Lambda-proton femtoscopy in collisions of Ar+KCl at 1.76 AGeV with HADES

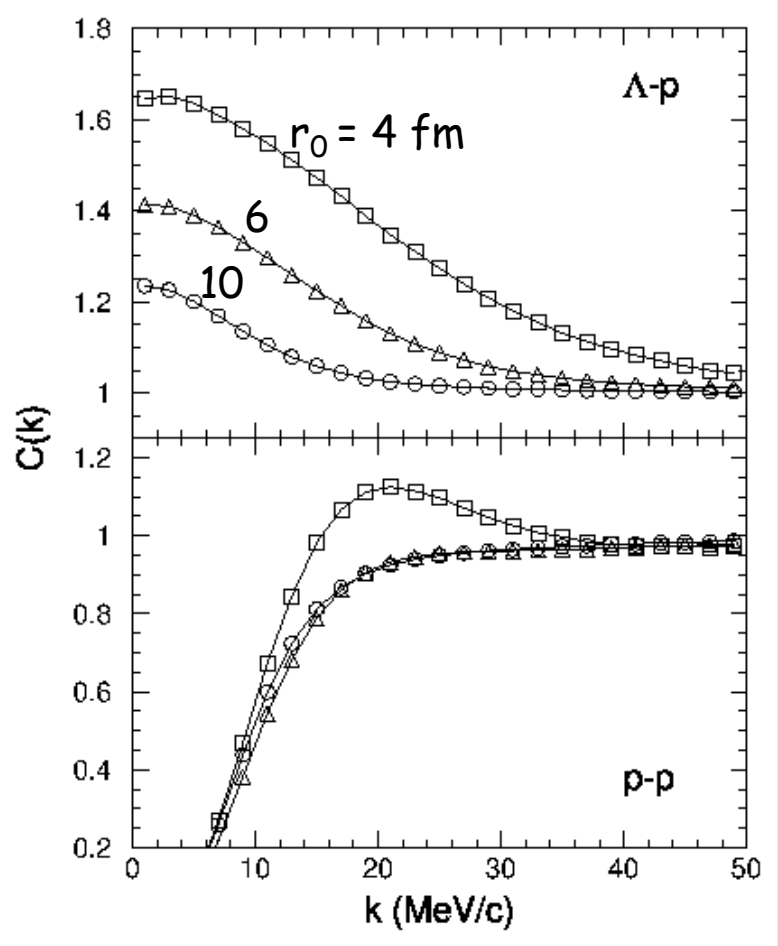
- basics
  - the correlation function (CF)
  - model predictions: Λp vs. pp CF
- exp. data (HADES)
  - prerequisites: high quality Λ selection
  - Λp relative-momentum CF (comparison to pp, $\pi\pi$)
- simulation
  - PLUTO => GEANT => Embedding => CFs of uncorrelated Λp pairs
  - to correct exp. CF
- results
  - comparison to model => Λp source radius
  - comparison to other data

The correlation function (CF)

$$C(\mathbf{p}_1, \mathbf{p}_2) = N \frac{\sum Y_{12}(\mathbf{p}_1, \mathbf{p}_2)}{\sum Y_{12,mix}(\mathbf{p}_1, \mathbf{p}_2)}$$

- sum Σ runs over all events and pairs
- mix: take particles 1, 2 from different events
- projection on rel. momentum in pair c.m. frame ($\mathbf{p}_1+\mathbf{p}_2=0$): $k = |\mathbf{p}_1-\mathbf{p}_2|/2 = |\mathbf{p}|$
- normalization N: $C \Rightarrow 1$ at high k (100-150 MeV/c)

Theoretical predictions*



Λp correlations:

- strong interaction only (attractive Λp potential)

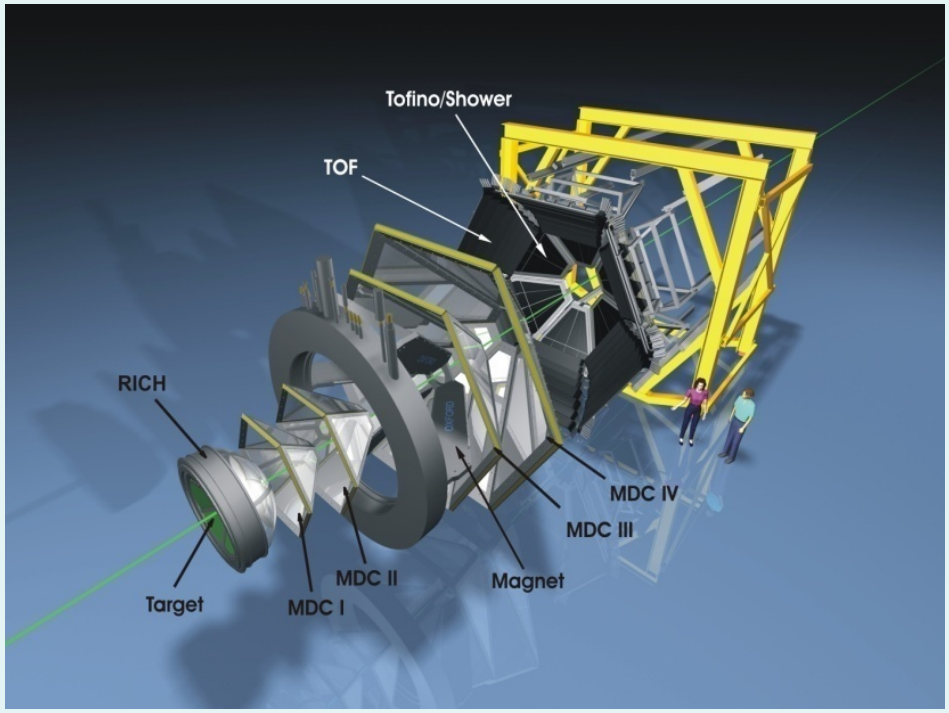
r_0 : Gaussian source radius

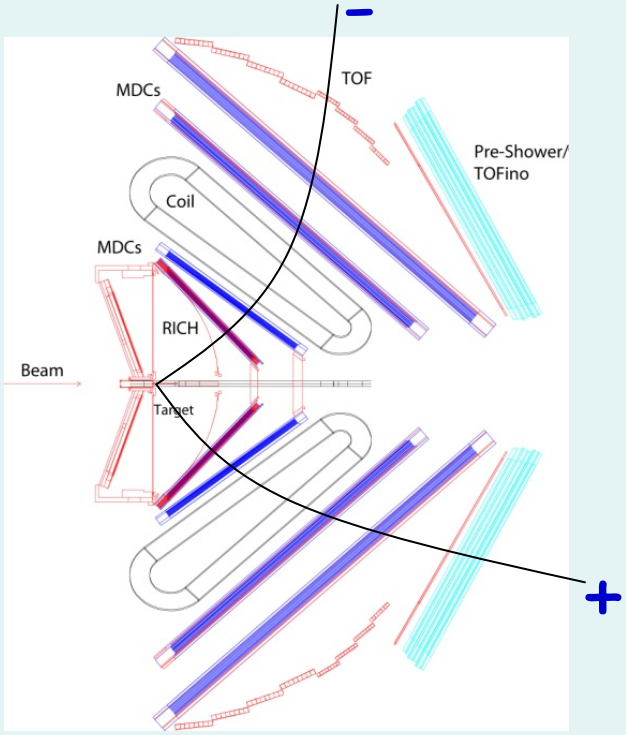
pp correlations:

- attractive NN potential
- repulsive Coulomb potential
- suppression due to quantum (Fermi-Dirac) statistics

* F. Wang and S. Pratt, PRL 83 (1999) 3138

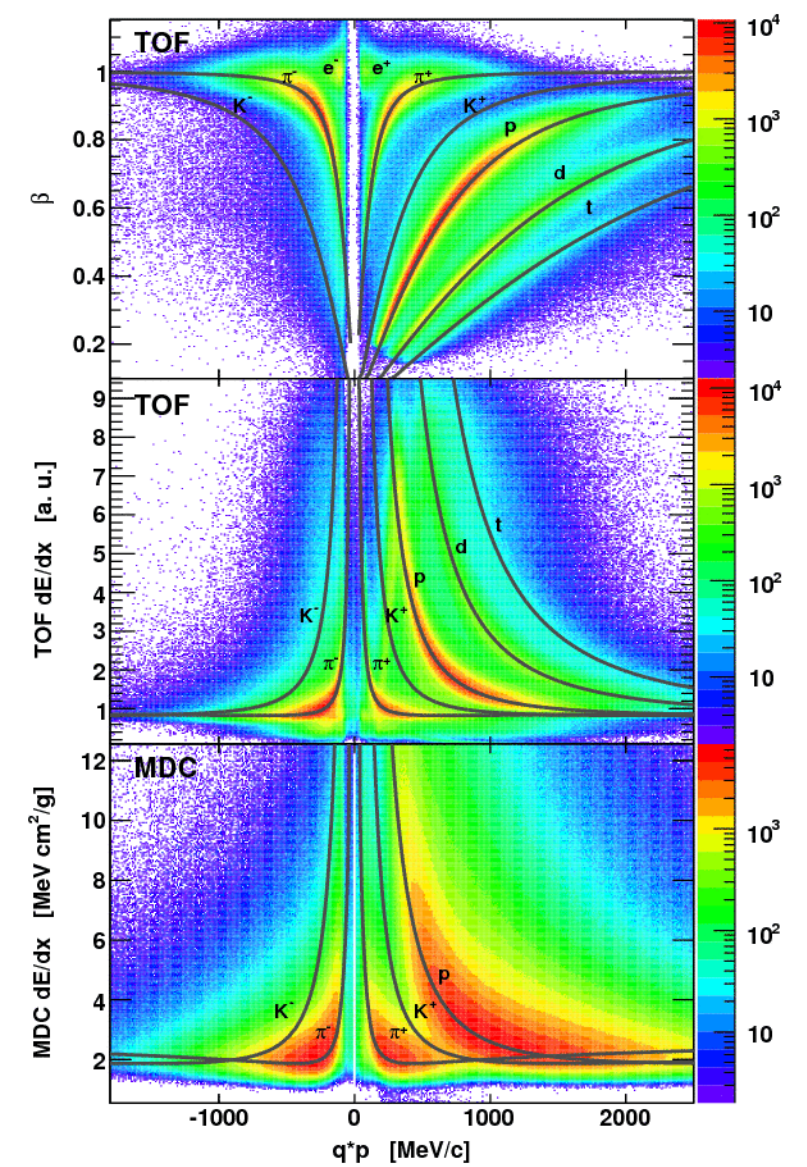
High Acceptance Di-Electron Spectrometer HADES @ SIS18, GSI Darmstadt





- high geometrical acceptance
- particle identification via dE/dx and ToF
- momentum resolution ~ 2-5 %

Particle ID with HADES (I)

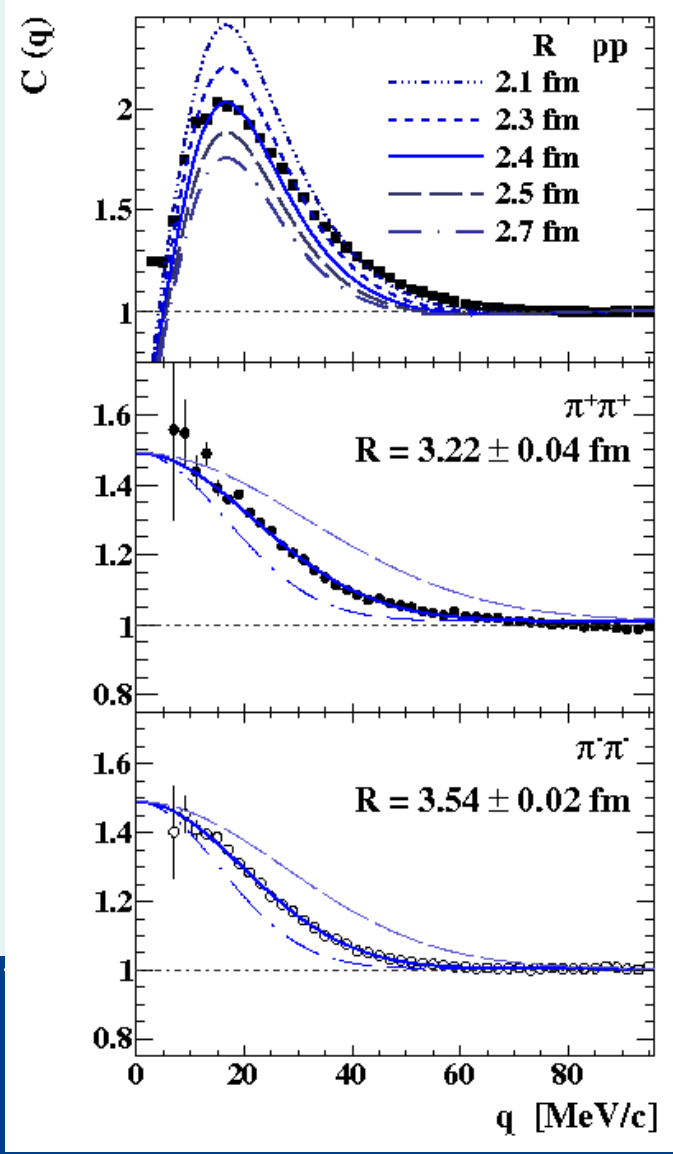


protons and pions well identified

pp and ππ correlations*

curves: Koonin model# for various Gaussian radii

curves: Gaussian fits to Gamov corrected correlation fct. and optimum radius ±1 fm



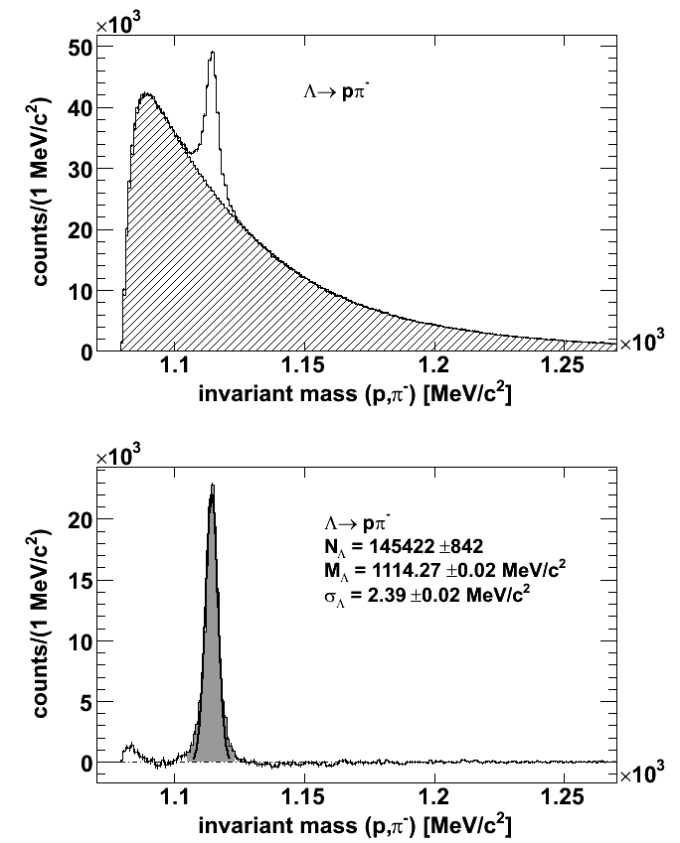
$r_0 = (2.4 \pm 0.1\,^{+0.3}_{-0.1})$ fm

S.E. Koonin, PLB 70 (1977) 43

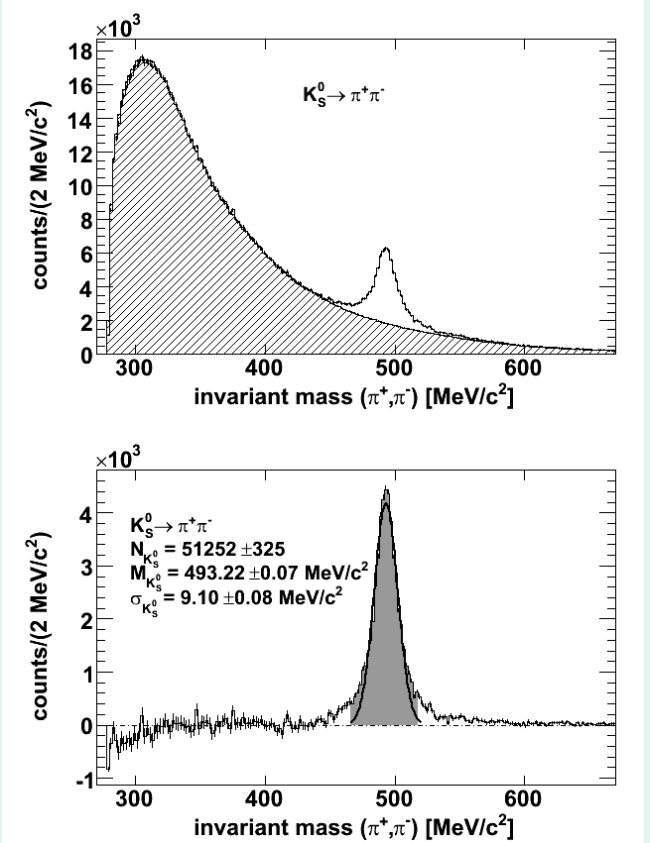
* C. Wendisch, Diploma thesis, Techn. Univ. Dresden, 2009

Particle ID with HADES (II)

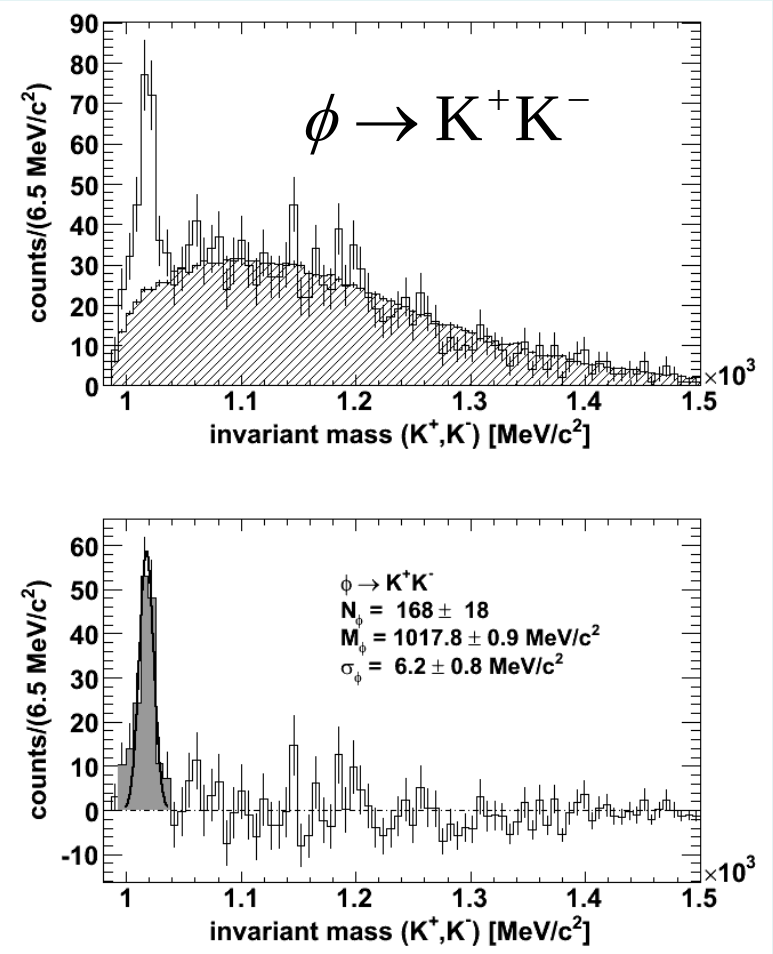
$\Lambda \rightarrow p\pi^-$



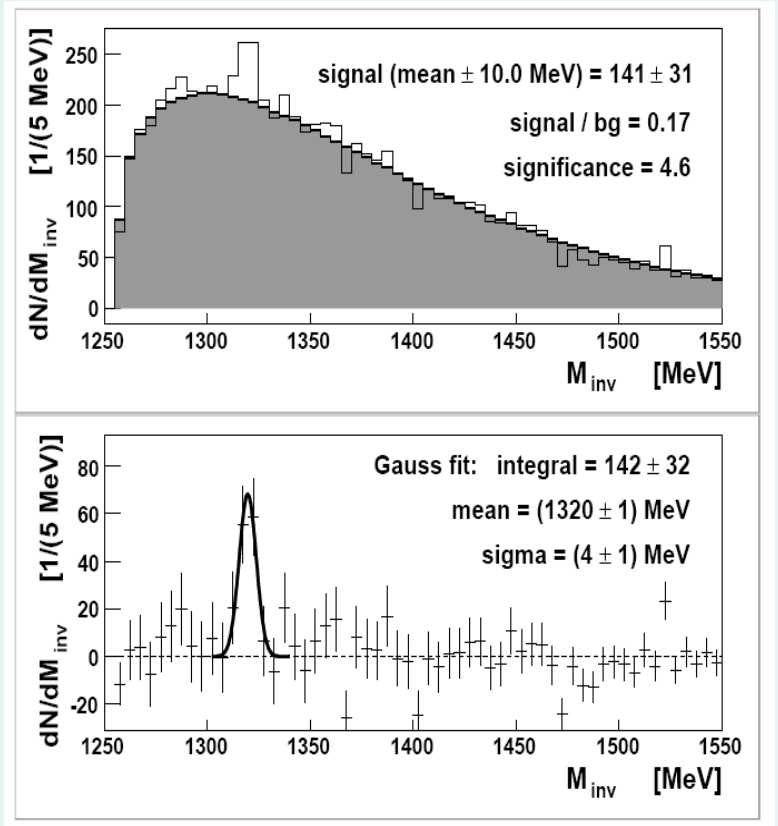
$K_S^0 \rightarrow \pi^+\pi^-$



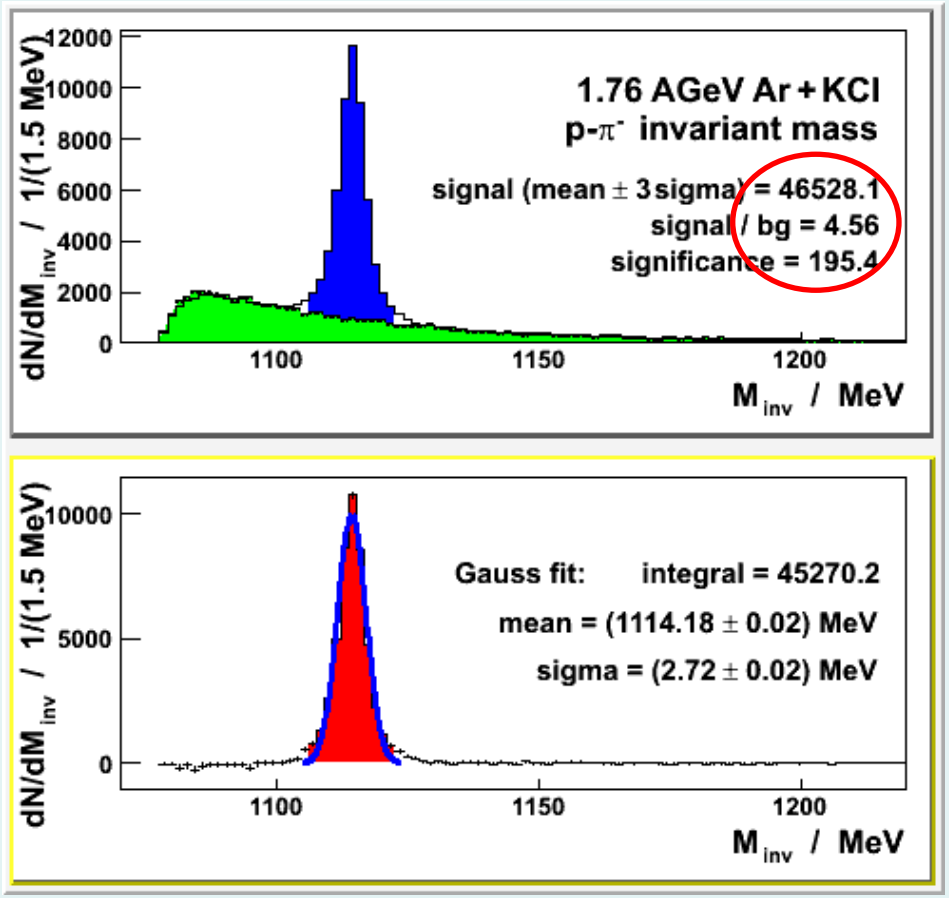
Particle ID with HADES (III)



$\Xi^- \rightarrow \Lambda\pi^-$



Prerequisite of Λp correlation study: An almost pure high-yield Λ sample



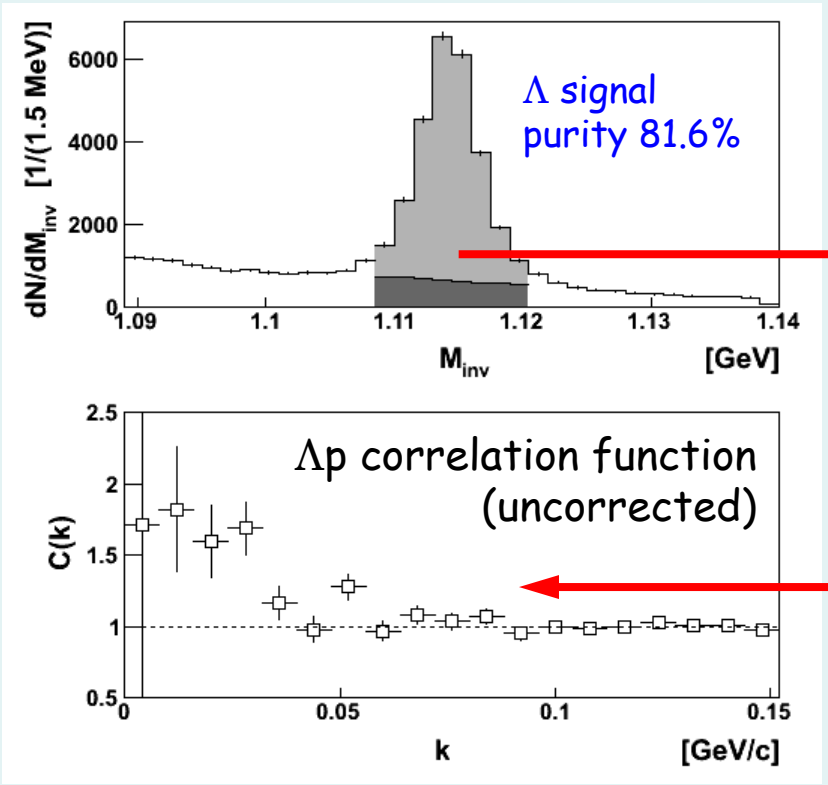
- 700 mio semi-central events (35%, <b>=3.5 fm)
- Λ cuts optimized for large signal/bg ratio

Λ yield:

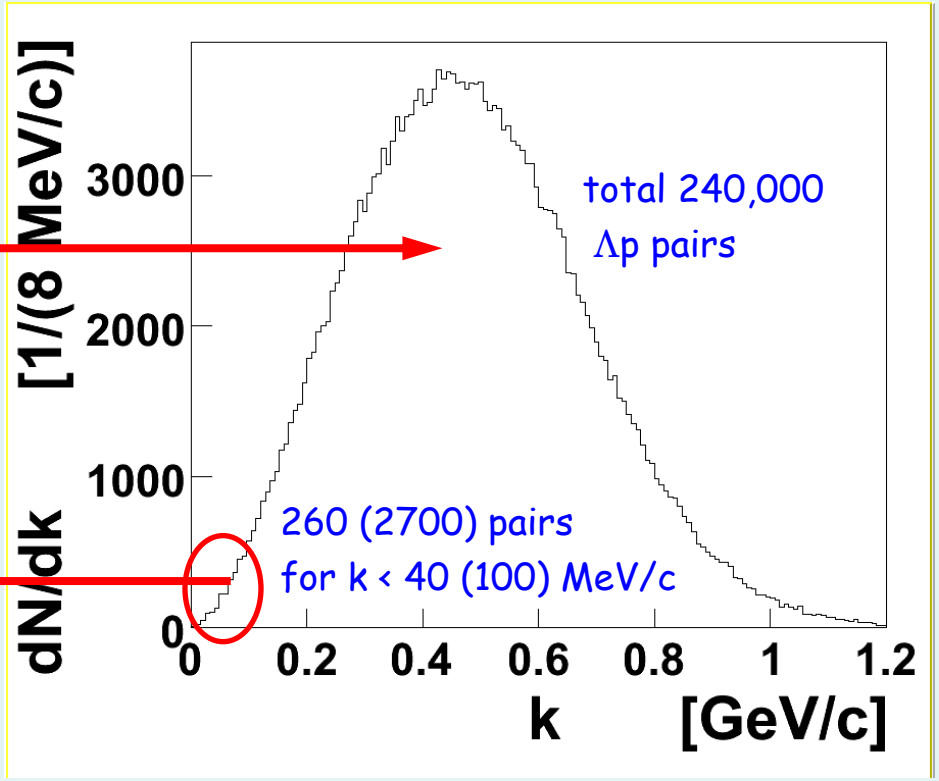
$N_\Lambda = 46528 \pm 566$

Λp correlations – Exp. Data

pπ⁻ invariant mass distribution



Λp relative-momentum distribution

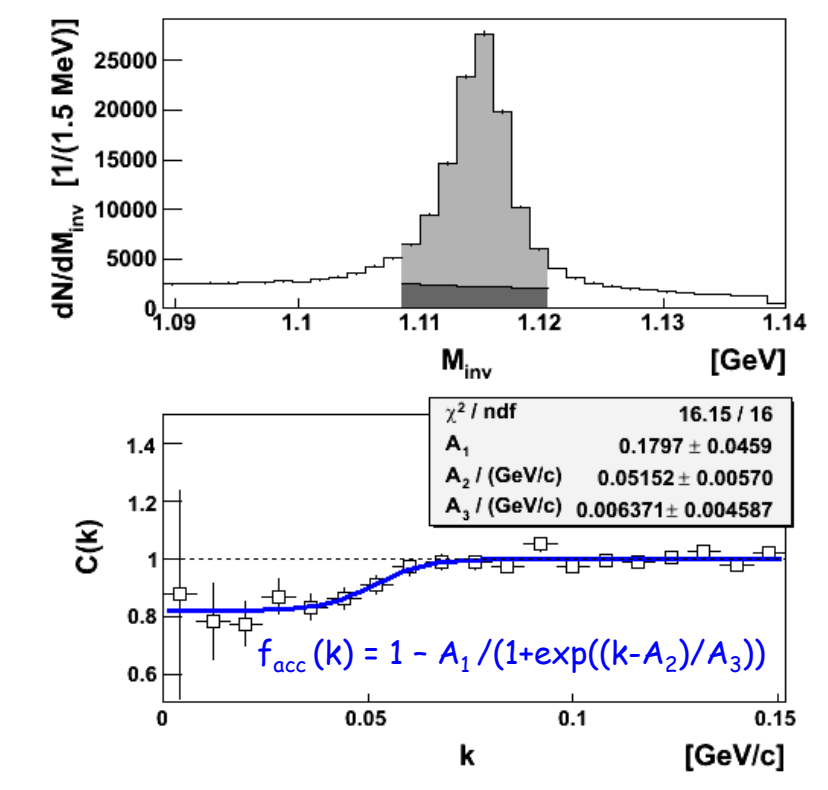


Simulations

- generate 25 million thermal Λ's (T=95 MeV, σ_y=0.42) with PLUTO* event generator (1 Λ/evt)
- run GEANT (HADES detector acceptance, granularity, resolution, etc.) for PLUTO Λ's
- embed GEANT output into exp. data
- analyse like exp. data => correlation function for uncorrelated Λp pairs (Λ: simu, p: exp)

* PoS(ACAT)076 (2007)

Λp correlations - Simulation



simulated Λ's (decay products embedded into exp. data)

flat Λp correlation expected:

apparent negative correlation
(due to finite near-track resolution)
used for correction of exp. CF

Corrections to the experimental Λp correlation function

- close-track correction: $C(k) \Rightarrow C(k)/f_{acc}(k)$

  fit to CF of simulated Λ's embedded into exp. data (A_1=0.180 ± 0.046)

- purity correction: $C(k) \Rightarrow 1 + (C(k)-1)/\text{PairPurity}$

PairPurity = LambdaPurity * ProtonPurity (0.95 ± 0.02)

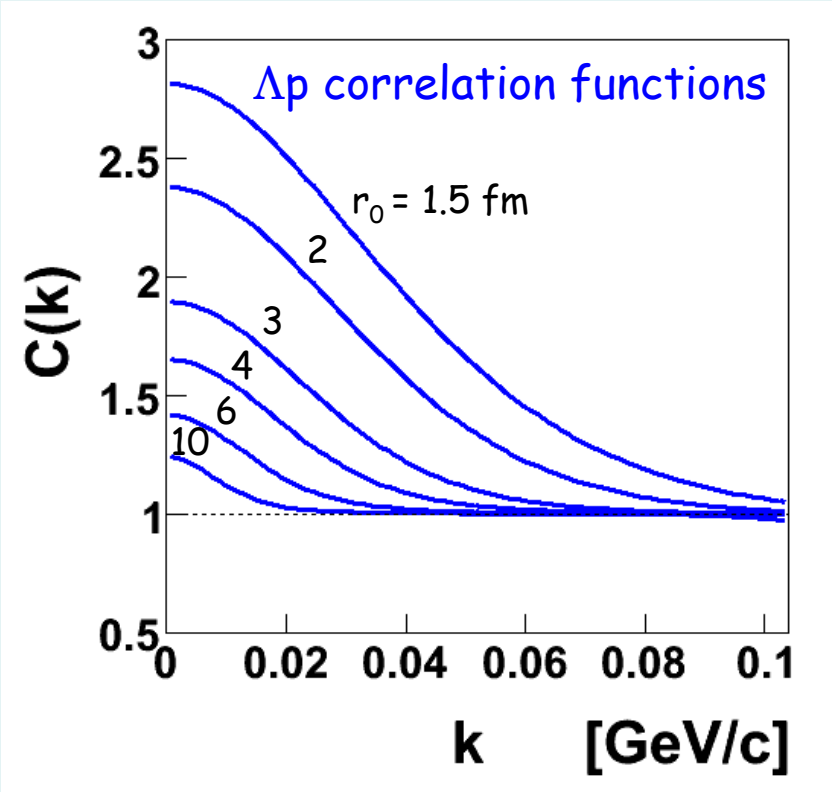
LambdaPurity = LambdaSignalPurity * PrimaryLambda

LambdaSignalPurity = 0.816 ± 0.013 <= $p\pi^-$ inv. mass distr.

PrimaryLambda = 0.90 ± 0.10 <= 20% feeding from Σ^0 (UrQMD)
50% loss of $\Sigma^0 p$ corr. after $\Sigma^0 \rightarrow \Lambda\gamma$

The Analytical Model by Lednicky and Lyuboshitz[#]

Variation of Gaussian source radius:

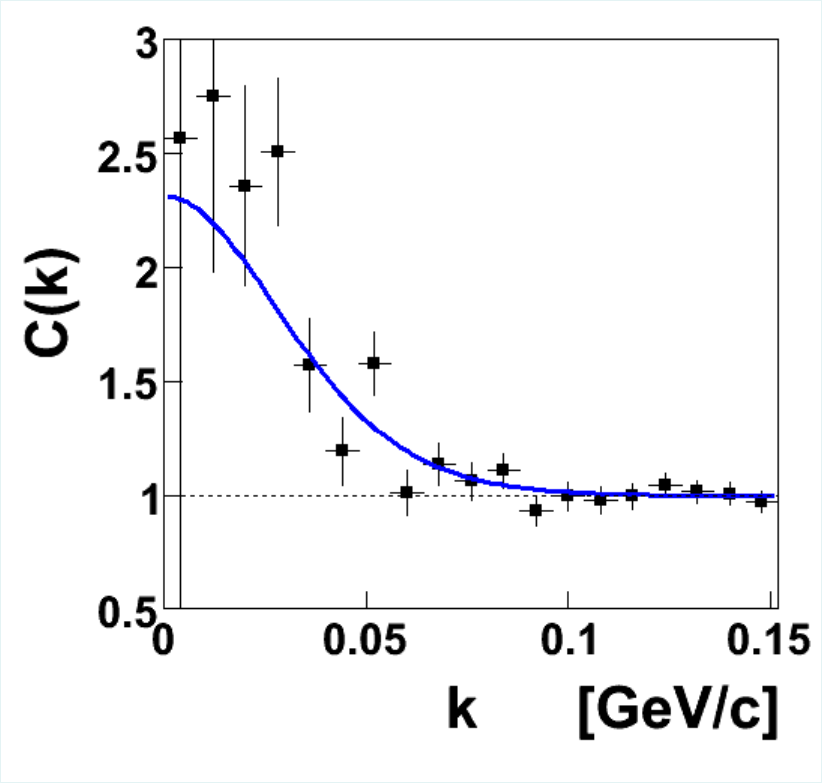


r_0: the only free parameter

=> radius affects both height AND width of CF

[#] R. Lednicky, V.L. Lyuboshitz, Sov. J. Nucl. Phys. 35 (1982) 770; see: J. Adams et al. (STAR), PRC 74 (2006) 064906

Close-track resolution and purity corrected Λp correlation function - Fit with Lednicky Analytical Model



maximum likelihood* =>

$$r_0 = (2.09 \pm 0.16\ ^{+0.12}_{-0.10}\ ^{+0.09}_{-0.16}\ ^{+0.09}_{-0.11})\ \text{fm}$$

syst. errors:

#1: uncertainty of close-track correction

#2: uncertainty of purity correction

#3: variation of scattering lengths (in model) by ±25%

* L. Ahle et al. (E802), PRC 66 (2002) 054906

Varying the whole set of scattering lengths and effective ranges + Fit with Lednicky Analytical Model

	singlet		triplet		
parameter / data set	f_0^s [fm]	d_0^s [fm]	f_0^t [fm]	d_0^t [fm]	r_0 [fm]
EFT '06 [1]	-1.91	1.39	-1.23	2.16	2.13±0.15
Jülich '04 [1]	-2.56	2.75	-1.66	2.93	2.15±0.15
Nijmegen NSC97f [1]	-2.51	3.03	-1.75	3.32	2.11±0.15
Wang & Pratt [2]	-2.88	2.92	-1.66	3.78	2.09±0.16

quite similar source radii => Λp correlation function hardly sensitive to specifics of Λp potential

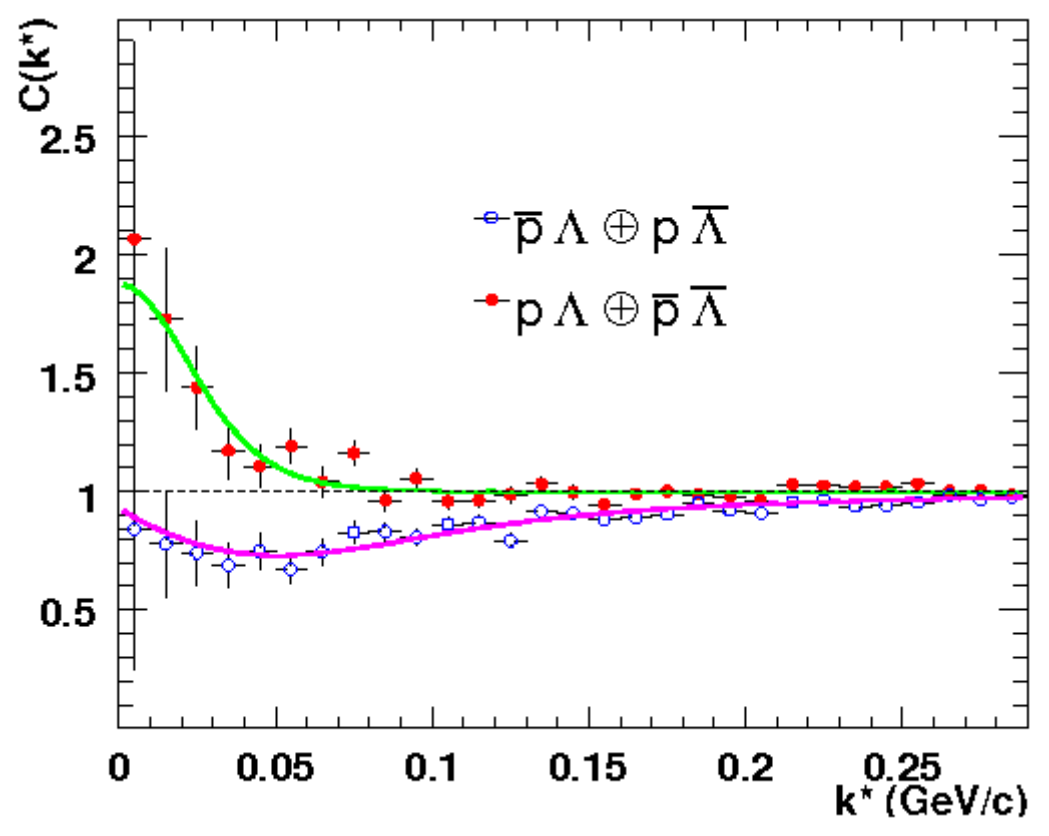
⇑

results of maximum likelihood fit

[1] J. Haidenbauer et al., Lect. Notes Phys. 724 (2007) 113
[2] F. Wang and S. Pratt, PRL 83 (1999) 3138

Comparison with RHIC data*

Central (10%) Au+Au @ $\sqrt{s_{NN}}$ = 200 GeV



Lines: fits with Analytical Model by Lednicky and Lyuboshitz#

$r_0 = (3.1 \pm 0.3 \pm 0.2)$ fm

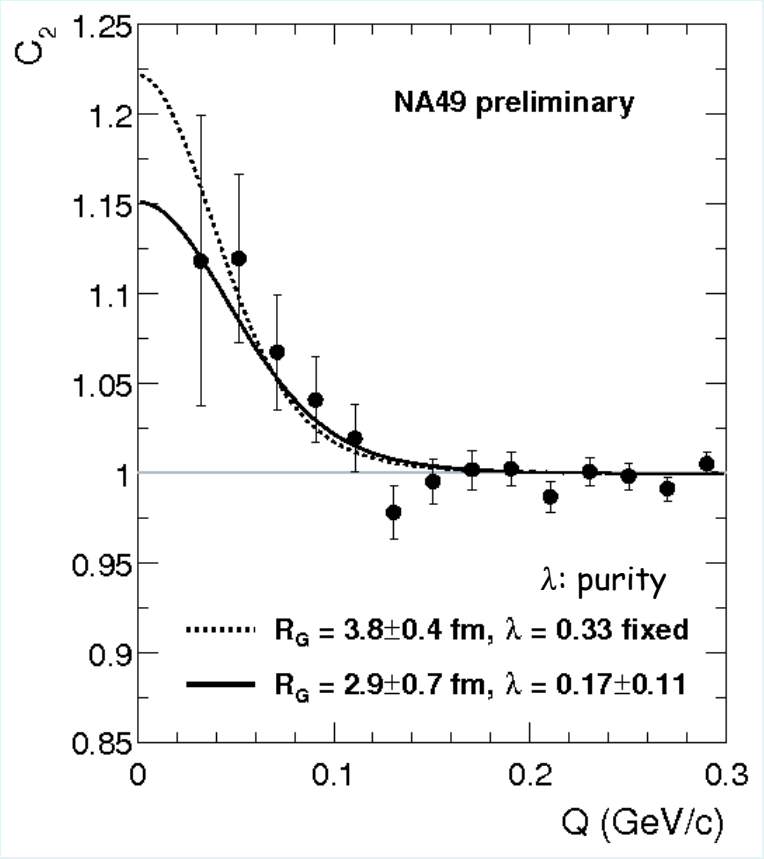
($k^* = |\mathbf{p}_1 - \mathbf{p}_2|/2$ in pair c.m. frame)

R. Lednicky and V.L. Lyuboshitz, Sov. J. Nucl. Phys. 35 (1982) 770

* J. Adams et al. (STAR), PRC 74 (2006) 064906

Comparison with SPS data*

Central (10%) Pb+Pb @ 158 AGeV



Lines: fits with Analytical Model by Lednicky and Lyuboshitz#

r_0 = 3 - 4 fm

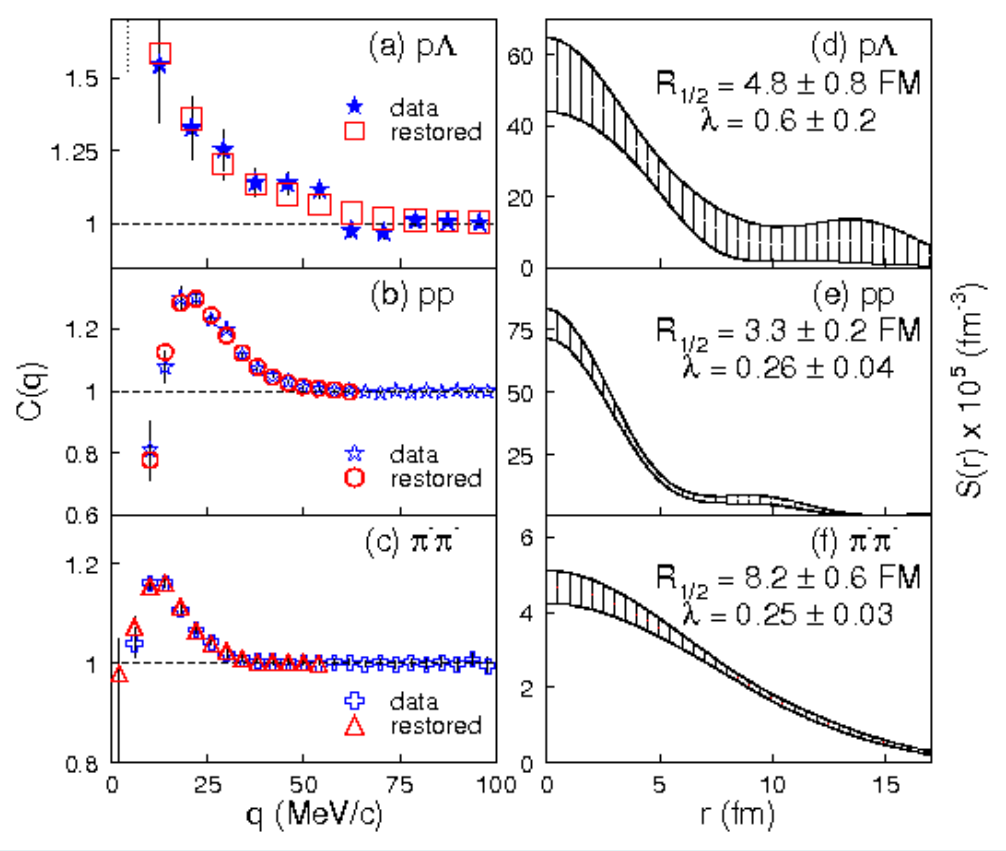
(Q=|$\mathbf{p}_1$-$\mathbf{p}_2$| in pair c.m. frame)

R. Lednicky and V.L. Lyuboshitz, Sov. J. Nucl. Phys. 35 (1982) 77

* C. Blume et al. (NA49), Proc. Quark Matter 2002, Nantes, France, NPA 715 (2003) 55c

Comparison with AGS data*

Semi-central (23%) Au+Au @ 6 AGeV



left: correlation functions (CFs)

right: imaged sources by numerical inversion of CF

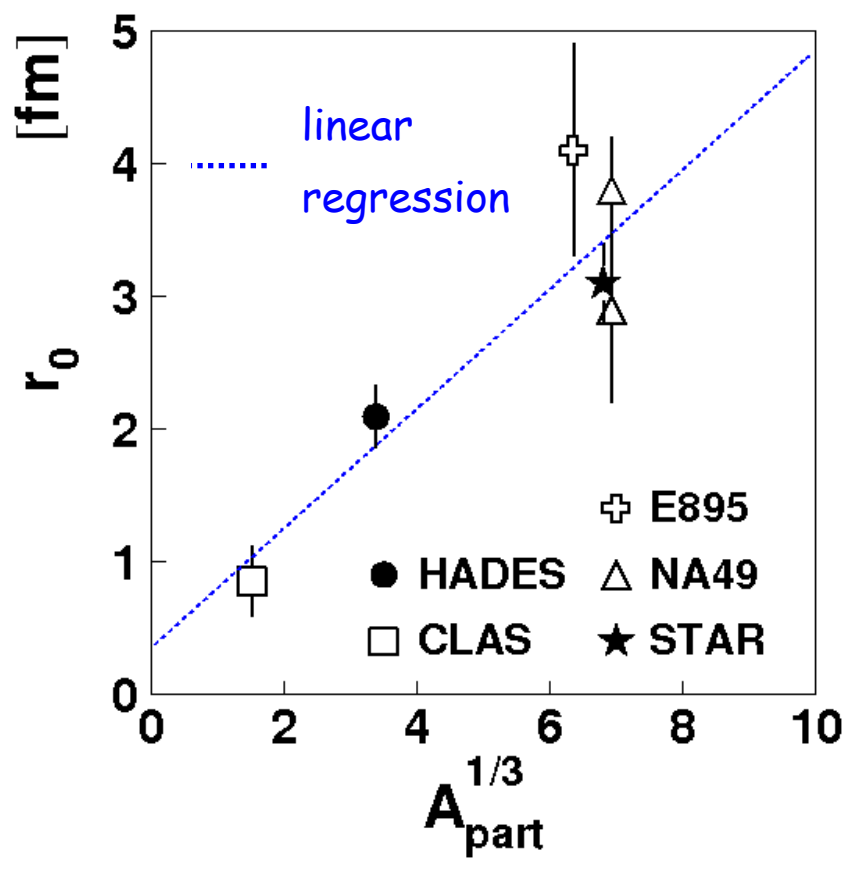
$R_{1/2}$: half-maximum radius

=> $r_0(p\Lambda) = (4.1 \pm 0.7)$ fm

($q=|\mathbf{p}_1-\mathbf{p}_2|/2$ in pair c.m. frame)

* P. Chung et al. (E895), PRL 91 (2003) 162301

System-size dependence of Λp source radius



E895: Au+Au [PRL 91 (2003) 162301]

NA49: Pb+Pb [NPA 715 (2003) 55c]

STAR: Au+Au [PRC 74 (2005) 064906]

CLAS: e+^{3,4}He [Phys. Atom. Nucl. 72 (2009) 668]

HADES: Ar+KCl (note the precision!)

=> almost linear increase

Summary

- first time at SIS energies (Ar+KCl @ 1.76 AGeV): Λp correlations*
- prerequisite: high-yield and high-purity Λ sample
- comparison to model by Lednicky & Lyuboshitz

  => Gaussian radius of Λp emission source

$$r_0 = (2.09 \pm 0.16\,^{+0.17}_{-0.22})\ \text{fm}$$

- Λp correlation function hardly sensitive to specifics of Λp potential
- r_0 slightly smaller than pp correlation radius
- Λp radius in Ar+KCl smaller than in Au+Au/Pb+Pb but larger than in e+He => linear increase of r_0 with $A_{part}^{1/3}$

* G. Agakishiev et al., PRC 82 (2010) 021901

The HADES collaboration

Catania (INFN - LNS), Italy
Coimbra (Univ.), LIP, Portugal
Cracow (Univ.), Poland
Darmstadt (GSI), Germany
Dresden (FZD), Germany
Dubna (JINR), Russia
Frankfurt (Univ.), Germany
Giessen (Univ.), Germany
Milano (INFN, Univ.), Italy
Moscow (ITEP,MEPhI,RAS), Russia
Munich (TUM), Germany
Nicosia (Univ.), Cyprus
Orsay (IPN), France
Rez (CAS, NPI), Czech Rep.
Sant. de Compostela (Univ.), Spain
Valencia (Univ.), Spain