RIKEN's Programs for Junior Scientists

HENP High Energy Nuclear Physics

Unique approach for precise determination of binding energies of hypernuclei with nuclear emulsion and machine learning

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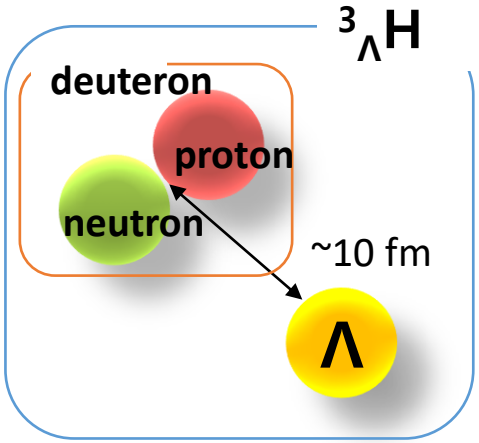
Rikkyo University, Nishina Center, RIKEN

Contents

Hypertriton puzzle

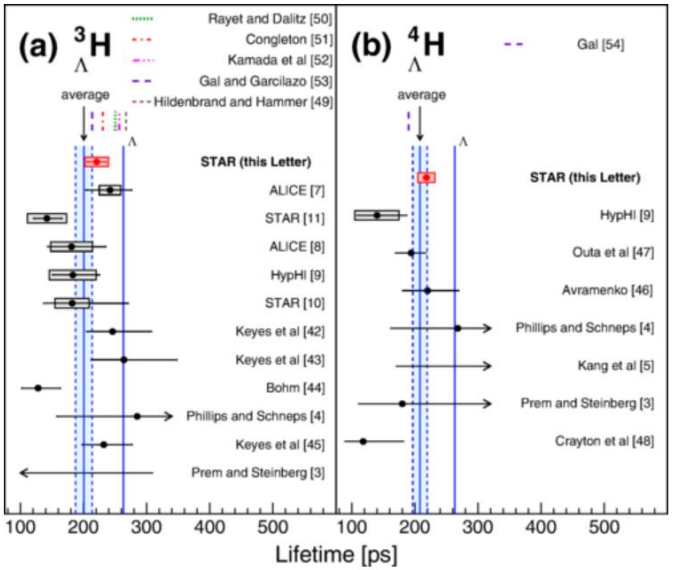


- The simplest hypernuclear system, $^{3}_{\Lambda}$H
  - a benchmark in hypernuclear physics

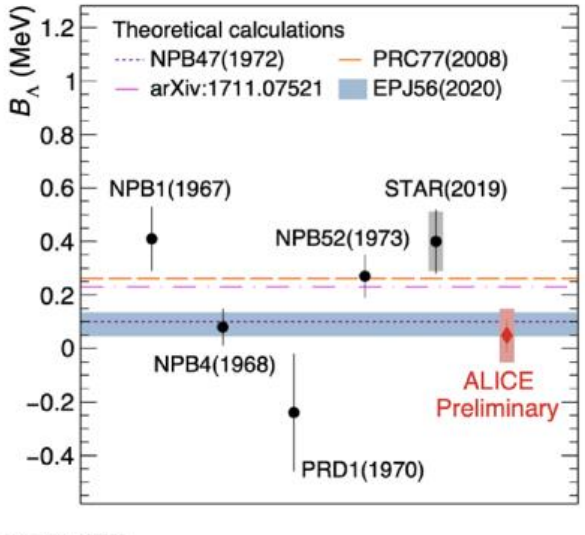
Lifetime

Binding energy

Talk:
Hiroyuki Ekawa
Wed-IVa



STAR Collaboration Phys. Rev. Lett. **128**, 202301 (2022)

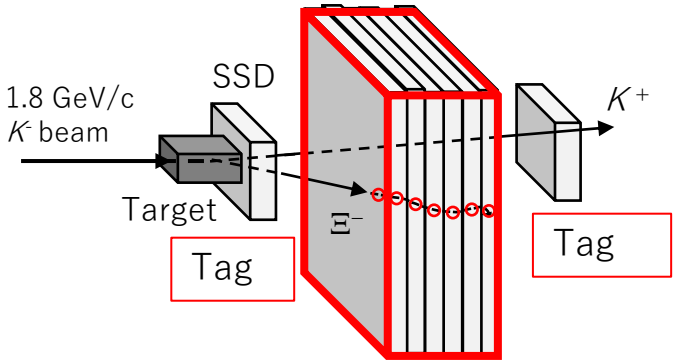


Al. Calivà, (SQM 2021) ,
EPJ Web of Conferences **259**, 03004 (2022)

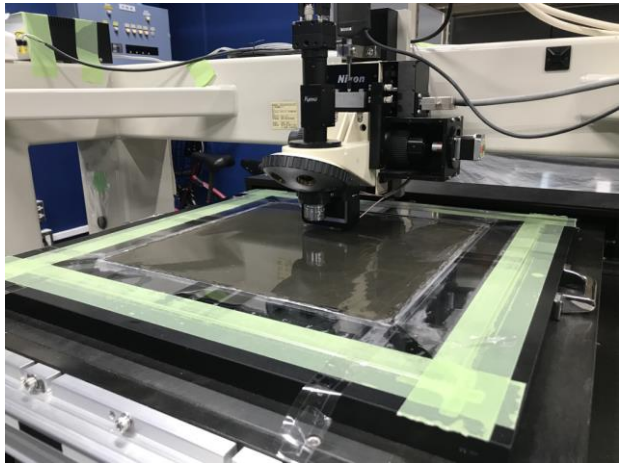
Differ from conventional interpretations

Our approach : Nuclear emulsion & State-of-the-art technology

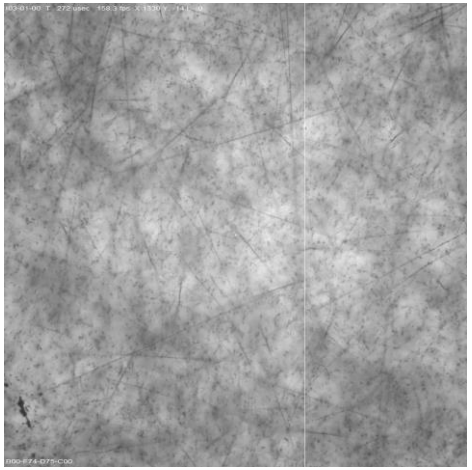
Nuclear emulsion



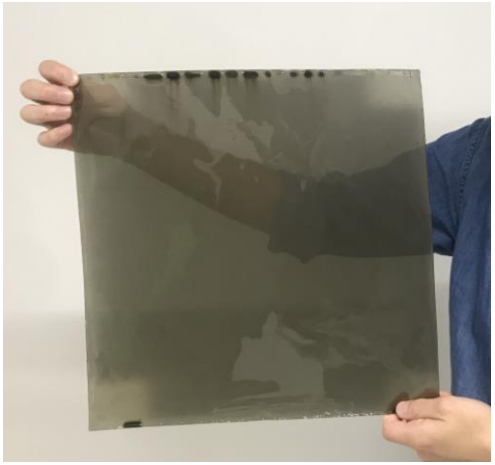
- J-PARC E07 Experiment
  - To search for double hypernuclei
  - ～1300 emulsion sheets
  - Non-triggered events
    - Thousands of double hypernuclei
    - Millions of single hypernuclei
- Overall scanning



microscope



100 μm

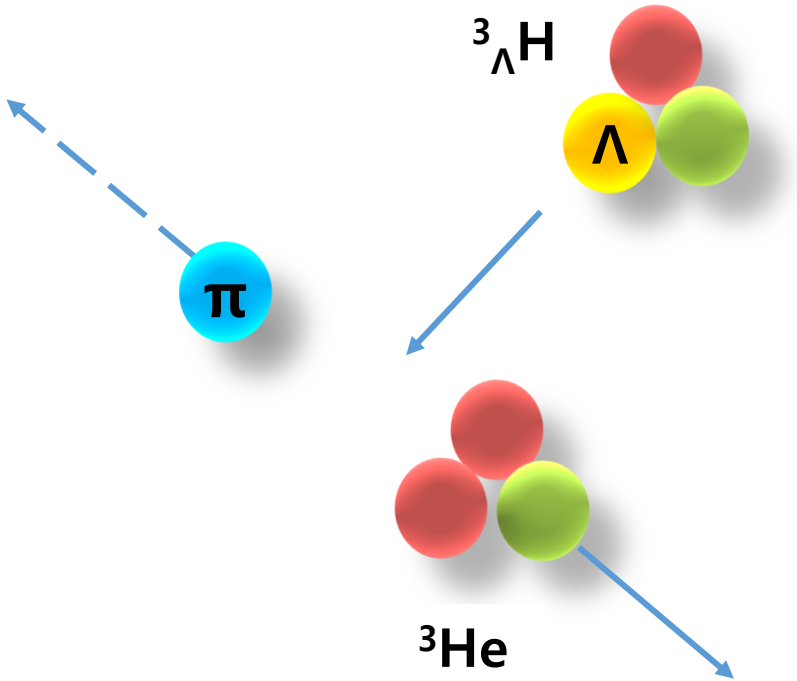


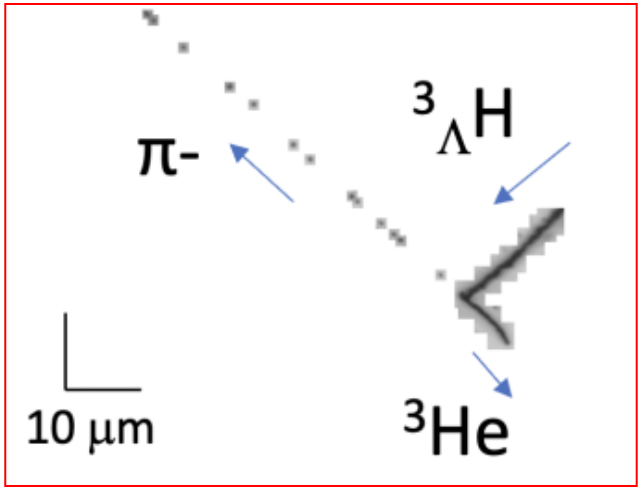
Data size: 140 PB
Background: 10^{10} events
Eye check : ～560 years

→ Machine learning

Hypernuclear events on nuclear emulsion

- ${}^{3}_{\Lambda}H$ decay event



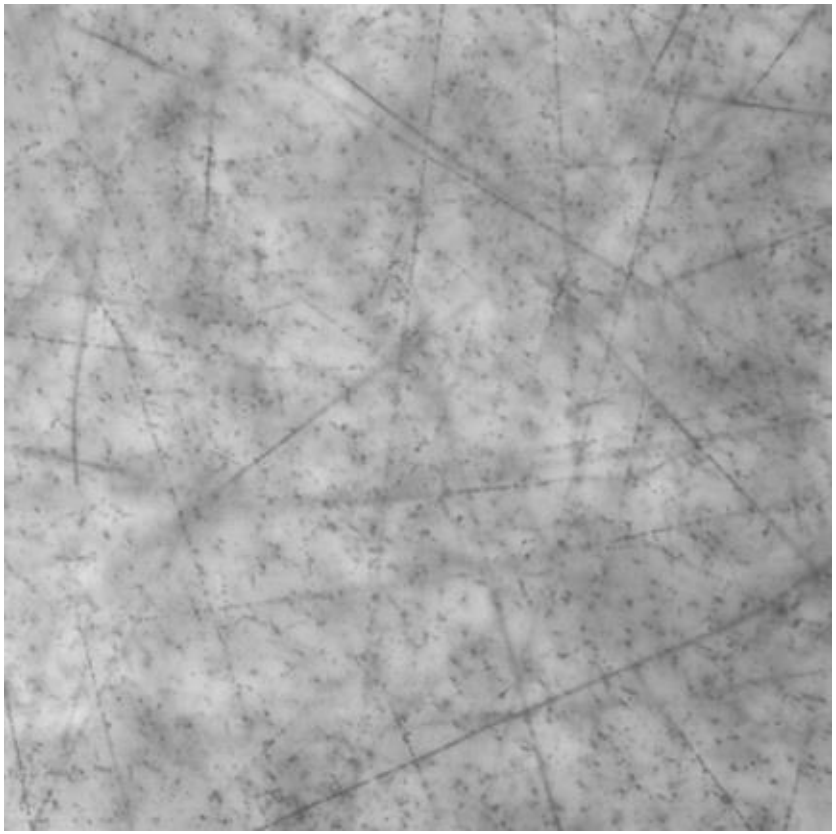


Detection is suitable for machine learning, but no training data
→ Create simulated images from physics simulations

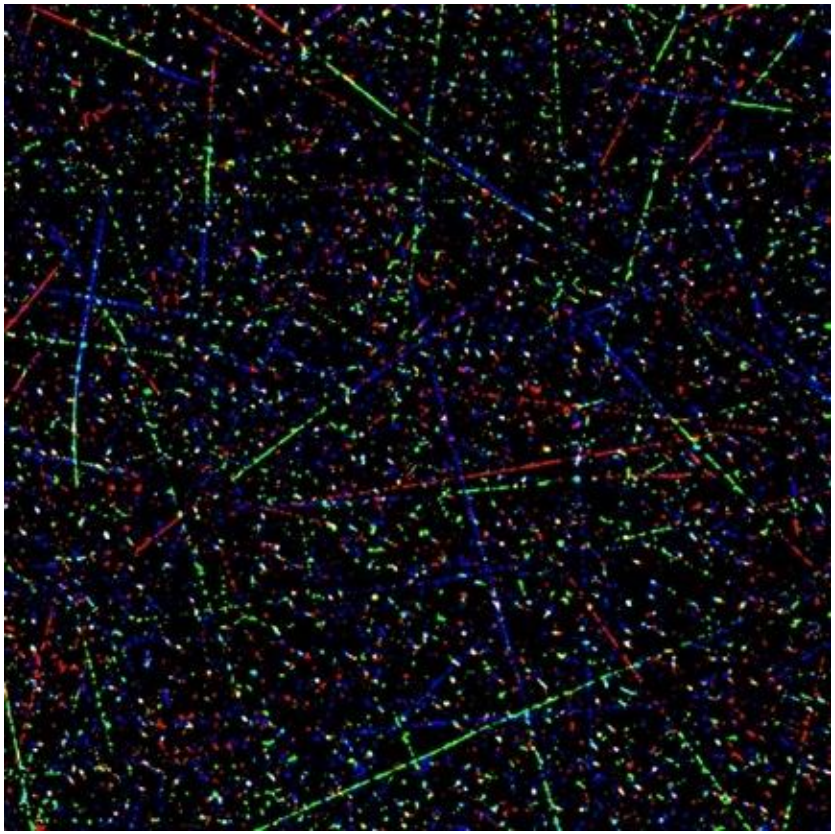
Production of Simulated Image
①Train

Color → Depth

real image



line image



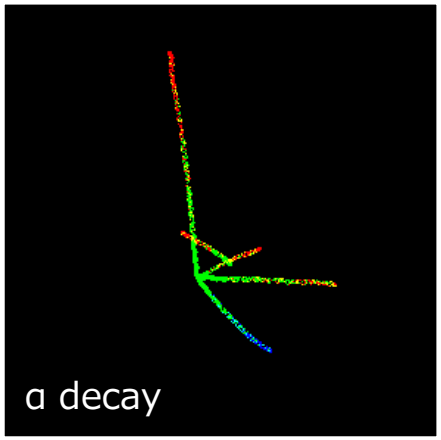
answer

question

produce model (GAN)

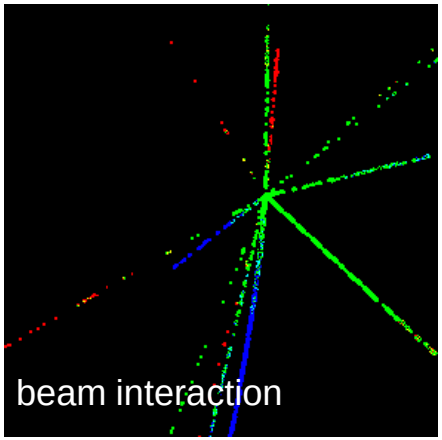
Production of Simulated Image
②Generate data

positive sample

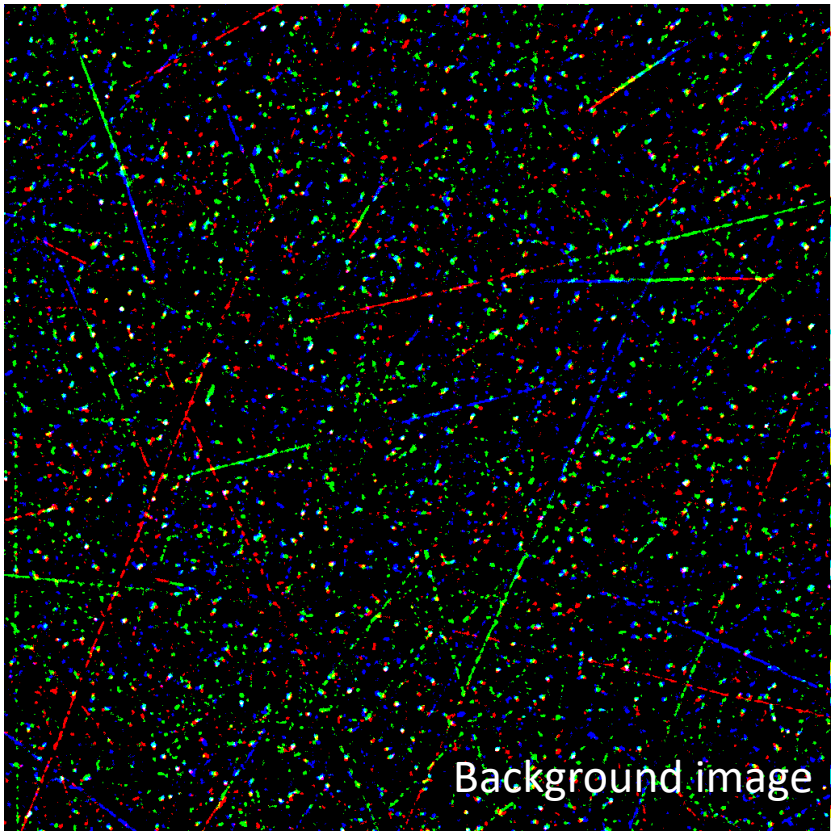


50 μm

negative sample

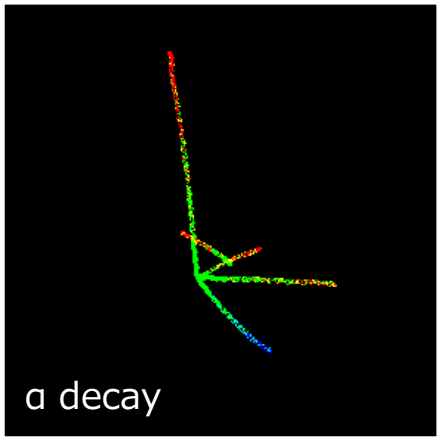


line image from real image



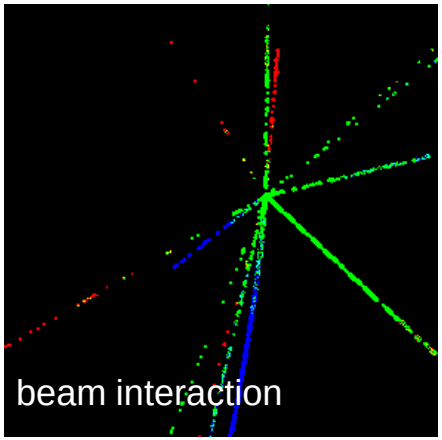
Production of Simulated Image
②Generate data

positive sample



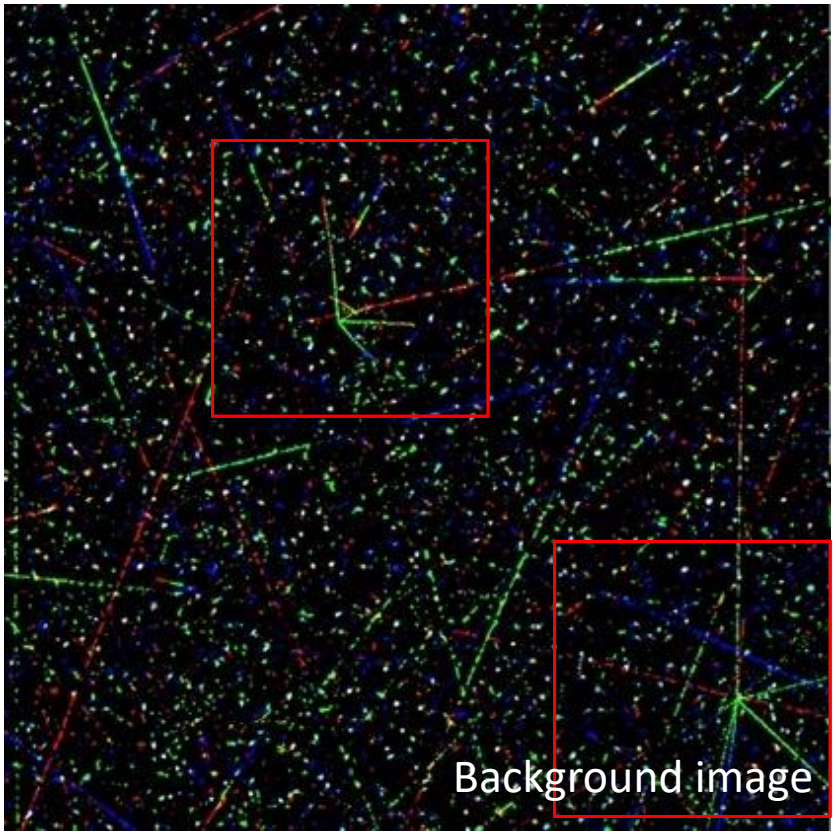
50 μm

negative sample



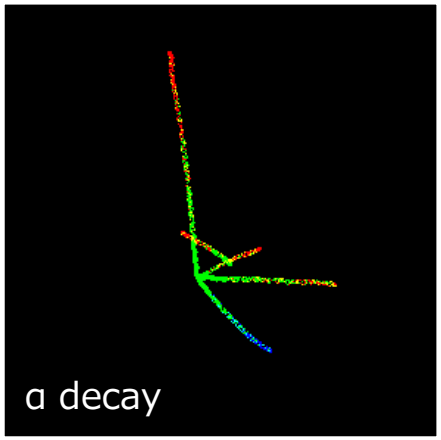
Mix

line image from real image

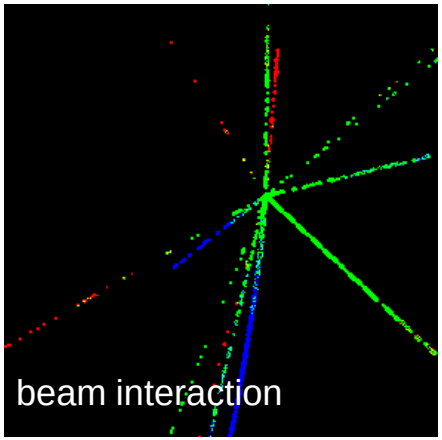


Production of Simulated Image
②Generate data

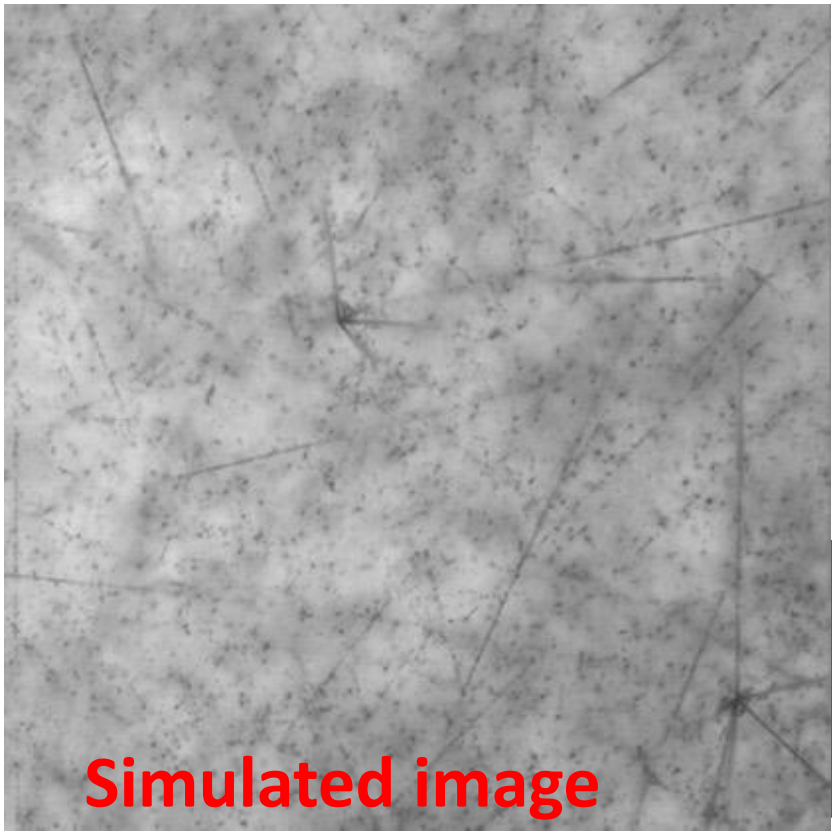
positive sample



negative sample

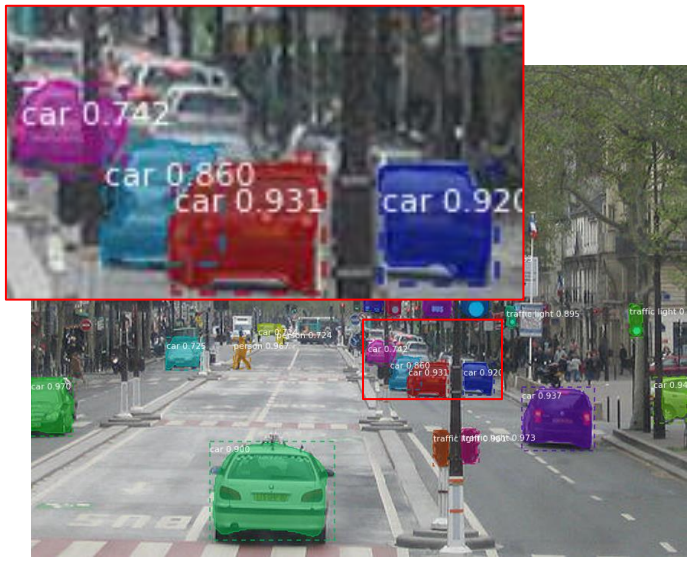


50 μm



Trained model → $^{3}_{\Lambda}H$ simulated image Production

$^{3}_{\Lambda}$H event detection using object detection



Mask R-CNN

Object detection model

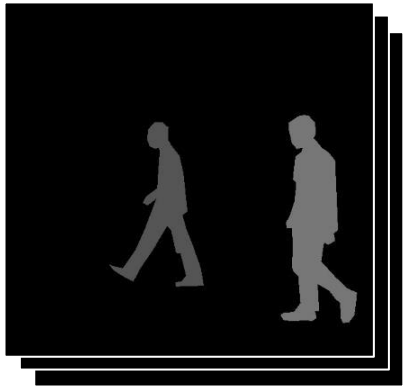
https://arxiv.org/abs/1703.06870

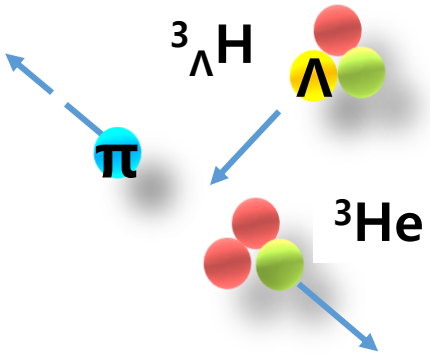
example of train data

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

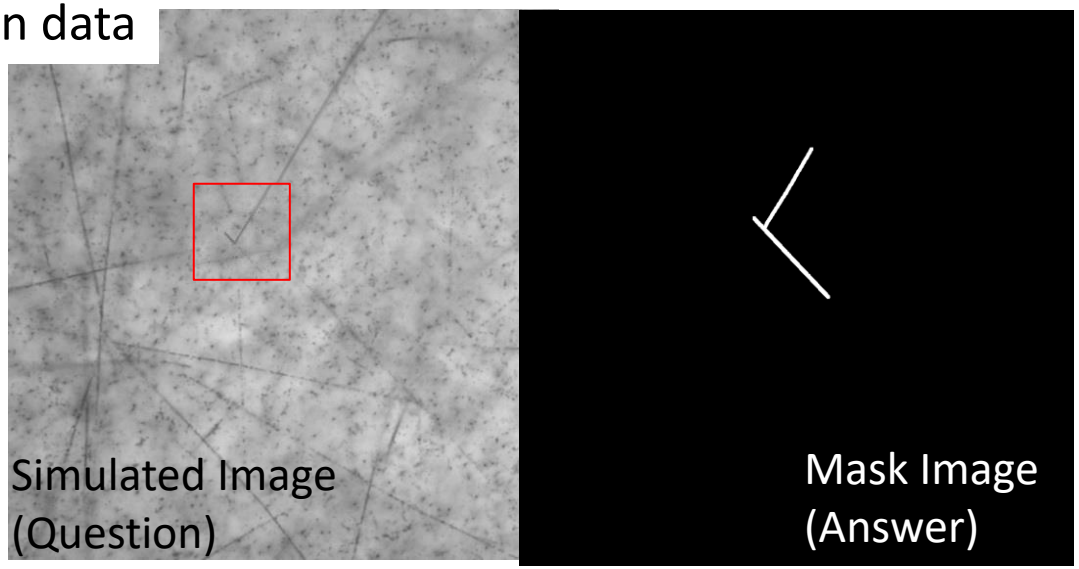
Image

Mask



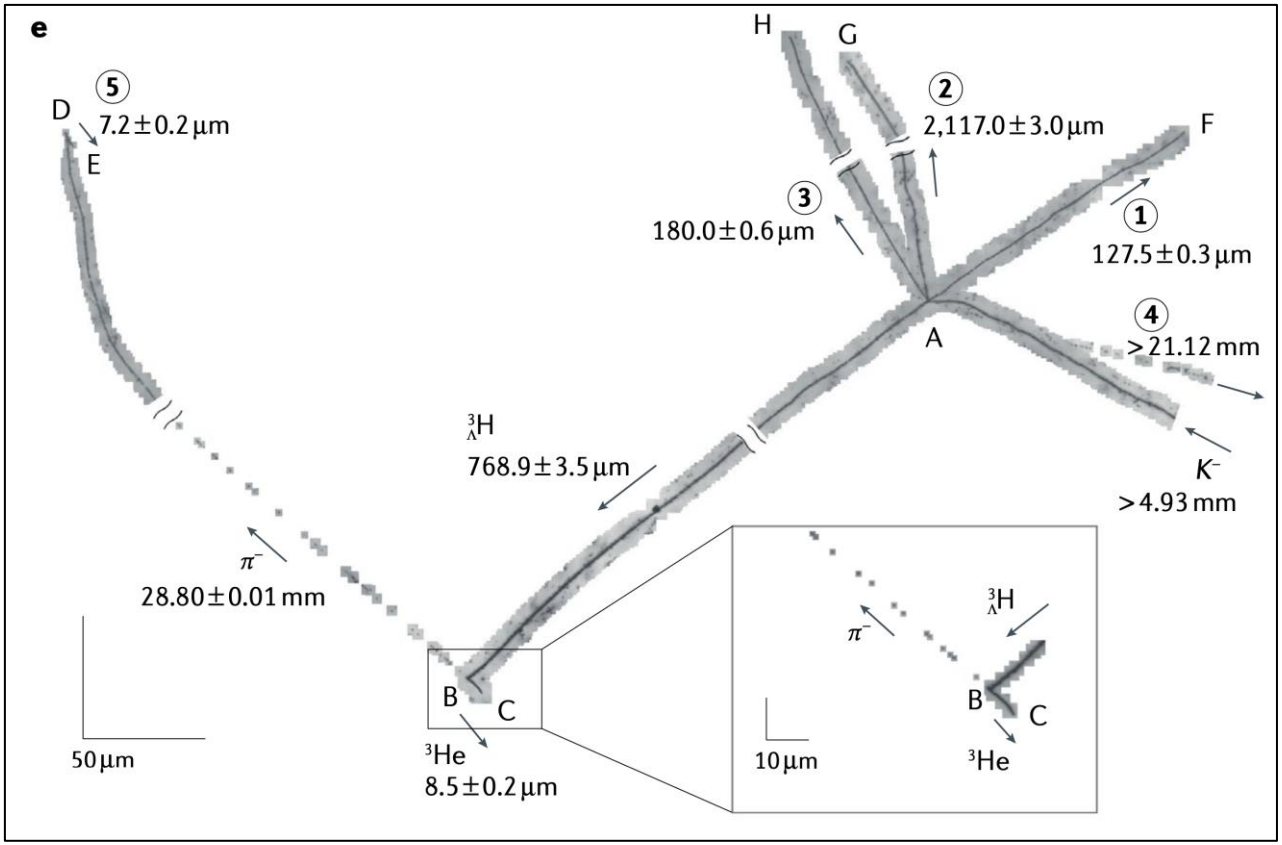


Train data



$^{3}_{\Lambda}$H event observation

T.R. Saito, *et al.,* Nat Rev Phys **3,** 803–813 (2021).



→ Established method

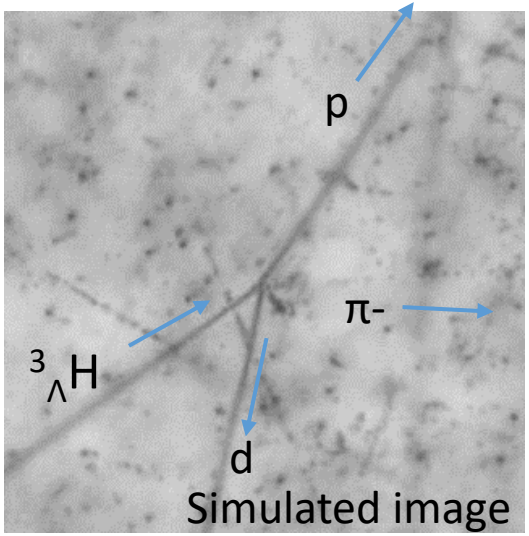
400 events → 30keV(stat.), 30keV(sys.)

E. Liu, et al., Eur. Phys. J. A (2021) 57:327

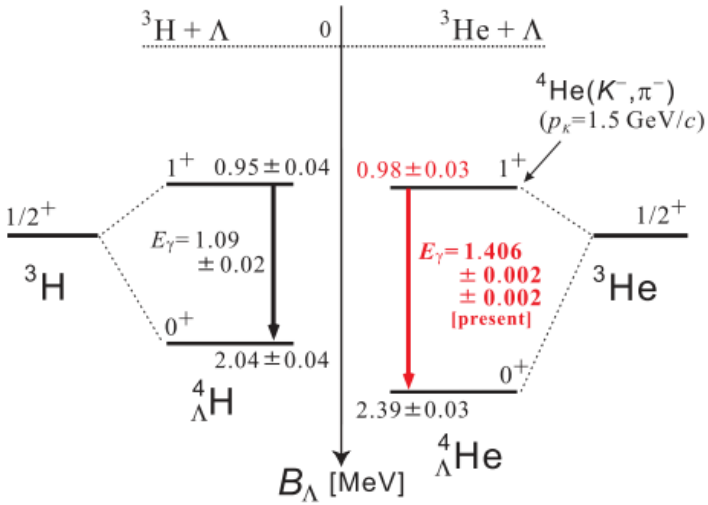
Ph.D thesis will be done by Ayumi Kasagi
Gifu Univ., RIKEN

Single hypernucler search

- Three-body decay
  - Many hypernuclei decay with many-body decay
  - Especially ${}^{3}_{\Lambda}$H, ${}^{4}_{\Lambda}$H &${}^{4}_{\Lambda}$He
    - ${}^{3}_{\Lambda}$H : Comparison with 2-body decay
    - ${}^{4}_{\Lambda}$H : Comparison with MAMI
    - ${}^{4}_{\Lambda}$He: Only old emulsion data
- Under development



Charge symmetry breaking



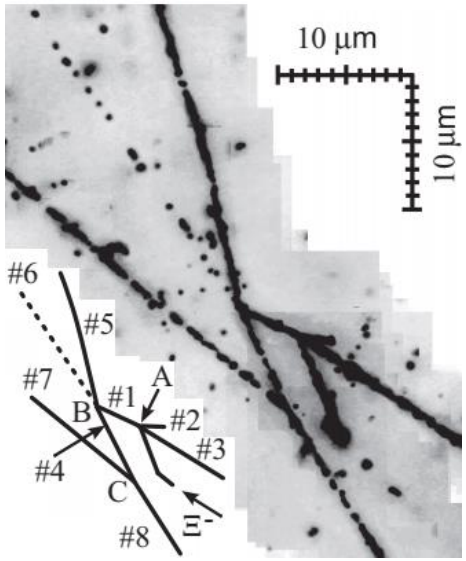
T. O. Yamamoto, et al.,
Phys. Rev. Lett. **115**, 222501 (2015)

M thesis will be done by Shohei Sugimoto
Saitama Univ., RIKEN

Double hypernucler search

- Double hypernuclear event
  - Observe new double hypernuclei
  - Increase statistics of known double hypernuclei

- Under development



NAGARA

$\Xi^{-}{}^{12}C \rightarrow {}^{6}_{\Lambda\Lambda}He\ \alpha\ t$

${}^{6}_{\Lambda\Lambda}He \rightarrow {}^{5}_{\Lambda}He\ p\ \pi^{-}$

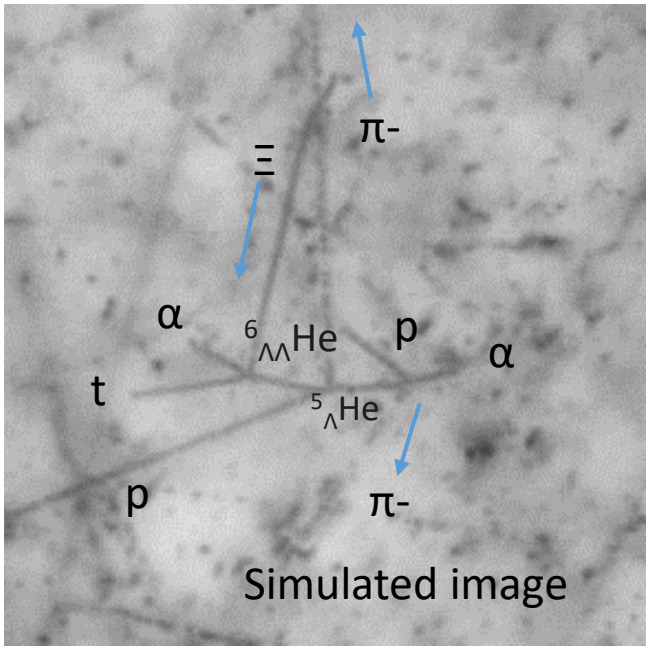
${}^{5}_{\Lambda}He \rightarrow p\ p\ n(s)$

$\Xi^{-}{}^{12}C \rightarrow {}^{6}_{\Lambda\Lambda}He\ \alpha\ t$

${}^{6}_{\Lambda\Lambda}He \rightarrow {}^{5}_{\Lambda}He\ p\ \pi^{-}$

${}^{5}_{\Lambda}He \rightarrow \alpha\ p\ \pi^{-}$

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



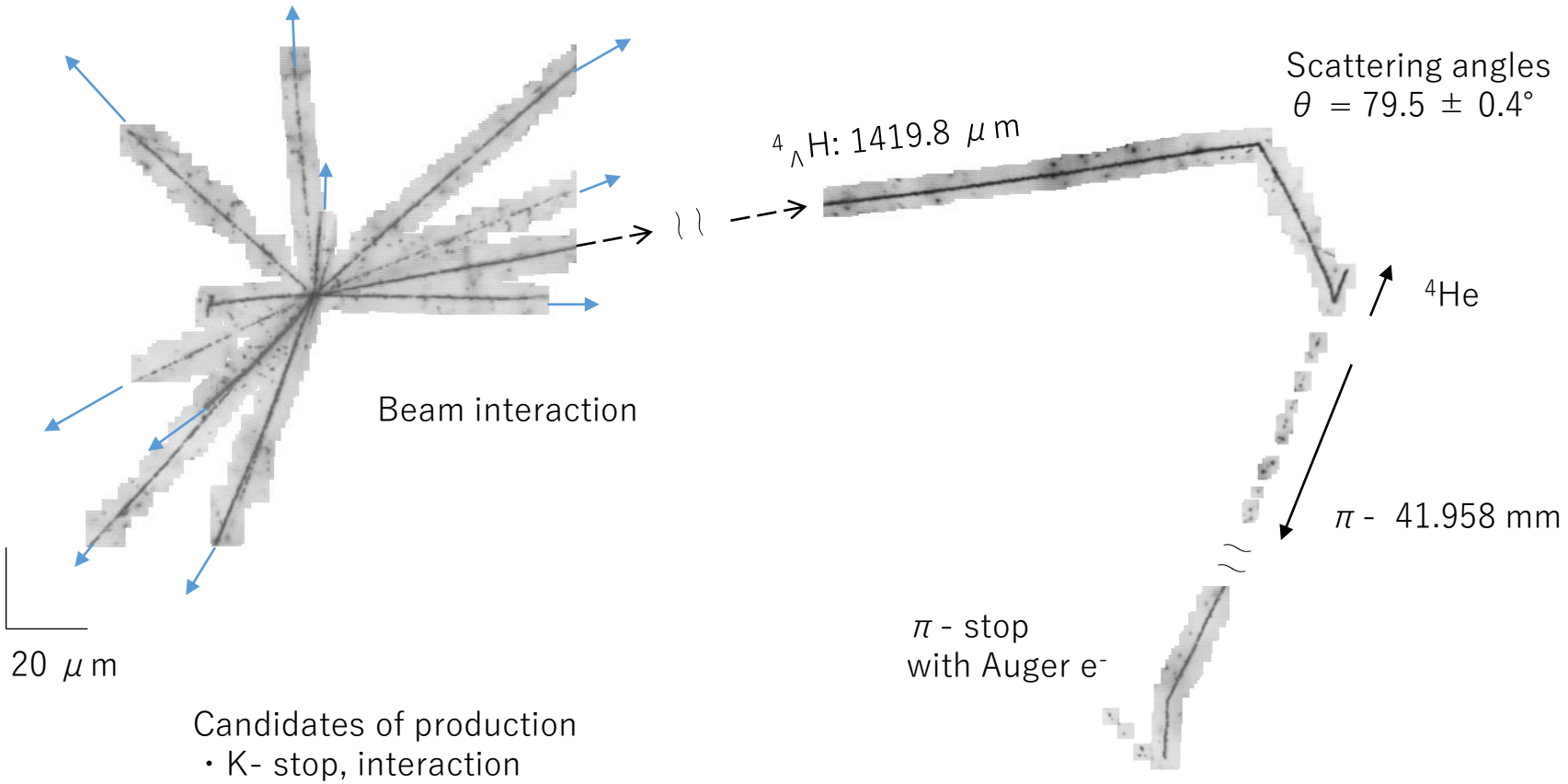
Ph.D thesis will be done by Yan He
Lanzhou Univ., RIKEN

Summary & Perspective

- Binding energies of hypernuclei
  - Precise measurement is needed
- Nuclear emulsion
  - For J-PARC E07 experiment
  - Overall scanning
- Machine learning
  - Simulated image from Geant4 + GAN
  - Object detection
- On-going search
  - Two-body decay (at rest) of ${}^{3}_{\Lambda}\mathrm{H}$ & ${}^{4}_{\Lambda}\mathrm{H}$
- Under development
  - Single hypernuclear search
  - Double hypernuclear search

BACKUP

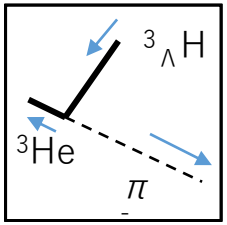
Hypernuclear Scattering



Candidates of production
- K- stop, interaction
- Ξ^- Σ^- stop
- Decay of Double-strangeness Hypernucleus

Precise measurement with Nuclear Emulsion

・Background-free measurement
Hypertriton decay can be visually observed.
Unique topology in two-body decay
($^{3}_{\Lambda}$H: ～28 mm, $^{4}_{\Lambda}$H: ～42 mm)



	$^{3}_{\Lambda}$H	$^{4}_{\Lambda}$H	$^{6}_{\Lambda}$He	$^{7}_{\Lambda}$He
He, Li etc… [μm]	～8	～8	～2	～2
π^- [mm]	～28	～42	～24	～28

～
～

・Calibration

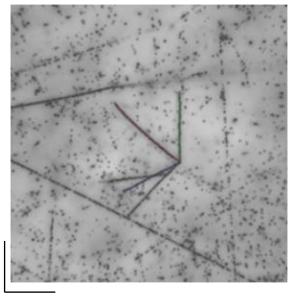
	～1970s	In our analysis
Calibration source	Proton ($\Sigma^+ \rightarrow p + \pi^0$)	^{4}He (RI in emulsion)
Volume	6.5 × 10^3 cm^3	5 cm^3

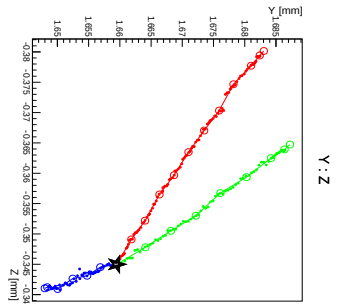
K.E of proton depends on Mass of Σ^+.
($K^- + p \rightarrow \Sigma^+ + \pi^-$, $\Sigma^+ \rightarrow p + \pi^0$)

・Kinematical analysis
$^{3}_{\Lambda}$H → ^{3}He(～8 μm) + π^-(～28 mm)

～1970s: Measurement of Mass of Λ
($\Lambda \rightarrow p + \pi^-$) π^-: 10～20 mm

Range measurement for α tracks by fitting

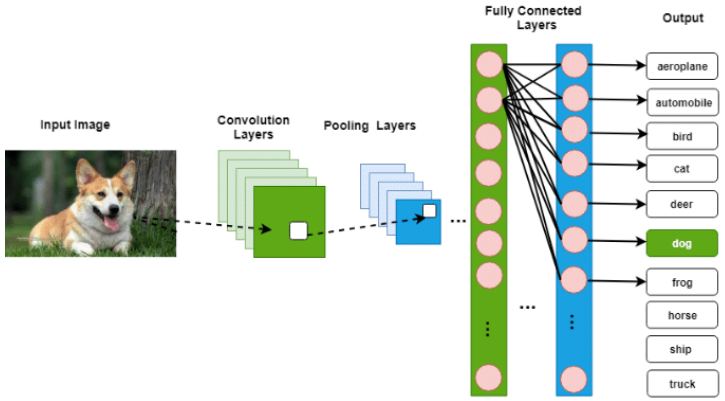




・^{3}He, ^{4}He calibrated by ^{4}He
・Calibration in each small volume
→ We can achieve ～30 keV syst. error.
・Analysis of $^{4}_{\Lambda}$H at the same systematic

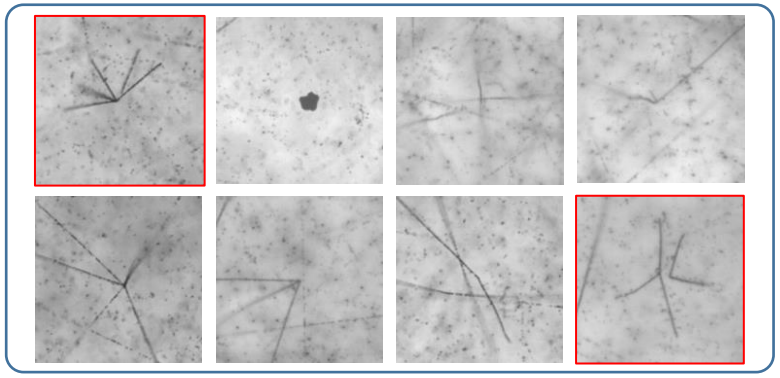
CNN filter

Convolutional Neural Network

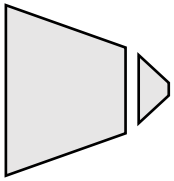


- images and correct answer labels (training data)
- Quantify features by convolutional operations
- Iteratively updating the calculation weights (parameters) in each layer

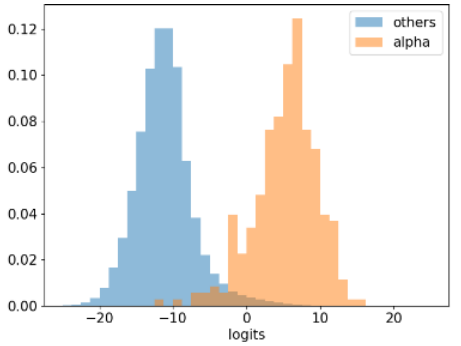
→Making the best model



Model



Noise



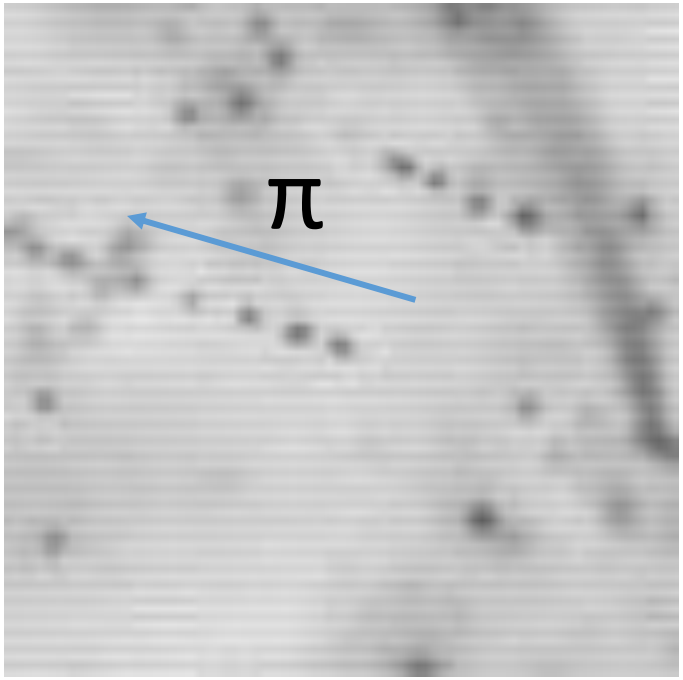
Signal

Automatic Tracking of π Track

- Tracking of π track takes long time

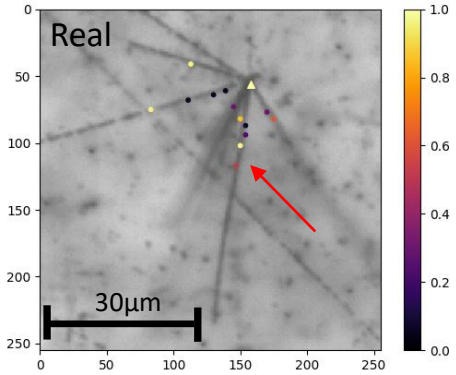
→ automation by Reinforcement Learning

- Under development

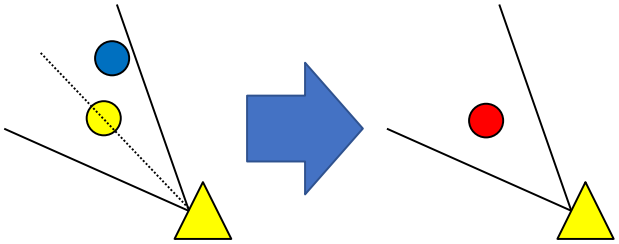


フィルター2 (飛跡の本数)

クラスタリング



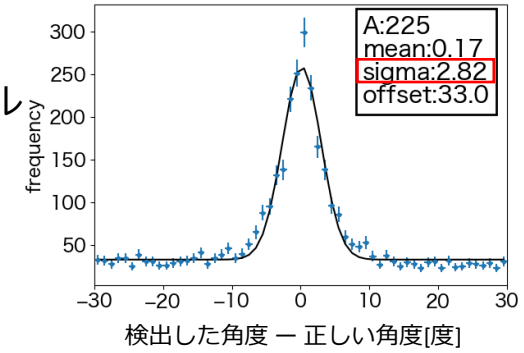
複数検出をまとめる
必要がある



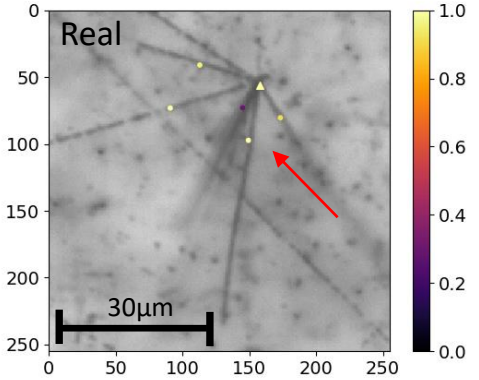
Vertexからの角度で同じ飛跡を検出しているか判断
→幅を求める

シミュレーション画像
を作成し機械学習モデル
に適用

機械学習モデルの角度分解能



3sigma度以内にある
点をまとめる
score: 合計
角度: 重み付き平均



Σ hypernuclei