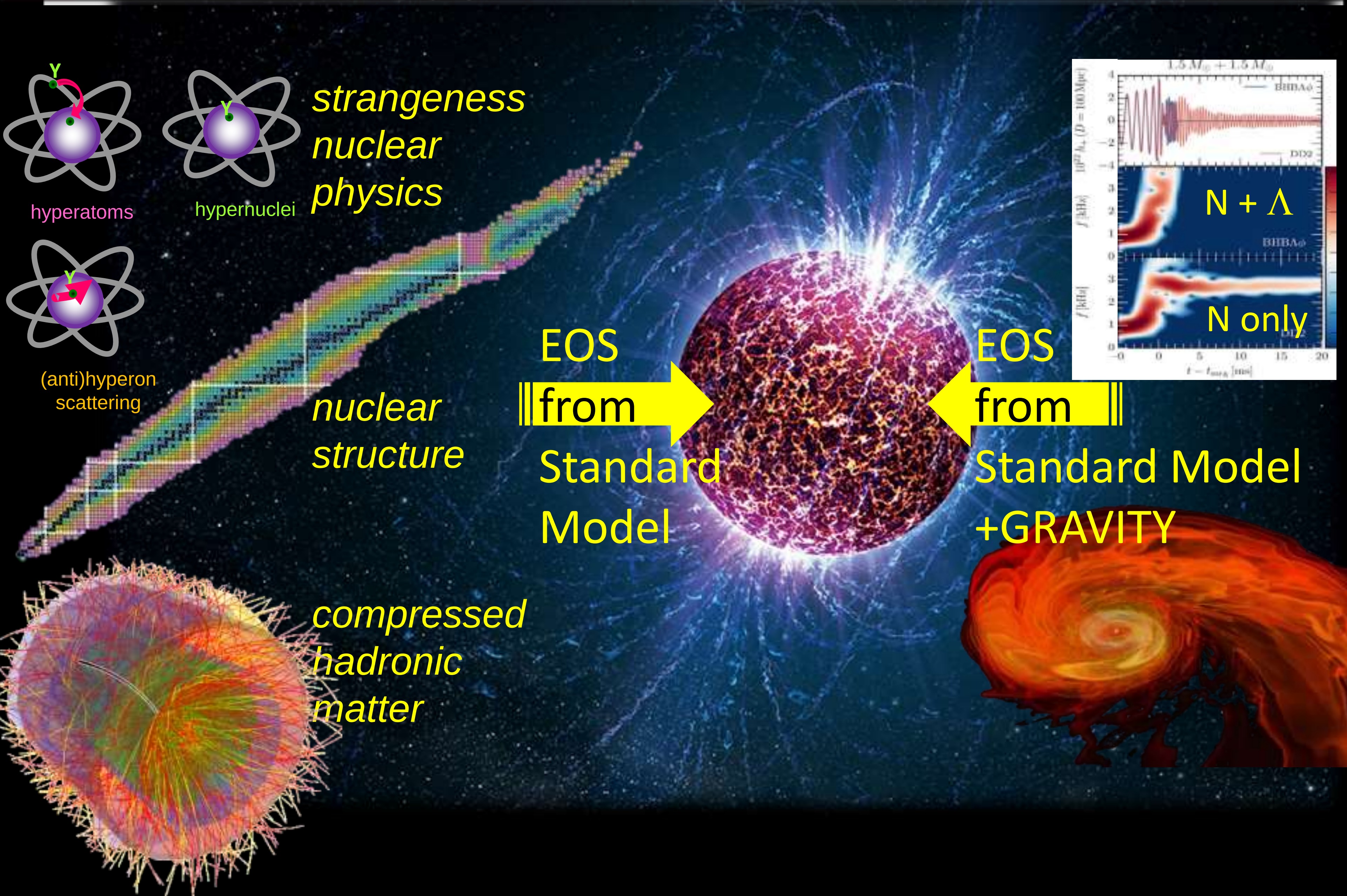


hyperatoms
hypernuclei
(anti)hyperon scattering
strangeness nuclear physics
nuclear structure
compressed hadronic matter
EOS from Standard Model
EOS from Standard Model +GRAVITY
N + Λ
N only

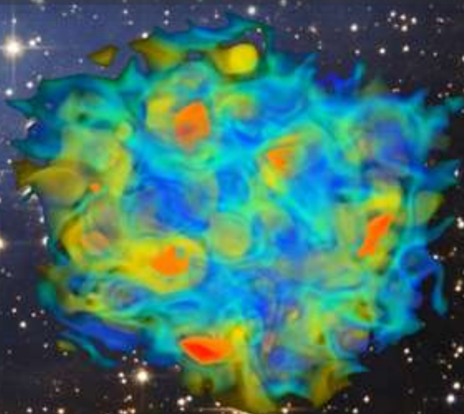
2nd EMMI Workshop
Anti-matter, hyper-matter and exotica production at the LHC
Turin November 2017

Strangeness Nuclear Physics with $\bar{P}$ANDA

Josef Pochodzalla

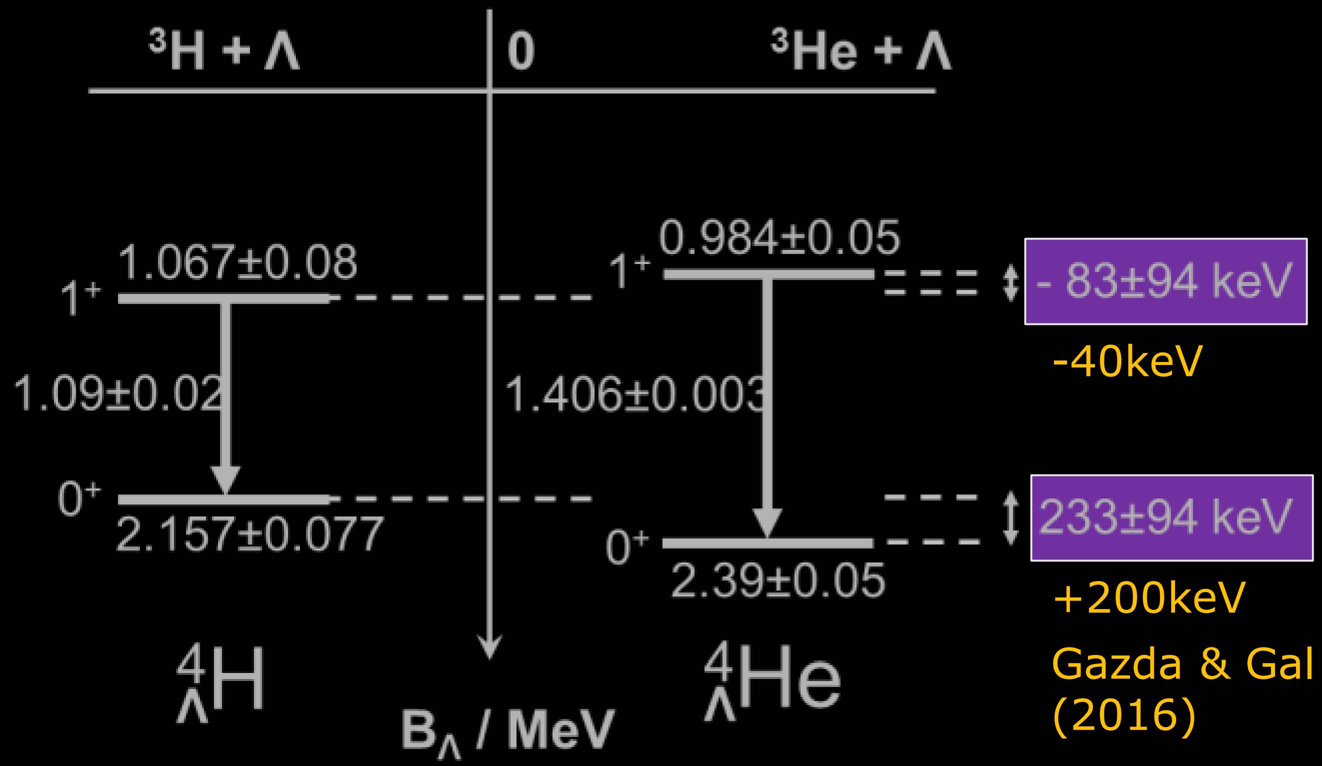
JGU Mainz & Helmholtz-Institut Mainz

o



CSB in A=4 Hypernuclei *2016*

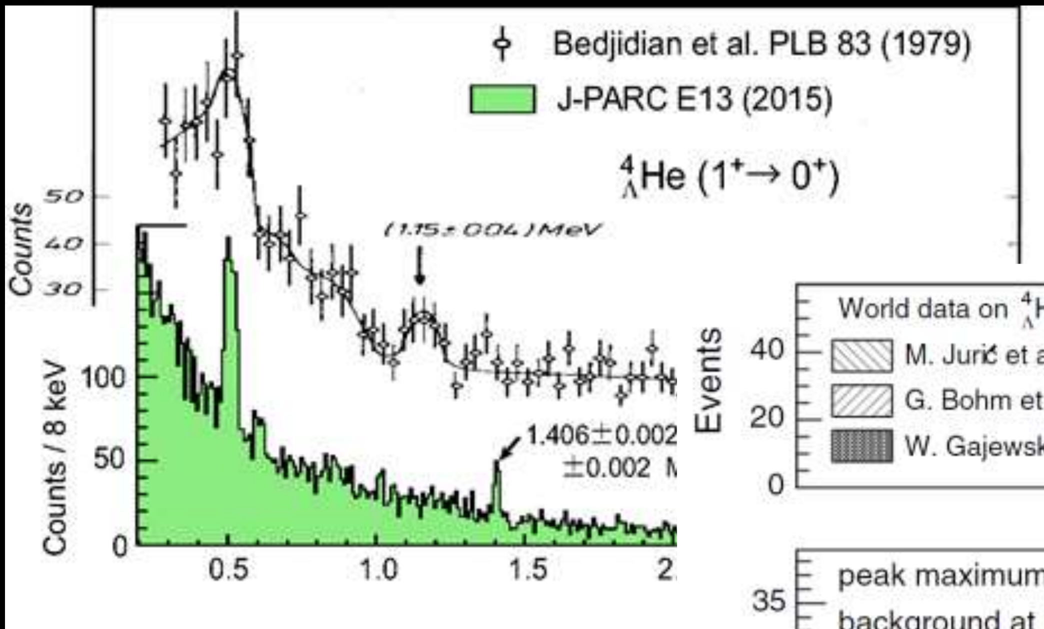
A1 Collaboration, Nuclear Physics A 954(2016) 149



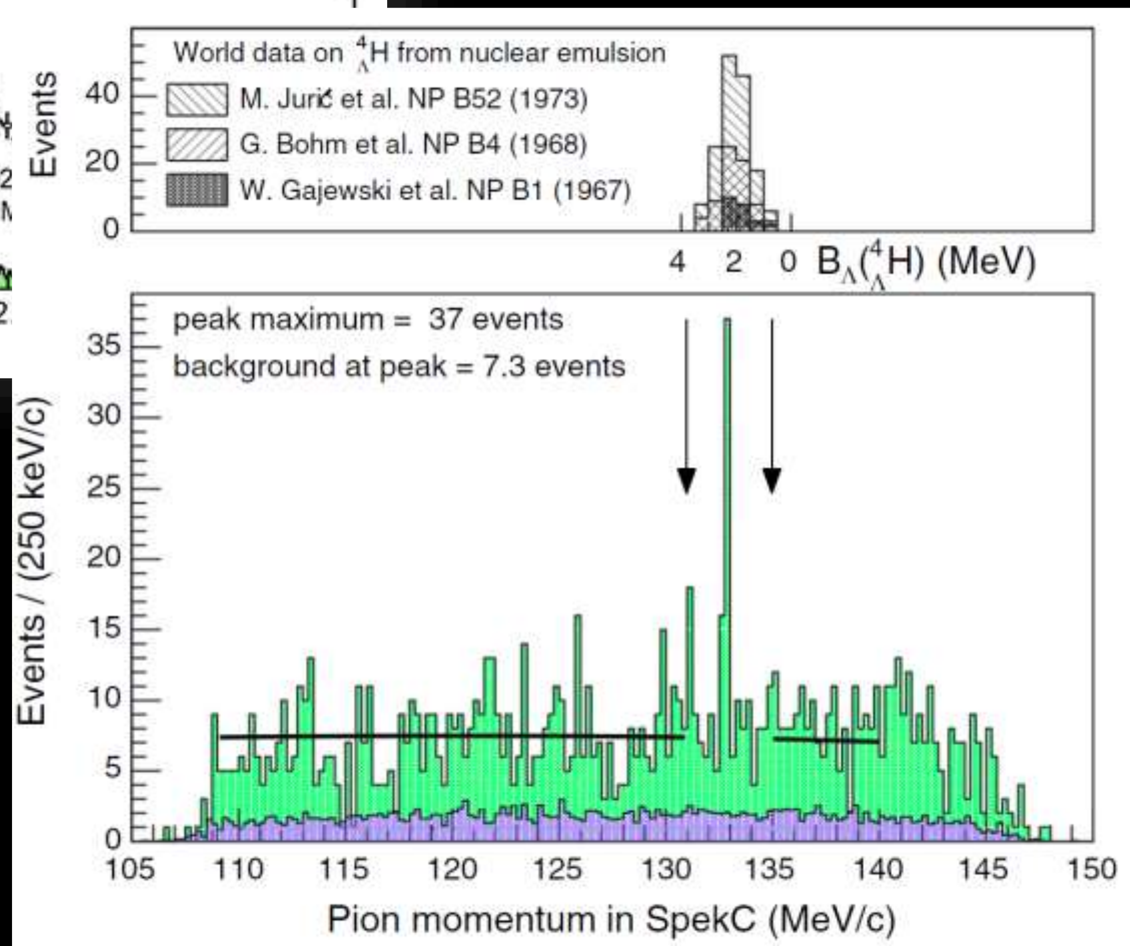
- 2015: strong, spin-dependent charge symmetry breaking (CSB) in *A* = 4 mirror hypernuclei !
- Compatible with *ab initio* calculations

Success of novel Techniques

Phys. Rev. Lett. **114**, 232501 (2015)



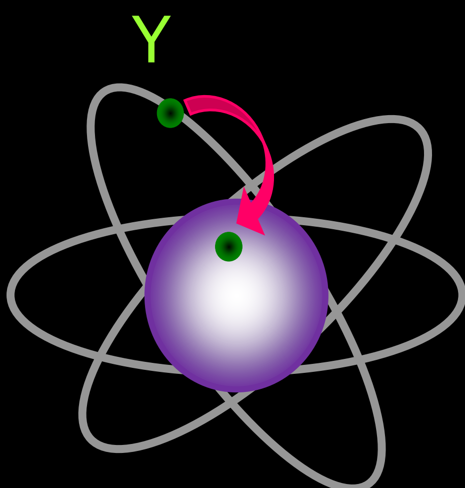
Phys. Rev. Lett. **115**, 222501 (2015)



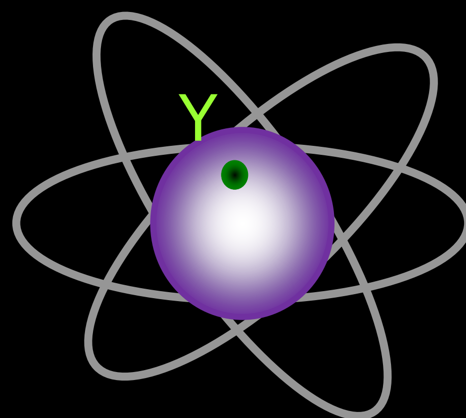
- Demonstrates the need for complementary experiments and good resolution

Strangeness Nuclear Physics

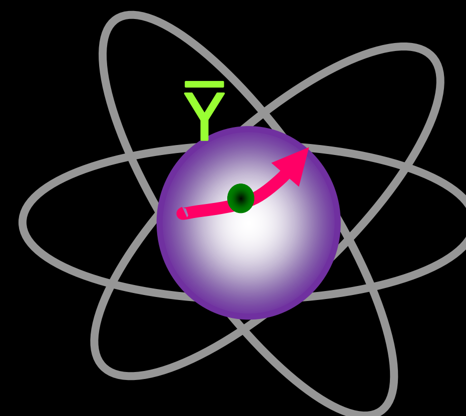
= Strangeness in cold nuclei



hyperatoms



hypernuclei

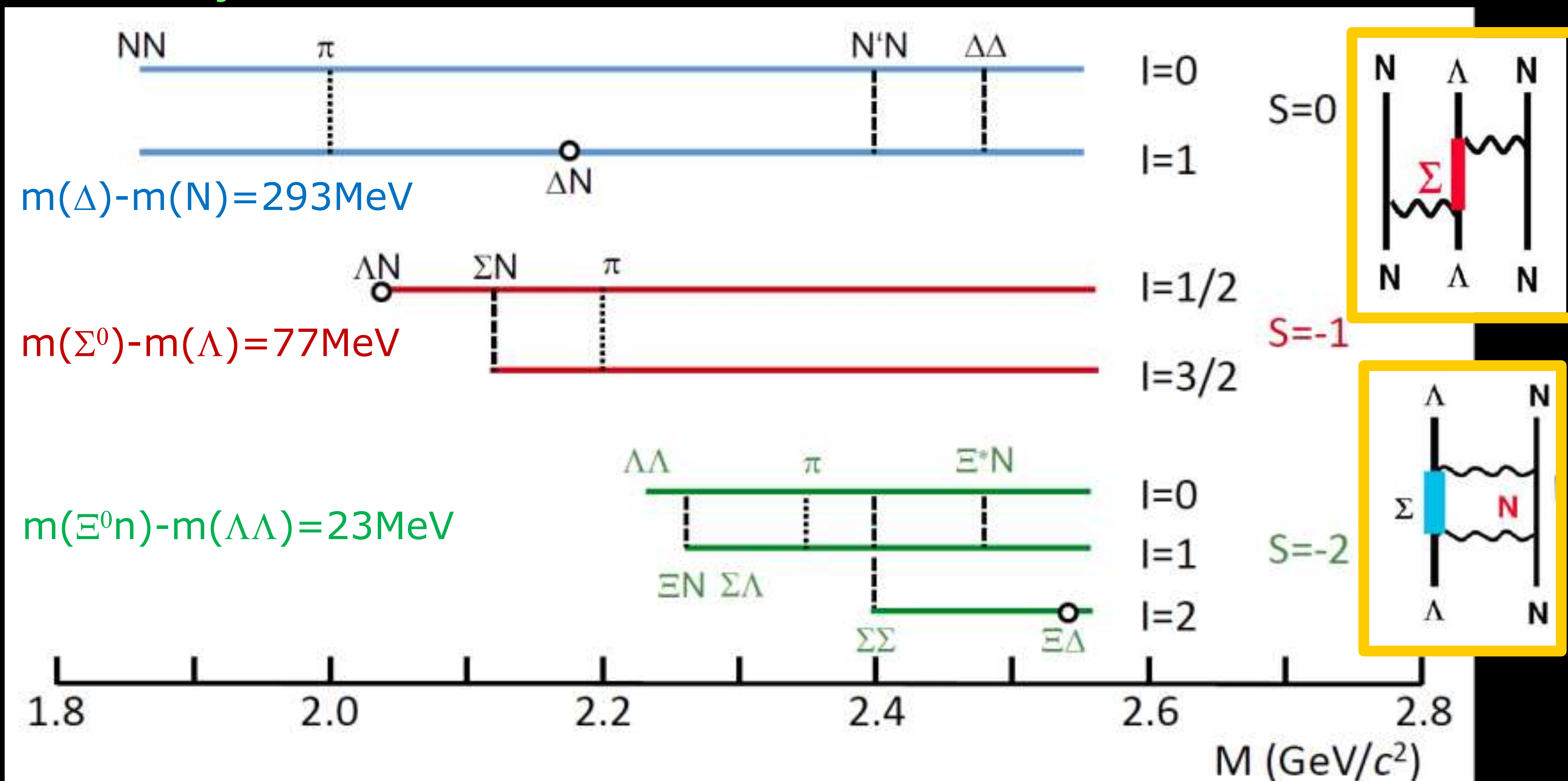


(anti)hyperon scattering

Why CSB in Hypernuclei so large?

- Mass difference between Σ and Λ in single hypernuclei is small

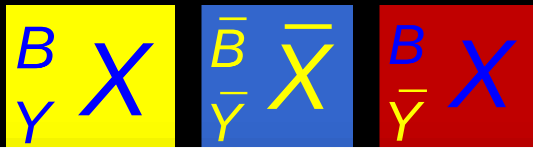
Thomas Rijken



- hyperon coupling important phenomenon in hypernuclei

Double Hypernuclei

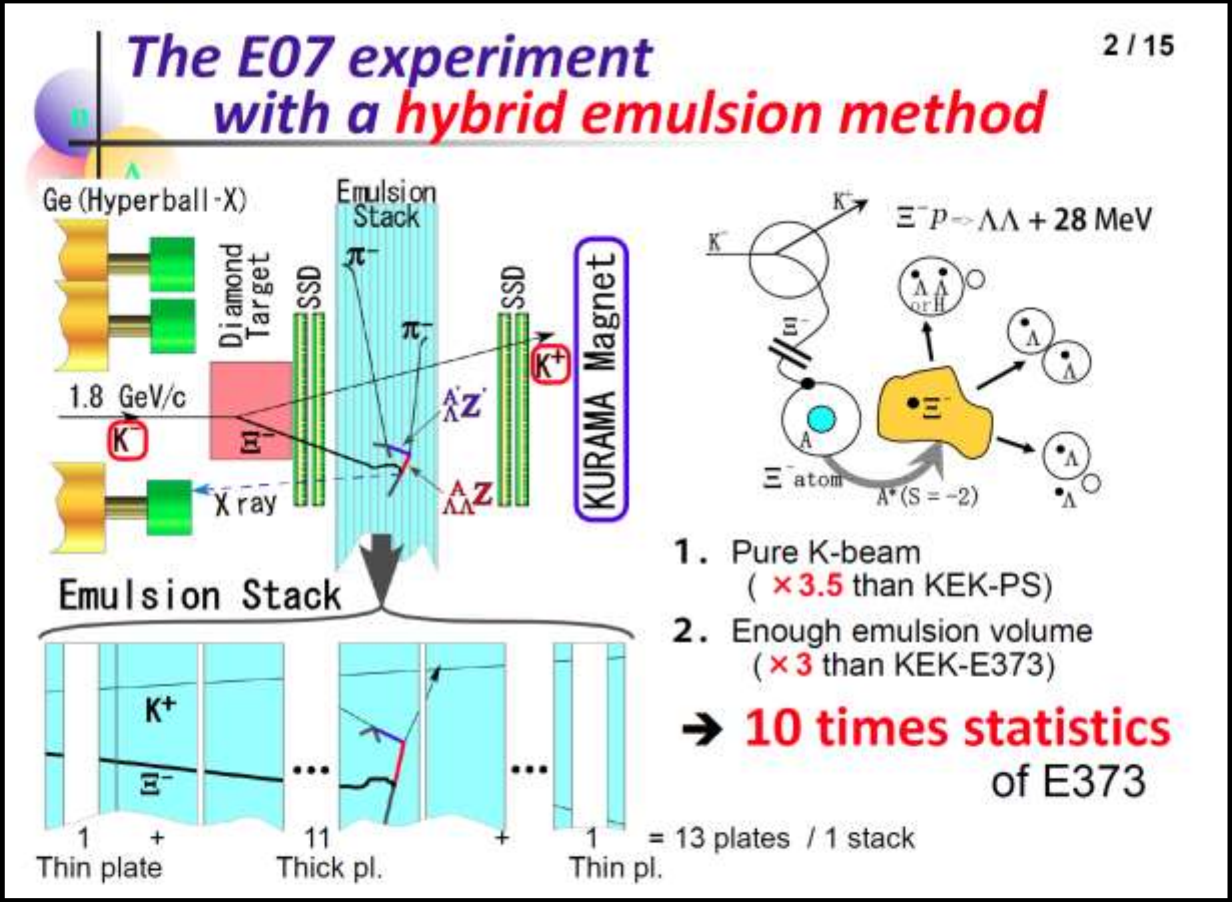
H. Takahashi et al., PRL 87, 212502-1 (2001)



Nucleus	$\Delta B_{\Lambda\Lambda}(^{A}_{\Lambda\Lambda}Z)$ (MeV)	Experiment	Reference	Remark
$^{10}_{\Lambda\Lambda}$Be	4.3 ± 0.4	Danysz (1963)	[77, 78] [74]	K^- + nuclear emulsion; $\Delta B_{\Lambda\Lambda}$ consistent with NAGARA if decay to $^{9}_{\Lambda}$Be* at $E_x \approx 3$ MeV [81, 11]
$^{6}_{\Lambda\Lambda}$He	4.7 ± 0.6	Prowse (1966)	[198]	K^- + nuclear emulsion only schematic drawing
$^{10}_{\Lambda\Lambda}$Be or $^{13}_{\Lambda\Lambda}$B	-4.9 ± 0.7 0.6 ± 0.8	KEK-E176 (1991) Aoki event	[20, 245] [88, 24, 172]	hybrid-emulsion $(K^-,K^+)\Xi^-_{stopped}$
$^{6}_{\Lambda\Lambda}$He	0.67 ± 0.17	KEK-E373 (2001) NAGARA event	[226, 172] [11]	hybrid emulsion
$^{10}_{\Lambda\Lambda}$Be or $^{10}_{\Lambda\Lambda}$Be*	-1.65 ± 0.15	KEK-E373 (2001) DEMACHIYANAGI event	[10, 172] [11]	$B_{\Lambda\Lambda}$ consistent with Danysz if $E_x \approx 2.8$ MeV
$^{6}_{\Lambda\Lambda}$He or $^{11}_{\Lambda\Lambda}$Be*	3.77 ± 1.71 3.95 ± 3.00 or 4.85 ± 2.63	KEK-E373 (2003) MIKAGE event	[227, 11]	
$^{12}_{\Lambda\Lambda}$Be or $^{11}_{\Lambda\Lambda}$Be*	2.00 ± 1.21 2.61 ± 1.34	KEK-E373 (2010) HIDA event	[172, 11]	

$\Xi^- p \rightarrow \Lambda\Lambda + 28$MeV

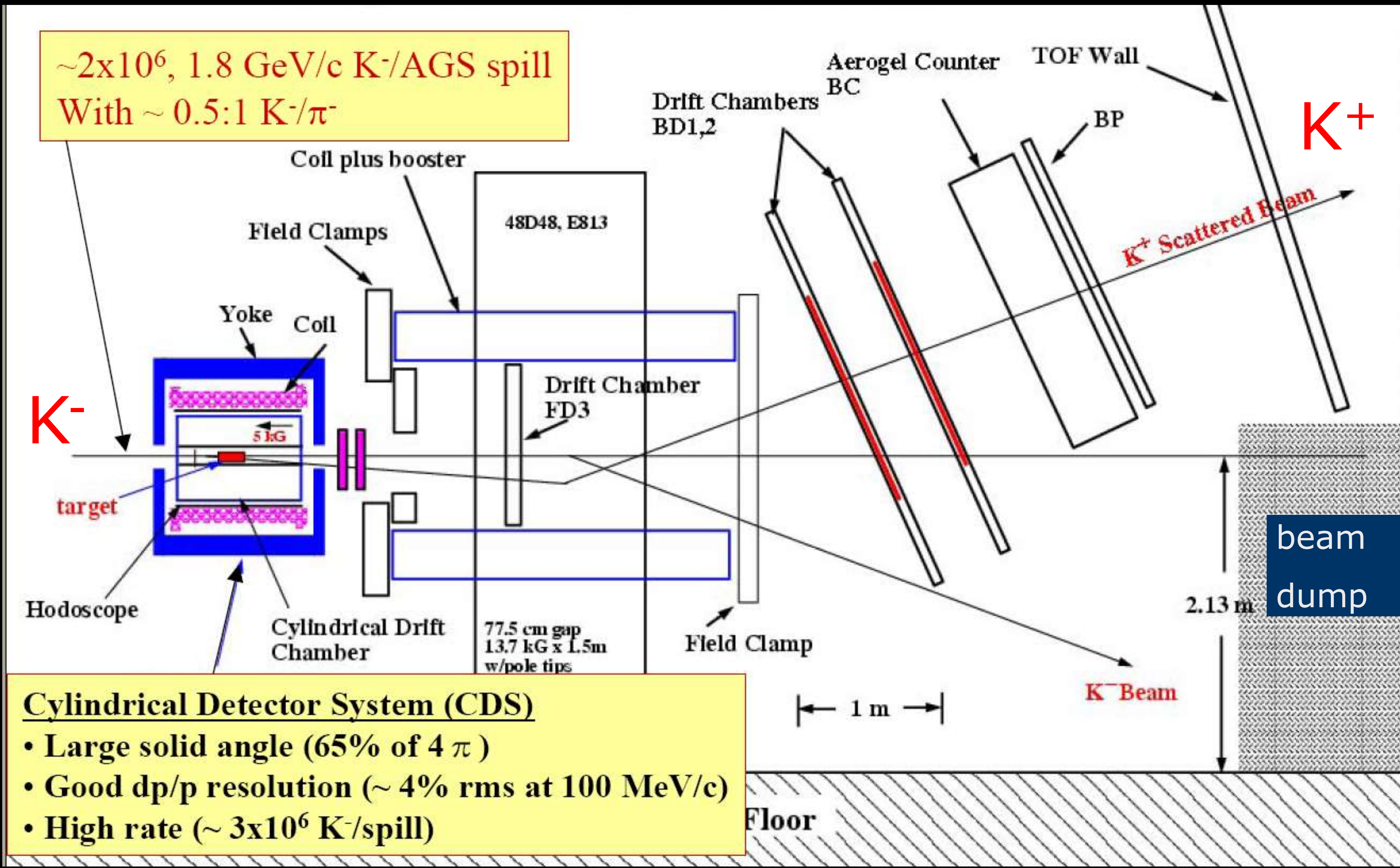
E07 @ J-PARC



- Beam exposure has successfully been performed for all emulsion stacks in 2016/2017
- auto-scanning has started
- limitation: only ground state masses for $\Lambda\Lambda$-hypernuclei can be determined

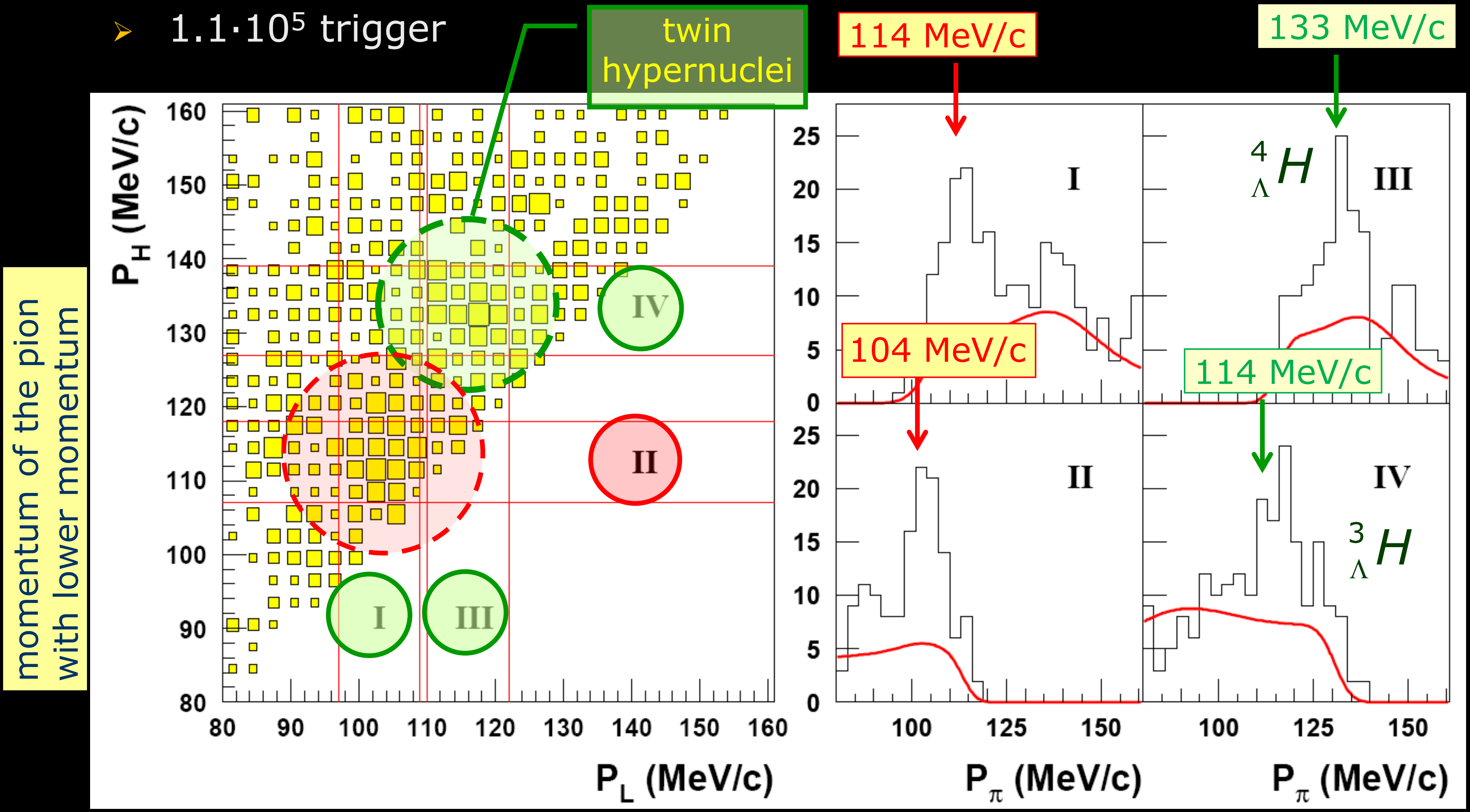
The E906 experiment

- $^{9}Be(K^{-},K^{+})\pi^{-}\pi^{-}$



E906

- $9 \cdot 10^{11}$ K^- on Be target
- $1.1 \cdot 10^5$ trigger



momentum of the pion with lower momentum

E906 – What is it?

VOLUME 87, NUMBER 13 PHYSICAL REVIEW LETTERS 24 SEPTEMBER 2001

Production of $^{4}_{\Lambda\Lambda}$H Hypernuclei

J. K. Ahn,[13] S. Ajimura,[10] H. Akikawa,[7] B. Bassalleck,[9] A. Berdoz,[2] D. Carman,[2] R. E. Chrien,[1] C. A. Davis,[8,14]
P. Euge… K. Imai,[7]
S. H. … Landry,[8]
M. May, … K. Paschke,[2]
P. Pile,[1] M. Prokhabatilov,[6] R. P. Quinn,[2] V. Rasin,[6] A. Rusek,[1] H. Schmitt,[3] R. A. Schumacher,[2] M. Sekimoto,[5]

$$^{4}_{\Lambda\Lambda}H \rightarrow \pi^{-}_{114MeV/c} + {}^{4}_{\Lambda}He \rightarrow \pi^{-}_{114MeV/c} + \pi^{-}_{97MeV/c} + {}^{4}H$$

PHYSICAL REVIEW C **66**, 014003 (2002)

Pionic weak decay of the lightest double-Λ hypernucleus $^{4}_{\Lambda\Lambda}$H

Izumi Kumagai-Fuse and Shigeto Okabe
Center for Information and Multimedia Studies, Hokkaido University, Sapporo 060-0811, Japan
(Received 31 December 2001; published 22 July 2002)

$$^{3}_{\Lambda}H + {}^{6}_{\Lambda}He$$

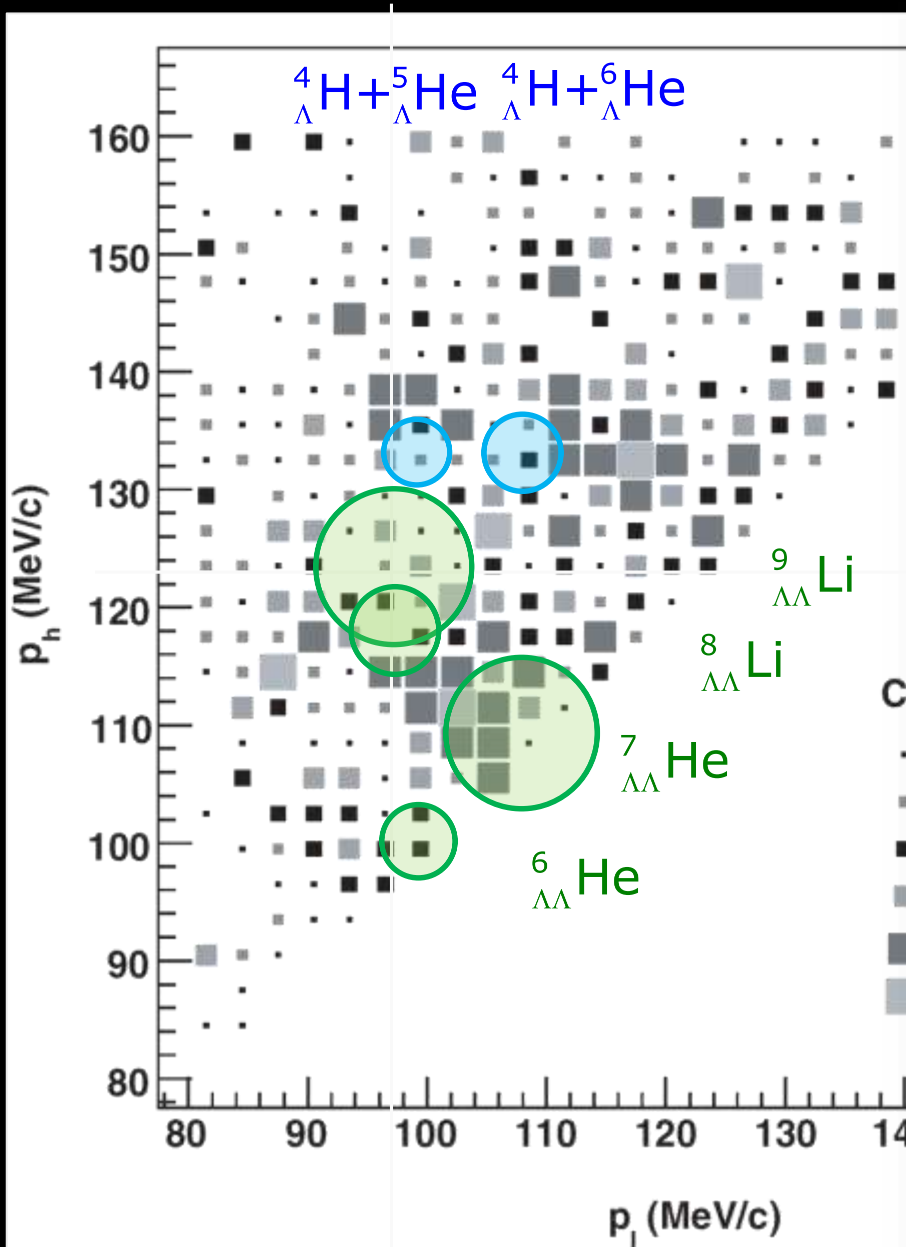
$$^{7}_{\Lambda\Lambda}He$$

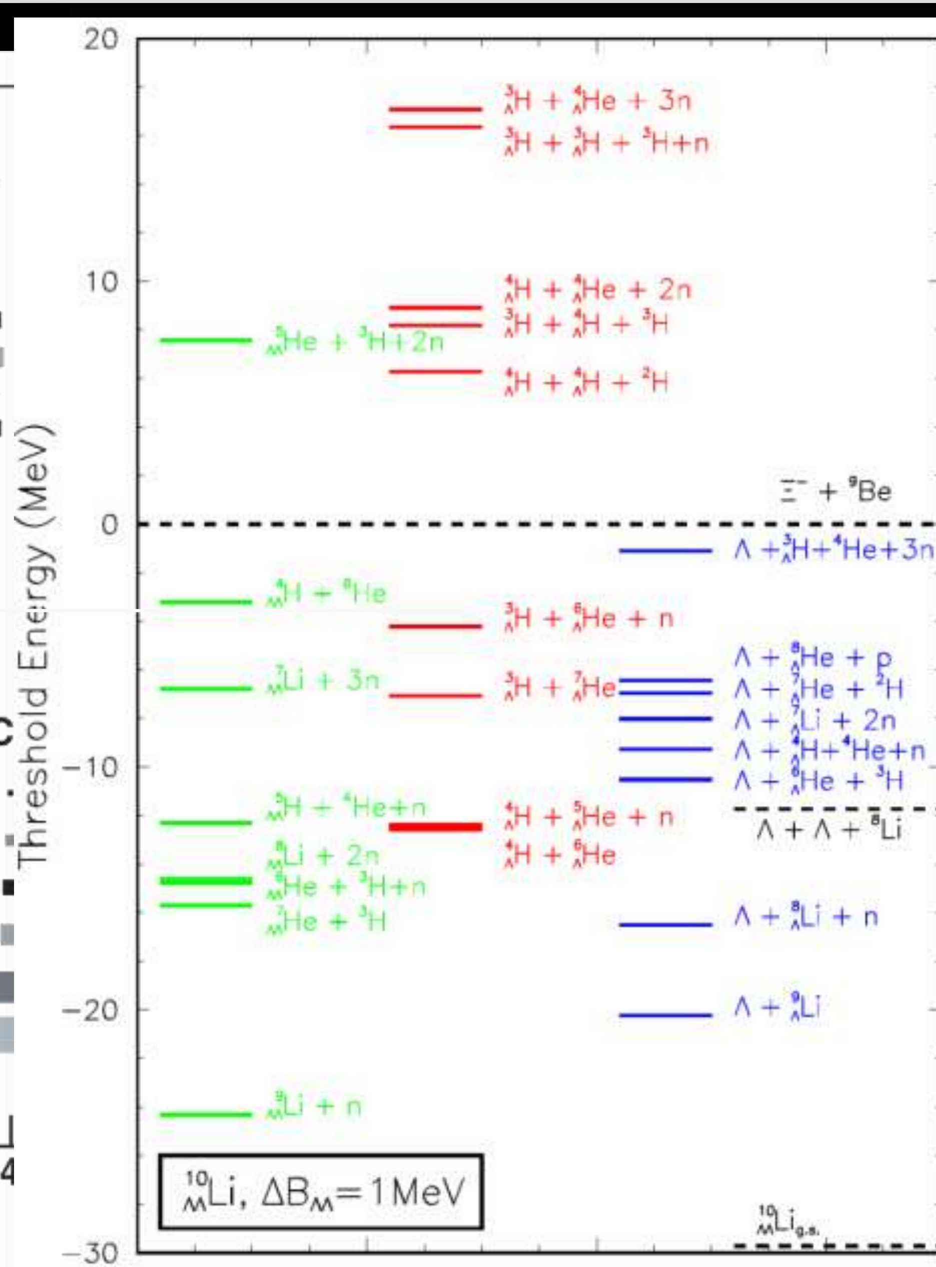
PHYSICAL REVIEW C **76**, 064308 (2007)

Reevaluation of the reported observation of the $^{4}_{\Lambda\Lambda}$H hypernucleus

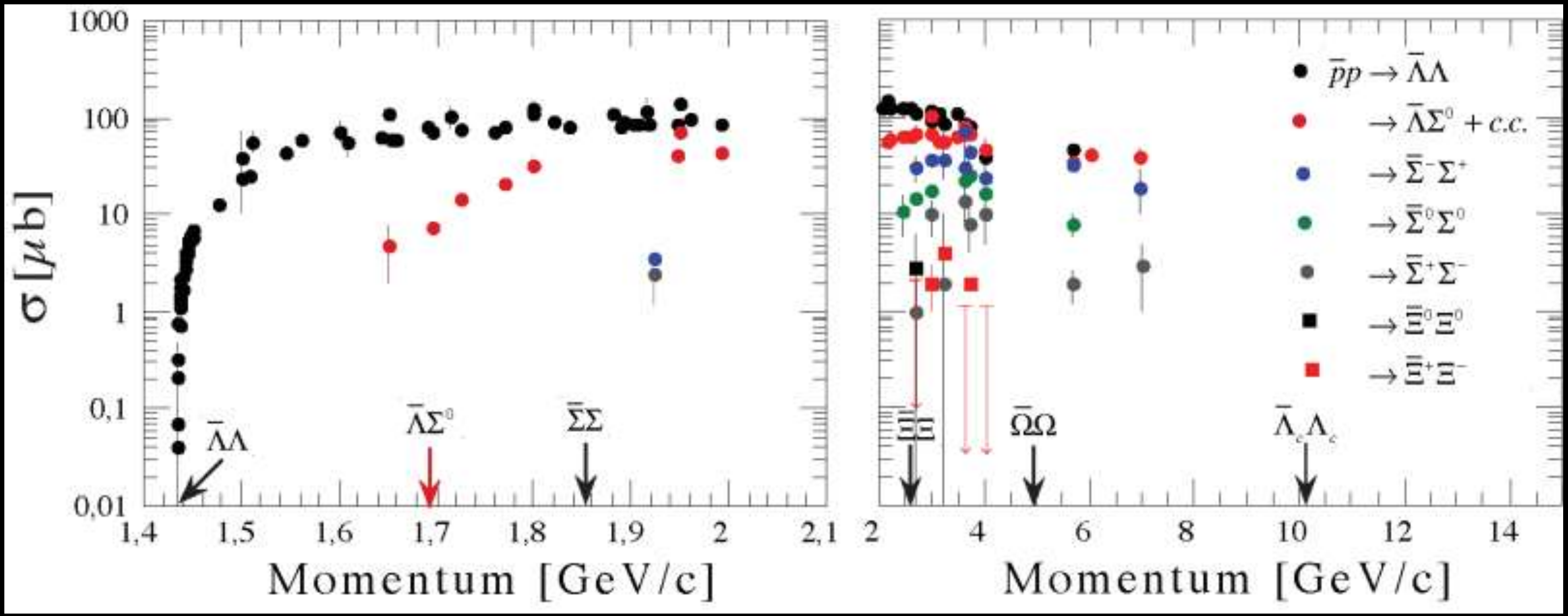
S. D. Randeniya and E. V. Hungerford
Department of Physics, University of Houston, Houston, Texas 77204, USA
(Received 11 June 2007; published 10 December 2007)

Ξ^- Stopping & Fusion: $\Xi^- + {}^9Be \rightarrow {}^{10}_{\Lambda\Lambda}Li^*$





$\bar{P}$ANDA – a Factory for strange *and* charmed $Y\bar{Y}$-Pairs



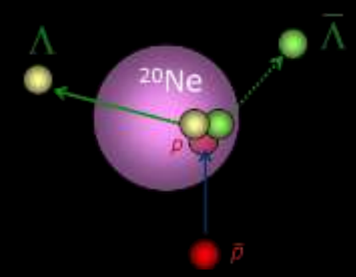
Production Rates (1-2 (fb)$^{-1}$/y)

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

Phase 1

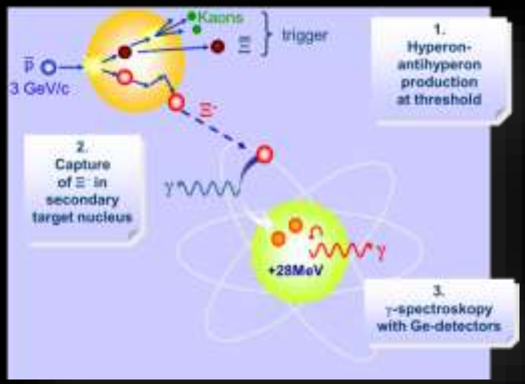
- Antihadrons in atomic nuclei
  - Nuclear potential of antihadrons and hadrons
  - Search for Antilambda bound states
  - Exploring the neutron skin of nuclei
  - $K^*/\bar{K}^*$ in nuclei



JP PLB **669**, 306 (2008)
Sanchez *et al.*, PLB 749, 421 (2015)

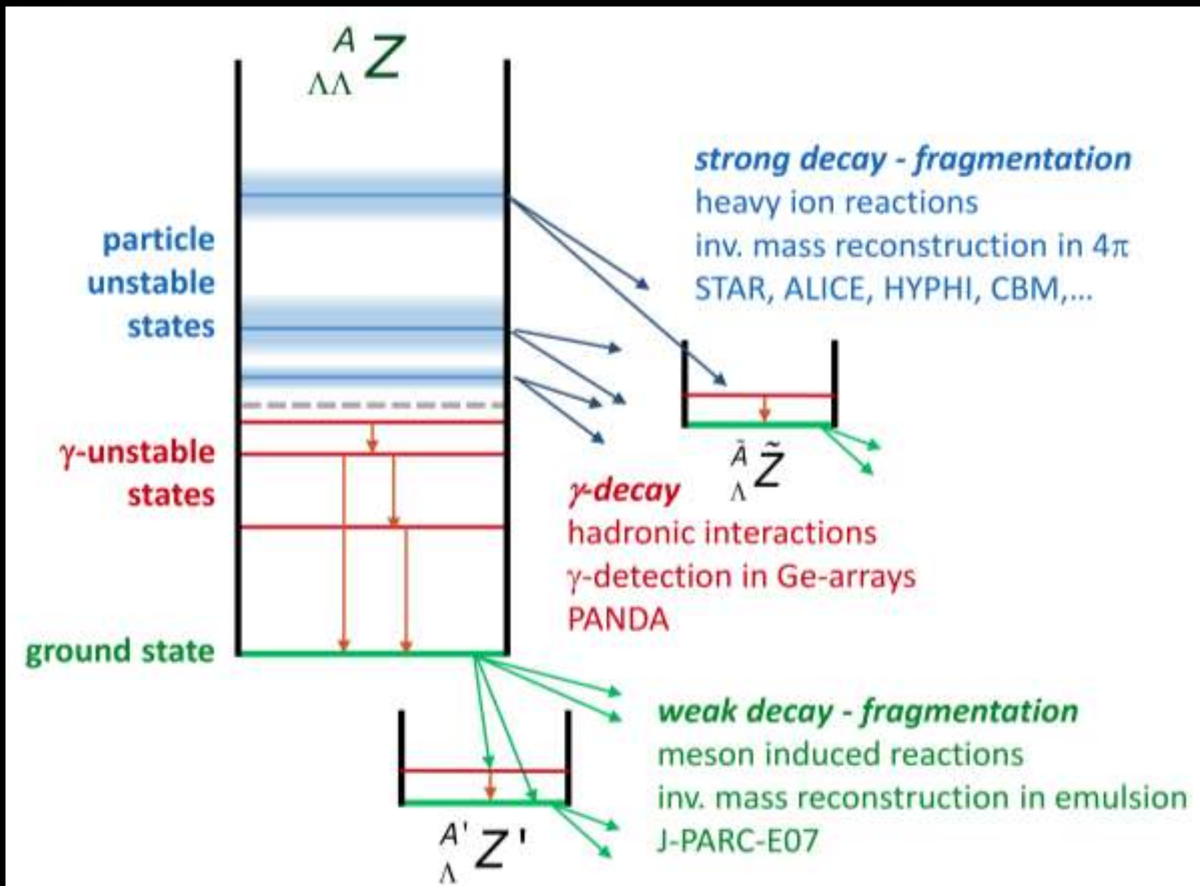
Pahse 2

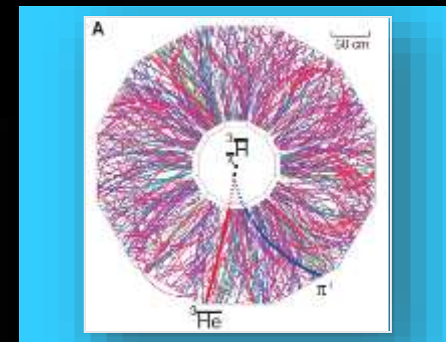
- High resolution γ-Spectroscopy
  - Atomic transitions in heavy hyperonic (S=2,3) atoms
  - Excited particle stable state spectroscop of light $\Lambda\Lambda$ hypernuclei

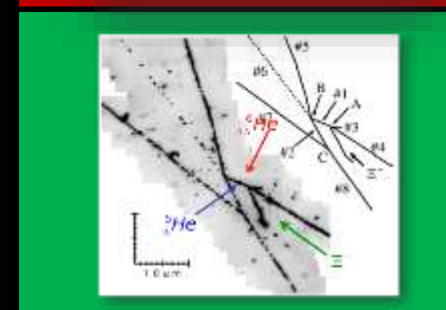


S=-2 systems

- Ξ capture and $\Xi^{-}p \rightarrow \Lambda$ $\Rightarrow$ $\Lambda\Lambda$ hypernuclei J-PARC, FAIR
- $\Lambda\Lambda$ coalescence $\Rightarrow$ $\Lambda\Lambda$ hypernuclei HI

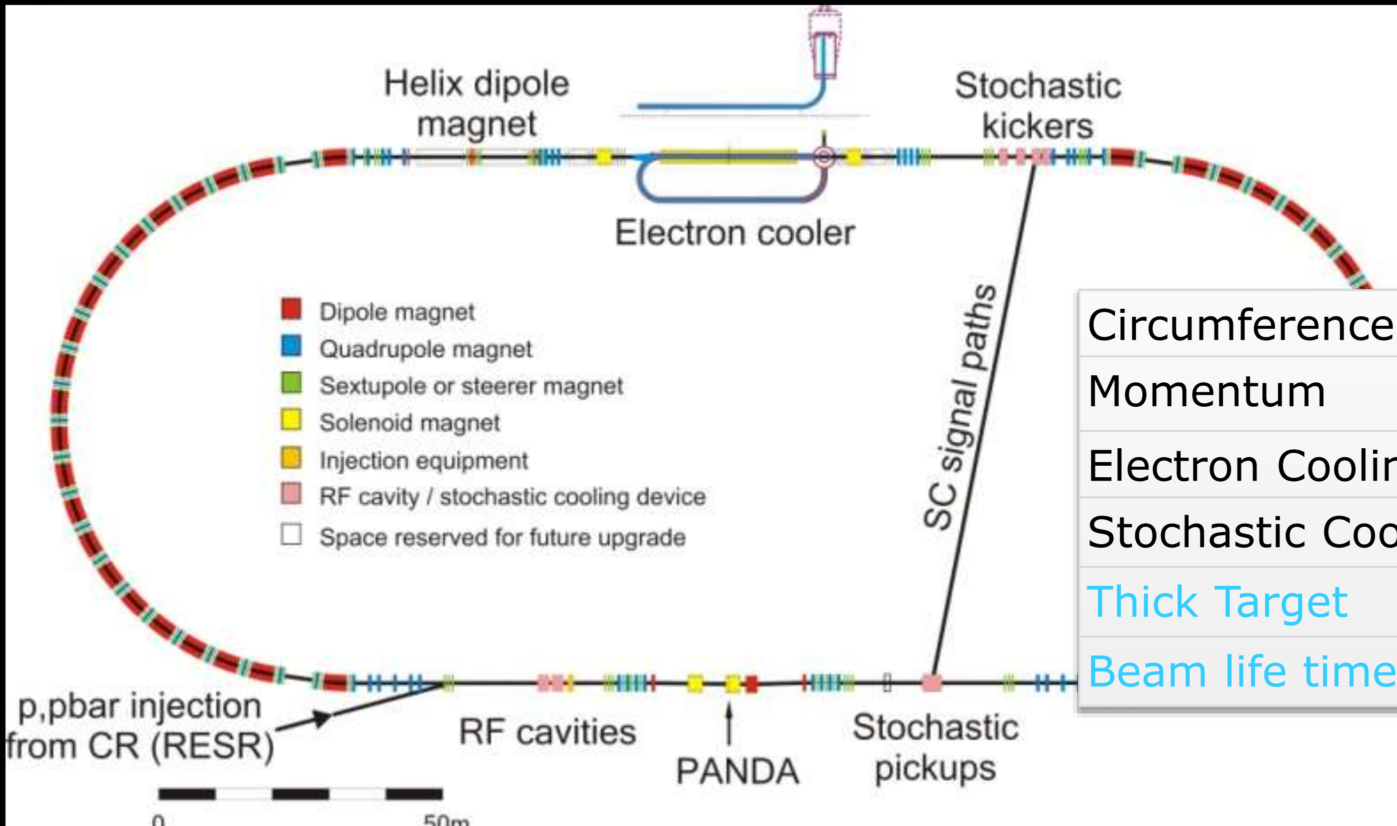






- missing mass (K^{-},K^{+}) reactions $\Rightarrow$ Ξ bound state J-PARC
- Ξ capture $\Rightarrow$ Ξ atoms J-PARC, FAIR
- final state interaction $\Rightarrow$ $\Lambda\Lambda$, Ξp… HI

HESR with PANDA and Electron Coole

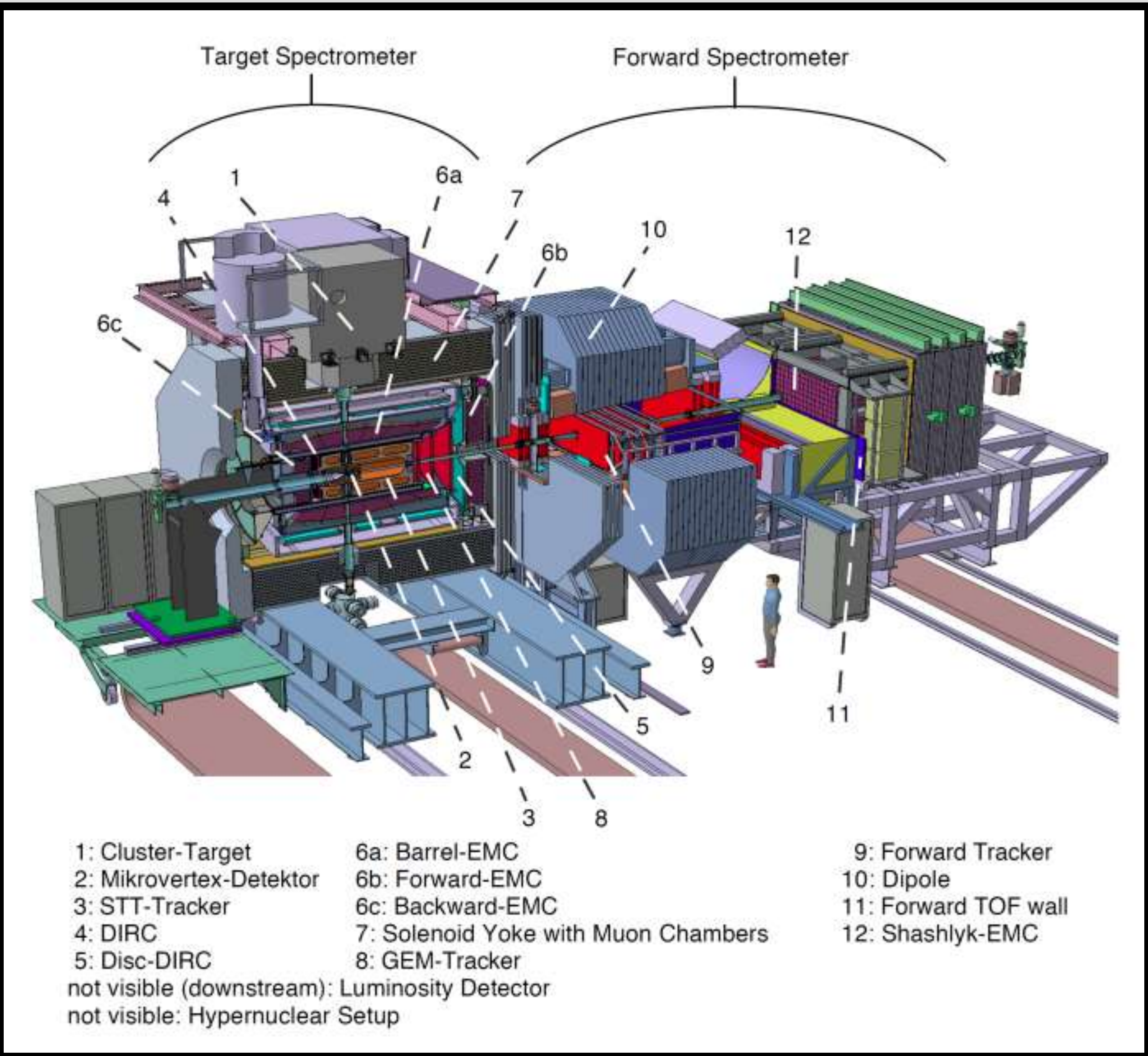


Circumference	575 m
Momentum	1.5 – 15 GeV/c
Electron Cooling	up to 9 GeV/c
Stochastic Cool.	Full range
Thick Target	$4\cdot10^{15}$ cm^{-2}
Beam life time	>30 min

- High resolution mode
  - e^- cooling $1.5 \leq p \leq 8.9$ GeV/c
  - 10^{10} antiprotons stored
  - Luminosity up to $2\cdot10^{31}$ cm^{-2}s^{-1}
  - $\Delta p/p \leq 4\cdot10^{-5}$

- High luminosity mode
  - Stochastic cooling $p \geq 3.8$ GeV/c
  - 10^{11} antiprotons stored
  - Luminosity up to $2\cdot10^{32}$ cm^{-2}s^{-1}
  - $\Delta p/p \leq 2\cdot10^{-4}$

The PANDA Detector



Strange Systems at PANDA

Ξ^- production
$\bar{p}N \rightarrow \Xi^- + X$

rescattering in
primary target nucleus

deceleration in
secondary target

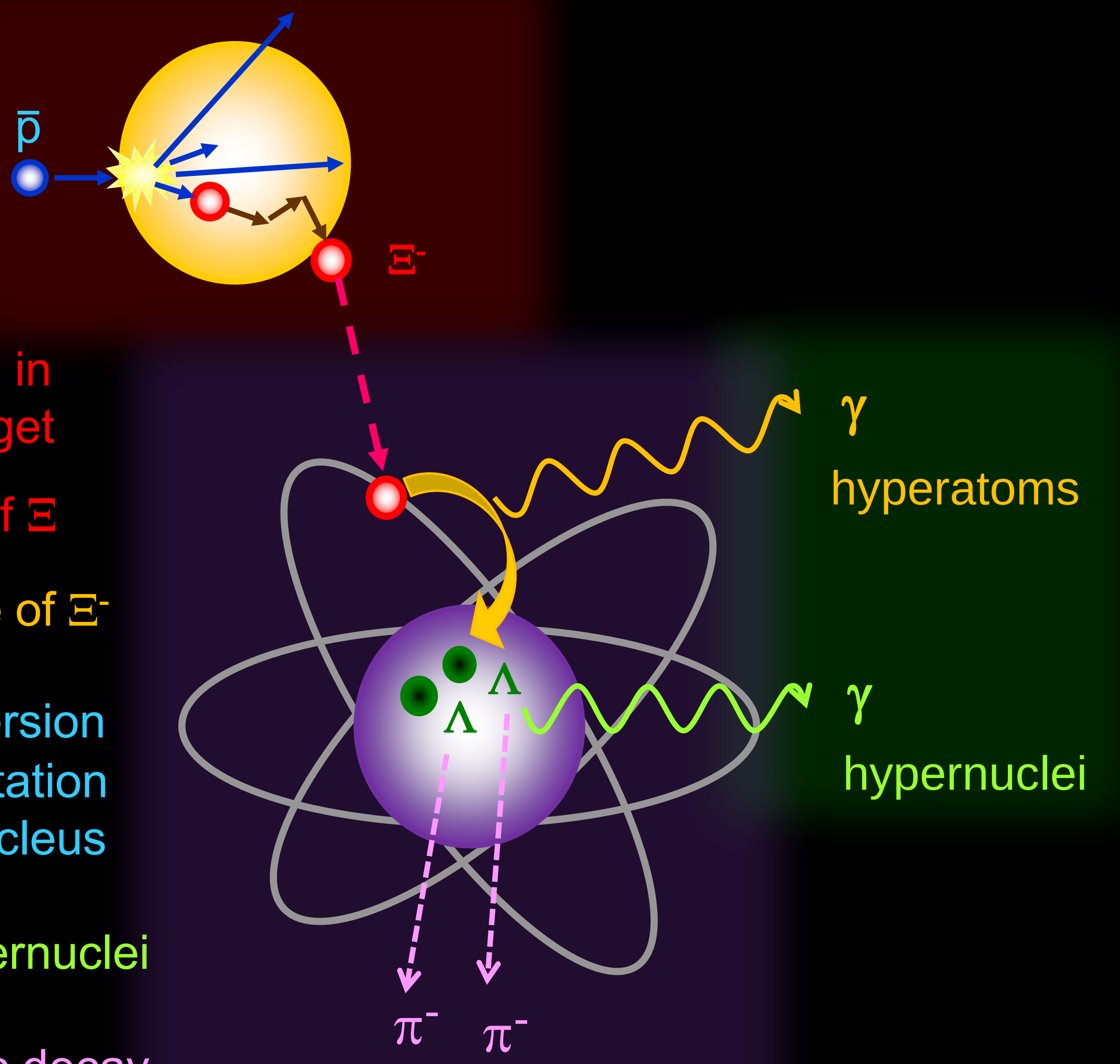
capture of Ξ

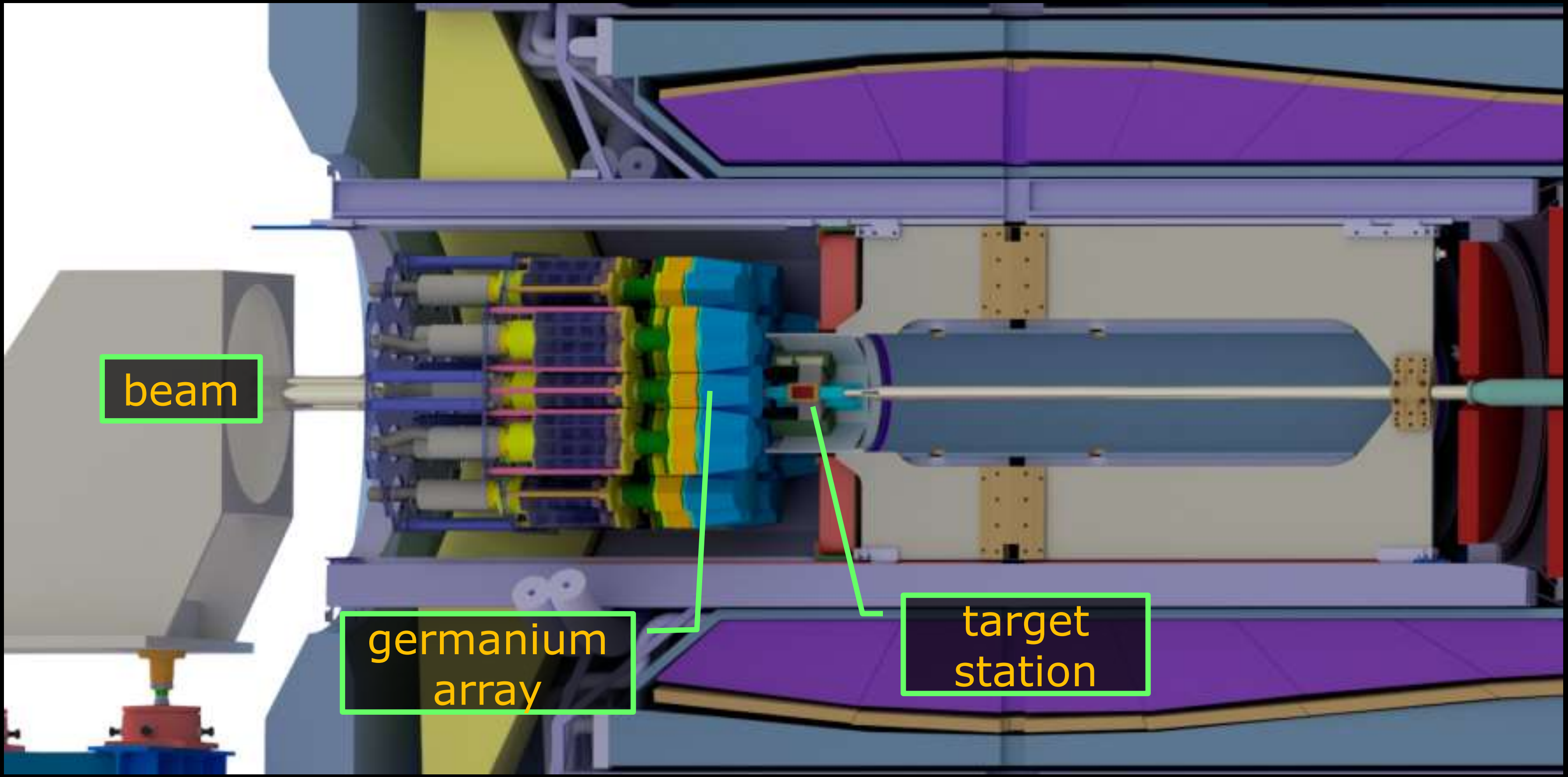
atomic cascade of Ξ^-

$\Xi^- p \rightarrow \Lambda\Lambda$ conversion
fragmentation
$\rightarrow$ excited $\Lambda\Lambda$-nucleus

γ-decay of $\Lambda\Lambda$ hypernuclei

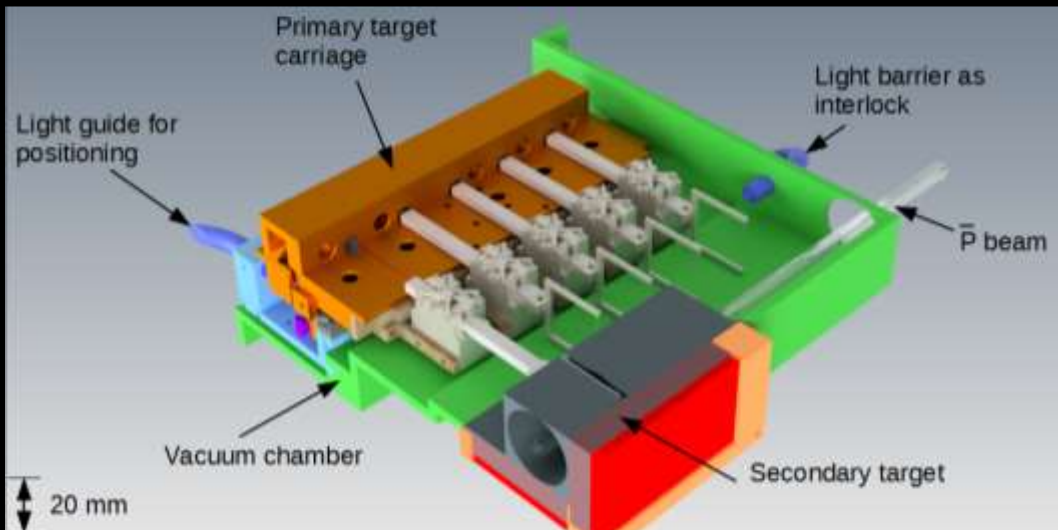
weak pionic decay

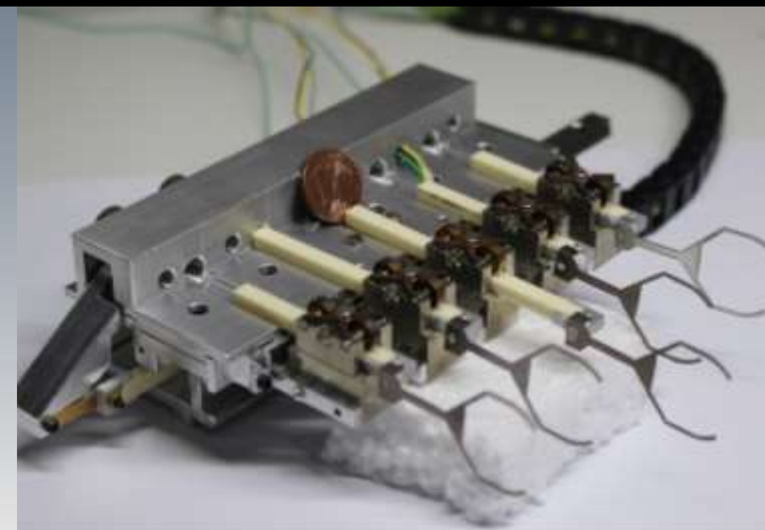



beam
germanium array
target station

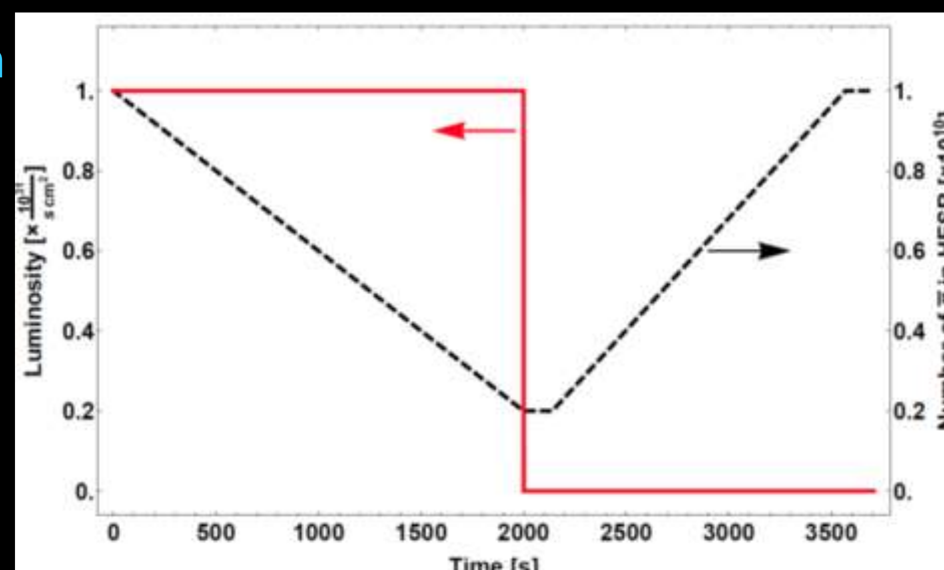
Primary Target

- Task: maximize slow Ξ^- production



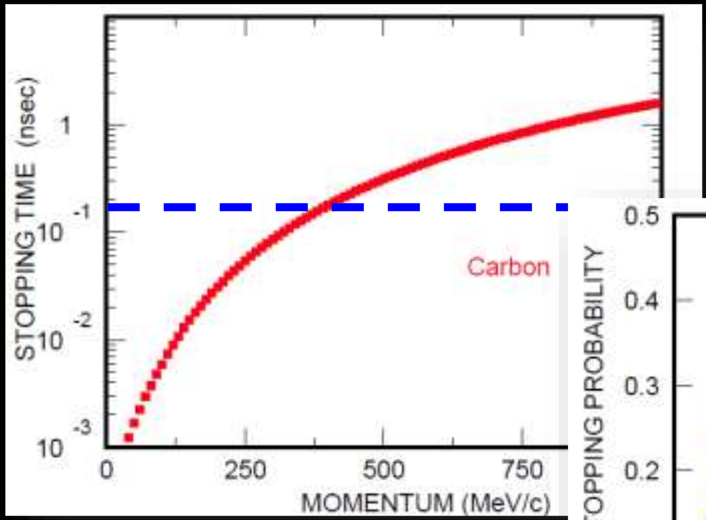


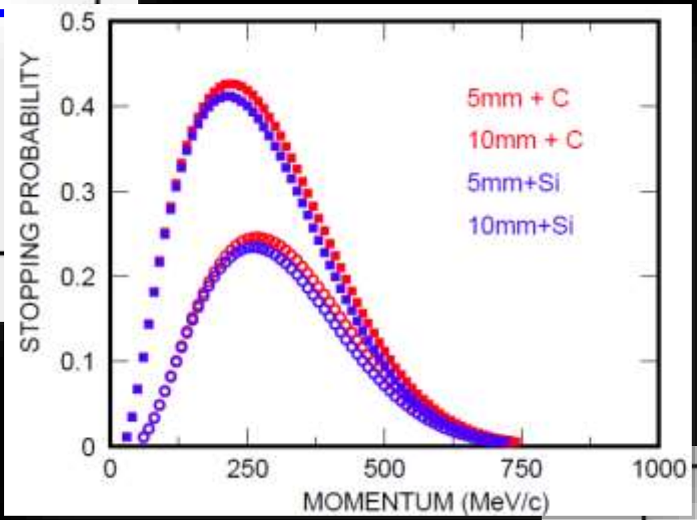
- Target material: C filament 5μm
  - production cross section
  - slow down process
  - beam losses…
- ultra high vacuum
- magnetic field
- radiation hardness
  e.g. passive position control
- …

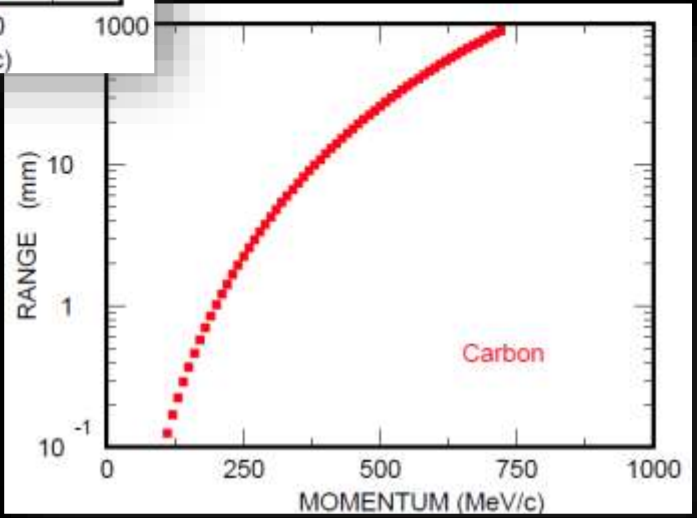


Ξ^- properties determine setup

- Ξ^- mean life 0.164 nsec



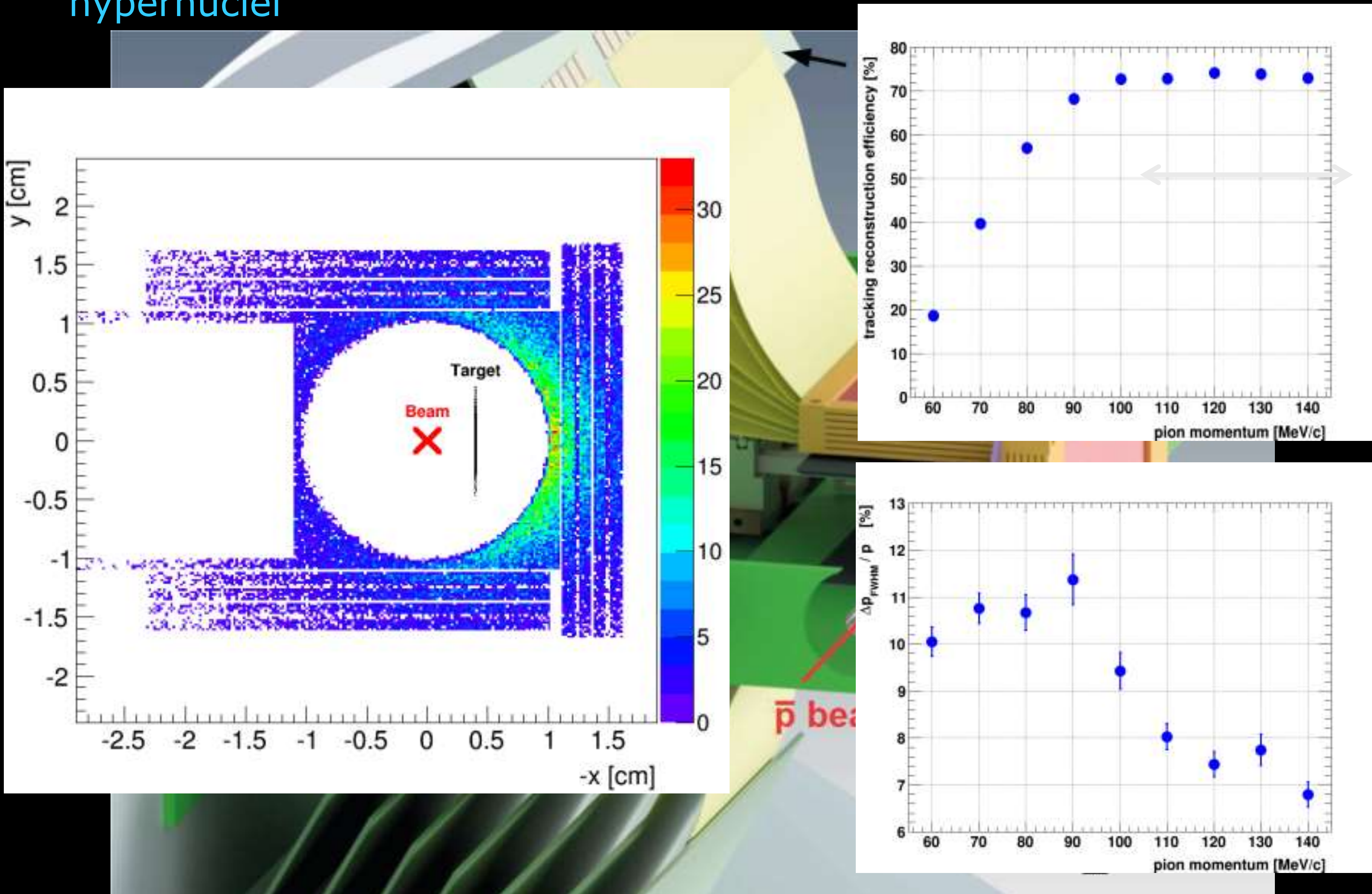




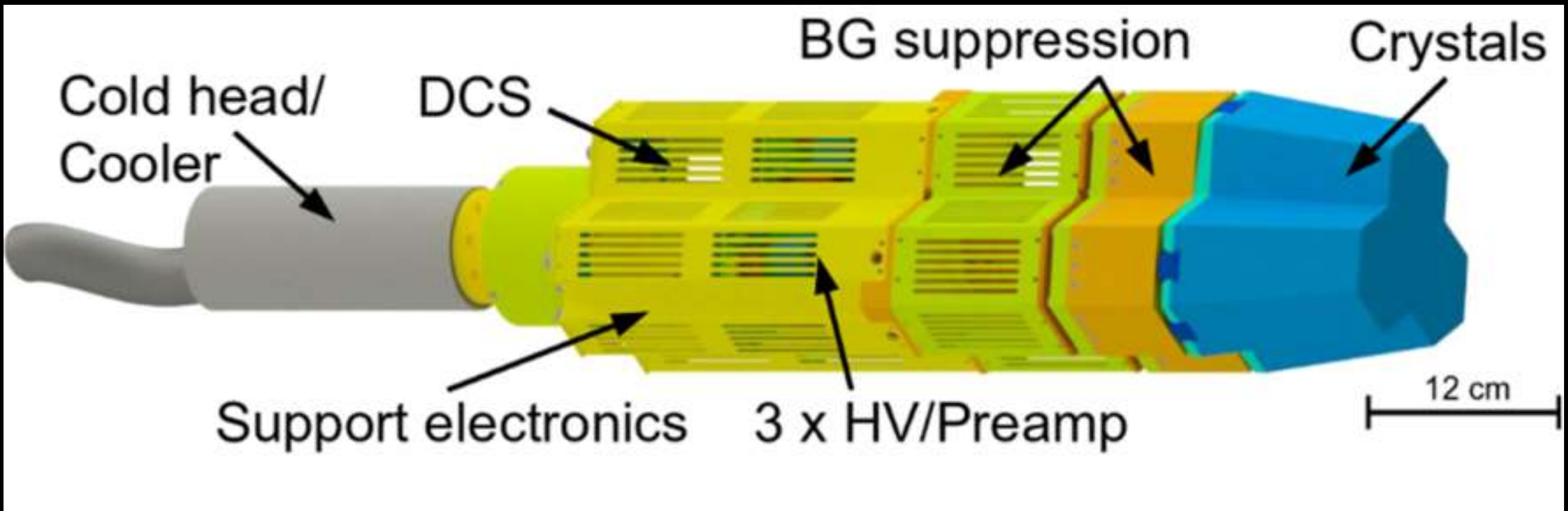
- minimizeminimize distance production & capture
- initial momentum 100-500 MeV/c
- thickness od secondary target few mm

Secondary target

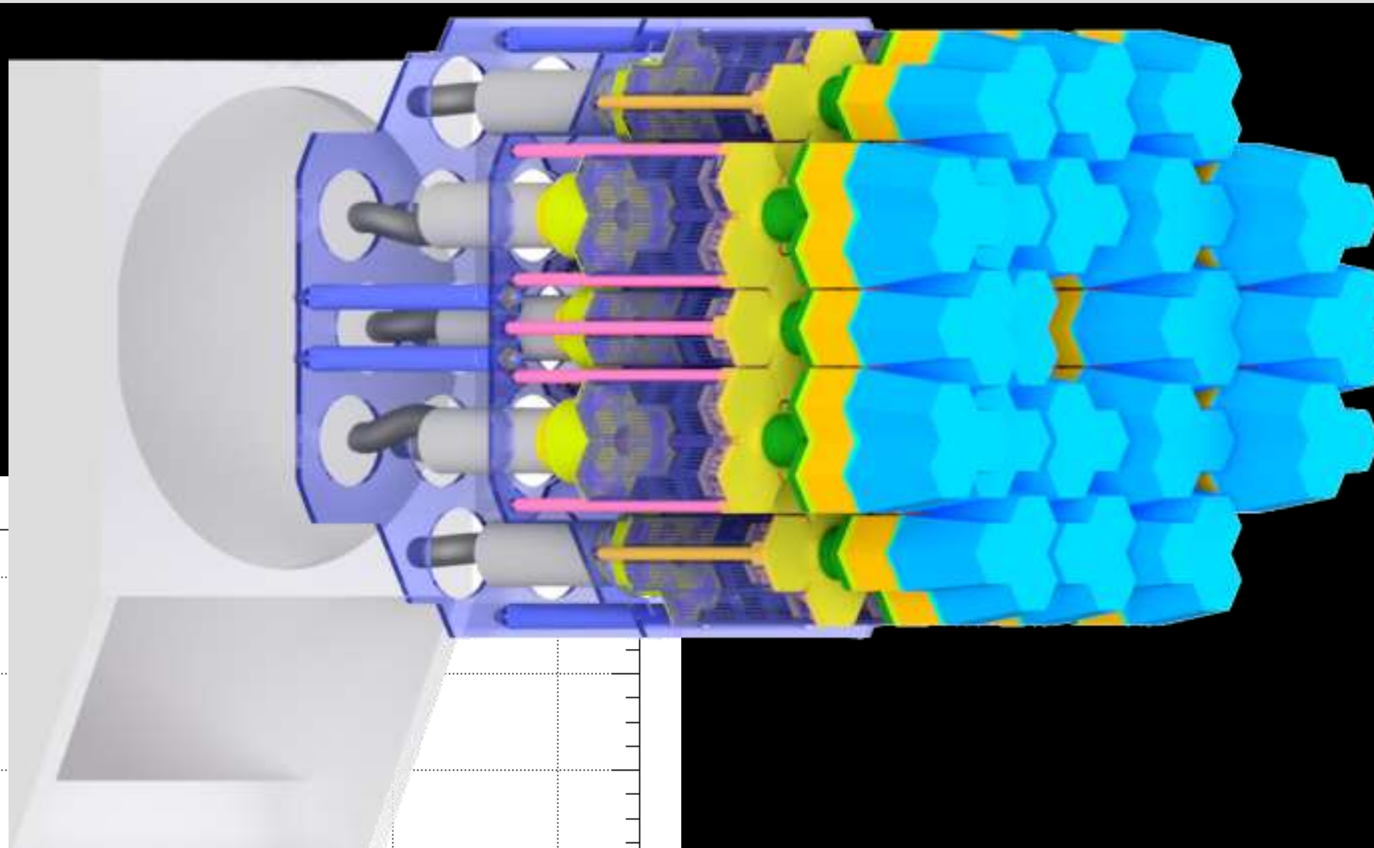
- Task: stopping of Ξ^- and tracking of 2 π^- from weak decay of double hypernuclei

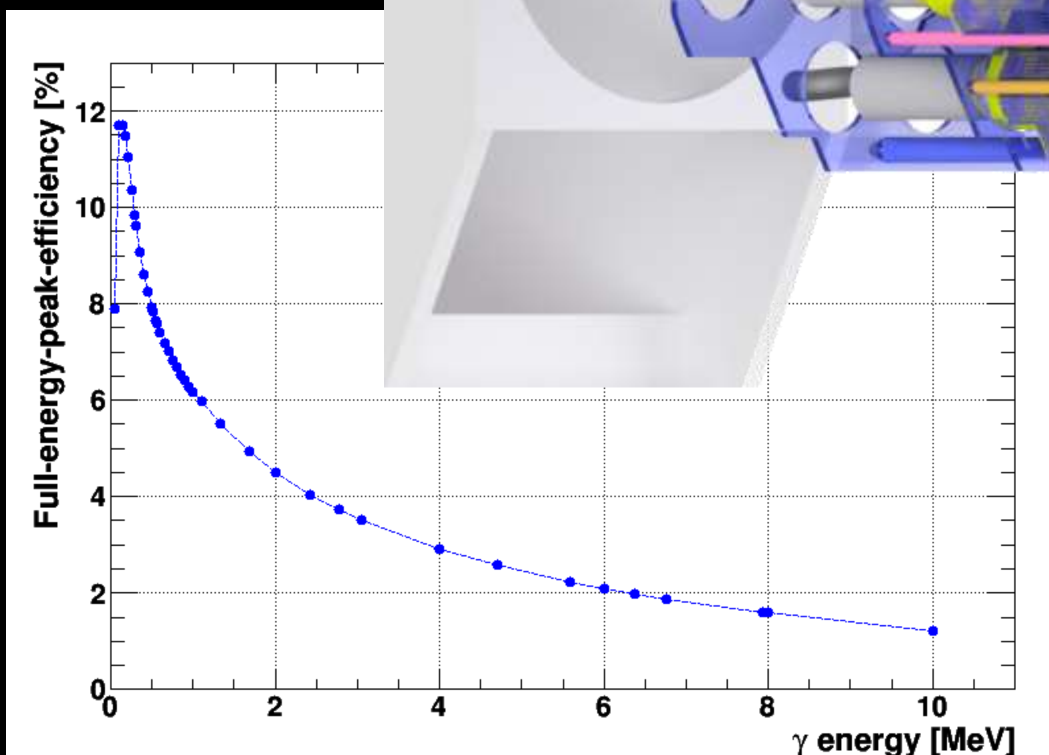


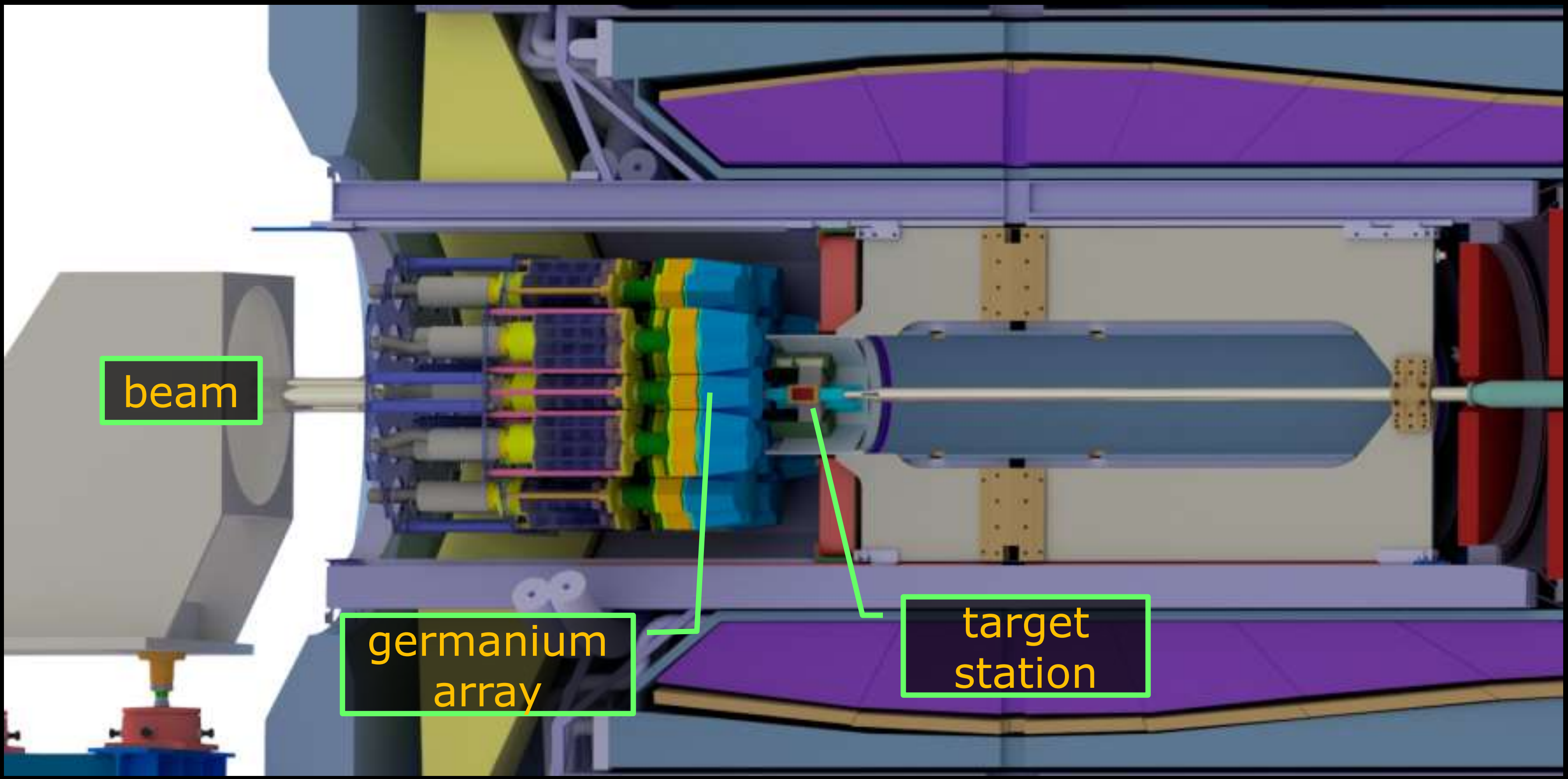
PANGEA



Cold head/
Cooler
DCS
BG suppression
Crystals
Support electronics
3 x HV/Preamp
12 cm

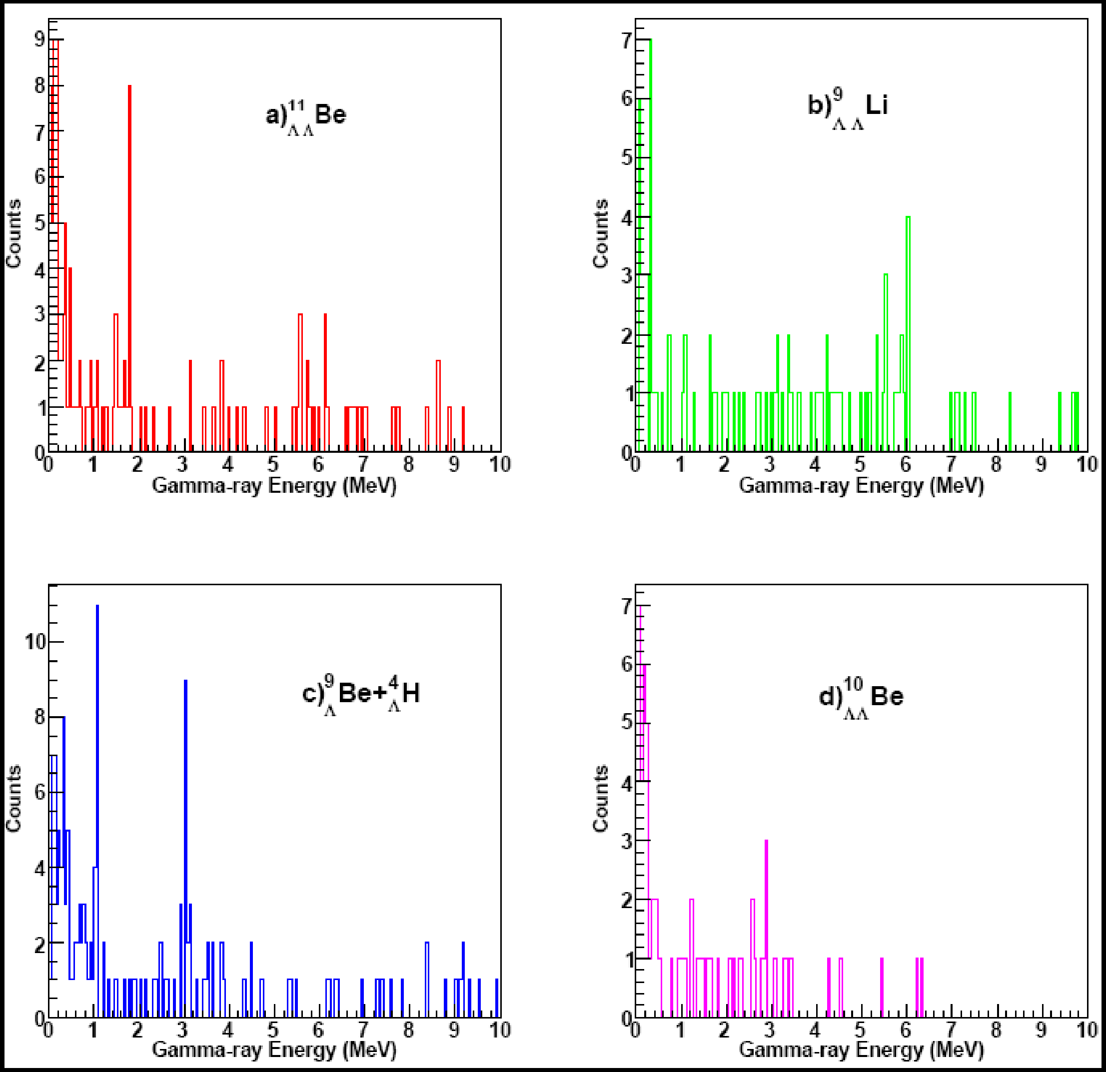



Full-energy-peak-efficiency [%]
γ energy [MeV]
0
2
4
6
8
10
12

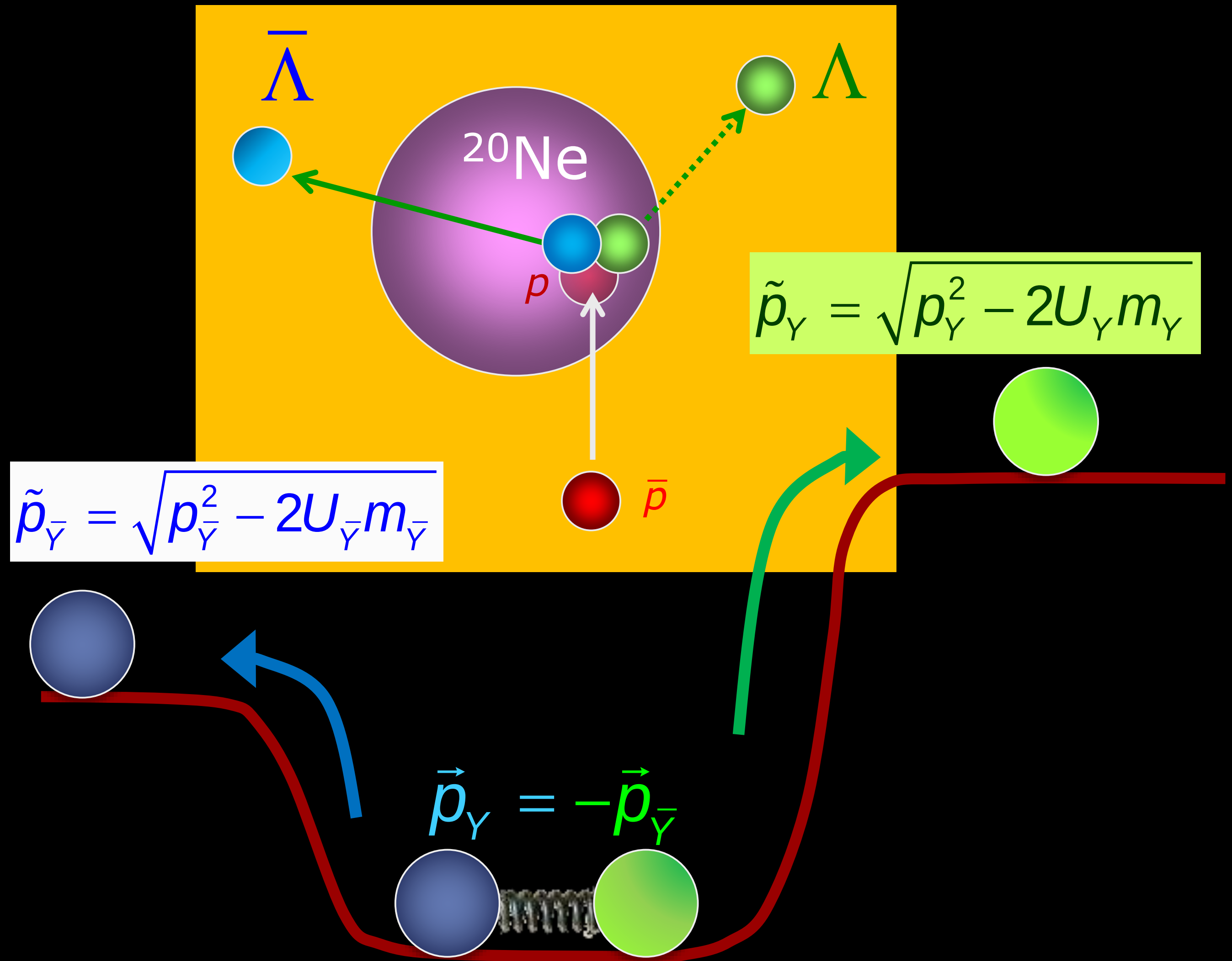

beam
germanium array
target station

Simulation within PANDA_ROOT…

- Example: secondary ^{12}C target (~2 weeks)



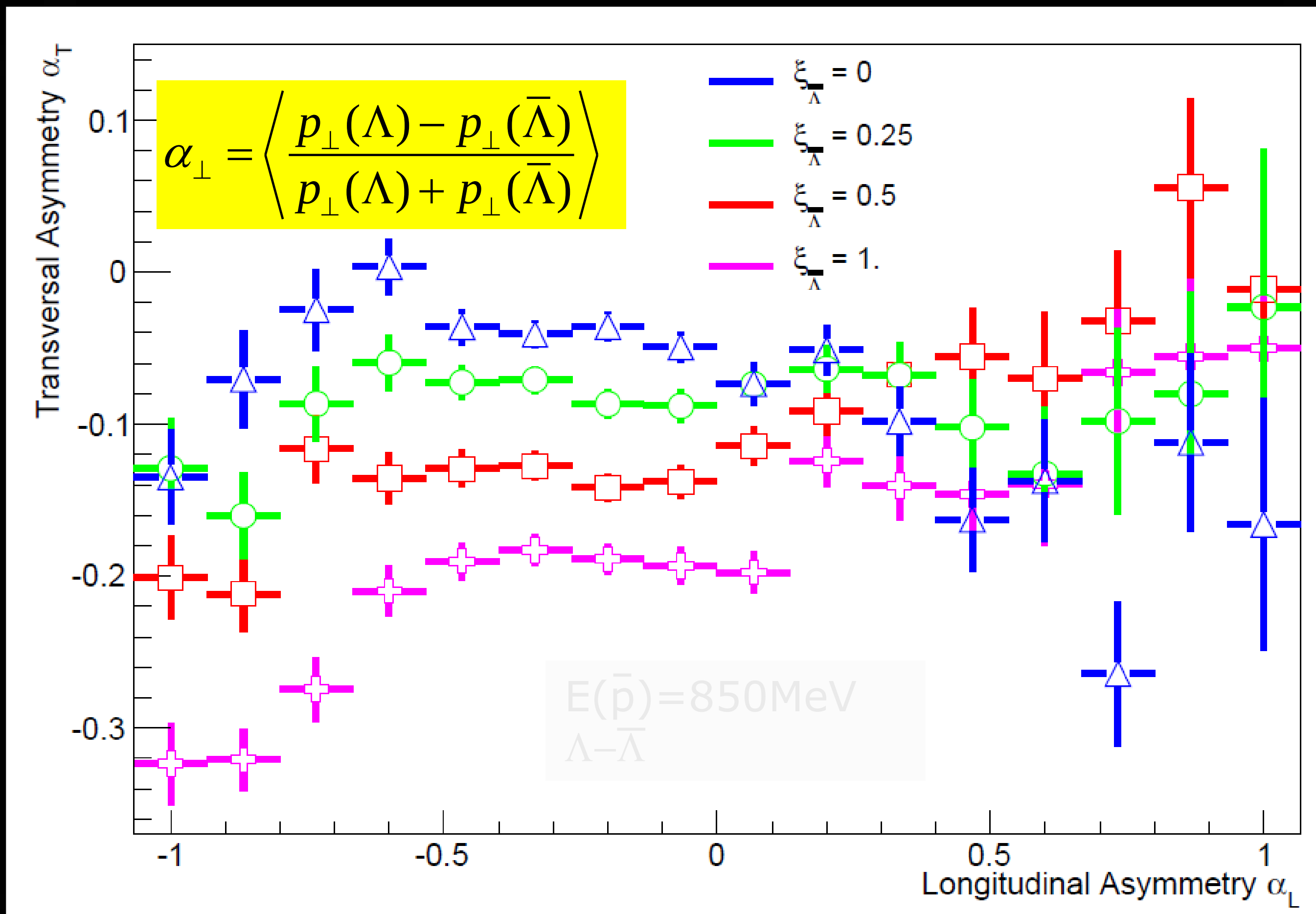
Task 5: $\bar{\Lambda}$ Potential in Nuclei

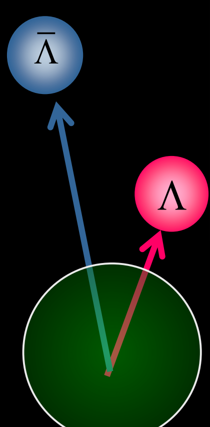


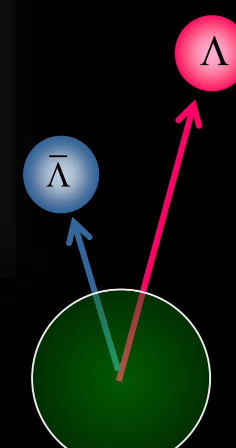
JP PLB **669**, 306 (2008)
Sanchez *et al.*, PLB 749, 421 (2015)

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

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



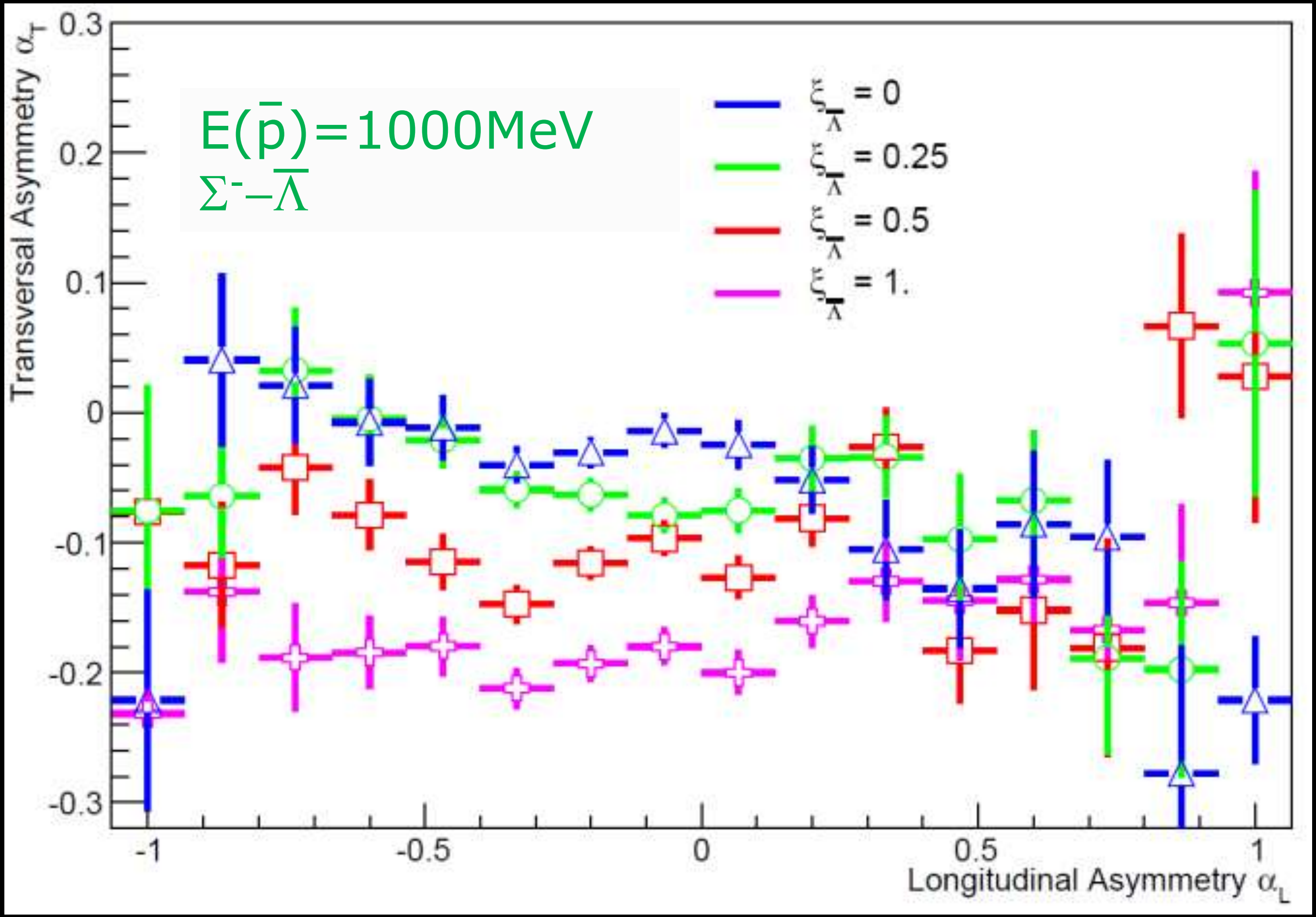




$$\alpha_L = \frac{p_L(\Lambda) - p_L(\bar{\Lambda})}{p_L(\Lambda) + p_L(\bar{\Lambda})}$$

Other |s|=1 channels @ 1000MeV

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



BUU predictions

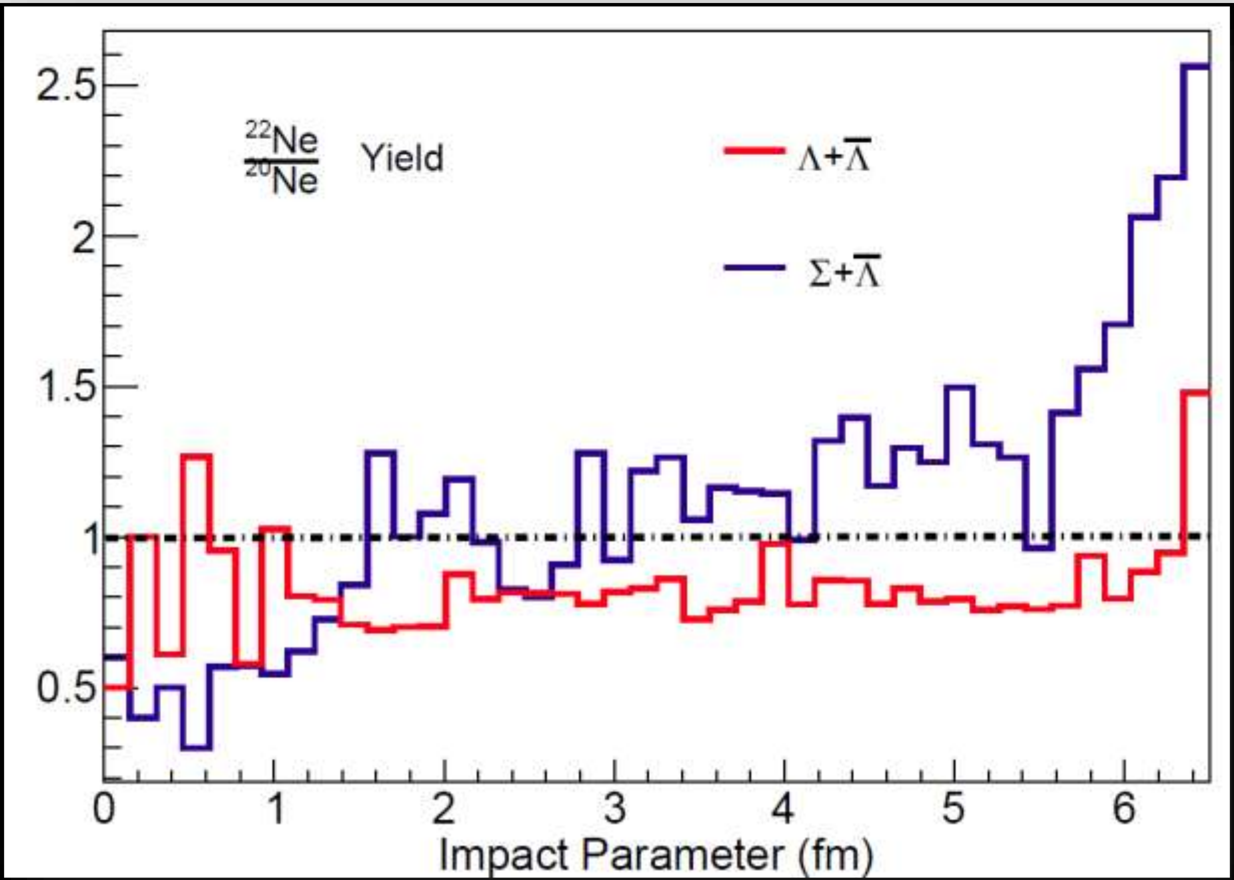


Table I. Production yield of $\overline{\Lambda}\Lambda$ and $\overline{\Lambda}\Sigma^-$-pairs in $\overline{p}$-Ne interactions. The last line gives the double-ratio for $\overline{\Lambda}\Sigma^-$ and $\overline{\Lambda}\Lambda$ production.

Target	$\overline{\Lambda}\Sigma^-$	$\overline{\Lambda}\Lambda$
^{20}Ne	3667	18808
^{22}Ne	4516	15733
ratio ^{22}Ne/^{20}Ne	1.23	0.84
ratio($\overline{\Lambda}\Sigma^-$)/ratio($\overline{\Lambda}\Lambda$)	1.46	

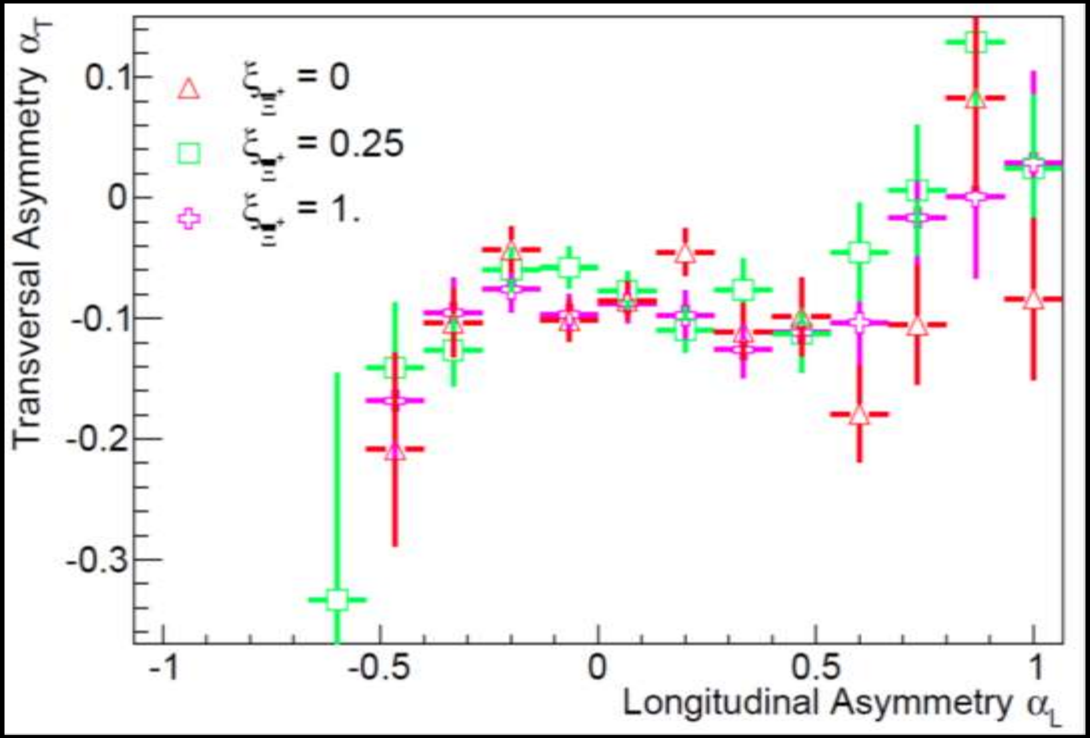
Future Options

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

    $\Lambda(1520)$ (Γ= 15.6 MeV)

    $\Xi(1530)$ (Γ=9.9 MeV)

    $\Lambda_c(2880)$ (Γ=5.8MeV)



Strangeness Nuclear Physics

strangeness in nuclei

- *Y^nN^m interaction are important*
- *precision studies are needed*
- *after 60 still many puzzles*

PANDA offers a broad physics program

- *antihyperons in nuclei → PANDA day-1*
- *excited state spectroscopy of double hypernuclei*

many things could not be mentioned

- *hyper atoms*
- *neutron skin*
- *hyperon structure e.g. E2(Ω) ?*
- *mini $\bar{p}p$ collider ?*


Thank you
for your attention