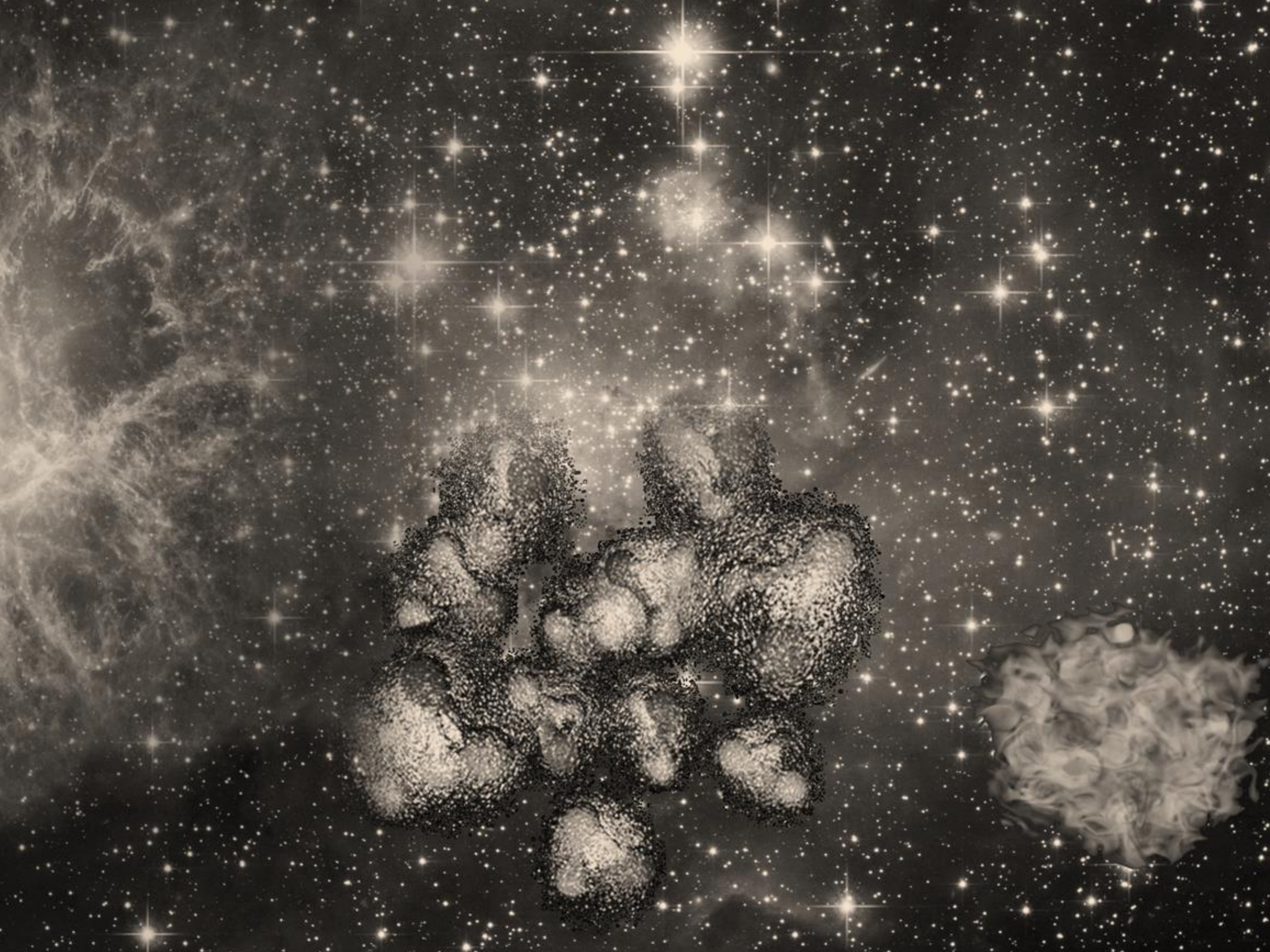
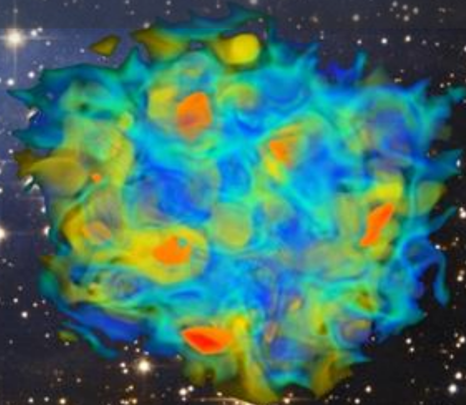


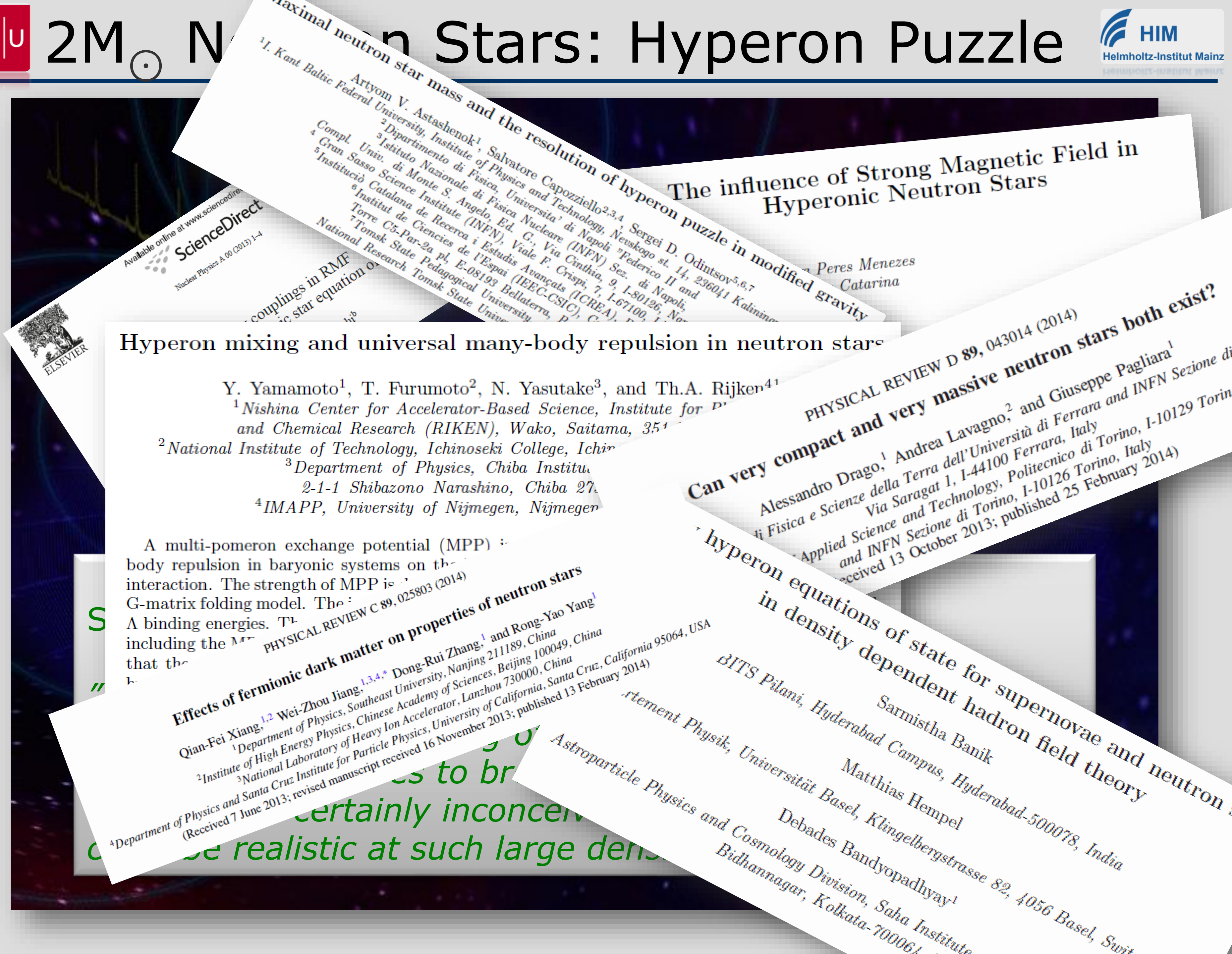
Physics of strange systems with electrons @MAMI and antiprotons @ PANDA

Josef Pochodzalla

Helmholtz-Institut Mainz



2M$_{\odot}$ N n Stars: Hyperon Puzzle



aximal neutron star mass and the resolution of hyperon puzzle in modified gravity

Artyom V. Astashenok[1], Salvatore Capozziello[2,3,4], Sergei D. Odintsov[5,6,7]
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[5]Institució Catalana de Recerca i Estudis Avançats (ICREA),
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National Research Tomsk State Unive

The influence of Strong Magnetic Field in
Hyperonic Neutron Stars

Peres Menezes
Catarina

Available online at www.sciencedire
ScienceDirect
Nuclear Physics A 00 (2013) 1–4
ELSEVIER

couplings in RMF
ic star equation o

Hyperon mixing and universal many-body repulsion in neutron stars

Y. Yamamoto[1], T. Furumoto[2], N. Yasutake[3], and Th.A. Rijken[4,1]
[1]Nishina Center for Accelerator-Based Science, Institute for
and Chemical Research (RIKEN), Wako, Saitama, 351
[2]National Institute of Technology, Ichinoseki College, Ichi
[3]Department of Physics, Chiba Institu
2-1-1 Shibazono Narashino, Chiba 27
[4]IMAPP, University of Nijmegen, Nijmegen

A multi-pomeron exchange potential (MPP)
body repulsion in baryonic systems on th
interaction. The strength of MPP is
G-matrix folding model. The
Λ binding energies. T
including the M
that th

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

Can very compact and very massive neutron stars both exist?

Alessandro Drago,[1] Andrea Lavagno,[2] and Giuseppe Pagliara[1]
di Fisica e Scienze della Terra dell'Università di Ferrara and INFN Sezione di
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Applied Science and Technology, Politecnico di Torino, I-10129 Torin
and INFN Sezione di Torino, I-10126 Torino, Italy
eceived 13 October 2013; published 25 February 2014)

PHYSICAL REVIEW C 89, 025803 (2014)

Effects of fermionic dark matter on properties of neutron stars

Qian-Fei Xiang,[1,2] Wei-Zhou Jiang,[1,3,4,*] Dong-Rui Zhang,[1] and Rong-Yao Yang[1]
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[2]Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China
[3]National Laboratory of Heavy Ion Accelerator, Lanzhou 730000, China
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(Received 7 June 2013; revised manuscript received 16 November 2013; published 13 February 2014)

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

Sarmistha Banik
BITS Pilani, Hyderabad Campus, Hyderabad-500078, India
Matthias Hempel
rtement Physik, Universität Basel, Klingelbergstrasse 82, 4056 Basel, Swit
Debades Bandyopadhyay[1]
Astroparticle Physics and Cosmology Division, Saha Institute
Bidhannagar, Kolkata-70006

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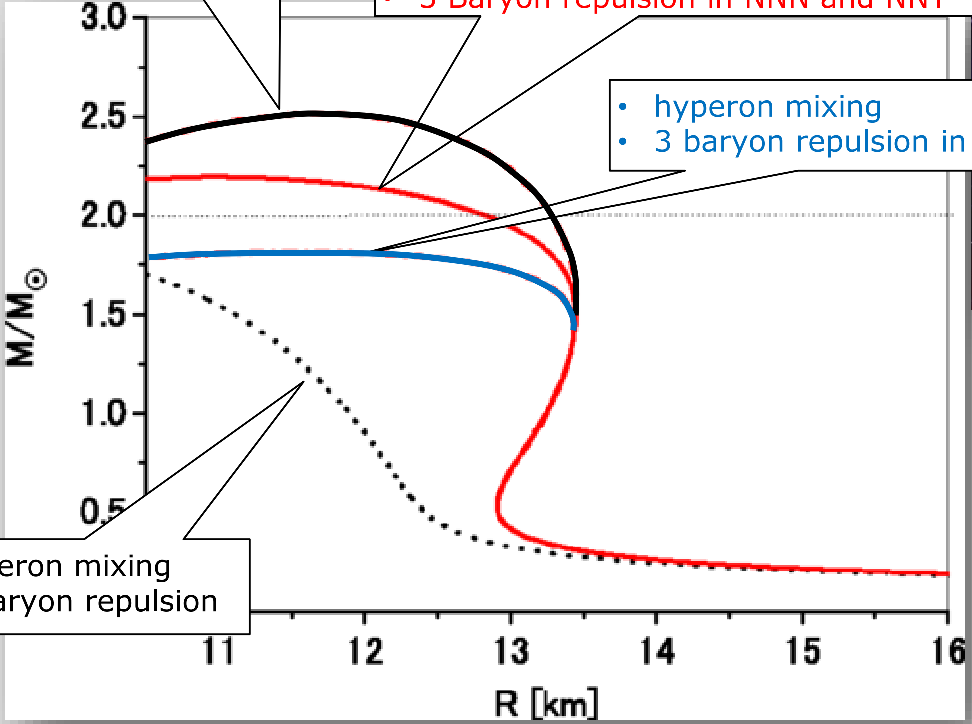
certainly inconcei

c be realistic at such large dens

The Hyperon Puzzle…

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

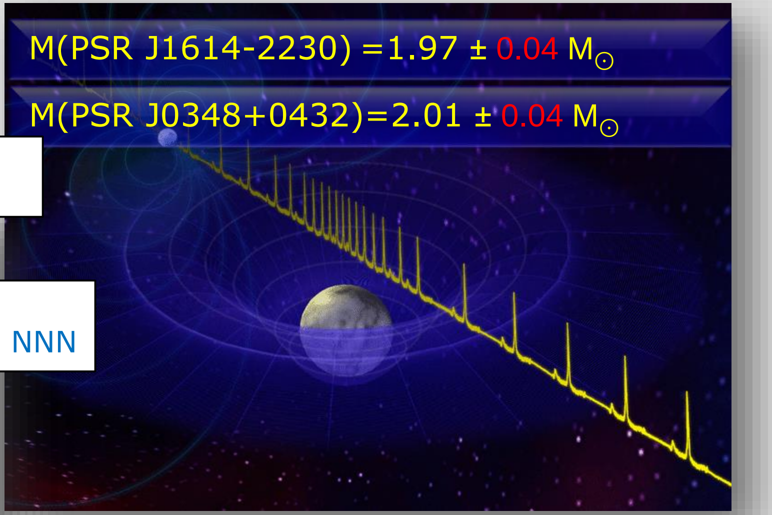


- no hyperon mixing
- 3 Baryon repulsion

- hyperon mixing
- 3 Baryon repulsion in NNN and NNY

- hyperon mixing
- 3 baryon repulsion in NNN

- no hyperon mixing
- no 3 baryon repulsion



M(PSR J1614-2230) =1.97 ± 0.04 $M_\odot$

M(PSR J0348+0432)=2.01 ± 0.04 $M_\odot$

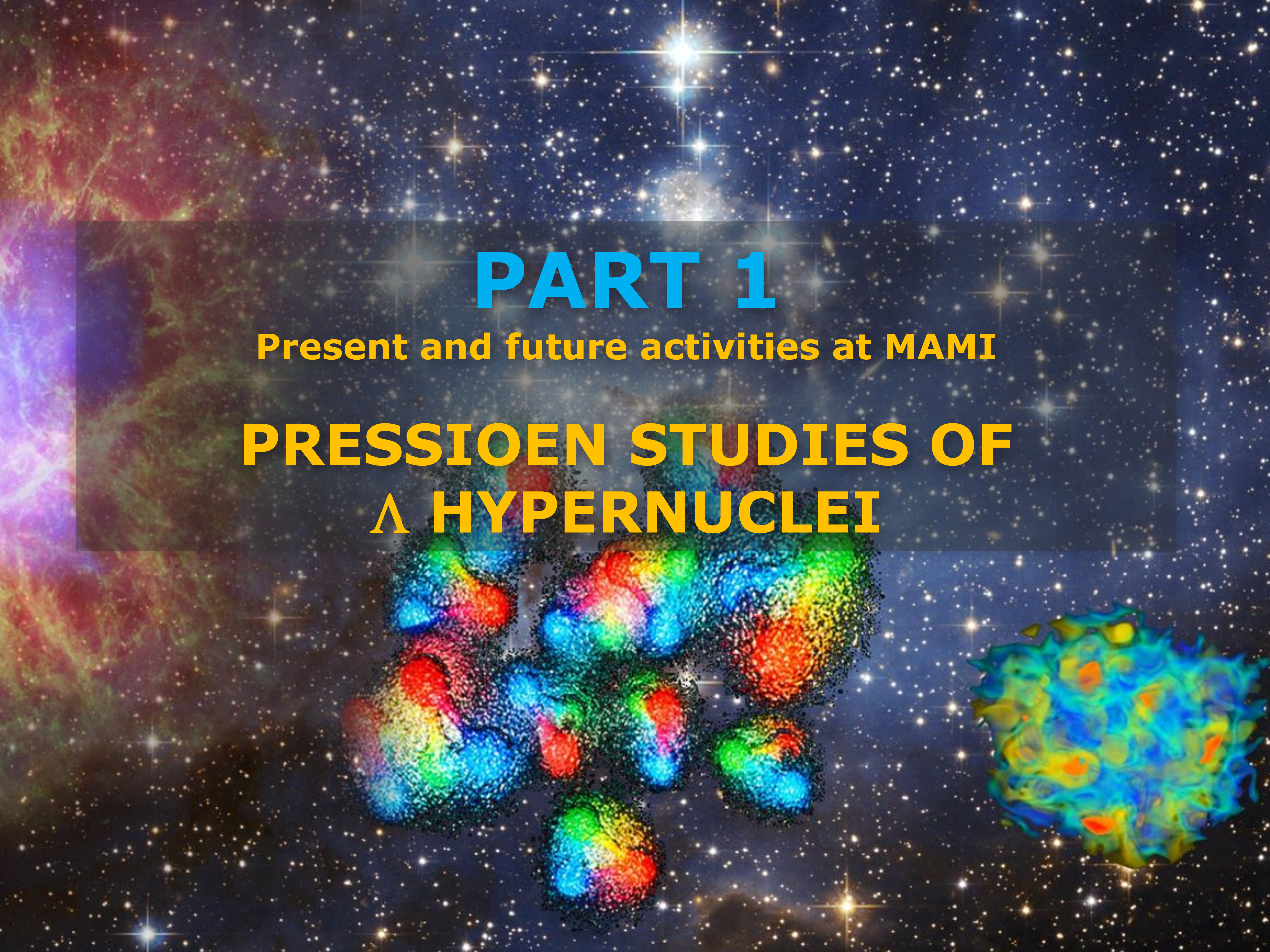
- model constrained by terrestrial experiments
- universal many-body repulsion
- no ad hoc parameter to stiffen EOS

Yamamota (HYP2015):

"Including 3- and 4-body repulsions leads to massive neutron stars with $2M_\odot$ in spite of significant softening of EOS by hyperon mixing"….

"Hyperon puzzle is a quantitative problem"

Once solved, we may look at the interaction between baryonic matter and dark matter in compact stars



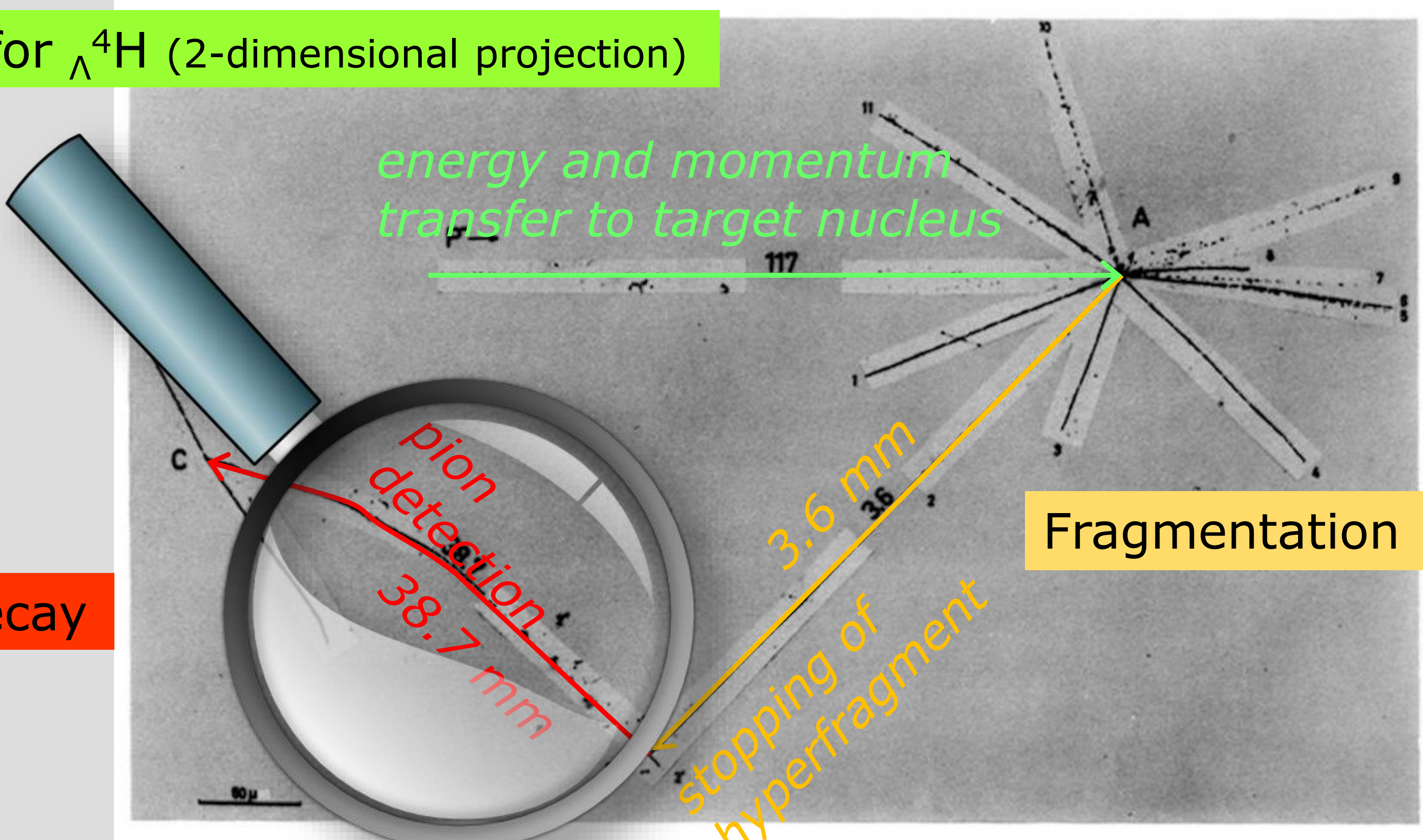
PART 1

Present and future activities at MAMI

PRESSIOEN STUDIES OF Λ HYPERNUCLEI

Decay-pion spectroscopy in emulsion

Example for $_{\Lambda}^{4}$H (2-dimensional projection)



energy and momentum transfer to target nucleus

Fragmentation

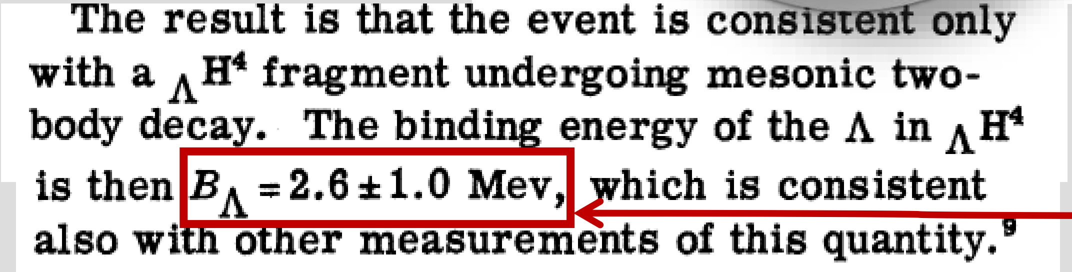
3.6 mm

stopping of hyperfragment

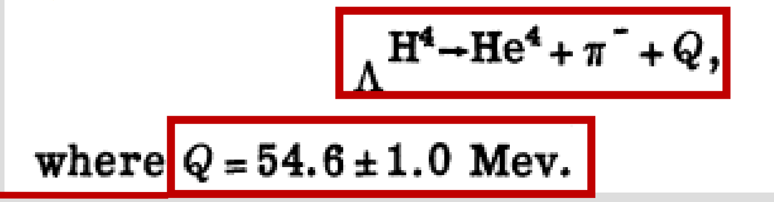
pion detection

38.7 mm

Pionic decay



The result is that the event is consistent only with a $_{\Lambda}H^{4}$ fragment undergoing mesonic two-body decay. The binding energy of the Λ in $_{\Lambda}H^{4}$ is then $\boxed{B_{\Lambda} = 2.6 \pm 1.0 \text{ Mev},}$ which is consistent also with other measurements of this quantity.[9]

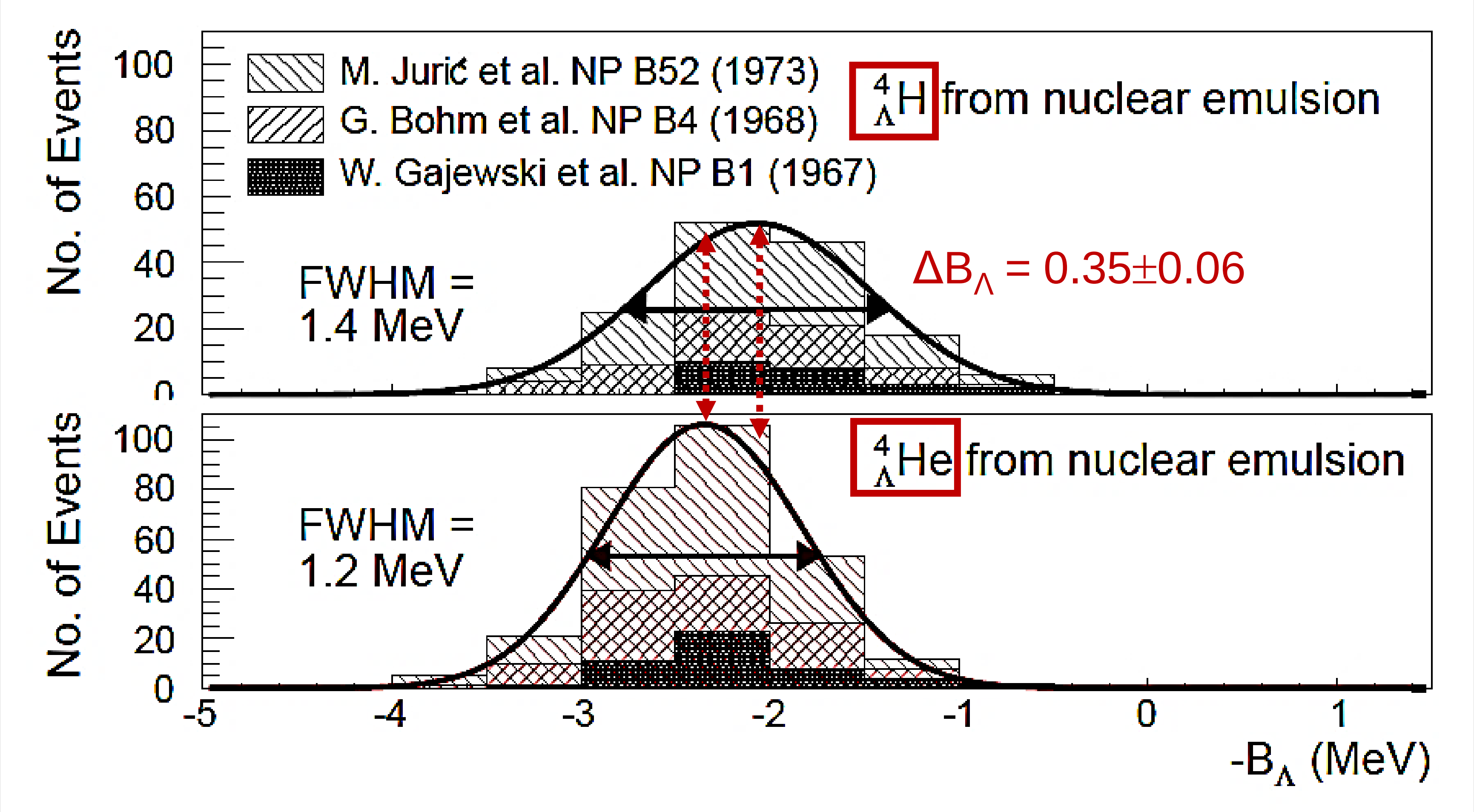


$$\boxed{_{\Lambda}H^{4} \to He^{4} + \pi^{-} + Q,}$$

where $\boxed{Q = 54.6 \pm 1.0 \text{ Mev.}}$

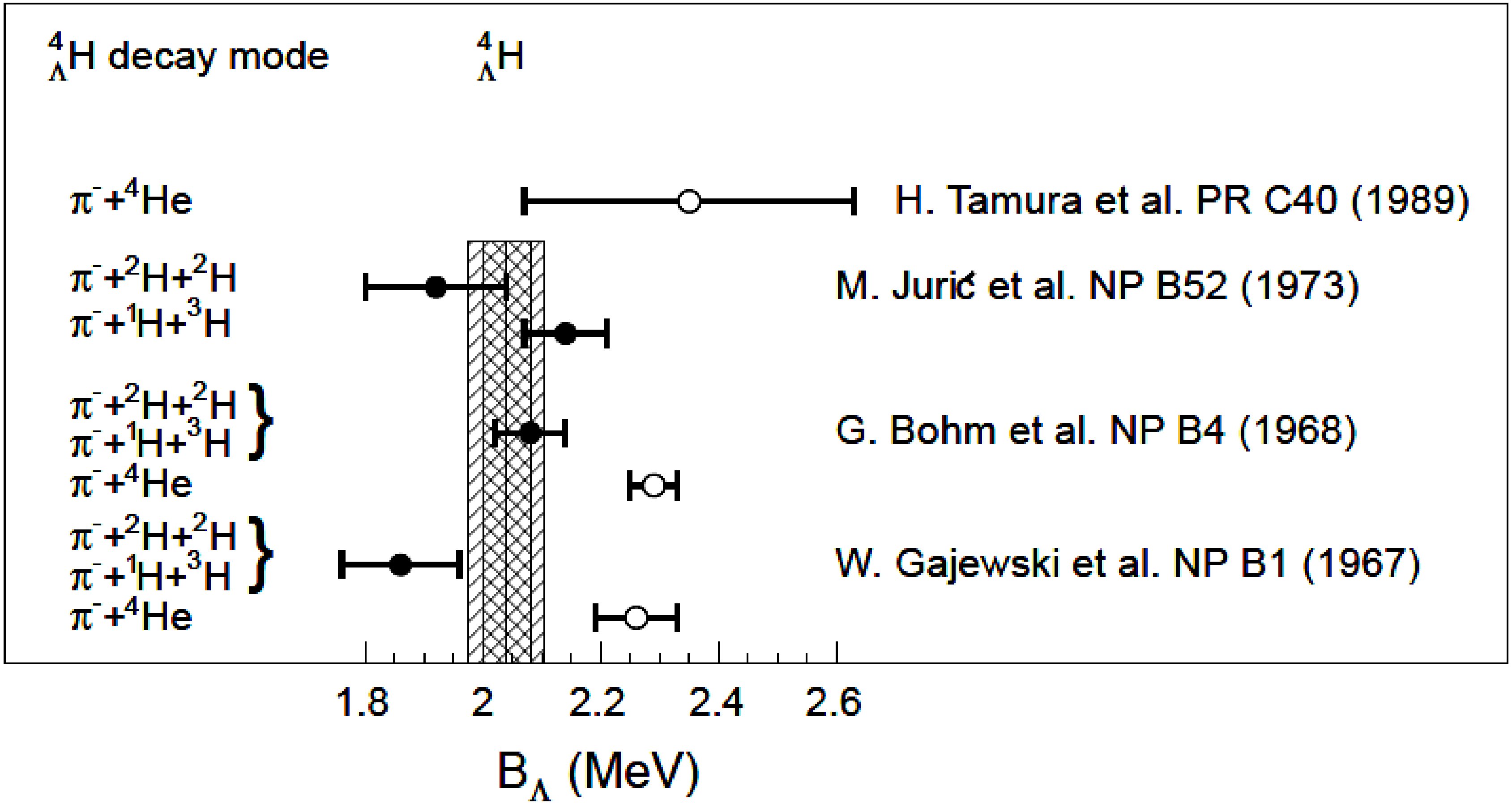
[A.G. Ekspong et al., Phys. Rev. Lett. **3** (1959) 103]

Emulsion results on ${}_{\Lambda}^{4}H$ and ${}_{\Lambda}^{4}He$



- donly three-body decay modes used for hyperhydrogen
- 155 events for hyperhydrogen, 279 events for hyperhelium

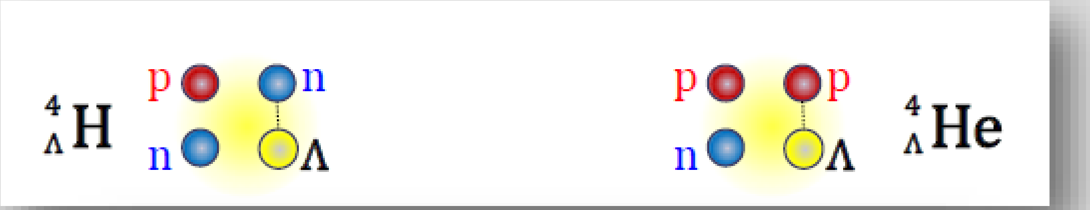
A close look at ${}_{\Lambda}^{4}$H

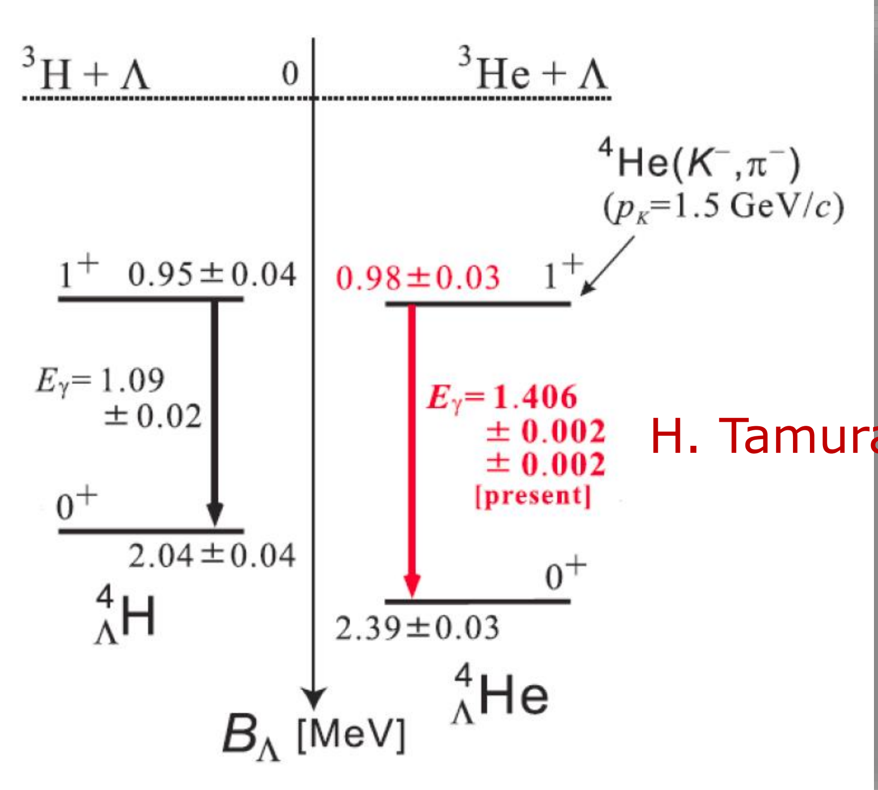


$$\left.\begin{aligned} {}_{\Lambda}^{4}\mathrm{H} \rightarrow \pi^- + \mathrm{H} + {}^3\mathrm{H}: \quad & B_\Lambda = 2.14 \pm 0.07 MeV \\ {}_{\Lambda}^{4}\mathrm{H} \rightarrow \pi^- + {}^2\mathrm{H} + {}^2\mathrm{H}: \quad & B_\Lambda = 1.92 \pm 0.07 MeV \end{aligned}\right\} \ 0.22\,\mathrm{MeV\ difference}$$

Charge Symmetry Breaking

- CSB for NN interactions is 70 keV in the mirror nuclei ^{3}H and ^{3}He
- Coulomb corrections are < 50 keV for the $^4_\Lambda$H - $^4_\Lambda$He pair

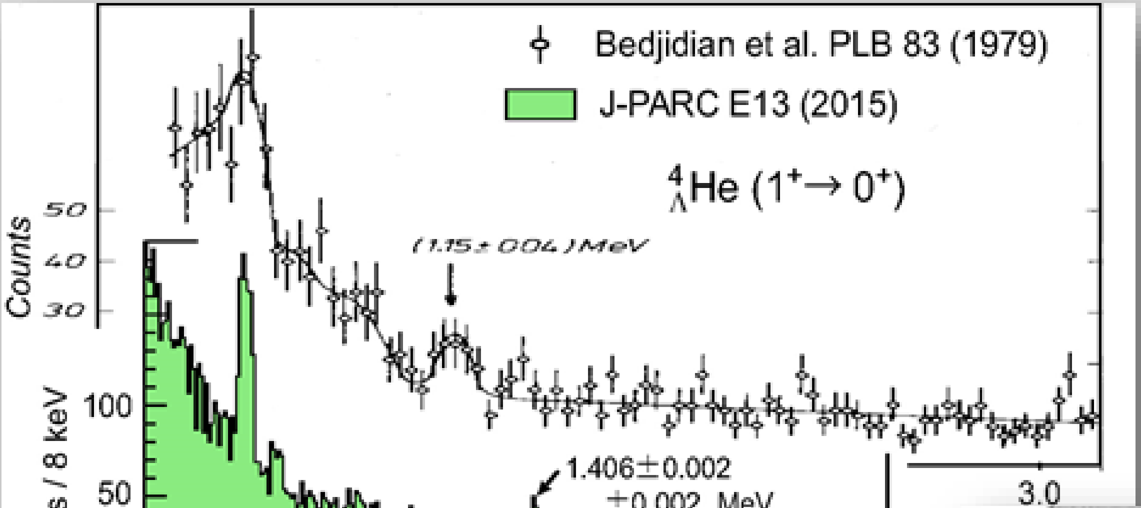




H. Tamura

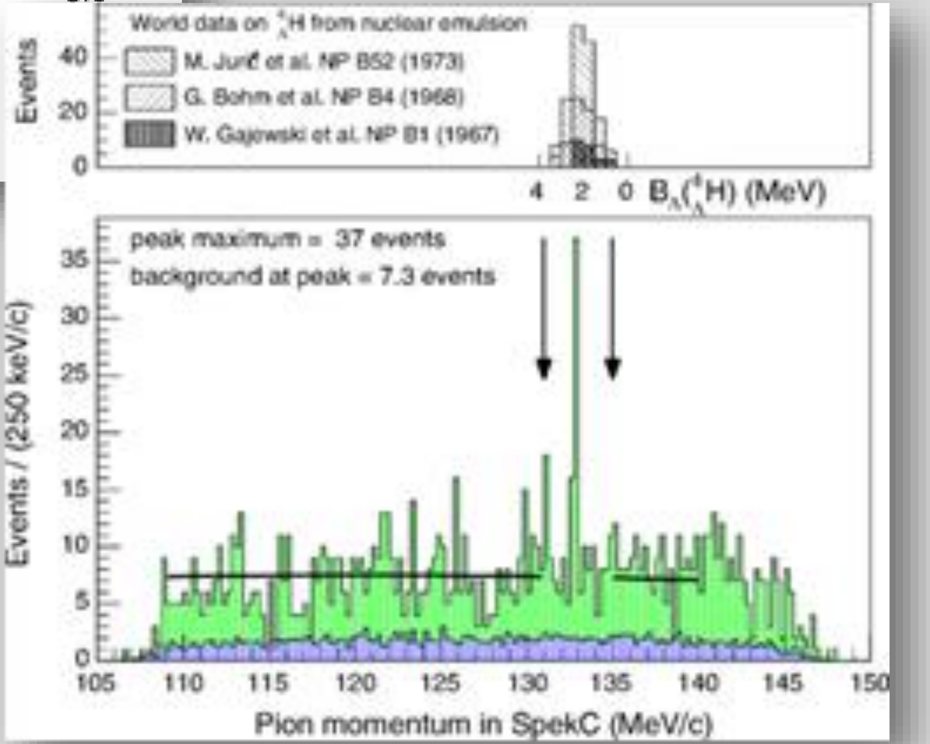
- strong, spin-dependent charge symmetry breaking (CSB) in *A* = 4 mirror hypernuclei !

Success of novel Techniques



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

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

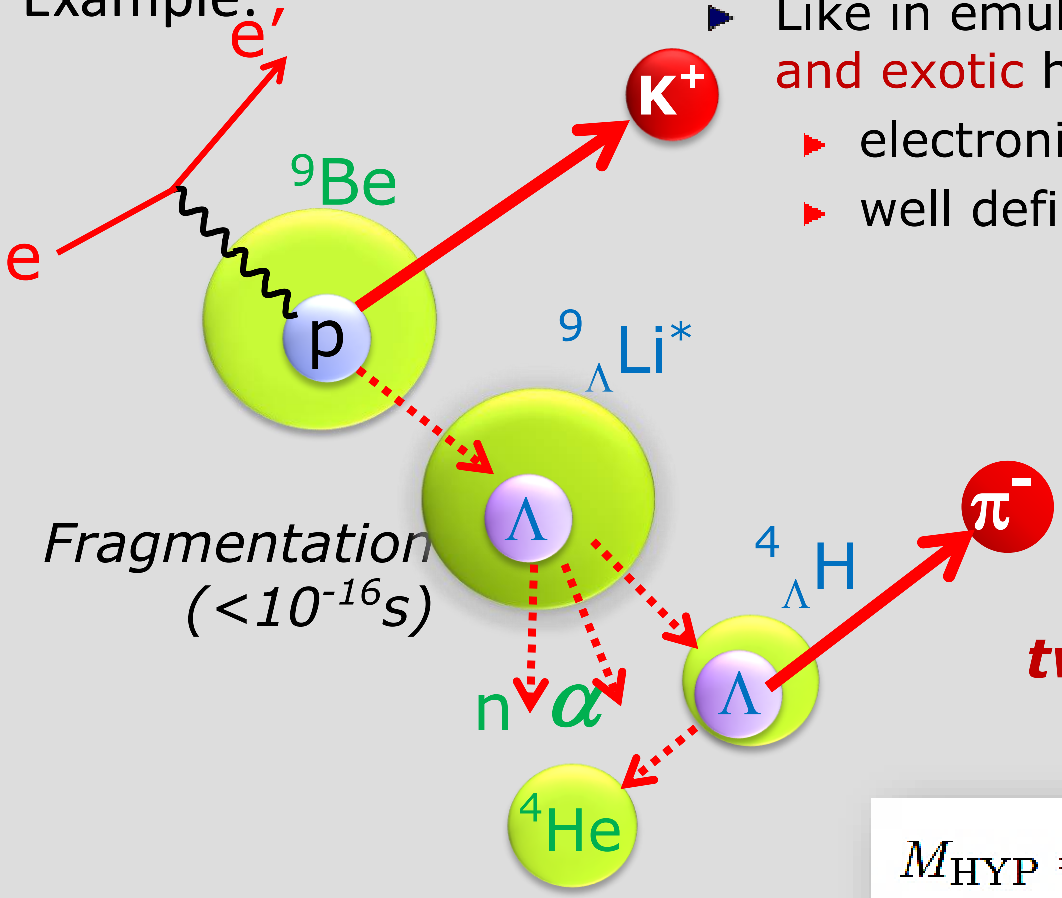


- Demonstrate the need for complementary experiments

Decay pion spectroscopy

- Two-body decay ⇒ mono-energetic pions
- high resolution: Λ binding energy resolution limited by π^- momentum resolution
- Like in emulsion access to variety of light and exotic hypernuclei, but
  - electronic experiment
  - well defined initial target nucleus

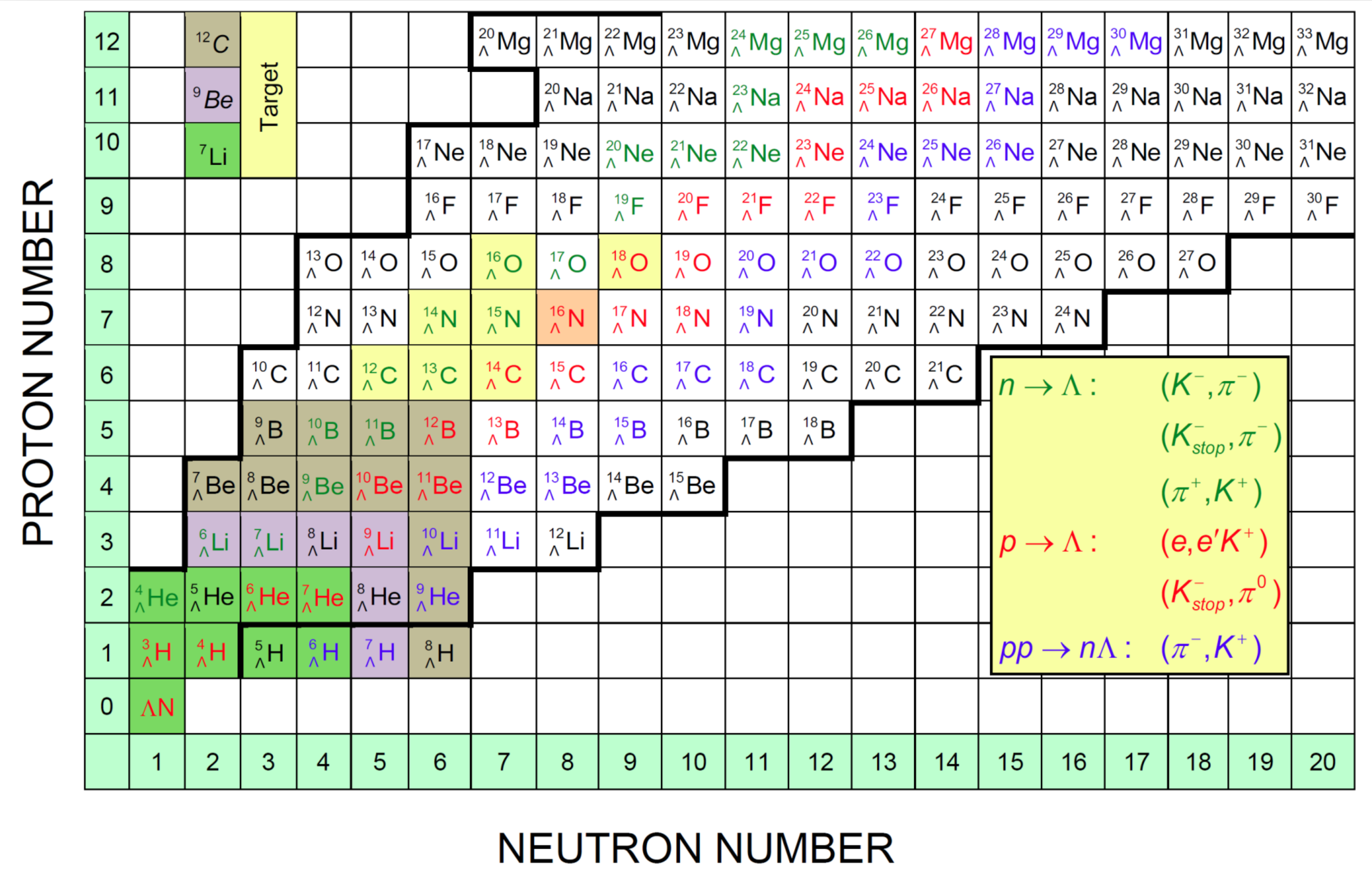
Example:



Weak mesonic
two-body *decay (~10^{-10}s)*
at rest

$$M_{\mathrm{HYP}} = \sqrt{M_{\mathrm{ncl}}^2 + p_{\pi^-}^2} + \sqrt{M_{\pi^-}^2 + p_{\pi^-}^2}$$

The prospects



PROTON NUMBER

12		^{12}C	Target				$^{20}_{\Lambda}\mathrm{Mg}$	$^{21}_{\Lambda}\mathrm{Mg}$	$^{22}_{\Lambda}\mathrm{Mg}$	$^{23}_{\Lambda}\mathrm{Mg}$	$^{24}_{\Lambda}\mathrm{Mg}$	$^{25}_{\Lambda}\mathrm{Mg}$	$^{26}_{\Lambda}\mathrm{Mg}$	$^{27}_{\Lambda}\mathrm{Mg}$	$^{28}_{\Lambda}\mathrm{Mg}$	$^{29}_{\Lambda}\mathrm{Mg}$	$^{30}_{\Lambda}\mathrm{Mg}$	$^{31}_{\Lambda}\mathrm{Mg}$	$^{32}_{\Lambda}\mathrm{Mg}$	$^{33}_{\Lambda}\mathrm{Mg}$
11		^{9}Be						$^{20}_{\Lambda}\mathrm{Na}$	$^{21}_{\Lambda}\mathrm{Na}$	$^{22}_{\Lambda}\mathrm{Na}$	$^{23}_{\Lambda}\mathrm{Na}$	$^{24}_{\Lambda}\mathrm{Na}$	$^{25}_{\Lambda}\mathrm{Na}$	$^{26}_{\Lambda}\mathrm{Na}$	$^{27}_{\Lambda}\mathrm{Na}$	$^{28}_{\Lambda}\mathrm{Na}$	$^{29}_{\Lambda}\mathrm{Na}$	$^{30}_{\Lambda}\mathrm{Na}$	$^{31}_{\Lambda}\mathrm{Na}$	$^{32}_{\Lambda}\mathrm{Na}$
10		^{7}Li				$^{17}_{\Lambda}\mathrm{Ne}$	$^{18}_{\Lambda}\mathrm{Ne}$	$^{19}_{\Lambda}\mathrm{Ne}$	$^{20}_{\Lambda}\mathrm{Ne}$	$^{21}_{\Lambda}\mathrm{Ne}$	$^{22}_{\Lambda}\mathrm{Ne}$	$^{23}_{\Lambda}\mathrm{Ne}$	$^{24}_{\Lambda}\mathrm{Ne}$	$^{25}_{\Lambda}\mathrm{Ne}$	$^{26}_{\Lambda}\mathrm{Ne}$	$^{27}_{\Lambda}\mathrm{Ne}$	$^{28}_{\Lambda}\mathrm{Ne}$	$^{29}_{\Lambda}\mathrm{Ne}$	$^{30}_{\Lambda}\mathrm{Ne}$	$^{31}_{\Lambda}\mathrm{Ne}$
9						$^{16}_{\Lambda}\mathrm{F}$	$^{17}_{\Lambda}\mathrm{F}$	$^{18}_{\Lambda}\mathrm{F}$	$^{19}_{\Lambda}\mathrm{F}$	$^{20}_{\Lambda}\mathrm{F}$	$^{21}_{\Lambda}\mathrm{F}$	$^{22}_{\Lambda}\mathrm{F}$	$^{23}_{\Lambda}\mathrm{F}$	$^{24}_{\Lambda}\mathrm{F}$	$^{25}_{\Lambda}\mathrm{F}$	$^{26}_{\Lambda}\mathrm{F}$	$^{27}_{\Lambda}\mathrm{F}$	$^{28}_{\Lambda}\mathrm{F}$	$^{29}_{\Lambda}\mathrm{F}$	$^{30}_{\Lambda}\mathrm{F}$
8				$^{13}_{\Lambda}\mathrm{O}$	$^{14}_{\Lambda}\mathrm{O}$	$^{15}_{\Lambda}\mathrm{O}$	$^{16}_{\Lambda}\mathrm{O}$	$^{17}_{\Lambda}\mathrm{O}$	$^{18}_{\Lambda}\mathrm{O}$	$^{19}_{\Lambda}\mathrm{O}$	$^{20}_{\Lambda}\mathrm{O}$	$^{21}_{\Lambda}\mathrm{O}$	$^{22}_{\Lambda}\mathrm{O}$	$^{23}_{\Lambda}\mathrm{O}$	$^{24}_{\Lambda}\mathrm{O}$	$^{25}_{\Lambda}\mathrm{O}$	$^{26}_{\Lambda}\mathrm{O}$	$^{27}_{\Lambda}\mathrm{O}$		
7				$^{12}_{\Lambda}\mathrm{N}$	$^{13}_{\Lambda}\mathrm{N}$	$^{14}_{\Lambda}\mathrm{N}$	$^{15}_{\Lambda}\mathrm{N}$	$^{16}_{\Lambda}\mathrm{N}$	$^{17}_{\Lambda}\mathrm{N}$	$^{18}_{\Lambda}\mathrm{N}$	$^{19}_{\Lambda}\mathrm{N}$	$^{20}_{\Lambda}\mathrm{N}$	$^{21}_{\Lambda}\mathrm{N}$	$^{22}_{\Lambda}\mathrm{N}$	$^{23}_{\Lambda}\mathrm{N}$	$^{24}_{\Lambda}\mathrm{N}$				
6			$^{10}_{\Lambda}\mathrm{C}$	$^{11}_{\Lambda}\mathrm{C}$	$^{12}_{\Lambda}\mathrm{C}$	$^{13}_{\Lambda}\mathrm{C}$	$^{14}_{\Lambda}\mathrm{C}$	$^{15}_{\Lambda}\mathrm{C}$	$^{16}_{\Lambda}\mathrm{C}$	$^{17}_{\Lambda}\mathrm{C}$	$^{18}_{\Lambda}\mathrm{C}$	$^{19}_{\Lambda}\mathrm{C}$	$^{20}_{\Lambda}\mathrm{C}$	$^{21}_{\Lambda}\mathrm{C}$						
5			$^{9}_{\Lambda}\mathrm{B}$	$^{10}_{\Lambda}\mathrm{B}$	$^{11}_{\Lambda}\mathrm{B}$	$^{12}_{\Lambda}\mathrm{B}$	$^{13}_{\Lambda}\mathrm{B}$	$^{14}_{\Lambda}\mathrm{B}$	$^{15}_{\Lambda}\mathrm{B}$	$^{16}_{\Lambda}\mathrm{B}$	$^{17}_{\Lambda}\mathrm{B}$	$^{18}_{\Lambda}\mathrm{B}$								
4		$^{7}_{\Lambda}\mathrm{Be}$	$^{8}_{\Lambda}\mathrm{Be}$	$^{9}_{\Lambda}\mathrm{Be}$	$^{10}_{\Lambda}\mathrm{Be}$	$^{11}_{\Lambda}\mathrm{Be}$	$^{12}_{\Lambda}\mathrm{Be}$	$^{13}_{\Lambda}\mathrm{Be}$	$^{14}_{\Lambda}\mathrm{Be}$	$^{15}_{\Lambda}\mathrm{Be}$										
3		$^{6}_{\Lambda}\mathrm{Li}$	$^{7}_{\Lambda}\mathrm{Li}$	$^{8}_{\Lambda}\mathrm{Li}$	$^{9}_{\Lambda}\mathrm{Li}$	$^{10}_{\Lambda}\mathrm{Li}$	$^{11}_{\Lambda}\mathrm{Li}$	$^{12}_{\Lambda}\mathrm{Li}$												
2	$^{4}_{\Lambda}\mathrm{He}$	$^{5}_{\Lambda}\mathrm{He}$	$^{6}_{\Lambda}\mathrm{He}$	$^{7}_{\Lambda}\mathrm{He}$	$^{8}_{\Lambda}\mathrm{He}$	$^{9}_{\Lambda}\mathrm{He}$														
1	$^{3}_{\Lambda}\mathrm{H}$	$^{4}_{\Lambda}\mathrm{H}$	$^{5}_{\Lambda}\mathrm{H}$	$^{6}_{\Lambda}\mathrm{H}$	$^{7}_{\Lambda}\mathrm{H}$	$^{8}_{\Lambda}\mathrm{H}$														
0	$\Lambda\mathrm{N}$																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

NEUTRON NUMBER

$n \to \Lambda :$ (K^-, π^-)

(K^-_{stop}, π^-)

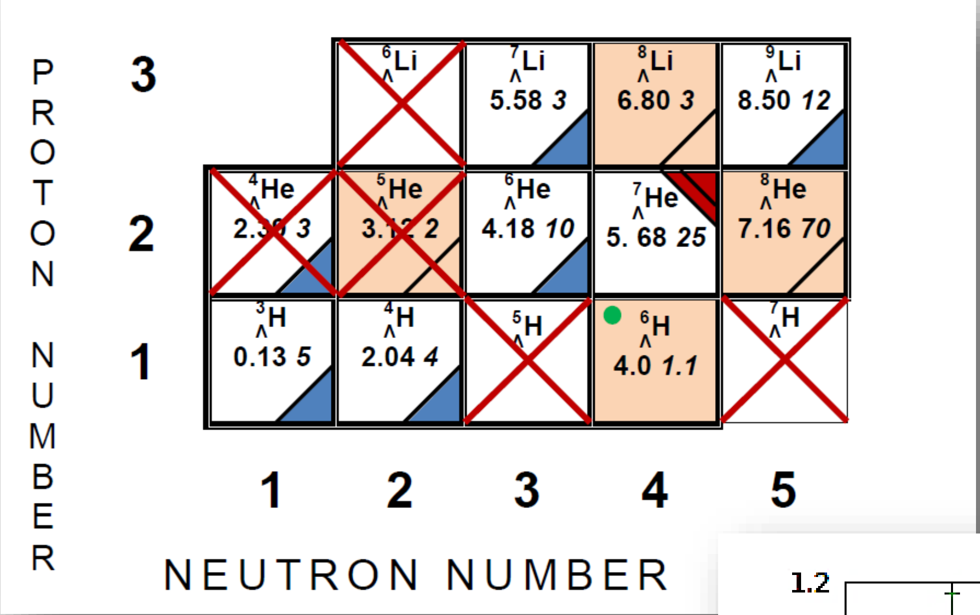
(π^+, K^+)

$p \to \Lambda :$ $(e, e'K^+)$

(K^-_{stop}, π^0)

$pp \to n\Lambda :$ (π^-, K^+)

Accessible hyperisotopes with ^{9}Be



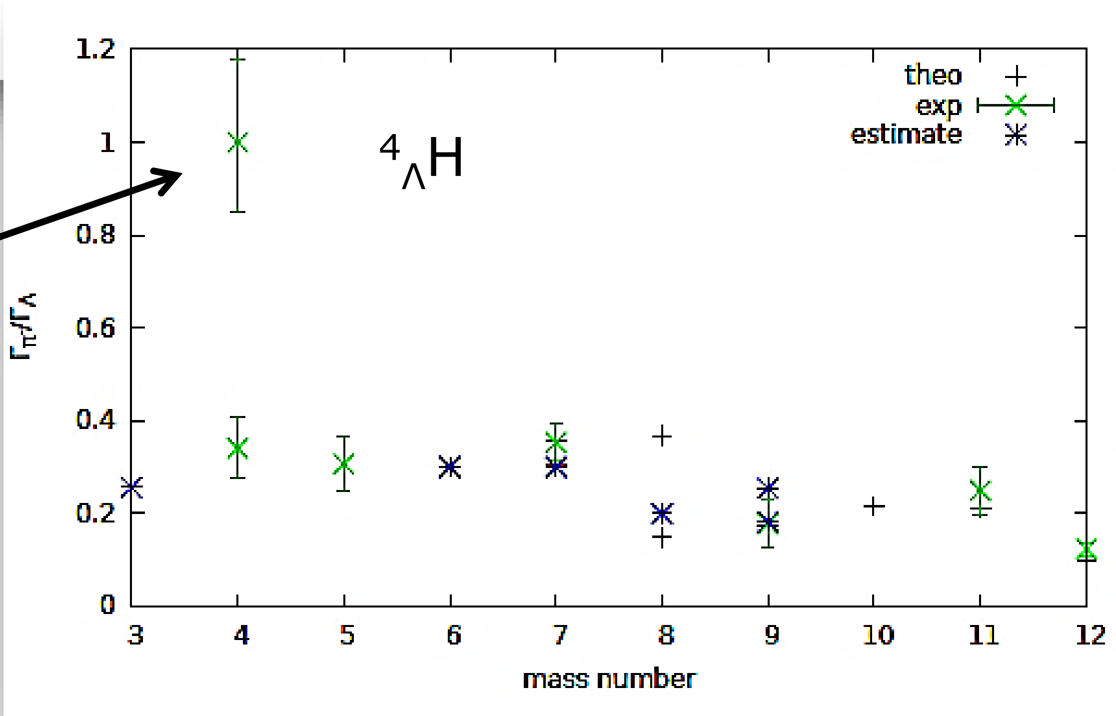
PROTON NUMBER	1	2	3	4	5
3		$^6_\Lambda$Li	$^7_\Lambda$Li 5.58 *3*	$^8_\Lambda$Li 6.80 *3*	$^9_\Lambda$Li 8.50 *12*
2	$^4_\Lambda$He 2.39 *3*	$^5_\Lambda$He 3.12 *2*	$^6_\Lambda$He 4.18 *10*	$^7_\Lambda$He 5. 68 *25*	$^8_\Lambda$He 7.16 *70*
1	$^3_\Lambda$H 0.13 *5*	$^4_\Lambda$H 2.04 *4*	$^5_\Lambda$H	$^6_\Lambda$H 4.0 *1.1*	$^7_\Lambda$H

NEUTRON NUMBER

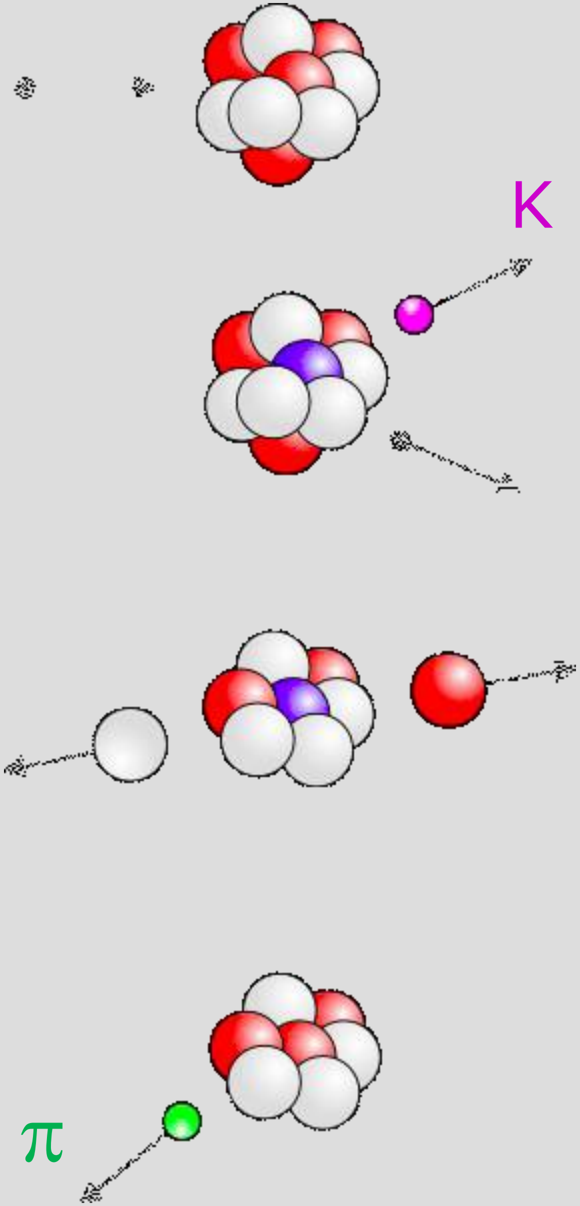
✗ no 2-body decay

▨ inaccessible by missing mass spectroscopy

highest pionic decay width



The experiment in a nutshell



- Electroproduction of excited hypernuclei on ^{9}Be Target
- Event tagging by kaon detection
- Fragmentation produces several light hypernuclei
- Mesonic weak decay and groundstate mass reconstruction by spectroscopy of pions from two-body decay

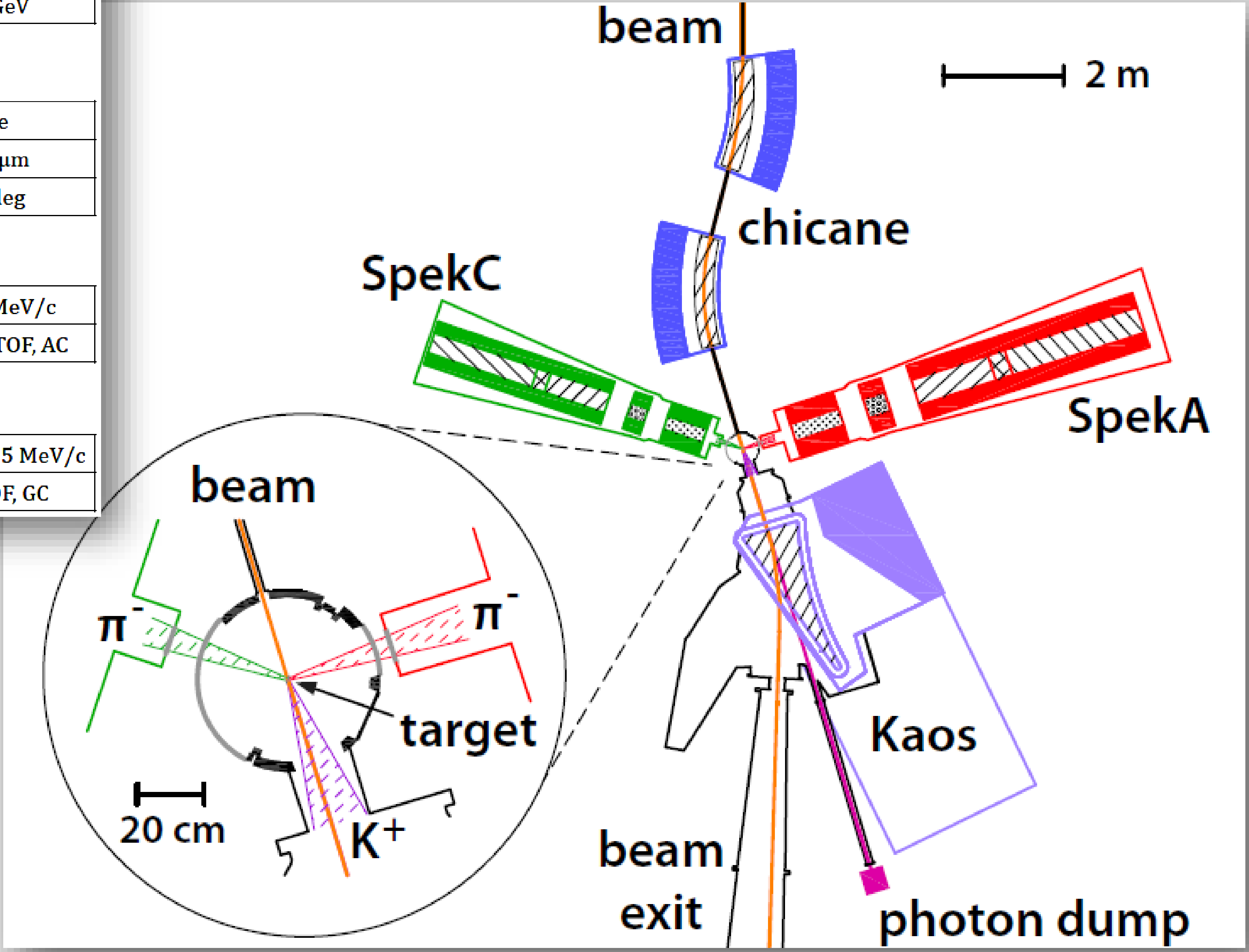
Experimental realization at MAMI

Primary Beam	
Energy	1.5 GeV

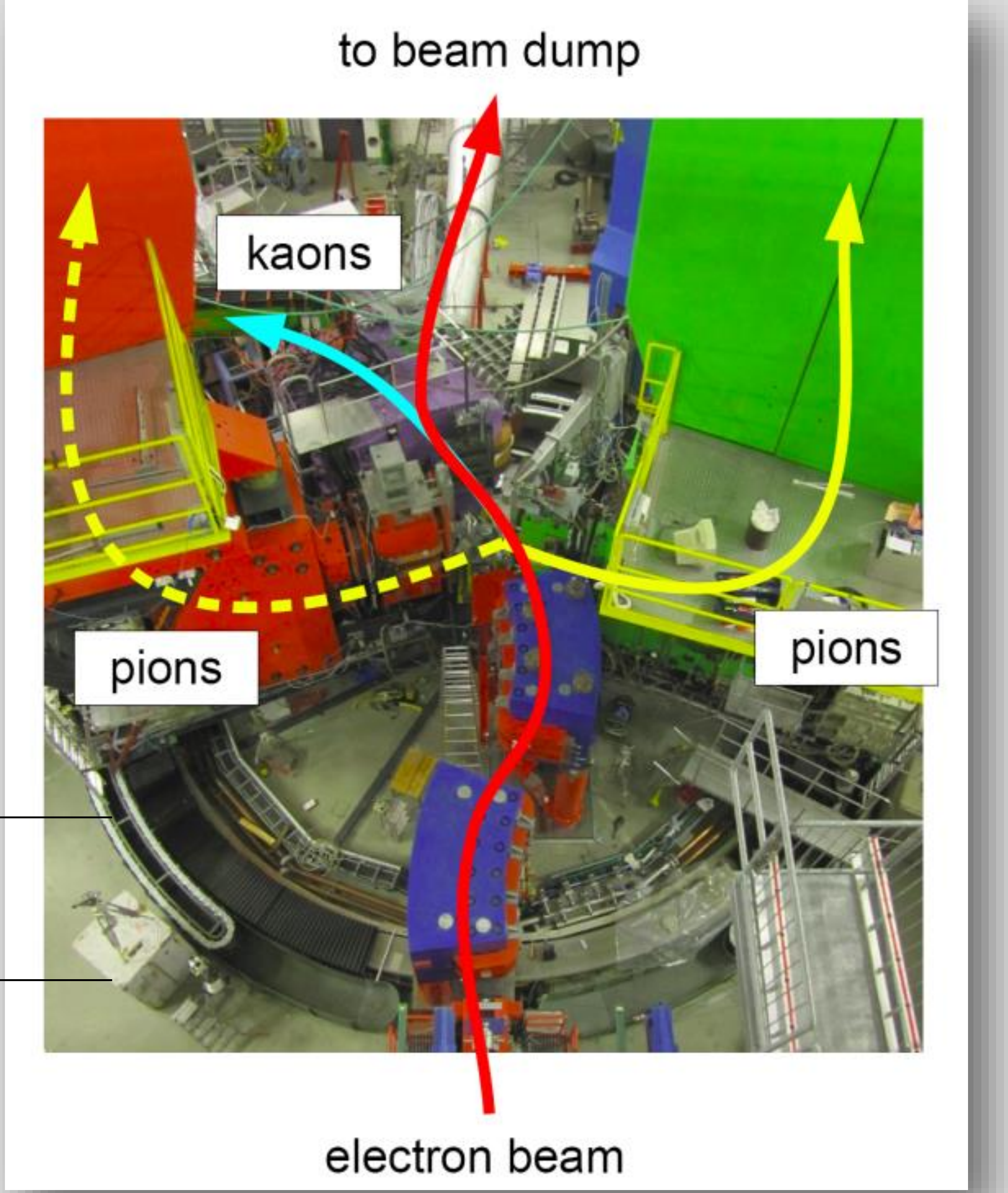
Target	
Material	^{9}Be
Thickness	125 μm
Tilt angle	54 deg

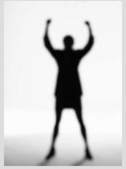
Kaos	
Cent. Mom	+900 MeV/c
Detector	MWPC, TOF, AC

Spek-A, C	
Cent. Mom	- 115/ -125 MeV/c
Detector	DC, TOF, GC

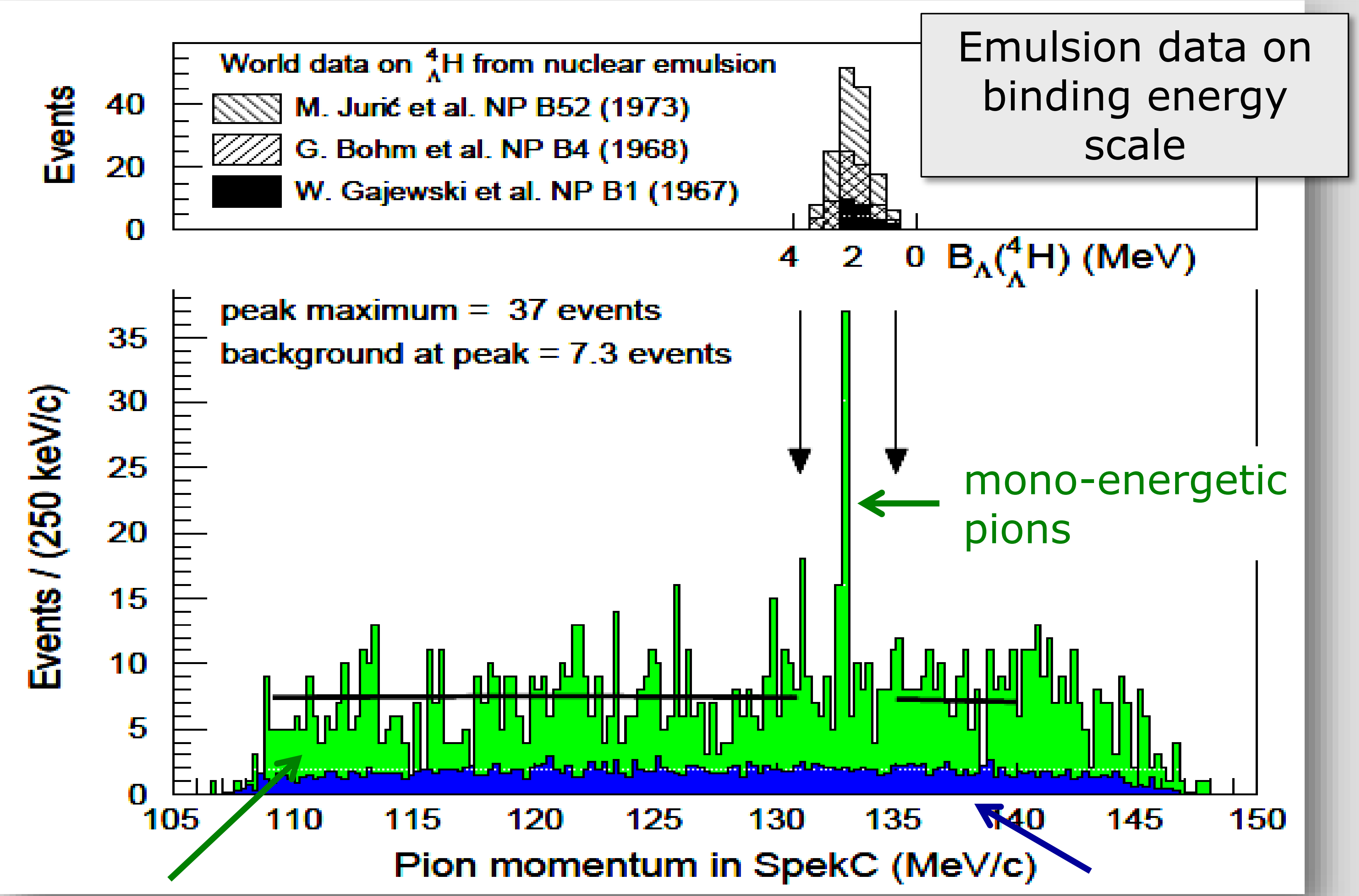


…in Reality





Decay pion spectrum



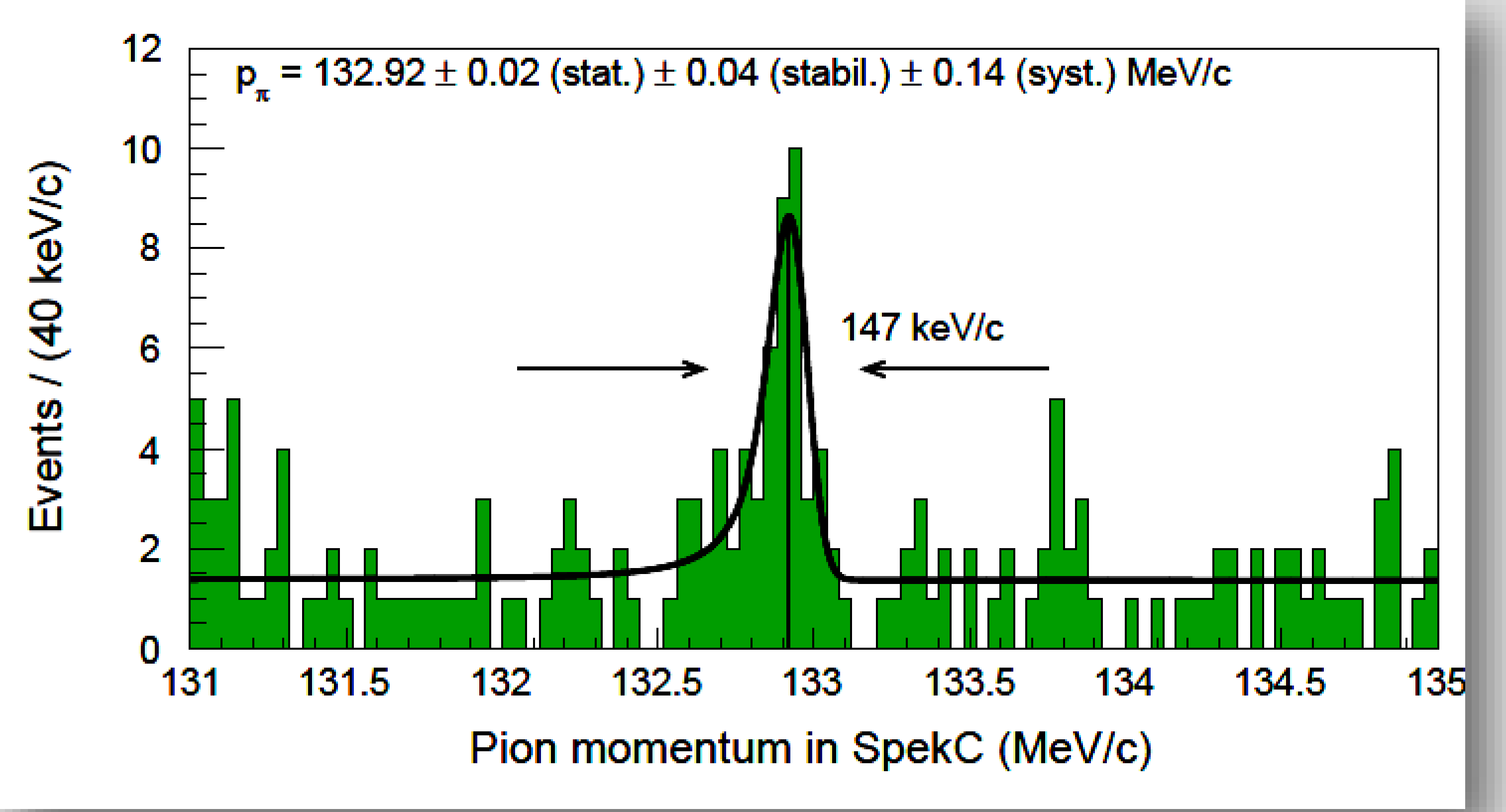
Emulsion data on binding energy scale

mono-energetic pions

decays of quasi-free produced hyperons

accidental background reactions

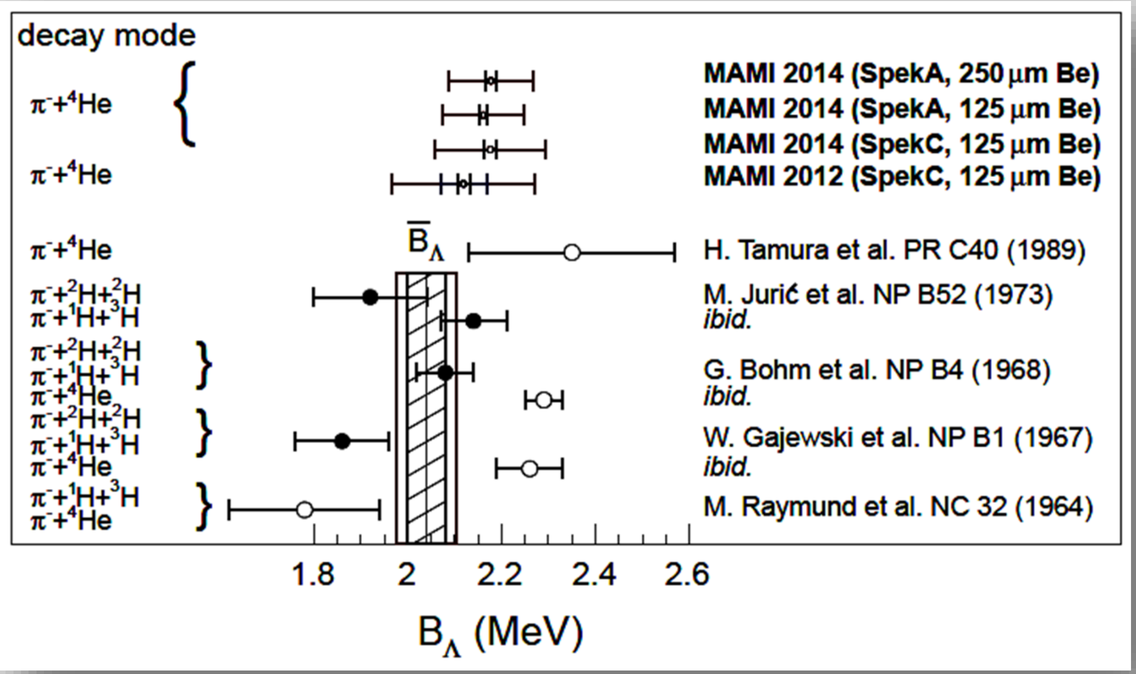
Result



- Extensive calibrations
- Main systematic error due to uncertainty of the absolute MAMI beam energy

Continuation of Experiment in 2014

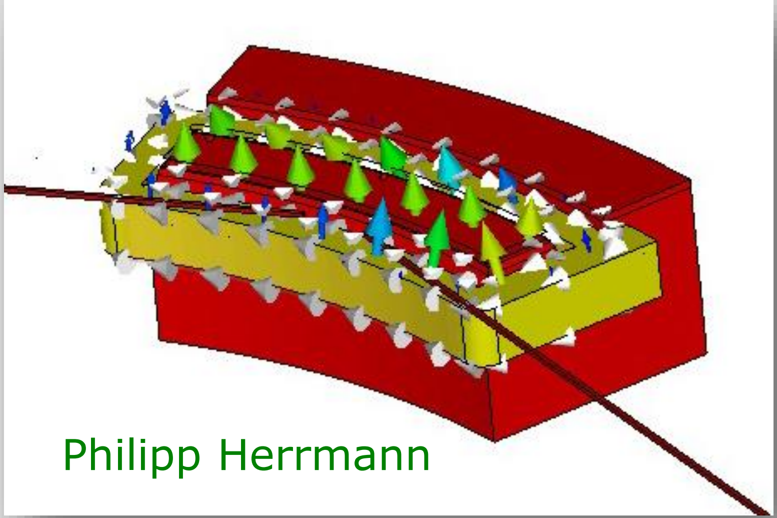
- Many inmprovements
  - better pion rejection by improved aerogel
  - suppression of background by improved shielding
  - suppression of background by trigger upgrade in SpekA & C
  - suppression of background by beam-line upgrade
  - dedicated collimator for decay region
  - better control of magnet field variations
  - full overlap of SpekA and SpekC momentum acceptance



- independent measurement in two spectr., two targets, two beam-times
- consistent result for $B_\Lambda({}^4_\Lambda\text{H})$ from MAMI 2012 and MAMI 2014

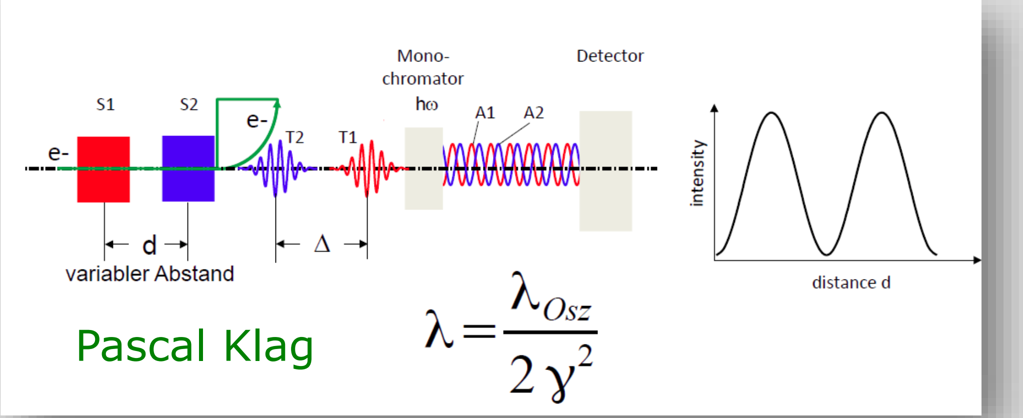
Reducing the systematic error

- two options to measure MAMI energy $O(10^{-4})$
  - measuring the absolute MAMI enery in a precisely calibrated magnet



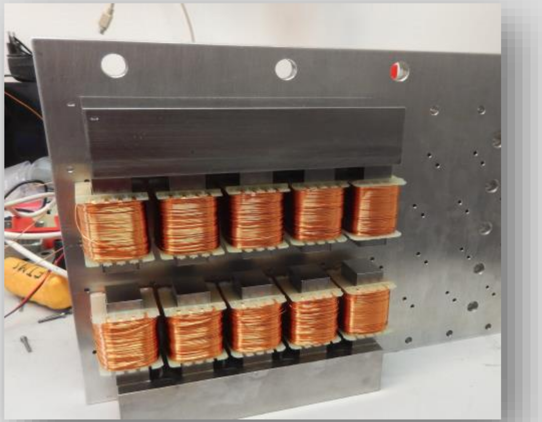
Philipp Herrmann

  - Interference of undulator radiation



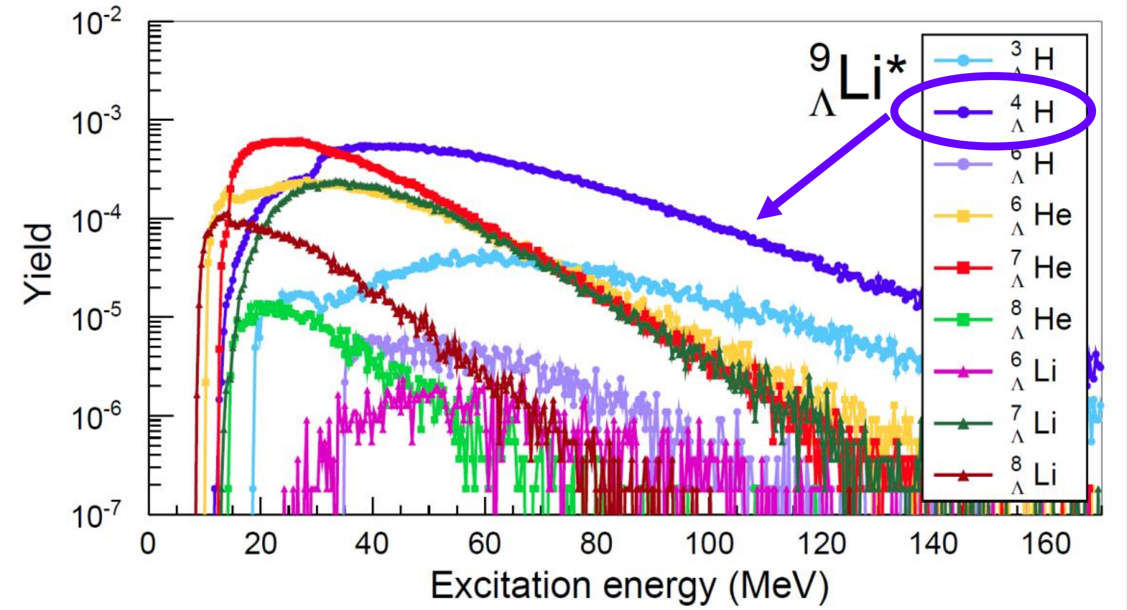
Pascal Klag

$$\lambda = \frac{\lambda_{Osz}}{2\gamma^2}$$



Why no other Hypernuclei? (1)

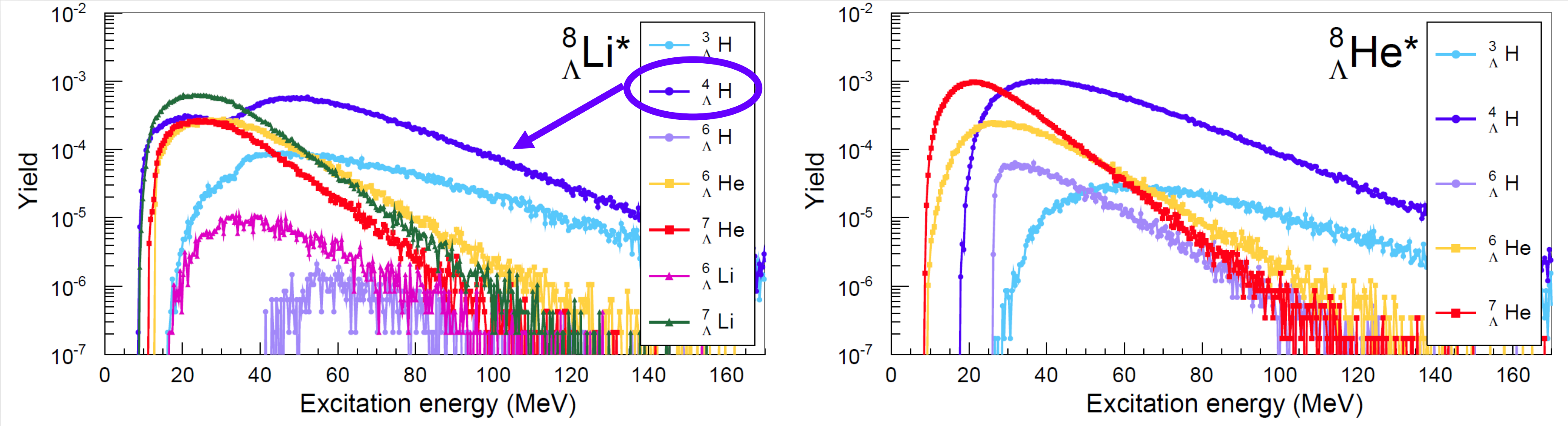
- Statistical decay calculations were performed
- Scenario 1: direct production of ${}^{9}_{\Lambda}Li^*$



- Expected excitation energy
  - convert proton into $\Lambda \Rightarrow$ proton hole state ~ 20 MeV
  - kinetic energy of captured Λ $p_{FERMI}^2/2M_{\Lambda}$ ~ 20 MeV
  - Binding energy of Λ ~ 10 MeV
- at E_x~50 MeV ${}^{4}_{\Lambda}H$ most probable and other nuclei more than factor 3 less likely produced

Why no other Hypernuclei? (2)

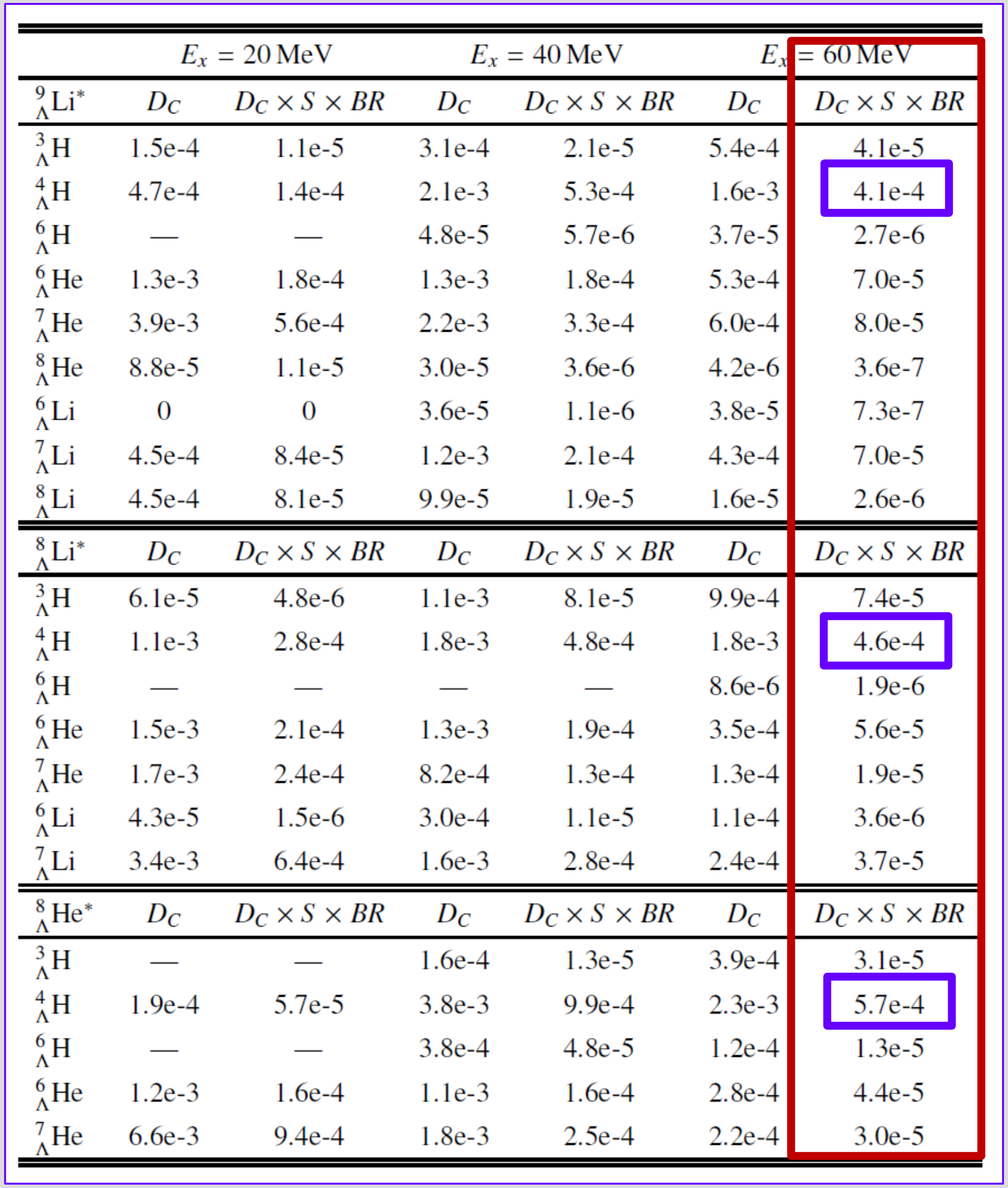
- Scenario 2:Λ is slowed down by kicking out a neutron or proton $\Rightarrow$ formation of ${}^{8}_{\Lambda}$Li* ${}^{8}_{\Lambda}$He*



- Expected excitation energy
  - convert proton into $\Lambda \Rightarrow$ proton hole state ~ 20 MeV
  - addition hole state ~ 20 MeV
  - kinetic energy of captured Λ $p_{FERMI}^2/2M_\Lambda$ ~ 20 MeV
  - Binding energy of Λ ~ 10 MeV
- at 70 MeV ${}^{4}_{\Lambda}$H most probably produced and other nuclei more than factor 6 less likely

Why no other Hypernuclei? (3)

- Taking into account
  - stopping probability *S* of secondary hyperfragments in target
  - pionic two-body decay probability *BR*
- ${}^{4}_{\Lambda}$H most likely
- All other nuclei are typically an order of magnitude less likely to be observed

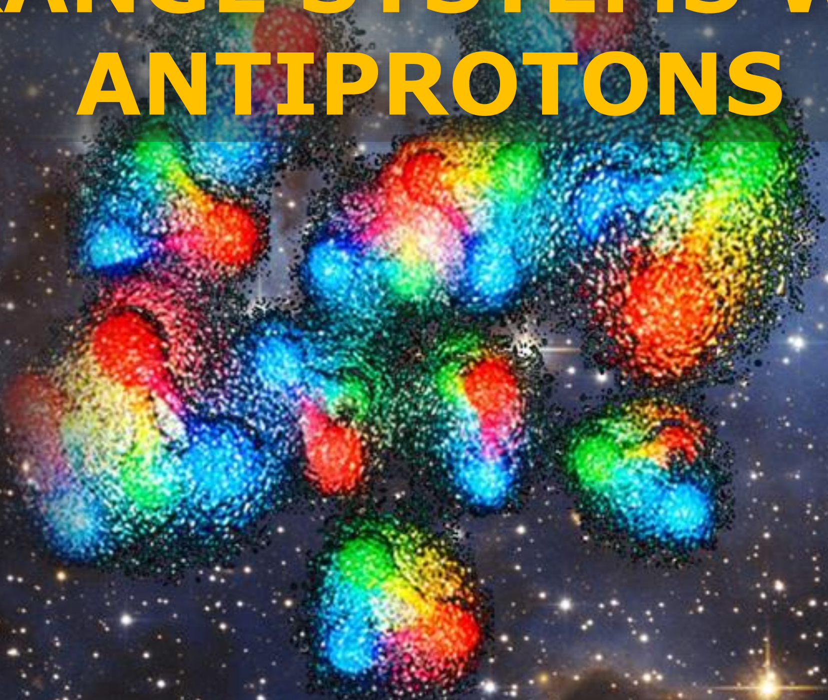


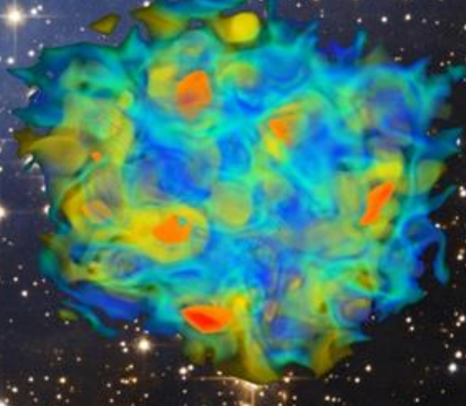
	E_x = 20 MeV		E_x = 40 MeV		E_x = 60 MeV	
${}^{9}_{\Lambda}$Li*	D_C	$D_C \times S \times BR$	D_C	$D_C \times S \times BR$	D_C	$D_C \times S \times BR$
${}^{3}_{\Lambda}$H	1.5e-4	1.1e-5	3.1e-4	2.1e-5	5.4e-4	4.1e-5
${}^{4}_{\Lambda}$H	4.7e-4	1.4e-4	2.1e-3	5.3e-4	1.6e-3	4.1e-4
${}^{6}_{\Lambda}$H	—	—	4.8e-5	5.7e-6	3.7e-5	2.7e-6
${}^{6}_{\Lambda}$He	1.3e-3	1.8e-4	1.3e-3	1.8e-4	5.3e-4	7.0e-5
${}^{7}_{\Lambda}$He	3.9e-3	5.6e-4	2.2e-3	3.3e-4	6.0e-4	8.0e-5
${}^{8}_{\Lambda}$He	8.8e-5	1.1e-5	3.0e-5	3.6e-6	4.2e-6	3.6e-7
${}^{6}_{\Lambda}$Li	0	0	3.6e-5	1.1e-6	3.8e-5	7.3e-7
${}^{7}_{\Lambda}$Li	4.5e-4	8.4e-5	1.2e-3	2.1e-4	4.3e-4	7.0e-5
${}^{8}_{\Lambda}$Li	4.5e-4	8.1e-5	9.9e-5	1.9e-5	1.6e-5	2.6e-6
${}^{8}_{\Lambda}$Li*	D_C	$D_C \times S \times BR$	D_C	$D_C \times S \times BR$	D_C	$D_C \times S \times BR$
${}^{3}_{\Lambda}$H	6.1e-5	4.8e-6	1.1e-3	8.1e-5	9.9e-4	7.4e-5
${}^{4}_{\Lambda}$H	1.1e-3	2.8e-4	1.8e-3	4.8e-4	1.8e-3	4.6e-4
${}^{6}_{\Lambda}$H	—	—	—	—	8.6e-6	1.9e-6
${}^{6}_{\Lambda}$He	1.5e-3	2.1e-4	1.3e-3	1.9e-4	3.5e-4	5.6e-5
${}^{7}_{\Lambda}$He	1.7e-3	2.4e-4	8.2e-4	1.3e-4	1.3e-4	1.9e-5
${}^{6}_{\Lambda}$Li	4.3e-5	1.5e-6	3.0e-4	1.1e-5	1.1e-4	3.6e-6
${}^{7}_{\Lambda}$Li	3.4e-3	6.4e-4	1.6e-3	2.8e-4	2.4e-4	3.7e-5
${}^{8}_{\Lambda}$He*	D_C	$D_C \times S \times BR$	D_C	$D_C \times S \times BR$	D_C	$D_C \times S \times BR$
${}^{3}_{\Lambda}$H	—	—	1.6e-4	1.3e-5	3.9e-4	3.1e-5
${}^{4}_{\Lambda}$H	1.9e-4	5.7e-5	3.8e-3	9.9e-4	2.3e-3	5.7e-4
${}^{6}_{\Lambda}$H	—	—	3.8e-4	4.8e-5	1.2e-4	1.3e-5
${}^{6}_{\Lambda}$He	1.2e-3	1.6e-4	1.1e-3	1.6e-4	2.8e-4	4.4e-5
${}^{7}_{\Lambda}$He	6.6e-3	9.4e-4	1.8e-3	2.5e-4	2.2e-4	3.0e-5

PART 2

Future activities at PANDA

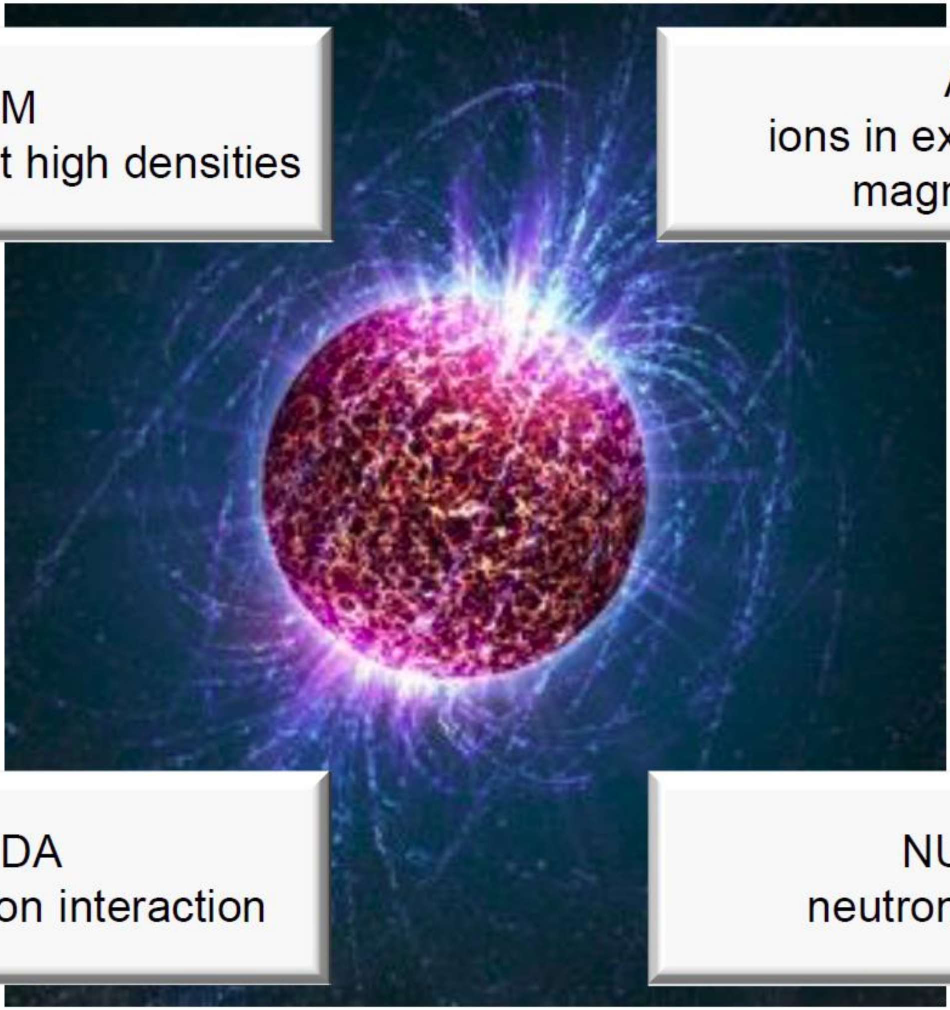
PRESSIOEN STUDIES OF STRANGE SYSTEMS WITH ANTIPROTONS





P̄ANDA: a personal view

- Boris Sharkov, PANDA Meeting September 2015

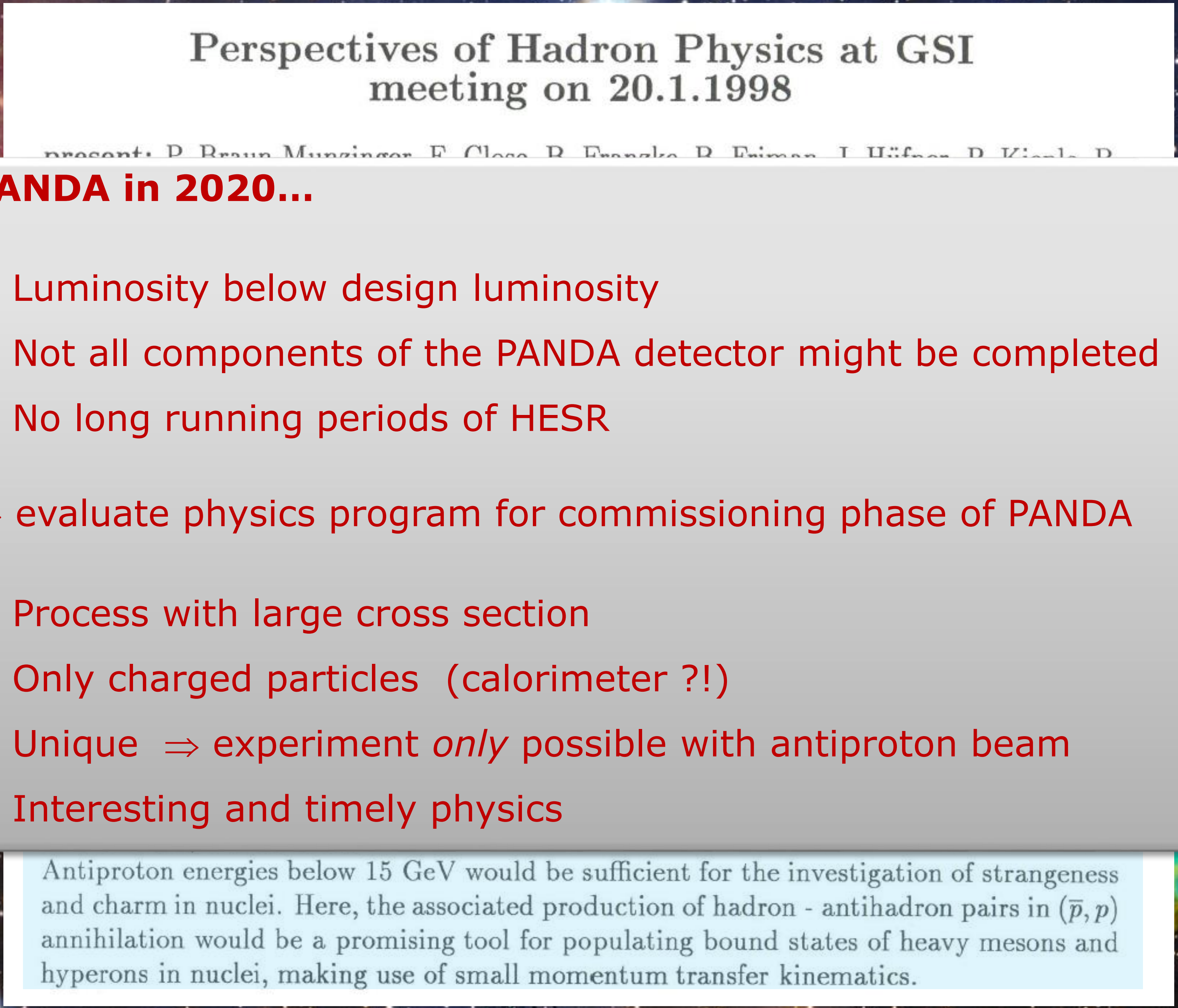


CBM
nuclear matter at high densities

APPA
ions in extreme electro-magnetic fields

PANDA
hyperon-hyperon interaction

NUSTAR
neutron-rich nuclei



Perspectives of Hadron Physics at GSI
meeting on 20.1.1998

present: P Braun Munzinger F Close B Franzke B Friman J Hüfner P Kienle P

PANDA in 2020…

- Luminosity 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 $(\overline{p}, p)$ annihilation would be a promising tool for populating bound states of heavy mesons and hyperons in nuclei, making use of small momentum transfer kinematics.

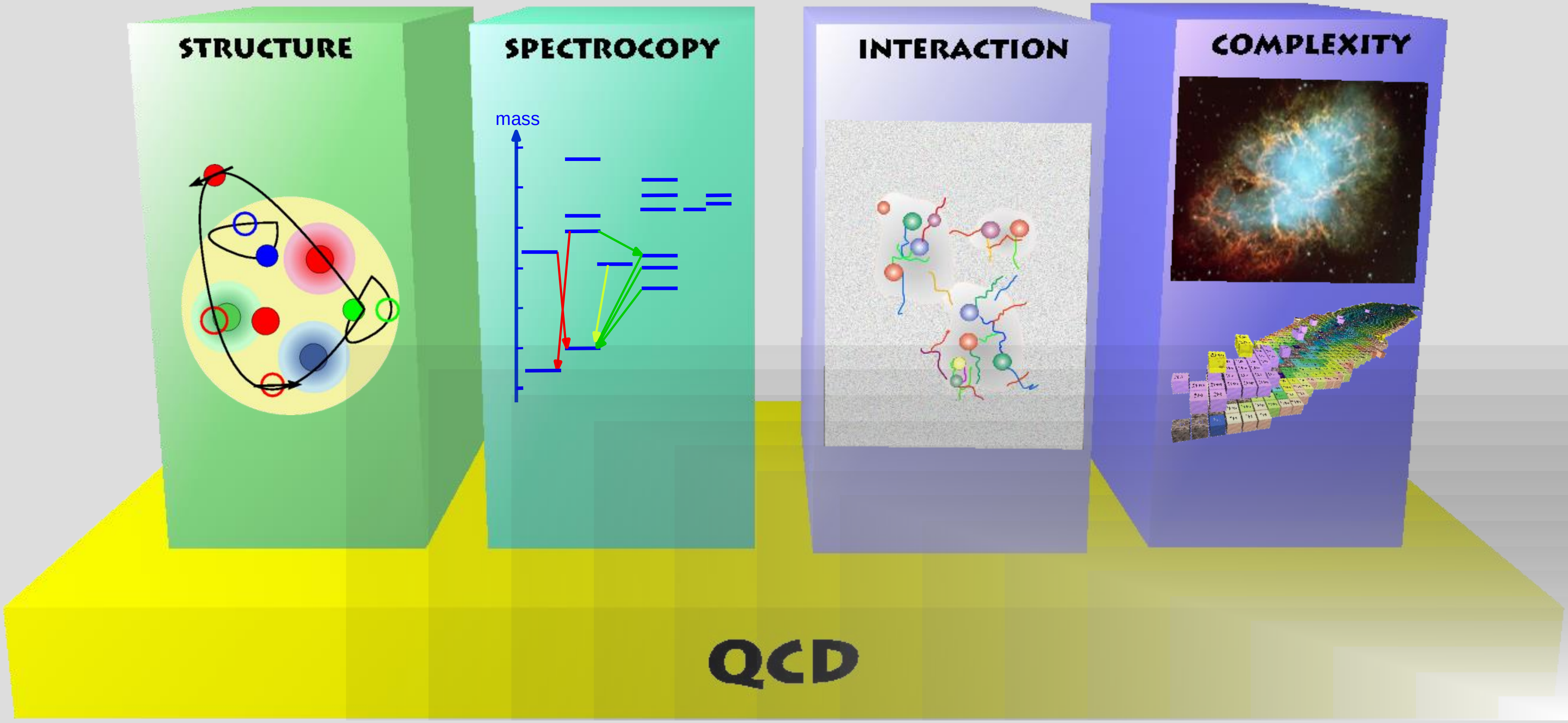
Strangeness in Nuclei at PANDA

…a unique laboratory for strong interactions and baryon structure

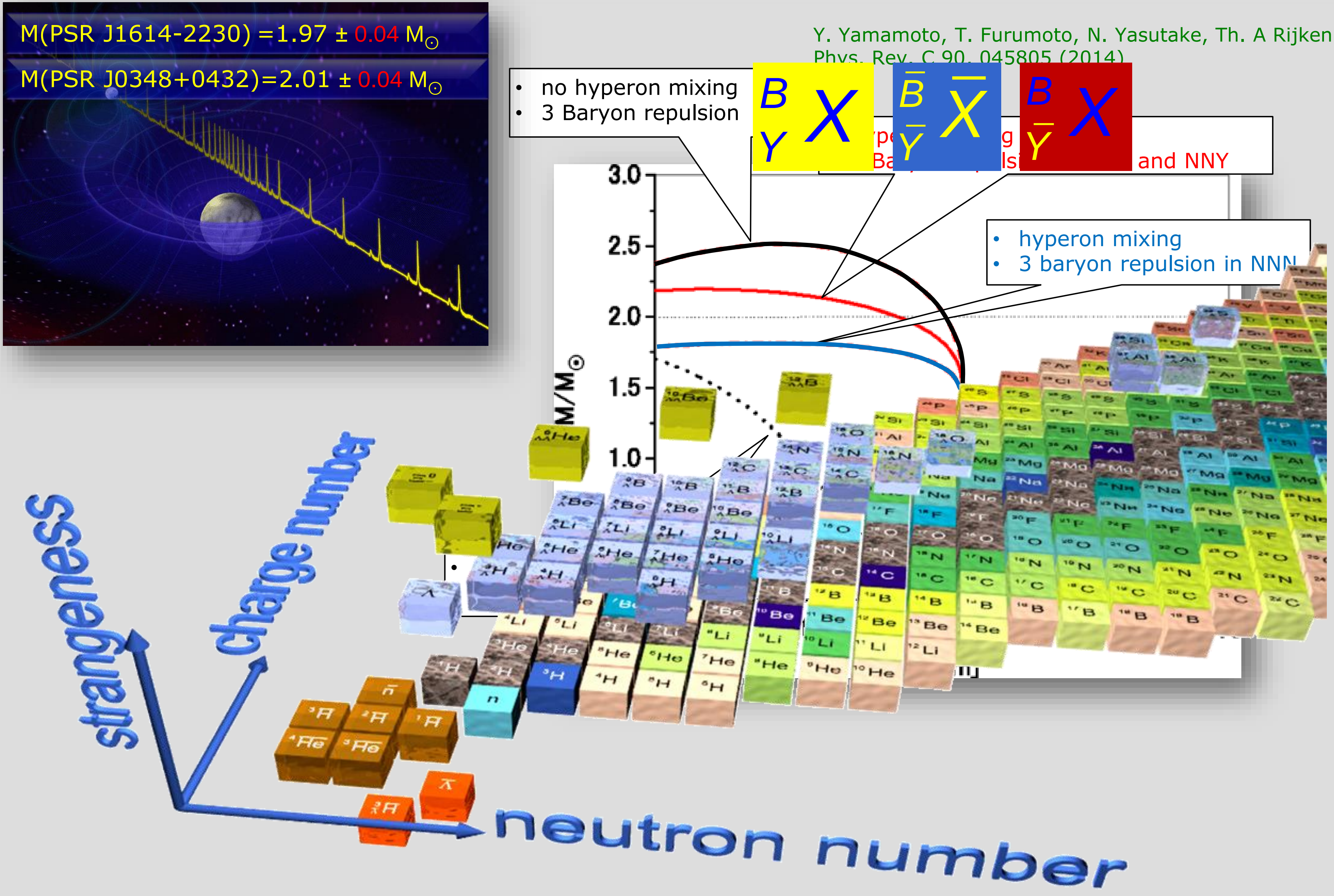
from hyperatoms
to hyperonstructure

(anti)hadrons
in nuclei

multistrange
hypernuclei



Role of multi-nucleon interaction



M(PSR J1614-2230) =1.97 ± 0.04 $M_\odot$

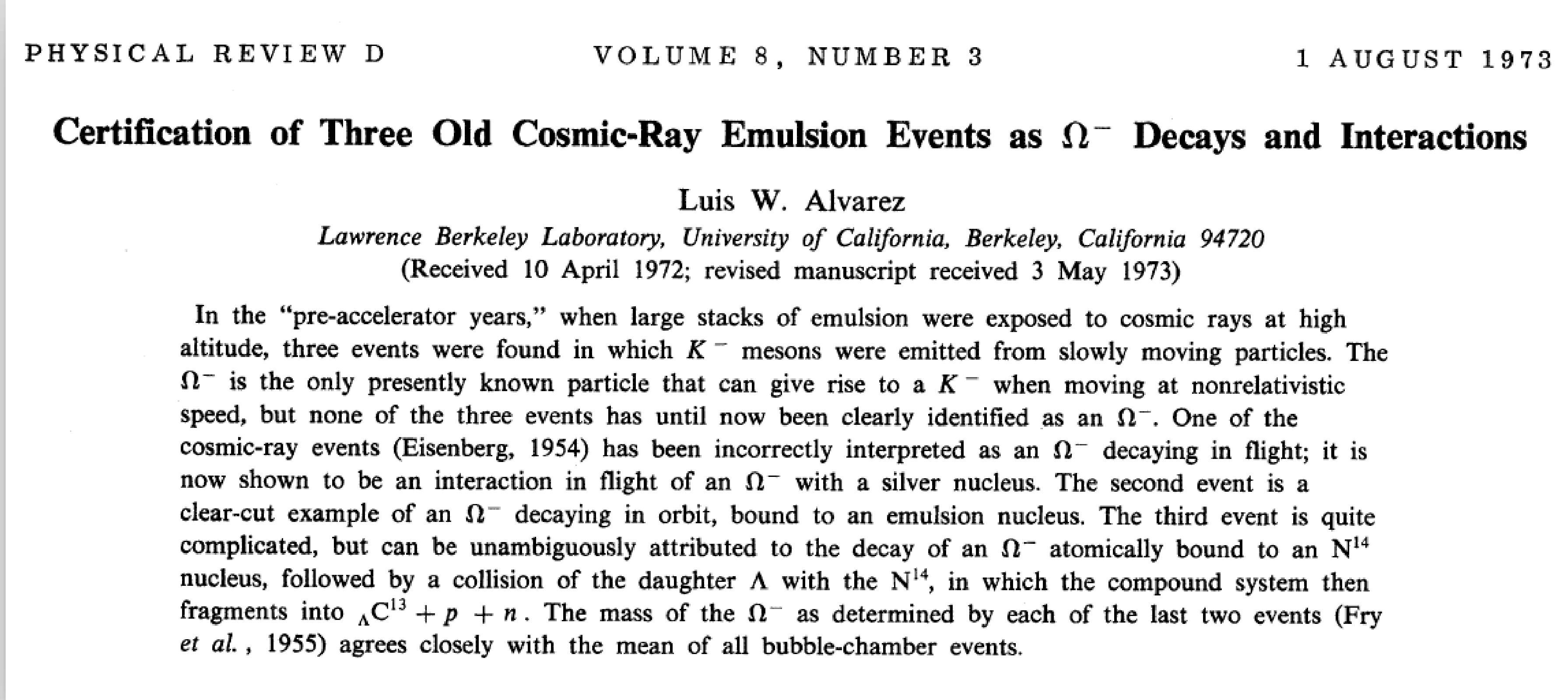
M(PSR J0348+0432)=2.01 ± 0.04 $M_\odot$

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

- no hyperon mixing
- 3 Baryon repulsion

- hyperon mixing
- 3 baryon repulsion in NNN

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



PHYSICAL REVIEW D VOLUME 8, NUMBER 3 1 AUGUST 1973

Certification of Three Old Cosmic-Ray Emulsion Events as Ω^- Decays and Interactions

Luis W. Alvarez
Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720
(Received 10 April 1972; revised manuscript received 3 May 1973)

In the "pre-accelerator years," when large stacks of emulsion were exposed to cosmic rays at high altitude, three events were found in which K^- mesons were emitted from slowly moving particles. The Ω^- is the only presently known particle that can give rise to a K^- when moving at nonrelativistic speed, but none of the three events has until now been clearly identified as an Ω^-. One of the cosmic-ray events (Eisenberg, 1954) has been incorrectly interpreted as an Ω^- decaying in flight; it is now shown to be an interaction in flight of an Ω^- with a silver nucleus. The second event is a clear-cut example of an Ω^- decaying in orbit, bound to an emulsion nucleus. The third event is quite complicated, but can be unambiguously attributed to the decay of an Ω^- atomically bound to an N^{14} nucleus, followed by a collision of the daughter Λ with the N^{14}, in which the compound system then fragments into ${}_{\Lambda}C^{13} + p + n$. The mass of the Ω^- as determined by each of the last two events (Fry *et al.*, 1955) agrees closely with the mean of all bubble-chamber events.

- Note: in nuclei secondary processes possible

$$\bar p + n \to \bar\Xi^- + \Xi^0 \qquad \Xi^0 + X \to \Omega^- + K^+ + X$$
$$\bar p + p \to \bar\Xi^- + \Xi^- \qquad \Xi^- + X \to \Omega^- + K^0 + X$$

…seen in emulsions ~10 years prior to the „discovery" at Brookhaven

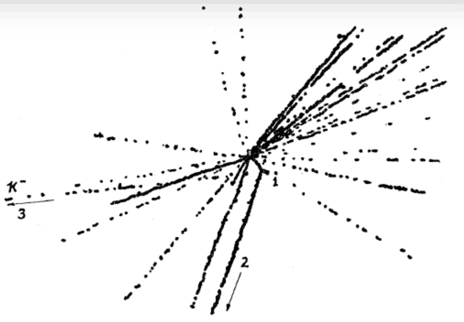
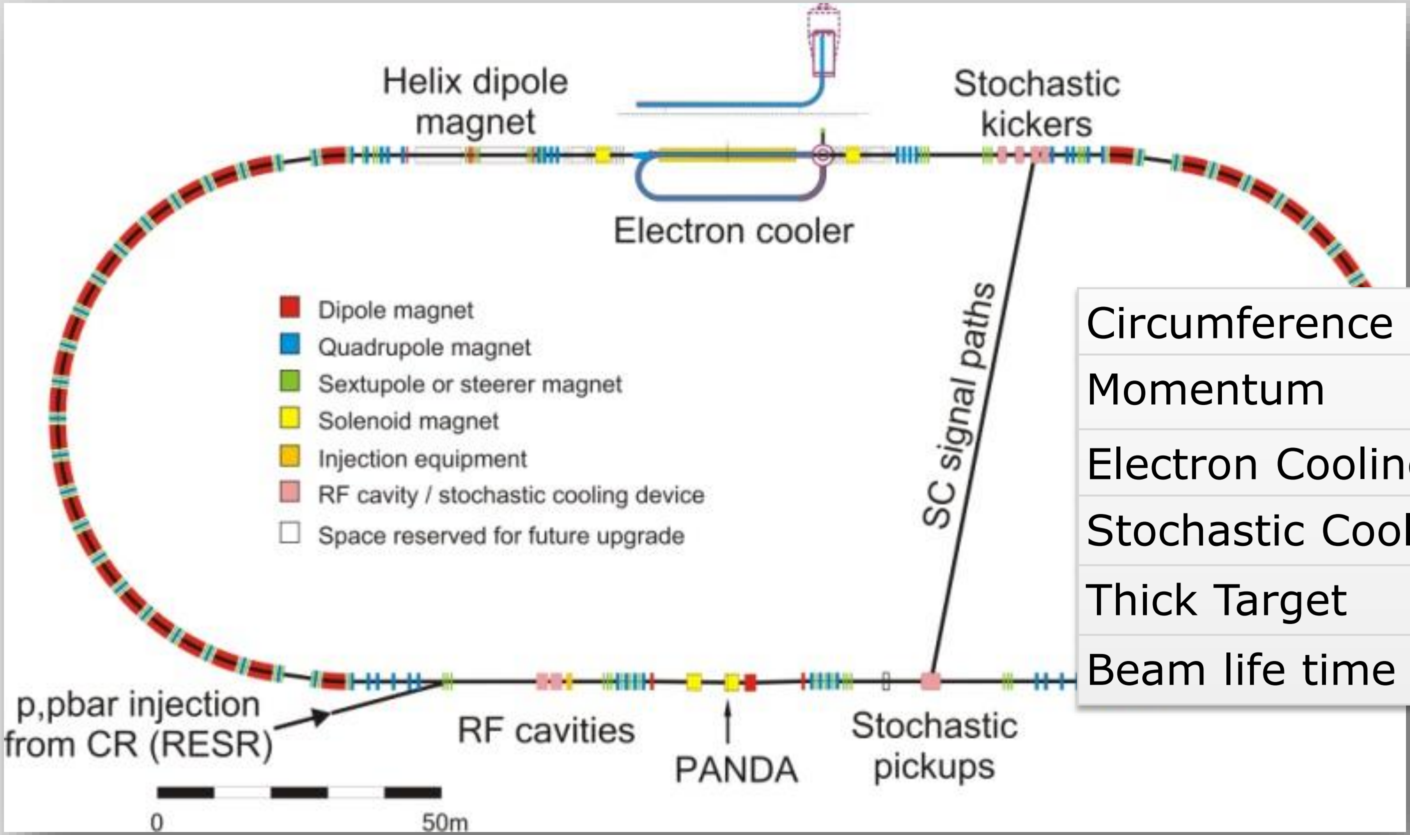


FIG. 1. A projection drawing of the K-mesonic decay of a slow particle is shown above. Track 1 is a short recoil. Track 2 was produced by a particle of $Z=1$. Track 3 was produced by a negative K-meson. A few tracks of particles from the primary star which are in the same direction as the connecting track, but at a different depth, were omitted from the drawing for the sake of clarity.

HESR with PANDA and Electron Cooler

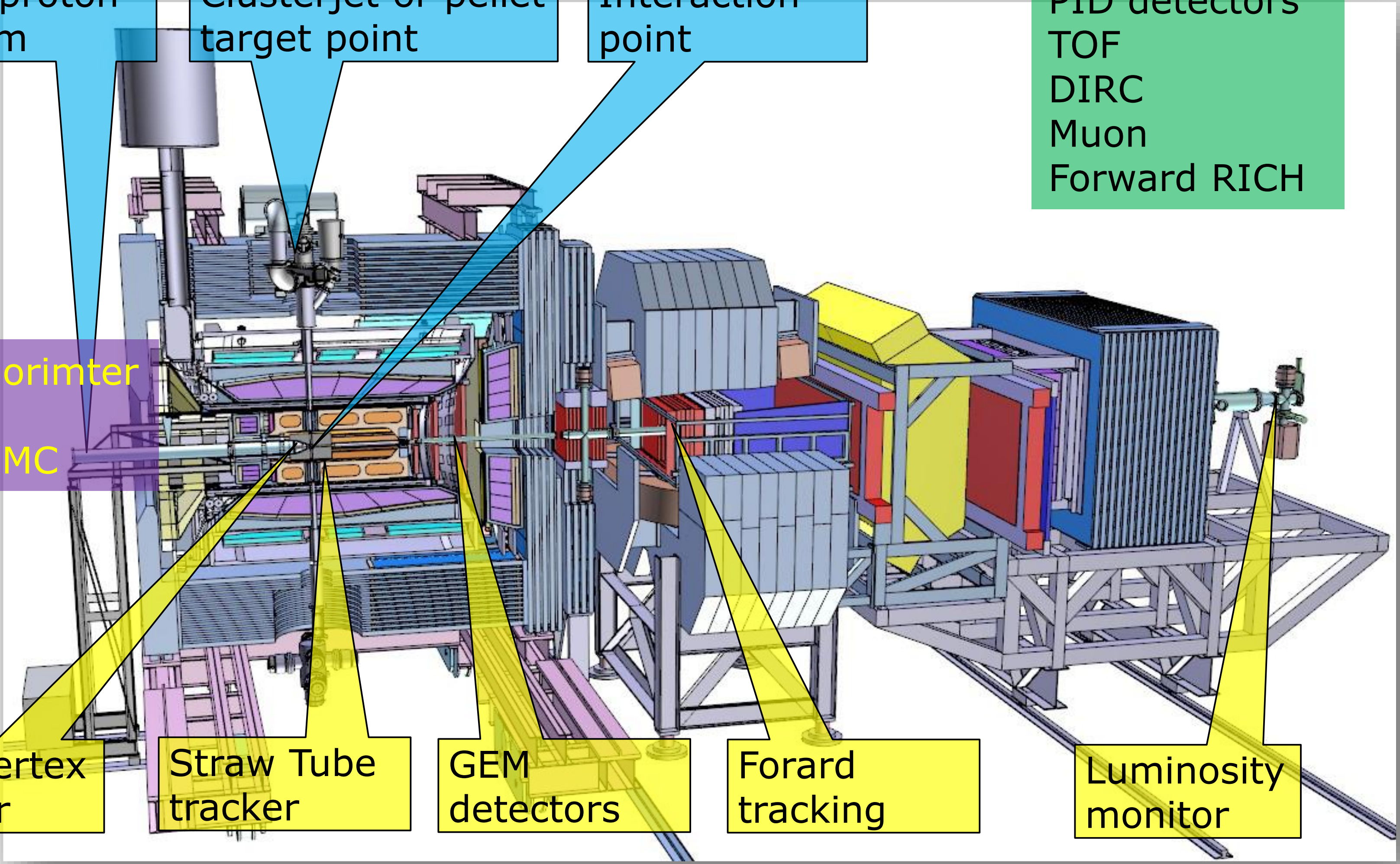


Circumference	575 m
Momentum	1.5 – 15 GeV/c
Electron Cooling	up to 9 GeV/c
Stochastic Cool.	Full range
Thick Target	$4 \cdot 10^{15}$ cm^{-2}
Beam life time	>30 min

- 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



Antiproton beam

Clusterjet or pellet target point

Interaction point

PID detectors
TOF
DIRC
Muon
Forward RICH

PWO Caolorimter
Forward
Shaslyk EMC

Micro vertex detector

Straw Tube tracker

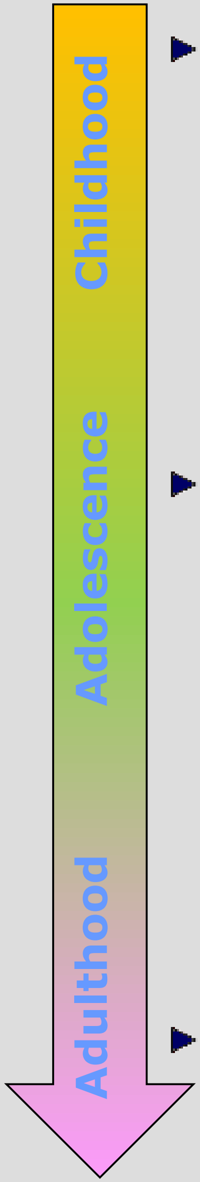
GEM detectors

Forard tracking

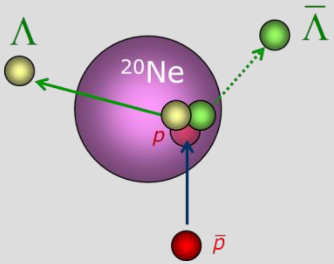
Luminosity monitor

- Official timeline
  - 2013-2017: (partial) pre-assembling at COSY, Jülich
  - ≥2018: first beam expected at FAIR

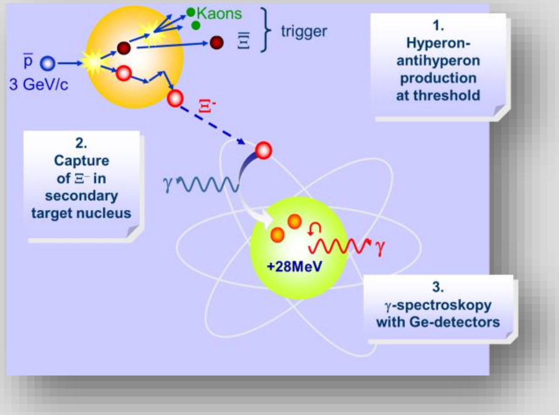
Exploring (anti-)hadron interactions



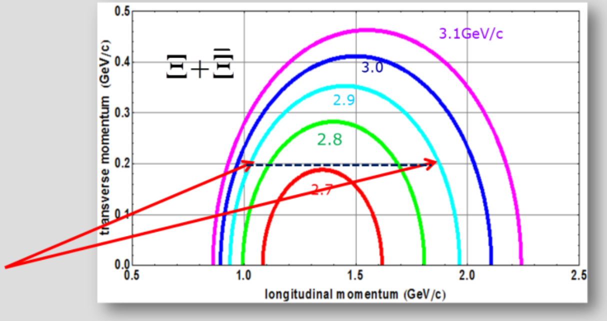
- Antihadrons in atomic nuclei
  - Nuclear potential of antihadrons and hadrons
  - Search for Antilambda bound states
  - Exploring the neutron skin of nuclei
  - K*/$\bar{K}$* in nuclei



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



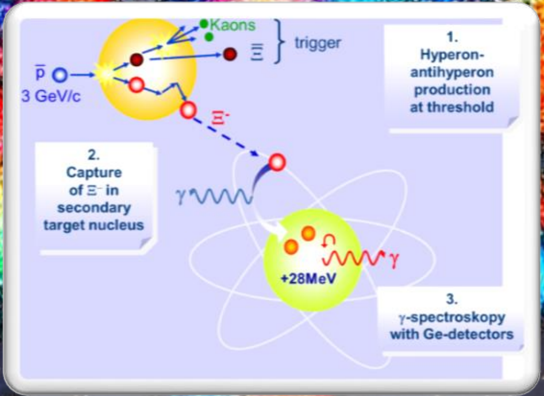
- Secondary scattering of momentum tagged, polarized hyperons and antihyperons

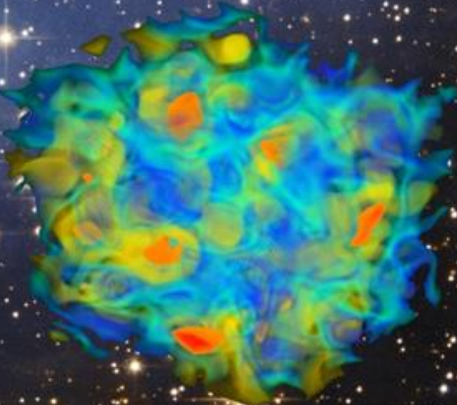


EXAMPLE 1

Approaching the hyperonization puzzle

ΛΛ HYPERNUCLEI
at PANDA

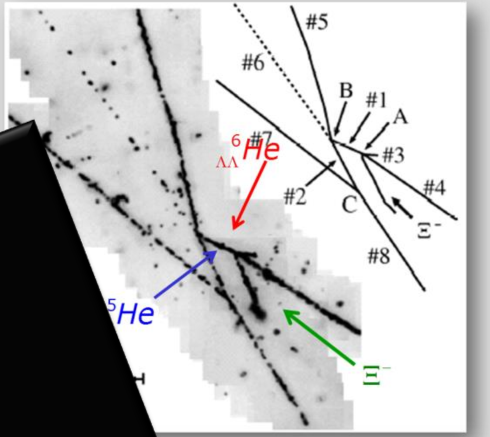


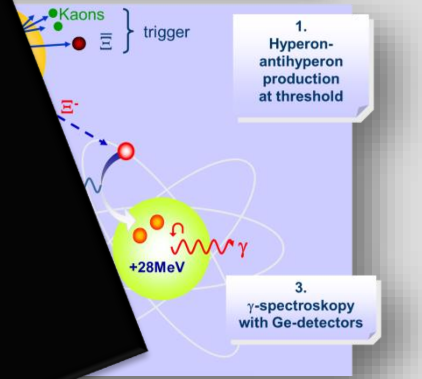


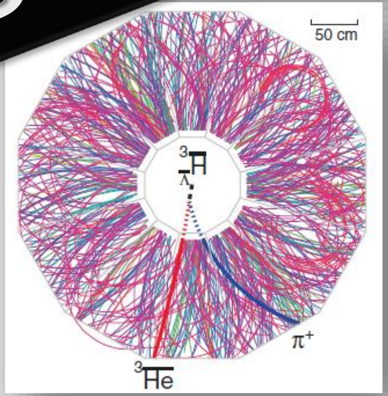
Many ways to double hypernuclei

- 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, ALICE

P̄ANDA is unique and complements worldwide activities

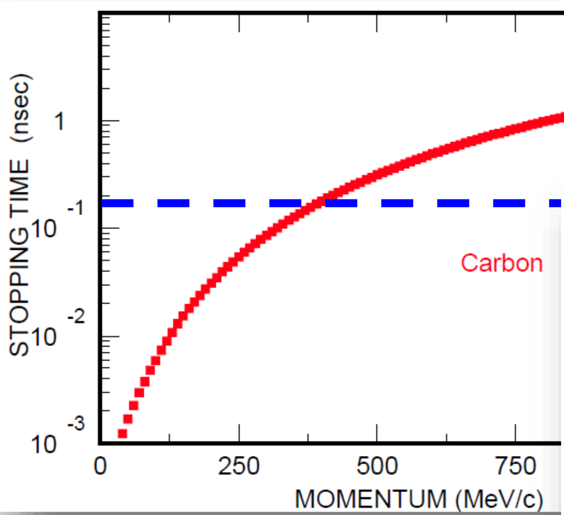


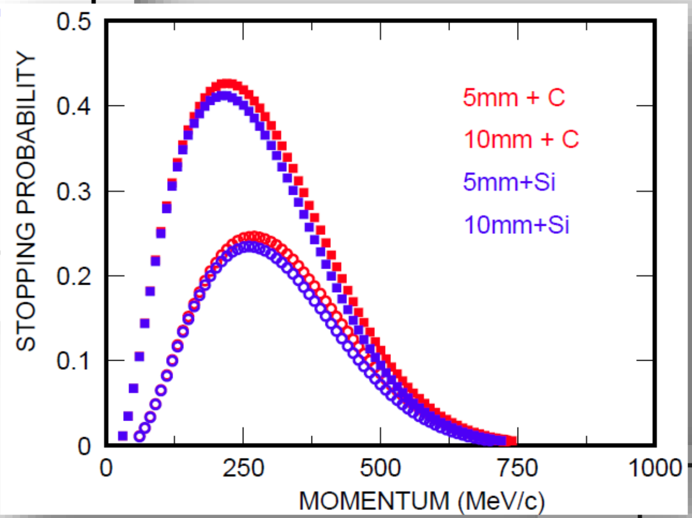


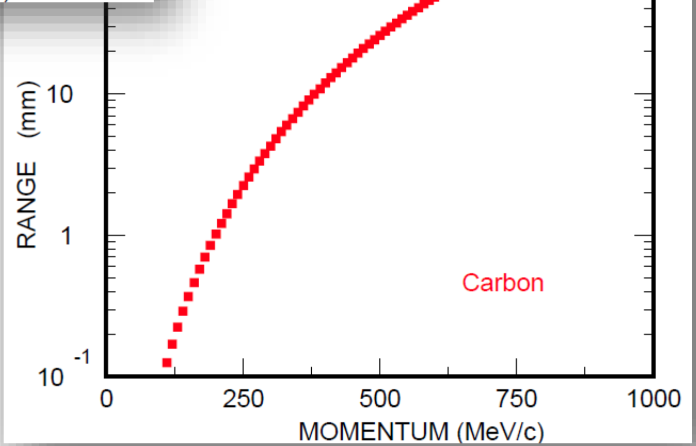


Ξ^- properties determine setup

- Ξ^- mean life 0.164 nsec

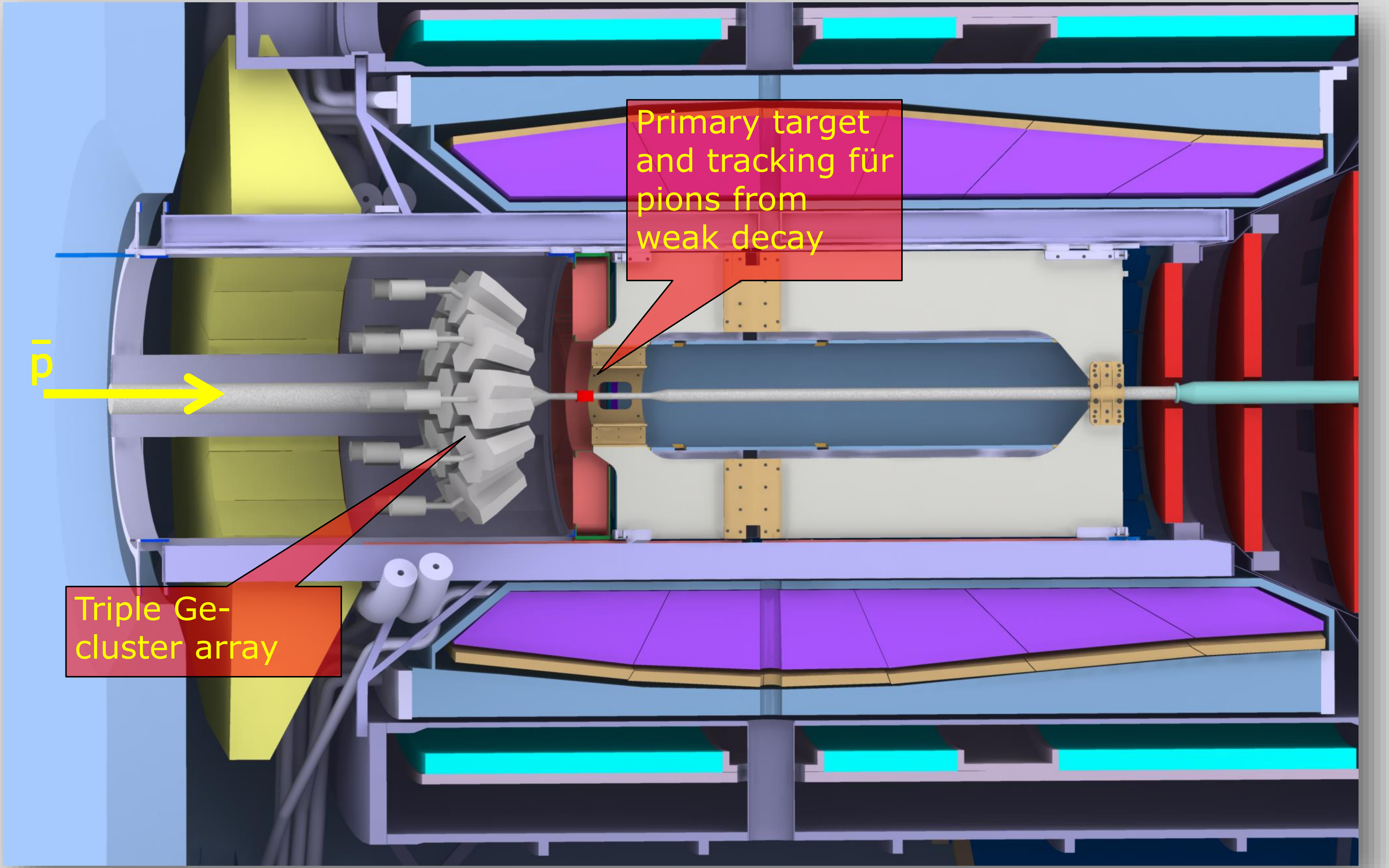






- minimizeminimize distance production & capture
- initial momentum 100-500 MeV/c
- thickness od secondary target few mm

The HYP setup at PANDA

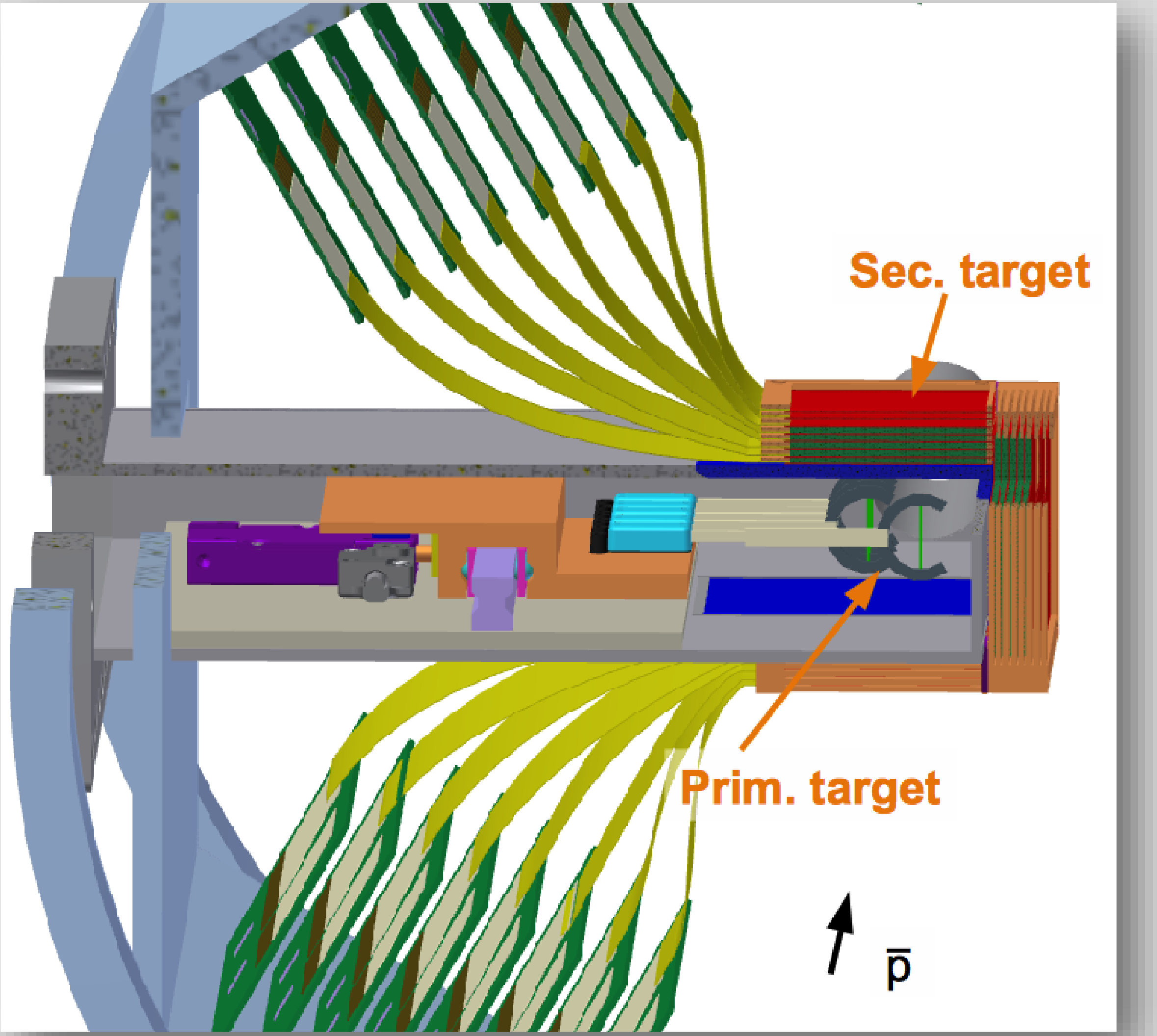


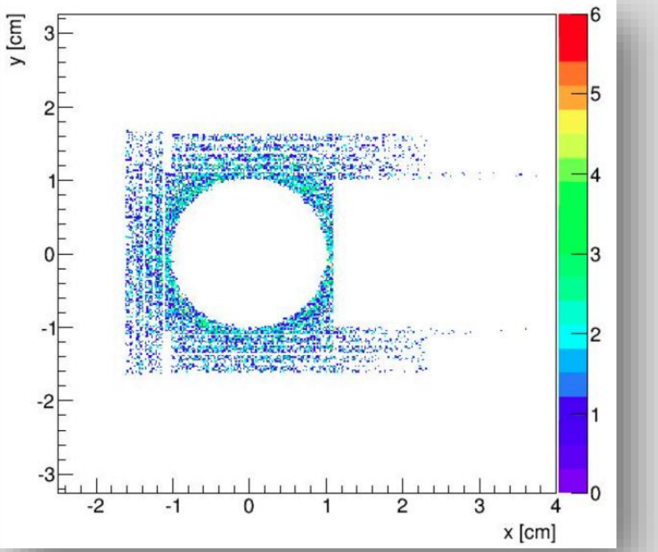
Primary target and tracking für pions from weak decay

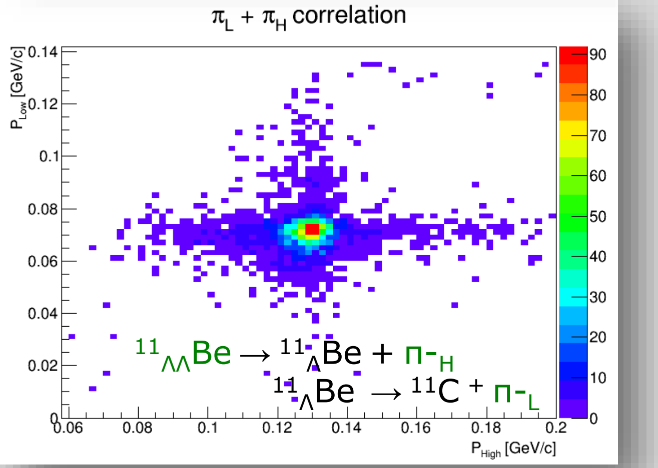
Triple Ge-cluster array

Status and expected count rate

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



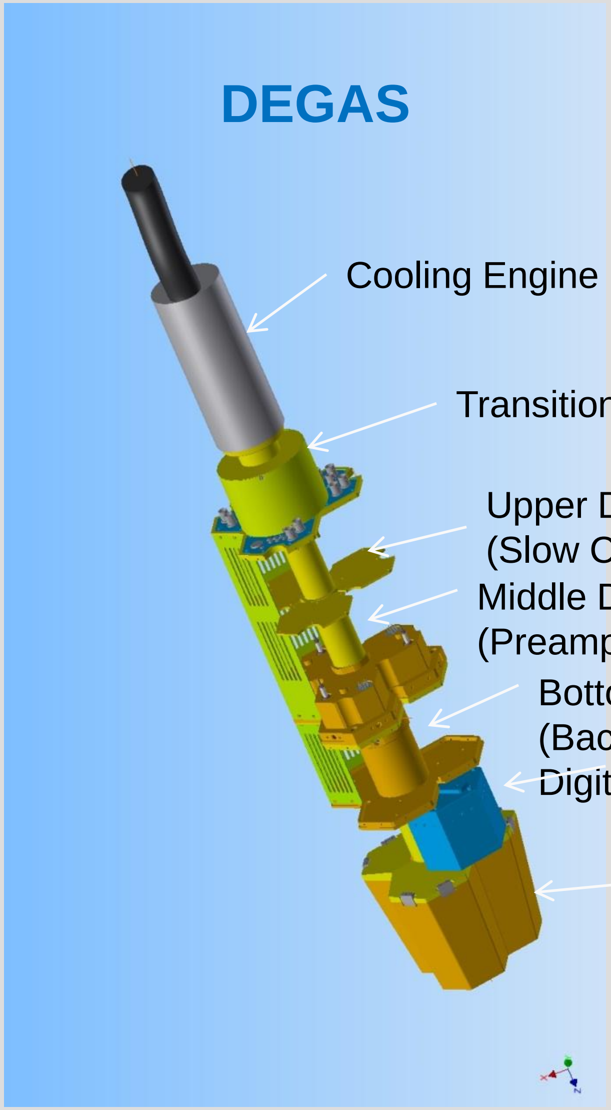



$\pi_L + \pi_H$ correlation

$^{11}_{\Lambda\Lambda}Be \rightarrow {}^{11}_{\Lambda}Be + \pi^-_H$

$^{11}_{\Lambda}Be \rightarrow {}^{11}C + \pi^-_L$

From DEGAS@FRS …



Cooling Engine

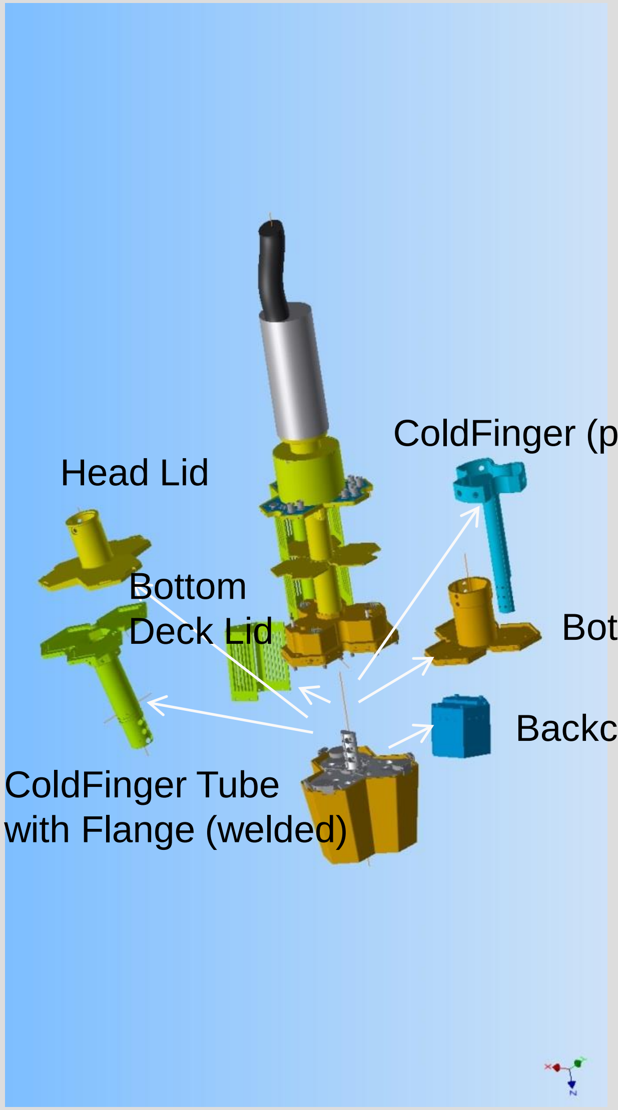
Transition Section

Upper Deck
(Slow Control, Power)

Middle Deck
(Preamplifiers and HV Modules)

Bottom Deck
(Backcatcher electronics or Digitizers)

Detector Head



Head Lid

ColdFinger (partly)

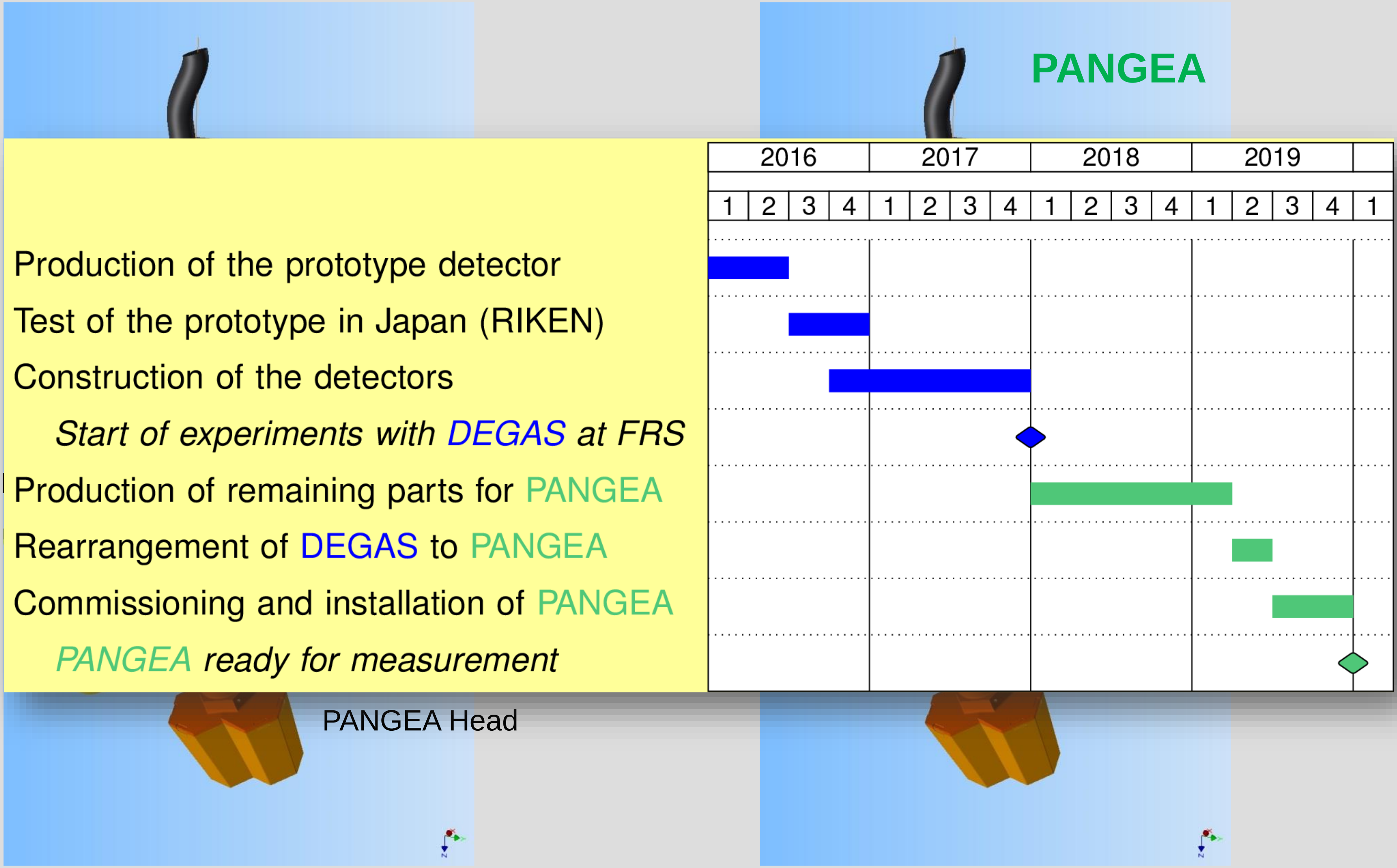
Bottom
Deck Lid

Bottom Deck

Backcatcher

ColdFinger Tube
with Flange (welded)

…to PANGEA@PANDA



Production of the prototype detector

Test of the prototype in Japan (RIKEN)

Construction of the detectors

Start of experiments with DEGAS at FRS

Production of remaining parts for PANGEA

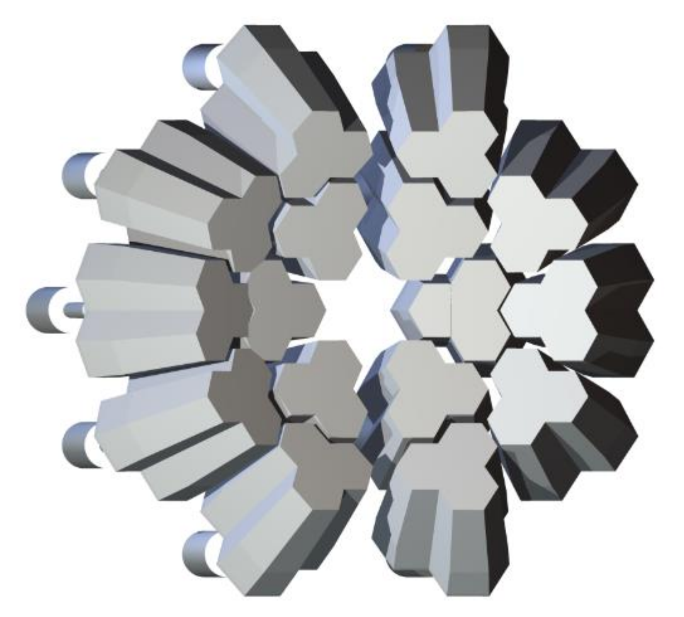
Rearrangement of DEGAS to PANGEA

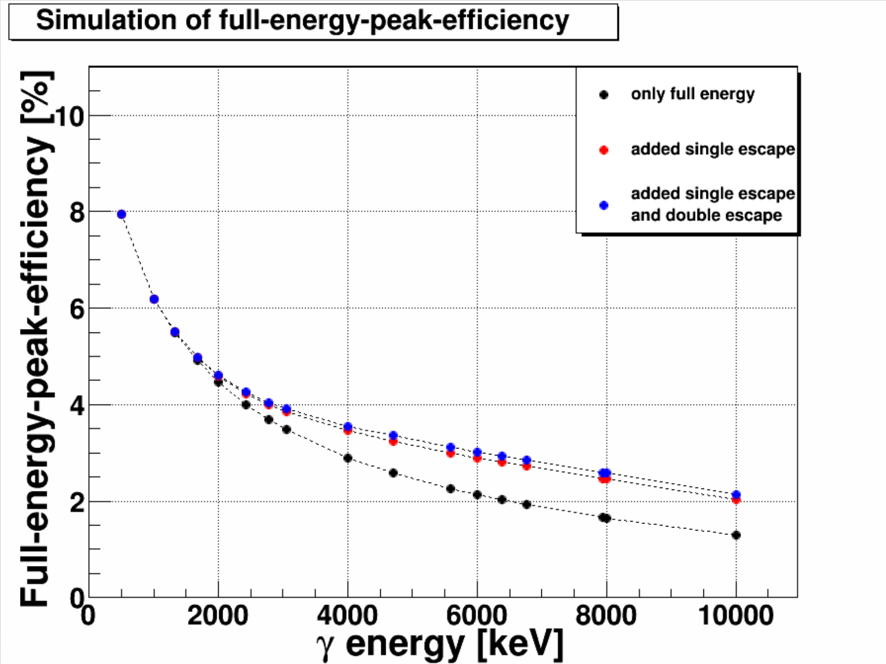
Commissioning and installation of PANGEA

PANGEA ready for measurement

Status and expected count rate

- HPGe Cluster Array

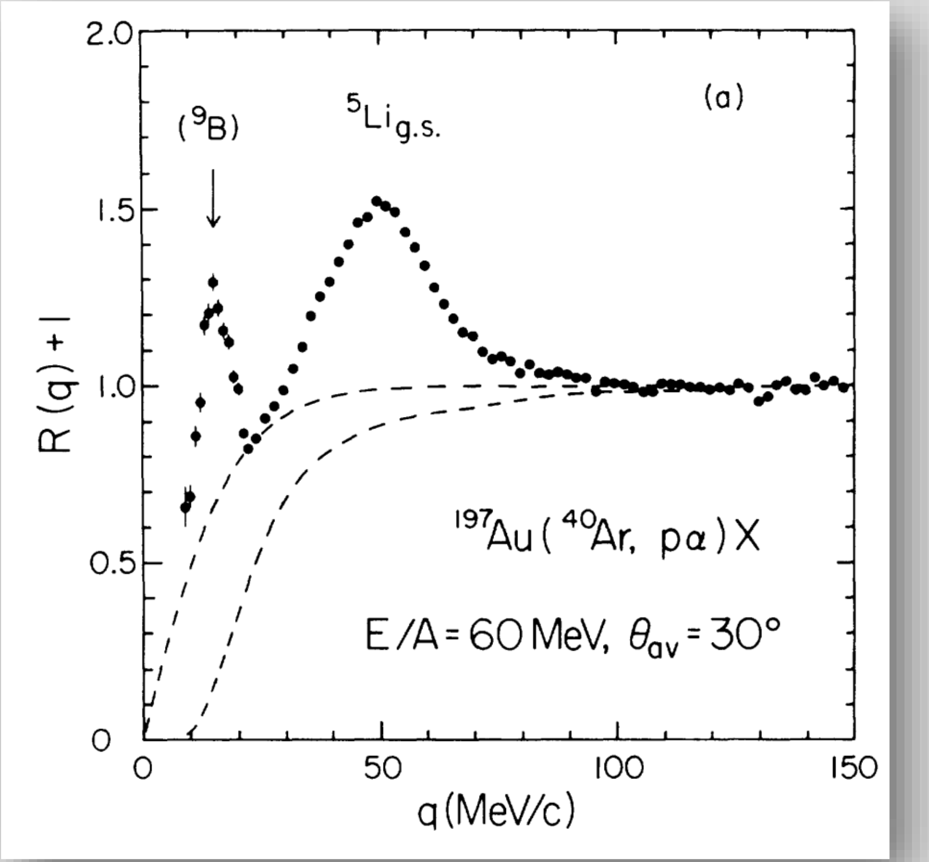




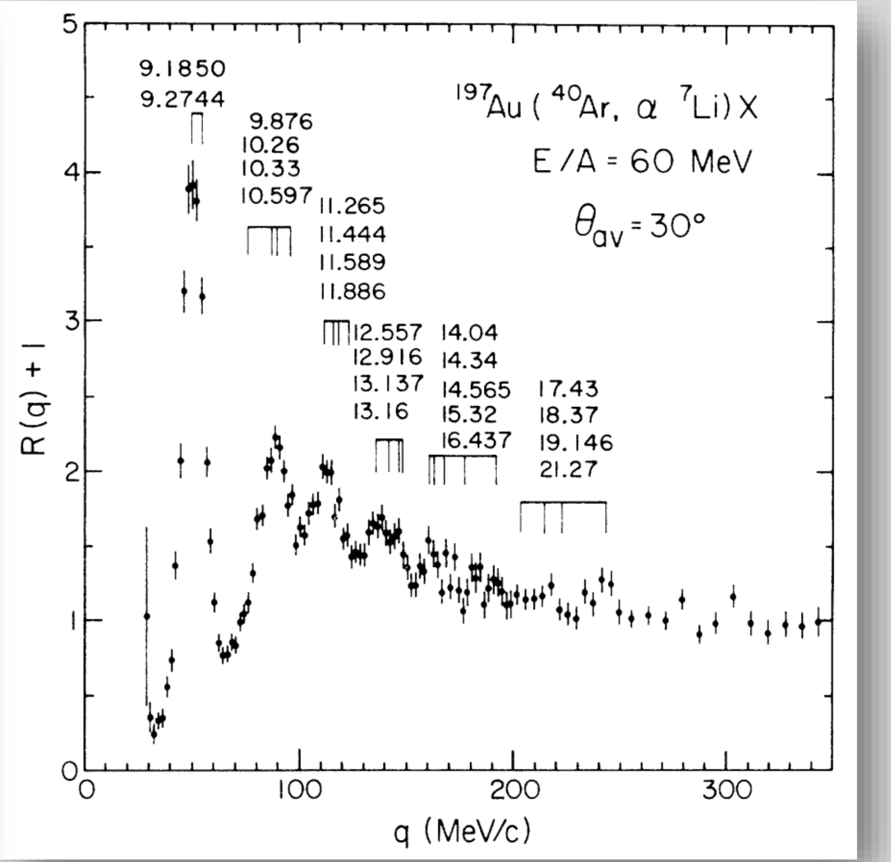
- triple detector under production
- frontend electronics being testet
- radiation hardness…
- Rates at $5\cdot10^6$ interactions per second (Boron absorber)
  - produced Ξ^- per second: 110
  - stopped Ξ^- per day: 51800
  - …
  - detected $^{11}_{\Lambda\Lambda}$Be transitions ∧ 2 pions in 4 months: 26

Small relative momentum correlation

- Well established method for conventional nuclei

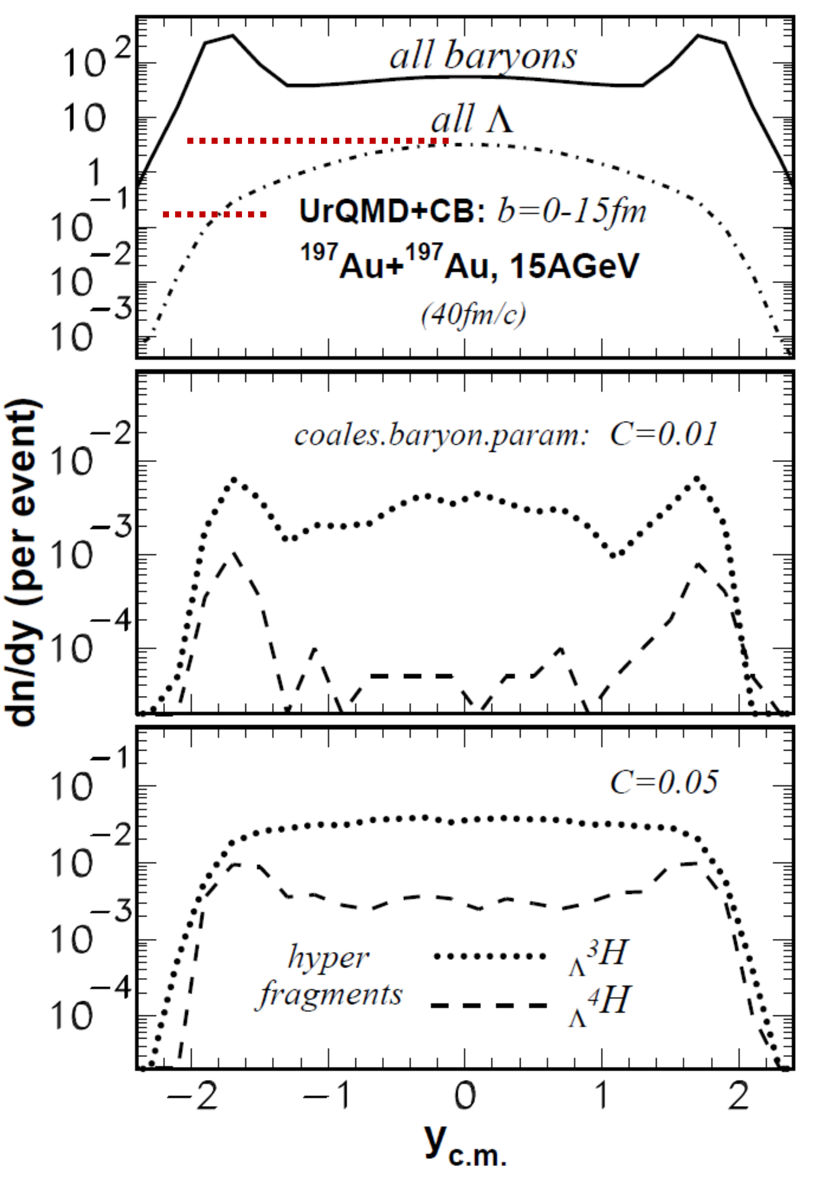


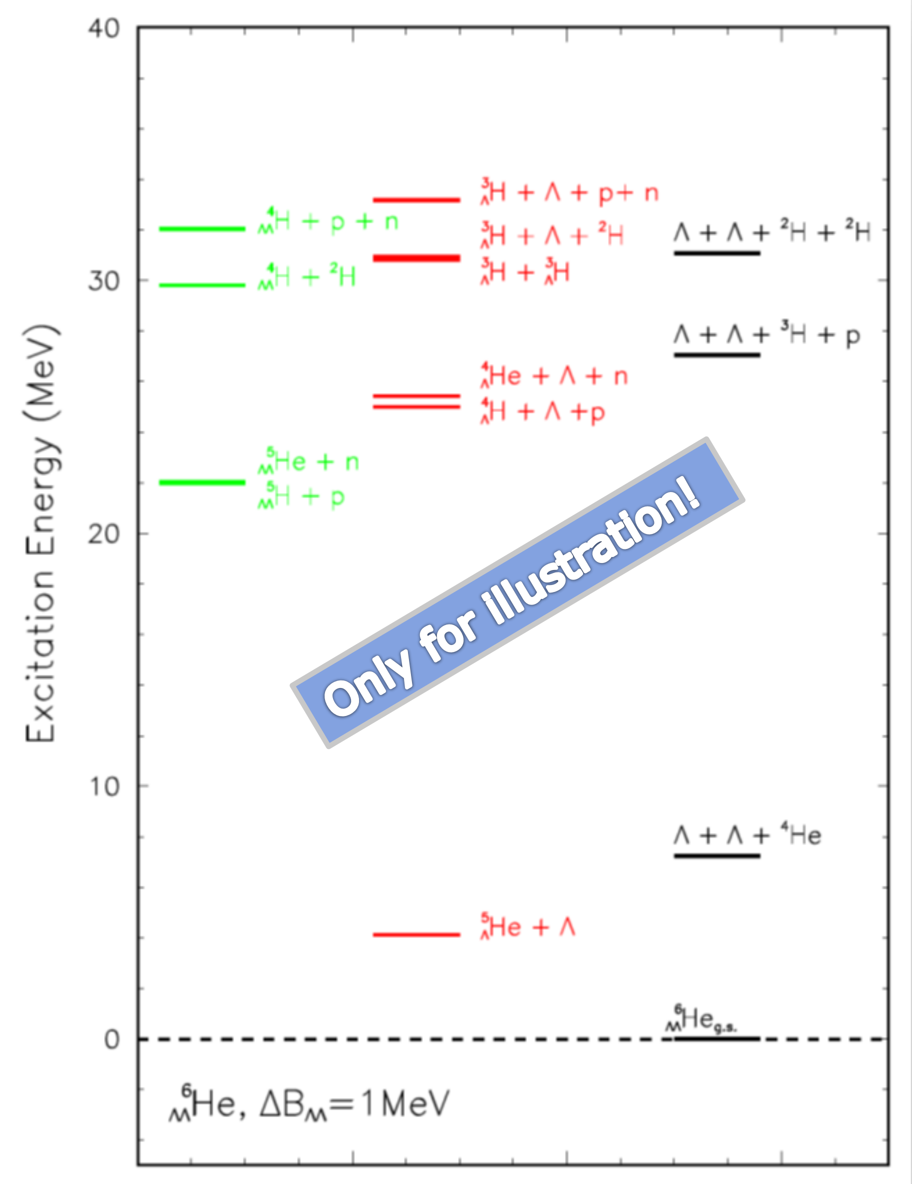
J.P *et al*, PLB 161B, 256 (1985)



J.P *et al*, PRC 35, 1695 (1987)

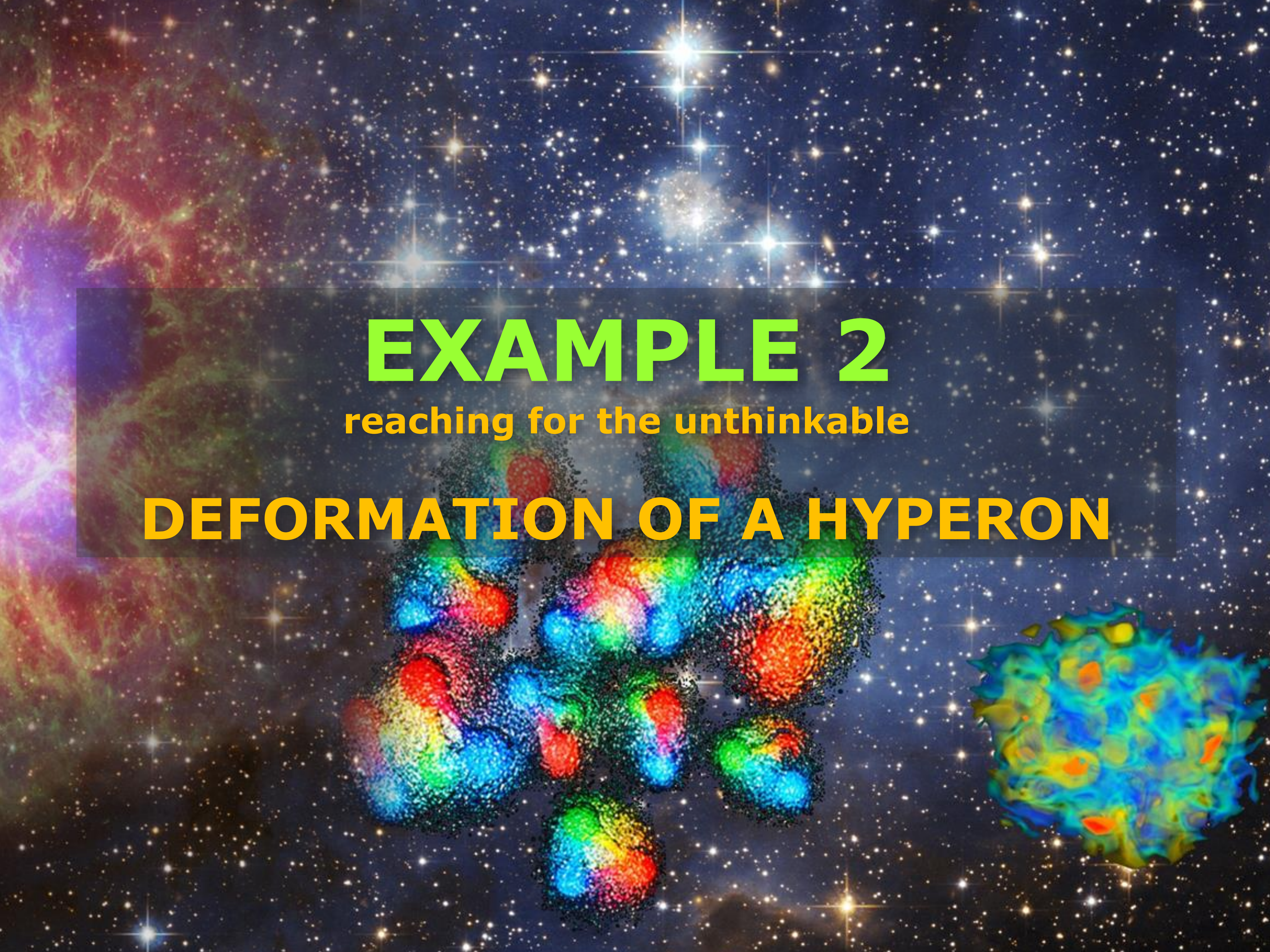
Search for particle unbound states ?





Only for illustration!

A. Botvina, J. Pochodzalla *et al.*

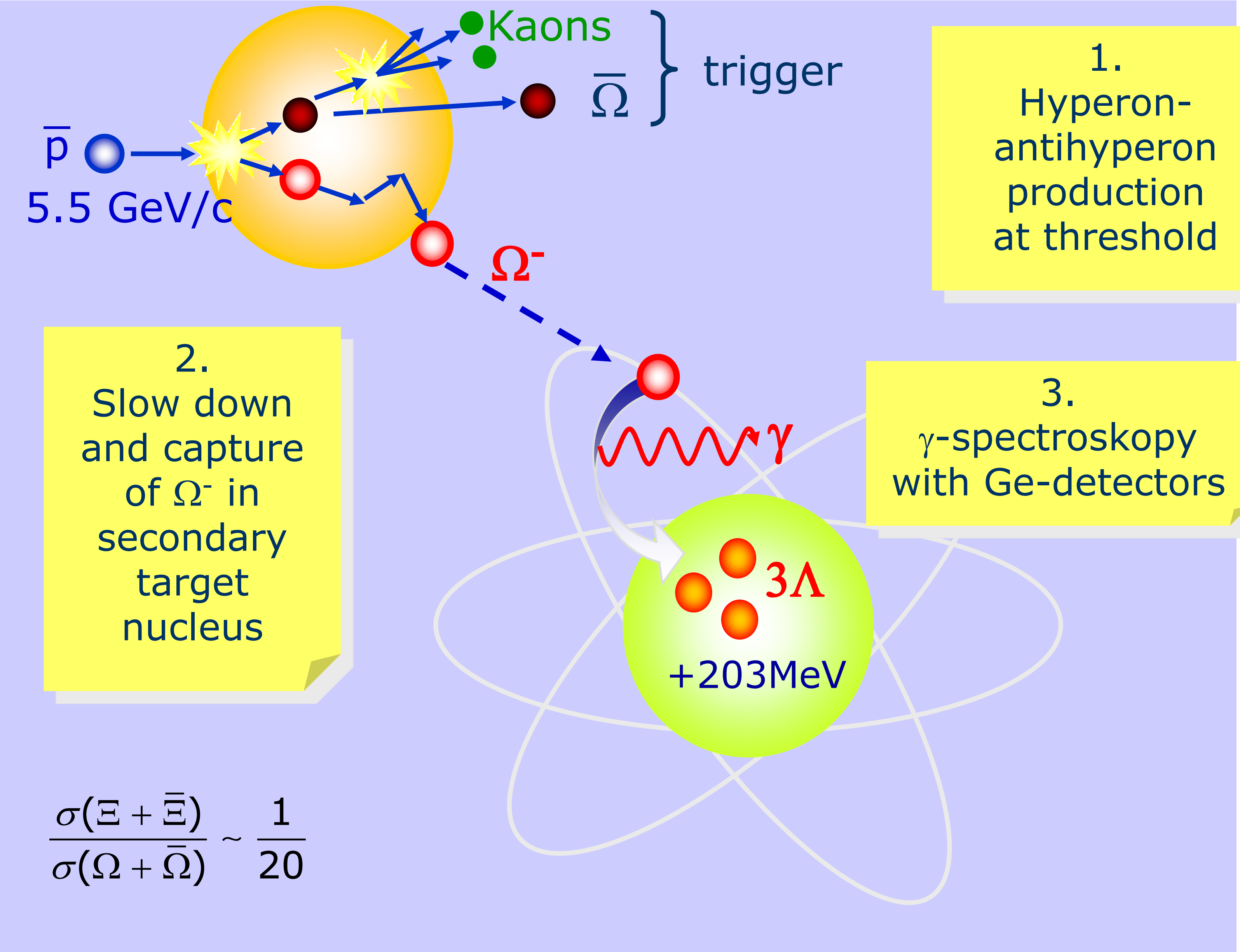


EXAMPLE 2

reaching for the unthinkable

DEFORMATION OF A HYPERON

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

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

What we (probably) also can‘t do

- triple hypernuclei via $p\bar{p} \rightarrow \Omega\bar{\Omega}$ $\Omega pn \rightarrow \Lambda\Lambda\Lambda + 203 MeV$?
  - lower cross section
  - large momenta $\Rightarrow$ lower stopping probability
  - large Q-value $\Rightarrow$ low probability for triple Λ nuclei
  - γ-spectroscopy most likely not practical at the beginning
- Λ_c hypernuclei
  - production via primary + secondary target not possible because of short lifetime of $\tau_{\Lambda c}$ =0.2ps which exceeds stopping time
  - direkt production via pp → $\Lambda_c\Lambda_c$bar or $\pi^- p \rightarrow \Lambda_c D^-$ difficult because of high momenta involved (very low sticking probability)
  - does a two-step process *within one nucleus* work?

$$\bar{p} + p \rightarrow D^+ + D^-$$

$$D^+ + p \rightarrow \Lambda_c^+ + \pi^+$$

detected

captured in the nucleus A-2

  - determination of the Λ_c hypernucleus mass via missing mass
    - needs good knowledge of beam momentum (10^{-4})
    - excellent momentum resolution for π^+ and D^- (resp. decay products)
  - expected rate ~0.01 day^{-1} (??? rescattering → 1day^{-1} ???)

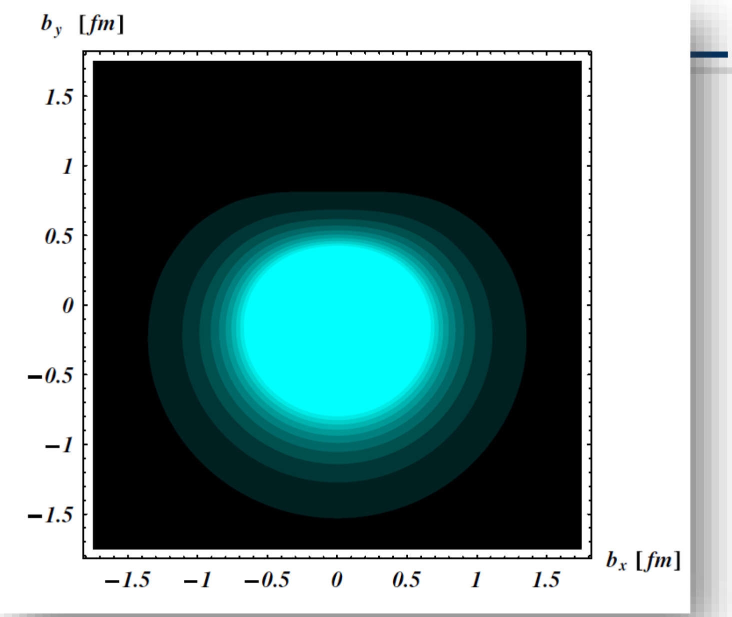
Proton vs. Omega

PHYSICAL REVIEW D **83,** 054011 (2011)

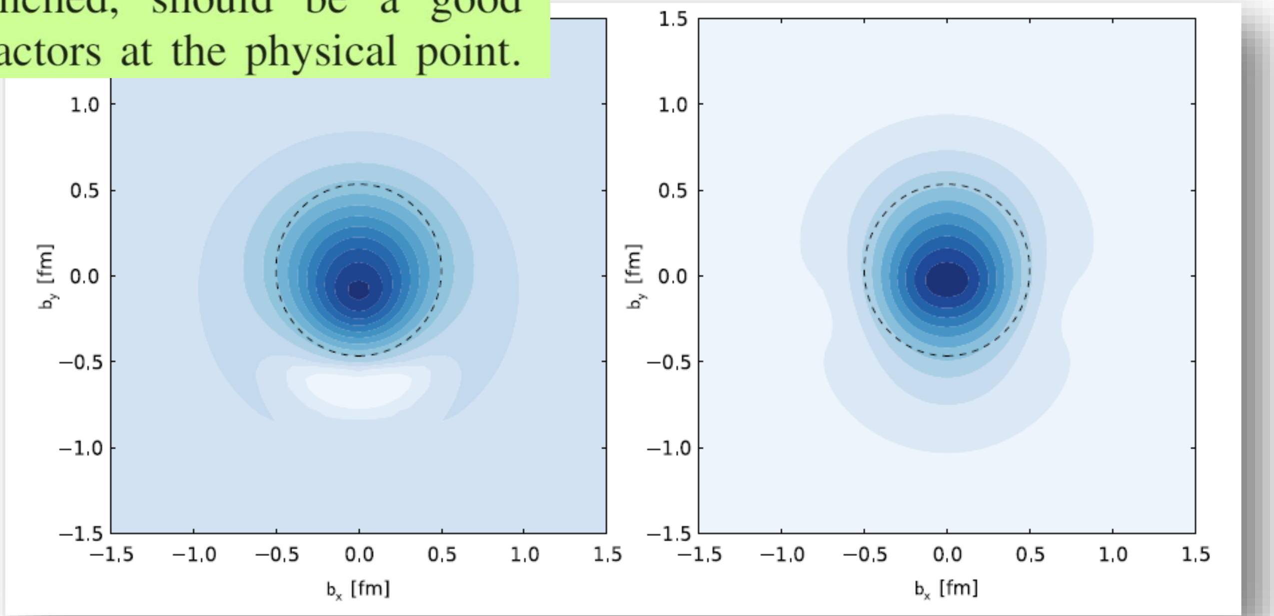
Extracting the Ω^- electric quadrupole moment from lattice QCD data

G. Ramalho[1] and M. T. Peña[1,2]

Another important issue is that in sea quark effects for the Ω^- only at most one single light quark participates, and therefore the pion has no role in this case. As in chiral perturbation theory loops involving mesons heavier than the pion are suppressed, the Ω^- becomes then a special case where meson cloud corrections to the valence quark core are expected to be small. A consequence of the smallness of the meson cloud effects is that lattice QCD simulations, quenched or unquenched, should be a good approximation to Ω^- form factors at the physical point.



he x axis. Left: $\rho^{\Omega}_{T3/2}(\vec{b})$. Right: $\rho^{\Omega}_{T1/2}(\vec{b})$. A
valuation of the densities we used the dipole



Deformation of a Baryon

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

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

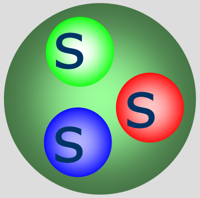
$$Q_s \propto (3J_z^2 - J(J+1)) \xrightarrow[J_z=1/2]{J=1/2} 0$$

- 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 [fm^2]**	**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 $\Delta E_{ls} \sim (aZ)^4\, l \cdot m_\Omega$

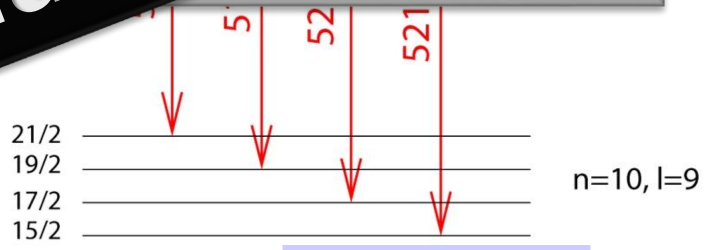
quadrupole $\Delta E_\Theta \sim (aZ)$

$\Omega\bar{\Omega}$ comp

Produ
Stoppi
Single X

⇒ For the within reach

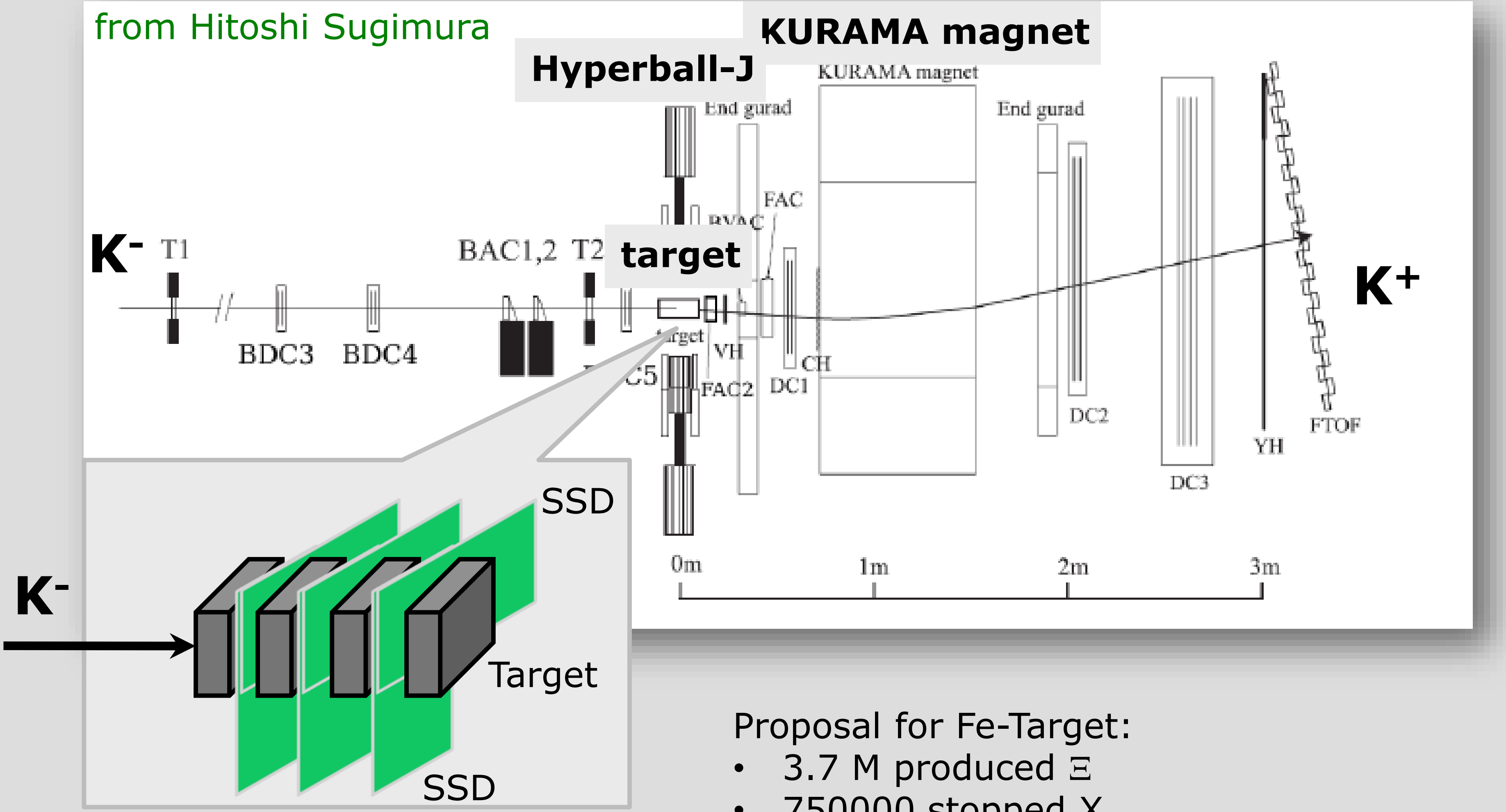
- cali
- $\Delta E_\Theta \sim$ fe



Q_Ω=0.02fm^2

P̄ANDA is the only experiment where this measurement is imaginable

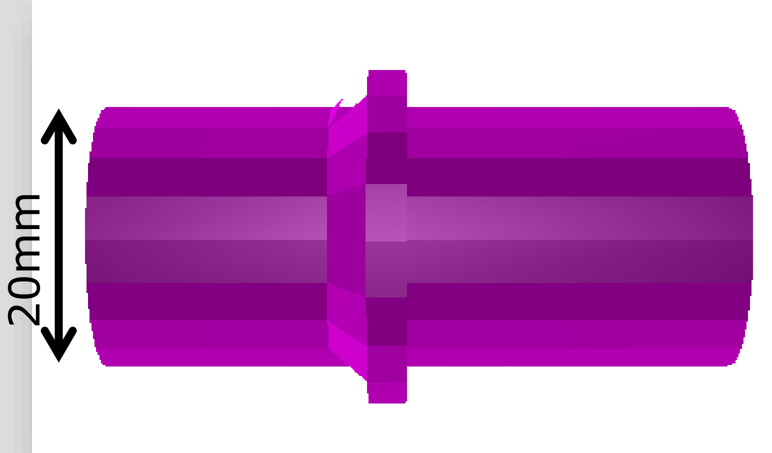
J-PARC E03:Detector Set up

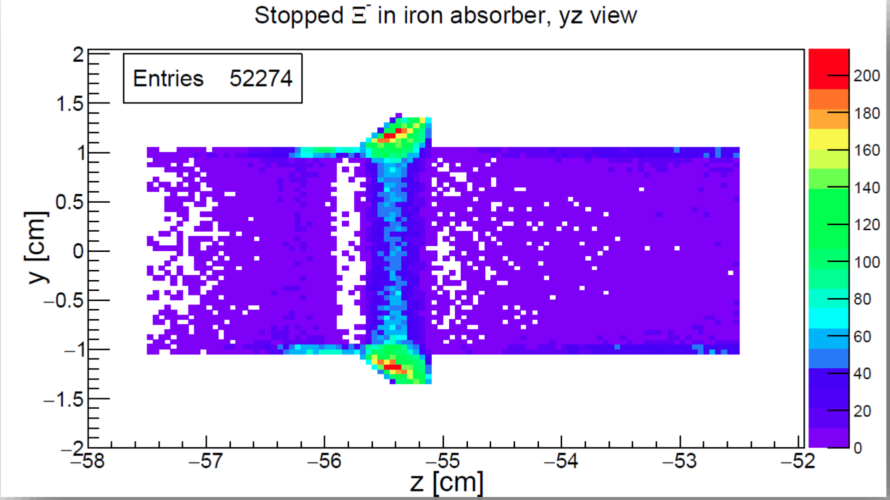


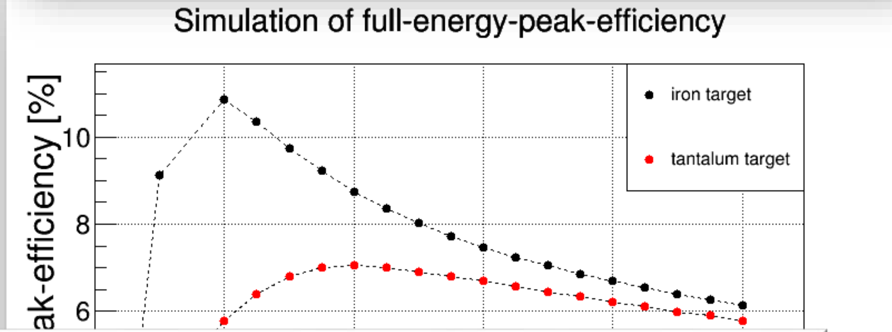
Proposal for Fe-Target:

- 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

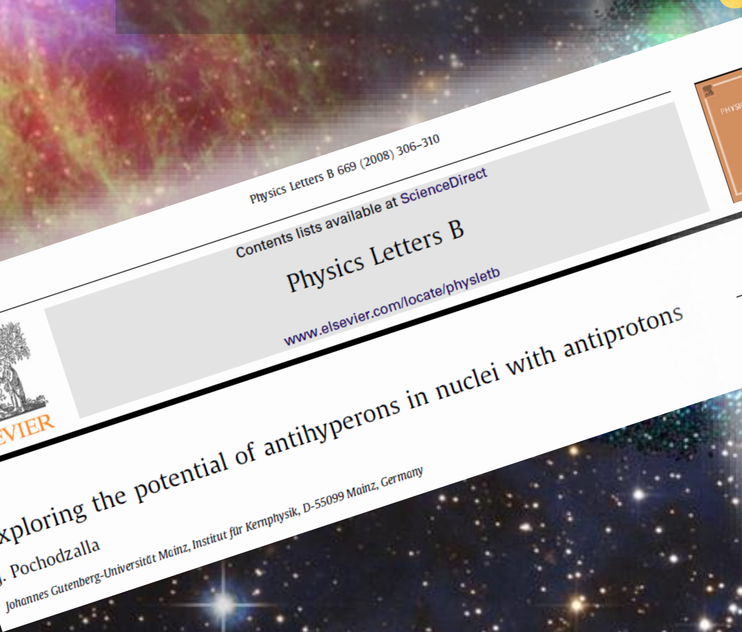
for Ta target ~ 25% less

⇒ ideal for comissioning phase of hypernucleus setup

EXAMPLE 3

A one day day-one experiment

ANTIHYPRONS IN NUCLEI
at PANDA



Physics Letters B 669 (2008) 306–310

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www.elsevier.com/locate/physletb

xploring the potential of antihyperons in nuclei with antiprotons

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Physics Letters B 749 (2015) 421–424

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Physics Letters B

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Antihyperon potentials in nuclei via exclusive antiproton–nucleus reactions

Alicia Sanchez Lorente[a], Sebastian Bleser[a], Marcell Steinen[a], Josef Pochodzalla[a,b,*]

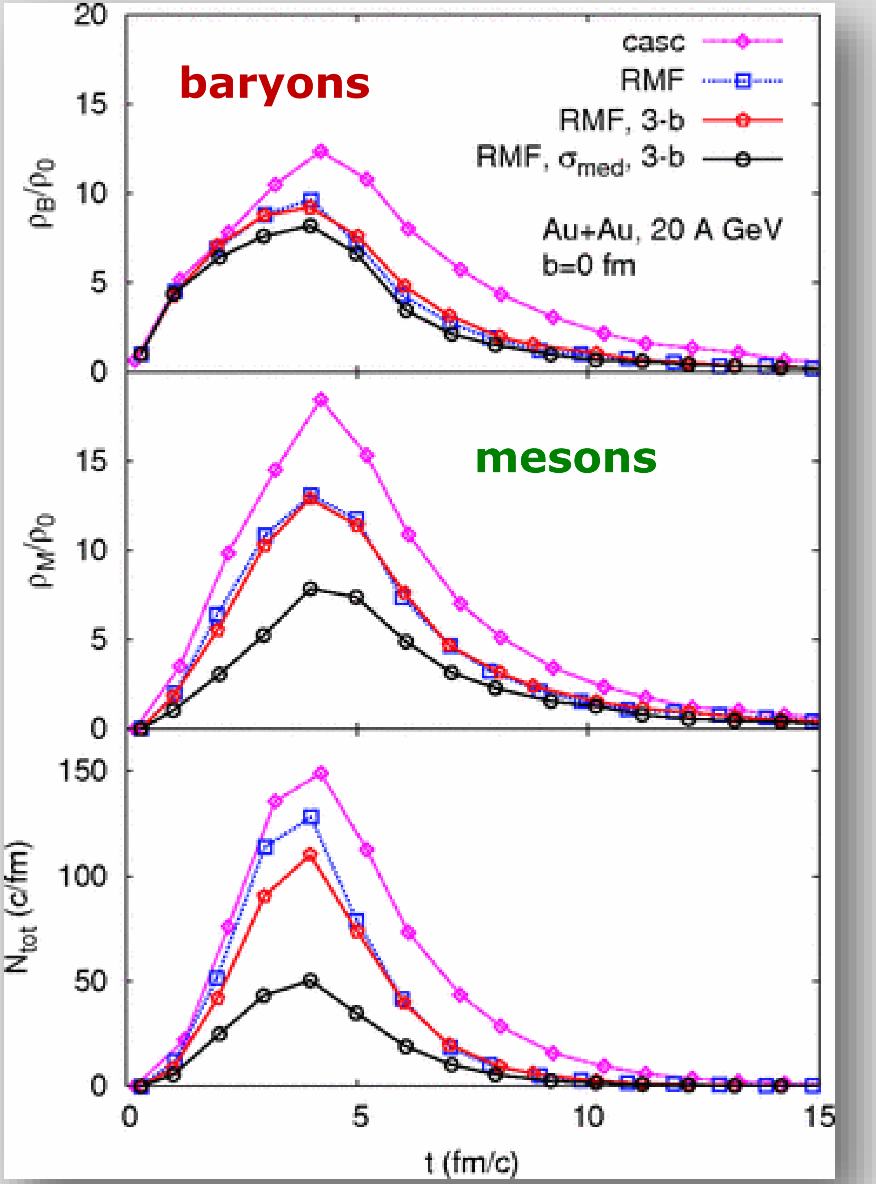
[a] Helmholtz Institut Mainz, Johannes Gutenberg-Universität Mainz, D-55099 Mainz, Germany

[b] Institut für Kernphysik, Johannes Gutenberg-Universität Mainz, D-55099 Mainz, Germany

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

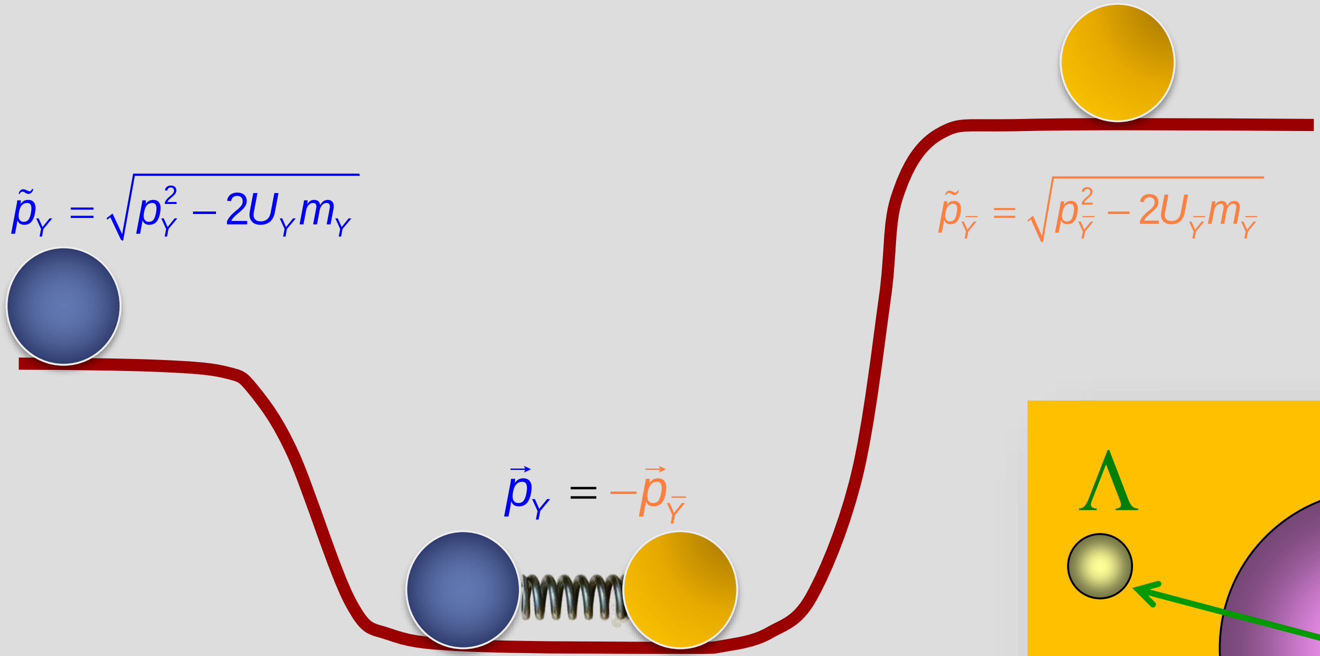
⇒ Let us try an complementary approach to dense baryonic matter



A.B. Larionov, O. Buss, K. Gallmeister, and U. Mosel
Phys. Rev. C 76, 044909 (2007)

$\bar{\Lambda}$ Potential (in Neutron Matter)

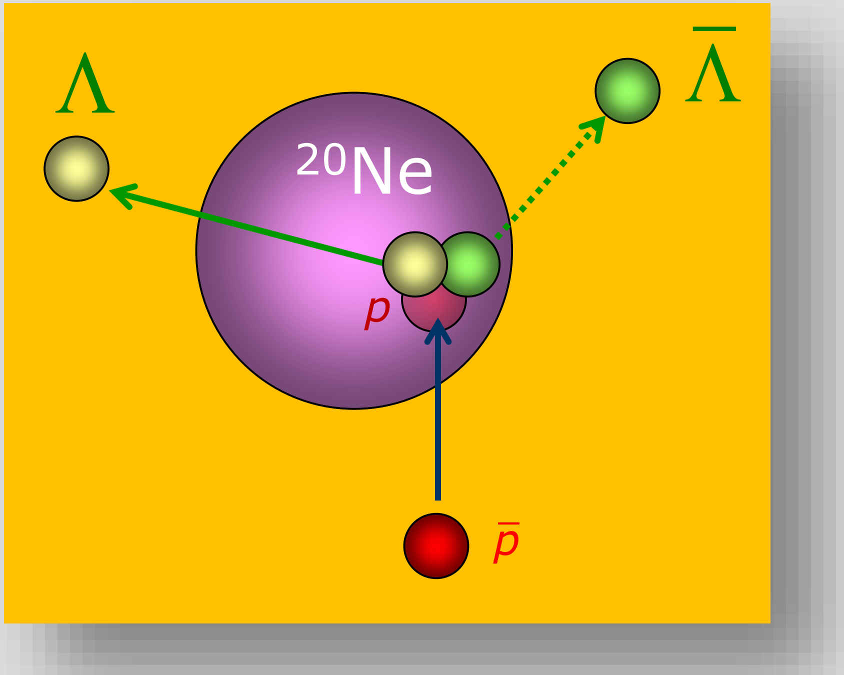
- exclusive $\bar{p}+p(A) \rightarrow Y+\bar{Y}$ close to threshold within a nucleus
- Λ and $\bar{\Lambda}$ that leave the nucleus will have different asymptotic momenta depending on the respective potential



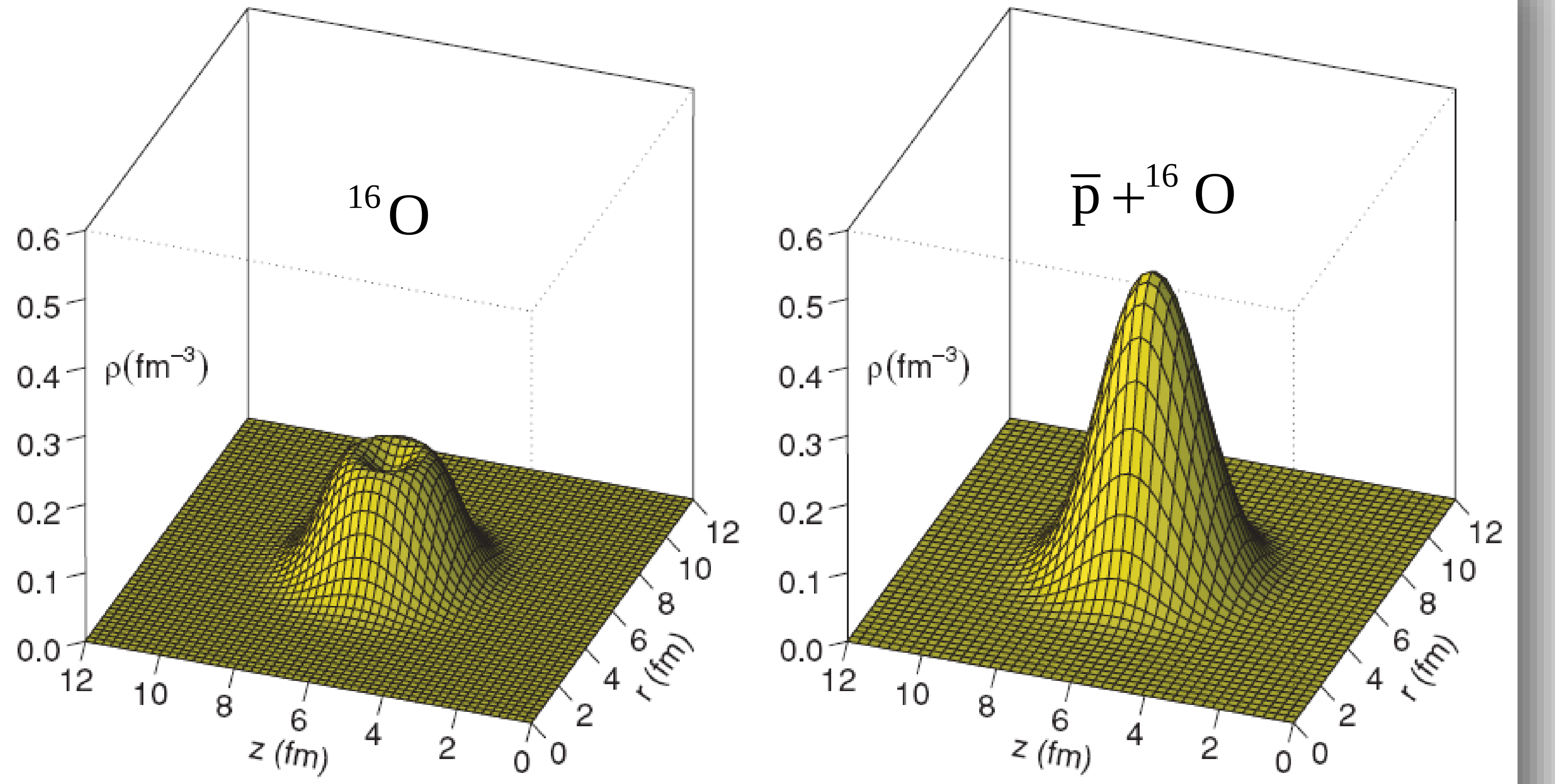
- $\Rightarrow$ *transverse* momentum close to threshold of *coincident* $Y\bar{Y}$ pairs

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

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



Cold compression by antibaryons ?



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

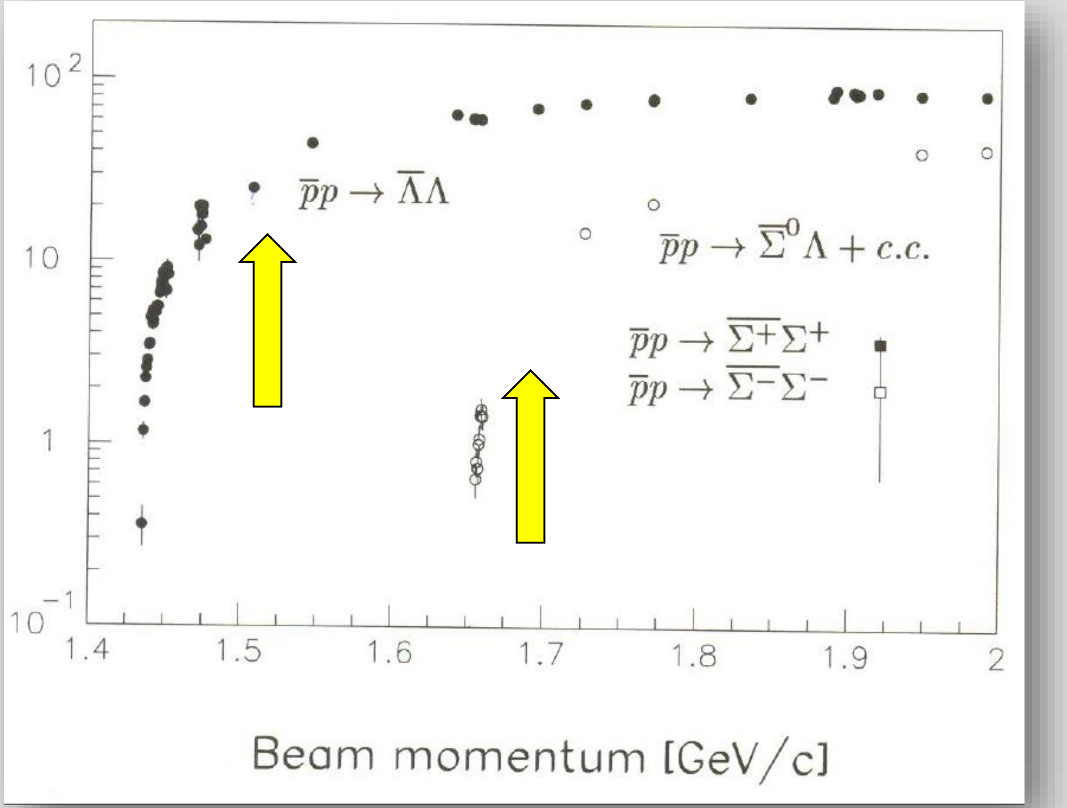
I. N. Mishustin, L. M. Satarov, T. J. Bürvenich, H. Stöcker, and W. Greiner

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

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

- GiBUU
  - G-parity used to estimate anti-baryon potentials except for N̄
  - Approximately 15k exclusive $\Lambda\bar{\Lambda}$ pairs in each set
    corresponds to < 10 min P̄ANDA 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 α_T to a scaling of the real Ȳ potential
  - Proof the feasibility of a measurement at P̄ANDA
  - Trigger a fully self-consistent dynamical treatment of antihyperons in nuclei

GiBUU 1.5

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

Institut für Theoretische Physik, JLU Giessen

GiBUU

The Giessen Boltzmann-Uehling-Uhlenbeck Project

- G-parity used to estimate anti-baryons potential
  - except for $\bar{N}$: Antiproton potential is scaled by 0.22 to obtain -150MeV

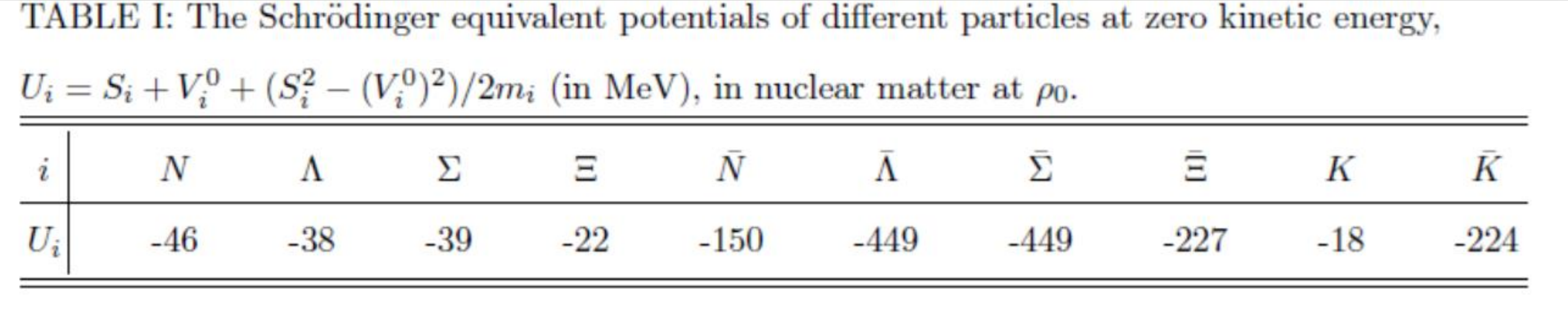


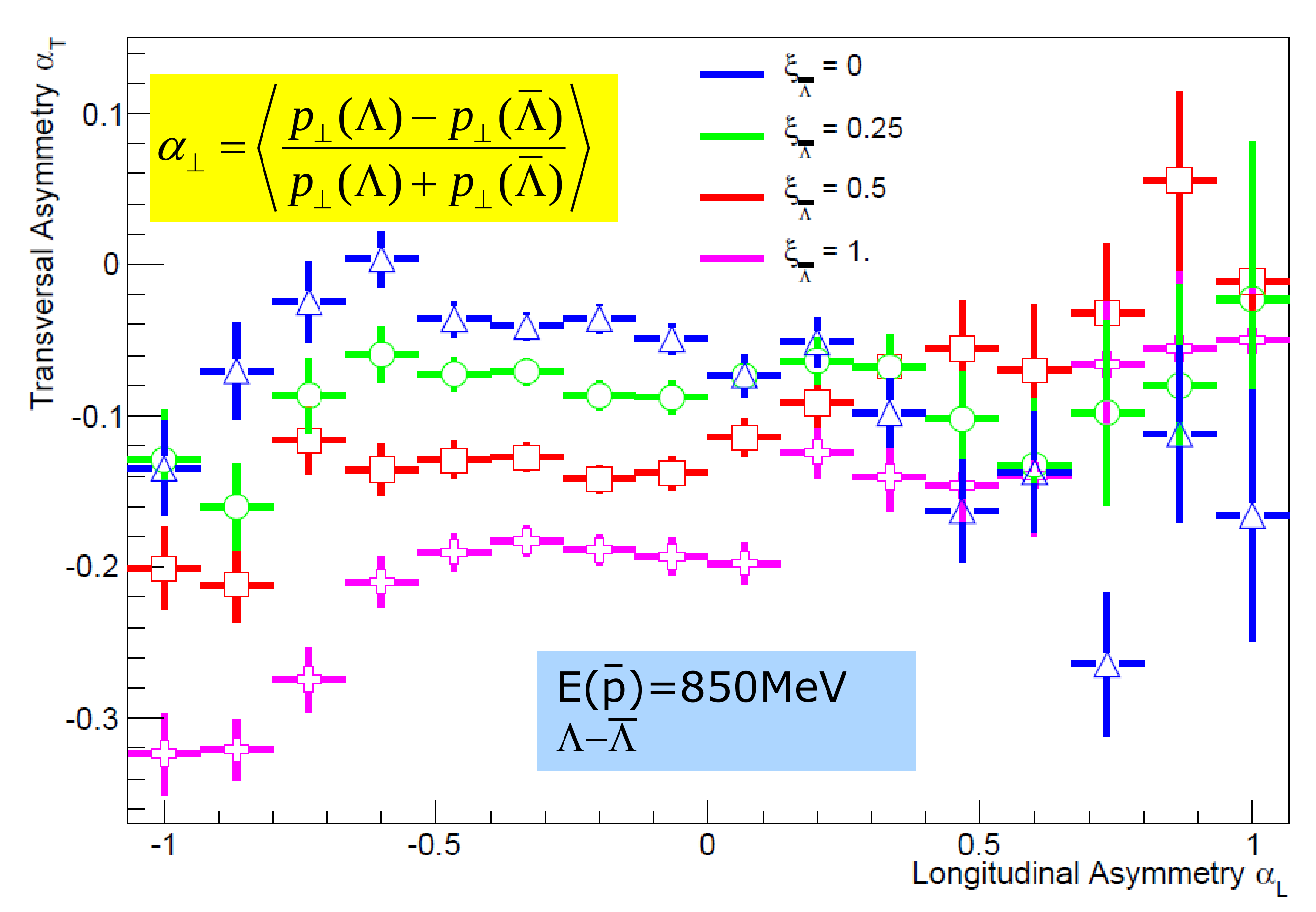
TABLE I: The Schrödinger equivalent potentials of different particles at zero kinetic energy, $U_i = S_i + V_i^0 + (S_i^2 - (V_i^0)^2)/2m_i$ (in MeV), in nuclear matter at ρ_0.

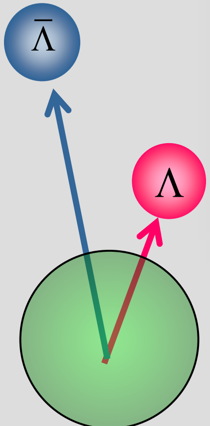
i	N	Λ	Σ	Ξ	$\bar{N}$	$\bar{\Lambda}$	$\bar{\Sigma}$	$\bar{\Xi}$	K	$\bar{K}$
U_i	-46	-38	-39	-22	-150	-449	-449	-227	-18	-224

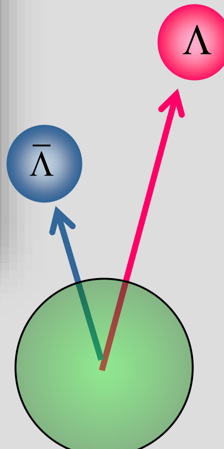
- Aim of the present work
  - Explore sensitivity of α_T to a scaling of the real $\bar{Y}$ potential
  - Proof the feasibility of a measurement at $\bar{\mathrm{P}}$ANDA
  - Trigger a fully self-consistent dynamical treatment of antihyperons in nuclei

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

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





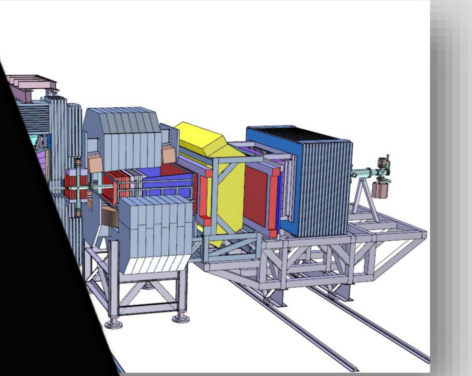


$$\alpha_L = \frac{p_L(\Lambda) - p_L(\bar{\Lambda})}{p_L(\Lambda) + p_L(\bar{\Lambda})}$$

Antihyperon-Hyperon Pairs in P̄ANDA

- 202x first beam in P̄ANDA 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

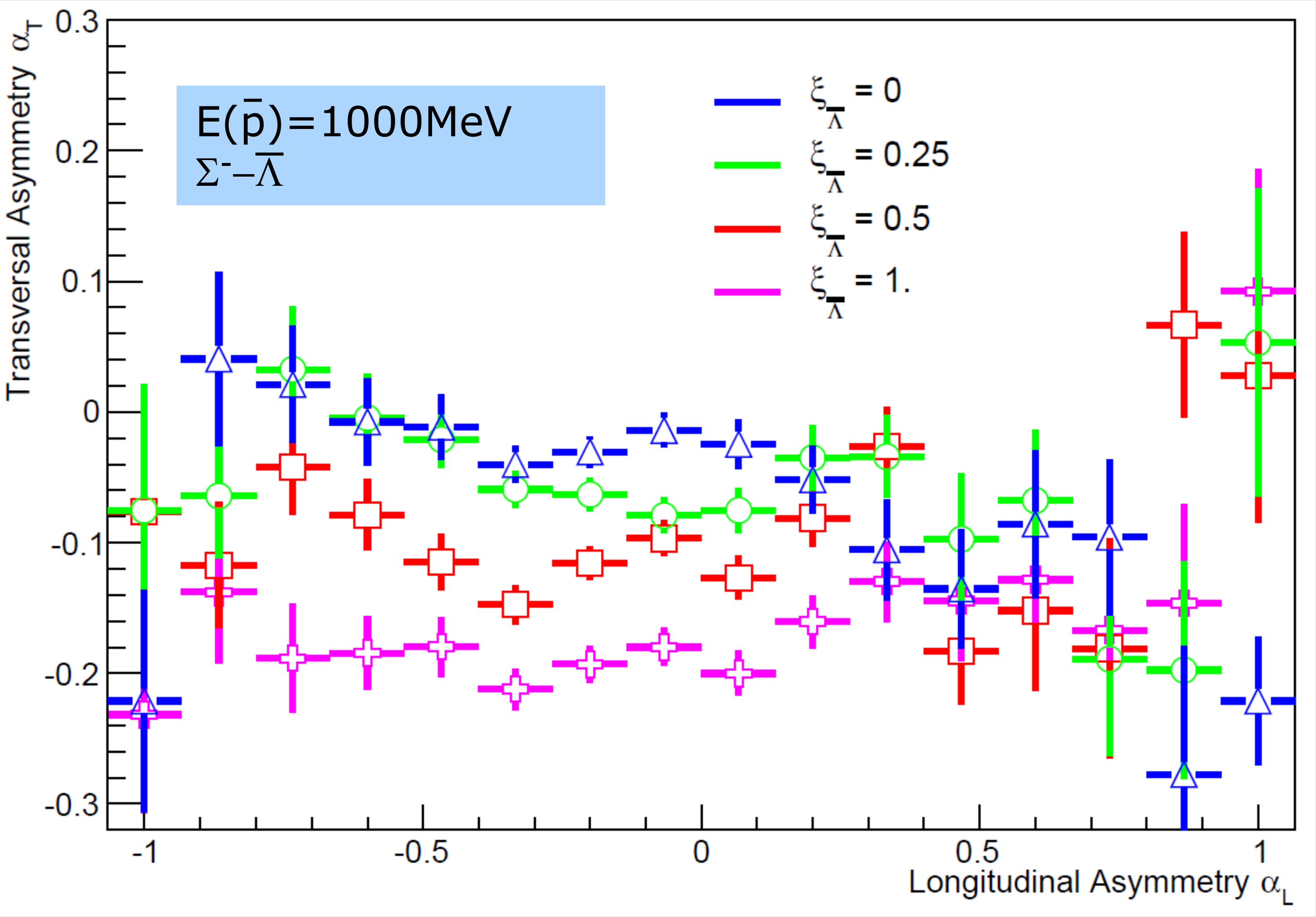
  - Moderate data taking period *~14 days Ne target + 7 days p-target*

    ⇒ 130 × present GiBUU simulations

P̄ANDA is the only experiment where this measurement is possible

Other |s|=1 channels @ 1000MeV

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



Probing the Neutron Skin of Nuclei

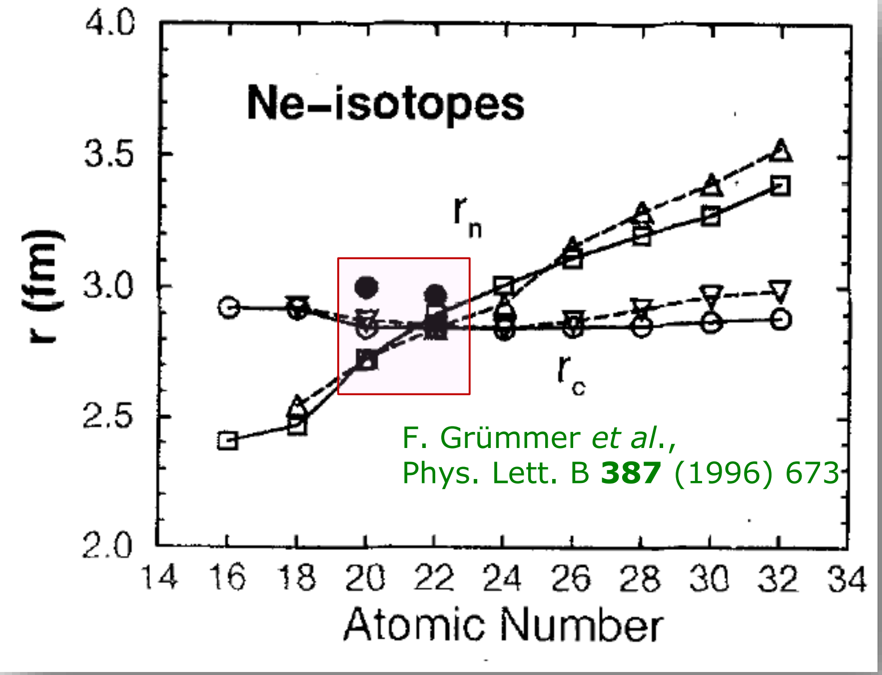
- $\boxed{\bar{p}+p\to\bar{\Lambda}+\Lambda}$ $\quad \bar{p}+p\to\bar{\Sigma}^0+\Lambda$ $\quad \boxed{\bar{p}+n\to\bar{\Lambda}+\Sigma^-}$ $\quad \bar{p}+n\to\bar{\Sigma}^++\Lambda$

absorption length of p̄ $\quad r_{abs} = \frac{1}{\sigma_{abs}\rho} \sim \frac{1}{100mb \cdot 0.17fm^{-3}} \approx \frac{\rho_0}{\rho} 0.6fm$

survival probability $\quad p_{survival} = \exp(-\Delta r / r_{abs})$

- going from ^{20}Ne vs. ^{22}Ne

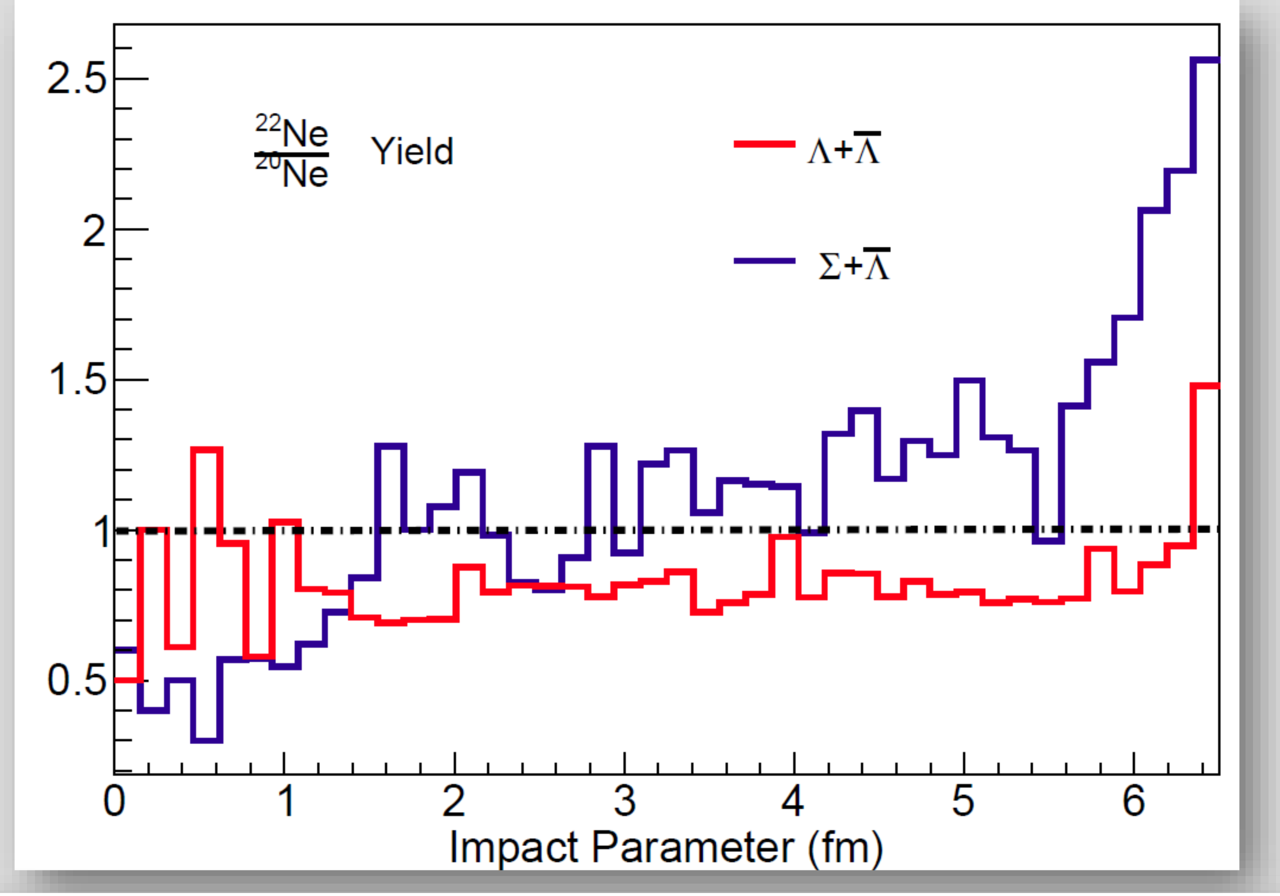
$$p_{survival}(\rho / \rho_0 = 0.5) \approx 0.84 = 1 - p_{abs}$$



F. Grümmer *et al.*, Phys. Lett. B **387** (1996) 673

- additional absorption of antiprotons in neutron skin:
  - $\bar{\Lambda}+\Sigma^-$ will increase in ^{22}Ne with respect to ^{20}Ne by $1+p_{abs} \approx 1.16$
  - $\bar{\Lambda}+\Lambda^-$ will decrease in ^{22}Ne with respect to ^{20}Ne by $1-p_{abs} \approx 0.84$

BUU predictions



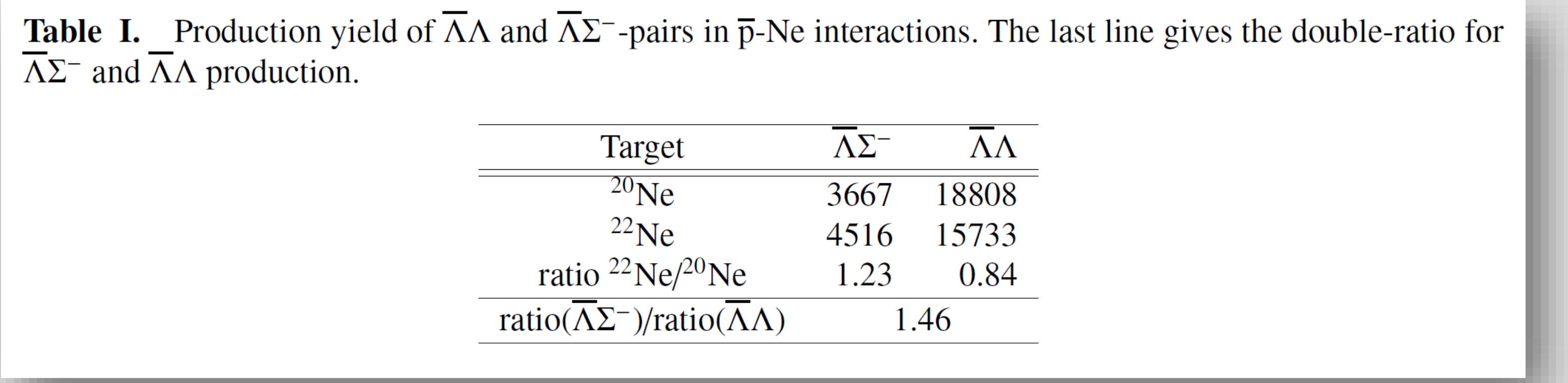


Table I. Production yield of $\overline{\Lambda}\Lambda$ and $\overline{\Lambda}\Sigma^-$-pairs in $\overline{\mathrm{p}}$-Ne interactions. The last line gives the double-ratio for $\overline{\Lambda}\Sigma^-$ and $\overline{\Lambda}\Lambda$ production.

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	

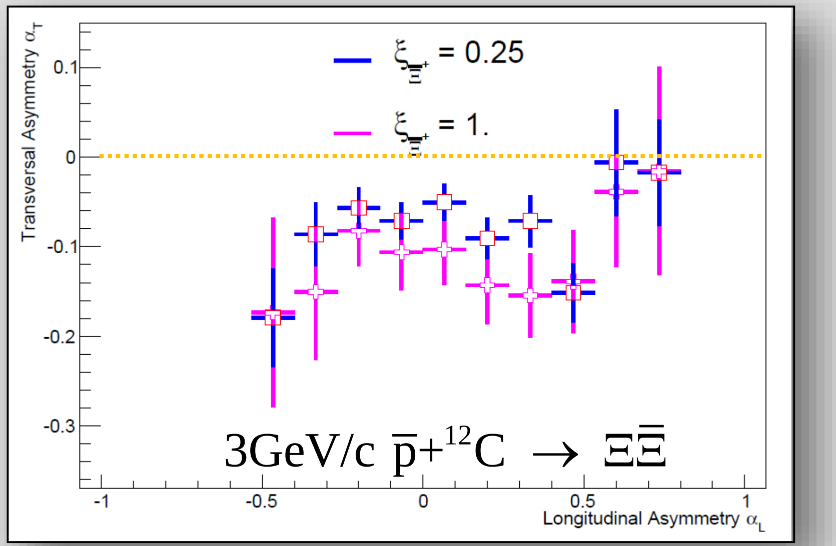
Future Options

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

    Λ(1520) (Γ= 15.6 MeV)

    Ξ(1530) (Γ=9.9 MeV)

    Λ_c(2880) (Γ=5.8MeV)

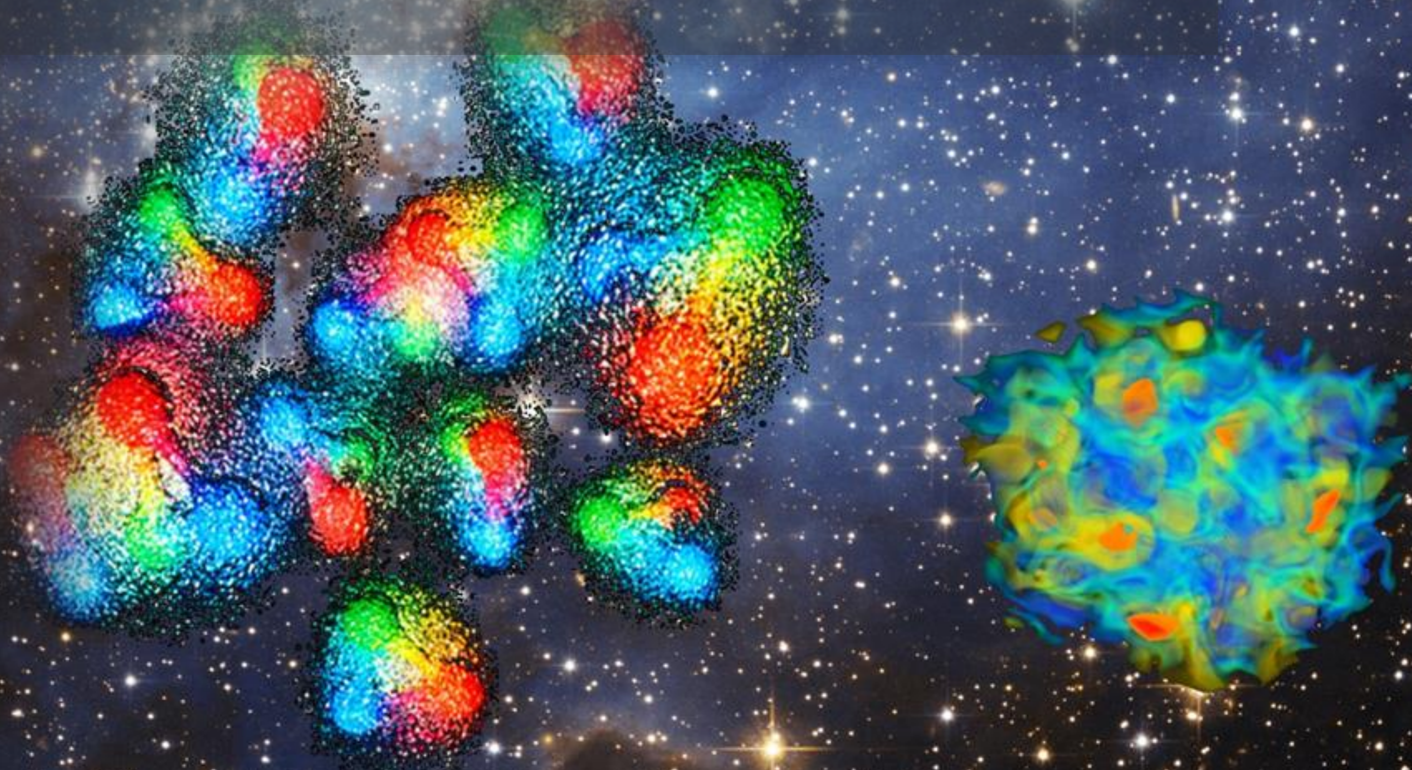


- Unique change to study charmed baryons in nuclear systems ?

EXAMPLE 4

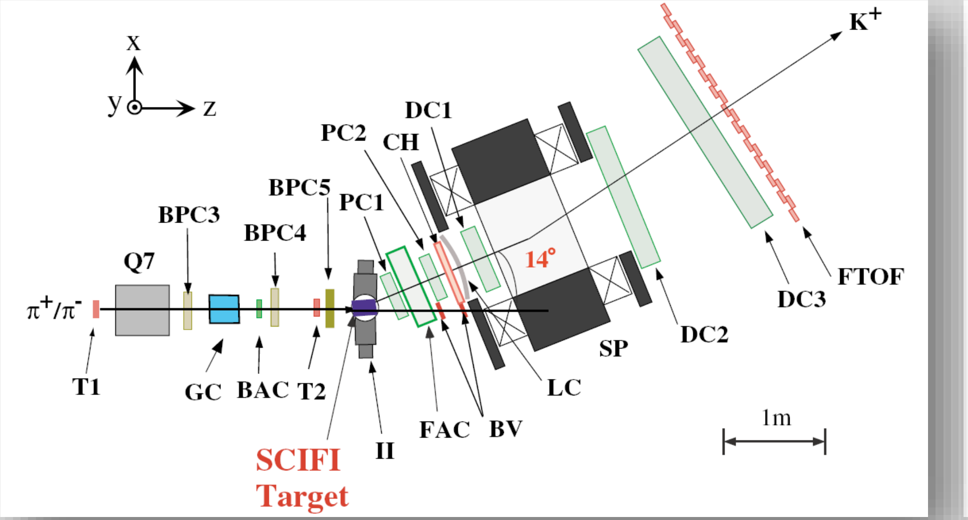
A unique tool to study elementary (anti)hyperon-nucleon interactions

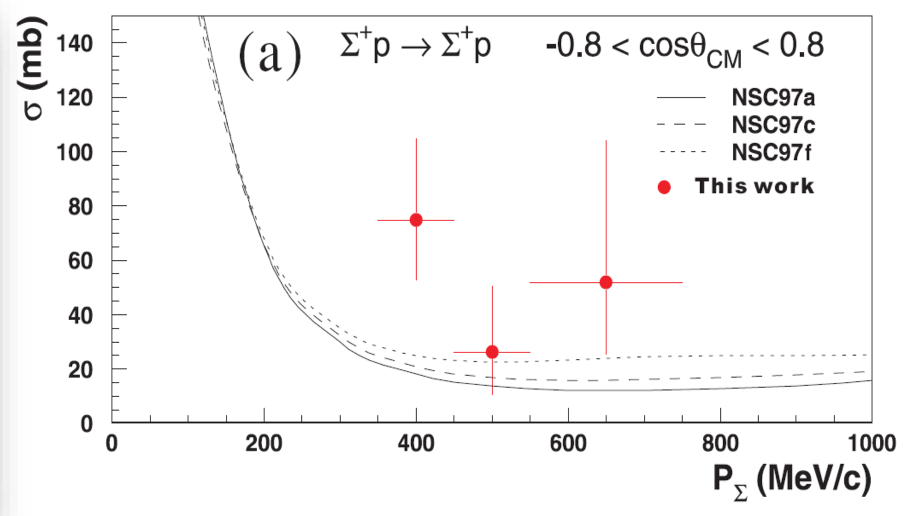
$\bar{p}+p \rightarrow Y - \bar{Y}$ pair production



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
    - Σ^-p: KEK-PS E289 (π^-,K^+) $\Rightarrow$ 30 events
    - Σ^+p: KEK-PS 251 & KEK-PS E289 (π^+,K^+) $\Rightarrow$ 31 events each
    - Ξ^- p: (K^-,K^+) $\Rightarrow$ 1 candidate

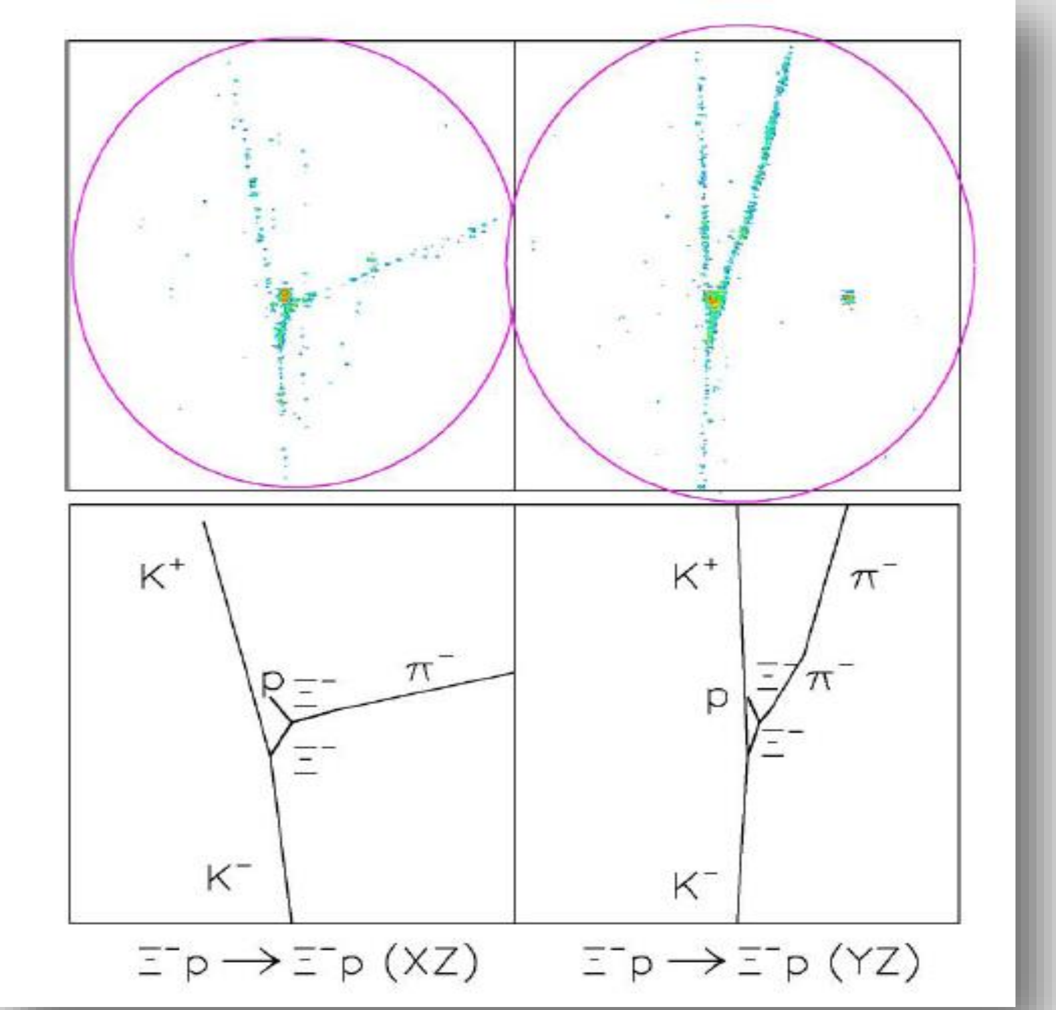




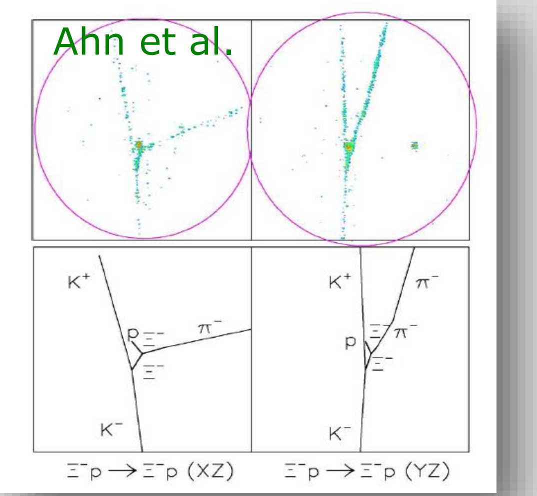
-
  -
    - JPARC: ~1000 events/day
- hyperon-hyperon final state interaction
  - feasible but difficult to interpret
- Tagged hyperon-antihyperon pair production and secondary scattering

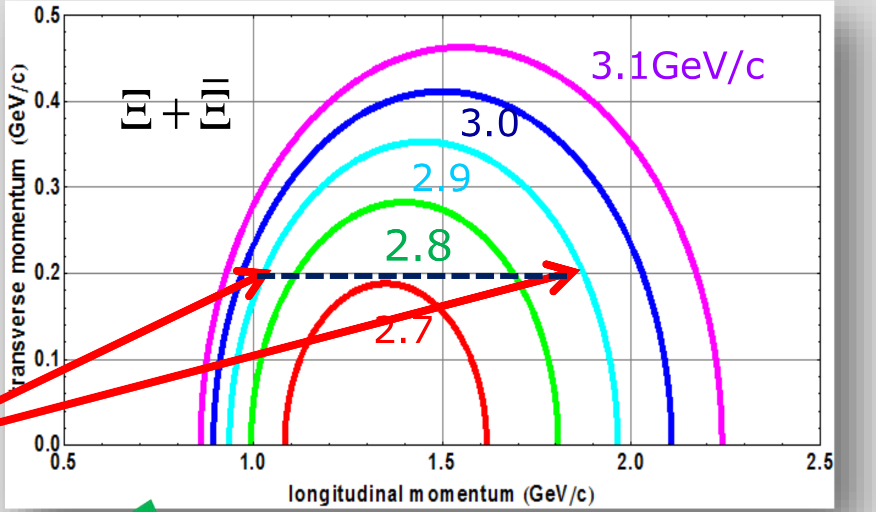
Ξ^- scattering

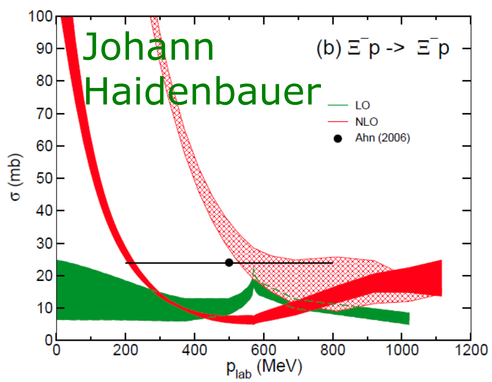
- Ahn et al.

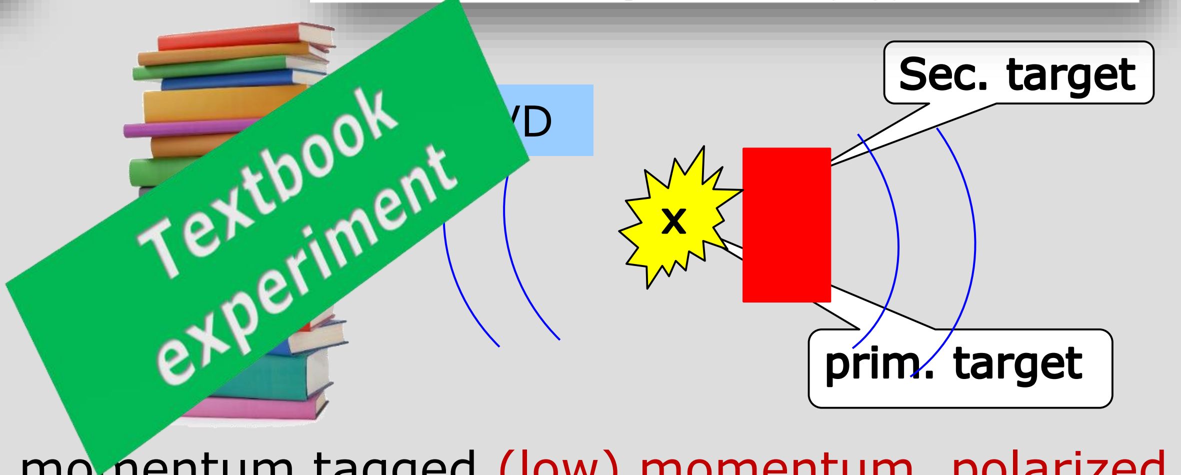


Ξ^- scattering





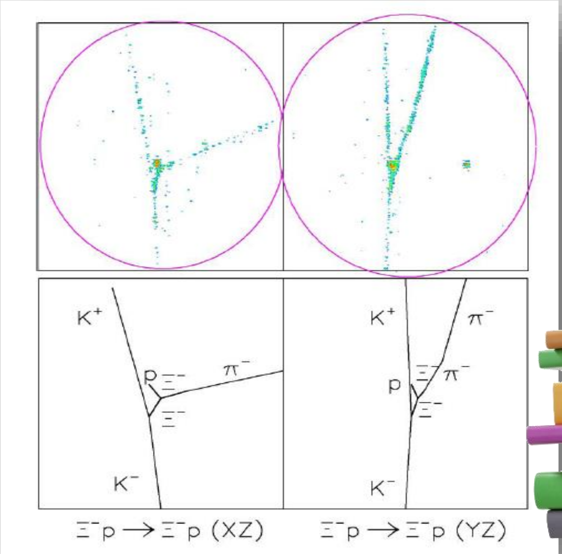


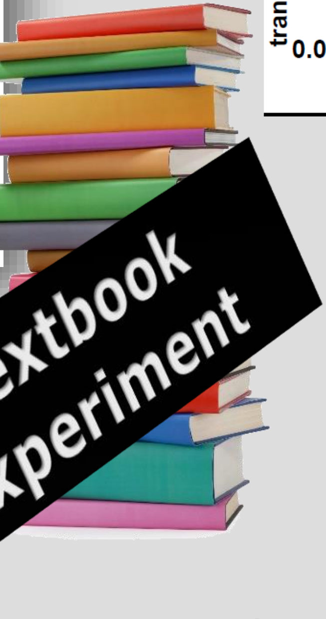


- $\bar{p}+p\rightarrow \bar{Y}+Y$ provides momentum tagged (low) momentum, polarized hyperon *or* antihyperon beams
- scattering experiment with low momentum (anti)hyperons possible
- *long term future:low energy p-$\bar{p}$ collider*

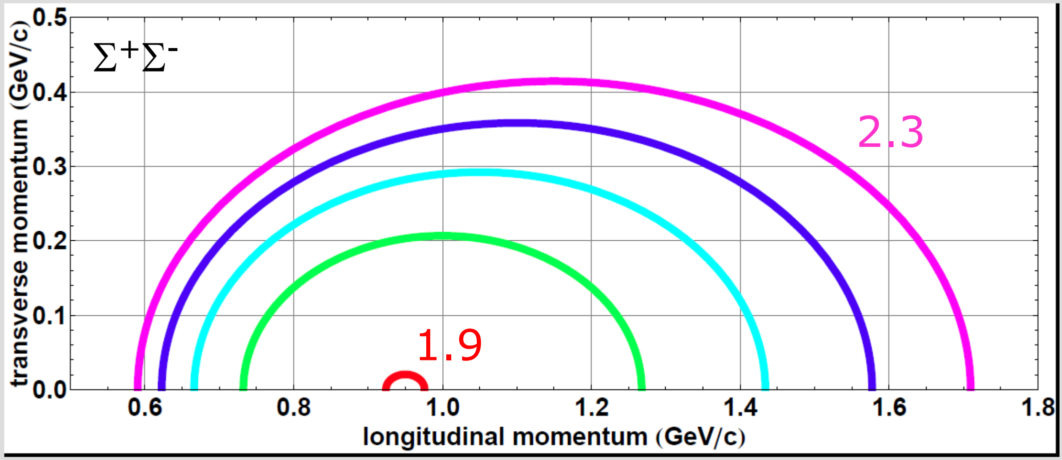
Σ scattering

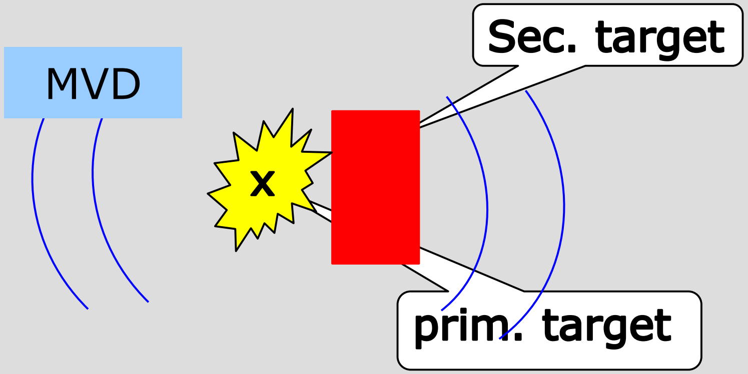
- Ahn et al.





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

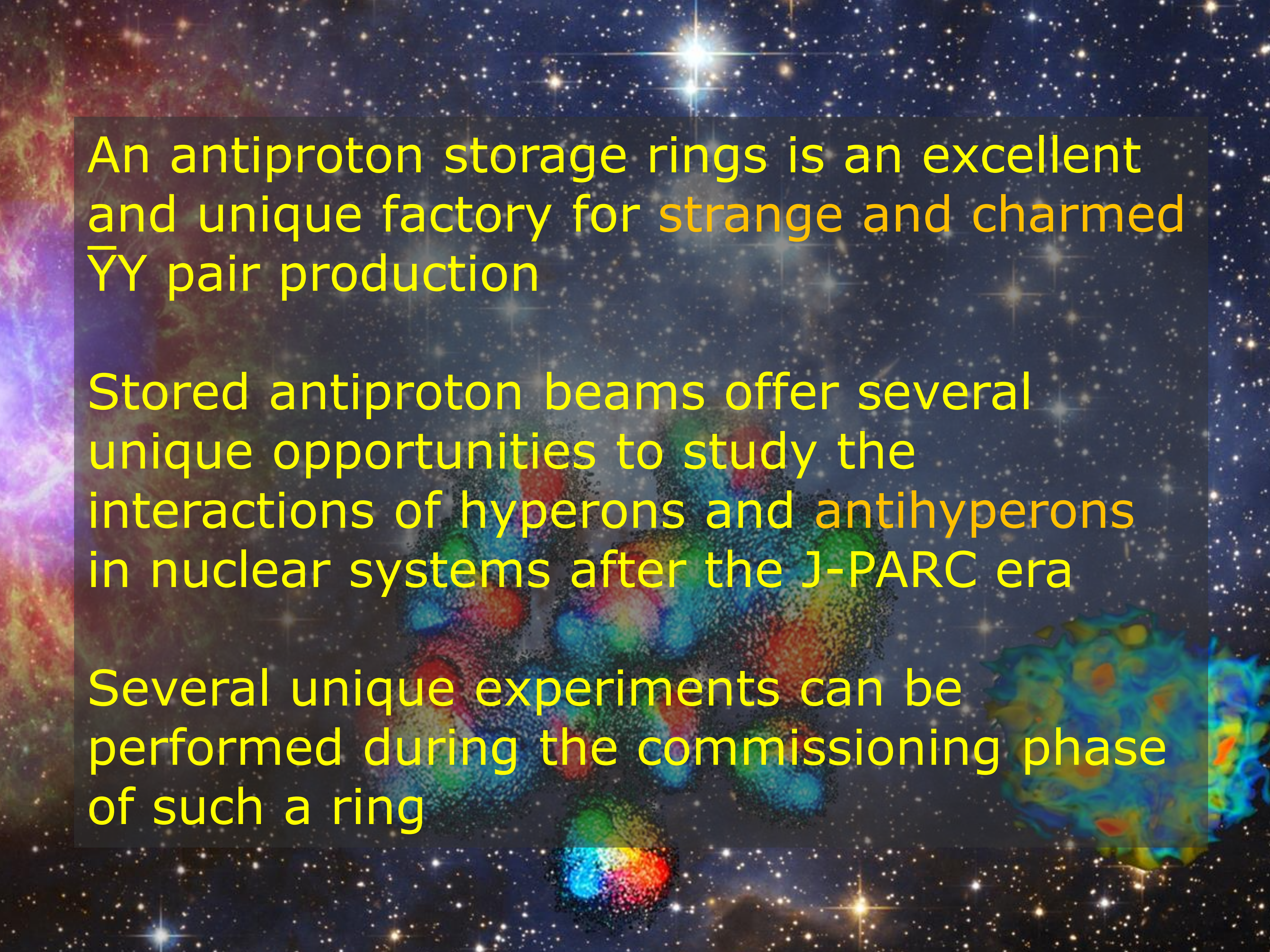




- $\bar{p}+p \rightarrow \bar{Y}+Y$ provides momentum tagged (low) momentum, polarized hyperon *or* antihyperon beams
- scattering experiment with low momentum (anti)hyperons possible

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 era

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