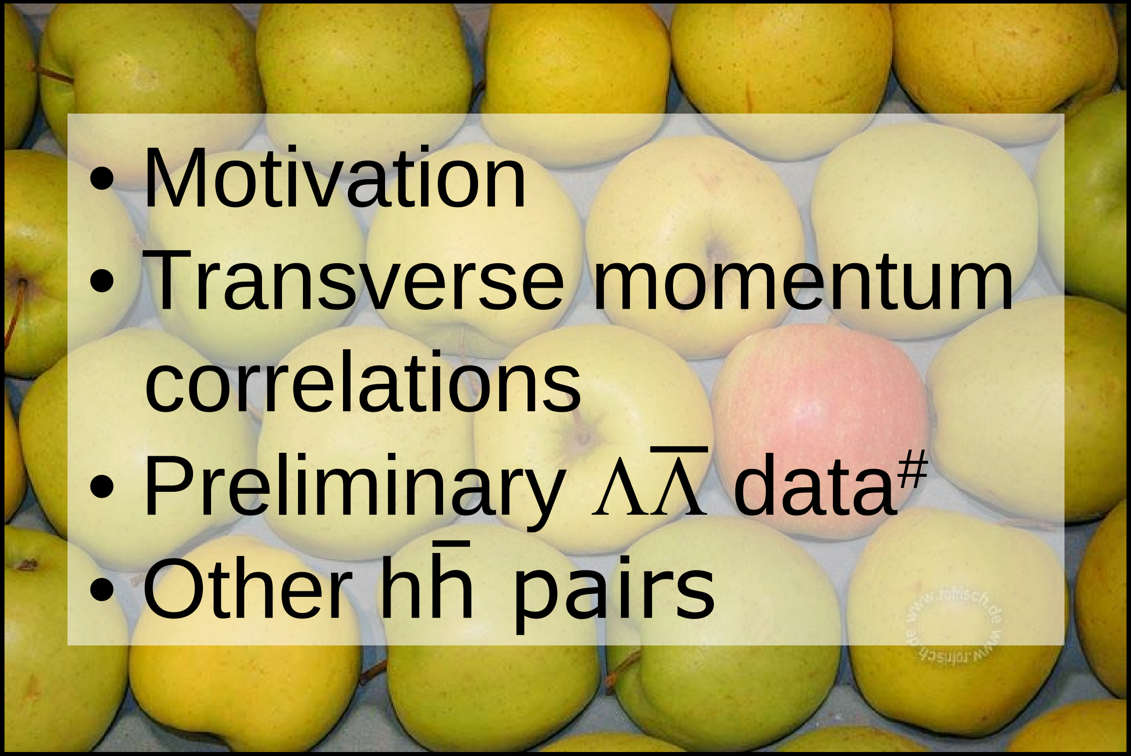
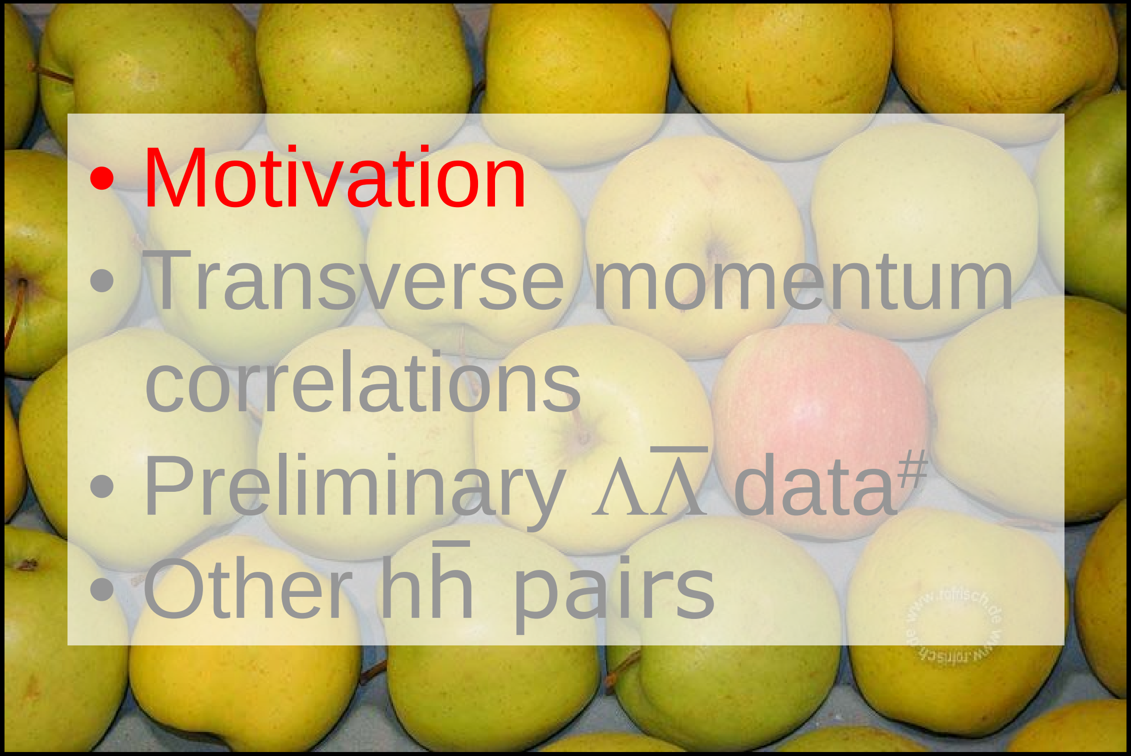
EXPLORING THE POTENTIAL OF ANTIBARYONS IN NUCLEI WITH ANTIPROTONS

arXiv:0807.3302



- Motivation
- Transverse momentum correlations
- Preliminary $\Lambda\bar{\Lambda}$ data#
- Other $h\bar{h}$ pairs

#*Very preliminary* PS185 data thanks to Stephan Pomp & Tord Johansson



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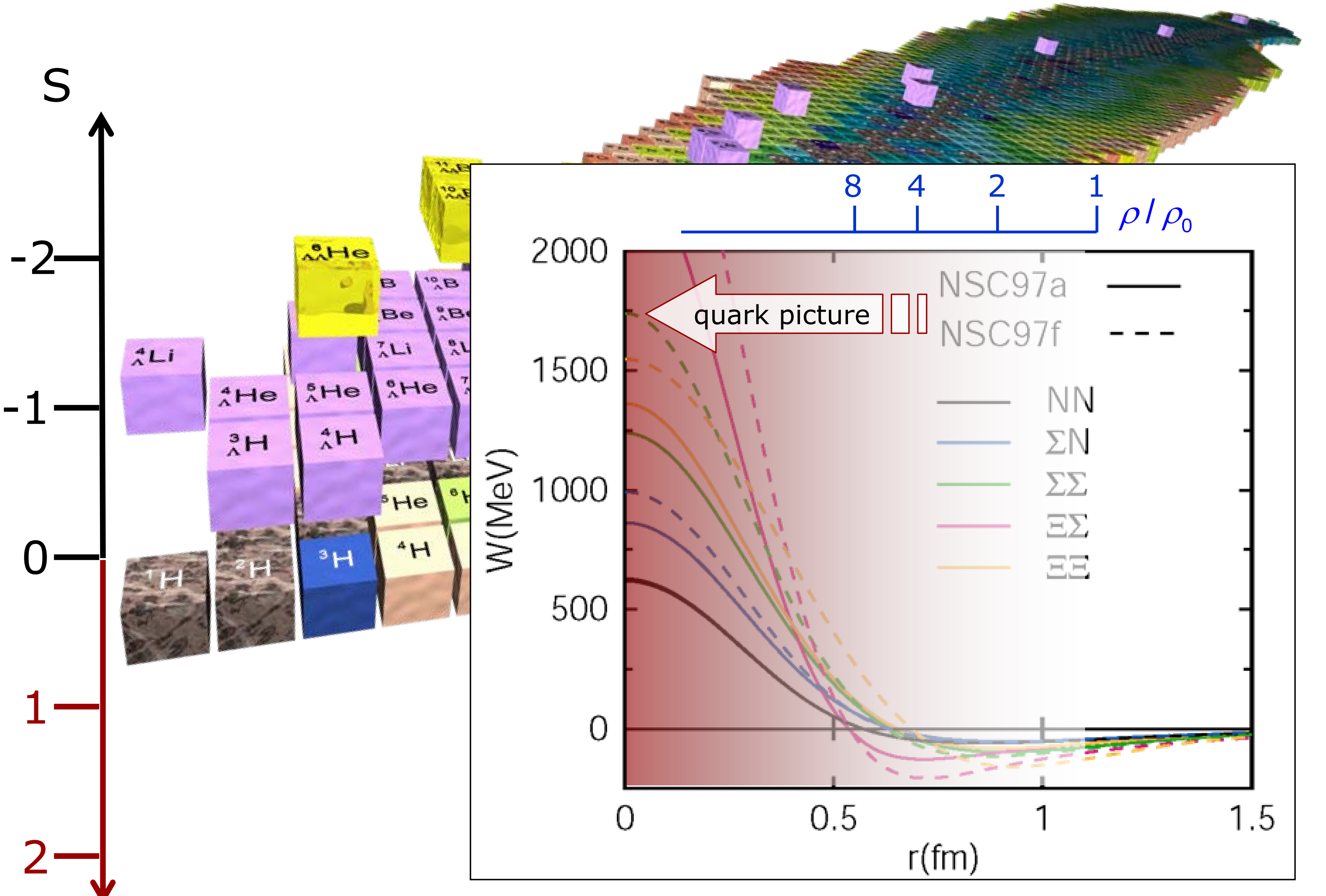
Antihyperons in Nuclei



Elastic Antiproton-Nucleus Scattering

Elastic Scattering of Antiprotons from Complex Nuclei*

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

(Received May 5, 1958)

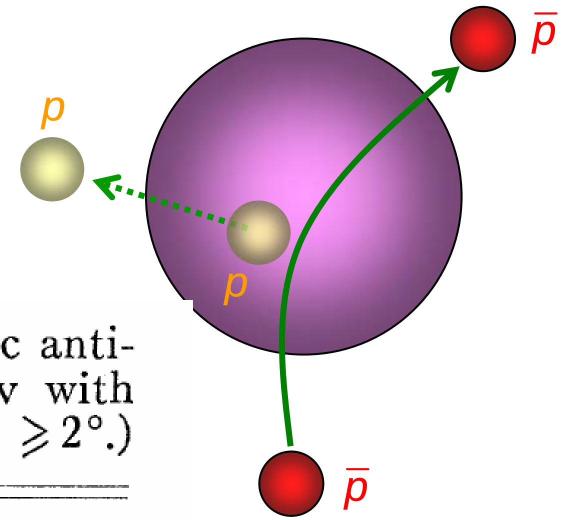


TABLE III. Comparison of experimental data for elastic antiproton-nucleus scattering of energy $T_{\bar{p}}=80$ to 200 Mev with Glassgold's calculations at $T_{\bar{p}}=140$ Mev. (Projected angle $\gtrsim 2°$.)

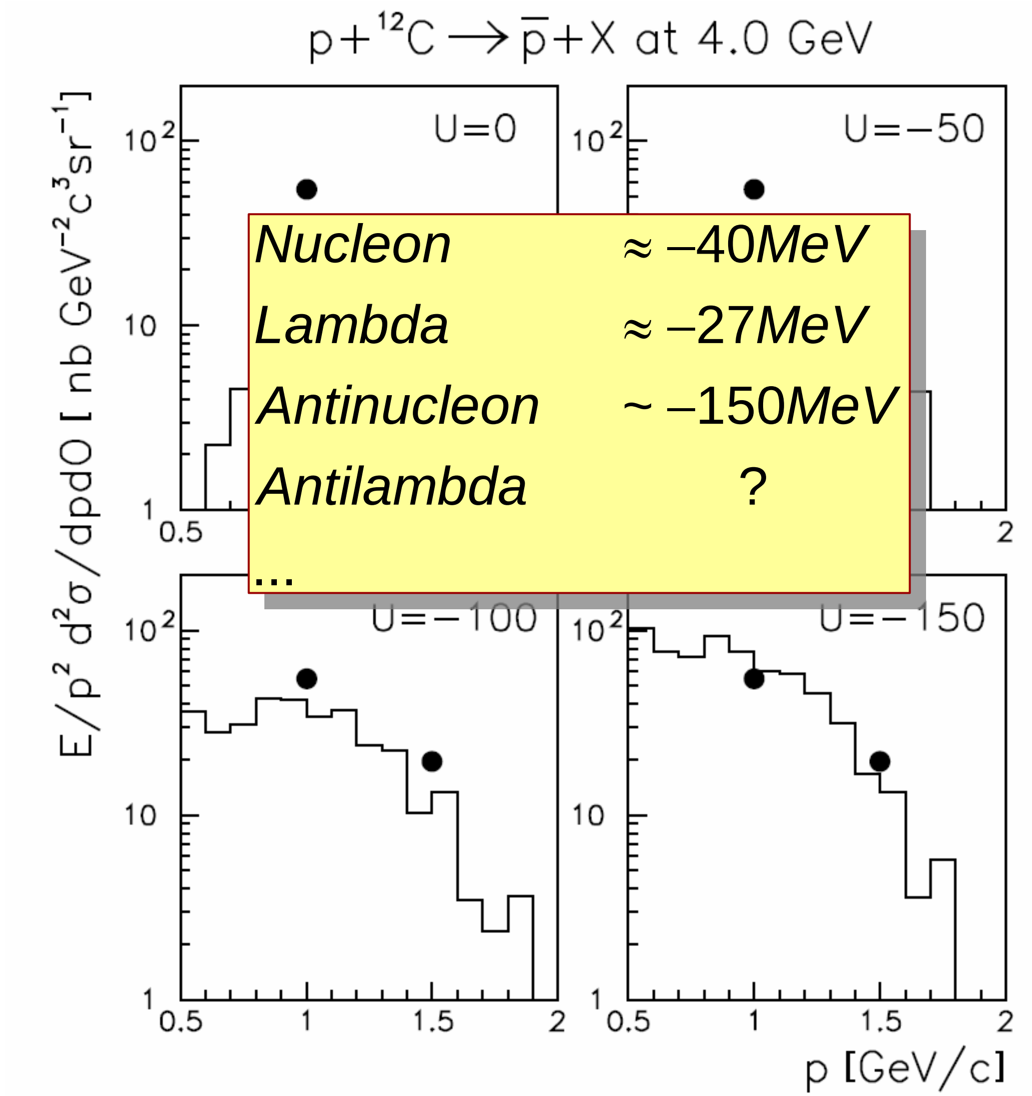
Angular interval (degrees)	Experimental ($T_{\bar{p}}=80$ to 200 Mev)	Number of events Calculated for potential[a] $V=-15$ Mev $W=-50$ Mev	Calculated for potential[a] $V=-528$ Mev $W=-50$ Mev
2–6	54	56	71
6–12	20	17.1	24
12–24	5	4.3	10
24–180	1	1.4	9.5
2–180	80	78.8	114.5

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)



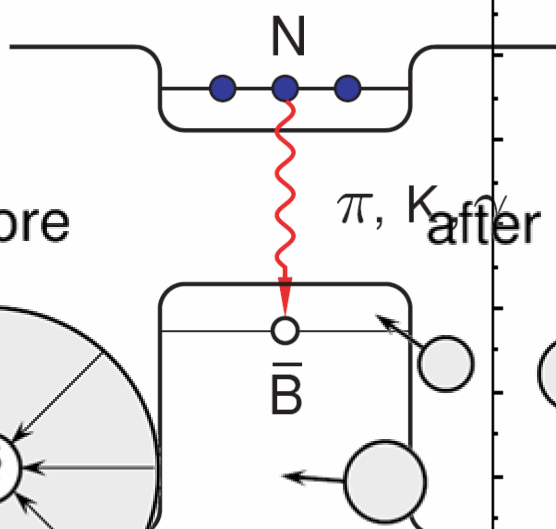
Nucleon	$\approx -40 MeV$
Lambda	$\approx -27 MeV$
Antinucleon	$\sim -150 MeV$
Antilambda	?
...	

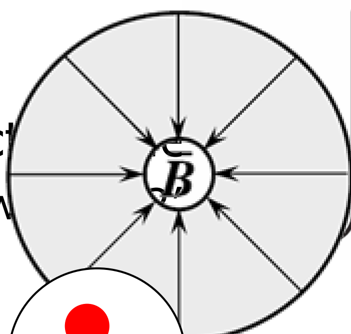
Antihyperons stopped in Nuclei

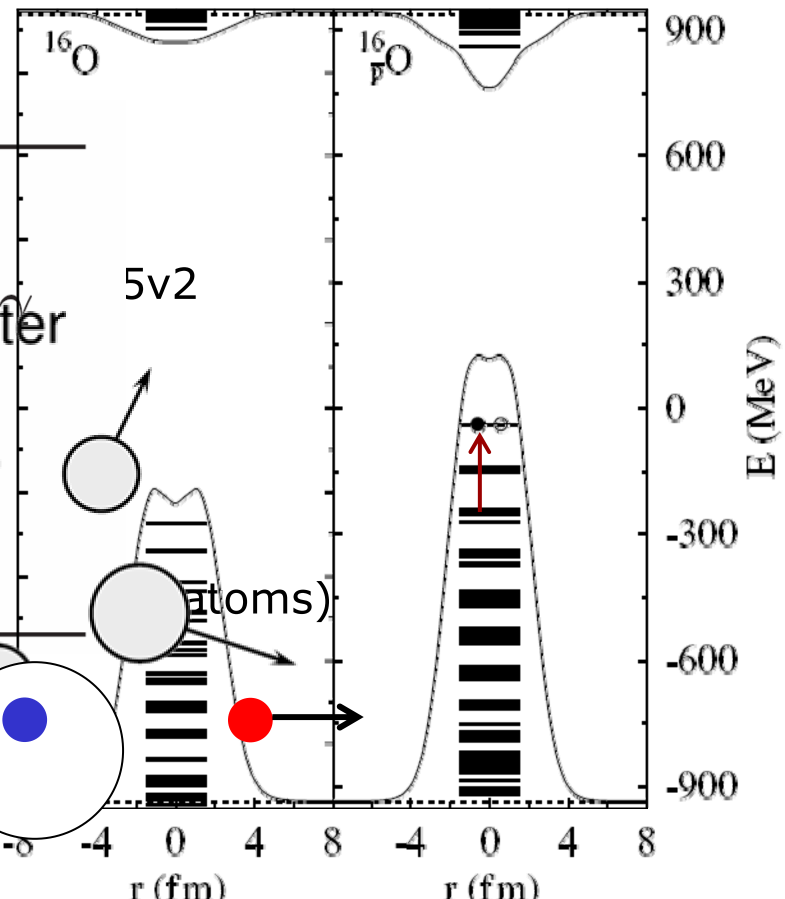
- antibaryons stopped in nuclei

$$\bar{p} + \mathrm{A} \rightarrow {}_{\bar{B}}\mathrm{A} + X$$

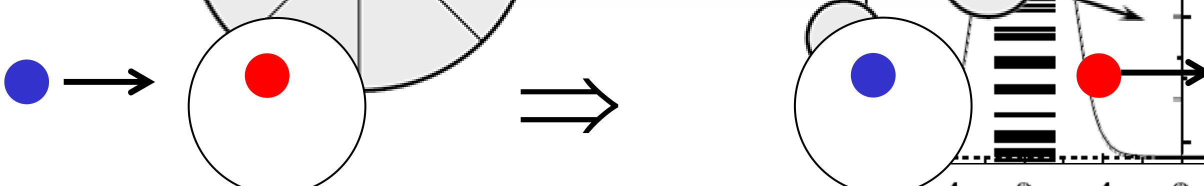
  - I.N. Mishustin *et al.*, Phys. Rev. C 71, 035201 (2005)
  - suggested observables
    - "Super-transitions" from Fermi to Dirac sea (mono-energetic mesons)
    - Transitions between levels of each
    - Explosio after ant A.B. Lar
    - formatio

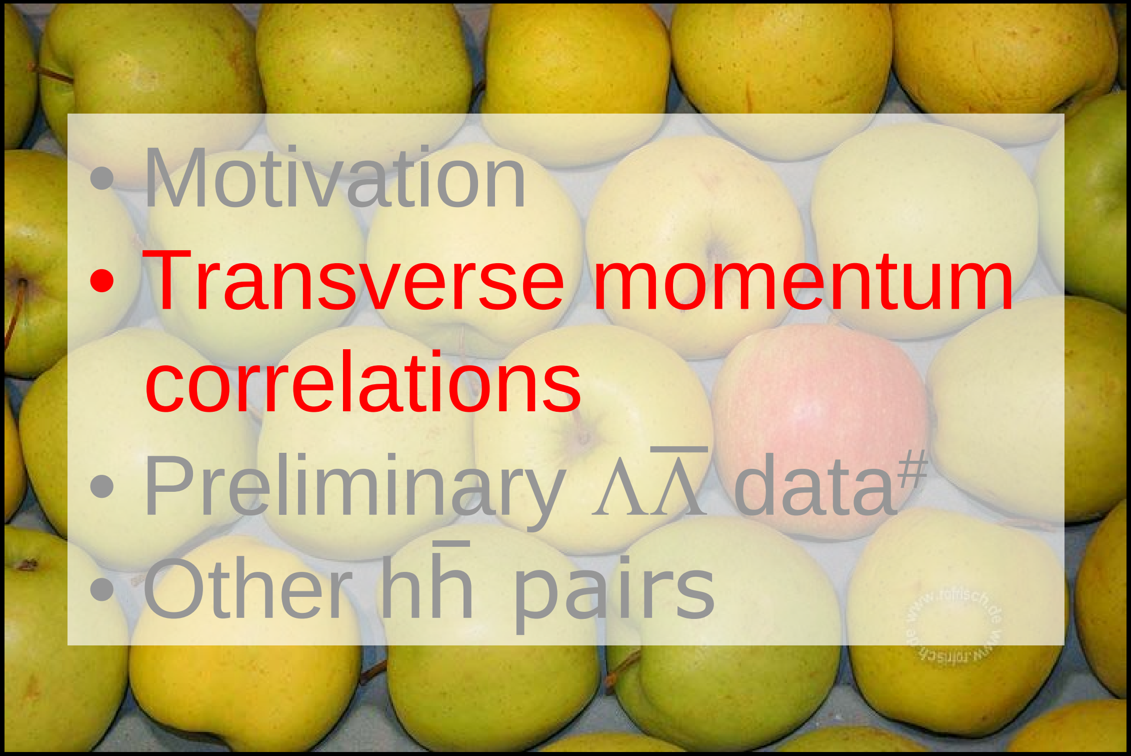






- Produc
  - forw atoms)





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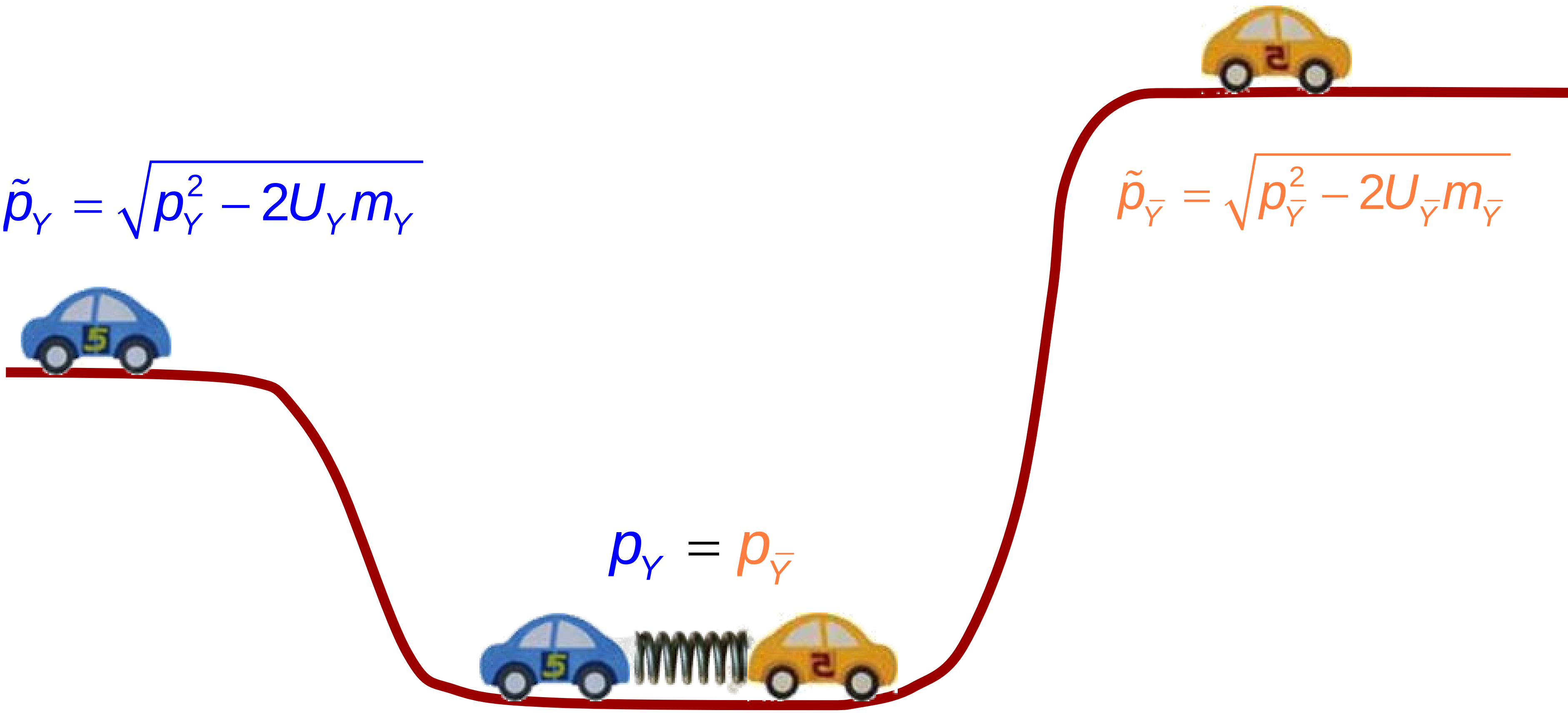
- Other $h\bar{h}$ pairs

How to measure a potential (difference)



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

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

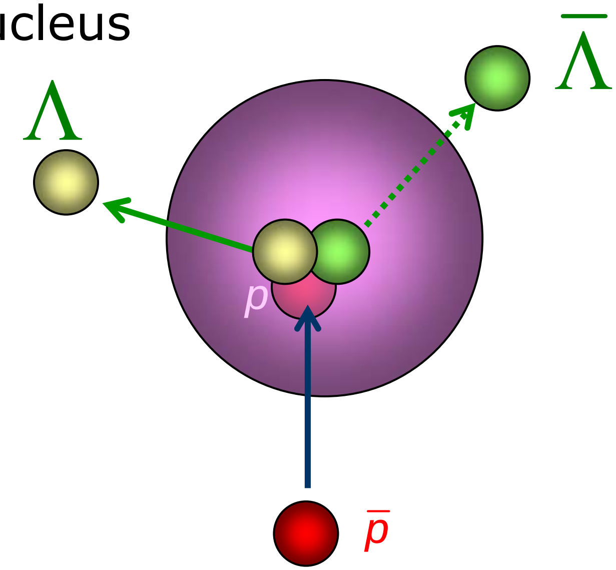
$$p_Y = p_{\bar{Y}}$$

- 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
- $p+\bar{p} \rightarrow Y+\bar{Y}$ 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(ρ)
  - Exclusiveness

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

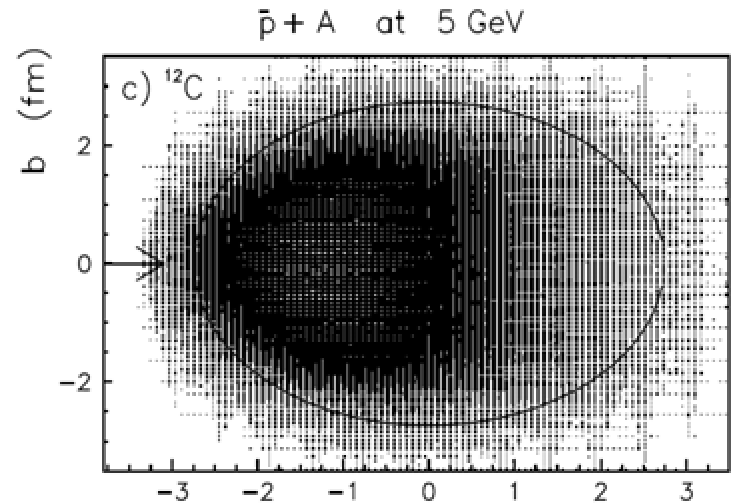
Schematic model

$\bar{p}$ Absorption → $\Lambda\bar{\Lambda}$ creation within the nuclear potentials → Propagation of Λ and $\bar{\Lambda}$ out of nucleus

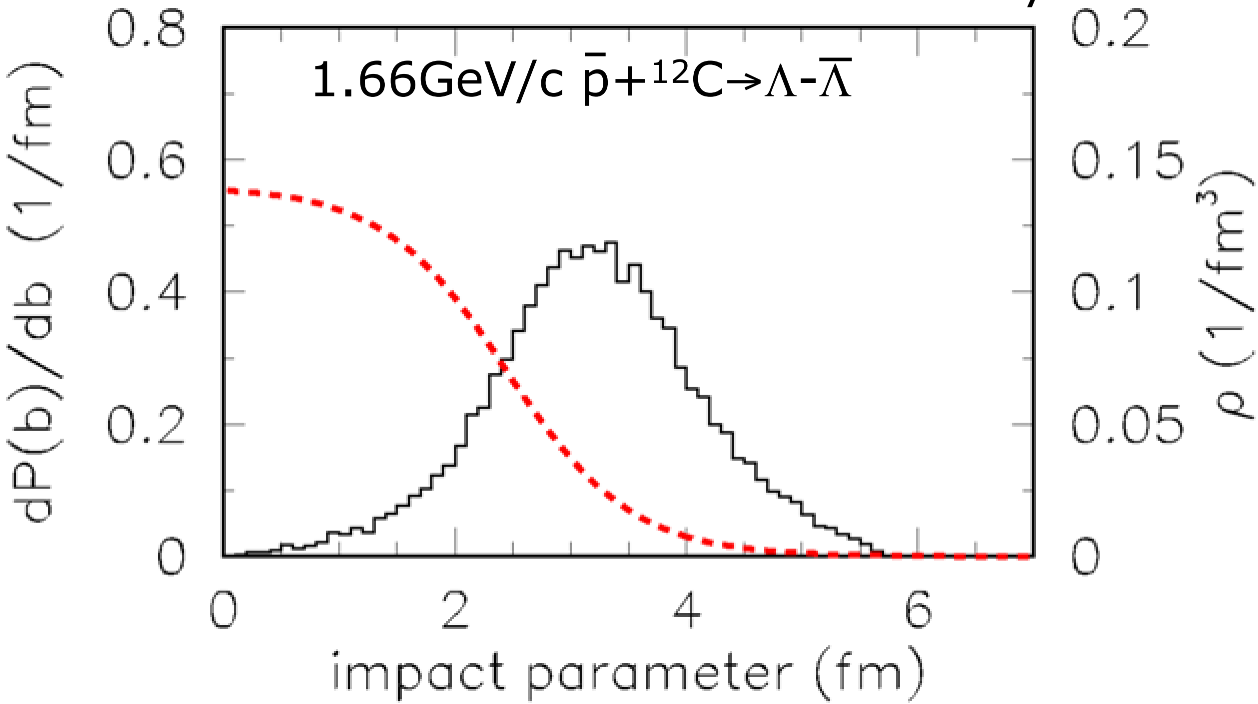
- Classical and schematic model
- Basic input:
  - energy and momentum conservation
  - experimental information
- goals:
  - robustness - explore sensitivity to various parameters
  - feasibility - expected count rate
  - starting point - trigger more detailed calculations
- Testcase: 1.66GeV/c $\bar{p}+{}^{12}C \rightarrow \bar{\Lambda}$-$\Lambda$

Annihilation Zone

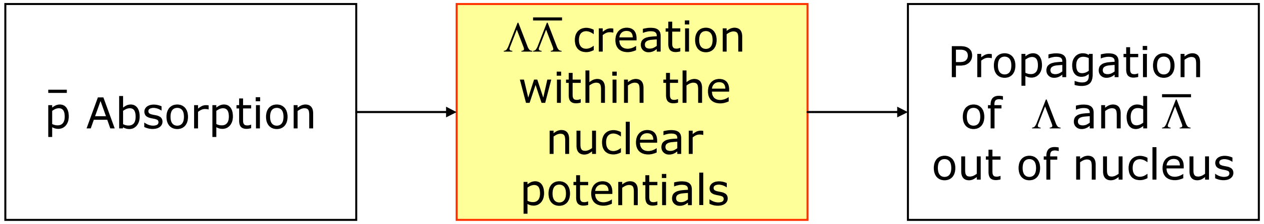
- Anti-baryons are strongly absorbed:
  - $\bar{p}$: 50 mb
  - Λ: 20 mb
  - $\bar{\Lambda}$: 100 mb/(1+$p_{\bar{\Lambda}}$/GeV)
- Emission of $\Lambda\bar{\Lambda}$ pair is anisotropic in center-of-mass
- Coincident detection of Λ and $\bar{\Lambda}$ constraints annihilation points
- Creation zone is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



Sibirtsev *et al*



$\Lambda\bar{\Lambda}$ creation



- Fermi momentum p_F=220MeV/c
- Λ, $\bar{\Lambda}$ angular distribution of free events $\bar{p}+p \rightarrow \Lambda+\bar{\Lambda}$
- Default potential
  - 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

Λ and $\bar{\Lambda}$ propagation

$\bar{p}$ Absorption →	$\Lambda\bar{\Lambda}$ creation within the nuclear potentials →	Propagation of Λ and $\bar{\Lambda}$ out of nucleus

- Straight tracks - rescattering neglected

$$\left\langle \int \rho_N ds \right\rangle \approx \frac{1}{1000mb}$$

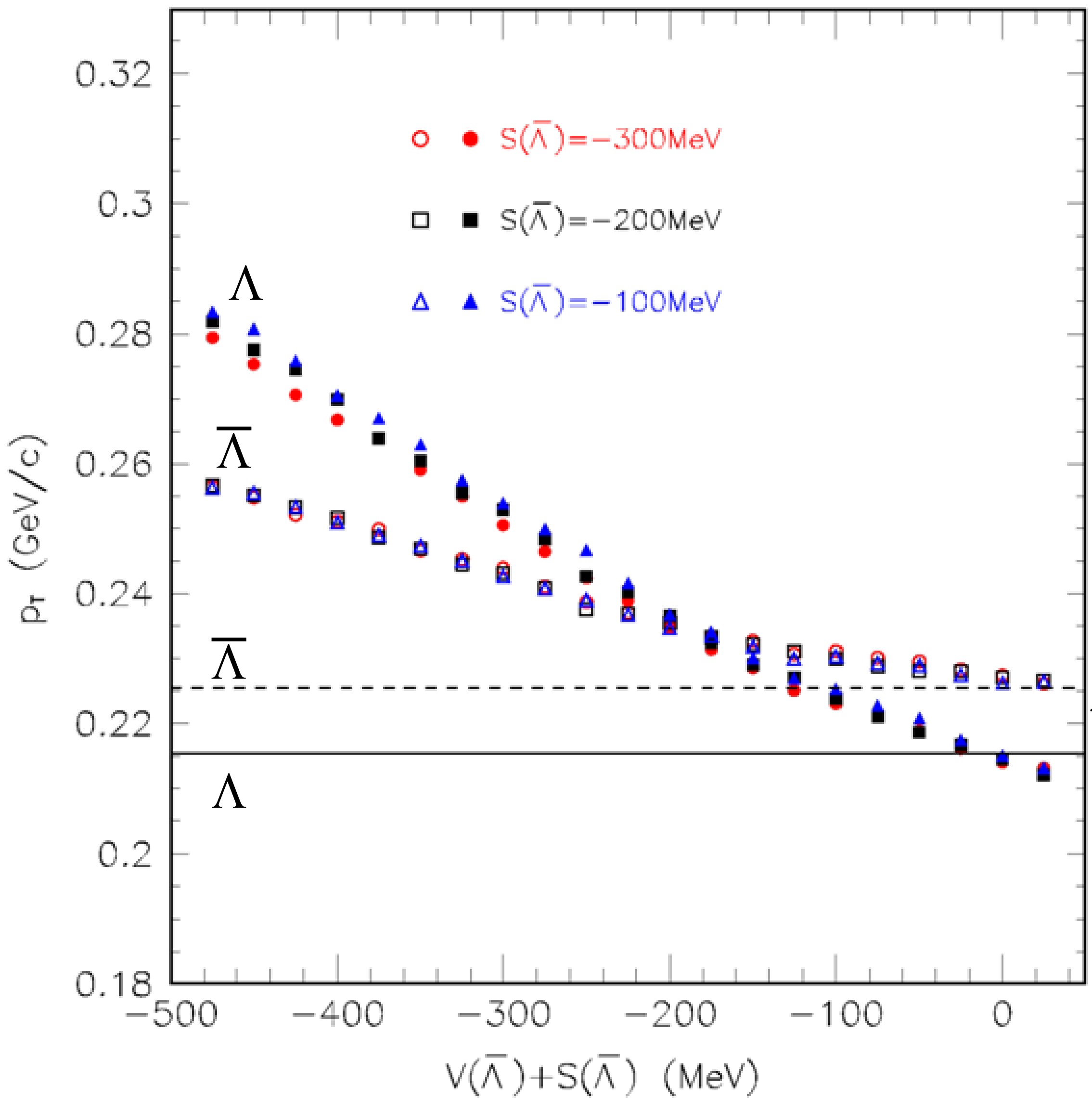
- Propagation and emission

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

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

Transverse Momenta

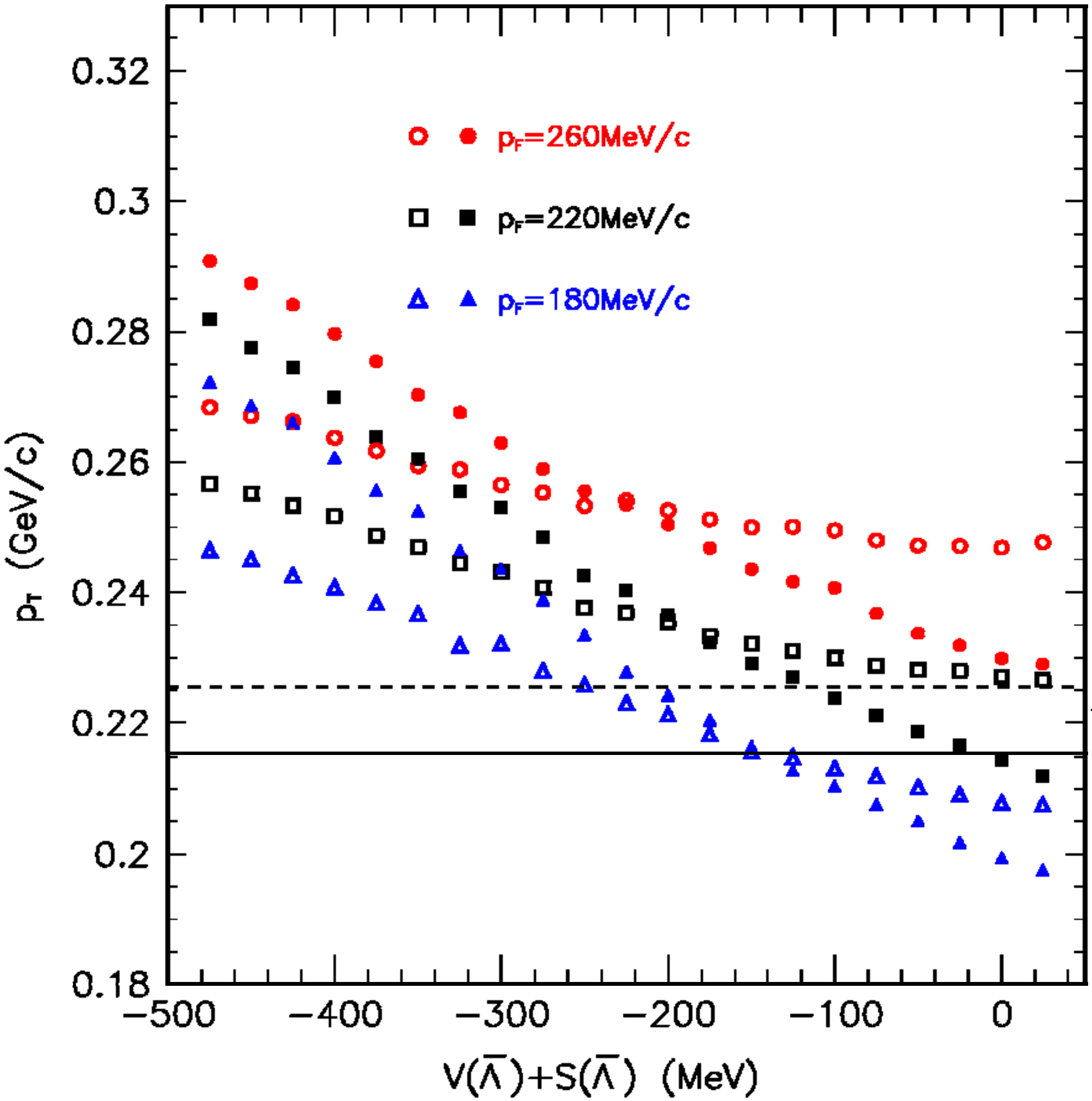
- 1.66GeV/c $\bar{p}+p \rightarrow \bar{\Lambda}-\Lambda$



All $\bar{\Lambda}$ and Λ potentials set to zero

Transverse Momenta

- 1.66GeV/c $\bar{p}+p\rightarrow\bar{\Lambda}$-$\Lambda$



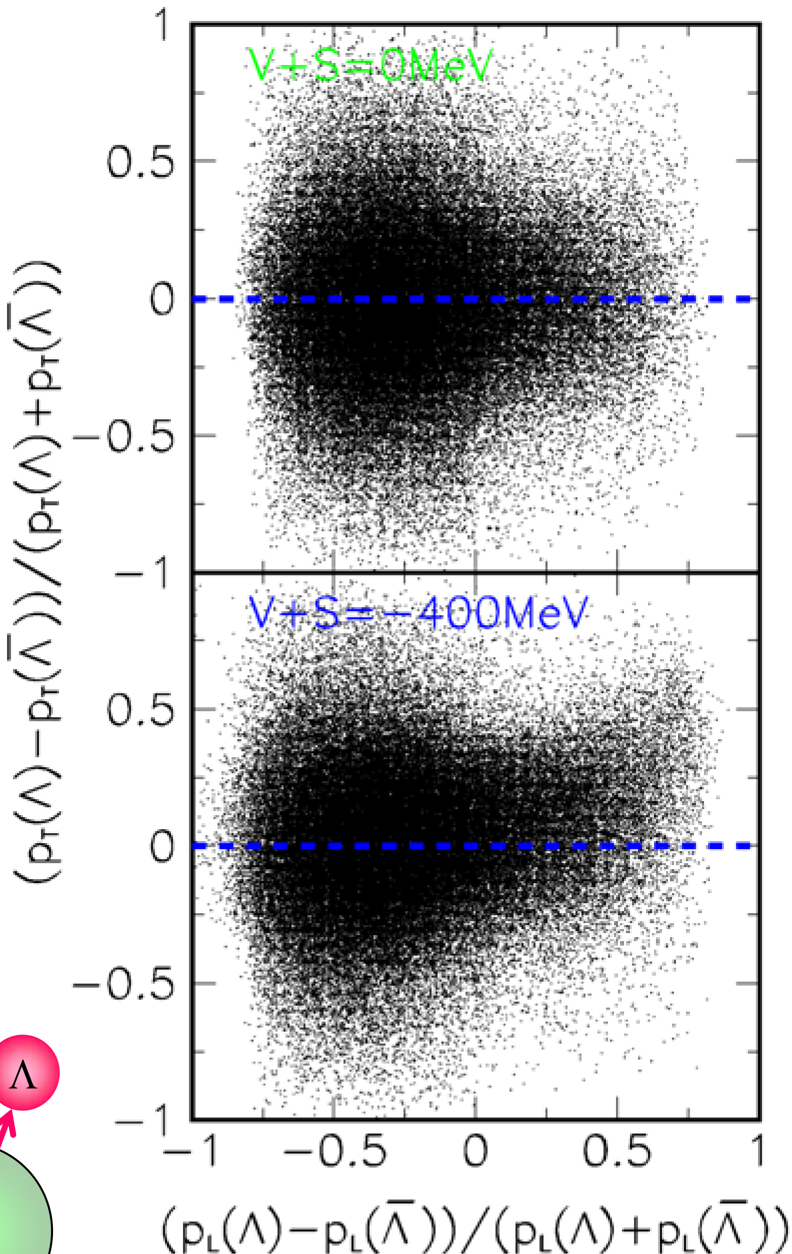
- Major sensitivity to assumed Fermi motion and angular distribution
- $\langle p_t \rangle$ is not sufficient to determine the potential parameters unambiguously
- Need to look at event-by-event correlations

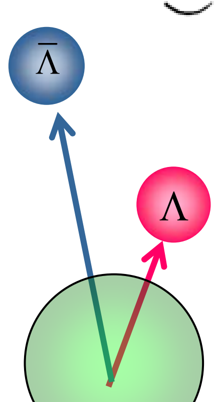
All $\bar{\Lambda}$ and Λ potentials set to zero

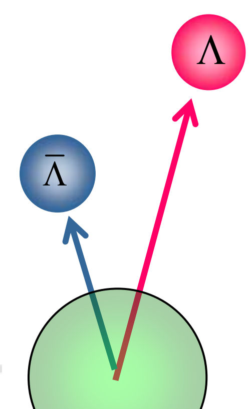
Transverse Momentum Correlations

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

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

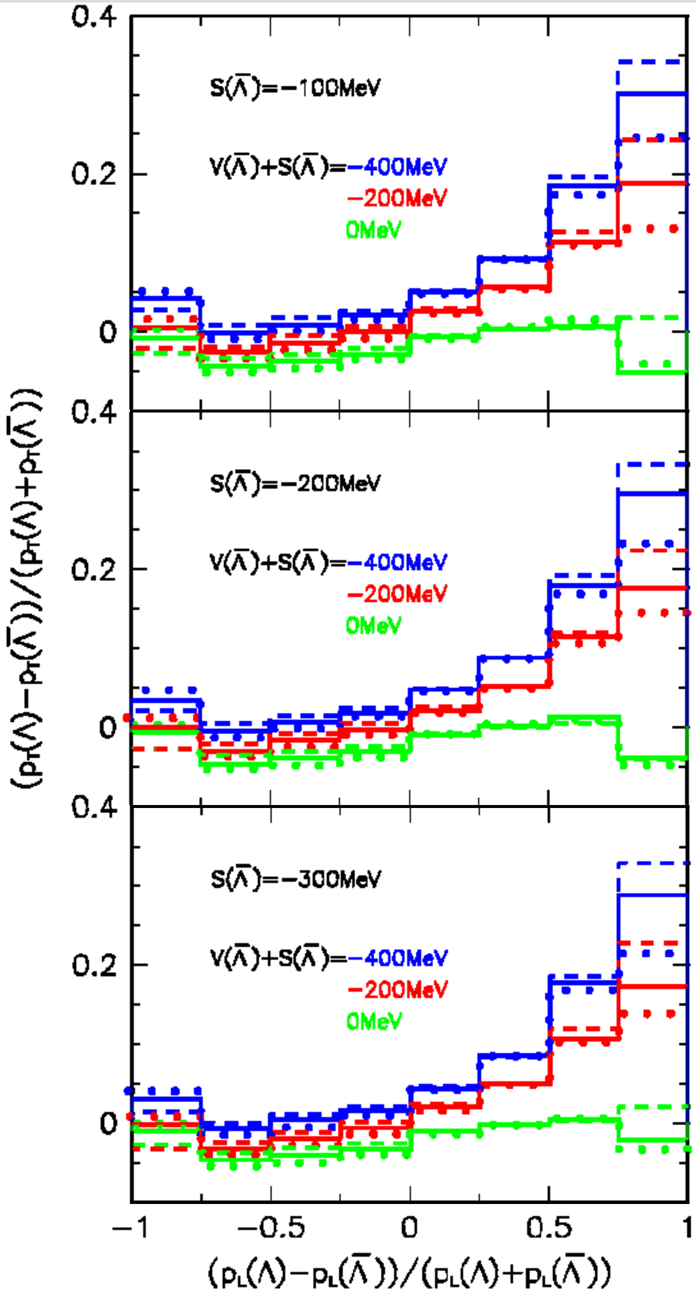






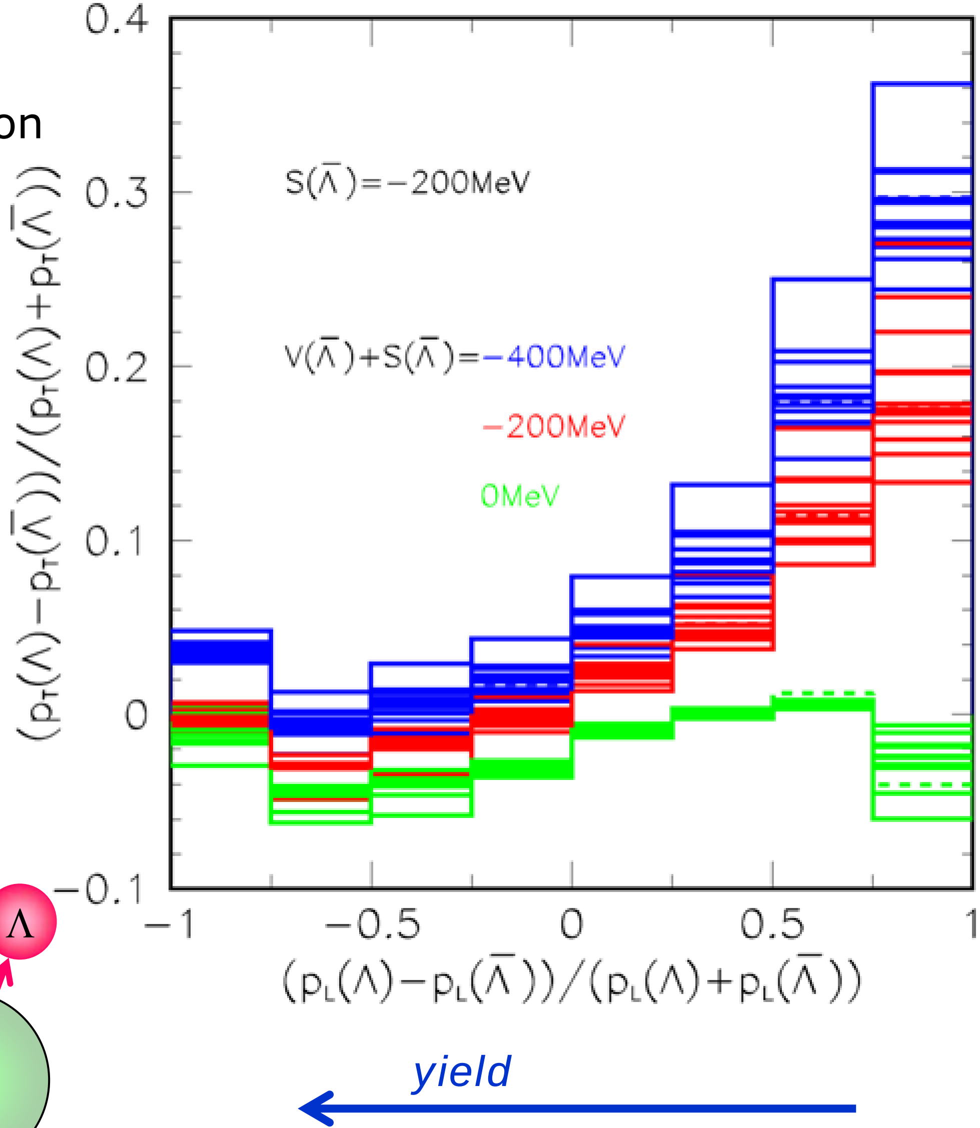
Influence of $\bar{\Lambda}$ Potential on α_T

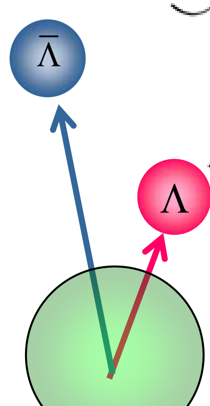
- Transverse asymmetry mainly determined by total potential
- Effect largest for backward emitted $\bar{\Lambda}$
- α_T non-zero even if V+S=0

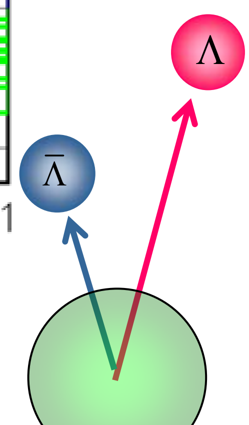


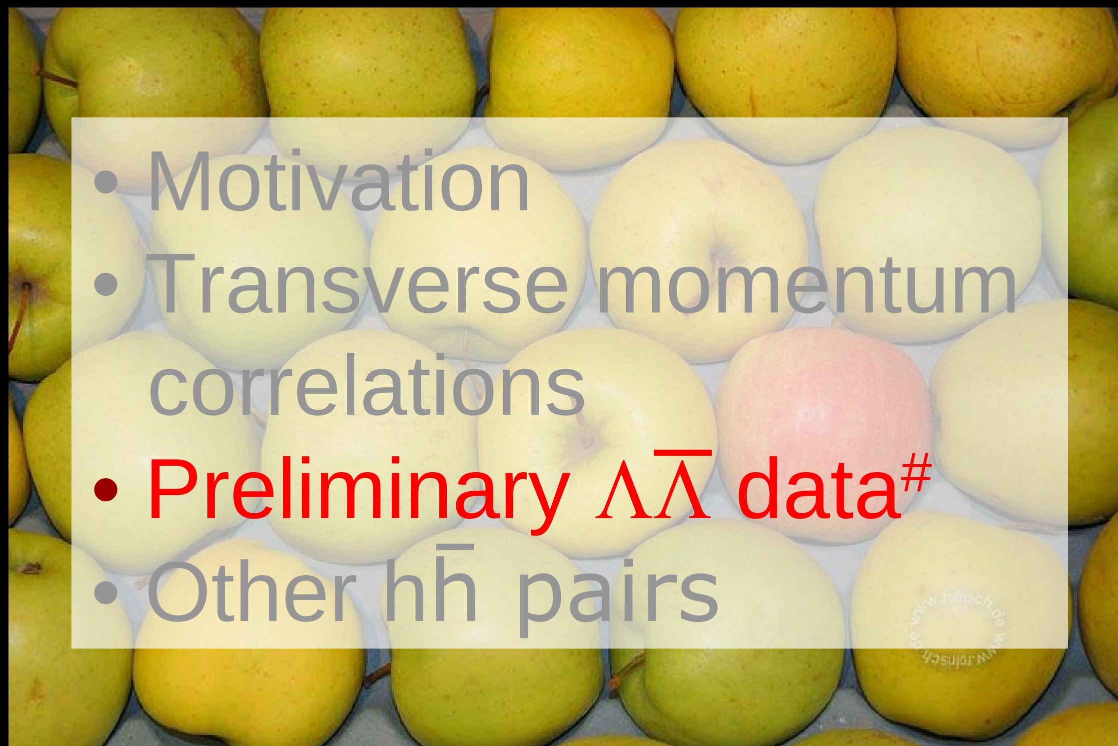
Parameter Scan

- Parameter variation by ±50%
  - potentials
  - absorption cross sections
  - angular distribution
  - diffuseness





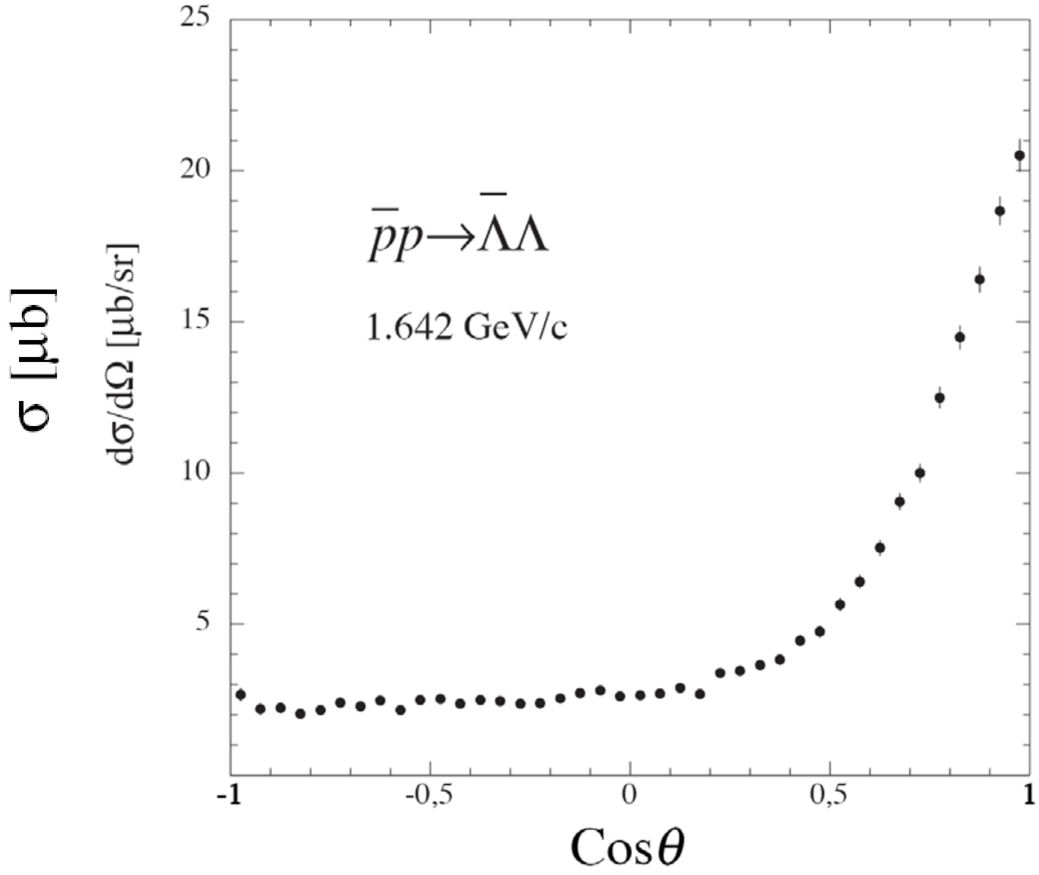


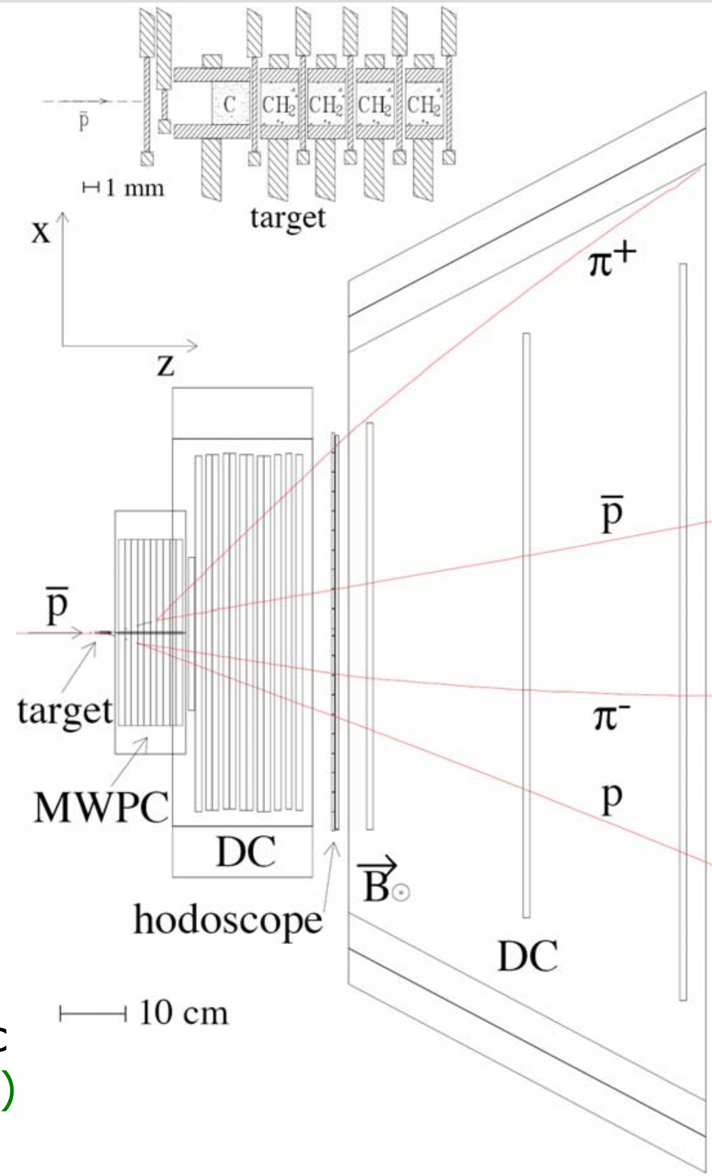


#*Very preliminary* PS185 data thanks to Stephan Pomp & Tord Johansson

PS185 at LEAR

- $p+\bar{p} \rightarrow Y+\bar{Y}$ at 1.4-2 GeV/c





- 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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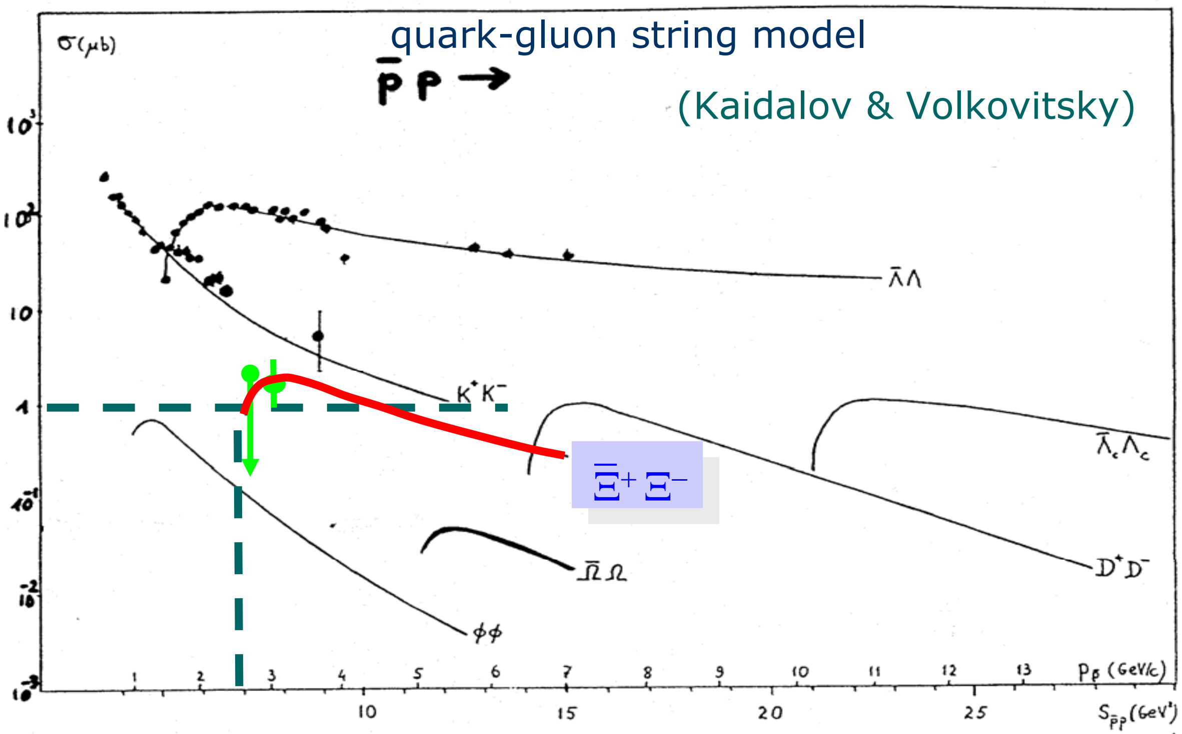
Production hadron-antihadron pairs

- the (exclusive) production of h-$\bar{h}$ pairs in nuclei by antiproton beams may offer the possibility to study the behaviour of other antibaryons in nuclei



- Kaidalov and Volkovitsky, Z. Phys. C63, 517 (1994)

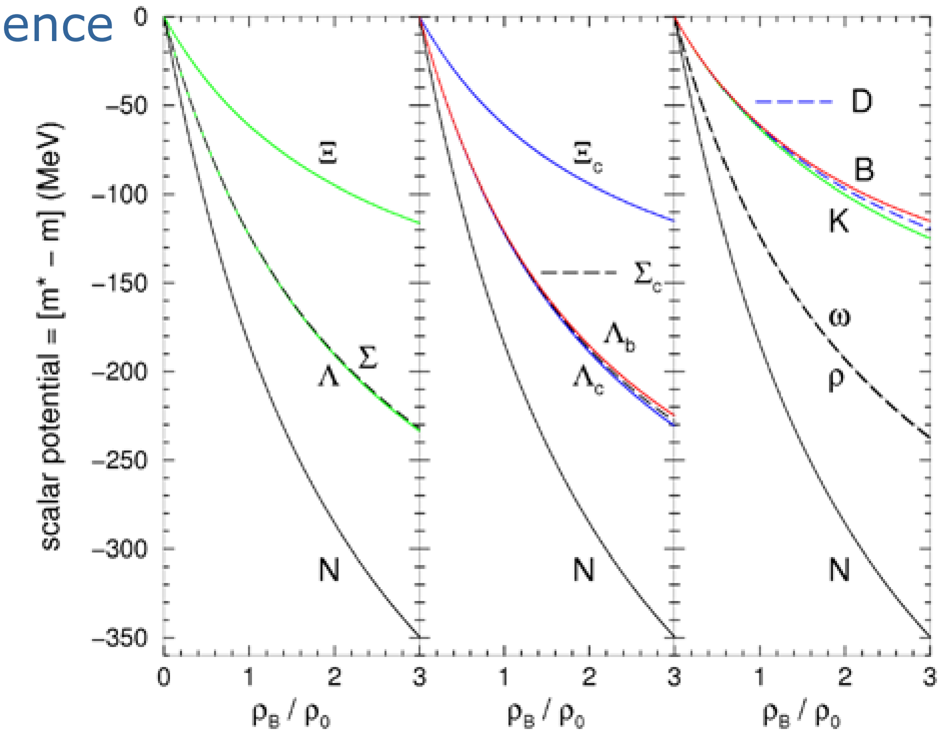
Choice of Potentials

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

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

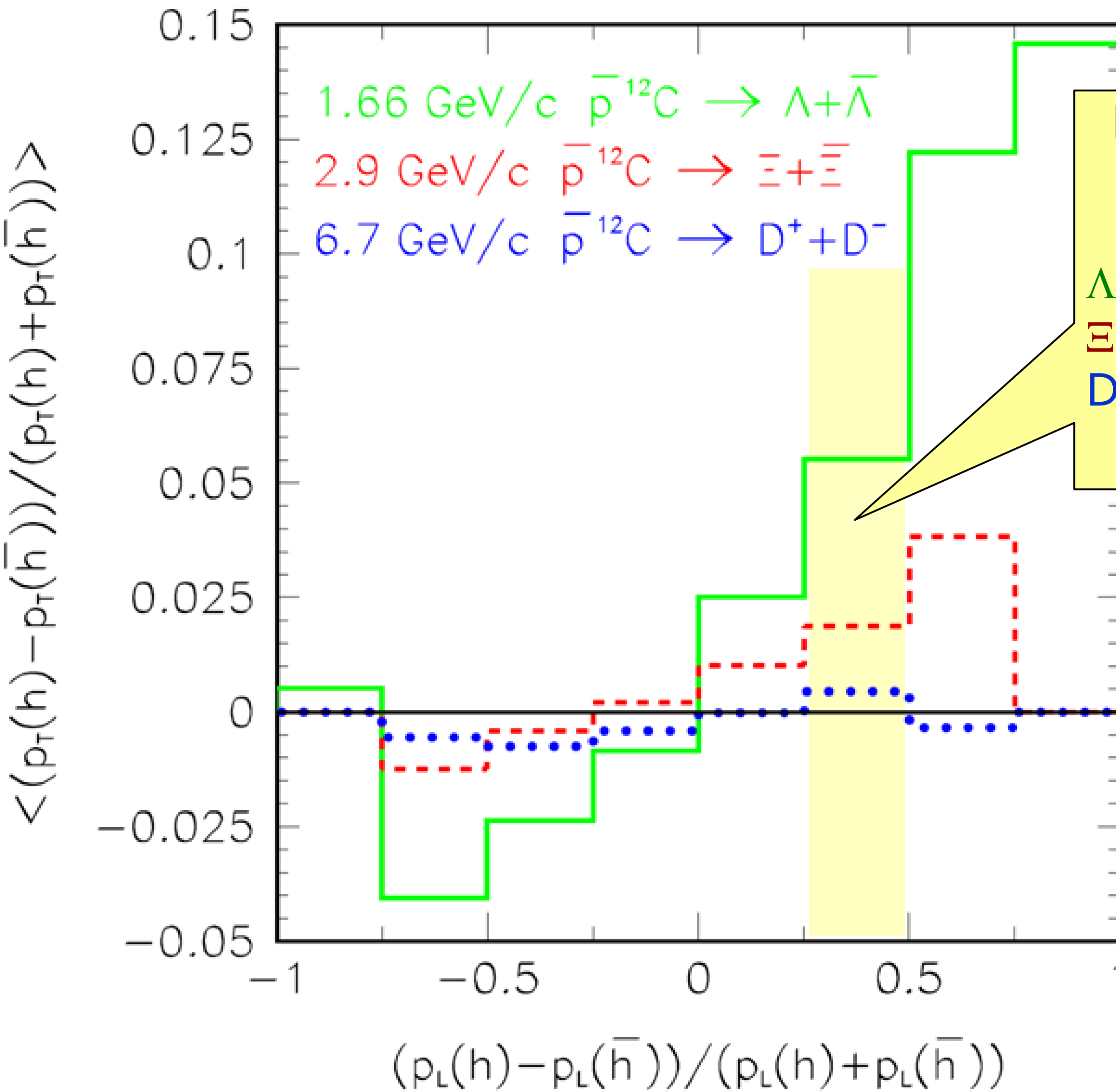
  - Vector Potential
    - N=Z:

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



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 $\delta\alpha/\alpha$=10%:

$\Lambda\bar{\Lambda}$: 1 h

$\Xi\bar{\Xi}$: 1 week

$D\bar{D}$: several month

at PANDA

Summary and Outlook

- Antiproton collisions with nuclei are the ideal tool to produce 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

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


Thank you!