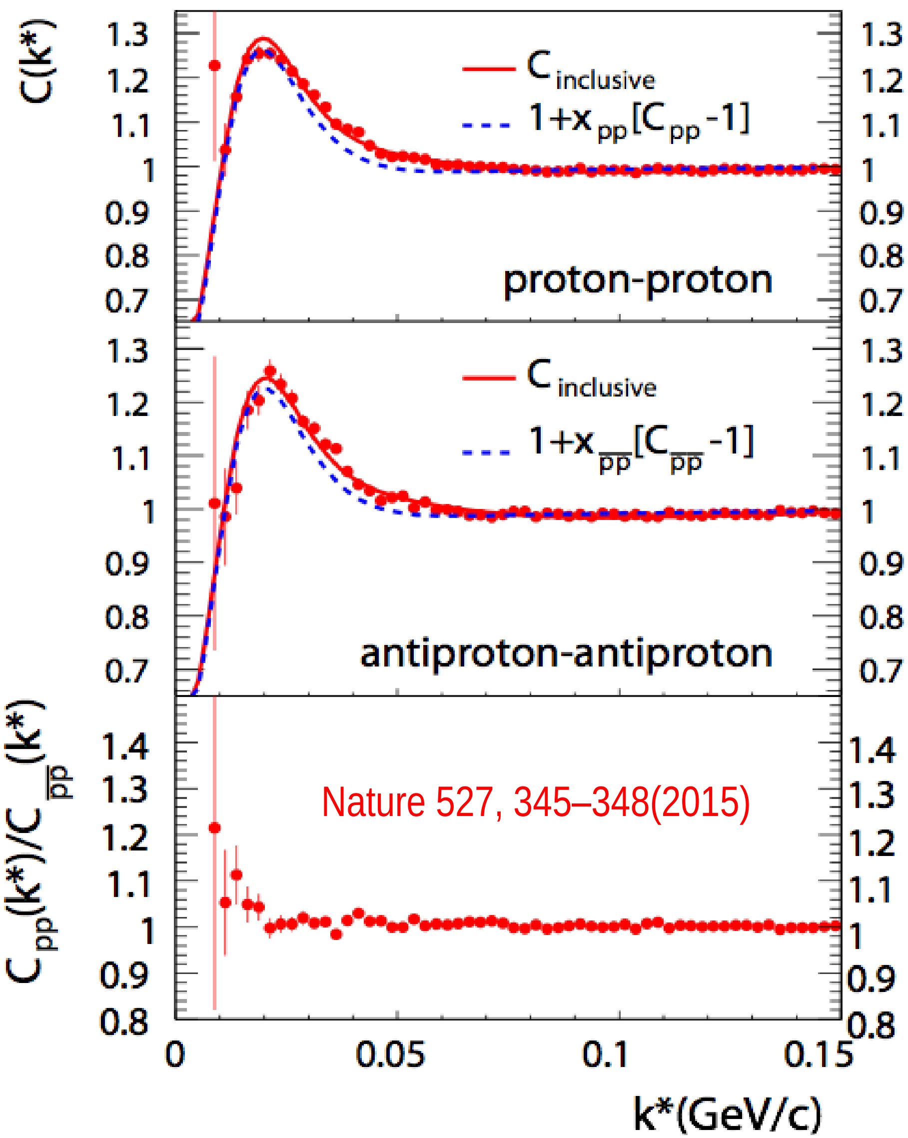
Nuclear force between **antinucleons** is studied for the first time.

The knowledge of interaction between two anti-protons is **fundamental** to understand the properties of more sophisticated antinuclei.



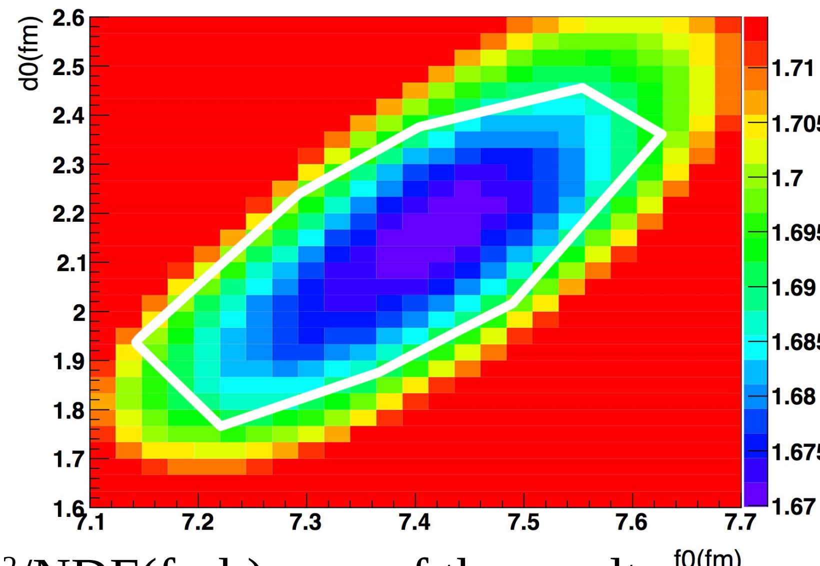
Nature 527, 345–348(2015)

Proton Femtoscopy @200 GeV



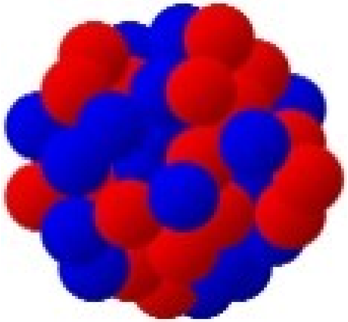
Fit results:
p-p CF,
R=2.75±0.01fm; χ2/NDF = 1.66;

antiproton-antiproton CF,
R=2.80±0.02fm , f_0=7.41±0.19fm,
d_0=2.14±0.27fm; χ2/NDF=1.61



χ^2/NDF(f_0,d_0) map of the results between measured function and fitted one to find the best valeus of f_0, d_0 parameters

Proton Femtoscopy @200 GeV - Parameters: f_0 and d_0



The scattering length f_0: determines low-energy scattering.

The elastic cross section, σ_e, (at low energies) determined

solely by the scattering length,

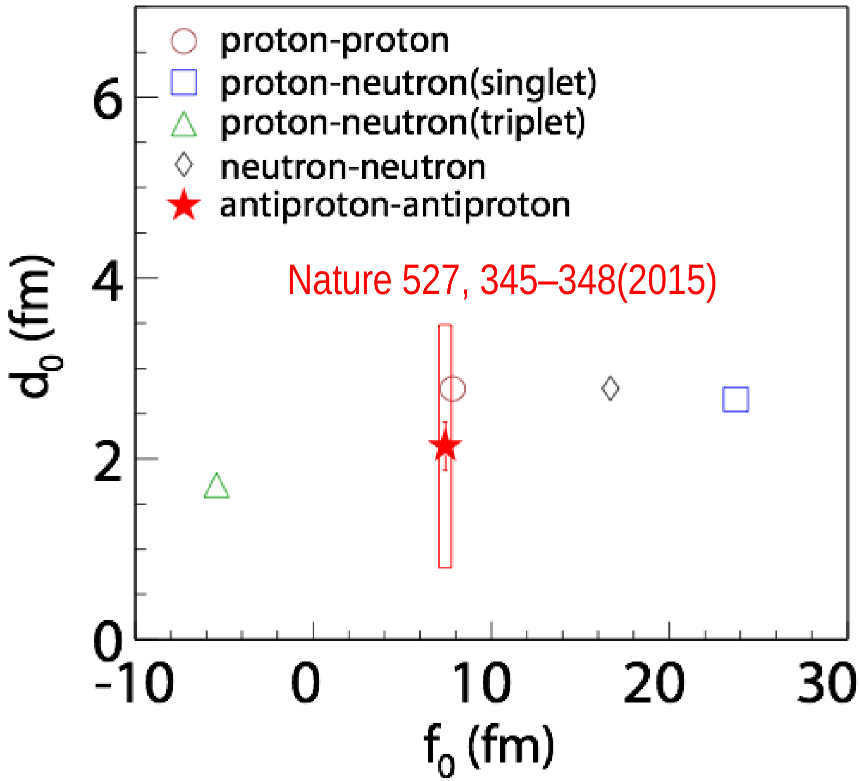
$$\lim_{k \to 0} \sigma_e = 4\pi f_0^2$$

d_0 - the effective range of strong interaction between two particles.
It corresponds to the range of the potential in an extremely simplified scenario - the square well potential.

- f_0 and d_0 - two important parameters of strong interaction between two particles.

- Theoretical correlation function depends on: source size, k^*, f_0 and d_0.

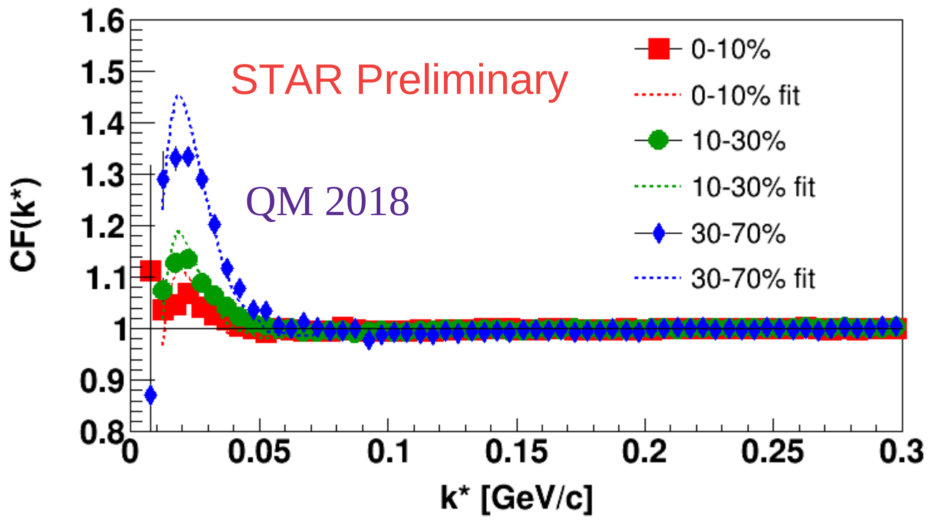
Proton Femtoscopy @200 GeV - Parameters: f_0 and d_0



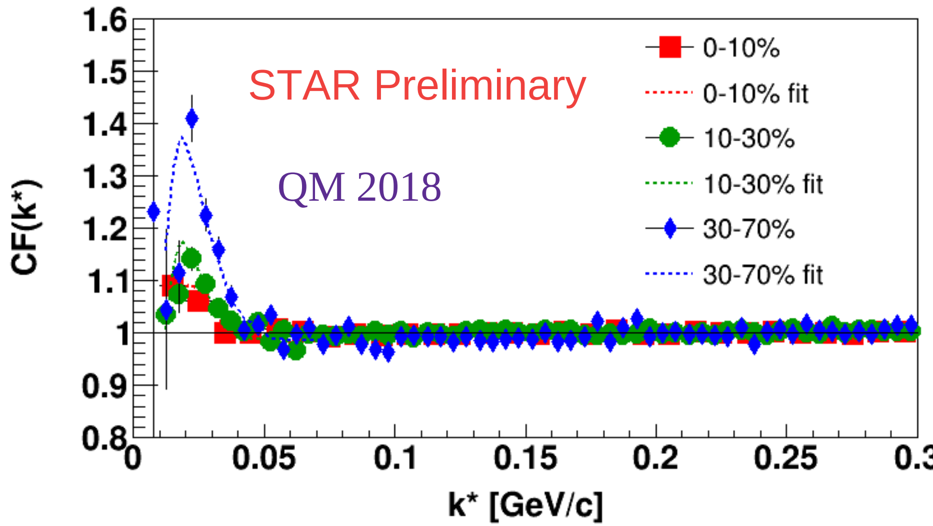
- f_0 and d_0 for the antiproton-antiproton interaction consistent with parameters for the proton-proton interaction.
- Descriptions of the interaction among antimatter (based on the simplest systems of anti-nucleons) determined.
- A quantitative verification of matter-antimatter symmetry in context of the forces responsible for the binding of (anti)nuclei.

Proton Femtoscopy in BES – Centrality Dependence

proton-proton @39 GeV



antiproton-antiproton @39 GeV

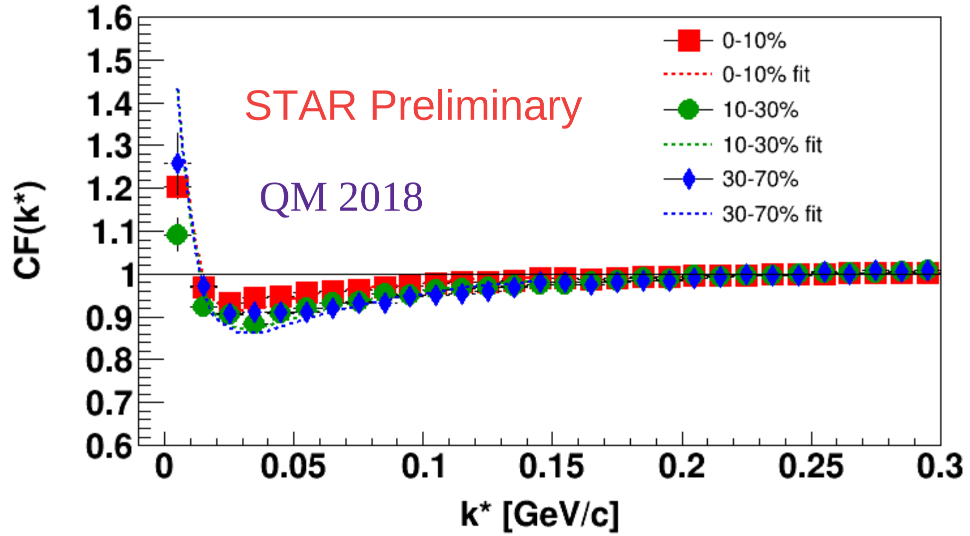


centrality	R_{inv} $p-p$ [fm]	R_{inv} $\overline{p}-\overline{p}$ [fm]	R_{inv} $p-\overline{p}$ [fm]
0-10%	$\mathbf{4.00} \pm 0.15 \pm 0.02$	$\mathbf{3.83} \pm 0.20 \pm 0.03$	$\mathbf{3.39} \pm 0.12 \pm 0.14$
10-30%	$\mathbf{3.61} \pm 0.13 \pm 0.17$	$\mathbf{3.68} \pm 0.15 \pm 0.11$	$\mathbf{2.69} \pm 0.10 \pm 0.12$
30-70%	$\mathbf{2.72} \pm 0.07 \pm 0.07$	$\mathbf{2.95} \pm 0.11 \pm 0.08$	$\mathbf{2.56} \pm 0.09 \pm 0.12$

No significant difference between proton-proton and antiproton-antiproton correlation functions

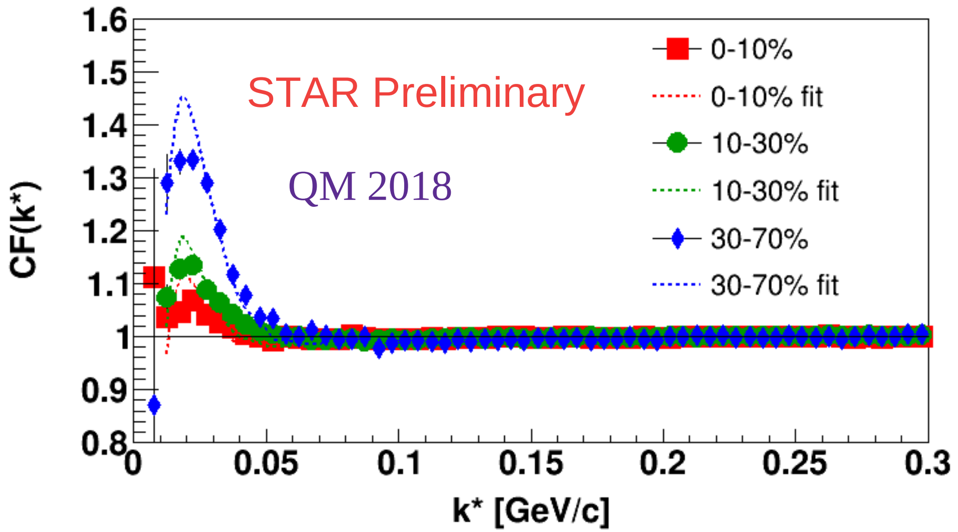
Proton Femtoscopy in BES – System Dependence

Radii from proton-proton and antiproton-antiproton systems differ from those from proton-antiprootn system → Residual Correlations.
Residual feed-down correction needs to be applied.



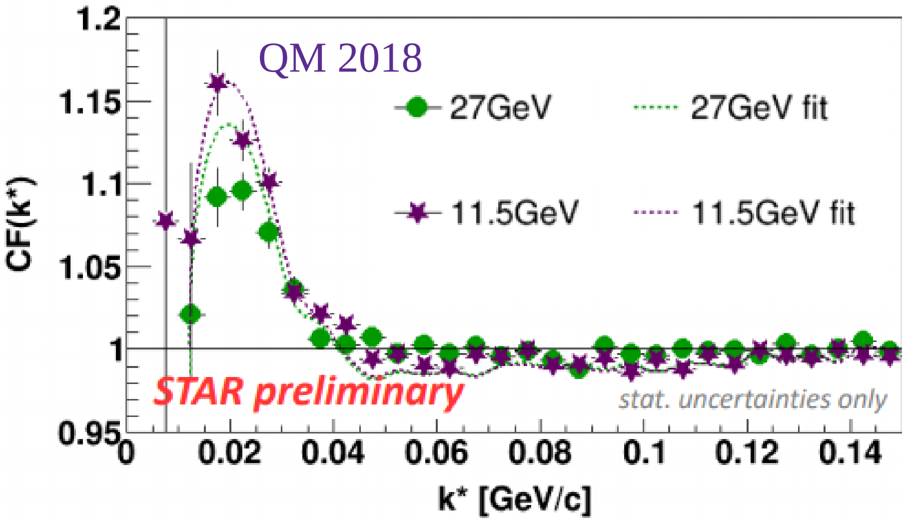
proton-proton @39 GeV

proton-antiproton @39 GeV

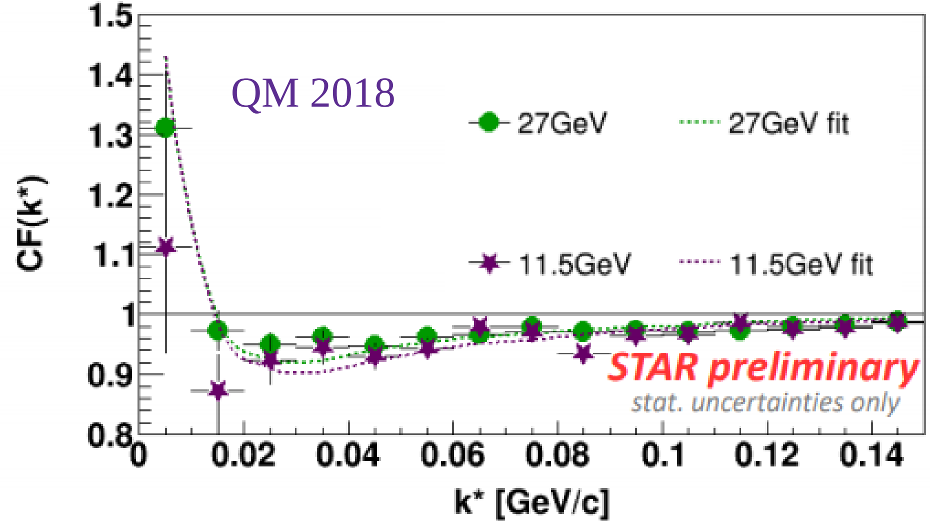


Proton Femtoscopy in BES – System Dependence

proton-proton, centrality 0-10%



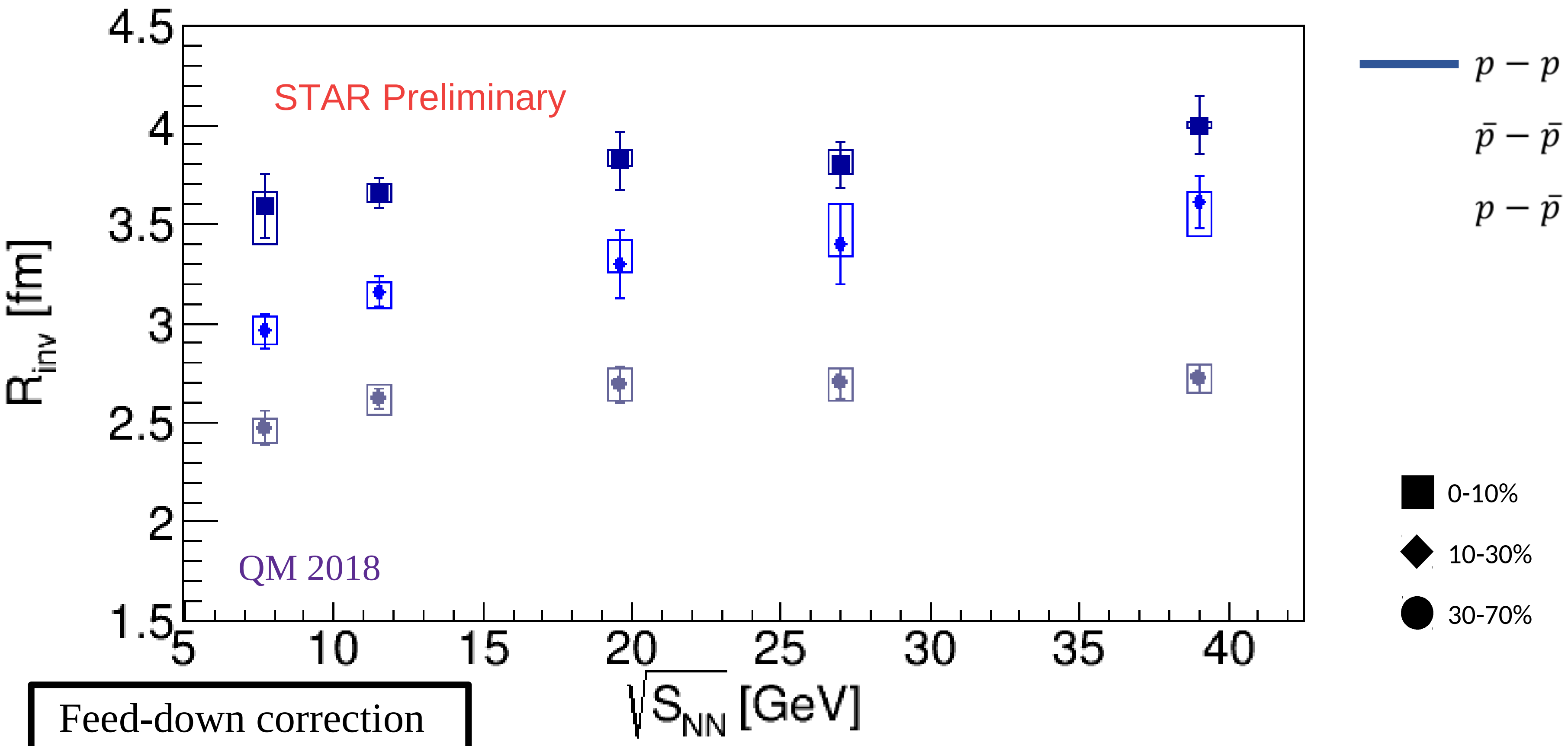
proton-antiproton, centrality 0-10%



energy	R_{inv} $p-p$ [fm]	R_{inv} $p-\overline{p}$ [fm]
7.7 GeV	$\mathbf{3.59} \pm 0.16 \pm 0.19$	
11.5 GeV	$\mathbf{3.66} \pm 0.08 \pm 0.05$	$\mathbf{3.30} \pm 0.42 \pm 0.28$
19.6 GeV	$\mathbf{3.82} \pm 0.15 \pm 0.06$	$\mathbf{3.32} \pm 0.25 \pm 0.13$
27 GeV	$\mathbf{3.80} \pm 0.12 \pm 0.08$	$\mathbf{3.49} \pm 0.25 \pm 0.16$
39 GeV	$\mathbf{4.00} \pm 0.15 \pm 0.02$	$\mathbf{3.39} \pm 0.12 \pm 0.14$

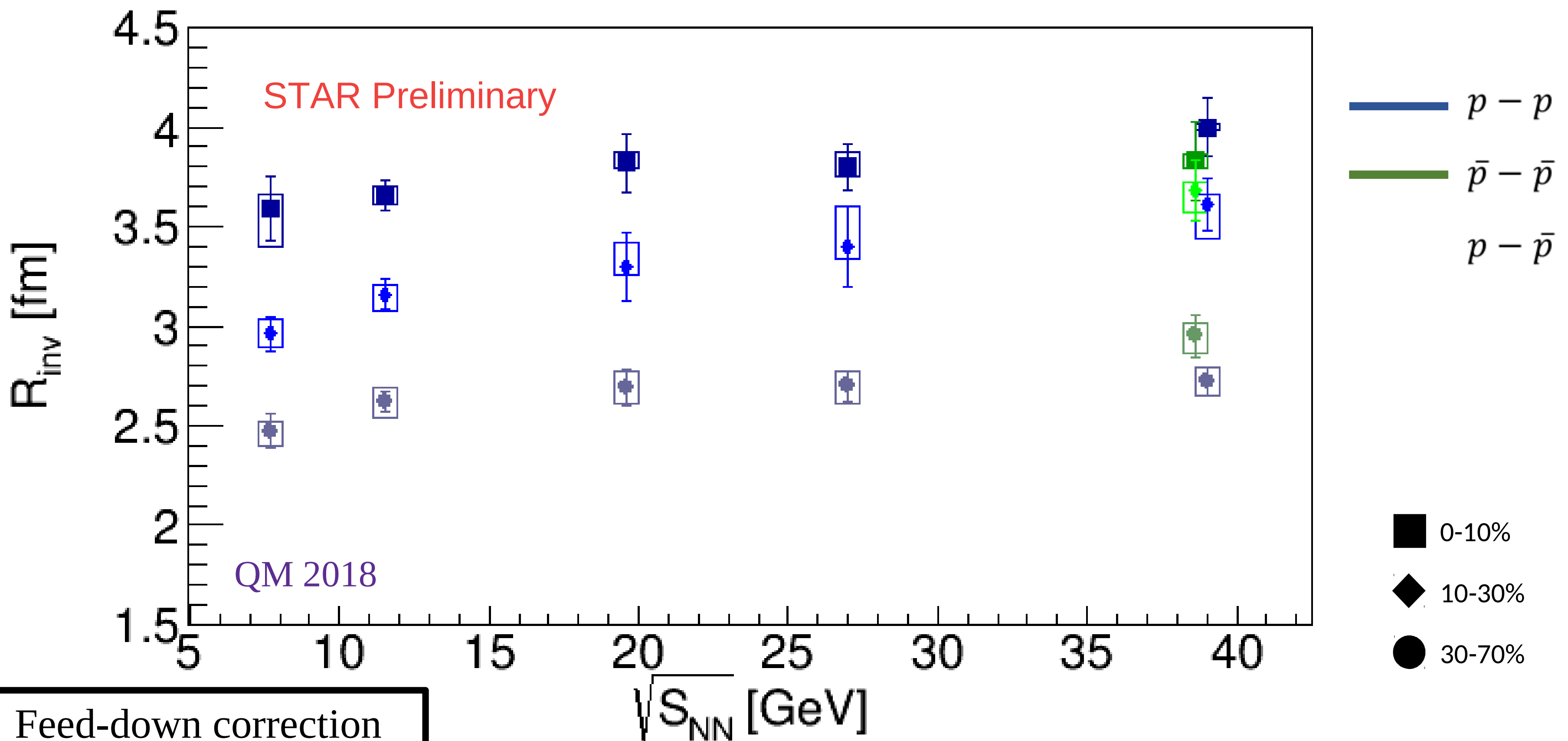
Energy dependence more significant for proton-proton than for proton-antiproton system.

Proton Femtoscopy in BES



Feed-down correction may decrease significance of the centrality dependence.

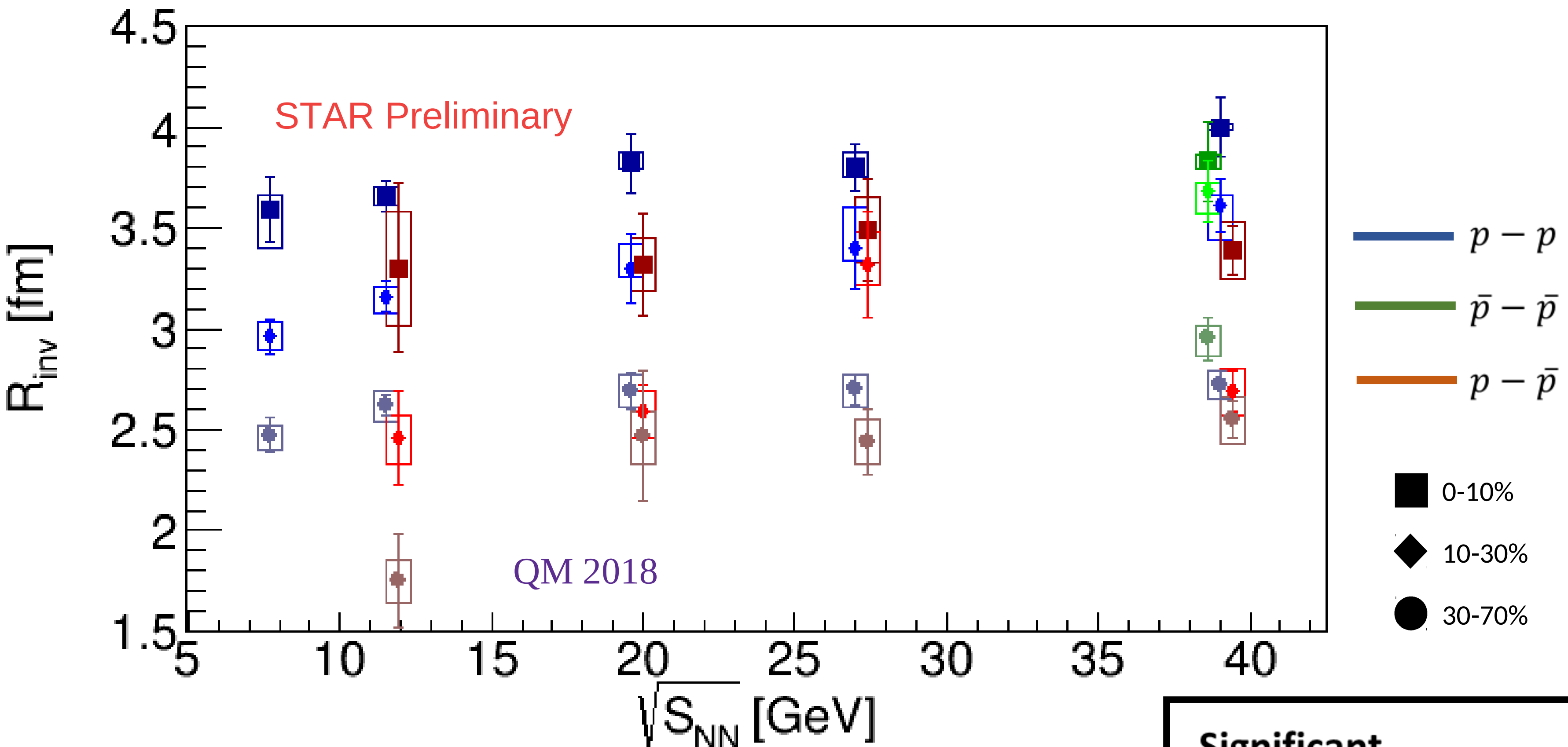
Proton Femtoscopy in BES



Feed-down correction may decrease significance of centrality dependence.

No significant difference between $p-p$ and $\bar{p}-\bar{p}$ correlation functions at $\sqrt{s_{NN}}$ = 39 GeV

Proton Femtoscopy in BES



Feed-down correction may decrease significance of centrality dependence.

No significant difference between $p-p$ and $\bar{p}-\bar{p}$ correlation functions at $\sqrt{s_{NN}}$ = 39 GeV

Significant centrality dependence.

$\sqrt{s_{NN}}$ dependence weak for all centralities.

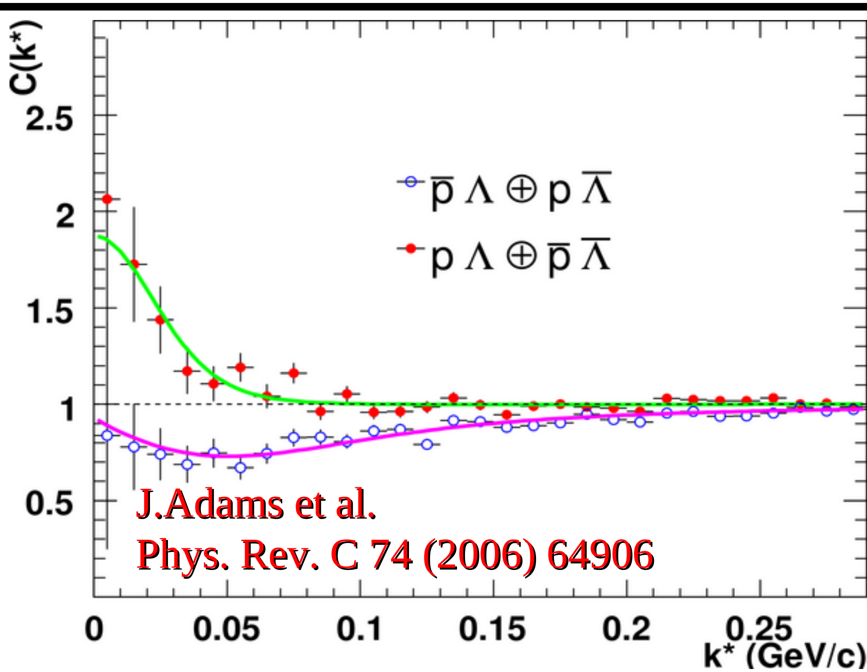
Strange Baryon Correlations (Including Λ Hyperons)

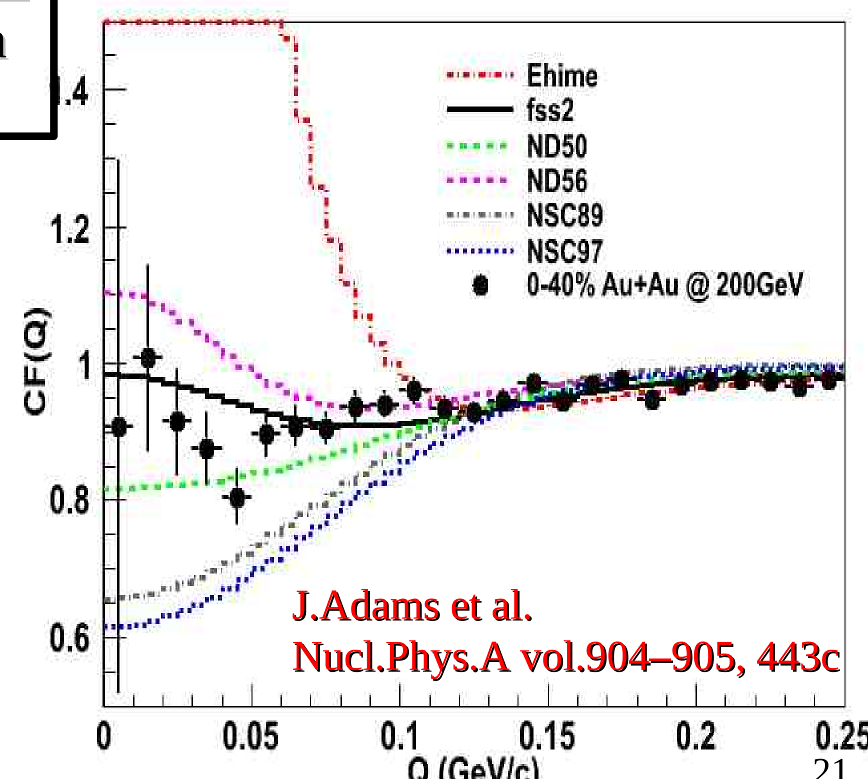
<u>proton-lambda correlations:</u>
sensitive to the Strong FSI only

<u>lambda-lambda correlations:</u>
sensitive to the Quantum Statistical effects and Strong FSI

<u>lambda-lambda and proton-lambda correlations:</u>
contain contributions from Residual feed-down Correlations

System	r_0 (fm)
$p-\Lambda$	$2.97 \pm 0.34^{+0.19}_{-0.25} \pm 0.2$
$\overline{p}-\overline{\Lambda}$	$3.24 \pm 0.59^{+0.24}_{-0.14} \pm 0.2$
$p-\Lambda \oplus \overline{p}-\overline{\Lambda}$	$3.09 \pm 0.30^{+0.17}_{-0.25} \pm 0.2$
$\overline{p}-\Lambda$	$1.56 \pm 0.08^{+0.10}_{-0.14} \pm 0.3$
$p-\overline{\Lambda}$	$1.41 \pm 0.10 \pm 0.11 \pm 0.3$
$\overline{p}-\Lambda \oplus p-\overline{\Lambda}$	$1.50 \pm 0.05^{+0.10}_{-0.12} \pm 0.3$





Conclusions & Summary

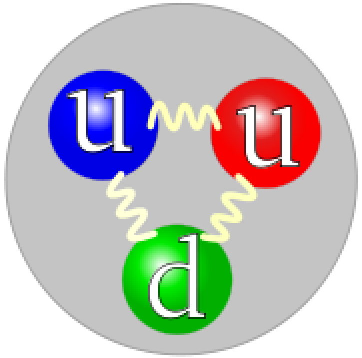
Summary from results of baryon-baryon from $\sqrt{s_{NN}}$ = 200 GeV

- Result of baryon-baryon correlation function from heavy-ion collisions shown

- Direct information on interaction between two anti-protons fundamental to understand the structure and properties of more complex antinuclei

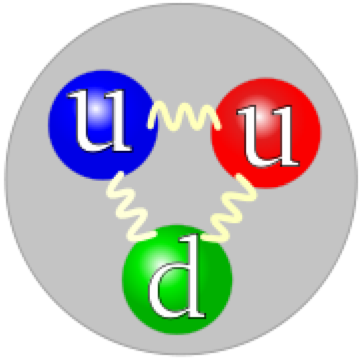
  Parameters of antiproton-antiproton interations: f_0, d_0 extracted

- The interaction between two antiprotons found as attractive



Summary from results of baryon-baryon at BES

- Clear centrality dependence of source size at BES energies
- Visible energy dependence of source size at BES energies
- **No visible difference between proton-proton and antiproton-antiproton correlation functions at $\sqrt{s_{NN}}$ = 200 GeV**
- **Correlation functions contaminated by residual correlations – residual correction required**



Thank you!

Backup

Correlation Function

$$CF(k^*) = \frac{\sum_{pair} \delta(k^*_{pair} - k^*) w(k^*, r^*)}{\sum_{pair} \delta(k^*_{pair} - k^*)}$$

$$w(k^*, r^*) = |\psi^{S(+)}_{-k^*}(r^*) + (-1)^S \psi^{S(+)}_{k^*}(r^*)|^2/2$$

$$\psi^{S(+)}_{-k^*}(r^*) = e^{i\delta_c}\sqrt{A_c(\eta)}[e^{-ik^*r^*}F(-i\eta, 1, i\xi) + f_c(k^*)\frac{\widetilde{G}(\rho,\eta)}{r^*}]$$

$$f_c(k^*) = [\frac{1}{f_0} + \frac{1}{2}d_0 k^{*2} - \frac{2}{a_c}h(k^* a_c) - ik^* A_c(k*)]^{-1}$$

is the s-wave scattering amplitude renormalized by Coulomb interaction.

$A_C(k^*) = (2\pi/k^* a_c)\frac{1}{exp(2\pi/k^* a_c)-1}$, $h(x) = \frac{1}{x^2}\sum_{n=1}^{\infty}\frac{1}{n(n^2+x^{-2})} - C + ln|x|$,

and $\widetilde{G}(\rho, \eta) = \sqrt{A_c(k^*)}(G_0(\rho,\eta) + iF_0(\rho,\eta))$ is a combination of regular (F_0) and singular (G_0) s-wave Coulomb functions.