Study of the neutron-rich nucleus ^6H in electron scattering experiment at MAMI-A1

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Outline

- Motivation
- Experiment principle
- MAMI-A1 setup
- Calibration
- Data analysis
- Summary

Motivation

2-He-4	2-He-5	2-He-6	2-He-7	2-He-8
Jπ 0+ Stable	Jπ 3/2- 0.648 MeV n ?	Jπ 0+ 806.7 (15) ms β- 100%	Jπ (3/2)- 150 (20) keV n ?	Jπ 0+ 119.1 (12) ms β- 100% β- n 1
1-H-3	**1-H-4**	**1-H-5**	**1-H-6**	**1-H-7**
Jπ 1/2+ 12.32 (2) y β- 100%	Jπ 2- n 100%	Jπ (1/2+) 5.3 (4) MeV 100%	Jπ ? 1.55 (44) MeV ?	Jπ (1/2+) 0.09 (+94-6) MeV ?

- ^{4}H, ^{5}H： clear signal observed
- ^{6}H, ^{7}H ： Indistinct signal, controversial results
- Largest neutron-to-proton ratios known so far. Good platforms to study NN and NNN interactions in neutron-rich environments.

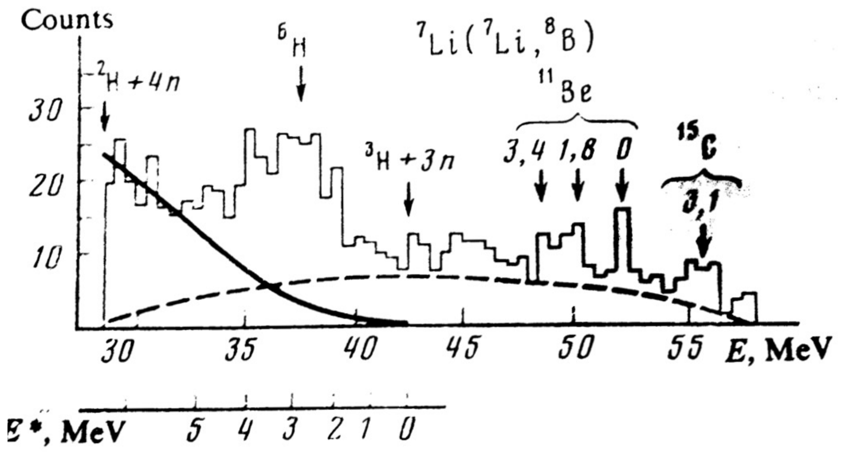
Motivation

- Experiments with ^{6}H signal

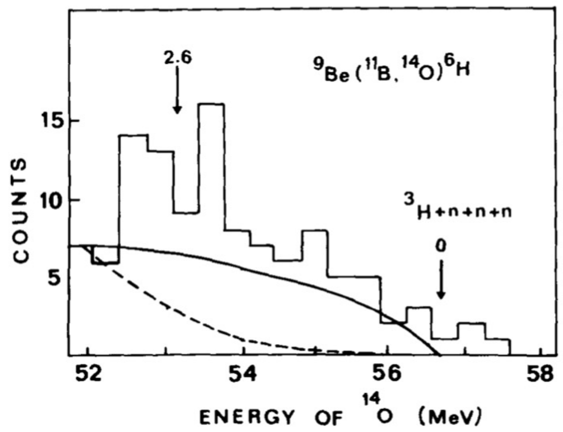
TABLE I. Experimental results of ^{6}H ground state energy.

Reaction	E [MeV]	Γ [MeV]	Publish year
^{7}Li(^{7}Li,^{8}B)^{6}H	2.7±0.4	1.8±0.5	1984
^{9}Be(^{11}B,^{14}O)^{6}H	2.6±0.5	1.3±0.5	1986
^{9}Be(π^-, pd)^{6}H	6.6±0.7	5.5±2.0	2003
^{11}B(π^-, p^{4}H)^{6}H	7.4±1.0	5.8±2.0	2003
^{12}C(^{8}He,^{6}H → t + 3n)^{14}N	$2.91^{+0.85}_{-0.95}$	$1.52^{+1.77}_{-0.35}$	2008
^{2}H(^{8}He,^{4}He)^{6}H	> 4.5	5	2022

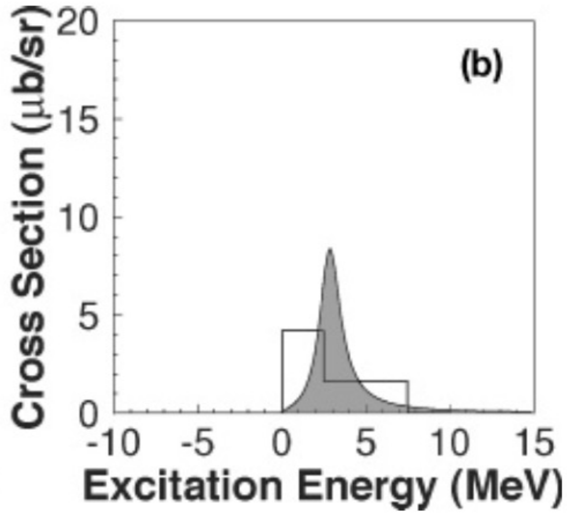
D. Aleksandrov et al. , Yadernaya Fizika 39 (1984), pp. 513–517



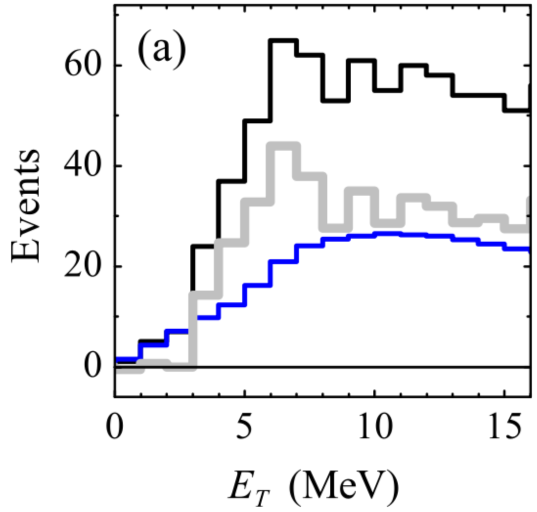
A. Belozyorov et al. , Nuclear Physics A 460.2 (1986), pp. 352–360



M. Caaman˜o et al. , PHYSICAL REVIEW C **78**, 044001 (2008)



E. Yu. Nikolskii et al. , PHYSICAL REVIEW C 105, 064605 (2022)



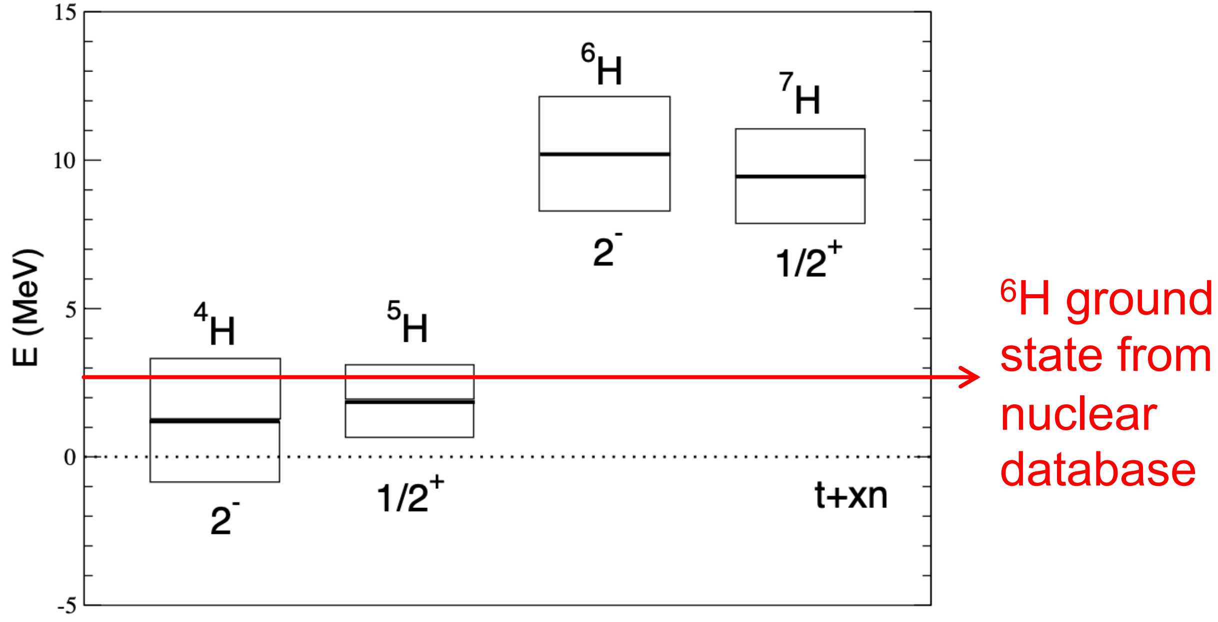
Motivation

- Theoretical calculations

TABLE II. Theoretical results of ^{6}H ground state energy.

Author	E [MeV]	J^π	Ref.
Poppelier et. al.,	2.8	0^-	PL 1985
Bevelacqua et. al.,	1.34	1^+	PRC 1986
Gorbatov et. al.,	6.3	2^-	YF 1989
Aoyama et. al.,	6.6		NPA 2004
Hiyama et. al.,	10	2^-	PLB 2022

E. Hiyama et. al., Physics Letters B 833 (2022) 137367

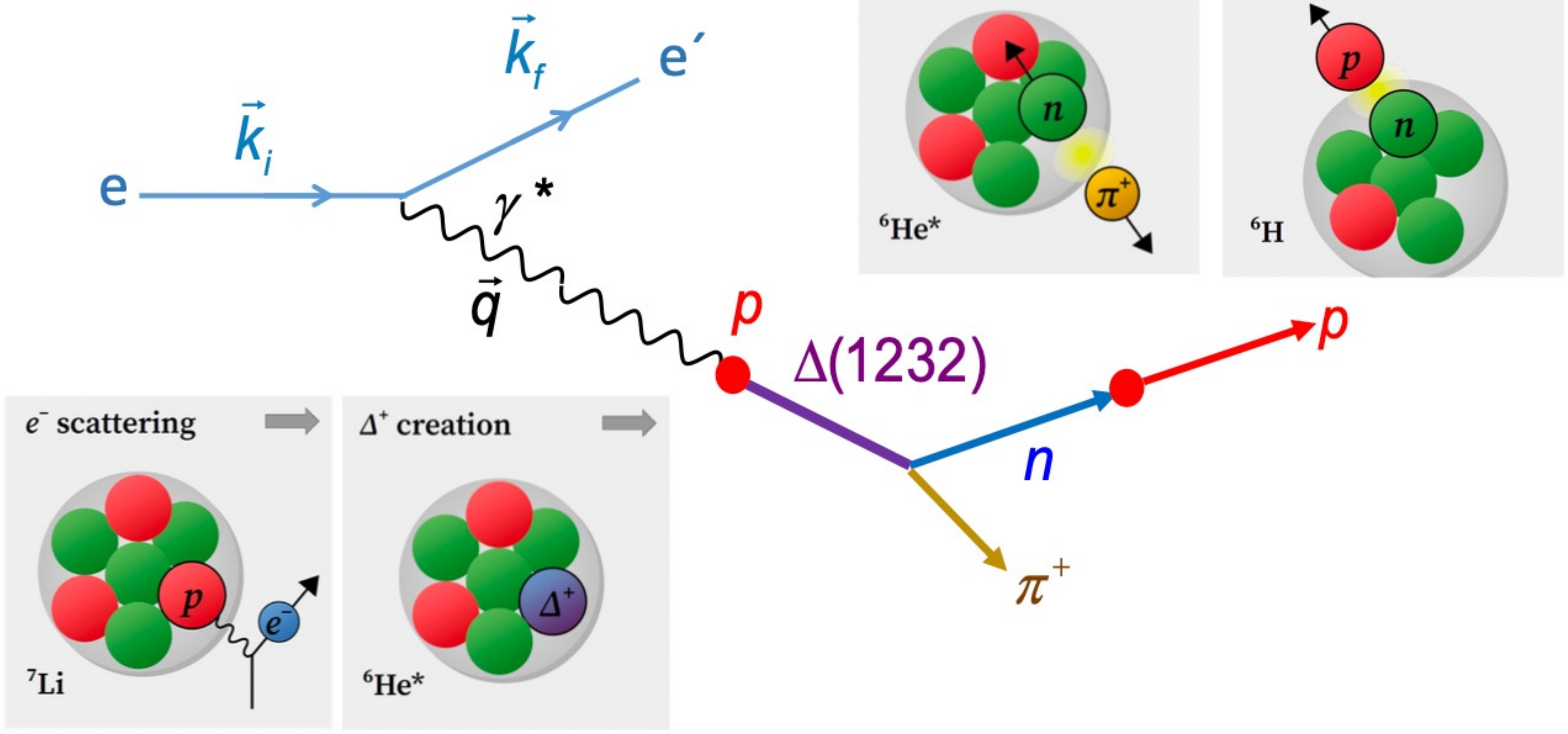


Any relations between hydrogen-6 and hyper hydrogen-6?

Experiment principle

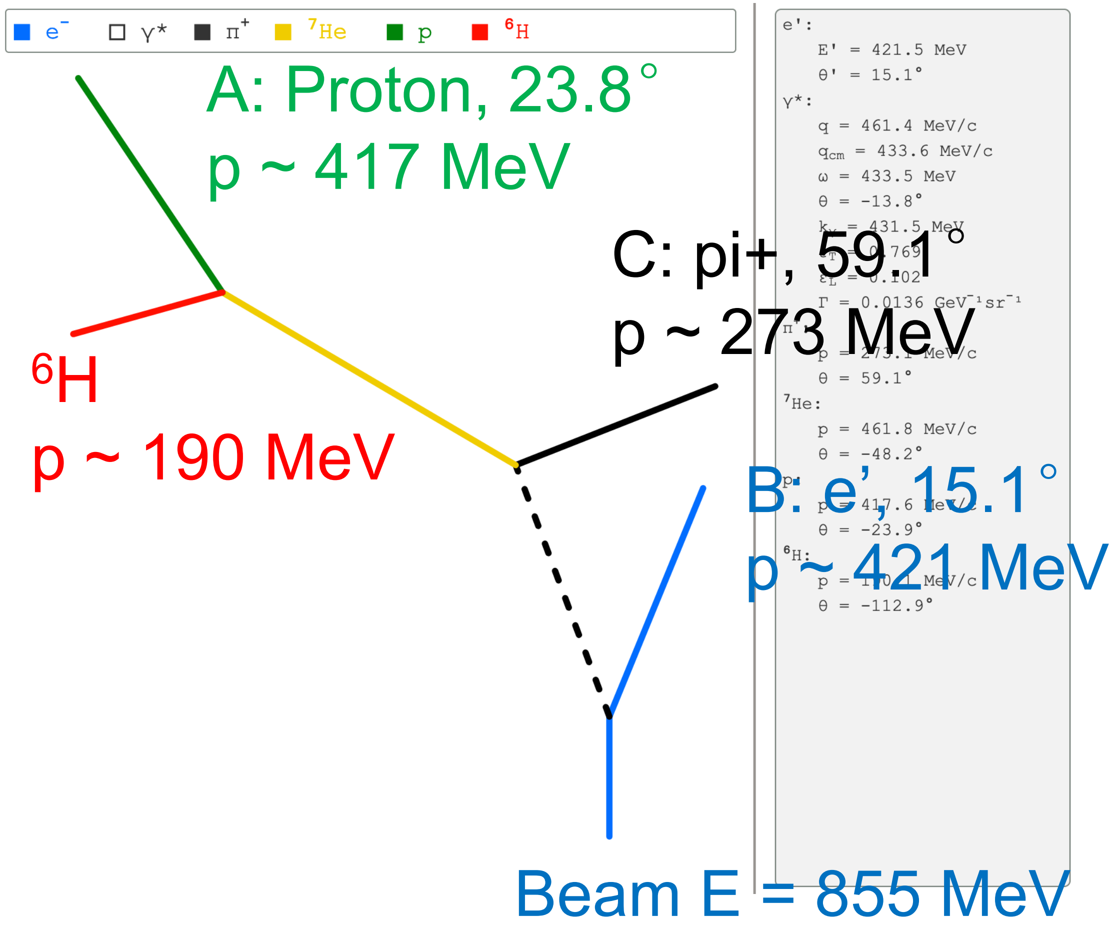
- Reaction: $^{7}Li(e, e'p\pi^{+})$
- Measure the momentum of the scattered electron, the produced proton and pi+. Then reconstruct the miss-mass spectrum.
- Expected rate: 1 count in interested region per day.
- Expected missing mass resolution: 1.21 MeV with 1mm thickness target

$$p + \gamma^{*} \rightarrow \Delta^{+} \rightarrow n + \pi^{+}$$



Experiment principle

- Choice of kinematics: 1. W ~ 1200 MeV for proton to produce Delta$^+$(1232); 2. low momentum transfer to ^{6}H; 3. feasible with the setups of three spectrometers.

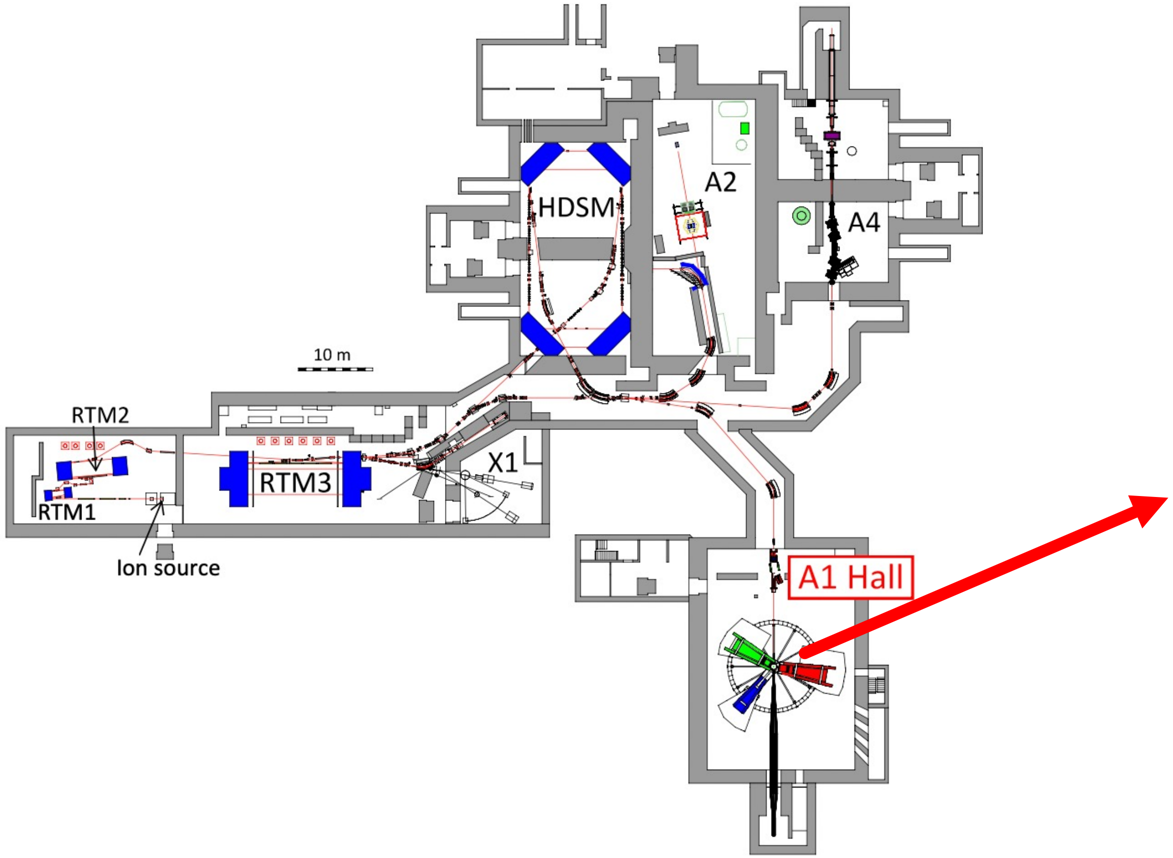


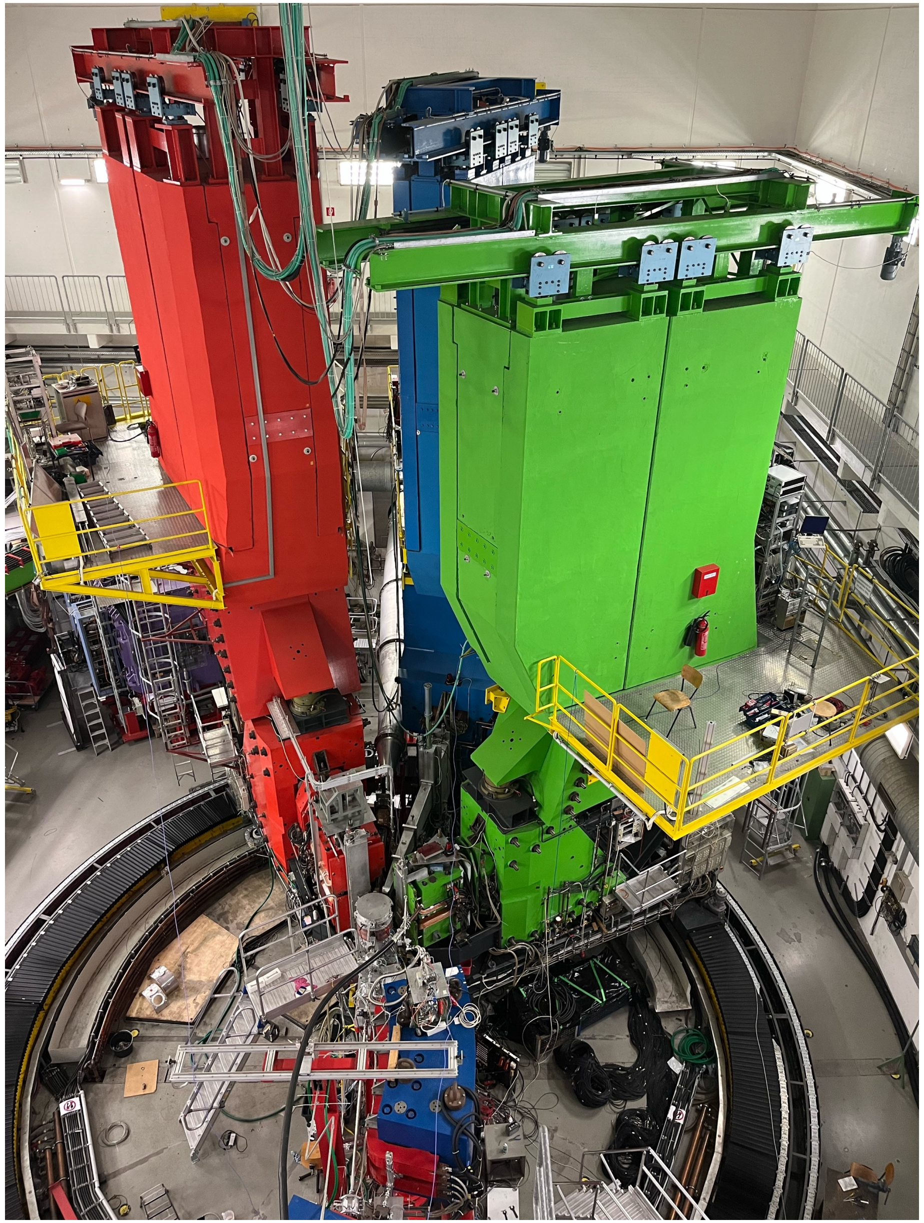
Optical properties of the A1 spectrometers

	units	A	B	C
Configuration	-	QSDD	D	QSDD
dispersive plane	-	point-ponit	point-ponit	point-ponit
non dispersive plane	-	parallel-ponit	point-ponit	parallel-ponit
Maximum momentum	[MeV/c]	735	870	551
Reference momentum	[MeV/c]	630	810	459
Central Momentum	[MeV/c]	665	810	490
Solid Angle	[msr]	28	5.6	28
Scattering Angle	-	-	-	-
minimum angle	-	18°	7°	8°
maximum angle	-	160°	62°	160°
Momentum acceptance	-	20%	15%	25%

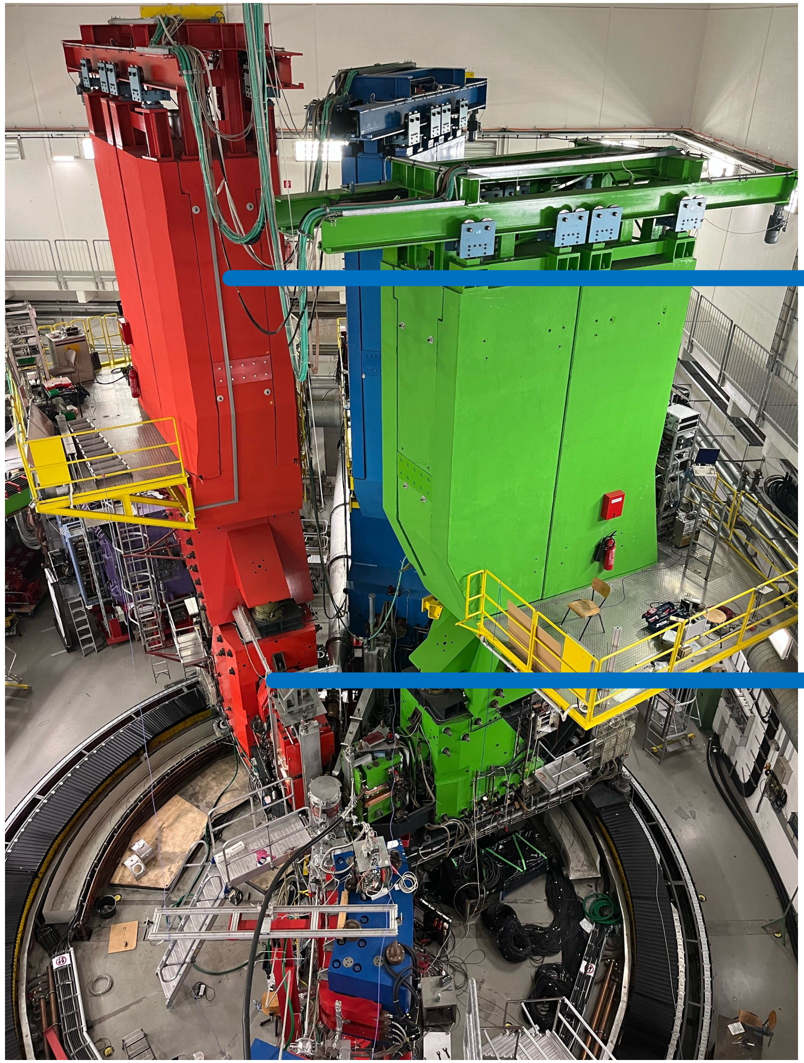
MAMI-A1 setup

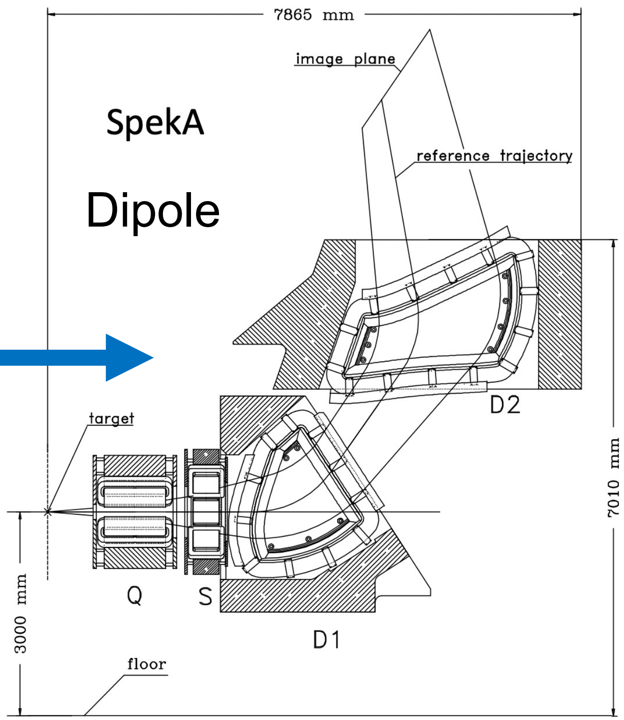
- MAMI-B: 855 MeV electron beam

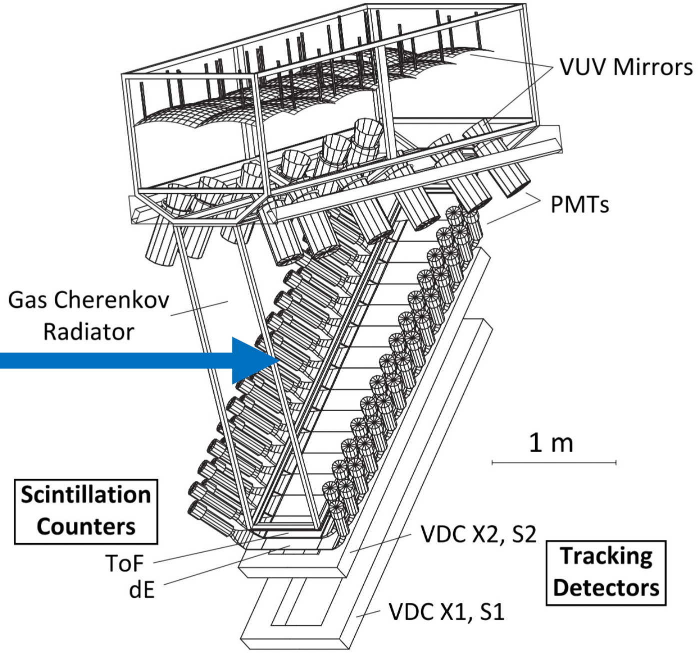




MAMI-A1 setup





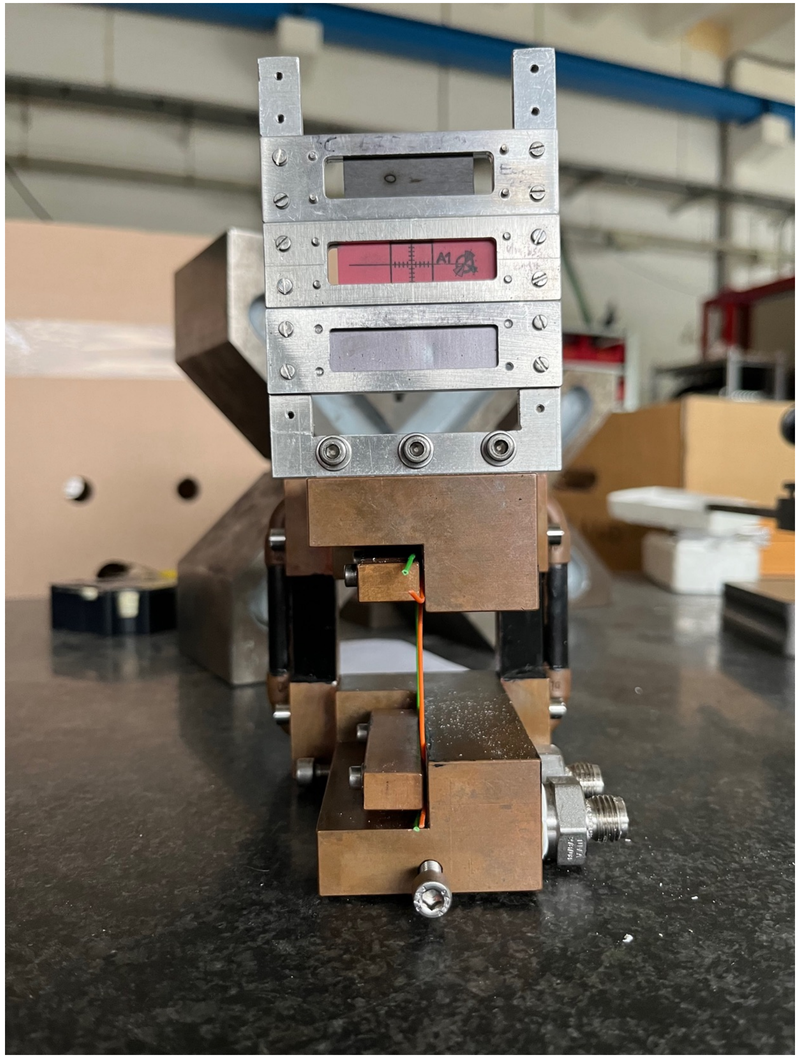


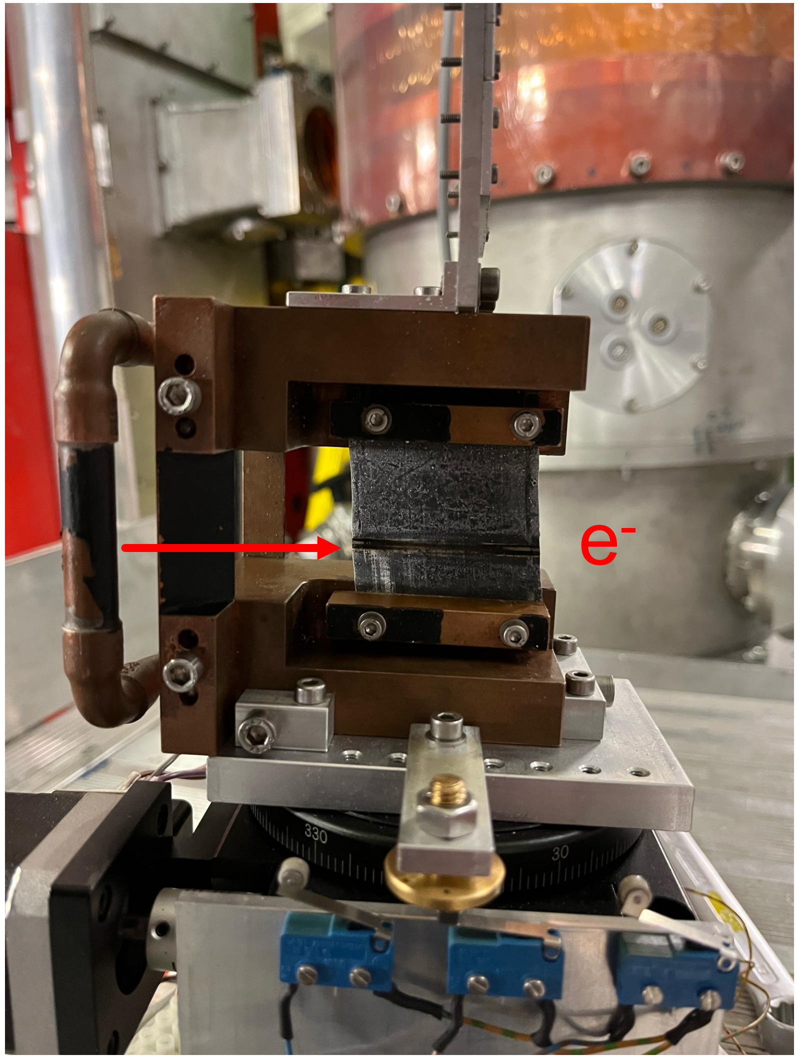
Detector system：

- VDC： track reconstruction
- dE： Energy loss measurement
- TOF： Energy loss and time of flight
- Cherenkov： identify electron and pion

Target setup

- Empty
- C12
- Aluminum
- Ta
- Li-7 (run_2023: 92.7% natural lithium, run_2024: 99.99% enriched lithium-7)





Beam time summary

Date	July 2023	July 2023	Sep 2023	April 2024
Beam energy (MeV)	855	855	855	855
Beam current (nA)	400	400	400	700
Kinematic	1	2	2	2
Target	Natural Li	Natural Li	Natural Li	Enriched ^{7}Li
Target length (cm)	4.5	4.5	4.5	2.5
Target width (mm)	0.75	0.75	0.75	1.0
Effective time	~ 120 h	~ 120 h	~ 160 h	~ 160 h

Kinematic 1

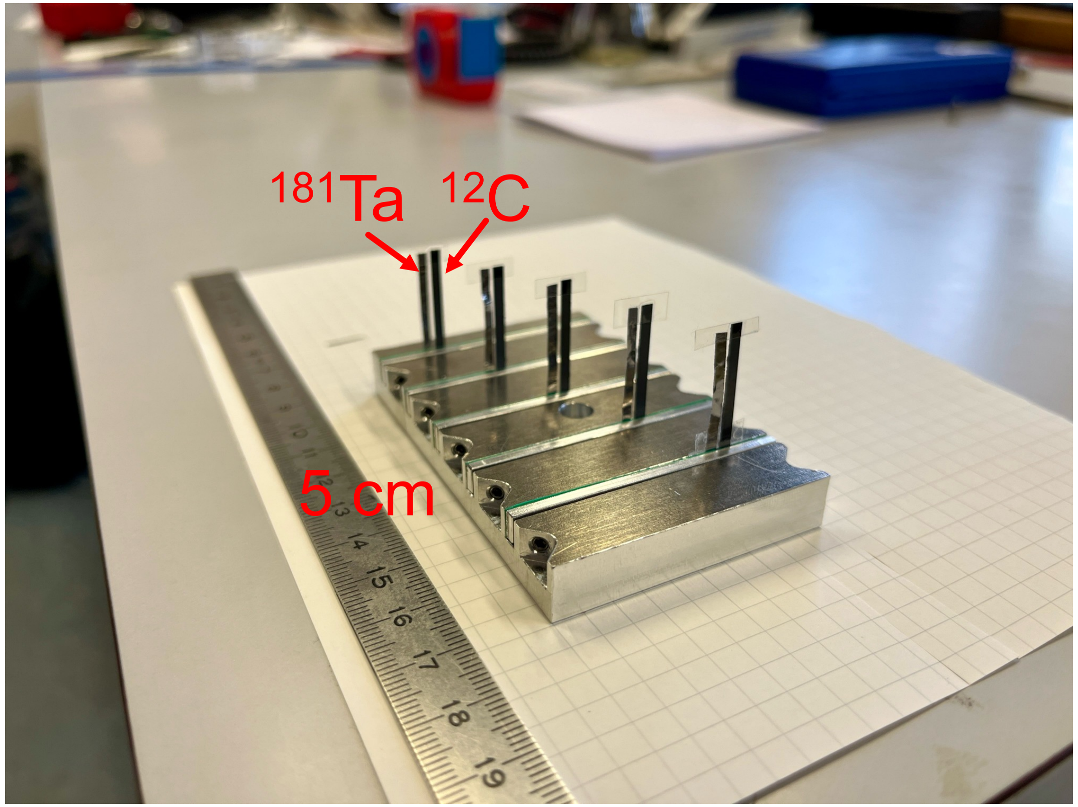
Spectrometer	Degree (°)	Momentum (MeV/c)
A (proton)	-23.8	379
B (e’)	15.1	531
C (π^+)	59.1	162

Kinematic 2

Spectrometer	Degree (°)	Momentum (MeV/c)
A (proton)	-23.8	417
B (e’)	15.1	421
C (π^+)	59.1	273

Momentum calibration

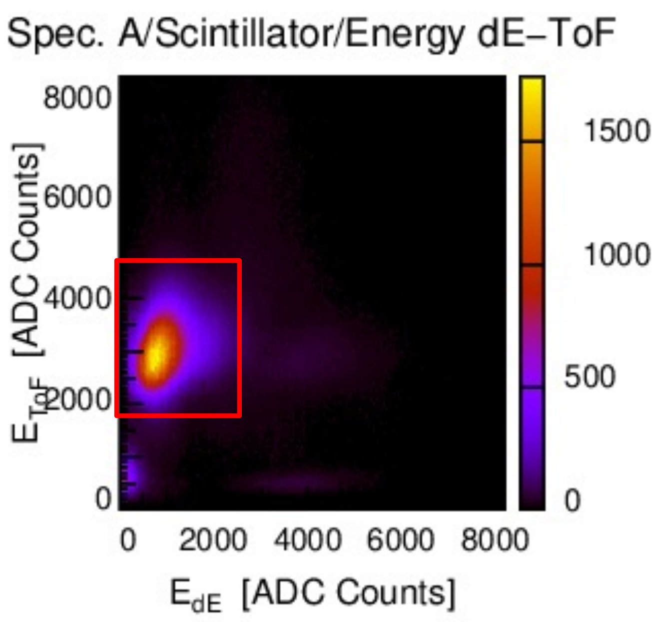
- Principle： Electron scattering with ^{181}Ta and ^{12}C target. Compare with the certain input momentum the correction factors can be obtained.
- Ebeam (MeV) = 180, 195, 210 with undulator (~10keV uncertainty); 225, 420 without undulator (~160 keV uncertainty)
- Electron scattering with several target positions and momentum settings.
- Calibration beam time has been done in May 2024.



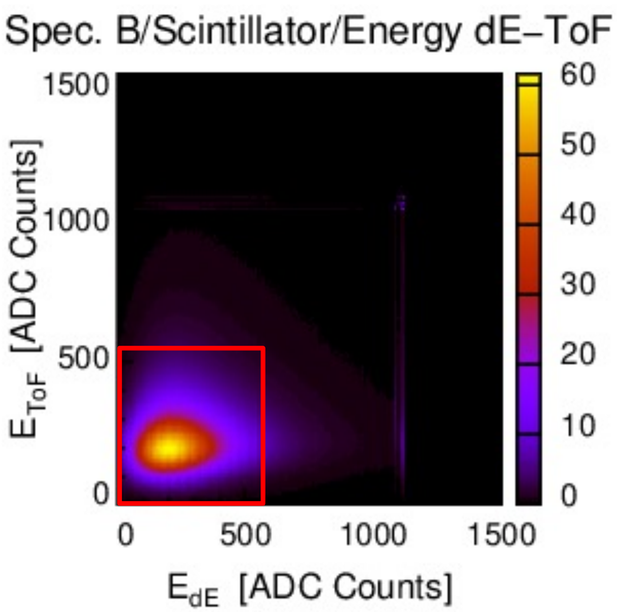
Also see in Ryoko Kino’s talk on Wednesday morning.

Data analysis

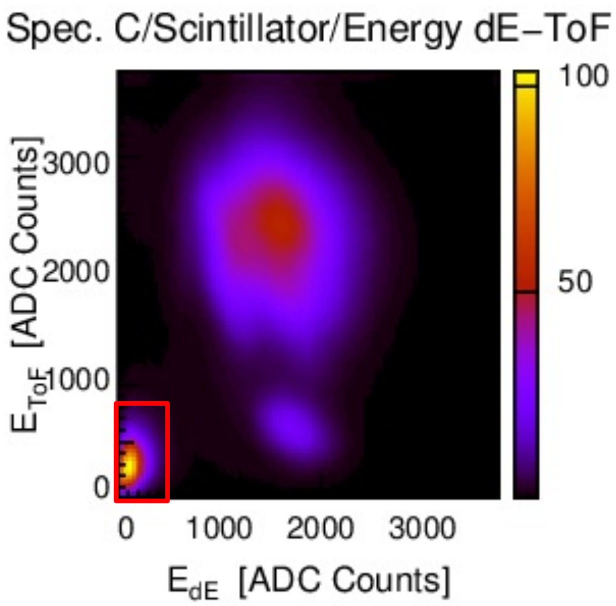
- Particle identification: according to the energy loss in scintillators.



A: Proton



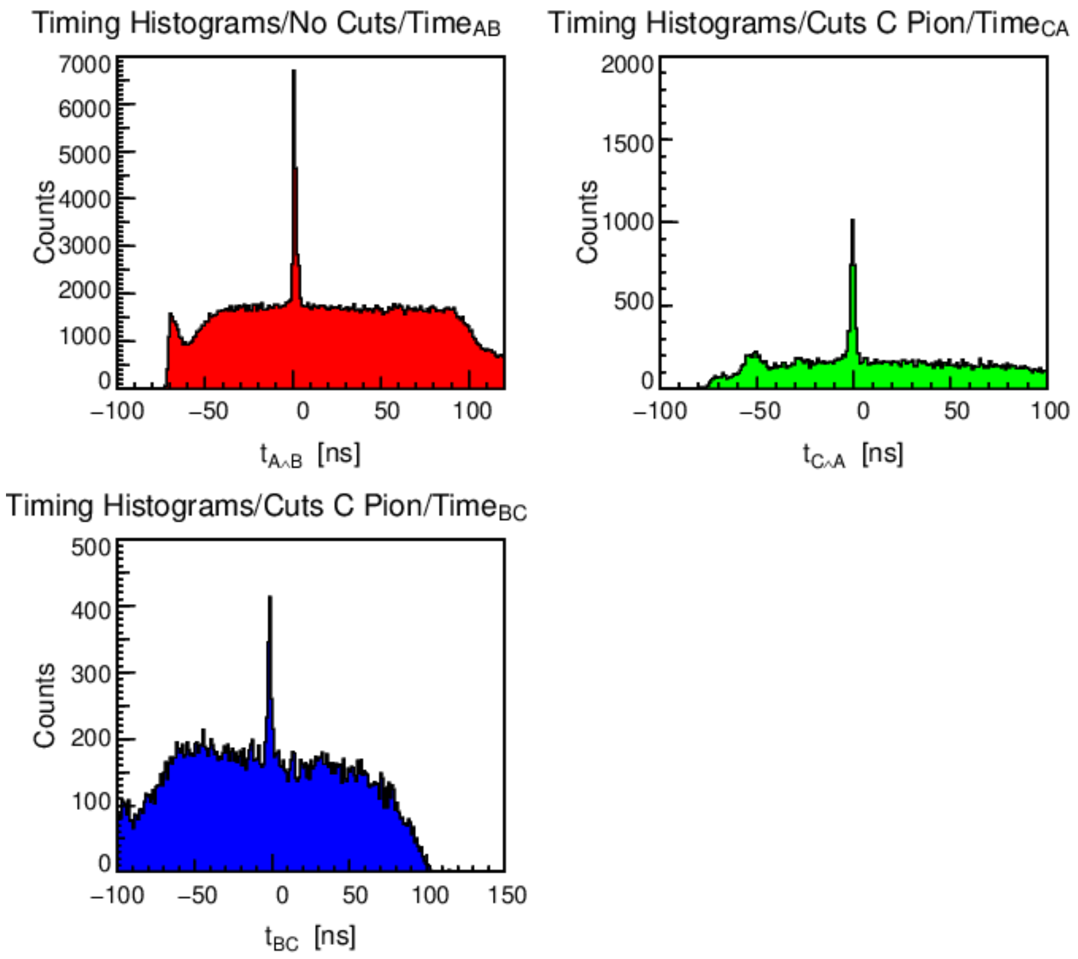
B: electron

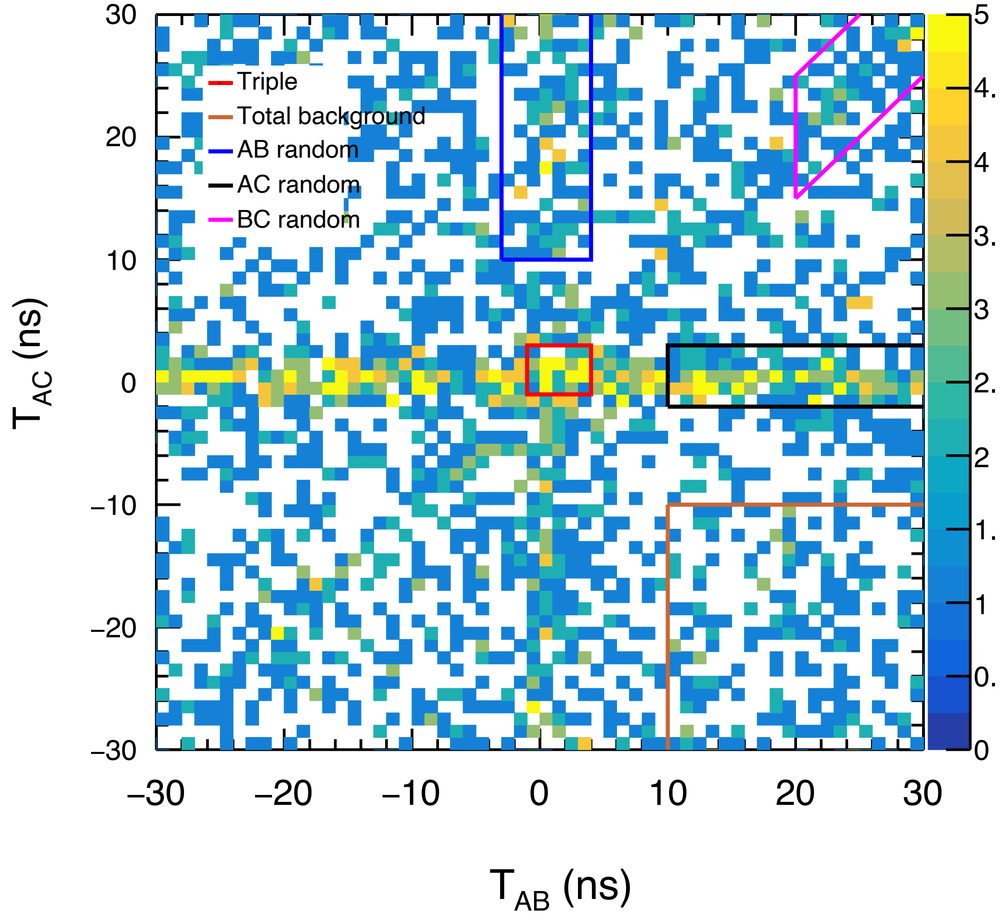


C: pi+ and proton

Data analysis

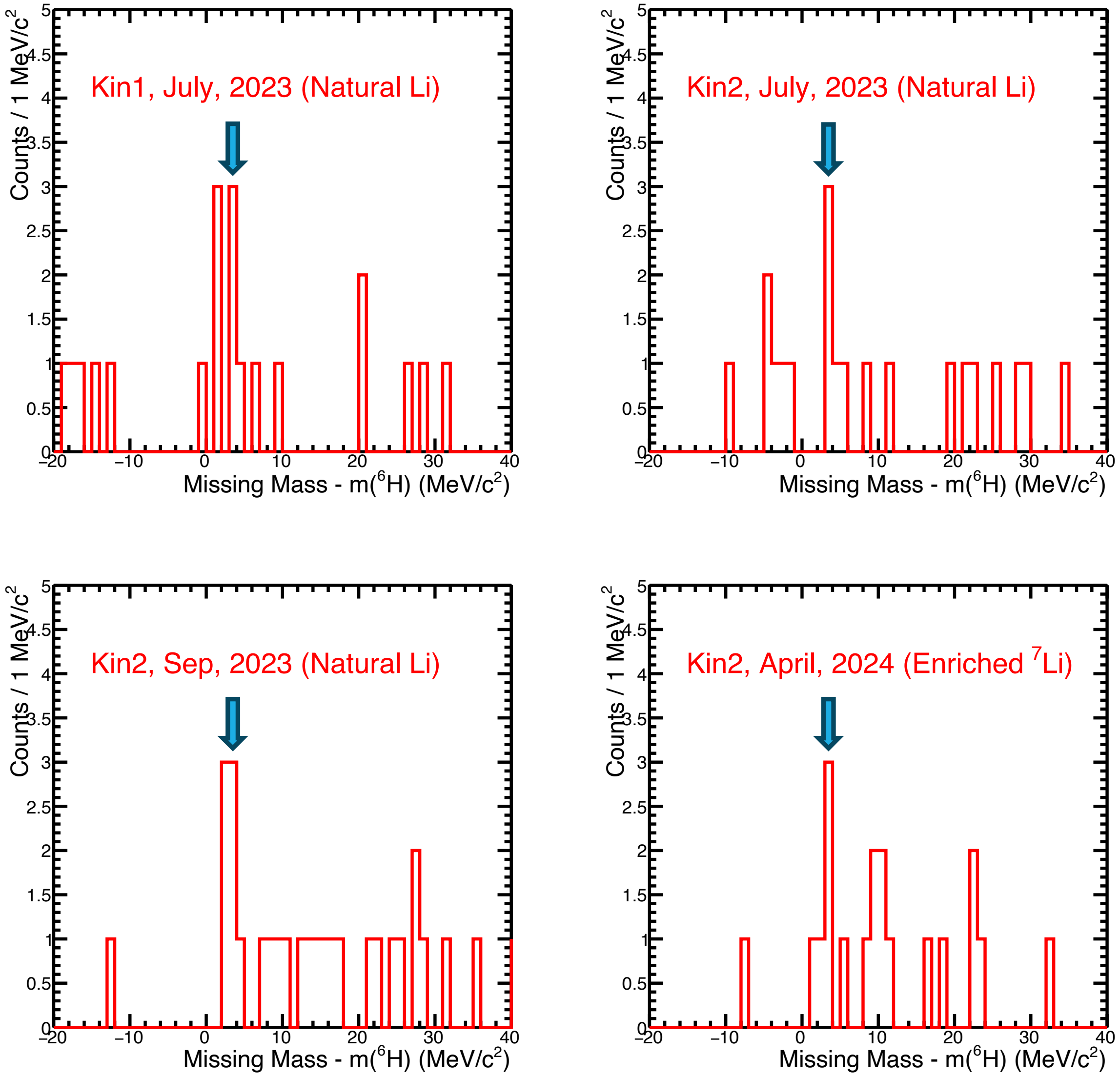
- Select the events in the region of triple coincidence.





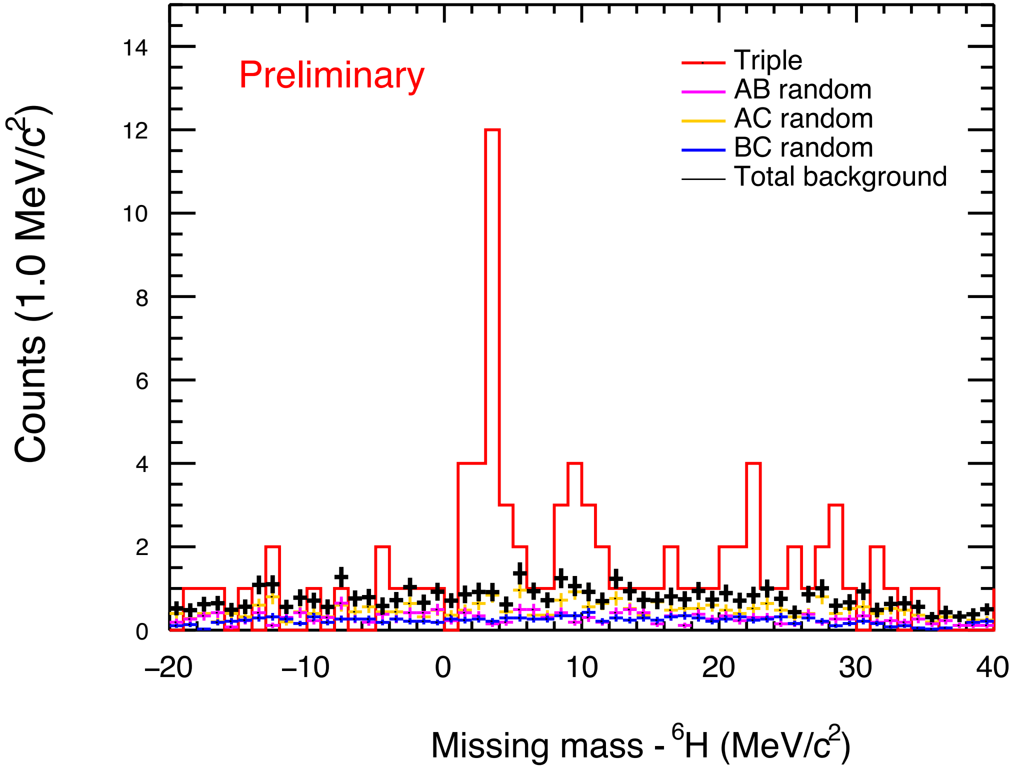
Data analysis

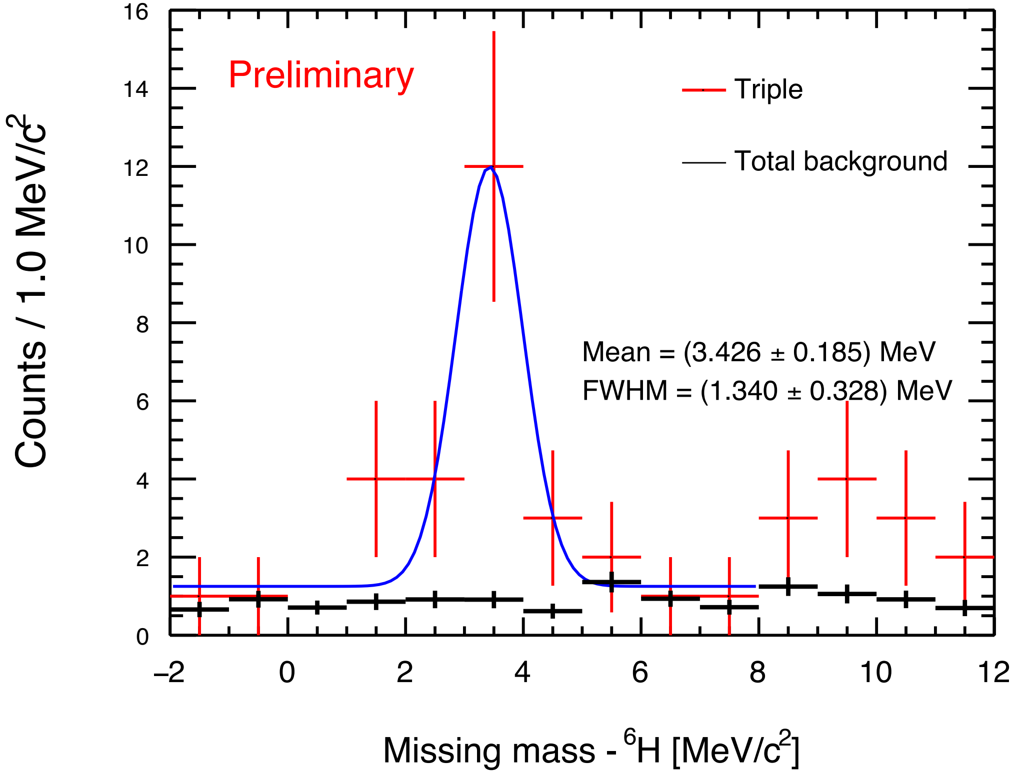
- Missing mass = (Ebeam + Etarget - Eproton - Eelectron - Epion).mass
- E_(H6) = Missing mass – mass(t + 3n)
- Peak structures near 3 MeV are seen in all setups.



Data analysis

- Combine the data from all setups, run_2023 + run_2024.
- H6 ground state ~ 3.4 MeV, width ~ 1.3 MeV Preliminary!
- Count and resolution are similar as we expected.





Summary

- To study the neutron-rich nucleus ^{6}H, an electron scattering experiment with triple coincidence is designed and done with 3 beam times at MAMI-A1.
- Calibration data taking for the three spectrometers are done.
- Preliminary results show the ground state ^{6}H energy is E ~ 3.4 MeV, W ~ 1.3 MeV.

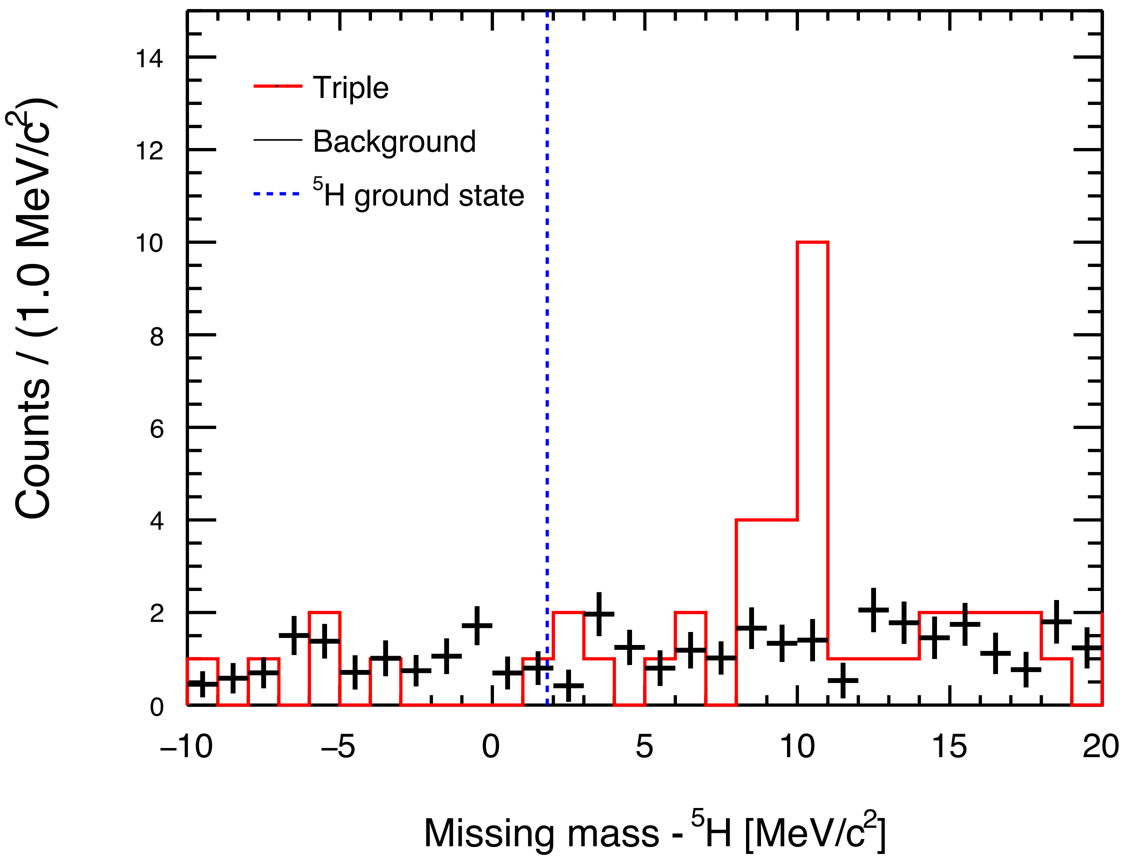
Outlook

- Analyze the calibration data in detail.
- Analyze the systematic uncertainties for the result.

Data analysis

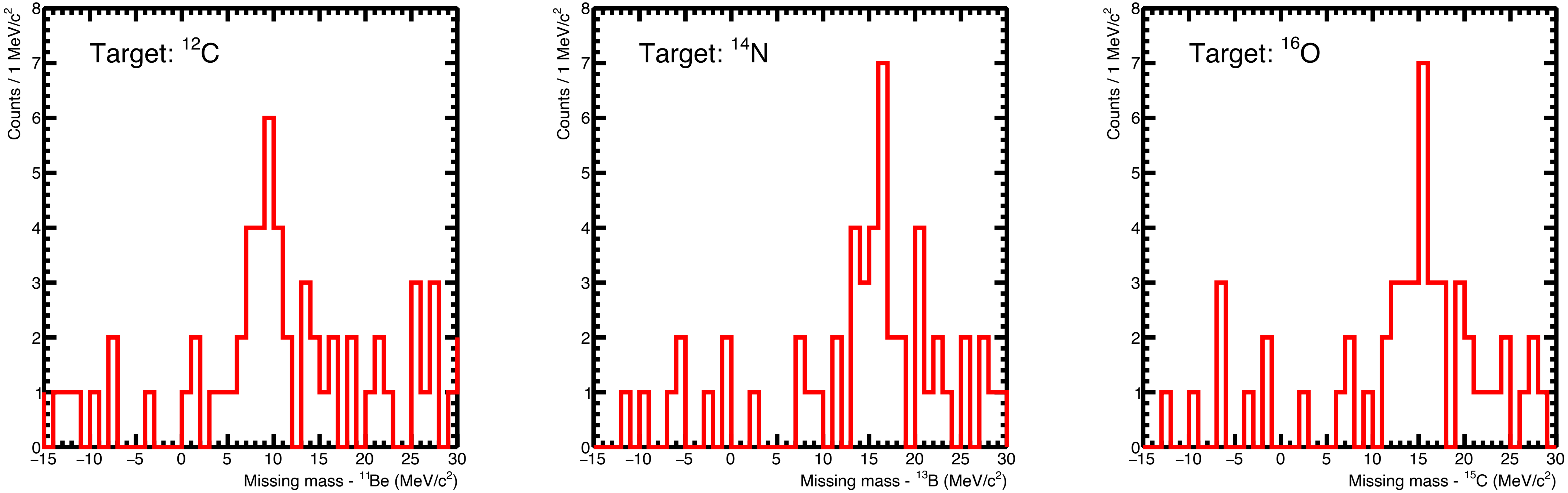
- Can the signal come from ^{6}Li which can produce ^{5}H? About 7.3% ^{6}Li in natural lithium.
- The peak near 3 MeV can also be seen with enriched ^{7}Li target.
- Replace ^{7}Li with ^{6}Li in analysis. The energy is about 10 MeV, which is much large than ^{5}H ground state ~ 1.8 MeV.

Reaction: $^6Li(e,e'p\pi^+)$



Backup

- Can the signal come from the C, N, and O in air?
- Replace the target with C, N, or O. The obtained energies are also much larger than ground states.



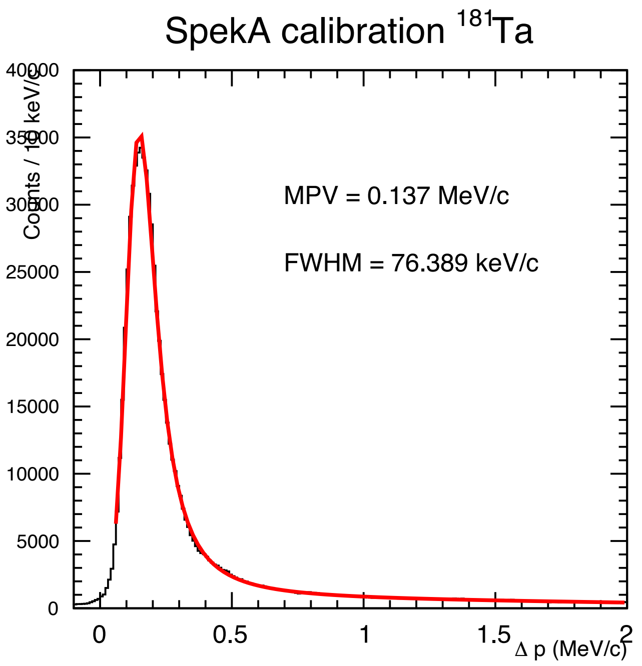
Backup: Momentum calibration

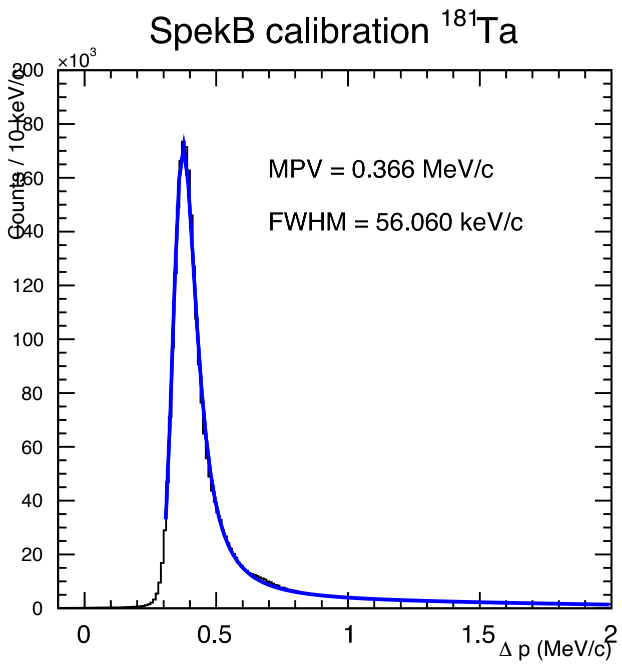
- Scattering electron on ^{181}Ta target
- $\Delta p = p_{in} - p_{measured}$, energy losses in target and detector system are considered.
- Fit function: Landau (energy loss) and Gaussian (detector resolution) convolution.

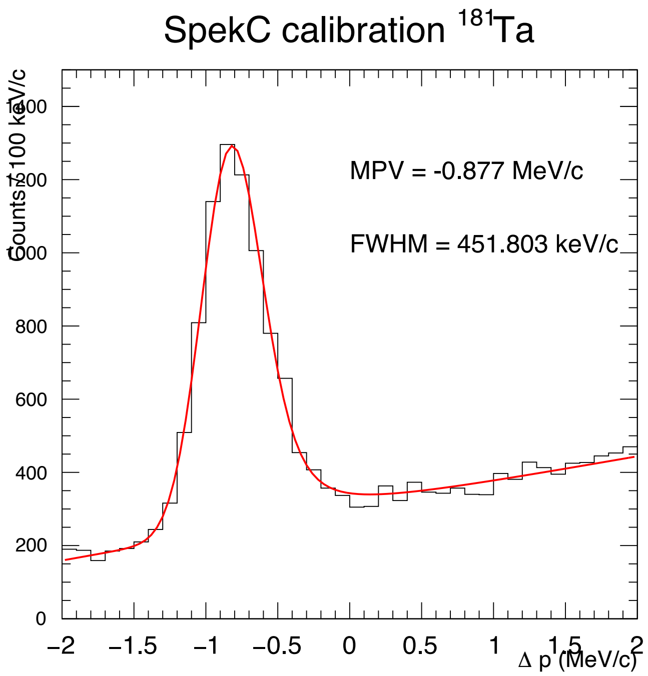
Spectrometer	Δp (MeV/c)	Correction factor
A	0.136821	1.00032587
B	0.36578	1.00087166
C	-0.87746	0.99791517

Momentum calibration

- Scattering electron on ^{181}Ta target
- $\Delta p = p_{in} - p_{measured}$, energy losses in target and detector system are considered.
- Fit function: Landau (energy loss) and Gaussian (detector resolution) convolution.







Momentum calibration

- Correction factor check: missing mass spectrum of ^{12}C ground and excited states.