Hypernuclear physics with heavy ion beams, nuclear emulsions and machine learning

Take R. Saito

High Energy Nuclear Physics Laboratory,

Cluster for Pioneering Research (CPR),

RIKEN,

Japan

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

FRS/NUSTAR department,

GSI Helmholtz Center for Heavy Ion Research,

Germany

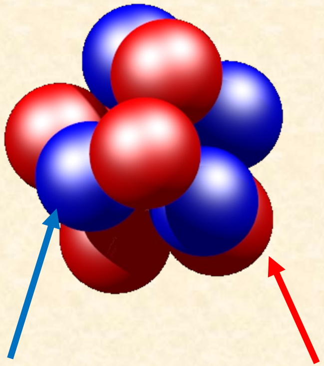
Saitama University

Japan

NSTAR2024, York, UK, 17th – 21st June, 2024

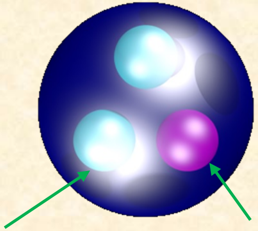
Quarks and sub-atomic nuclei

Sub-atomic nucleus



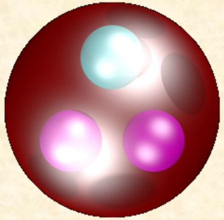
Hyperon	Quarks	$I(J^P)$	Mass (MeV)
Λ	uds	$0(1/2^+)$	1115
Σ^+	uus	$1(1/2^+)$	1189
Σ^0	uds	$1(1/2^+)$	1193
Σ^-	dds	$1(1/2^+)$	1197
Ξ^0	uss	$1/2(1/2^+)$	1315
Ξ^-	dss	$1/2(1/2^+)$	1321
Ω^-	sss	$0(3/2^+)$	1672

neutron



d-quark u-quark

proton

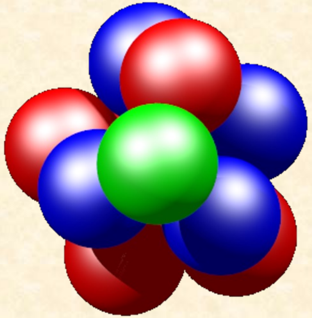


hyperon (Λ)

Lifetime: 10^{-10} s

s-quark: distinguishable from u- and d-quarks

hypernucleus



Micro-laboratory to study baryonic-interactions

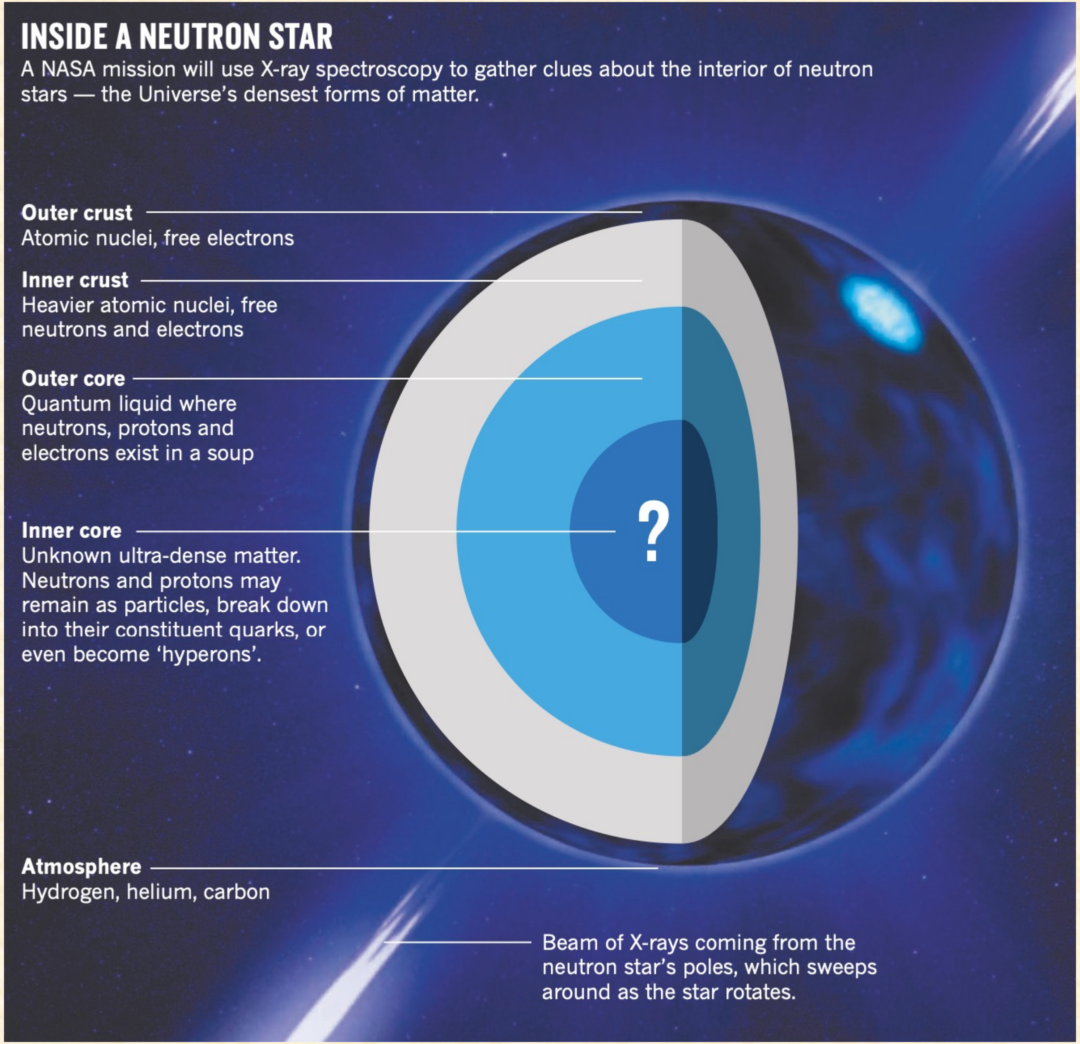

INSIDE A NEUTRON STAR
A NASA mission will use X-ray spectroscopy to gather clues about the interior of neutron stars — the Universe's densest forms of matter.
Outer crust
Atomic nuclei, free electrons
Inner crust
Heavier atomic nuclei, free neutrons and electrons
Outer core
Quantum liquid where neutrons, protons and electrons exist in a soup
Inner core
Unknown ultra-dense matter. Neutrons and protons may remain as particles, break down into their constituent quarks, or even become 'hyperons'.
?
Atmosphere
Hydrogen, helium, carbon
Beam of X-rays coming from the neutron star's poles, which sweeps around as the star rotates.

Chart of ordinary nuclei

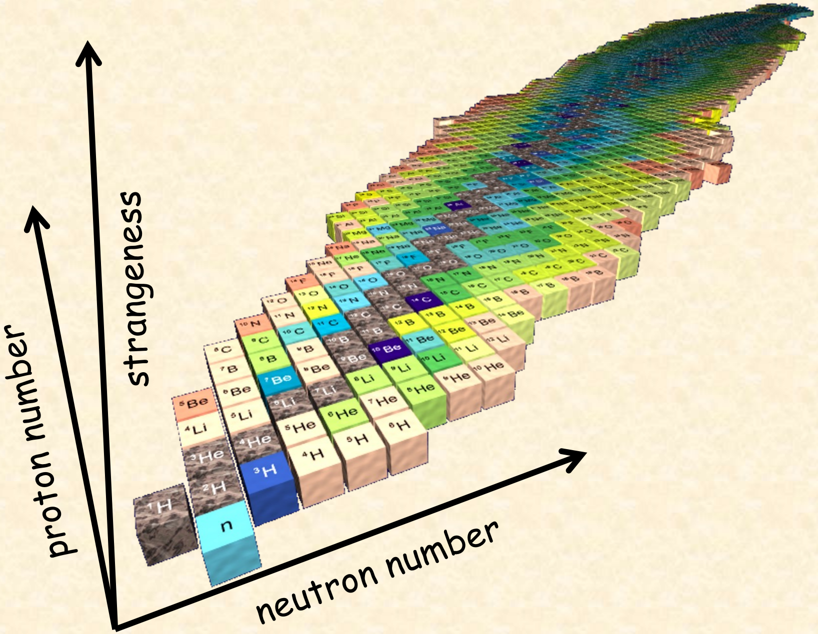
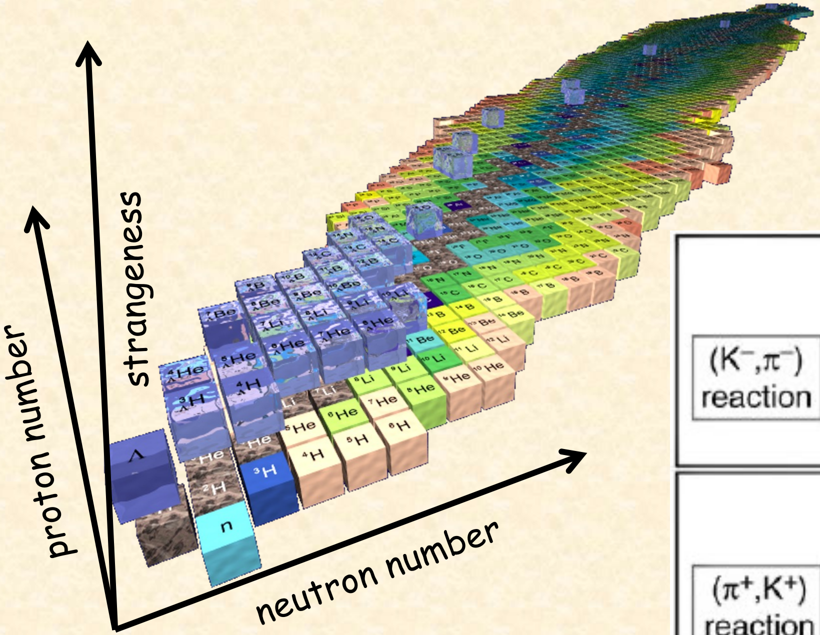


Chart of single-strangeness hypernuclei



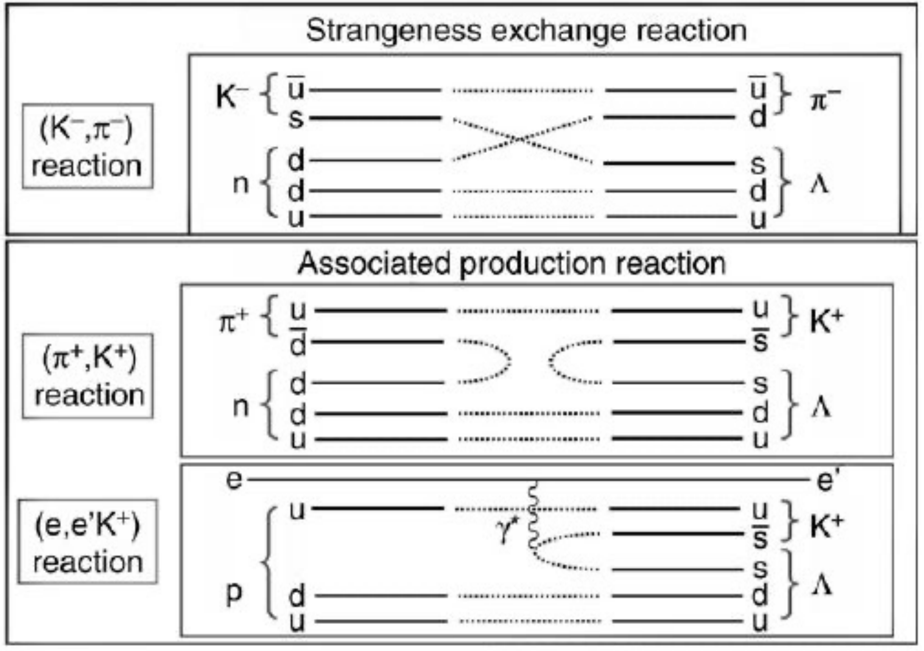
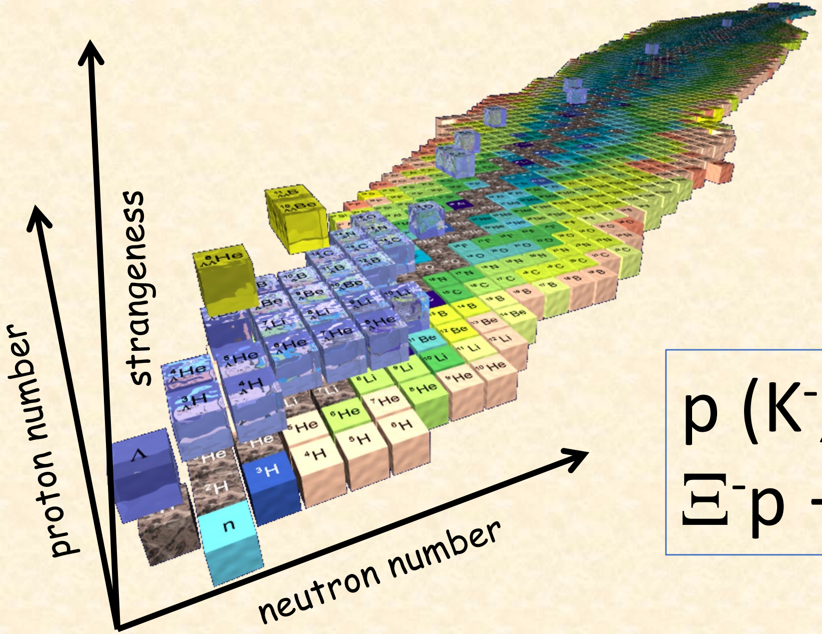


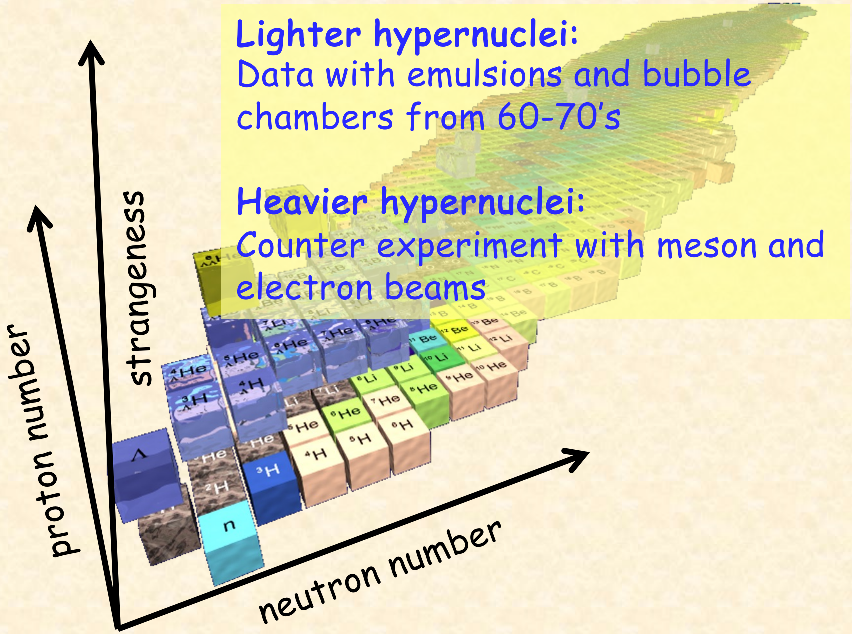
Chart of double-strangeness hypernuclei



$p\,(K^-,K^+)\,\Xi^-$

$\Xi^- p \rightarrow \Lambda\Lambda$

Chart of double-strangeness hypernuclei



Lighter hypernuclei:
Data with emulsions and bubble chambers from 60-70's

Heavier hypernuclei:
Counter experiment with meson and electron beams

Advantage
- Precise spectroscopy
  - Structure in detail
- Clean experiment

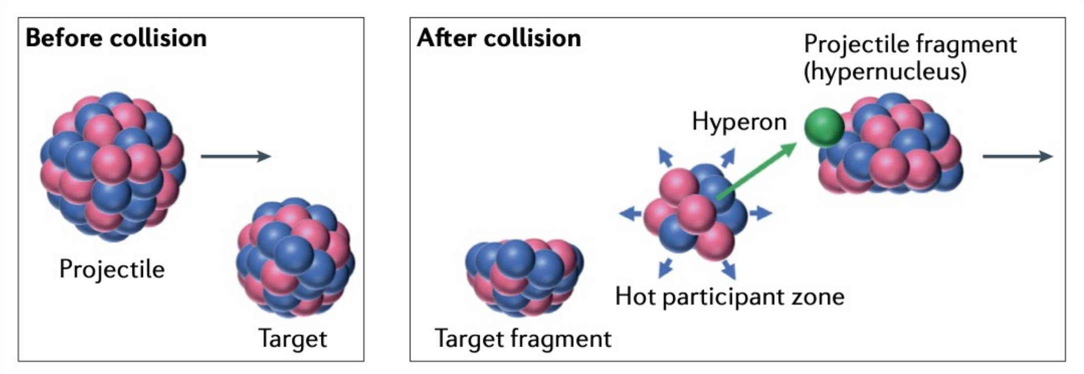
Difficulties
- Limited isospin
- Small momentum transfer to separate hypernuclei
- Difficulties on decay studies
- Only up to double-strangeness

Hypernuclear spectroscopy with heavy ion beams

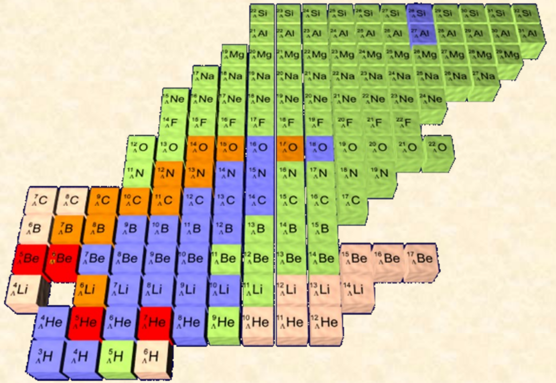
HypHI project, started in 2005

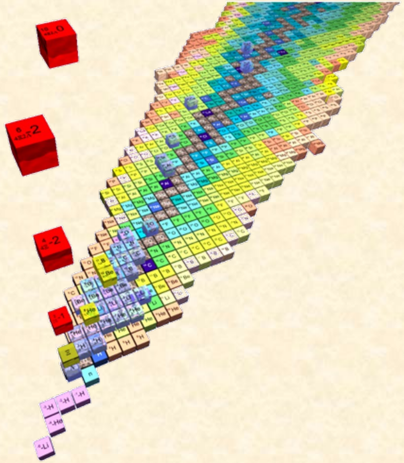
Hypernuclear spectroscoy with **H**eavy **I**on Beam

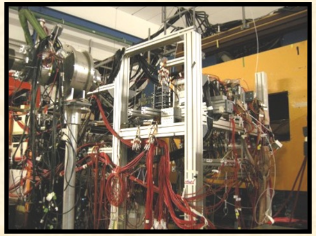
The HypHI Phase 0 at GSI (2006-2012)

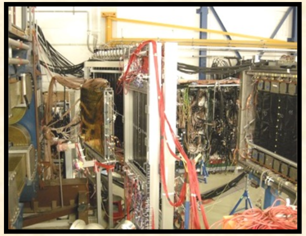


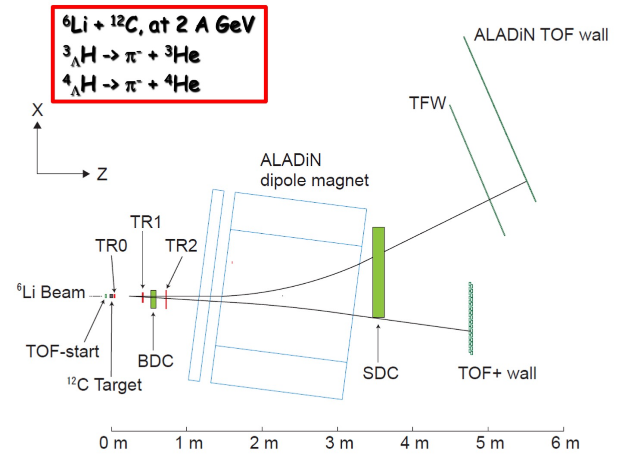
TRS et al., Nature Reviews Physics 3, 803-813 (2021)











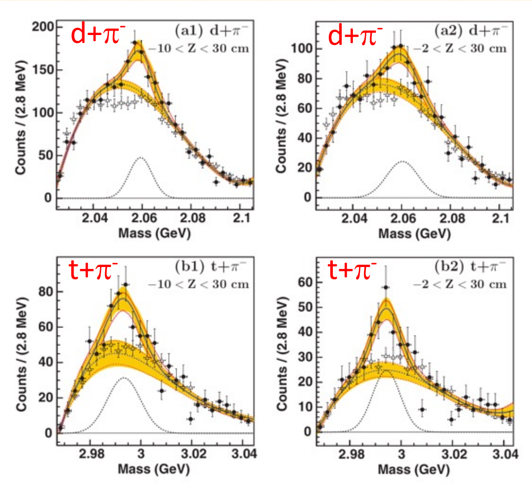
Two outcomes (mysteries) by HypHI

Signals indicating nnΛ bound state

<u>All theoretical calculations are negative</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



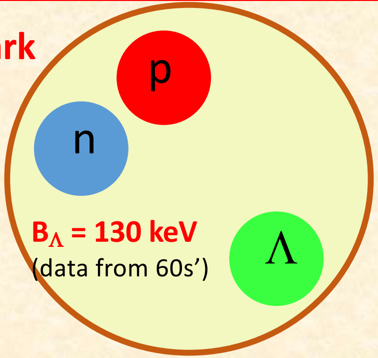
C. Rappold et al., PRC 88 (2013) 041001

Short lifetime of $^3_\Lambda$H

C. Rappold et al., Nucl. Phys. A 913 (2013) 170

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

Benchmark

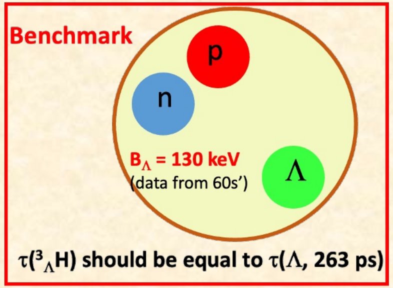


$\tau(^3_\Lambda\mathrm{H})$ should be equal to $\tau(\Lambda$, 263 ps)

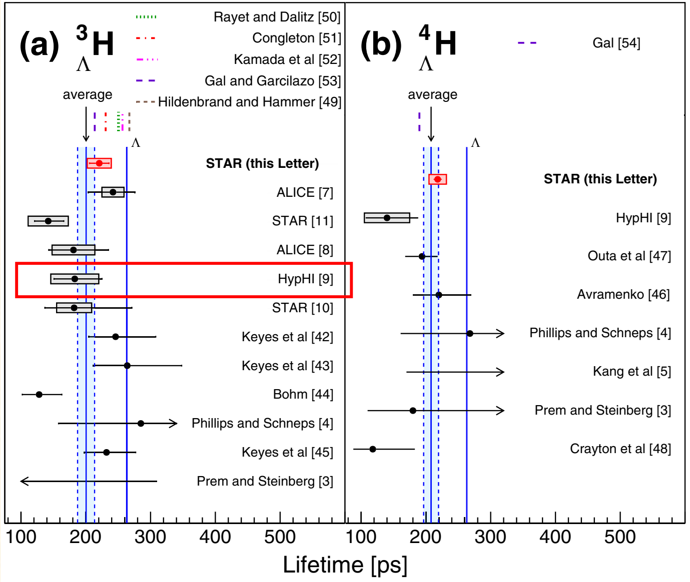
Stimulated other **<u>big</u>** experiments

The world situation of three-body hypernuclei

On hypertriton



Average
200 ± 13 ps



STAR Collaboration, PRL **128** (2022) 202301

On Λnn

$^{3}_{\Lambda}$H Binding energy

B$_{\Lambda}$($^{3}_{\Lambda}$H) : 0.13 ± 0.05 MeV

G. Bohm et al., NPB **4** (1968) 511

M. Juric et al., NPB **52** (1973) 1

STAR (2020)

0.41 ± 0.12 ± 0.11 MeV

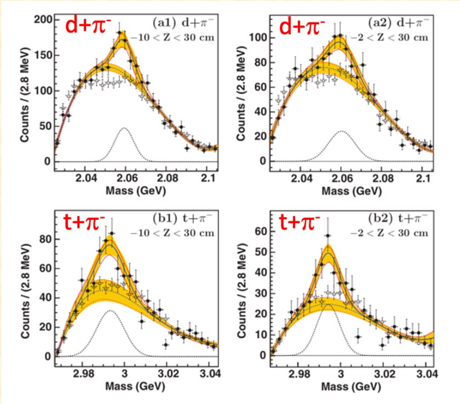
STAR Collaboration,

Nat. Phys. **16** (2020) 409

ALICE

0.102 ± 0.063 ± 0.067 MeV

Phys. Rev. Lett. **131**, 102302 (2023)



HypHI., PRC 88 (2013) 041001

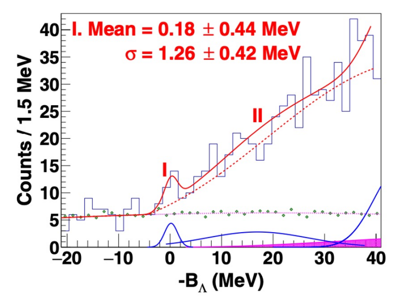
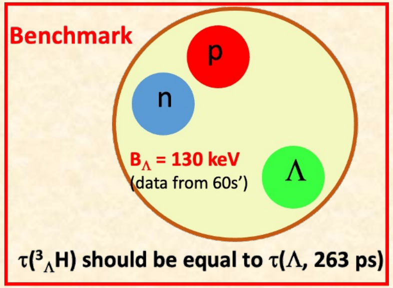


FIG. 5. The enlarged mass spectrum around the Λnn threshold. Two additional Gaussians were fitted together with the known contributions (the accidentals, the Λ quasifree, the free Λ, and the ^{3}He contamination). The one at the threshold is for the small peak, while the broad one is for the additional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

JLab E12-17-003., PRC 105 (2022) L051001

The world situation of three-body hypernuclei

On hypertriton



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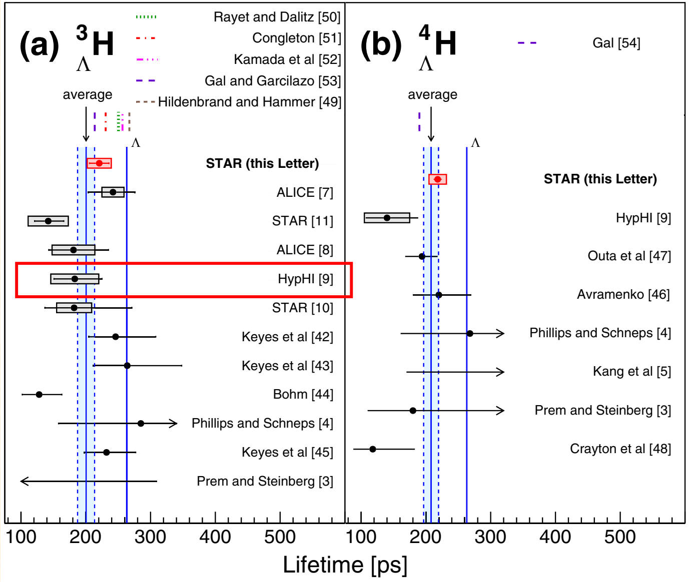

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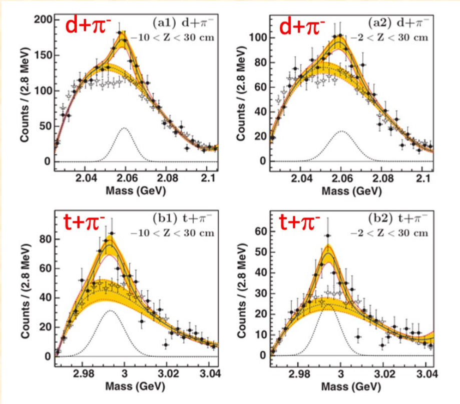

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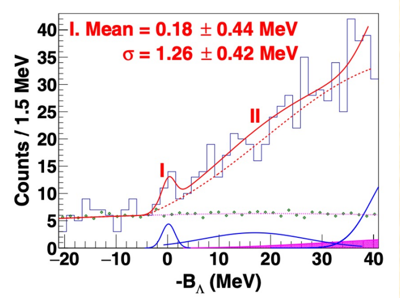

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JLab E12-17-003., PRC 105 (2022) L051001

Our approach:

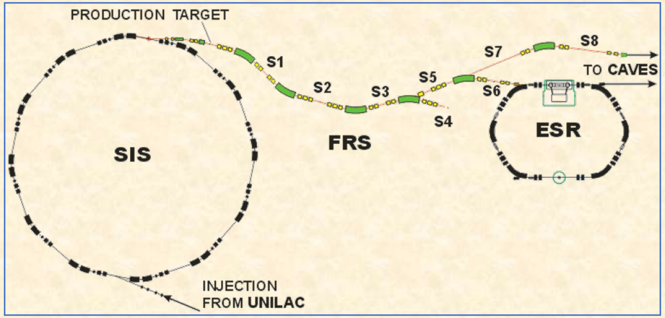
With heavy ion beams:

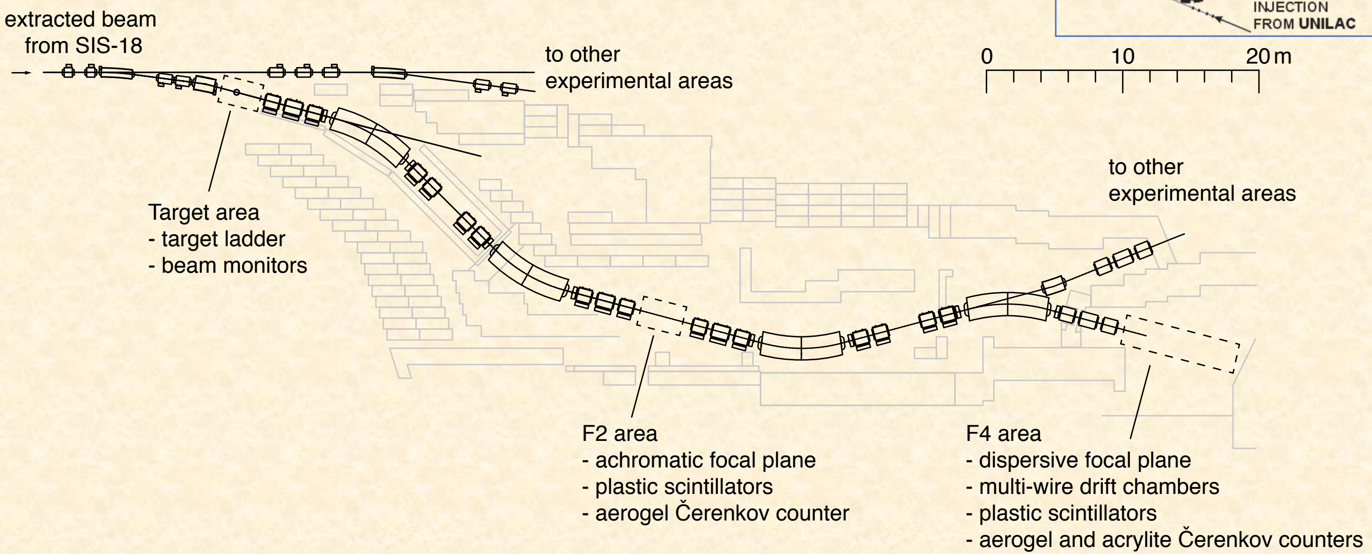
- Lifetime
- Λnn

Emulsion + Machine Learning

- Binding energy

The novel technique with FRS at GSI (2016-)





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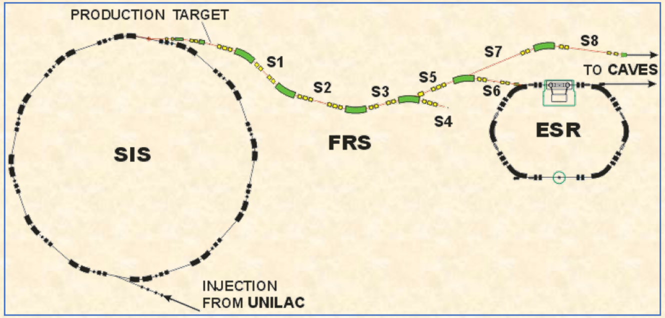

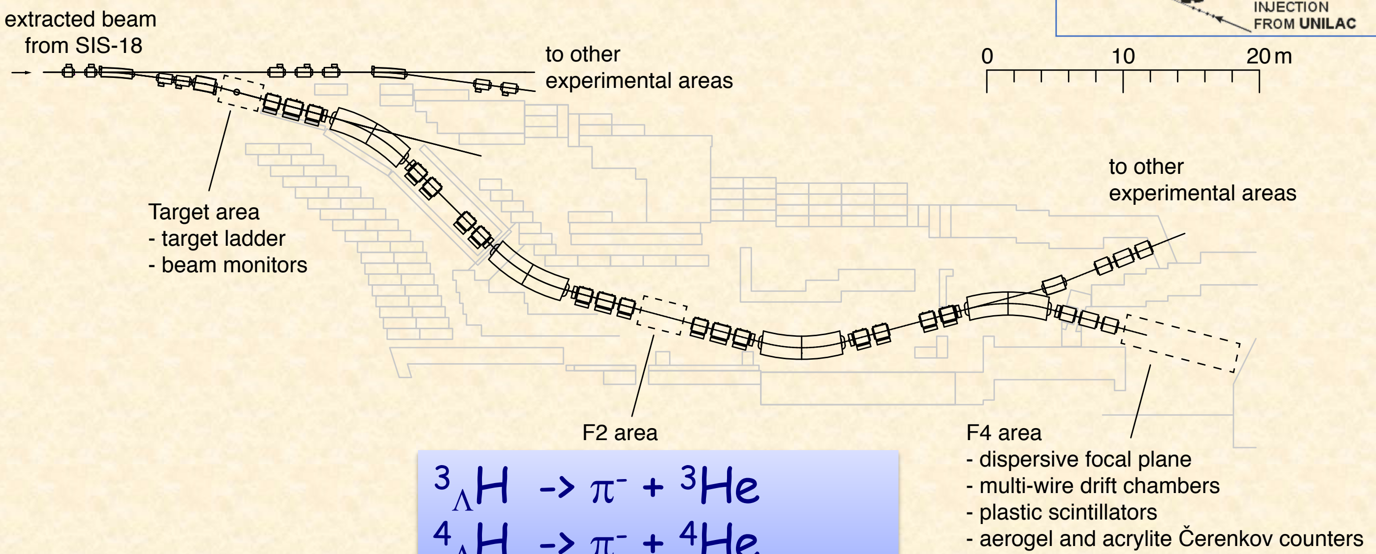

$^{3}_{\Lambda}H \rightarrow \pi^{-} + {}^{3}He$

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

$nn\Lambda \rightarrow \pi^{-} + d \quad + n$

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

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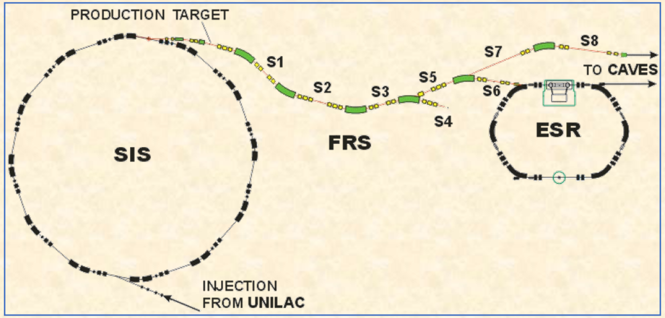

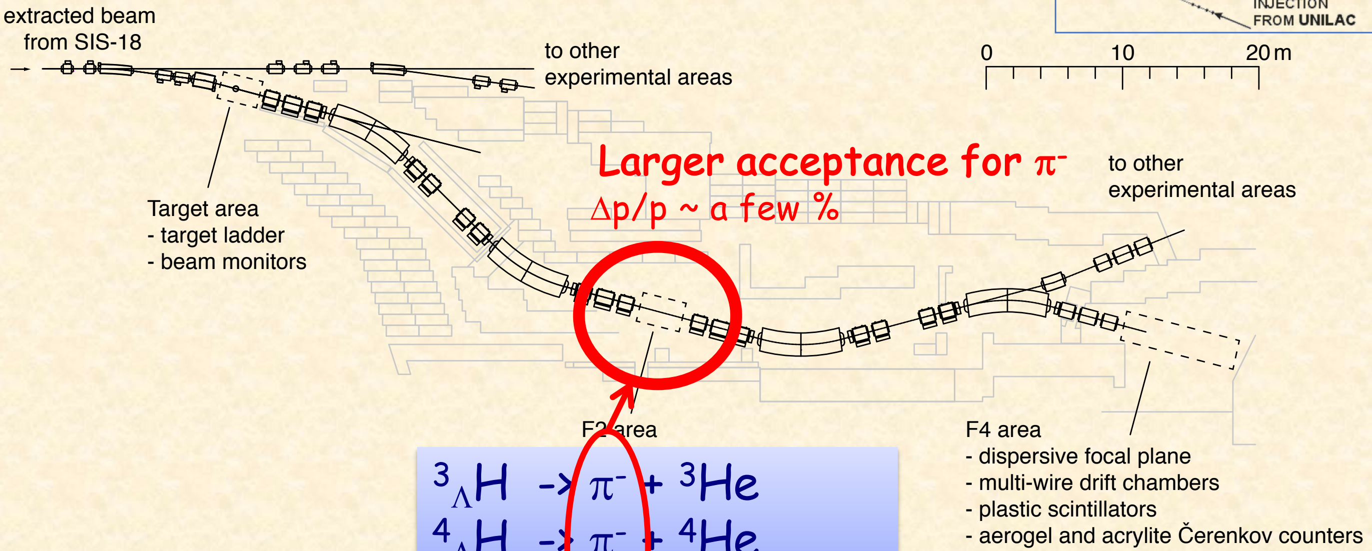

Larger acceptance for π^-

$\Delta p/p$ ~ a few %

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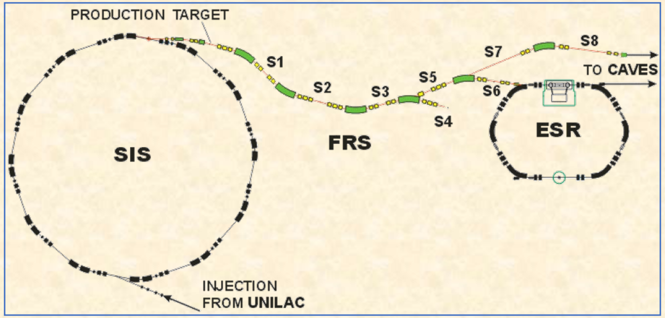

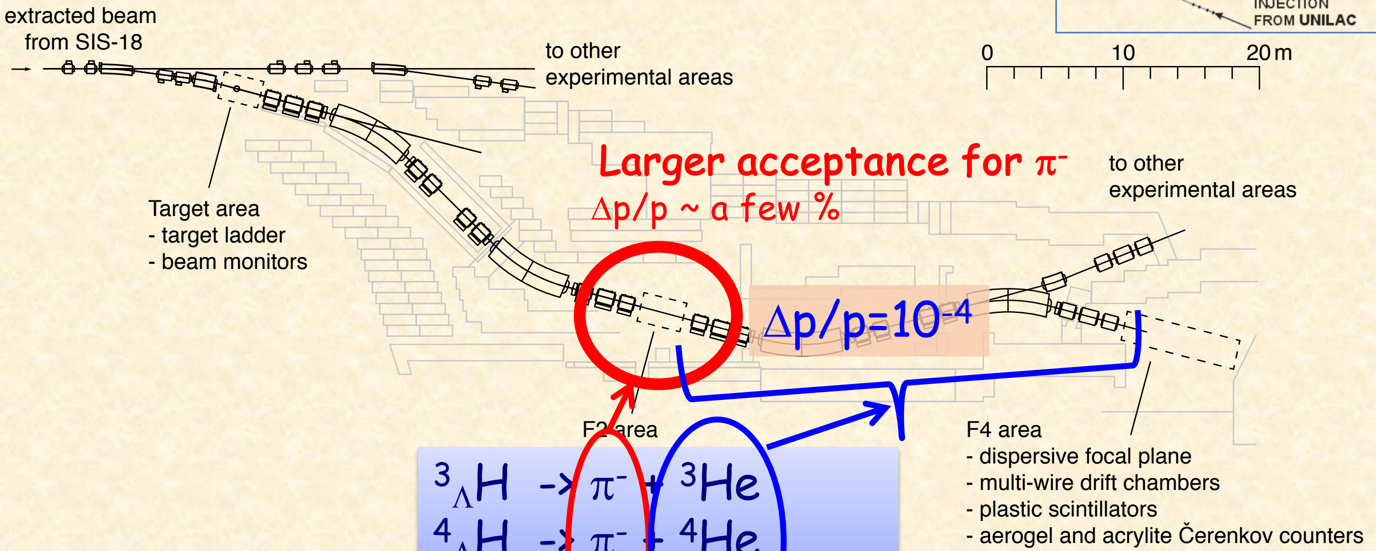

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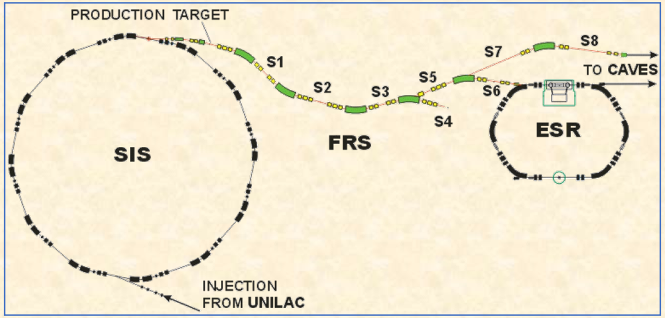

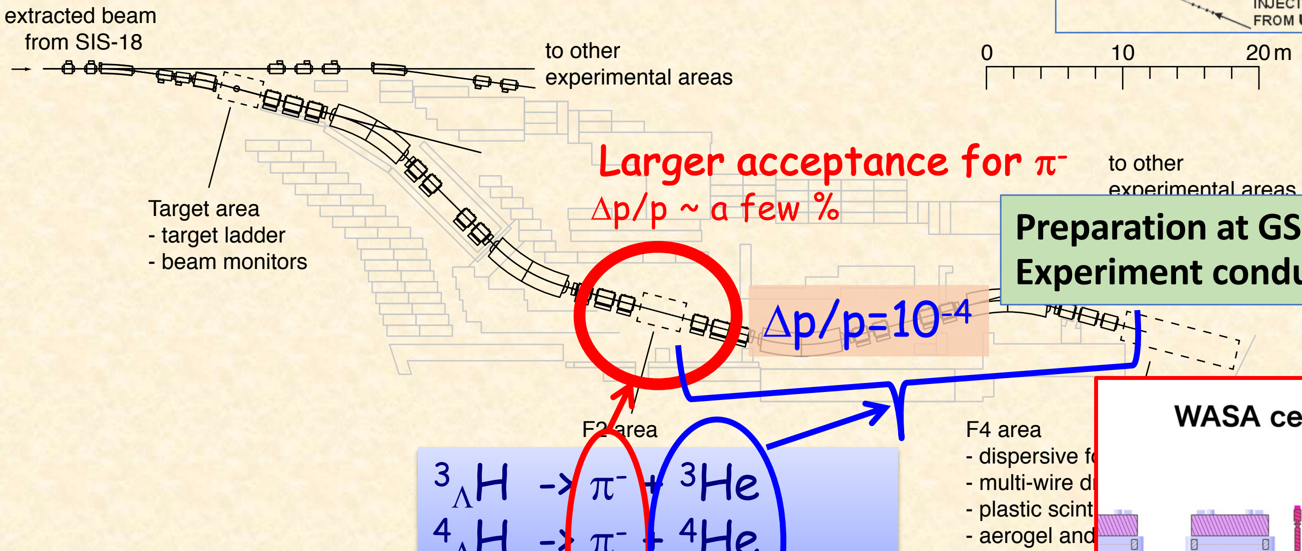

Larger acceptance for π^-

$\Delta p/p$ ~ a few %

$\Delta p/p=10^{-4}$

Preparation at GSI started in March 2019

Experiment conducted in January-March 2022

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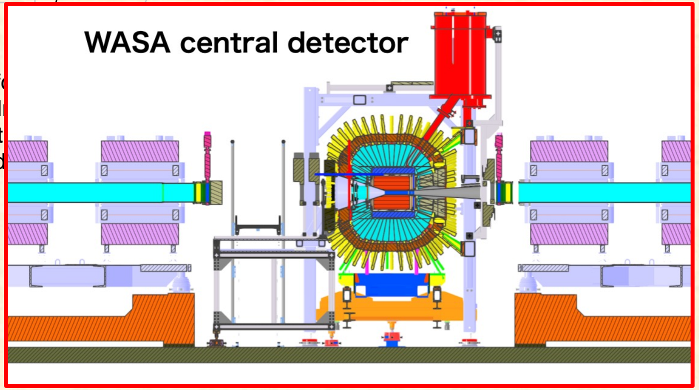
$^{4}_{\Lambda}H \rightarrow \pi^- + {}^{4}He$

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

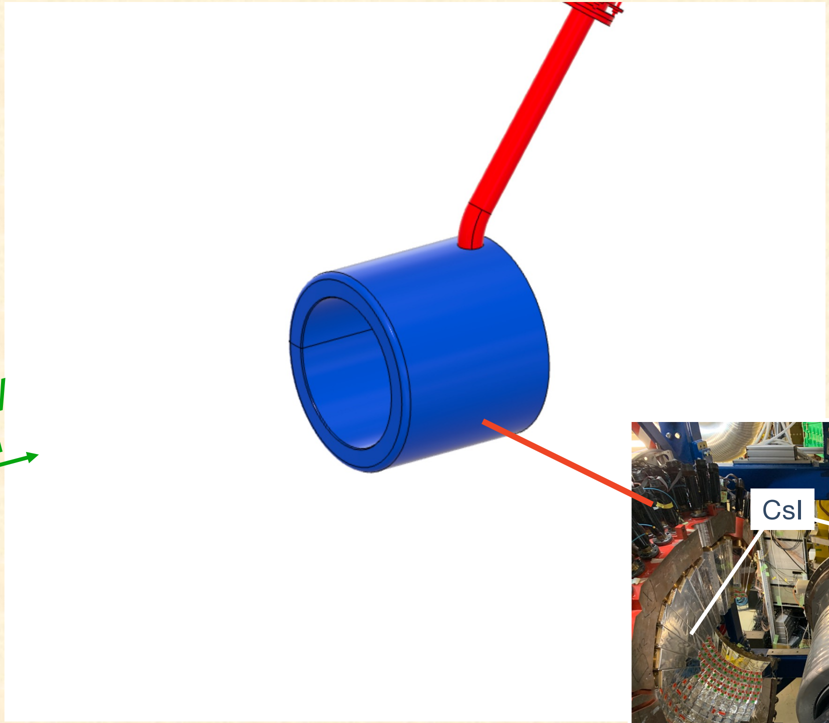
With $^{6}Li+^{12}C$ at 2 A GeV

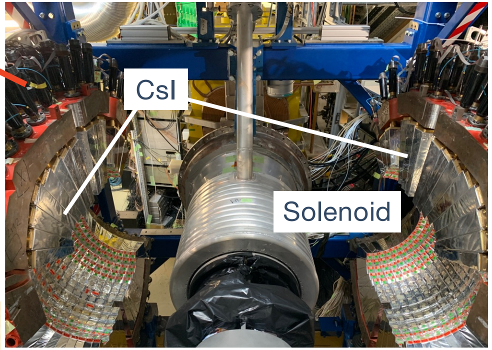


The WASA-FRS setup

Existing	Newly developed
WASA Solenoid CsI MDC	PSB / PSFE / PSBE / T0 Fiber Trackers Cryogenics Readout electronics

^{6}Li / ^{12}C, 1.96 A GeV
Beam





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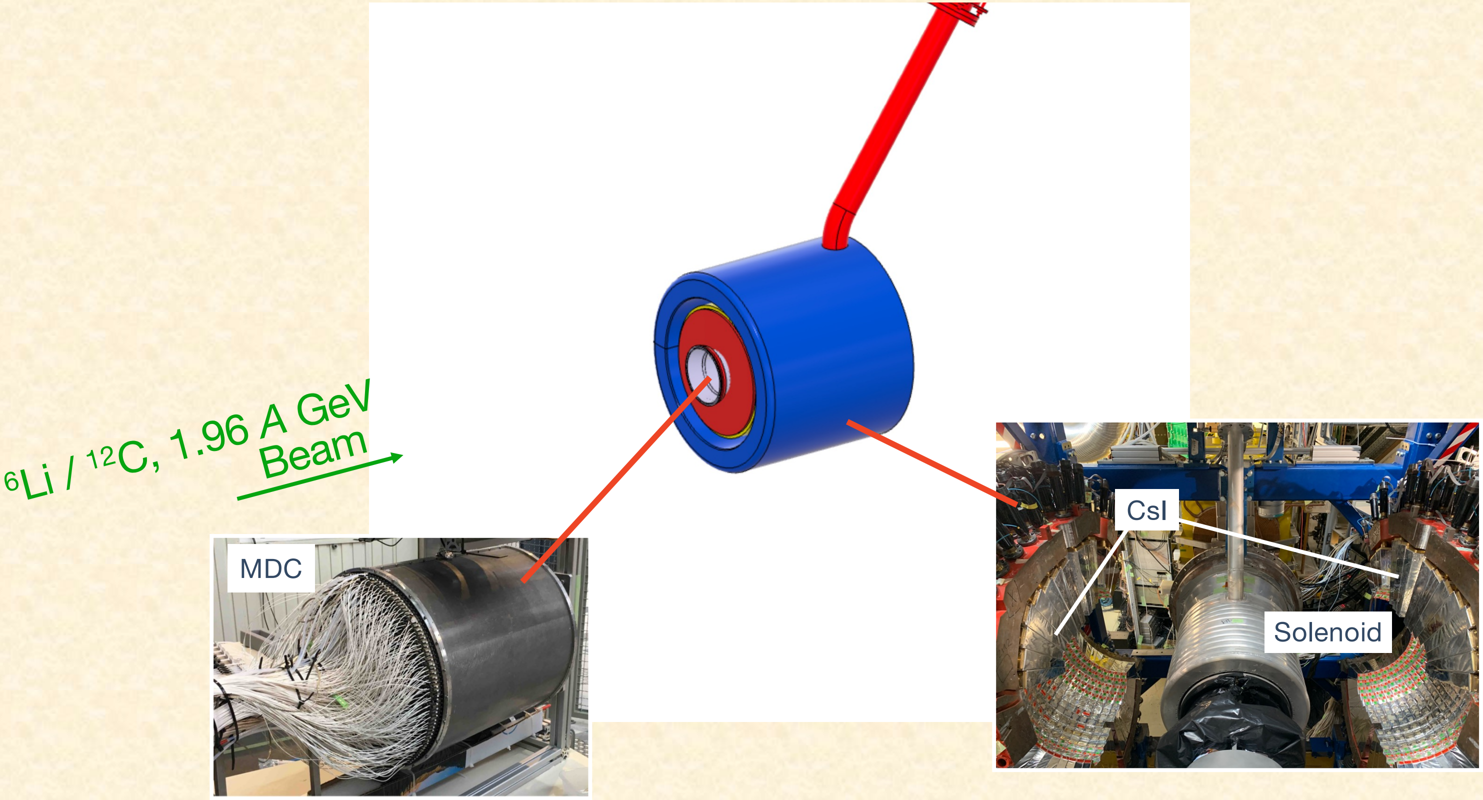

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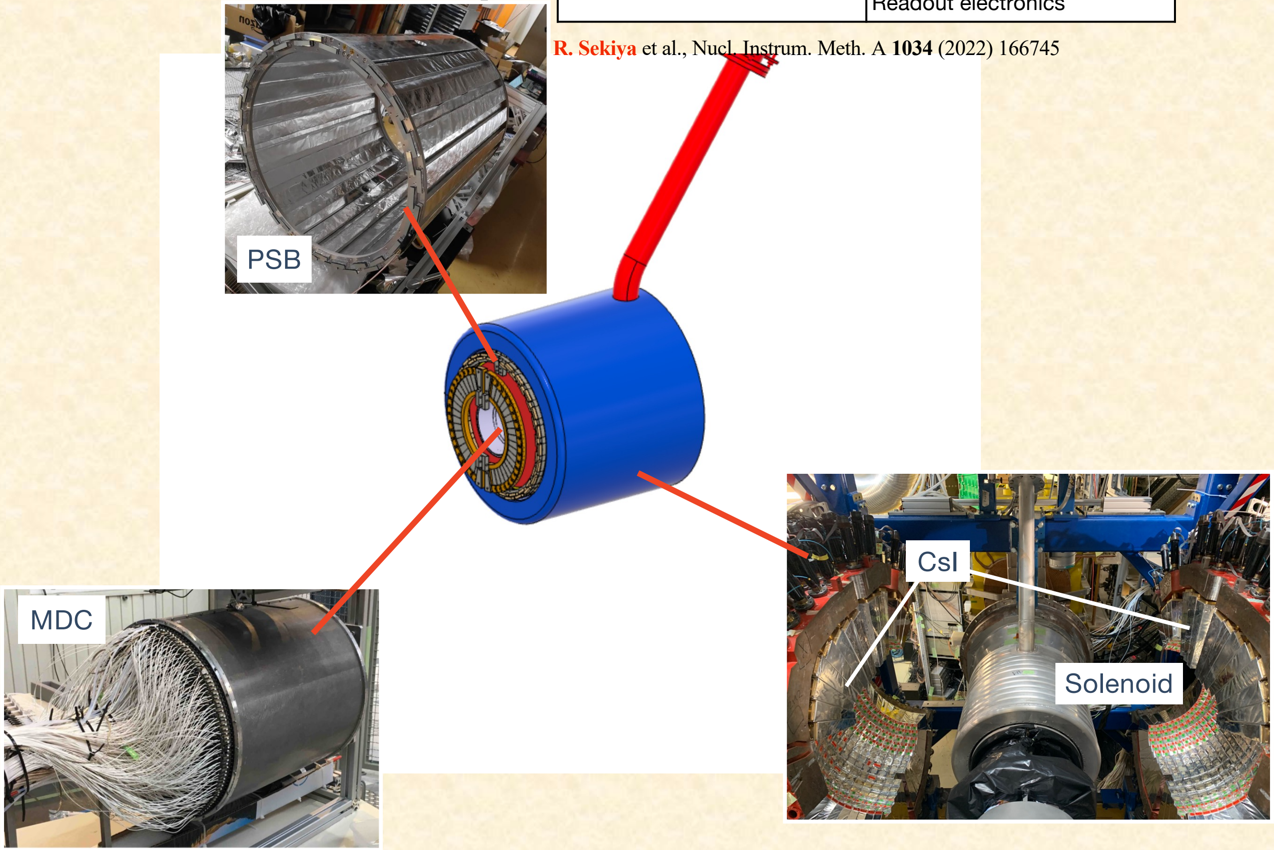
R. Sekiya et al., Nucl. Instrum. Meth. A **1034** (2022) 166745



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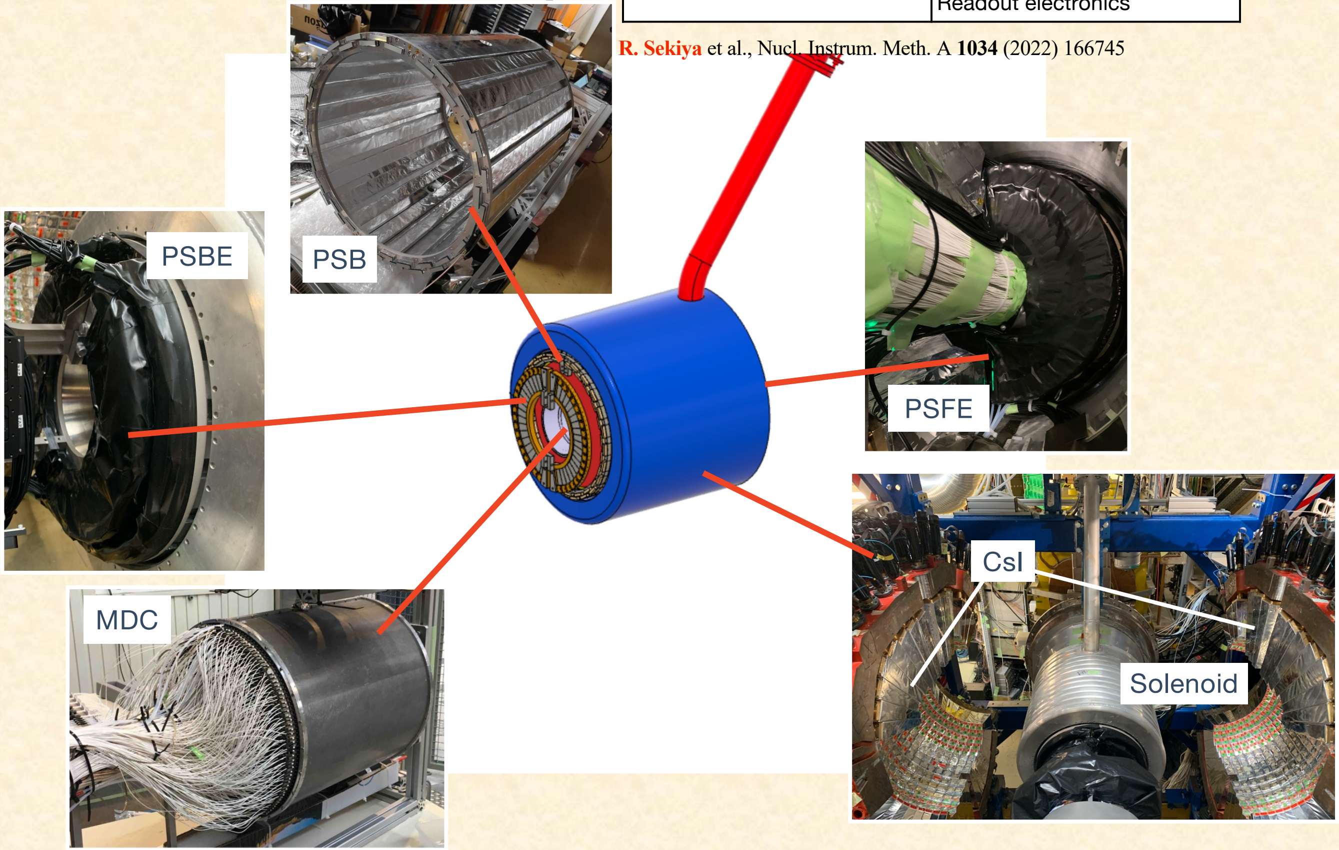

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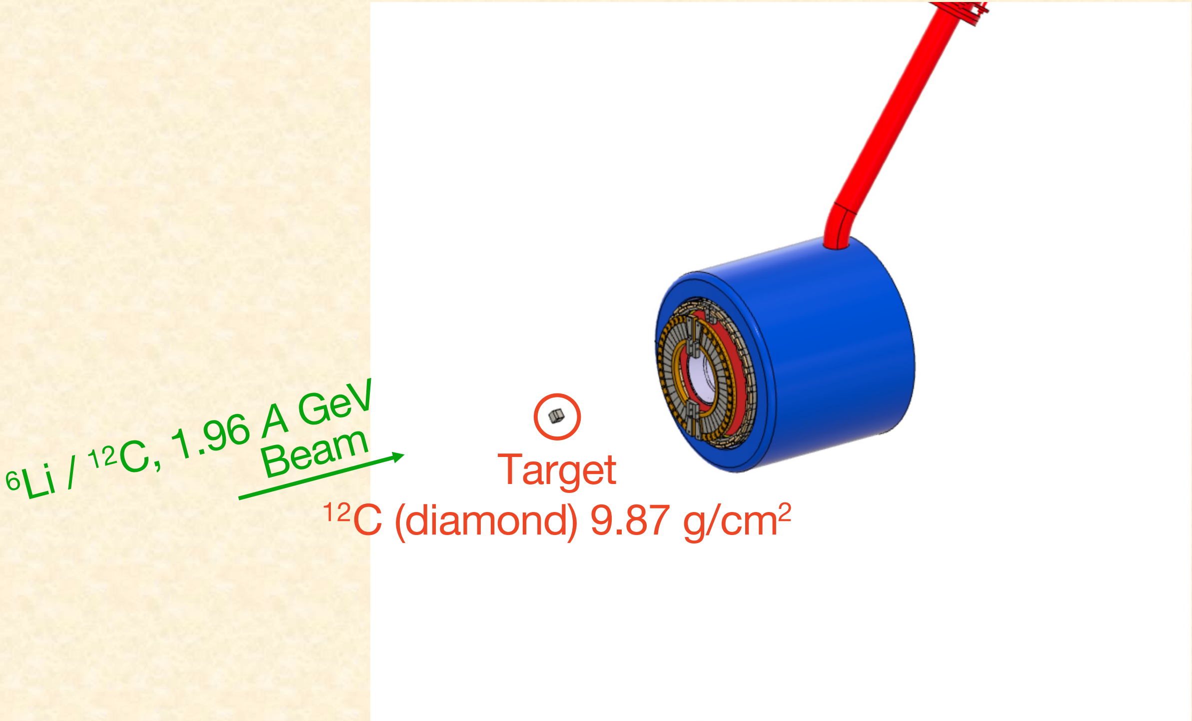

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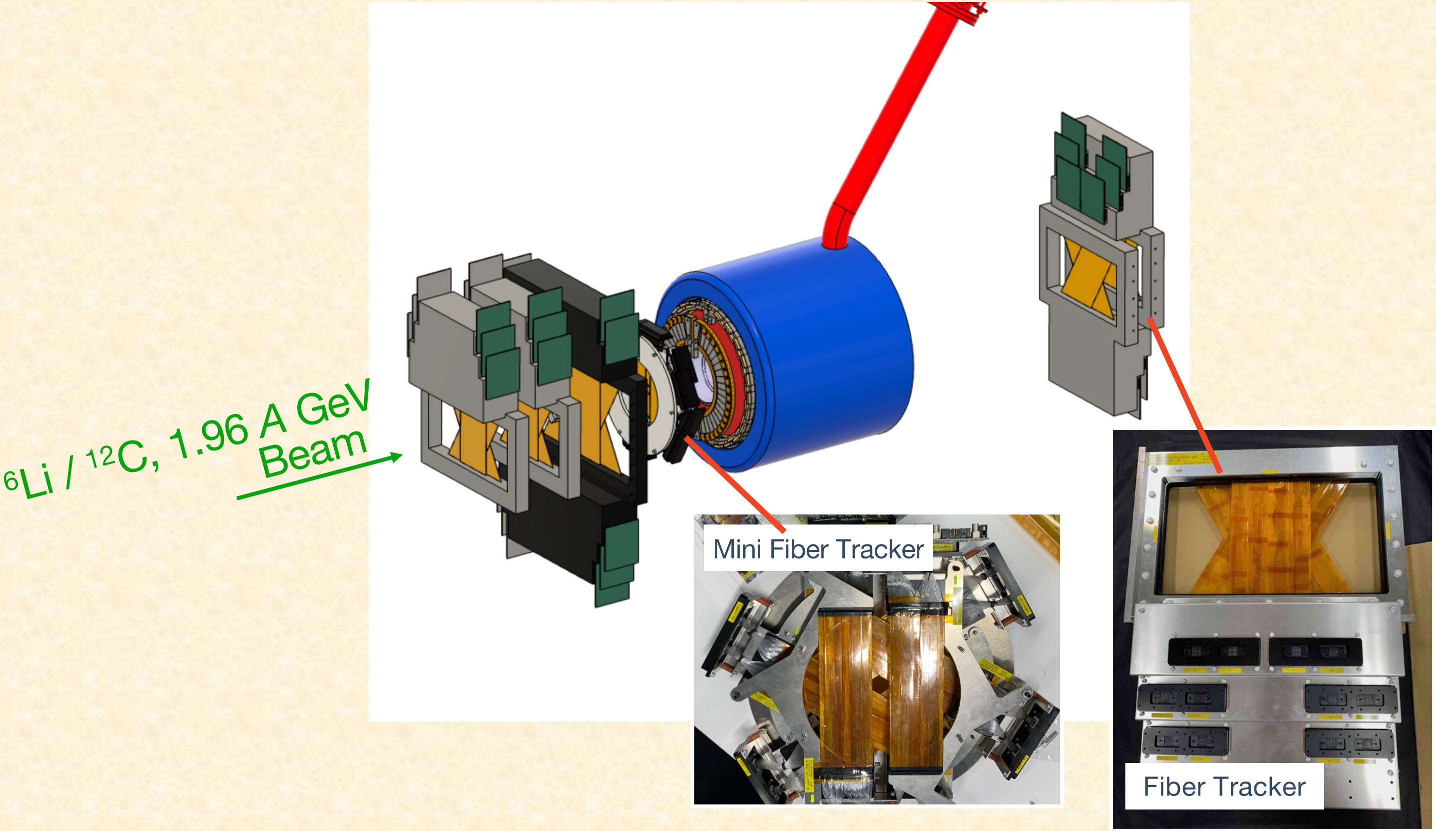

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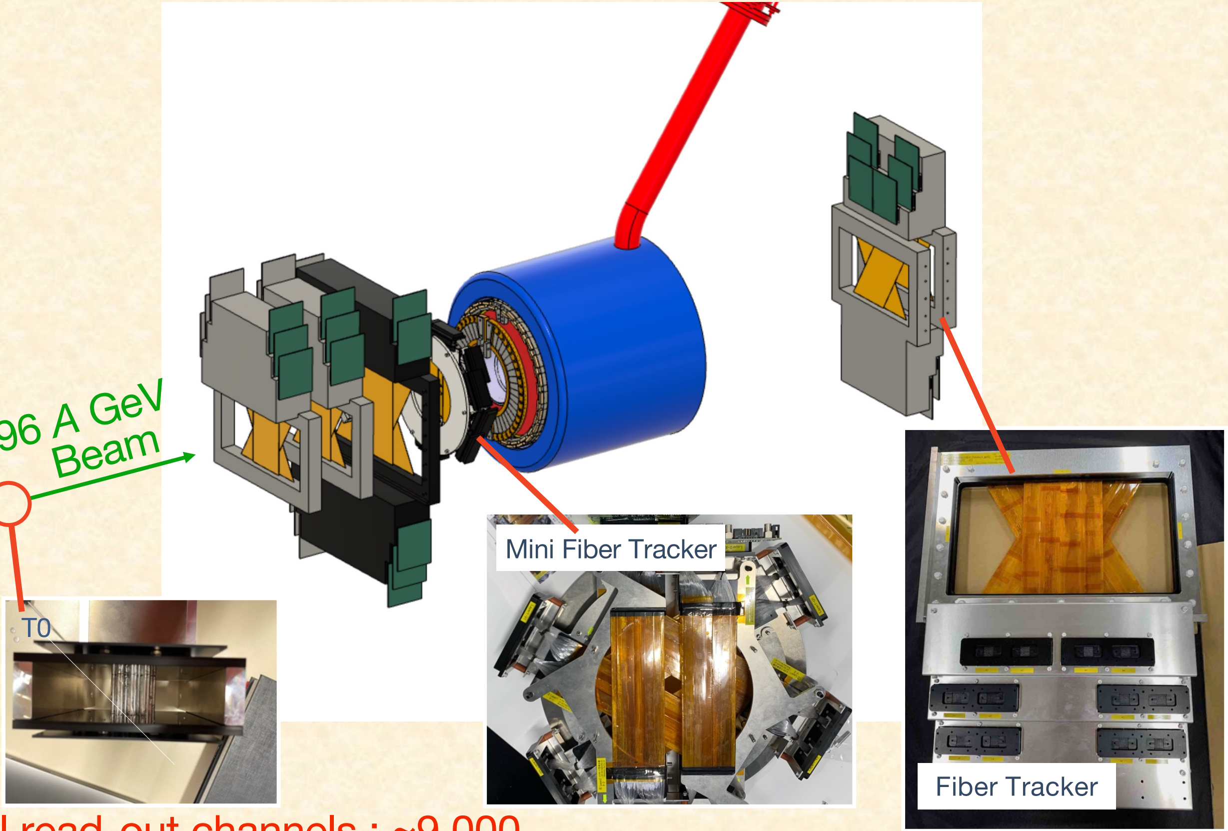

E. Liu, et al.,
to be published

Total read-out channels : ~9,000

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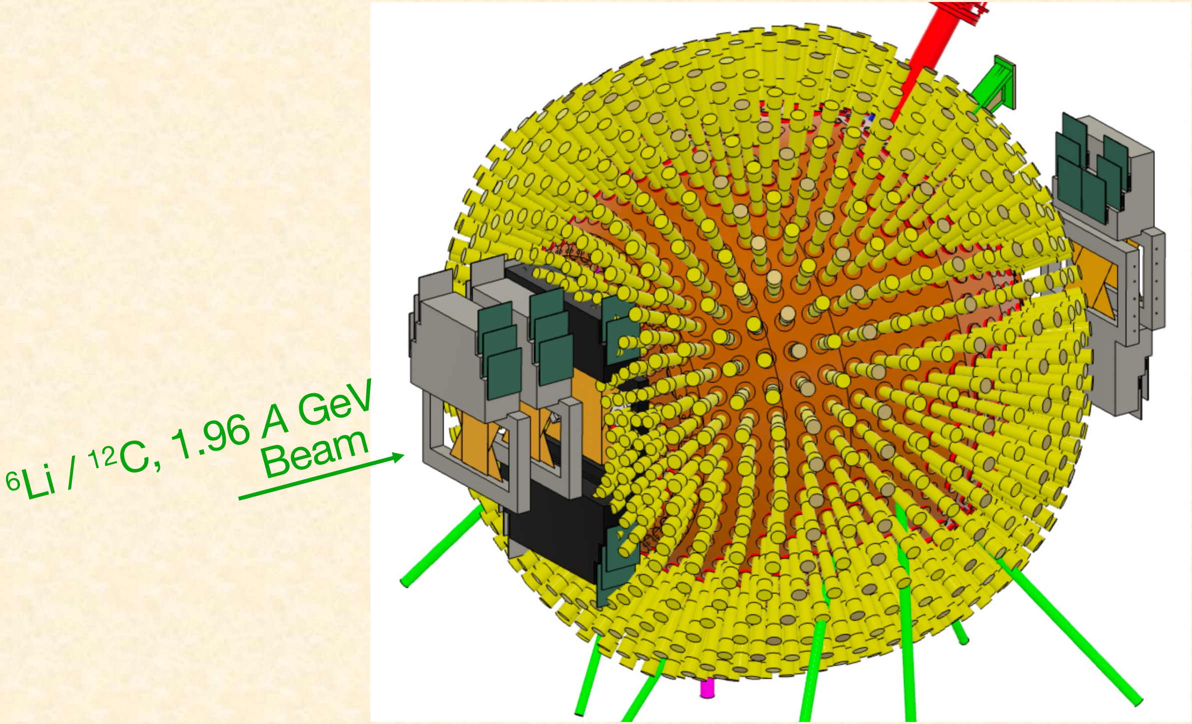

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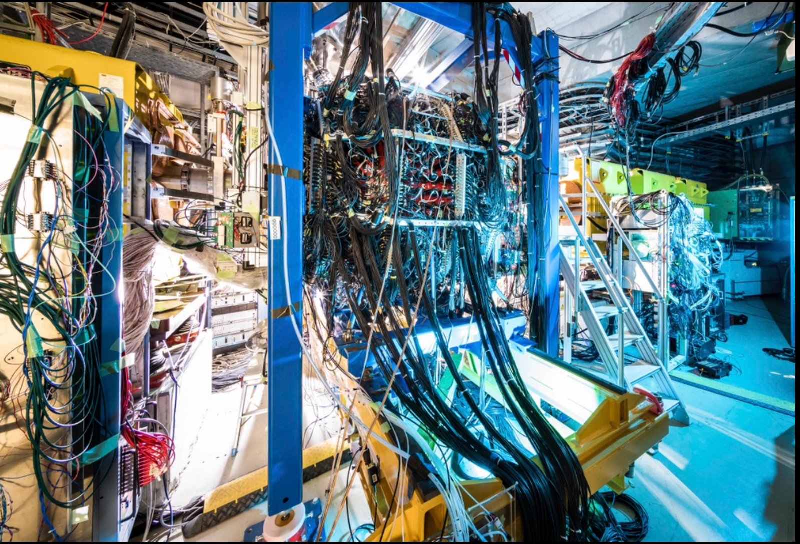
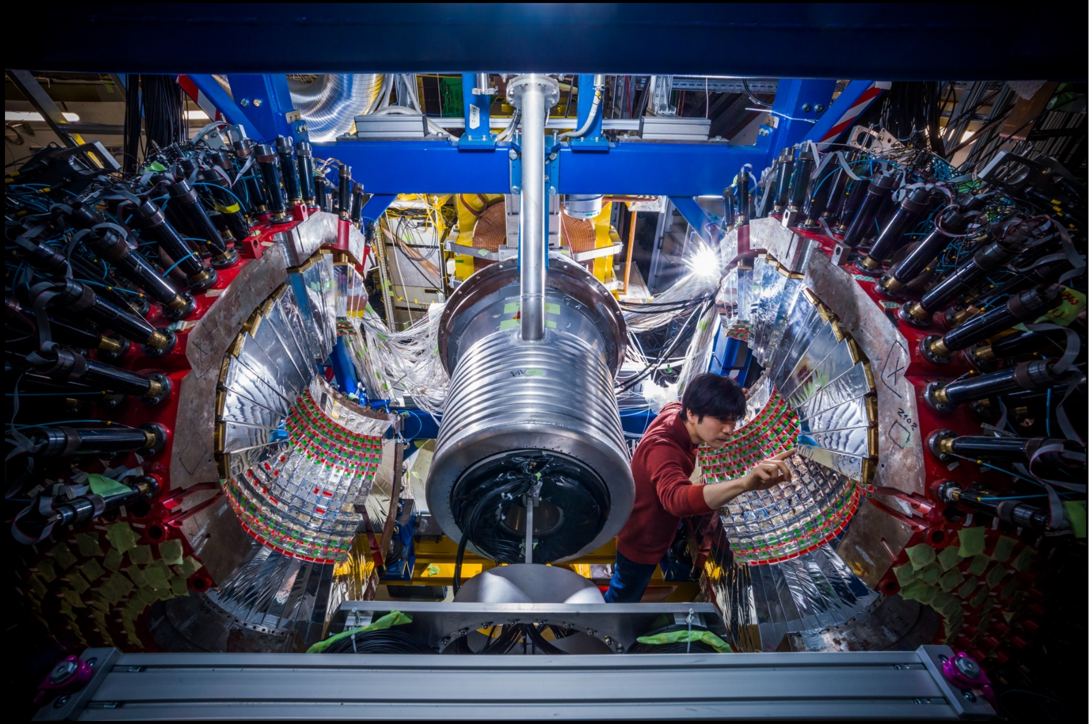




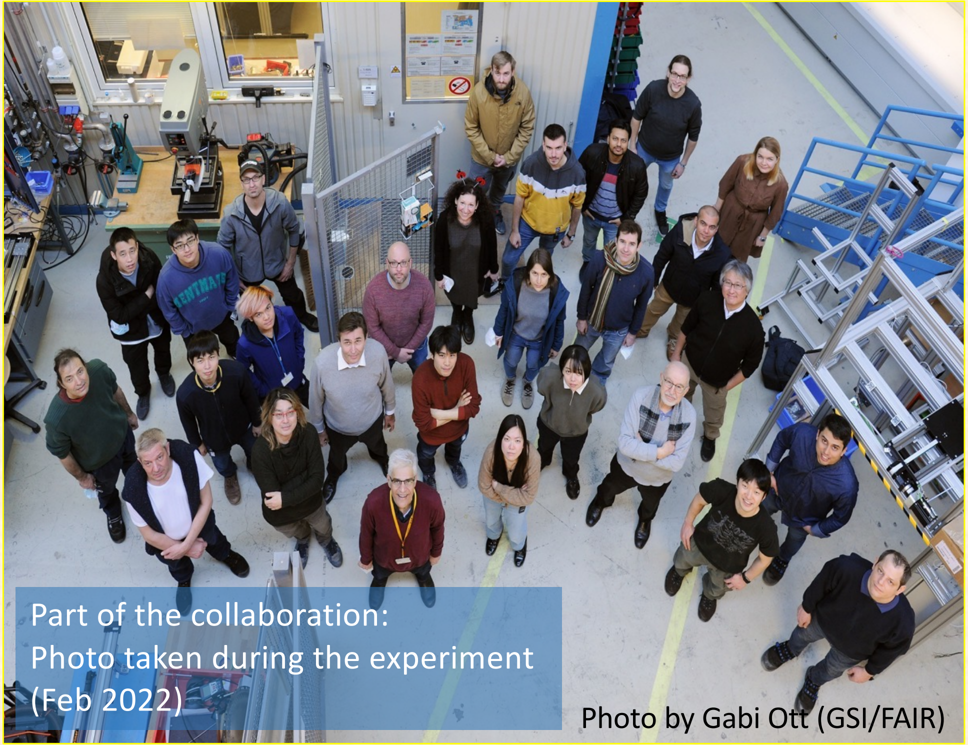
Photos by Jan Hosan and GSI/FAIR

The International WASA-FRS collaboration

T.R. Saito[a,b,c,1], P. Achenbach[d,e], H. Alibrahim Alfaki[b], F. Amjad[b], M. Armstrong[b,f], K.-H. Behr[b], J. Benlliure[g], Z. Brencic[h,i], T. Dickel[b,j], V. Drozd[b,k], S. Dubey[b], H. Ekawa[a], S. Escrig[l,a], M. Feijoo-Fontán[g], H. Fujioka[m], Y. Gao[a,n,o], H. Geissel[b,j], F. Goldenbaum[p], A. Graña González[g], E. Haettner[b], M.N. Harakeh[k], Y. He[a,c], H. Heggen[b], C. Hornung[b], N. Hubbard[b,q], K. Itahashi[r,s,2], M. Iwasaki[r,s], N. Kalantar-Nayestanaki[k], A. Kasagi[a,t], M. Kavatsyuk[k], E. Kazantseva[b], A. Khreptak[u,v], B. Kindler[b], R. Knoebel[b], H. Kollmus[b], D. Kostyleva[b], S. Kraft-Bermuth[w], N. Kurz[b], E. Liu[a,n,o], B. Lommel[b], V. Metag[j], S. Minami[b], D.J. Morrissey[x], P. Moskal[v,y], I. Mukha[b], A. Muneem[a,z], M. Nakagawa[a], K. Nakazawa[t], C. Nociforo[b], H.J. Ong[n,aa,ab], S. Pietri[b], J. Pochodzalla[d,e], S. Purushothaman[b], C. Rappold[l], E. Rocco[b], J.L. Rodríguez-Sánchez[g], P. Roy[b], R. Ruber[ac], S. Schadmand[b], C. Scheidenberger[b,j], P. Schwarz[b], R. Sekiya[ad,r,s], V. Serdyuk[p], M. Skurzok[v,y], B. Streicher[b], K. Suzuki[b,ae], B. Szczepanczyk[b], Y.K. Tanaka[a,3], X. Tang[n], N. Tortorelli[b], M. Vencelj[h], H. Wang[a], T. Weber[b], H. Weick[b], M. Will[b], K. Wimmer[b], A. Yamamoto[af], A. Yanai[ag,a], J. Yoshida[a,ah], J. Zhao[b,ai], (WASA-FRS/Super-FRS Experiment Collaboration)

[a] *High Energy Nuclear Physics Laboratory, RIKEN Cluster for Pioneering Research, RIKEN, 351-0198 Wako, Saitama, Japan,*
[b] *GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany,*
[c] *School of Nuclear Science and Technology, Lanzhou University, 730000 Lanzhou, China,*
[d] *Institute for Nuclear Physics, Johannes Gutenberg University, 55099 Mainz, Germany,*
[e] *Helmholtz Institute Mainz, Johannes Gutenberg University, 55099 Mainz, Germany,*
[f] *Institut für Kernphysik, Universität Köln, 50923 Köln, Germany,*
[g] *Universidade de Santiago de Compostela, 15782 Santiago de Compostela, Spain,*
[h] *Jozef Stefan Institute, 1000 Ljubljana, Slovenia,*
[i] *University of Ljubljana, 1000 Ljubljana, Slovenia,*
[j] *Universität Gießen, 35392 Gießen, Germany,*
[k] *University of Groningen, 9747 AA Groningen, The Netherlands,*
[l] *Instituto de Estructura de la Materia - CSIC, 28006 Madrid, Spain,*
[m] *Tokyo Institute of Technology, 152-8550 Tokyo, Japan,*
[n] *Institute of Modern Physics, Chinese Academy of Sciences, 730000 Lanzhou, China,*
[o] *School of Nuclear Science and Technology, University of Chinese Academy of Sciences, 100049 Beijing, China,*
[p] *Institut für Kernphysik, Forschungszentrum Jülich, 52425 Jülich, Germany,*
[q] *Institut für Kernphysik, Technische Universität Darmstadt, 64289 Darmstadt, Germany,*
[r] *Meson Science Laboratory, Cluster for Pioneering Research, RIKEN, 2-1 Hirosawa, 351-0198 Wako, Saitama, Japan,*
[s] *Nishina Center for Accelerator-Based Science, RIKEN, 2-1 Hirosawa, 351-0198 Wako, Saitama, Japan,*
[t] *Graduate School of Engineering, Gifu University, 501-1193 Gifu, Japan ,*
[u] *INFN, Laboratori Nazionali di Frascati, Frascati, 00044 Roma, Italy,*
[v] *Institute of Physics, Jagiellonian University, 30-348 Kraków, Poland,*
[w] *TH Mittelhessen University of Applied Sciences, 35390 Gießen, Germany,*
[x] *National Superconducting Cyclotron Laboratory, Michigan State University, MI 48824 East Lansing, USA,*
[y] *Center for Theranostics, Jagiellonian University, 30-348 Krakow, Poland,*
[z] *Faculty of Engineering Sciences, Ghulam Ishaq Khan Institute of Engineering Sciences and Technology, 23640 Topi, Pakistan,*
[aa] *Joint Department for Nuclear Physics, Lanzhou University and Institute of Modern Physics, Chinese Academy of Sciences, 730000 Lanzhou, China,*
[ab] *Research Center for Nuclear Physics, Osaka University, 567-0047 Osaka, Japan,*
[ac] *Uppsala University, 75220 Uppsala, Sweden,*
[ad] *Kyoto University, 606-8502 Kyoto, Japan,*
[ae] *Ruhr-Universiät Bochum, Institut für Experimentalphysik I, 44780 Bochum, Germany,*
[af] *KEK, 305-0801 Tsukuba, Ibaraki, Japan,*
[ag] *Saitama University, Sakura-ku, 338-8570 Saitama, Japan,*
[ah] *Tohoku University, 980-8578 Sendai, Japan,*
[ai] *Peking University, 100871 Beijing, China,*

Author list of the EMIS2022 proceedings



Part of the collaboration:
Photo taken during the experiment
(Feb 2022)

Photo by Gabi Ott (GSI/FAIR)

Collaboration of hypernuclear physicists and low-energy nuclear physicists

Data taking (January – March 2022)

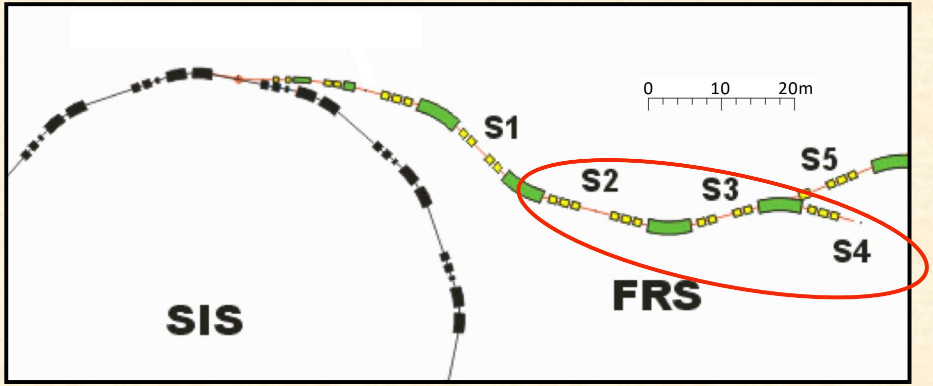
Run	Period	Data size
Commissioning run	28th Jan. - 7th Feb.	7 TB
Physics run for η' nuclei	22nd Feb. - 28th Feb.	40 TB
Physics run for HypHI	10th Mar. - 19th Mar.	48 TB

92 % of the prop.

Acquired data for S447 (hypernuclei)

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

FRS analysis

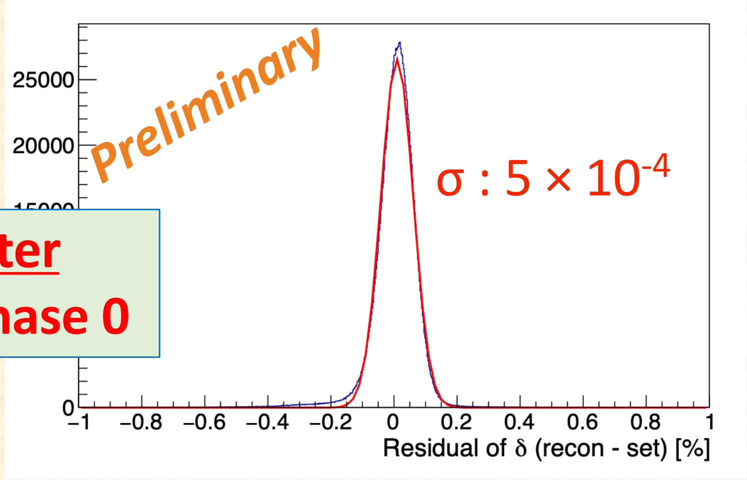


Fragments PID

- identified in S3 - S4
- Plastic scintillators
- TOF, dE

Momentum and Angle reconstruction

- S2 DFTs & S4 MWDC
- Momentum : 5×10^{-4} (σ)
- Angular : ~0.8 mrad (σ)

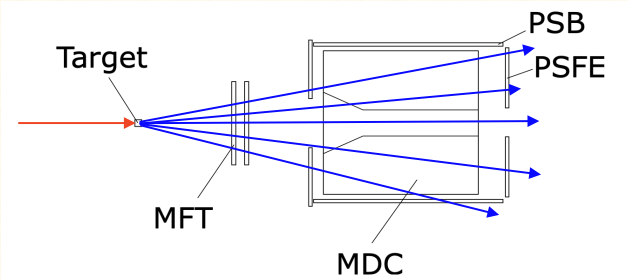


100 times better than HypHI Phase 0

Enqiang Liu
Ph.D. thesis, May 2024, Lanzhou University

Graph Neural Network (GNN) for WASA

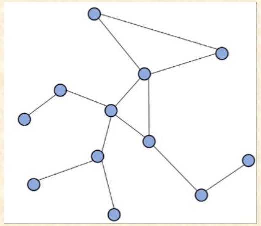
Track Finding

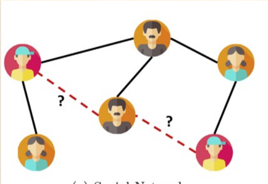


- Multi particles in HI reaction
- Combinatorial background

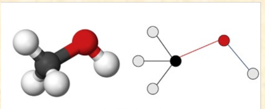
Track Finding with Graph Neural Network (GNN)

Graph



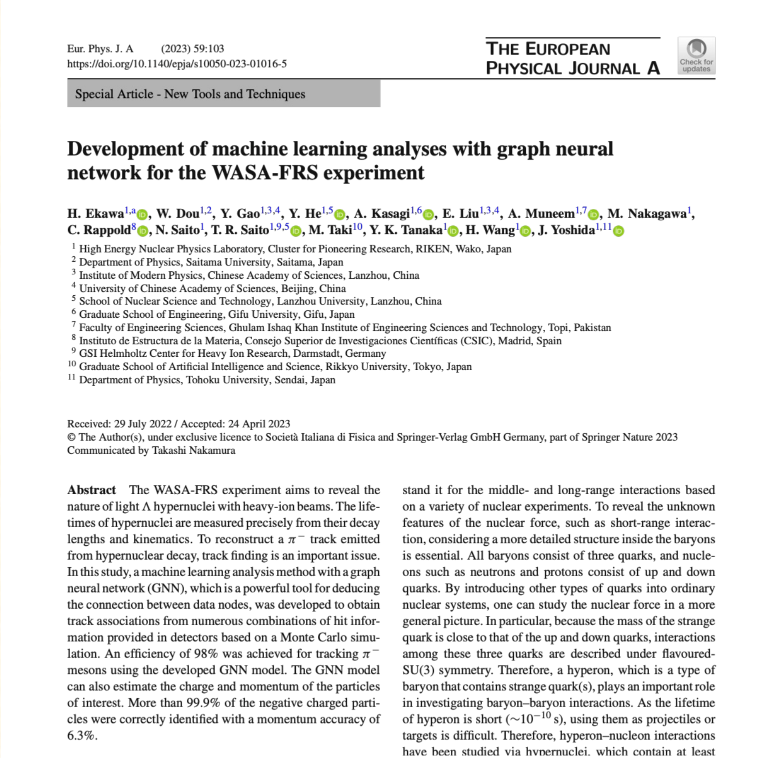


(e) Social Network


(b) Molecule

- Node : Data point
- Edge : Connection

Jie Zhou *et al.*, AI Open 1 (2020) 57–81



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THE EUROPEAN PHYSICAL JOURNAL A

Special Article - New Tools and Techniques

Development of machine learning analyses with graph neural network for the WASA-FRS experiment

H. Ekawa[1,a], W. Dou[1,2], Y. Gao[1,3,4], Y. He[1,5], A. Kasagi[1,6], E. Liu[1,3,4], A. Muneem[1,7], M. Nakagawa[1], C. Rappold[8], N. Saito[1], T. R. Saito[1,9,5], M. Taki[10], Y. K. Tanaka[1], H. Wang[1], J. Yoshida[1,11]

1 High Energy Nuclear Physics Laboratory, Cluster for Pioneering Research, RIKEN, Wako, Japan
2 Department of Physics, Saitama University, Saitama, Japan
3 Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou, China
4 University of Chinese Academy of Sciences, Beijing, China
5 School of Nuclear Science and Technology, Lanzhou University, Lanzhou, China
6 Graduate School of Engineering, Gifu University, Gifu, Japan
7 Faculty of Engineering Sciences, Ghulam Ishaq Khan Institute of Engineering Sciences and Technology, Topi, Pakistan
8 Instituto de Estructura de la Materia, Consejo Superior de Investigaciones Científicas (CSIC), Madrid, Spain
9 GSI Helmholtz Center for Heavy Ion Research, Darmstadt, Germany
10 Graduate School of Artificial Intelligence and Science, Rikkyo University, Tokyo, Japan
11 Department of Physics, Tohoku University, Sendai, Japan

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Communicated by Takashi Nakamura

Abstract The WASA-FRS experiment aims to reveal the nature of light Λ hypernuclei with heavy-ion beams. The lifetimes of hypernuclei are measured precisely from their decay lengths and kinematics. To reconstruct a π^- track emitted from hypernuclear decay, track finding is an important issue. In this study, a machine learning analysis method with a graph neural network (GNN), which is a powerful tool for deducing the connection between data nodes, was developed to obtain track associations from numerous combinations of hit information provided in detectors based on a Monte Carlo simulation. An efficiency of 98% was achieved for tracking π^- mesons using the developed GNN model. The GNN model can also estimate the charge and momentum of the particles of interest. More than 99.9% of the negative charged particles were correctly identified with a momentum accuracy of 6.3%.

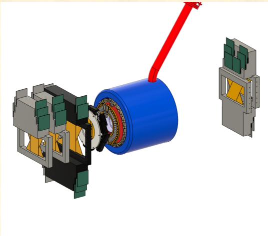
stand it for the middle- and long-range interactions based on a variety of nuclear experiments. To reveal the unknown features of the nuclear force, such as short-range interaction, considering a more detailed structure inside the baryons is essential. All baryons consist of three quarks, and nucleons such as neutrons and protons consist of up and down quarks. By introducing other types of quarks into ordinary nuclear systems, one can study the nuclear force in a more general picture. In particular, because the mass of the strange quark is close to that of the up and down quarks, interactions among these three quarks are described under flavoured-SU(3) symmetry. Therefore, a hyperon, which is a type of baryon that contains strange quark(s), plays an important role in investigating baryon–baryon interactions. As the lifetime of hyperon is short ($\sim 10^{-10}$ s), using them as projectiles or targets is difficult. Therefore, hyperon–nucleon interactions have been studied via hypernuclei, which contain at least

Published in EPJA (May 2023)

H. Ekawa et al., Eur. Phys. J. A (2023) **59**, 103

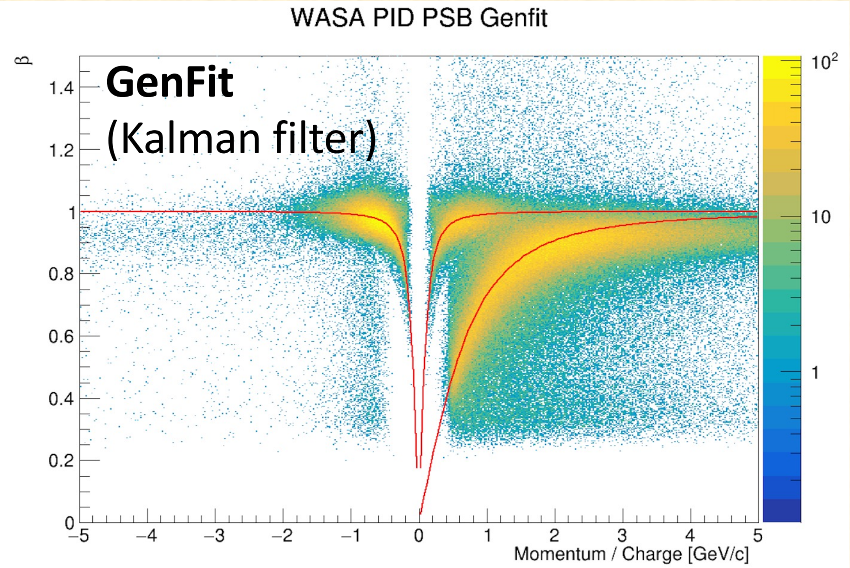
DOI : 10.1140/epja/s10050-023-01016-5

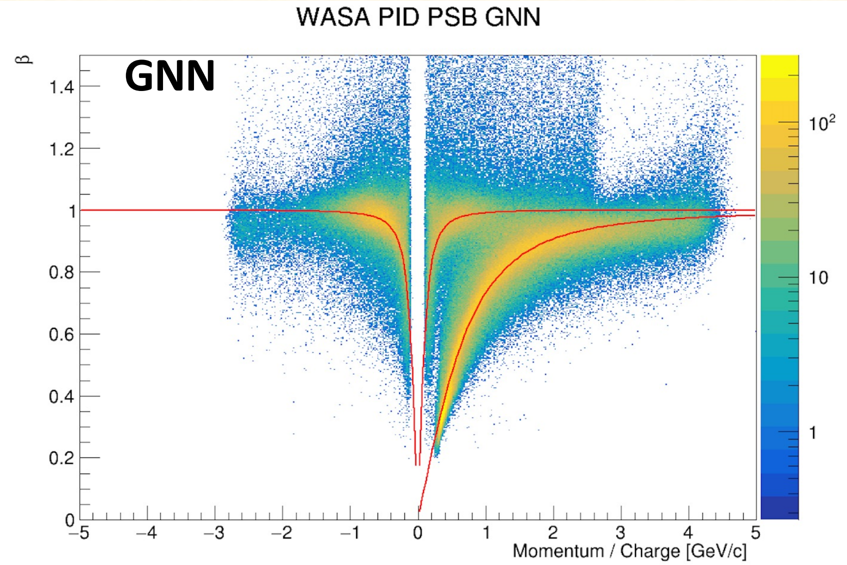
Data analyses with the GNN



Only <u>partial data</u> with
- T0
- Fiber detectors
- MDC
- PSB
- FRS

Both with GNN track finder

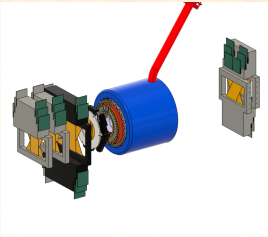




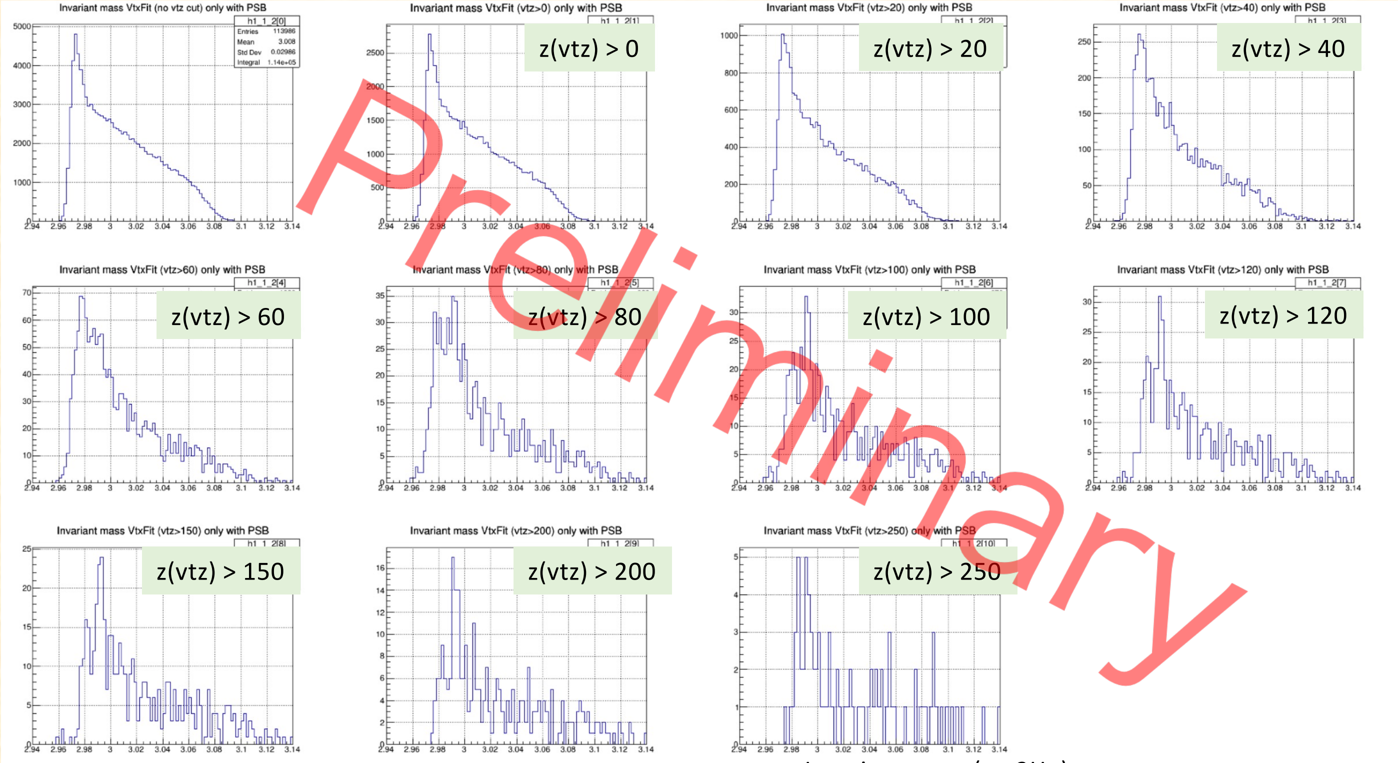
Efficiency: 30 %
Resolution: $\Delta p/p$ = 8.23%

Efficiency: > 90 %
Resolution: $\Delta p/p$ = 8.26% (2M training)
→ (7.7 % (4M training))

Data analyses with the GNN



Only **partial data** with
- T0
- Fiber detectors
- MDC
- PSB
- FRS



Invariant mass (π^-+3He)

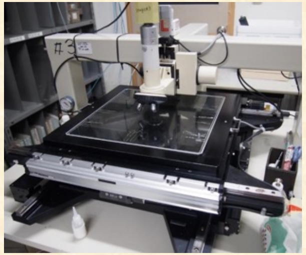
Our challenges on the hypertriton binding energy

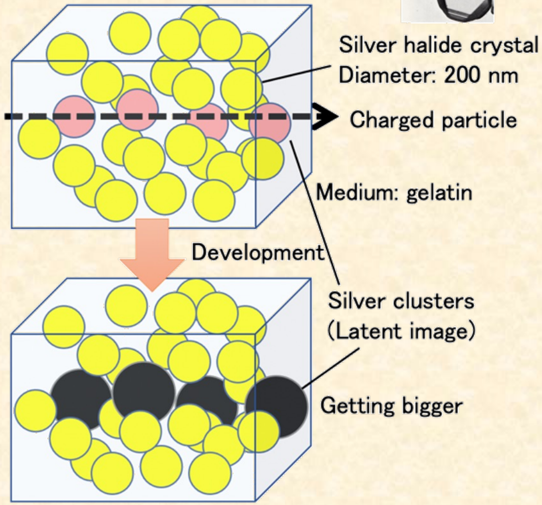
<u>Nuclear Emulsion</u>:

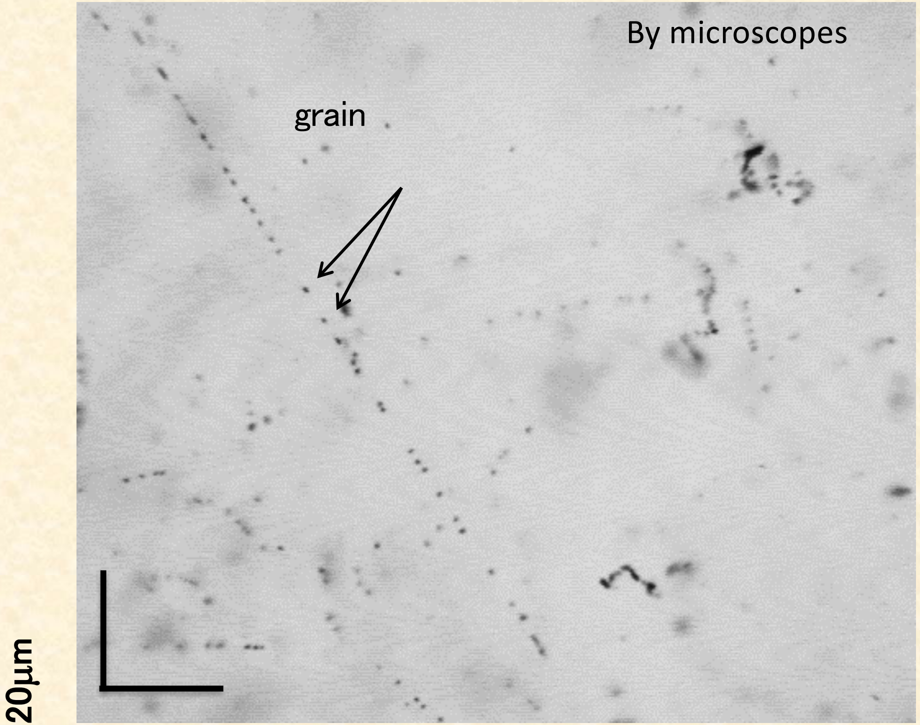
Charged particle tracker with

<u>the best spatial resolution</u>

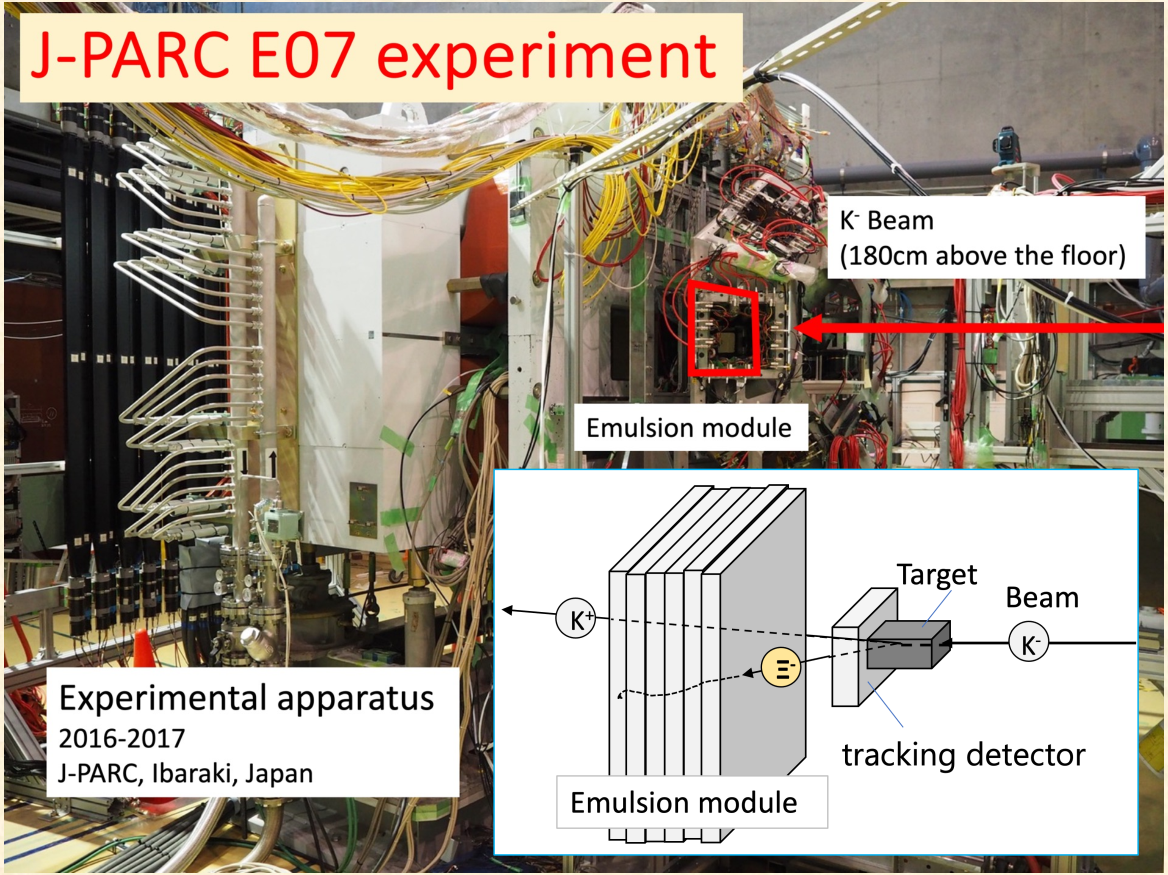
<u>(easy to be < 1 μm, 11 nm at best)</u>







J-PARC E07 experiment

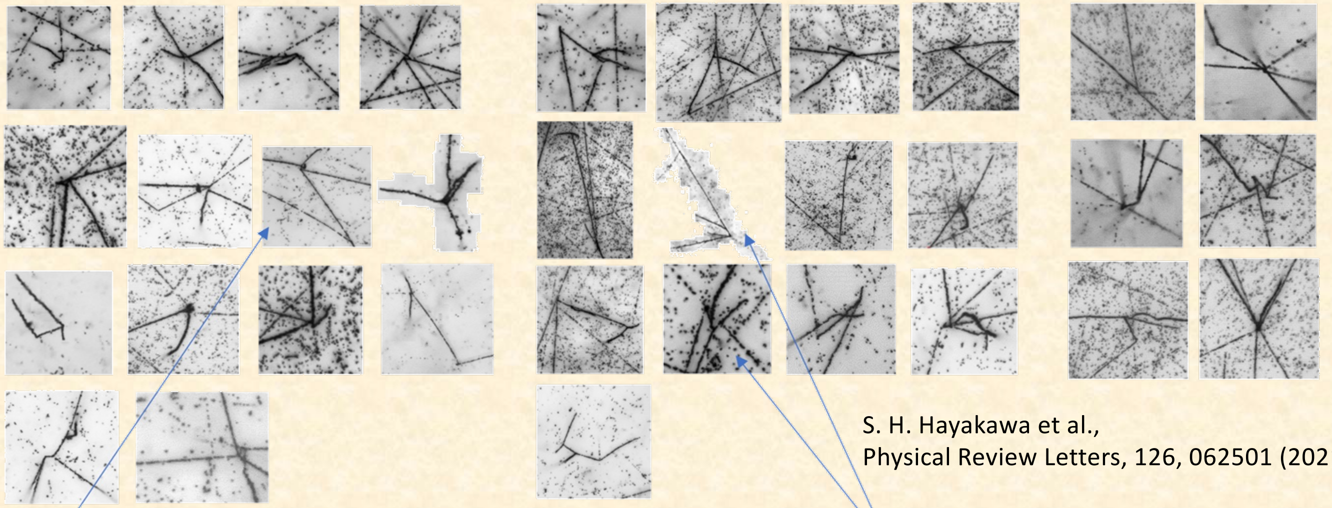


Results from J-PARC E07 (Hybrid method)

$\Lambda\Lambda$ candidates: 14

Twin Λ events: 13

Others: 6



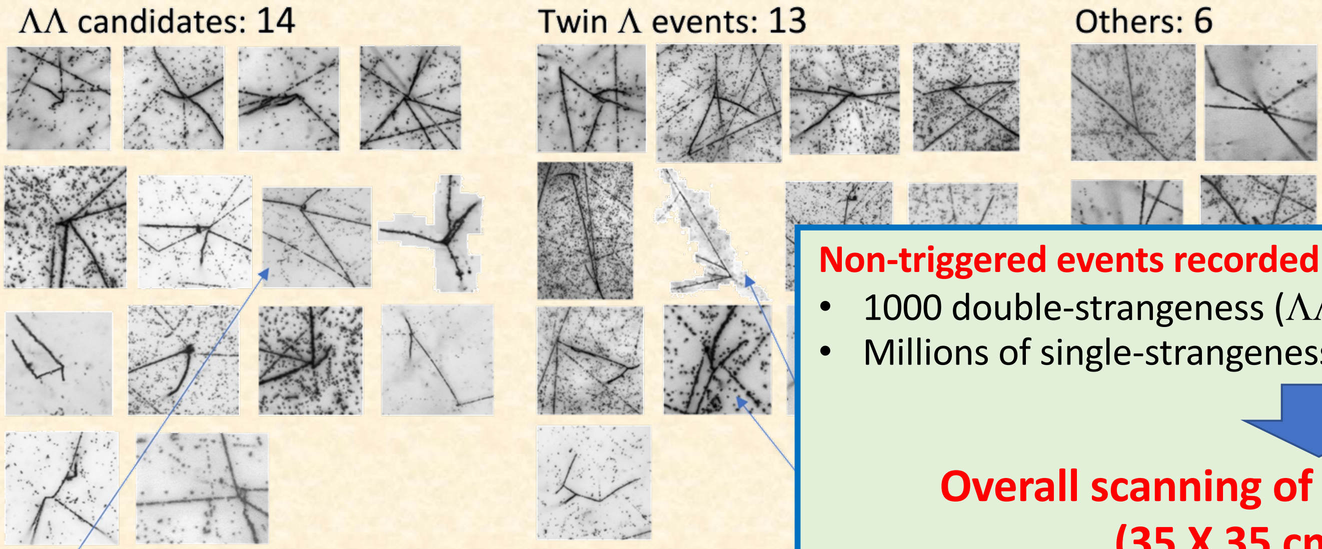
S. H. Hayakawa et al.,
Physical Review Letters, 126, 062501 (2021)

M. Yoshimoto et al.,
Prog. Theor. Exp. Phys. 2021, 073D02

$^{15}_{\Xi}C$

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

Results from J-PARC E07 (Hybrid method)



Non-triggered events recorded in 1300 emulsions sheets

- 1000 double-strangeness (ΛΛ- and Ξ-) hypernuclear events
- Millions of single-strangeness hypernuclear events

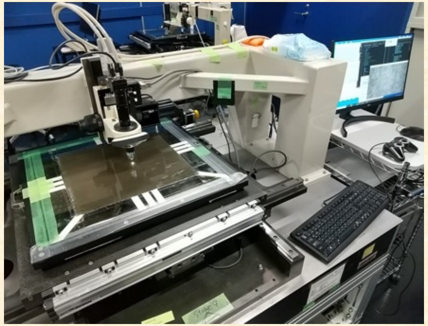
Overall scanning of all emulsion sheets
(35 X 35 cm^2 X 1000)

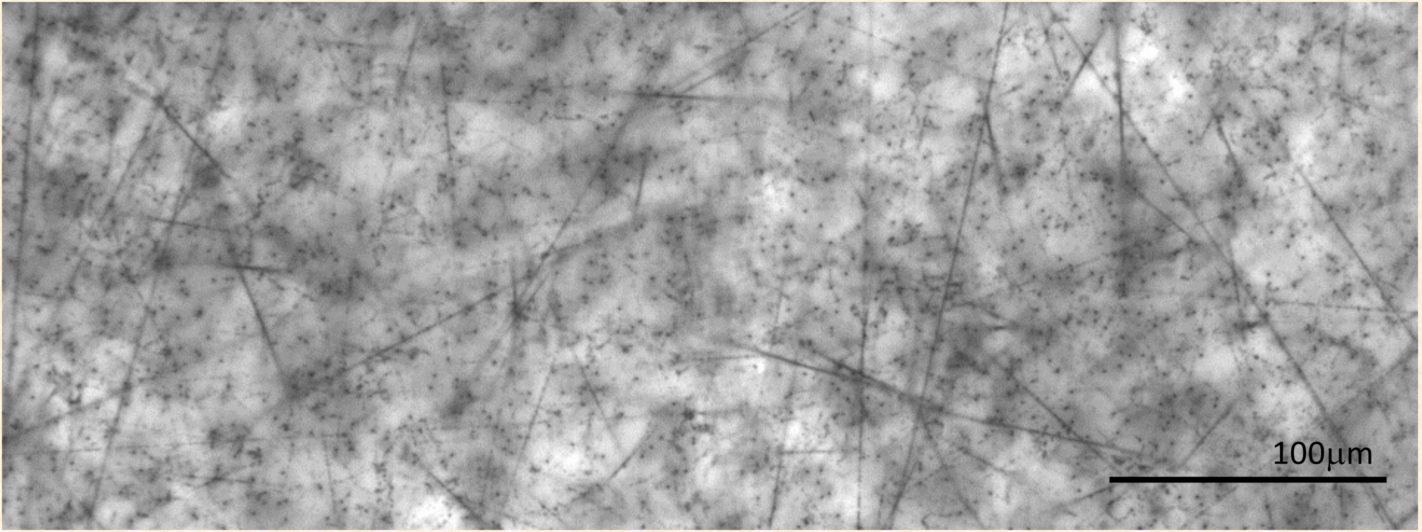
M. Yoshimoto
Prog. Theor. Exp. Phys. 2021, 073D02

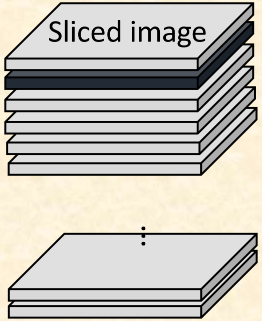
${}^{15}_{\Xi}C$

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

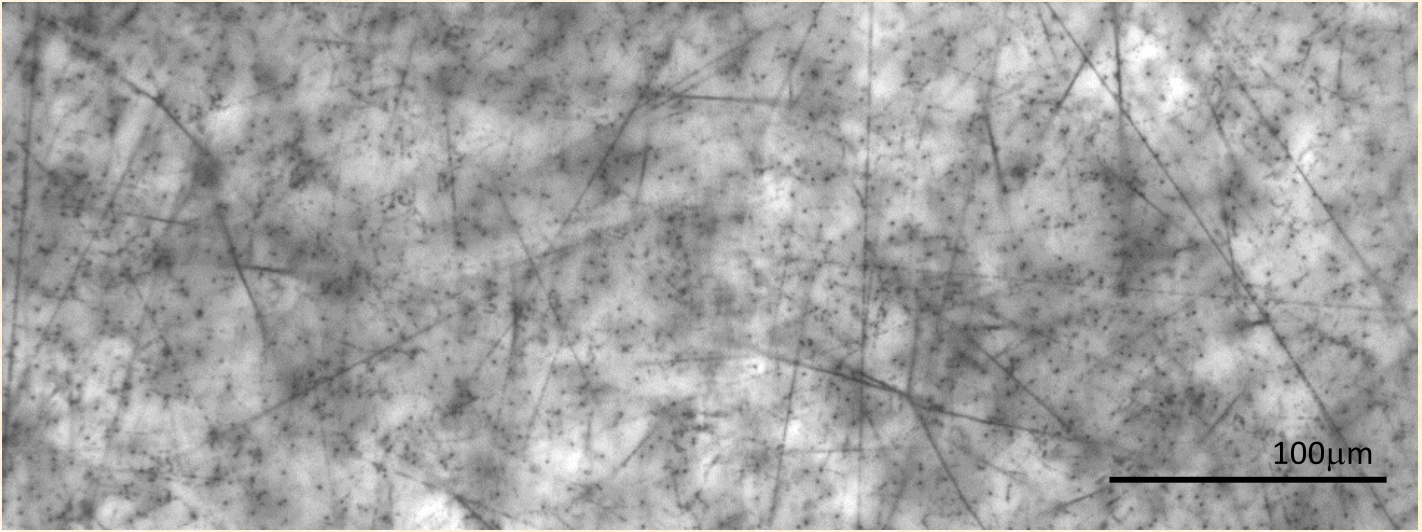
Overall scanning for E07 emulsions

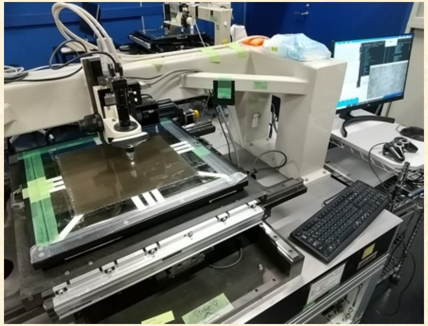


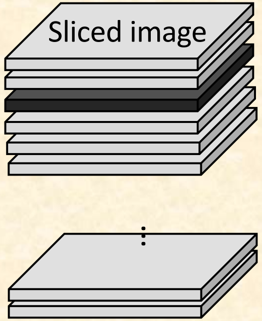




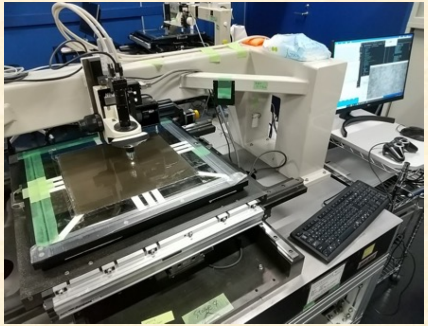
Overall scanning for E07 emulsions

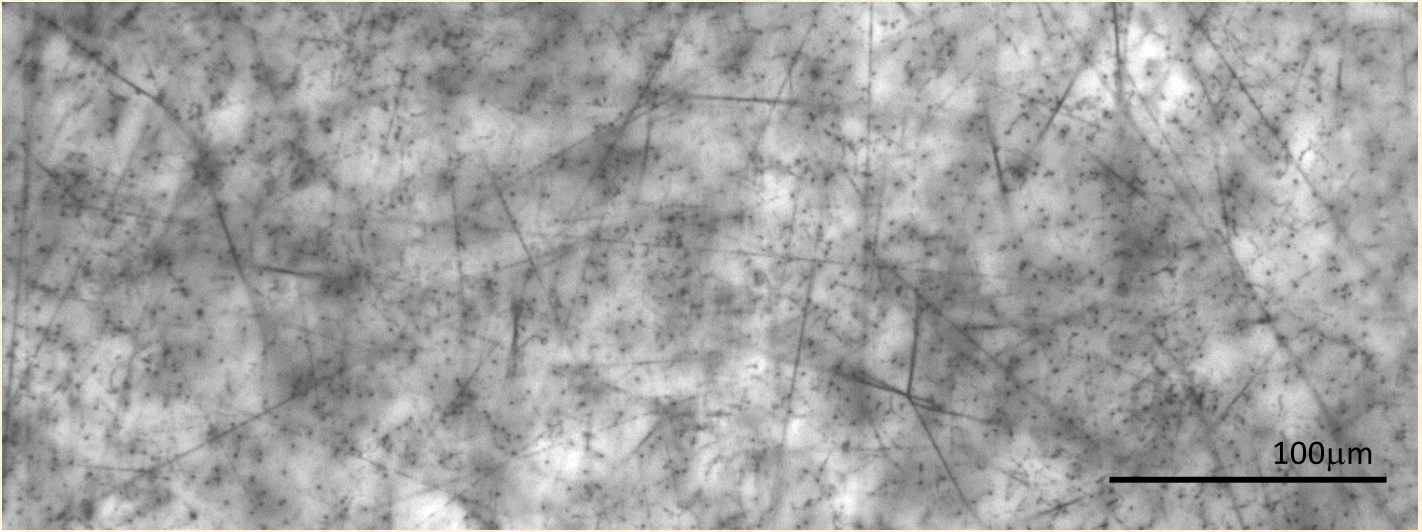


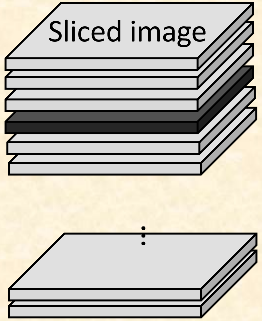




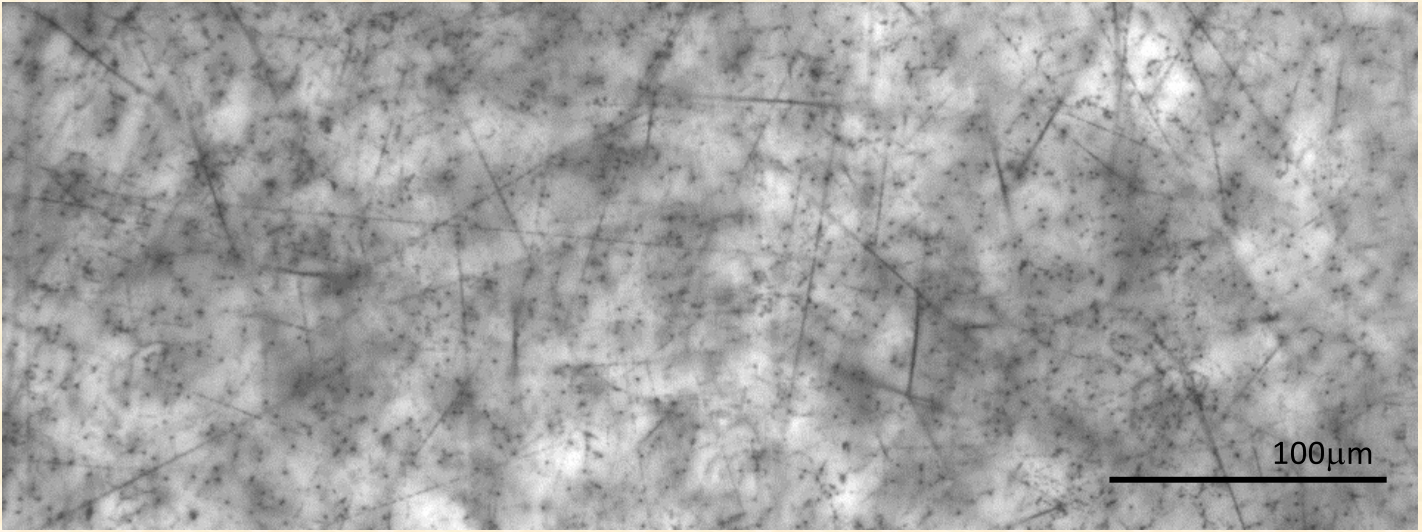
Overall scanning for E07 emulsions

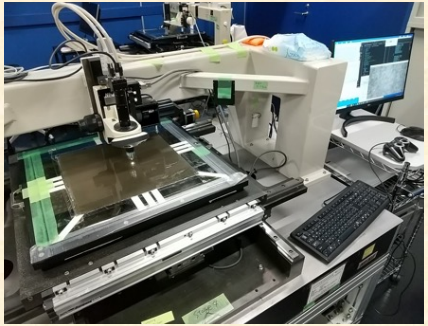


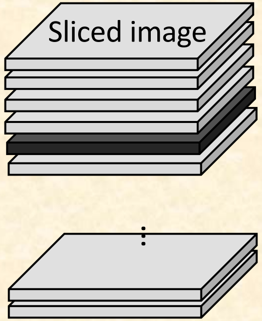




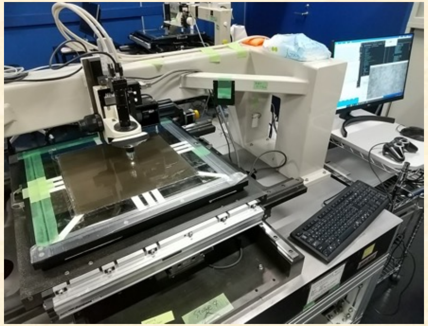
Overall scanning for E07 emulsions







Overall scanning for E07 emulsions

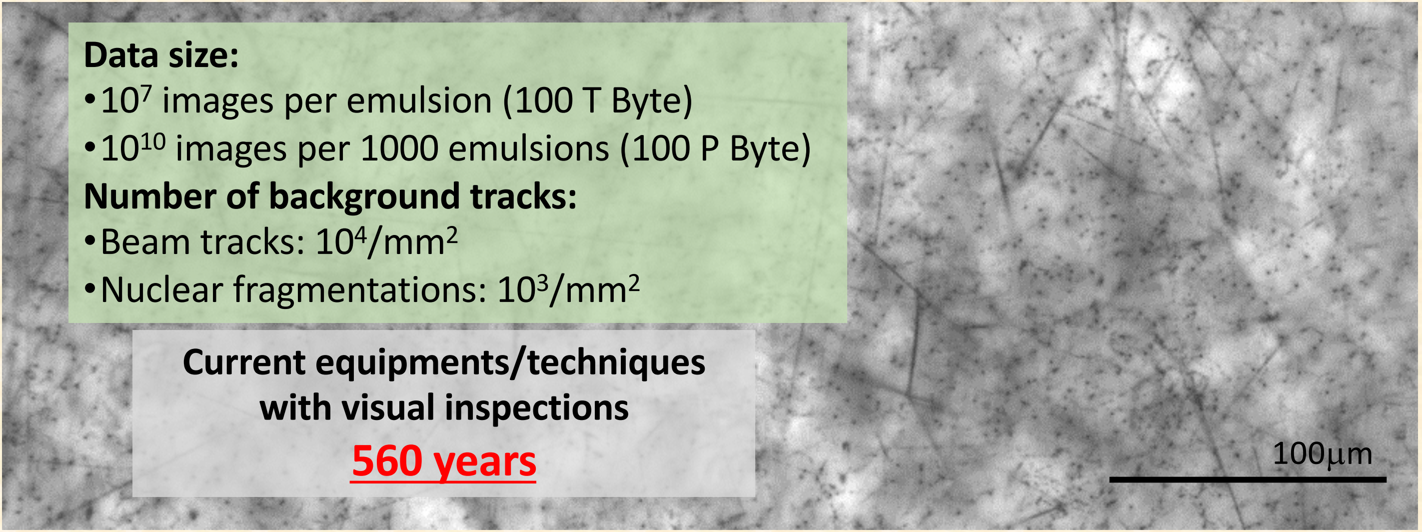


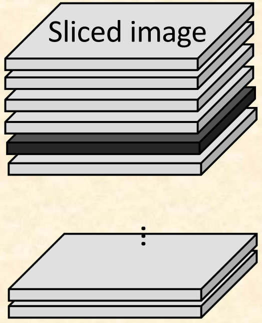
Data size:
- 10^7 images per emulsion (100 T Byte)
- 10^{10} images per 1000 emulsions (100 P Byte)

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

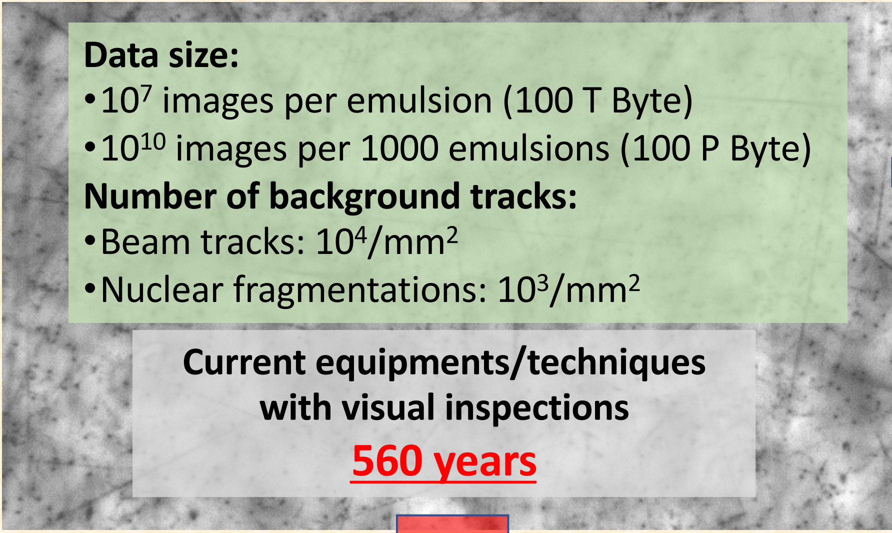
Current equipments/techniques with visual inspections

560 years





Overall scanning for E07 emulsions



Data size:

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

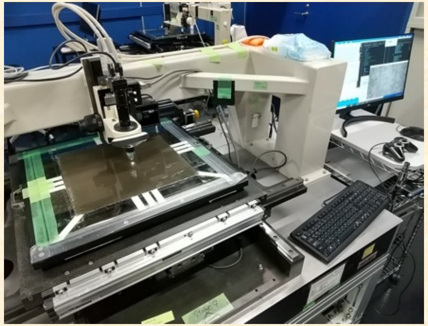
Number of background tracks:

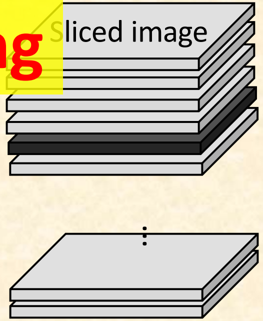
- Beam tracks: $10^4/mm^2$
- Nuclear fragmentations: $10^3/mm^2$

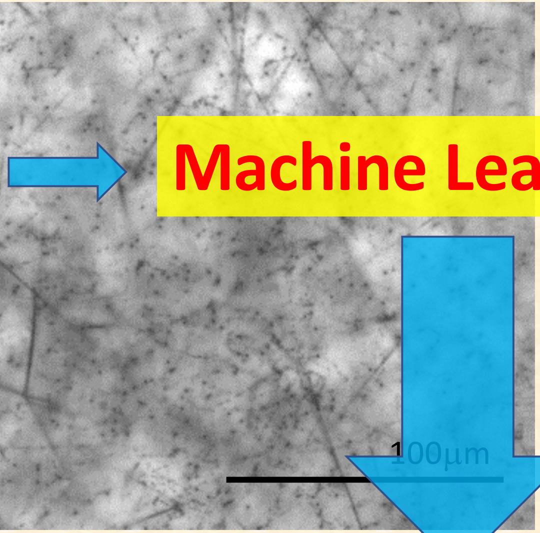
Current equipments/techniques with visual inspections

560 years

3 years







Machine Learning

Millions of single-strangeness hypernuclei

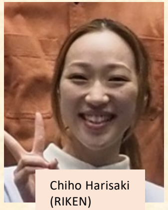
1000 double strangeness hypernuclei (formerly only 5)

Setup for analyzing emulsions at the High Energy Nuclear Physics Laboratory in RIKEN

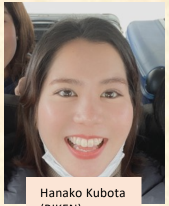
- Hypernuclear physics
- Neutron imaging

Part-timer staffs working for emulsion & microscopes

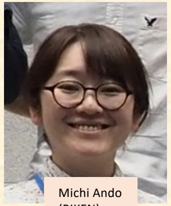
Risa Kobayashi (RIKEN)



Chiho Harisaki (RIKEN)



Hanako Kubota (RIKEN)



Michi Ando (RIKEN)

Challenges for Machine Learning Development

MOST IMPORTANT:

- **Quantity and quality of training data**

However,

No existing data for hypertriton with emulsions for training

Our approaches:

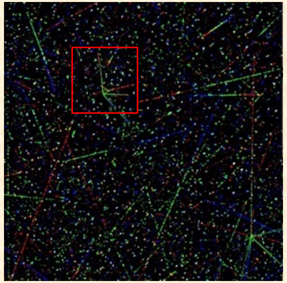
Producing training data with

- Monte Carlo simulations
- Image transfer techniques

Production of training data

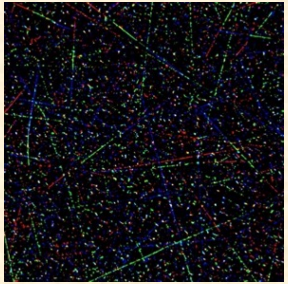
Monte Carlo simulations and GAN(Generative Adversarial Networks)

Binarized tracks from MC simulations
+ background from the real data

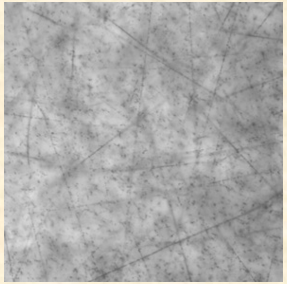


Imitated
emulsion image

GAN: pix2pix



Binarized (like for simulations)



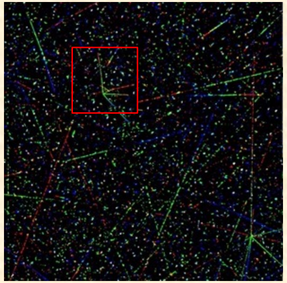
Real emulsion image

Ayumi Kasagi. Ph.D. thesis (2023)
A.Kasagi et.al, NIM A1056, (2023) 168663

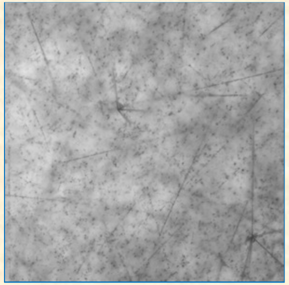
Production of training data

Monte Carlo simulations and GAN(Generative Adversarial Networks)

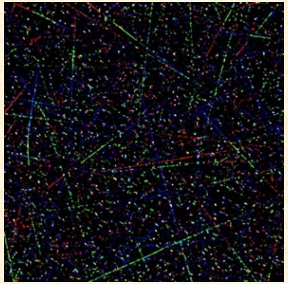
Binarized tracks from MC simulations
+ background from the real data



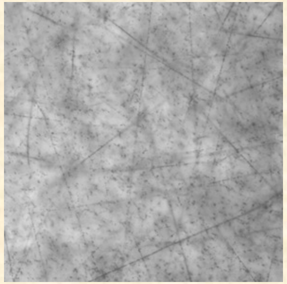
Produced training data



GAN: pix2pix



Binarized (like for simulations)

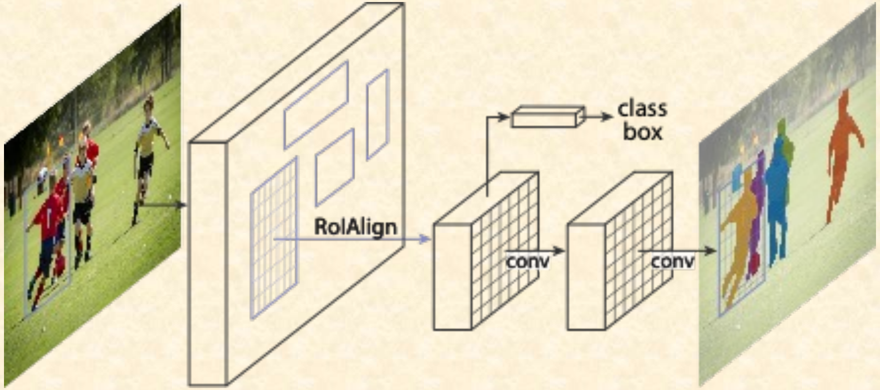


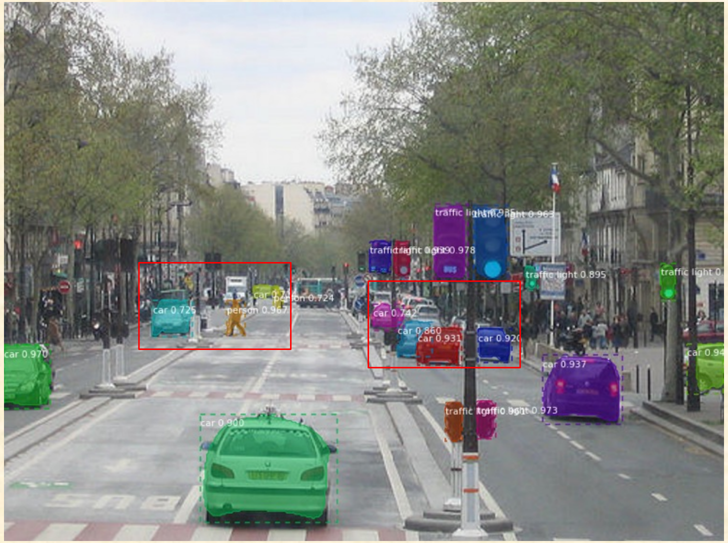
Real emulsion image

Ayumi Kasagi. Ph.D. thesis (2023)
A.Kasagi et.al, NIM A1056, (2023) 168663

Detection of hypertriton events

With Mask R-CNN model



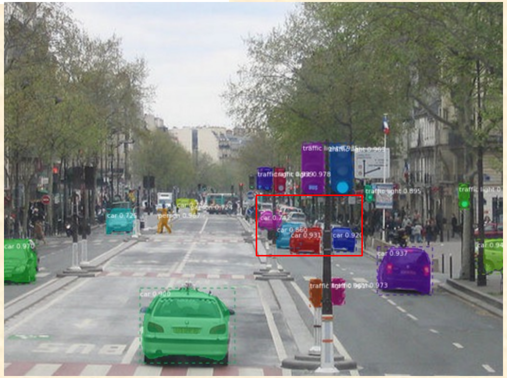


Detection of each object

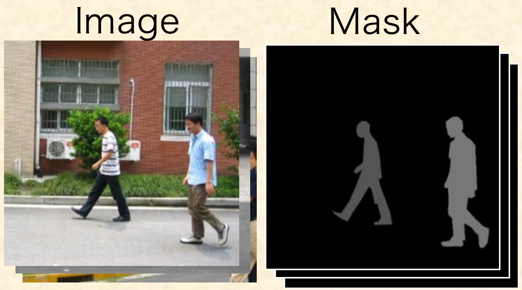
At large object density

Training of Mask R-CNN with Simulated image

Mask R-CNN



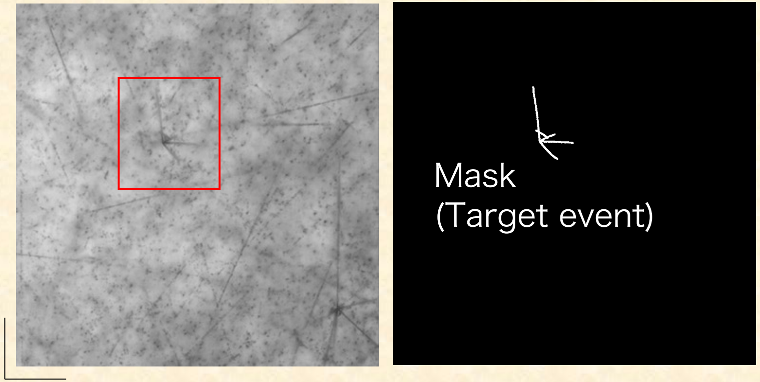
Example of training dataset



A Pedestrian dataset

https://www.cis.upenn.edu/~jshi/ped_html/

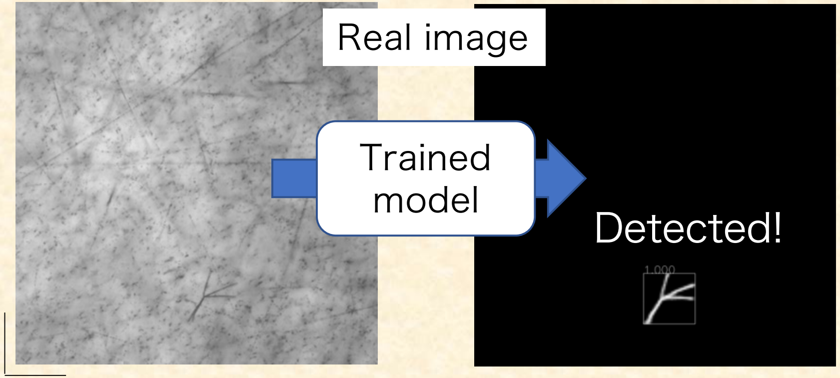
Training data (Simulated image)



50 μm

Masks are automatically produced

Performance of α-decay detection



50 μm

Efficiency = No. detected/No. total
Purity = Truth Positive/No. candidates

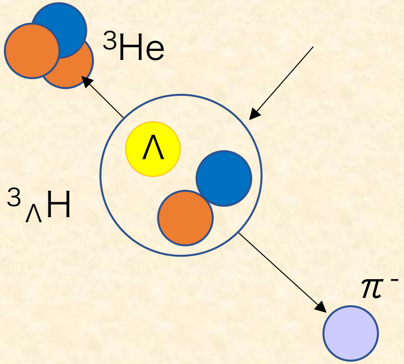
	Efficiency [%]	Purity [%]
Vertex picker	～40%	～1%
Mask R-CNN	～80%	～20%

→ 2nd step done

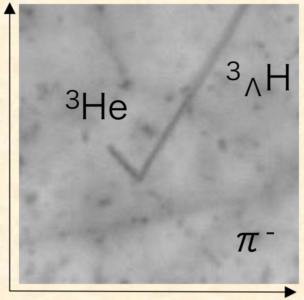
A.Kasagi et.al,
NIM A1056, (2023) 168663.

Hypertriton search with Mask R-CNN

Two body decay of ${}^{3}_{\Lambda}H$



Simulated image

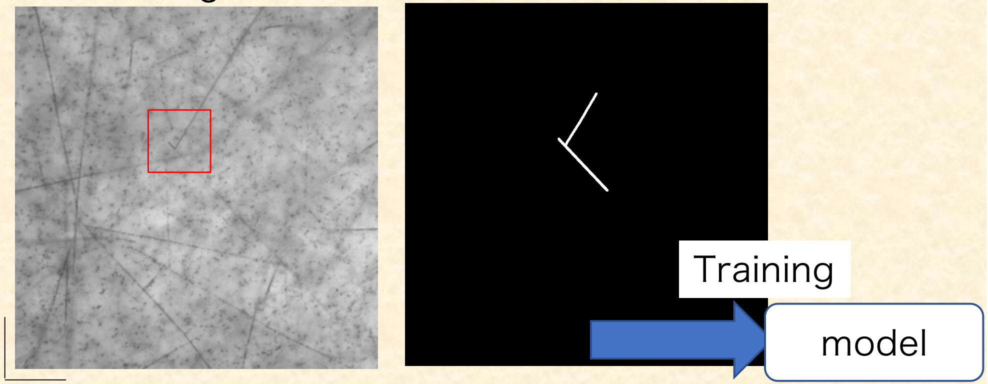


50 μm

Training dataset (Simulated images)

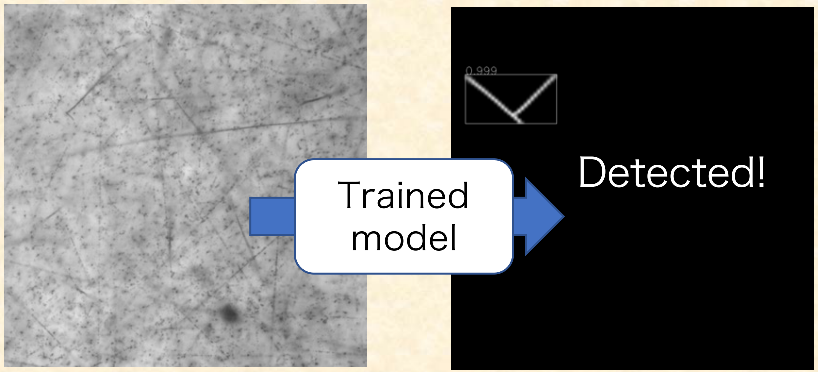
Image

Mask



50 μm

Real image



Discovery of the first hypertriton event in E07 emulsions

nature reviews physics

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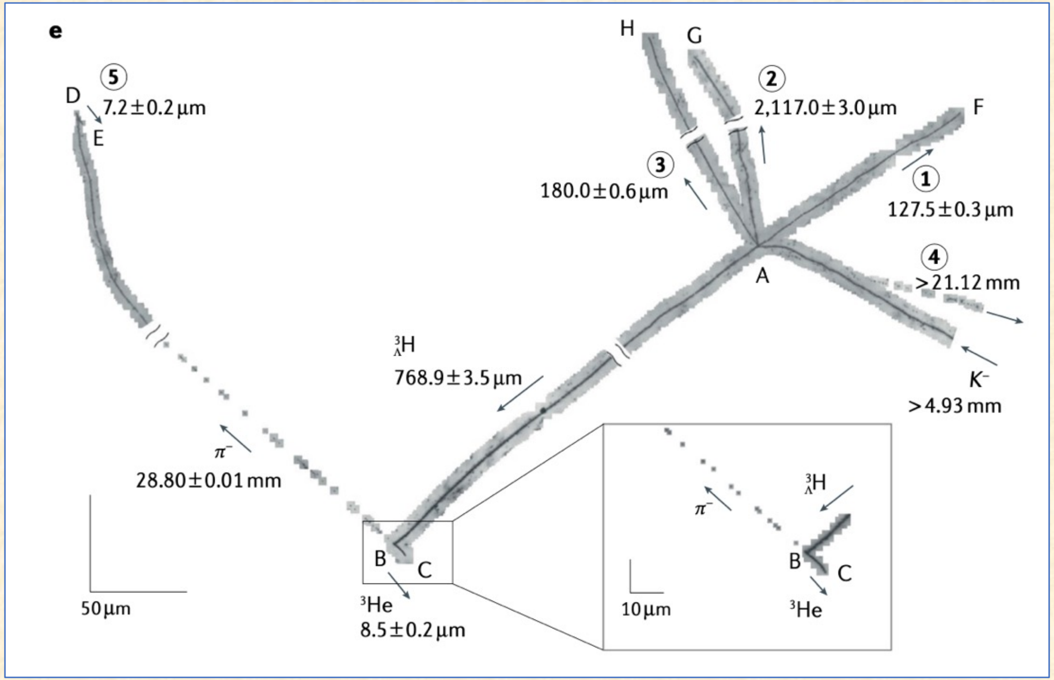
nature > nature reviews physics > perspectives > article

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

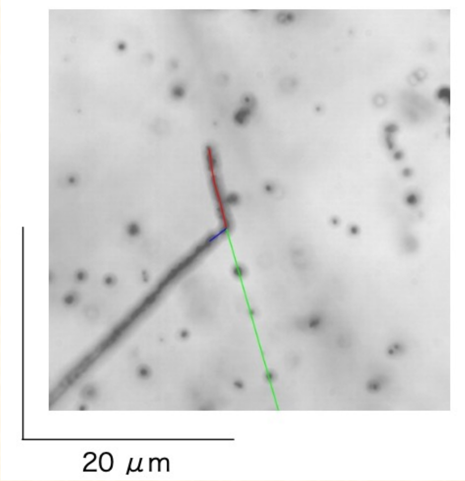
E. Liu et al., EPJ A57 (2021) 327

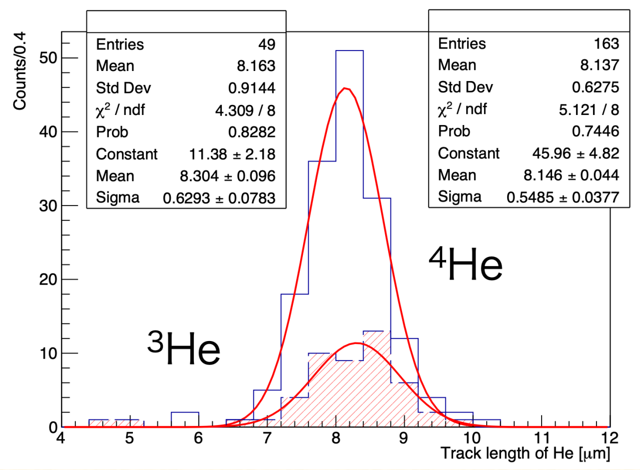
Ayumi Kasagi.
Ph.D. thesis (2023)

Towards the hypertriton binding energy

- Calibration of the nuclear emulsion (density/shrinkage) for each event
- Increasing statistics (**so far only 0.6 % of the entire data**)

	Identified	Calibrated
$^{3}_{\Lambda}H$	49	49
$^{4}_{\Lambda}H$	101 (163 detected)	101 (138 detected)





A. Kasagi et al., to be published soon

Towards the hypertriton binding energy

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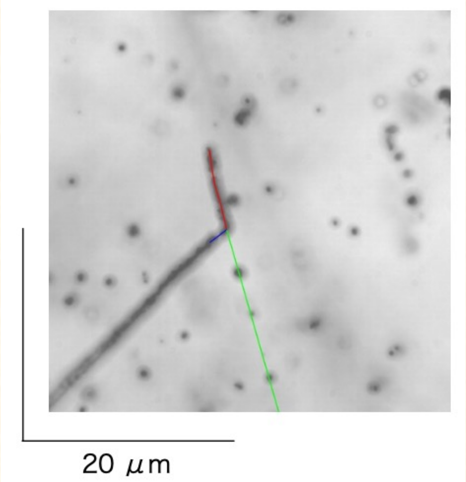
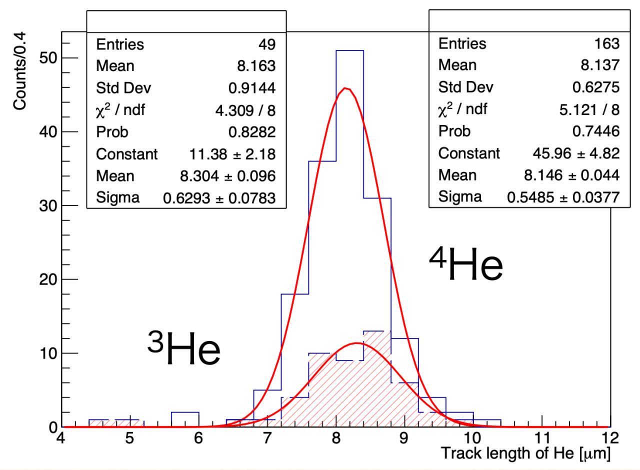
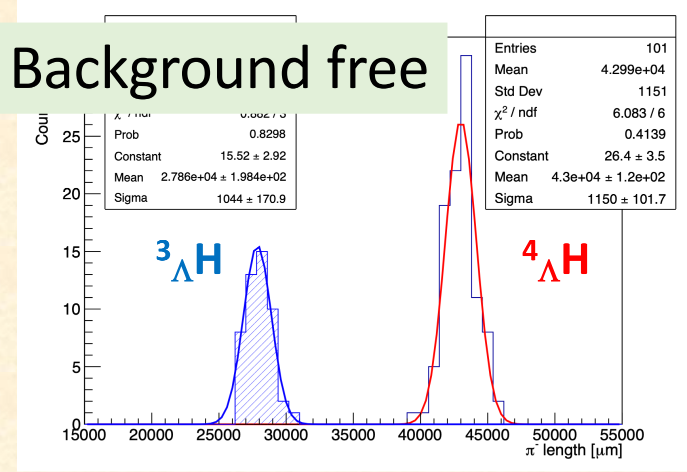
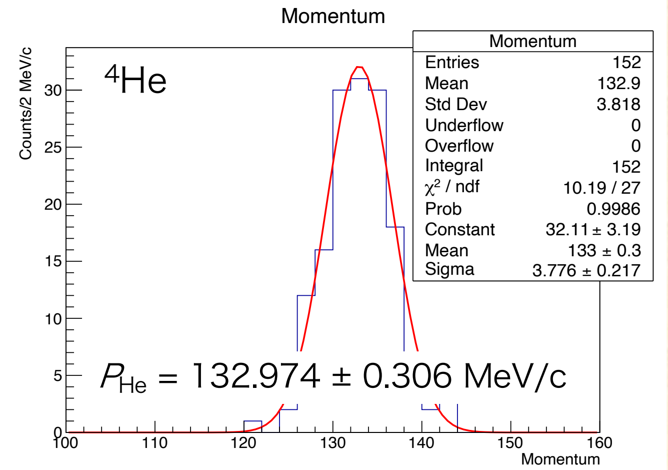




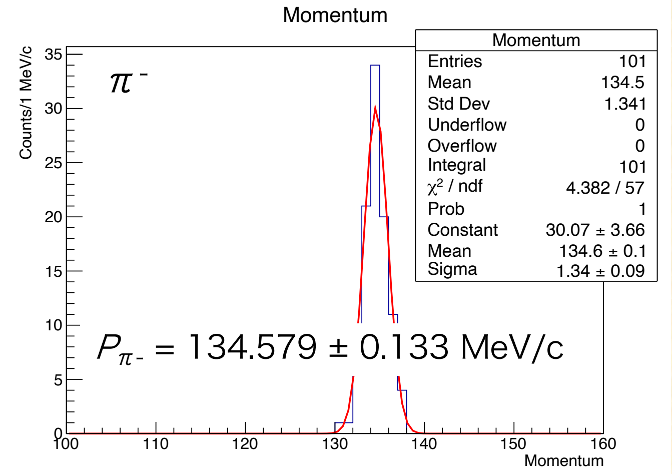


A. Kasagi et al., to be published soon

Problems on π^-

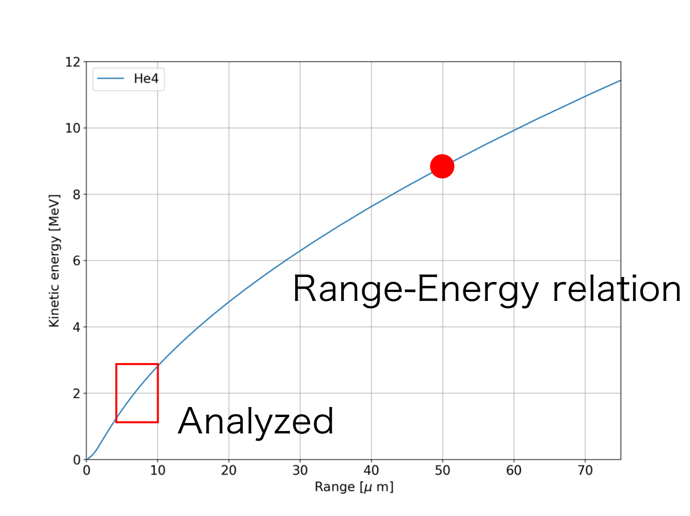


P_{He} = 132.974 ± 0.306 MeV/c



P_{π^-} = 134.579 ± 0.133 MeV/c

MAMI: P_{π^-} = 132.851 ± 0.011 (stat.) ± 0.101 (syst.) MeV/c



We confirmed that **the Range-Energy Relation for energetic π is not correct**

Affecting all emulsion results at KEK and J-PARC

A. Kasagi et al., to be published soon

Range of the deduced binding energy

Manner / B_Λ		π- only [MeV]		π- & Helium [MeV]	
		$^3_\Lambda H$	$^4_\Lambda H$	$^3_\Lambda H$	$^4_\Lambda H$
Factor	Momentum	0.265 ± 0.108	2.175 ± 0.096	0.274 ± 0.118	2.196 ± 0.103
	K.E	0.239 ± 0.108	2.175 ± 0.096	0.250 ± 0.108	2.196 ± 0.103
	Density	0.196 ± 0.105	2.175 ± 0.096	0.210 ± 0.117	2.184 ± 0.101
	Range	0.216 ± 0.108	2.175 ± 0.096	0.228 ± 0.118	2.183 ± 0.103
Shift	Momentum	0.417 ± 0.109	2.176 ± 0.097	0.417 ± 0.119	2.196 ± 0.103
	K.E	0.514 ± 0.110	2.176 ± 0.098	0.509 ± 0.119	2.182 ± 0.105
	Density	0.198 ± 0.105	2.176 ± 0.093	0.211 ± 0.117	2.184 ± 0.101
	Range	0.693 ± 0.107	2.176 ± 0.096	0.673 ± 0.117	2.182 ± 0.103

$^3_\Lambda H$: 196 – 693 keV
(with only 0.6 % of the entire data)

$^3{}_\Lambda H$ Binding energy

$B_\Lambda(^3{}_\Lambda H)$: 0.13 ± 0.05 MeV

G. Bohm et al., NPB **4** (1968) 511

M. Juric et al., NPB **52** (1973) 1

STAR (2020)

0.41 ± 0.12 ± 0.11 MeV

STAR Collaboration,

Nat. Phys. **16** (2020) 409

ALICE

0.102 ± 0.063 ± 0.067 MeV

Phys. Rev. Lett. **131**, 102302 (2023)

A. Kasagi et al., to be published soon

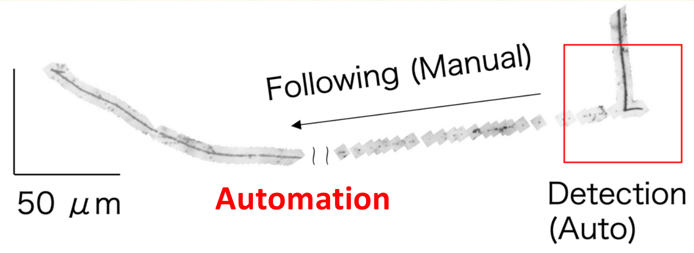
Our current shopping list

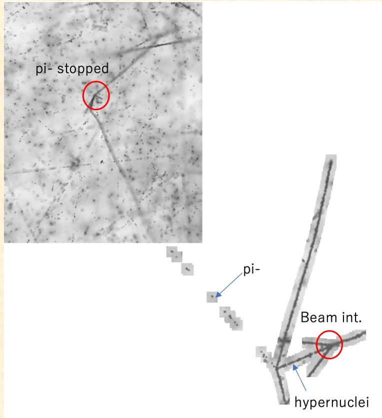
S = -1

- ΛNN: Hypertriton puzzle: $^{3}_{\Lambda}H$
- Charge symmetry braking(A = 4): $^{4}_{\Lambda}H$, $^{4}_{\Lambda}He$
- A = 6 Hypernuclei as $\Lambda\alpha N$: $^{6}_{\Lambda}He$
- Caribration for HIHR in J-PARC: $^{12}_{\Lambda}C$

S = -2

- $\Lambda\Lambda$-ΞN mixing $^{5}_{\Lambda\Lambda}H$, $^{5}_{\Lambda\Lambda}He$, $^{6}_{\Lambda\Lambda}He$
- Ξ_{1s} nuclear state: $^{13}_{\Xi}B$, $^{15}_{\Xi}C$, $^{17}_{\Xi}N$





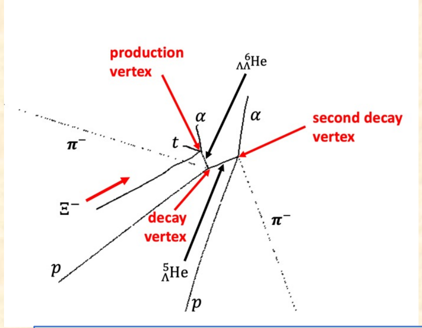
Shohei Sugimoto, Master thesis

Searching for double-strangeness hypernuclei

Yan He
(LZU/RIKEN)
Ph.D. thesis

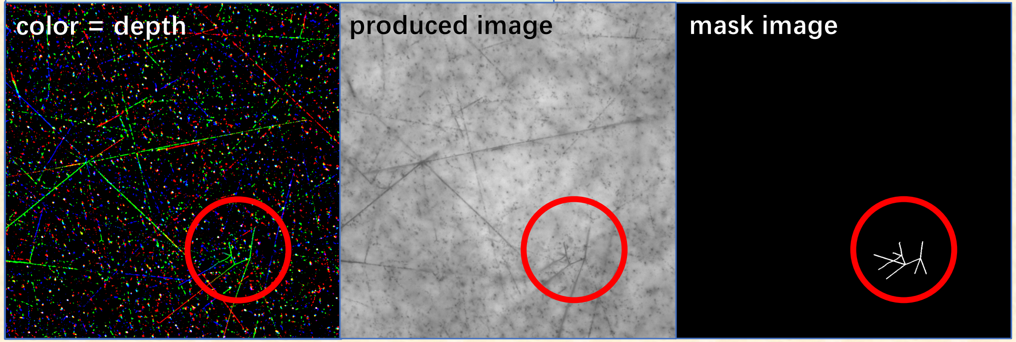
- Prepare training dataset

$^{6}_{\Lambda\Lambda}\mathrm{He}$

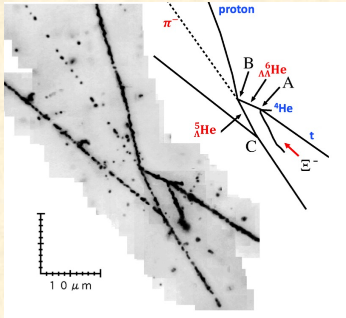


Double-strangeness hypernuclei event topology — **"three vertices"**

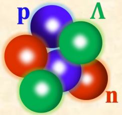
Geant4 simulation, image process, machine learning — GAN: pix2pix



- Model performance

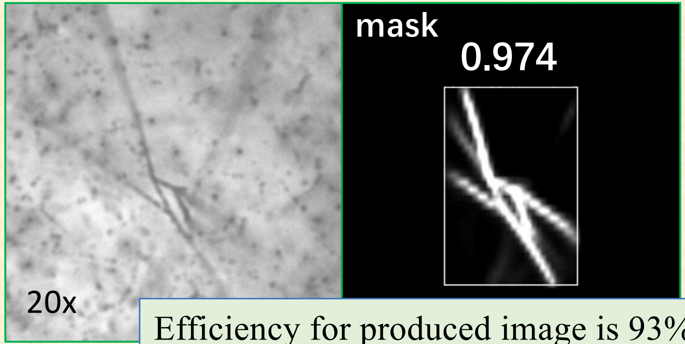


$^{6}_{\Lambda\Lambda}\mathrm{He}$



triple-close shell

H.Takahashi et. al, Phys. Rev. Lett. 87 (2001) 212502.



Efficiency for produced image is 93%

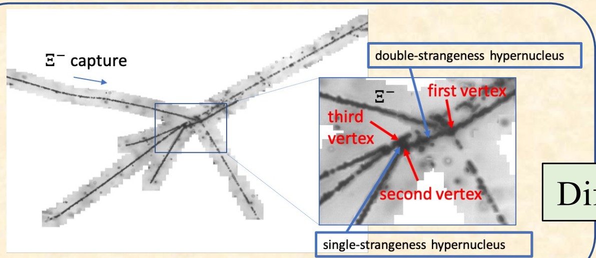
Searching for double-strangeness hypernuclei

Yan He
(LZU/RIKEN)
Ph.D. thesis

Current status and near future

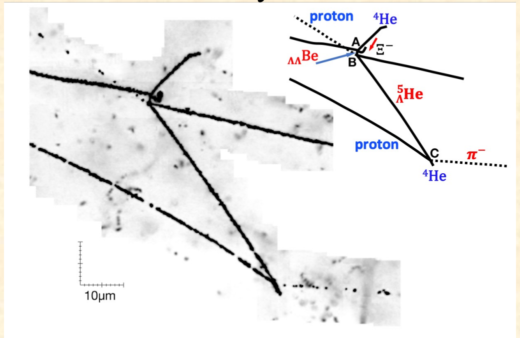
- Analyzed **0.2%** of the entire data, **6 candidates** found.
- Searching for double-strangeness hypernuclei with newly developed machine-learning method is in progress.

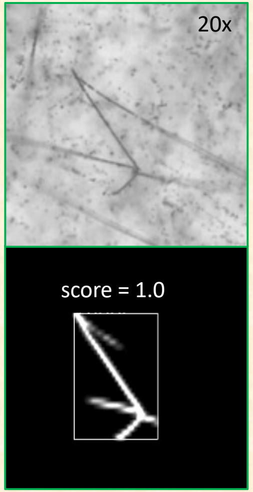
One of new candidates



Difficult to identify

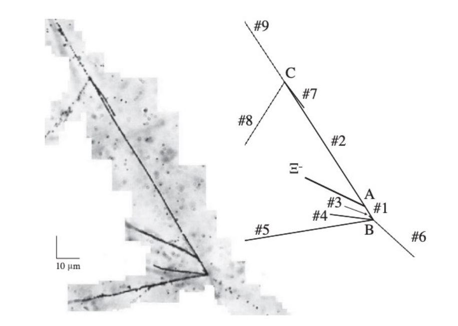
- MINO event from E07 hybrid

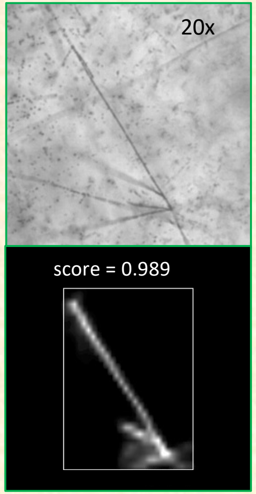




H. Ekawa et al., Prog. Theor. Exp. Phys. 2019, 021D02 (2019b) E.

- IBUKI event from E07 hybrid

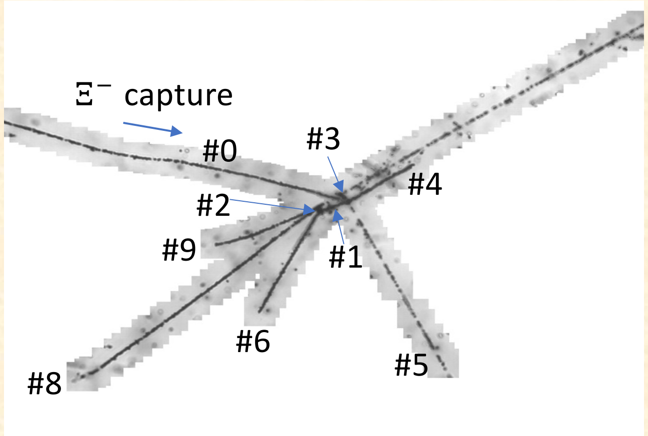


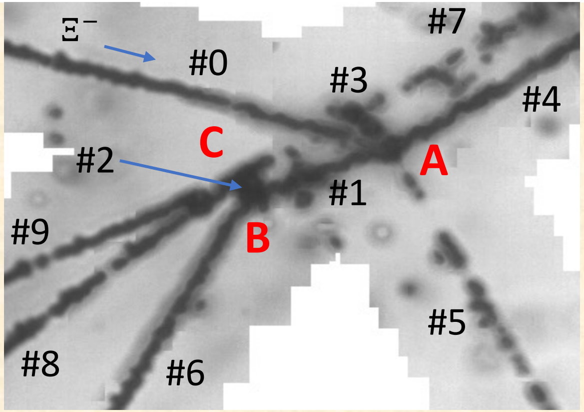


S.H. Hayakawa et al., Phys. Rev. Lett. 126, 062501 (2021)

V3451: MOD100 PL02 AREA00

Yan He
(LZU/RIKEN)
Ph.D. thesis





- density: 3.6401 ± 0.018
- shrinkage factor: 1.877
- angle and range error decided by track fitting and measurement

Vertex	Track id	Range[μm]	Theta[°]	Phi[°]	
A	#0	--	113.09±0.87	344.40±0.67	Ξ^-
	#1	9.49±0.34	125.28±0.90	20.88±0.81	double-Λ hypernucleus
	#3	18.20±0.50	8.19±0.48	308.04±3.43	
	#4	22.61±0.34	53.58±0.80	211.87±0.73	
	#5	3294.17±36.31	123.25±0.96	117.55±0.79	
B	#2	3.26±0.49	158.54±2.95	282.63±7.55	single-Λ hypernucleus
	#6	30.87±0.27	72.43±0.94	58.81±0.80	
C	#7	7093.55±118.55	121.97±0.98	210.79±0.81	
	#8	72.47±0.24	90.11±1.31	38.22±0.75	
	#9	26.33±0.29	92.89±1.19	25.02±0.76	

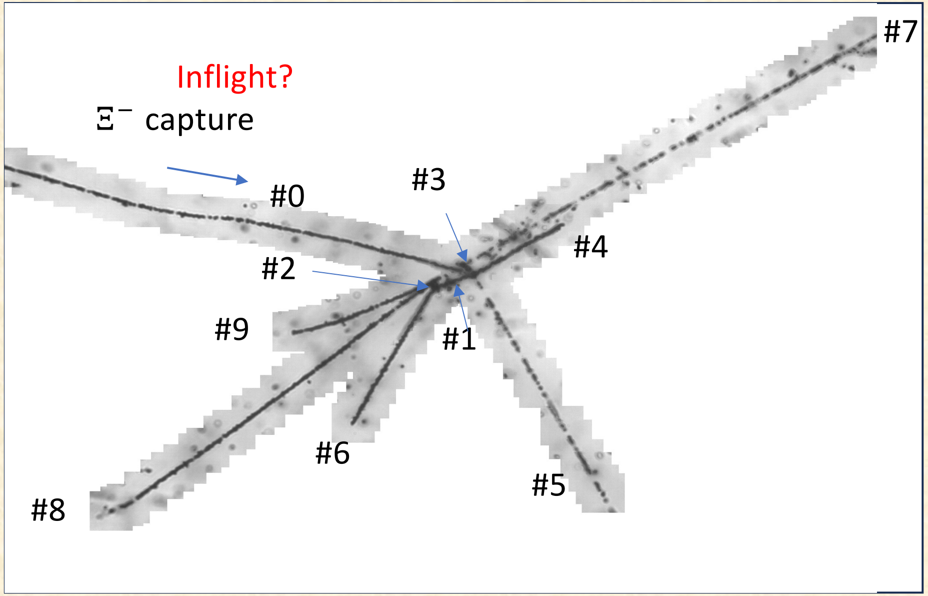
V3451: MOD100 PL02 AREA00

Yan He
(LZU/RIKEN)
Ph.D. thesis

without neutron, momentum balance

- No minimum Q value cut -20 MeV
- 10 solutions remain when momentum balance in "3σ"

"Xi- & N14 -> H5LL + t + Li6 + p	x
"Xi- & N14 -> H6LL + d + Li6 + p	x
"Xi- & N15 -> H6LL + t + Li6 + p	x
"Xi- & O16 -> He6LL + d + Li8 + p	x
"Xi- & O16 -> He6LL + t + Li7 + p	
"Xi- & O18 -> H4LL + He4 + Li9 + d	x
"Xi- & O18 -> H5LL + He3 + Li9 + d	x
"Xi- & O18 -> He7LL + t + Li8 + p	x
"Xi- & O18 -> He8LL + d + Li8 + p	x
"Xi- & O18 -> He8LL + t + Li7 + p	

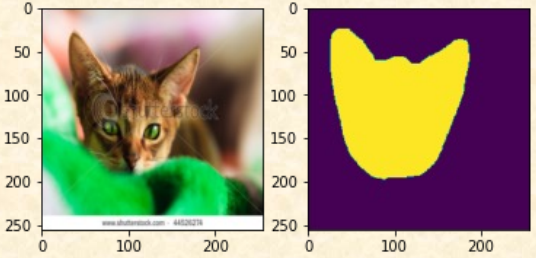


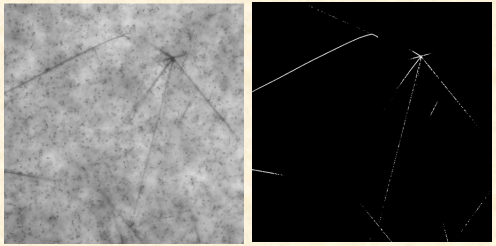
- #4 stop and no other particle emitted

Detailed analyses in progress

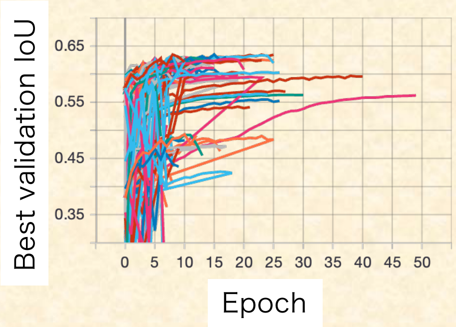
Segmentation task to detect hit infomation

- Binary segmentation (background or track)
- Training from scratch (with 40k surrogate images)



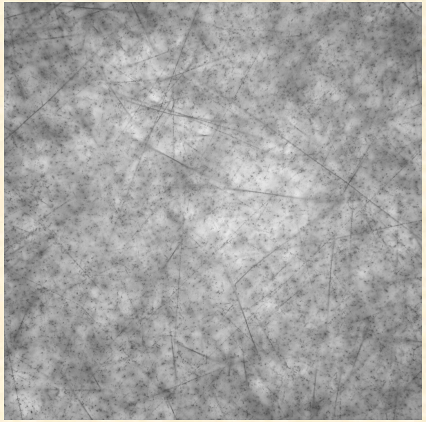


Hyperparameter search with Optuna

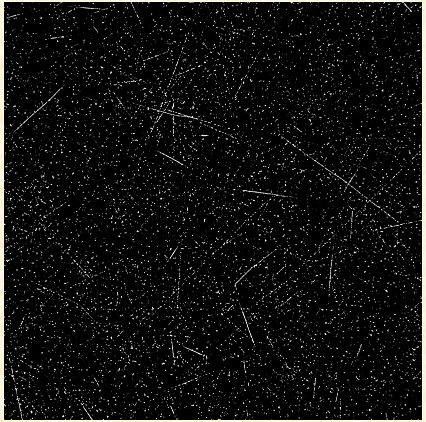


IoU	0.659
F1_score	0.795
Accuracy	0.998
Precision	0.748
Recall	0.805

Raw data



Conventional processing



Present work

- Noise reduction
- Datasize: 1/200

→ E07 image data
140 PB -> 750 TB

Nuclear Emulsion + Machine Learning Collaboration

W. Dou[a,b], V. Drozd[a,c,d], H. Ekawa[a], S. Escrig[a,e], Y. Gao[a,f,g], Y. He[a,h], A. Kasagi[a,i,j], E. Liu[a,f,g], A. Muneem[a,k], M. Nakagawa[a], K. Nakazawa[a,i,l], C. Rappold[e], N. Saito[a], T.R. Saito[a,d,h], S. Sugimoto[a,b], M. Taki[j], Y.K. Tanaka[a], A. Yanai[a,b], J. Yoshida[a,m], M. Yoshimoto[n], and H. Wang[a]

[a] High Energy Nuclear Physics Laboratory, RIKEN, Japan
[b] Department of Physics, Saitama University, Japan
[c] Energy and Sustainability Research Institute Groningen, University of Groningen, Netherlands
[d] GSI Helmholtz Centre for Heavy Ion Research, Germany
[e] Instituto de Estructura de la Materia, Spain
[f] Institute of Modern Physics, Chinese Academy of Sciences, China
[g] University of Chinese Academy of Sciences, China
[h] School of Nuclear Science and Technology, Lanzhou University, China
[i] Graduate School of Engineering, Gifu University, Japan
[j] Graduate School of Artificial Intelligence and Science, Rikkyo University, Japan
[k] Faculty of Engineering Sciences, Ghulam Ishaq Khan Institute of Engineering Sciences and Technology, Pakistan
[l] Faculty of Education, Gifu University, Japan
[m] Department of physics, Tohoku University, Japan
[n] RIKEN Nishina Center, RIKEN, Japan

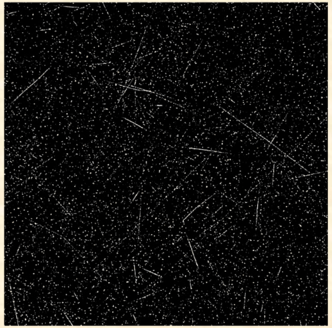
New proposal at KLF/Jlab (Mikhail Bashkanov and TRS)

Neutral-K beams behind the Glue-X setup

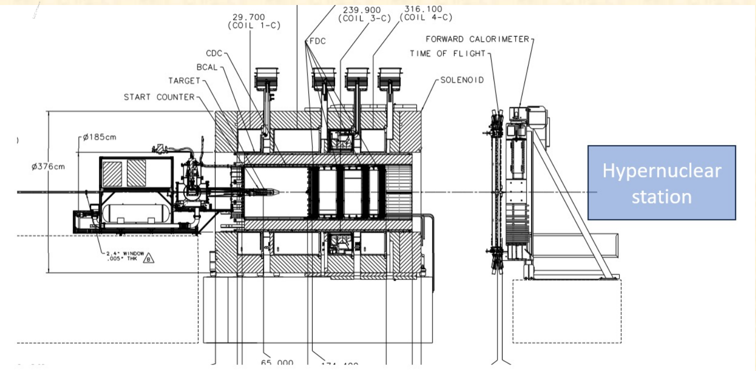
Talk by Professor Moskov Amaryan, at 10:00 today

- No beam tracks in the emulsion
  - We can leave emulsions, no movement
  - Main background: high energy gamma-rays

With K^- beams
like in the J-PARC E07 exp.



With K^0 beams
In the proposed project



- Intensity: 0.7 X 10^4 anti-K^0 /s
  - Two years from 2027: 200 days per year (a total of 400 days)
  - **2.3 times more** than J-PARC E07 (**2.3 k double-strangeness hypernuclei**) with **HIGH QUALITY DATA**

High Energy Nuclear Physics laboratory at RIKEN

Assistant:

Yukiko Kurakata

Staff scientists:

Yoshiki Tanaka, He Wang

Postdocs:

Hiroyuki Ekawa, Manami Nakagawa

Ph.D. Students:

Yiming Gao (IMP), Yan He (LZU), Wenzhen Xu (Shandong U.), Ayari Yanai (Saitama U.)

Technical staffs:

Michi Ando, Risa Kobayashi

Trainee:

Snehankit Pattnaik (Bochum U. and GSI)

Visiting researchers:

Ayumi Kasagi (Rikkyo U.), Kazuma Nakazawa (Gifu U.)

Associated members:

Vasyl Drozd (Groningen U., defending Ph.D.), Samuel Escrig (CSIC-Madrid, writing Ph.D. thesis), Enqiang Liu (IMP, defending Ph.D.), Abdul Muneem (GIK)

Chief scientists:

Take R. Saito

Takehiko R. Saito
takehiko.saito@riken.jp