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

THEIA Workshop, Speyer, 27.11.2019

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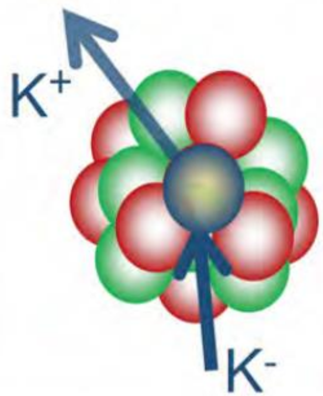
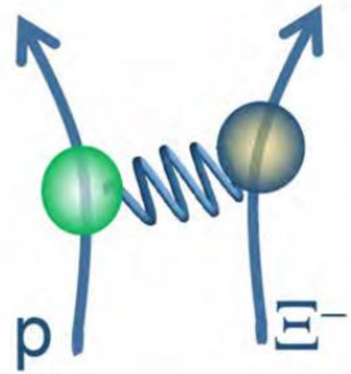
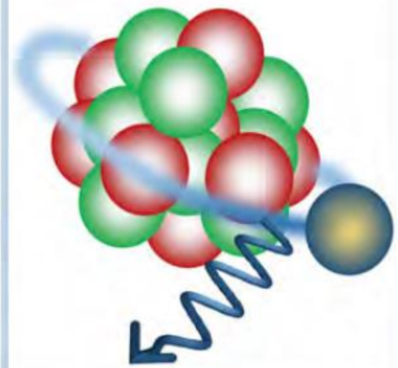
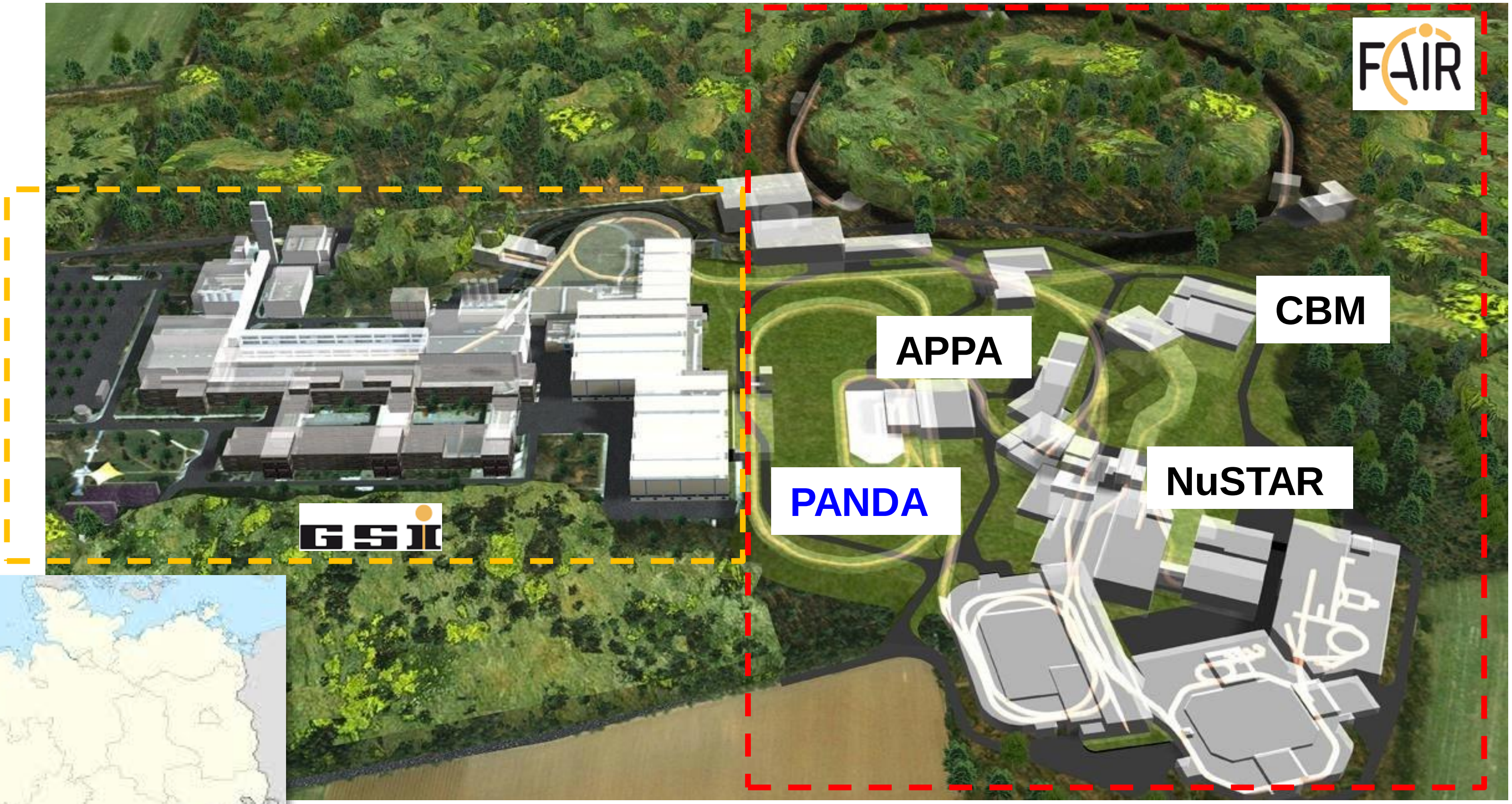
Ξ^--nucleus interaction

	Ξ^- hypernuclei decays in emulsion	missing mass spectroscopy of Ξ^- hypernuclei (K^-,K^+) reactions	scattering or final state interaction	γ-spectroscopy of Ξ^- hyperatoms
	 $^{A}_{\Xi}Z \rightarrow ^{A_1}_{\Lambda}Z_1 + ^{A_2}_{\Lambda}Z_2$ *K. Nakazawa et al., PTEP (2015) 033D02*		 *S. Acharya et al. Phys. Rev. Lett. 123, 112002*	
Past		KEK E224 BNL E885	*Talk: A. Mathis*	
Present	J-PARC E07	J-PARC E05	STAR ALICE	J-PARC E07
Future		J-PARC E70		J-PARC E03 P̄ANDA

Topics

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

FAIR



Facility for Antiproton and Ion Research

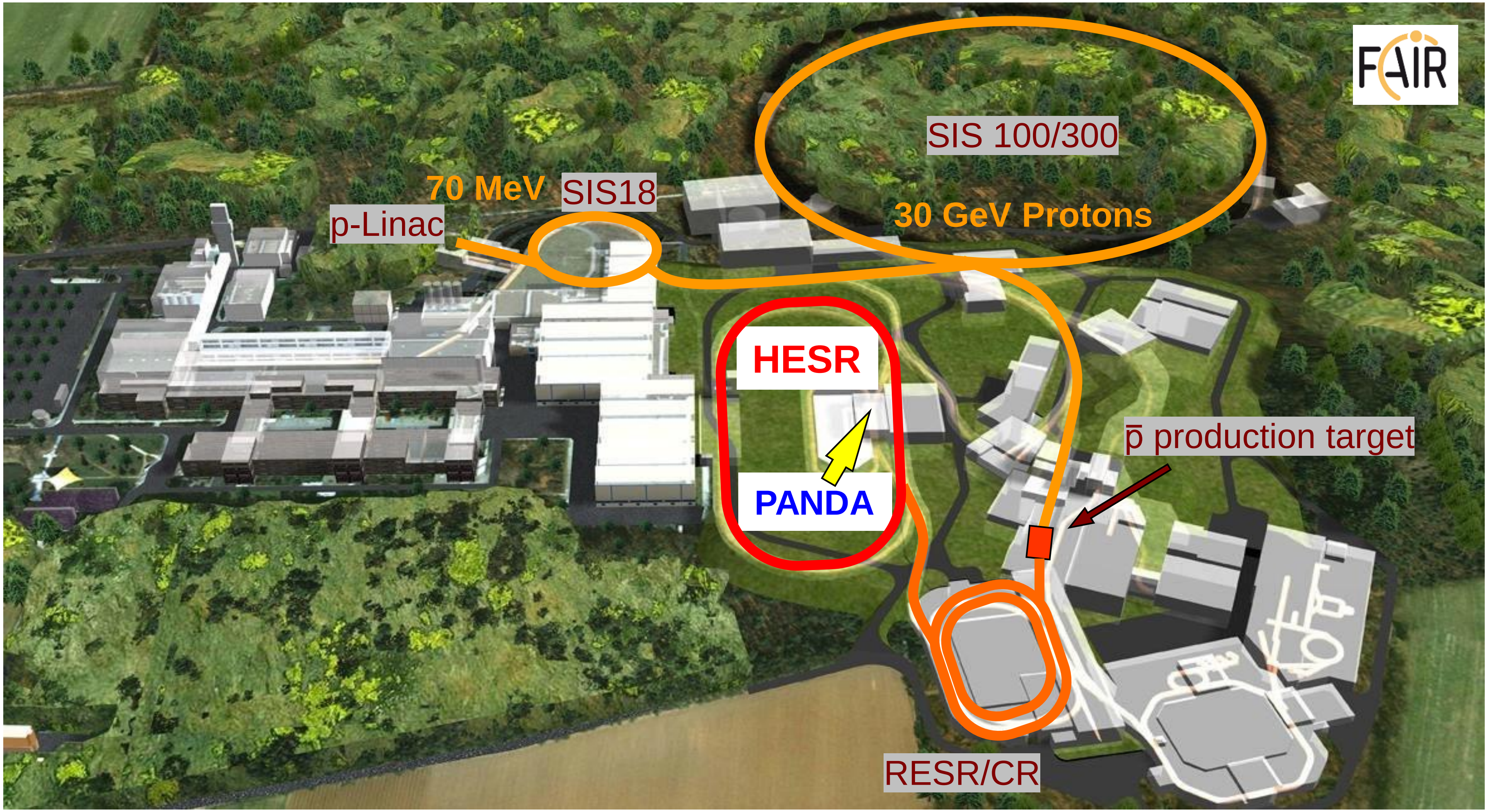
FAIR - under construction

SIS 100 Ring – Sep./Oct. 2019

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

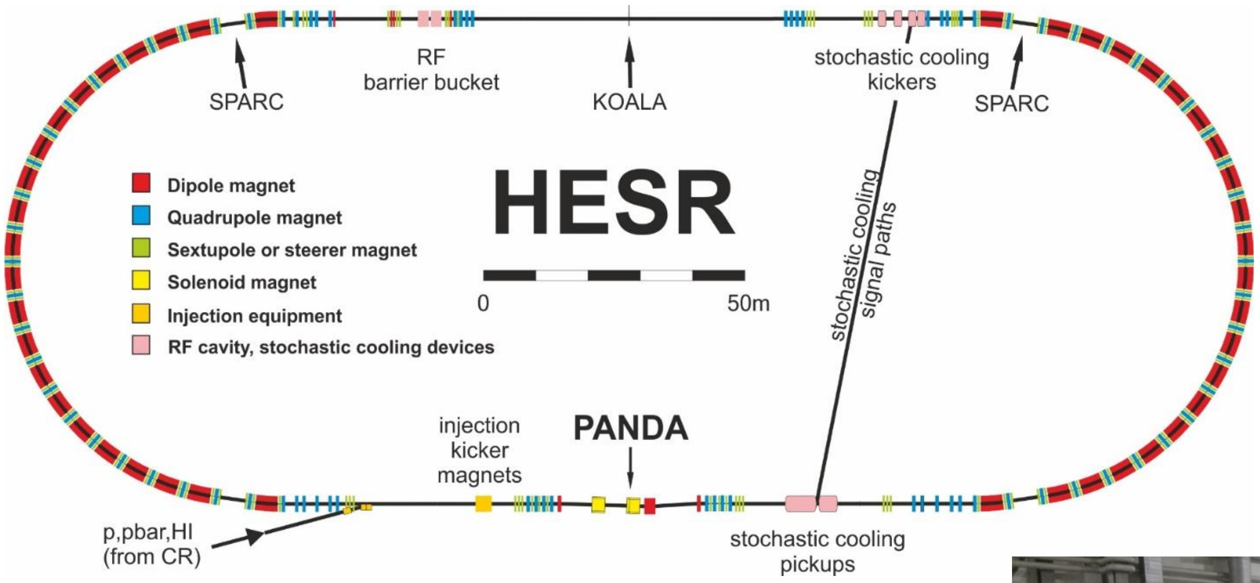
https://www.gsi.de/forschungbeschleuniger/fair/bau_von_fair/bilder_und_videos.htm

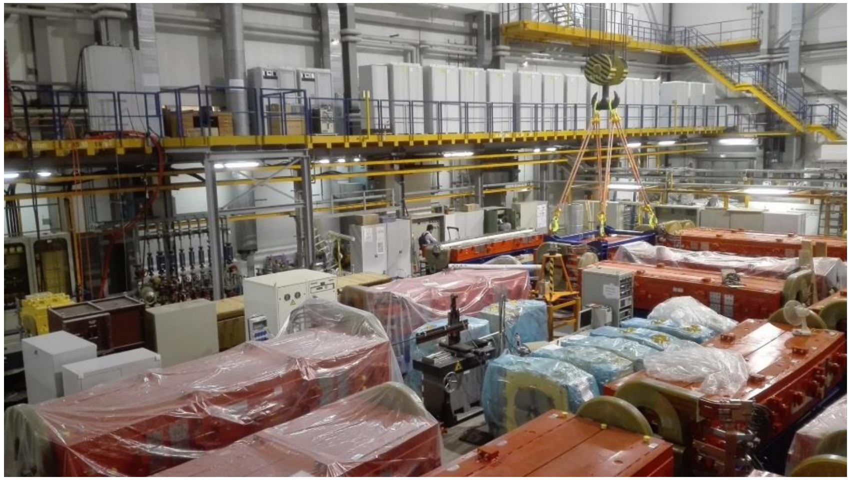
P̄ANDA at FAIR



P̄ANDA situated in **H**igh **E**nergy **S**torage **R**ing

HESR





- Modularized start version
  - 10^{10} $\bar{p}$ stored
  - Luminosity up to $2x10^{31}$ cm^{-2} s^{-1}
  - $p_{\bar{p}} = 1.5 – 15$ GeV/c
  - $\Delta p/p \leq 5x10^{-5}$

Physics pillars of $\bar{\text{P}}$ANDA

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

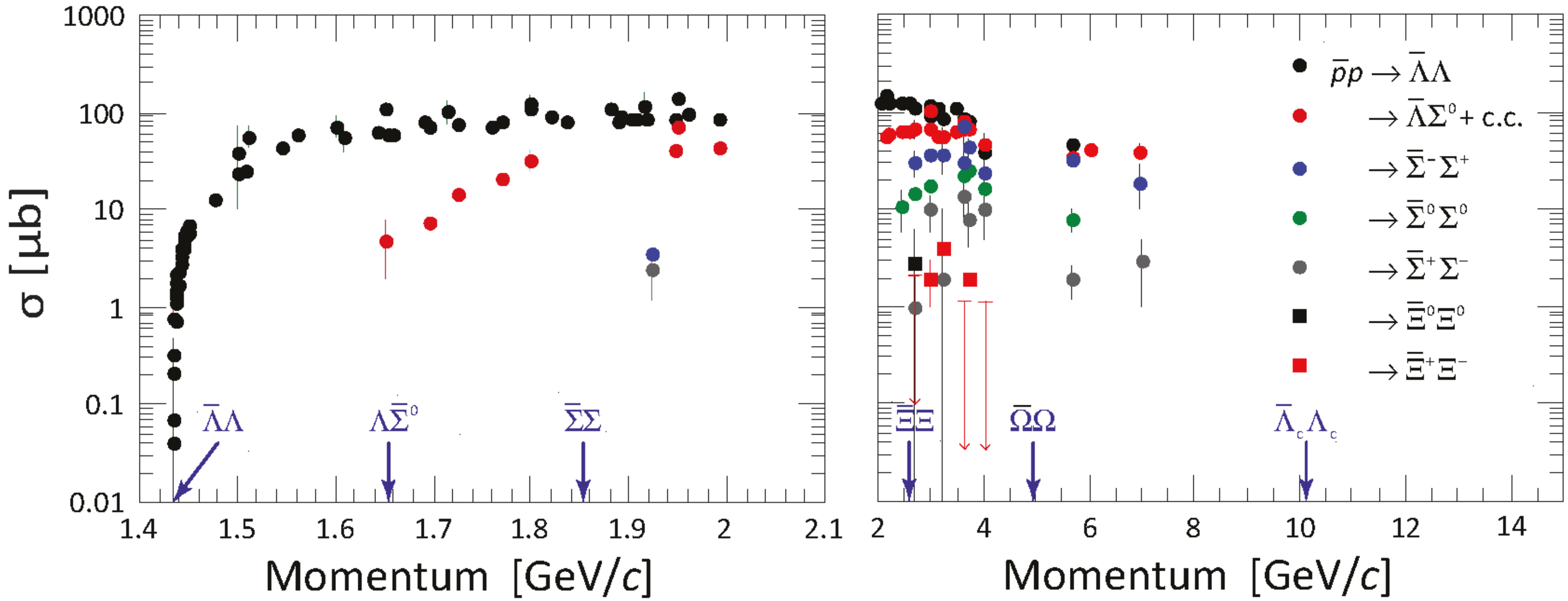
Strange baryon spectroscopy
Hyperon production & pol.
Hyperon transition form factors

Strangeness in $\bar{p}p$

Hadrons in nuclei
Hyperon-nucleus dynamics
Hypernuclei and Hyperatoms

Nuclear physics

$\bar{P}$ANDA as hyperon factory

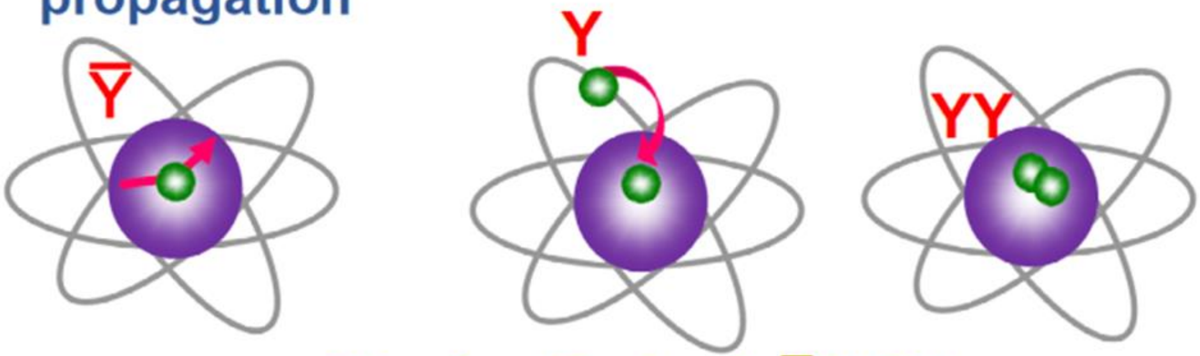


T. Johansson, AIP Conf. Proc. Of LEAP 2003, p. 96

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 P̄ANDA

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

Methodology

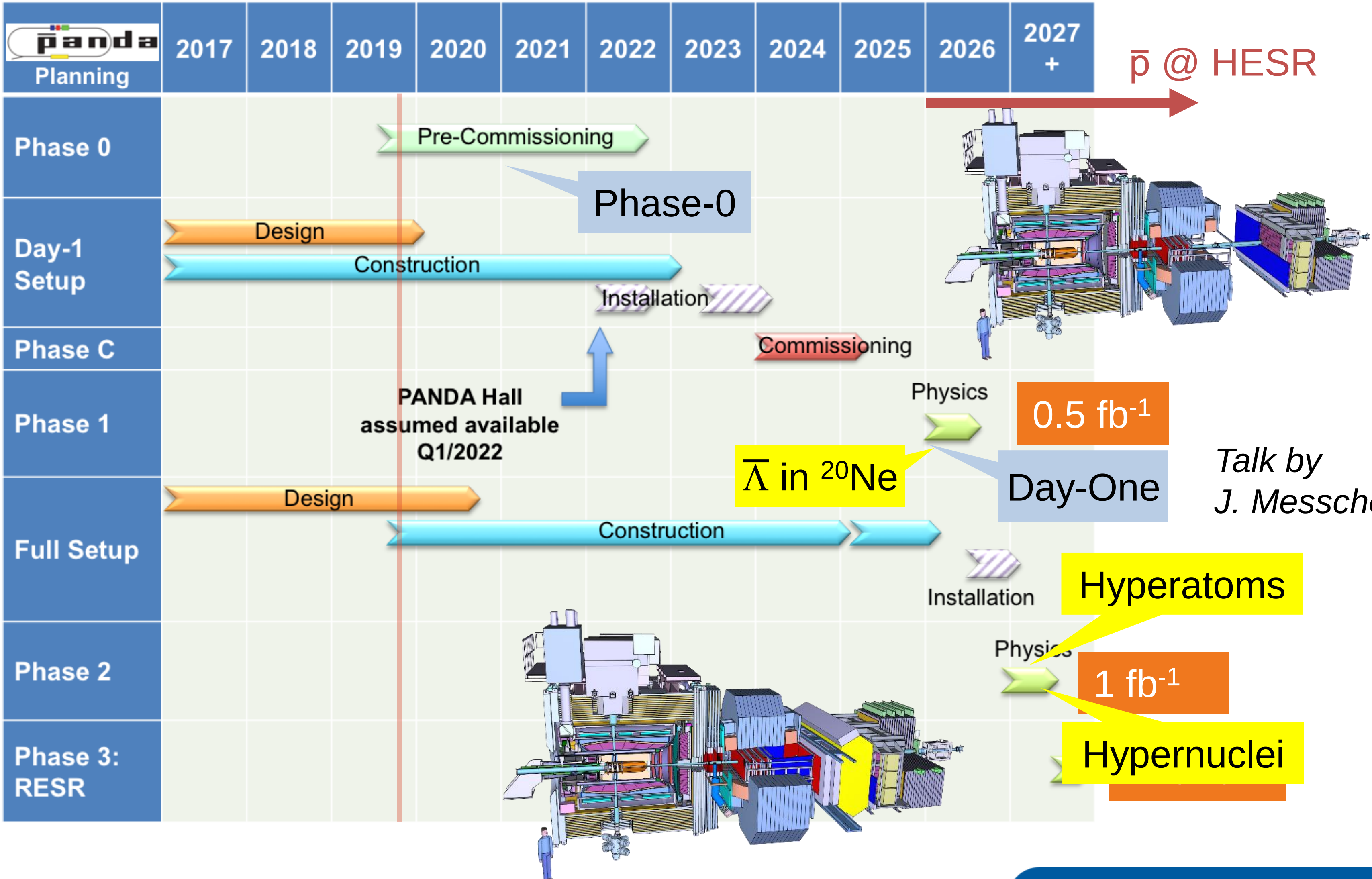
YȲ momentum correlations at threshold	Width and shift of atomic levels in Ξ^- ^{208}Pb atoms	Excited state spectrum of light $\Lambda\Lambda$ hypernuclei

See talk by J. Pochodzalla

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

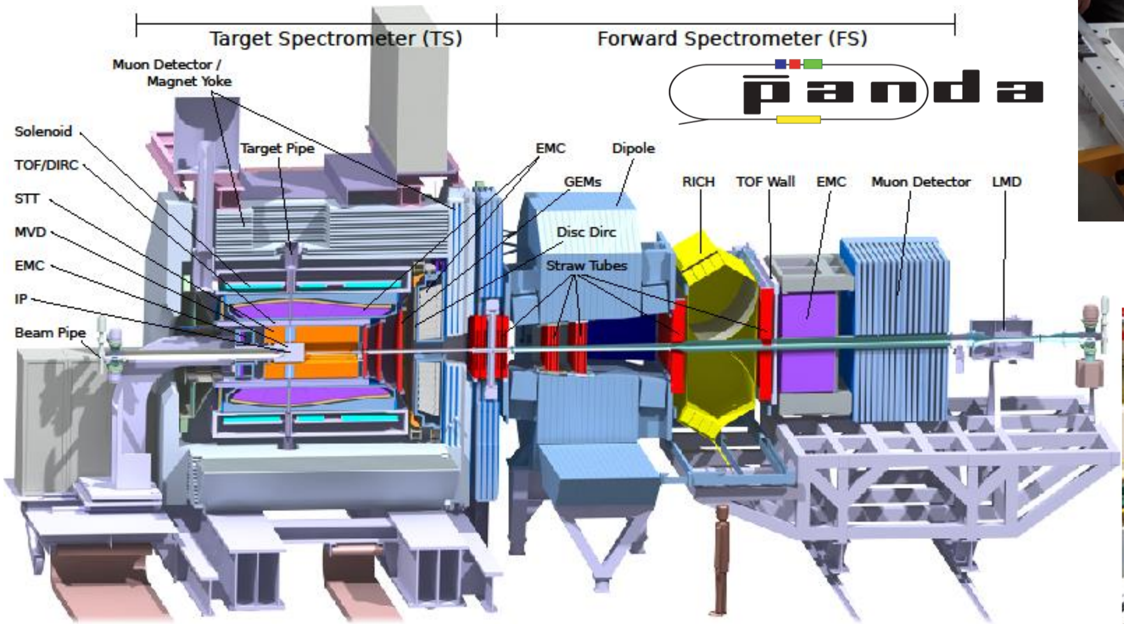
Pochodzalla et al., Nuclear Physics A 954 (2016) 323–34

P̄ANDA schedule

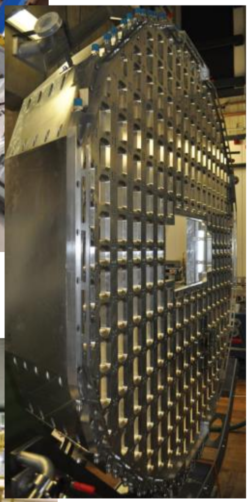


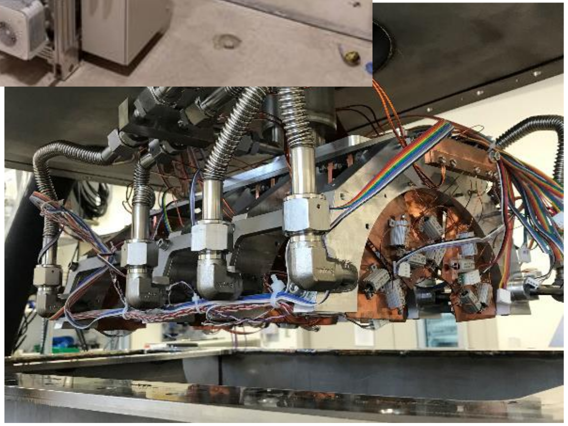
Talk by J. Messchendorp

$\bar{\text{P}}$ANDA detector



Hypernuclear/atom setup not shown



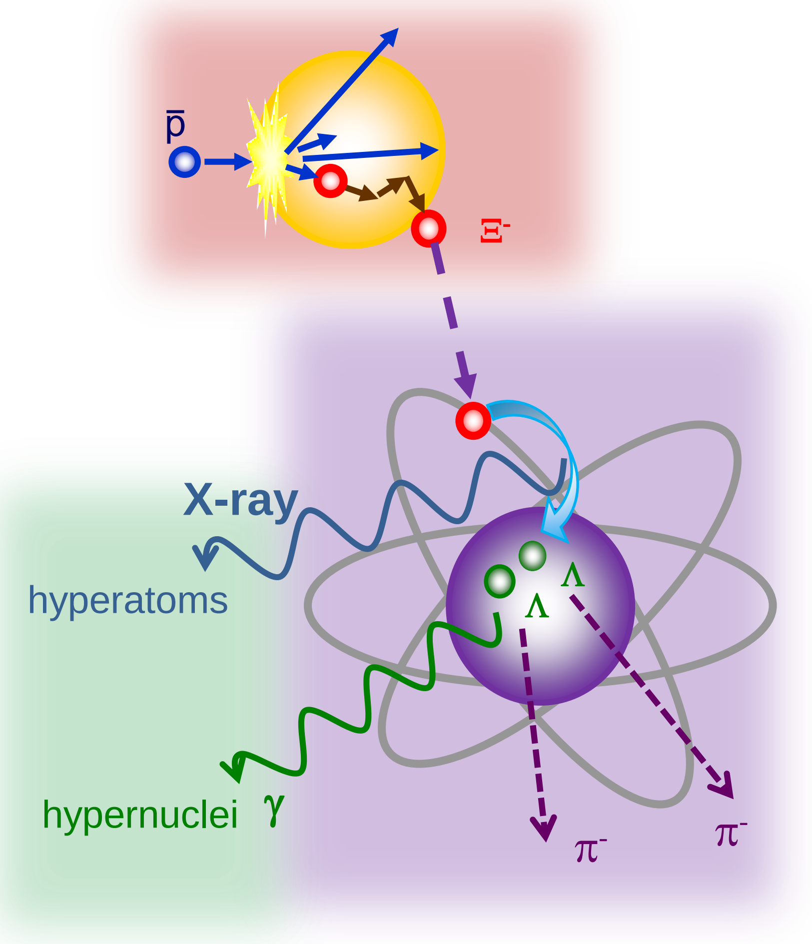


- Almost 4π
- Avg. 20 MHz
- Software trigger

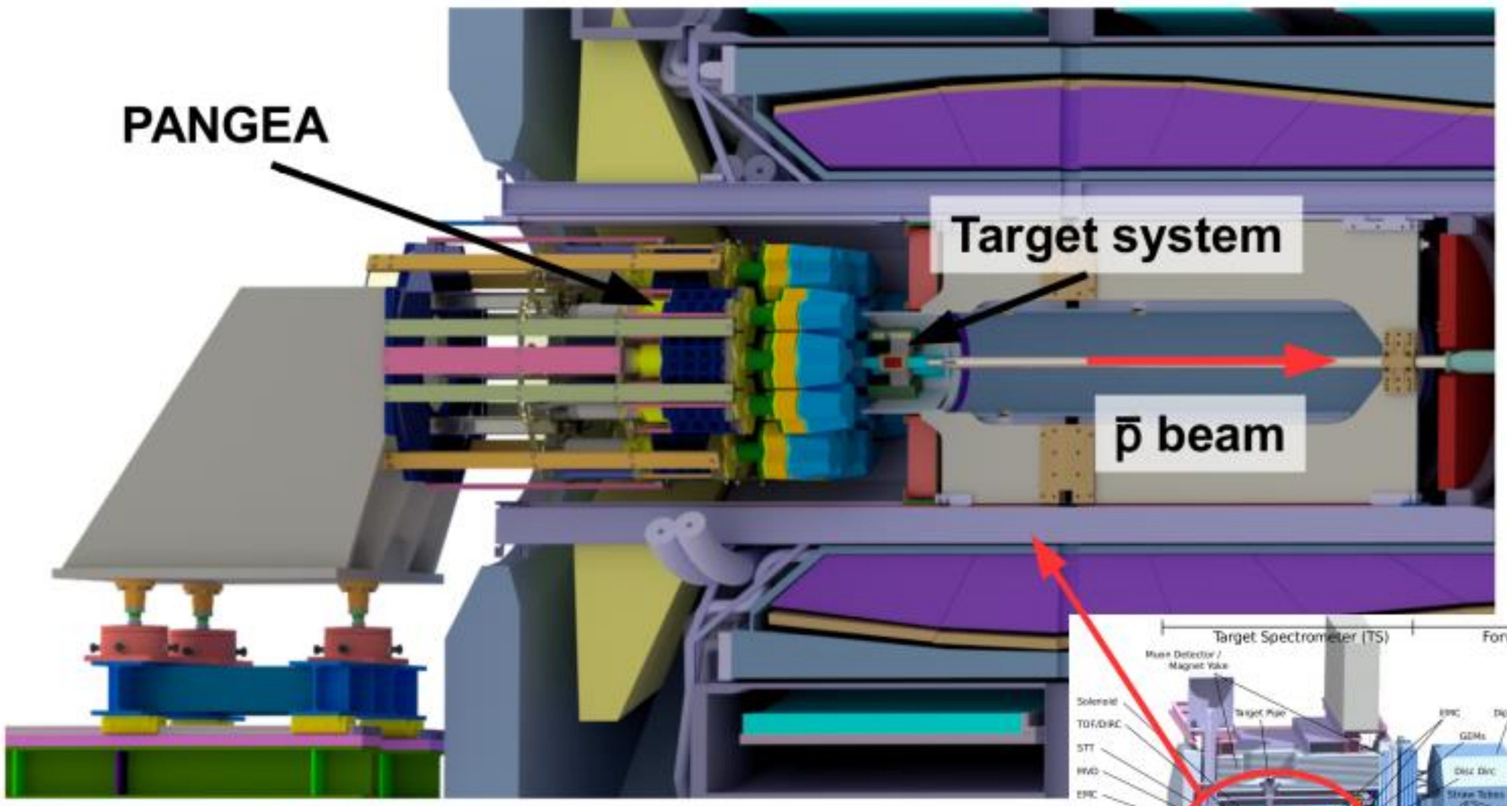
- High res. tracking + PID
- Vertex reconstr. for e.g. D, K^0_S, hyperons
- PWO calorimeter

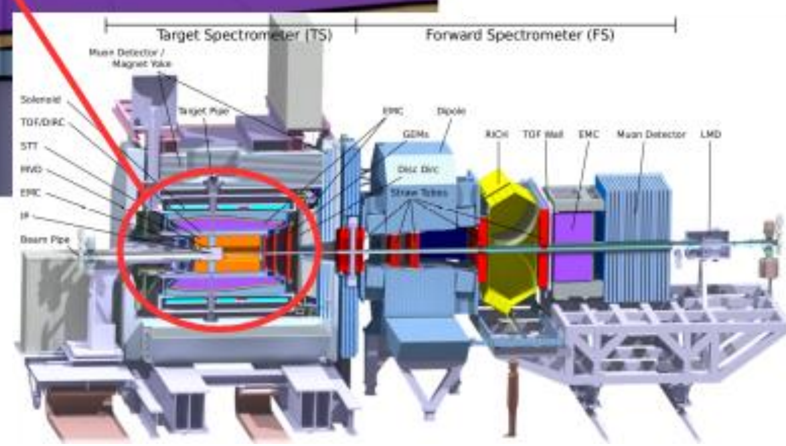
Production of hyperatoms/nuclei

- **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)



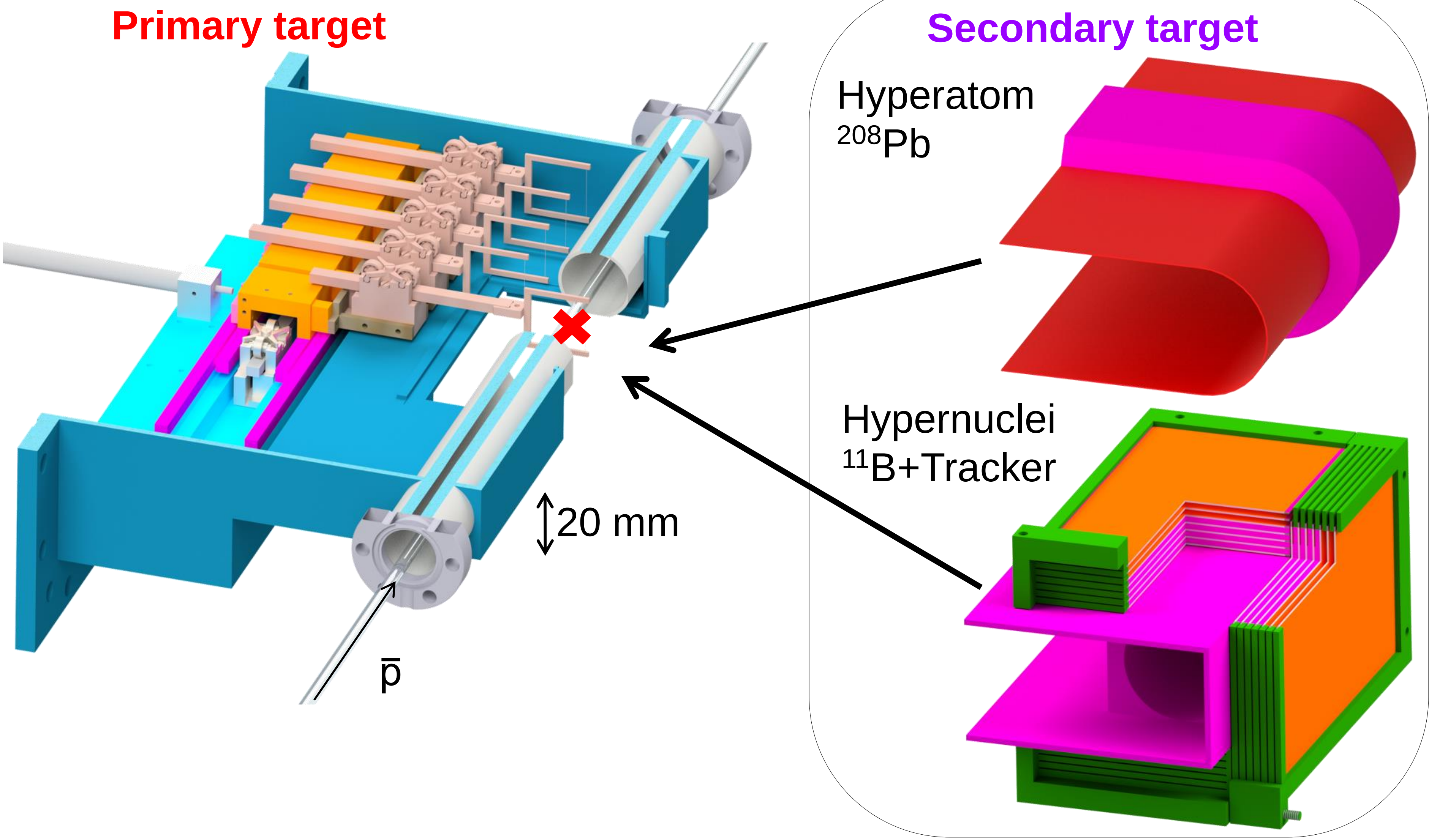
Hypernuclear/atom setup



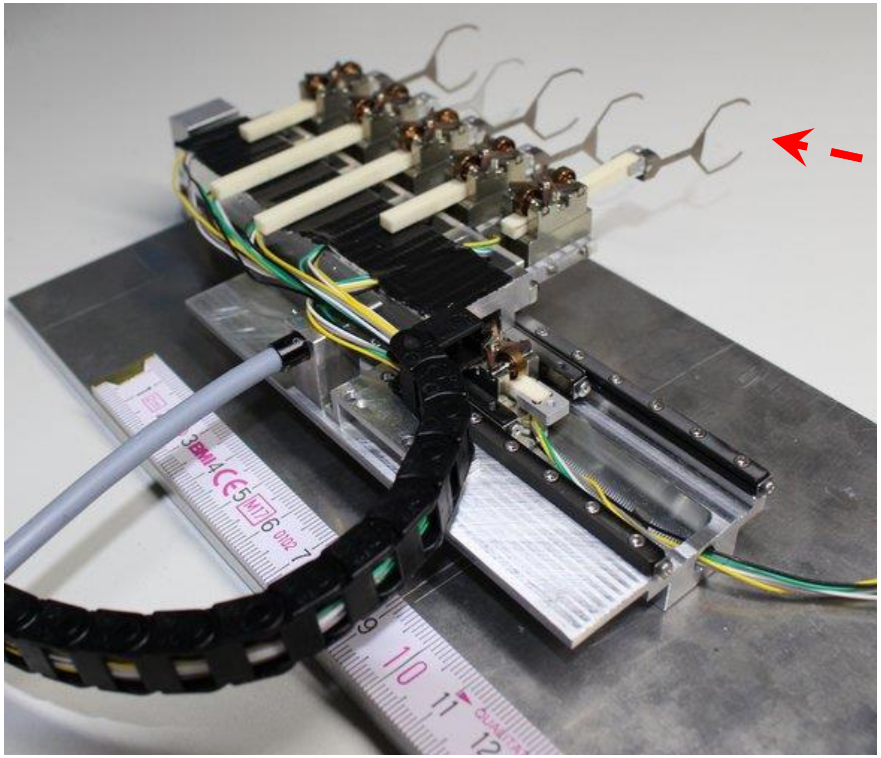


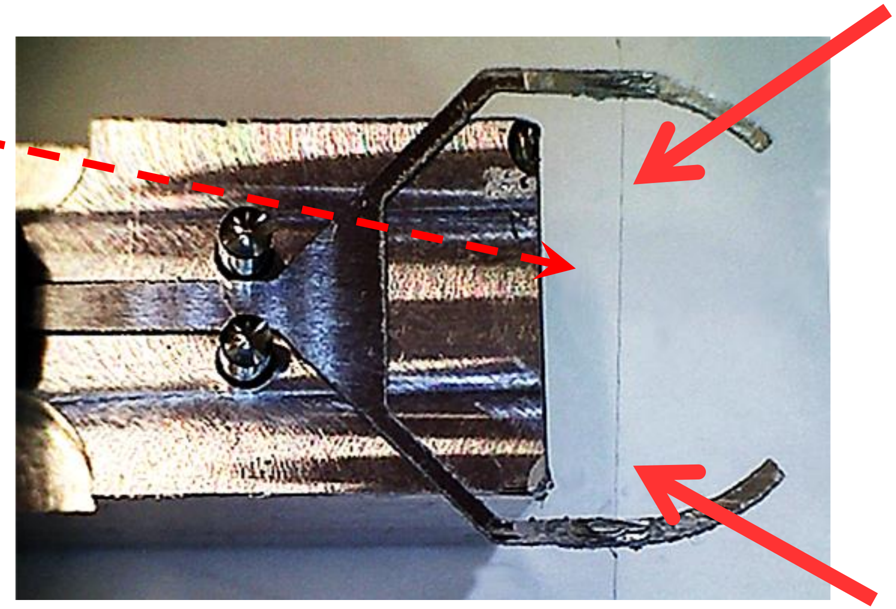
- Dedicated target system
- PANGEA

Target system



Primary target - Prototype



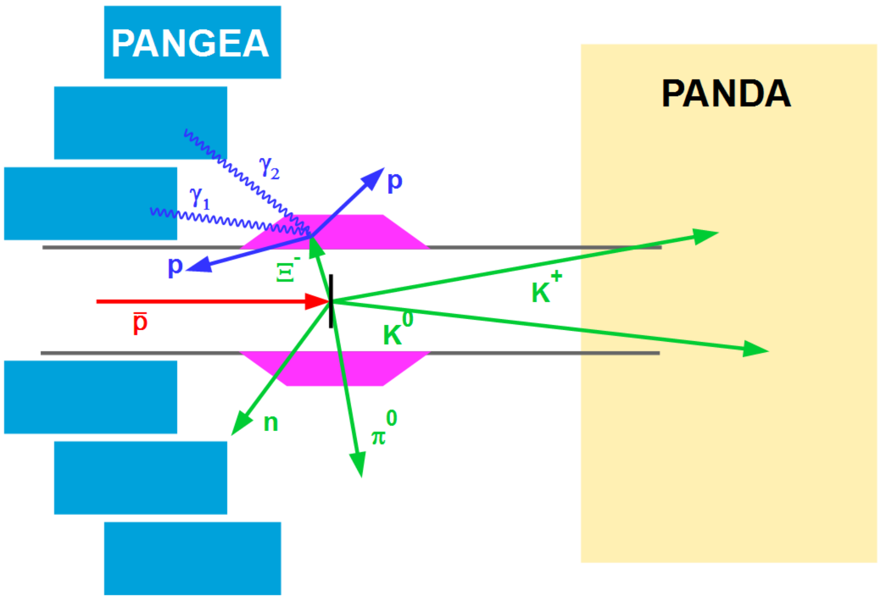


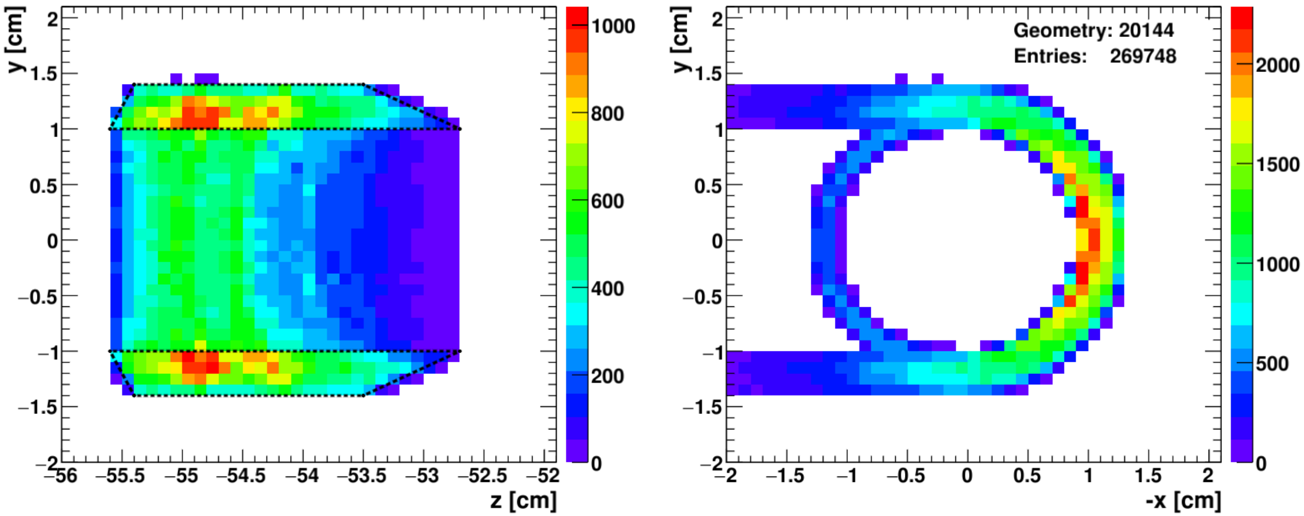
Carbon filament (r ~3µm)

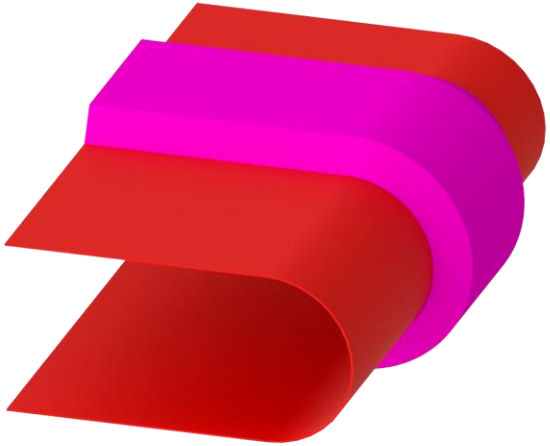
- 2D positioning system
  - Several targets
  - Steerable for constant luminosity
  - Small
  - UHV compatible, magnetic field and radiation hard

Secondary target optimization

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



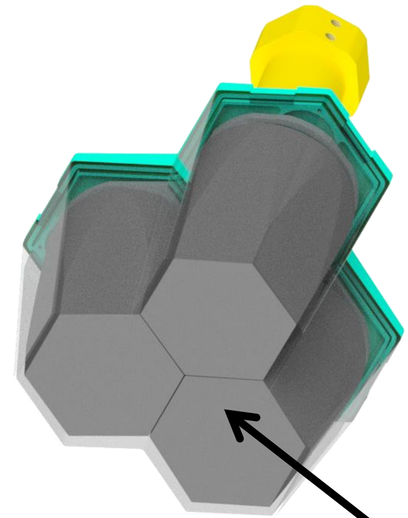


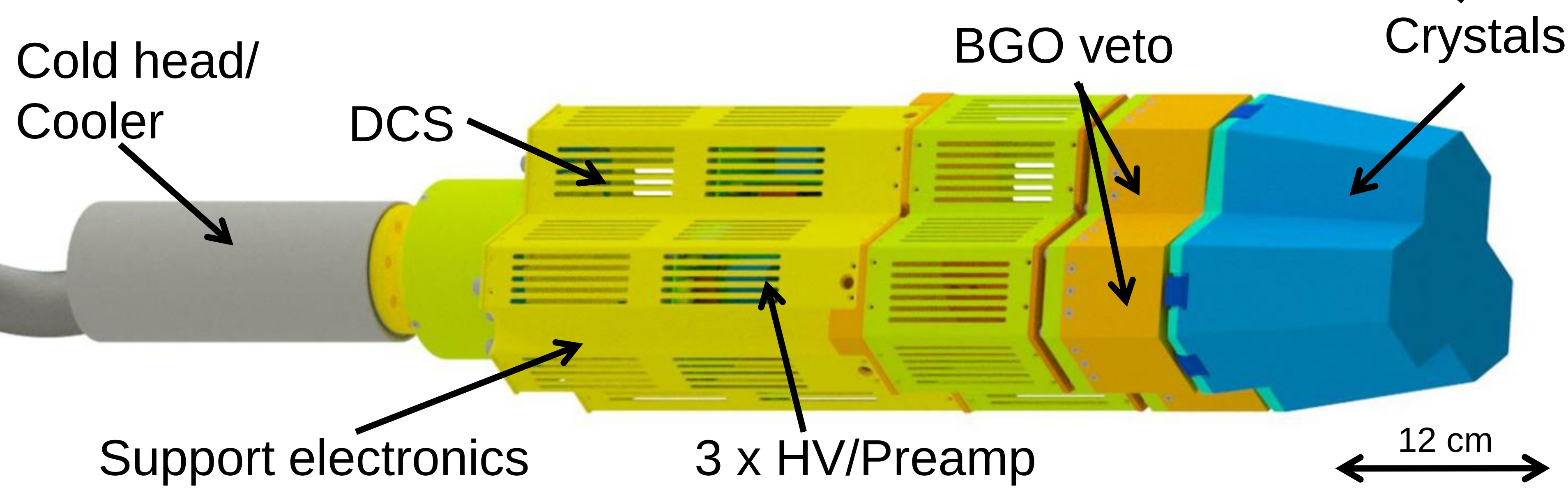


Based on events generated in GiBUU

PANda GErmanium Array

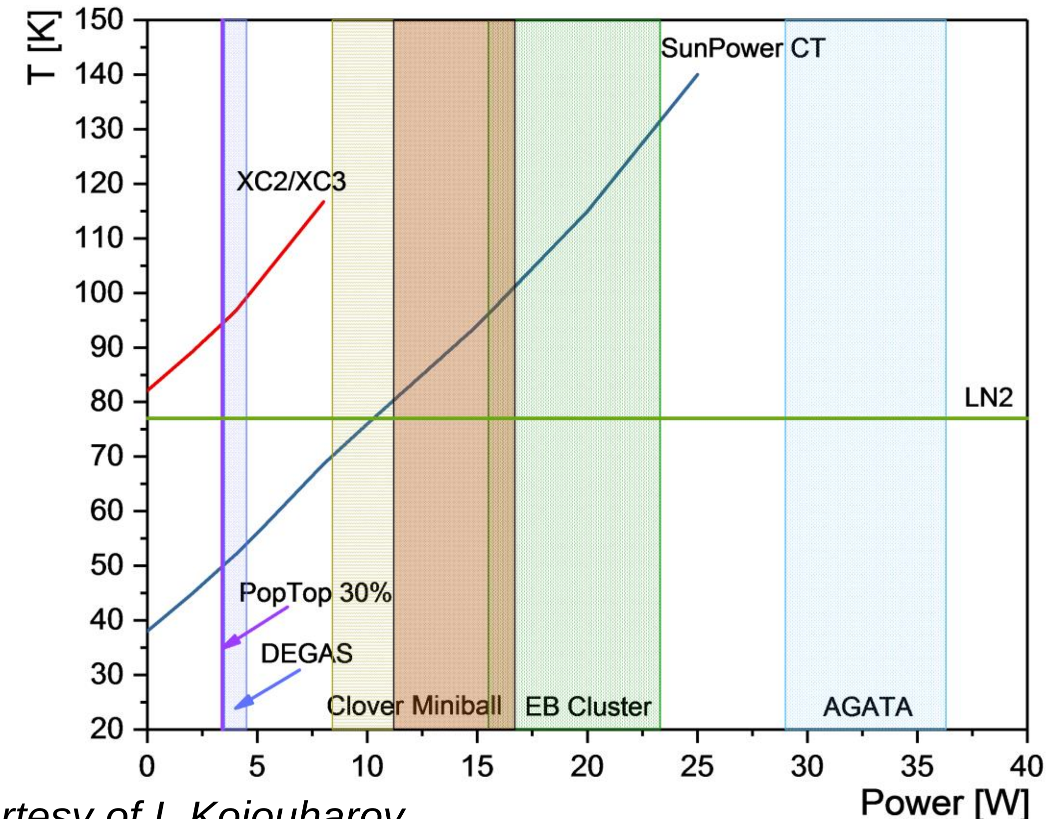
- Collaboration with NuSTAR (DEGAS)
- 20 triple HPGe detectors
- Full energy efficiency ~5 % @ ^{60}Co
- Electro-mechanical cooling (~LN2 temp.)
- BGO veto
- Fully integrated design



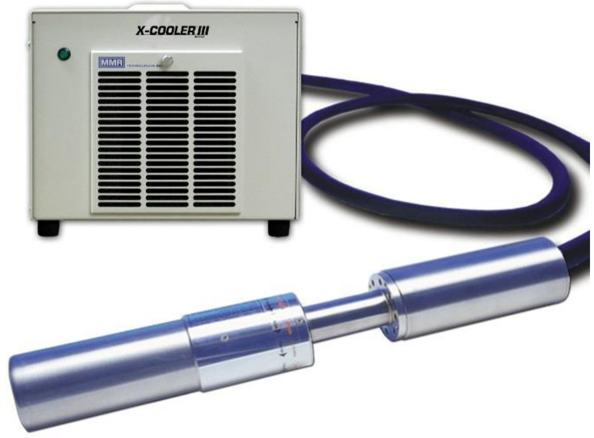


HIM HELMHOLTZ Helmholtz-Institut Mainz

PANGEA: Cooling

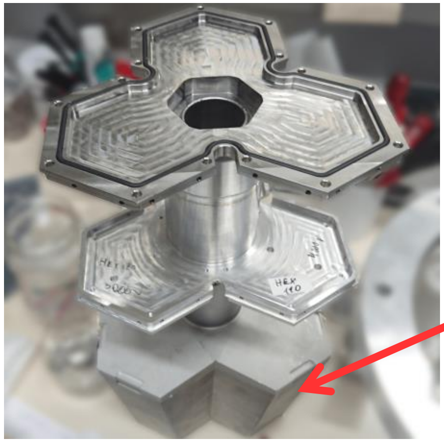


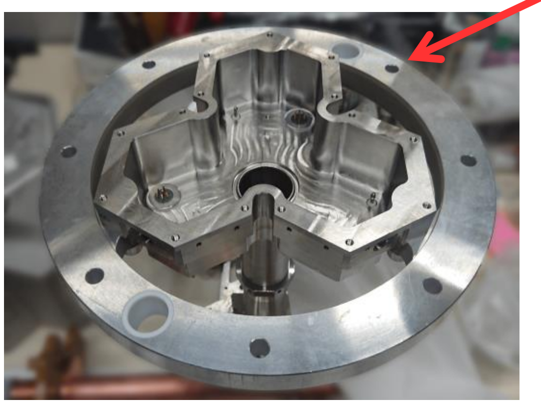
Courtesy of I. Kojouharov



- Improved thermal insulation
- X-Cooler II/III too weak

PANGEA - Prototype

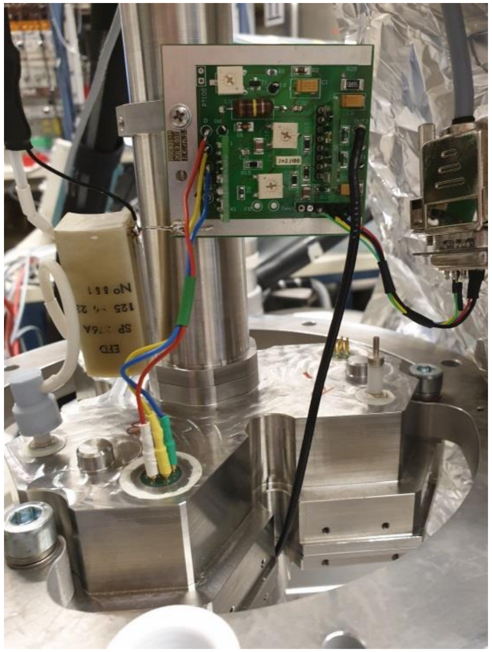




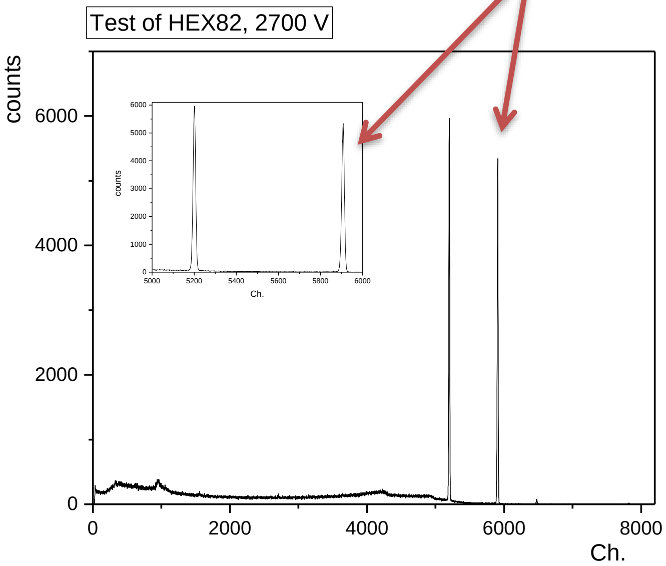
Courtesy of I. Kojouharov

PANGEA: First spectrum

Flying assembly with prototype of preamplifier



FWHM: 2.8 keV (^{60}Co)

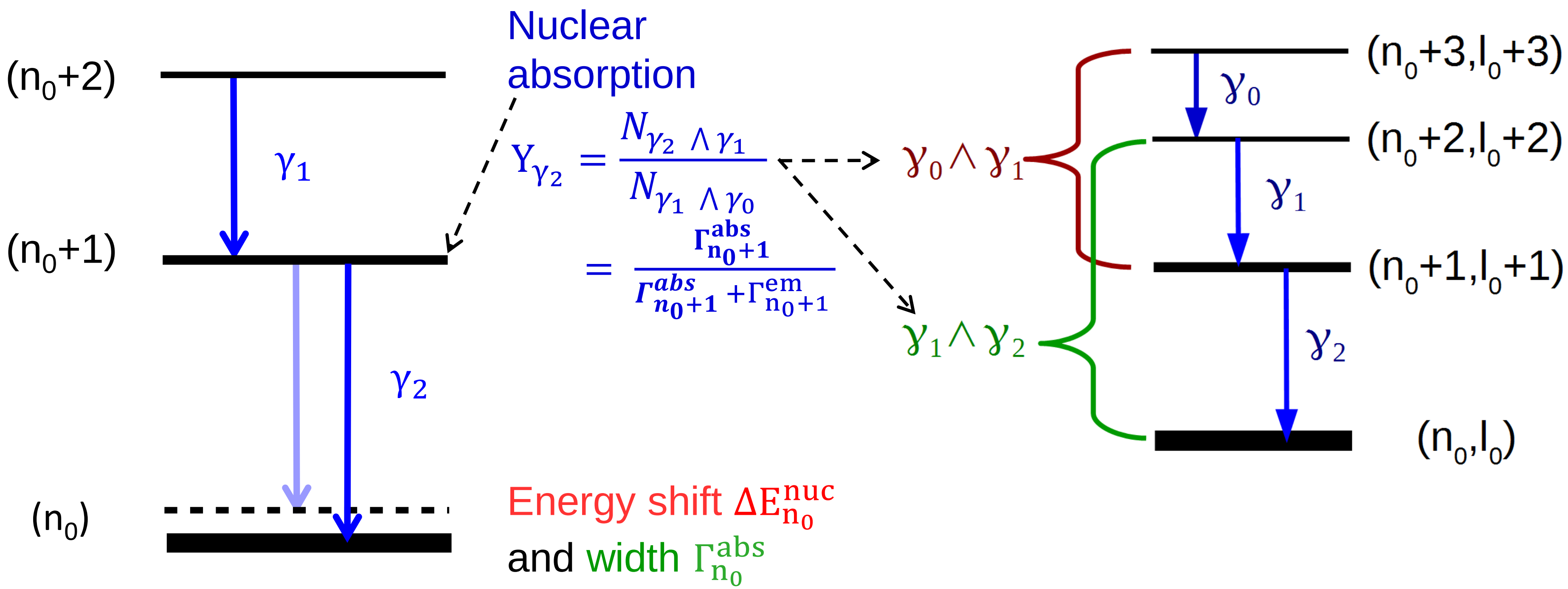


Too high temperatures prevented fully biasing!

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:

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

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

$b_0 = 0.25 + i0.04$

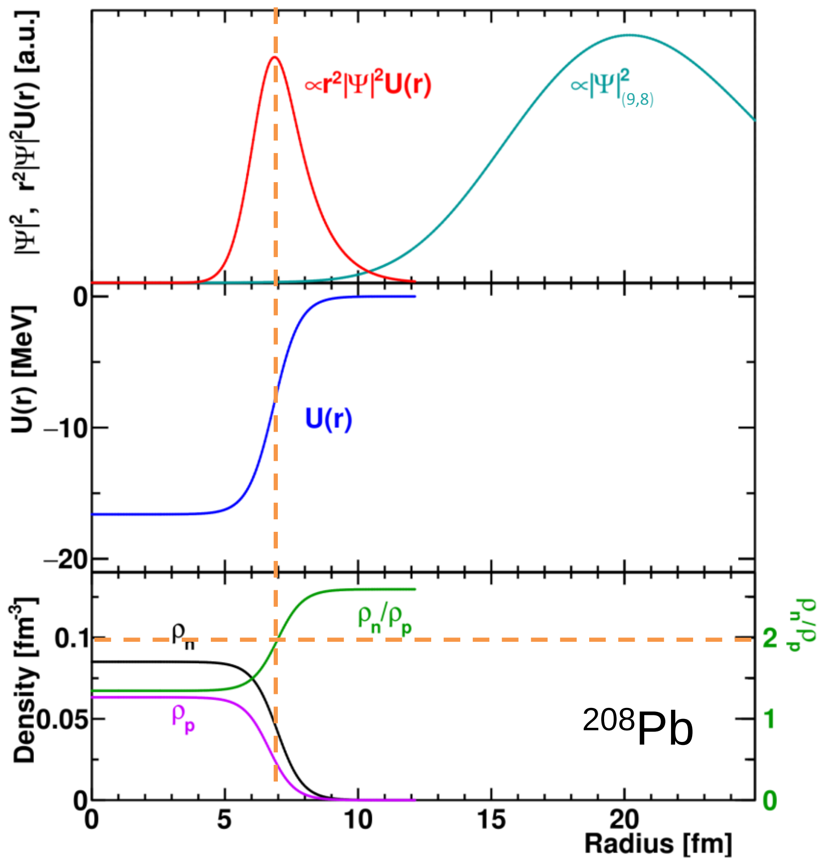
$a_n = a_p$

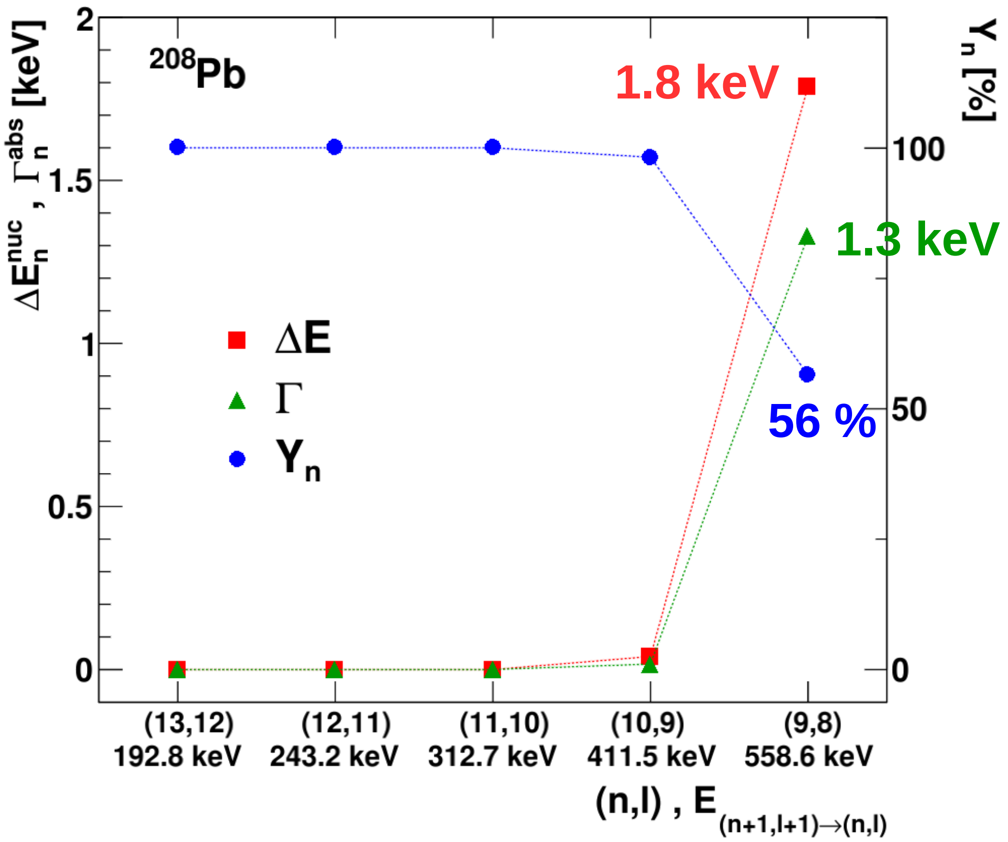
$c_{n,p}$ fixed by $R_{p,rms}$ and n skin

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

Schematic calculations to explore experimental sensitivity.

Ξ^- - ^{208}Pb

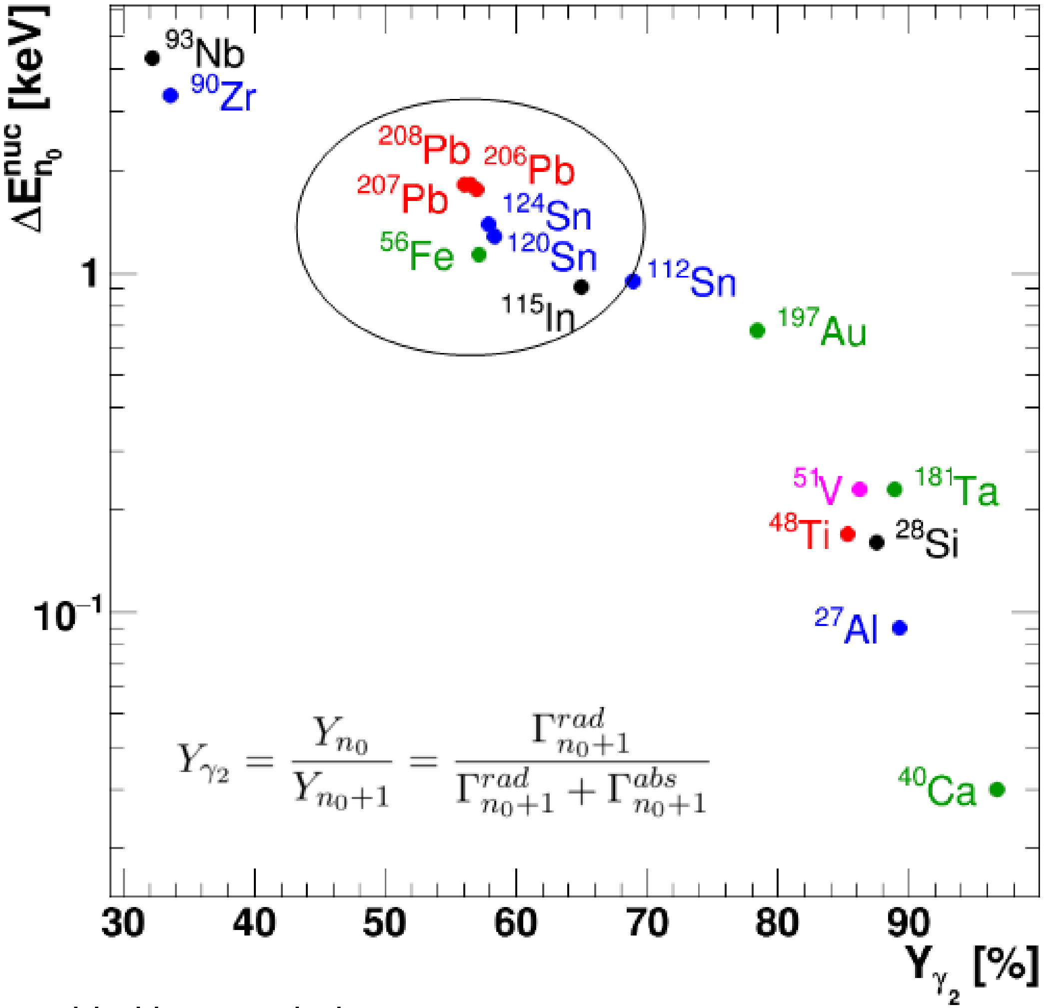




Calculations performed with code provided by E. Friedman

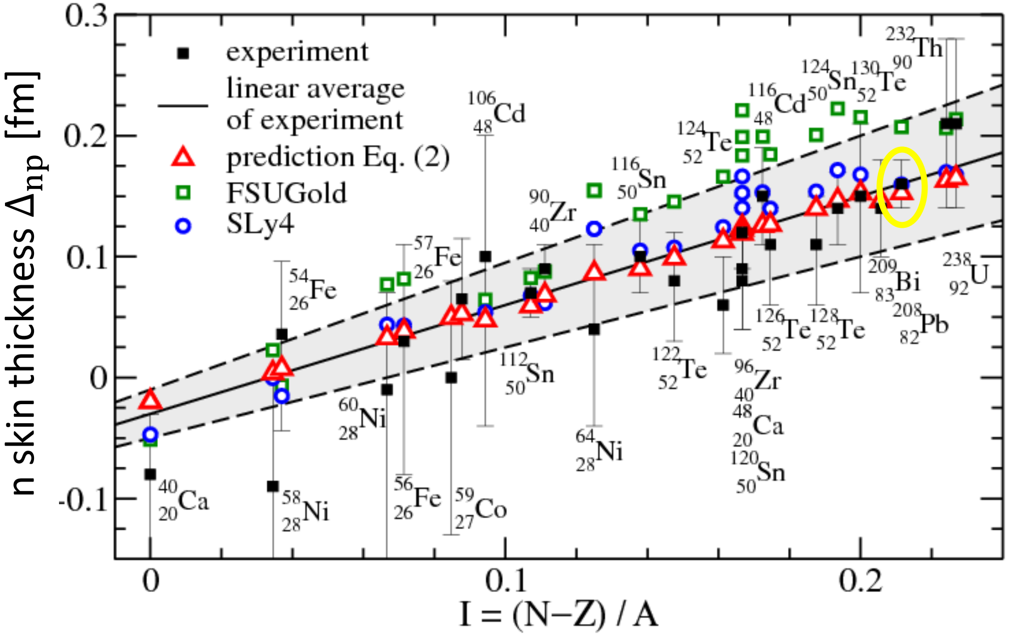
Possible targets

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

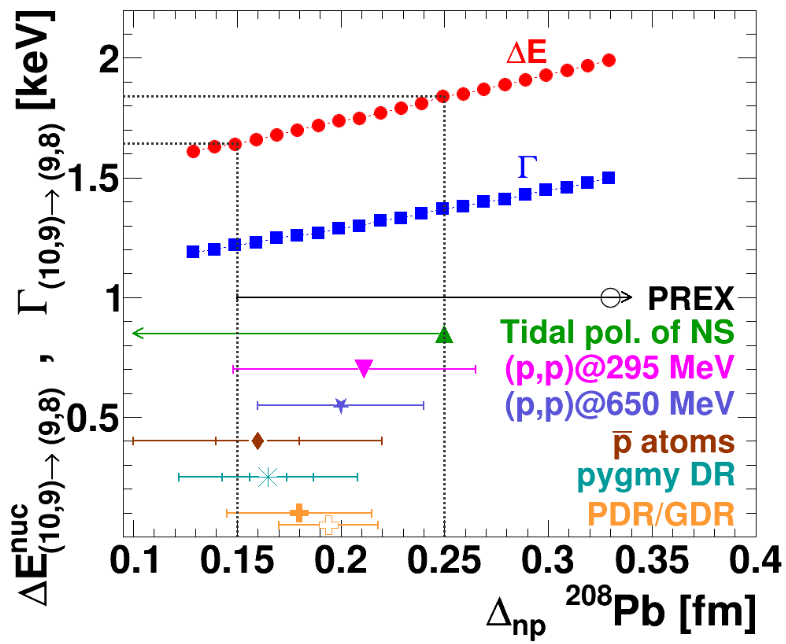


Calculations performed with code provided by E. Friedman

Systematic uncertainties

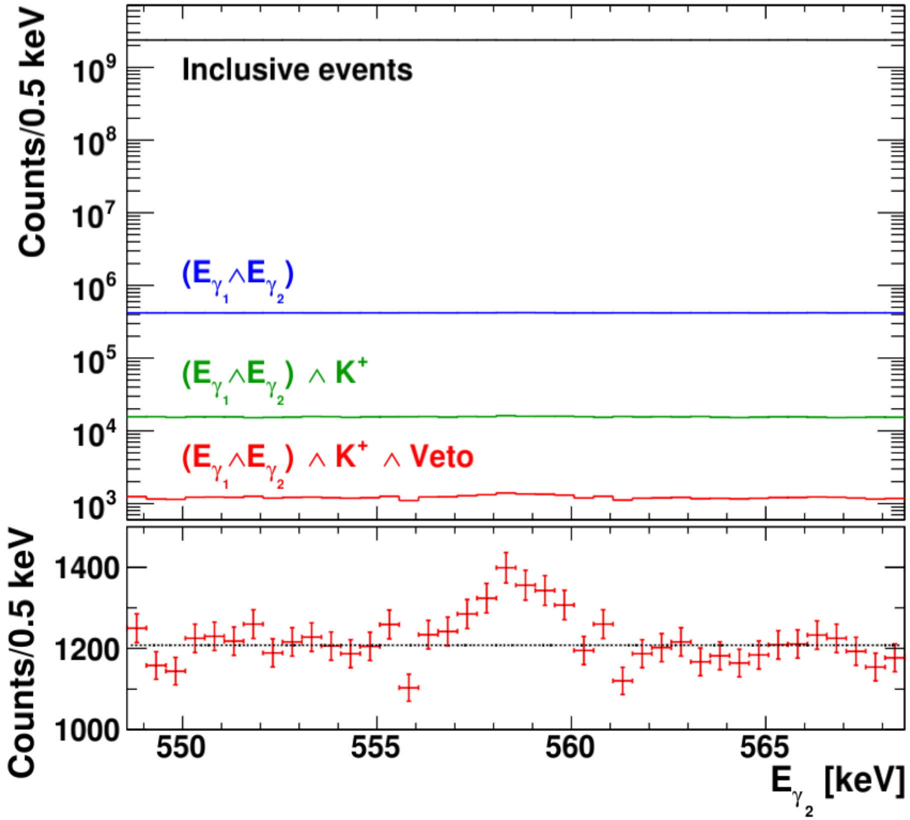


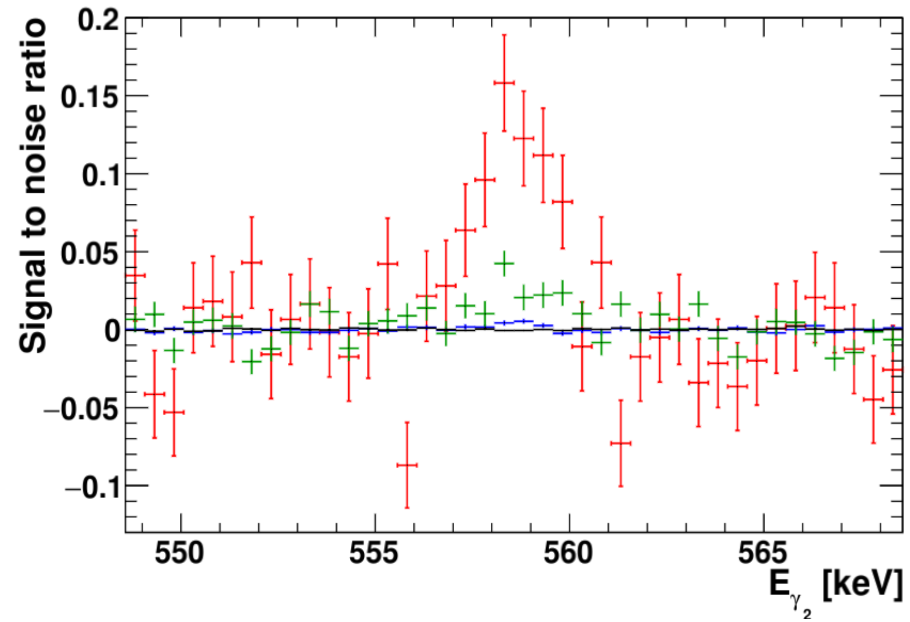
Centelles et al., Phys.Rev.Lett. 102 (2009) 122502

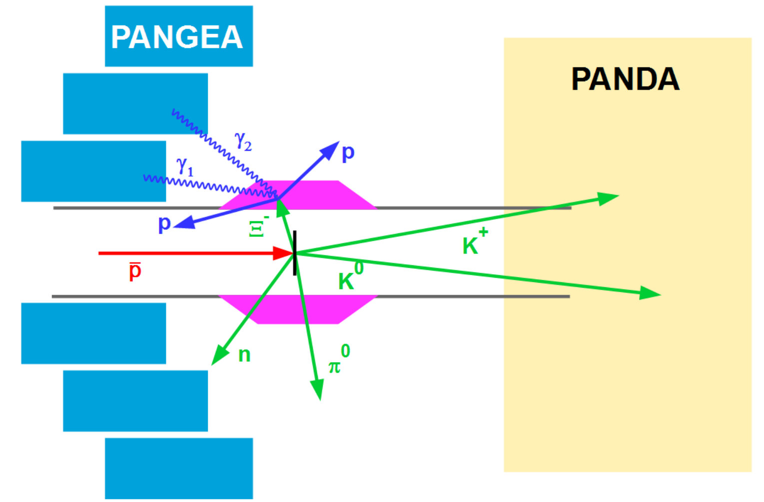


- Neutron skin Δ_{np} in ^{208}Pb well-established
- Present uncertainty of Δ_{np} -> Systematic uncertainty in observables
- $\boldsymbol{\delta\left(\Delta E^{nuc}_{(10,9)\rightarrow(9,8)}\right)_{sys}}$ **~ ± 100 eV**

Full simulation

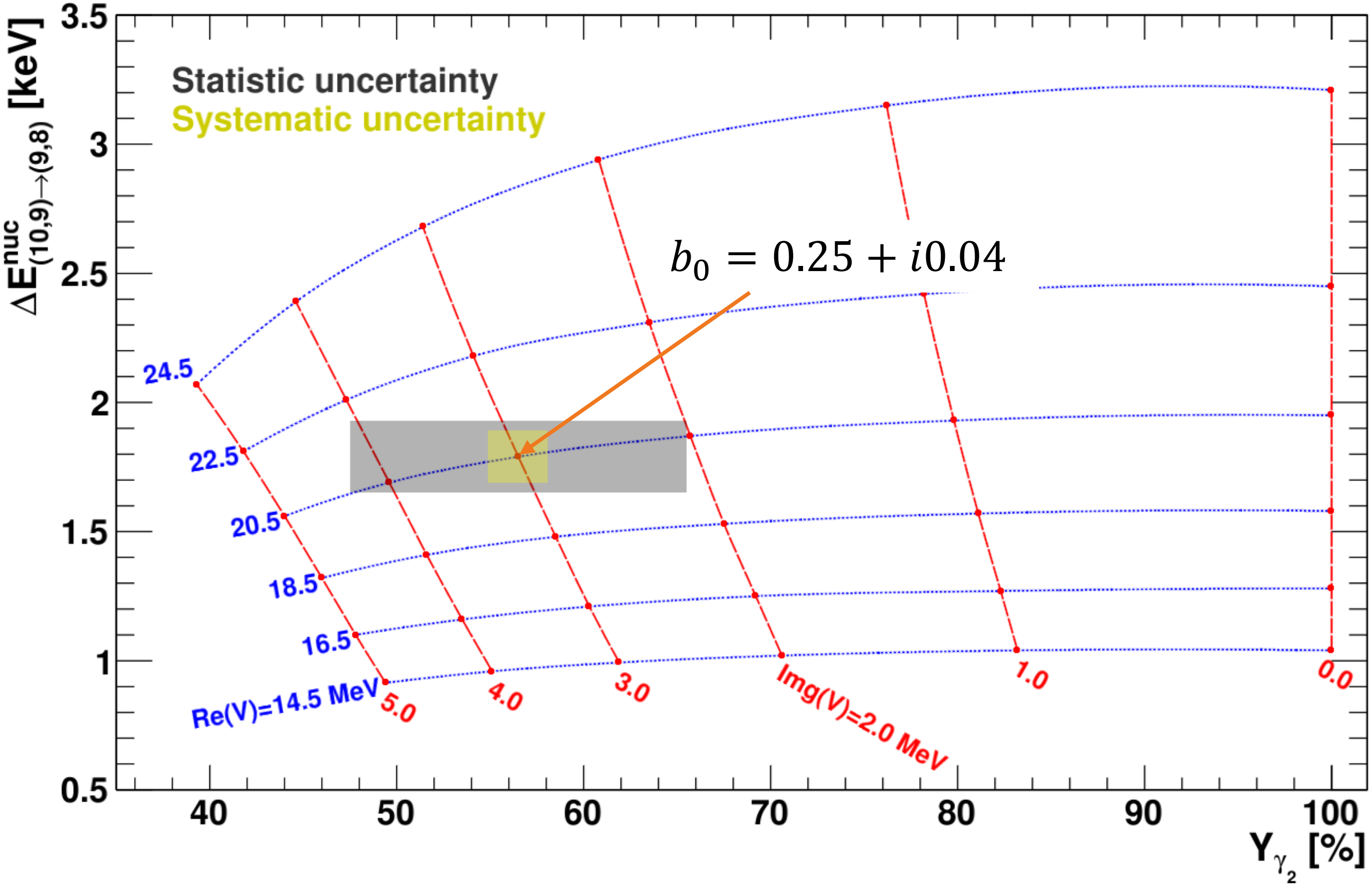






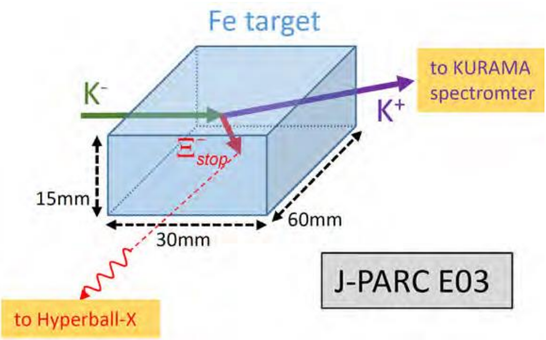
- Signals after cuts and efficiencies 1237
  - 180 days at 2 MHz $\bar{p}$C
- $\delta\left(\Delta E^{nuc}_{(10,9)\to(9,8)}\right)_{stat}$ = ± 140 eV

Estimation of V_Ξ

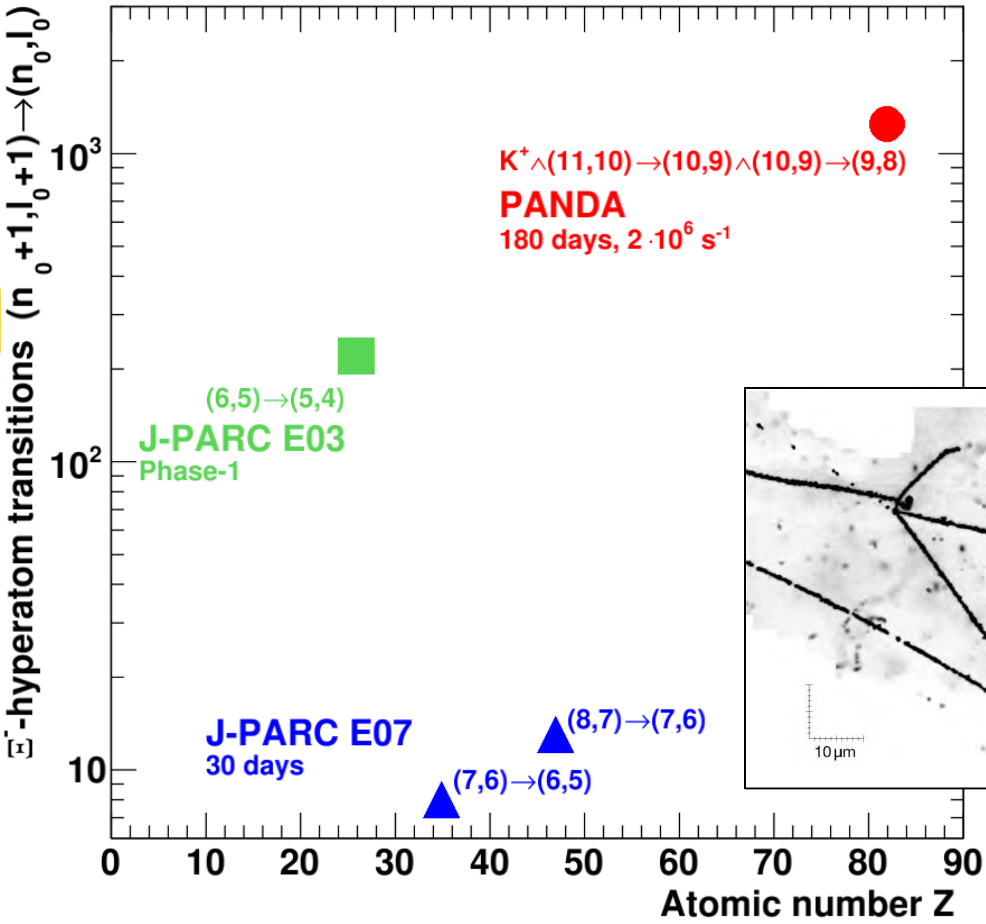


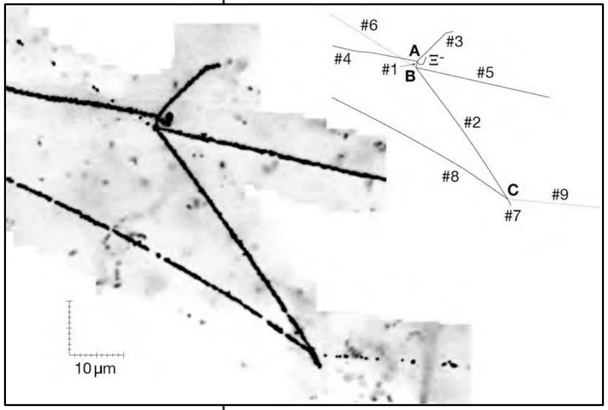
$$\boldsymbol{\delta(\mathrm{Re}(V_\Xi))_{stat} \approx \delta(\mathrm{Im}(V_\Xi))_{stat} \approx 1\ \mathrm{MeV}}$$

Complementary experiments



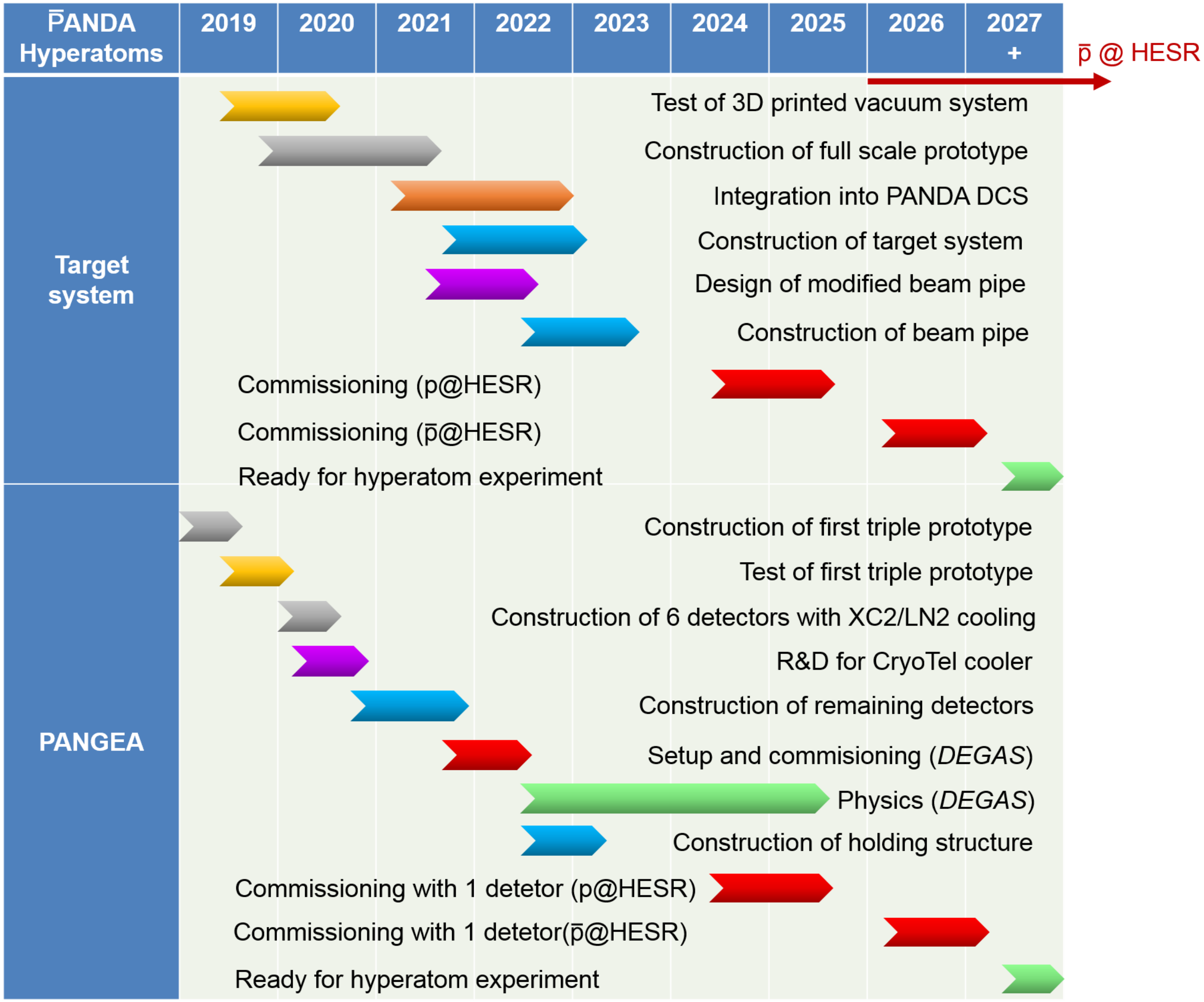
See talk before lunch
K. Tanida





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

Timeline



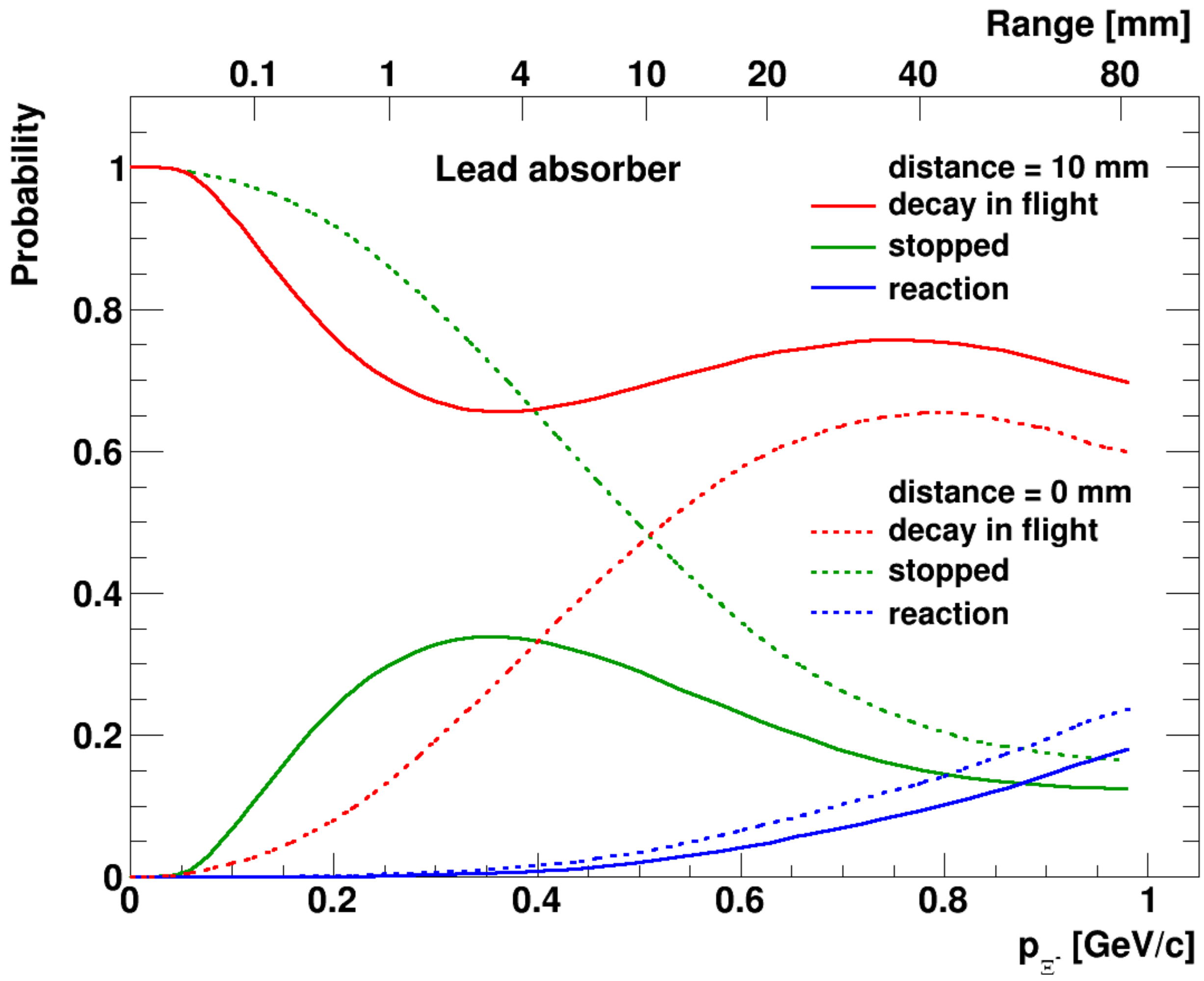
P̄ANDA Hyperatoms
2019
2020
2021
2022
2023
2024
2025
2026
2027 +
p̄ @ HESR
Target system
Test of 3D printed vacuum system
Construction of full scale prototype
Integration into PANDA DCS
Construction of target system
Design of modified beam pipe
Construction of beam pipe
Commissioning (p@HESR)
Commissioning (p̄@HESR)
Ready for hyperatom experiment
PANGEA
Construction of first triple prototype
Test of first triple prototype
Construction of 6 detectors with XC2/LN2 cooling
R&D for CryoTel cooler
Construction of remaining detectors
Setup and commisioning (*DEGAS*)
Physics (*DEGAS*)
Construction of holding structure
Commissioning with 1 detetor (p@HESR)
Commissioning with 1 detetor(p̄@HESR)
Ready for hyperatom experiment

Take-home message

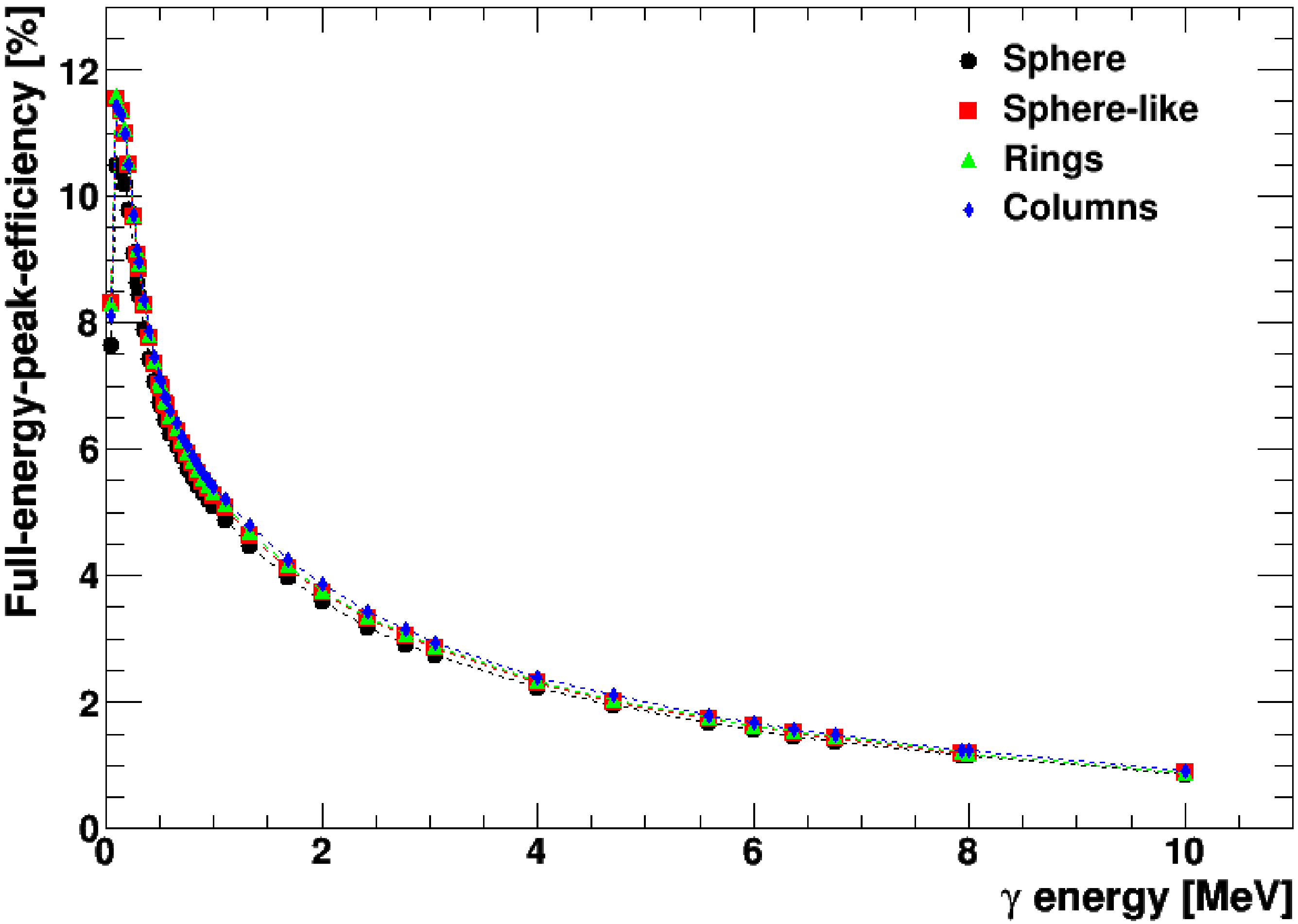
- $\bar{P}$ANDA@FAIR is a versatile experiment with a broad physics program
- Strangeness nuclear physics is an important pillar of $\bar{P}$ANDA
- Heavy hyperatoms unique for $\bar{P}$ANDA, complementary to J-PARC E03/07

Backup Slides

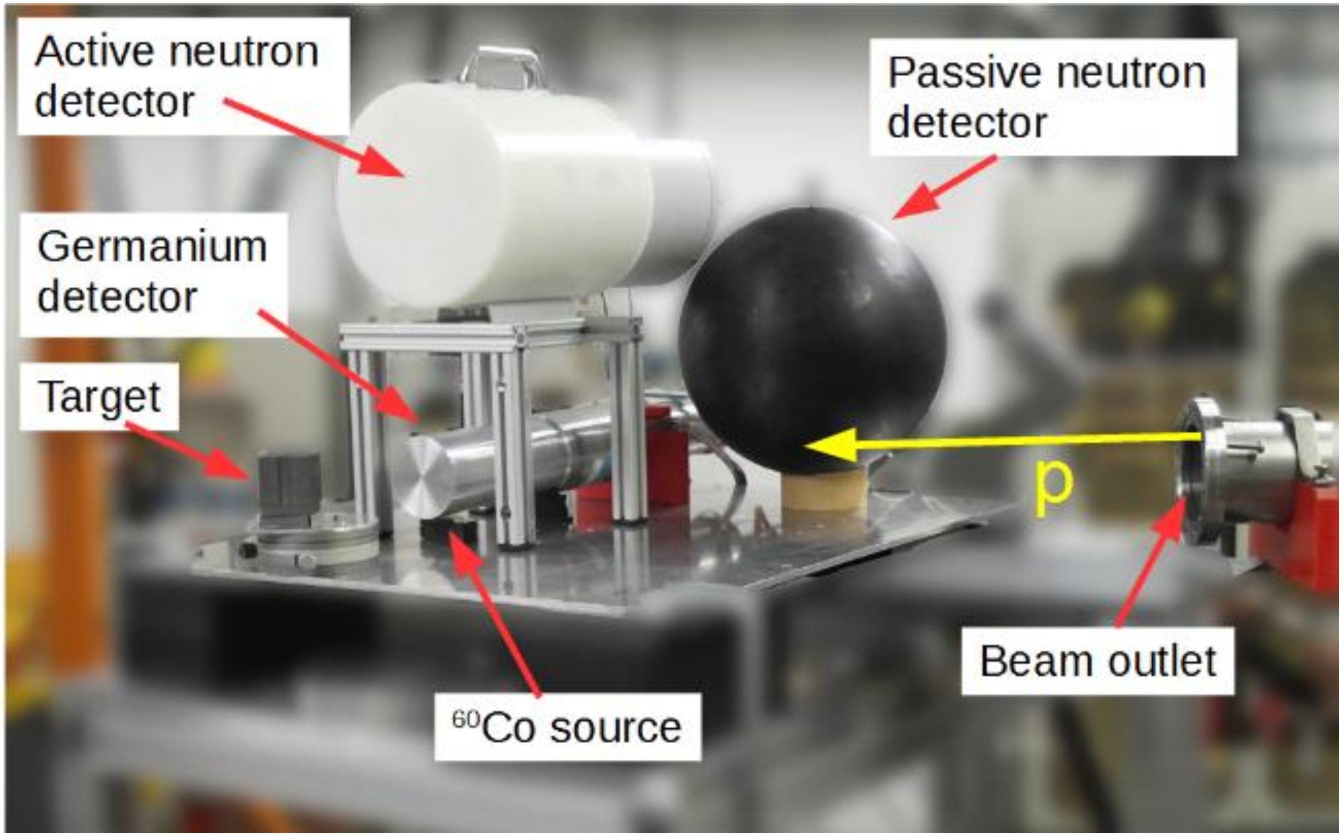
Stopping of secondary Ξ^-



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)