Measuring the Potential of antihyperons in nuclei with antiprotons at PANDA

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Alicia Sanchez Lorente
on behalf of the PANDA Collaboration

SPHERE Meeting,

Prague, 9. -11. September 2014

Nuclei with (anti)hyperons

- Link between NN $\Rightarrow$ $N\bar{N}$
- G-Parity $G = C \cdot e^{i\pi I_2}$

  G=charge conjugation + 180° rotation around 2nd axis in isospin

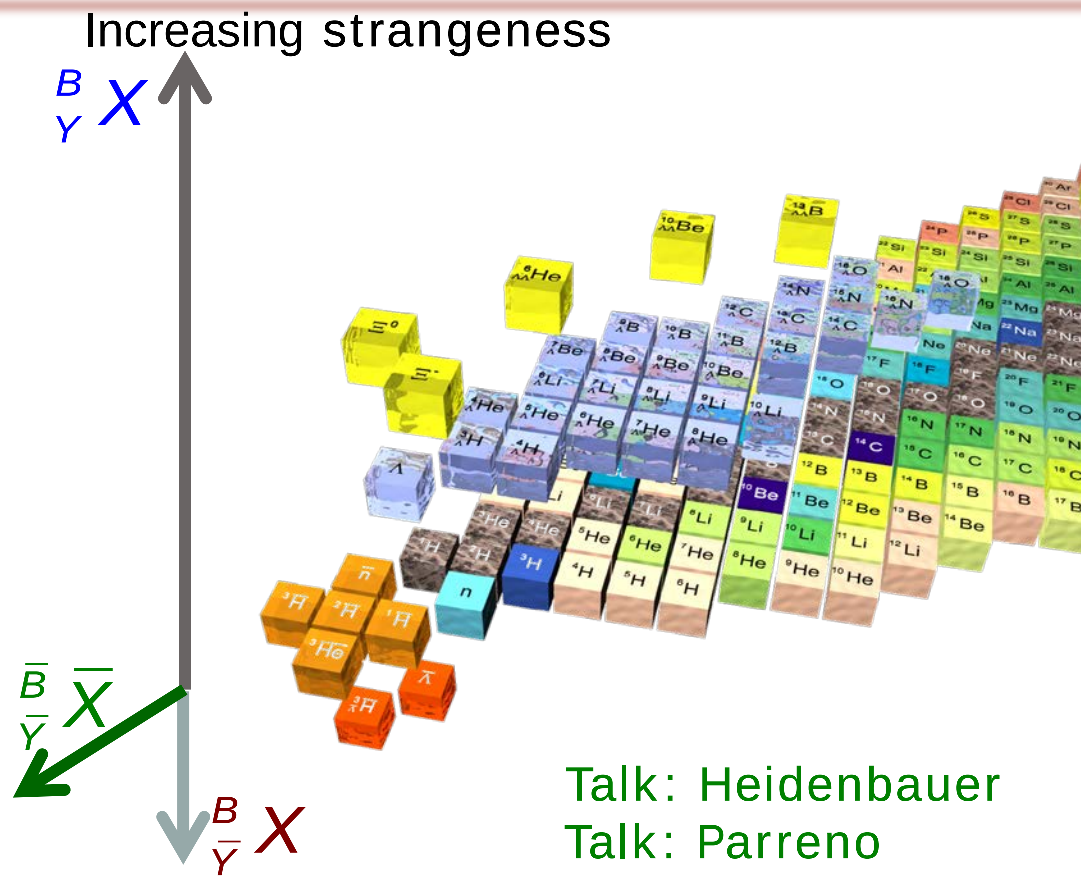
  (Lee und Yang 1956, L. Michel 1952)

- Hans Peter Dürr and E. Teller

  (Phys. Rev. ***101****, 494 (1956))*

$$V(NN)(r) = \sum_M V_M(r) \rightarrow V(N\bar{N})(r) = \sum_M G_M V_M(r)$$

- Caveat: meson picture will probably not work at small distance
- chance to study transition from meson to quark-gluon regime



Talk: Heidenbauer
Talk: Parreno

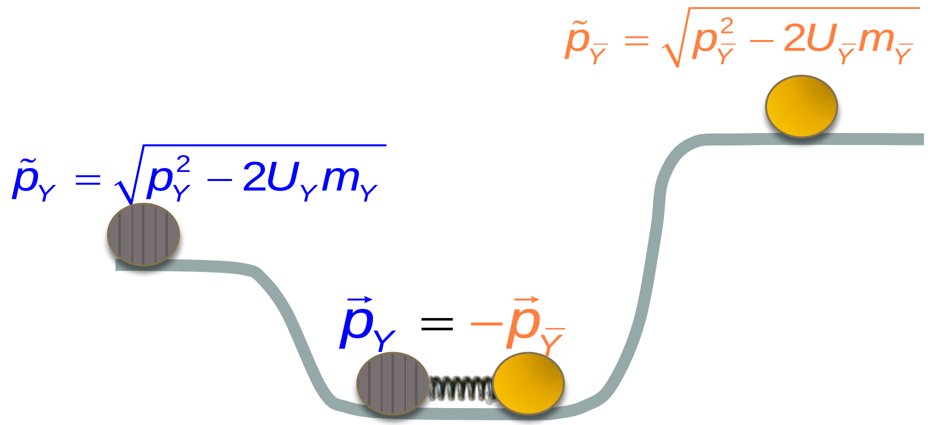
Nucleon	≈ -40MeV
Lambda	≈ -27MeV
Cascade	~ -15MeV
Antinucleon	~ -150MeV
Antilambda	?
Anticascade	?

Antibaryons in nuclei are a novel probe for short range interactions of strange baryons in nuclei

No exp. info on nuclear potential of antihyperons exists so far

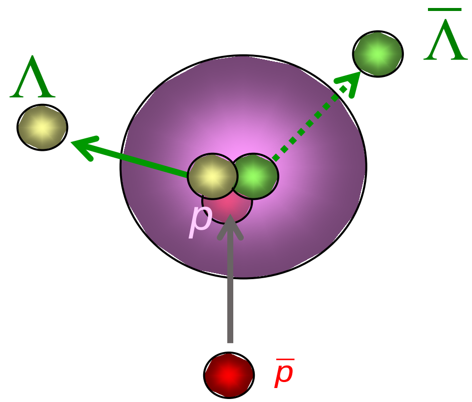
$\overline{\Lambda}$ Potential (in nucleon Matter)

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



A. Gal ,Phys. Rev. Lett. **64B**, 2 (1976)
J.P., PLB **669** (2008) 306

⇒ Advantage: well defined geometry , kinematics determined by energy and momentum conservation of a (nearly) two-body reactions



⇒ need to look at transverse momentum close to threshold of coincident $Y\overline{Y}$ pairs

⇒ But, studying only the average transverse momentum separately does not allow to extract unambiguous information

(Nearly) two-body kinematics

- Distribution of the produced baryon-antibaryon, not isotropic
- Absorption of antibaryon in the periphery
- Rescattering

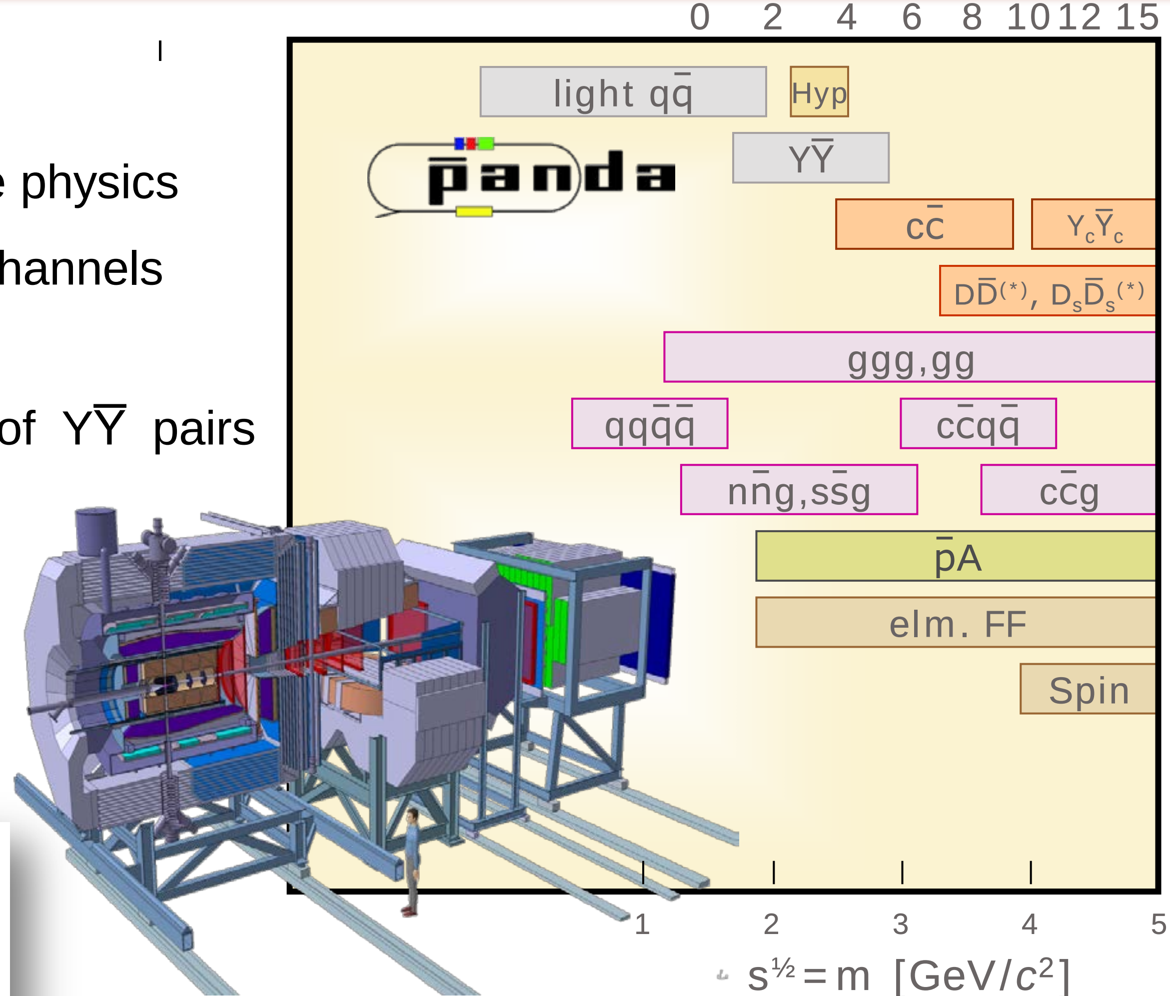
⇒ A difference between tranverse momenta of the coincident $Y\bar{Y}$ reflects the different potentials

Studying their correlation and to reduce the influence of the cm. anisotropy by exploring the tranverse asymmetry as a function of the longitudinal asymmetry

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

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

$Y\bar{Y}$ pairs production at PANDA



PANDA can provide solid and unique physics

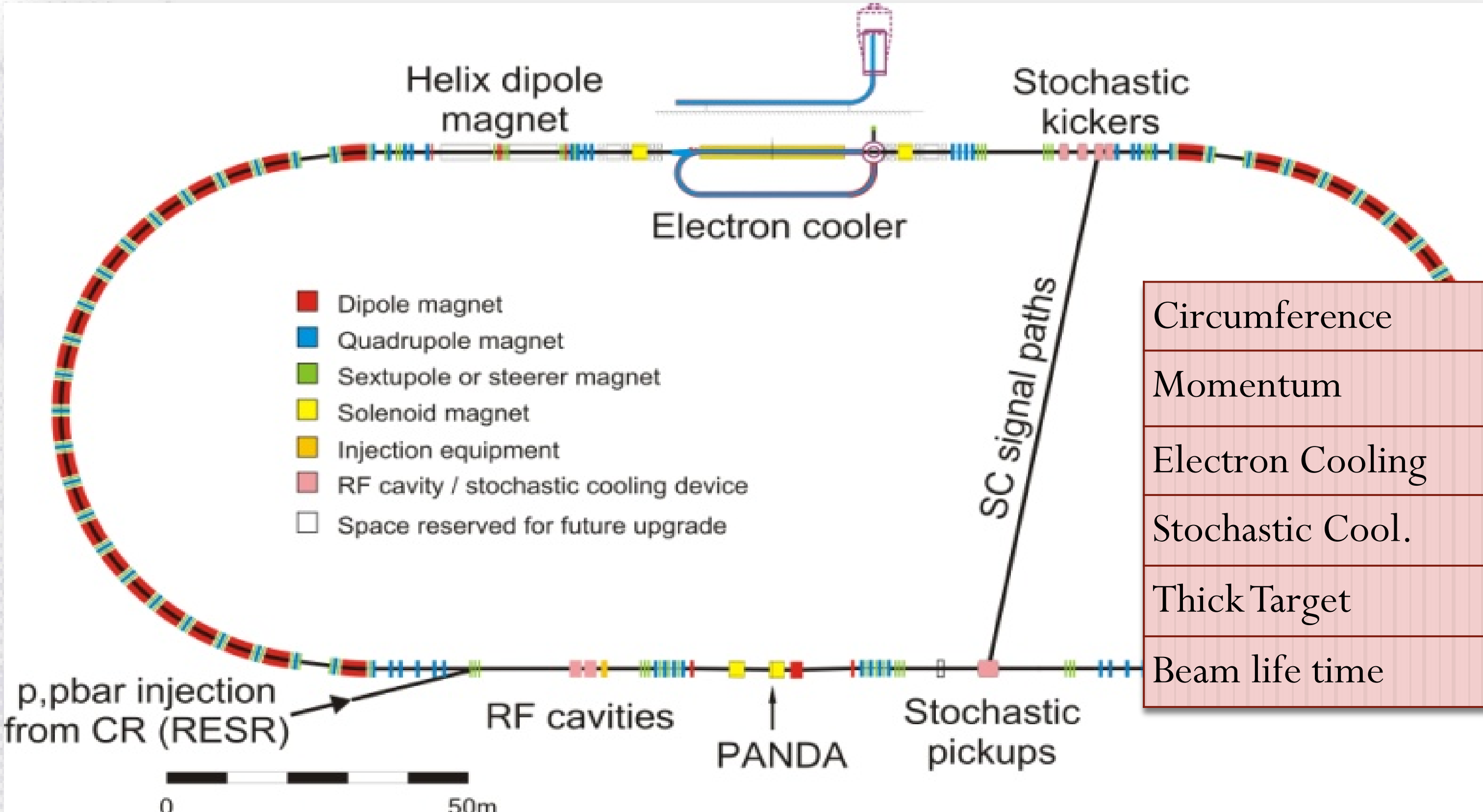
for the $\bar{p}$+p $\Rightarrow$ Y+$\bar{Y}$ in strangeness channels

- significant elementary production of $Y\bar{Y}$ pairs
- low background

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 $2 \cdot 10^{32} cm^{-2}s^{-1}$

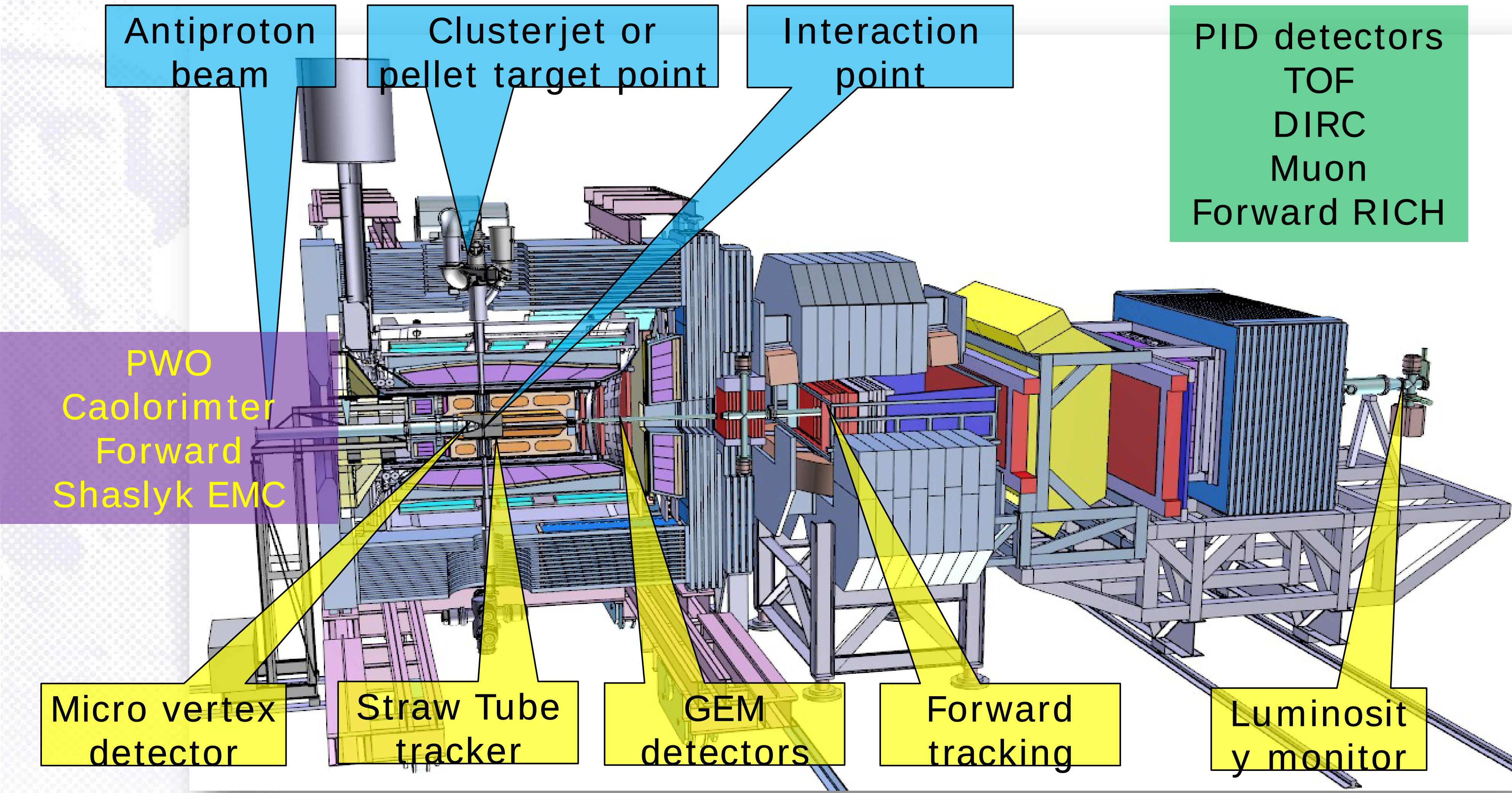
HESR with PANDA and Electron Cooler



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

- High resolution mode
  - e^- cooling $1.5 \leq p \leq 8.9$ GeV/c
  - 10^{10} antiprotons stored
  - Luminosity up to $2 \cdot 10^{31}$ cm^{-2}s^{-1}
  - $\Delta p/p \leq 4 \cdot 10^{-5}$
- High luminosity mode
  - Stochastic cooling $p \geq 3.8$ GeV/c
  - 10^{11} antiprotons stored
  - Luminosity up to $2 \cdot 10^{32}$ cm^{-2}s^{-1}
  - $\Delta p/p \leq 2 \cdot 10^{-4}$

The P̄ANDA detector



GiBUU 1.5

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

Institut für Theoretische Physik, JLU Giessen

GiBUU

The Giessen Boltzmann-Uehling-Uhlenbeck Project

- Antiproton potential needs to be scaled by 0.22 to obtain -150MeV

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

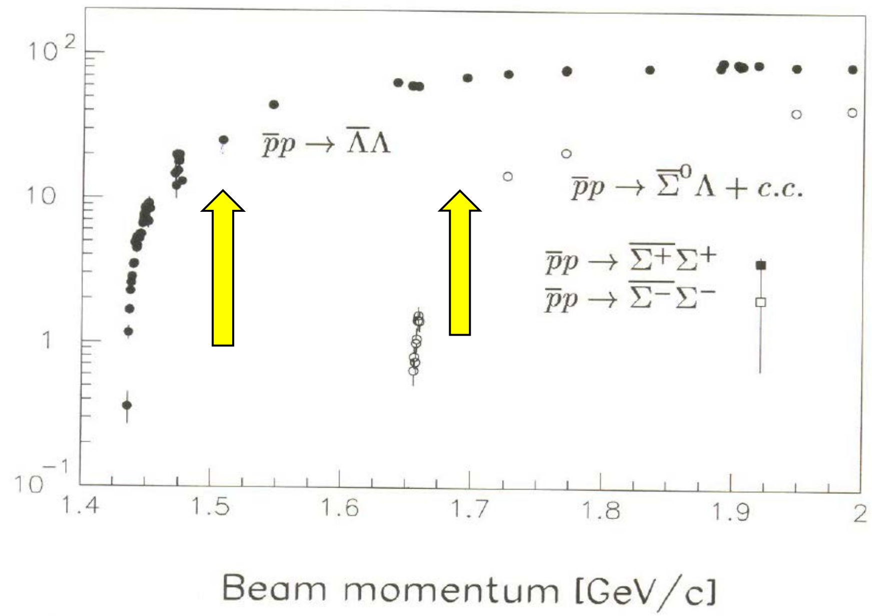
GiBUU Simulations $\bar{p}+{}^{20}Ne \to \Lambda\bar{\Lambda}+X$

- GIBUU: *Phys. Rev. C 85, 024614 (2012)*

Talk T. Gaitanos

- G-parity used to estimate anti-baryons potential
- Approximately 10k exclusive $\Lambda\bar{\Lambda}$ pairs in each set

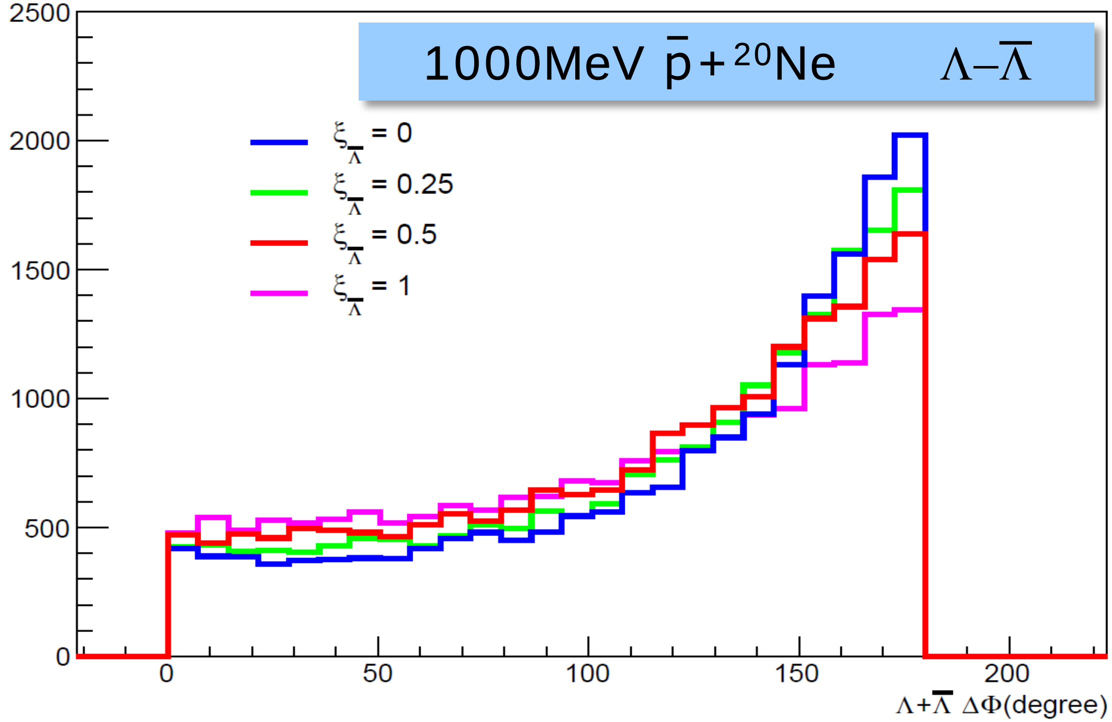
Energy (MeV)	Momentum (MeV/c)	Excess energy (MeV)
850	1522	30.6
1000	1696	92.0

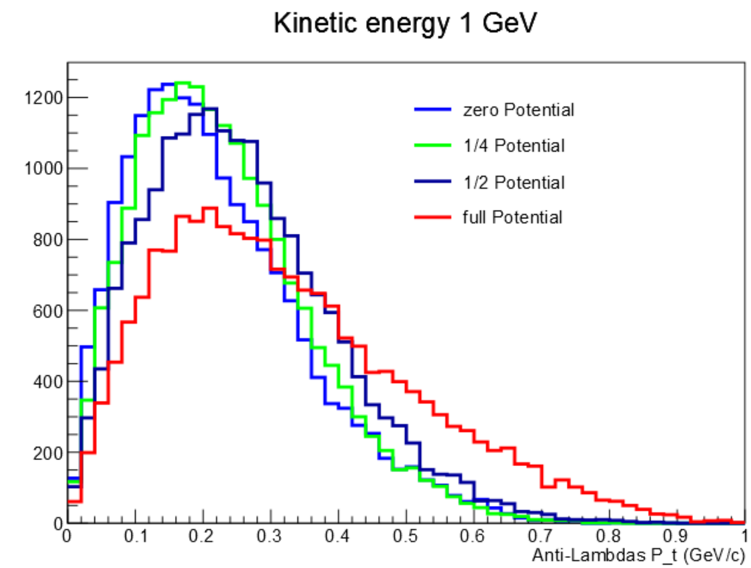


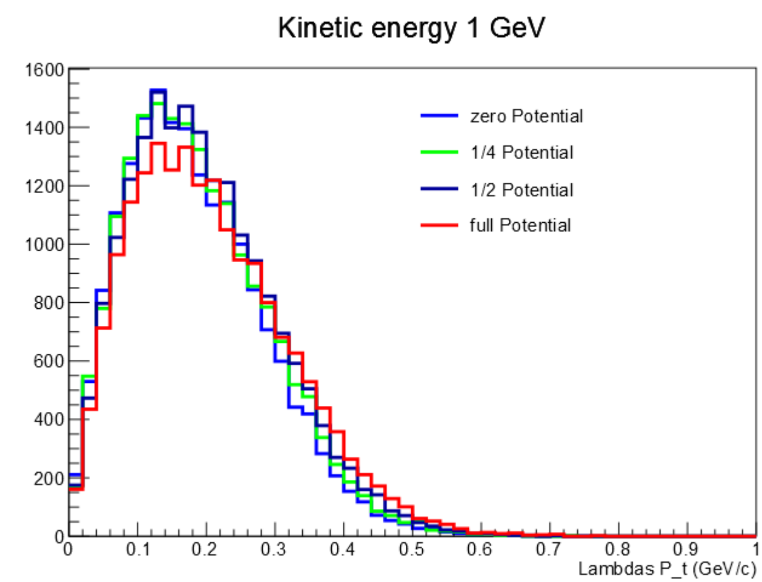
- Aim of the present work
  - Explore sensitivity of α_T to a scaling of the real $\bar{Y}$ potential
  - Proof the feasibility of a measurement at PANDA
  - Trigger a fully self-consistent dynamical treatment of antihyperons in nuclei

Rescattering effects

- Typical 15000 $\bar{\Lambda}\Lambda$ pairs produced
- $U(\bar{\Lambda})$= -449MeV, -225MeV, -112MeV, 0MeV
- $\xi_{\bar{\Lambda}}$ scaling factor
- All other potentials unchanged







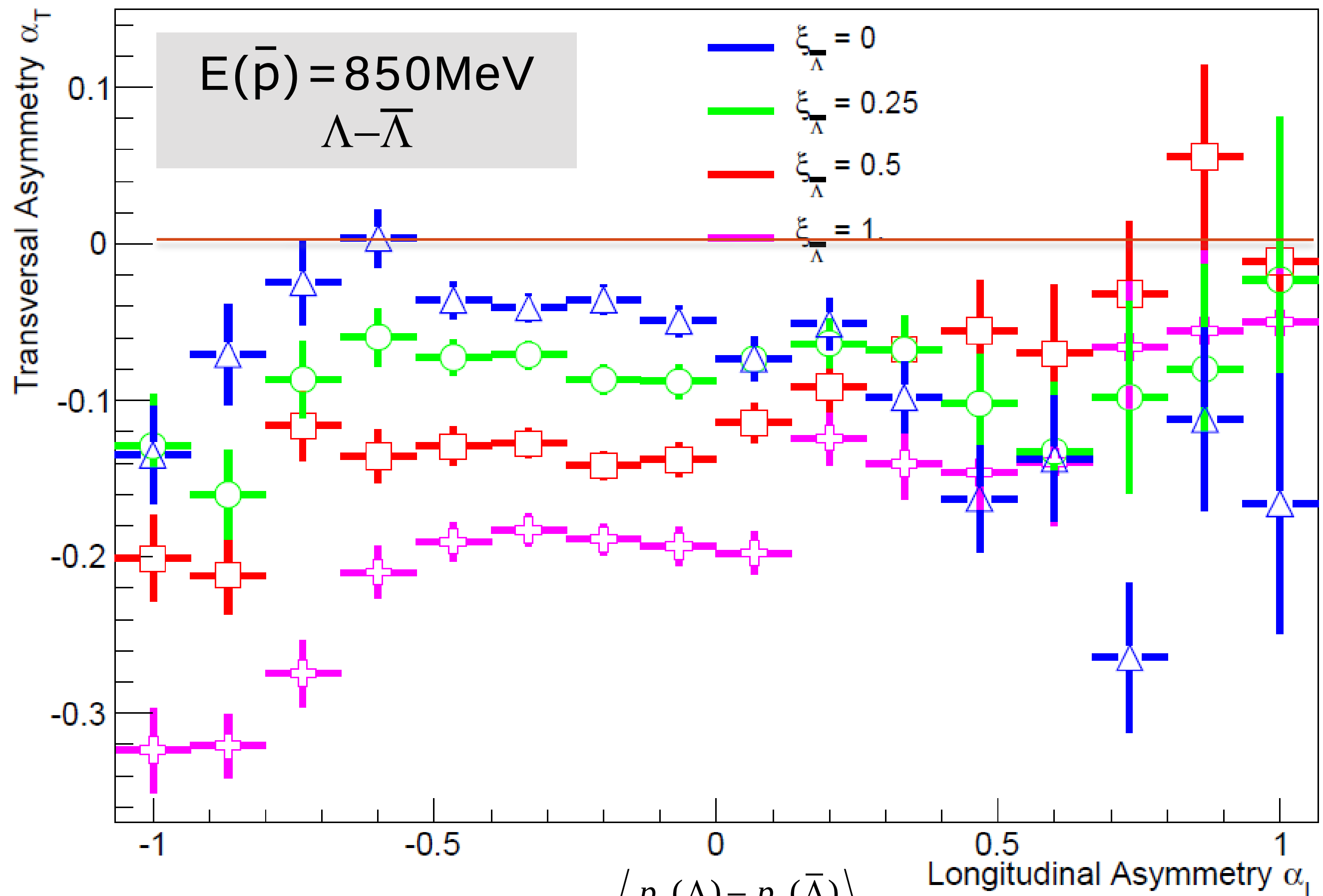
- Coplanarity distorted ⇒ strong rescattering effects

Scan of $\overline{\Lambda}$ potential

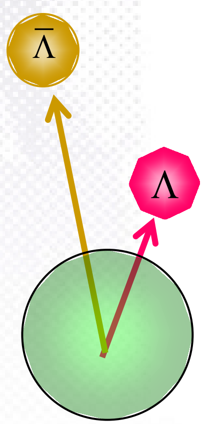
- $U(\overline{\Lambda})$= -449MeV, -225MeV, -112MeV, 0MeV
- $\xi_{\overline{\Lambda}}$ scaling factor
- All other potentials unchanged

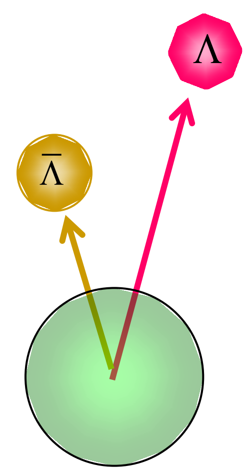
$$\alpha_{\perp} = \left\langle \frac{p_{\perp}(\Lambda) - p_{\perp}(\overline{\Lambda})}{p_{\perp}(\Lambda) + p_{\perp}(\overline{\Lambda})} \right\rangle$$

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



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

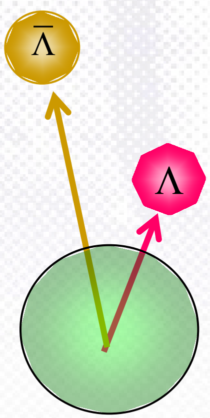


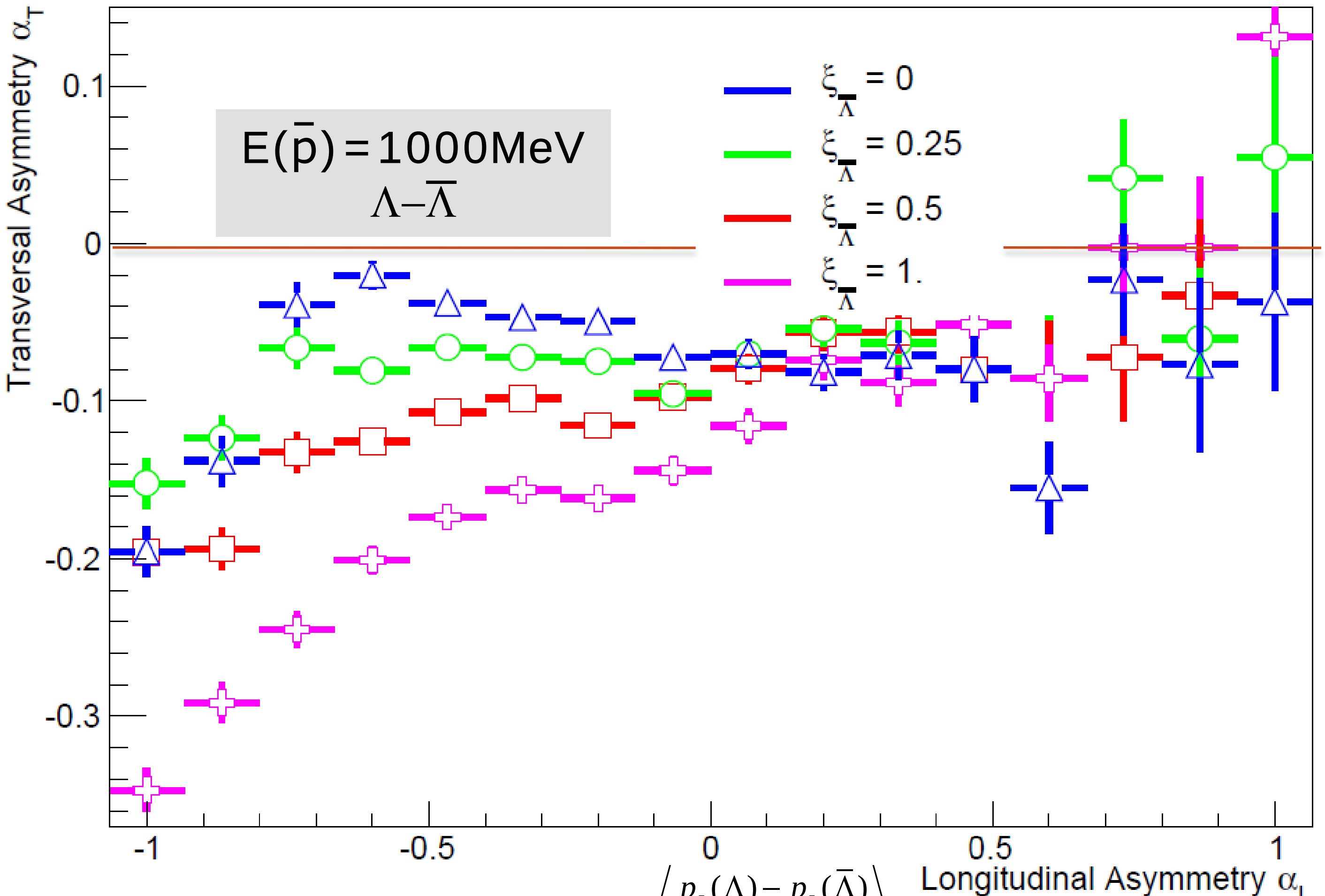


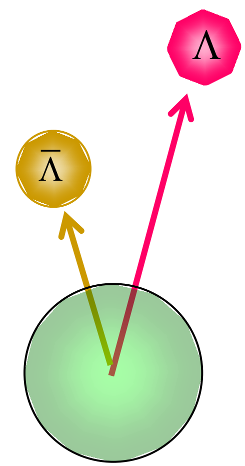
Scan of $\bar{\Lambda}$ potential

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

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





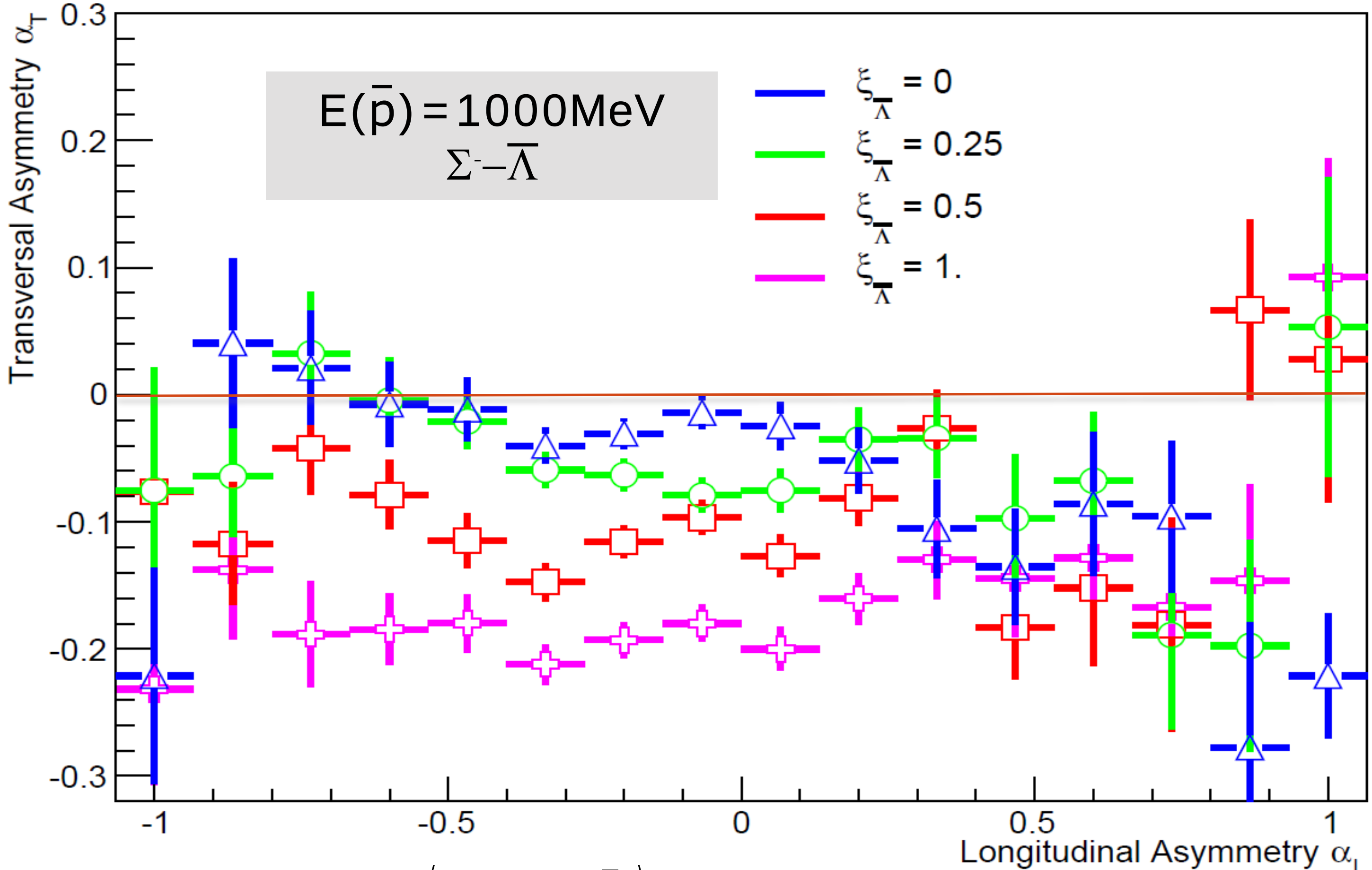


$$\alpha_{L} = \left\langle \frac{p_{L}(\Lambda) - p_{L}(\bar{\Lambda})}{p_{L}(\Lambda) + p_{L}(\bar{\Lambda})} \right\rangle$$

Other |s|=1 channels @ 1000MeV

- $\bar{p}+p\rightarrow\bar{\Lambda}+\Lambda$ $\bar{p}+p\rightarrow\bar{\Sigma}^0+\Lambda$
- $\bar{p}+n\rightarrow\bar{\Lambda}+\Sigma^-$ $\bar{p}+n\rightarrow\bar{\Sigma}^++\Lambda$

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

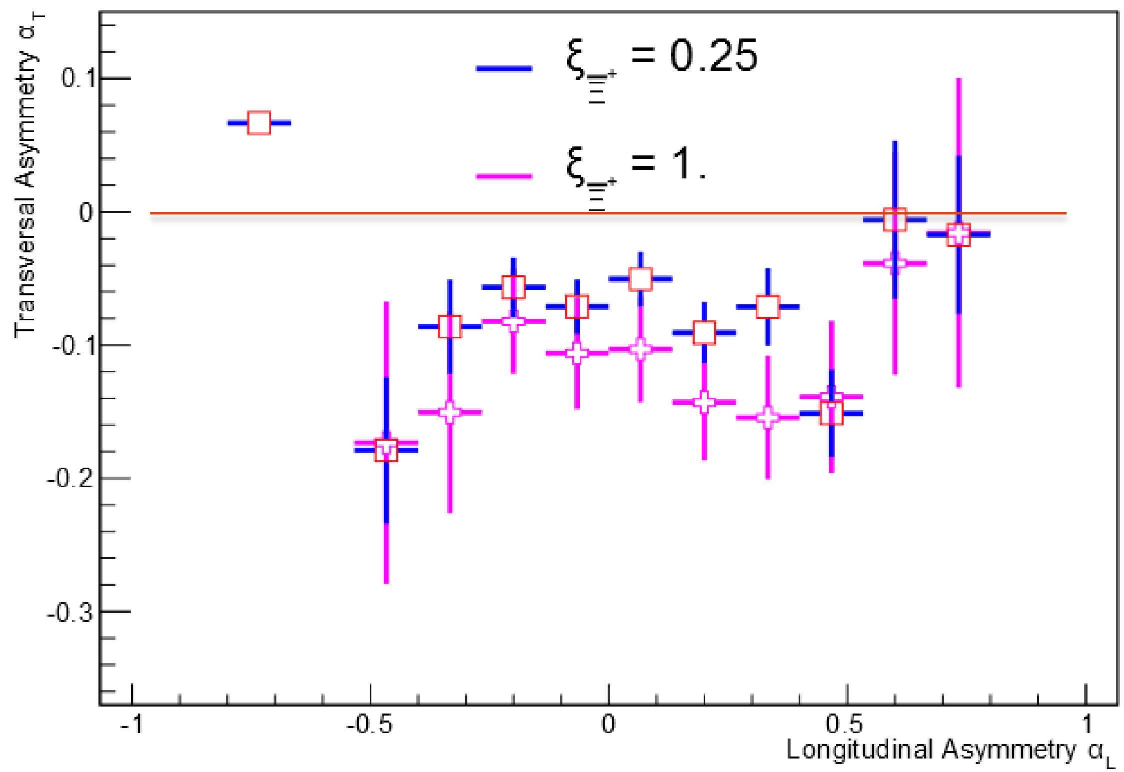


$$\alpha_L = \left\langle \frac{p_L(\Lambda) - p_L(\bar{\Lambda})}{p_L(\Lambda) + p_L(\bar{\Lambda})} \right\rangle$$

Further 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)

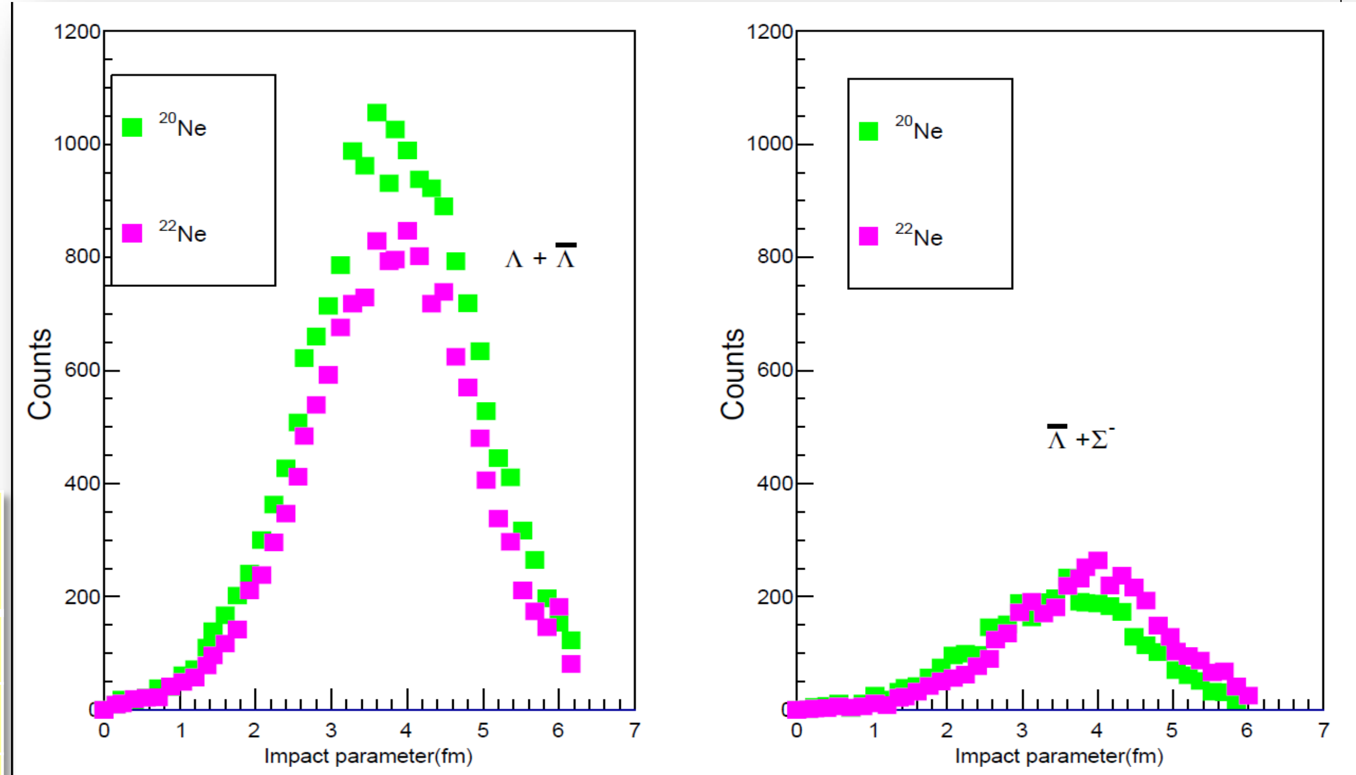
- $\overline{\Xi}^+ + \Xi^-$ production
  - $\overline{p}+{}^{12}C$
  - 2.9 GeV/c
  - 60M events
  - $\sim 500\ \overline{\Xi}^+ + \Xi^-$ pairs



Reactions within the Neutron Skin

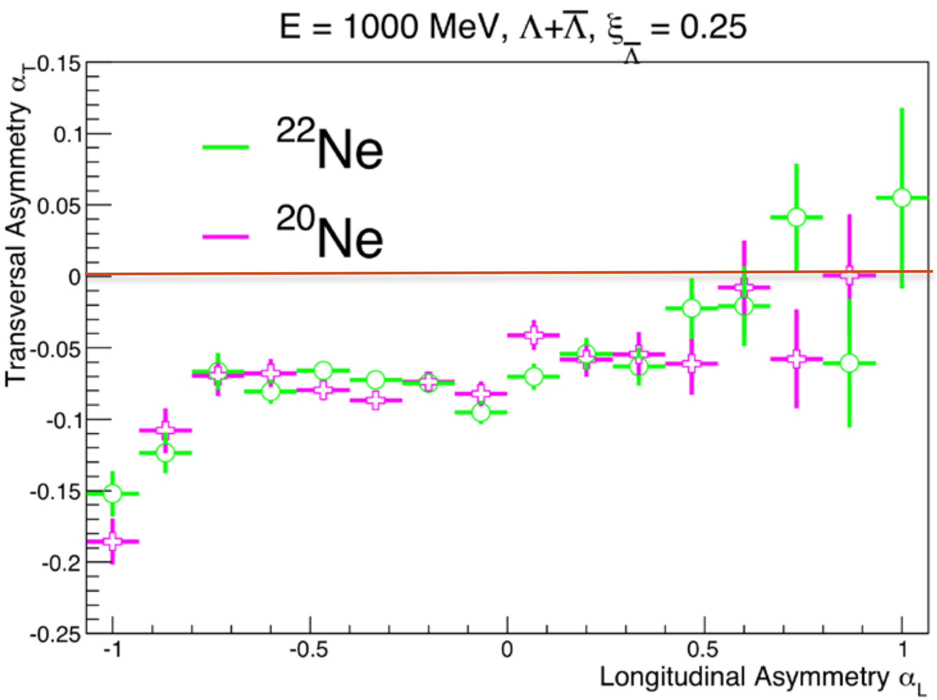
- 1000MeV $\bar{p}+^{20}Ne$ and $\bar{p}+^{22}Ne$;
- $\xi(\bar{\Lambda}) = 0.25$

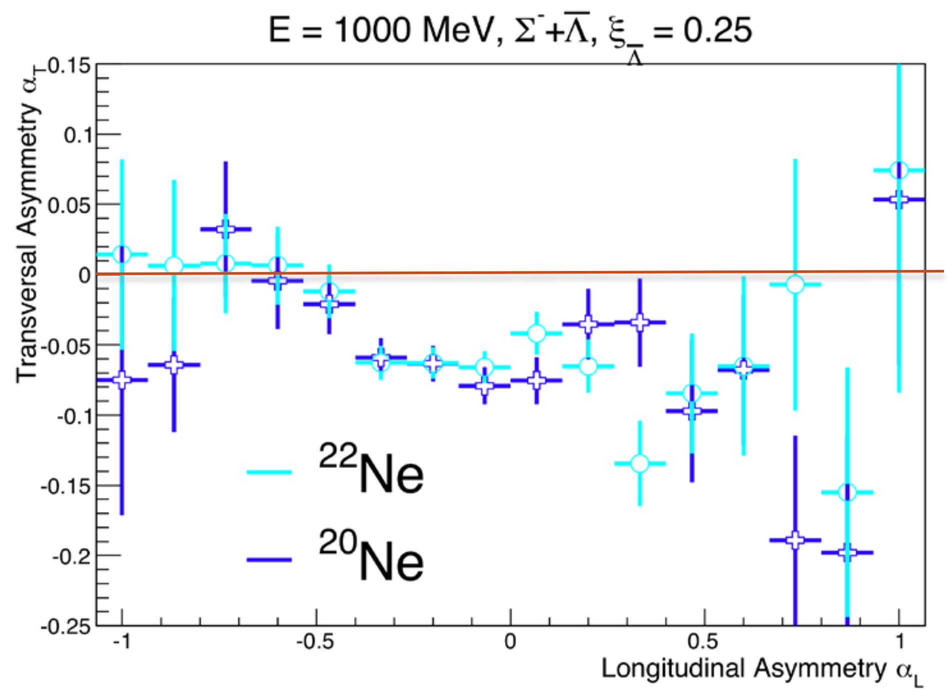
	$\bar{p}+p \rightarrow \bar{\Lambda}+\Lambda$	$\bar{p}+n \rightarrow \bar{\Lambda}+\Sigma^-$
^{20}Ne	18808	3667
^{22}Ne	15733	4516
$^{22}Ne/^{20}Ne$	0.84	1.23



- When going from ^{20}Ne to ^{22}Ne
  - 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 $\bar{\Lambda}+\Lambda$ may probe the neutron skin
- Possibility to explore potentials in neutron-rich environment ?

^{20}Ne and ^{22}Ne asymmetries

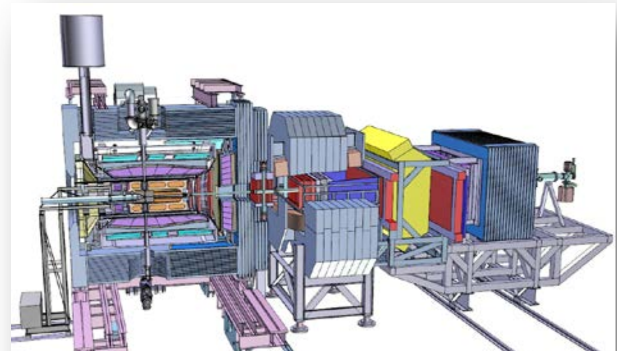




Antihyperon-Hyperon Pairs at PANDA

- 2018 first beam in PANDA 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



	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Efficiency Llbar	1,41	4,31	1,48	2,17
Efficiency L	11,23	18,12	11,95	15,98
Effiency Lbar	10,41	16,73	10,55	14,2

Scenario 1 : Full Setup (no Lambda discs) + full Mag. field, 2 T

Scenario 2 : Full Setup (no Lambda discs) + half Mag. field, 1 T

Scenario 3 : Reduced Setup (no Emc, no Fwd Spec, no Lambda discs) + full Mag. field

Scenario 4 : Reduced Setup (no Emc, no Fwd Spec, no Lambda discs) + half Mag. field

All : Realistic Tracking , PID, Mass Constraint Filter

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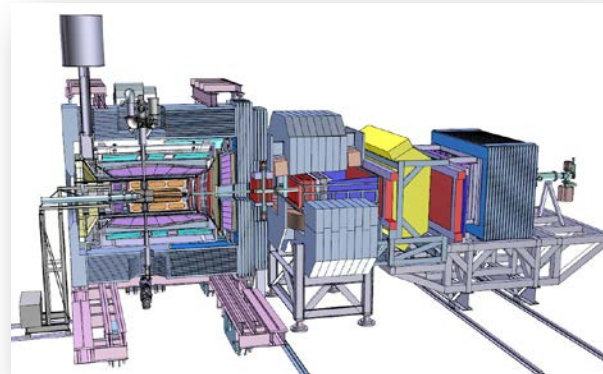
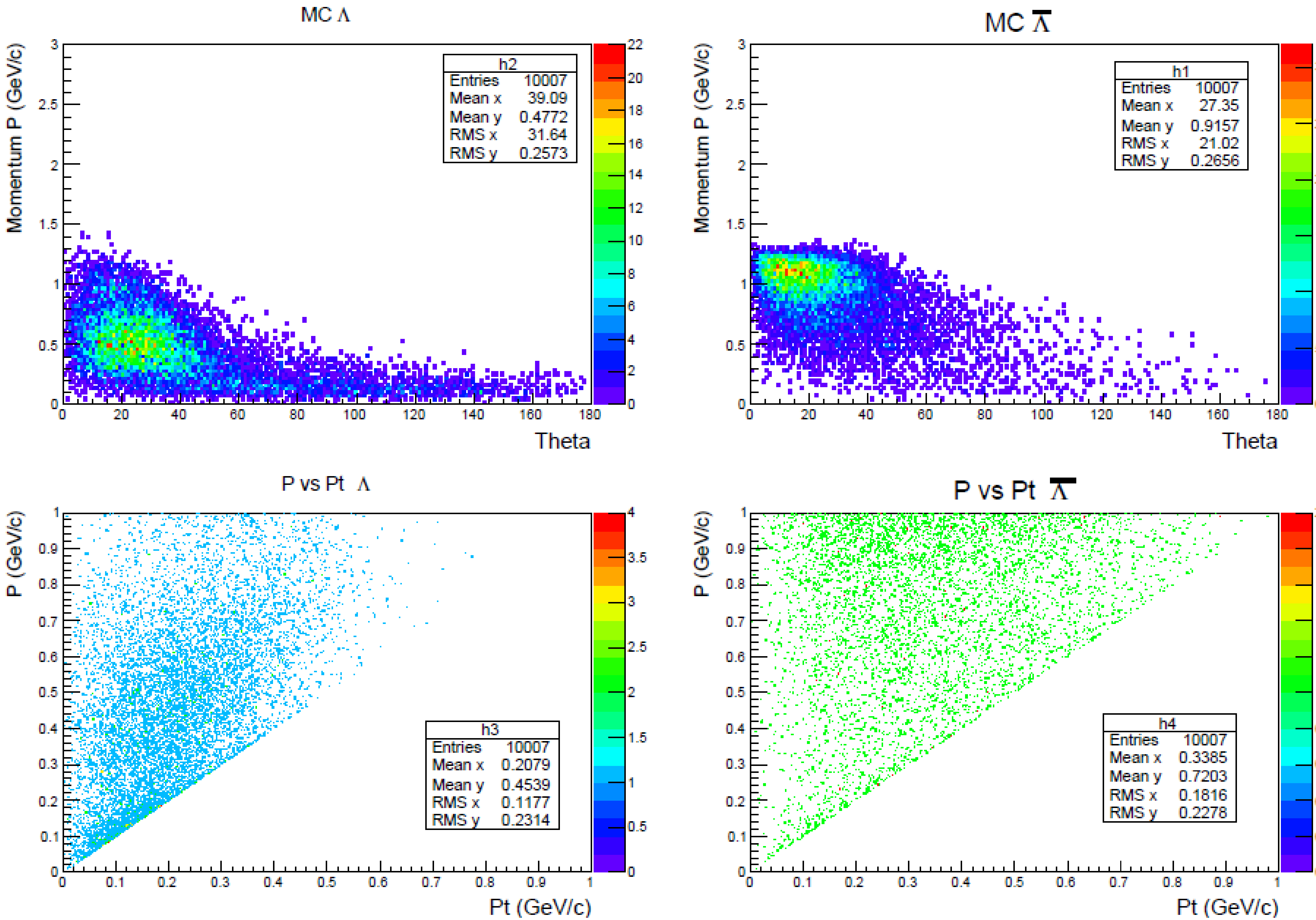
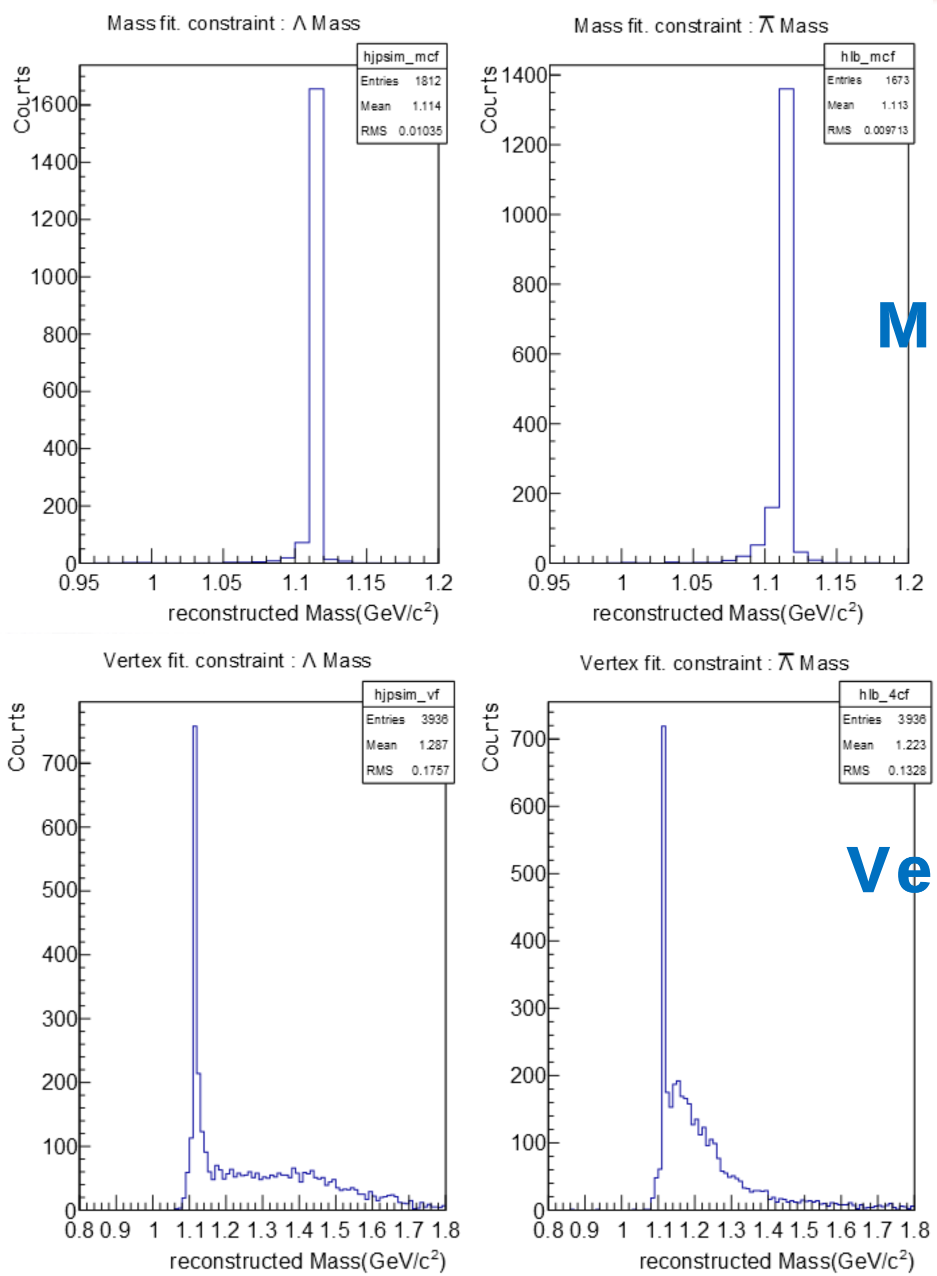


- MC Simulation Procedure:
  - Generation of $\Lambda + \overline{\Lambda}$, GiBUU-based events
  - Transport of particles through entire spectrometer
  - Generation of detector signal, digitization
  - Pattern Recogn./Tracking of charged particles
  - Particle Identification, particle mass assigment
  - Λ / $\overline{\Lambda}$ reconstruction from particles cand. Lists.
  - Fitting, Mass constraint / Vertex filter
  - Looking for $\Lambda + \overline{\Lambda}$ pairs event-by event
  - Asymmetries

MC Events Generation



Λ / $\bar{\Lambda}$ Reconstruction



- Full PANDA set up.
- 1T Solenoid Magnetic field.

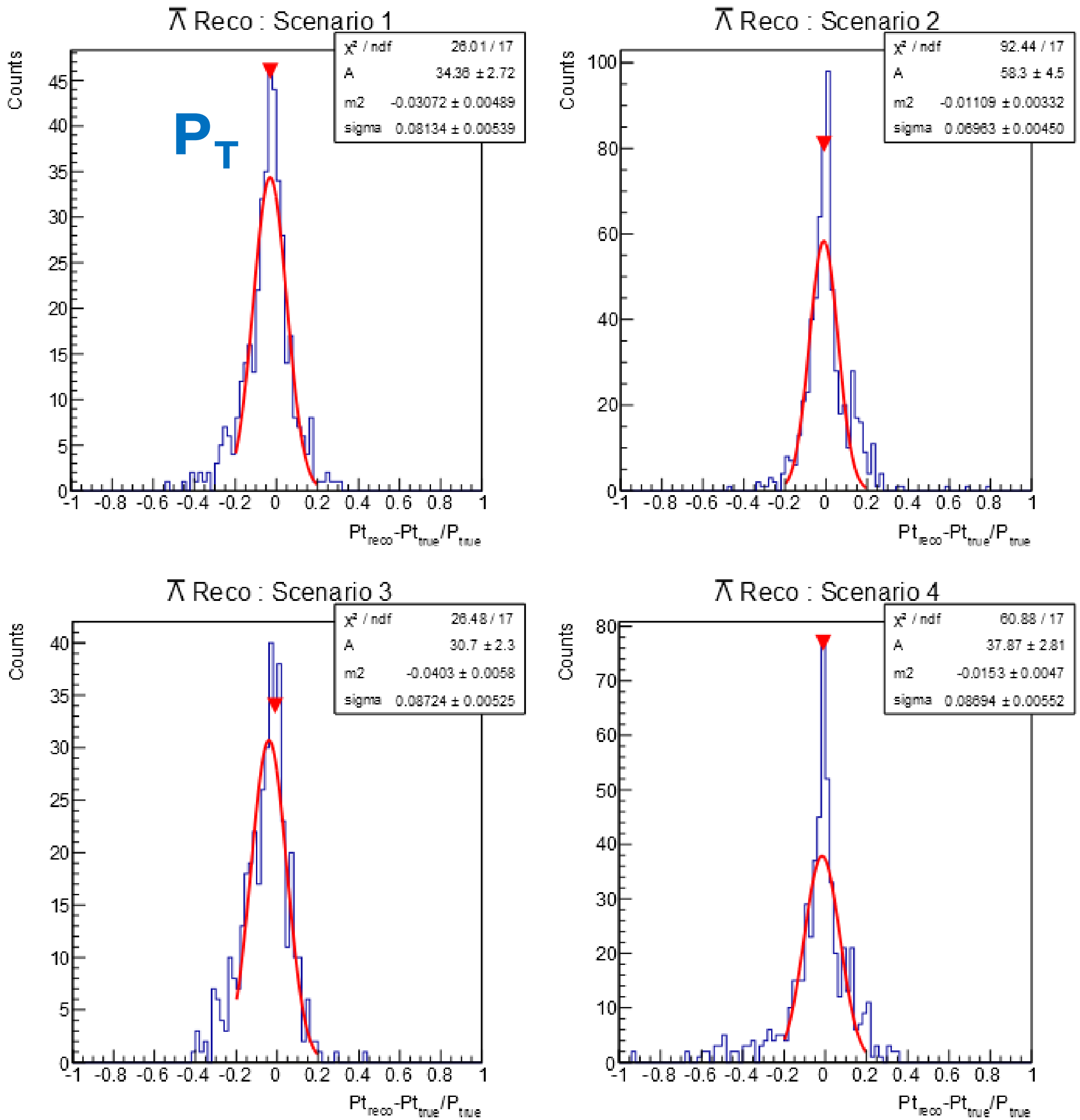
Mass CF

- Mass Filter constraint
- Good performance

Vertex CF

- Vertex filter constraint
- Not so good performance
  - Not able to reconstruct decay products properly

Building Asymmetries: Pull P_T and P_Z

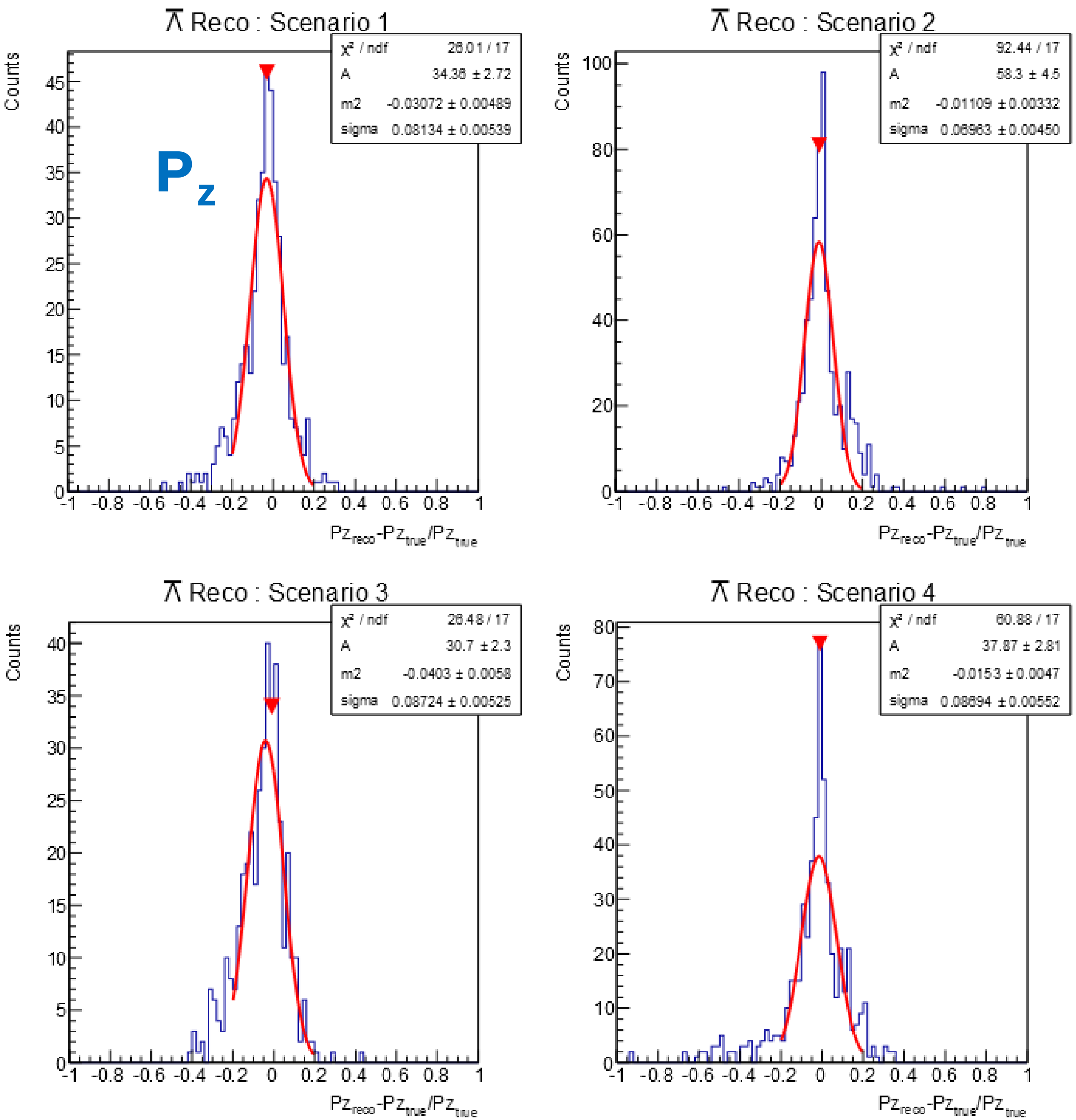


- 4 scenarios of the PANDA set up.
- 1T Solenoid Magnetic field.

  - Λ / $\bar{\Lambda}$ Candidates selected which fulfill Mass Filter const.

  - Poor tracking efficiency for P_T
  - Better behavior for P_Z
  - Improvement are needed.

Building Asymmetries: Pull P_T and P_Z



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- We are right now exploring different scenarios
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and other important aspects like

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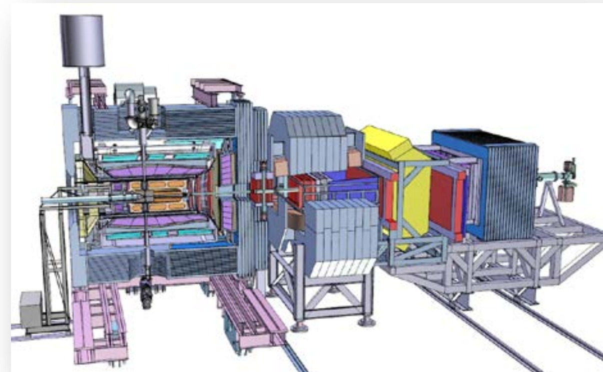


- Typical (*preliminary*) $\Lambda\bar{\Lambda}$ pair efficiency ≈ 3-5% (better at higher momenta)
- $\Lambda+\bar{\Lambda}$
  - ^{nat}Ne target, H for calibration
  - only charged particle detection *easy*
  - Assume average interactions rate $10^5 s^{-1}$ i.e. *~1% of default luminosity*
  - Moderate data taking period *~ 30 days*

  ⇒ $2.6 \cdot 10^{11}$ detected interactions

  - pair reconstruction efficiency 4%

  ⇒ 0.5M events detected $\Lambda+\bar{\Lambda}$ pairs

40 × present GiBUU simulations

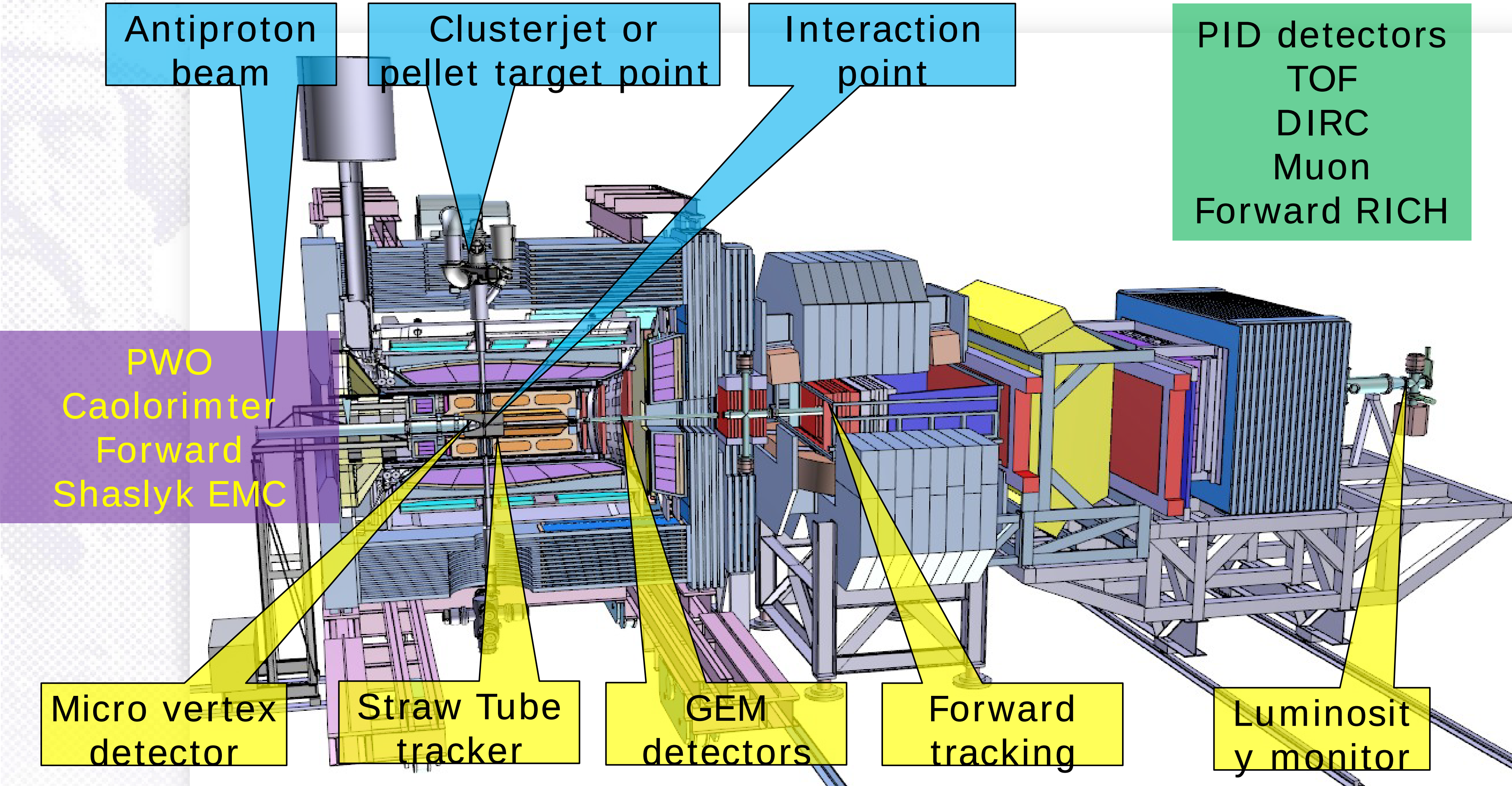
Summary and conclusion

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

The antihyperon-hyperon production is an ideal experiment for the commissioning phase of PANDA

THANK YOU FOR YOUR ATTENTION

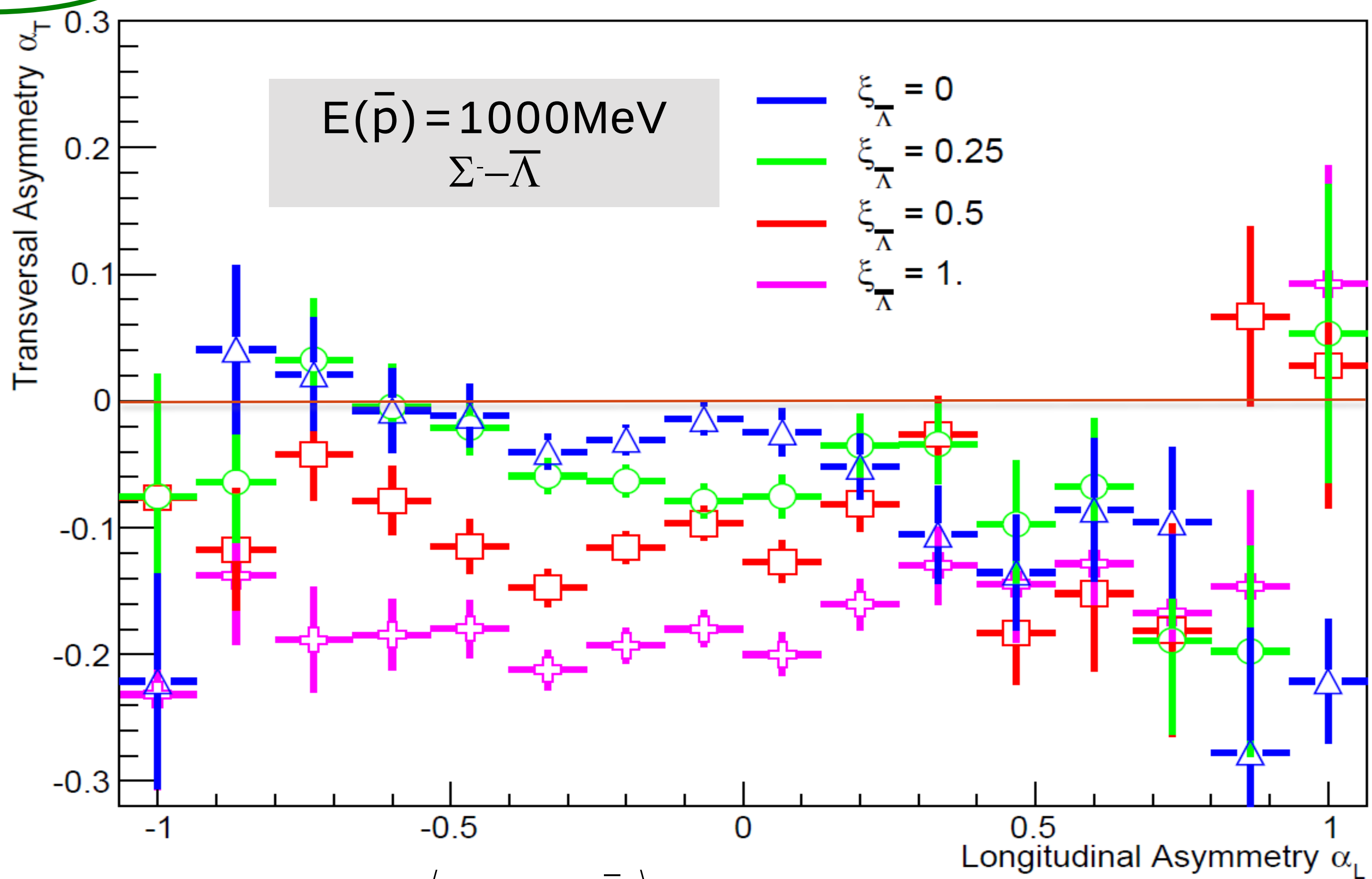
The P̄ANDA detector



Other |s|=1 channels @ 1000MeV

- p+p→$\bar{\Lambda}$+Λ   p+p→$\bar{\Sigma}^0$+Λ
- p+n→$\bar{\Lambda}$+Σ^- p+n→$\bar{\Sigma}^+$+Λ

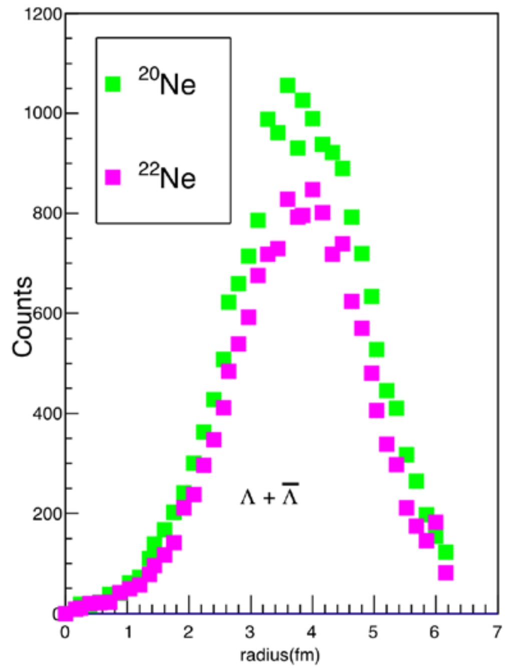
$$\alpha_\perp = \left\langle \frac{p_\perp(\Lambda) - p_\perp(\bar{\Lambda})}{p_\perp(\Lambda) + p_\perp(\bar{\Lambda})} \right\rangle$$

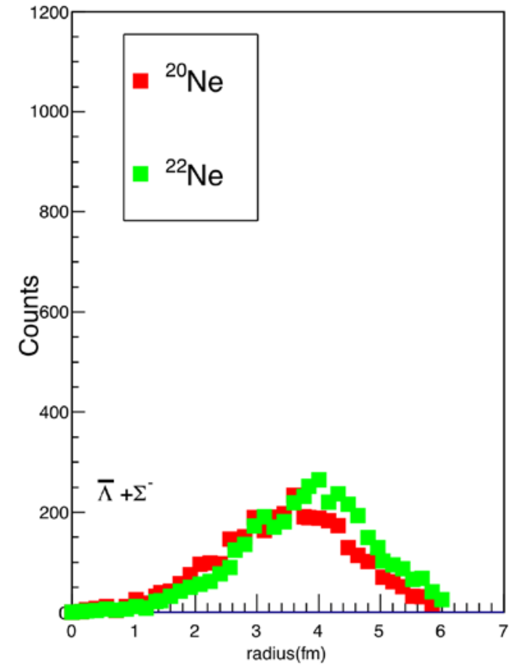


$$\alpha_L = \left\langle \frac{p_L(\Lambda) - p_L(\bar{\Lambda})}{p_L(\Lambda) + p_L(\bar{\Lambda})} \right\rangle$$

^{20}Ne and ^{22}Ne

- target composition : Neon :
  90.92 % ^{20} Ne , 8.82% ^{22}Ne
- 1000 MeV p+^{20}Ne and p+^{22}Ne
- Scaling factor for potential $\xi(\overline{\Lambda}) = 0.25$





	$p+p\to\overline{\Lambda}+\Lambda$	$p+n\to\overline{\Lambda}+\Sigma^-$
^{20}Ne	18868 (3.68)	3667 (3.88)
^{22}Ne	15733 (3.92)	4516 (3.92)
^{22}Ne/^{20}Ne =R	0.83	1.23
$R(\overline{\Lambda}+\Sigma^-)/R(\overline{\Lambda}+\Lambda)$	1.34	

- explore potentials in neutron-rich environment by neutron rich targets