Studies of light hypernuclei with the WASA-FRS, nuclear emulsions and machine learning

Take R. Saito

High Energy Nuclear Physics Laboratory,

Cluster for Pioneering Research,

RIKEN,

Japan

HRS-HYS Research Group
(High ReSolution - HYpernuclear Spectroscopy),

FRS/NUSTAR department,

GSI Helmholtz Center for Heavy Ion Research,

Germany

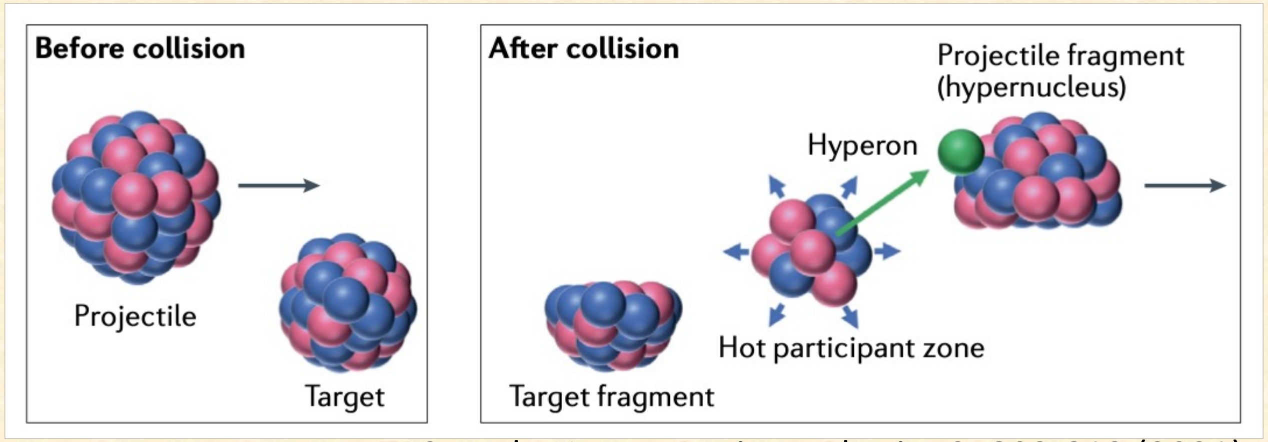
EMMI workshop "Meson and Hyperon interactions with nuclei
Sept 14th – 16th, 2022, Kitzbühel, Austria

RIKEN

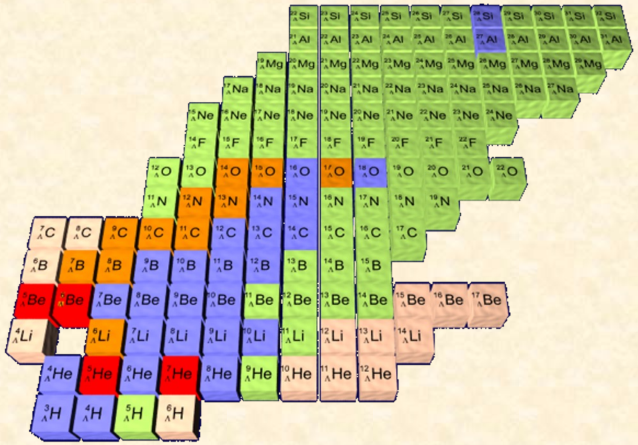
HENP
High Energy Nuclear Physics

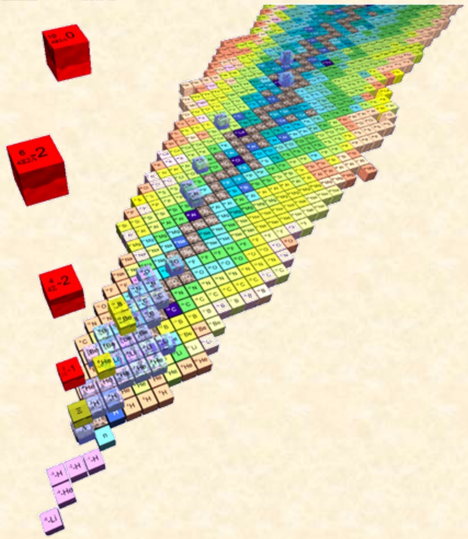
GSI

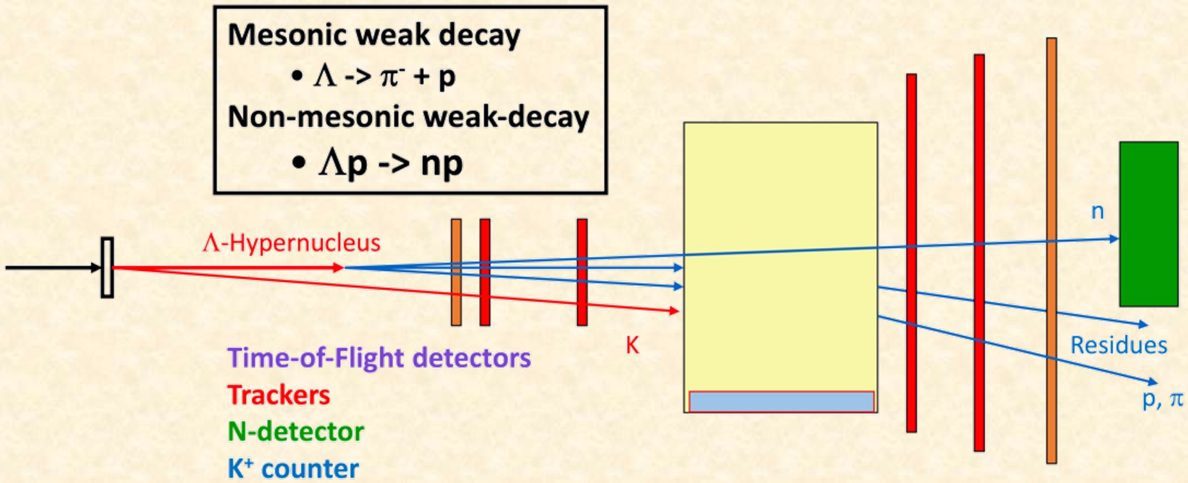
Hypernuclear production with HypHI



TRS et al., Nature Reviews Physics 3, 803-813 (2021)

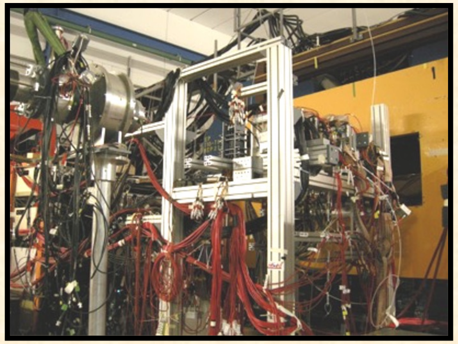


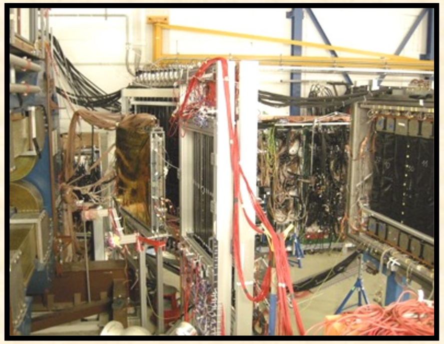


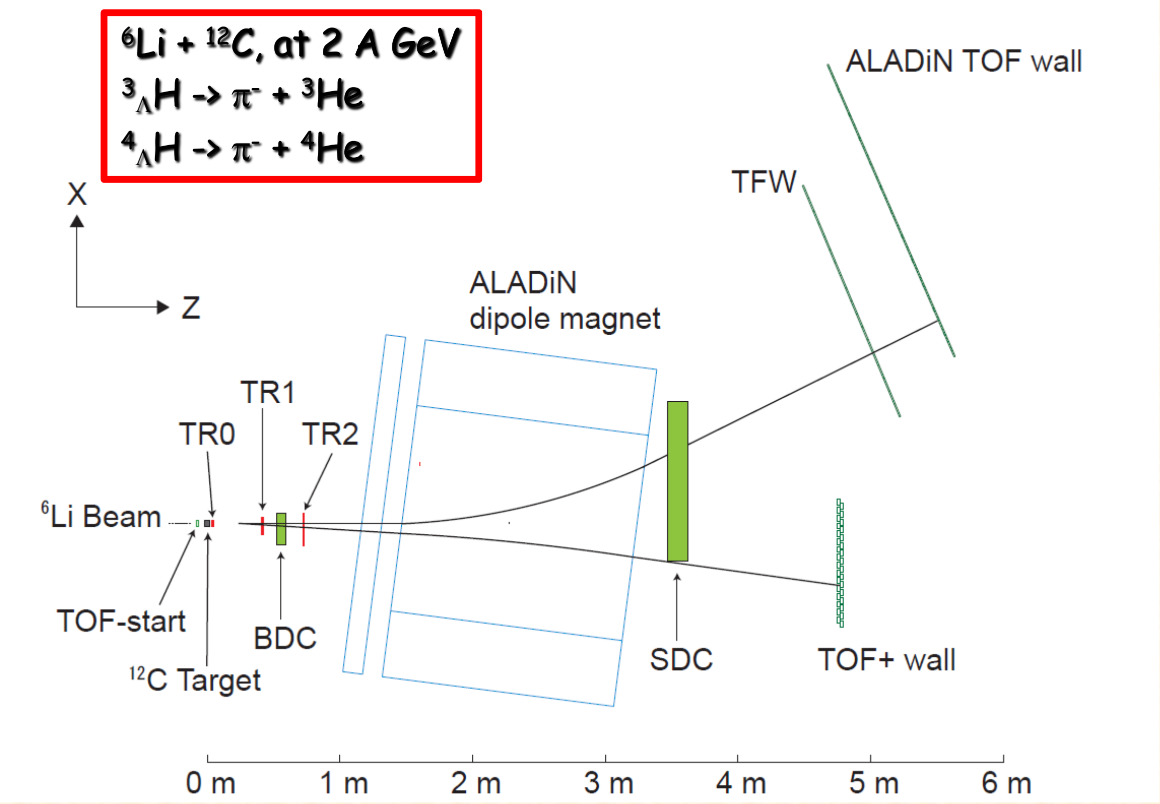


Pioneering experiment: HypHI Phase 0 (2009)

- To demonstrate the feasibility of precise hypernuclear spectroscopy with ^{6}Li primary beams at 2 A GeV on a carbon target







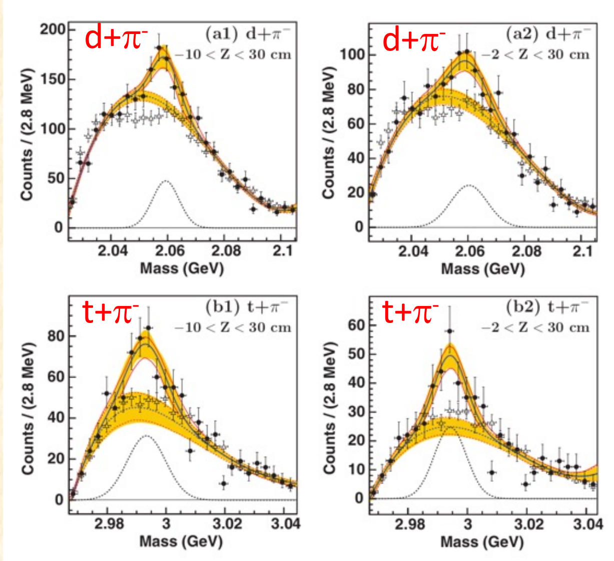
Two puzzles initiated by HypHI

Signals indicating nnΛ bound state

<u>All theoretical calculations show negative results</u>

- E. Hiyama et al., Phys. Rev. C89 (2014) 061302(R)
- A. Gal et al., Phys. Lett. B736 (2014) 93
- H. Garcilazo et al., Phys. Rev. C89 (2014) 057001

and much more publication

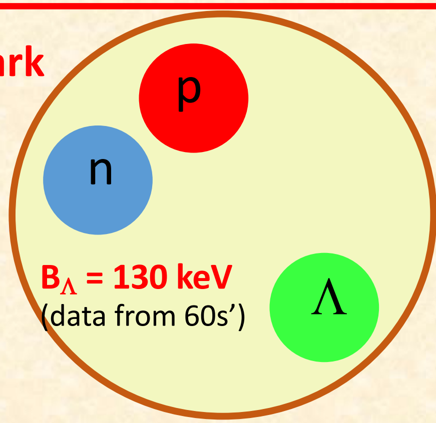


C. Rappold et al., PRC 88 (2013) 041001

Short lifetime of $^{3}_{\Lambda}H$ C. Rappold et al., Nucl. Phys. A 913 (2013) 170

- HypHI Phase 0: 183^{+42}_{-32} ps

Benchmark



$\tau(^{3}_{\Lambda}H)$ should be equal to $\tau(\Lambda$, 263 ps)

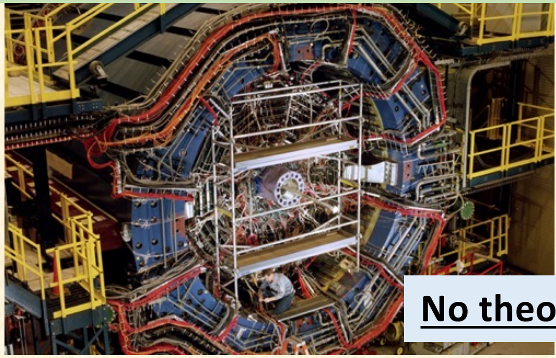
Lifetime of hypertriton

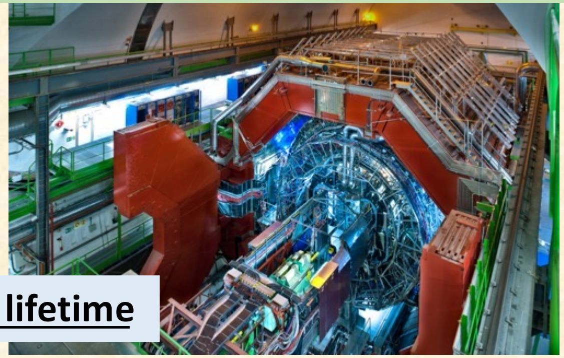
STAR at RHIC

ALICE at LHC

Hot topics in nuclear experiments:
STAR, ALICE, J-PARC, ELPH, HADES and WASA-FRS

We would provide one data point with very small errors





No theories to reproduce the short lifetime

STAR: 155^{+25}_{-22} ps

↓

142^{+24}_{-21} ps

↓

221±15 ps PRL 128 (2022) 202301

HypHI
183^{+42}_{-32} ps

ALICE: 181^{+54}_{-39} ps

↓

237^{+34}_{-38} ps

PLB 128 (2019) 134905

Binding energy of hypertriton

NATURE PHYSICS | VOL 16 | APRIL 2020 | 409–412 | www.nature.com/naturephysics

nature physics

LETTERS

https://doi.org/10.1038/s41567-020-0799-7

Check for updates

Measurement of the mass difference and the binding energy of the hypertriton and antihypertriton

The STAR Collaboration*

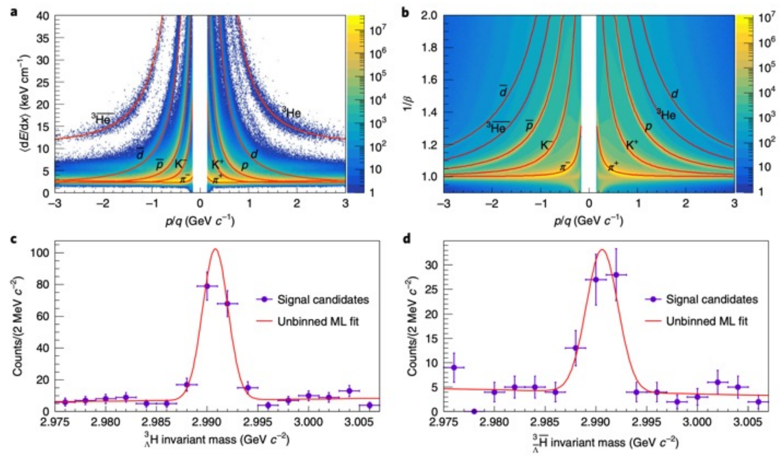


Fig. 2 | Particle identification and the invariant mass distributions for ${}^3_\Lambda$H and ${}^3_{\bar\Lambda}\overline{\mathrm{H}}$ reconstruction. a,b, ⟨d*E*/d*x*⟩ (mean energy loss per unit track length in the gas of the TPC) versus *p*/*q* (where *p* is the momentum and *q* is the electric charge in units of the elementary charge *e*) (**a**) and 1/*β* (where *β* is the speed of a particle in units of the speed of light) versus *p*/*q* (**b**). ⟨d*E*/d*x*⟩ is measured by the TPC and 1/*β* is measured by the TOF detector in conjunction with the TPC. In both cases, the coloured bands show the measured data for each species of charged particle, while the red curves show the expected values. Charged particles are identified by comparing the observed ⟨d*E*/d*x*⟩ and 1/*β* with the expected values. **c,d**, Utilizing both 2-body and 3-body decay channels, the invariant mass distributions of ${}^3_\Lambda$H (**c**) and ${}^3_{\bar\Lambda}\overline{\mathrm{H}}$ (**d**) are shown. The error bars represent statistical uncertainties (s.d.). The red curves represent a fit with a Gaussian function plus a linear background, using the unbinned maximum likelihood (ML) method.

The Λ binding energy, B_Λ, for ${}^3_\Lambda$H and ${}^3_{\bar\Lambda}\overline{\mathrm{H}}$ is calculated using the mass measurement shown in equation (1). We obtain

$$B_\Lambda = 0.41 \pm 0.12(\mathrm{stat.}) \pm 0.11(\mathrm{syst.})\ \mathrm{MeV} \quad (3)$$

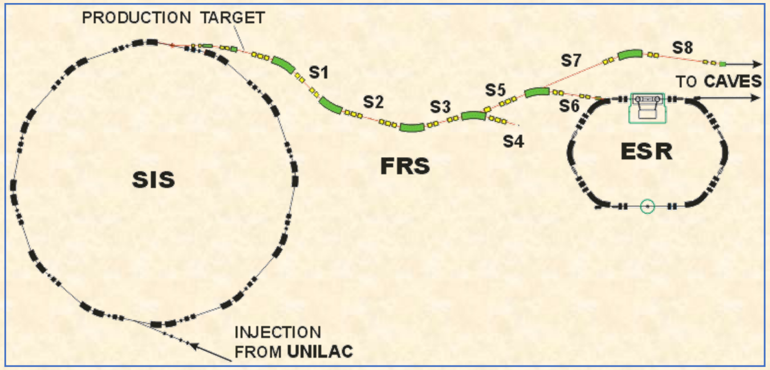
average value of 0.13 ± 0.05(stat.) MeV. When applied to our value of 0.41 ± 0.12(stat.) MeV it yields a significantly smaller value of $7.90^{+1.71}_{-0.93}$ fm. The larger B_Λ and shorter effective scattering length suggest a stronger YN interaction between the Λ and the relatively low-density nuclear core of the ${}^3_\Lambda$H (ref. [36]). This, in certain models, requires SU(3) symmetry breaking and a more repulsive YN interaction at high density, consistent with implications from the range of masses observed for neutron stars[5].

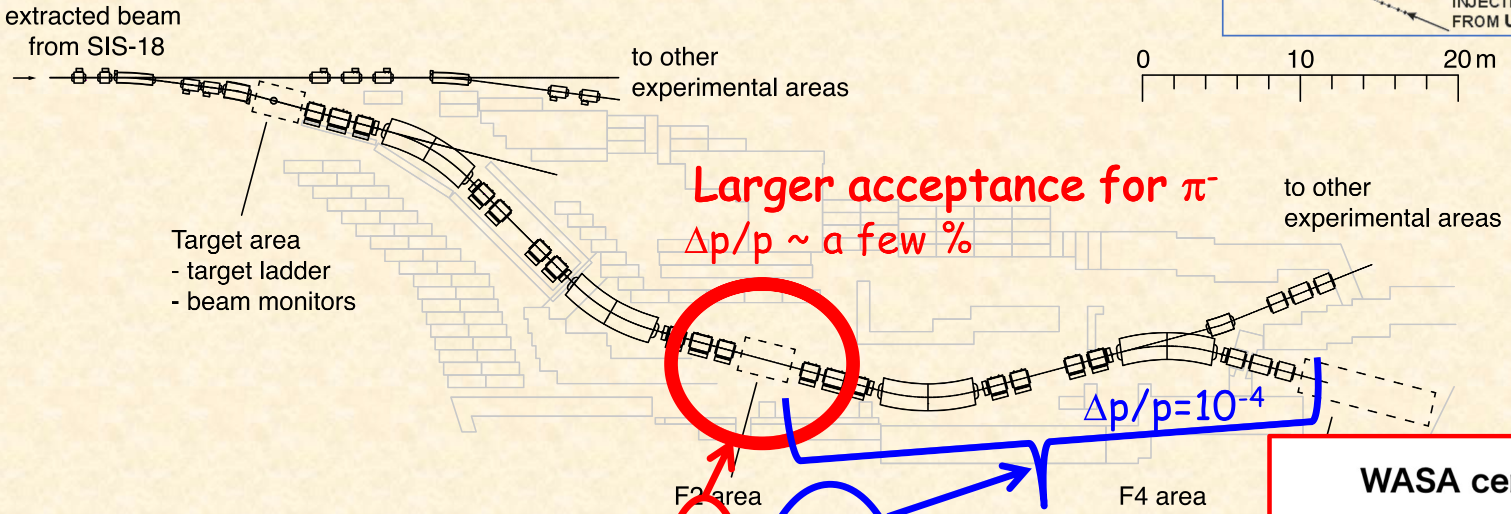
Former value by emulsion (data from 60's)

0.13 ± 0.05 MeV

Our challenges on the hypertriton lifetime

The novel technique with FRS at GSI



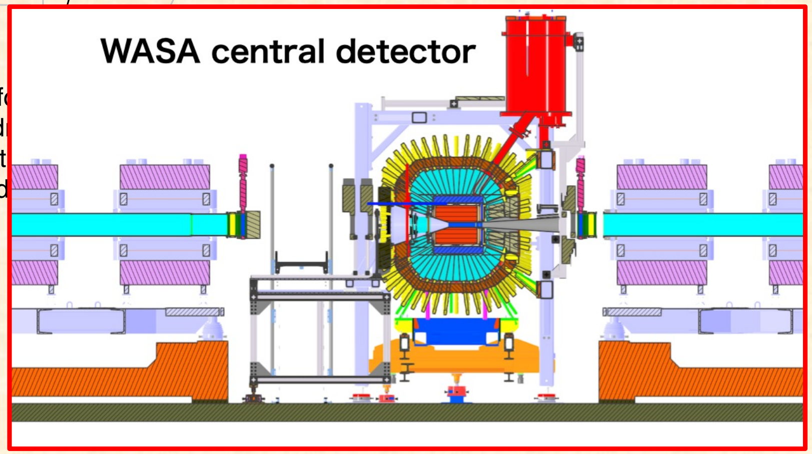


$^{3}_{\Lambda}H \rightarrow \pi^- + {}^{3}He$

$^{4}_{\Lambda}H \rightarrow \pi^- + {}^{4}He$

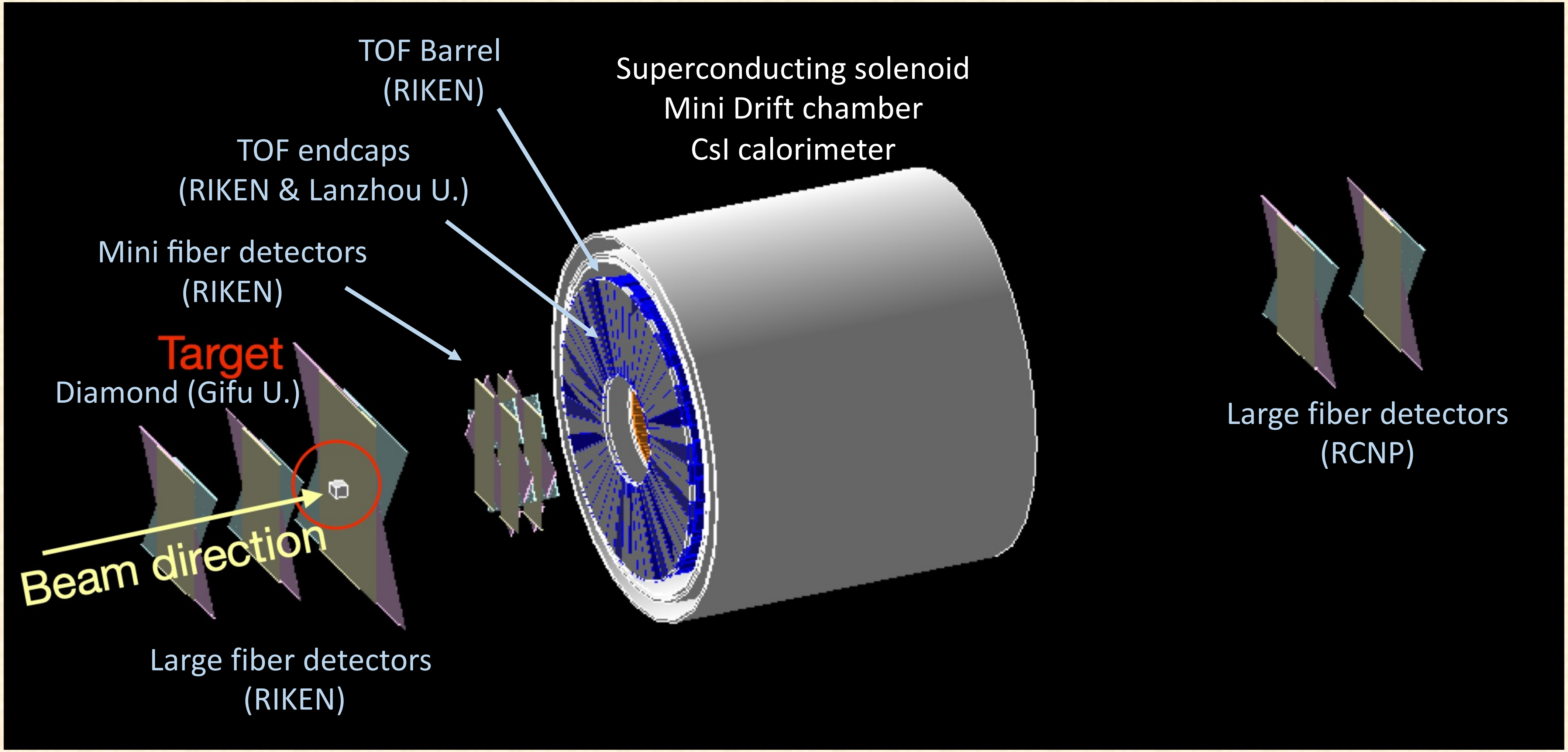
$nn\Lambda \rightarrow \pi^- + d + n$

With $^{6}Li+^{12}C$ at 2 A GeV



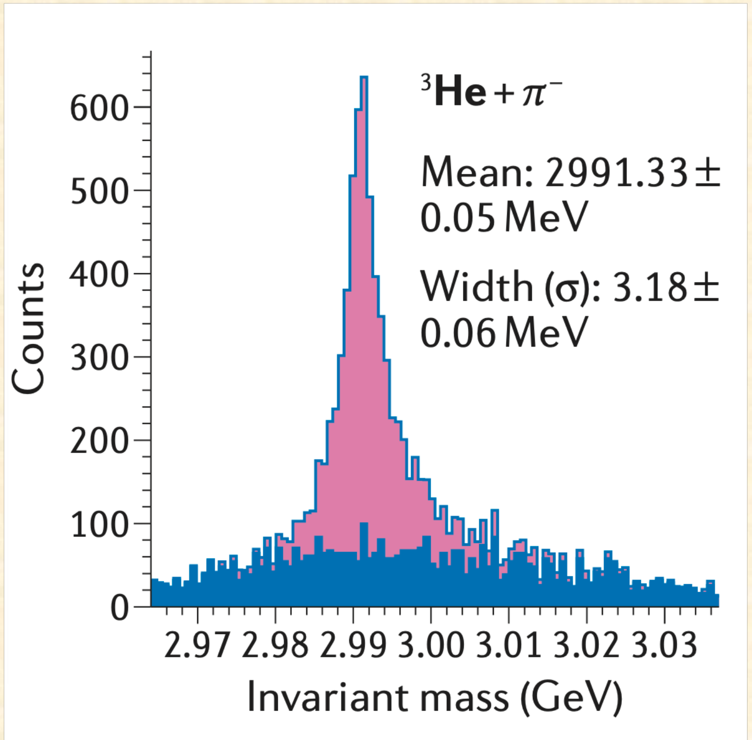
March 2019: WASA moved from Juelich to GSI

The WASA-FRS experiment at GSI (FAIR Phase 0)



Expected performance of the WASA-FRS at GSI

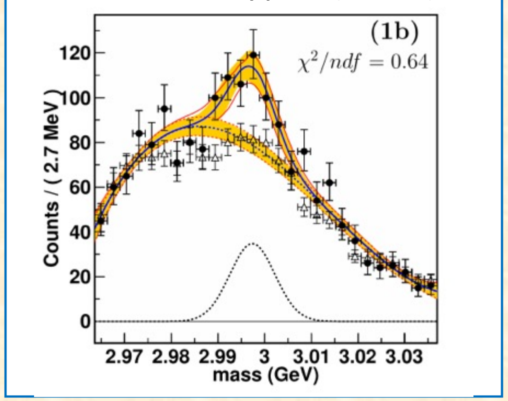
Expected results by updated MC simulations



4 days measurement

TRS et al., Nature Reviews Physics 3, 803-813 (2021) Supplement

Former HypHI (2012)



target position: z=25 cm
vertex z cut: 35 – 50 cm
#layer(MDC): > 6
cldst cut: < 0.3 cm

Mass resolution:

- 3.2 MeV/c^2 (1 T field)
- 1.5 times better than HypHI

Statistics

- About 5800 in the peak for 4 days
- 38 times more than HypHI
- 120 σ significance

Expected Lifetime accuracy

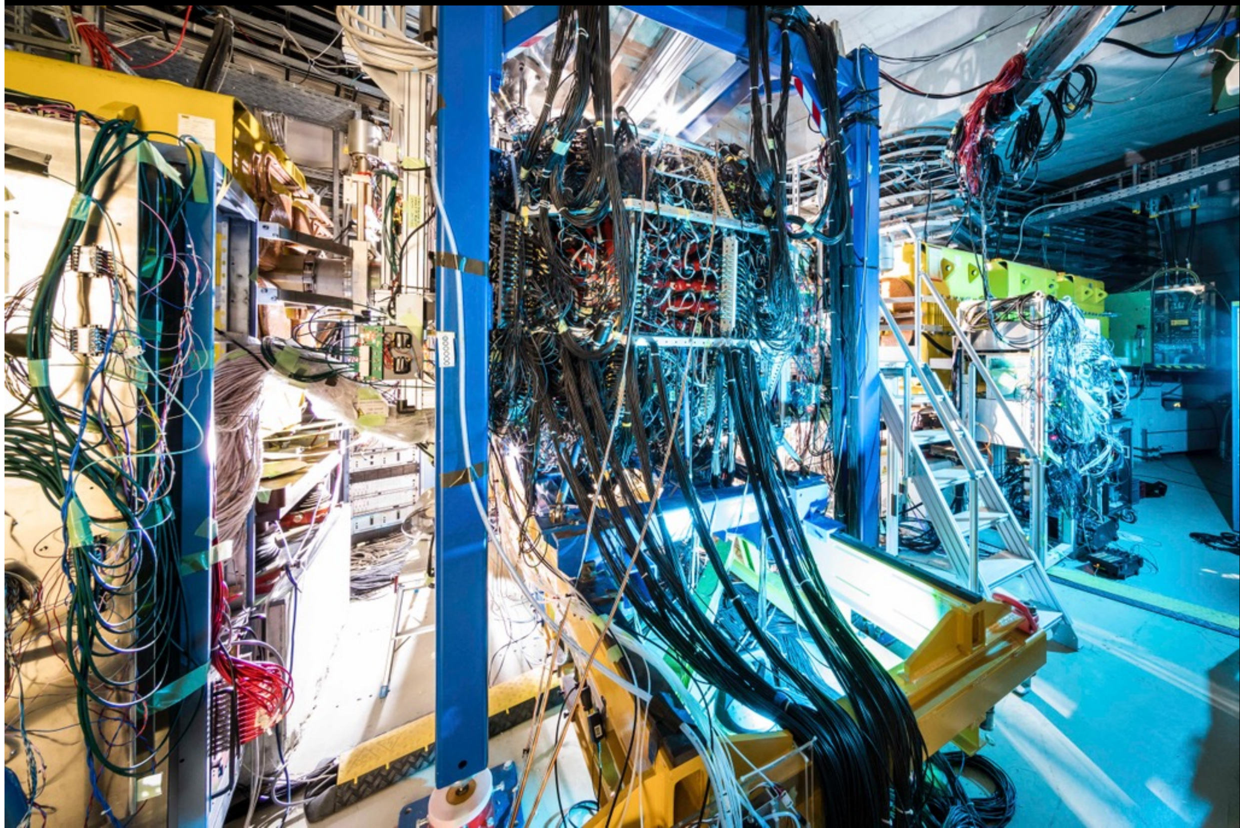
- **8 ps**
- 5 times better than HypHI

The existence or not of nnΛ will be confirmed with large confidence level

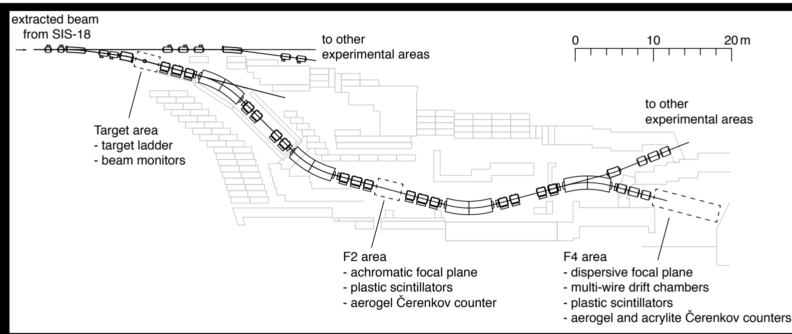
Also with Machine lerning (GNN)

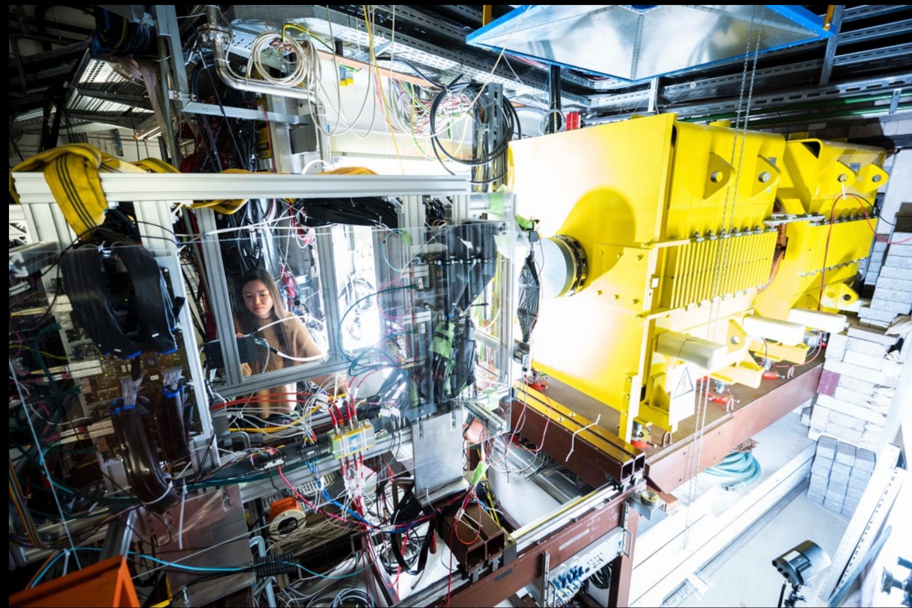
H. Ekawa et al., submitted to EPJA

Experiment already performed in January – March 2022



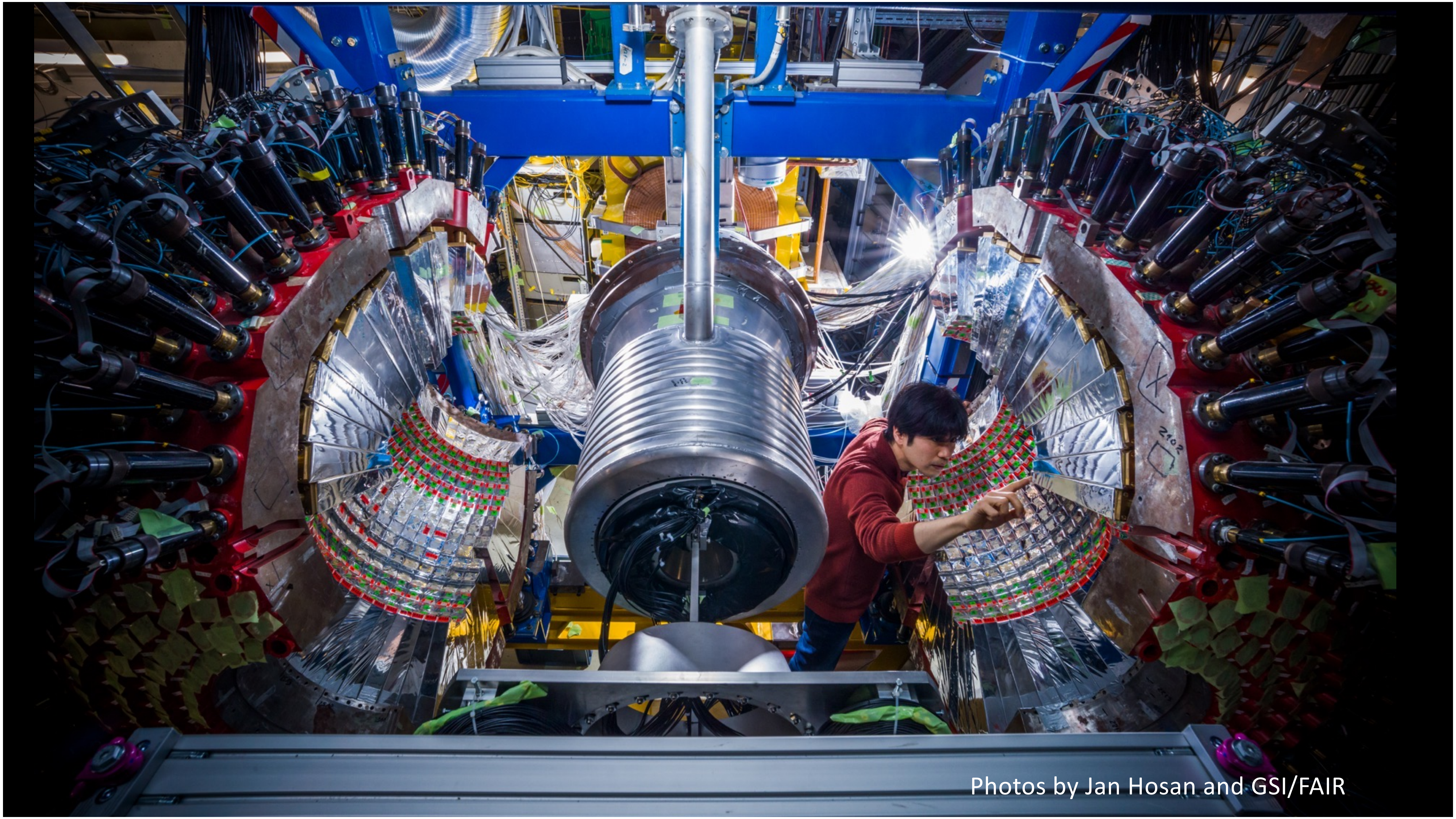
WASA at S2 of FRS



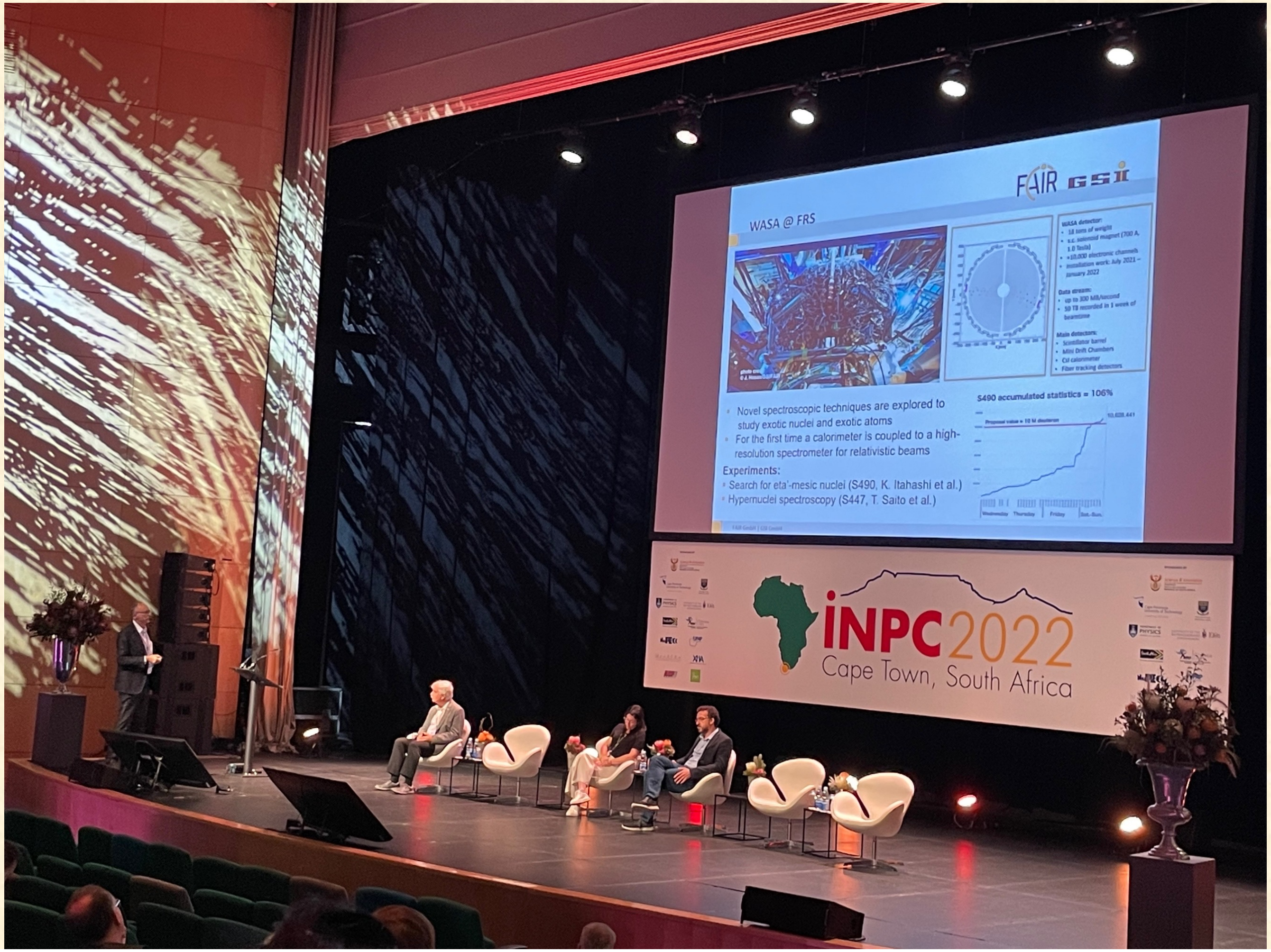


S4 of FRS

Photos by Jan Hosan and GSI/FAIR


Photos by Jan Hosan and GSI/FAIR

INPC2022 in Cape Town: talk by Paolo Giubellino (September 14th 2022)



Data taking

Run	Period	Data size
Commissioning run	28th Jan. - 7th Feb.	7 TB
Physics run for η’ nuclei	22nd Feb. - 28th Feb.	40 TB
Physics run for HypHI	10th Mar. - 19th Mar.	48 TB

Acquired data

Beam	Fragment at S4	Amount	Time	Accepted trigger rate	
^{6}Li beam	^{3}He	3.3×10^{8}	40.9 hours	2600 Hz	**${}^{3}_{\Lambda}$H**
	^{4}He	0.9×10^{8}	43.9 hours	1800 Hz	**${}^{4}_{\Lambda}$H**
	deuteron	1.8×10^{8}			**nnΛ**
	proton (mid-rapidity)	5.3×10^{6}	3.2 hours	680 Hz	**Λ**
^{12}C beam	^{3}He	1.0×10^{8}	13.5 hours	2400 Hz	**${}^{3}_{\Lambda}$H**
	^{9}C	2.4×10^{5}			**${}^{9}_{\Lambda}$B**

Radius of hypertriton by measuring interaction cross section

Experiment at JLab searching for nnΛ

PHYSICAL REVIEW C **105**, L051001 (2022)

Letter

Spectroscopic study of a possible Λnn resonance and a pair of ΣNN states using the (e, $e'K^+$) reaction with a tritium target

B. Pandey,[1] L. Tang,[1,2,*] T. Gogami,[3,4] K. N. Suzuki,[4] K. Itabashi,[3] S. Nagao,[3] K. Okuyama,[3] S. N. Nakamura,[3] D. Abrams,[5] I. R. Afnan,[6] T. Akiyama,[3] D. Androic,[7] K. Aniol,[8] T. Averett,[9] C. Ayerbe Gayoso,[9] J. Bane,[10] S. Barcus,[9] J. Barrow,[10] V. Bellini,[11] H. Bhatt,[12] D. Bhetuwal,[12] D. Biswas,[1] A. Camsonne,[2] J. Castellanos,[13] J-P. Chen,[2] J. Chen,[9] S. Covrig,[2] D. Chrisman,[14,15] R. Cruz-Torres,[16] R. Das,[17] E. Fuchey,[18] C. Gal,[5] B. F. Gibson,[19] K. Gnanvo,[5] F. Garibaldi,[11,20] T. Gautam,[1] J. Gomez,[2] P. Gueye,[1] T. J. Hague,[21] O. Hansen,[2] W. Henry,[2] F. Hauenstein,[22] D. W. Higinbotham,[2] C. Hyde,[22] M. Kaneta,[3] C. Keppel,[2] T. Kutz,[17] N. Lashley-Colthirst,[1] S. Li,[23,24] H. Liu,[25] J. Mammei,[26] P. Markowitz,[13] R. E. McClellan,[2] F. Meddi,[11] D. Meekins,[2] R. Michaels,[2] M. Mihovilovič,[27,28,29] A. Moyer,[30] D. Nguyen,[16,31] M. Nycz,[21] V. Owen,[9] C. Palatchi,[5] S. Park,[17] T. Petkovic,[7] S. Premathilake,[5] P. E. Reimer,[32] J. Reinhold,[13] S. Riordan,[32] V. Rodriguez,[33] C. Samanta,[34] S. N. Santiesteban,[23] B. Sawatzky,[2] S. Širca,[27,28] K. Slifer,[23] T. Su,[21] Y. Tian,[35] Y. Toyama,[3] K. Uehara,[3] G. M. Urciuoli,[11] D. Votaw,[14,15] J. Williamson,[36] B. Wojtsekhowski,[2] S. Wood,[2] B. Yale,[23] Z. Ye,[32] J. Zhang,[5] and X. Zheng[5]
(Hall A Collaboration)

Possibility for nnΛ

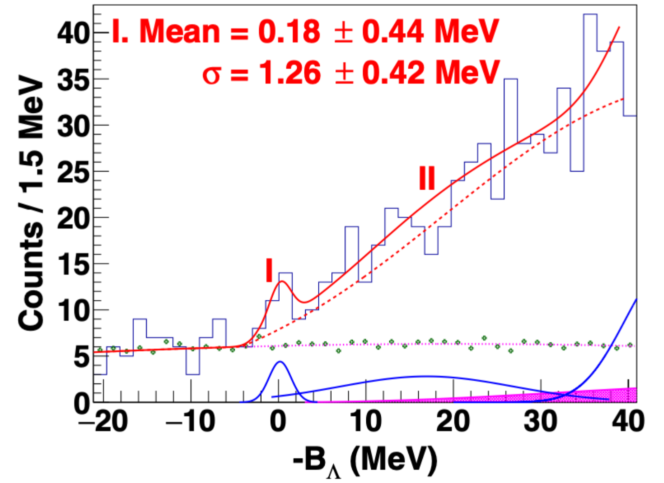


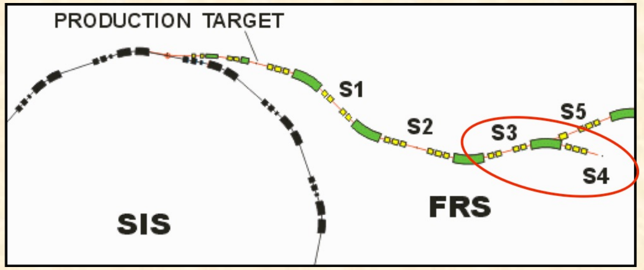
FIG. 5. The enlarged mass spectrum around the Λnn threshold. Two additional Gaussians were fitted together with the known contributions (the accidentals, the Λ quasifree, the free Λ, and the ^{3}He contamination). The one at the threshold is for the small peak, while the broad one is for the additional strength above the predicted quasifree distribution.

However, different interpretation from the same collaboration

- K. Itabashi et al., Few Body Syst. 63 (2022) 1, 16 (January 2022)
- K.N. Suzuki et al, PTEP, Volume 2022, Issue 1, January 2022, 013D01

We have 1.8 x 10^8 deuterons recorded at S4

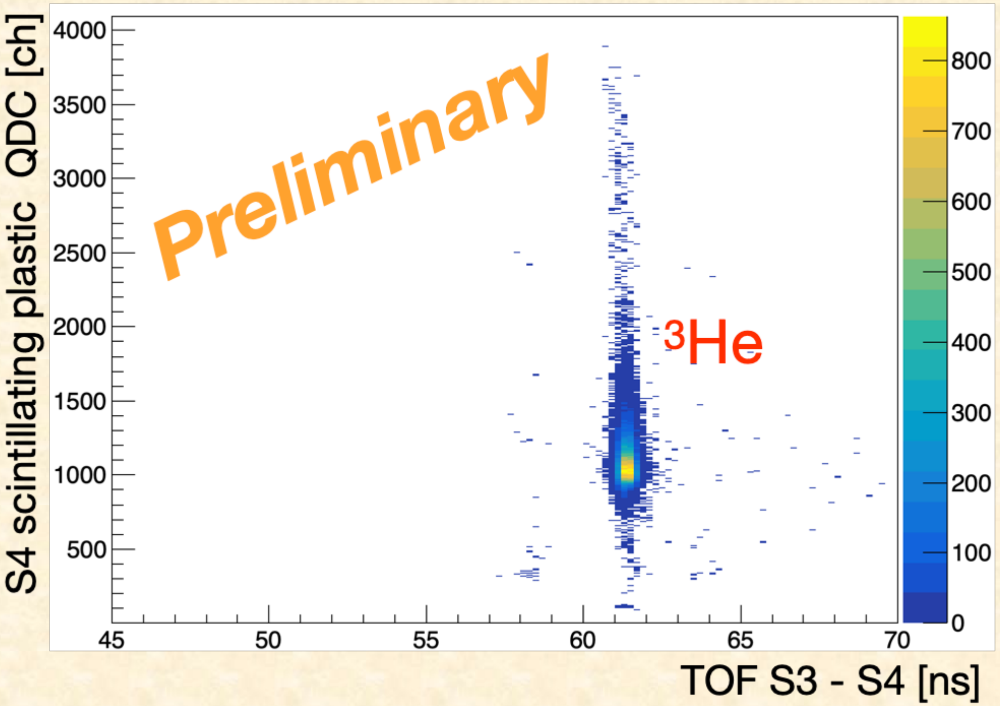
Preliminary data analyses



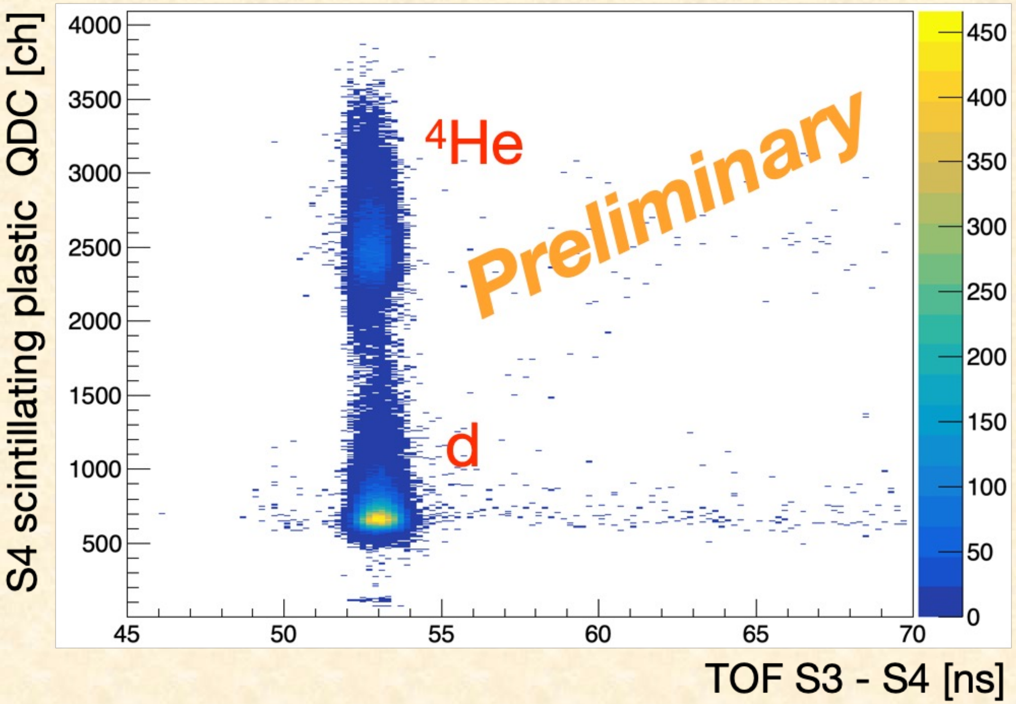
Momentum analysis in progress:

Preliminary: $\Delta p/p \sim 5 \times 10^{-4}$

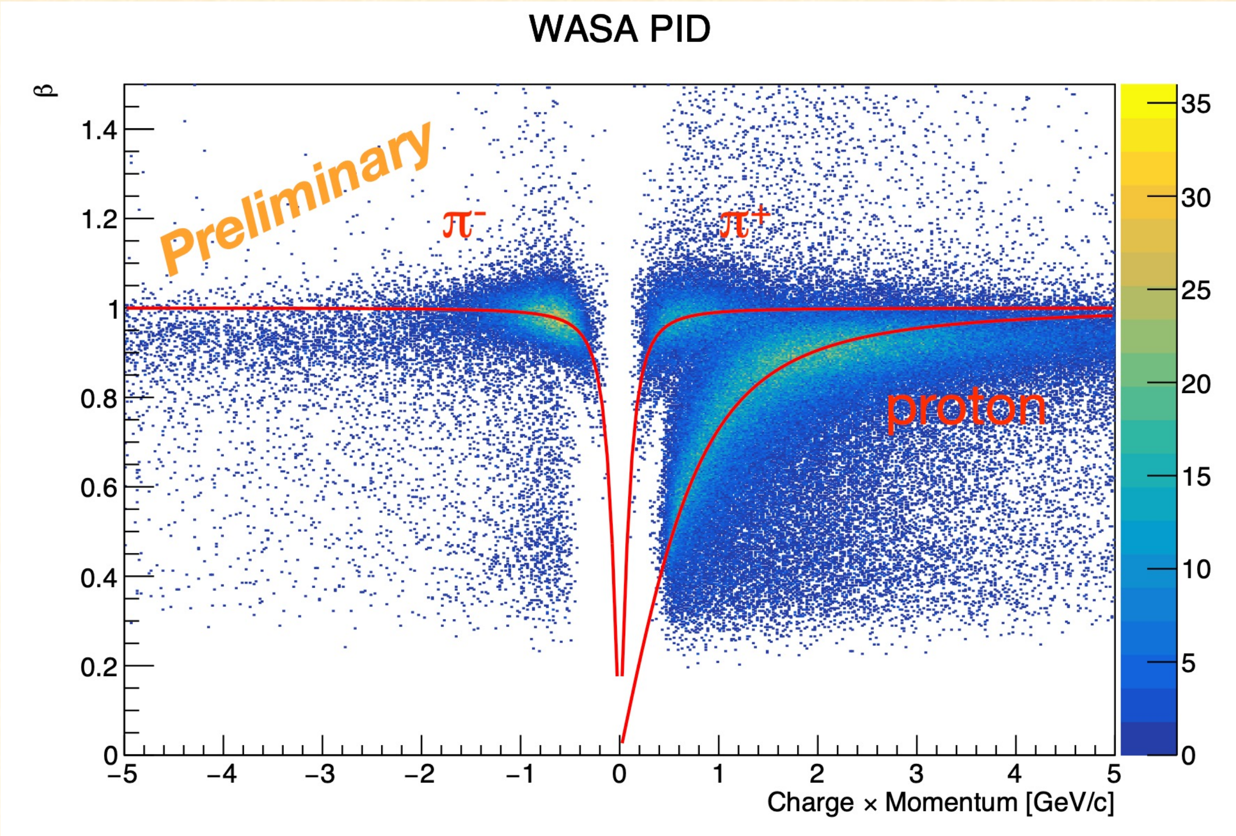
^{3}He setting (^{6}Li beam)



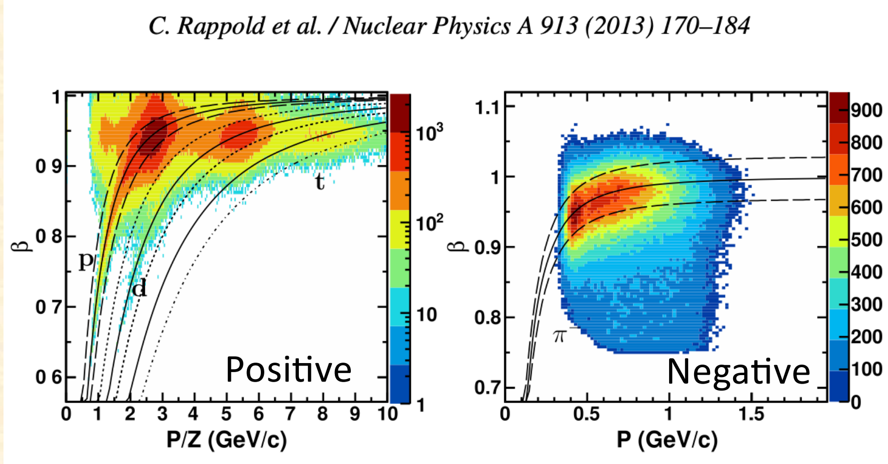
^{4}He/d setting (^{6}Li beam)



Preliminary data analyses



HypHI (2009)



Ph.D theses:

Vasyl Drozd (Groningen U/GSI/RIKEN, 2023)
Enqiang Liu (IMP/RIKEN, 2023)
Samuel Escrig (CSIS-Madrid/RIKEN, 2023)
Yiming Gao (IMP/RIKEN, 2025)

Master thesis:

Ayari Yanai (Saitama U/RIKEN, 2024)

The WASA-FRS collaboration (only core members)

- **<u>High Energy Nuclear Physics Laboratory, RIKEN, Japan</u>:**
  H. Ekawa, Y. Gao, Y. He, A. Kasagi, E. Liu, A. Muneem, M. Nakagawa, T.R. Saito, Y. Tanaka, A. Yanai, J. Yoshida, H. Wang
- **<u>HRS-HYS group, GSI, Germany</u>**
  H. Alibrahim Alfaki, V. Drozd, T.R. Saito, T. Weber
- **<u>FRS/SFRS Research Group, GSI, Germany:</u>**
  K.-H. Behr, B. v. Chamier Gliszezynski, T. Dickel, S. Dubey, J. Eusemann, D. Kostyleva, B. Franczak, H. Geissel, E. Haettner, C. Hornung, P. Roy, C. Scheidenberger, P. Schwarz, B. Szczepanczyk, M. Will, J. Zhao
- **<u>Meson Science Laboratory, RIKEN, Japan</u>:**
  K. Itahashi, R. Sekiya
- **<u>Instituto de Estructura de la Materia – CSIC, Spain</u>:**
  S. Escrig, C. Rappold
- **<u>Cryogenic Department, GSI, Germany:</u>**
  A. Beusch, H. Kollmus, C. Schroeder, B. Streicher
- **<u>Experiment Electronics Department, GSI, Germany</u>:**
  H. Heggen, N. Kurz, S. Minami
- Detector Laboratory, GSI, Germany:
  C. Nociforo, E. Rocco
- Nuclear Spectroscopy Group, GSI, Germany:
  M. Armstrong, N. Hubbard, K. Wimmer
- Super-FRS Project, GSI, Germany:
  F. Amjad, E. Kazantseva, R. Knöbel, I. Mukha, S. Pietri, S. Purushothaman, H. Weick
- Target Laboratory, GSI, Germany:
  B. Kindler, B. Lommel
- Institut für Kernphysik, Technische Universität Darmstadt, Germany:
  G. Schaumann
- University of Applied Sciences, Giessen, Germany:
  S. Kraft
- Department of Engineering, Gifu University, Japan:
  A. Kasagi, K. Nakazawa
- ESRIG - Energy and Sustainability Research Institute Groningen, University of Groningen, The Netherlands:
  V. Drozd, M. Harakeh, N. Kalantar-Nayestanaki, M. Kavatsyuk
- Institute of Modern Physics, China
  L. Duan, Y. Gao, E. Liu, J. Ong, X. Tang
- Institute of Physics, Jagiellonian University, Poland
  A. Khreptak, M. Skurzok
- Department of Low and Medium Energy Physics, Jožef Stefan Institute, Slovenia
  Z. Brencic
- Department of Physics, Kyoto University, Japan:
  R. Sekiya
- School of Nuclear Science and Technology, Lanzhou University, China
  Y. He, J. Ong, T.R. Saito, X. Tang
- Institut für Kernphysik, Johannes Gutenberg-Universität Mainz, Germany
  P. Achenbach, J. Pochdzalla
- Michigan State University, USA:
  D. Morrissey
- Universidad de Santiago de Compostela, Spain:
  J. Benlliure, M. Fontan, A. Gonzalez, G. Jimenez, J. Rodríguez-Sánchez

Young Driving Forces in the WASA-FRS project

- Yoshiki Tanaka
  (staff, High Energy Nuclear Physics Lab., RIKEN)
- Vasyl Drozd
  (Ph.D. student, HRS-HYS group, GSI, and Groningen Univ.)
- Philipp Schwarz
  (Engineer, FRS/SFRS research group, GSI)
- Tobias Weber
  (Engineer, HRS-HYS group, GSI)
- Hiroyuki Ekawa
  (postdoc, High Energy Nuclear Physics Lab., RIKEN)
- Samuel Escrig
  (Ph.D. student, CSIS-Madrid)
- Yiming Gao
  (Ph.D. student, High Energy Nuclear Physics Lab., RIKEN, and IMP-Lanzhou)
- Ayumi Kasagi
  (Ph.D. student, High Energy Nuclear Physics Lab., RIKEN, and Gifu University)
- Enqiang Liu
  (Ph.D. student, High Energy Nuclear Physics Lab., RIKEN, and IMP-Lanzhou)
- Manami Nakagawa
  (postdoc, High Energy Nuclear Physics Lab., RIKEN)
- Cristophe Rappold
  (Group leader, CSIS-Madrid)
- Ryohei Sekiya
  (Ph.D. student, Meson Science Lab., RIKEN, and Kyoto University)
- Ayari Yanai
  (Master student, High Energy Nuclear Physics Lab., RIKEN, and Saitama University)

Part of the WASA-FRS collaboration

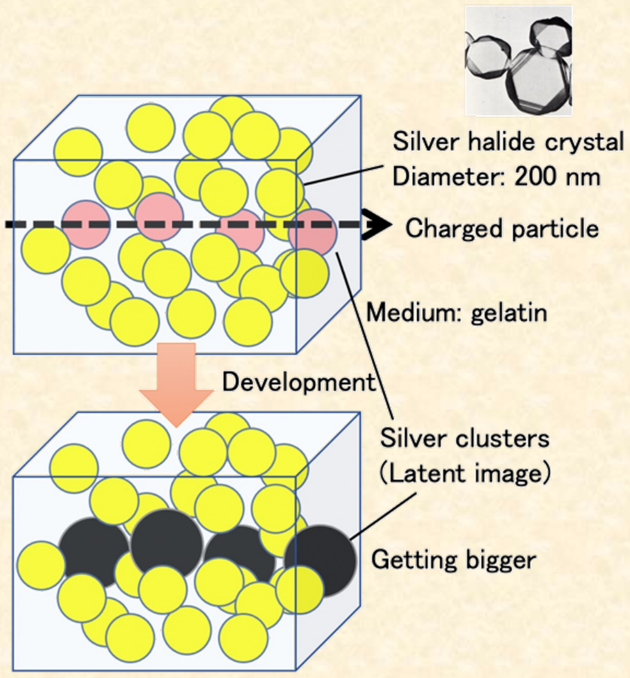
How about
the hypertriton binding energy?

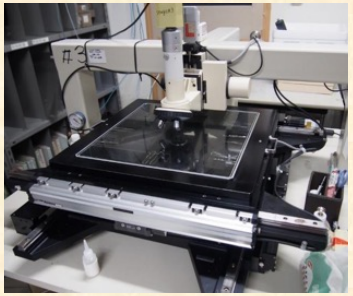
Nuclear Emulsion:

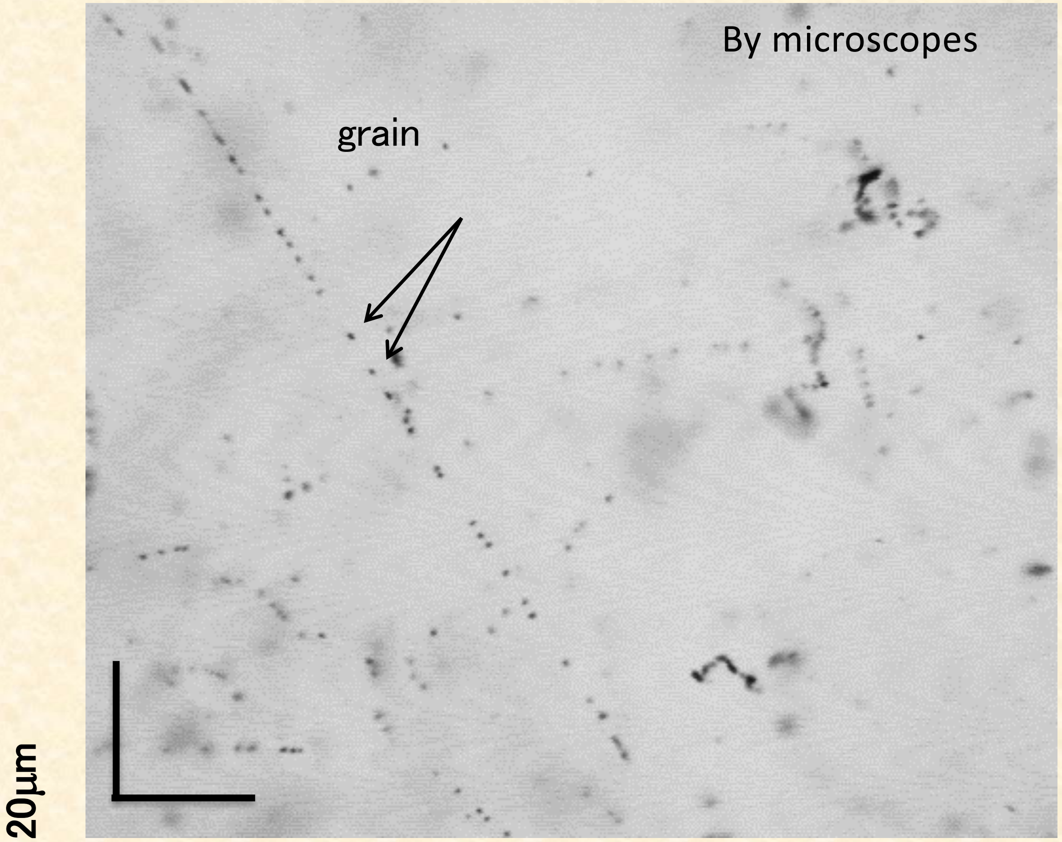
Charged particle tracker with

the best spatial resolution

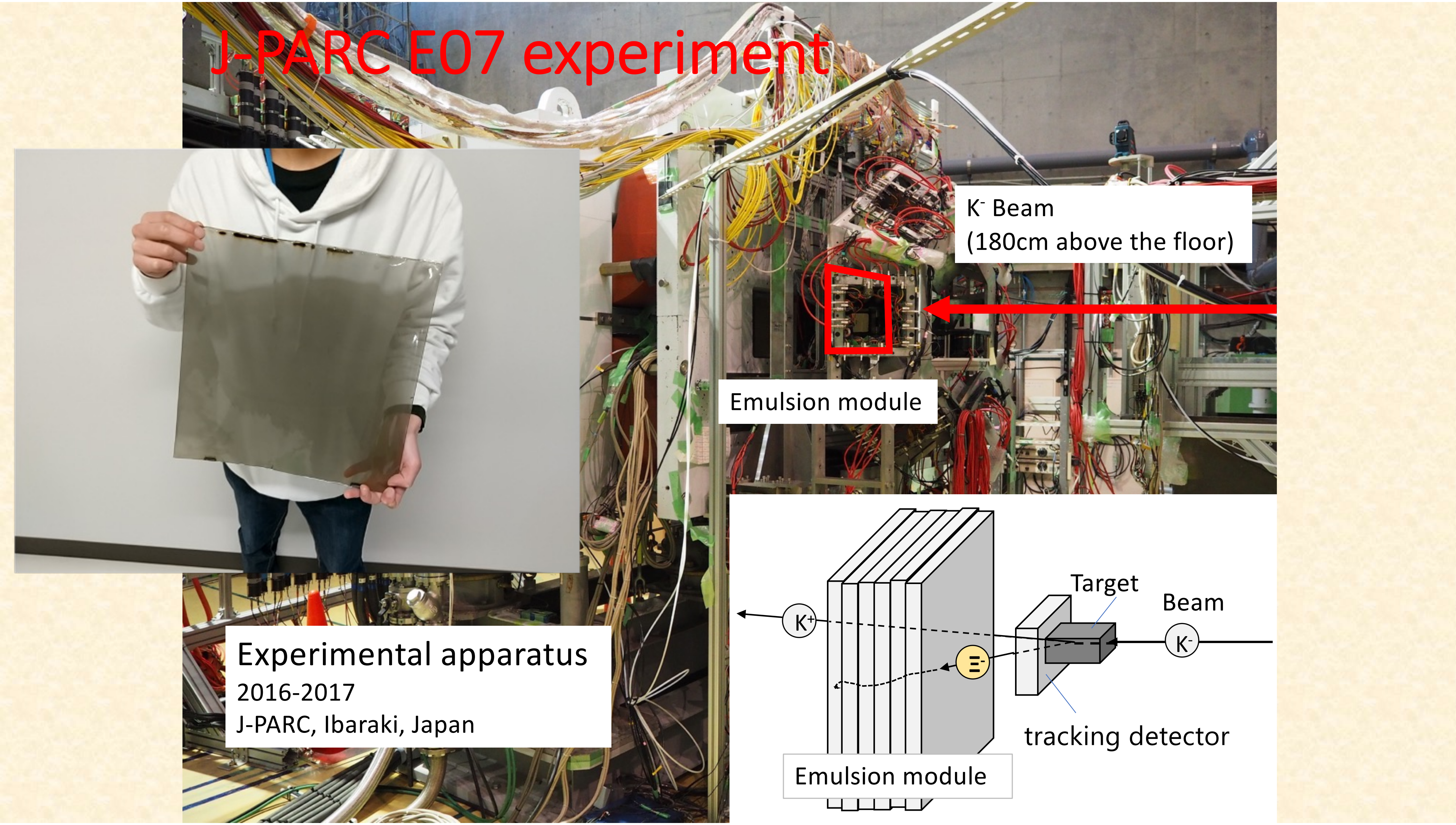
(easy to be < 1 μm, 11 nm at best)





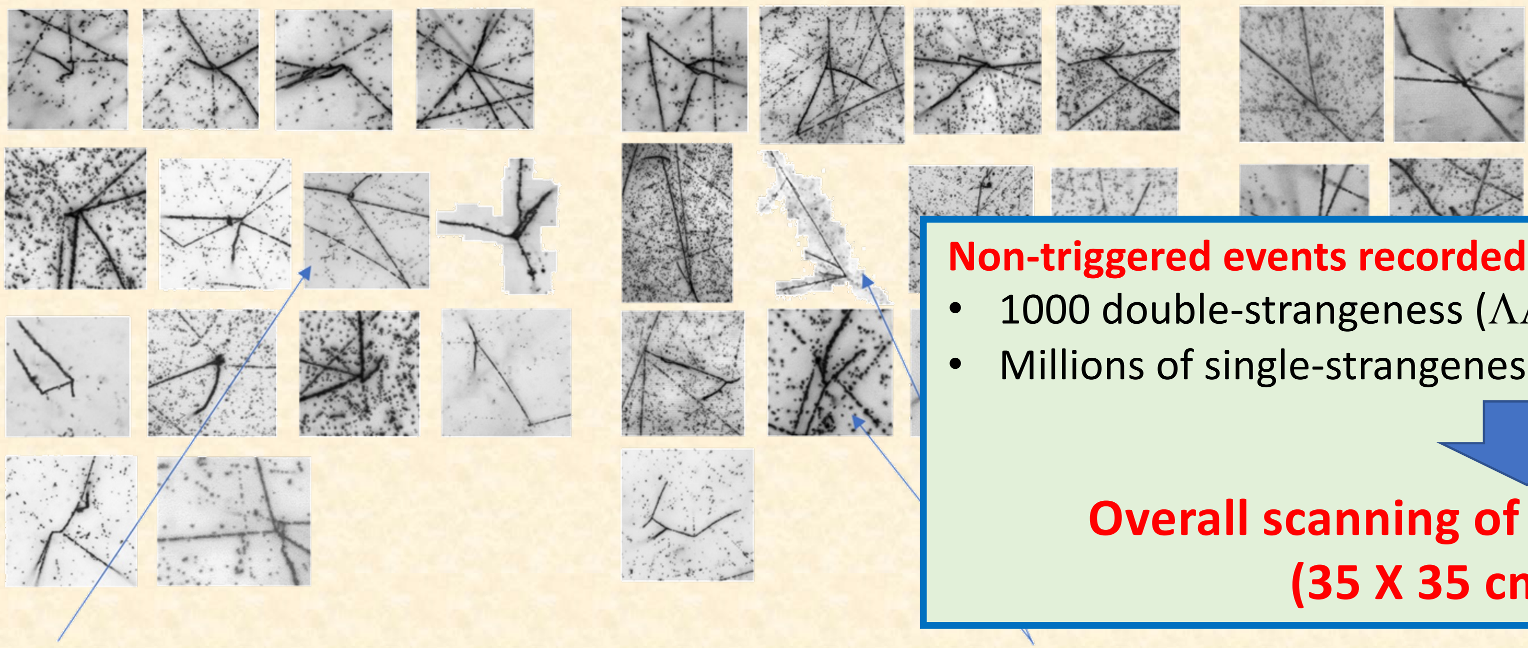


J-PARC accelerator facility


J-PARC E07 experiment
K- Beam
(180cm above the floor)
Emulsion module
Experimental apparatus
2016-2017
J-PARC, Ibaraki, Japan
Target
Beam
K+
K-
Ξ-
tracking detector
Emulsion module

Results from J-PARC E07 (Hybrid method)

$\Lambda\Lambda$ candidates: 14 Twin Λ events: 13 Others: 6



Non-triggered events recorded in 1000 emulsions sheets

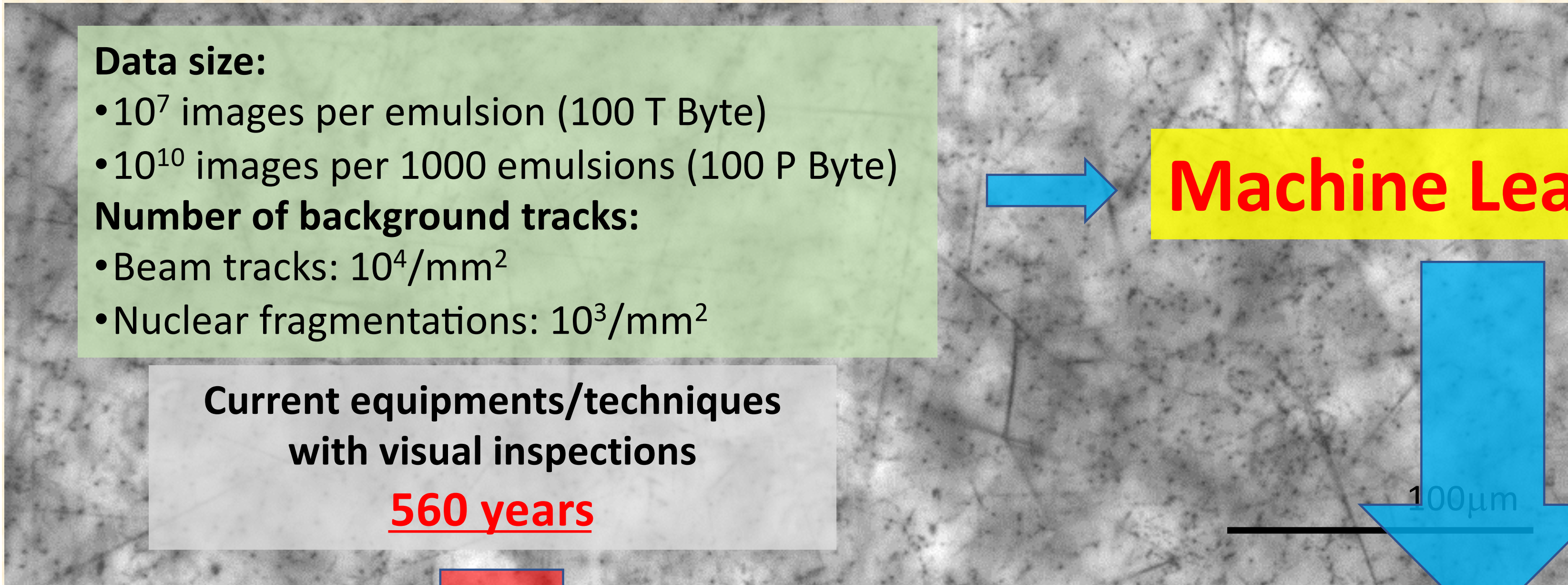
- 1000 double-strangeness ($\Lambda\Lambda$- and Ξ-) hypernuclear events
- Millions of single-strangeness hypernuclear events

Overall scanning of all emulsion sheets
(35 X 35 cm^2 X 1000)

$_{\Lambda\Lambda}$Be
H. Ekawa et al., Prog. Theor. Exp. Phys. 2019, 021D02

$^{15}_{\Xi}$C
S. H. Hayakawa et al.,
Physical Review Letters, 126, 062501 (2021)

Overall scanning for E07 emulsions



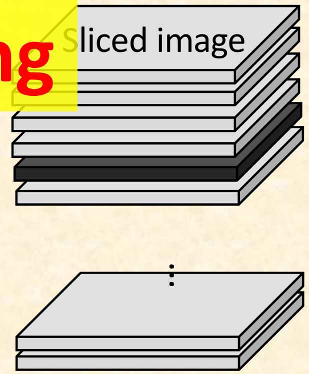
Data size:
- 10^7 images per emulsion (100 T Byte)
- 10^{10} images per 1000 emulsions (100 P Byte)

Number of background tracks:
- Beam tracks: $10^4/mm^2$
- Nuclear fragmentations: $10^3/mm^2$

Current equipments/techniques with visual inspections

560 years

Machine Learning



3 years

Millions of single-strangeness hypernuclei
1000 double strangeness hypernuclei (formerly only 5)

Challenges for Machine Learning Development

MOST IMPORTANT:

- **Quantity and quality of training data**

However,

No existing data for hypertriton with emulsions for training

What have been done since 2020:

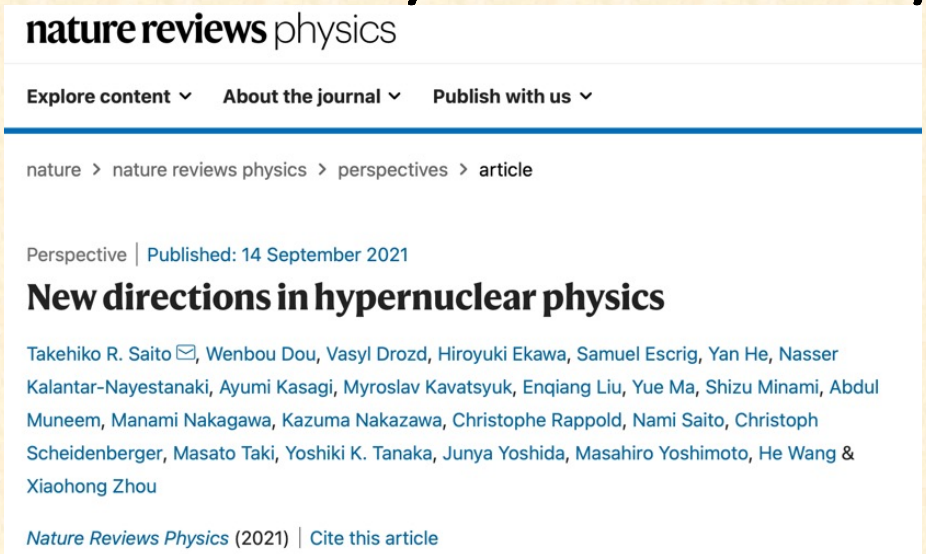
Production of training data

- Monte Carlo simulations
- Image transfer techniques, GAN(Generative Adversarial Networks)

Detection of stopped-hypertriton decay (^{3}He + π^-)

- Mask R-CNN model

Discovery of the first hypertriton event in E07 emulsions



nature reviews physics

Explore content ⌄ About the journal ⌄ Publish with us ⌄

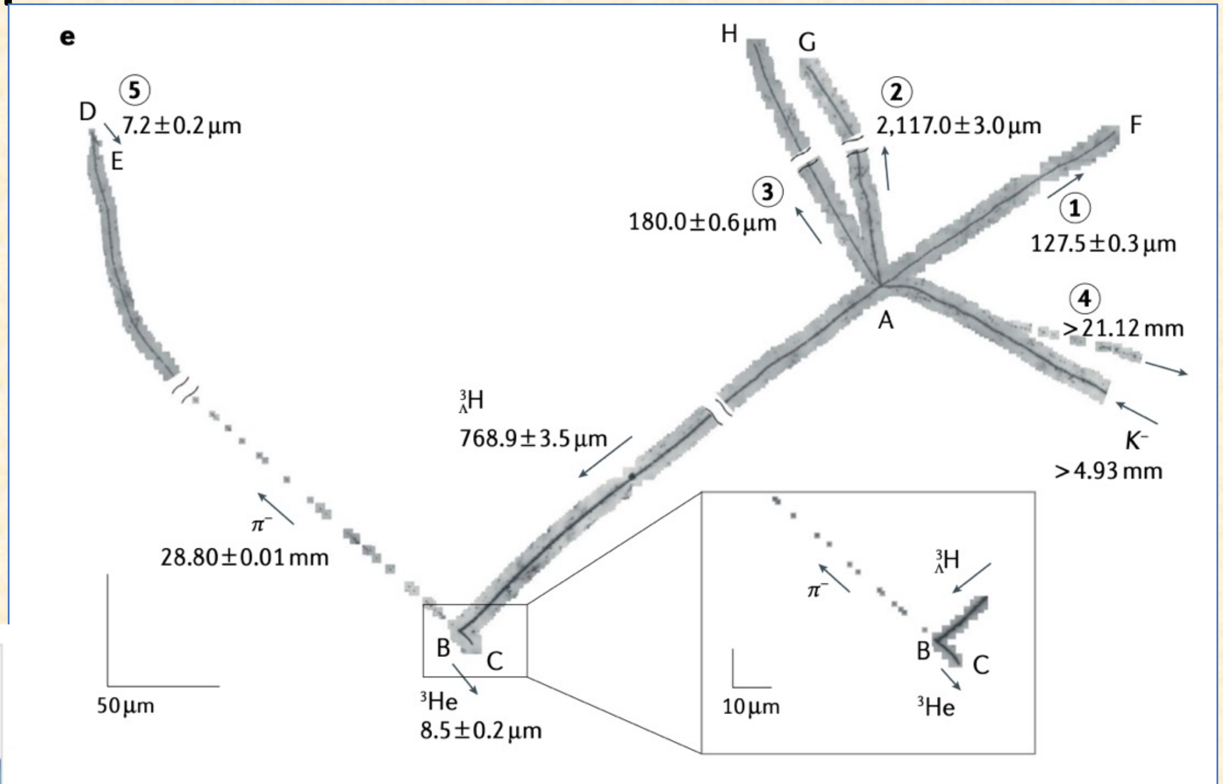
nature › nature reviews physics › perspectives › article

Perspective | Published: 14 September 2021

New directions in hypernuclear physics

Takehiko R. Saito, Wenbou Dou, Vasyl Drozd, Hiroyuki Ekawa, Samuel Escrig, Yan He, Nasser Kalantar-Nayestanaki, Ayumi Kasagi, Myroslav Kavatsyuk, Enqiang Liu, Yue Ma, Shizu Minami, Abdul Muneem, Manami Nakagawa, Kazuma Nakazawa, Christophe Rappold, Nami Saito, Christoph Scheidenberger, Masato Taki, Yoshiki K. Tanaka, Junya Yoshida, Masahiro Yoshimoto, He Wang & Xiaohong Zhou

Nature Reviews Physics (2021) | Cite this article



TRS et al., Nature Reviews Physics, 803-813 (2021)
Cover of December 2021 issue

Guaranteeing the determination of the hypertriton binding energy SOON

Precision: 28 keV

E. Liu et al., EPJ A57 (2021) 327

Nuclear Emulsion + Machine Learning Collaboration

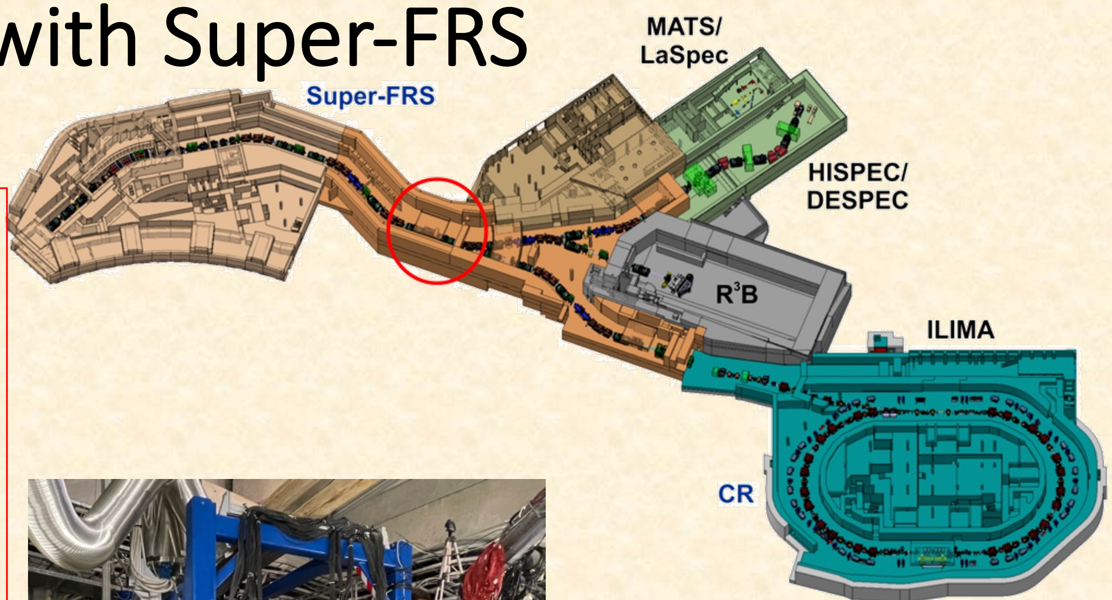
- High Energy Nuclear Physics Laboratory, RIKEN, Japan
  Michi Ando, Wenbo Dou, Hiroyuki Ekawa, Yiming Gao, Chiho Harisaki, Yan He, Risa Kobayashi, Hanako Kubota, Enqiang Liu, Manami Nakagawa, Nami Saito, Takehiko R. Saito, Shohei Sugimoto, Yoshiki Tanaka, Junya Yoshida, Masahiro Yoshimoto, He Wang
- Instituto de Estructura de la Materia, Consejo Superior de Investigaciones Científicas (CSIC), Spain
  Christophe Rappold
- Department of Engineering, Gifu University
  Ayumi Kasagi, Kazuma Nakazawa
- Faculty of Engineering Sciences, Ghulam Ishaq Khan Institute of Engineering Sciences and Technology, Pakistan
  Abdul Muneem
- Institute of Modern Physics, Chinese Academy of Sciences, China
  Yiming Gao, Enqiang Liu
- School of Nuclear Science and Technology, Lanzhou University, China
  Yan He, Takehiko R. Saito
- Graduate School of Artificial Intelligence and Science, Rikkyo University, Japan
  Masato Taki
- Department of Physics, Saitama University, Japan
  Wenbo Dou, Shohei Sugimoto
- Department of Physics, Tohoku University, Japan
  Junya Yoshida

Administration:
•High Energy Nuclear Physics Laboratory, RIKEN
Yukiko Kurakata

Perspective

Hypernuclear experiments with Super-FRS

One of Day-1 experiments of NUSTAR at FAIR



Single-strangeness hypernuclei

Up to A~20

Also with multibody-decay channels

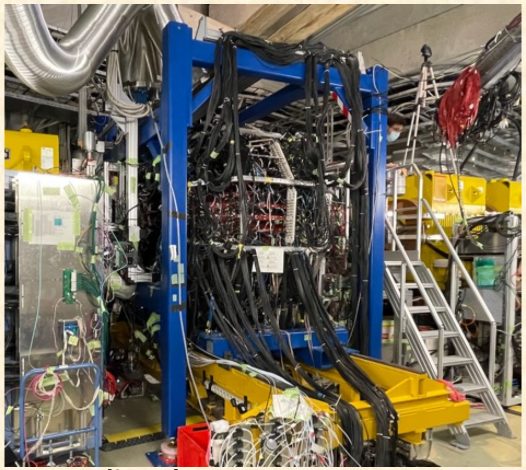
- Hypernuclear lifetime
  very precisely
- Hypernuclear binding energy
  reasonably precise
- Hypernuclear resonance
- **Hypernuclear cross section and kinematics**
  Revealing the production mechanism

- Proton rich hypernuclei
  with proton-rich RI-beams
  C. Rappold et al., Phys. Rev. C 94, 044616 (2016)

- **Extremely neutron-rich hypernuclei**
  with charge exchange reactions

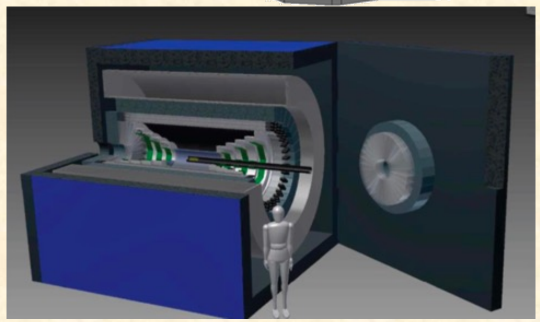
MISSING MASS method

TRS et al., EPJ A57 (2021) 159



Upgrading the WASA

- Inner drift chamber
  In progress with the MOST fund at Lanzhou University
- New solenoid magnet (2 T) with Cryocooler



New detector development

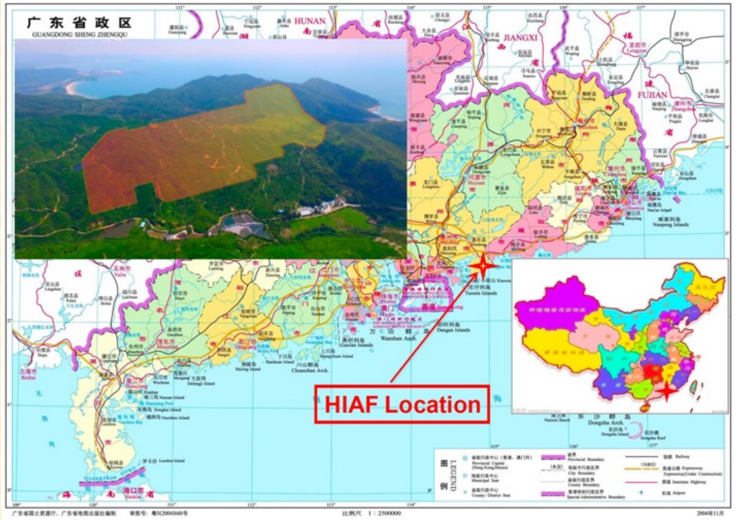
- Large super-conducting solenoid
- Inner- and outer-detectors

Hypernuclear project at HIAF in China

HIAF (High Intensity heavy ion Accelerator Facility)

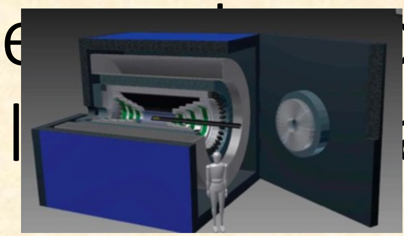
- To be operational in 2025

TRS is leading the new hypernuclear project since 2016

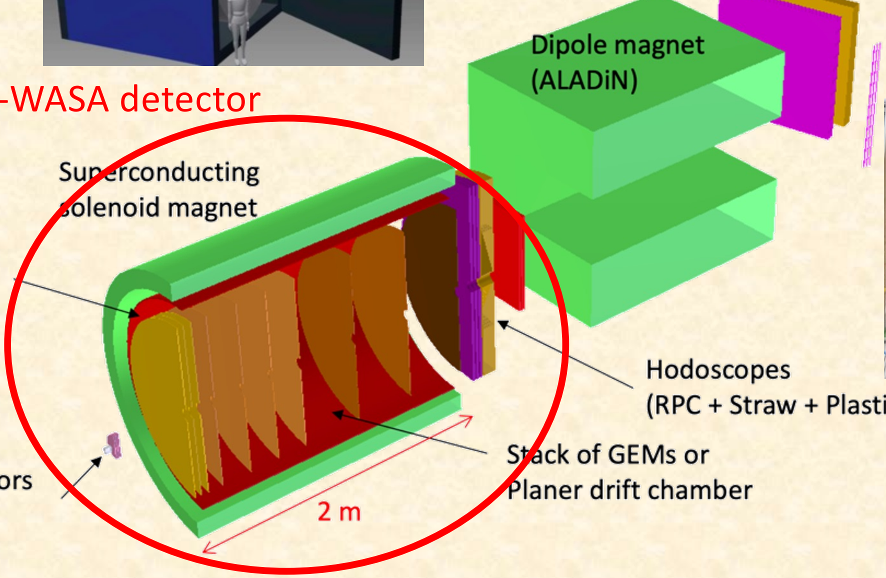


New institute to be built in Huizhou

Hype roject (4.25 A GeV) at HI a



Post-WASA detector



$d + \Xi^- \to {}^{3}_{\Xi^-}n \to n\Lambda\Lambda$

$t + \Xi^- \to {}^{4}_{\Xi^-}n \to nn\Lambda\Lambda$

${}^{3}He + \Xi^- \to {}^{4}_{\Xi^-}H \to {}^{4}_{\Lambda\Lambda}H$

${}^{4}He + \Xi^- \to {}^{5}_{\Xi^-}H \to {}^{5}_{\Lambda\Lambda}H$

${}^{6}Li + \Xi^- \to {}^{7}_{\Xi^-}He \to {}^{7}_{\Lambda\Lambda}He$

${}^{6}Li + \Xi^- \to {}^{7}_{\Xi^-}He \to {}^{6}_{\Lambda\Lambda}He + n$

${}^{7}Li + \Xi^- \to {}^{8}_{\Xi^-}He \to {}^{8}_{\Lambda\Lambda}He$

${}^{9}Be + \Xi^- \to {}^{10}_{\Xi^-}Li \to {}^{10}_{\Lambda\Lambda}Li$

${}^{10}Be + \Xi^- \to {}^{11}_{\Xi^-}Li \to {}^{11}_{\Lambda\Lambda}Li$

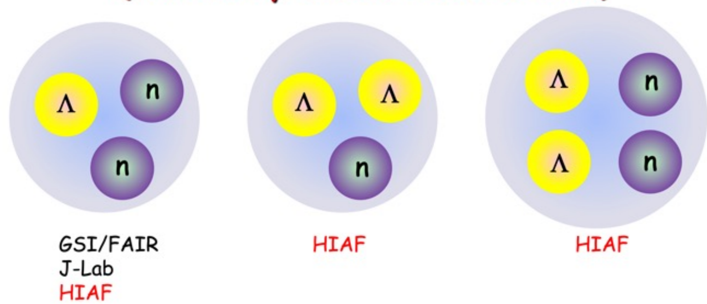
${}^{10}B + \Xi^- \to {}^{11}_{\Xi^-}Be \to {}^{11}_{\Lambda\Lambda}Be$

${}^{11}B + \Xi^- \to {}^{12}_{\Xi^-}Be \to {}^{12}_{\Lambda\Lambda}Be$

	Single-strangeness hypernuclei	Double-strangeness hypernuclei
Observation per week	6×10^6	6×10^2
Lifetime accuracy	**~ 1 ps**	**~ 10 ps**
Binding energy accuracy	~ 100 keV	Sub MeV

Hypernuclear scattering experiment feasible

Femto Neutron Stars
(named by Josef Pochodzalla)



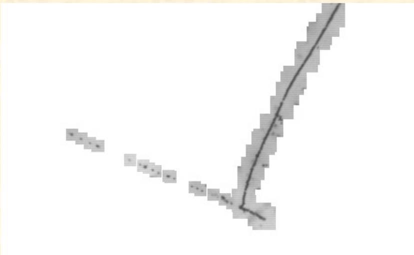
Precise measurement of Hypernuclei

Binding energy

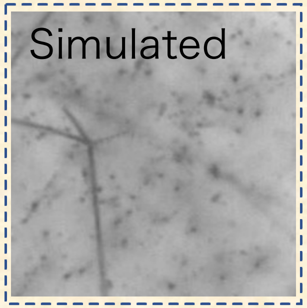
$^{3}_{\Lambda}$H, $^{4}_{\Lambda}$H, $^{4}_{\Lambda}$He, $^{5}_{\Lambda}$He…

Chage symmetry breaking

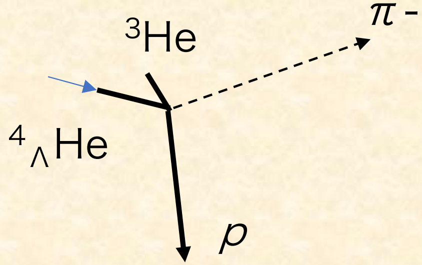
$^{4}_{\Lambda}$H (2-body decay)



$^{4}_{\Lambda}$He (3-body decay)

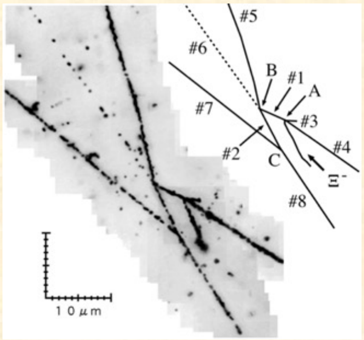


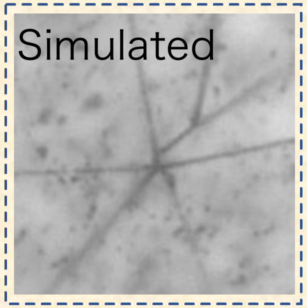
10 μm



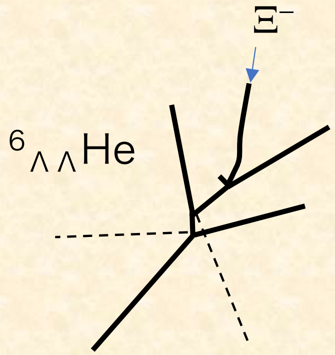
S. Sugimoto, Master thesis, Saitama University

Double-strangeness hypernuclei





10 μm



Y. He, PhD thesis, Lanzhou University

Measurements for Lifetime, Decay mode, Magnetic moment Hypernuclear scattering etc…

at FAIR in Germany (S = -1)

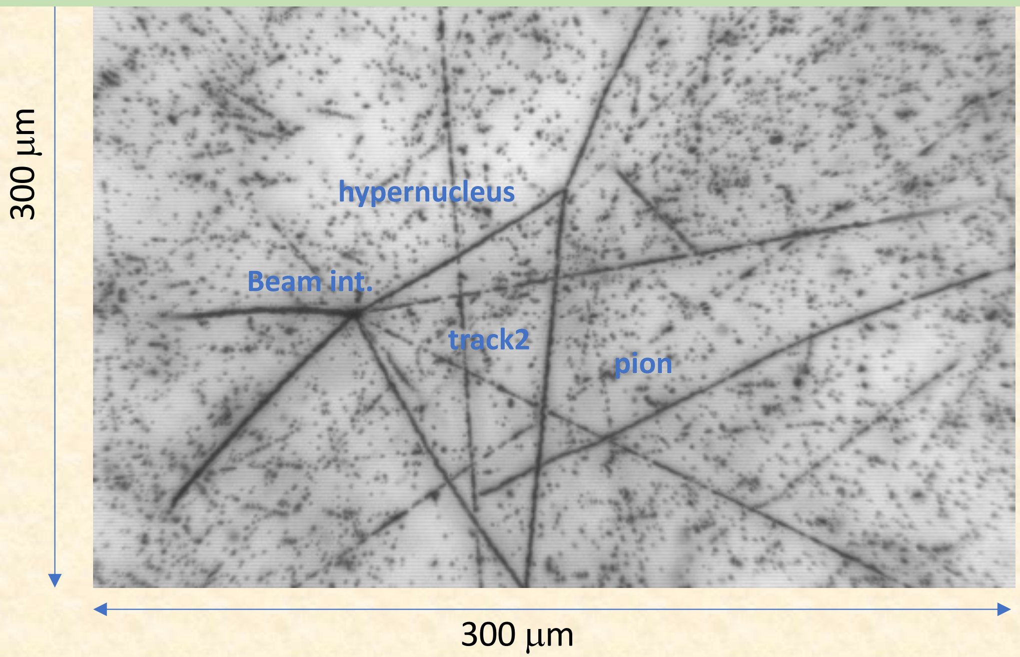
at HIAF in China (S = -2)

Guaranteeing precise binding energy measurements on hypernuclei with multi-body decays

For example;

- $^{4}_{\Lambda}$He (charge symmetry breaking)and $^{5}_{\Lambda}$He
- Three body decay channels: $^{3}_{\Lambda}$H, $^{4}_{\Lambda}$H and heavier hypernuclei

Sept 13th 2022)



Scanned dada: only 5 × 5 cm^2

sibilities:

$_{\Lambda}H \rightarrow p + p + \pi^- + n$

$B_{\Lambda} = 1.02 \pm 0.49$ MeV

$^{5}_{\Lambda}H \rightarrow t + p + \pi^- + n$

$B_{\Lambda} = 0.12 \pm 0.75$ MeV

Very neutron rich nucleus
Not observed
Predicted by R.H. Dalitz & R Levi Setti
(Il Nuovo Cimento (1955-
1965) volume 30, pages 489–501 (1963))

S. Sugimoto, master thesis, Saitama University

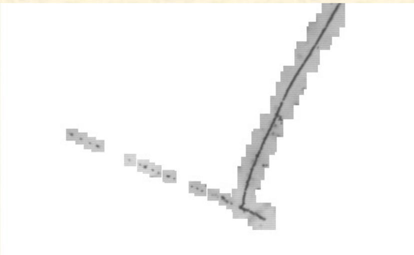
Precise measurement of Hypernuclei

Binding energy

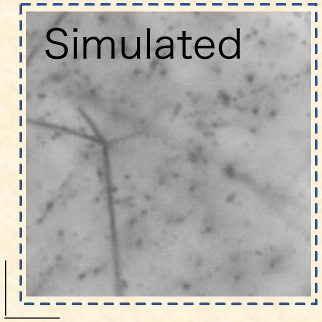
$^{3}{}_{\Lambda}$H, $^{4}{}_{\Lambda}$H, $^{4}{}_{\Lambda}$He, $^{5}{}_{\Lambda}$He…

Chage symmetry breaking

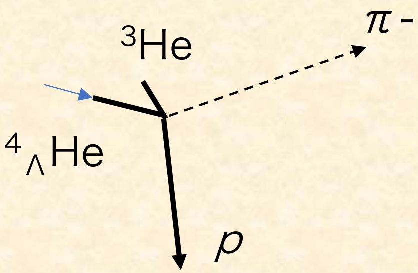
$^{4}{}_{\Lambda}$H (2-body decay)



$^{4}{}_{\Lambda}$He (3-body decay)

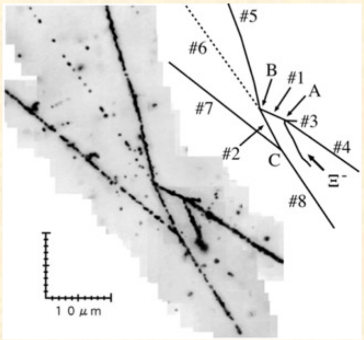


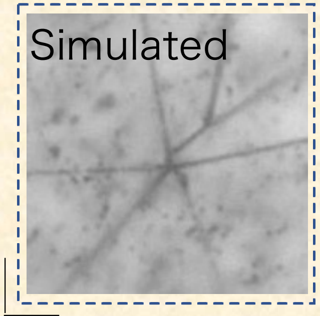
10 μm



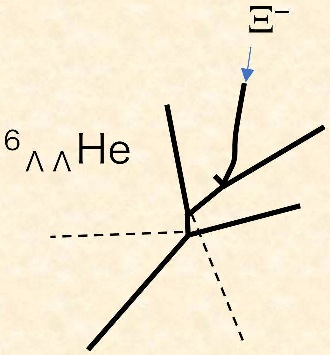
S. Sugimoto, Master thesis, Saitama University

Double-strangeness hypernuclei





10 μm



Y. He, PhD thesis, Lanzhou University

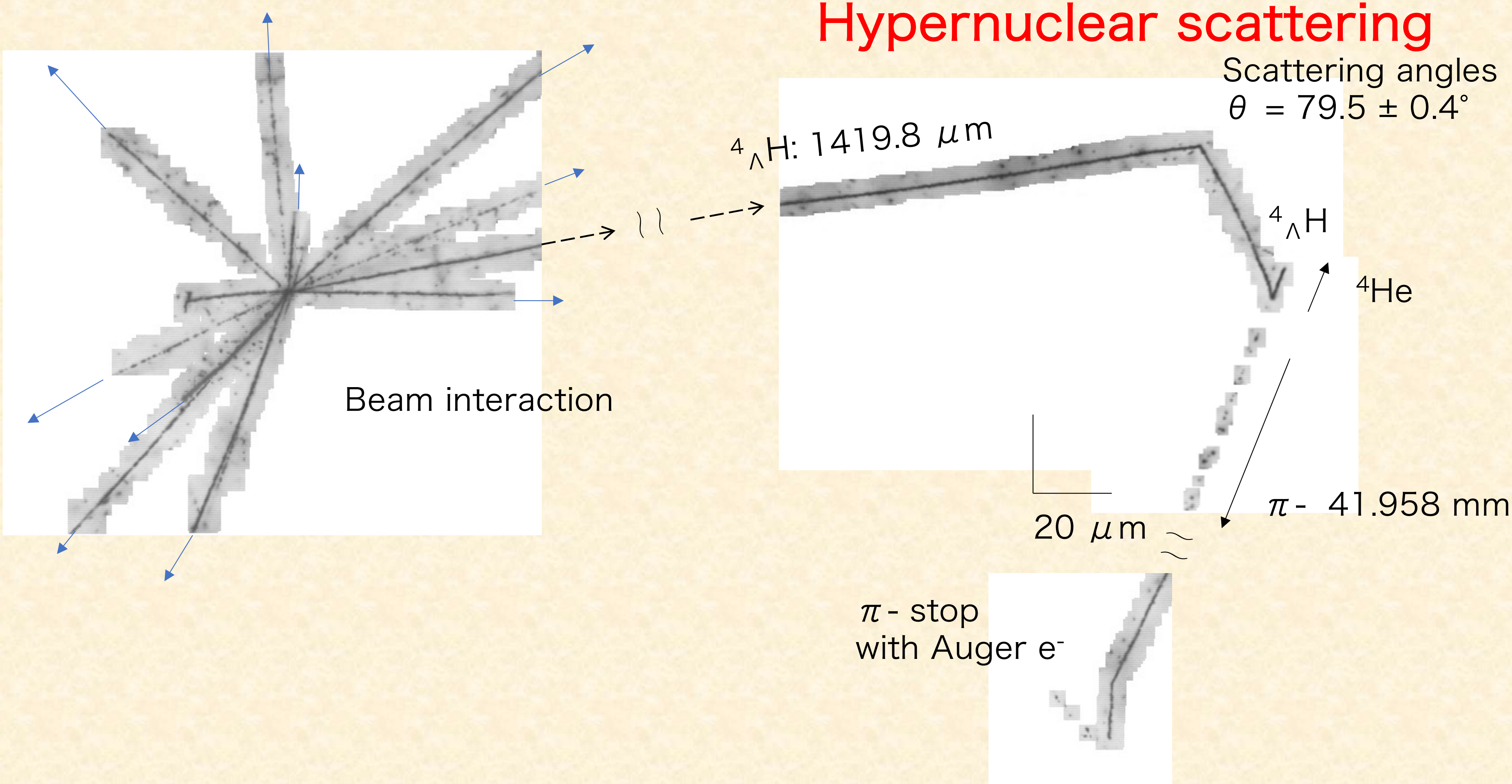
Measurements for Lifetime, Decay mode, Magnetic moment Hypernuclear scattering etc…

at FAIR in Germany (S = -1)

at HIAF in China (S = -2)

Other new discovery 1:

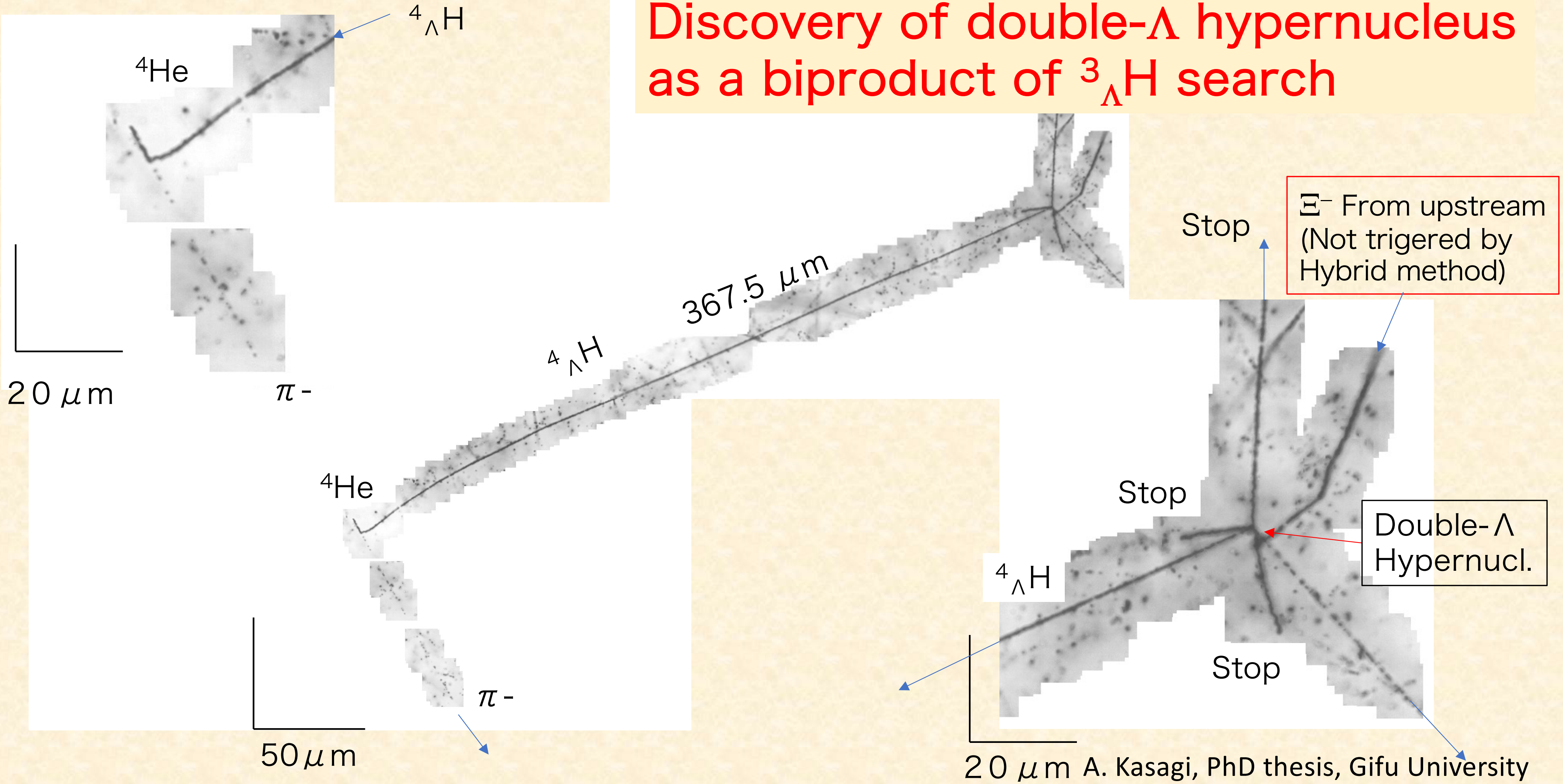
Hypernuclear scattering



A. Kasagi, PhD thesis, Gifu University

Other new discovery 2:

Discovery of double-Λ hypernucleus as a biproduct of $^3{}_\Lambda H$ search



A. Kasagi, PhD thesis, Gifu University

Summary

nature reviews physics

Explore content ⌄ About the journal ⌄ Publish with us ⌄

nature › nature reviews physics › perspectives › article

Perspective | Published: 14 September 2021

New directions in hypernuclear physics

Takehiko R. Saito, Wenbou Dou, Vasyl Drozd, Hiroyuki Ekawa, Samuel Escrig, Yan He, Nasser Kalantar-Nayestanaki, Ayumi Kasagi, Myroslav Kavatsyuk, Enqiang Liu, Yue Ma, Shizu Minami, Abdul Muneem, Manami Nakagawa, Kazuma Nakazawa, Christophe Rappold, Nami Saito, Christoph Scheidenberger, Masato Taki, Yoshiki K. Tanaka, Junya Yoshida, Masahiro Yoshimoto, He Wang & Xiaohong Zhou

Nature Reviews Physics (2021) | Cite this article

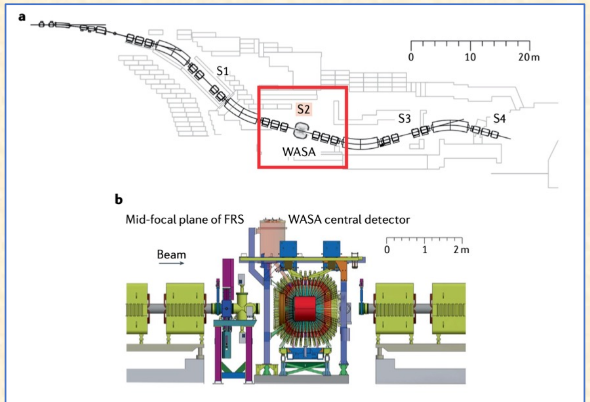
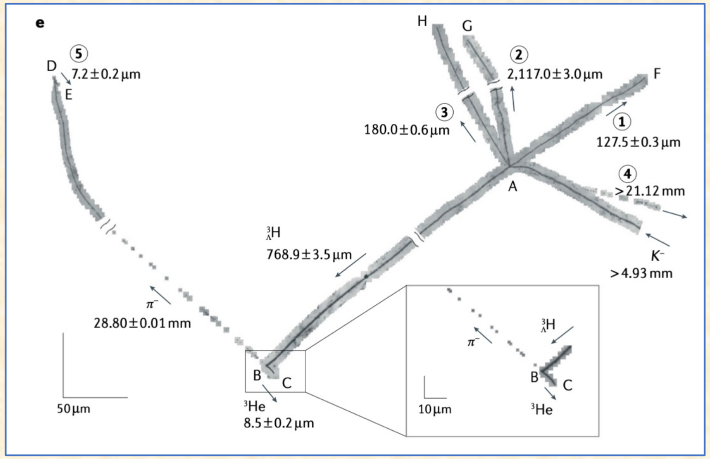


Fig. 1 | **The WASA-FRS hypernuclear experiment. a** | Schematic drawing of the fragment separator (FRS) at GSI. The ^{6}Li primary beams at 2 *A* GeV are delivered to the diamond target located at the mid-focal plane of the FRS, referred to as S2, to produce hypernuclei of interest. Residual nuclei of the π^- weak decays of hypernuclei are transported from S2 to S4 in the FRS, and measured precisely with a momentum-resolving power of 10^{-4}. The π^- mesons produced by the hypernuclear decays are measured at S2 by the Wide Angle Shower Apparatus (WASA) central detector. **b** | The WASA central detector. Panel **b** is adapted with permission from REF.[76].



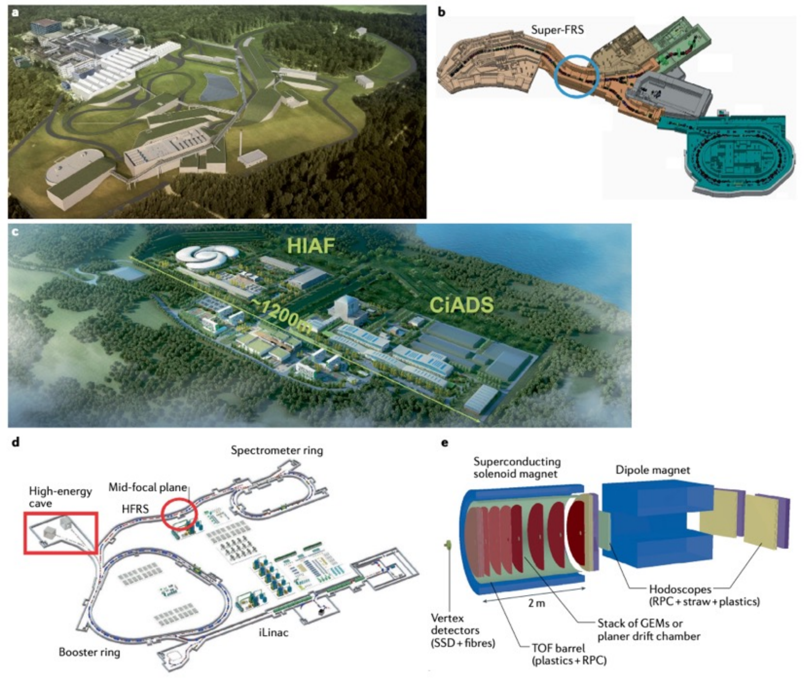


Fig. 3 | **Upcoming hypernuclear experiments. a** | A rendered bird's-eye view image of the Facility for Antiproton and Ion Research (FAIR) facility. **b** | A schematic layout of the NUSTAR facility. The Super-FRS is shown with its pre-separator and main separator in light brown and orange, respectively. A dedicated experimental setup for hypernuclear experiments will be installed in the mid-focal plane, indicated by the blue circle. **c** | A rendered bird's-eye view image of the High Intensity Heavy-ion Accelerator Facility (HIAF), together with the China initiative Accelerator Driven System (CiADS). **d** | Layout of the HIAF accelerator complex. **e** | The proposed detector setup in the high-energy cave. A part of the setup with the superconducting solenoid magnet will also be used in the mid-focal plane (indicated by the red circle in panel **d**) of the high-energy fragment separator (HFRS). GEMs, gas electron multipliers; RPC, resistive plate chamber; SSD, Si-strip detector; TOF, time-of-flight. Panel **b** is adapted with permission from REF.[76].

TRS et al., Nature Reviews Physics, 803-813 (2021)