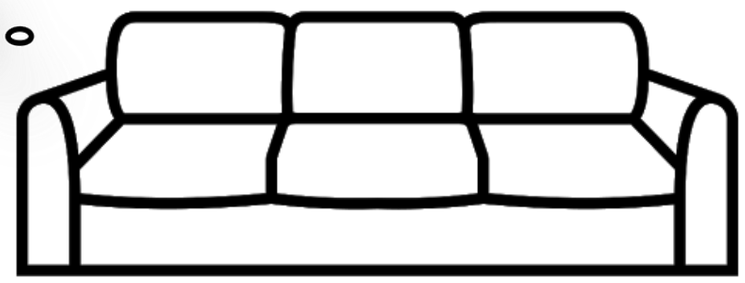
10/12/2020

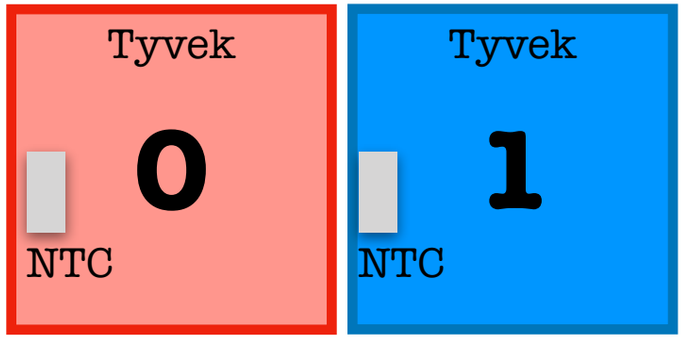
Study of the light absorption in BGO crystals

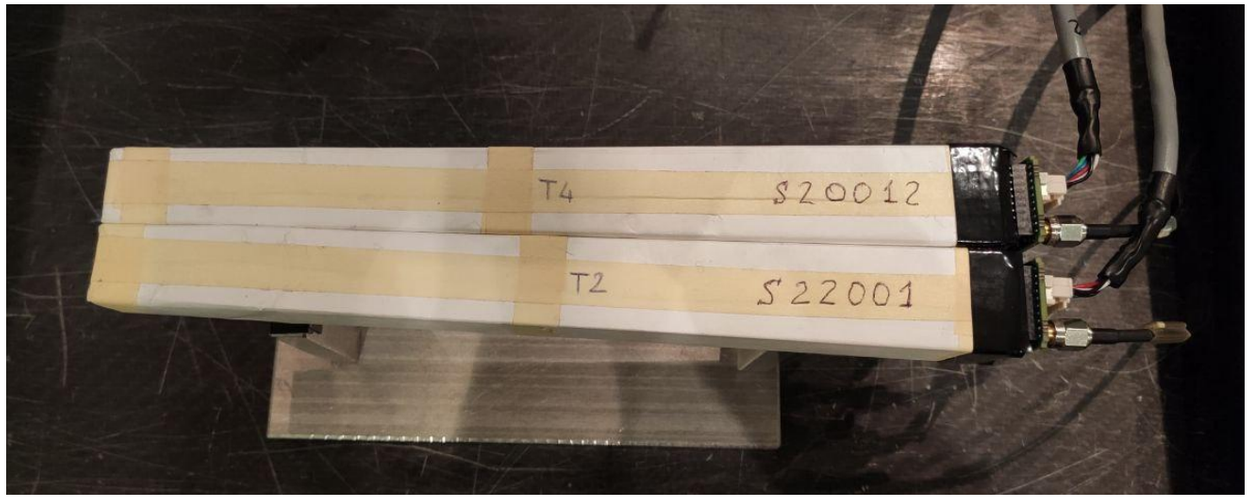
IX Collaboration Meeting



S. Argirò, N. Bartosik, F. Cavanna, P. Cerello, G. Giraudo, E. Lopez Torres, M. Mignone, L. Ramello, **L. Scavarda**, M.Sitta

TEST BEAM SETUP





SETUP

1. Temperature monitoring of both crystals
2. One scan (70-220 MeV proton, 115-400 MeV/A C) with BGO+**WaveDream** setup
3. Scan along the crystal length with 70, 170 MeV proton beam and 115, 260 MeV/A carbon beam

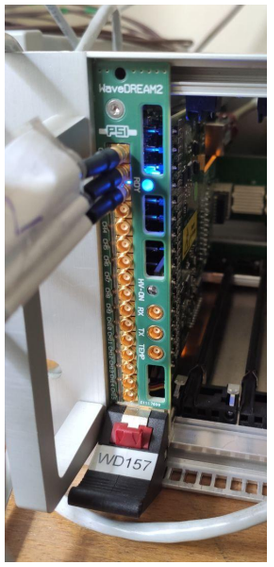
GOAL

1. Understand better the temperature fluctuations
2. Study the performance (energy resolution) of BGO+WaveDream
3. Study the optical light absorption along the crystal

- frequency: 1GS/s (1024 samplings in 1μs)
- gain: 0.5
- HV SiPM: 34.5V

Wavedream

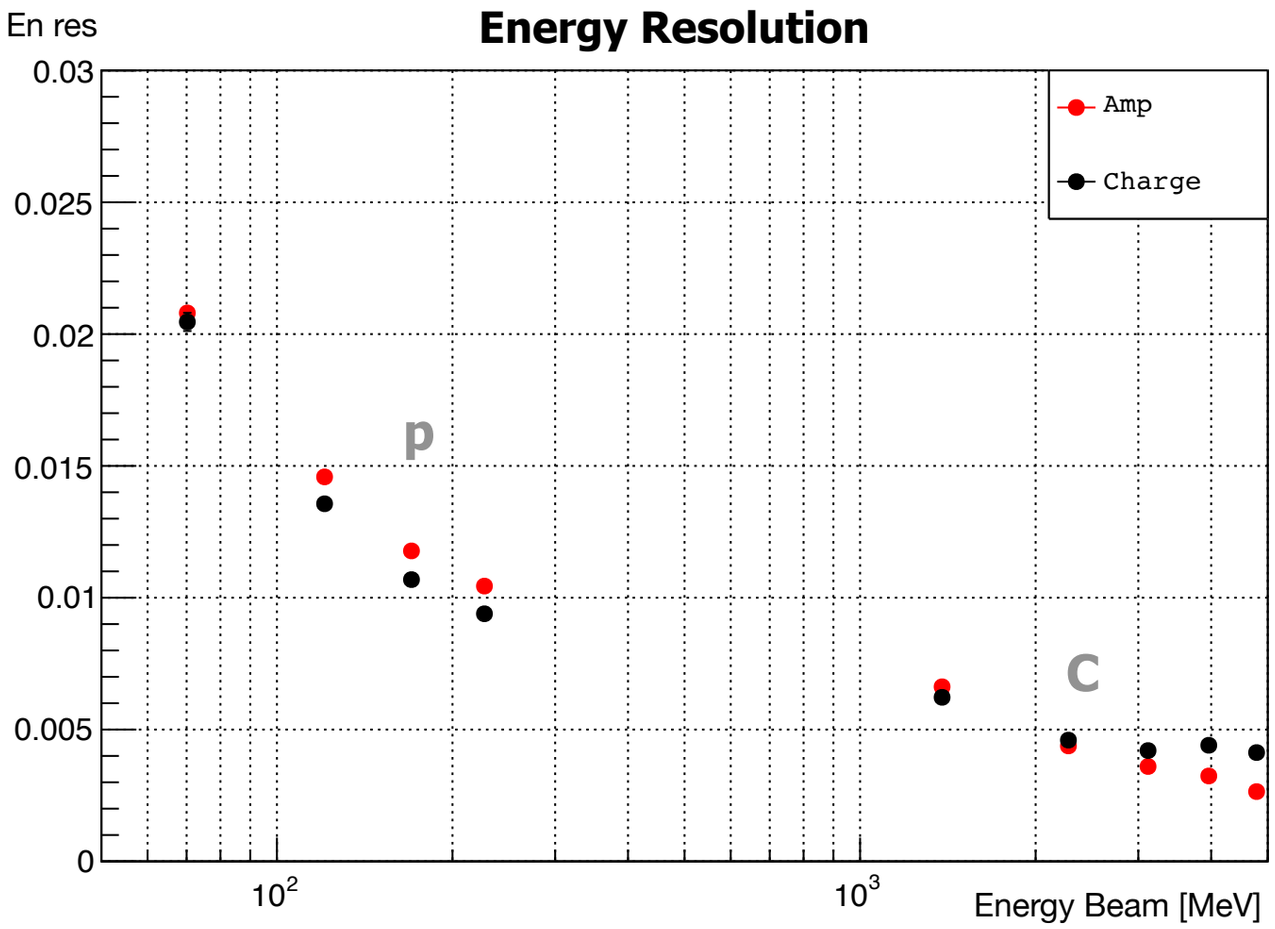
Read SiPM signals

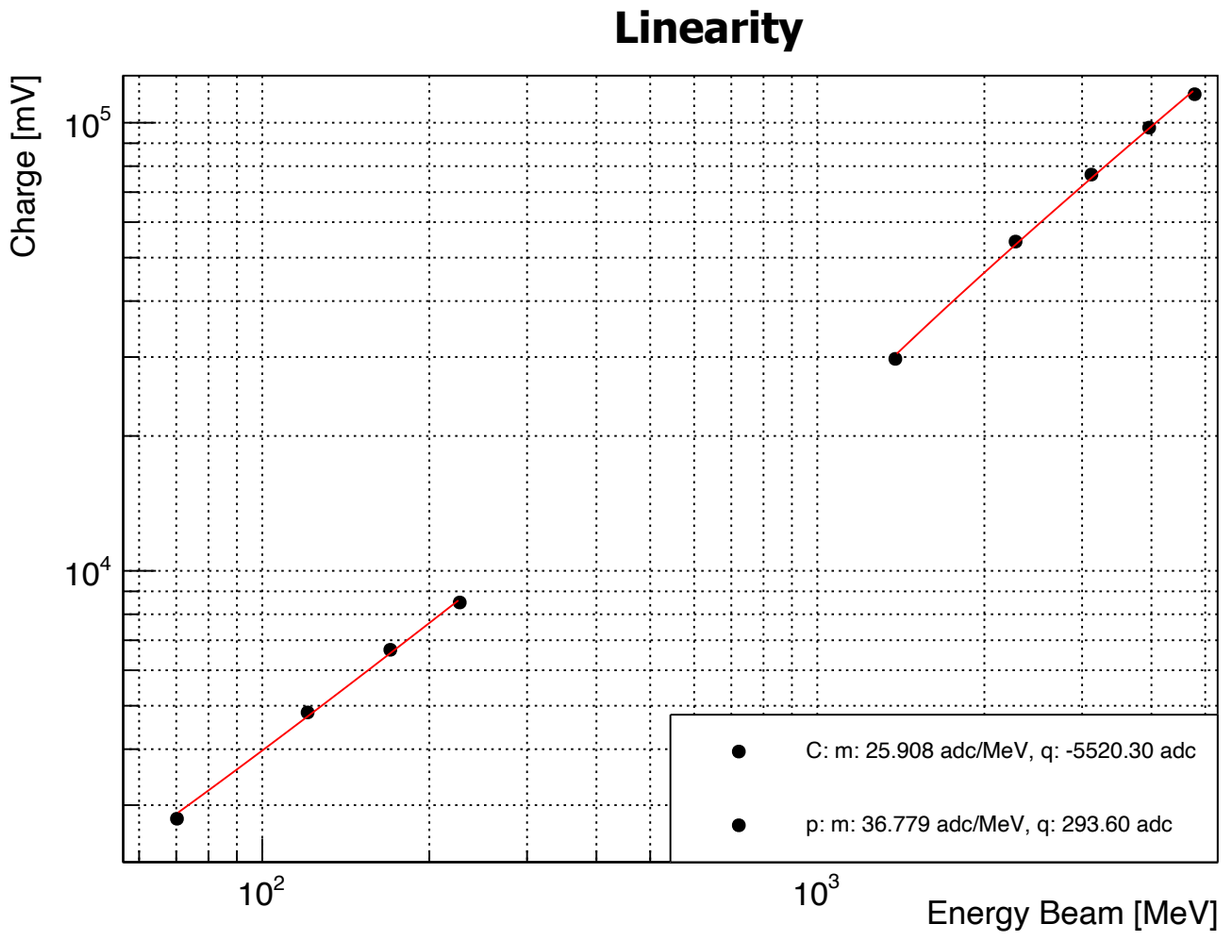


v1740 (10V)

Read temperature sensor

Calorimeter Performances





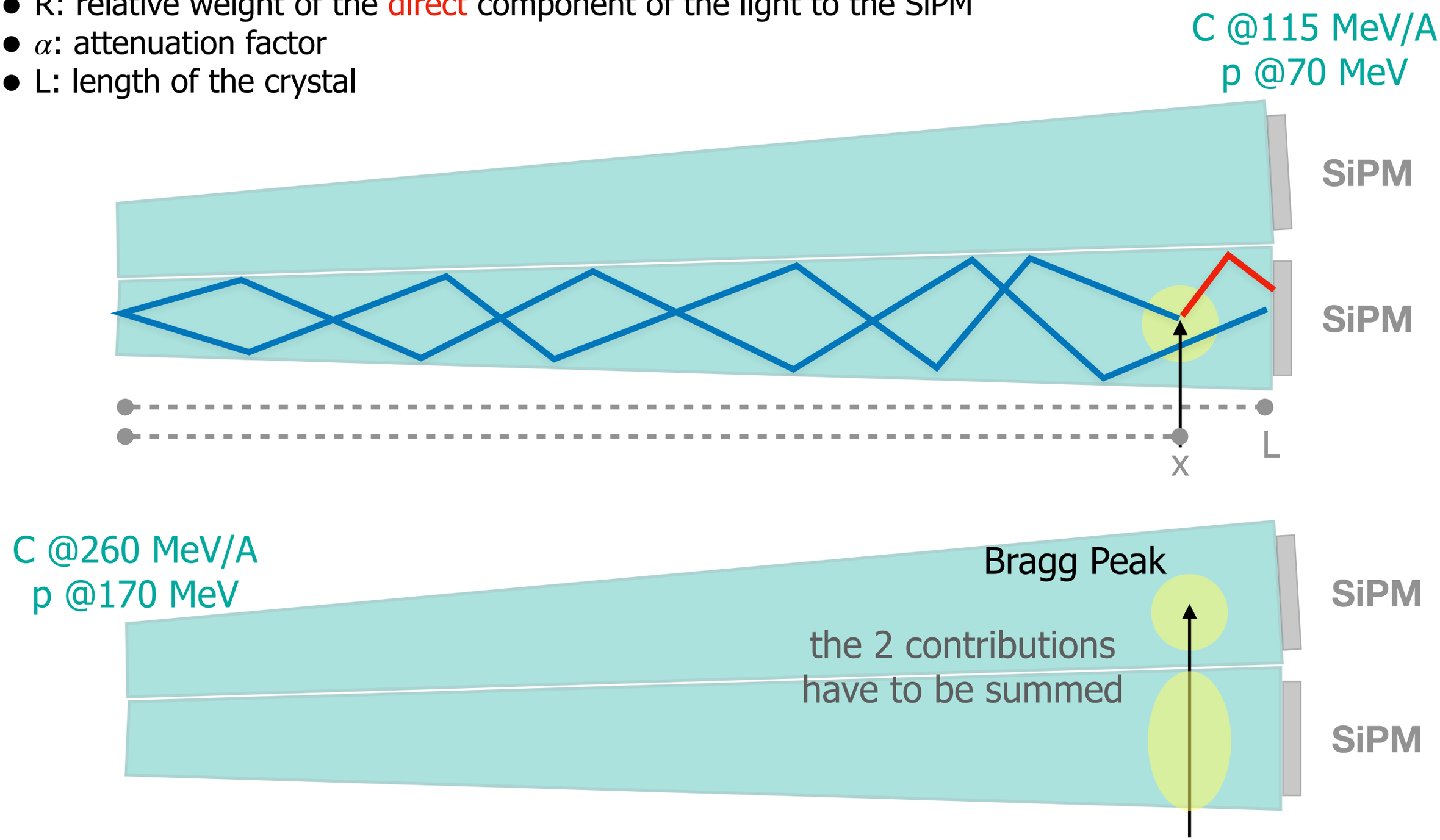
Performances achieved:

- Energy resolution < 2% (both for amplitude and charge analysis)
- No optical saturation

Light absorption

$$f(x) = A \cdot [R \cdot e^{-\alpha \cdot (L-x)} + (1-R) \cdot e^{-\alpha \cdot (L+x)}]$$

- A: normalisation factor
- R: relative weight of the direct component of the light to the SiPM
- α: attenuation factor
- L: length of the crystal



Light absorption

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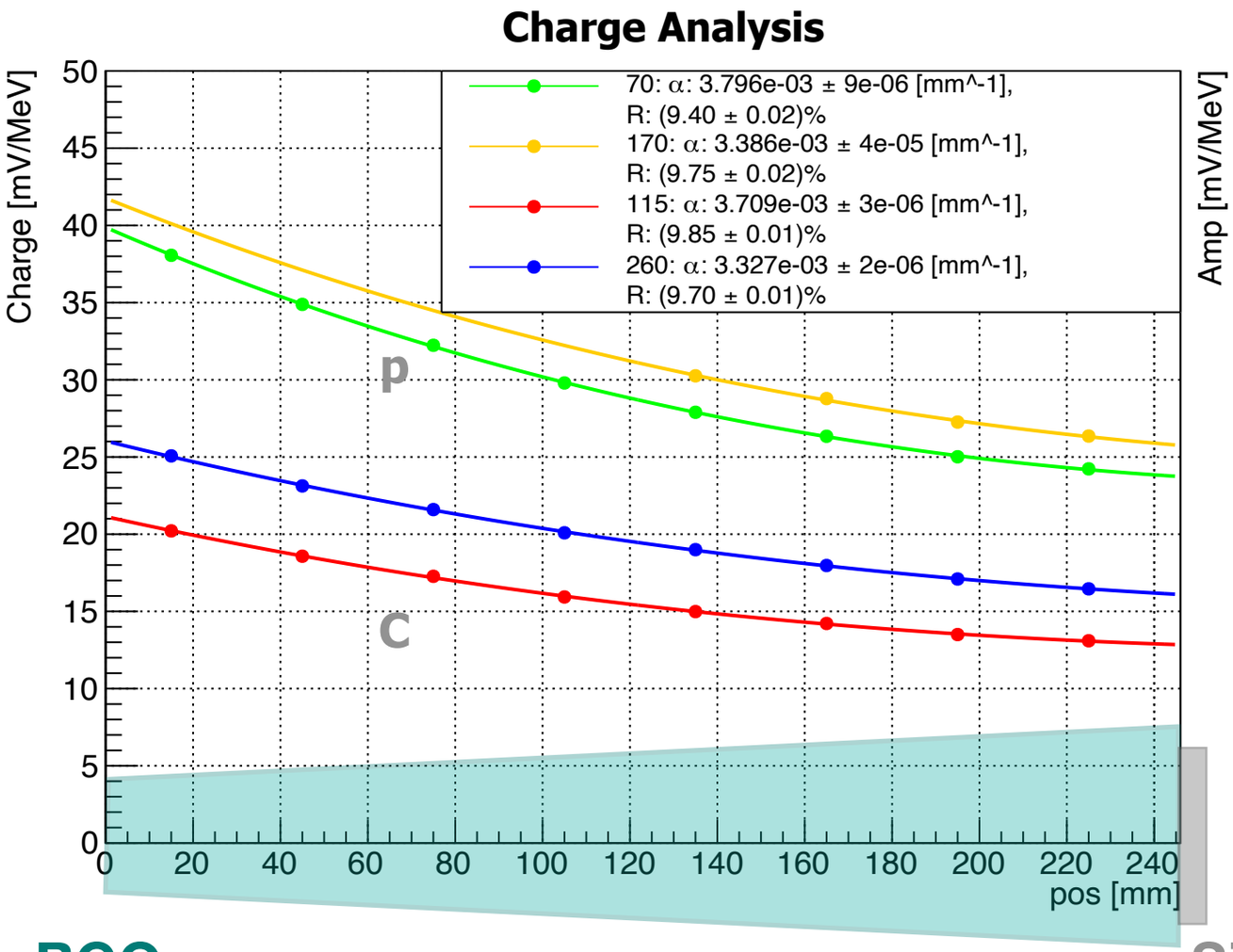
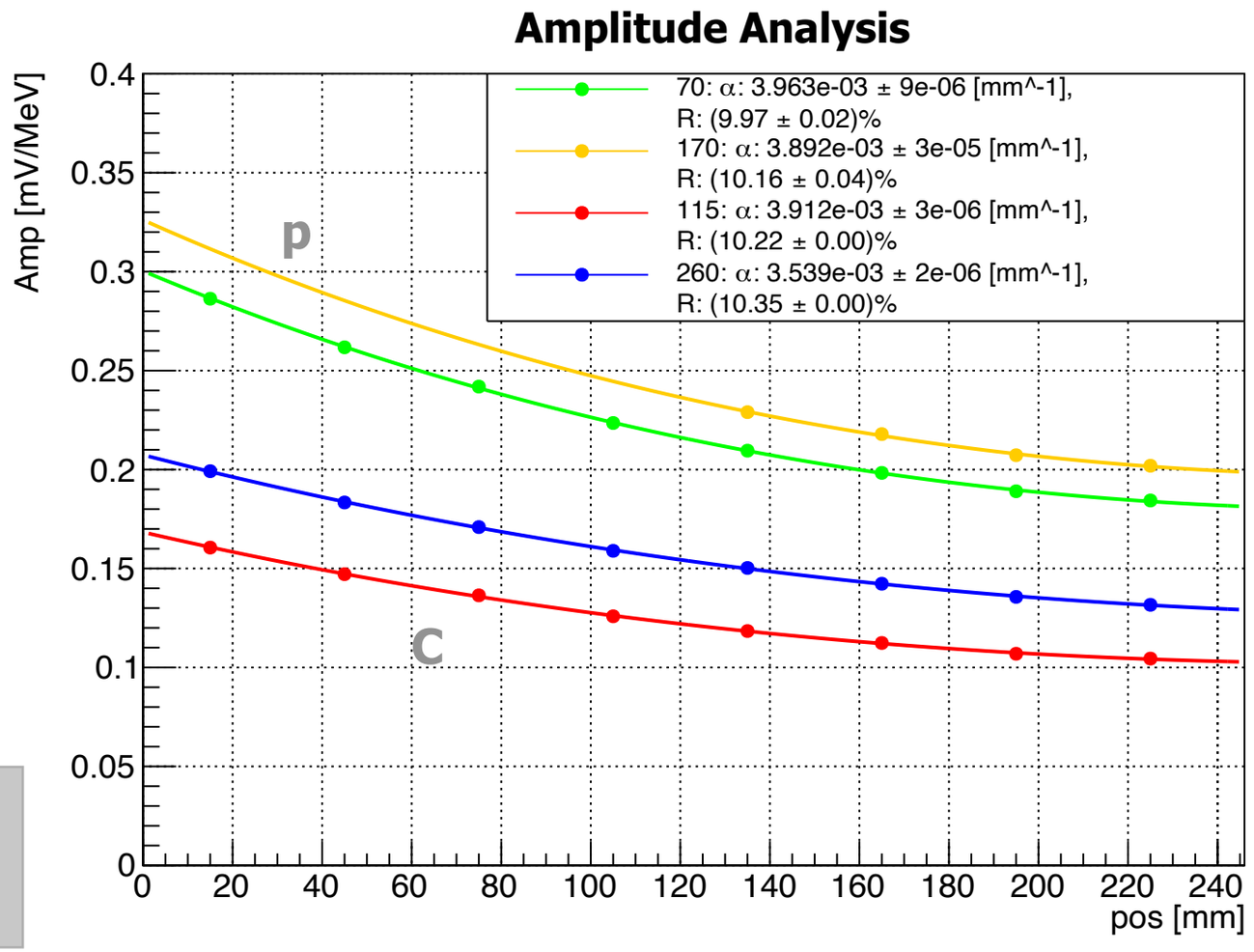
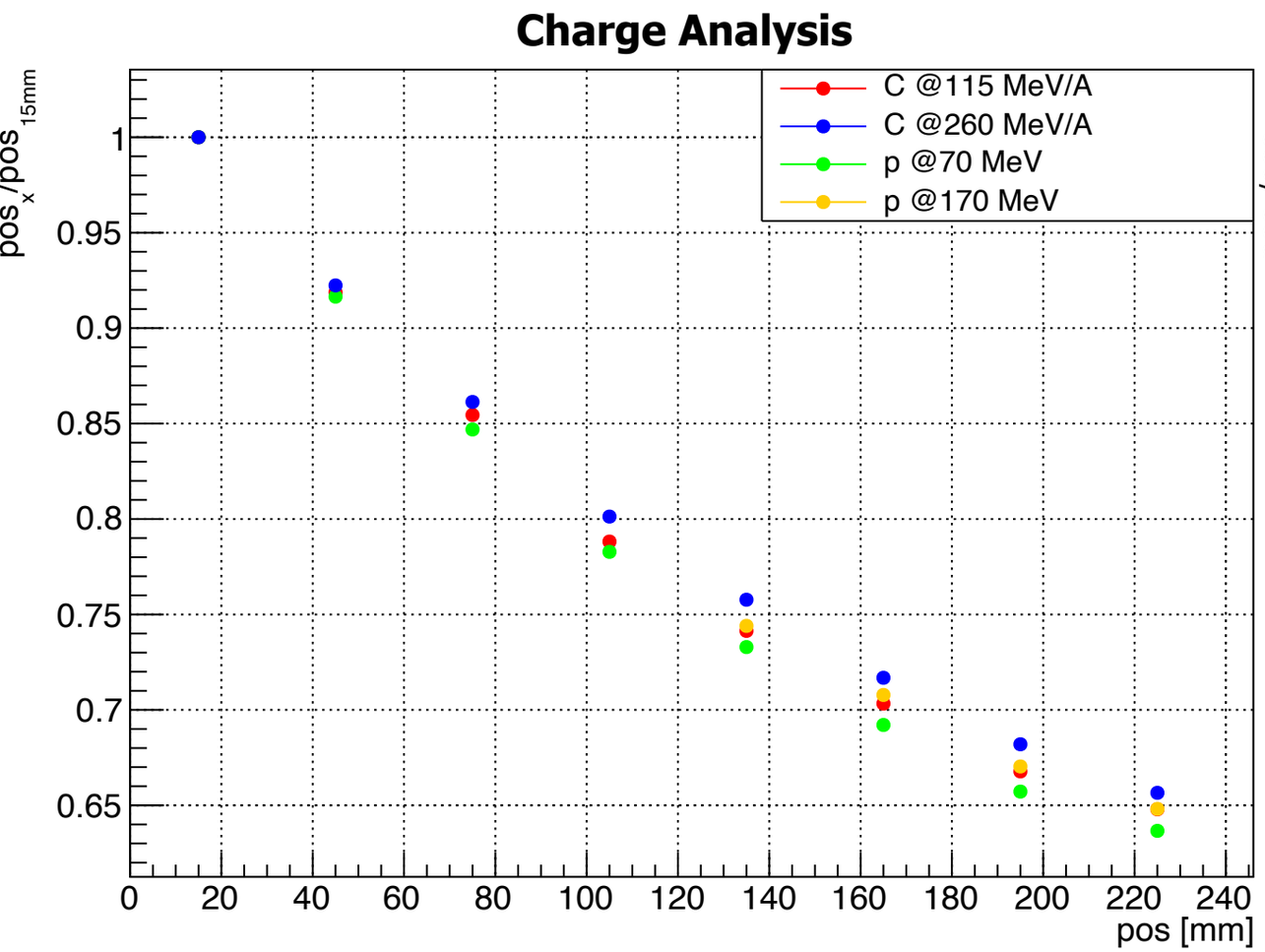


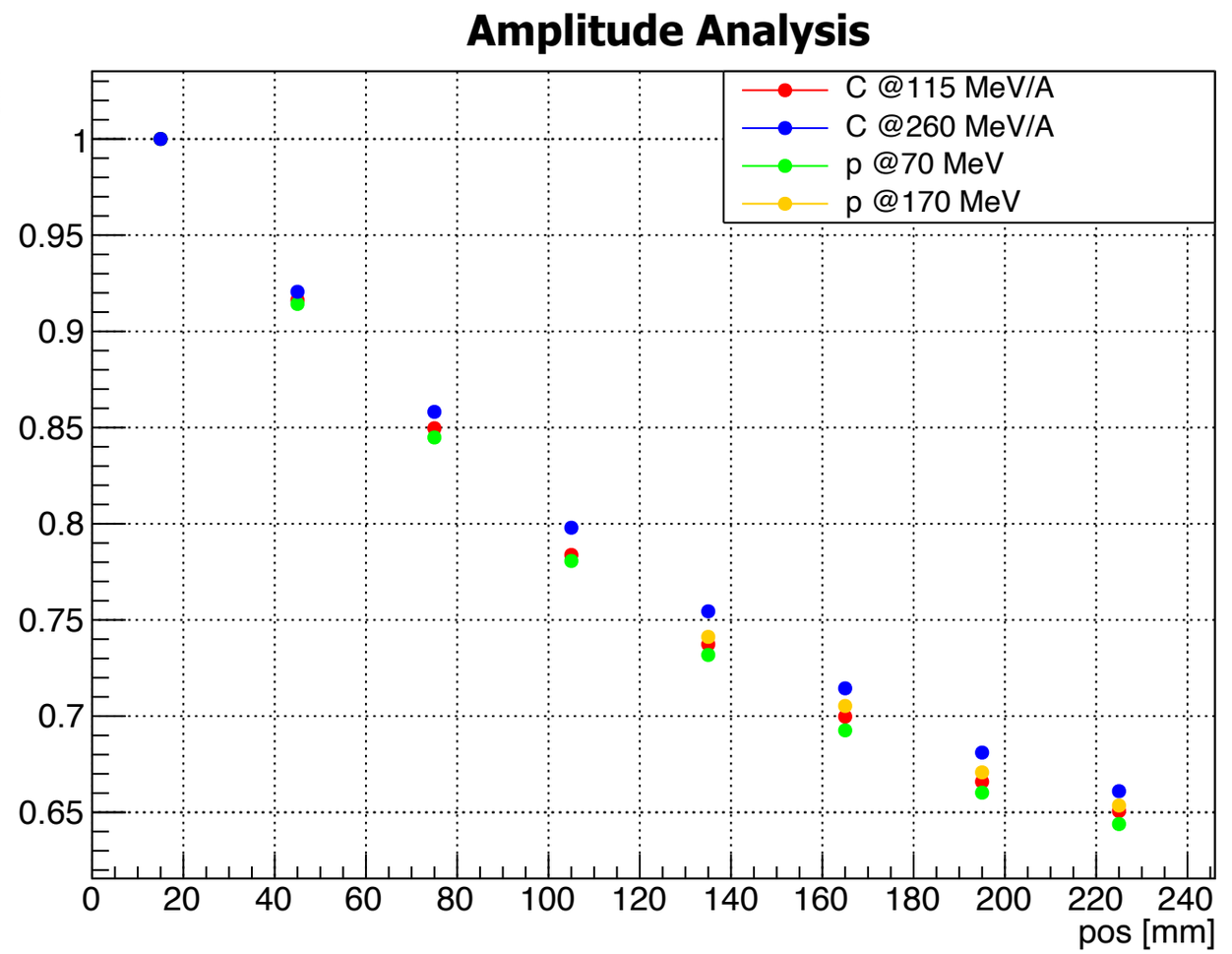


BGO **SiPM**

Light absorption

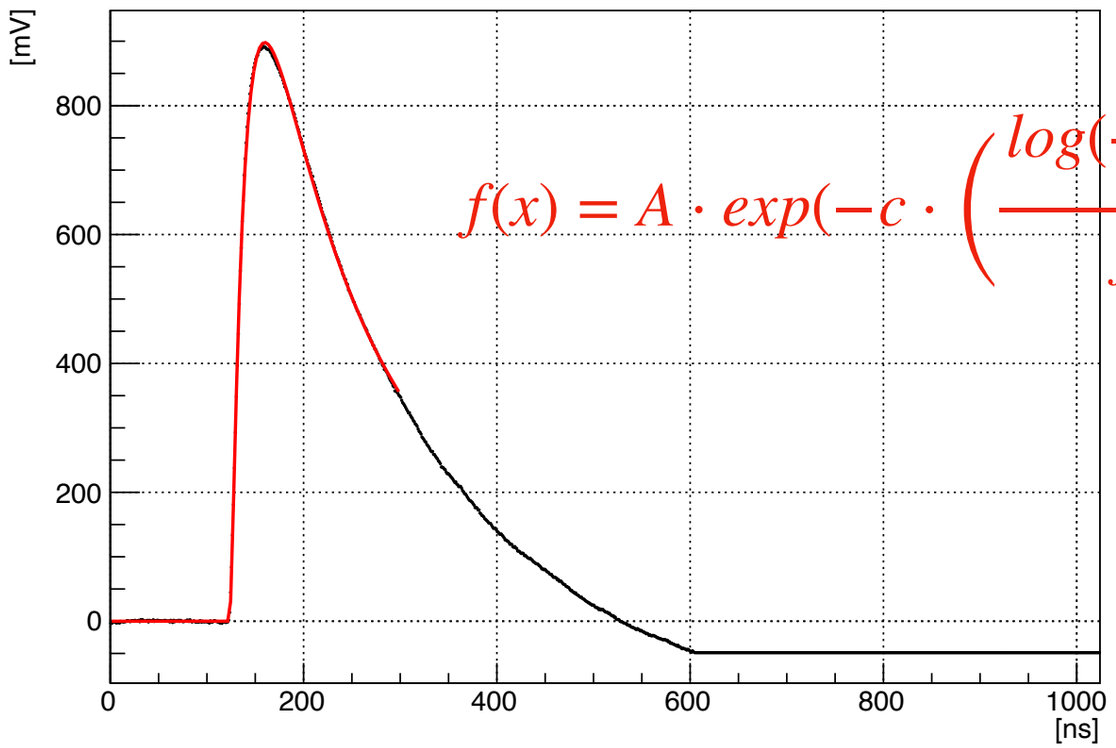
In order to compare better the different particles the ratio between the light collected in the different positions and light collected at 15 mm is showed:





This contribution is not negligible even if it seems constant between different particles/energies

Pulse shape analysis

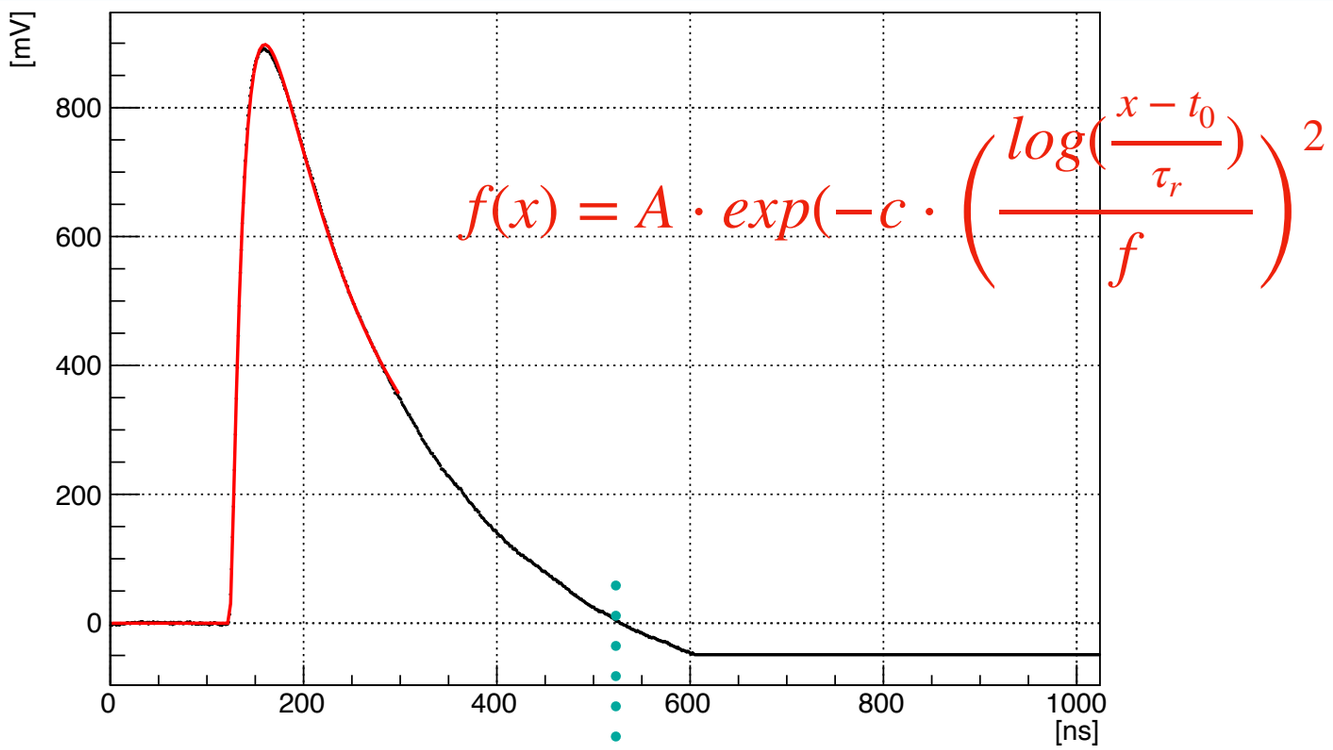


$$f(x) = A \cdot exp(-c \cdot \left(\frac{log(\frac{x - t_0}{\tau_r})}{f} \right)^2$$

- A: amplitude
- c: curvature of rising time
- τ_r: rising time
- t_0: start time
- f: falling shape

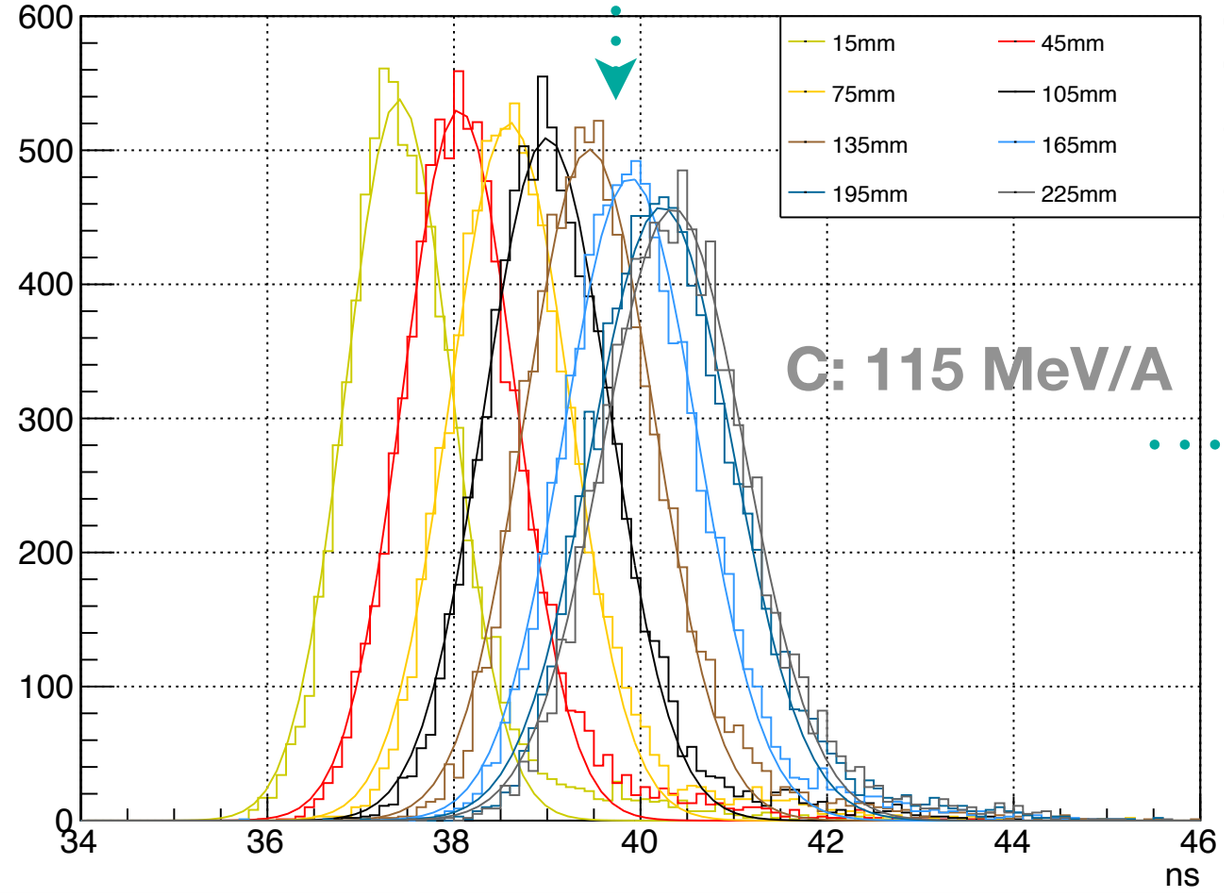
Clearly visible two different rising time populations

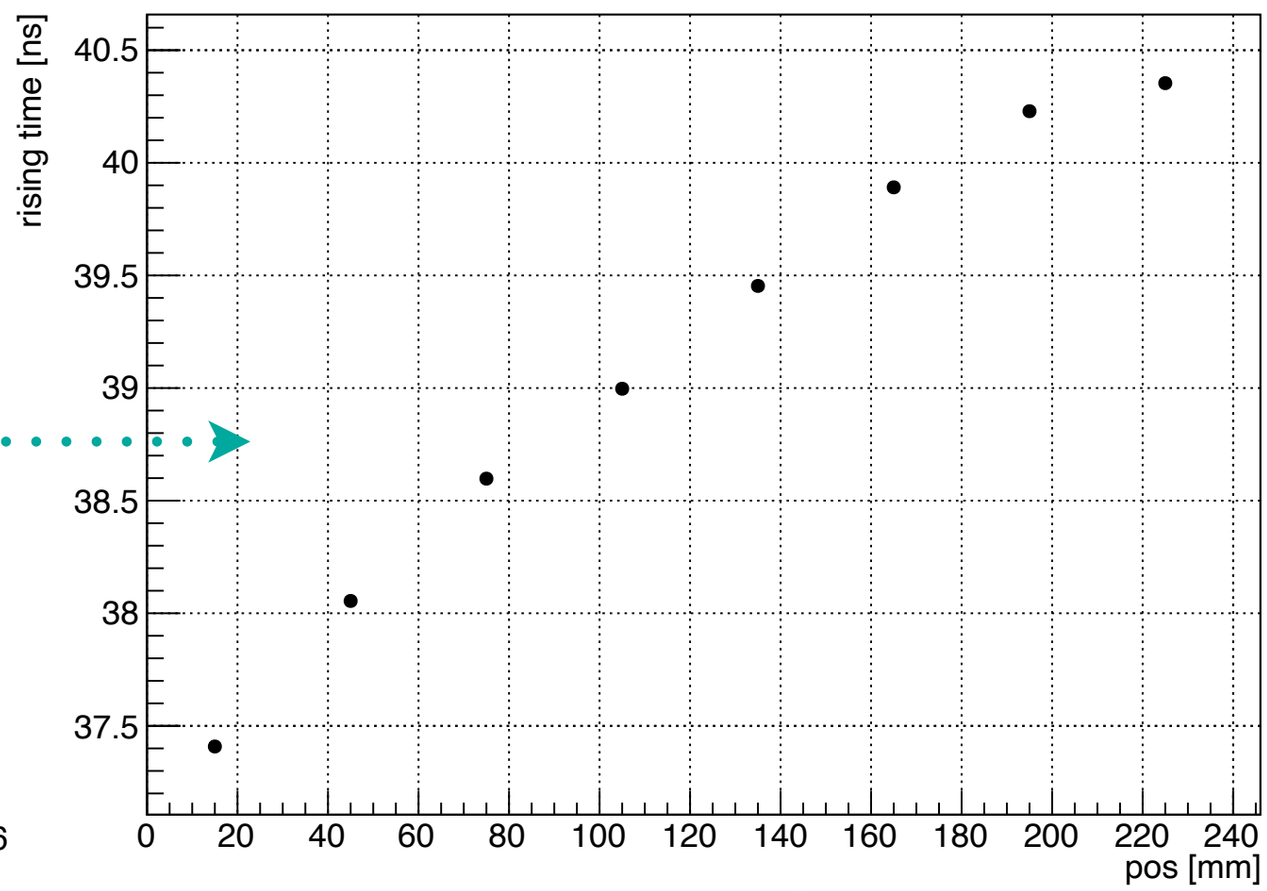
Pulse shape analysis



$$f(x) = A \cdot exp(-c \cdot \left(\frac{log(\frac{x - t_0}{\tau_r})}{f} \right)^2$$

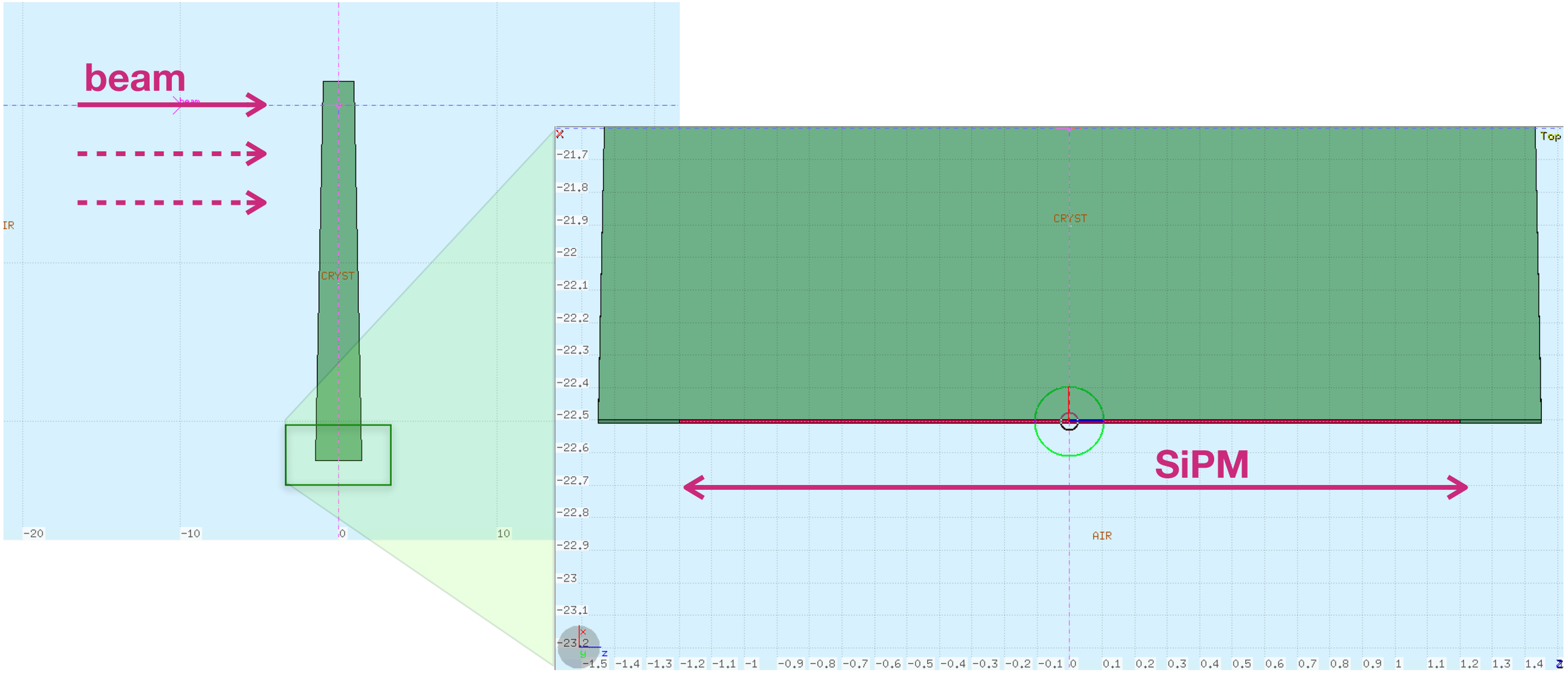
When the beam is shot closer to the SiPM more time is needed to collect all photons since there are more reflections





FLUKA simulation geometry

- 1 single BGO crystal rotated 90°
- proton beam @70MeV
- 1 primary proton/event x 100 events
- SiPM area: 2.4x2.4 cm^2
- Beam positions: 15, 45, 75, 105, 135, 165, 195, 225 mm
- BGO size:
  - front face 2x2 cm^2
  - back face 3x3 cm^2
  - length 24 cm



FLUKA simulation parameters

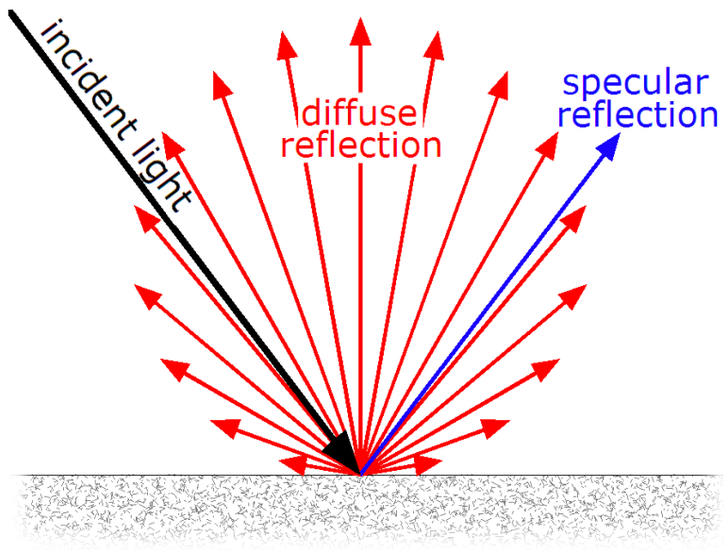
Fixed FLUKA simulation parameters

- Range of wavelengths of transported optical photons: $320\ nm < \lambda < 6.5\ nm$
- Peak of the wavelengths distribution of transported optical photons: $\lambda_{max} = 480\ nm$
- Photon energy at maximum wavelength: $E = 2.5\ eV$
- Fraction of deposited energy going into scintillation photon emission: $f = 0.02\ eV$
- Refraction index of BGO: $i_r = 2.15$
- Diffusion coefficient at the central wavelength (coefficient of Reyleigh scattering): $d = 0.02\ cm^{-1}$
- all properties of glue and air …

Varied parameters:

- Reflectivity index of Tyvek at the central wavelength $r = 100\,\%\,,\ 90\,\%\,,\ 70\,\%\,,\ 50\,\%$
- Absorption coefficient at the central wavelength: $a = [0,\ 0.010,\ 0.015,\ 0.03,\ 0.06]\ cm^{-1}$

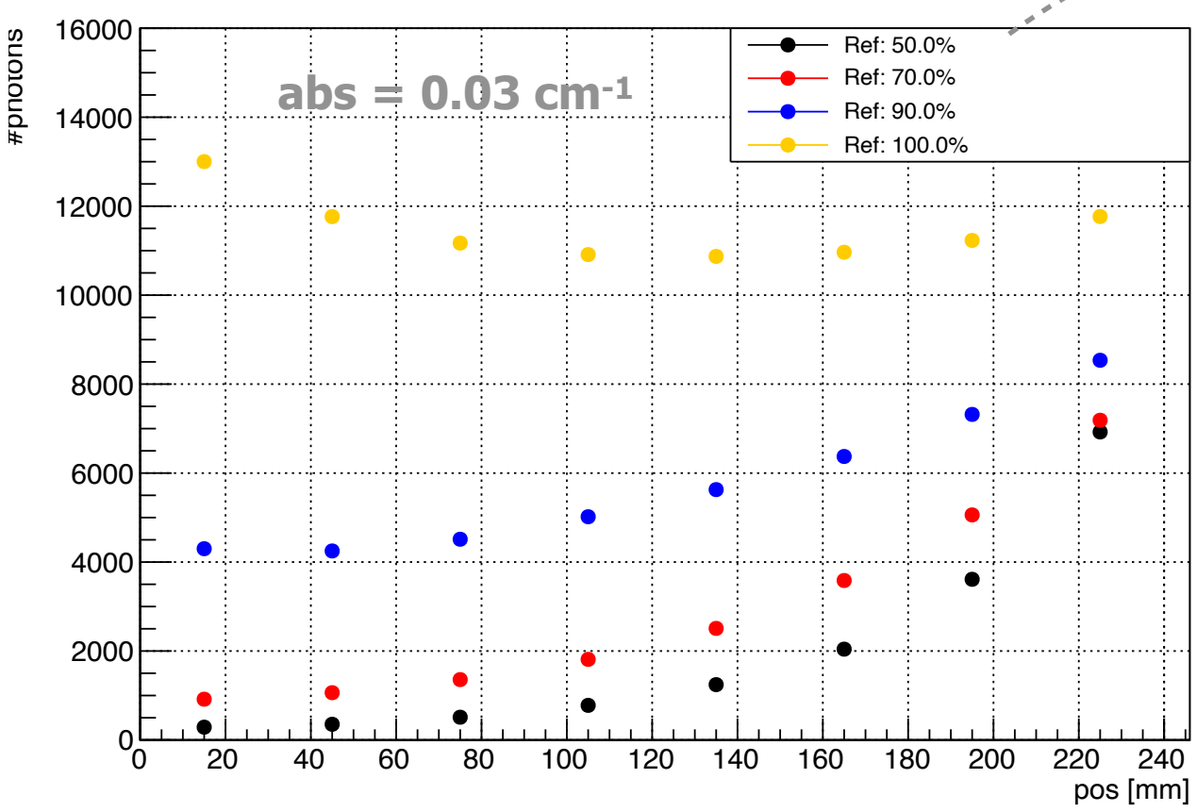
This simulations use **specular reflection** for Tyvek. However, tyvek has significant component of **diffuse reflection**, which would further increase the number of reflections, amplifying the effect of absorption in BGO, which goes in the right direction



FLUKA simulation results

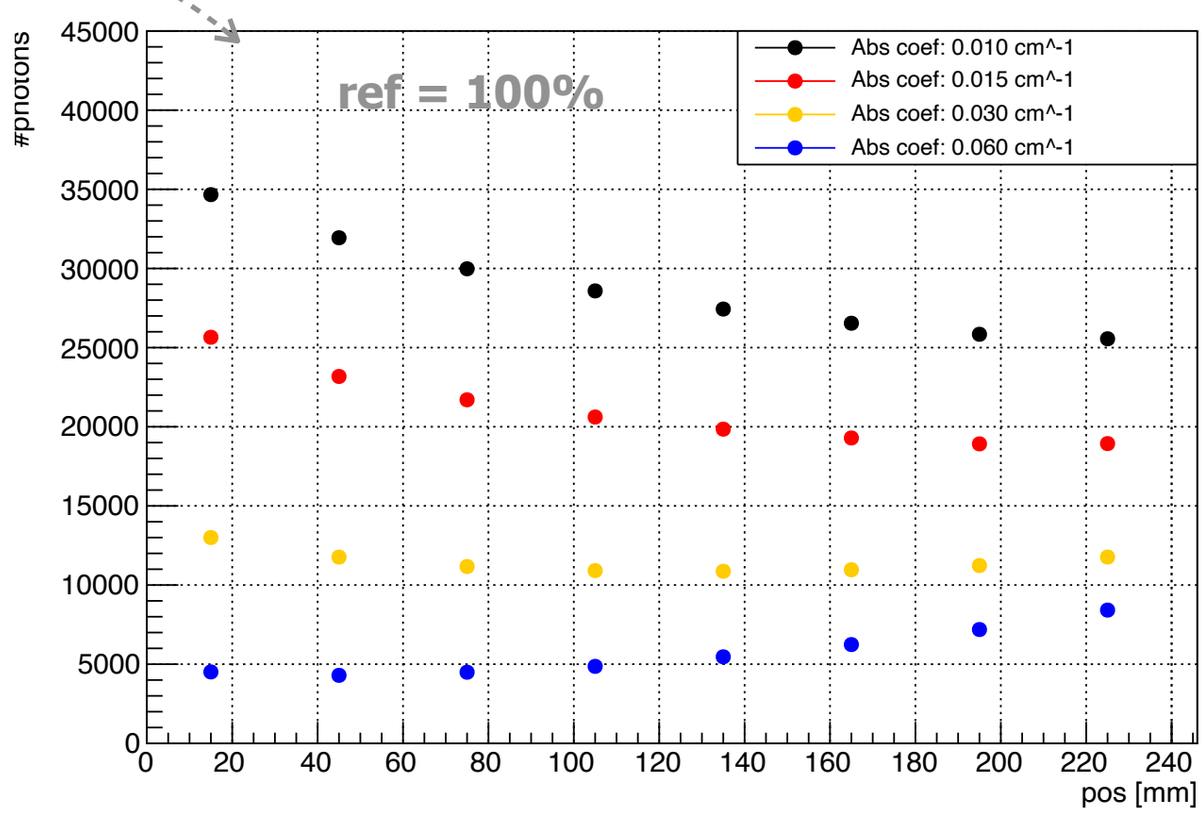
The plots show the average numbers of photons collected in 100 event

Simulation results with different reflection indexes of Tyvek (50%, 70%, 90% and 100%) and absorption coefficient fixed to 0.03 cm^{-1}



With ref = 100% the light collected between 15 mm and 135 mm decreases. (as we have observed at CNAO)

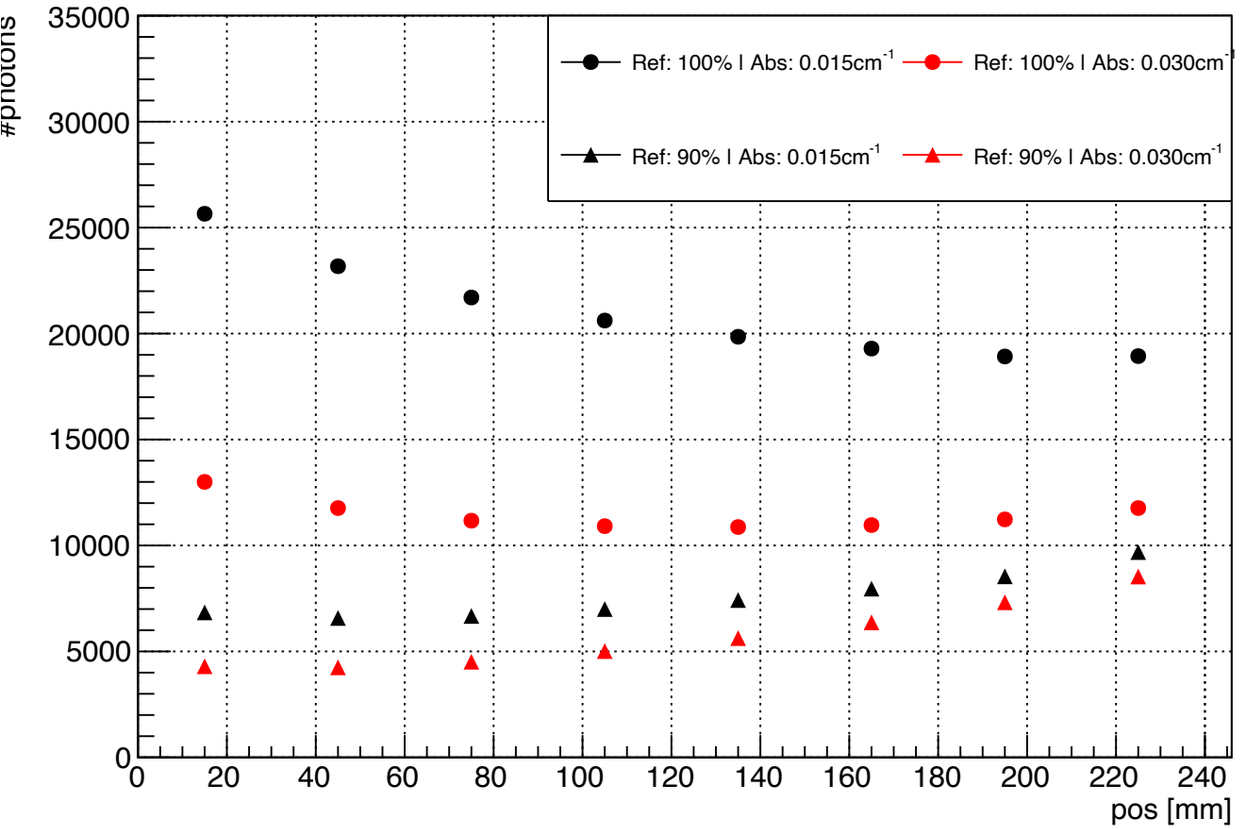
For the next simulations the reflectivity has been fixed to 100%, and absorption coefficient has been varied: (0.010, 0.015, 0.030 and 0.060 cm^-1)



For abs = 0.010 and abs = 0.015 the light collected decreases in each beam position

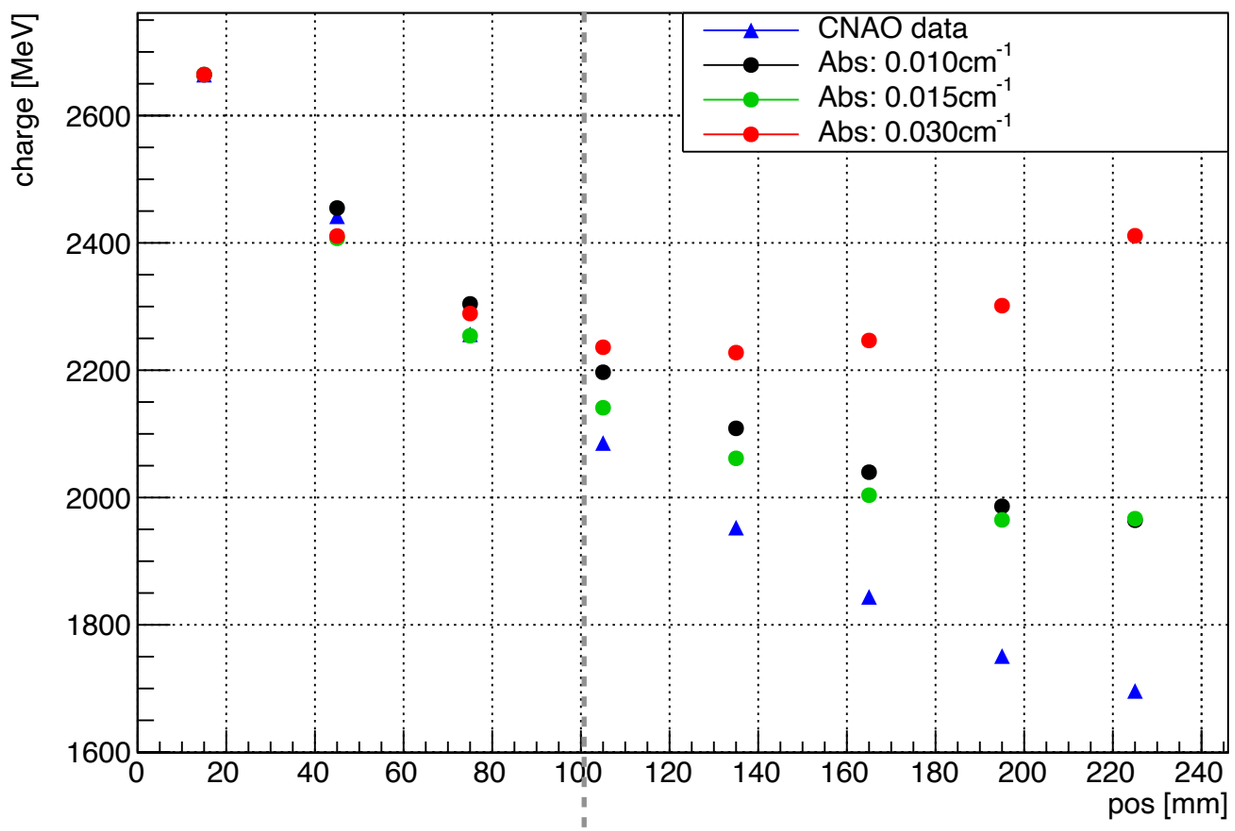
FLUKA and data Comparison

Comparison between different combinations of Tyvek reflectivity values (100% and 90%) and absorption coefficients of BGO (0.015 and 0.030)



- For ref=90% the light collected increase with the position for any values of absorption
- For ref=100% and absorption = 0.030 cm^{-1} the light collected decrease only up to 135 mm
- For ref=100% and absorption = 0.015 cm^{-1} the light collected decrease for all beam positions

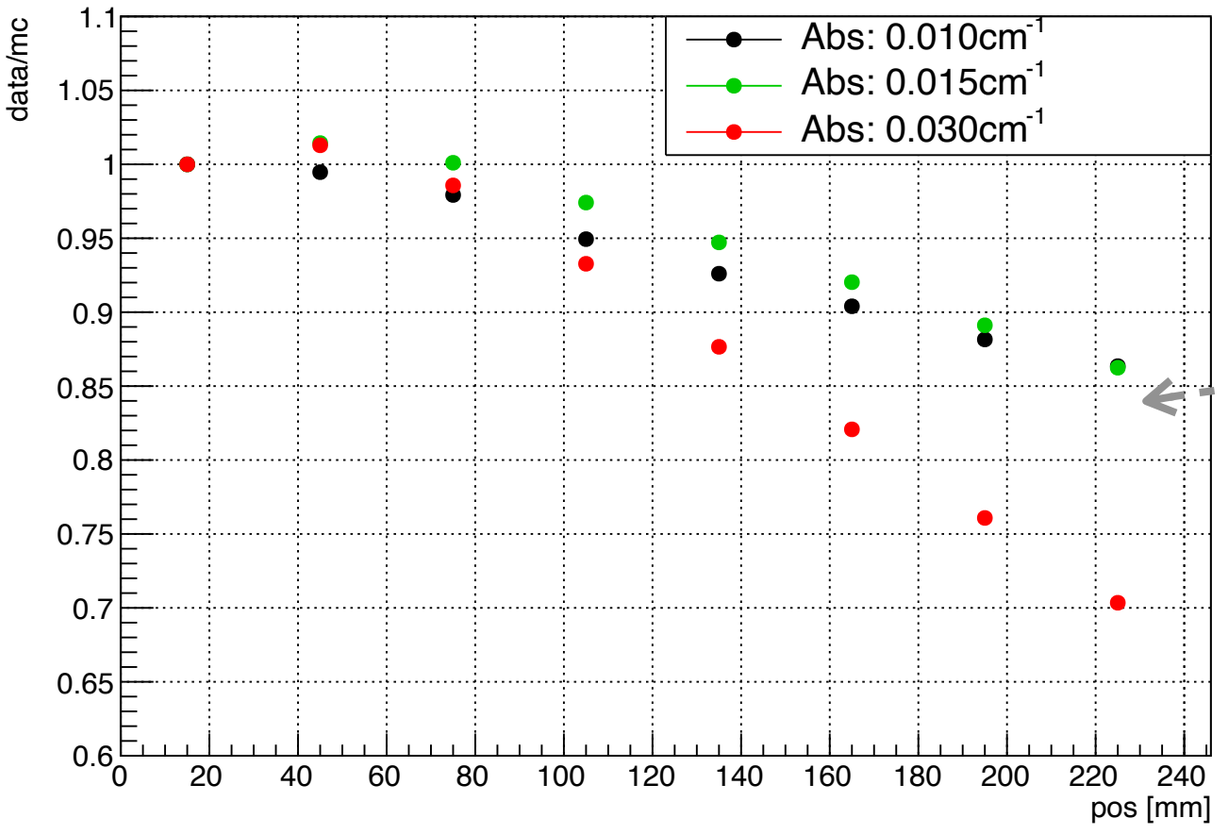
Comparison between CNAO data and FLUKA simulations with Tyvek reflectivity of 100% and different absorption coefficients of BGO (0.010, 0.015 and 0.030 cm^{-1})



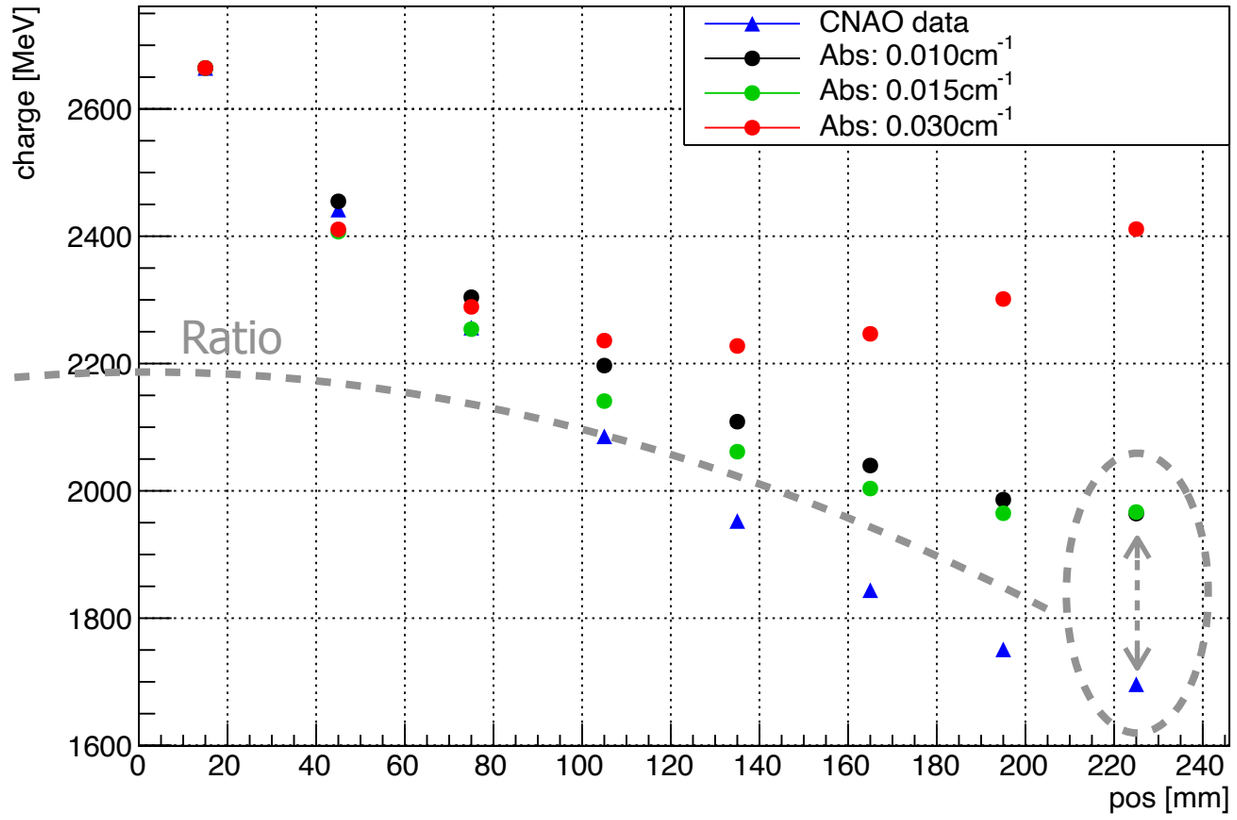
- Good agreement before 100 mm

FLUKA and data Comparison

Ratio between the CNAO data end the MC simulations for each position



Comparison between CNAO data and FLUKA simulations with Tyvek reflectivity of 100% and different absorption coefficients of BGO (0.010, 0.015 and 0.030 cm^{-1})

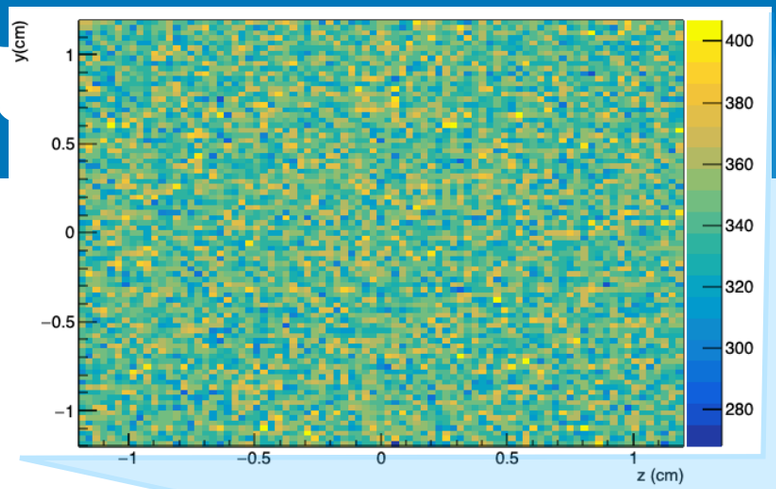


- Good agreement before 100 mm ✓
- For 0.010 and 0.015 cm^{-1} there is a discrepancy up to ~15% ✗

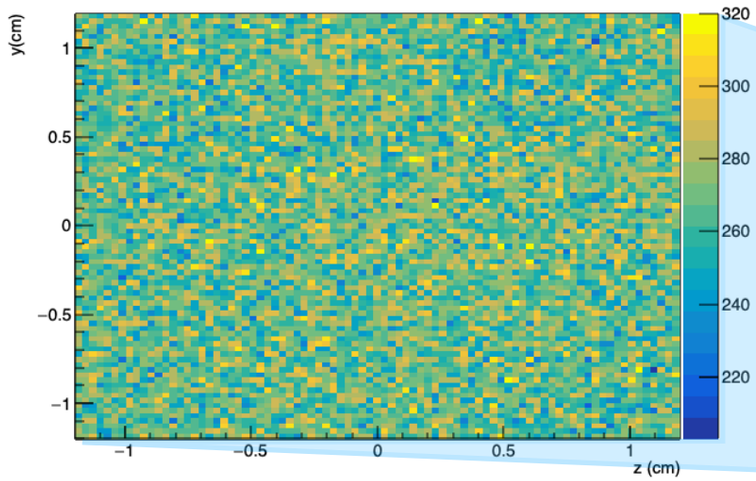
Probably more effects have to be taken into account

Diffuse reflection would amplify the effect of absorption in BGO, like the CNAO data suggests

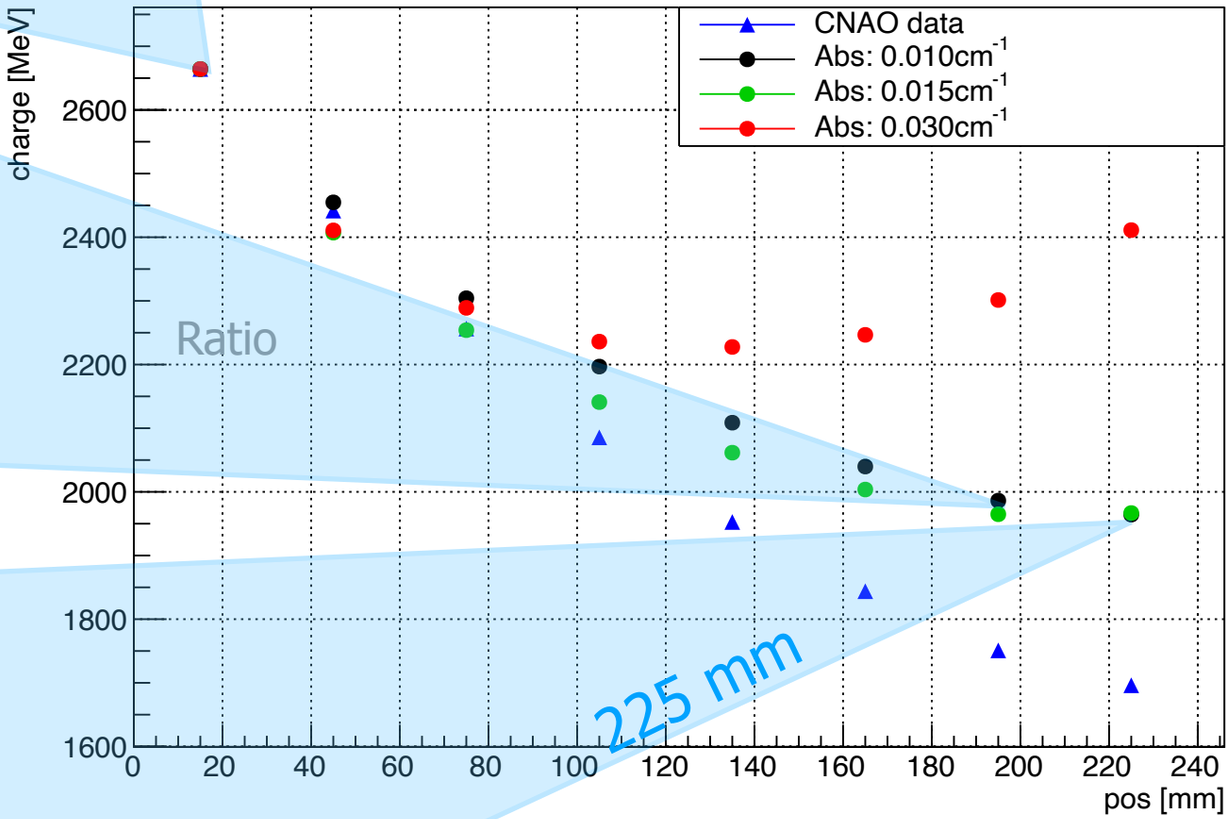
FLU Comparison



15 mm

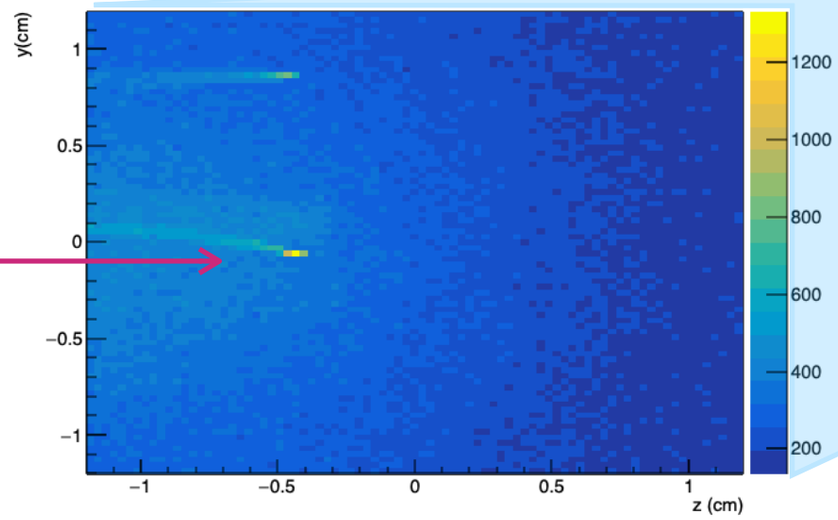


195 mm



225 mm

Beam direction
in the simulation



- Good agreement before 100 mm ✓
- For 0.010 and 0.015 cm^{-1} there is a discrepancy up to ~15% ✗

Uniformity of the light on the SiPM surface for each position except for the last beam position ⇢ points very close to the SiPM can be affected by SiPM cell recovery time and uninstrumented area

Conclusions & Next Steps

Conclusions:

- The design requirements of Calorimeter performance achieved with the Wavedream board
- The study of the absorbed light along the crystal showed that the effect is not negligible but it is constant between different particles and energies.
- After a first fine tuning of the MC parameters, the simulations have shown the light absorption for different beam positions seen during the test beam
- There is a good agreement between data and MC up to 100 mm, and a discrepancy for the other beam positions, up to 15% for 225 mm

Next Steps:

- Perform other MC simulations with other Tyvek reflective parameters (95% and 97%)
- Take into account the diffuse component of Tyvek reflectivity (how can I configure or implement this type of reflection in FLUKA?)
- In order to study the discrepancy between data and MC simulations include the recovery time of the microcells of the SiPMs in the analysis