

2<sup>nd</sup> international Symposium on Science at J-PARC July 2014

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

Josef Pochodzalla & Alicia Sanchez Lorente

on behalf of the  $\bar{\text{P}}\text{ANDA}$  Collaboration

- Motivation
- The  $\bar{\text{P}}\text{ANDA}$  experiment
- Antihyperons in nuclei at  $\bar{\text{P}}\text{ANDA}$
- Status of the Simulations
- Future options



## Hyperon mixing and universal many-body repulsion in neutron stars

Y. Yamamoto<sup>1</sup>, T. Furumoto<sup>2</sup>, N. Yasutake<sup>3</sup>, and Th.A. Rijken<sup>4</sup>

<sup>1</sup>Nishina Center for Accelerator-Based Science, Institute for Particle and Chemical Research (RIKEN), Wako, Saitama, 351-0192, Japan

<sup>2</sup>National Institute of Technology, Ichinoseki College, Ichinoseki, Ibaraki, 310-2265, Japan

<sup>3</sup>Department of Physics, Chiba Institute of Science, 2-1-1 Shibazono Narashino, Chiba 276-8580, Japan

<sup>4</sup>IMAPP, University of Nijmegen, Nijmegen, The Netherlands

A multi-pomeron exchange potential (MPP) is proposed as many-body repulsion in baryonic systems on the basis of the Extended Skyrme interaction. The strength of MPP is determined by analyzing the G-matrix folding model. The interaction in  $\Lambda N$  channels is shown to be repulsive, which leads to  $\Lambda$  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  $2M_{\odot}$  if hyperon mixing is included on the basis of model-parameters determined from the hyperon-nucleon interaction.

⇒ 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?

PHYSICAL REVIEW D **89**, 043014 (2014)

Alessandro Drago,<sup>1</sup> Andrea Lavagno,<sup>2</sup> and Giuseppe Pagliara<sup>1</sup>  
<sup>1</sup> Dipartimento di Fisica e Scienze della Terra dell'Università di Ferrara and INFN Sezione di Ferrara, Italy  
Via Saragat 1, I-44100 Ferrara, Italy  
<sup>2</sup> Dipartimento di Scienze e Tecnologie, Politecnico di Torino, I-10129 Torino, Italy  
and INFN Sezione di Torino, I-10126 Torino, Italy  
Received 13 October 2013; published 25 February 2014

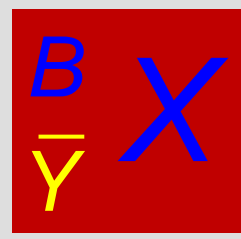
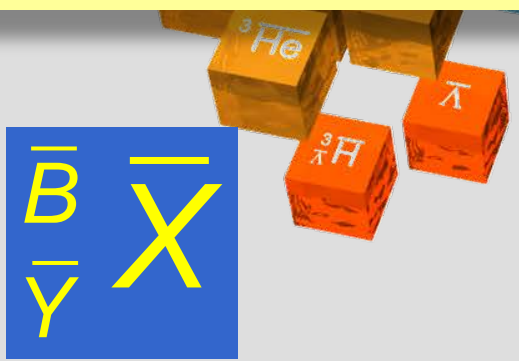
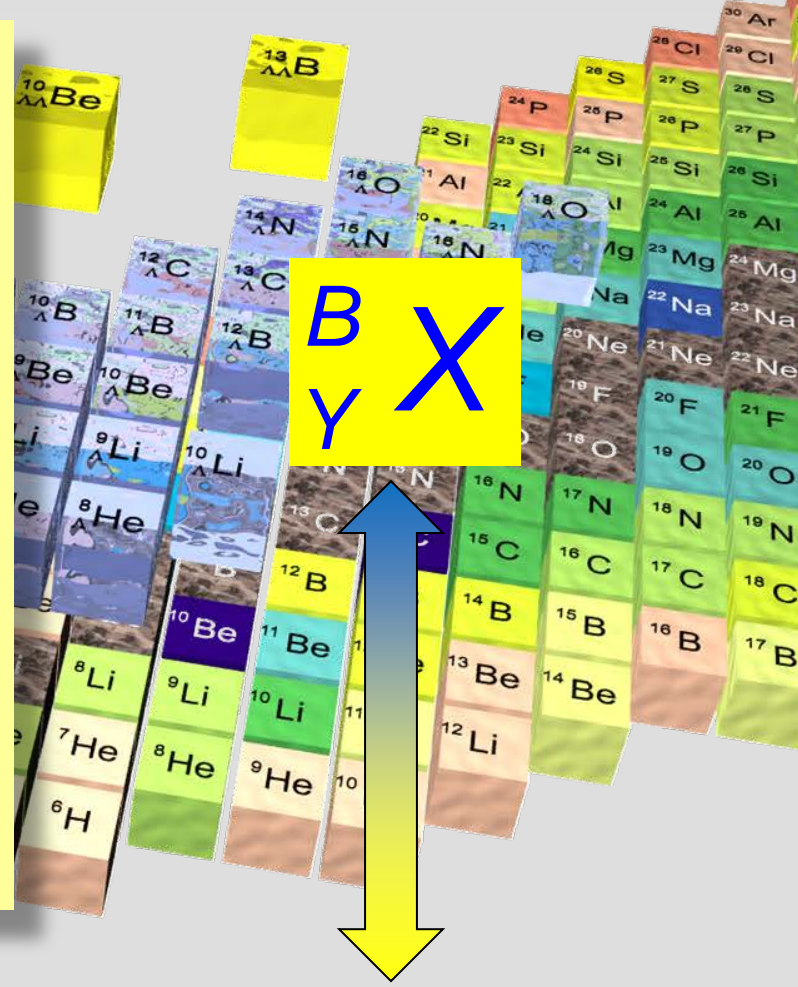
## New hyperon equations of state for supernovae and neutron stars

in density dependent hadron field theory

Department Physik, BITS Pilani, Hyderabad Campus  
Sarmistha Bandyopadhyay  
Astronomy Department, University of Basel, Sternwartstrasse 7, CH-4056 Basel, Switzerland  
Bidyottam Saha  
Department of Physics, Bidhannagar, Kolkata-700061, India

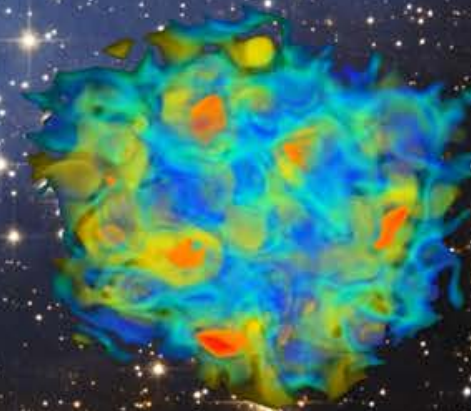
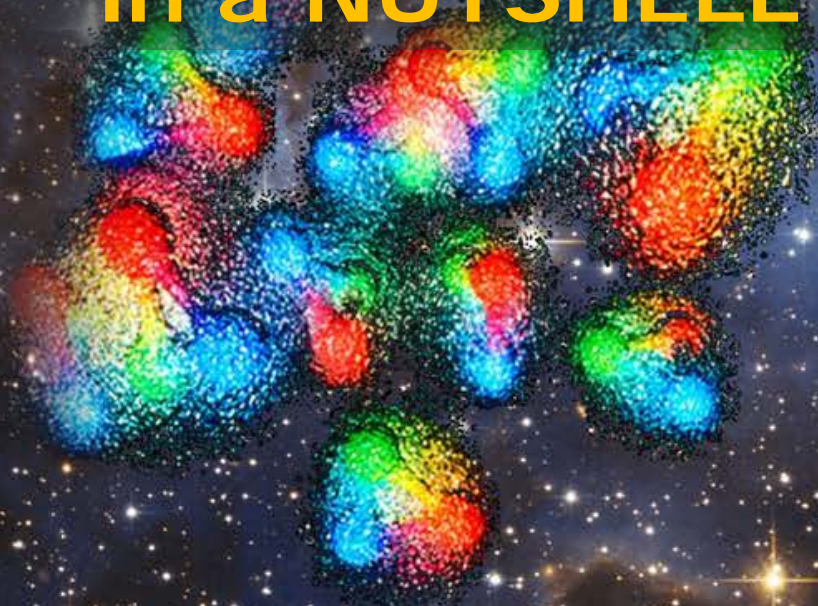
# Nuclei with (Anti)hyperons

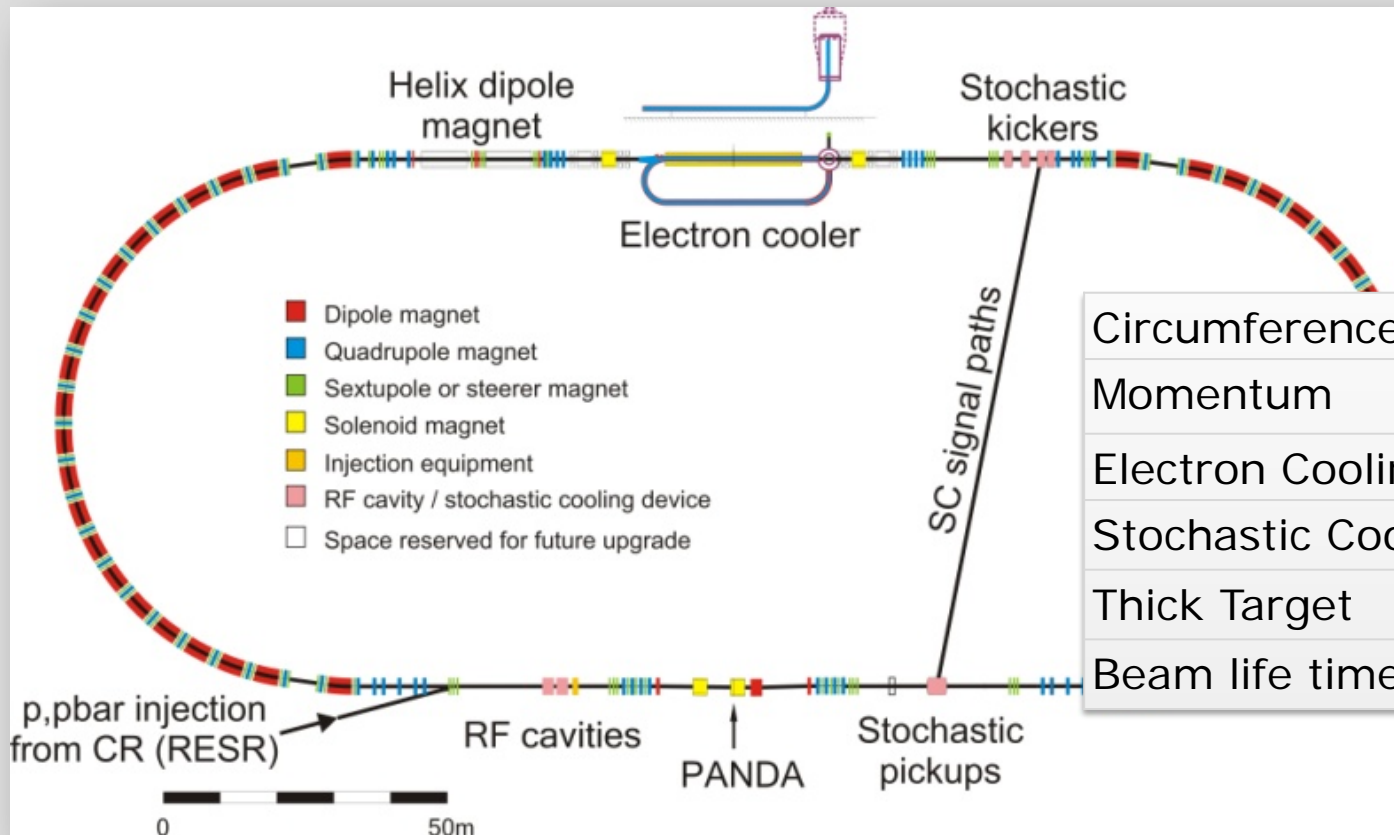
- ▶ G-parity relates  $NN$  with  $N\bar{N}$  interaction (Dürr & Teller 1956)
- ▶ Coupling of baryons or antibaryons in nuclei could be related
- ▶ But: G-parity is broken for nucleons ( $V \sim -150\text{MeV}$ )
- ▶ To what extent is G-parity broken with strange quarks ?
- ▶ Antibaryons in nuclei are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





**THE  $\bar{P}$ ANDA EXPERIMENT  
in a NUTSHELL**





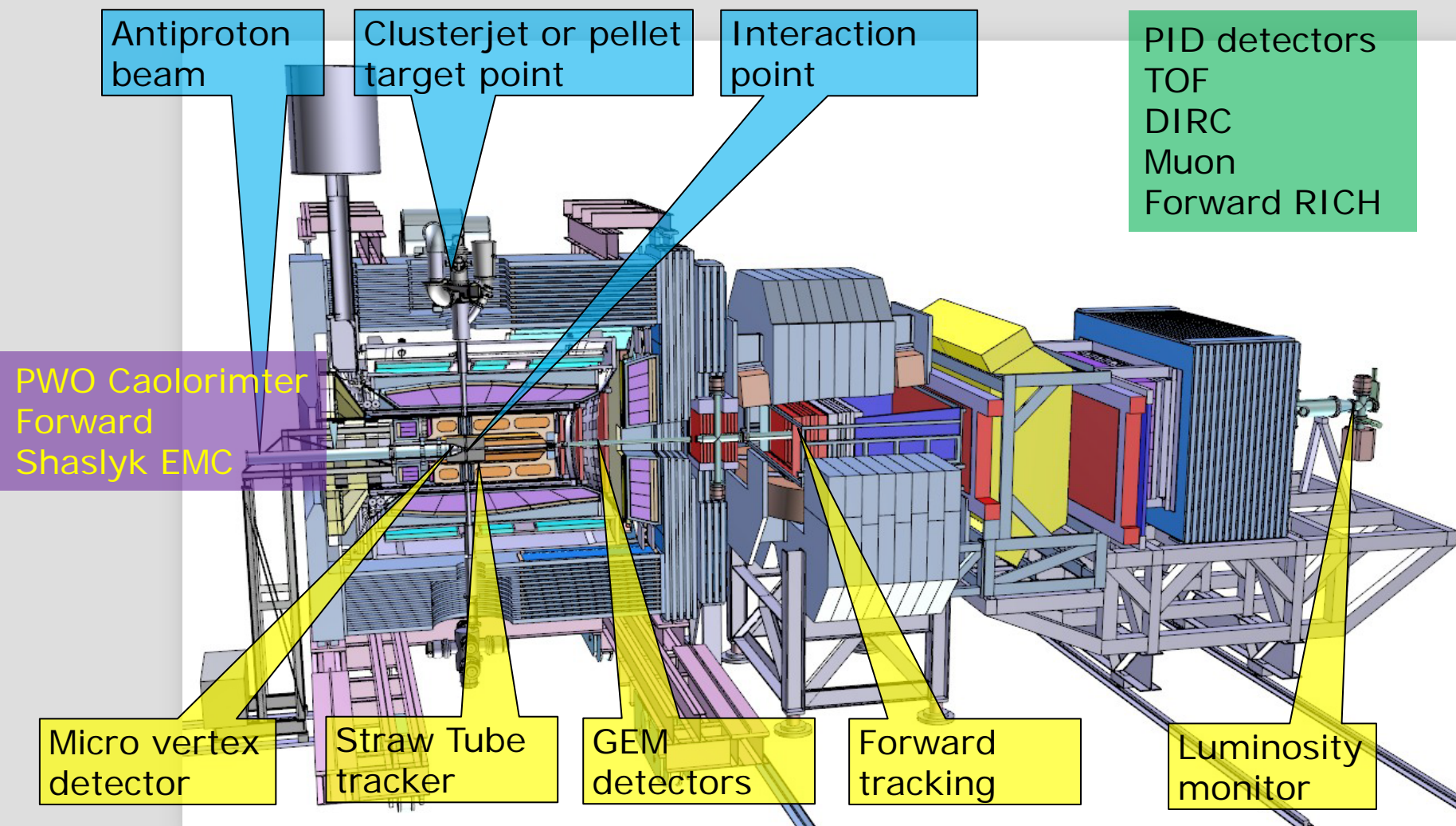
Circumference	575 m
Momentum	1.5 – 15 GeV/c
Electron Cooling	up to 9 GeV/c
Stochastic Cool.	Full range
Thick Target	$4 \cdot 10^{15} \text{ cm}^{-2}$
Beam life time	>30 min

### ► High resolution mode

- $e^-$  cooling  $1.5 \leq p \leq 8.9 \text{ GeV/c}$
- $10^{10}$  antiprotons stored
- Luminosity up to  $2 \cdot 10^{31} \text{ cm}^{-2}\text{s}^{-1}$
- $\Delta p/p \leq 4 \cdot 10^{-5}$

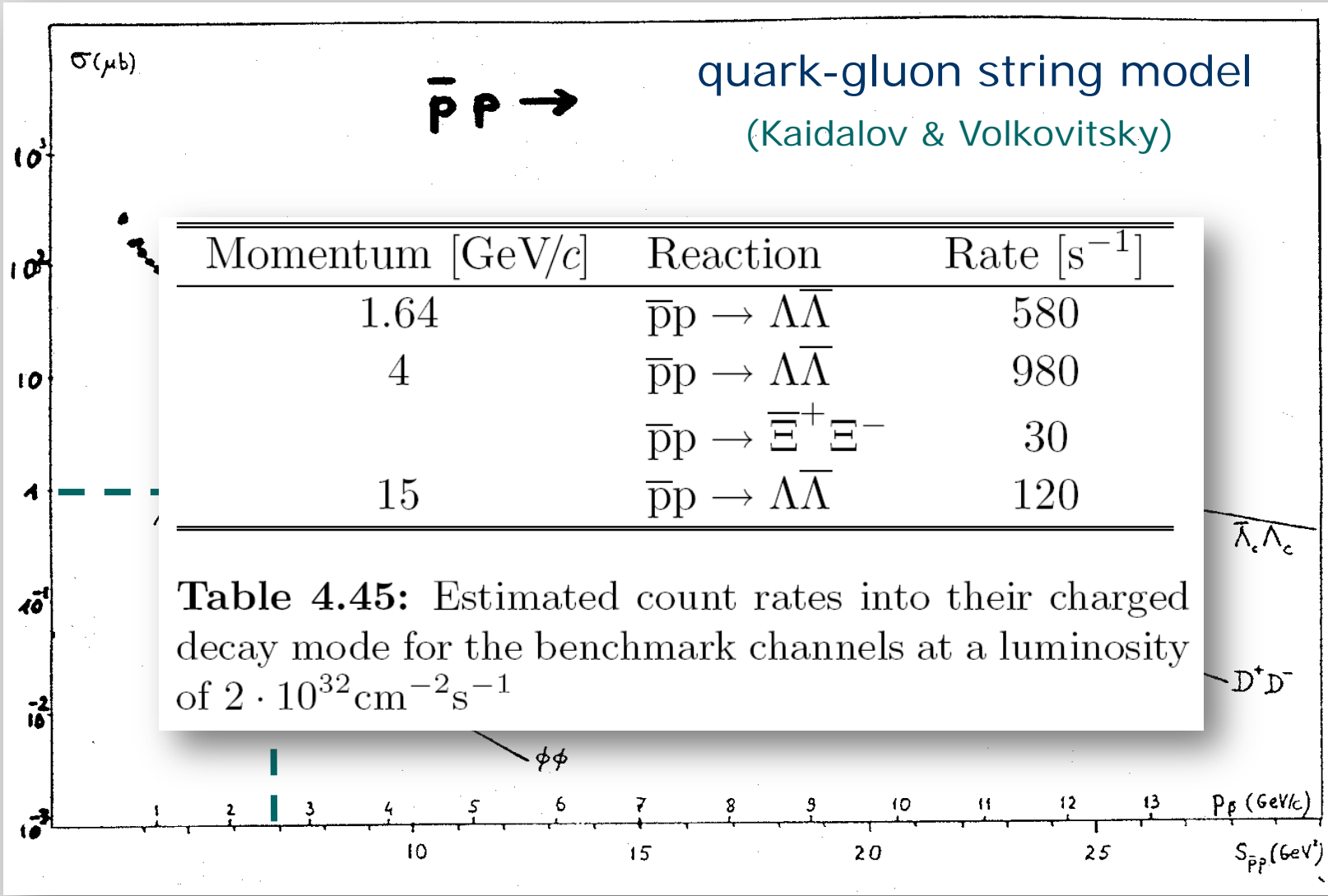
### ► High luminosity mode

- Stochastic cooling  $p \geq 3.8 \text{ GeV/c}$
- $10^{11}$  antiprotons stored
- Luminosity up to  $2 \cdot 10^{32} \text{ cm}^{-2}\text{s}^{-1}$
- $\Delta p/p \leq 2 \cdot 10^{-4}$



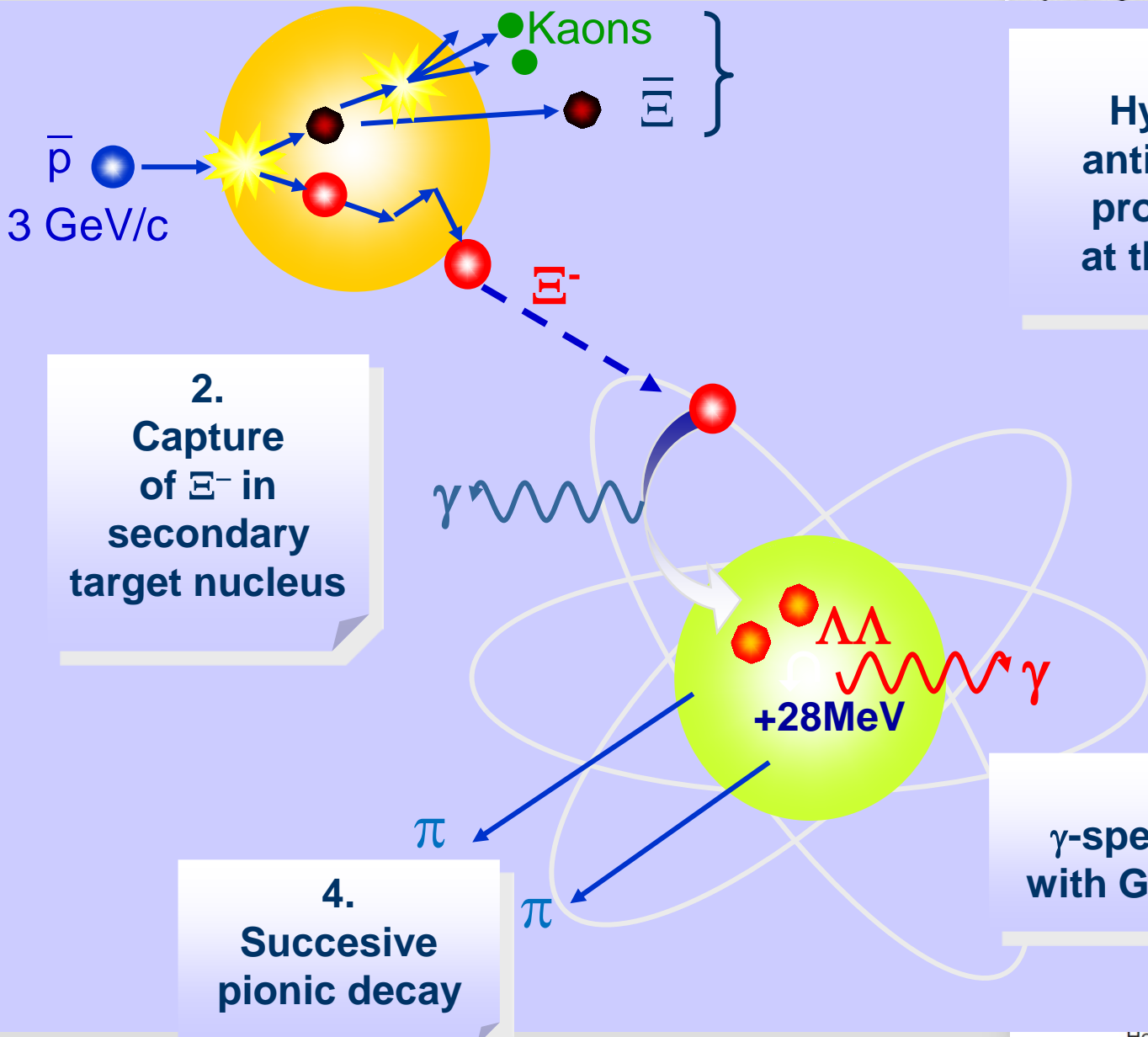
## ► Official timeline

- 2013-2017: (partial) pre-assembling at COSY, Jülich
- $\geq 2018$ : first beam expected at FAIR





\#5



**1.**  
Hyperon-antihyperon production at threshold

**2.**  
Capture of  $\Xi^-$  in secondary target nucleus

**3.**  
 $\gamma$ -spectroscopy with Ge-detectors

**4.**  
Successive pionic decay

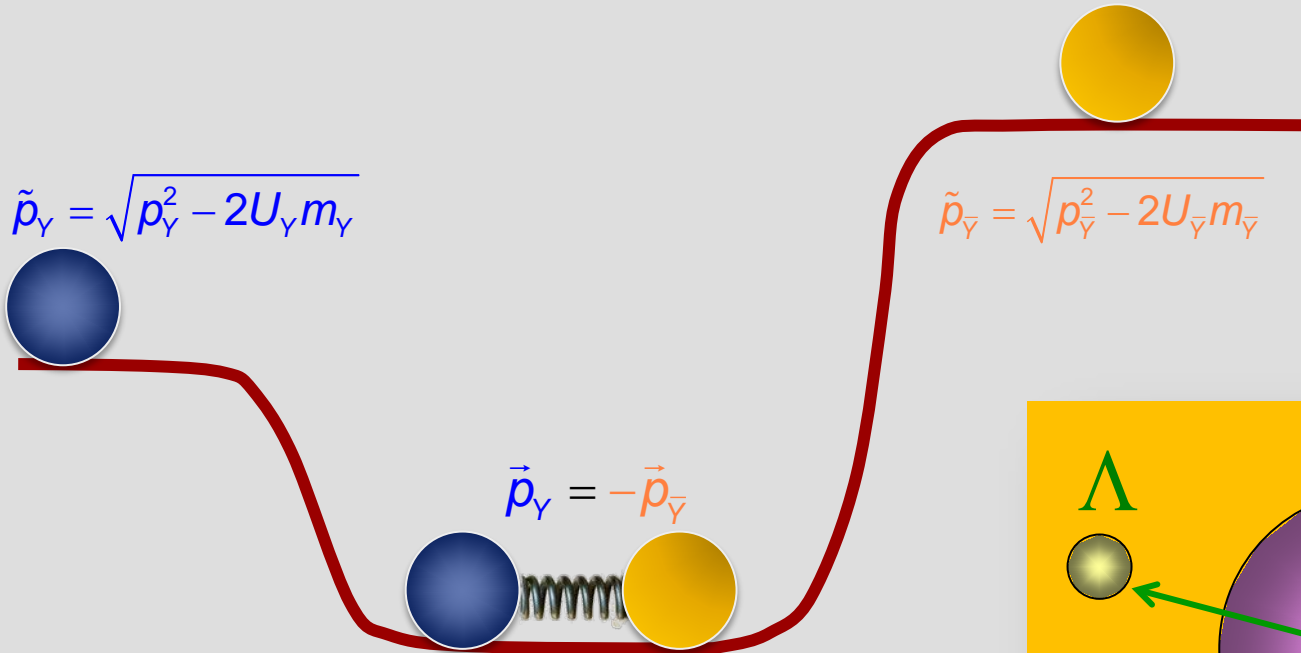


reaching for the unthinkable

**ANTIHYPRONS IN NUCLEI  
AT PANDA**



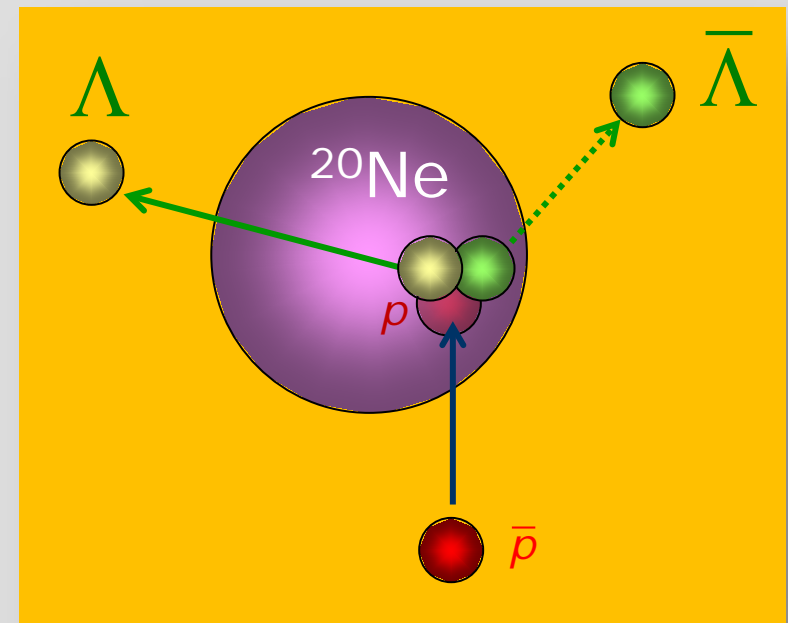
- ▶ **exclusive**  $\bar{p}+p(A) \rightarrow Y+\bar{Y}$  **close to threshold** **within a nucleus**
- ▶  $\Lambda$  and  $\bar{\Lambda}$  that **leave the nucleus** will have different asymptotic momenta depending on the respective potential



- ▶  $\Rightarrow$  *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



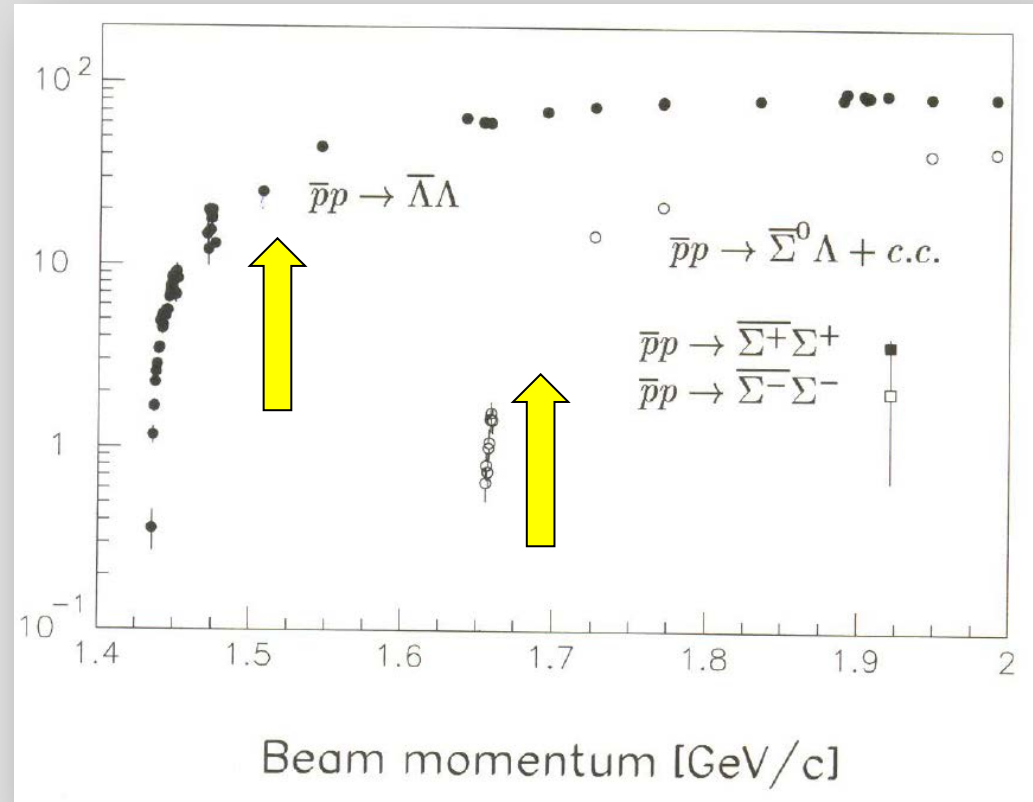
# GiBUU Simulations $\bar{p} + {}^{20}\text{Ne} \rightarrow \Lambda \bar{\Lambda} + X$

## ▶ 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  $< 10$  min  $\bar{\text{P}}\text{ANDA}$  incl. efficiency



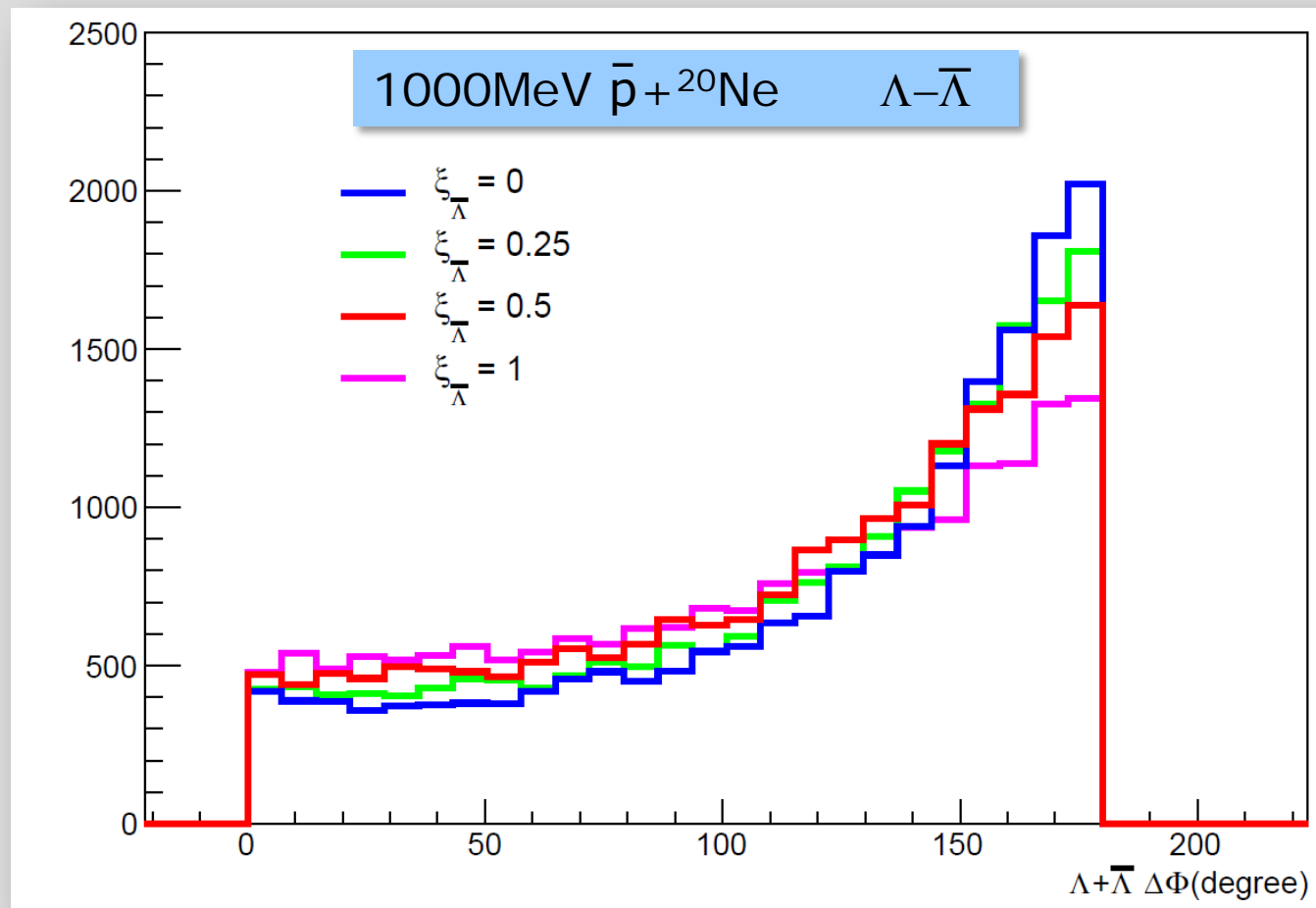
Energy (MeV)	Momentum (MeV/c)	Excess energy (MeV)
850	1522	30.6
1000	1696	92.0



## ▶ Aim of the present work

- ▶ Explore sensitivity of  $\alpha_T$  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

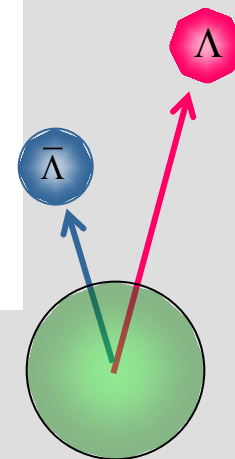
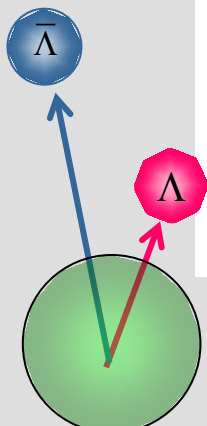
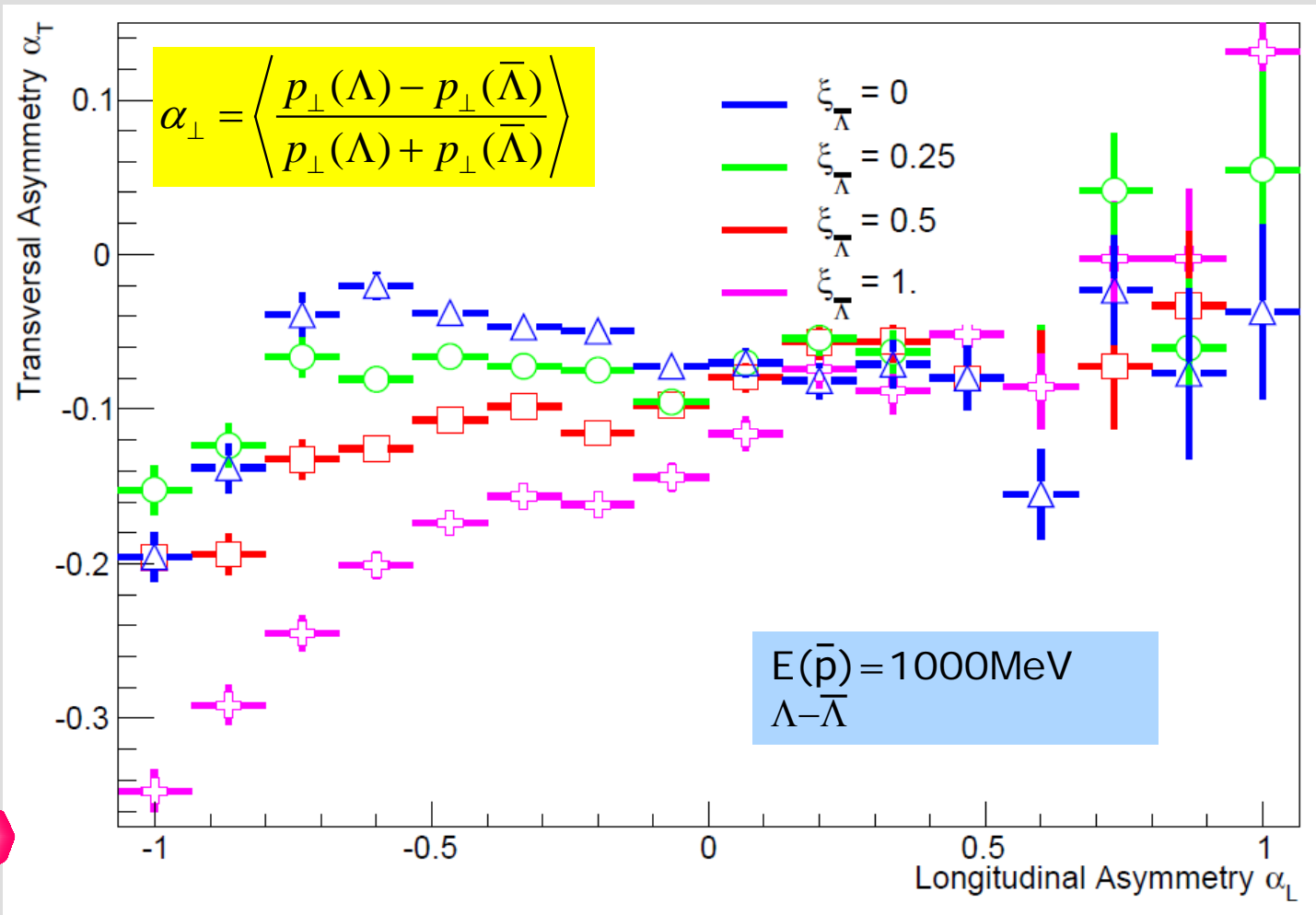
- ▶ Typical 15000  $\bar{\Lambda}\Lambda$  pairs produced



- ▶ Coplanarity distorted  $\Rightarrow$  strong refractive and/or rescattering effects

# Scan of $\bar{\Lambda}$ Potential

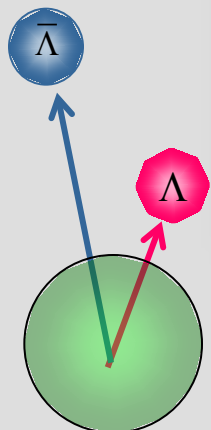
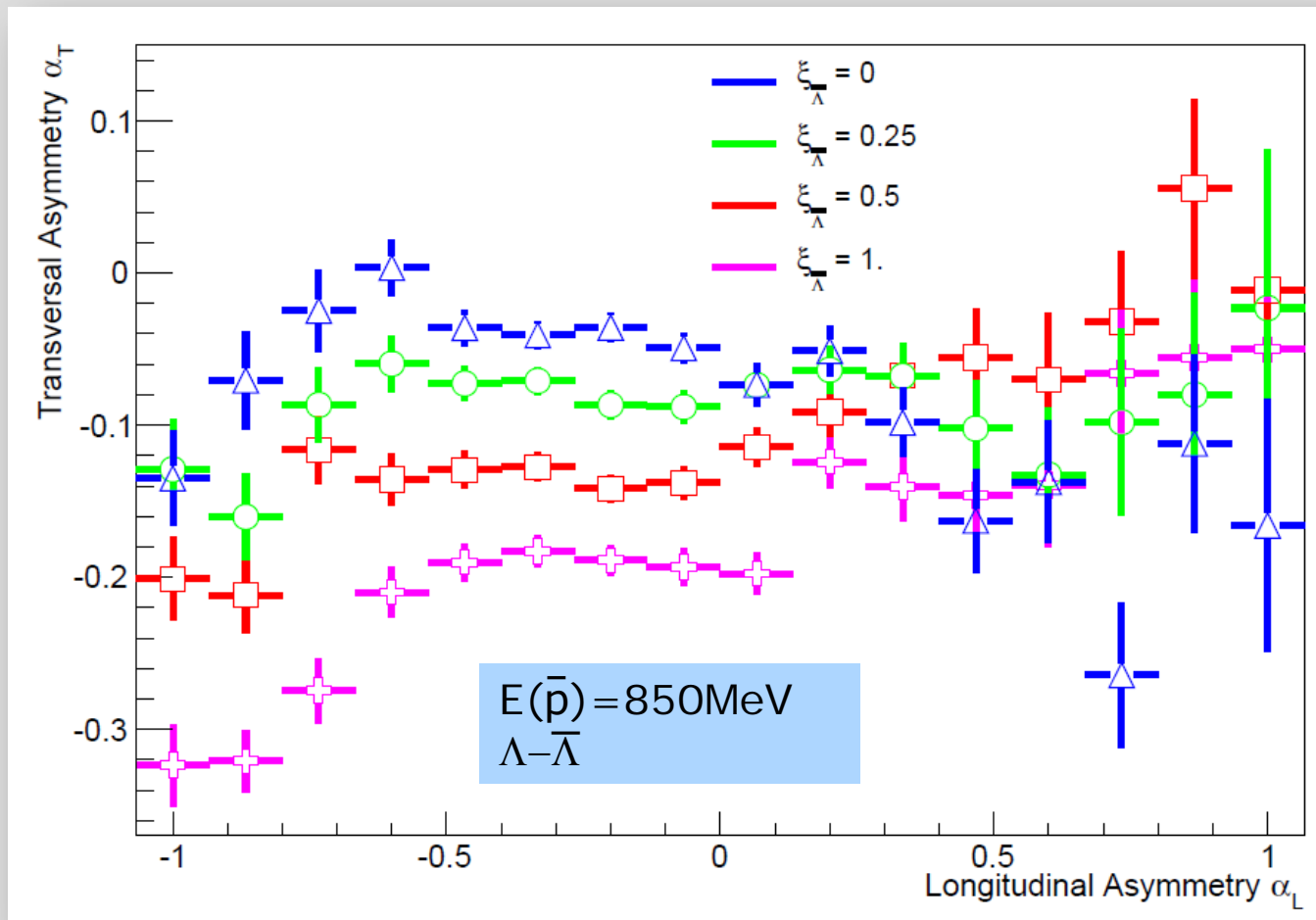
- ▶  $U(\bar{\Lambda}) = -449\text{MeV}, -225\text{MeV}, -112\text{MeV}, 0\text{MeV}$
- ▶ All other potentials unchanged



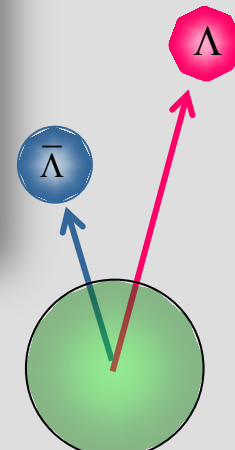
$$\alpha_L = \frac{p_L(\Lambda) - p_L(\bar{\Lambda})}{p_L(\Lambda) + p_L(\bar{\Lambda})}$$

# Scan of $\bar{\Lambda}$ Potential

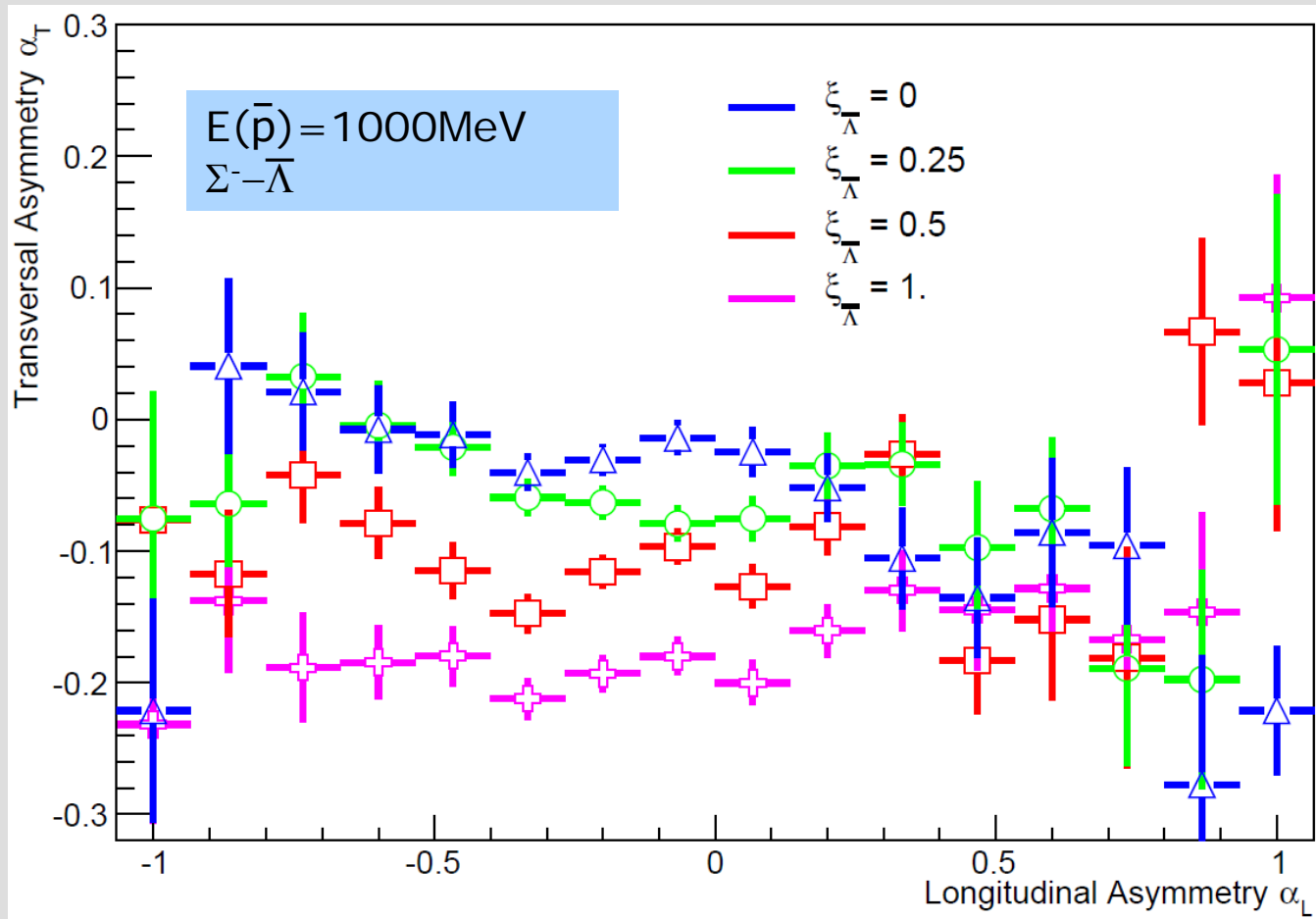
- ▶  $U(\bar{\Lambda}) = -449\text{MeV}, -225\text{MeV}, -112\text{MeV}, 0\text{MeV}$
- ▶ All other potentials unchanged



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

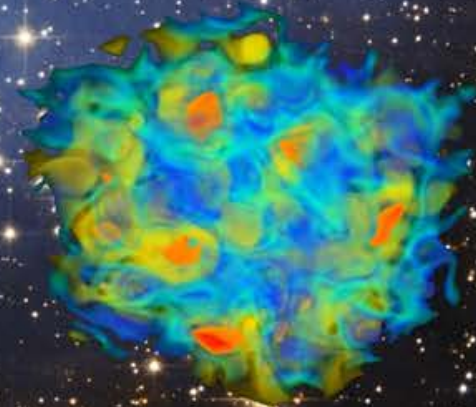


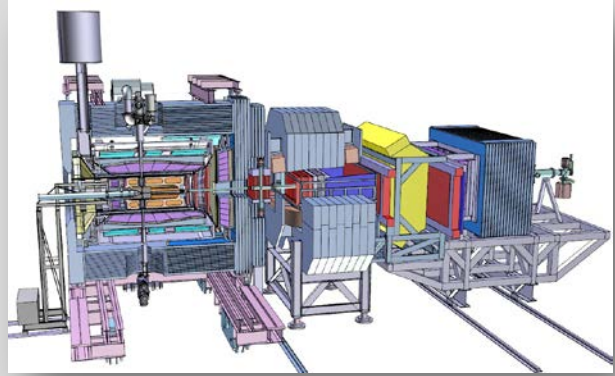
- ▶  $\bar{p} + p \rightarrow \bar{\Lambda} + \Lambda$        $\bar{p} + p \rightarrow \bar{\Sigma}^0 + \Lambda$
- ▶  $\bar{p} + n \rightarrow \bar{\Lambda} + \Sigma^-$        $\bar{p} + n \rightarrow \bar{\Sigma}^+ + \Lambda$
- ▶ all antihyperon potentials scaled by same factor





**ANTI HYPERON-HYPERON  
PRODUCTION IN  
THE  $\bar{P}$ ANDA EXPERIMENT**



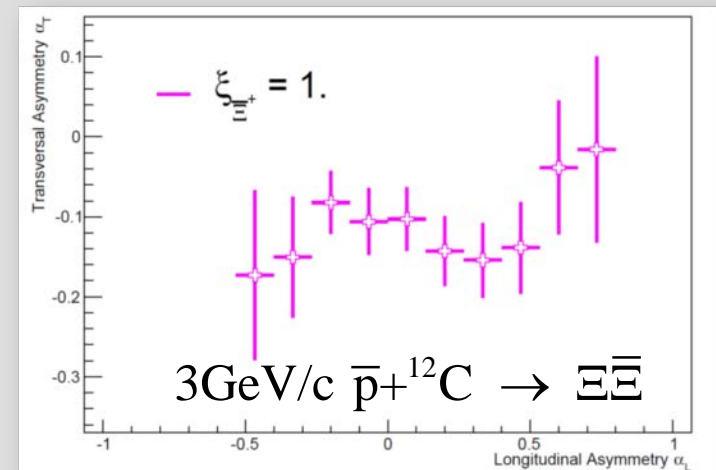
- ▶ 2018 first beam in  $\bar{P}$ ANDA expected → commissioning phase
  - ▶ We are right now exploring different scenarios
    - ▶ Different detector availability
    - ▶ Different solenoid fields (1T, 0.5T,...)
 and other important aspects like
    - ▶ Luminosity
    - ▶ Length of typical running period
- 
- ▶ Typical (*preliminary*)  $\bar{\Lambda}\Lambda$  pair efficiency  $\approx 3\text{-}5\%$  (better at higher momenta)
  - ▶  $\bar{\Lambda}+\Lambda$ 
    - ▶  $^{\text{nat}}\text{Ne}$  target, H for calibration
    - ▶ only charged particle detection *easy*
    - ▶ Assume average interactions rate  $10^5\text{s}^{-1}$  i.e. *~ 1% of default luminosity*
    - ▶ Moderate data taking period *~ 30 days*
      - ⇒  $2.6 \cdot 10^{11}$  detected interactions
    - ▶ pair reconstruction efficiency 4%
      - ⇒ 0.5M events detected  $\bar{\Lambda}+\Lambda$  pairs

**40 × present GiBUU simulations**

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

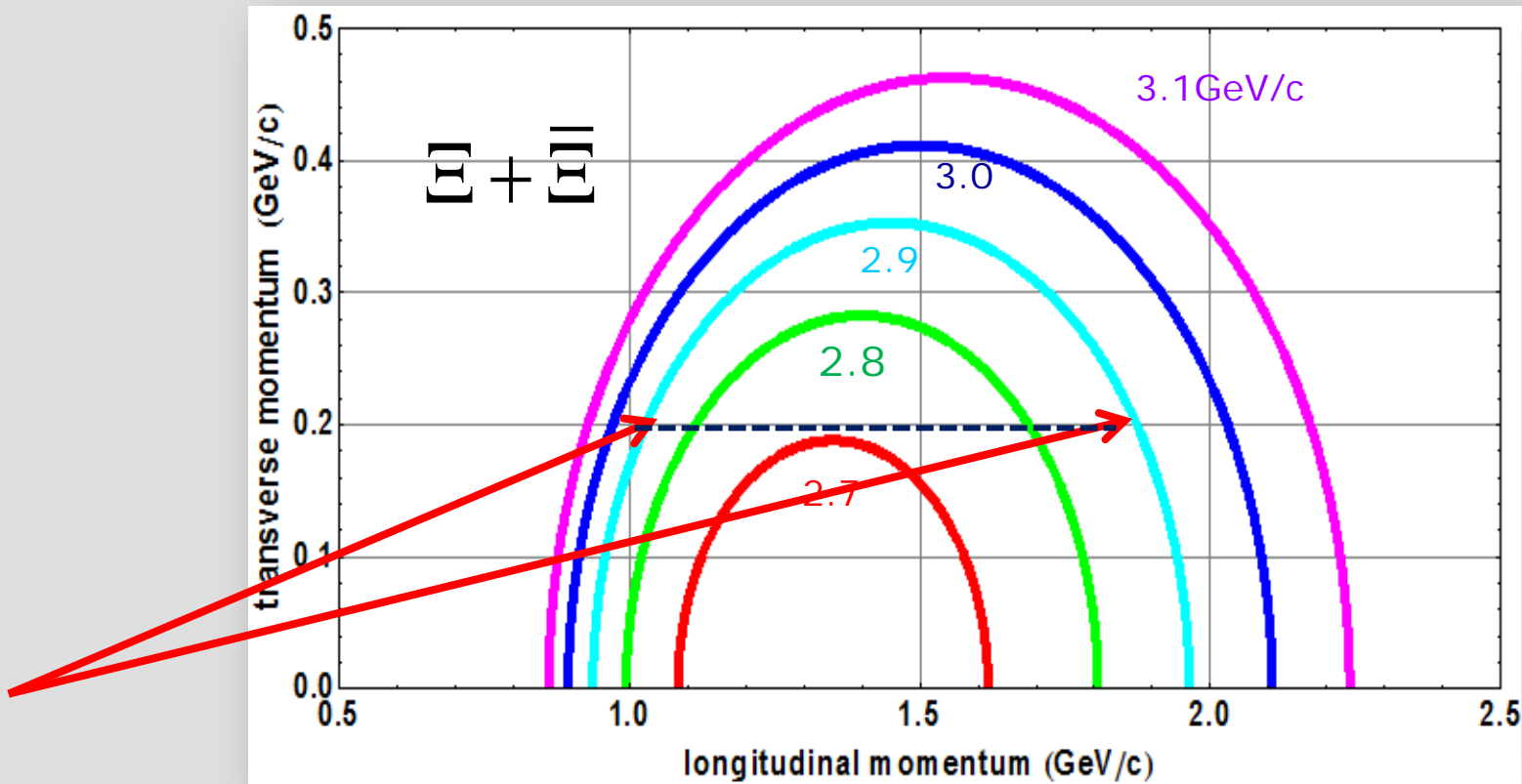
▶ Further options:

- ▶ 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

# Beyond $\bar{P}$ ANDA: $YN, \bar{Y}N$ scattering



- ▶  $\bar{p} + p \rightarrow \bar{Y} + Y$  provides momentum tagged low momentum, polarized hyperon *or* antihyperon beams
- ▶ scattering experiment with low momentum (anti)hyperons possible
- ▶ Optimal: Low momentum asymmetric  $\bar{p}$ -p collider HESR +



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

$\bar{P}$ ANDA is a 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