Systematic study on the number of isotopes reconstructed, mass and its resolution, and cross section evaluation depending on

- Momentum

- TOF

- Kinetic energy

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TIFPA Trento Institute for Fundamental Physics and Applications

UNIVERSITÀ DEGLI STUDI DI TRENTO

Introduction

- Simulation:
  - ^{16}O 200 MeV/u on C_2H_4
  - $2.5x10^8$ primaries (2880551 interactions -> 1.15 %)
  - Geometry V15

- Selection:
  - Cross all the detectors
  - Tracks originated in the target
  - 5.5 < Z reco < 6.5
  - Fit $\chi^2 < 5$

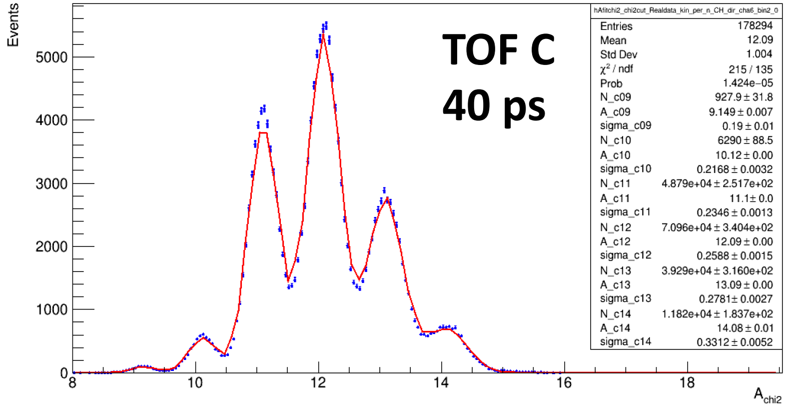
$$A_1 = \frac{p}{U\beta\gamma c}$$

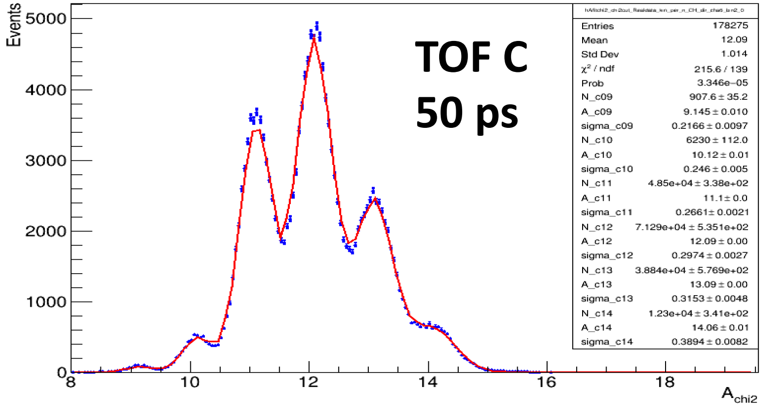
$$A_2 = \frac{E_k}{Uc^2(1-\gamma)}$$

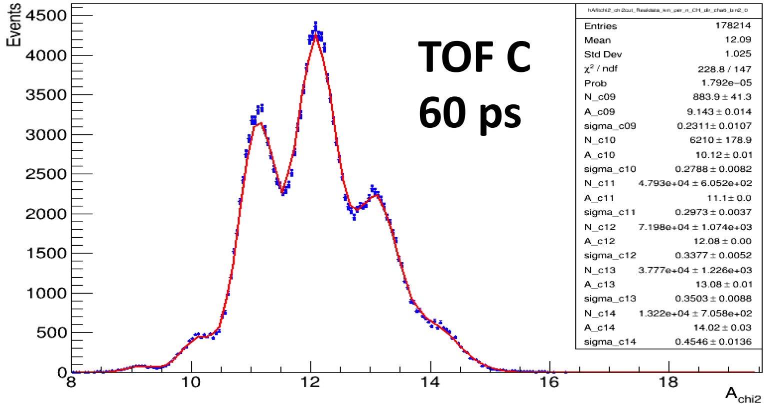
$$A_3 = \frac{pc^2 - {E_k}^2}{2Uc^2 E_k}$$

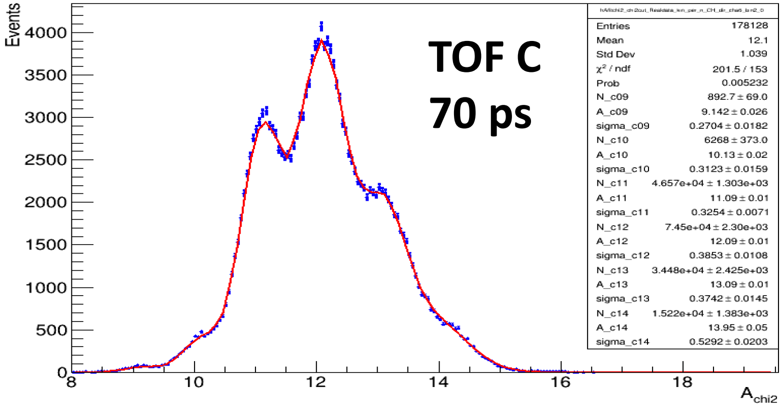
- 2 parameters fixed and 1 changed in from the ideal to the worse scenario:
  - 40 ps < TOF on carbon < 100 ps
  - 2.5 % < momentum resolution < 5.5 %
  - 1 % < kinetic energy resolution < 2.8 %

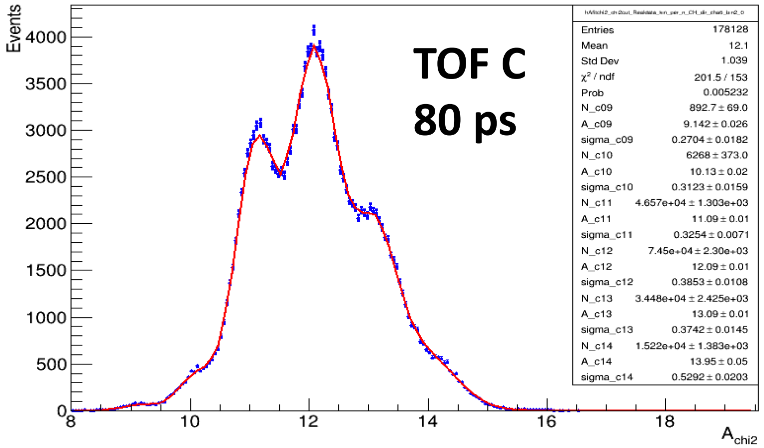
ΔEkin/Ekin	1.5%
Δp/p	3.7%

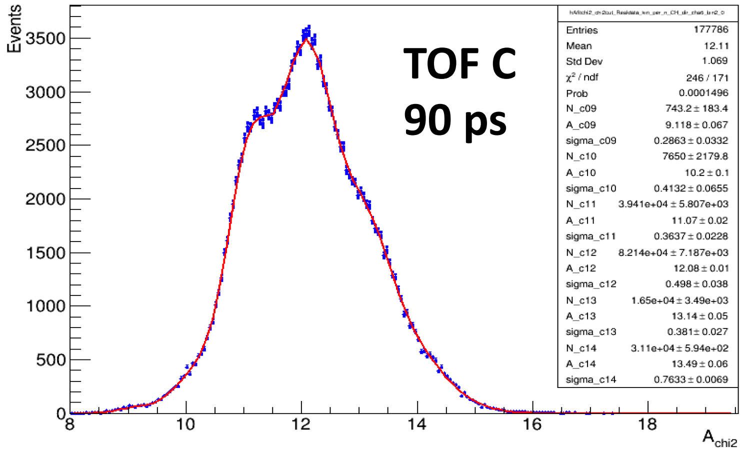


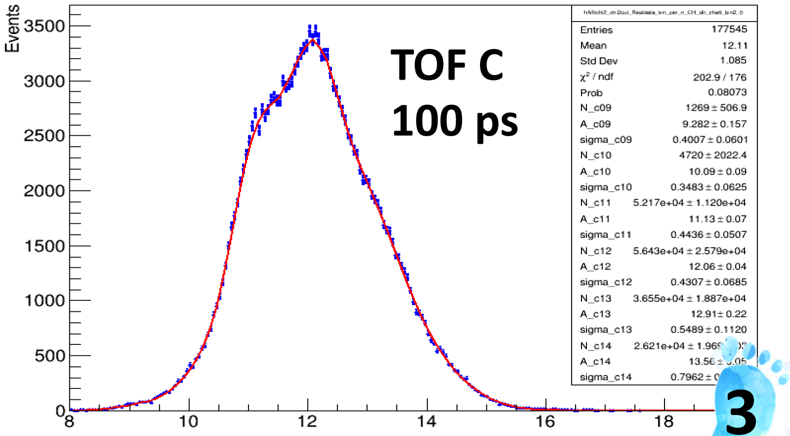




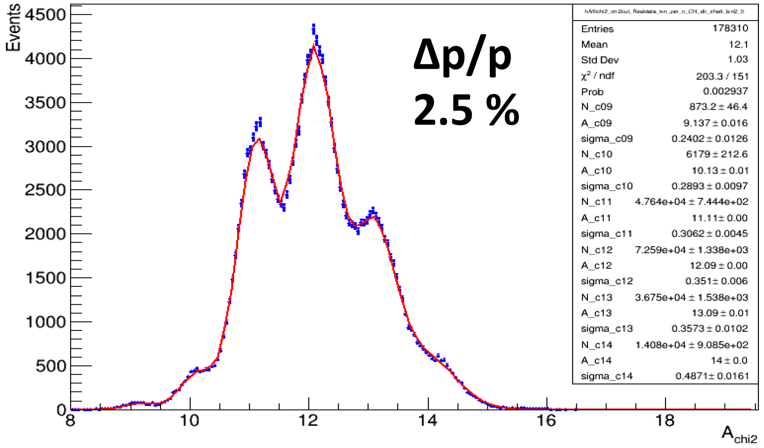


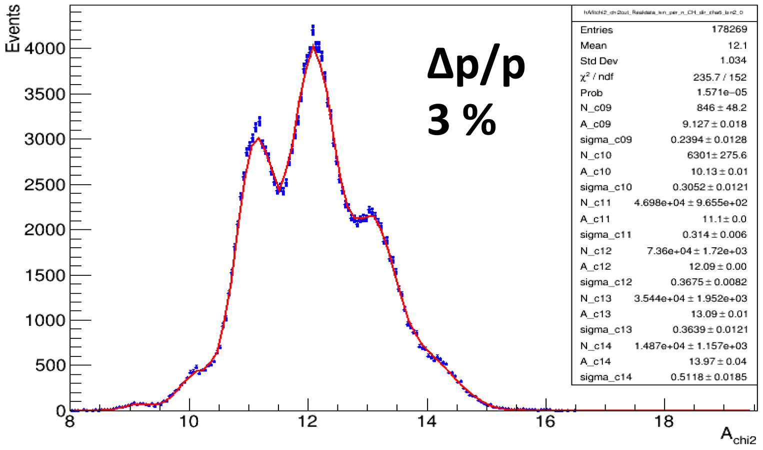


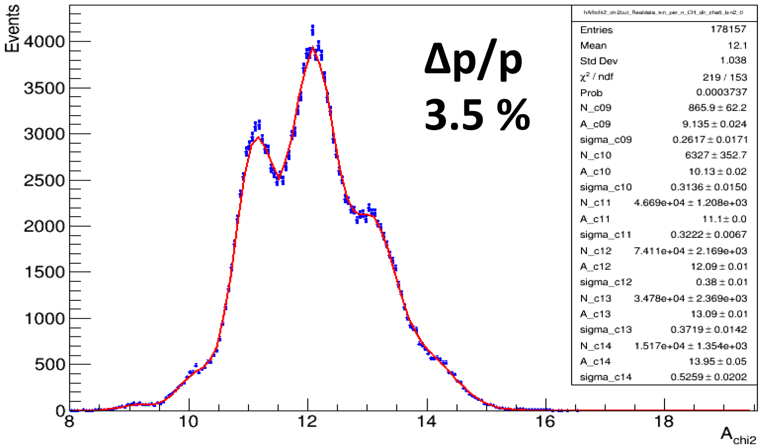


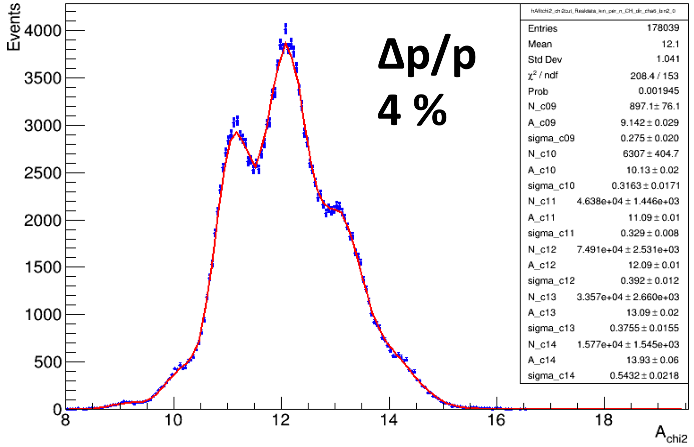


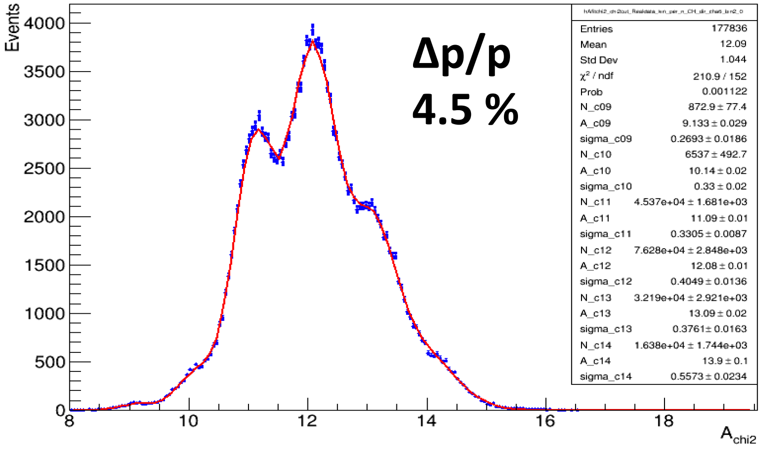
TOF on C	70 ps
ΔEkin/Ekin	1.5 %

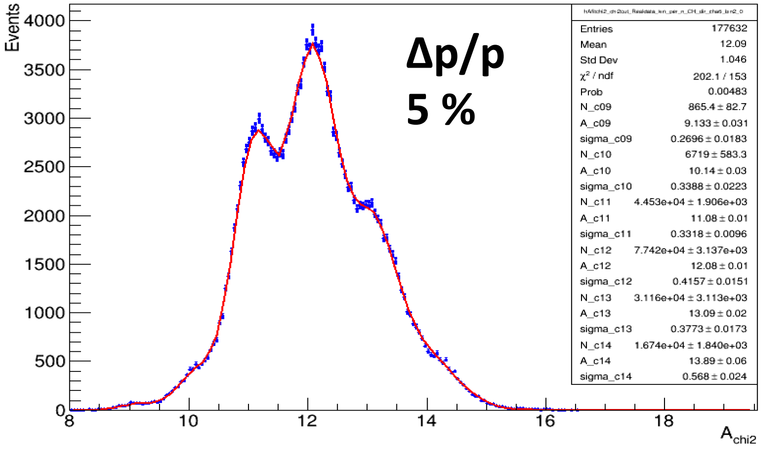


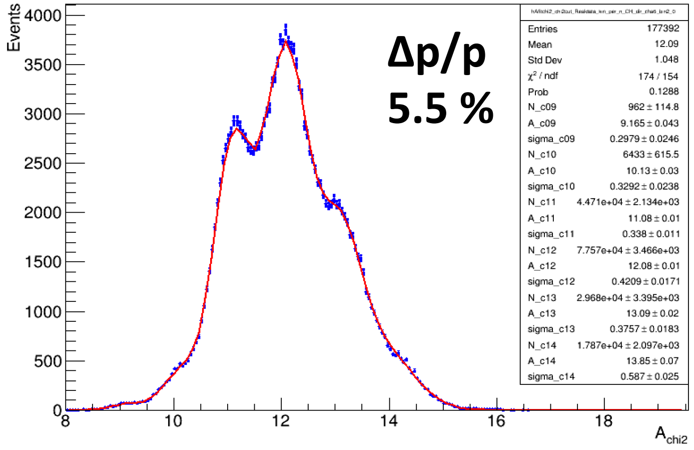




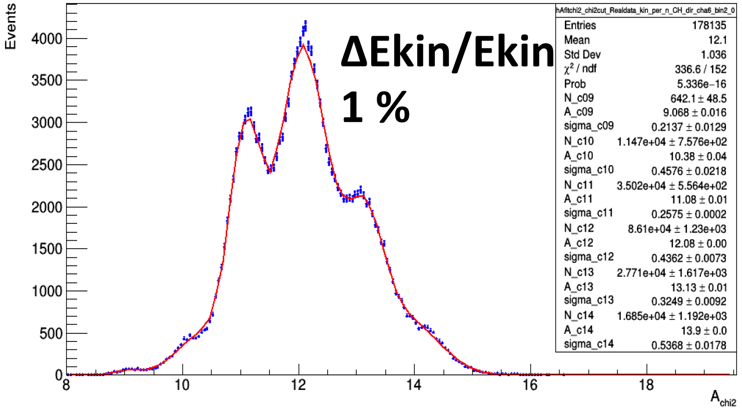


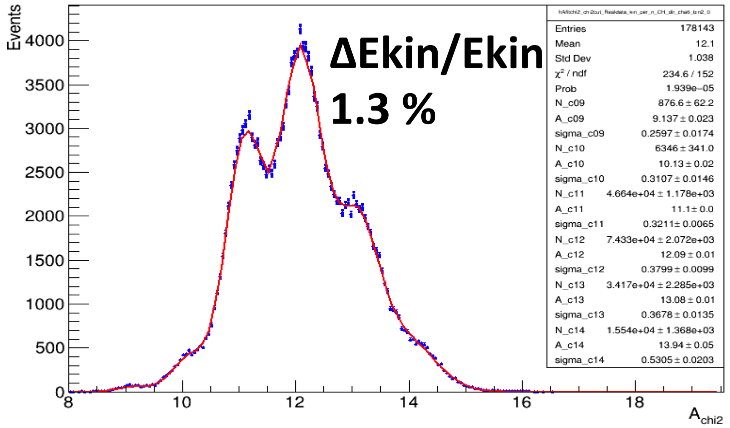


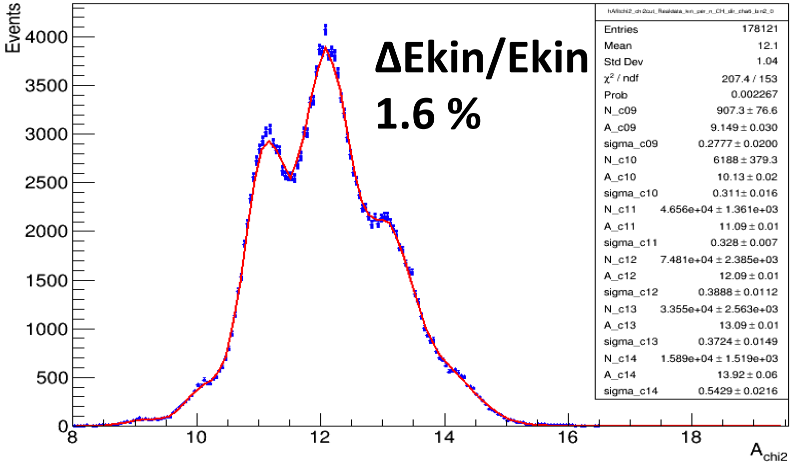


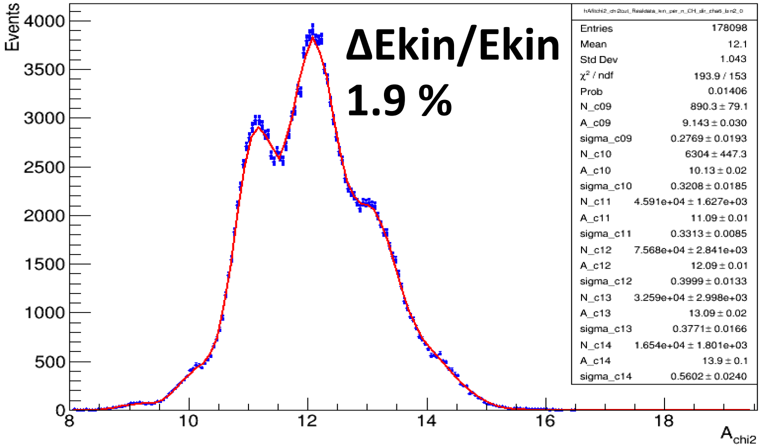


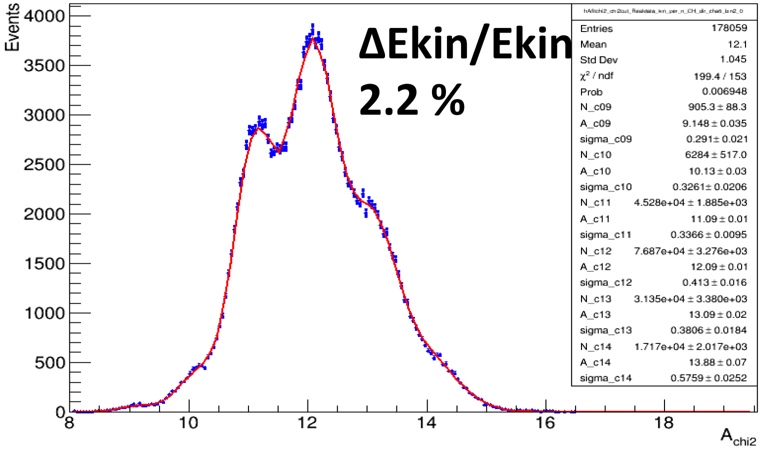
TOF on C	70 ps
Δp/p	3.7 %

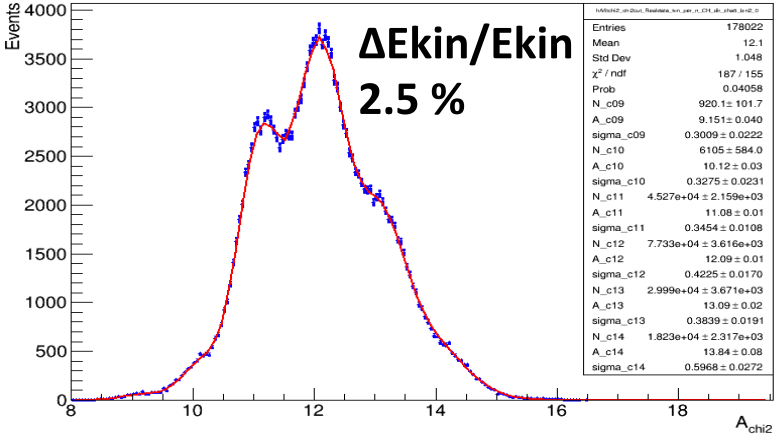


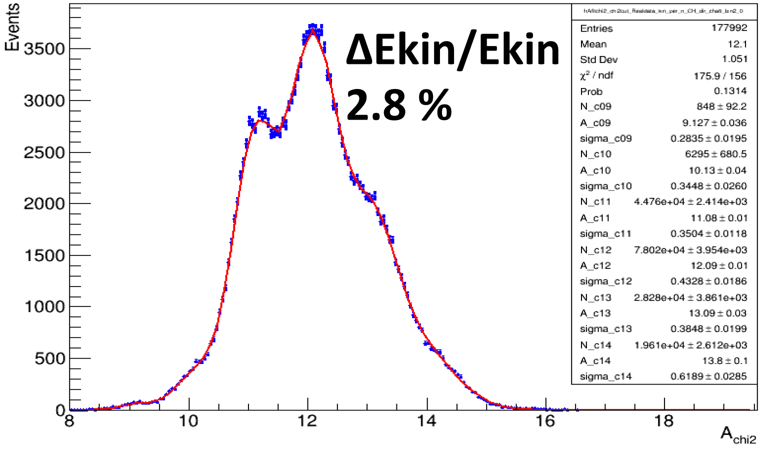




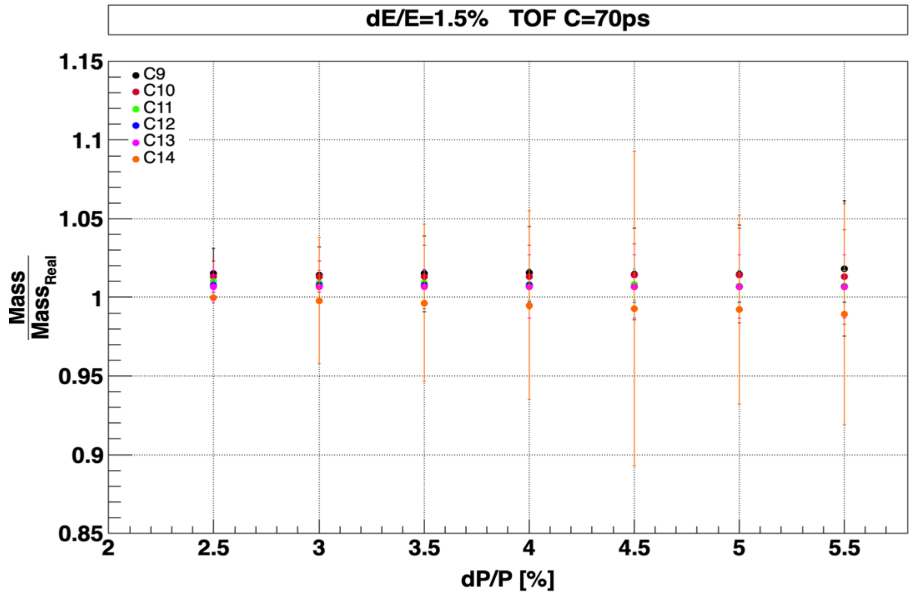


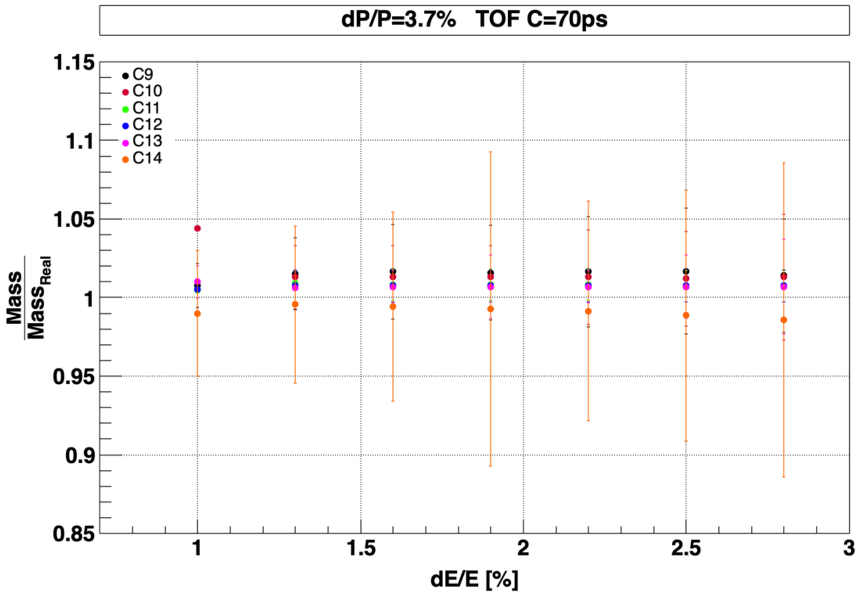


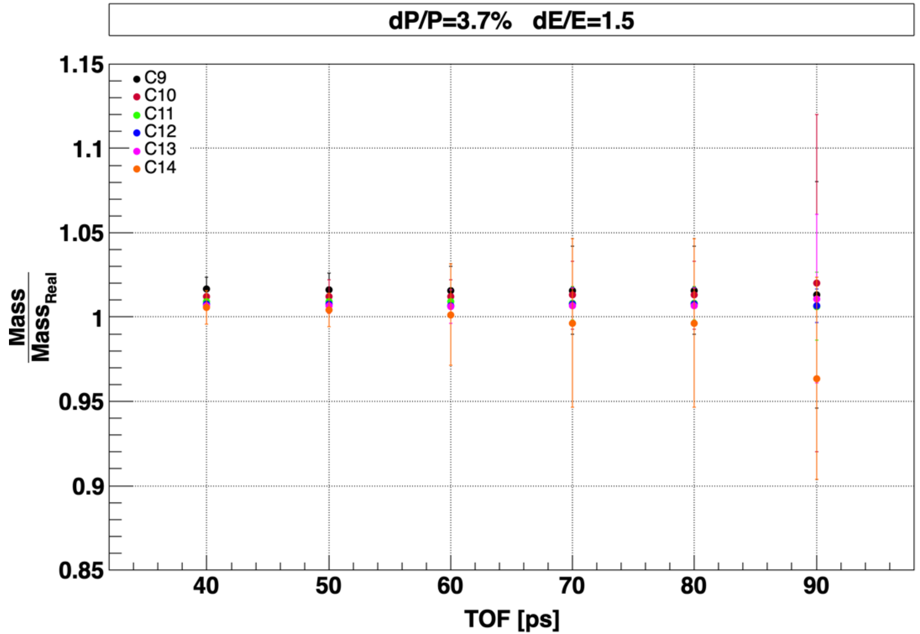




Mass (wrt real mass)

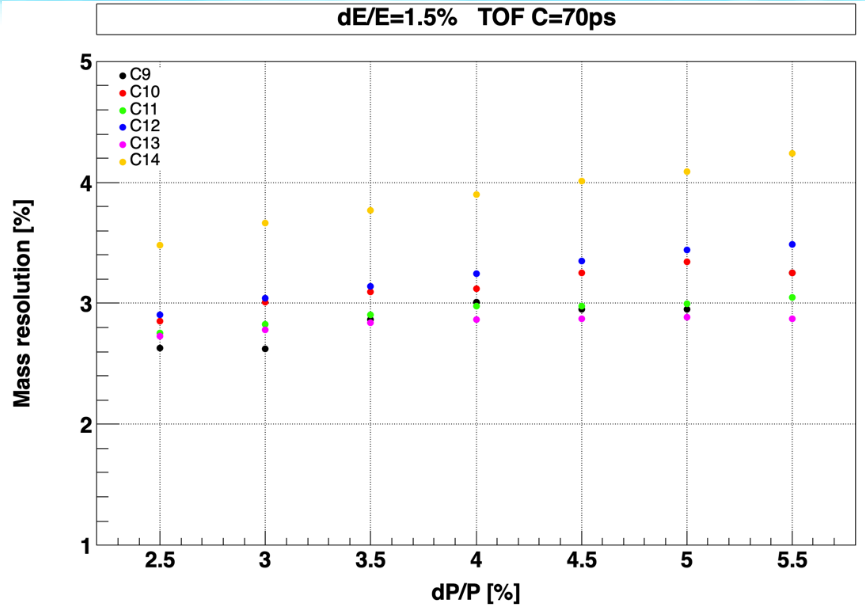


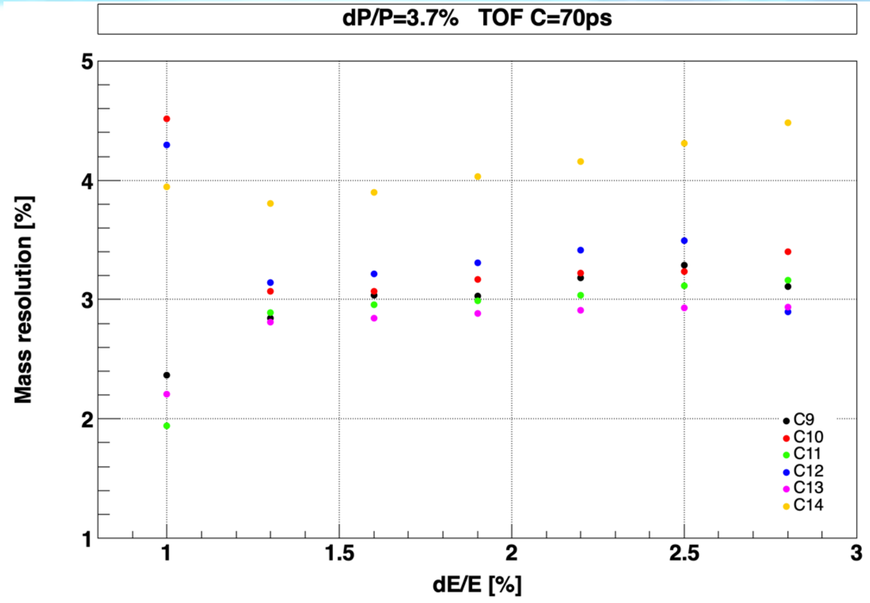


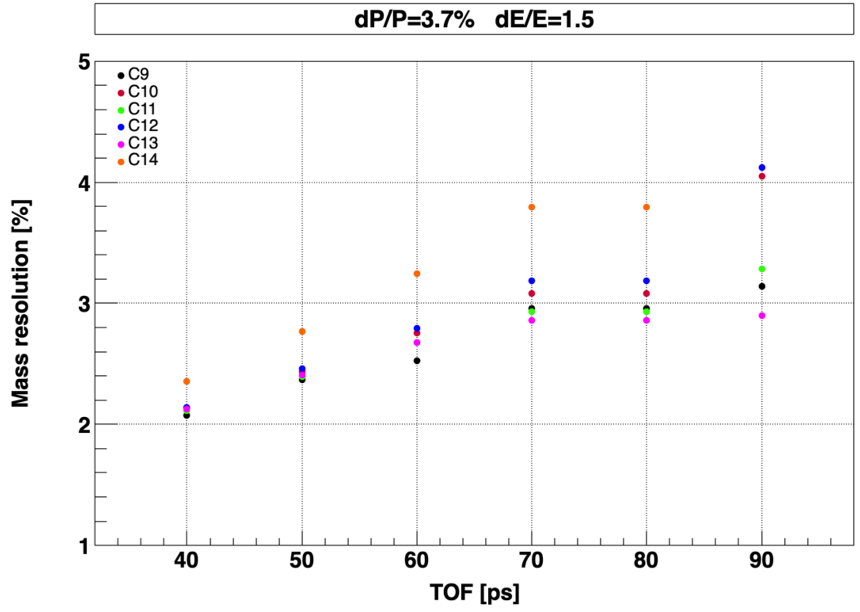


In most of the cases there is a small shift (≈ 1%) 'on the right' of the real mass

Mass resolution

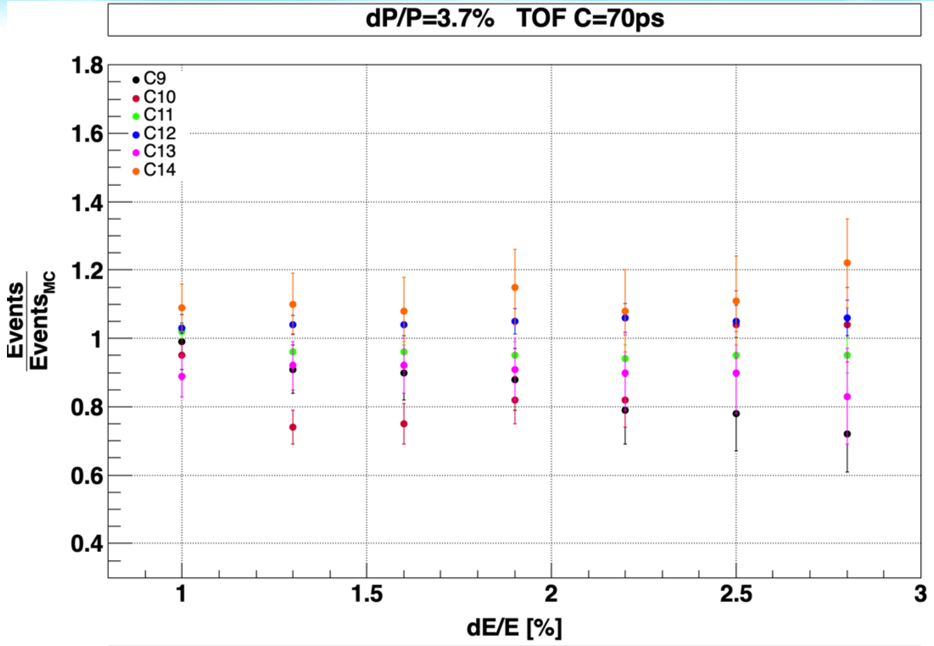


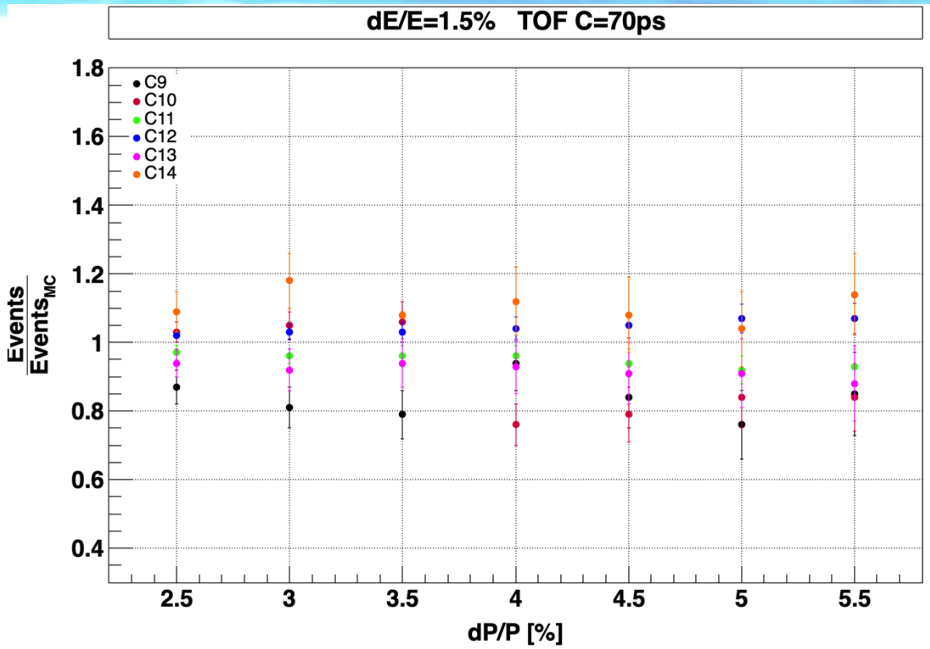


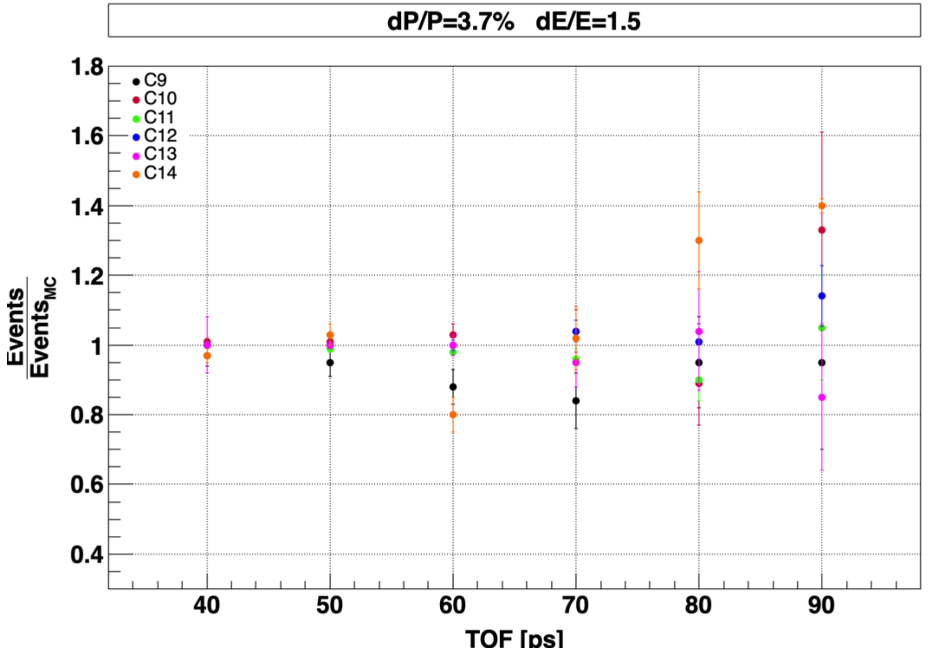


- Mass resolution get worse with increasing the resolution on p, Ekin, TOF
- Fit for ΔEkin/Ekin=1% needs improvement

Events (wrt MC events)



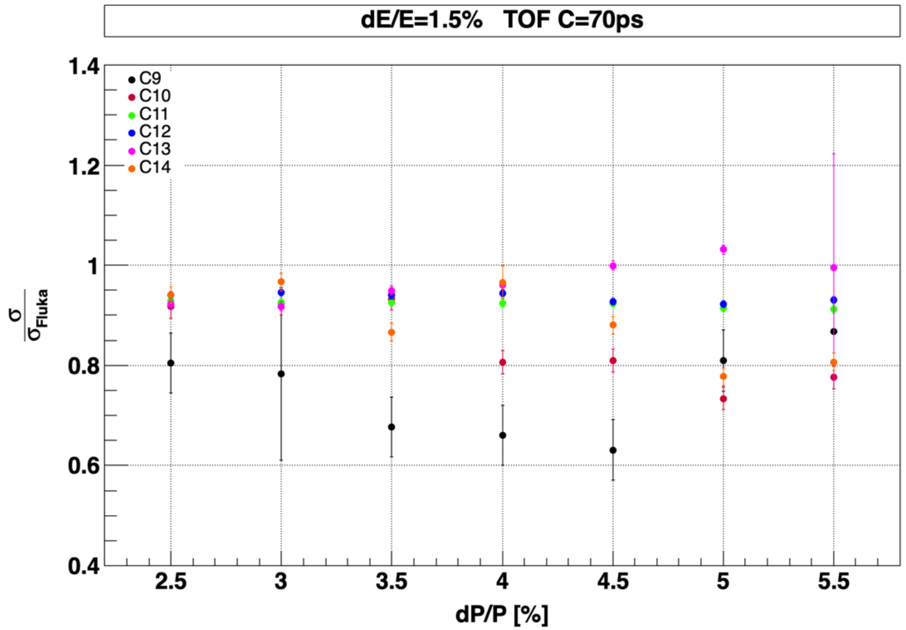


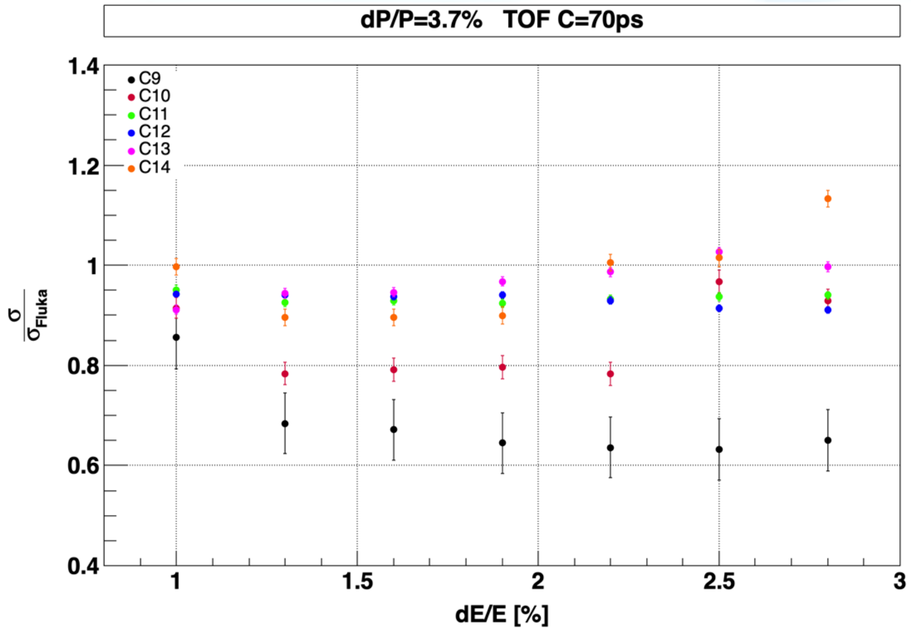


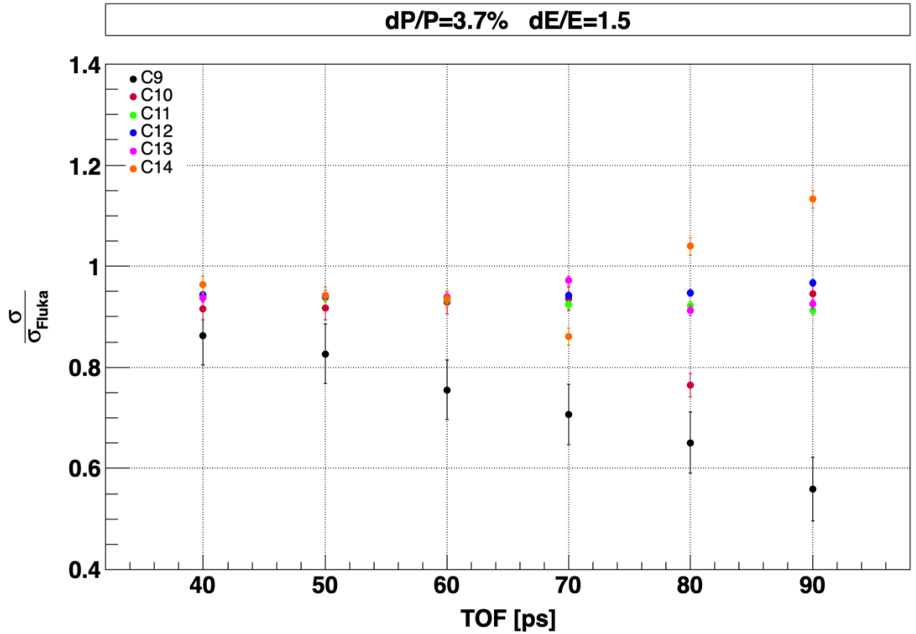
- Difference wrt MC events of ≈ 1% up to 7% for the isotopes with a good statistics (C11, C12, C13)

- Increasing the TOF has a strong impact on the analysis and leads to large deviations compared to MC, especially for low-statistics isotopes

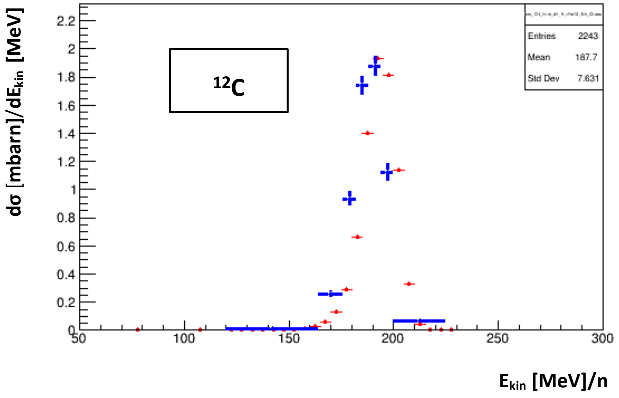
Cross section (wrt MC cross section)







For the isotopes with a good statistics the cross section value is always underestimated of about 5 %



Systematic shift in the Ekin recostruction

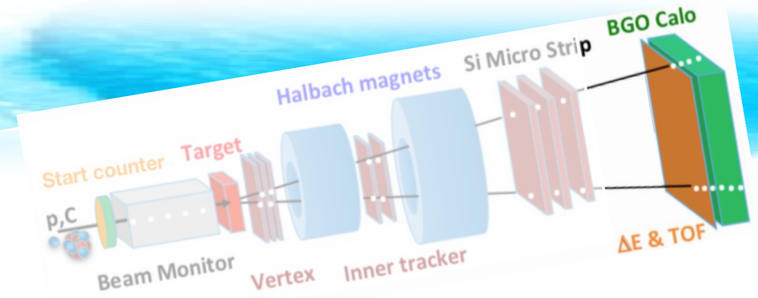
Conclusions

- C9, C10, C14 has a low statistic, so maybe the systematic study could be focused only on C11, C12, C13
- The TOF is the most sensible parameter in terms of isotope identification
- Cross section measurement shows a behaviour already observed. Maybe it could be related to the fact that we always have a 5% shift in the peak position, but need to be investigated more and understand better

Next steps

- Switch to higher beam energy simulations: ^{16}O 400 MeV/u and 700 MeV/u
- Start the study about neutrons

BACKUP SLIDES



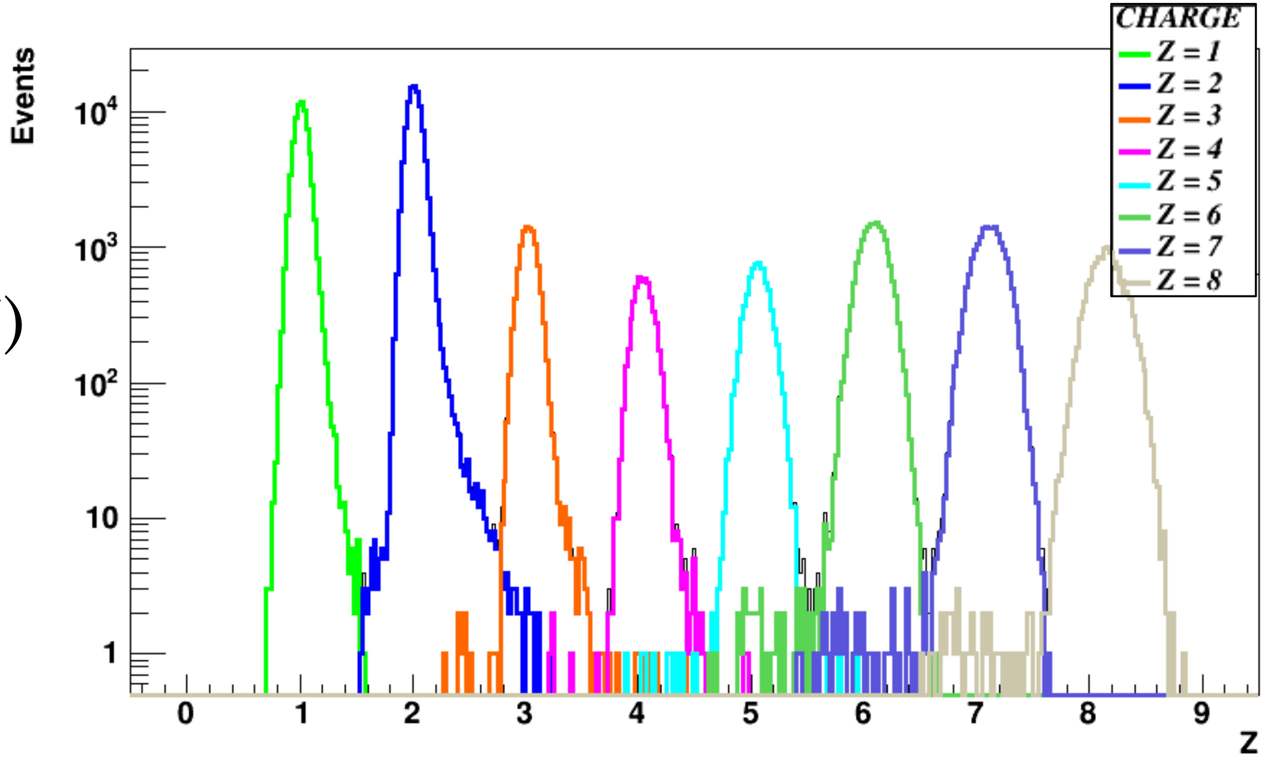
Charge identification

The Z determination is obtained by the mean **energy loss** of charged particle deposited in the **plastic scintillator (SCN)** and by the TOF measurement (Start Counter – SCN)

$$-\frac{dE}{dx} = \frac{\rho \cdot Z}{A} \frac{4\pi N_A m_e c^2}{M_U} \left(\frac{e^2}{4\pi\epsilon_0 m_e c^2} \right)^2 \frac{z^2}{\beta^2} \left[\ln \left(\frac{2 m_e c^2 \beta^2}{I \cdot (1-\beta^2)} \right) - \beta^2 \right]$$

Charge and velocity of the fragment (divided by c)

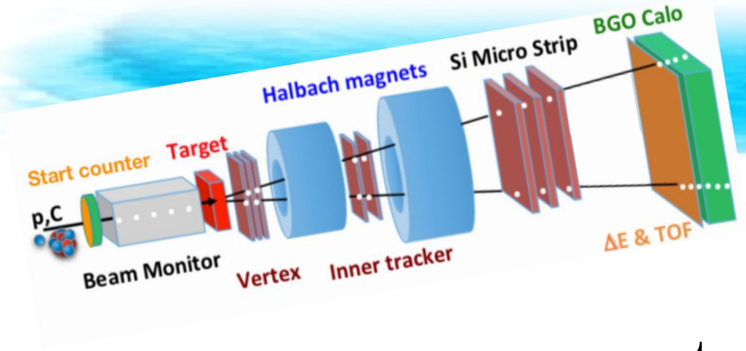
- Resolution: **2%** (^{16}O) – **6%** (^{1}H)
- Wrong charge assignment < 1%



Fluka simulation

^{16}O (200 MeV/u) → C_2H_4

Mass identification



Combination of reconstructed quantities:

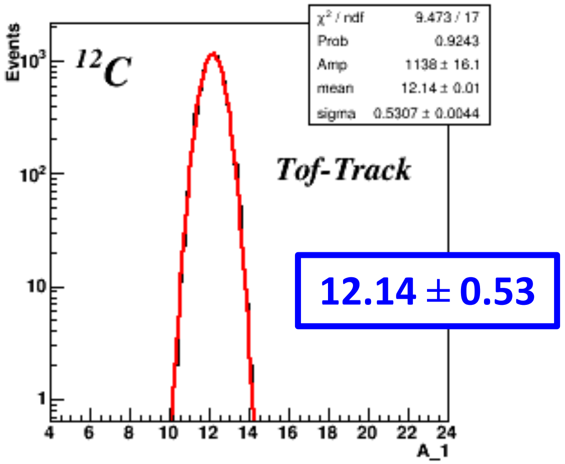
- Momentum (**magnetic spectrometer**)
- ToF (**scintillator**)
- Kinetic energy (**calorimeter**)

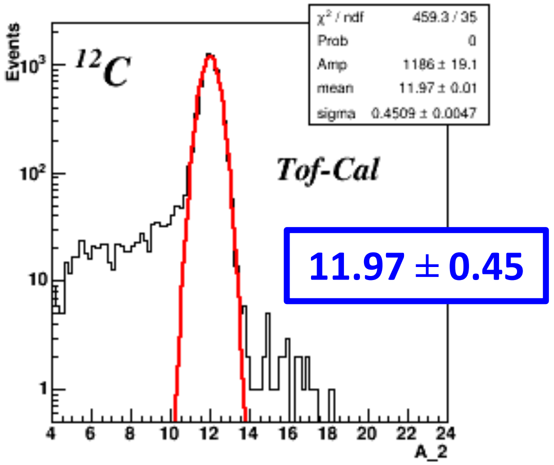
$$A_1 = \frac{p}{U\beta\gamma c} \qquad A_2 = \frac{E_k}{Uc^2(1-\gamma)} \qquad A_3 = \frac{pc^2 - E_k{}^2}{2Uc^2E_k}$$

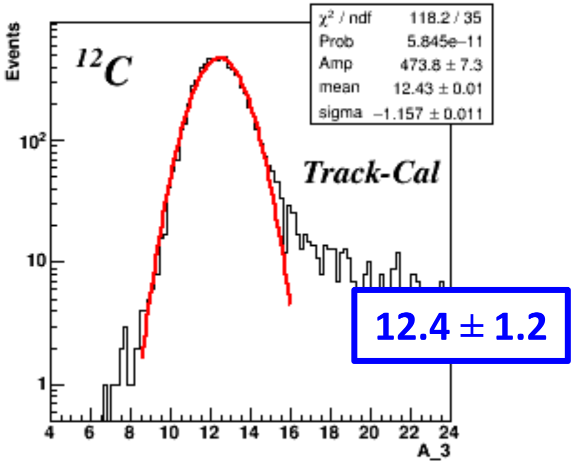
Fluka simulation

^{16}O (200 MeV/u) → C_2H_4

(Example of ^{12}C)







Best determination of A throught:

- Standard χ^2 fit
- Augmented Lagrangian Method (ALM)

- Peak position centered around the expected values
- Resolution: **4%** (^{16}O) – **6%** (^{1}H)

Mass reconstruction and fit

TOF (β) – TRACKER (p)

$$A_1 = \frac{m}{U} = \frac{p}{U\,\beta\,\gamma}$$

TOF (β)– CALO (E_{kin})

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

TRACKER (p) – CALO (E_{kin})

$$A_3 = \frac{m}{U} = \frac{p^2 - {E_{kin}}^2}{2E_{kin}}$$

- **Standard χ^2 Fit**
  - Taking into account the correlation between A_1, A_2 and A_3 (reconstructed quantities)
  - Minimization method based on a function *f* defined by:

$$f = \left(\frac{(tof_{reco} - t)}{\sigma tof_{reco}}\right)^2 + \left(\frac{(p_{reco} - p)}{\sigma p_{reco}}\right)^2 + \left(\frac{(E_{kin,reco} - E_{kin})}{\sigma E_{kin,reco}}\right)^2 + (A_1 - A \quad A_2 - A \quad A_3 - A)\begin{pmatrix} C_{00} & C_{01} & C_{02} \\ C_{10} & C_{11} & C_{12} \\ C_{20} & C_{21} & C_{22} \end{pmatrix}\begin{pmatrix} A_1 - A \\ A_2 - A \\ A_3 - A \end{pmatrix}$$

$$C = (A \cdot A^T)^{-1}$$ Correlation matrix →

$$A = \begin{pmatrix} \frac{\partial A_1}{\partial t} dt & \frac{\partial A_1}{\partial p} dp & 0 \\ \frac{\partial A_2}{\partial t} dt & 0 & \frac{\partial A_2}{\partial E_{kin}} dE_{kin} \\ 0 & \frac{\partial A_3}{\partial p} dp & \frac{\partial A_3}{\partial E_{kin}} dE_{kin} \end{pmatrix}$$

Machinery for the cross section evaluation of C fragments

Differential cross sections (E_{kin}, θ) of each produced fragment

$$\frac{d\sigma_f}{dE_{kin}} = \frac{(Y_f - Bkg_f)^U}{N_{Prim} \, . \, N_t \, . \, \Omega_{Ekin} \, \epsilon_f}$$

- f -> fragment: all Carbon Isotopes
- N_{prim} -> number of primary events
- N_t -> number of scattered center per unit area
- ε_f -> efficiency
- Ω_{Ekin} -> phase space

- Bkg -> Background : events counted with A=12, but generated with A≠ 12 (≈ 11%)
- U -> Unfolding : the reconstructed distribution must be corrected from the experimental effects
  - $(Y_f – Bkg_f)^u$ Unfolded (Yield – Bkg) of the fragment