Data analysis GSI-CNAO

What happened since December 2019

- CNAO and GSI data fully analyzed
  - Stand-alone software refined, carefully checked, and speed increased
    - Needed it for CNAO analysis and to get quick results for thesis work
  - TOF and energy calibrations performed with CNAO and GSI data
  - Resolutions studied
  - Spectra in E, TOF and Z with and without target extensively investigated
- Roberto Zarrella graduated with laude, 'borsa di studio' with Pisa now for 6 months
- Marco Montefiori joined group for Master thesis, will work with Matteo, at the moment analyzing data taken in December 2019 at CNAO (3 bars, different photodetectors)
- Abstracts sent to IEEE (Boston), SIF (Trieste), and Real Time (Vietnam)
- This presentation, short summaries of
  - Data processing
  - Calibration: energy, TOF
  - A few plots for CNAO and GSI

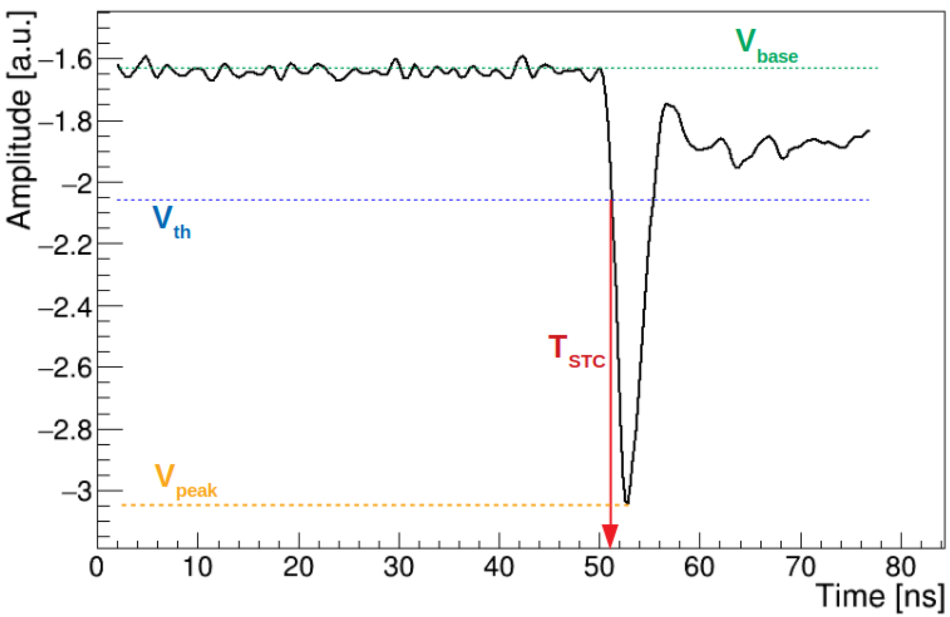
Data processing in stand-alone code: STC

Thanks to Roma group

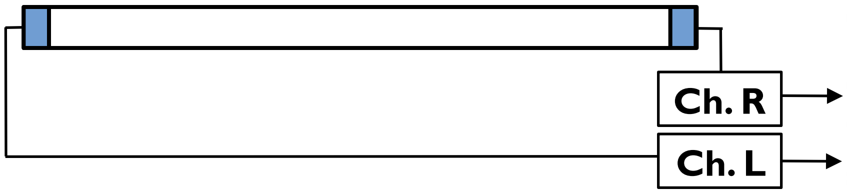
- Sum of the 8 STC waveforms
- Constant Fraction Discriminator:
  - Find baseline and peak
  - Set threshold to a fraction of the amplitude

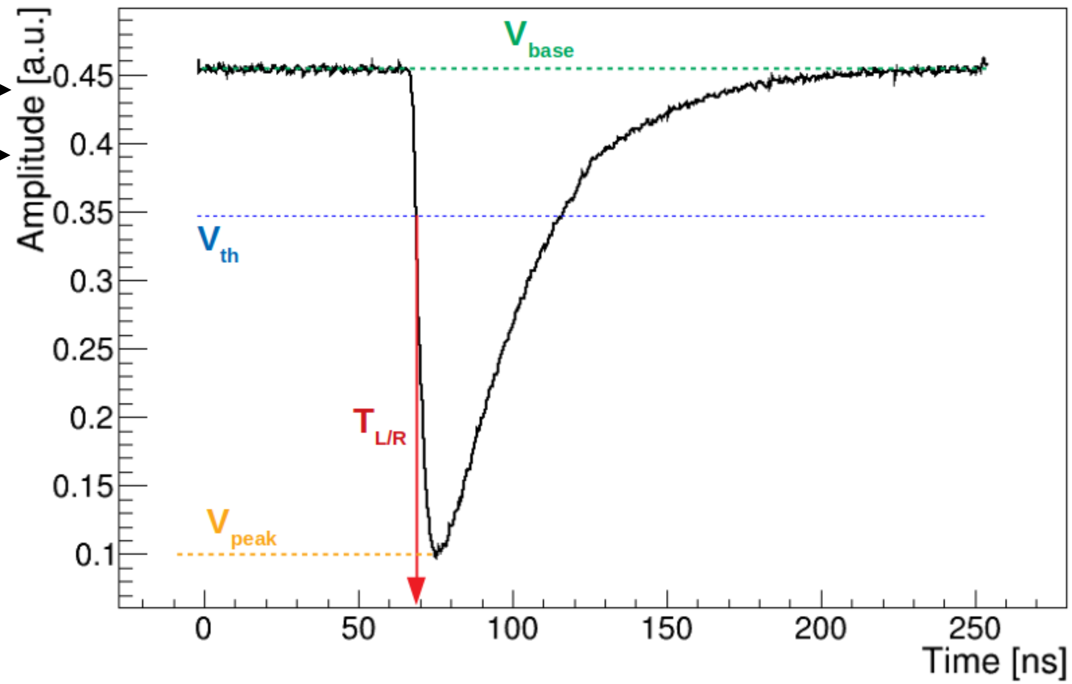
$$V_{th} = V_{base} - f_{CFD} \cdot (V_{peak} - V_{base})$$

  - f_{CFD} = 0.3 from former studies
  - T_{STC} → time when the WF crosses V_t (using interpolation)



Data processing in stand-alone code: TW





- CFD algorithm applied to both channels of each bar hit in the event
- Extracted data:
  - Time stamp of the channel $T_{L/R}$
  - Total charge collected in the channel $Q_{L/R}$ = integral of the WF

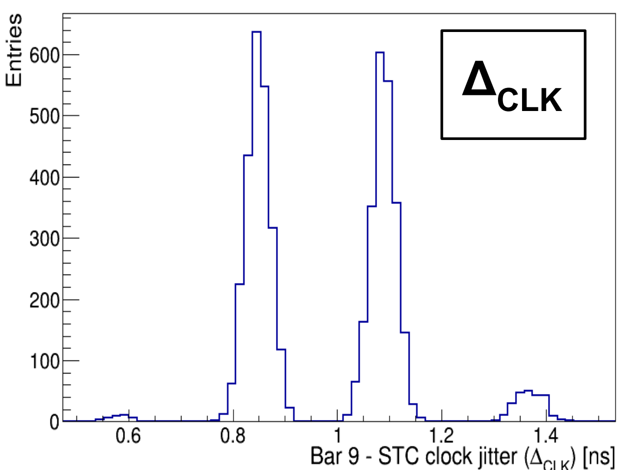
Channel synchronization

For each event, channel synchronization with clock signals (thanks for help to Roma group)

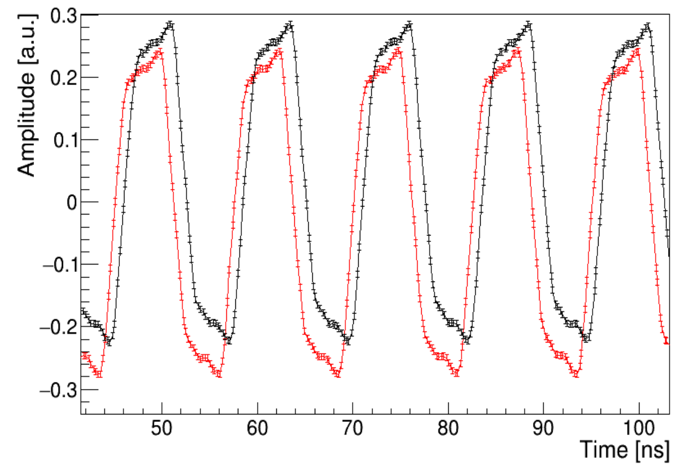
- Sampling frequency phase jitter → align TW channels with STC
- CLK phases ϕ_{CLK} extracted through linear fit → intercept

$$\Delta_{CLK} = \phi_{CLK,ch} - \phi_{CLK,STC}$$

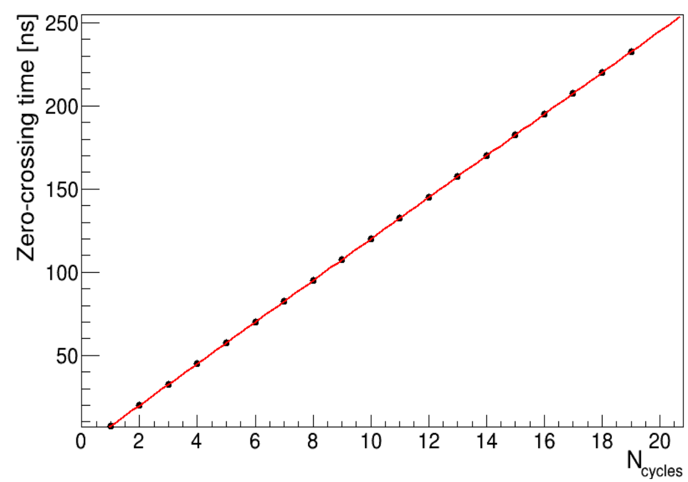
- Phase jitter → width of the gaussian (σ~25-30 ps)
- Trigger cell jitter → multiple gaussian distributions



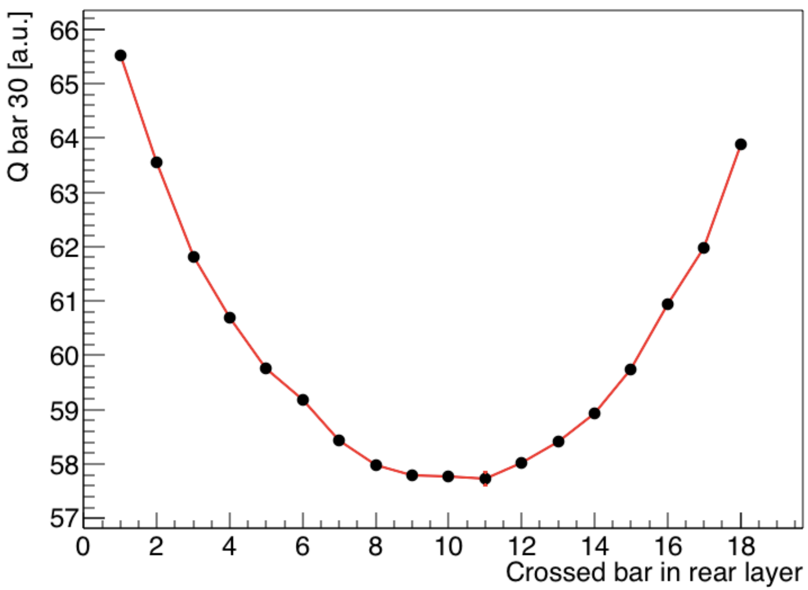
CLK signals of TW (black) and STC (red)

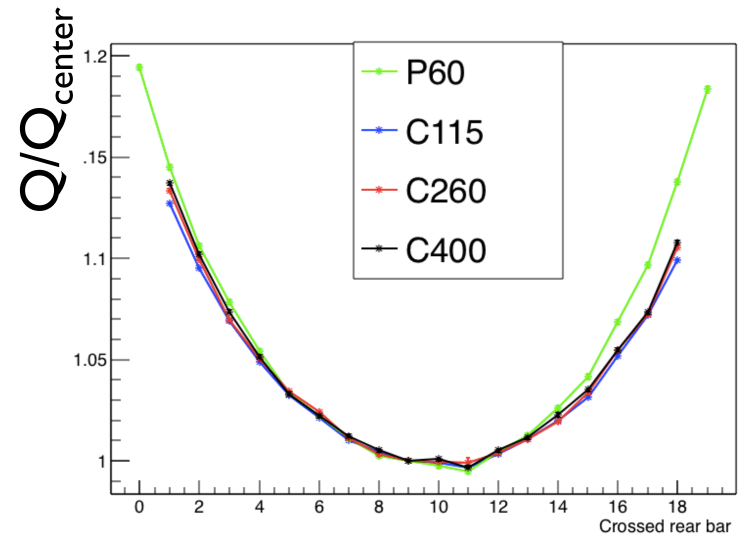


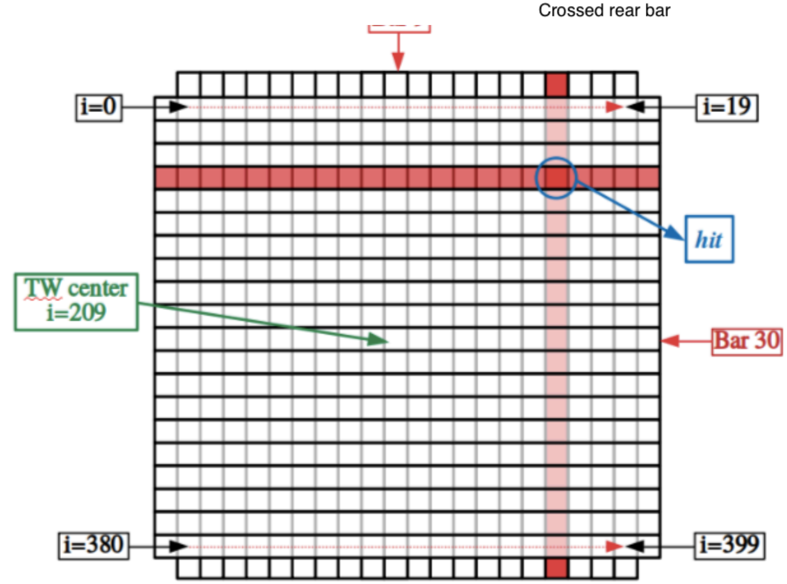
CLK phase calculation



Charge dependence versus position







Observations:

- Strong dependence on position along bar
- Irregular: parameterization would also be artificial → investigate how to improve this
- Dependence on particle? Unclear!
  - Not much, but some; p differs from C

→Practical and safe solution for these data: Position-by-position calibration (apply Birks 2*400 times)

Energy calibration

Details see presentation May 27!

Goal: relate the deposited charge to a real deposited energy value (or anything related to that)

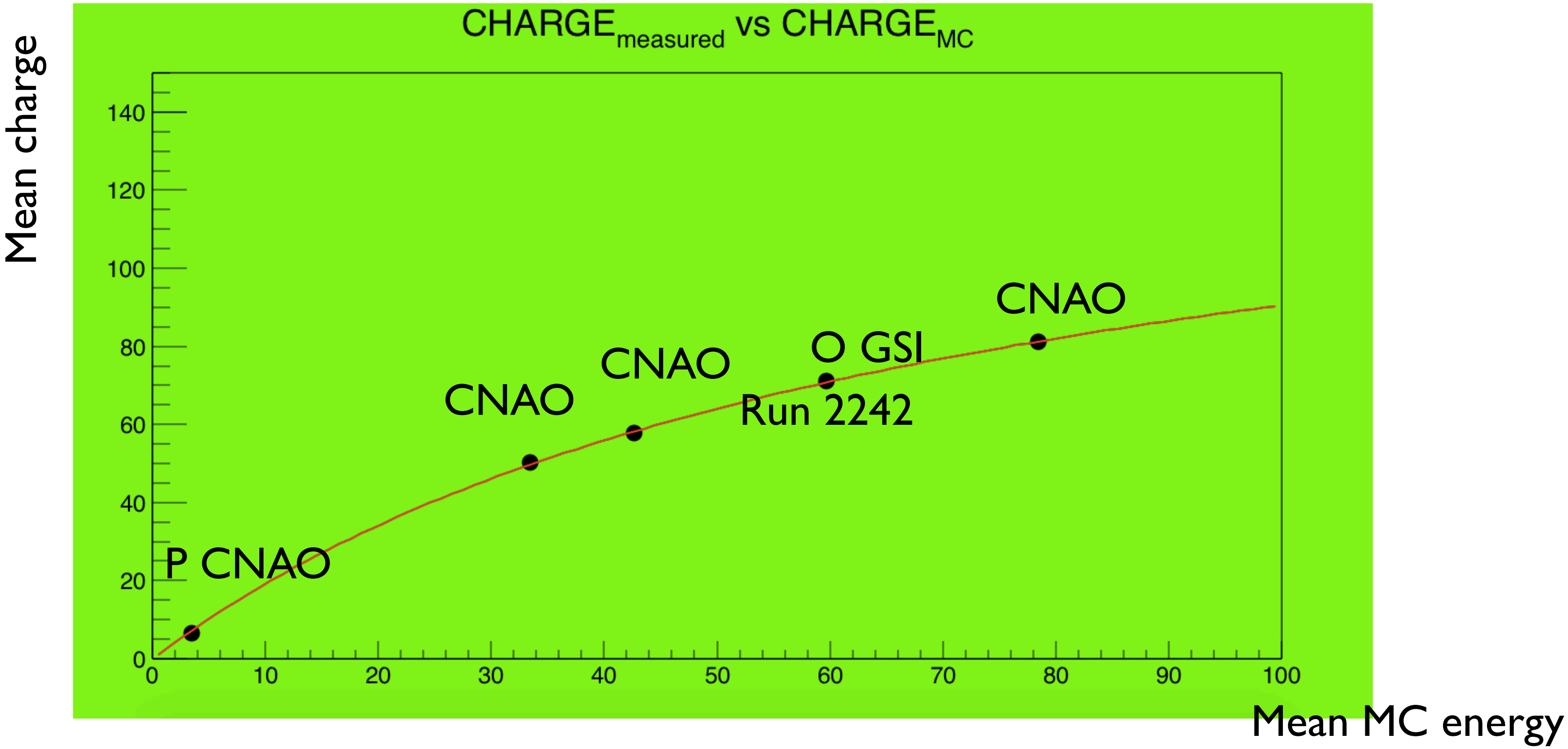
2 totally independent calibration methods tested

1. Position-by-position: equalize each position (determined with cross position of 2 planes) with MC, apply Birks in all positions hit
   - Advantage:
     - All positions studied independently
     - Most precise: best energy resolution
   - Disadvantage:
     - Ideally, all positions should be irradiated with say >40 events per energy
2. In the center, equalize all charges to the values in the center, apply Birks once per plane
   - Advantage: somewhat simpler
   - Disadvantage:
     - Less precise (loose resolution)
     - Depends strongly on charge in one position

- We tested both. Note that in the end, it's similar; parameterize the response of the bars in some way to a reference value (MC, central value, respectively). To get energy resolution, we need to get an answer related to deposited energy.
- Results in next slides from method 1

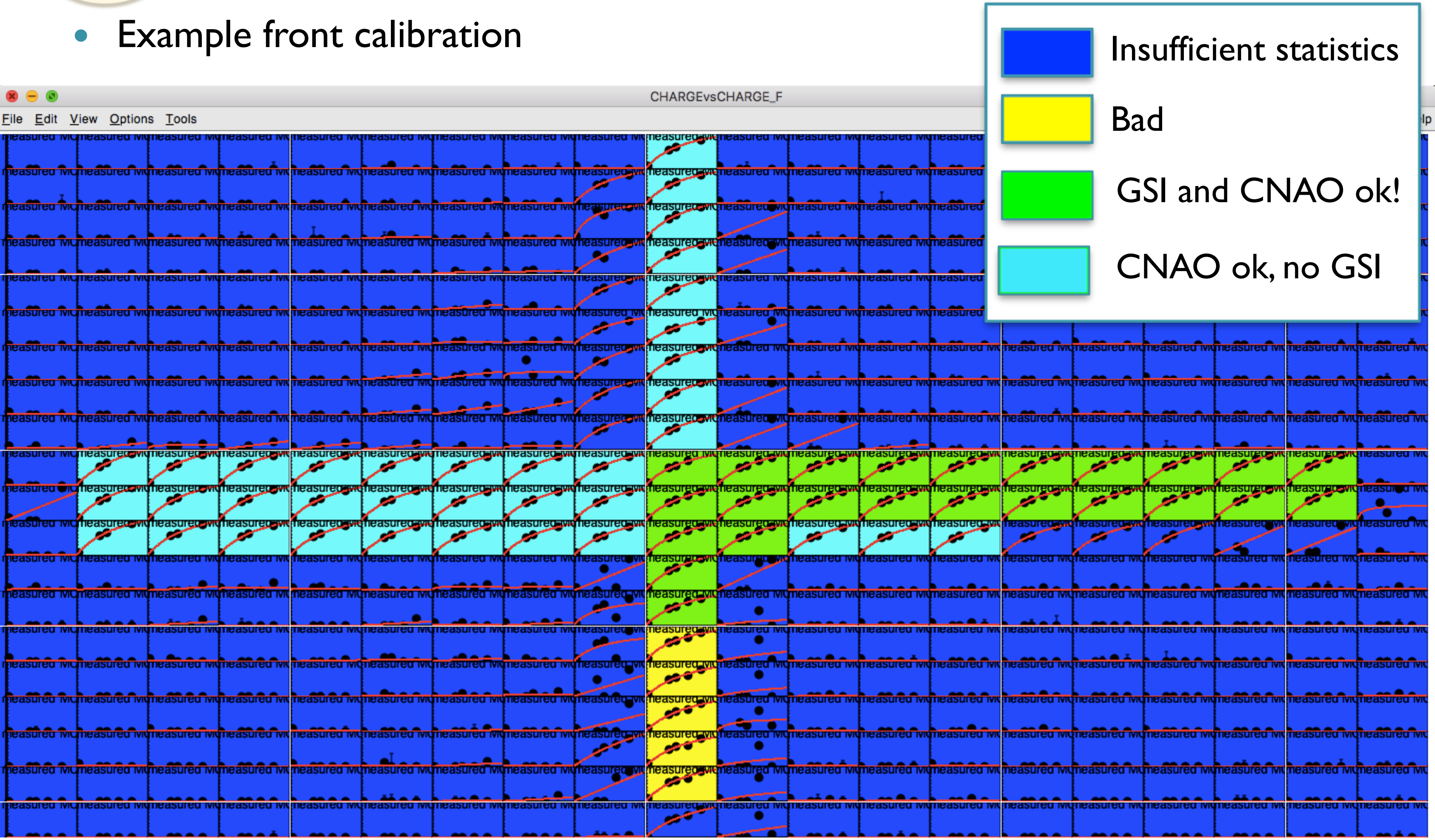
Energy calibration

- Calibrate with data without target, known particles and energies that hit bars
- In a given position (from crossing of bars), take mean charge values and relate to mean MC
- Example of calibration in one position→ GSI point fits generally in OK
- This is the case in most positions, not in all → used the ones where it was good



Energy calibration

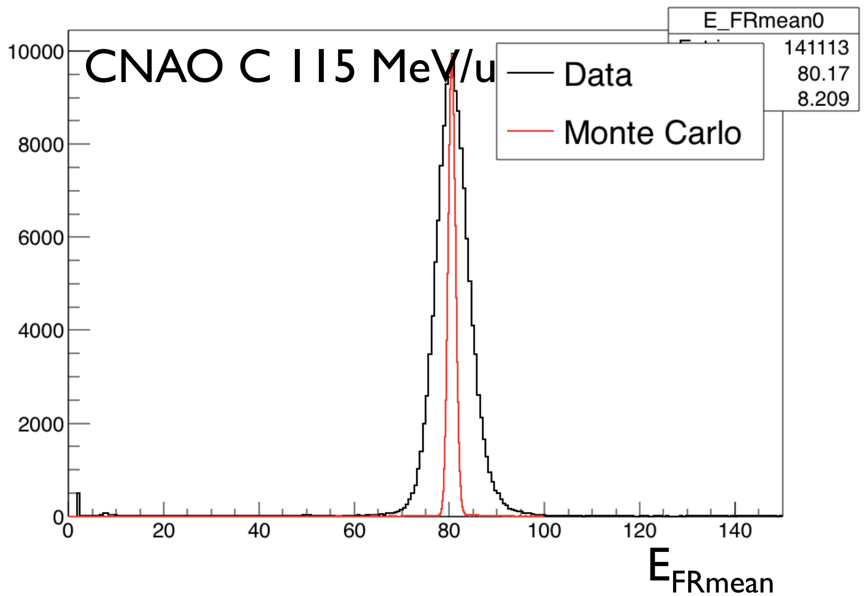
- Example front calibration

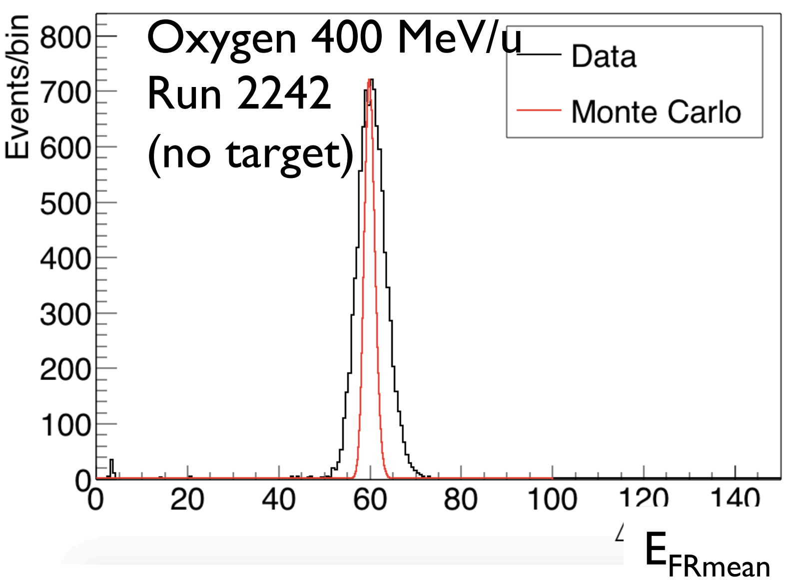


Energy spectra: examples

- Now apply the calibration to our measurements without target
- Sum all well-calibrated positions, apply cut (E_F-E_R)/((E_F+E_R)/2)<0.2
  → overall spectra with look VERY NICE for CNAO and GSI
- Looks very good in all bars, both in the central and all other bars!!

→ Now can parameterize the energy resolution!

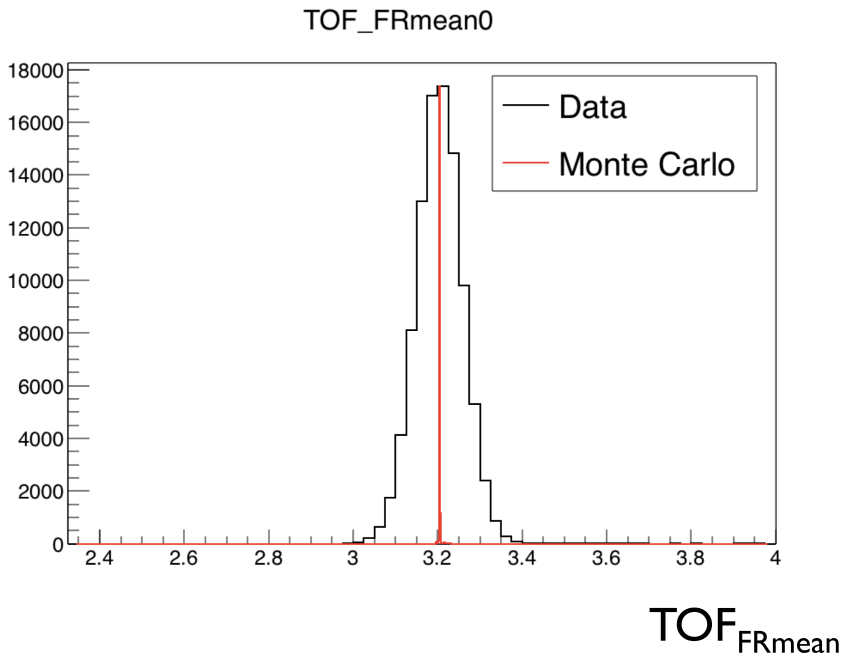


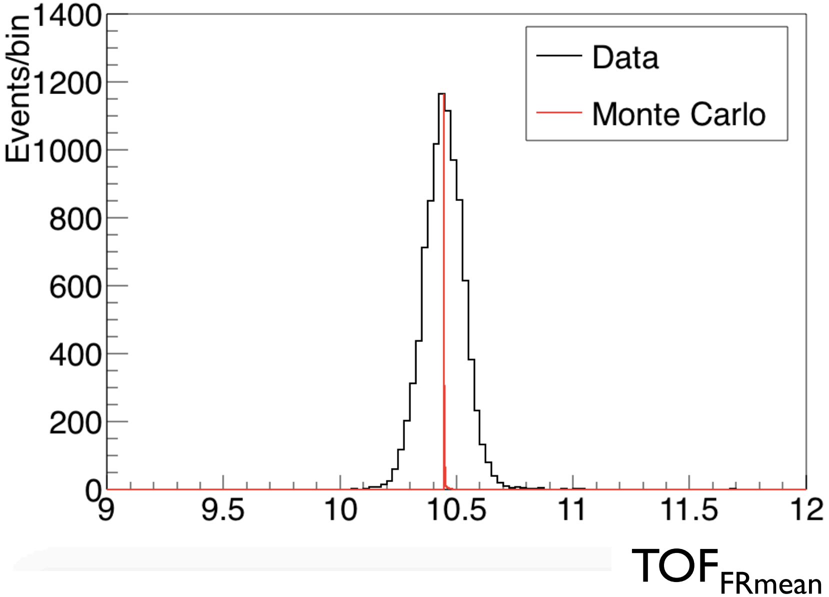


We would expect a very nice energy calibration, at least in the range with energy losses from 35-80 MeV

TOF Calibration

- For known particles with known energies, equalize the measured TOF with expected time of flight → Get offset value





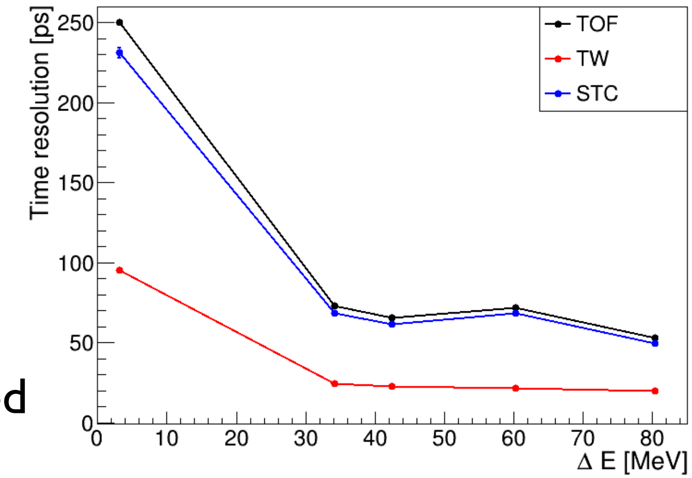
Resolutions

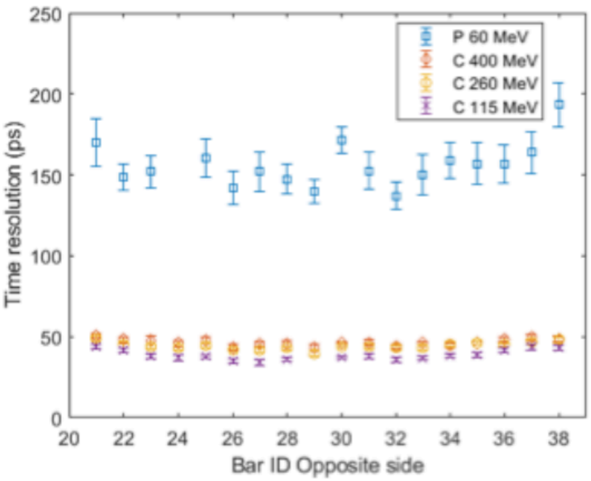
- TW resolution → time difference between bars
- STC resolution:

$$\sigma^2_{TOF} = \sigma^2_{TW} + \sigma^2_{STC}$$

- TOF resolution dominated by the STC

TOF resolution



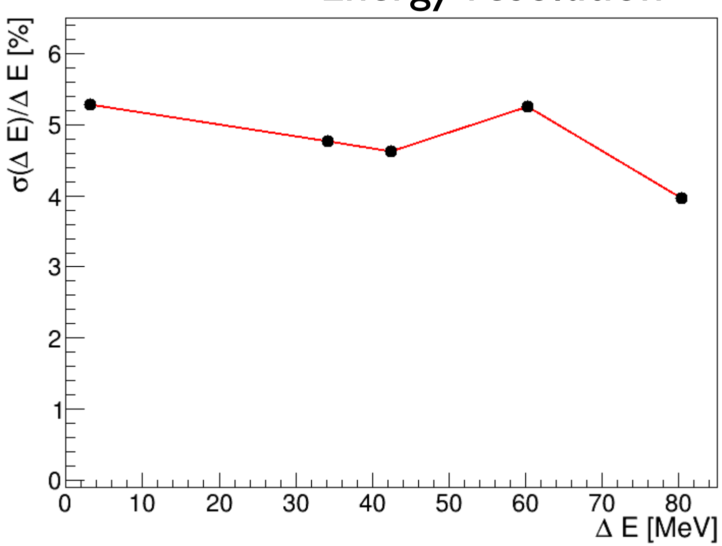


Resolution at GSI slightly worse

- Detectors in front of TW
- More air

→ To be checked

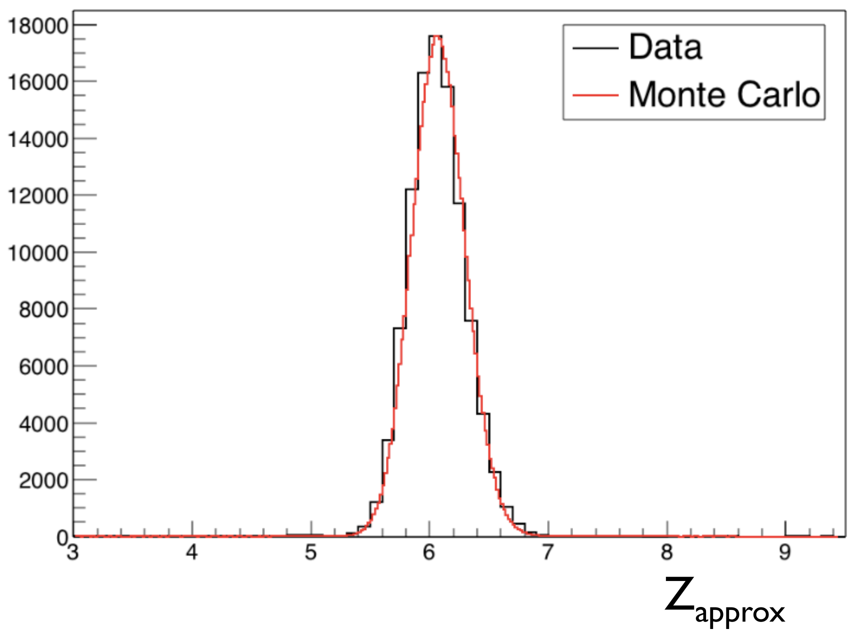
Energy resolution



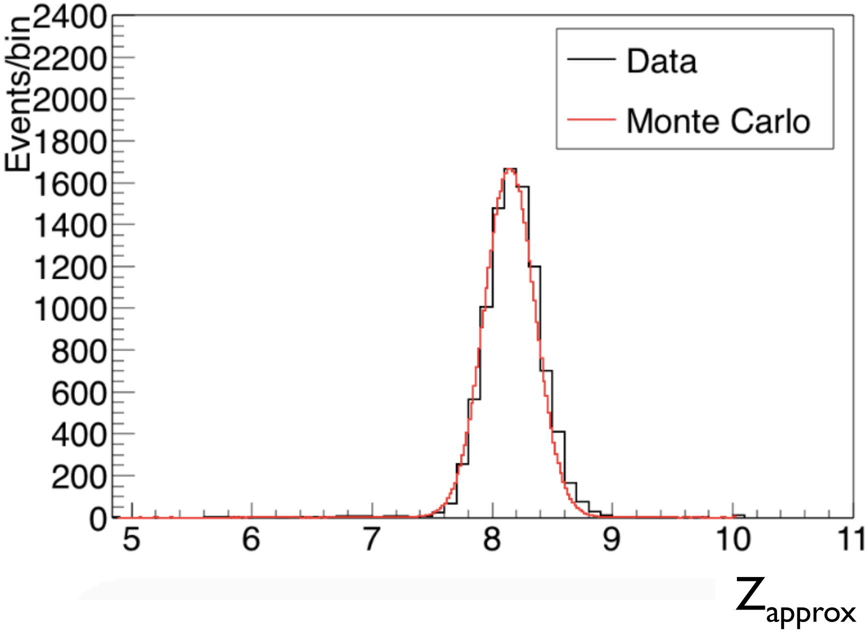
Energy and TOF with resolutions included

- Example of acquisitions without target, with resolutions included (first estimate)
- Calculate Z_{approx} by inverting BB formula. This is just an approximation!!! (was meant as cross check). FLUKA has a more advanced expression for energy loss (including corrections), so don't get back exact Z values in MC and data.

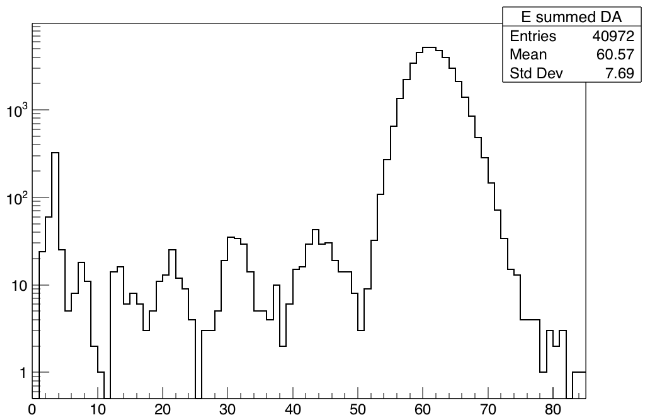
CNAO carbon 400 MeV/u

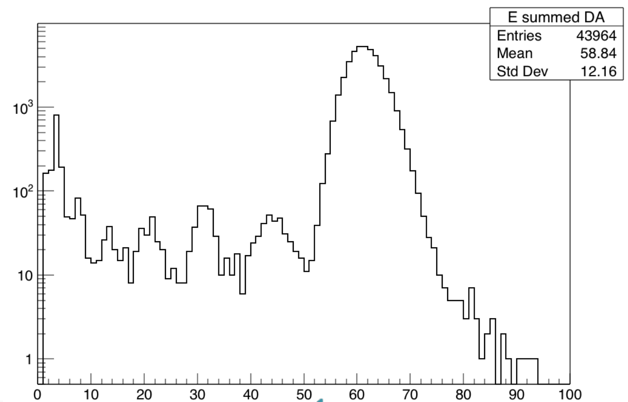


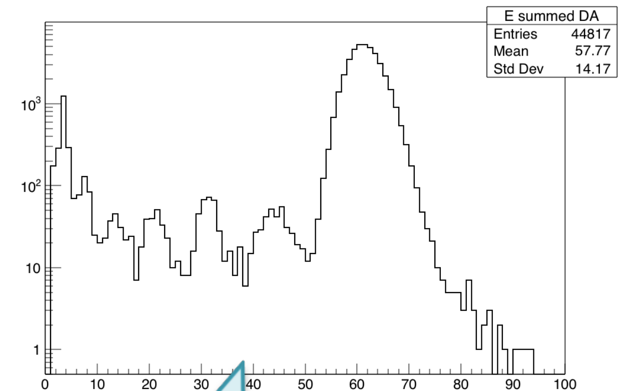
GSI oxygen 400 MeV/u



Fragmentation run: energy spectra for 3 cases





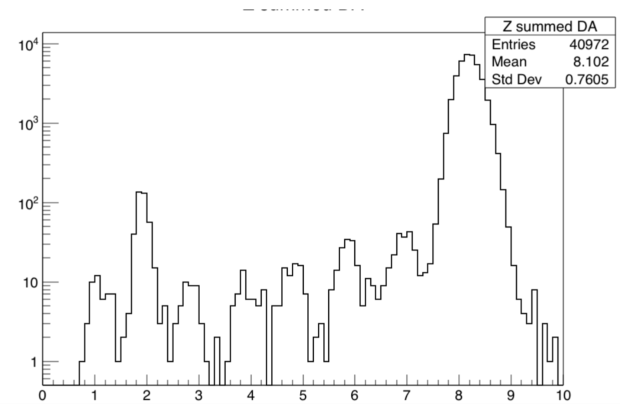


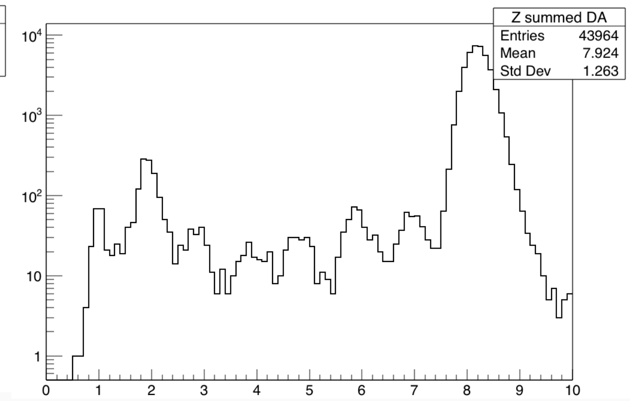
1) All well-calibrated positions: Front and Rear good! (40972)

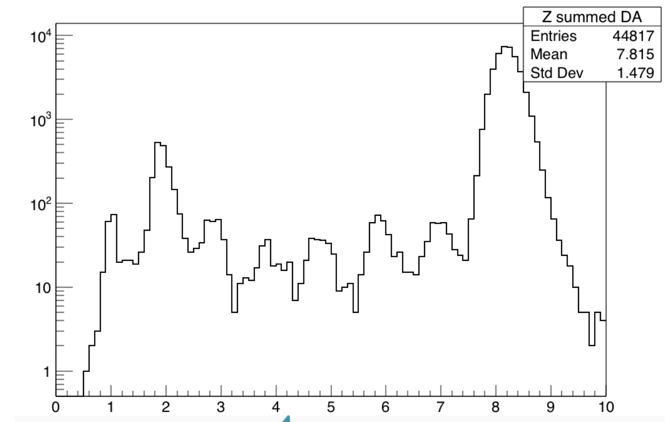
2) All well-calibrated positions+ positions where either Front or Rear were good!

As 2), but additionally try to recover all positions: where no calibration was available, use value of central bar, if it was reasonable.

Fragmentation run: Z spectra for 3 cases







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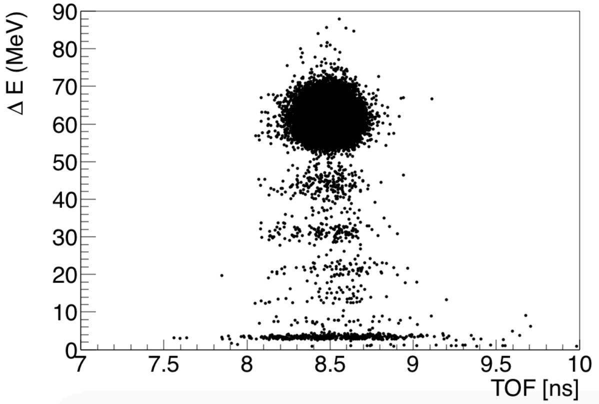
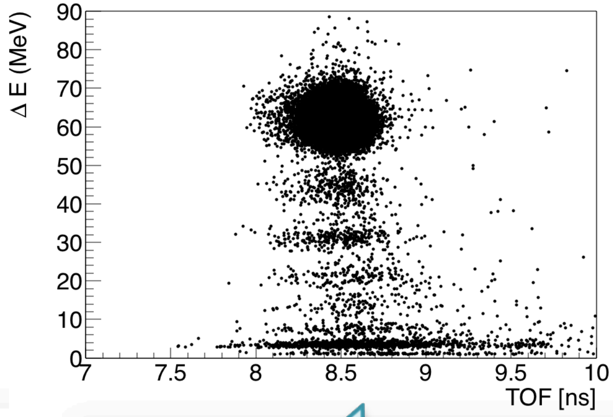
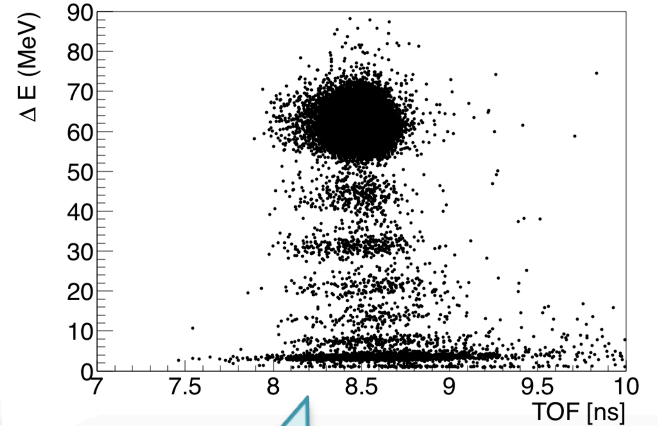
Fragmentation run: 2-D plot







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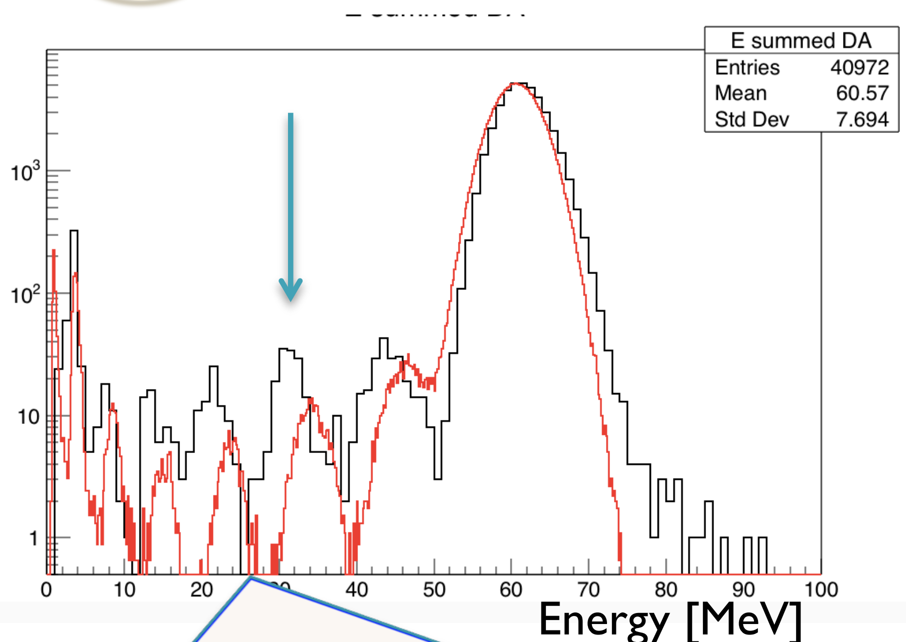
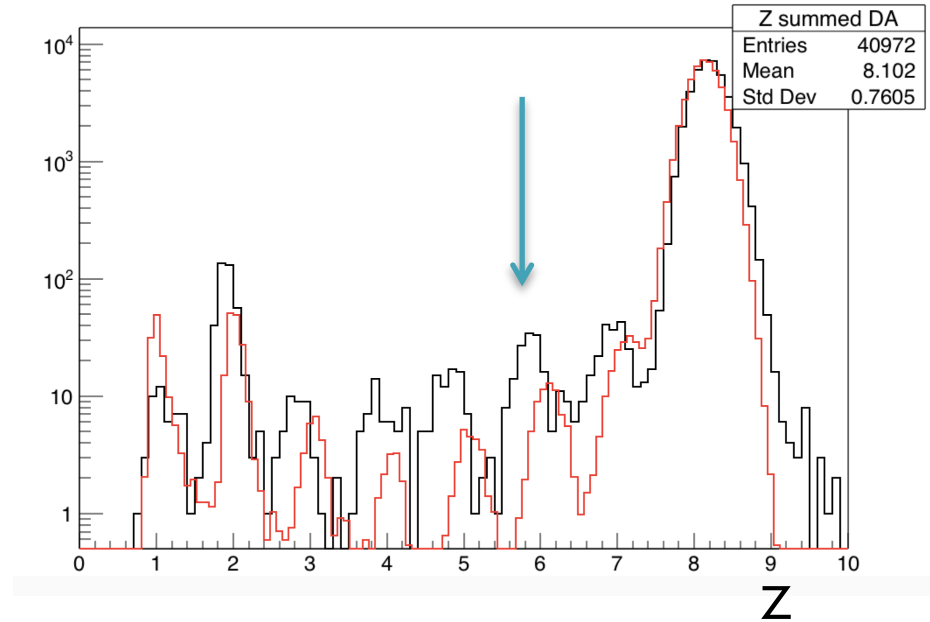
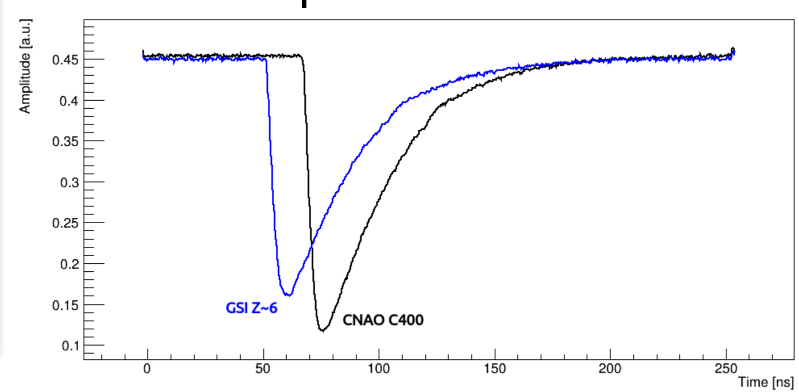
Fragmentation run: together with smeared MC





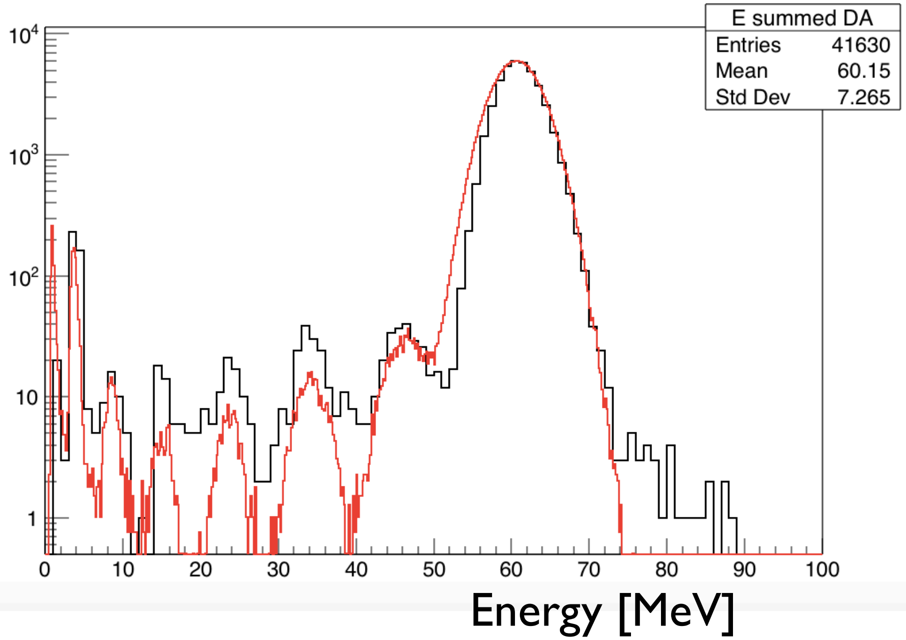
- Lots of effort done to understand shift→ for details see presentation 26-5-2020 (gains? hardware issues? CNAO/GSI incompatibilities? Beam energies? Dependence of Birks on particle type? Saturation/quenching at high energy deposits? Other detectors? Ghost cut? Dependence on event rate? Cross talk/reflection? …→ **For many issues, need more data**
- We can forget about the CNAO curves and tune the curves to make it fit

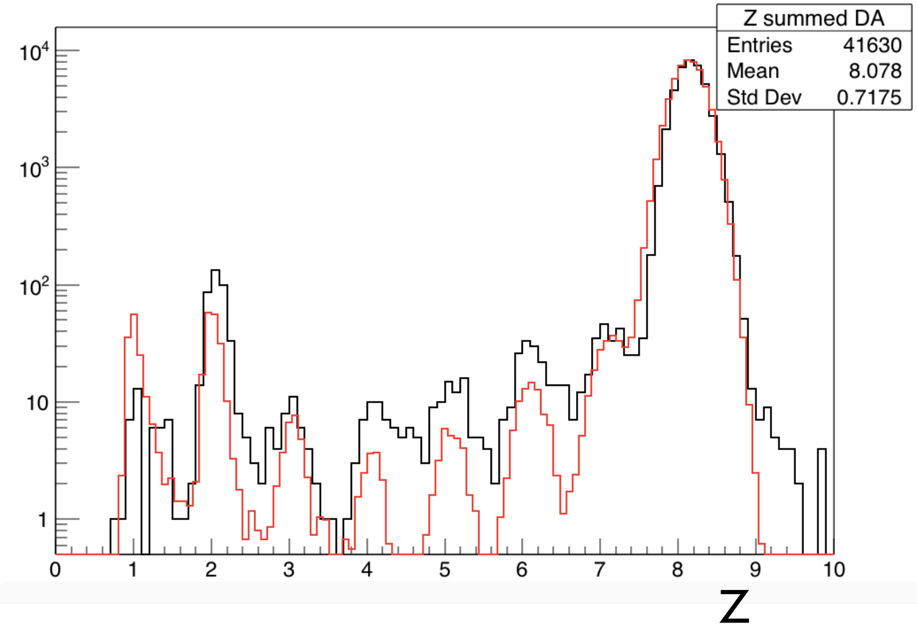
Example waveform for C



Fragmentation run: together with MC

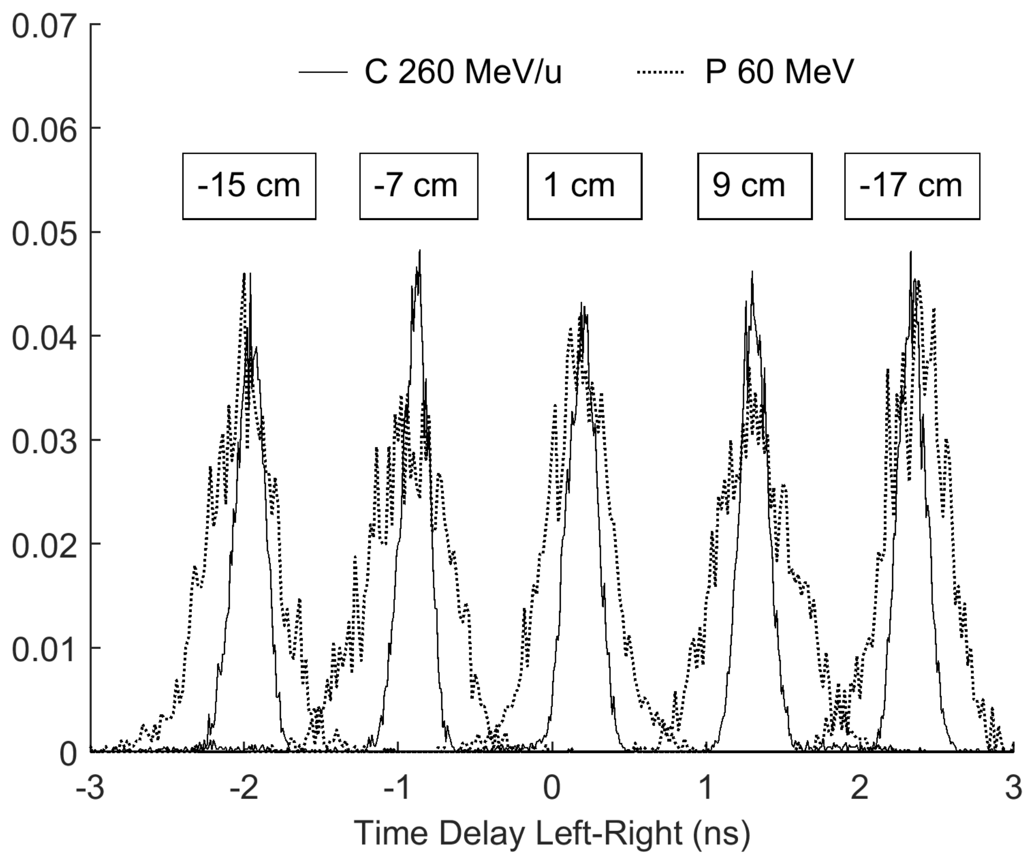
If we forget about the CNAO curves





Hit position from time information

- Not used in this analysis, but hit position can be recovered from time difference between bar ends
- FWHM (C260) =1.65±0.22cm and FWHM (P60) = 3.48 ± 0.35 cm.



Conclusion

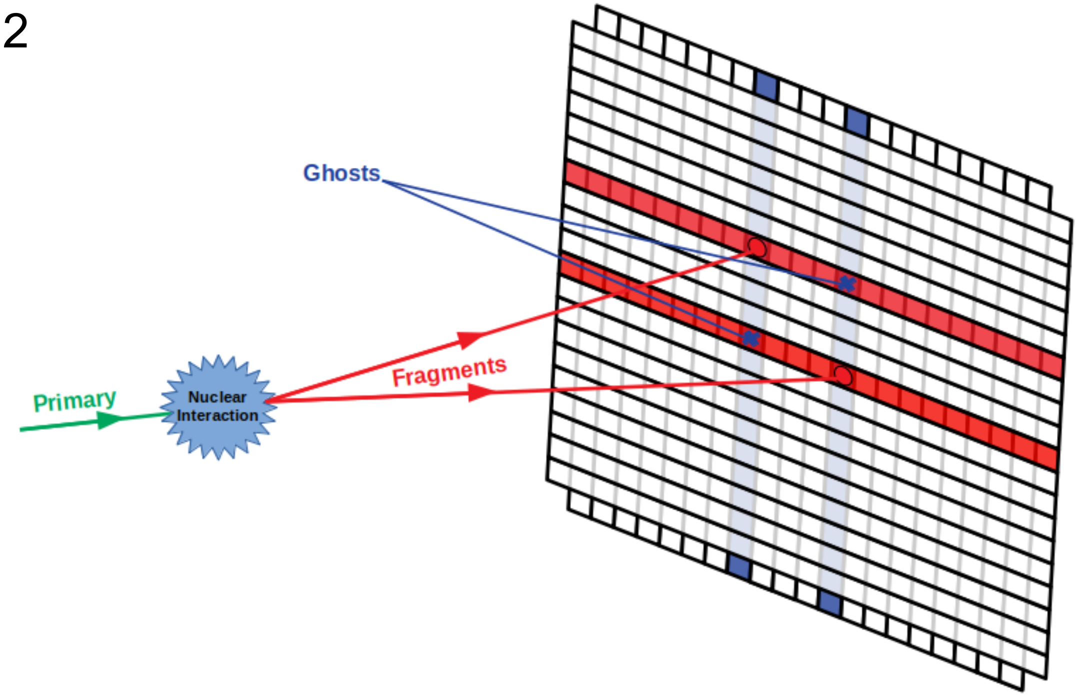
- Calibration procedure implemented and tested
- Practical solution chosen, aimed at obtaining maximum resolution
- Generally satisfying agreements
- Small differences in fragmentation spectrum to be investigated with more data (different ions, different event rates, different energies, stability checks, etc)
- Fragments with different charges discriminated well
- The data we took at CNAO and GSI are not optimal, but usable!
- Paper in preparation

backup

Two particles impinging on the TW at the same time can switch on 4 bars → 2 spurious “particles”

Proposed solution → **Energy filter**

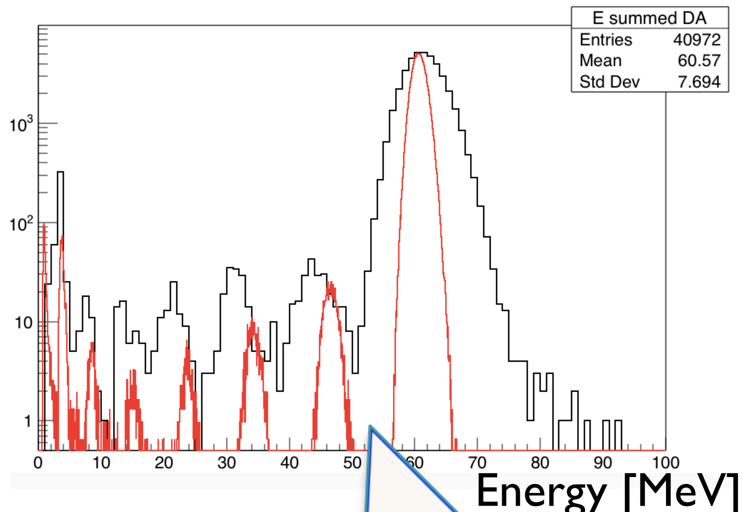
$$\frac{|\Delta E_{rear} - \Delta E_{front}|}{\Delta E} \leq 0.2$$

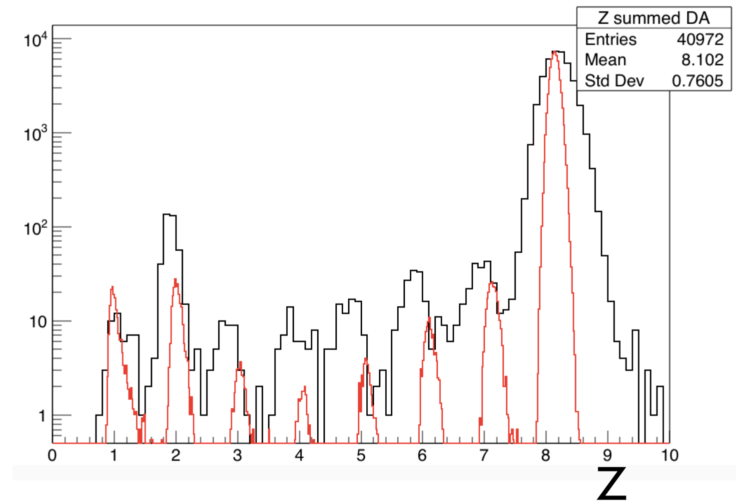


- Can still be improved
- Tracking system included in future acquisitions

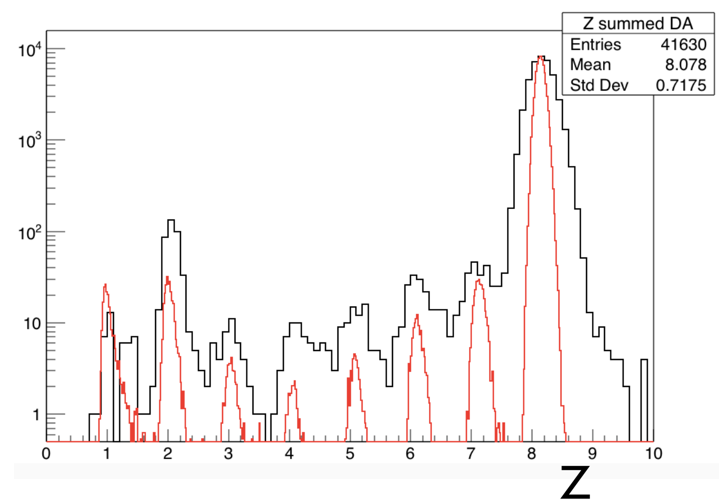
Fragmentation run: together with MC

- Calibration for CNAO+GSI→ use for comparison with MC→ not great!





- Lots of effort done to understand shift, see presentation 27-5-2020 (gains changed? beam energies in calibration? other detectors? Ghost cut?
- We can forget about the CNAO curves and tune the curves to make it fit



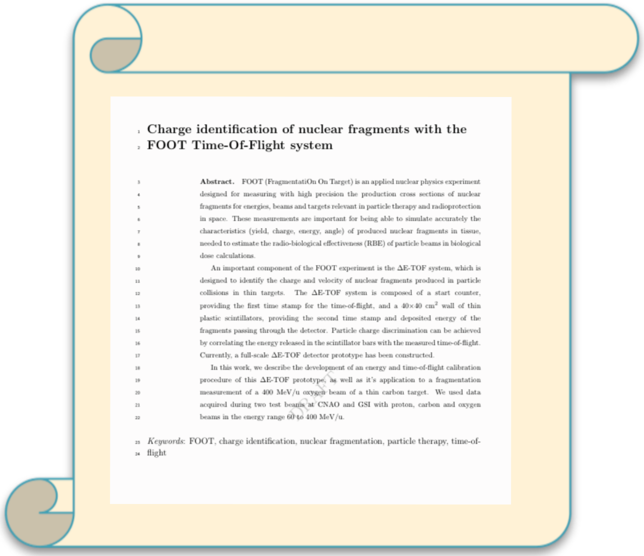
Proposal for paper content (I)

- Introduction:
  - Background FOOT
  - Motivation/what's new:
    - First time we would publish something with the full detector (past work was only with 2 or 4 single bars, now 80 bars)
    - First time TOF was measured with STC and TW together, all clocks synchronized, new software structure, etc. (past work didn't include STC)
    - First time system took data with oxygen
    - Show full max performance
- Materials and methods
  - TOF Wall system with 80 bars, STC ("full-scale TOF-Wall prototype" ?)
  - Data takings CNAO and GSI
  - Signal processing → **plot of charge along bar (slide 3)**
  - Calibration: by matching data of known projectiles with MC → **plot Birks (slide 7)**
  - 1 fragmentation measurement ?

Proposal for paper content (2)

- Results:
  - Validation of the energy and time calibration procedure: show a few examples (for well calibrated positions) , 3*2 plots:
    - Energy spectrum for Carbon oxygen 400 MeV/u without target
    - TOF spectrum for Carbon and oxygen400 MeV/u without target
    - Z spectrum for Carbon and oxygen400 MeV/u without target
  - Time resolution and maybe energy resolution → **table (slide 10)**
  - Fragmentation (for well calibrated positions)
    - All well-calibrated positions → **some plot**
- Conclusion
  - Full TW +STC system tested
  - Data processing, calibration
  - Performance of prototype evaluated

finalize paper



Charge identification of nuclear fragments with the FOOT Time-Of-Flight system

Abstract. FOOT (FragmentatiOn On Target) is an applied nuclear physics experiment designed for measuring with high precision the production cross sections of nuclear fragments for energies, beams and targets relevant in particle therapy and radioprotection in space. These measurements are important for being able to simulate accurately the characteristics (yield, charge, energy, angle) of produced nuclear fragments in tissue, needed to estimate the radio-biological effectiveness (RBE) of particle beams in biological dose calculations.

An important component of the FOOT experiment is the ΔE-TOF system, which is designed to identify the charge and velocity of nuclear fragments produced in particle collisions in thin targets. The ΔE-TOF system is composed of a start counter, providing the first time stamp for the time-of-flight, and a 40×40 cm^2 wall of thin plastic scintillators, providing the second time stamp and deposited energy of the fragments passing through the detector. Particle charge discrimination can be achieved by correlating the energy released in the scintillator bars with the measured time-of-flight. Currently, a full-scale ΔE-TOF detector prototype has been constructed.

In this work, we describe the development of an energy and time-of-flight calibration procedure of this ΔE-TOF prototype, as well as it's application to a fragmentation measurement of a 400 MeV/u oxygen beam of a thin carbon target. We used data acquired during two test beams at CNAO and GSI with proton, carbon and oxygen beams in the energy range 60 to 400 MeV/u.

Keywords: FOOT, charge identification, nuclear fragmentation, particle therapy, time-of-flight