Possibilities of Hypernuclear Studies with High Energy Proton Beams

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Germany

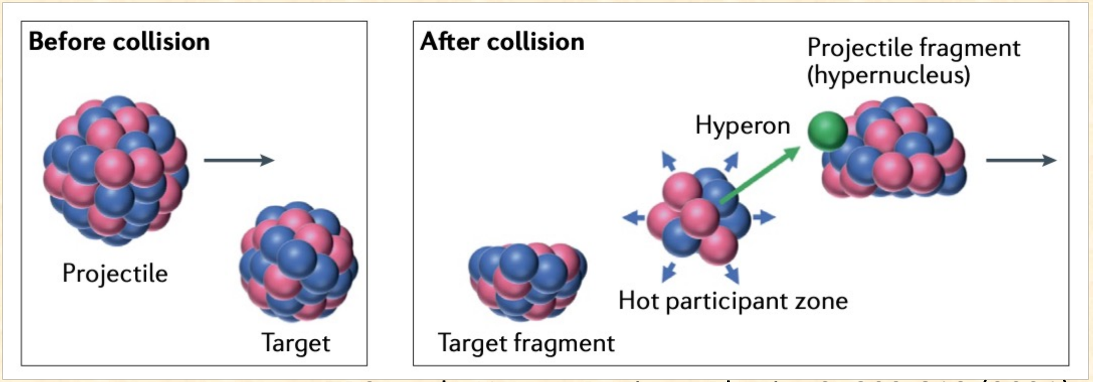
The Workshop on Physics Opportunities with Proton Beams at SIS100,
Wuppertal University, Wuppertal, Germany, 6th – 9th February, 2023

Just Brainstorming

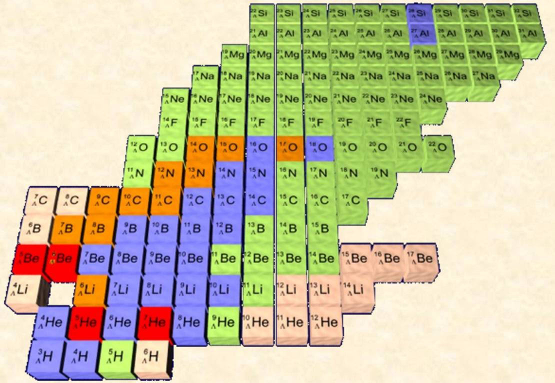
What can we do with high energy proton beams for studying hypernuclei?

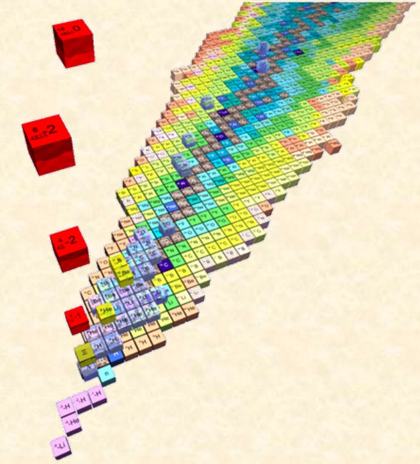
- With direct production by proton beams
- With secondary produced hyperons
- Comment for a possible new beamline for producing secondary meson beams

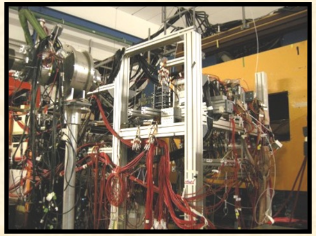
The HypHI Phase 0 at GSI (2006-2012)

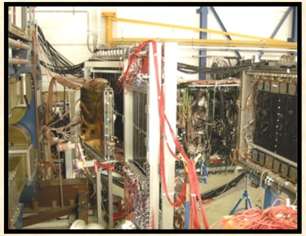


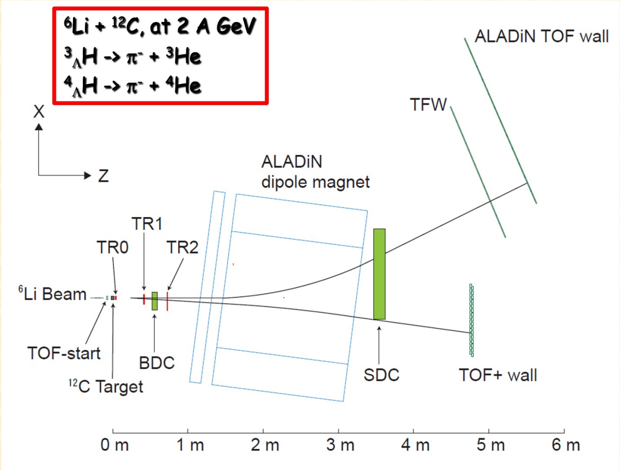
TRS et al., Nature Reviews Physics 3, 803-813 (2021)











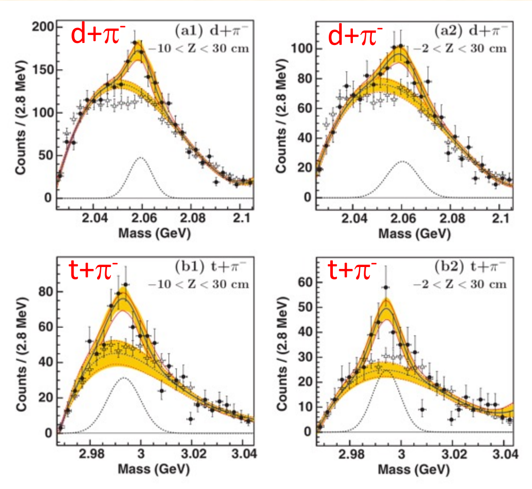
Two outcomes (mysteries) by HypHI

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

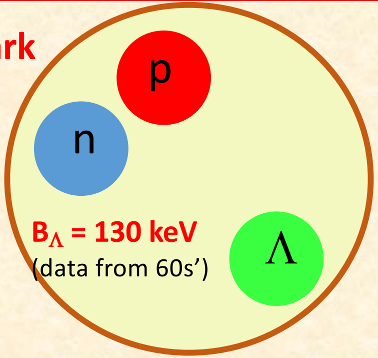


C. Rappold et al., PRC 88 (2013) 041001

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

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

Benchmark

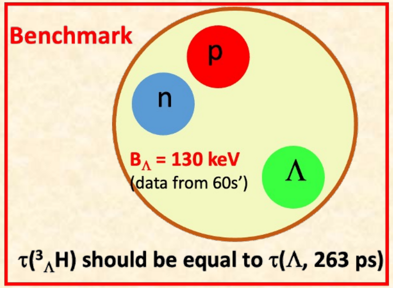


τ($^{3}_{\Lambda}$H) should be equal to τ(Λ, 263 ps)

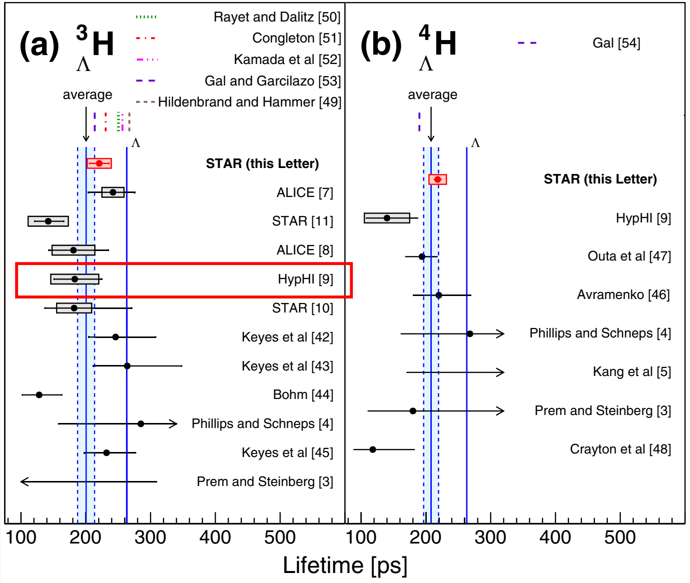
Stimulated other experiments

The world situation of three-body hypernuclei

On hypertriton



Average
200 ± 13 ps



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

The world situation of three-body hypernuclei

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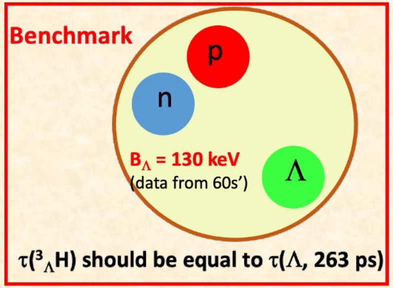

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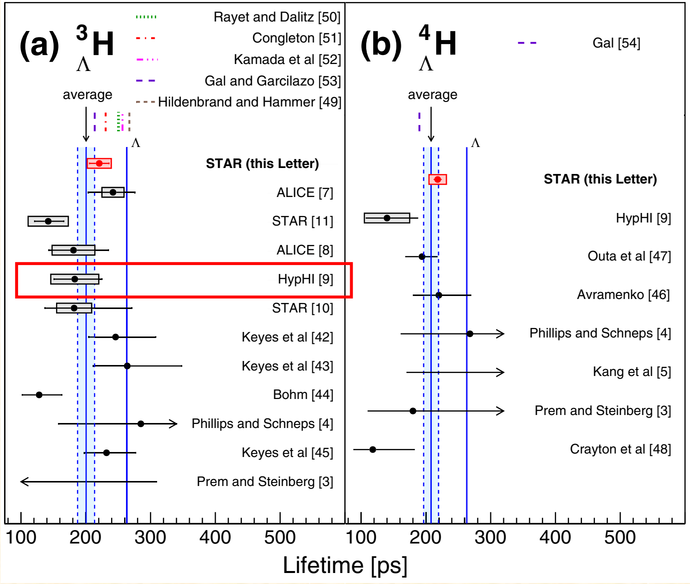


STAR Collaboration, PRL **128** (2022) 202301

$^3_\Lambda$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

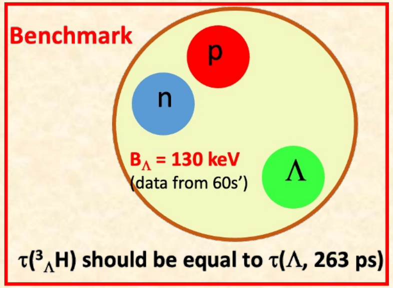
0.102 ± 0.063 ± 0.067 MeV

To be appeared in

Phys. Rev. Lett. (2023)

The world situation of three-body hypernuclei

On hypertriton



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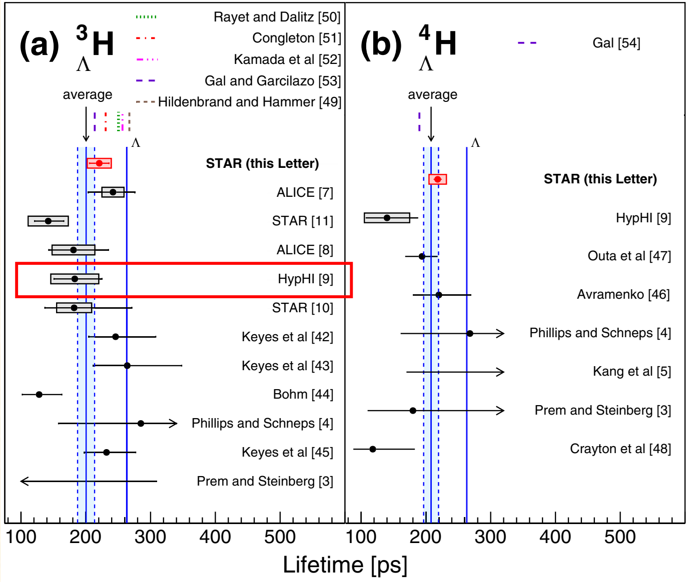

STAR Collaboration, PRL **128** (2022) 202301

On Λnn

$^3_\Lambda$H Binding energy

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

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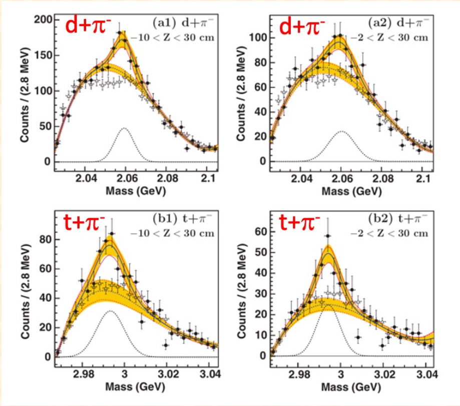


HypHI., PRC 88 (2013) 041001

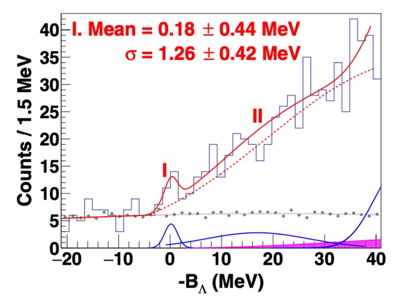
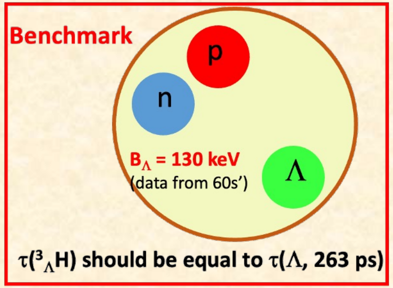


FIG. 5. The enlarged mass spectrum around the Λnn threshold. Two additional Gaussians were fitted together with the known contributions (the accidentals, the Λ quasifree, the free Λ, and the ^{3}He contamination). The one at the threshold is for the small peak, while the broad one is for the additional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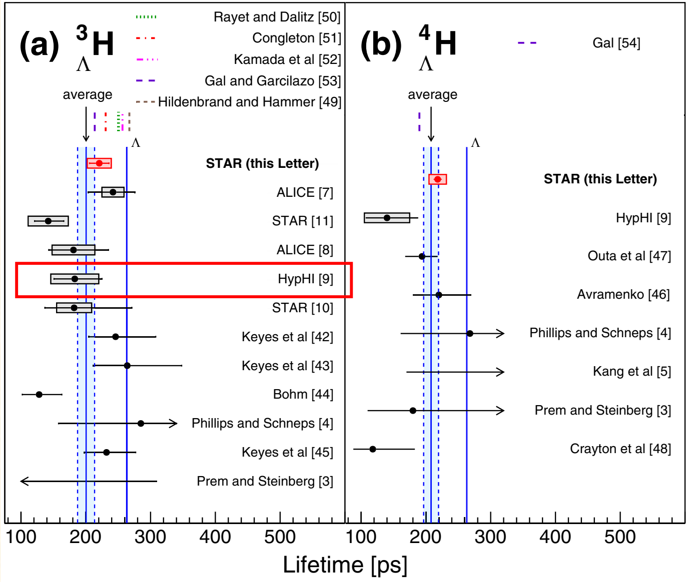

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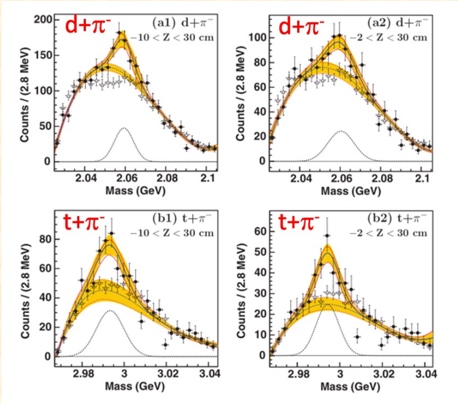
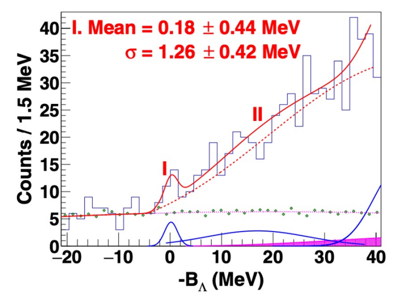


HypHI., PRC 88 (2013) 041001



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

Our approach:

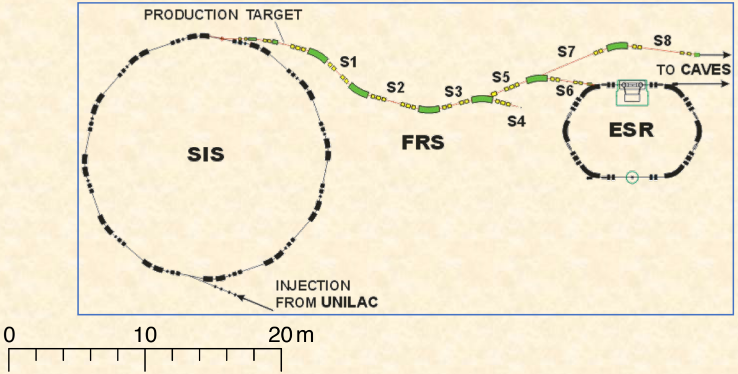
<u>With heavy ion beams:</u>

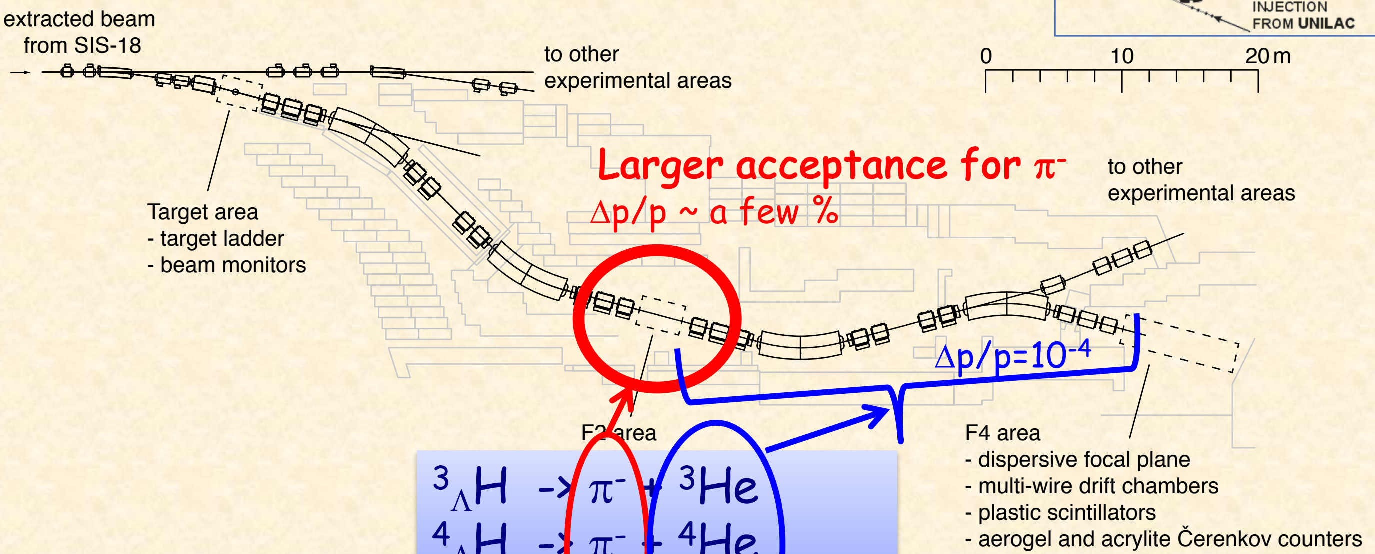
- Lifetime
- Λnn

<u>Emulsion + Machine Learning</u>

- Binding energy

The novel technique with FRS at GSI (2016-)





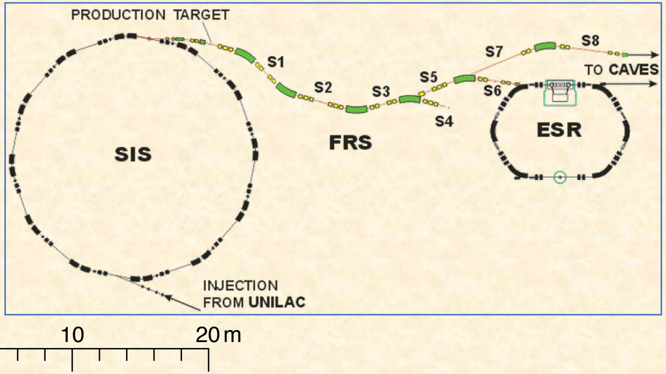
$^{3}_{\Lambda}H \rightarrow \pi^- + {}^{3}He$

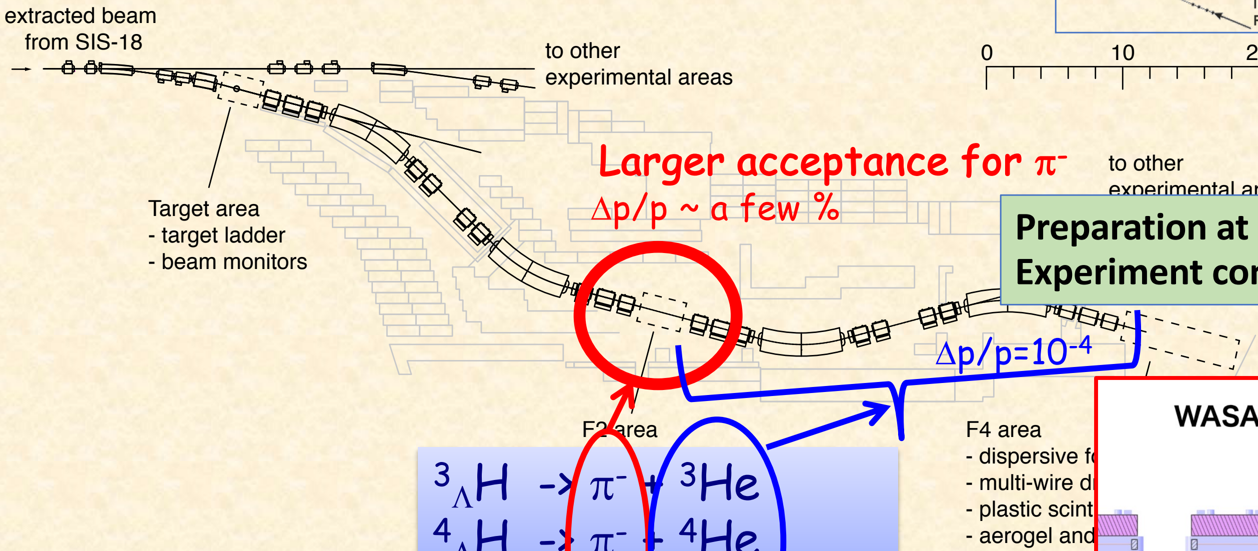
$^{4}_{\Lambda}H \rightarrow \pi^- + {}^{4}He$

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

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

The novel technique with FRS at GSI (2016-)





Larger acceptance for π^-

$\Delta p/p$ ~ a few %

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

Preparation at GSI started in March 2019

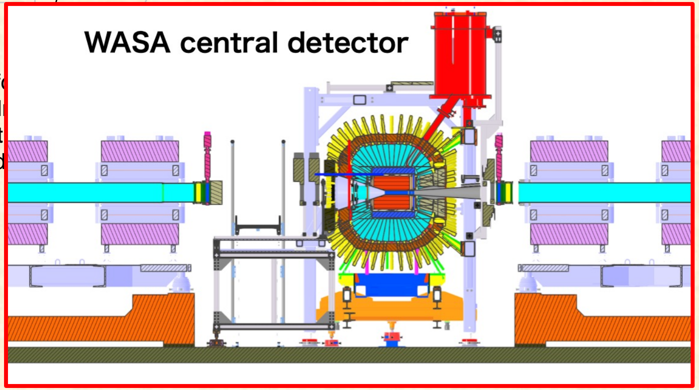
Experiment conducted in January-March 2022

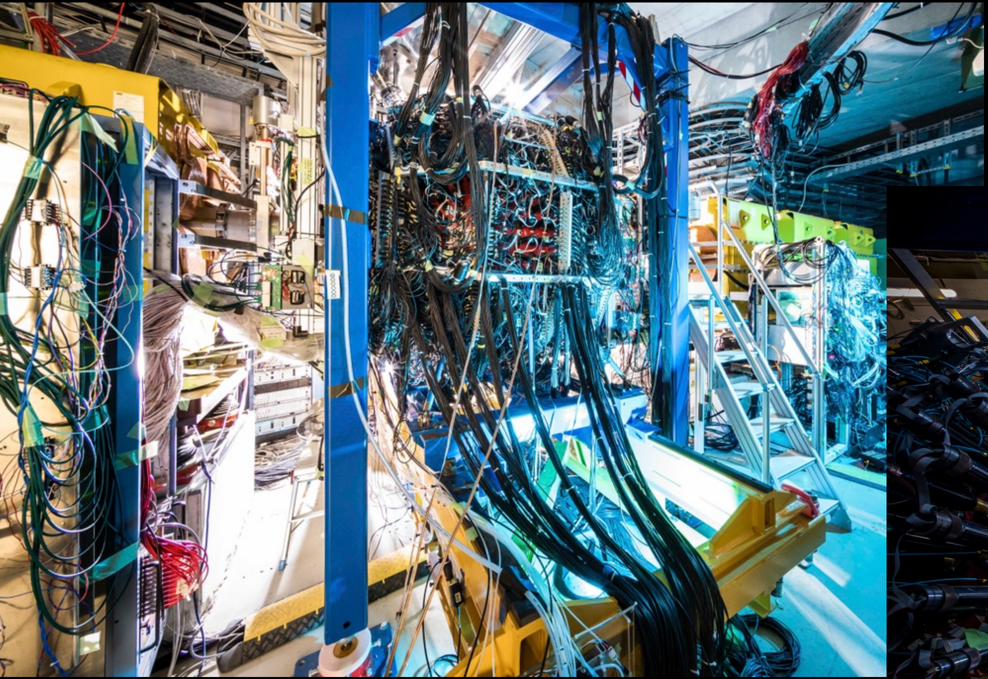
$^{3}_{\Lambda}H \ \text{->}\ \pi^- + {}^{3}He$

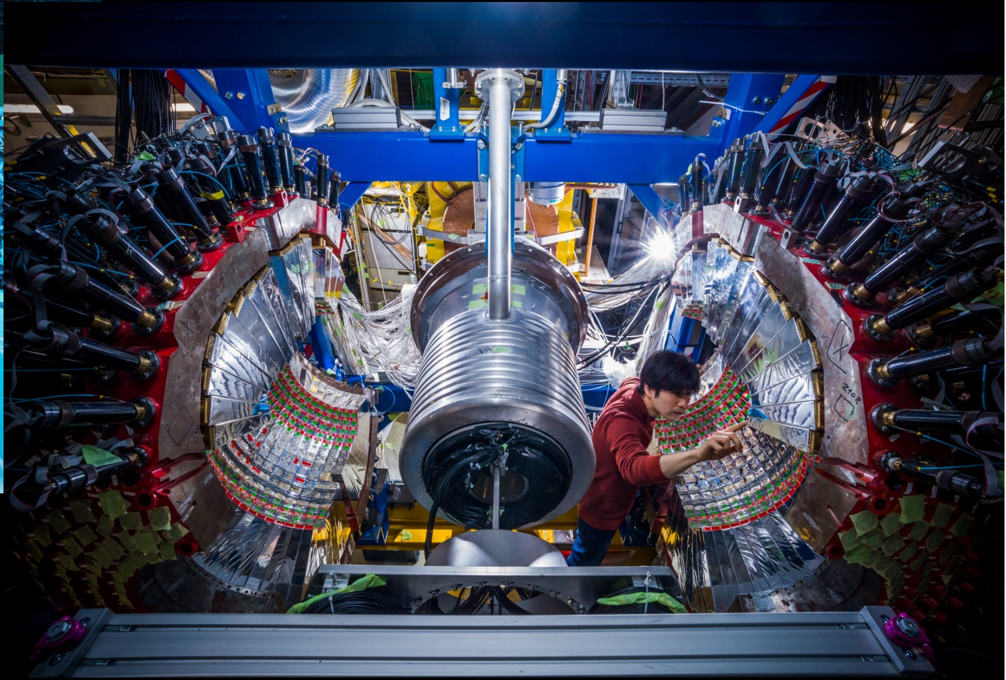
$^{4}_{\Lambda}H \ \text{->}\ \pi^- + {}^{4}He$

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

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







Photos by Jan Hosan and GSI/FAIR

Hypernuclear production with proton beams

$p + {}^{A}Z \rightarrow {}^{A+1}_{\Lambda}Z + K^+$

- Large momentum transfer to produced Λ
- Small production cross section

$p + {}^{A}Z \rightarrow {}^{A}_{\Lambda}(Z\text{-}1) + p + K^+$

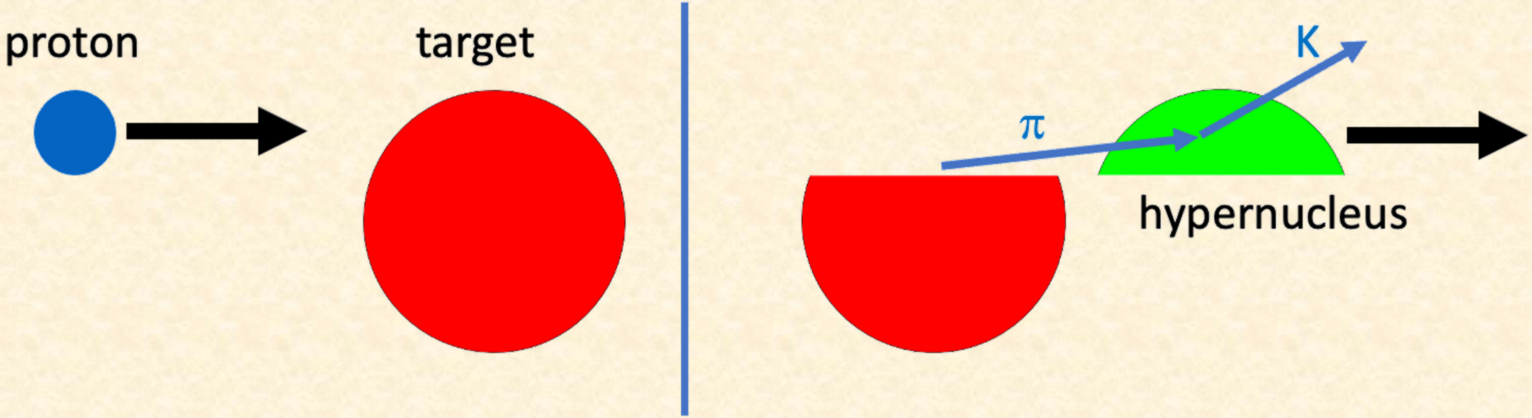
- Selecting a proper (large) momentum region of out-going momentum

  $\rightarrow$ Λ with a small momentum transfer

  H. Jing et al., arXiv:0805.0398v2 (2008)
- However, not very competitive to other production methods

Spallation-like production

Spallation-like hypernuclear production



My consideration in 2008 (presented in NP08 conference in Mito/Japan):

Can we measure hypernuclear magnetic moments?

Hypernuclear magnetic moments

- **Very sensitive probe of Λ-wave function in hypernuclei**
- Small ΛN configuration mixing due to weak ΛN interactions
  - Theoretical calculations rather straight forward
    - Schmidt diagrams, Y. Tanaka, Phys. Lett B 227 (1989) 195.

- Simplest case : ${}^{5}_{\Lambda}He$ (Λ + ${}^{4}He$), Nucl. Phys. A 625 (1997) 95
  - Pure isoscaler and only one Kaon exchanging current (two kaon exchange is negligible),
  - Core polarization effect suppressed (tensor forces, no pion exchanging current),
  - Small Λ-Σ mixing (incoherent Λ-Σ coupling),
  - **Kaon exchanging current is only the source of the deviation of the magnetic moment of free-Λ -> -8.8%**

${}^{5}_{\Lambda}He$ is a good case to look for exotic phenomena like the quark Pauli effect and the medium modification of the Λ magnetic moment (Nucl. Phys. A 446 (1985)467c).

Hypernuclear magnetic moments on ${}^{5}_{\Lambda}He$

If the magnetic moment of ${}^{5}_{\Lambda}He$ is deviated from the theoretical prediction (8.8 % reduction from the Λ value)

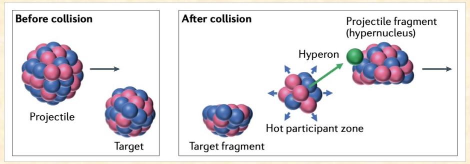
- Modification of Λ properties in nuclei?
- A sort of EMC effect?
- Quark-gluon contributions?
- Some unexpected sources?

Maybe important for compressed nuclear matters

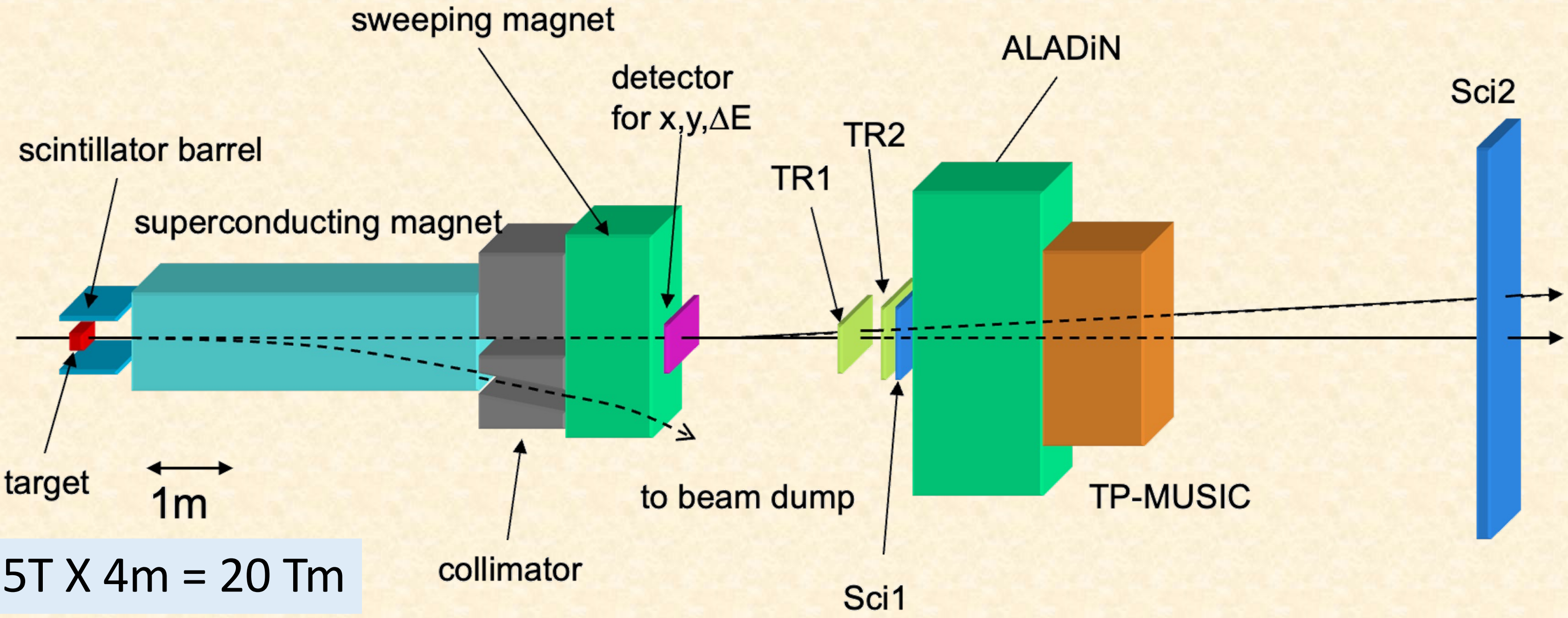
Initial idea of hypernuclear magnetic moments measurement (2004)

- **With meson and electron beam induced hypernuclear production**
  - Very small recoil momentum of produced hypernuclei
  - Almost impossible to perform direct measurements of hypernuclear magnetic moments
  - B(M1) measurements with γ-ray spectroscopy
    - Hyperball-J at J-PARC
    - Contributions from nuclear collective motion have to be subtracted

- **Initial idea with with heavy ion beams (2004)**
  - Hypernuclei at projectile rapidity $\rightarrow$ relativistic hypernuclei
  - Hypernuclei can be separated by a magnetic spectrometer
  - Precession of hypernuclear spin alignment in magnetic field
    - Perturbed π^- asymmetry $\rightarrow$ magnetic moments
  - Can be performed only at FAIR in near future

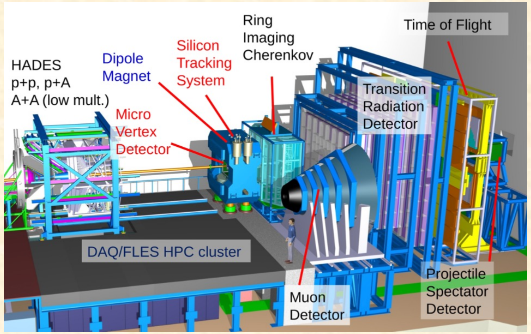


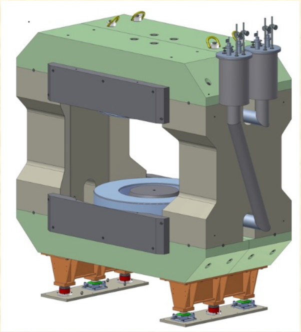
Initial idea of hypernuclear magnetic moments measurement (2004, HypHI Phase 3)



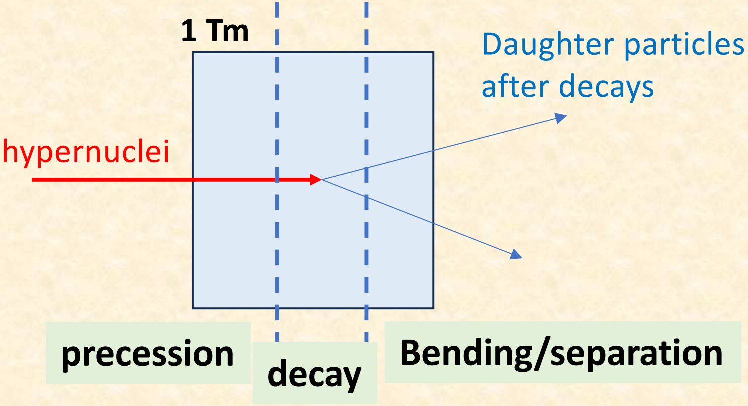
5T X 4m = 20 Tm

Can we measure magnetic moments with CBM?





EPJ Web of Conferences **138**, 12001 (2017)



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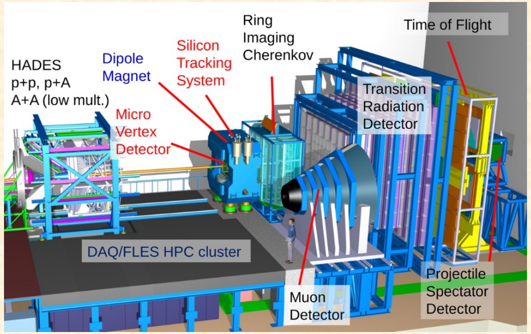

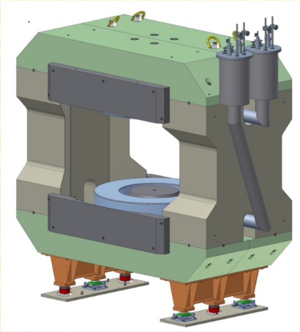

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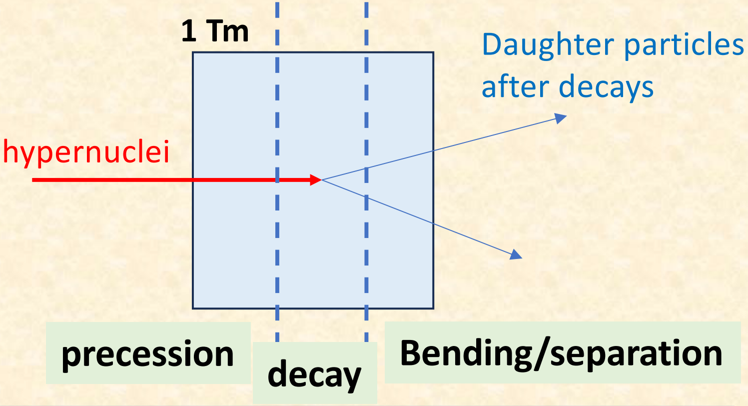
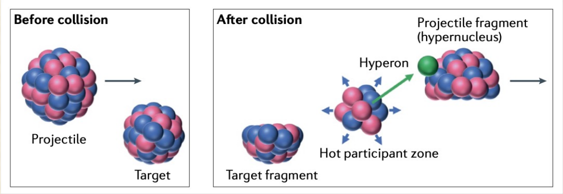
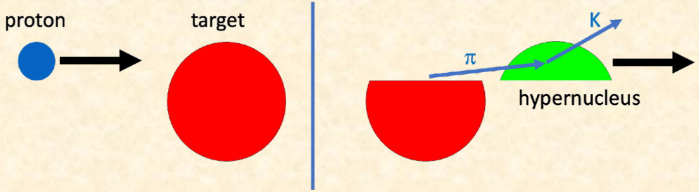




With heavy ion beams

- Large velocity (γ ~ 20)

  Small precession angle



With proton beams

- Small velocity (γ ~ 3)

  Larger precession angle

Spallation-like hypernuclear production

GIBUU calculations for the case of J-PARC at 50 GeV (2008)

T. Gaitanos et al. / Physics Letters B 675 (2009) 297–304

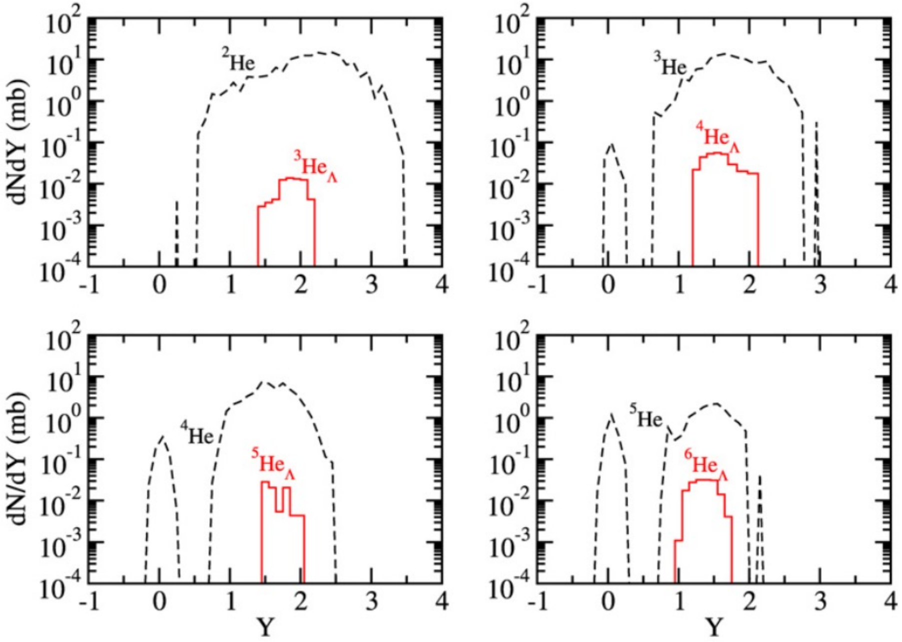


Fig. 9. Rapidity distributions of different particle types for the system $p + {}^{12}C$@50 GeV.

y	γ
1.0	1.5
2.0	3.8
3.0	10.1
4.0	27.3
5.0	74.2

$y = \frac{1}{2} \ln((1+\beta_z)/(1-\beta_z))$

Estimation for $^{5}_{\Lambda}He$ with CBM

For 50 GeV proton beams (similar to the SIS100 case)

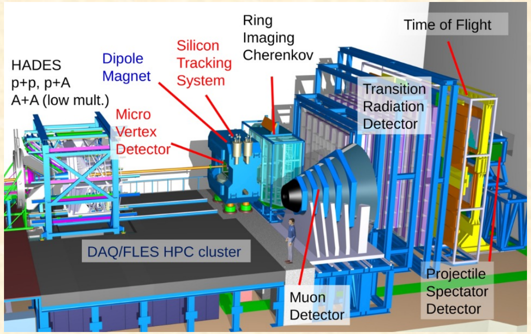
With the current CBM magnet

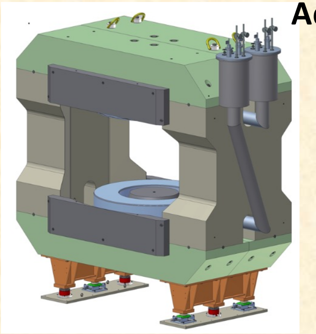
- Lorentz factor: $\gamma \sim 3$
- Magnetic rigidity for
  - Making nuclear precession: 0.3 Tm (0.3 m)
  - Decay volume 0.4 Tm (0.4 m)
  - Separation and bending 0.3 Tm (0.4 m)
- Estimated production cross section: $\sim 100\ \mu b$
- Beam intensity: 10^{12} /s
- Target: ^{12}C, 12 g/cm^2

Expected rate: 8.6X10^4 reconstructed events /week

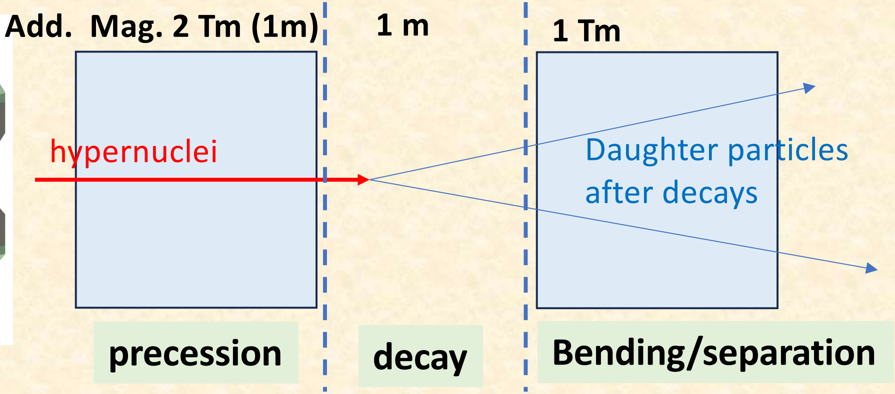
Spin precession angle: 1.5 degrees

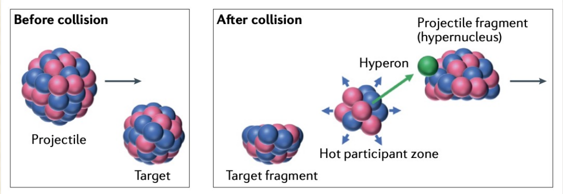
Can we measure magnetic moments with CBM?





EPJ Web of Conferences **138**, 12001 (2017)

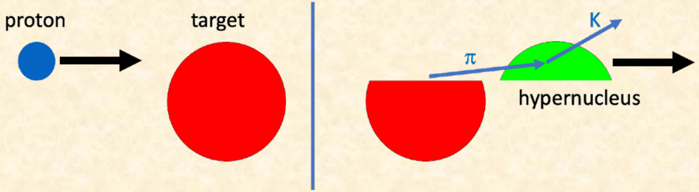




With heavy ion beams

- Large velocity ($\gamma \sim 20$)

  Small precession angle



With proton beams

- Small velocity ($\gamma \sim 3$)

  Larger precession angle

Estimation for $^{5}_{\Lambda}He$ with CBM

For 50 GeV proton beams (similar to the SIS100 case)

With a longer and stronger magnet (2 T * 3 m = 6Tm)

- Lorentz factor: $\gamma \sim 3$
- Magnetic rigidity for
  - Making nuclear precession: 2 Tm (1 m, additional magnet)
  - Decay volume: free space 0 Tm (1 m)
  - Separation and bending 1 Tm (CBM magnet)
- Estimated production cross section: $\sim$ 100 μb
- Beam intensity: 10^{12} /s
- Target: ^{12}C, 12 g/cm^2

Expected rate: 1X10^5 reconstructed events /week

Spin precession angle: 20 degrees

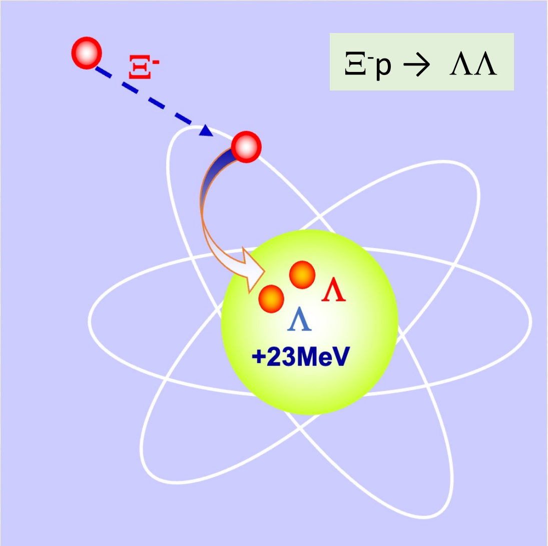
With secondary produced hyperons

Example:

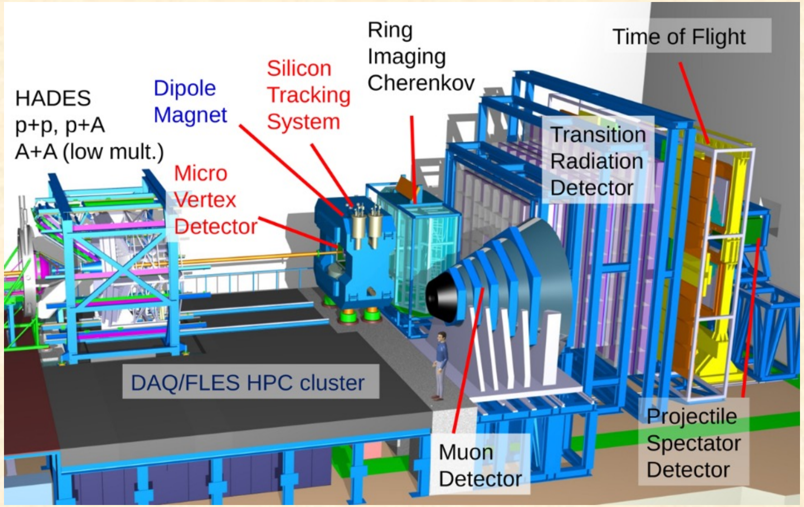
$p + {}^{12}C \rightarrow \Xi^- + K^+ + K^0 + X$

Similar to the J-PARC E07 experiment
or/and
Using our machine learning technique for emulsions

To secondary target (nuclear emulsion)



CBM detector

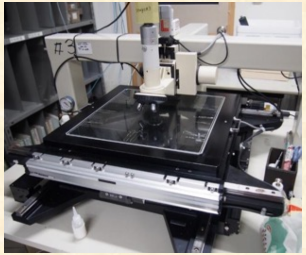


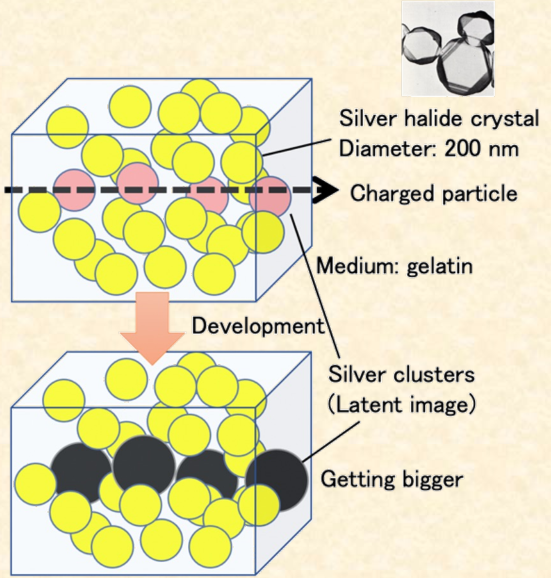
Nuclear Emulsion:

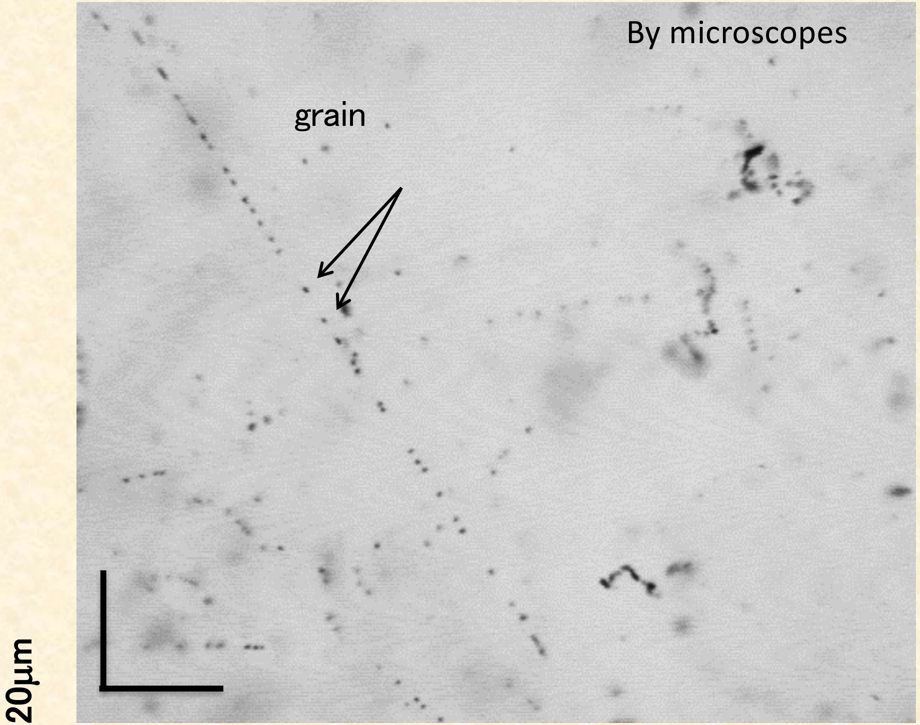
Charged particle tracker with

the best spatial resolution

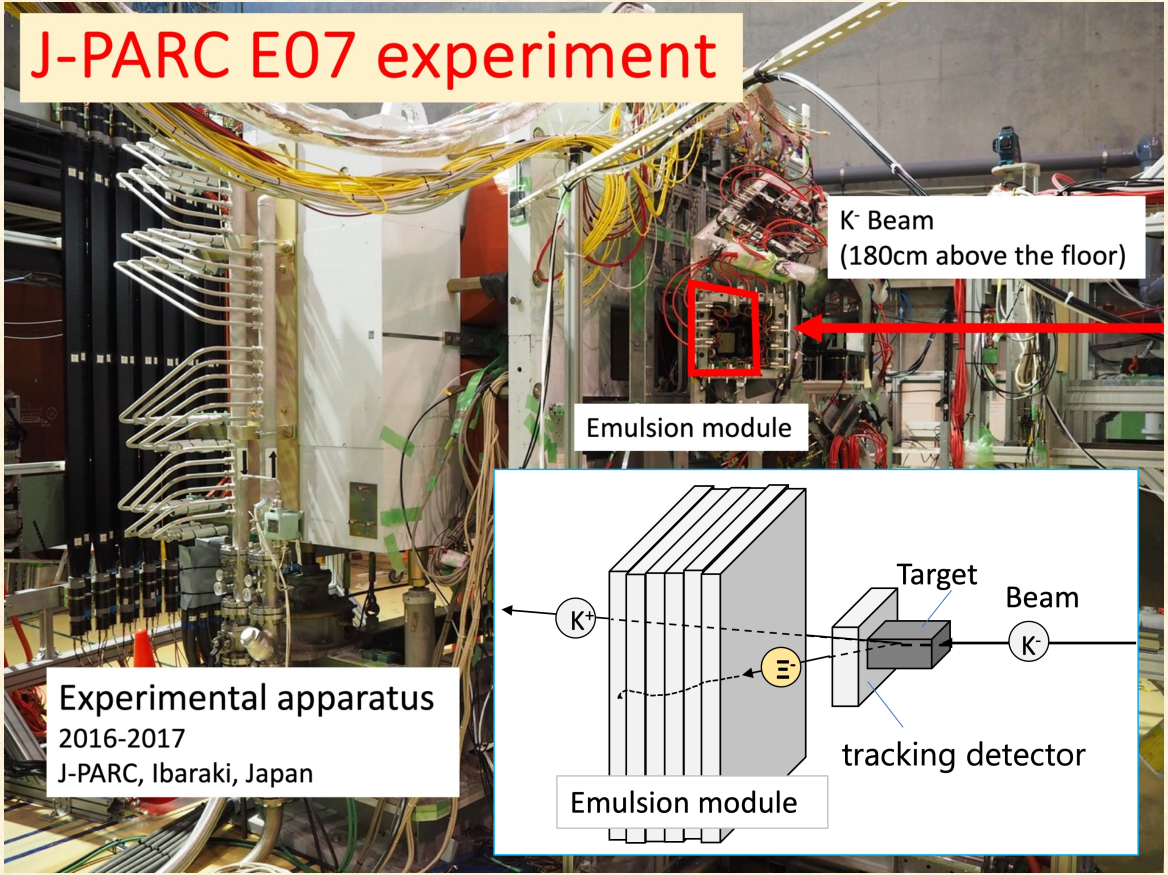
(easy to be < 1 μm, 11 nm at best)





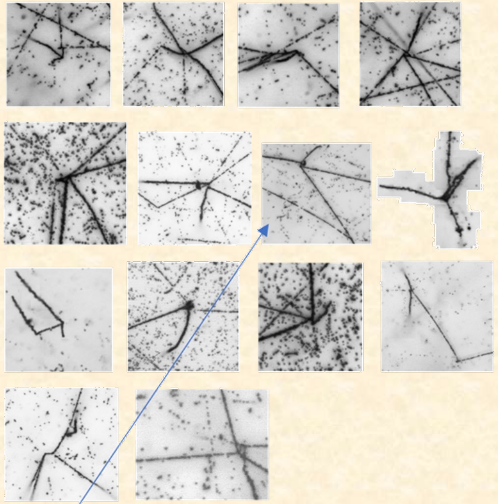


J-PARC E07 experiment

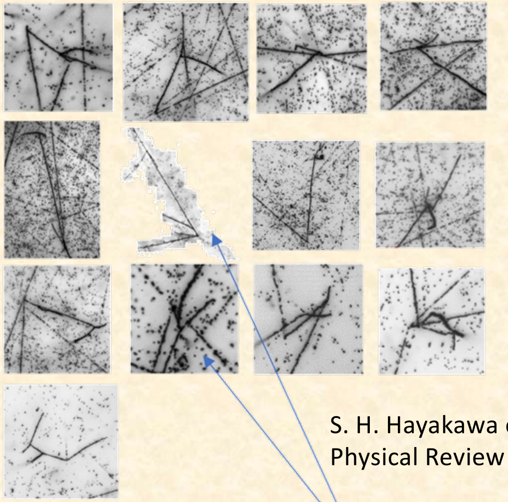


Results from J-PARC E07 (Hybrid method)

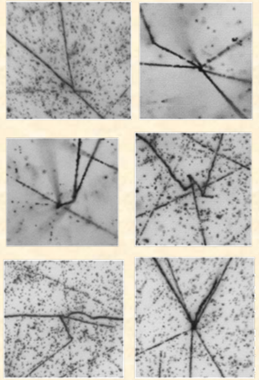
ΛΛ candidates: 14



Twin Λ events: 13



Others: 6



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

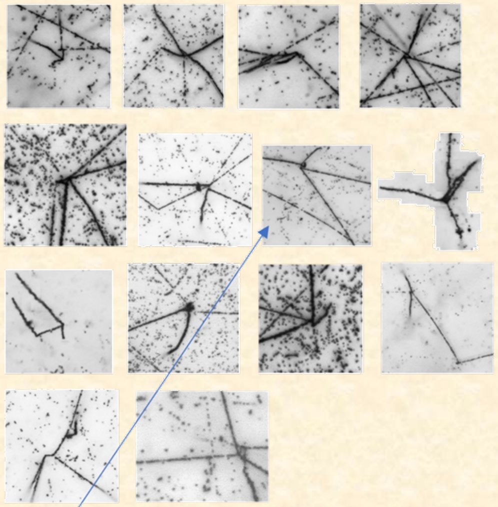
M. Yoshimoto et al.,
Prog. Theor. Exp. Phys. 2021, 073D02

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

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

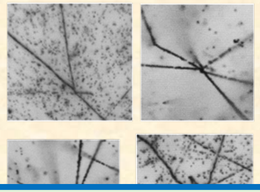
Results from J-PARC E07 (Hybrid method)

$\Lambda\Lambda$ candidates: 14



Twin Λ events: 13

Others: 6



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)

M. Yoshimoto

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

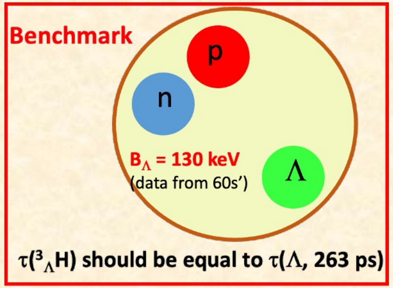
$^{15}_{\Xi}$C

$_{\Lambda\Lambda}$Be

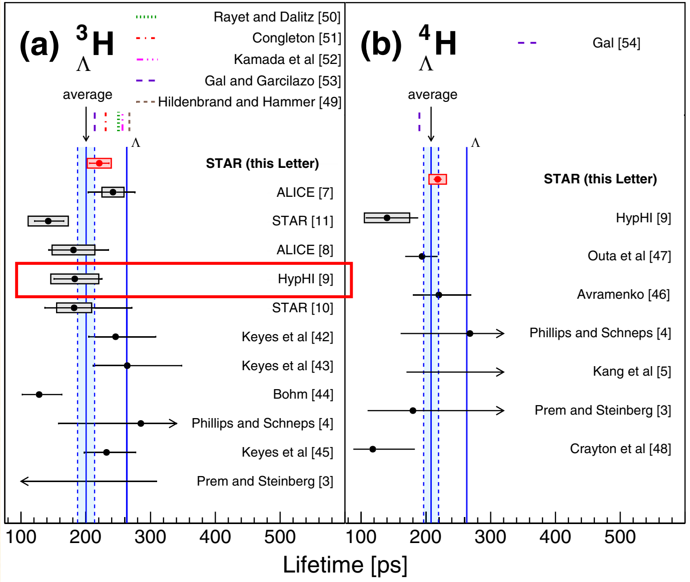
H. Ekawa et al., Prog. Theor. Exp. Phys. 2019, 021D02

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

To be appeared in

Phys. Rev. Lett. (2023)

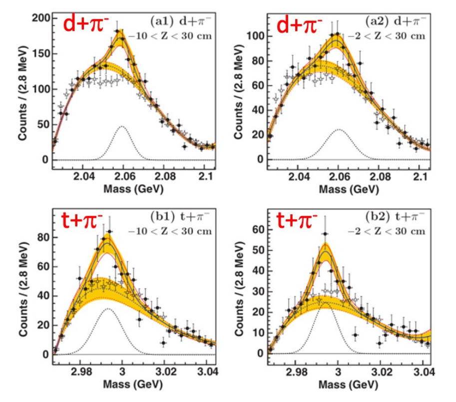
Our approach:

<u>With heavy ion beams:</u>

- Lifetime
- Λnn

<u>Emulsion + Machine Learning</u>

- Binding energy



HypHI., PRC 88 (2013) 041001

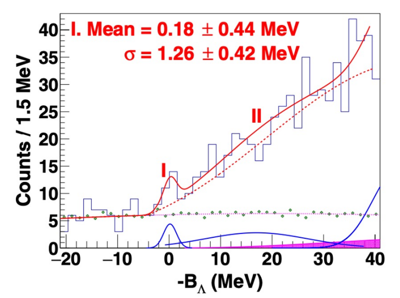
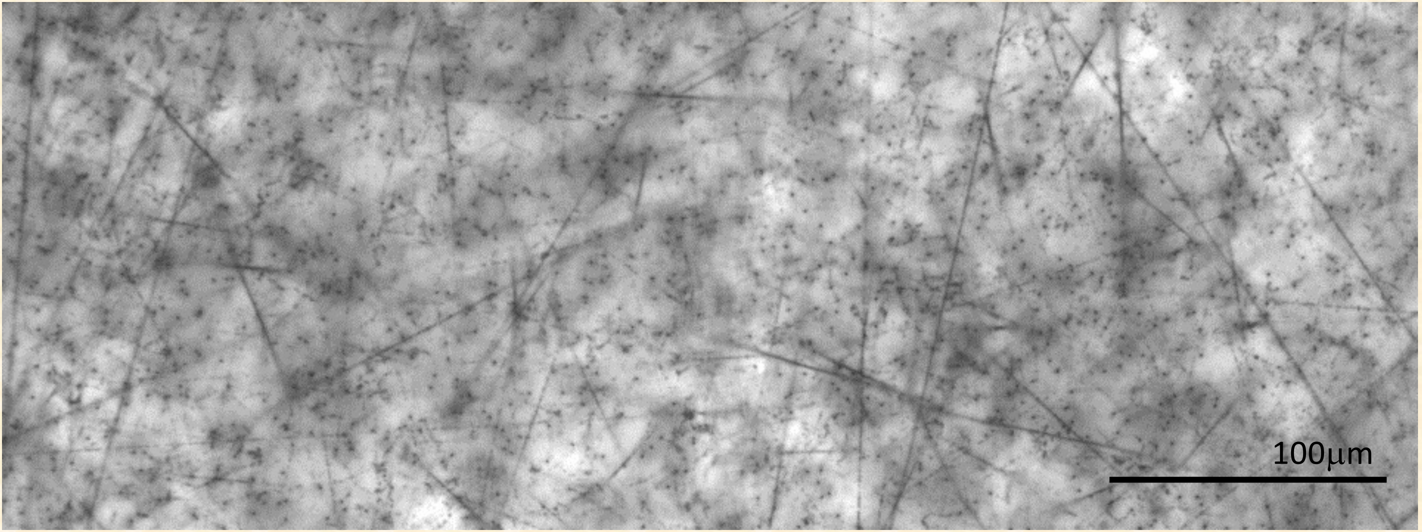
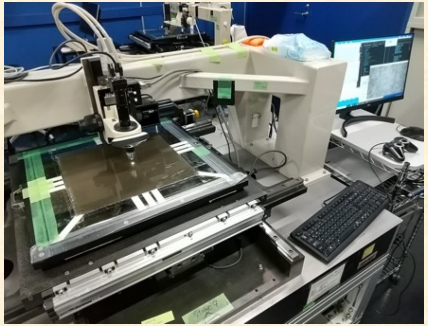


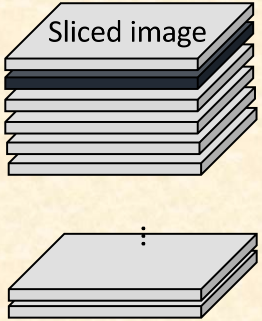
FIG. 5. The enlarged mass spectrum around the Λnn threshold. Two additional Gaussians were fitted together with the known contributions (the accidentals, the Λ quasifree, the free Λ, and the ³He contamination). The one at the threshold is for the small peak, while the broad one is for the additional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

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

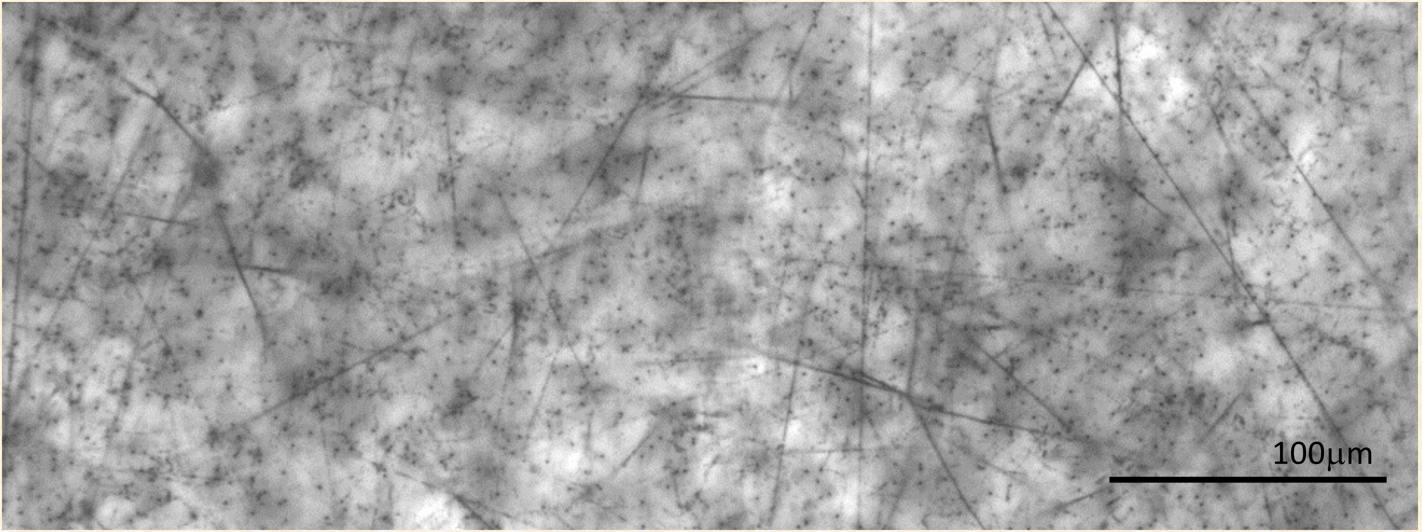
Overall scanning for E07 emulsions

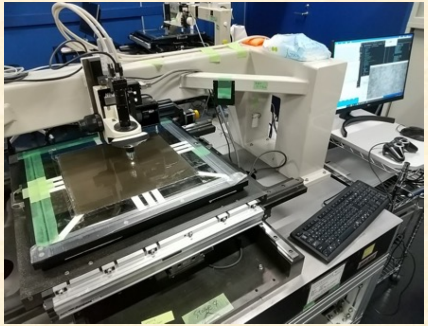


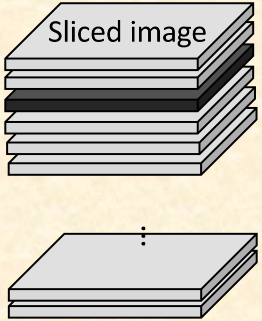




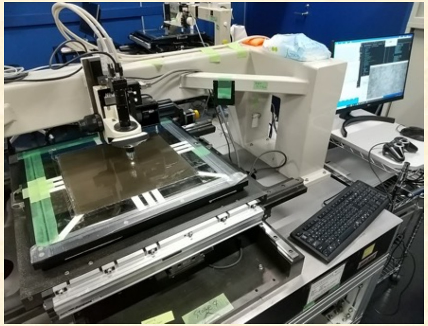
Overall scanning for E07 emulsions

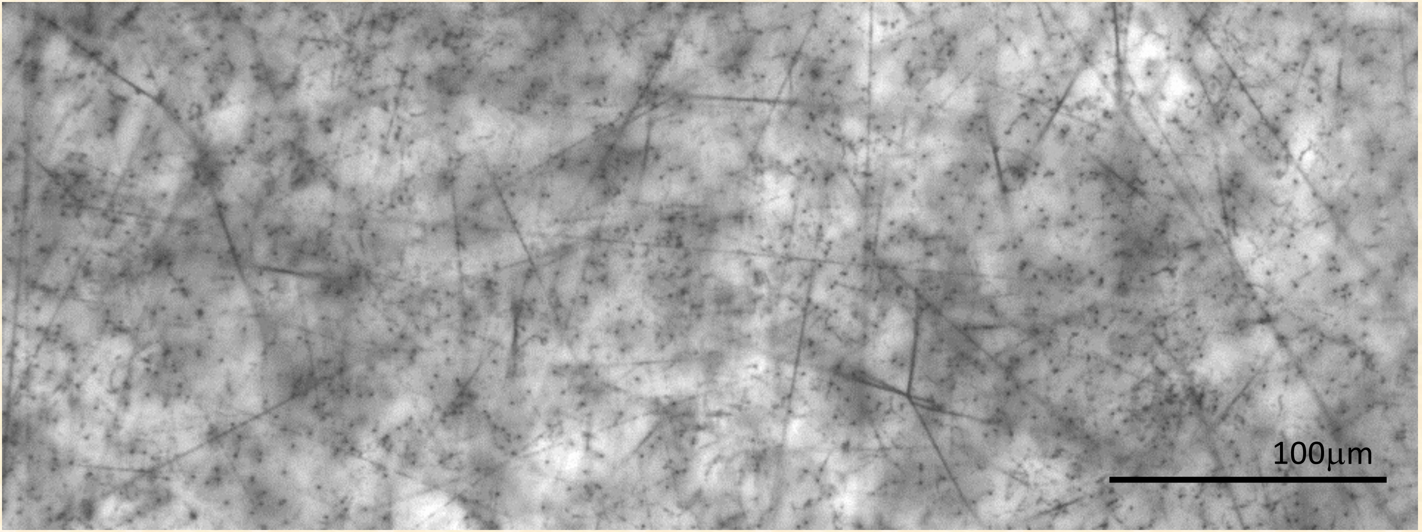


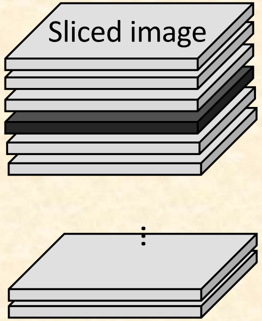




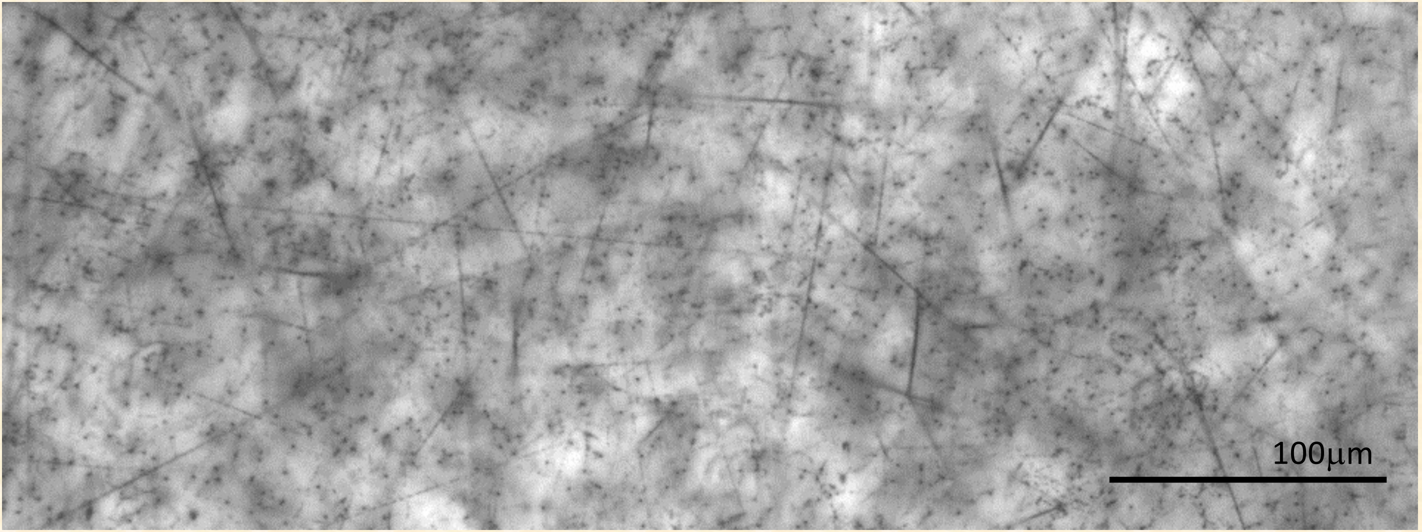
Overall scanning for E07 emulsions

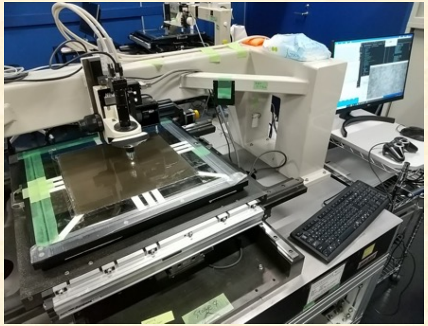


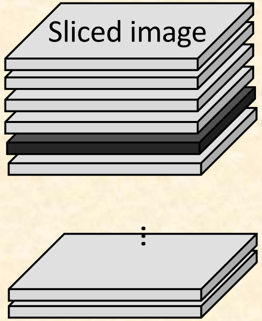




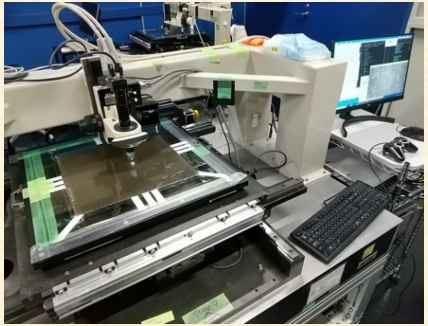
Overall scanning for E07 emulsions

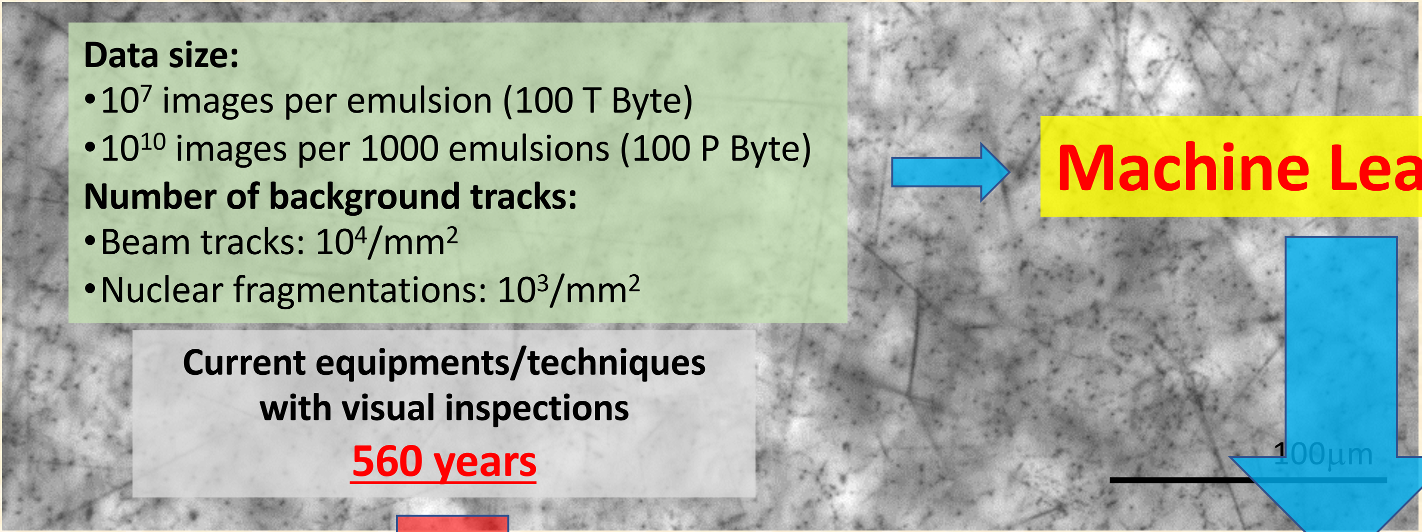






Overall scanning for E07 emulsions





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

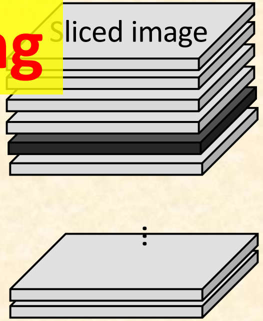
Number of background tracks:
- Beam tracks: $10^4/\text{mm}^2$
- Nuclear fragmentations: $10^3/\text{mm}^2$

Current equipments/techniques with visual inspections

560 years

3 years

Machine Learning



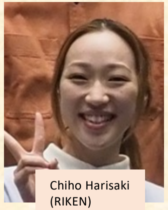
Millions of single-strangeness hypernuclei
1000 double strangeness hypernuclei (formerly only 5)

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

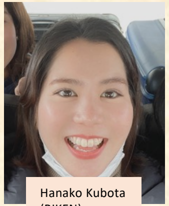
- Hypernuclear physics
- Neutron imaging

Part-timer staffs working for emulsion & microscopes

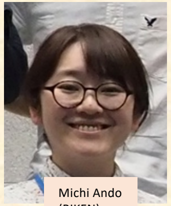
Risa Kobayashi (RIKEN)



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:

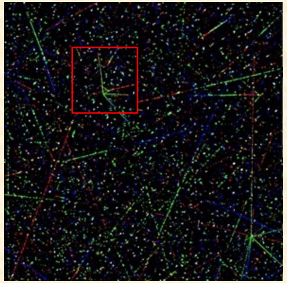
Producing training data with

- Monte Carlo simulations
- Image transfer techniques

Production of training data

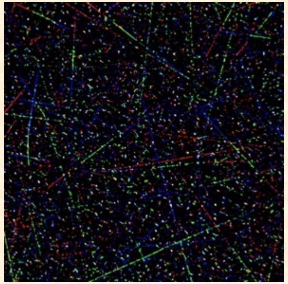
Monte Carlo simulations and GAN(Generative Adversarial Networks)

Binarized tracks from MC simulations
+ background from the real data

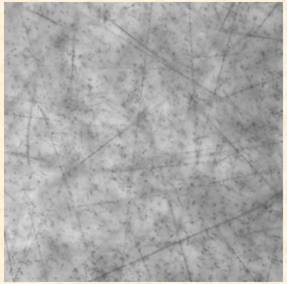


Imitated
emulsion image

GAN: pix2pix



Binarized (like for simulations)



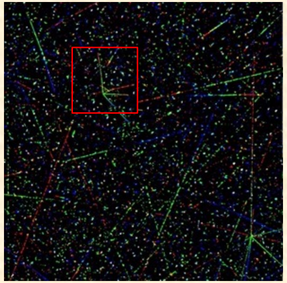
Real emulsion image

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

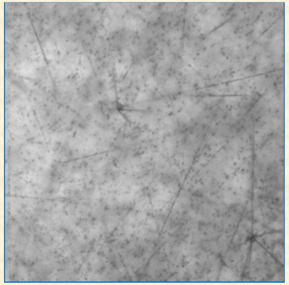
Production of training data

Monte Carlo simulations and GAN(Generative Adversarial Networks)

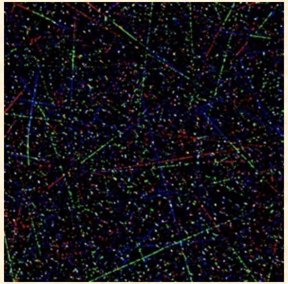
Binarized tracks from MC simulations
+ background from the real data



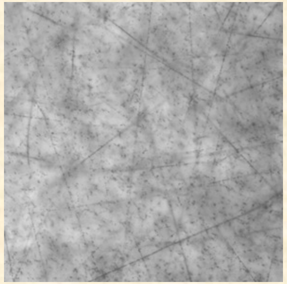
Produced training data



GAN: pix2pix



Binarized (like for simulations)

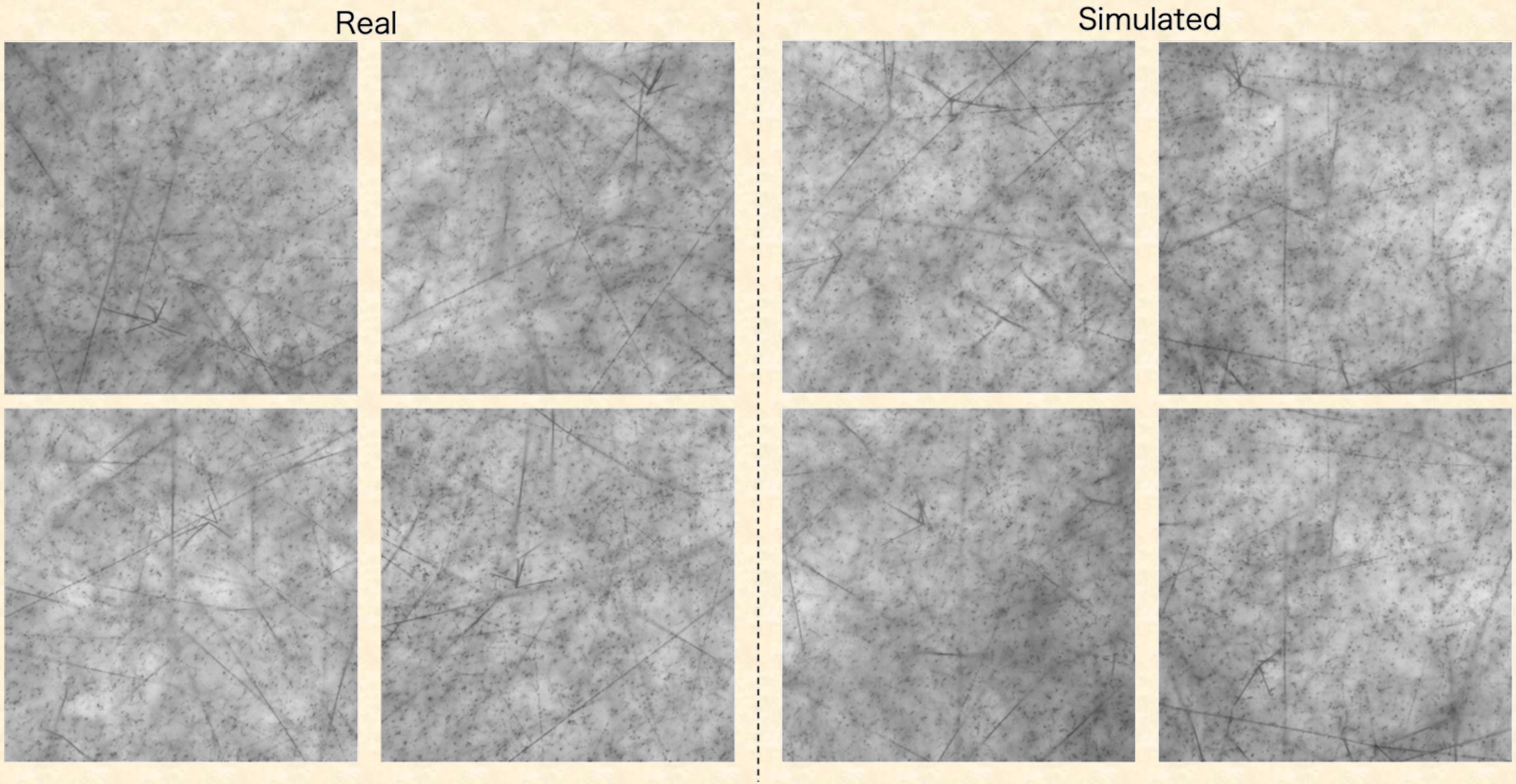


Real emulsion image

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

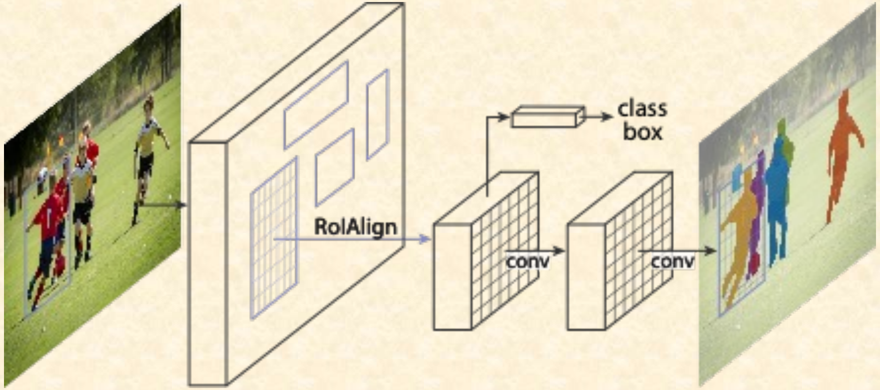
Production of training data

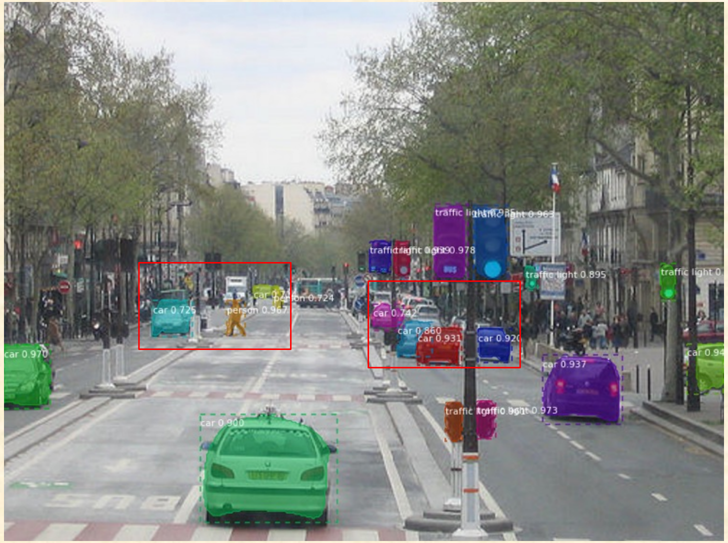
Monte Carlo simulations and GAN(Generative Adversarial Networks)



Detection of hypertriton events

With Mask R-CNN model



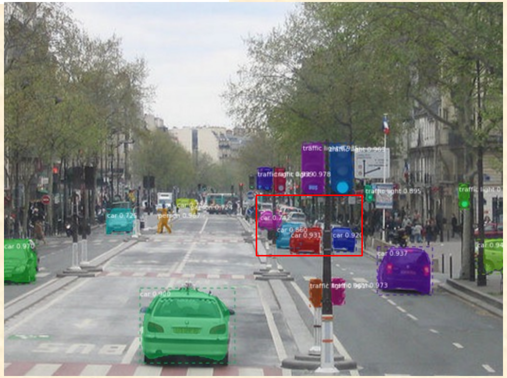


Detection of each object

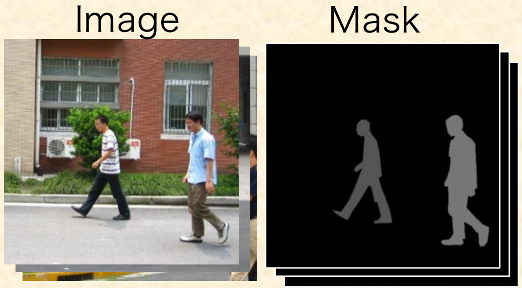
At large object density

Training of Mask R-CNN with Simulated image

Mask R-CNN



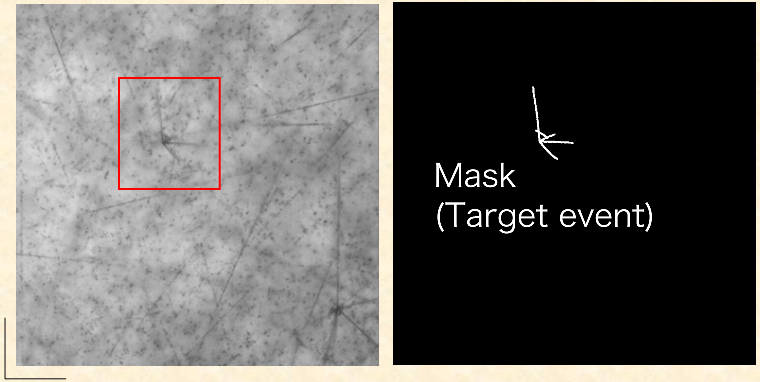
Example of training dataset



A Pedestrian dataset

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

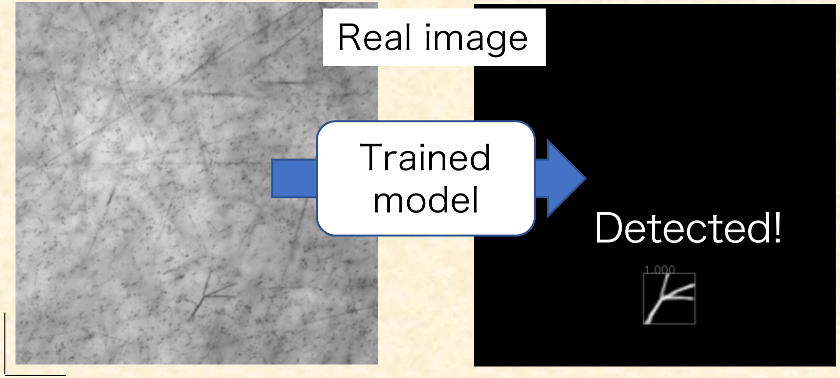
Training data (Simulated image)



50 μm

Masks are automatically produced

Performance of α-decay detection



50 μm

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

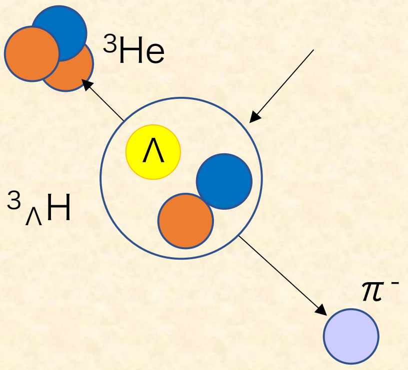
	Efficiency [%]	Purity [%]
Vertex picker	~40%	~1%
Mask R-CNN	~80%	~20%

→ 2nd step done

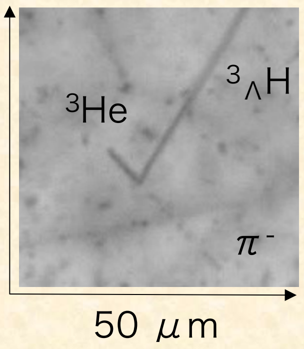
A.Kasagi et.al,
NIM A1056, (2023) 168663.

Hypertriton search with Mask R-CNN

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

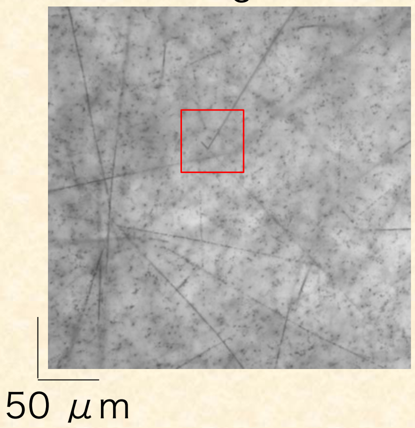


Simulated image

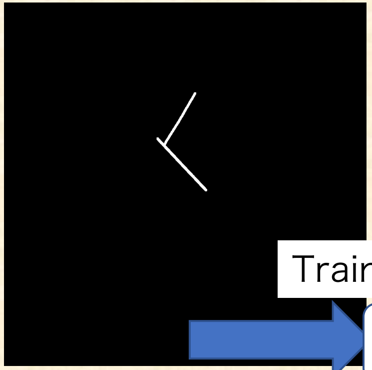


Training dataset (Simulated images)

Image



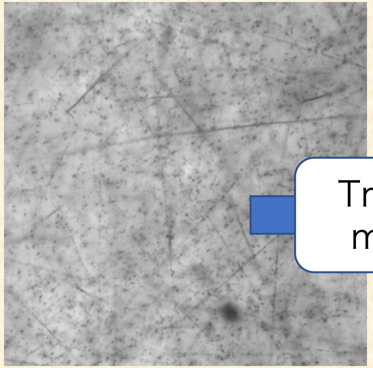
Mask



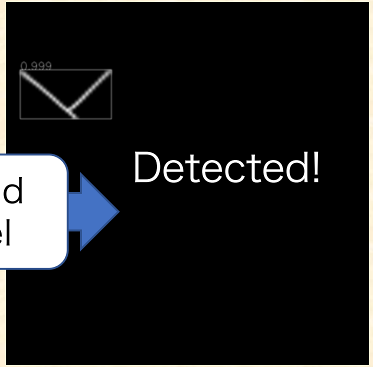
Training

model

Real image



Trained model



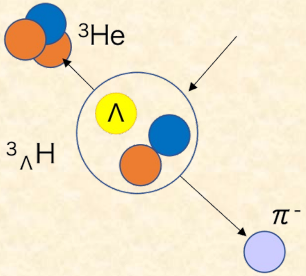
Our unique machine learning development

Producing training data by Monte Carlo simulations and machine learning techniques

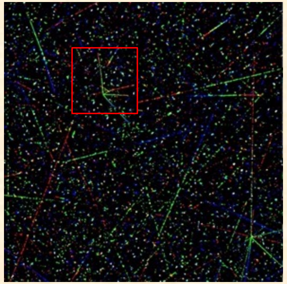
- Development with Generative Adversarial Networks (GAN)

Detection of 2-dody hypernuclear decay at rest

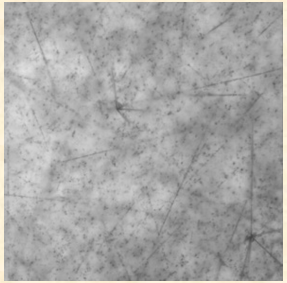
- Development with Mask-R CNN model



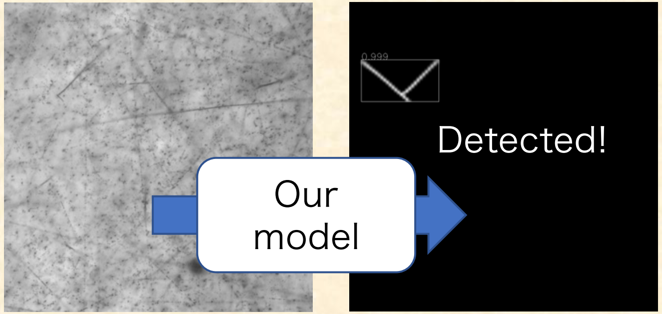
Monte Carlo simulations + binarized image from real emulsions



Produced training data



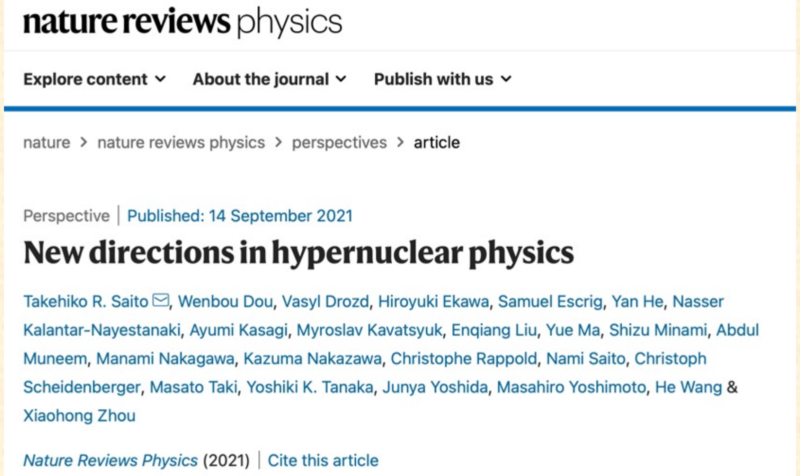
Real nuclear emulsion data



With two AI experts:
Masato Taki (Rikkyo U.) and Nami Saito (RIKEN)

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

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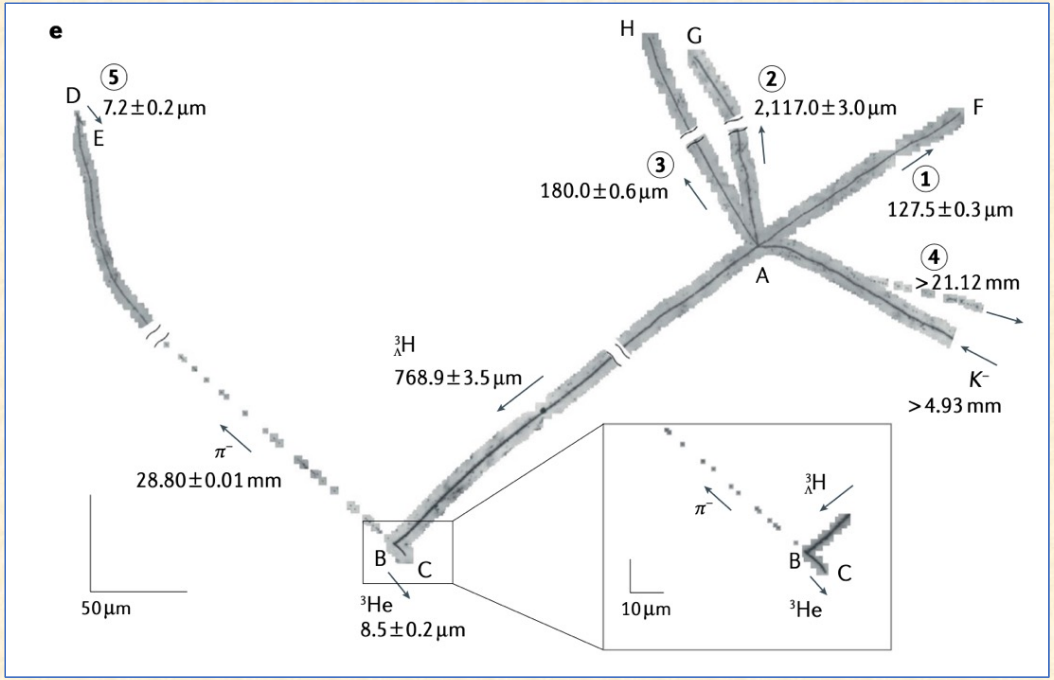
nature > nature reviews physics > perspectives > article

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)

Current status (as of December 2023)

No. events: 188 (0.6% of the entire E07 data)

- $^{3}_{\Lambda}H$: 41
- $^{4}_{\Lambda}H$: 147 (Identified: 91 + Penetrated: 56)

Calibrated events: 174

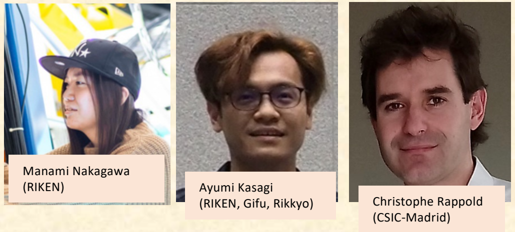
- $^{3}_{\Lambda}H$: 36
- $^{4}_{\Lambda}H$: 138 (Identified: 87 + Penetrated: 51)

- **Deducing the $^{3}_{\Lambda}H$ binding energy is in progress**
- **Statistics can be 167 times larger**
- **Estimated systematic error: 28 keV or smaller**

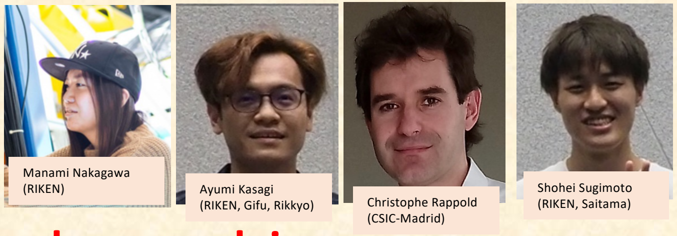
Current machine learning developments

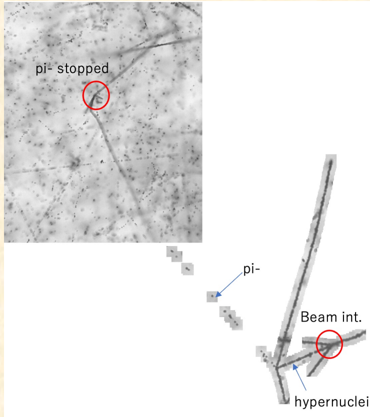
Improvements for the hypertriton binding energy

- Automated pion tracking
- Automated emulsion calibration



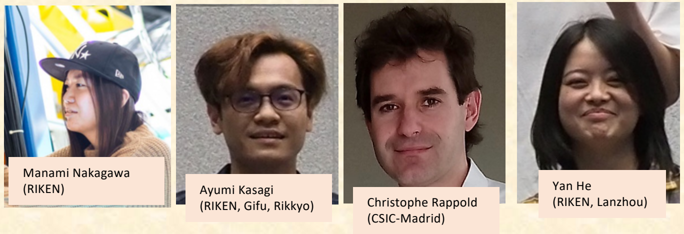
Detection of three- and multi-body single-Λ hypernuclear decay (from May 2022)

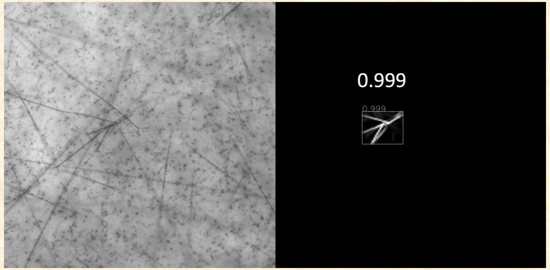




Shohei Sugimoto, Master thesis

Search for double-strangeness hypernuclei (from June 2022)



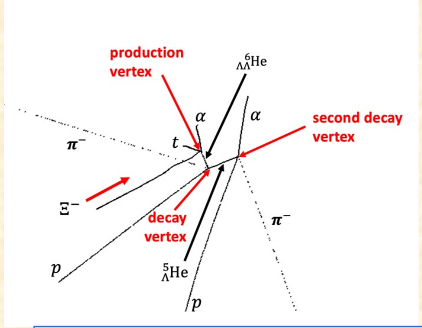


Yan He, Ph.D. thesis

Searching for double-strangeness hypernuclei

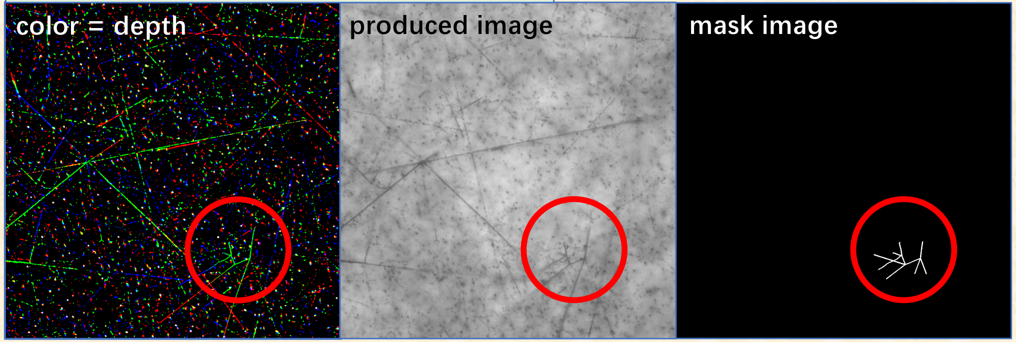
Yan He
(LZU/RIKEN)
Ph.D. thesis

Prepare training dataset

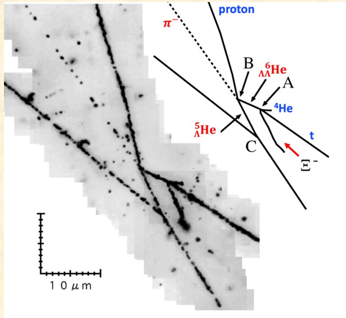


Double-strangeness hypernuclei event topology — **"three vertices"**

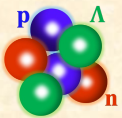
Geant4 simulation, image process, machine learning — GAN: pix2pix



Model performance

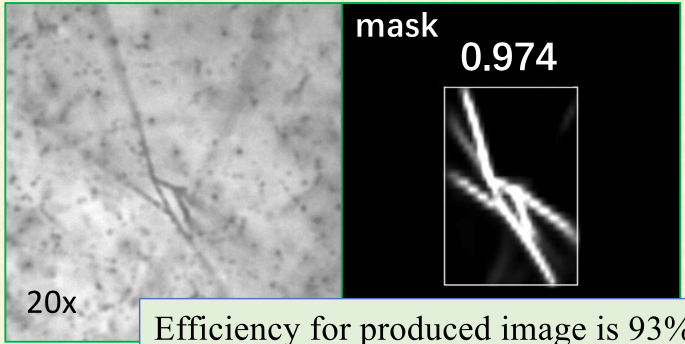


$^{6}_{\Lambda\Lambda}He$



triple-close shell

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



Efficiency for produced image is 93%

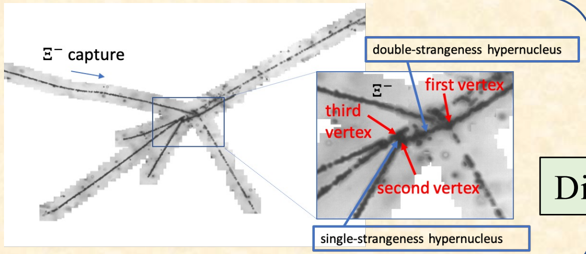
Searching for double-strangeness hypernuclei

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

Current status and near future

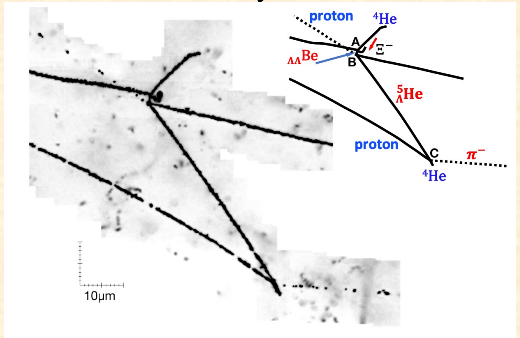
- Analyzed 0.2% of the entire data, one candidate found.
- Searching for double-strangeness hypernuclei with newly developed machine-learning method is in progress.

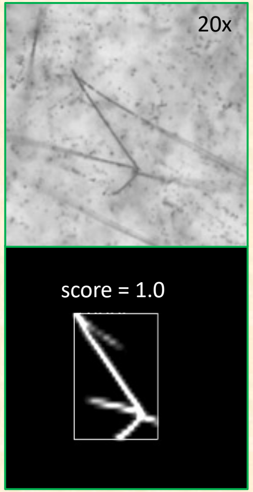
New candidate



Difficult to identify

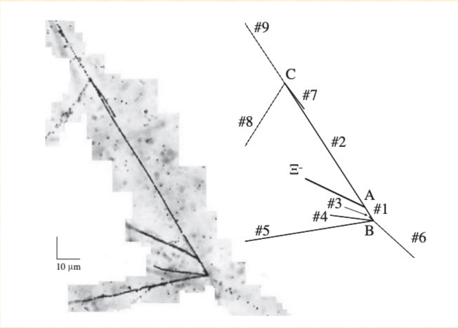
- ☐ MINO event from E07 hybrid

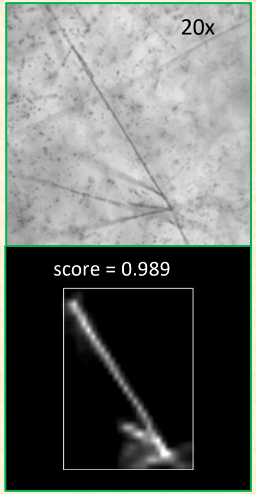




H. Ekawa et al., Prog. Theor. Exp. Phys. 2019, 021D02 (2019b) E.

- ☐ IBUKI event from E07 hybrid

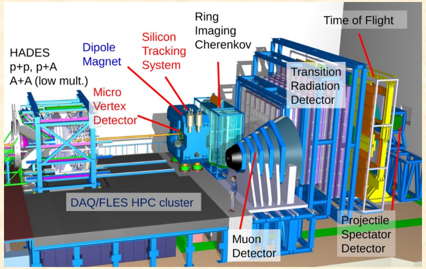




S.H. Hayakawa et al., Phys. Rev. Lett. 126, 062501 (2021)

With secondary produced hyperons

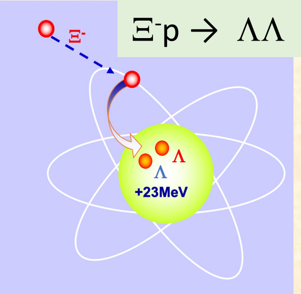
CBM detector



Example:

$$p + {}^{12}C \rightarrow \Xi^- + K^+ + K^0 + X$$

To secondary target (nuclear emulsion)



Complementary to hypernuclear studies with heavy ion beams at CBM

- Heavier hypernuclei
- Very precise binding energies (even with one event)

Additional comment

J-PARC hadron hall

- Very unique beam lines to produce secondary meson beams (K and π)
- In addition, a program with heavy ion beams with a fixed target (J-PARC HI) in under discussion

Similar direction to CBM

Additional comment

J-PARC hadron hall

- Very unique beam lines to produce secondary meson beams (K and π)
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Similar direction to CBM

The original CBM experiment

- Very unique program with heavy ion beams with a fixed target
- Now, we are discussing physics opportunities with proton beams
- Can we also consider to make a secondary beam line for K and π?

Similar direction to J-PARC

Summary (my personal considerations)

Spallation-like hypernuclear production with proton beams

- Hypernuclear magnetic moments with the CBM setup

Double-strangeness hypernuclei with secondary produced Ξ^-

- Using developed technology with nuclear emulsions and machine learning models by the RIKEN High Energy Nuclear Physics Laboratory
- With kaon trigger by the CBM detector (not mandatory) for hybrid method

Secondary meson beam line together with the CBM setup

High Energy Nuclear Physics Lab. at RIKEN since 2019

Hypernuclear physics with
- Heavy ion beams
- Machine learning + Emulsion

Mesic-nuclei and mesic-atoms

Short-range correlations for NN and ΛN in exotic nuclei

Very precise neutron imaging and CT

One more Ph.D. student from April 2024

On June 3rd 2022

Secretary:
- Yukiko Kurakata

Staff researchers:
- Yoshiki Tanaka
- He Wang

Postdocs:
- Hiroyuki Ekawa
- Manami Nakagawa

Ph.D. students:
- Vasyl Drozd
- Samuel Escrig
- Yiming Gao
- Yan He
- Ayumi Kasagi
- Enqiang Liu
- Abdul Muneem
- Snehankit Pattnaik

Master students:
- Shohei Sugimoto
- Ayari Yanai

Technical staffs:
- Michi Ando
- Chiho Harisaki
- Risa Kobayashi
- Hanako Kubota

Chief scientist:
- Take R. Saito