Analysis report for GSI and CNAO data

Riccardo Ridolfi
on behalf of the Bologna group
riccardo.ridolfi@bo.infn.it

FOOT Physics Skype Meeting – 29 October 2019

Outline

GSI data (from Chiara's bachelor thesis)

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

Outline

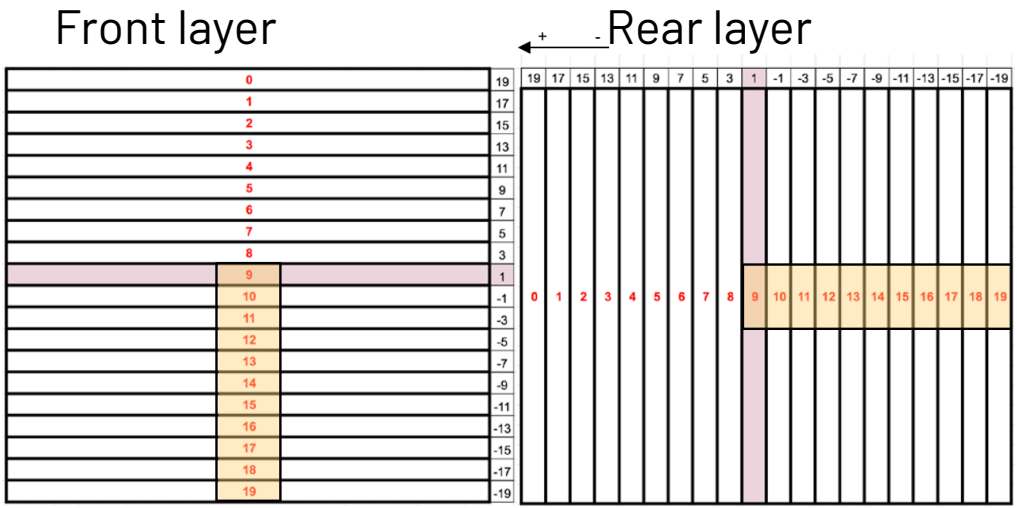
GSI data (from Chiara's bachelor thesis)

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

CNAO data (from Caterina's bachelor thesis)

- Calibration with Carbon and proton beams
- Measurement of effective attenuation length of a bar

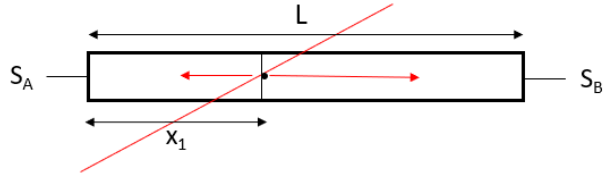
GSI data: how to handle



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

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

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

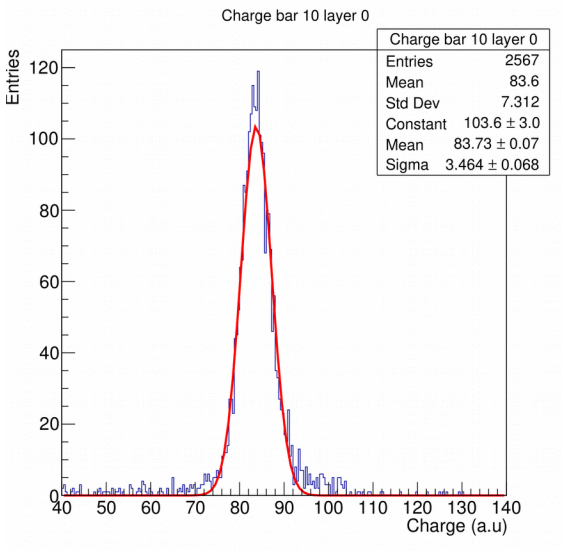


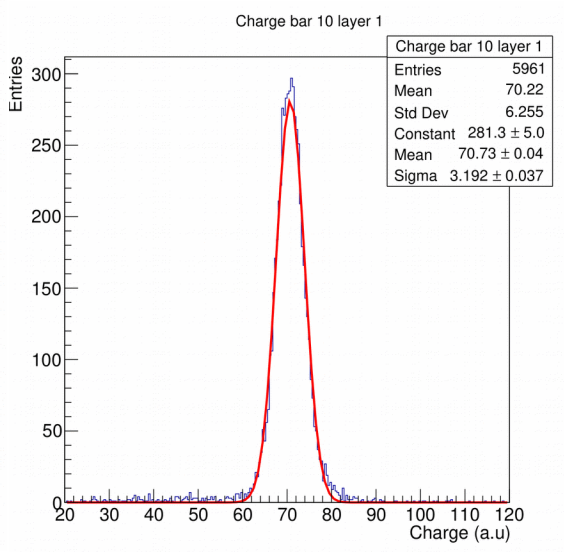
Calibration run (nr. 2242) ~70k events, physics runs (nr. 2239-40-41) ~60k events in total

Calibration of bars

Analysis report for GSI and CNAO data

Riccardo Ridolfi

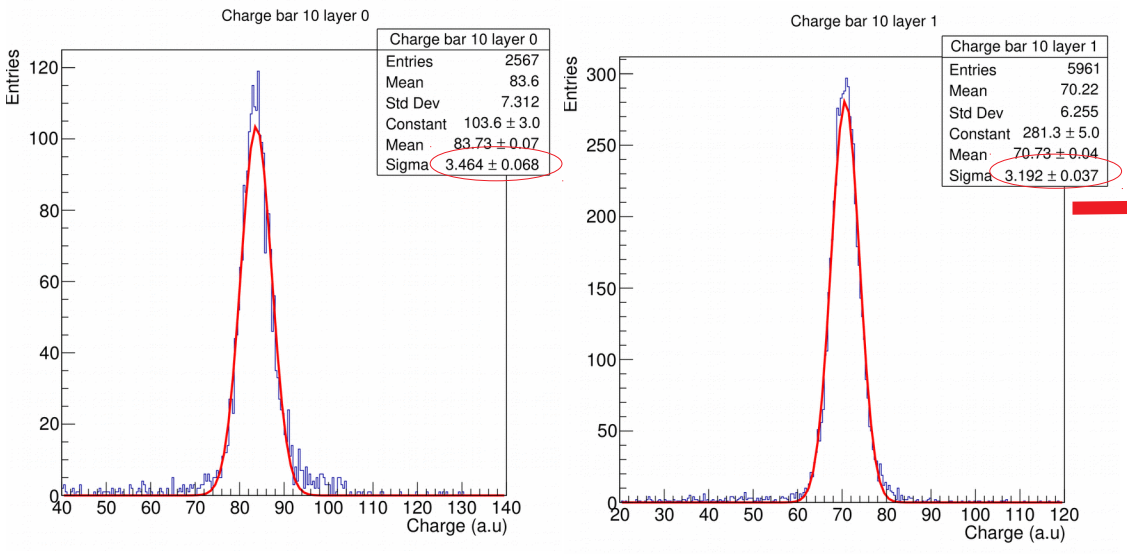




Calibration of bars

Analysis report for GSI and CNAO data

Riccardo Ridolfi



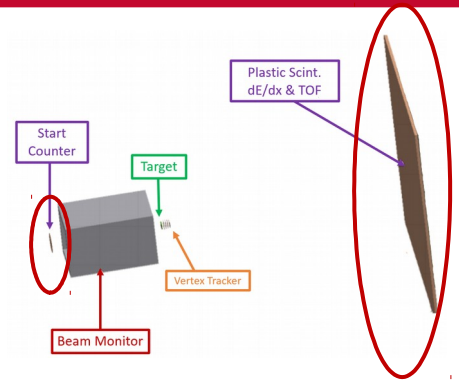
dE/dx resolution ~ **4%**

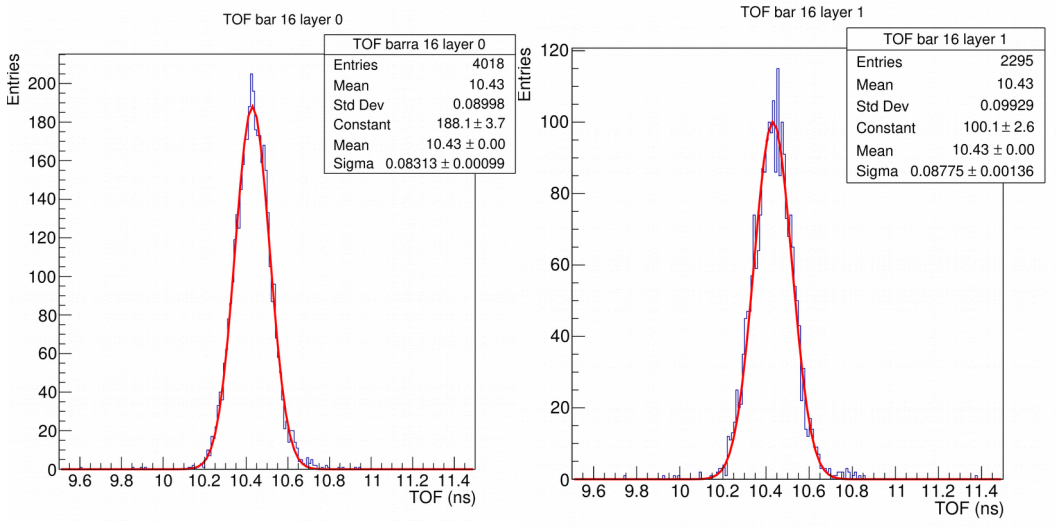
TOF resolution

Analysis report for GSI and CNAO data

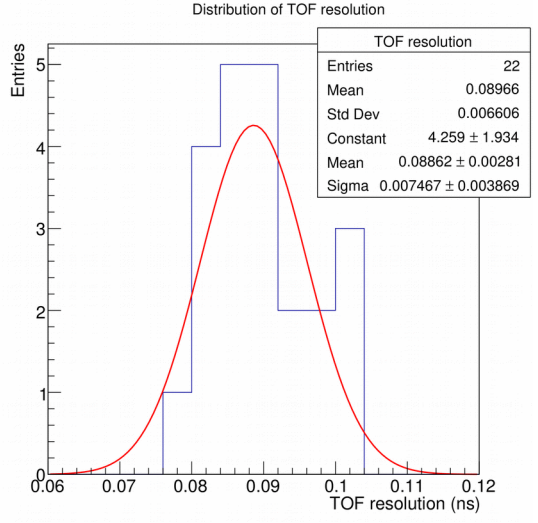
Riccardo Ridolfi

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

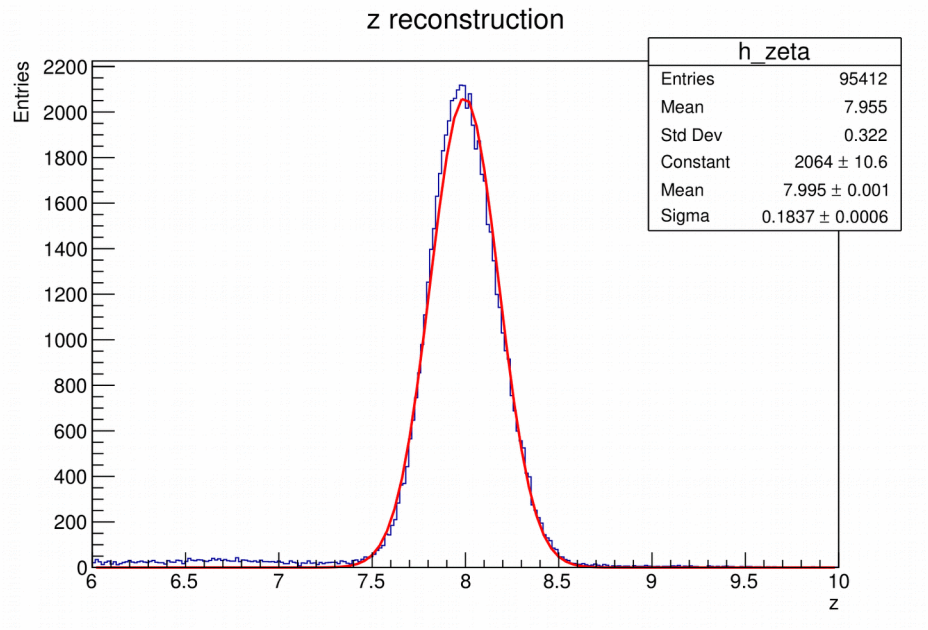


Checking charge of GSI Oxygen

Analysis report for GSI and CNAO data

Riccardo Ridolfi

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



Resolution on Z reconstruction **~ 2%**

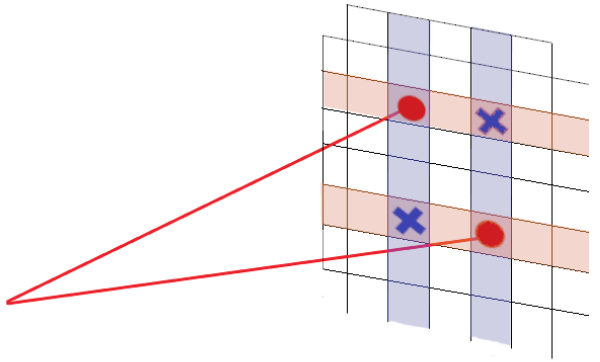
Fragmentation runs

Analysis report for GSI and CNAO data

Riccardo Ridolfi

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

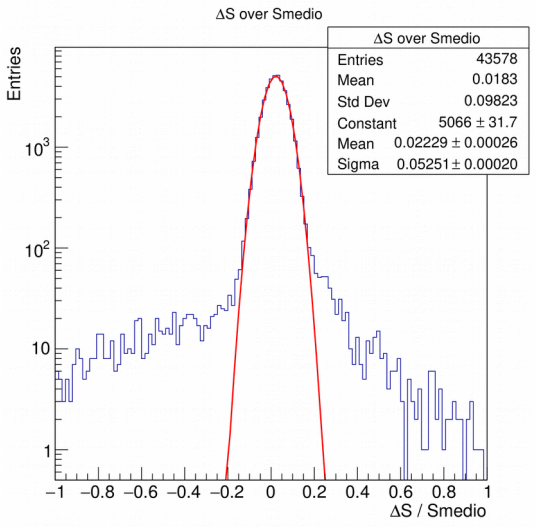
$$\frac{\Delta S}{S_{mean}} = \frac{S_{oriz} - S_{vert}}{\left(\frac{S_{oriz}+S_{vert}}{2}\right)} \qquad \frac{\Delta T}{T_{mean}} = \frac{T_{oriz} - T_{vert}}{\left(\frac{T_{oriz}+T_{vert}}{2}\right)}$$

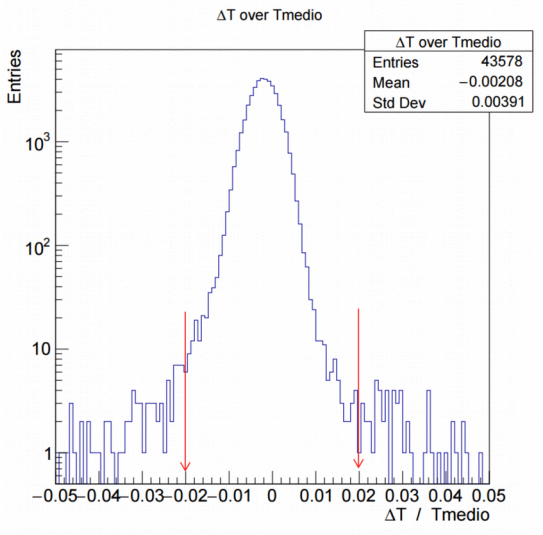


Two hits in two layers tagged as **good combination** if:

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

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

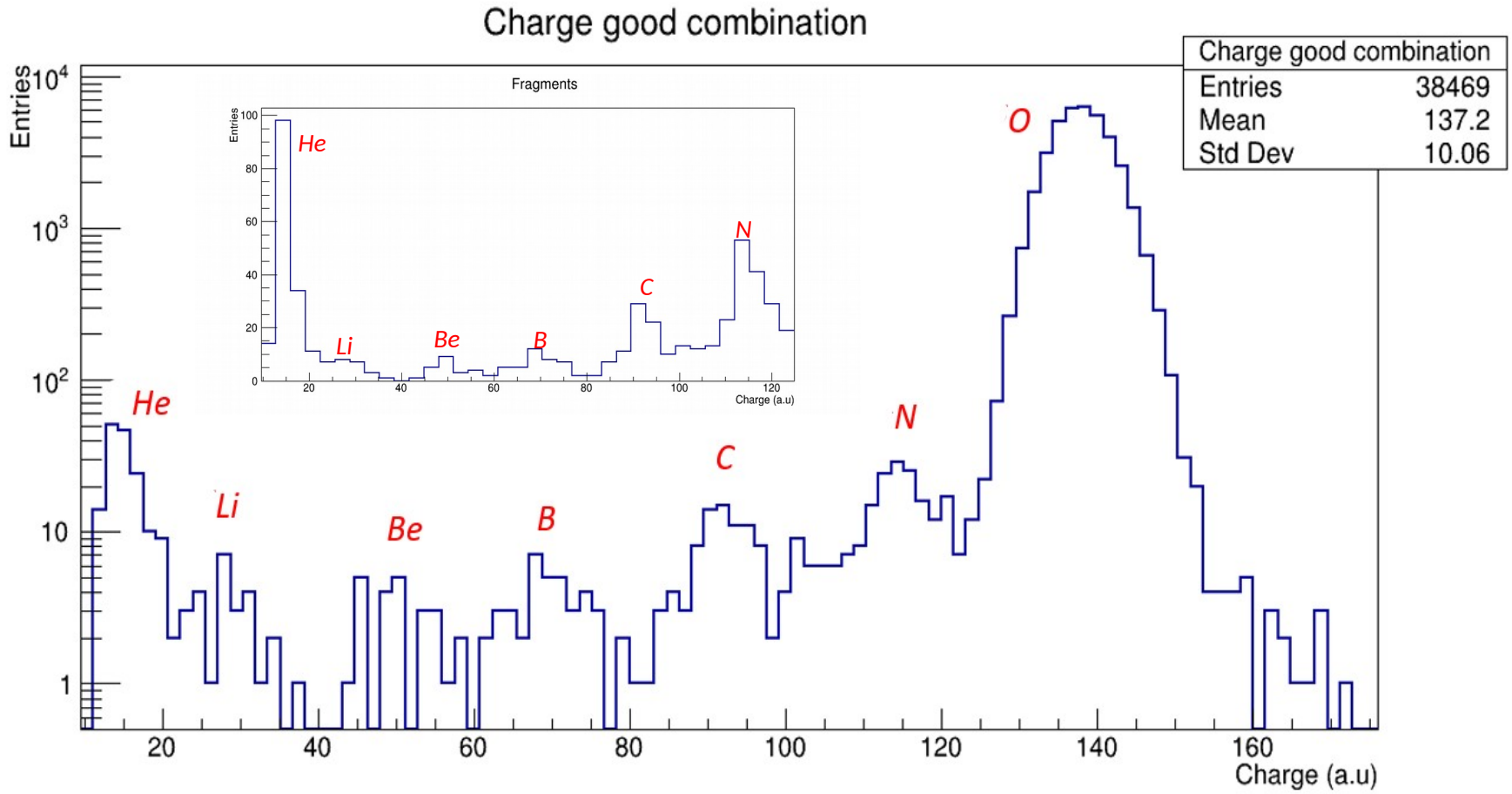




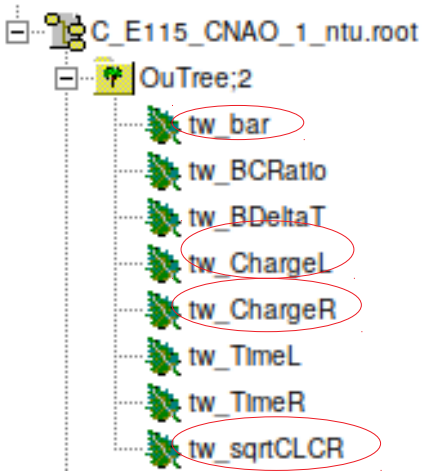
Spotted fragments in FOOT

Analysis report for GSI and CNAO data

Riccardo Ridolfi



CNAO data: ntuple format



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

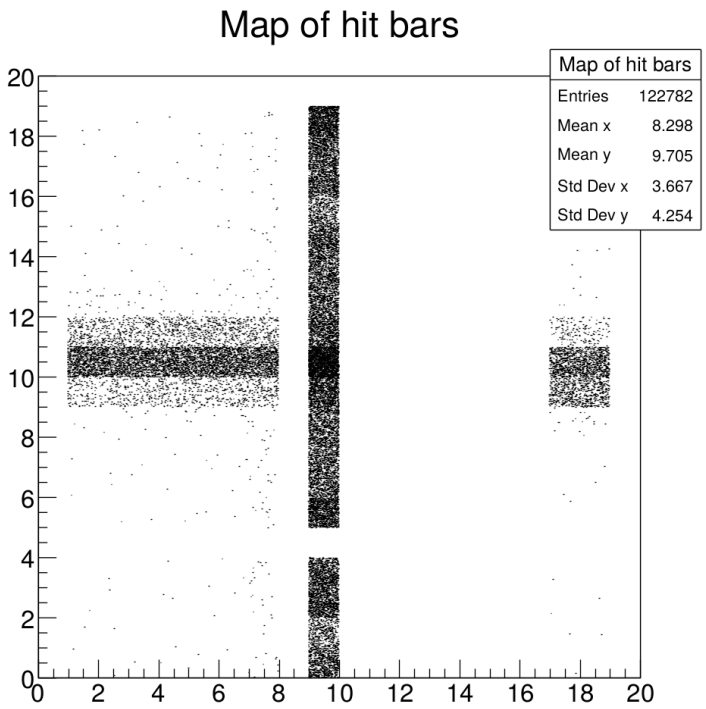
Every .root file is the sum of all runs at the same energy

Layout of hit bars

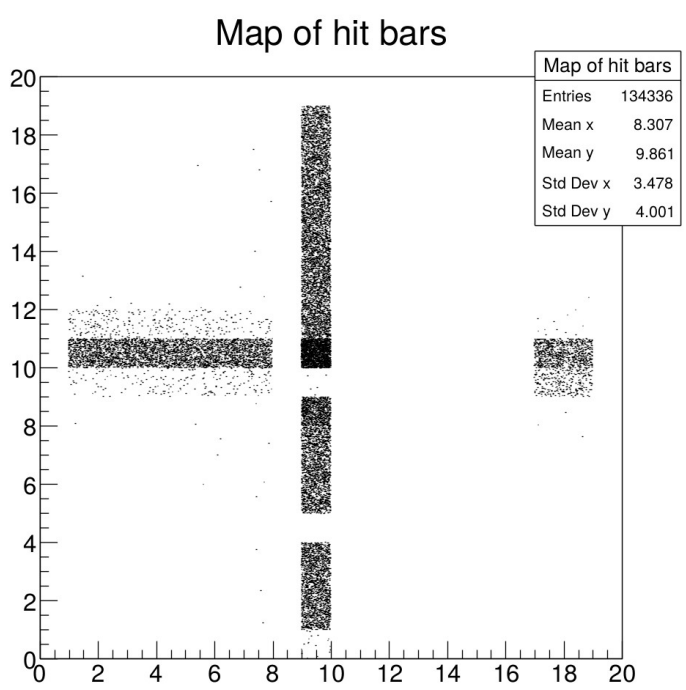
Analysis report for GSI and CNAO data

Riccardo Ridolfi

p@60



C@115

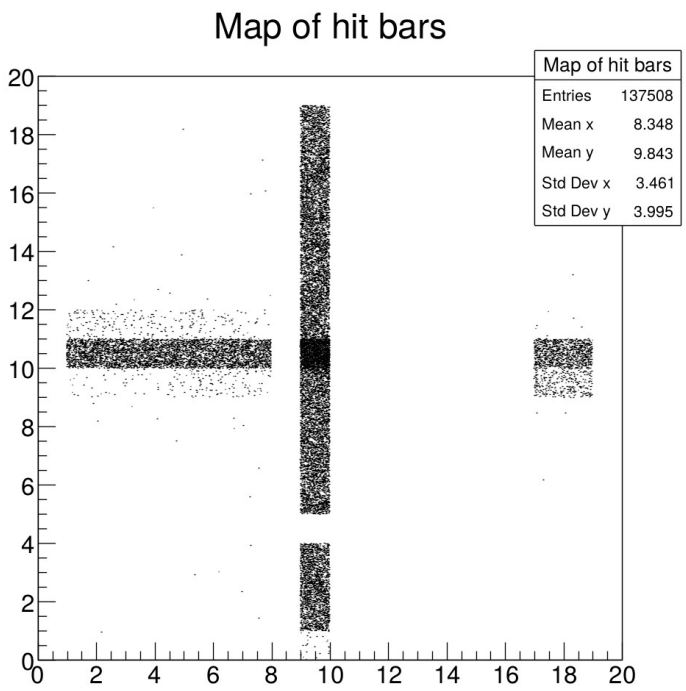


Layout of hit bars

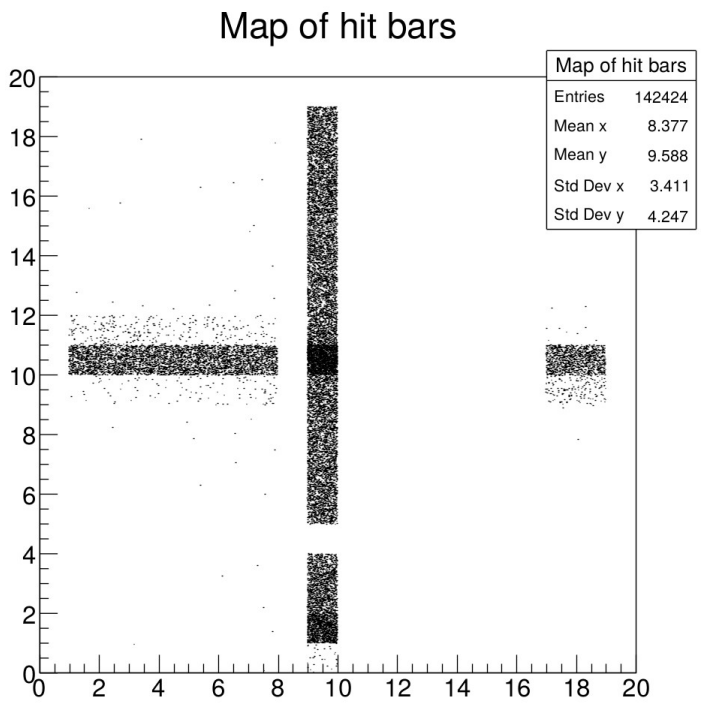
Analysis report for GSI and CNAO data

Riccardo Ridolfi

C@260



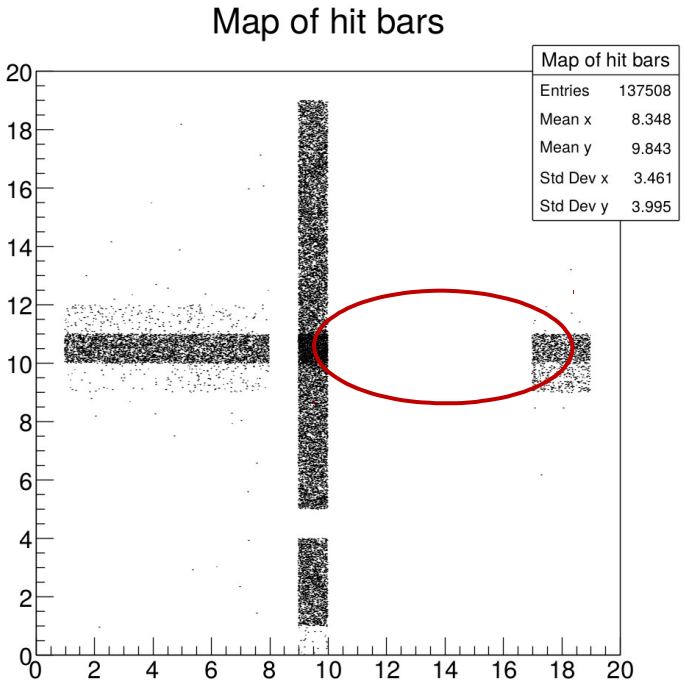
C@400

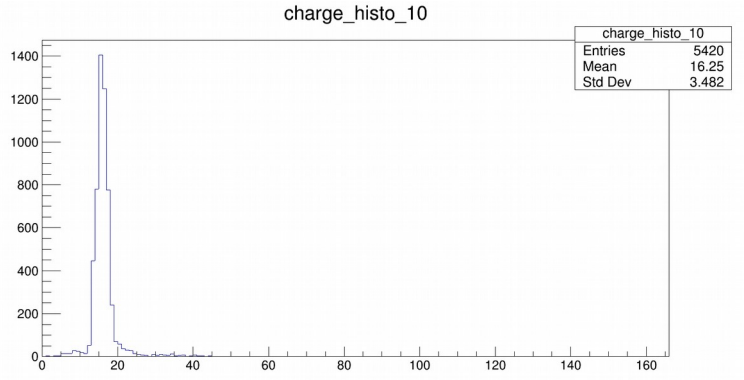


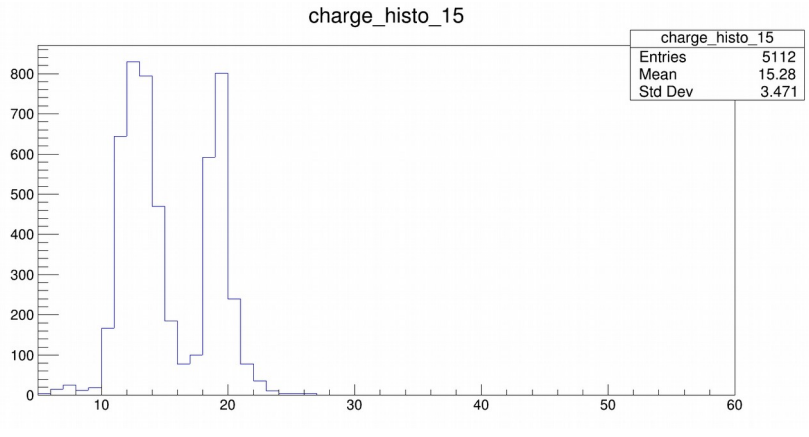
Why those holes?

Analysis report for GSI and CNAO data

Riccardo Ridolfi







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

Light vs energy: Birks' Law

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

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

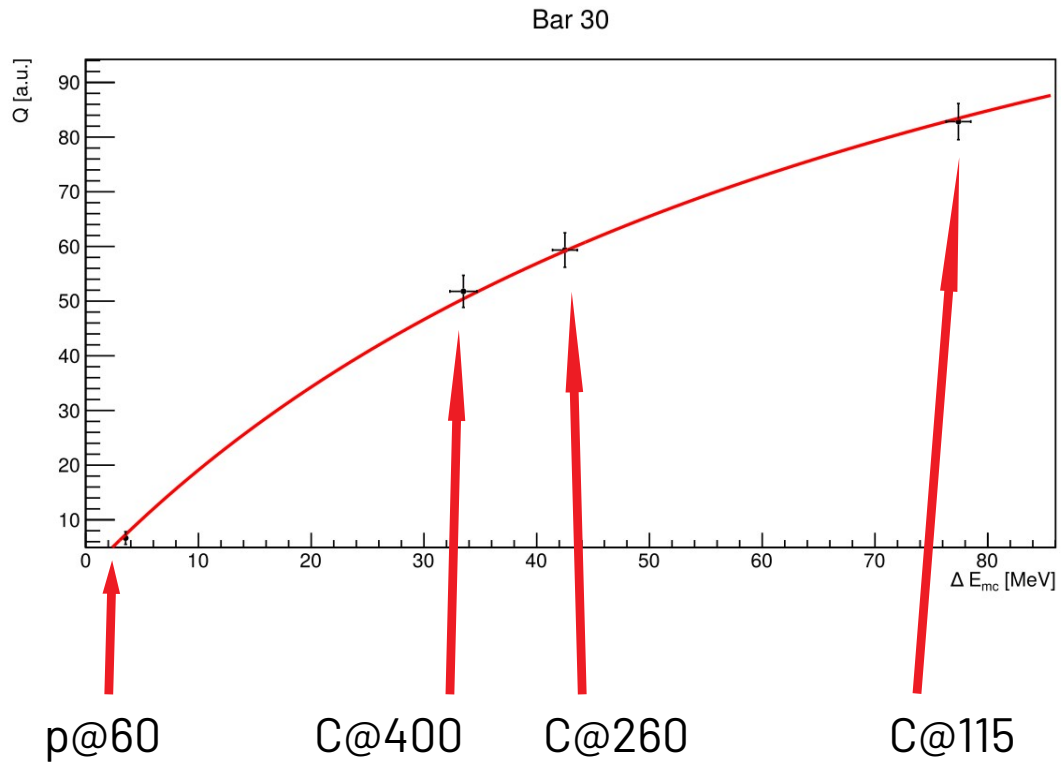
absolute normalization

Birks constant x quenching parameter

From FLUKA simulation

ΔEmc (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



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

$$p_a = 2.15 \pm 0.24\,\mathrm{e/MeV}$$
$$p_b = (1.29 \pm 0.34) \times 10^{-2}\,\mathrm{MeV}^{-1}$$

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

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			

The following plots are fitted with:

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

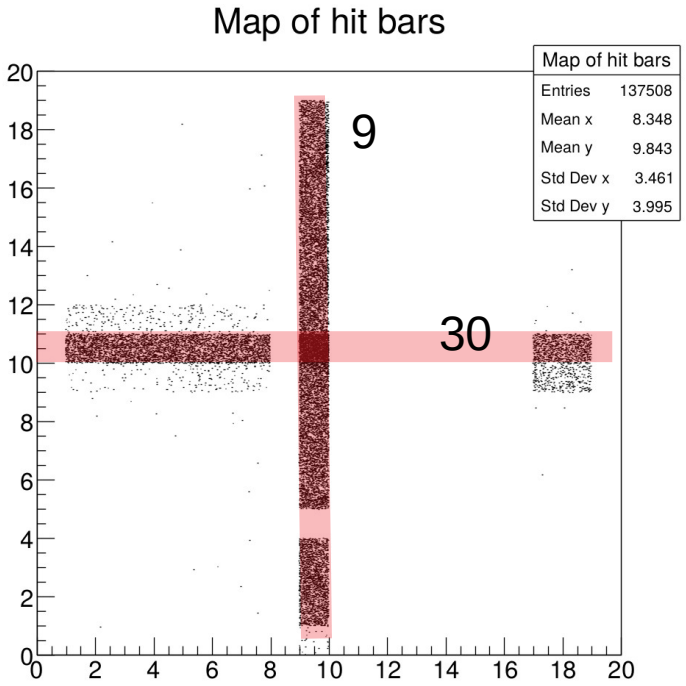
from *Development and characterization of a ΔE-TOF detector prototype for the FOOT experiment* paper by FOOT collaboration

Evaluation of attenuation length

Analysis report for GSI and CNAO data

Riccardo Ridolfi

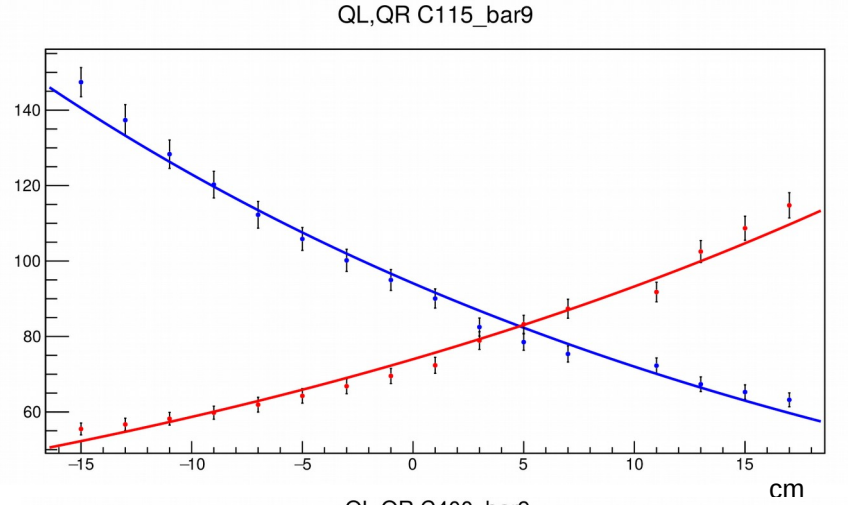
We choose two bars (9 and 30) with most of statistics and we evaluate the **attenuation length,** results from **bar 9** are reported

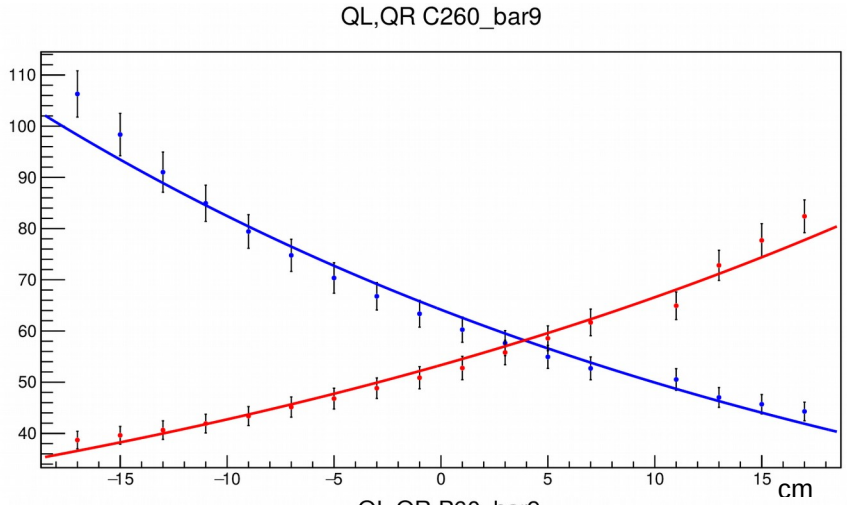


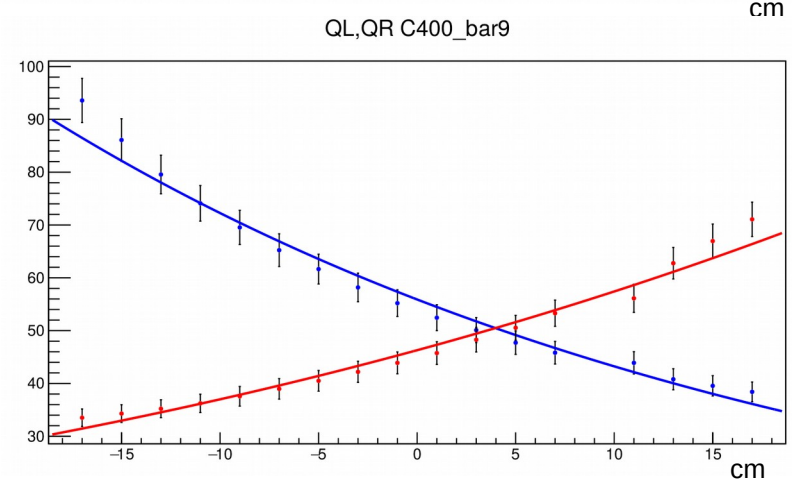
C@115, 260, 400 MeV/u and p@60 MeV

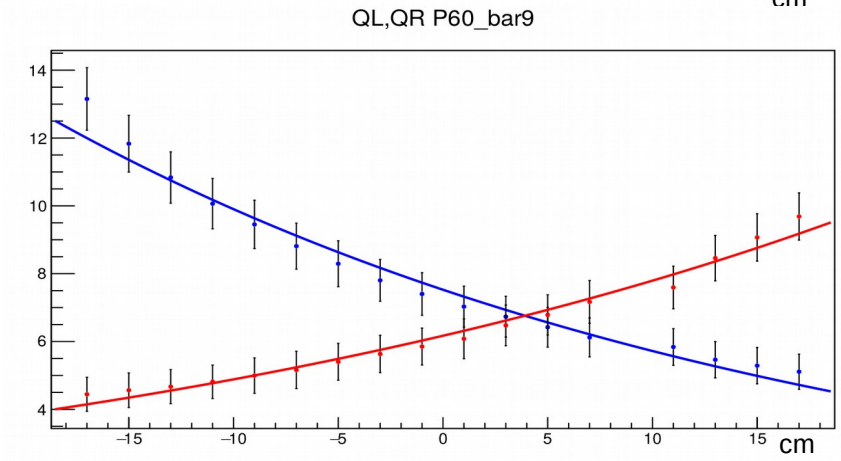
Analysis report for GSI and CNAO data

Riccardo Ridolfi









Results for bar 30

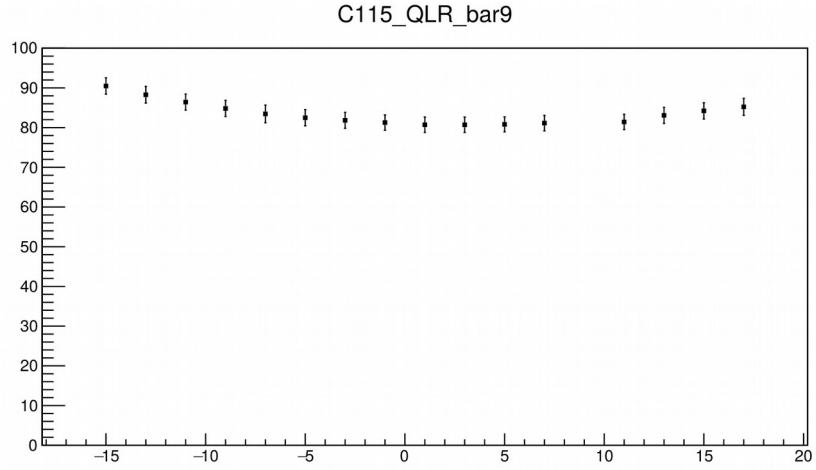
	C@115MeV/u	C@260MeV/u	C@400MeV/u	p@60MeV
λ_{left} [cm]	**43±1.4**	**45.1±2.1**	**45.5±2.4**	**42.8±4.1**
λ_{right} [cm]	**37.4±1.1**	**39.9±1.6**	**38.9±1.7**	**36.5±2.8**

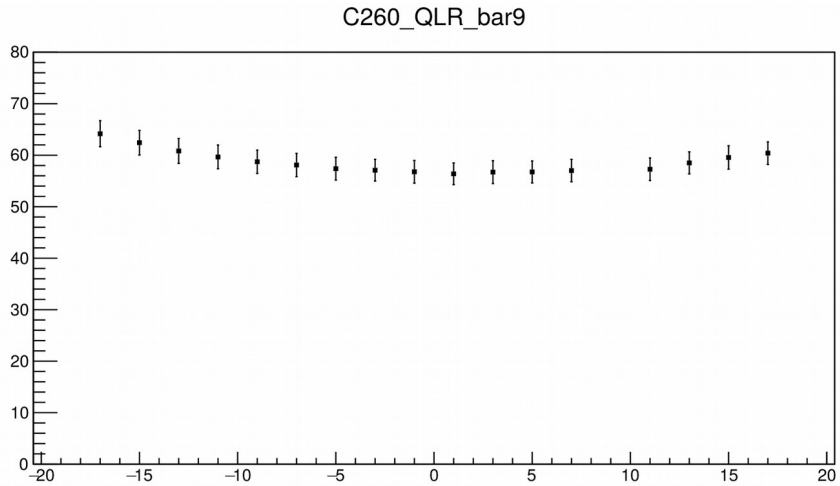
Systematic **difference** between λ left and right, results are compatible over different energies!

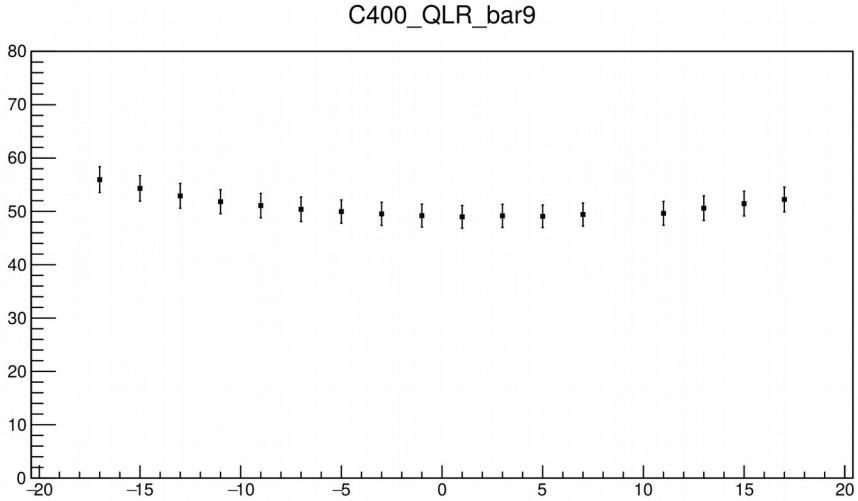
Behaviour of $\sqrt{QLQR}$

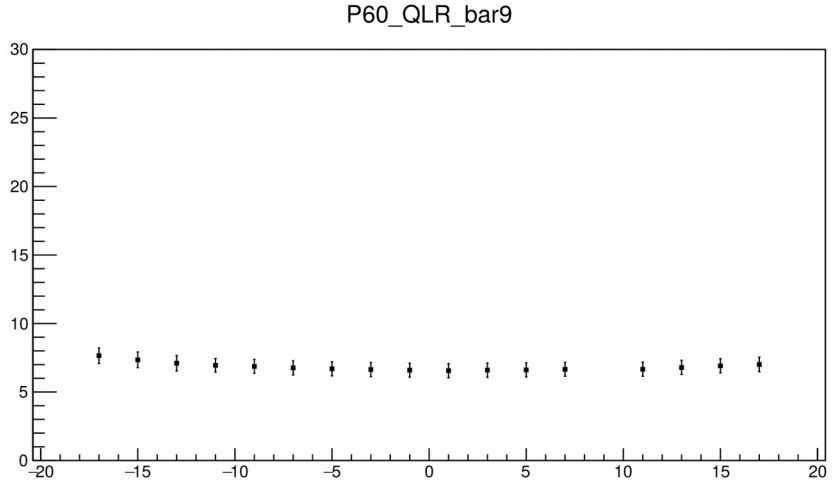
Analysis report for GSI and CNAO data

Riccardo Ridolfi









Conclusions

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:

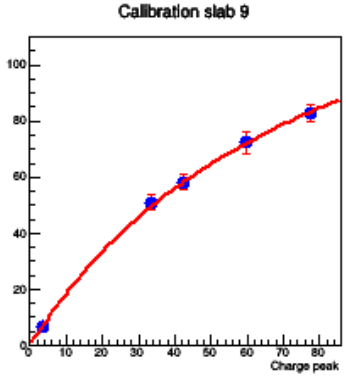
- Calibration of bars with Birks' law
- Attenuation length is consistent over different energies

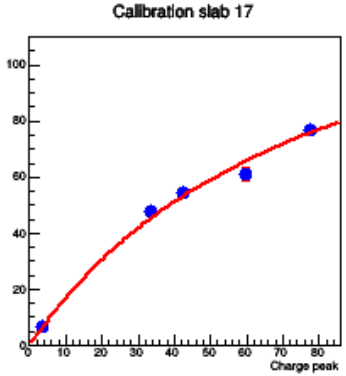
Future steps:

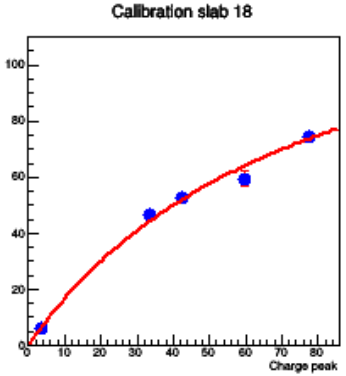
- Add GSI Oxygen point to new CNAO data (made by Roberto with old data)
- Use updated calibration to reconstruct Z of GSI fragments

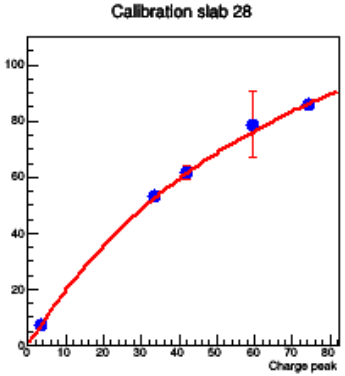
Thank for your attention!

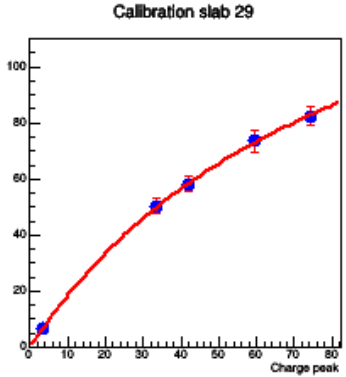
Calibration using CNAO and GSI Data: Slab 9 - 33

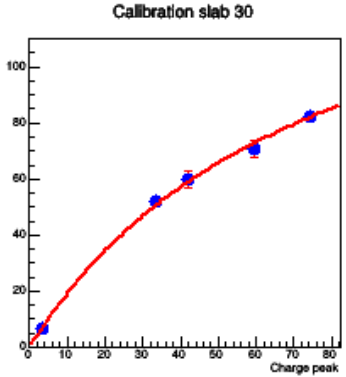


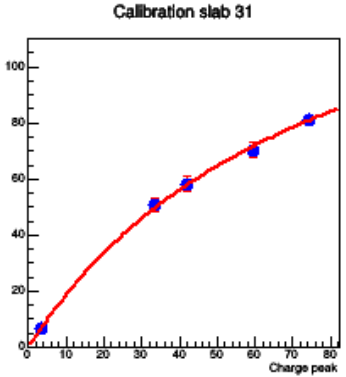


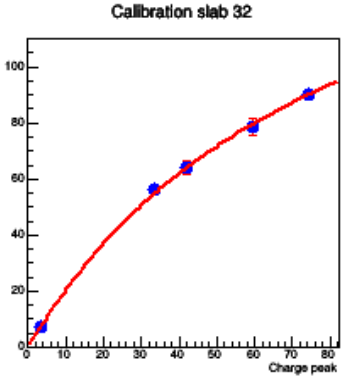












Calibration using CNAO and GSI Data: Slab 34 - 38