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Proton-proton correlations

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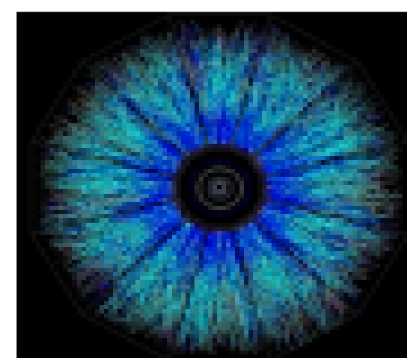


Internation Conference on New Frontiers in Physics
Kolumbari, Creete – Greece - 2016

Introduction

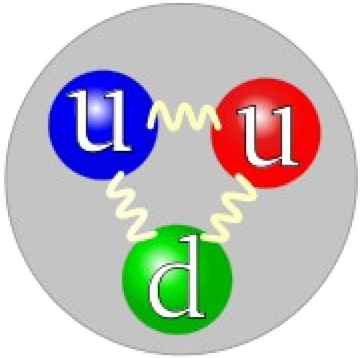
1) Motivation

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

Nuclear force between **antinucleons** was not studies so far.

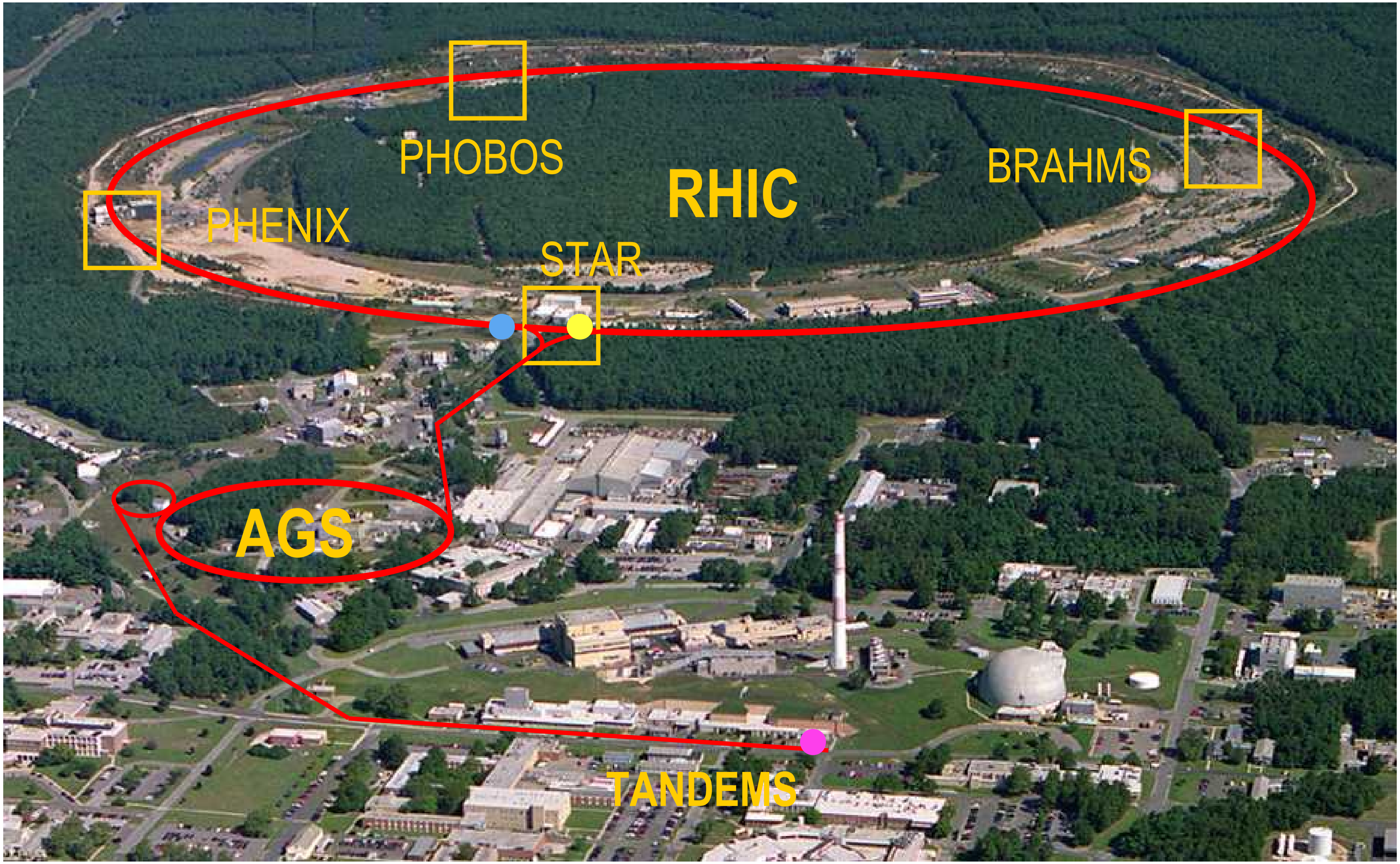
The knowledge of interaction between two anti-protons is **fundamental** to understand the properties of more sophisticated antinuclei.

RHIC has the excellent capability to conduct such studies.



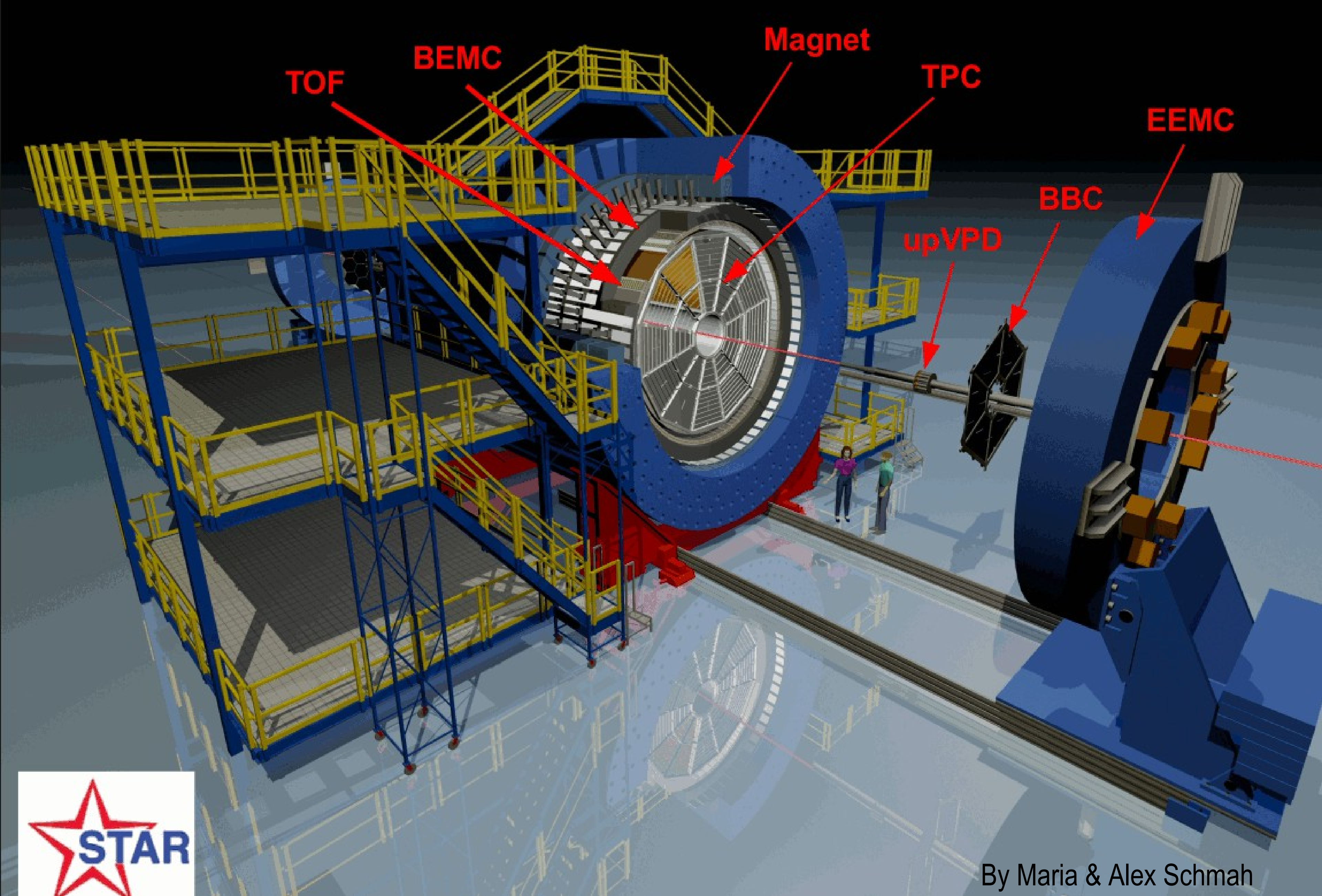
Nature 527, 345–348(2015)

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



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

3) The Solenoidal Tracker At RHIC



4) Few words about femtoscopy

Single- and two- particle distributions

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

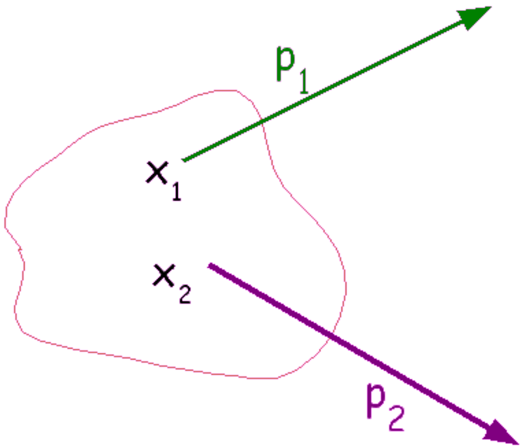
S(x,p) – emission function: the distribution of source density probability of finding particle with x and p

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

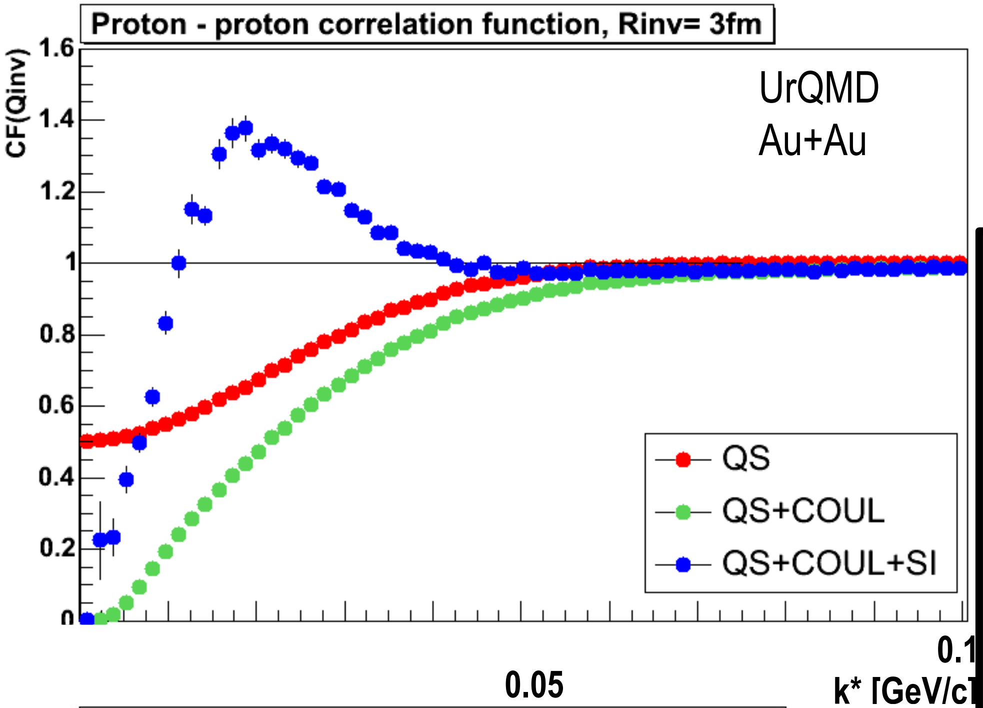
The correlation function

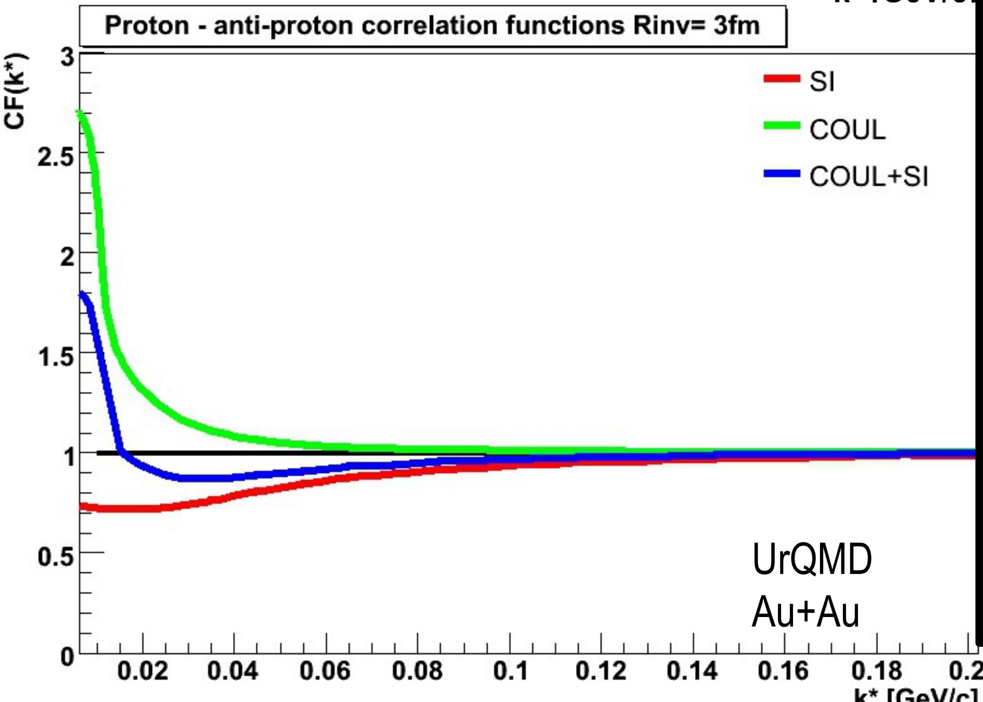
$$C(p_1,p_2) = \frac{P_2(p_1,p_2)}{P_1(p_1)P_1(p_2)}$$

$$C_{corrected} = \frac{C_{measured}(k^{star})-1}{PairPurity(k^{star})}+1$$



5) Proton- (anti)proton correlations





Identical baryon- baryon

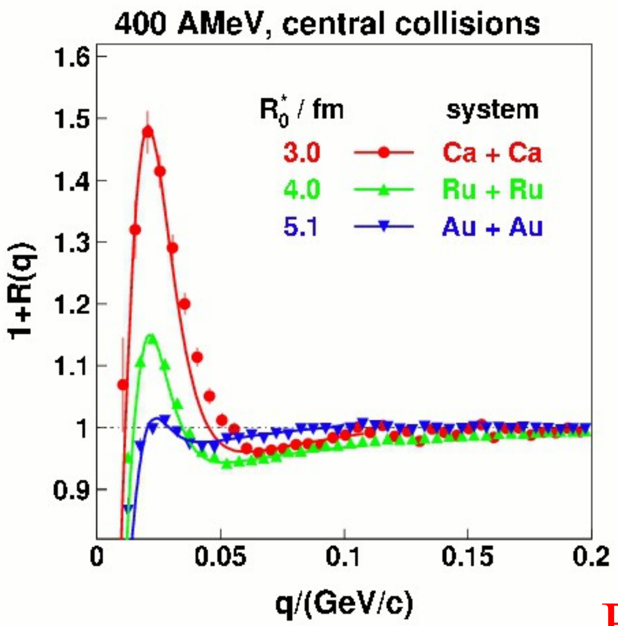
- Quantum Statistics- QS
- Final State Interactions- FSI
  - Coulomb
  - Strong

Nonidentical baryon- (anti)baryon

- Final State Interactions- FSI
  - Coulomb
  - Strong

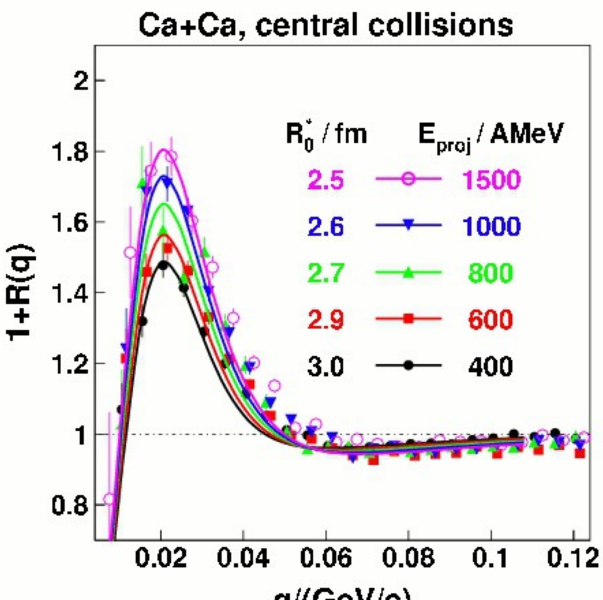
Results

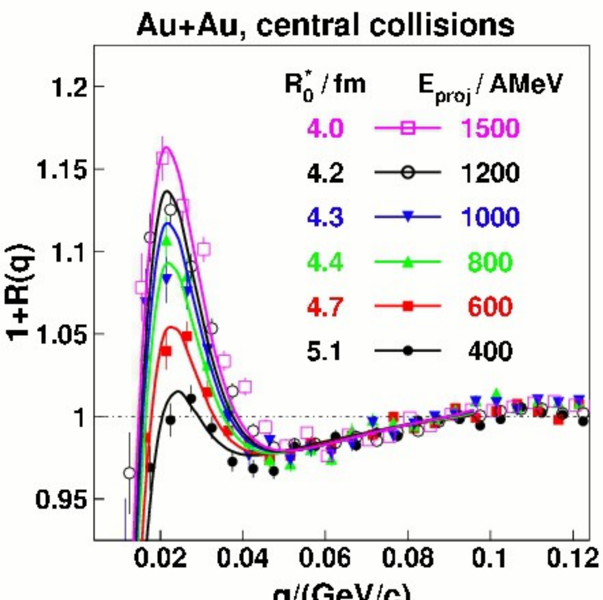
1) Results of p-p correlations from lower energies



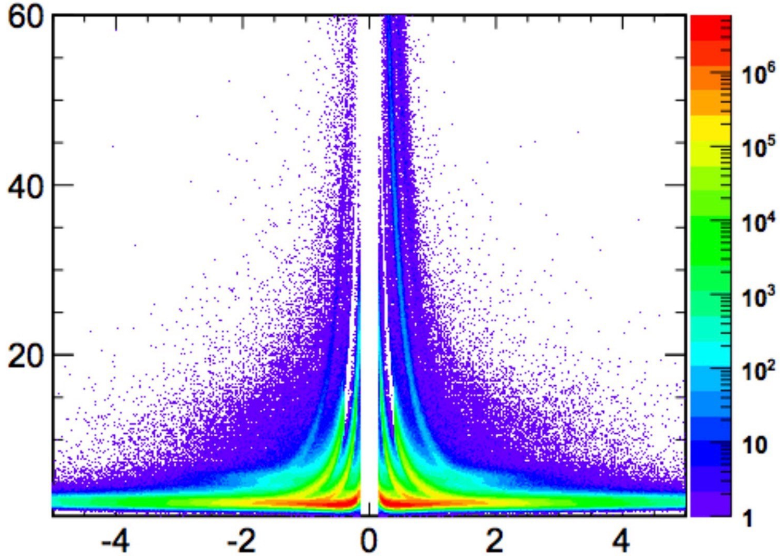
SIS → AGS/SPS →RHIC

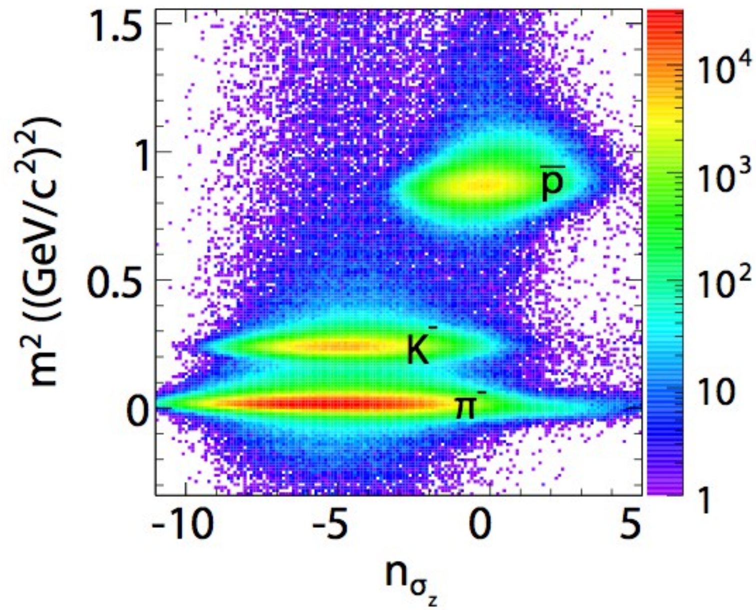
Eur.J.Phys.A23:271-278,2005





2) Particle Identification





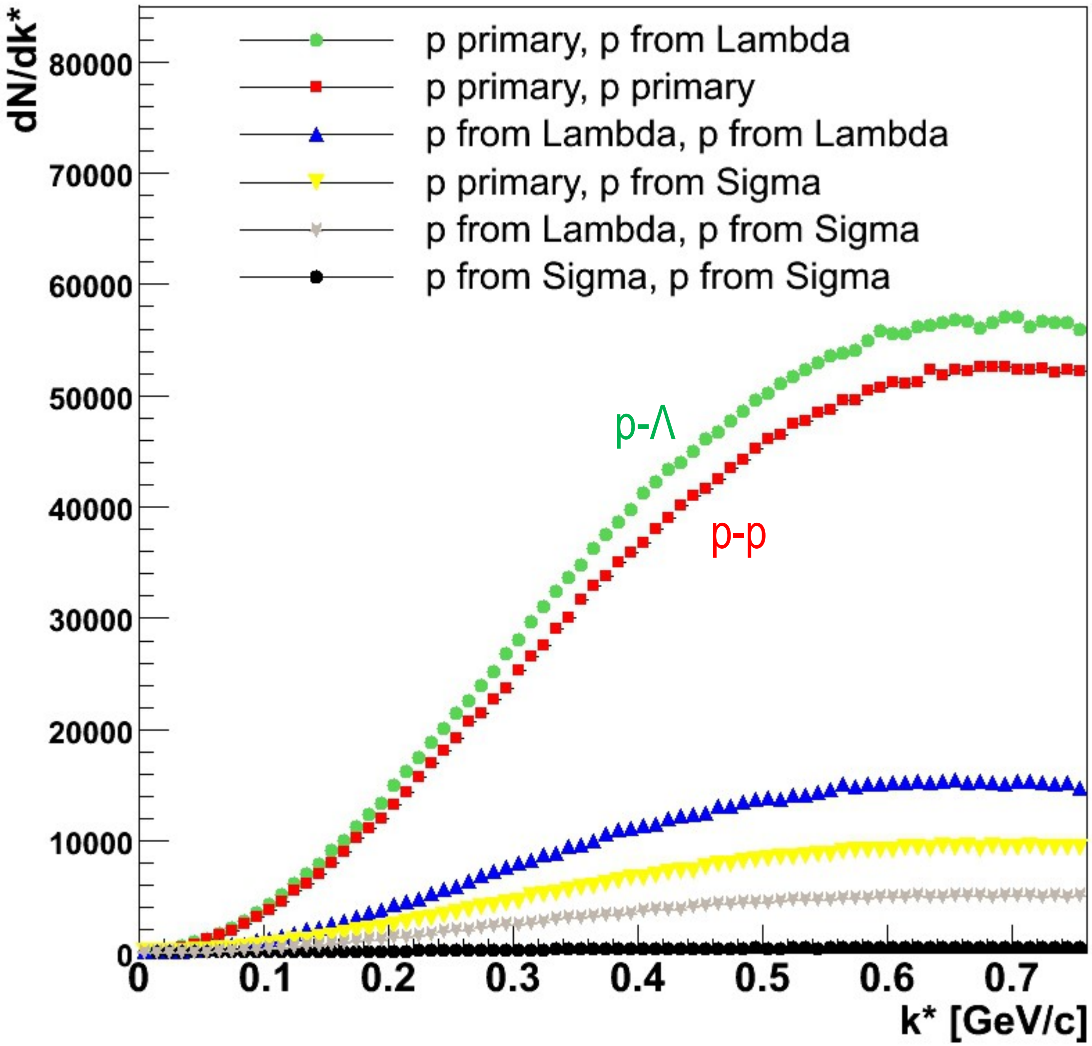
m^2 vs $n\sigma_p$: Negative Charge

→ TPC and TOF for the particle identification.

→ The purity for anti-proton over 99%.

3) Proton femtoscopy @ 200 GeV – contribution to the measured correlation function

$$CF_{true}(k_{star}) = \sum_{x,y=p,\Lambda,\Sigma} CF_{x-y}(k_{star}) F_{x-y}(k_{star})$$



$$F_{x-y}(k_{star}) = \frac{f_{x-y}(k_{star})}{\sum f_{i,j}(k_{star})}$$

$$x,y = [p, \Lambda, \Sigma]$$

weak decay channels of interest:

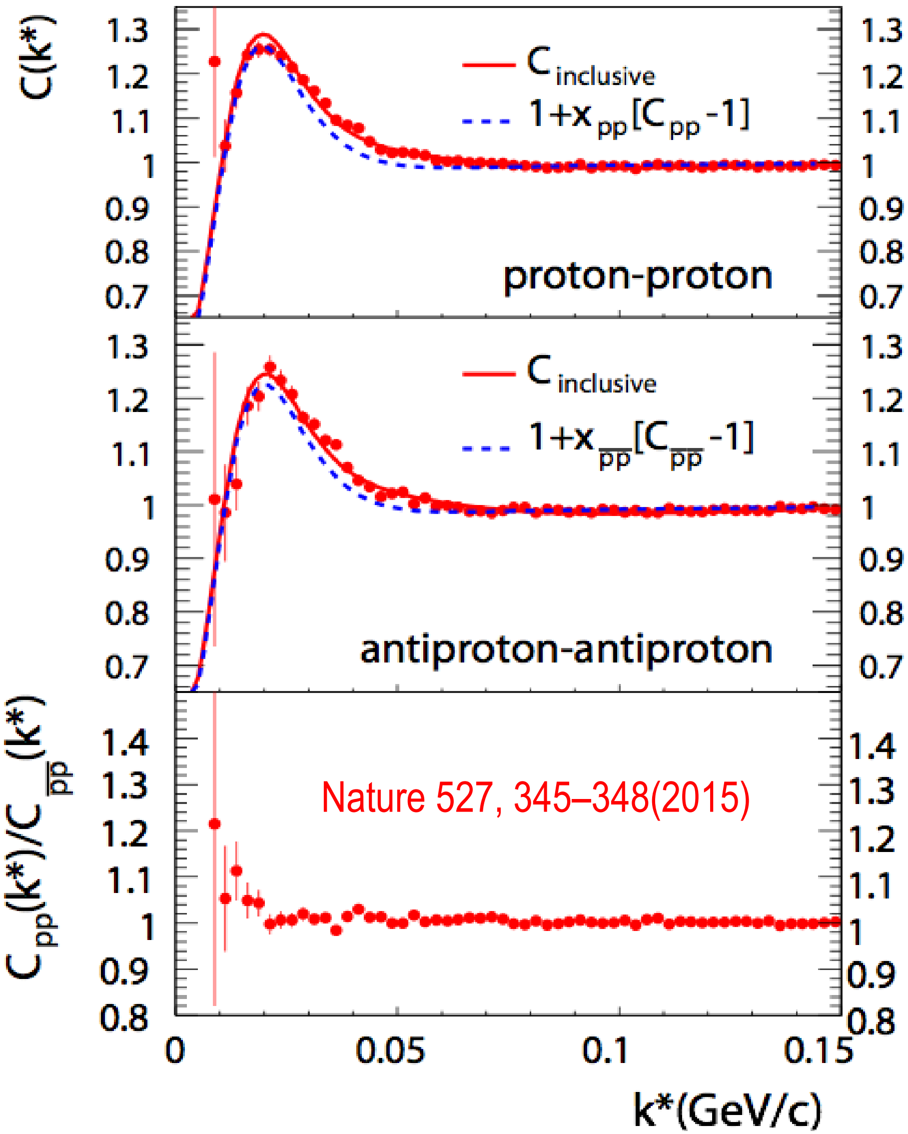
$\Lambda \to p + \pi^-$, $\Lambda_{bar} \to p_{bar} + \pi^+$

$\Sigma^+ \to p + \pi^0$, $\Sigma^+_{bar} \to p_{bar} + \pi^0$

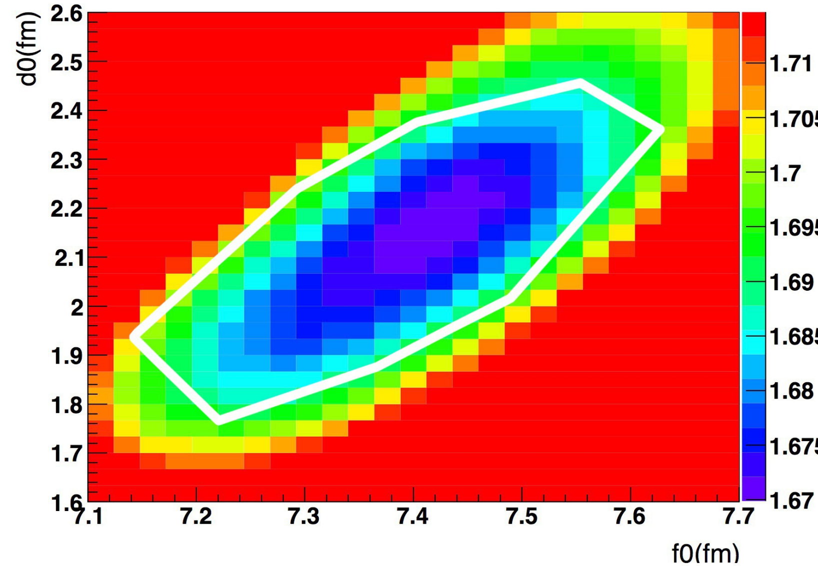
THERMal heavy IoN generATOR (Broniowski, Florkowski, Kisiel, Tałuć: nucl-th/0504047)

4) Correlation functions

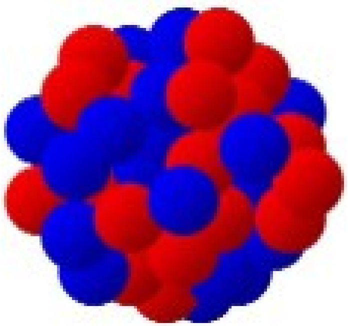
Fit



Fit results:
p-p CF,
R=2.75}0.01fm; NDF = 1.66;
pbar-pbar CF,
R=2.80}0.02fm , f_0=7.41}0.19fm,
d_0=2.14}0.27fm; NDF=1.61



5) Parameters: f_0 and d_0



The scattering length f0: describes low-energy scattering.

The elastic cross section, σe , (at low energies) determined solely by the scattering length, $\lim_{k \to 0} \sigma_e = 4\pi f_0^2$

d0 - 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.

- f0 and d0 - two important parameters in strong interaction between two particles.

- The part $C_{pp}(k^*; R_{pp})$ in the equation we used to fit the data is calculated based on f0 and d0.

5) f_0 and d_0 for antiproton-antiproton

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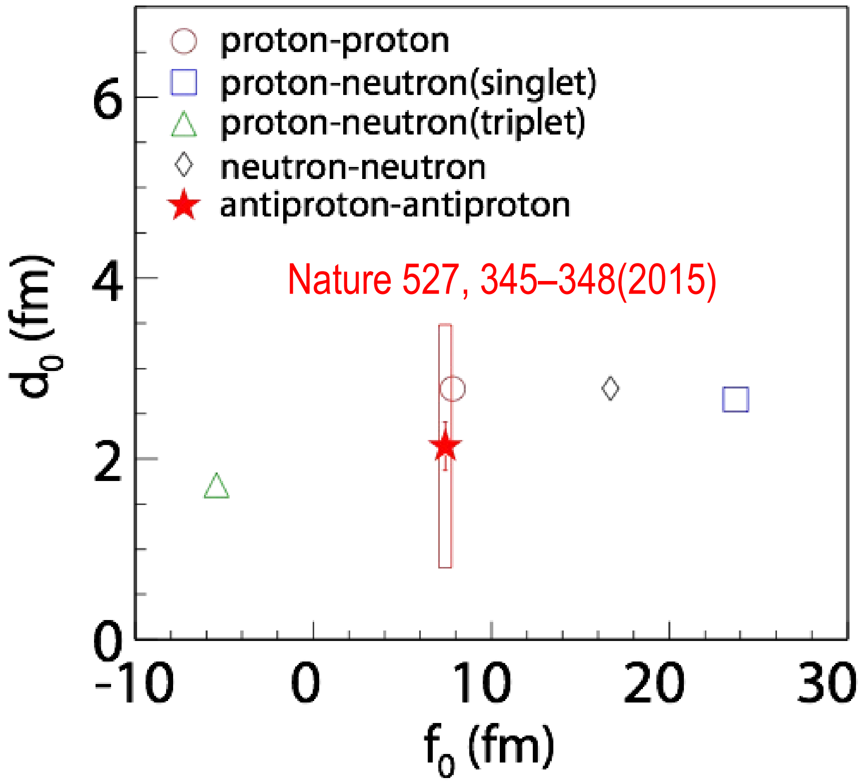


- f0 and d0 for the antiproton-antiproton interaction consistent with parameters for the proton-proton interaction.
- Descriptions of the interaction among antimatter (based on the simplest systems of anti-nucleons).
- A quantitative verification of Matter-antimatter symmetry in context of the forces responsible for the binding of (anti)nuclei.

6) Strange baryon correlations (including Λ hyperons)

pΛ correlations:

sensitive to the Strong FSI only

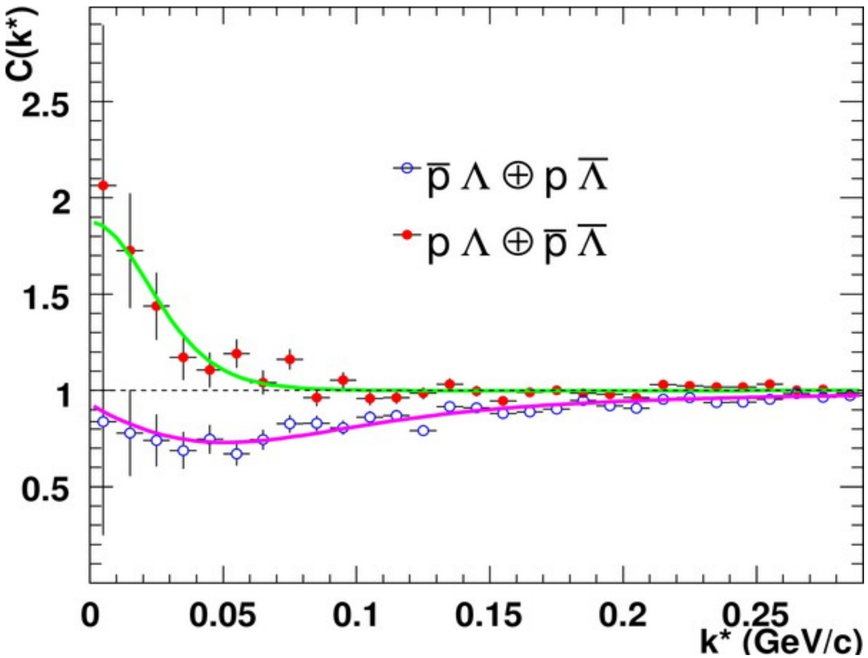
ΛΛ correlations:

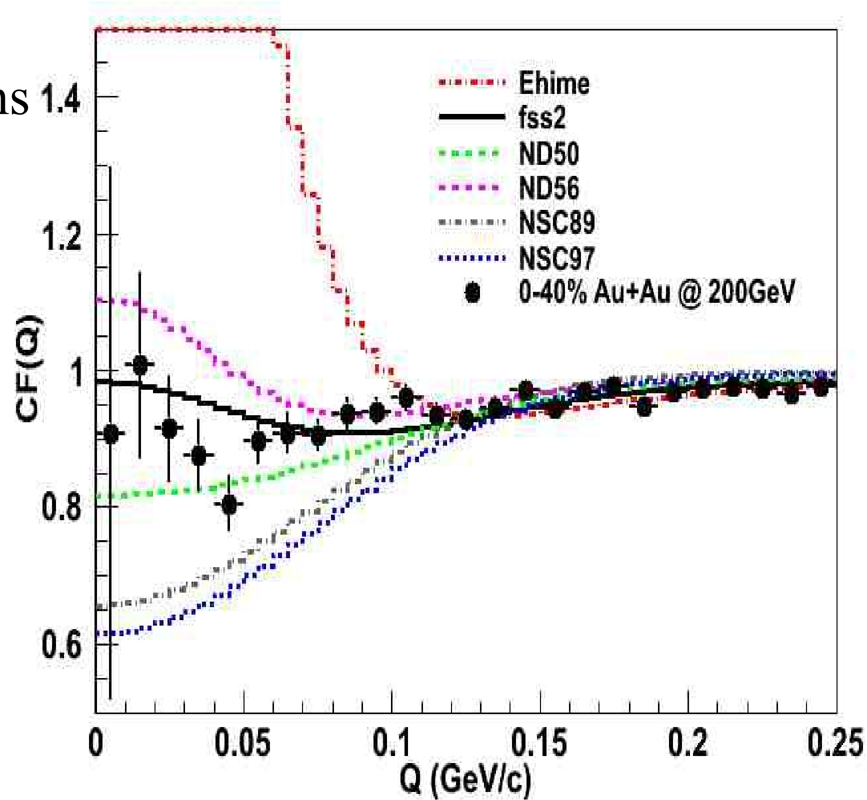
sensitive to the Quantum Statistic effects and Strong FSI

ΛΛ and pΛ correlations:

contain contribution of Residual Correlations

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

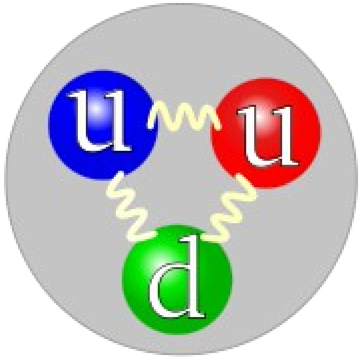




Conclusions & Summary

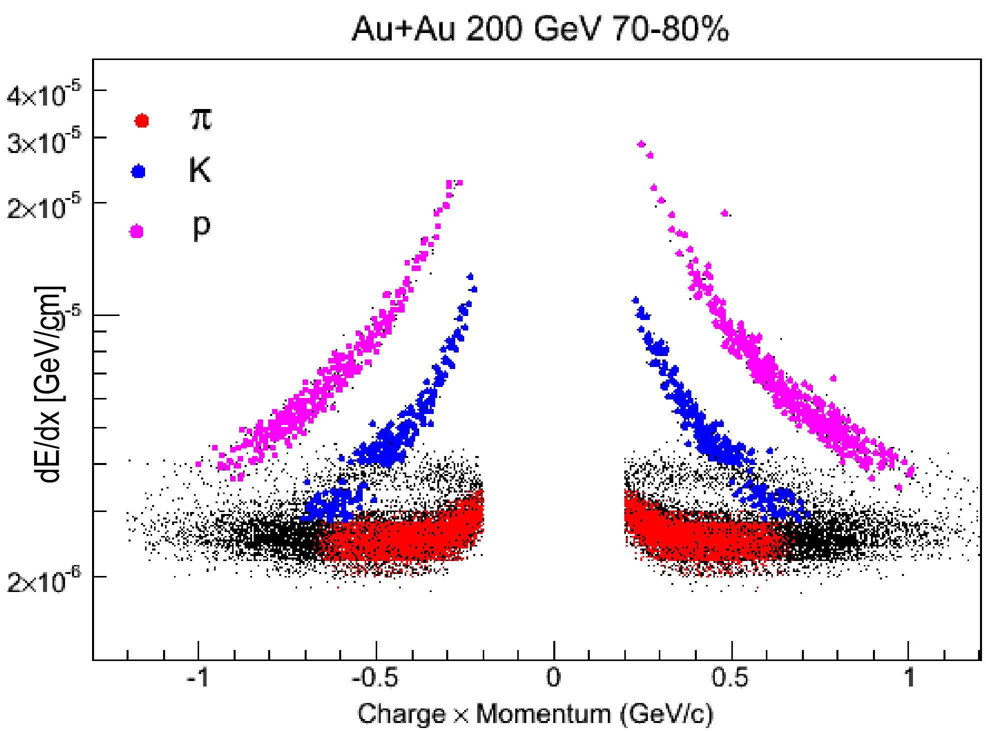
Summary

- Result of antiproton-antiproton correlation function from $\sqrt{(s_{NN})}$ = 200GeV Au+Au collisions shown
- Parameters f_0, d_0 extracted
- The interaction between two antiprotons attractive
- Direct information on interaction between two anti-protons fundamental to understand the structure and properties of more complex antinuclei
- More detailed studies started



Thank you!

Analysed data, particle identification - PID



$$-\frac{dE}{dx}=\frac{4\pi}{m_e c^2}\frac{nz^2}{\beta^2}\frac{e^2}{4\pi\varepsilon_0}\left[\ln\frac{2m_e c^2\beta^2}{I\left(1-\beta^2\right)}-\beta^2\right]$$

E- energy
x- distance
β=v/c (v- particle velocity,
c- speed of light)
m_e - electron mass
z- particle charge
n – density of e- inside medium
$n=N_A Z\rho/A$
N_A- Avogadro's number
A, Z- atomic and mass numbers
ρ – medium density
I- ionization potential

Analysed data:

$\sqrt{s_{NN}}$ = 39 GeV: 96 M

$\sqrt{s_{NN}}$ = 200 GeV: 112 M

3 centrality classes (the percentage of the total hadronic cross-section of the collision):

- 0-10%
- 10-30%
- 30-80%

Selected protons and antiprotons:

$p \in [0.4, 3.0]$ GeV/c
$p_T \in [0.4, 2.5]$ GeV/c
$\eta \in [-0.5, 0.5]$

Correlation Function

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

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

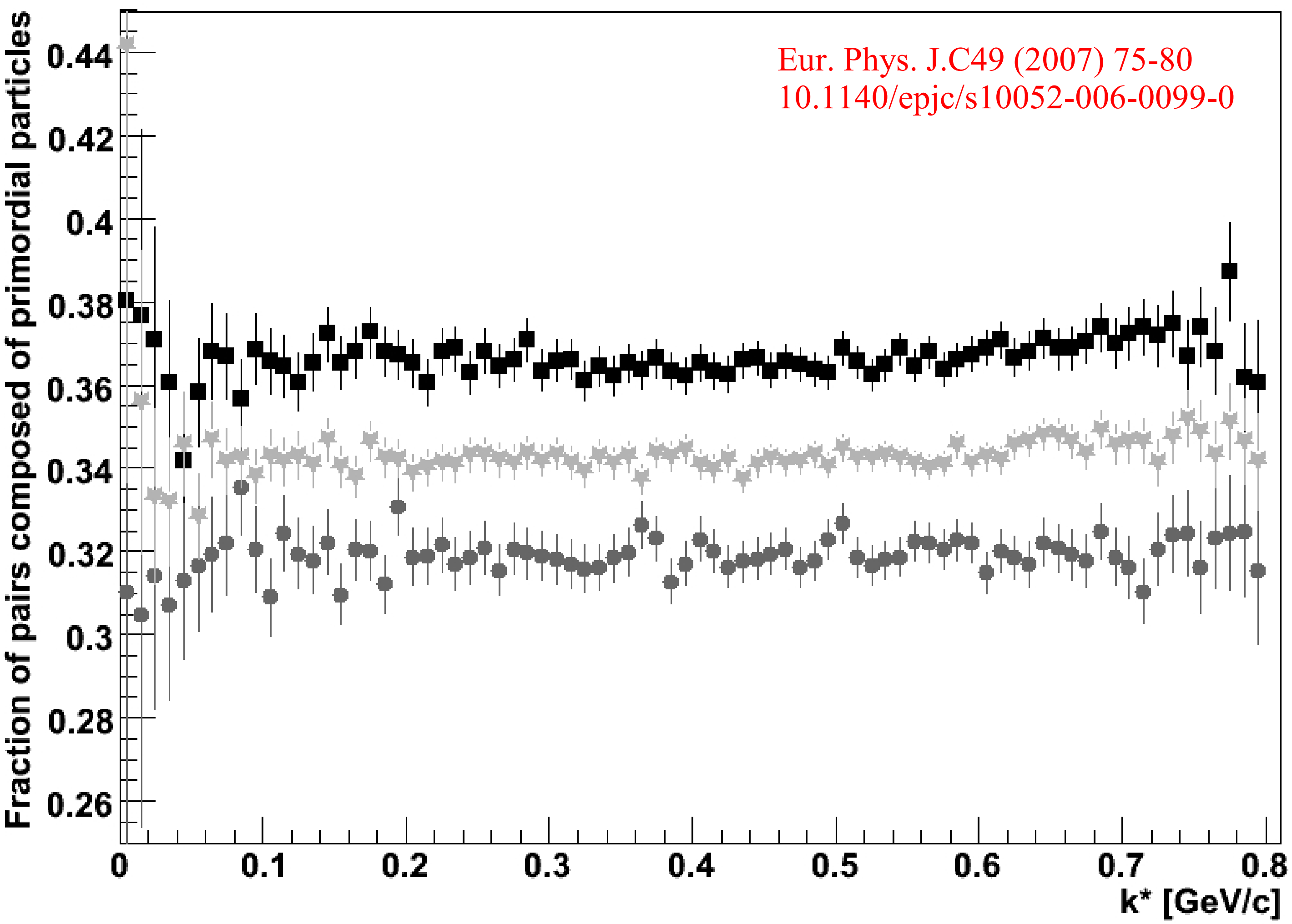
$$\psi^{S(+)}_{-k^*}(r^*) = e^{i\delta_c}\sqrt{A_c(\eta)}[e^{-ik^*r^*}F(-i\eta, 1, i\xi) + f_c(k^*)\frac{\widetilde{G}(\rho,\eta)}{r^*}]$$

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

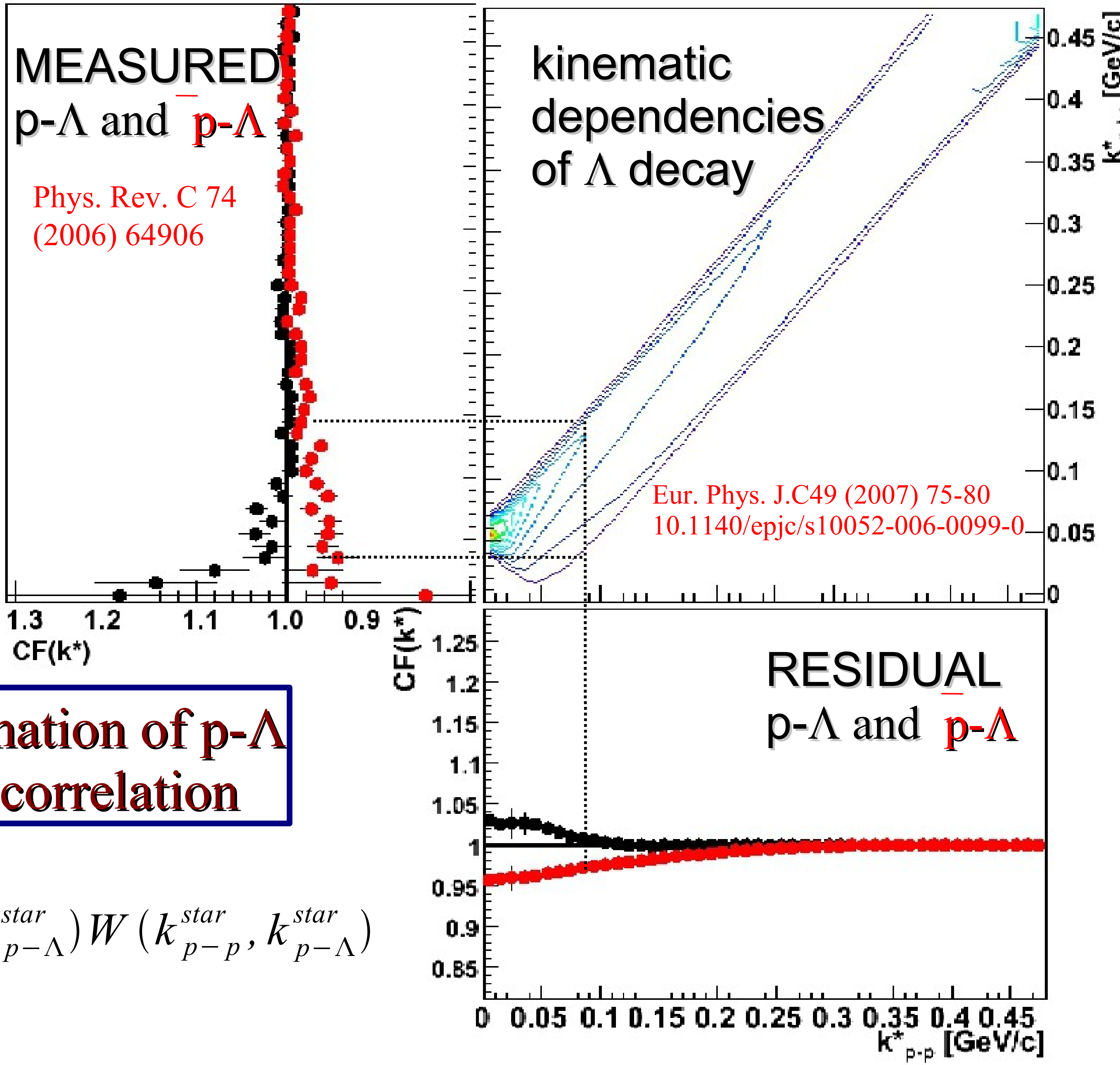
$A_C(k^*) = (2\pi/k^* a_c)\frac{1}{exp(2\pi/k^* a_c) - 1}$, $h(x) = \frac{1}{x^2}\sum_{n=1}^{\infty}\frac{1}{n(n^2 + x^{-2})} - C + ln|x|$,

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.

3) Proton femtoscopy @ 200 GeV –
- fractions of pure p-p pairs from Therminator



Therminator,
Au+Au @ 200 GeV



The estimation of p-Λ residual correlation

$$\sum_{k^{star}_{p-\Lambda}} CF^{meas}_{p-\Lambda}(k^{star}_{p-\Lambda})\, W(k^{star}_{p-p}, k^{star}_{p-\Lambda})$$