Summary talk: Nuclear Physics
Our Hypernuclear Studies with Machine Learning

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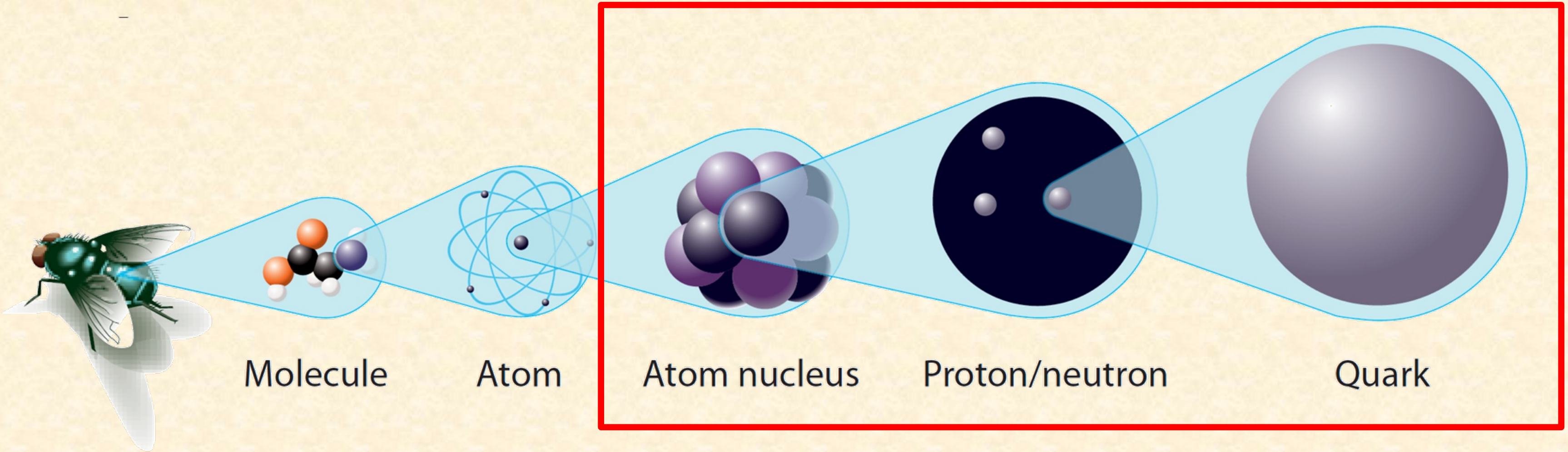
The second "European AI for Fundamental Physics Conference" (EuCAIFCon) , Cagliari
16th – 20th June, 2025

Building block of the matter



Interactions among particles

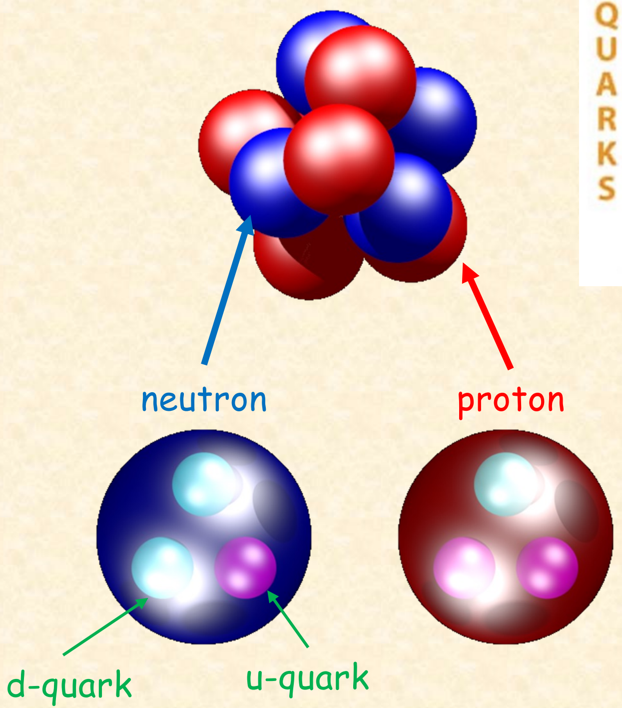
- Strong interaction
- Weak interaction

Hierarchy of the matter

Evolution of the very early universe

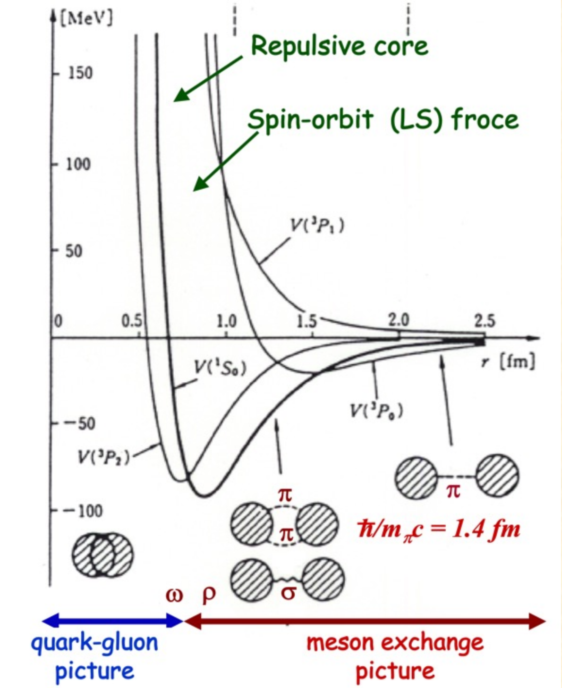
Quarks and sub-atomic nuclei

Sub-atomic nucleus



QUARKS

UP	CHARM	TOP
mass 2,3 MeV/c²	1,275 GeV/c²	173,07 GeV/c²
charge ⅔	⅔	⅔
spin ½	½	½
u	c	t
DOWN	**STRANGE**	**BOTTOM**
4,8 MeV/c²	95 MeV/c²	4,18 GeV/c²
-⅓	-⅓	-⅓
½	½	½
d	s	b



There are many identical quarks

Nuclear physics with AI

Experimental Data Analysis

- Track Reconstruction

  AI, especially Graph Neural Networks (GNN) and Convolutional Neural Networks (CNN) for reconstructing particle tracks in detectors such as TPCs and silicon trackers.

- Noise Reduction & Event Classification

  Extracting meaningful signals from large datasets by removing noise and classifying relevant events.

Theoretical Modeling of Nuclear Structure and Reactions

- Finding the best parameters

  ML techniques, including Bayesian optimization, for fiting parameters in energy density functionals (e.g., Skyrme, Gogny) based on experimental nuclear properties.

- Prediction of Properties of Exotic Nuclei

  To predict properties (mass, half-life, radii) of neutron-rich or superheavy nuclei that are difficult to measure experimentally.

Nuclear Astrophysics and Equation of State (EoS) Studies

- EoS Prediction for Neutron Stars

  Integrate data from nuclear experiments and astrophysical observations (e.g., gravitational waves, X-ray spectra) to explore the EoS of dense nuclear matter.

Automated Experiment Design and Data Pipelines

- Inverse Experimental Design

  AI can suggest optimal experimental conditions, such as beam species, energy, and target material.

- Multivariate Visualization

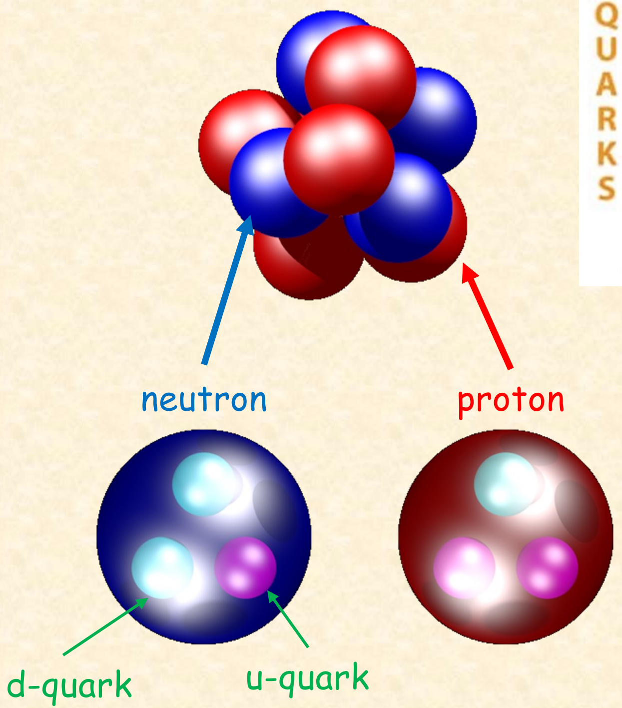
  AI aids in reducing dimensionality and visualizing physical patterns in large.

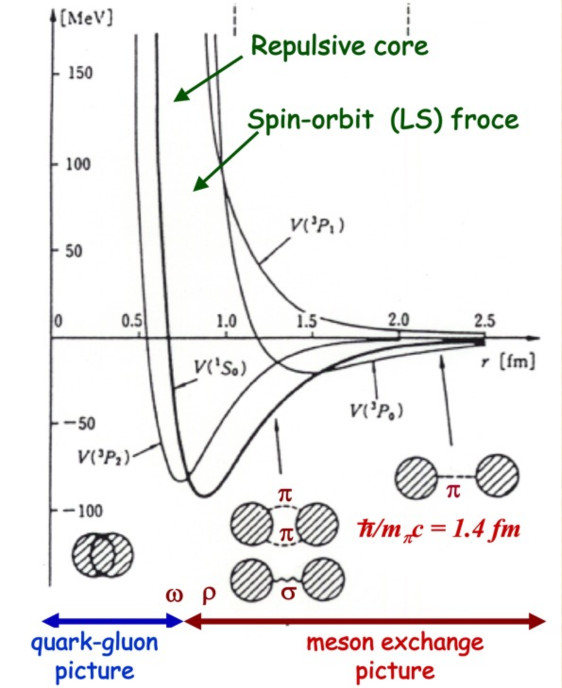
Accelerator and Beam Optimization

- Beam Stabilization and Tuning
- Real-Time Anomaly Detection

Quarks and sub-atomic nuclei

Sub-atomic nucleus





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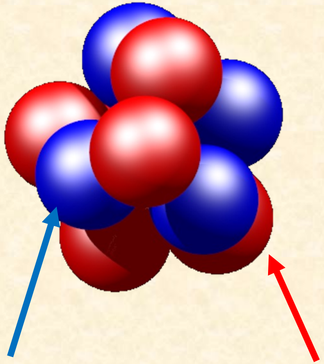
Quarks and sub-atomic nuclei

Sub-atomic nucleus

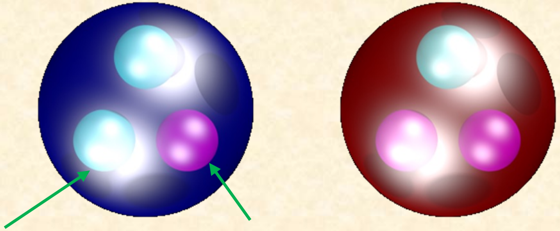


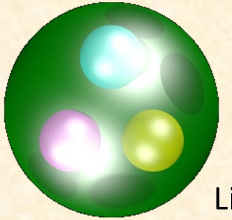
Hyperon	Quarks	$I(J^P)$	Mass (MeV)
Λ	uds	$0(1/2^+)$	1115
Σ^+	uus	$1(1/2^+)$	1189
Σ^0	uds	$1(1/2^+)$	1193
Σ^-	dds	$1(1/2^+)$	1197
Ξ^0	uss	$1/2(1/2^+)$	1315
Ξ^-	dss	$1/2(1/2^+)$	1321
Ω^-	sss	$0(3/2^+)$	1672

neutron

proton

hyperon (Λ)





Lifetime: 10^{-10} s

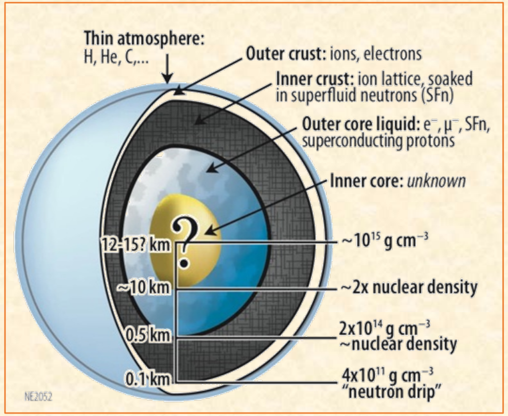
d-quark

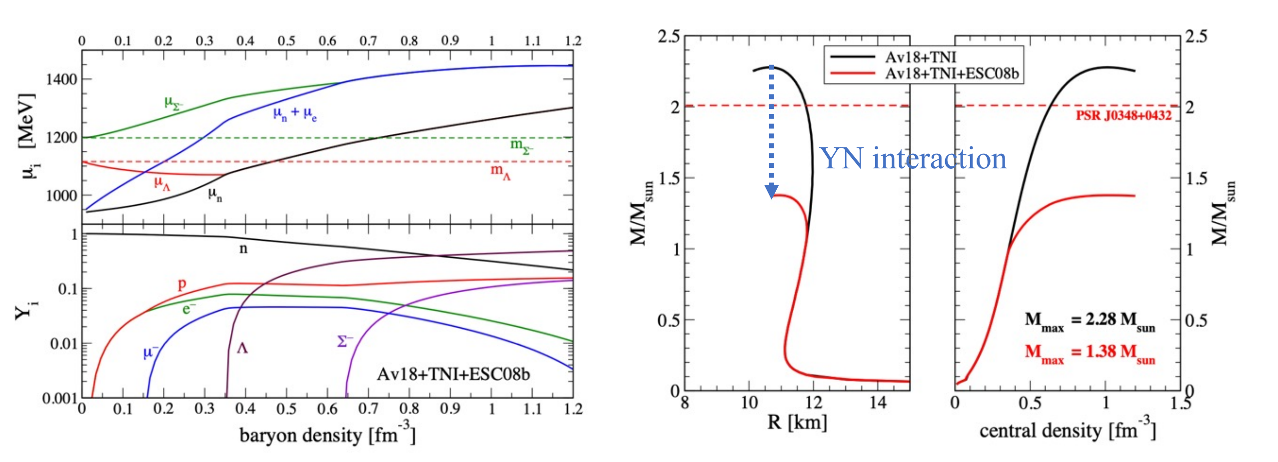
u-quark

There are many identical quarks

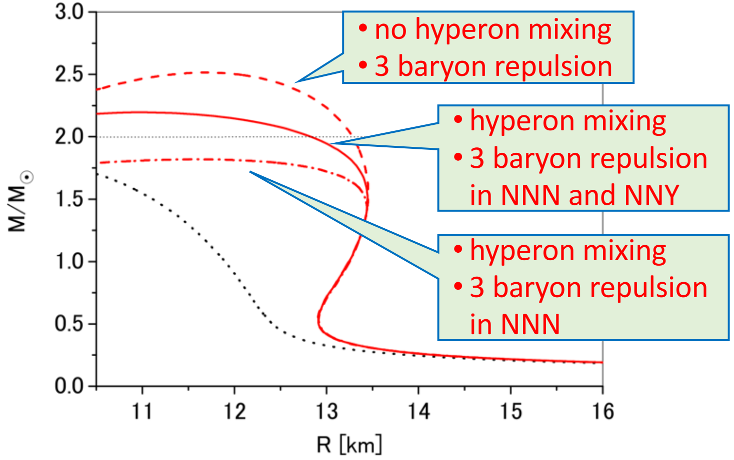
s-quark: distinguishable from u- and d-quarks

Neutron stars and dense nuclear matter





Y. Yamamoto, T. Furumoto, N. Yasutake, Th.A. Rijken,
Phys. Rev. C90 045805 (2014)

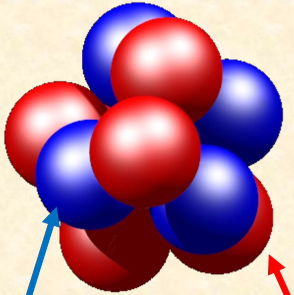


Baryon interaction

- N−N
- Λ−N
- Σ−N
- Λ−Λ, Σ−Σ, Λ−Σ
- Ξ−N
- Ξ−Λ, Ξ−Σ
- Ξ−Ξ

Quarks and sub-atomic nuclei

Sub-atomic nucleus



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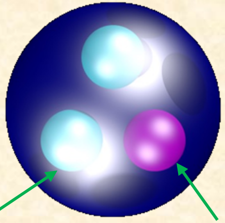
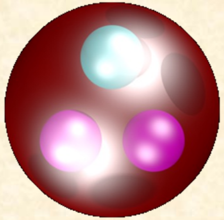
neutron



proton



d-quark

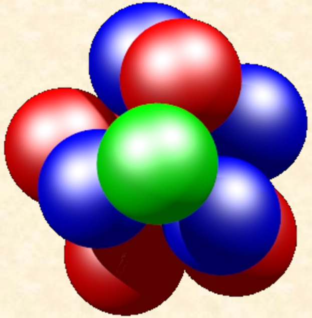
u-quark

hyperon (Λ)

Lifetime: 10^{-10} s

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

hypernucleus

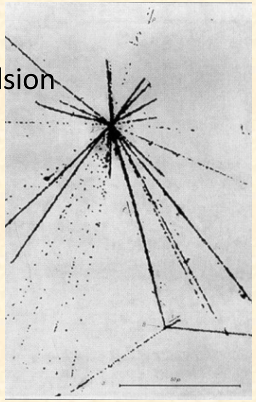


Micro-laboratory to study baryonic-interactions

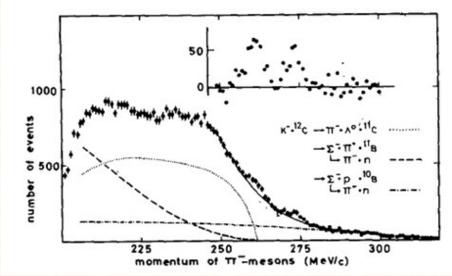
History of hypernuclear Experiments before HI (only a major part)

1953 – 1970
With nuclear emulsion

Marian Danysz (left) and Jerzy Pniewski, who first observed a hypernucleus.



1970 - 1985
Kaon beams at CERN



1985 - 2005
Kaon and pion beams at AGS/BNL and PS/KEK

FINUDA

From 21st century
Kaon beams at J-PARC and electron beams at JLab

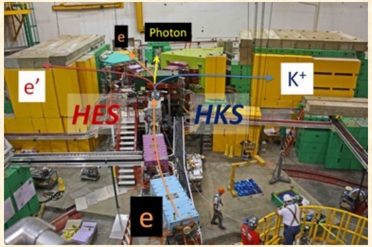


Chart of ordinary nuclei

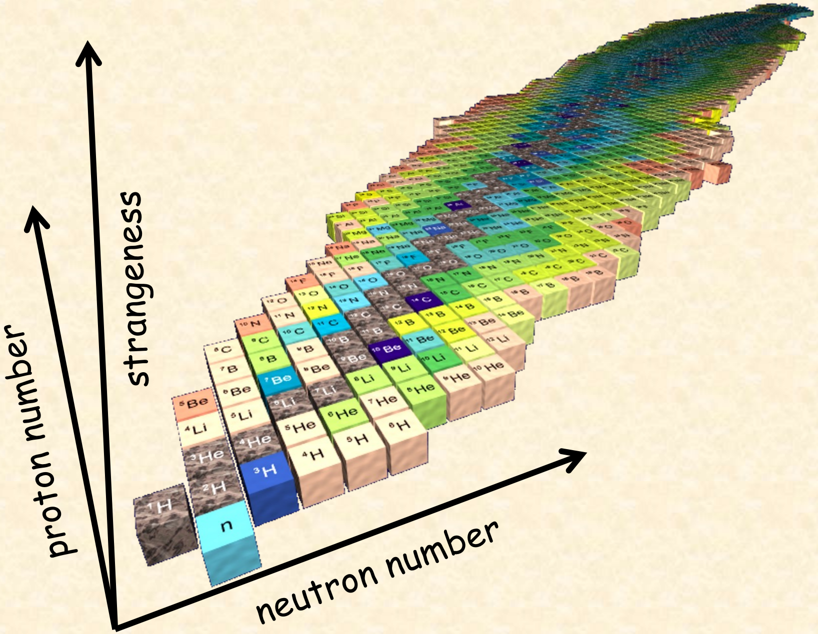


Chart of single-strangeness hypernuclei

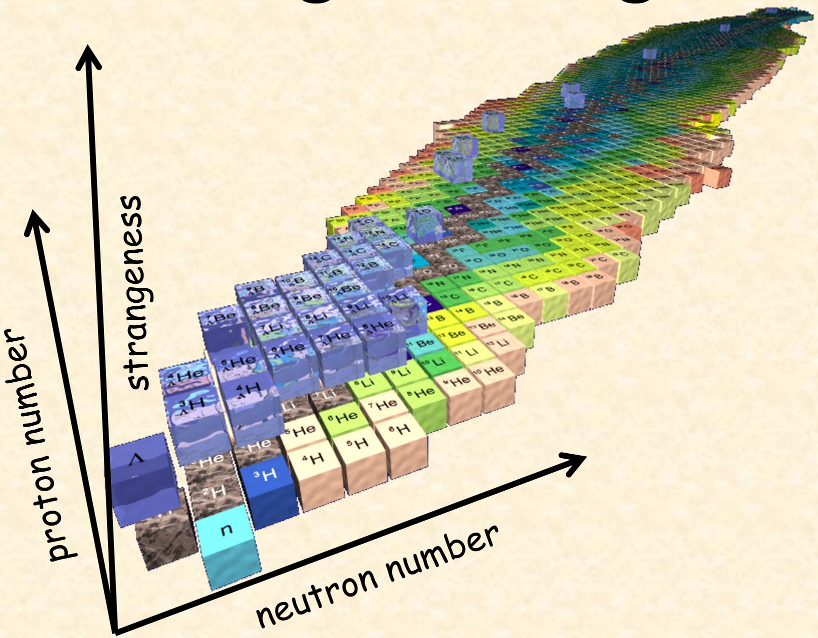


Chart of double-strangeness hypernuclei

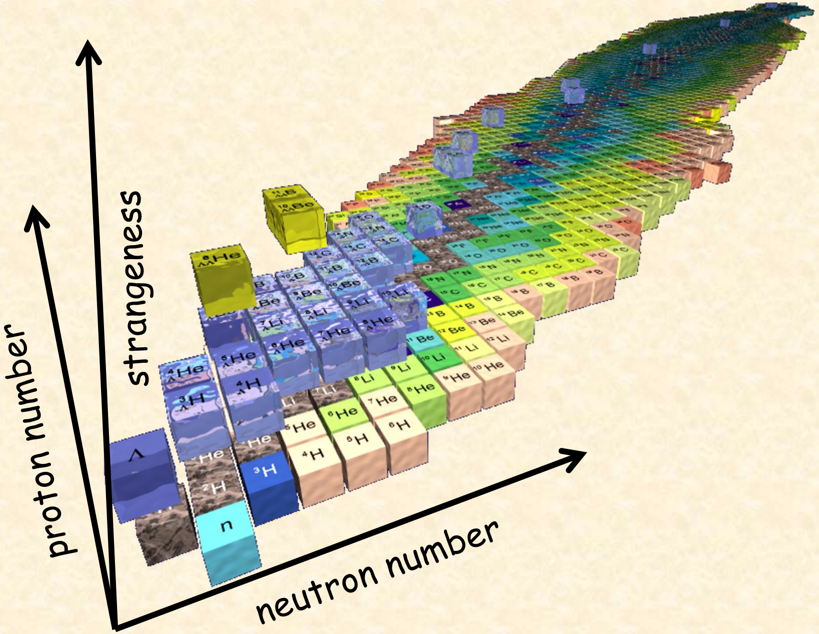
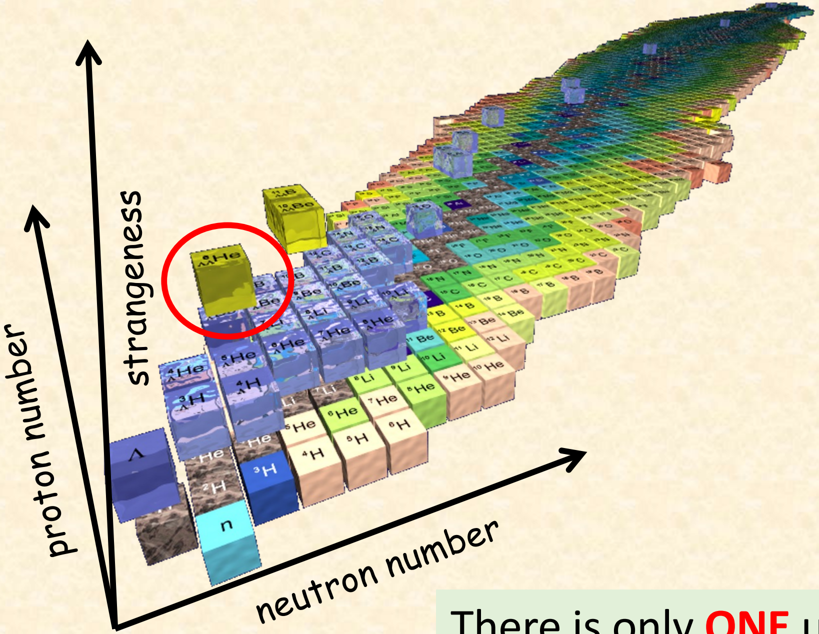


Chart of double-strangeness hypernuclei



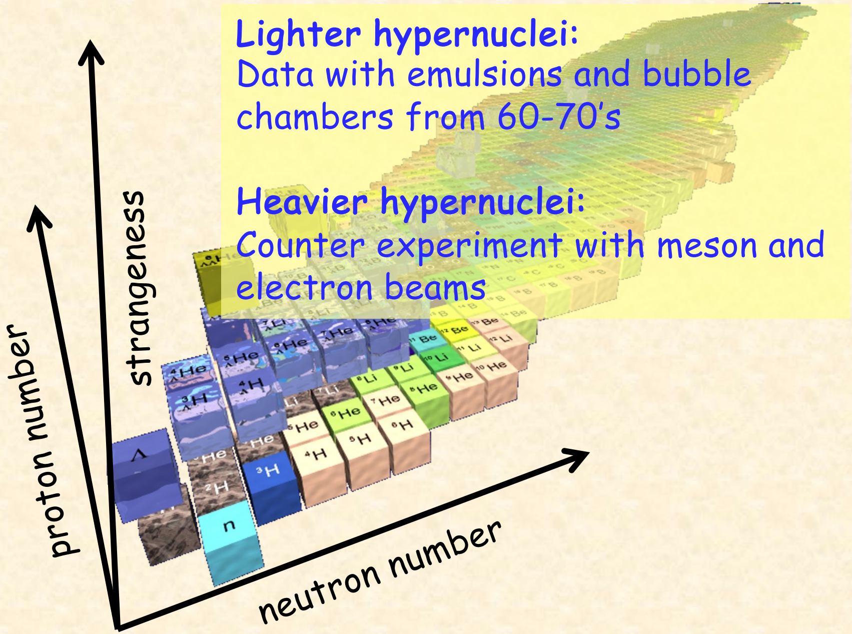
There is only **ONE** uniquely unidentified S=-2 hypernucleus
Nagara event, $^{6}_{\Lambda\Lambda}$**He**

$\Delta B_{\Lambda\Lambda} = 0.67 \pm 0.17$ MeV

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

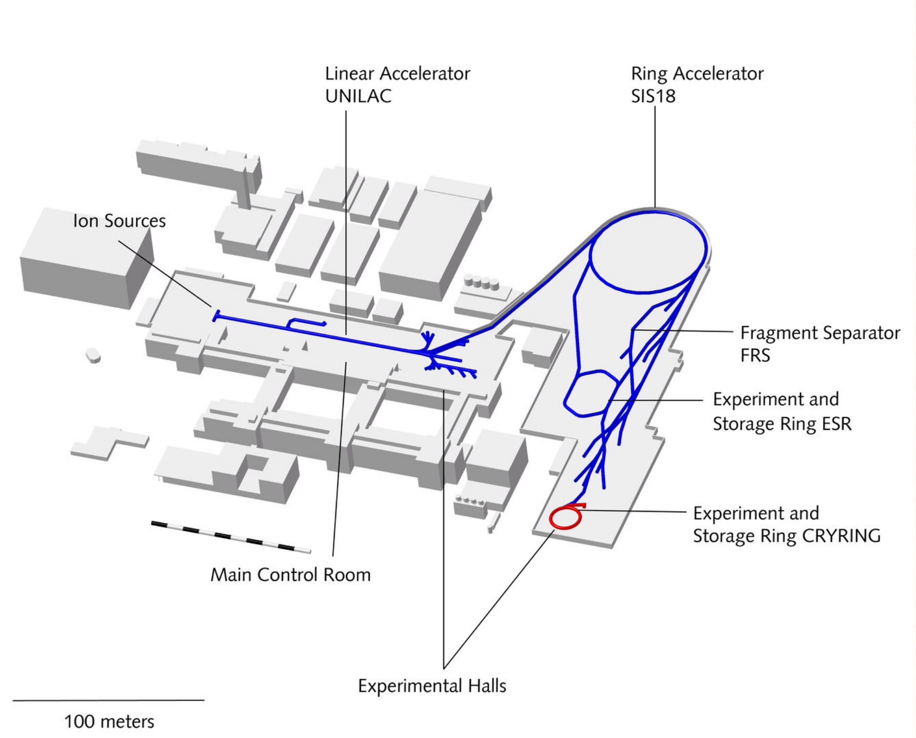
Difficulties
- Limited isospin
- Small momentum transfer to separate hypernuclei
- Difficulties on decay studies
- Only up to double-strangeness

Hypernuclear spectroscopy with heavy ion beams

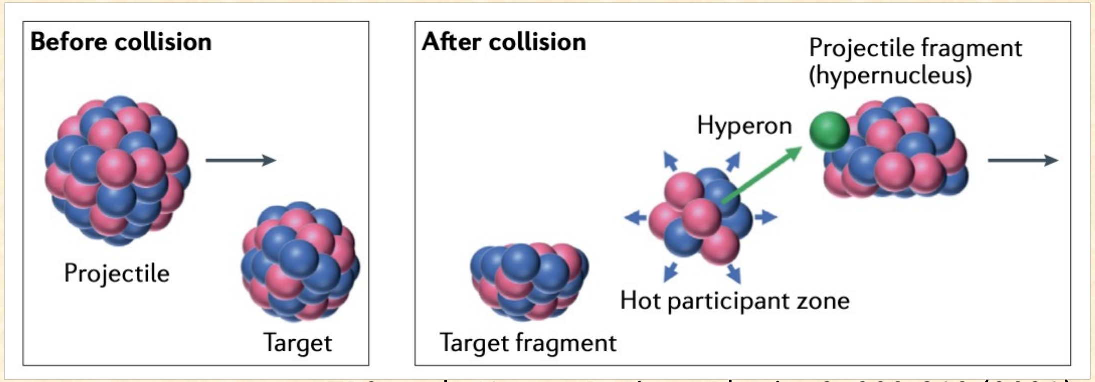
HypHI project, started in 2005

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

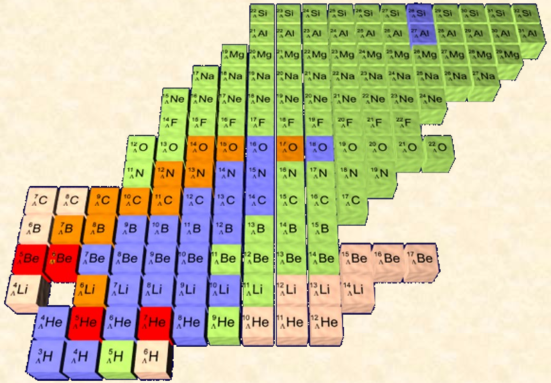
GSI and FAIR in Germany

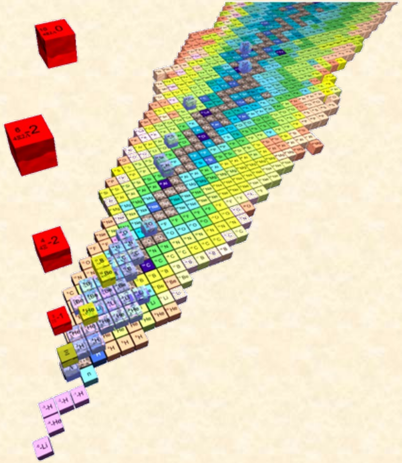


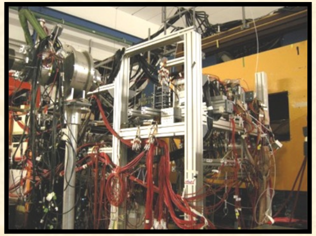
The HypHI Phase 0 at GSI in Germany (2006-2012)

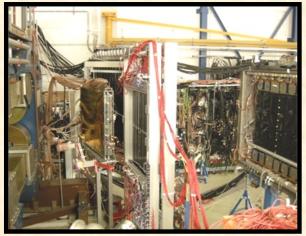


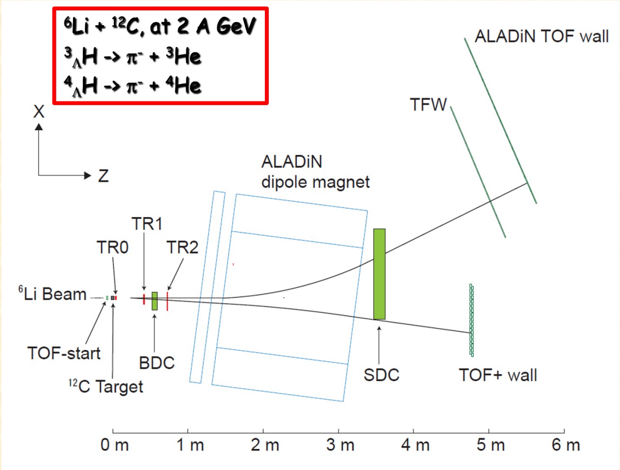
TRS et al., Nature Reviews Physics 3, 803-813 (2021)





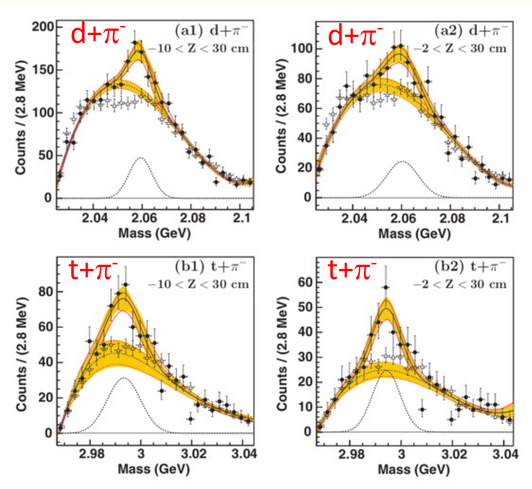






Two outcomes (mysteries) by HypHI

Signals indicating nnΛ bound state



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

<u>All theoretical calculations are negative</u>

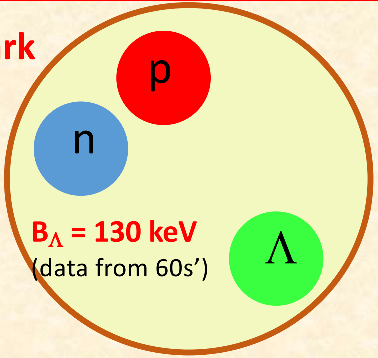
- E. Hiyama et al., Phys. Rev. C89 (2014) 061302(R)
- A. Gal et al., Phys. Lett. B736 (2014) 93
- H. Garcilazo et al., Phys. Rev. C89 (2014) 057001

and much more publication

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

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

Benchmark

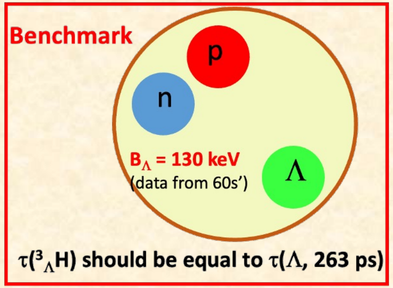


$\tau(^{3}_{\Lambda}H)$ should be equal to $\tau(\Lambda$, 263 ps)

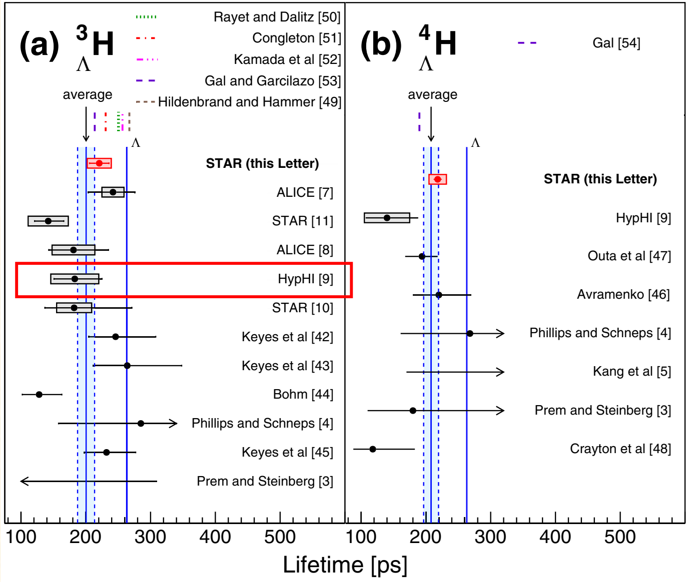
Stimulated other **<u>big</u>** experiments

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

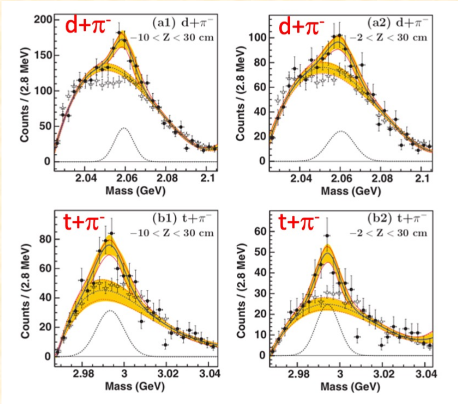
STAR Collaboration,

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

ALICE

0.102 ± 0.063 ± 0.067 MeV

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



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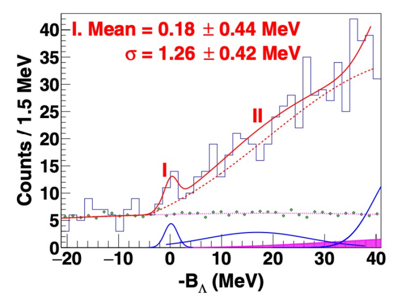

FIG. 5. The enlarged mass spectrum around the Λnn threshold. Two additional Gaussians were fitted together with the known contributions (the accidentals, the Λ quasifree, the free Λ, and the ^{3}He contamination). The one at the threshold is for the small peak, while the broad one is for the additional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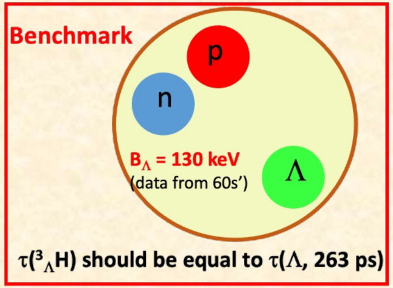
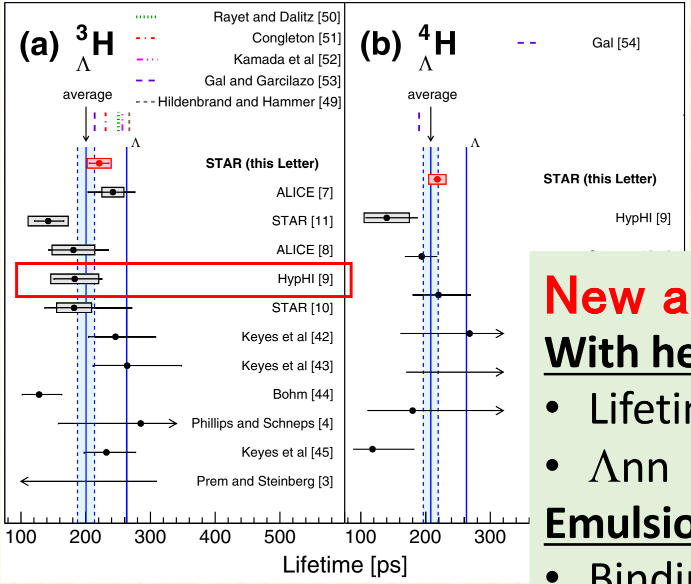
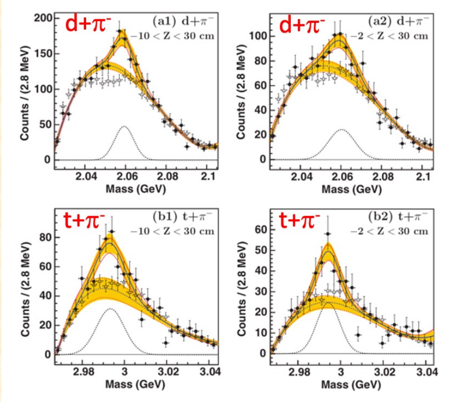


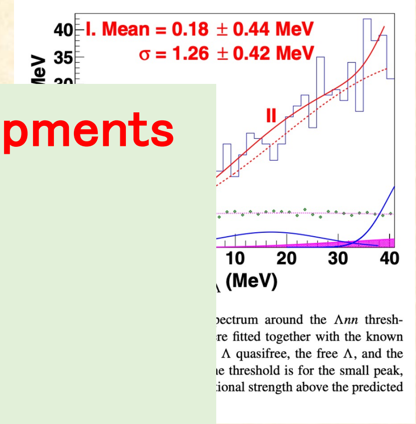


STAR Collaboration, PRL **128** (2022) 20230…

On Λnn



HypHI., PRC 88 (2013) 041001



…, PRC 105 (2022) L051001

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

ALICE

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

New approaches with new developments

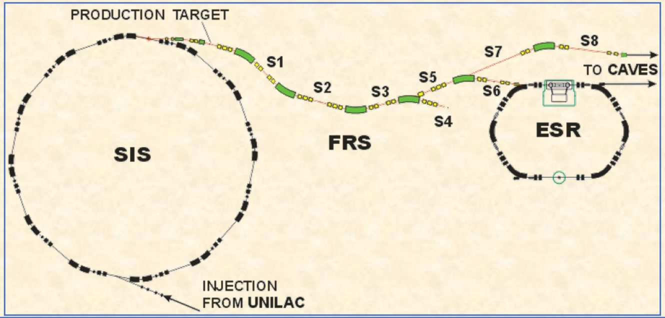
With heavy ion beams:

- Lifetime
- Λnn

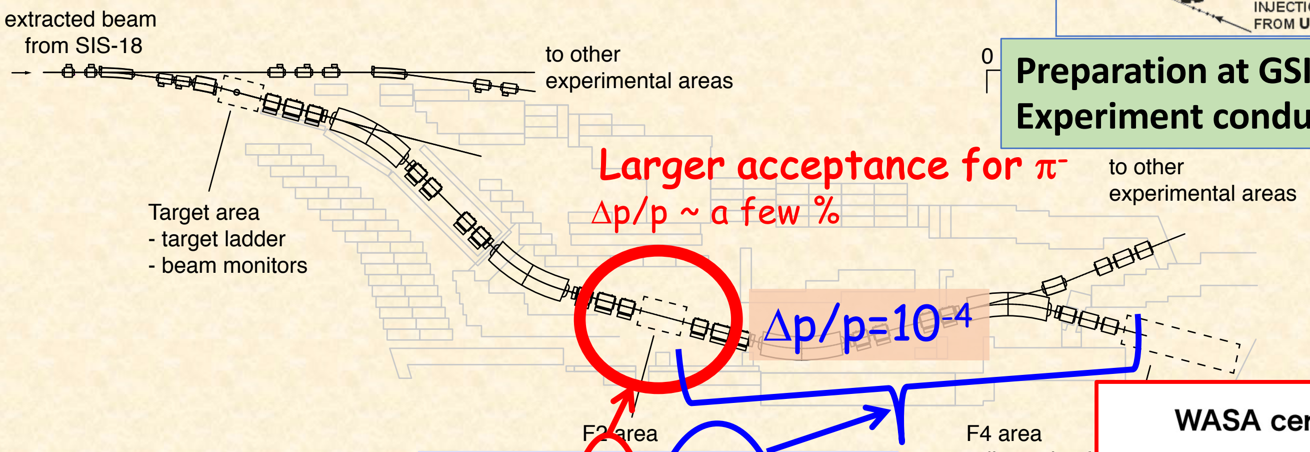
Emulsion + Machine Learning

- Binding energy

The novel technique with FRS at GSI (2016-)



Preparation at GSI started in March 2019
Experiment conducted in January-March 2022

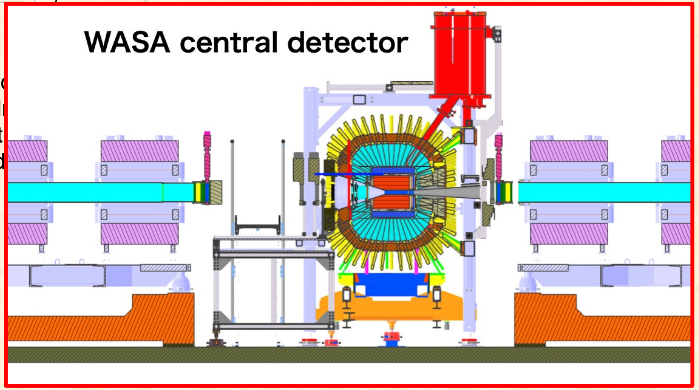


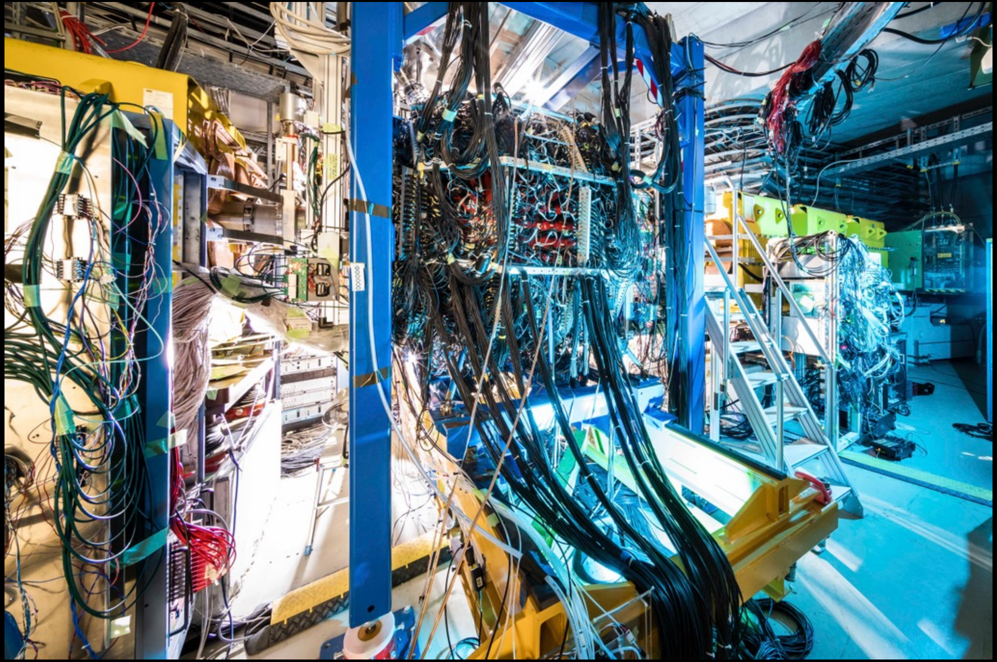
$^{3}_{\Lambda}H$ -> π^- + ^3He

$^{4}_{\Lambda}H$ -> π^- + ^4He

$nn\Lambda$ -> π^- + d + n

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





Photos by Jan Hosan and GSI/FAIR


GSI REPORT 2023-1

GSI-FAIR SCIENTIFIC REPORT 2022

An overview of the 2022 achievements in science and technology

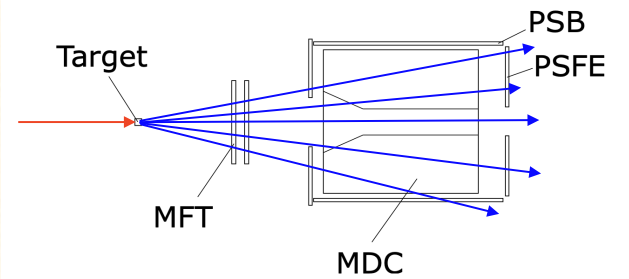
FAIR Phase-0 Research Program

GSI FAIR

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

Graph Neural Network (GNN) for WASA

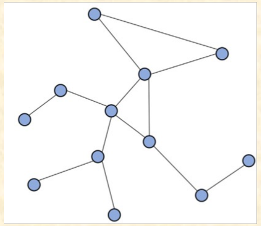
Track Finding

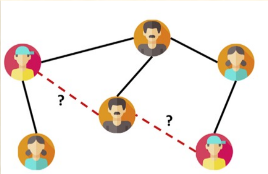


- Multi particles in HI reaction
- Combinatorial background

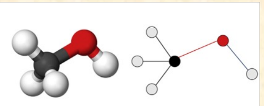
→ Track Finding with Graph Neural Network (GNN)

Graph



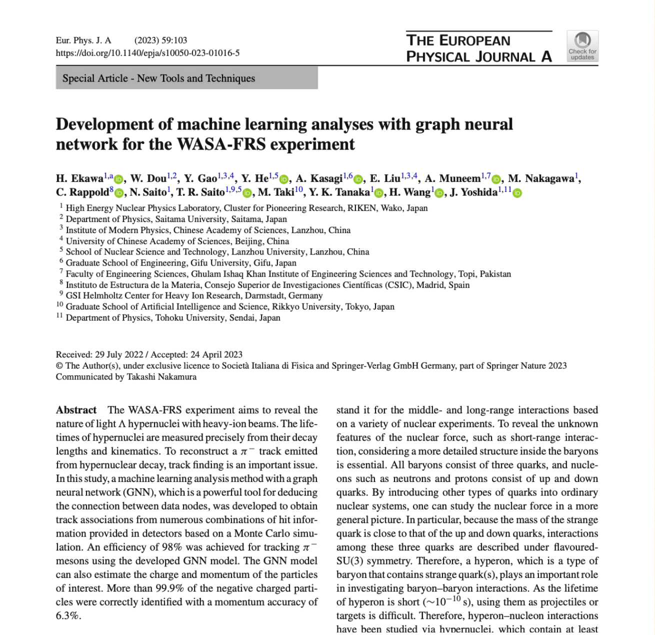


(e) Social Network


(b) Molecule

- Node : Data point
- Edge : Connection

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



Eur. Phys. J. A (2023) 59:103
https://doi.org/10.1140/epja/s10050-023-01016-5
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

Received: 29 July 2022 / Accepted: 24 April 2023

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%.

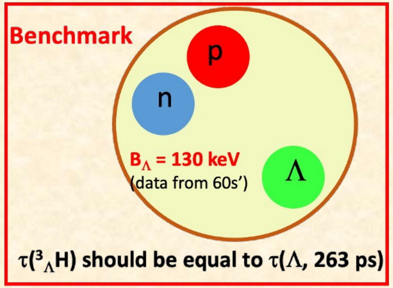
stand it for the middle- and long-range interactions based on a variety of nuclear experiments. To reveal the unknown features of the nuclear force, such as short-range interaction, considering a more detailed structure inside the baryons is essential. All baryons consist of three quarks, and nucleons 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

H. Ekawa et al., Eur. Phys. J. A (2023) **59**, 103
DOI : 10.1140/epja/s10050-023-01016-5

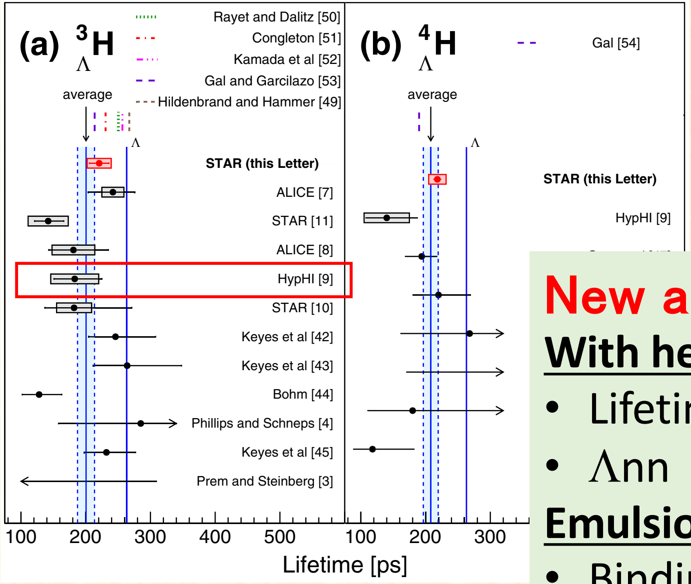
David Calonge, "Track Inference of the Ion-optics of WASA-FRS based on machine learning models", **Poster session B**

The world situation of three-body hypernuclei

On hypertriton



Average
200 ± 13 ps



STAR Collaboration, PRL **128** (2022) 20230…

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

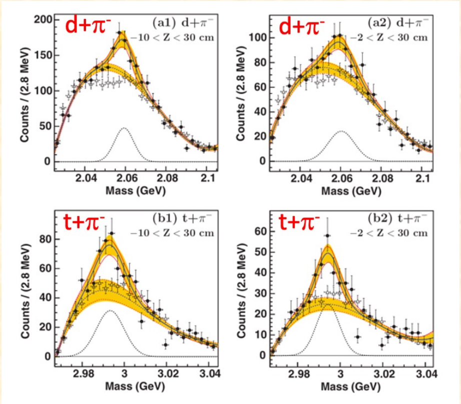
STAR Collaboration,

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

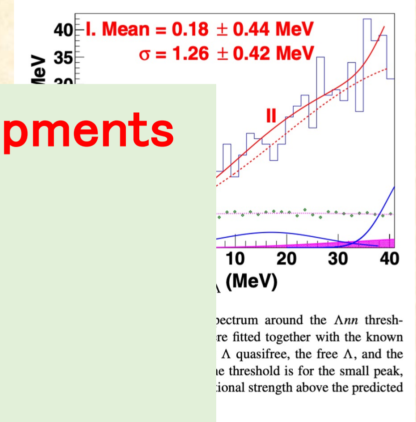
ALICE

0.102 ± 0.063 ± 0.067 MeV

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



HypHI., PRC 88 (2013) 041001



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

New approaches with new developments

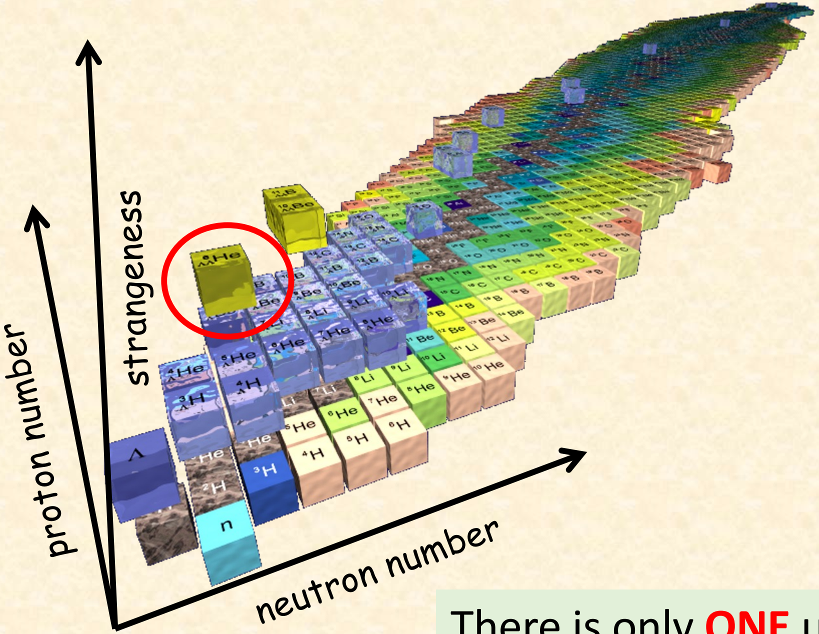
With heavy ion beams:

- Lifetime
- Λnn

Emulsion + Machine Learning

- Binding energy

Chart of double-strangeness hypernuclei



There is only **<u>ONE</u>** uniquely unidentified S=-2 hypernucleus

Nagara event, $^{6}_{\Lambda\Lambda}$**He**

$\Delta B_{\Lambda\Lambda} = 0.67 \pm 0.17$ MeV

Our challenges on Hypernuclei

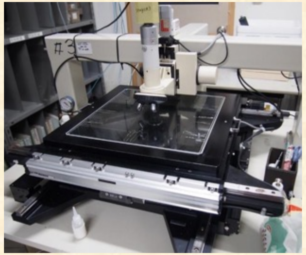
with image analyses
and
machine learning

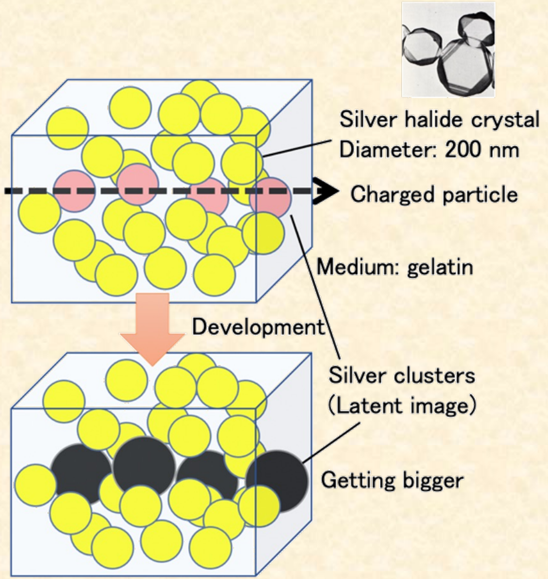
Nuclear Emulsion:

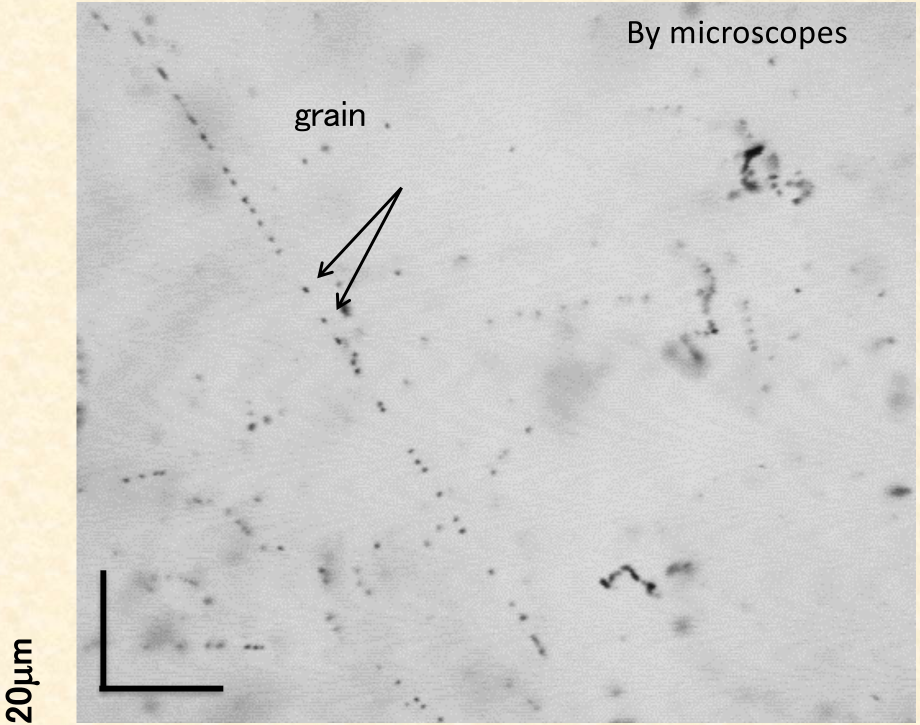
Charged particle tracker with

the best spatial resolution

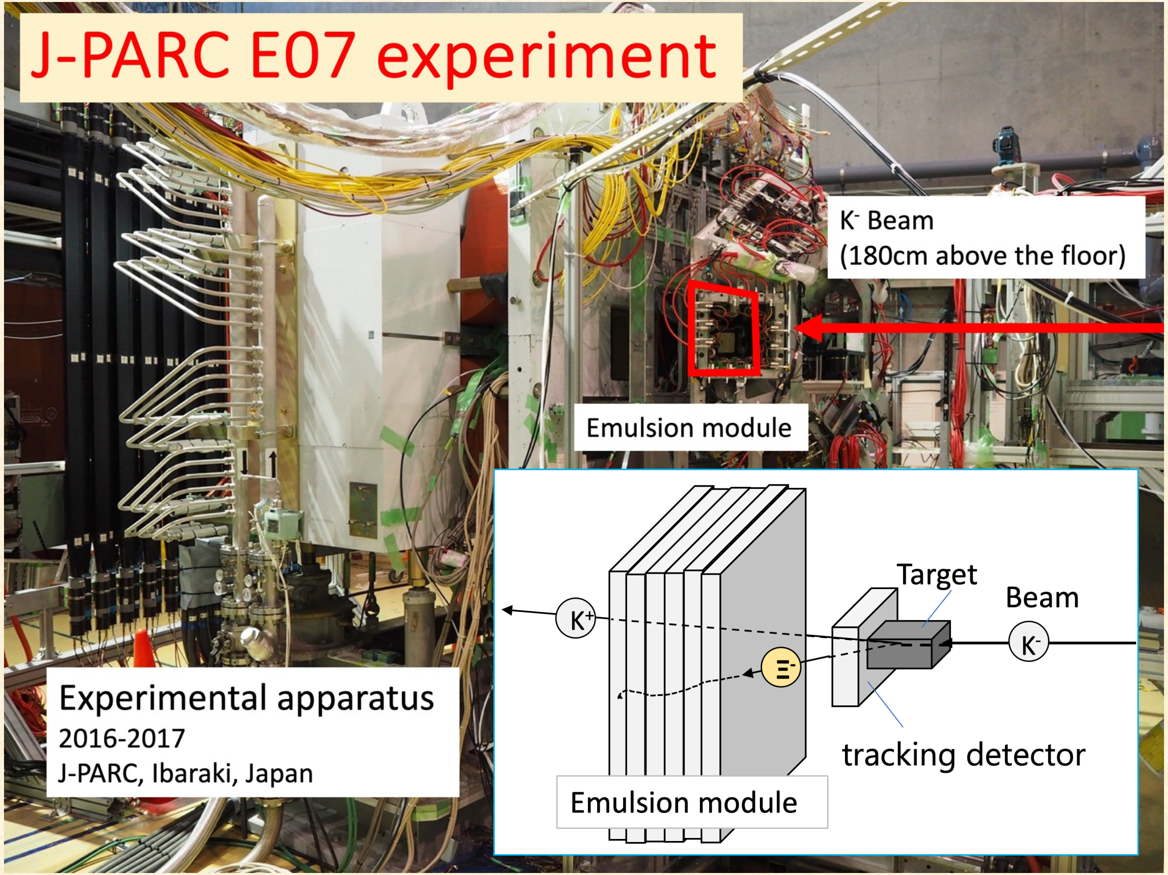
(easy to be < 1 μm, 11 nm at best)





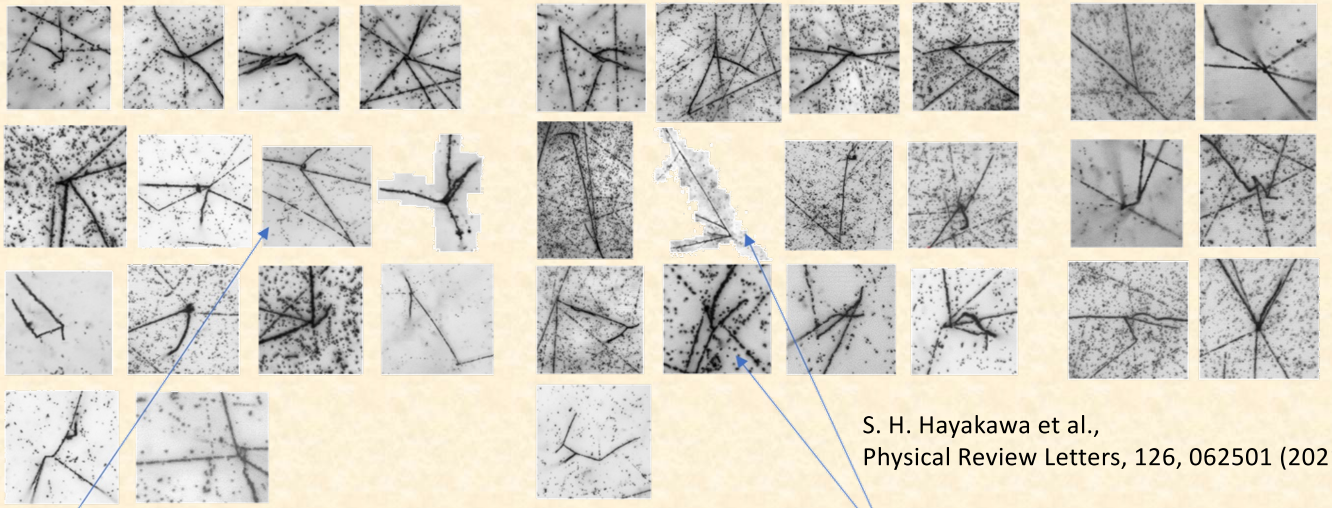


J-PARC E07 experiment



Results from J-PARC E07 (Hybrid method)

ΛΛ candidates: 14 Twin Λ events: 13 Others: 6



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

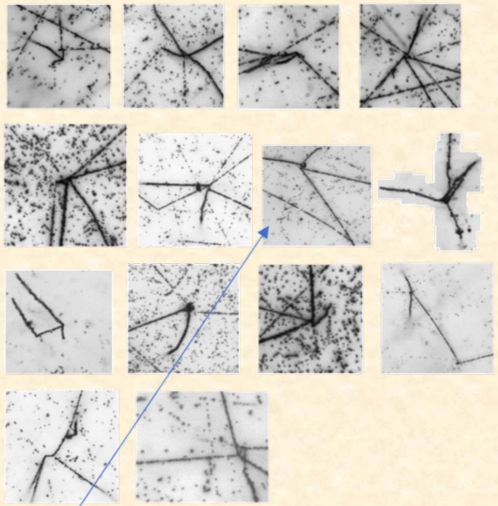
M. Yoshimoto et al.,
Prog. Theor. Exp. Phys. 2021, 073D02

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

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

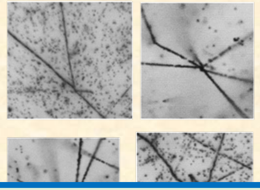
Results from J-PARC E07 (Hybrid method)

$\Lambda\Lambda$ candidates: 14



Twin Λ events: 13

Others: 6



$_{\Lambda\Lambda}$Be

H. Ekawa et al., Prog. Theor. Exp. Phys. 2019, 021D02

M. Yoshimoto

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

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

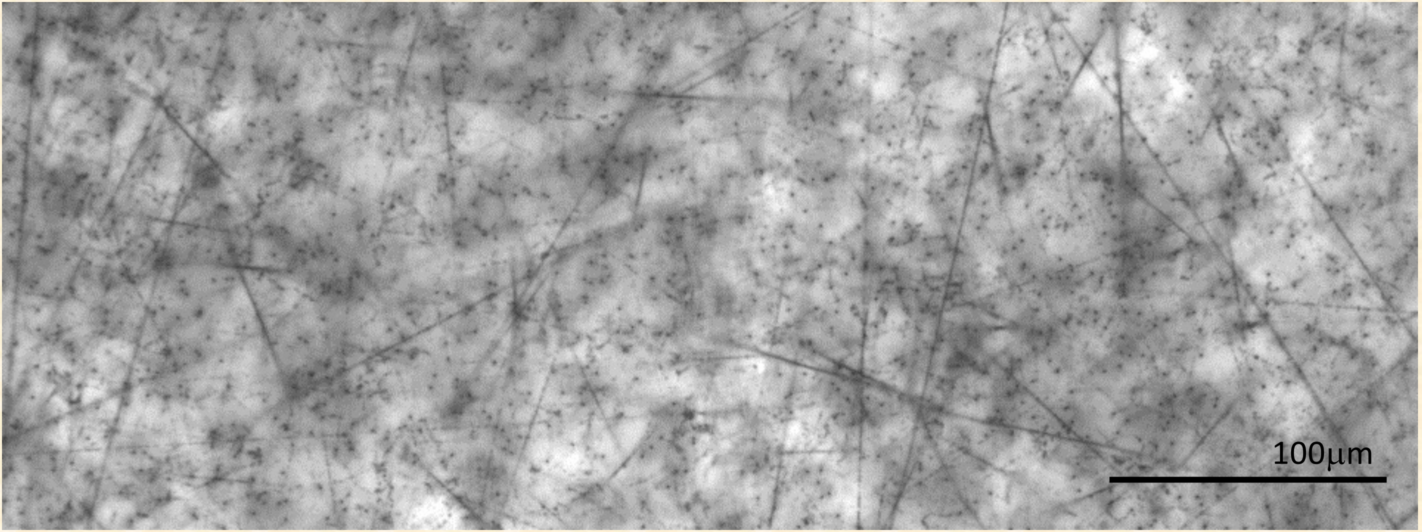
Non-triggered events recorded in 1300 emulsions sheets

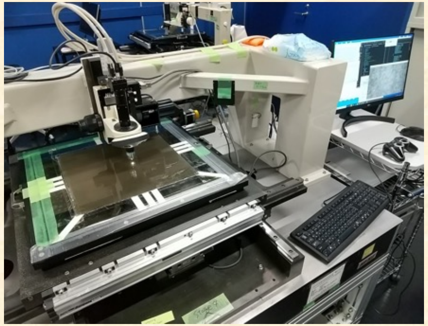
- 1000 double-strangeness ($\Lambda\Lambda$- and Ξ-) hypernuclear events
- Millions of single-strangeness hypernuclear events

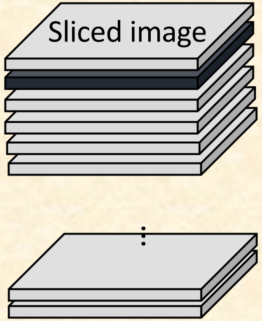
Overall scanning of all emulsion sheets

(35 X 35 cm^2 X 1000)

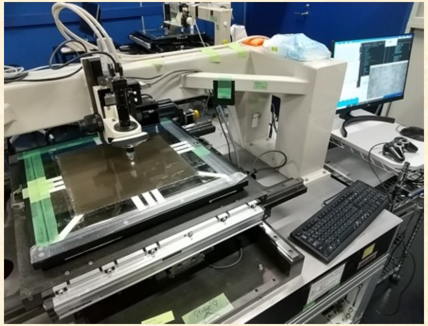
Overall scanning for E07 emulsions

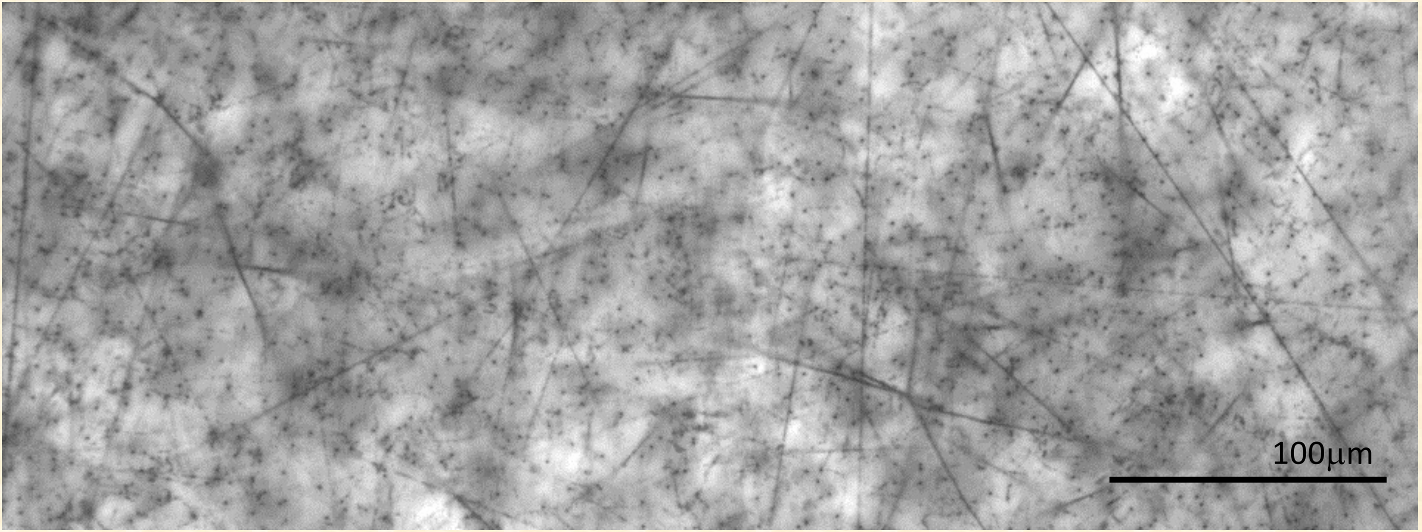


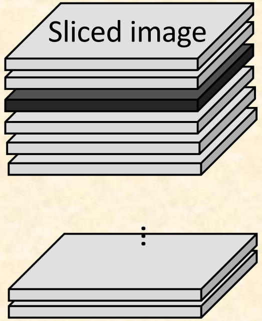




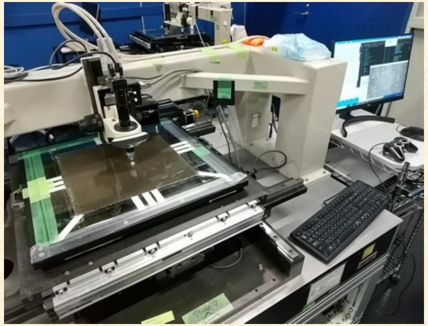
Overall scanning for E07 emulsions

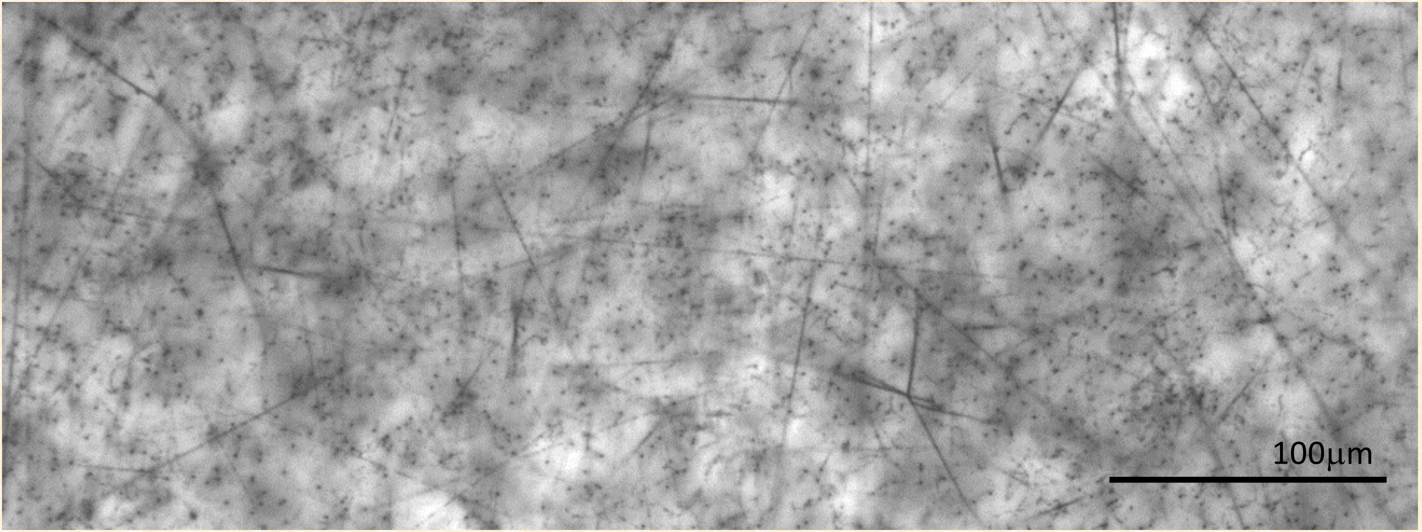


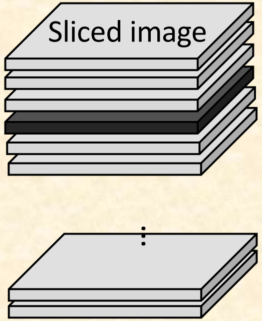




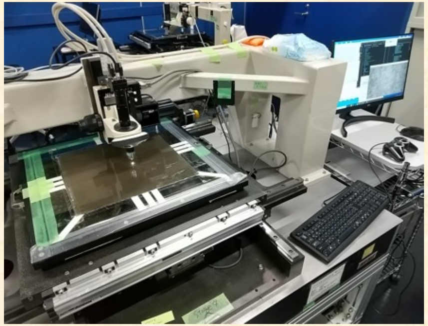
Overall scanning for E07 emulsions

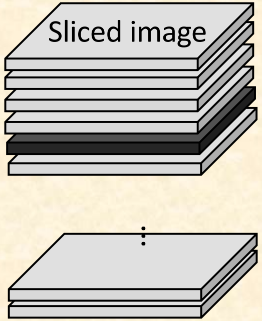


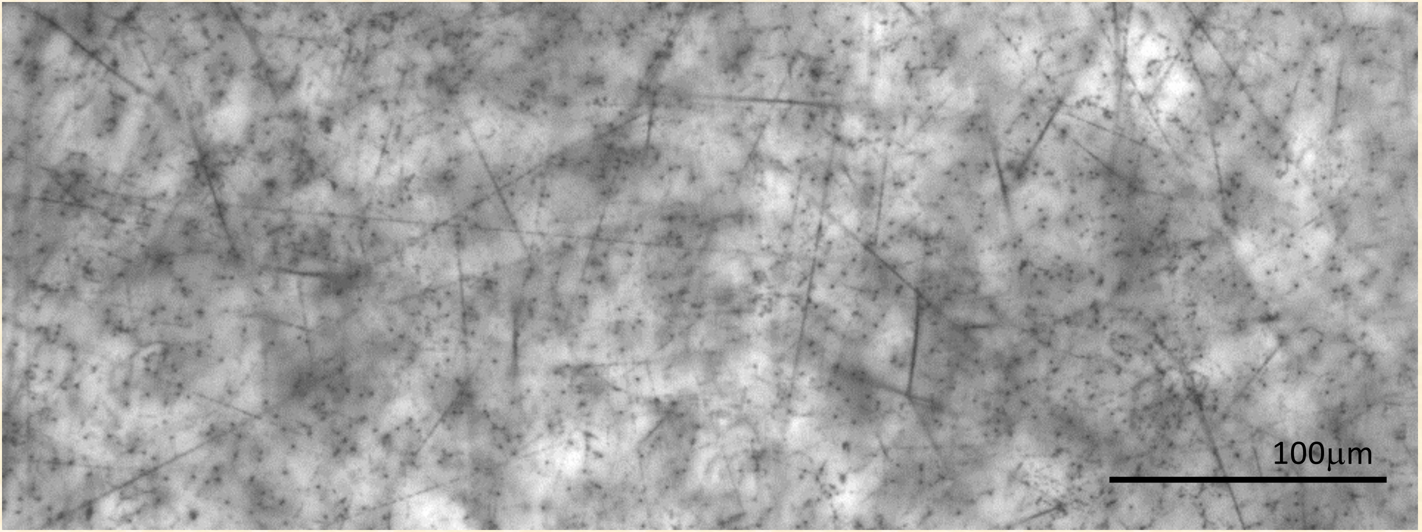




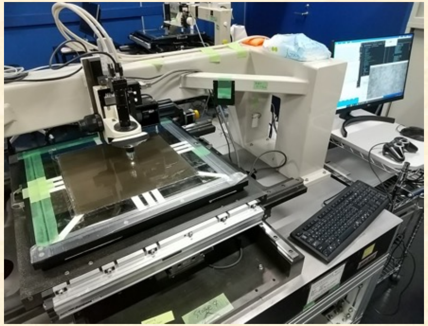
Overall scanning for E07 emulsions







Overall scanning for E07 emulsions

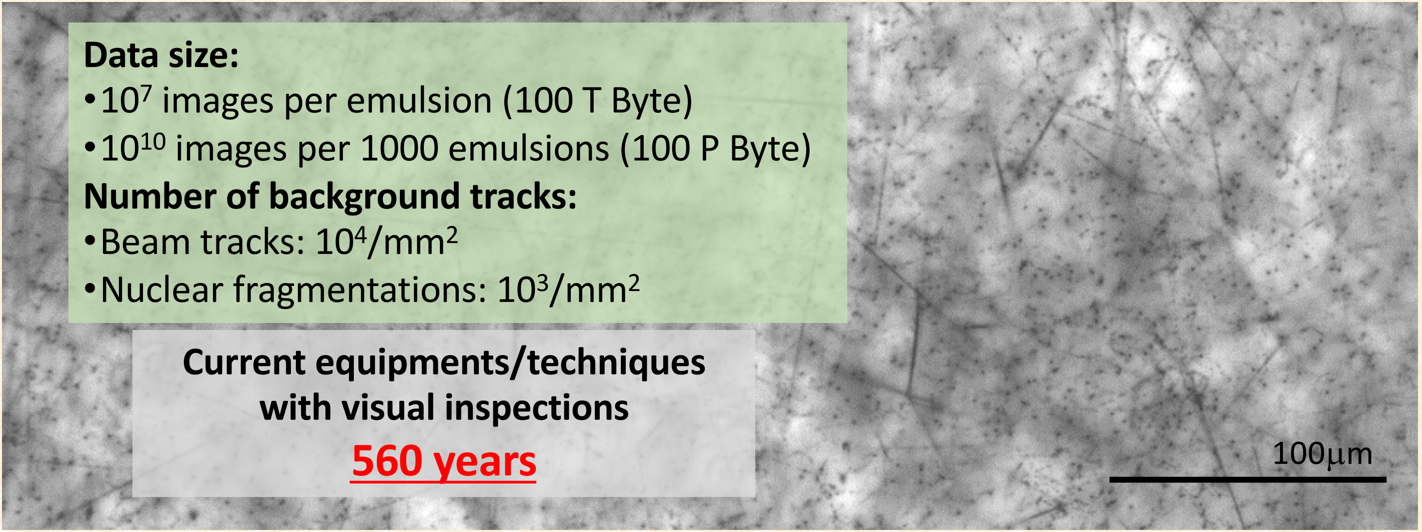


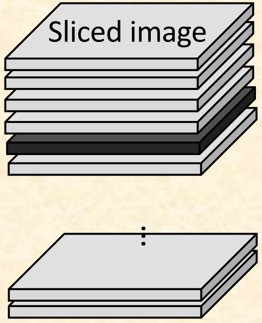
Data size:
- 10^7 images per emulsion (100 T Byte)
- 10^{10} images per 1000 emulsions (100 P Byte)

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

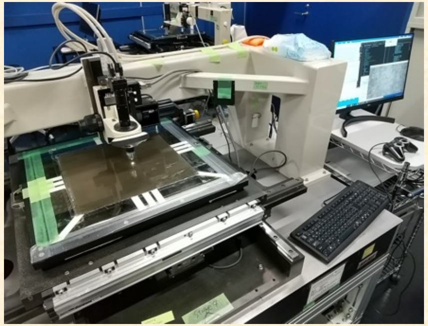
Current equipments/techniques with visual inspections

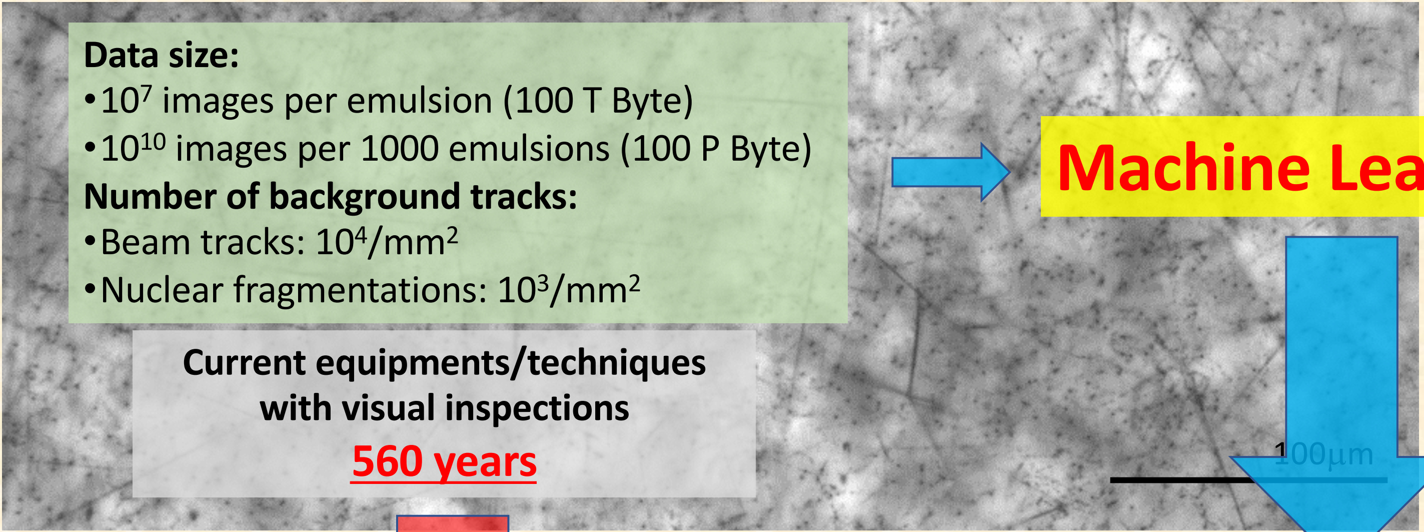
<u>560 years</u>





Overall scanning for E07 emulsions





Data size:

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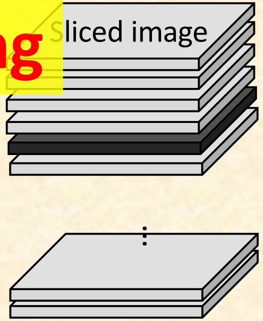
Current equipments/techniques with visual inspections

560 years

Machine Learning



3 years

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

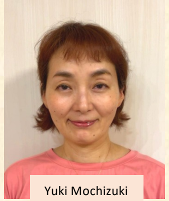
Setup for analyzing emulsions at the High Energy Nuclear Physics Laboratory in RIKEN

- Hypernuclear physics
- Neutron imaging

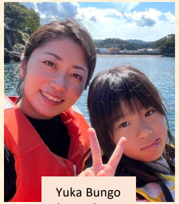
Technical staffs working for emulsion & microscopes

Current members

Risa Kobayashi (RIKEN)

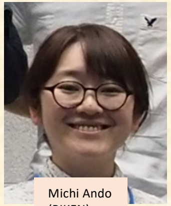


Yuki Mochizuki (RIKEN)

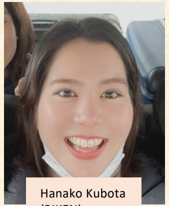


Yuka Bungo (RIKEN)

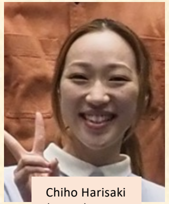
Former members



Michi Ando (RIKEN)



Hanako Kubota (RIKEN)



Chiho Harisaki (RIKEN)

Keiko Sudo (RIKEN)

Currently 7 microscope stages running

Challenges for Machine Learning Development

Ideas : 2018
Implementations: 2020-2021

MOST IMPORTANT:

- **Quantity and quality of training data**

However,
No existing data for hypertriton with emulsions for training

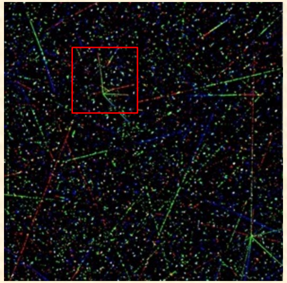
Our approaches:
Producing training data with

- Monte Carlo simulations
- Image transfer techniques

Production of training data

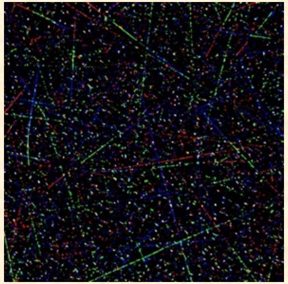
Monte Carlo simulations and GAN(Generative Adversarial Networks)

Binarized tracks from MC simulations
+ background from the real data

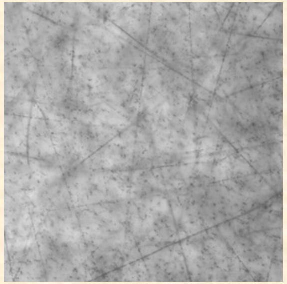


Imitated
emulsion image

GAN: pix2pix



Binarized (like for simulations)



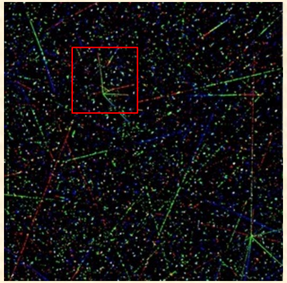
Real emulsion image

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

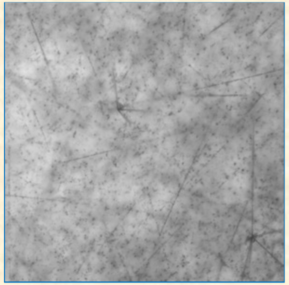
Production of training data

Monte Carlo simulations and GAN(Generative Adversarial Networks)

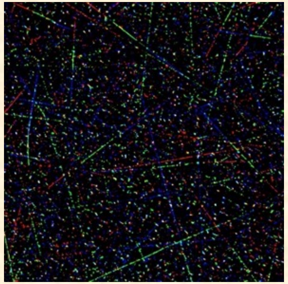
Binarized tracks from MC simulations
+ background from the real data



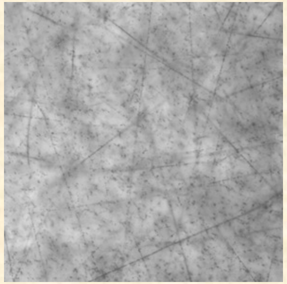
Produced training data



GAN: pix2pix



Binarized (like for simulations)

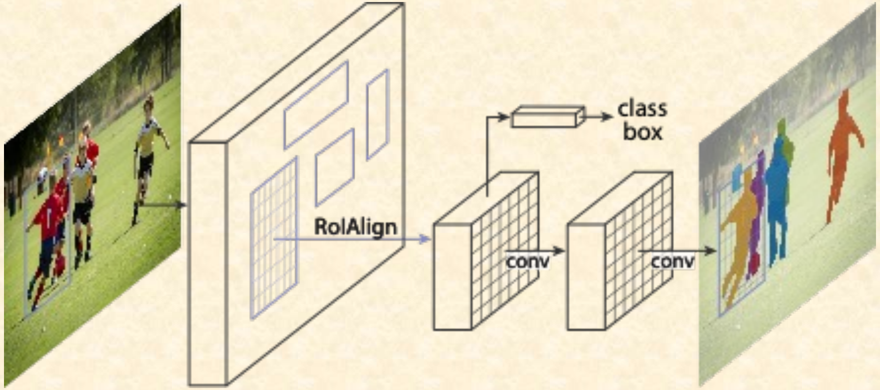


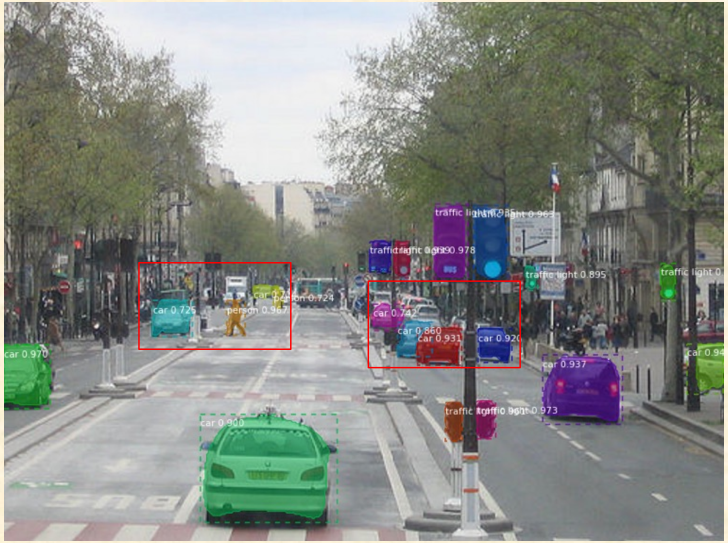
Real emulsion image

Ayumi Kasagi. Ph.D. thesis (2023)
A.Kasagi et.al,
Nucl. Instrum. Meth. A1056, (2023) 168663

Detection of hypertriton events

With Mask R-CNN model



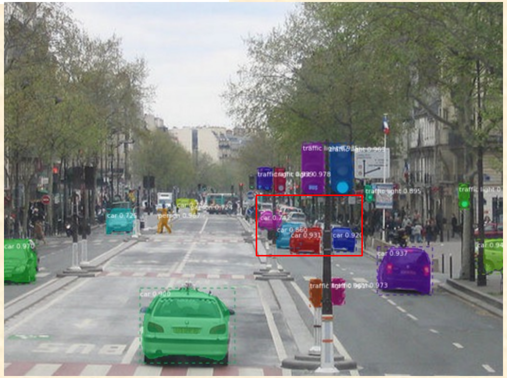


Detection of each object

At large object density

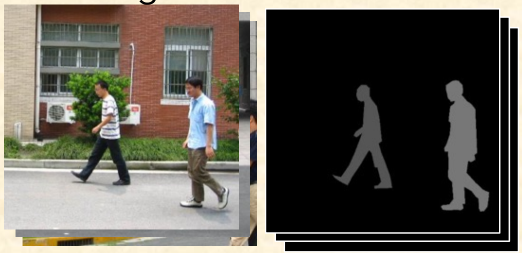
Training of Mask R-CNN with Simulated image

Mask R-CNN



Example of training dataset

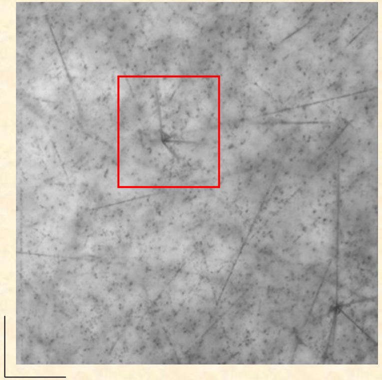
Image | Mask



A Pedestrian dataset

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

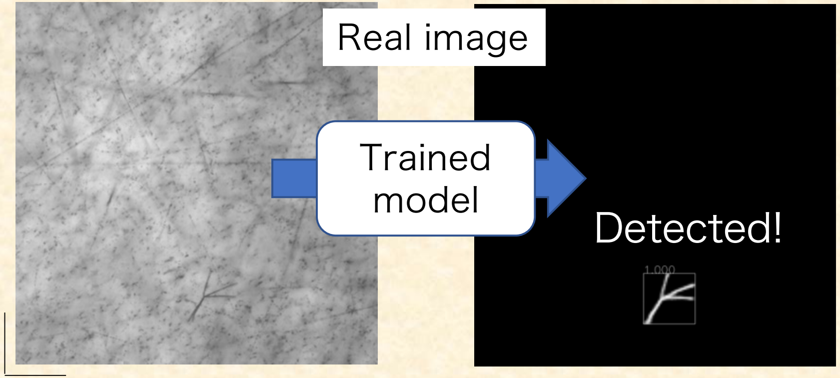
Training data (Simulated image)



50 μm

Masks are automatically produced

Performance of α-decay detection



50 μm

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

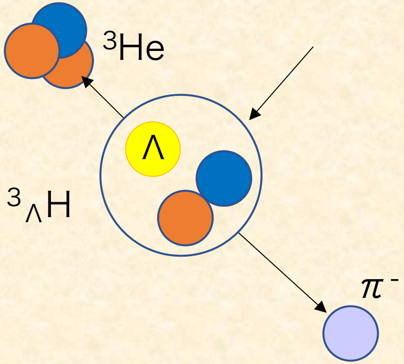
	Efficiency [%]	Purity [%]
Vertex picker	~40%	~1%
Mask R-CNN	~80%	~20%

→ 2nd step done

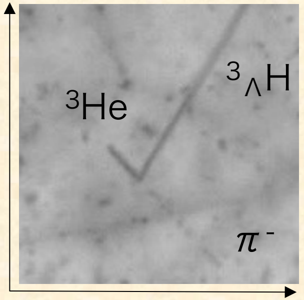
A.Kasagi et.al,
Nucl. Instrum. Meth. A 1056, (2023) 168663.

Hypertriton search with Mask R-CNN

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

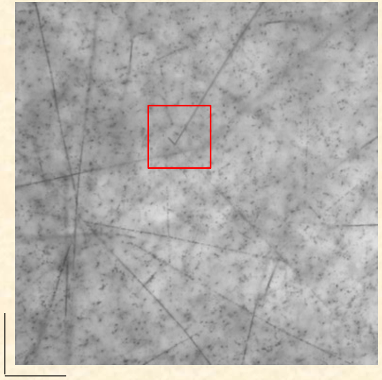


Simulated image

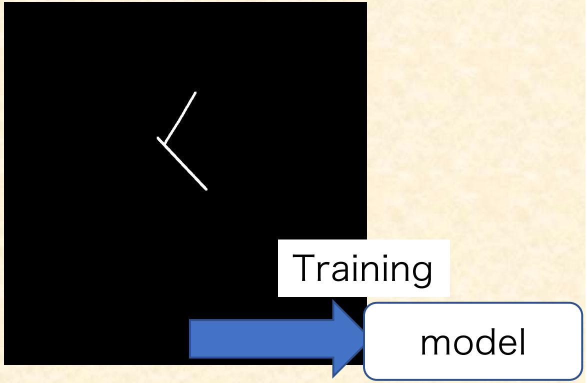


Training dataset (Simulated images)

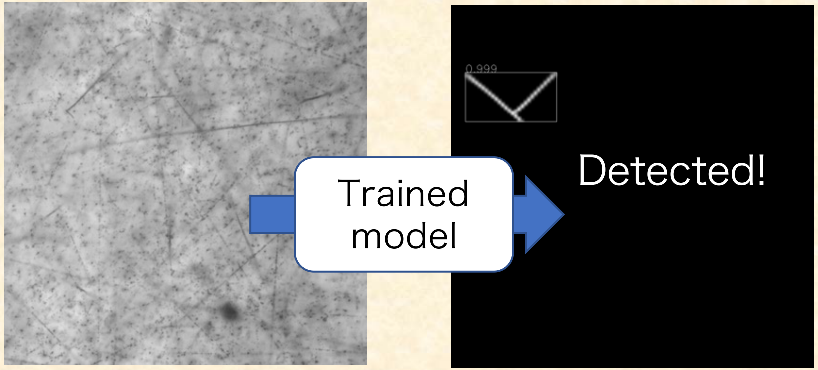
Image



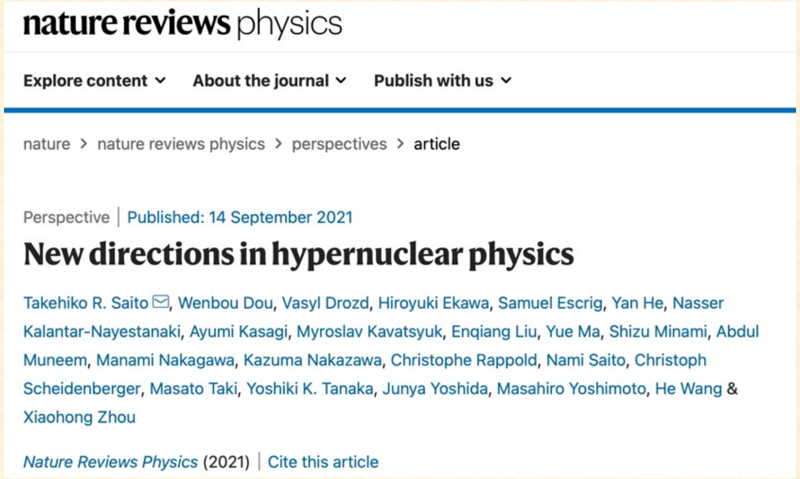
Mask



Real image



Discovery of the first hypertriton event in E07 emulsions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nature > nature reviews physics > perspectives > article

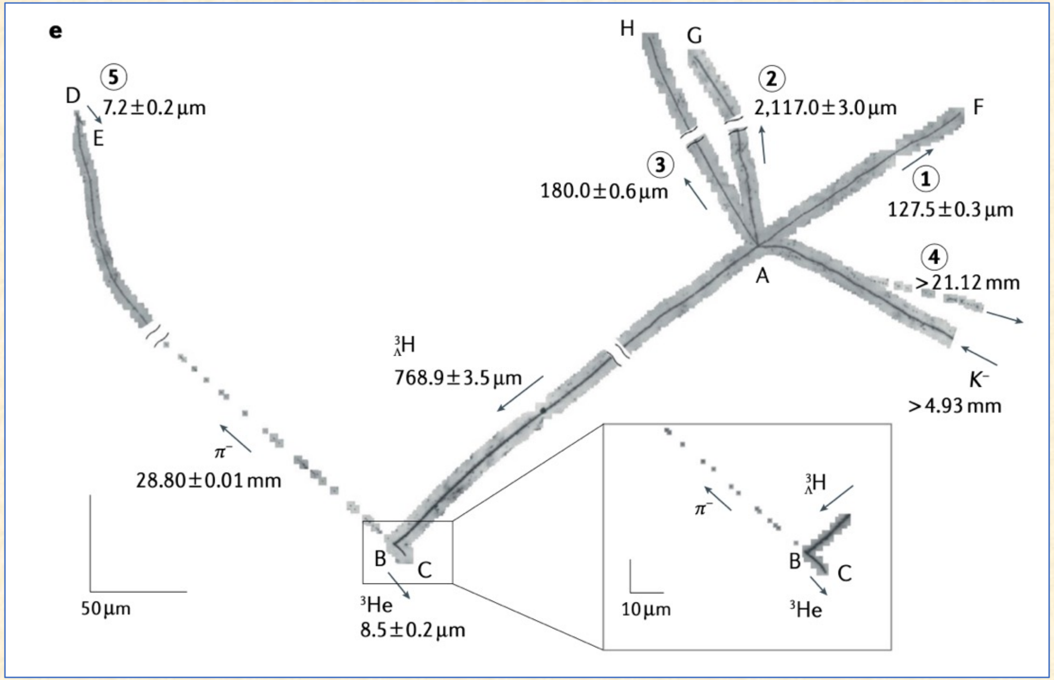
Perspective | Published: 14 September 2021

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

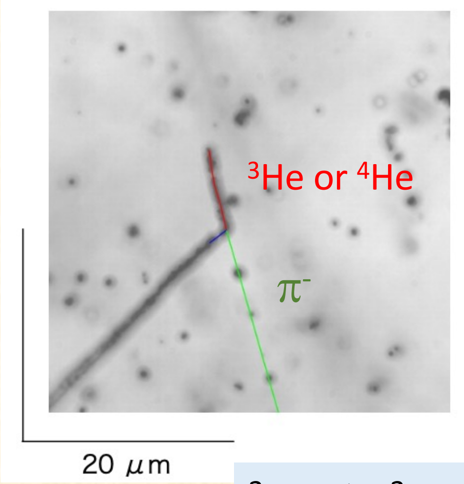
E. Liu et al., EPJ A57 (2021) 327

Ayumi Kasagi.
Ph.D. thesis (2023)

Towards the hypertriton binding energy

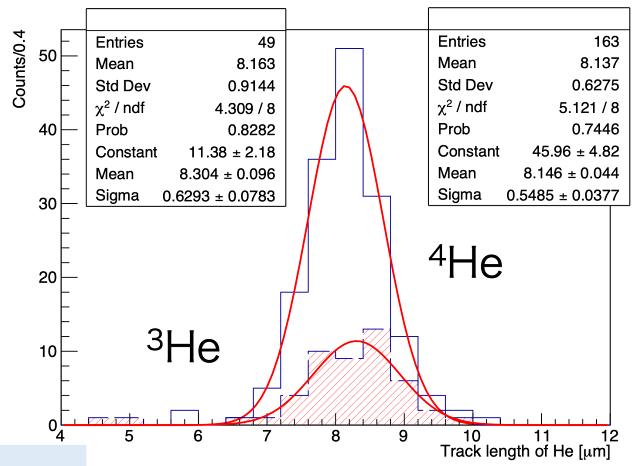
- Calibration of the nuclear emulsion (density/shrinkage) for each event
- Increasing statistics (<u>**so far only 0.6 % of the entire data**</u>)

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

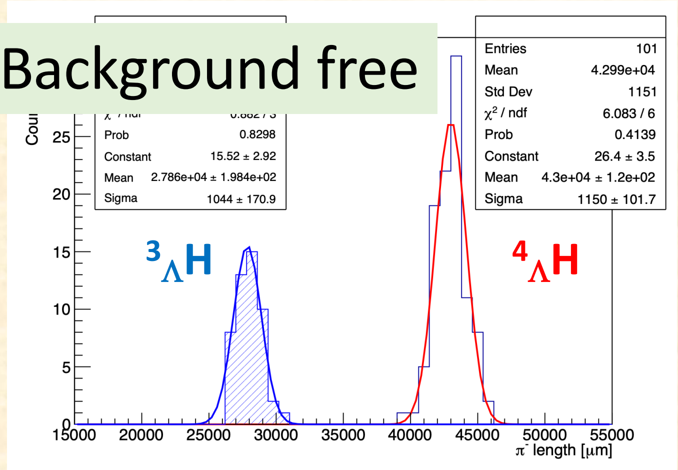


$^{3}_{\Lambda}H \rightarrow {}^{3}He + \pi^-$

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

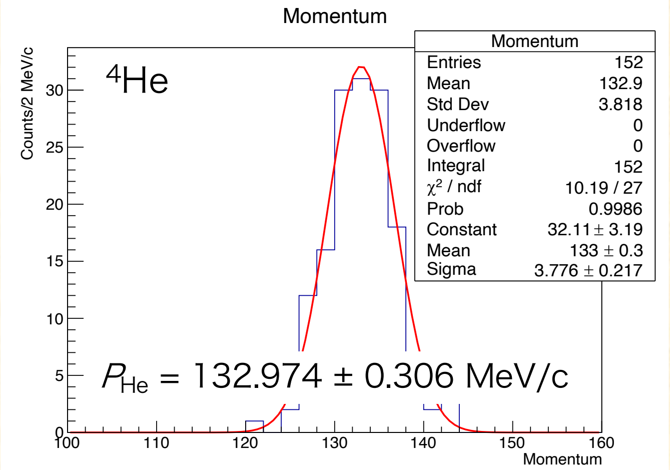


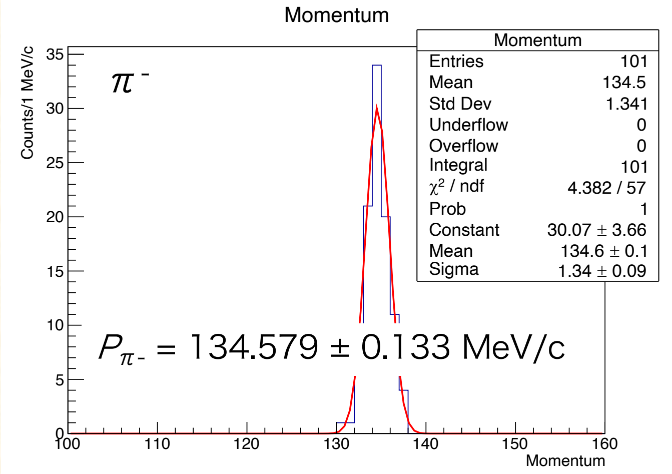
Background free



A. Kasagi et al., under review
arXiv:2504.01601

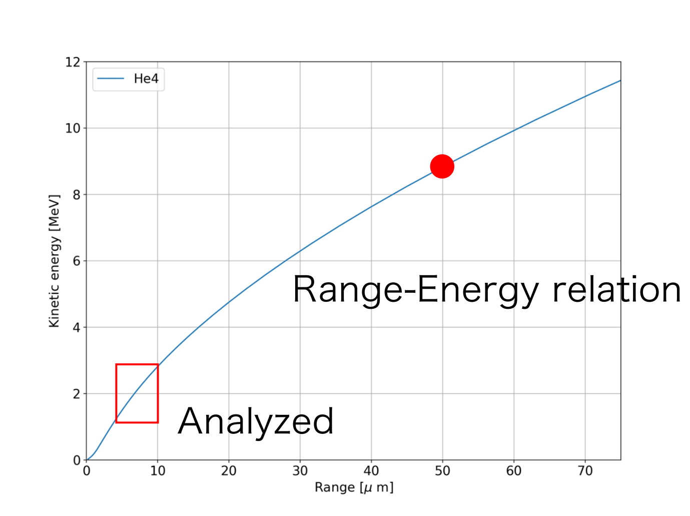
Problems on π^-





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

Nucl. Phys. A 954, 149 (2016)



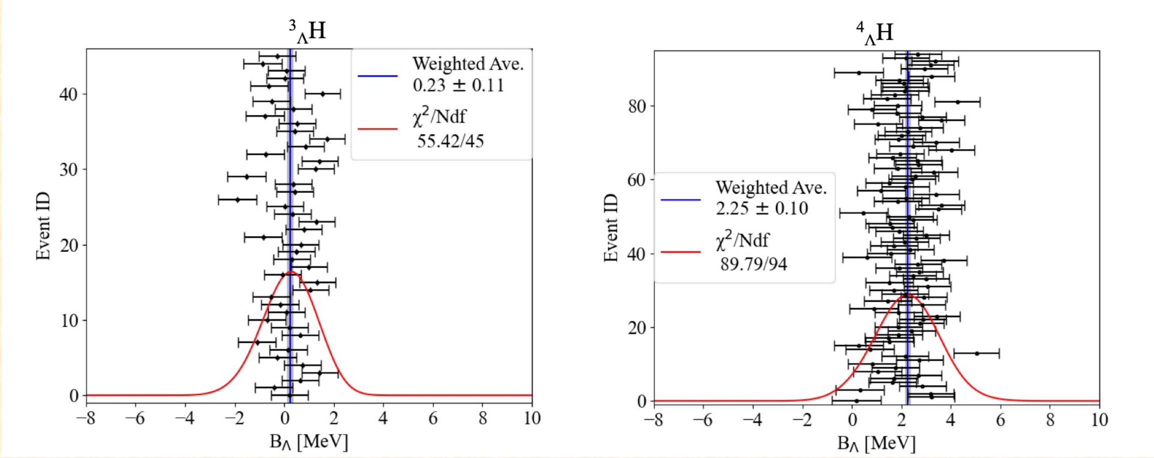
We confirmed that **the Range-Energy Relation for energetic π is not correct**

Known Range-Energy Relation is different because the difference of emulsion compositions

May affect emulsion results at KEK (E373) and J-PARC (E07)

A. Kasagi et al., under review
arXiv:2504.01601

Binding energy of $^{3}_{\Lambda}H$ and $^{4}_{\Lambda}H$



MAMI C:
2.12 ± 0.01 (stat.) ± 0.09 (sys.) MeV

$^{3}_{\Lambda}$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

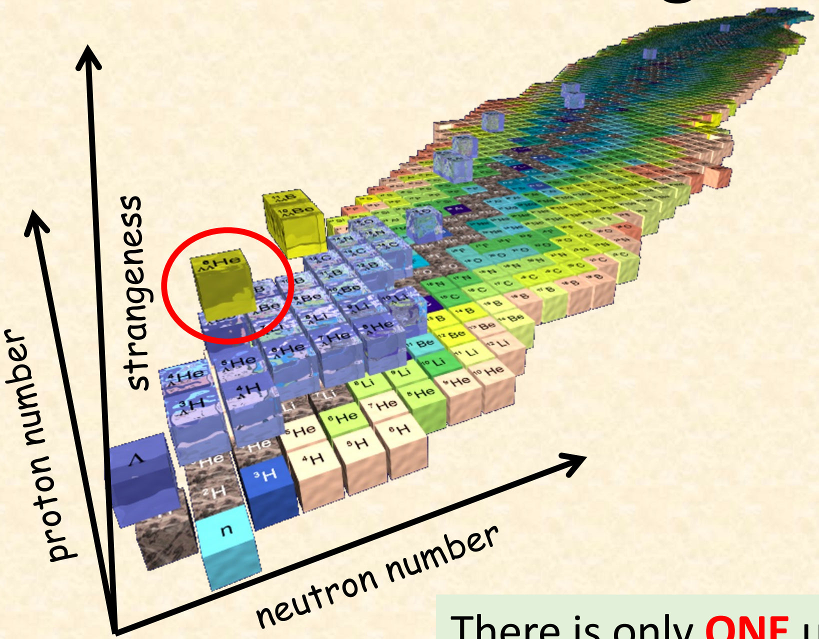
Phys. Rev. Lett. **131**, 102302 (2023)

0.6 % of the entire data

A. Kasagi et al., under review
arXiv:2504.01601

A. Kasagi et al., under review
arXiv:2504.01601

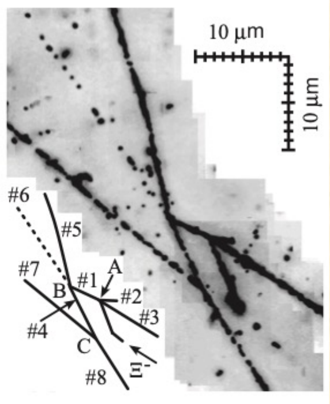
Chart of double-strangeness hypernuclei



There is only **ONE** uniquely unidentified S=-2 hypernucleus
Nagara event, $^{6}_{\Lambda\Lambda}\mathbf{He}$
$\Delta B_{\Lambda\Lambda} = 0.67 \pm 0.17$ MeV

${}^{6}_{\Lambda\Lambda}$He (the Nagara event)

Results in the NAGARA paper
https://doi.org/10.1103/PhysRevLett.87.212502
https://doi.org/10.1103/PhysRevC.88.014003



$$^{12}C + \Xi^- \to {}^{6}_{\Lambda\Lambda}He + {}^{4}He + t$$
$$\hookrightarrow {}^{5}_{\Lambda}He + p + \pi^- .$$

VertexA(Production)
$\Delta B_{\Lambda\Lambda} - B_{\Xi} = 0.69 \pm 0.20$ MeV
VertexB(Decay)
$\Delta B_{\Lambda\Lambda} = 0.6 \pm 0.6$ MeV

$B_{\Lambda\Lambda} = 6.79 + 0.91 B_{\Xi^-}$ ($\pm$ 0.16) MeV
$\Delta B_{\Lambda\Lambda} = 0.55 + 0.91 B_{\Xi^-}$ ($\pm$ 0.17) MeV

$B_{\Lambda\Lambda} = 6.91 \pm 0.16$ MeV
$\Delta B_{\Lambda\Lambda} = 0.67 \pm 0.17$ MeV
(Assumpusion: $B_{\Xi^-} = 0.13$ MeV (*3D*))

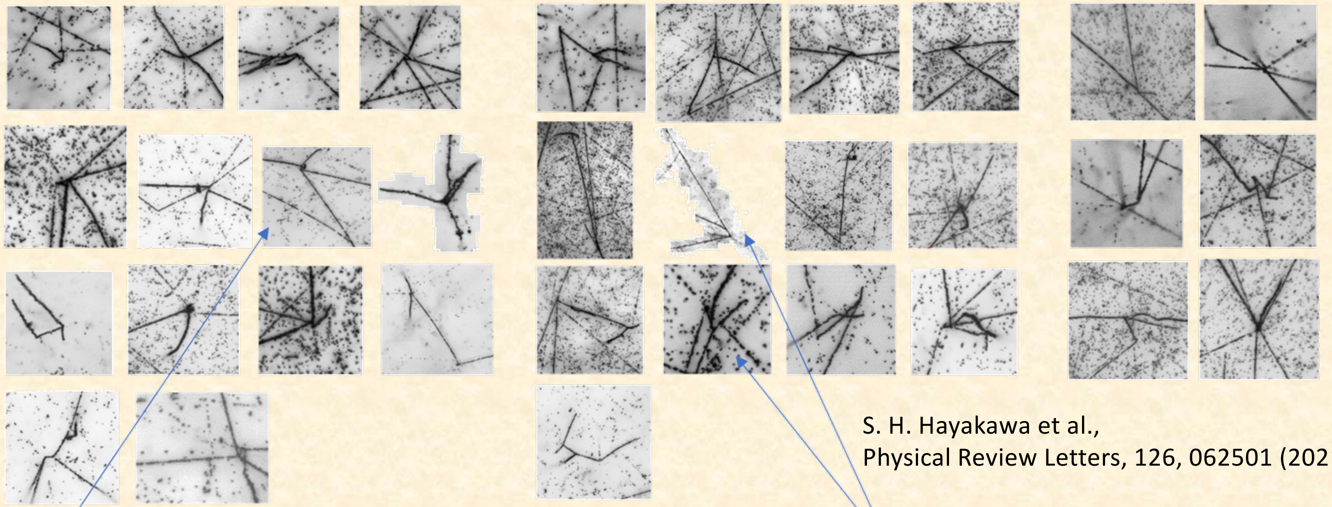
PRELIMINARY

$\Delta B_{\Lambda\Lambda}$: 2 – 3 times larger

A. Kasagi et al., to be published

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

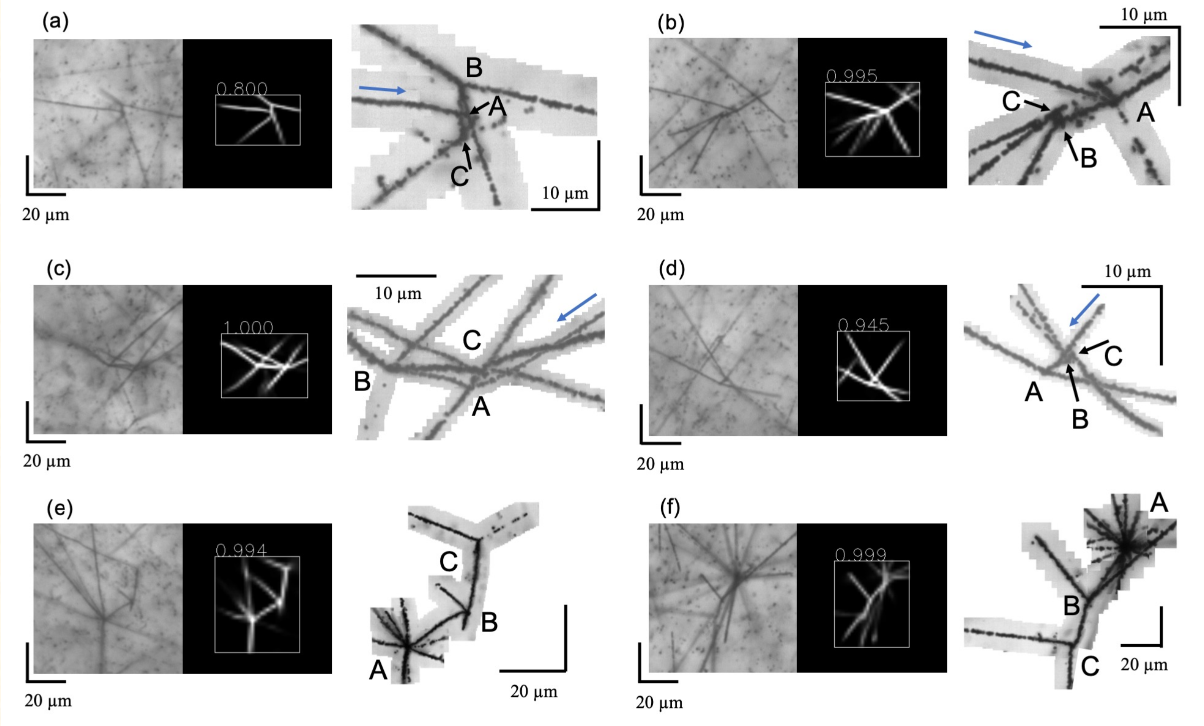
Only 33 candidates

No unique identification for double-Λ hyp.

Searching for double-strangeness hypernuclei

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

- Analyzed **0.2%** of the entire data, **more than 10 candidates** found.
- Searching for double-strangeness hypernuclei with newly developed machine-learning method is in progress.

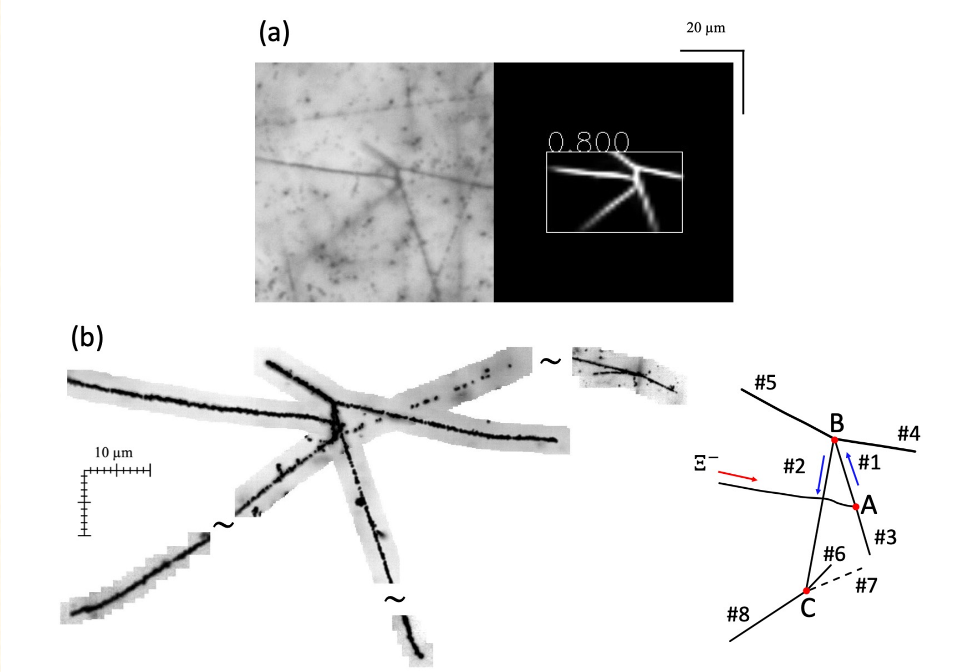


1000 candidates

~5000

Yan He, et al., Nucl. Instrum. Meth. A 1073 (2025) 170196

Our discovery



$^{13}_{\Lambda\Lambda}B$:

Uniquely identified

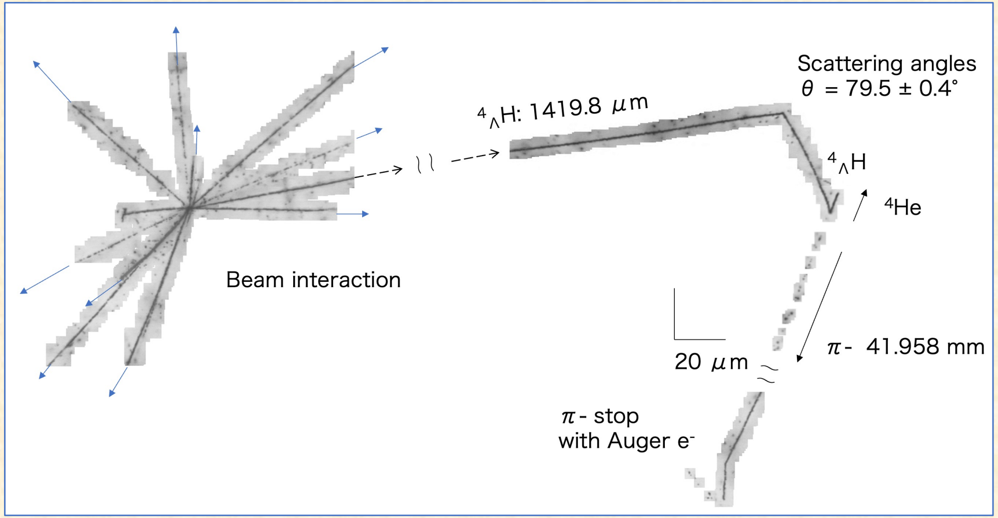
2nd case in the history

$$B_{\Lambda\Lambda} = 25.57 \pm 1.18(\text{stat.}) \pm 0.07(\text{syst.})\text{MeV}$$

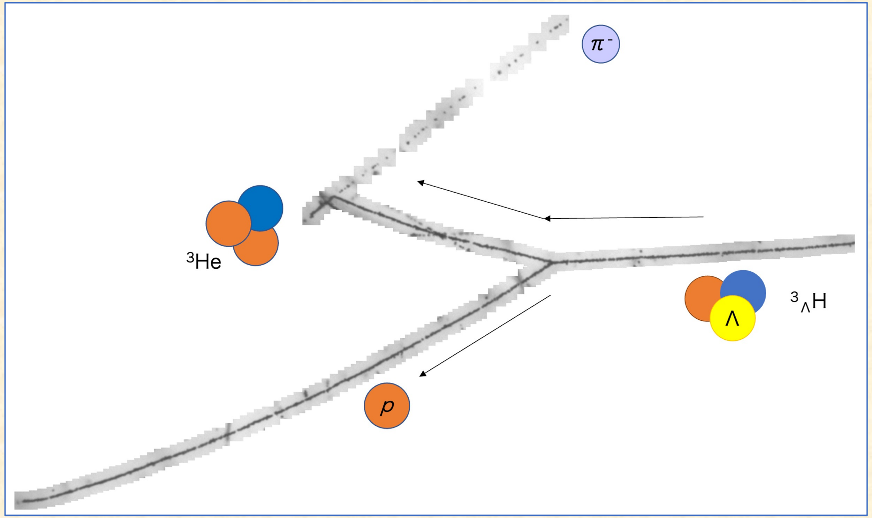
$$\Delta B_{\Lambda\Lambda} = 2.83 \pm 1.18(\text{stat.}) \pm 0.14(\text{syst.})\text{MeV}$$

Yan He, et al., under review
arXiv:2505.05802

Hypernuclear scattering



$^4{}_\Lambda H$ scattering



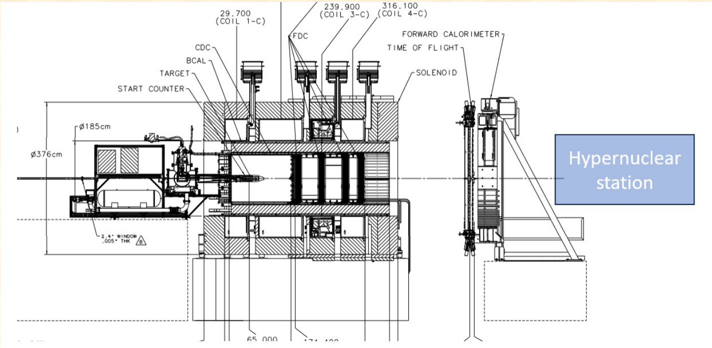
$^3{}_\Lambda H$ scattering

New proposal at KLF/JLab

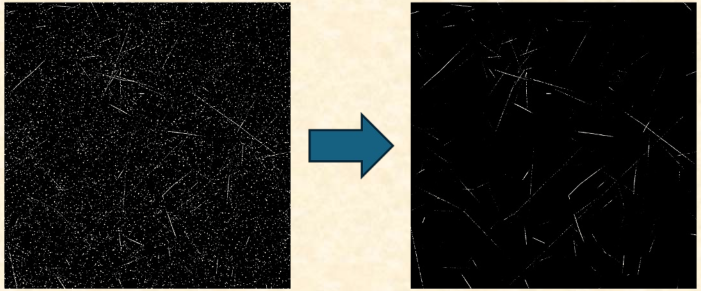
Neutral-K beams behind the Glue-X setup

Hypernuclear station behind the Glue-X

- **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: 0.7×10^4 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**

FNTD (Al_2O_3:C,Mg)
- Used for neutron imaging
- Recyclable

New pro

Neutral-K bea

Hypernuclear

- **No beam tra**
  - We can l
  - Main bac

With K⁻ beams
like in the J-PA

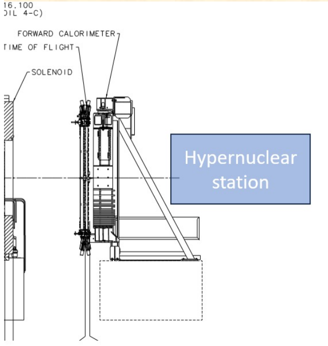
- Intensity: 0.
  - Two year
  - **2.3 time hypernu**

The Hypernuclear station at KLF
(Technical Note)

M. Bashkanov*
Department of Physics, University of York, Heslington, York, Y010 5DD, UK

T.R. Saito†
High Energy Nuclear Physics Laboratory, RIKEN, Japan

(Dated: August 19, 2024)



D (Al_2O_3:C,Mg)
sed for neutron
aging
ecyclable

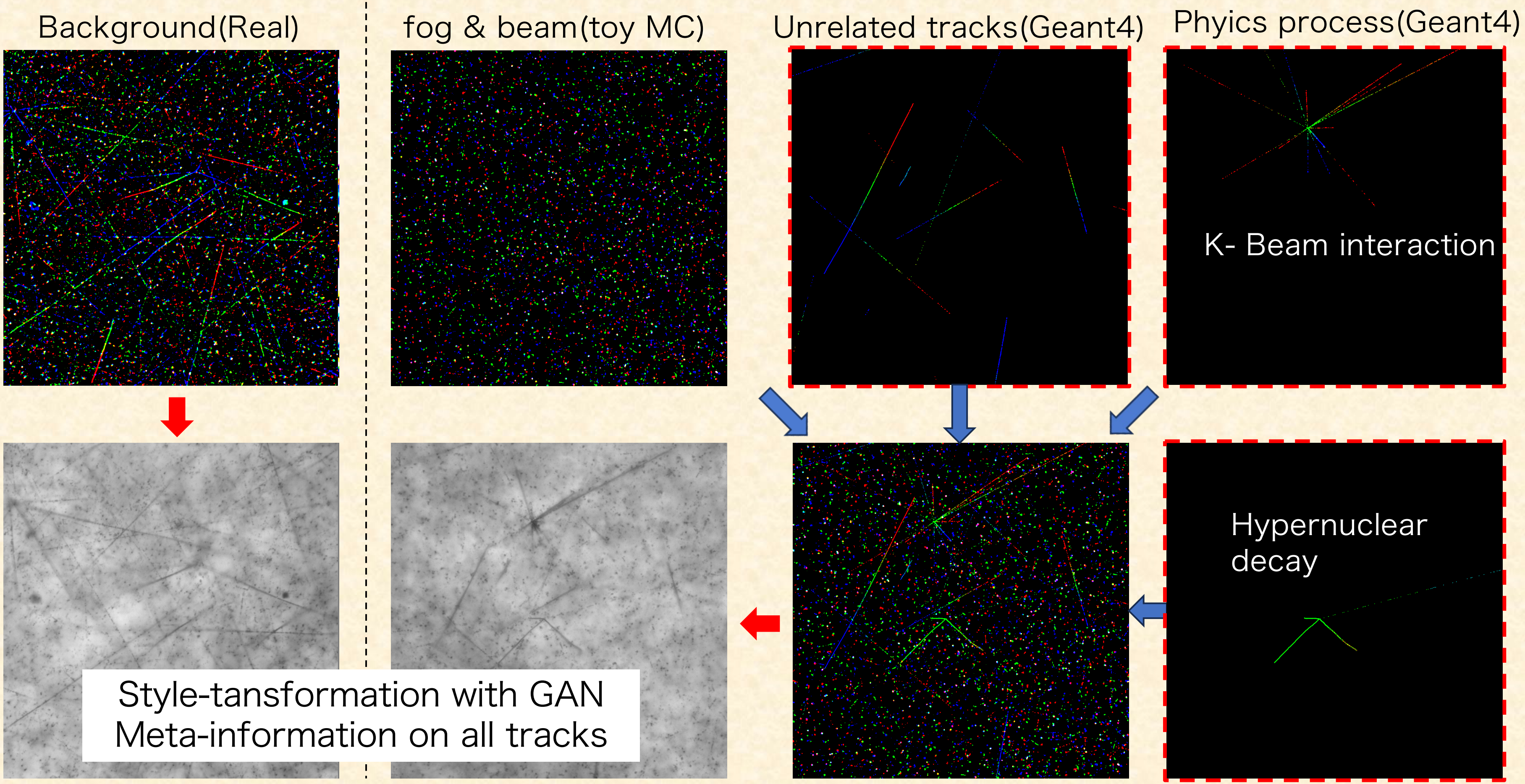
We are inviting physicists with AI expertise and students to work together for

- Hypernuclear physics with image analyses and AI
- Hypernuclear physics with heavy ion beams at FAIR in Germany and HAIF in China
- Very precise neutron imaging, with image reconstruction by AI
  - ✓ 3D semiconductors and power semiconductors
  - ✓ Lives related to space biology
  - ✓ Lithium metal batteries
  - ✓ Hydrogen/deuterium concentration in nano-structure metals (related to cold fusion)
- Cosmic-rays and radiation measurements on the moon by using solid-state tracking detectors

Take R. Saito   takehiko.saito@riken.jp

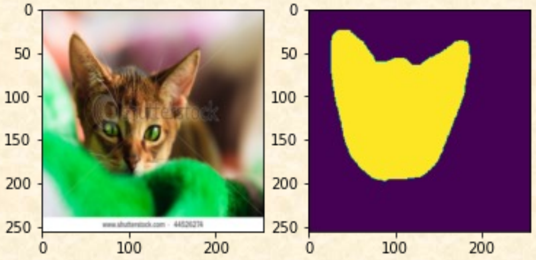
Spare slides

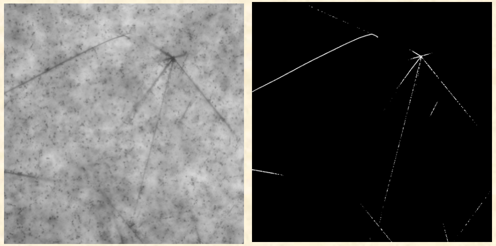
New training data (Geant4 simulation + GAN)



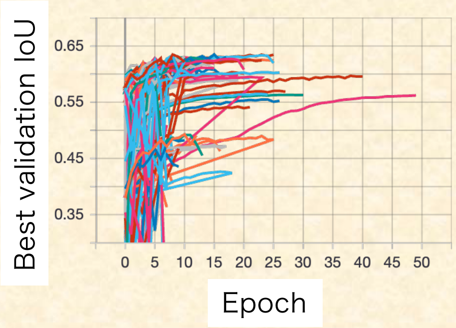
Segmentation task to detect hit infomation

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



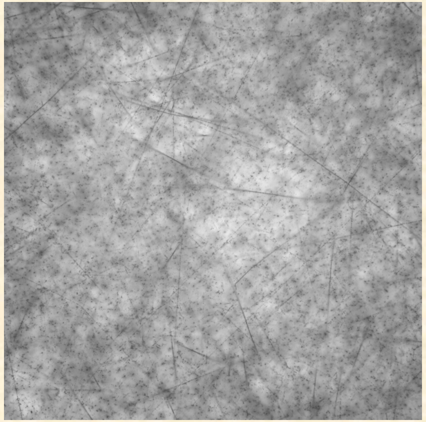


Hyperparameter search with Optuna

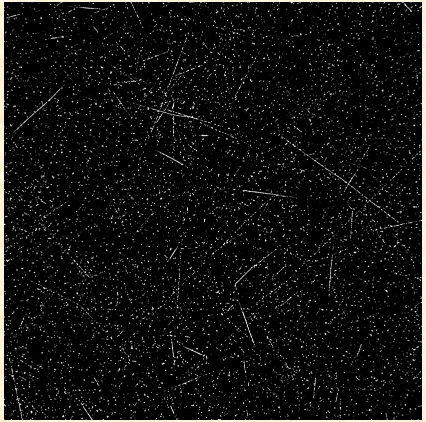


IoU	0.659
F1_score	0.795
Accuracy	0.998
Precision	0.748
Recall	0.805

Raw data



Conventional processing



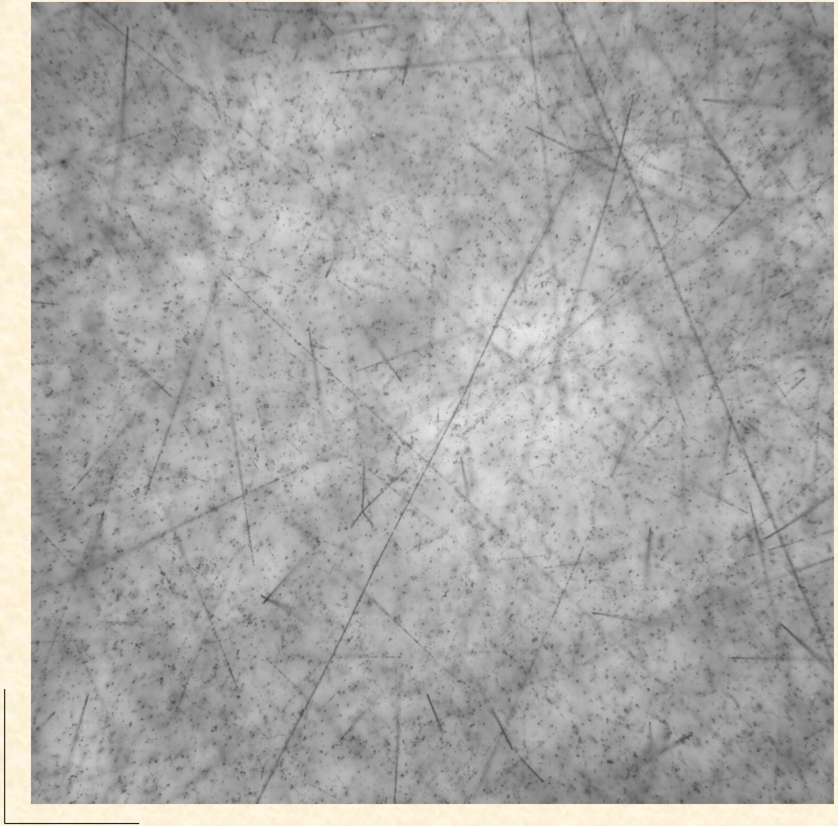
Present work

- Noise reduction
- Datasize: 1/200

→ E07 image data
140 PB -> 750 TB

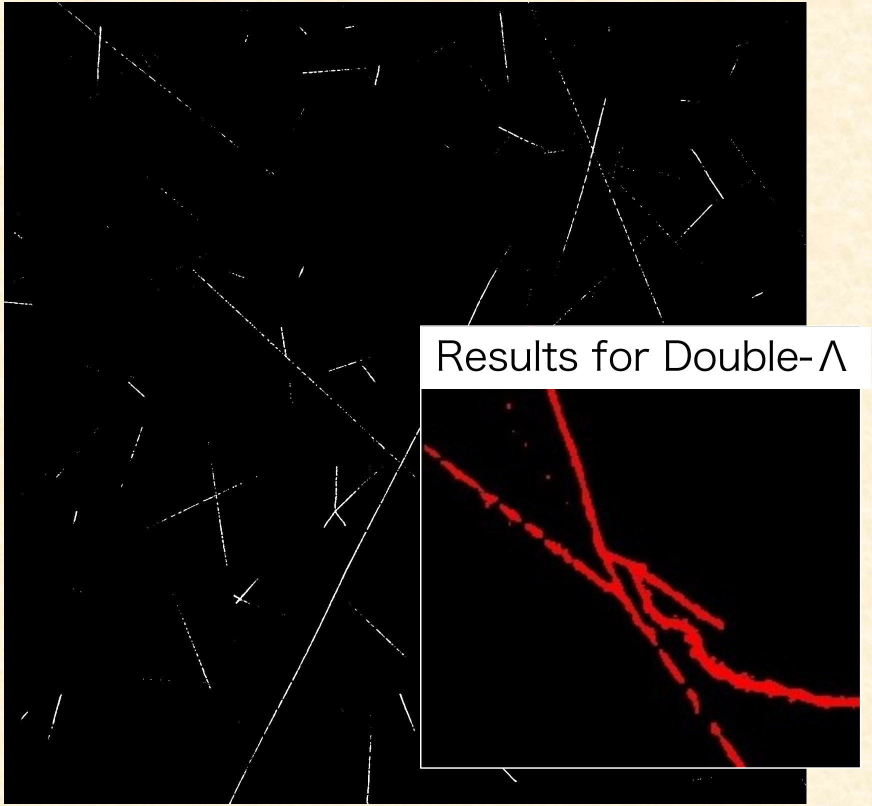
Segmentation task to detect hit infomation

Raw data: 200 MB



100 μm

Segmentation: 1MB

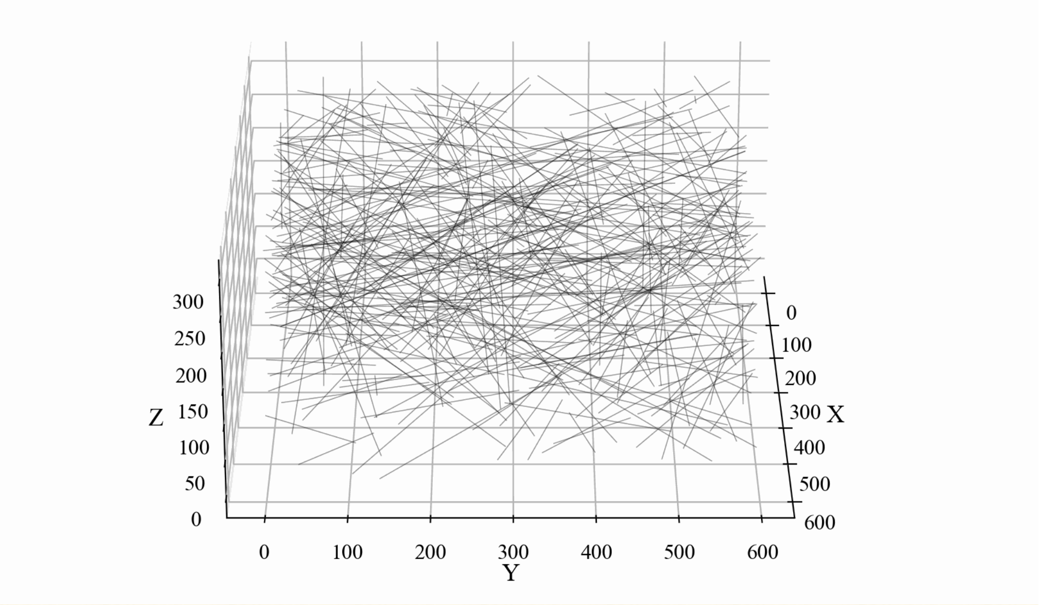


Kasagi, Nakazawa, Rappold, Shimizu, Yokota, to be published

Reconstruction of track

Gabor filter & Connected Components

3D track reconstruction



・Image -> meta information of tracks: Data size will be negligible
・Reconstruction of dizzy track & vertex: Ongoing

Kasagi, Nakazawa, Rappold, Shimizu, Yokota, to be published