Fragment Identification

Fragment is univocally determined by Z and A

performed @200 MeV/u (hadrontherapy) and 700 MeV/u (radioprotection)

Charge determination (Z):

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

SCN (dE/dx)

TOF (β)

Number of mass determination (A):

- Reconstruction

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

TRACKER (p), TOF ($\beta\gamma$)

$$A_2 = \frac{m}{U} = \frac{\boldsymbol{E}_{\boldsymbol{kin}}}{U(\boldsymbol{\gamma}-1)}$$

CALO (E_{kin}), TOF (γ)

$$A_3 = \frac{m}{U} = \frac{\boldsymbol{p}^2 - \boldsymbol{E}_{\boldsymbol{kin}}{}^2}{2\boldsymbol{E}_{\boldsymbol{kin}}}$$

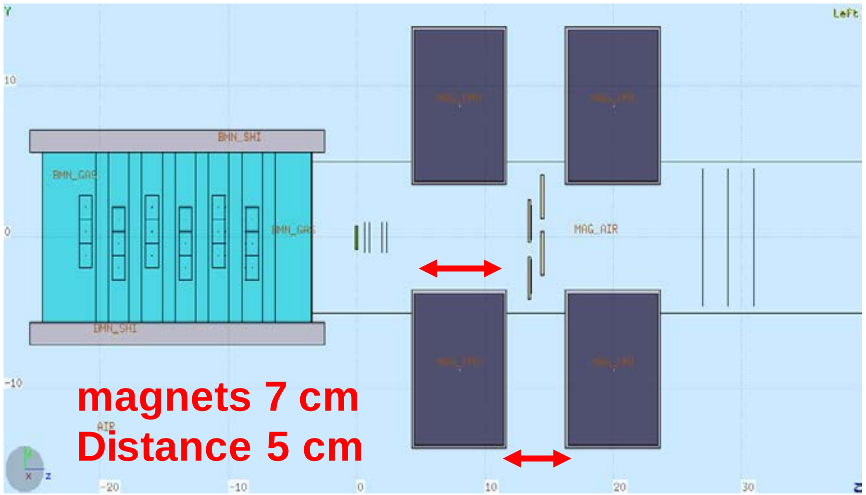
TRACKER (p), CALO (E_{kin})

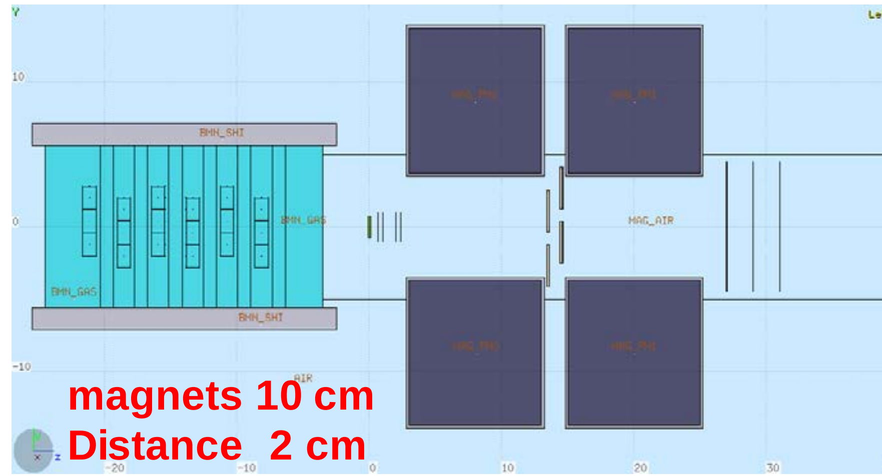
- Fit Methods

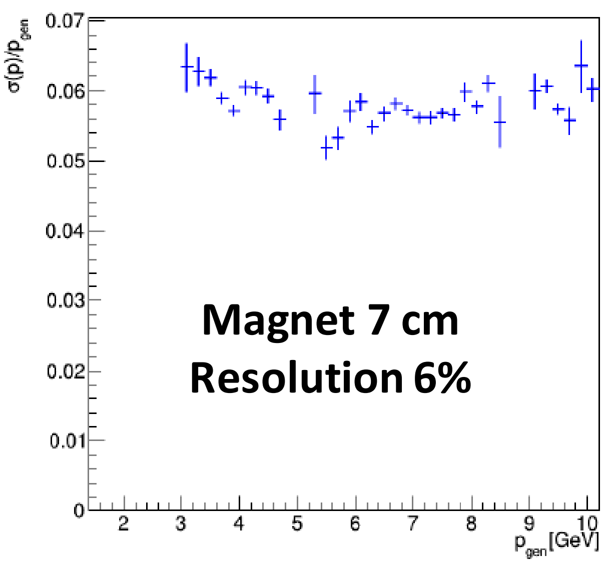
STANDARD χ^2 and **ALM**

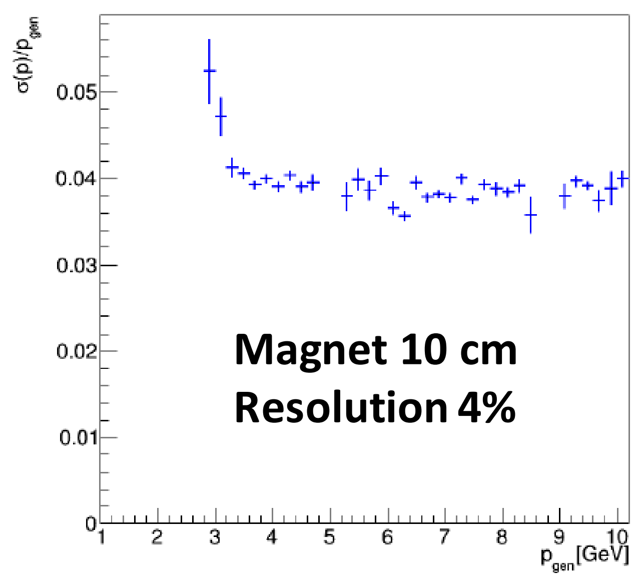
p Resolution @ 200 MeV/u

Fluka Simulation: ^{16}O (200 MeV/u) on C_2H_4 target



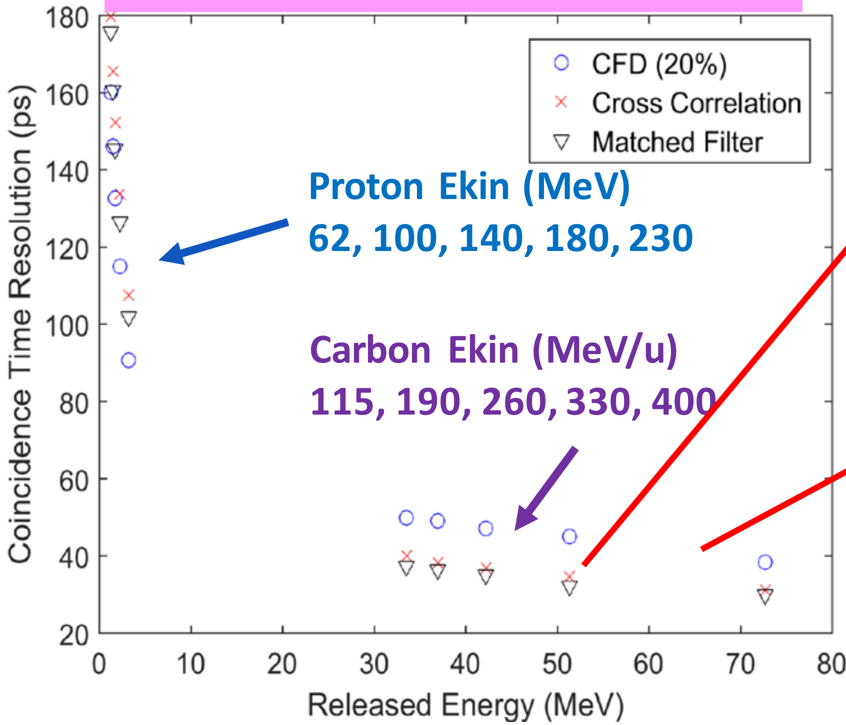




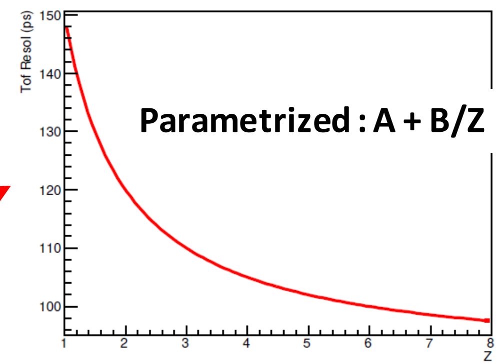


Tof & E_{kin} resolution

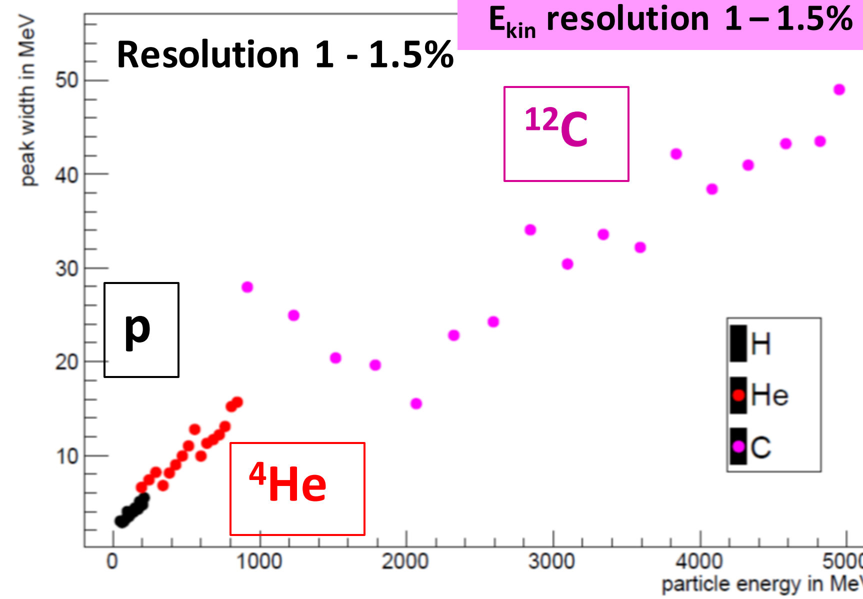
Test beam @CNAO:
Tof resolution (heavy fragments) ~ 50 ps



Test on a single SCN, supposing the same resolution in the SC → Tof Resolution = 70 ps

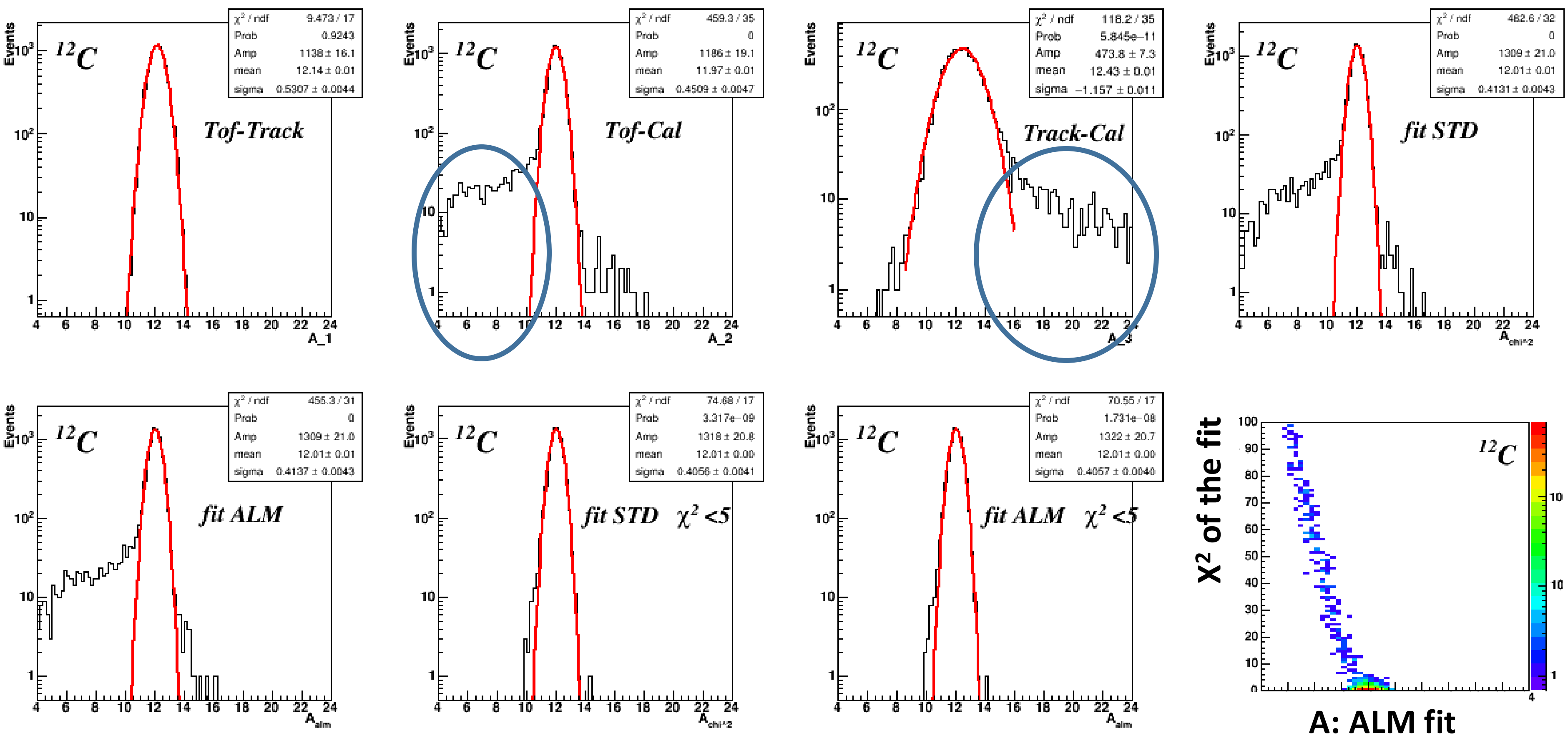


Test beam @GSI:
E_{kin} resolution 1 – 1.5%



Quantity	Resolution Magnet 7 cm	Resolution Magnet 10 cm
Tof (ps)	70 (C) – 140 (H)	70 (C) – 140 (H)
E_{kin} (%)	1.5	1.5
p (%)	6	4
Standard Setup (SCN & CAL at 1m)		

A determination @200 MeV with Magnet 10 cm (example of Carbon)



17% of the produced Carbon fragments on CALO → neutron production → Energy loose → wrong A determination (same for Magnet with 7 cm)

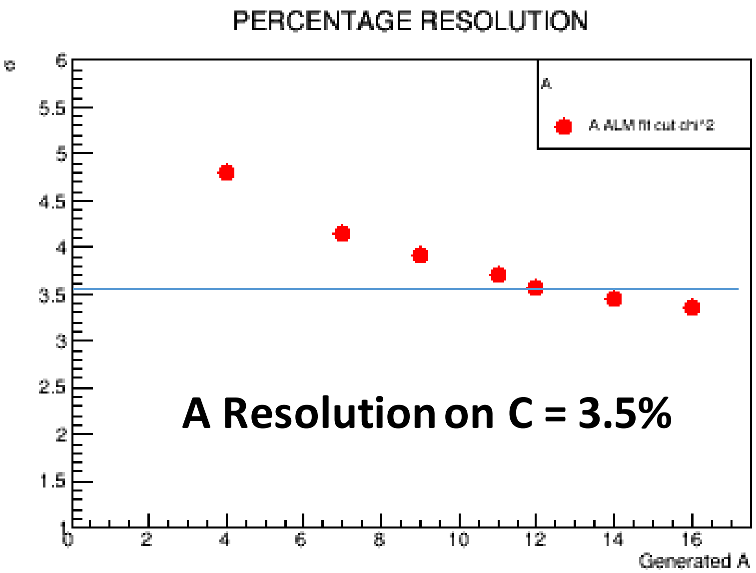
FOOT Redundancy

Possibility to select and remove these events with a χ^2 cut on the Fit methods

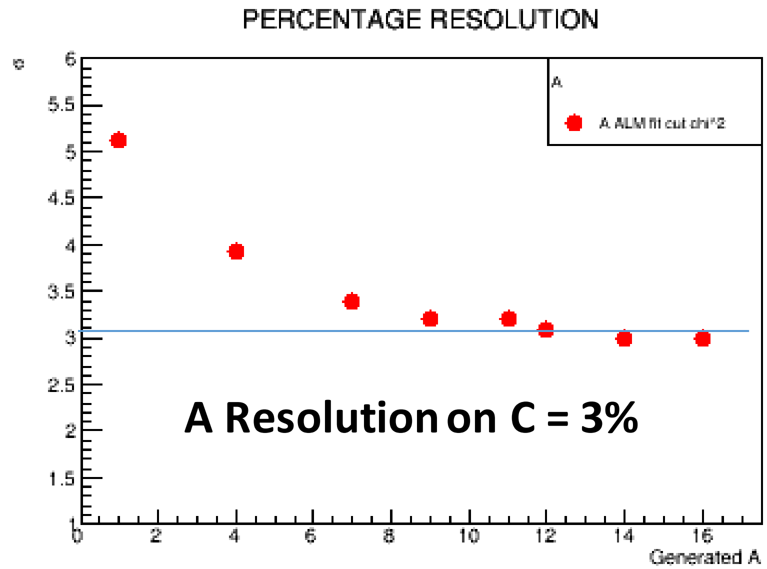
Number of Mass Resolution @200 MeV (example of Carbon)

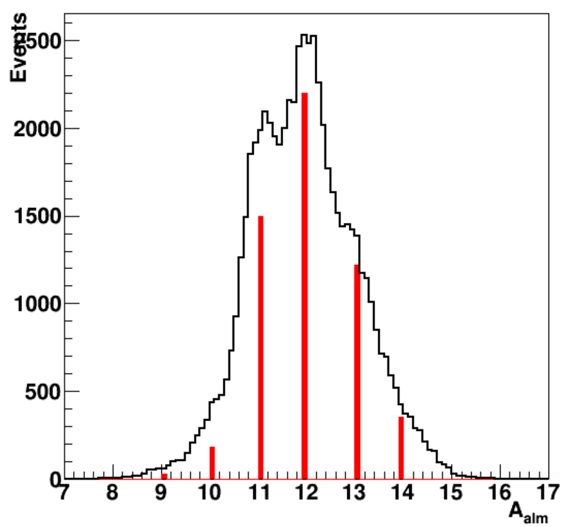
ALM Fit Method

Magnet 7 cm (Δp/p=6.0%)

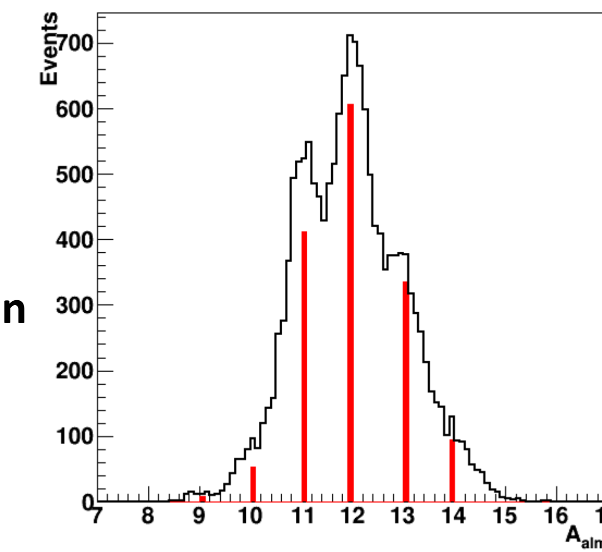


Magnet 10 cm (Δp/p=4.0%)

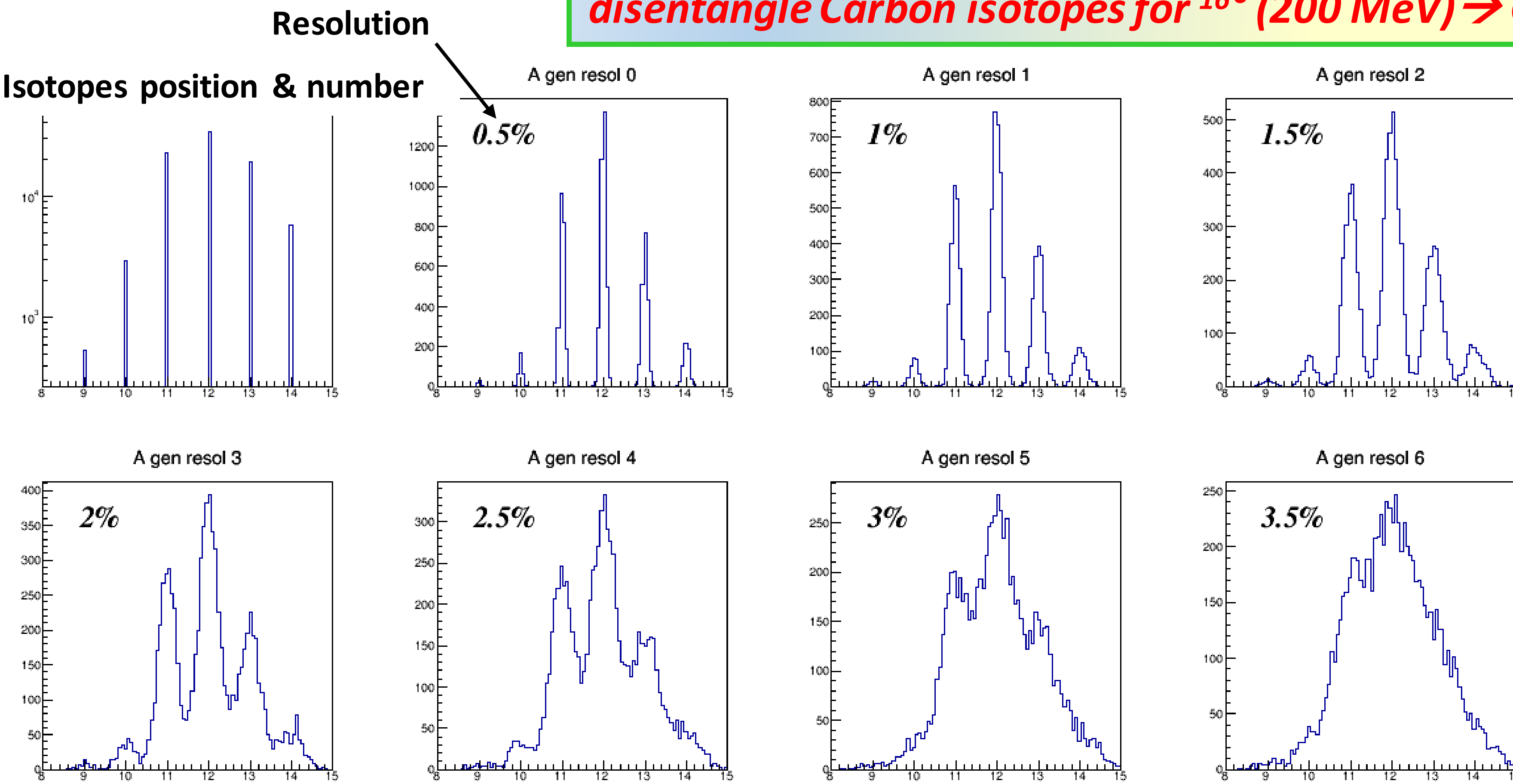


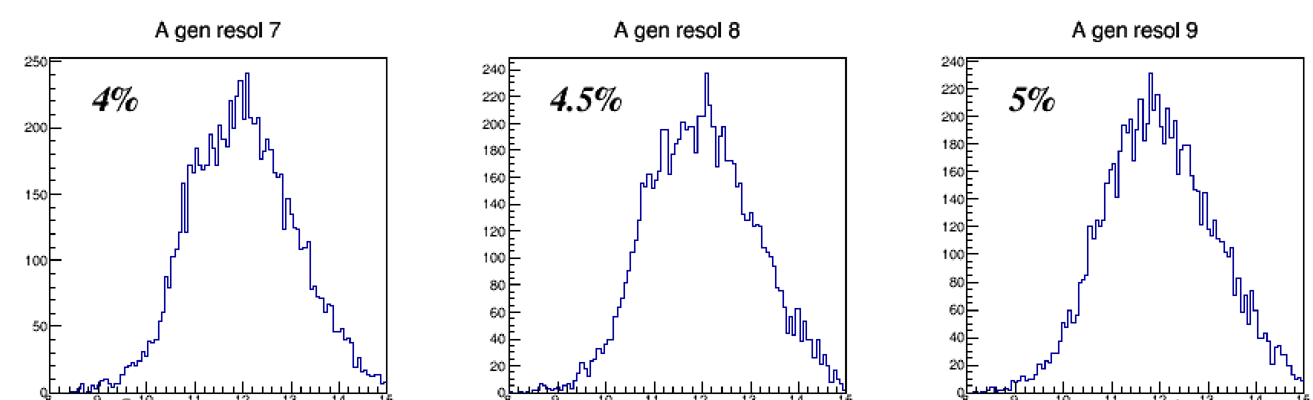


Better Isotope separation with magnets of 10 cm



disentangle Carbon isotopes for ^{16}O (200 MeV) → C2H4

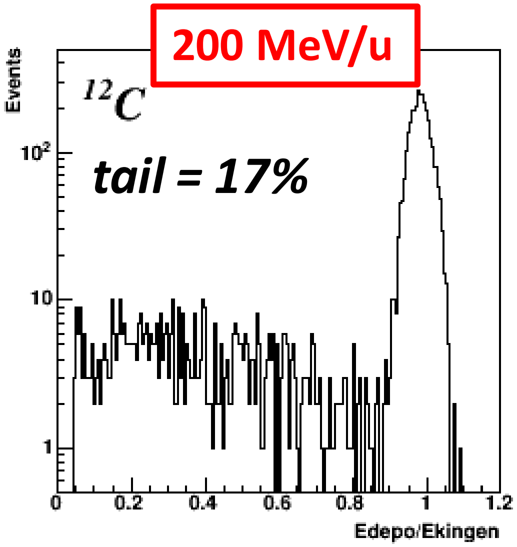


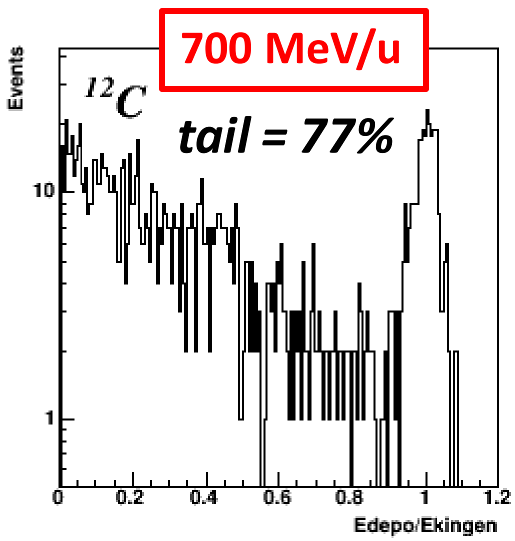


To disentangle Carbon Isotope → A resolution of 2.5%

700 MeV/u: Problem 1 (example of ^{12}C)

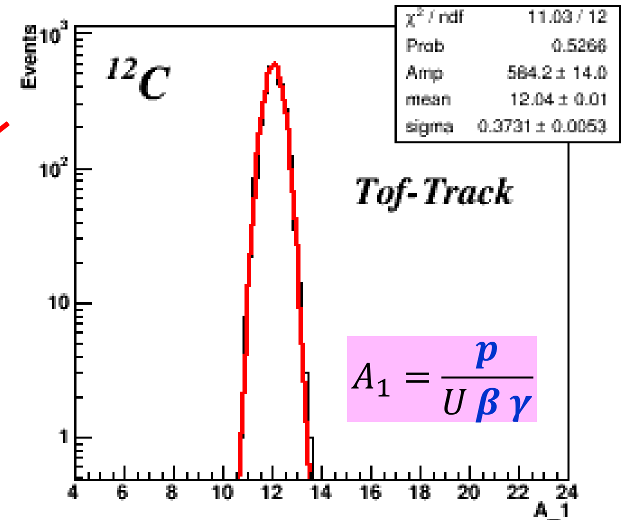
Fraction of deposited energy



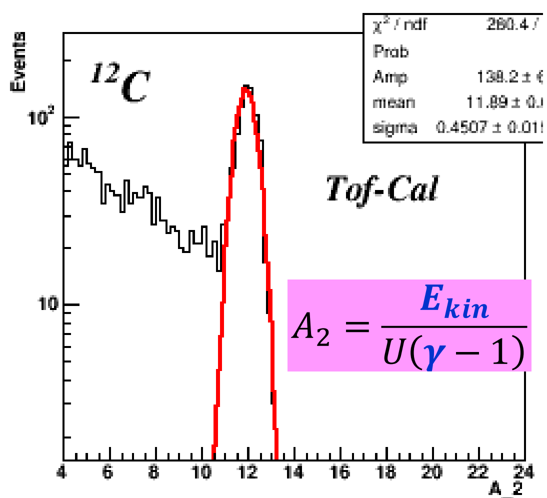


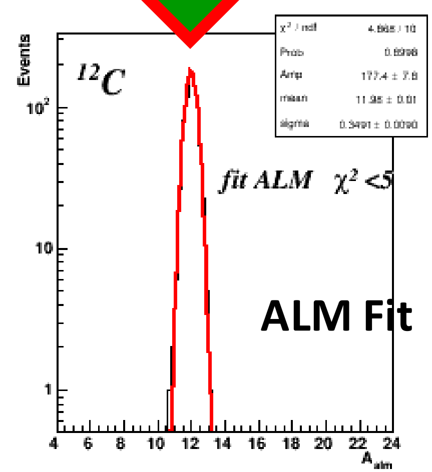
SOLUTION

Use Tof-Tracker method: NO TAIL



Only 20% of the fragments well reconstructed



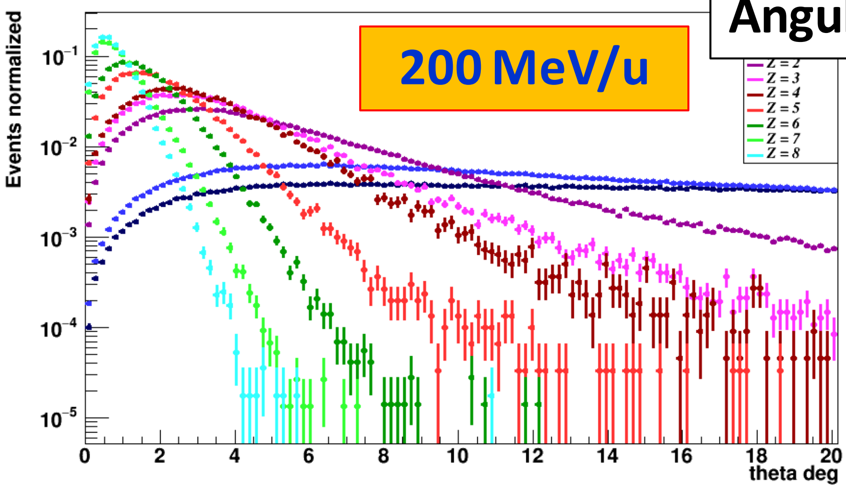


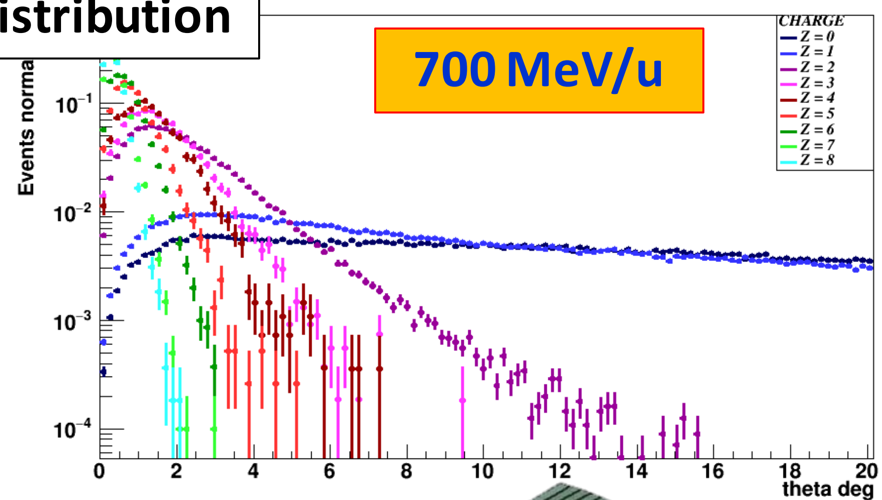
700 MeV/u: Problem 2

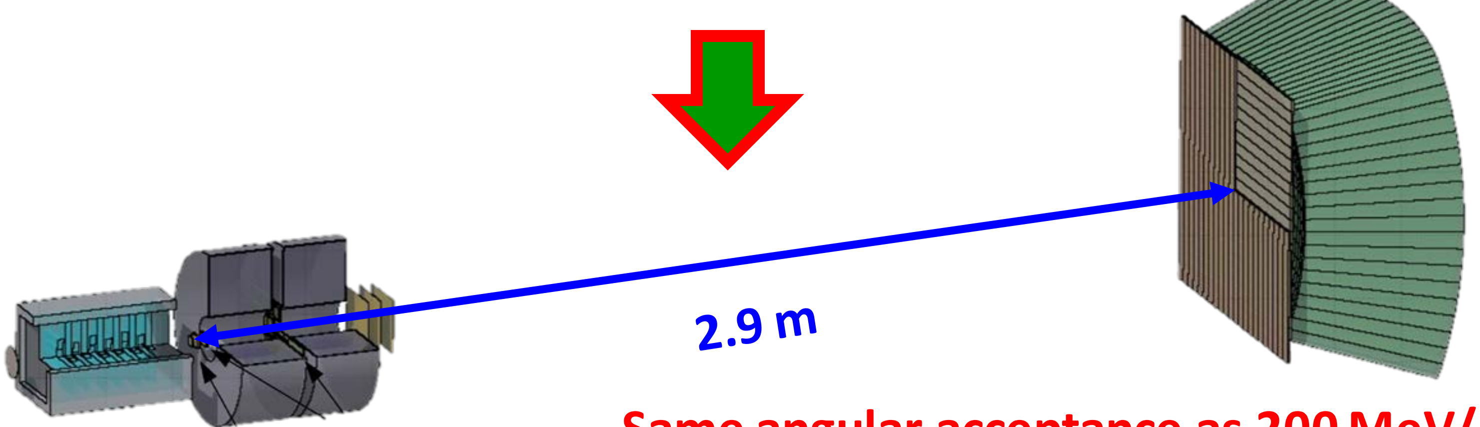
higher energy fragment→ lower Energy deposition but similar tof resolution (see pag 3)

Fragments with higher β → lower Tof → lower relative resolution

Angular distribution





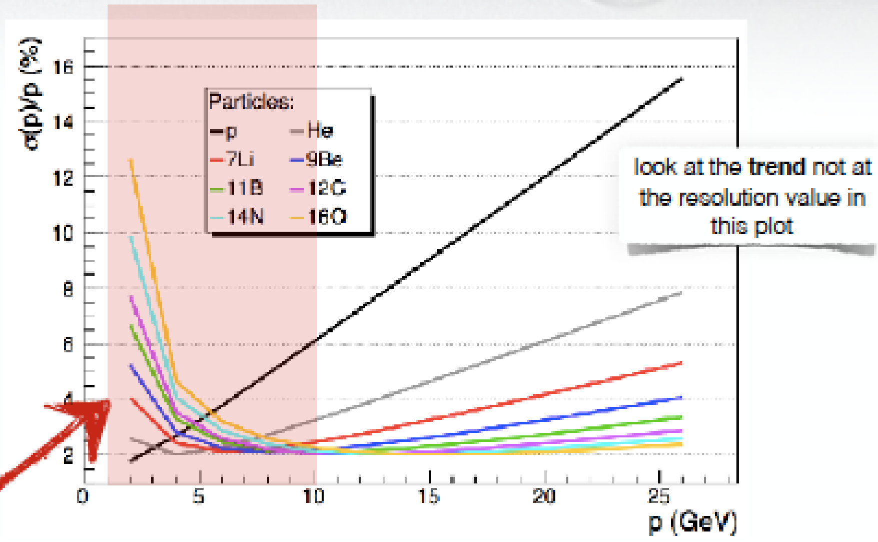


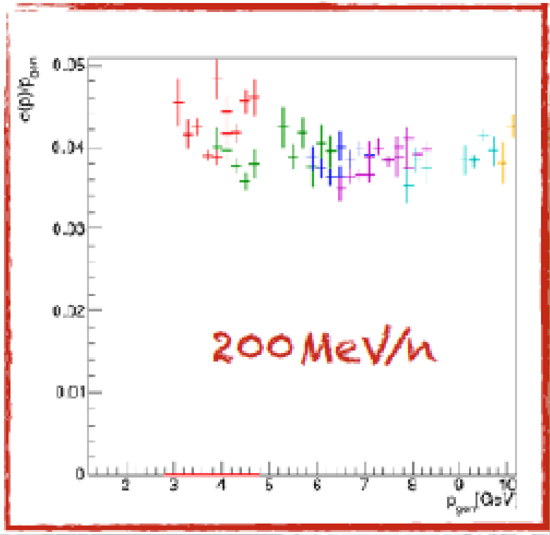
Same angular acceptance as 200 MeV/u

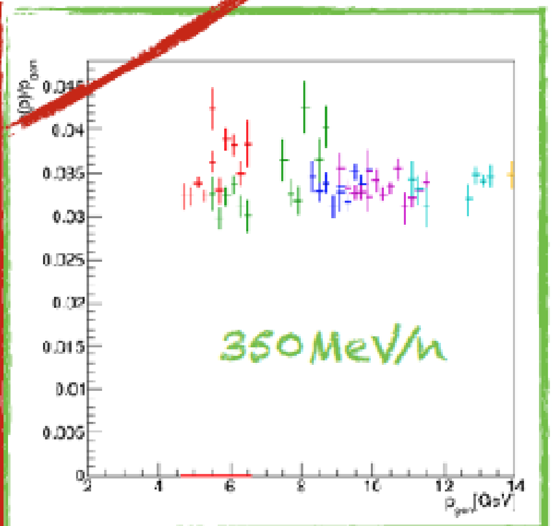
Same β resolution

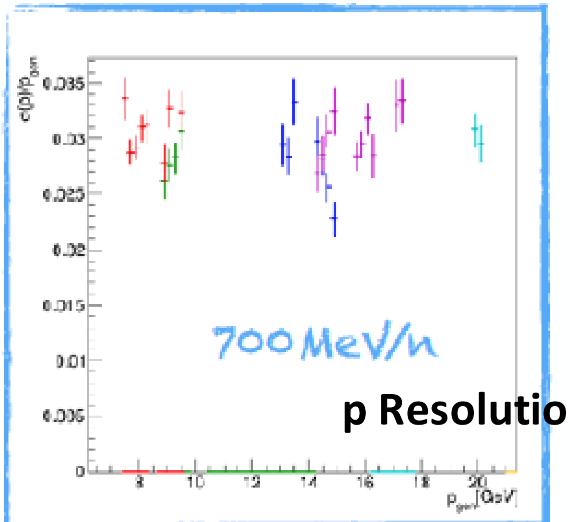
p Resolution @ 700 MeV/u

- At 200MeV/n, all elements are in the "decreasing" part, dominated by MS contribution;
  - **heavy-elements** have high p so almost at minimum (that is at lower-p), MS not so high anymore;
- At 700MeV/n, all in region dominated by spatial resolution;
  - **light elements** (steeper growth, lower-p minimum) have low p; still close to the minimum
  - **heavy elements** (grows slower, higher-p minimum) have higher p but still close to the minimum









p Resolution ~ 3%

@ 700 MeV/u p resolution is better due to the lower contribution of the Multiple Scattering

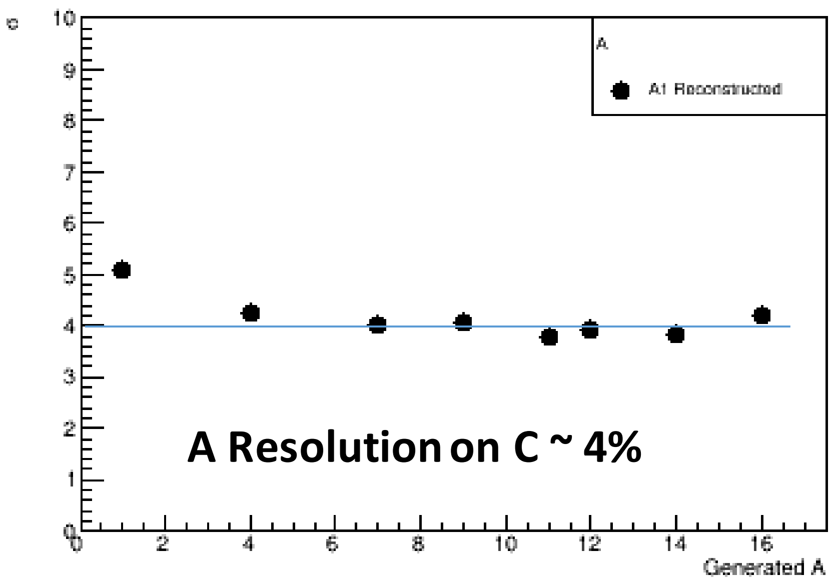
Number of Mass Resolution @700 MeV

Quantity	Resolution Magnet 7 cm	Resolution Magnet 10 cm
Tof (ps)	70 (C) – 140 (H)	70 (C) – 140 (H)
E_{kin} (%)	1.5	1.5
p (%)	3.5	2.5
Setup (SCN & CAL at 2.9 m)		

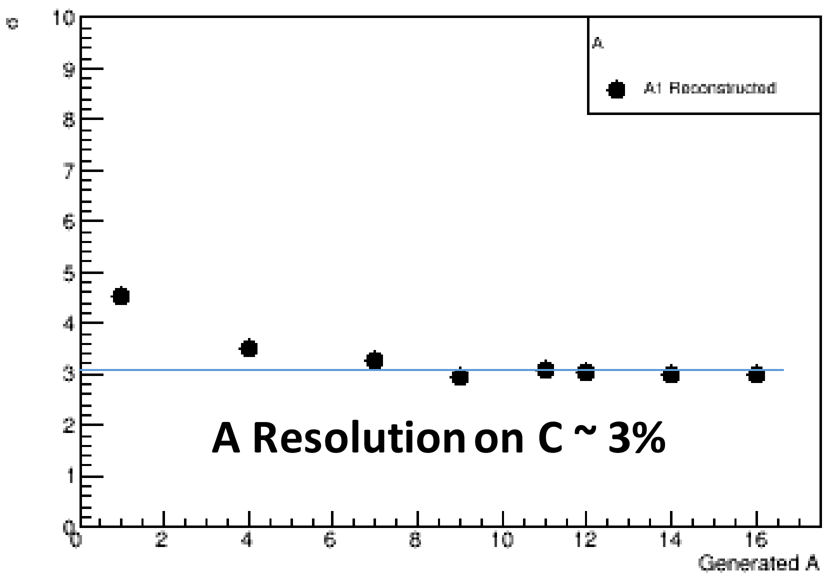
Same as @200 MeV/u (see pag 3)

Mass reconstructed with Tof + Tracker Method

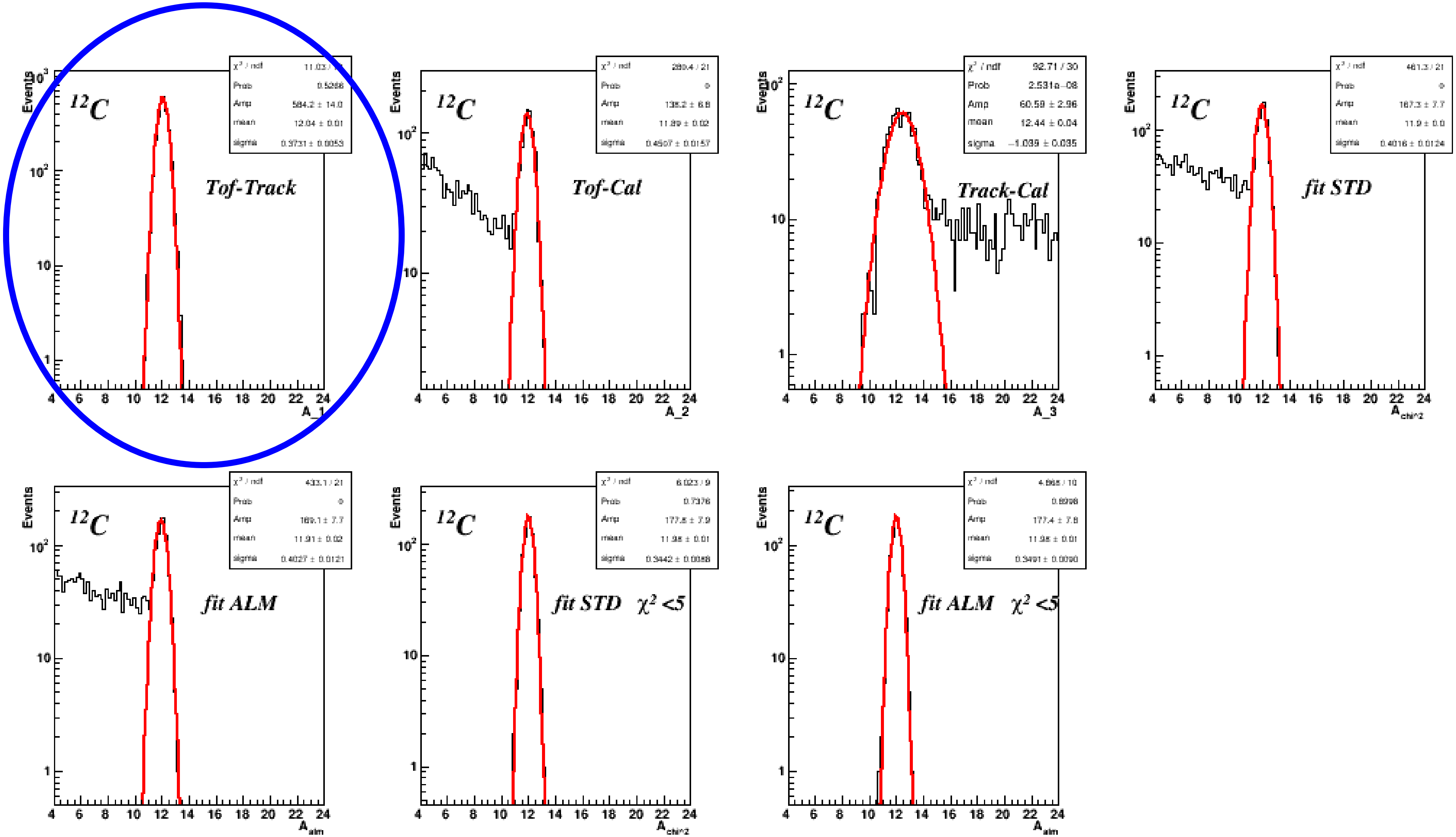
Magnet 7 cm (Δp/p = 3.5%)



Magnet 10 cm (Δp/p = 2.5%)



A determination @700 MeV with Magnet 10 cm (example of Carbon)

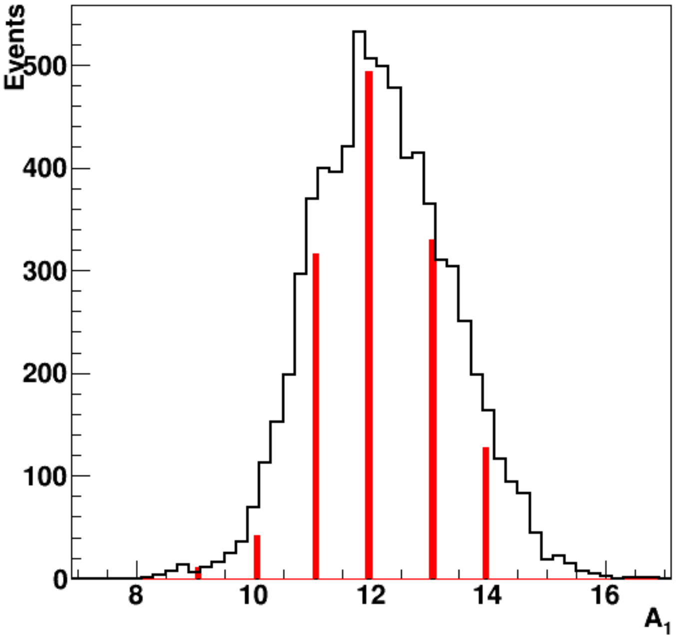


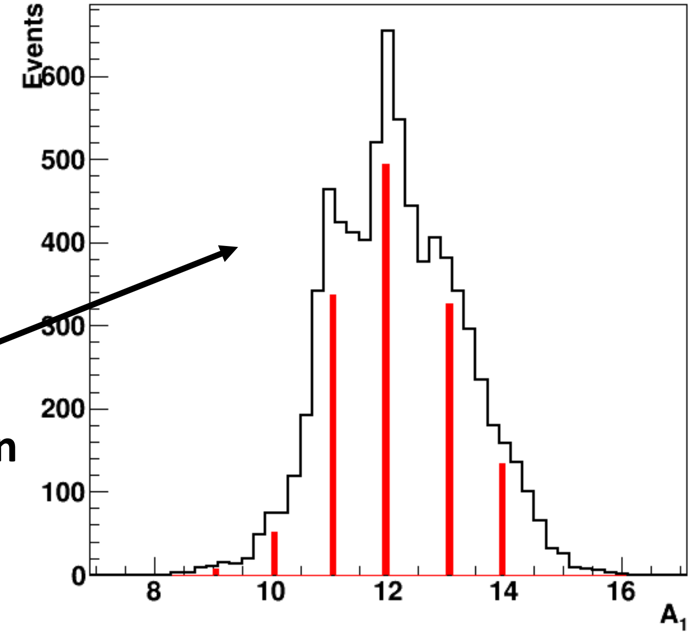
Carbon Isotopes separation @700 MeV

Magnet 7 cm ($\Delta p/p$ = 3.5%)

Magnet 10 cm ($\Delta p/p$ = 2.5%)

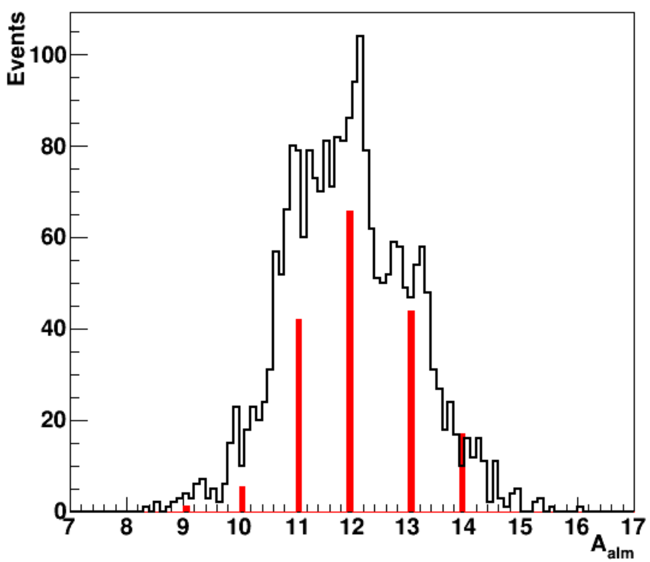
Tof + Tracker Method

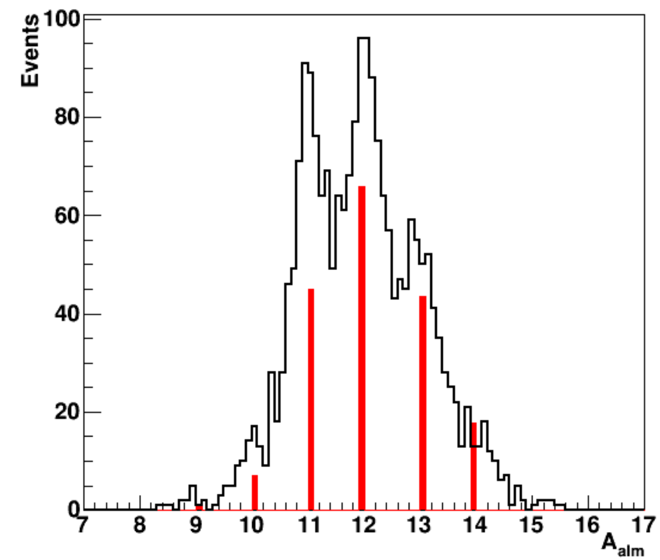




Better isotope separation

ALM Fit Method



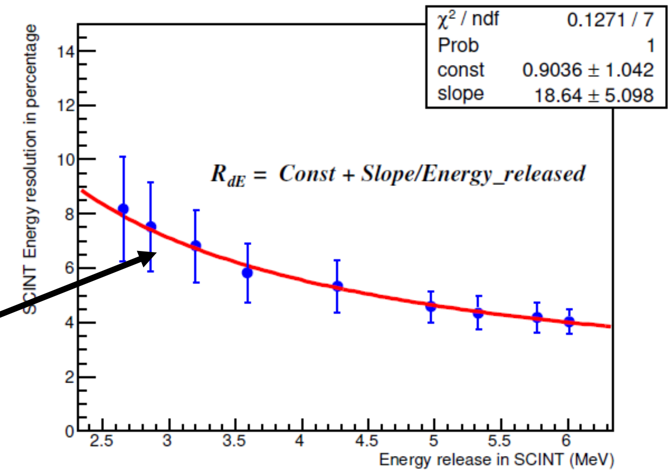


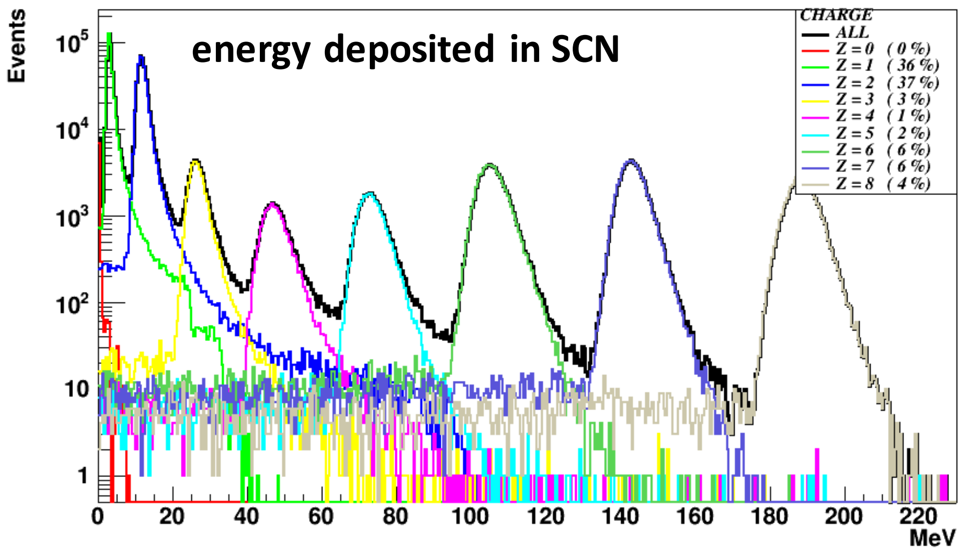
Only for well reconstructed fragments (20% of the statistics)

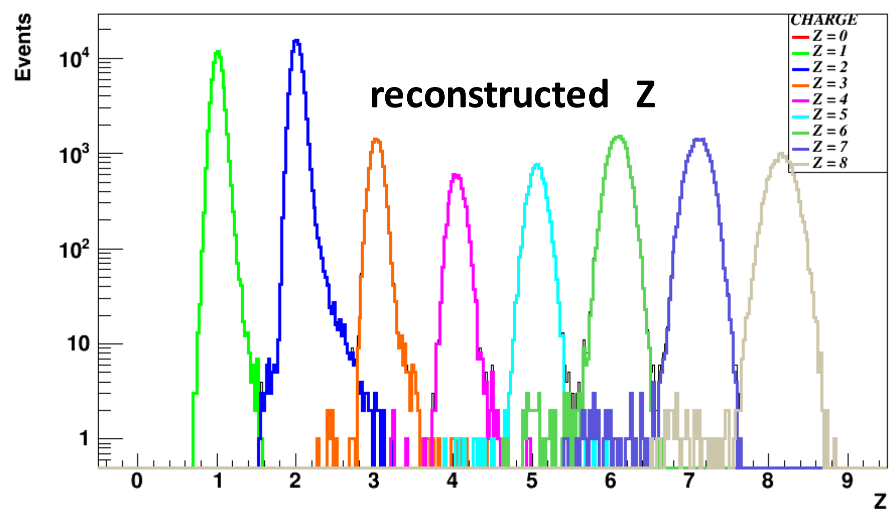
Z Reconstruction @200 MeV

Fluka simulation ^{16}O (200 MeV/u)→ C_2H_4

SCN energy resolution parametrization from test beam







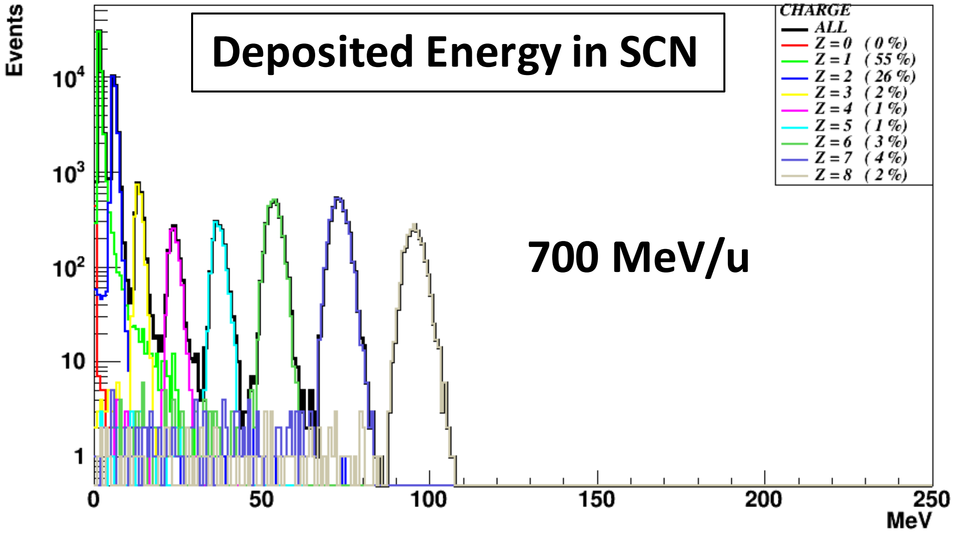
^{1}H	^{4}He	^{7}Li	^{9}Be	^{11}B	^{12}C	^{14}N	^{16}O
1	2	3	4	5	6	7	8
1.01±0.09	2.01±0.06	3.03±0.08	4.05±0.09	5.06±0.10	6.09±0.12	7.11±0.14	8.15±0.15

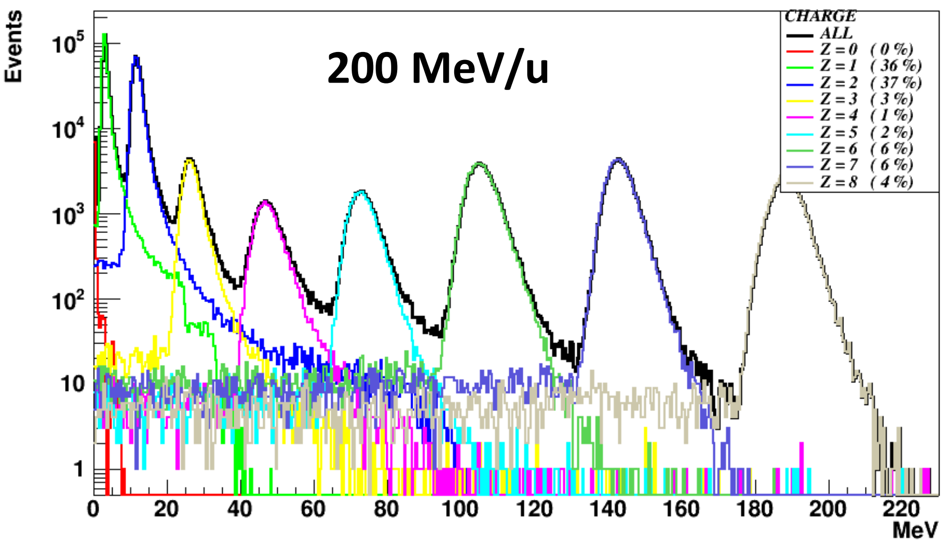
Z Resol : 9% 3% 2.0%

wrong charge assignment < %

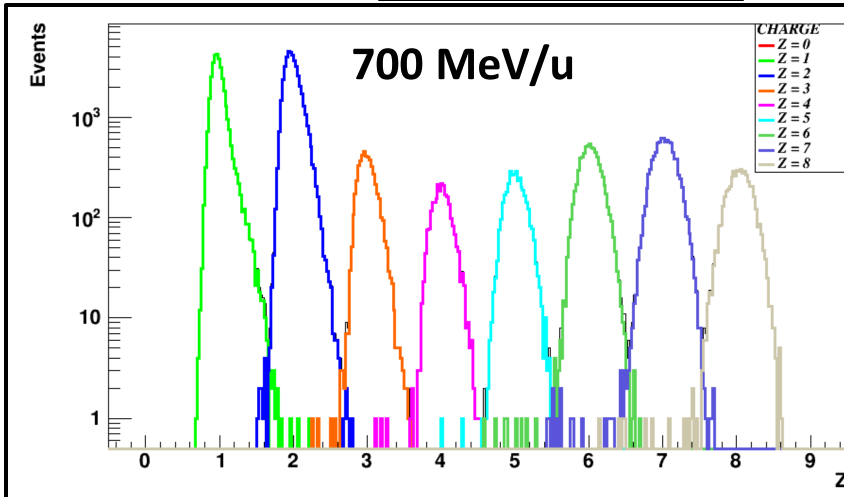
Z Reconstruction @700 MeV

Fluka simulation ^{16}O (700 MeV/u)→ C_2H_4





reconstructed Z



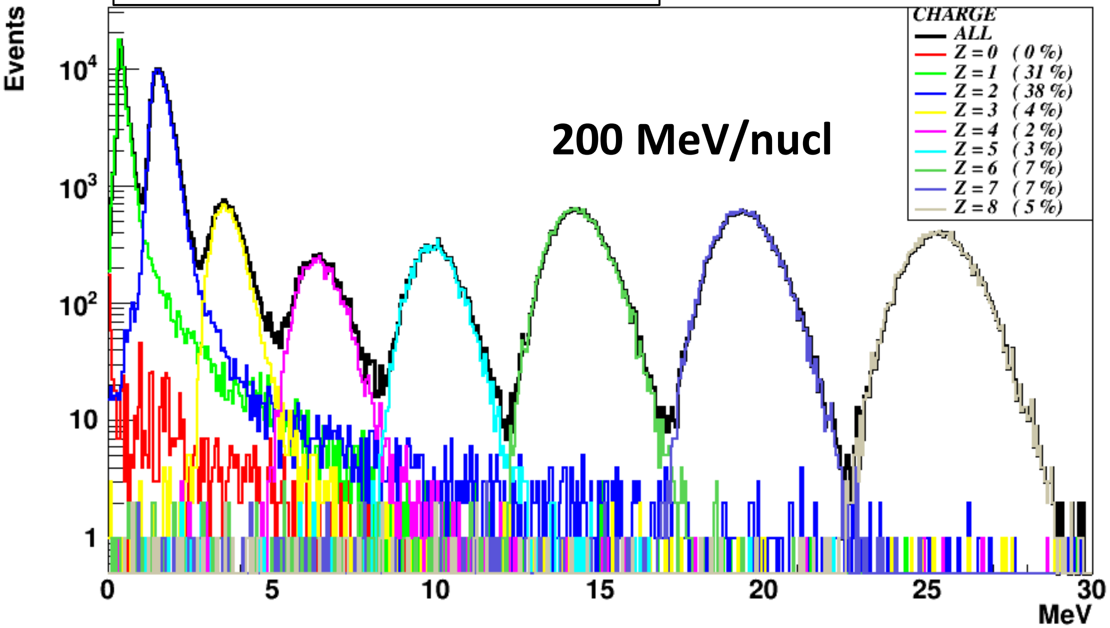
Z:	1	2	3	4	8
Resol (200 MeV):	9%	3.0%	2.0%	2.0%	2.0%
Resol (700 MeV):	9%	4.5%	3.6%	3.0%	2.1%

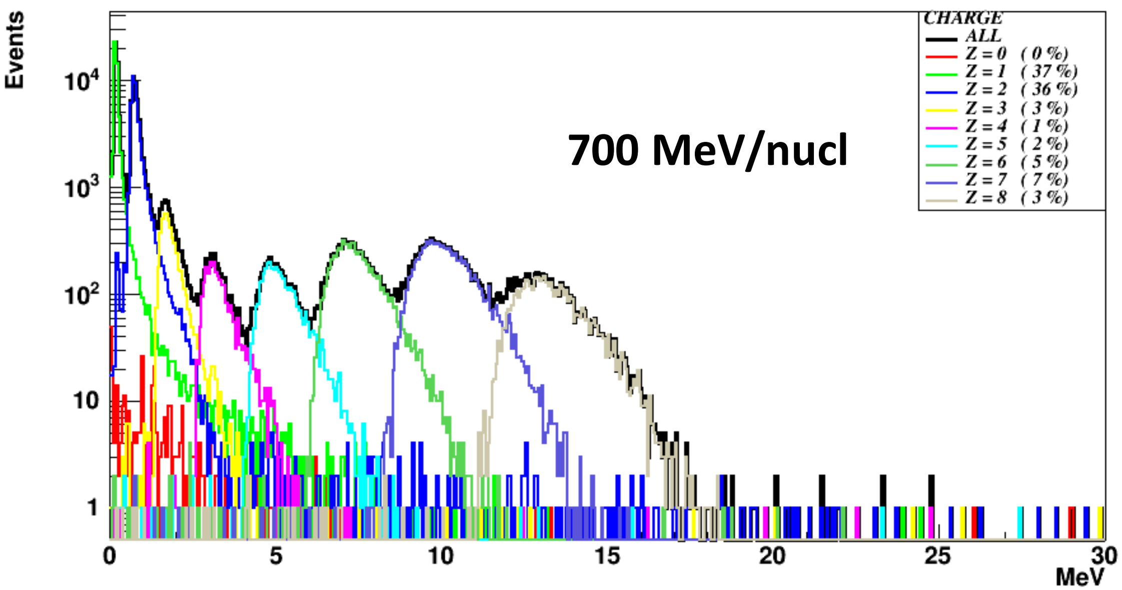
wrong charge assignment < %

^{1}H	^{4}He	^{7}Li	^{9}Be	^{11}B	^{12}C	^{14}N	^{16}O
1	2	3	4	5	6	7	8
0.97±0.08	1.99±0.09	3.00±0.11	4.01±0.12	5.01±0.13	6.03±0.14	7.03±0.16	8.04±0.17

Z Reconstruction @200 & 700 MeV with MSD

Deposited Energy in MSD





Fluka simulation:
^{16}O (200 &700 MeV/u)→ C_2H_4

450 µm of Silicon
Peaks resolved @200 & 700 MeV/u
No smearing included

Possibility to combine the Z determination with the SCN

Summary

- **Z determination:**
  - ^{16}O (200 MeV/u & 700 MeV/u): Z Resolution in the range [2-5]% → wrong charge identification less than percent (SCN + MSD)

- **A determination**
  - @200 MeV/u: FIT METHOD with SCN, TRACKER and CALO (Tof, p, E_{kin})

200 MeV/u	Δp/p	ΔA/A (example of C)
Magnet 7 cm	6%	3.5%
Magnet 10 cm	4%	3.0%

→ Good Isotope separation

  - @700 MeV/u: FIT method possible only on 20% of statistics (missed energy)

TOF + TRACKER METHOD & different FOOT Setup

700 MeV/u	Δp/p	ΔA/A (example of C)
Magnet 7 cm	3.5%	4.0%
Magnet 10 cm	2.5%	3.0%

→ Isotope separation

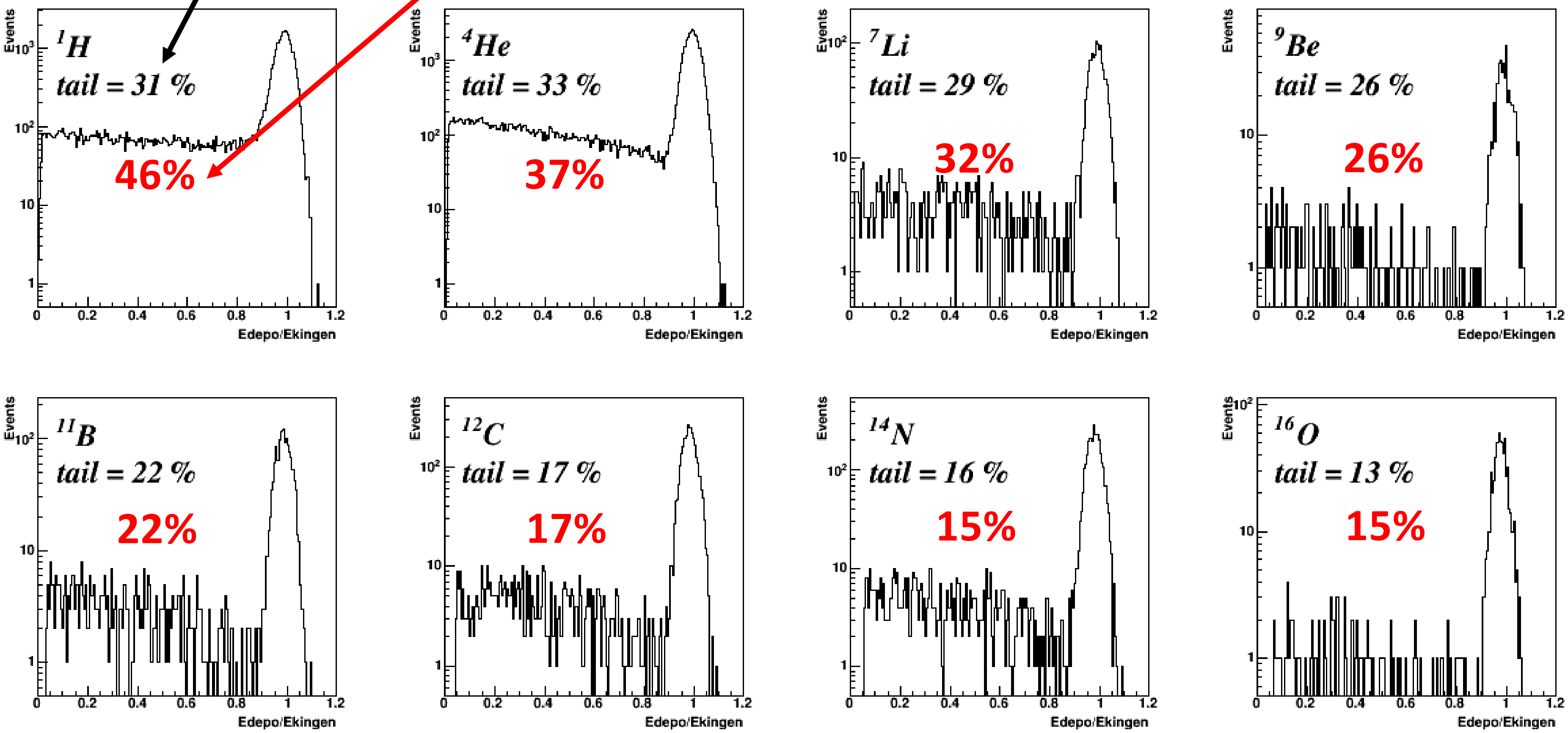
Backup slides

Fraction on deposited energy @ 200 MeV/u

% Events outside peak (ratio<0.9), calo 21 cm

Energy deposited SCINT + CALO / Kinetic Energy generated

calo 7 cm



^{1}H	^{4}He	^{7}Li	^{9}Be	^{11}B	^{12}C	^{14}N	^{16}O
0.985	0.990	0.988	0.985	0.981	0.975	0.972	0.968

A 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 (T)

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

- **Standard χ^2 Fit**
  - Taking into account the correlation between A_1, A_2 and A_3

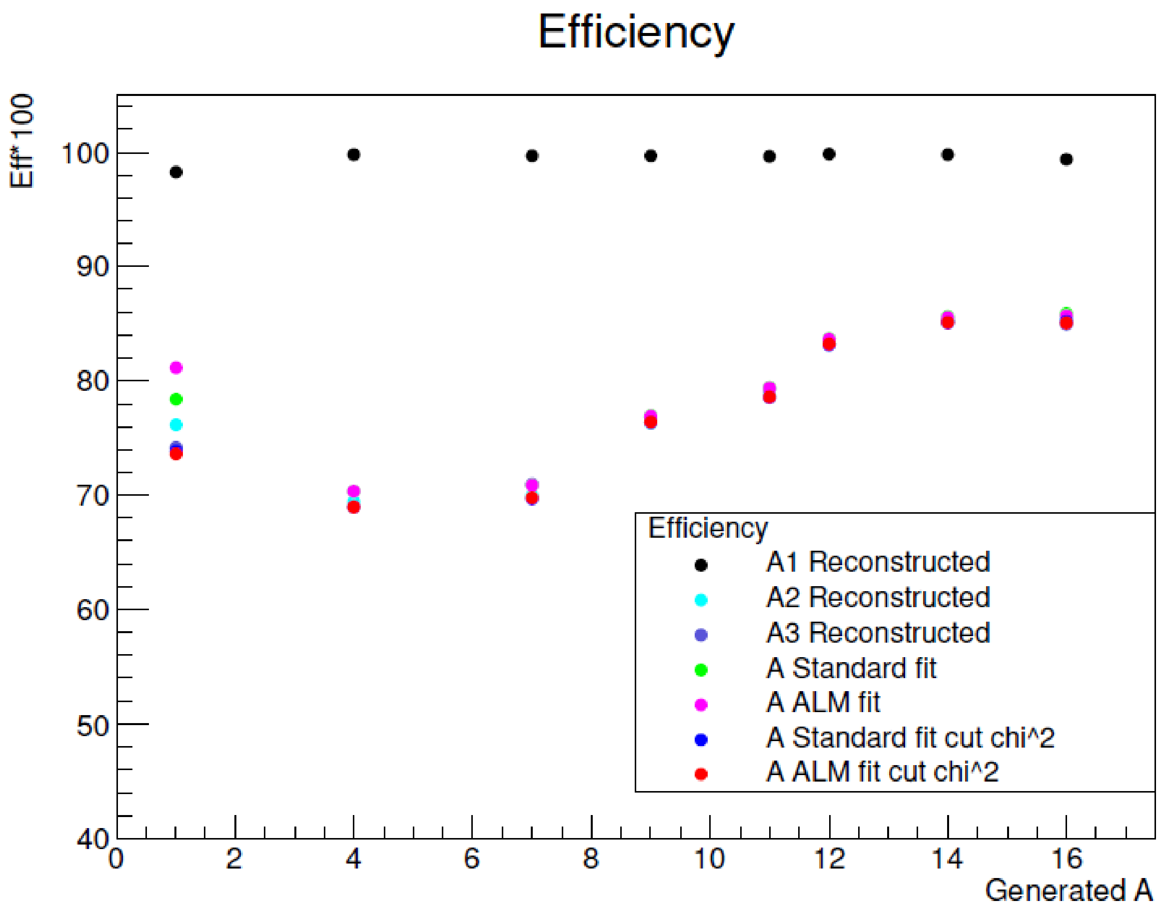
$$f = \left(\frac{(tof_{reco} - t)}{\sigma tof_{reco}}\right)^2 + \left(\frac{(p_{reco} - p)}{\sigma p_{reco}}\right)^2 + \left(\frac{(T_{reco} - T)}{\sigma T_{reco}}\right)^2 + (A_1 - A \quad A_2 - A \quad A_3 - A)\begin{pmatrix} C_{00} & C_{01} & C_{02} \\ C_{10} & C_{11} & C_{12} \\ C_{20} & C_{21}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

$$C = (A \cdot A^T)^{-1} \qquad A = \begin{pmatrix} \frac{\partial A_1}{\partial t}dt & \frac{\partial A_1}{\partial p}dp & 0 \\ \frac{\partial A_2}{\partial t}dt & 0 & \frac{\partial A_2}{\partial T}dT \\ 0 & \frac{\partial A_3}{\partial p}dp & \frac{\partial A_3}{\partial T}dT \end{pmatrix}$$

- **Augmented LagrangianFit (ALM)**

$$\tilde{\mathcal{L}}(\vec{x}\,;\lambda,\,\mu) \equiv f(\vec{x}) - \sum_a \lambda_a c_a(\vec{x}) + \frac{1}{2\mu}\sum_a c_a^2(\vec{x}).$$

A reconstruction efficiency



Tof +Tracker

Reconstruction efficiency ~ 70-80 % depending on the fragment