Heavy Ξ^- hyperatoms at $\bar{\text{P}}$ANDA

Marcell Steinen – on behalf of the $\bar{\text{P}}$ANDA Collaboration
In collaboration with E. Friedman
Helmholtz-Institut Mainz

STRANEX, ECT* Trento, 24.10.2019

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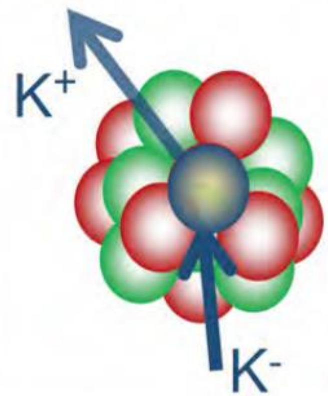
Ξ⁻-nucleus interaction

Ξ⁻ hypernuclei decays in emulsion

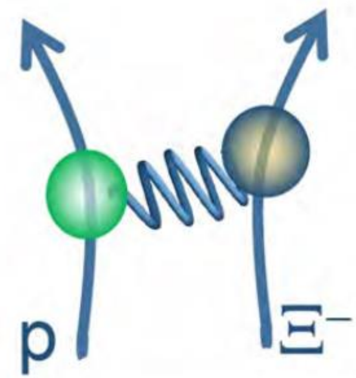
$${}^{A}_{\Xi}Z \rightarrow {}^{A_1}_{\Lambda}Z_1 + {}^{A_2}_{\Lambda}Z_2$$

K. Nakazawa et al., PTEP (2015) 033D02

missing mass spectroscopy of Ξ⁻ hypernuclei (K⁻,K⁺) reactions



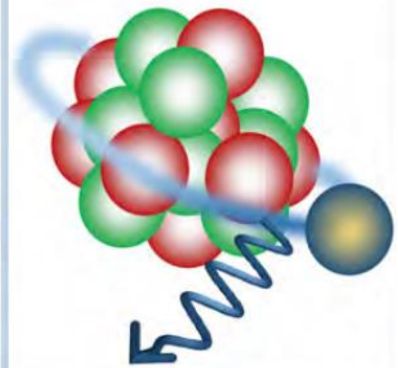
scattering or final state interaction



S. Acharya et al. Phys. Rev. Lett. 123, 112002

Talk: B. Hohlweger

γ-spectroscopy of Ξ⁻ hyperatoms

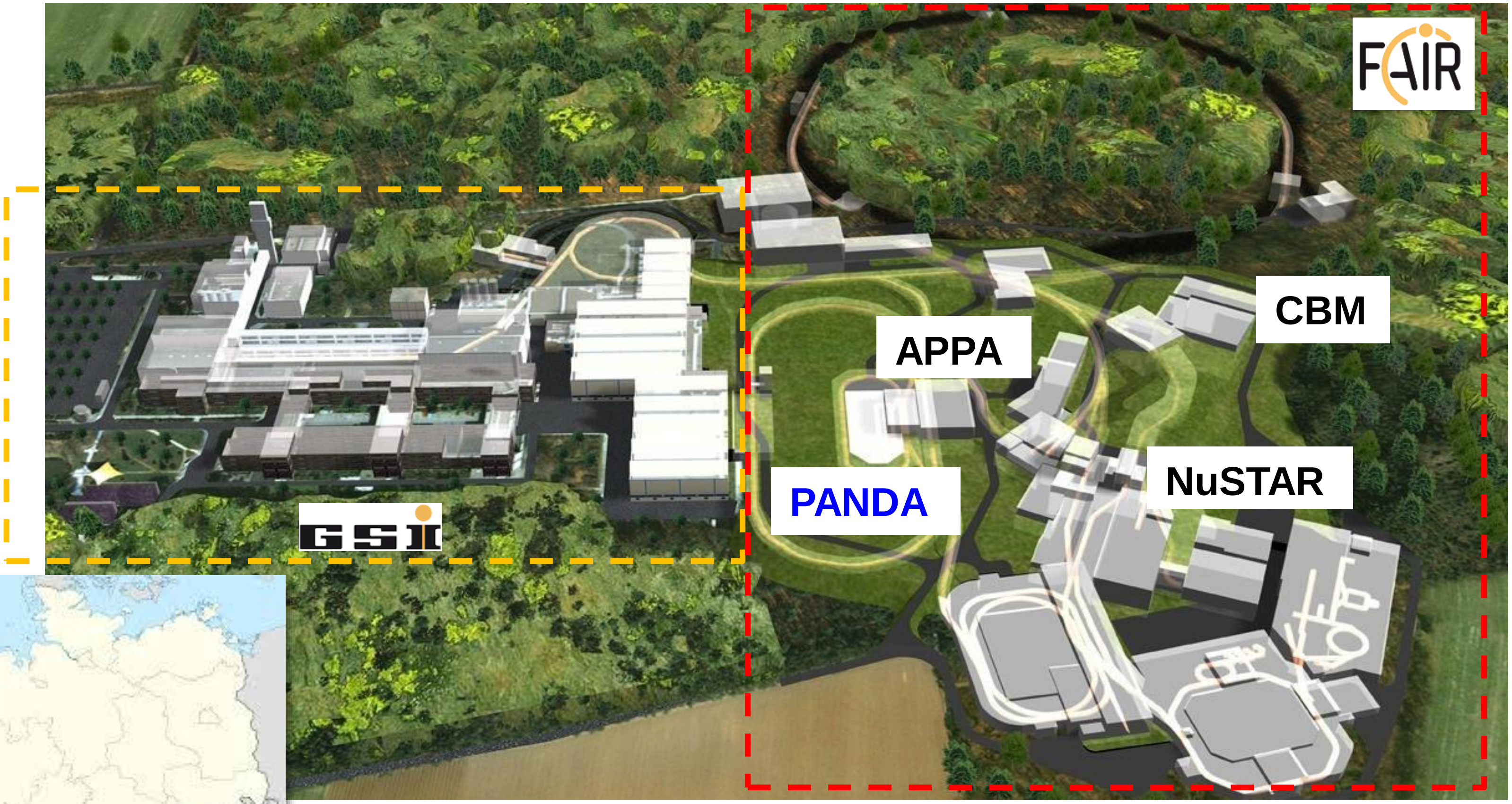


	Ξ⁻ hypernuclei decays in emulsion	missing mass spectroscopy	scattering or final state interaction	γ-spectroscopy of Ξ⁻ hyperatoms
Past		KEK E224 BNL E885		
Present	J-PARC E07	J-PARC E05	STAR ALICE	J-PARC E07
Future		J-PARC E70		J-PARC E03 P̄ANDA

Topics

- The $\bar{\text{P}}$ANDA experiment at FAIR
- Strangeness nuclear physics at $\bar{\text{P}}$ANDA
- $\Xi^{-}\ {}^{208}$Pb hyperatom exeriment at $\bar{\text{P}}$ANDA

FAIR



Facility for Antiproton and Ion Research

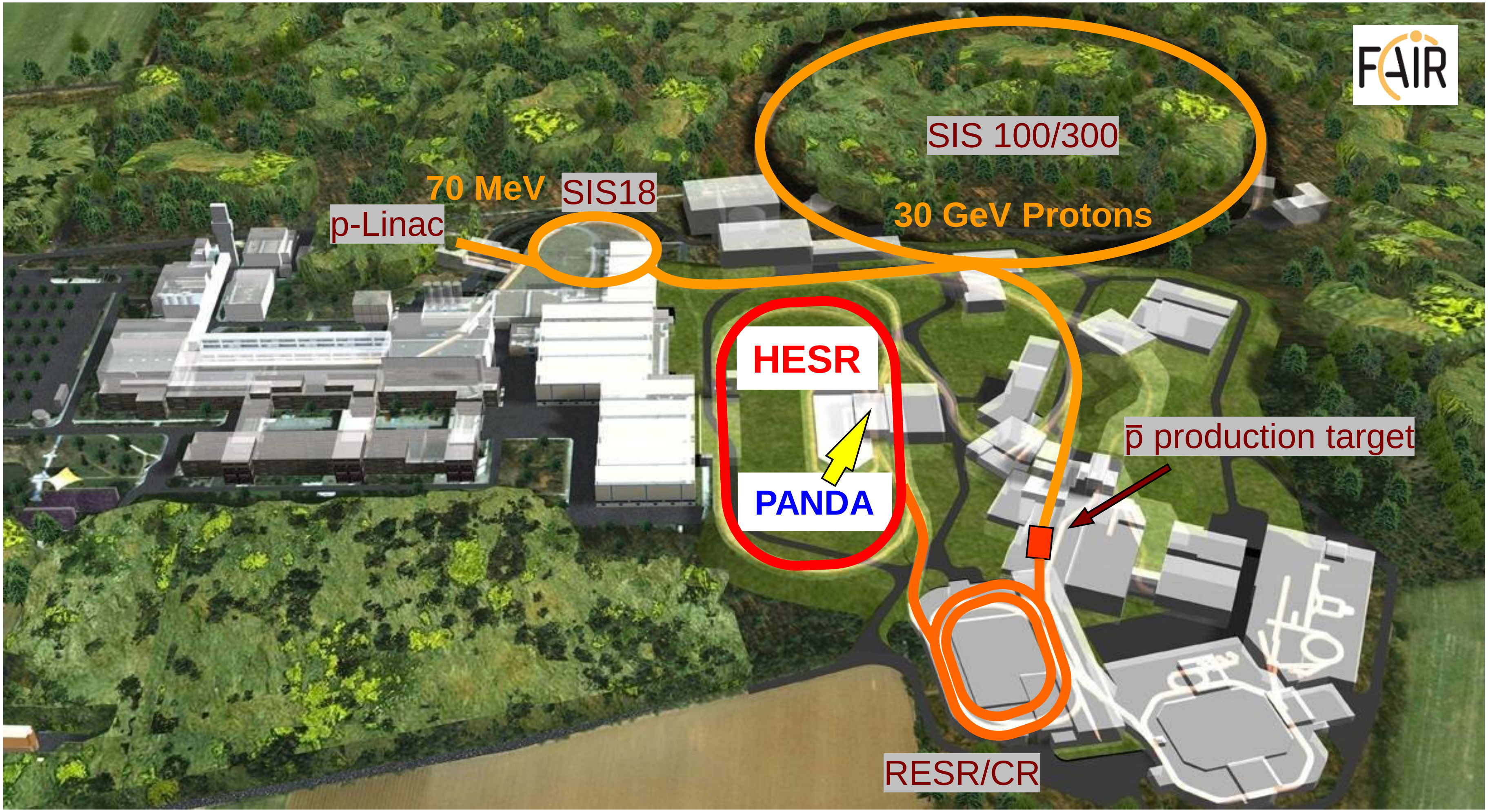
FAIR - under construction

SIS 100 Ring – September 2019

Concrete: 8 x Frankfurt stadium
Steel: 9 x of Eiffel Tower

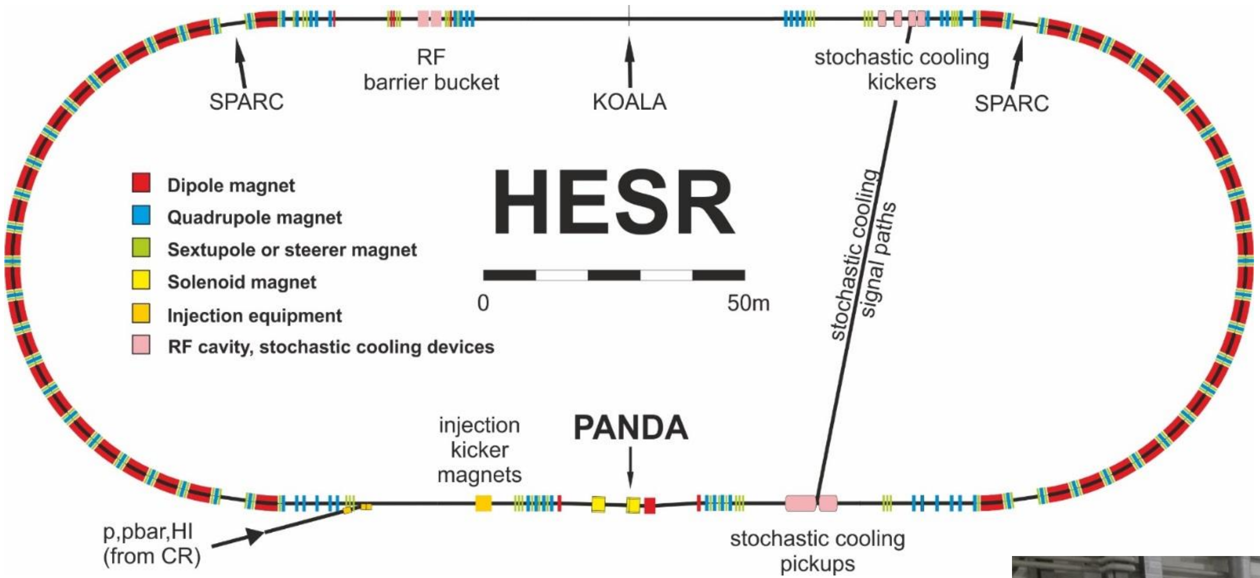
https://www.gsi.de/forschungbeschleuniger/fair/bau_von_fair/bilder_und_videos.htm

$\bar{P}$ANDA at FAIR

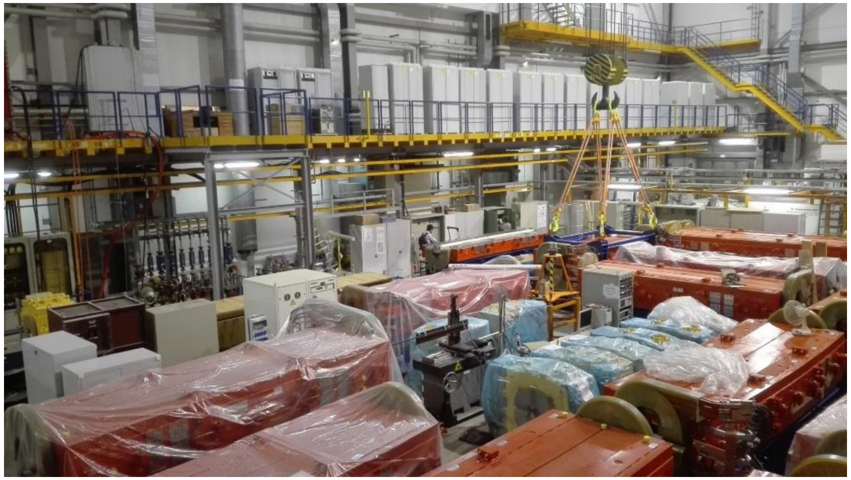


$\bar{P}$ANDA situated in **H**igh **E**nergy **S**torage **R**ing

HESR



- Modularized start version
  - 10^{10} $\bar{p}$ stored
  - Luminosity up to 2×10^{31} cm^{-2} s^{-1}
  - $p_{\bar{p}} = 1.5 – 15$ GeV/c
  - $\Delta p/p \leq 5 \times 10^{-5}$



Physics pillars of P̄ANDA

Spectroscopy

Hidden/open-charm states
Gluon-rich QCD states
Light-meson systems

Nucleon structure

Generalized parton distributions
Drell Yan process
Time-like form factors

Bound states and dynamics of QCD

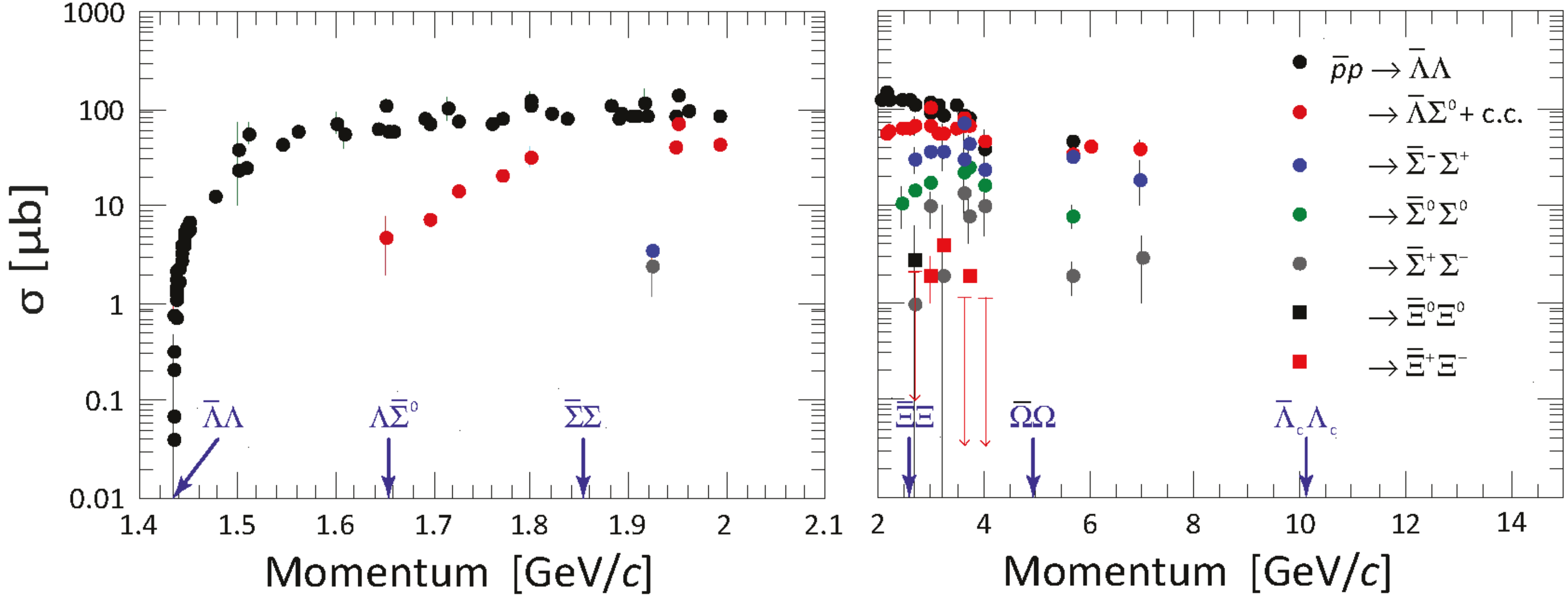
Strange baryon spectroscopy
Hyperon production & pol.
Hyperon transition form factors

Strangeness in $\bar{p}p$

Hadrons in nuclei
Hyperon-nucleus dynamics
Hypernuclei and **Hyperatoms**

Nuclear physics

P̄ANDA as hyperon factory

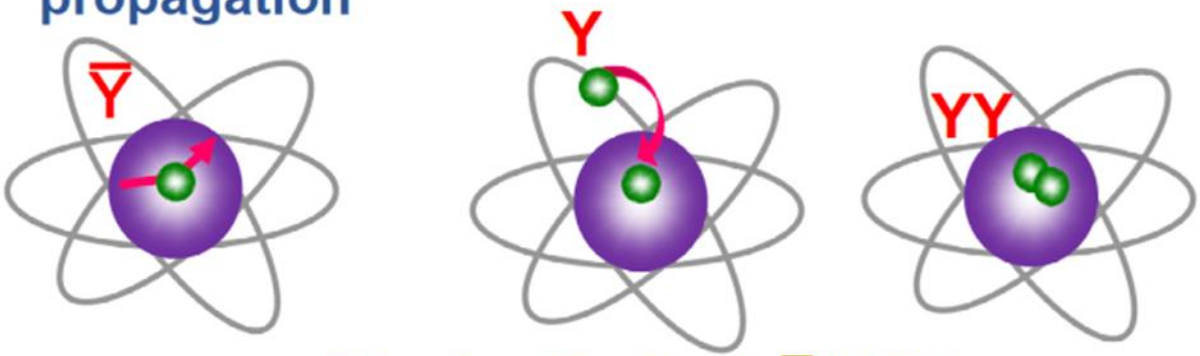


Panda Collaboration, Physics Performance Report for PANDA

Production rates:	$\Lambda\bar{\Lambda}$	~1000 /s
@ 2 MHz p̄p	$\Xi^-\bar{\Xi}^+$	~100 /s

Strangeness nuclear physics

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



Physics Topic at $\bar{P}$ANDA

antihyperon potential in cold baryonic matter	Ξ^- potential in neutron-rich baryonic matter	Structure of double $\Lambda\Lambda$ hypernuclei, hyperon mixing

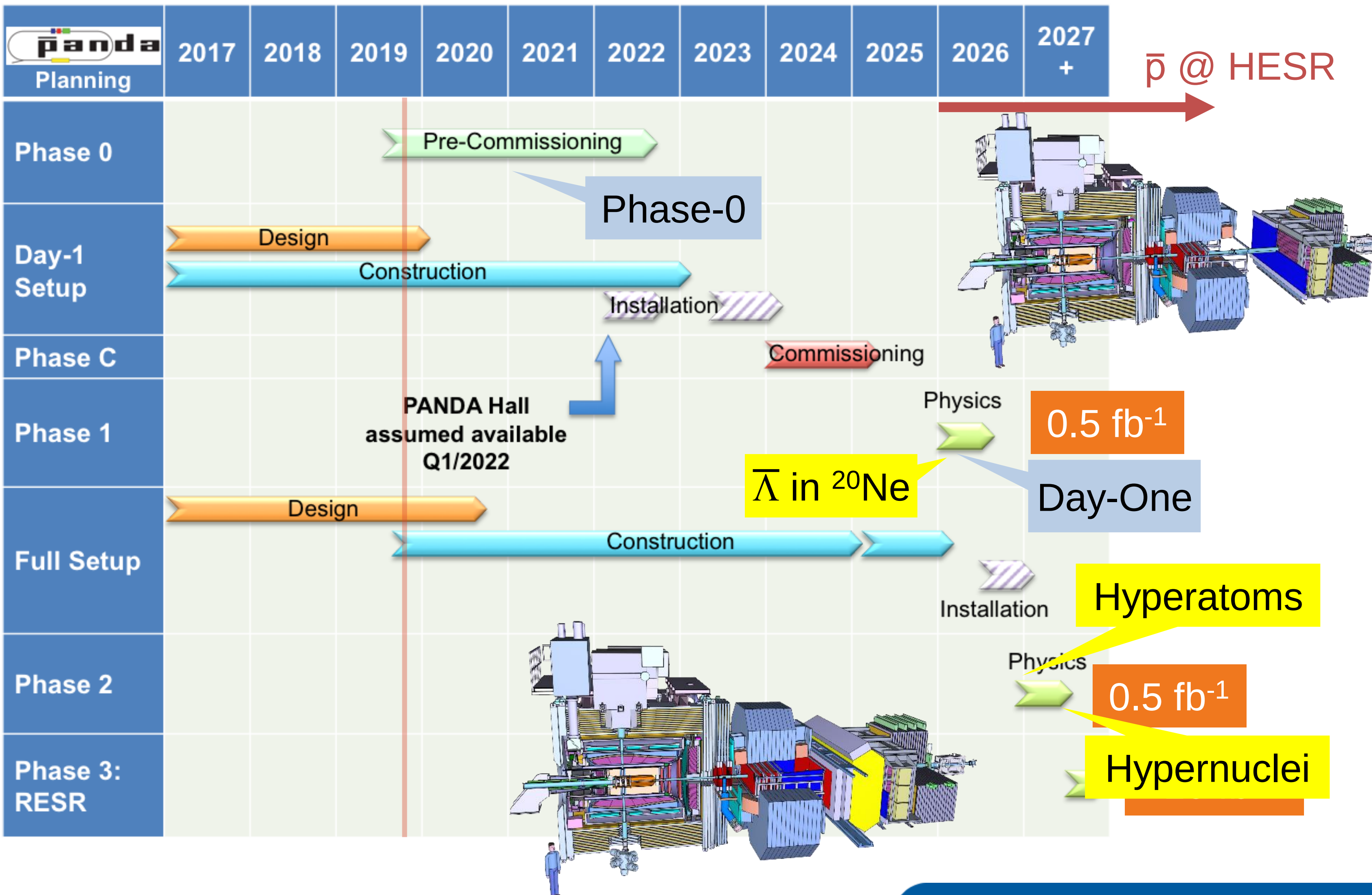
Methodology

$Y\bar{Y}$ momentum correlations at threshold	Width and shift of atomic levels in Ξ^- ^{208}Pb atoms	Excited state spectrum of light $\Lambda\Lambda$ hypernuclei

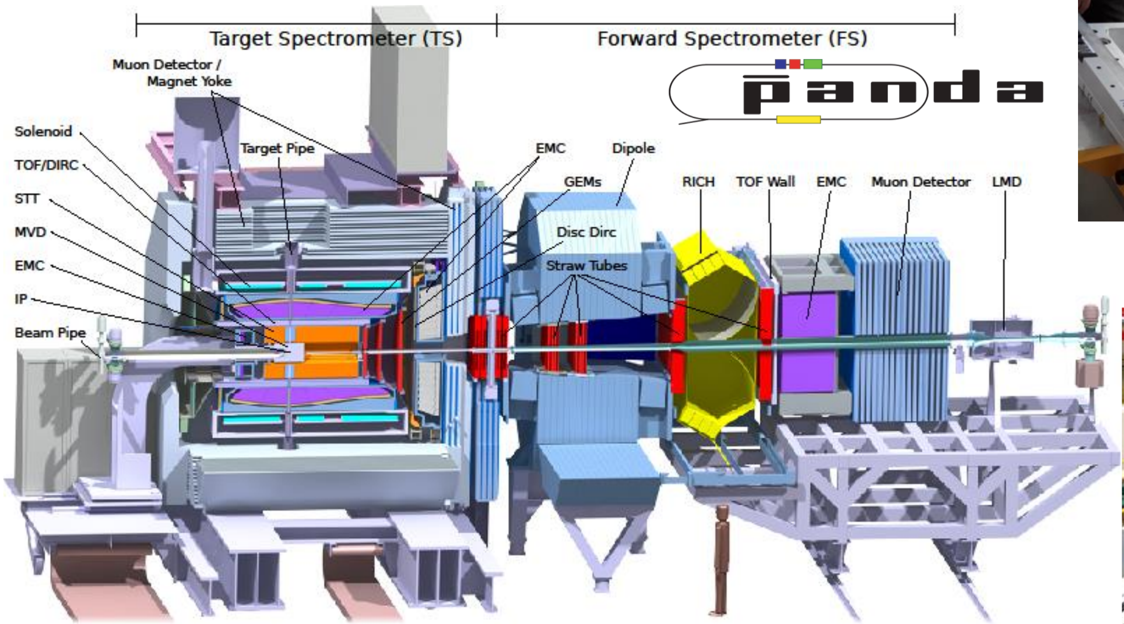
Sanchez Lorente et al., Physics Letters B 749 (2015), pp. 421-424

Pochodzalla et al., Nuclear Physics A 954 (2016) 323–34

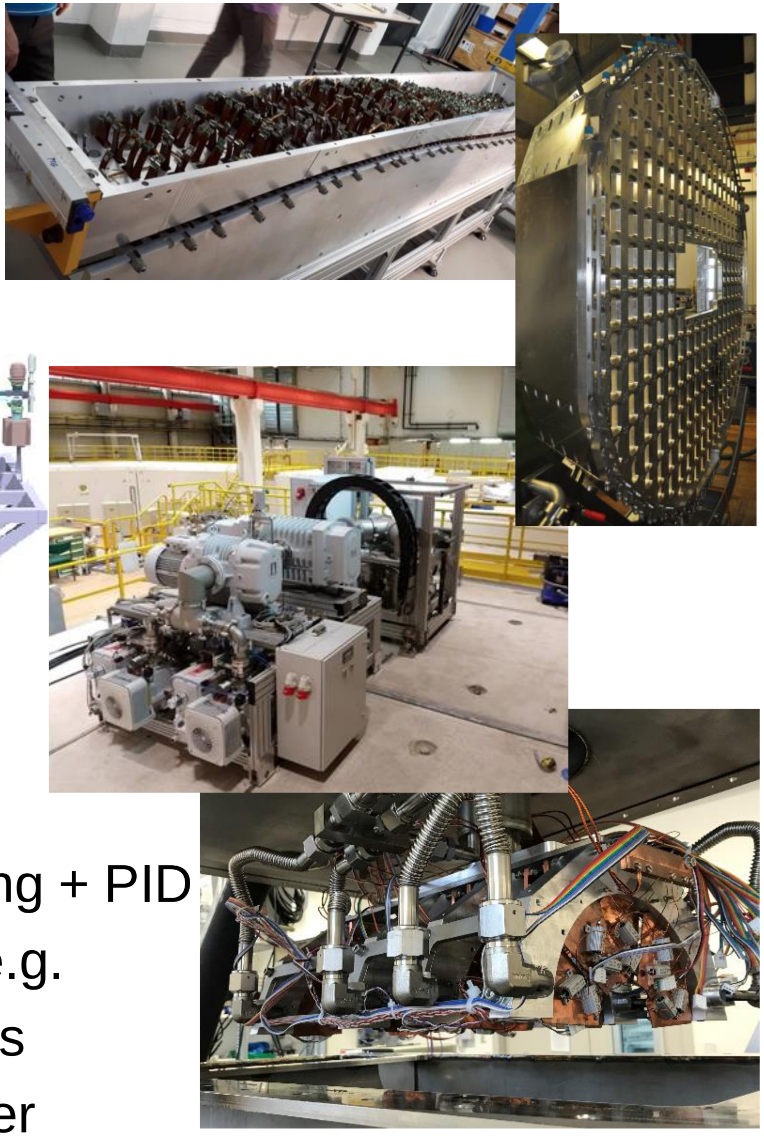
$\bar{P}$ANDA schedule



P̄ANDA detector



Hypernuclear/atom setup not shown



- Almost 4π
- Avg. 20 MHz
- Software trigger
- High res. tracking + PID
- Vertex rec. for e.g. D, K^0_S, hyperons
- PWO calorimeter

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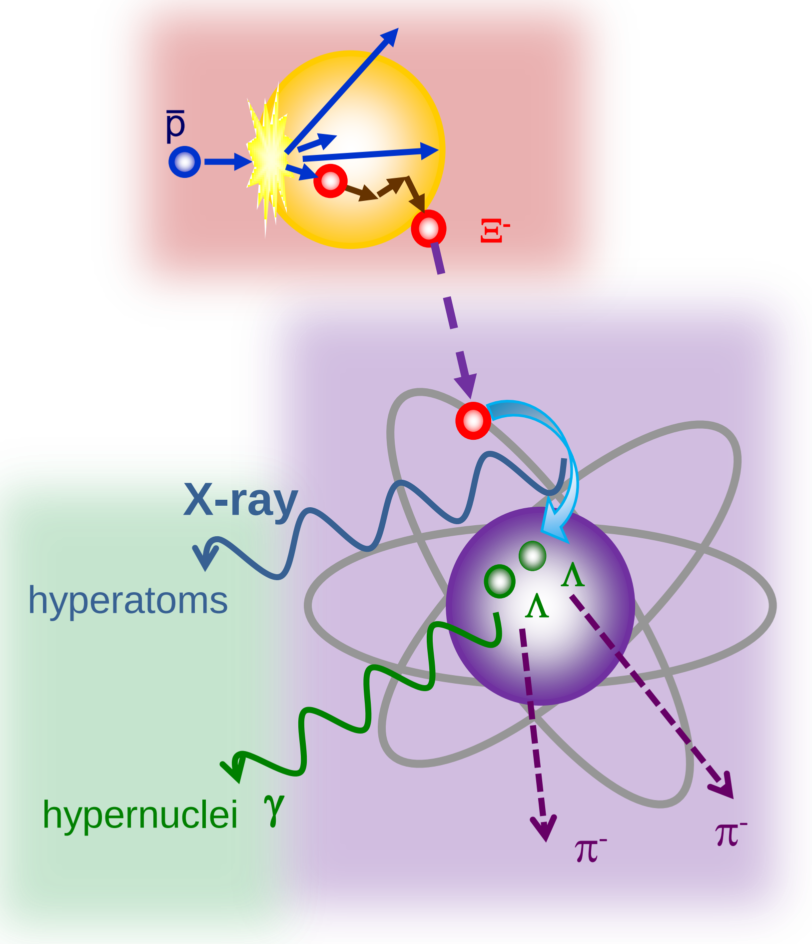
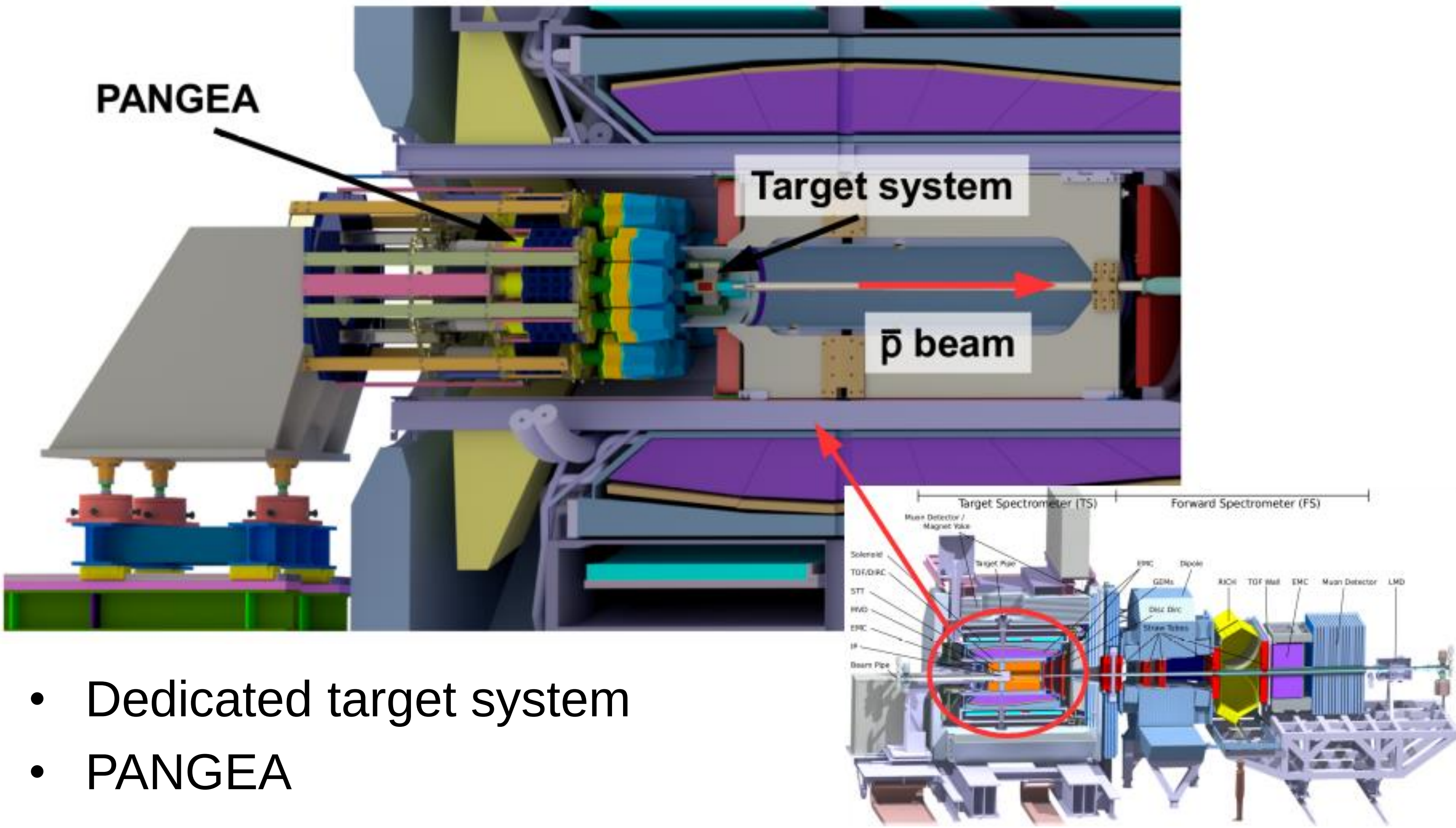
Production of hyperatoms/nuclei

- **Primary target**
  - Production of Ξ^-
    $\bar{p}N \rightarrow \Xi^- \bar{\Xi}^{+/0}$
- **Secondary target**
  - Stopping of Ξ^-
  - **Atomic** cascade of Ξ^-
  - Nuclear conversion
    $\Xi^- + p \rightarrow \Lambda\Lambda + 28\ MeV$
- **PANGEA**
  - X-Ray spectroscopy of heavy Ξ^- **hyperatoms** (0.1 - 1 MeV)
  - γ spectroscopy of light $\Lambda\Lambda$ hypernuclei (0.1 - 10 MeV)

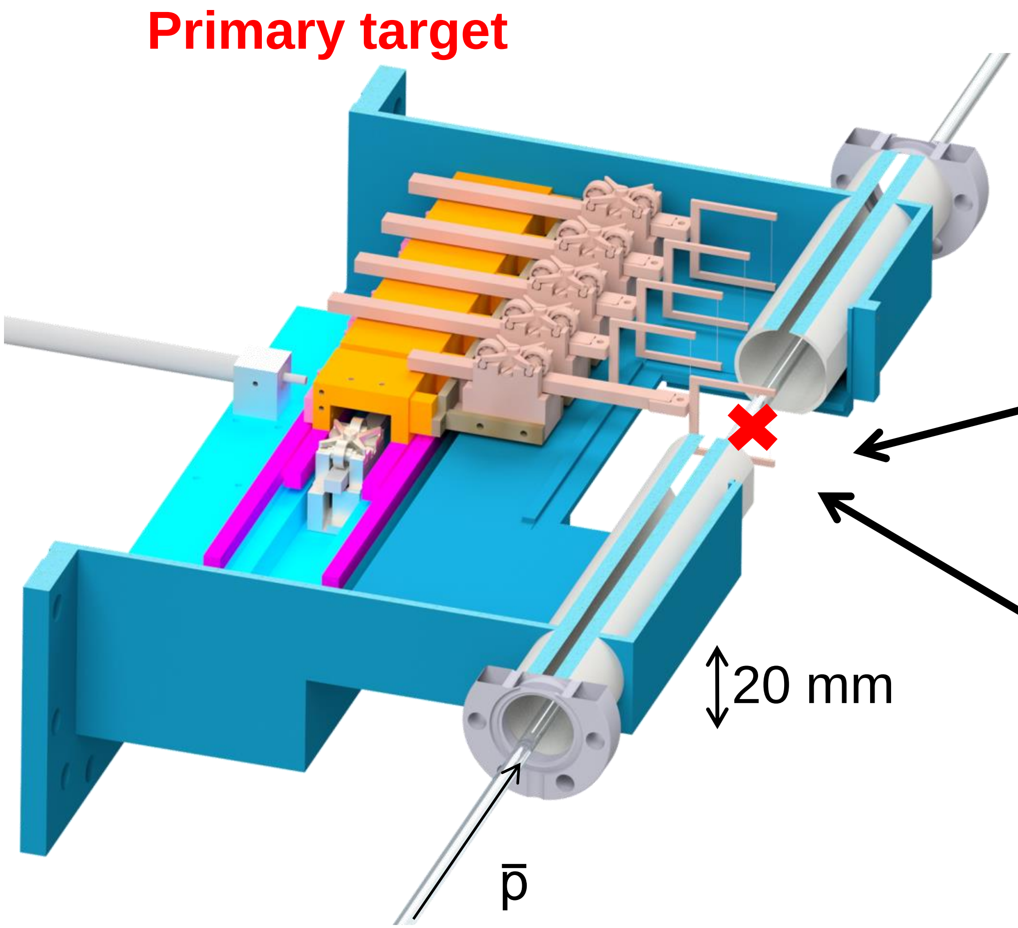


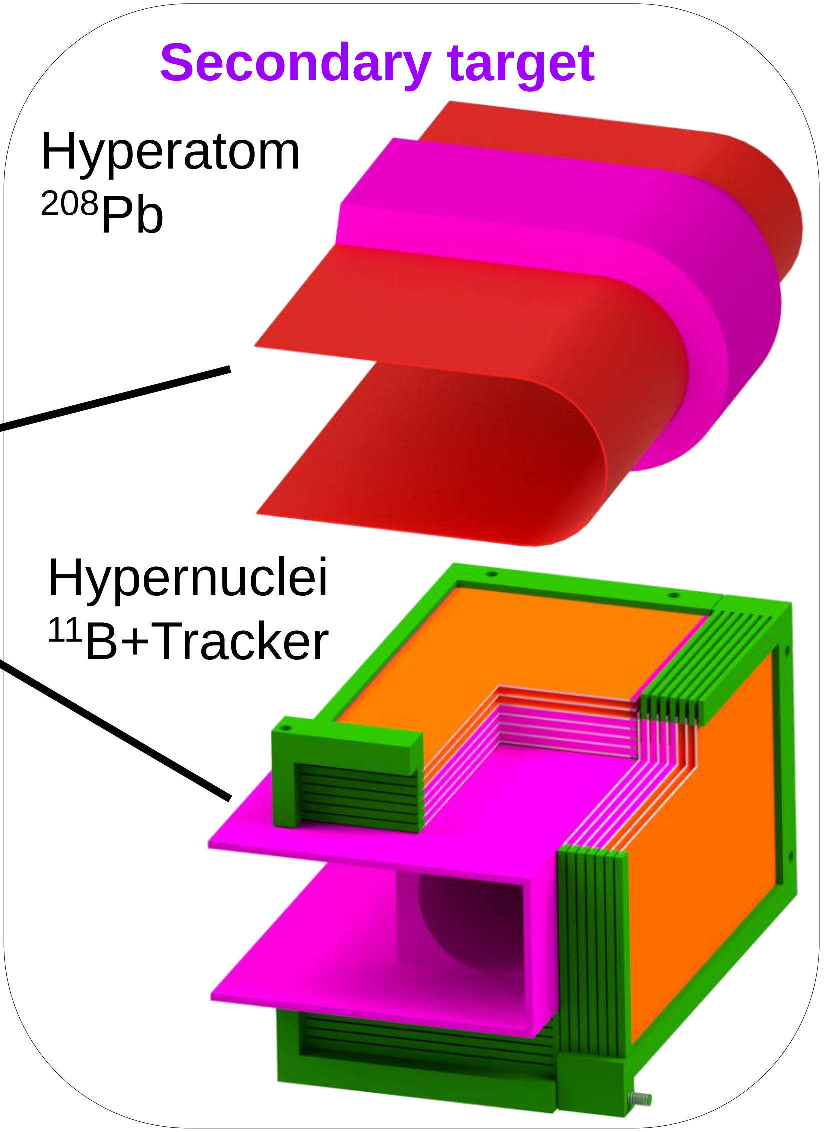
Hypernuclear/atom setup



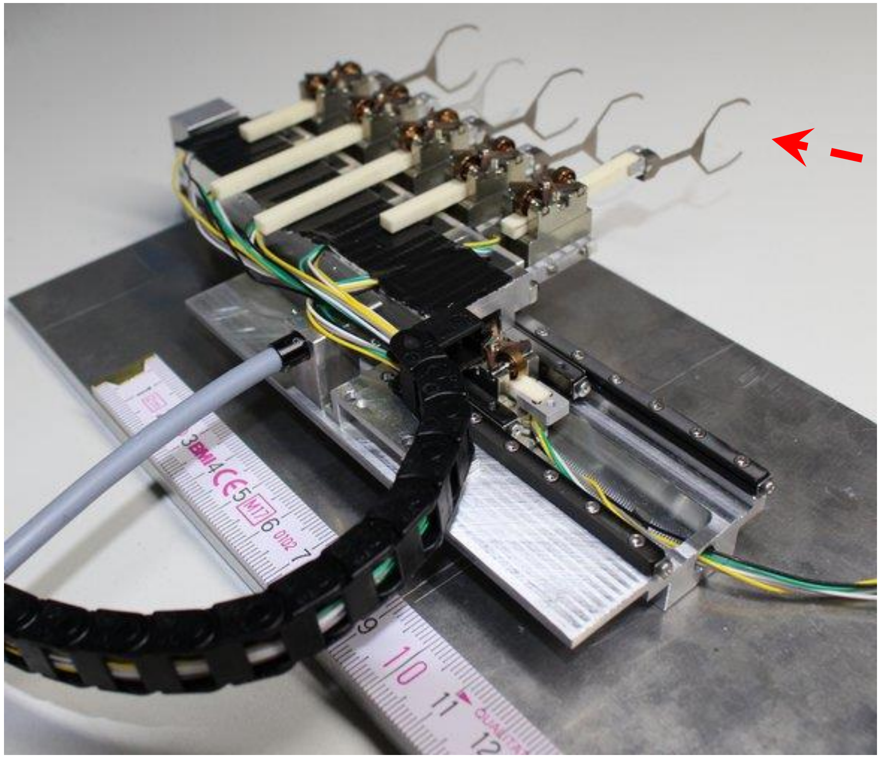
- Dedicated target system
- PANGEA

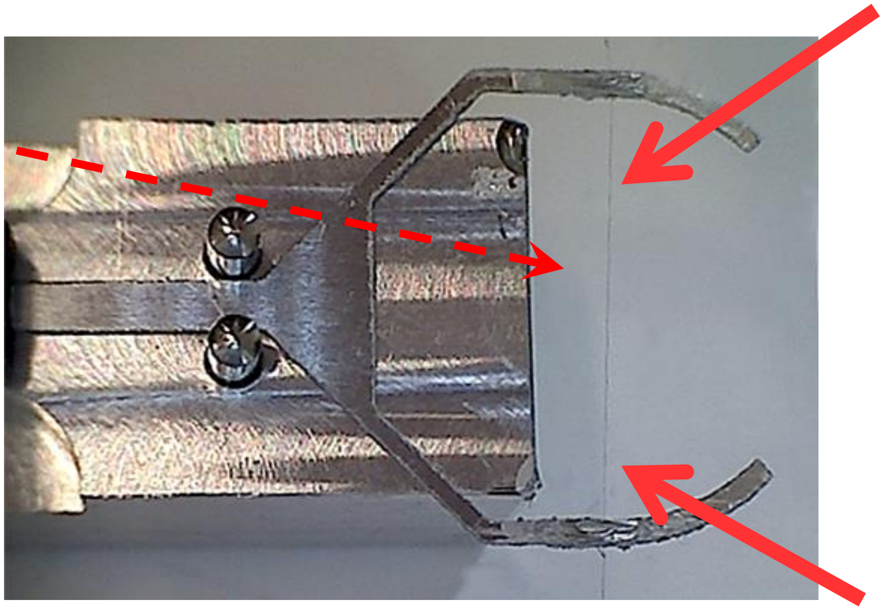
Target system





Primary target - Prototype



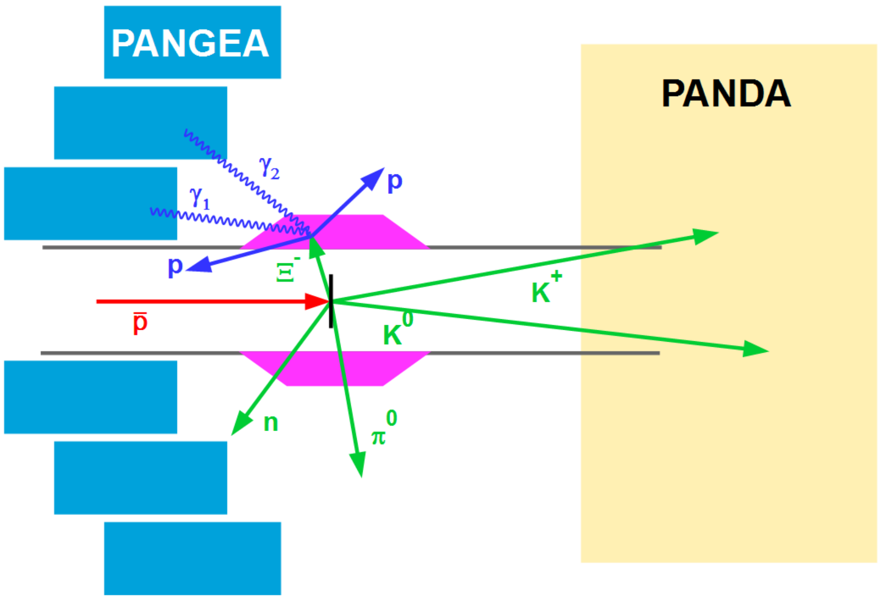


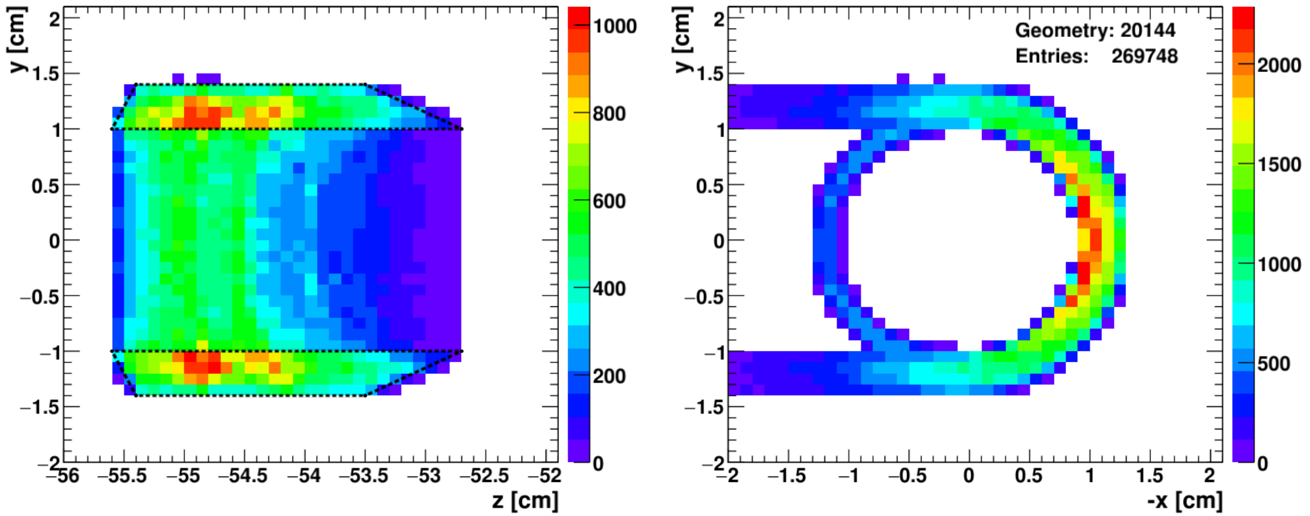
Carbon filament (r ~3µm)

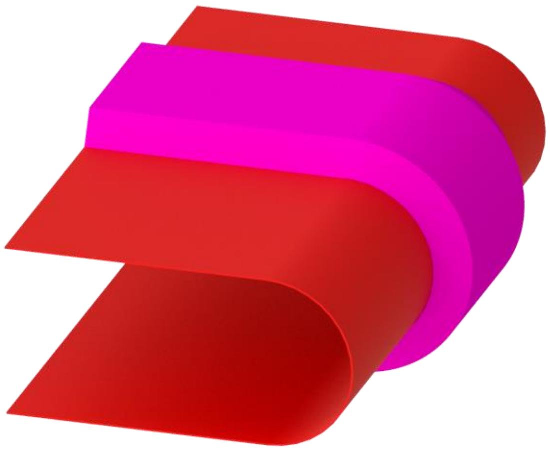
- 2D positioning system
  - Several targets
  - Steerable for constant luminosity
  - Small
  - UHV compatible, magnetic field and radiation hard

Secondary target optimization

- Optimization of absorber shape
  - Maximize Ξ^- stopping
  - Minimize X-ray absorption



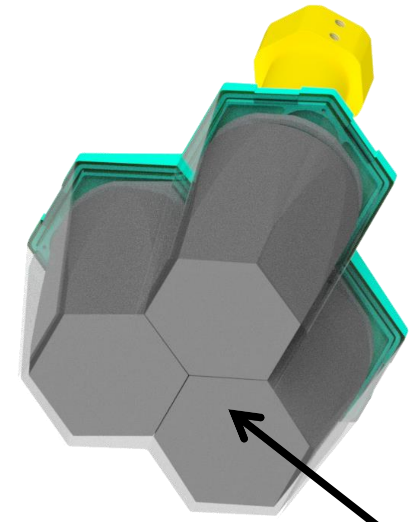


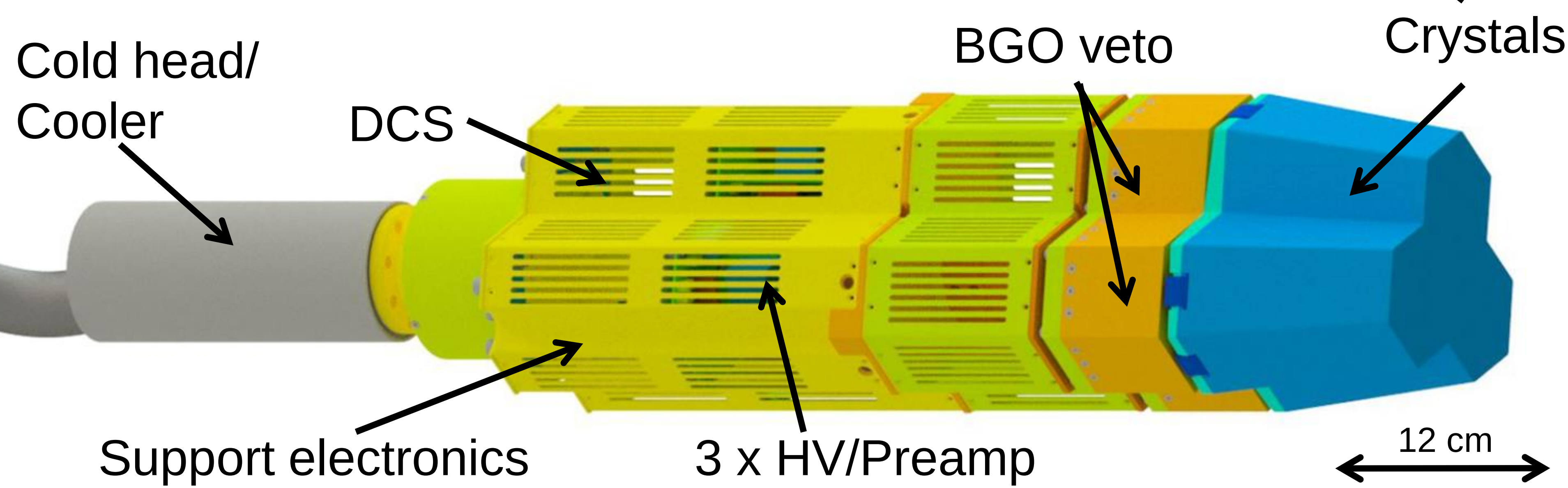


Based on events generated in GiBUU

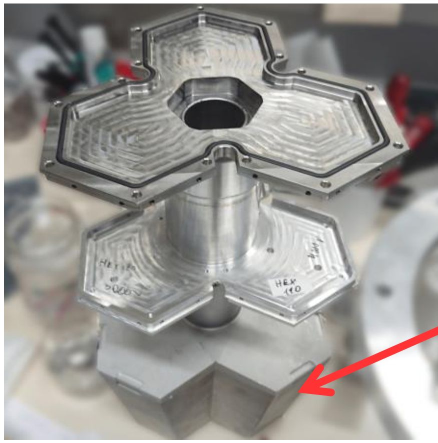
PANda GErmanium Array

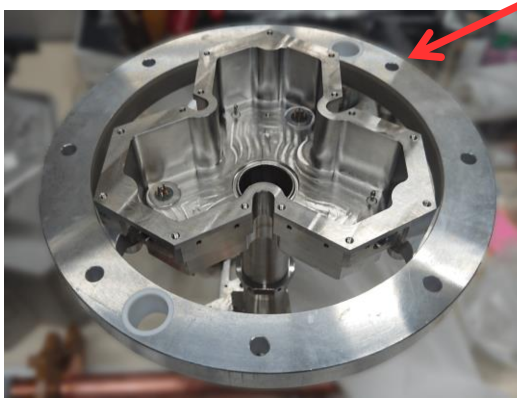
- Collaboration with NuSTAR (DEGAS)
- 20 triple HPGe detectors
- Full energy efficiency ~5 % @ ^{60}Co
- Electro-mech. cooling (~LN2 temp.)
- BGO veto
- Fully integrated design

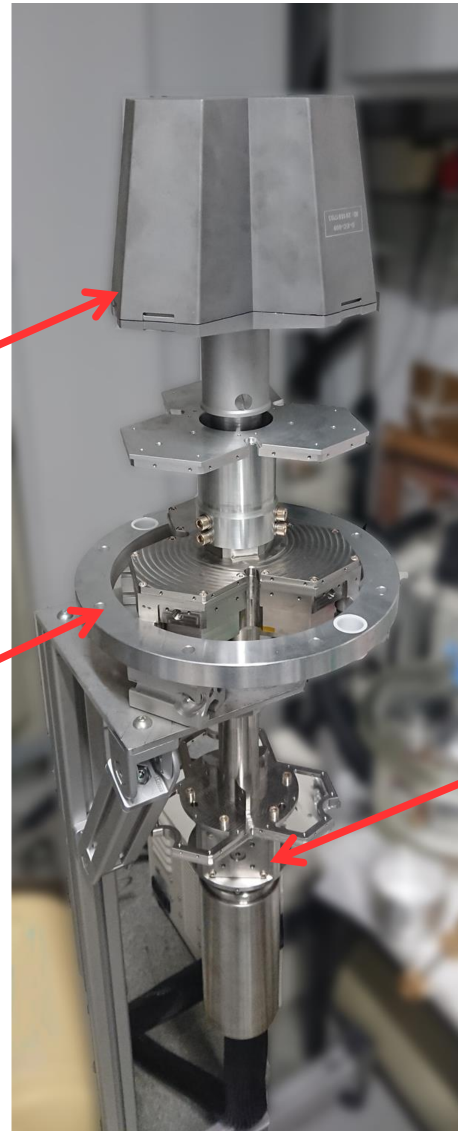




PANGEA - Prototype



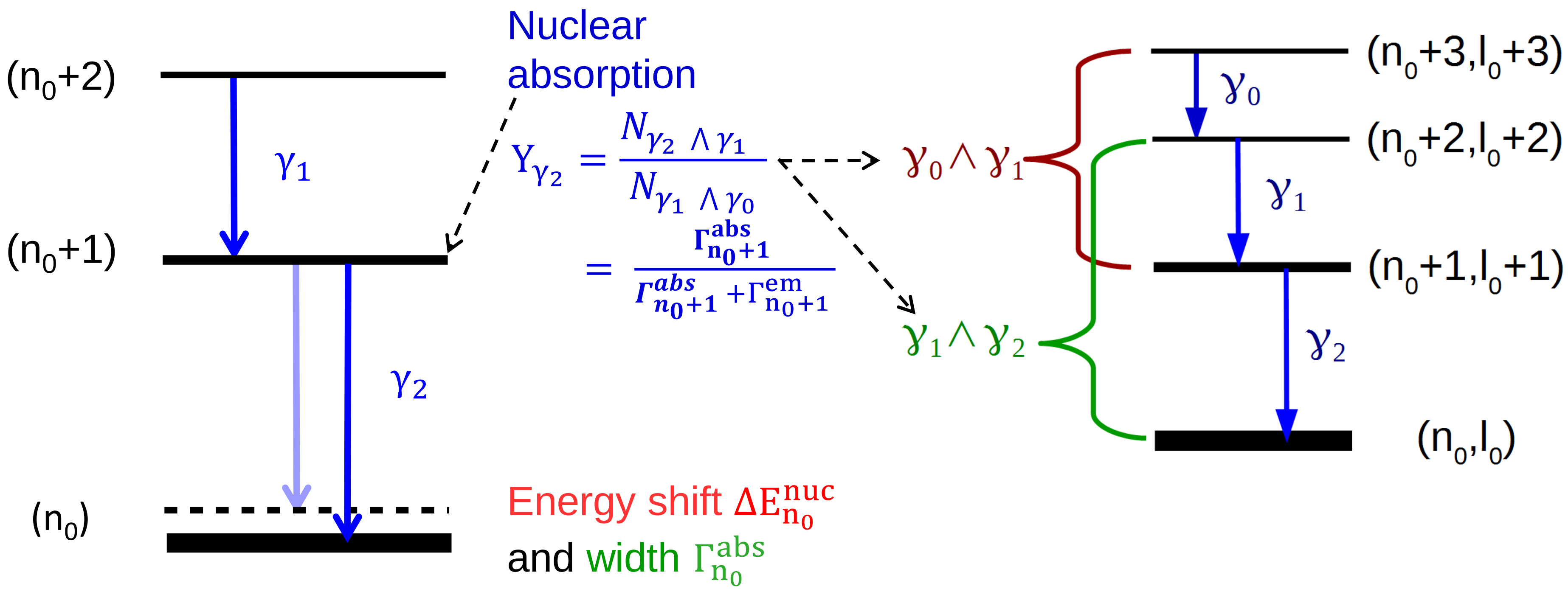




Courtesy of I. Kojouharov

X-ray spectroscopy of Ξ^-- hyperatoms

Observables



Ξ^--nucleus potential

PHYSICAL REVIEW C VOLUME 59, NUMBER 1 JANUARY 1999

Experiments with Ξ^- atoms

C. J. Batty,[1] E. Friedman,[2] and A. Gal[2]
[1]*Rutherford Appleton Laboratory, Chilton, Didcot, Oxon, OX11 0QX, United Kingd*
[2]*Racah Institute of Physics, The Hebrew University, Jerusalem 91904, Israel*

(Received 14 September 1998)

Experiments with Ξ^- atoms are proposed in order to study the nuclear interaction of
production of Ξ^- in the (K^-,K^+) reaction, the Ξ^- stopping in matter, and its atomic casca
within a realistic evaluation of the results expected for Ξ^- x-ray spectra across the peri
assumed Ξ-nucleus optical potential V_{opt}. Several optimal targets for measuring the s
and width of the x-ray transition to the "last" atomic level observed are singled out

Simplified assumption:

$$U(r) \propto \left(1+\frac{\mu}{M}\right) b_0 \left(\rho_n(r)+\rho_p(r)\right)$$

$$\rho_{n,p}(r) = \rho^0_{n,p} \frac{1}{1+\exp\left(\frac{r-c_{n,p}}{a_{n,p}}\right)}$$

$b_0 = 0.25 + i0.04$

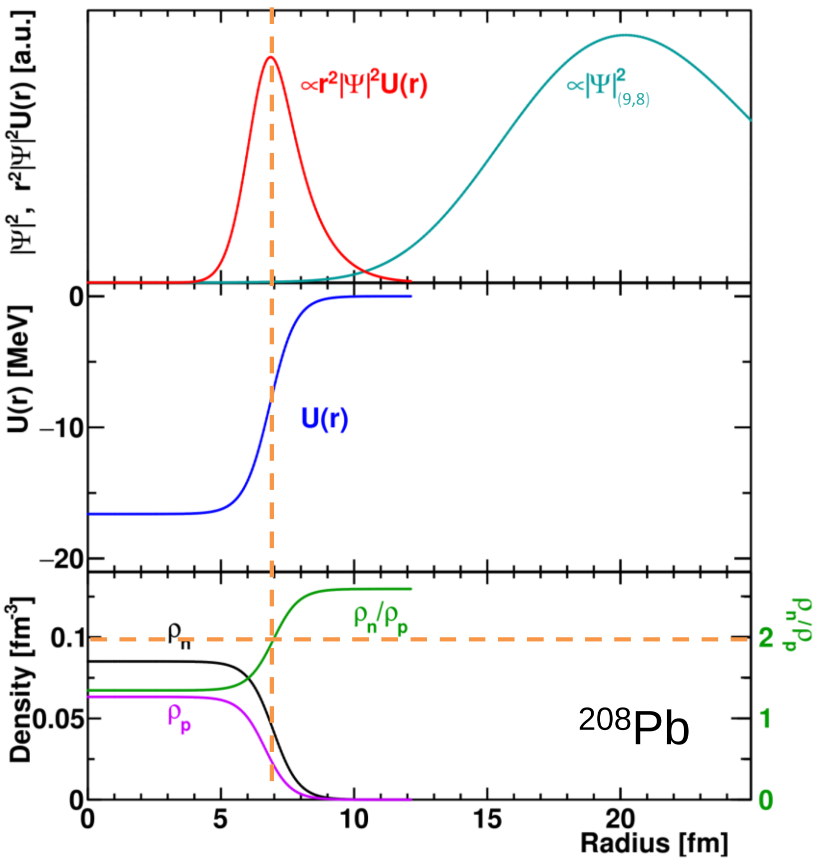
$a_n = a_p$

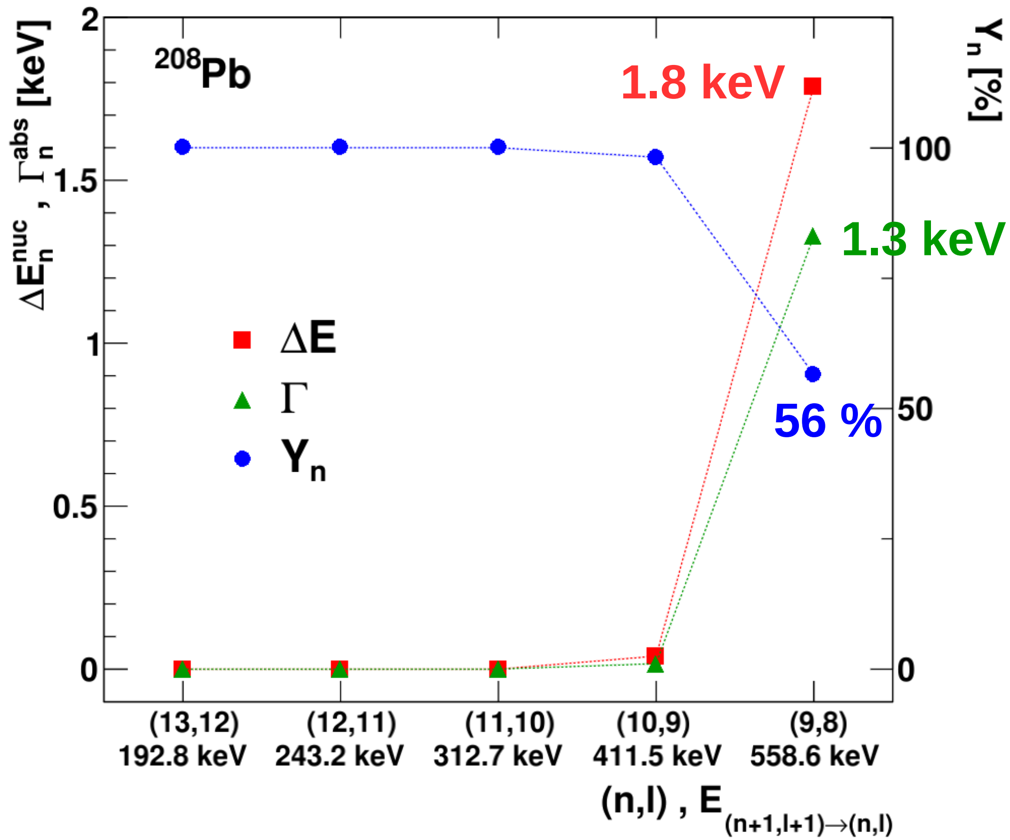
$c_{n,p}$ fixed by $R_{p,rms}$ and n skin

$\rho^0_{n,p}$ from N and Z

Schematic calculations to explore experimental sensivity.

$\Xi^- - {}^{208}Pb$

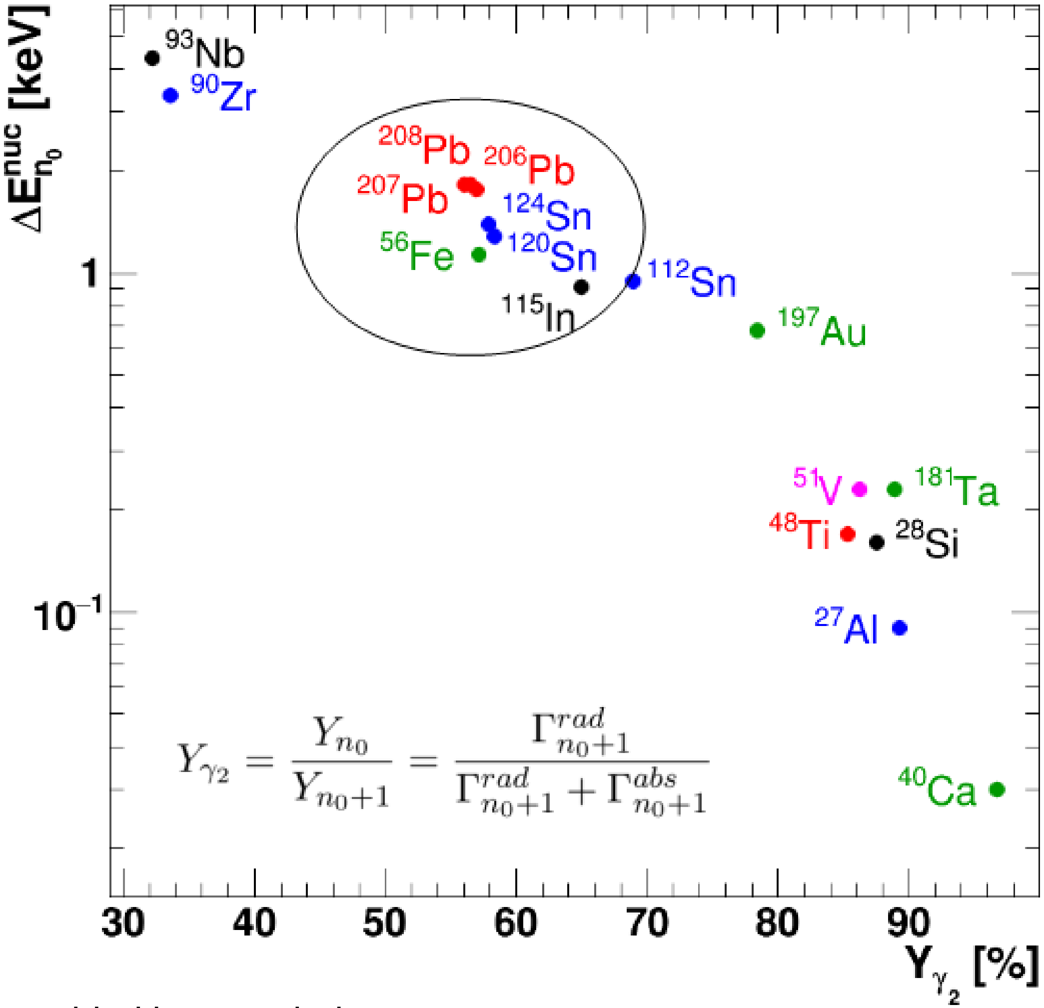




Calculations performed with code provided by E. Friedman

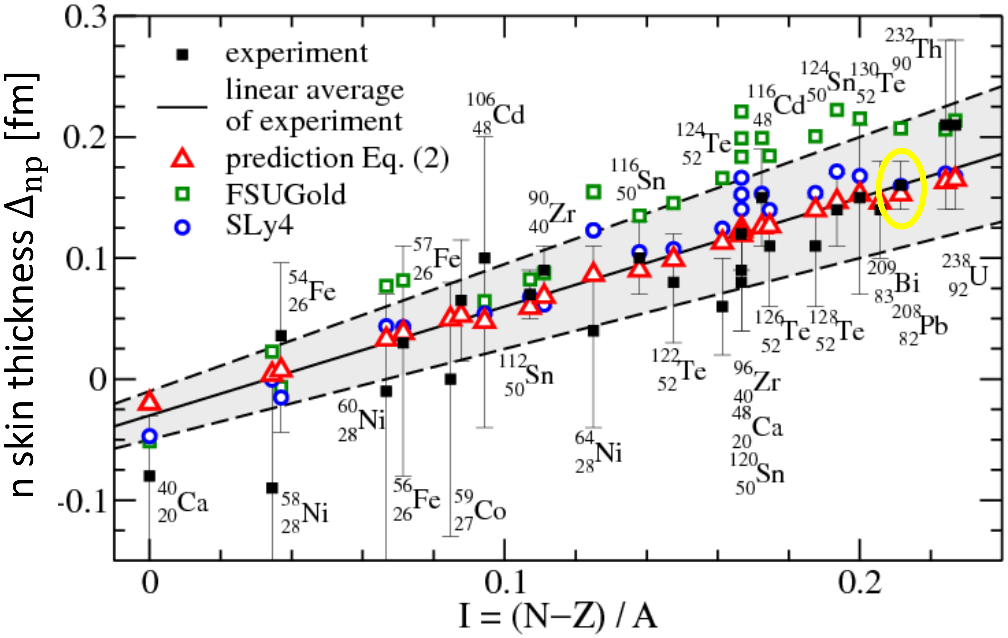
Possible targets

FWHM$_{Ge}$(558 keV) ~ 1,4 keV

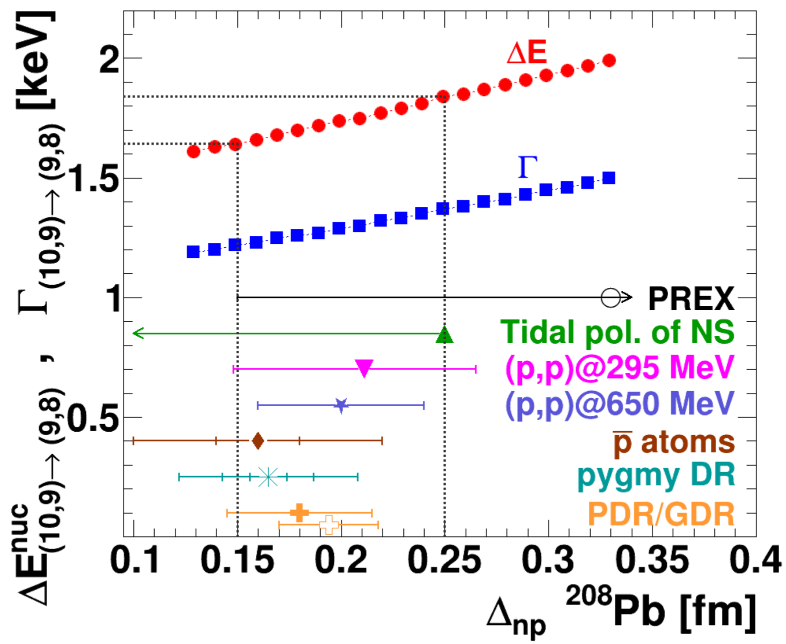


Calculations performed with code provided by E. Friedman

Systematic uncertainties

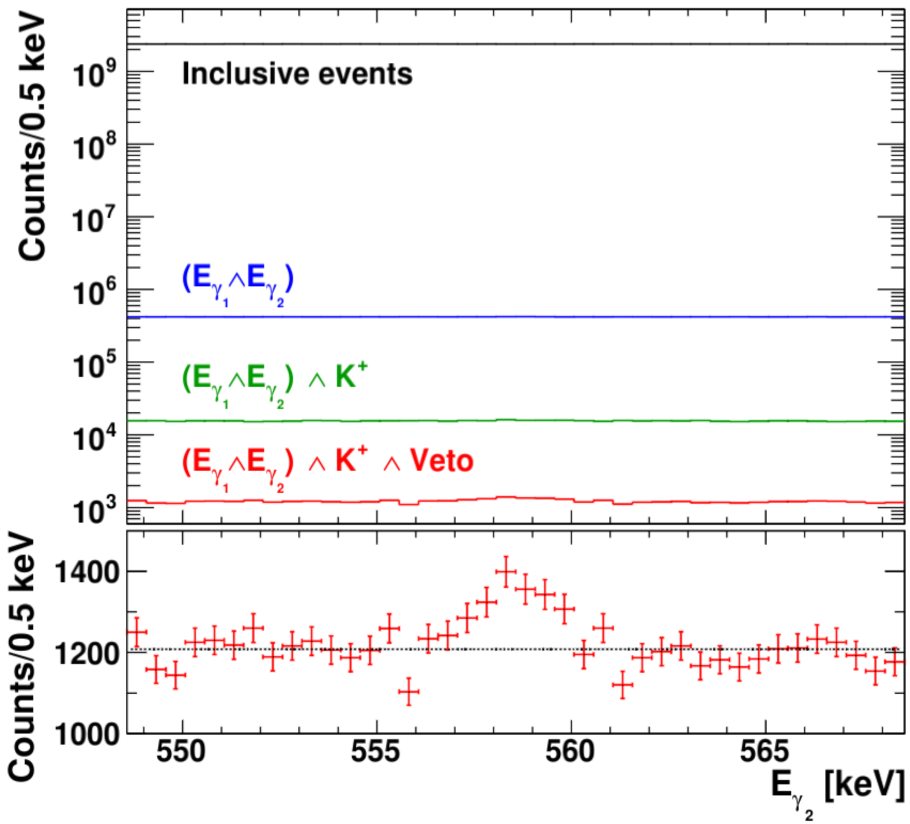


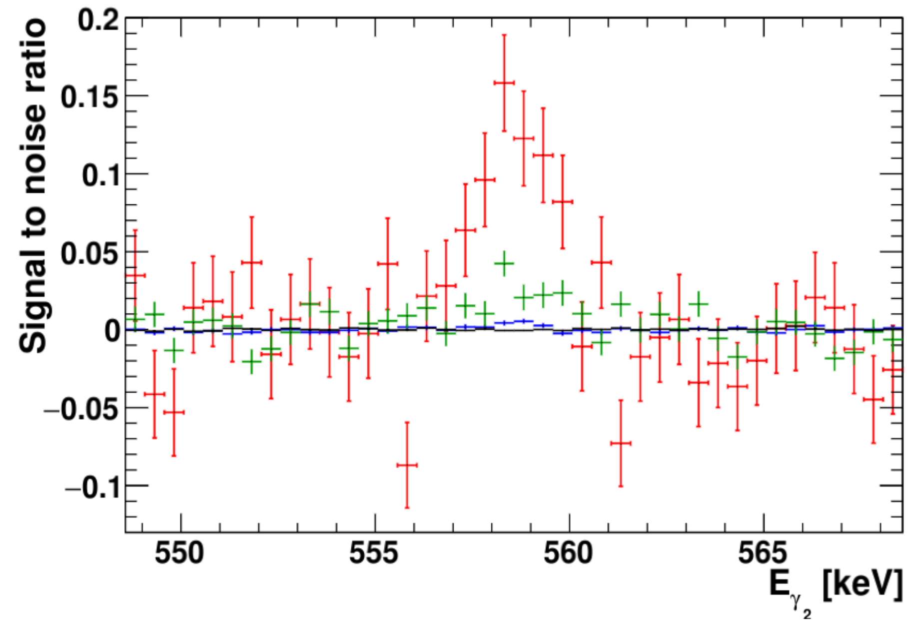
Centelles et al., Phys.Rev.Lett. 102 (2009) 122502

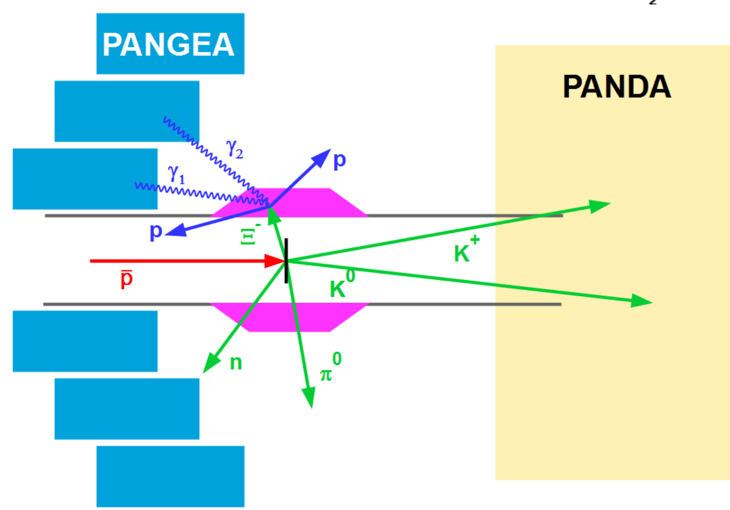


- Neutron skin Δ_{np} in ^{208}Pb well-established
- Present uncertainty of Δ_{np} -> Systematic uncertainty in observables
- $\boldsymbol{\delta\left(\Delta E^{nuc}_{(10,9)\to(9,8)}\right)_{sys}}$ **~ ± 100 eV**

Full Simulation

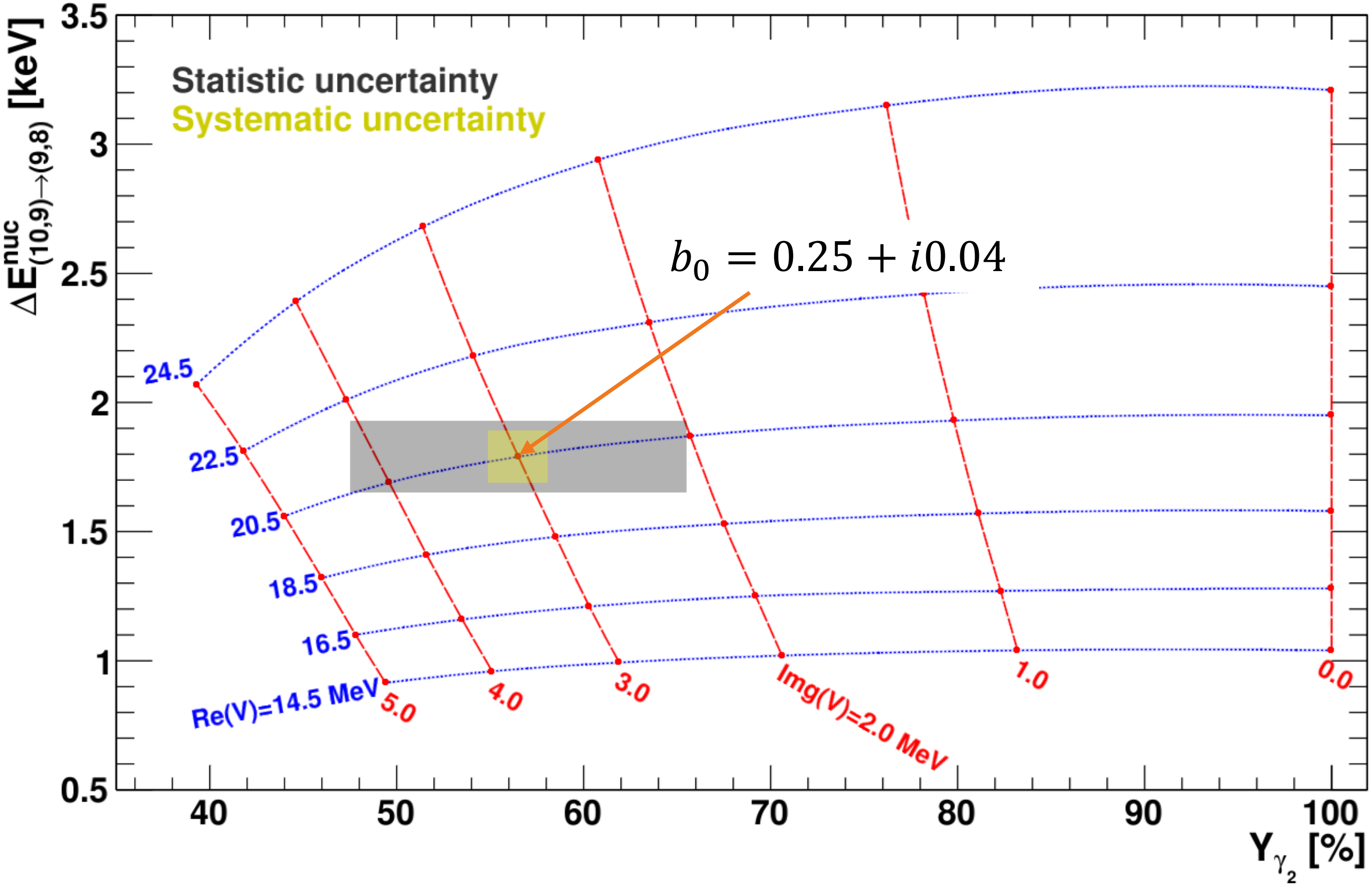






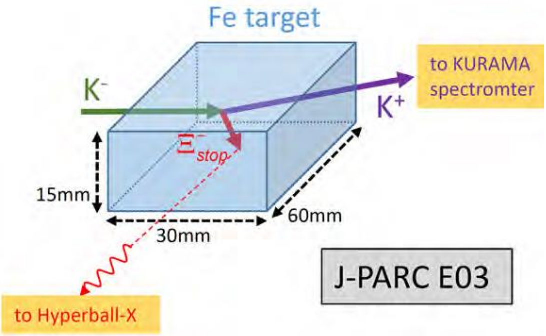
- Signals after cuts and efficiencies 1237
  - 180 days at 2 MHz p̄C
- $\delta\left(\Delta E^{nuc}_{(10,9)\to(9,8)}\right)_{stat}$ = ± 140 eV

Estimation of V_Ξ

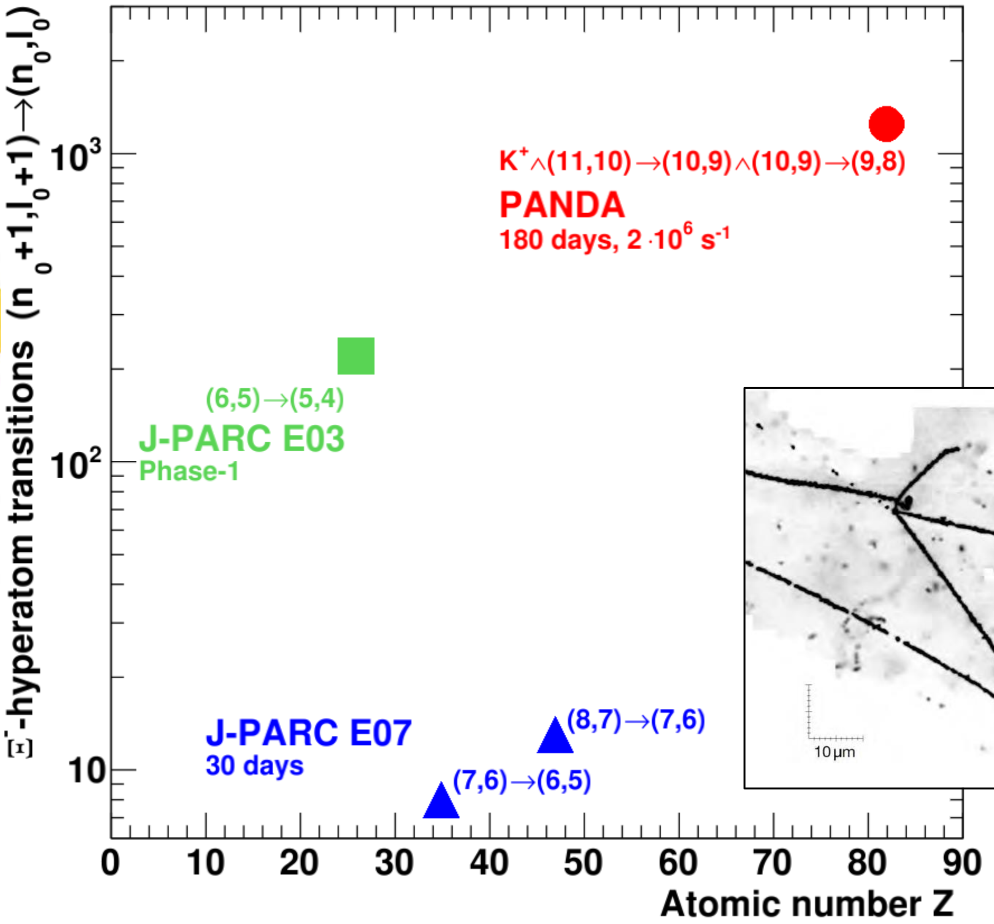


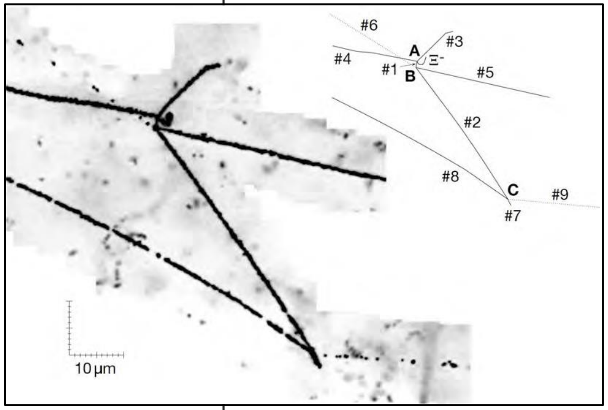
$$\delta(\mathrm{Re}(V_\Xi))_{stat} \approx \delta(\mathrm{Im}(V_\Xi))_{stat} \approx 1\ \mathrm{MeV}$$

Complementary experiments



See Talk after lunch T. Yamamoto





J-PARC E07: Ξ^--C hyperatoms not included

Take-home message

- $\bar{\text{P}}$ANDA@FAIR is a versatile experiment with a broad physics program
- Strangeness nuclear physics is an important pillar of $\bar{\text{P}}$ANDA
- Heavy hyperatoms unique for $\bar{\text{P}}$ANDA, complementary to J-PARC E03/07

THEIA-STRONG2020 - Workshop 2019

25-29 November 2019 Technik Museum Speyer, Germany

https://indico.gsi.de/event/8950/overview

STRONG 2020

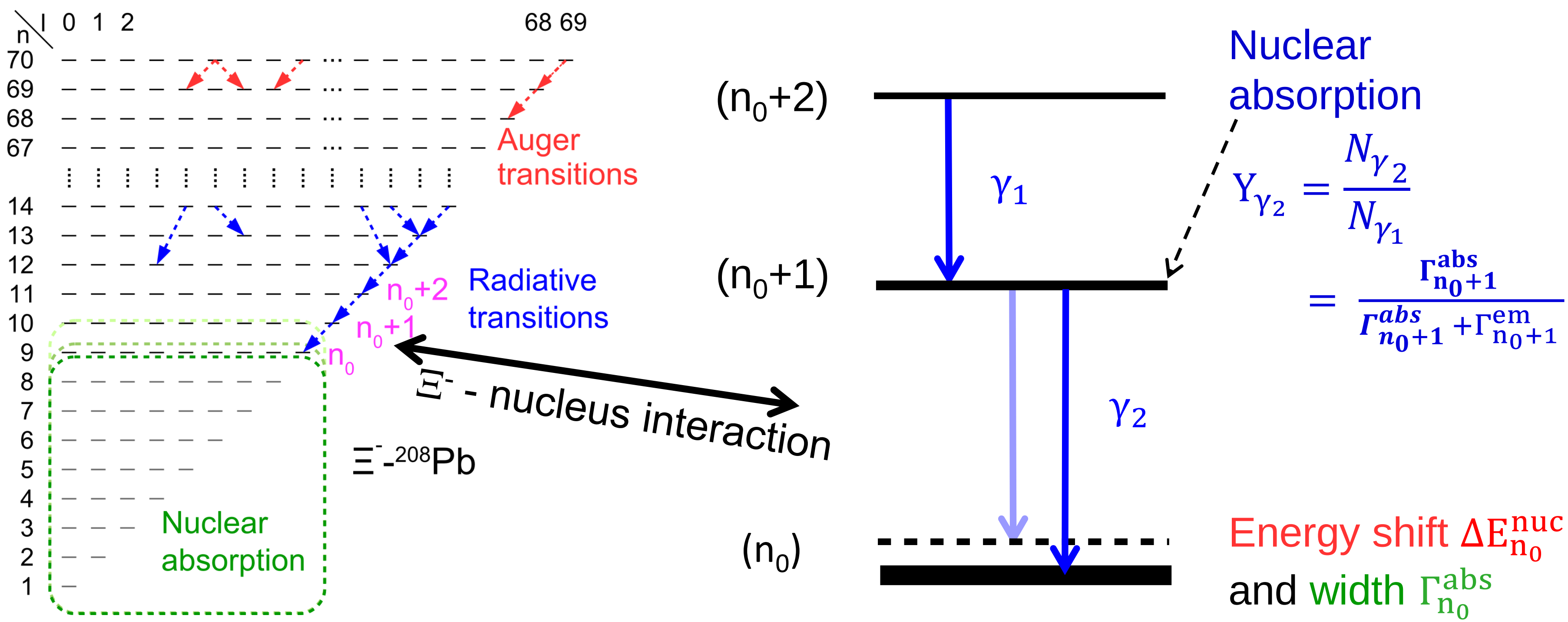
HIM HELMHOLTZ Helmholtz-Institut Mainz

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

JG|U

Backup Slides

X-ray spectroscopy of Ξ^-- hyperatoms

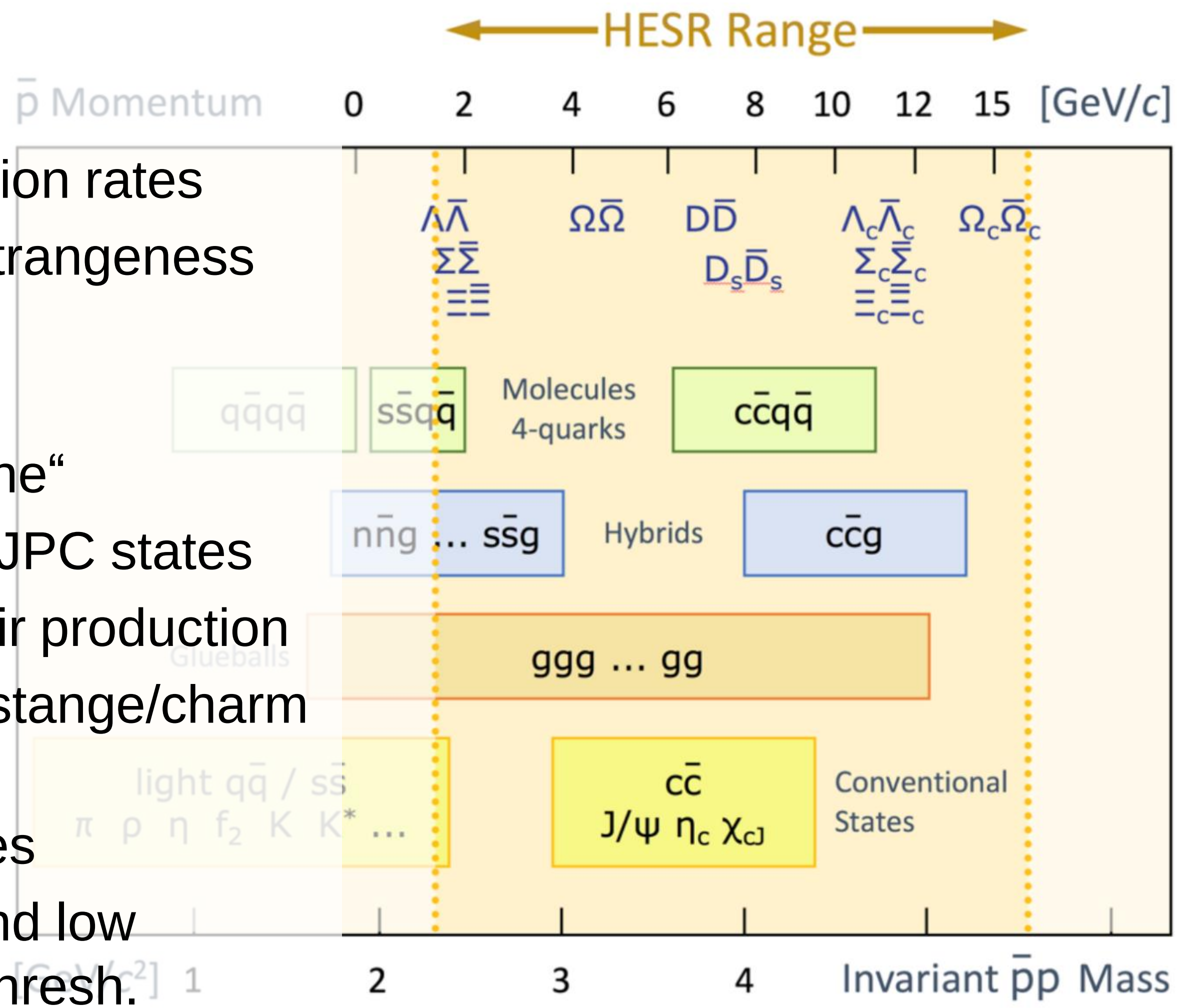


Adaptation from T. Aramaki et al Astroparticle Physics 49 (2013), pp. 52-62

→ **Measurement of V_{Ξ^-}**

Versatility of antiprotons

- $\sqrt{s}$: 2 – 5.5 GeV
- High hadronic production rates
  – High statistics of strangeness and charm
  – New exotics
  – Already at „Day-One“
- Direct formation of all JPC states
- Associated hadron-pair production
  – Access to hidden-stange/charm hadrons
  – Tagging possibilities
  – Good resolution and low background near thresh.



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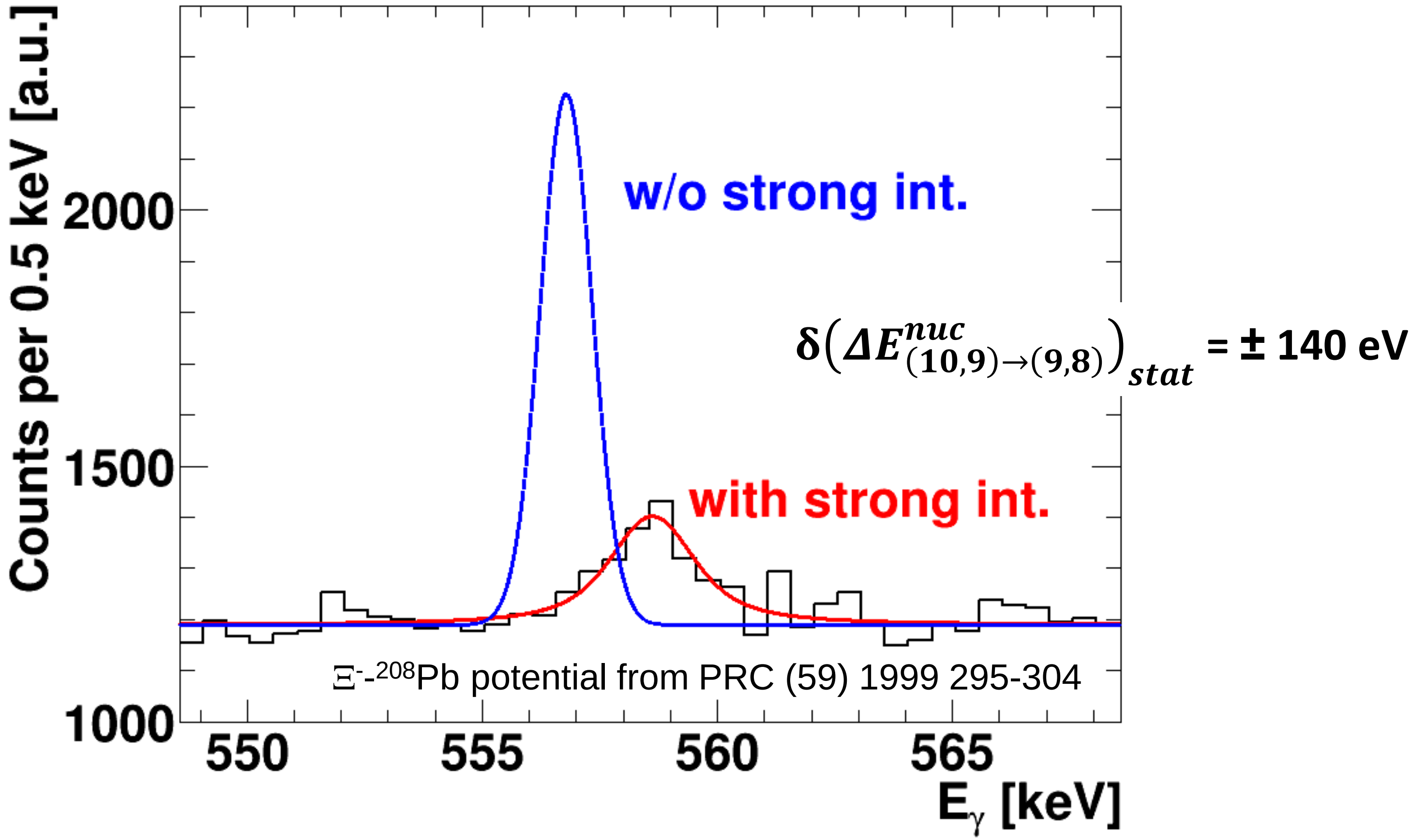
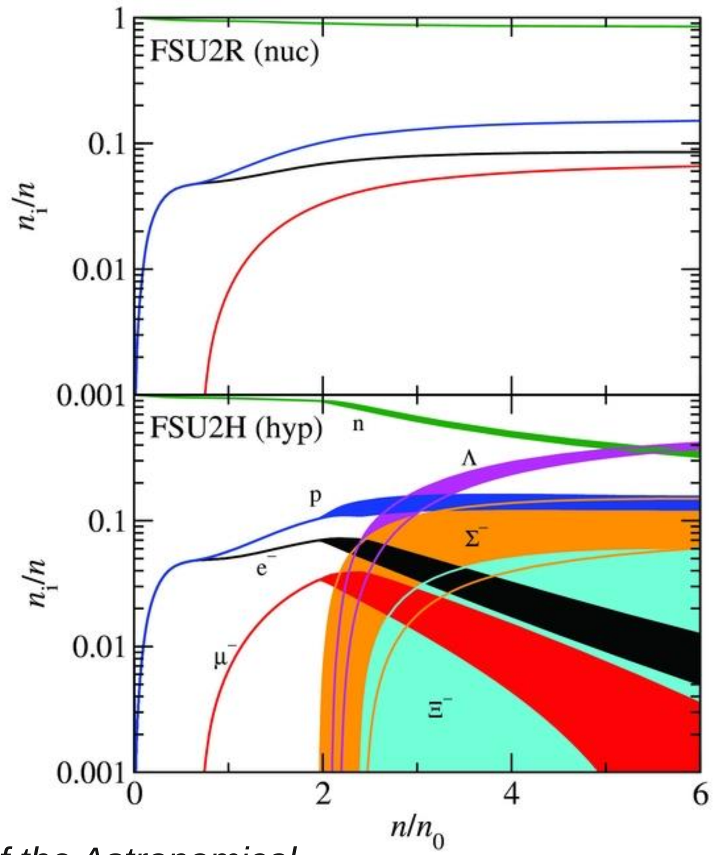
P̄ANDA expectations



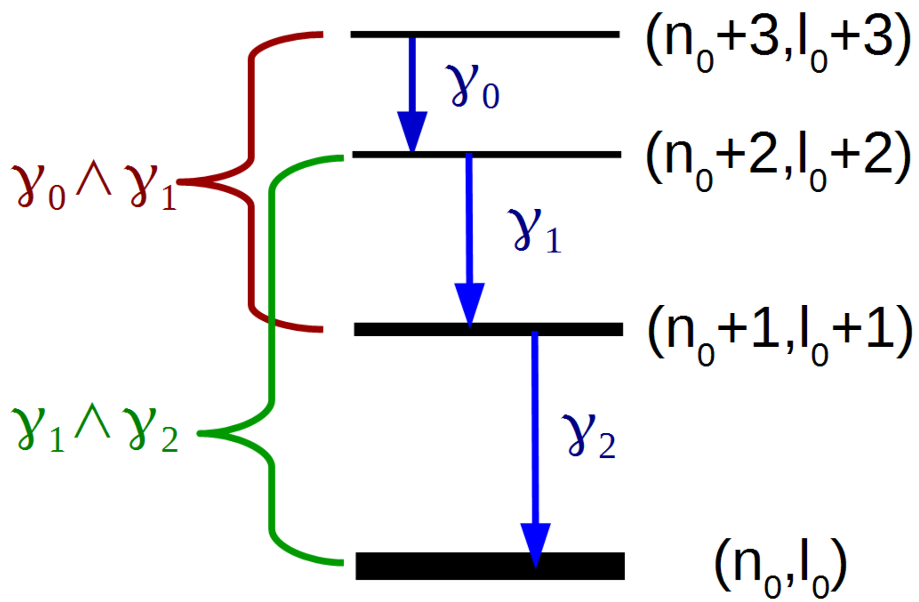
- Full simulation
- Data taking: 180 days
- Average interaction rate: 2 MHz

Hyperons in neutron stars

- Sequence of hyperon appearence depends on B-B interaction
- Σ – N interaction repulsive -> Σ will probably appear last

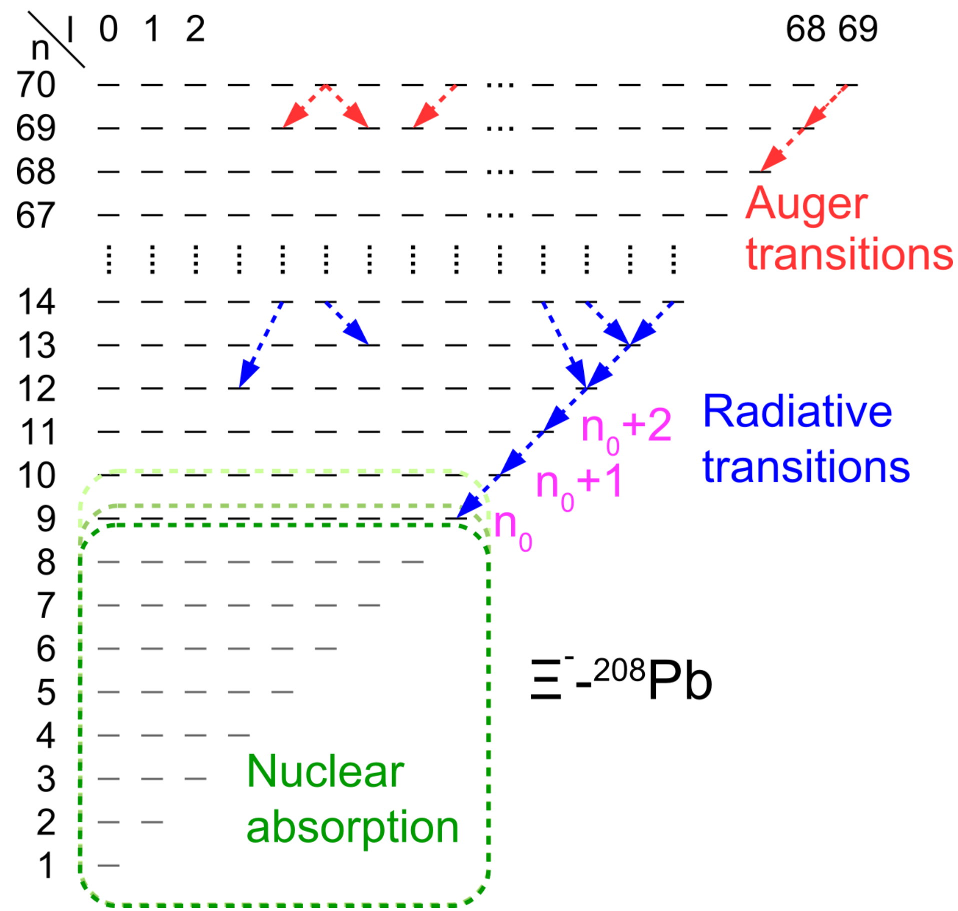


Tolos et al., Publications of the Astronomical Society of Australia, 34, E065. *(2017)*


(n_0+3,l_0+3)
γ_0
(n_0+2,l_0+2)
$\gamma_0 \wedge \gamma_1$
γ_1
(n_0+1,l_0+1)
$\gamma_1 \wedge \gamma_2$
γ_2
(n_0,l_0)

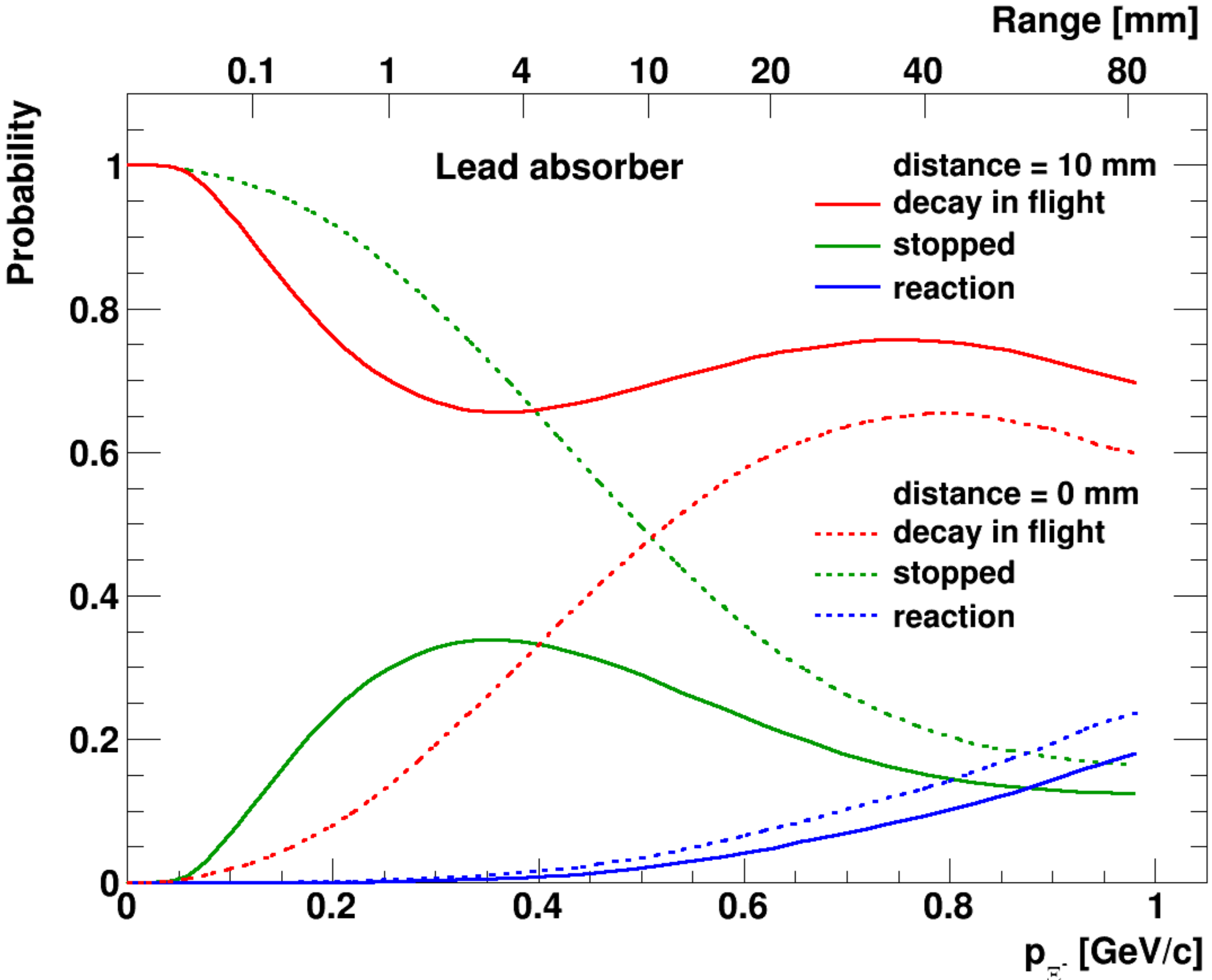
Ξ^- hyperatoms

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

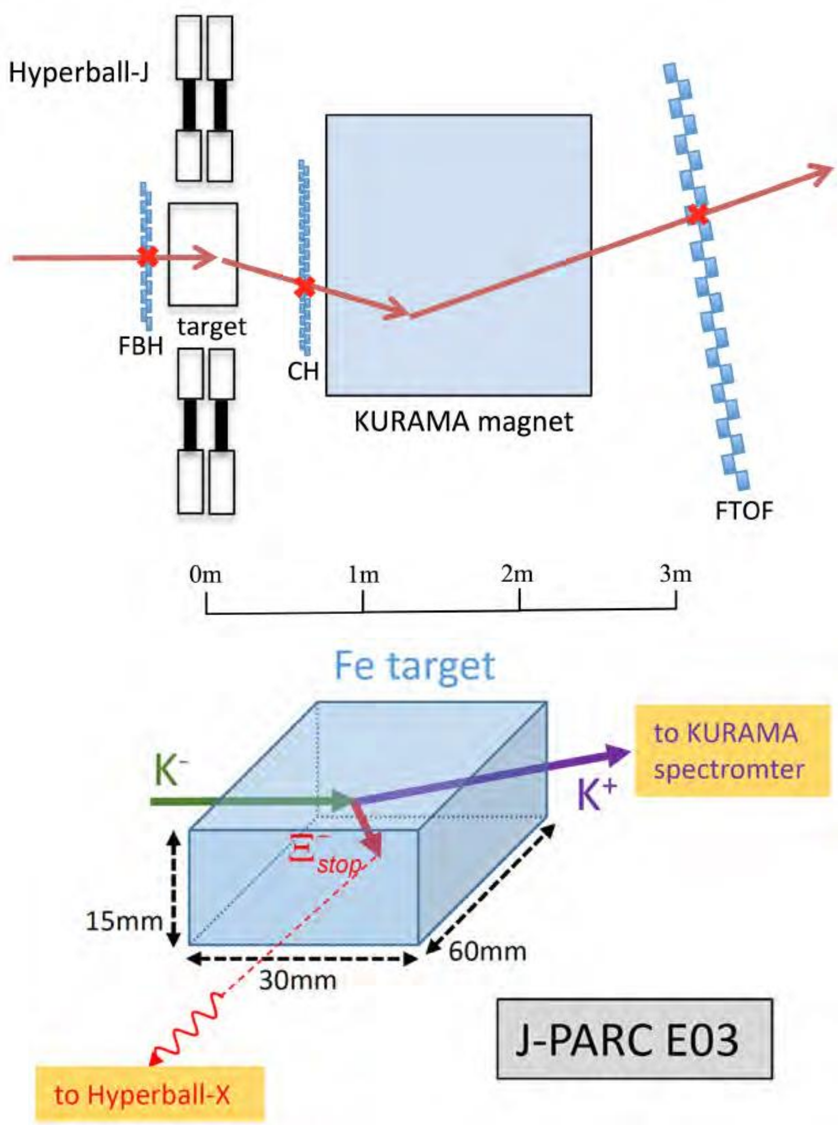


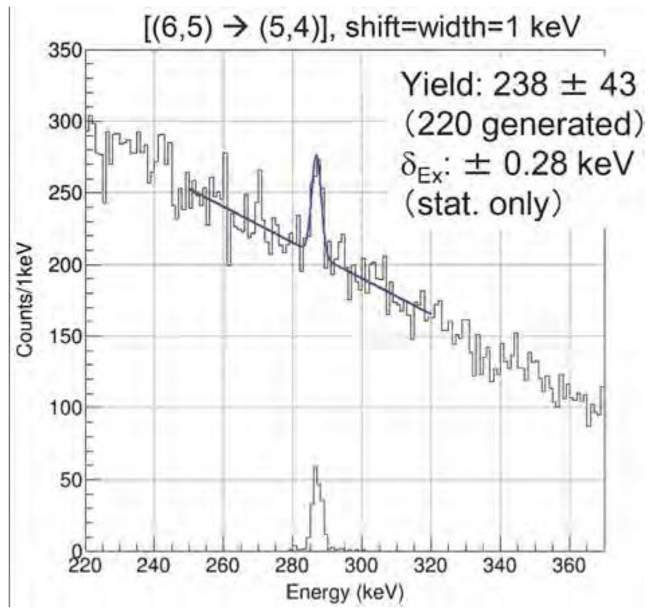
Adaptation from T. Aramaki et al Astroparticle Physics 49 (2013), pp. 52-62

Stopping of secondary Ξ-



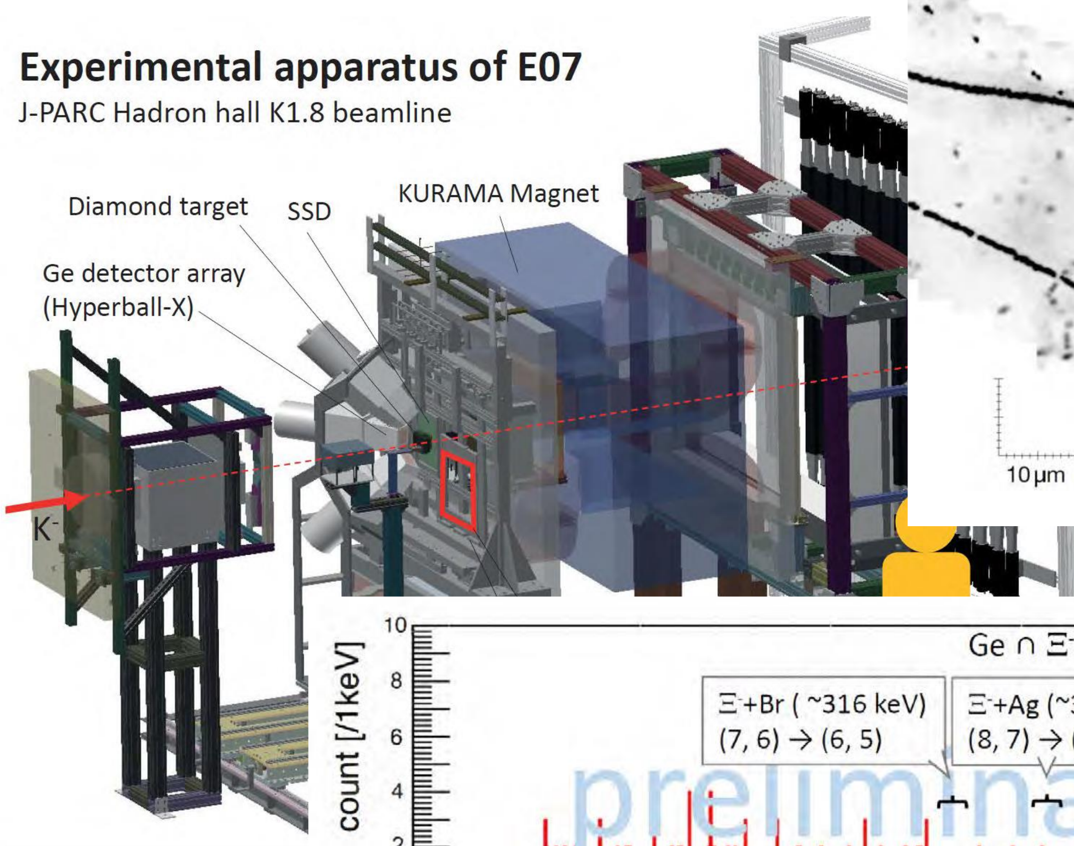
J-PARC E03

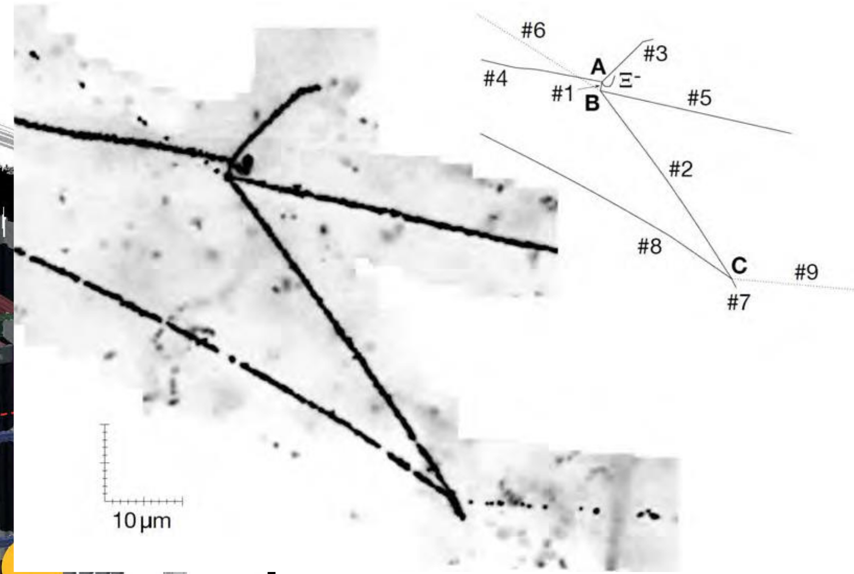


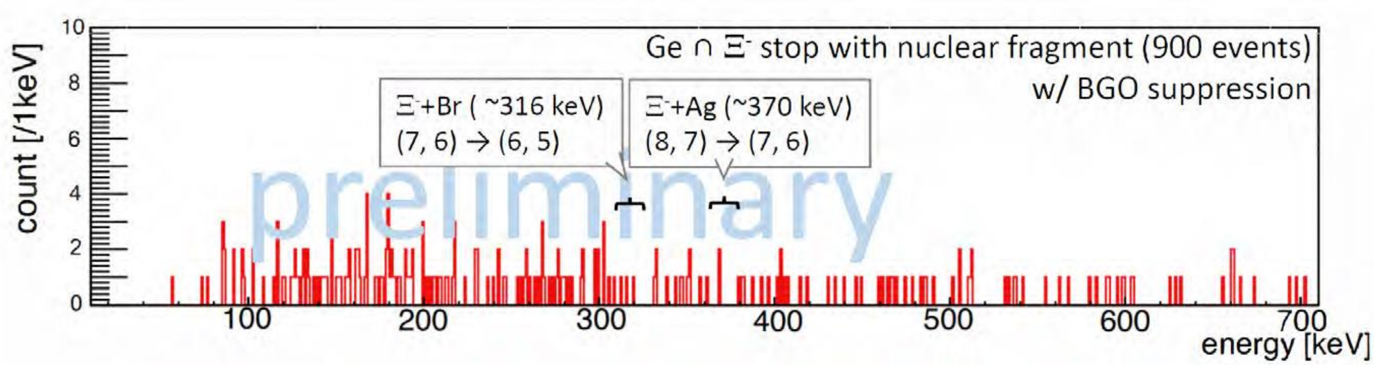


K. Tanida, 27th J-PARC PAC Meeting (2019)

J-PARC E07

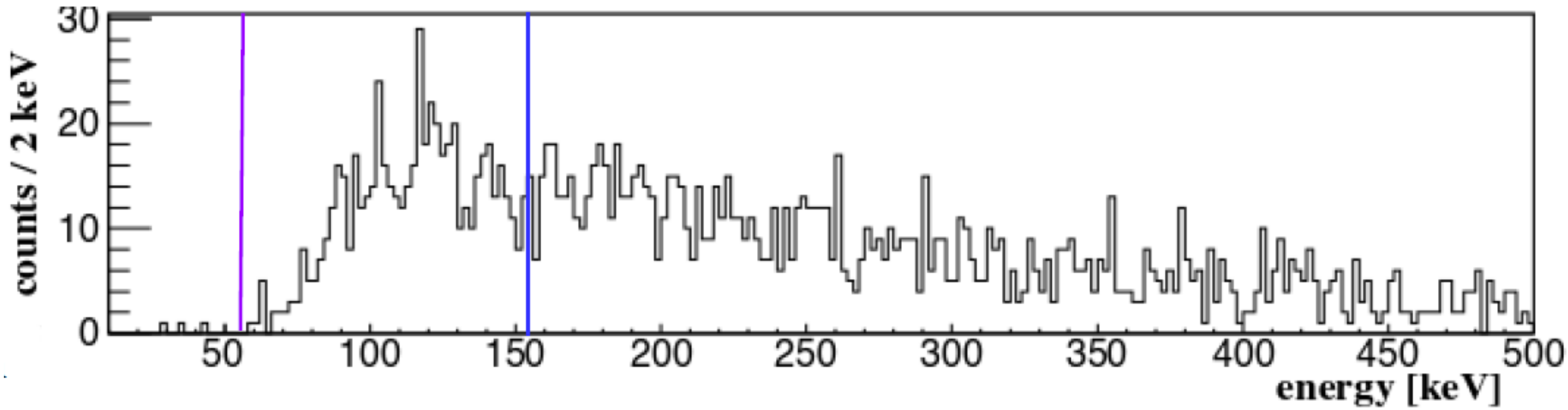




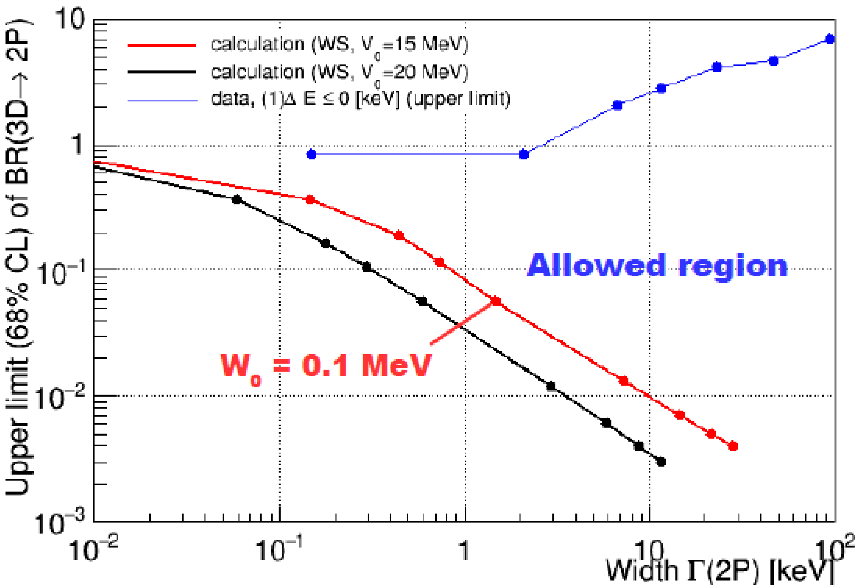


M. Fujita, X⁻-C hyperatoms, JPS autumn meeting 2019

E07: Ξ⁻-C hyperatoms

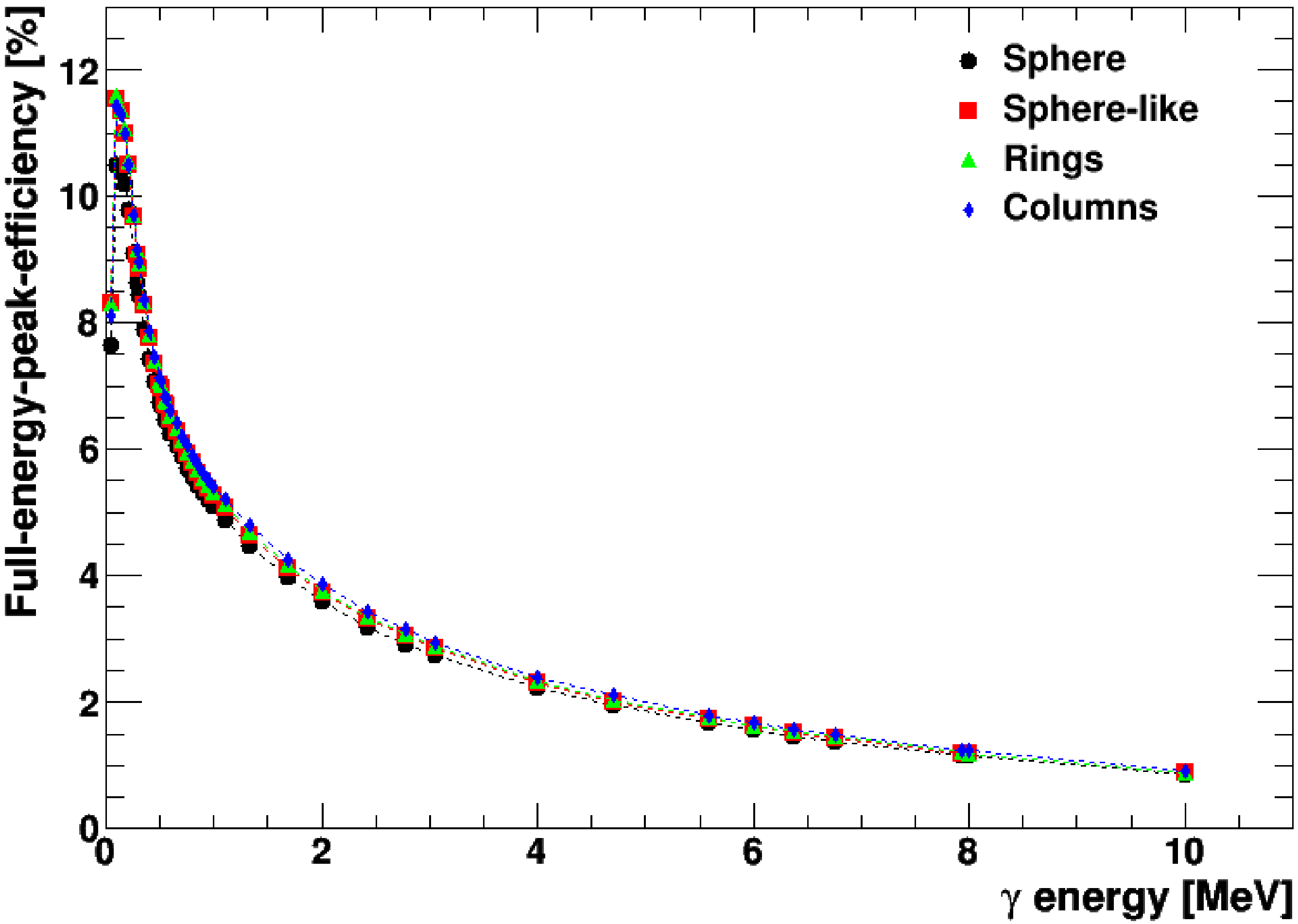


- No evident X-ray peak
- Insufficient statistics for upper limit in yield

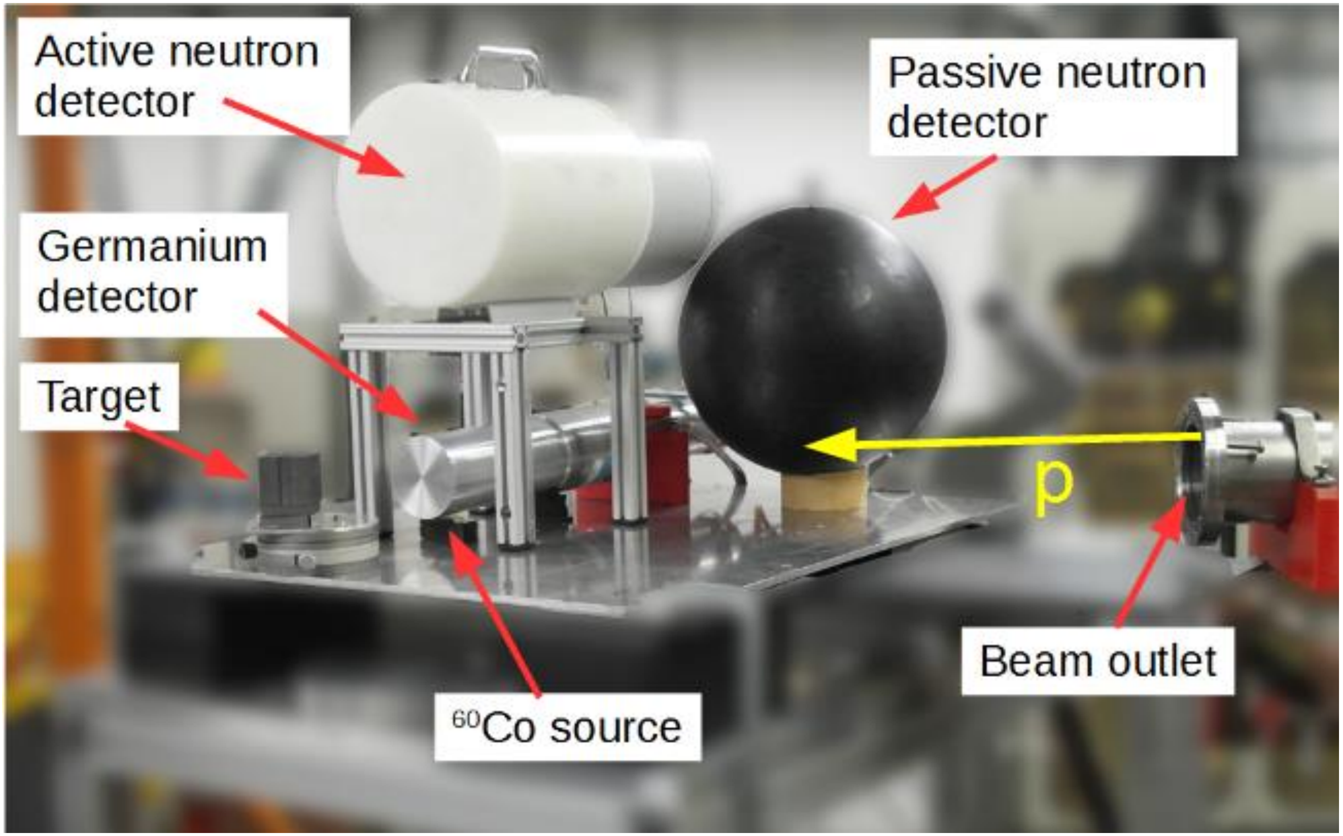


M. Fujita, X⁻-C hyperatoms, JPS autumn meeting 2019

FEP-efficiency PANGEA



HPGe irradiation test



- Irradiation test at COSY with single crystal prototype
- 5.5 days COSY
  → 96 days $\bar{\text{P}}$ANDA

Results

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