The strangeness S = -2 nuclear physics setup at $\bar{\text{P}}$ANDA: Status and prospects

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on behalf of the $\bar{\text{P}}$ANDA Collaboration

in collaboration with J.Gerl, I. Kojouharov, E. Friedman

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DPG 2019, Munich ,HK 52.1, 03/21/2019

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Outline

- Strangeness S = -2 program of $\overline{\text{P}}$ANDA
- Dedicated detector setup of the S = -2 program
- Irradiation test of a germanium detector at COSY

Strangeness S = -2 program

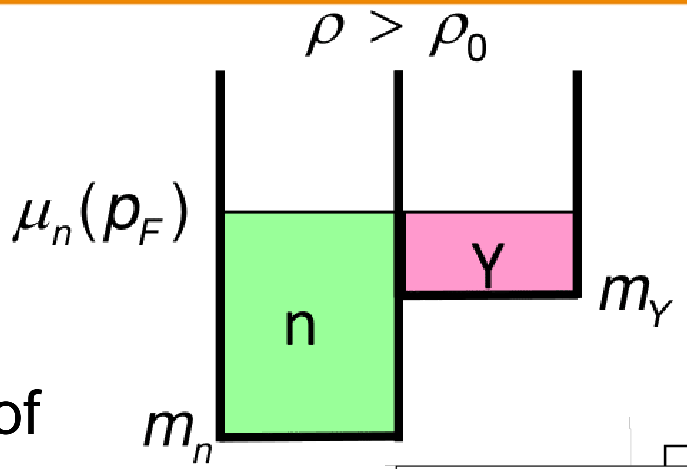
Strangeness S = -2 program of $\overline{\text{P}}$ANDA

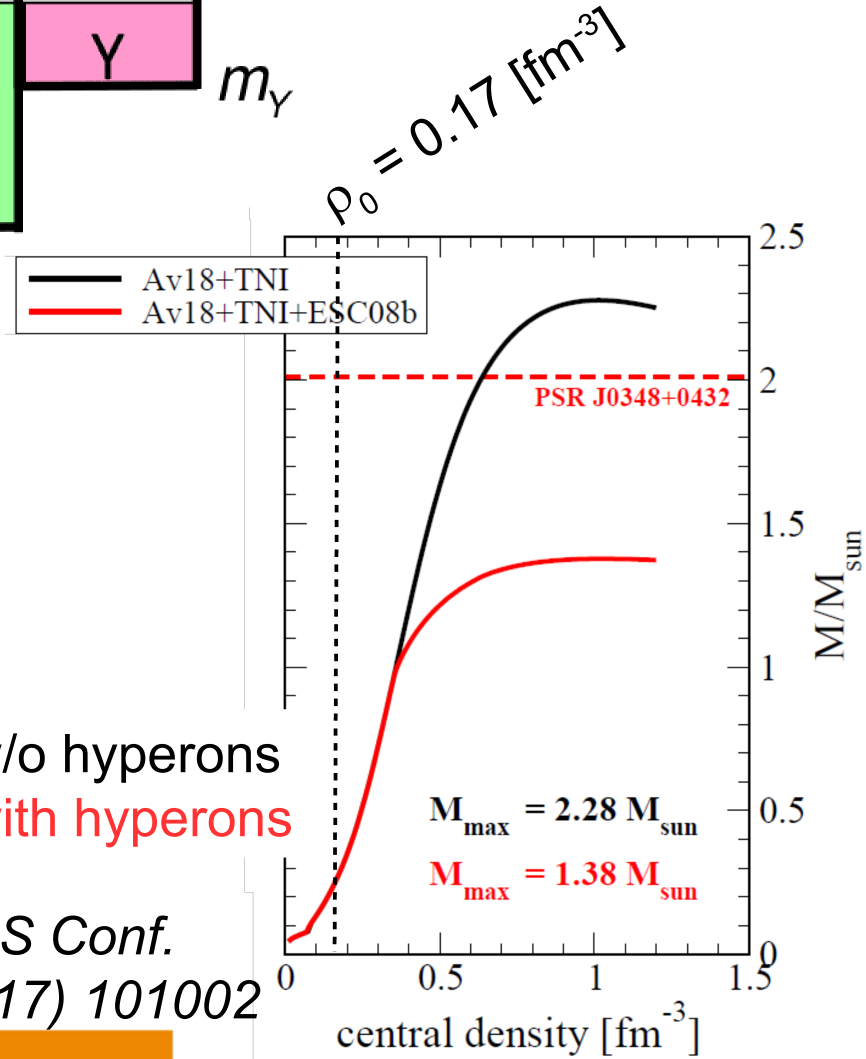
Motivation

- Neutron stars
  - Hyperons energetically favored at $\rho_{NS} > 2\text{-}3 \cdot \rho_0$
  - Hyperons soften equation of state
    ->Too soft for $m_{NS} = 2\ M_{\odot}$
    (PSR J0348-0432)

→ **Hyperon puzzle**

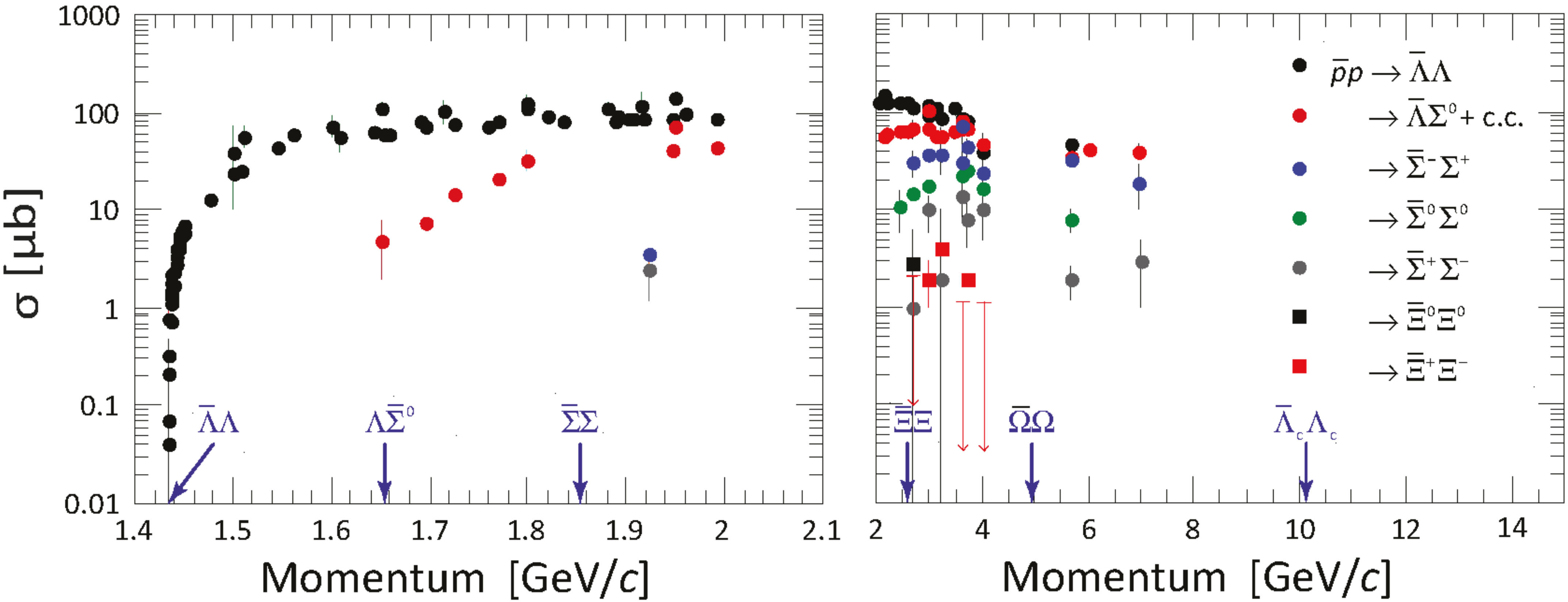
→ **Experimental input for hyperon interactions required!**





Bombaci, JPS Conf. Proc. 17 (2017) 101002

PANDA @ HESR as "hyperon factory"

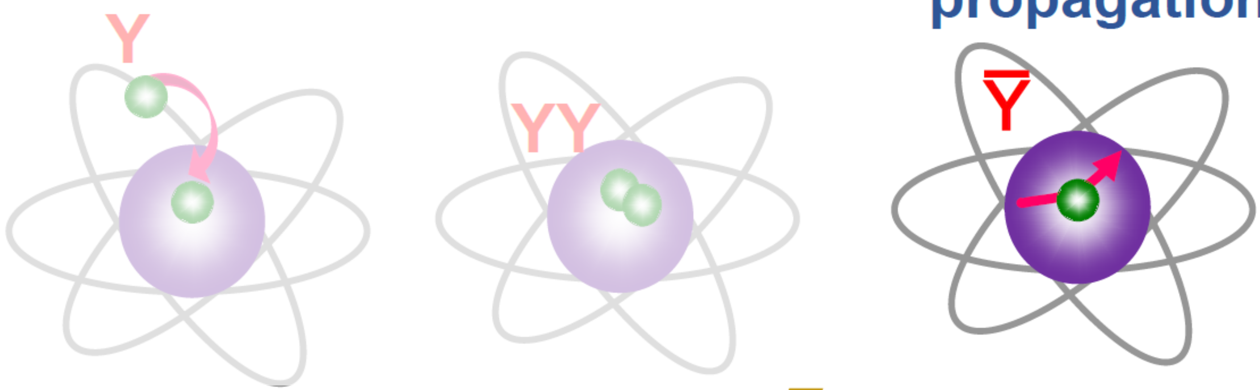


Panda Collaboration, Physics Performance Report for PANDA

Production rates:	$\Lambda\bar{\Lambda}$	1200 /s
@ 2 MHz p̄p	$\Xi^-\bar{\Xi}^+$	80 /s

S = -2 experiments @ $\bar{P}$ANDA

Ξ^- hyperatoms | $\Lambda\Lambda$ hypernuclei | (anti)hyperon propagation



Physics Topic at $\bar{P}$ANDA

Ξ^- potential in neutron-rich baryonic matter

Structure of double $\Lambda\Lambda$ hypernuclei, hyperon mixing

antihyperon potential in cold baryonic matter

Methodology

Width and shift of atomic levels in Ξ^- ^{208}Pb atoms

Excited state spectrum of light $\Lambda\Lambda$ hypernuclei

$Y\bar{Y}$ momentum correlations at threshold

Pochodzalla et al., Nuclear Physics A 954 (2016) 323–340

Sanchez Lorente et al., Physics Letters B 749 (2015), pp. 421-424

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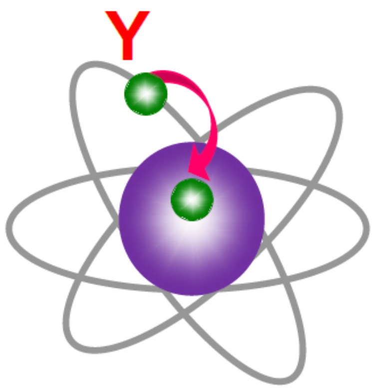
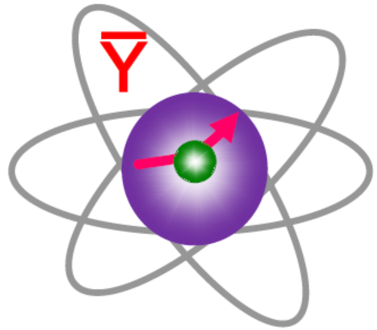
Ξ^- hyperatoms | **$\Lambda\Lambda$ hypernuclei** | **(anti)hyperon propagation**





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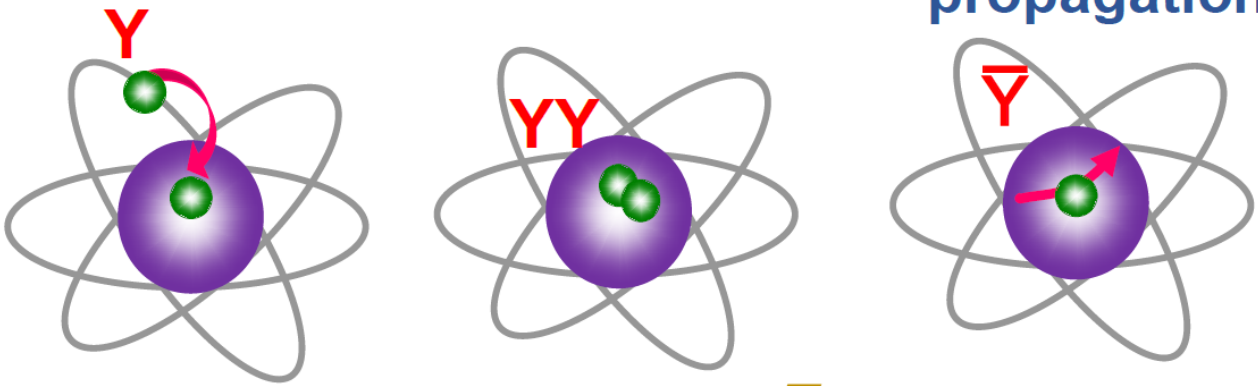

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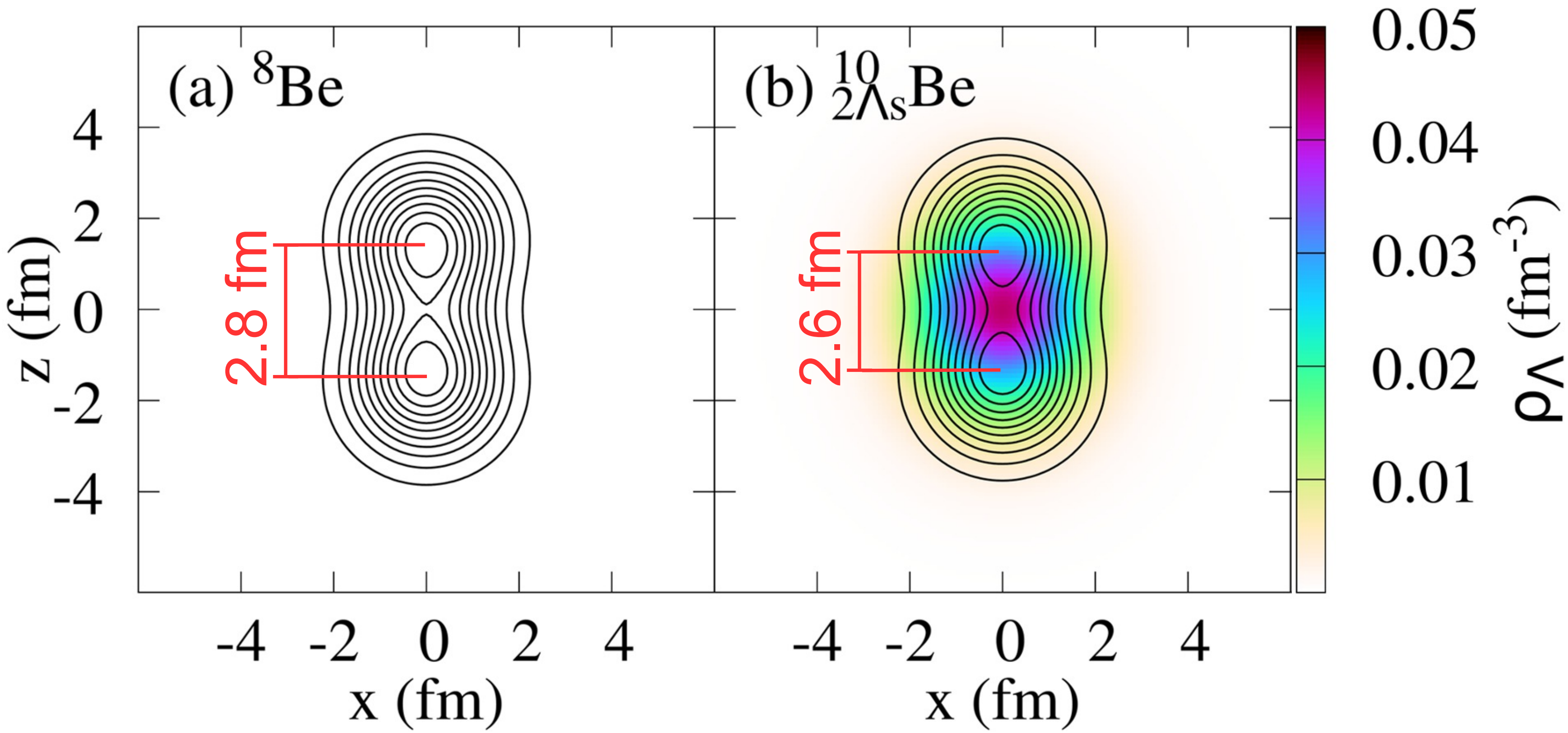
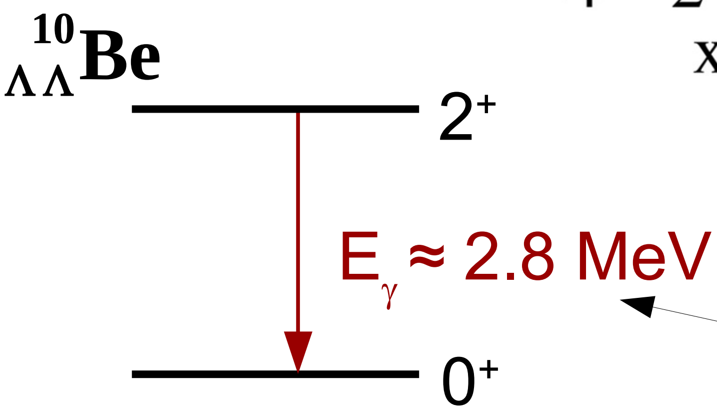
γ spectroscopy of ΛΛ hypernuclei



Tanimura, arXiv:1812.07713 [nucl-th].

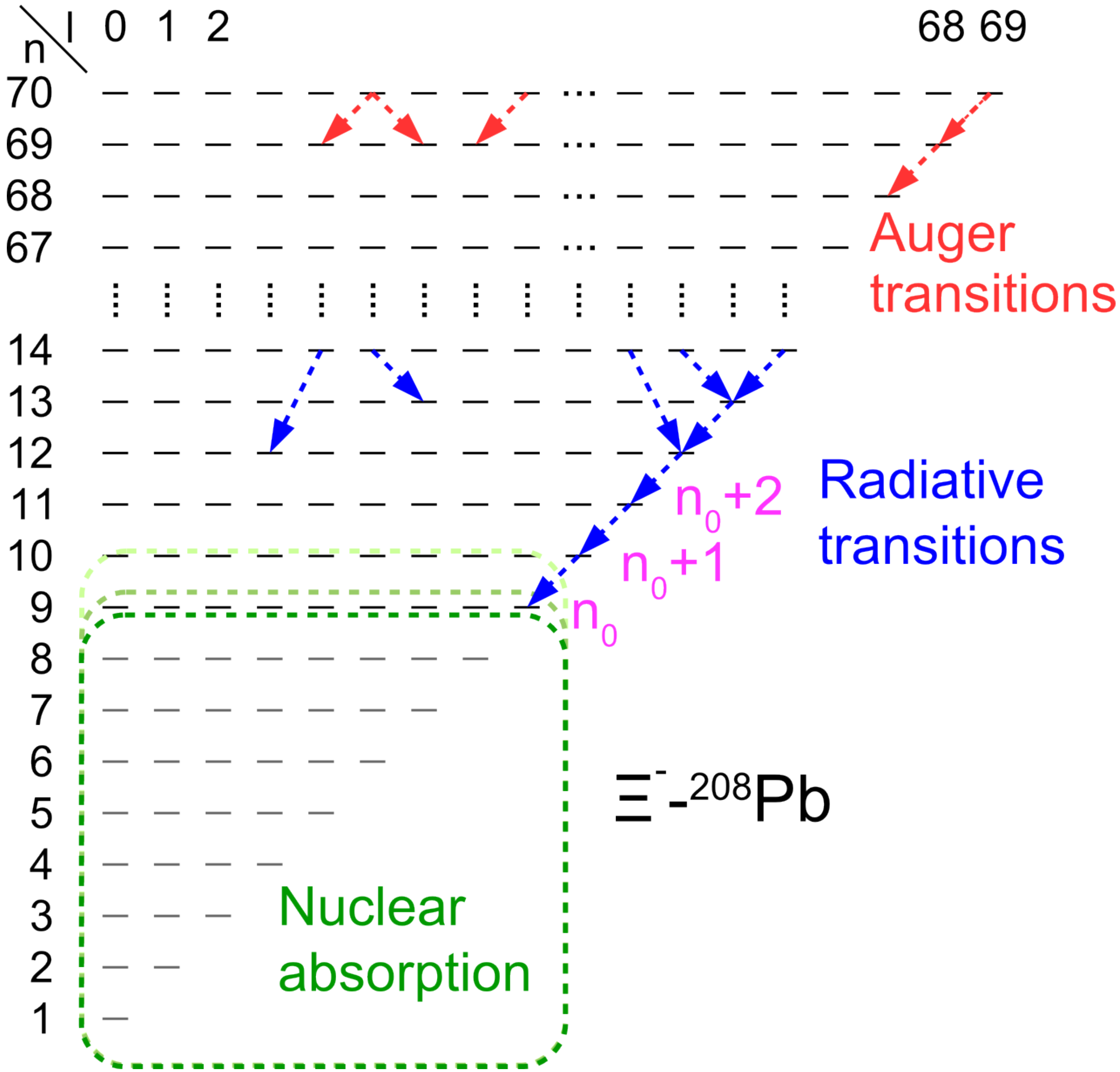


$$E_J = \hbar^2 \frac{J(J+1)}{2\Theta_{eff}}$$

(assuming rigid rotator)

Ξ^- - ^{208}Pb hyperatoms

- Ξ^- - ^{208}Pb: $m_{\mathrm{red},\Xi} \approx 2570 \cdot m_{\mathrm{red},e}$
  - High initial (n,l) states
  - X-ray energy to keV-MeV
    → Germanium detectors
  - Radius of states $r_n \propto \frac{n^2}{m_{\mathrm{red}}}$
    → Nuclear interaction in neutron rich periphery

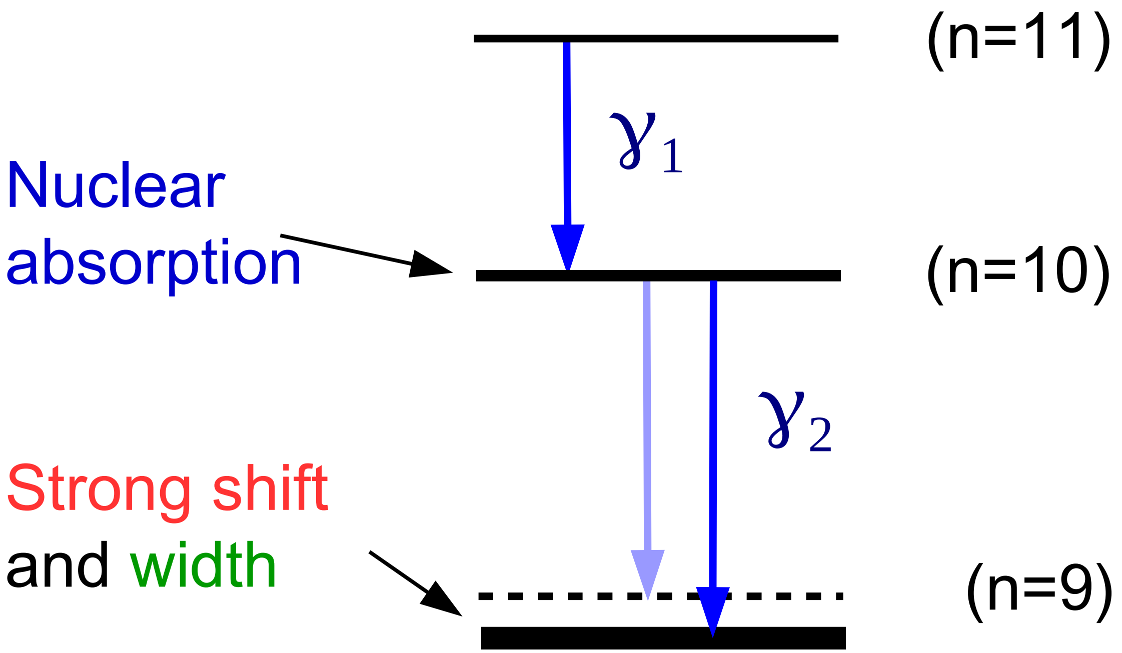


Adaptation from T. Aramaki et al Astroparticle Physics 49 (2013), pp. 52-62

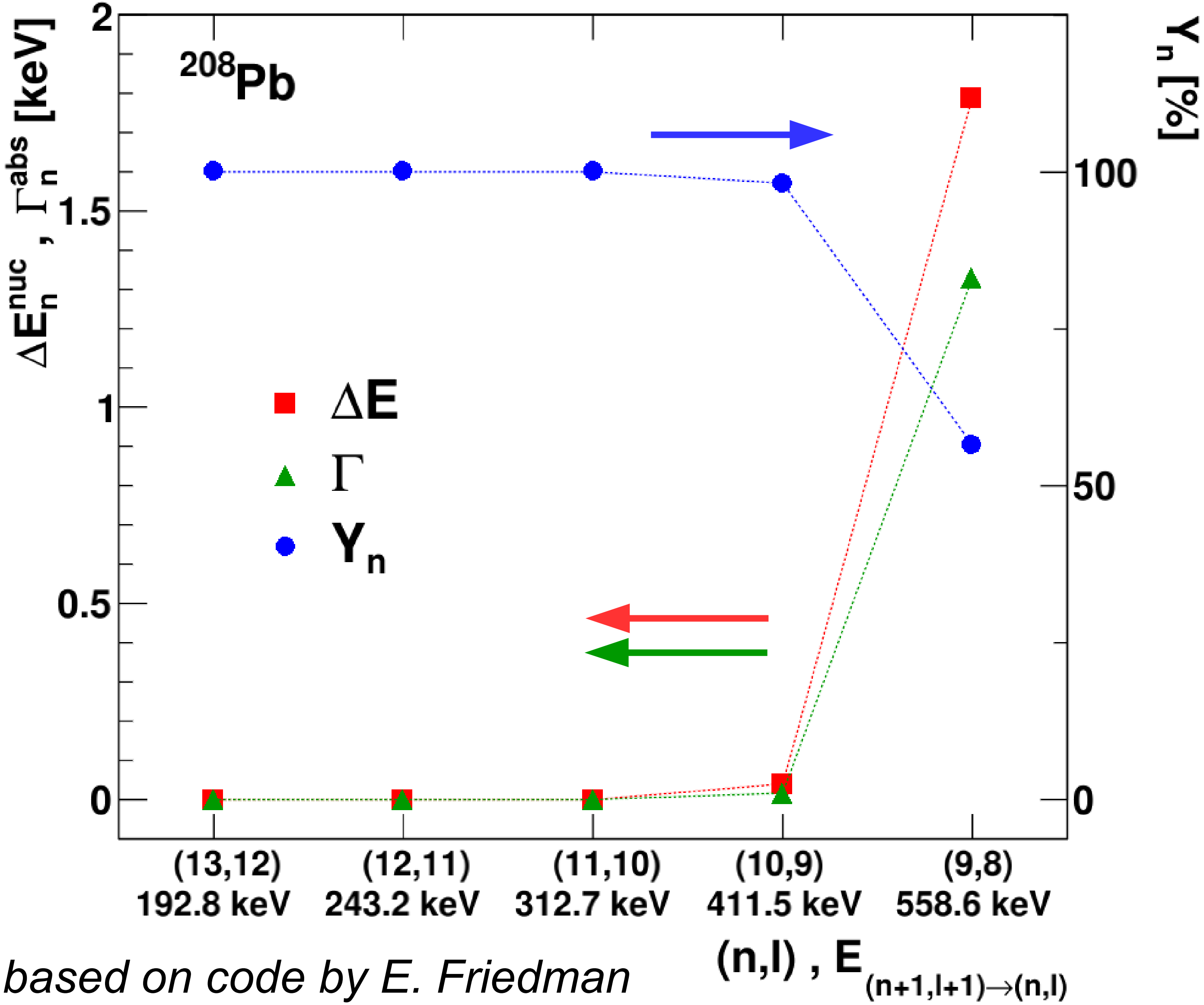
Hyperatom experiment - observables

- Observables of nuclear interaction:
  - Energy shift of γ_2 $\Delta E_{n_0}^{nuc}$
  - Width of (n_0,l_0) $\Gamma_{n_0}^{abs}$
  - Yield of γ_2 Y_{γ_2}

$\rightarrow \Gamma_{n_0+1}^{abs}$



Ξ^- - ^{208}Pb observables



(9,8):

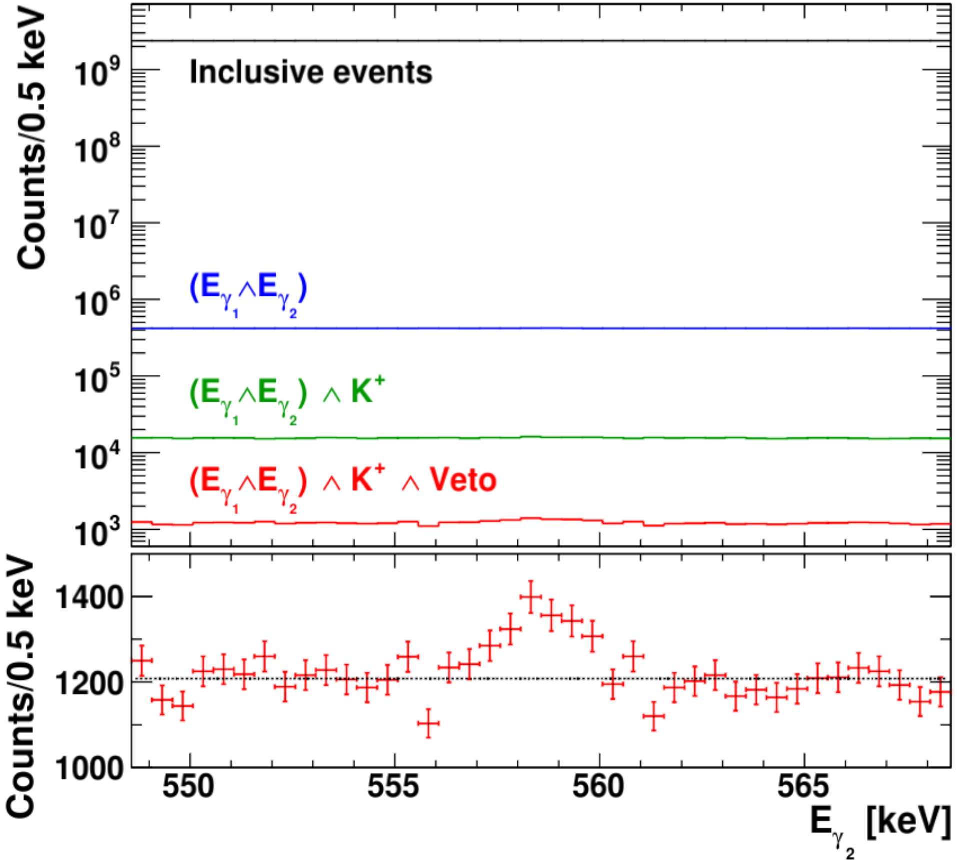
1.83 keV

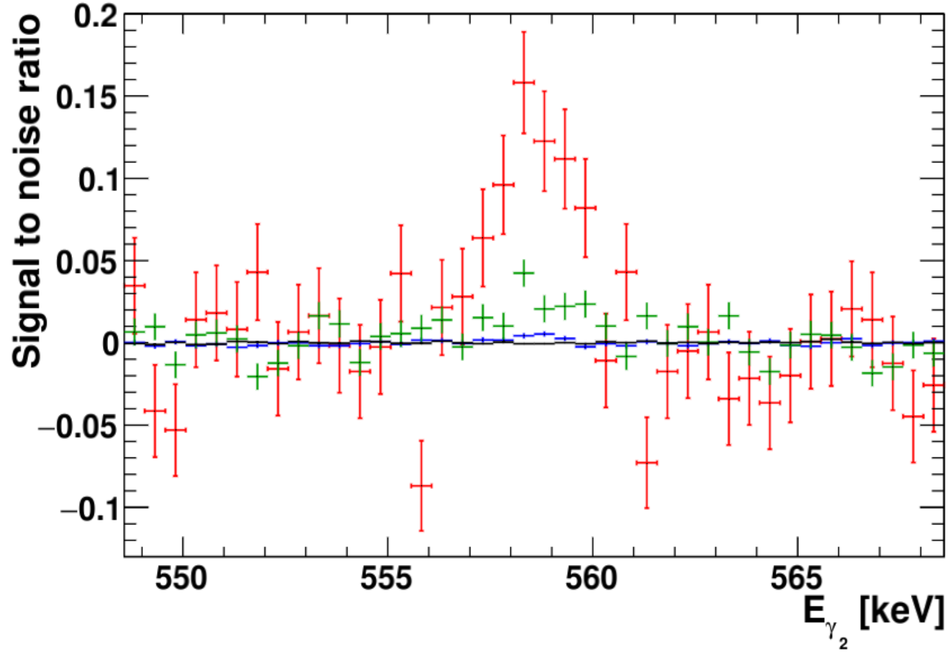
1.33 keV

56.5 %

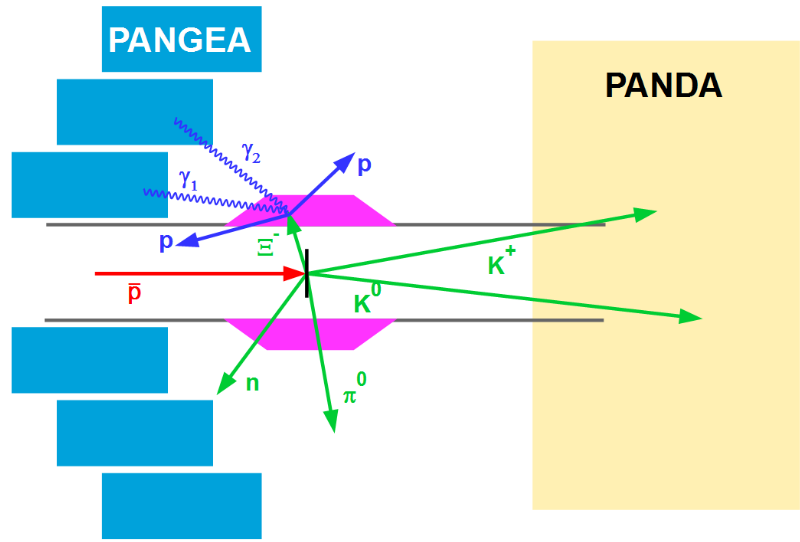
Calculations based on code by E. Friedman

Hyperatom experiment - event selection

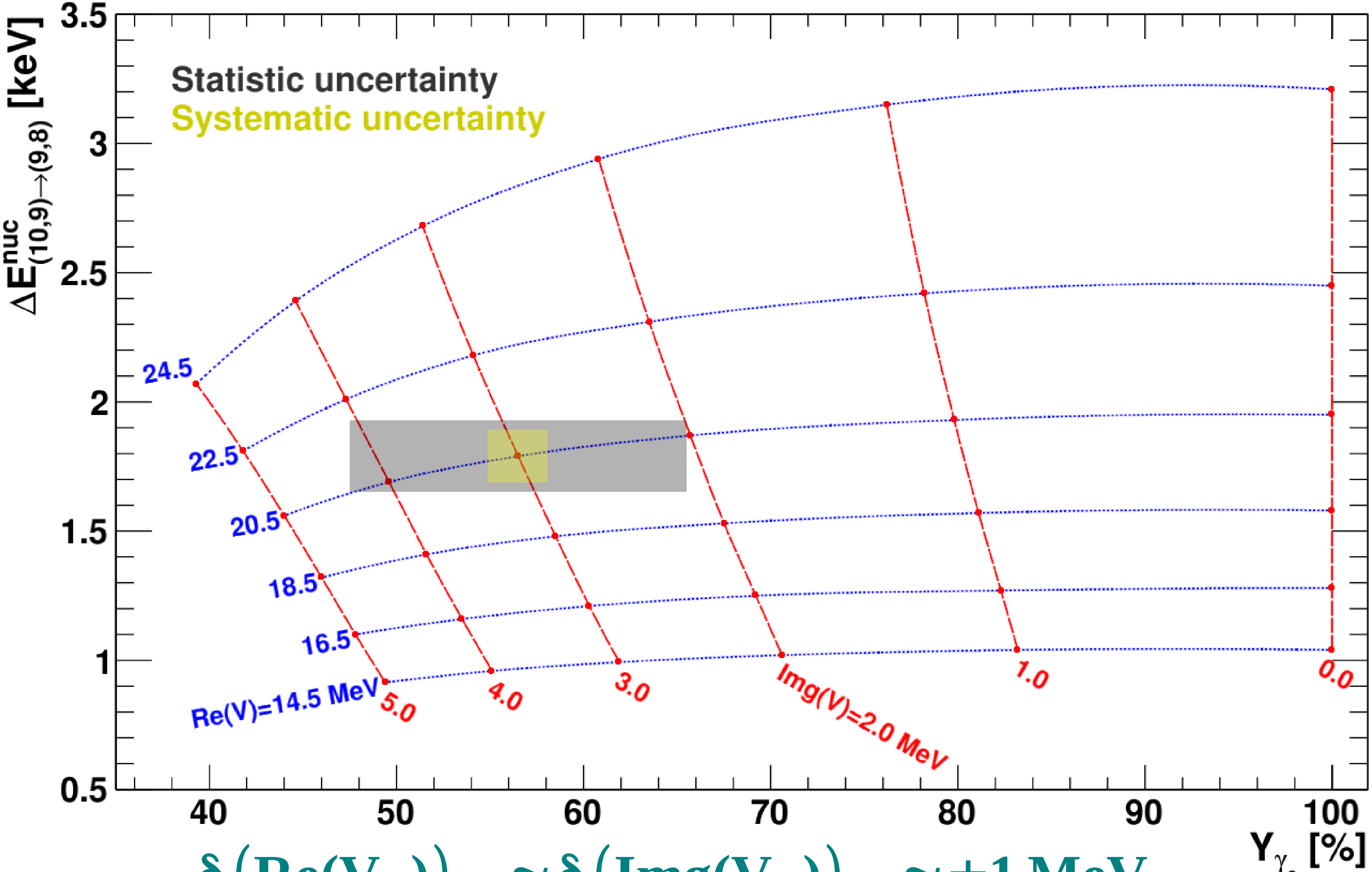




- Signals events after cuts (180 days): 1237
- Signal efficiency: 0.9 %
- Background suppression : $2 \cdot 10^6$

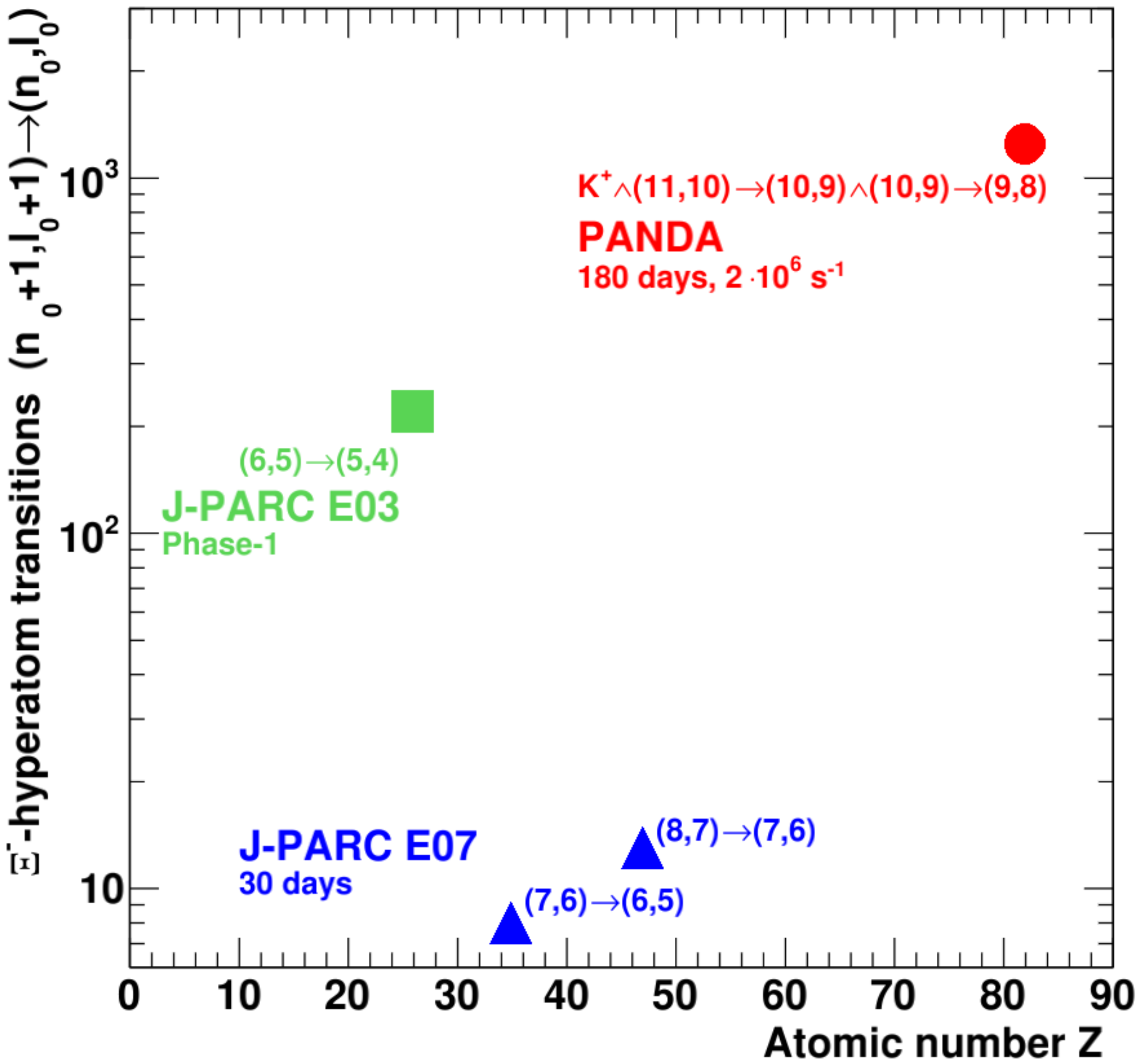


Hyperatom experiment - predictions



$$\delta\left(Re(V_{\Xi})\right)_{stat} \approx \delta\left(Img(V_{\Xi})\right)_{stat} \approx \pm 1\ \text{MeV}$$

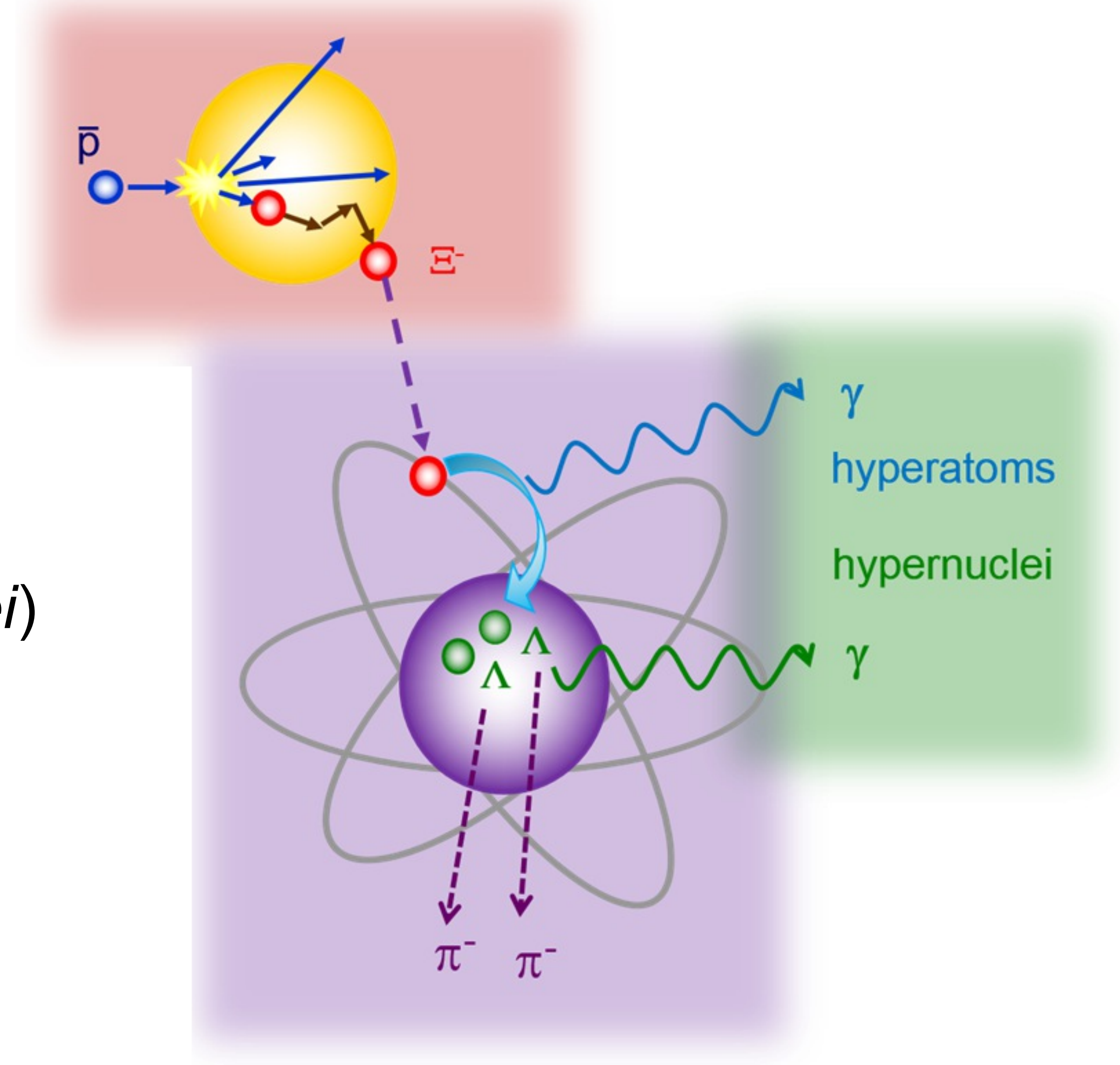
Hyperatom experimental landscape



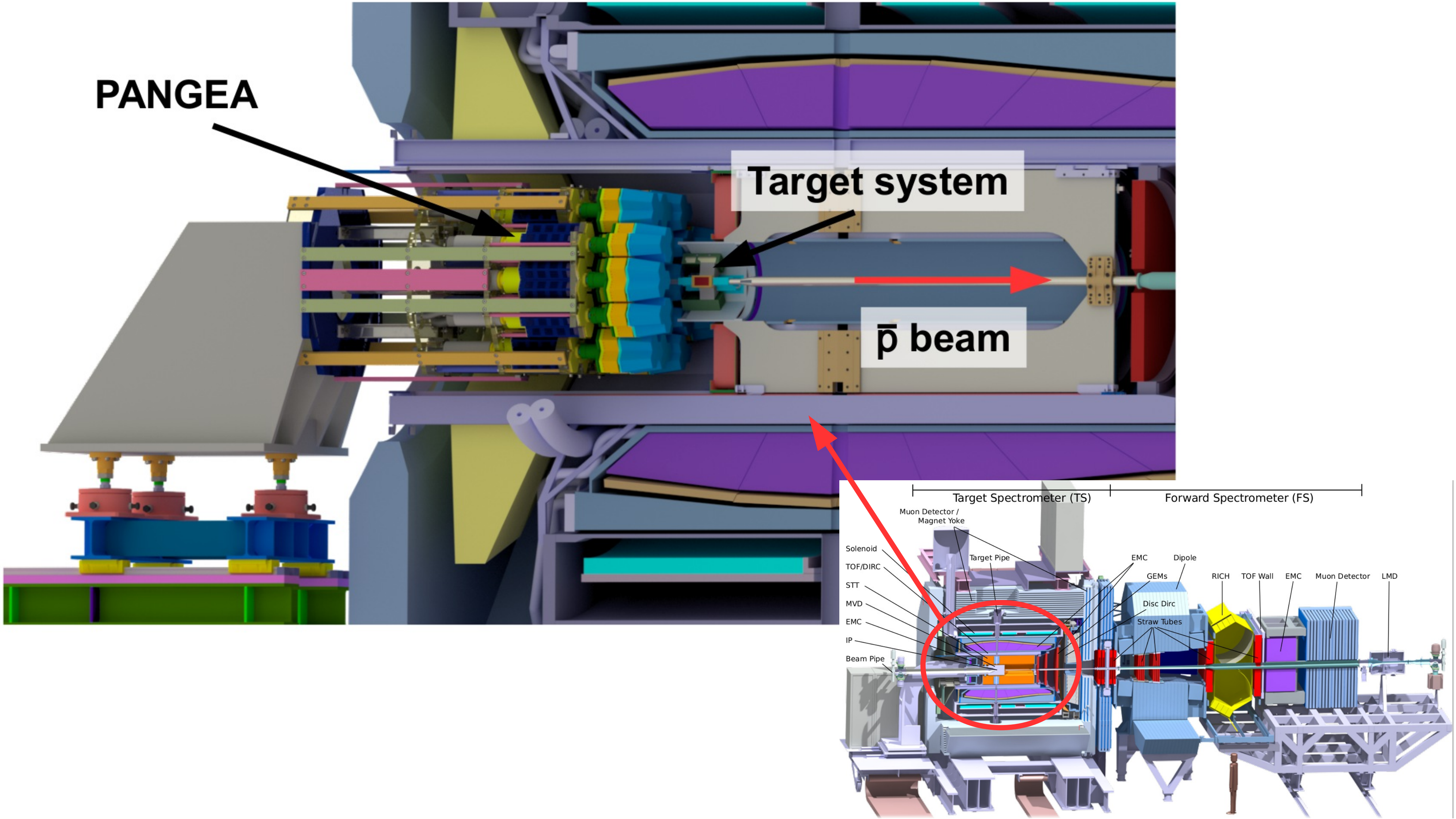
Dedicated detector setup of the S = -2 program

Hypernuclei/atoms production @ $\bar{\text{P}}$ANDA

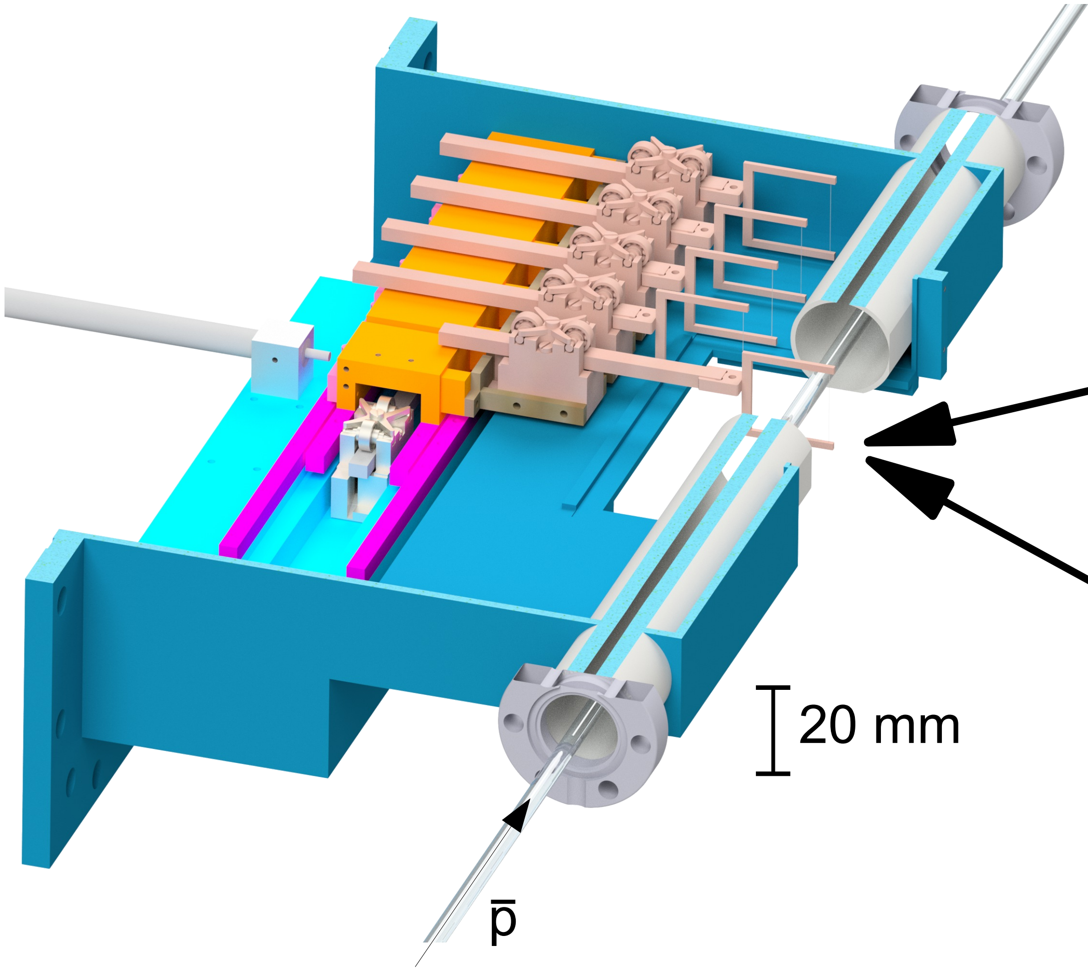
- **Primary target**
  - Production of Ξ^-
- **Secondary target**
  - Stopping of Ξ^-
  - Atomic/nuclear conversion
  - Decay π^- tracking (*hypernuclei*)
- **PANGEA**
  - X-Ray / γ spectroscopy

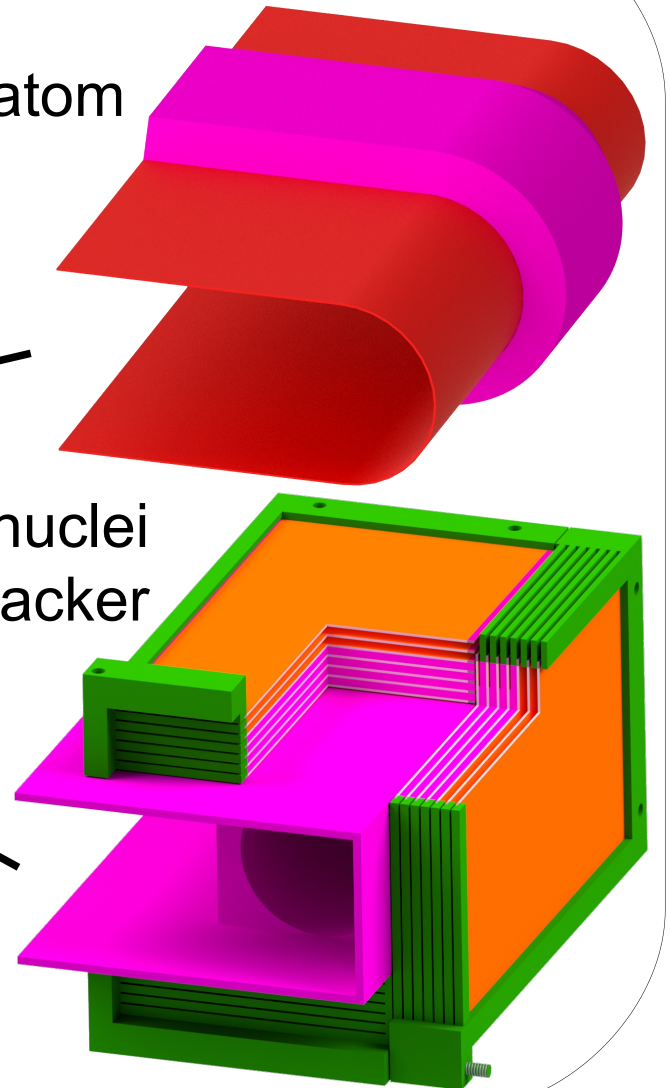


Modifications of $\bar{\text{P}}$ANDA spectrometer



Two-stage target system



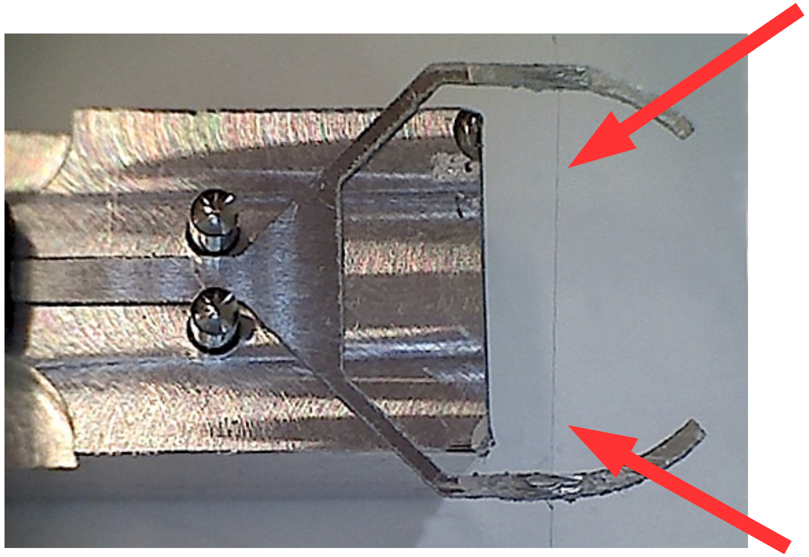


Ξ^- life time determines size

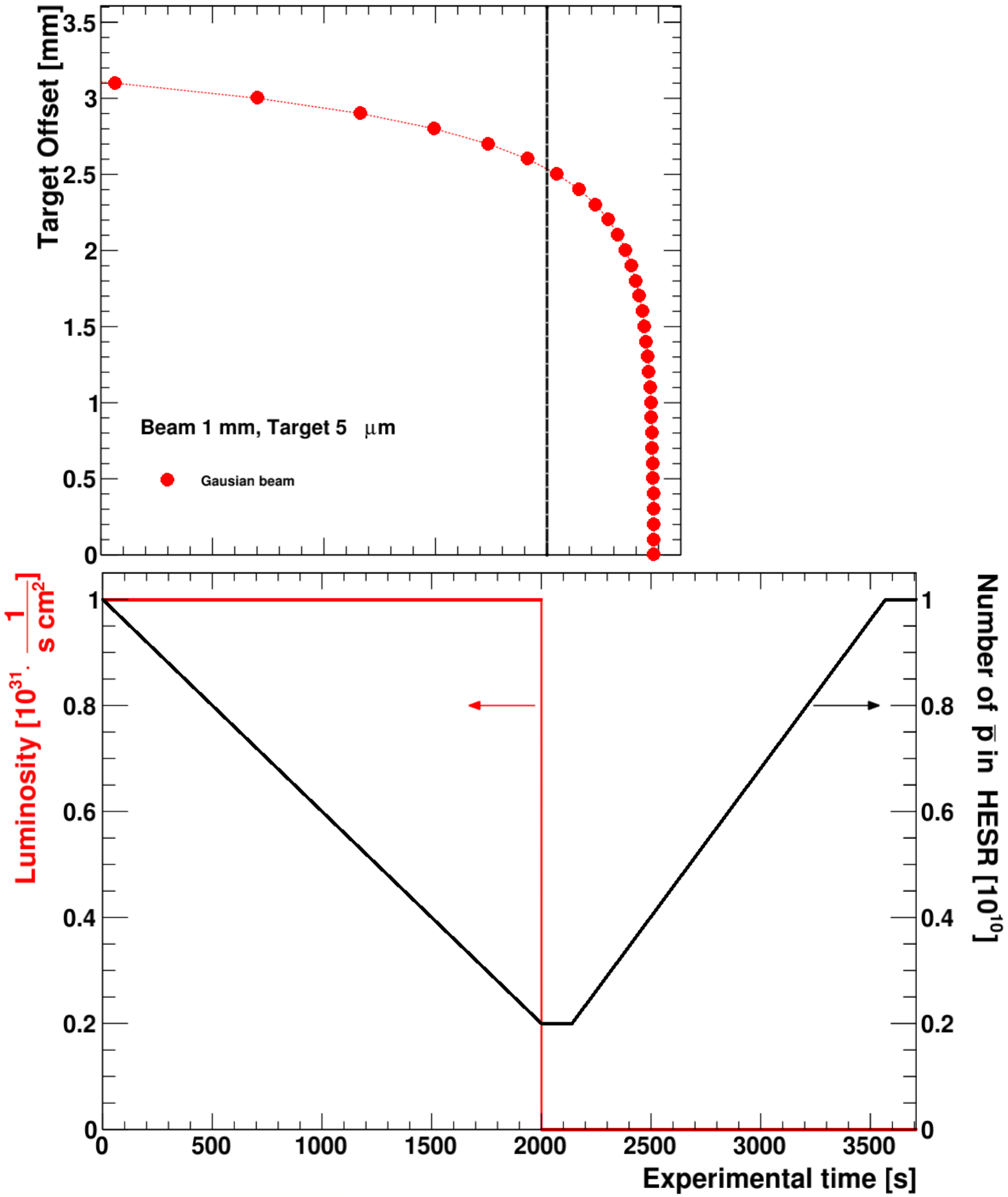
Primary target system – internal target

- Internal target in storage ring

  → **carbon filament (r ~3 µm)**



- Constant luminosity by steering of the filament

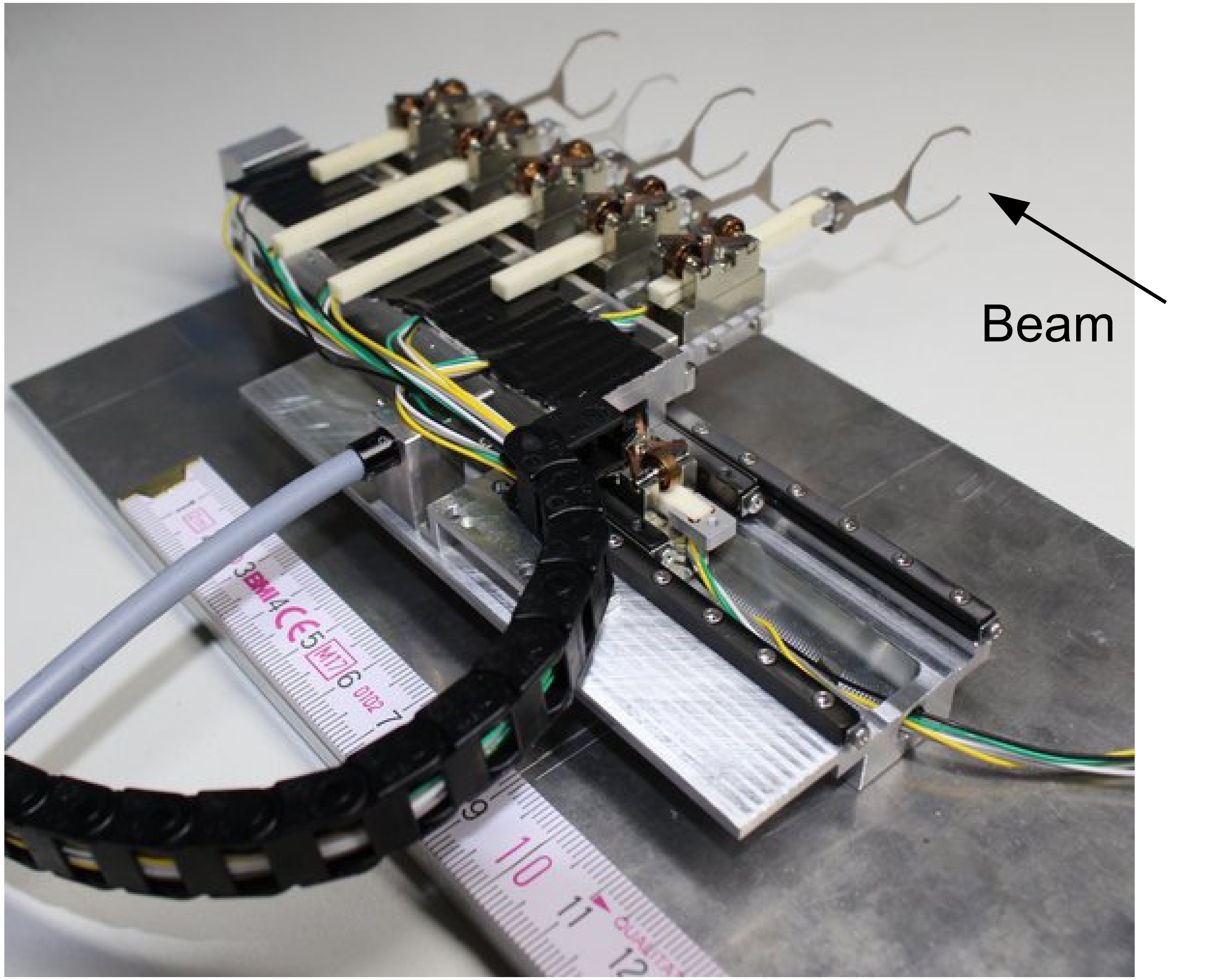


Prototype of the Primary target system

- No access during beam time
  → Replaceable targets
  → **2D moving system**

- Size
- Environment
  → **Piezo actuators**

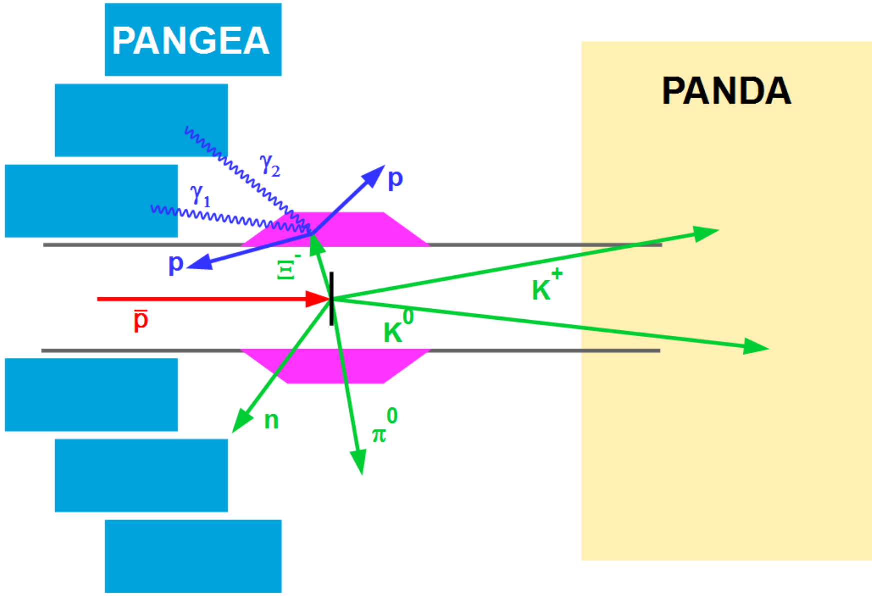
- Radiation hard positioning system
  - IR reflections of trapezoidal structure
  - σ_z = 10 µm

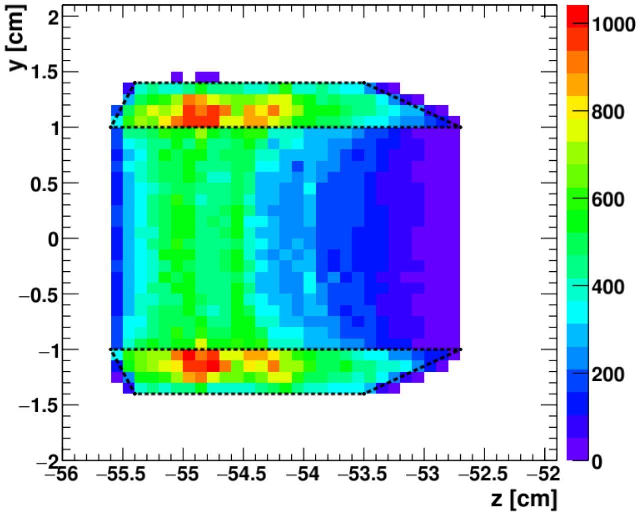


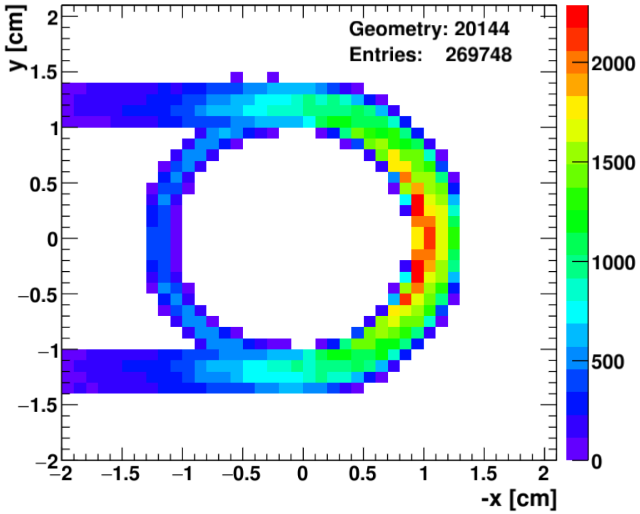
Secondary target - hyperatom

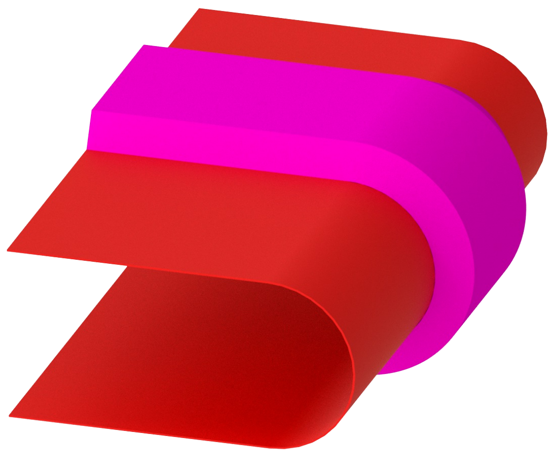
- Optimization:
  - Max. Ξ^- stopping
  - Min. X-ray absorption

- Based on events generated in GiBUU transport code



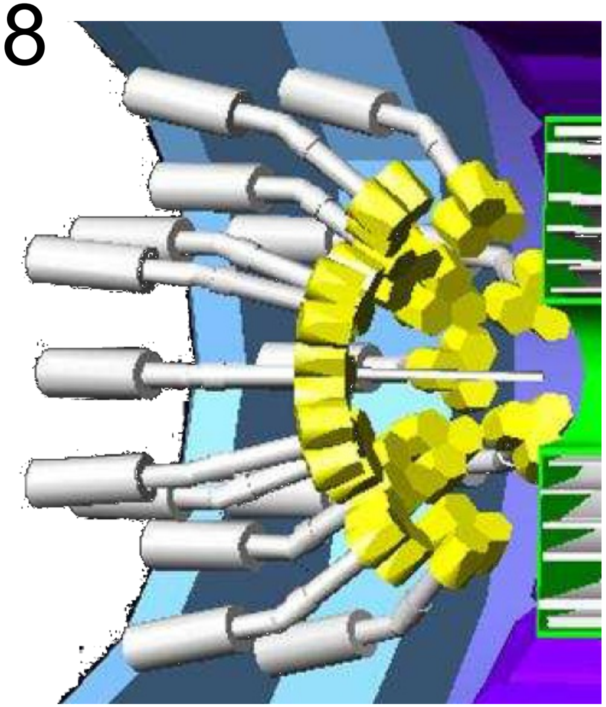






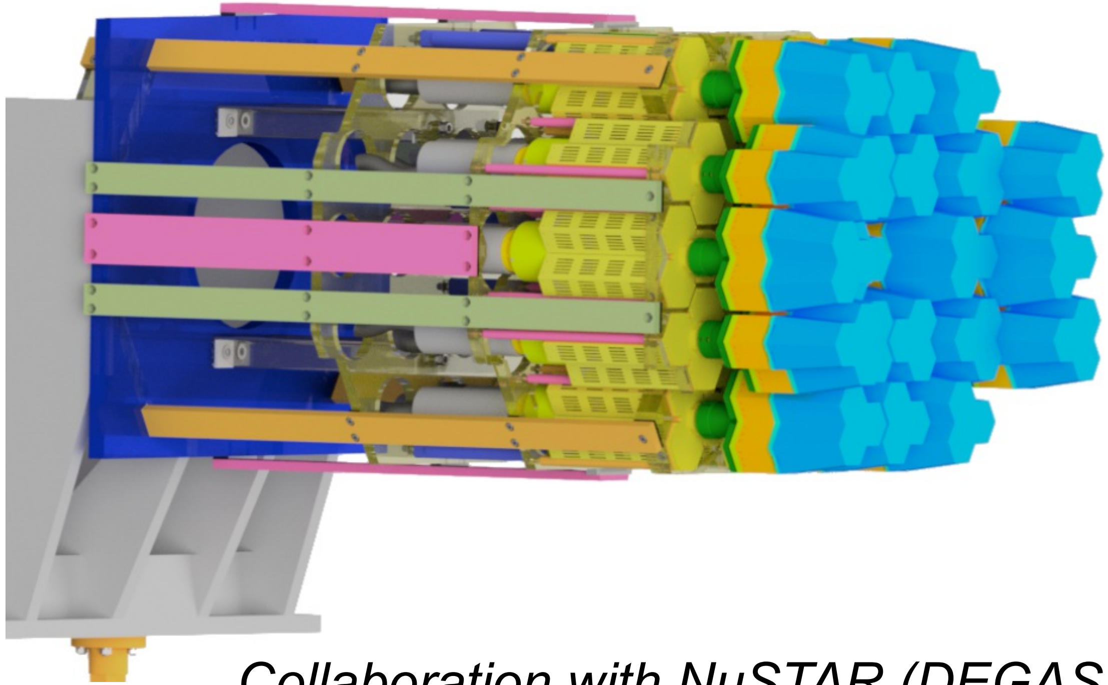
PAnda GErmanium Array (PANGEA)

2008



Beam

2019

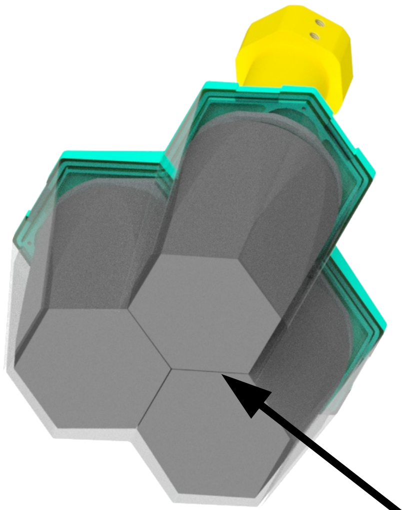


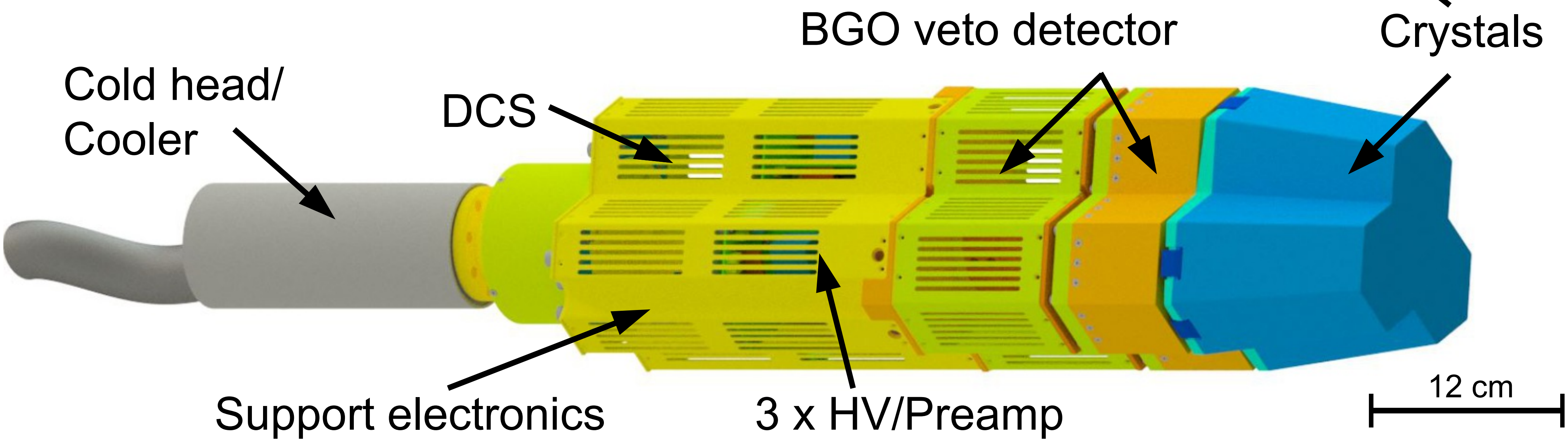
Collaboration with NuSTAR (DEGAS)

- Identical detectors
- Additional Crystals (48 → 60)
  → improved efficiency (~4.8 % FEP @ 1.332 MeV ^{60}Co)

PANGEA - triple detector

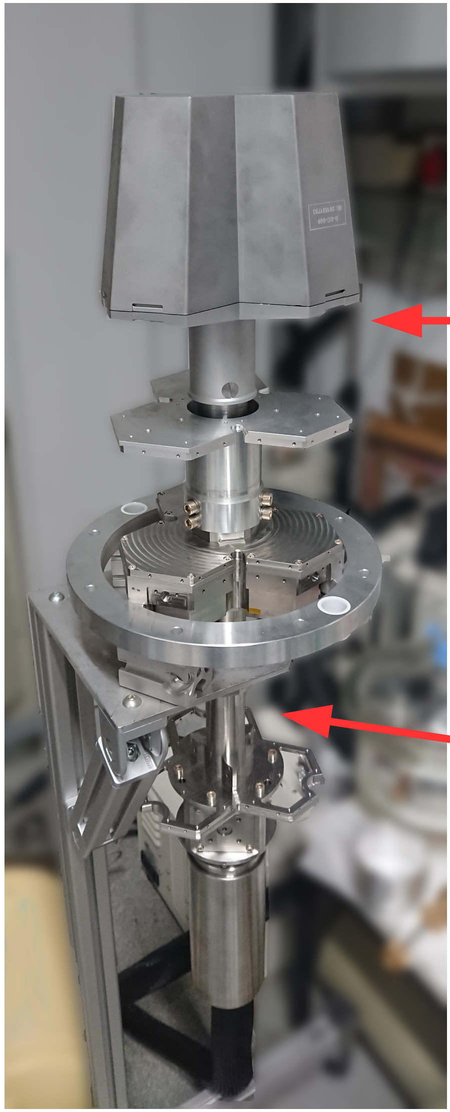
- 3 HPGe crystals in triangular arrangement
- Electro-mech. cooling (~LN2 temperatures)
- BGO veto detector
- Fully integrated design

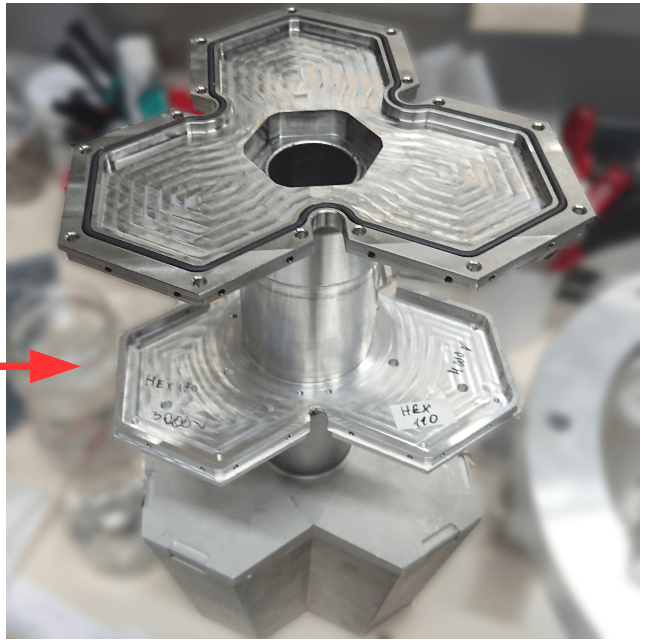


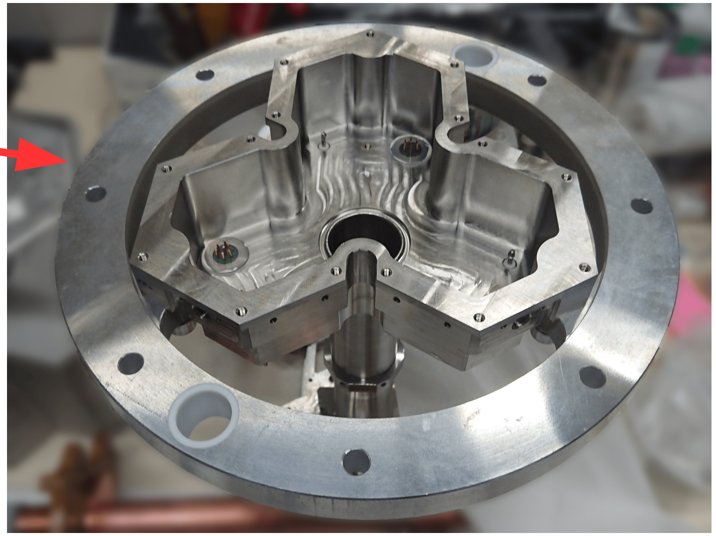


Courtesy of I. Kojouharov

Triple detector prototype





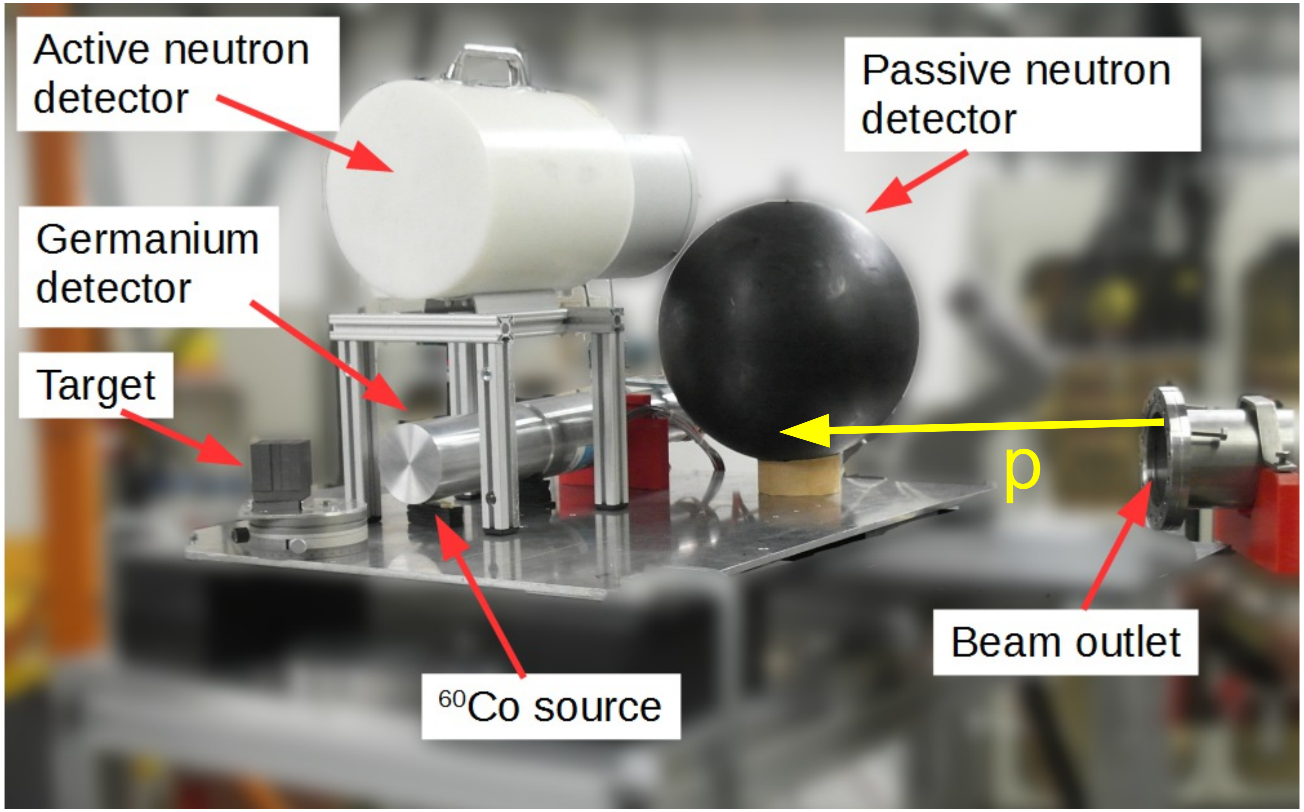


Courtesy of I. Kojouharov

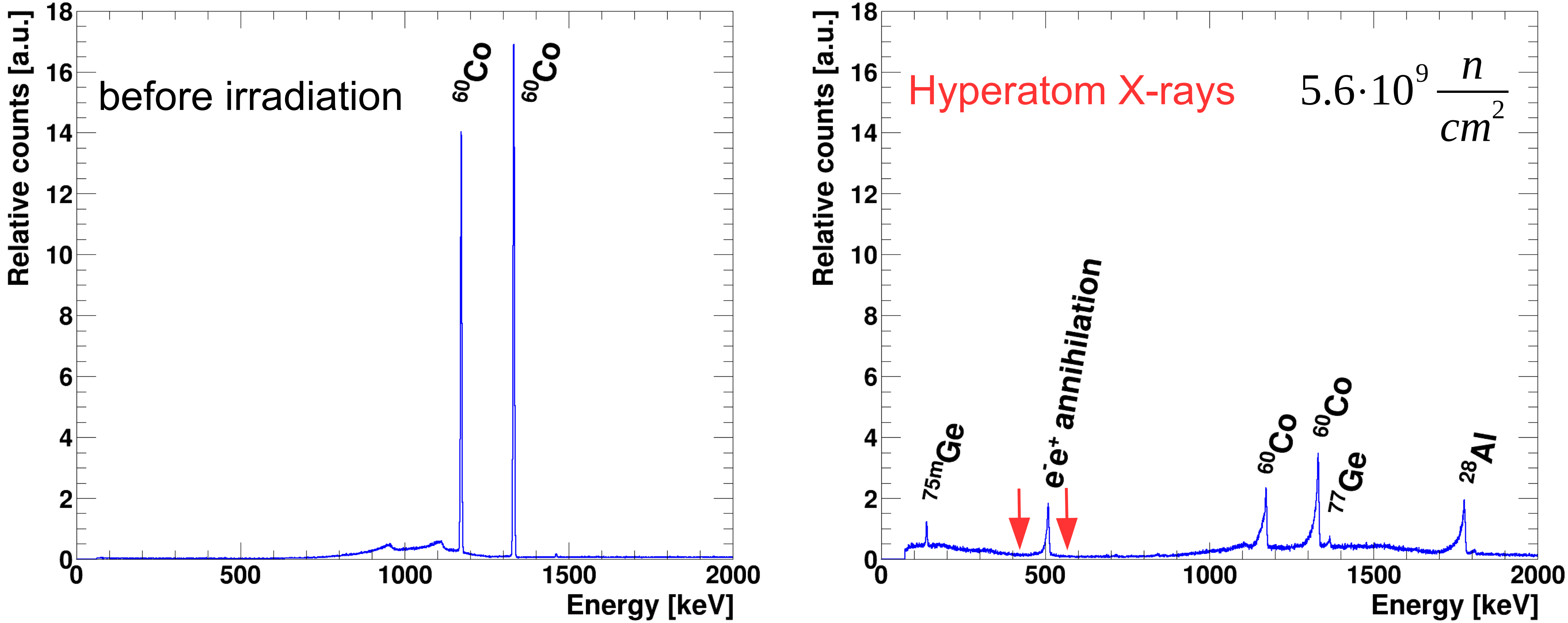
Irradiation test of a germanium detector at COSY

Germanium detector irradiation test

- HPGe crystals susceptible to neutron irradiation
- $\overline{\text{P}}$ANDA (180 days): neutron fluence $\approx 10^{10}$ n/cm^2
- Irradiation test at COSY
- 5.5 days COSY
  → 96 days $\overline{\text{P}}$ANDA



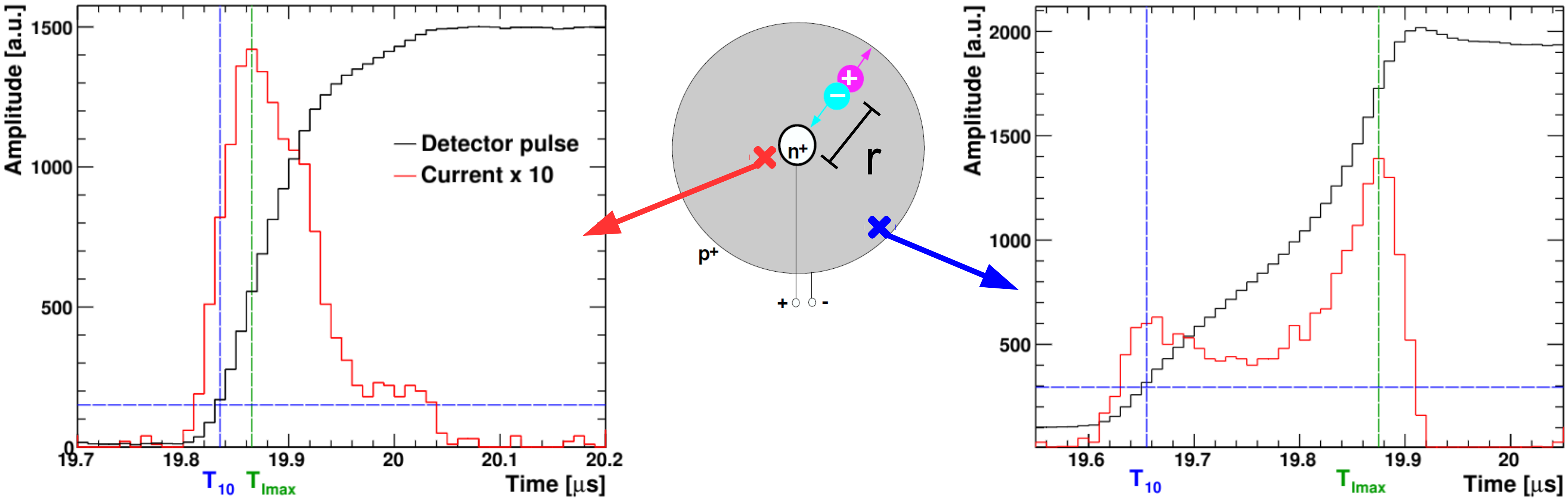
Irradiation test - ^{60}Co spectrum



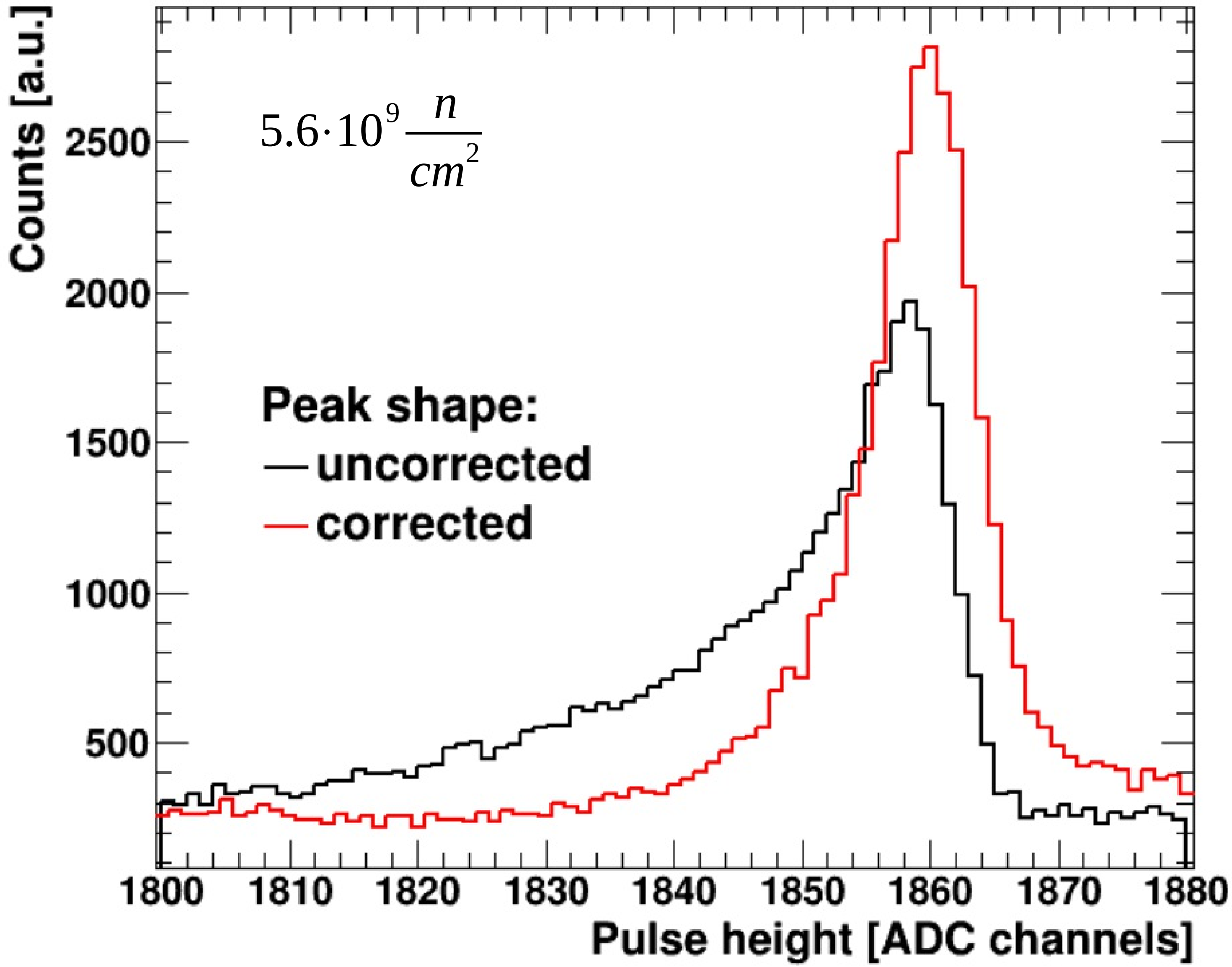
- Additional lines; enhanced compare to P̄ANDA
- Line shape changes: Low energy tails, worse resolution
  - Pulse shape analysis (PSA) allows partial recovery

Radiation damage correction

- Low energy tails due to hole trapping
- Trapping prob. depends on path length of holes
- Analysis of rising edge of detector signal
  → Radial interaction point

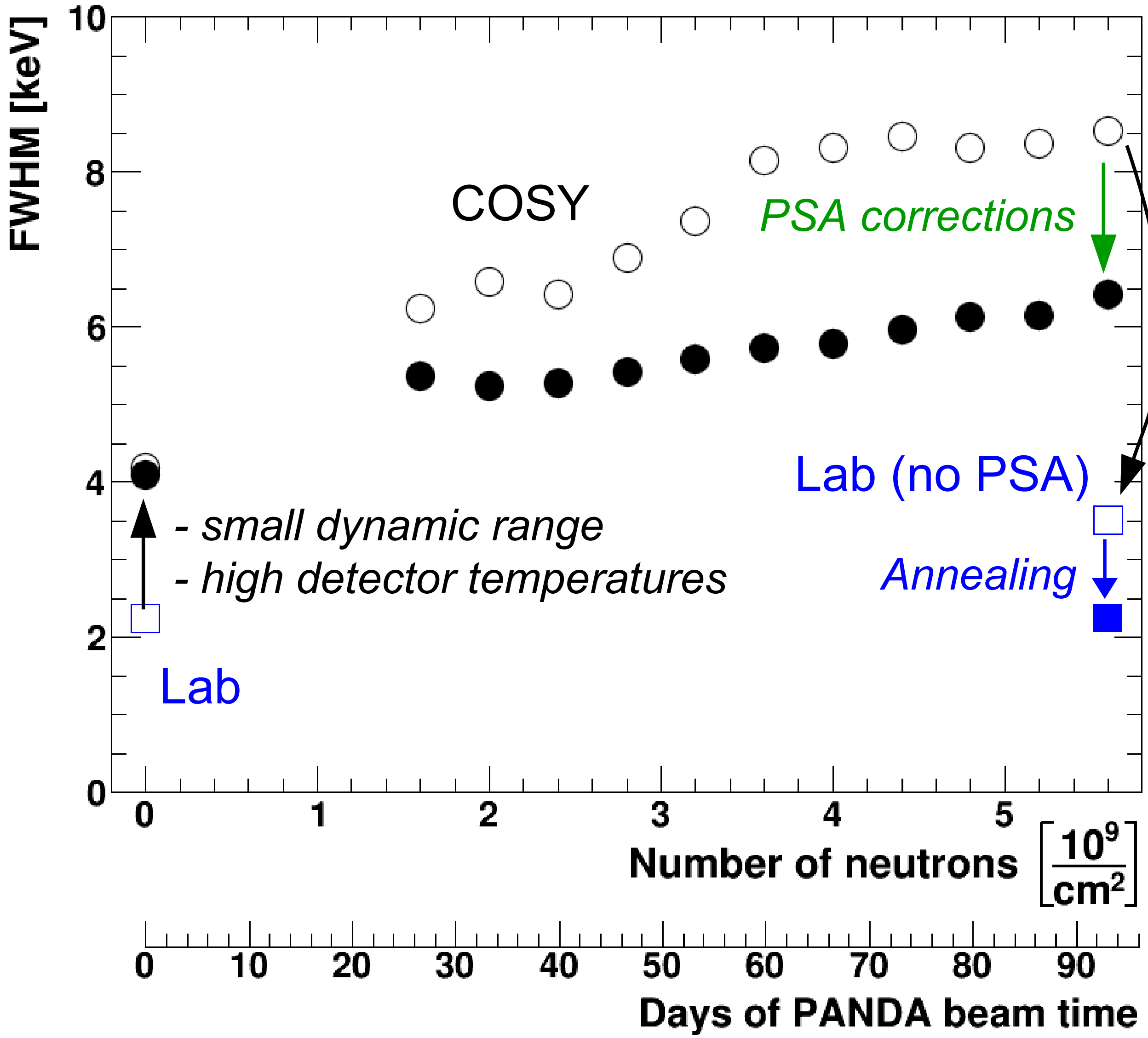


Corrections: Gaussian shape recovered



Irradiation test - results

- DAQ and thermal issues decrease performance
- PSA allows partial resolution recovery
- Annealing recovers initial crystal performance
  → Detector withstands irradiation
- New systematic test: TRIGA reactor (2019/20)



Summary

- $\bar{P}$ANDA offers multiple ways to study (anti)hyperon interaction
  - (Anti)Hyperon propagation
  - Light $\Lambda\Lambda$ hypernuclei
  - Ξ^--^{208}Pb hyperatoms
- Development of the dedicated setup is far advanced
  - Prototype of primary target available
  - Design of secondary target finished
  - Germanium detector prototype under construction
- Promising irradiation test at COSY
  - PSA allows partial recovery of radiation damage
  - Improved, systematic test planned at TRIGA in 2019/2020