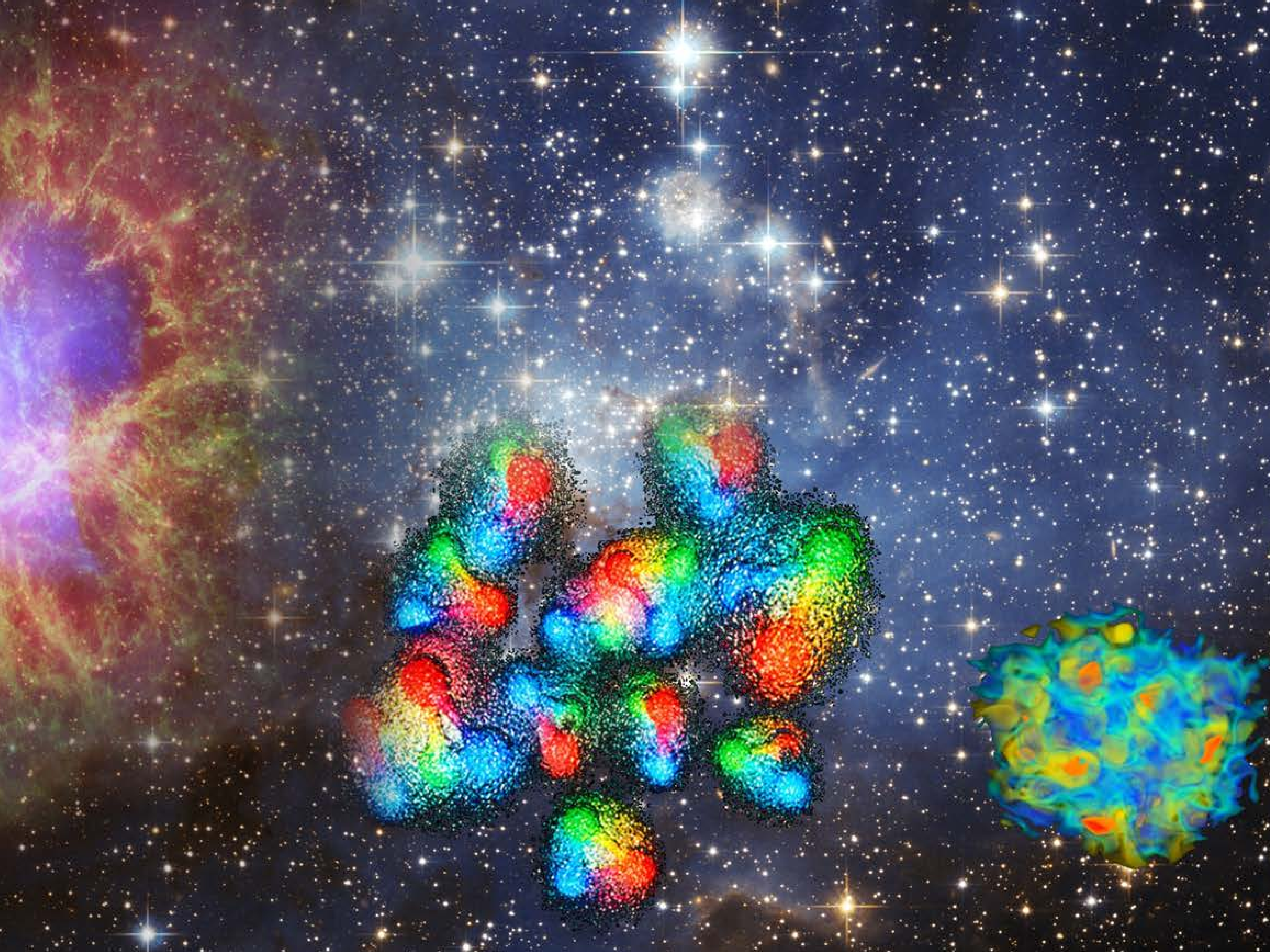


Perspectives of Hadron Physics at GSI
meeting on 20.1.1998

present: P. Braun-Munzinger, F. Close, B. Franzke, B. Friman, J. Hüfner, P. Kienle, P.

PANDA in 2018…2020…

- Luminosity ~~probably~~ below design luminosity
- Not all components of the PANDA detector might be completed
- No long running periods of HESR

⇒ evaluate physics program for commissioning phase of PANDA

- Process with large cross section
- Only charged particles (calorimeter ?!)
- Unique ⇒ experiment *only* possible with antiproton beam
- Interesting and timely physics

Antiproton energies below 15 GeV would be sufficient for the investigation of strangeness and charm in nuclei. Here, the associated production of hadron - antihadron pairs in $(\overline{p}, p)$ annihilation would be a promising tool for populating bound states of heavy mesons and hyperons in nuclei, making use of small momentum transfer kinematics.

International Conference on Science and Technology for FAIR in Europe

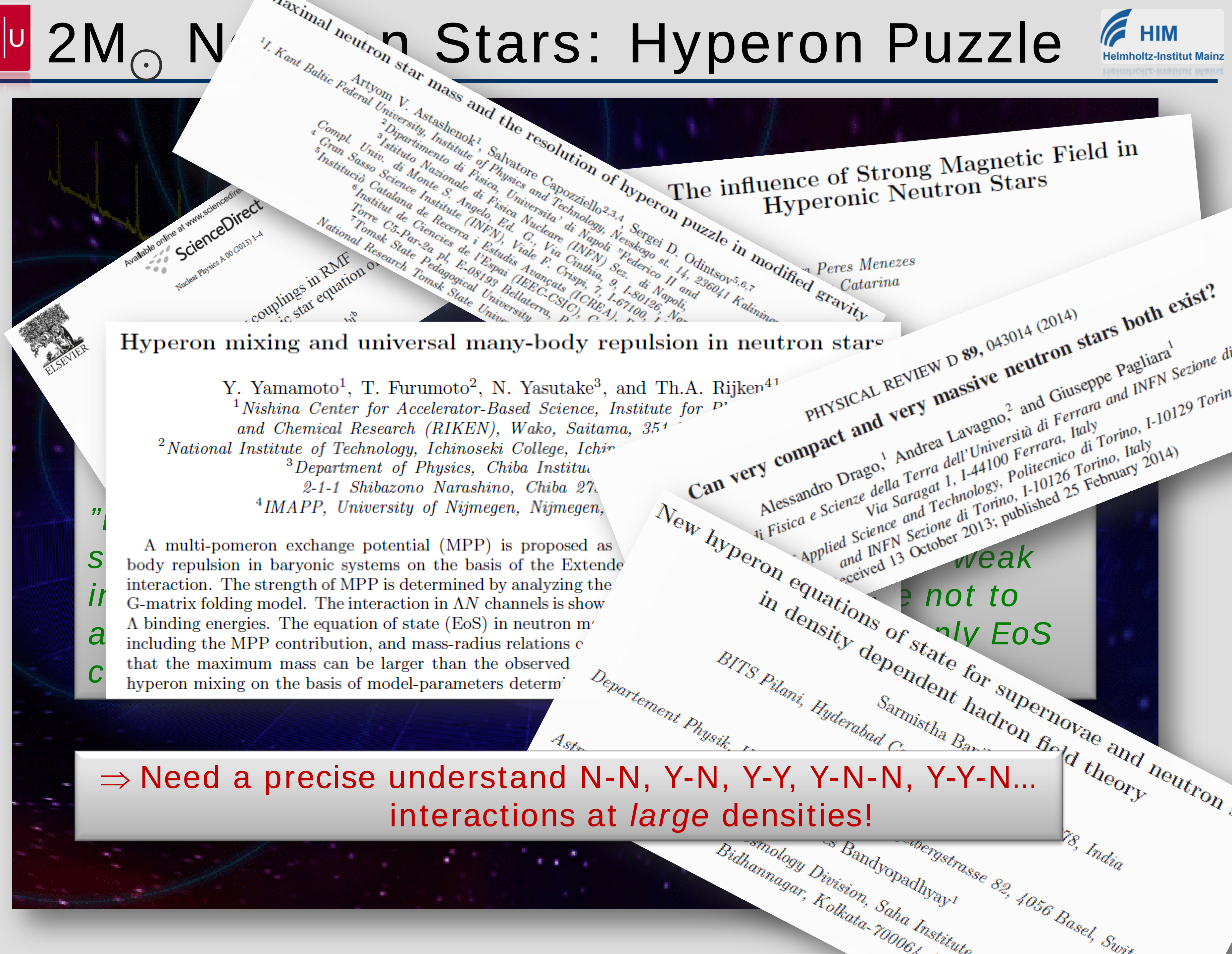
Strange baryons and antibaryons in nuclei: unique opportunities for $\bar{\mathrm{P}}$ANDA@FAIR

Josef Pochodzalla & Alicia Sanchez Lorente

Helmholtz-Institut Mainz

- **Motivation**
- **Antihyperons in nuclei at $\bar{\mathrm{P}}$ANDA**
- **Future options**

2M$_\odot$ Neutron Stars: Hyperon Puzzle

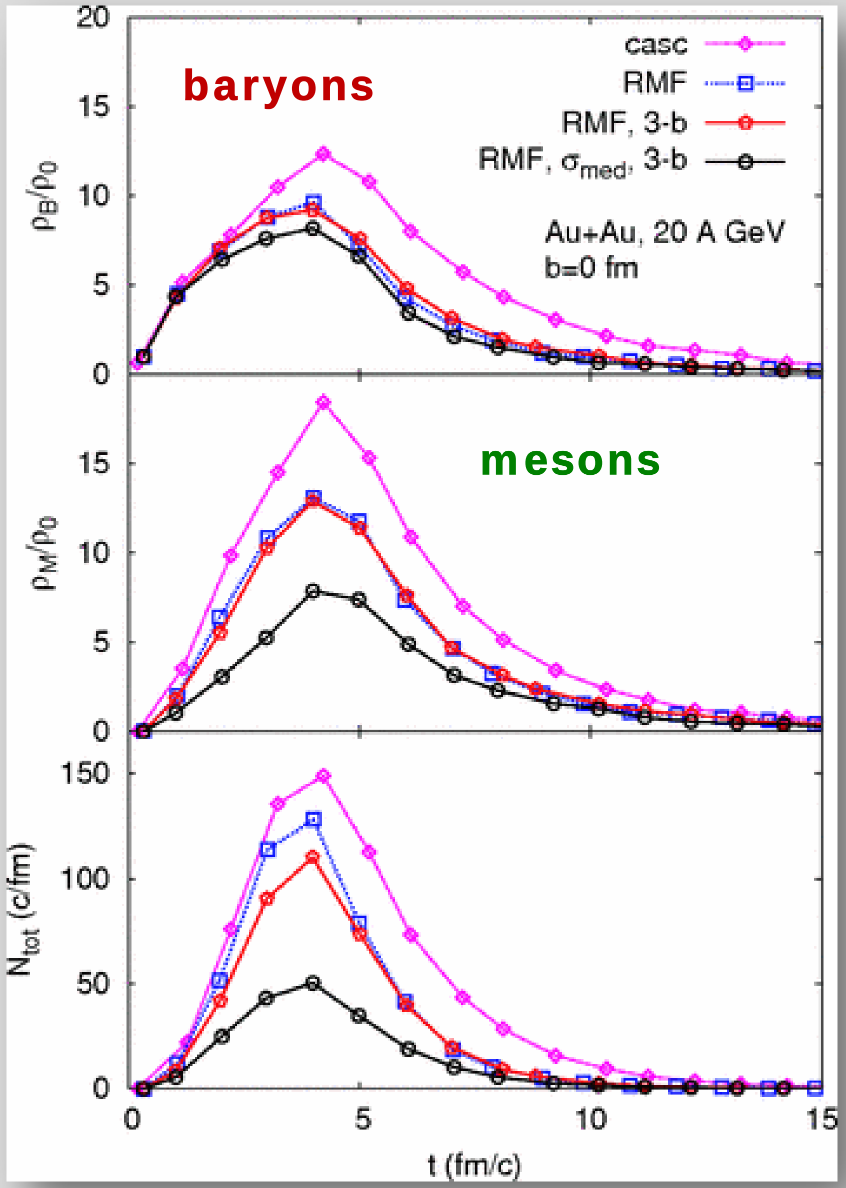


⇒ Need a precise understand N-N, Y-N, Y-Y, Y-N-N, Y-Y-N…
interactions at *large* densities!

The Short Distance Challenge

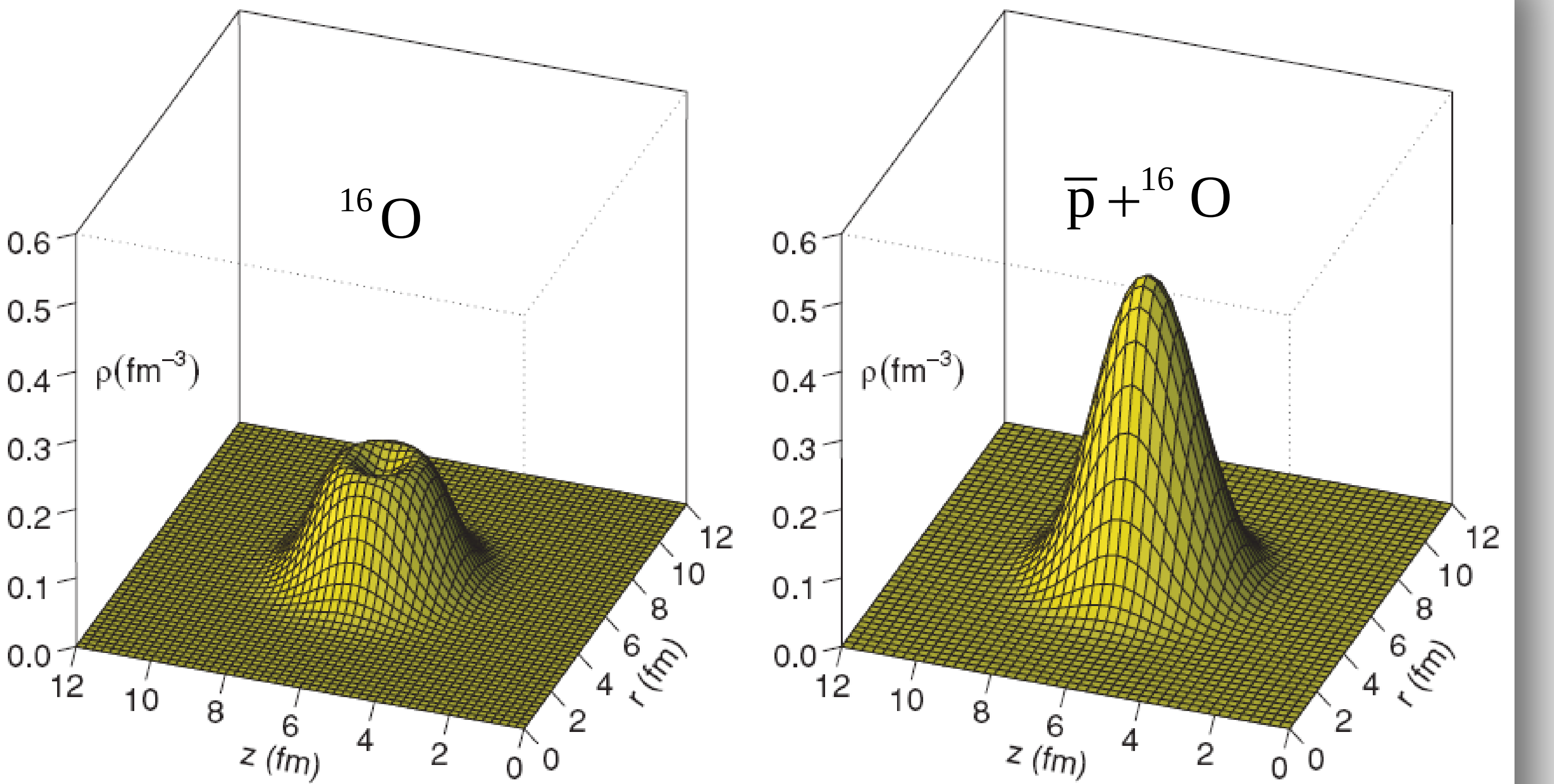
- Central heavy ion collisions are the conventional tool to probe high densities
- But...
  - Central collisions → hot hadronic finite matter with mesons and baryons
  - Neutron stars → Cold baryonic infinite matter

⇒ Let us try an complementary approach to dense baryonic matter



A.B. Larionov, O. Buss, K. Gallmeister, and U. Mosel
Phys. Rev. C 76, 044909 (2007)

Cold compression by antibaryons ?



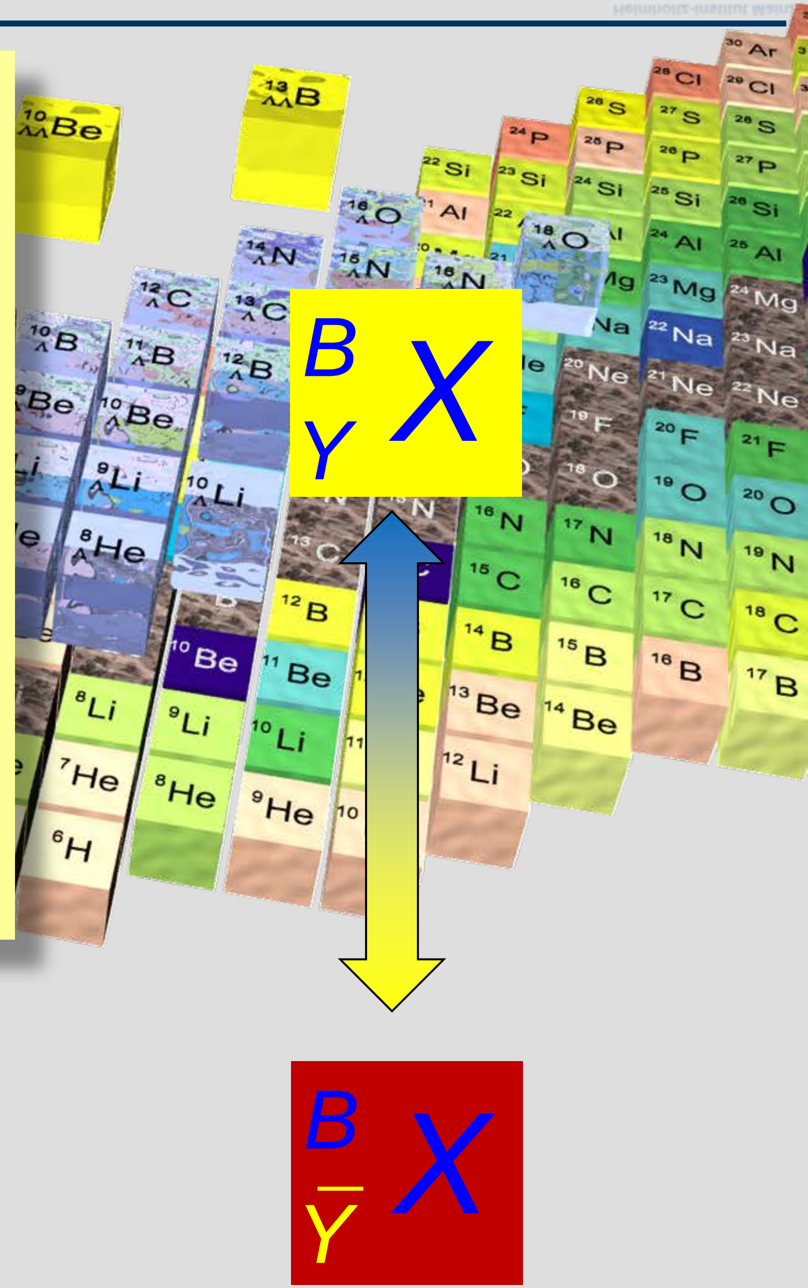
nucleon density in the ^{16}O nucleus (left) and in the bound $\overline{p}$ + ^{16}O system (right)

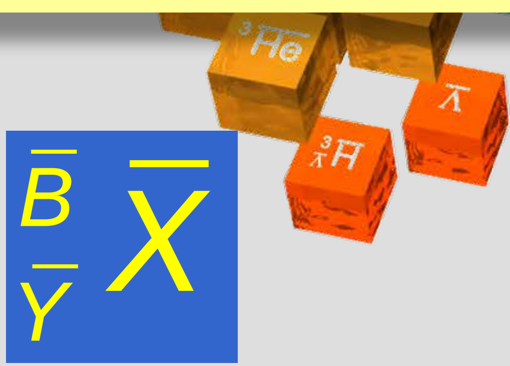
I. N. Mishustin, L. M. Satarov, T. J. Bürvenich, H. Stöcker, and W. Greiner

PHYSICAL REVIEW C **71**, 035201 (2005)

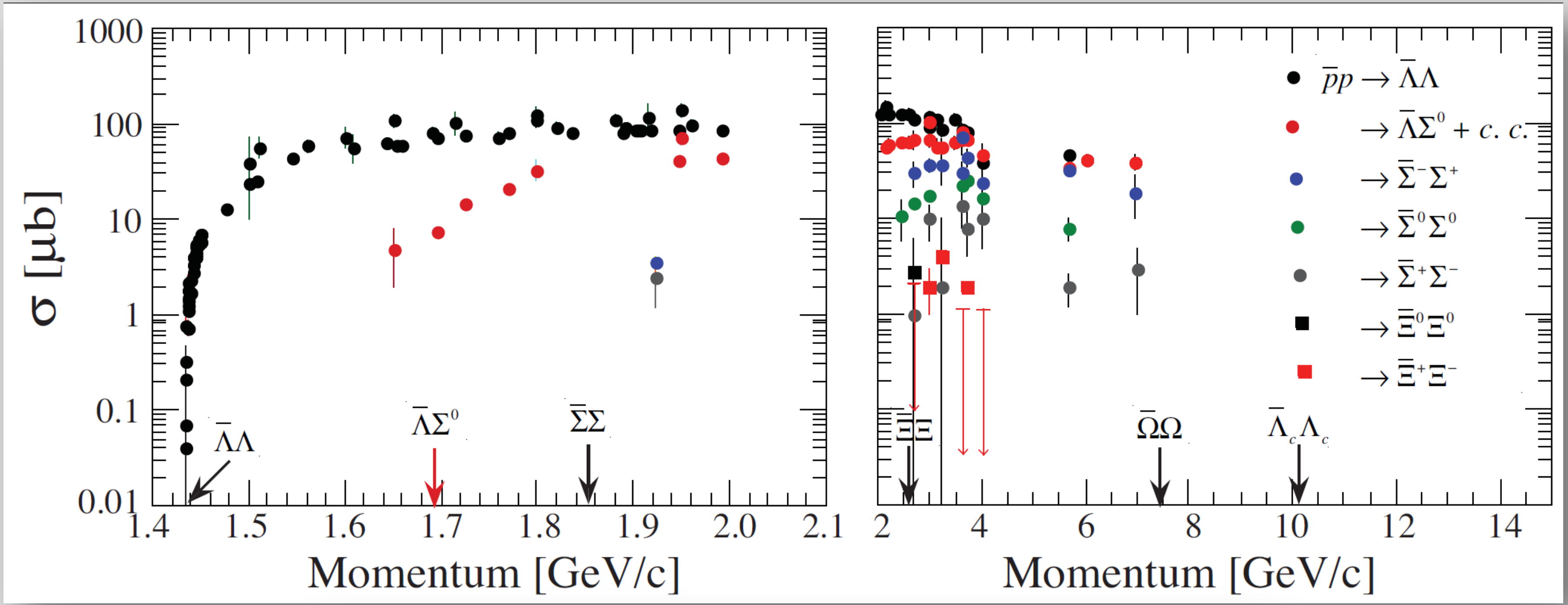
Nuclei with (Anti)hyperons

- G-parity relates NN with N$\bar{N}$ interaction (Dürr & Teller 1956)
- Coupling of baryons or antibaryons in nuclei could be related
- But: G-parity is broken for nucleons (V~-150MeV)!   Why?
- To what extent is G-parity broken with strange quarks ?
- Antibaryons in nuclei are a novel probe for short range interactions of strange baryons in nuclei





P̄ANDA – a Factory for strange *and* charmed YȲ-Pairs

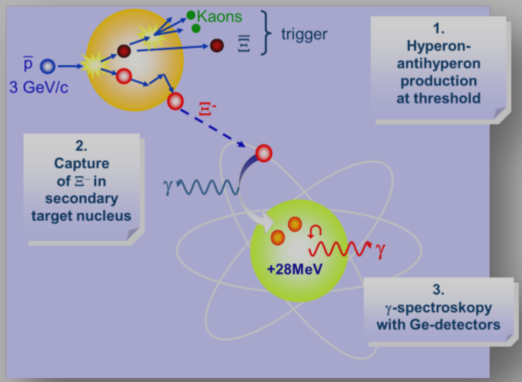


Momentum [GeV/c]	Reaction	Rate [s^{-1}]
1.64	$\overline{p}p \rightarrow \Lambda\overline{\Lambda}$	580
4	$\overline{p}p \rightarrow \Lambda\overline{\Lambda}$	980
	$\overline{p}p \rightarrow \overline{\Xi}^{+}\Xi^{-}$	30
15	$\overline{p}p \rightarrow \Lambda\overline{\Lambda}$	120

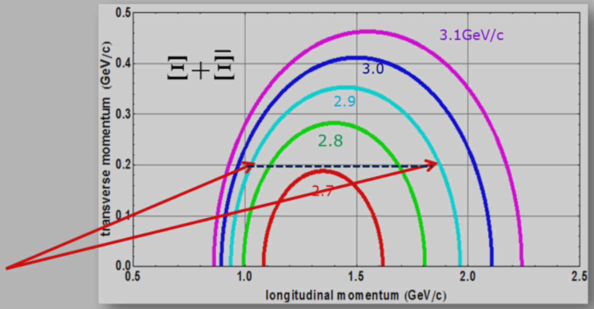
Table 4.45: Estimated count rates into their charged decay mode for the benchmark channels at a luminosity of $2 \cdot 10^{32} cm^{-2} s^{-1}$

Exploring (anti-)hyperon interactions

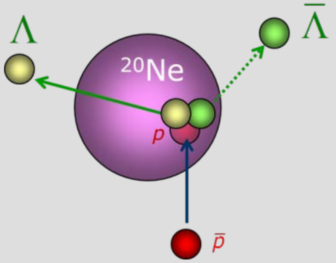
- Excited particle stable state spectroscopy
  - γ-spectroscopy PANDA@FAIR



- Secondary scattering of momentum tagged hyperons and antihyperons



- Antihyperons in atomic nuclei

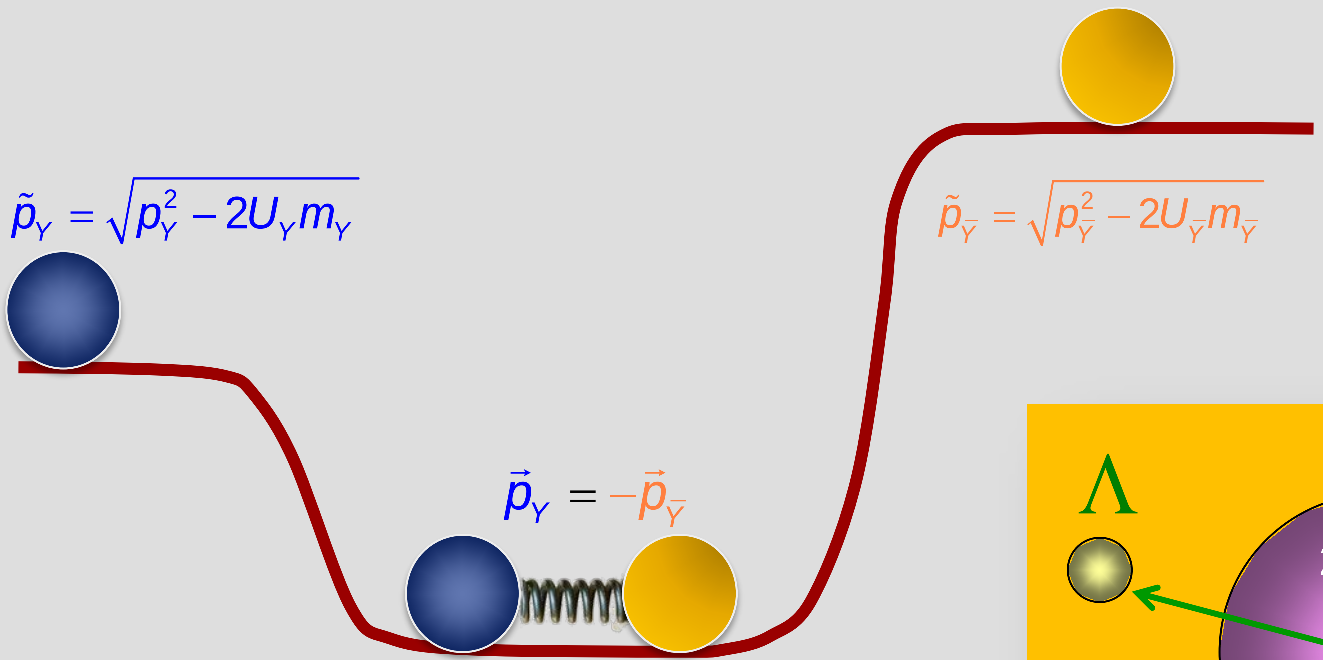


reaching for the unthinkable

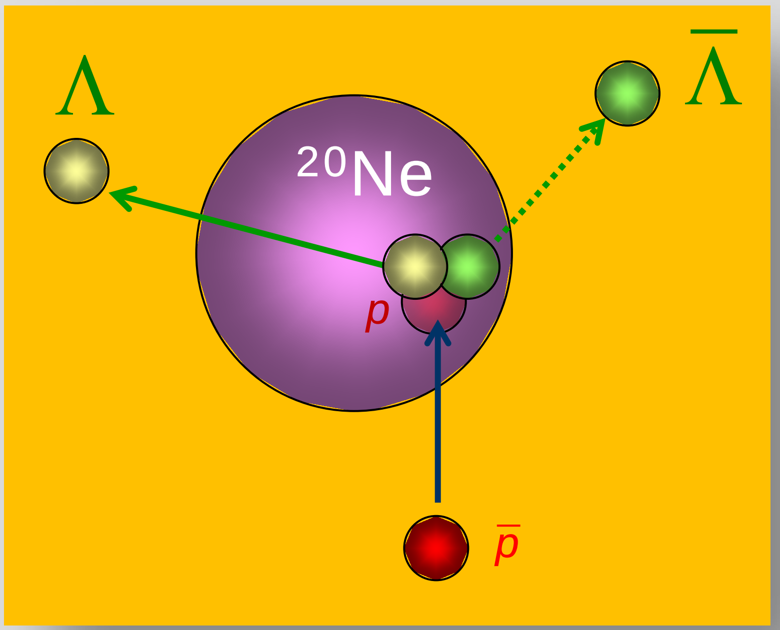
ANTIHYPRONS IN NUCLEI at PANDA

$\bar{\Lambda}$ Potential (in Neutron Matter)

- exclusive $\bar{p}+p(A) \rightarrow Y+\bar{Y}$ close to threshold within a nucleus
- Λ and $\bar{\Lambda}$ that leave the nucleus will have different asymptotic momenta depending on the respective potential



J.P., PLB **669** (2008) 306



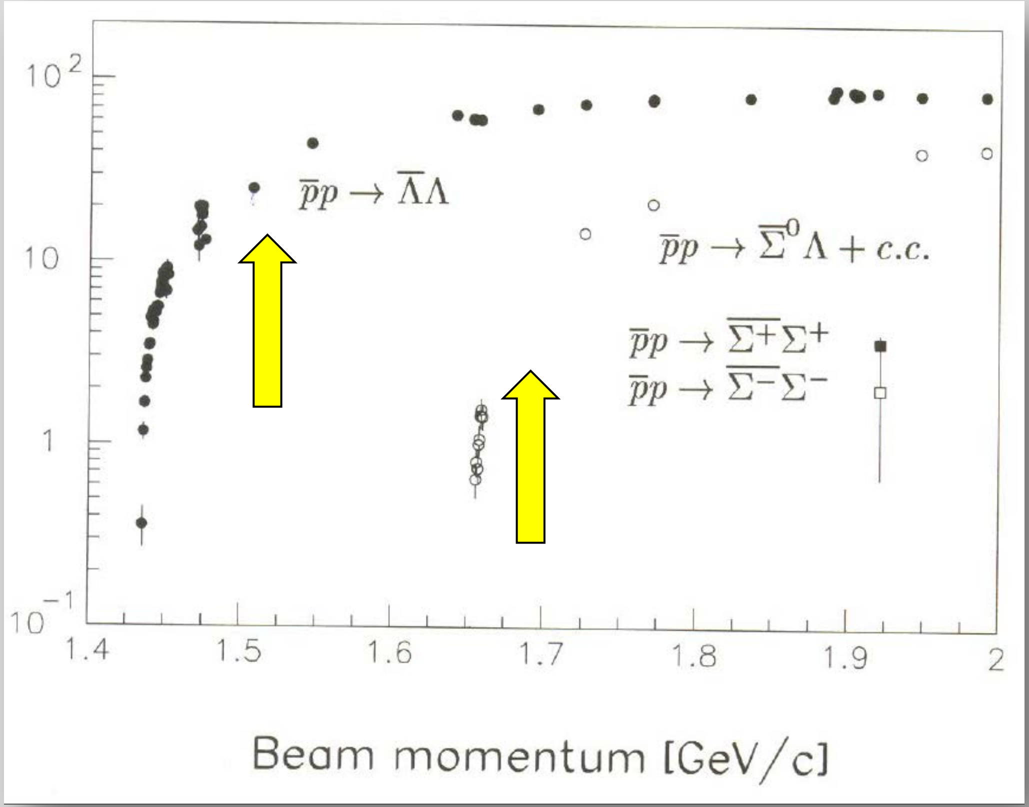
- ⇒ *transverse* momentum close to threshold of *coincident* $Y\bar{Y}$ pairs

$$\alpha_\perp = \left\langle \frac{p_\perp(\Lambda) - p_\perp(\bar{\Lambda})}{p_\perp(\Lambda) + p_\perp(\bar{\Lambda})} \right\rangle$$

GiBUU Simulations $\overline{p}+{}^{20}Ne \rightarrow \Lambda\overline{\Lambda}+X$

- GiBUU
  - G-parity used to estimate anti-baryon potentials except for $\overline{N}$
  - Approximately 15k exclusive $\Lambda\overline{\Lambda}$ pairs in each set
    corresponds to ~15 min $\overline{P}$ANDA incl. efficiency at $10^7 s^{-1}$

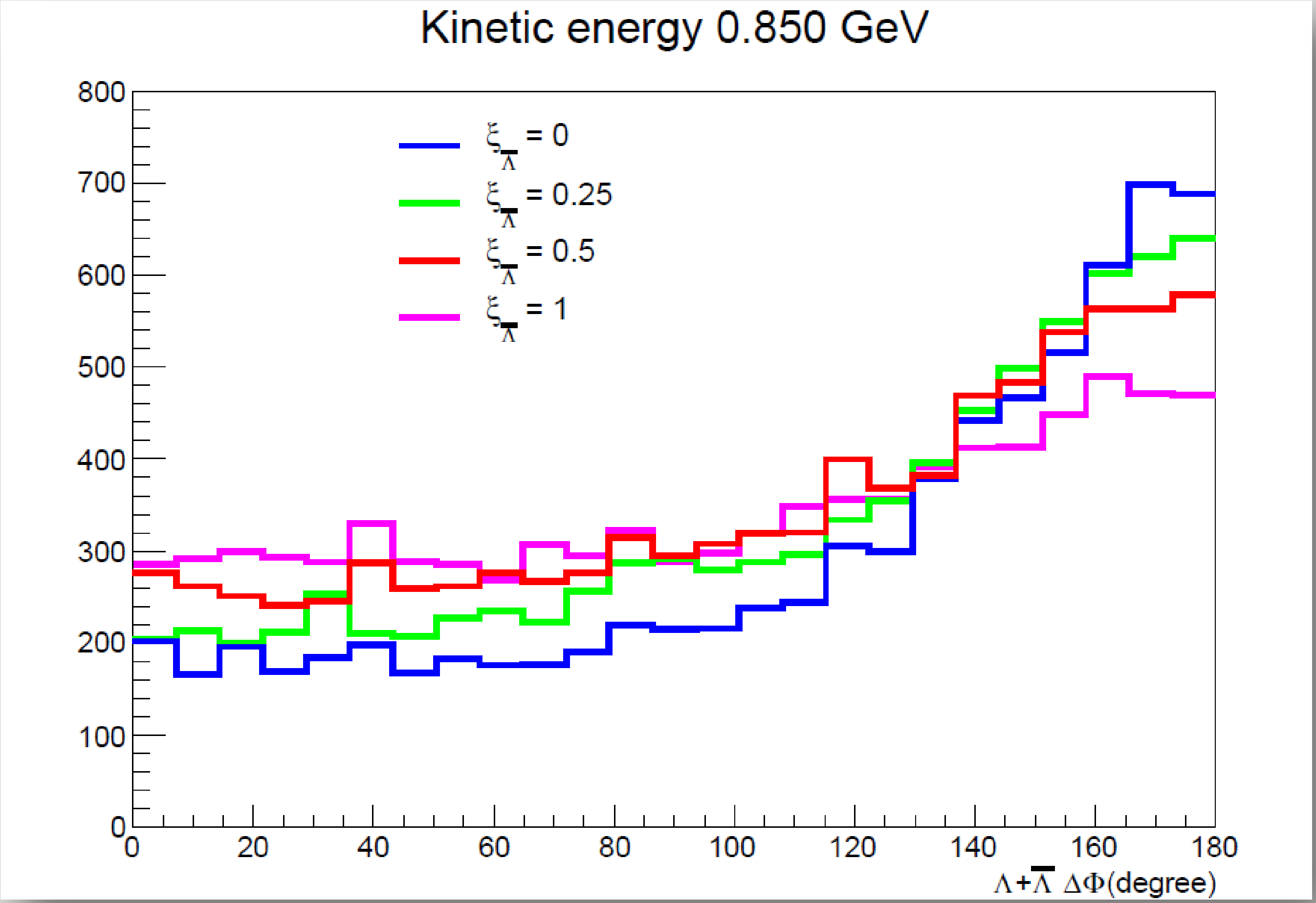
Energy (MeV)	Momentum (MeV/c)	Excess energy (MeV)
850	1522	30.6
1000	1696	92.0



- Aim of the present work
  - Explore sensitivity of α_T to a scaling of the real $\overline{Y}$ potential
  - Proof the feasibility of a measurement at $\overline{P}$ANDA
  - Trigger a fully self-consistent dynamical treatment of antihyperons in nuclei

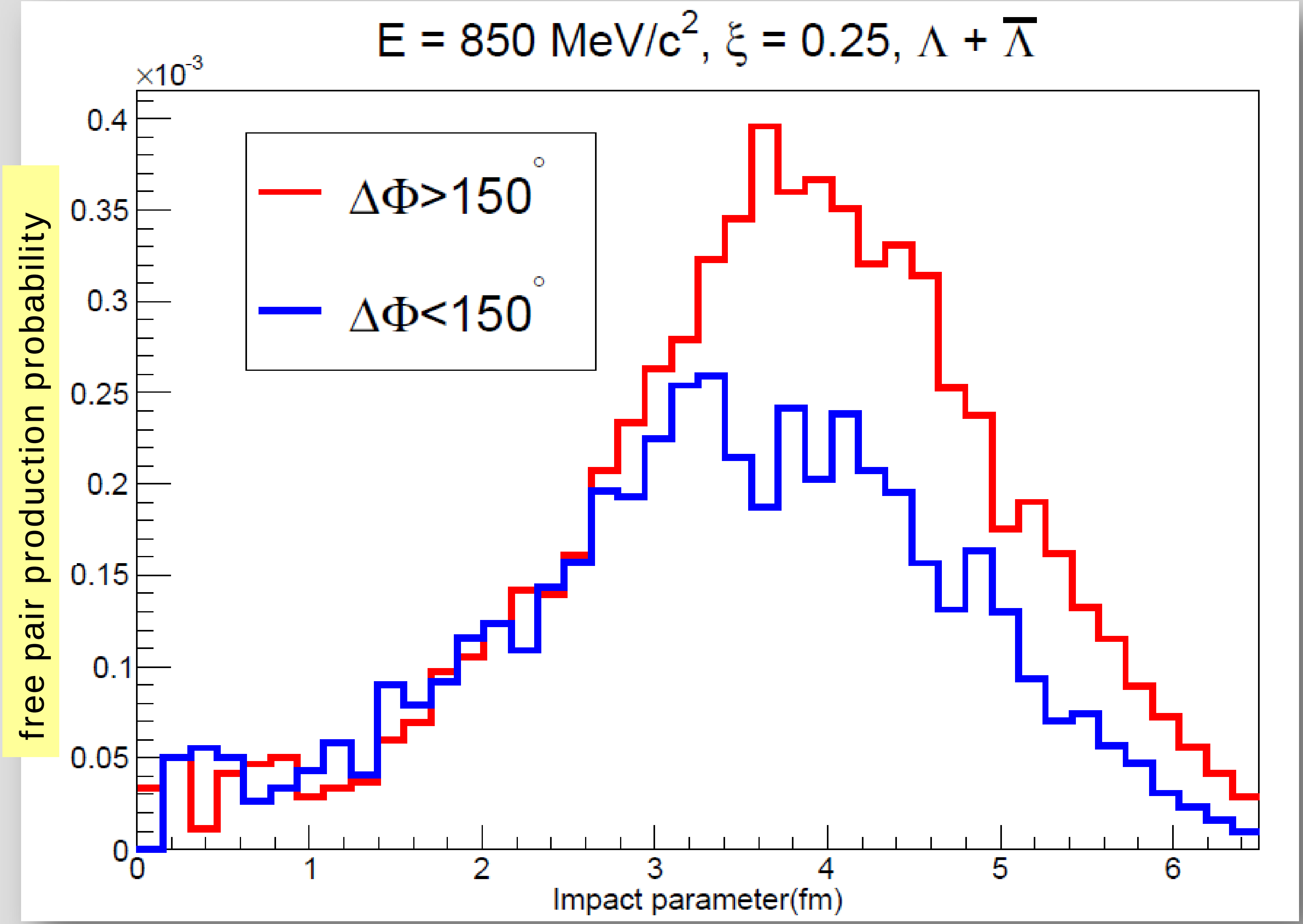
Rescattering effects

- Typical 15000 $\bar{\Lambda}\Lambda$ pairs produced



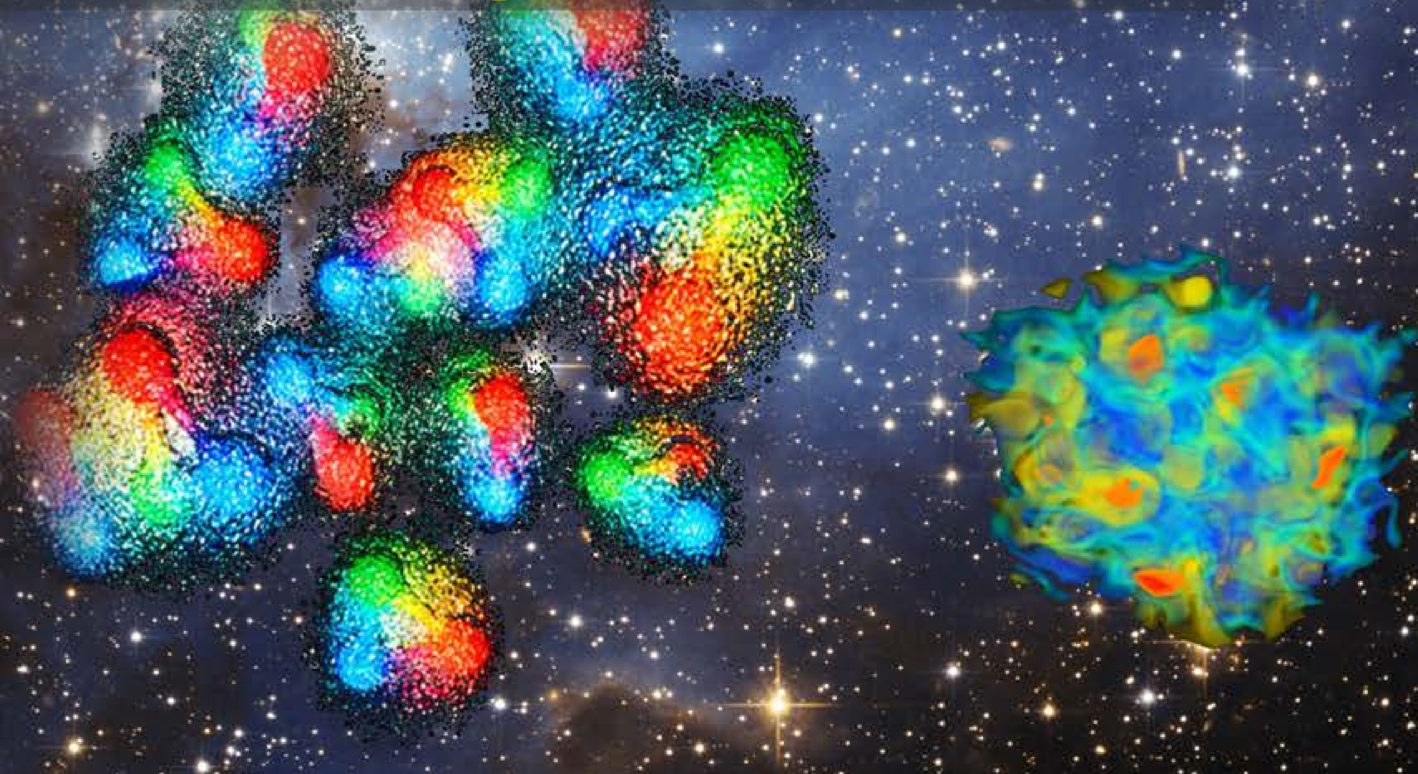
- Coplanarity distorted $\Rightarrow$ strong rescattering

Absorption, rescattering, geometry…



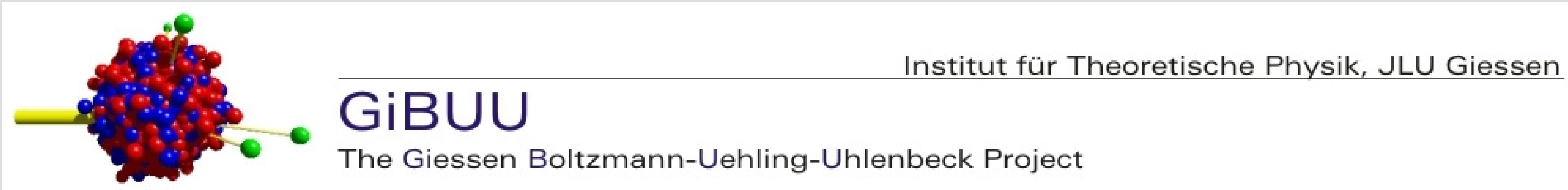
Is $Y - \bar{Y}$ pair production at all sensitive to the $\bar{Y}$ potential ?

Test case: Λ-$\bar{\Lambda}$ production



GiBUU 1.5

- https://gibuu.hepforge.org/trac/wiki



- G-parity used to estimate anti-baryons potential (except for $\bar{N}$)

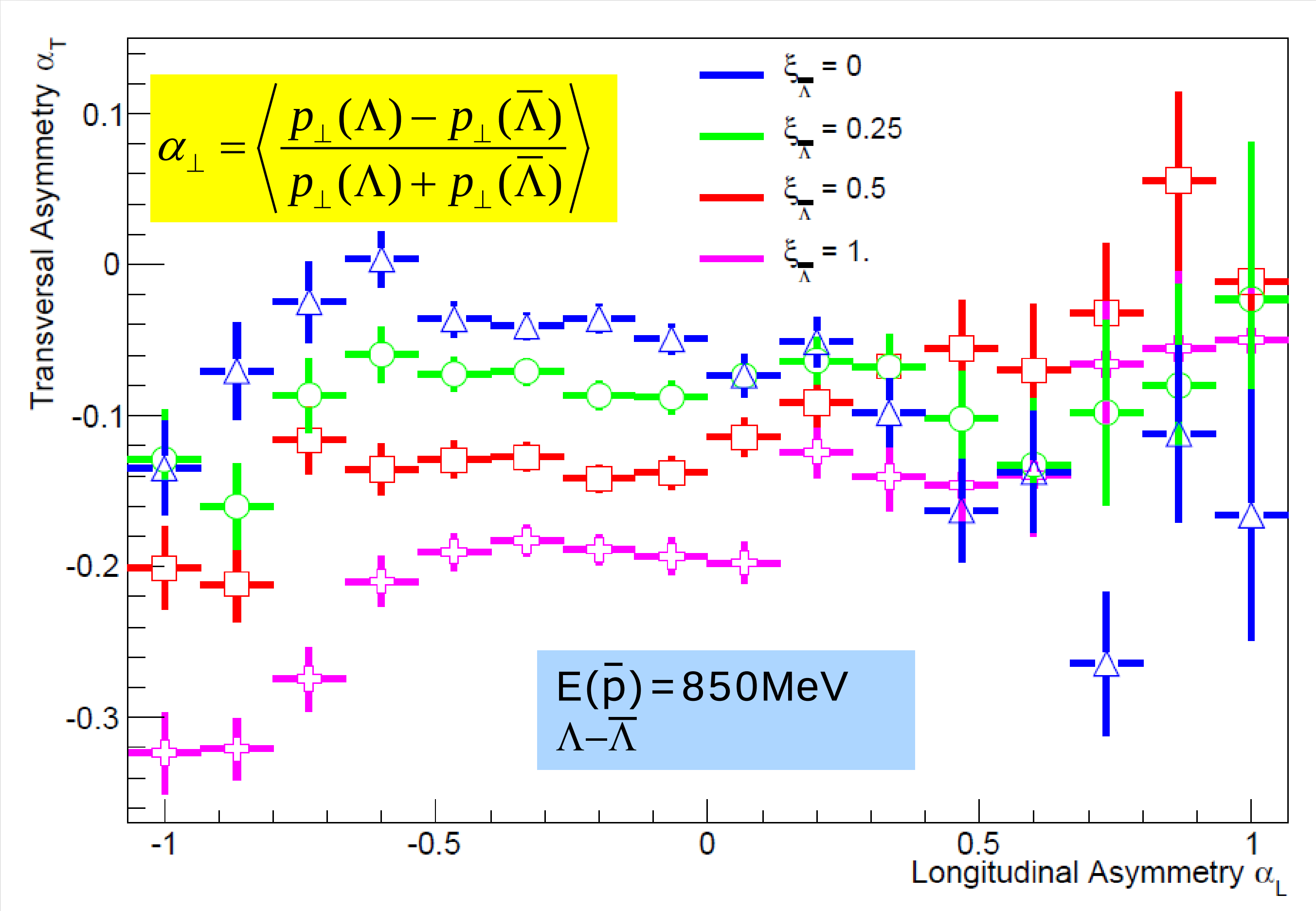
TABLE I: The Schrödinger equivalent potentials of different particles at zero kinetic energy, $U_i = S_i + V_i^0 + (S_i^2 - (V_i^0)^2)/2m_i$ (in MeV), in nuclear matter at ρ_0.

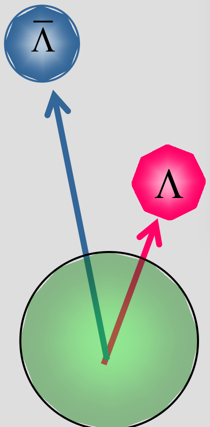
i	N	Λ	Σ	Ξ	$\bar{N}$	$\bar{\Lambda}$	$\bar{\Sigma}$	$\bar{\Xi}$	K	$\bar{K}$
U_i	-46	-38	-39	-22	-150	-449	-449	-227	-18	-224

- Antiproton potential is scaled by 0.22 to obtain -150MeV

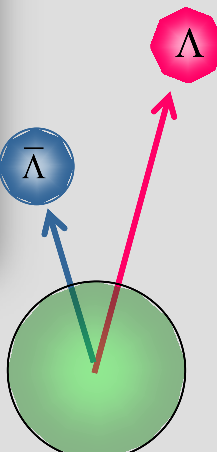
Scan of $\bar{\Lambda}$ Potential

- $U(\bar{\Lambda})$ = -449MeV, -225MeV, -112MeV, 0MeV
- All other potentials unchanged



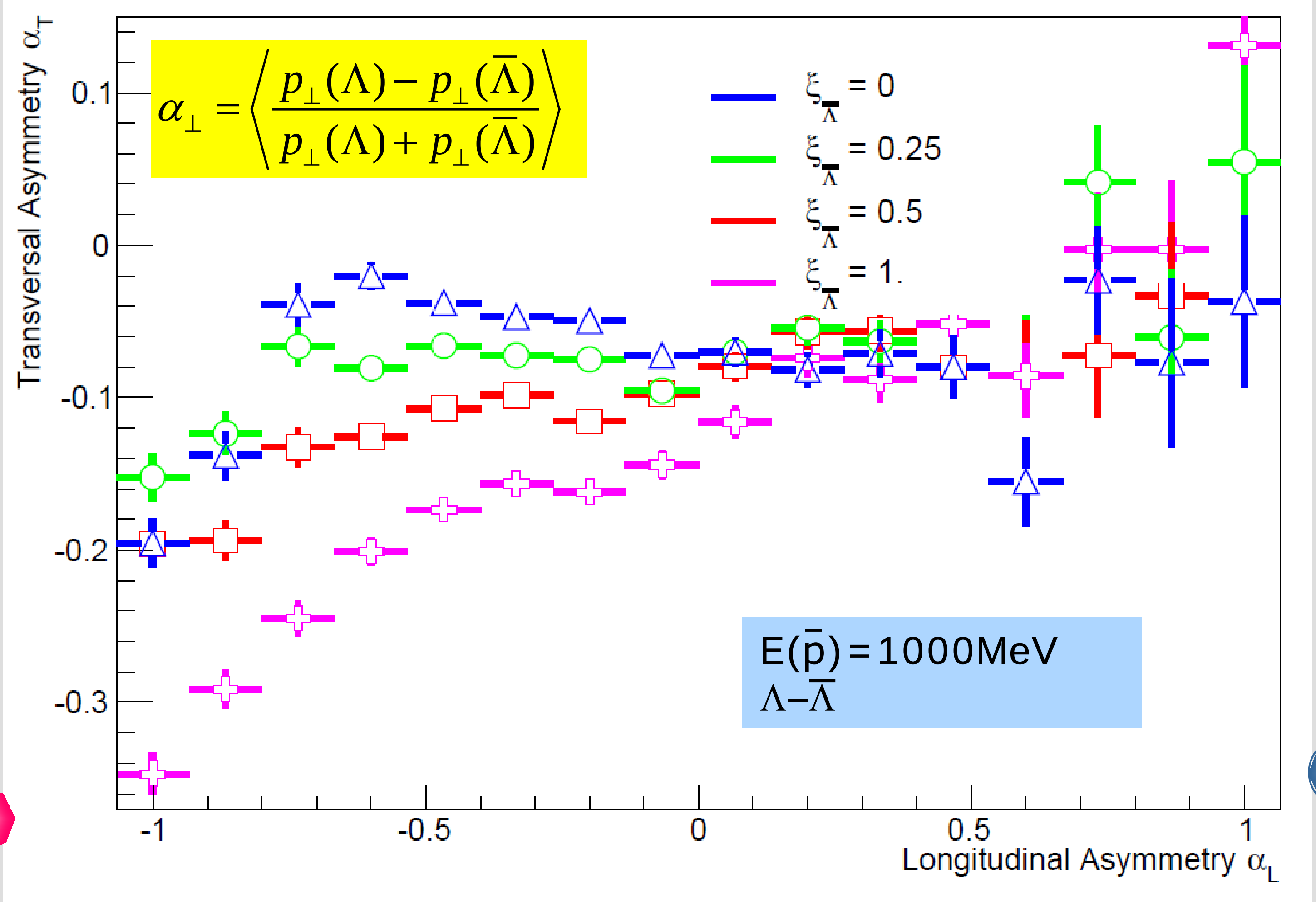


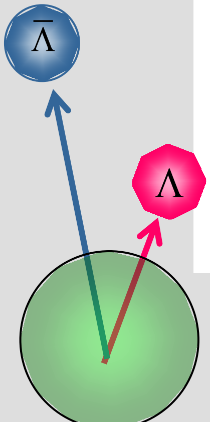
$$\alpha_L = \frac{p_L(\Lambda) - p_L(\bar{\Lambda})}{p_L(\Lambda) + p_L(\bar{\Lambda})}$$



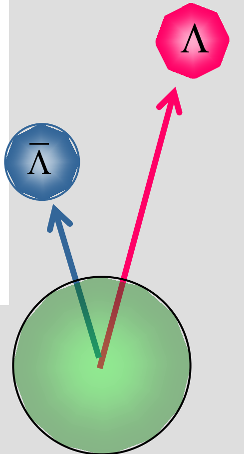
Scan of $\bar{\Lambda}$ Potential

- $U(\bar{\Lambda})$ = -449MeV, -225MeV, -112MeV, 0MeV
- All other potentials unchanged





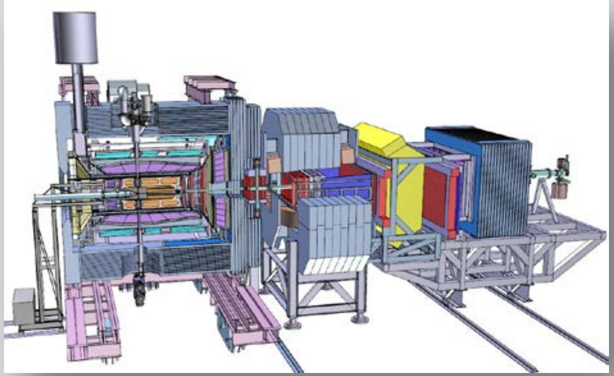
$$\alpha_L = \frac{p_L(\Lambda) - p_L(\bar{\Lambda})}{p_L(\Lambda) + p_L(\bar{\Lambda})}$$



Antihyperon-Hyperon Pairs in $\overline{\mathrm{P}}$ANDA

- 2018 first beam in $\overline{\mathrm{P}}$ANDA expected → commissioning phase
- We are right now exploring different scenarios
  - different detector availability
  - different solenoid fields (1T, 0.5T,...)

  and other important aspects like
  - luminosity
  - length of typical running period



- Typical (*preliminary*) $\overline{\Lambda}\Lambda$ pair efficiency ≈ 3-5% (better at higher momenta)
- $\overline{\Lambda}+\Lambda$ case
  - ^{nat}Ne target, H for calibration — systematic check
  - only charged particle detection — easy
  - assume average interactions rate — $10^6 s^{-1}$ (~10% of default luminosity)
  - pair reconstruction efficiency — ~3%

    ⇒ 144k detected $\overline{\Lambda}+\Lambda$ pairs per day ⇒ 10 × GiBUU

  - Moderate data taking period — *~14 days Ne target + 7 days p-target*

    ⇒ 130 × present GiBUU simulations

Future Options

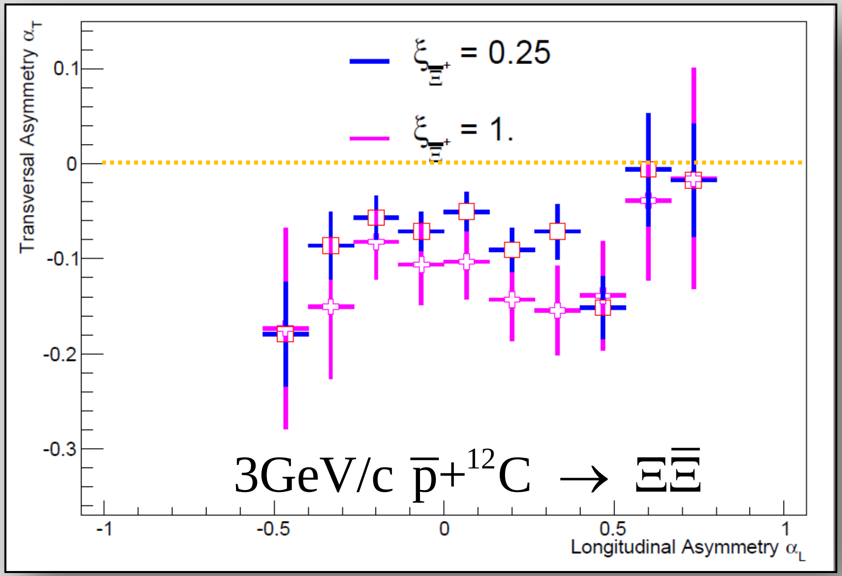
- $\overline{\Lambda}+\Sigma^-$
  - Ideal probe for interactions in the neutron skin
  - ^{20}Ne; ^{22}Ne, H for calibration; later: ^{86}Kr (36 Protons, 50 Neutrons)
  - Σ^- tracking, $\Sigma^- \rightarrow n\pi^-$
  - similar production rate (at least in light nuclei)

- Further options:
  - Any other pair: Σ-$\overline{\Sigma}$, Ξ-$\overline{\Xi}$, $\Lambda_c\overline{\Lambda}_c$
  - Long lived resonances in nuclei

    $\Lambda(1520)$ (Γ= 15.6 MeV)

    $\Xi(1530)$ (Γ=9.9 MeV)

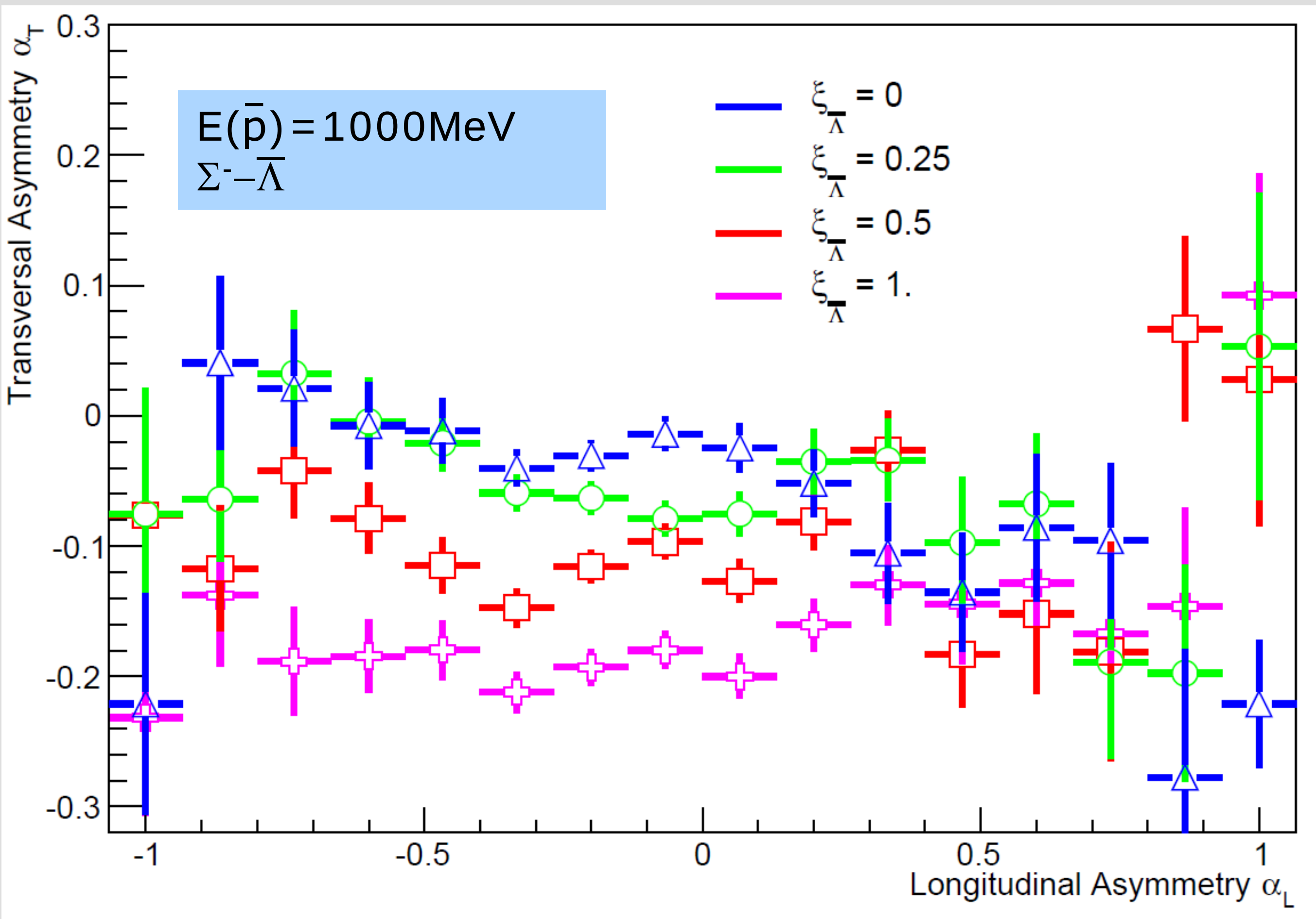
    $\Lambda_c(2880)$ (Γ=5.8MeV)



- Unique change to study charmed baryons in nuclear systems ?

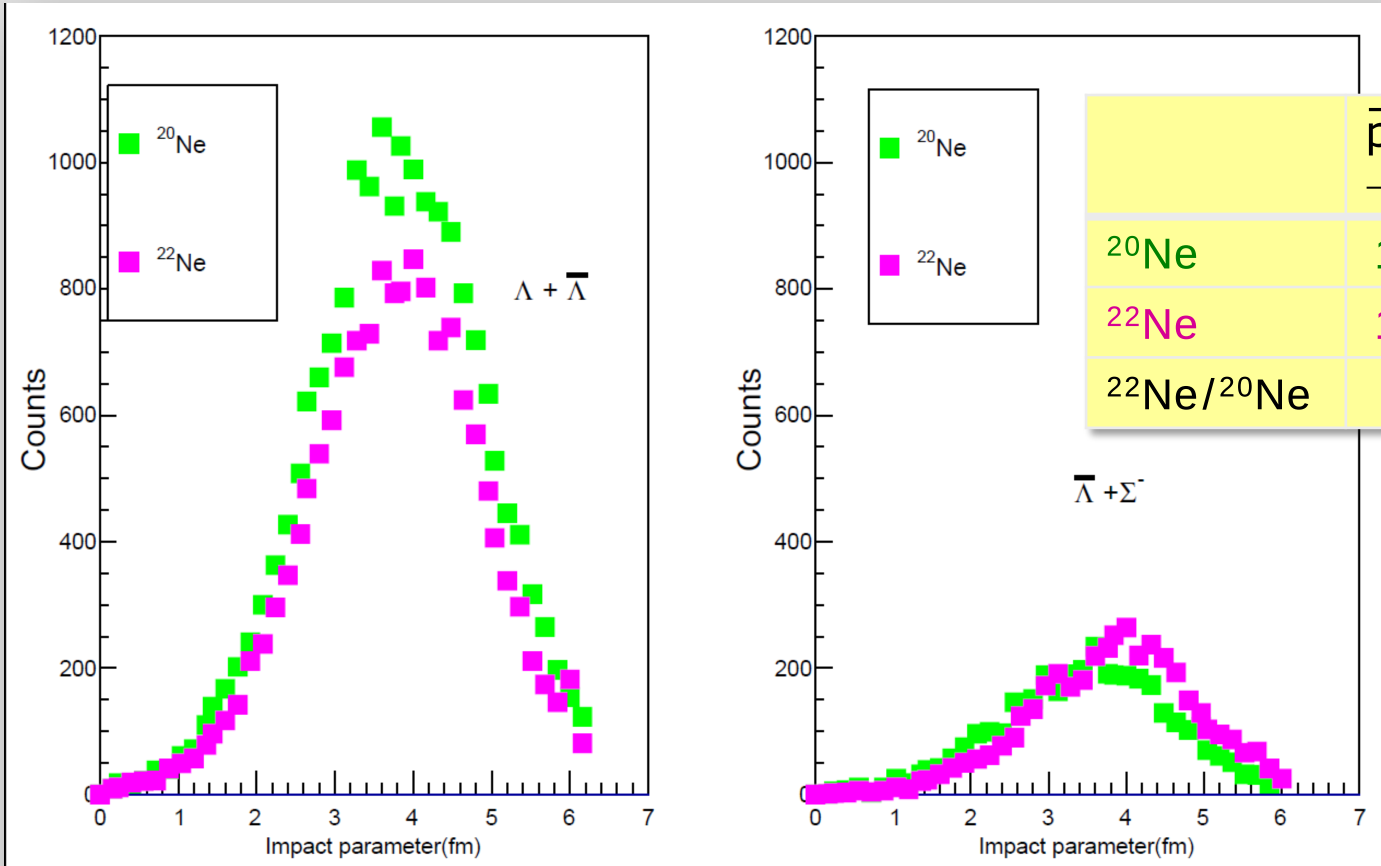
Other |s|=1 channels @ 1000MeV

- $\bar{p} + p \to \bar{\Lambda} + \Lambda$ $\quad\quad$ $\bar{p} + p \to \bar{\Sigma}^0 + \Lambda$
- $\bar{p} + n \to \bar{\Lambda} + \Sigma^-$ $\quad\quad$ $\bar{p} + n \to \bar{\Sigma}^+ + \Lambda$
- all antihyperon potentials scaled by same factor



Reactions within the Neutron Skin

- 1000MeV $\bar{p}+{}^{20}Ne$ and $\bar{p}+{}^{22}Ne$; $\xi(\bar{\Lambda}) = 0.25$



	$\bar{p}+p \to \bar{\Lambda}+\Lambda$	$\bar{p}+n \to \bar{\Lambda}+\Sigma^-$
^{20}Ne	18808	3667
^{22}Ne	15733	4516
^{22}Ne/^{20}Ne	0.84	1.23

- When going from ^{20}Ne to ^{22}Ne two competing effects
  - more absorption of ingoing $\bar{p}$ in thicker n-skin $\Rightarrow$ less $\bar{\Lambda}\Lambda$ and more $\bar{\Lambda}\Sigma^-$
  - more absorption of outgoing $\bar{\Lambda}$ in thicker n-skin $\Rightarrow$ less $\bar{\Lambda}\Lambda$ and less $\bar{\Lambda}\Sigma^-$
- $\bar{\Lambda}+\Sigma^-$ and $\bar{\Lambda}+\Lambda$ production may probe the neutron skin
- Possibility to explore potentials in neutron-rich environment ?

Stored antiproton beams at FAIR offer several unique opportunities to study the interactions of hyperons and antihyperons in nuclear systems

$\bar{\text{P}}$ANDA is an excellent and unique factory for strange and charmed $\bar{Y}Y$ pairs

The $\bar{\Lambda}$-Λ production is an ideal experiment for the commissioning phase of $\bar{\text{P}}$ANDA