Exploring the Potential of Antibaryons in Nuclei with Antiprotons

Josef Pochodzalla and the PS185 Collaboration

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- motivation
- proposed method
- PS185 data
- outlook

J.P. , Physics Letters **B** 669 (2008) 306–310

PS185 data thanks to Stephan Pomp & Tord Johansson

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5 decades of hyperons in neutron stars

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

NEUTRON STAR MODELS

A. G. W. Cameron
Atomic Energy of Canada Limited, Chalk River, Ontario, Canada
Received June 17, 1959

Another reason why the writer has not taken into account complications inherent in using a relativistic equation of state is that no such things as pure neutron stars can be expected to exist. The neutrons must always be contaminated with some protons and sometimes with other kinds of nucleons (hyperons or heavy mesons).

- Alastair G.W. Cameron, Astrophysical Journal, vol. 130, p.884 (1959)

Hyperons in neutron stars (2008)

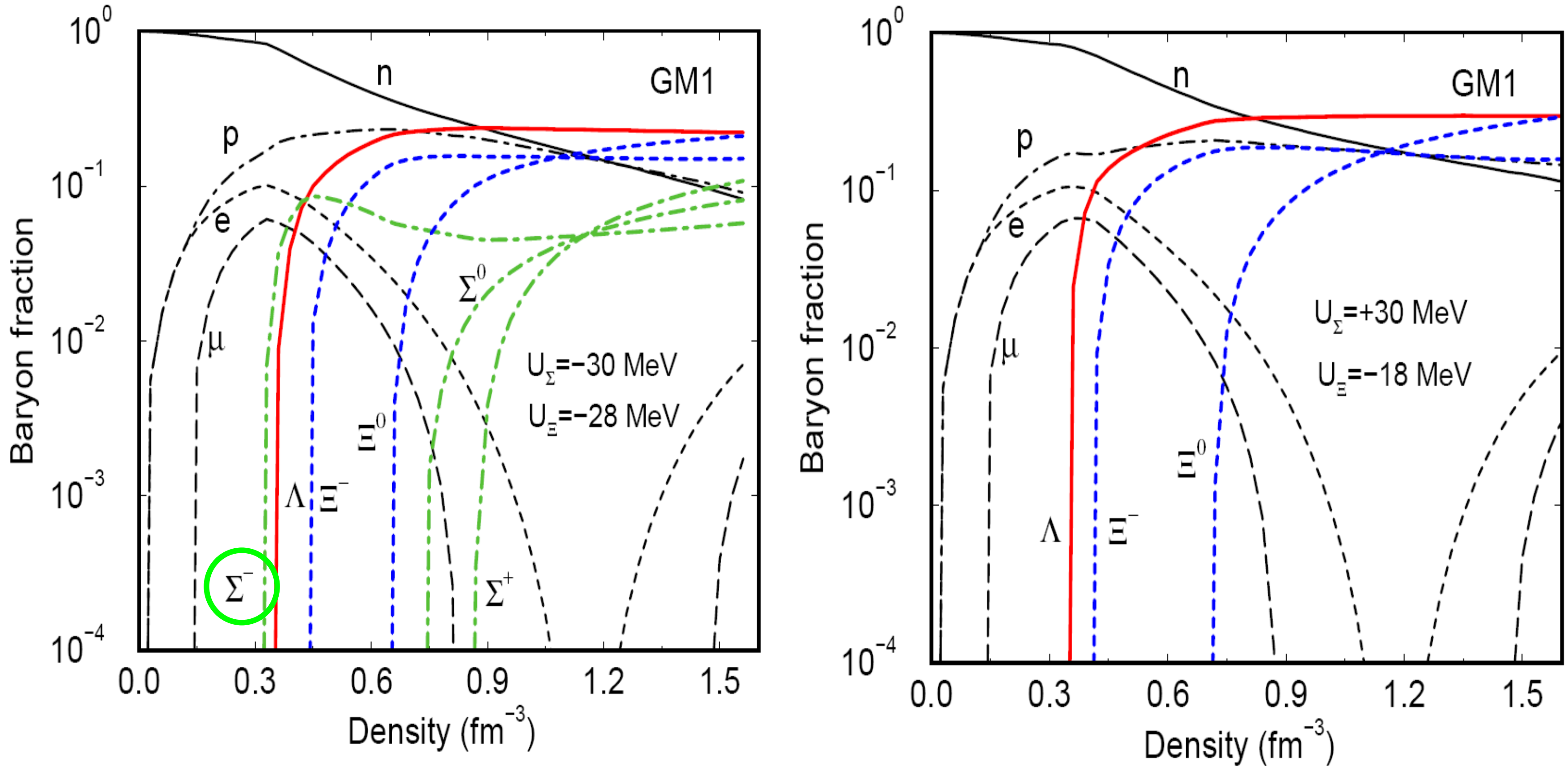
- Haris Djapo, Bern-Jochen Schäfer and Jochen Wambach
  arXiv:0811.2939v1 [nucl-th] 18 Nov 2008

In conclusion, irrespective of the YN interactions, incompressibility and symmetry parameter used, hyperons will appear in dense nuclear matter at densities around $\sim 2\rho_0$. This immediately leads to a softening of the EoS which in turn results in a smaller maximum mass of a neutron star. Notably, the predicted maximum masses of

nuclear matter. With the prediction of a low onset of hyperon appearance it becomes practically impossible to ignore strangeness when considering neutron stars. Even though the prediction for the maximum masses of neutron stars are too low, the appearance of hyperons in neutron stars is necessary and any approach to dense matter must address this issue.

Baryon stars

- Input: Baryons in chemical Equilibrium, conservation laws, interaction

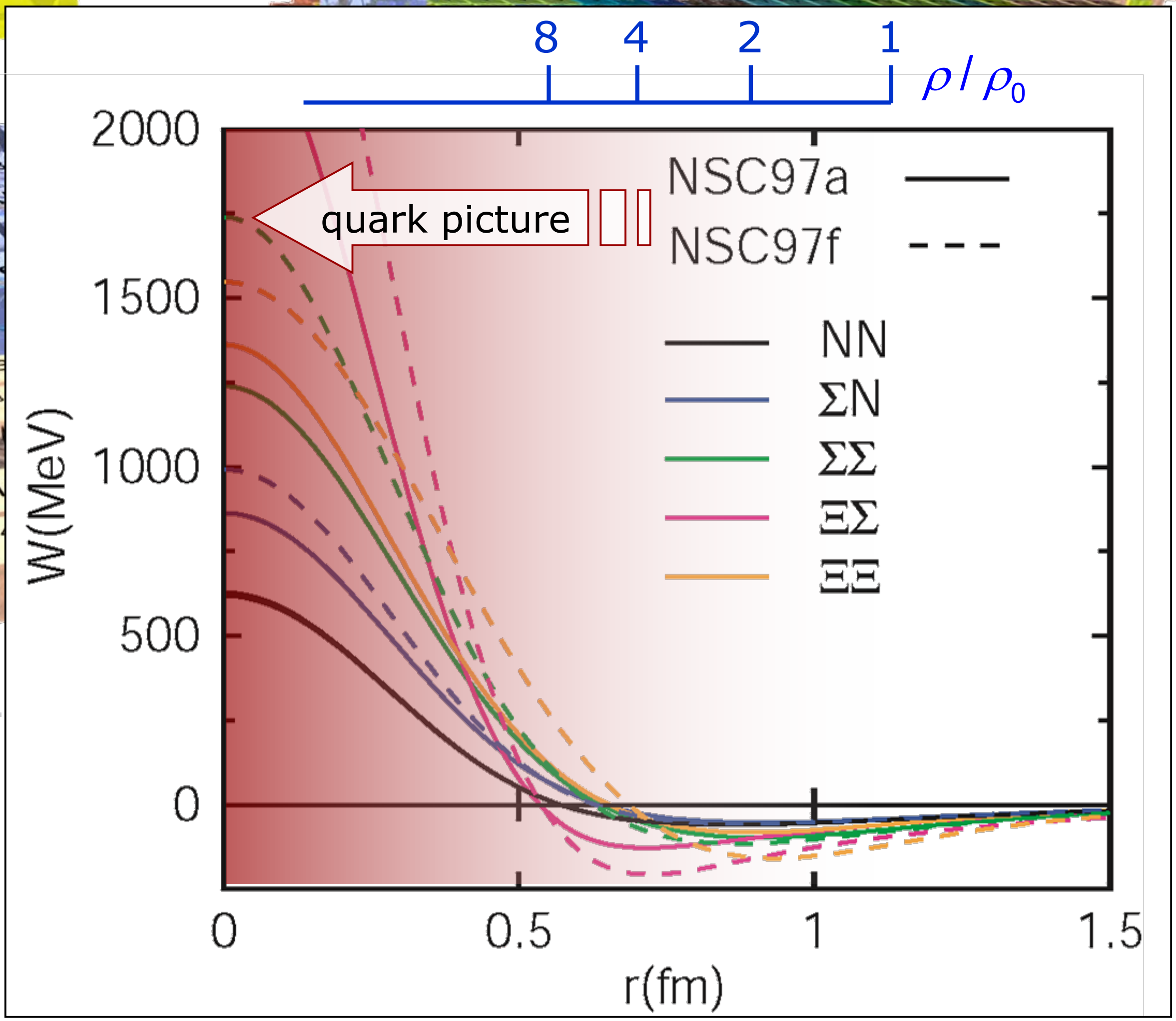


N. K. Glendenning, Phys. Rev. C **64**, 025801 (2001)

- beyond $2\rho_0$ hyperons may play a significant role in neutron stars
- in the core hyperons may even be more abundant than neutrons

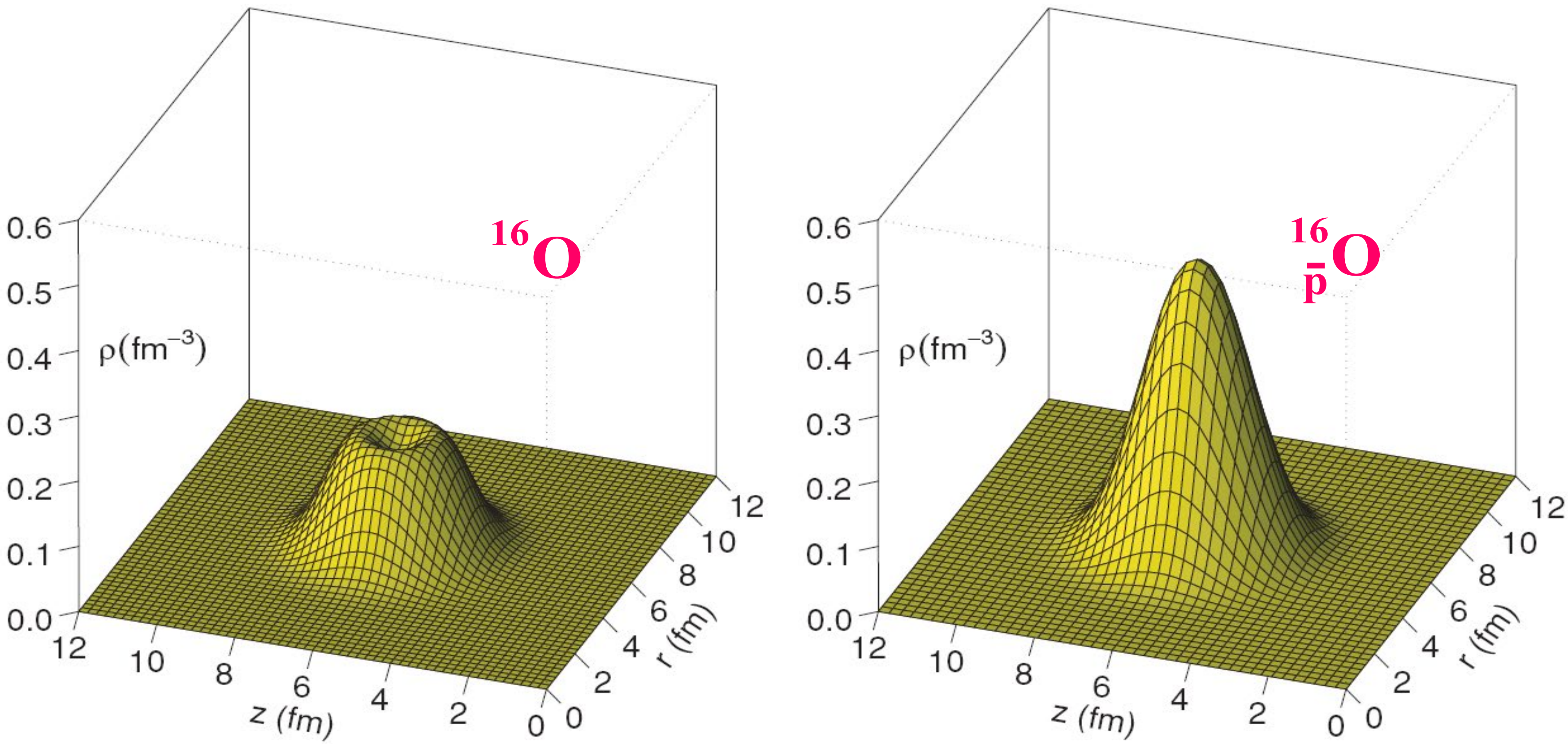
- needed: BB interaction at high density= at small distances

The present nuclear chart



Why do antihyperons in matter matter?

- strong cold compression $\Rightarrow$ color degrees of freedom might become very important
  - I.N. Mishustin *et al*., PRC 71, 035201 (2005)



Elastic Antiproton-Nucleus Scattering

Elastic Scattering of Antiprotons from Complex Nuclei*

GERSON GOLDHABER† AND JACK SANDWEISS‡

Physics Department and Radiation Laboratory, University of California, Berkeley, California

(Received May 5, 1958)

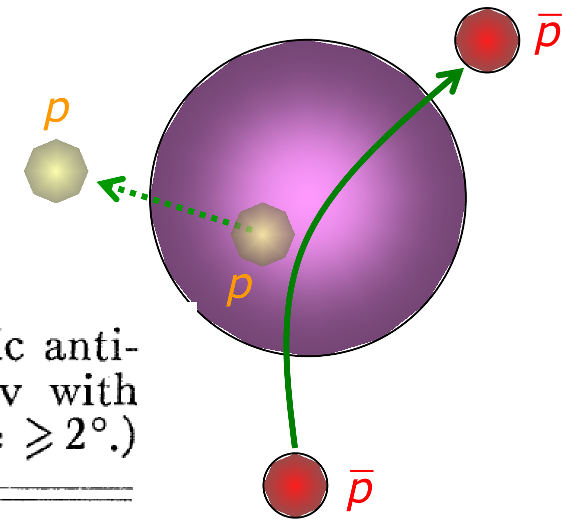
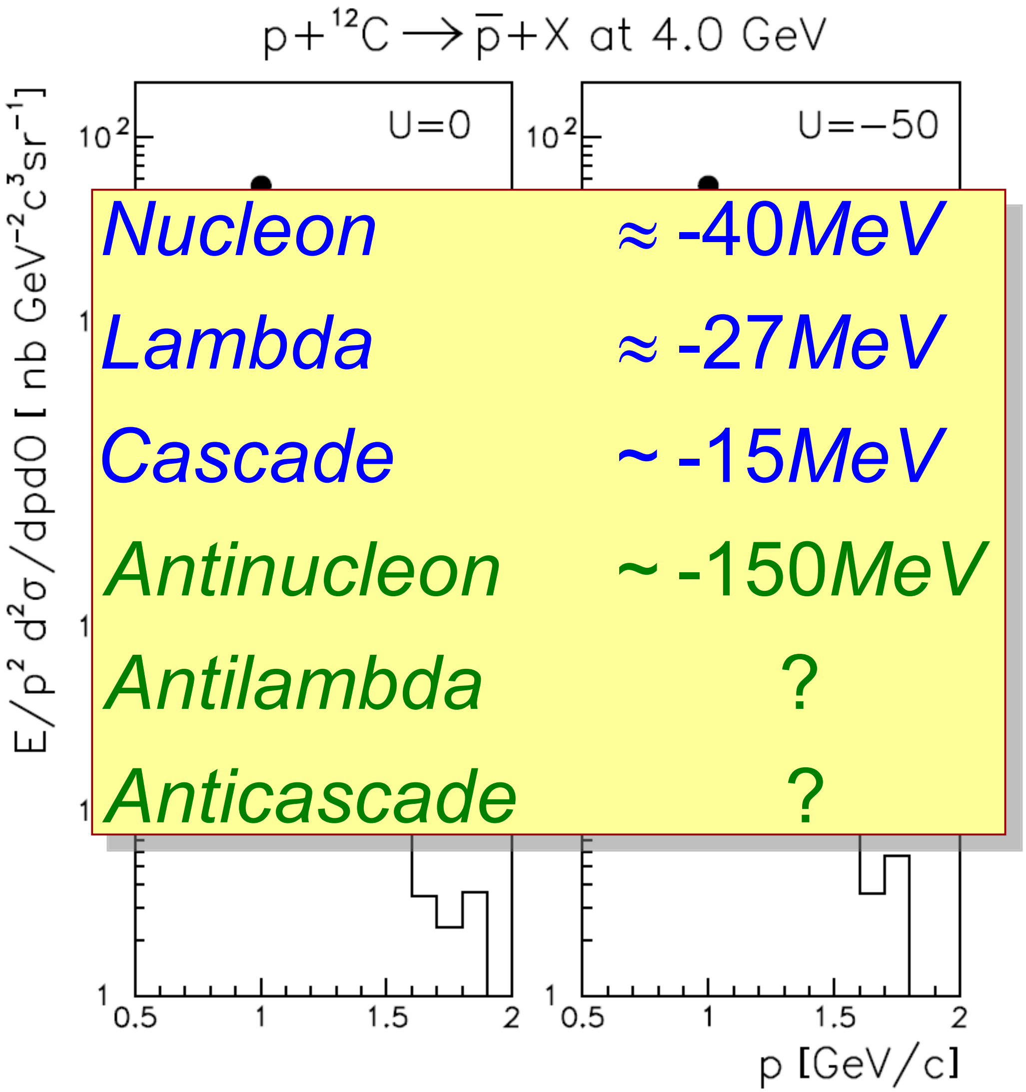


TABLE III. Comparison of experimental data for elastic antiproton-nucleus scattering of energy $T_{\bar{p}}=80$ to 200 Mev with Glassgold's calculations at $T_{\bar{p}}=140$ Mev. (Projected angle $\gtrsim 2°$.)

Angular interval (degrees)	Experimental ($T_{\bar{p}}=80$ to 200 Mev)	Number of events: Calculated for potential[a] $V=-15$ Mev $W=-50$ Mev	Calculated for potential[a] $V=-528$ Mev $W=-50$ Mev
2–6	54	56	71
6–12	20	17.1	24
12–24	5	4.3	10
24–180	1	1.4	9.5
2–180	80	78.8	114.5

Antiprotonproduction in HI Collisions

- see e.g.
  - A. Sibirtsev, W. Cassing *et al*., Nucl. Phys. A **632**, 131 (1998)
  - C. Spieles *et al*., Phys. Rev. C **53**, 2011-2013 (1996)



Nucleon	$\approx$ -40*MeV*
Lambda	$\approx$ -27*MeV*
Cascade	~ -15*MeV*
Antinucleon	~ -150*MeV*
Antilambda	?
Anticascade	?

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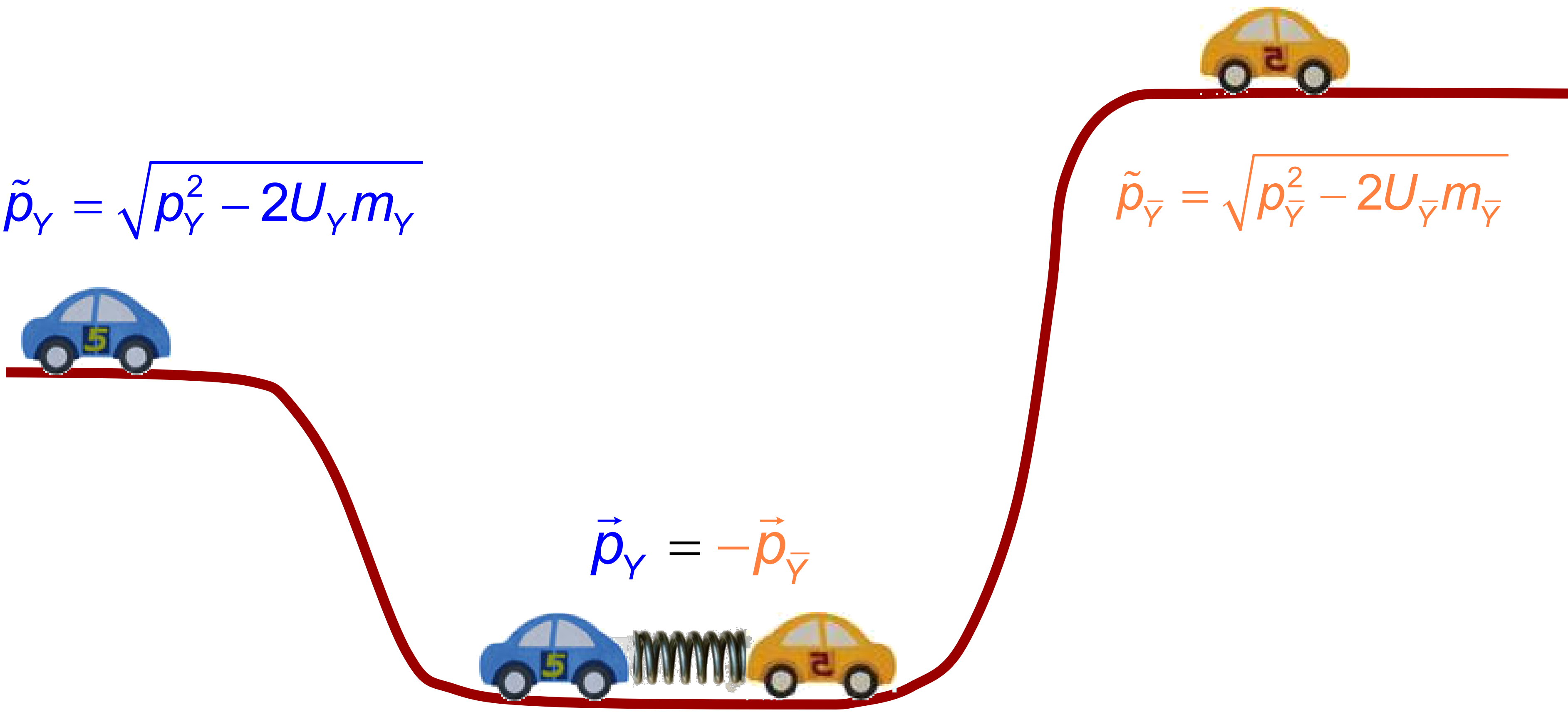
How to measure a potential (difference)



$$\tilde{p}_Y = \sqrt{p_Y^2 - 2U_Y m_Y}$$

$$\tilde{p}_{\bar{Y}} = \sqrt{p_{\bar{Y}}^2 - 2U_{\bar{Y}} m_{\bar{Y}}}$$

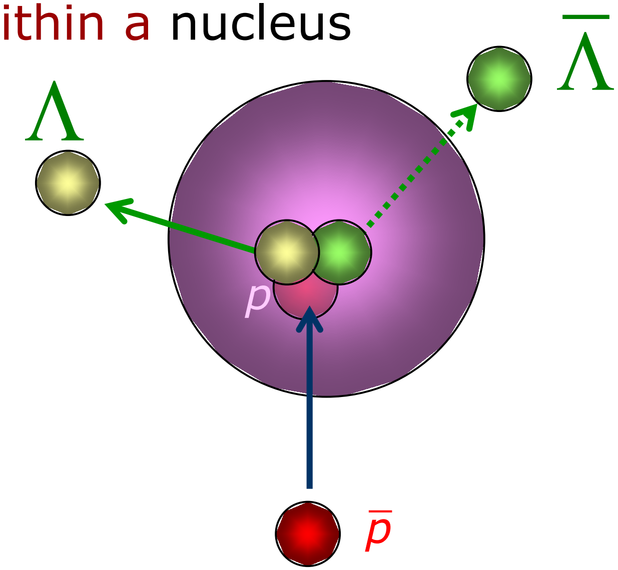
$$\vec{p}_Y = -\vec{p}_{\bar{Y}}$$

- If $m_Y \approx m_{\bar{Y}} \approx m$ and $U_Y \approx U_{\bar{Y}} \approx U \Rightarrow$

$$\alpha = \frac{\tilde{p}_Y - \tilde{p}_{\bar{Y}}}{\tilde{p}_Y + \tilde{p}_{\bar{Y}}} = \frac{\sqrt{p_0^2 - 2m_Y U_Y} - \sqrt{p_0^2 - 2m_{\bar{Y}} U_{\bar{Y}}}}{\sqrt{p_0^2 - 2m_Y U_Y} + \sqrt{p_0^2 - 2m_{\bar{Y}} U_{\bar{Y}}}} \approx \frac{U_{\bar{Y}} - U_Y}{4\left(\frac{p_0^2}{2m} - U\right)} \approx \frac{U_{\bar{Y}} - U_Y}{4E_{kin}}$$

Can we measure the potential for $\bar{Y}$?

- antiprotons are optimal for the production of mass without large momenta
- consider $p+\bar{p}$ ® $Y+\bar{Y}$ close to threshold within a nucleus
- Λ and $\bar{\Lambda}$ that leave the nucleus will have different asymptotic momenta depending on the respective potential

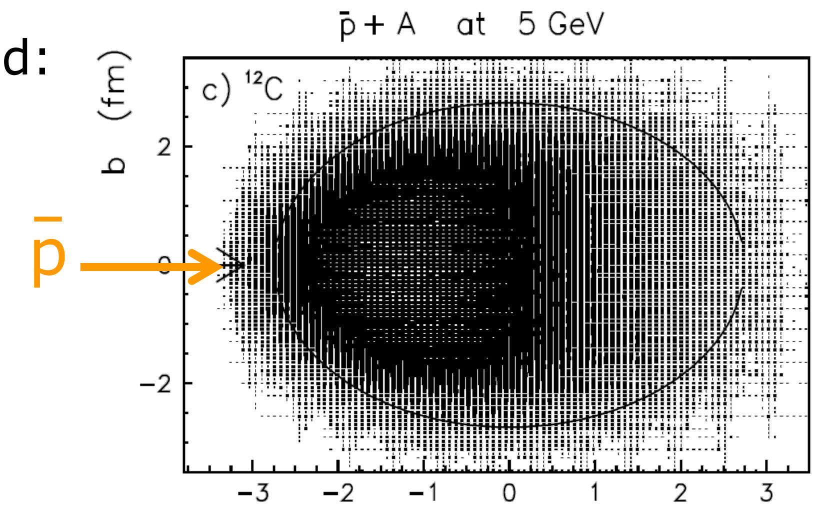


- experimental complications
  - Fermi motion of struck proton
  - Non-isotropic production
  - Density distribution $U(\rho)$
  - Exclusiveness

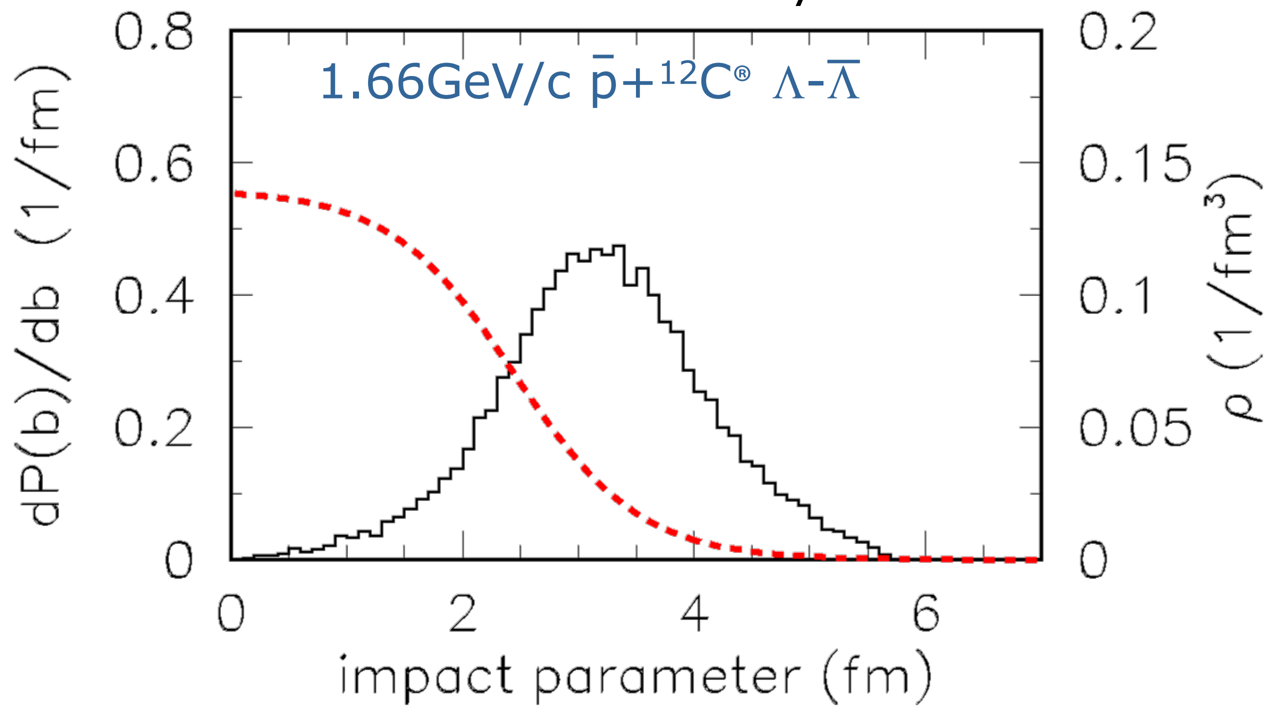
$\Rightarrow$ need to look at average *transverse* momentum close to threshold of *coincident* $Y\bar{Y}$ pairs

Annihilation Zone

- Anti-baryons are strongly absorbed:
  - $\bar{p}$: 50 mb
  - Λ: 20 mb
  - $\bar{\Lambda}$: 100 mb/(1+$p_{\bar{\Lambda}}$/GeV)
- Emission of $\Lambda\bar{\Lambda}$ pair is anisotropic in center-of-mass
- Coincident detection of Λ and $\bar{\Lambda}$ constraints annihilation points
- Creation zone is sensitive to density distribution



Sibirtsev *et al*



The potentials

- Fermi momentum p_F=220MeV/c
- Λ, $\bar{\Lambda}$ angular distribution of free events $\bar{p}$+p® $\Lambda+\bar{\Lambda}$
- Potentials and propagation

$$(E-V)^2=(M_0+S)^2+\vec{P}_{in}^2$$

$$\vec{P}_{out}^2+M_0^2=\left(\sqrt{(M_0+S)^2+\vec{P}_{in}^2}+V\right)^2$$

  - Momentum independent

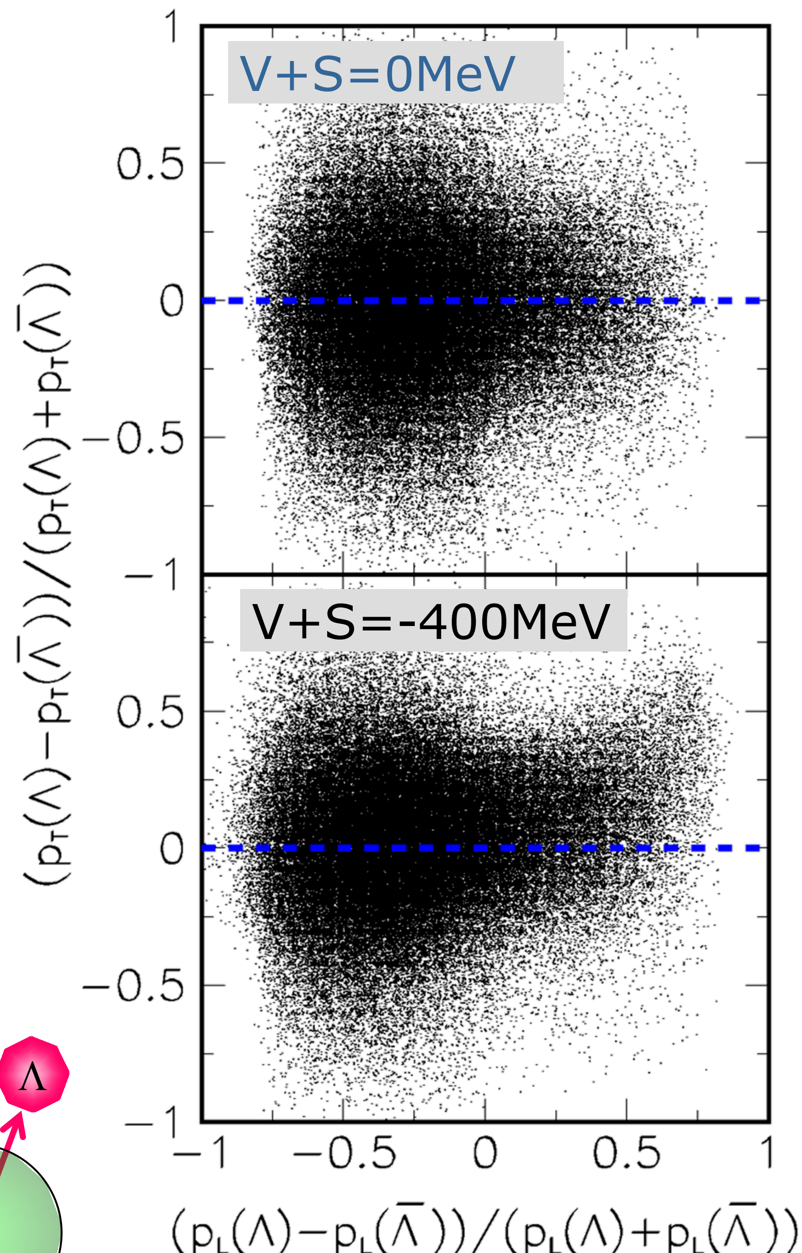
Potential at ρ_0	p	$\bar{p}$	Λ
V [MeV]	300	200	200
S [MeV]	-342	-342	-228
V+S [MeV]	-42	-142	-28

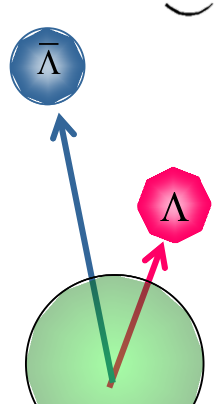
  - Potentials scaled linearly with local nucleon density
  - No compression by the presence of the Y and $\bar{Y}$
  - Potentials act instantaneously at the $\bar{p}$ annihilation time

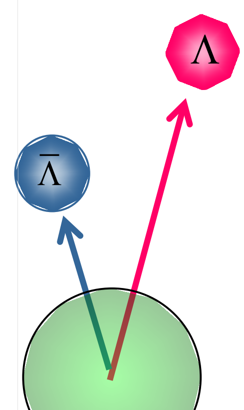
Transverse Momentum Correlations

$$\alpha_T = \frac{p_T^{\Lambda} - p_T^{\bar{\Lambda}}}{p_T^{\Lambda} + p_T^{\bar{\Lambda}}}$$

- $\langle \alpha_T \rangle \equiv 0$ for elementary reaction $\bar{p}+p \rightarrow \bar{\Lambda}+\Lambda$

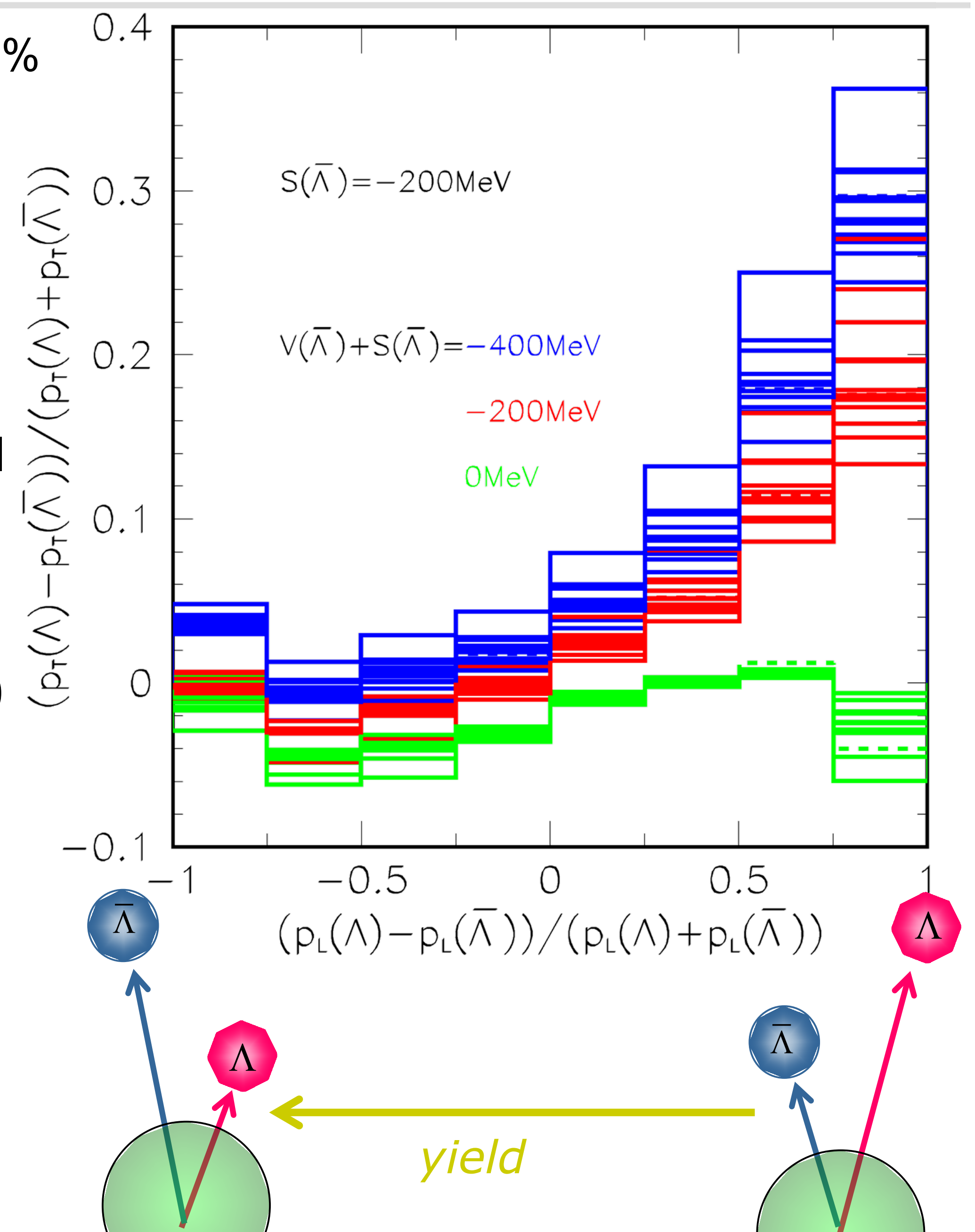






Parameter Scan

- Parameter variation by ±50%
  - Other potentials ($p,\bar{p},\Lambda$)
  - absorption cross sections
  - angular distribution
  - diffuseness
- Transverse asymmetry mainly determined by total potential
- Effect largest for backward emitted $\bar{\Lambda}$
- α_T non-zero even if V+S=0



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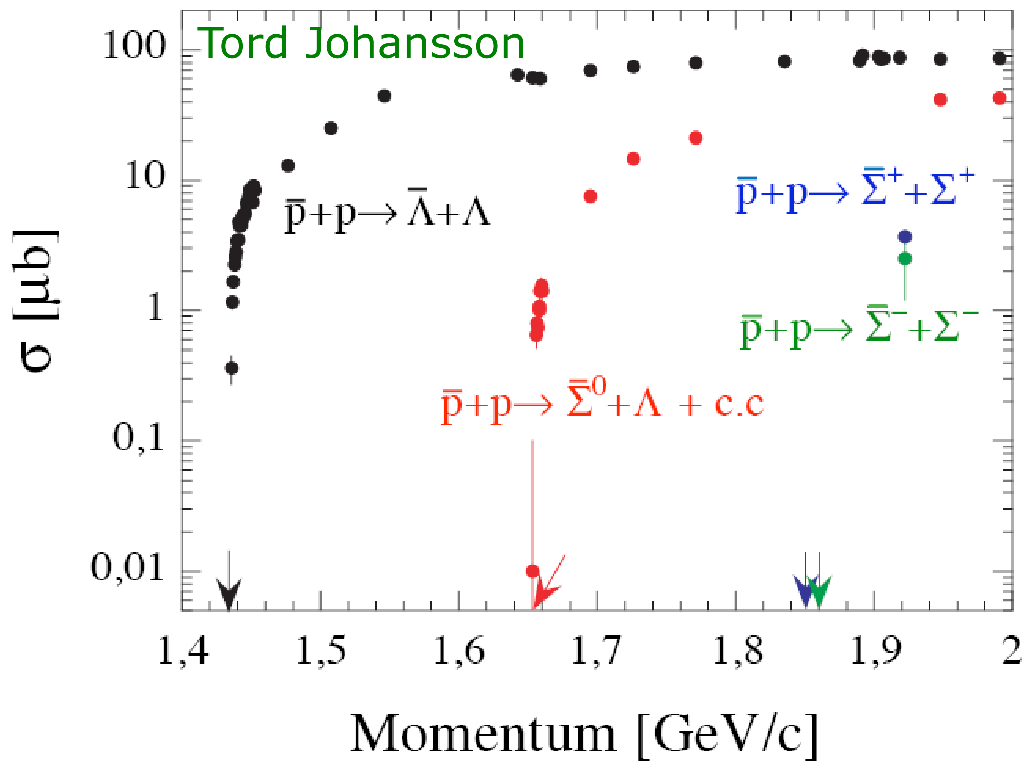
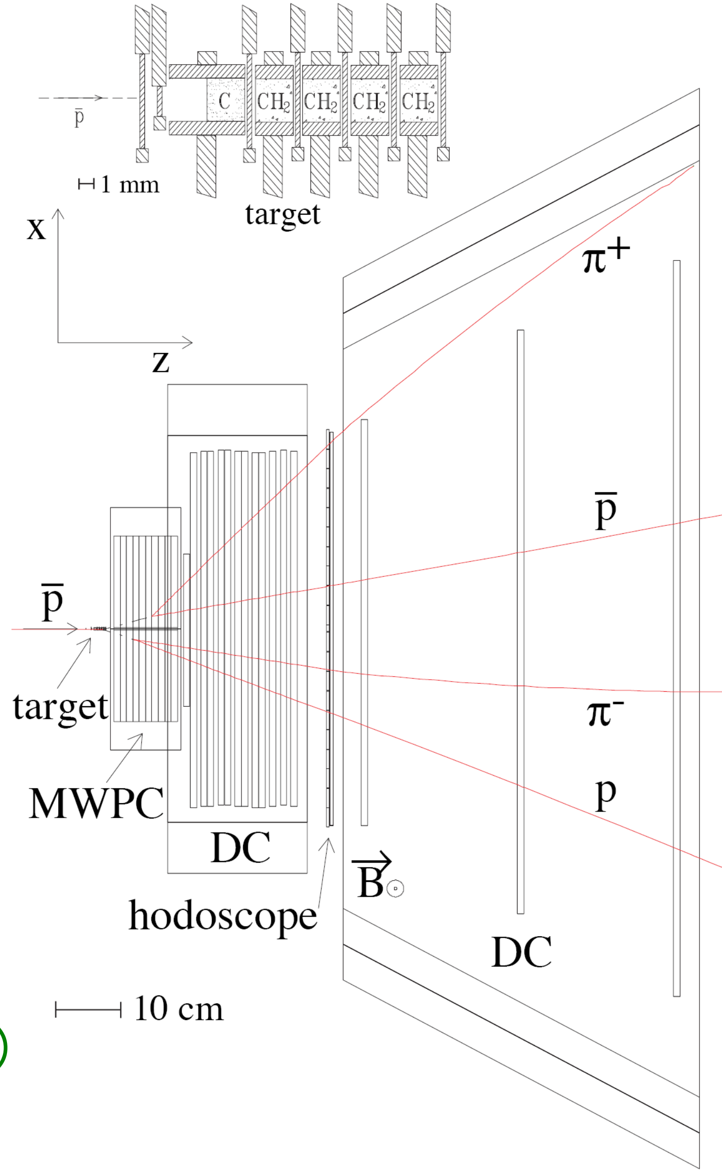
PS185 at LEAR

- $p+\bar{p}$® $Y+\bar{Y}$ at 1.4-2 GeV/c
- CH_2 and C targets





- For $\bar{p}+^{12}C$ data at 1.45, **1.66** and 1.77GeV/c been analyzed: Stephan Pomp, thesis (1999) priv. com
- Only polarization data published so far

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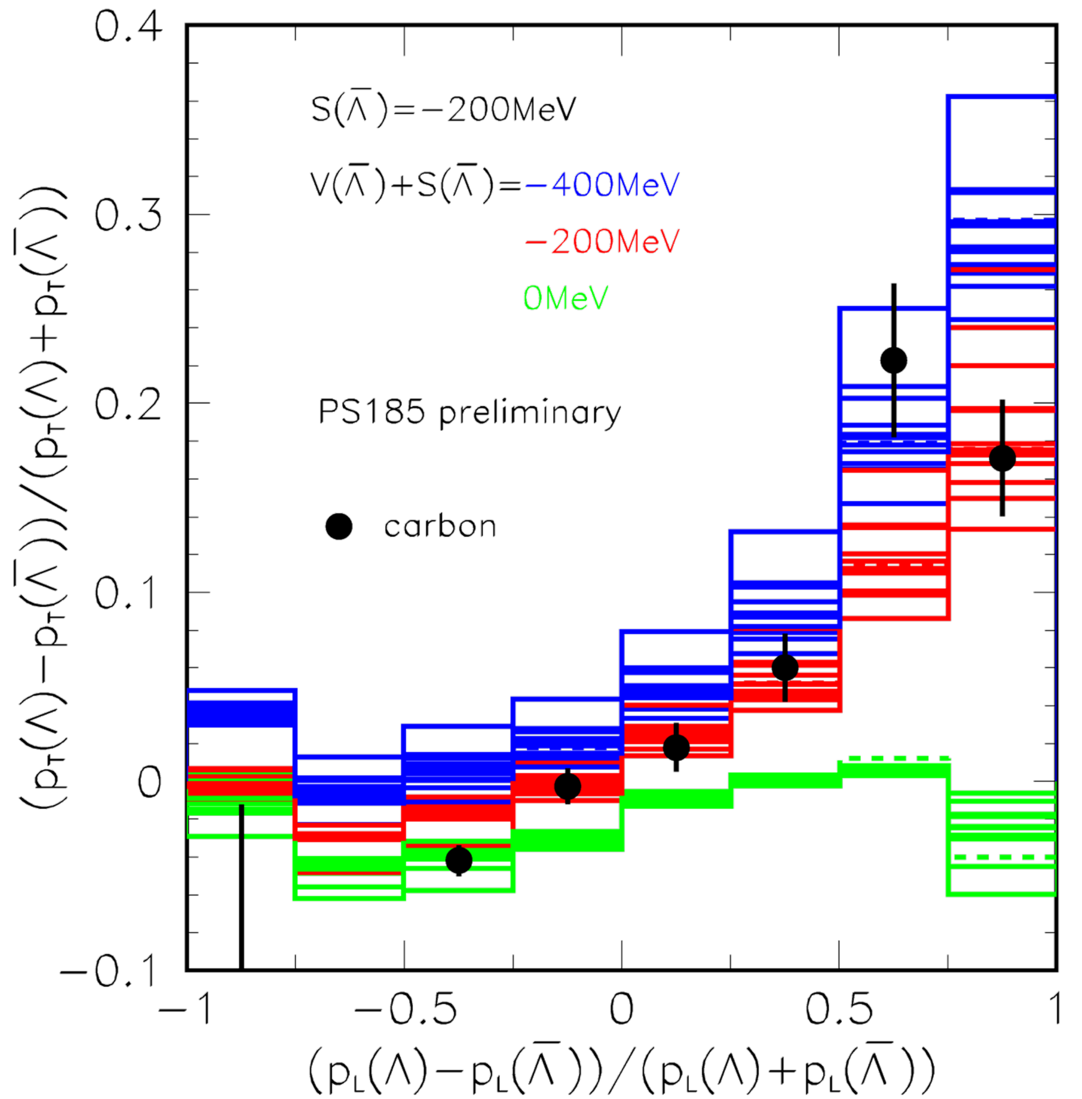
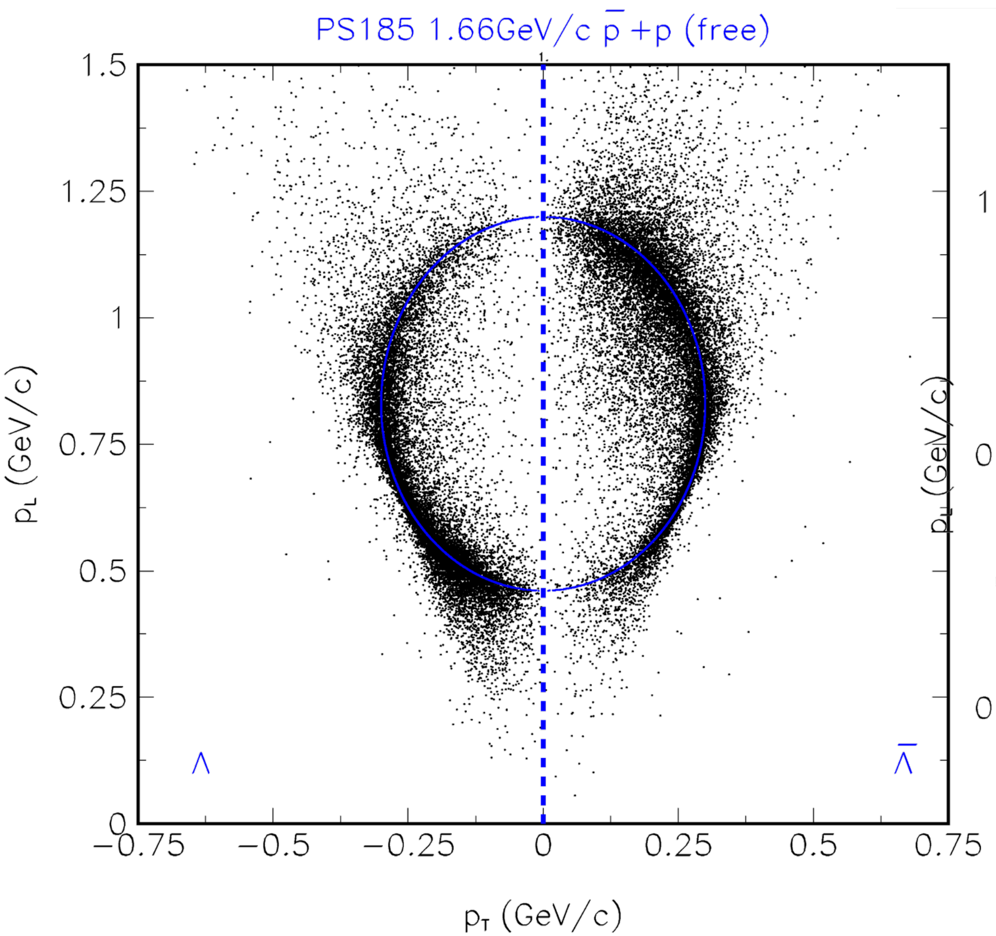
The good news…

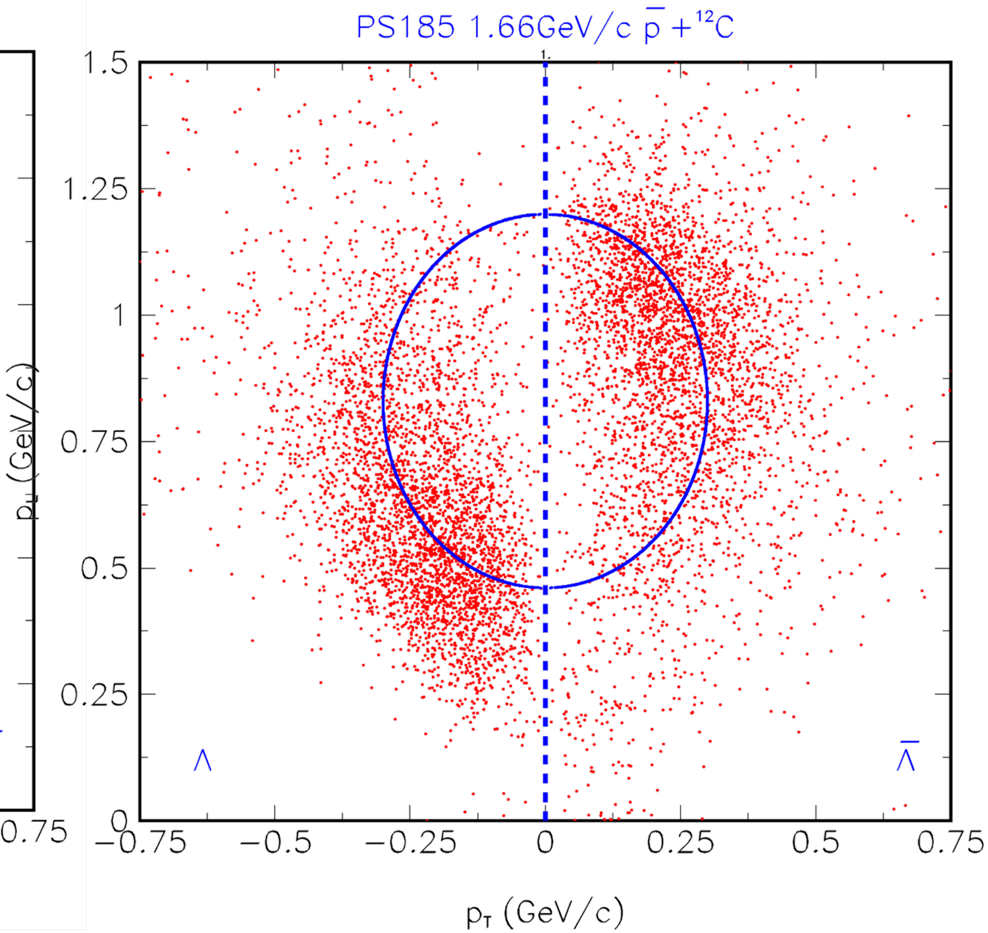
- Calculations are probably not incompatible with available data



PS185: the problem

- Elementary reaction not completely understood
- But: Measurements are possible !!!





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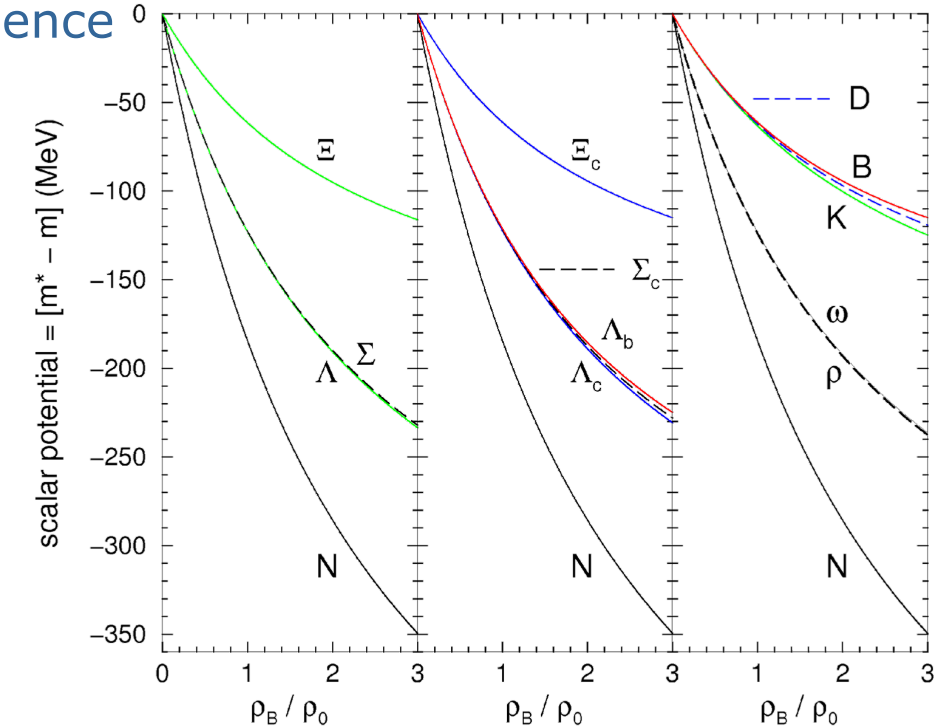
Choice of Potentials

- K. Saito, K. Tsushima, A.W. Thomas, Prog.Part.Nucl.Phys. 58 (2007) 1
- Here: no momentum dependence
  - Scalar Potential

$$U_V = U_V(\rho_0)\cdot\frac{\rho}{\rho_0}$$

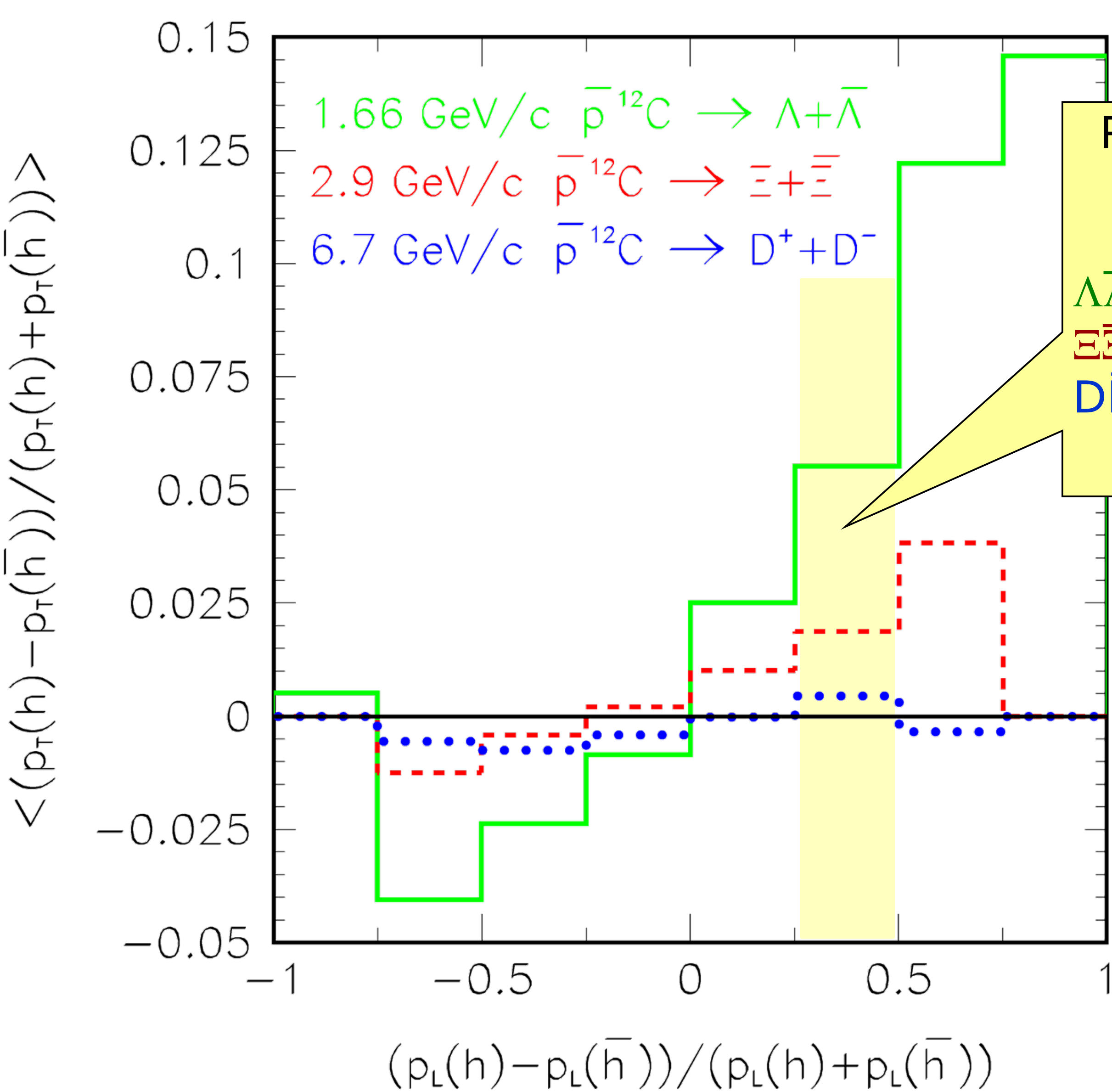
  - Vector Potential
    - N=Z:

$$U_V = 41.8\cdot(n_q - n_{\bar{q}})\frac{\rho}{\rho_0}$$



potential	p	$\bar{p}$	Λ	p	$\bar{p}$	Λ	$\bar{\Lambda}$	Ξ	$\bar{\Xi}$	D^+	D^-
V [MeV]	300	200	200	125	-125	84	-84	42	-42	-42	42
S [MeV]	-342	-342	-228	-184	-184	-123	-123	-61	-61	-61	-61
V+S [MeV]	-42	-142	-28	-59	-309	-39	-207	-19	-103	-103	-19

Other hadron-antihadron pairs



Required running time for $\delta a/a = 10\%$:

$\Lambda\bar{\Lambda}$: few minutes

$\Xi\bar{\Xi}$: several h

$D\bar{D}$: several months

at PANDA

Summary

- Antiproton collisions with nuclei are the ideal tool to produce exclusive hyperon-antihyperon pairs in nuclei at moderate momenta

- Transverse momentum correlations of hyperon-antihyperon pairs produced close to threshold offer a unique opportunity to explore the potential of antihyperons relative to that of hyperons

THANK YOU

- Existing data of PS185 are encouraging e.g. fot PANDA, but not conclusive

- Many improvements needed/open questions
  - Momentum dependence of potentials
    - Reduce effect particularly for $\Xi\bar{\Xi}$
    - Angular dependence of $\alpha_T \Leftrightarrow$ study momentum-dependence
  - Rescattering
    - influence of nuclear mass $\Rightarrow$ use light nucleus to reduce rescattering
  - Formation time
    - coherence length of $\Lambda\bar{\Lambda}$ pair: $t \sim \hbar/E_F \sim 5$fm/c $\Leftrightarrow$ nuclei of different size