Analysis update on GSI and CNAO data

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VII FOOT Collaboration Meeting – 4 December 2019

Outline

GSI data

- Calibration with 400 MeV/u Oxygen ions
- Evaluation of TOF resolution
- Checking reconstructed charge of Oxygen in calibration run
- Analysis of fragmentation runs

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GSI data

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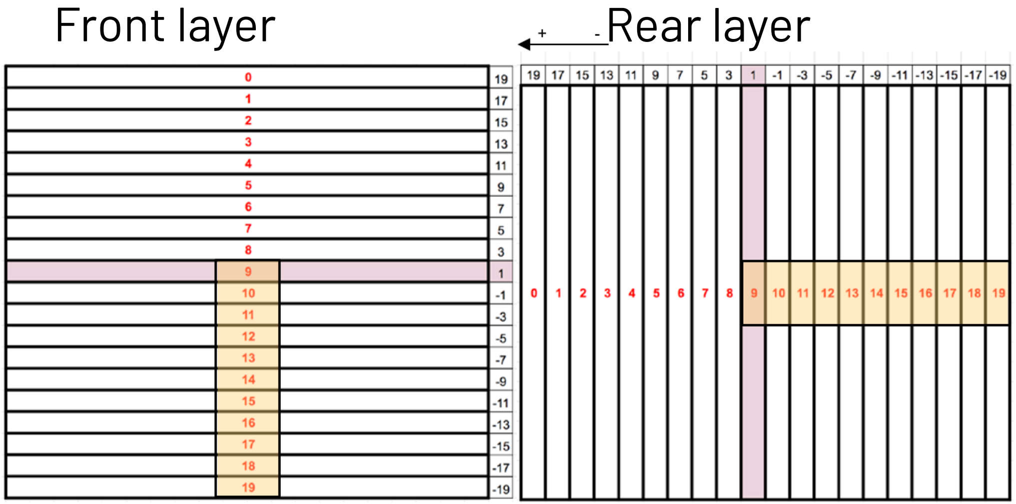
CNAO data

- Calibration with Carbon and proton beams
- Z reconstruction on GSI data with CNAO calibration
- Measurement of effective attenuation length of a bar
- Discussion on calibration strategy

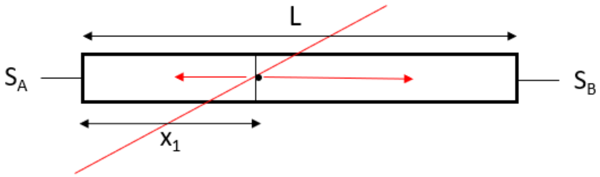
GSI data: how to handle



From FLUKA simulation we got that 400 MeV/u Oxygen loses ~**59 MeV** (in each bar)

$$S_A = S_0 e^{-\lambda x_1} \qquad S_B = S_0 e^{-\lambda (L - x_1)}$$

$$S_f = \sqrt{S_A \cdot S_B}$$



Calibration run (nr. 2242) ~70k events, physics runs (nr. 2239-40-41) ~60k events in total

Calibration of bars

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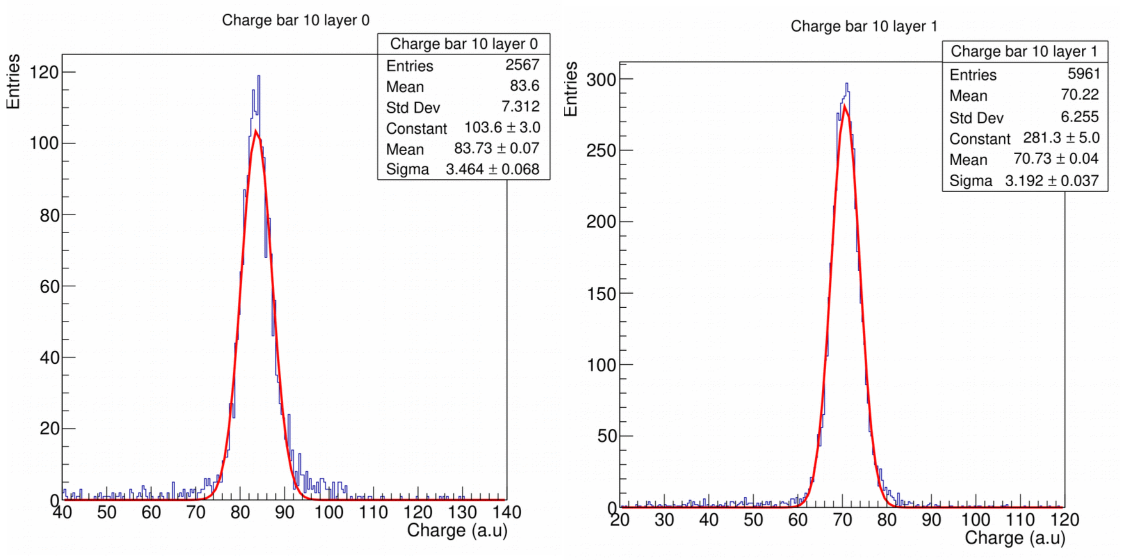

Calibration of bars

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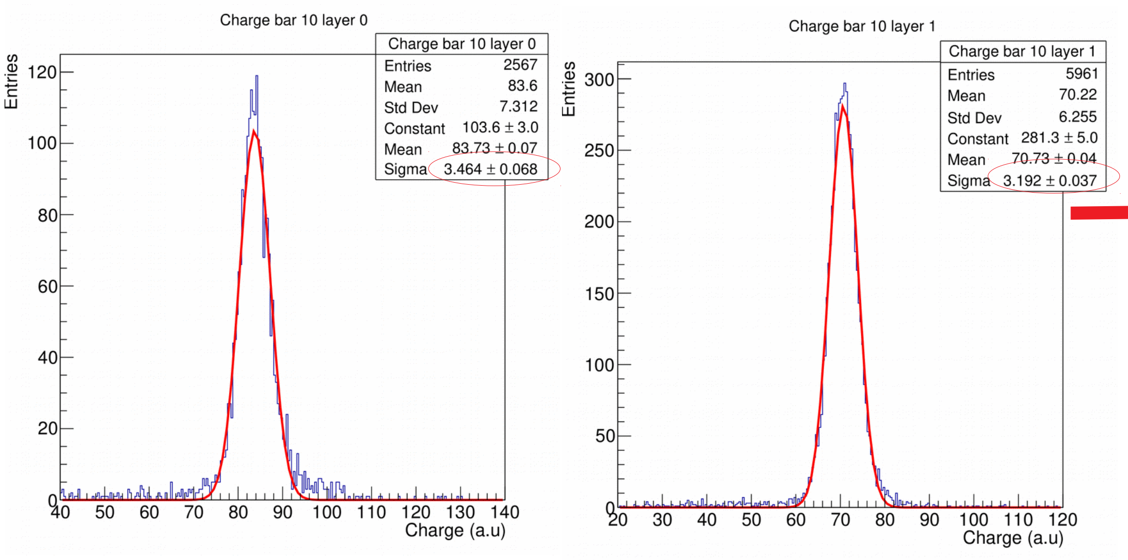

dE/dx resolution ~ **4%**

TOF resolution

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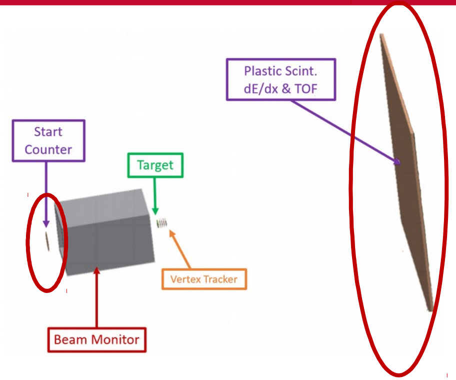
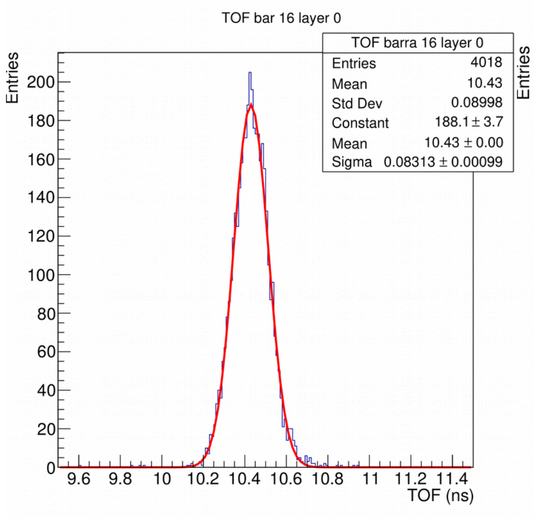
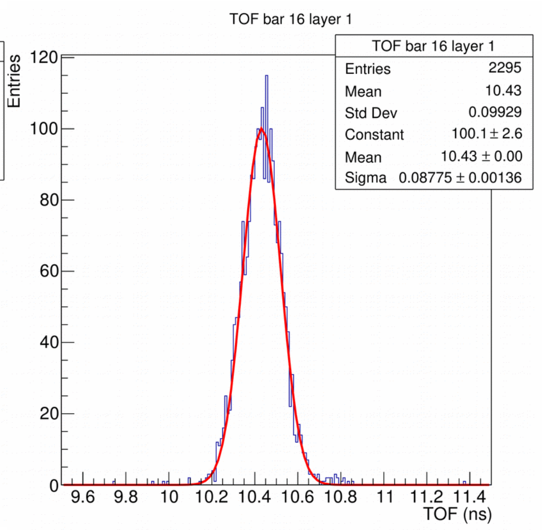
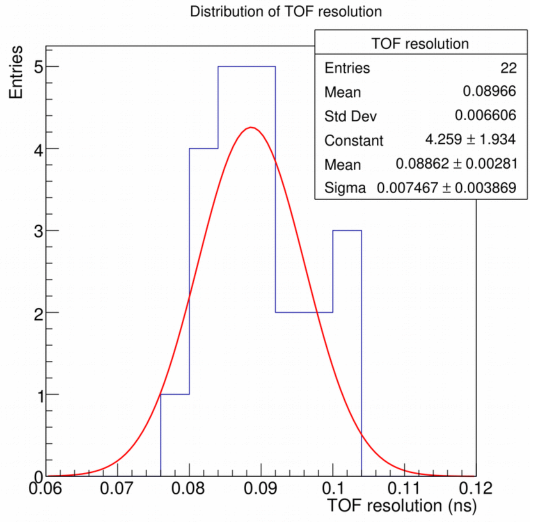
As there is no measurement of the delay due to cables and electronics, the **offset** is evaluated using the time spent by the Oxygen to travel from SC to TW (**223.1 cm** in **~10.43 ns**)







✓ TOF resolution ~ (89±1) ps



Checking charge of GSI Oxygen

Analysis update on GSI and CNAO data

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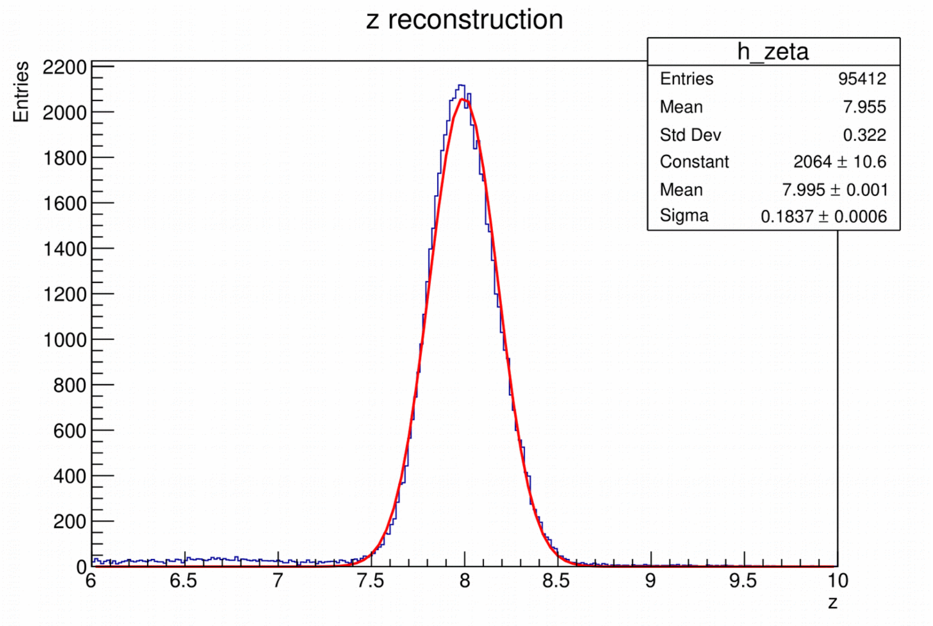
From Bethe-Bloch formula $\frac{dE}{dx} \propto \frac{z^2}{\beta^2}$



Resolution on Z reconstruction ~ **2%**

Fragmentation runs

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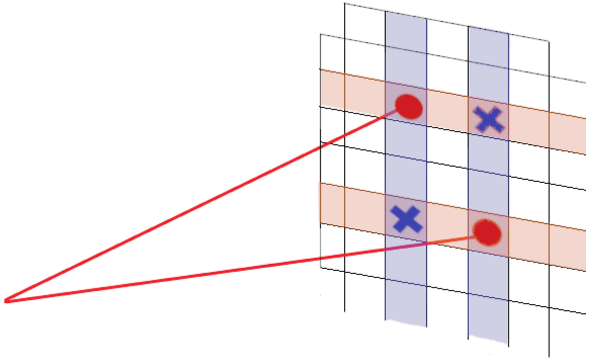
Get rid of **ghosts** looking at two quantities:

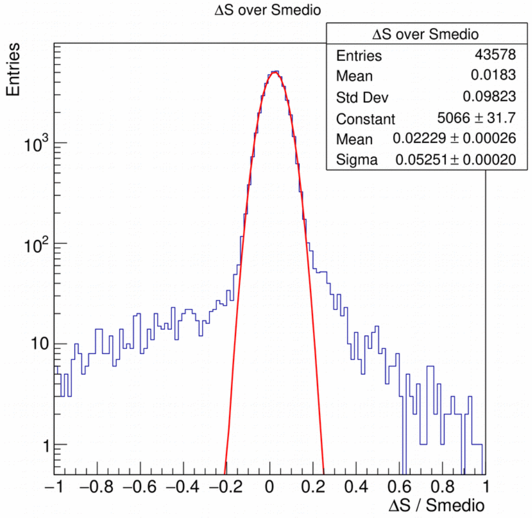
$$\frac{\Delta S}{S_{mean}} = \frac{S_{oriz} - S_{vert}}{\left(\frac{S_{oriz}+S_{vert}}{2}\right)} \qquad \frac{\Delta T}{T_{mean}} = \frac{T_{oriz} - T_{vert}}{\left(\frac{T_{oriz}+T_{vert}}{2}\right)}$$

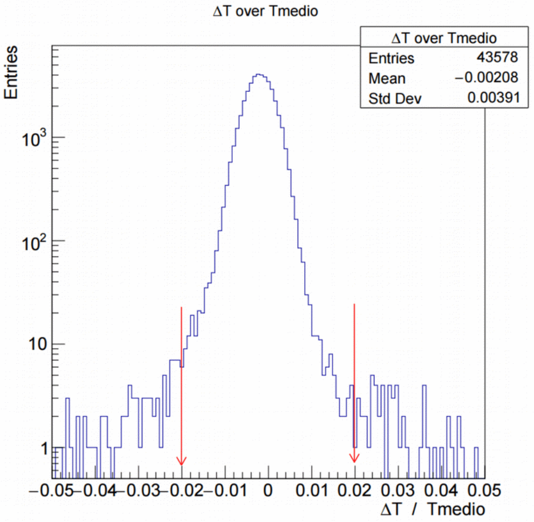


Two hits in two layers tagged as **good combination** if:

$$\frac{|\Delta S|}{S_{mean}} < 0.1$$

$$\frac{|\Delta T|}{T_{mean}} < 0.02$$





Spotted fragments in FOOT

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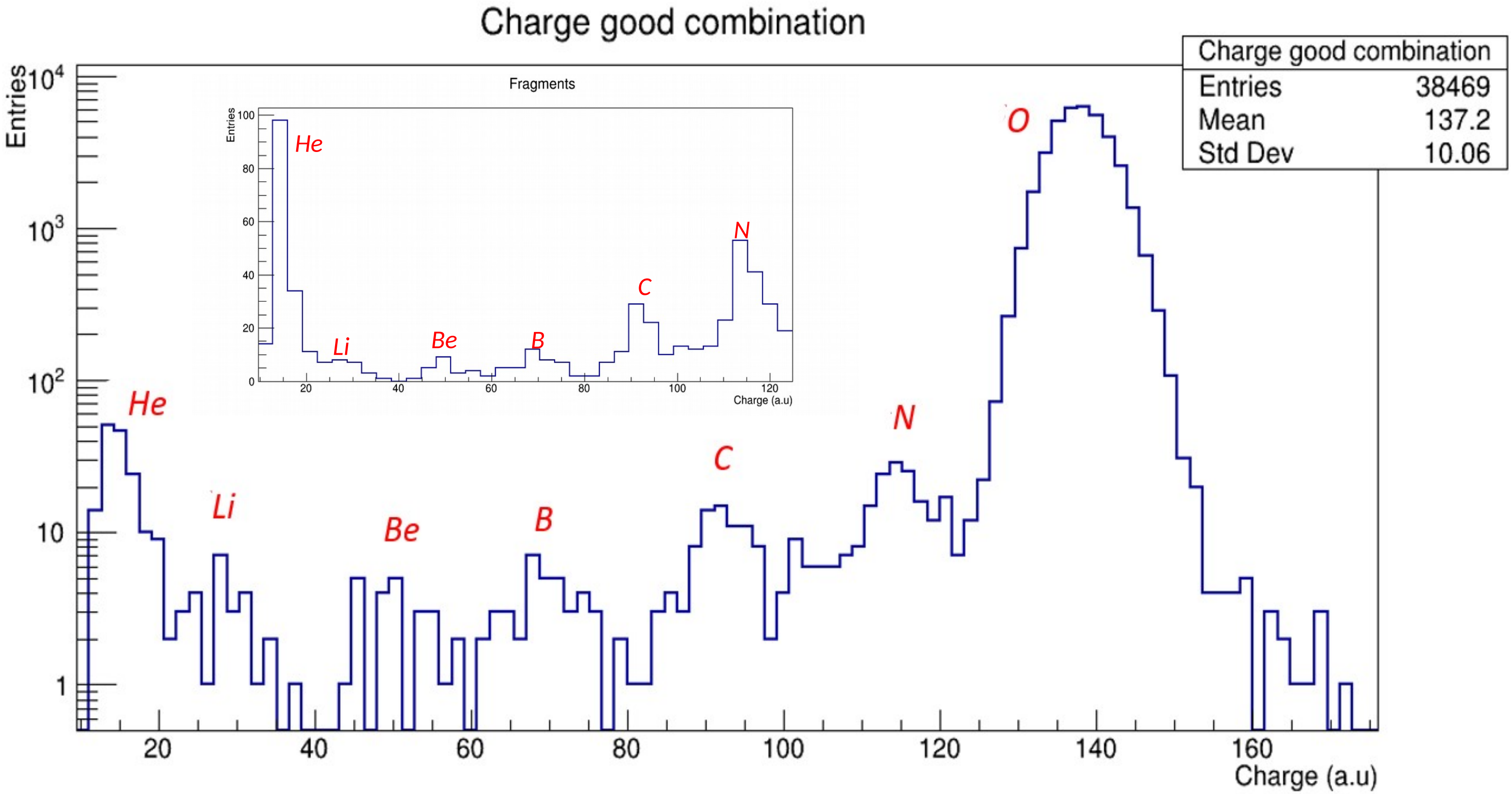

CNAO data: ntuple format

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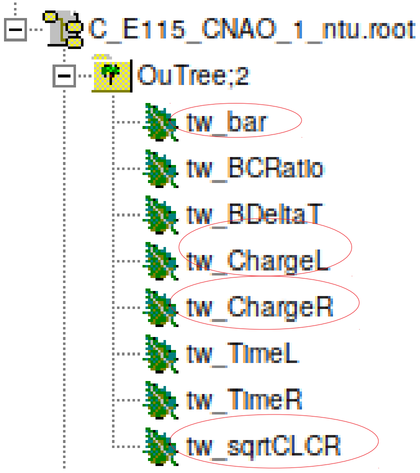

there is no **tw_layer**, **tw_bar** is a vector<int> indicating if a bar is fired or not

/home/FOOT-T3/amengarelli/CNAO_ntuple/*_1_ntu*

3 Carbon beams: **115**, **260**, **400** MeV/u
1 proton beam: **60** MeV

Every .root file is the sum of all runs at the same energy

Layout of hit bars

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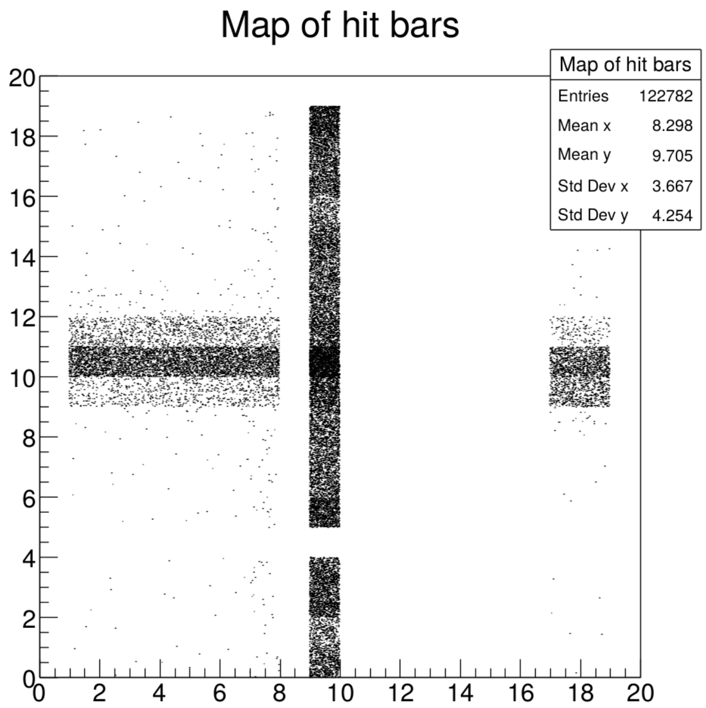
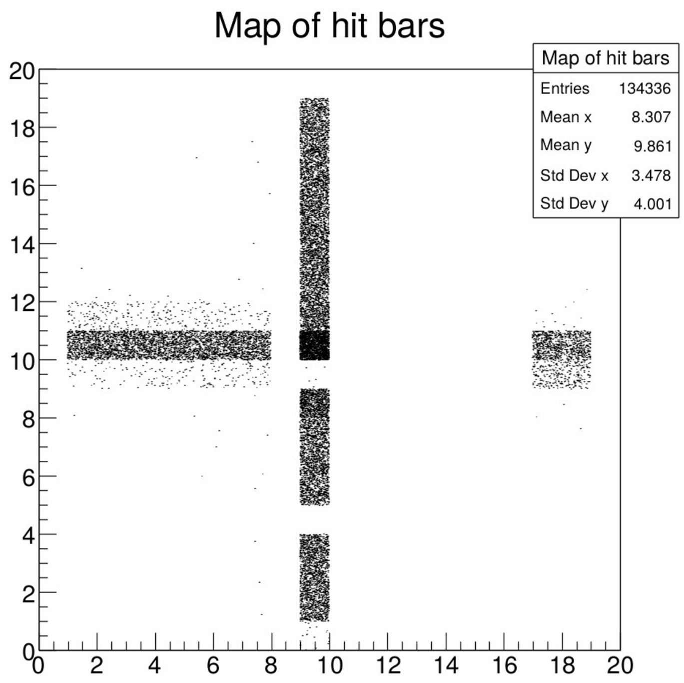
p@60



C@115



Layout of hit bars

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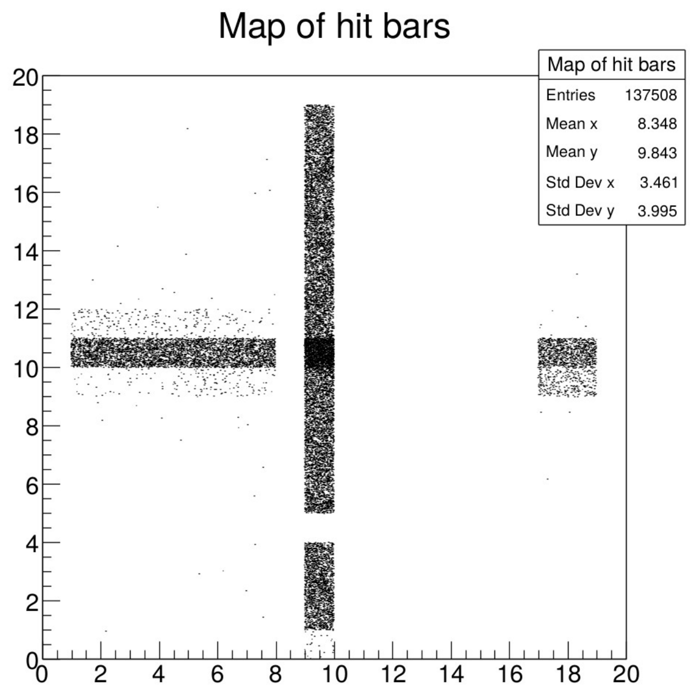
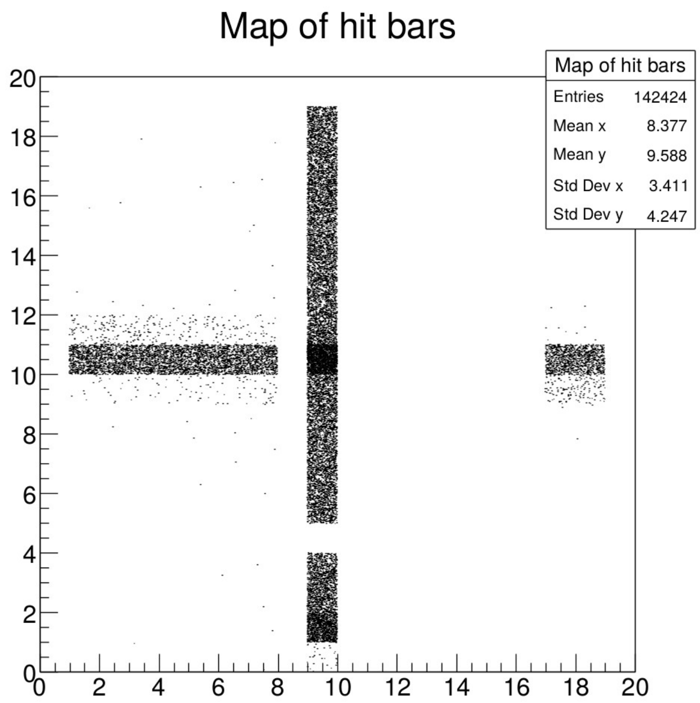
C@260



C@400



Why those holes?

Analysis update on GSI and CNAO data

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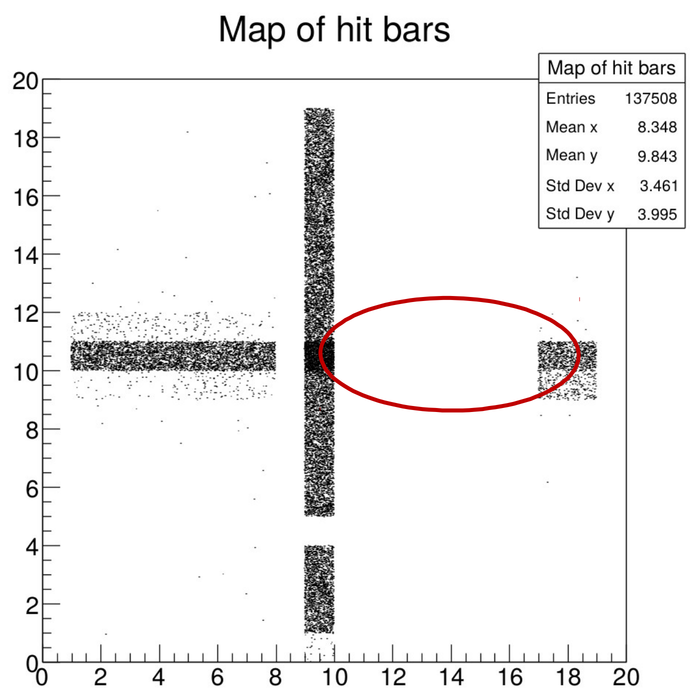

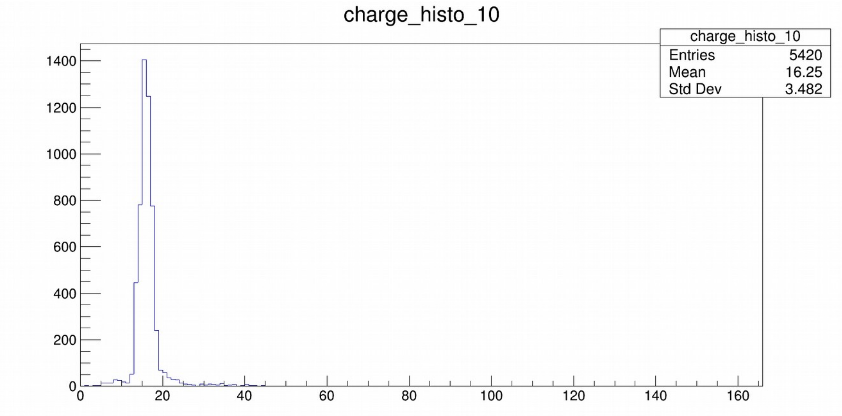

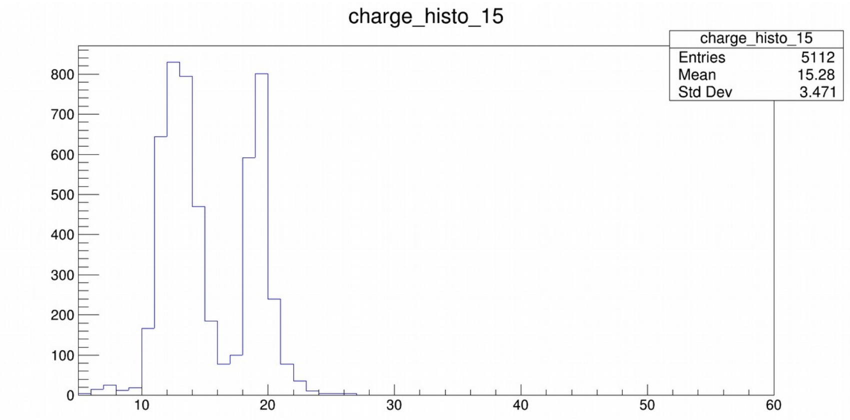

Too **low values** wrt other bars, we decided not to calibrate them

Light vs energy: Birks' Law

Analysis update on GSI and CNAO data

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For **organic scintillators**, the relation between the emitted light and the energy deposited by an ionizing particle is **not linear**

$$Q = p_a \frac{\Delta E_{mc}}{1 + p_b \Delta E_{mc}}$$

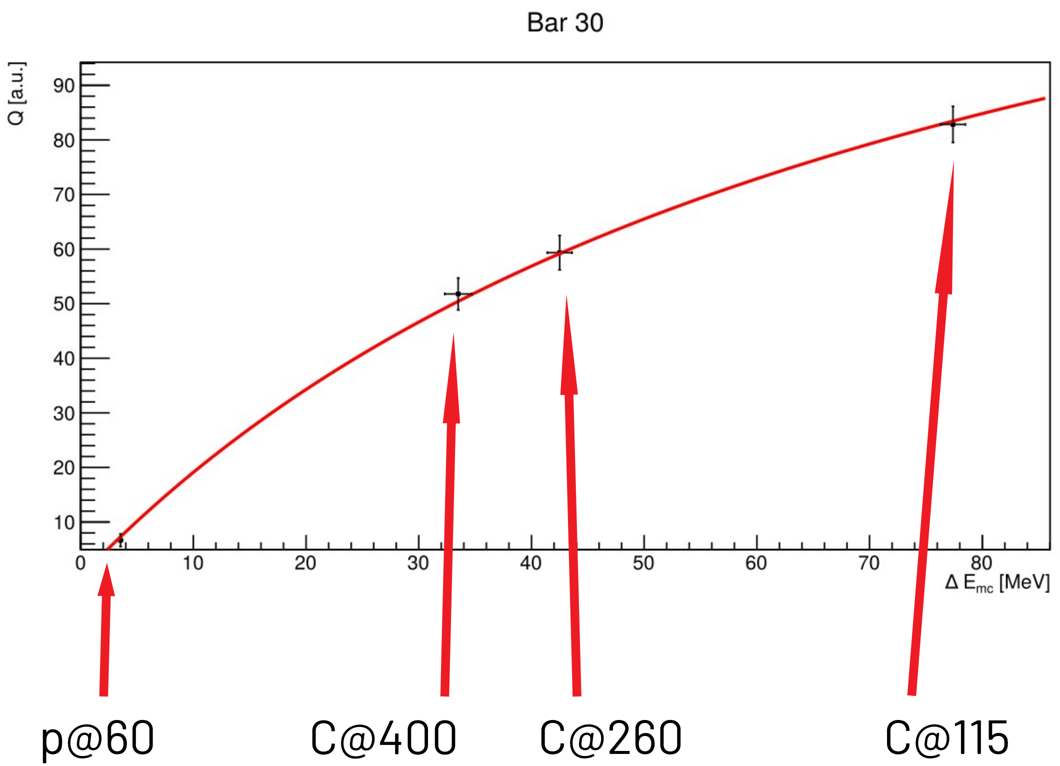
absolute normalization (p_a)

Birks constant x quenching parameter (p_b)

From FLUKA simulation

ΔE_{mc} (MeV)	P @ 60	C @400	C @260	C @115
Front	3.37 ± 0.16	33.4 ± 1.2	42.2 ± 1.1	74.1 ± 1.1
Rear	3.54 ± 0.17	33.5 ± 1.2	42.5 ± 1.1	77.4 ± 1.1

Example of calibration



$$Q = p_a \frac{\Delta E_{mc}}{1 + p_b \Delta E_{mc}}$$

$$p_a = 2.13 \pm 0.18\, e/\mathrm{MeV}$$
$$p_b = (1.19 \pm 0.26) \times 10^{-2}\, \mathrm{MeV}^{-1}$$

The calibration procedure is in *Charge identification of nuclear fragments in particle therapy* paper by Pisa group

Adding GSI Oxygen to Birks

Analysis update on GSI and CNAO data

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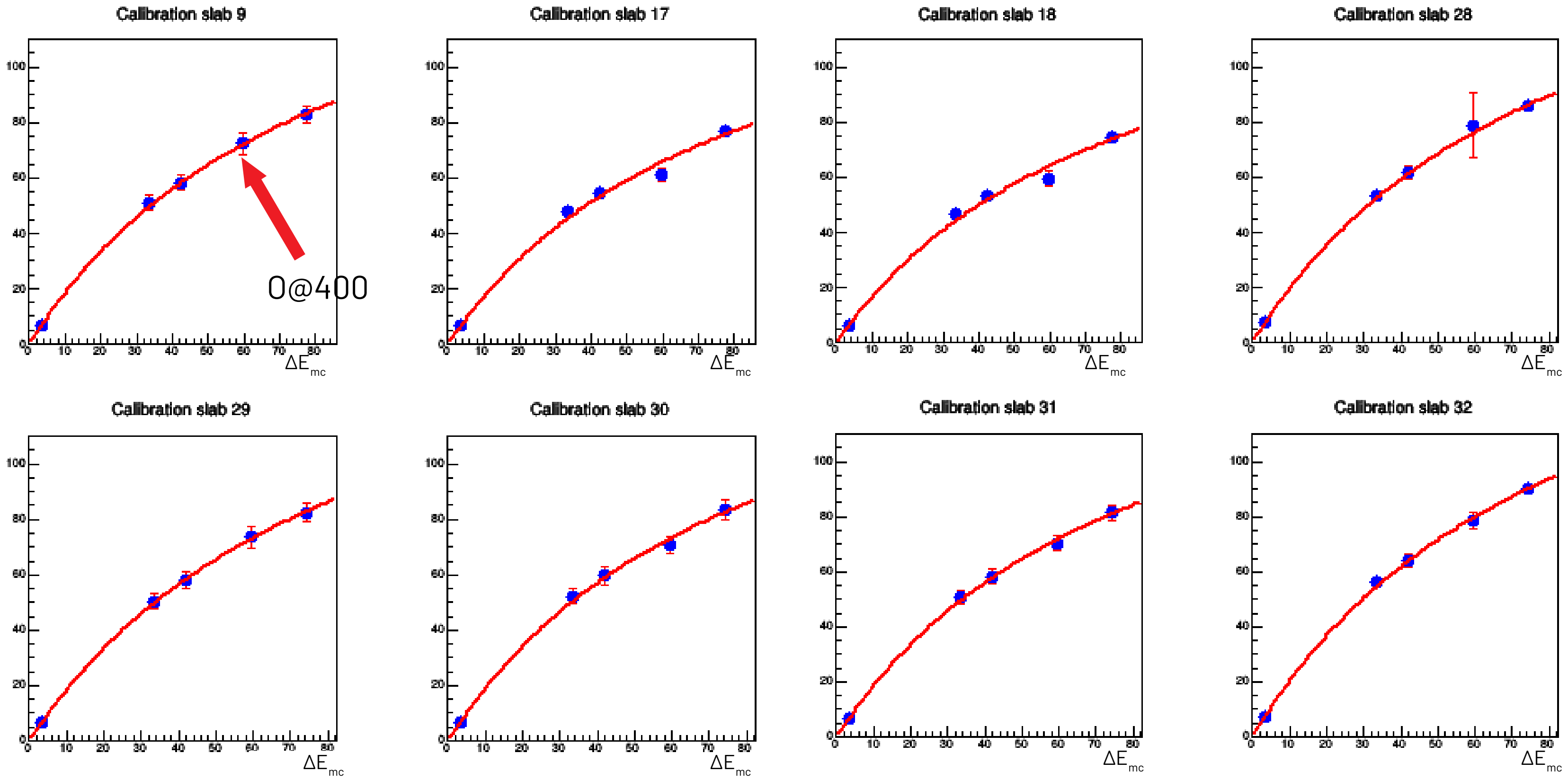

Adding GSI Oxygen to Birks

Analysis update on GSI and CNAO data

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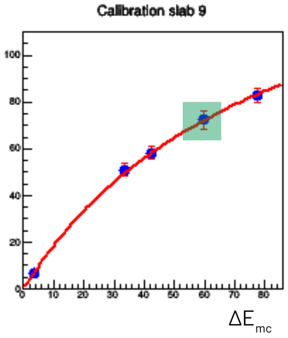
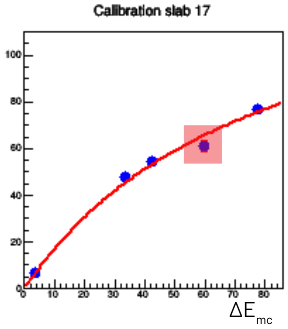
Some Oxygen points lies on the curve, some not→ visible from χ^2 values

Oxygen weight is **lower** than Carbon due to lower statistics→ **fit results** with or w/o Oxygen are the **same**





	Calibration Parameters without Oxygen			with Oxygen		
Slab	p_a	$p_b \cdot 10^2$	χ^2	p_a	$p_b \cdot 10^2$	χ^2
1	1.97 ± 0.14	1.13 ± 0.20	0.7			
2	2.10 ± 0.15	1.13 ± 0.20	0.7			
3	1.92 ± 0.13	1.13 ± 0.20	0.6			
4	2.27 ± 0.15	1.17 ± 0.19	0.6			
5	2.27 ± 0.15	1.19 ± 0.19	0.5			
6	2.13 ± 0.15	1.18 ± 0.19	0.5			
7	2.02 ± 0.14	1.19 ± 0.20	0.5			
9	2.06 ± 0.16	1.19 ± 0.24	0.3	2.06 ± 0.16	1.19 ± 0.24	0.3
17	1.94 ± 0.14	1.22 ± 0.21	0.7	1.92 ± 0.14	1.25 ± 0.21	4.1
18	1.88 ± 0.13	1.22 ± 0.20	0.9	1.86 ± 0.13	1.23 ± 0.21	4.4
20	2.27 ± 0.14	1.34 ± 0.22	1.7			
21	2.20 ± 0.15	1.30 ± 0.22	1.2			
22	2.36 ± 0.16	1.24 ± 0.21	0.8			
23	2.14 ± 0.15	1.21 ± 0.21	0.8			
24	2.33 ± 0.27	1.45 ± 0.37	0.6			
25	1.71 ± 0.13	1.16 ± 0.22	0.2			
26	2.18 ± 0.15	1.18 ± 0.21	0.2			
27	2.27 ± 0.16	1.20 ± 0.21	0.2			
28	2.20 ± 0.16	1.20 ± 0.21	0.2	2.20 ± 0.16	1.20 ± 0.21	0.2
29	2.05 ± 0.17	1.14 ± 0.25	0.1	2.05 ± 0.17	1.13 ± 0.25	0.1
30	2.13 ± 0.18	1.19 ± 0.26	0.2	2.14 ± 0.18	1.24 ± 0.26	0.9
31	2.10 ± 0.17	1.22 ± 0.24	0.2	2.10 ± 0.17	1.24 ± 0.25	0.5
32	2.28 ± 0.16	1.17 ± 0.20	0.4	2.28 ± 0.16	1.18 ± 0.20	0.5
33	1.91 ± 0.14	1.16 ± 0.21	0.3	1.91 ± 0.14	1.16 ± 0.21	0.4
34	2.29 ± 0.19	1.41 ± 0.30	1.1	2.32 ± 0.19	1.56 ± 0.30	2.9
36	1.94 ± 0.15	1.11 ± 0.23	0.6	1.92 ± 0.16	1.16 ± 0.24	5.9
37	1.98 ± 0.15	1.18 ± 0.23	0.5	1.98 ± 0.16	1.29 ± 0.25	7.9
38	2.21 ± 0.17	1.27 ± 0.23	0.8	2.20 ± 0.17	1.35 ± 0.24	6.8

Z reconstruction of GSI fragments

Analysis update on GSI and CNAO data

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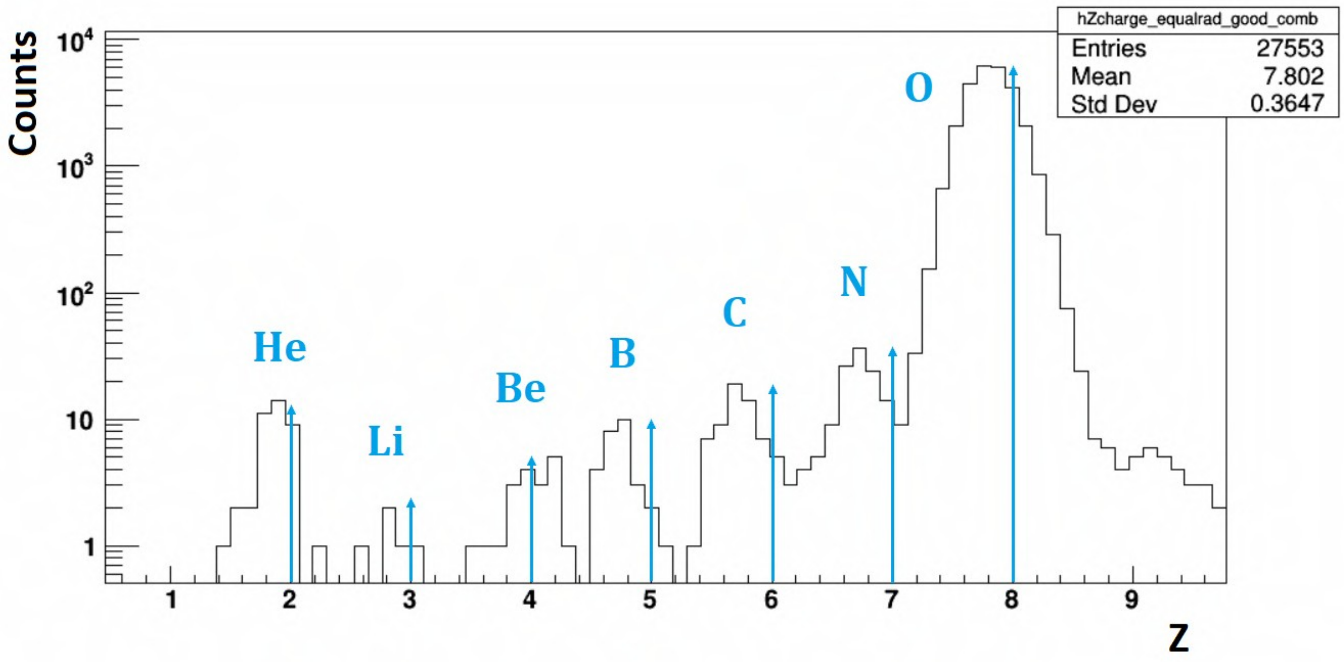

Systematic **shift** on Z reconstruction under investigation → despite low statistics FOOT is able to **identify** all produced **fragments**

Evaluation of attenuation length

The light attenuation length **is not** the attenuation along the bar (losses, reflections etc…)

We expect a **lower value** for the attenuation length in a 40x2x0.3 cm bar

PROPERTIES	EJ-200	EJ-204	EJ-208	EJ-212
Light Output (% Anthracene)	64	68	60	65
Scintillation Efficiency (photons/1 MeV e⁻)	10,000	10,400	9,200	10,000
Wavelength of Maximum Emission (nm)	425	408	435	423
Light Attenuation Length (cm)	380	160	400	250
Rise Time (ns)	0.9	0.7	1.0	0.9
Decay Time (ns)	2.1	1.8	3.3	2.4
Pulse Width, FWHM (ns)	2.5	2.2	4.2	2.7
No. of H Atoms per cm^3 ($x10^{22}$)	5.17	5.15	5.17	5.17
No. of C Atoms per cm^3 ($x10^{22}$)	4.69	4.68	4.69	4.69
No. of Electrons per cm^3 ($x10^{23}$)	3.33	3.33	3.33	3.33
Density (g/cm^3)	1.023	1.023	1.023	1.023
Polymer Base	Polyvinyltoluene			
Refractive Index	1.58			
Softening Point	75°C			
Vapor Pressure	Vacuum-compatible			
Coefficient of Linear Expansion	7.8×10^{-5} below 67°C			
Light Output vs. Temperature	At 60°C, L.O. = 95% of that at 20°C No change from 20°C to -60°			
Temperature Range	-20°C to 60°C			

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The following plots are fitted with:

$$f_l(x) = A_l \exp\left(-\frac{L/2 + x}{\lambda}\right), \quad f_r(x) = A_r \exp\left(-\frac{L/2 - x}{\lambda}\right)$$

from *Development and characterization of a ΔE-TOF detector prototype for the FOOT experiment* paper by FOOT collaboration

Evaluation of attenuation length

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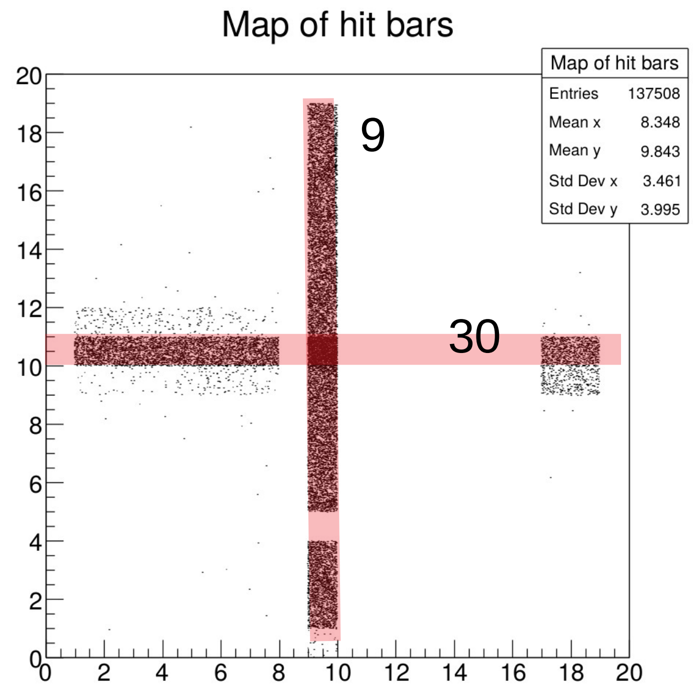
We choose two bars (9 and 30) with most of statistics and we evaluate the **attenuation length,** results from **both bars** are reported



C@115, 260, 400 MeV/u and p@60 MeV

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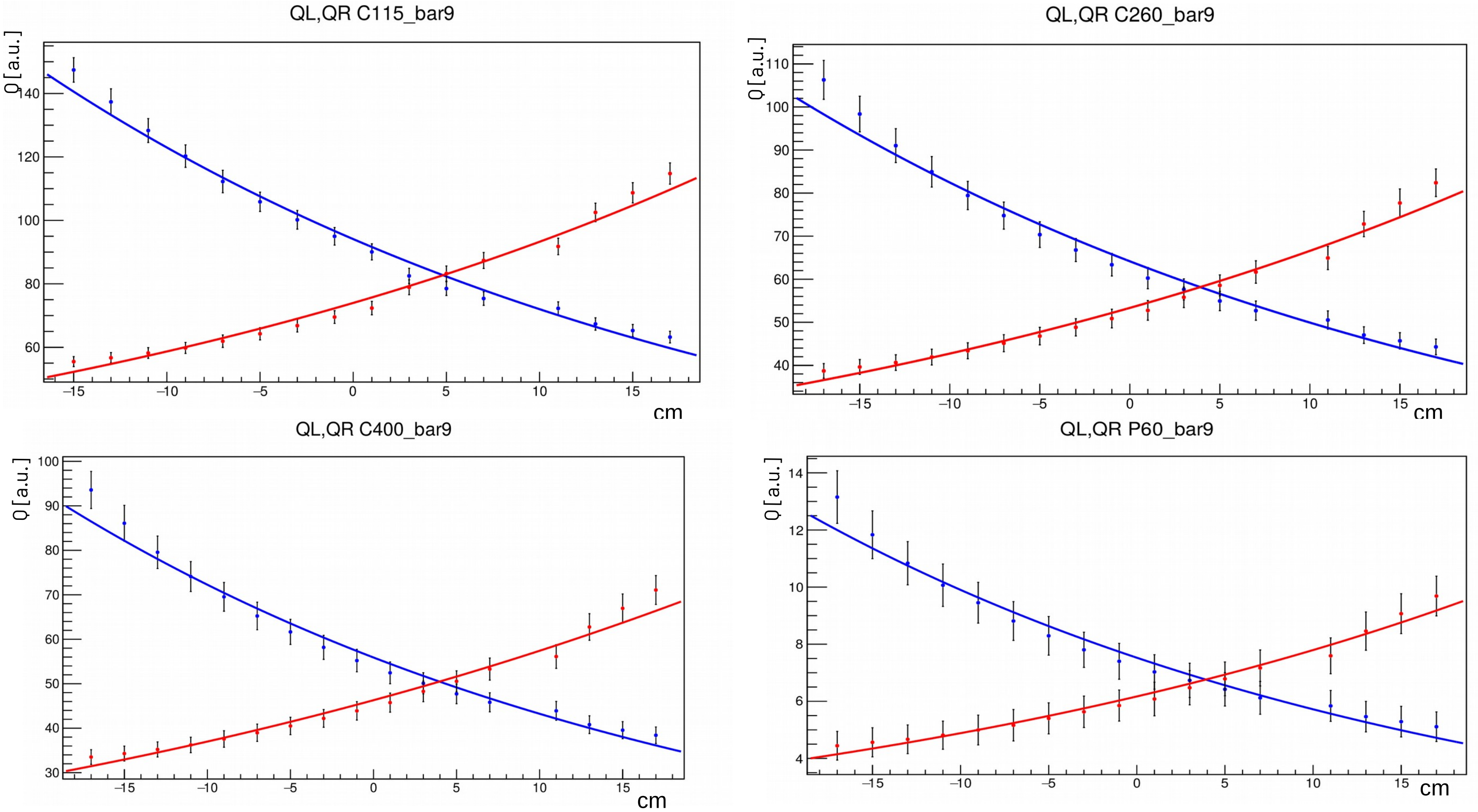

Results for bar 9

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	C@115MeV/u	C@260MeV/u	C@400MeV/u	p@60MeV
λ_{left} [cm]	**43±1.4**	**45.1±2.1**	**45.5±2.4**	**42.8±4.1**
λ_{right} [cm]	**37.4±1.1**	**39.9±1.6**	**38.9±1.7**	**36.5±2.8**

Systematic **difference** between λ left and right, maybe due to a different coupling between bar and left/right SiPM?
Results are compatible over different energies!

Results for bar 30

Riccardo Ridolfi

	C@115MeV/u	C@260MeV/u	C@400MeV/u	p@60MeV
λ_{left} [cm]	**43.0±1.6**	**42.1±2.2**	**42.0±2.3**	**41.9±4.5**
λ_{right} [cm]	**43.5±1.6**	**43.4±2.1**	**42.2±2.3**	**39.2±3.8**

No systematic **difference** between λ left and right, results are compatible over different energies!

Behaviour of $\sqrt{Q_L Q_R}$

Analysis update on GSI and CNAO data

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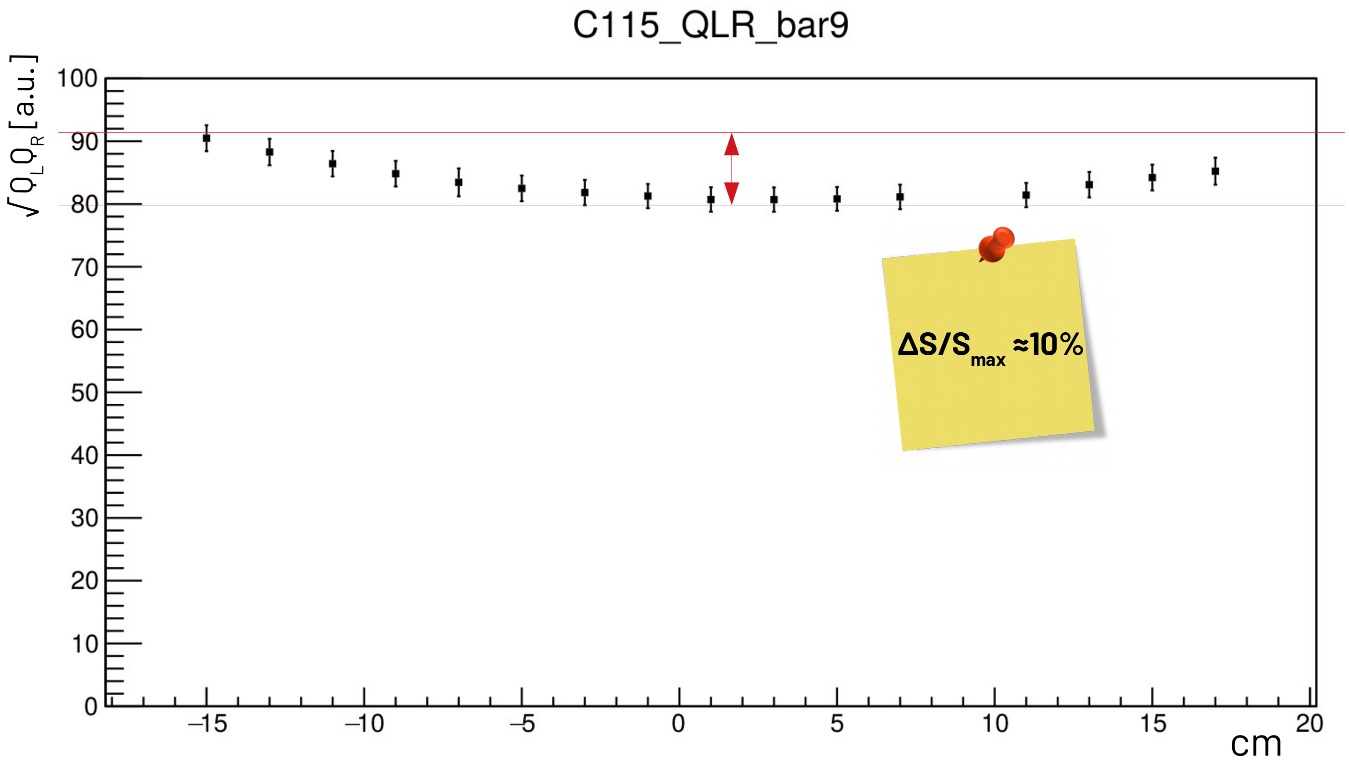

Relative **difference** between maximum and mimimum $\sqrt{Q_L Q_R}$ values is **≈ 10% →** if corrected, better resolution can be achieved!

Behaviour of $\sqrt{QLQR}$

Analysis update on GSI and CNAO data

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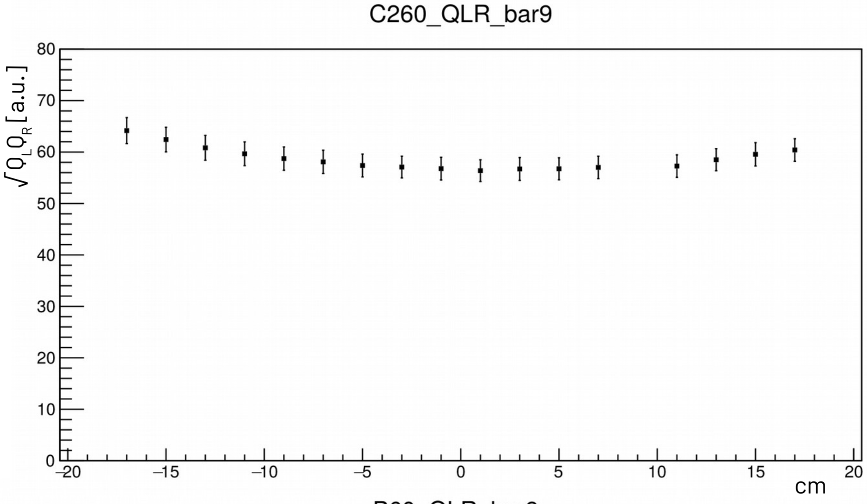
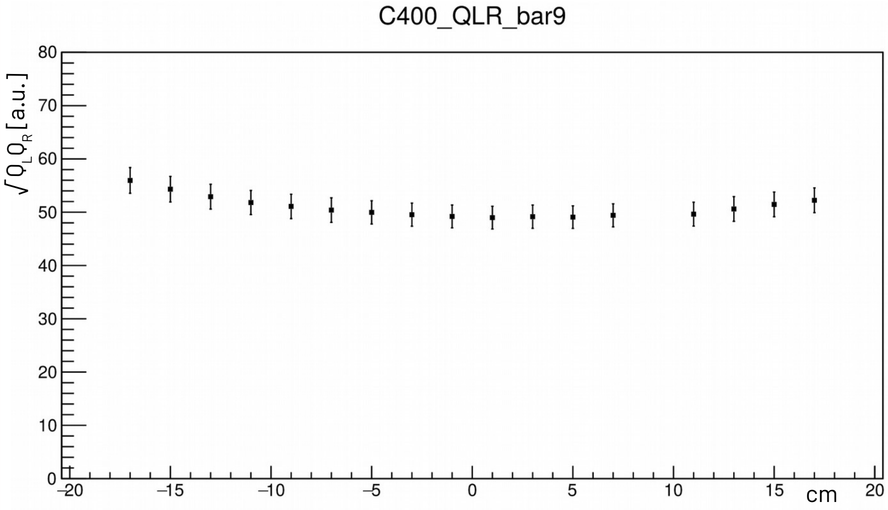
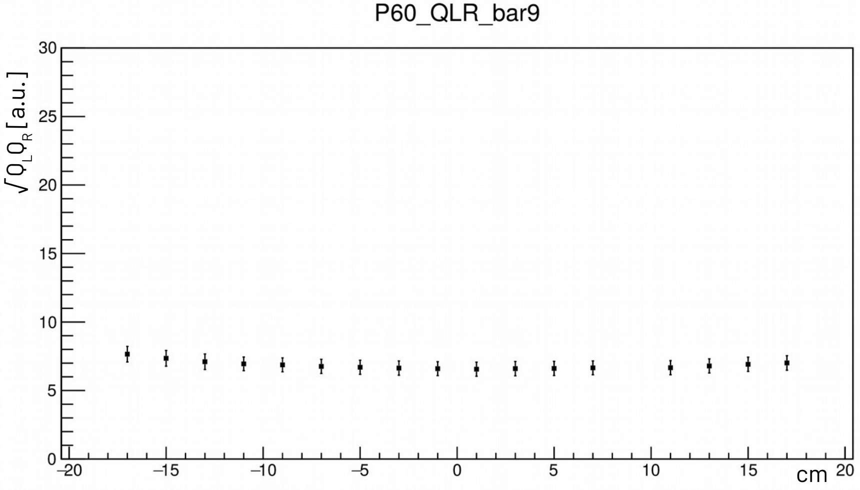
Same trend observed for all Carbon energies and protons (relative difference ~10%)







Conclusions

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GSI data:

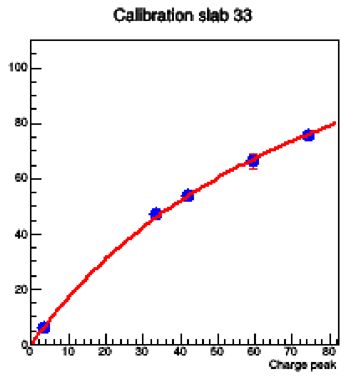
- dE/dx resolution ~4%
- TOF resolution (89±1) ps, below 100 ps
- Resolution on Z reconstruction ~2%
- First fragments in FOOT

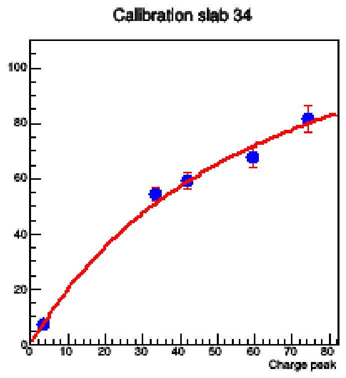
CNAO data:

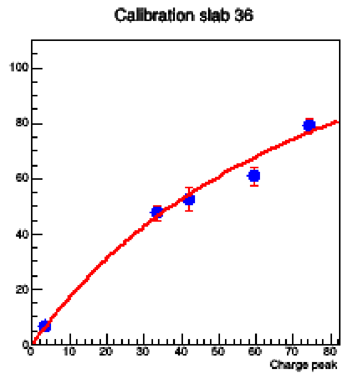
- Calibration of bars with Birks' law
- Z reconstruction on GSI data, systematic shift observed → Oxygen underestimation, difference between GSI and CNAO setup?
- Attenuation length is consistent over different energies
- Observed systematic λ difference in bar 9→ bar-SiPM coupling?
- Signal $\sqrt{Q_L Q_R}$ shows position dependency, up to 10% difference from the centre to the end of the bar → more precise calibration needed ("pixel by pixel")?

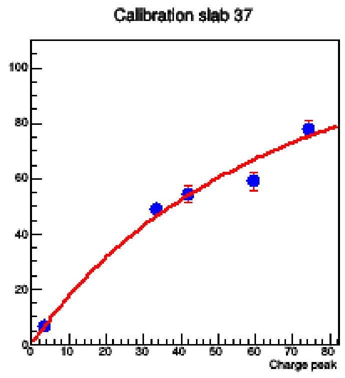
Thank for your attention!

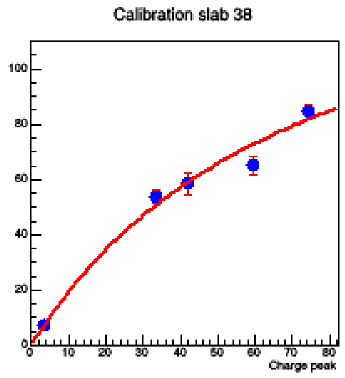
Calibration using CNAO and GSI Data: Slab 34 - 38

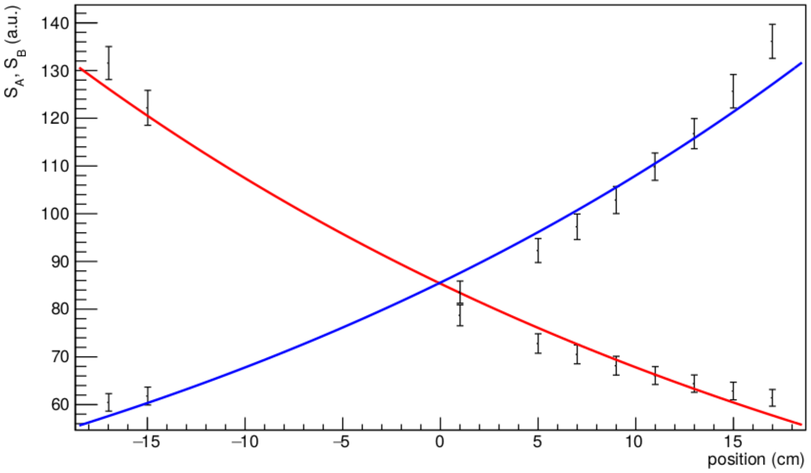




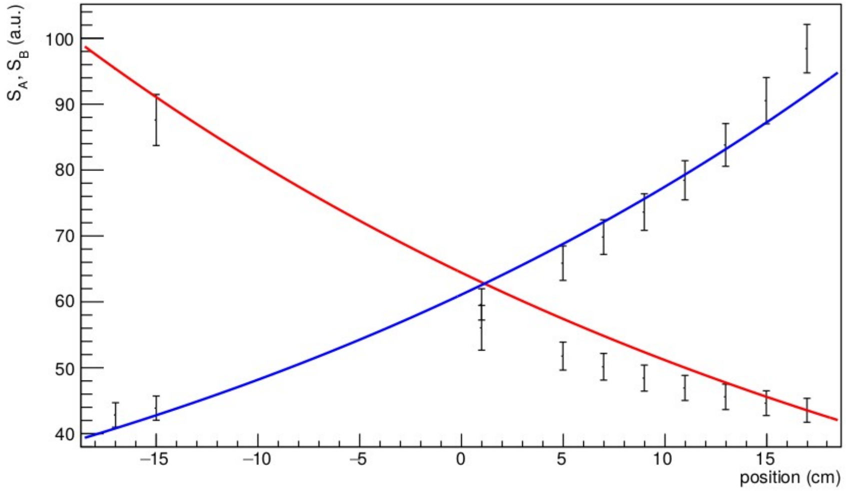




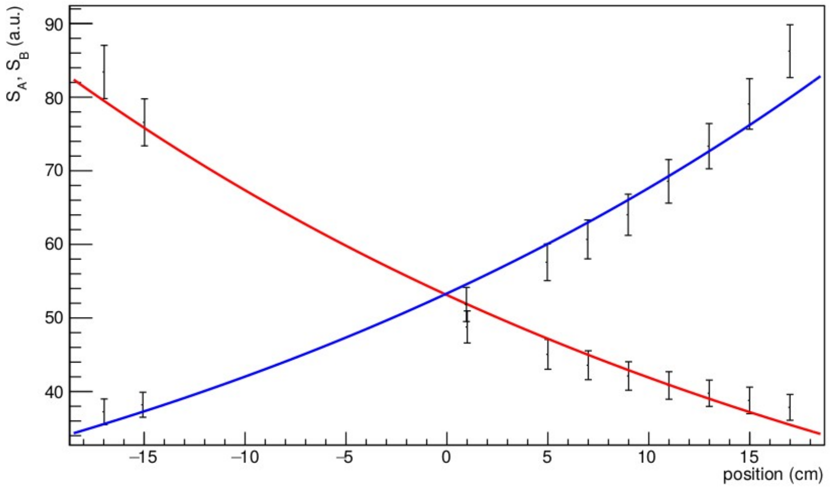




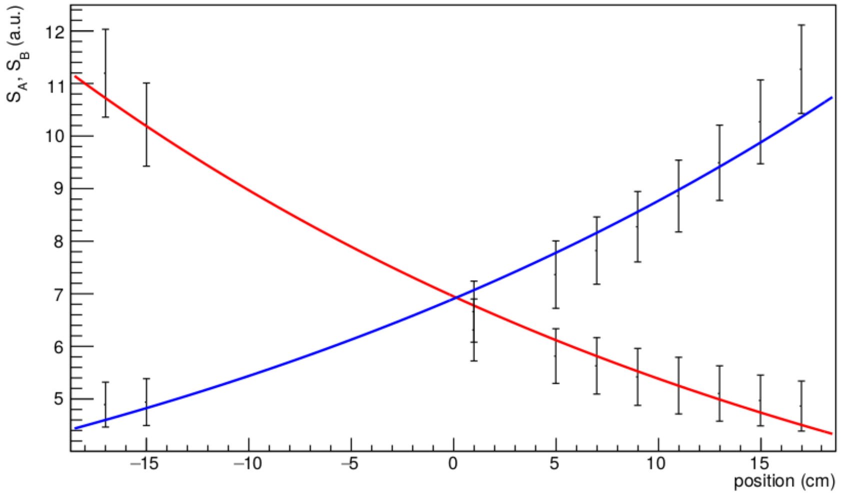
(a) *Fascio di ioni carbonio a 115 MeV/u*



(b) *Fascio di ioni carbonio a 260 MeV/u*



(c) *Fascio di ioni carbonio a 400 MeV/u*



(d) *Fascio di protoni a 60 MeV*