Application of ML for TPC tracking

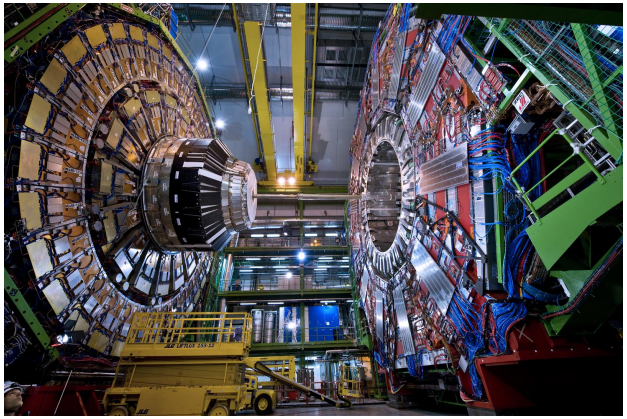
Yongsun Kim (Sejong Univ.)

Korea-UK FP meeting

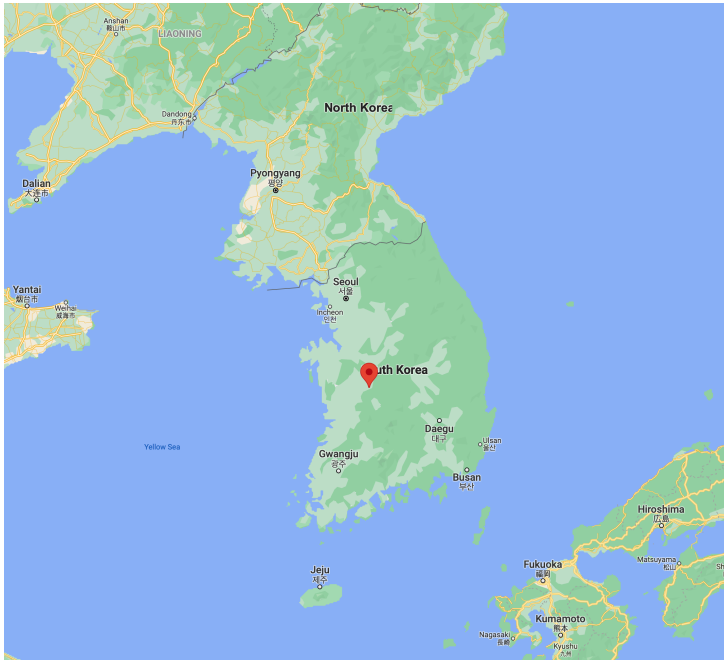
2021.11.17

About me

- Yongsun Kim, Sejong Univ.
- CMS collaboration (2008 — *present)*
  - Mainly working for Heavy Ion Physics Analysis Group to study Quark Gluon Plasma
  - CMS Forward group leader (Level 3) in 2020
  - CMS heavy ion group convener (Level 2) in 2020 — 2022
- **LAMPS collaboration (2018 — *present*)**
  - **Experiment at RAON**
- 2018 — *present* : *a*ssistant professor at Sejong University

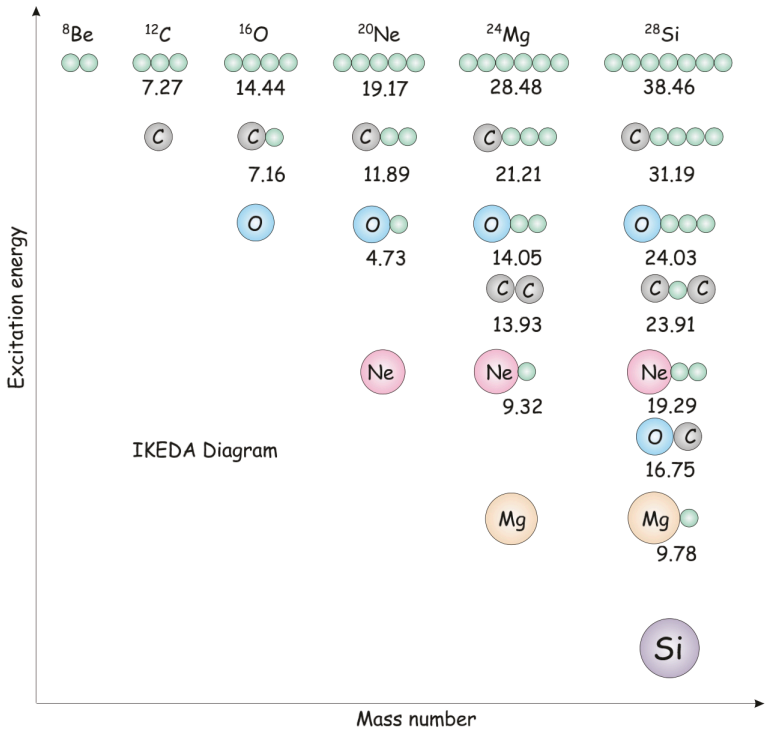


RAON

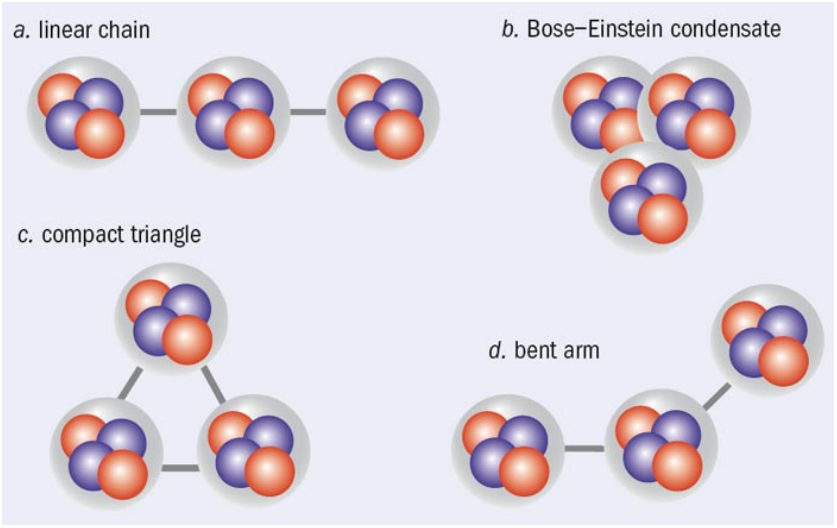


- **R**are isotope **A**ccelerator complex for **ON**-line experiment
- First heavy ion accelerator in Korea
- Built to study the nuclear symmetry structure,
- Can produce very asymmetric rare isotopes at E=10 — 100 MeV/u at high intensity
- Commissioning starts next year for low energy stable beam sectors - O(10) MeV

α clusters in nuclei



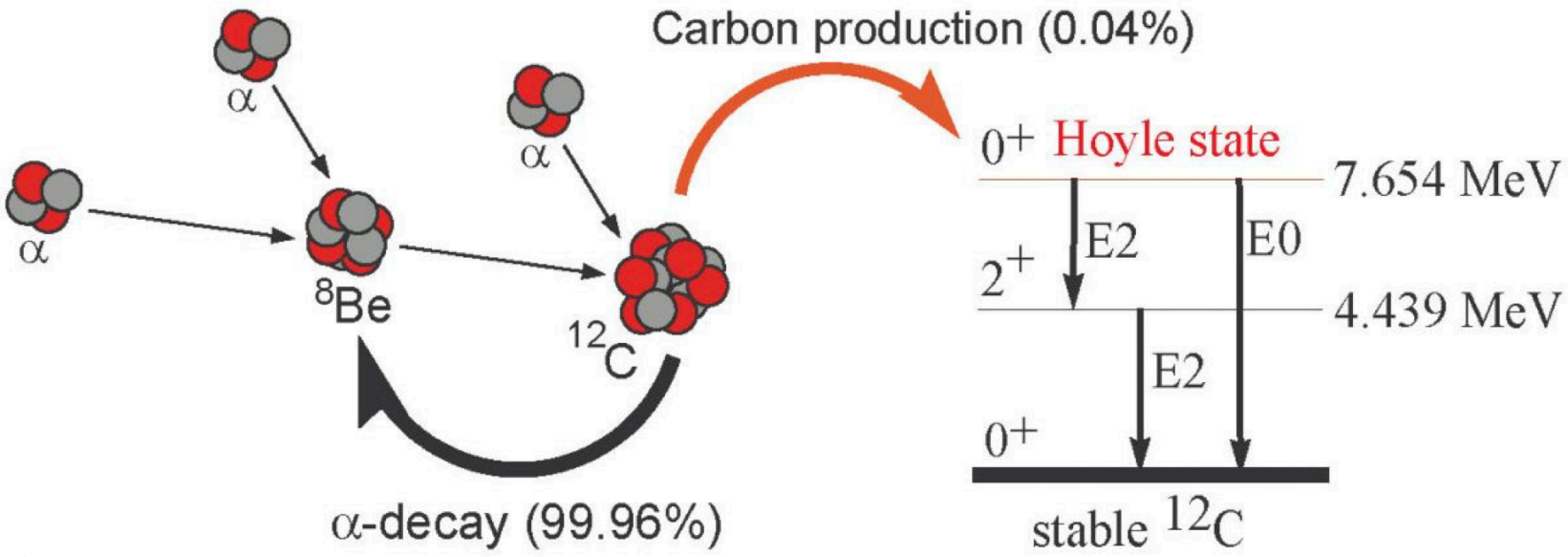
- Ikeda diagram for α conjugate nuclei



- α cluster structure in ^{12}C

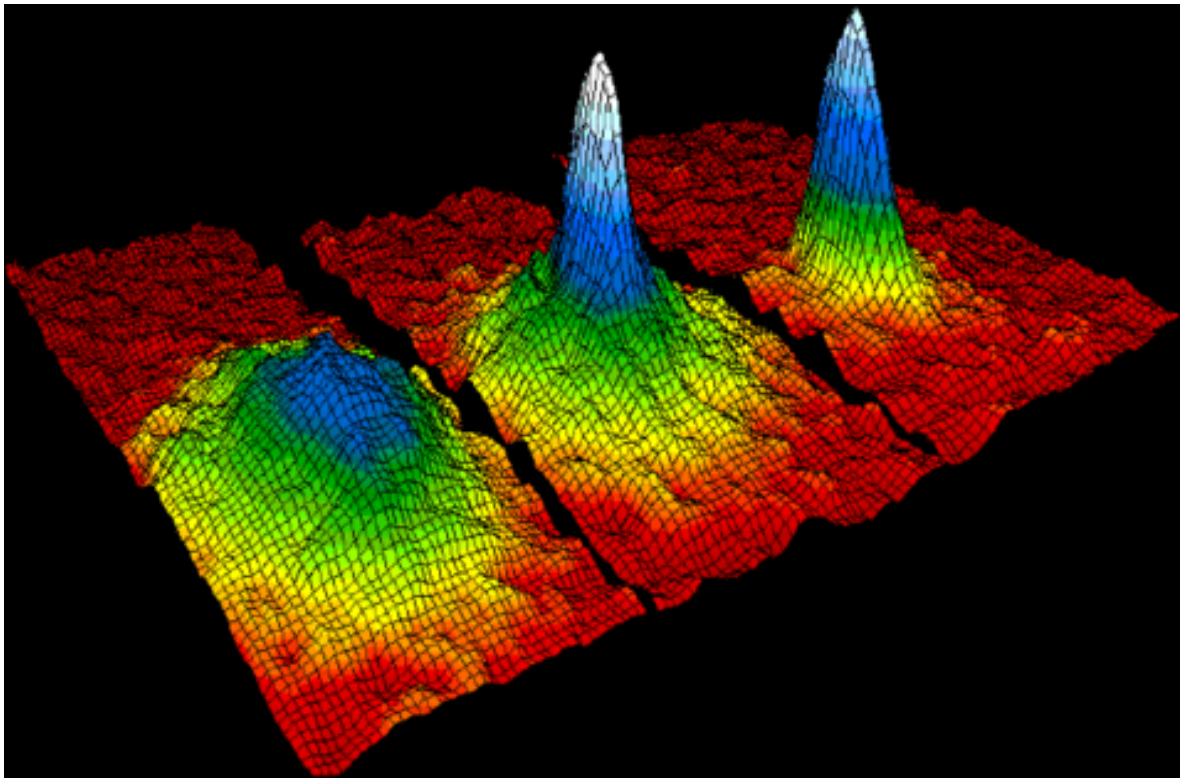
Hoyle state in ^{12}C

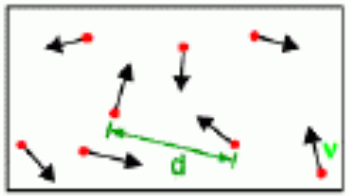
The triple alpha process



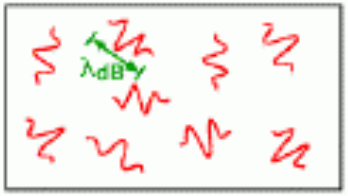
- Hoyle state (E=7.65 MeV) hypothesized by Fred Hoyle in 1950s to explain the stellar abundance of carbon, and later confirmed by many experiments
- Several literature suggests that the Hoyle state is composed of dilute gas state of 3α clusters

BEC state

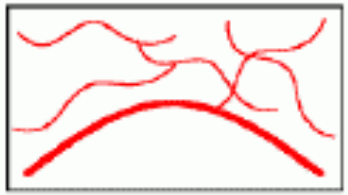




High Temperature T:
thermal velocity v
density d^{-3}
"Billiard balls"



Low Temperature T:
De Broglie wavelength
$\lambda_{dB}=h/mv \propto T^{-1/2}$
"Wave packets"



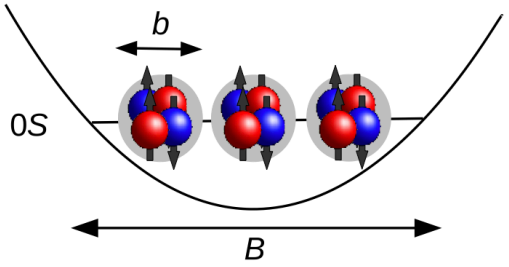
$T=T_{crit}$:
Bose-Einstein Condensation
$\lambda_{dB} \sim d$
"Matter wave overlap"

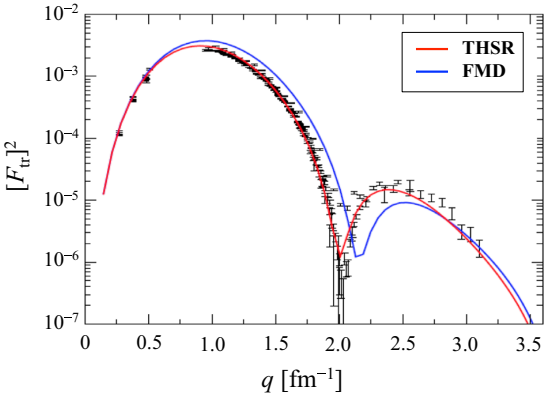
T=0:
Pure Bose condensate
"Giant matter wave"

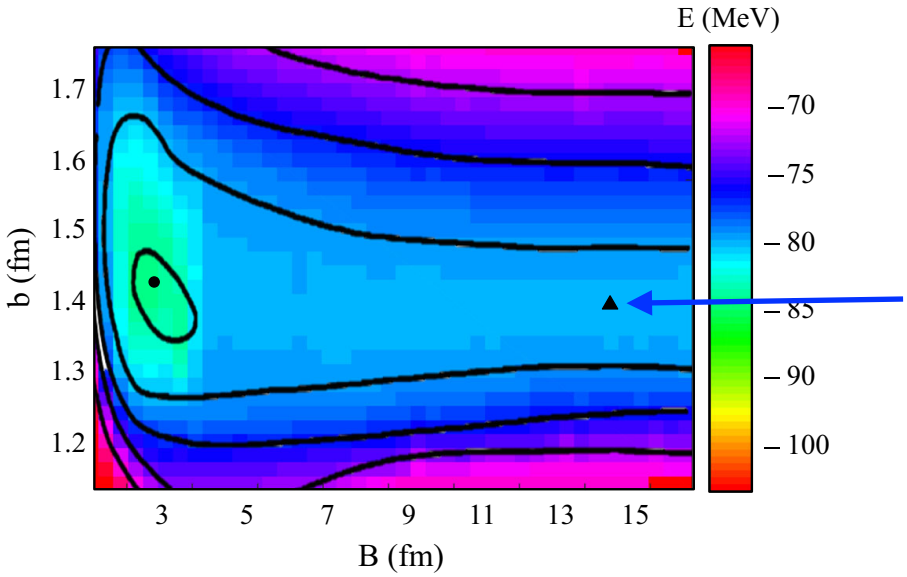
- A macroscopic quantum state formed by correlation of bosons at the same ground state
- Nobel winning discovery of BEC state in dilute atom gas at O(100)nK temperature
  - Cornell, Kettlerle, Weiman

Theoretical background

- THSR model [PRL87.192501 (2001)]
  - Tohsaki, Horiuchi, Schuck, Ropke
  - Suggests that alpha cluster may retain the boson identity if clusters are far separated from each other
  - Possibly happens for 8Be, 12C and 16O



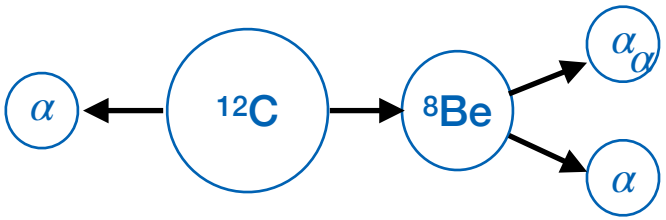




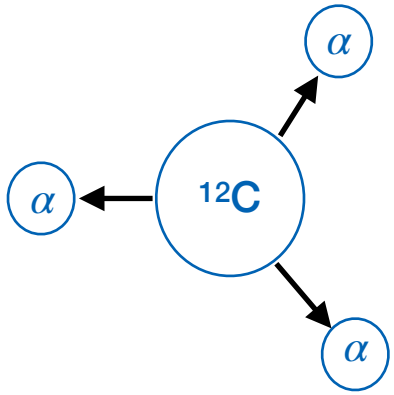
- Saddle point
- Hoyle state candidate b ~ 1.4 fm, B ~ 14 fm
- Large volume makes 12C dilute alpha cluster gas system

Branching ratio

$$^{12}C_{0_2^+} \rightarrow \boxed{^{8}Be_{0_1^+}} + \alpha$$
$$\rightarrow {}^{8}Be_{2_1^+} + \alpha$$
$$\rightarrow \alpha + \alpha + \alpha$$

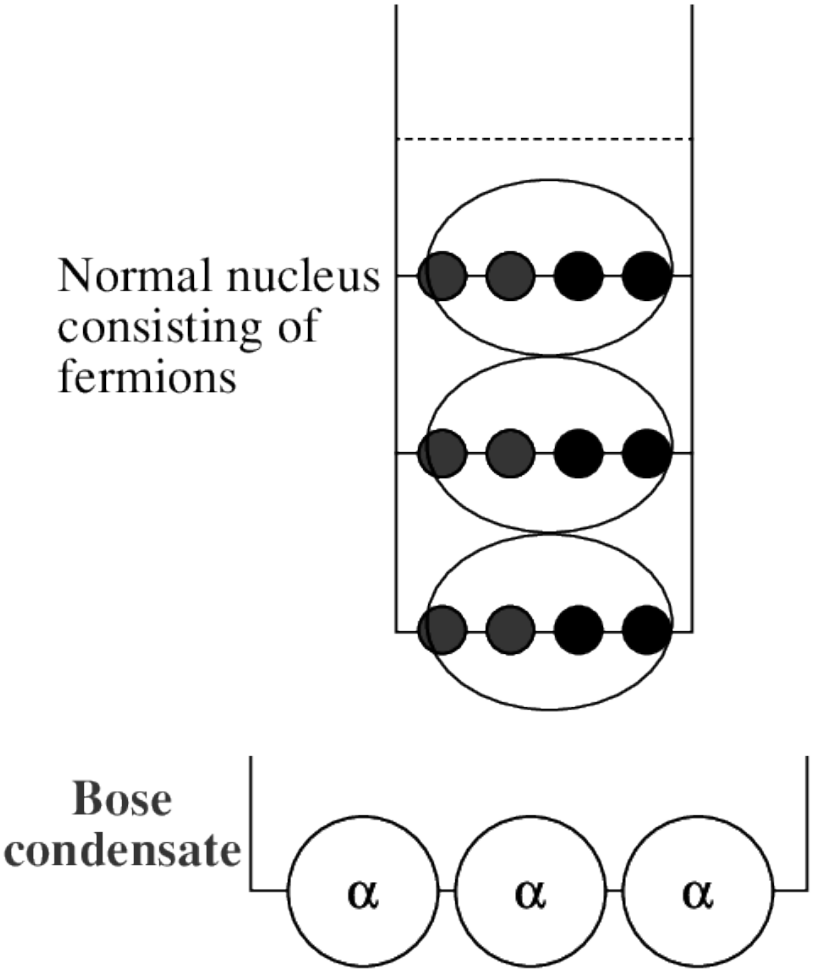


$$^{12}C_{0_2^+} \rightarrow \alpha + \alpha + \alpha$$



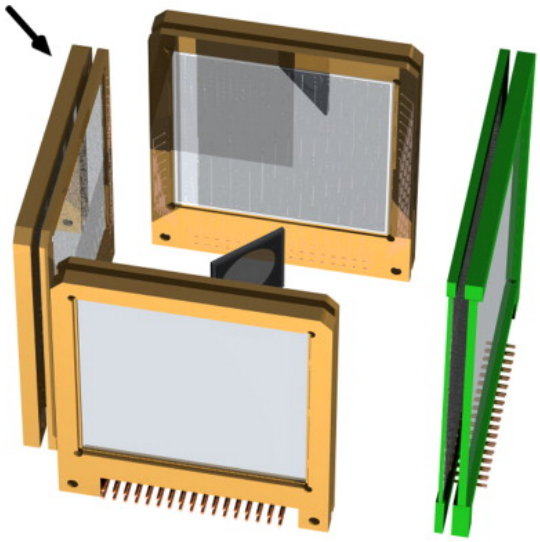
- Kokalova, Itagaki, von Oertzen, Wheldon in PRL 96,192502 (2006)
- Relative BR can be a signature of the alpha condensation
- If they are in the BEC, so all alpha share the 0s state, the BR is determined only by the phase space and Coulomb barrier
- BR ($^{12}C \rightarrow 3\alpha$) < 10^{-4} —> Very challenging!

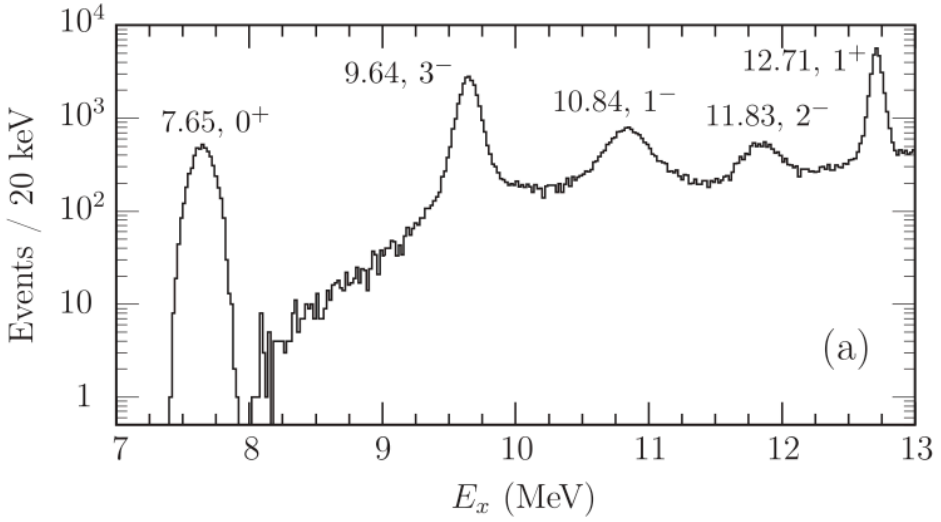
Brief history of BEC hunting

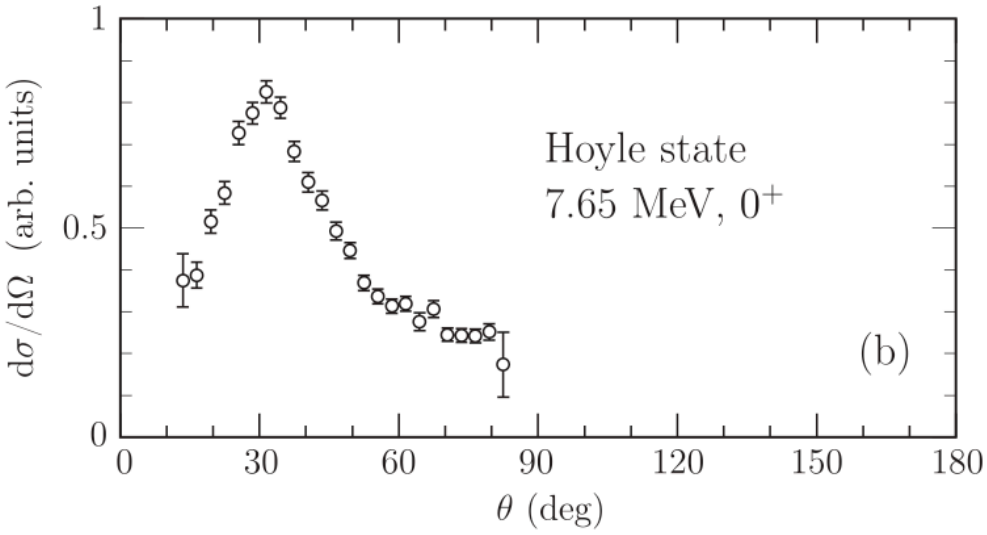


Previous result 1 - *PRL 108, 202501 (2012)*

- O.S. Kirsebom et al (2012)
  - 11B(3He, d) at E = 8.5 MeV
  - Silicon Strip telescope
    - Position resolution : 2 - 3 mm
  - Observed 3α + deuteron
  - Result: BR (3α) < 10^{-3}

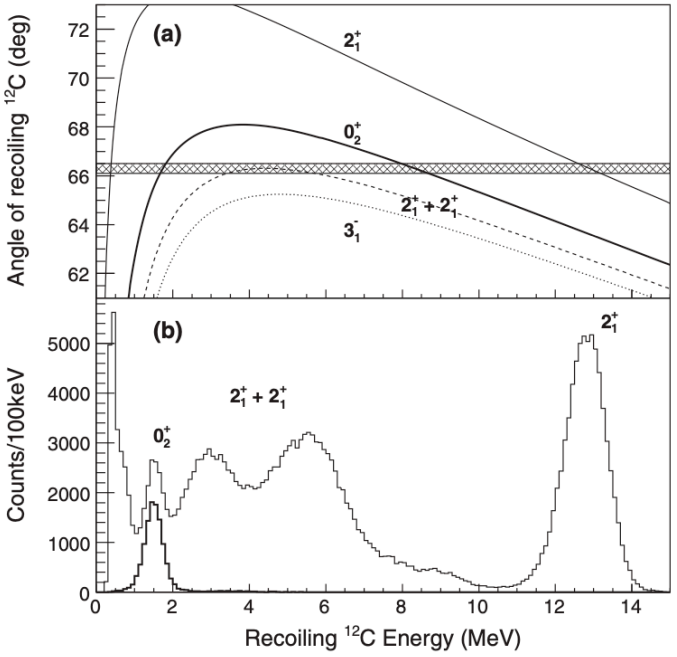


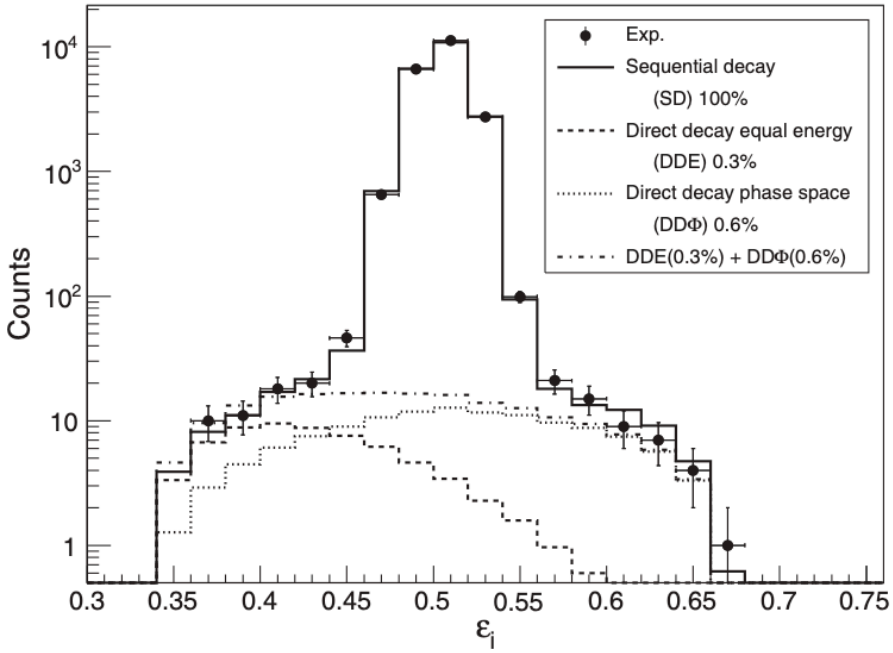


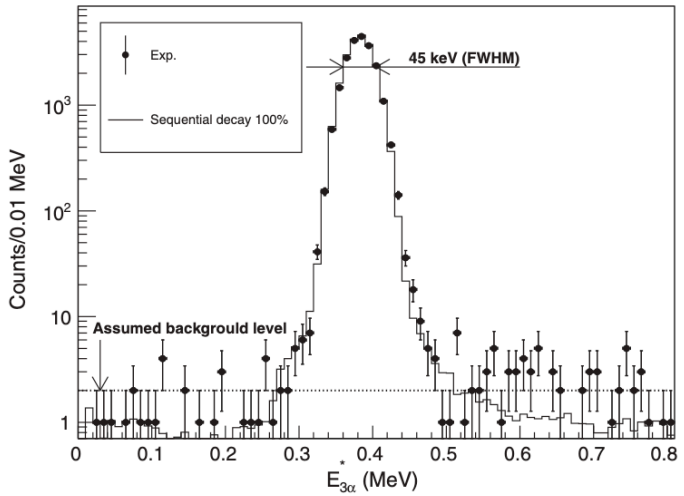


Previous result 2 - *PRL 113, 102501 (2014)*

- Tohoku group (Itoh, et al) in 2014
  - 12C(12C, 3α)12C
  - CYRIC beam: $12C^{4+}$ at E = 110 MeV
  - Double-sided silicon detercor
    - resolution ~ 35 keV
  - BR (3α) was measured to be ~ 10^{-3}

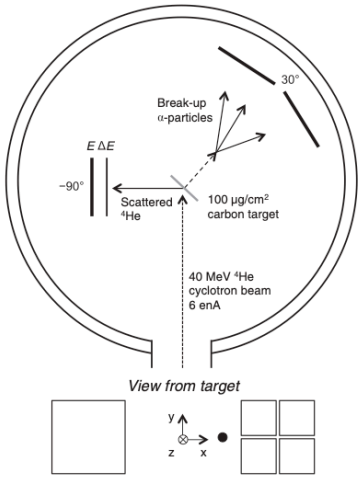


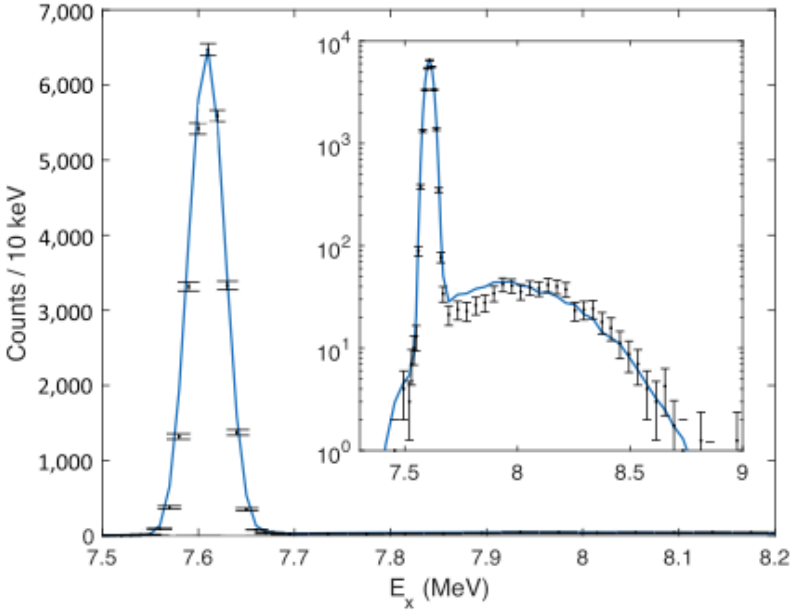


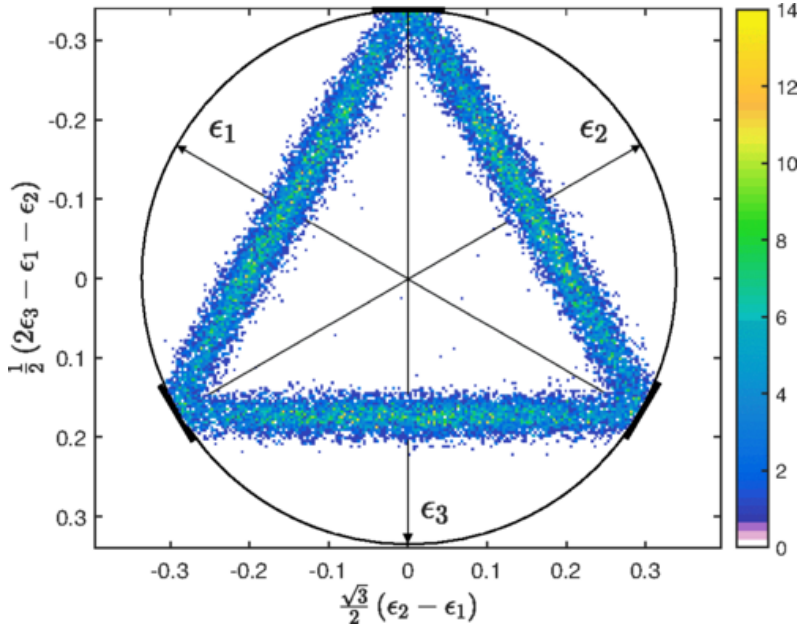


Previous result 3 - *PRL 119, 132502 (2017)*

- Birmingham group (Smith, et al) in 2017
  - 12C(4He, α)3α
  - 40 MeV $^4He^{2+}$ beam at Birmingham cyclotron
  - DSSD 5x5cm^2 , resolution ~ 35 keV
  - Counted 24000 Hoyle state events
  - BR (3α) < 4.7*10^{-4}

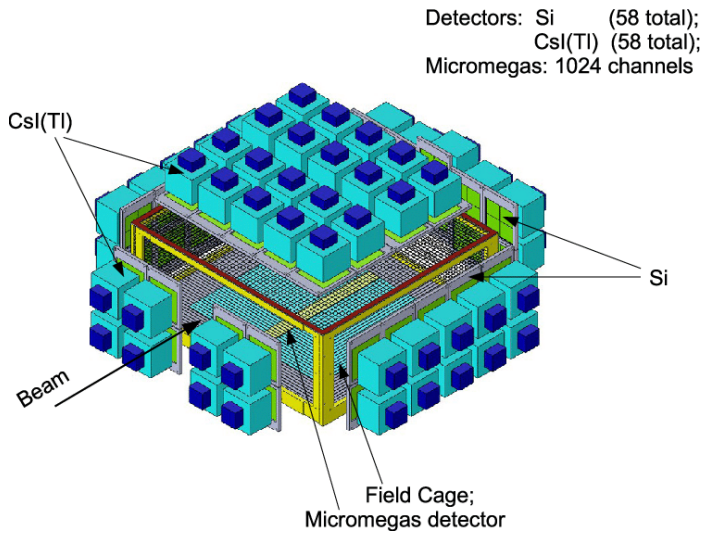


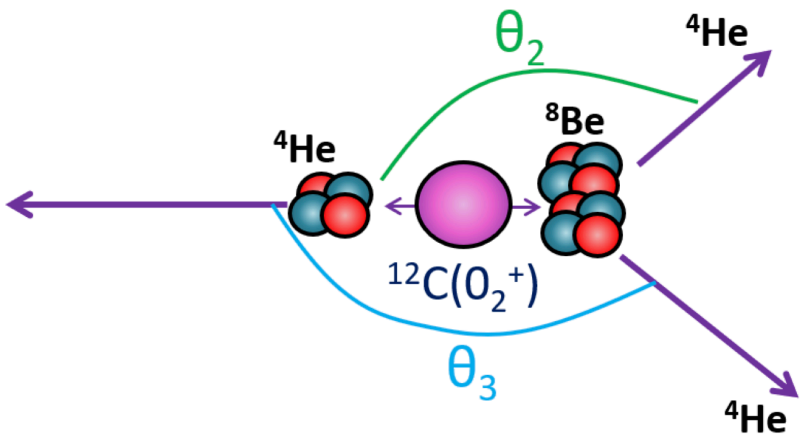


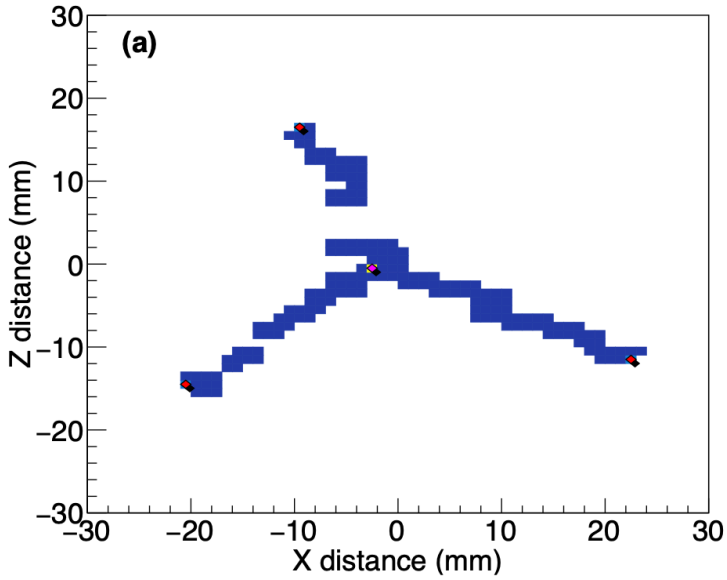


Previous result 4 - *PRC 102, 041303 (2020)*

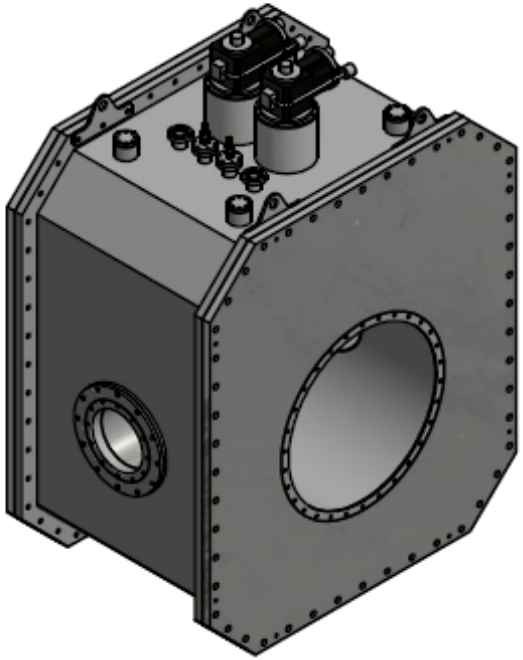
- TexAT group (Bishop, et al)
  - Beta-delayed charged-particle spectroscopy of ^{12}N
  - produced from 3He(^{10}B, ^{12}N)n
  - using 11 MeV/u ^{10}B beam
  - BR (3α) $< 4.3*10^{-4}$





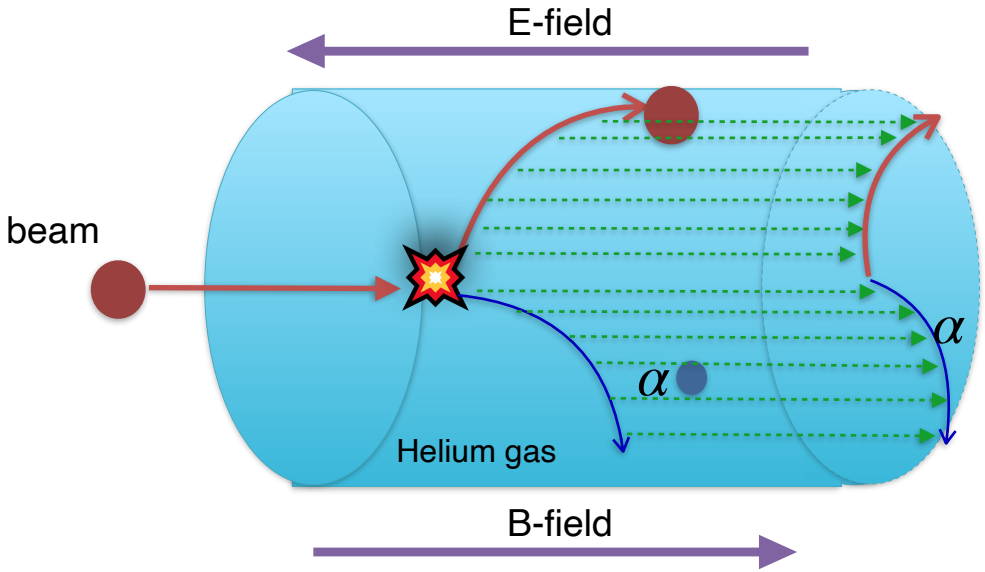


Low Energy LAMPS Experiment



Superconducting magnet

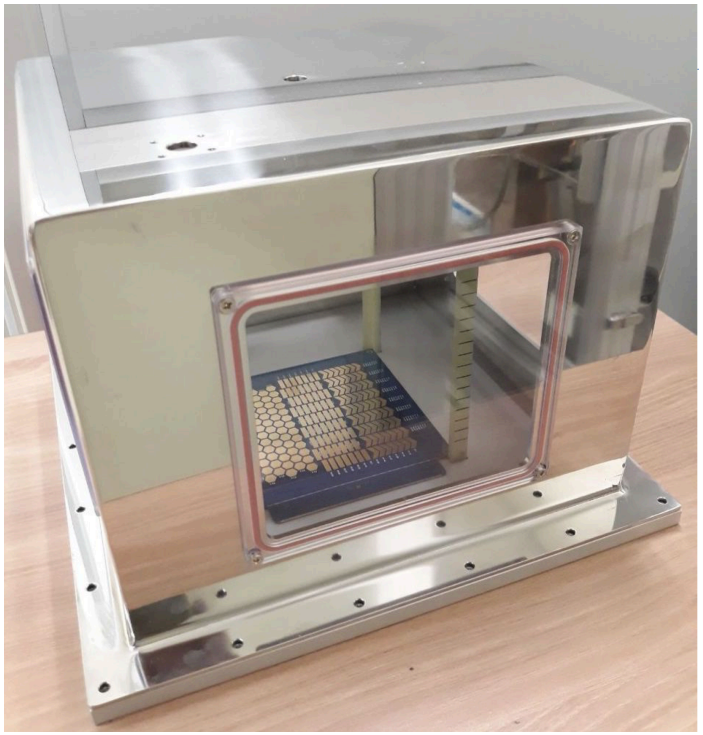
- B = 1.5 T
- diameter = 60 cm

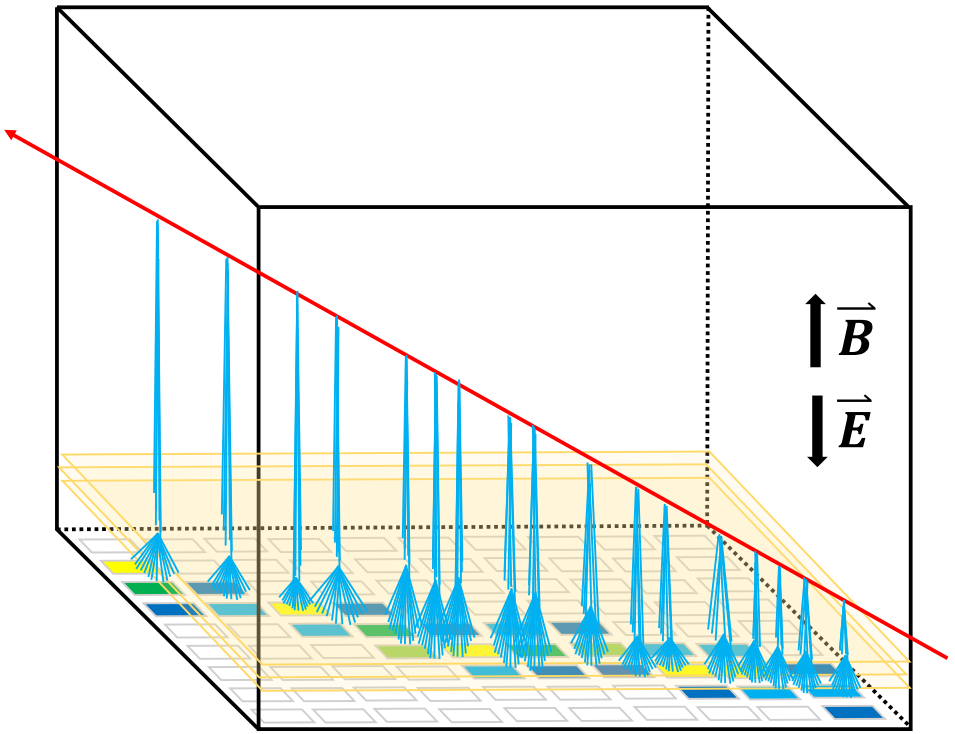


Active-Target TPC

- ^{4}He or Isobutane targets

AT-TPC prototype

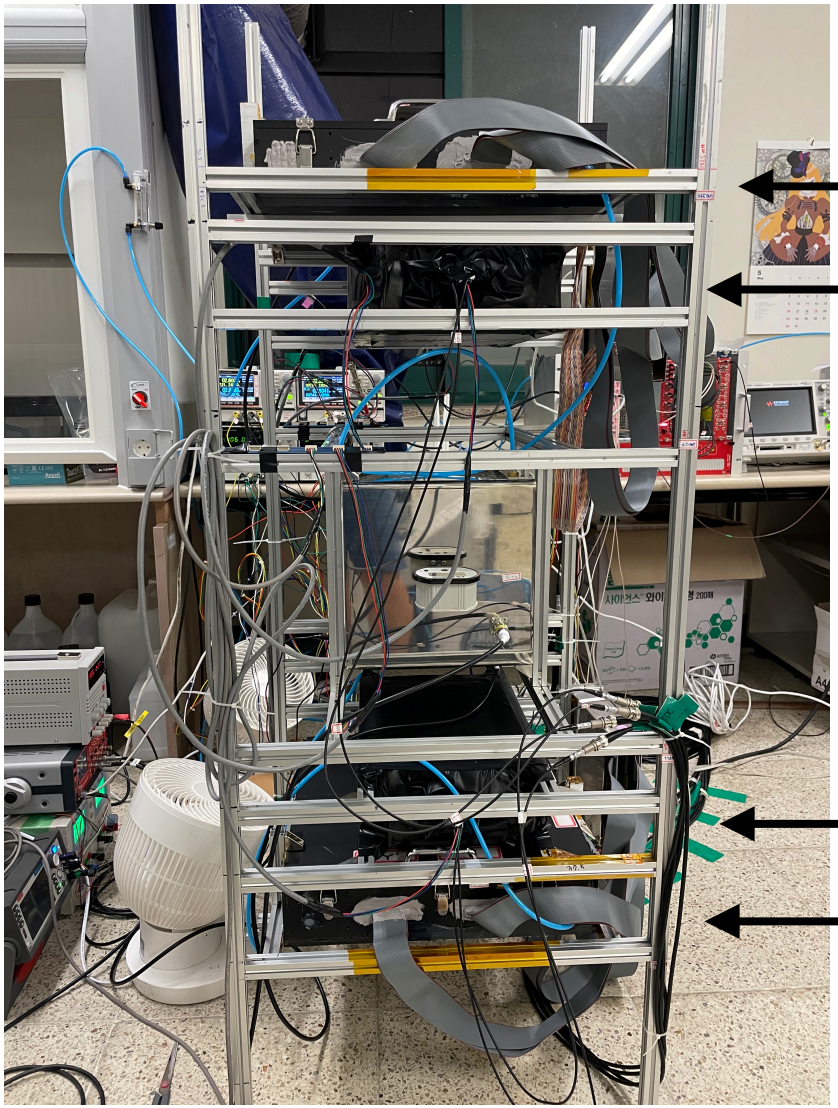




Prototype Ver.1

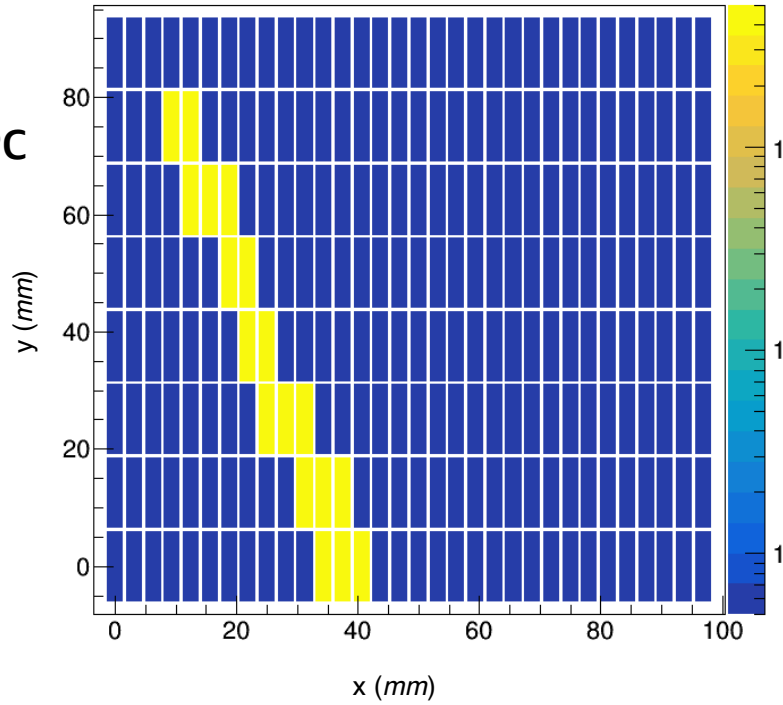
- 256ch readouts (8 * 32 rectangular)
- Beam test using 100 MeV proton beam (KOMAC) and cosmic muons

Detector test with cosmic muons

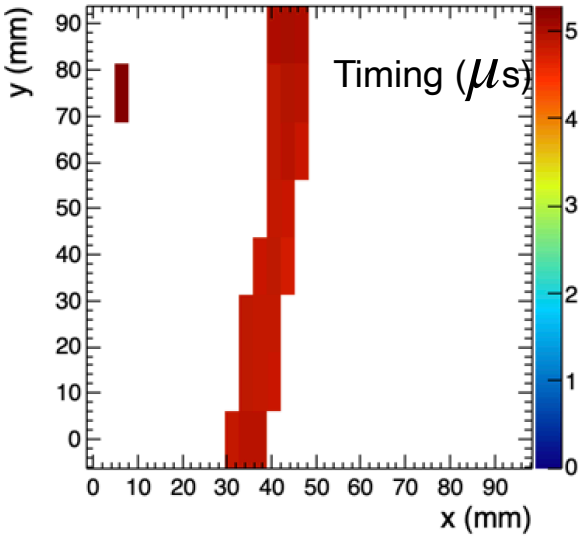


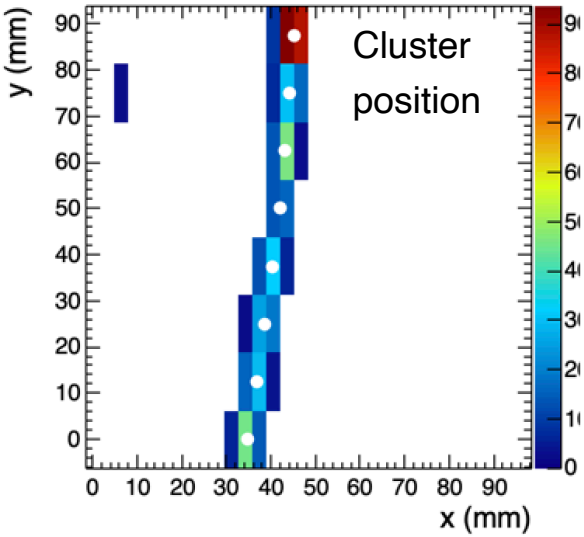
Goal is to measure the tracking resolution of AT-TPC

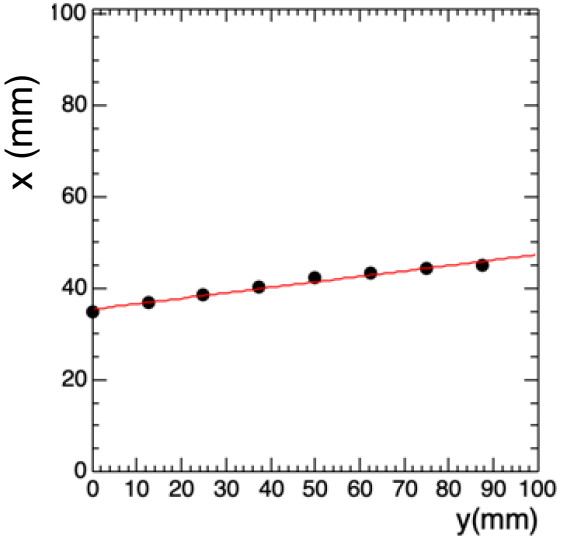
* BDC (Beam Drift Chamber) will provide the accurate muon position as reference

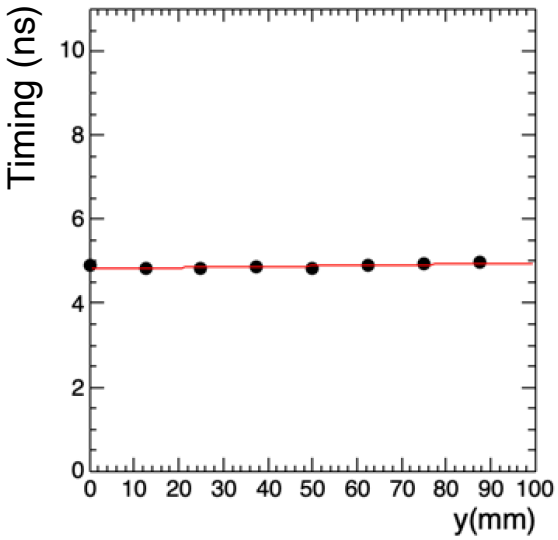


Detector test with cosmic muons



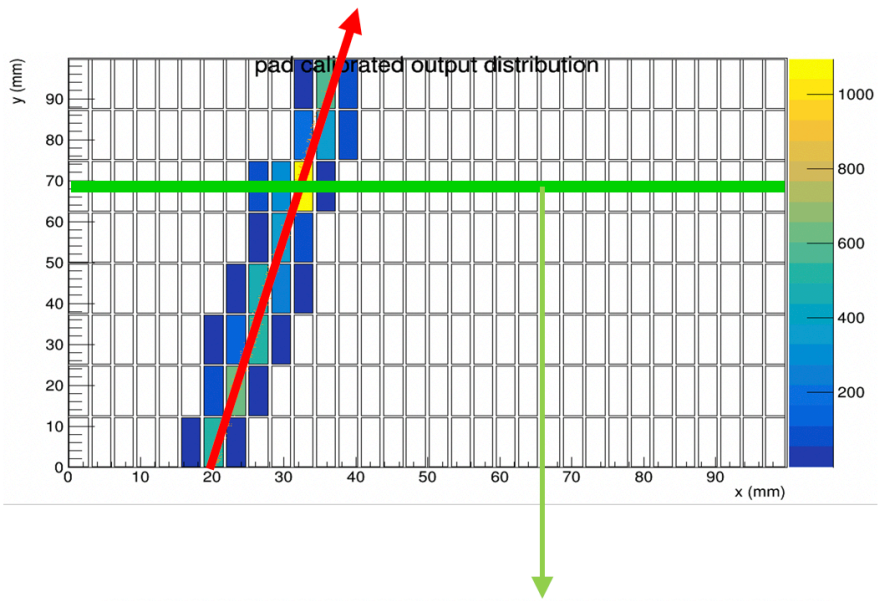




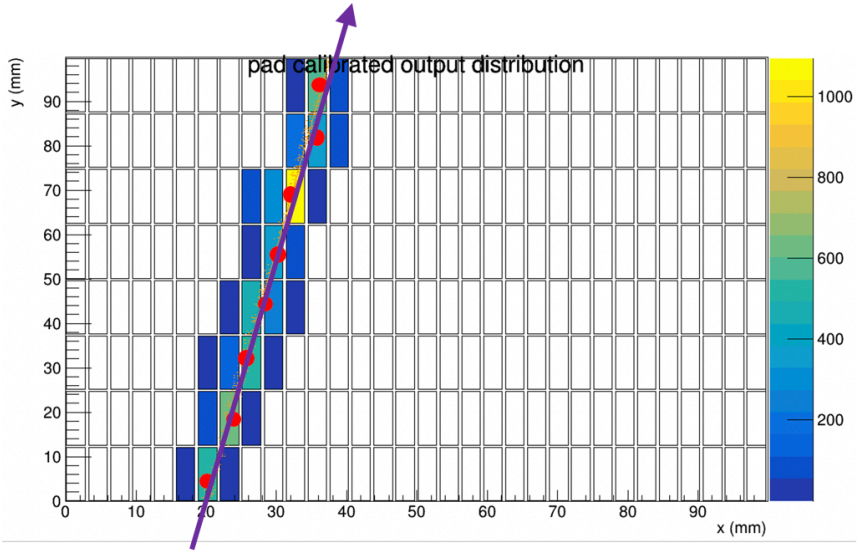


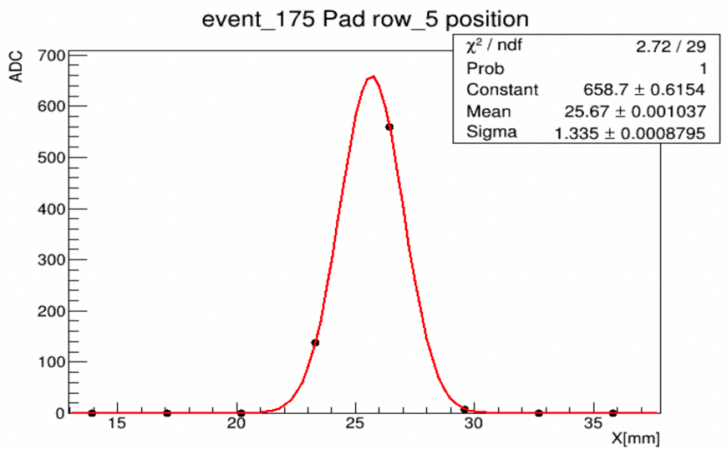
ML approach

Real track



Reconstruction track



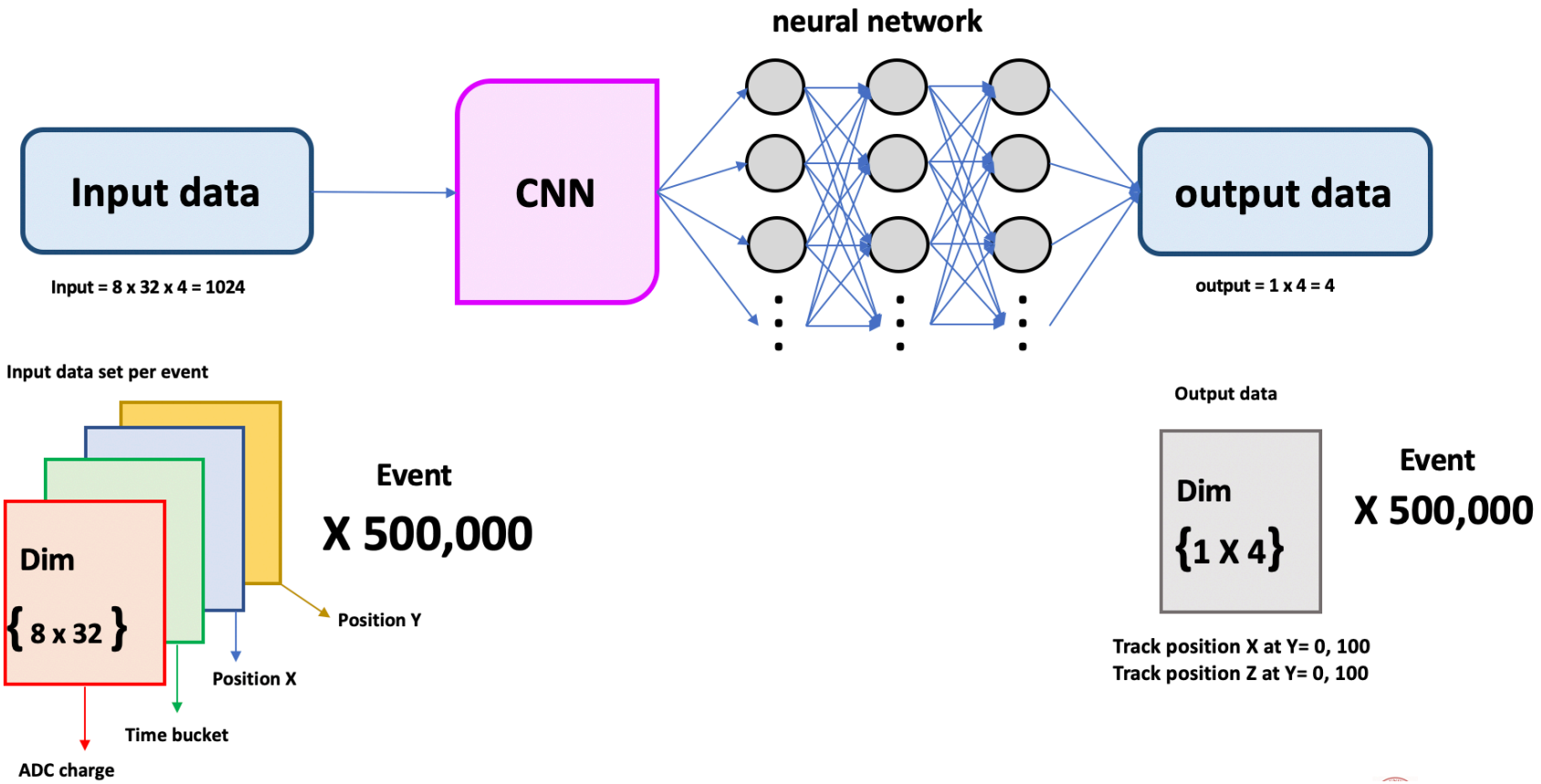


Traditional tracking

1. ADC clustering by row
2. Cluster point Fitting

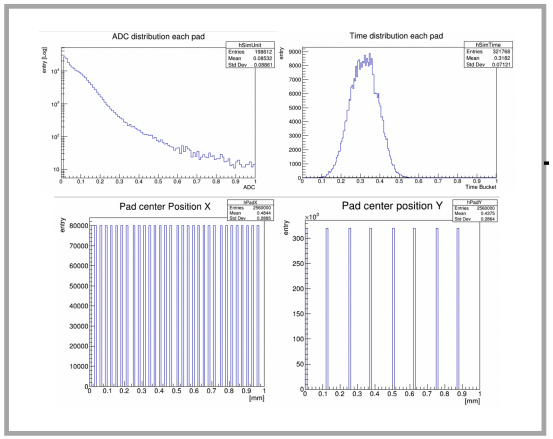
ML approach

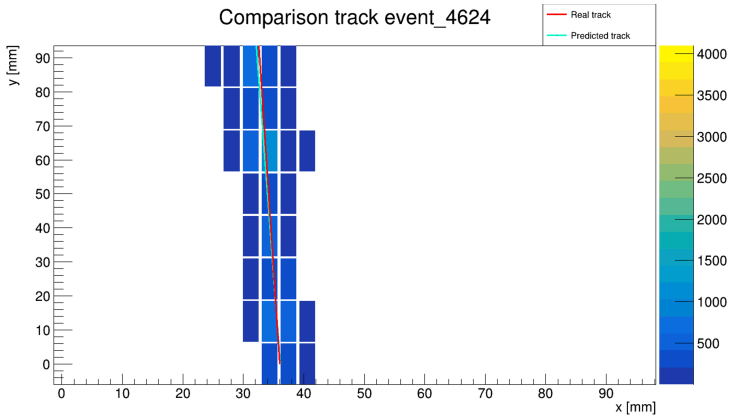
1) Train model

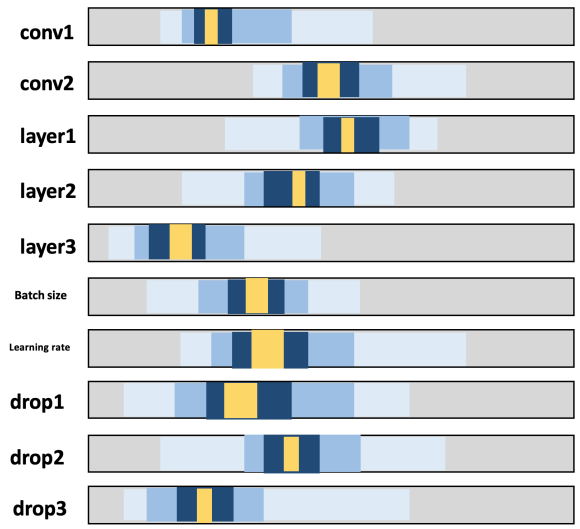


ML approach

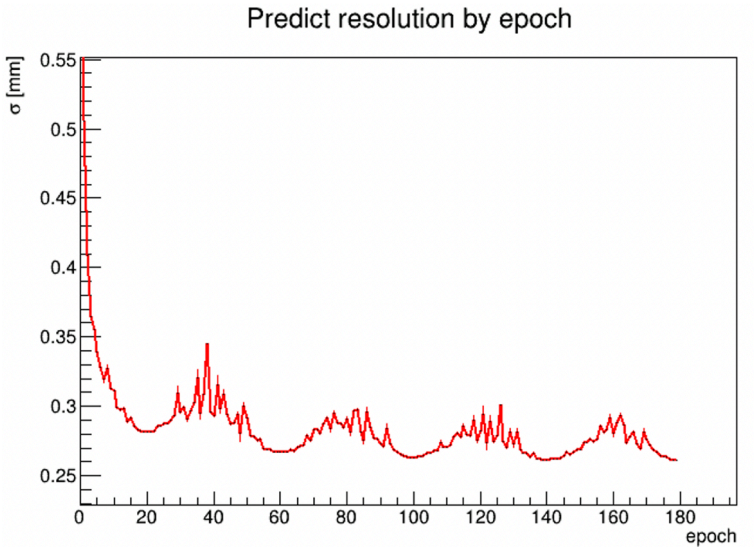
Input data set distribution







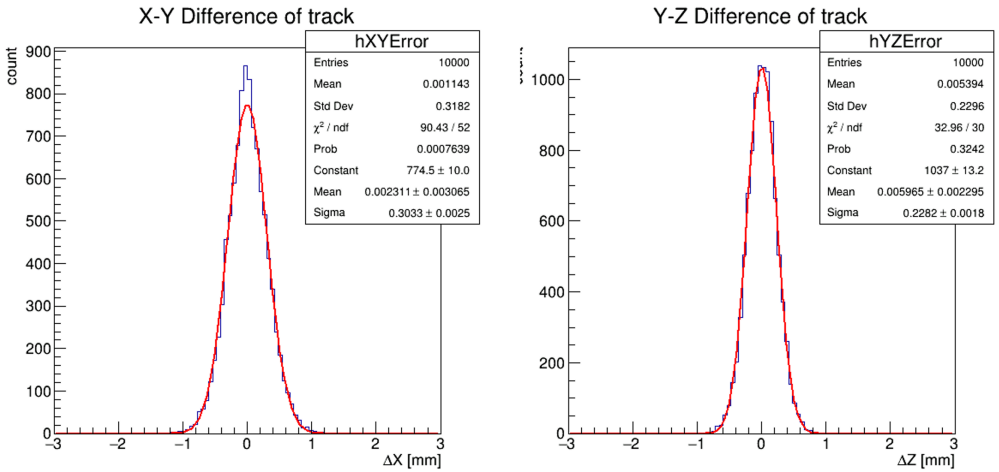
CNN 2 + RNN 3 model

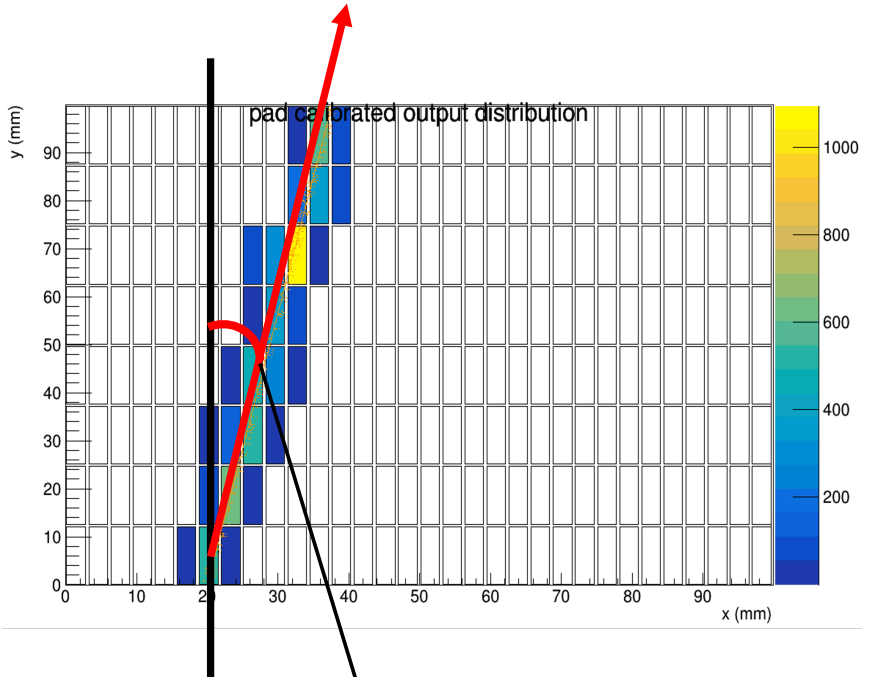


- Used 500k events Geant4 MC simulation for training
- Optimization was done for batch size, drop out ratio, number of CNN layers, etc.
- Still investigating to fully utilize CNN for track reconstruction

Result

- Resolution of intercepts in xy and yz plane





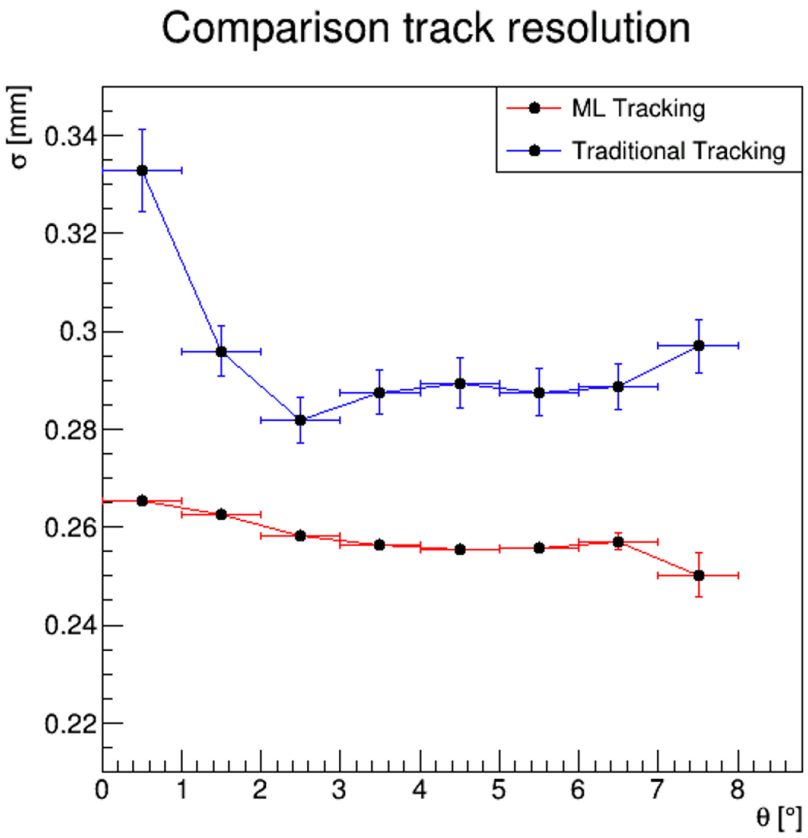
X-Y plane

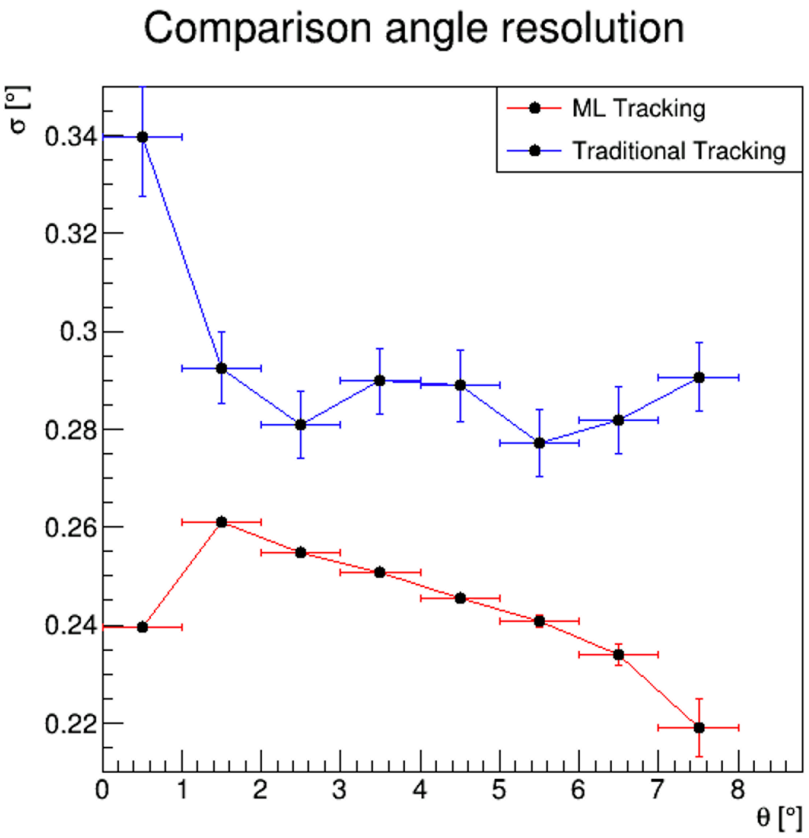
Resolution = 300 um

Y-Z plane

Resolution = 230 um

Comparison with the traditional method



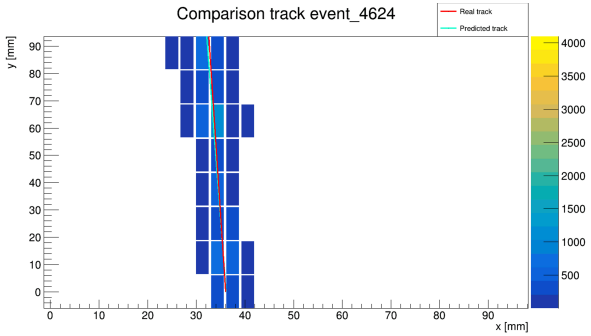


- The result is very promising. We were able to enhance the tracking resolution by 30% by undergraduate research program for 12 months!

Plan

To measure BEC in ^{12}C, we need …

- High event rate for low energy light nuclei beams
- High resolution for α tracking using ML approach
  - Angle, curvature, dE/dx

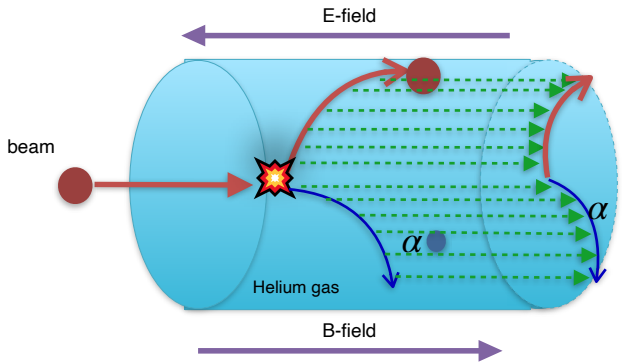


Near future (2021 – 2022)

- Finalize prototype performance study with 256 ch. by **2021.FALL**
- Development of 1024 ch. TPC by **2022.SUMMER**
- Development of circular TPC with 4k channels

Far future (2023 –)

- **2023.SPRING** – Construction of nominal detector (4 – 5 k channels)
- **202X.YYYY** – Experiment with RAON beams from



Active-Target TPC

- ^{4}He or Isobutane targets