

Perspectives of Hadron Physics at GSI meeting on 20.1.1998

present: P. Braun-Munzinger, F. Cloos, R. Franzke, R. Friesen, I. Hüfner, D. Kiesel, D.

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 (\bar{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.

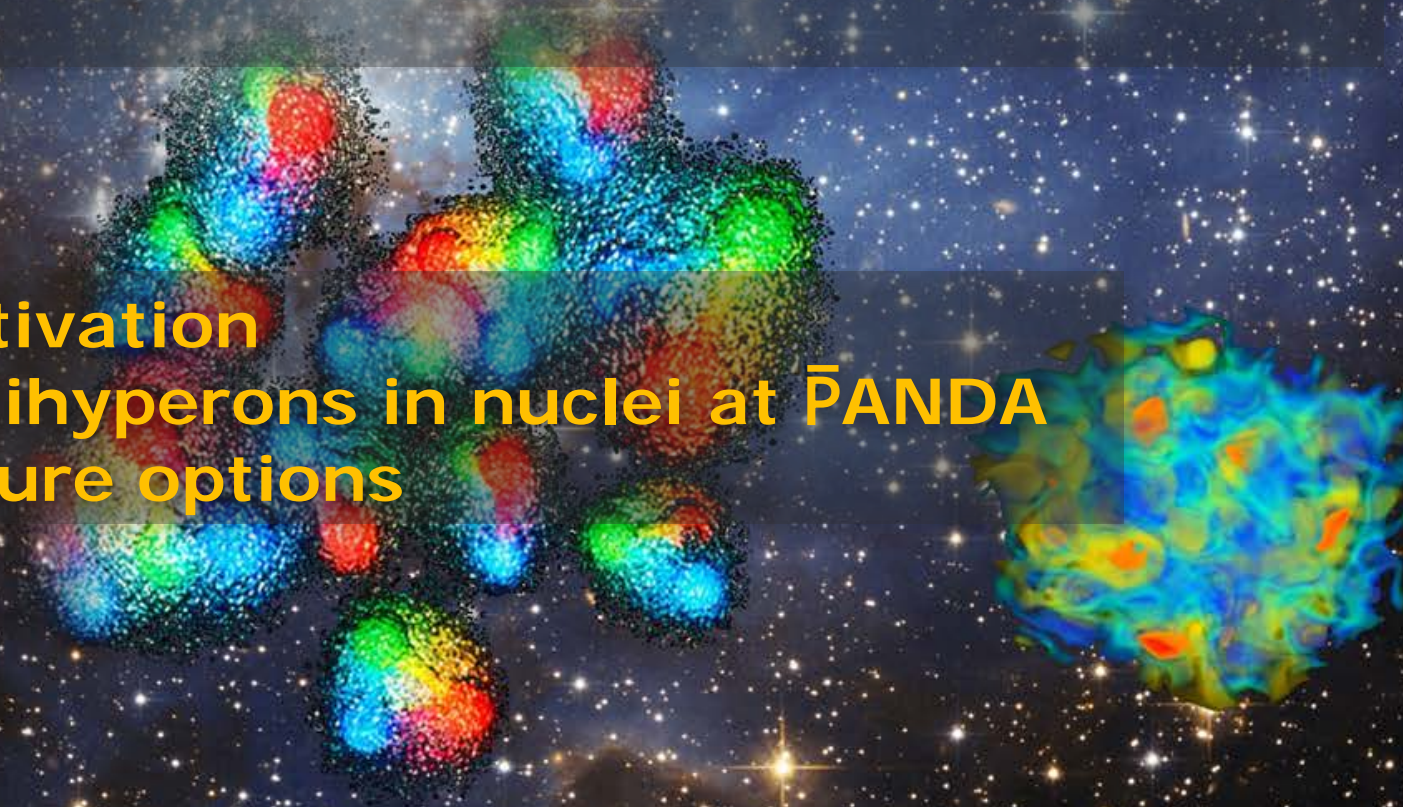
International Conference on Science and Technology for FAIR in Europe

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

Josef Pochodzalla & Alicia Sanchez Lorente

Helmholtz-Institut Mainz

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



Hyperon mixing and universal many-body repulsion in neutron stars

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A multi-pomeron exchange potential (MPP) is proposed as many-body repulsion in baryonic systems on the basis of the Extended Walecka model. The strength of MPP is determined by analyzing the G-matrix folding model. The interaction in ΛN channels is shown to be repulsive. The Λ binding energies. The equation of state (EoS) in neutron matter including the MPP contribution, and mass-radius relations are calculated. It is shown that the maximum mass can be larger than the observed maximum mass of neutron stars. Hyperon mixing on the basis of model-parameters determined by the MPP is also discussed.

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

The influence of Strong Magnetic Field in Hyperonic Neutron Stars

Peres Menezes
Catarina

Can very compact and very massive neutron stars both exist?

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New hyperon equations of state for supernovae and neutron stars in density dependent hadron field theory

weak
not to
only EoS

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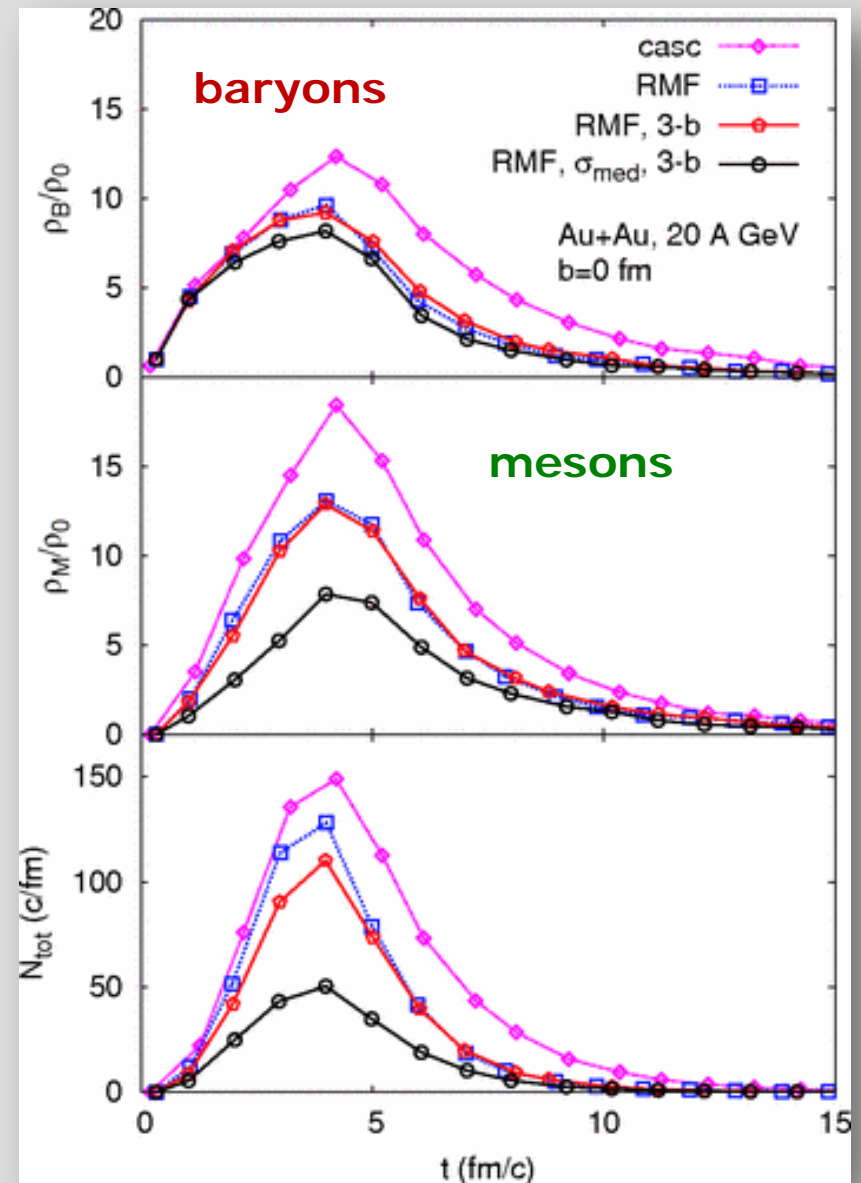
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Nuclear Physics A 00 (2013) 1-4

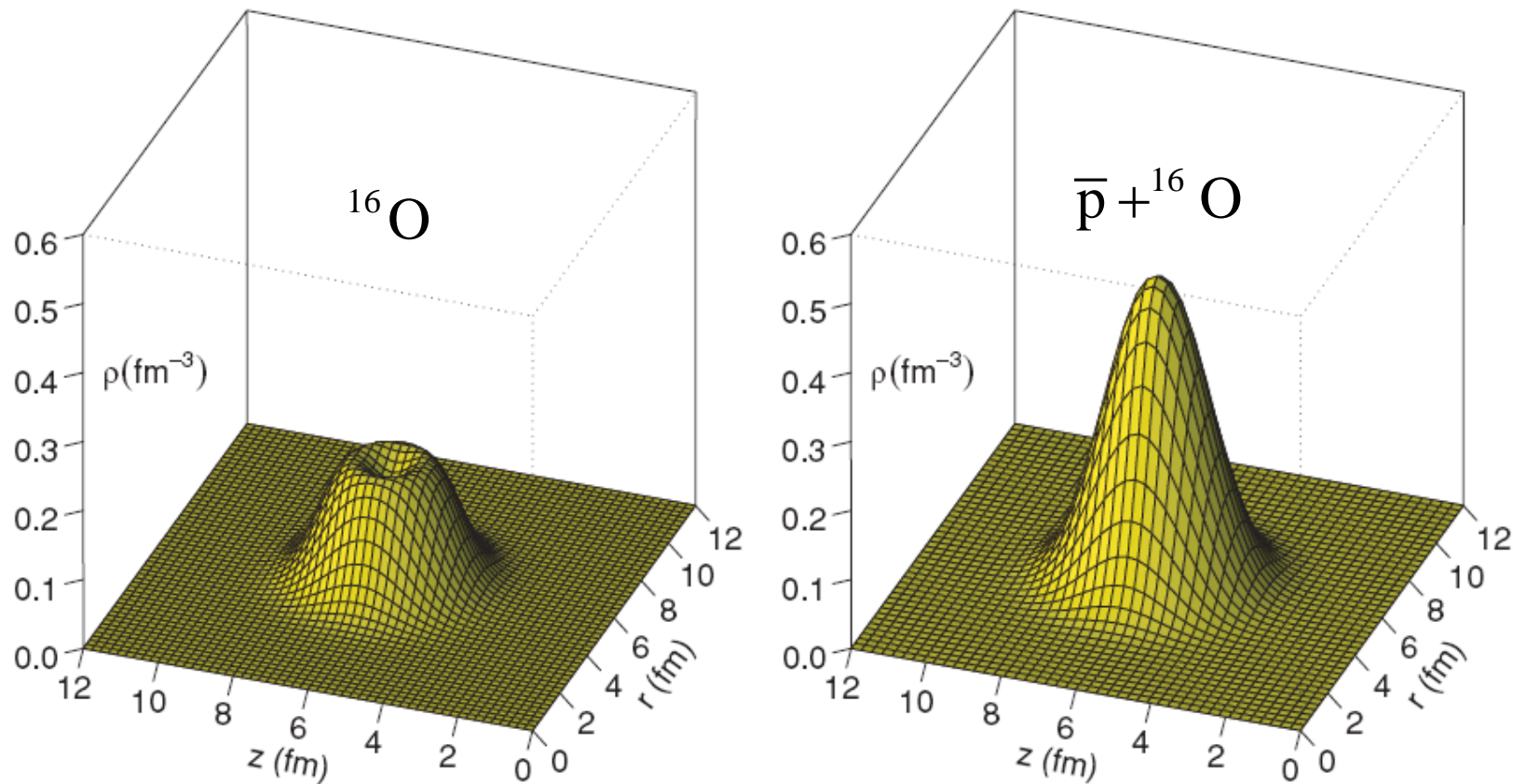


The Short Distance Challenge

- ▶ 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





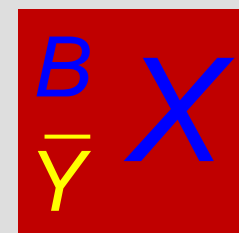
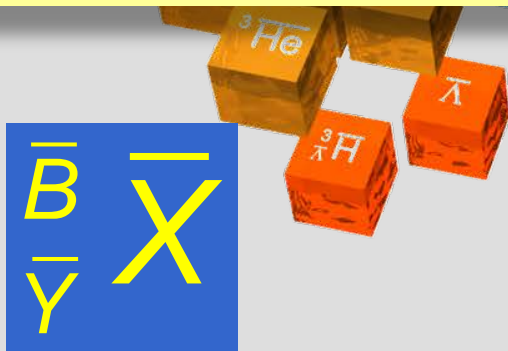
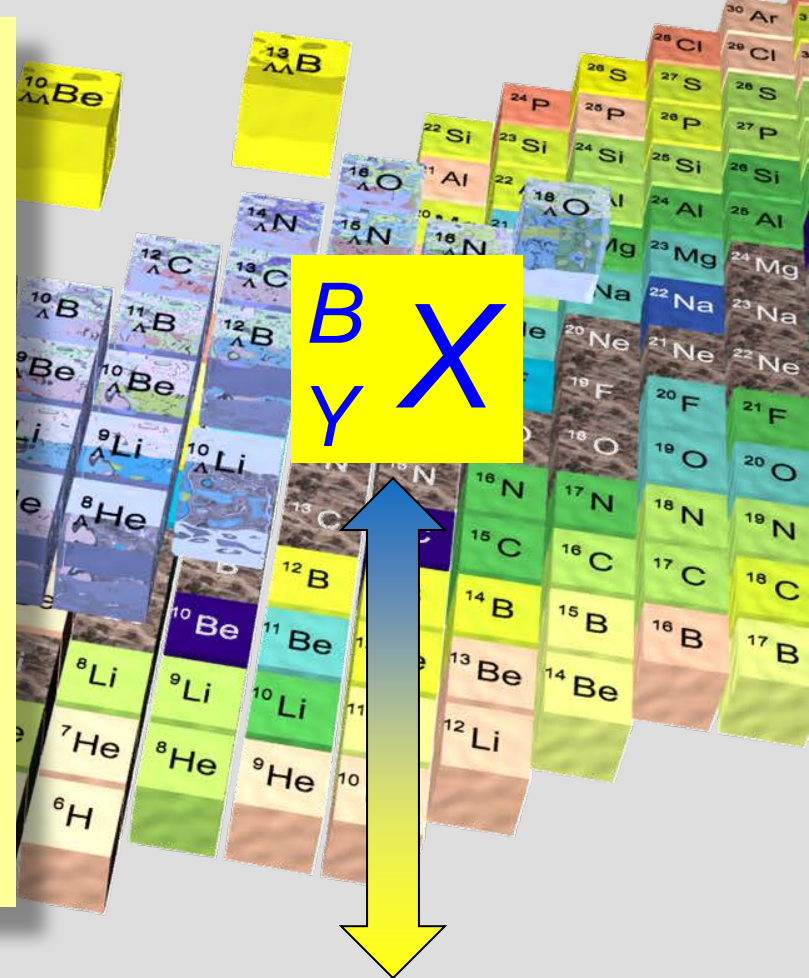
nucleon density in the ^{16}O nucleus (left) and in the bound $\bar{p} + ^{16}\text{O}$ system (right)

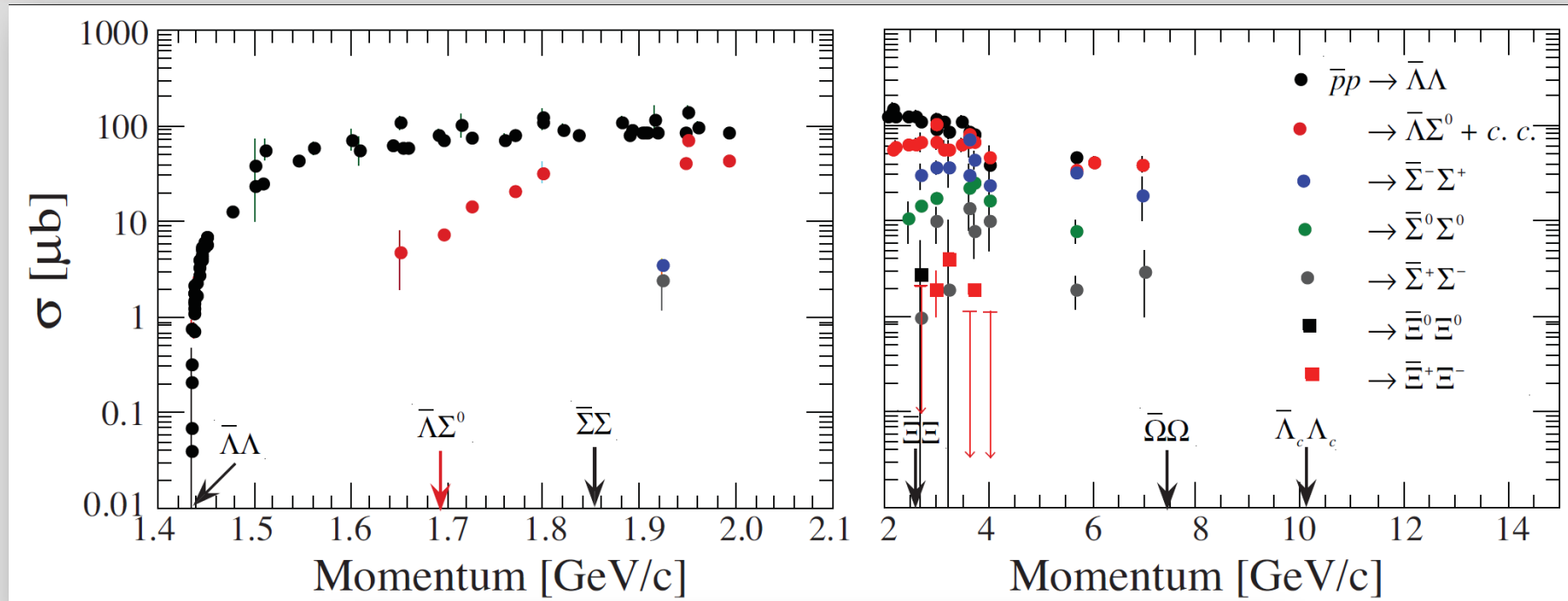
I. N. Mishustin, L. M. Satarov, T. J. Bürvenich, H. Stöcker, and W. Greiner

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 ($V \sim -150\text{MeV}$)! 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

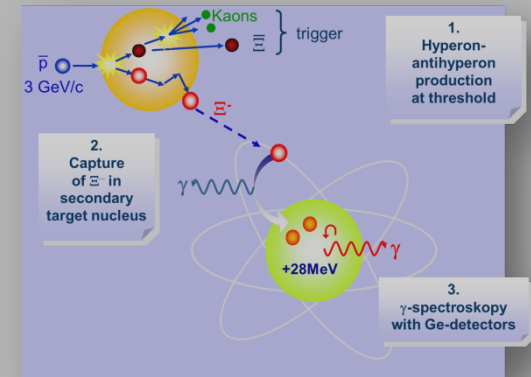




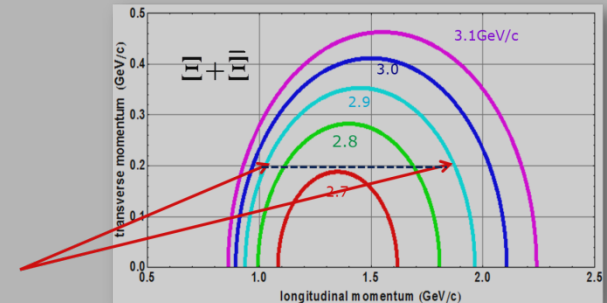
Momentum [GeV/c]	Reaction	Rate [s^{-1}]
1.64	$\bar{p}p \rightarrow \Lambda\bar{\Lambda}$	580
4	$\bar{p}p \rightarrow \Lambda\bar{\Lambda}$	980
	$\bar{p}p \rightarrow \bar{\Xi}^+\Xi^-$	30
15	$\bar{p}p \rightarrow \Lambda\bar{\Lambda}$	120

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

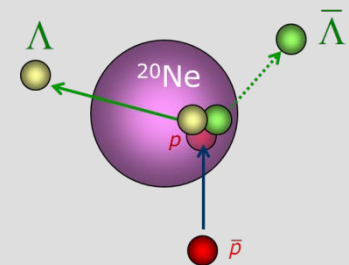
- ▶ Excited particle stable state spectroscopy
 - ▶ γ -spectroscopy **PANDA@FAIR**



- ▶ Secondary scattering of momentum tagged hyperons and antihyperons

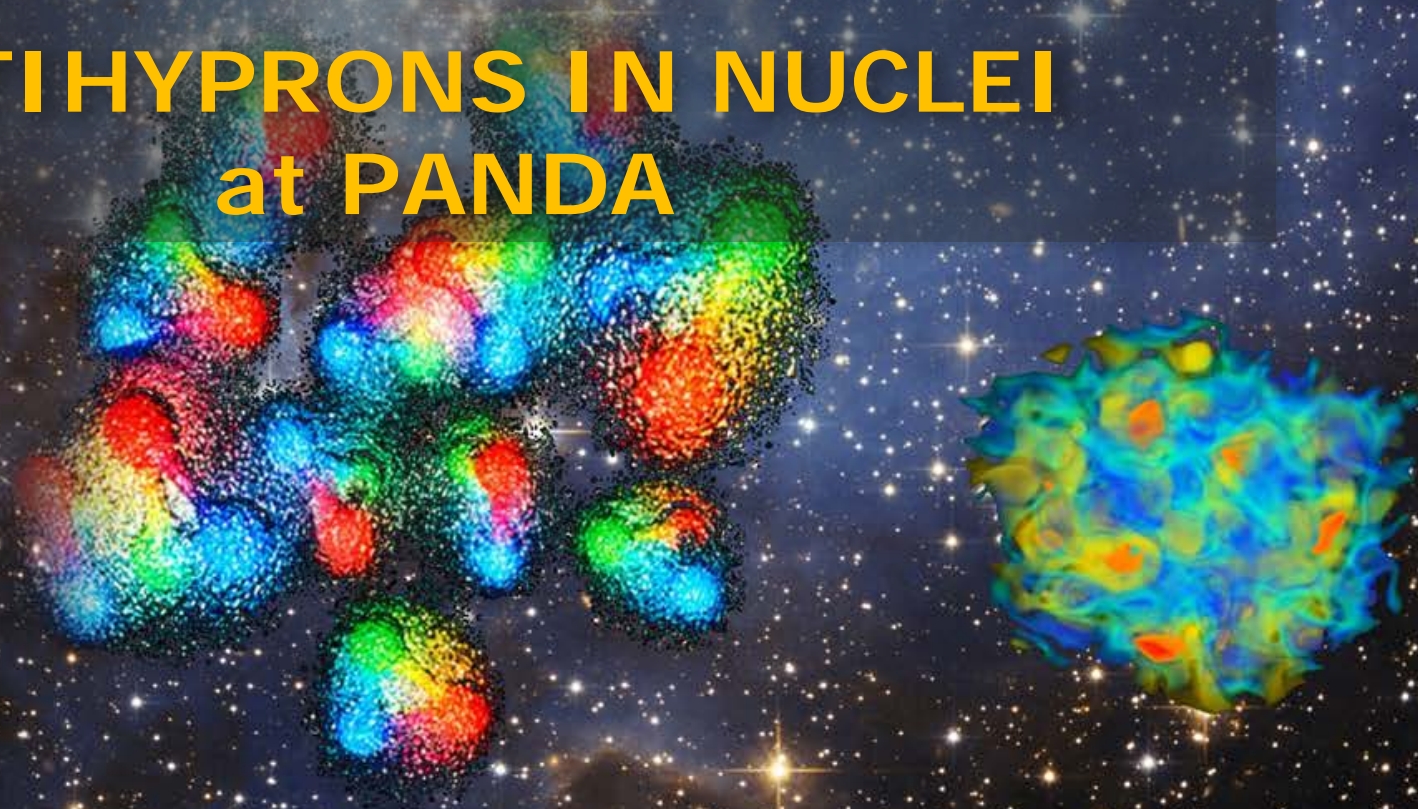


- ▶ Antihyperons in atomic nuclei

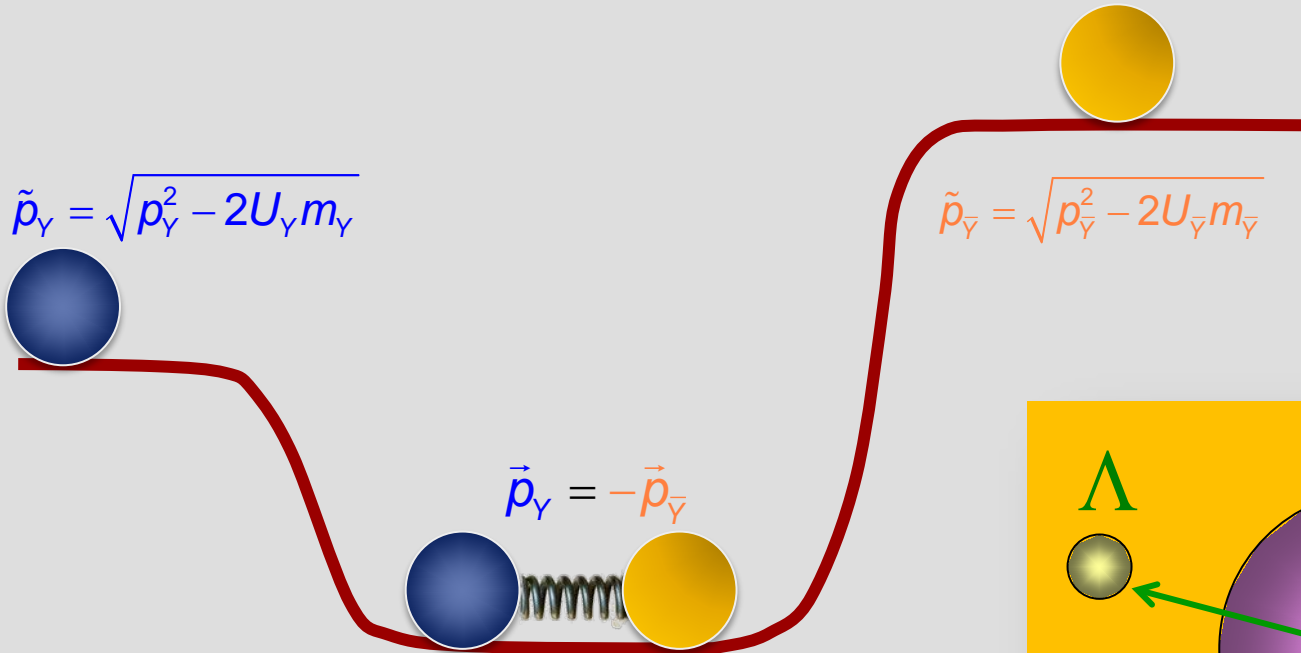


reaching for the unthinkable

**ANTIHYPRONS IN NUCLEI
at PANDA**



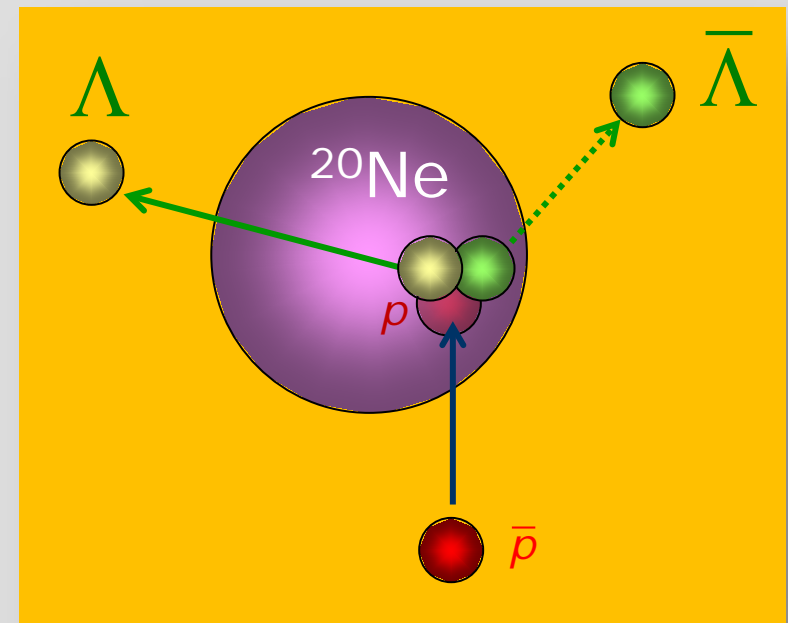
- ▶ **exclusive** $\bar{p}+p(A) \rightarrow Y+\bar{Y}$ **close to threshold** **within a nucleus**
- ▶ Λ and $\bar{\Lambda}$ that **leave the nucleus** will have different asymptotic momenta depending on the respective potential



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

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

J.P., PLB 669 (2008) 306

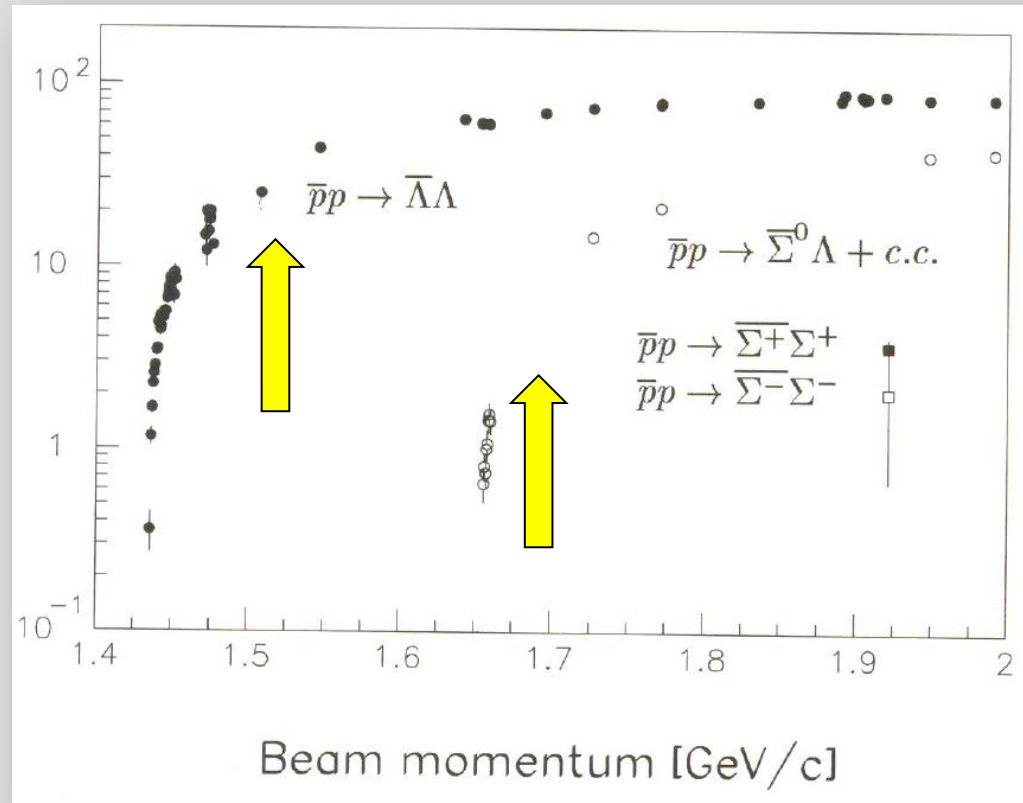


► GiBUU

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



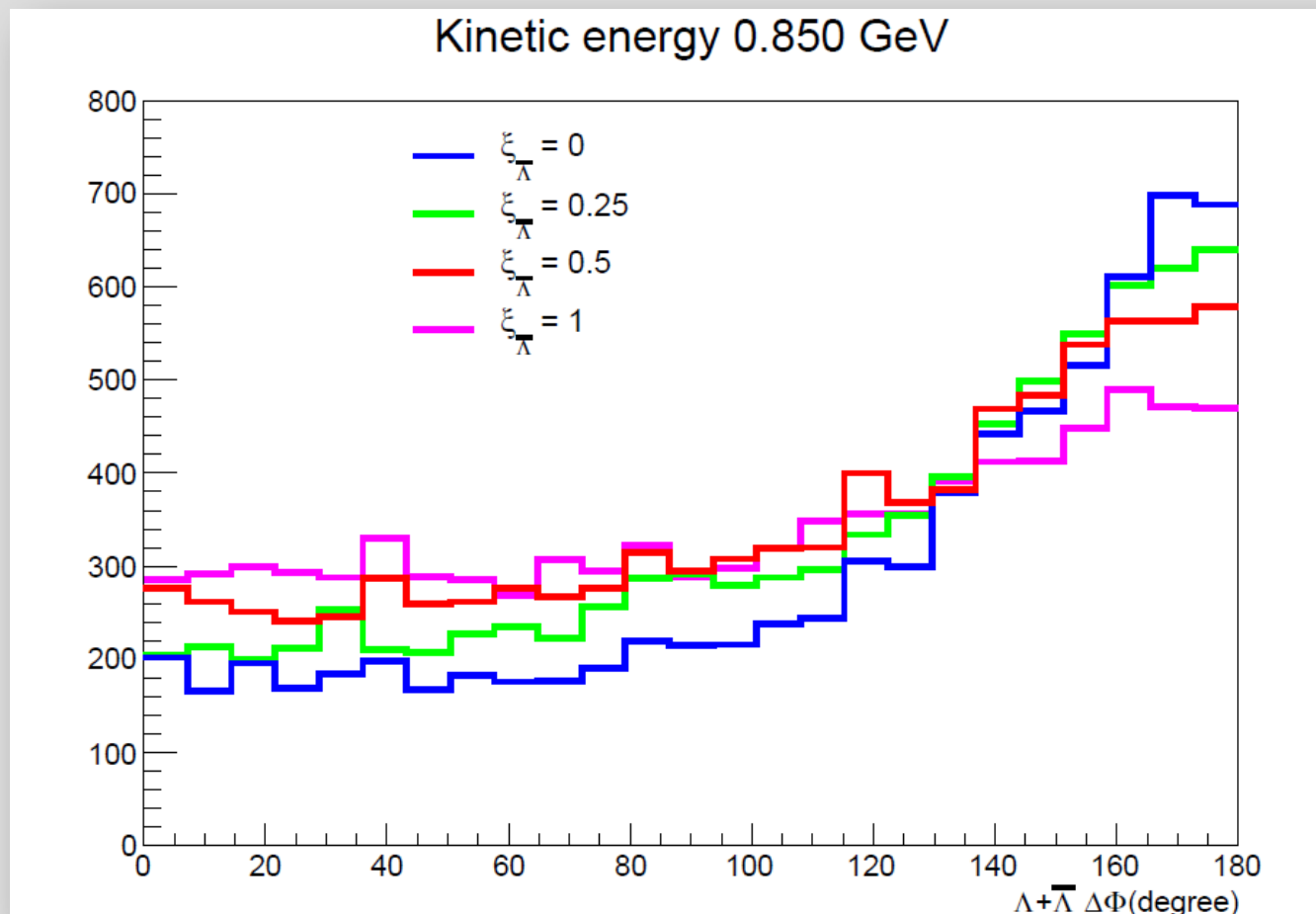
Energy (MeV)	Momentum (MeV/c)	Excess energy (MeV)
850	1522	30.6
1000	1696	92.0



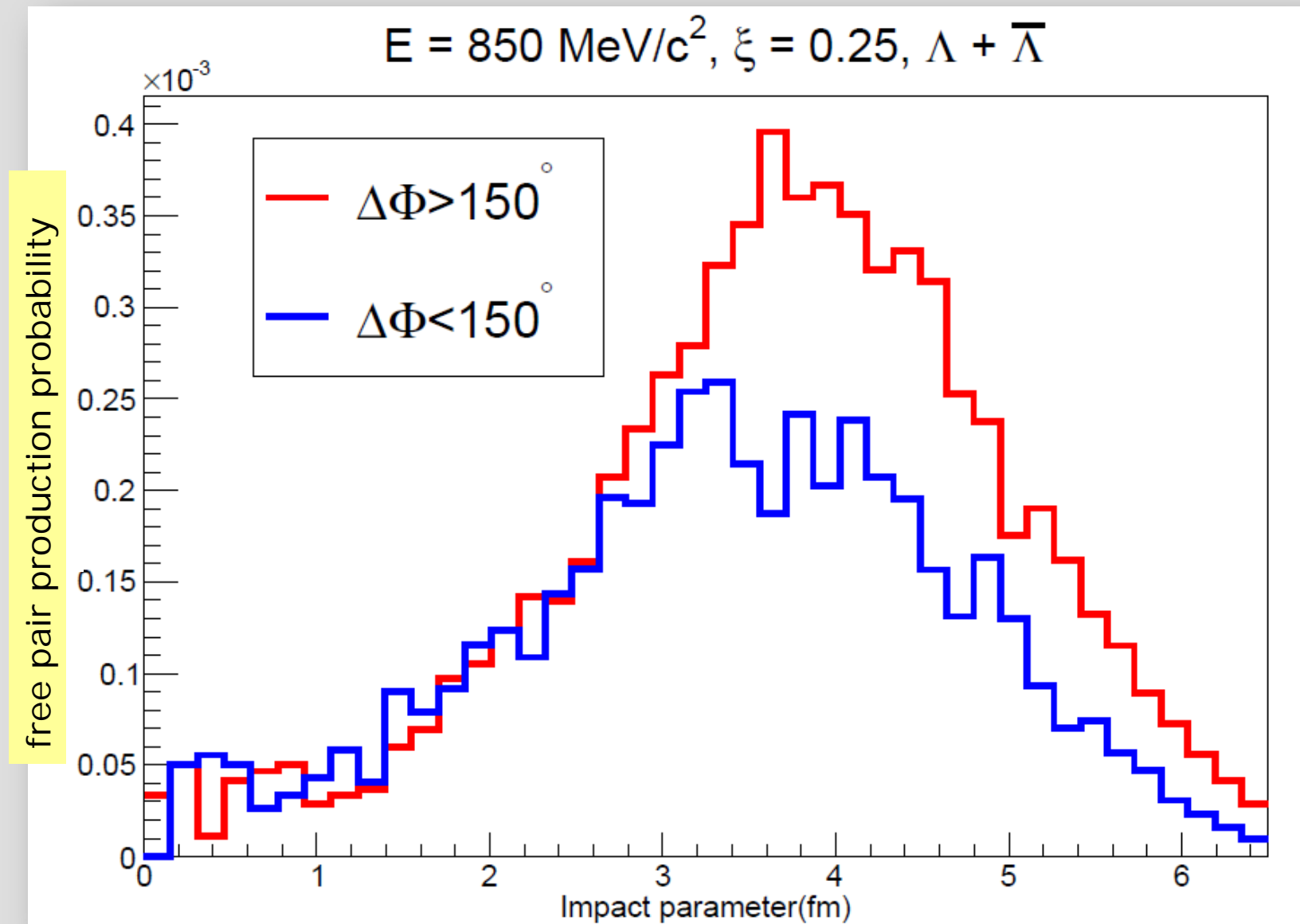
► Aim of the present work

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

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

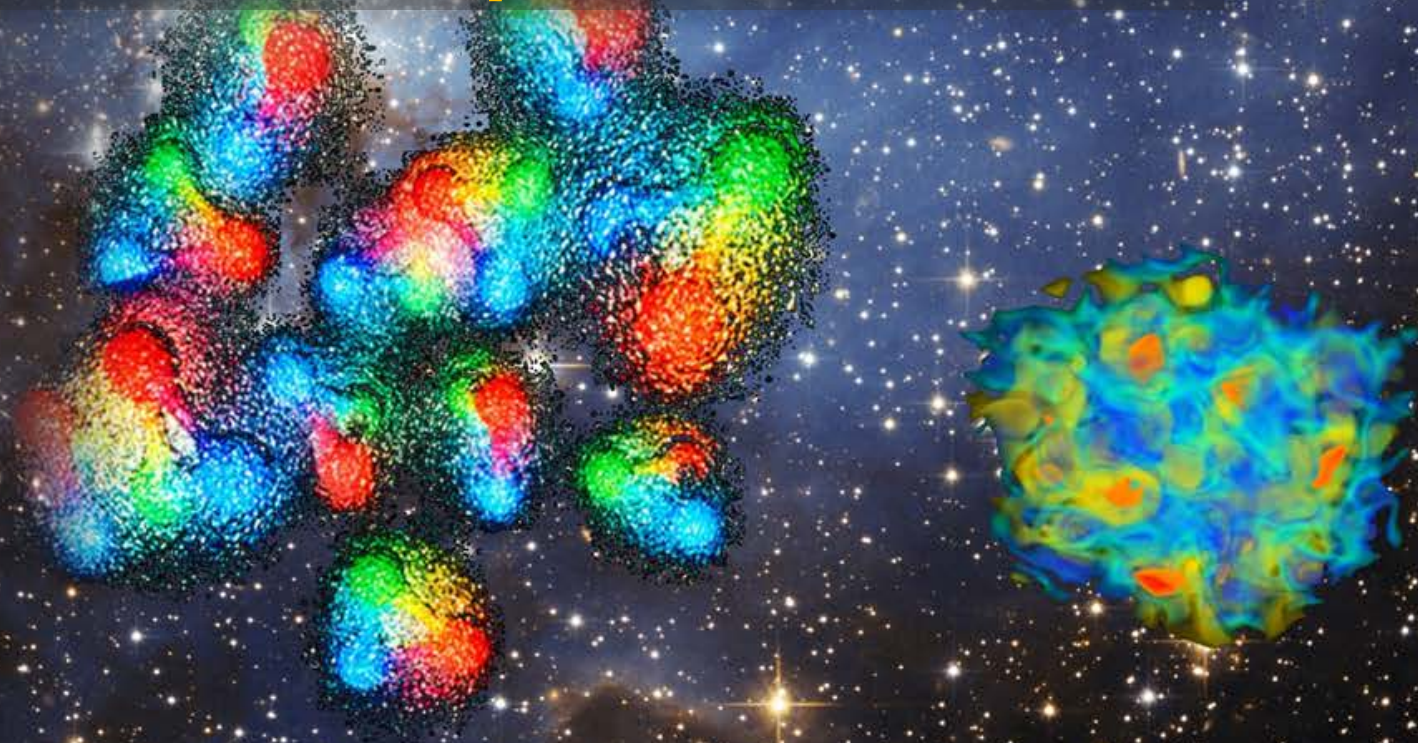


- ▶ Coplanarity distorted \Rightarrow strong rescattering

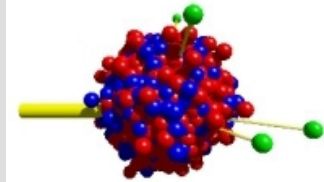


Is $\Upsilon - \bar{\Upsilon}$ pair production at all sensitive to the $\bar{\Upsilon}$ potential ?

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



- ▶ <https://gibuu.hepforge.org/trac/wiki>


GiBUU

The Giessen Boltzmann-Uehling-Uhlenbeck Project

Institut für Theoretische Physik, JLU Giessen

- ▶ 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,

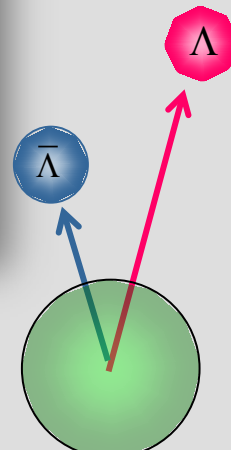
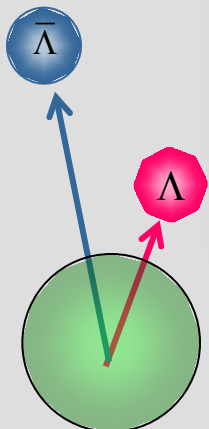
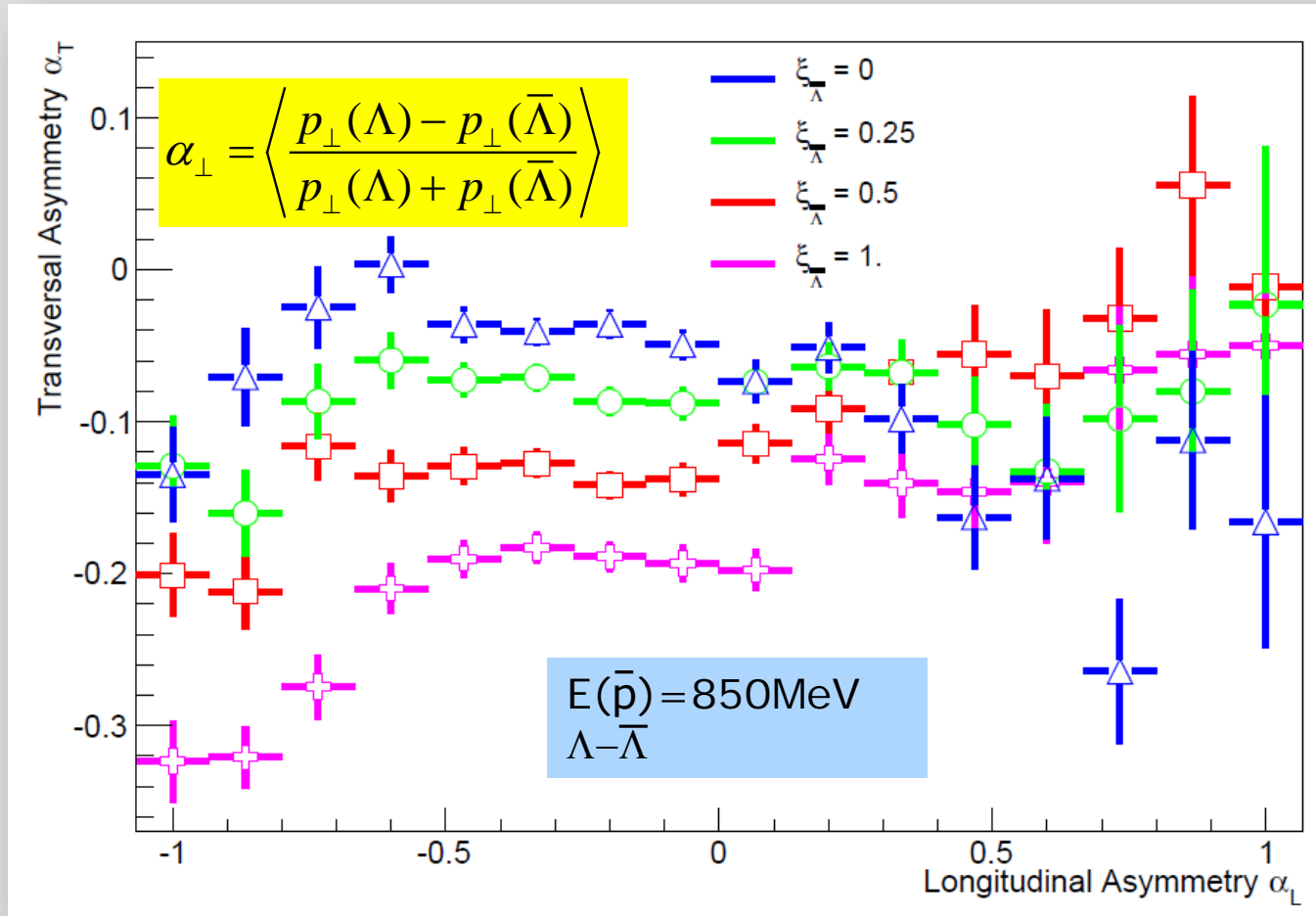
 $U_i = S_i + V_i^0 + (S_i^2 - (V_i^0)^2)/2m_i$ (in MeV), in nuclear matter at ρ_0 .

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

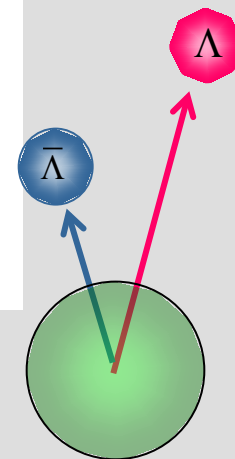
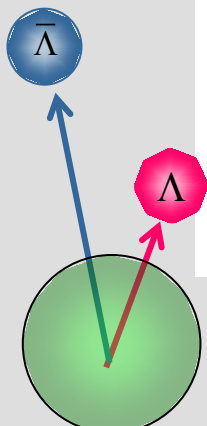
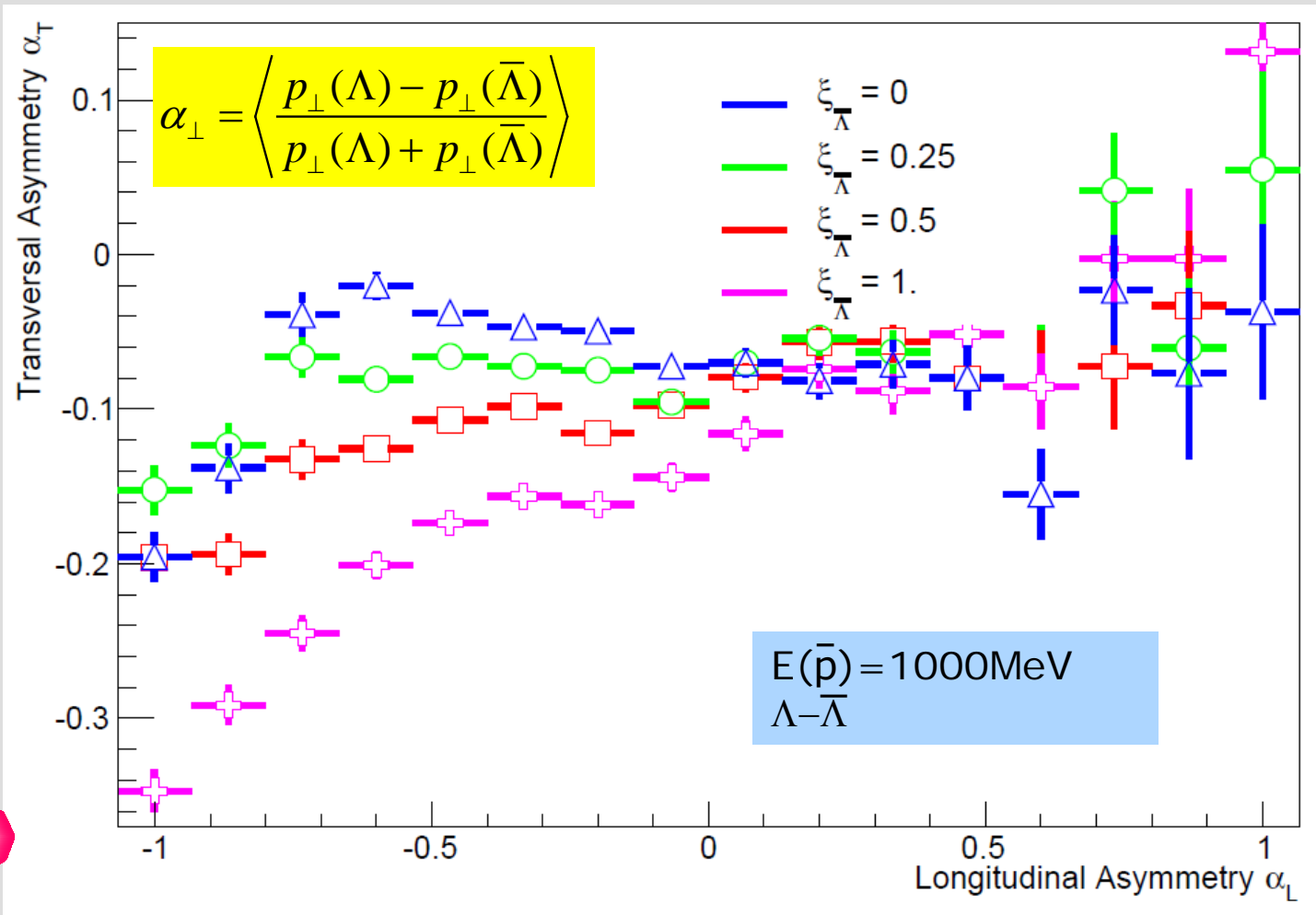
Scan of $\bar{\Lambda}$ Potential

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



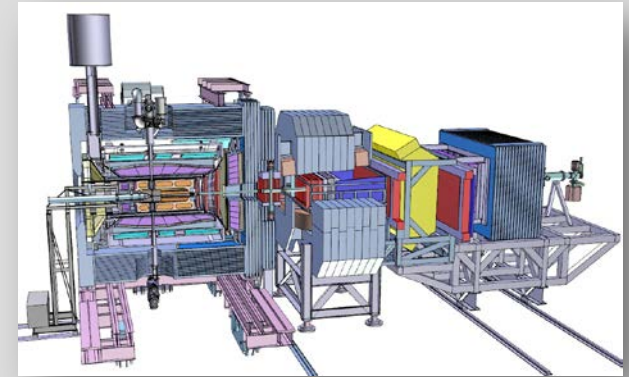
Scan of $\bar{\Lambda}$ Potential

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



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

- ▶ 2018 first beam in $\bar{P}ANDA$ 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

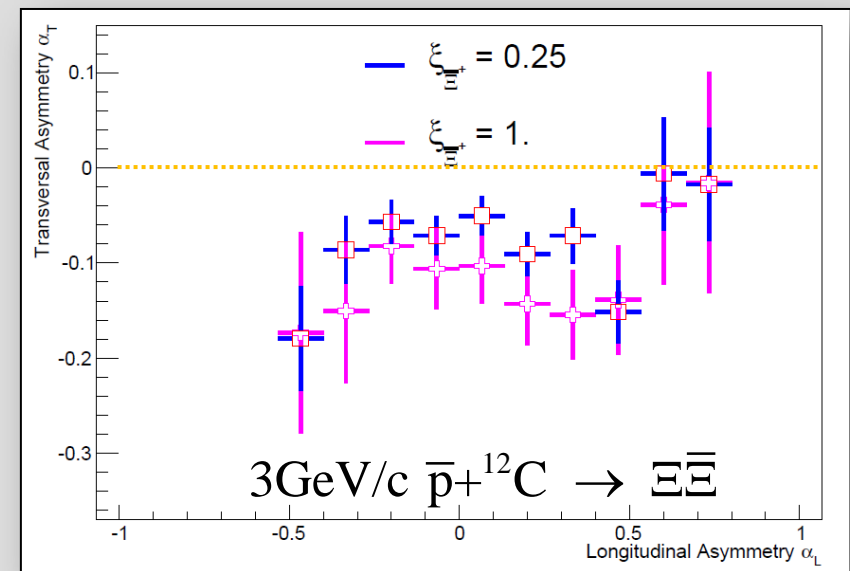


- ▶ Typical (*preliminary*) $\bar{\Lambda}\Lambda$ pair efficiency $\approx 3\text{-}5\%$ (better at higher momenta)
- ▶ $\bar{\Lambda} + \Lambda$ case
 - ▶ $^{\text{nat}}\text{Ne}$ target, H for calibration systematic check
 - ▶ only charged particle detection easy
 - ▶ assume average interactions rate 10^6s^{-1} ($\sim 10\%$ of default luminosity)
 - ▶ pair reconstruction efficiency $\sim 3\%$
 - \Rightarrow **144k detected $\bar{\Lambda} + \Lambda$ pairs per day** \Rightarrow **10 × GiBUU**
 - ▶ Moderate data taking period *~ 14 days Ne target + 7 days p-target*
 - \Rightarrow **130 × present GiBUU simulations**

- ▶ $\bar{\Lambda} + \Sigma^-$
 - ▶ 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)

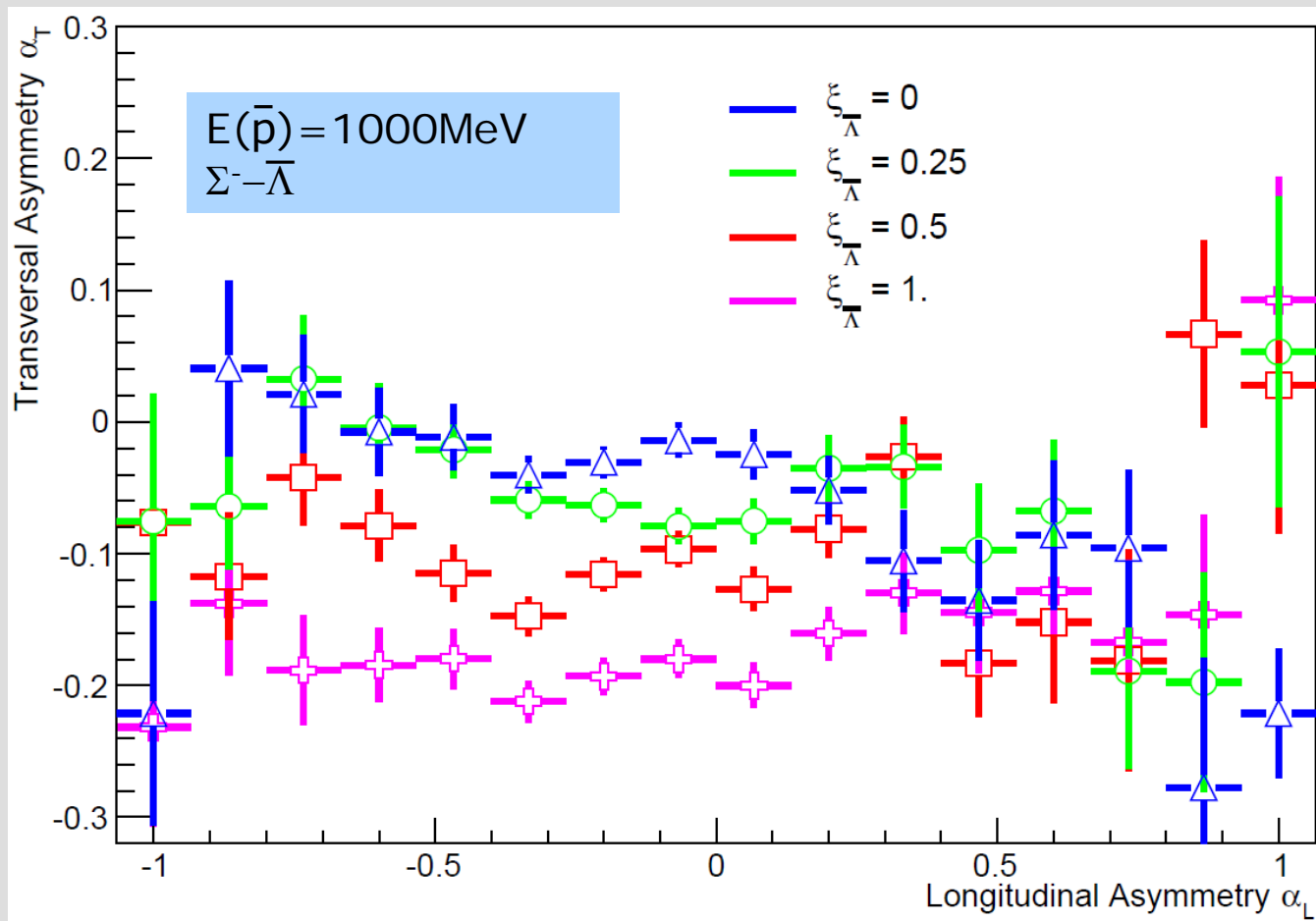
▶ Further options:

- ▶ Any other pair: $\Sigma^- \bar{\Sigma}^-$, $\Xi^- \bar{\Xi}^-$, $\Lambda_c \bar{\Lambda}_c$
- ▶ Long lived resonances in nuclei
 - $\Lambda(1520)$ ($\Gamma = 15.6$ MeV)
 - $\Xi(1530)$ ($\Gamma = 9.9$ MeV)
 - $\Lambda_c(2880)$ ($\Gamma = 5.8$ MeV)

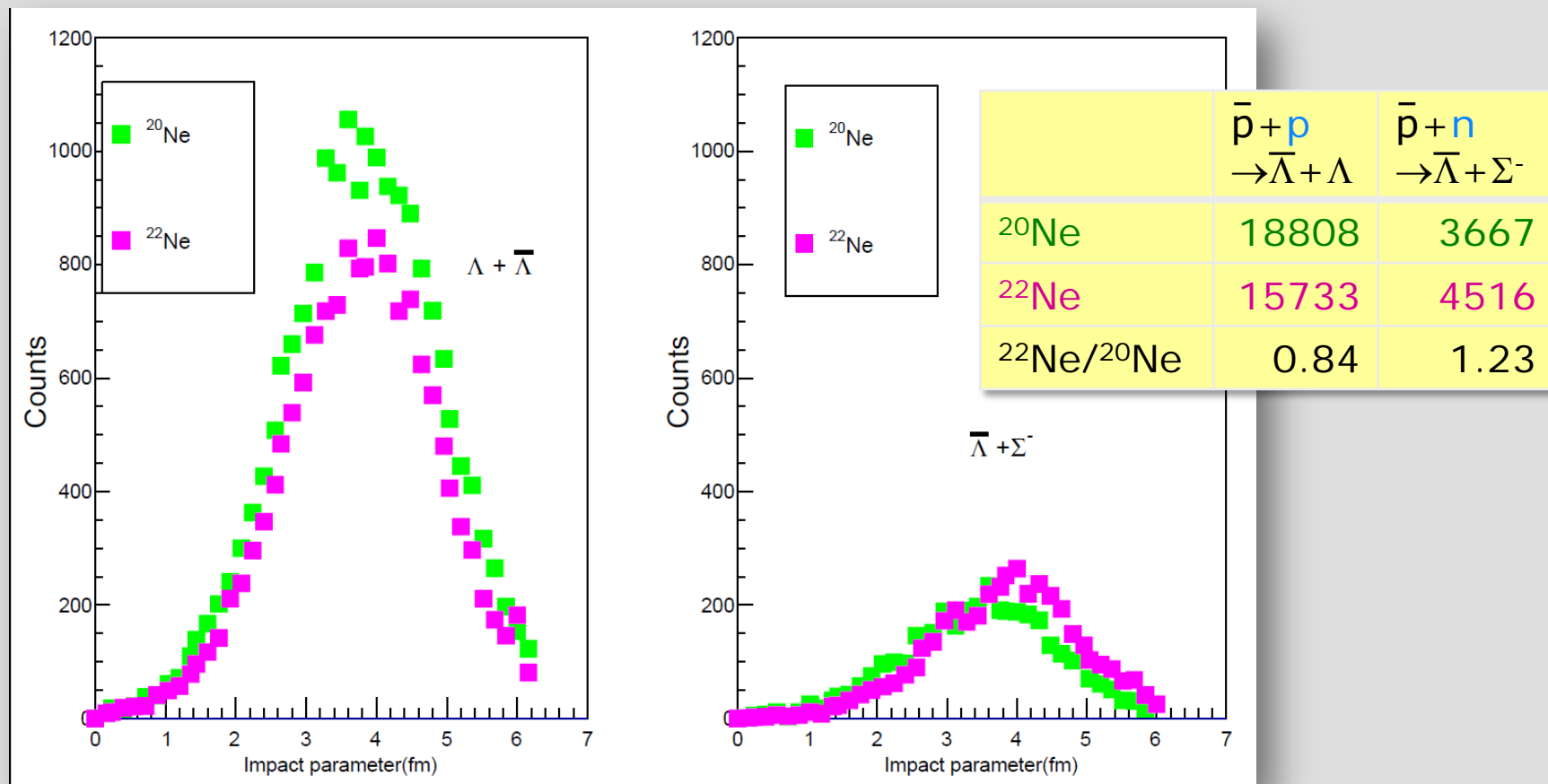


- ▶ Unique change to study charmed baryons in nuclear systems ?


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



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



- ▶ 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 ?

The background of the slide is a deep space image featuring a dense field of stars of various colors and sizes. In the lower half, there are several colorful, multi-colored nebulae or star-forming regions, with colors ranging from blue and green to red and orange. The overall scene is a rich, multi-colored star field.

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

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

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