Physics of multistrange systems with antiprotons

from J-PARC to FAIR

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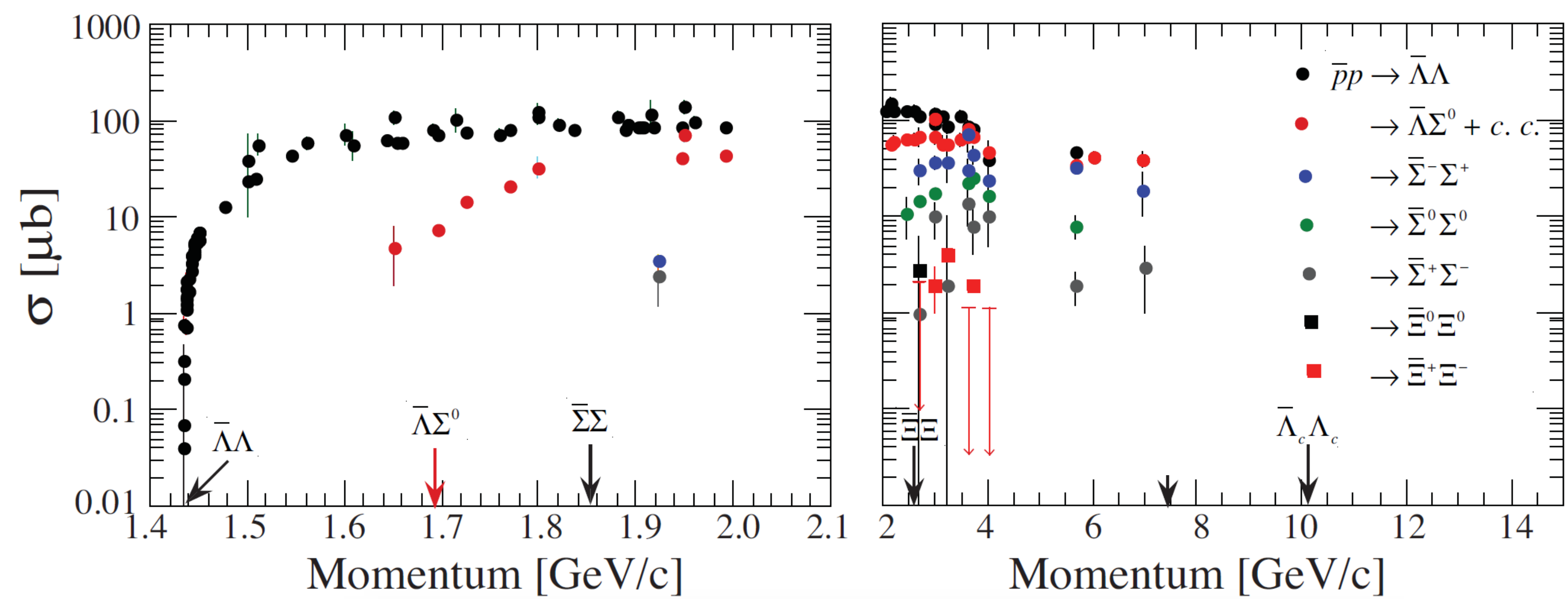
Helmholtz-Institut Mainz

NUFRA 2015

October 3rd - October 11th 2015

Kemer Turkey

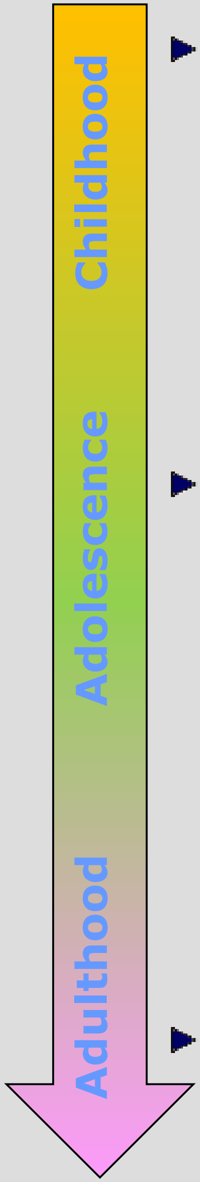
P̄ANDA – a Factory for strange *and* charmed YȲ-Pairs



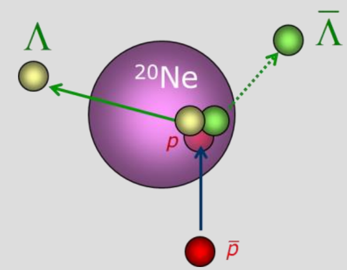
Production Rates (1-2 (fb)$^{-1}$/y)

Final State	cross section	# reconstr. events/y
Meson resonance + anything	100μb	10^{10}
$\Lambda\bar{\Lambda}$	50μb	10^{10}
$\Xi\bar{\Xi}$ ($\rightarrow_{\Lambda\Lambda}$ A)	2μb	10^8 (10^5)
$D\bar{D}$	250nb	10^7
J/ψ ($\rightarrow e^+e^-, \mu^+\mu^-$)	630nb	10^9
χ_2 ($\rightarrow J/\psi + \gamma$)	3.7nb	10^7
$\Lambda_c\bar{\Lambda}_c$	20nb	10^7
$\Omega_c\bar{\Omega}_c$	0.1nb	10^5

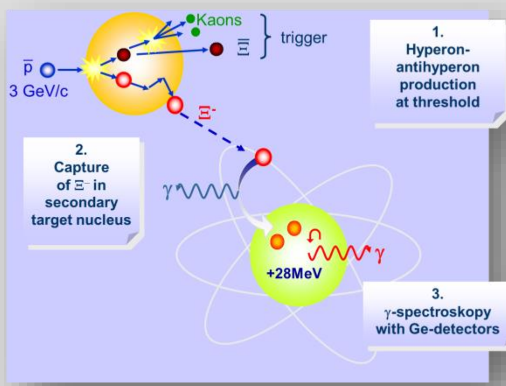
Exploring (anti-)hadron interactions



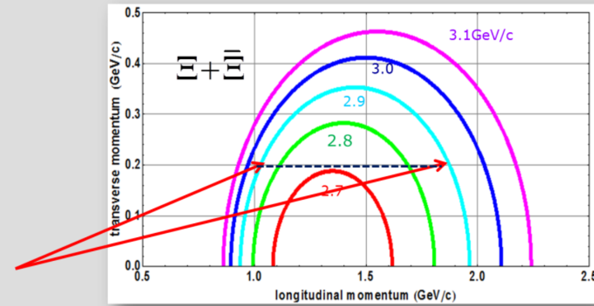
- Antihadrons in atomic nuclei
  - Nuclear potential of antihadrons and hadrons
  - Search for Antilambda bound states
  - Exploring the neutron skin of nuclei
  - $K^*/\bar{K}^*$ in nuclei



- High resolution γ-Spectroscopy
  - Excited particle stable state spectroscop of light $\Lambda\Lambda$ hypernuclei
  - Atomic transitions in heavy hyperonic (S=2,3) atoms



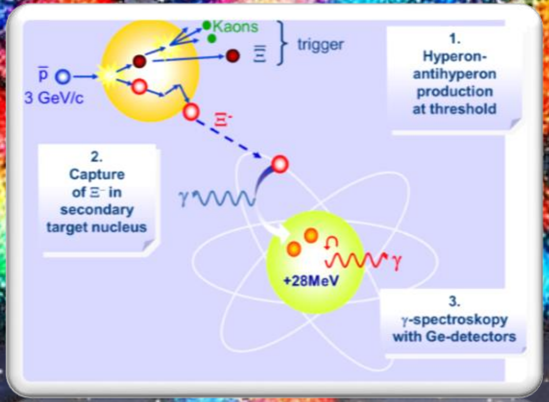
- Secondary scattering of momentum tagged, polarized hyperons and antihyperons



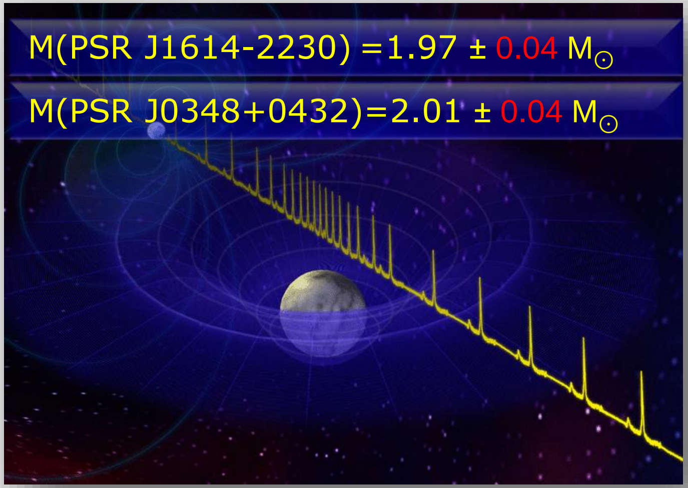
EXAMPLE 1

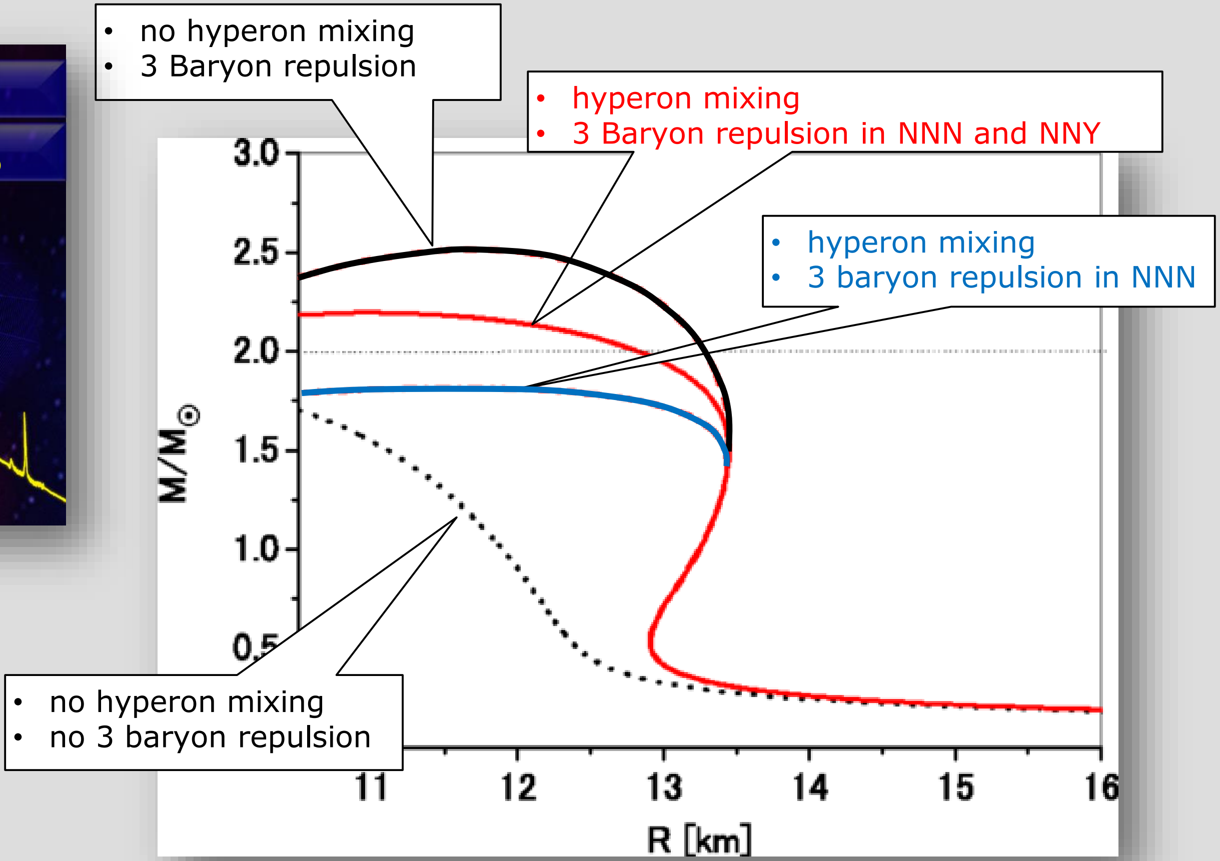
Approaching the hyperonization puzzle

ΛΛ HYPERNUCLEI at PANDA



Role of multi-nucleon interaction

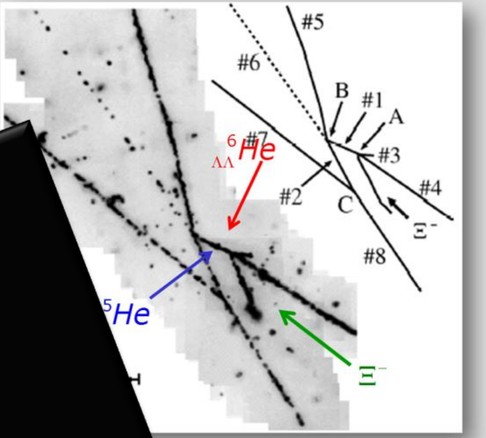




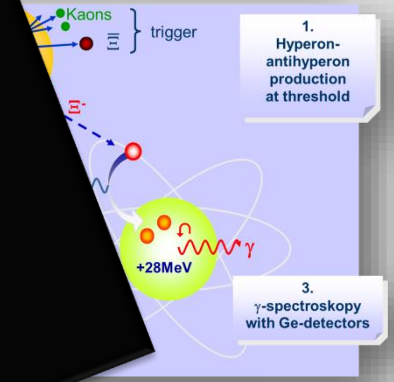
Y. Yamamoto, T. Furumoto, N. Yasutake, Th. A Rijken,
Phys. Rev. C 90, 045805 (2014)

Many ways to double hypernuclei

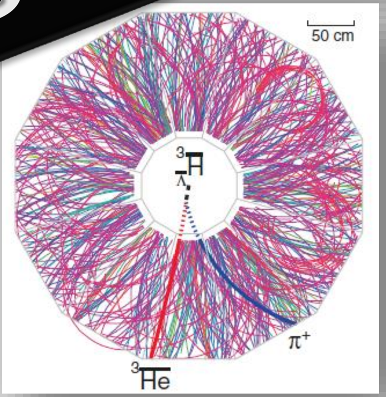
- Ground state masses
  - Hybrid-emulsion technique
  - J-PARC E07
  - Goal: factor of 10 („overall scanning" … compared to existing data



- Exci…
  - γ-…
  - PA…

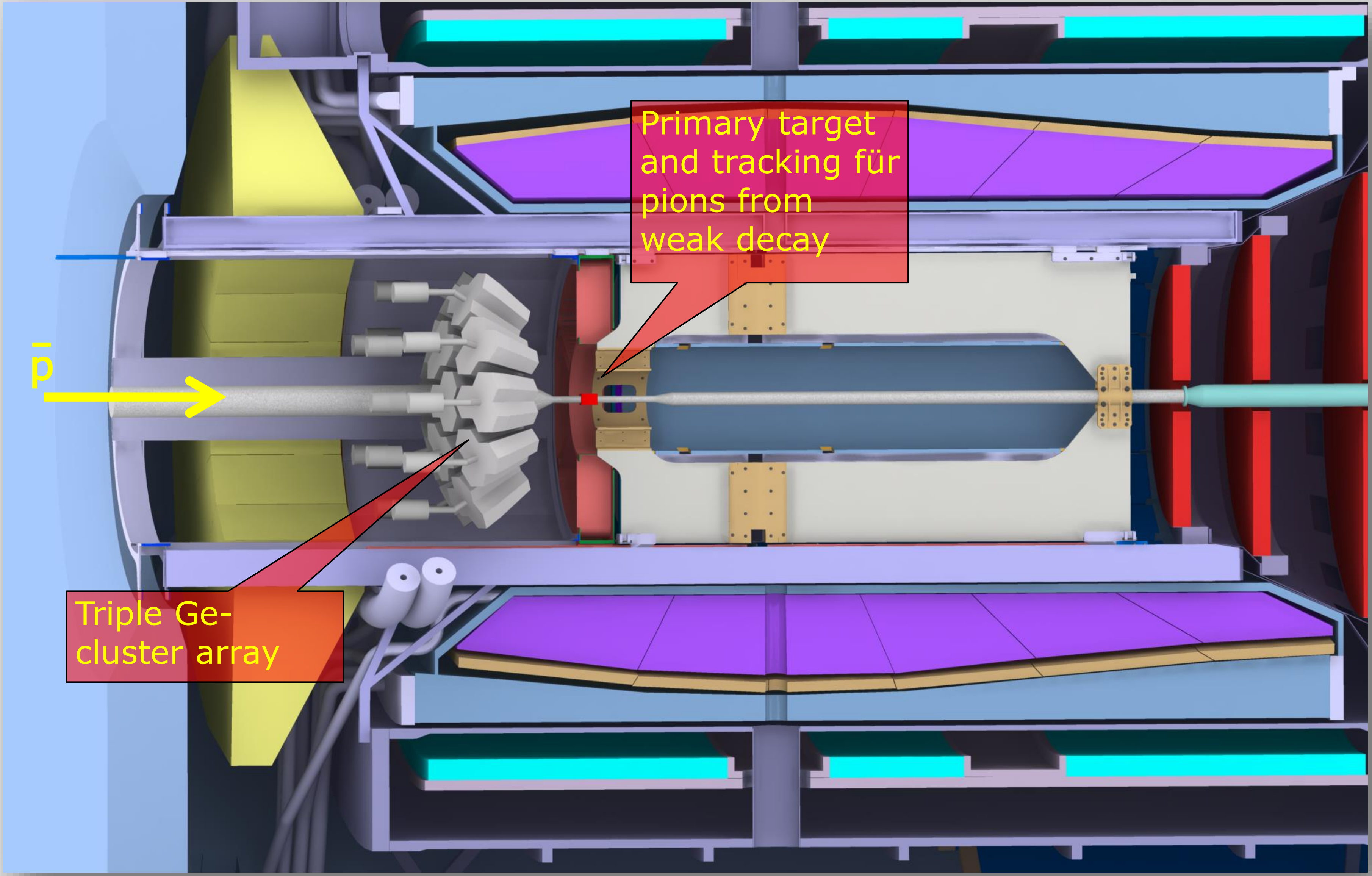


- Excited u… single hyp…
  - Invarian… …ei-Λ correlations
  - CBM and …
  - STAR, ALIC…



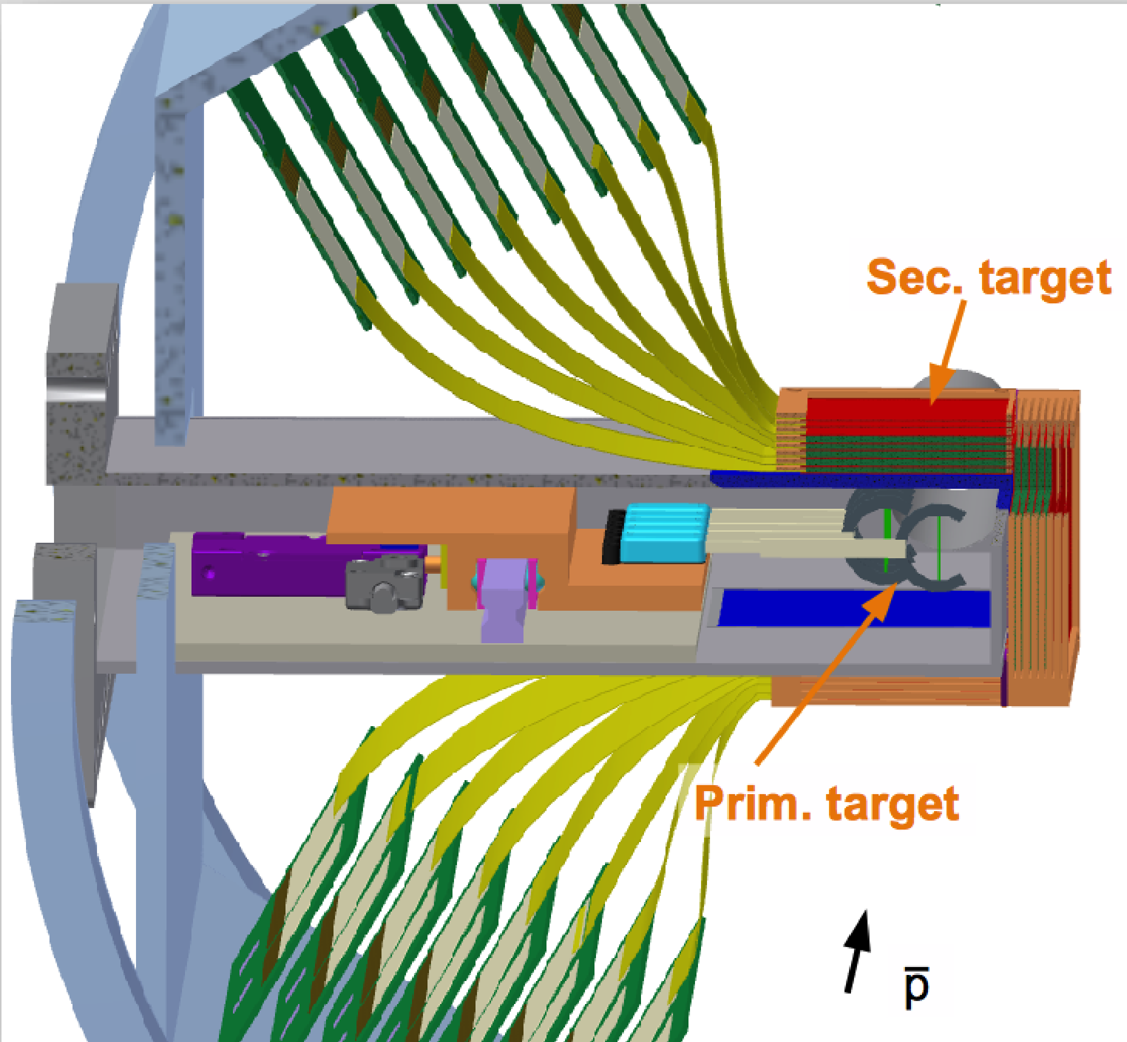
$\bar{\mathrm{P}}$ANDA is unique and complements worldwide activities

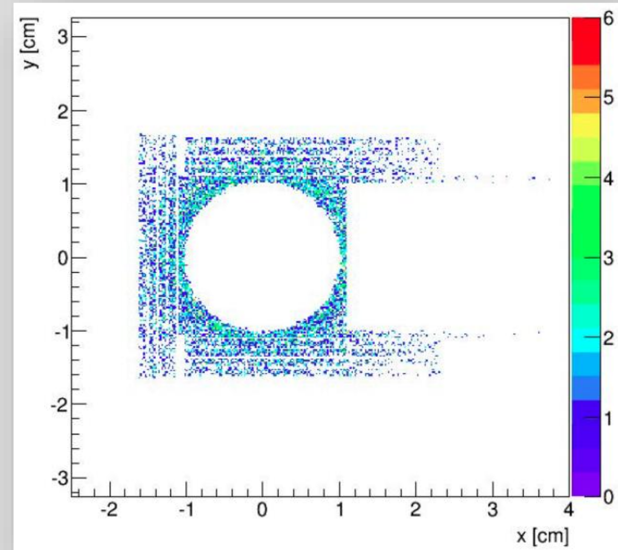
The HYP setup at PANDA

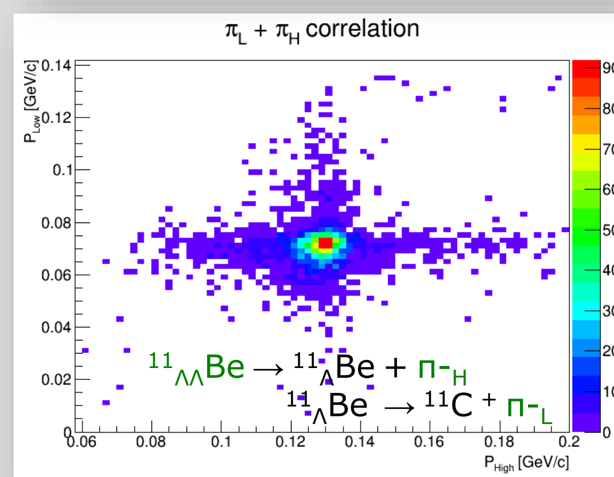


Status and expected count rate

- Primary and Secondary active target (GEANT, GiBUU,…)

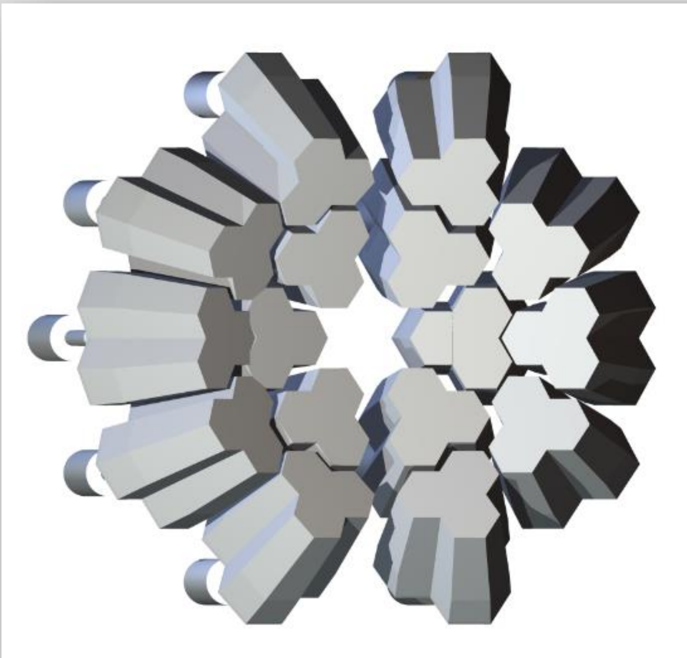


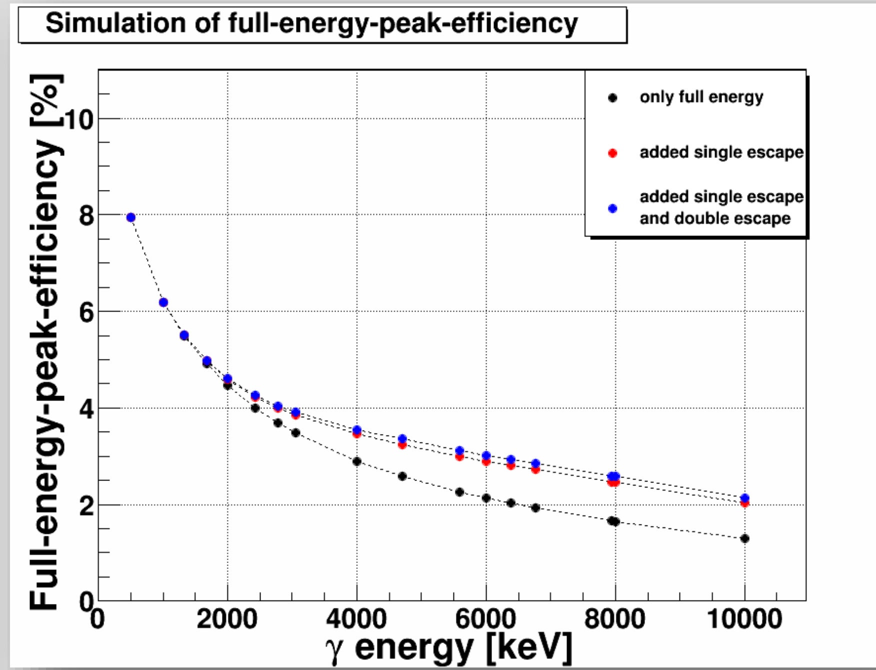




Status and expected count rate

- HPGe Cluster Array



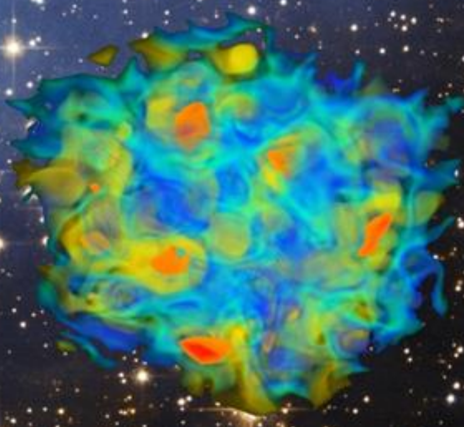


- triple detector under production
- frontend electronics being testet
- radiation hardness…
- Rates at $5 \cdot 10^6$ interactions per second (Boron absorber)
  - produced Ξ^- per secondy: 110
  - stopped Ξ^- per day: 51800
  - …
  - detected $^{11}_{\Lambda\Lambda}$Be transitions ∧ 2 pions in 4 months: 26

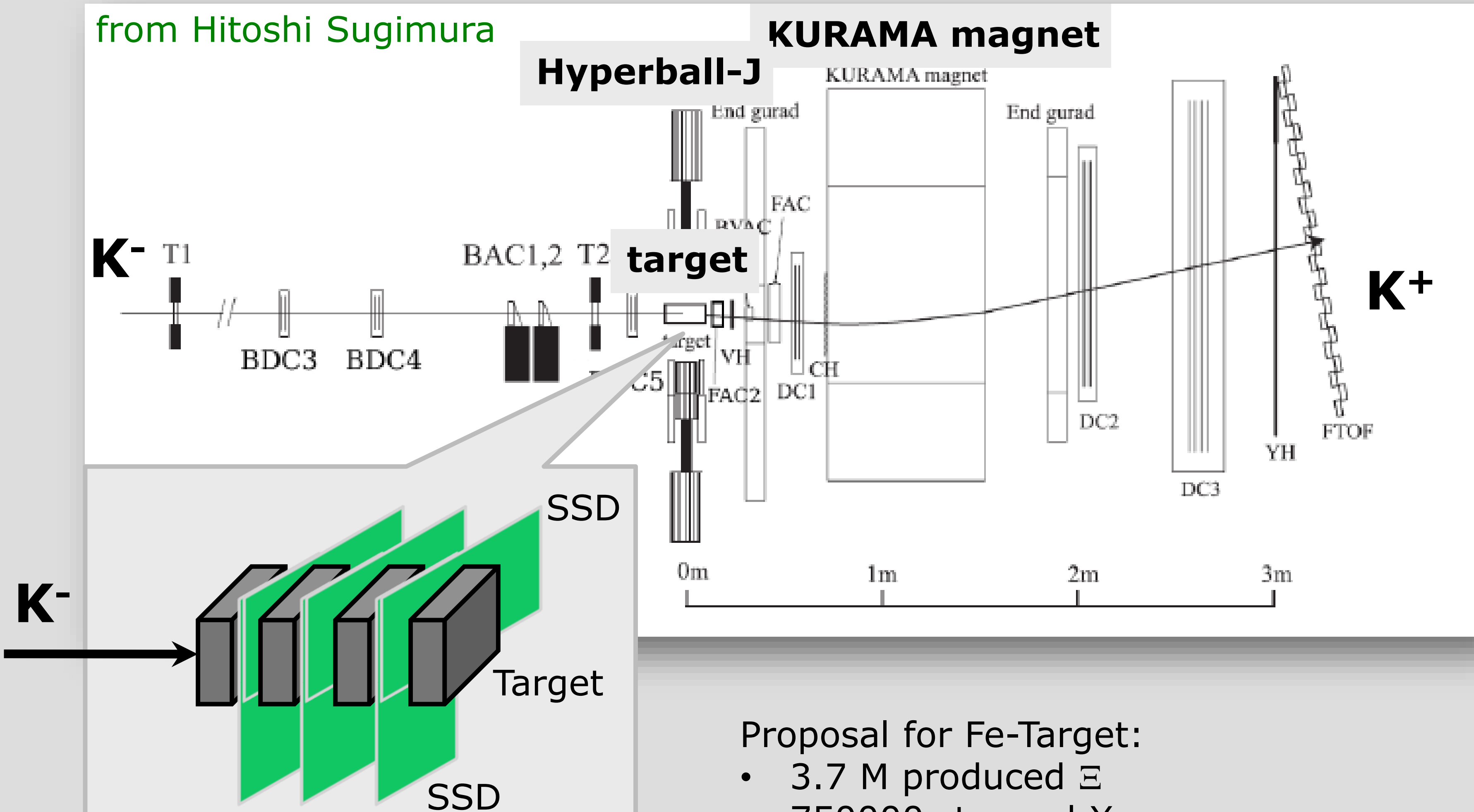
EXAMPLE 2

reaching for the unthinkable

DEFORMATION OF A HYPERON



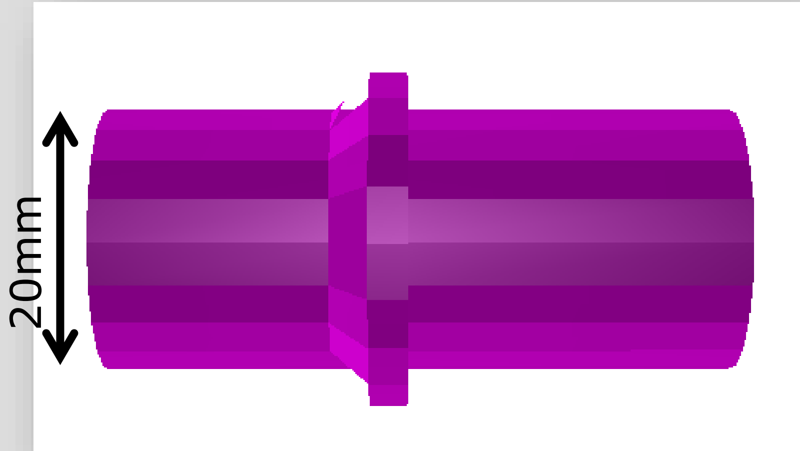
J-PARC E03:Detector Set up

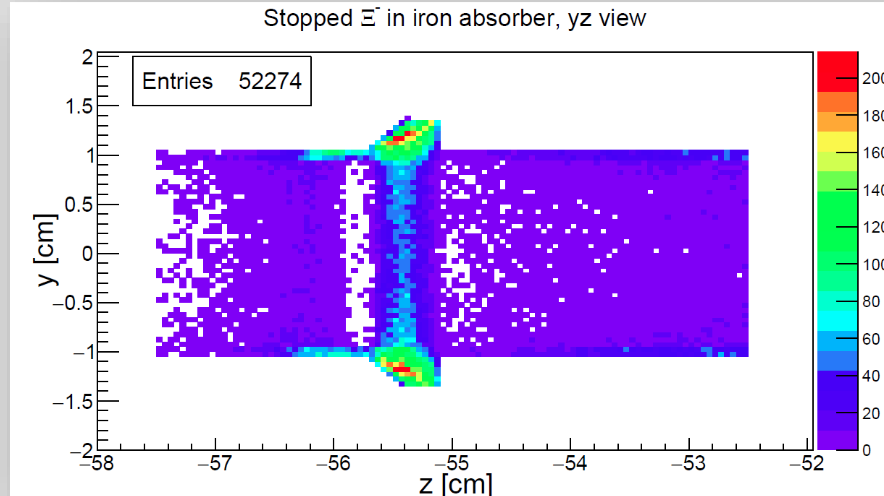


Proposal for Fe-Target:

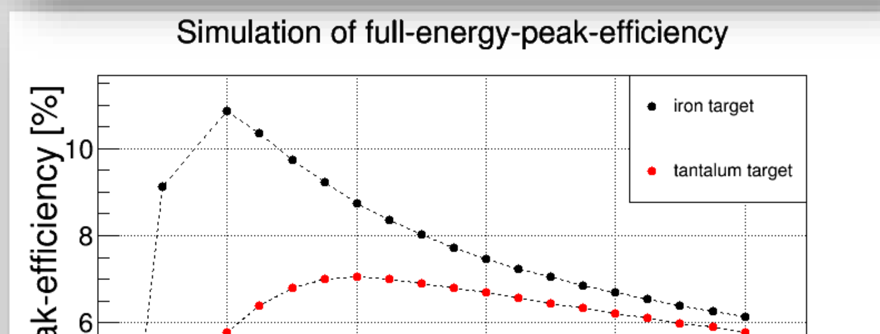
- 3.7 M produced Ξ
- 750000 stopped X
- 2500 x-rays for (6, 5) → (5, 4)

PANDA Setup for Hyperatoms



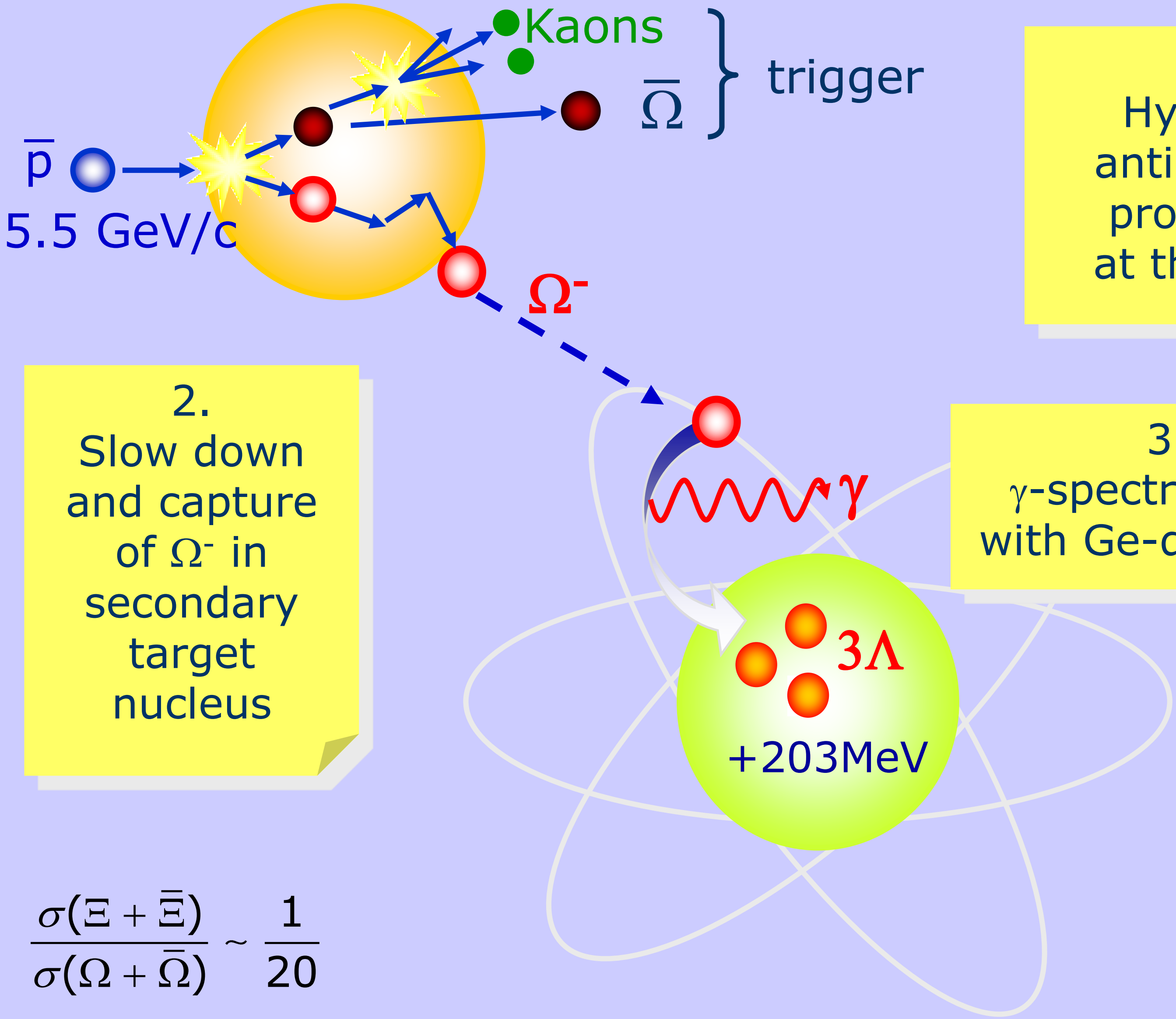


- Primary and secondary target separated
- very thin primary target
- relative thin secondary target ⇒ moderate x-ray absorption



For Fe absorber:
Single X-ray lines (6,5)→(5,4): ~3400/month
Cascade events (7,6)→(6,5)∧(6,5)→(5,4) ~100/month
for Ta target ~ 25% less
⇒ ideal for comissioning phase of hypernucleus setup

Perspective: Production of Ω-Atoms



1. Hyperon-antihyperon production at threshold

2. Slow down and capture of Ω^- in secondary target nucleus

3. γ-spectroskopy with Ge-detectors

$$\frac{\sigma(\Xi + \bar{\Xi})}{\sigma(\Omega + \bar{\Omega})} \sim \frac{1}{20}$$

Deformation of a Baryon

- J=1/2 baryons have no *spectroscopic* quadrupole moment

$$Q_i = \int d^3r\, \rho(r)(3z^2 - r^2)$$

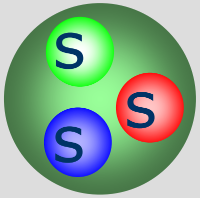
$$Q_s \propto (3J_z^2 - J(J+1)) \xrightarrow[J_z=1/2]{J=1/2} 0$$

- The Ω^- Baryon is the only „elementary“ particle whose quadrupole moment can be measured
  - J=3/2
  - long mean lifetime $0.82 \cdot 10^{-10}$ s

- Contributions to *intrinsic* quadrupole moment of baryons
  - General: One-gluon exchange and meson exchange
  - Ω: only one-gluon contributions to quadrupole moment

  A.J. Buchmann Z. Naturforsch. **52** (1997) 877-940

    - sensitive to SU(3) symmetry e.g. within SU(3) limit $m_u/m_s=1$



$$Q_\Omega = Q_\Delta(gluon)$$

Ω^- Quadrupole Moment

Model	Q [fm²]	Reference
NRQM	0.018	S.S. Gershtein,Yu.M., ZinovievSov. J. Nucl. Phys. 33, 772 (1981)
NRQM	0.004	J.-M. Richard, Z. Phys. C 12, 369 (1982)
NRQM	0.031	N. Isgur, G. Karl, R. Koniuk, Phys. Rev. D 25, 2395 (1982)
SU(3) Bag model	0.052	M.I. Krivoruchenko, Sov. J. Nucl. Phys. 45, 109 (1987)
QCD-SR	0.1	K. Azizi, Eur. Phys. J C 61, 311 (2009); T.M. Aliev, etal., arxiv: 0904.2485
NRQM with mesons	0.0057	W.J. Leonard, W.J. Gerace, Phys. Rev. D 41, 924 (1990)
NQM	0.028	M.I. Krivoruchenko, M.M. Giannini, Phys. Rev. D 43, 3763 (1991)
Lattice QCD	0.005	D.B. Leinweber, T. Draper, R.M. Woloshyn, Phys. Rev. D 46, 3067 (1992)
HBχPT	0.009	M.N. Butler, M.J. Savage, R.P. Springer, Phys. Rev. D 49, 3459 (1994)
Skyrme	0.024	J. Kroll, B. Schwesinger, Phys. Lett. B 334, 287 (1994)
Skyrme	0.0	Yoongseok Oh, ep-ph/9506308
QM	0.022	A.J. Buchmann, Z. Naturforschung 52a, 877 (1997)
χQM	0.026	G. Wagner, A.J. Buchmann, A. Faessler, J. Phys. G 26, 267 (2000)
GP QCD	0.024	A.J. Buchmann, E.M. Henley, Phys. Rev. D 65,073017 (2002)
χPT+qlQCD	0.0086	L.S. Geng, J. Martin Camalich, M.J. Vicente Vacas, Phys. Rev. D80, 034027 (2009)
Lattice QCD	0.0096±0.0002	G. Ramalho, M.T. Pena, Phys.Rev.D83:054011 (2011), arxiv:1012.2168

A very strange Atom

- hyperfine splitting in Ω-atom
  ⇒ electric quadrupole moment of Ω

spin-orbit	$\Delta E_{ls} \sim (aZ)^4\, l \cdot m_{\Omega}$
quadrupole	$\Delta E_{\Theta} \sim (aZ)$

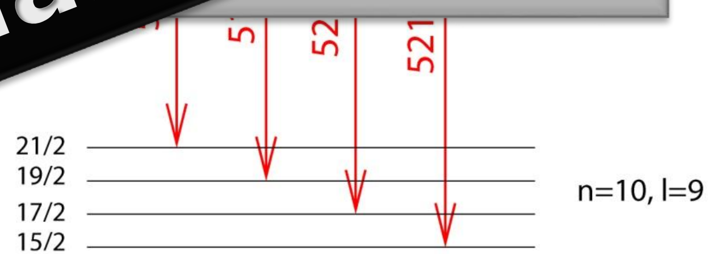
$\Omega\bar{\Omega}$ comp

Produ
Stoppi
Single X

⇒ For the ... within reach

- call
- $\Delta E_{\Theta} \sim$ fe

$\bar{\text{P}}$ANDA is the only experiment where this measurement is imaginable

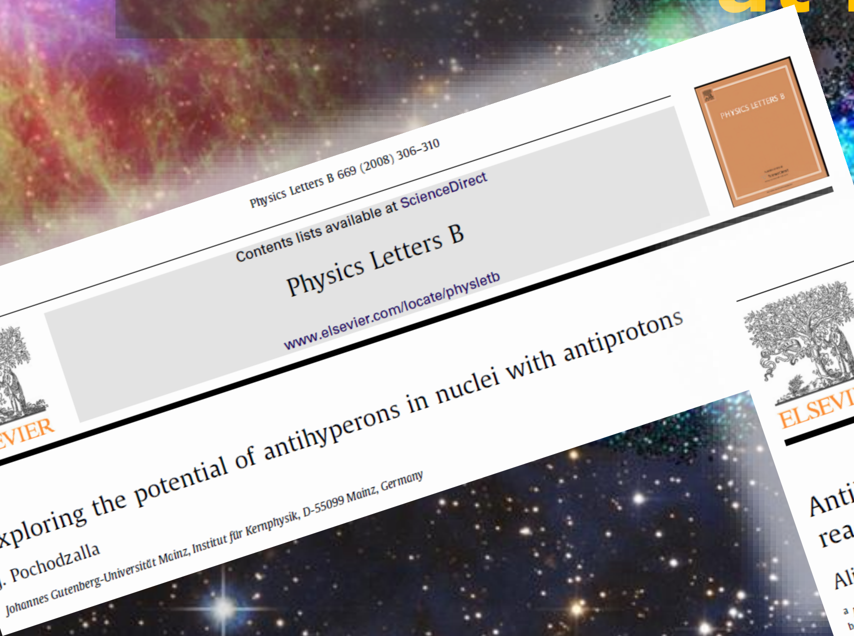


Q_{Ω}=0.02fm^2

EXAMPLE 3

A one day day-one experiment

ANTIHYPRONS IN NUCLEI
at PANDA



Physics Letters B 669 (2008) 306–310
Contents lists available at ScienceDirect
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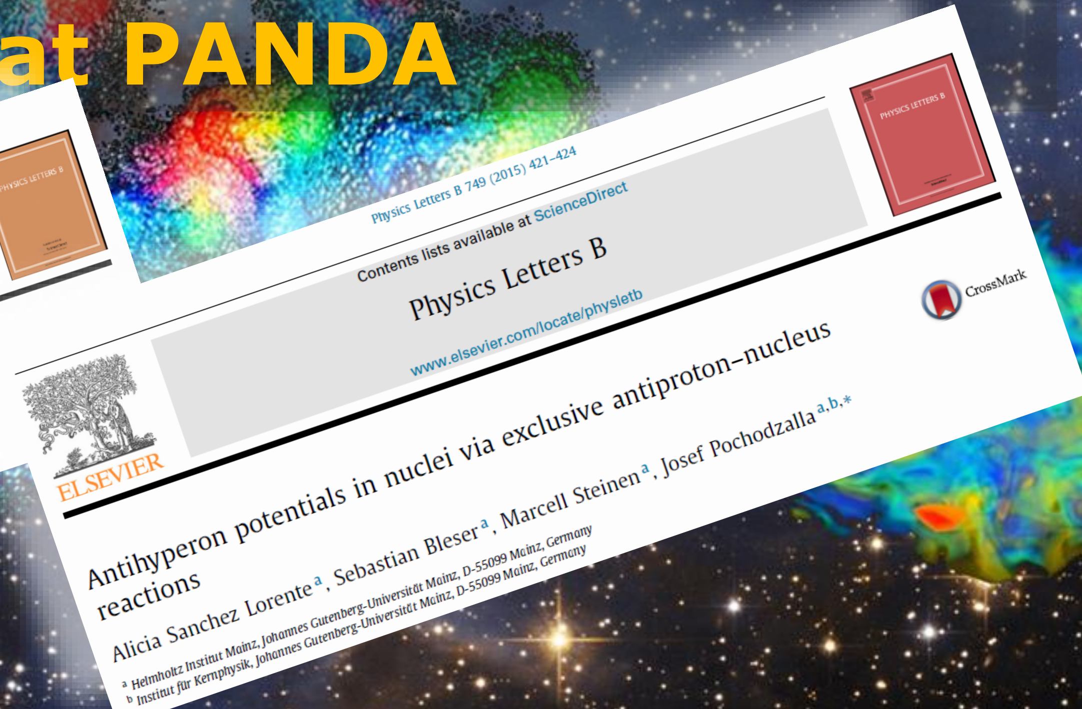
www.elsevier.com/locate/physletb

xploring the potential of antihyperons in nuclei with antiprotons

. Pochodzalla
Johannes Gutenberg-Universität Mainz, Institut für Kernphysik, D-55099 Mainz, Germany



Physics Letters B 749 (2015) 421–424
Contents lists available at ScienceDirect
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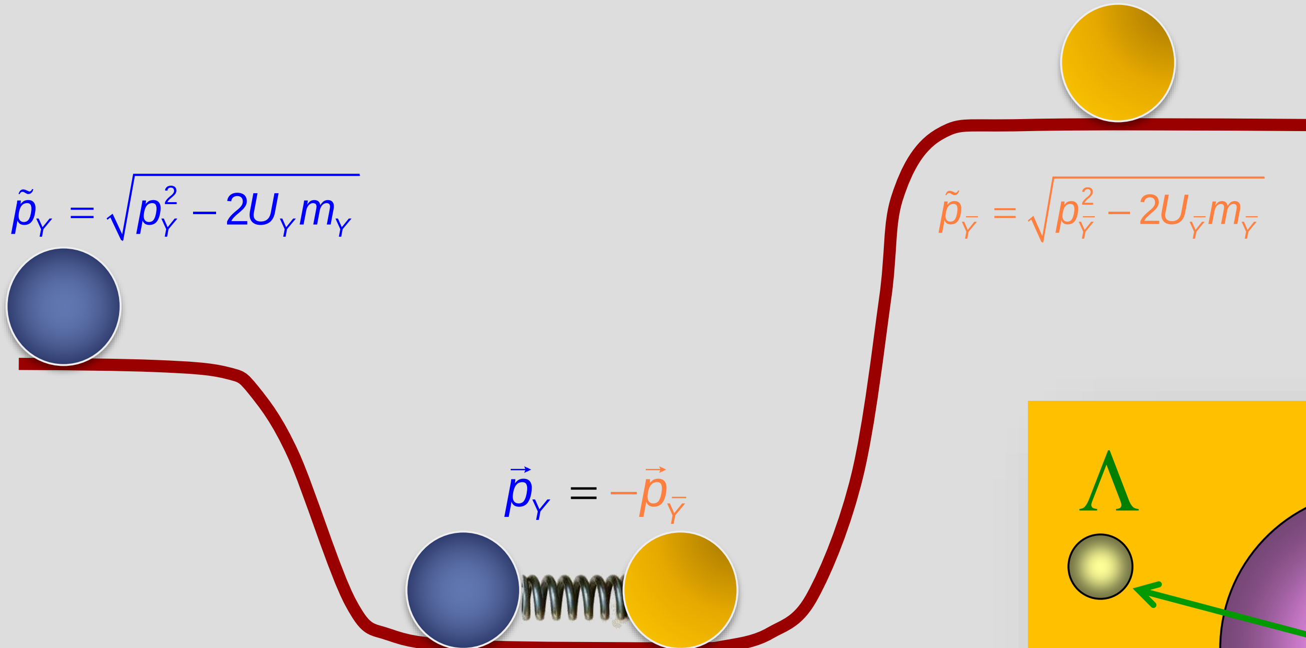
www.elsevier.com/locate/physletb

Antihyperon potentials in nuclei via exclusive antiproton–nucleus reactions

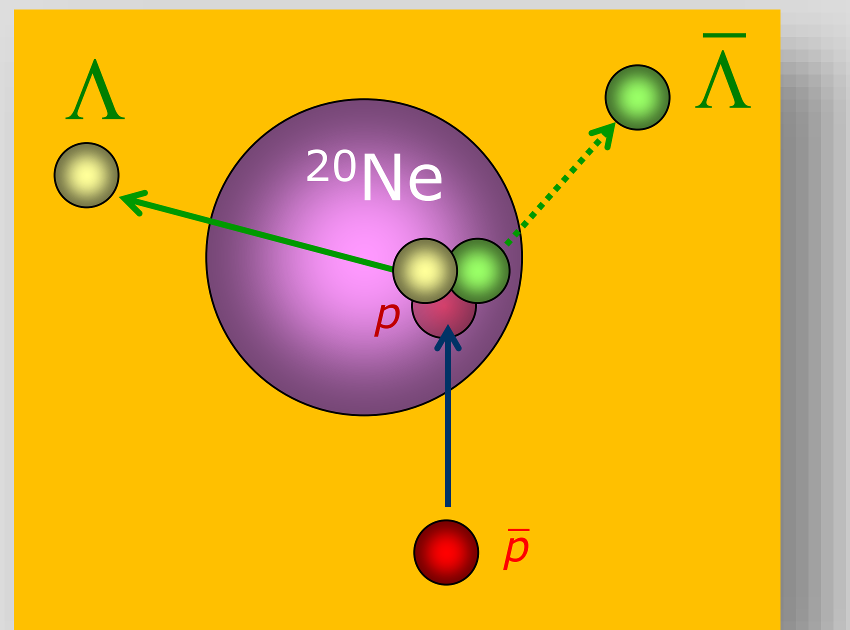
Alicia Sanchez Lorente [a], Sebastian Bleser [a], Marcell Steinen [a], Josef Pochodzalla [a,b,*]
[a] Helmholtz Institut Mainz, Johannes Gutenberg-Universität Mainz, D-55099 Mainz, Germany
[b] Institut für Kernphysik, Johannes Gutenberg-Universität Mainz, D-55099 Mainz, Germany

$\bar{\Lambda}$ 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



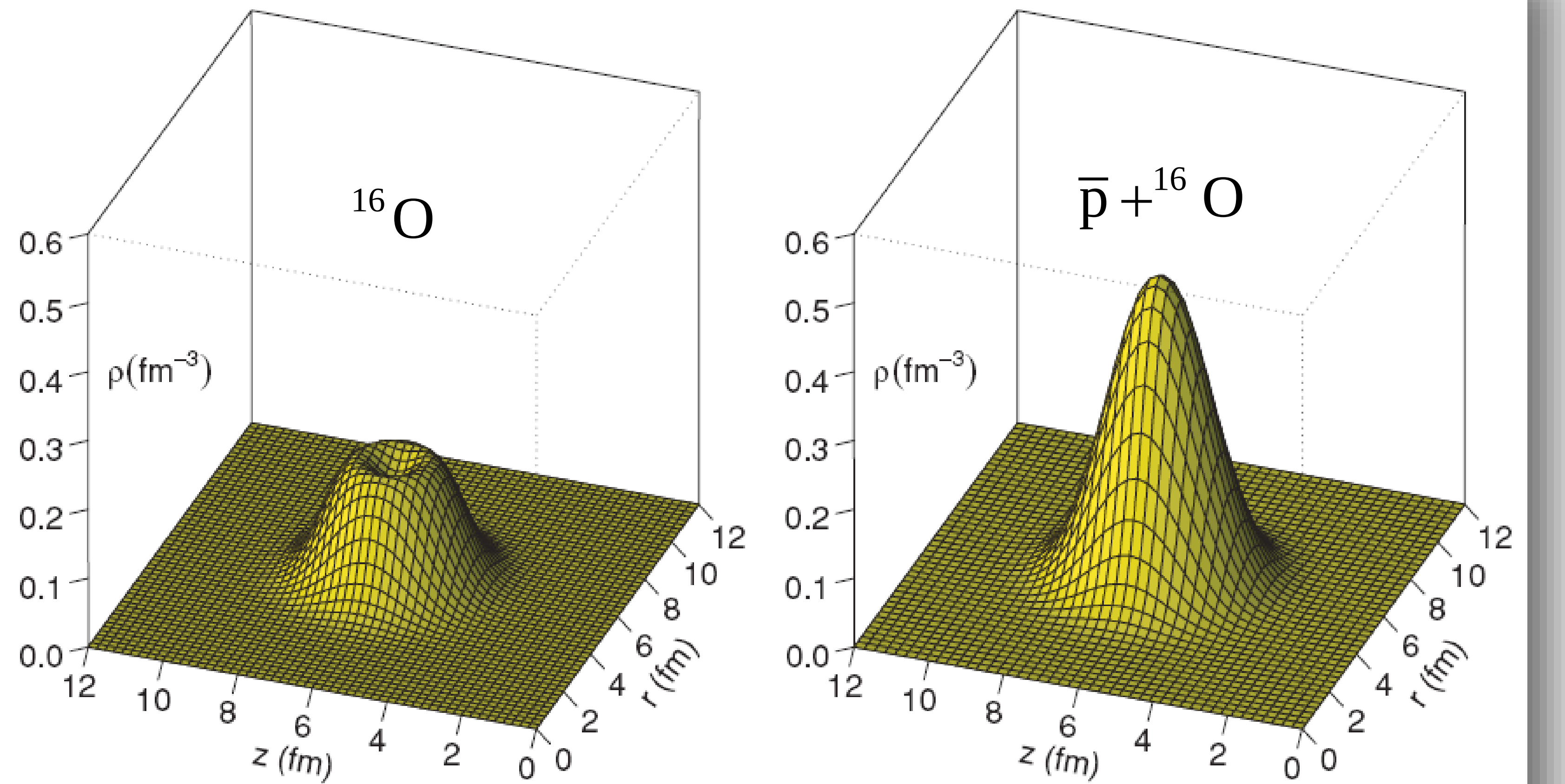
J.P., PLB **669** (2008) 306



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

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

Cold compression by antibaryons ?



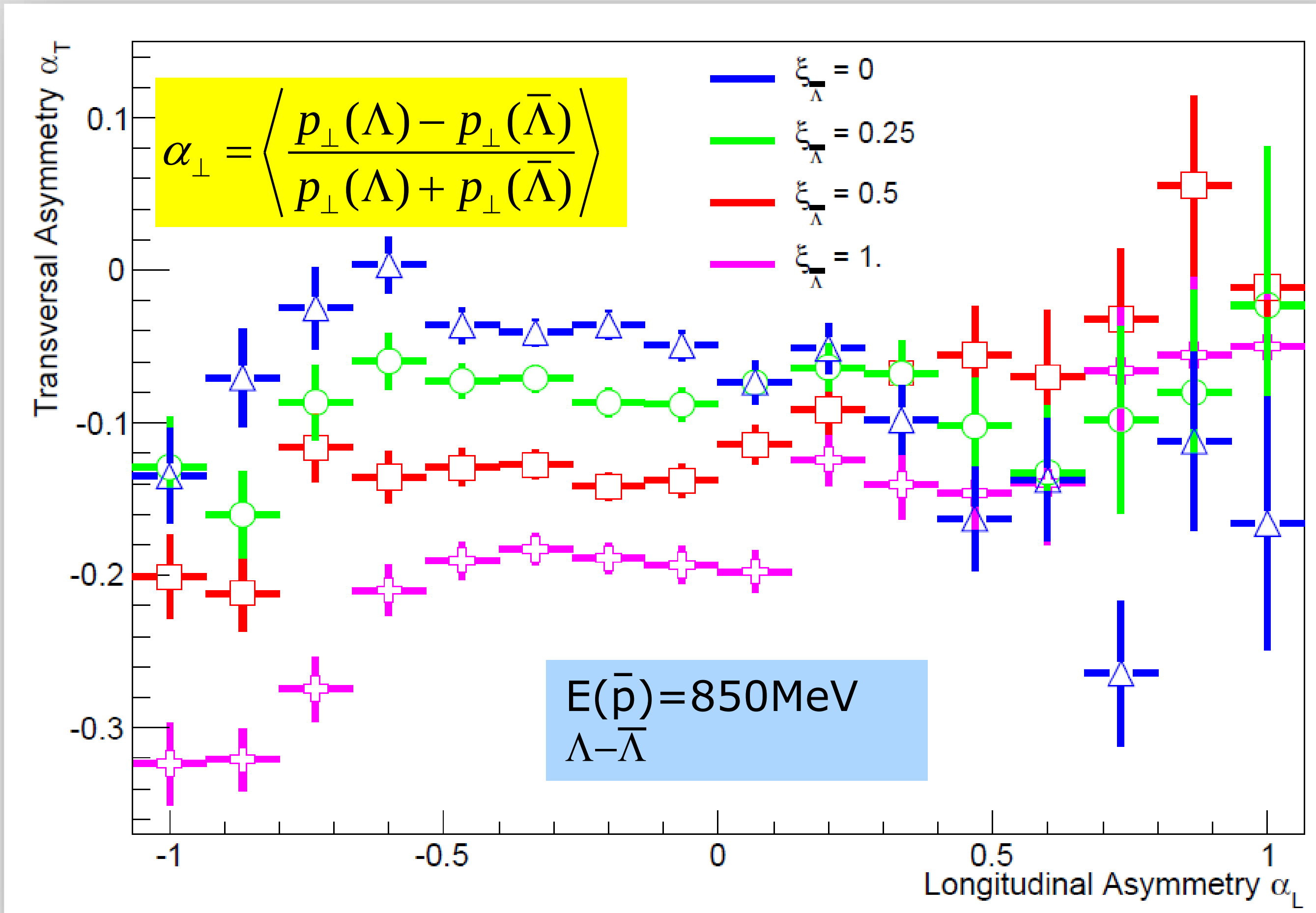
nucleon density in the ^{16}O nucleus (left) and in the bound $\bar{p}$ + ^{16}O system (right)

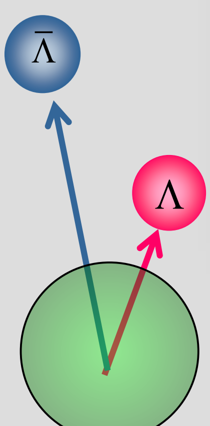
I. N. Mishustin, L. M. Satarov, T. J. Bürvenich, H. Stöcker, and W. Greiner

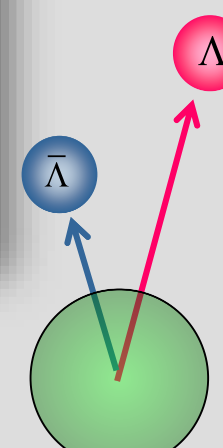
PHYSICAL REVIEW C **71**, 035201 (2005)

Scan of $\bar{\Lambda}$ Potential with GiBUU

- $U(\bar{\Lambda})$= -449MeV, -225MeV, -112MeV, 0MeV
- All other potentials unchanged PLB 749, 421 (2015)





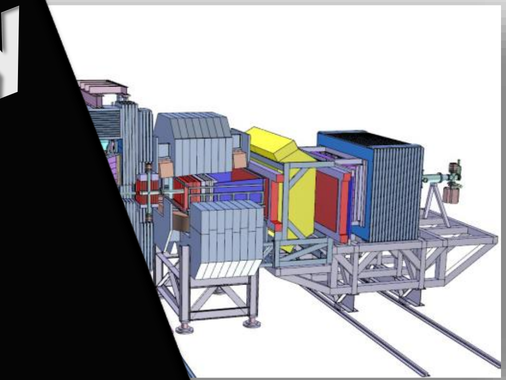


$$\alpha_L = \frac{p_L(\Lambda) - p_L(\bar{\Lambda})}{p_L(\Lambda) + p_L(\bar{\Lambda})}$$

Antihyperon-Hyperon Pairs in $\bar{\text{P}}$ANDA

- 202x first beam in $\bar{\text{P}}$ANDA expected → commissioning phase
- We are right now exploring different scenario
  - different detector availability
  - different solenoid fields (1T

  and other important asp
  - luminosity
  - lengt



- Typica … at higher momen
- $\bar{\Lambda}+\Lambda$ case
  - ^{nat}Ne ta … eck
  - only cha
  - assume a … $10^6 s^{-1}$ (~10% of default luminosity)
  - pair recon … ~3%

    ⇒ **144k** … **$\bar{\Lambda}+\Lambda$ pairs per day** ⇒ **10 × GiBUU**

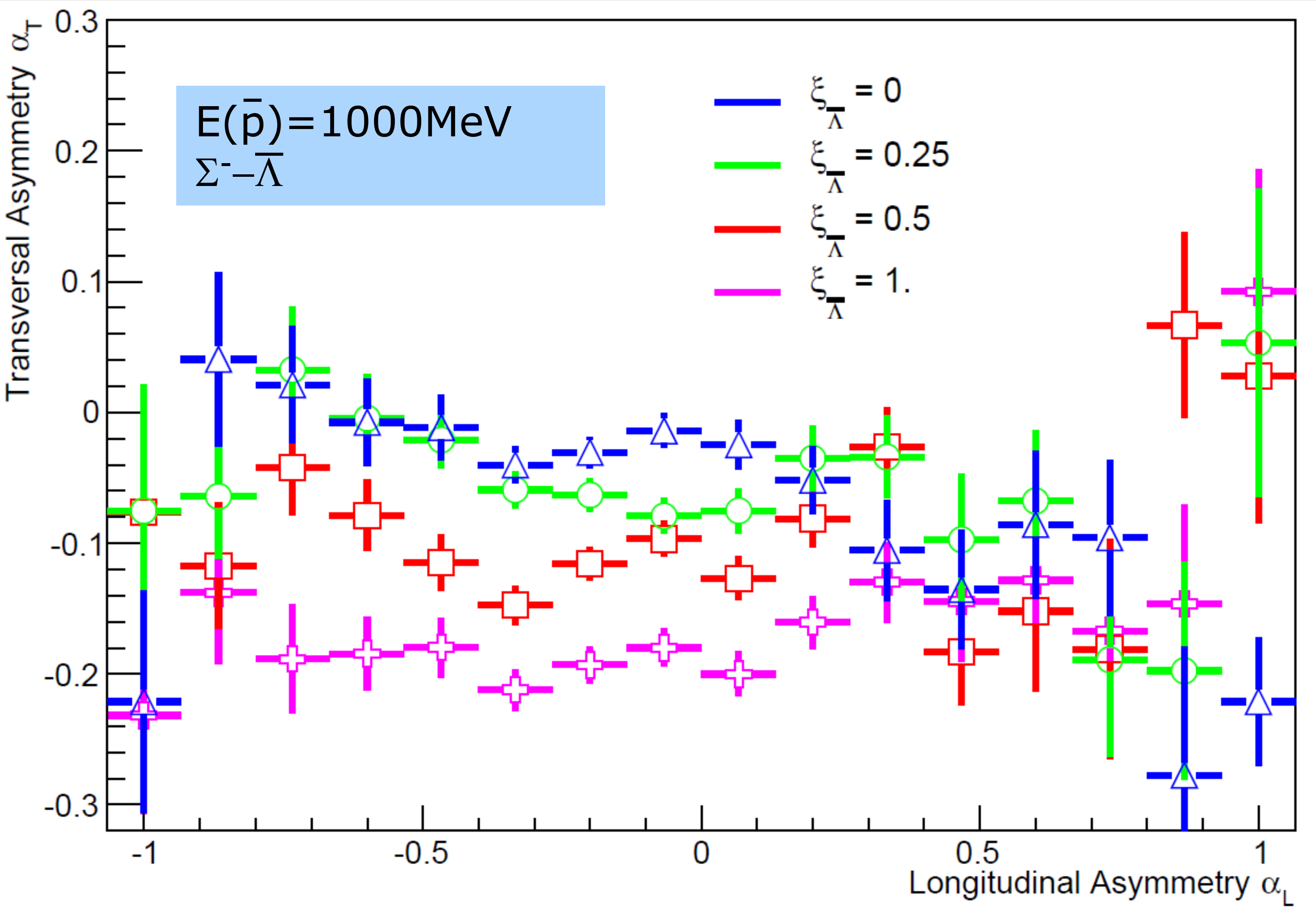
  - Moderate data taking period *~14 days Ne target + 7 days p-target*

    ⇒ **130 × present GiBUU simulations**

$\bar{\text{P}}$ANDA is the only experiment where this measurement is possible

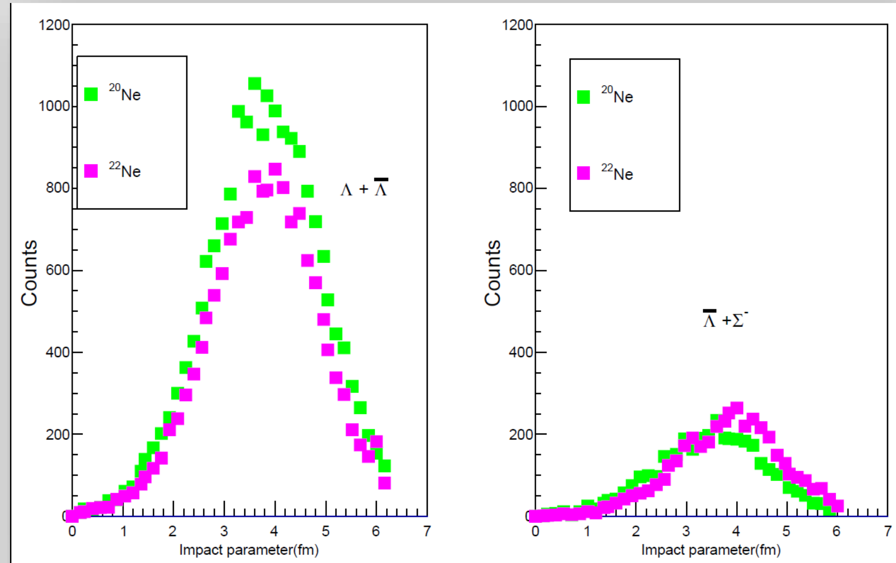
Other |s|=1 channels @ 1000MeV

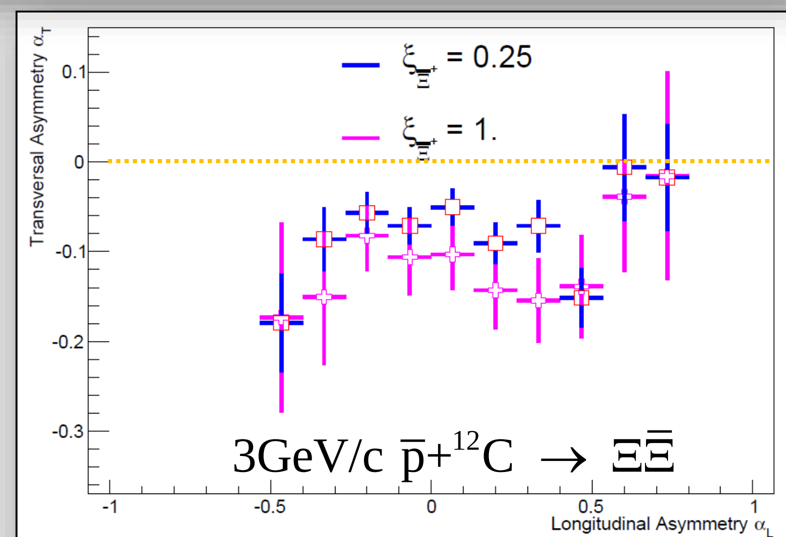
- $\bar{p}+p\to\bar{\Lambda}+\Lambda$ $\bar{p}+p\to\bar{\Sigma}^0+\Lambda$
- $\bar{p}+n\to\bar{\Lambda}+\Sigma^-$ $\bar{p}+n\to\bar{\Sigma}^++\Lambda$ ($\times$1/100)



Future Options

- $\overline{\Lambda}+\Sigma^-$
  - Ideal probe for interactions in the neutron skin
  - ^{20}Ne; ^{22}Ne
  - Σ^- tracking, $\Sigma^- \to n\pi^-$
  - similar production rate (at least in light nuclei)





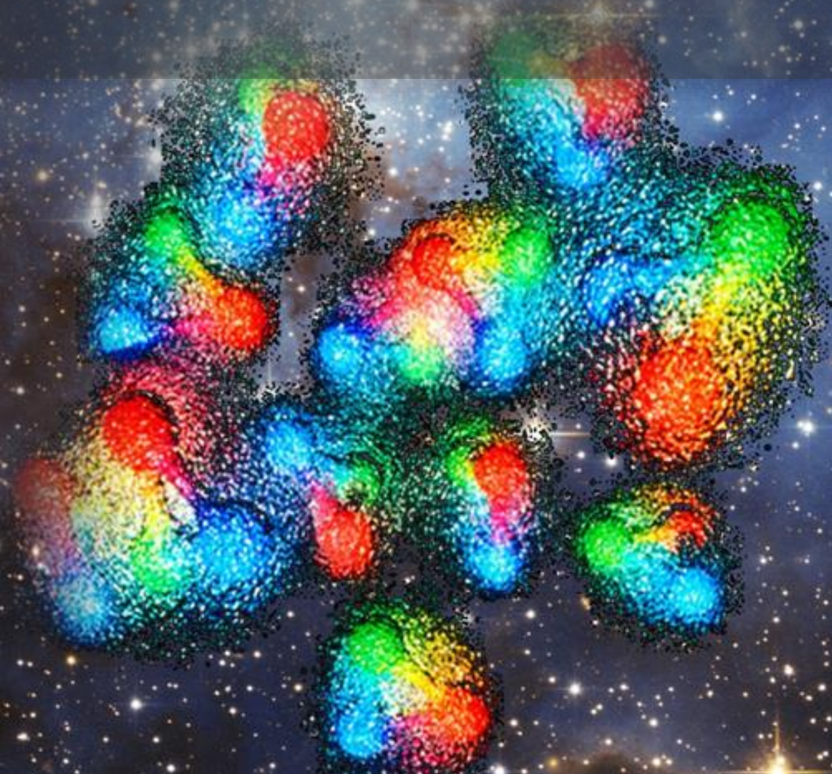
- Further options:
  - Any other pair: Σ-$\overline{\Sigma}$, Ξ-$\overline{\Xi}$, $\Lambda_c\overline{\Lambda}_c$
  - Long lived resonances in nuclei
    - $\Lambda(1520)$ (Γ= 15.6 MeV)
    - $\Xi(1530)$ (Γ=9.9 MeV)
    - $\Lambda_c(2880)$ (Γ=5.8MeV)

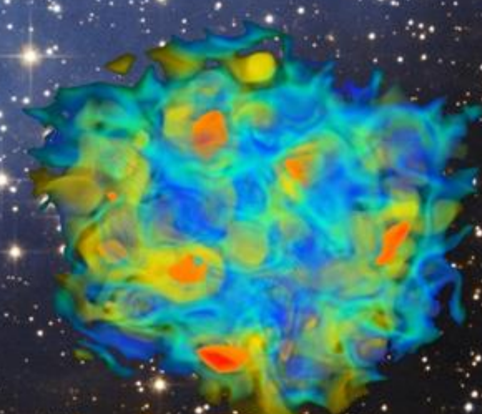
- Unique change to study charmed baryons in nuclear systems ?

EXAMPLE 4

A unique tool to study elementary (anti)hyperon-nucleon interactions

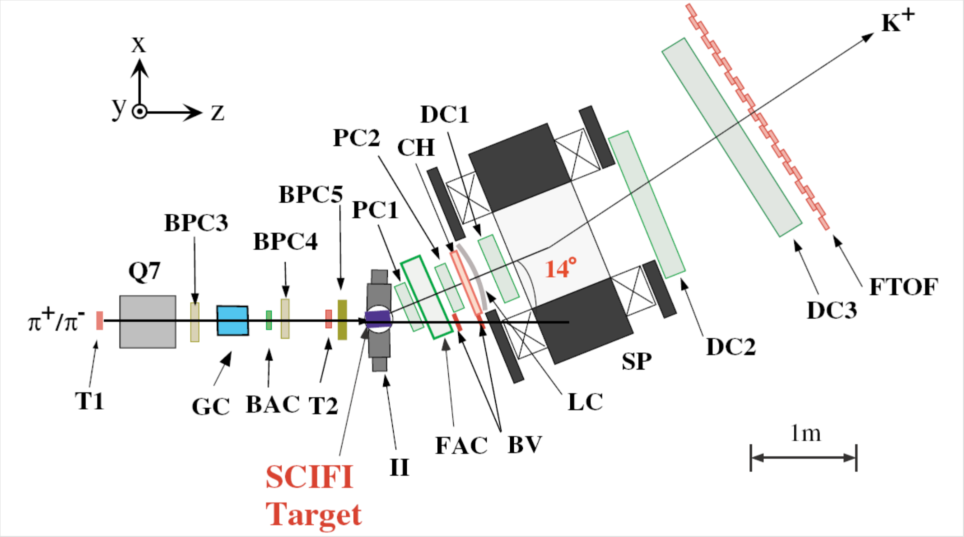
$\bar{p}+p \rightarrow Y - \bar{Y}$ pair production

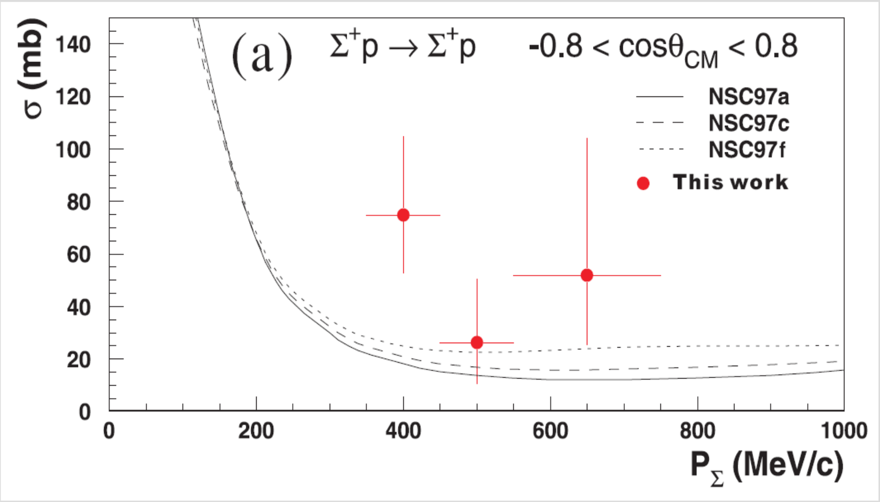




Exp. Approaches to Y-N interactions

- low energy baryon-baryon scattering
  - N-N: ~10^4 data points available
  - charged hyperon – proton: scattering in a scintillator target
    - ▷ $\Sigma^- p$: KEK-PS E289 (π^-,K^+) ⇒ 30 events
    - ▷ $\Sigma^+ p$: KEK-PS 251 & KEK-PS E289 (π^+,K^+) ⇒ 31 events each
    - ▷ Ξ^- p: (K^-,K^+) ⇒ 1 candidate



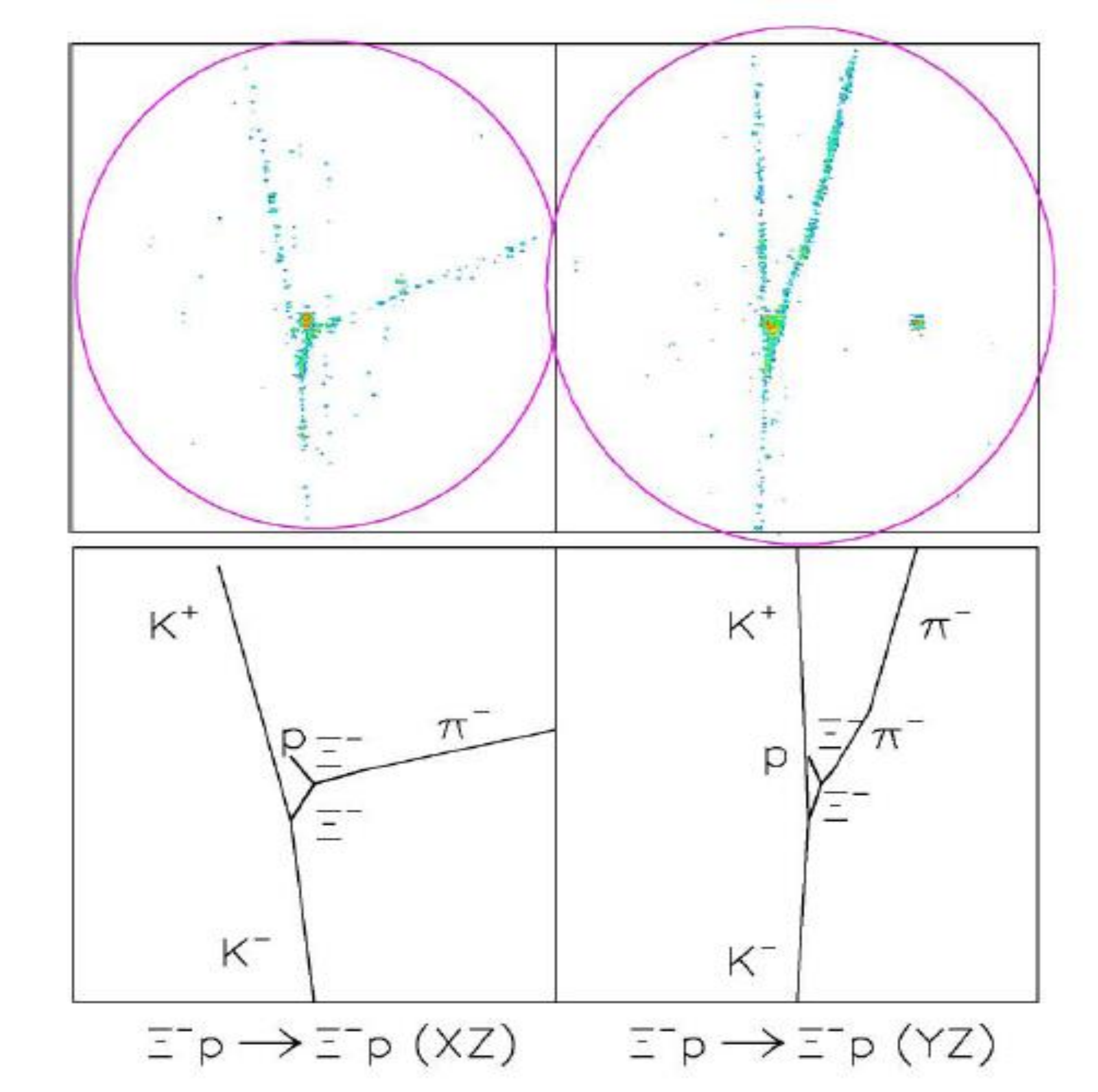


- ▷ JPARC: ~1000 events/day

- hyperon-hyperon final state interaction
  - feasible but difficult to interpret
- Tagged hyperon-antihyperon pair production and secondary scattering

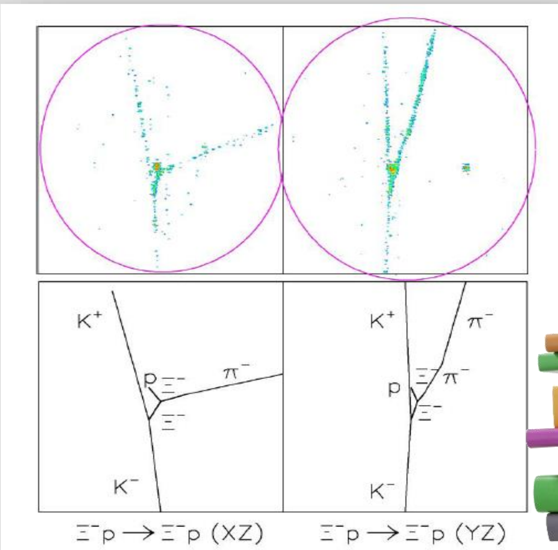
Ξ^- scattering

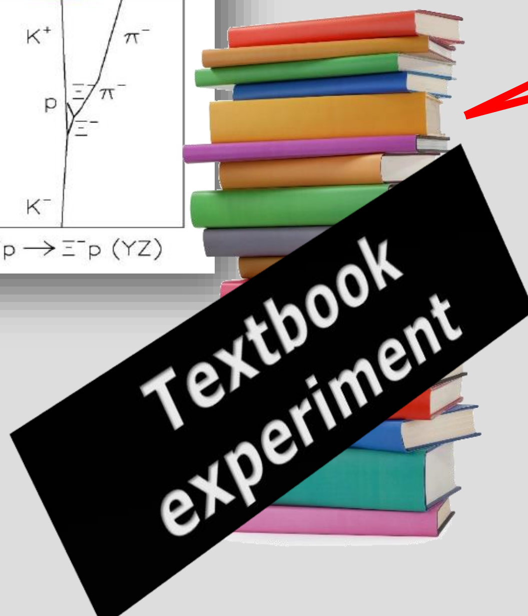
- Ahn et al.



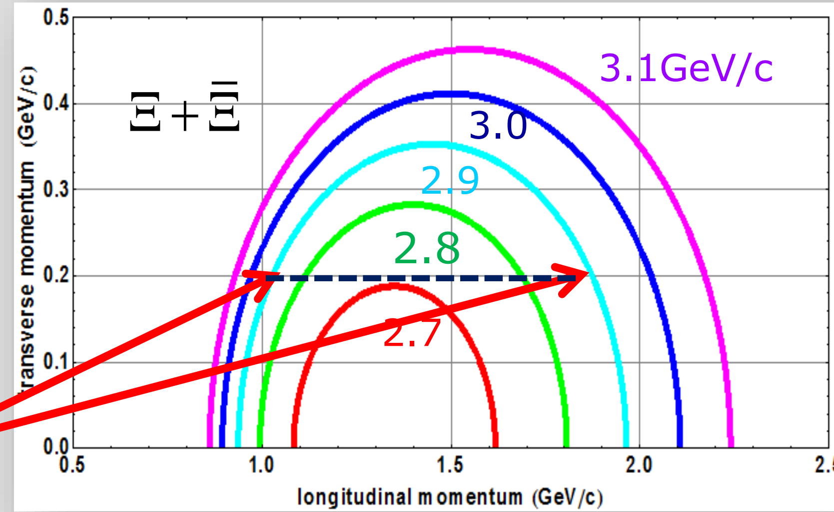
Ξ^- scattering

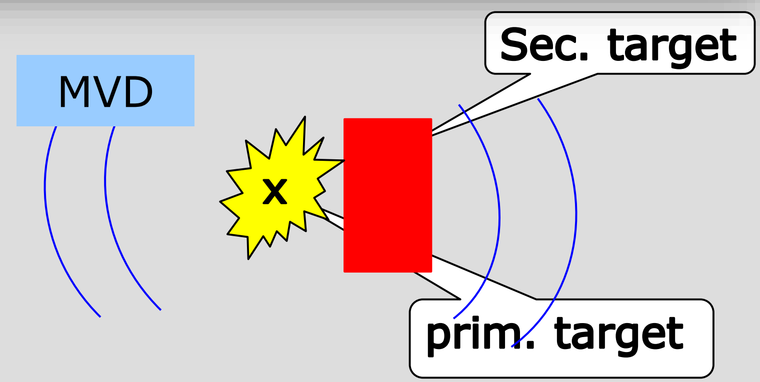
- Ahn et al.





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

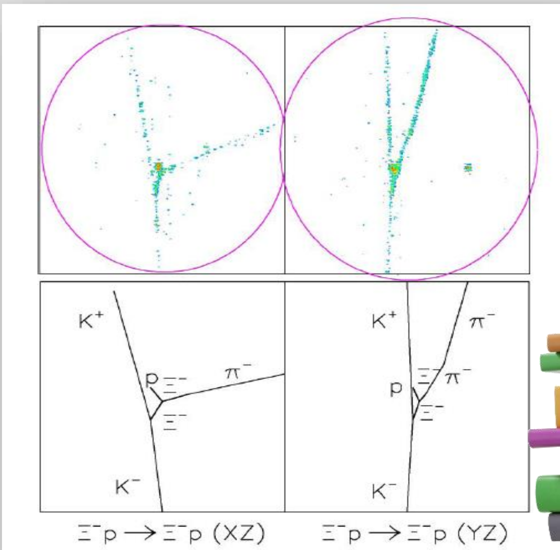


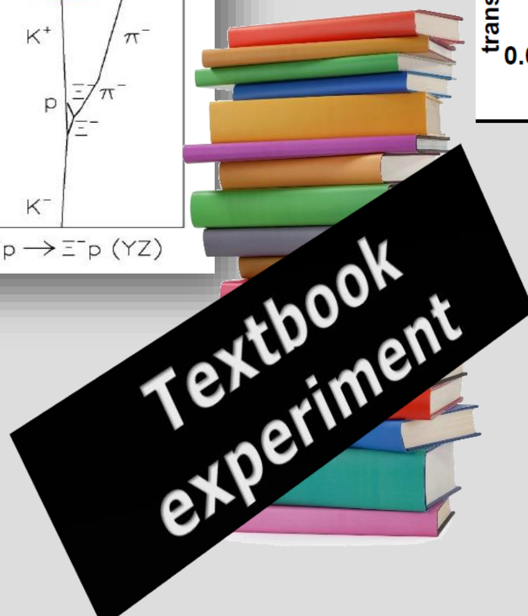


- $\bar{p}$+p→ $\bar{Y}$+Y provides momentum tagged (low) momentum, polarized hyperon *or* antihyperon beams
- scattering experiment with low momentum (anti)hyperons possible

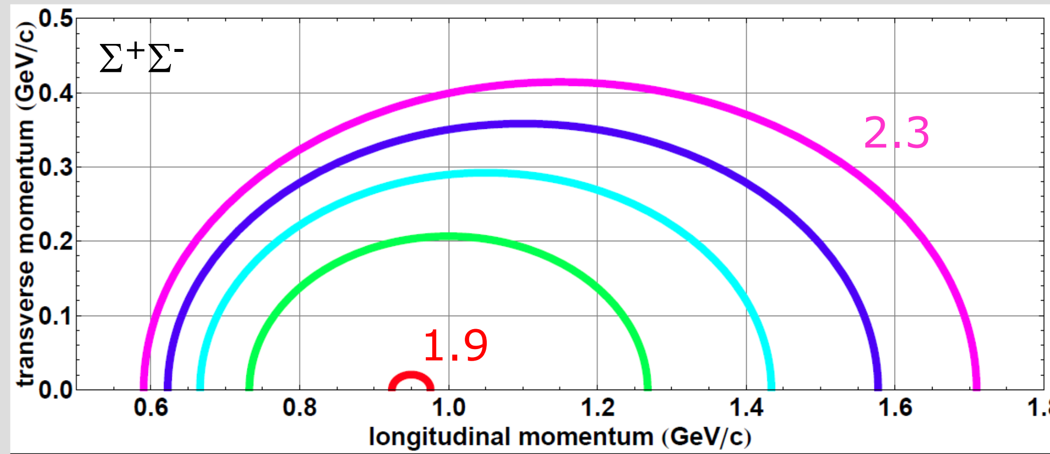
Σ scattering

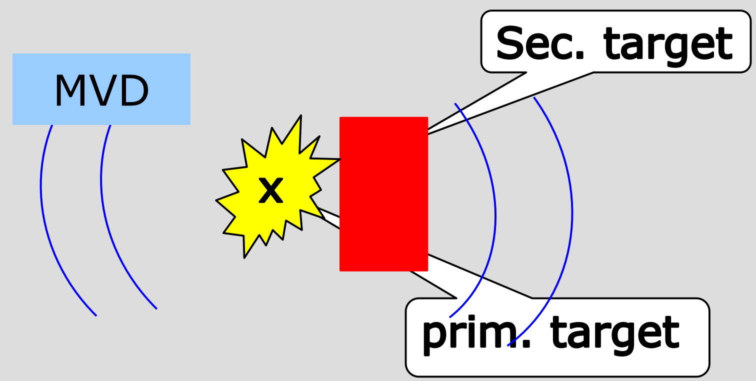
- Ahn et al.





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





- $\bar{p}+p \to \bar{Y}+Y$ provides momentum tagged (low) momentum, polarized hyperon *or* antihyperon beams
- scattering experiment with low momentum (anti)hyperons possible

Overview: Strangeness in Nuclei

	Physics topic	setup	luminosity requirement	primary target	secondary target	comple-mentarity
Early phase	$\bar{\Lambda}$ in nuclei	PANDA	moderate	Ne, Ar	-	none
	$\bar{\Lambda}$ bound state	PANDA	moderate	Ne, Ar	-	none
	$K^*/\bar{K}^*$ nuclear absorption	PANDA	moderate		-	
	Ξ-atoms	PANDA-HYP	moderate	C	Fe…Pb	JPARC
Standard conditions	$\bar{\Sigma}$, $\bar{\Xi}$ in nuclei; neutron skin	PANDA	standard	Ne, Ar	-	none
	$\Lambda\Lambda$-hypernuclei (γ-transitions)	PANDA-HYP	standard	C (Ti?)	B (Be, C)	JPARC (g.s.), CBM (p-u. s.)
Future options	Ω-atoms	PANDA-HYP	standard	C (Ti?)	Fe…Pb	none
	Λ_c and $\bar{\Lambda}_c$ in nuclei	PANDA	standard	Ne	-	none
	Y and $\bar{Y}$ secondary scattering	PANDA + sec. active target	standard	H	$(CH_2)_n$	JPARC (only Y)

An antiproton storage rings is an excellent and unique factory for strange and charmed $\bar{Y}Y$ pair production

Stored antiproton beams offer several unique opportunities to study the interactions of hyperons and antihyperons in nuclear systems after the J-PARC Phase I

Several unique experiments can be performed during the commissioning phase of such a ring

Thank you

A man doesn't plant a tree for himself.
He plants it for posterity.

Alexander Smith