Active target MAIKo and measurement of ^{10}C(α,α') at 75 MeV/u

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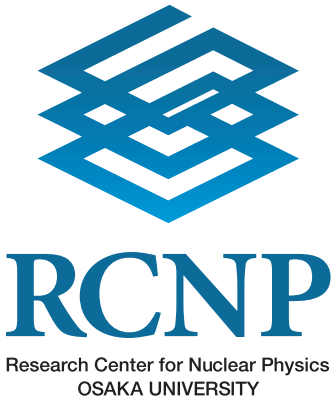

Collaboration

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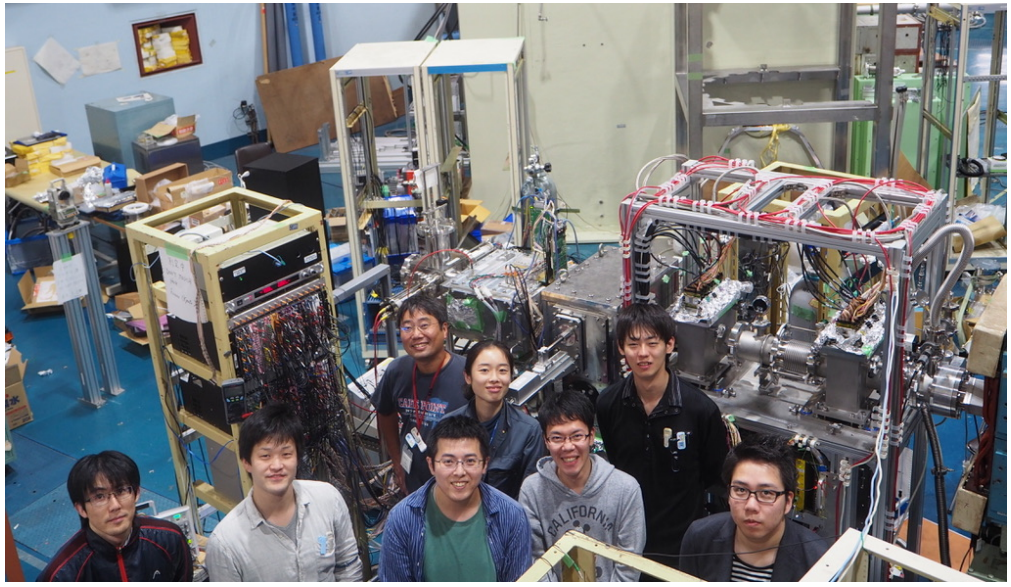
RCNP E463(Oct. 2017)



Contents

- Physics motivation
  - Clusters in unstable nuclei
- Active target MAIKo
- Test experiment with 50-MeV ^{4}He beam
  - Tracking algorithm
- RI beam experiment with 75-MeV/u ^{10}C beam
  - Preliminary results

- Physics motivation
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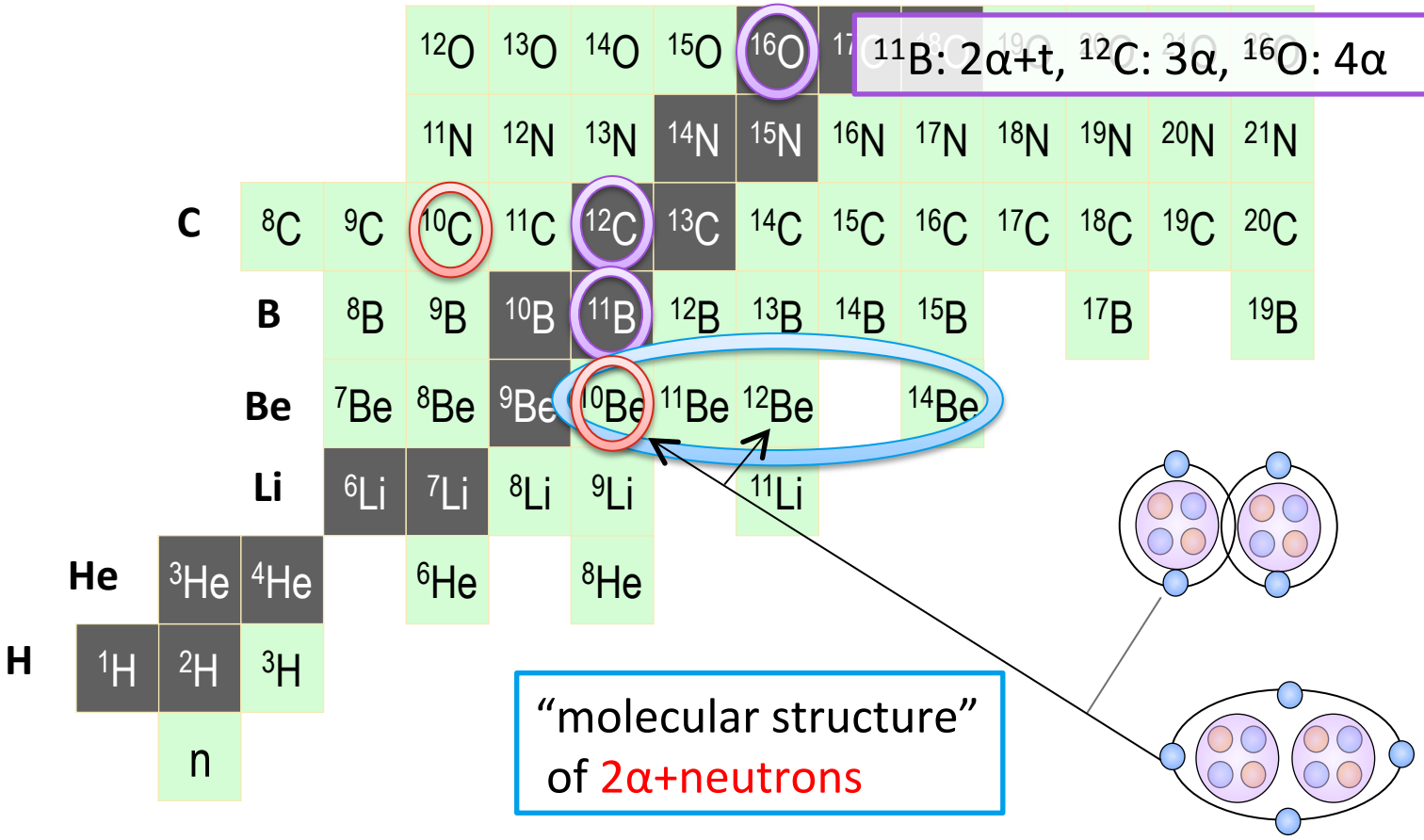
α clusters in unstable nuclei

α clustering is an important aspect of atomic nuclei.

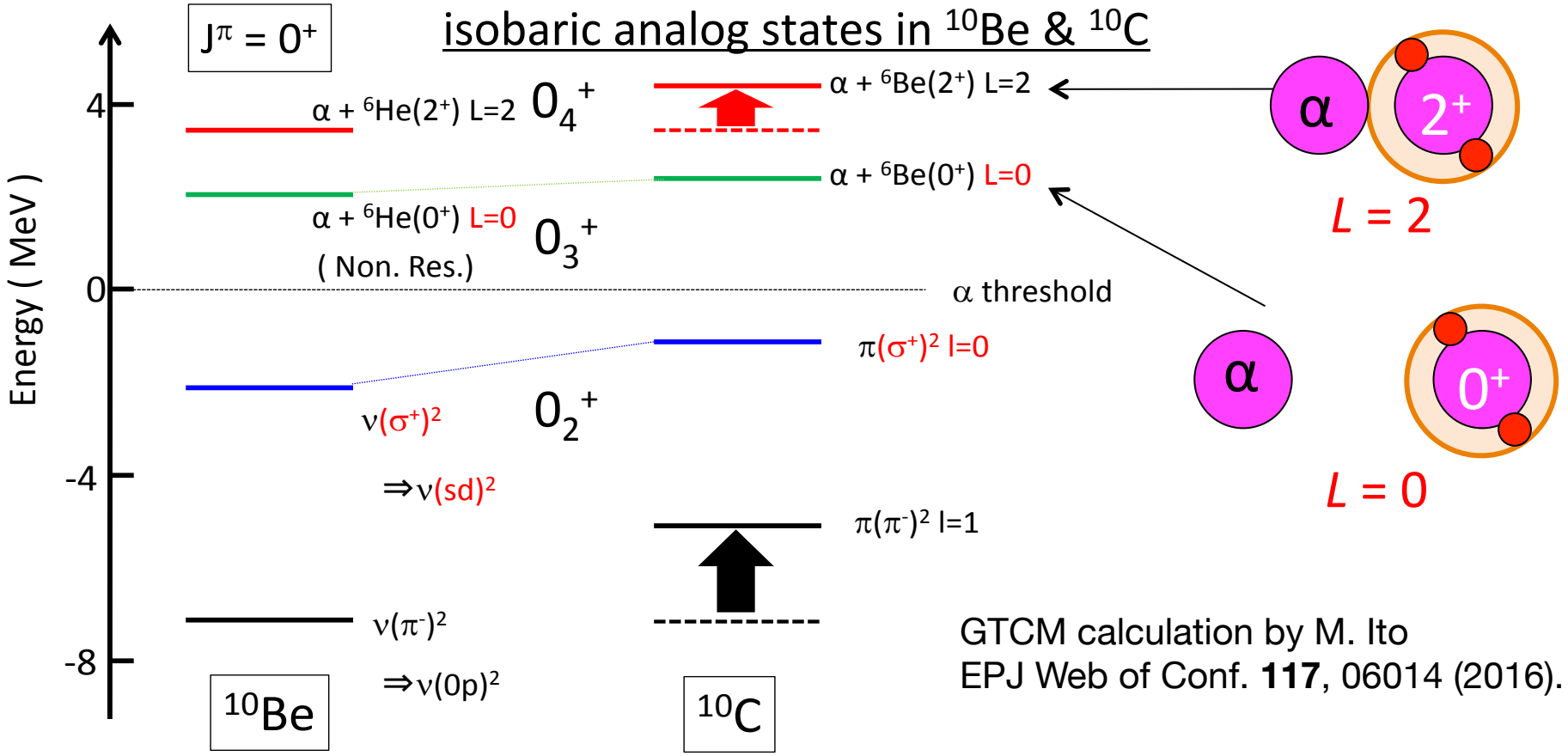


Can proton-rich nuclei also form α molecular structures?

We propose a study of the mirror symmetry of clustering in ^{10}C and ^{10}Be.

The mirror system of ^{10}C & ^{10}Be

The mirror system will give a new approach to α clusters.

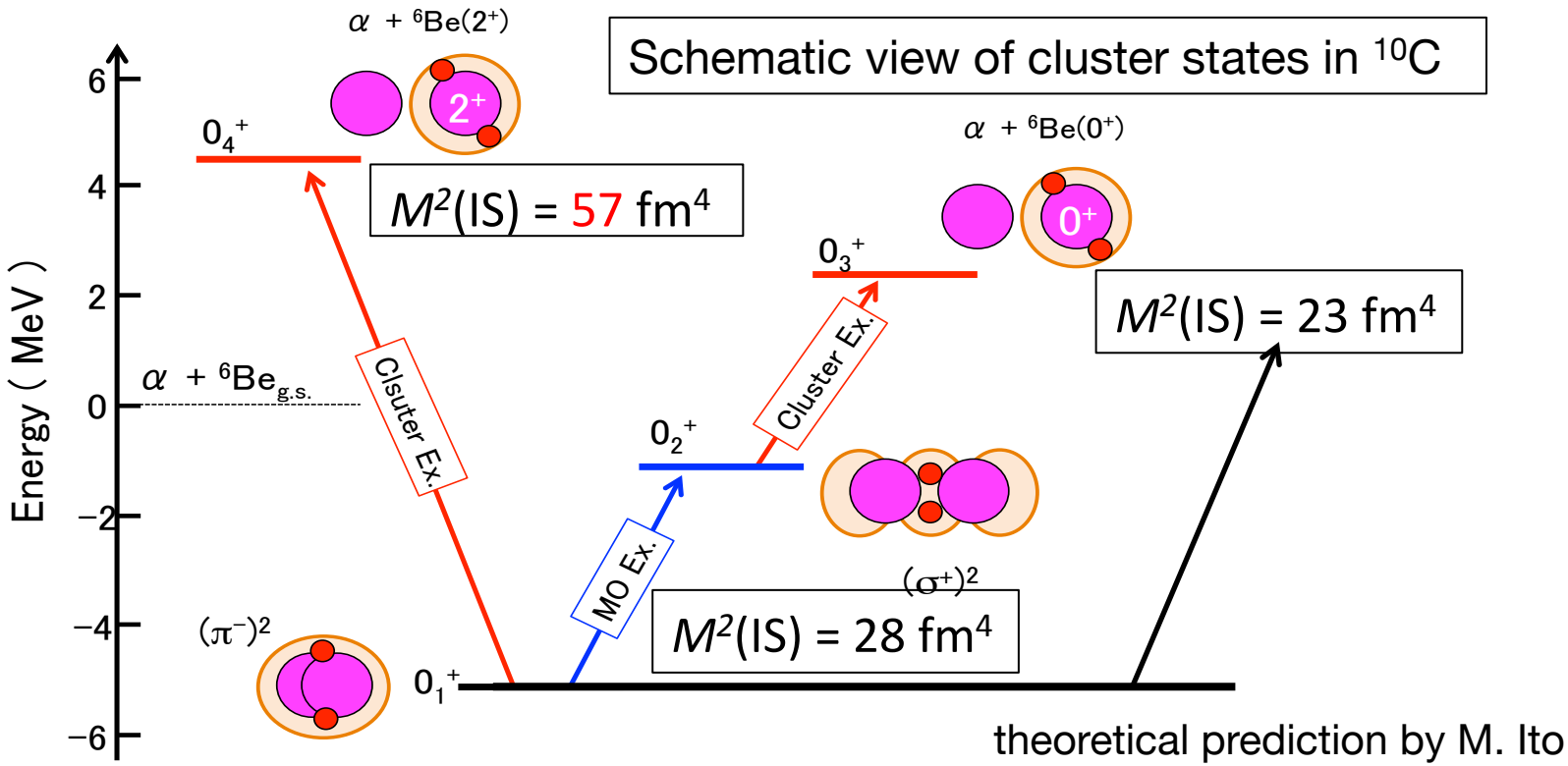


GTCM calculation by M. Ito
EPJ Web of Conf. **117**, 06014 (2016).

- Energy shift will be observed in 0_4^+ states (α+^{6}He/^{6}Be with *L=2*).
  → *Thomas-Ehrman shift (TES)* of "cluster structures"
- The T-E shift will unveil the inner structures of the clusters.

Monopole excitations in ^{10}C

Monopole strength is a key parameter to pin-down cluster structure.



theoretical prediction by M. Ito

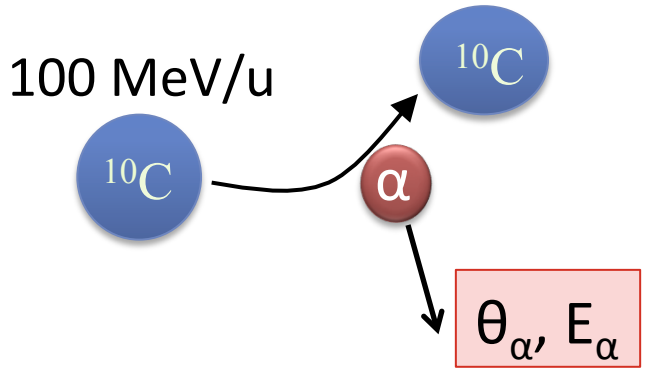
- M(IS) is enhanced for cluster excitations from the g.s.
- Characteristic pattern in M(IS) reflects the cluster structures.
- Measure M(IS) systematically by ^{10}C(α, α') scattering.

What to be measured

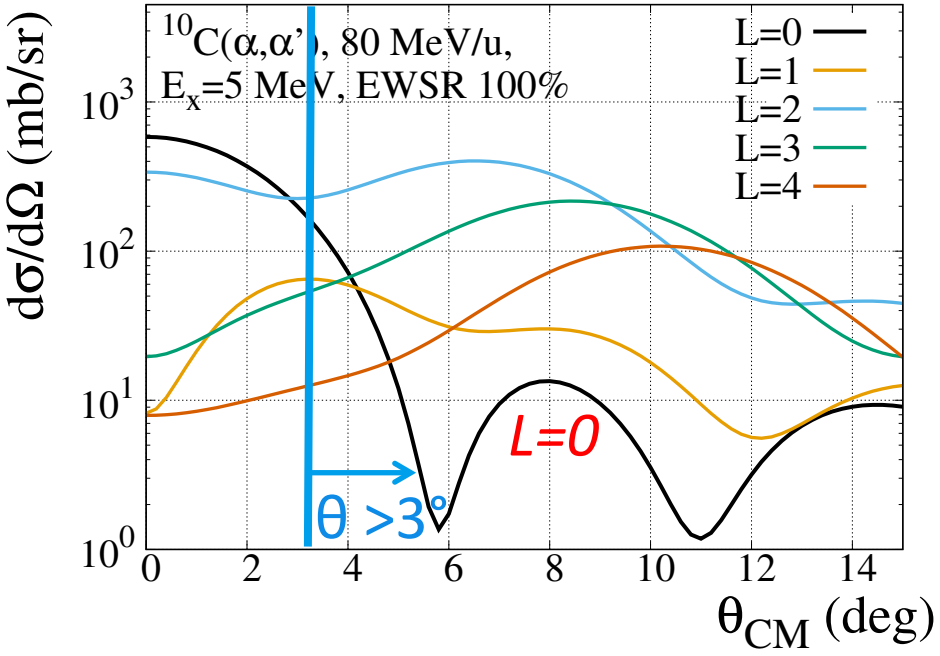
- Perform $^{10}C(\alpha, \alpha')$ scattering under the inverse kinematics condition.
  - ✓ ROI: 5 MeV < E_x < 15 MeV
- Incident energy: ~100 MeV/u
  - ✓ smaller physical background (c.f. Harakeh's textbook)
- Obtain E_x spectrum
- MDA analysis to determine J^π
- Measure the monopole strengths

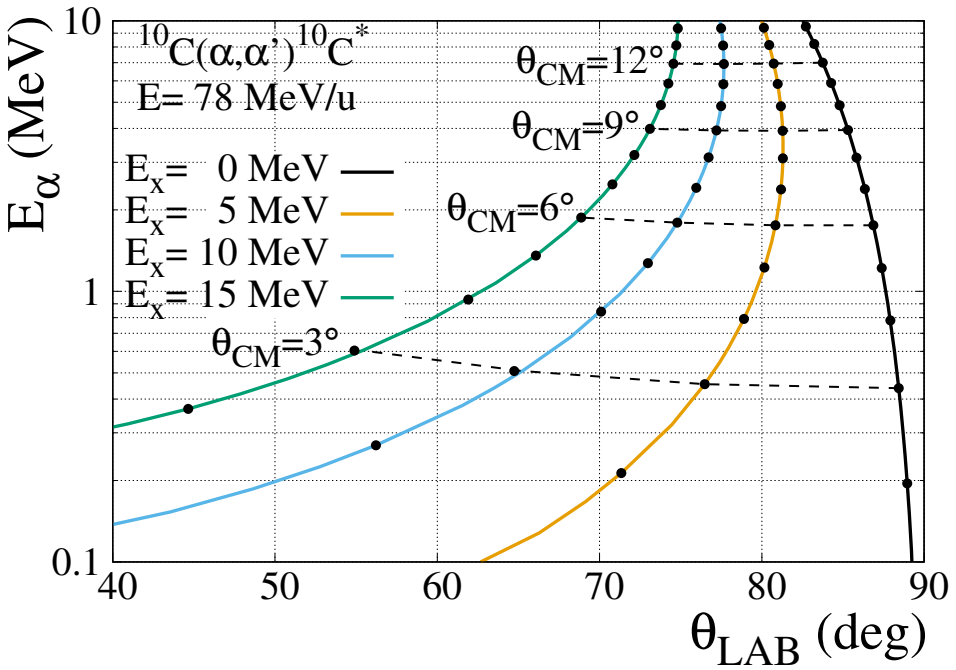
→ Compare with ^{10}Be (TES)

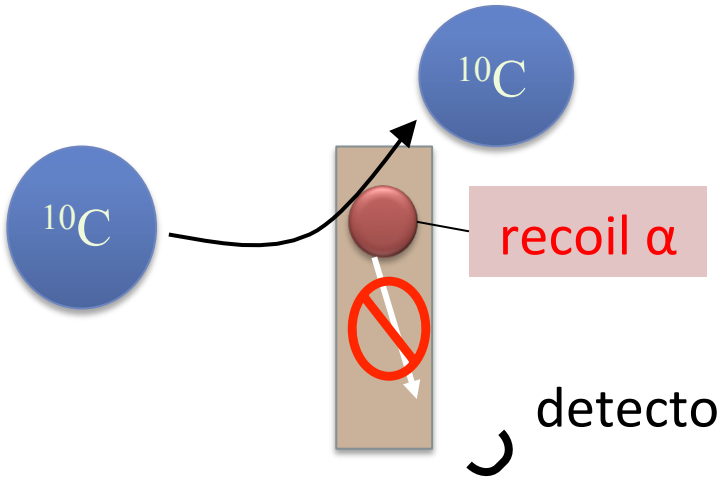
Missing mass spectroscopy is suitable to measure above thresholds, but …



Challenges in inverse kinematics







measurement @θ_{CM} > 3°

- ✓ E_α > 0.5 MeV
- ✓ 50° < θ_{LAB} < 90°

Need to detect very low-energy α with high resolution!!

- Physics motivation
  - Clusters in unstable nuclei
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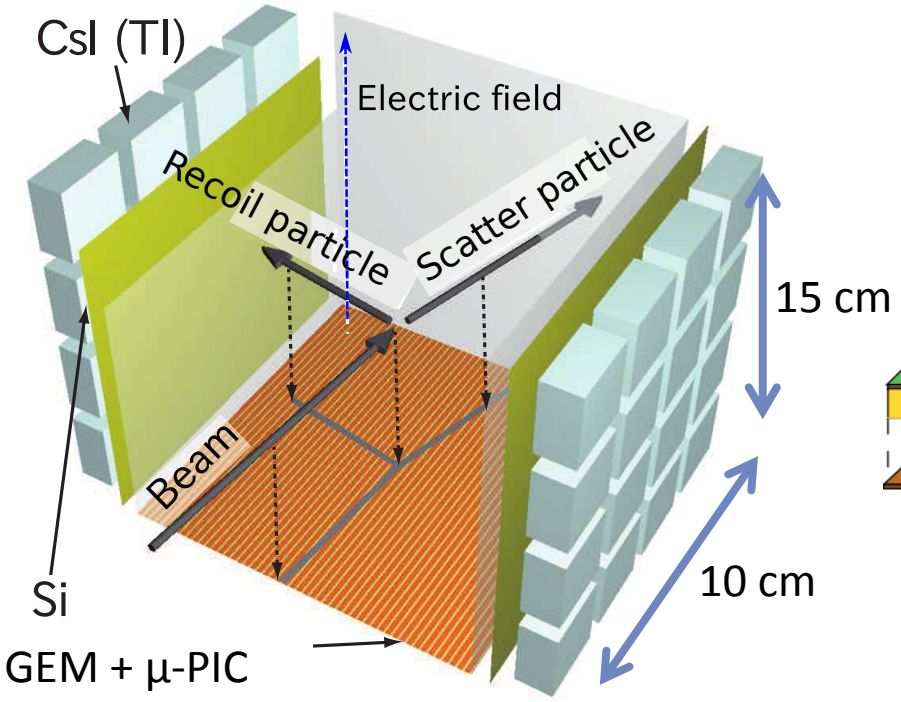
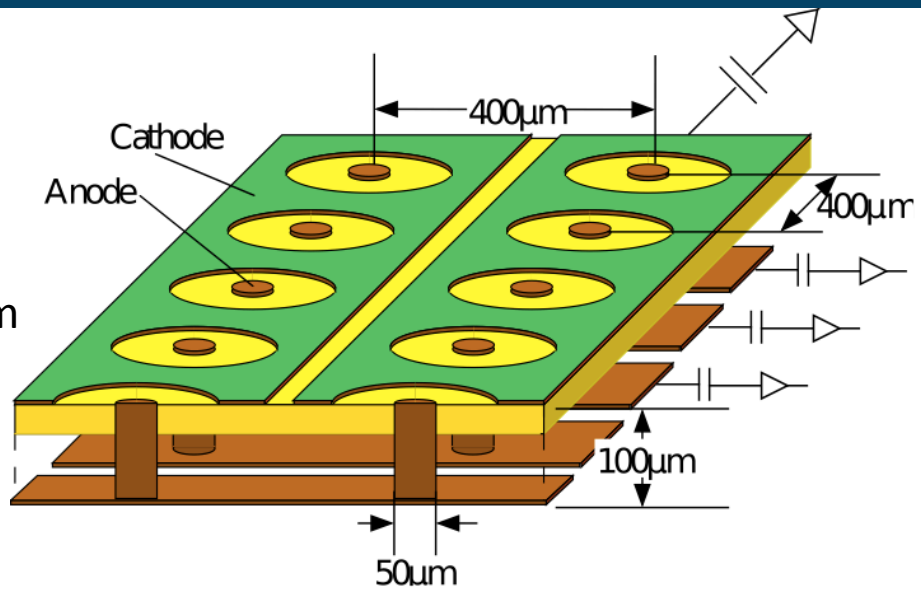
Mu-pic based Active target for Inverse Kinematics . (MAIKo)

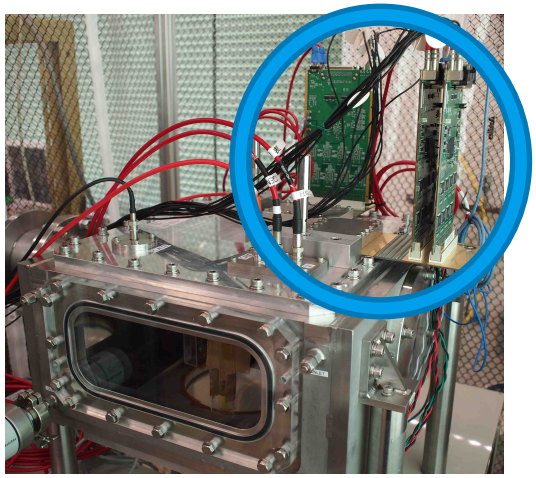




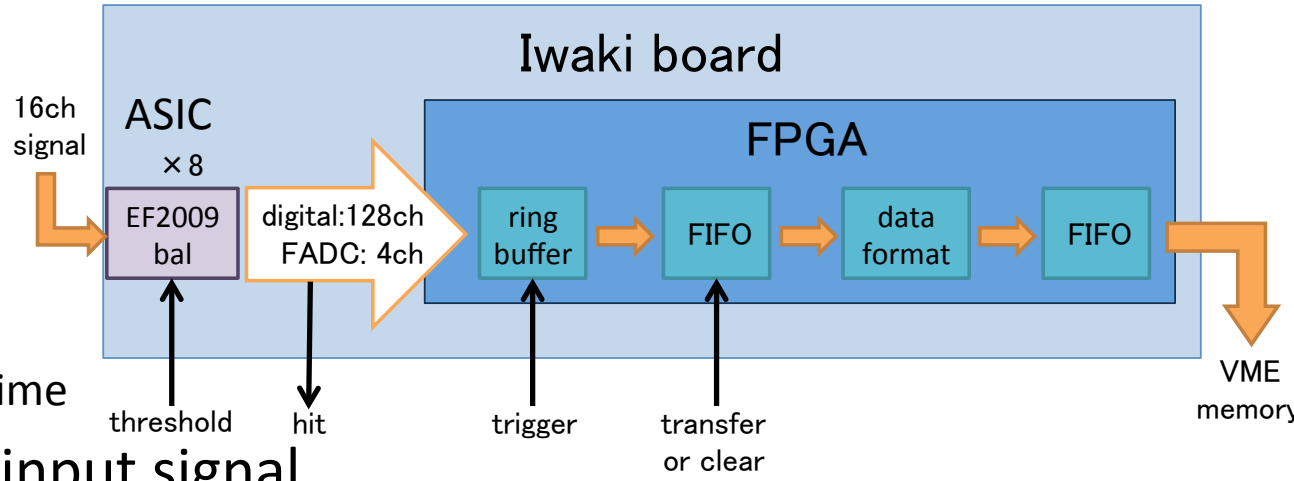
Micro-Pixel Chamber (µ-PIC)
A. Ochi, *et. al.* NIM A **478**, 196 (2002).

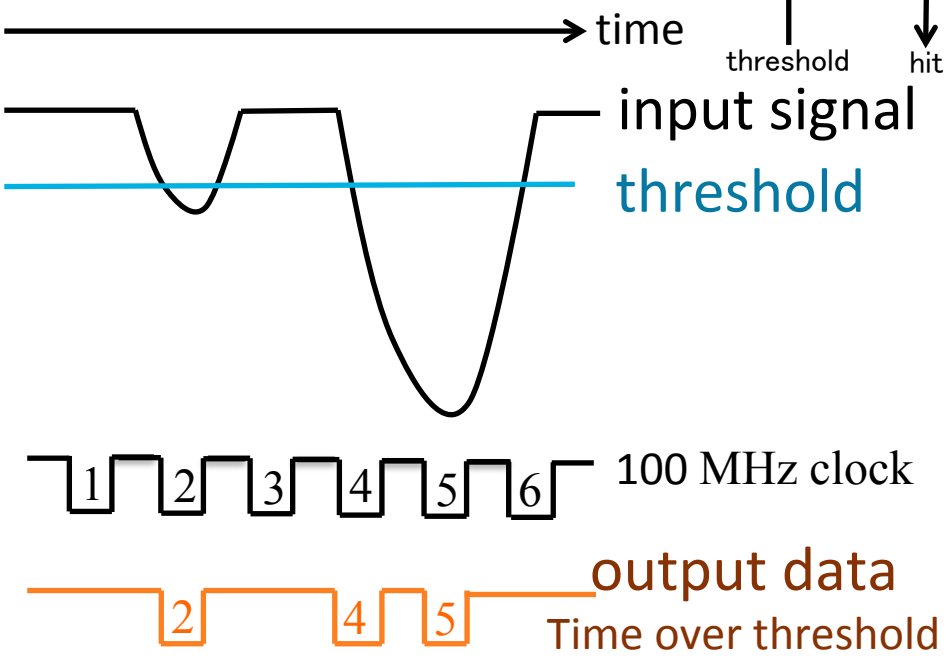
- Detection gas (He) = target gas → Detectable low-energy particles!
- Gas: He + CO_2(7%) @0.5 – 2.0 atm
- Introduce µ-PIC + GEM.
  - µ-PIC (gain~1000): 2-dimensional strip readout (400 µm pitch). 256A+256C = 512 ch.
  - GEM (gain~30): 140 µm pitch, d=70 µm, t=100 µm (thick GEM)
- TPC track → θ_α , range in the gas / Si+CsI → E_α

Readout system



Anode (256 ch) + Cathode (256 ch)

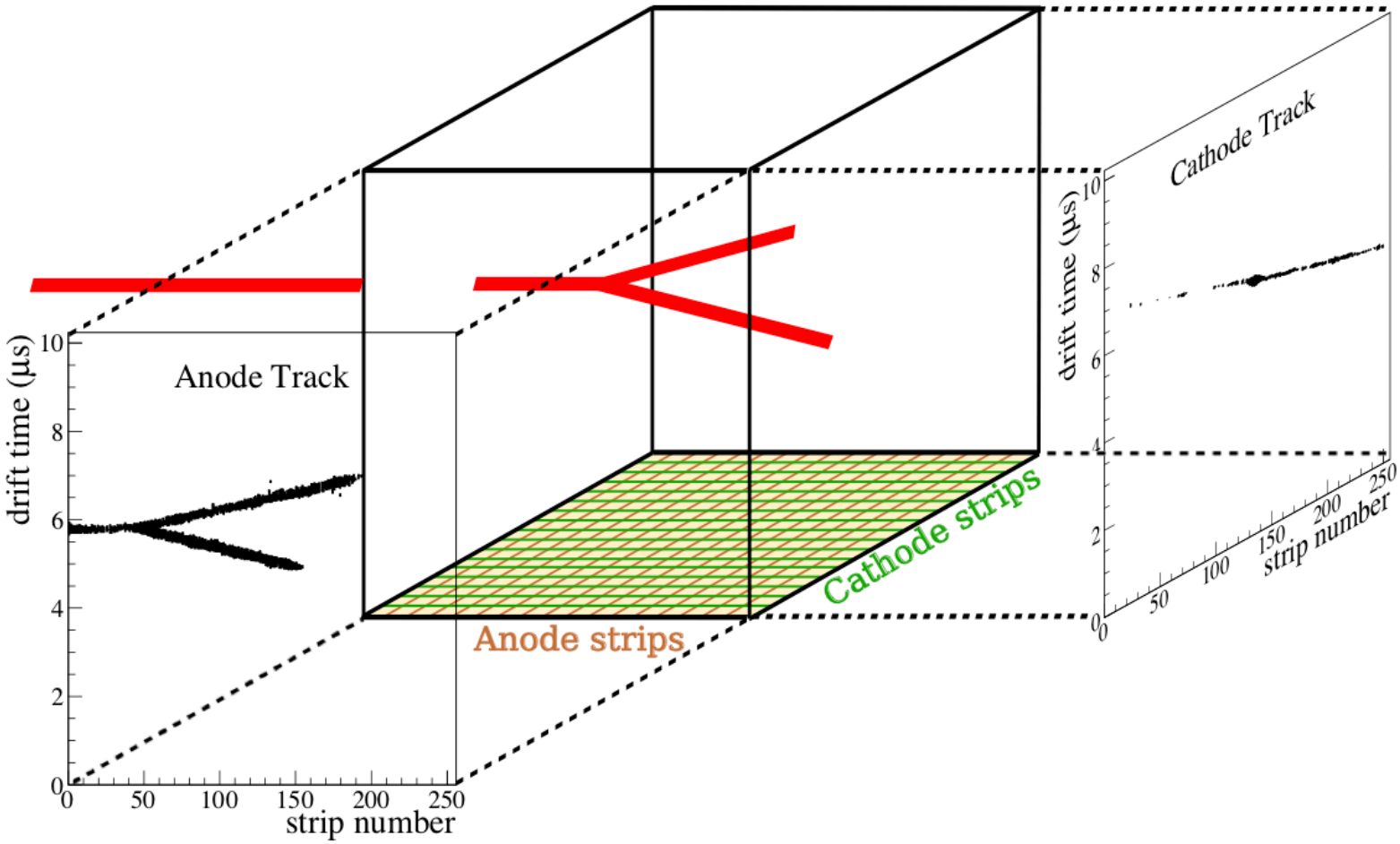




Trigger: TPC self / external

# of channel	128 ch/board
time window	10 μs (adjustable)
peaking time	30 ns
dynamic range	± 1000 fC
noise	~6000 electrons
time walk	< 6 ns
output data	TOT(128ch)+FADC(16ch)

Data structure



✓ Drift time as a function of μ-PIC strips provides two-dimensional projections.

✓ Anode + Cathode projections → 3D track reconstruction.

Performed experiments

Gas	Pressure	Beam	Reaction	Purpose
He + iC_4H_{10} (7%) He + CO_2 (7%)	430 hPa	^{4}He, 12.5 MeV/u @RCNP	(α, α)	test exp.
He + CF_4 (2%)	1000 hPa 2000 hPa	^{13}C, 60 MeV/u @RCNP	(α, α’)	test exp.
iC_4H_{10} (100%)	100 hPa	^{13}C, 60 MeV/u @RCNP	(p, p’), (p, d)	test exp.
He + CF_4 (2%)	2000 hPa	γ bean @New SUBARU E_γ = 22 – 32 MeV	^{4}He(γ, p+t) ^{4}He(γ, ^{3}He)n	Big-bang nuclear synthesis
He + CO_2 (4%)	500 hPa 1000 hPa	^{10}C, 75 MeV/u @RCNP	(α, α’)	cluster

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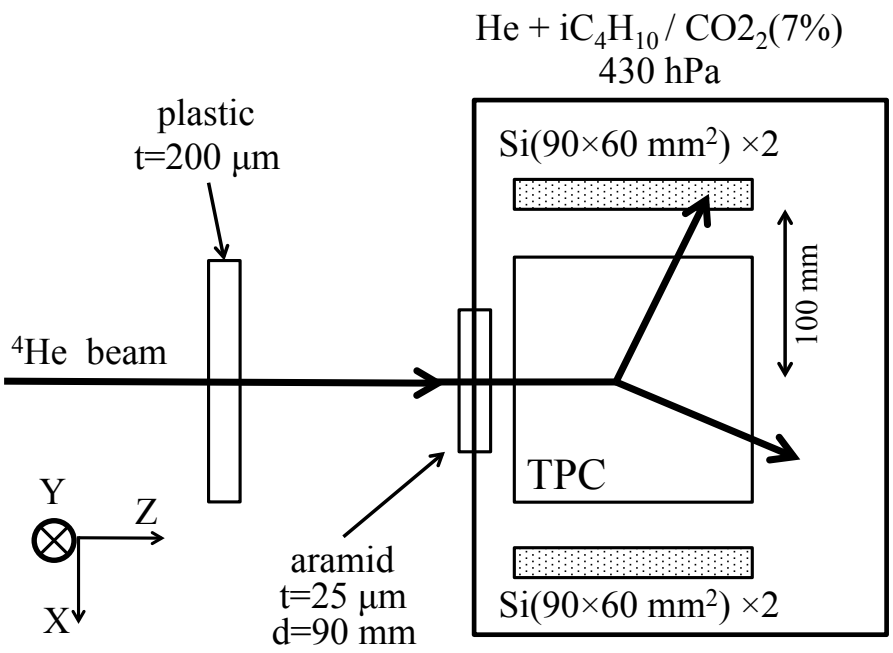
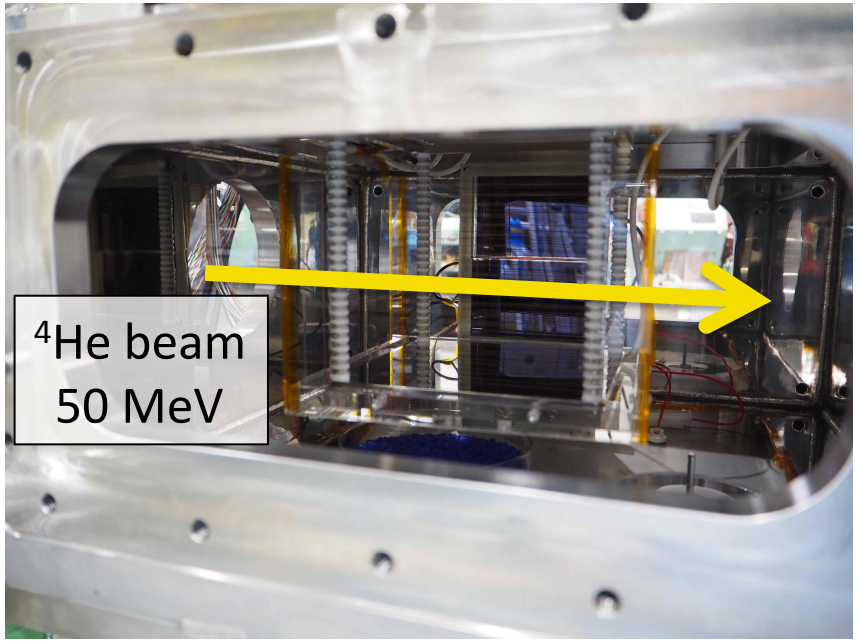
Test with a 50-MeV ^{4}He beam





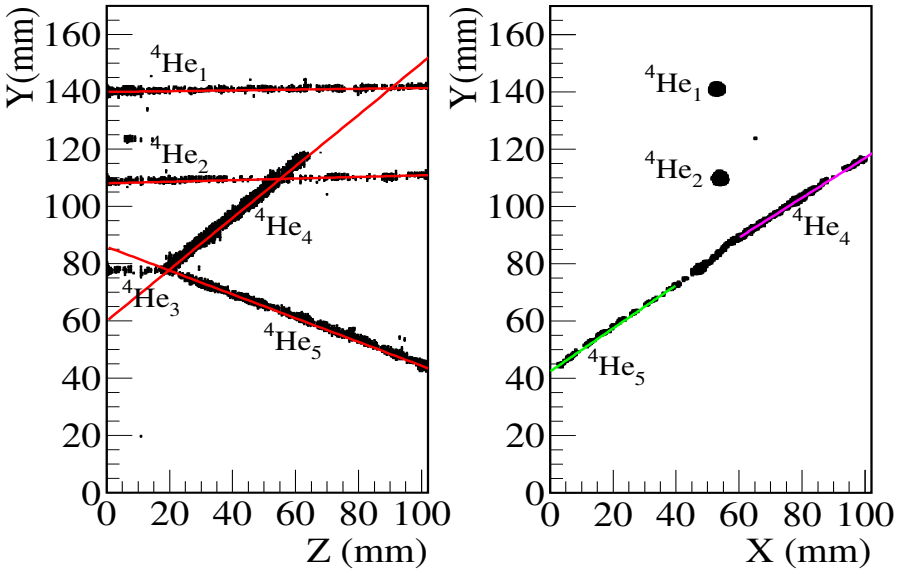
side view of the TPC and Si

Purposes of the test experiment

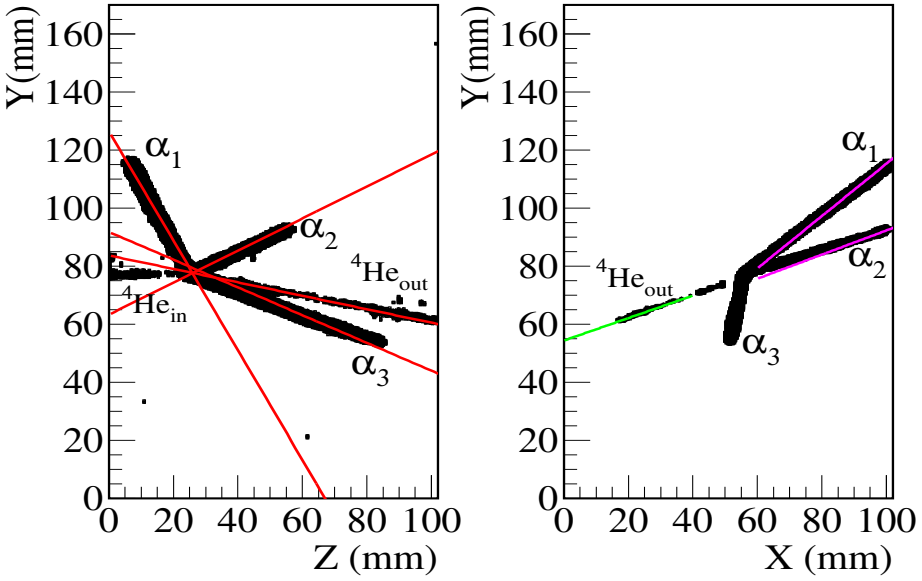
① Performance test of the He+ iso-C_4H_{10} / CO_2(7%) @ 430 hPa.
② Study TPC performance under high beam intensity (up to 300 kcps).
③ Acquire ^{4}He+^{4}He scattering events to develop a tracking algorithm.

Example of scattering events

^{4}He + ^{4}He elastic



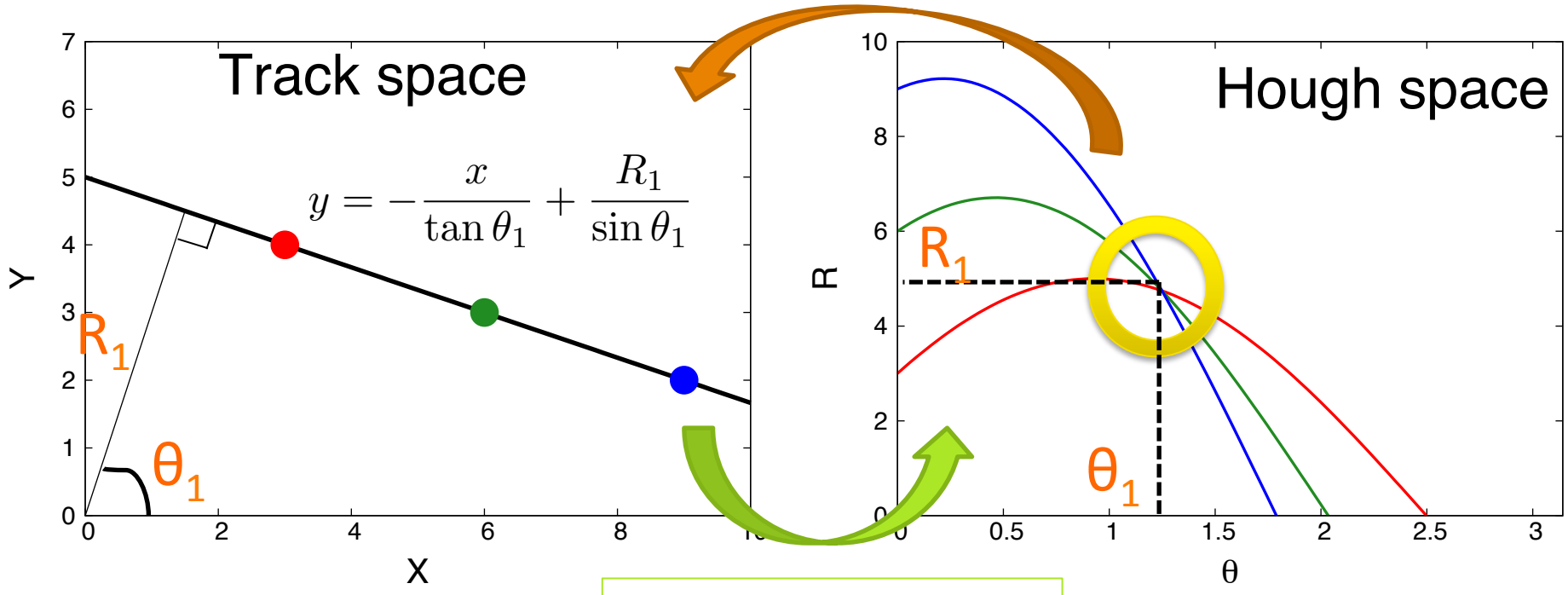
3α decay from ^{12}C*



- ✓ beam: ^{4}He @50 MeV
- ✓ gas: He(93%) + iC_4H_{10}(7%) @430 hPa

To identify the ^{4}He + ^{4}He elastic scattering,
tracking algorithm to reconstruct multiple tracks are needed !

Track finding by Hough transform

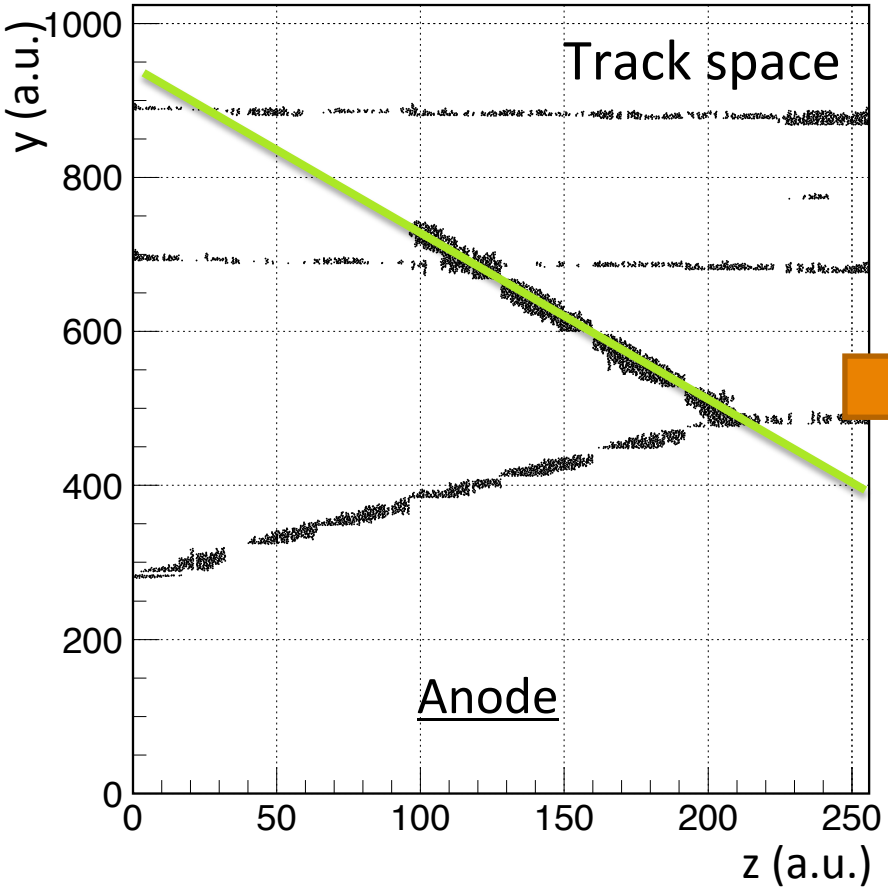


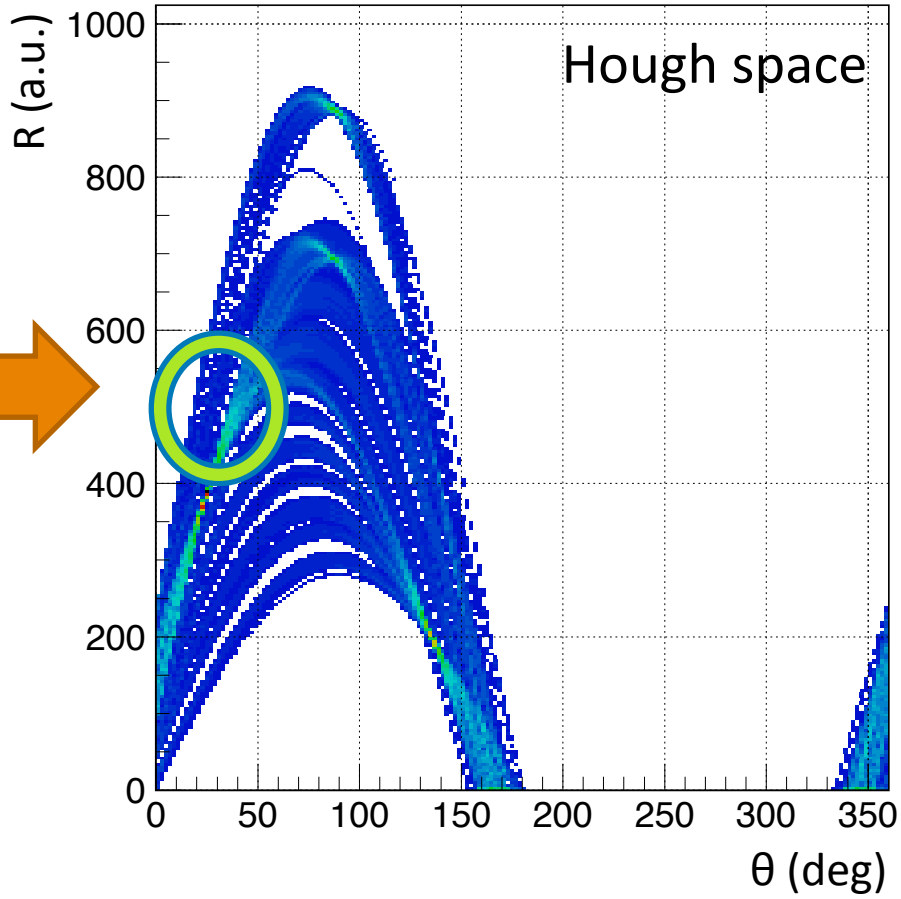
Hough transform

Point (*x*, *y*)	→	Curve $r = x*\cos\vartheta + y*\sin\vartheta$
Straight line	→	Convergent on a one point
Find a line	→	Find a local maximum point

Hough method is very suitable to find a straight line in the track space.

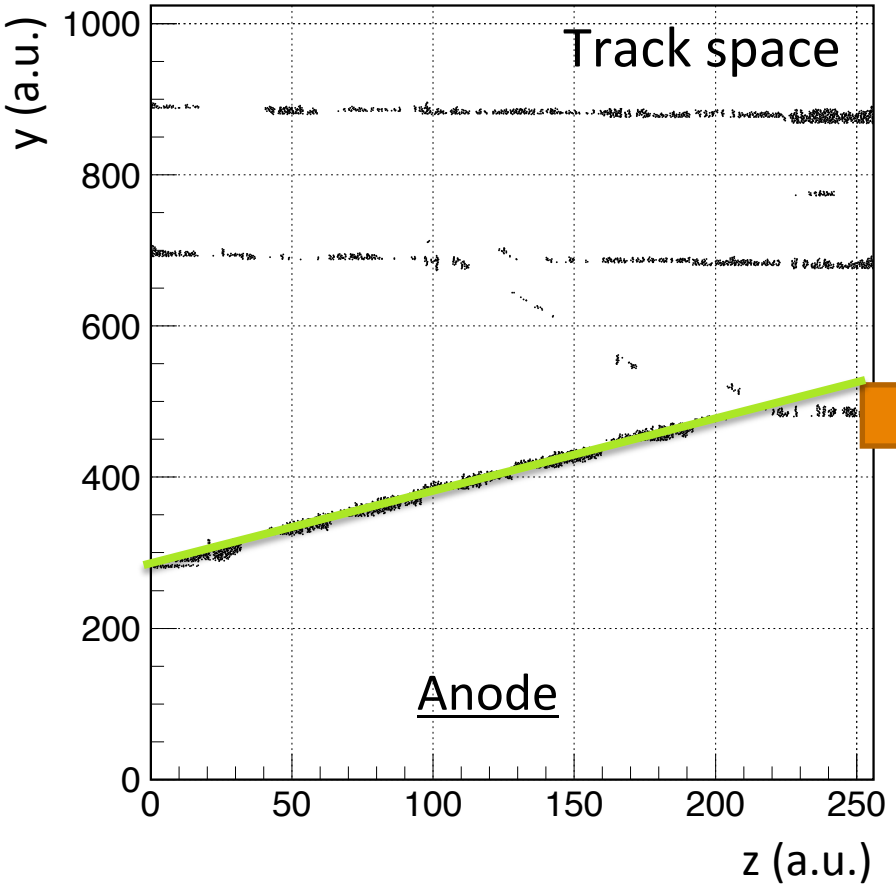
Tracking procedure

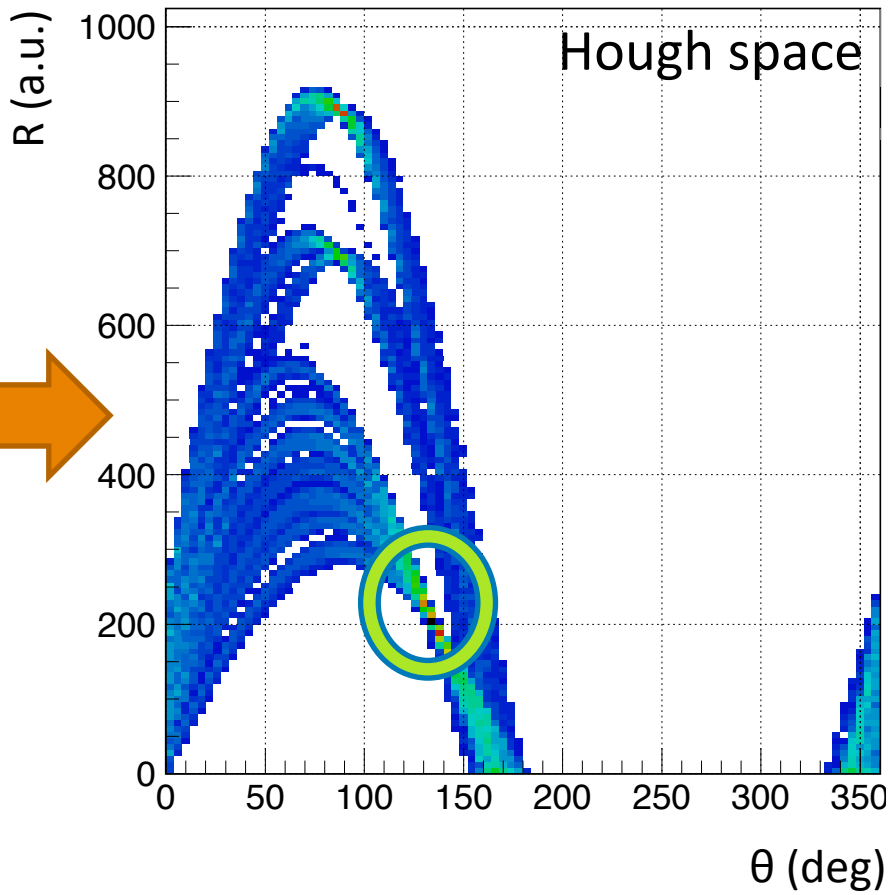




① Find the max points in Hough space to find a track.
② Delete the points along the line.
③ Hough transform again to find the second track.
④ Repeat ②--③.

Tracking procedure





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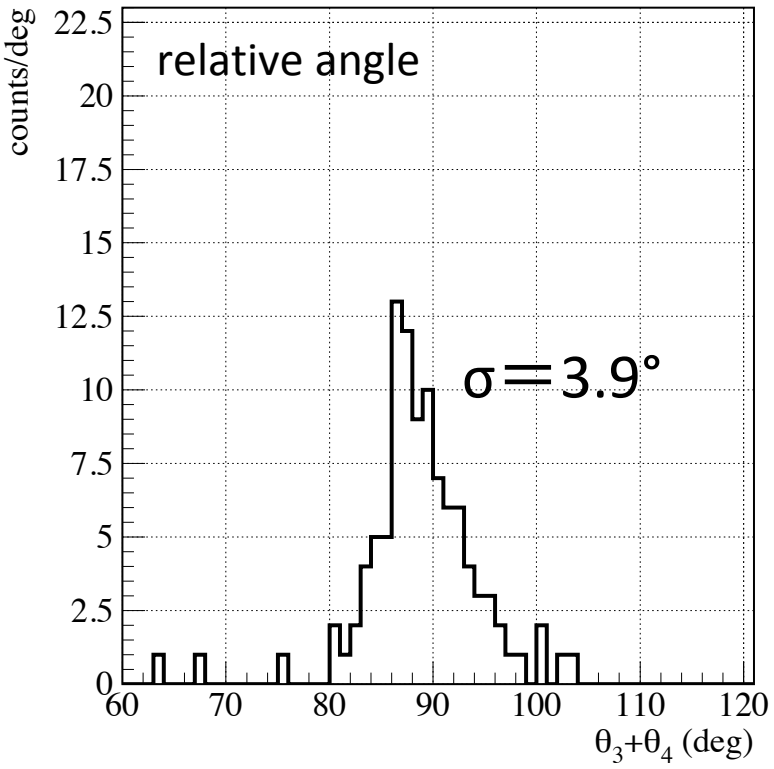
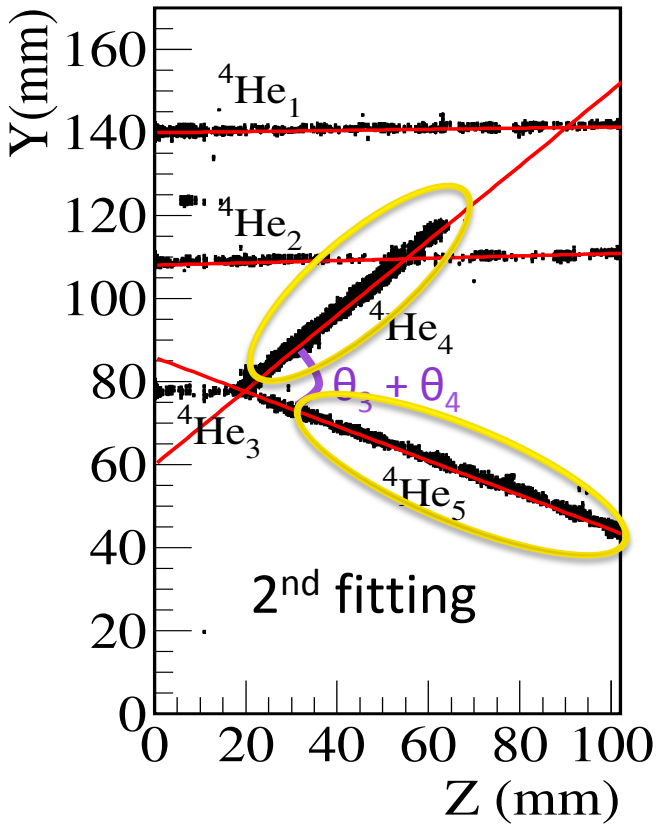
Analysis of ^{4}He+^{4}He scattering





- Elastic scattering of identical particles → $\theta_3 + \theta_4$ is always 90°
- Angular resolution of $\theta_3 + \theta_4$
  - ✓ Only Hough: σ=3.9°
  - ✓ Hough + fitting: σ=1.9

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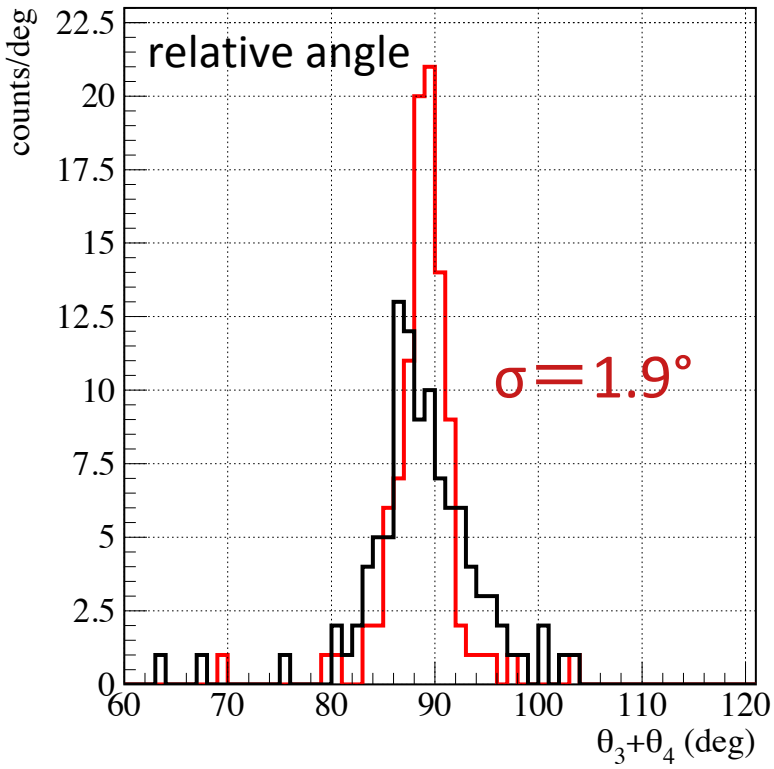

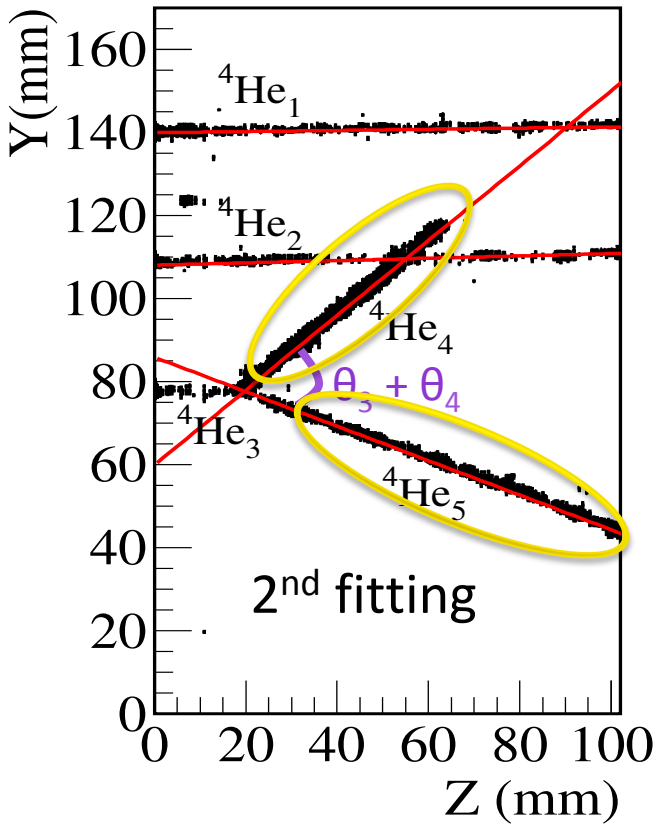

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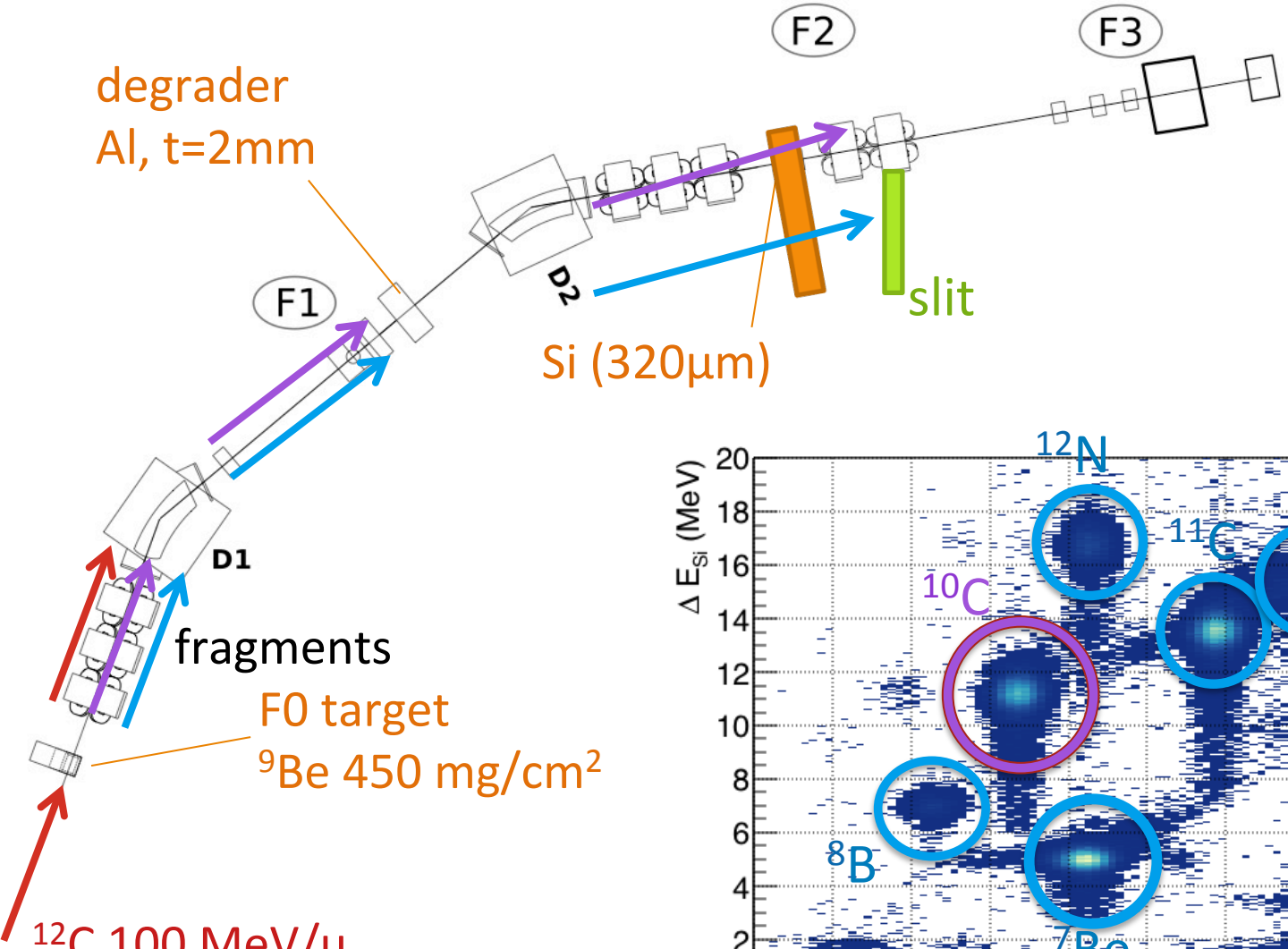
Experimental setup for $^{10}C(\alpha,\alpha')$



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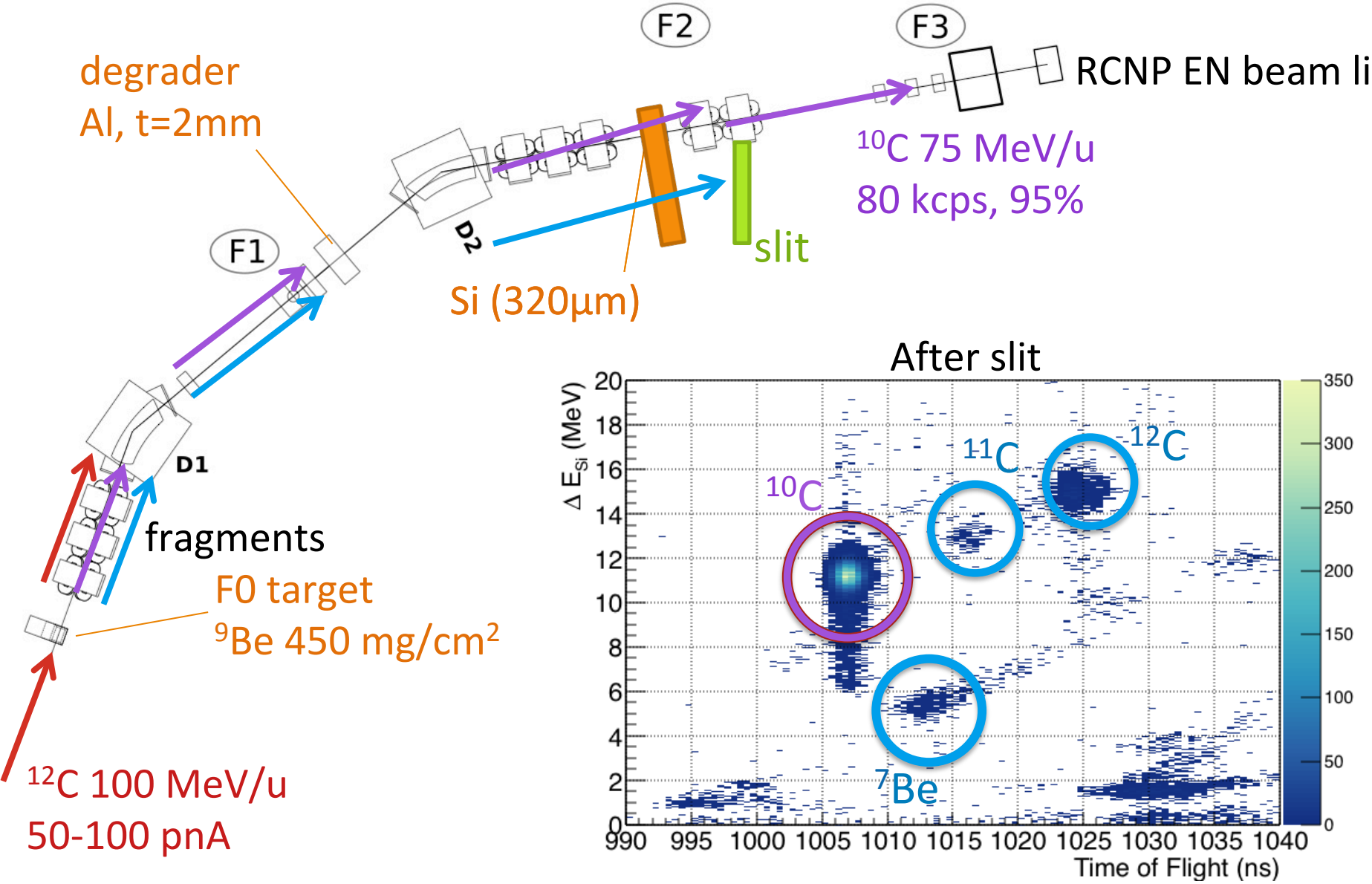

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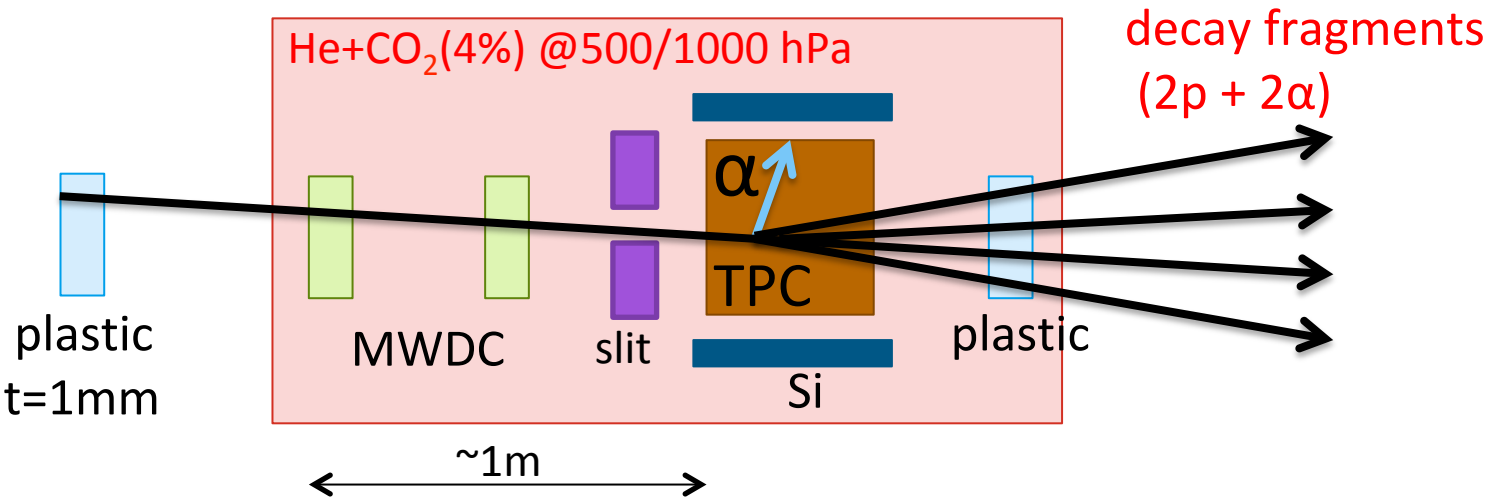
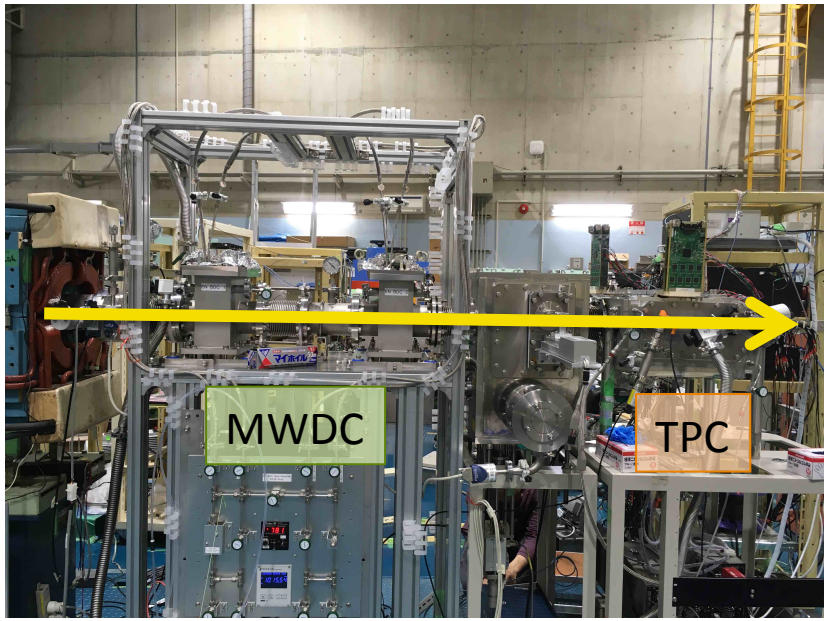




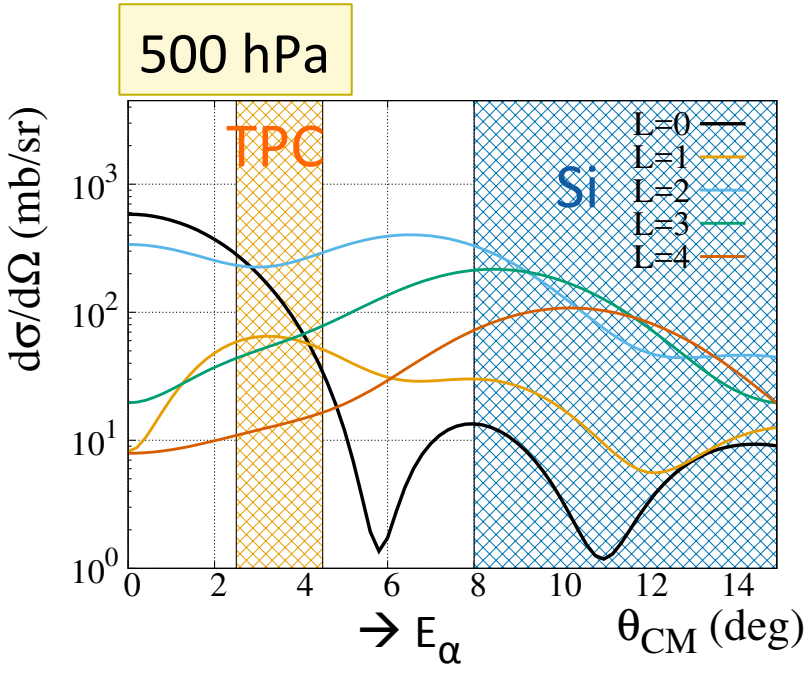
Beam line detectors

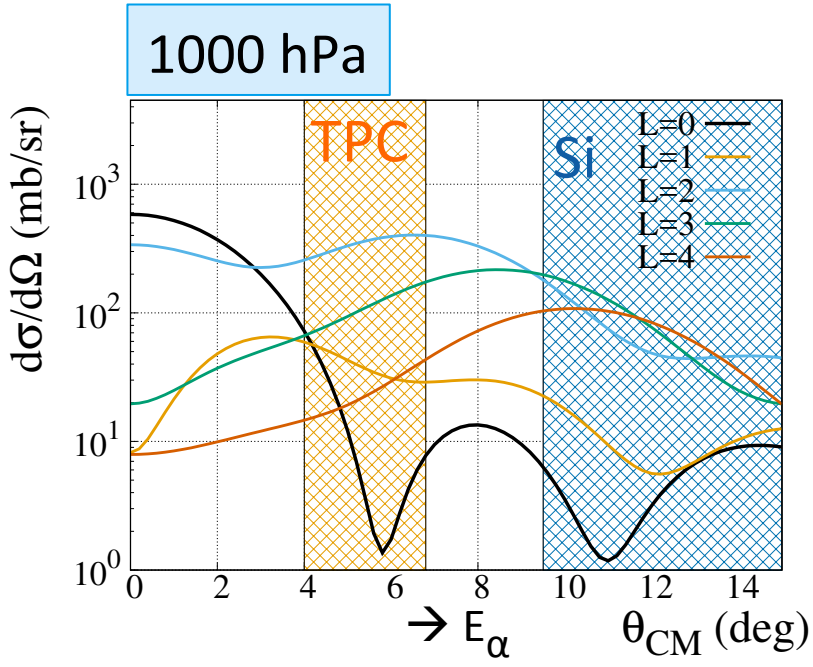
- ✓ plastic(t=1mm) , event by event PID
- ✓ Low pressure MWDC
  → ^{10}C beam tracking (σ~250 μm)
- ✓ plastic → ΔE of scattered ^{10}C / 2p+2α

DAQ trigger = TPC self (w/o beam axis)
＋ Si

Data summary

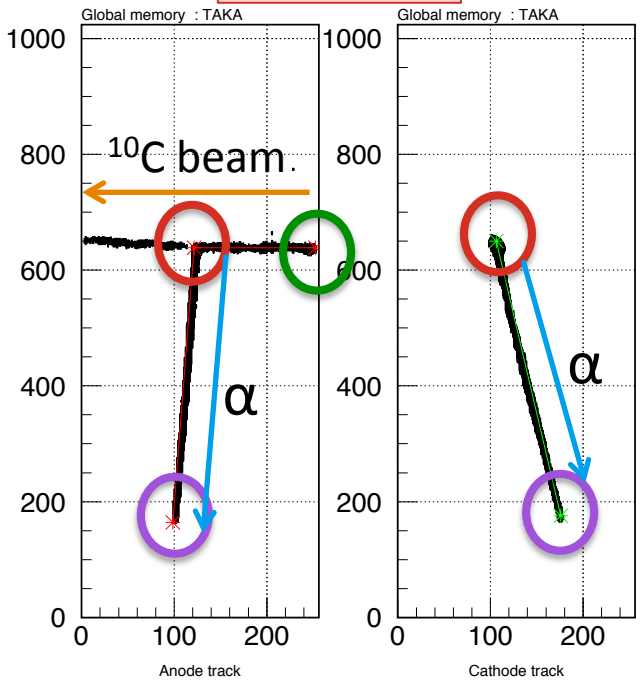
Beam	Reaction	Gas Pressure	Measurement Time	Purpose
^{10}C @80 kcps	^{10}C(α, α')	500 hPa	100 hours	Physics run
^{10}C @80 kcps	^{10}C(α, α')	1000 hPa	30 hours	Physics run
^{12}C @70 kcps	^{12}C elastic	500 hPa	5.8 hours	Eff. check
^{12}C @70 kcps	^{12}C elastic	1000 hPa	3.5 hours	Eff. check



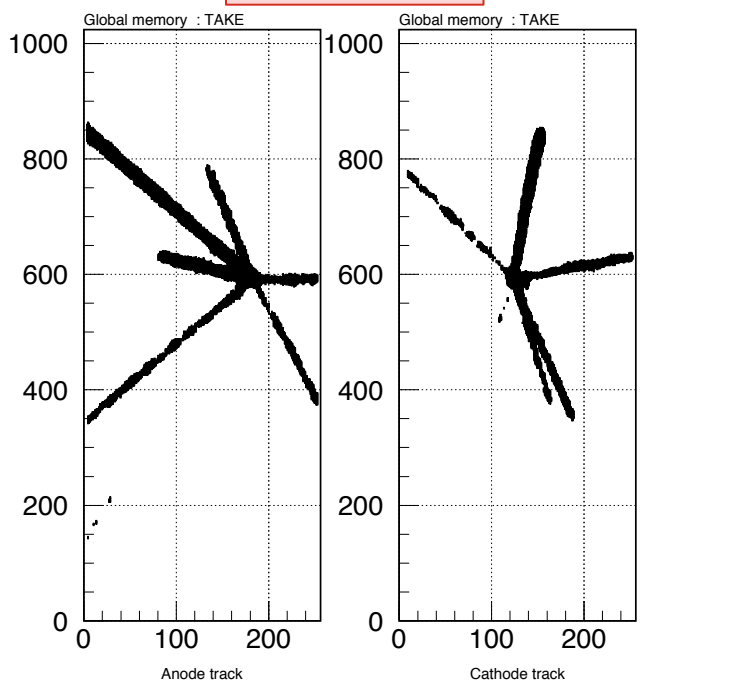


Track examples & Online analysis

$^{10}C(\alpha,\alpha')$



$^{10}C + CO_2$



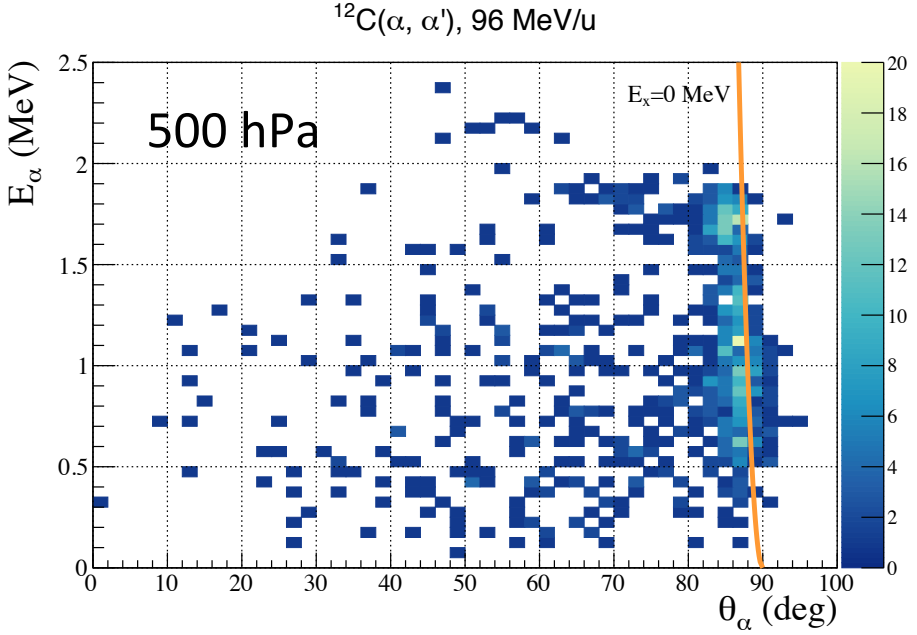
eye scanner

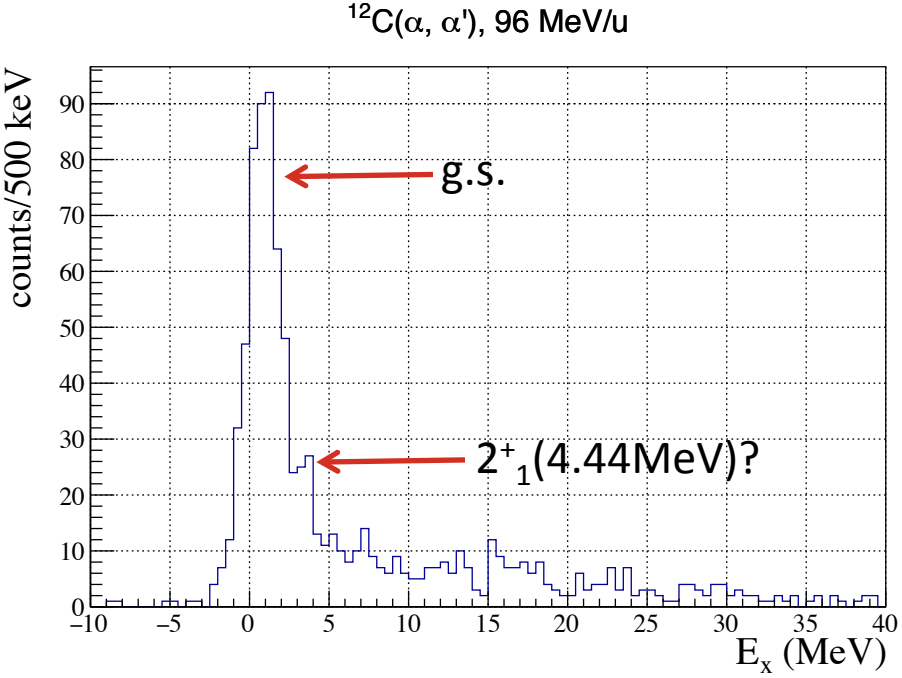
Eye scan analysis

1. Identify $^{10}C(\alpha,\alpha')$ events
2. Extract incident, vertex, track end
3. Reconstruct ϑ, range of the recoil α
4. Calculate the excitation energy

scanned 20,000 events during the beam time

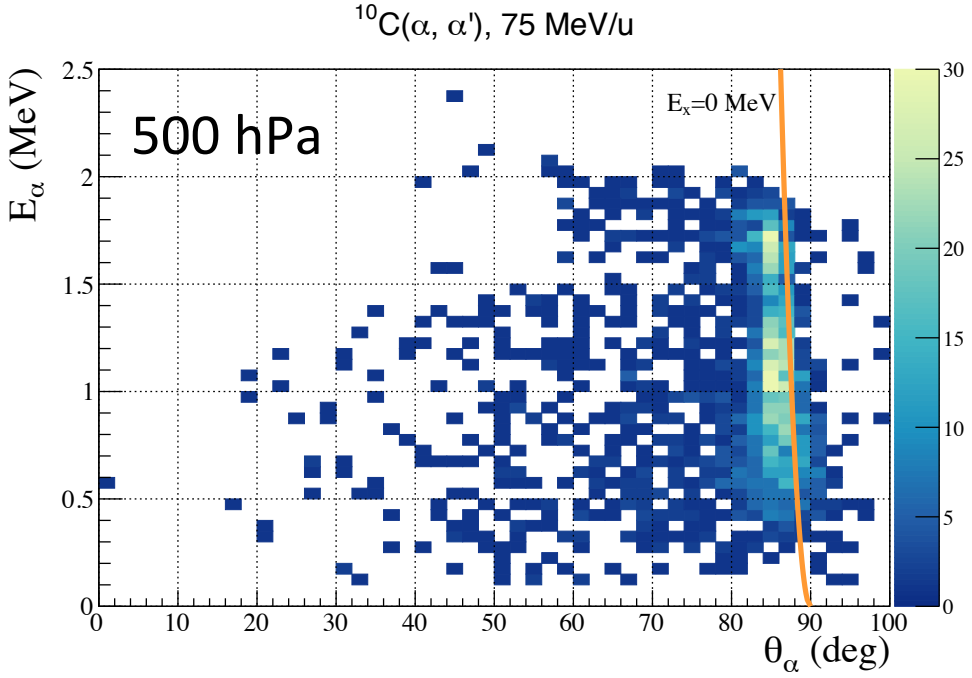
Online analysis of $^{12}C(\alpha,\alpha')$

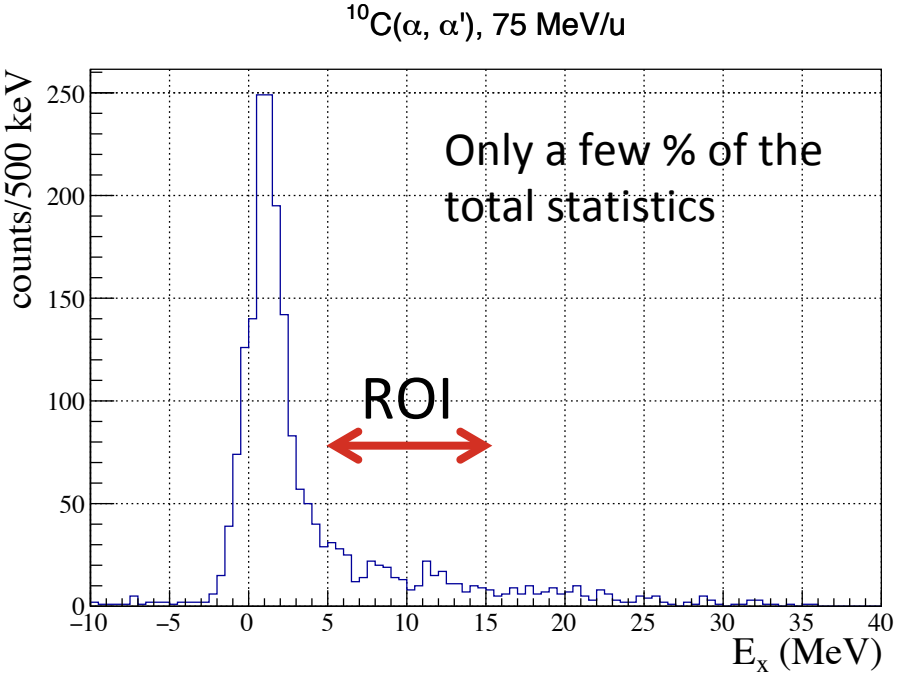




- ✓ Analyzed only the TPC data (w/o MWDCs)
- ✓ Detection threshold: ~500 keV
- ✓ Clear correlation of the elastic scattering
- ✓ E_x resolution (~1 MeV in σ) will be improved after calculate the beam angle from the MWDC

Online analysis of $^{10}C(\alpha,\alpha')$





Strategy of the analysis

1. Combine data of TPC and beam line detectors (eye scan)
2. Automatic track finding with Hough transform
3. PID for α by range-total charge correlation
4. Analyze all of the data.
5. Efficiency check by comparing with the ^{12}C elastic scatt. data

Summary

- α clustering is an important aspect of atomic nuclei.
- α clustering in mirror system will reveal the inner structure of the clusters. (Thomas-Ehrman shift)

- An active target MAIKo has beem developed for the measurement.
  - ✓ Detect low-energy recoil α particles.
  - ✓ TPC with μ-PIC+TGEM
  - ✓ Track finding with Hough transform → σ=1.3°

- The first RI beam experiment has been just completed！
  - ✓ ^{10}C (α, α') @75 MeV/u.
  - ✓ Detection threshold: 500 keV

- Analysis is on going！