Calorimeter calibration @ CNAO 2024: preliminary results

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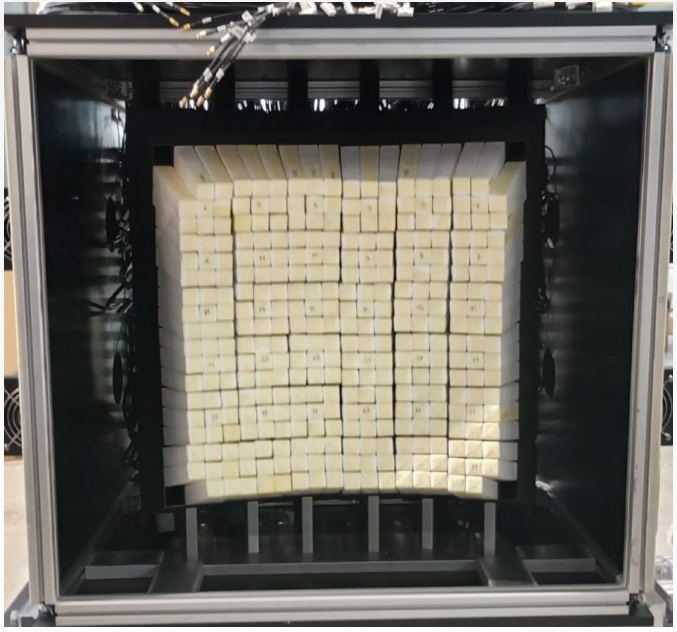
XVII FOOT Collaboration Meeting - Cherasco (CN)

Calibration runs

First calibration day: right crystals (back view)
>> CALO was shut down, then turned on for the second calibration day on left crystals
>> no further shutdown for the rest of data taking (and physics runs)



(Front view)

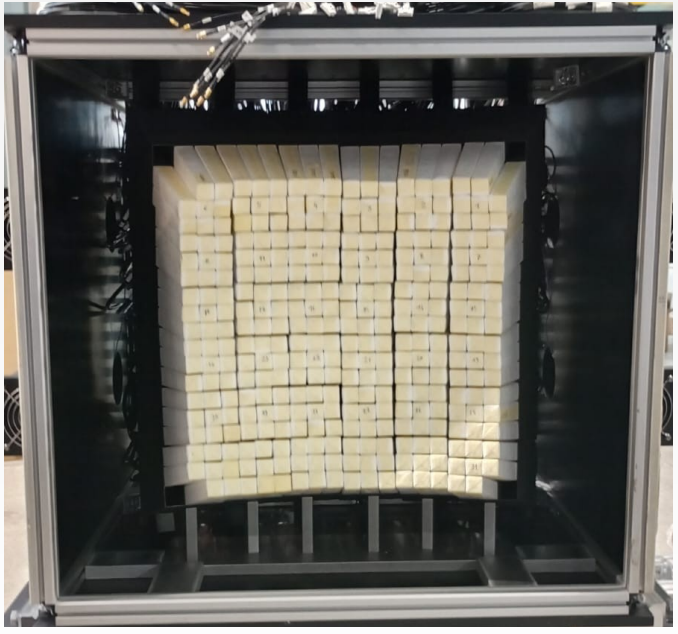
	1	2	9	10	11	18	19	20	27	28	29	36	37	38	45	46	
3	4	5	12	13	14	21	22	23	30	31	32	39	40	41	48	49	50
6	7	8	15	16	17	24	25	26	33	34	35	42	43	44	51	52	53
54	55	56	63	64	65	72	73	74	81	82	83	90	91	92	99	100	101
57	58	59	66	67	68	75	76	77	84	85	86	93	94	95	102	103	104
60	61	62	69	70	71	78	79	80	87	88	89	96	97	98	105	106	107
108	109	110	117	118	119	126	127	128	135	136	137	144	145	146	153	154	155
111	112	113	120	121	122	129	130	131	138	139	140	147	148	149	156	157	158
114	115	116	123	124	125	132	133	134	141	142	143	150	151	152	159	160	161
162	163	164	171	172	173	180	181	182	189	190	191	198	199	200	207	208	209
165	166	167	174	175	176	183	184	185	192	193	194	201	202	203	210	211	212
168	169	170	177	178	179	186	187	188	195	196	197	204	205	206	213	214	215
216	217	218	225	226	227	234	235	236	243	244	245	252	253	254	261	262	263
219	220	221	228	229	230	237	238	239	246	247	248	255	256	257	264	265	266
222	223	224	231	232	233	240	241	242	249	250	251	258	259	260	267	268	269
270	271	272	279	280	281	288	289	290	297	298	299	306	307	308	315	316	317
273	274	275	282	283	284	291	292	293	300	301	302	309	310	311	318	319	320
	277	278	285	286	287	294	295	296	303	304	305	312	313	314	321	322	

(Back view)

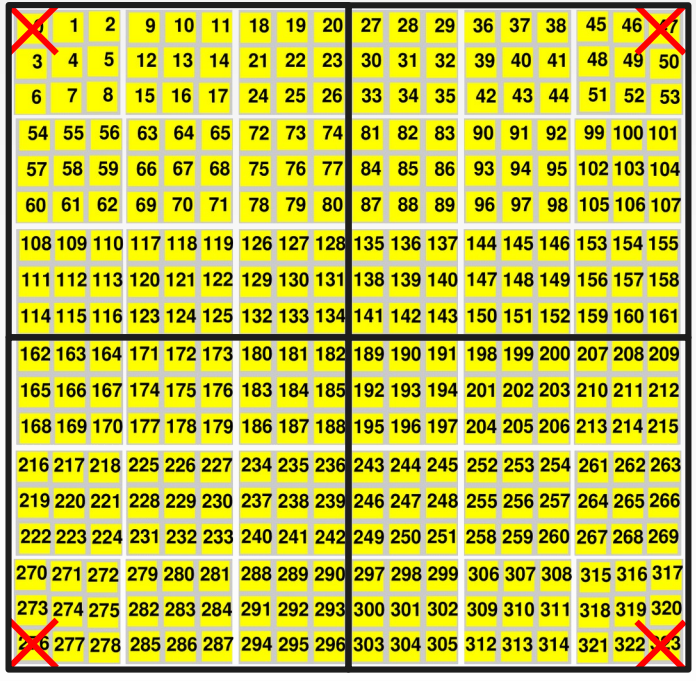
Calibration runs

First calibration day: right crystals (back view)
>> CALO was shut down, then turned on for the second calibration day on left crystals
>> no further shutdown for the rest of data taking (and physics runs)

Operational notes:
- LV @ 6V, HV @ 33V;
- WD threshold set to -5 mV;
- CALO scanned in quarters as usual.



(Front view)



(Back view)

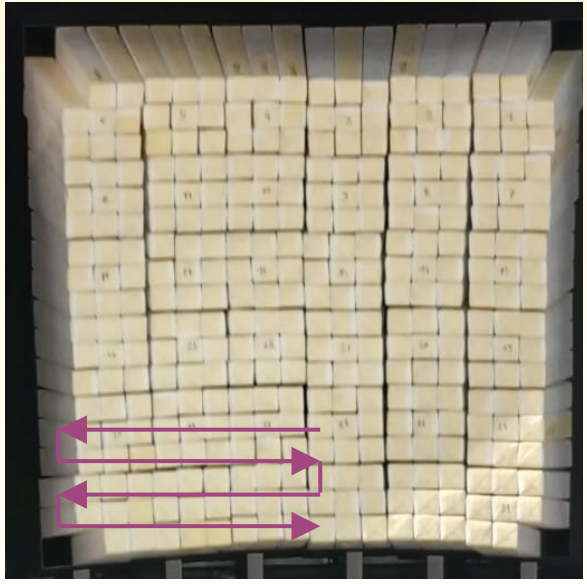
During the second calibration round:
- M32-9 unplugged due to tripping;
- M9-6 threshold was set to -10 mV (noisy channel).

Scanning with:
- p @ 100, 125, 150, 170, 230 MeV
- C @ 115, 200, 260, 300 MeV/u (also 400 MeV/u was attempted, but then discarded due to beam-sharing issues)

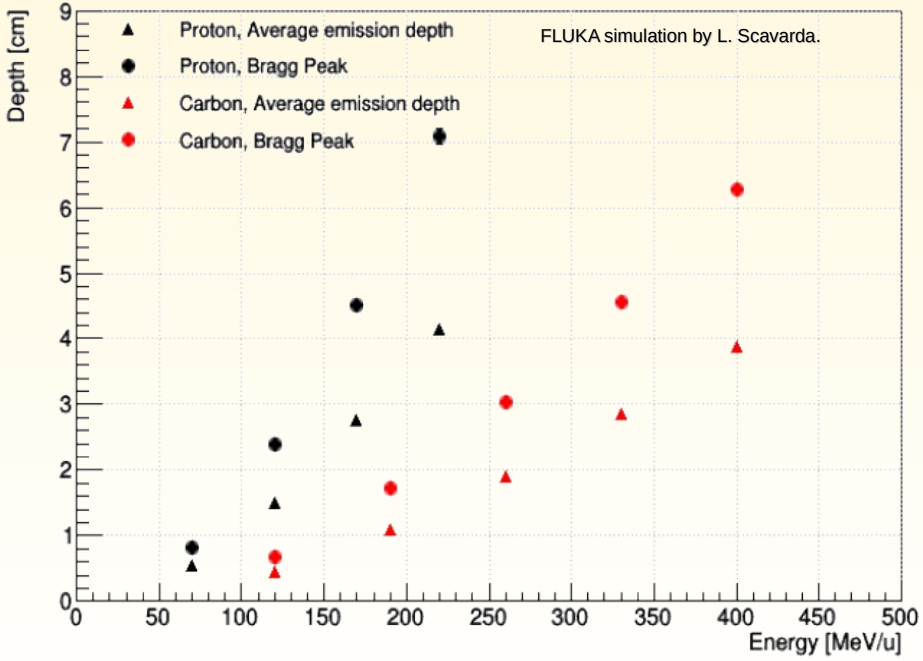
Beam sharing issues

Reminder(s):

- CNAO scanning magnets cover a 20x20 cm^2 surface → one CALO quarter at the time;
- CALO front face is concave, not flat;
- higher energies → higher range, but increase for p is faster than for C.

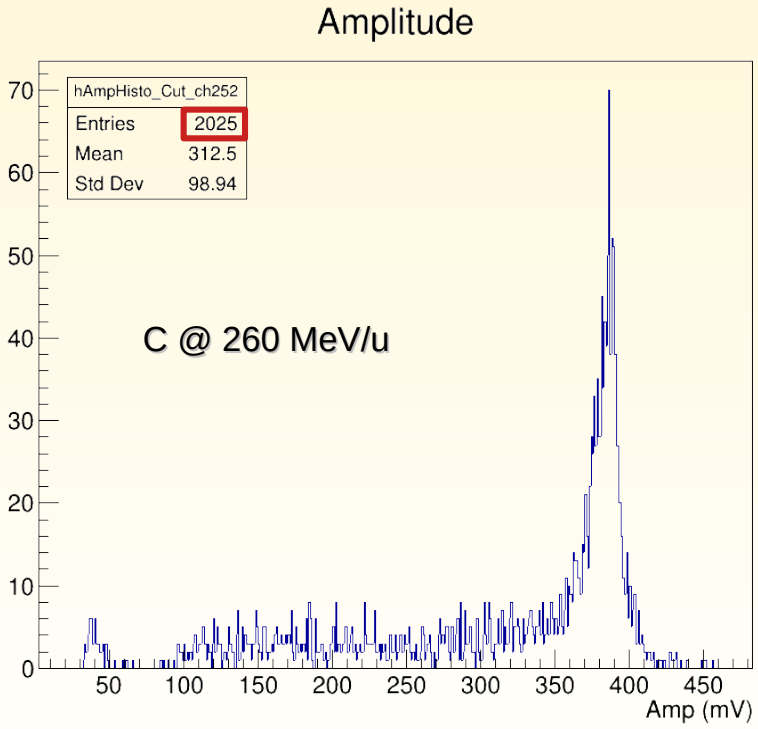


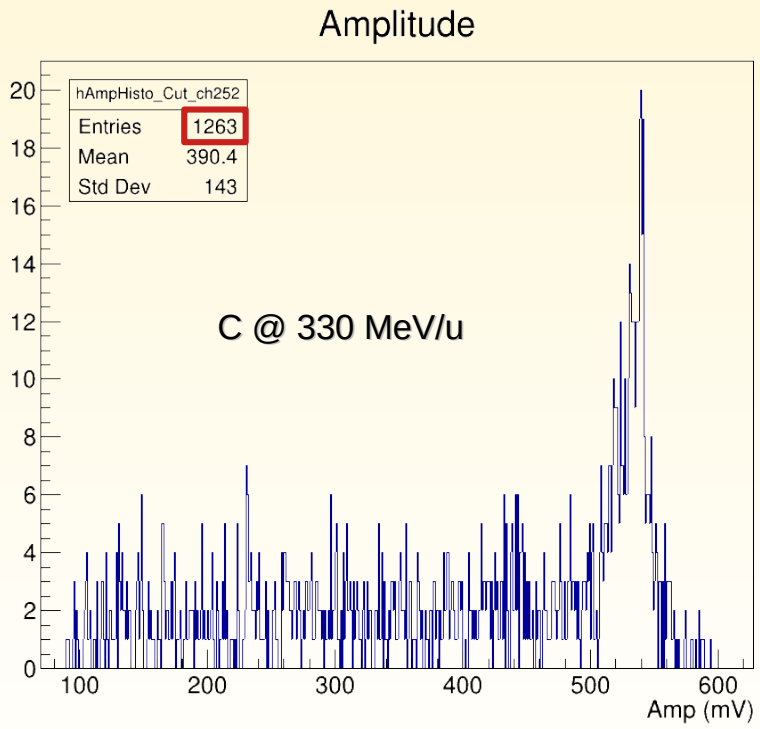
At higher energies, due to CALO-beam geometry:
>> particles cross multiple crystals with higher probability
>> charge-sharing phenomena between neighbor crystals become not negligible
>> peak events collection for p @ 230 MeV and C @ 330/400 MeV/u is harder.



Beam sharing issues

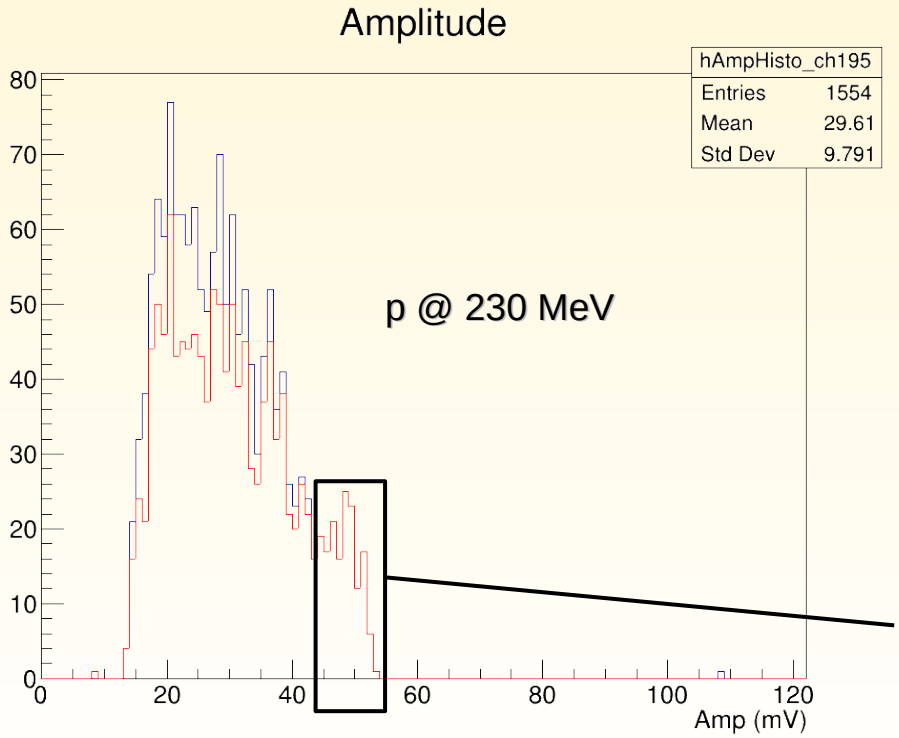
Sometimes, higher statistics is required (or more scanning precision)...

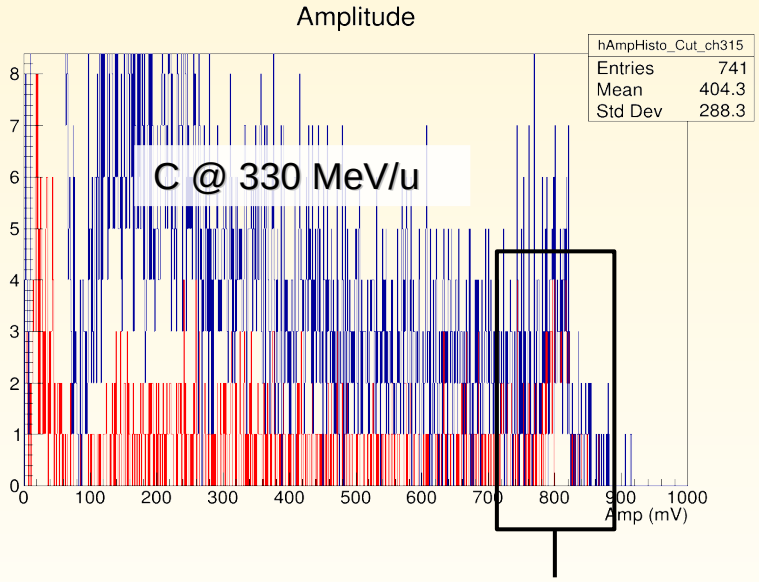




Beam sharing issues

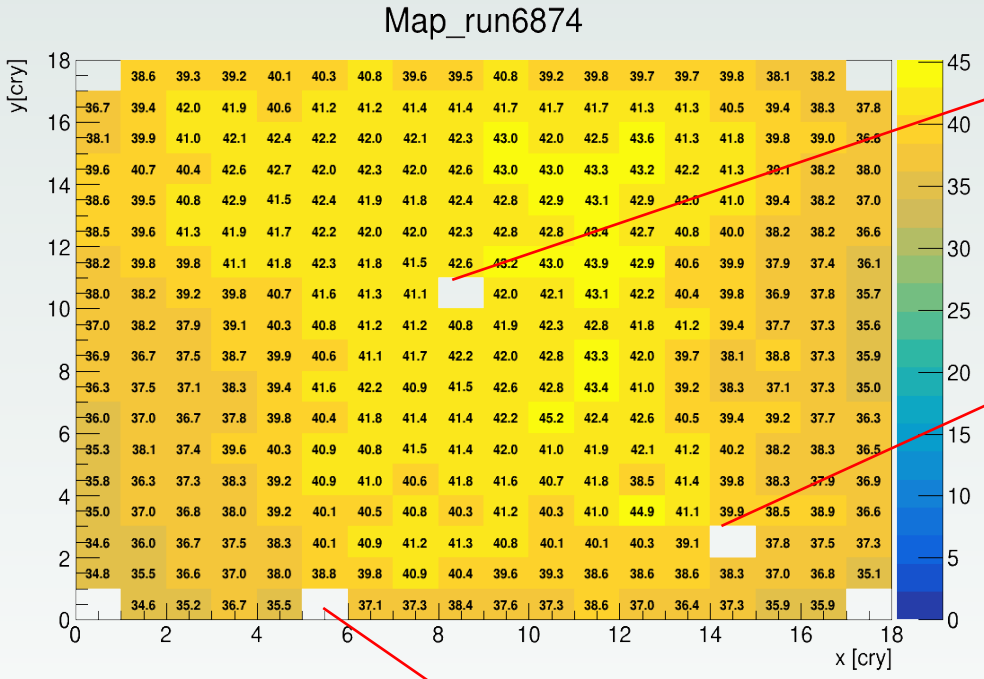
…sometimes it's not enough!
Even though the range of p in BGO is ≈ 7 cm, very few particles cross this full length due to the scanning geometry.
>> p @ 230 MeV/u were discarded from subsequent analysis, due to the lack of "full energy peak" events.





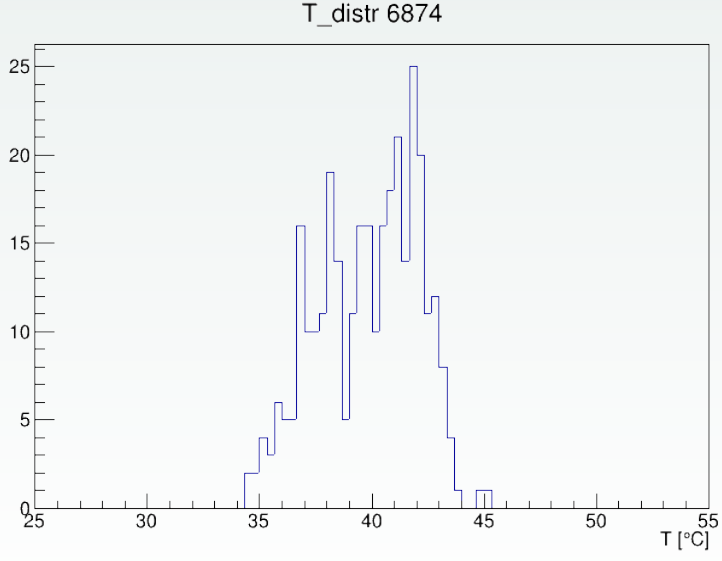
With p @ 230 MeV, statistics should be 4 times higher than with C @ 330 MeV/u in order to actually separate peak events from beam sharing ones.

Temperature analysis



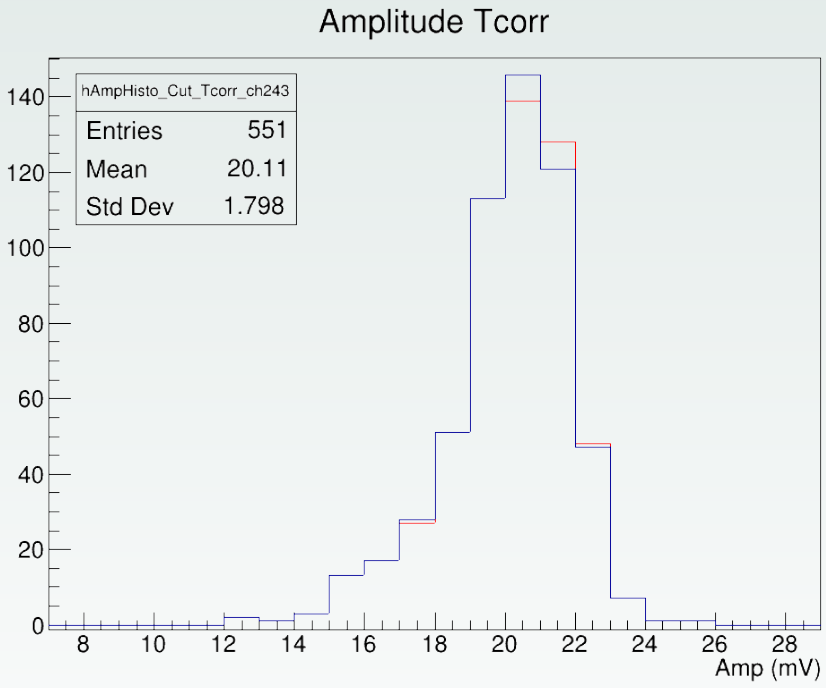
- M15-6 (131 in shoe) is working but T calibration coefficients are wrong (this crystal was unplugged last year due to tripping);

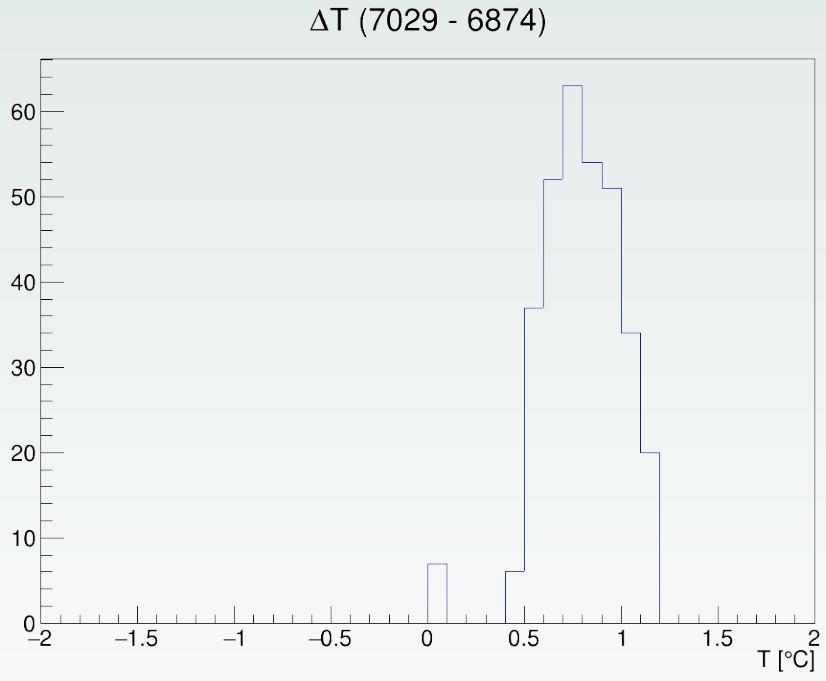
- M35-3 (308 in shoe) T sensor not working, but amplitude signals are properly read out.



- M32-9 (hardware num, 287 in shoe) sensor is working, but crystal was unplugged during the second round due to tripping;

Temperature analysis

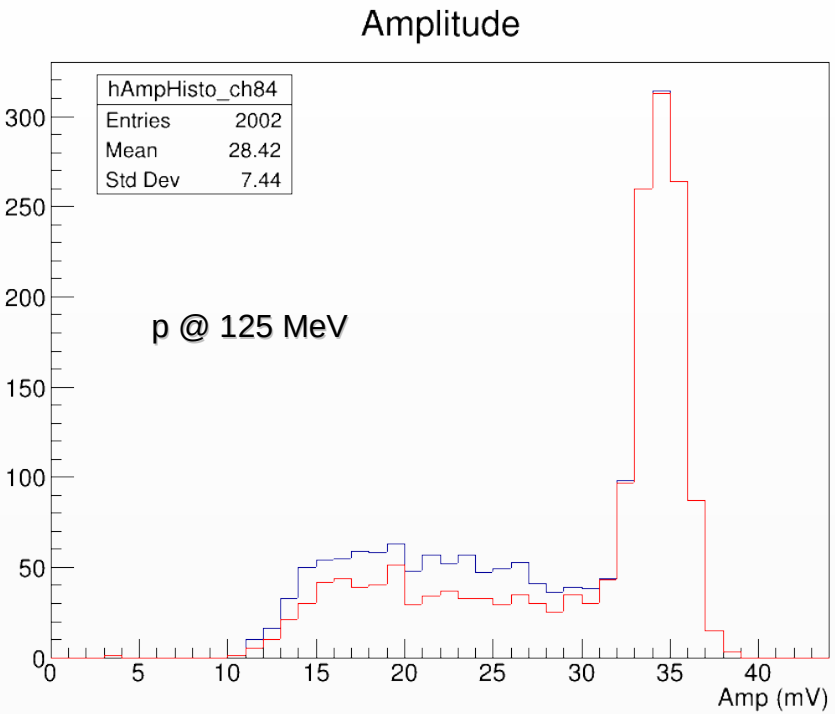




T corrections have small impact on calibration runs (in this case the difference between the average T on single crystal and full CALO was ≃ 10°C).

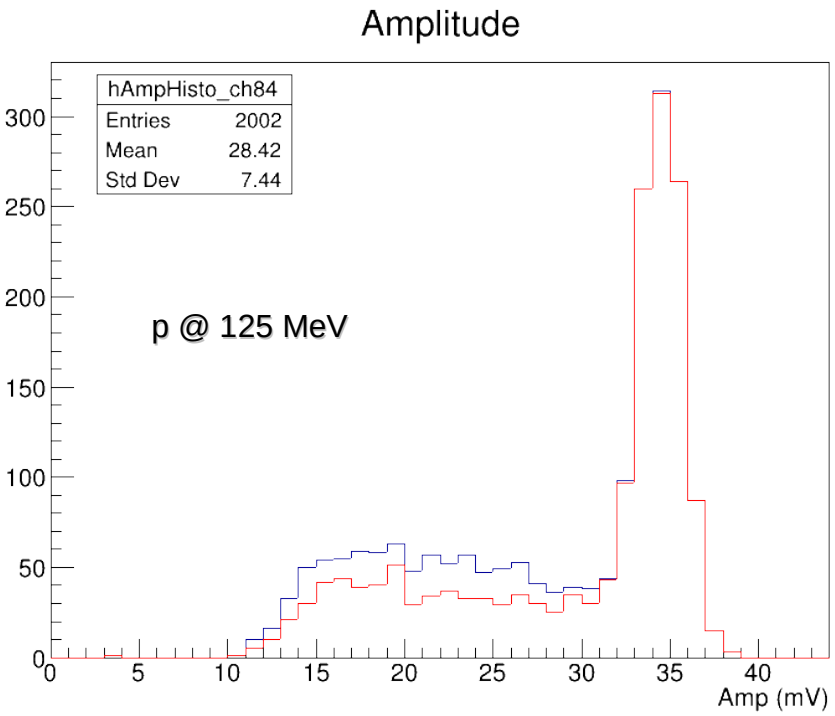
Single crystal variations between calibration run 6874 and physics run 7029 (3 days later) are ≈ 0.8°C → expected variation in ADC response < 1%.

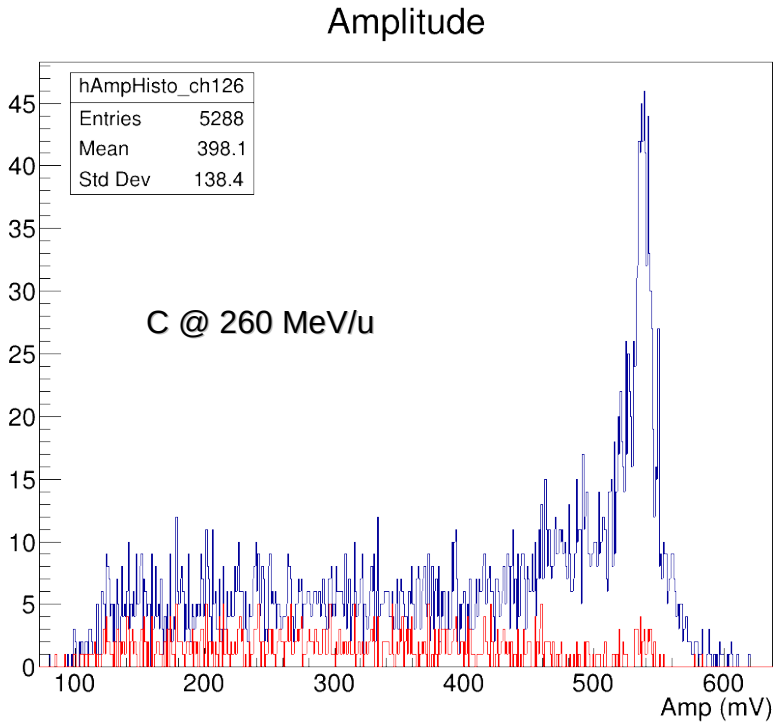
Peak analysis



First step: cutting out all events with amplitude > 0 in other crystals
>> events with multiplicity > 1 are discarded

Peak analysis

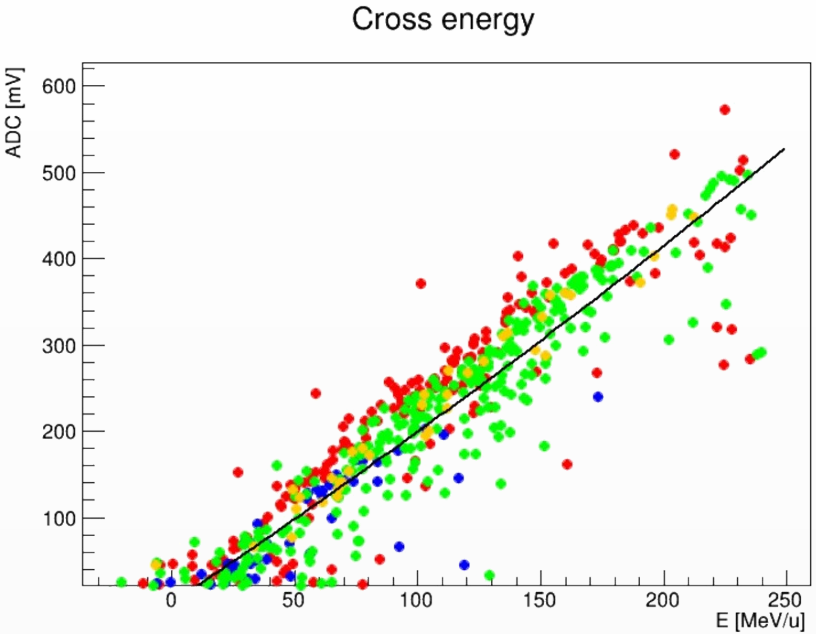




First step: cutting out all events with amplitude > 0 in other crystals
>> events with multiplicity > 1 are discarded

Sometimes, ~ all peak events feature small charge sharing with other crystals → underestimation of ADC response vs energy
>> what to do in such cases? How big is this underestimation?

First correction attempt

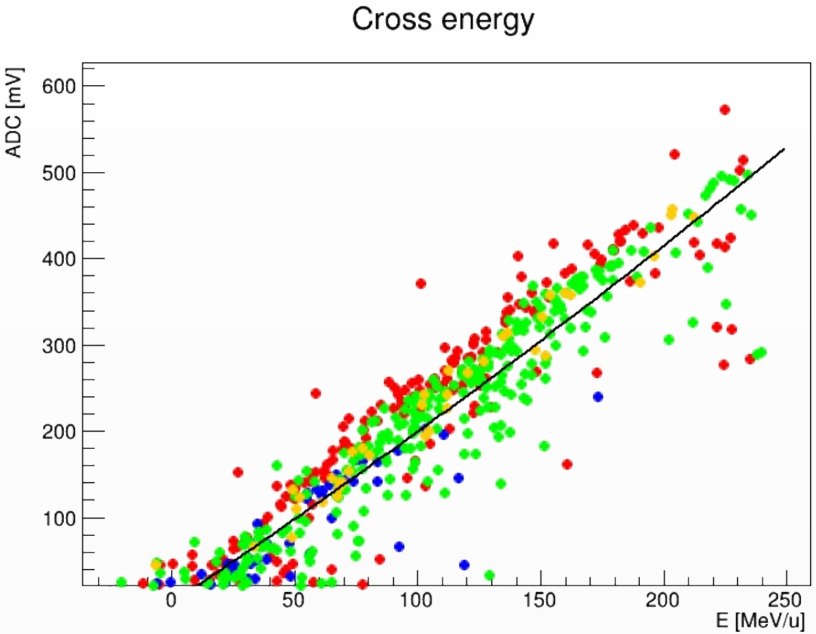


In cry 126, if we only preserve multiplicity = 1 events, there's no peak event for C @ 260 MeV/u.

However, if a neighbor crystal *i* is already calibrated, we can try reconstructing the energy in 126 as:

$E_{126} = E_{beam}$ (nominal energy) $- E_i$
→ $(ADC, E)_{126}$ scatter plot to be fitted with a MBF.

First correction attempt

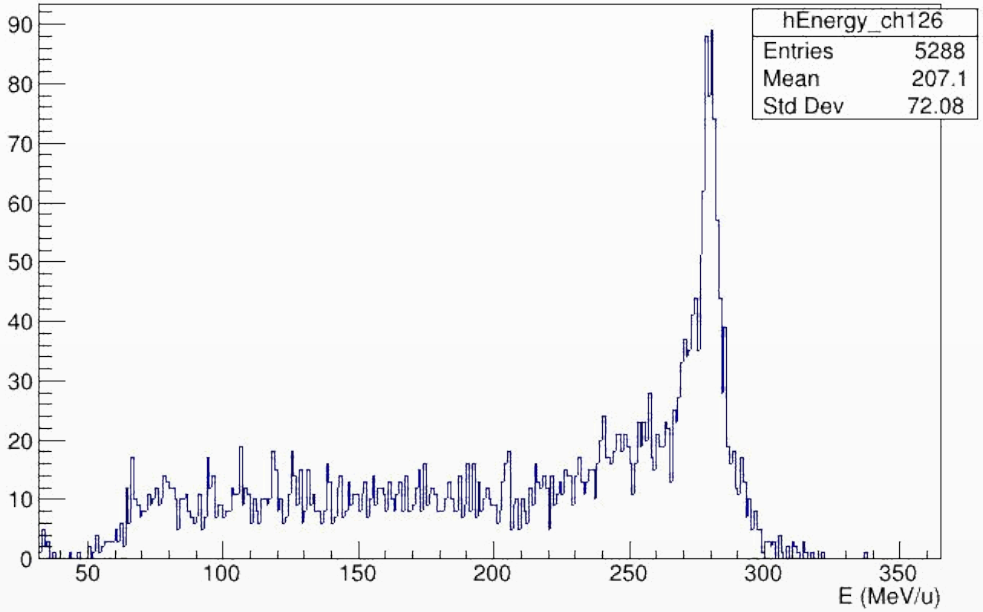


Unfortunately, events with multiplicity = 2 below 200 MeV/u are denser, thus “privileged” by MBF fit
>> the peak position is not well reconstructed (280 MeV/u instead of 260 MeV/u)
>> new multiplicity cut to be attempted.

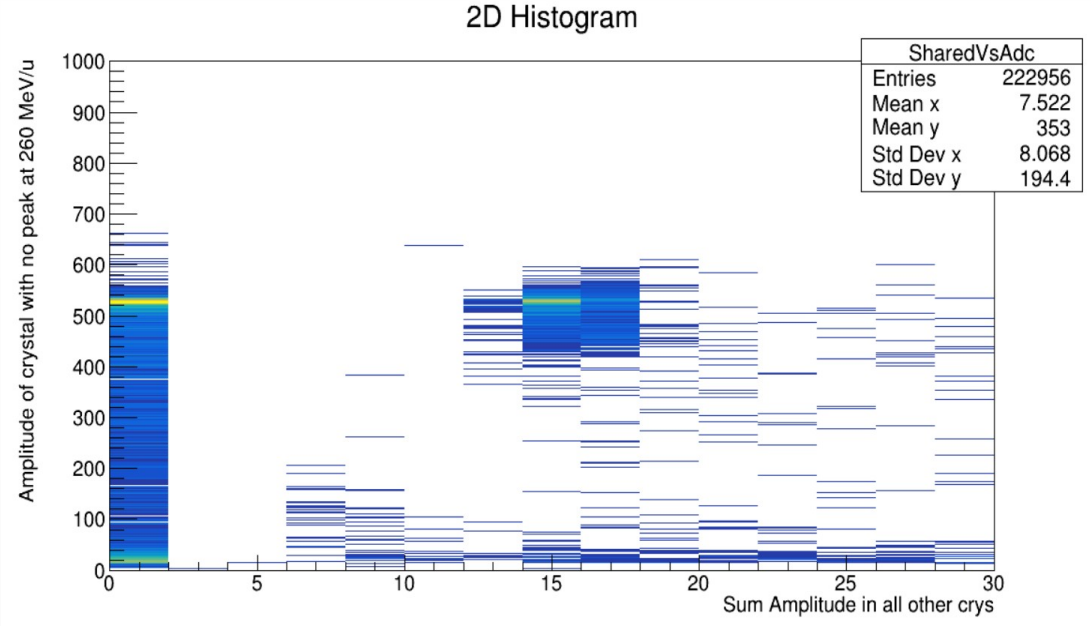
In cry 126, if we only preserve multiplicity = 1 events, there’s no peak event for C @ 260 MeV/u.

However, if a neighbor crystal *i* is already calibrated, we can try reconstructing the energy in 126 as:

$E_{126} = E_{beam}$ (nominal energy) $- E_i$
→ $(ADC, E)_{126}$ scatter plot to be fitted with a MBF.

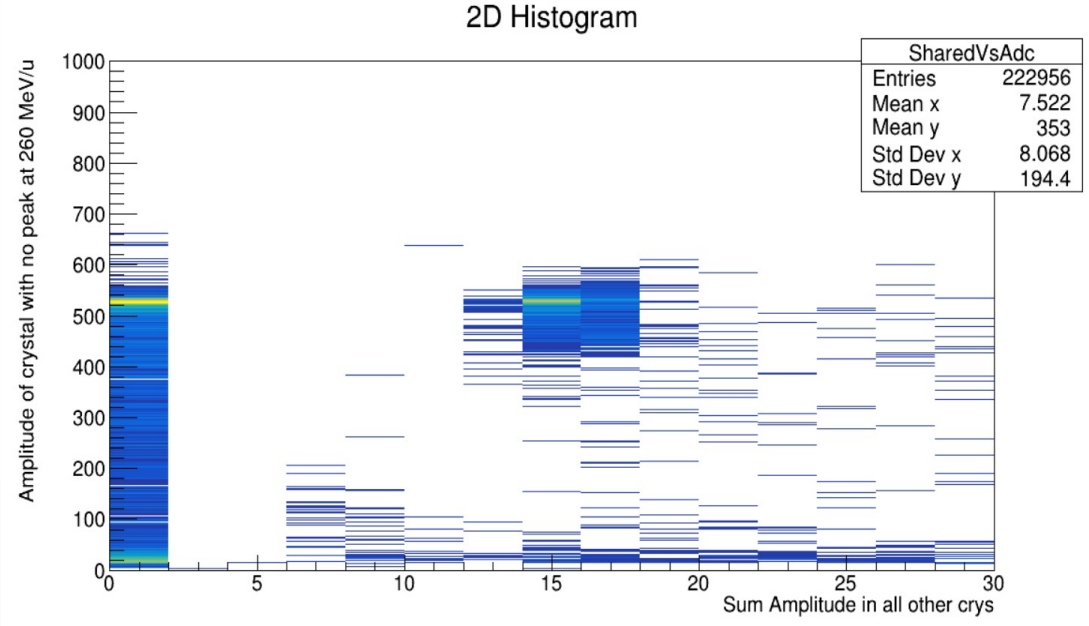


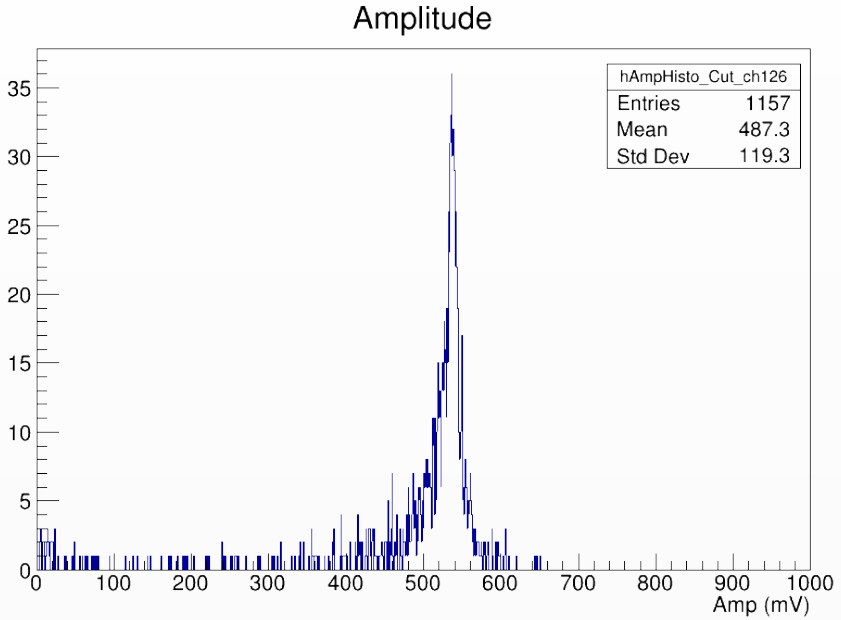
Second correction attempt



In this plot, the amplitude in Ch126 is plotted against the sum of amplitudes in other crystals → let's select the events where sum in other crystals / sum in single crystal is < 5%.

Second correction attempt



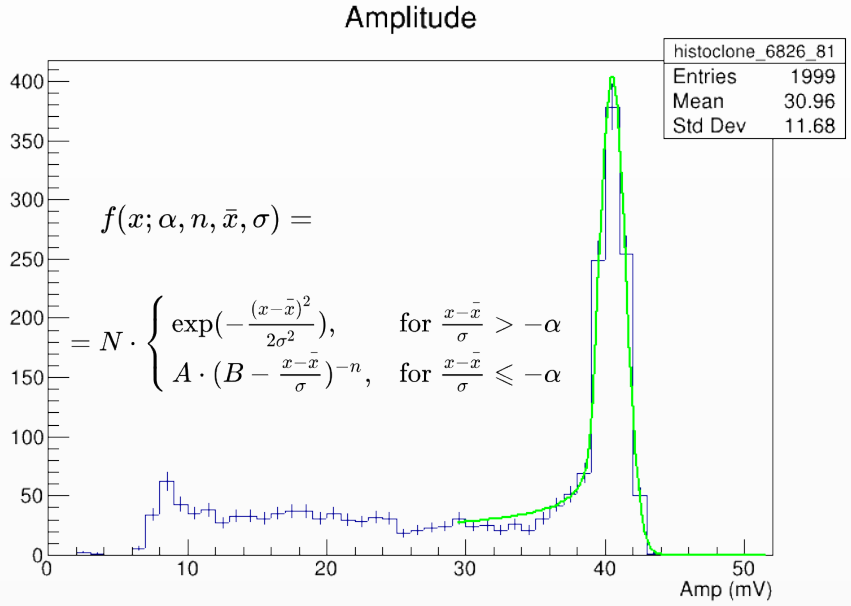


In this plot, the amplitude in Ch126 is plotted against the sum of amplitudes in other crystals → let's select the events where sum in other crystals / sum in single crystal is < 5%.

Now, the peak appears, and its position is underestimated of < 5% → this correction method is meaningful.

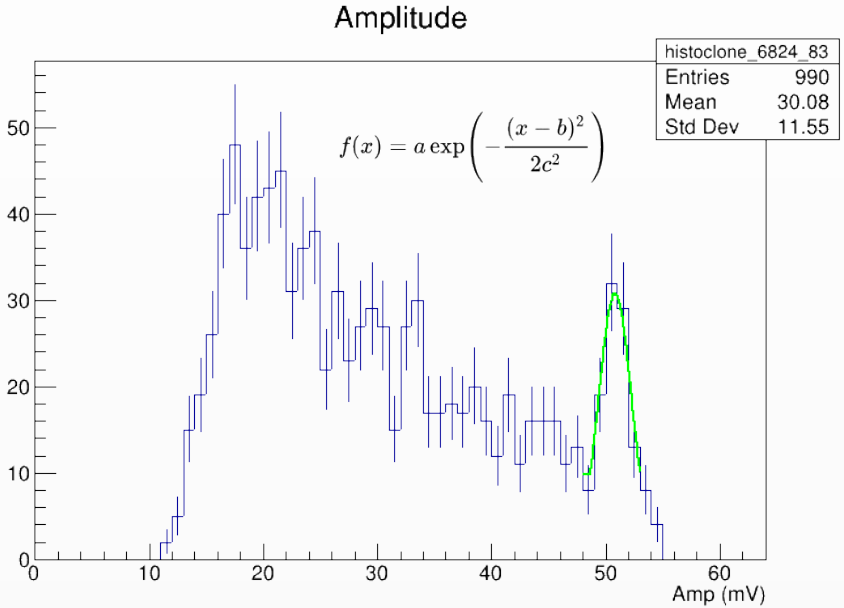
Peak analysis

Peaks are fitted with a crystal ball function → central gaussian region and decreasing “tail” under a certain threshold, to model small energy release events.



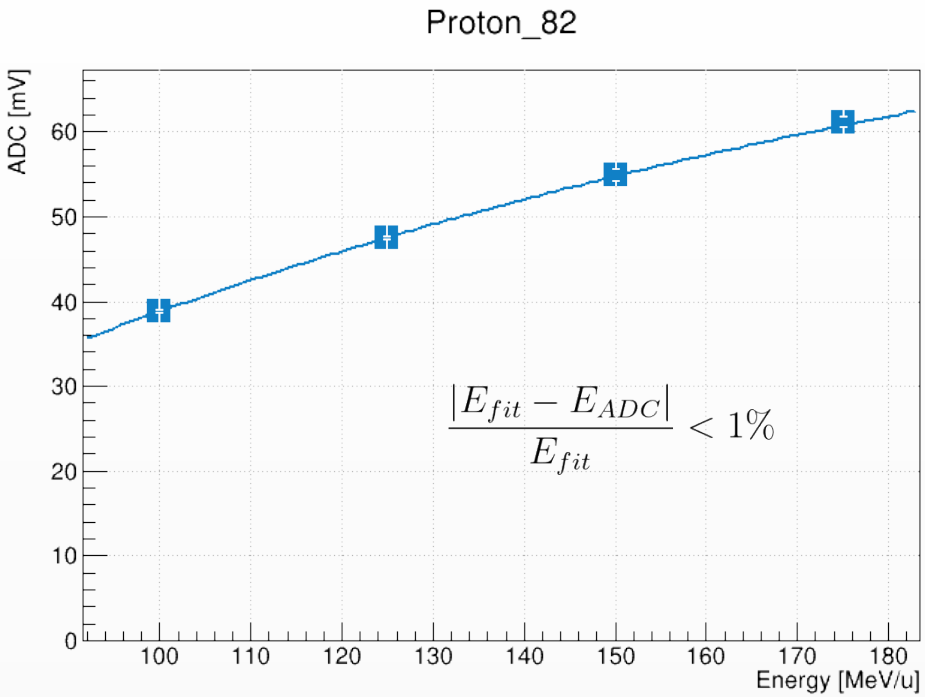
Minuit2 fit status, covariance matrix, reduced chi-square, etc. are always checked and the limits on range and σ are changed subsequently.

In some cases, small energy releases are dominated by beam-sharing effects → fit with Gauss function.



Some data points were taken in both rounds, in order to check stability → in almost all analyzed crystals, shifting in peak position was **< 2%**.

Peak analysis



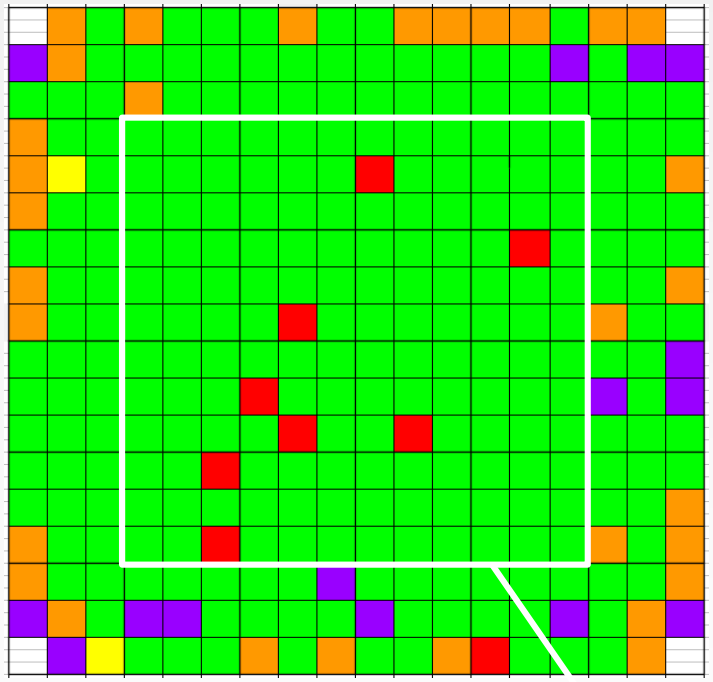
ADC response vs energy is then modeled with a modified Birks function (MBF):

$$\frac{dS}{dx} = \frac{A \cdot dE/dx}{1 + k \cdot B \cdot dE/dx}$$

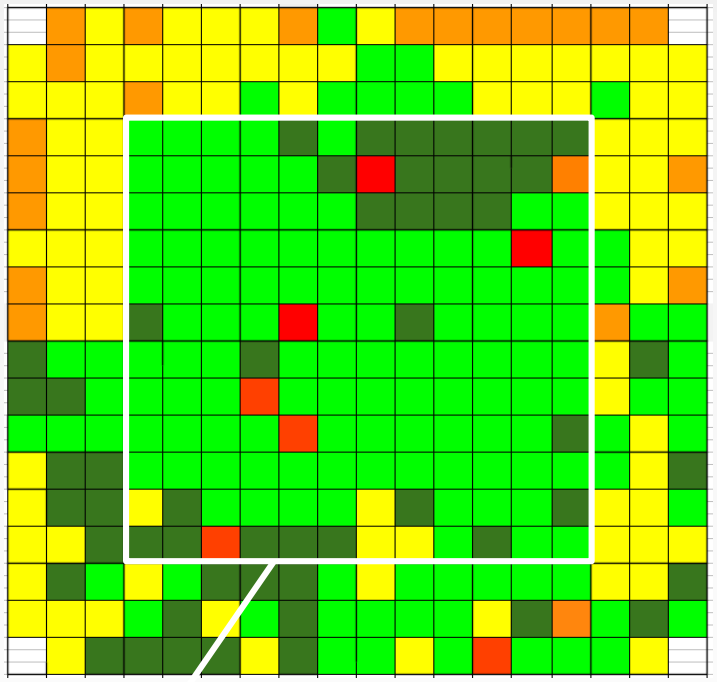
$$ADC(E) = \frac{p_0 x^2}{1 + p_1 x + p_2 x^2}$$

At least 3 points per crystal are needed.

Calibration status (front view)



Protons



Carbon

broken / not responding

problematic/lacking points

fit issues

3 points available

few events @ highest energy

4 points available

Let’s focus on the central 4x4 ones >> more useful for fragmentation analysis.

Energy correction

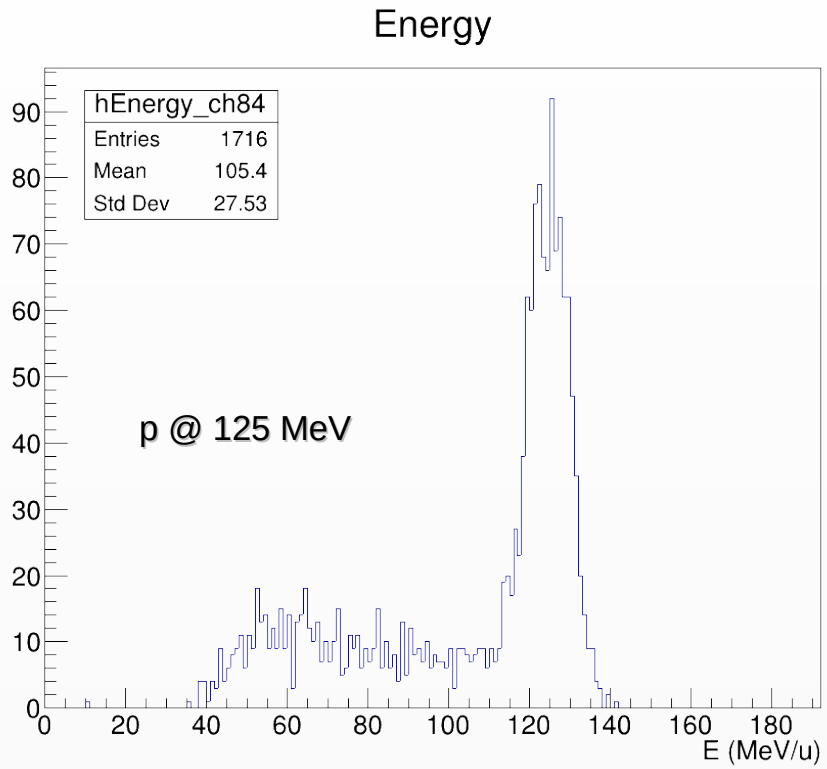
For green/light green single crystals (among the 4x4 central ones), energy could be reconstructed via the inverse equation:

$$E(ADC) = \frac{-p_1 ADC - \sqrt{(p_1 ADC)^2 - 4ADC(p_2 ADC - p_0)}}{2(p_2 ADC - p_0)}$$

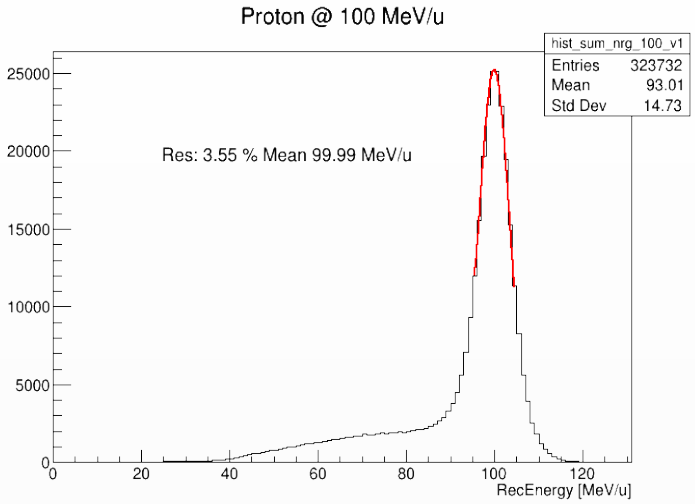
>> equalized energy spectra corresponding to a single nominal beam energy are summed up

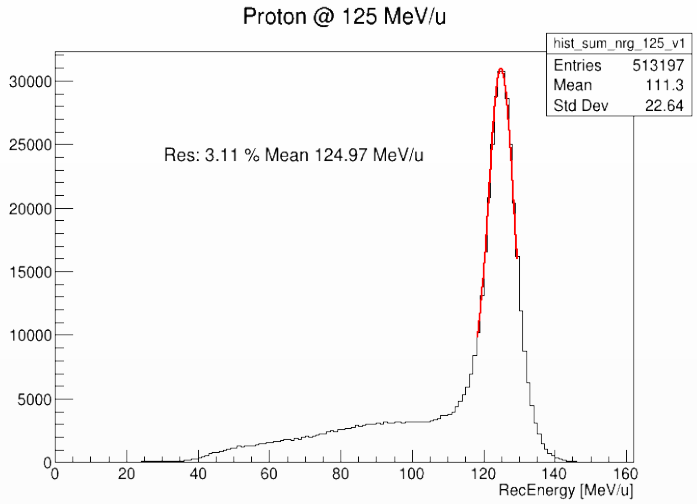
>> a histogram is obtained, then again fitted with a crystal ball function

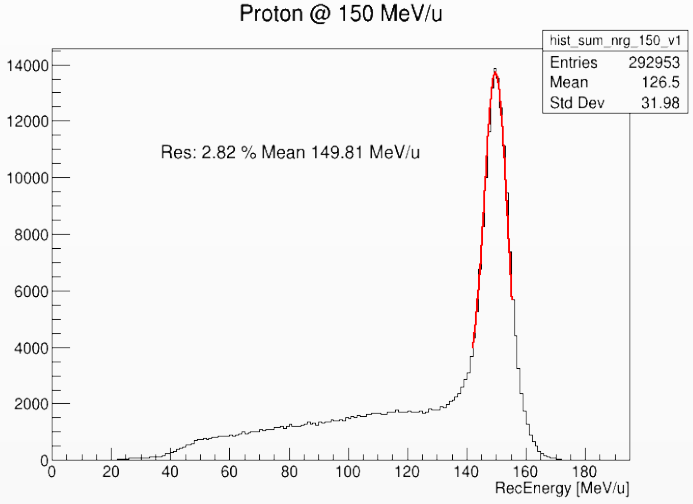
>> integral resolution is calculated.

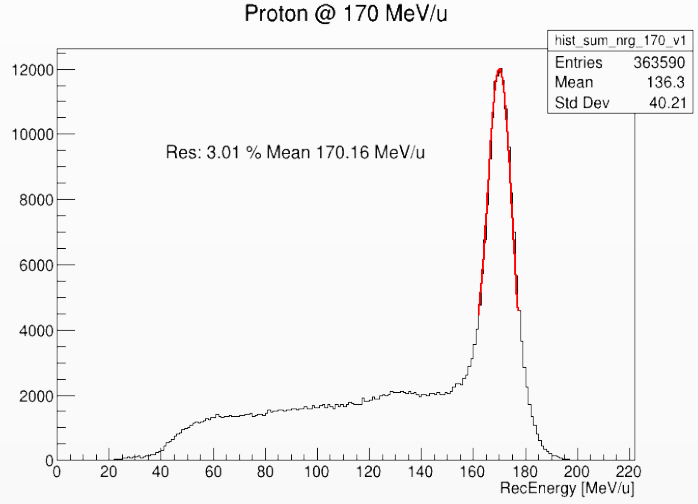


Integral resolution (protons)



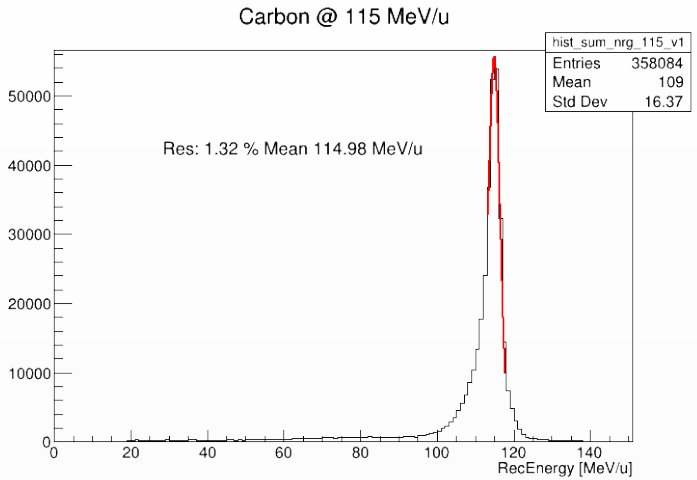


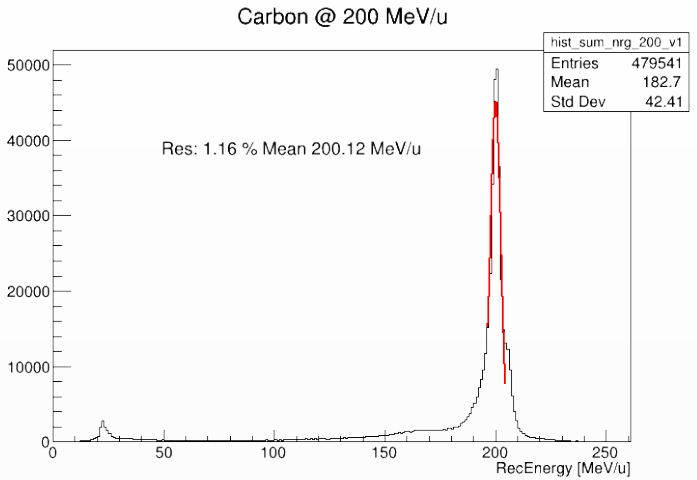


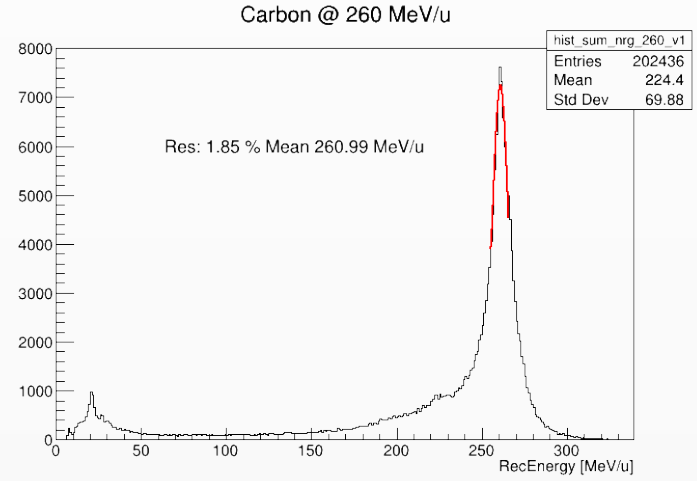


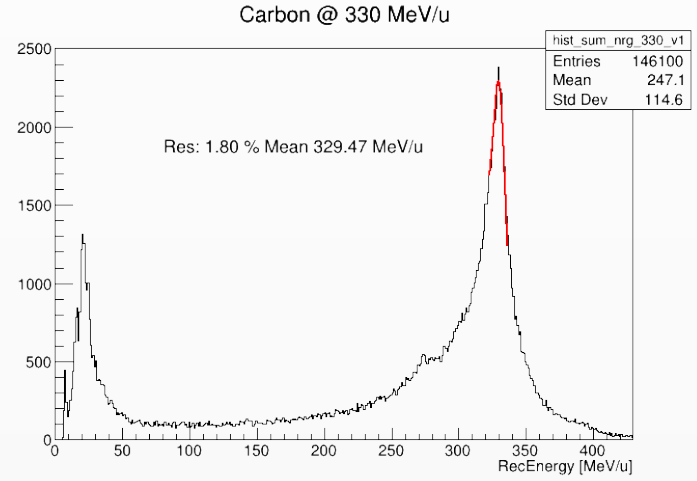
Resolution is around 3%;
in addition to this, the ratio between peak and low energy events progressively builds up @ higher beam energies, due to beam sharing phenomena.

Integral resolution (carbon)



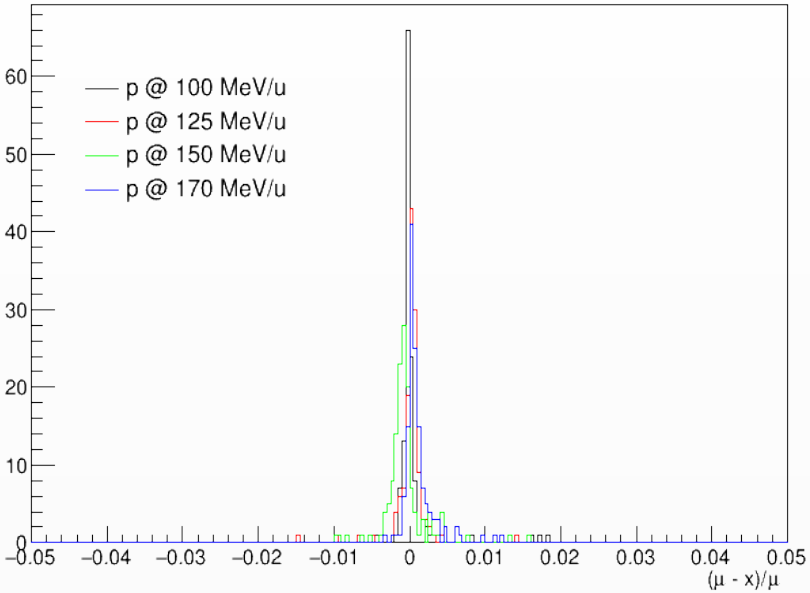


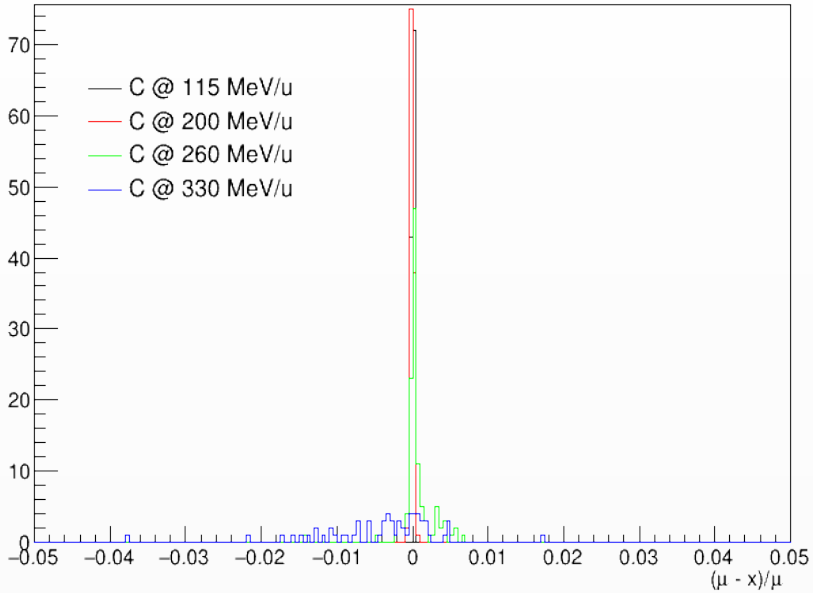




In carbon, energy resolution is well below 2%. In this case, low energy events due to beam sharing are limited within 0 and 50 MeV/u
>> geometrical reasons to be further investigated.

Residual distributions for MBF

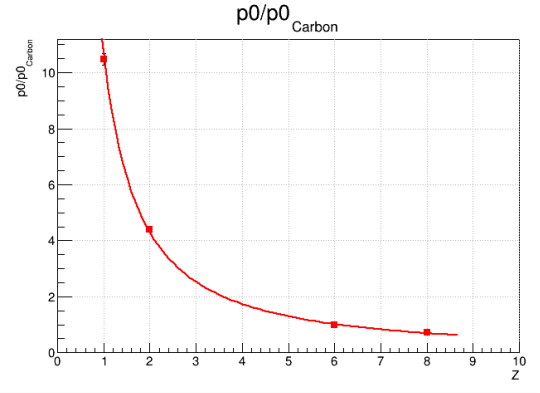


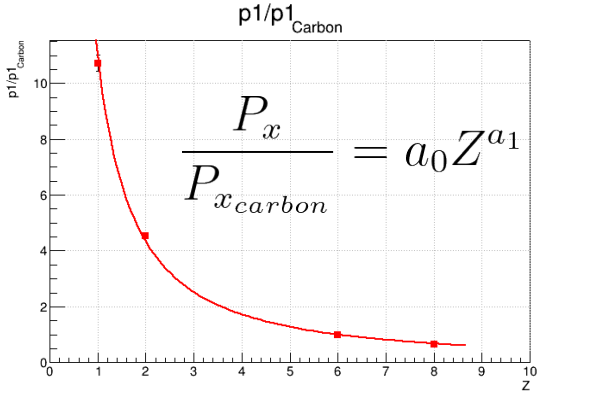


In both cases, residual distributions are limited within 1%
>> MBF reproduces nominal energy with the expected precision.

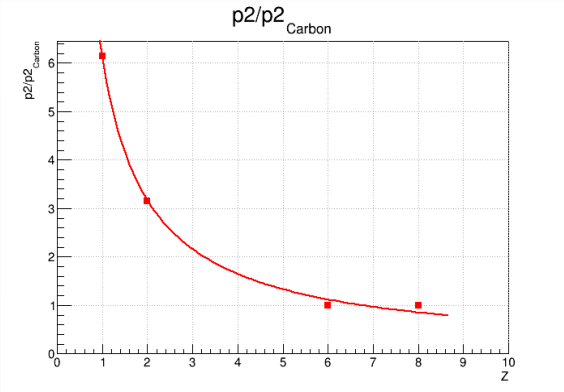
$$\frac{|E_{fit} - E_{ADC}|}{E_{fit}} < 1\%$$

MBF extrapolation using HIT2022 parameters



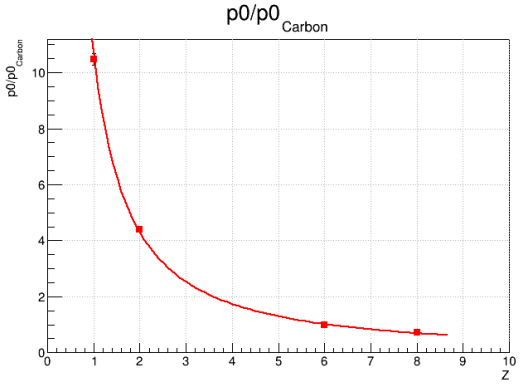


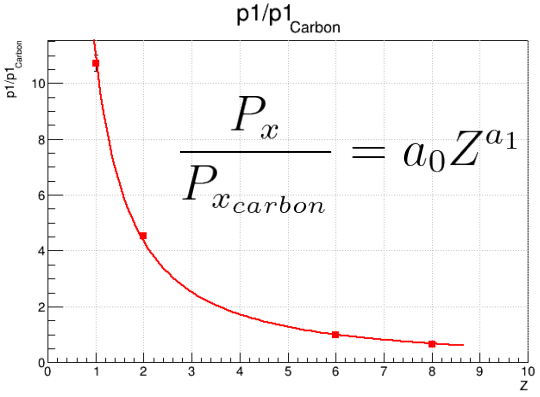
$$\frac{P_x}{P_{x_{carbon}}} = a_0 Z^{a_1}$$



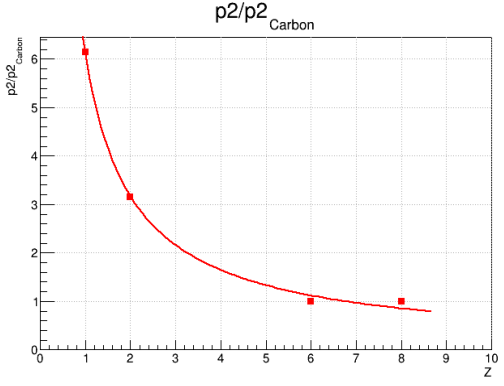
We tried using the power-law coefficient $(a_0, a_1)_{pi}$ extrapolated from HIT2022, to reconstruct proton MBF parameters (p_0, p_1, p_2) for each crystal @ CNAO2024 (see Alessandro's presentation).

MBF extrapolation using HIT2022 parameters



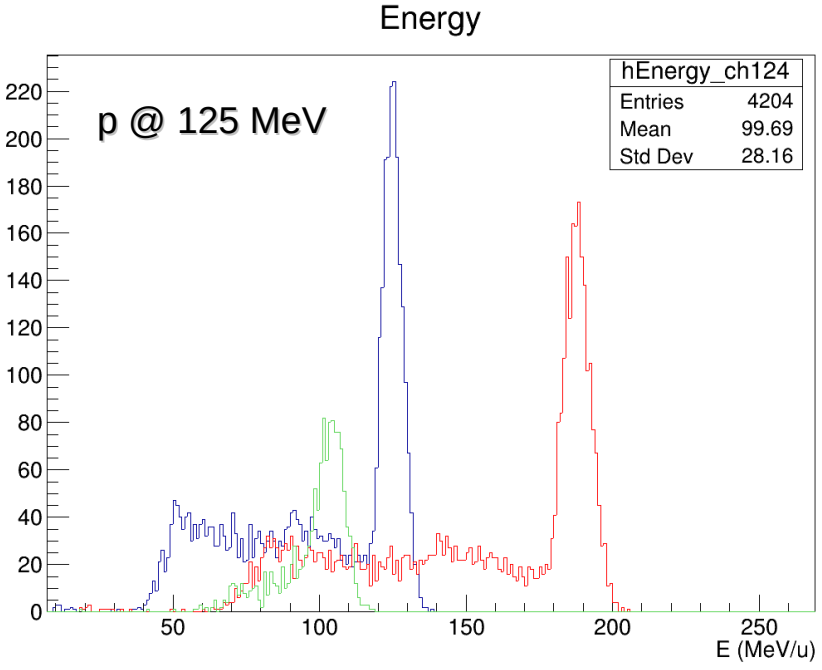


$$\frac{P_x}{P_{x_{carbon}}} = a_0 Z^{a_1}$$



We tried using the power-law coefficient $(a_0, a_1)_{pi}$ extrapolated from HIT2022, to reconstruct proton MBF parameters (p_0, p_1, p_2) for each crystal @ CNAO2024 (see Alessandro's presentation).

Blue: RecEnergy in ch124 via direct MBF fit
Red: RecEnergy in ch124 via p_i extrapolation
Green: RecEnergy in ch127 via p_i extrapolation.



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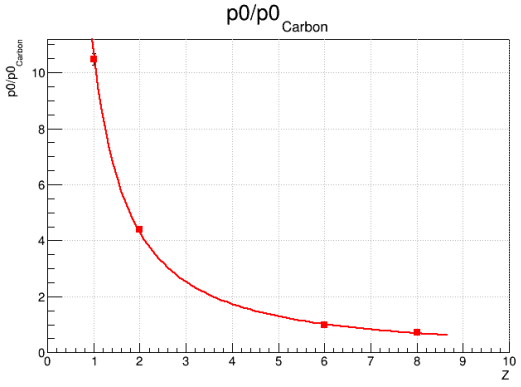

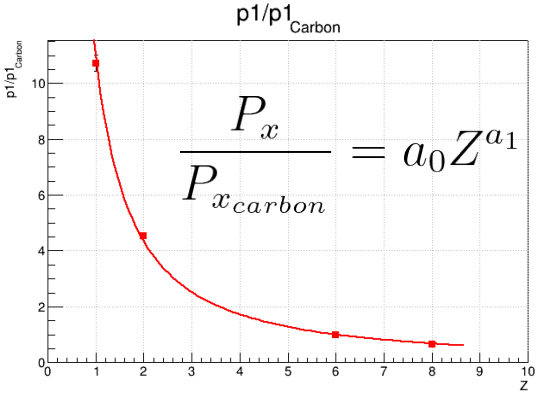

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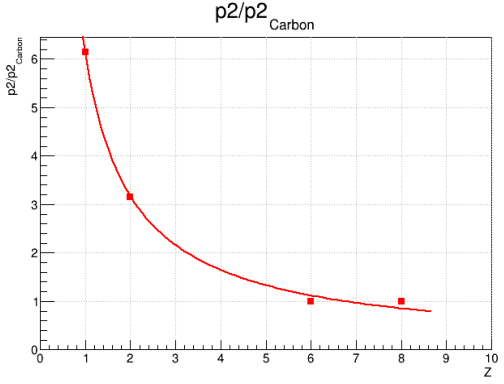

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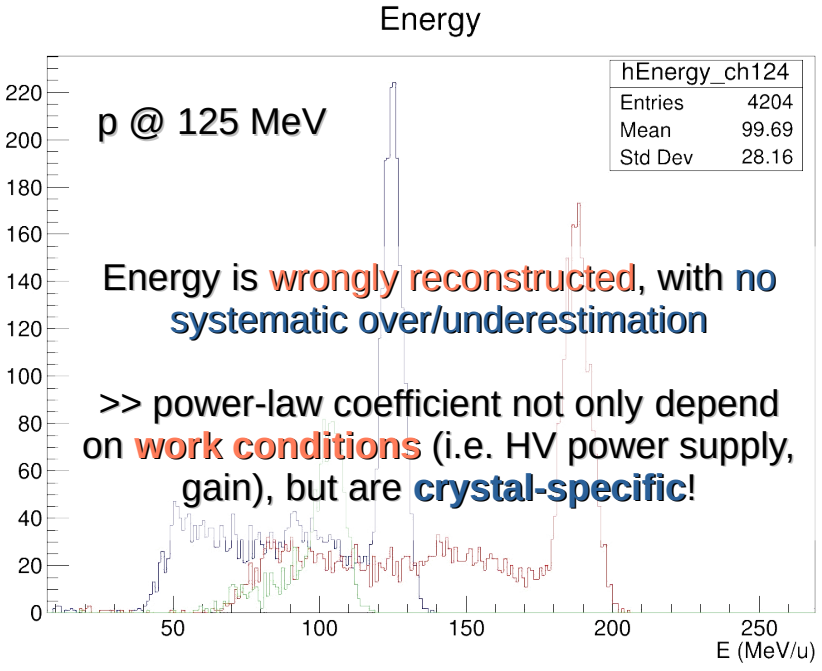
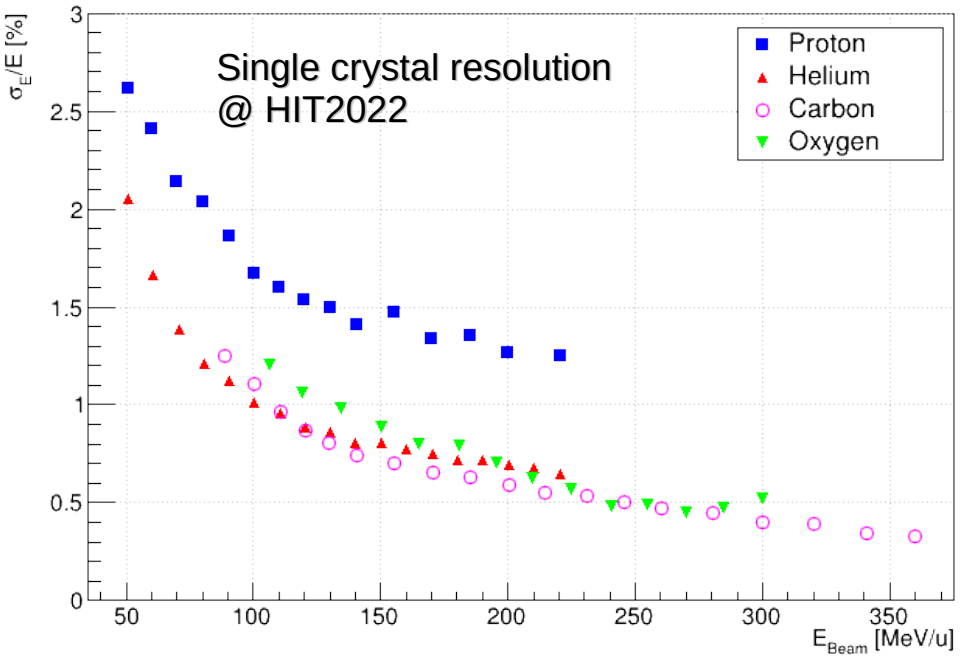


Energy is wrongly reconstructed, with no systematic over/underestimation

>> power-law coefficient not only depend on work conditions (i.e. HV power supply, gain), but are crystal-specific!

Conclusion

- By applying a new multiplicity cut, an integral resolution < 2% was achieved for the central 4x4 modules, in spite of beam sharing issues.



- For p, integral resolution was not below 2%: this was already known from the Heidelberg 2022 campaign, during which 2 crystals were calibrated singularly (no screen saver runs), thus excluding beam sharing issues.

- MBF parameters must be corrected with respect to Z for each crystal specifically. How to assess whether this is done effectively?

Upcoming tasks

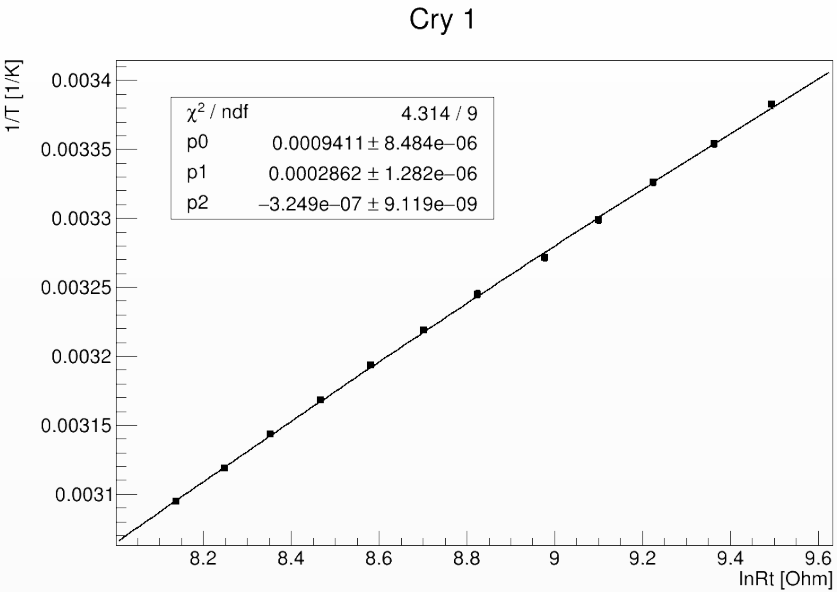
In order to assess the CALO energy reconstruction performances we need to:

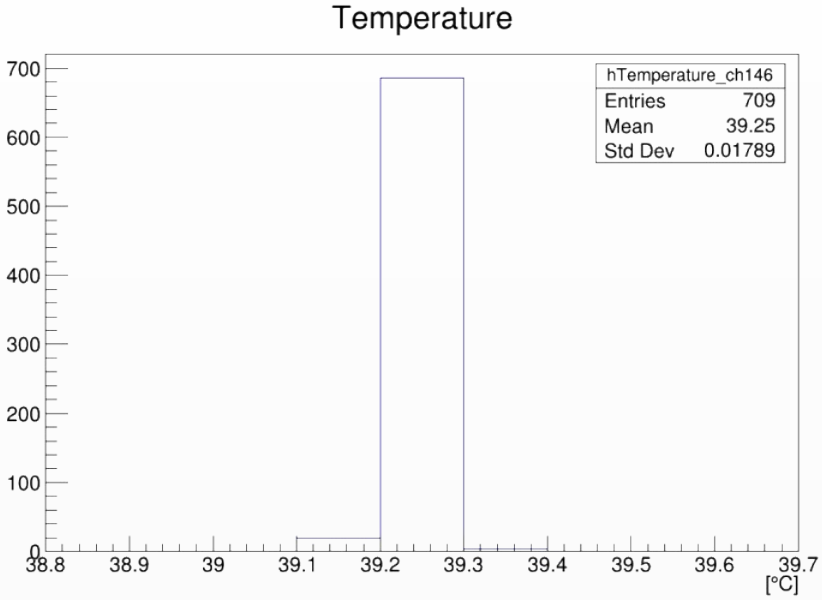
- obtain power-law coefficients (a_0, a_1) for all crystals suitable for p and C calibration;
- within CNAO2024 work conditions, try reconstructing the kinetic energy of a different ion species
  → ^{4}He produced during C → C fragmentation runs is the best choice;
- ^{4}He mass is our “bench-test”, to be obtained by the known formula:

$$A_2 = \frac{m}{u} = \frac{E_{kin}}{u(\gamma - 1)}$$

In parallel:
- calibration must be completed for modules outside the central 4x4 subset;
- integral resolution of the detector must be measured with all functioning crystals;
- does energy reconstruction still show good resolution performances when multiplicity > 1? To be checked.

Reminders (T calibration)





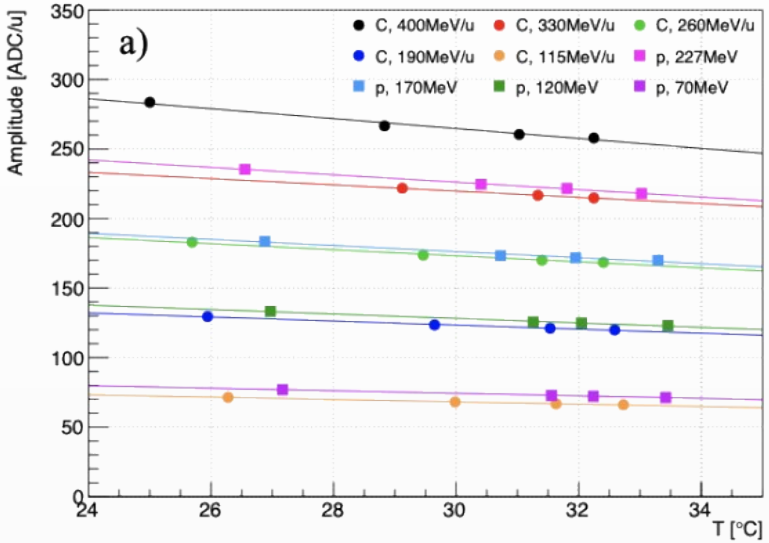
Arduino reads temperatures in ADC channels, to be converted into T values via the Steinhart – Hart expression:

$$\ln(1/T) = a_0 + a_1 \ln(T_{ADC}) + a_2 \ln(T_{ADC})^3$$

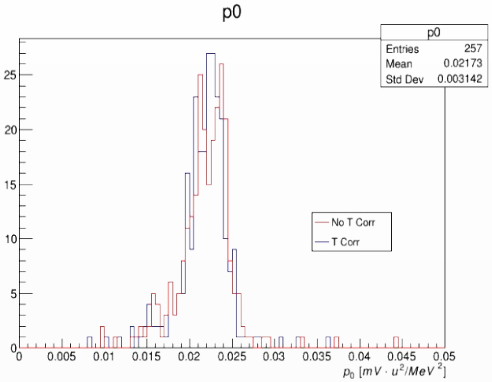
By using the so-obtained three coefficients a_0, a_1, a_2, a custom script plots a T histogram for each crystal. T is known with a 0.1 °C sensitivity.

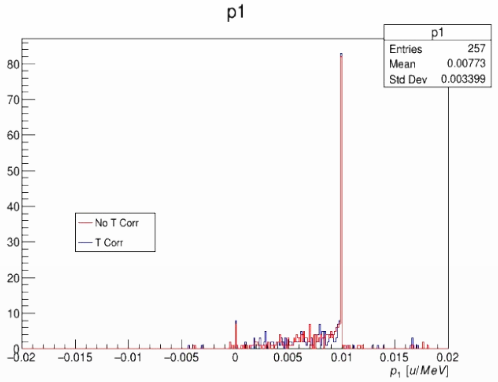
Reminders (T calibration)

Why is temperature correction necessary?

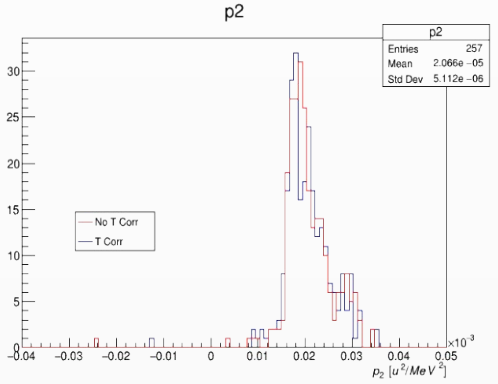


Analysis carried out on a single crystal shown that ADC signals due to beams with same energy decrease linearly with temperature.

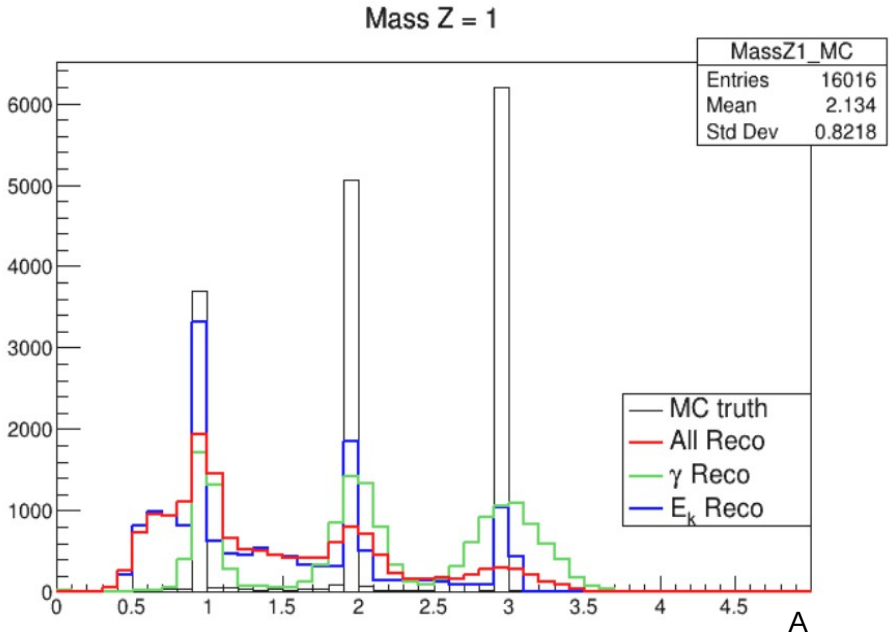


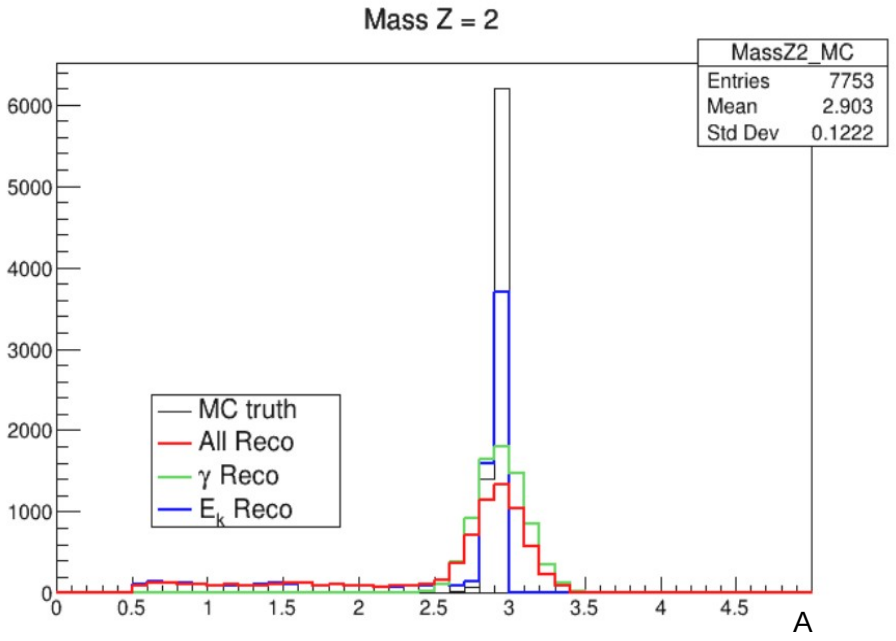


Temperature correction only slightly changes the distribution of the parameters p_0, p_1 and p_2 used for the energy calibration.



Reminders (simulated mass reconstruction)



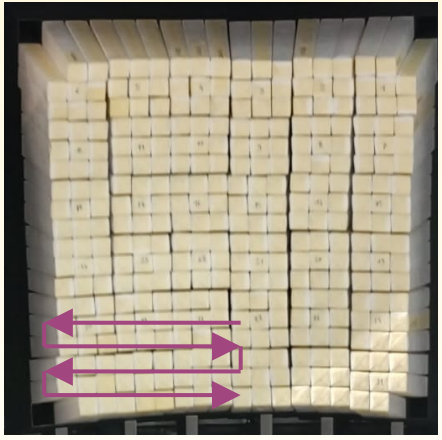


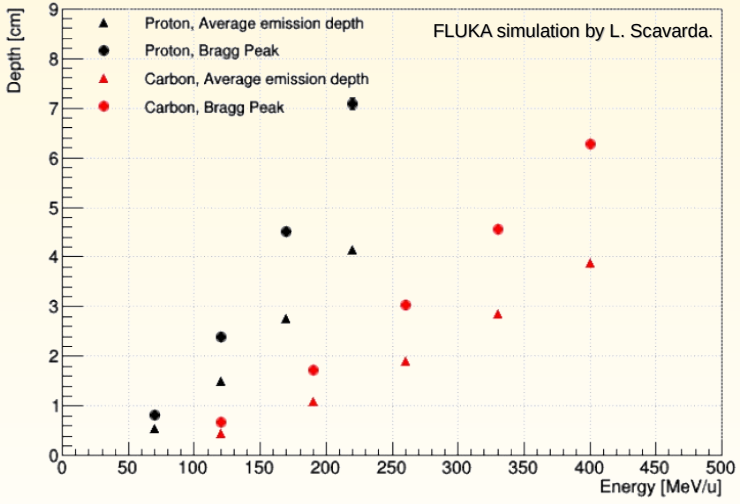
Beam sharing issues

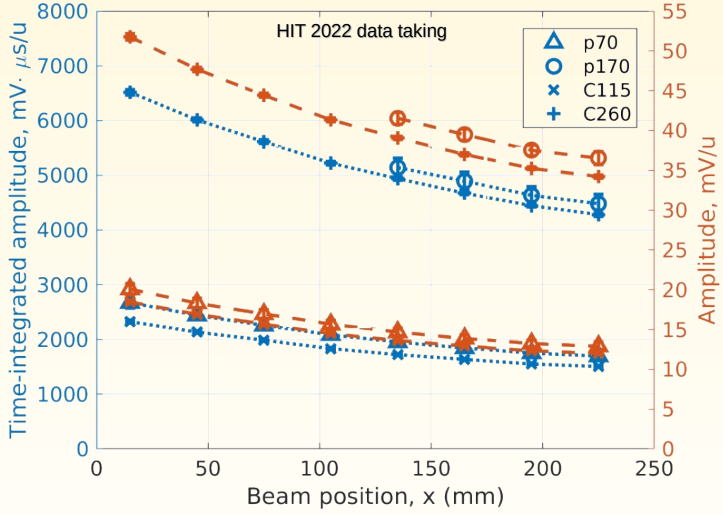
Reminder(s):

- Each “screen-saver” run for calibration covers a 20x20 cm^2 surface (one quarter);
- CALO front face is concave, not flat;
- higher energies → higher range (faster increase for p than C).

At higher energies, due to CALO-beam geometry:
>> particles cross multiple crystals with higher probability
>> charge-sharing phenomena between neighbor crystals become not negligible
>> peak events collection for p @ 230 MeV and C @ 330/400 MeV/u is harder.







In addition to this, readout amplitude depends on how particle-crystal interaction is close to the SiPM.