Track reconstruction in the High-Angle TPCs of the upgraded near detector of T2K

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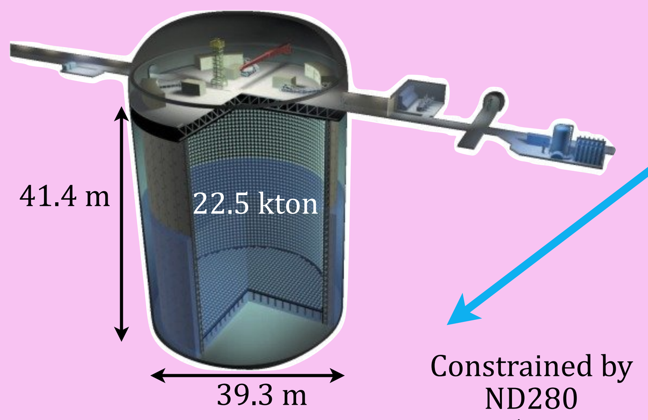
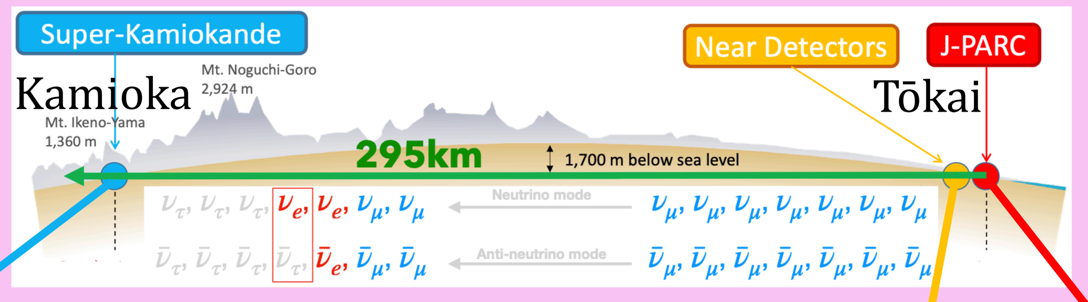
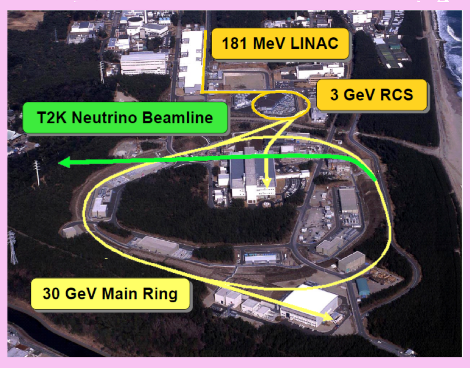
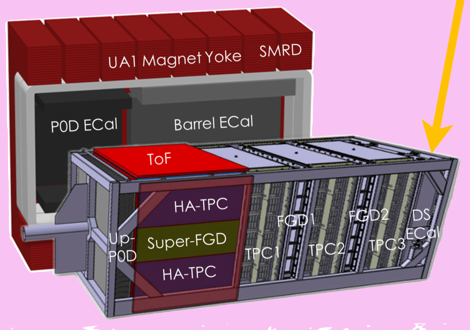
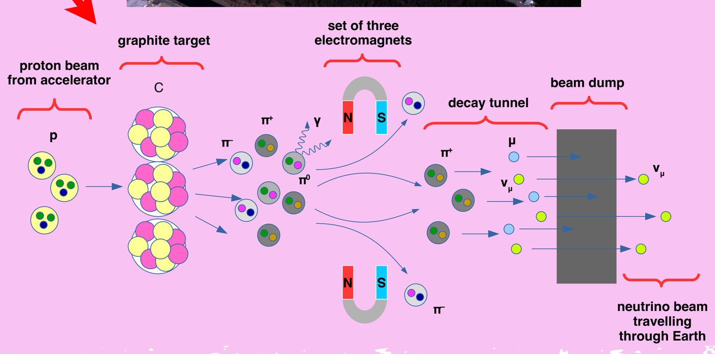
T2K











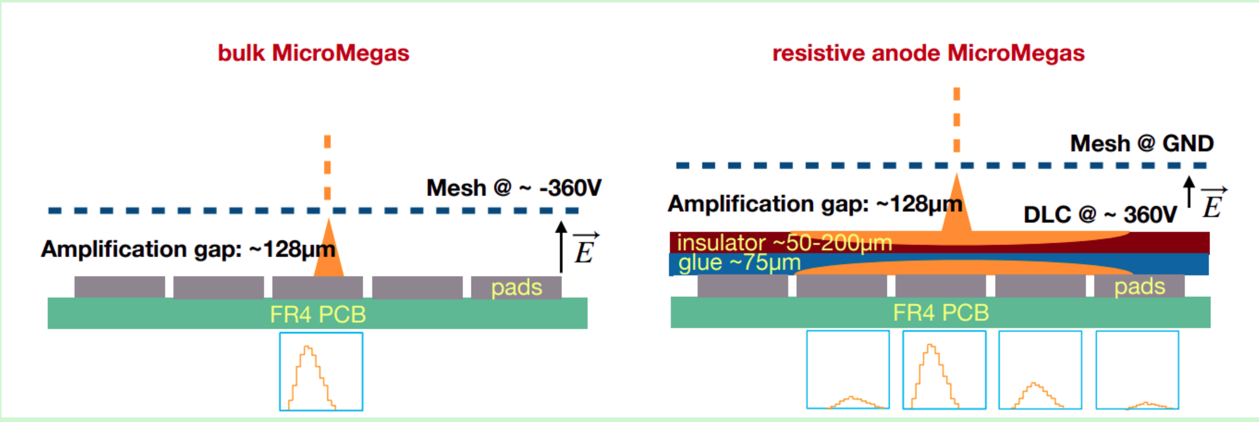
Constrained by ND280

$$R_{\nu_e} = \mathcal{P}_{\nu_\mu \to \nu_e}(E_\nu) \times \sigma(E_\nu) \times \Phi(E_\nu) \times \epsilon(E_\nu)$$

Event rate — Oscillation probability — ν x-sec — ν flux — Detector efficiency

- T2K is a long-baseline neutrino oscillation experiment which has taken data in Japan since 2010
- Measure the $\nu_\mu\,(\overline{\nu}_\mu)$ disappearance and the $\nu_e\,(\overline{\nu}_e)$ appearance at Super-Kamiokande in Kamioka, Gifu, Japan in an initial $\nu_\mu\,(\overline{\nu}_\mu)$ beam produced at the J-PARC in Tōkai, Ibaraki, Japan
- Both J-PARC beam line and ND280 (Near Detector located 280 m downstream of the graphite target) have recently been upgraded
- Upgraded ND280 contains 2 new HA-TPCs characterized at several test beam campaigns [1-4]
- The upgrade was completed in May 2024 and has already started to take data!

The ERAM technology



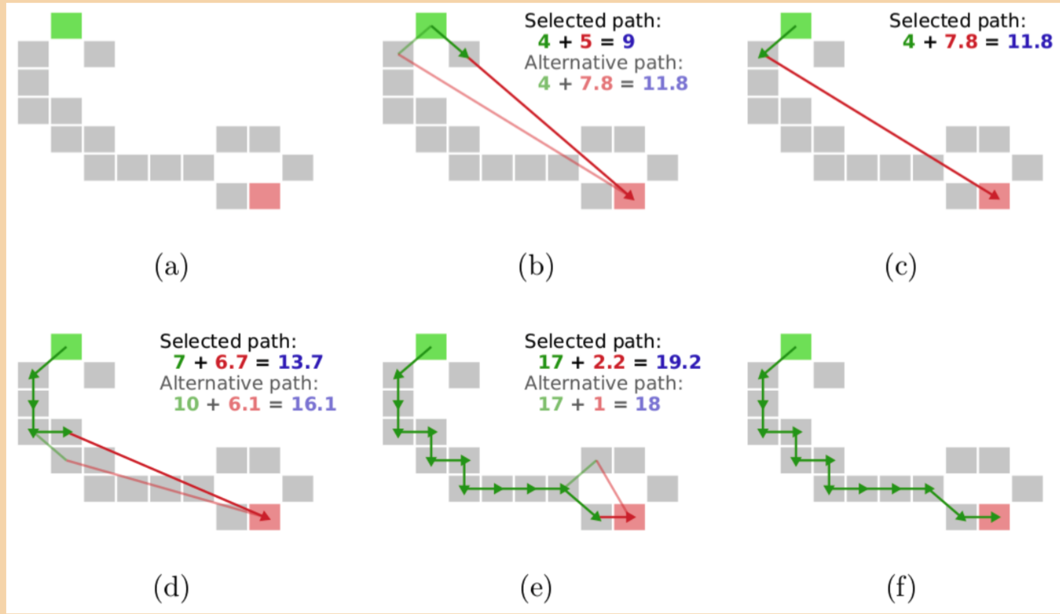
- Each Module Frame is equipped with 8 Encapsulated Resisive Anode MicroMegas (ERAM)
- Thanks to layers of insulator and glue, charge deposit is spread on neighboring pads

$$\rho(\vec{r}, t) = \frac{RC}{4\pi t} e^{-\frac{r^2 RC}{4t}}$$

- Compared to bulk MicroMegas used for vertical TPCs, spatial resolution is reduced from1.2 mm to 0.5 mm (for similar pad size: $1 \times 1\mathrm{cm}^2$)

The pattern recognition

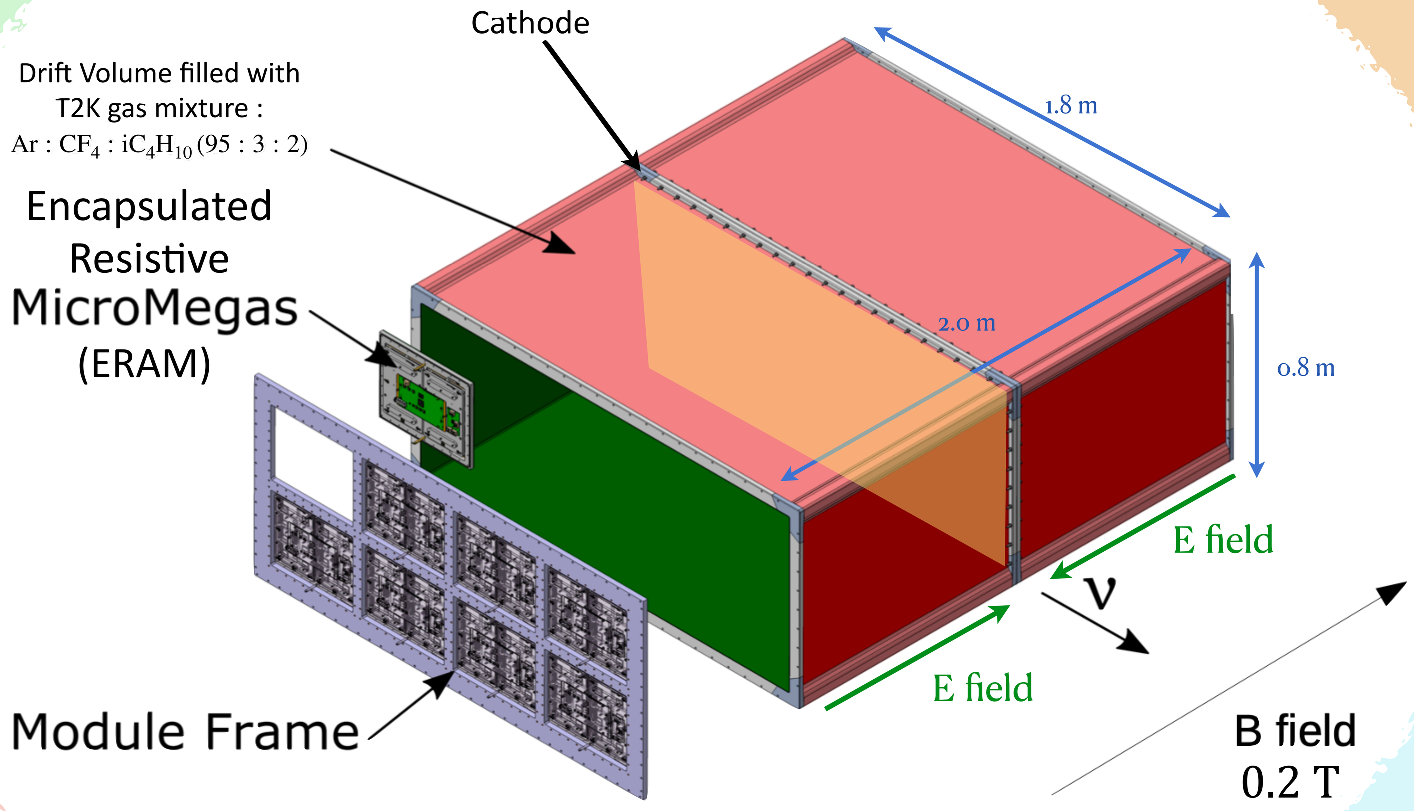
- Pattern recognition is performed by using A* algorithm



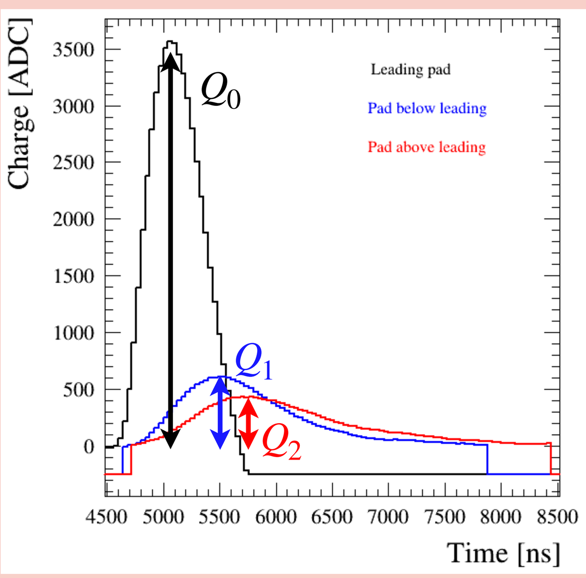
$$\mathrm{Cost_H}(\mathrm{node} \to \mathrm{end}) = f_{\mathrm{heuristic}} \sqrt{\Delta_x^2 + \Delta_y^2 + \Delta_z^2}$$

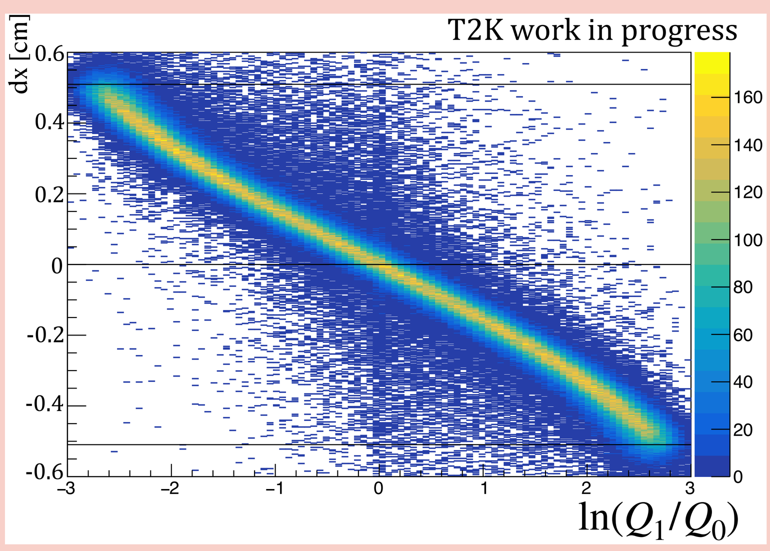
- Optimal path is found by minimizing the heuristic cost ($\mathrm{Cost_H}$)
- This value represents the sum of the individual costs to join pads between them

HA-TPC sketch view



The logQ method

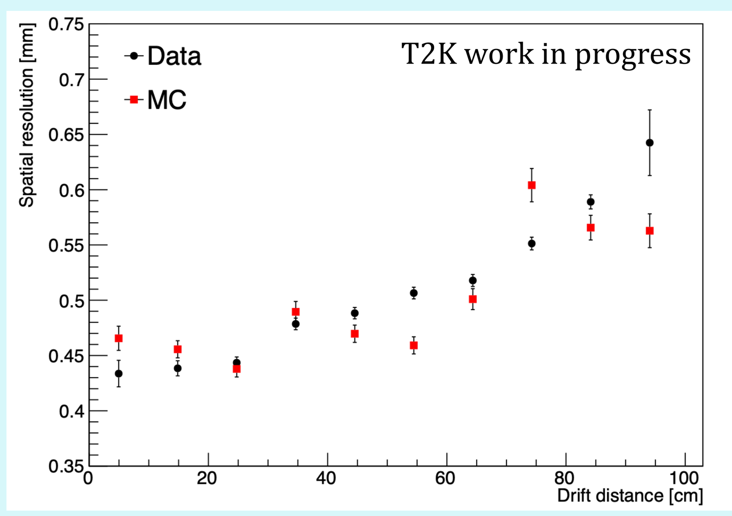




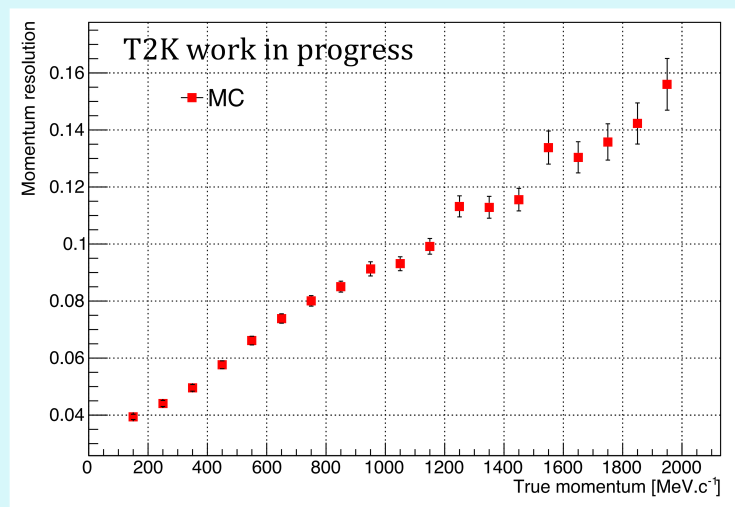
- Clusters of pads are done in an orientation perpendicular to track trajectory
- Track position in each cluster is reconstructed thanks to the logarithm of the ratio of waveforms' amplitudes in the pads:

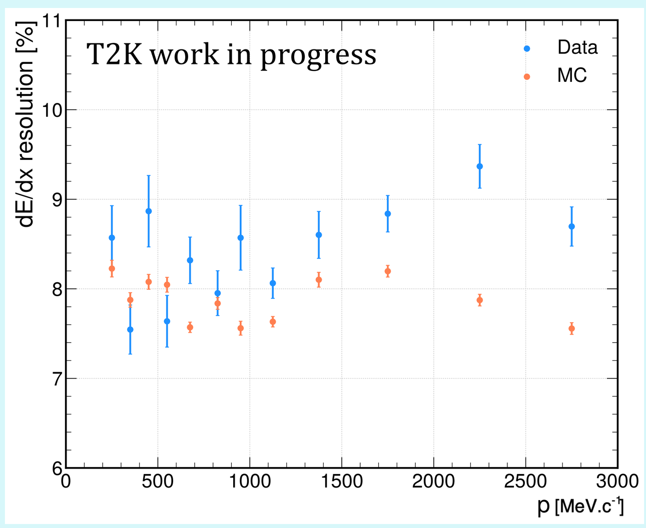
$$dx = \alpha_{10} \ln^3\left(\frac{Q_1}{Q_0}\right) + \beta_{10} \ln\left(\frac{Q_1}{Q_0}\right) \qquad dx = \alpha_{21} \ln^3\left(\frac{Q_2}{Q_1}\right) + \beta_{21} \ln\left(\frac{Q_2}{Q_1}\right)$$

Performances



- Spatial resolution of $\approx 500\,\mu$m has been observed for both cosmics data and MC
- Such accuracy allows momentum resolution better than 10% for vertical muons with momenta lower than $1.2\,\mathrm{GeV\,.\,c^{-1}}$ and L > 600 mm



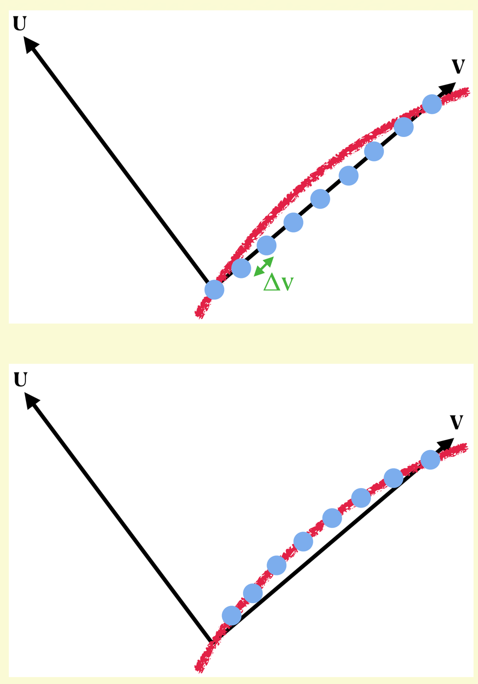


- dE/dx resolution better than 10% has been measured for both cosmics data and MC

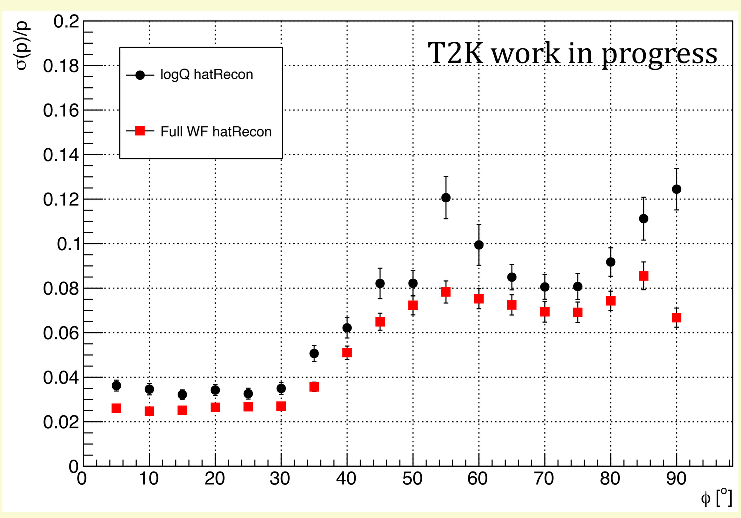
The Full WF method

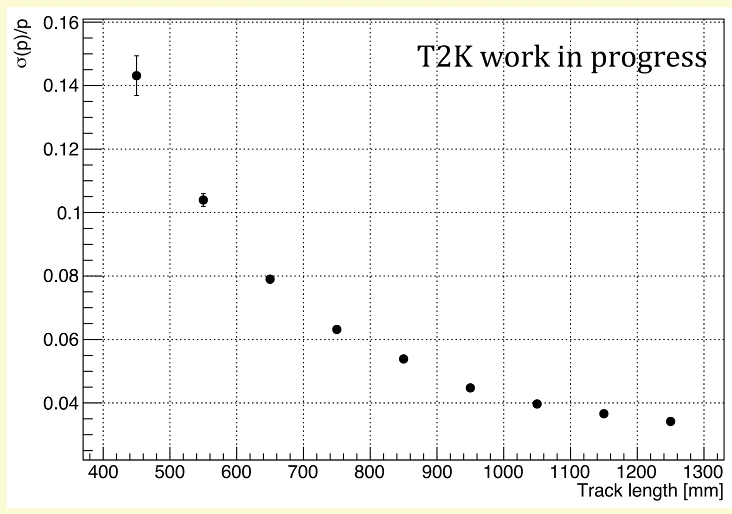
- Use all the track hits (weighted by their Qmax values) to define a $(\mathbf{u},\mathbf{v})$ working frame
- Put point charges (all of them are free parameters) on the $\mathbf{v}$ axis, separated by a length Δv (5~10 mm)
- 5 other free parameters are used to define track trajectory: $u_0, du/dv, q/p, t_0, dt/dv$
- Predict the waveform engendered by those point charges in the surrounding pads
- For N points charges, adjust the 5+N fit parameters to minimize the χ^2 between observed waveforms and predicted ones:

$$\chi^2 = \sum_{i(pad)} \sum_{j(timebin)} \frac{(Q_{i,j}^{Obs} - Q_{i,j}^{Predic})^2}{\sigma_{i,j}^2}$$



- This new method, exploiting the full waveform information improves a lot the momentum resolution compared to the currently used logQ method





- Momentum resolution as a function of track length, $1/L^{5/2}$ dependence
- p = 800 $\mathrm{MeV.c^{-1}}$ in both plots

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References

[1] Nucl.Instrum.Meth.A 957 (2020) 163286
[2] Nucl.Instrum.Meth.A 1025 (2022) 166109
[3] Nucl.Instrum.Meth.A 1052 (2023) 168248
[4] Nucl.Instrum.Meth.A 1056 (2023) 168534