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<u>DREB Conference 2024</u>

Single-particle states in fp-shell nuclei through the ^{50}Ca(d, p)^{51}Ca transfer reaction

C. Ferrera, K. Wimmer, D. Suzuki, N. Imai, A. Jungclaus et al for the SHARAQ12 collaboration.

Wiesbaden 27/06/2024

CSIC-IEM Madrid, Spain

CNS

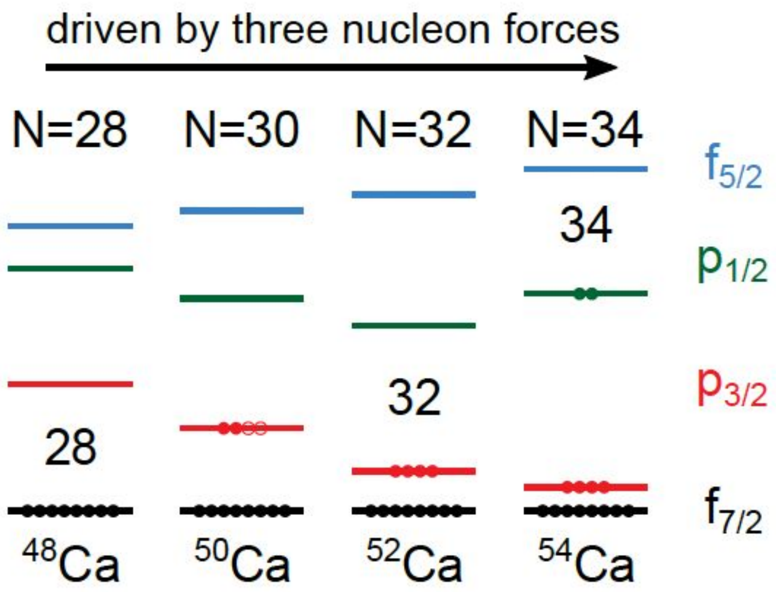
RIKEN NiSHiNA CENTER

Brief Introduction: Magic Numbers in neutron f-p shell

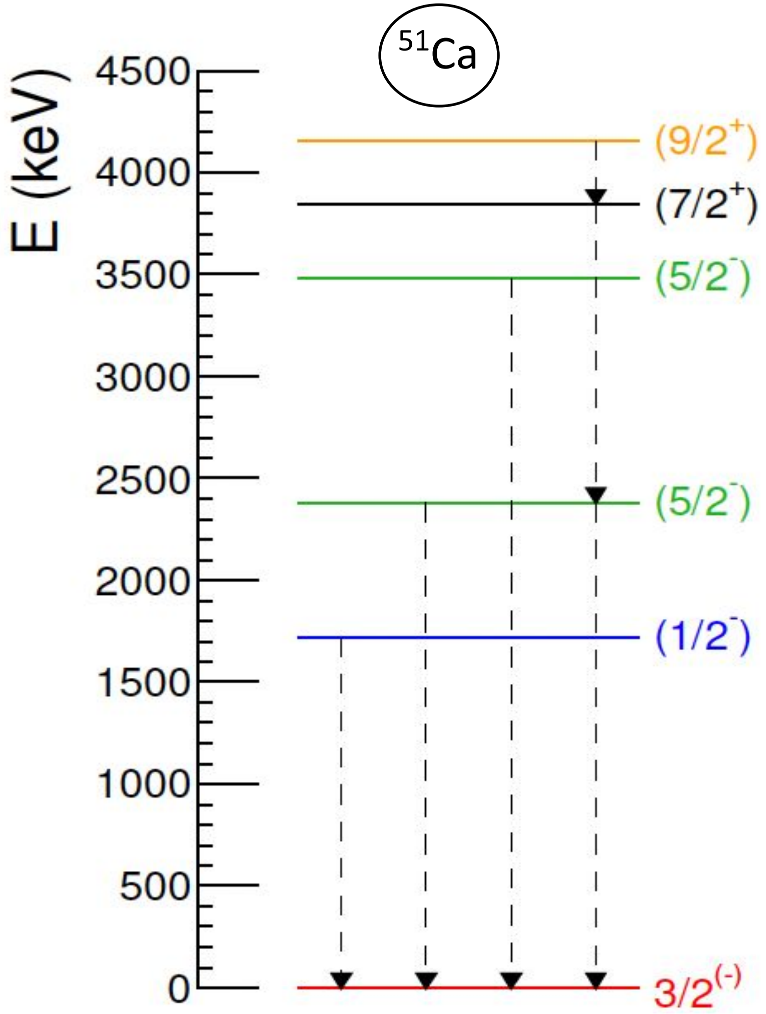
Neutron-rich Ca isotopes towards neutron number N = 34 are pivotal for exploring the evolution of the f-p shell orbitals. New magic numbers at N = 32 and 34 were established through spectroscopy of low-lying states and mass measurements.

Wienholtz, F., Beck, D., Blaum, K. *et al.* ***Nature*** **498, 346–349 (2013)**

Steppenbeck, D., Takeuchi, S., Aoi, N. *et al.* ***Nature*** **502, 207–210 (2013)**



Holt, J. D., Menéndez, J., Simonis, J. and Schwenk, A.
Phys. Rev. C 90, 024312, Aug 2014.



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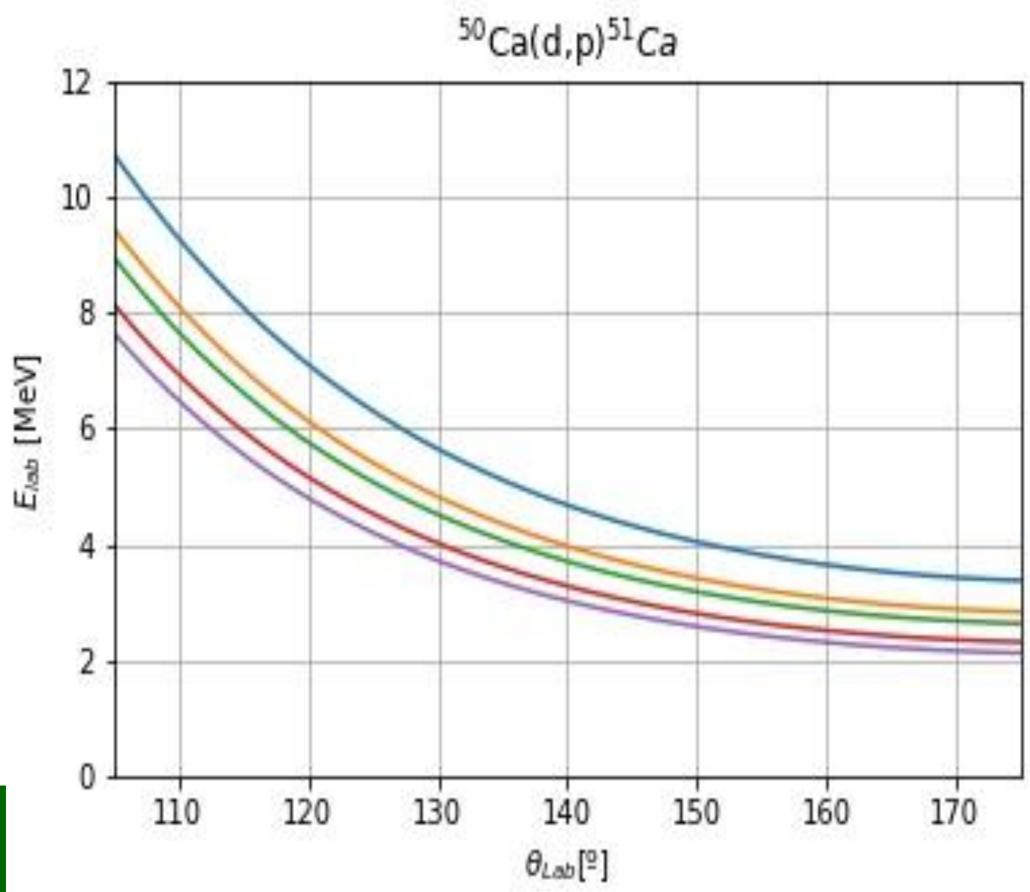
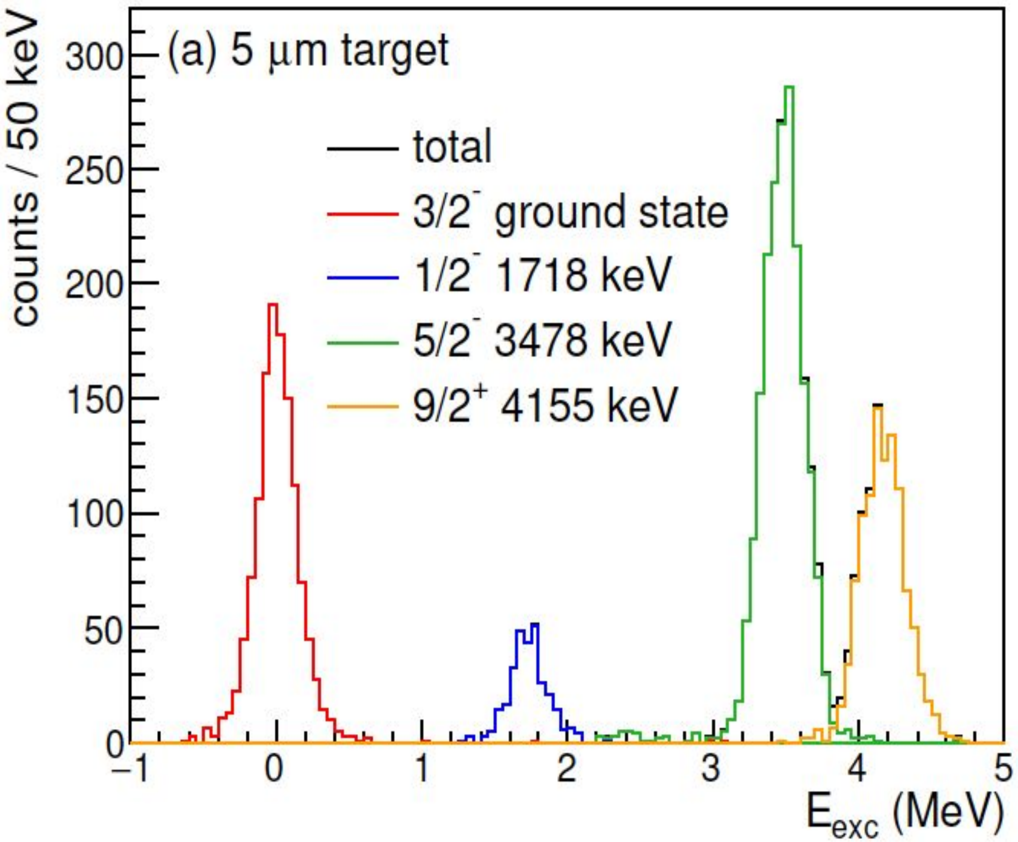
Brief Introduction: $^{50}Ca(d,p)\,^{51}Ca$ Transfer Reaction

The one-neutron transfer *(d, p)* reaction is an established and well-suited method for a direct approach to shell evolution in this region of the nuclear chart. For studying unstable nuclei, this reaction has to be performed in **inverse kinematics**.





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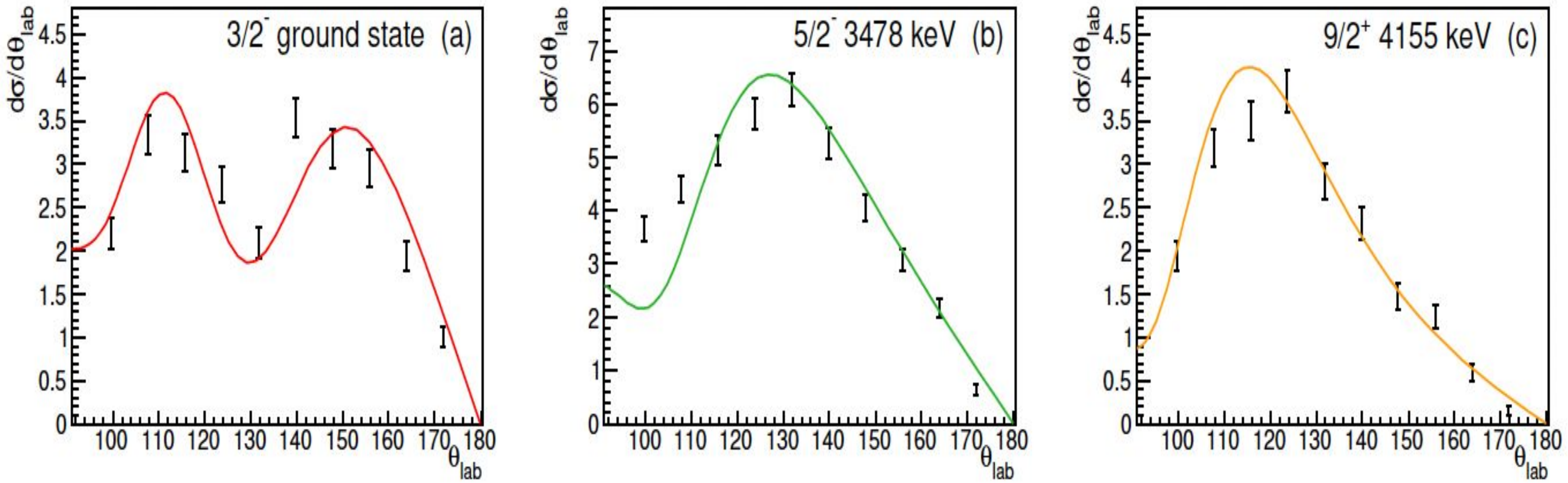
Brief Introduction: Proton angular distributions

From this transfer reaction, we expect to determine the **orbital angular momentum transfer** and to extract **spectroscopic factor** information from the angular distribution of the recoiling protons.



We only expect to populate states with a strong single-particle component.

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Experimental Set Up: Production of the ^{50}Ca beam

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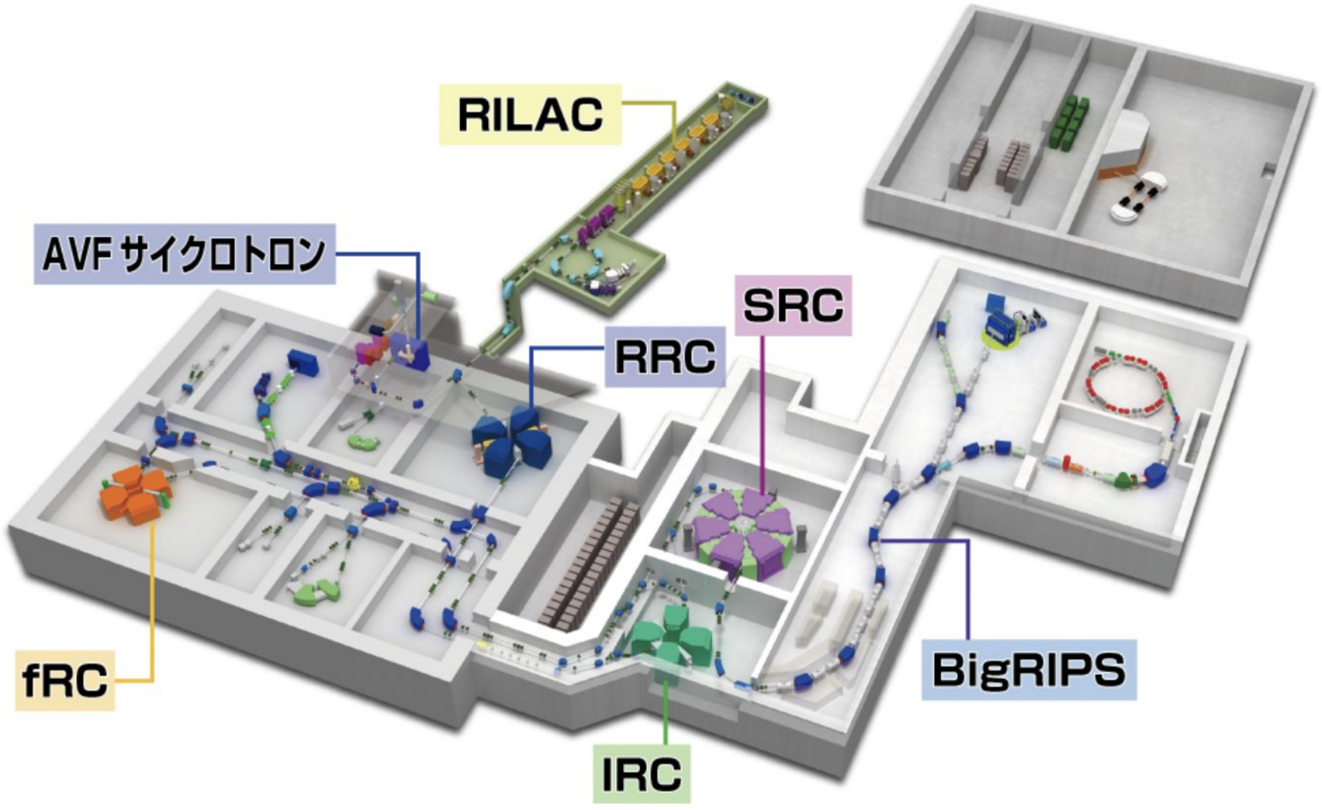
The SHARAQ12 experiment took place at the RIKEN-RIBF facility, where a **primary beam of ^{70}Zn** was produced at RILAC and reaccelerated through various stages to an energy of **345 MeV/nucleon**. The secondary beam was then produced at BigRIPS from the **fragmentation** of the primary beam on a **Be target**.



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Experimental Set Up: Degrading the ^{50}Ca beam

The ^{50}Ca beam is conducted from BigRIPS to the OEDO beamline, where a combination of an angle-tunable wedge-shaped degrader and an additional aluminum flat-plate degrader placed at FE9 reduced the beam energy to approximately 15 MeV/nucleon.

Beam

SHARAQ

OEDO

Experimental Set Up: SRPPACs for beam-tracking

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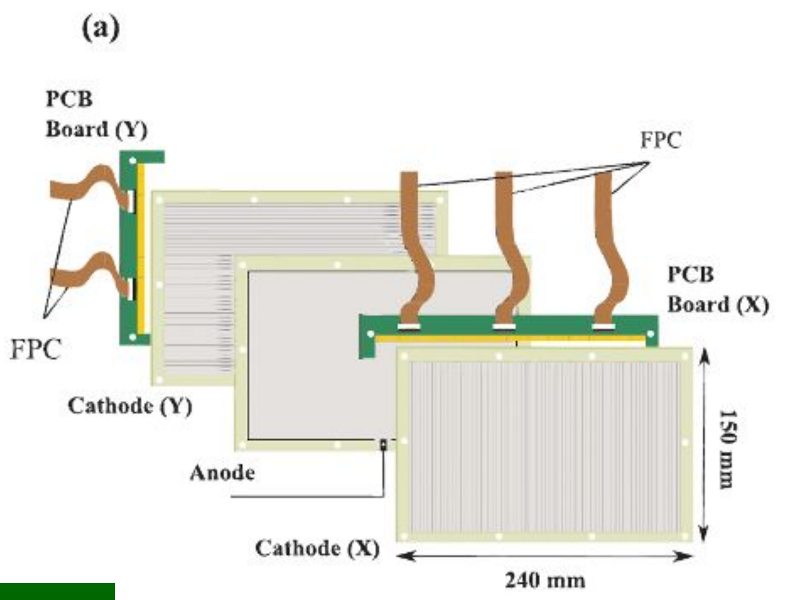
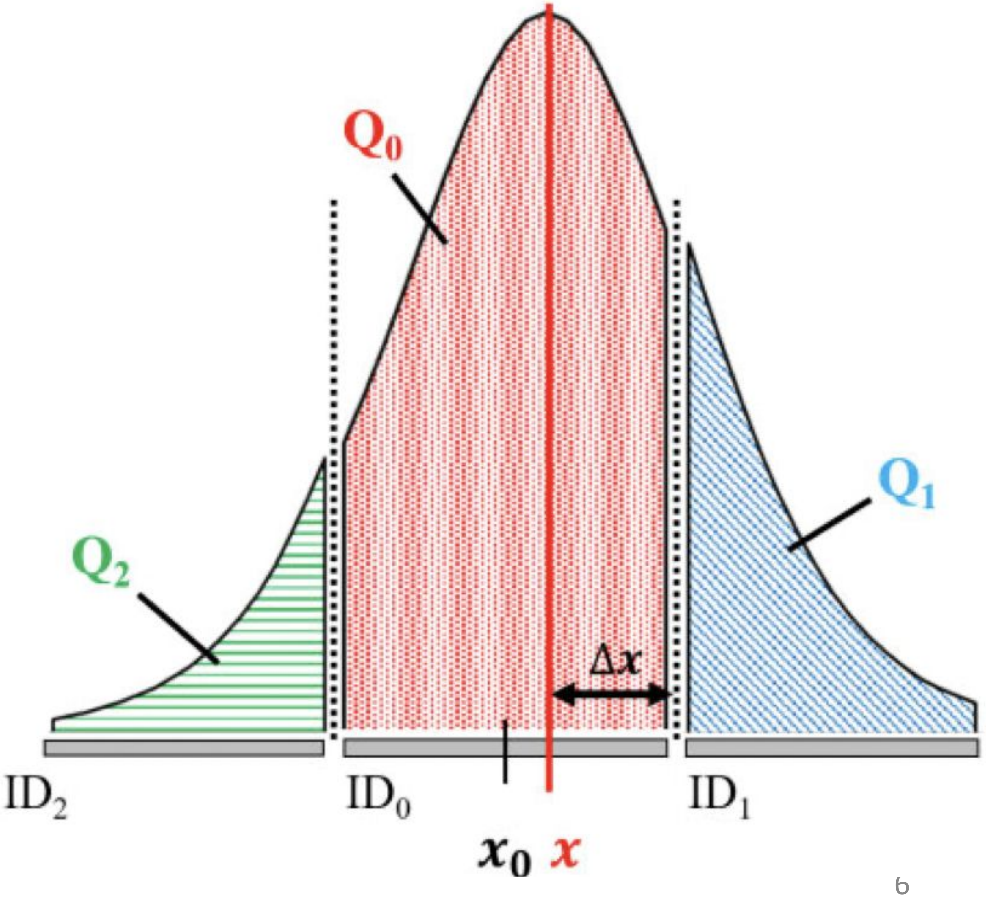
Strip-Readout Parallel-Plate Avalanche Counters (SR-PPACs) allow to track the beam at different stages of the OEDO-SHARAQ beamline. We use three pairs of them placed at FE9, FE12 and S1.

Table 1 Configuration of SR-PPAC

	Prototype	Standard
Sensitive area [mm^2]	150 (X) × 150 (Y)	240 (X) × 150 (Y)
Gap between anode and cathode [mm]	4	4.3
Strip width [mm]	2.57 (X, Y)	2.55 (X), 2.58 (Y)
Number of strips (channels)	58 (X, Y)	94 (X), 58 (Y)



Expected SR-PPAC resolution: FWHM =150 μm



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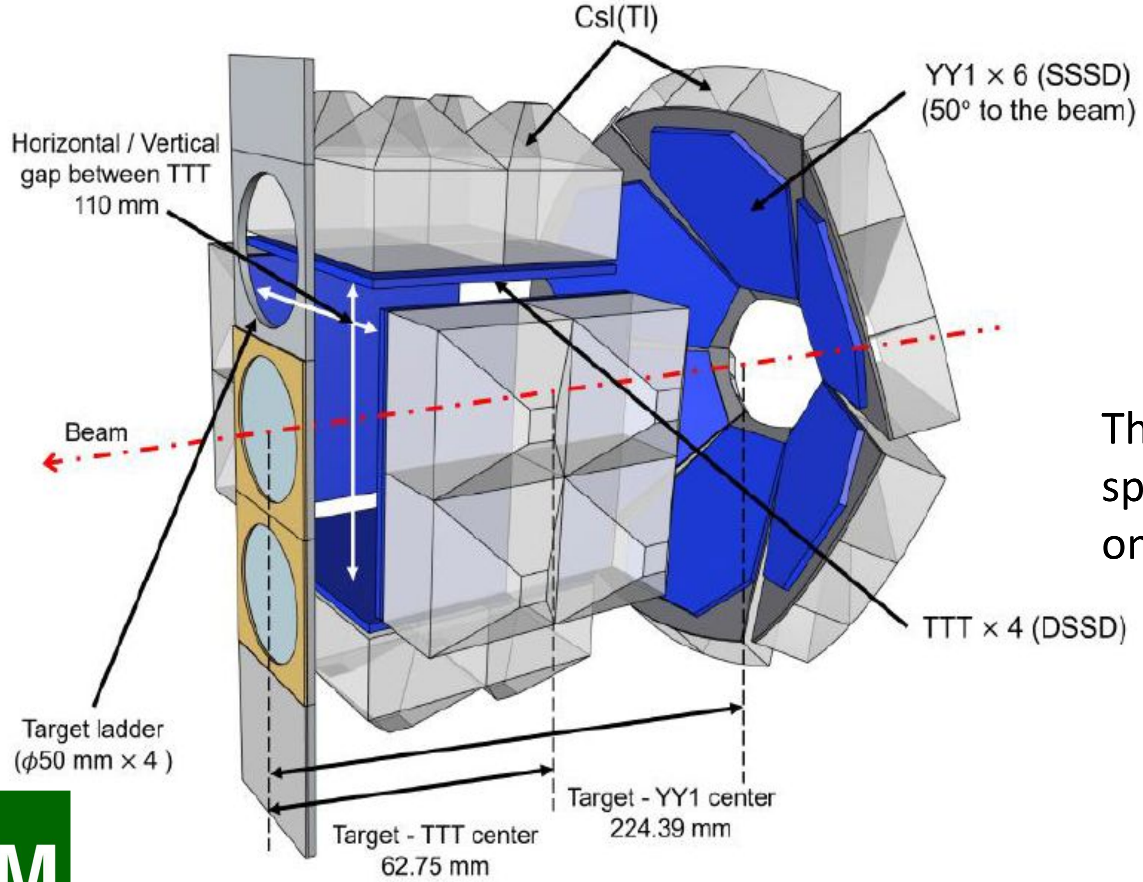
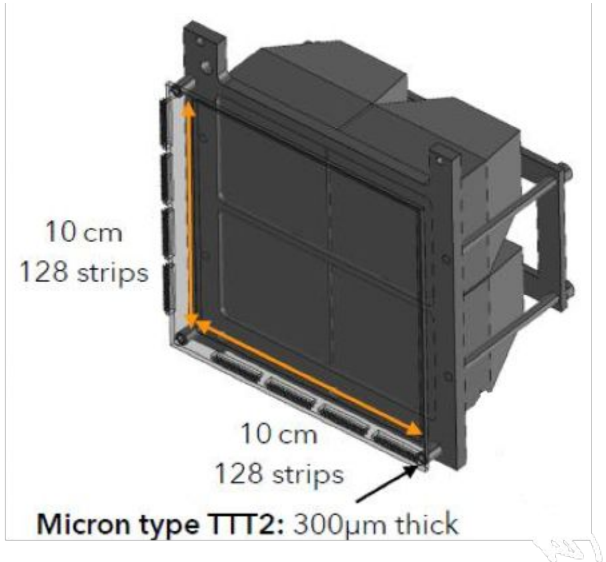
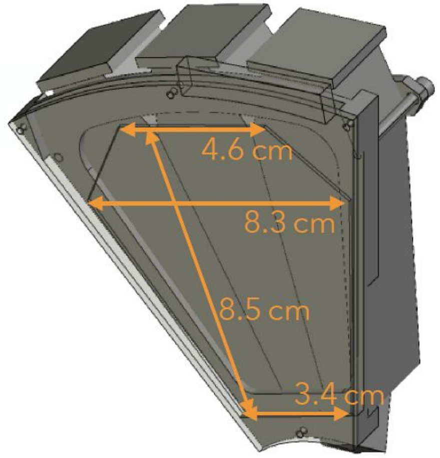
Hanai S. et al *Prog. of Theoretical and Experimental Physics*, Volume 2023, Issue 12, December 2023, 123H02,

Experimental Set Up: Reaction Chamber and TINA2 array

TINA2 consists of a box of **four TTT DSSSD backed by 16 CsI crystals** and a **backward annular YY1-type silicon strip detector array with CsI crystals behind.**

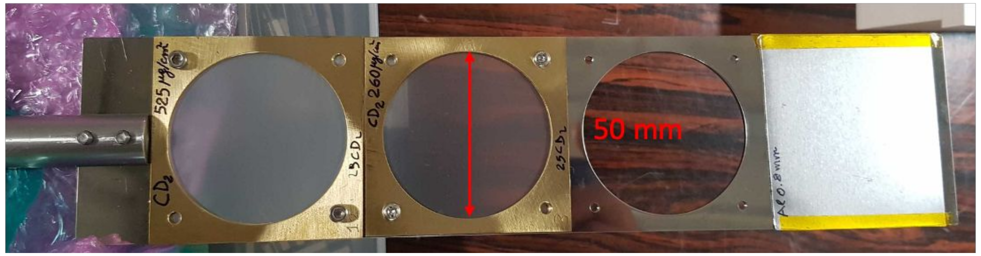






16 strips 300 μm thick

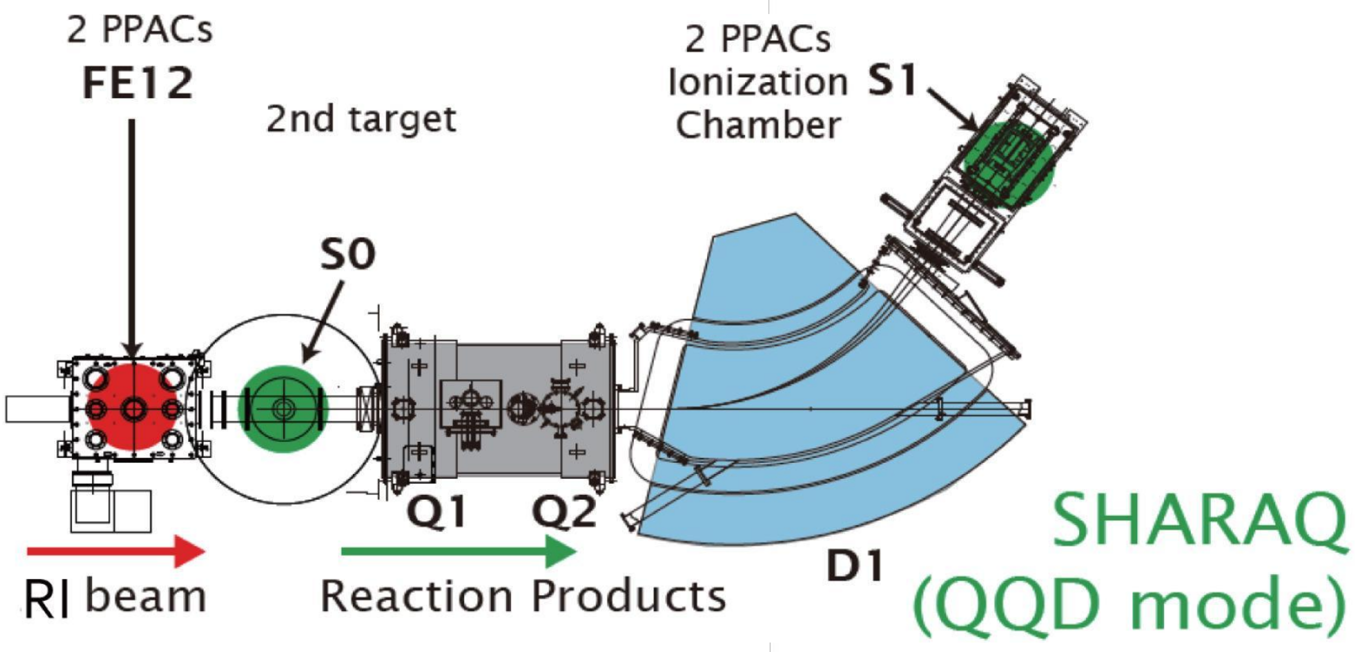
The **CD2 (260 μg/cm2) secondary target** was placed at the SHARAQ spectrometer reaction chamber with the purpose of inducing one-neutron transfer reactions.

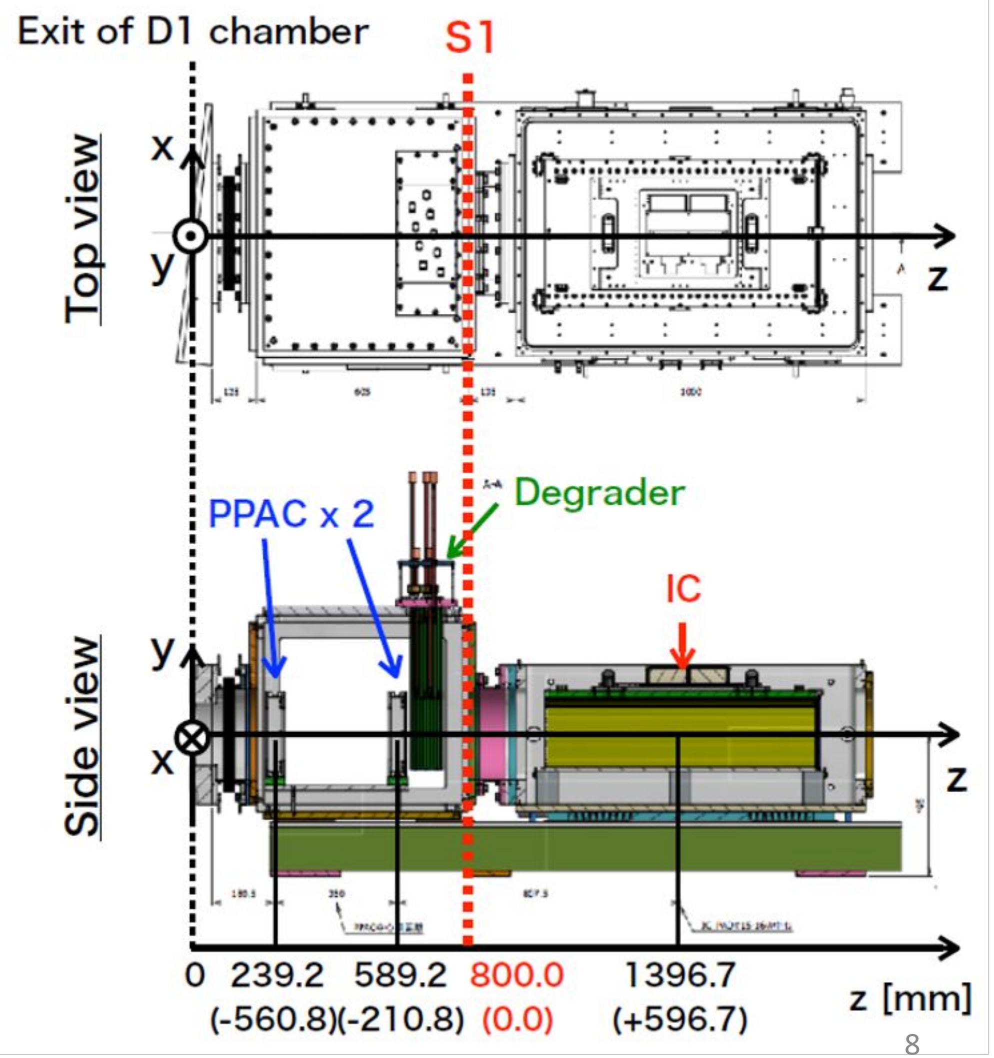


Target holder with the CD_2 secondary target.

Experimental Set Up: Ionization Chamber

There is an ionization chamber placed downstream to the reaction target, with the purpose of atomic number determination through Bragg-peak identification.

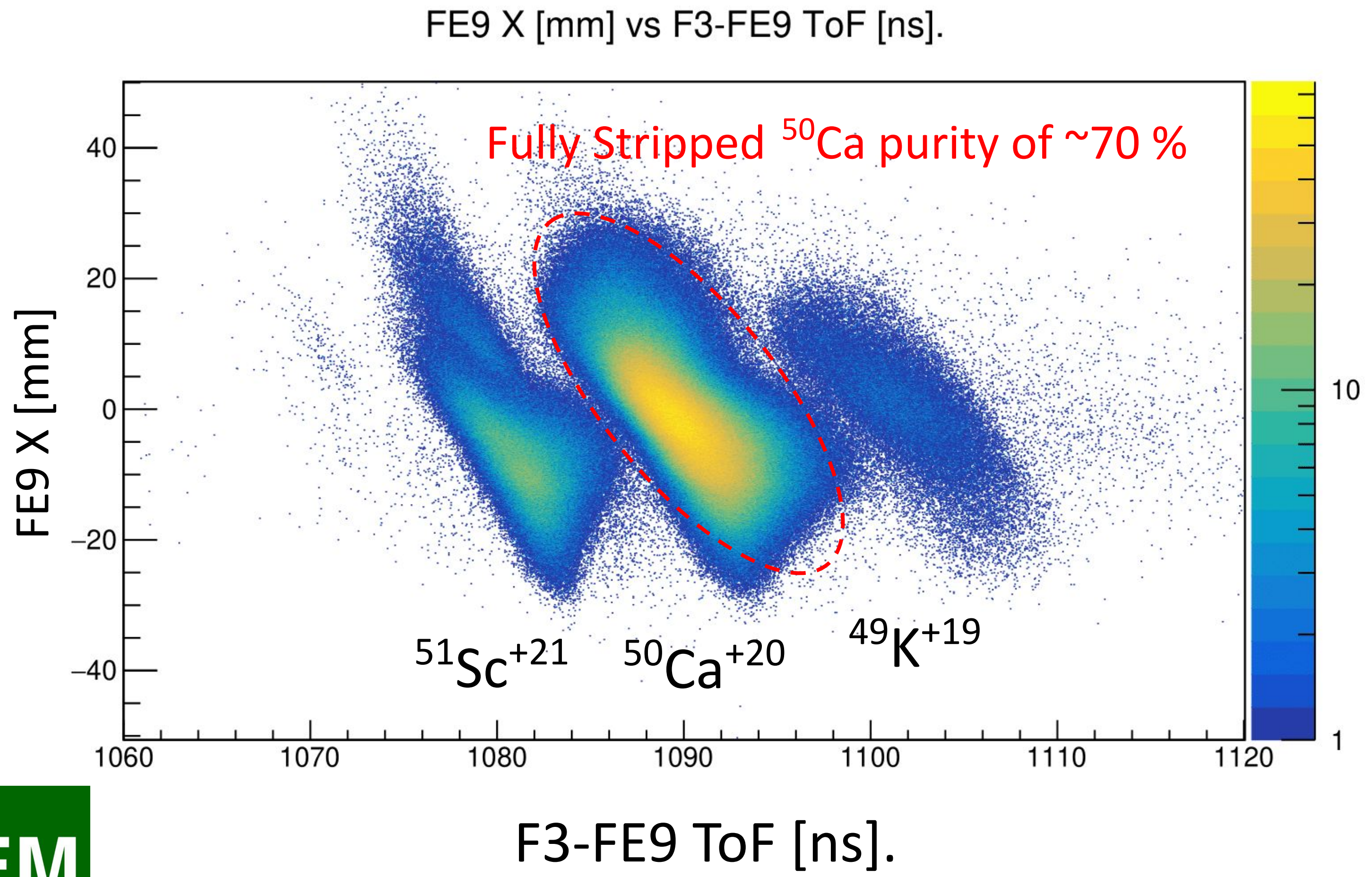


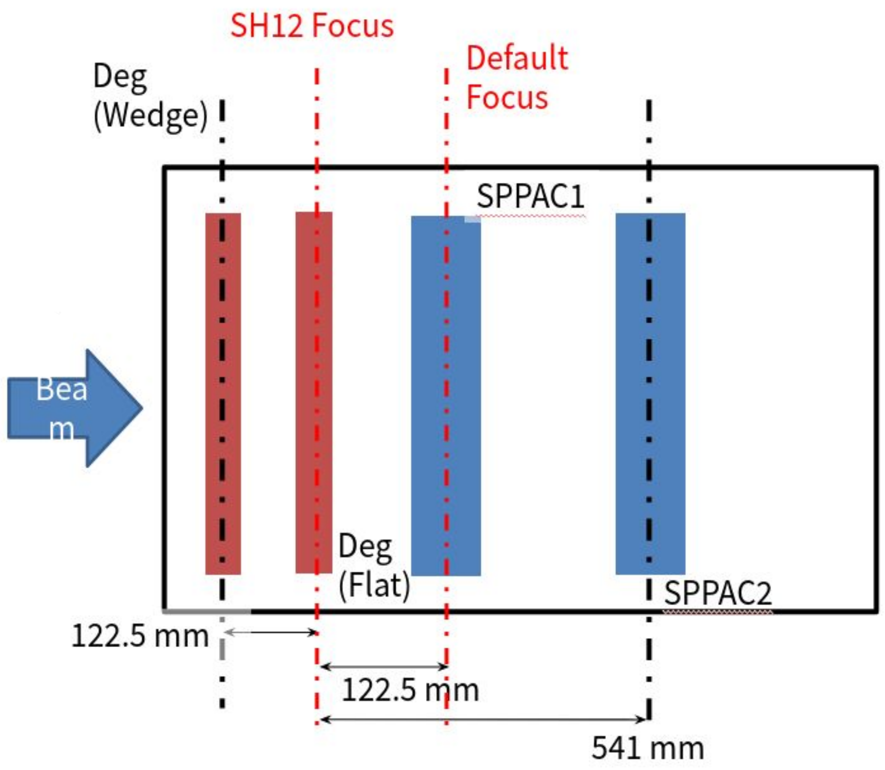


Analysis: Particle Identification of the incoming beam

From the Time-of-Flight between F3 and FE9 and the horizontal position at FE9 focal plane we identify the incoming beam.

22 kcps of ^{50}Ca for 89 h of beam-time.



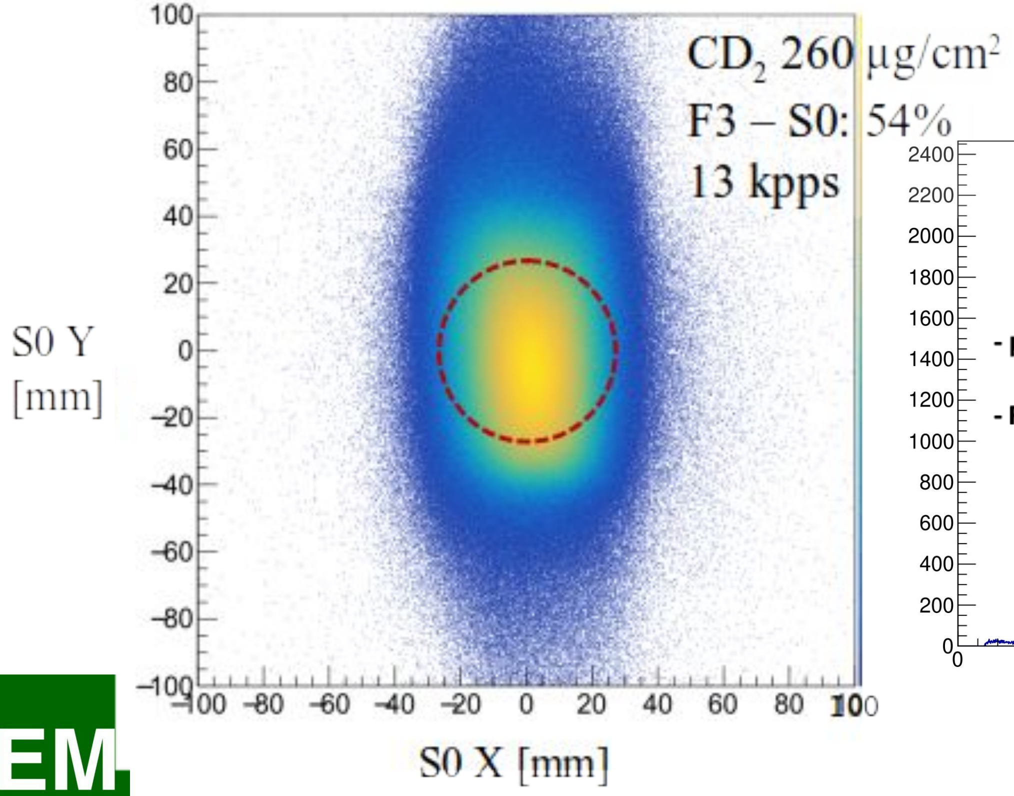


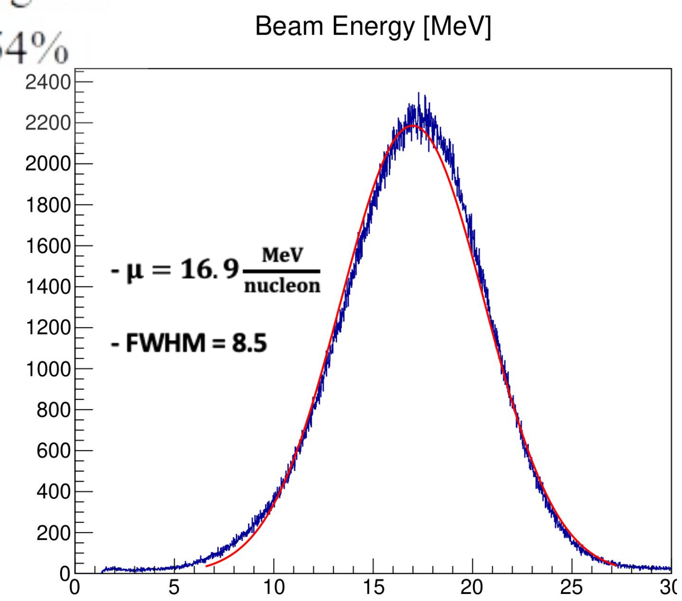
SR-PPACs for incoming PID

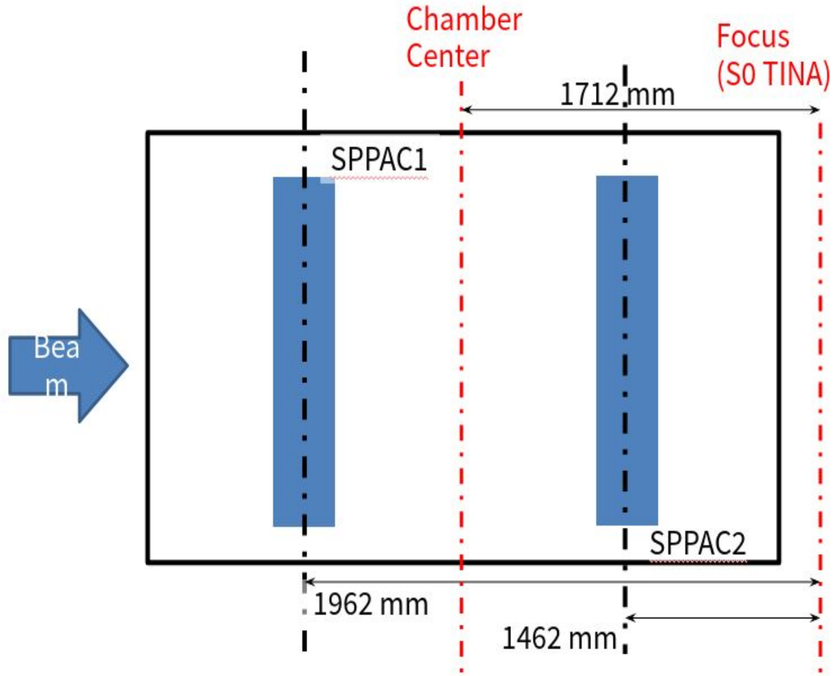
Analysis: Beam-tracking of the beam at the target

The energy and angle of the ^{50}Ca beam incident on the CD_2 secondary target are determined with the FE12 SRPPACS.

- Transmission from F3 to the target of 54 %.
- We have excessive energy and vertical position spread, which affects the transmission to S1.



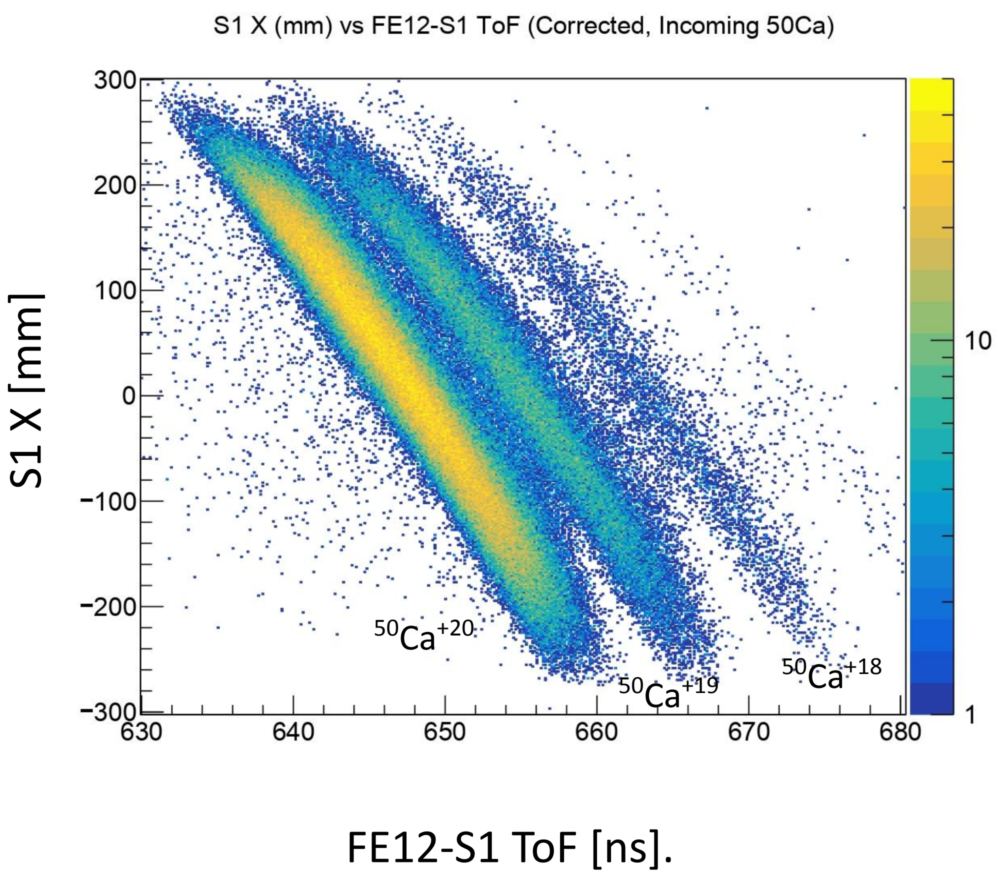




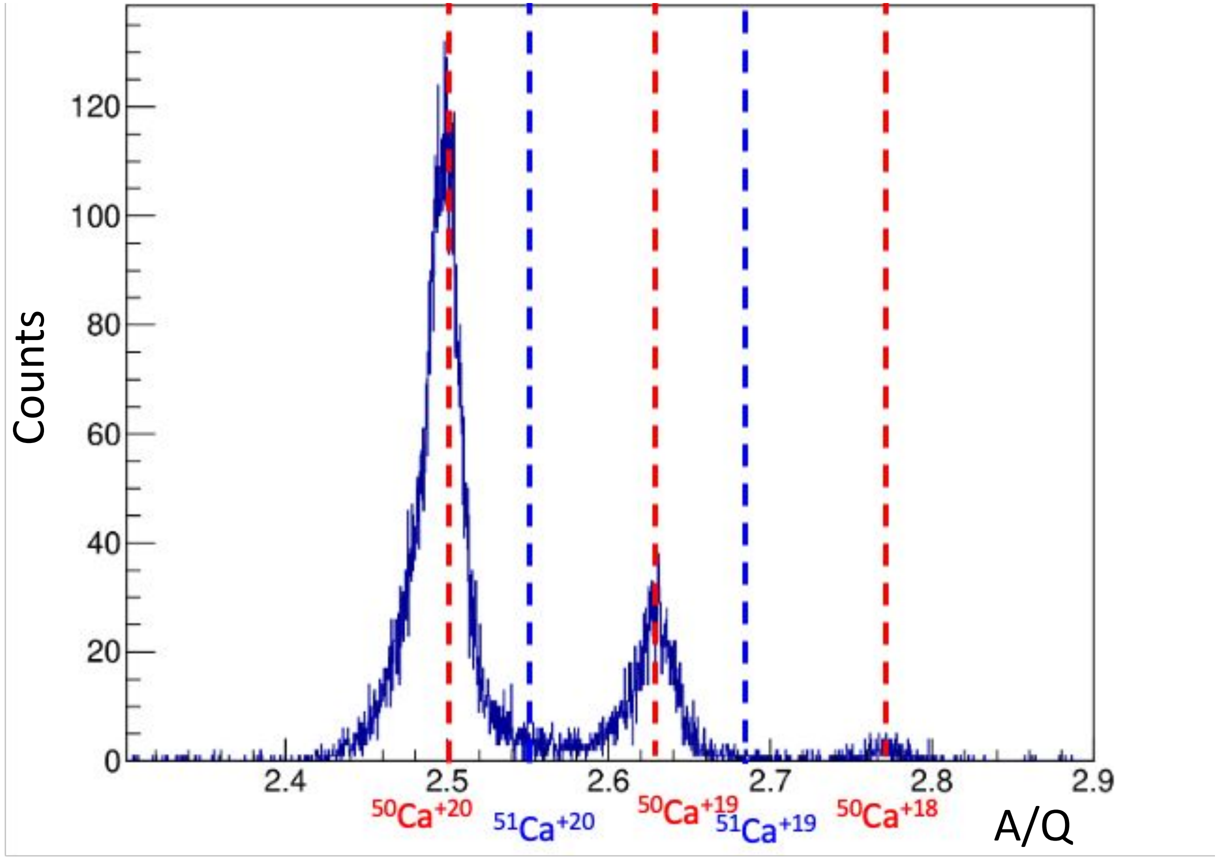
Analysis: After-target PID of the beam

We also identify the particles after-target in the search for reavy reaction products.

S0-S1 transmission is only 15 %.

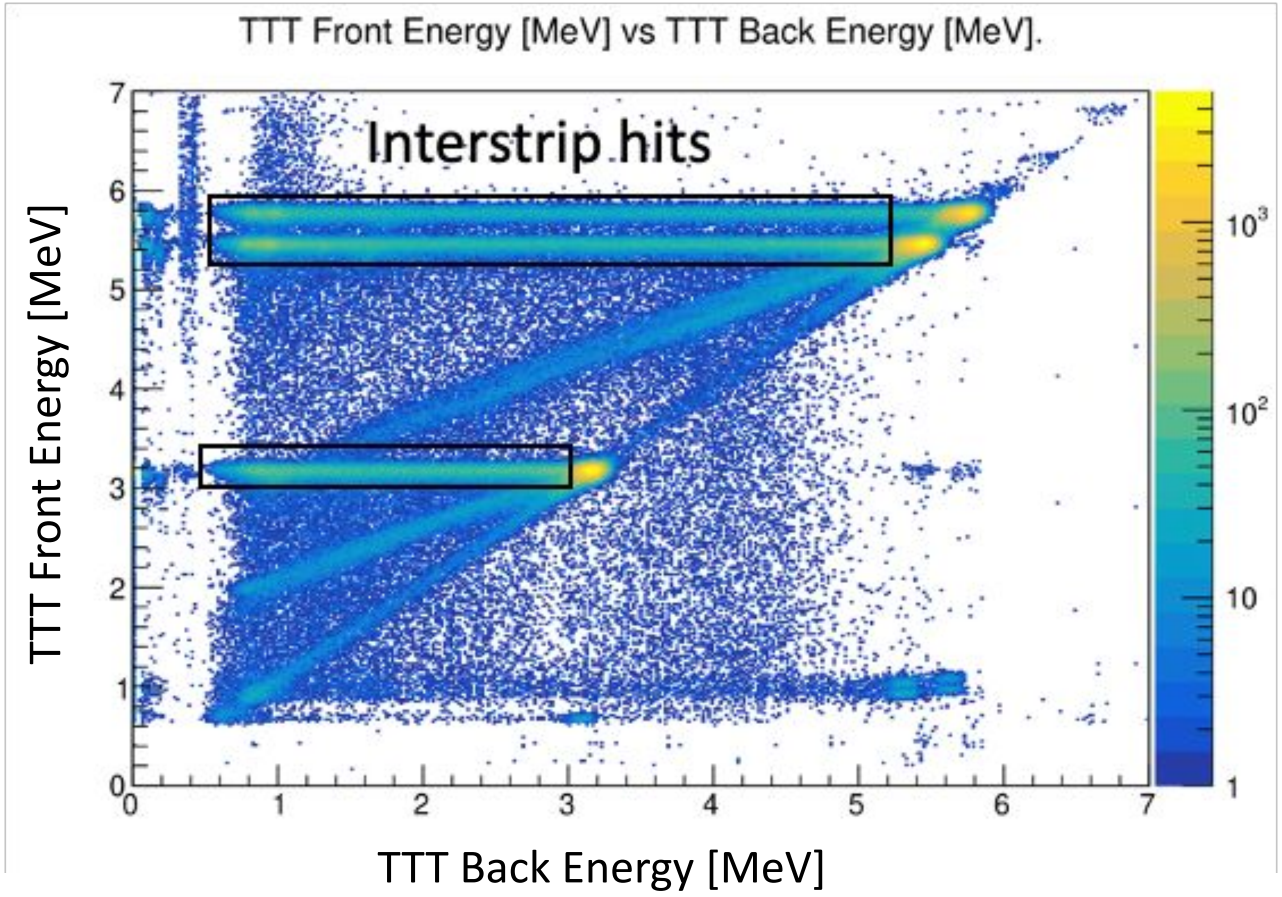


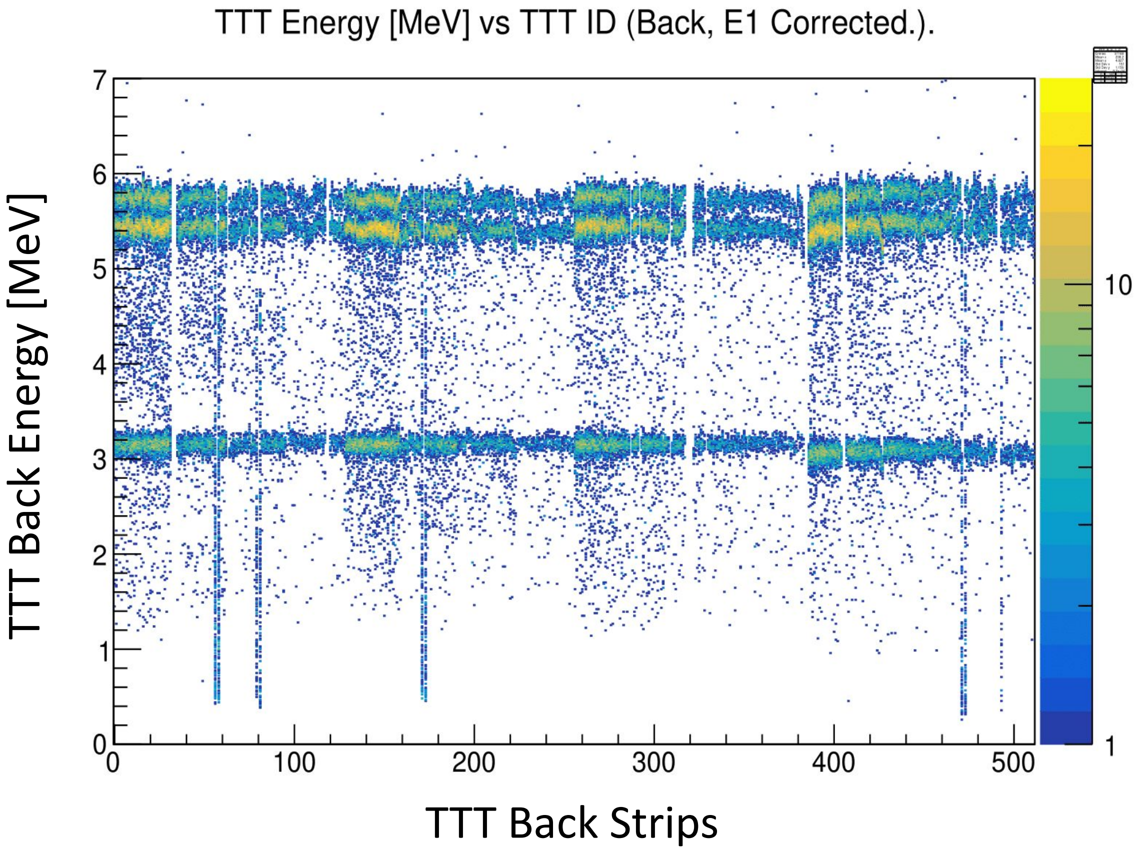
A/Q resolution is sufficient for ^{51}Ca ID



Analysis: TINA2 strips calibration

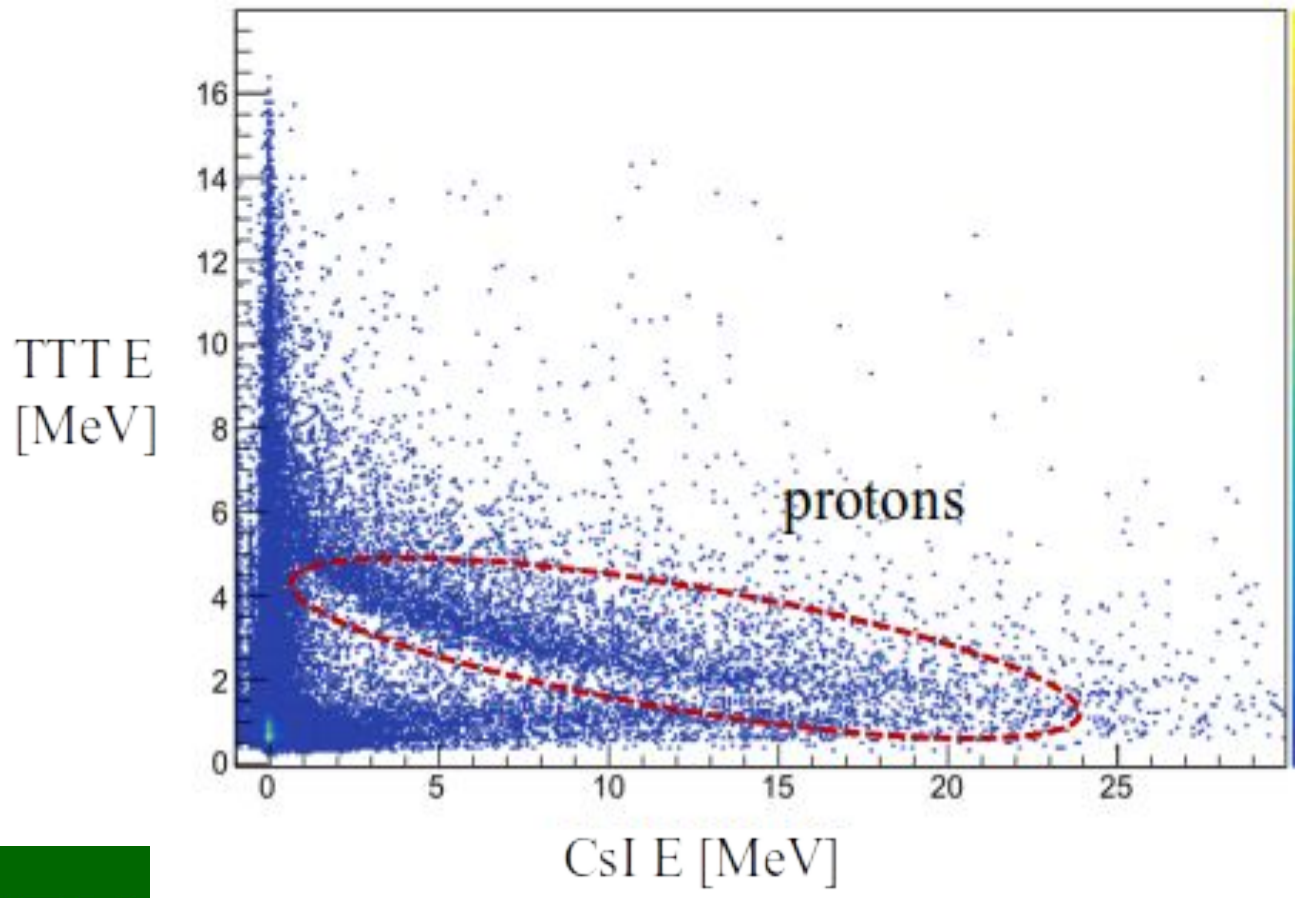
A triple α source was used for perfoming TTT (Squares) and YY1 (Trapezoids) silicon strip calibrations.

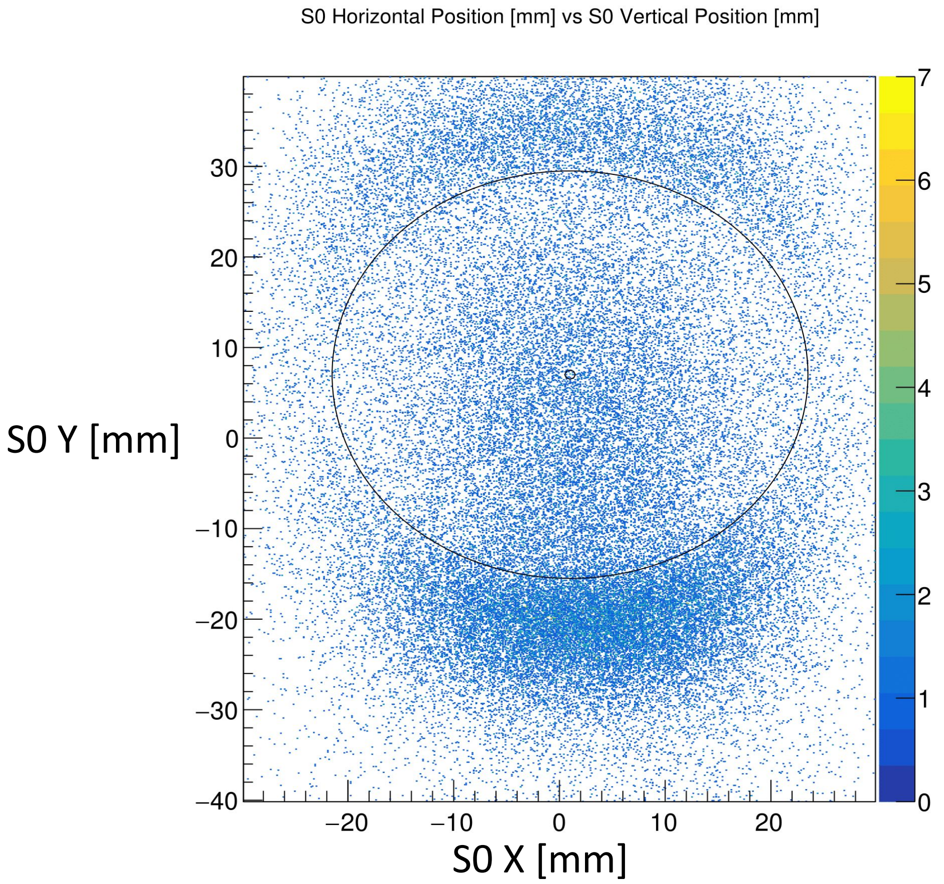




Analysis: TINA2 CsI calibration

The calibration runs for the CsI crystals could not be performed, this could instead be done wih the protons coming from the target, and particularly the target frame.





We observe a target shift of around 6 mm up.

Analysis: TTT – FE12 timing correlations

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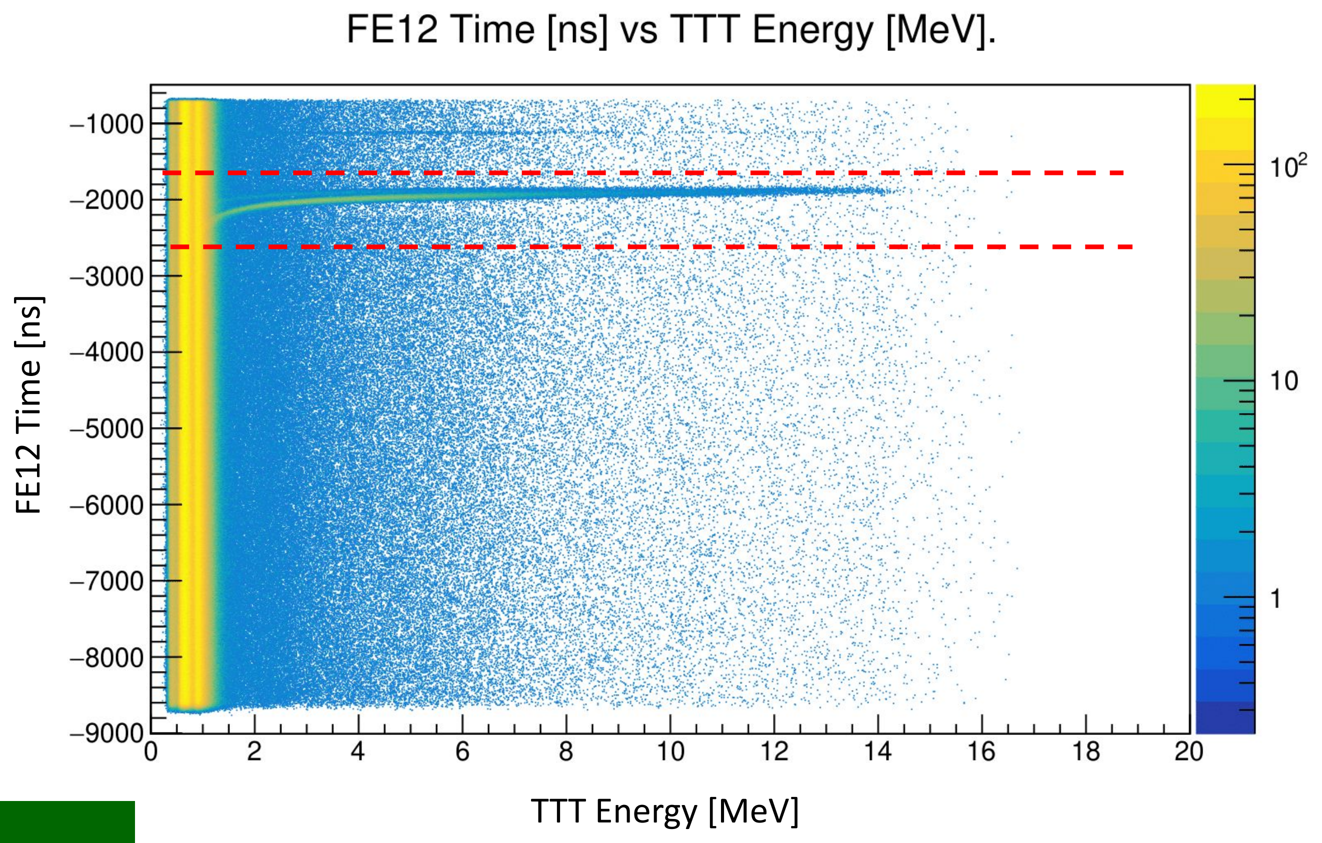
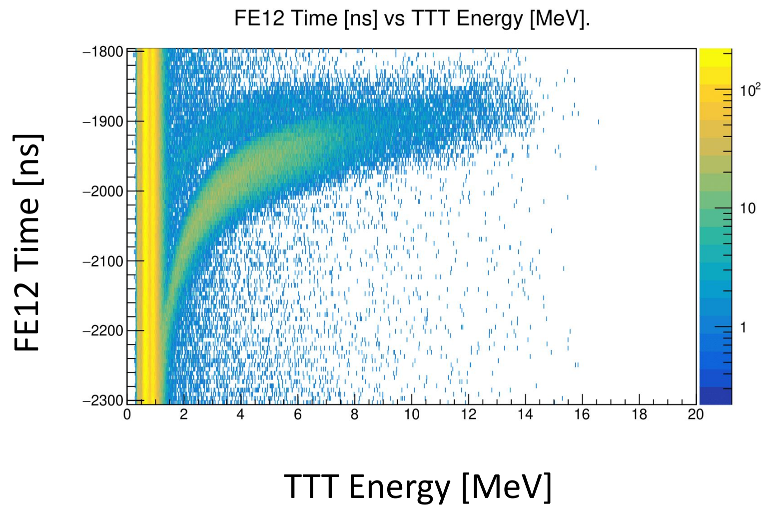
We identify the events in which there is timing correlation between FE12 SRPPACs and the TiNA2 array.





TTT Energy = TTT Front Energy.

- We impose **| TTT_F_E – TTT_B_E | < 0.5 energy correlation**.

- The same pattern can be observed for the YY1.

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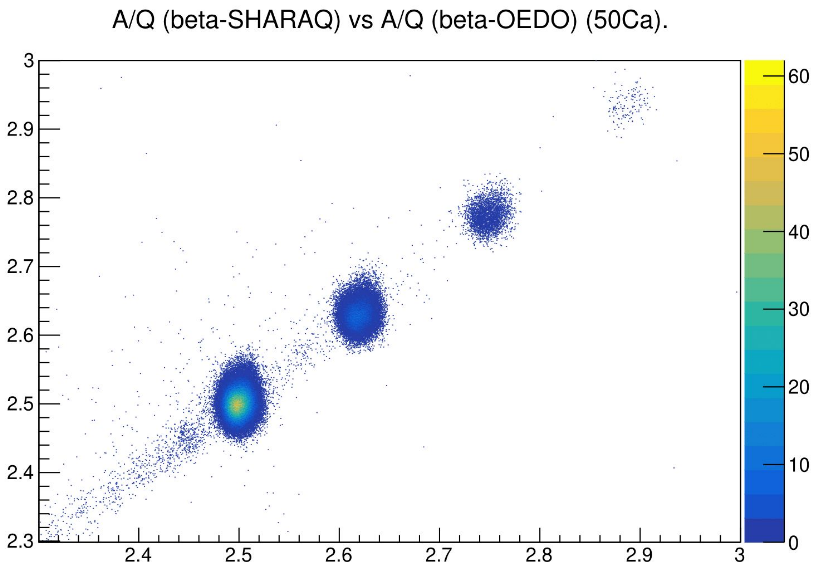
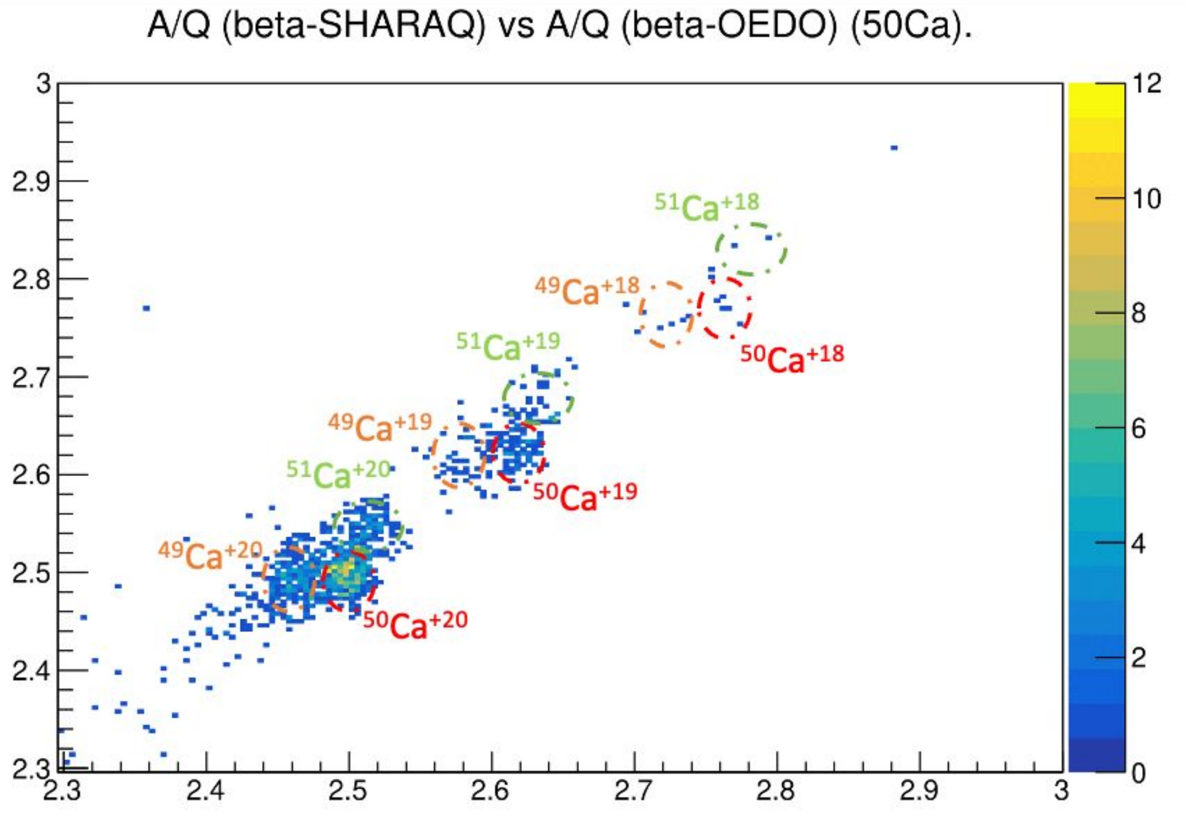
Analysis: Identification of ^{51}Ca

We calculate the A/Q at SHARAQ from both the FE12-S1 ToF (β-SHARAQ) and the FE9-FE12 ToF (β-OEDO), identifying some ^{51}Ca after applying TINA2 conditions.

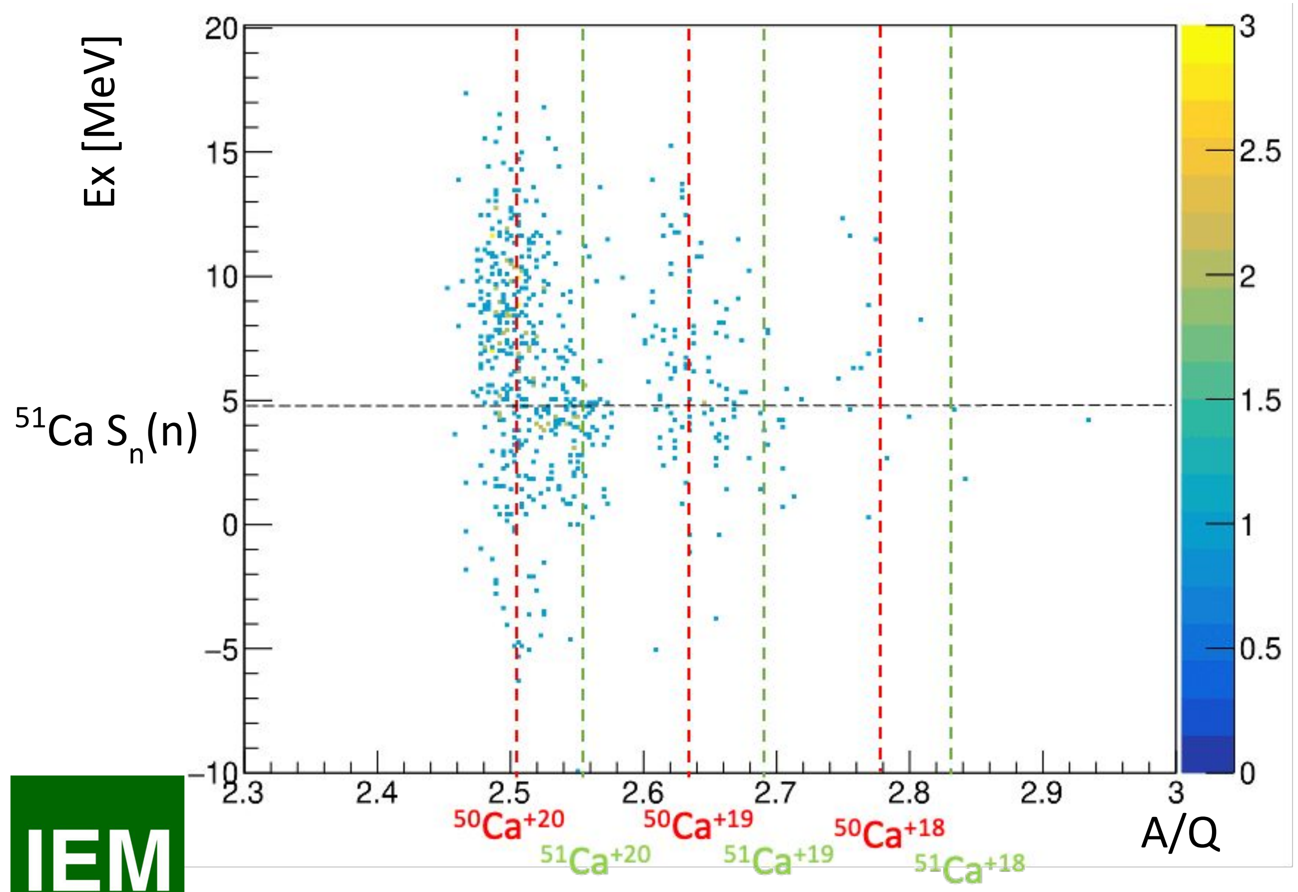


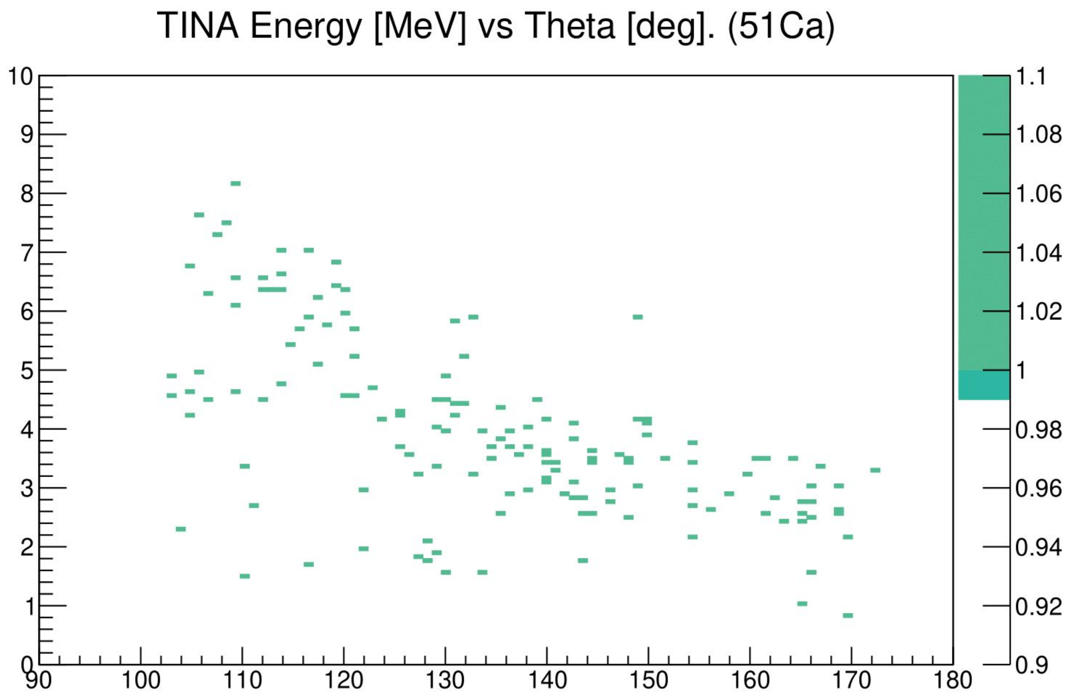
Nucleus	A/Q
$^{50}Ca^{+20}$	2.500
$^{50}Ca^{+19}$	2.632
$^{50}Ca^{+18}$	2.778
$^{50}Ca^{+20}$	2.550
$^{50}Ca^{+19}$	2.684
$^{50}Ca^{+18}$	2.833
$^{49}Ca^{+20}$	2.450
$^{49}Ca^{+19}$	2.579
$^{49}Ca^{+18}$	2.722



Analysis: Identification of ^{51}Ca

If we represent the missing mass excitation energy vs A/Q (β-SHARAQ), it can be observed how the proton emission remains approximately below the neutron separation energy for ^{51}Ca, S(n) = 4.814 MeV.





- Unfortunately, the number of identified ^{51}Ca ions is rather limited !

Conclusions

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- We have identified and tracked the ^{50}Ca beam ions along the OEDO beamline and the SHARAQ spectrometer in correlation with the TiNA2 silicon array, but unfortunately the number of ^{51}Ca ions produced via the one-neutron transfer reaction and identified behind the target is rather limited.

- Since the experiment was abruptly interrupted due to a failure in the SRC, the SHARAQ12 experiment could only be resumed in May 2024 and the new data has not been analyzed yet.

- In the second part of the experiment, an improved transmission was obtained, particularly from FE12 to S1, and furthermore a thicker CD_2 reaction target was used. We therefore hope that a significantly higher statistics can be obtained by combining both parts of the experiment.

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The End

Thank you for your attention