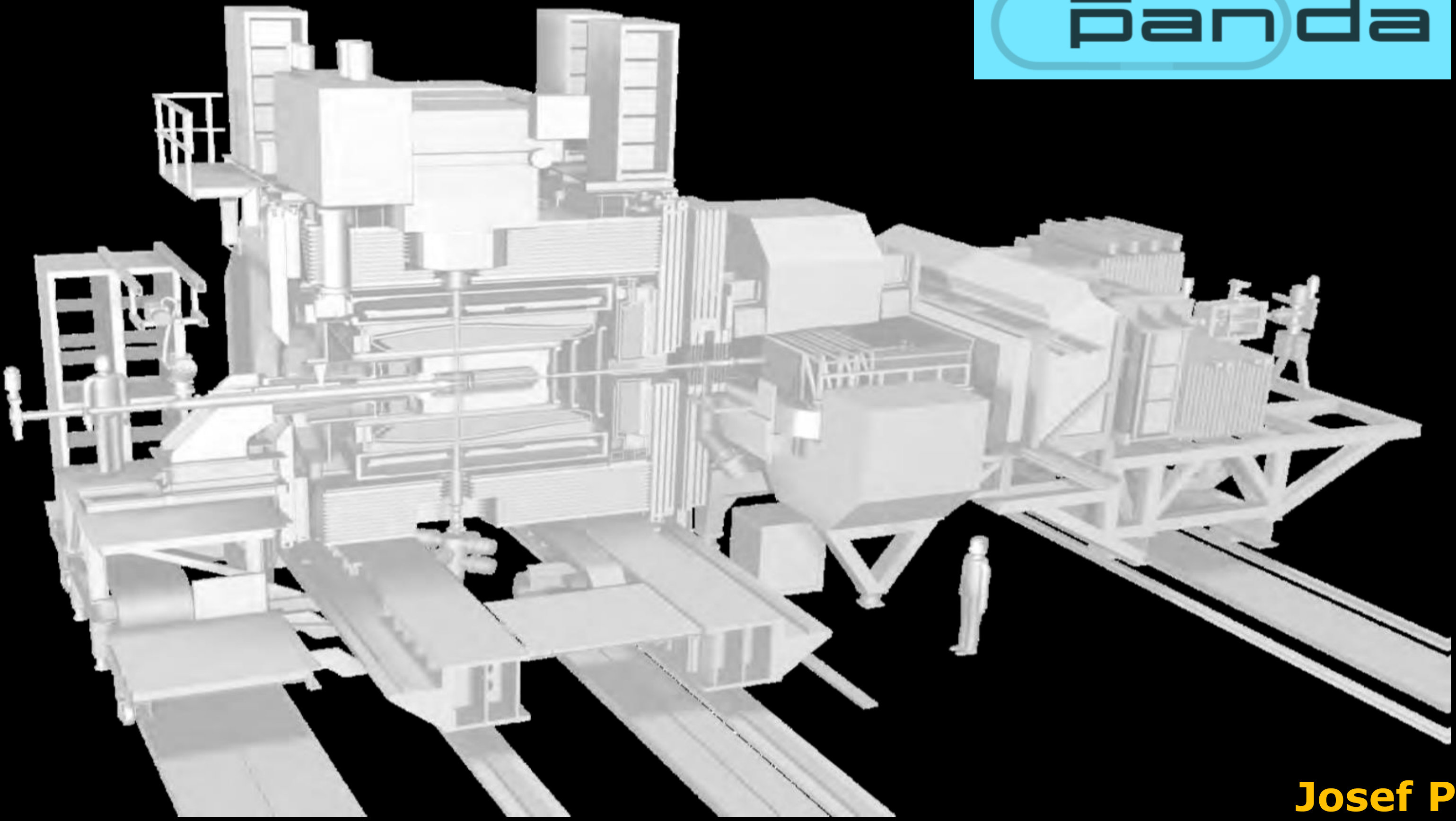
International workshop on the project
for the extended hadron experimental facility of J-PARC
26-28 March 2018
KEK Tokai Campus

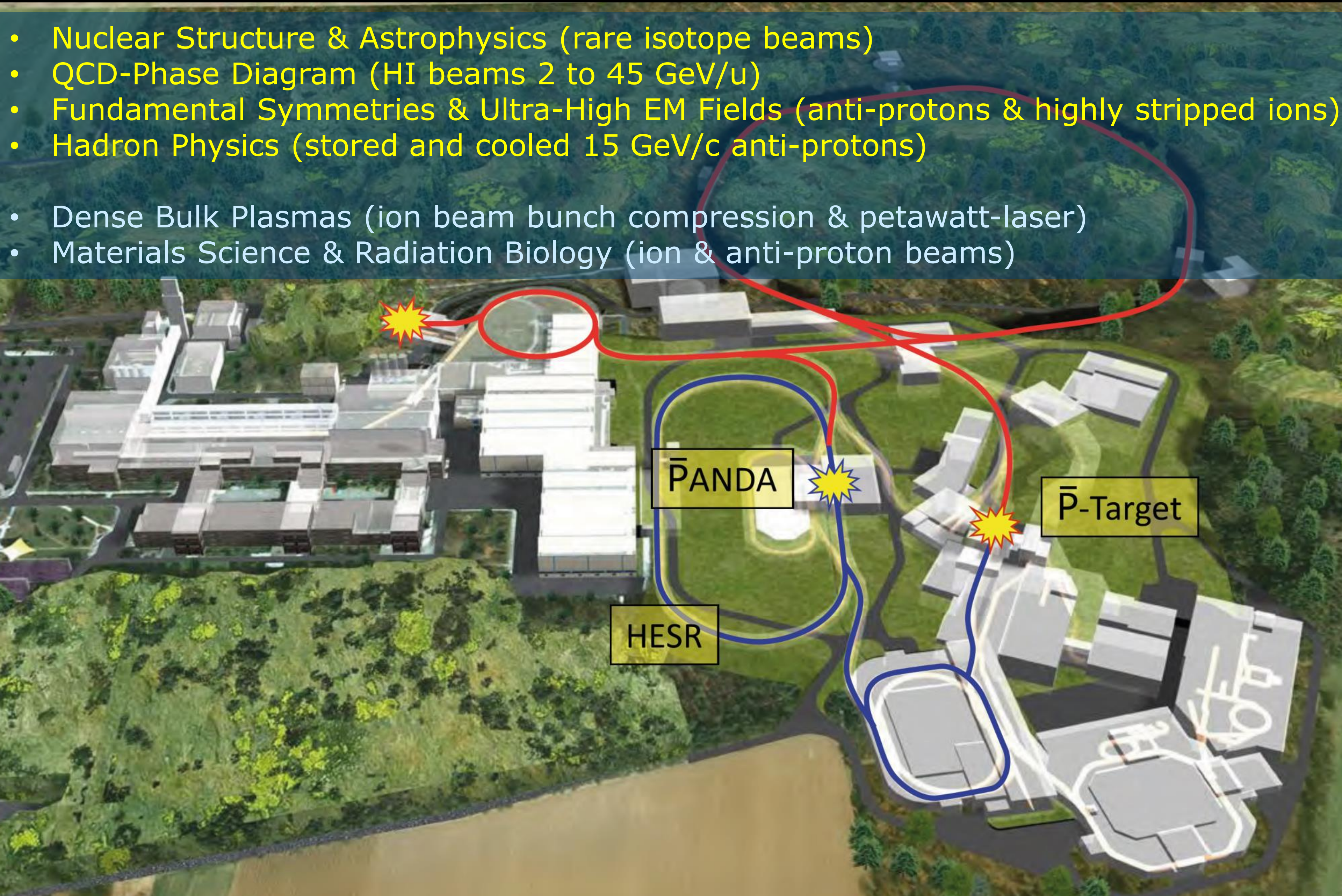
Strangeness nuclear physics at PANDA



Josef Pochodzalla

JGU Mainz & Helmholtz-Institut – Mainz – European Union

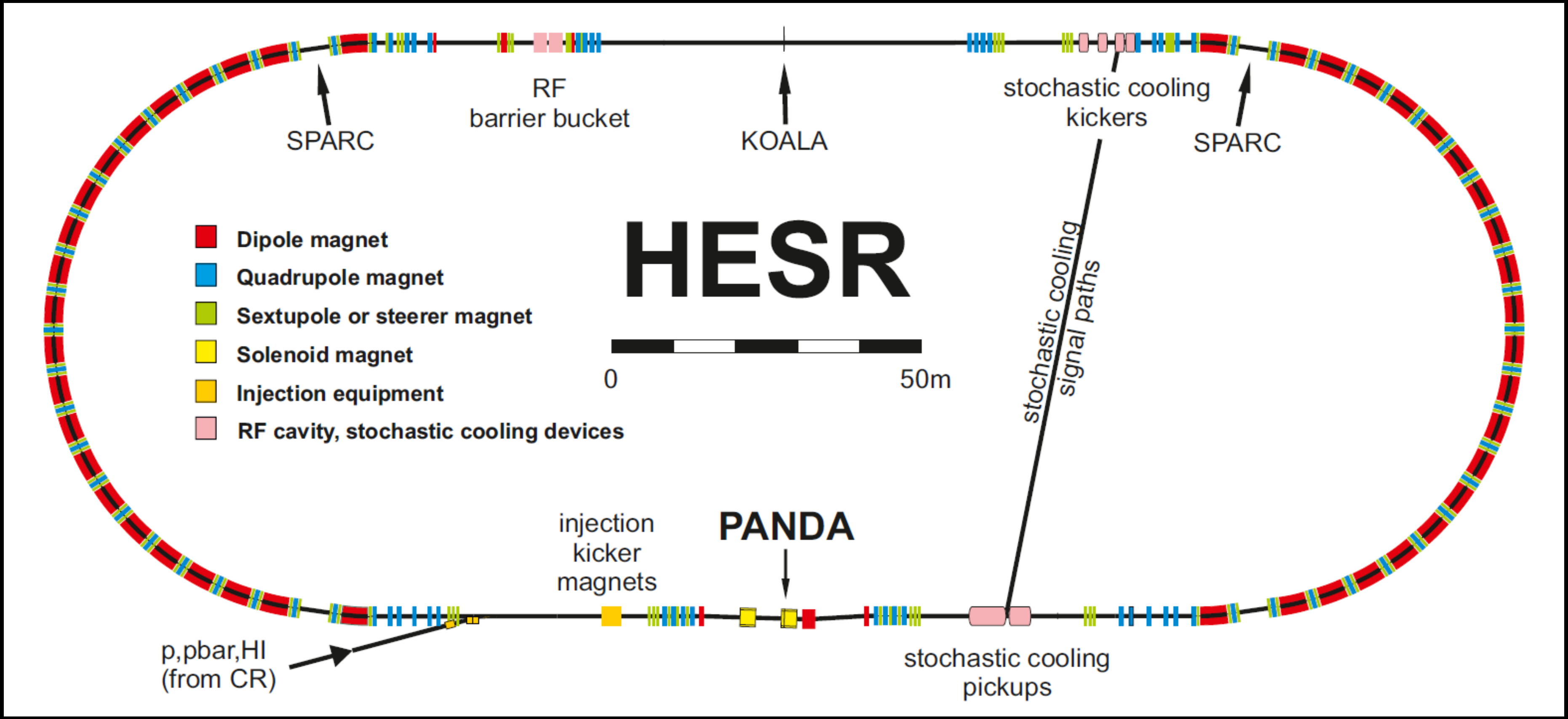
FAIR strongly interacting matter on all scales



- Nuclear Structure & Astrophysics (rare isotope beams)
- QCD-Phase Diagram (HI beams 2 to 45 GeV/u)
- Fundamental Symmetries & Ultra-High EM Fields (anti-protons & highly stripped ions)
- Hadron Physics (stored and cooled 15 GeV/c anti-protons)

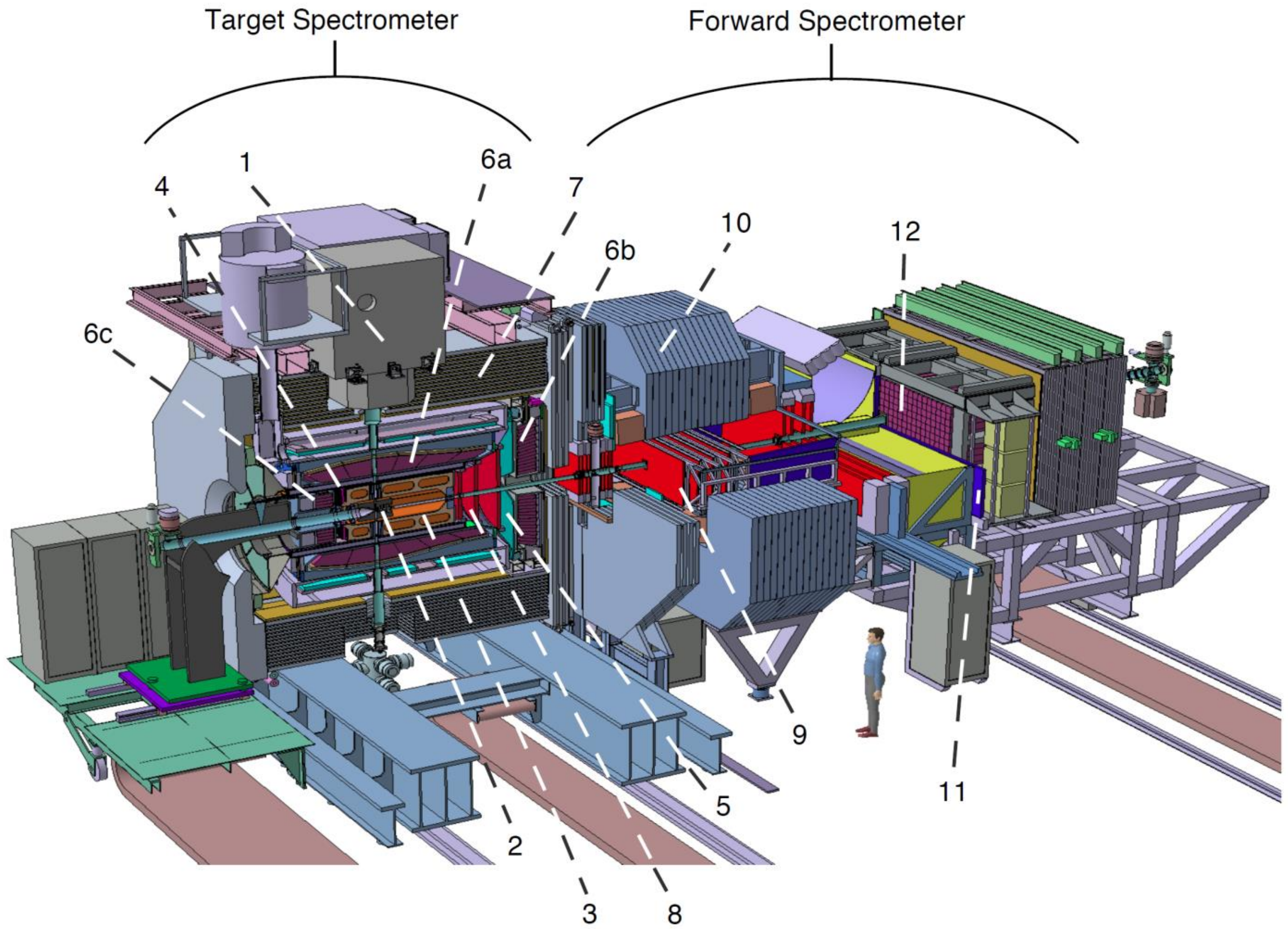
- Dense Bulk Plasmas (ion beam bunch compression & petawatt-laser)
- Materials Science & Radiation Biology (ion & anti-proton beams)

High Energy Storage Ring HESR



- Circumference 575 m
- Momentum 1.5 – 15 GeV/c
- Stochastic cooling
- 10^{11} antiprotons stored
- Luminosity up to $2 \cdot 10^{32}$ $cm^{-2}s^{-1}$
- $\Delta p/p \leq 2 \cdot 10^{-4}$

The PANDA Detector



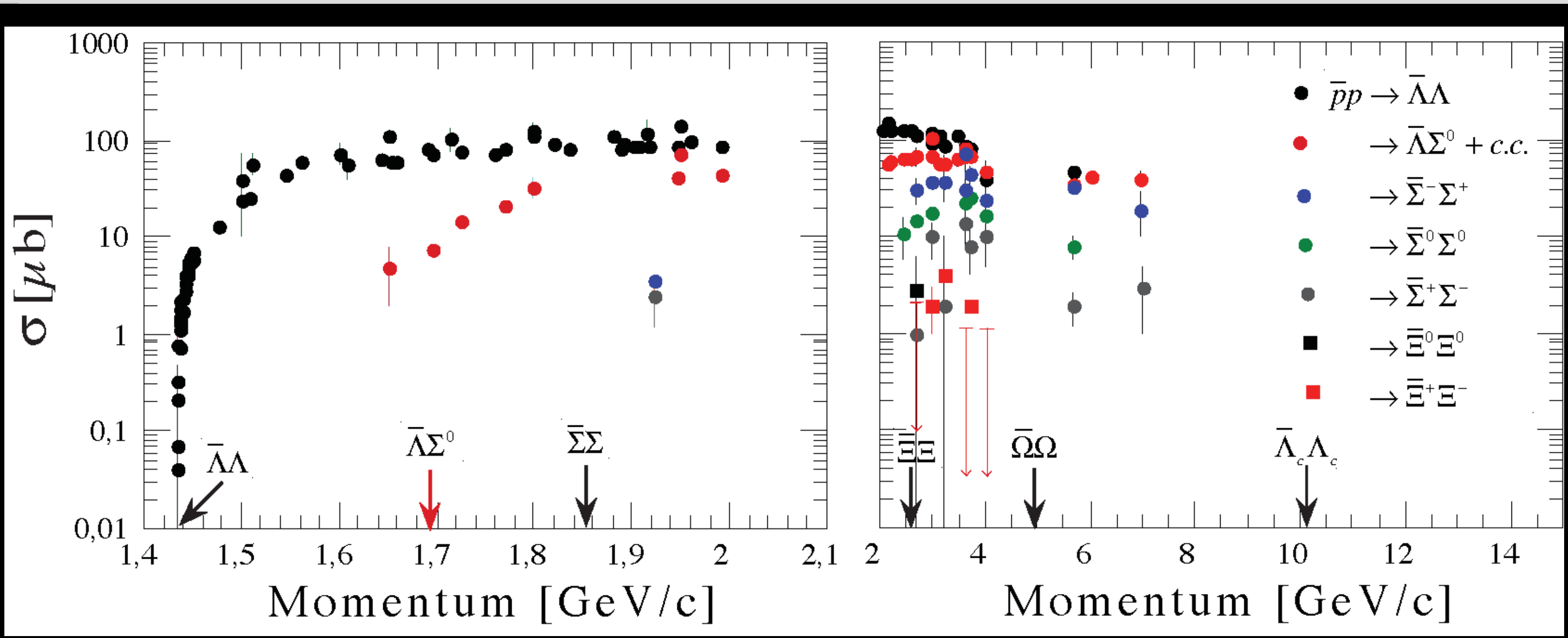
1: Cluster-Target
2: Mikrovertex-Detektor
3: STT-Tracker
4: DIRC
5: Disc-DIRC

6a: Barrel-EMC
6b: Forward-EMC
6c: Backward-EMC
7: Solenoid Yoke with Muon Chambers
8: GEM-Tracker

9: Forward Tracker
10: Dipole
11: Forward TOF wall
12: Shashlyk-EMC

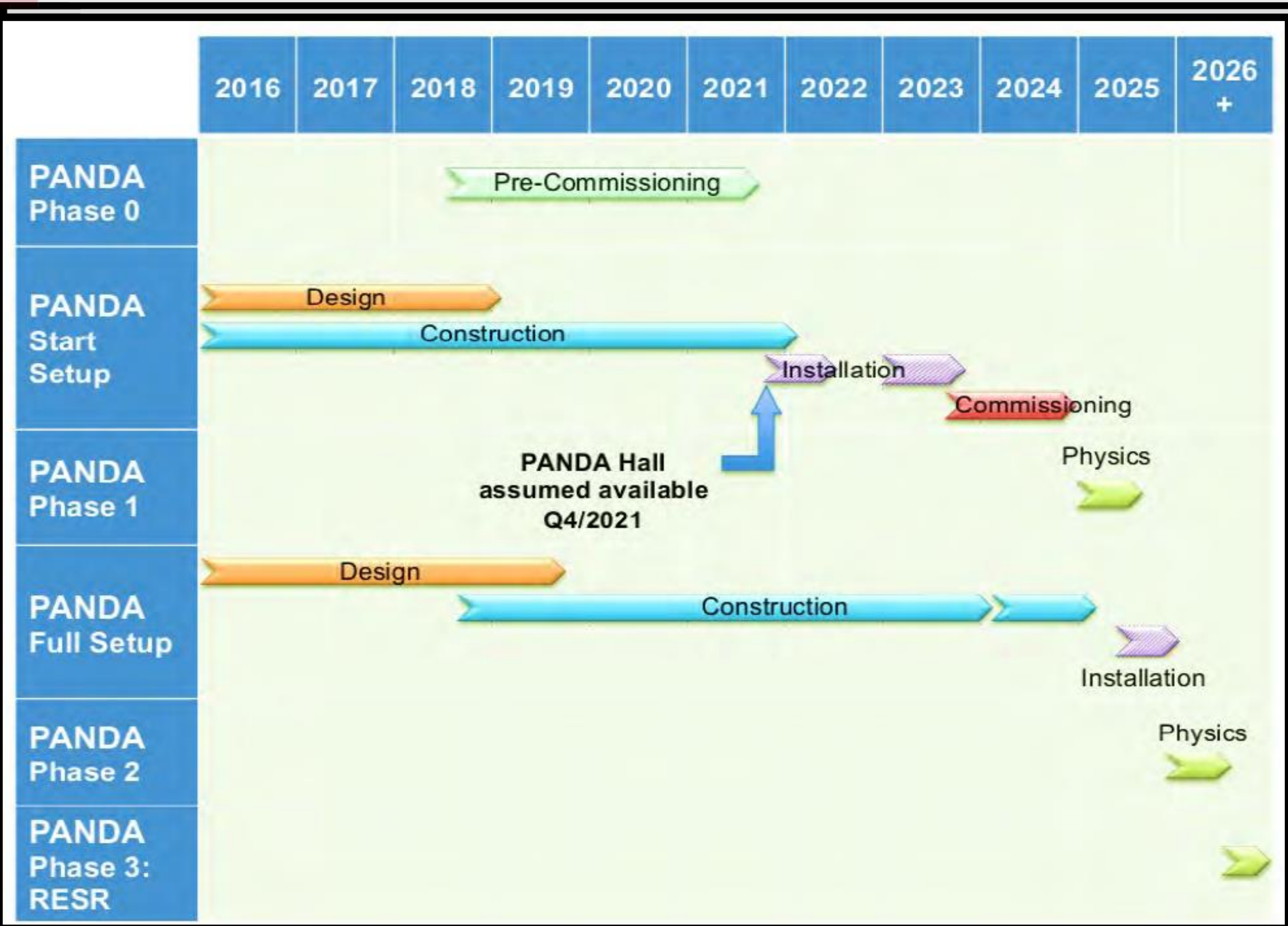
not visible (downstream): Luminosity Detector
not visible: Hypernuclear Setup

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



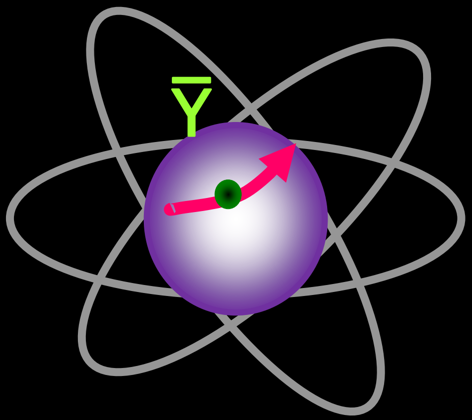
Momentum (GeV/c)	Reaction	σ (μb)	Efficiency (%)	Rate (with 10^{31} $cm^{-1}s^{-1}$)
1.64	$\bar{p}p \rightarrow \bar{\Lambda}\Lambda$	64	10	30 s^{-1}
4	$\bar{p}p \rightarrow \bar{\Lambda}\Sigma^0$	~40	30	30 s^{-1}
4	$\bar{p}p \rightarrow \bar{\Xi}^+\Xi^-$	~2	20	2 s^{-1}
12	$\bar{p}p \rightarrow \bar{\Omega}\Omega$	~0.002	30	~4 h^{-1}
12	$\bar{p}p \rightarrow \bar{\Lambda}_c\Lambda_c$	~0.1	35	~2 day^{-1}

Timeline


2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026 +
PANDA Phase 0
Pre-Commissioning
PANDA Start Setup
Design
Construction
Installation
Commissioning
PANDA Phase 1
Physics
PANDA Hall assumed available Q4/2021
PANDA Full Setup
Design
Construction
Installation
PANDA Phase 2
Physics
PANDA Phase 3: RESR

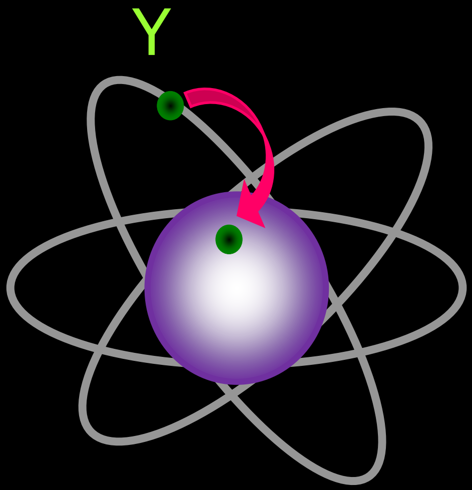
Strangeness Nuclear Physics at PAND

= Strangeness in cold nuclei



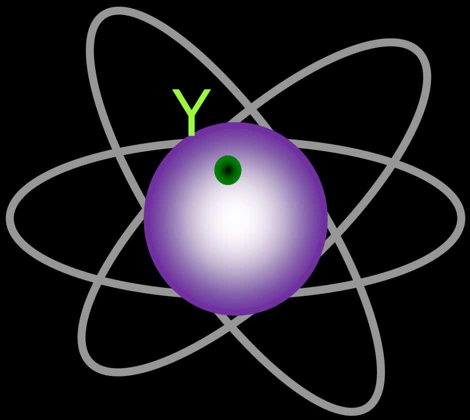
(anti)hyperons
in nuclei

PHASE-1
2025



Ξ^- hyperatoms

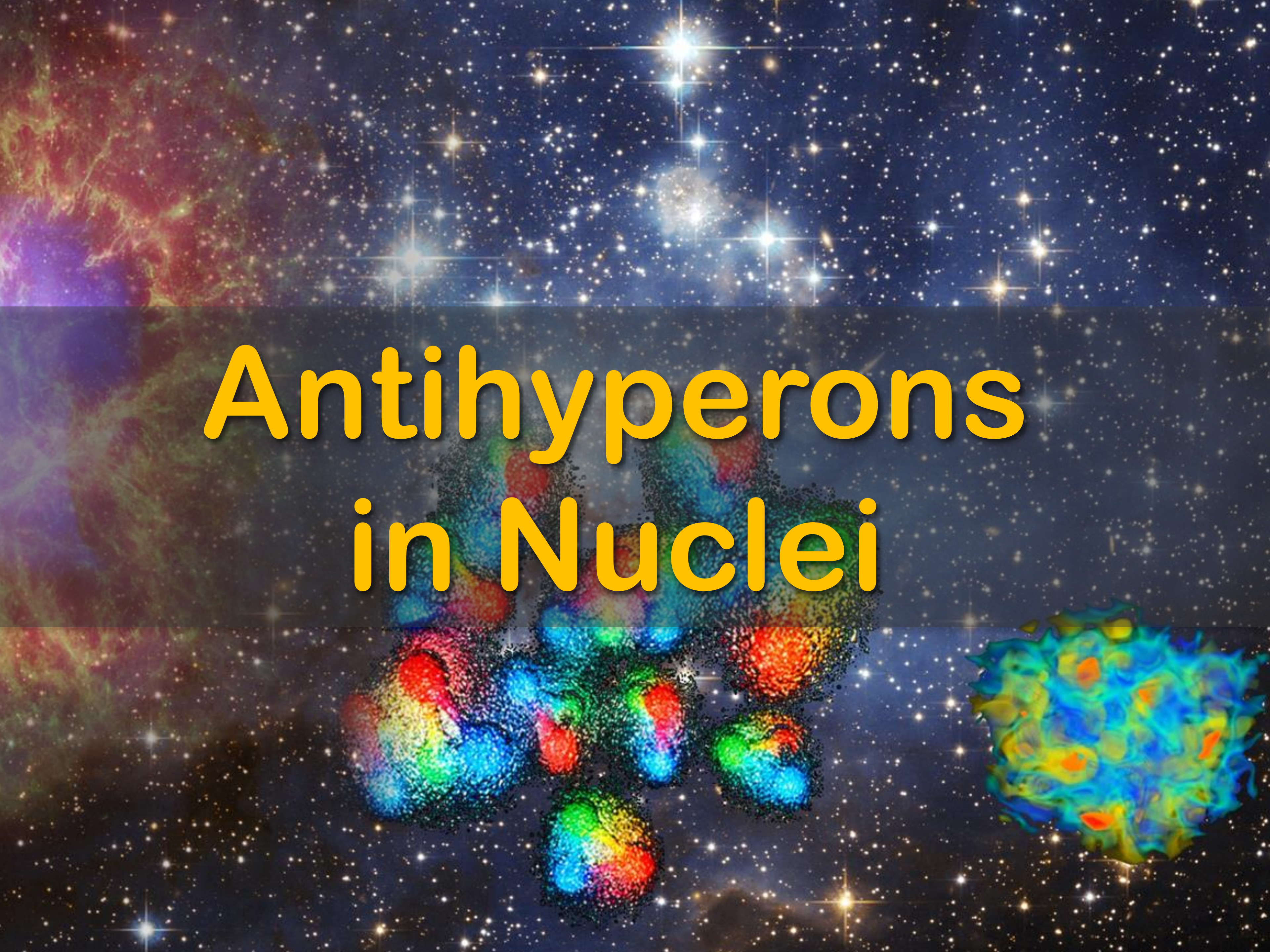
Phase-2
~2026+



ΛΛ hypernuclei

Phase-2
~2026++

Antihyperons in Nuclei



G-Parity and NN Potential

- G=charge conjugation + 180° rotation around 2nd axis in isospin (Lee und Yang 1956, L. Michel 1952 „Isoparität")

$$G = C \cdot e^{i\pi I_2}$$

- G-parity of particle-antiparticle multipletts

$$G\left|f\bar{f}\right\rangle = (-1)^I C\left|f\bar{f}\right\rangle = (-1)^{I+L+S}\left|f\bar{f}\right\rangle$$

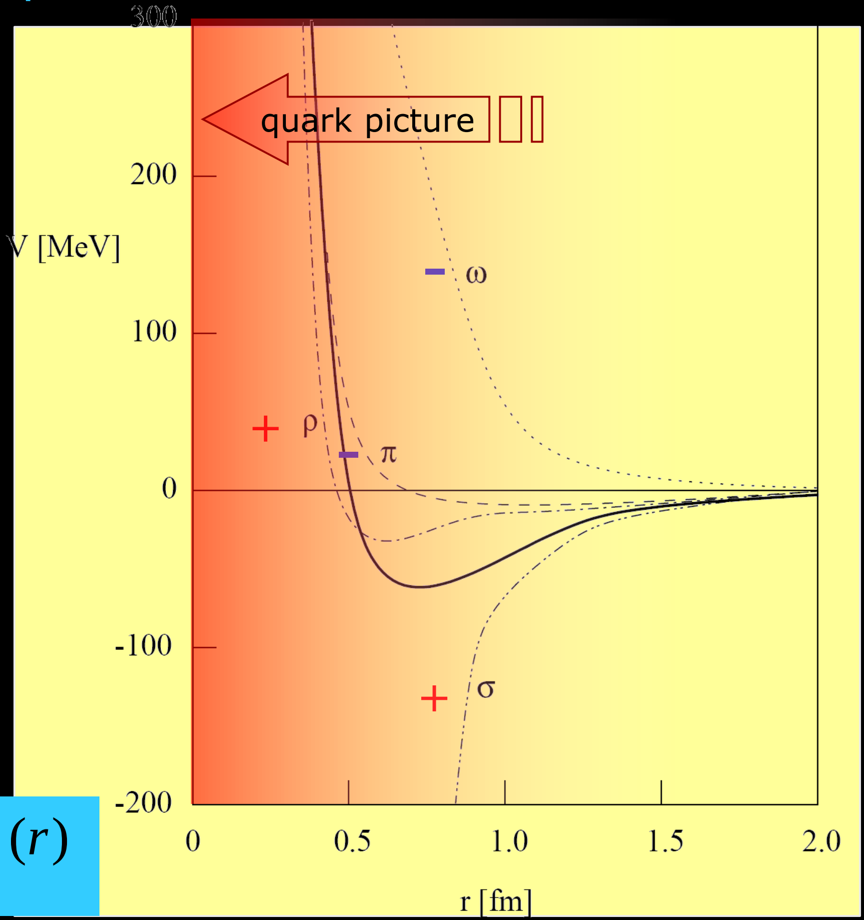
- Hans-Peter Dürr and Edward Teller, Phys. Rev. **101**, 494 (1956)
  - sign change in coupling constant when going from NN to N$\bar{\text{N}}$

$$G\left|\pi^{\pm 0}\right\rangle = (-1)^1 C\left|\pi^{\pm 0}\right\rangle = -\left|\pi^{\pm 0}\right\rangle$$

$$G\left|\rho\right\rangle = (-1)^1 C\left|\rho\right\rangle = +\left|\rho\right\rangle$$

$$G\left|\omega\right\rangle = (-1)^0 C\left|\omega\right\rangle = -\left|\omega\right\rangle$$

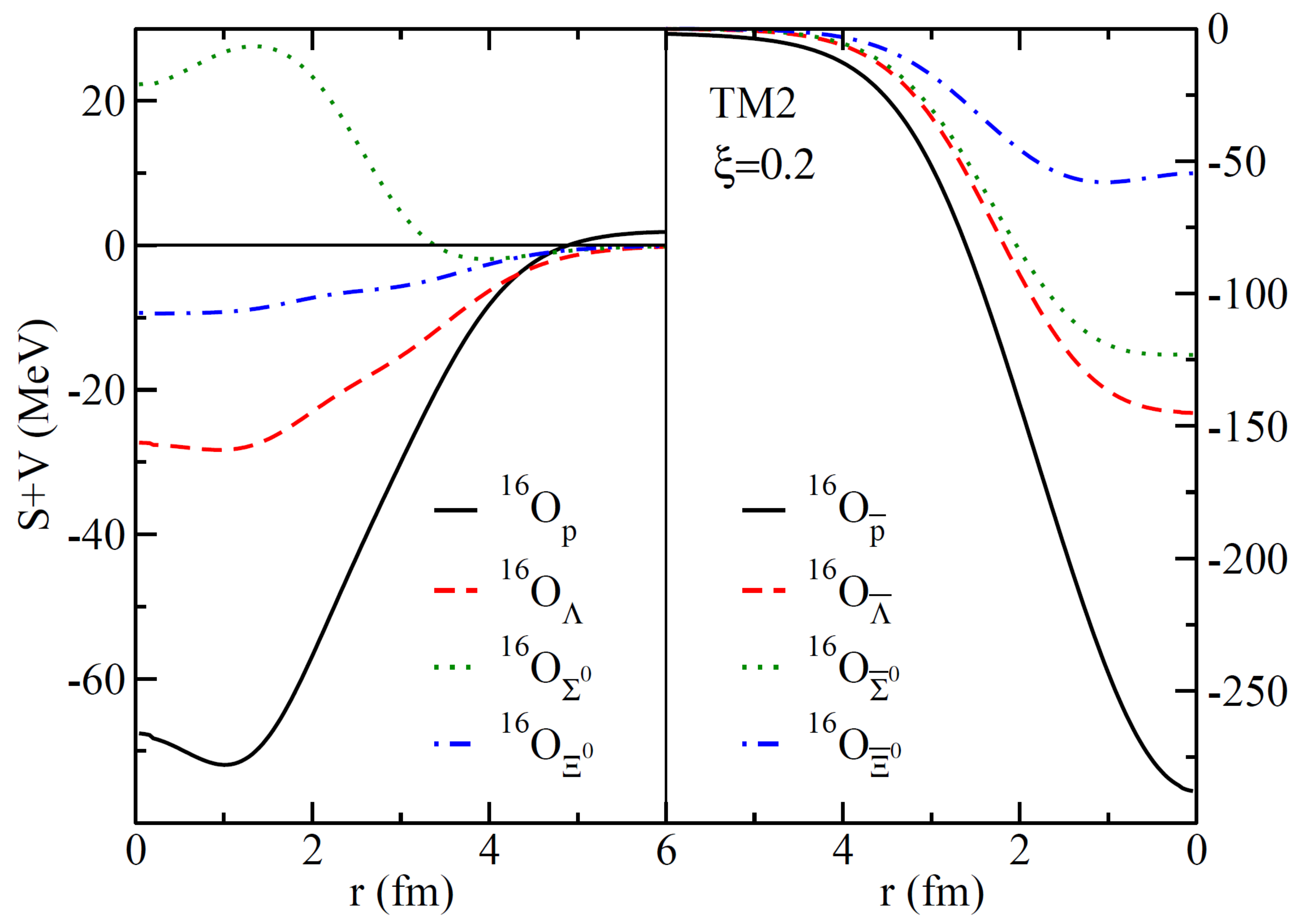
$$G\left|\sigma\right\rangle = (-1)^0 C\left|\sigma\right\rangle = +\left|\sigma\right\rangle$$



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

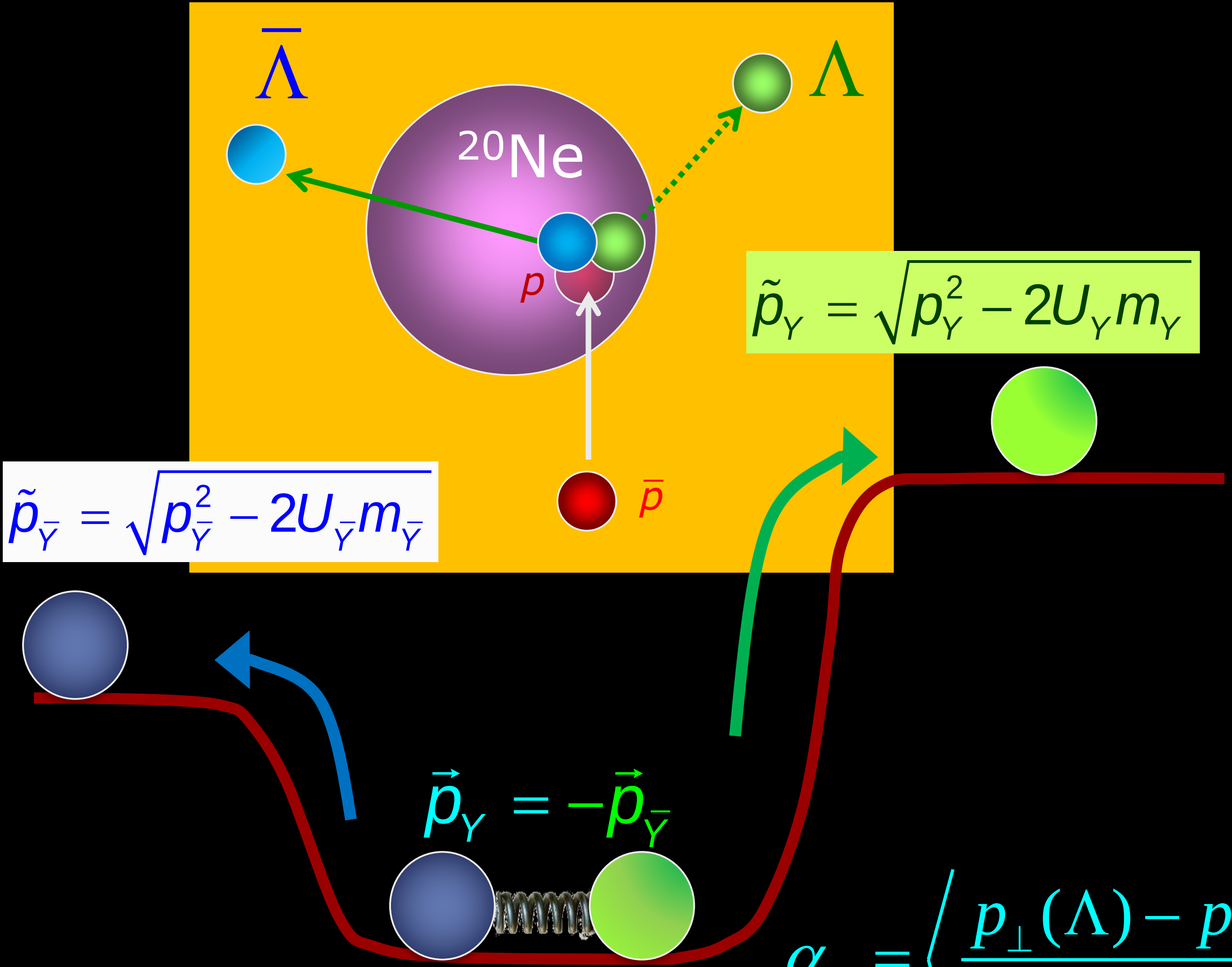
- Caveat: meson picture will probably not work at small distance
- Chance to study transition from meson to quark-gluon regime

Antibaryon in nuclear medium



Jaroslava Hrtánková, Jiří Mareš, arXiv:1710.02045 [nucl-th].

Phase-1 Experiment: $\bar{\Lambda}$ Potential in N



$$\tilde{p}_Y = \sqrt{p_Y^2 - 2U_Y m_Y}$$

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

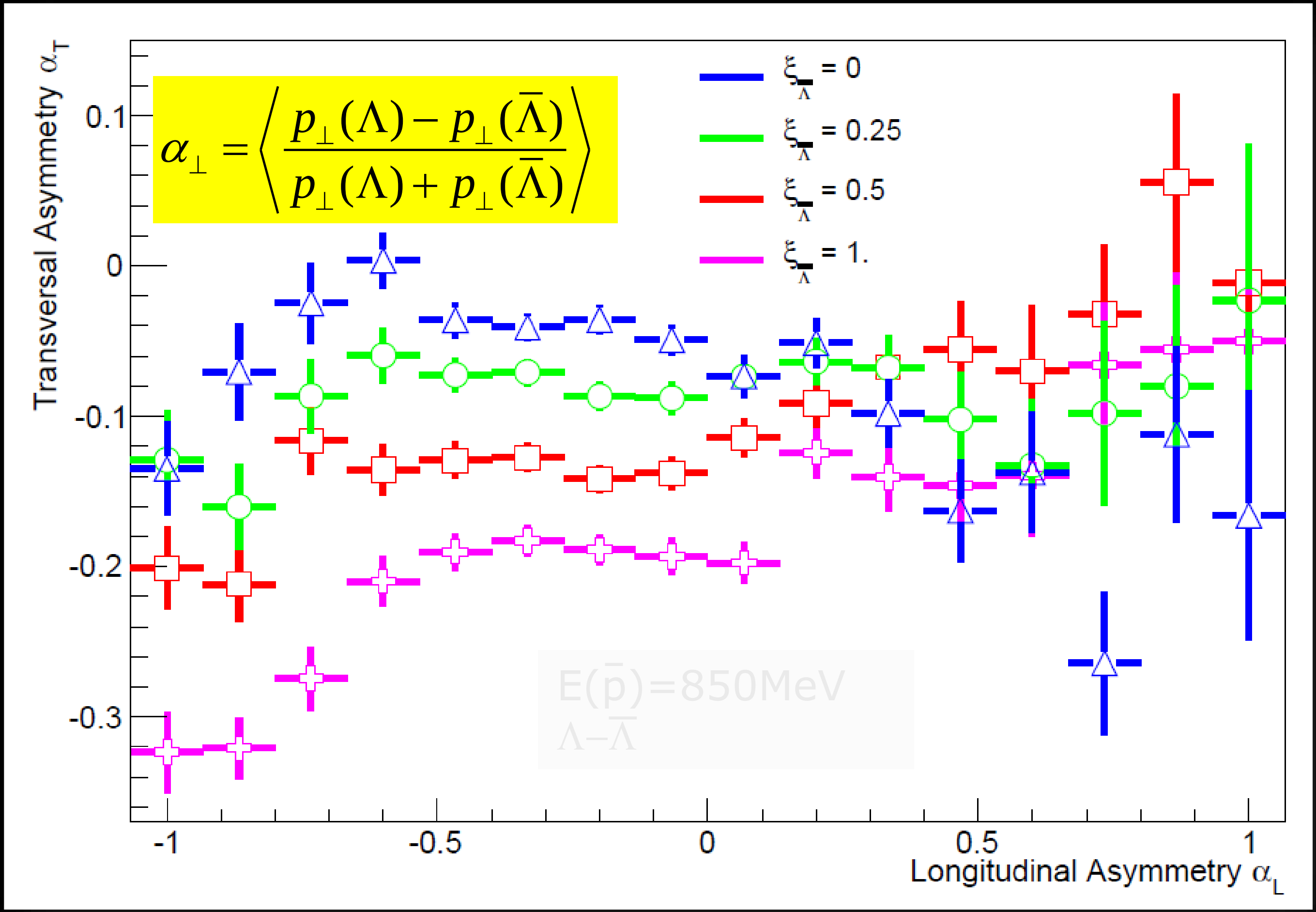
$$\vec{p}_Y = -\vec{p}_{\bar{Y}}$$

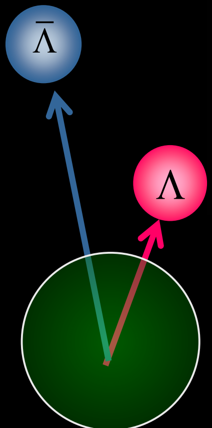
$$\alpha_\perp = \left\langle \frac{p_\perp(\Lambda) - p_\perp(\bar{\Lambda})}{p_\perp(\Lambda) + p_\perp(\bar{\Lambda})} \right\rangle$$

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

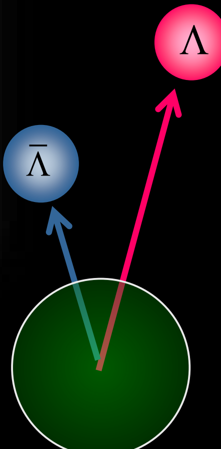
- $U(\bar{\Lambda})$= -449MeV, -225MeV, -112MeV, 0MeV
- All other potentials unchanged

PLB 749, 421 (2015)



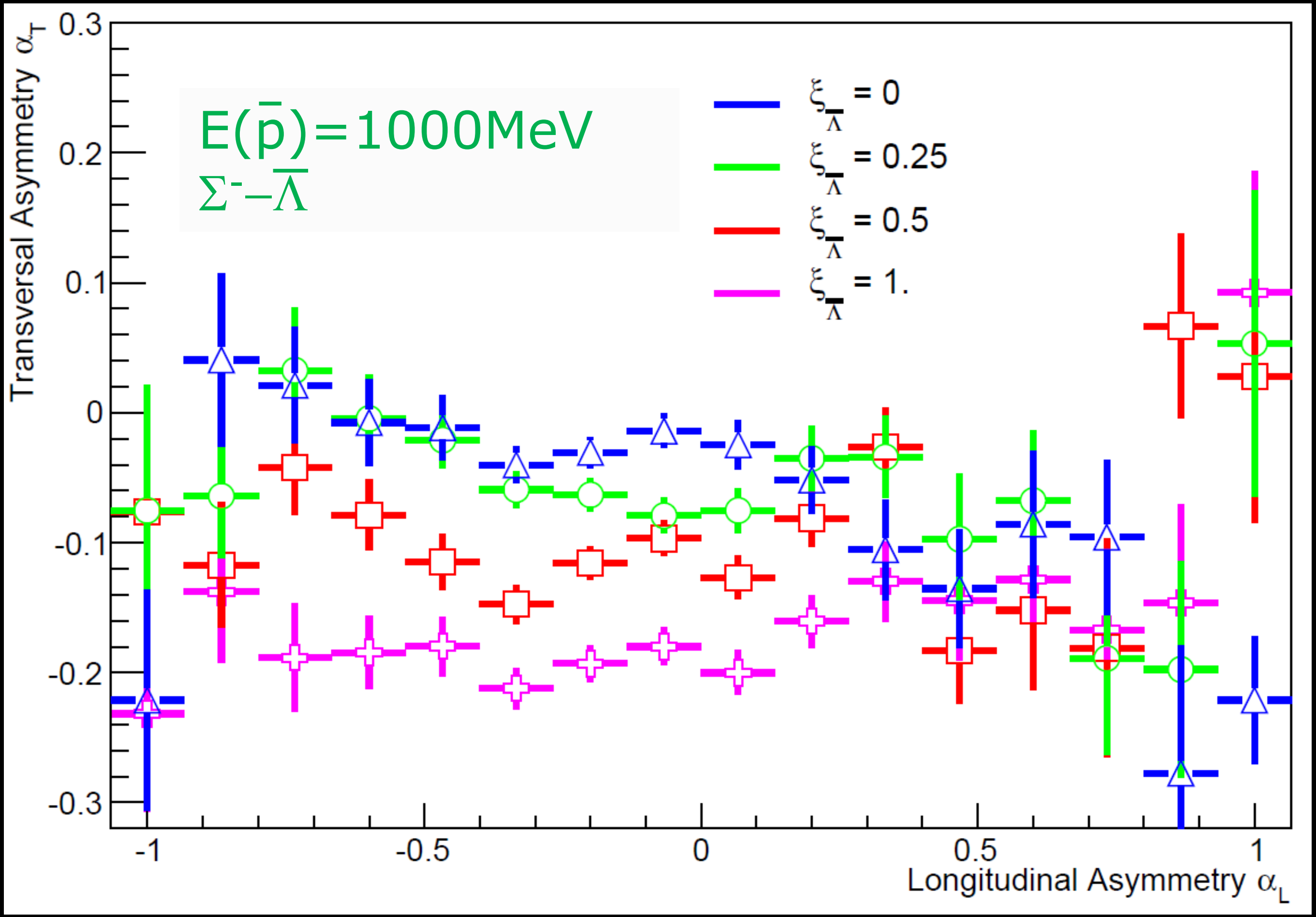


$$\alpha_L = \frac{p_L(\Lambda) - p_L(\bar{\Lambda})}{p_L(\Lambda) + p_L(\bar{\Lambda})}$$



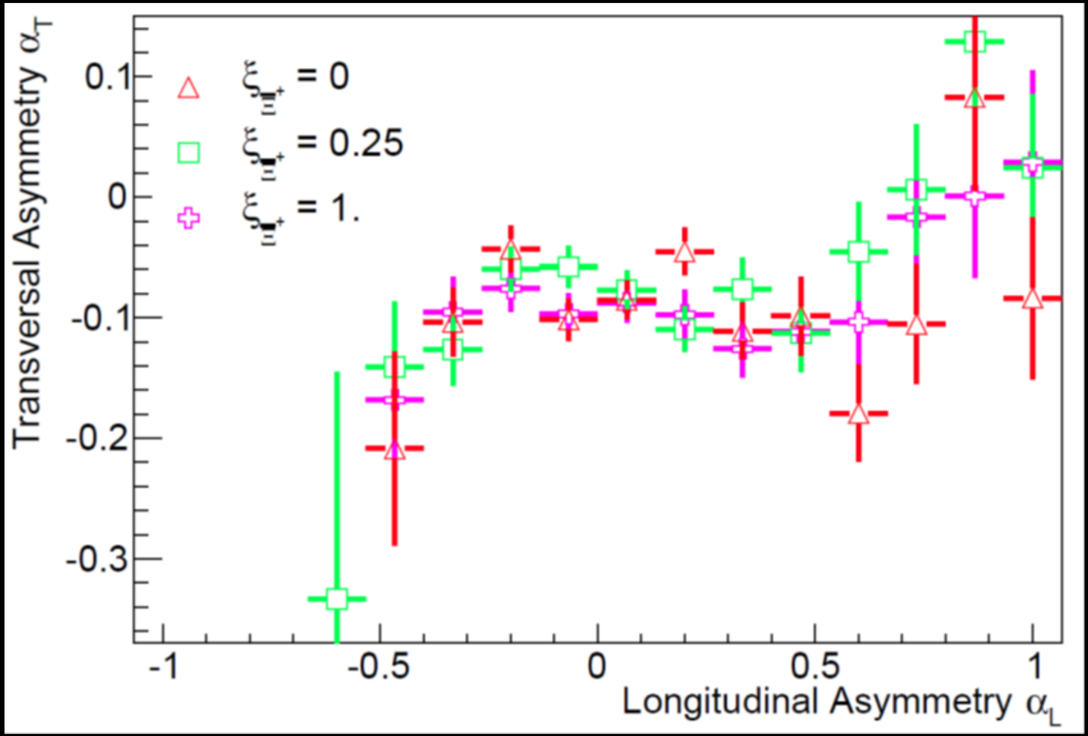
Other |s|=1 channels @ 1000MeV

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

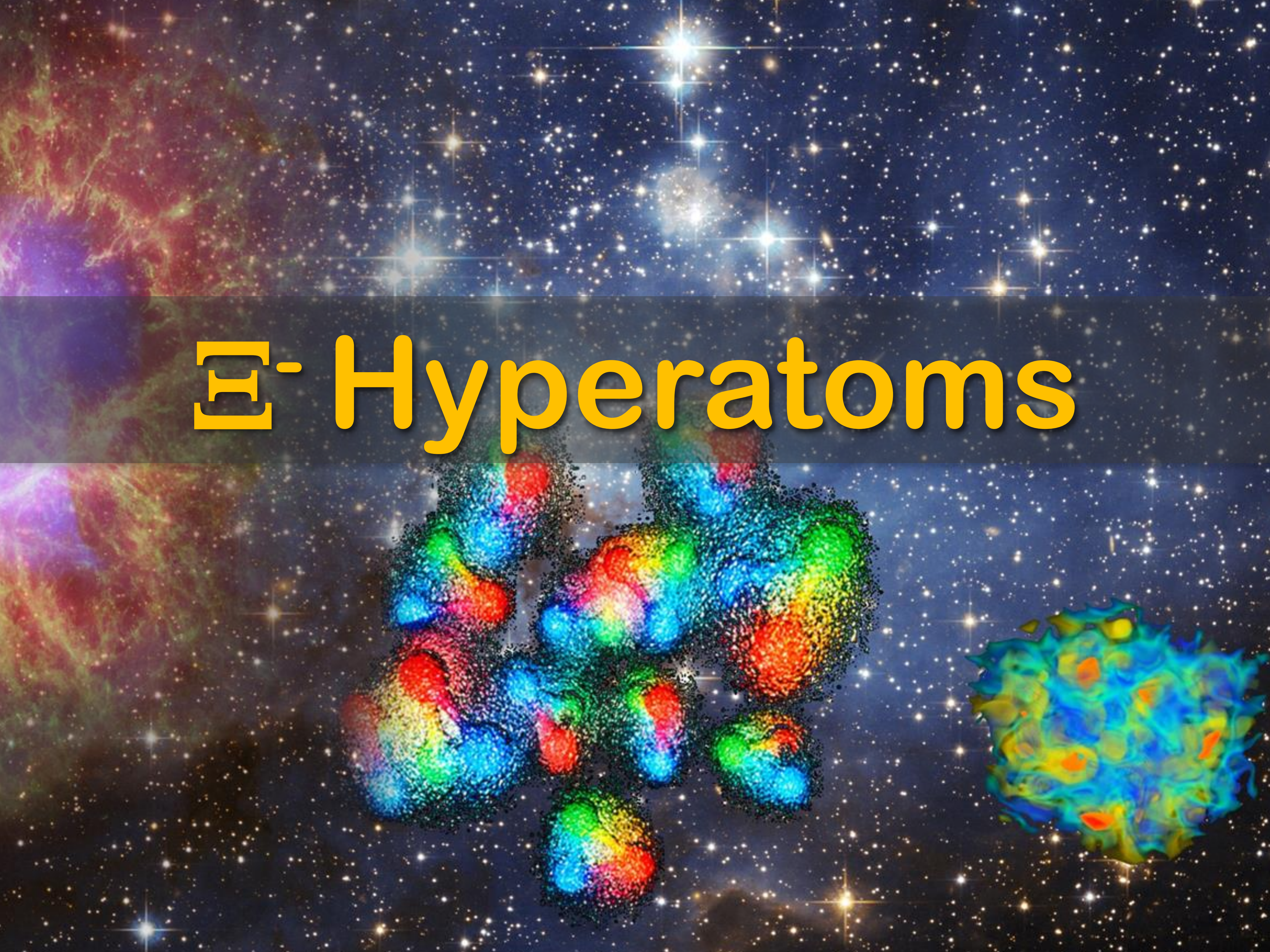


Future Options

- 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)

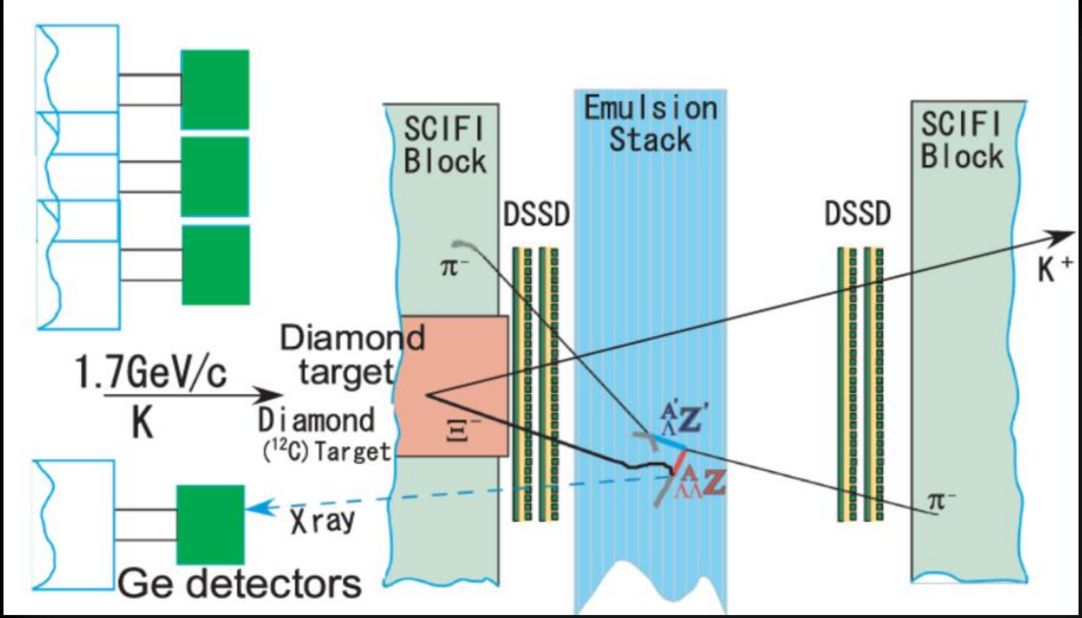


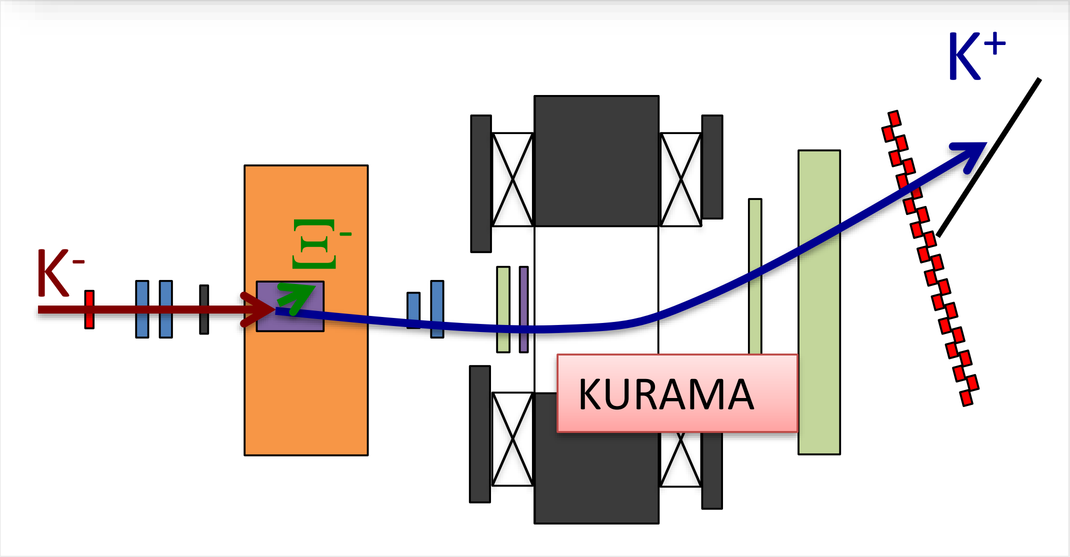
Ξ^- Hyperatoms



E03 and E07 @ J-PARC

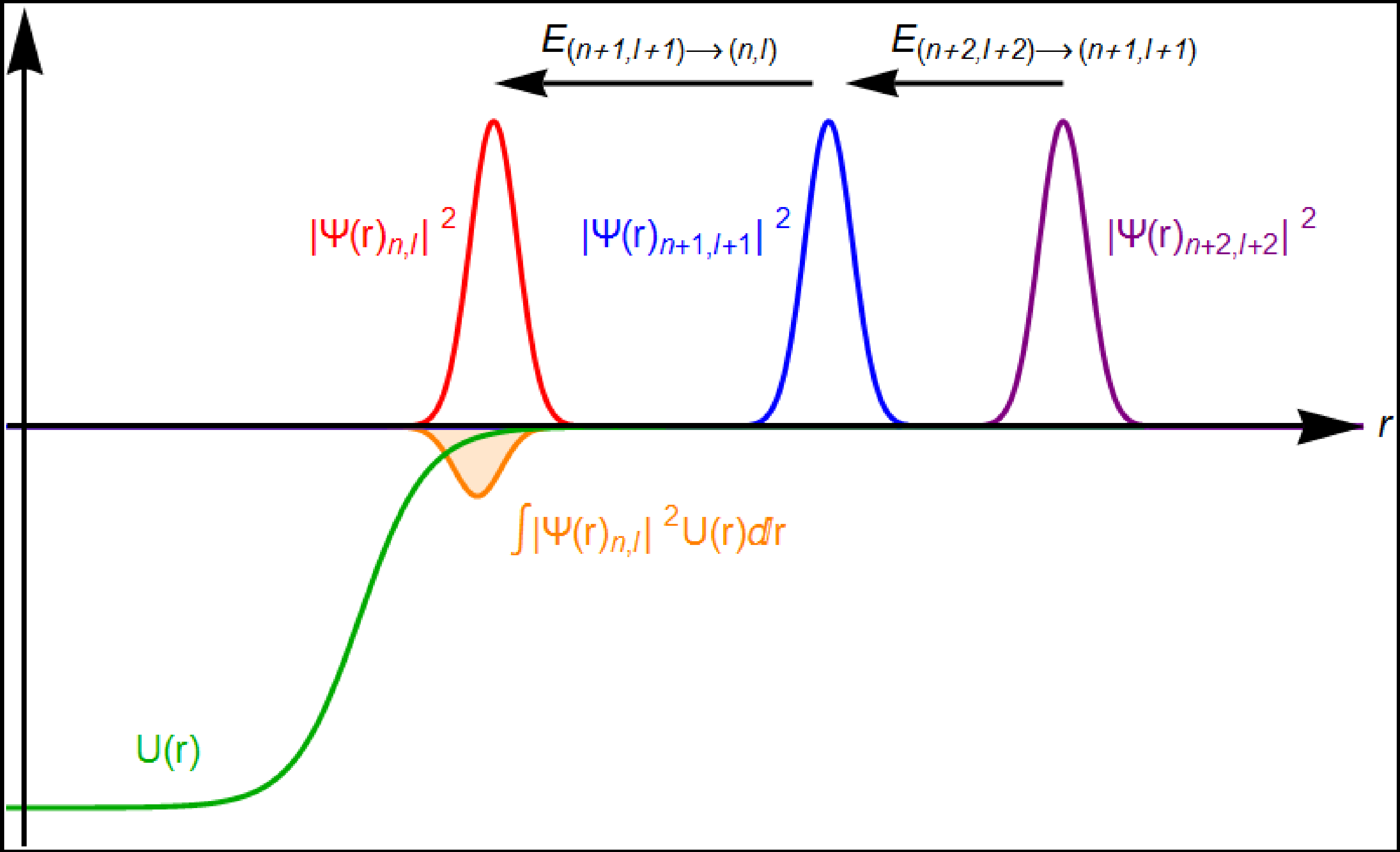
- E07
  - Beam exposure has successfully been performed for all emulsion stacks in 2016/2017
  - auto-scanning has started
  - ground state masses for ΛΛ-hypernuclei can be determined
  - Ξ⁻-Ag and Ξ⁻-Br X-rays
- E03
  - Ξ⁻-Fe X-rays (medium mass targets)





Ξ^- atom X-ray spectroscopy

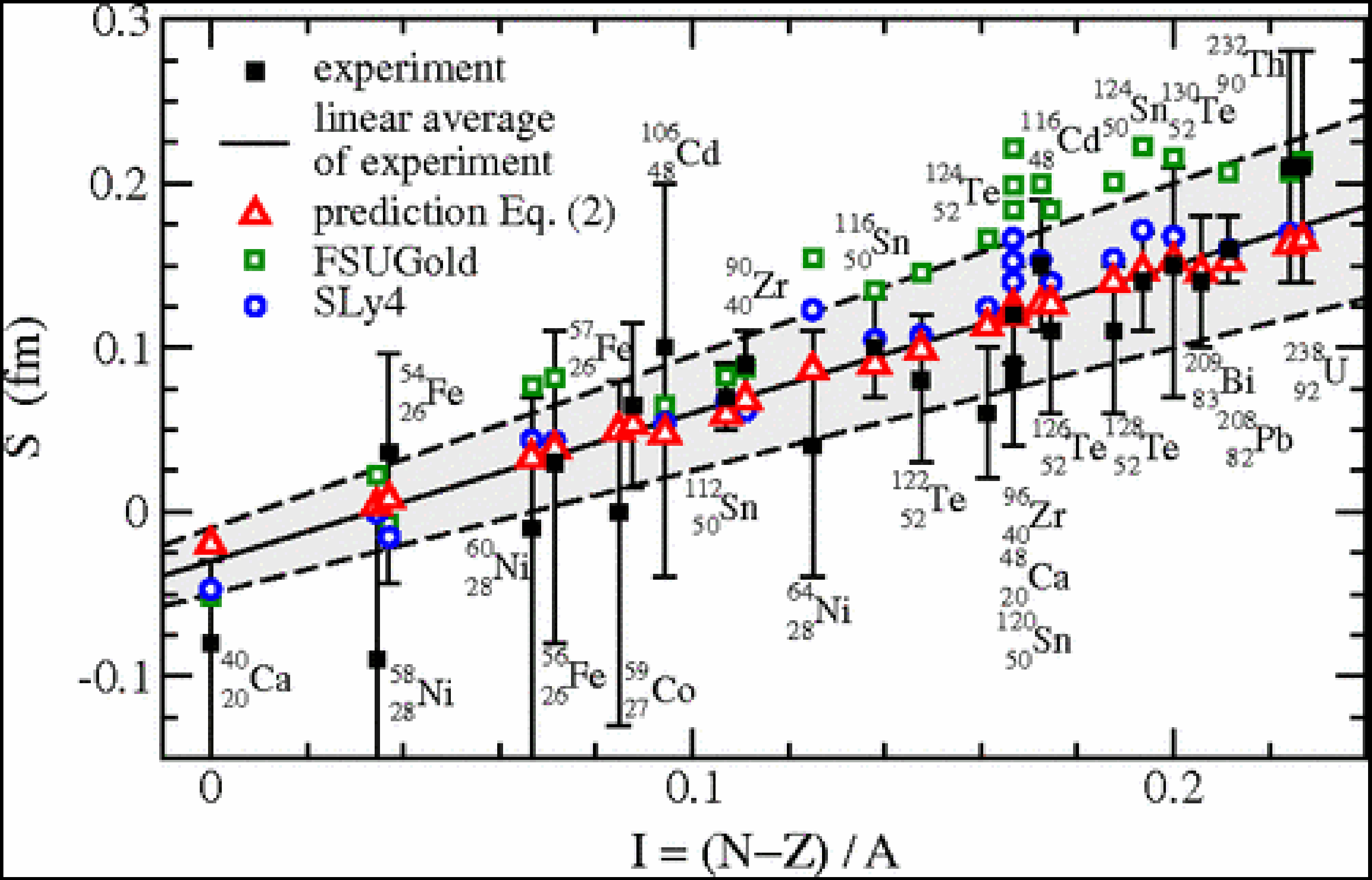
- Shift of „lowest“ atomic sensitive to Ξ^--nucleus interaction
- Interpretation requires knowledge on
  - the neutron and proton distribution
  - the isospin dependence of the baryon-baryon force



Isospin in Ξ⁻ atoms

- It is important to measure both, light nuclei with I=0 (N=Z) and heavy nuclei (neutron skin)
- Goal at PANDA: study well known double-magic nuclei

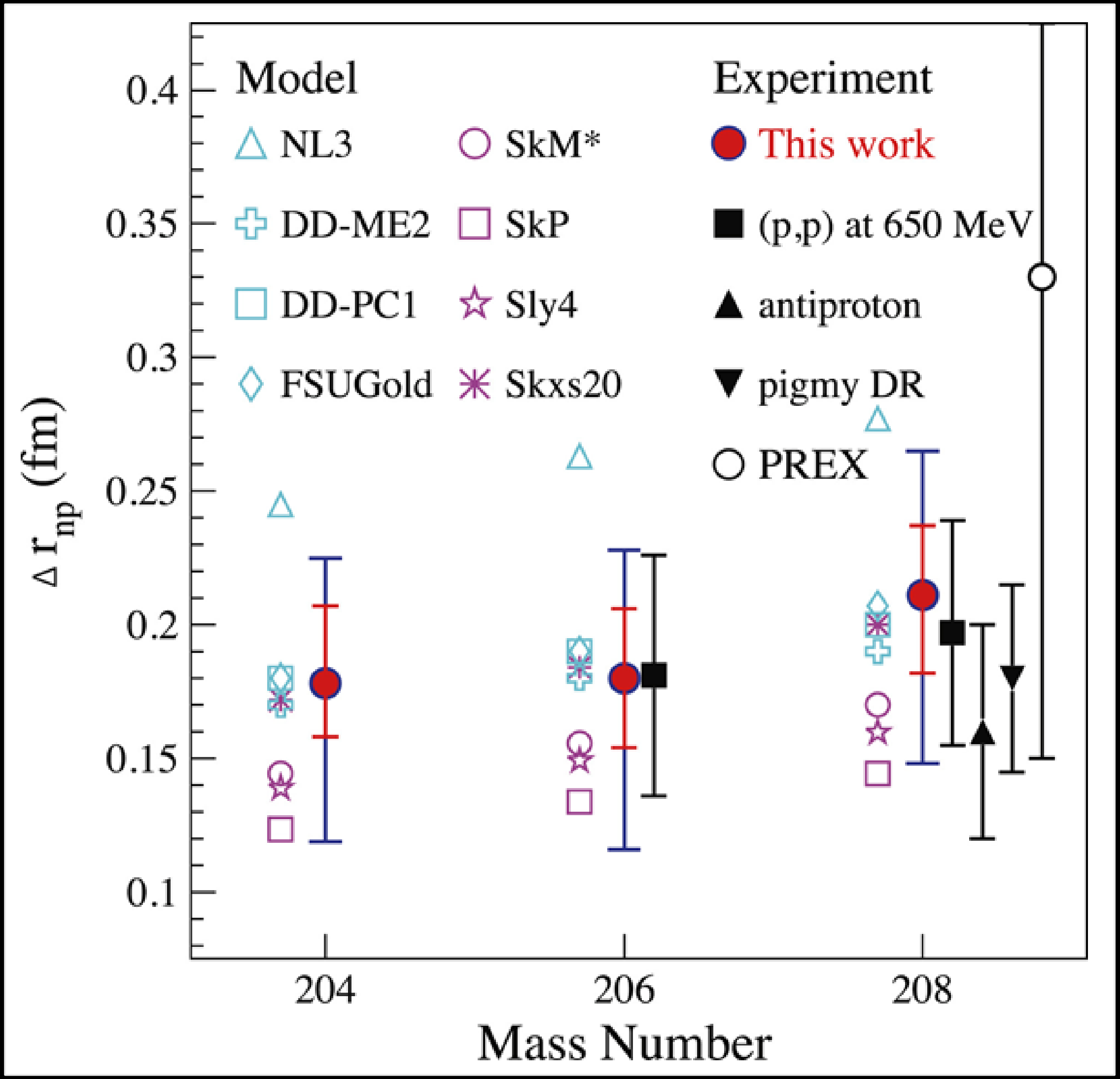
^{40}Ca



^{208}Pb

M. Centelles, X. Roca-Maza, X. Viñas, and M. Warda
Phys. Rev. Lett. 102, 122502

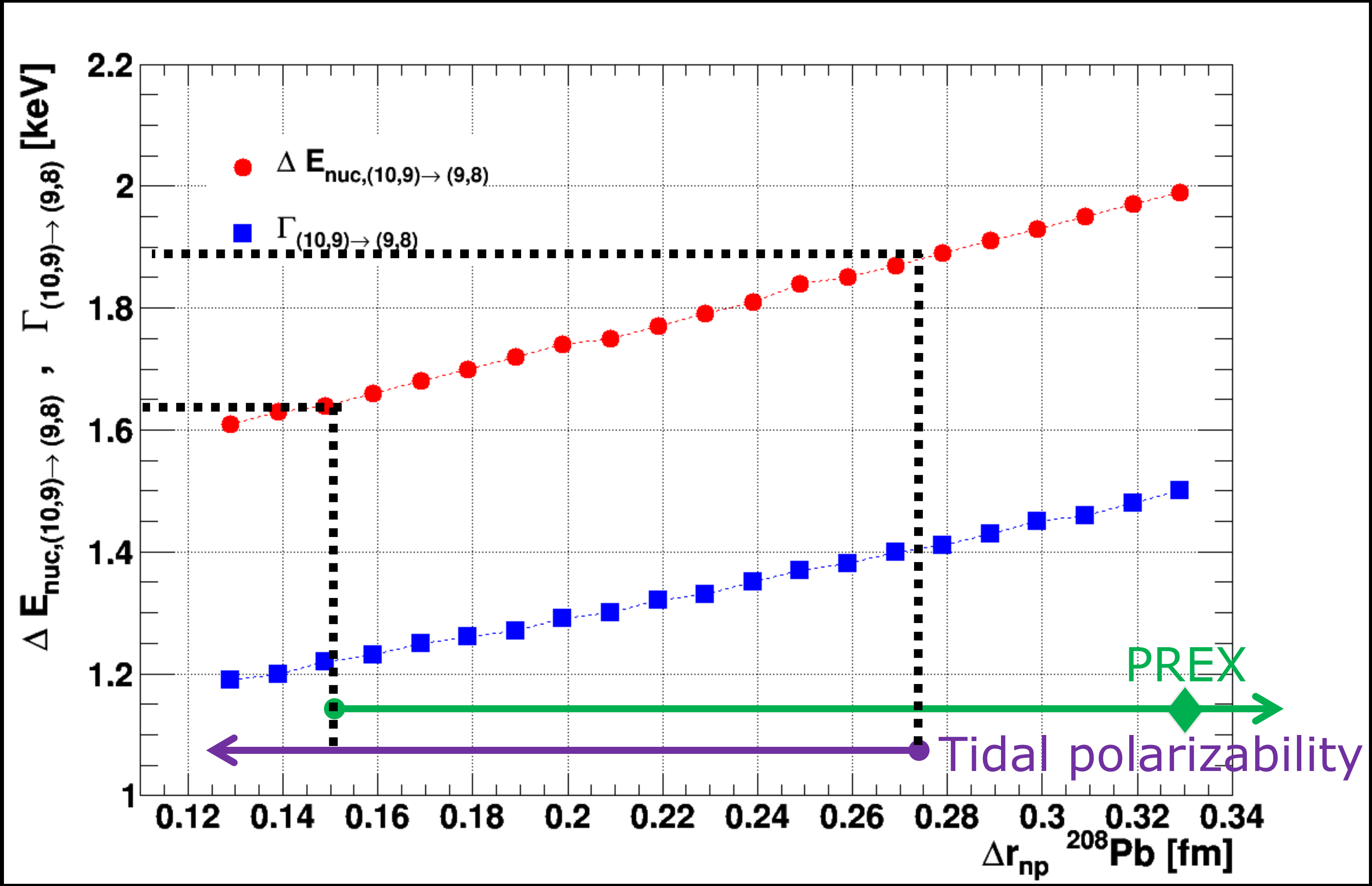
^{208}Pb – the known unknown



H.Sakaguchi and J.Zenihiro,
Progr. in Part. and Nucl.Physics 97, 1 (2017)

Sensitivity to ^{208}Pb structure

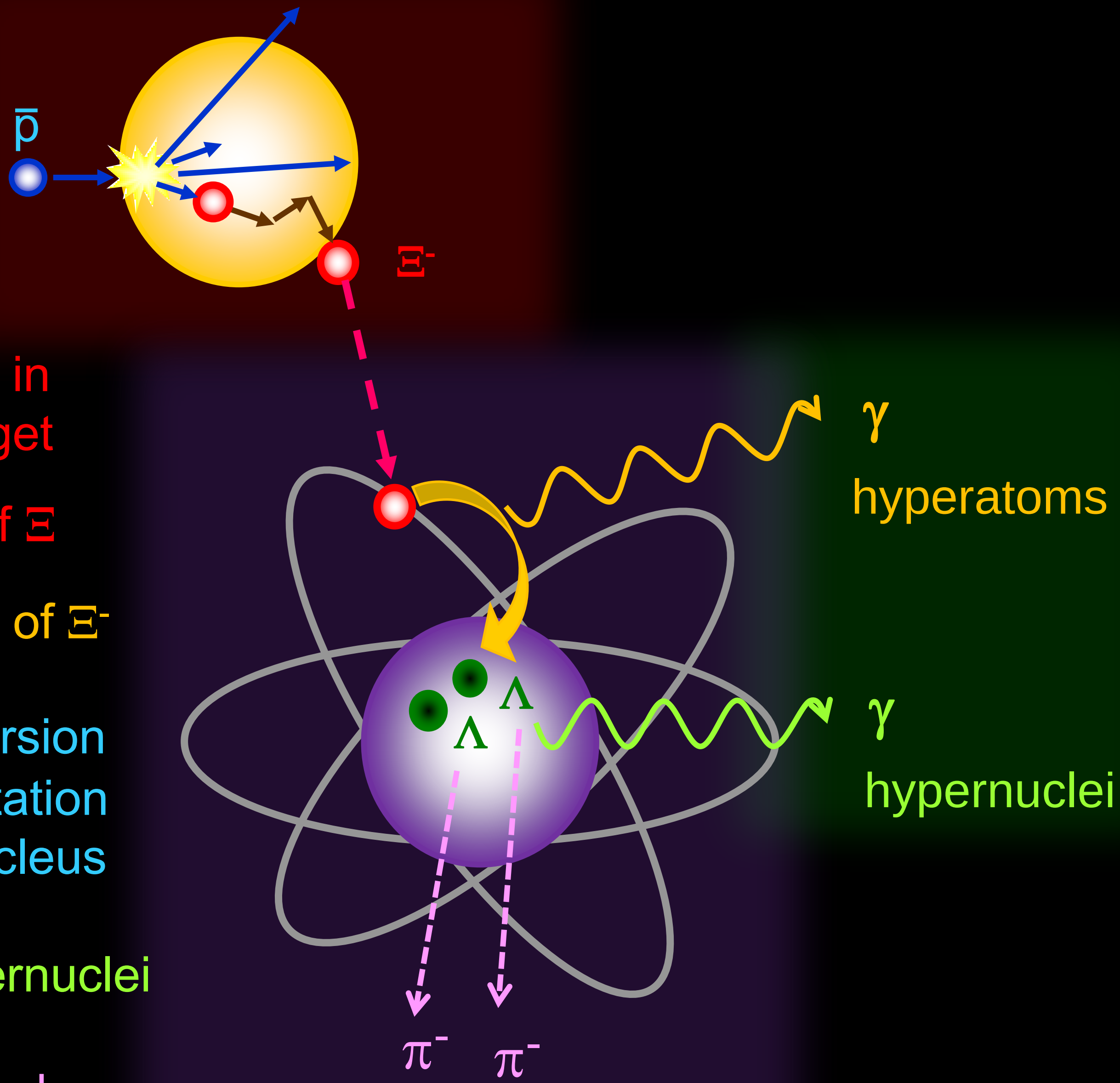
- changing thickness of neutron skin artificially in calculation



arXiv: 1711.06615

M. Steinen and Eli Friedman

Strange Systems at PANDA



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

rescattering in
primary target nucleus

deceleration in
secondary target

capture of Ξ

atomic cascade of Ξ^-

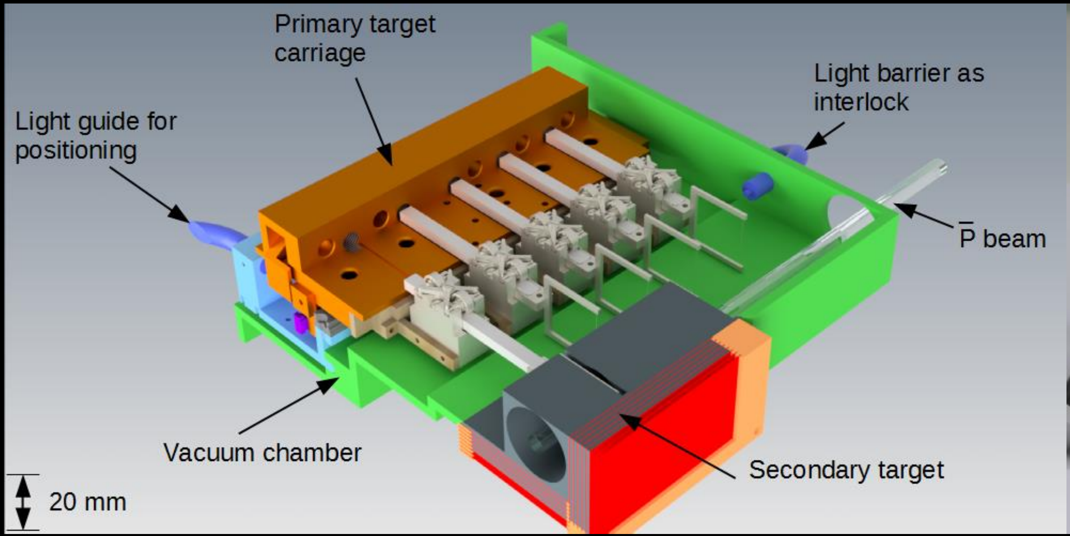
$\Xi^- p \to \Lambda\Lambda$ conversion
fragmentation
→ excited $\Lambda\Lambda$-nucleus

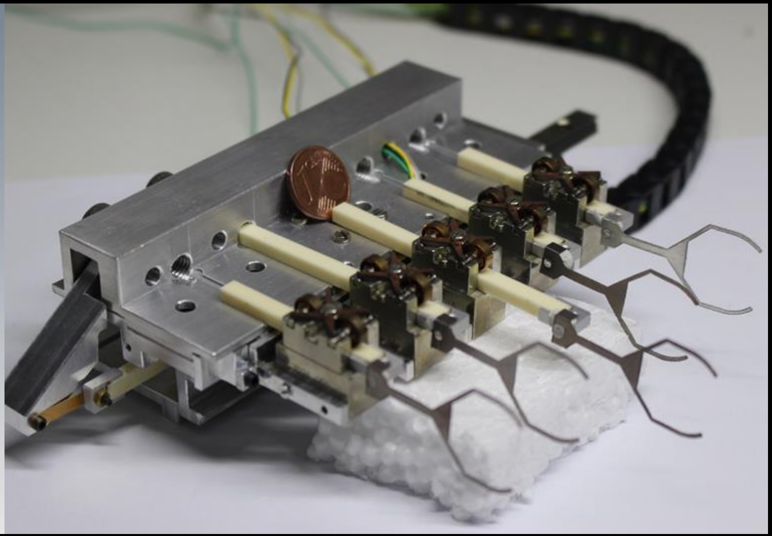
γ-decay of $\Lambda\Lambda$ hypernuclei

weak pionic decay

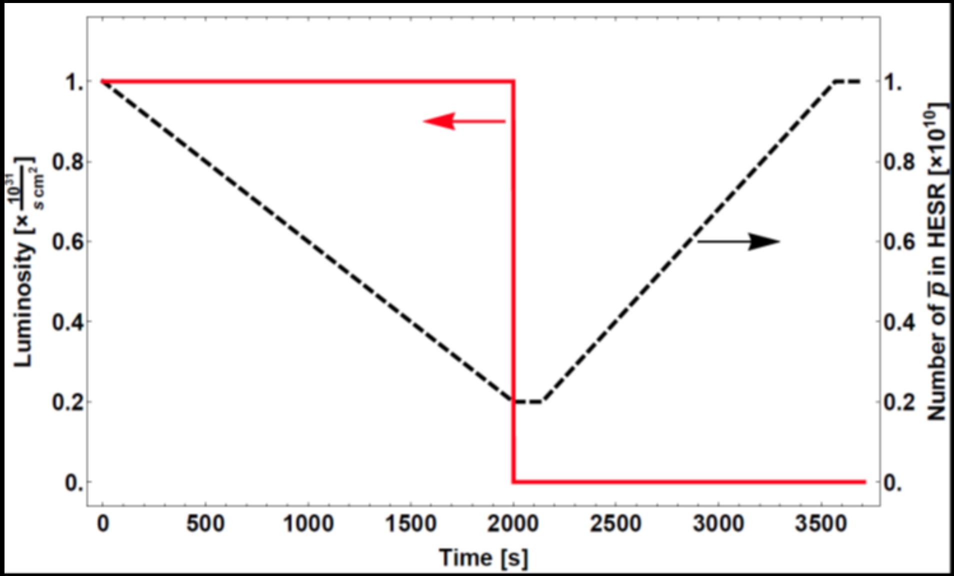
Primary Target

- Task: maximize slow Ξ^- production

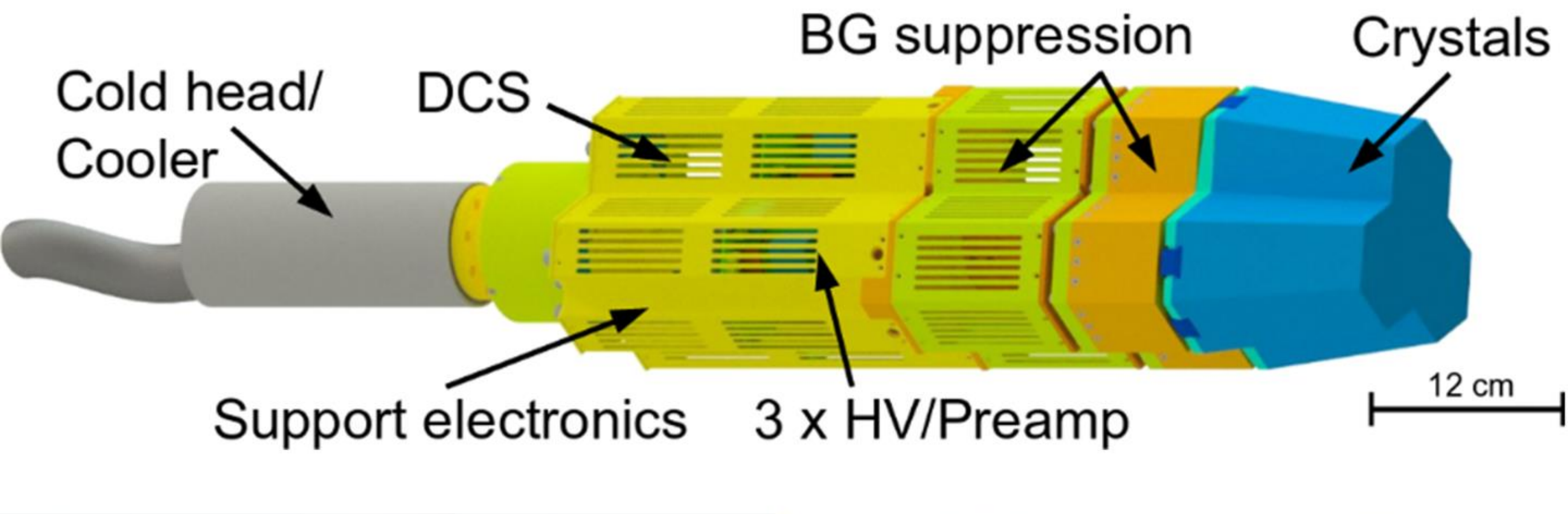


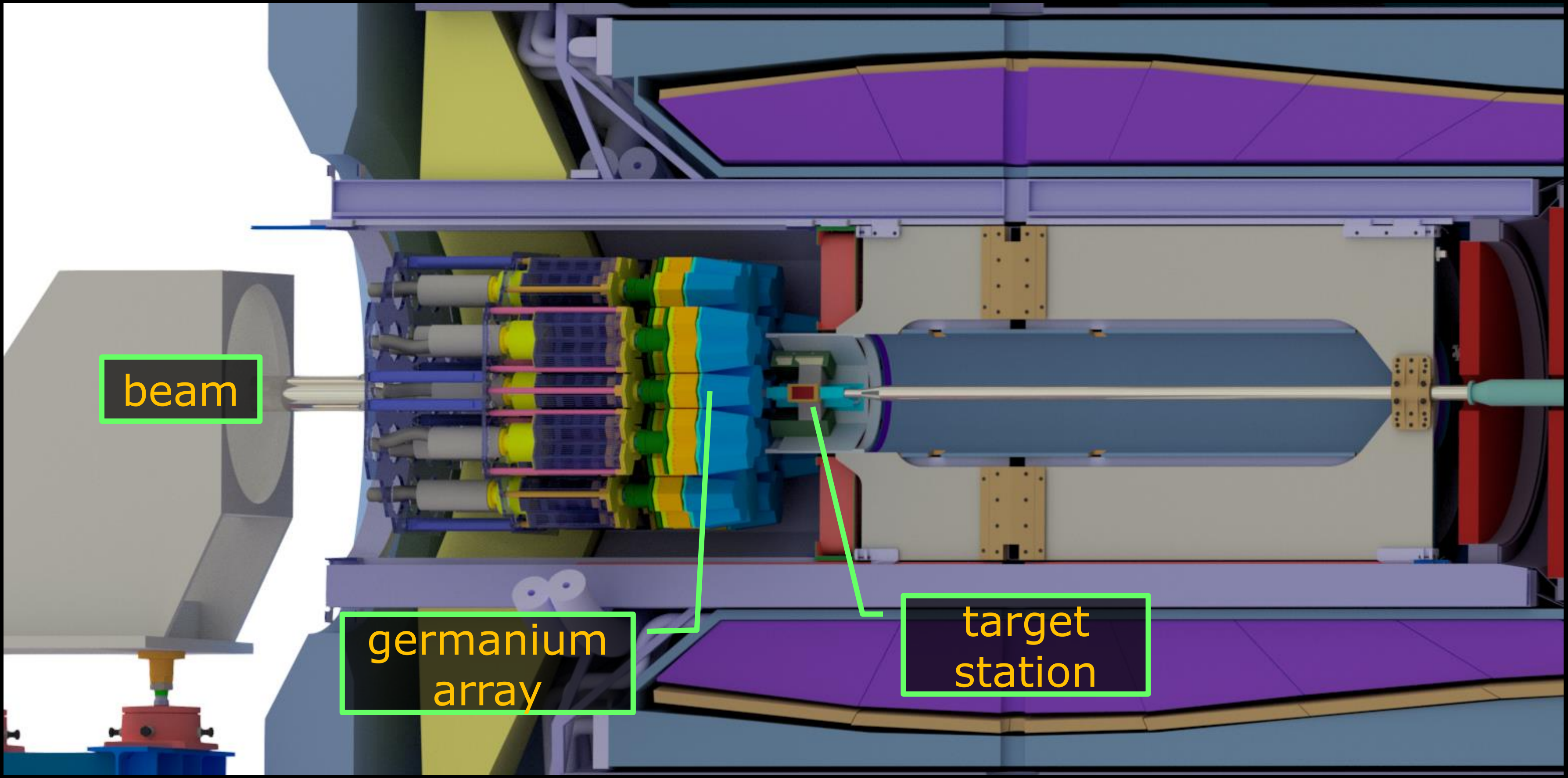


- Target material: C filament 5μm
  - production cross section
  - slow down process
  - beam losses…
- ultra high vacuum
- magnetic field
- radiation hardness
  e.g. passive position control
- …



PANGEA


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



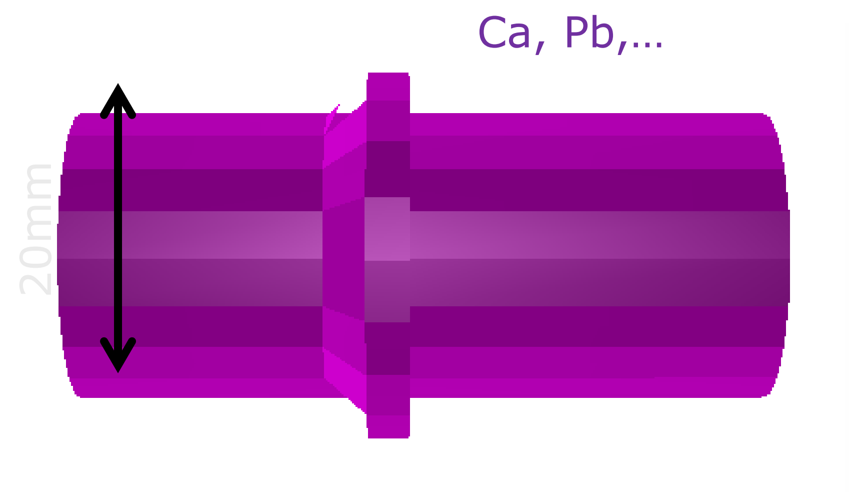
beam

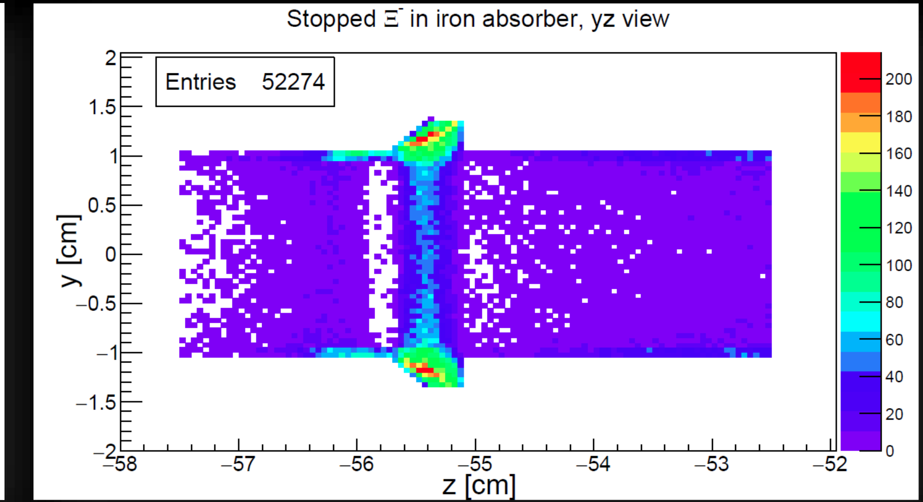
germanium array

target station

PANDA Setup for Hyperatoms

- Shape of absorber optimized by GiBBU+GEANT4 simulations





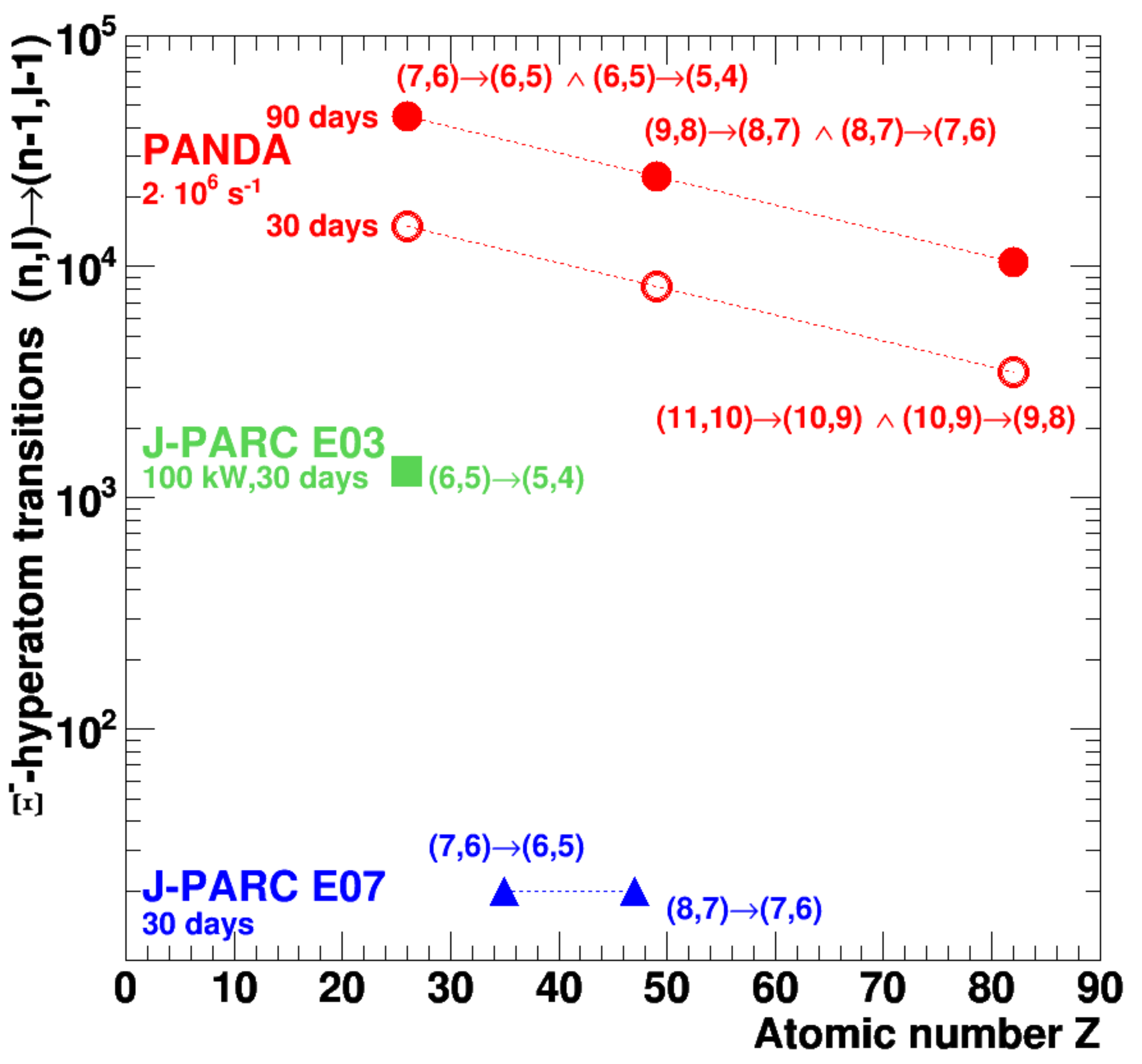
- very thin primary target
- primary and secondary target separated
- relative thin secondary target

  ⇒ moderate X-ray absorption

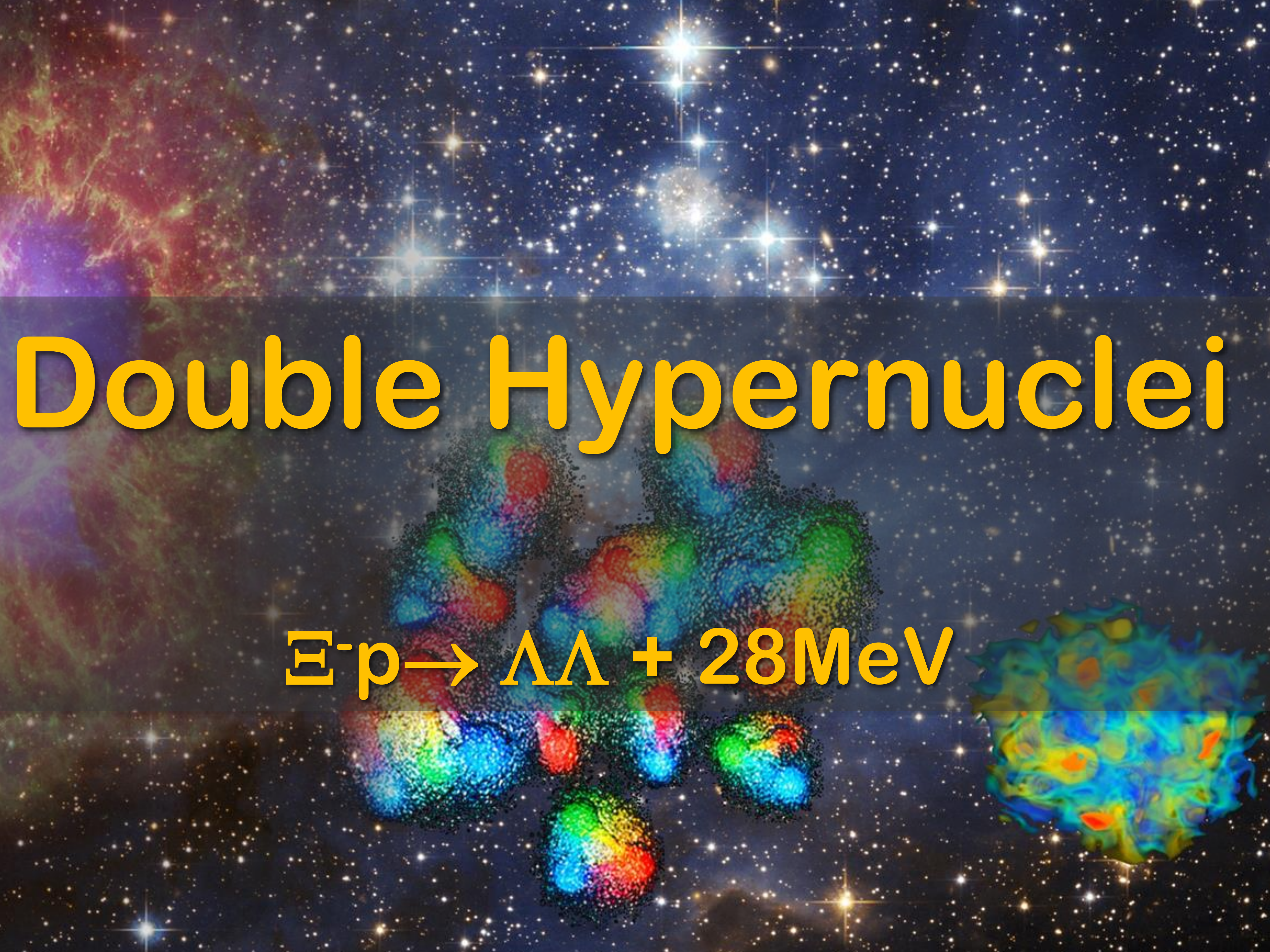
  ⇒ detection of cacades possible

  ⇒ heavy targets possible
- tracking secondary particles also possible ⇒ reduced background

Count rate: ×100 double hypernuclei ⇒ ideal for initial phase of PANDA

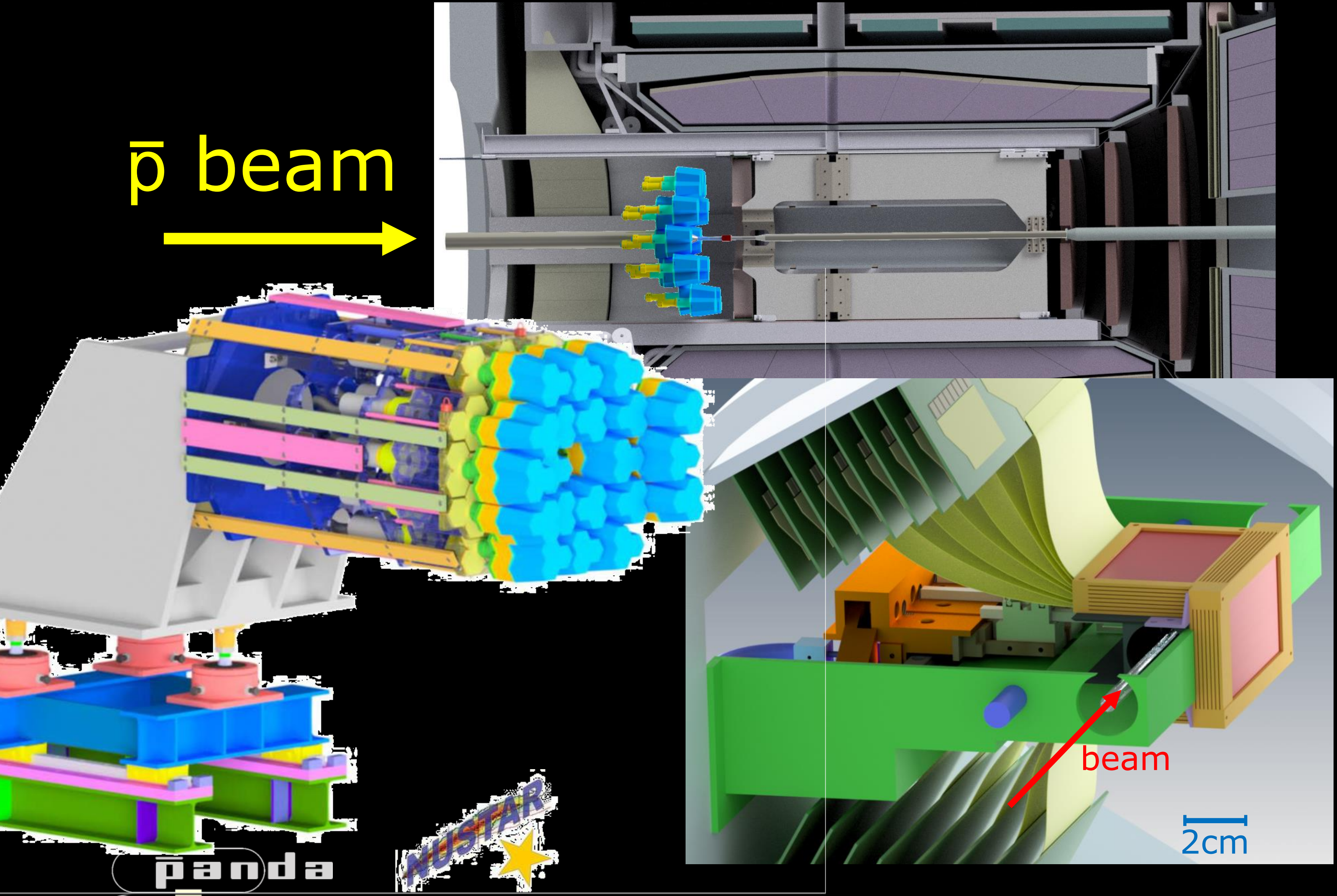

Ξ^--hyperatom transitions (n,l)→(n-1,l-1)
10^5
10^4
10^3
10^2
0
10
20
30
40
50
60
70
80
90
Atomic number Z
(7,6)→(6,5) ∧ (6,5)→(5,4)
90 days
PANDA
$2 \cdot 10^6$ s^{-1}
30 days
(9,8)→(8,7) ∧ (8,7)→(7,6)
(11,10)→(10,9) ∧ (10,9)→(9,8)
J-PARC E03
100 kW,30 days
(6,5)→(5,4)
(7,6)→(6,5)
J-PARC E07
30 days
(8,7)→(7,6)

Double Hypernuclei



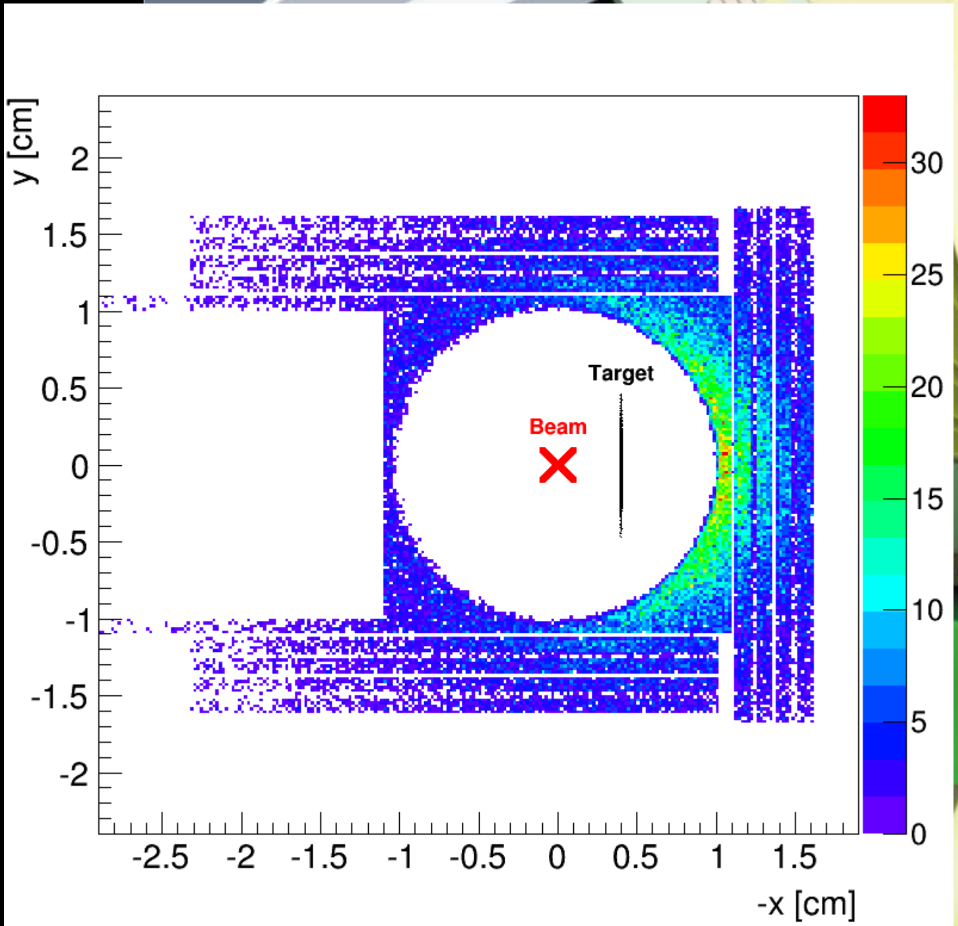
$\Xi^- p \rightarrow \Lambda\Lambda + 28\mathrm{MeV}$

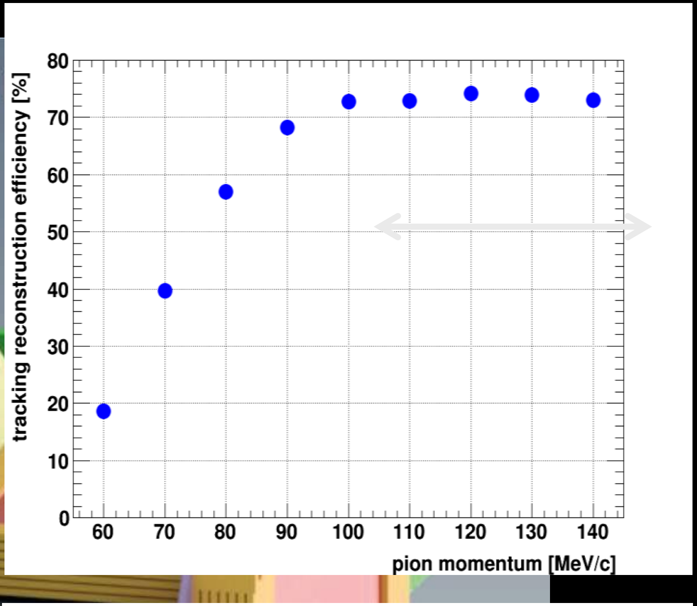
P̄ANDA-HYP setup

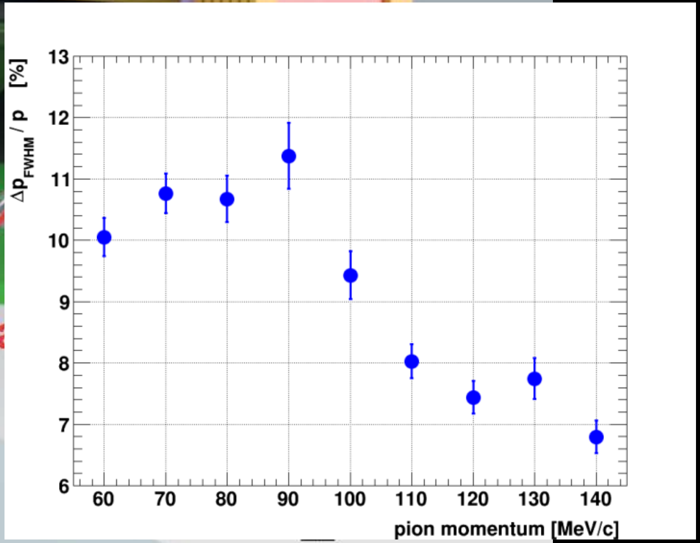


Secondary target

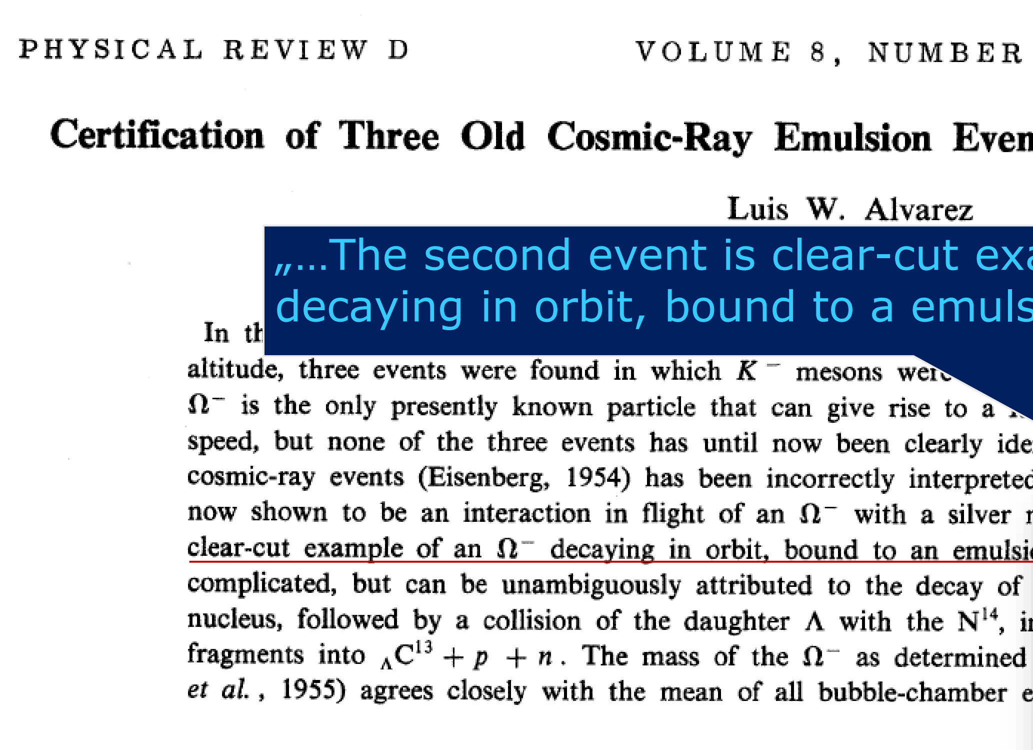
- Task: stopping of Ξ^- and tracking of 2 π^- from weak decay of double hypernuclei







Do Ω^- atoms exist?



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

„…The second event is clear-cut example of an Ω^- decaying in orbit, bound to a emulsion nucleus…"

In th t high
altitude, three events were found in which K^- mesons wer ly moving particles. The
Ω^- is the only presently known particle that can give rise to a ving at nonrelativistic
speed, but none of the three events has until now been clearly identi n Ω^-. One of the
cosmic-ray events (Eisenberg, 1954) has been incorrectly interpreted as an decaying in flight; it is
now shown to be an interaction in flight of an Ω^- with a silver
clear-cut example of an Ω^- decaying in orbit, bound to an emulsi
complicated, but can be unambiguously attributed to the decay of
nucleus, followed by a collision of the daughter Λ with the N^{14}, i
fragments into ${}_{\Lambda}C^{13} + p + n$. The mass of the Ω^- as determined
et al., 1955) agrees closely with the mean of all bubble-chamber e

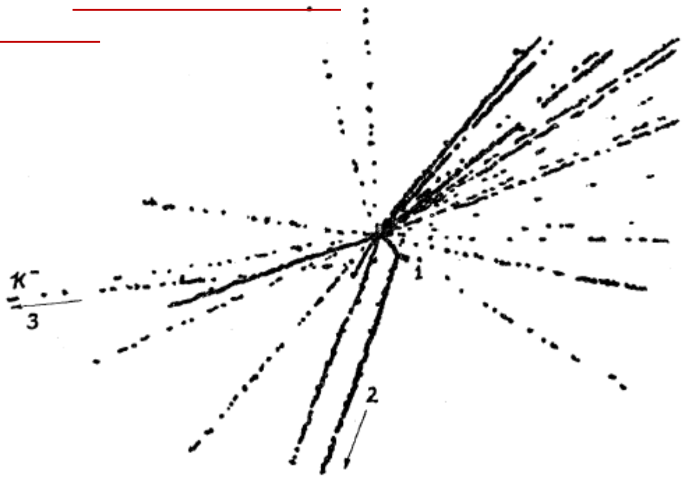


FIG. 1. A projection drawing of the K-mesonic decay of a slow particle is shown above. Track 1 is a short recoil. Track 2 was produced by a particle of $Z=1$. Track 3 was produced by a negative K-meson. A few tracks of particles from the primary star which are in the same direction as the connecting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

- *…seen in emulsions ~10 years prior to the „discovery" at Brookhaven in 1964*
- Note: in nuclei secondary processes possible

$$\bar{p} + n \rightarrow \bar{\Xi}^- + \Xi^0 \qquad \Xi^0 + X \rightarrow \Omega^- + K^+ + X$$

$$\bar{p} + p \rightarrow \bar{\Xi}^- + \Xi^- \qquad \Xi^- + X \rightarrow \Omega^- + K^0 + X$$

Thank you for your attention