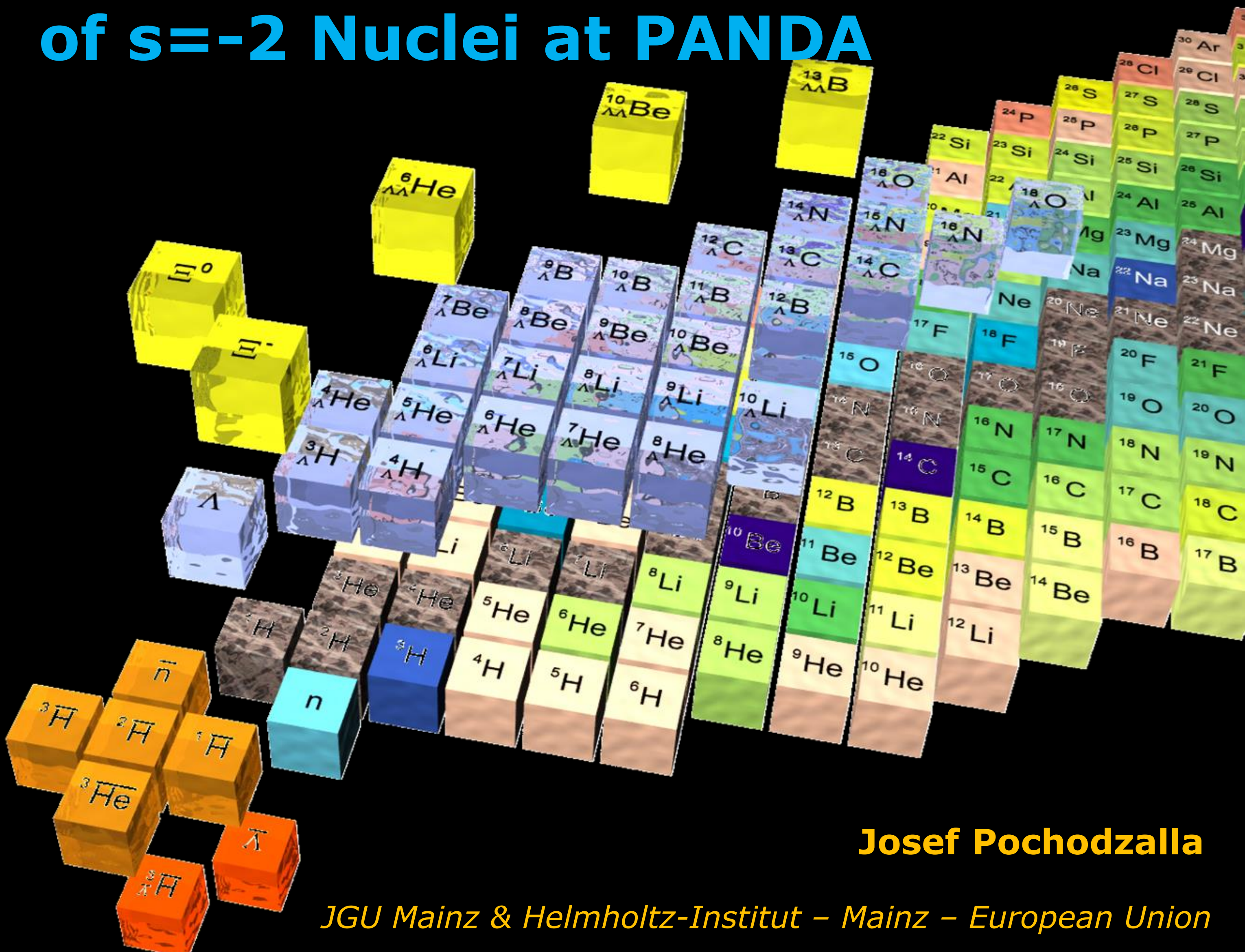
DEGAS Workshop

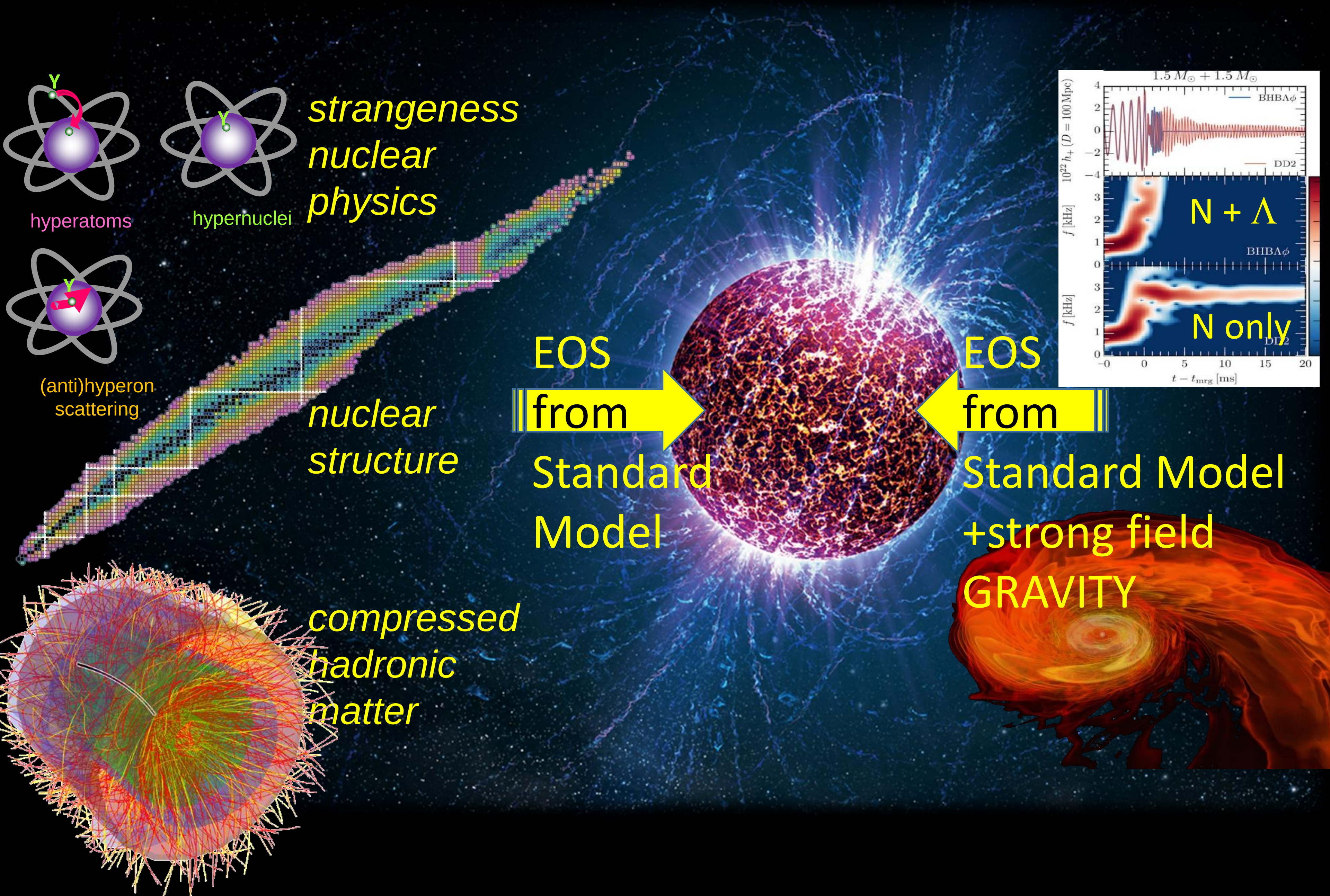
GSI - 26-27 February 2018

Gamma-Spectroscopy of s=-2 Nuclei at PANDA



Josef Pochodzalla

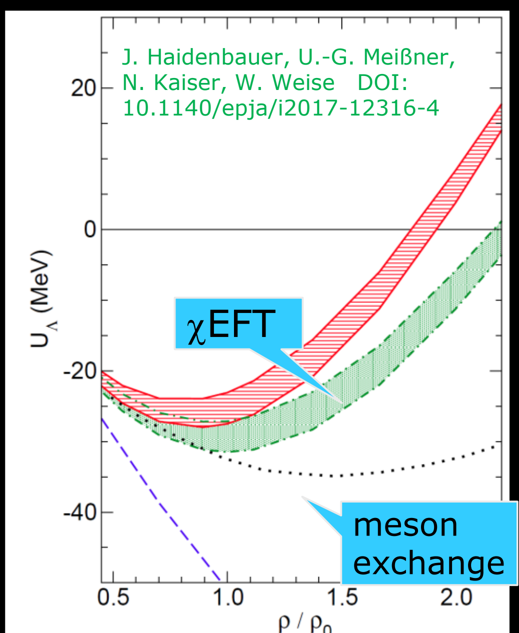
JGU Mainz & Helmholtz-Institut – Mainz – European Union


hyperatoms
hypernuclei
strangeness nuclear physics
(anti)hyperon scattering
nuclear structure
compressed hadronic matter
EOS from Standard Model
EOS from Standard Model +strong field GRAVITY
1.5 M⊙ + 1.5 M⊙
BHBΛφ
DD2
N + Λ
N only
$10^{22} h_+ (D = 100\,\mathrm{Mpc})$
f [kHz]
$t - t_{mrg}$ [ms]

Hyperons in dense nuclear matter

YN and YY Interaction

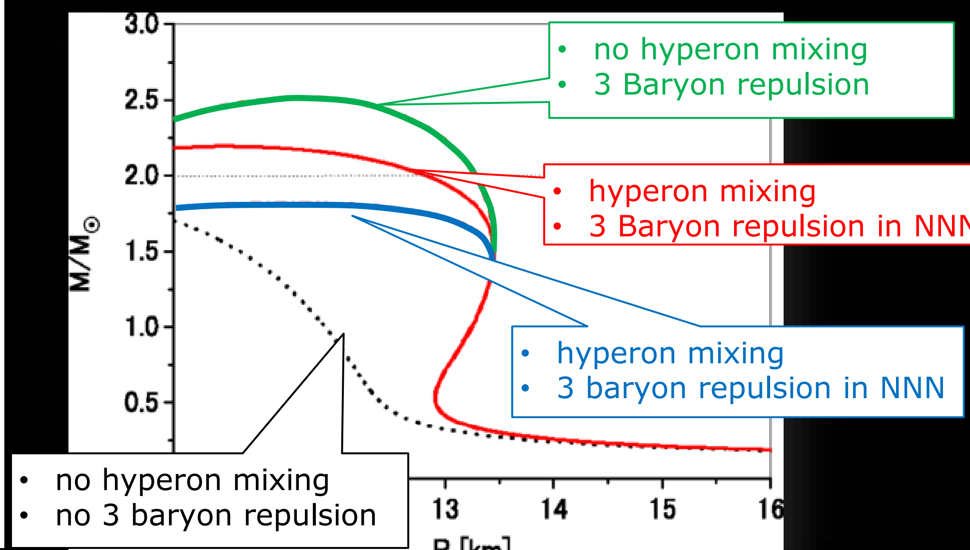
- YY vector meson repulsion: ϕ *meson coupled only to hyperons; yielding strong repulson at high* ρ
- Chiral forces: *YN from* χ*EFT predicts* Λ *s.p. potential more repulsive than from meson exchange*



Hyperonic Three-body force

- Natural solution based on the known importance of 3NN forces in nuclear physics

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



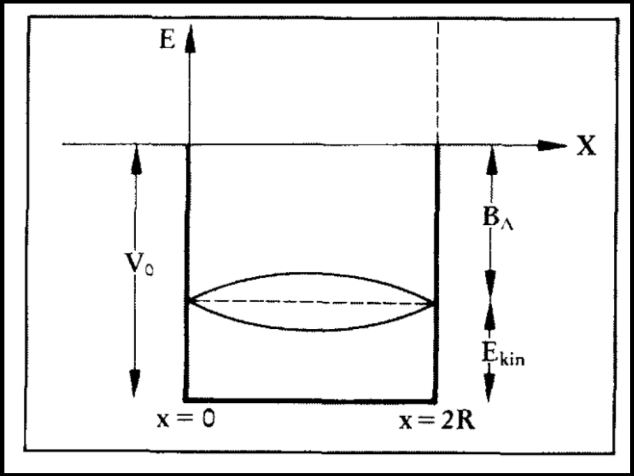
Quark Matter

- Phase transition to deconfined QM at densities lower than hyperon appearence
- That requires QM which
- (i) is significantly repulsive
- (ii) attractive enough to avoid reconfinement

inspired by I. Vidana

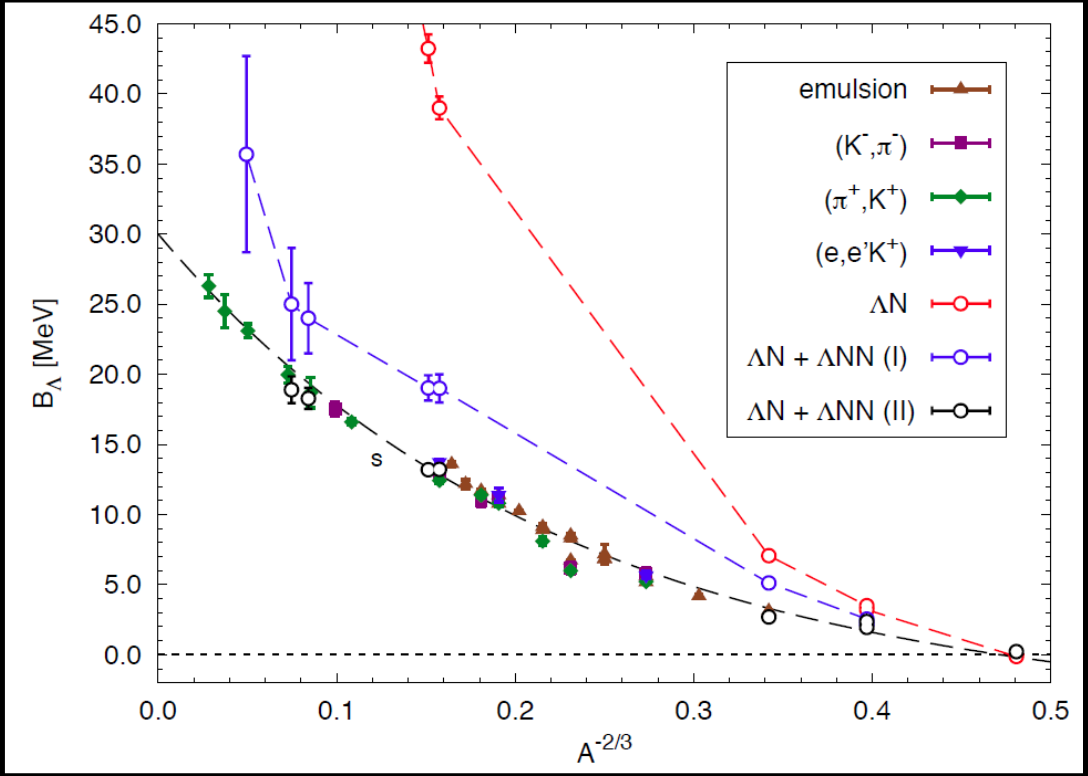
Three-body forces in Hypernuclei

Bogdan Povh, Michael Uhrmacher
Physik in unserer Zeit 5, 138 (1981)



Boxsize $L = 2r_0 \cdot A^{1/3}$

$$\Rightarrow E_{g.s.} = V_0 - B_\Lambda = \frac{3\hbar^2\pi^2}{8m_\Lambda r_0^2} A^{-2/3}$$



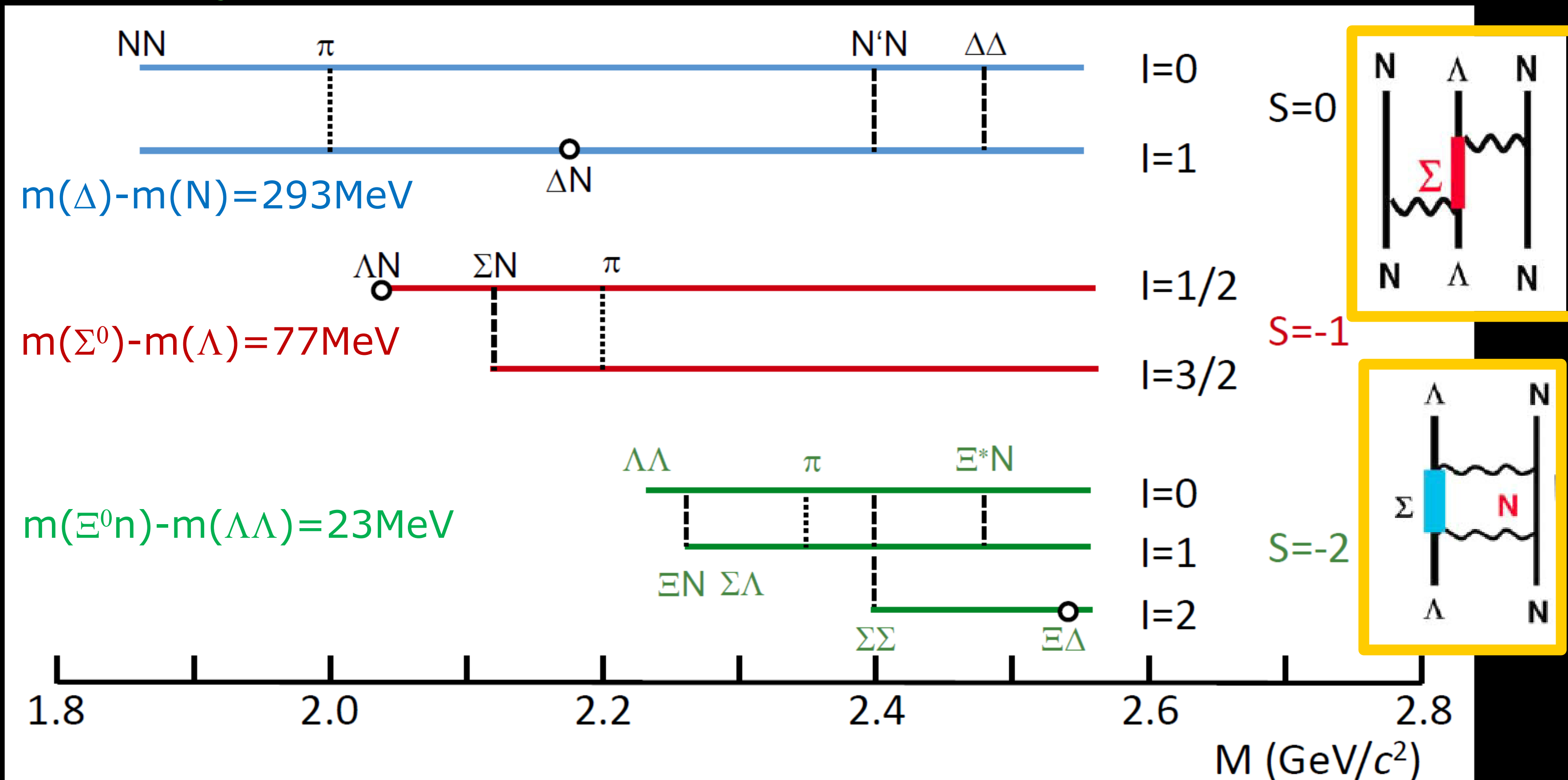
Stefano Gandolfi Diego Lonardoni,
arXiv: 1512.06832

Three baryon interactions involving hyperons are essential
$\Rightarrow$ precission studies of light hypernuclei

Mixing in Hypernuclei

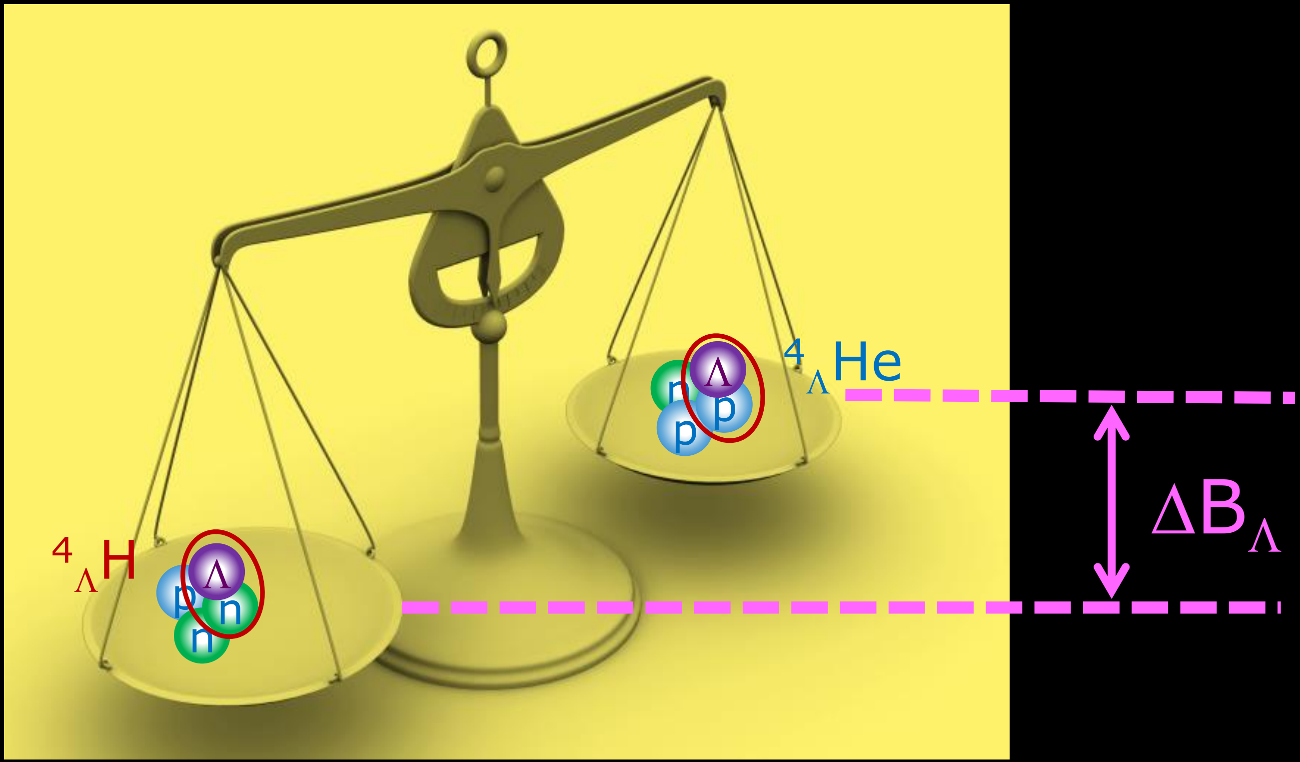
- Mass difference between Σ and Λ in single hypernuclei is small

Thomas Rijken



- hyperon coupling important phenomenon in hypernuclei

Charge Symmetry Breaking

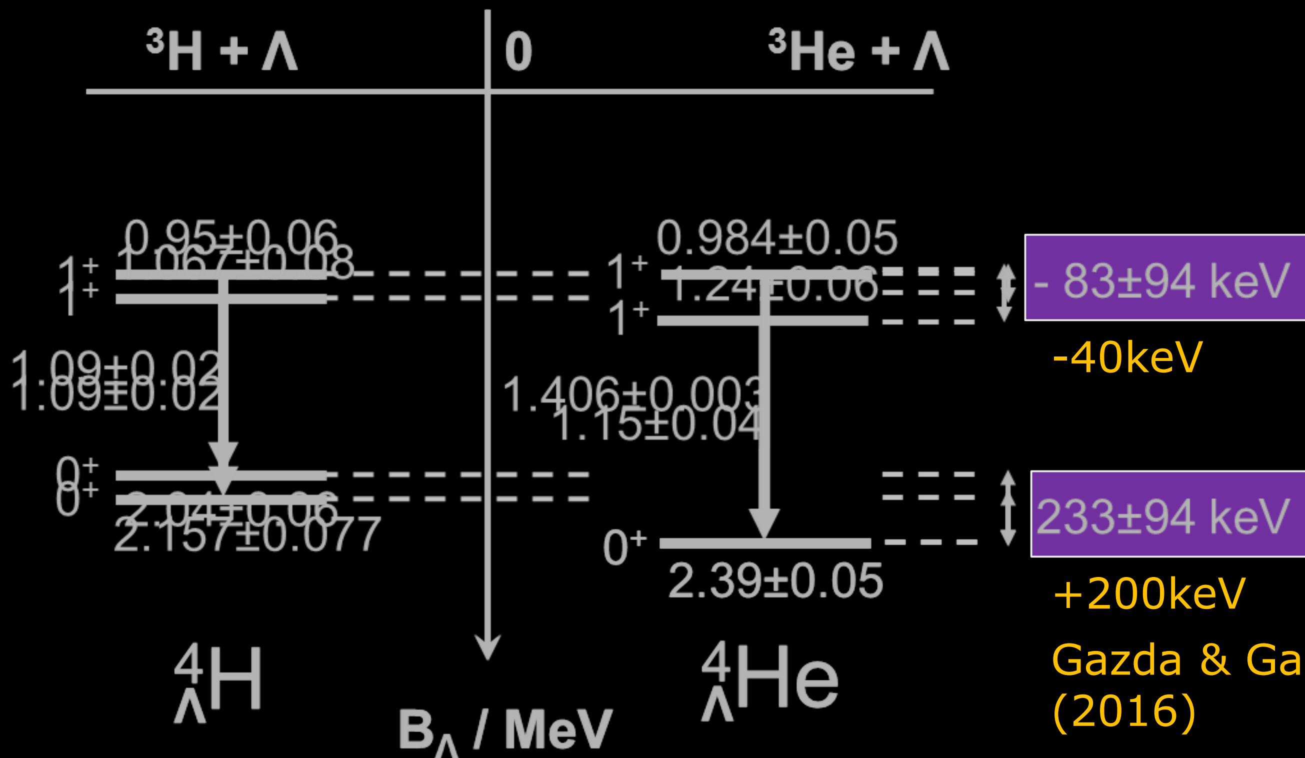


- Binding energy difference ΔB_{Λ} direct measure of CSB (Coulomb corrections are small ~50keV)
- $^{4}_{\Lambda}$H - $^{4}_{\Lambda}$He ground state mass difference exceptionally large ~300keV

What is the spin dependence of the NΛ CSB?

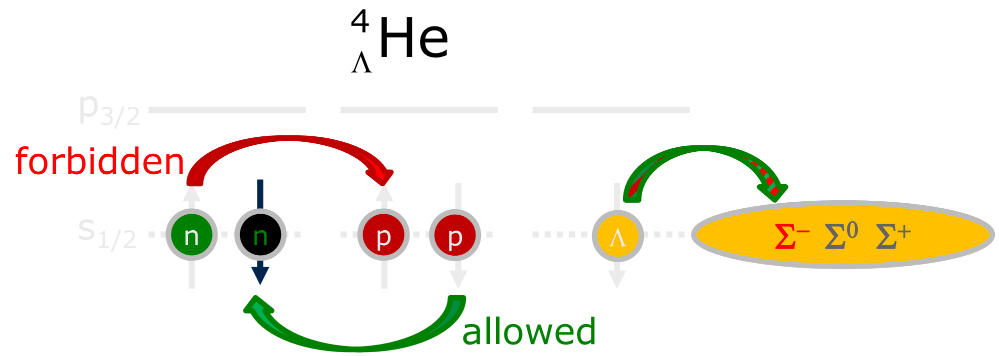
CSB in A=4 Hypernuclei *2016*

- before 2015: not compatible with *all* state-of-the-art calculations

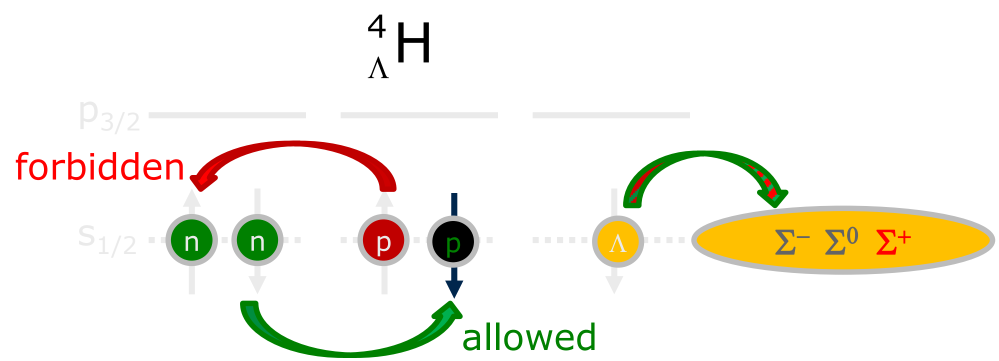


- 2015: strong, spin-dependent charge symmetry breaking (CSB) in A = 4 mirror hypernuclei !
- Compatible with *ab initio* calculations

Mixing in A=4 Hypersystems

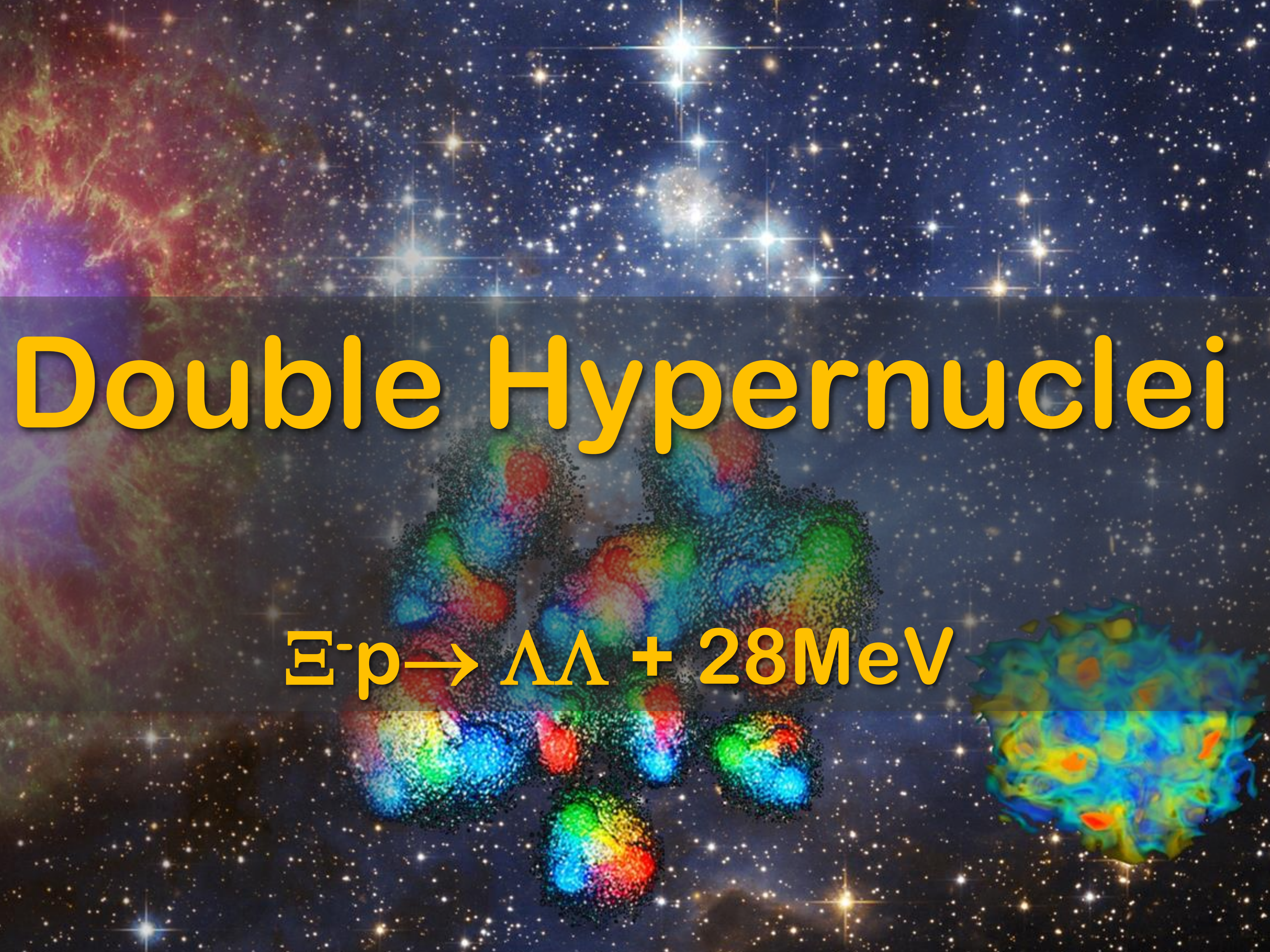


$$\left|{}^4_\Lambda\mathrm{He}\right\rangle = \alpha\left|\Lambda \otimes {}^3\mathrm{He}\right\rangle + \beta\left|\Sigma^0 \otimes {}^3\mathrm{He}\right\rangle + \gamma\left|\Sigma^+ \otimes {}^3\mathrm{H}\right\rangle$$

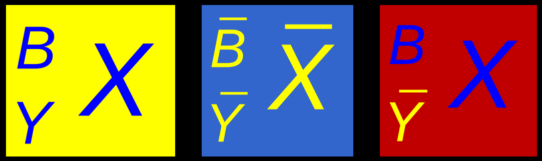


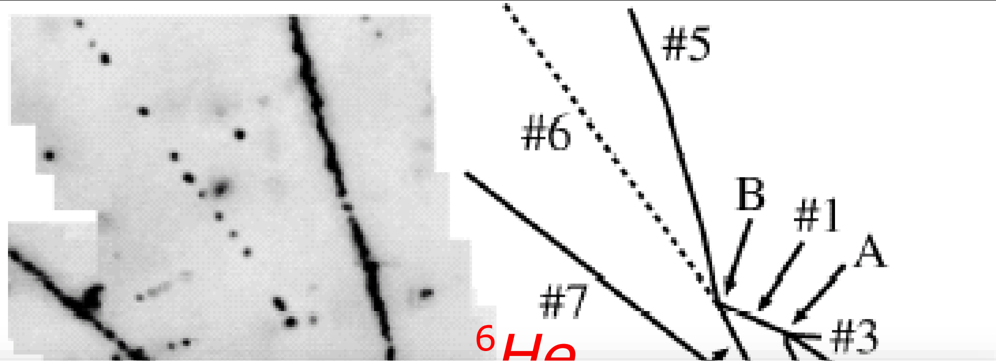
$$\left|{}^4_\Lambda\mathrm{H}\right\rangle = \alpha\left|\Lambda \otimes {}^3\mathrm{H}\right\rangle + \beta\left|\Sigma^0 \otimes {}^3\mathrm{H}\right\rangle + \gamma\left|\Sigma^- \otimes {}^3\mathrm{He}\right\rangle$$

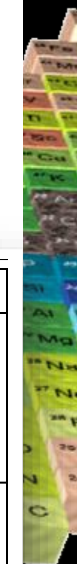
- Coulomb interaction and mass difference in Σ isotriplet is important (Gibson, Goldberg, Weiss 1972)


Double Hypernuclei
$\Xi^- p \rightarrow \Lambda\Lambda + 28\mathrm{MeV}$

Double Hypernuclei are Shy

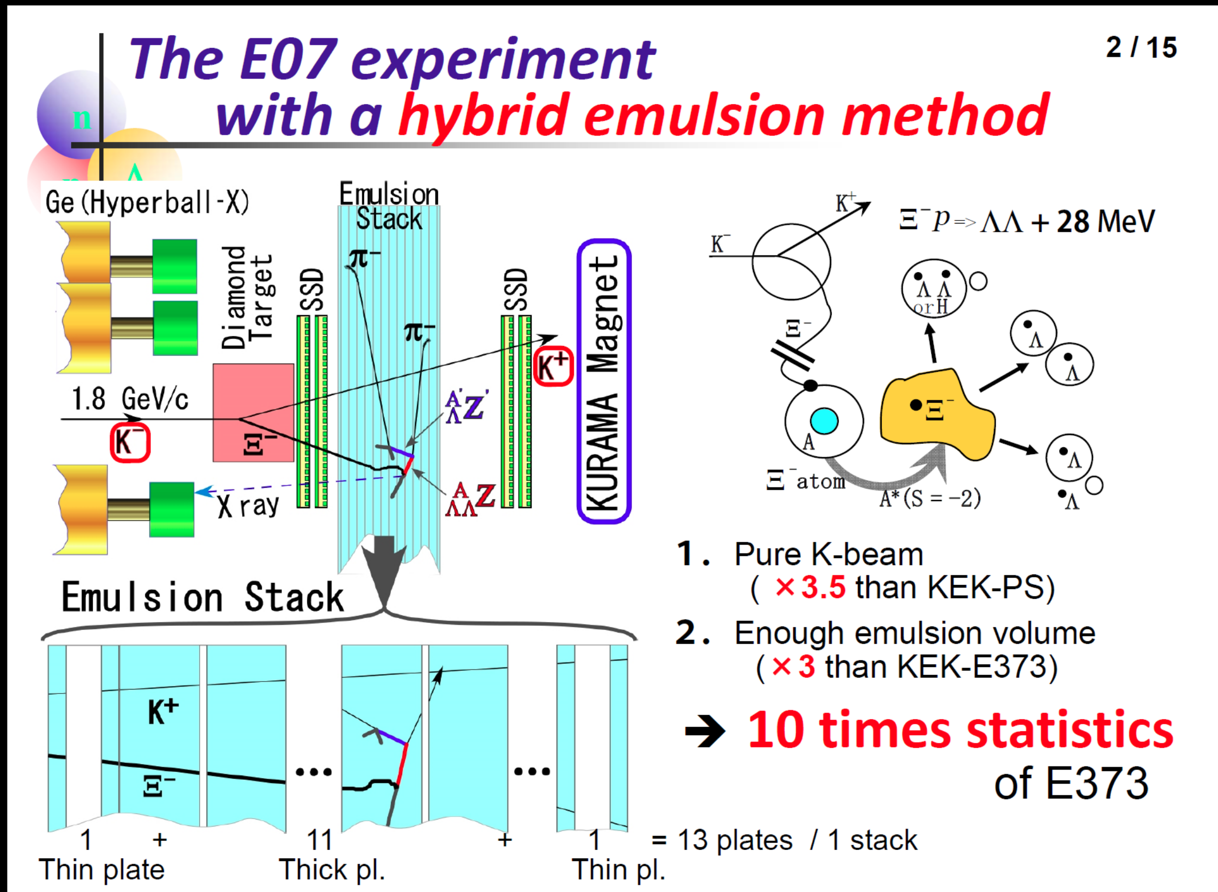






Nucleus	$\Delta B_{\Lambda\Lambda}(^{A}_{\Lambda\Lambda}Z)$ (MeV)	Experiment	Reference	Remark
$^{10}_{\Lambda\Lambda}$Be	4.3 ± 0.4	Danysz (1963)	[77, 78] [74]	K^- + nuclear emulsion; $\Delta B_{\Lambda\Lambda}$ consistent with NAGARA if decay to $^{9}_{\Lambda}$Be* at $E_x \approx 3$ MeV [81, 11]
$^{6}_{\Lambda\Lambda}$He	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]	

E07 @ J-PARC

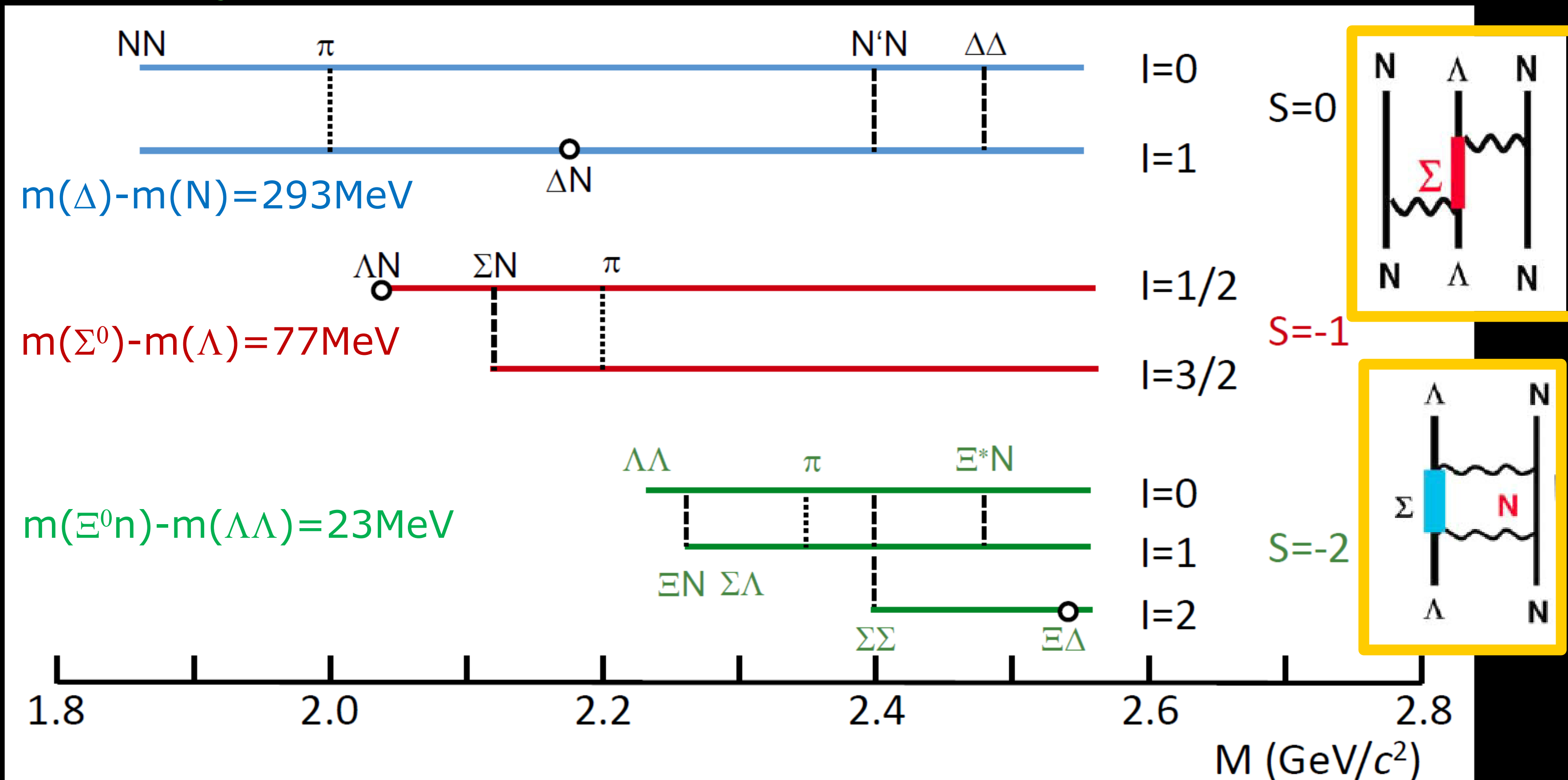


- Beam exposure has successfully been performed for all emulsion stacks in 2016/2017
- auto-scanning has started
- limitation: only ground state masses for $\Lambda\Lambda$-hypernuclei can be determined

Mixing in Hypernuclei

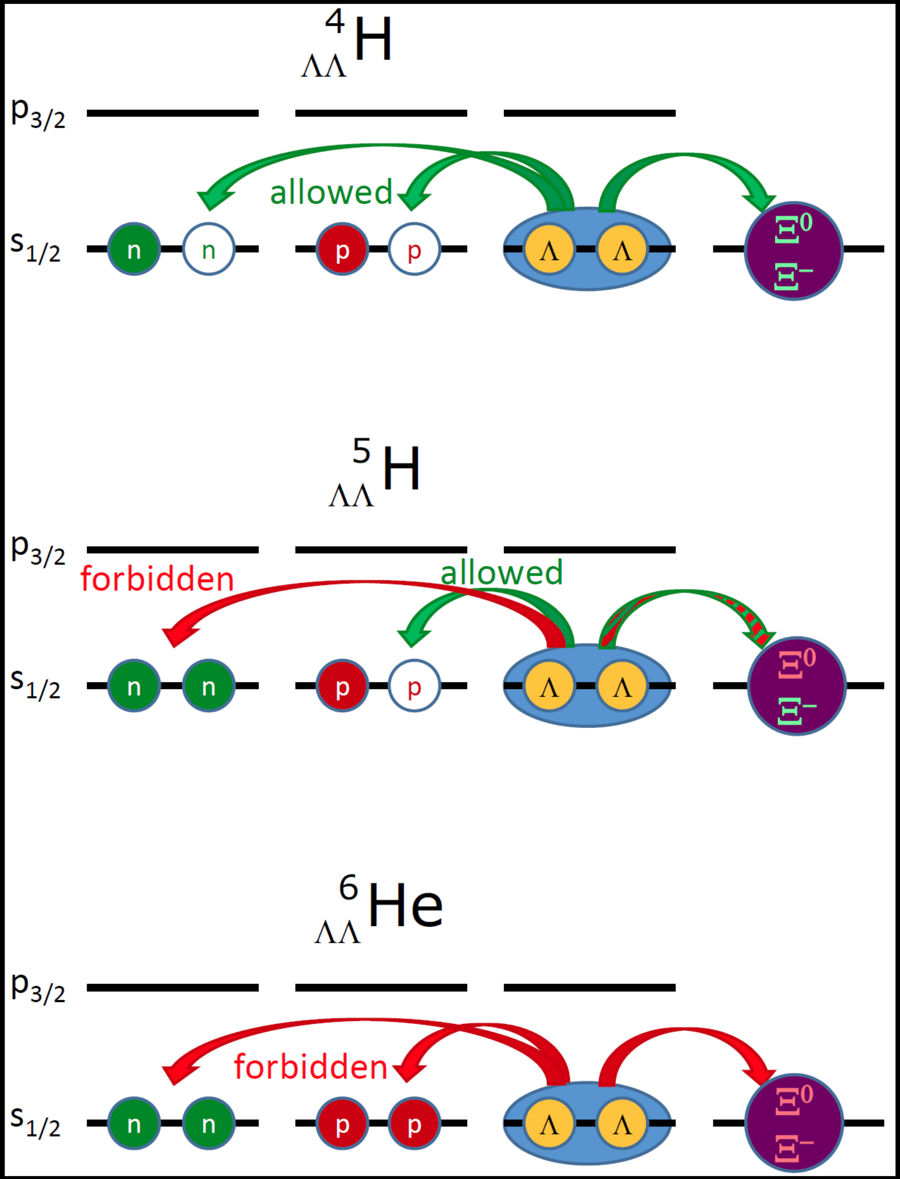
- Mass difference between Σ and Λ in single hypernuclei is small

Thomas Rijken



- hyperon coupling important phenomenon in hypernuclei

Mixing in Double Hypernuclei

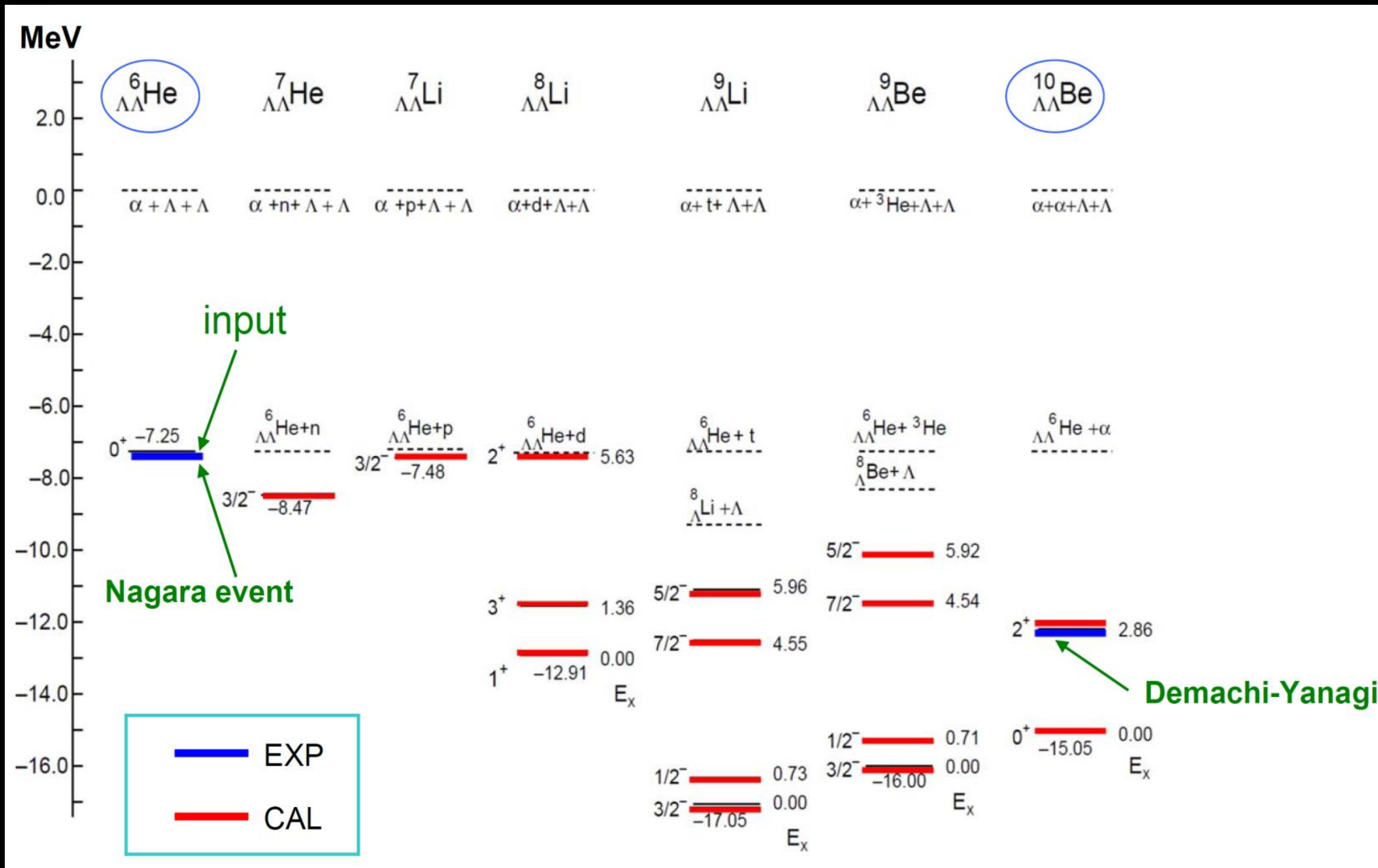


- mixing and Pauli repulsion may procduce an effectivde 3-body repulsion
- depends on spin/nuclear structure of hypernculei
- this mixing might be reflected in the level scheme of double hypernuclei
- precise study needed

$\Rightarrow$ high resolution γ-spectroscopy

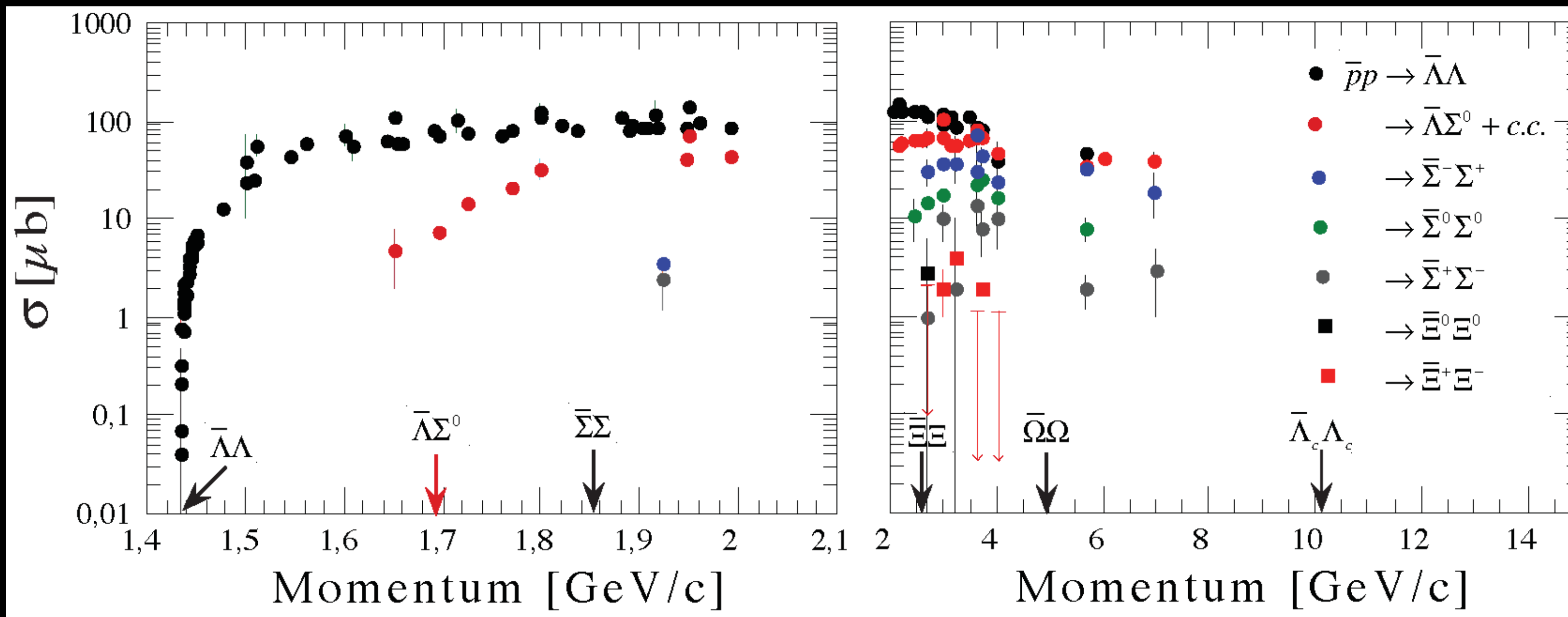
Spectroscopy of ΛΛ-hypernuclei

E. Hiyama, M. Kamimura, T.Motoba, T. Yamada and Y. Yamamoto
Phys. Rev. 66 (2002) , 024007



- many excited, particle stable states in double hypernuclei predicted
- level structure reflects in 0th order levels of core nucleus

$\vec{P}$ANDA – a Factory for strange *and* charmed $Y\vec{\bar{Y}}$-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
$J/\psi\ (\to e^+e^-, \mu^+\mu^-)$	630nb	10^9
$\chi_2\ (\to J/\psi + \gamma)$	3.7nb	10^7
$\Lambda_c\bar{\Lambda}_c$	20nb	10^7
$\Omega_c\bar{\Omega}_c$	0.1nb	10^5

Strange Systems at PANDA

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

rescattering in
primary target nucleus

deceleration in
secondary target

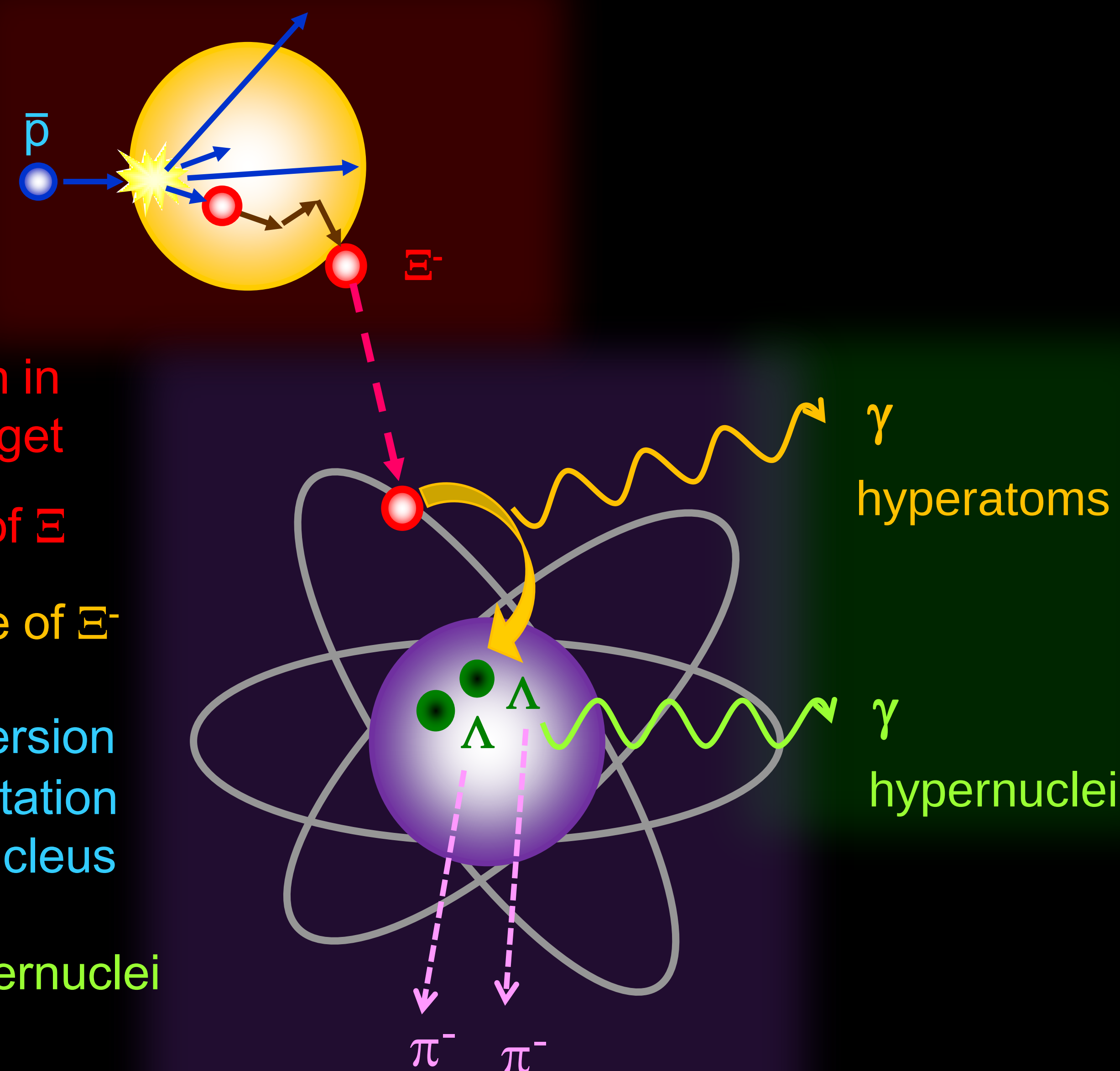
capture of Ξ

atomic cascade of Ξ^-

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

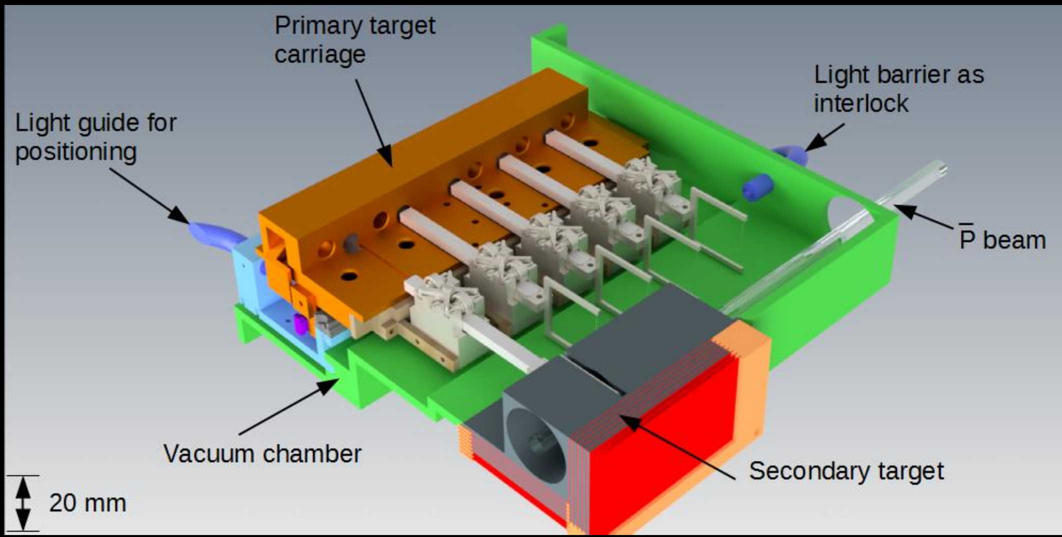
γ-decay of $\Lambda\Lambda$ hypernuclei

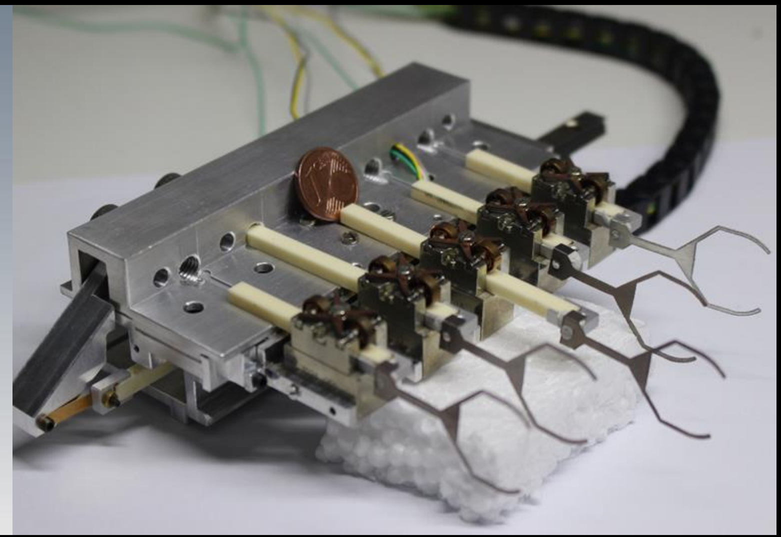
weak pionic decay



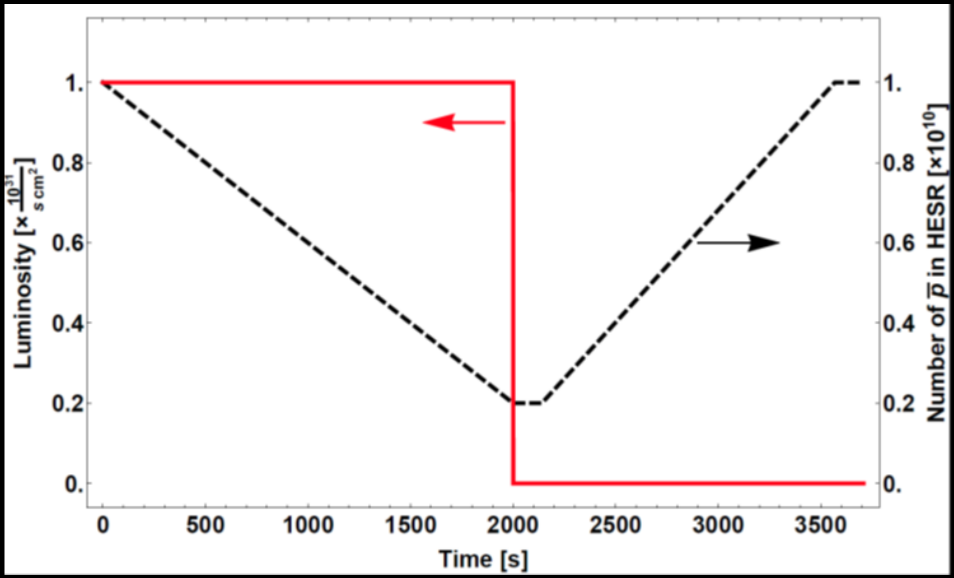
Primary Target

- Task: maximize slow Ξ^- production



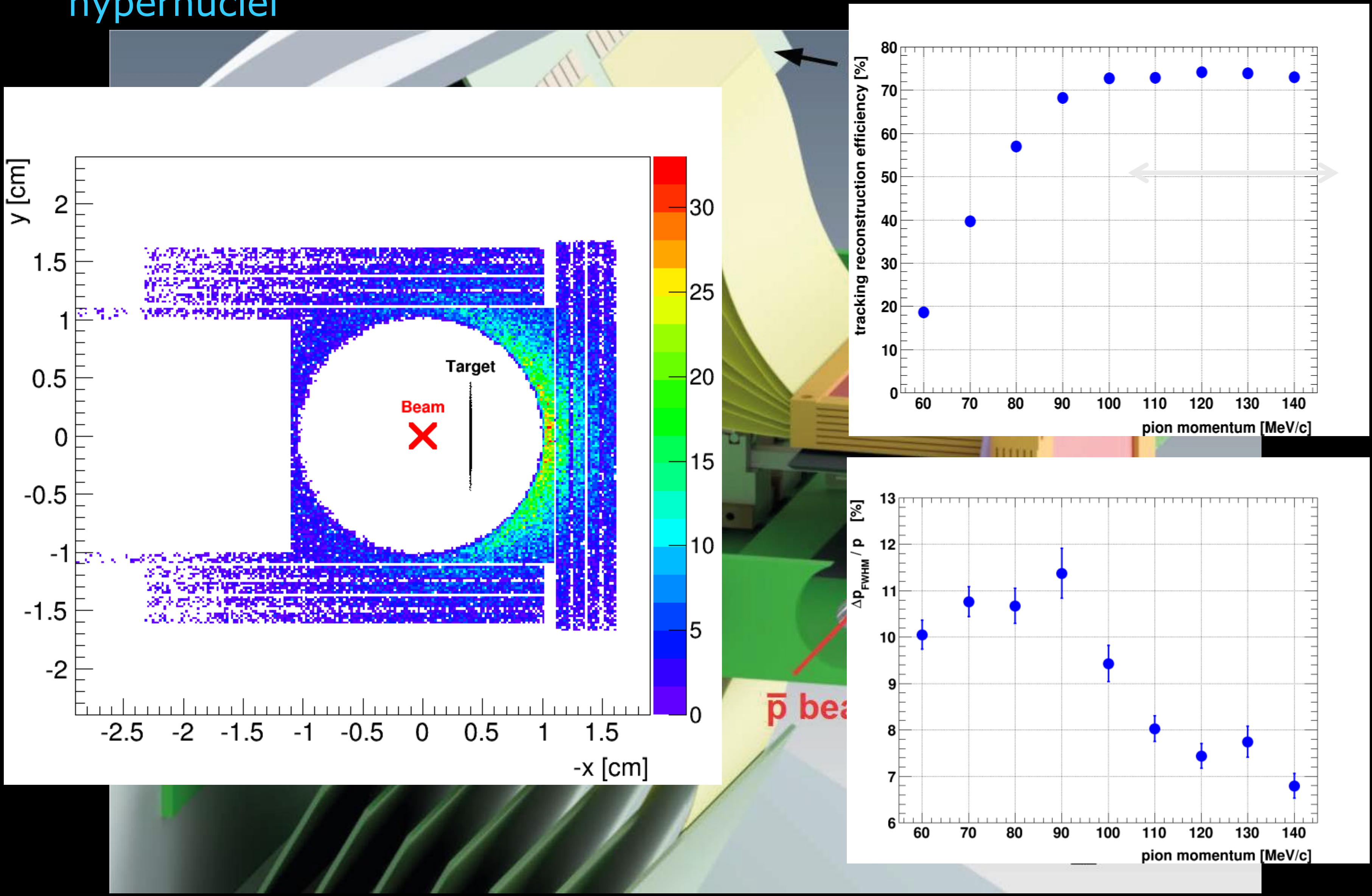


- Target material: C filament 5μm
  - production cross section
  - slow down process
  - beam losses…
- ultra high vacuum
- magnetic field
- radiation hardness
  e.g. passive position control
- …

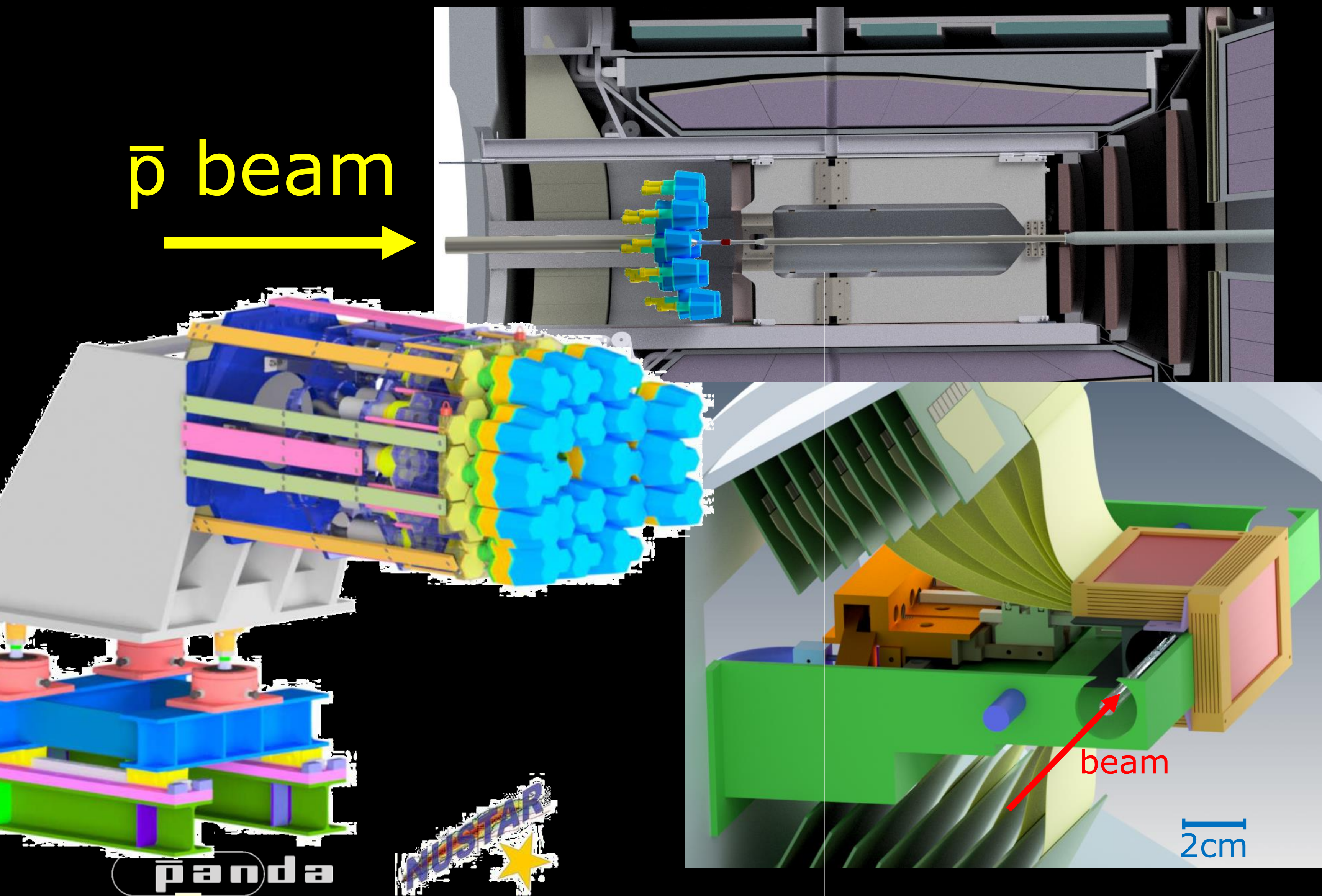


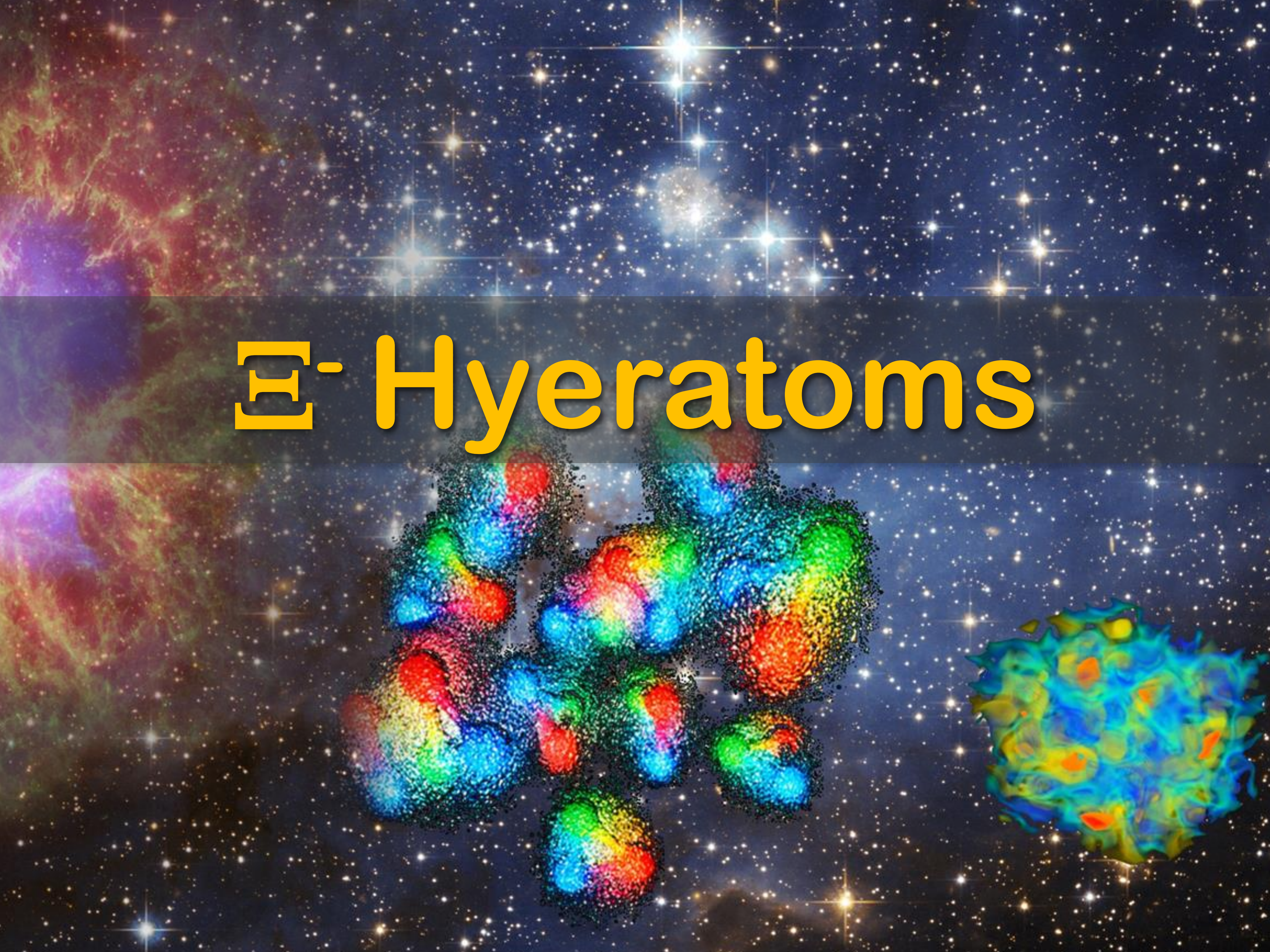
Secondary target

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

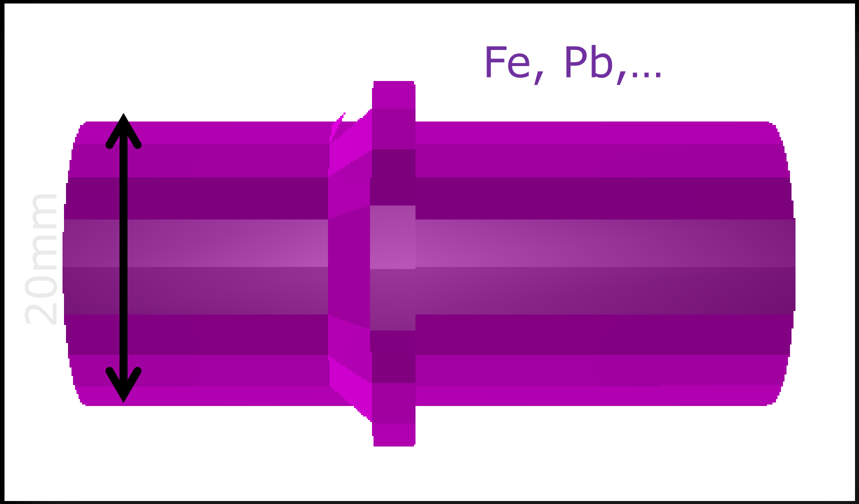


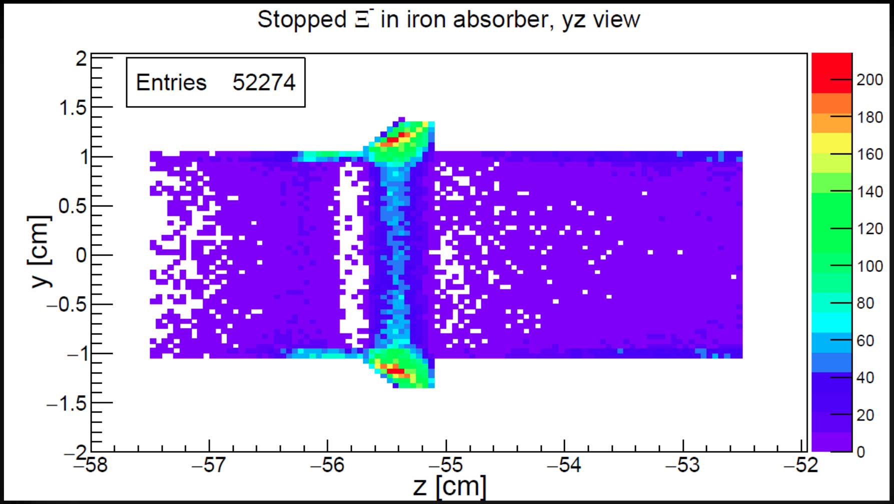
$\vec{\bar{\mathrm{P}}}$ANDA-HYP setup




Ξ^- Hyeratoms

PANDA Setup for Hyperatoms





Advantages compared to J-PARC:

- very thin primary target
- primary and secondary target separated
- relative thin secondary target
  - $\Rightarrow$ moderate x-ray absorption
  - $\Rightarrow$ detection of cacades possible
- tracking secondary particles possible $\Rightarrow$ reduced background

Count rate: $\times$100 double hypernuclei $\Rightarrow$ ideal for initial phase

J-PARC vs. FAIR

	J-PARC	FAIR
Double Hypernuclei	E07 • 1.8 GeV/c K^- beam • hybrid-emulsion • only ground state masses	PANDA • $\bar{p}$ in HESR • fully electronic • γ-spectroscopy
Ξ^- atoms	E03 • 1.8 GeV/c K^- beam • thick target • only light and medieum heavy elements (Fe)	• Primary and secondary target separeted • γ cascades • also heavy elements

Element	Z	A	Isotopic abundancy [%]	Energy 1 [keV]	Energy 2 [keV]	Shift 2 [keV]	Width 2 [keV]	Yield [%]
Fe	26	56	91.8	172.2	287	1.1	0.7	57.1
Nb	41	93	100	280.9	437.5	4.317	3.61	32.2
In	49	115	95.7	275.8	403.6	0.909	0.5	65
Ta	73	181	99.9	325.6	440.7	0.23	0.11	88.8
Au	79	197	100	381.7	517.1	0.68	0.43	78.4
Pb	82	208	52.4	411.5	558.5	1.8	1.3	56.5

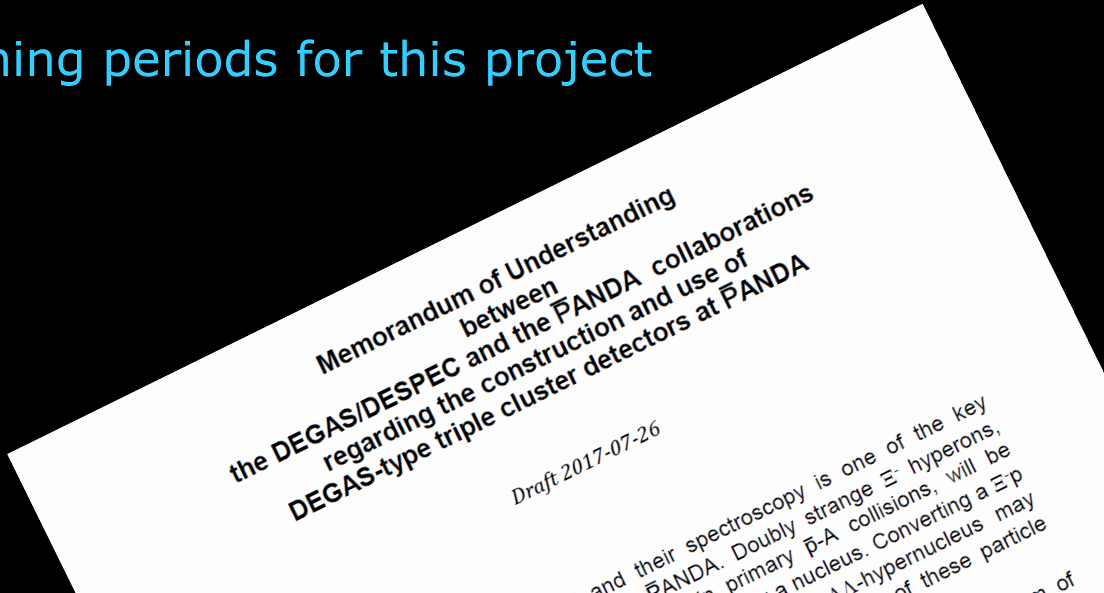
Timescale

- HIM will support the construction of DEGAS triple detectors
  - lab space at HIM
  - financial support (2018, 2019)

- $\bar{p}$ beam in HESR will be available ~2025
- if proton beam will be avaiable earlier
  - primray target test (radiation hardness)
  - secondary target test; tracking etc
  - test of ≥ 1 triple DEGAS cluster

- PANDA forsees two running periods for this project
  - >2025: hyperatoms
  - >20xx: hypernuclei

- Needed: MoU




Thank you
for your attention