Mass reconstruction @ CNAO2024

MC vs data comparison

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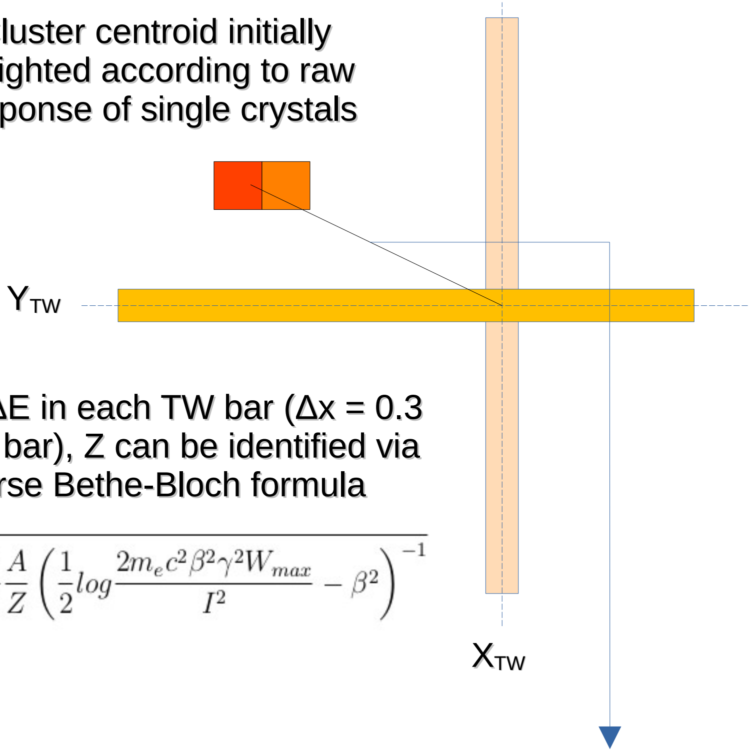
SEZIONE DI TORINO

Mass reconstruction @ CNAO2024

Cluster centroid initially weighted according to raw response of single crystals



Given ΔE in each TW bar (Δx = 0.3 cm per bar), Z can be identified via inverse Bethe-Bloch formula

$$Z_i = \sqrt{\frac{\Delta E_i}{\rho \Delta x}\frac{\beta^2}{K}\frac{A}{Z}\left(\frac{1}{2}log\frac{2m_e c^2\beta^2\gamma^2 W_{max}}{I^2} - \beta^2\right)^{-1}}$$

TW point and CALO cluster are matched according to minimum distance criterion.

Two TW hits (bars on) form a TW-point
>> TOF, Z and $(X,Y)_{TW}$ coordinates are assigned.

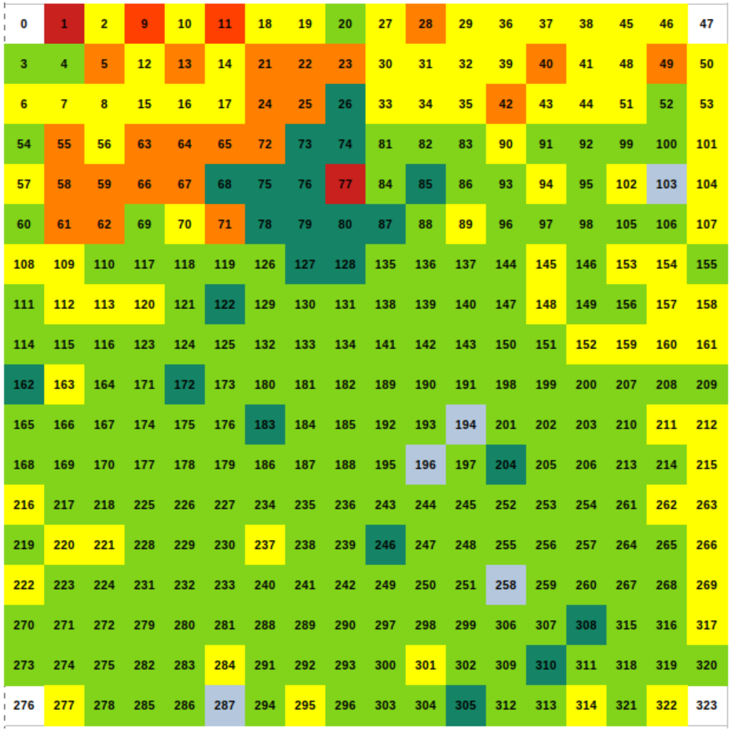
$$A[u] = \frac{E_{kin}[MeV]}{f(\gamma-1)c^2} \qquad f = \frac{0.931494\,MeV}{u * c^2}$$

E_{kin} obtained from CALO clusters → Z from the TW point is required for calibration.

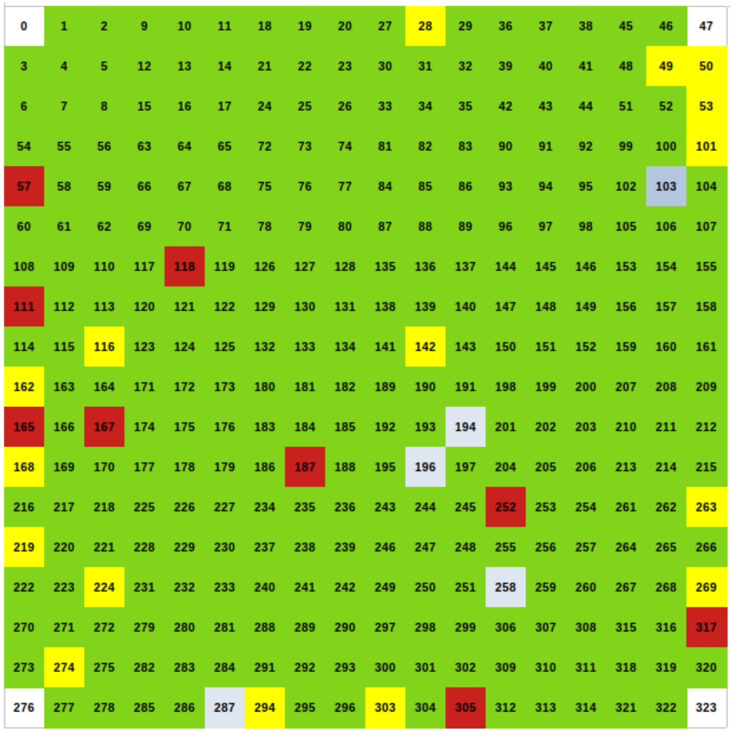
γ is obtained from β = L /TOF, where:
- L is the TG-TW point distance;
- TOF = $TOF_{TW\text{-}SC}$ – $TOF_{SC\text{-}TG}$, where $TOF_{TW\text{-}SC}$ is averaged on the two hits.

If multiple energy losses in same bar,
n. active X-bars ≠ n. active Y-bars
→ Z is assigned by the layer with most hits.

Calibration status



Carbon

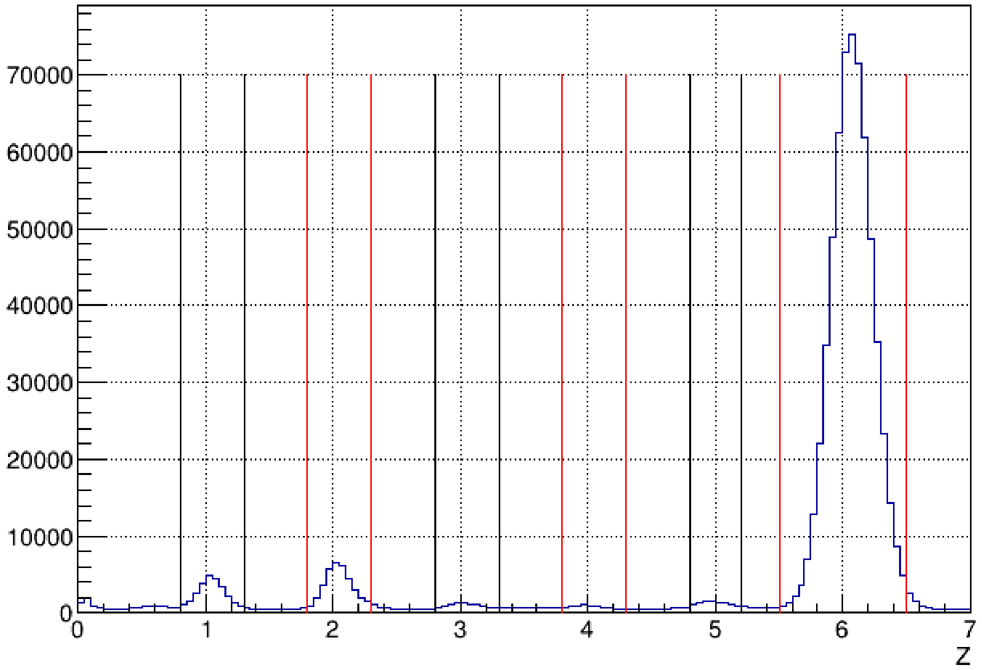


Proton

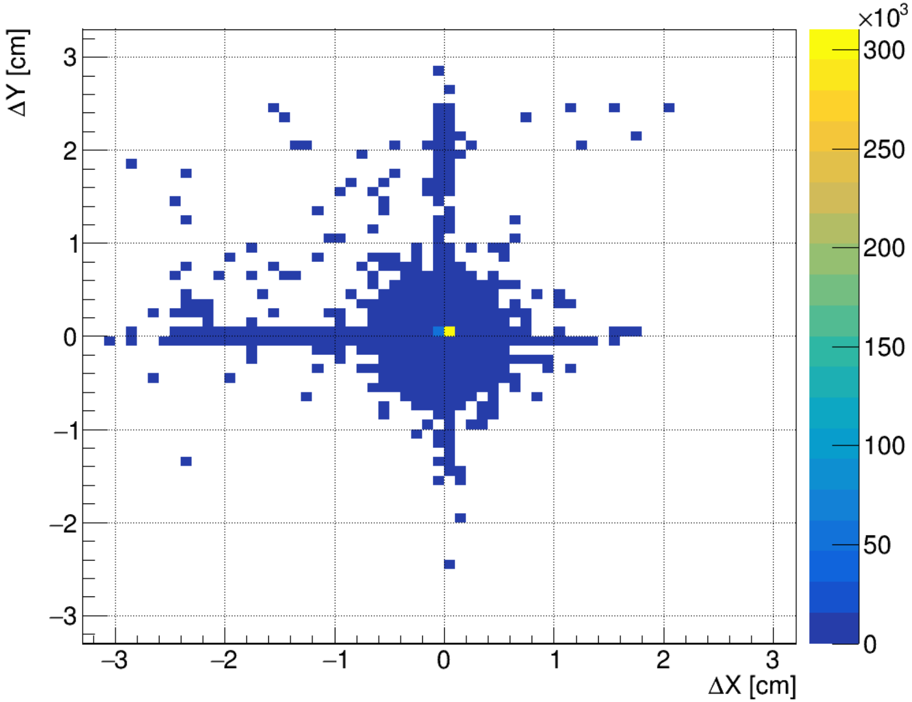
- lacking points
- few statistics
- not responding
- 3 points available
- 4 points with 5% cut
- 4 points available

Mass reconstruction @ CNAO2024

Z distribution for ≃ 800k fragmentation events
→ thresholds on Z selection.

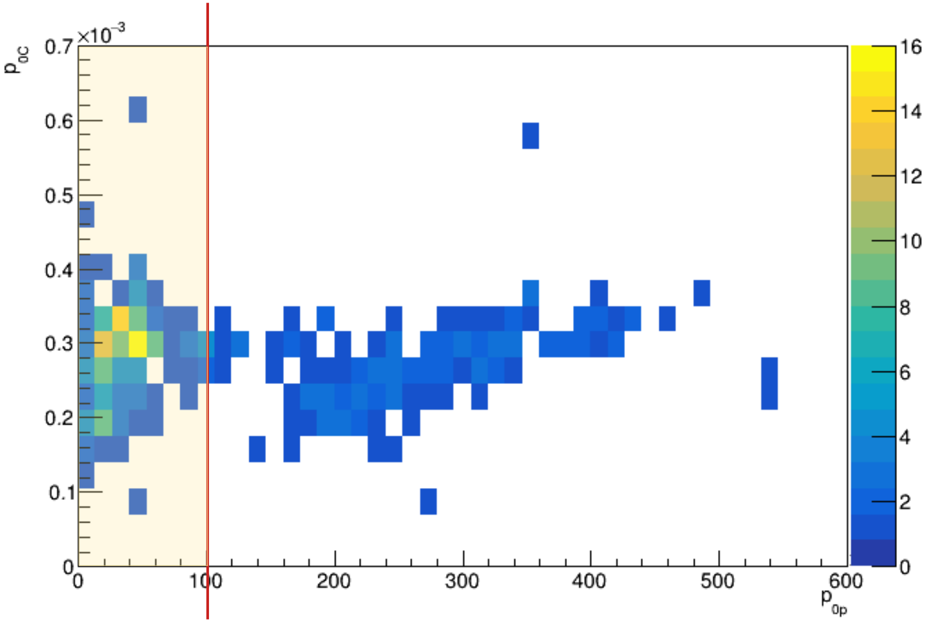


After the energy equalization, the shift in (X,Y) is < 0.1 cm for 80% of the clusters → threshold on cluster selection.

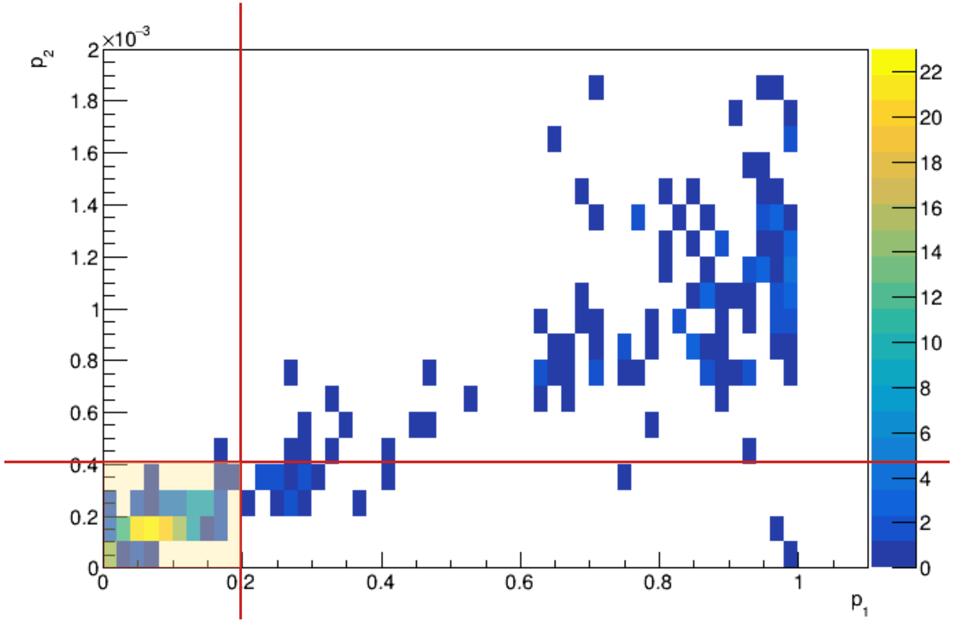


Mass reconstruction @ CNAO2024

Best-fit MBF parameters for p have wider dispersion than for C → further selection on crystals.
“Outliers” must be cured separately.



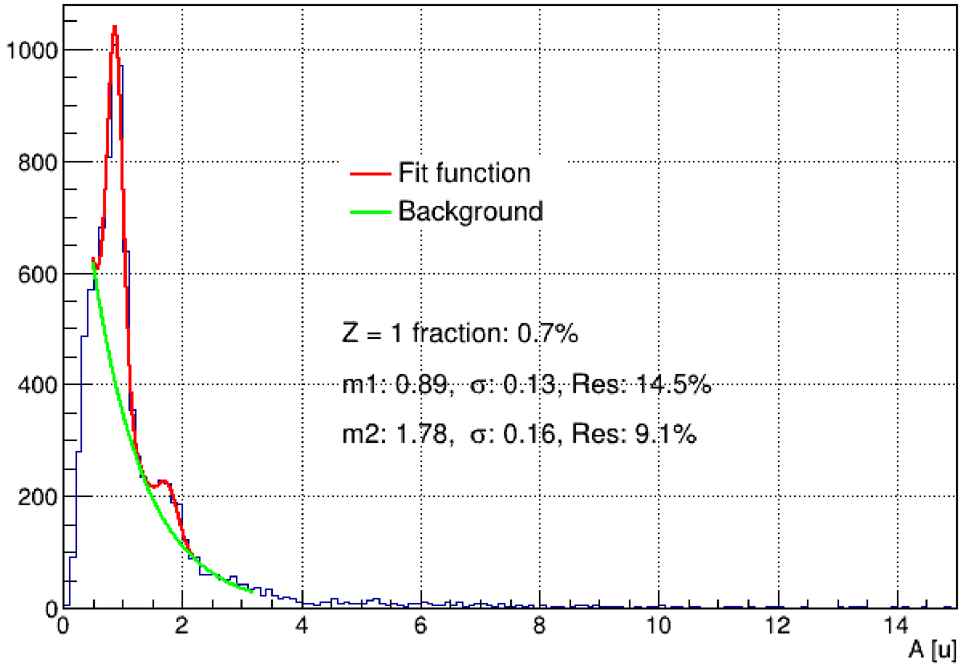
p_0 for C vs p_0 for p.

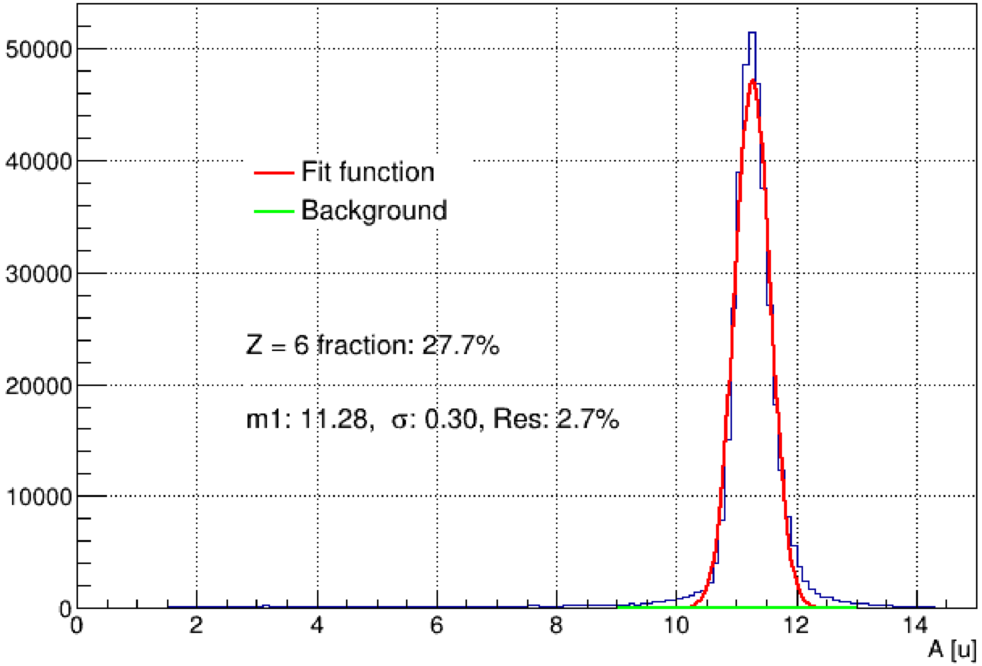


p_1 vs p_2 for p.

p and C reconstruction @ CNAO2024

For p and C, kinetic energy directly reconstructed → p, d and ^{12}C were identified (with resolution < 3% in the 2nd case).

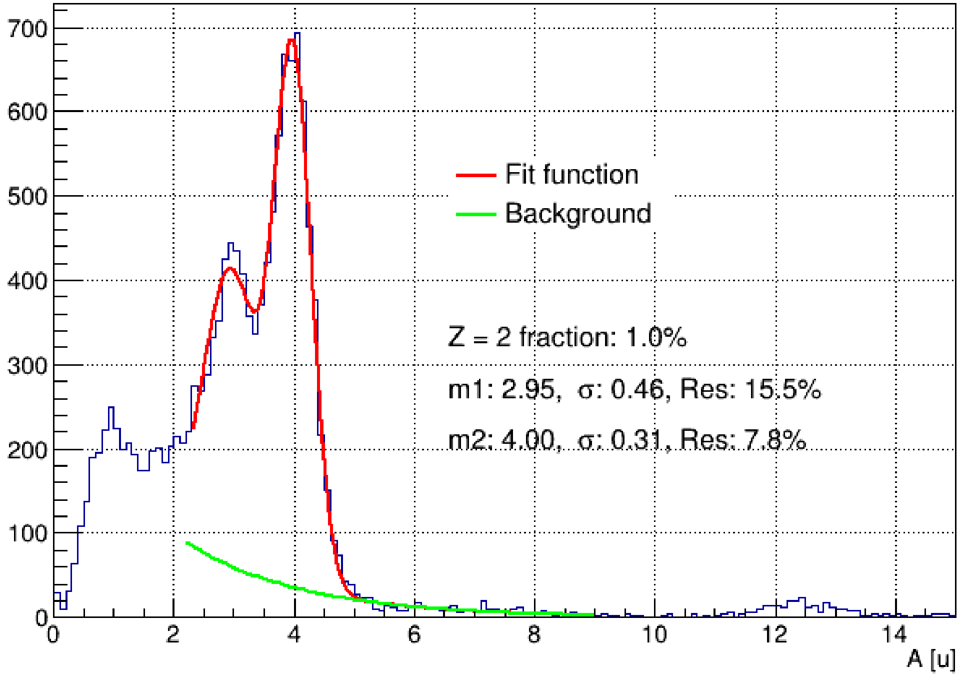


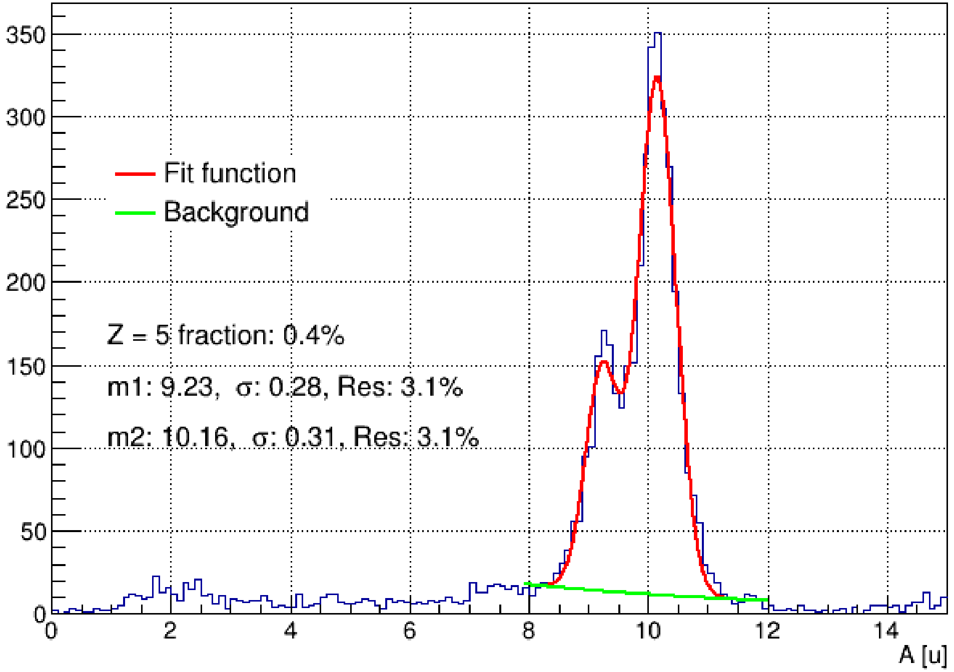


Reconstructed mass peaks were fitted with a gaussian function + decreasing exponential background.

He and B reconstruction @ CNAO2024

^{3}He, ^{4}He, ^{10}B and ^{11}B were reconstructed via power law function **(no direct reconstruction was available).**
For Be, resolution between 8-16%. For B, resolution ≈ 3%.

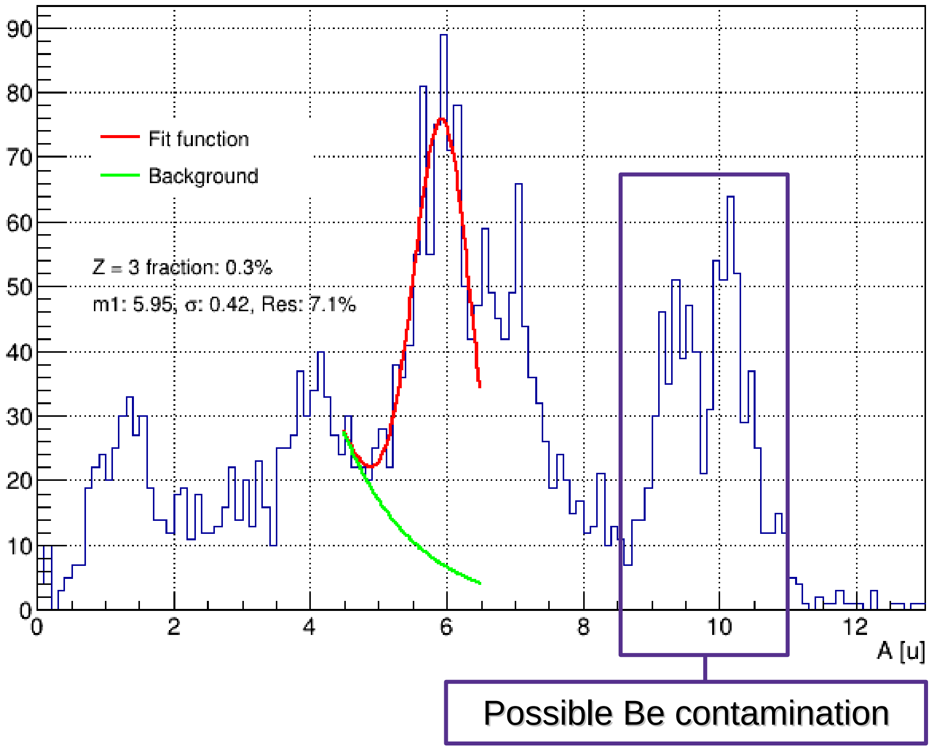


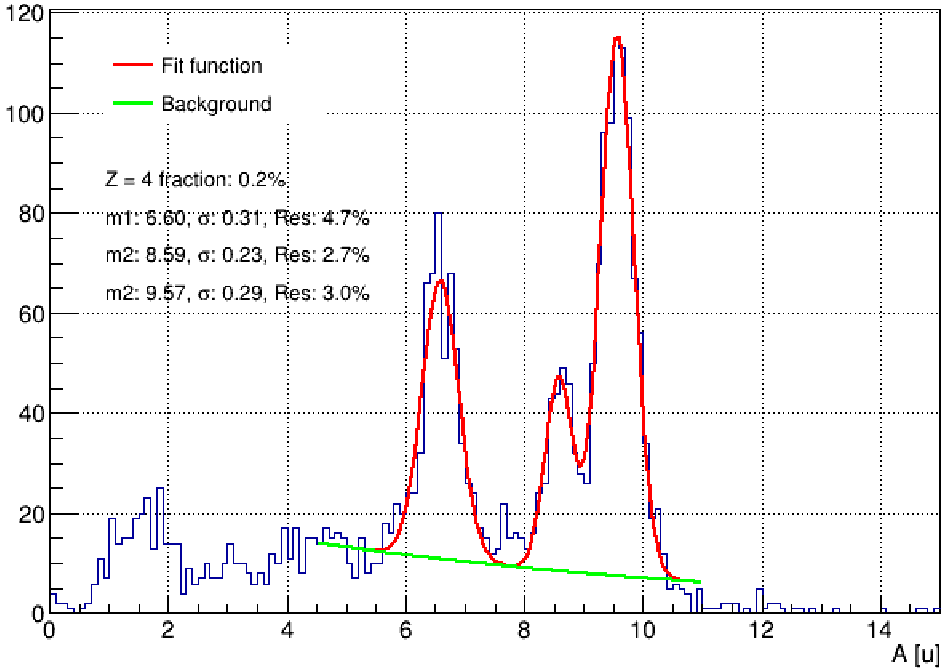


Li and Be reconstruction @ CNAO2024

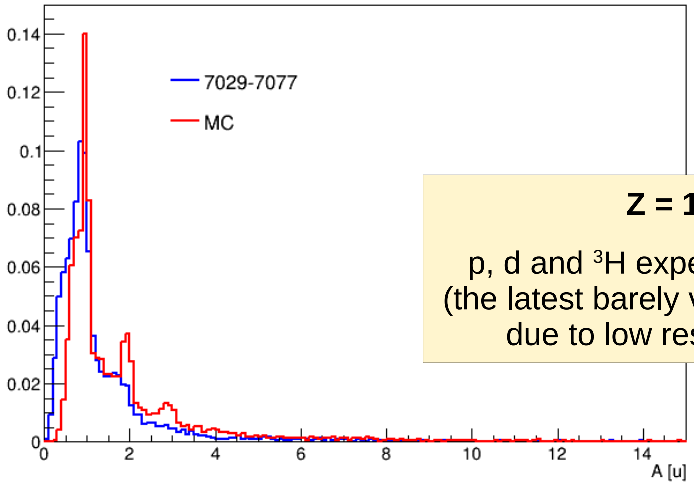
Reconstruction via power-law is worse for Z = 3 → only ^{6}Li, with 7% resolution.

For Z = 4, ^{7}Be, ^{9}Be, ^{10}Be identified with < 5% resolution.



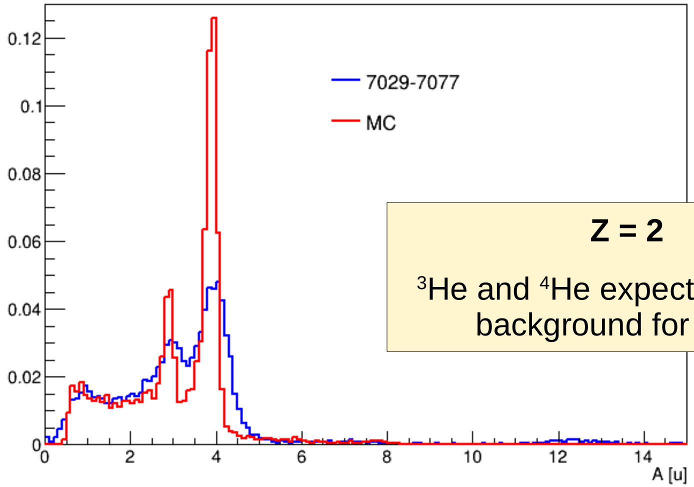


Mass comparison (MC vs data)



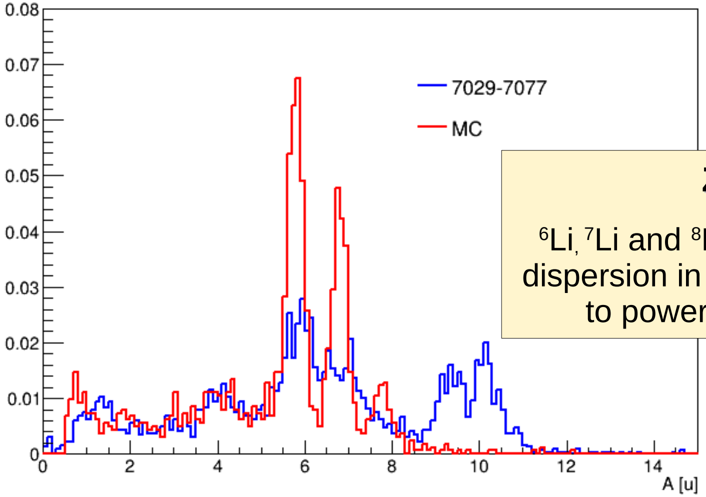
Z = 1

p, d and ^{3}H expected in MC (the latest barely visible in data due to low resolution).



Z = 2

^{3}He and ^{4}He expected; visible background for A ≈ 1.



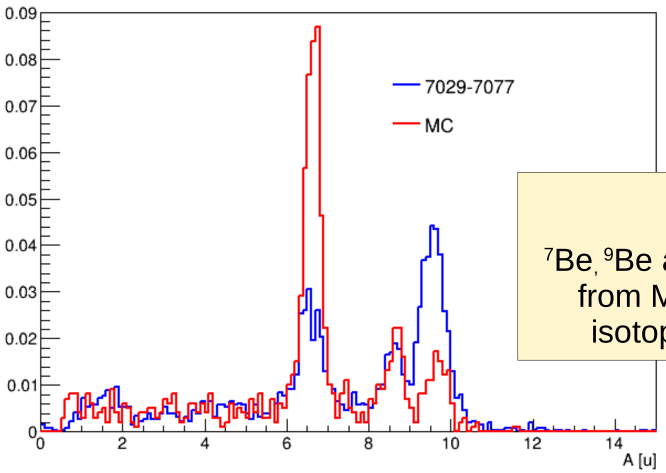
Z = 3

^{6}Li, ^{7}Li and ^{8}Li expected; high dispersion in data possibly due to power-law function.

In MC, CALO resolution (as modeled in slide 10) was added to statistical uncertainties.

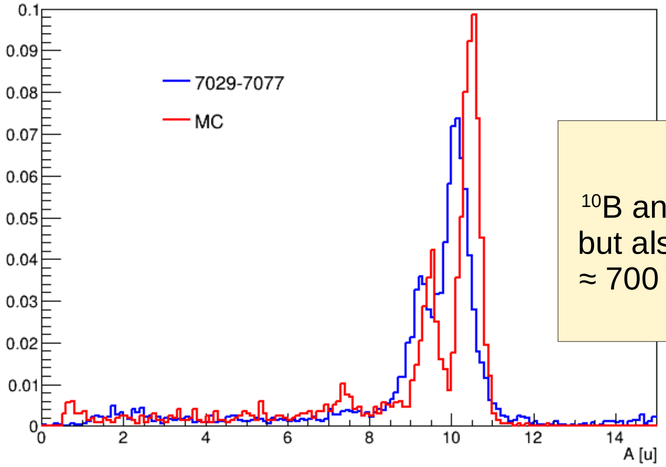
- Background due to TW-CALO mismatching / fragmentation in exp setup;
- Small shift between peaks obtained from MC and data.

Mass comparison (MC vs data)



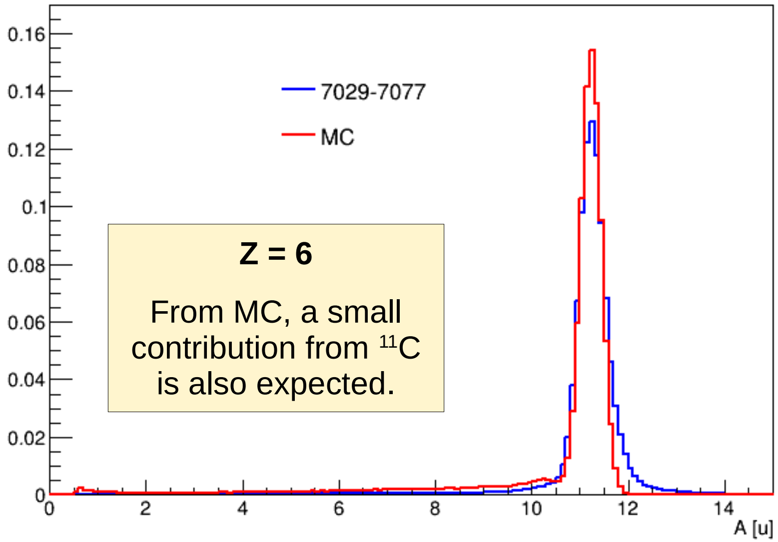
Z = 4

^{7}Be, ^{9}Be and ^{10}Be expected from MC with different isotopic abundance.



Z = 5

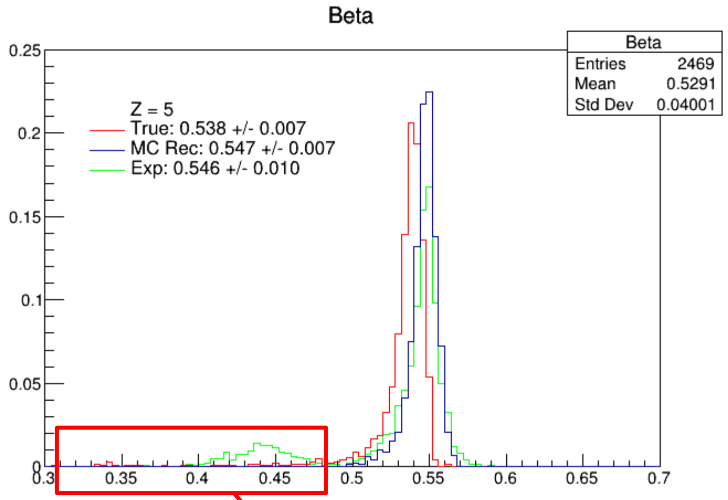
^{10}B and ^{11}B are expected from MC, but also a small ^{8}B contribution ($\tau_{1/2}$ ≈ 700 ms). Clear shift between MC and data mass peaks.

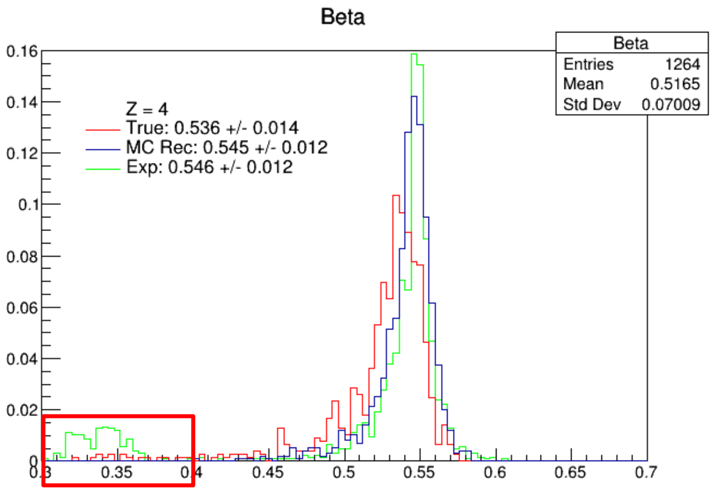


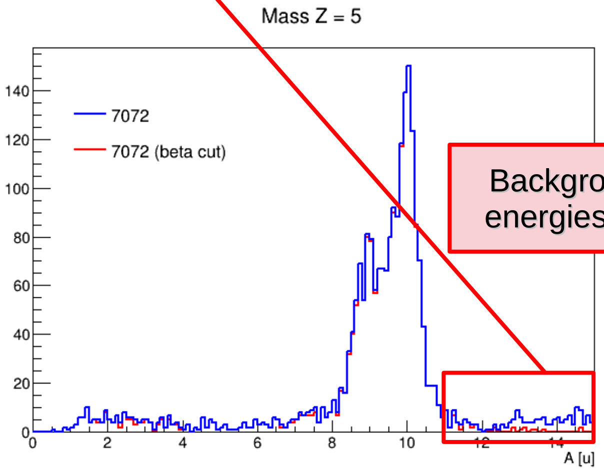
Z = 6

From MC, a small contribution from ^{11}C is also expected.

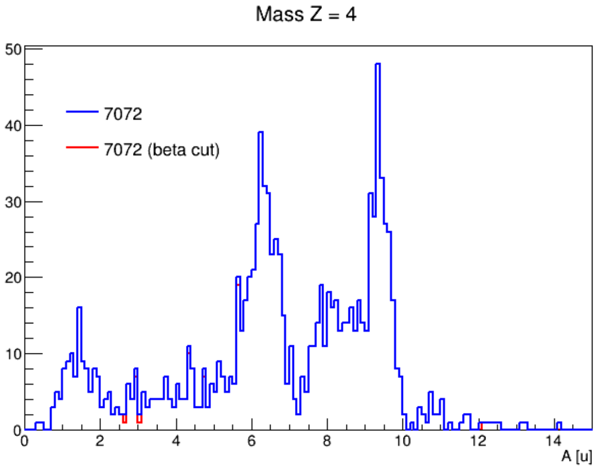
Beta cut at lower values





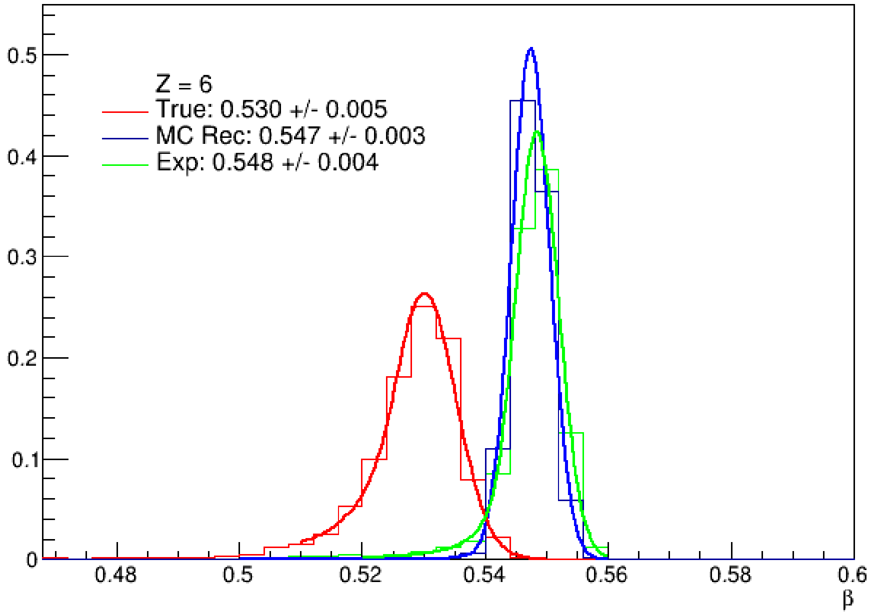


Background at higher energies was reduced



β effect on mass underestimation

Clear underestimation of mass peak values → let's compare data reconstruction and FLUKA MC simulation.



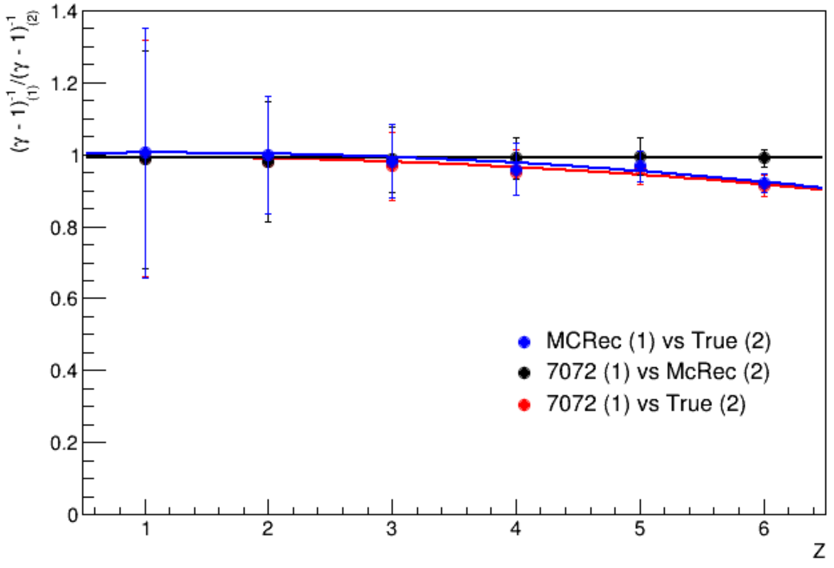
For ^{12}C, MC-truth shows that Lorentz velocity is underestimated in both reconstructions.

β = L/TOF, assuming uniform fragments velocities, neglects energy losses through 3 tracking layers
→ β overestimation
→ $(\gamma-1)^{-1}$ underestimated up to 8-9%.

From now on, all histograms are normalized with respect to their integral.

β effect on mass underestimation

β = L/TOF, assuming uniform fragments velocities, neglects energy losses through 3 tracking layers
→ β overestimation →$(\gamma-1)^{-1}$ underestimated up to 8-9%.



Given $K = (\gamma-1)^{-1}$, this plot shows:

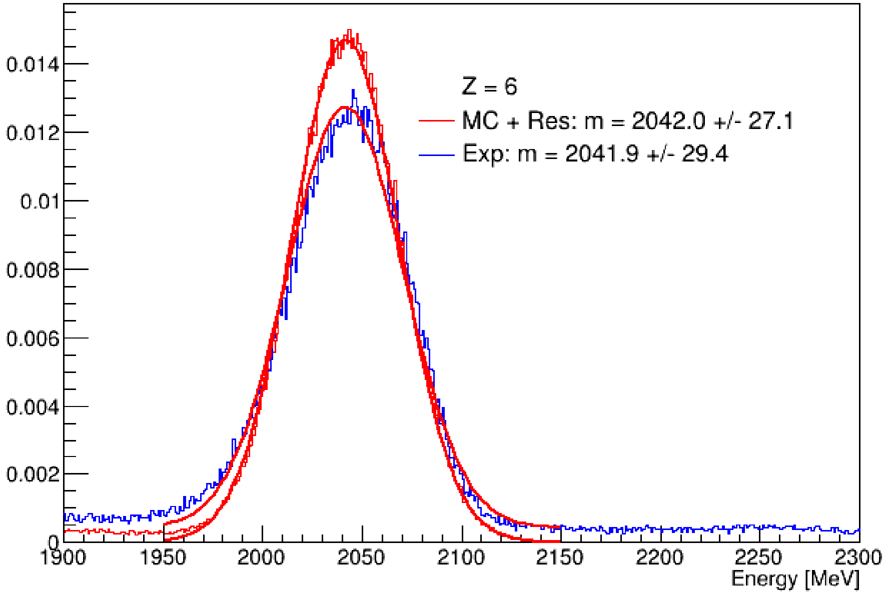
- in blue, K_{MCRec} / K_{true}, fitted with a 2nd order function with $p_0 = 1$ (no reconstruction error in absence of e.m. losses); dependence on Z^2 is expected based on Bethe-Bloch formula;

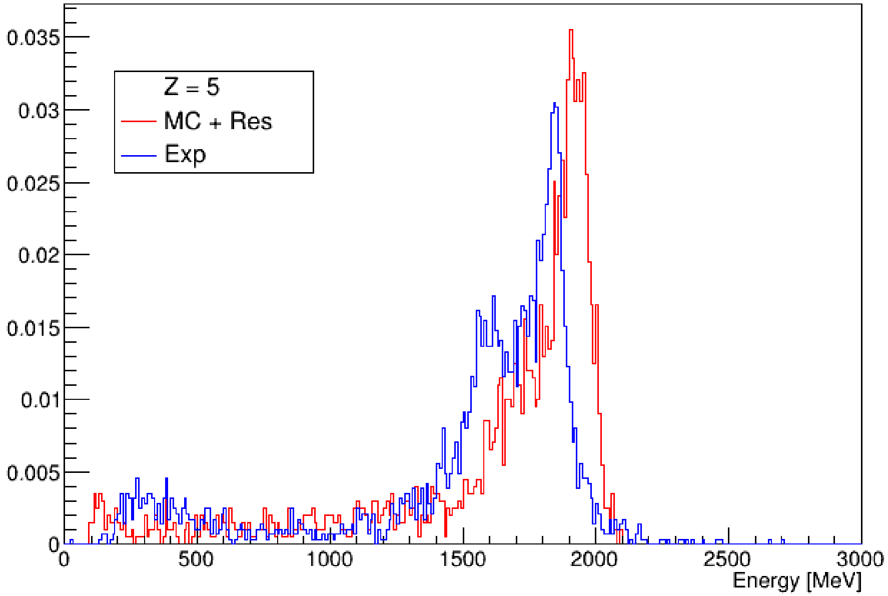
- in **black** K_{7072} / K_{MCRec} (7072 refers to a single fragmentation run), fitted with a uniform function $y = a_0$ (systematic error is expected); results $a_0 \approx 99.0\%$

-in red, K_{7072} / K_{True}, fitted with a 2nd order function having $p_0 = a_0$ (only systematic error in absence of e.m. losses).

At lower Z, uncertainties on β are ~ 10 times higher than at Z = 6 → however, β is most likely the main source of underestimation of nominal mass values.

E_{kin} effect on mass underestimation



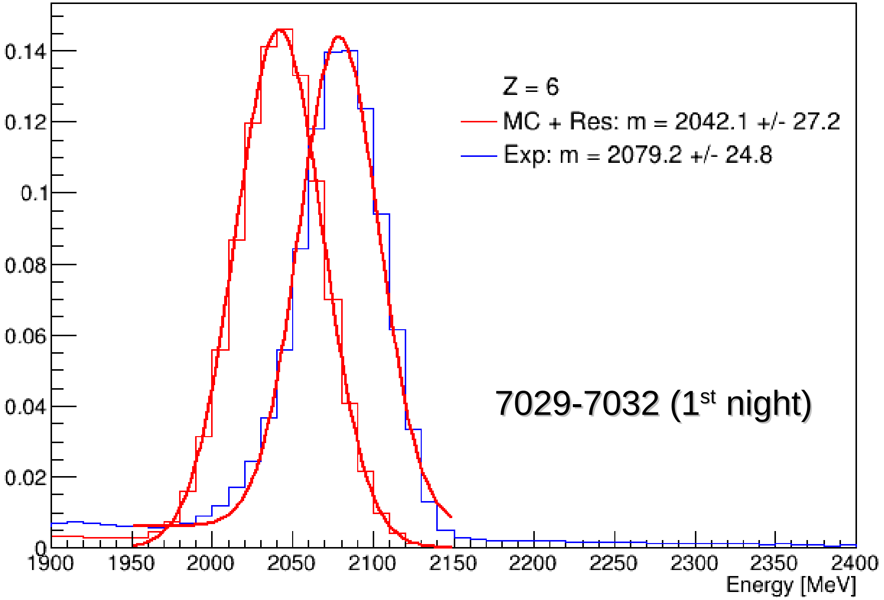


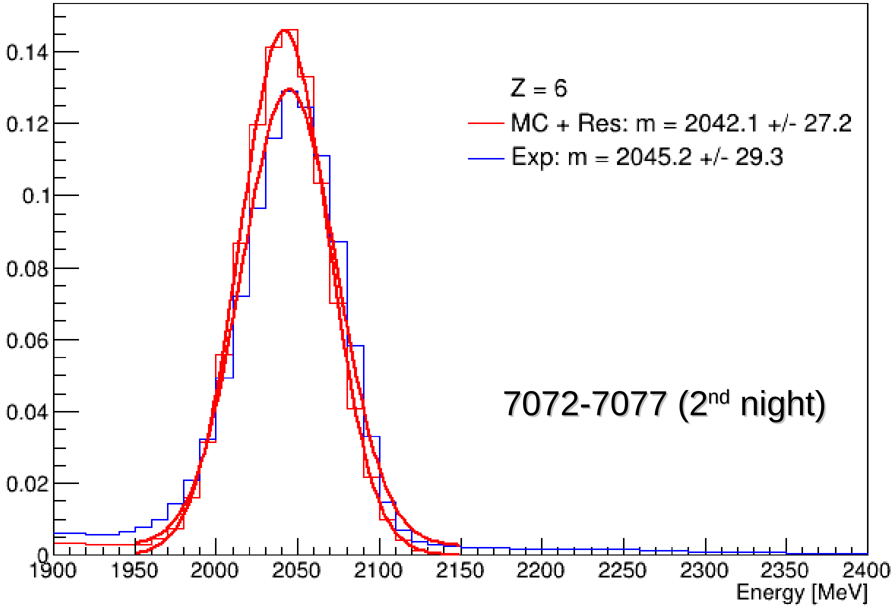
For Z = 6 MC E_{kin} distribution is well modeled by data (referred to run 7072).

For Z = 5, instead, there is a visible shift in the spectra → possibly, residual error due to power-law based calibration with respect to Z.

E_{kin} effect on mass underestimation

Previously, we only considered run 7072 for its higher statistics. Let's consider now all runs from 7029 to 7072.



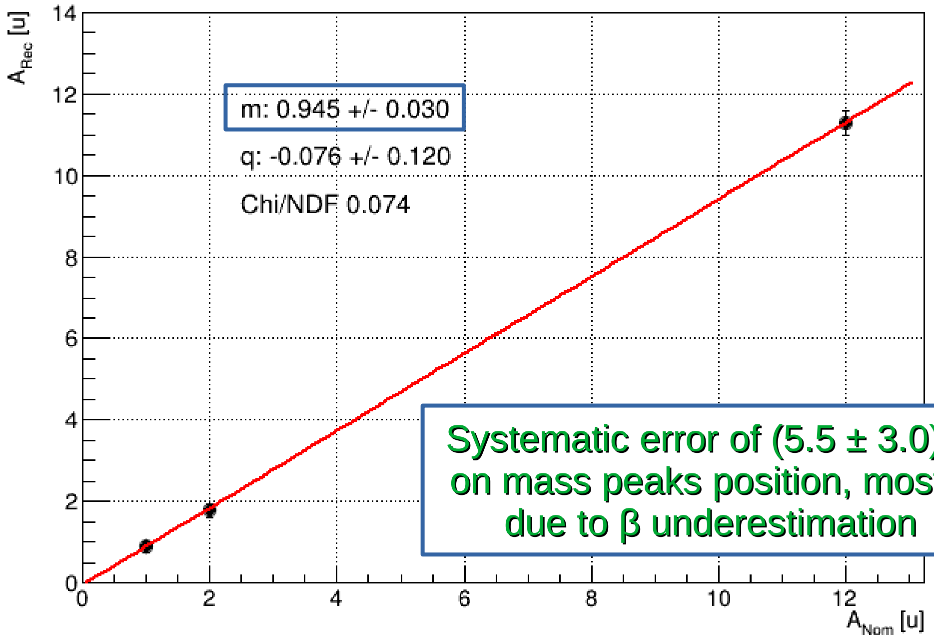


When considering all runs, there is a shift between MC and data peaks → to be investigated (different beam energy? Temperature shift?...)

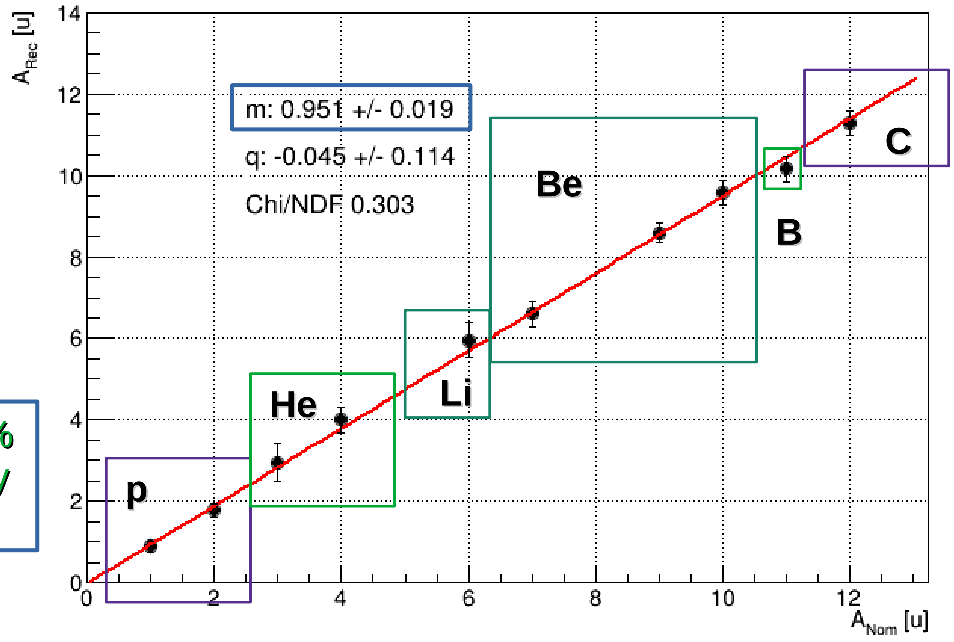
Reconstructed vs nominal A (in data)

A linear relationship was found between reconstructed and nominal mass peaks, and the offset is given by the same correction factor *m* obtained from p, d and ^{12}C only.

CALO calibration with respect to Z is meaningful!

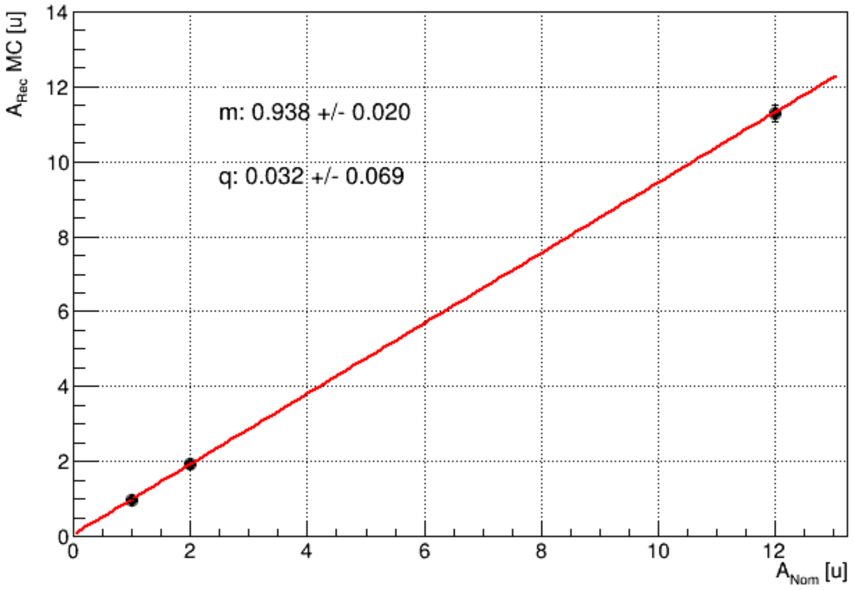


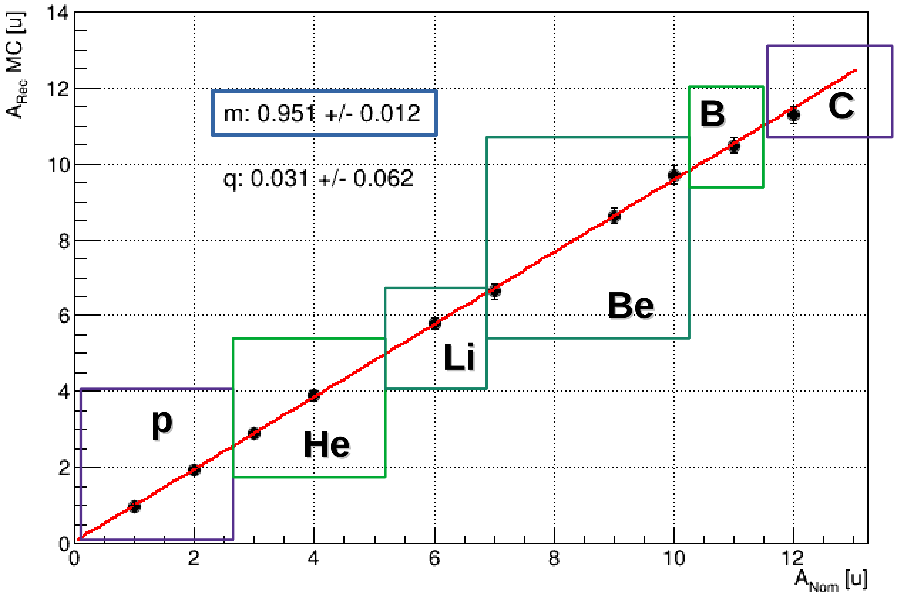
Systematic error of (5.5 ± 3.0)% on mass peaks position, mostly due to β underestimation



Reconstructed vs nominal A (in MC)

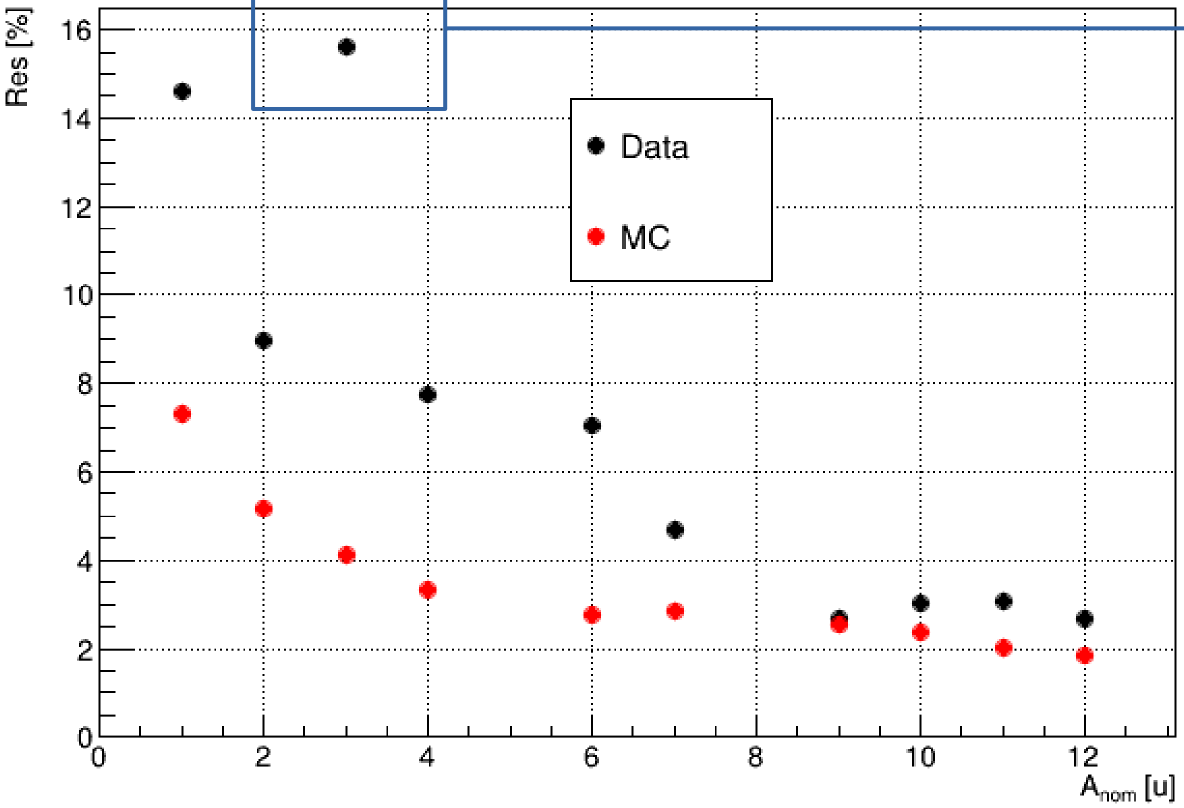
MC estimates an error on p, d, ^{12}C mass peak positions of (6.4 ± 2.0)% → higher than data.



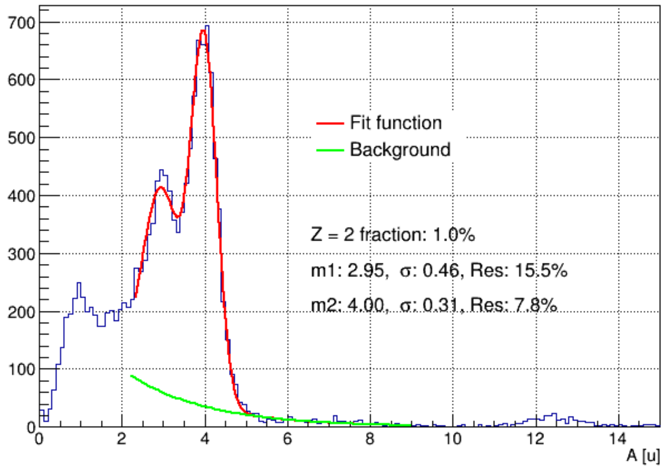


However, considering the same peaks analyzed in fragmentation runs, overall better agreement between A_{rec} and A_{nom} and between MC and data → systematic, beta-driven error as given by MC is (4.9 ± 1.2)%, considering CALO as the only experimental error source.

Mass resolution in data vs MC



Weird ^{3}He behavior



Conclusion

Many aspects in reconstruction need special care:

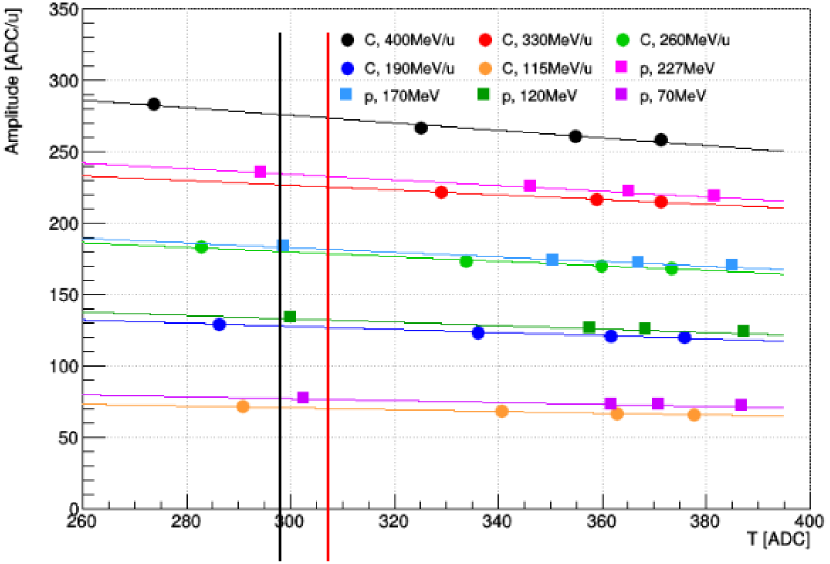
- crystals with unsuccessful calibration / weakly correlated MBF parameters were excluded;
- possible Z misidentification (due to TW-CALO matching, thresholds, “most-hit-layer” assumption, ...);
- power-law based calibration with Z → non-negligible impact on peak shifts and resolution;
- approximated trajectory (due to unavailability of full tracking system);
- uniform velocity approximation → systematic mass underestimation;
- fragmentation in setup + mismatching → background;
- more experimental uncertainties must be included in MC simulation;
- …

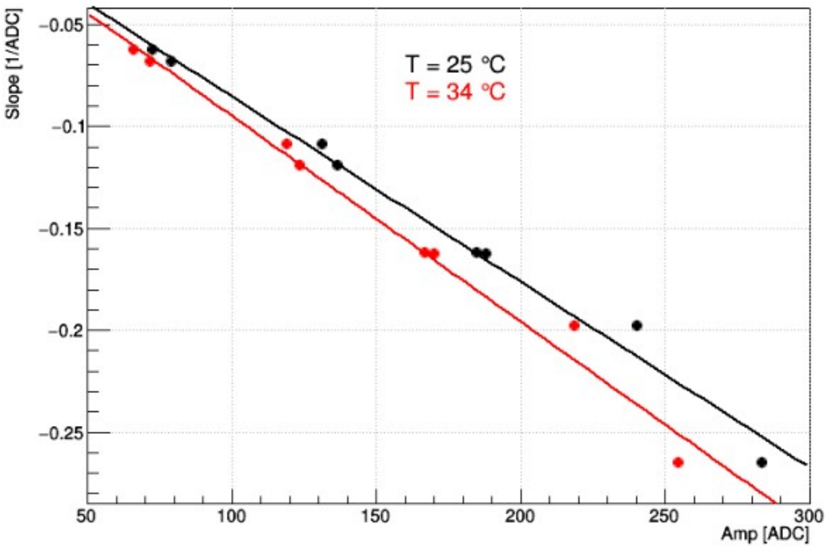
In spite of all these conditions, mass distributions were obtained from Z = 1 to Z = 6, and the discrepancy between nominal and reconstructed mass peaks can be modeled by a linear correction factor of < 10%.

→ All possible sources leading to a worsening in mass resolution must be investigated;
→ Optimization of CALO calibration parameters is needed (especially for excluded crystals).

Backup slides

T correction





We know that ADC response decreases with T depending on the primary beam energy.

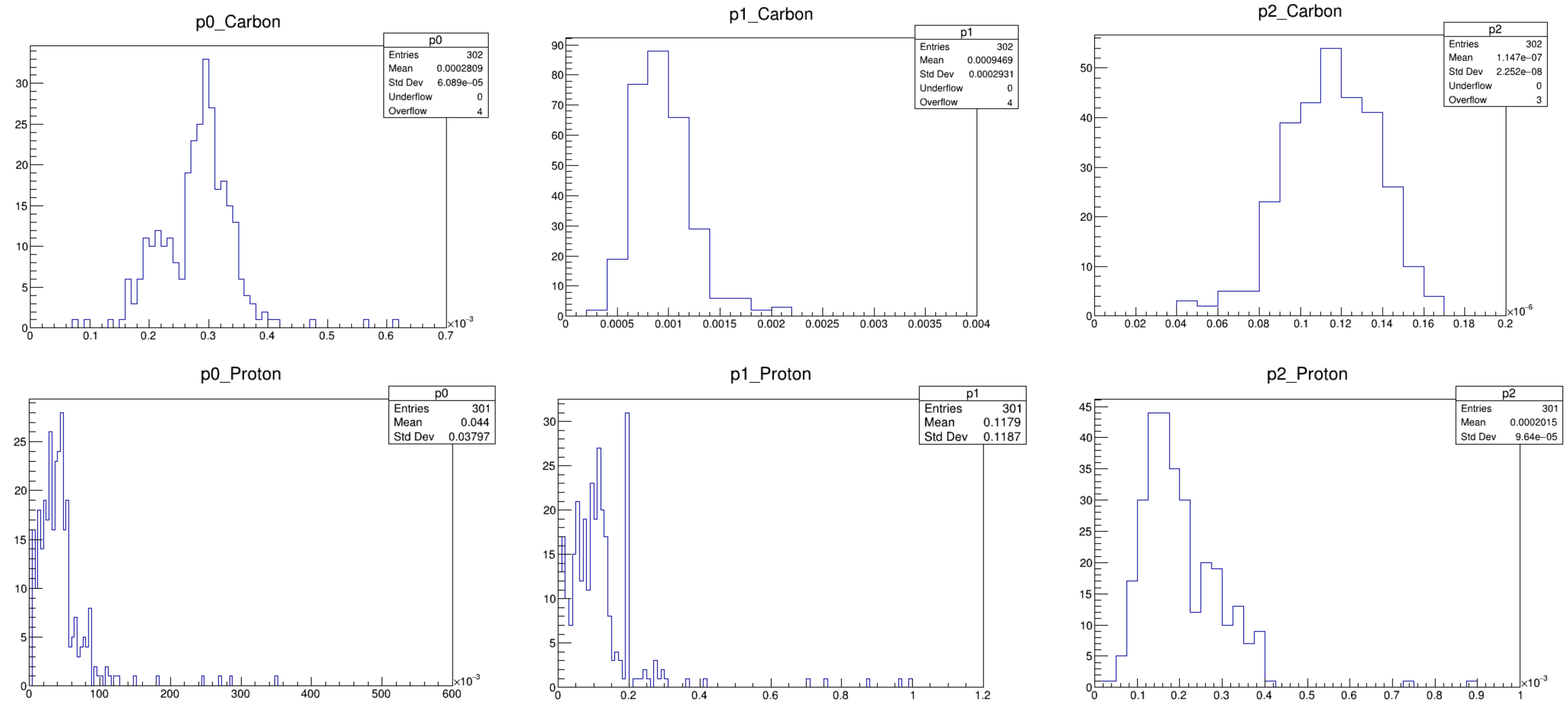
For a given ADC value, then, $m(ADC) = m_1(ADC) + (T_0 - T_1) * [m_2 (ADC) – m_1 (ADC)] / [T_2 – T_1]$, with: m_1 slope @ T_1 = 25°C, m_2 slope @ T_2 = 34°C and T_0 is the reference temperature.

Slope vs amplitude (ADC) was plotted @ two fixed temperatures, for a single crystal.

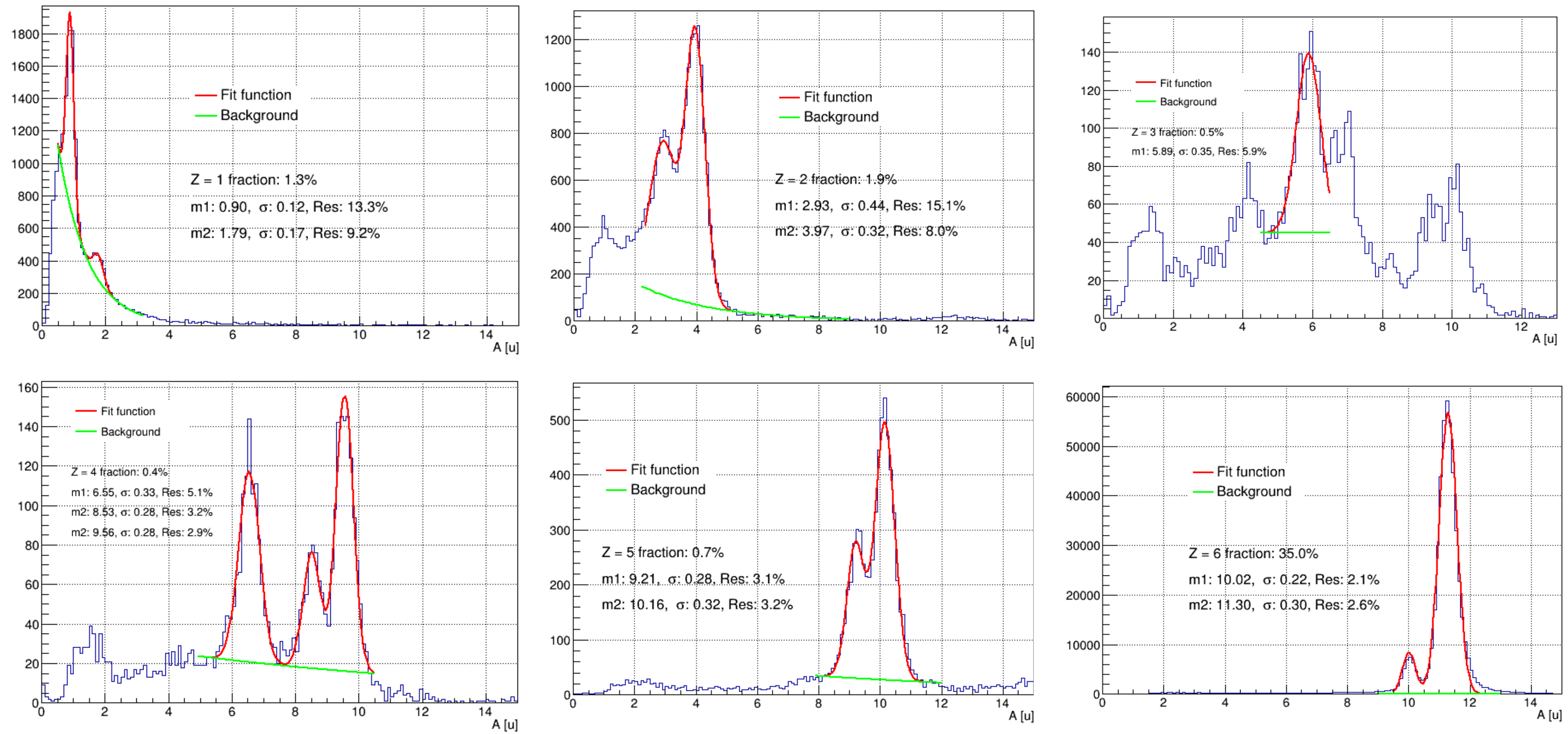
As $T_{ref} = T_0$ I took the average temperature during calibration runs for each crystal.

$$ADC(T) = ADC(T_0) + m(ADC) * (T-T_0)$$

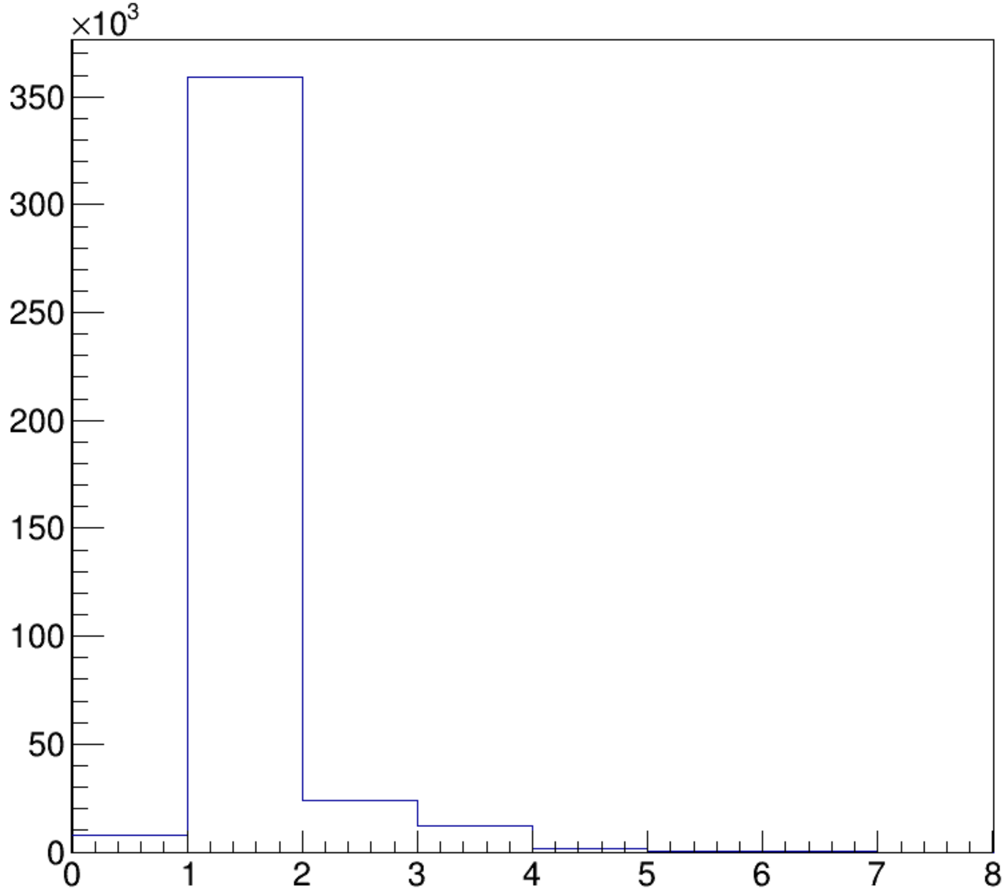
MBF distributions



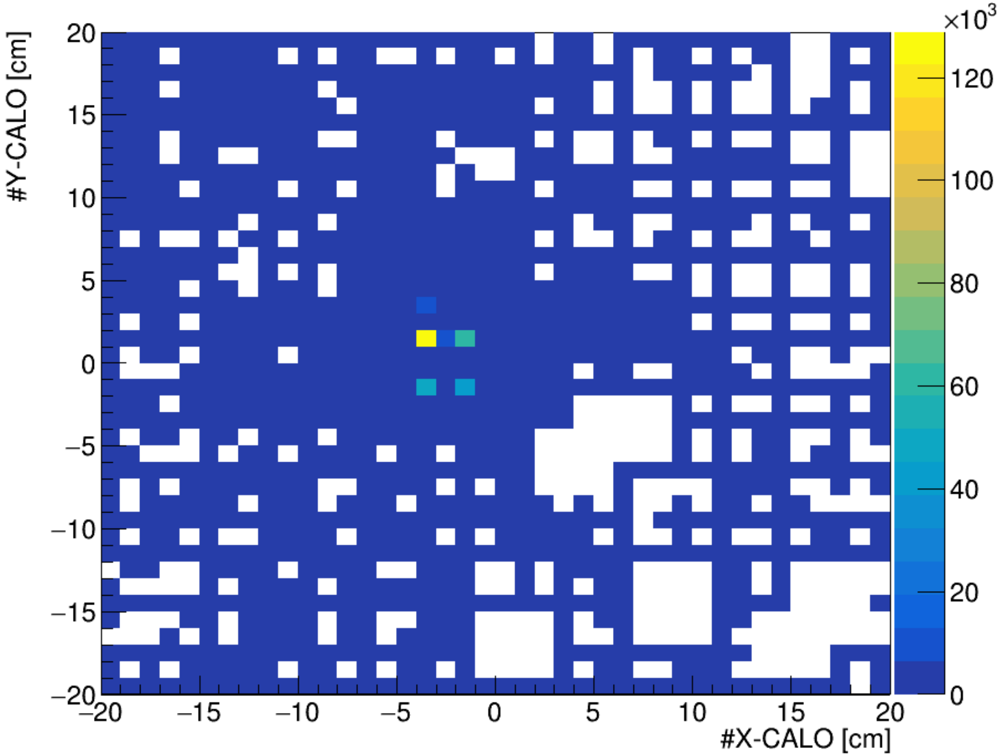
Mass distributions without MBF cuts

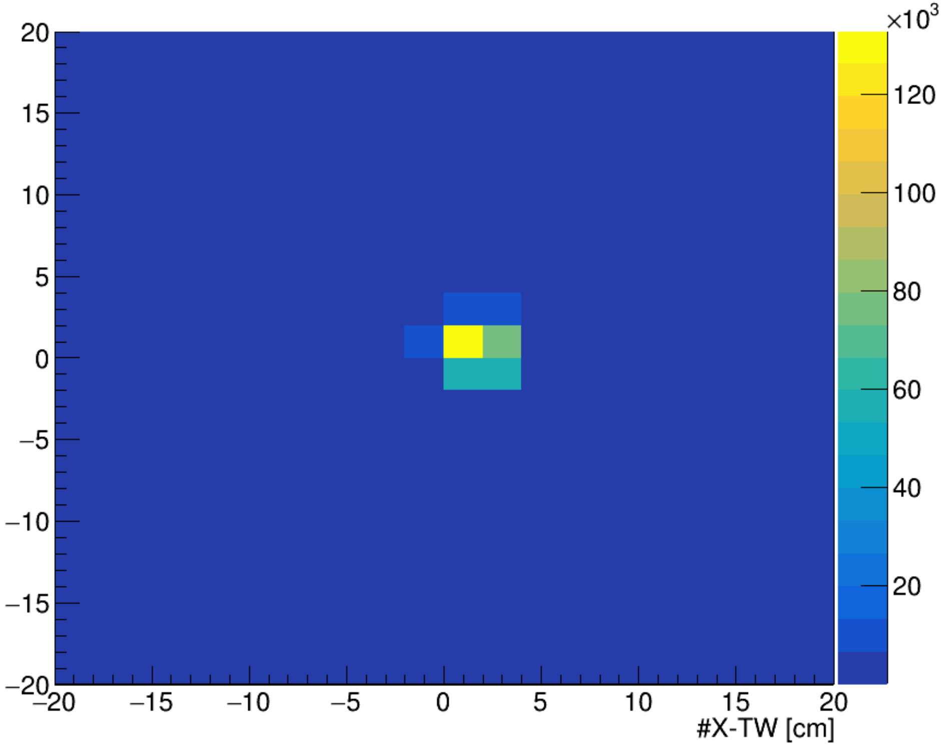


Matched clusters / event (run 7072)



Clusters and TW points distribution

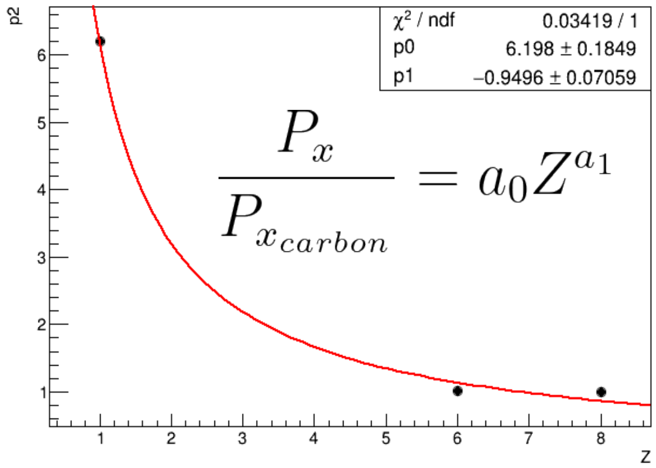


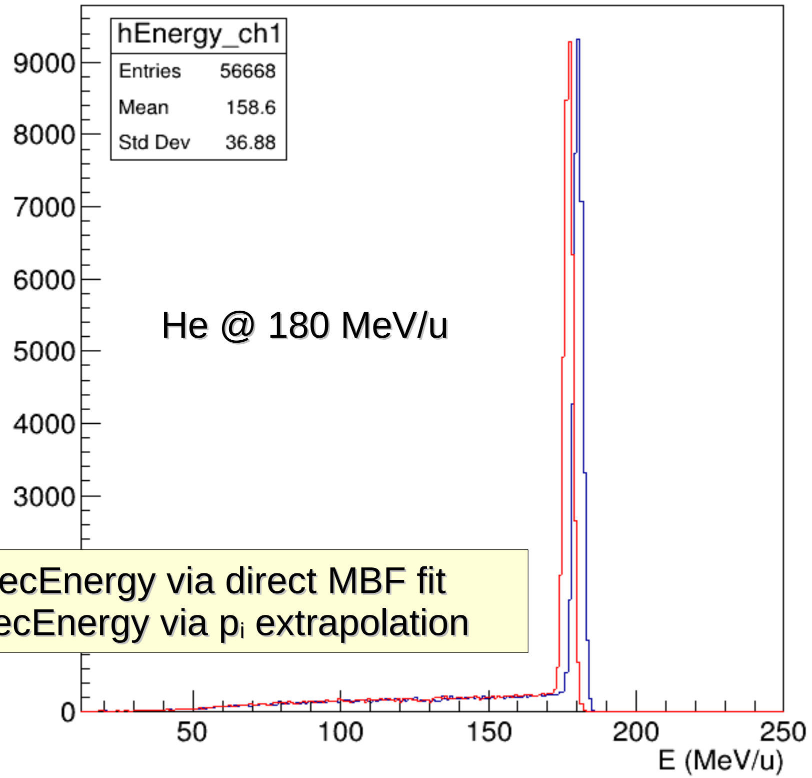


MBF dependency from Z

During a testing run in Heidelberg (2022) we irradiated a single crystal with p, He, C and O.

We tried fitting each MBF parameters p_i, normalized with respect to its value for C, via a power-law function with parameters $(a_0, a_1)_{pi}$.



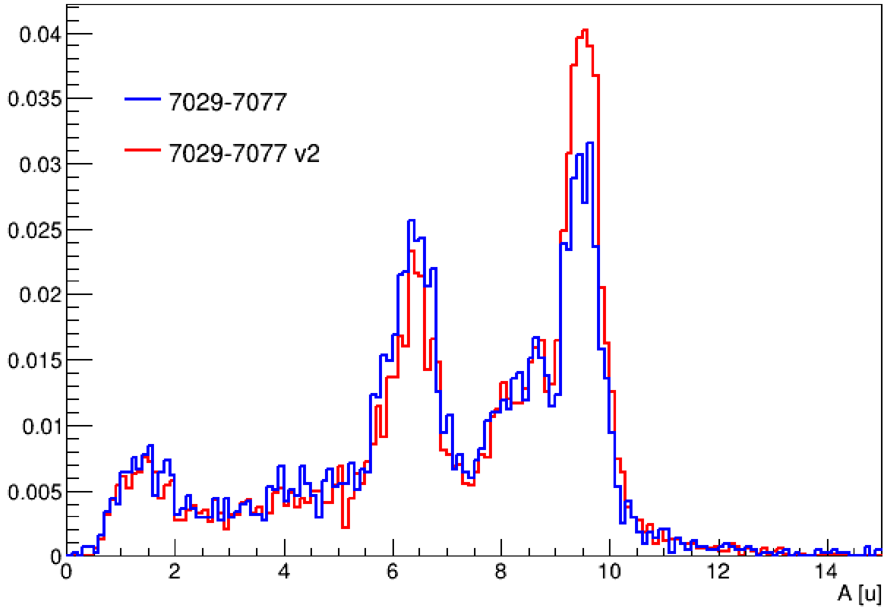


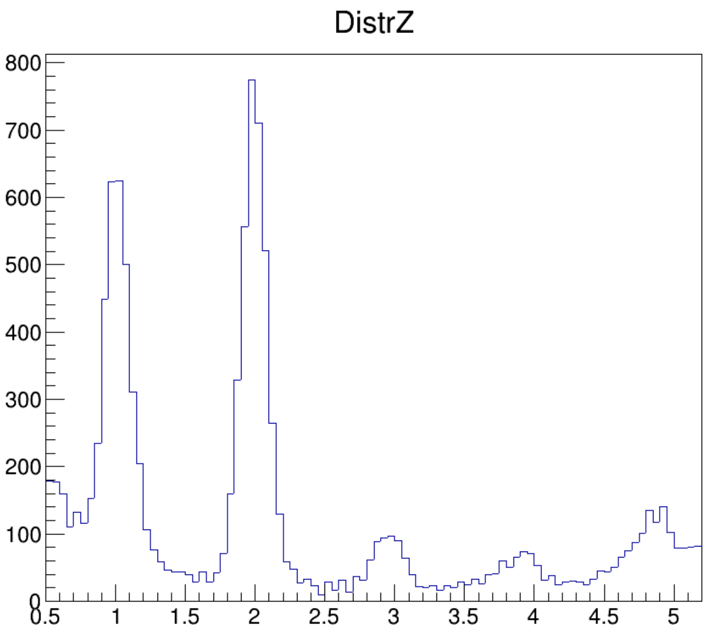
Blue: RecEnergy via direct MBF fit
Red: RecEnergy via p_i extrapolation

Since the trend was well modeled, we then extracted a_0, a_1 **without He** and obtained MBF parameters for He on **the same crystal**.

Accuracy on reconstructed p_i has small impact on peak reconstruction. However, power-law parameters are different for each crystal.

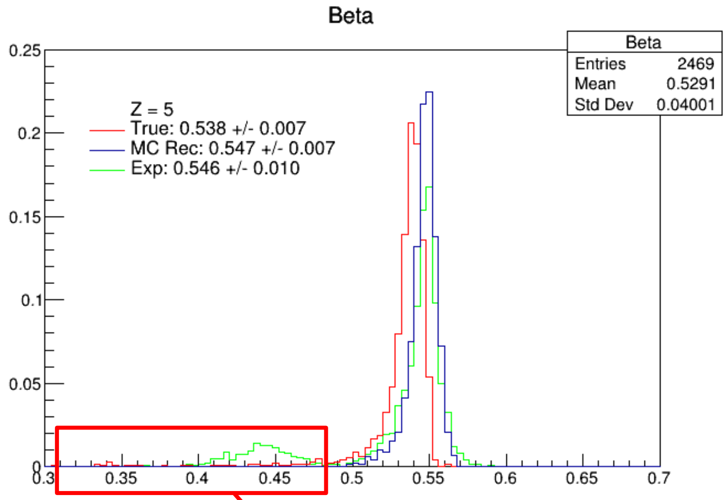
Alternate Z selection (Z = 4 case)

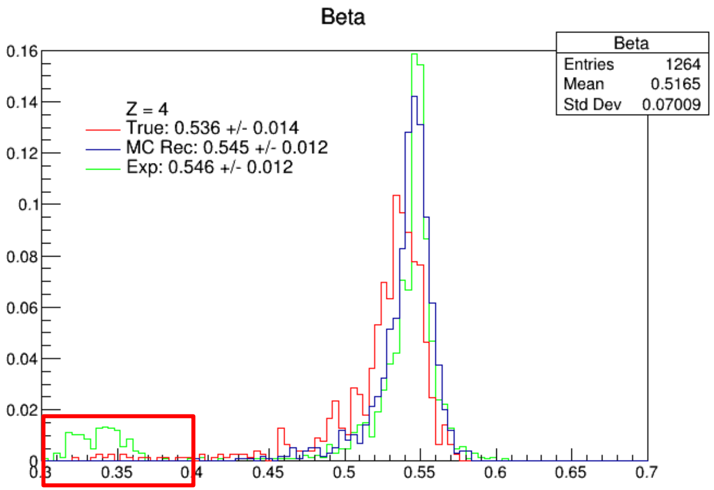


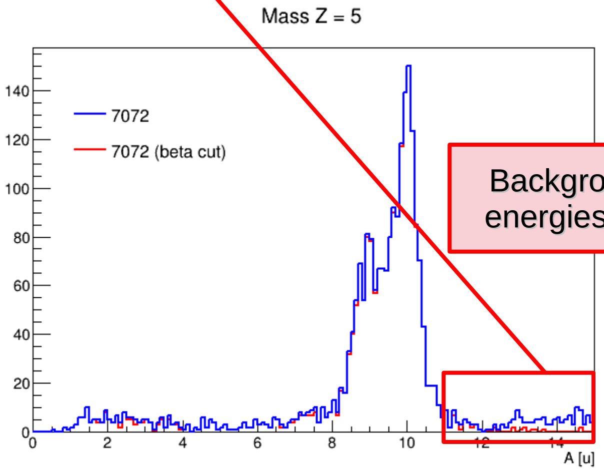


Z assigned according to the minimum dE/dx between the two TW hits
→ Z systematic underestimation;
→ no significative improvement in resolution / isotope distribution.

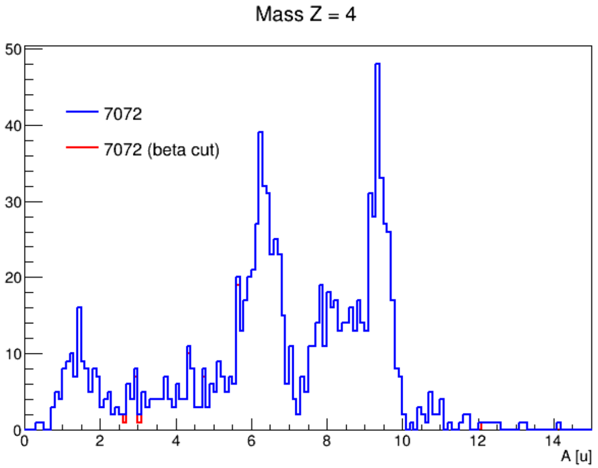
Beta cut at lower values







Background at higher energies was reduced



Beta comparison (MC vs data)