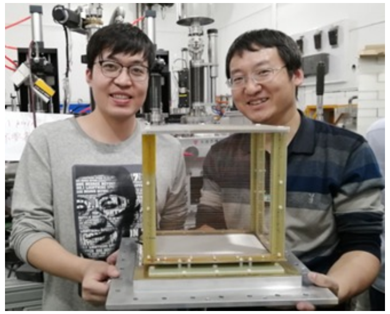
Time Projection Chambers for nuclear astrophysics studies

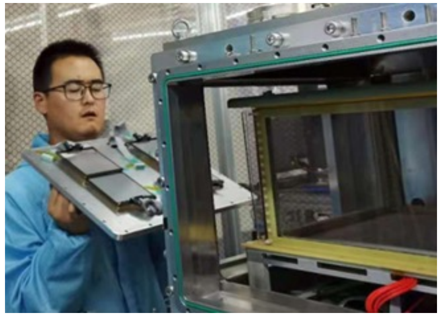
Ningtao Zhang, MATE Collaboration

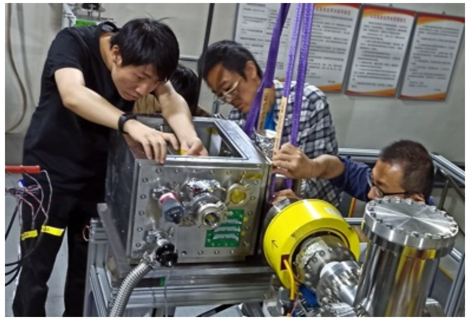
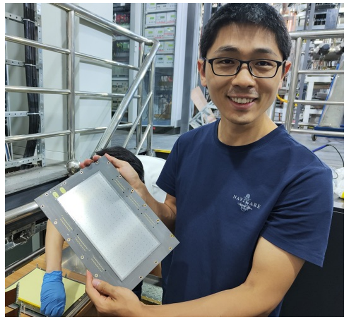
Institute of Modern Physics, Chinese Academy of Sciences

MATE TPC: *Multi-purpose Active-target Time projection chamber for nuclear Experiments*

07/2025



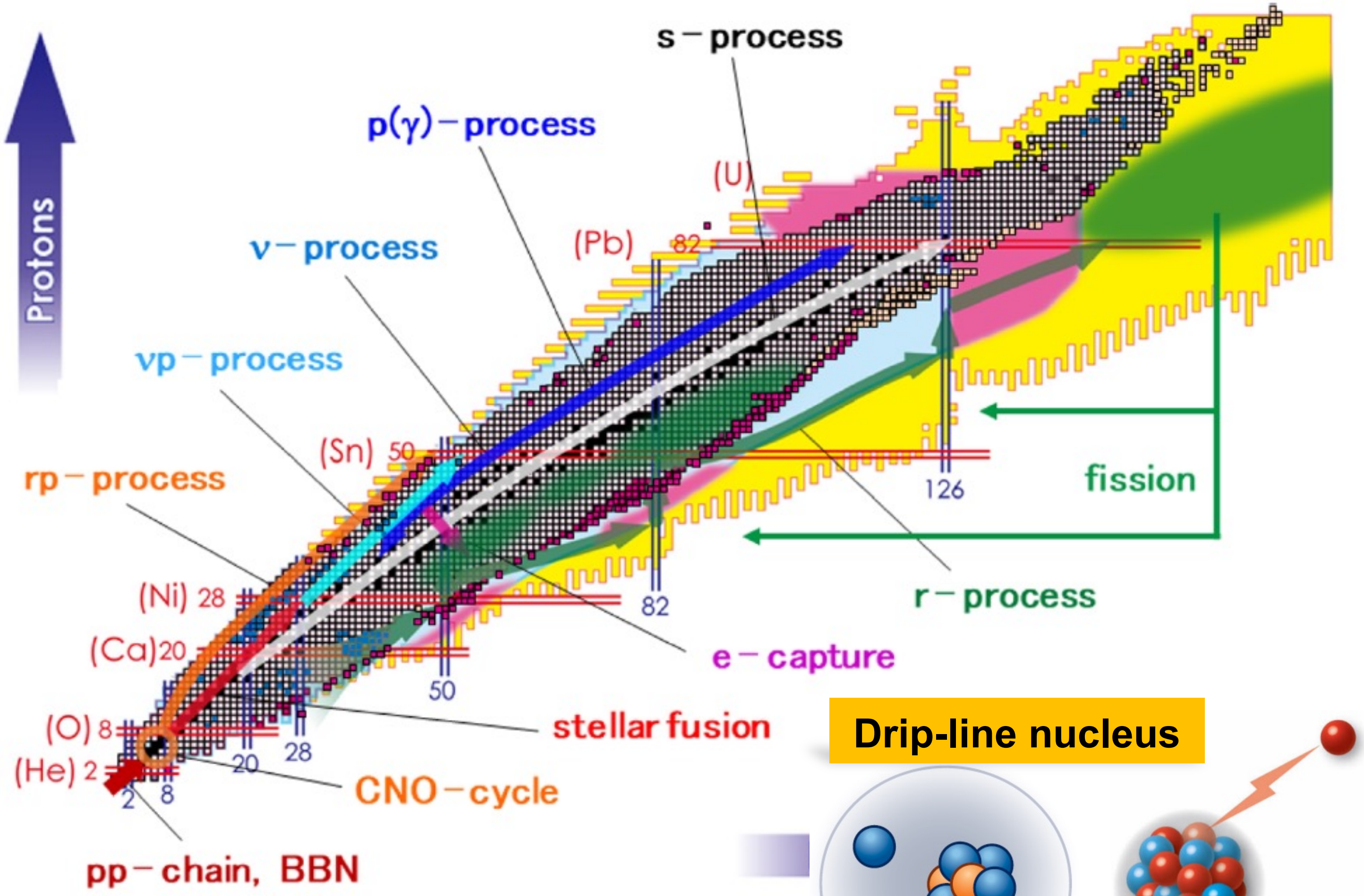



Outline

- Motivation
- Development of MATE TPC
  - pMATE→MATE→μMATE→Cylindrical MATE
- Experimental results
- Summary

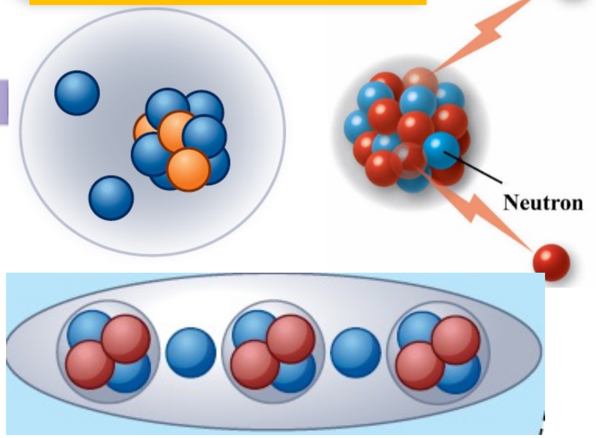
Reaction and structure studies using TPC



Aziz *et al.*, *AAPPS Bulletin* (2021) 31

① Origin of elements?

Drip-line nucleus



Motivation(astrophysics):

1, Direct reactions: (α,p), (p,α)

2, Fusion: intense beam(CC,CO,OO), neutron-rich RIB

3, Weak interaction：beta decay, (d,2p), (^{3}He,t)

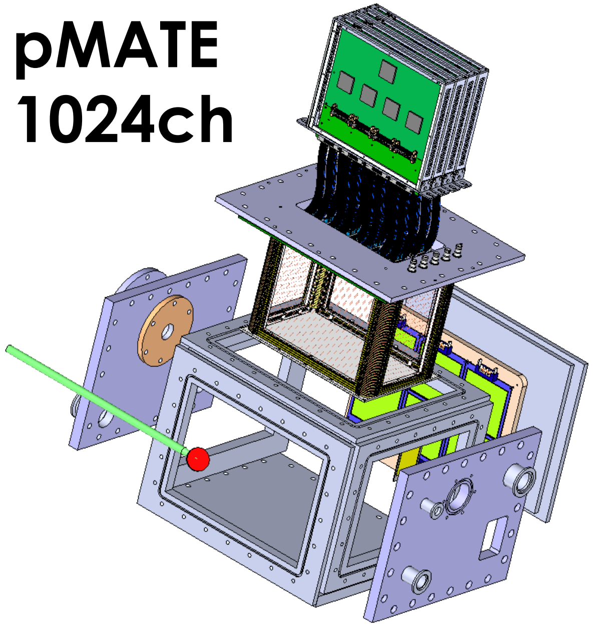
4, Fission(R)：(p,p*), (p,2p)

5, Giant resonance：(p,p*), (d,d*)

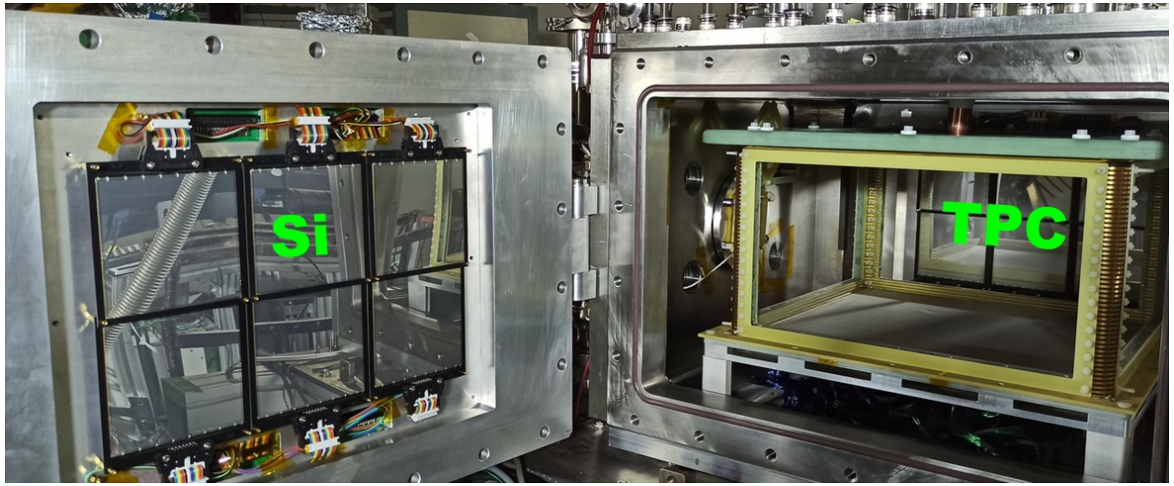
6, Nuclear structure：decay, transfer, scattering

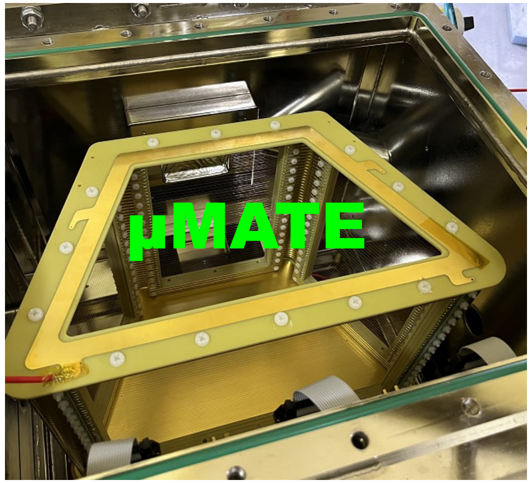
Prototype and MATE TPC: timeline

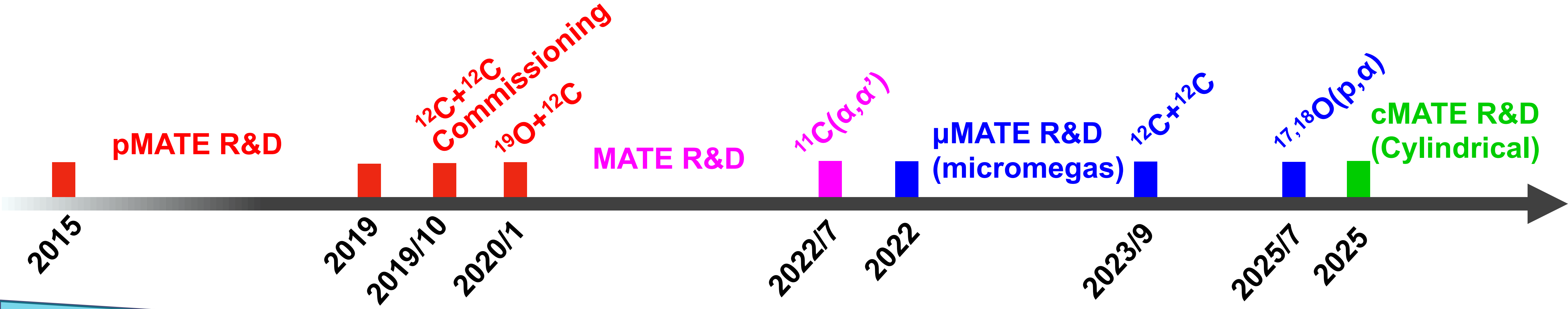
pMATE 1024ch



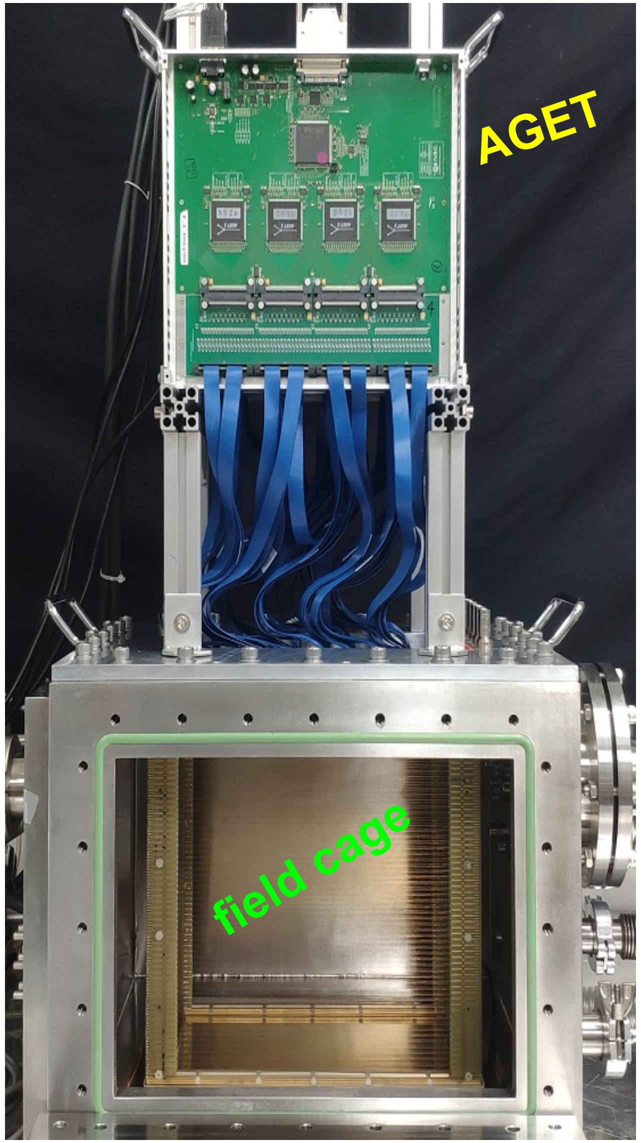
MATE 4000ch TPC

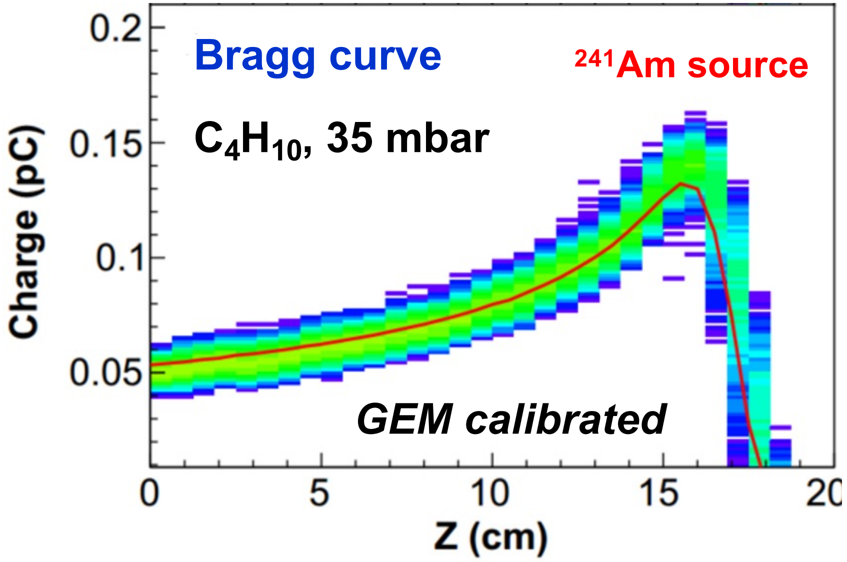




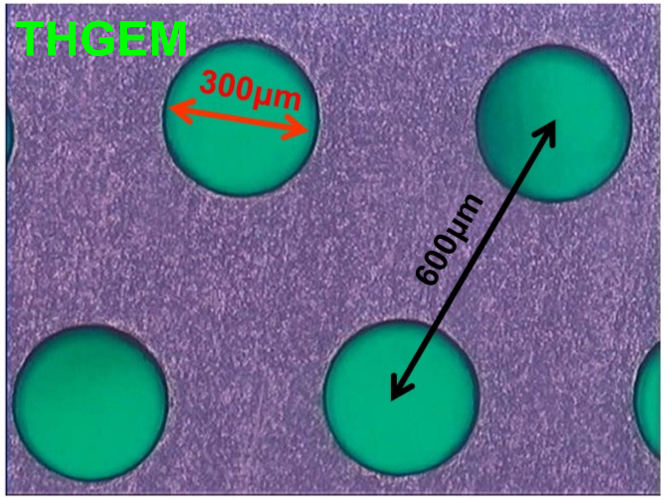


1024ch pMATE (prototype)

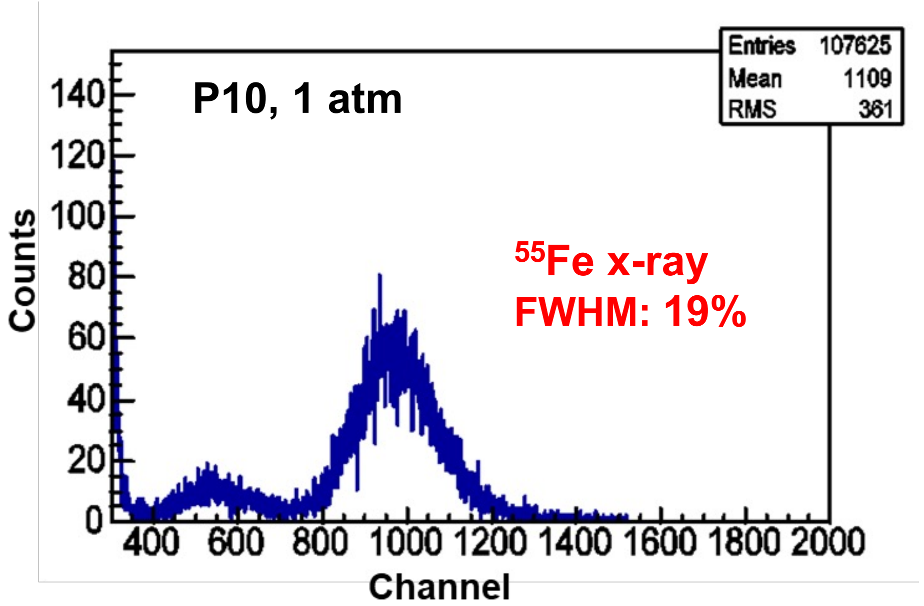




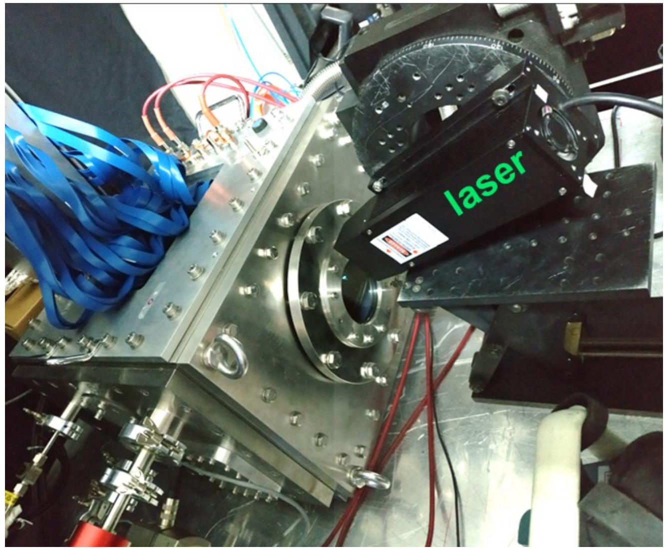
- **Active volume:**
  10cm(W)×20cm(L)×25cm(H)
- **Field cage: 3 layers of Be-Cu wires （Φ0.1mm）**
- **Double THGEMs: thickness 0.3mm**
- **Rectangular pad: 3×6mm^2, 1024 pads**



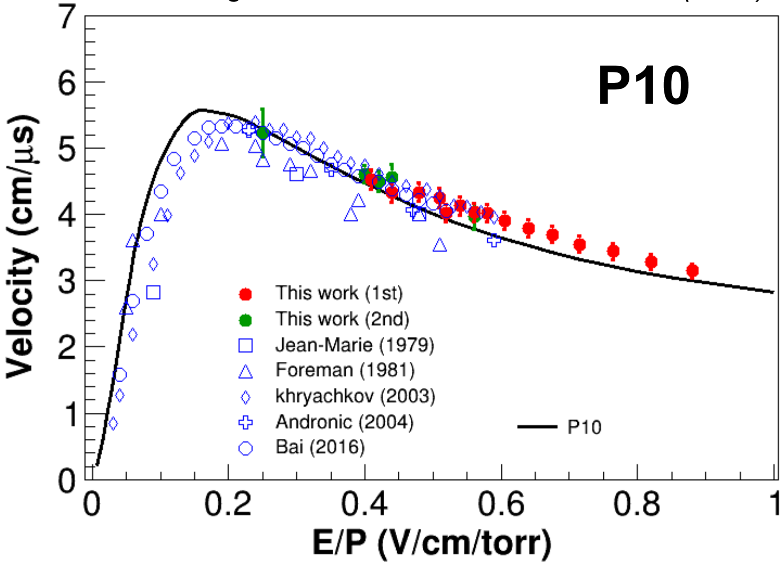
GEM by Q. Liu (UCAS)

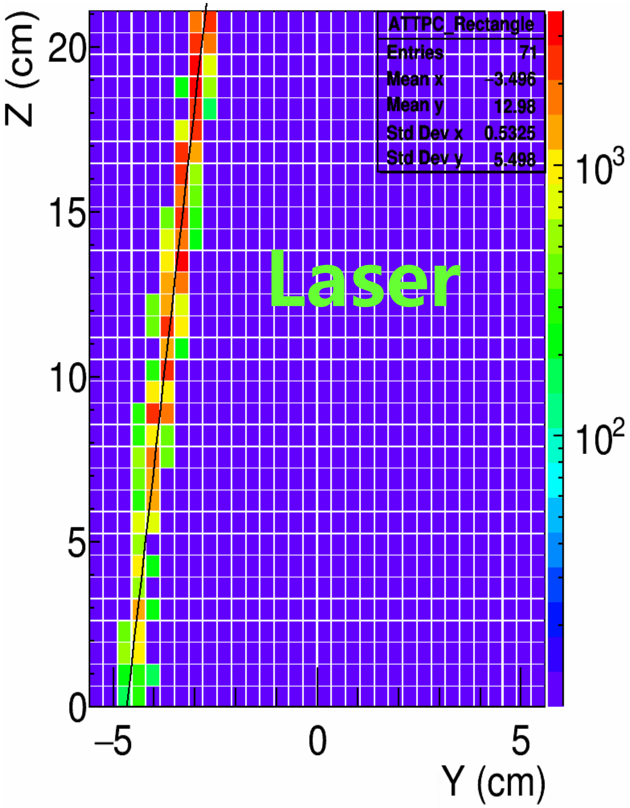


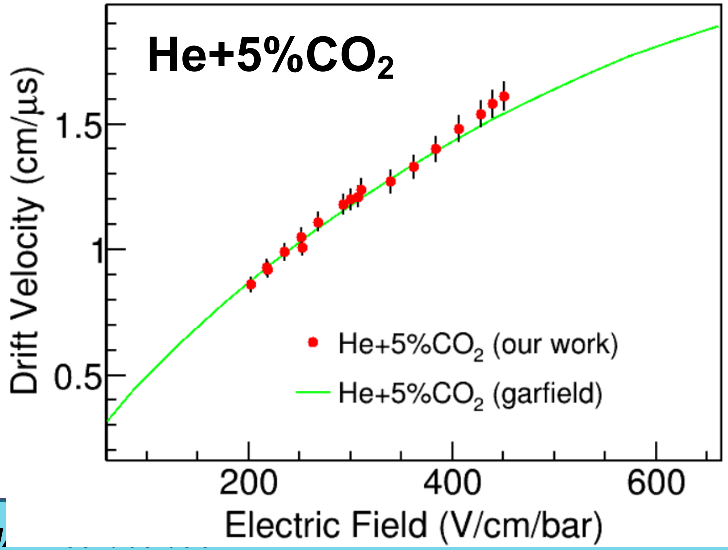
Calibration ......

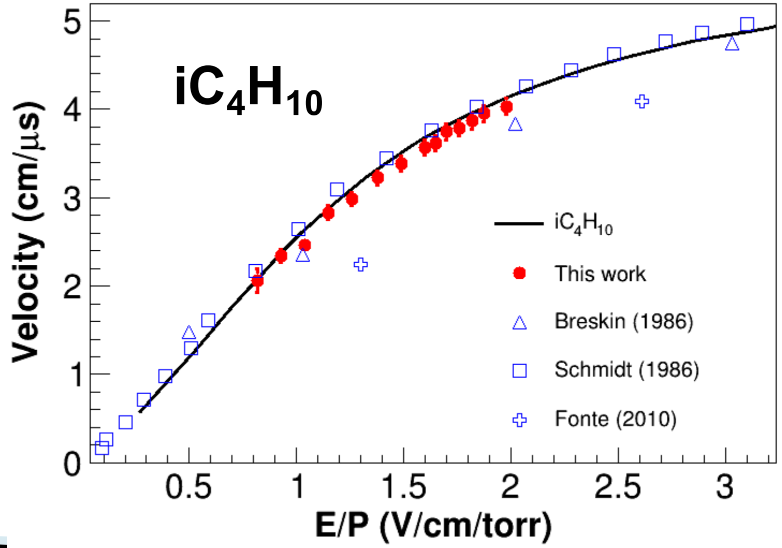


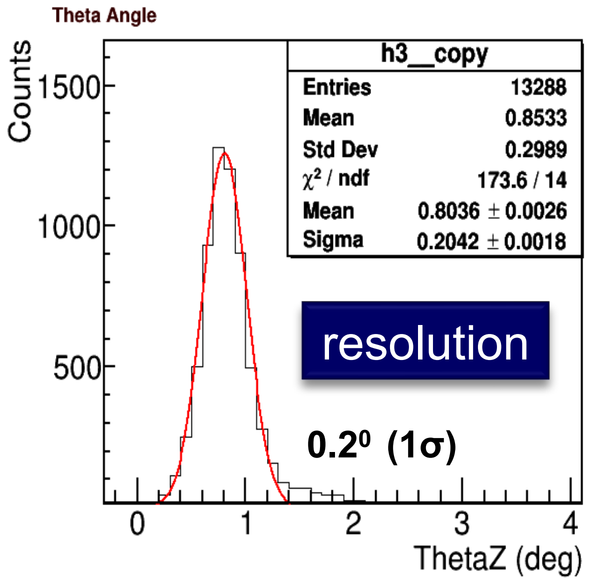
Z.C. Zhang…ZNT* et al., NIMA1016, 165740(2021)



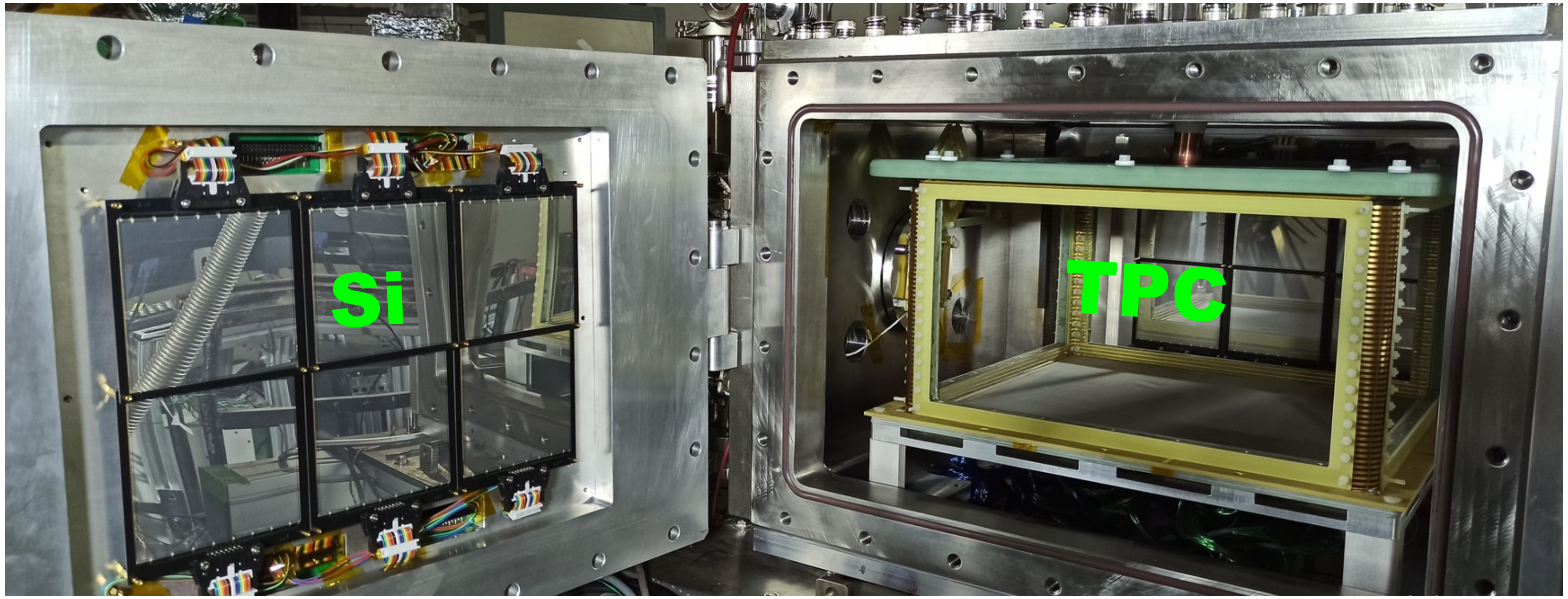


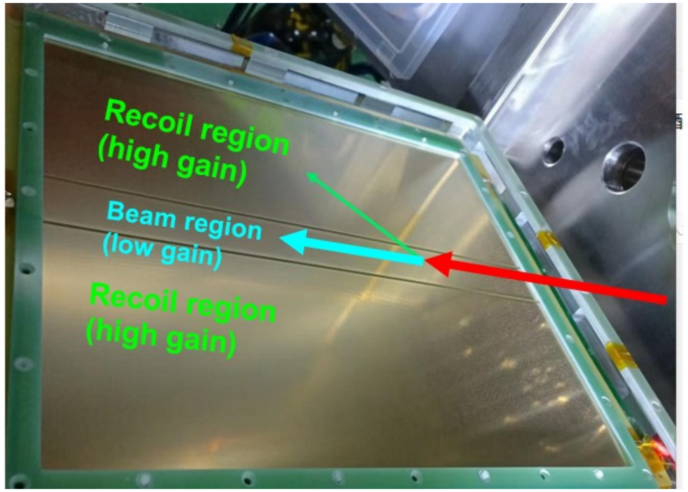






Full scale MATE-TPC





X.B. Li et al., *Nuclear Science and Techniques* 35 (2024) 131

TPC

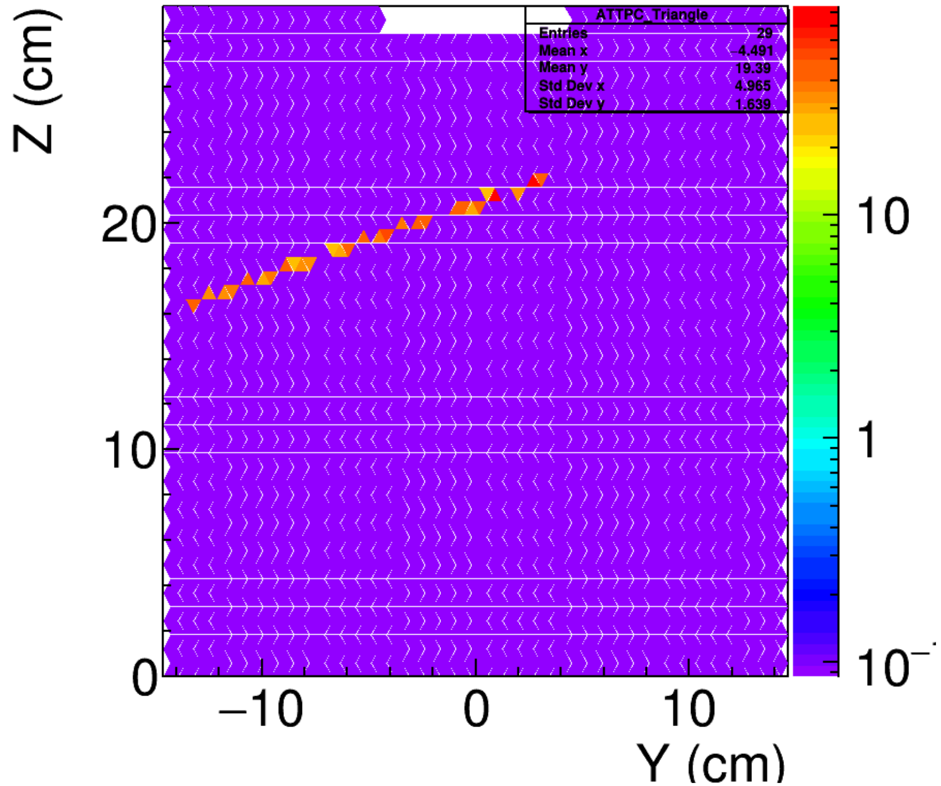
- ✓ 30x30x20(h) cm^3
- ✓ Double-layer segmented THGEM
- ✓ 3800 readout channels
- ✓ GET electronics

Si array

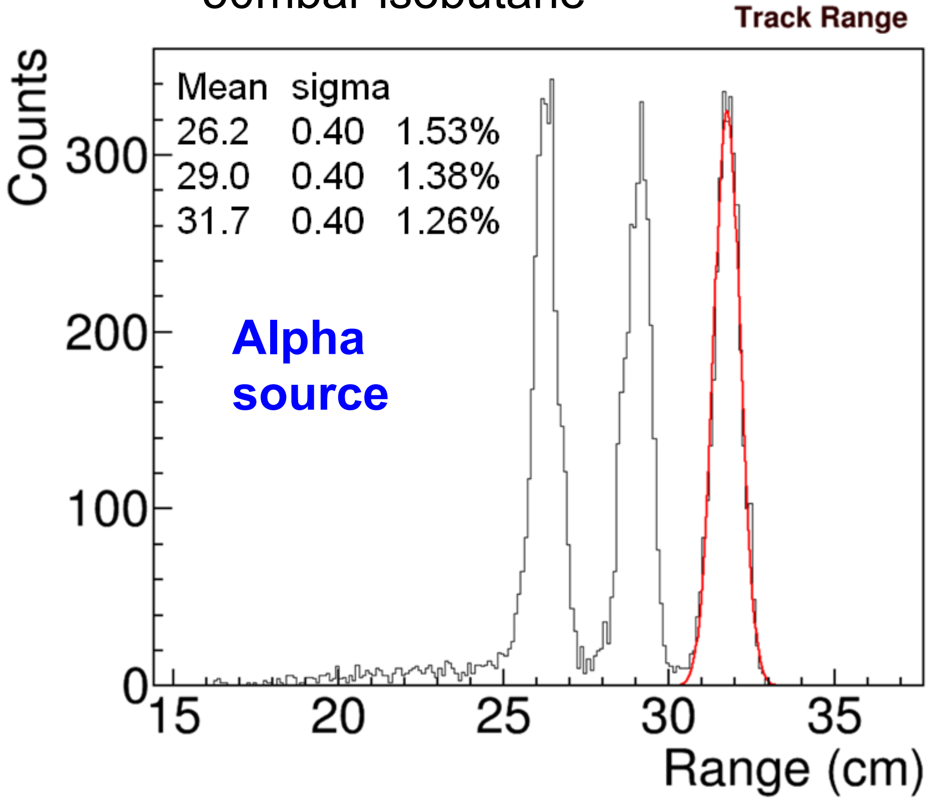
- Three silicon walls
- Sensitive area: 100×100 mm^2
- Thickness: 600 μm and 150 μm
- Angular coverage ~10%

Alpha measurement by MATE

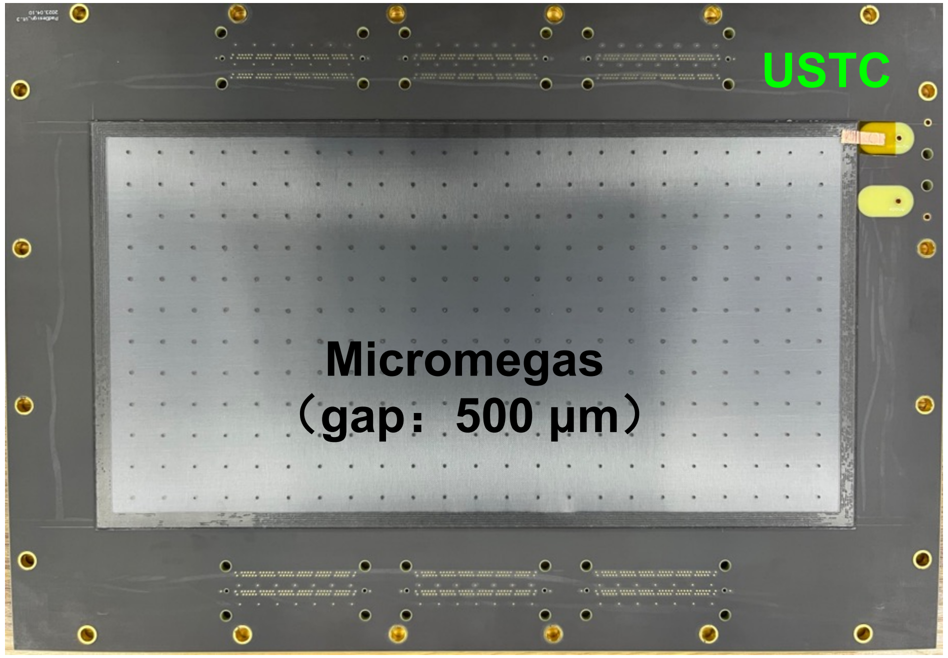
ATTPC_Triangle Alpha tracks in pad plane

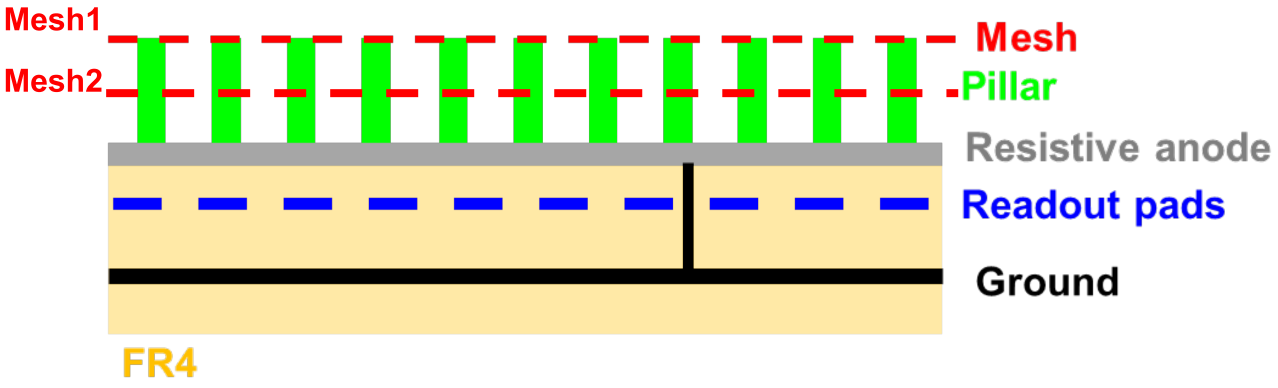


50mbar isobutane

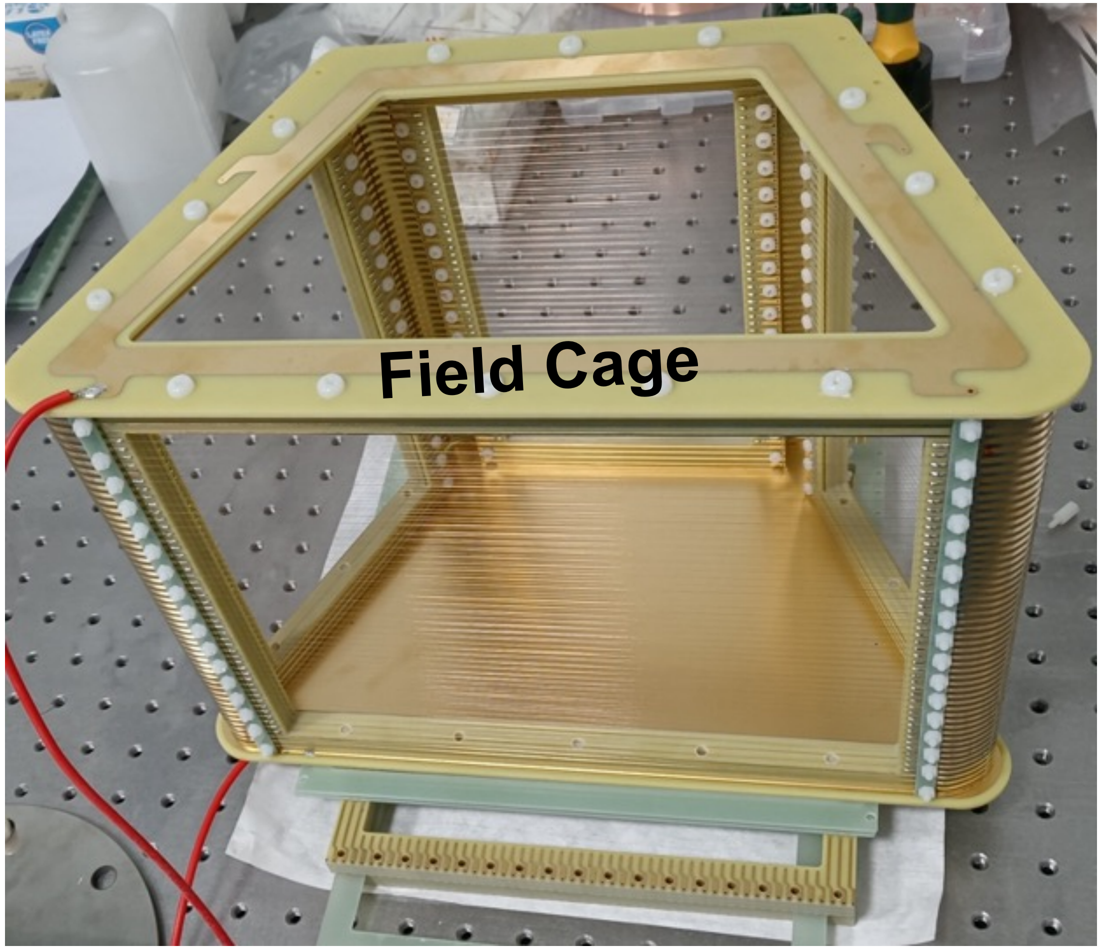


Low-pressure Micromegas-based TPC (μMATE)



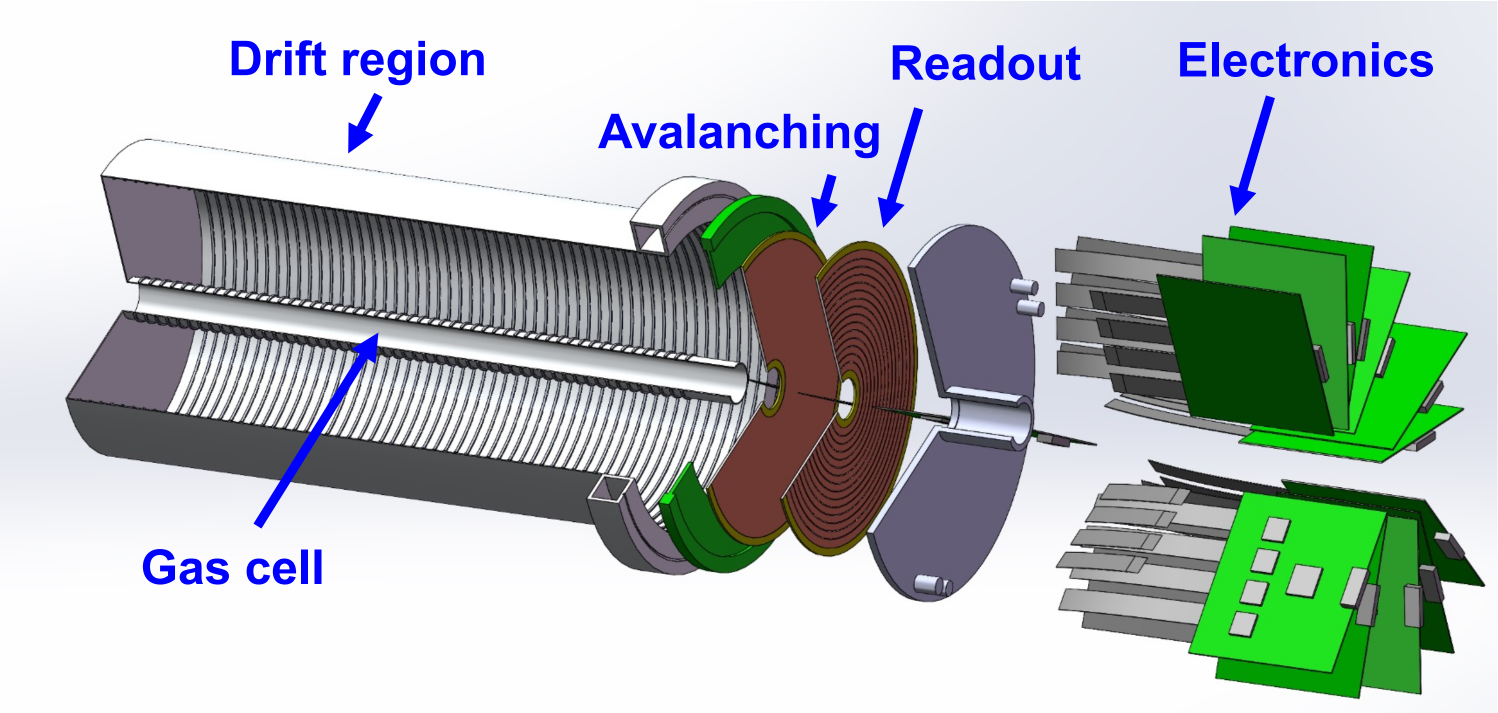


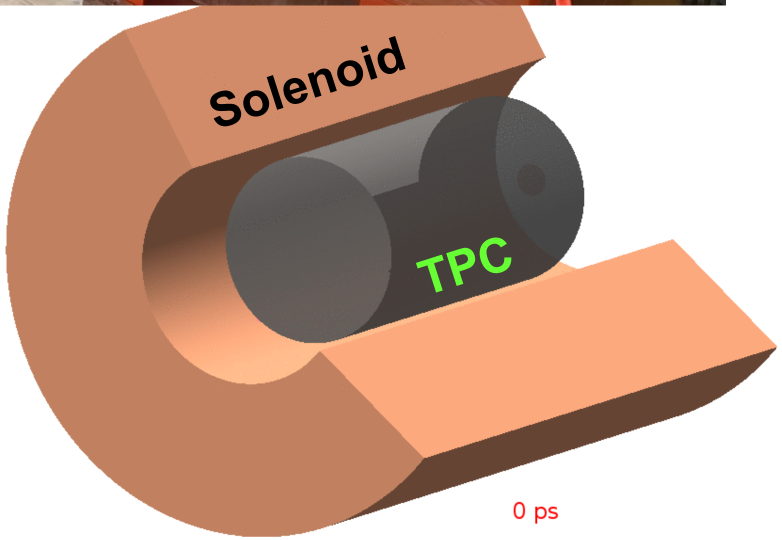
Micromegas provided by Zhiyong Zhang(USTC)*



Be used at ~70pμA experiment!

Cylindrical TPC (under design)

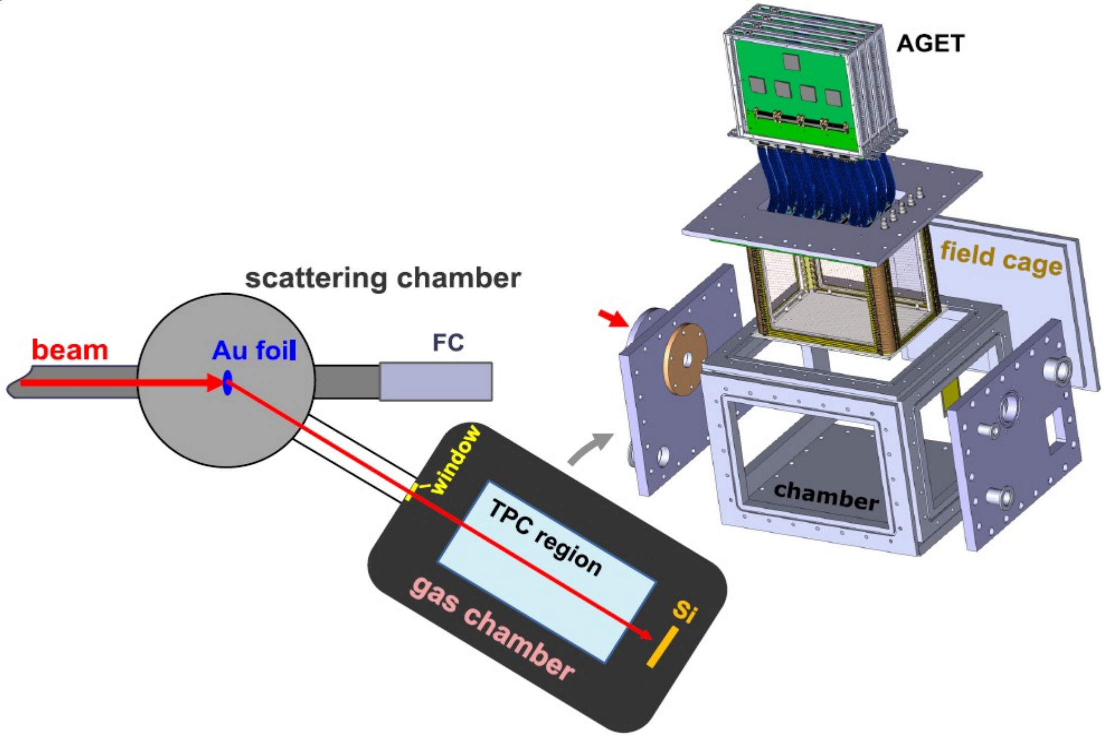


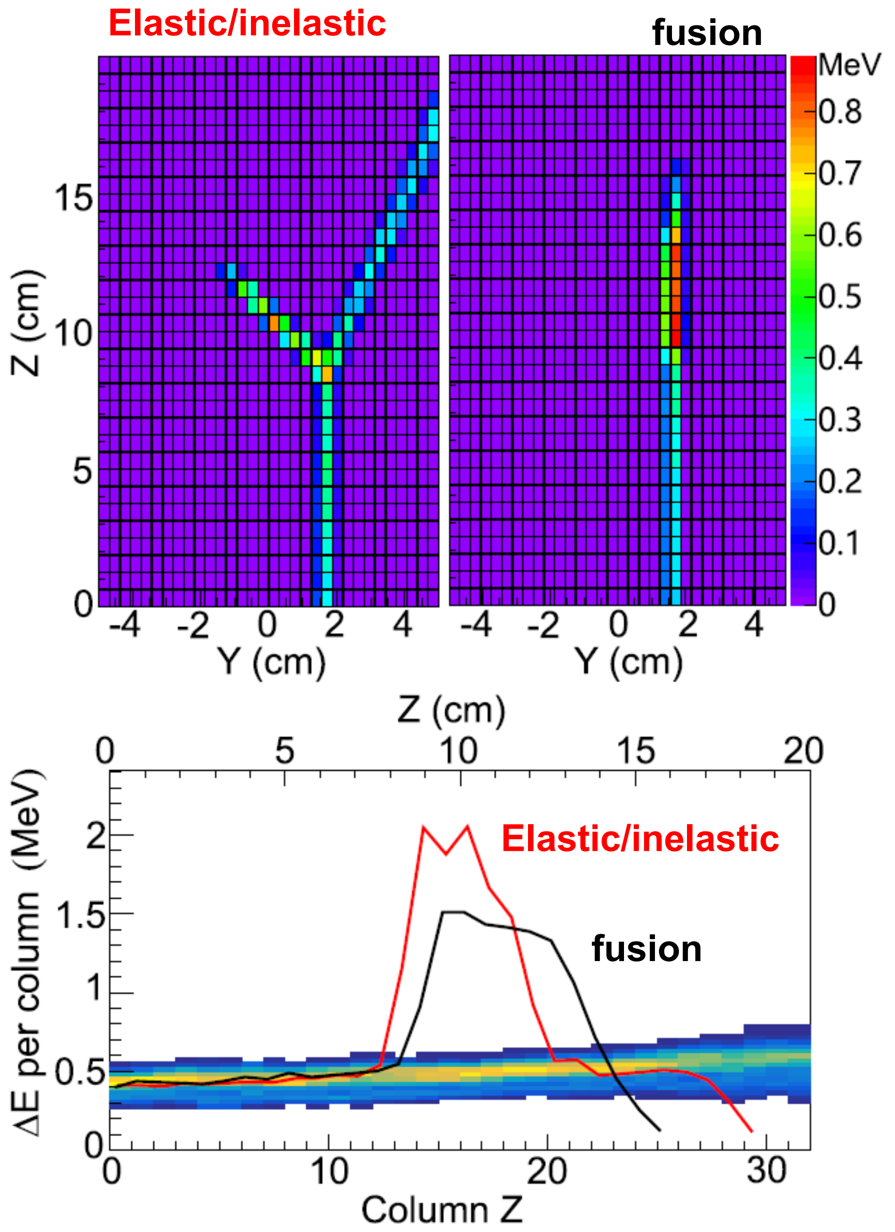


- Suppress delta rays in RIB experiments
- Achieve better particle identification
- Extend the measured dynamic energy range

0 ps

Commissioning experiment: $^{12}C+^{12}C$ fusion near coulomb barrier



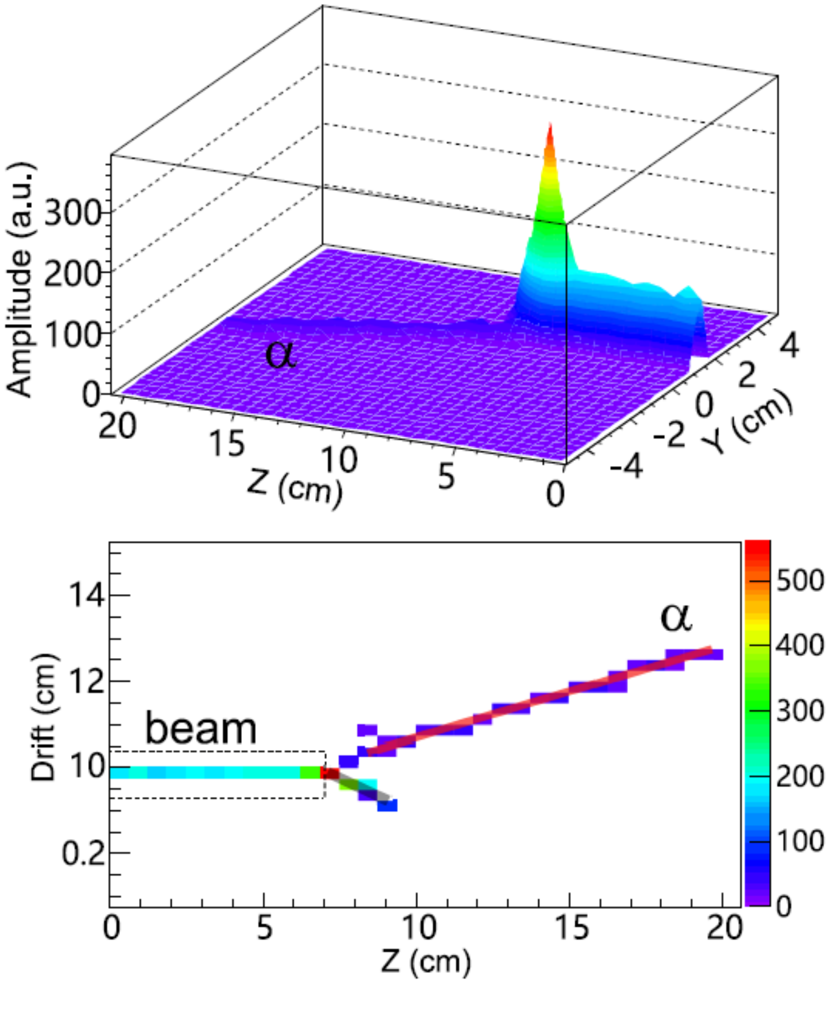


Experiments

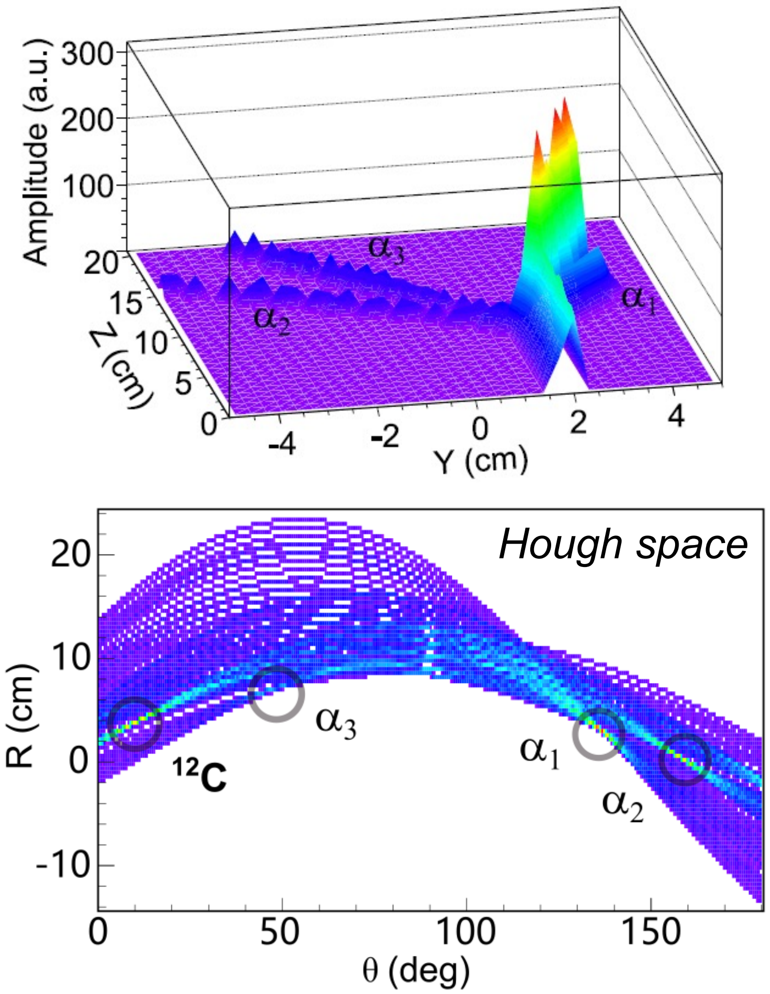
- $^{12}C^{4+}$ beam: 4.9 AMeV (HIRFL, IMP)
- TPC gas: C_4H_{10} at 50, 100 mbar
- Injection rate: 200-400 cps
- Beam time: 31.2 hours

Tracking for different channels

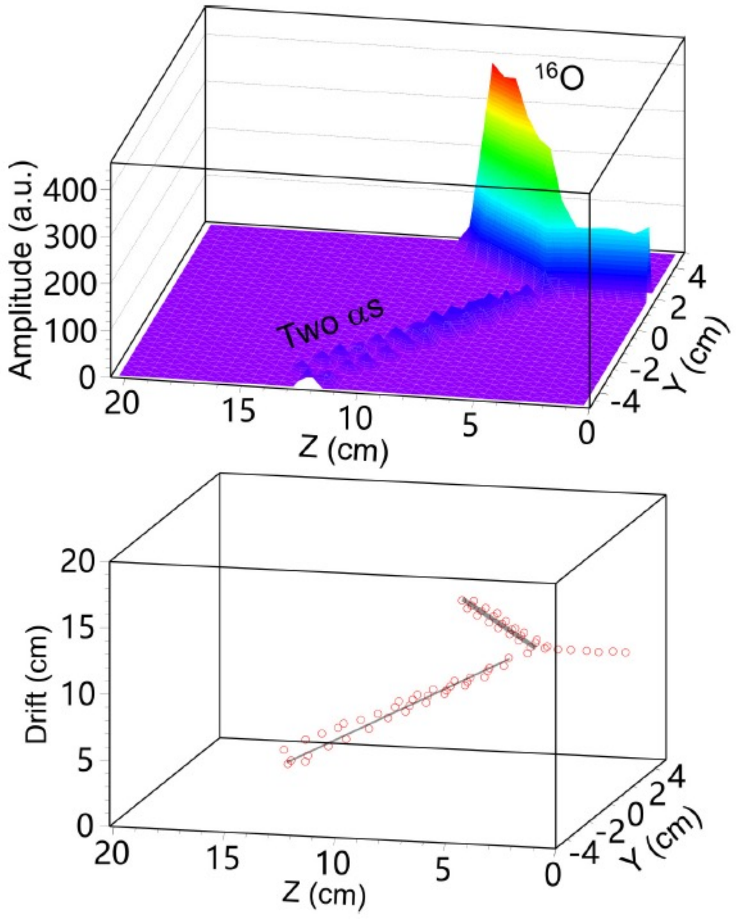
$^{12}C+^{12}C \rightarrow ^{20}Ne+\alpha$



$^{12}C+^{12}C \rightarrow ^{12}C+3\alpha$

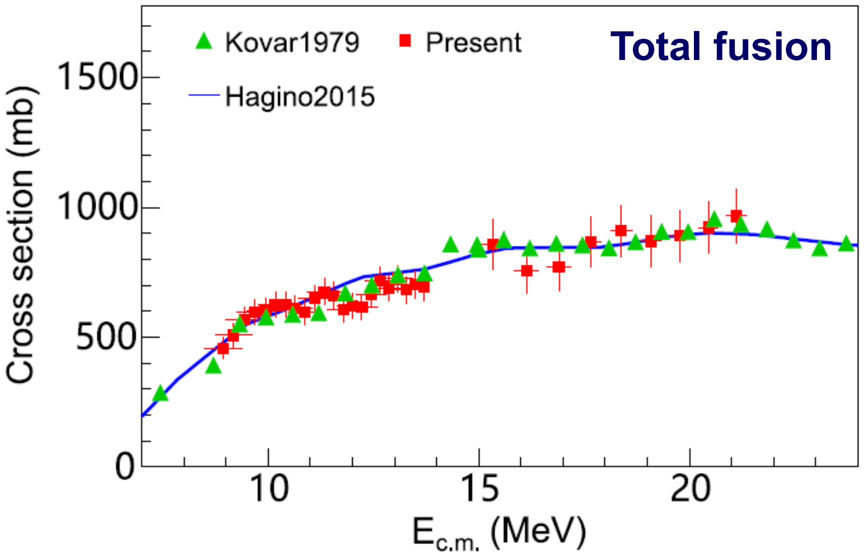


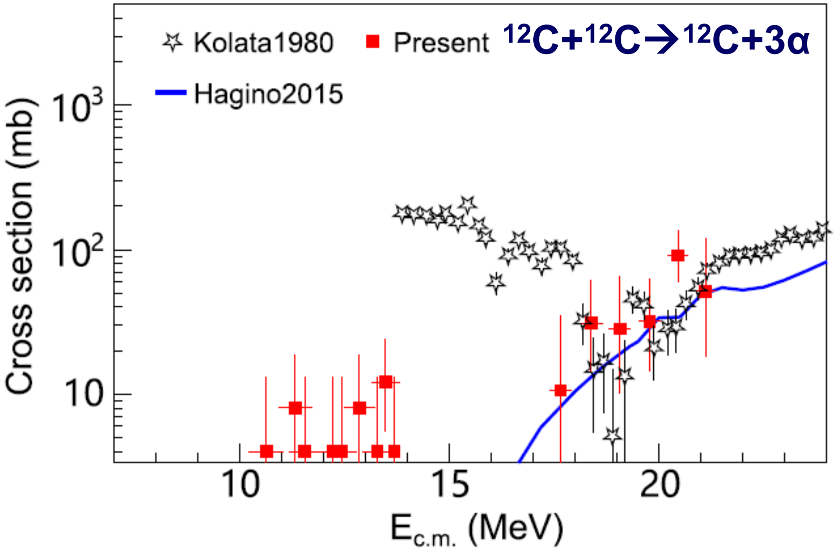
$^{12}C+^{12}C \rightarrow ^{16}C+^{8}Be(2\alpha)$



X.Y. Wang et al., CPC46, 104001(2022)

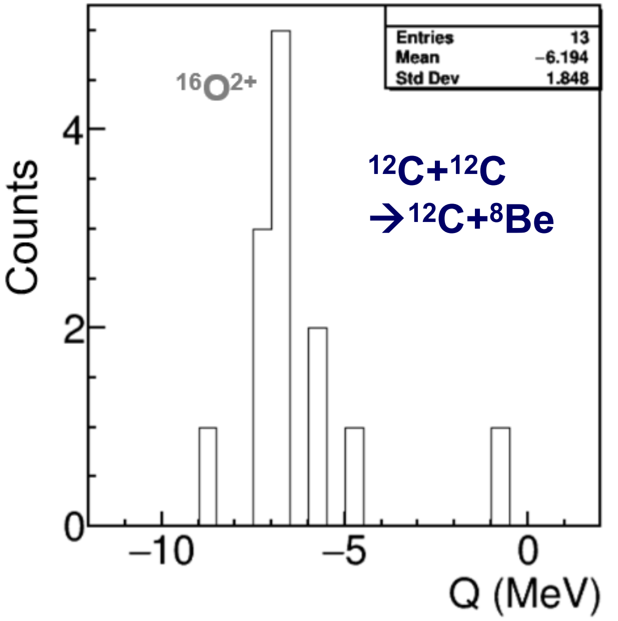
Experimental results



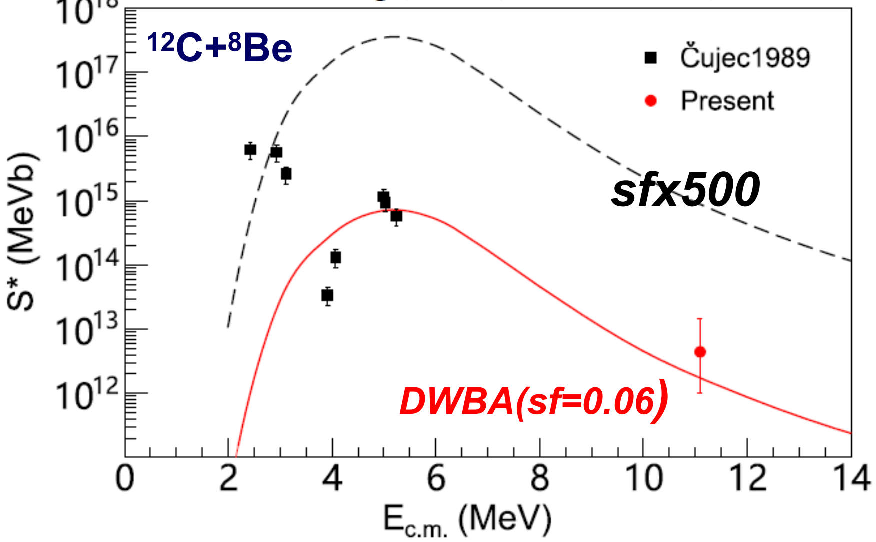


$^{12}C+^{12}C\rightarrow^{12}O+3a$

- ✓ Consistent with statistical calculations at E_{cm}>15 MeV
- ✓ At E_{cm}<15 MeV, other mechanisms are needed



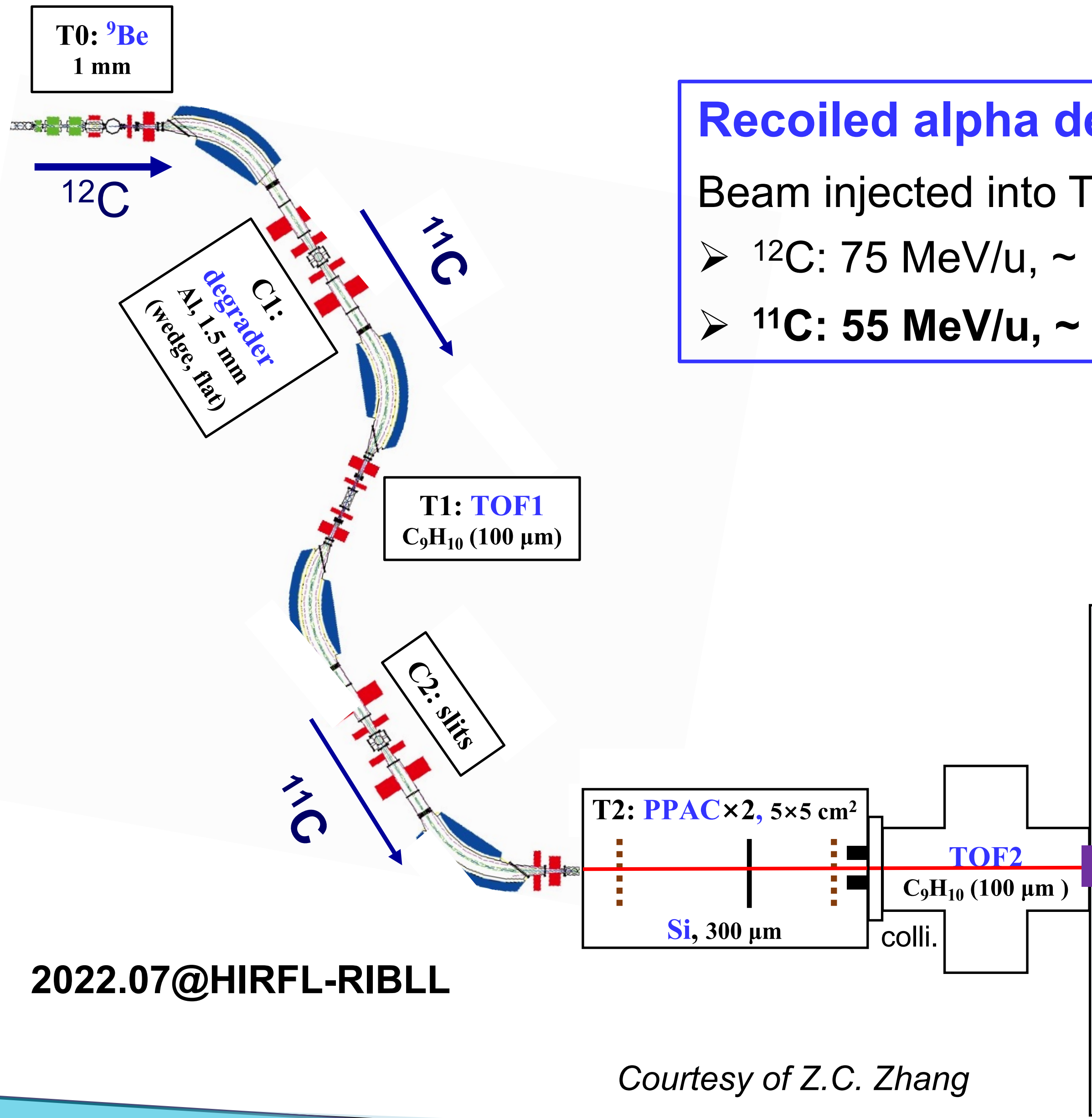
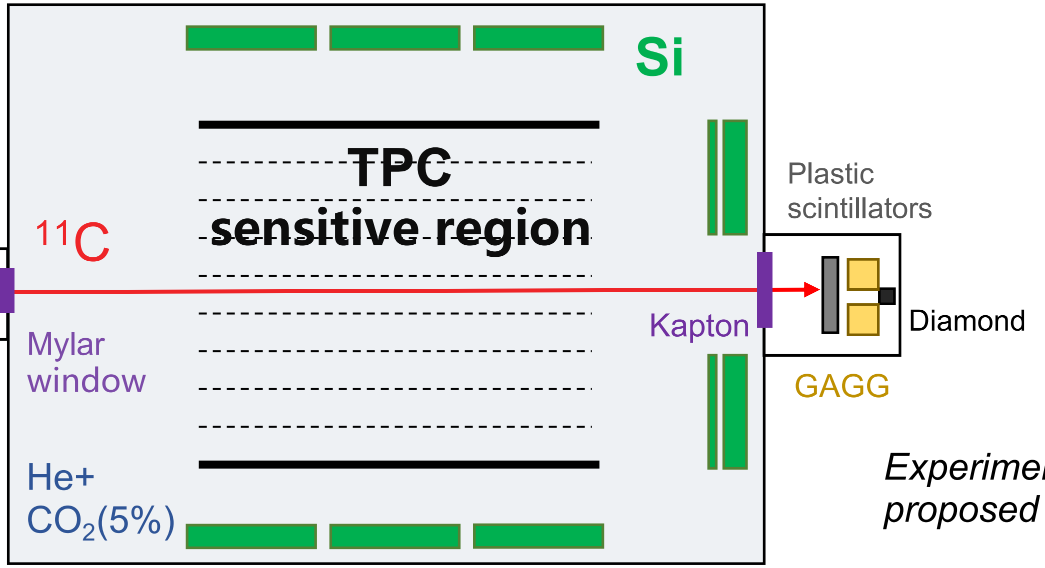
$$S^* = \sigma \cdot E \cdot \exp(87.21/\sqrt{E}+0.46E)$$



$^{12}C+^{12}C\rightarrow^{16}O+^{8}Be$

- ✓ At E_{cm}>3MeV, direct a-transfer reaction dominates
- ✓ At stellar energy(<3MeV), ^{8}Be decay can be detected by TPC

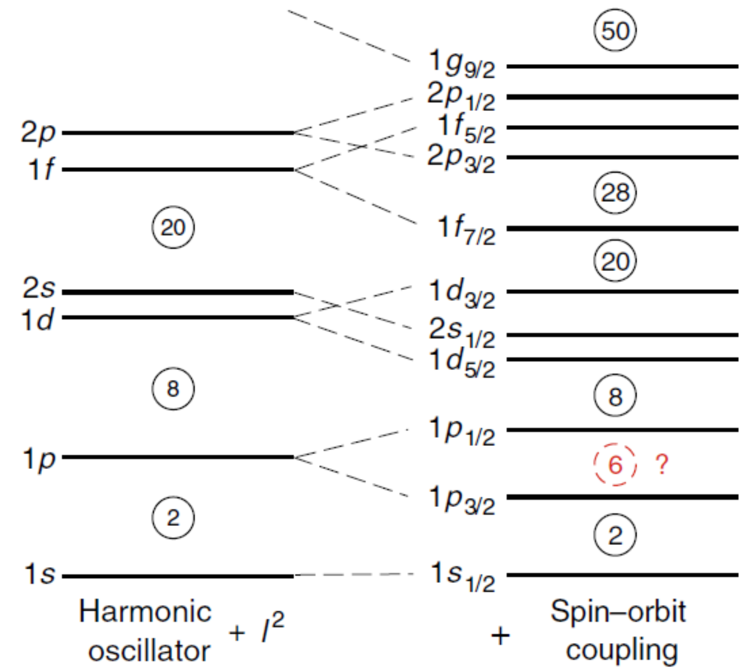
Study of ^{11,12}C+α scattering at high intense beams

Recoiled alpha detection

Beam injected into TPC

- ^{12}C: 75 MeV/u, ~ 10^4 pps
- **^{11}C: 55 MeV/u, ~ 10^4-10^5 pps**



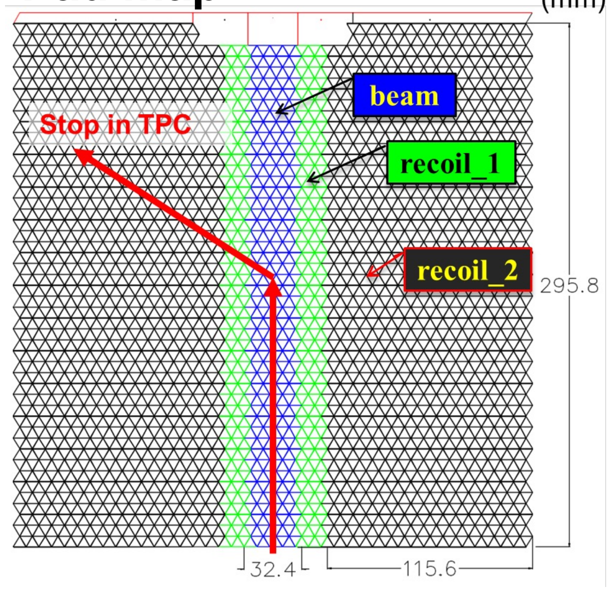
2022.07@HIRFL-RIBLL

Courtesy of Z.C. Zhang

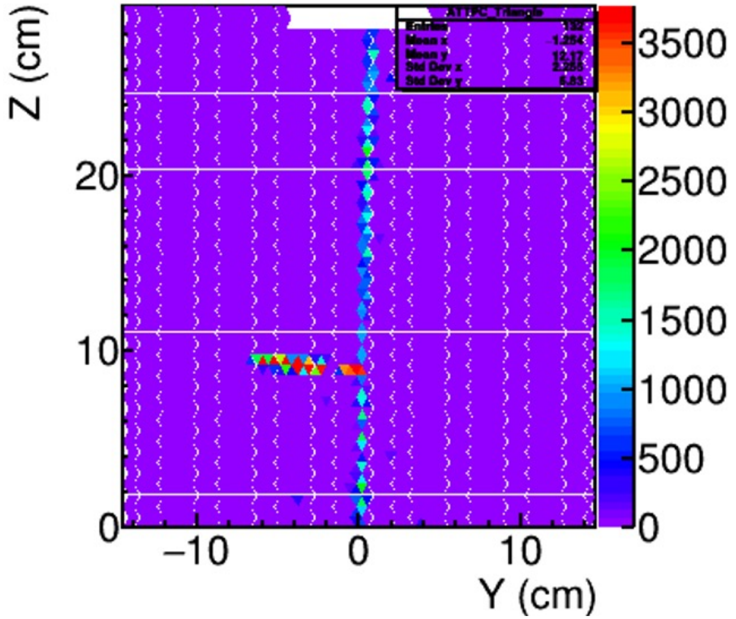
Experiment proposed by Ong Hooi Jin

Beam rate tests and preliminary results

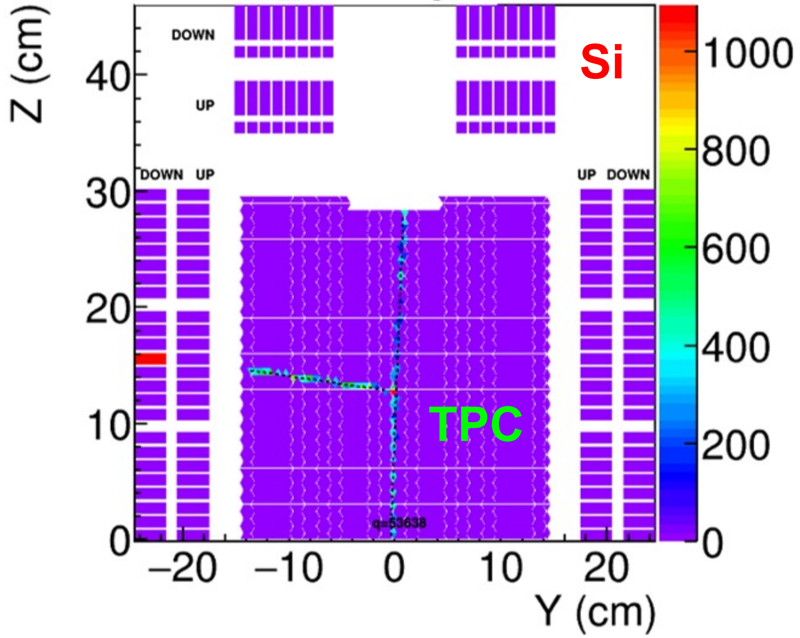
Pad map

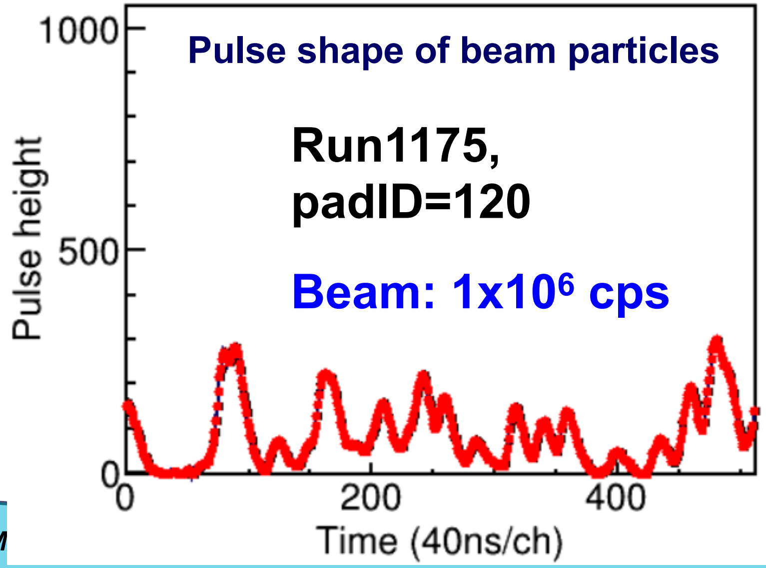


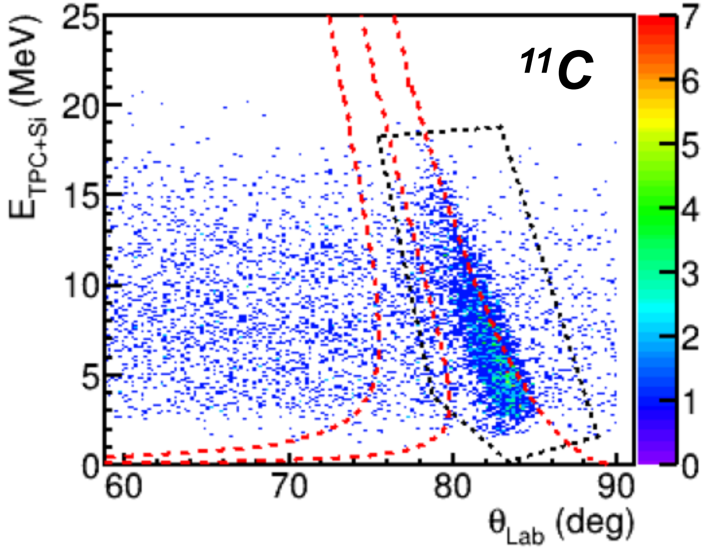
α stopped in TPC

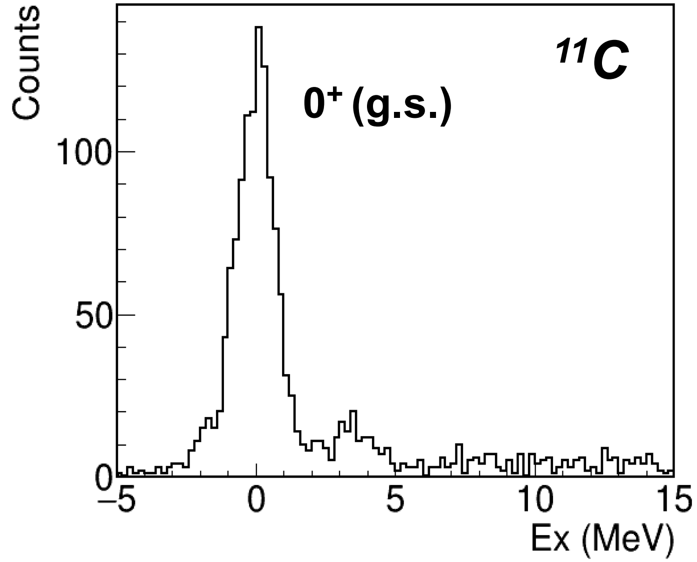


α detected by TPC+Si

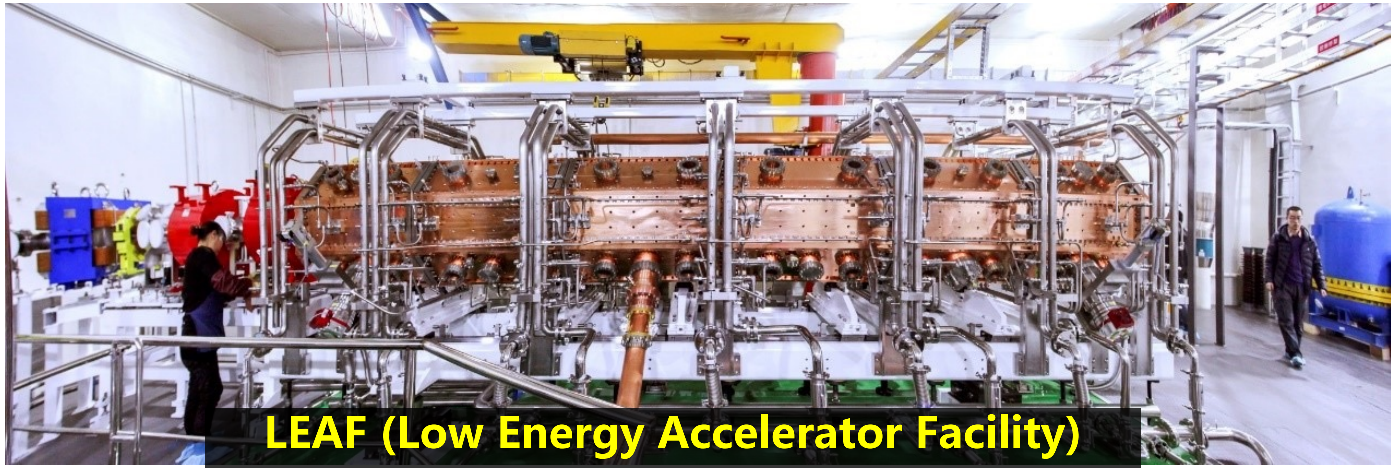




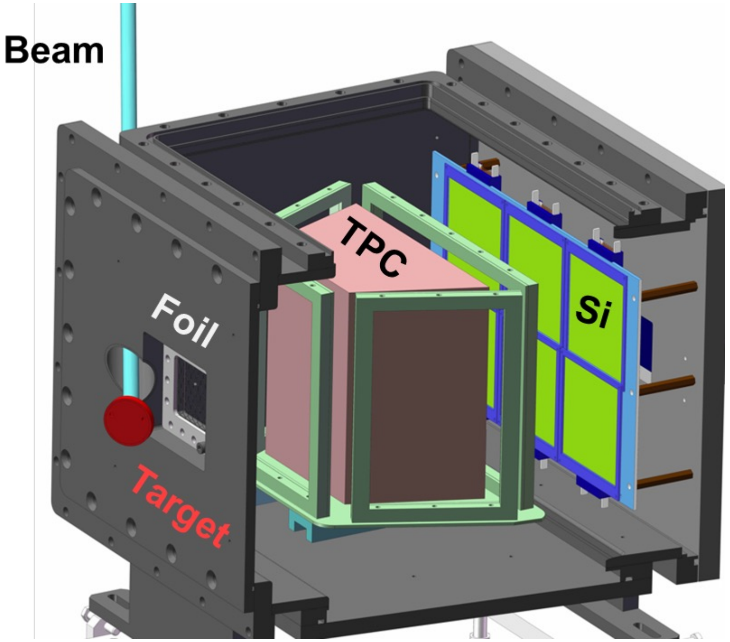




Direct measurement of $^{12}C+^{12}C$



TPC：50-130 mbar

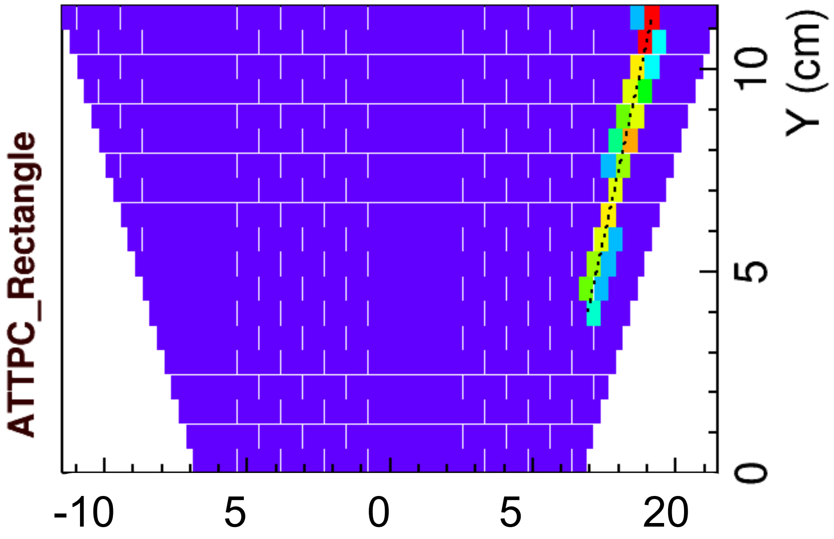


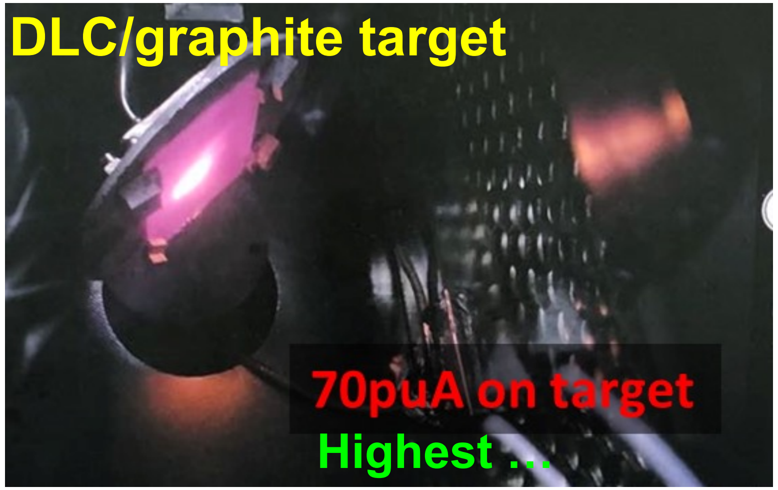
^{12}C: 0.38-0.63 MeV/u

Current: upto 80 pμA

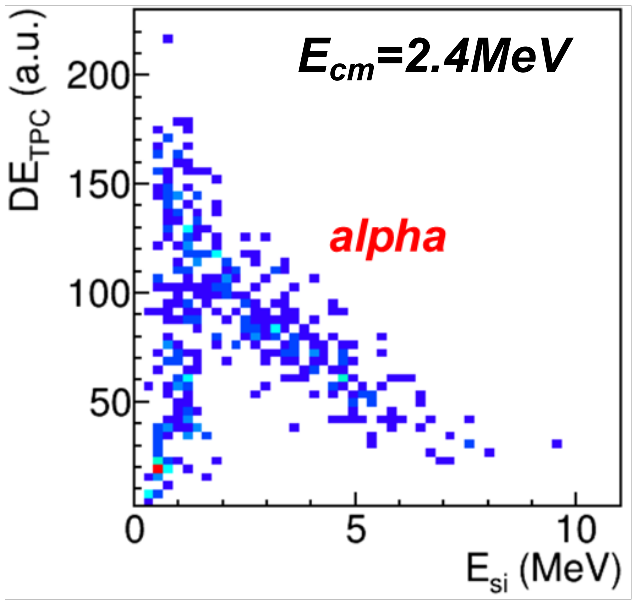
TPC gas: He mixture

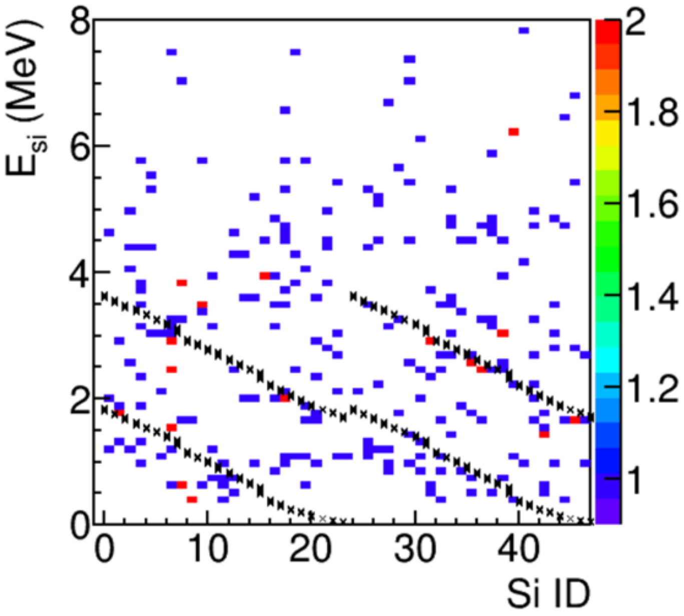
Pressure: 90-100 mbar

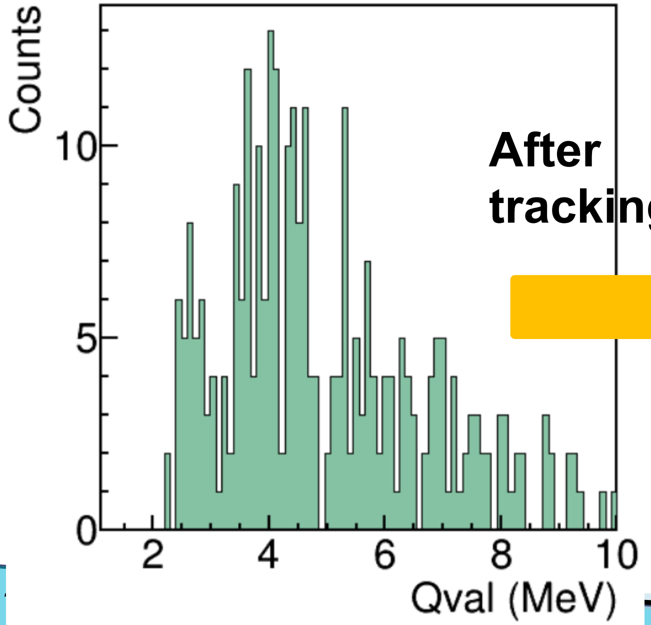




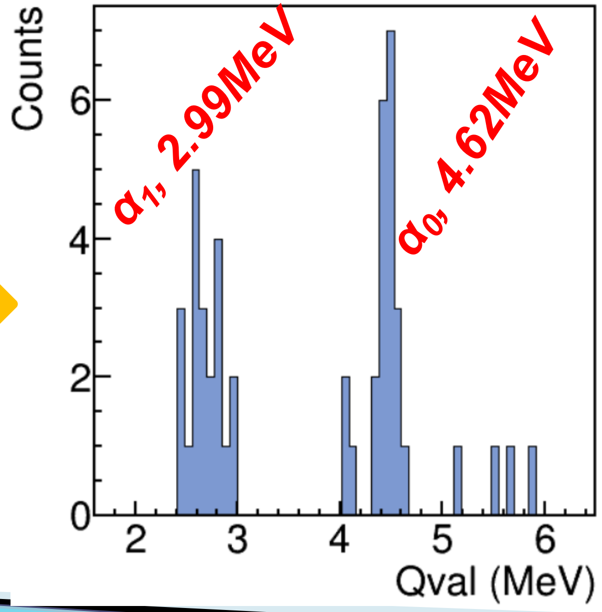
Background suppression



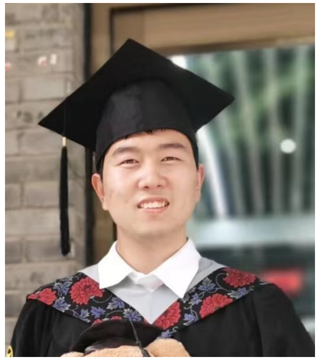




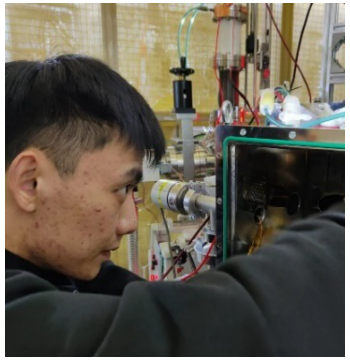
After tracking

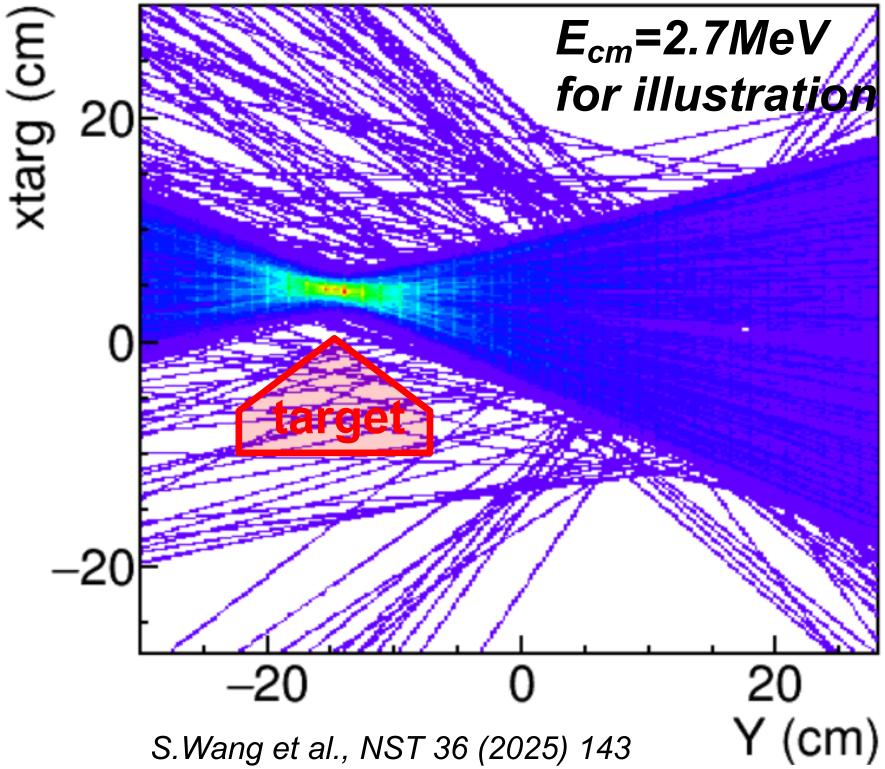


Yunzhen Li



Shuo Wang





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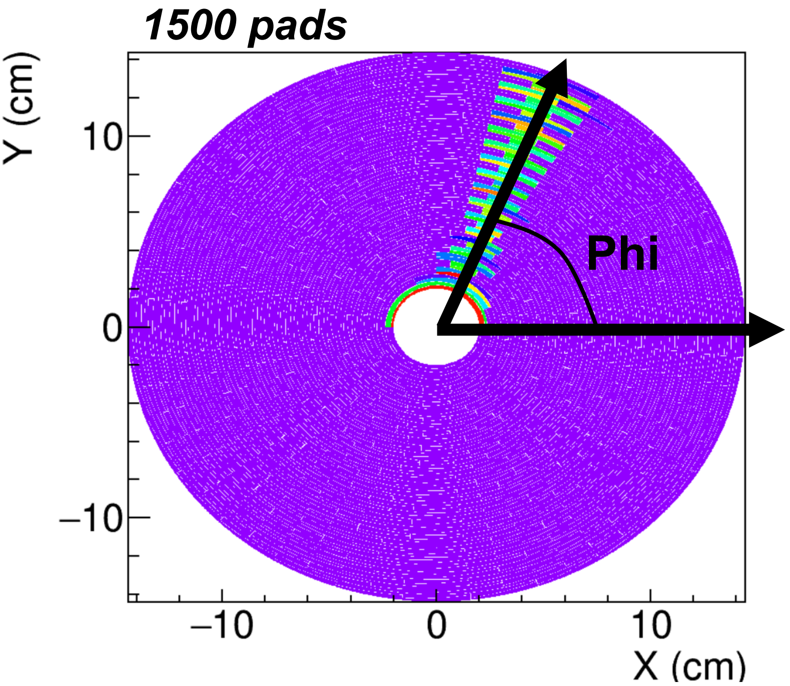
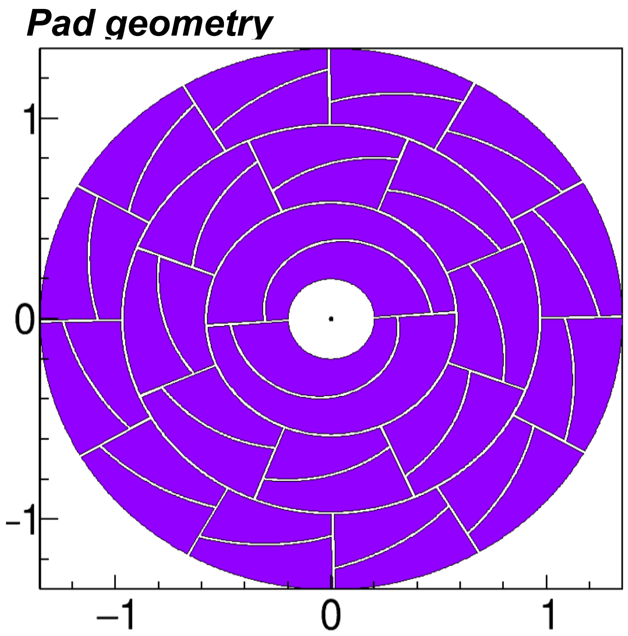
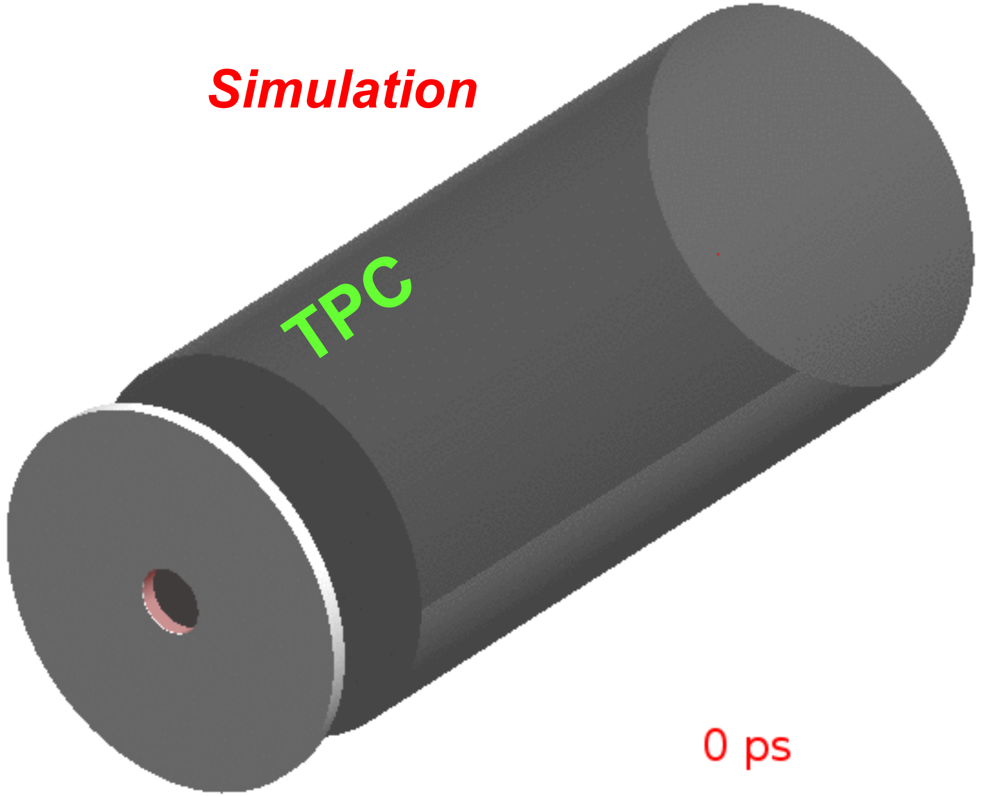
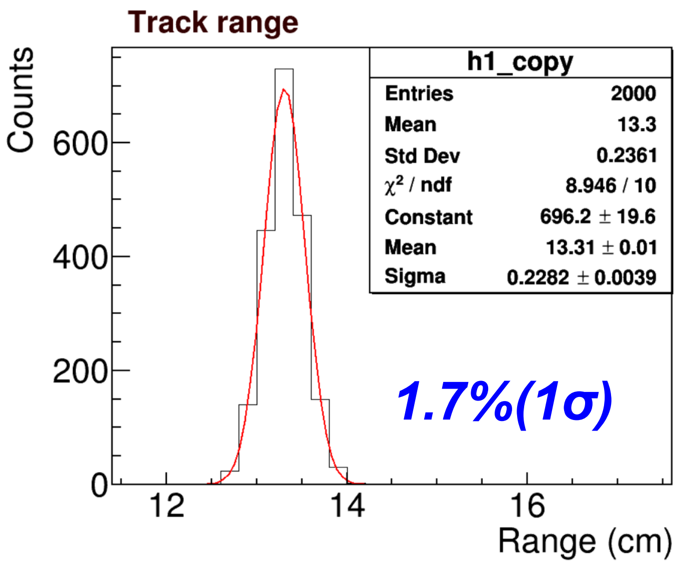
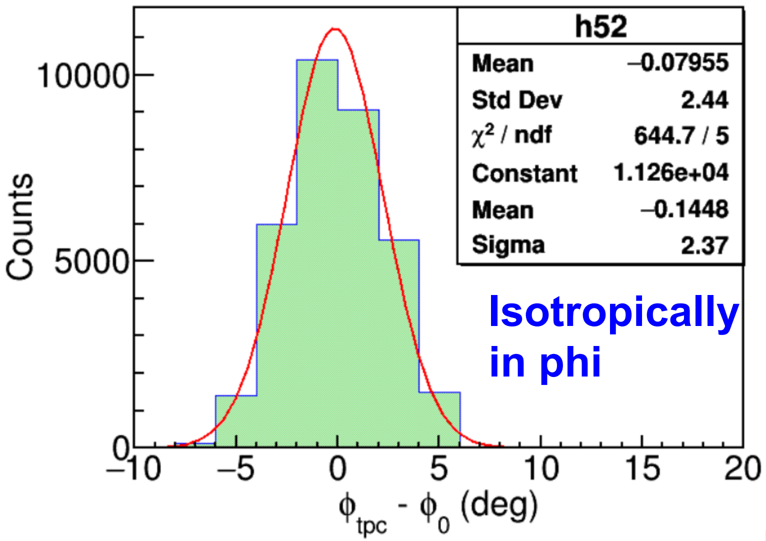
cMATE: range, angular resolution (design on simulation)





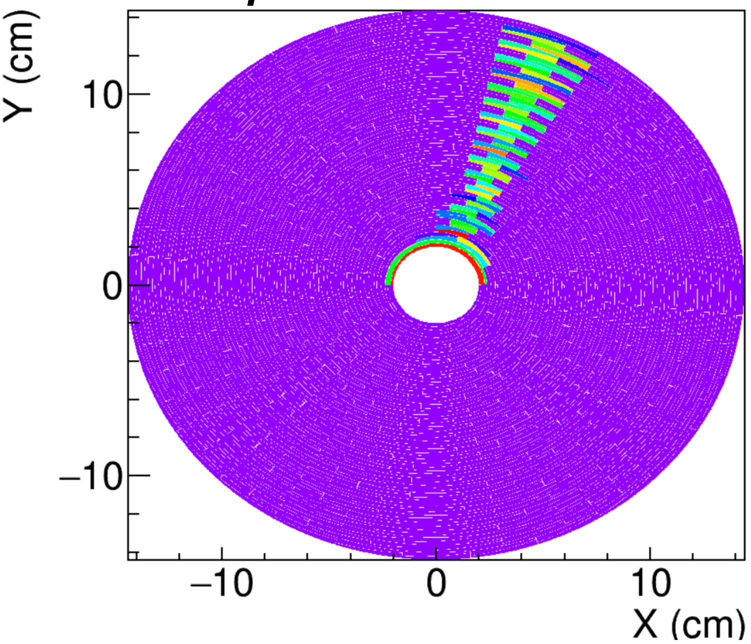




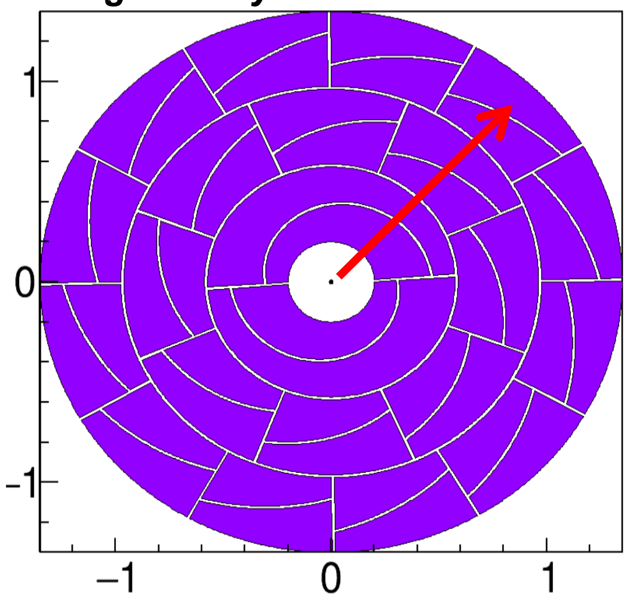


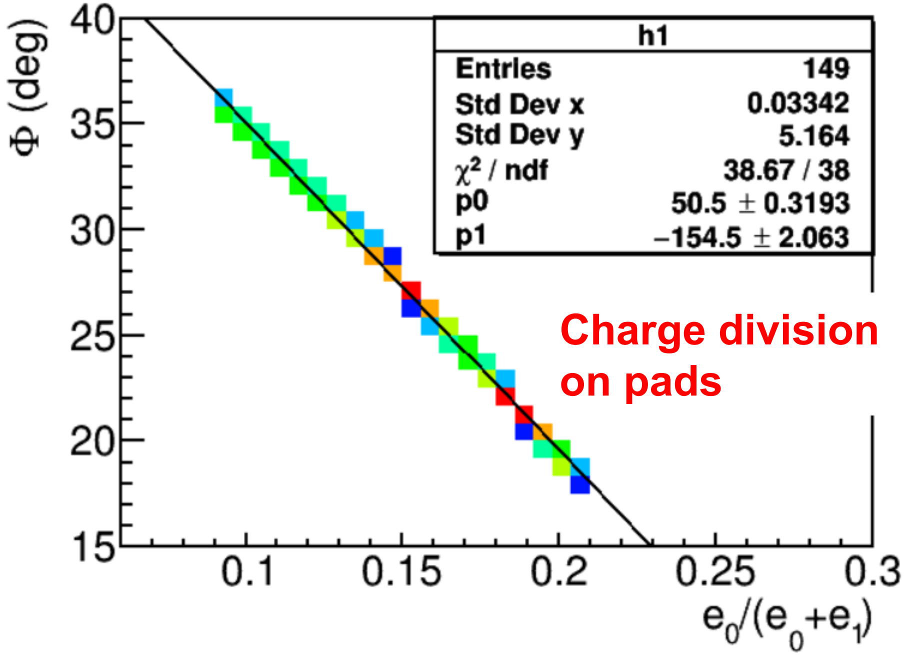
cMATE: range, angular resolution (design on simulation)

1500 pads

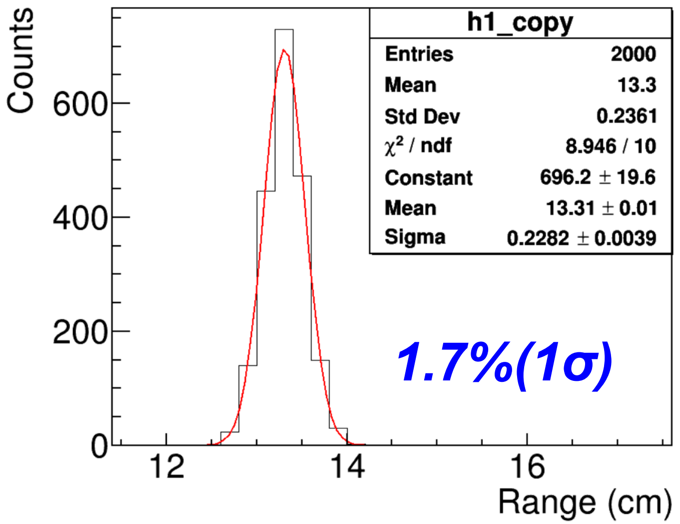


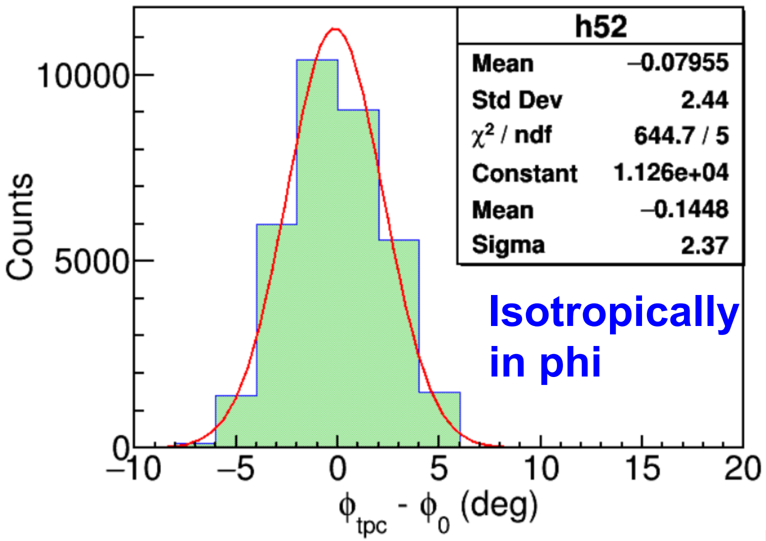
Pad geometry

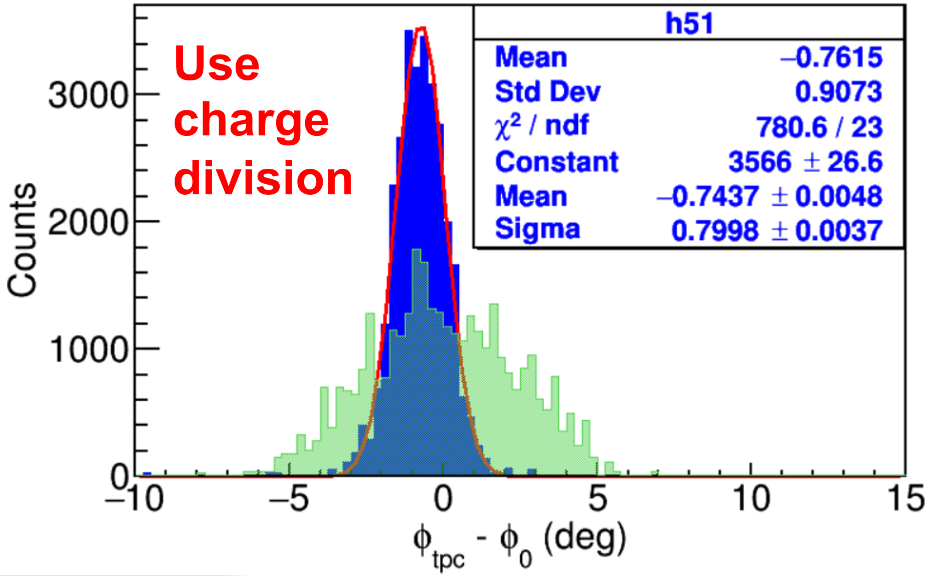




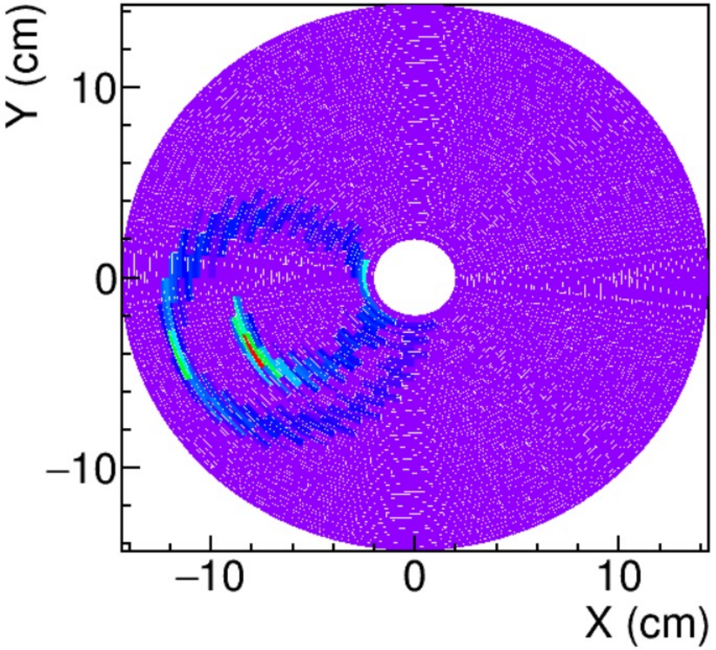
Track range

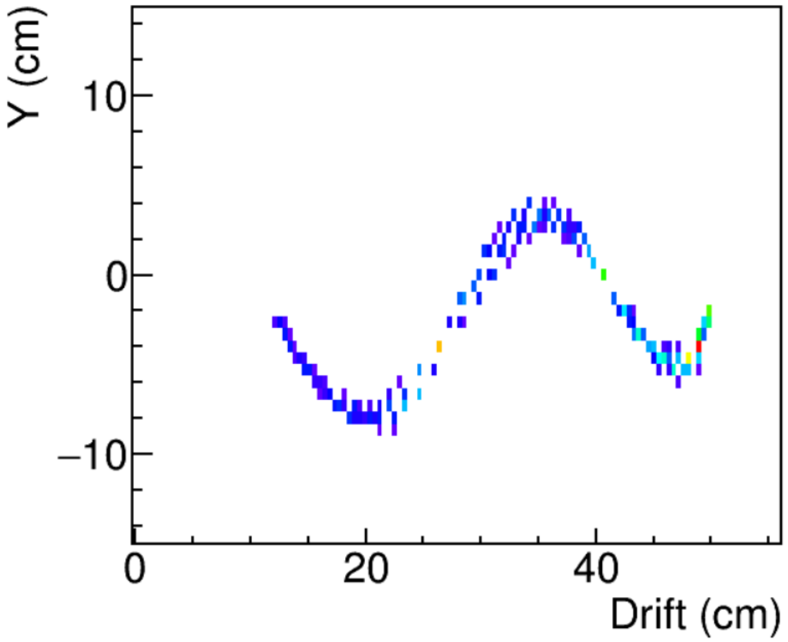


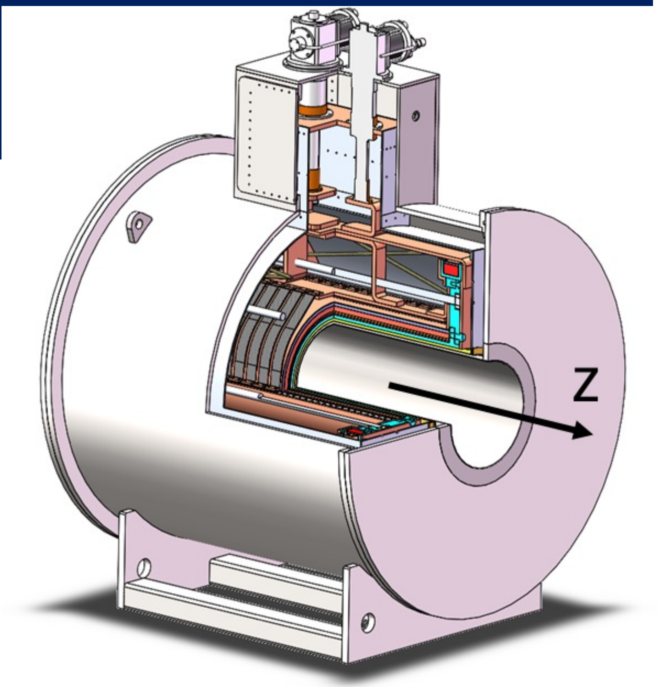


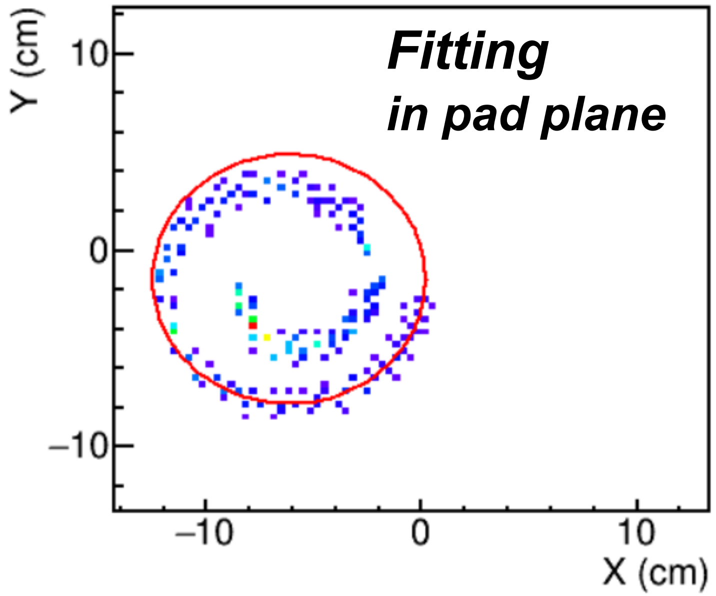


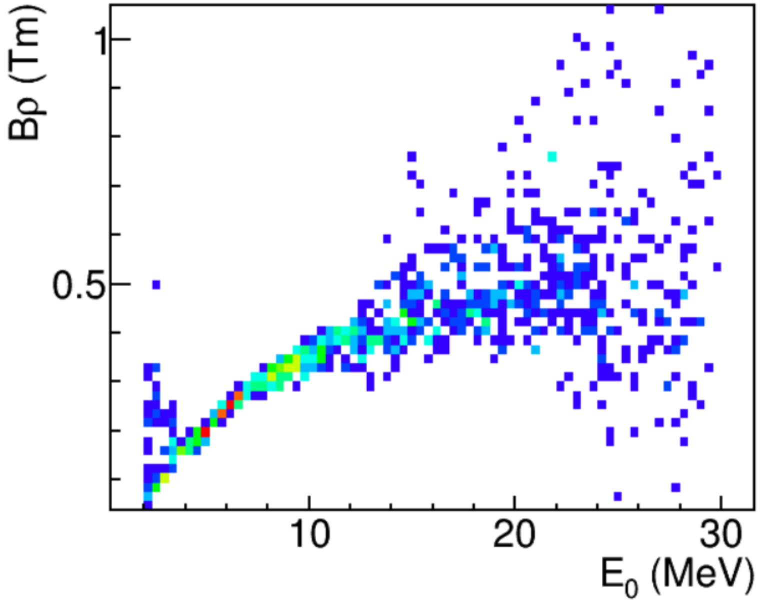
cMATE in solenoid (simulation)

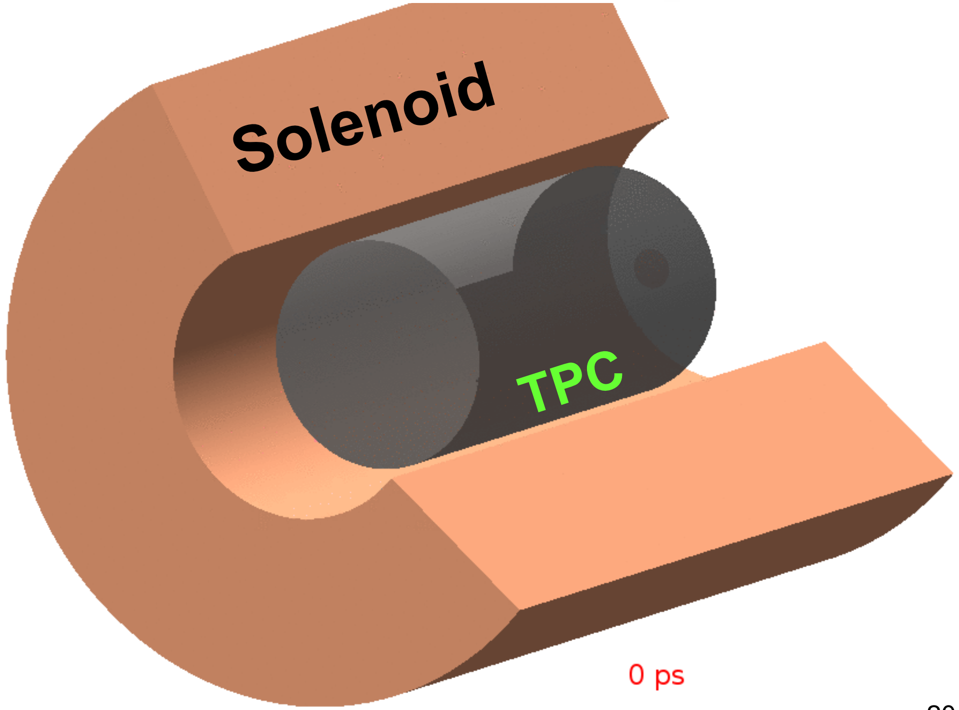








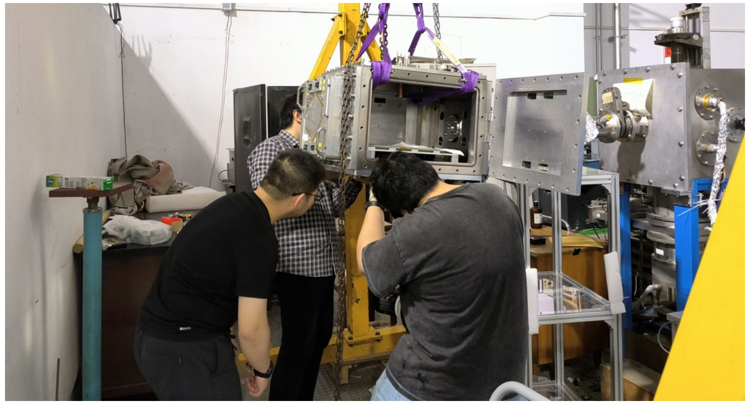




Summary

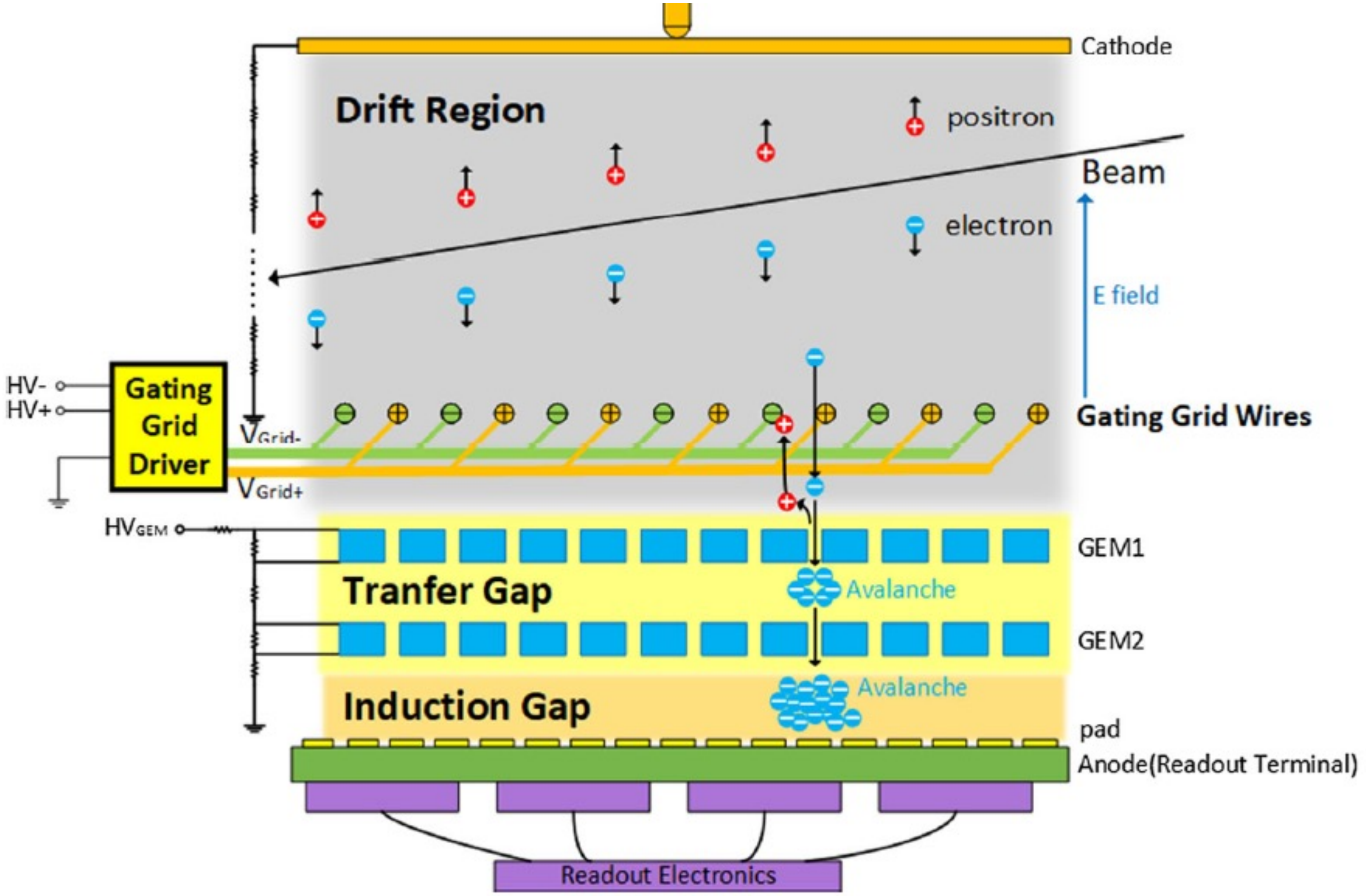
- MATE TPC have been constructed
- $^{12}C+^{12}C$, $^{19}O+^{12}C$ fusion measurements with beam rate ~ 100 cps
- $^{14}N$$^{14}O(\alpha,p)$ (challenging at 10^5 cps), $^{11}C(\alpha,\alpha')$ (fine) measurements at 10^5 cps
- $^{12}C+^{12}C$ direct measurement at stellar energies with beam intensity ~ 70 pμA
- To develop Cylindrical TPC working inside solenoid (under design)
- Decay measurement (in plan)
  - Gating Grid has been tested, but needs improvement

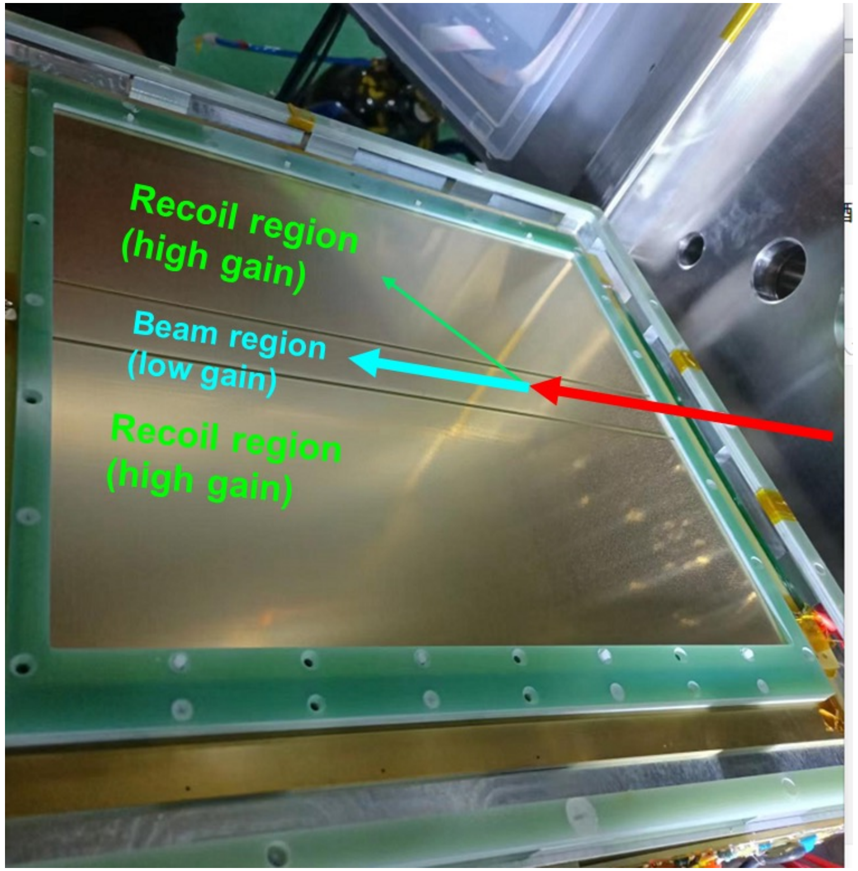
$^{12}C(p,p')$ test at Peking University



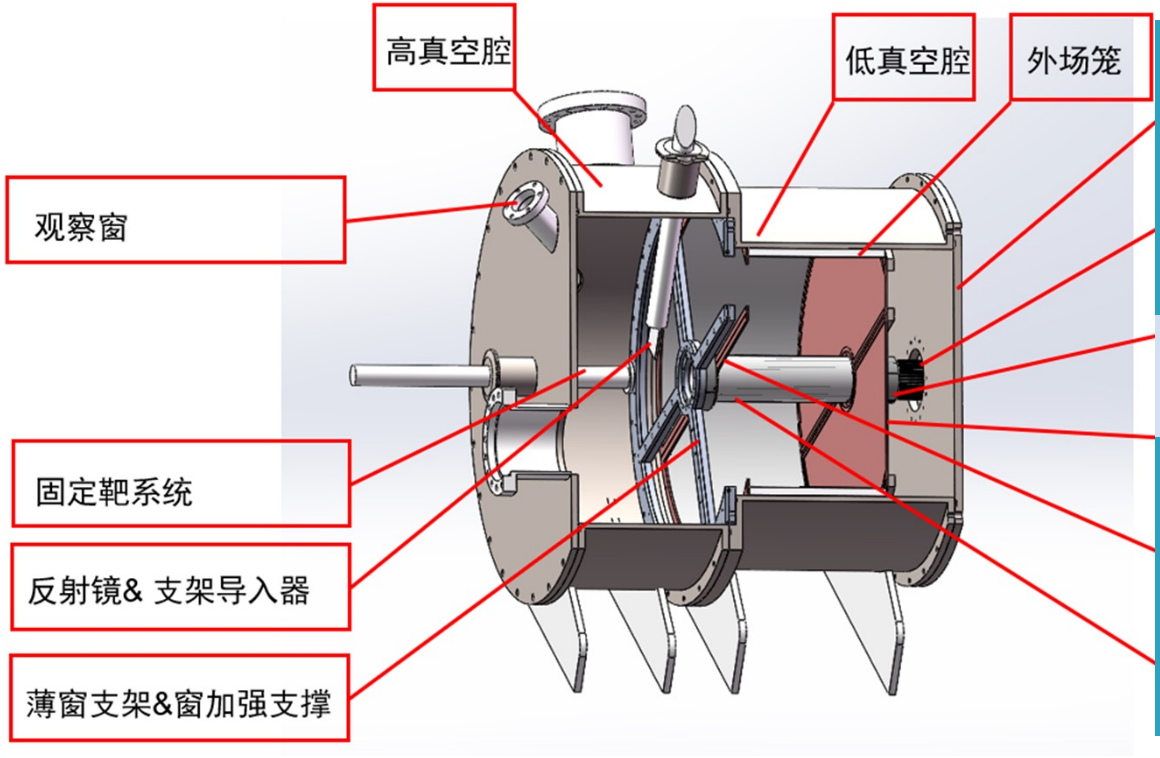
Trigger efficiency: make a reliable trigger

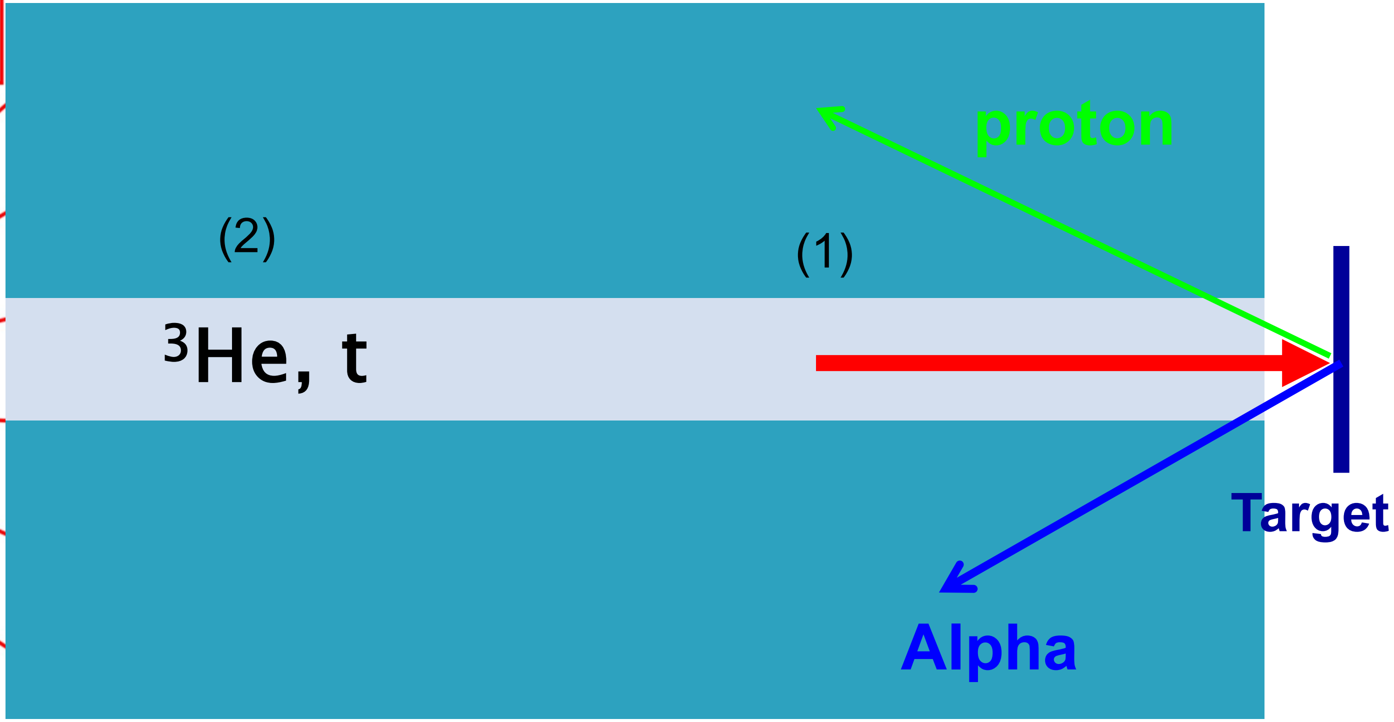
- GEM signal (recoil region) as trigger for GET
- Gating wires will be used to tune beam region



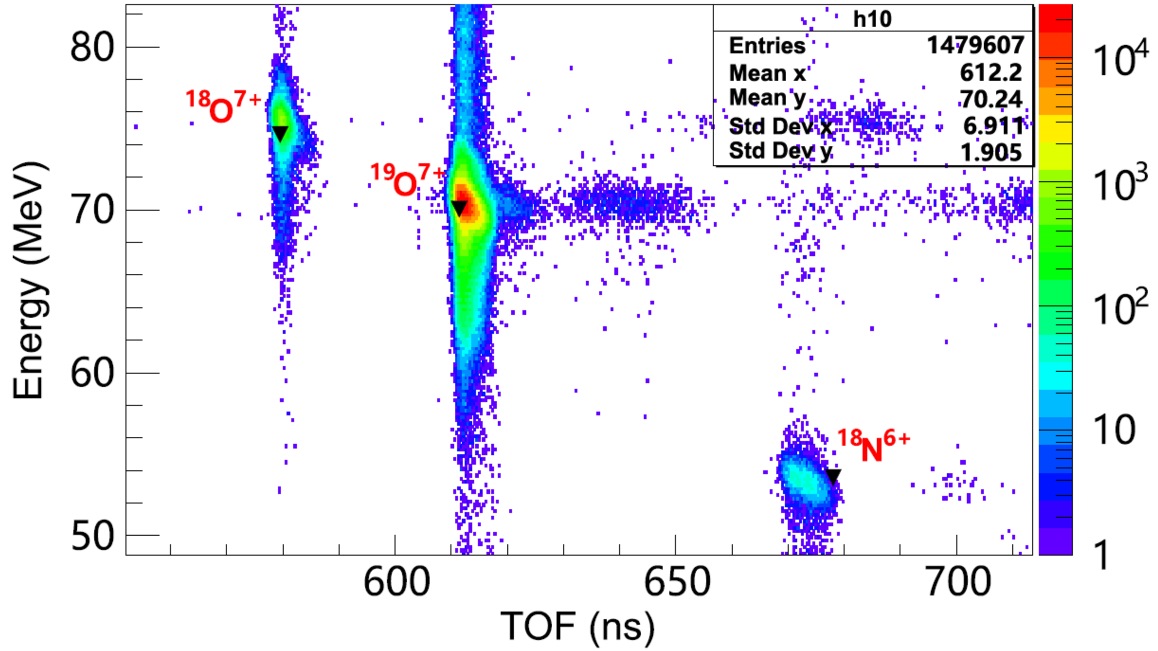


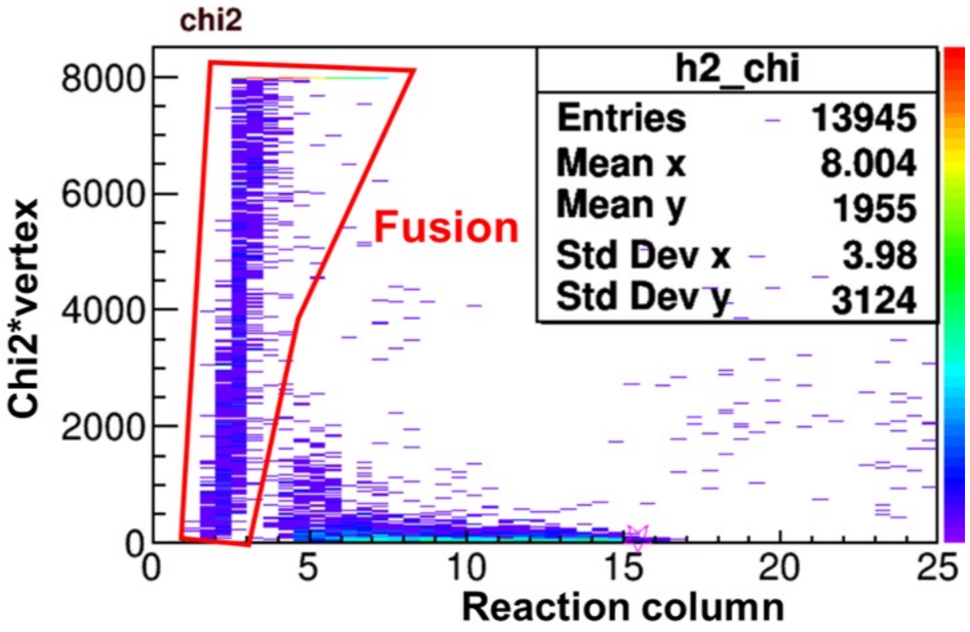
Cylindrical TPC

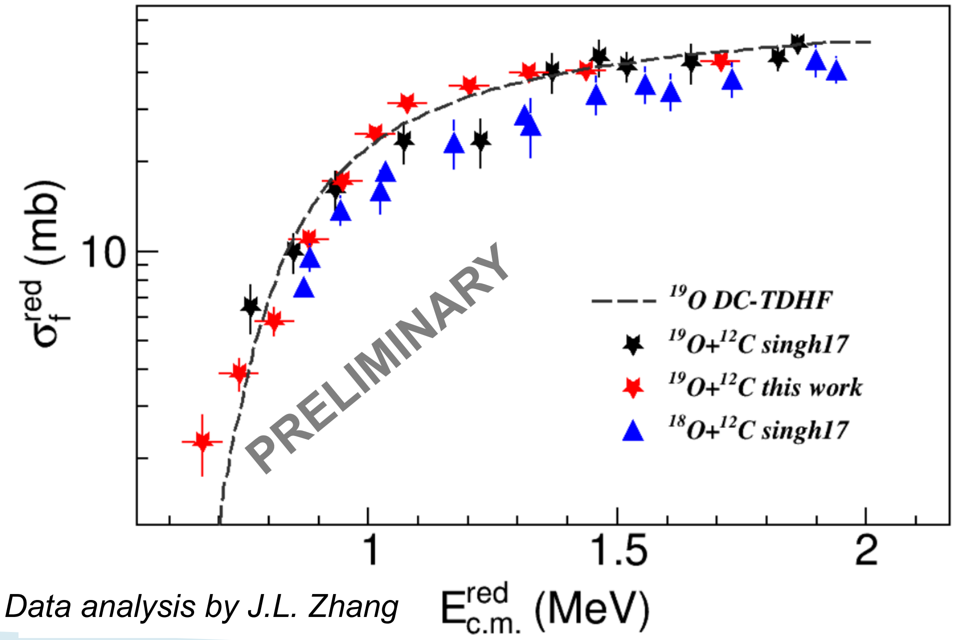




^{19}O+^{12}C reaction measurement at RIBLL



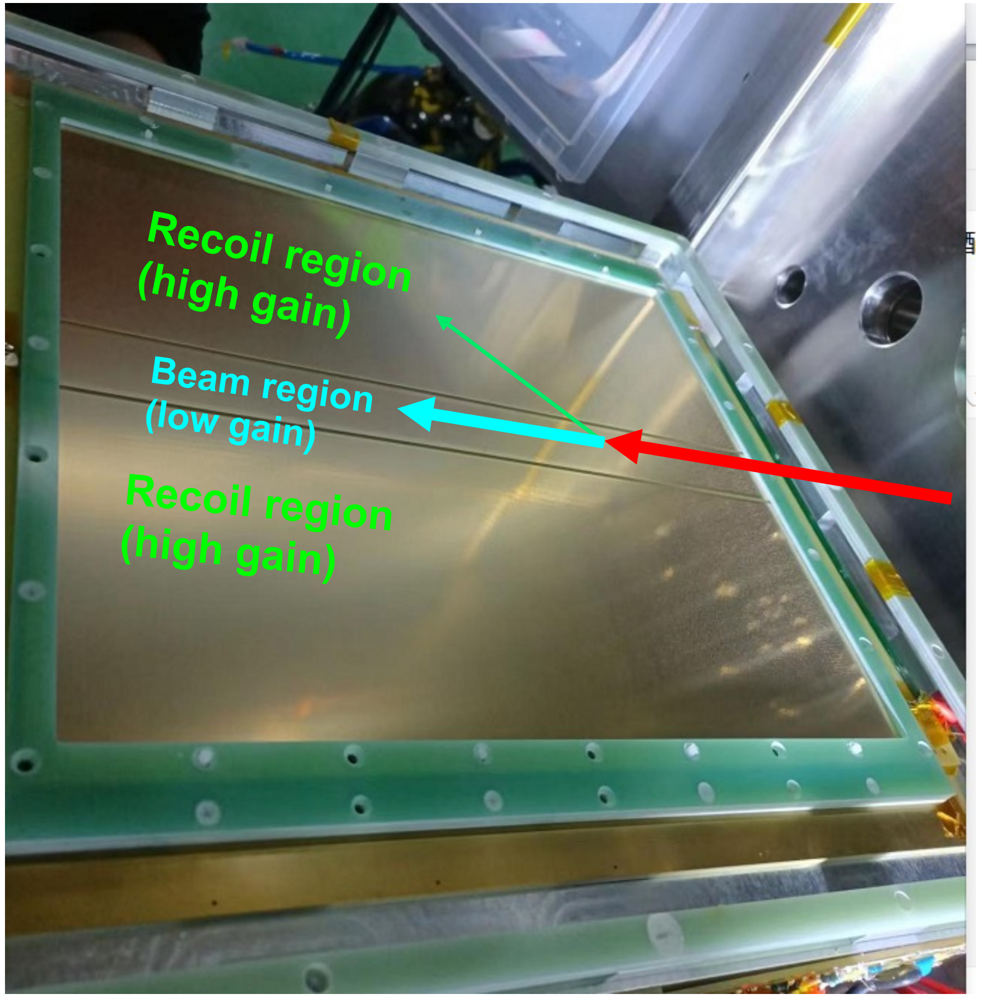




- Primary beam: $^{18}O^{8+}$, 6.17MeV/u, 260enA (HIRFL)
- Primary target: D_2 gas cooled by LN_2 at 150mbar, 500mbar
- Second beam: $^{19}O^{7+}$, ~10^3 pps
  - $^{18}O(d,p)^{19}O$ reaction
  - ^{19}O purity upto 95%
- TPC(pMATE) at 50 and 100 mbar isobutane

Data analysis by J.L. Zhang

Segmented THGEM



Collaboration with Shinsuke Ota-san (CNS & RCNP)

- **GEM area: 280x300mm^2**
- **GEM thickness: 400 μm**
- **Beam region and recoil regions are isolated**
- **Recoil region: light particles (gain > 1000)**
- **Beam region: beam particles (gain < 100)**
- **Gain difference in these two regions > 10**