Feasibility Study for Proton Upscattering on ^{12}C using MATE-TPC at PKU Tandem

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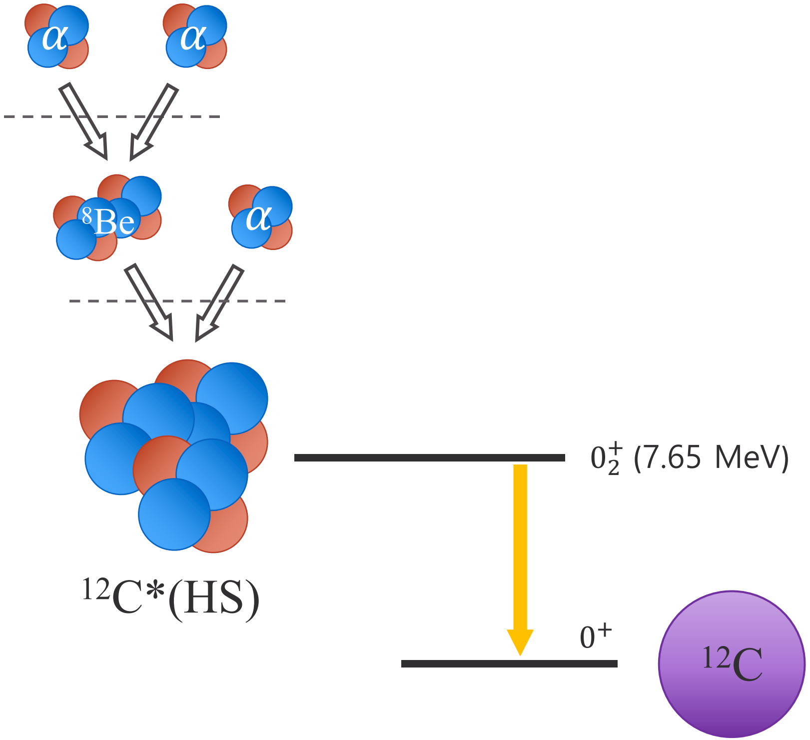
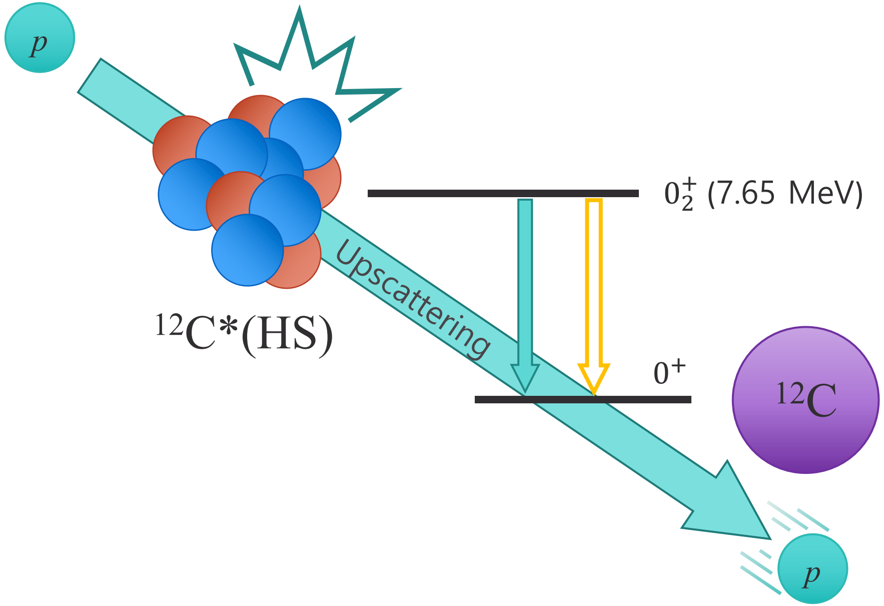
Tripple alpha process

- Triple-alpha process producing bound ^{12}C from three alpha particle, is a crucial mechanism in Helium burning stars which goes through second 0^+ state known as Hoyle state (7.65 MeV).
- The rate of bound ^{12}C production is proportional to the radiative decay width of $^{12}C^*$ Hoyle state (HS).



12C Upscattering

- At high temperature and high-density condition, inelastic scattering of light particles to $^{12}C^{*}(HS)$ may enhance the rate of bound ^{12}C formation.
- This process was named as particle upscattering recently.



Experimental method

- The rate of bound ^{12}C production is proportional to the radiative decay width of ^{12}C* Hoyle state (HS).
- At high temperature and high-density condition, inelastic scattering of light particles to ^{12}C*(HS) may enhance the rate of bound ^{12}C formation.
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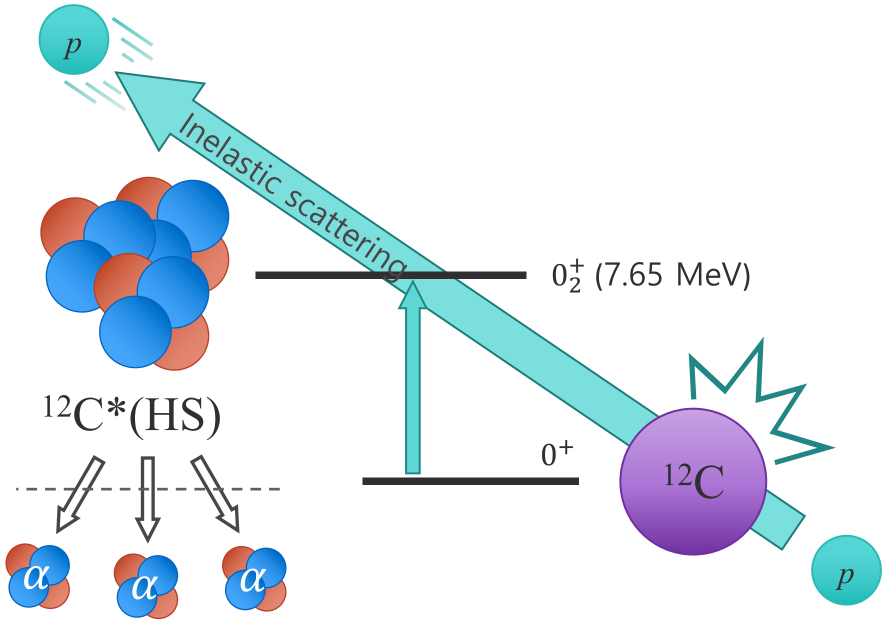
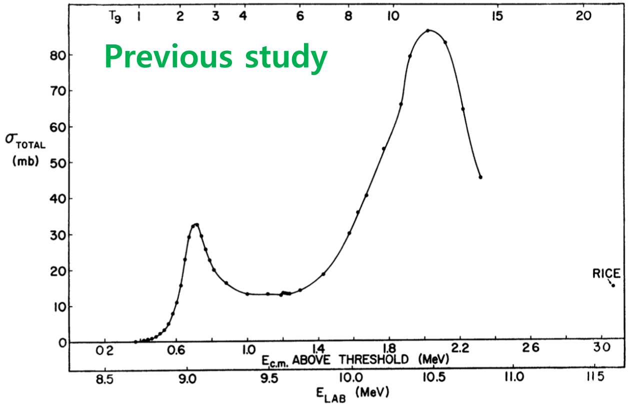


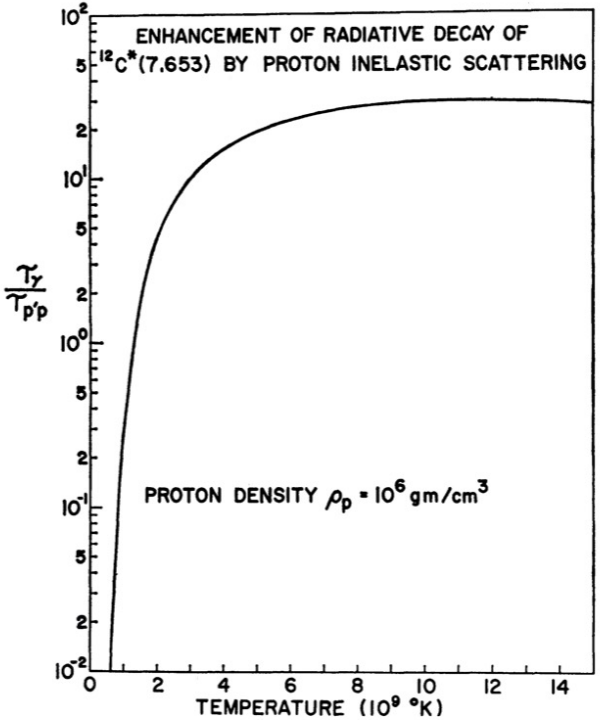
Previous Result

- Previous study for the proton upscattering on $^{12}\mathrm{C}^*(\mathrm{HS})$ measured total cross section of $^{12}\mathrm{C}(p,p')^{12}\mathrm{C}^*(\mathrm{HS})$ energy up to 2.3 MeV above HS threshold.

^{12}C*(p,p')^{12}C*(HS)

**Cary N. Davids et al., Astro. J. 166 (1971) 405*





Theoretical prediction

- The Hauser-Feshbach calculation cannot reproduce the resonance peaks, however, provide $2^+ \rightarrow 0_2^+$ cross-section data which cannot be measured experimentally.
- We propose to measure total cross section of proton energy range 8 - 18 MeV.

$^{12}C^*(p,p')^{12}C^*$(HS)

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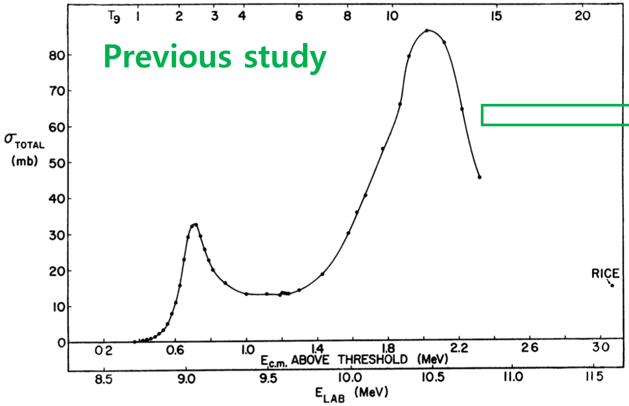
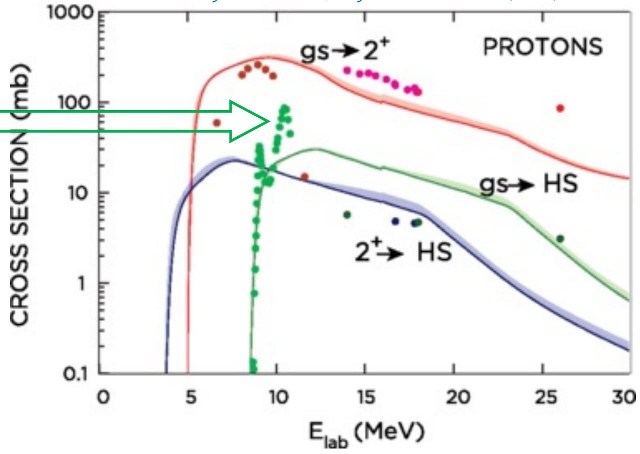


Hauser-Feshbach

**Mary Beard et al., Phys. Rev. Lett. 119 (2017) 112701*



Theoretical prediction

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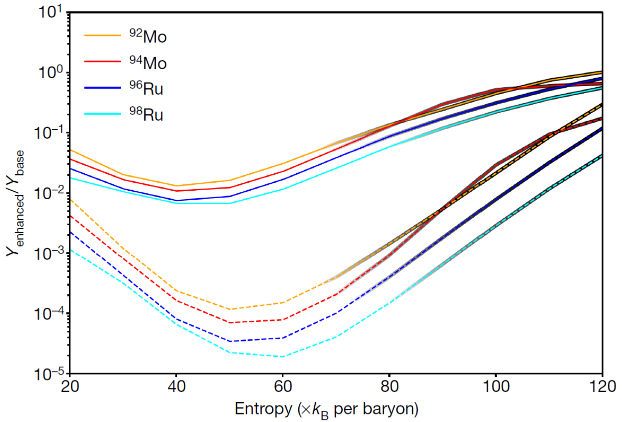
- We propose to measure total cross section of proton energy range 8 - 18 MeV.
- Inclusion of the in-medium enhancement of the triple-α rate suppress the production of ^{92,94}Mo and ^{96,98}Ru.

Abundance of Mo and Ru

Shilun Jin et al., Nature 588 (2020) 57



Hauser-Feshbach

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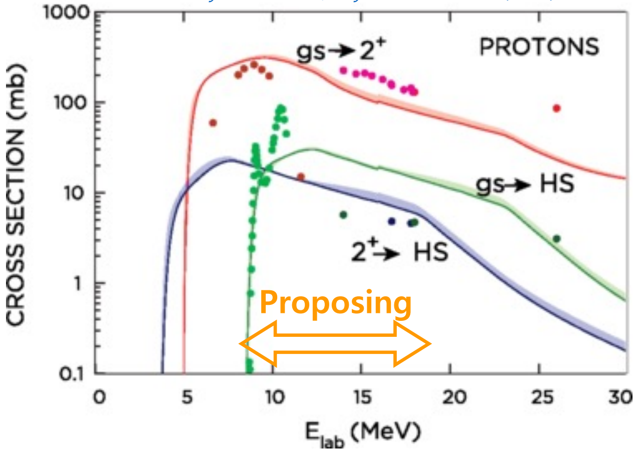
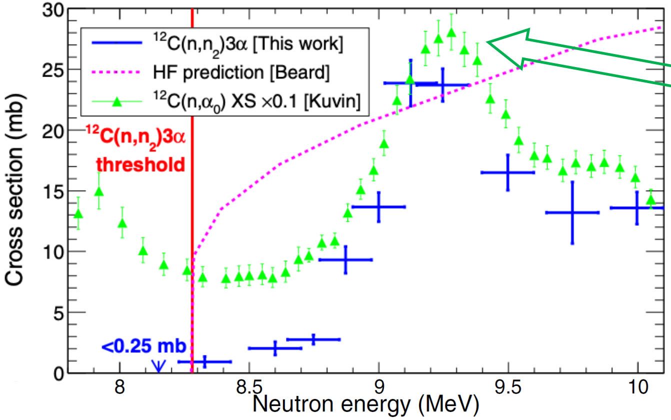


Theoretical prediction and neutron case

- Recently, the neutron upscattering experiment $^{12}C(n,n')^{12}C^{*}(HS)$ was measured which showed big discrepancy compared to the previous Hauser-Feshbach calculation.

$^{12}C^{*}(n,n')^{12}C^{*}$(HS)

J. Bishop et al., Nat. Commun. 13 (2022) 2151



Hauser-Feshbach

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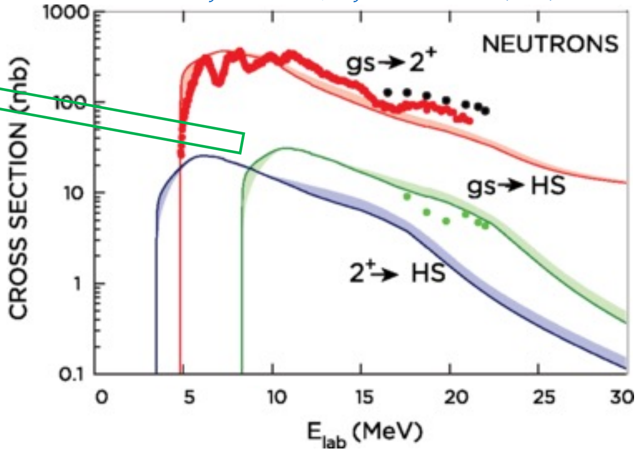
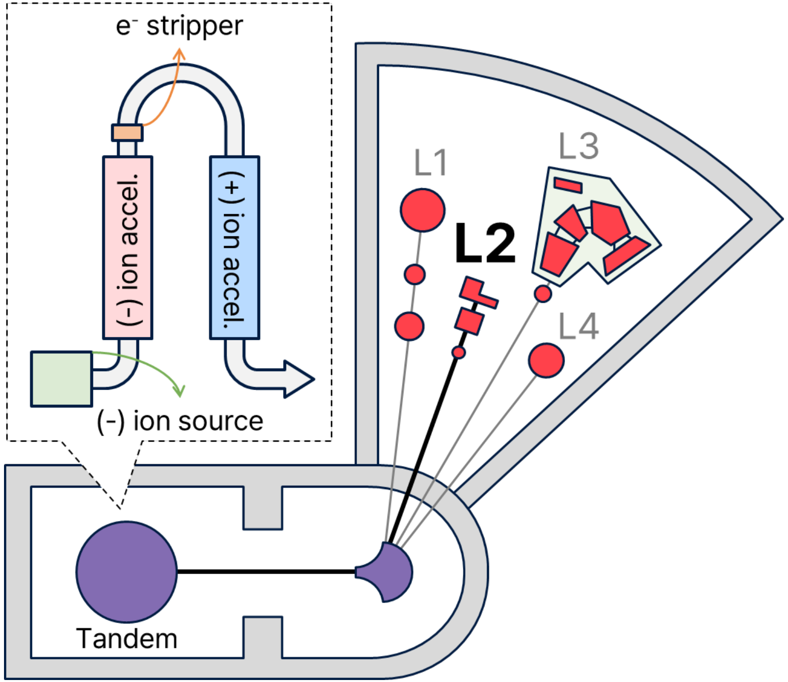


Main Experiment @ JAEA Tandem

- Main experiment will be performed at tandem accelerator of Japan Atomic Energy Agency (JAEA) located in Tokai-mura.
- Proton beam with energy of 8 – 20 MeV and intensity of 10^7 pps will be delivered to the experiment hall.
- Active target TPC, AToM-X will be used to measure the reaction.



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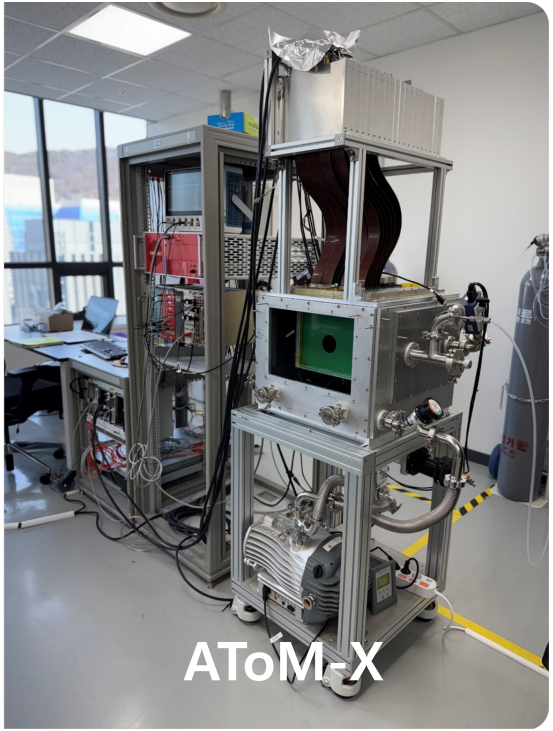
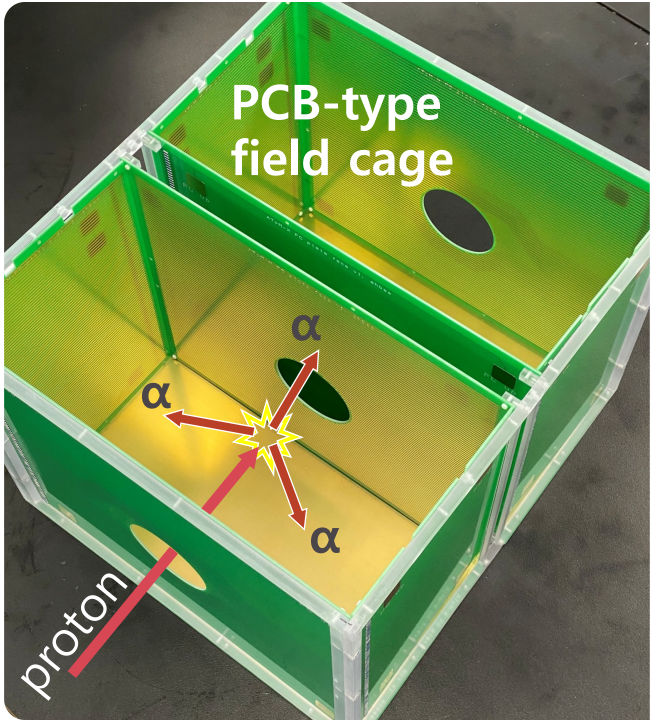
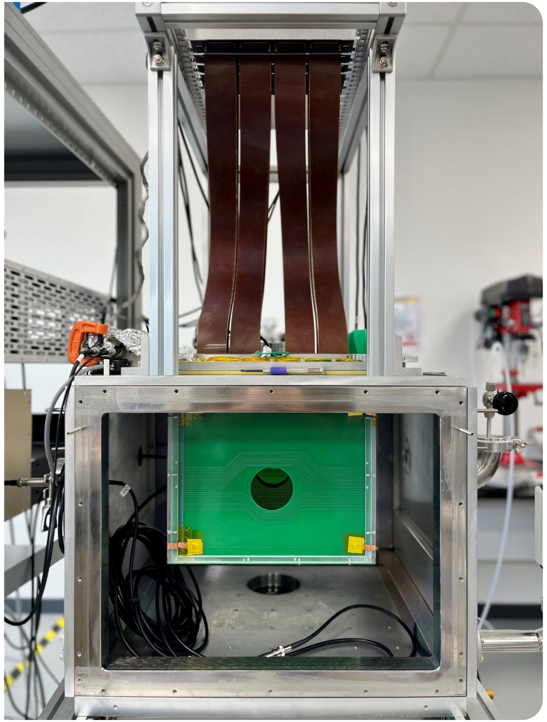


AToM-X





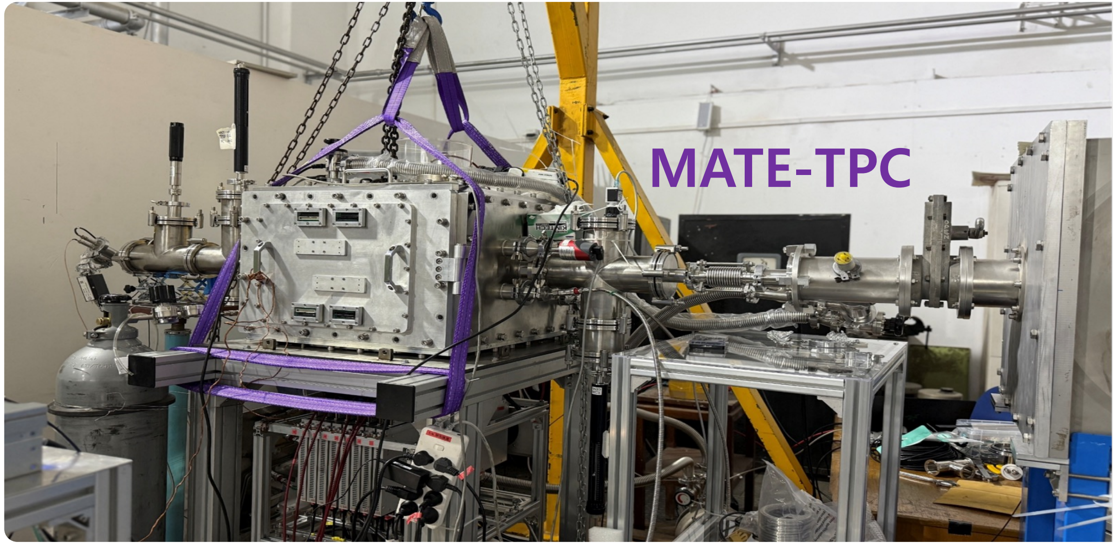
Issues

- Visibility of proton signal
  - If proton beam is invisible.
    - Only decay alpha track will be seen from the TPC.
    - We can use only TPC for the trigger.
  - If proton beam is visible, we need to check followings:
    1. Field distortion.
    2. Alpha tracks signal compared to proton beam pileup.
- Capability of beam intensity measurement (10^7 pps).

- We decided to prepare for the preview experiment!

Preview Experiment @ PKU Tandem

- Tandem at Peking University, MATE-TPC from Institute of Modern Physics (IMP).
- Aim to measure proton beam intensity and monitor TPC signal.



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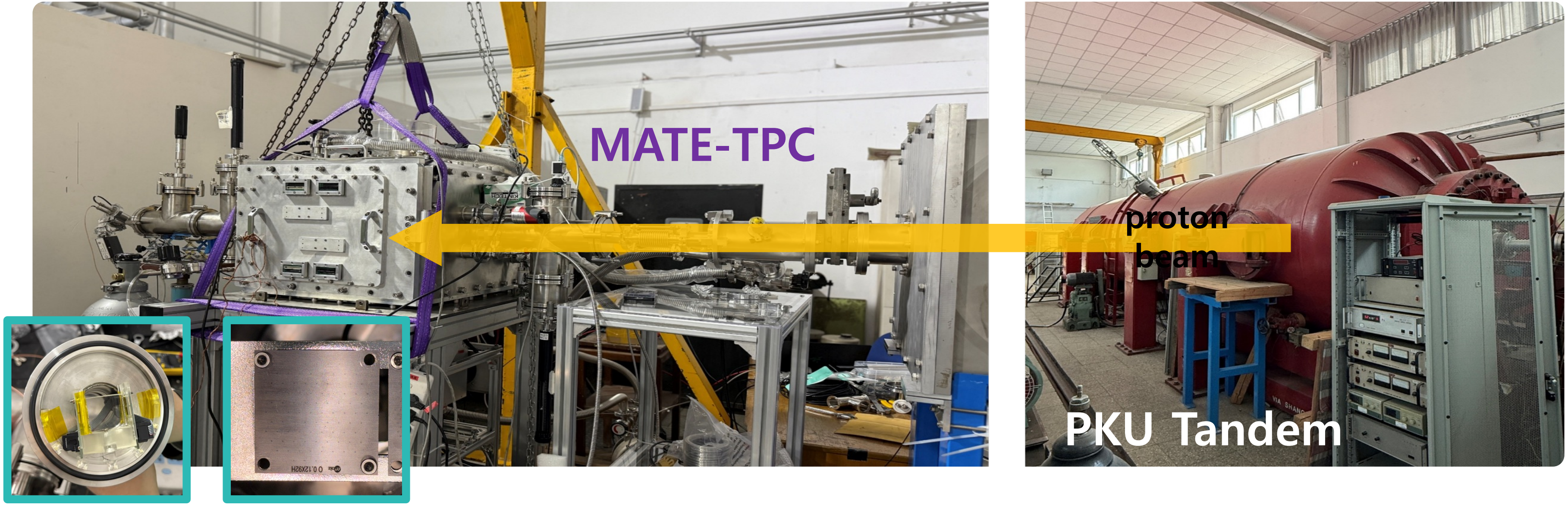
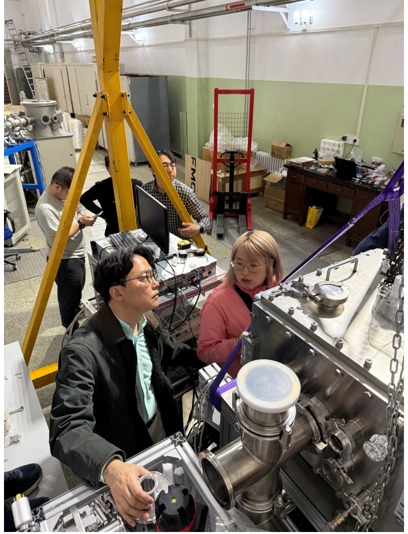
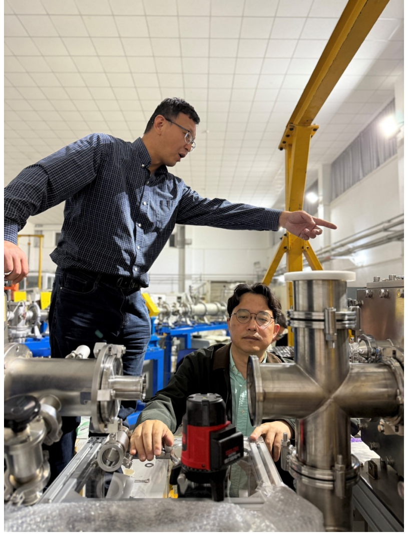
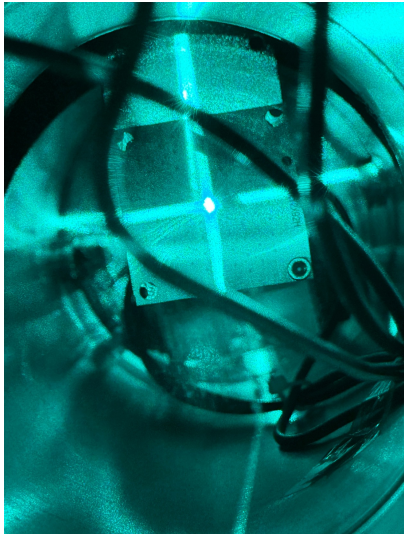
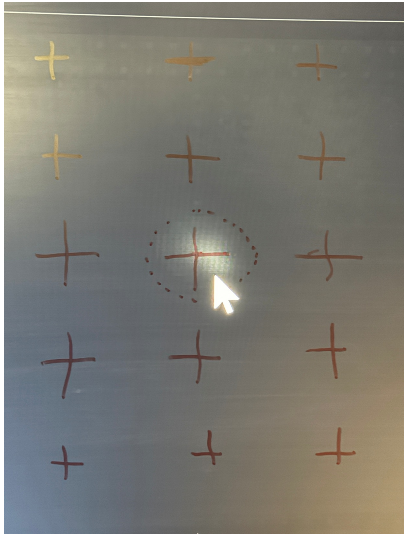




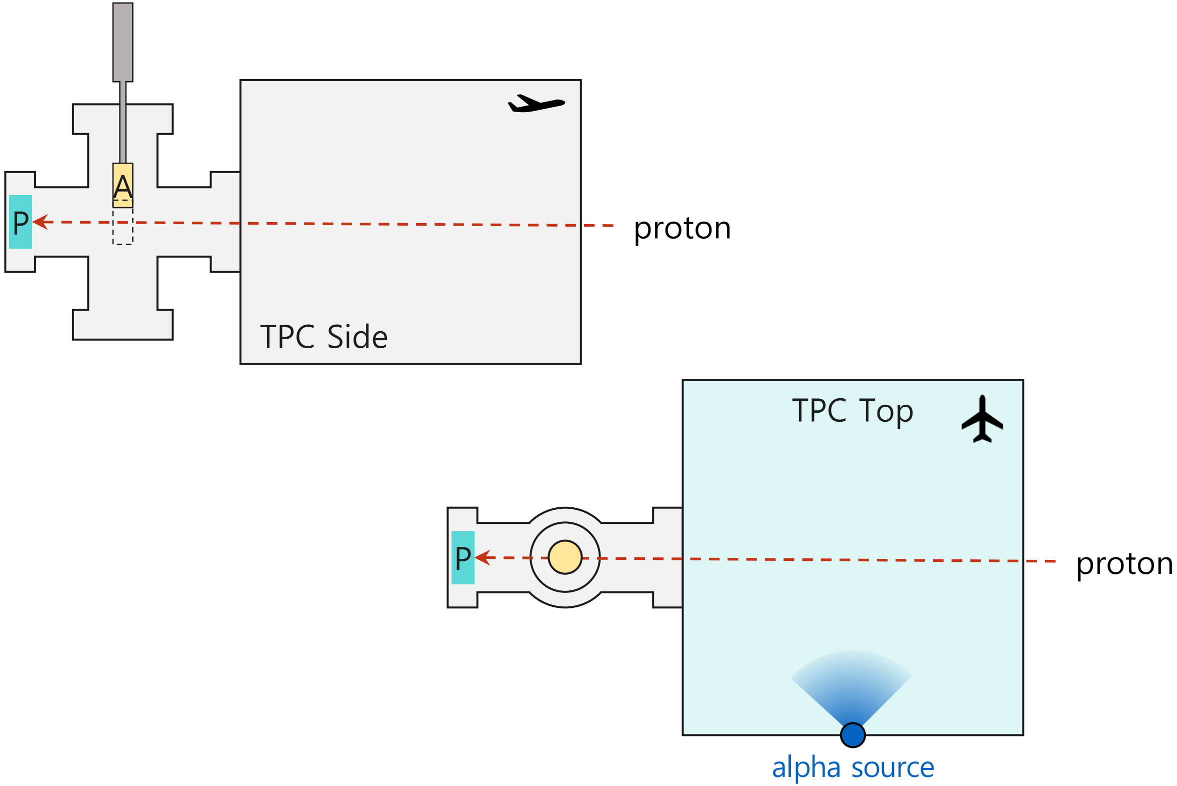




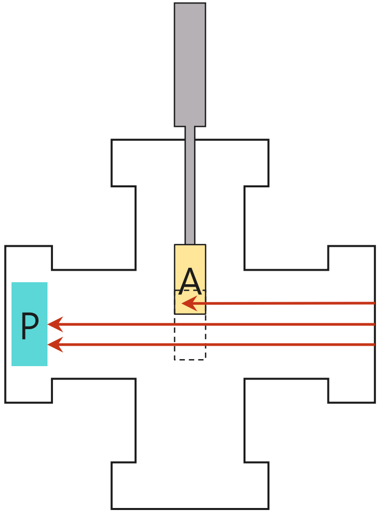


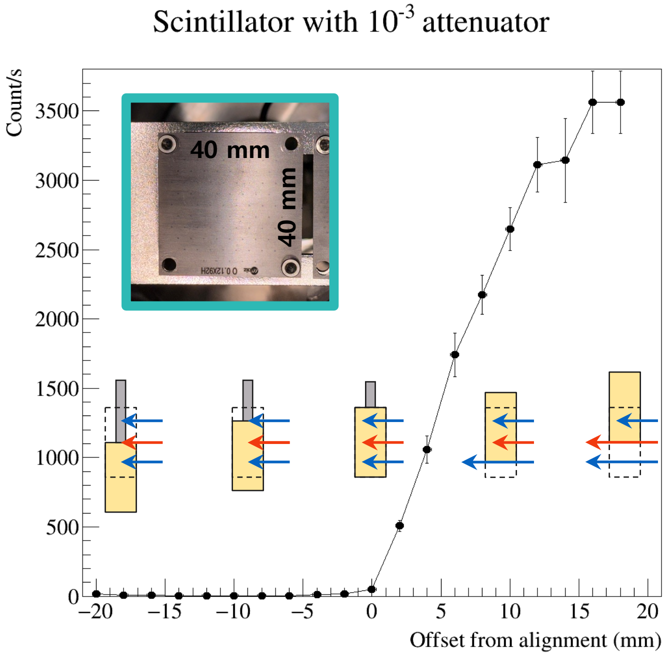
Preview Experiment @ PKU Tandem

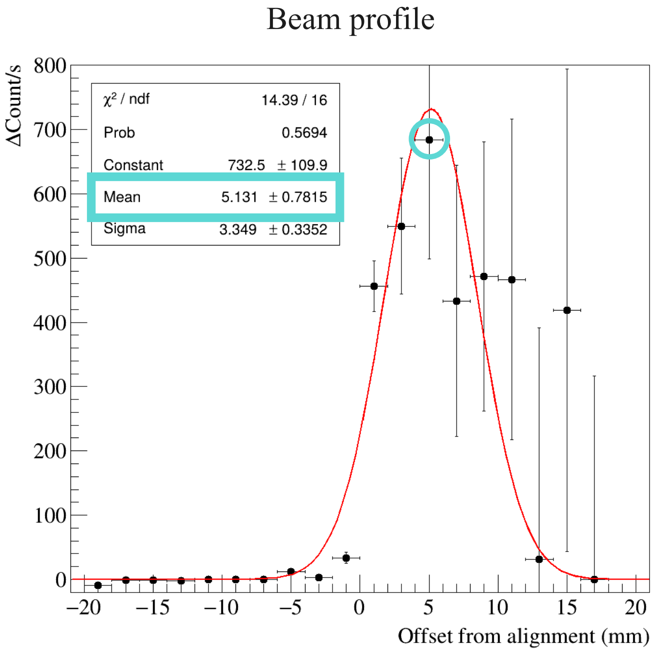
- Proton beam
  - 9 MeV
  - 4×10^6 pps
  - 3 BTU (3 x 8 hours)
- Detectors
  - MATE-TPC
  - Attenuator
  - Plastic scintillator
- Alpha source



Beam Position and Intensity measurement







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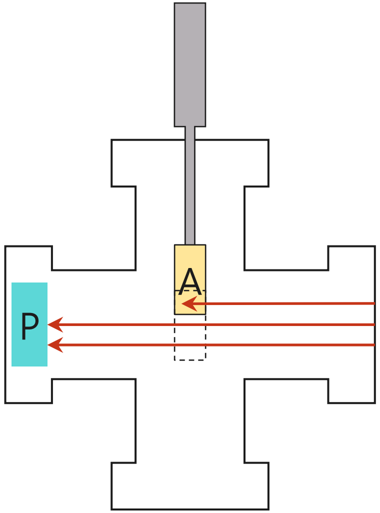
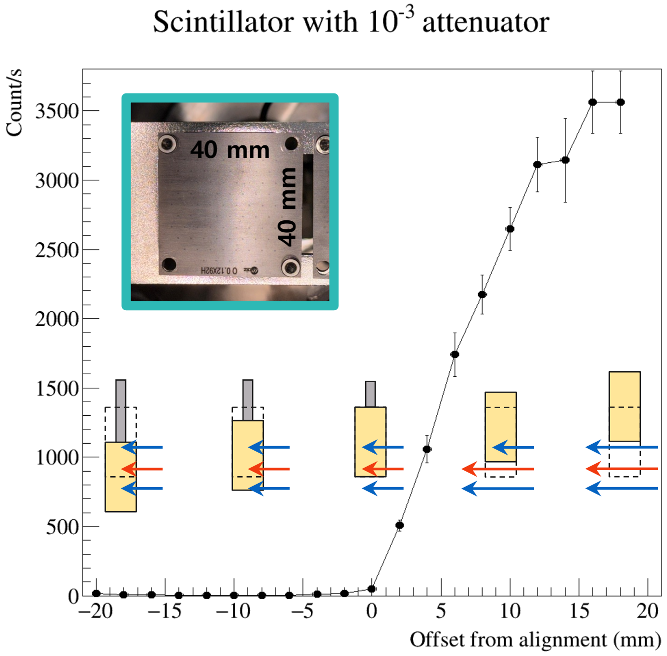
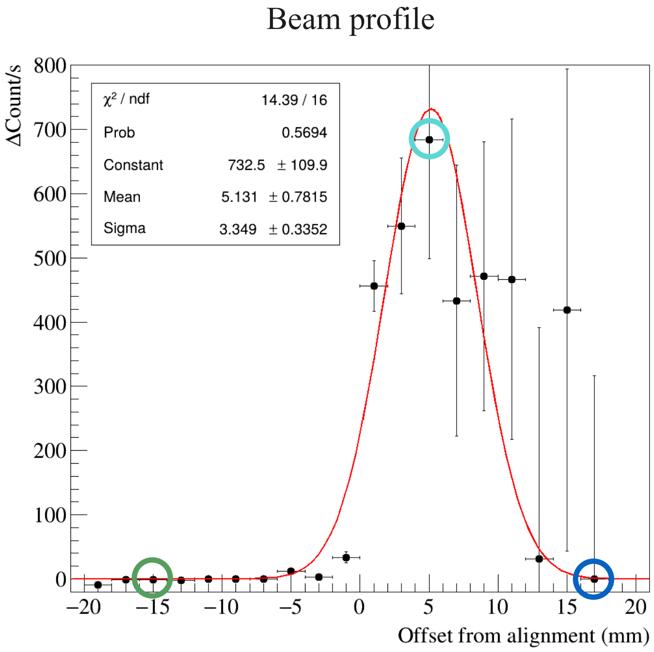
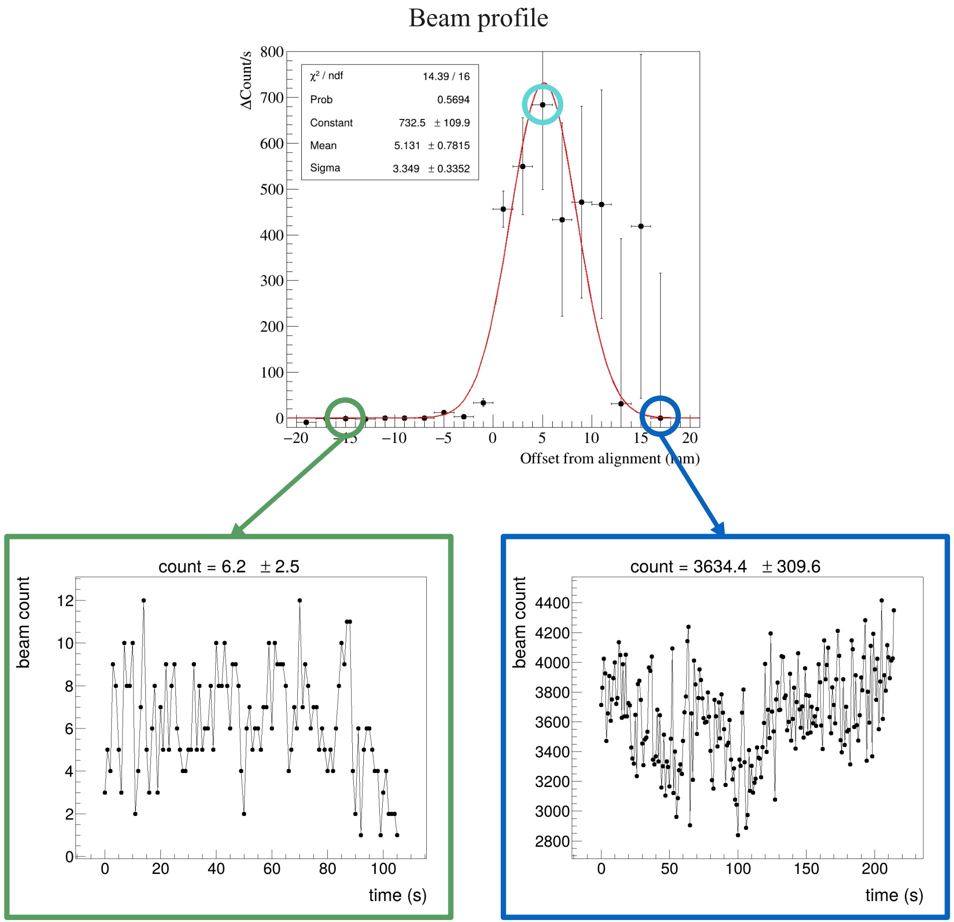






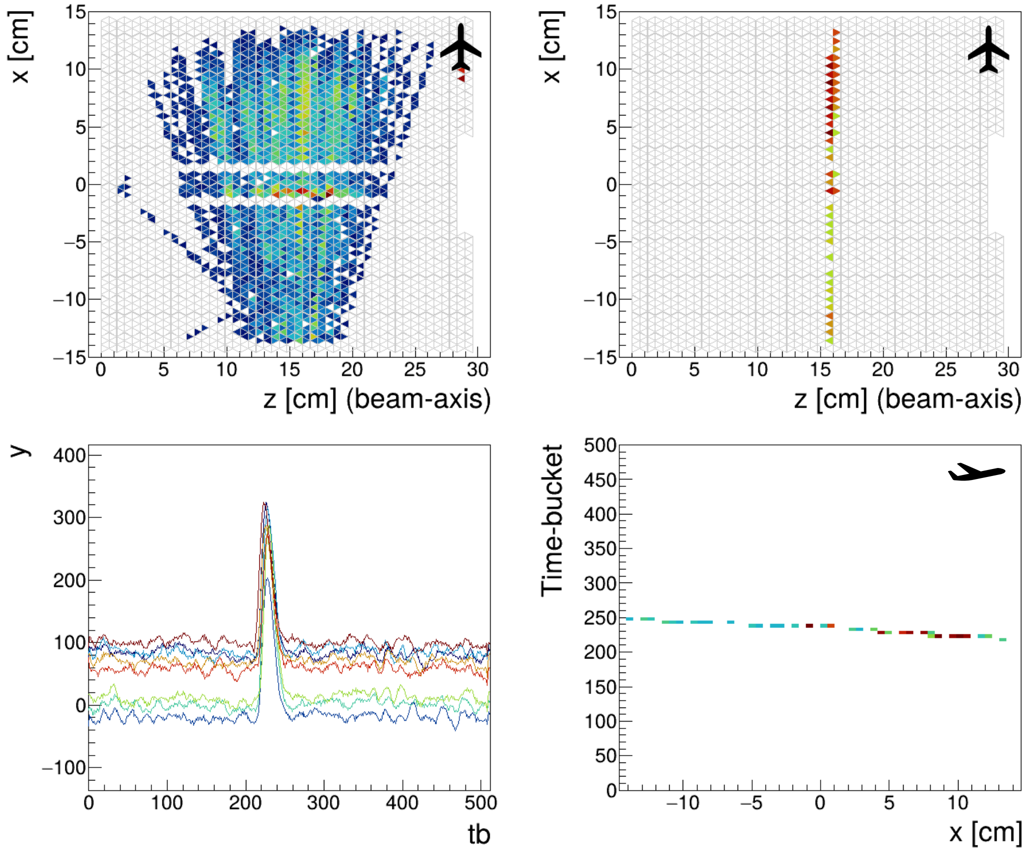
Attenuation factor

- Assuming beam intensity was stable through several runs, attenuation factor is 6.2/3634 ~ 1/600.
- Scintillator can measure up to 10^4 pps.
- Scintillator with attenuator can measure up to 6×10^6 pps.



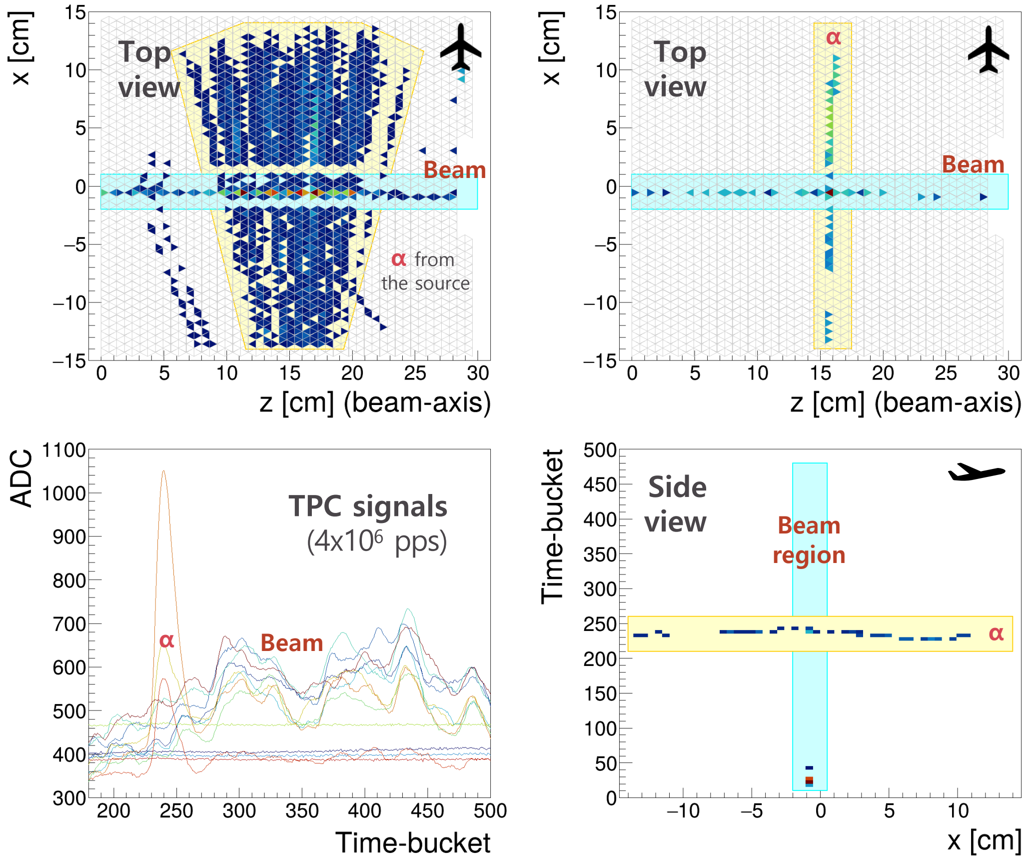
10^6 pps

- Only alpha source tracks are visible at this intensity



$4x10^6$ pps

- Proton beam pile up is visible at this point.
- Alpha track is straight meaning that the field is secured.
- Alpha signal is comparable or bigger compared to the beam pileup signal.



What we learned from this experiment

- Tandem proton beam is very narrow so it will not disturb side region.
- Proton signal is visible at the intensity of 10^6 pps.
- The pileup proton signal was distinguishable compared to the alpha track signal.
- Field is not distorted by the pileup proton electrons.
- Lowering the GEM bias voltage might remove the beam signa
- Beam intensity up to 10^7 pps can be measured.
- New strategy for the trigger is needed.
- Experiment will be challenging, but not impossible!