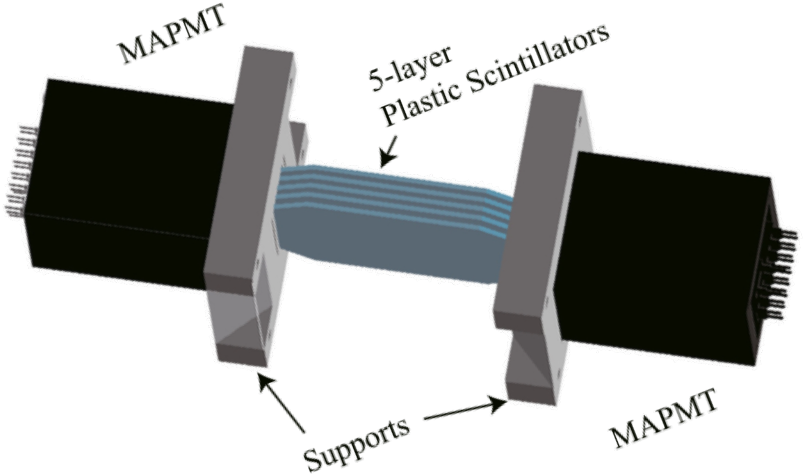
NUSTAR Annual meeting 2020

Multi-layer plastic-scintillator-based solid active proton target for inverse-kinematics experiments



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RCNP, Osaka University, Japan

Outline

- Motivation
- Concept and prototype
- Test experiment
- Data analysis
- Summary

Motivation

Tensor interactions

- Tensor interactions:
  - Fundamental nuclear interaction that provide attractive force
  - Plays an importance role in pion exchange.

- Evidences of tensor interactions:
  - Admixtures of D-wave in d, α
  - Deviation of magnetic moments (of double-closed+1 nuclei) for the Schmidt values
  - Varying magic number in neutron-rich nuclei

- Experimental probes:
  - H.J. Ong *et al.*, PLB **725**, 277 (2013),

    Probing effect of tensor interactions in ^{16}O via (p, d) reaction
  - S. Terashima et al., PRL**121**, 242501 (2018),

    Dominance of Tensor Correlations in High-Momentum Nucleon Pairs Studied by (p,pd) Reaction

H.J. Ong *et al.*, PLB **725**, 277 (2013), W. Horiuchi, Y. Suzuki, PRC**76**, 024311 (2007), S. Terashima et al., PRL**121**, 242501 (2018)

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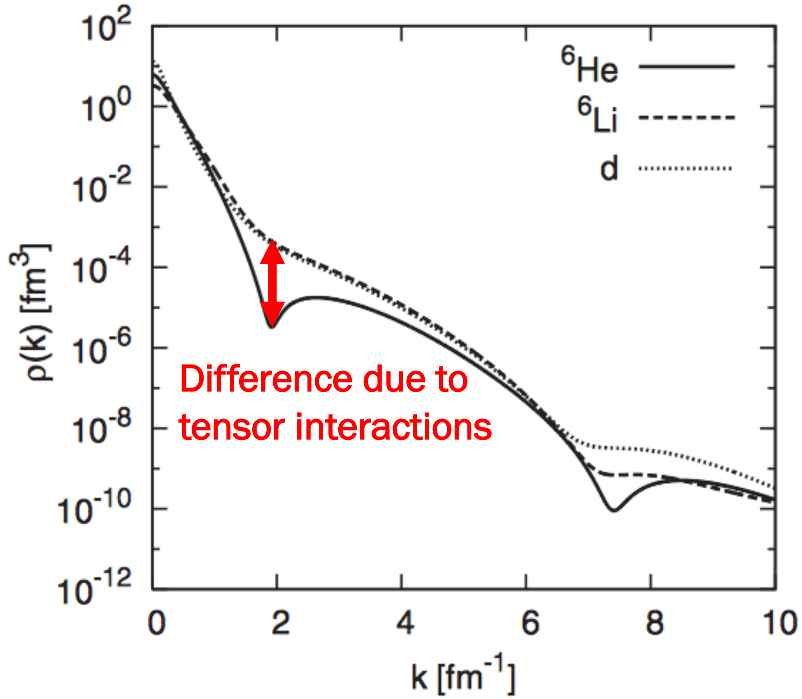
Motivation

Verification of tensor force effect in ^{6}He, ^{6}Li

- **Theoretical prediction:**

  possible different contribution of tensor interaction in ^{6}He and ^{6}Li nuclei.



- **Experiment probe:**

  via high-momentum-transfer (p,d) reactions in inverse kinematics at GSI, Germany.

- **Experimental conditions:**
  - Medium to High Energy Secondary Beam (400 - 800 MeV / u ~ 2 fm^{-1})
  - Beam intensity ~ 10^{7} Hz
  - Hydrogen target of sufficient thickness

- **What need to measurement:**
  - ✓ excitation energy with sufficient resolution (^{5}He, ^{5}Li)

H.J. Ong *et al.*, PLB **725**, 277 (2013), W. Horiuchi, Y. Suzuki, PRC**76**, 024311 (2007), S. Terashima et al., PRL**121**, 242501 (2018)

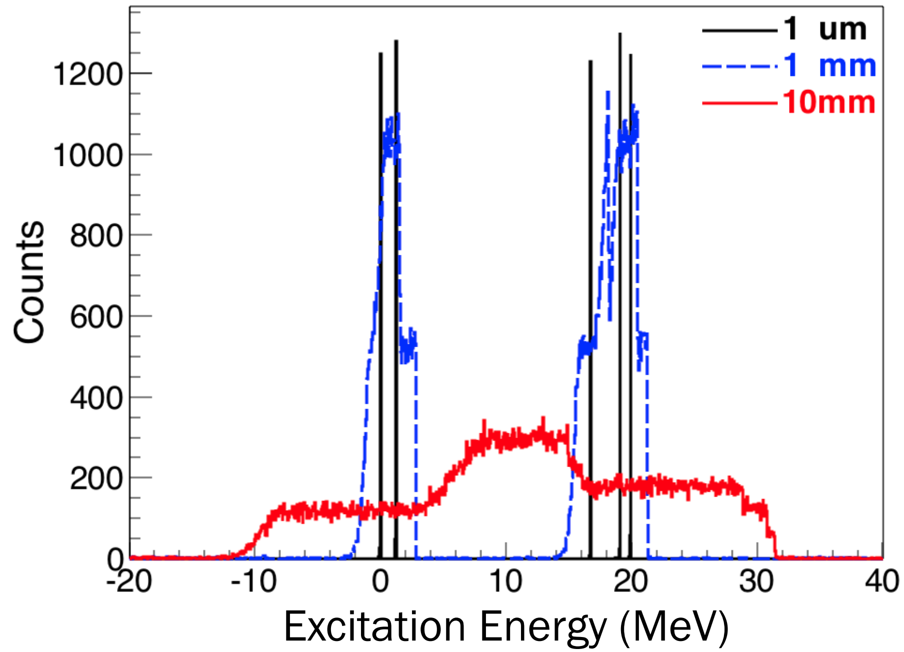
Motivation

Target selection

- Limitations:
  - Reaction cross section: < 0.2 mb/sr.
  - Beam intensity: $<10^7$ Hz.
  - Resolution of detectors.

- Thickness and counting-rate:

CH_2 [mm]	0.001	1	10
Rate [par./hr]	0.06	60	600
CH_4 at 1atm gas equiv.[mm]	0.1	850	8500



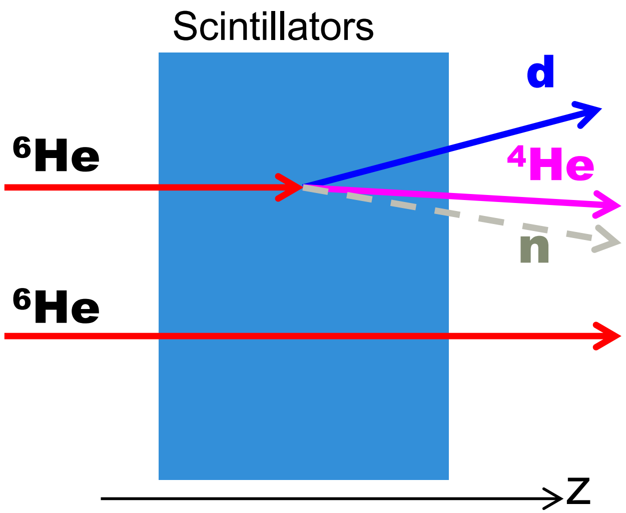
- Thickness and excitation-energy resolution:
  - Reacted position are needed

- Gases active target ?
  - MAIKo, AT-TPC, etc… are not suitable

=> A solid active target is requested

Concept

- Based on the difference of energy-loss before and after reaction point ***{ p(^{6}He,d) at 800MeV/u }***
  - Before: ΔE (^{6}He) = 1.24 MeV/mm ΔE_b = 1.24 MeV/mm
  - After: ΔE (d) = 1.88 MeV/mm, ΔE (^{4}He) = 1.15 MeV/mm ΔE_a = 3.03 MeV/mm



- Unreacted event:

$$E_{loss} = \text{constant} = 12.4 \ \text{(MeV)}$$

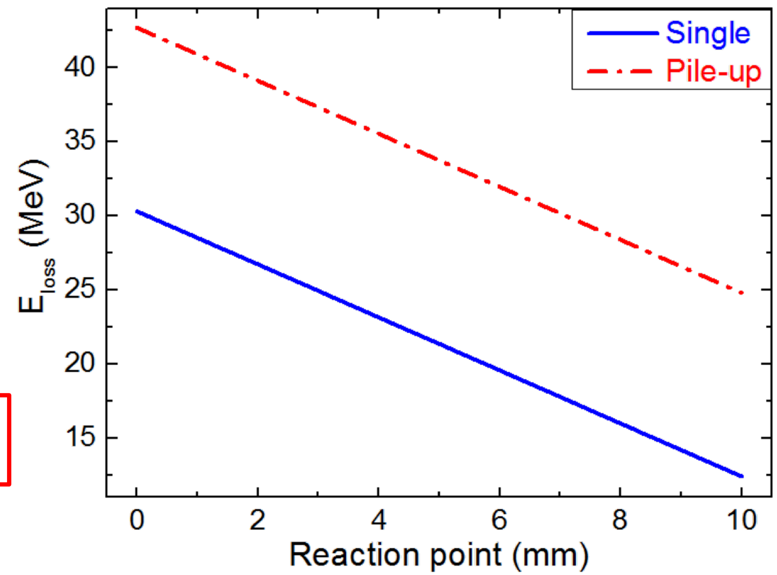
- Reacted event:

$$E_{loss}(z) = 1.24\,z + 3.03(10-z) \ \text{(MeV)}$$

- Normal pile-up event (Unreacted + reacted):

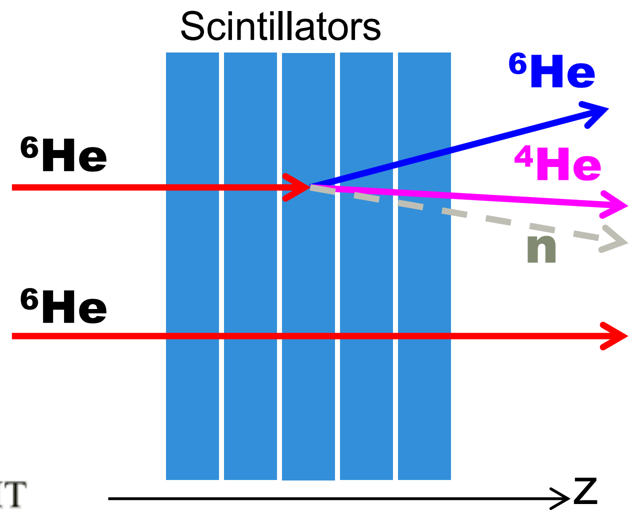
$$E_{loss}(z) = 12.4 + 1.24\,z + 3.03(10-z) \ \text{(MeV)}$$

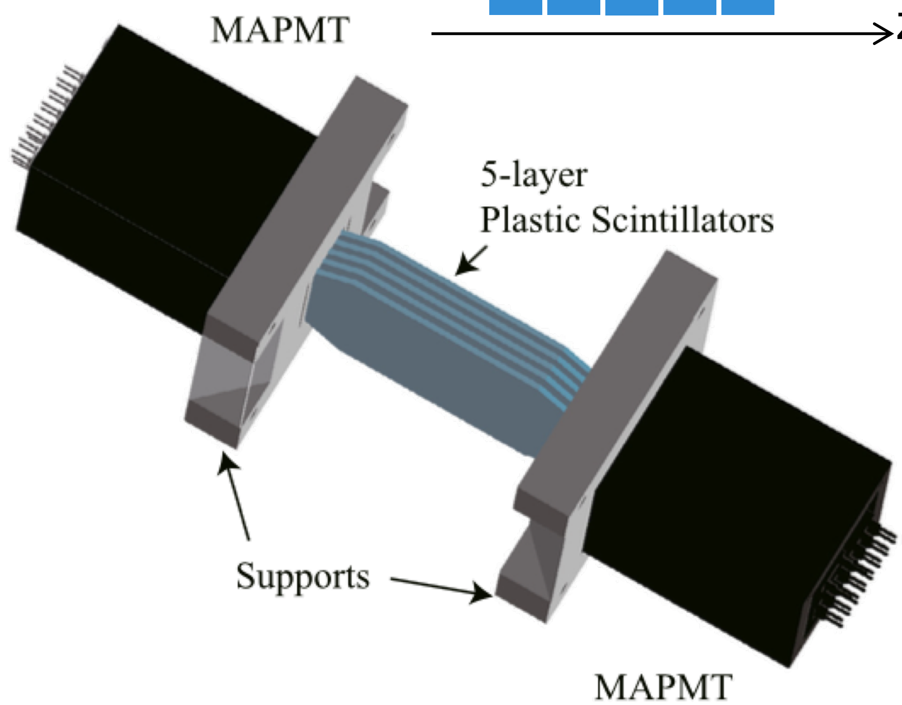
Reaction position is not correct for pile-up event



Concept and prototype

- Segmented target into multi-layers of 1mm with separated readout to remove pile-up events.
- Readout by 16-channel Linear Array PMT, H10515B-20, by Hamamatsu





Expected: position resolution < layer thickness (FWHM)

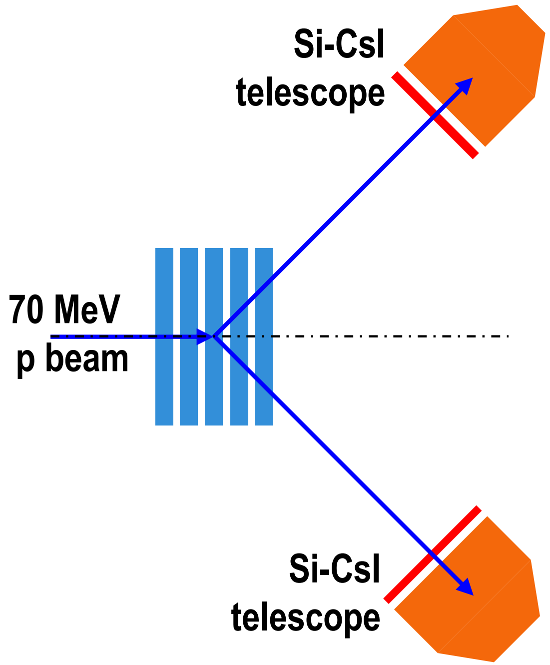
Test Experiment: proton-proton elastic scattering

- **Performed at Cyclotron and Radioisotope Center *(CYRIC)*, Tohoku University, Japan**
  - Proton beam at 70 MeV
  - Proton-proton elastic scattering

  E_{loss} similar with $p(^6He,d)$ at 800 MeV/u

- **Experimental setup**
  - 5x1mmt scintillator with separated readout from both sides.
  - 2 Telescopes (Si 10 strips and 50mmx50mm CsI crytal) located at 45 degree.

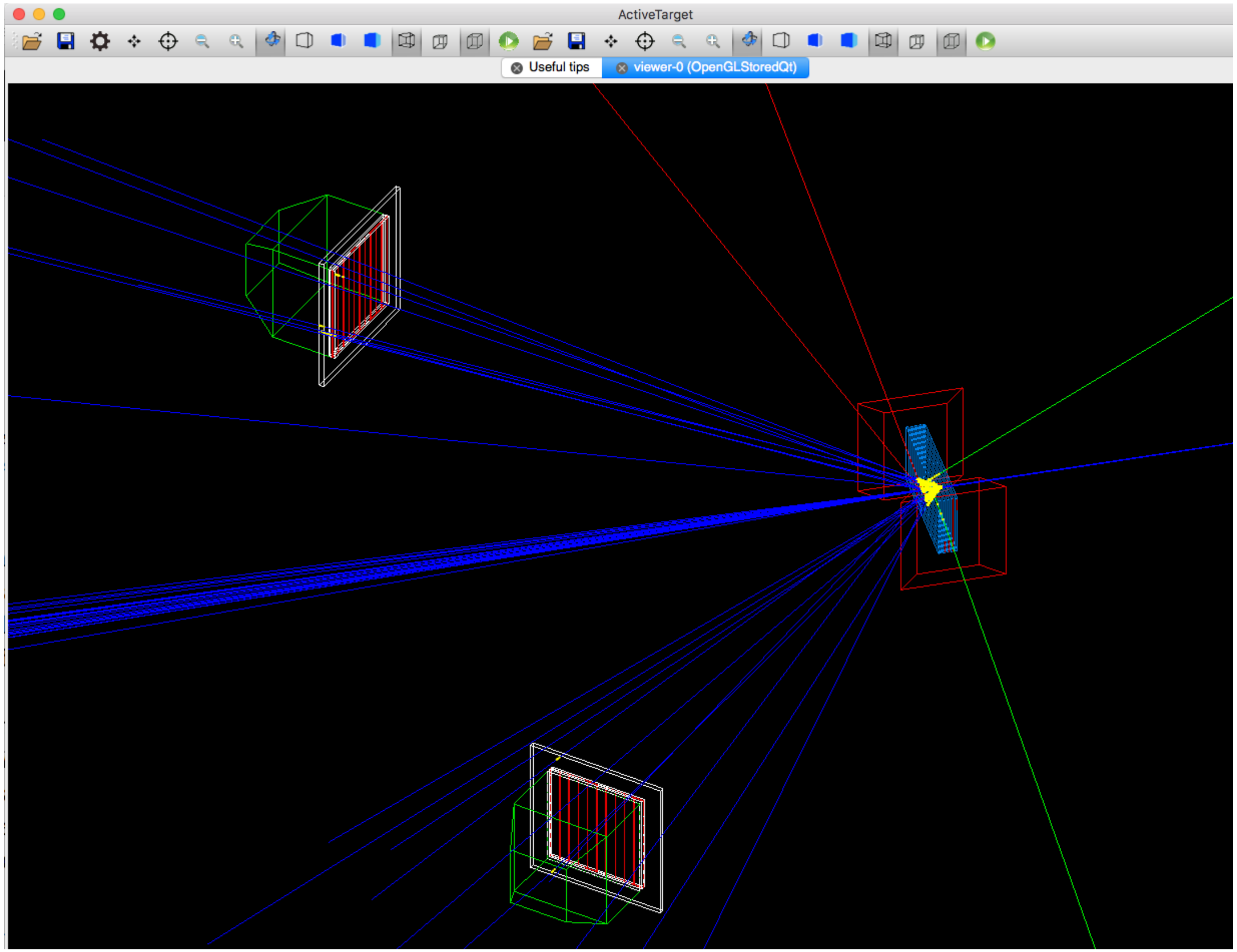
- **Reacted position determination**
  - using energy loss and scattering angle from telescopes.
  - using energy loss from proton active target

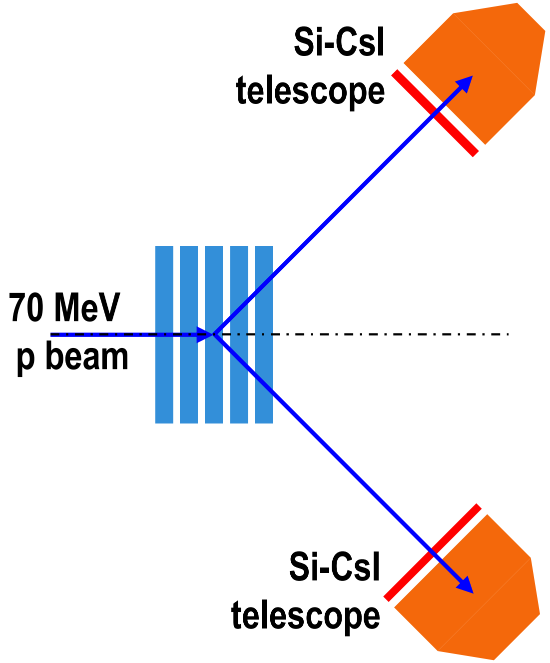


RCNP Test Experiment

Test Experiment: proton-proton elastic scattering

- Performed simulation using GEANT4



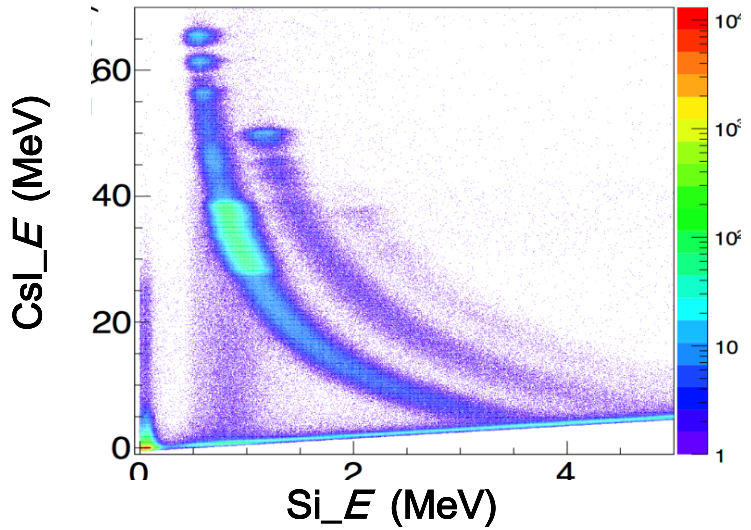


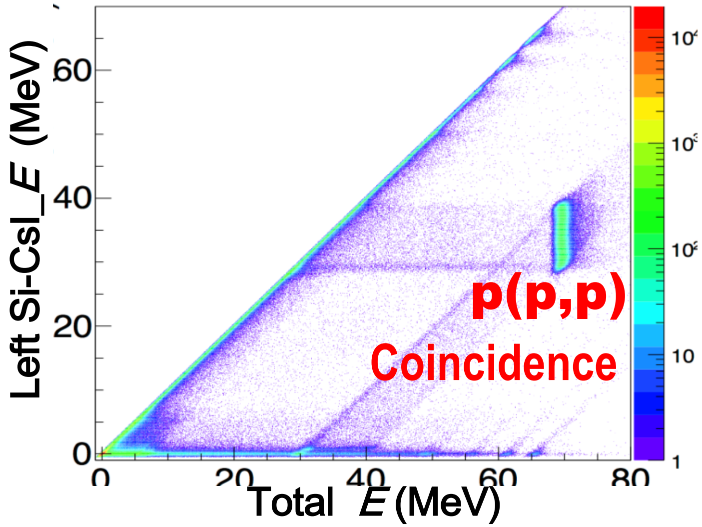
Data analysis

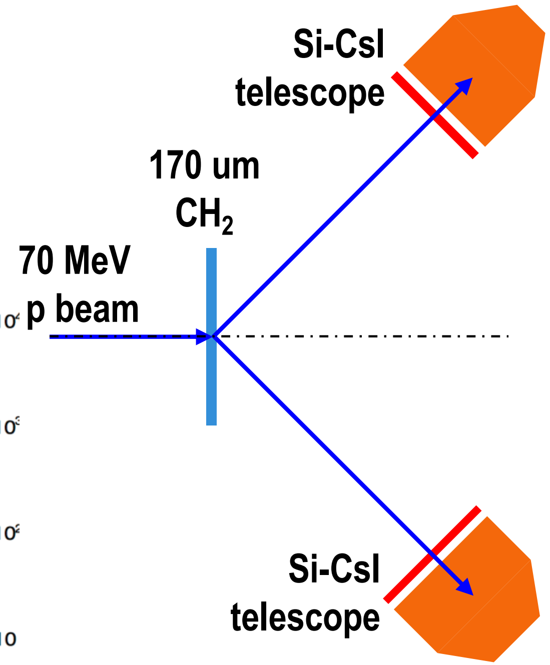
Data on CH_2 thin target

- **Target:** 170um CH_2
- **Purpose:**

calibration and evaluation of position resolution for telescopes

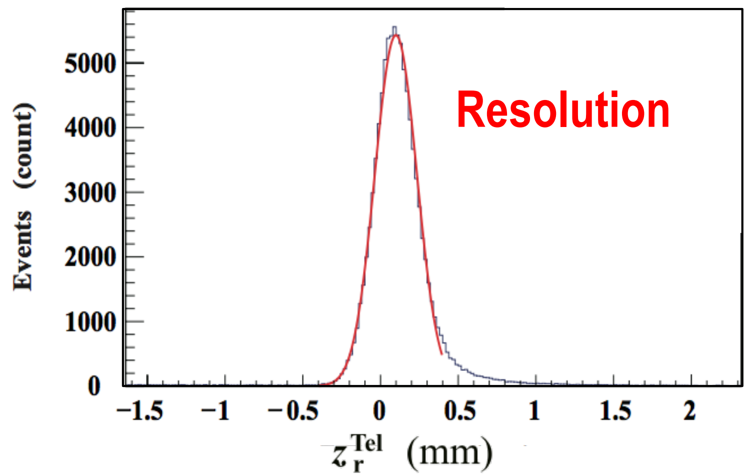






Intrinsic position resolution of telescopes:

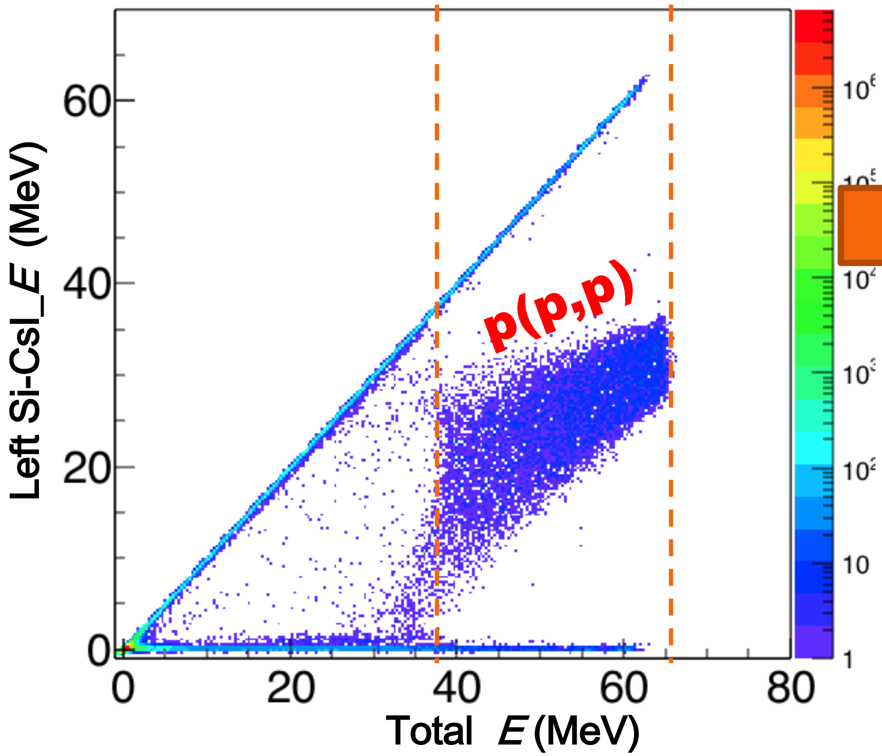
160 um

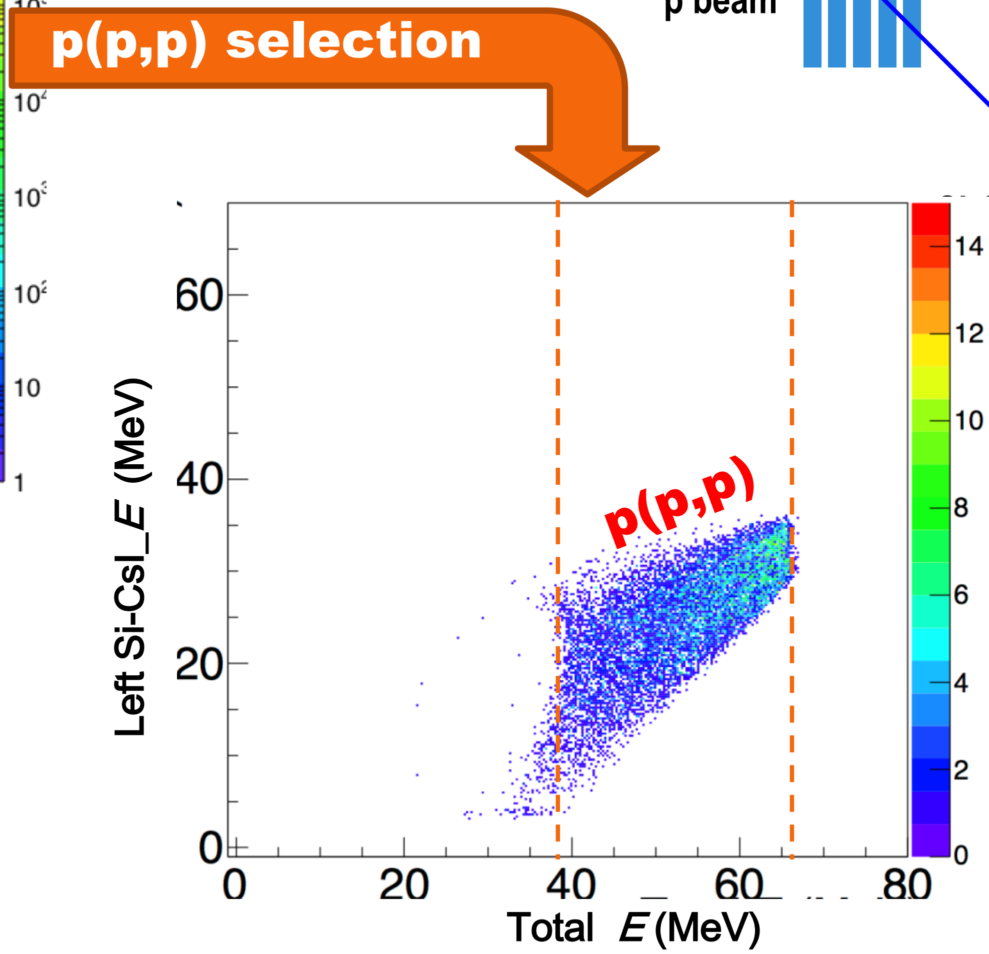


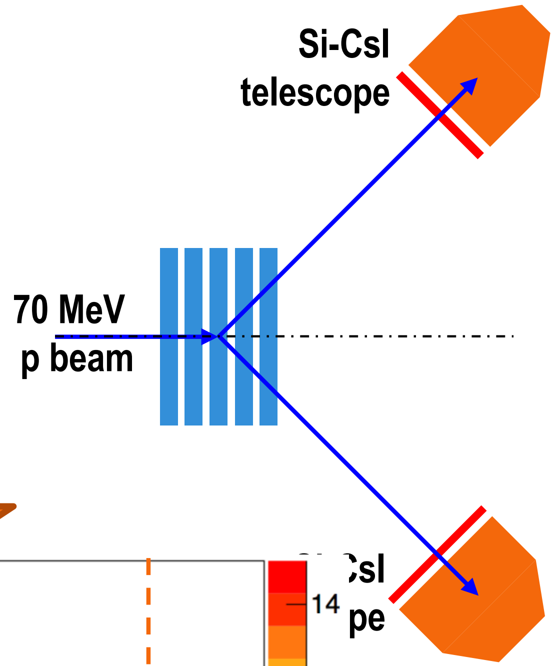
Data analysis

Reaction position via Si-CsI telescopes

- Using total energy loss in both telescopes



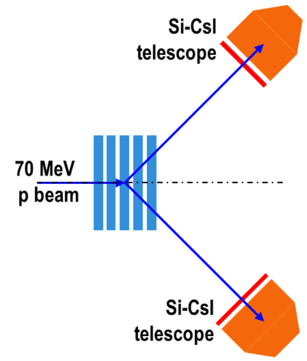


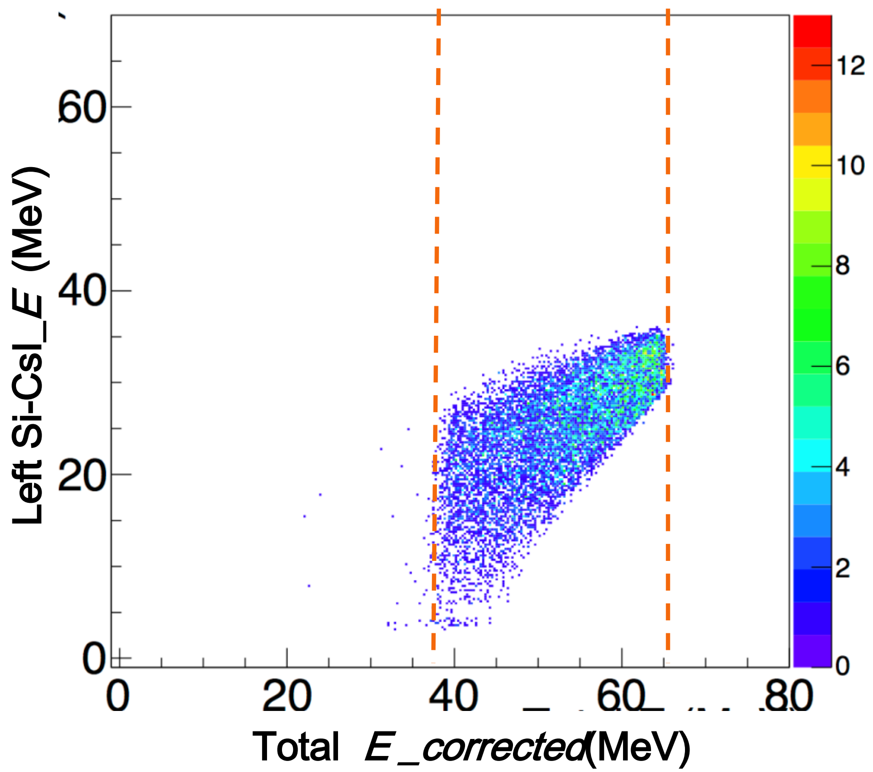


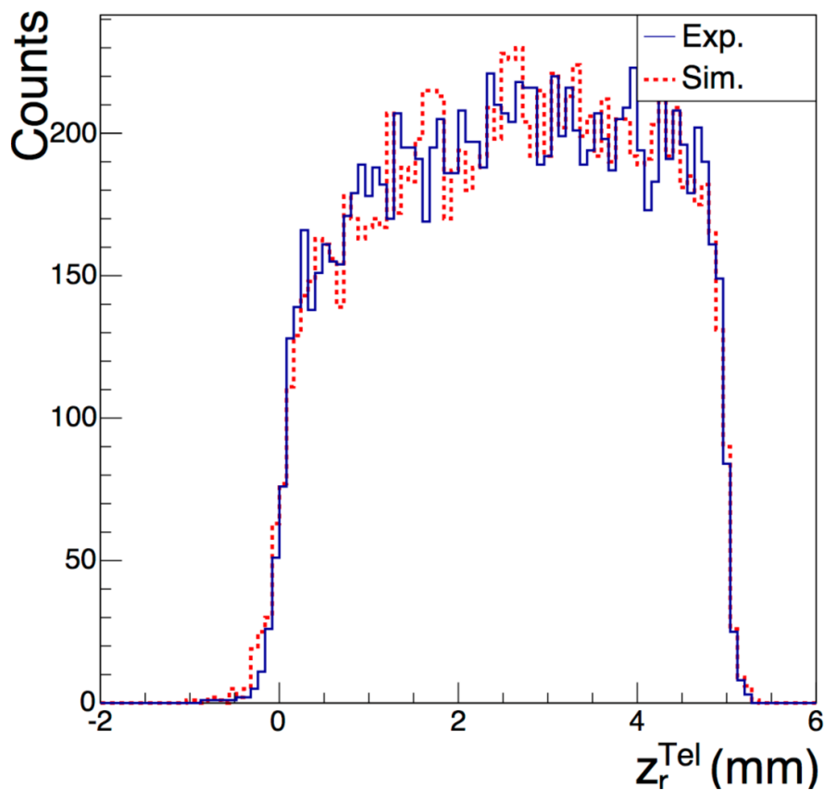
Data analysis

Reaction position via Si-CsI telescopes

- Using total energy loss in both telescopes
- Using strip ID to correct angular dependence
- Reaction position reconstructed from total corrected energy.
- Simulation reproduced the experimental data very well.



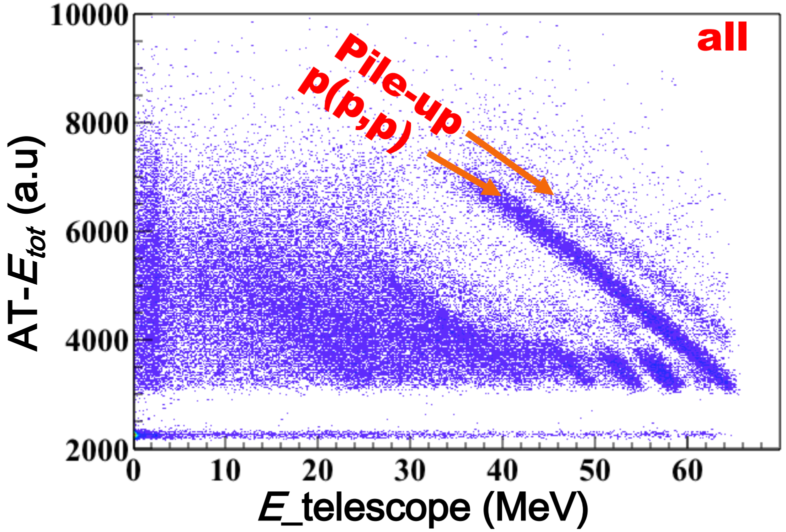


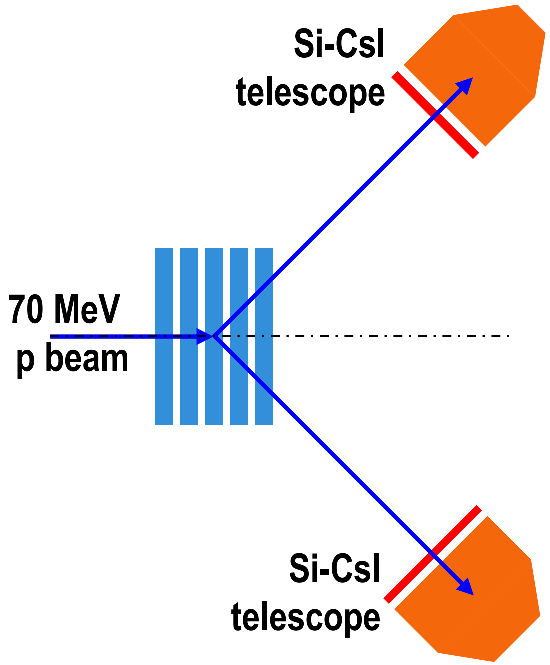


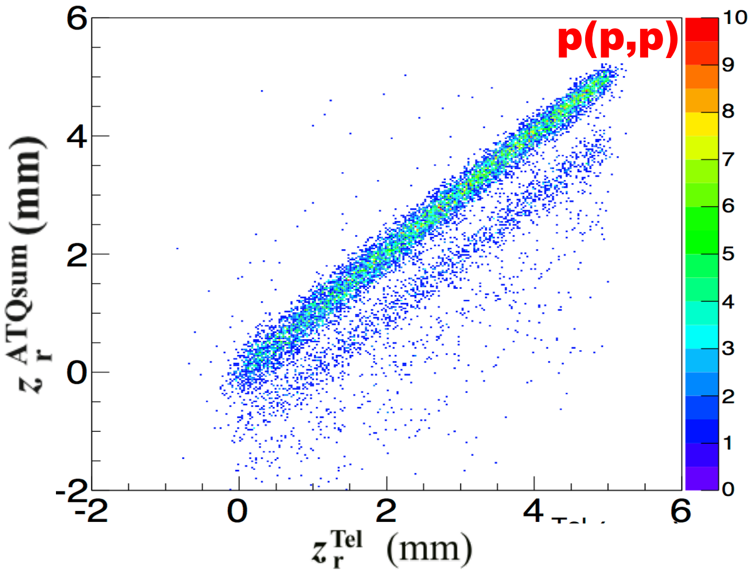
Data analysis

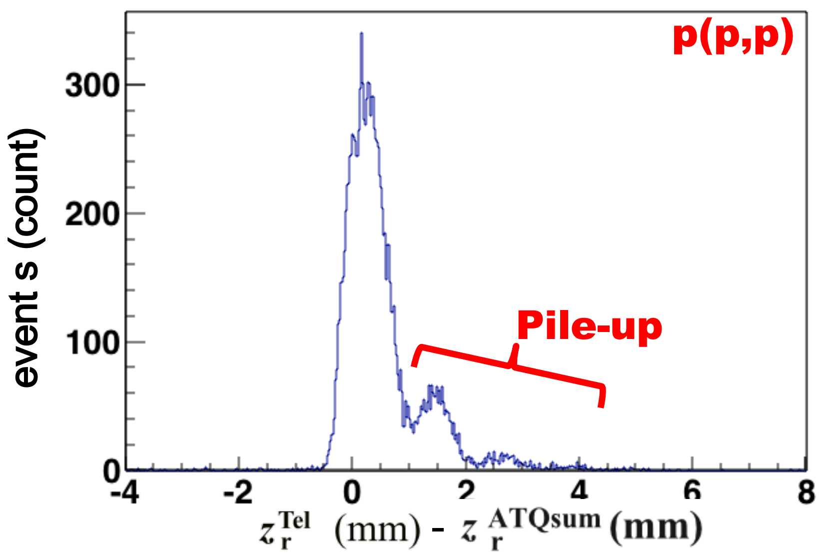
Reaction position via absolute energy loss

❑ Using total energy loss





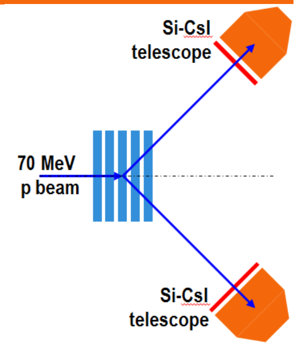


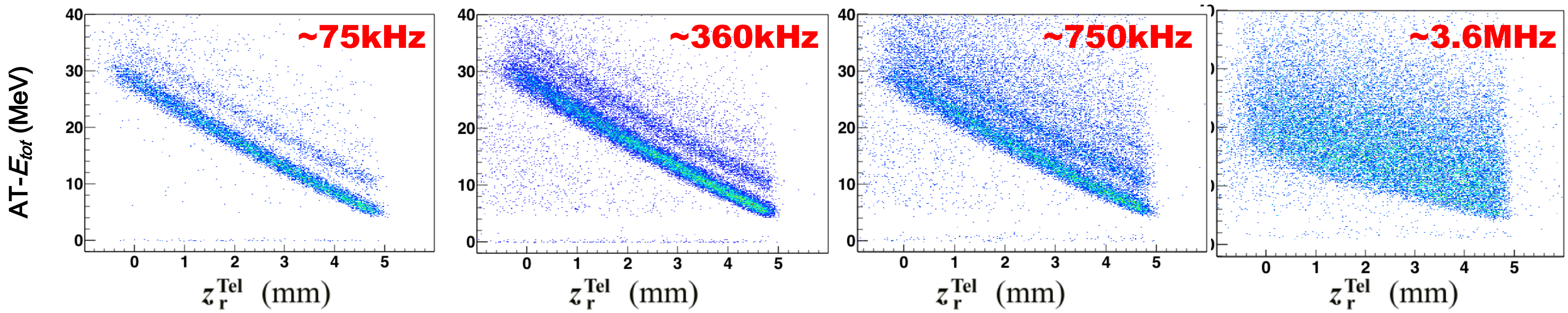


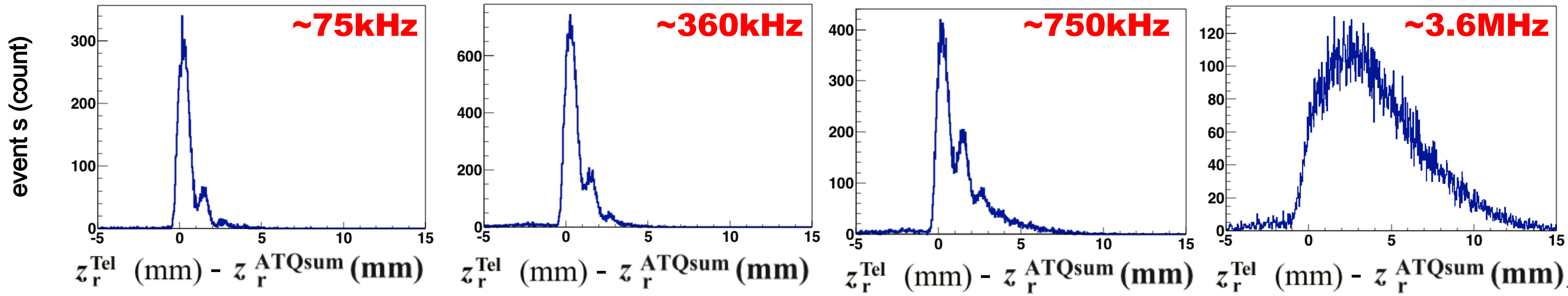
Data analysis

Beam rate dependence

- **Using total energy loss**
- **Rate dependence:**
  - Pile-up becomes serious at 1MHz
  - At 3MHz we cannot determine reaction position
  - At 2MHz the gain of PMT start to change



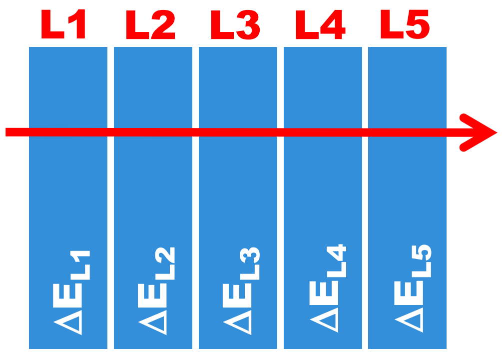


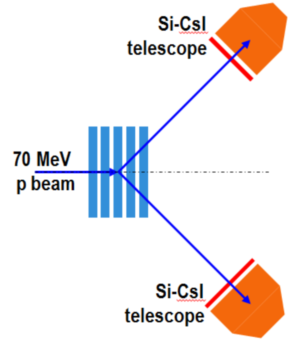


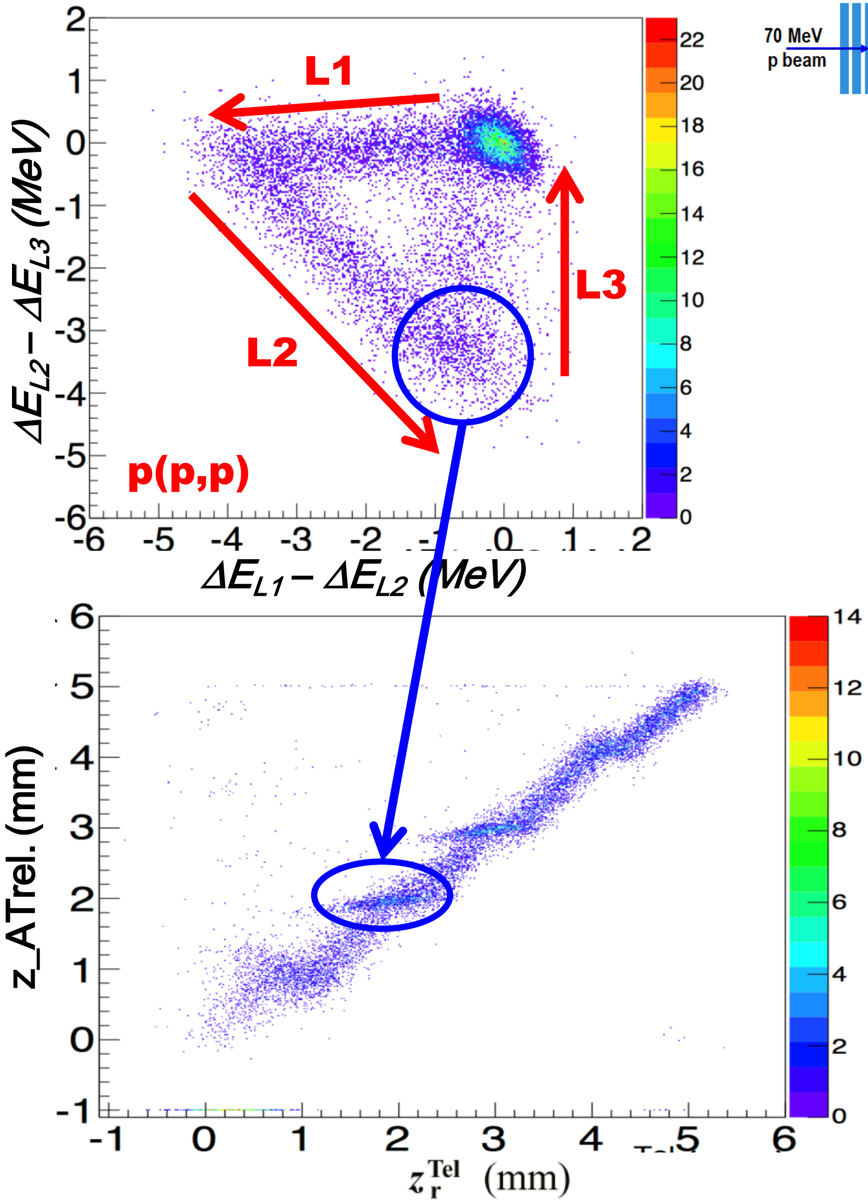
Data analysis

Reaction position via relative energy loss

- Using different energy in neighboring layers



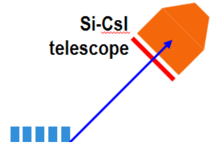




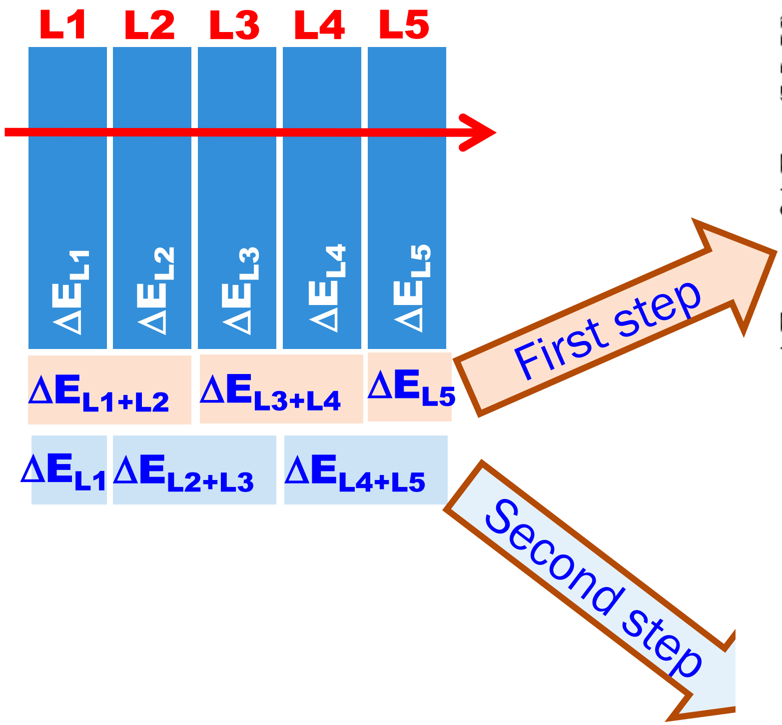
- Pile-up has been solved
- The uncertainties appear around borders of adjacent layers

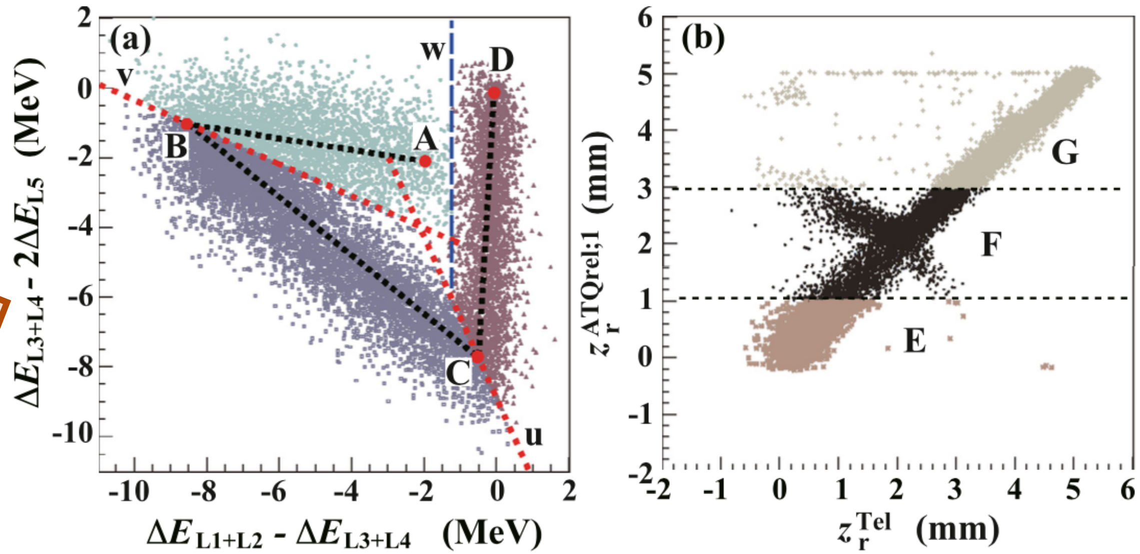
Data analysis

Reaction position via relative energy loss



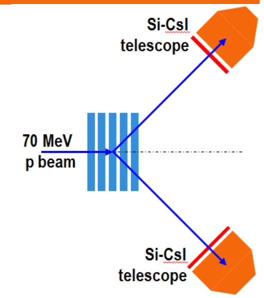
- Using different energy in 2 neighboring layers

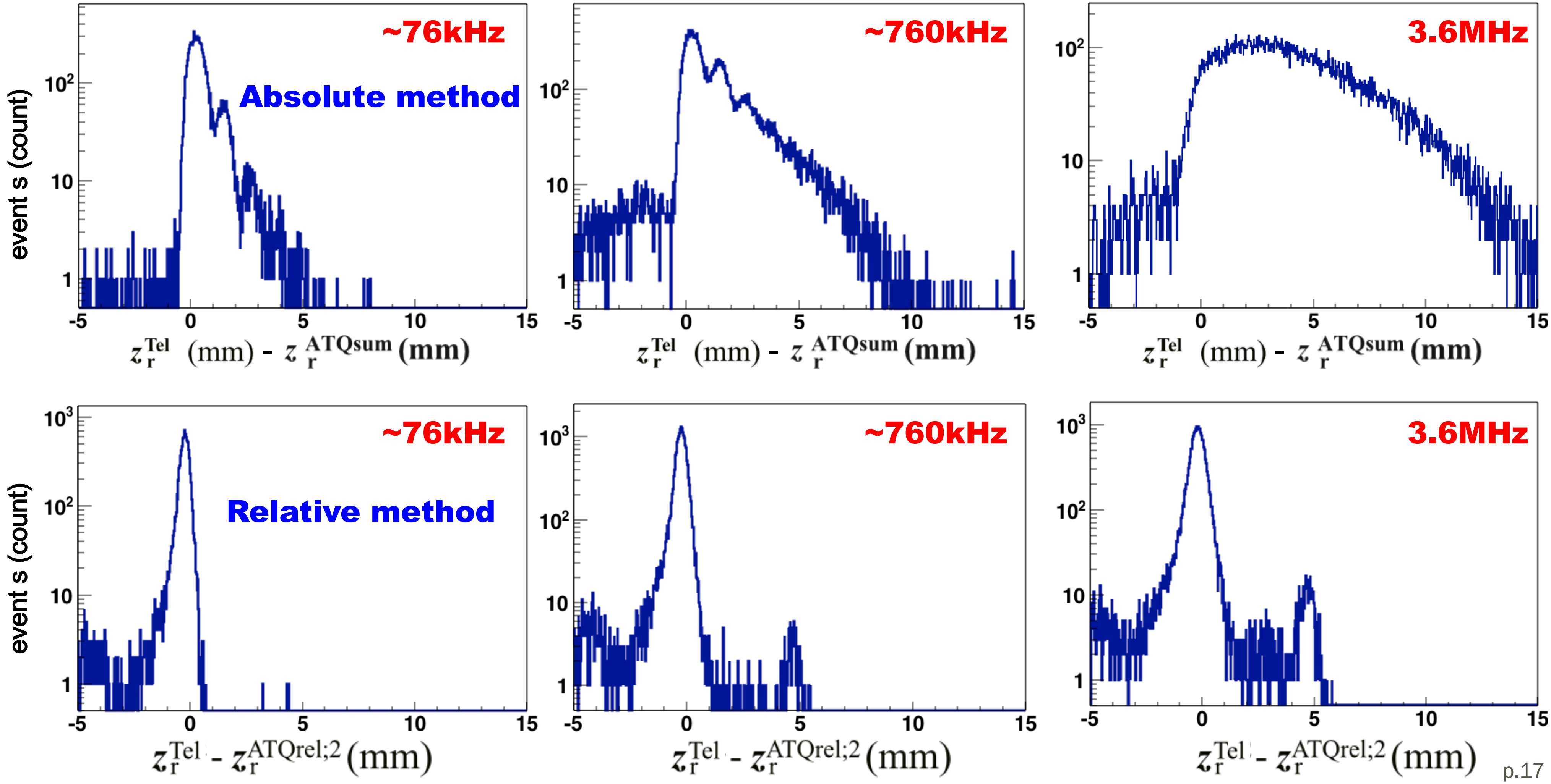




Comparison on rate dependence

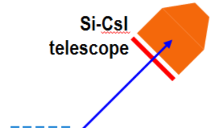
Rate dependence

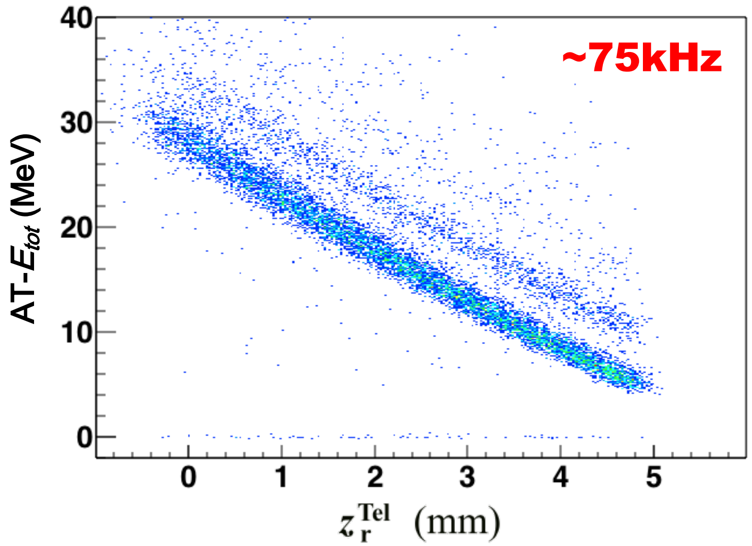


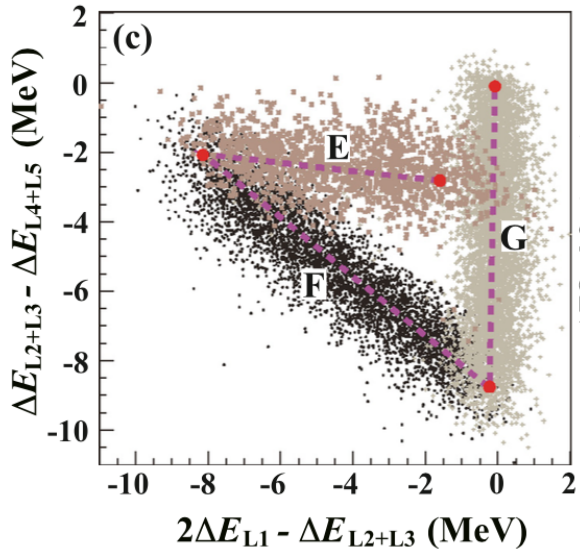


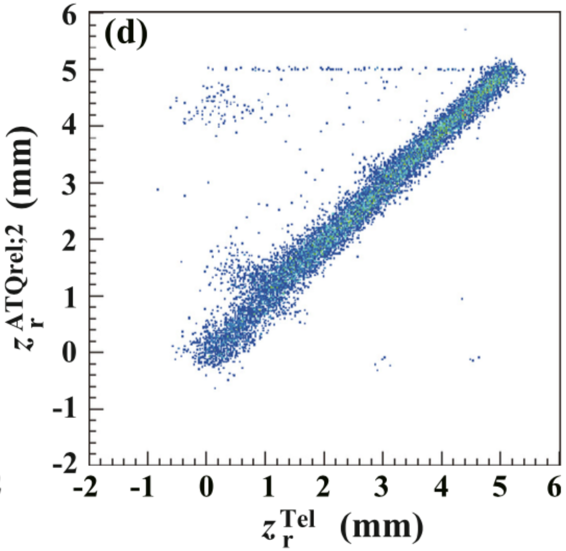
Data analysis

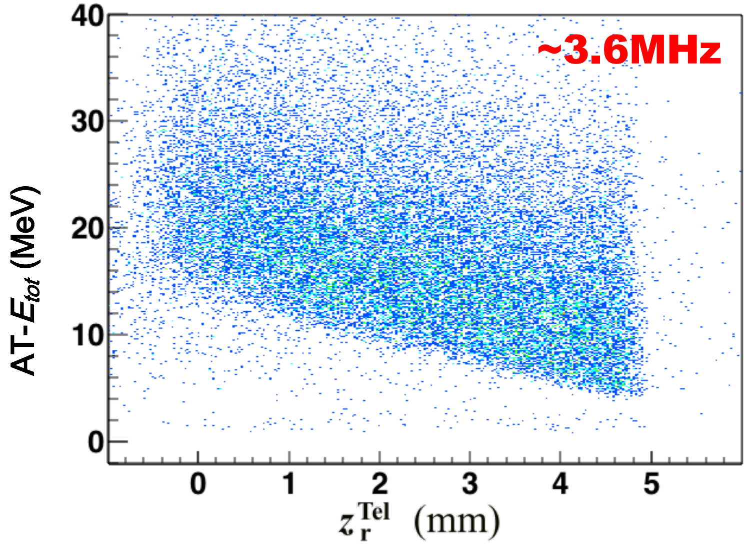
Gain shift

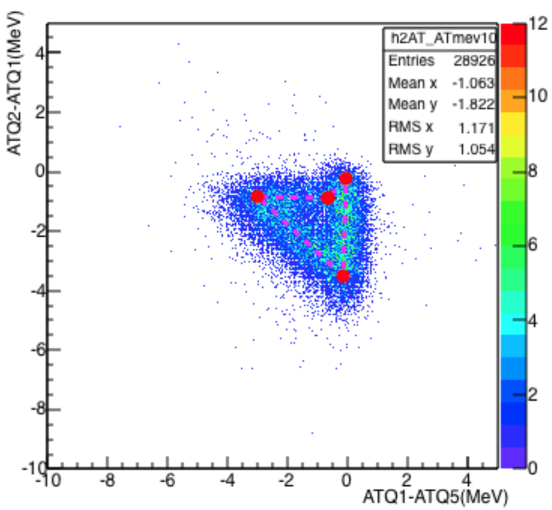


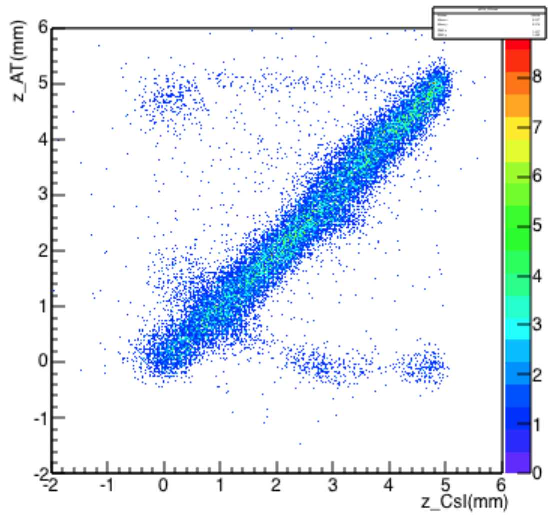








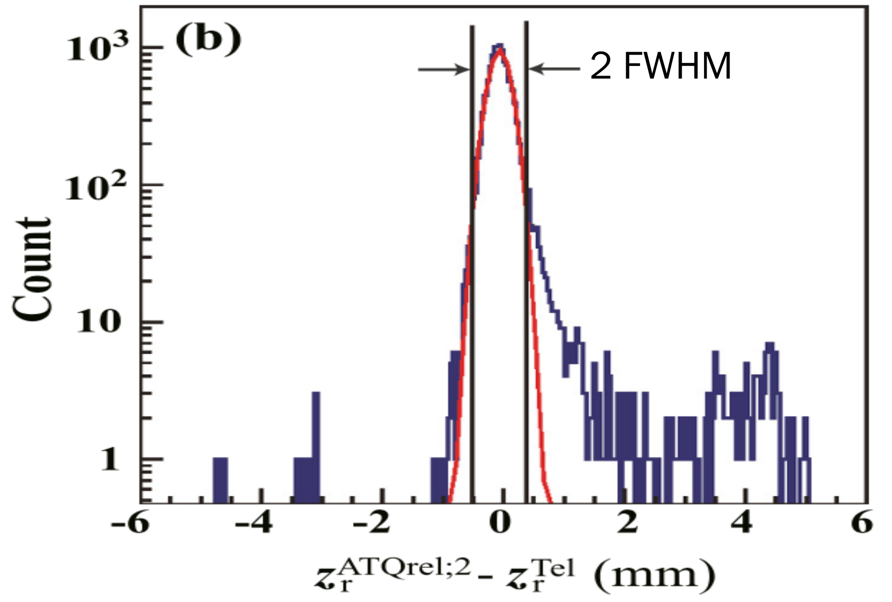




Data analysis

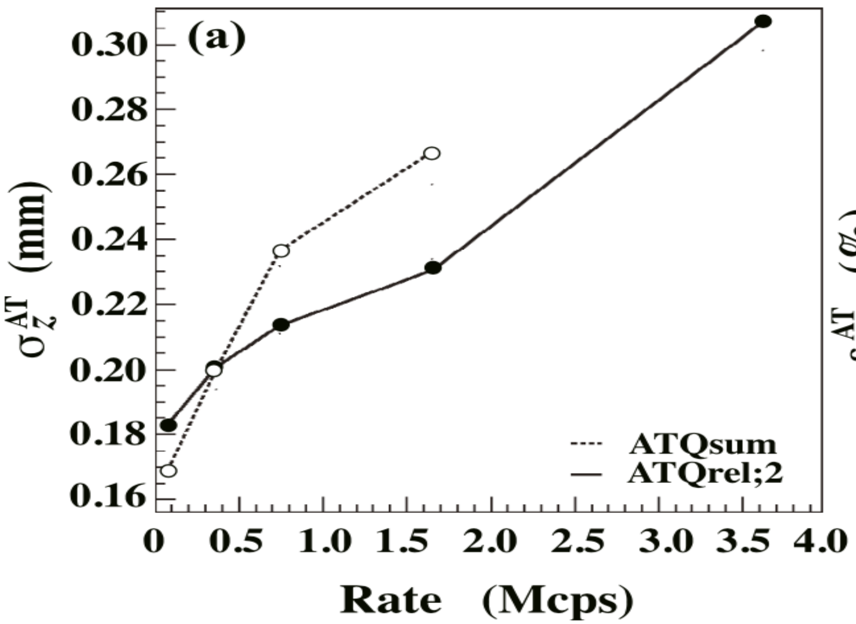
Resolution end Efficiency

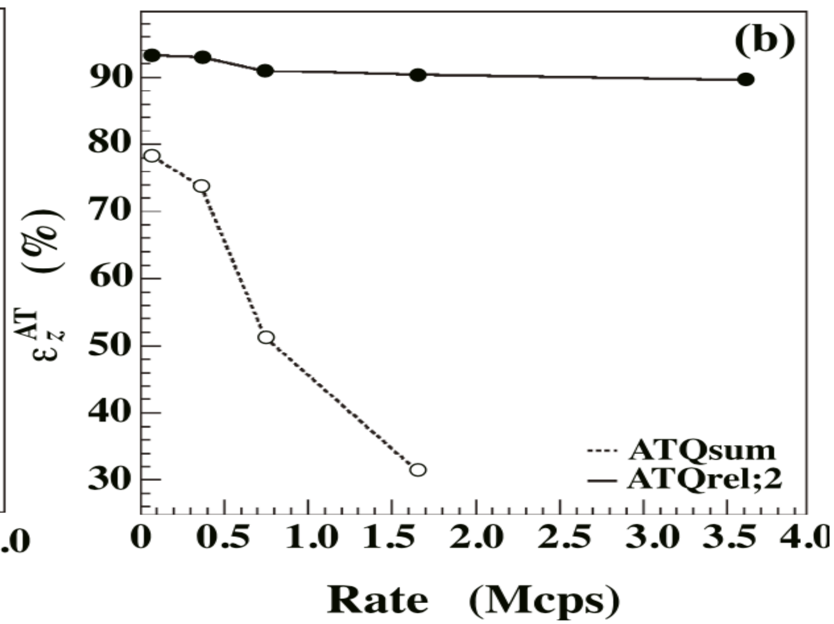
- **Resolution:**
  - Telescopes: 160 um



- **Detection efficiency:**

$$\varepsilon = N_{FWHM} \,/\, N_{total}$$

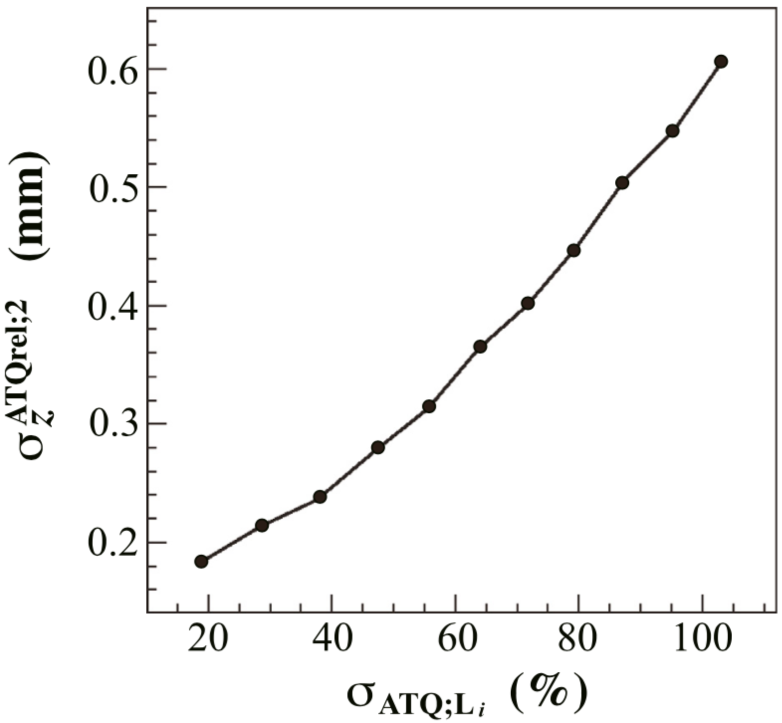




Data analysis

Effect of intrinsic resolution

- Energy intrinsic resolution at 75kHz is 18% (in sigma).
- Intrinsic resolution dependence of depth resolution was studied using simulation.



Summary

- A prototype of multilayer plastic-scintillator based active proton target was constructed.

- Development experiment was performed with proton-proton elastic scattering at 70 MeV.
  - ✦ Depth resolution at 3 MHz beam rate was found to be less than **0.31 mm (σ)** with detection efficiency of **92%**.
  - ✦ Gain shift was observed at rate above 1 MHz, a booster for PMT is needed for going to higher rate.

Collaborators

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Thank you for your attentions !