中国科学院近代物理研究所
Institute of Modern Physics, Chinese Academy of Sciences

Development of low-pressure micromegas TPC and application in nuclear astrophysics with high intense primary beams

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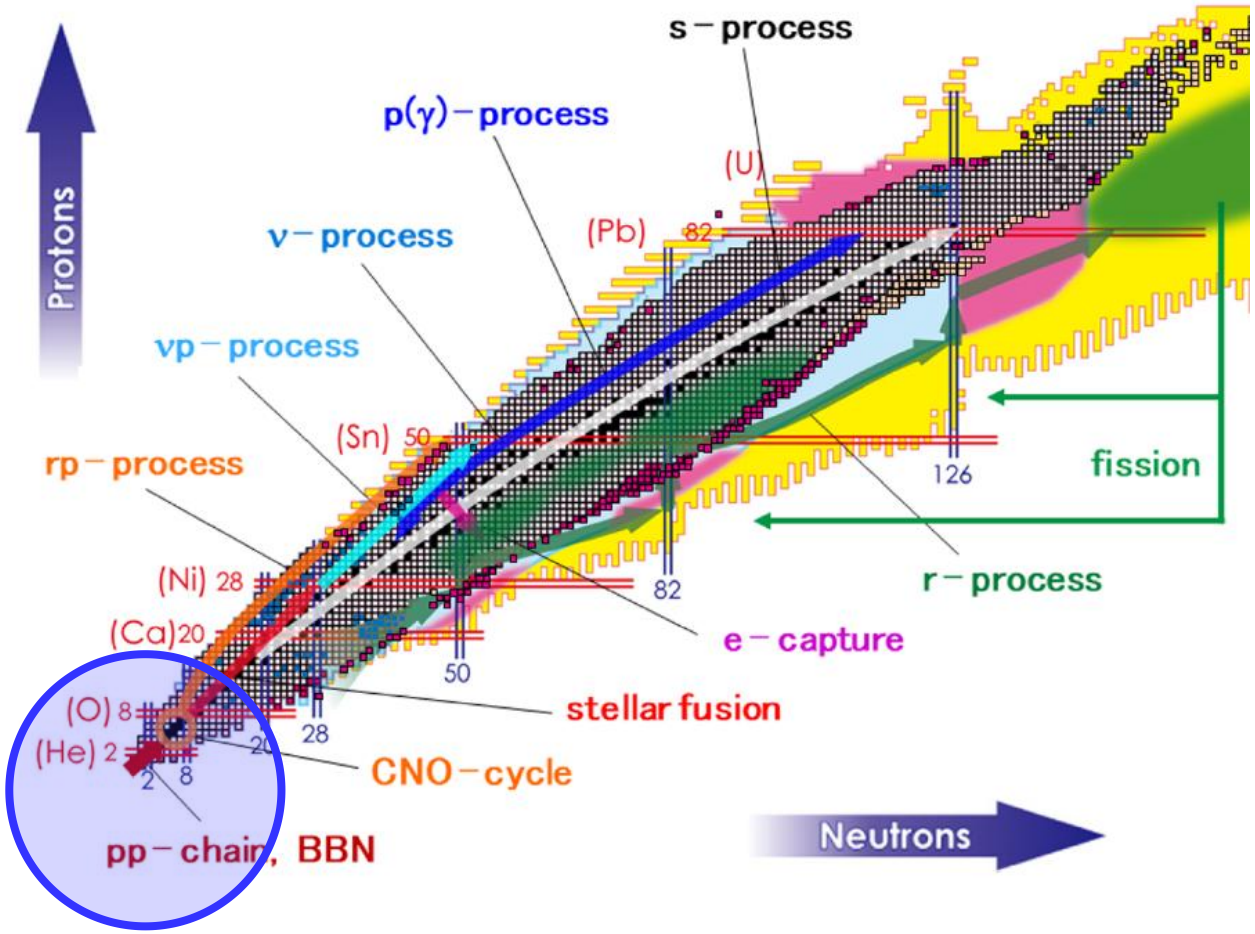
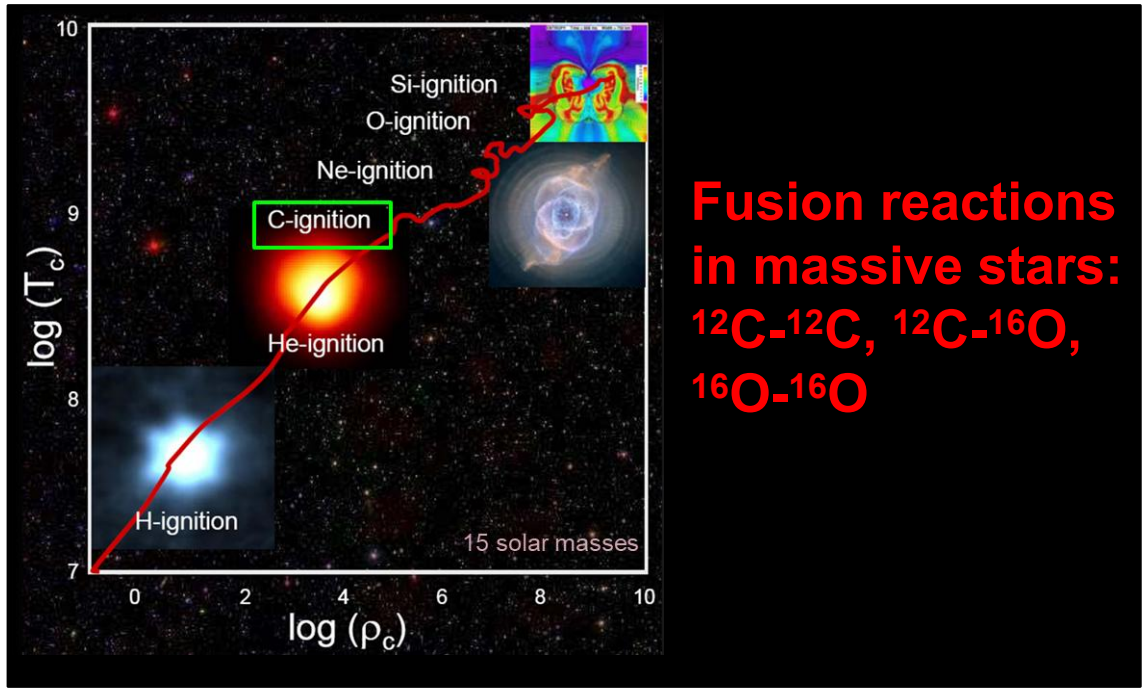
FATaNS2026, June 6-8, RIKEN

Outline

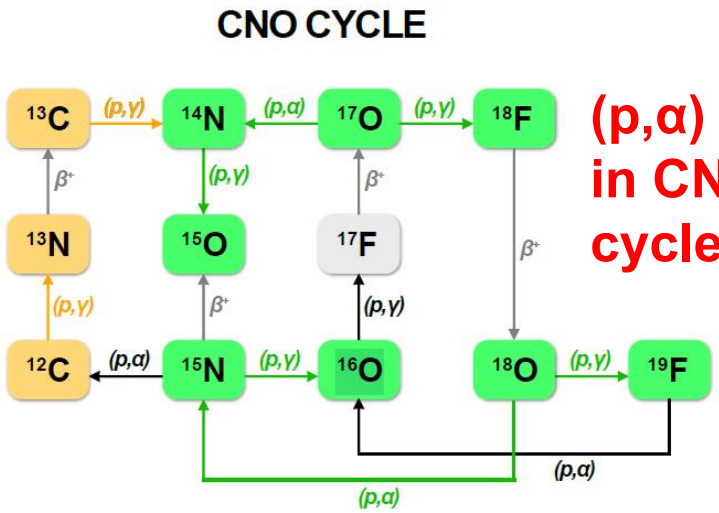
- Motivation
- Double Micro-Mesh (DMM) TPC under intense beams
  - Measurement of $^{12}C+^{12}C$ fusion reaction
  - Measurement of $^{18}O(p,\alpha)$ reaction
- Summary

Important thermonuclear reactions with charged particle emission





Fusion reactions in massive stars: ^{12}C-^{12}C, ^{12}C-^{16}O, ^{16}O-^{16}O

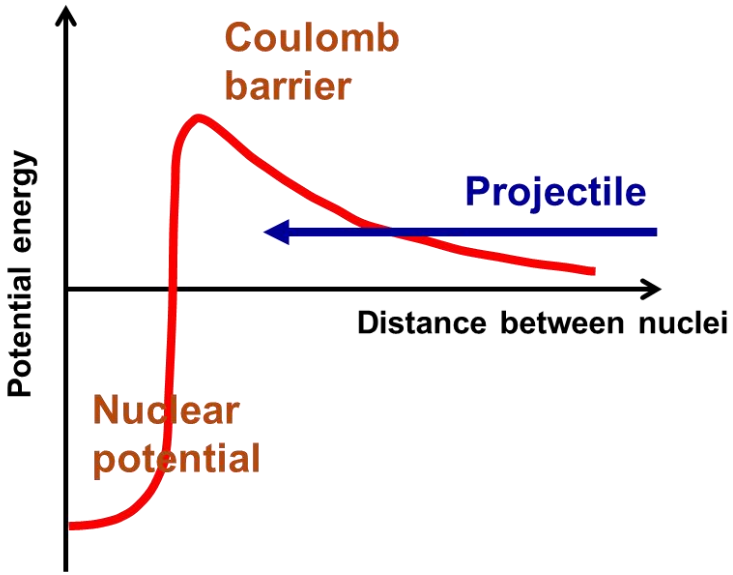


(p,α) closed reactions in CNO, NeNa, MgAl cycles

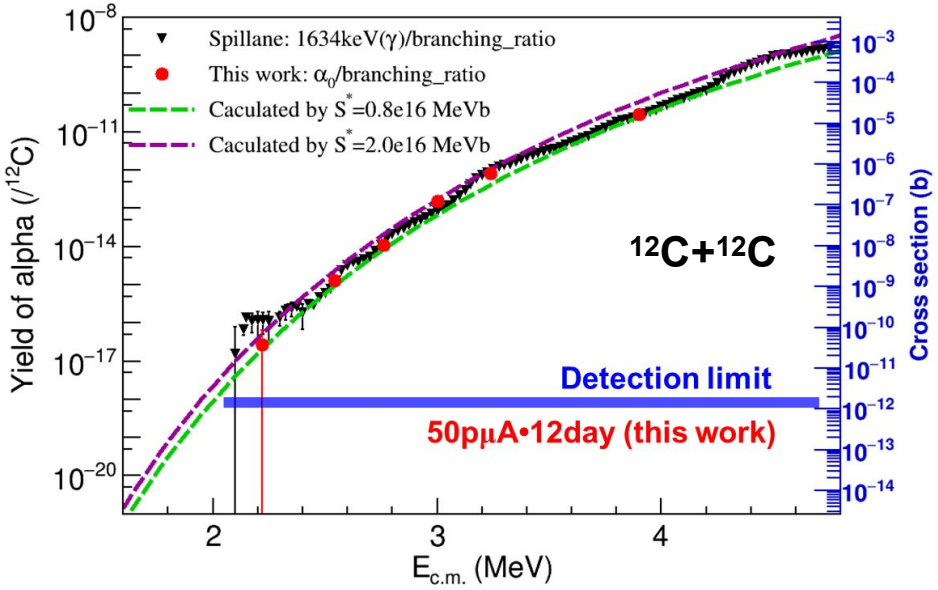
Nuclear physics is the key!

"Progress in nuclear astrophysics of east and southeast Asia", AAPPS Bulletin (2021) 31

Experimental challenges in direct measurements

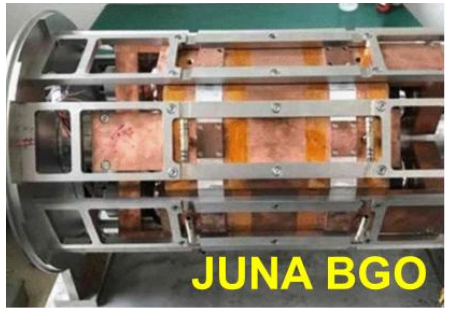


- ✓ Higher beam intensities
- ✓ Lower background

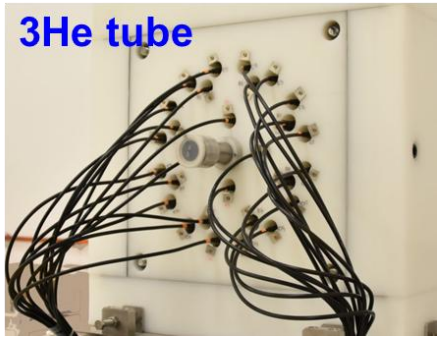


What do we measure?

Charged particle



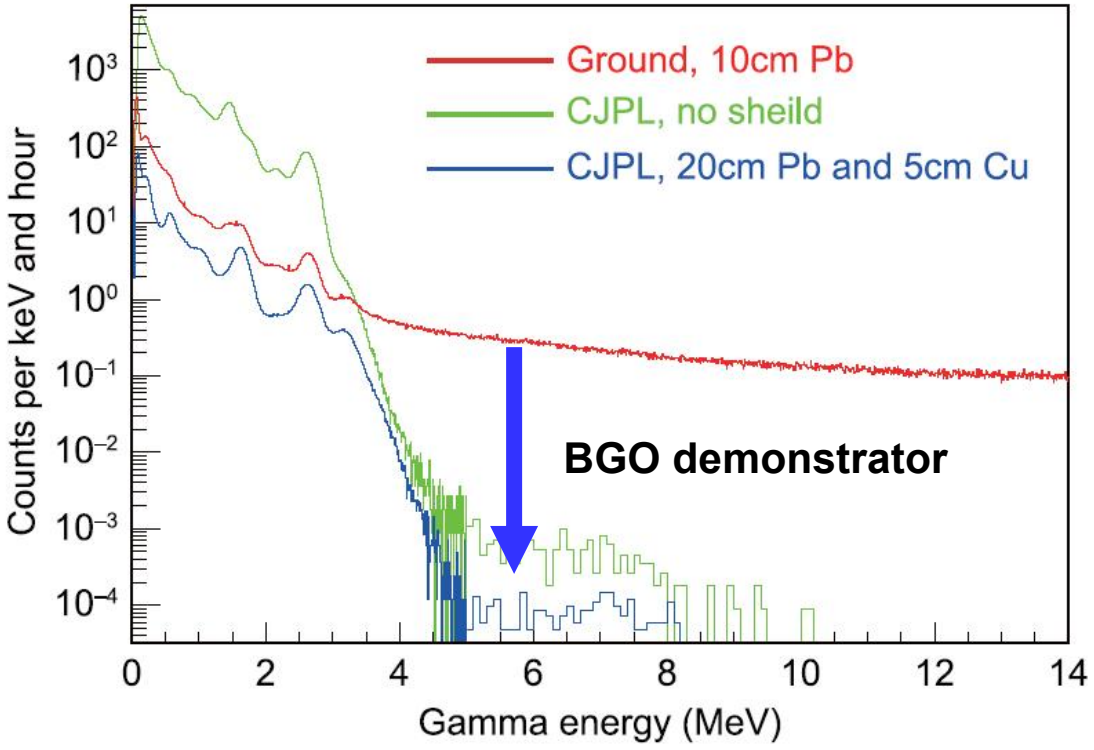
Gamma rays



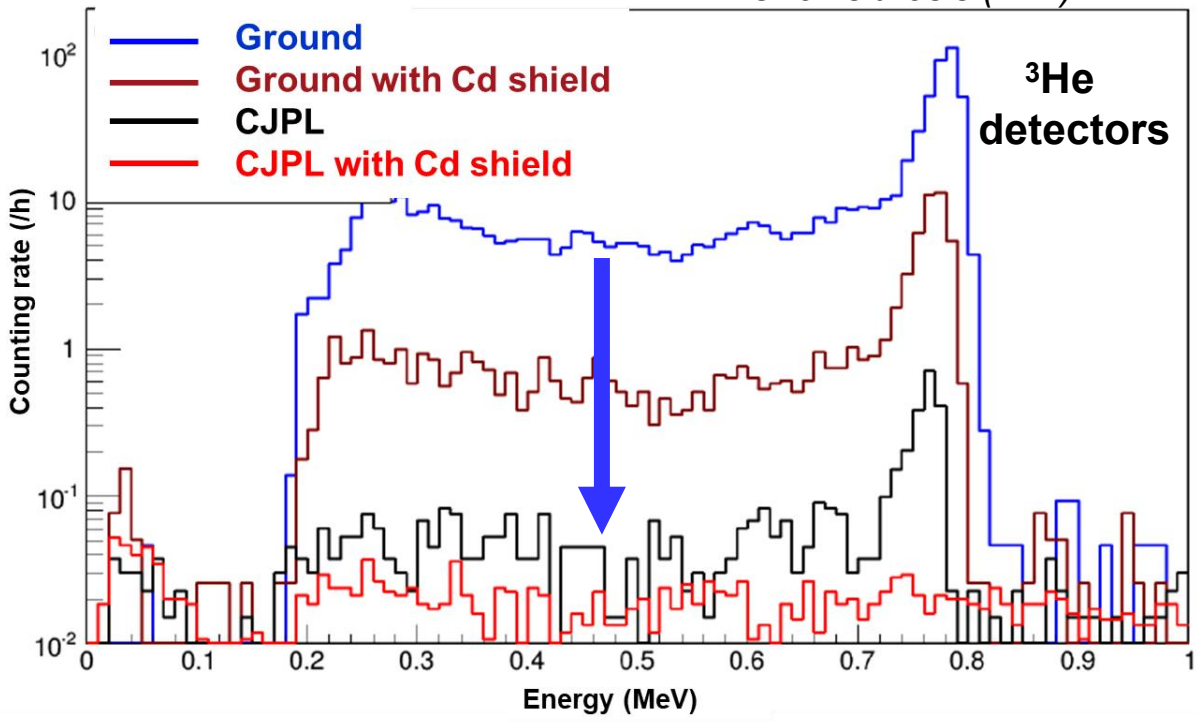
Neutron

Background of gamma and neutrons in JUNA underground lab

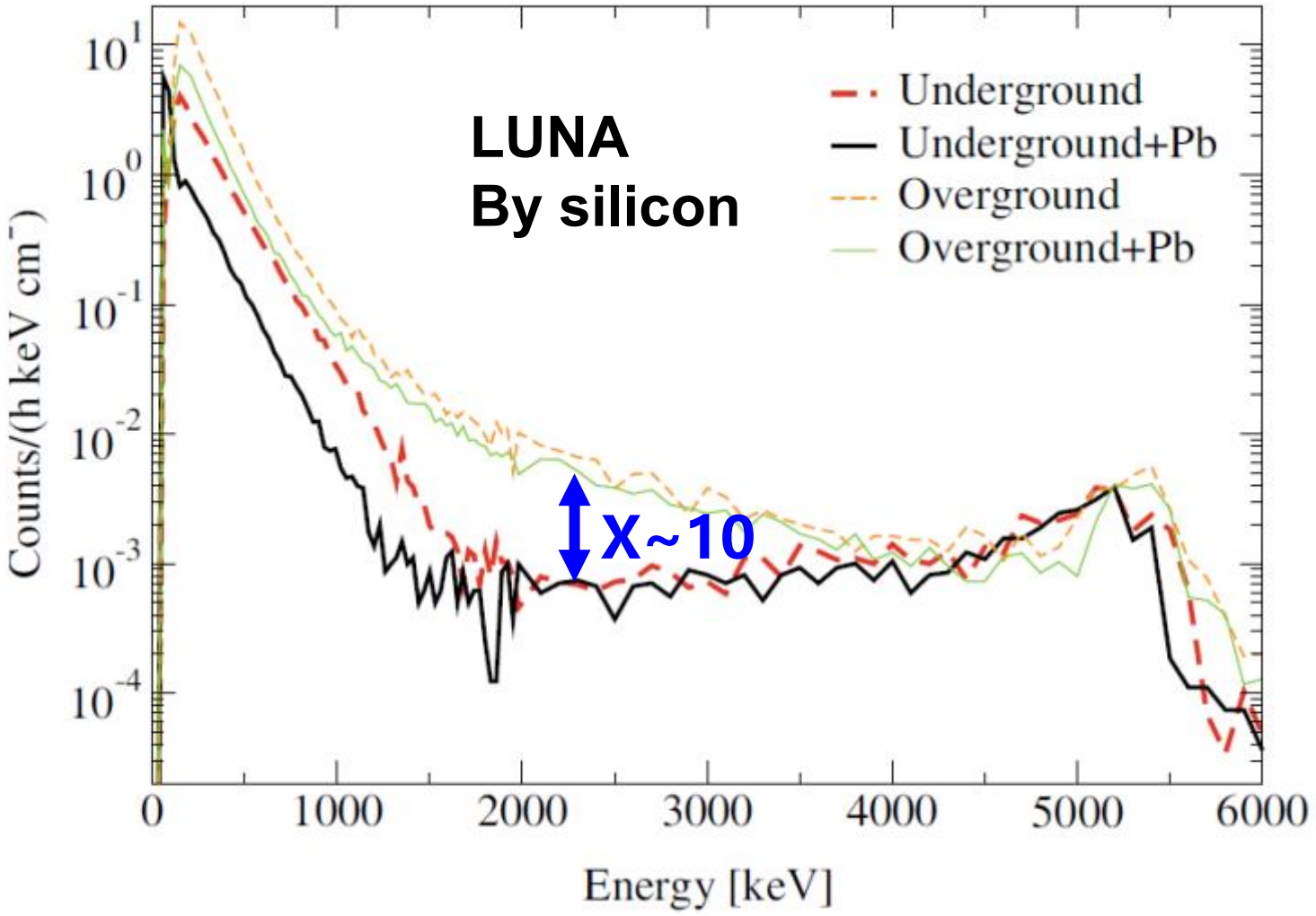
Y. P. Shen et al., Sci. China-Phys.Mech.Astron.102022(2017)60



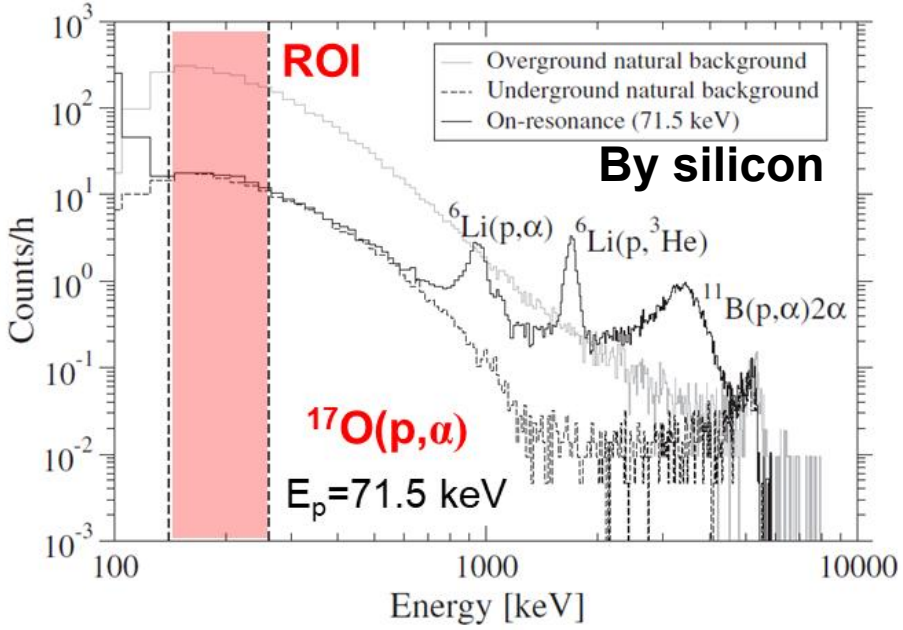
H. Chen's thesis (IMP)



Background of charged particles in LUNA

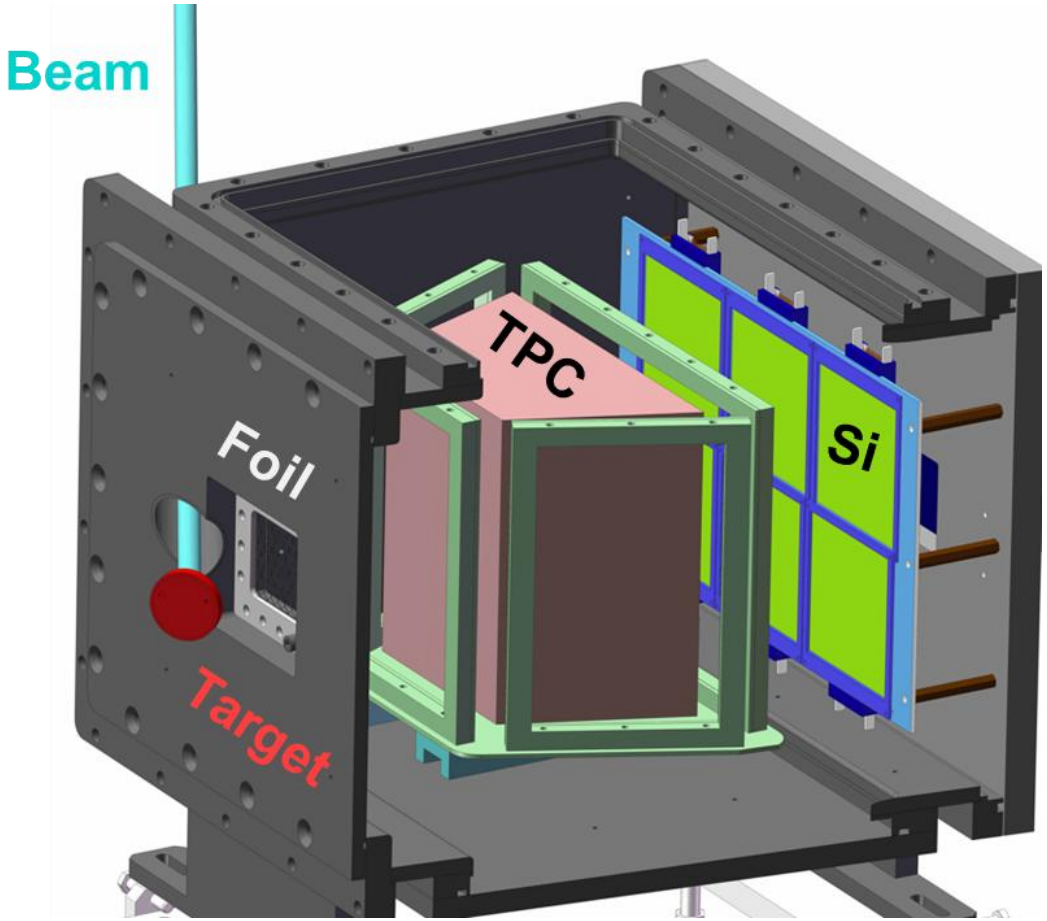


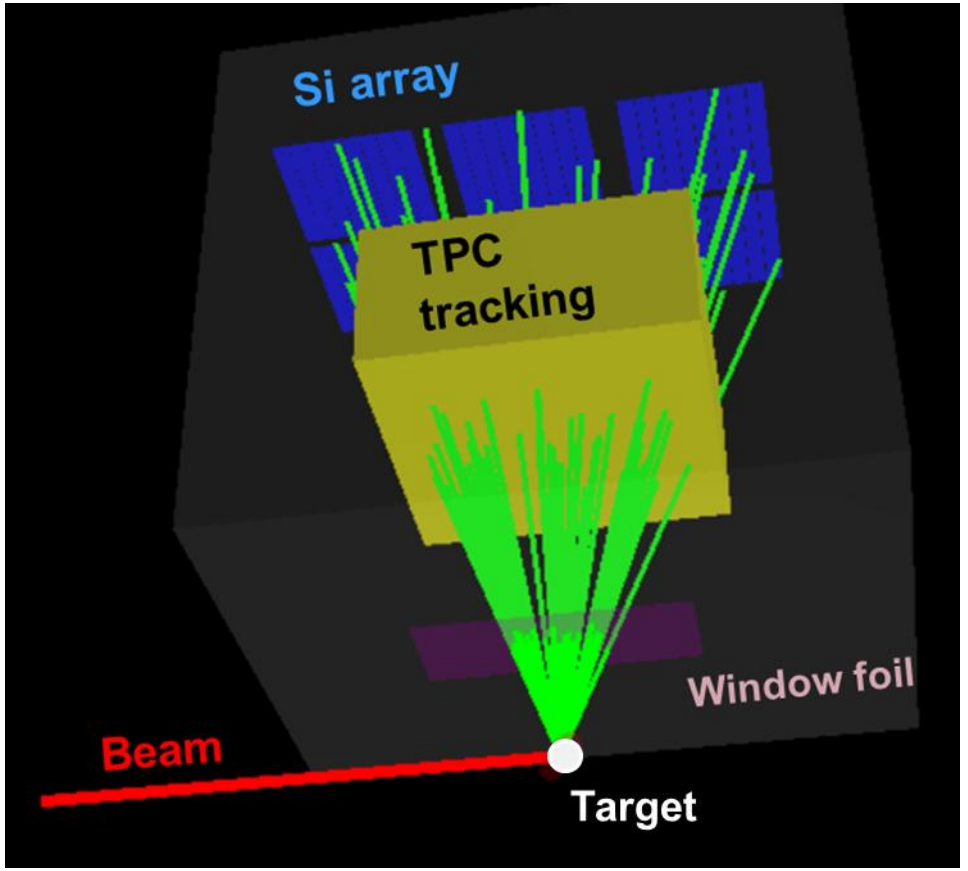
To charged-particle detection, underground shielding is effective -- but not enough!



Bruno et al., PRL 117, 142502 (2016)

TPC applied under intense stable beams



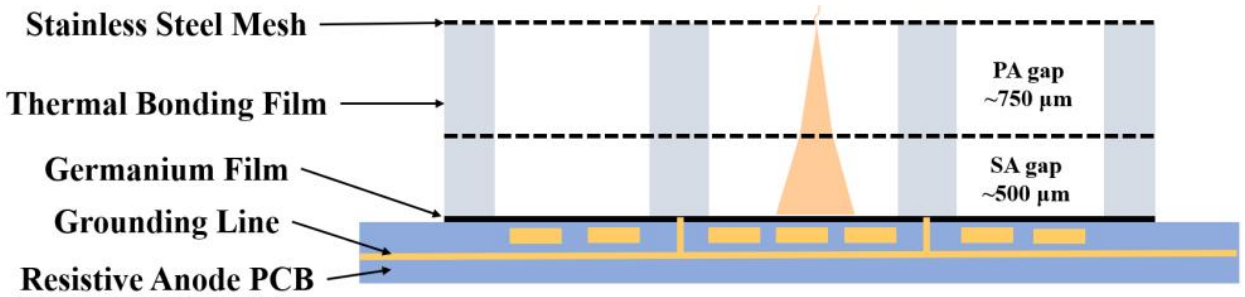


TPC: particle identification and suppression environmental background

Double micro-mesh (DMM) in TPC

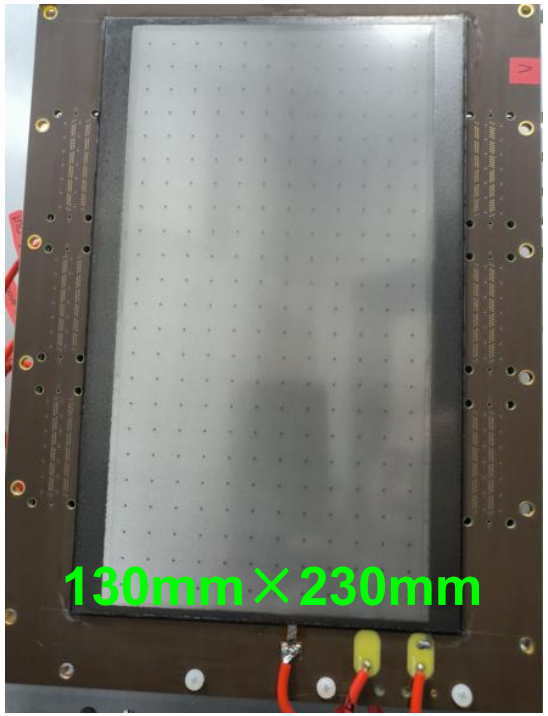
Experimental challenges and requirements:

- **0.5-5 MeV light particles and identification**
- **Stability at ~100mbar He-based gas**
- **Suppress environmental background**
- **Minimize the influence of X-rays and electrons under 100μA-10mA beams**

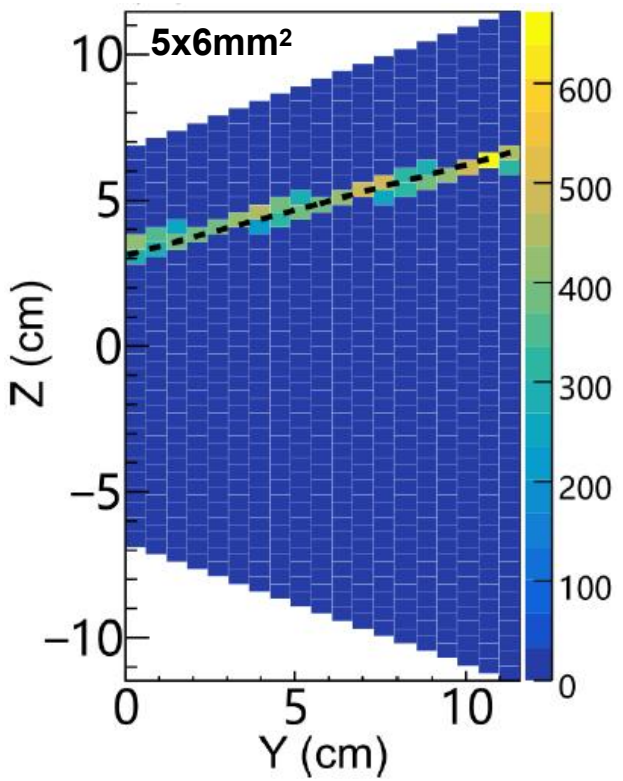


Made by USTC,
University of Science and Technology of China

DMM



684 channels



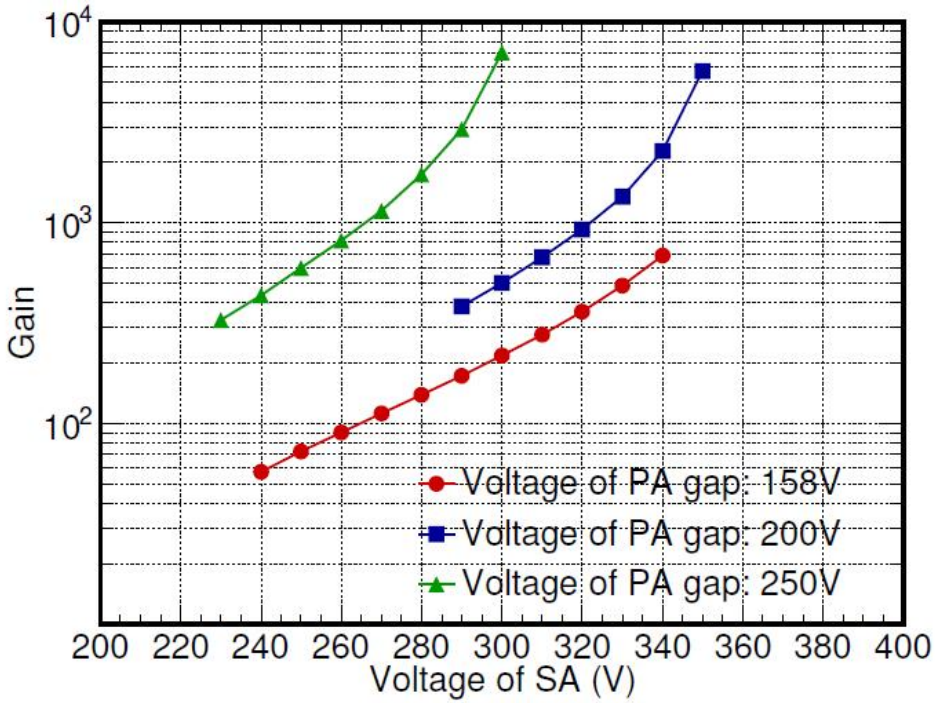
No discharge at 3-month beam running (70pμA ^{12}C beam)

JX Feng, ZY Zhang(张志永) et al., NIMA1031(2022)166595*
S Wang, ZNT et al., Nuclear Science and Techniques 36(2025)143

Performance test of DMM

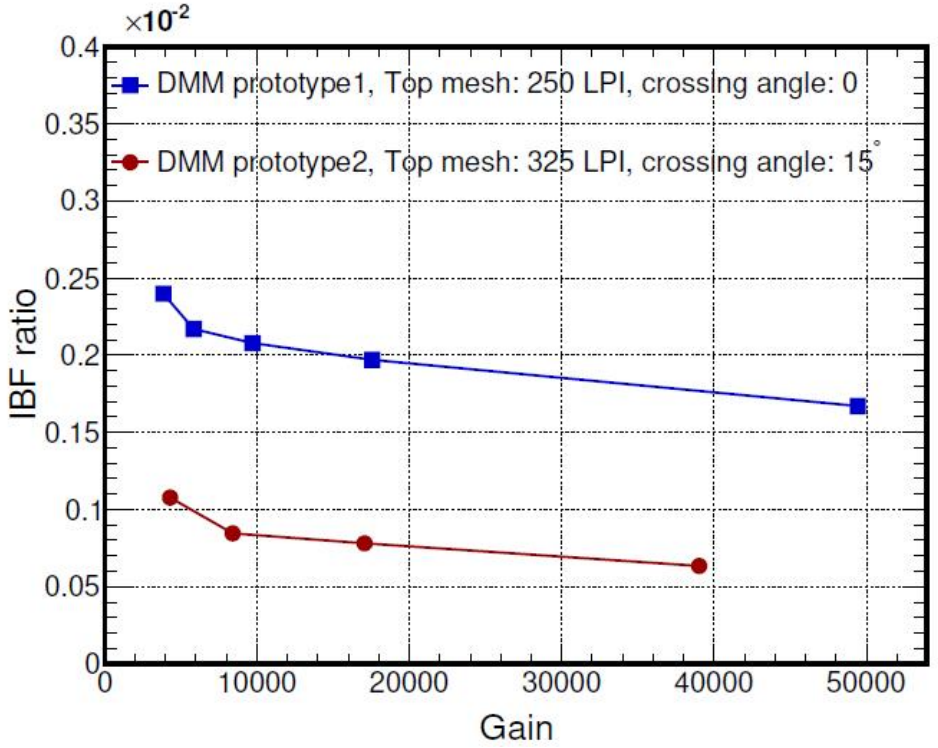
Gain

90%He + 5%CO_2 + 5%Ar at 110 mbar



Ion back flow

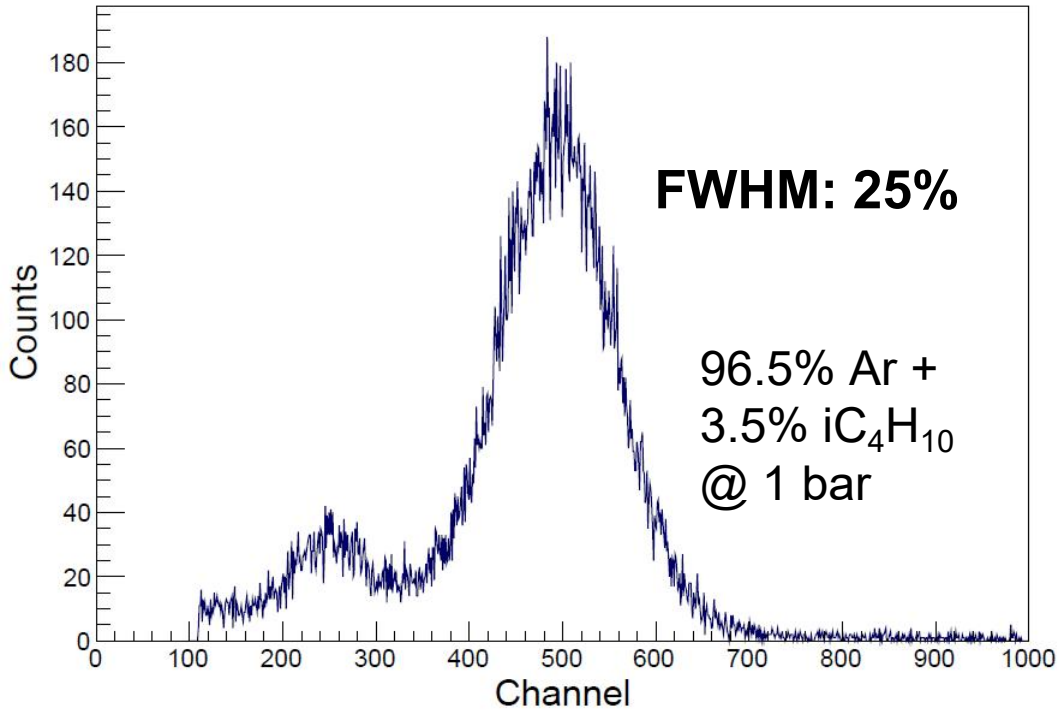
50%Kr + 15%CO_2 + 35%Ar at 110 mbar



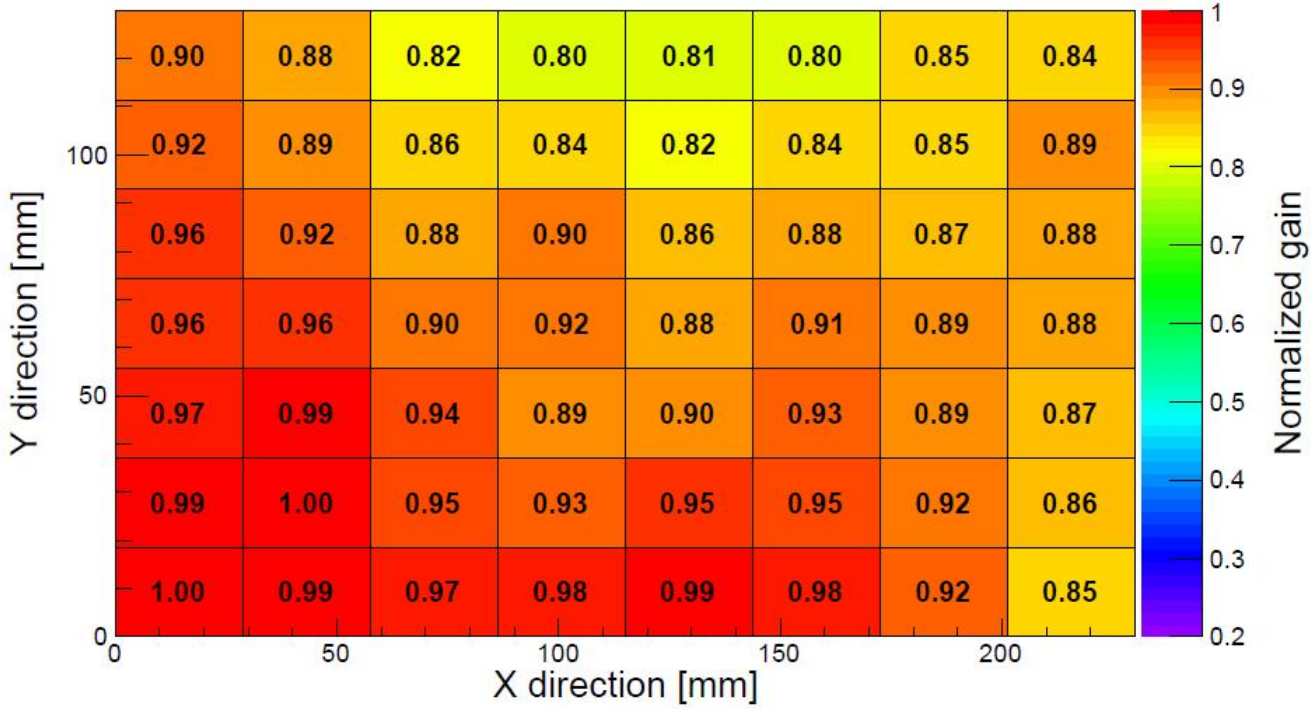
Measurement at USTC by S. Wang, X. Wang, Z.Y. Zhang

S Wang et al., DMM submitted to NIMA (under review)

Performance test of DMM



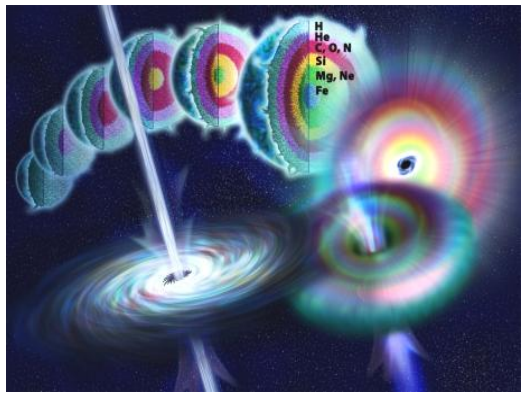
Non-uniformity distribution: 5.4%



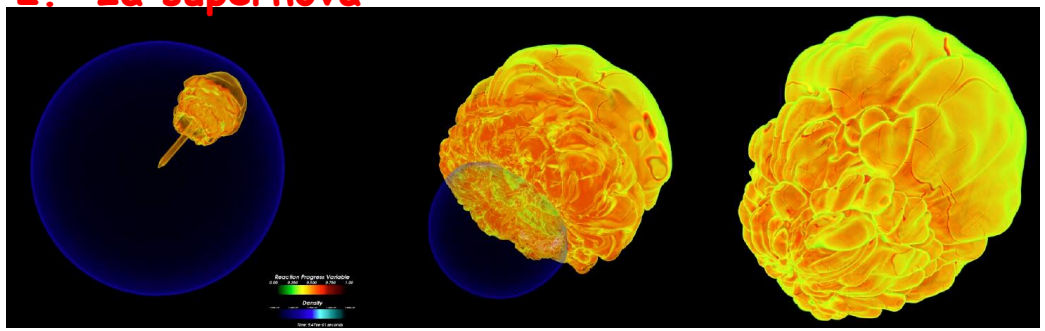
S Wang et al., DMM submitted to NIMA (under review)

$^{12}C+^{12}C$ fusion reaction at stellar energies

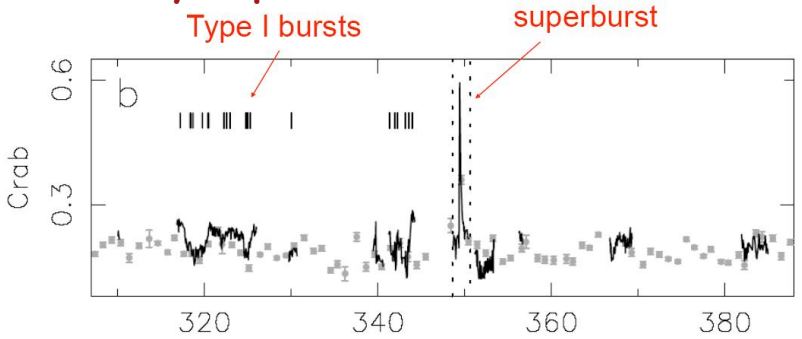
1. Massive star



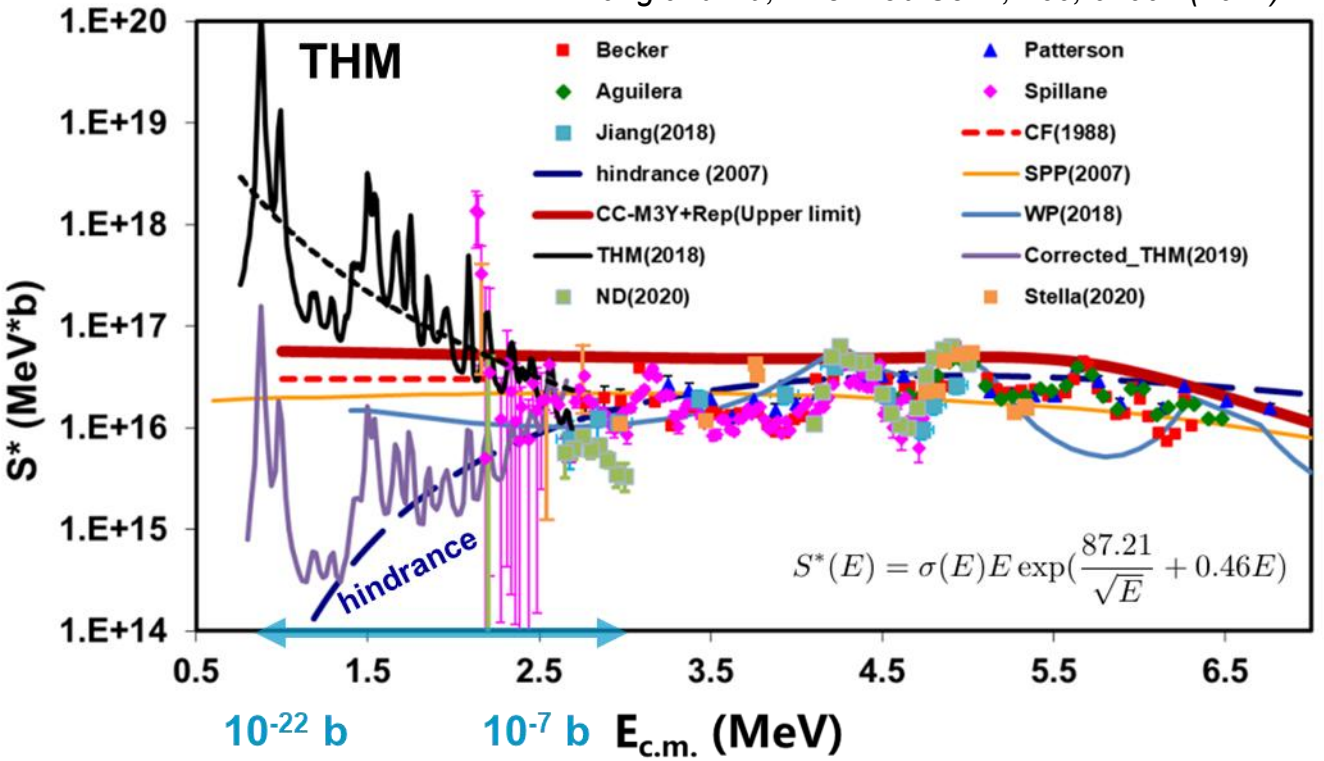
2. Ia supernova



3. X-ray Superburst



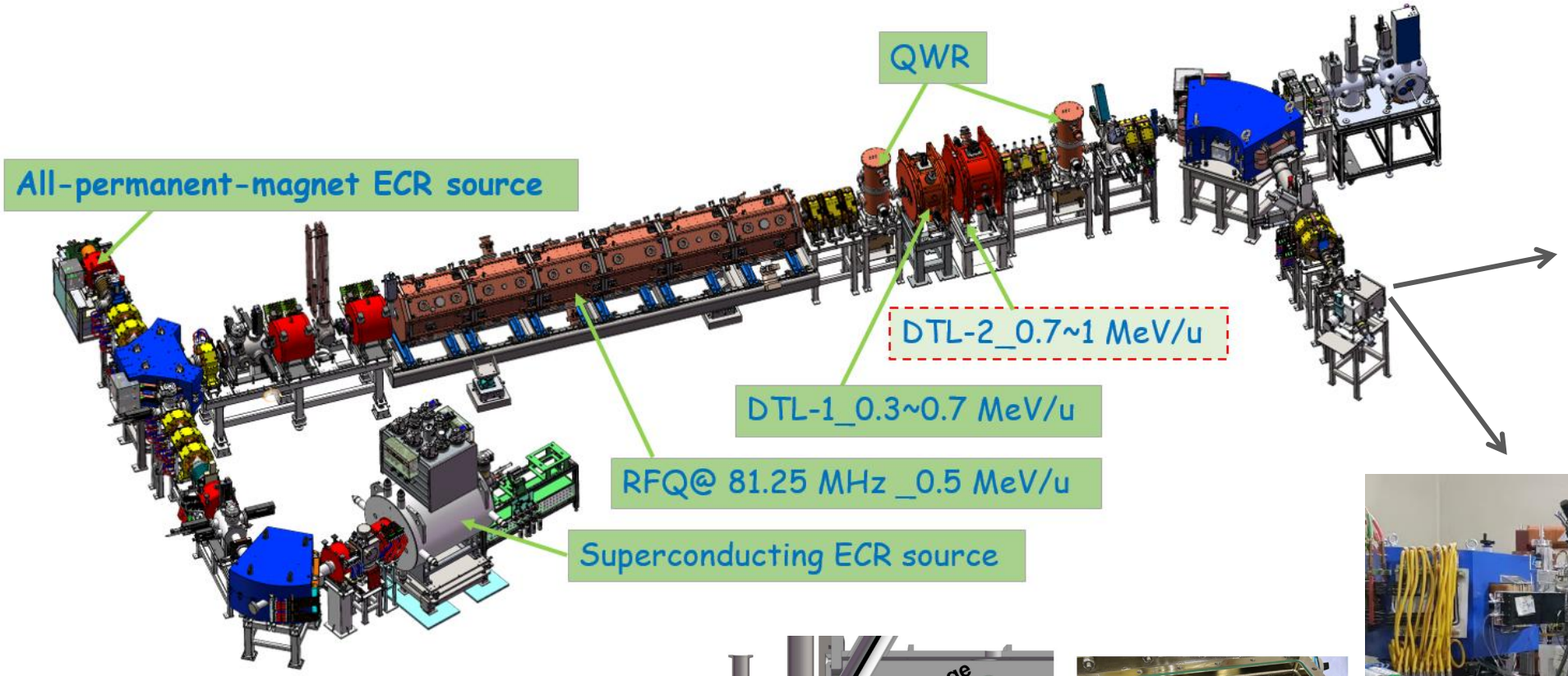
Tang and Ru, EPJ Web Conf., 260, 01002 (2022)



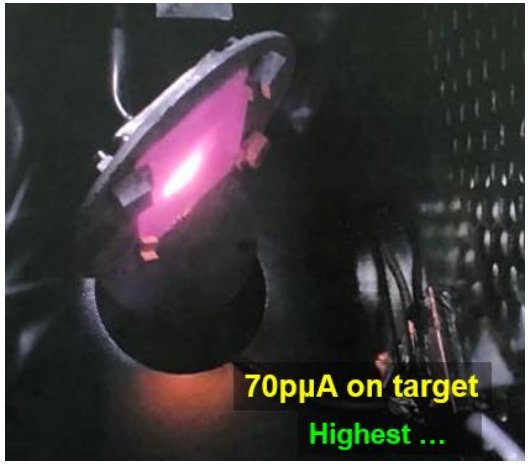
- Stellar energy region at 1-3 MeV: ~1 pb at E_{cm}=2 MeV
- Large discrepancy: up to 3-4 orders of magnitude

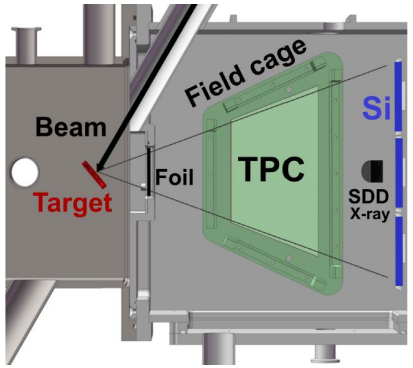
Direct measurement of $^{12}C+^{12}C$ at LEAF

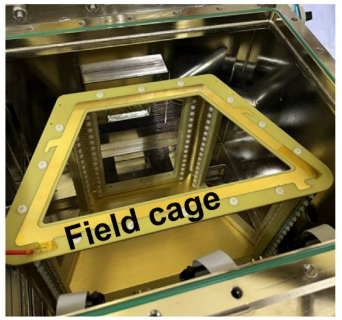
Low Energy high intensity heavy ion Accelerator Facility (LEAF), IMP, Lanzhou

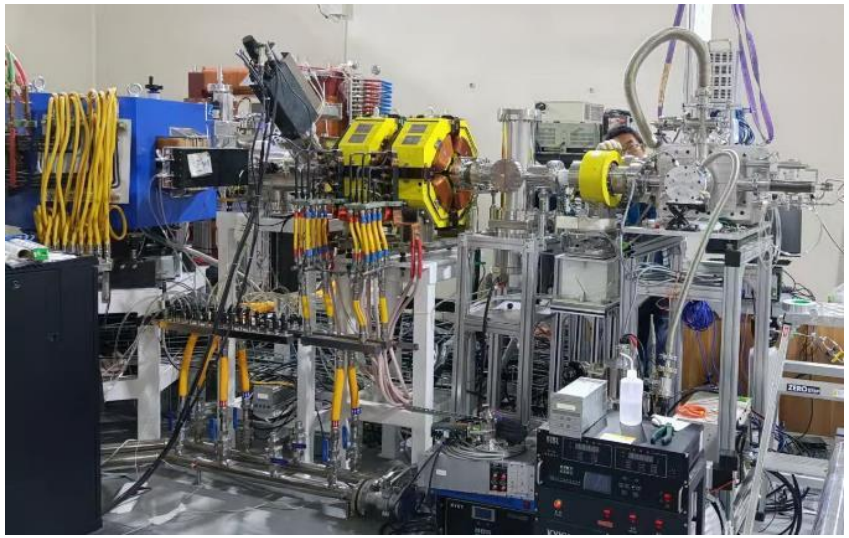


Courtesy of Yang Yao

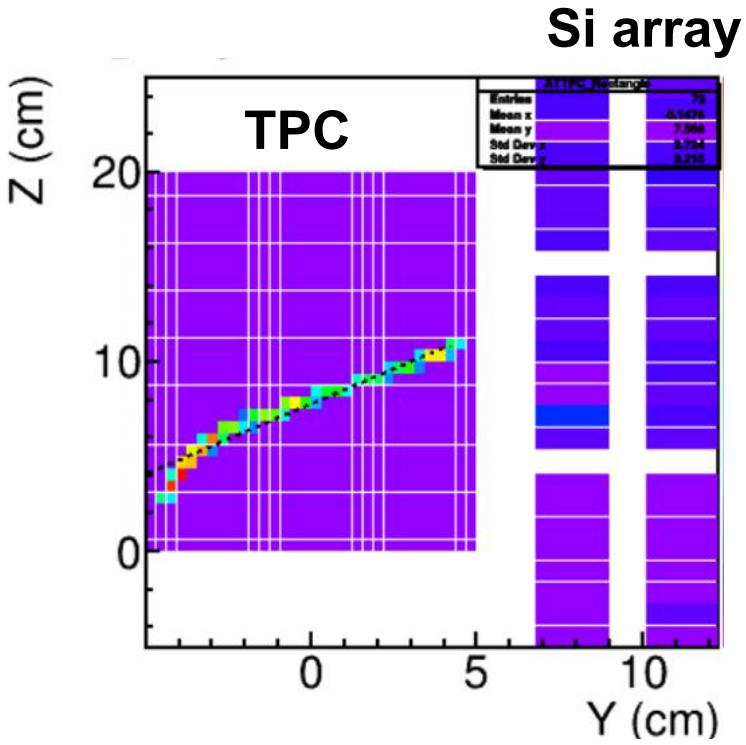




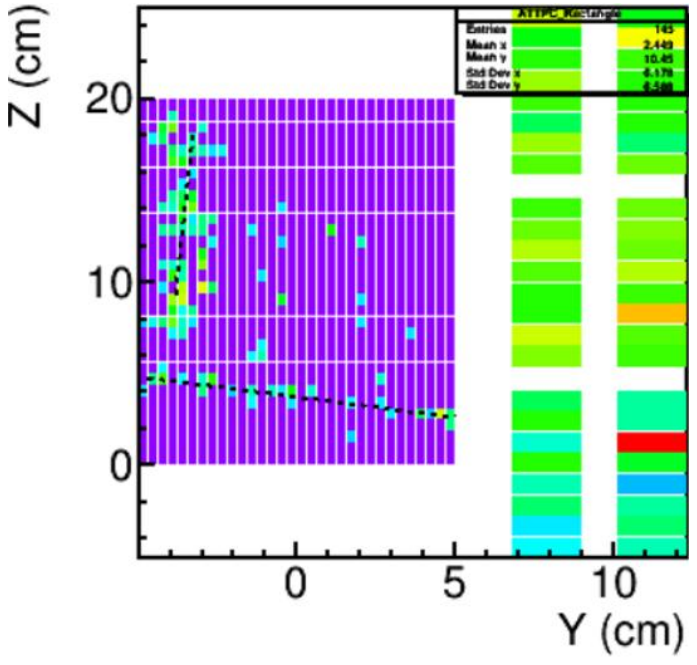




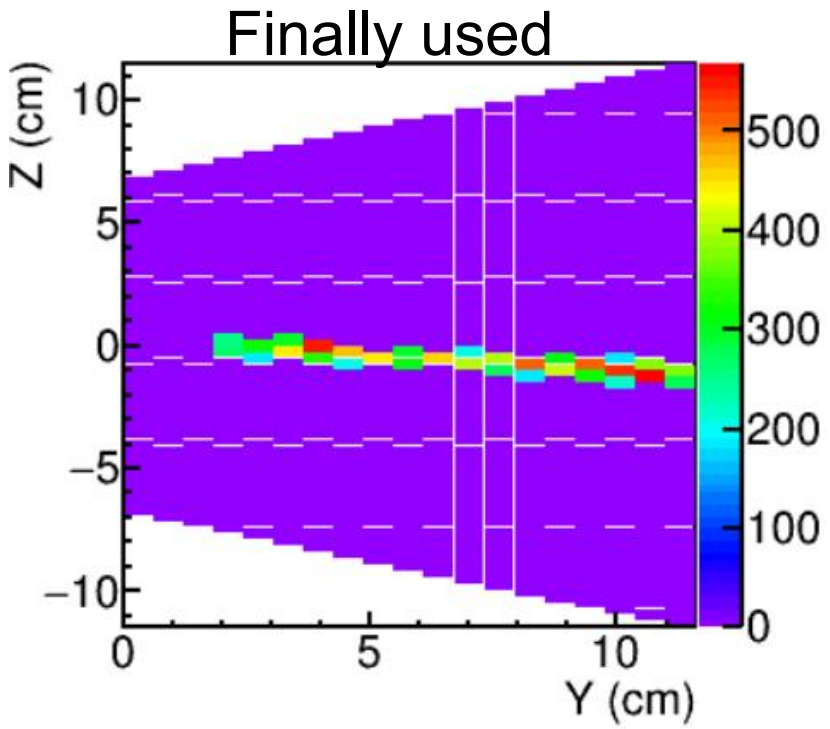
Alpha tracks during experiment



GEM-TPC
- 135-mbar He+5%CO_2
- 30 pμA ^{12}C beam

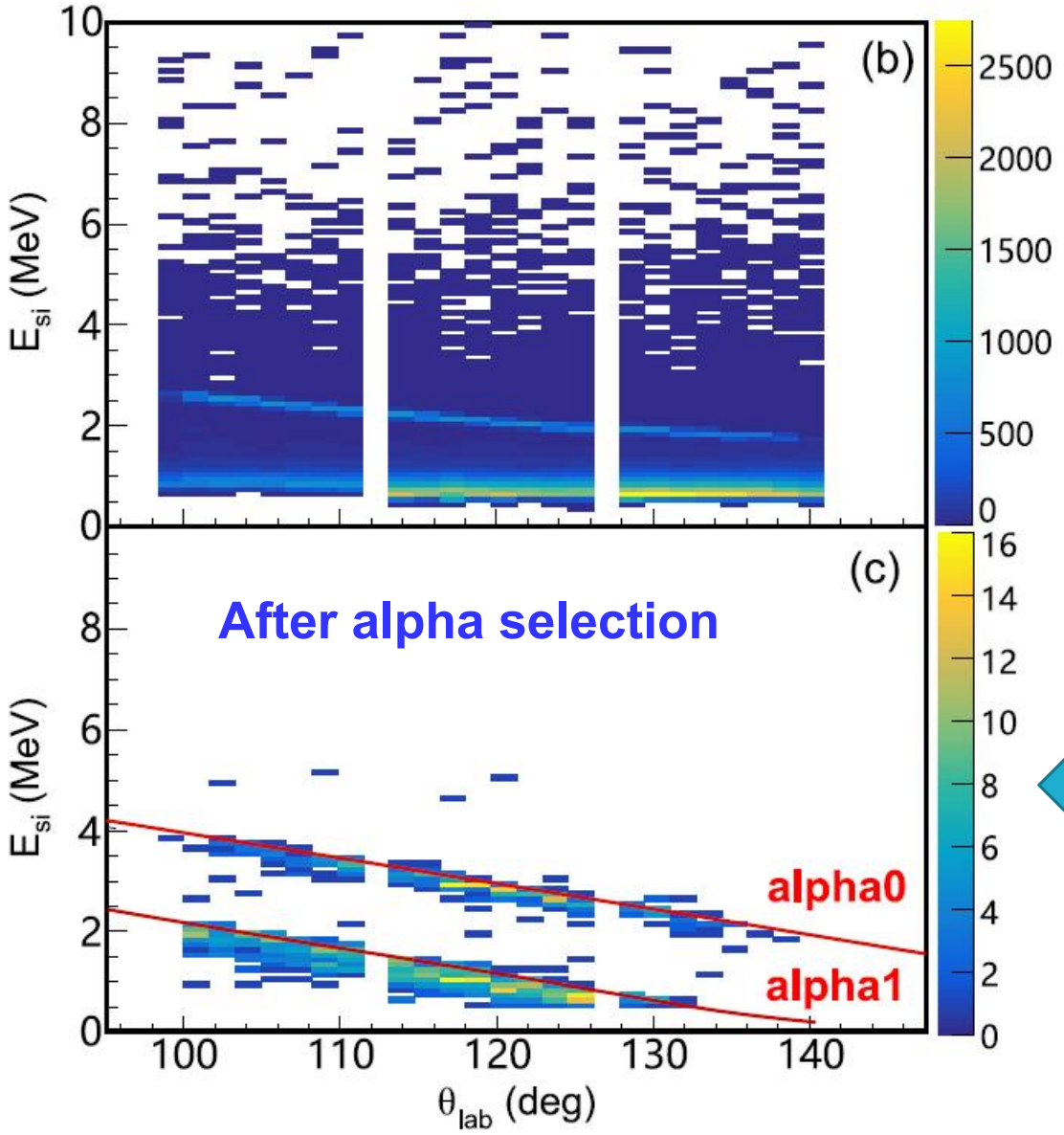


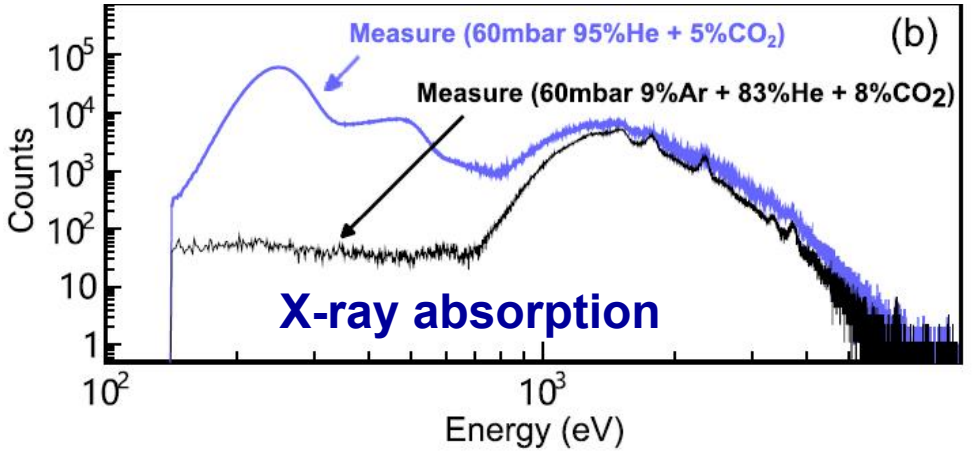
GEM-TPC
- 90-mbar He+5%CO_2
- 17 pμA ^{12}C beam



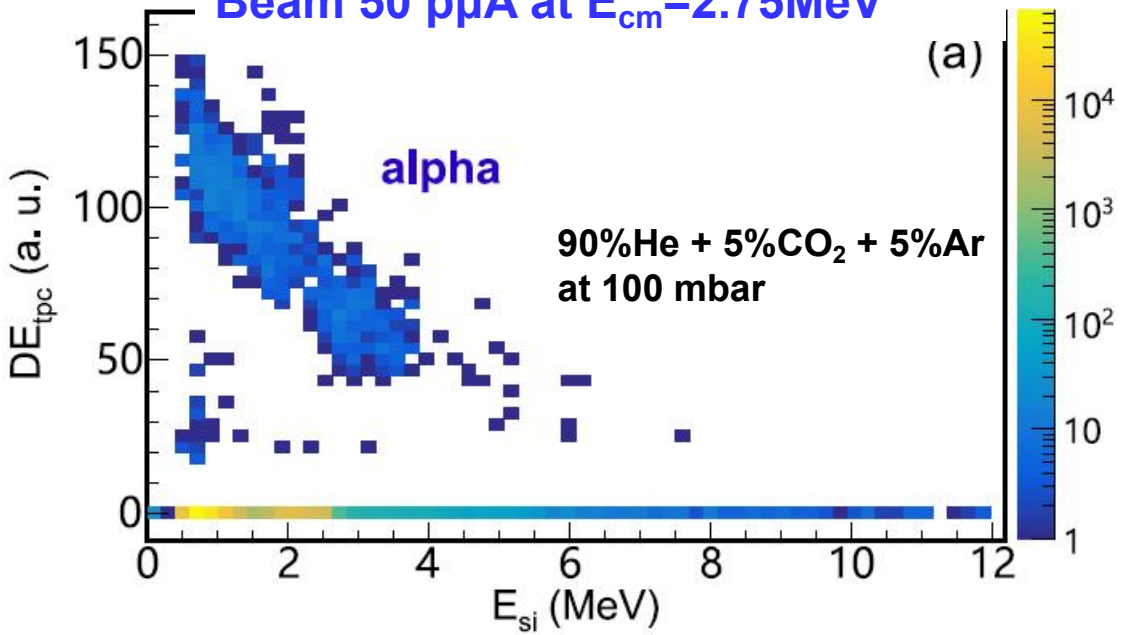
DMM-TPC
- 90-mbar He+5%CO_2+5%Ar
- 70 pμA ^{12}C beam

Alpha measurements at E_{cm}=2.75 MeV

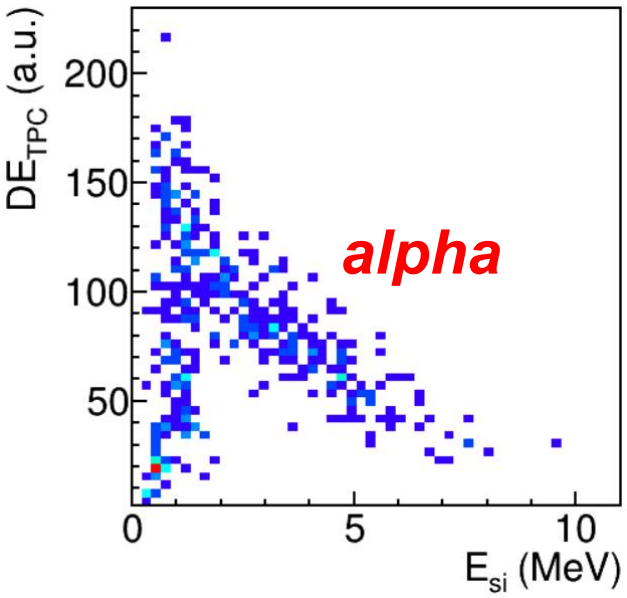


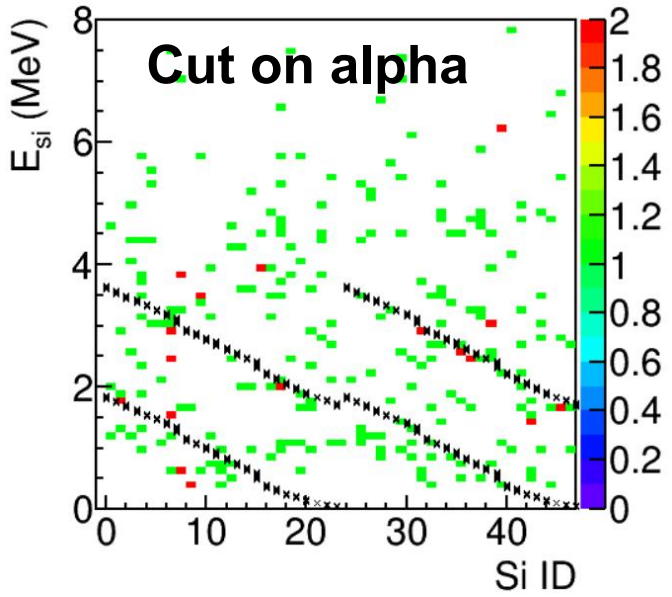


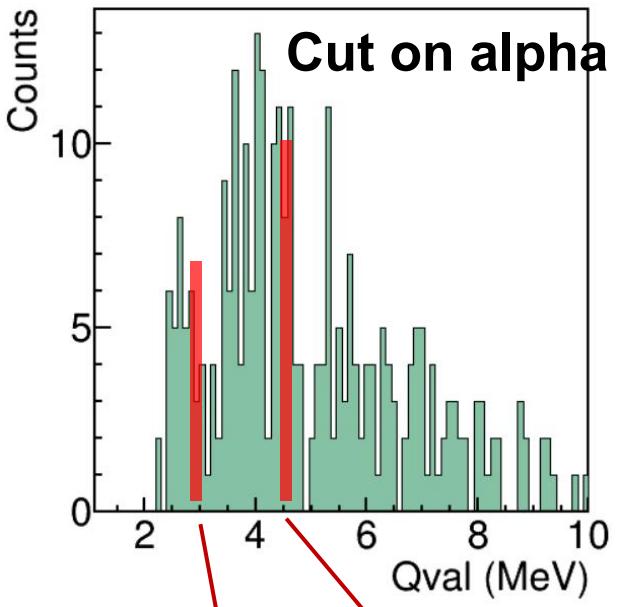
Beam 50 pμA at E_{cm}=2.75MeV

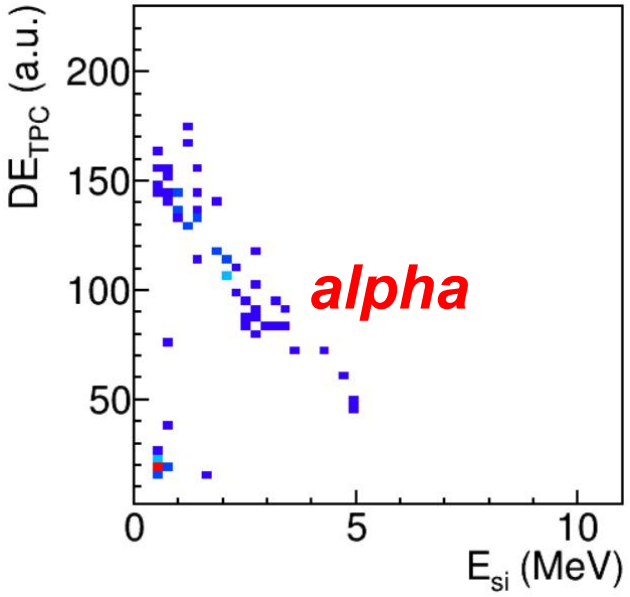


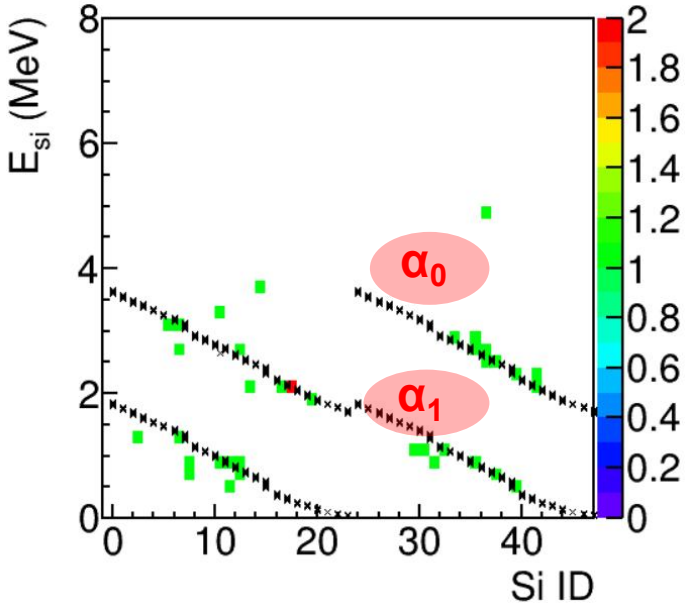
Alpha measurements at E_{cm}=2.40 MeV

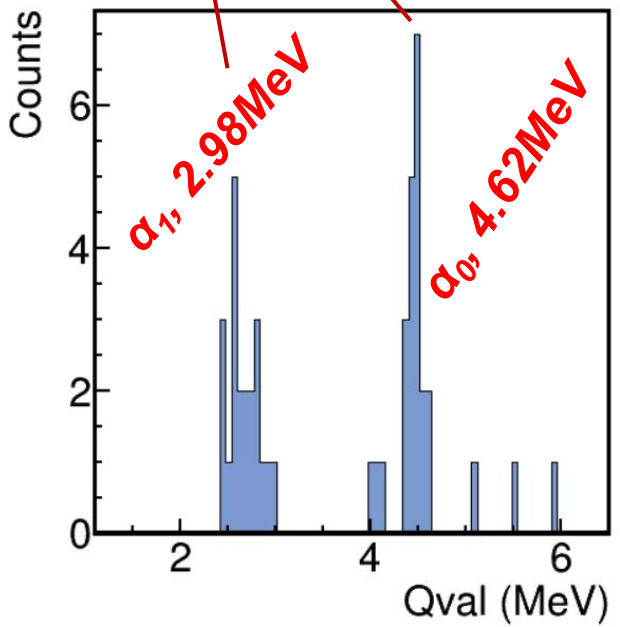










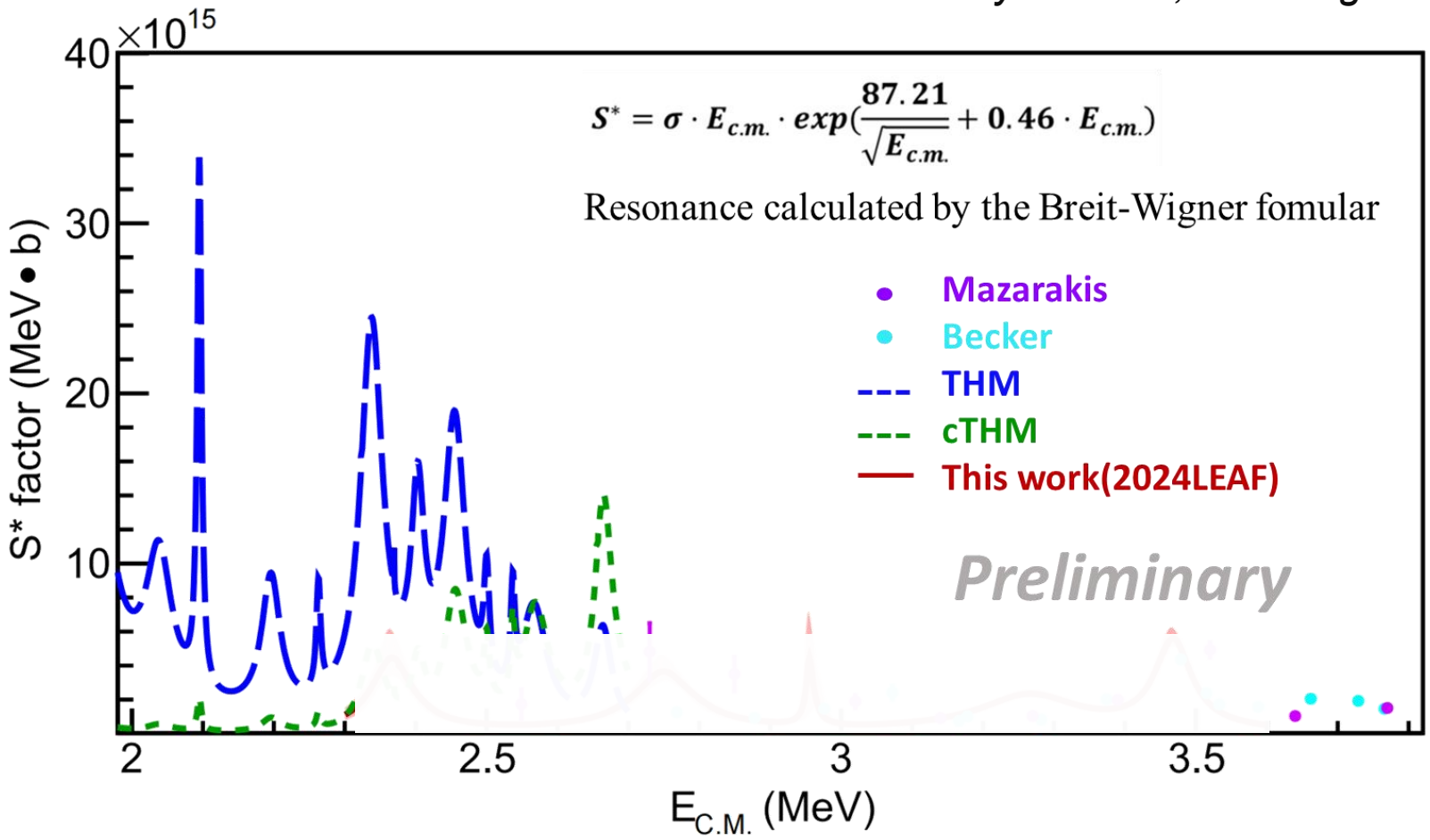


Original α spectra

α spectra after tracking

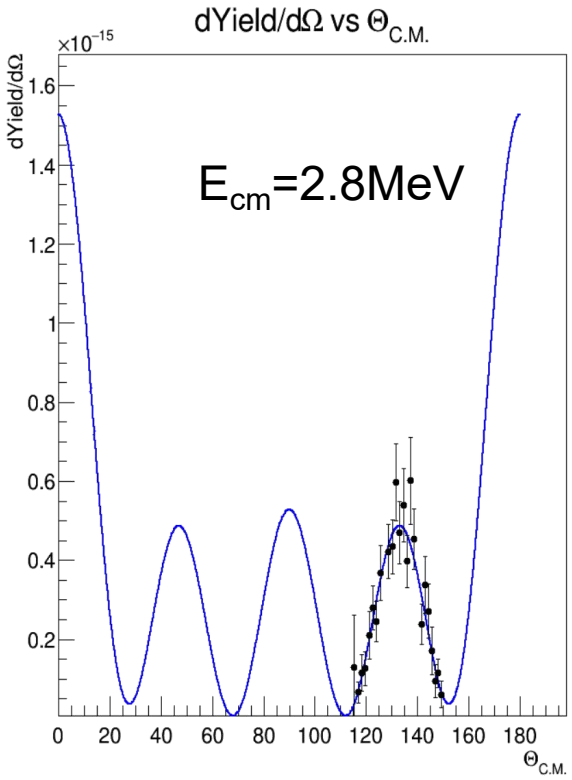
Preliminary result (α_0 channel)

Courtesy of YZ Li, XD Tang



Measurements: $\alpha_{0,1}$, $p_{0,1}$

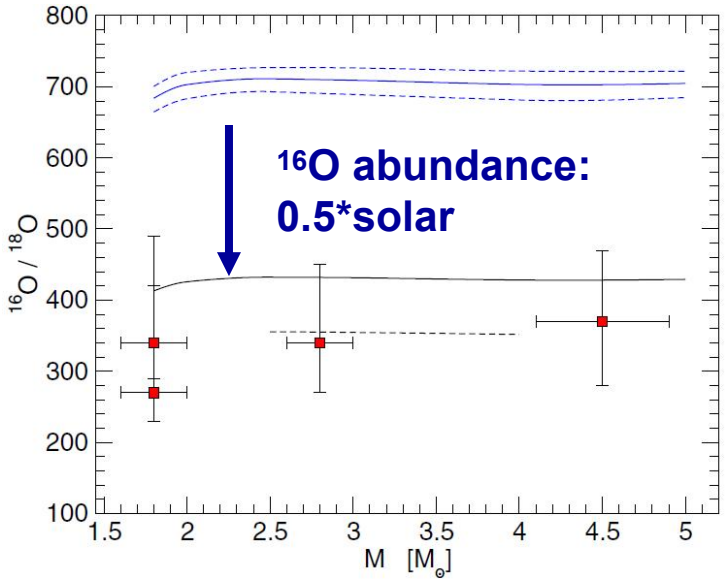
Ang. dist.: 100-140⁰ (LAB)



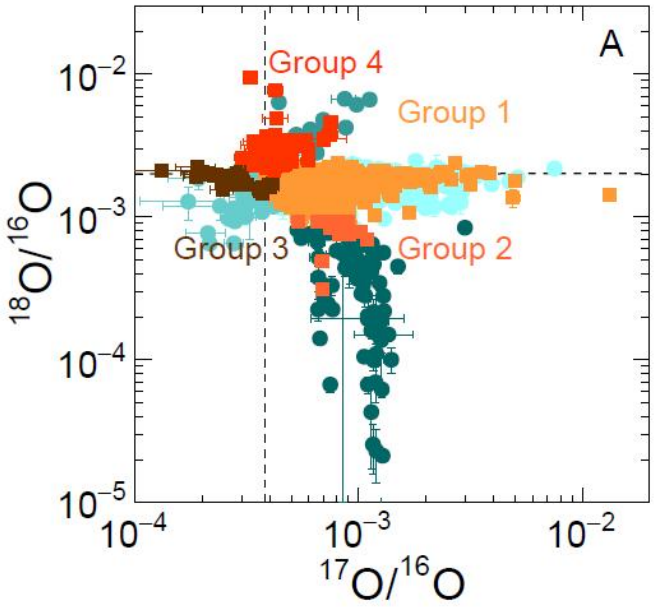
Data analysis: YunZhen Li, Shuo Wang, XiaoDong Tang, ZNT

Oxygen isotopic ratios in giant stars: $^{17,18}O(p,\alpha)$

Lebzelter et al., A&A 578, A33 (2015)

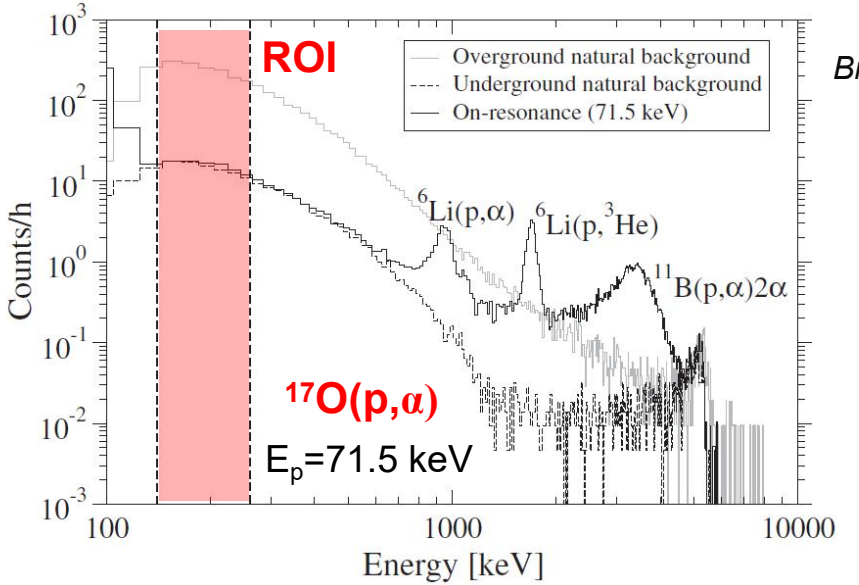


Palmerini et al., Universe 2021, 7, 175

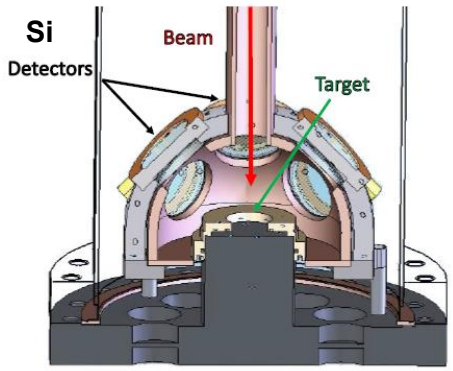


How to reproduce observations:

- Interplay between the production-destruction reactions, mixing processes



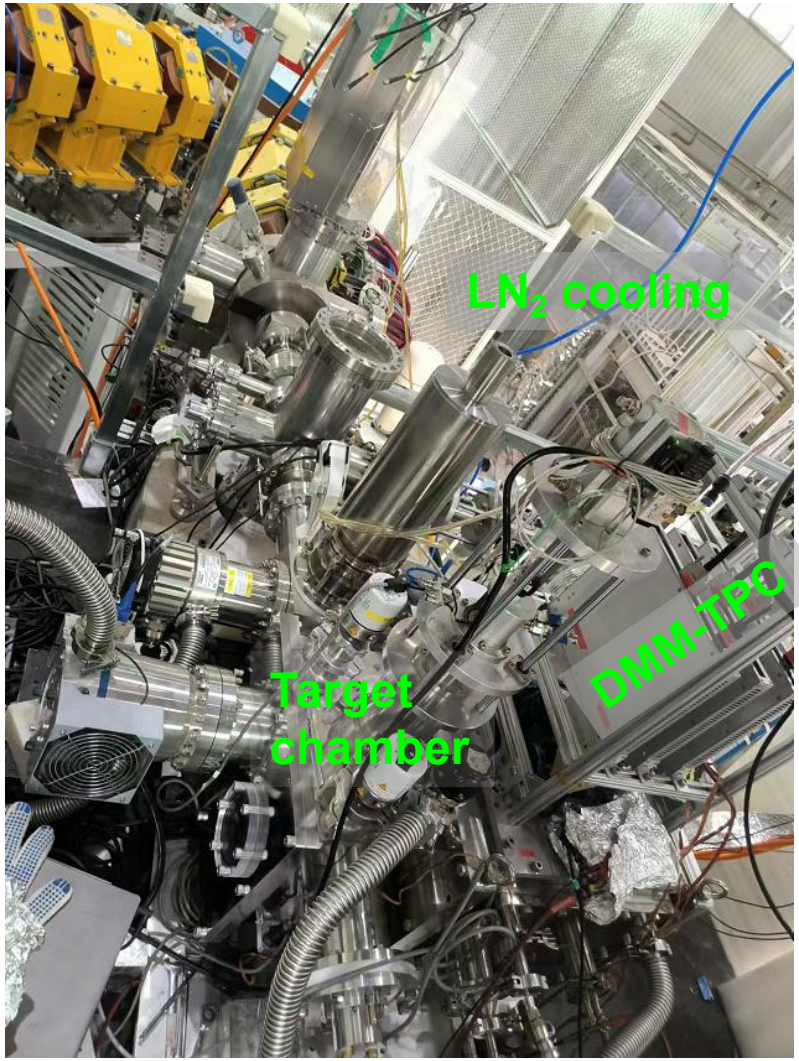
Bruno et al., PRL 117, 142502 (2016)



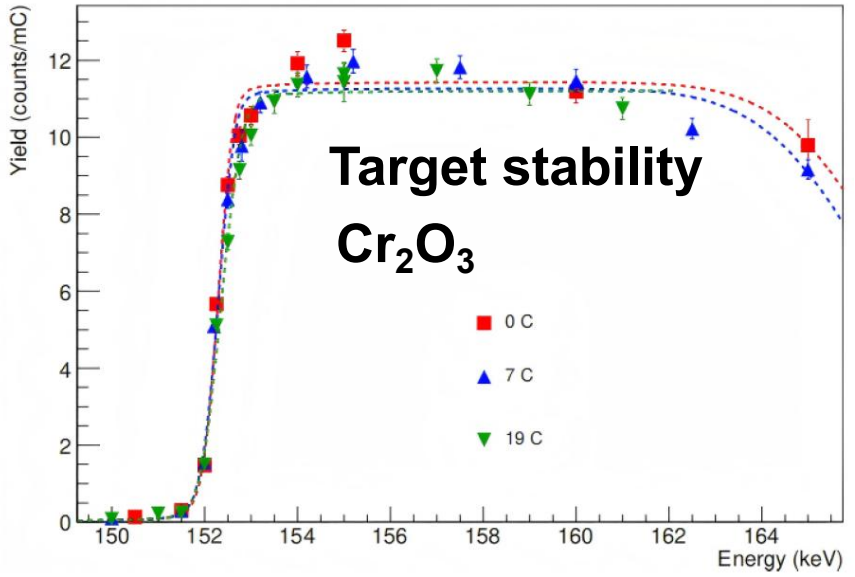
Main background

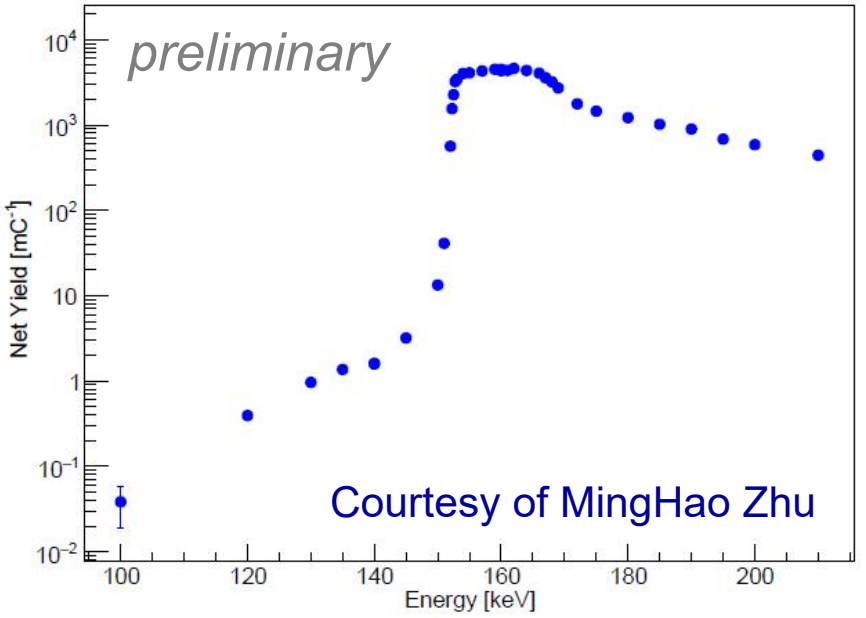
- $^{6}Li+p$
- $^{11}B(p,\alpha_{01})$
- Cosmic rays
- Environment radioactivity

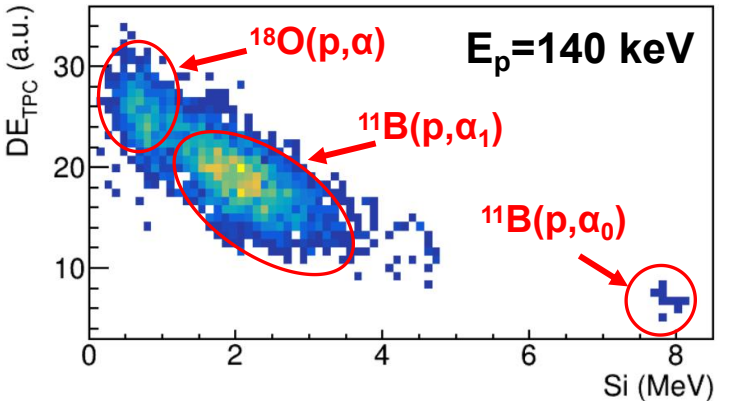
Measurements of $^{18}O(p,\alpha)$ reaction using 240 kV accelerator

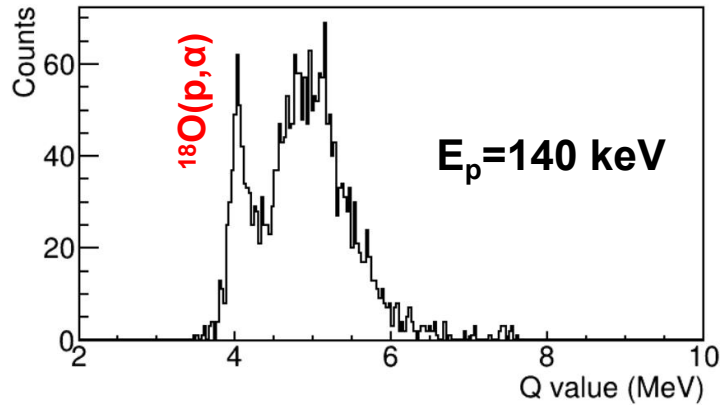


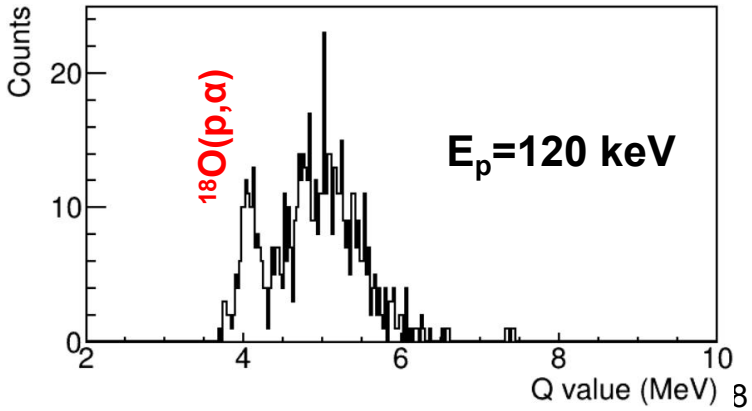
Proton accelerator: 240 kV (IMP), upto 15 mA







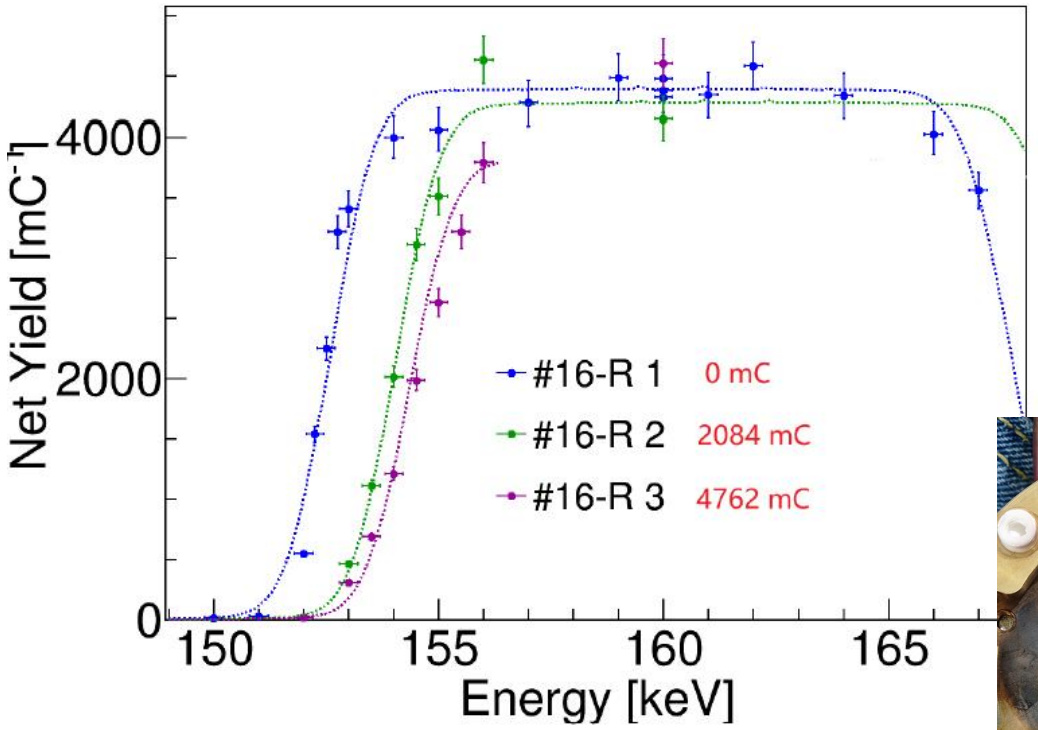


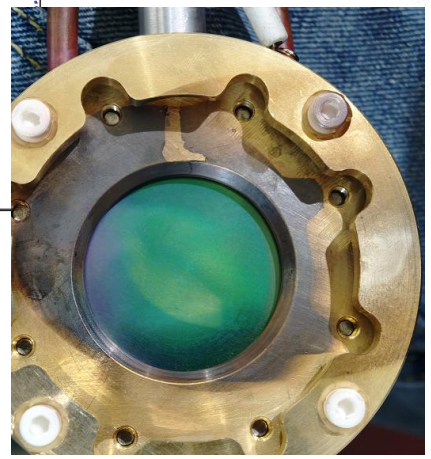


Big challenges in experiments

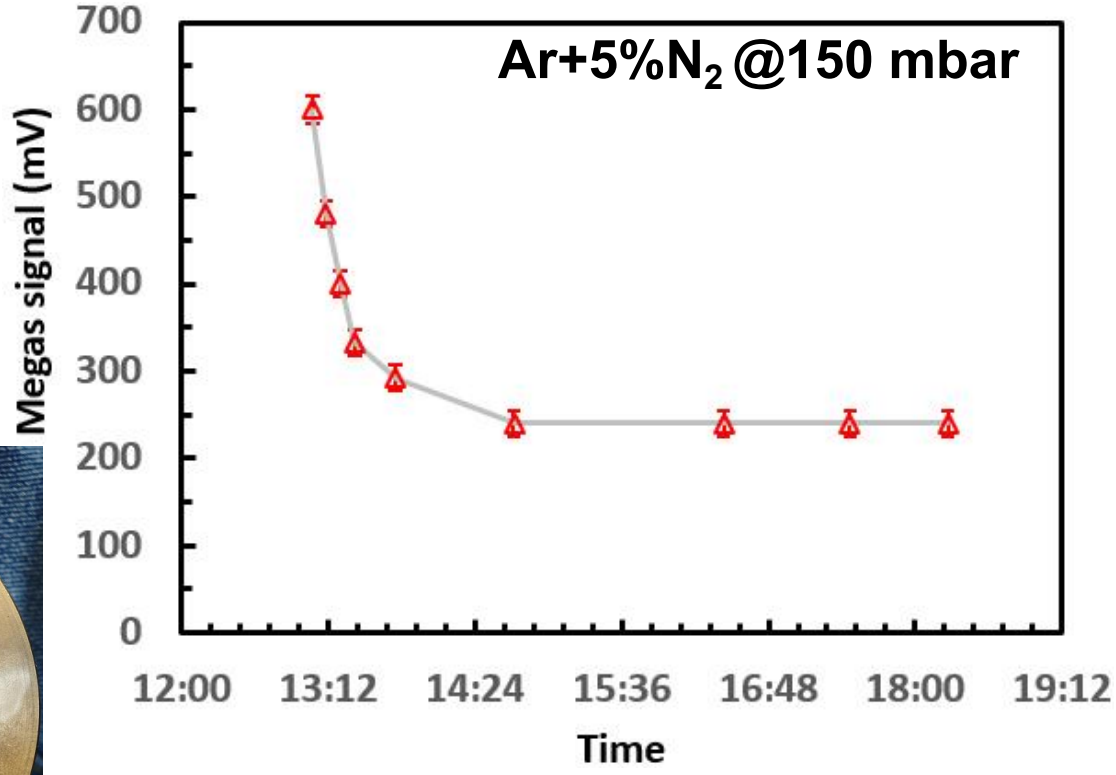
- ^{11}B contaminant in oxygen targets
- Carbon deposition due to working gas in TPC

Working gas: He+Ar+CO_2 @ 100 mbar



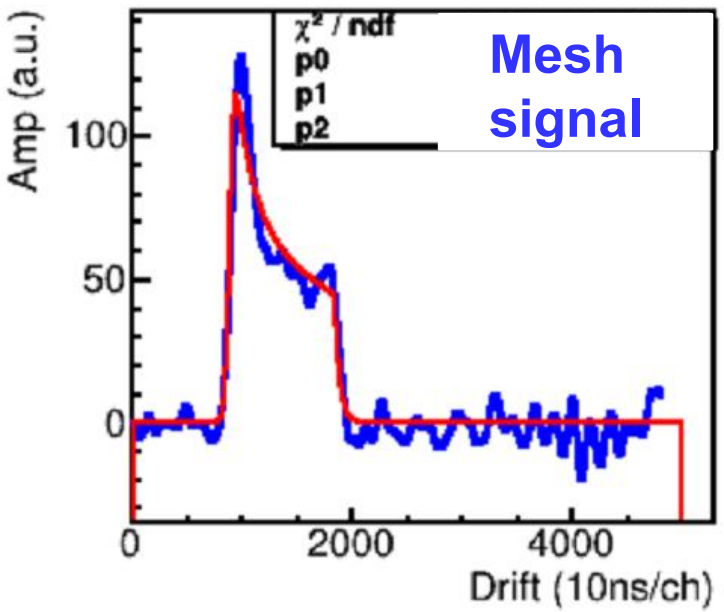


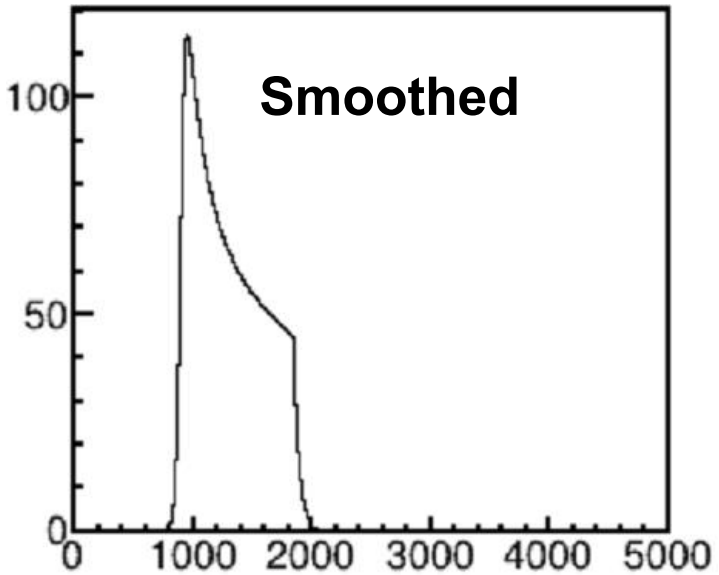
Replace CO_2 with N_2 ?

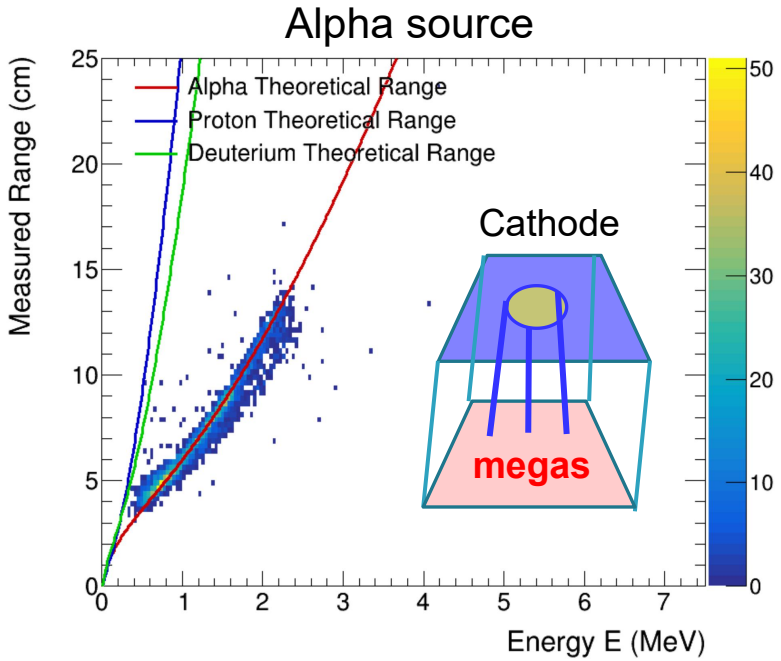


Summary

- **Double Micro-Mesh (DMM) TPC is developed and operated at 50-150 mbar gas pressure**
- **DMM-TPC as DE detector**
  - Measurement of low-energy charged particles of $^{12}C+^{12}C$ fusion reaction at stellar energy
  - Study of important (p,α) reactions in CNO with beam intensity of a few mA
- **DMM-TPC as Bragg detector (on going):** $^{10}B(\alpha,d/p)$ reactions important in primordial stars

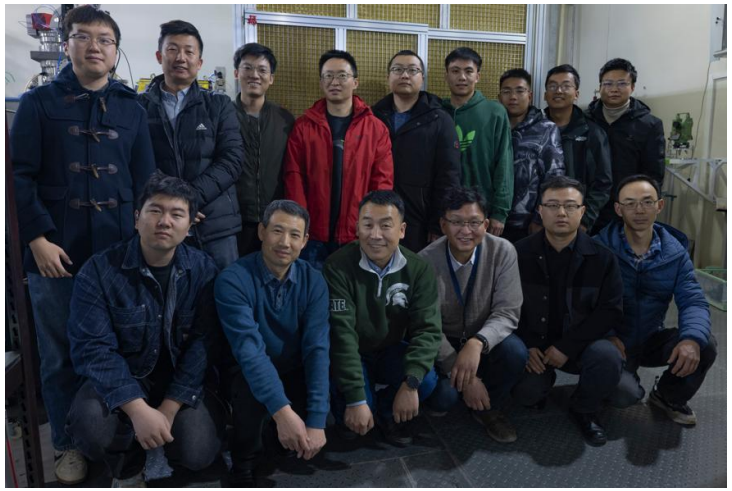
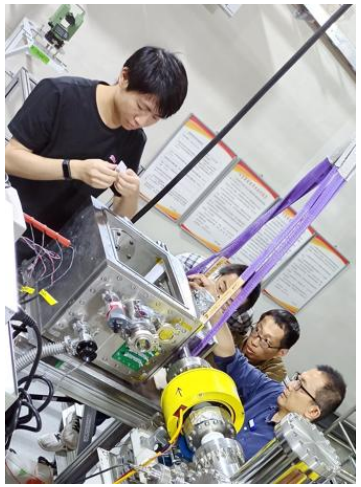
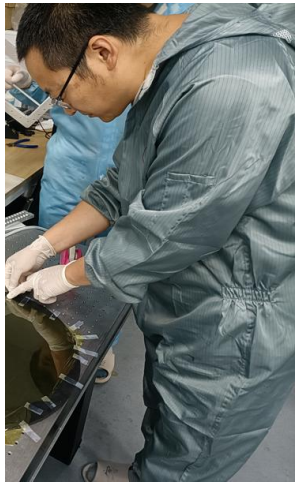
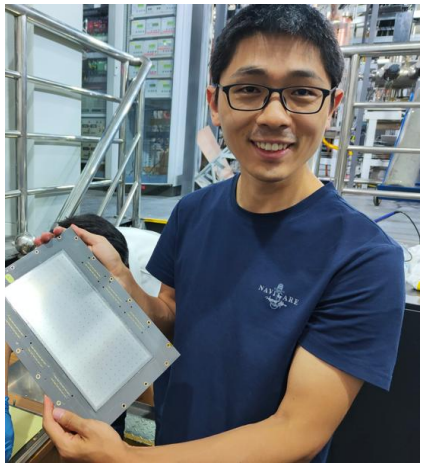
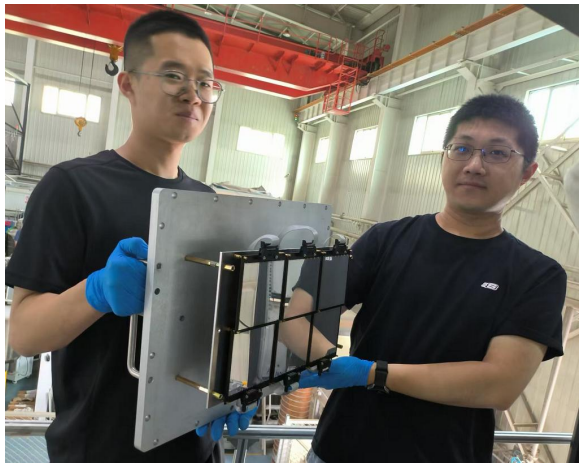






Courtesy Y.H. Fan

Acknowledgements

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