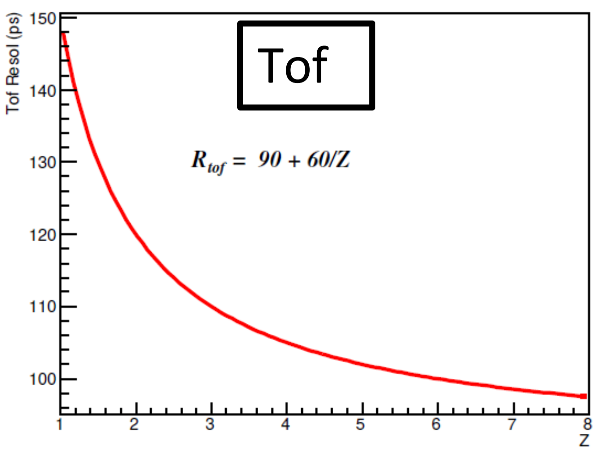
Performances on A and Z identification

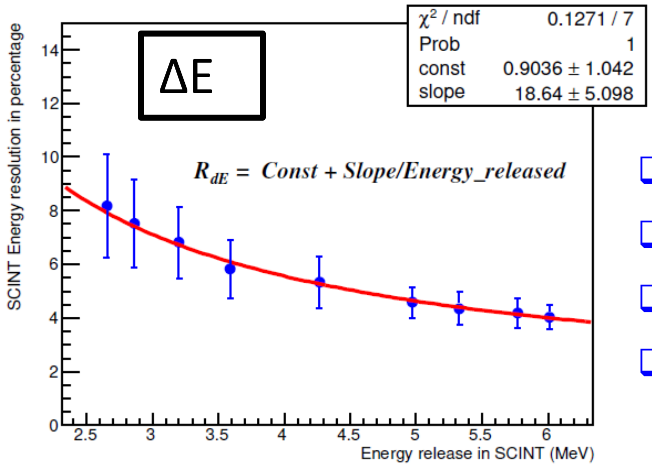
Outline:

Bologna, 4/12/2017

- Brief summary of the situation
- Resolution on A and Z identification;
  - $^{16}O \rightarrow C_2H_4$ @ 200 – 700 MeV/u
  - $^{4}He \rightarrow C_2H_4$ and C @ 700 MeV/u
- Possible new Energy reconstruction
- Different ways to disentangle the fragments → dE/dx vs E
- Next future

INPUT RESOLUTIONS:





- p → 5%
- E_{kin} (Calo) → 1.5%
- Tof : [100:150] ps
- ΔE (scint): [3:10]%

If changed from the last beam tests please let me know

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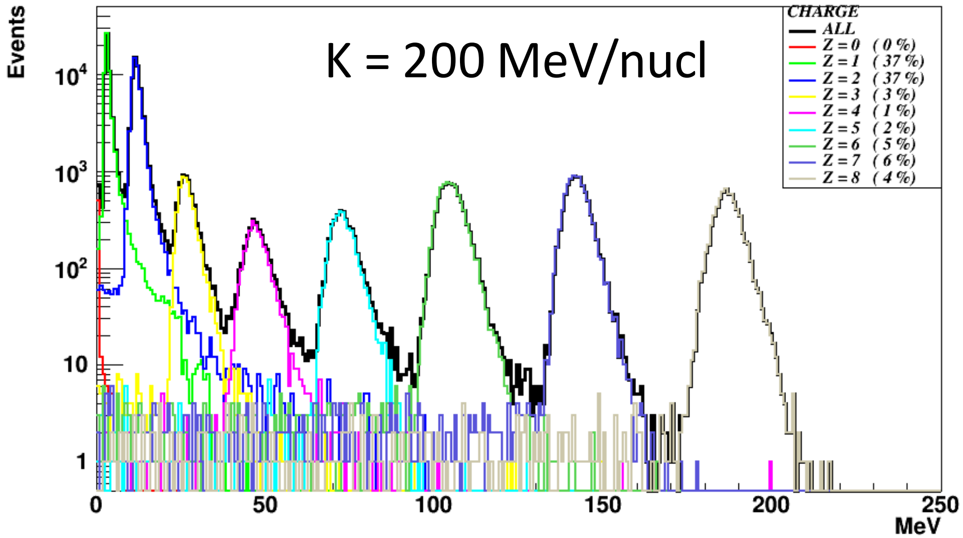
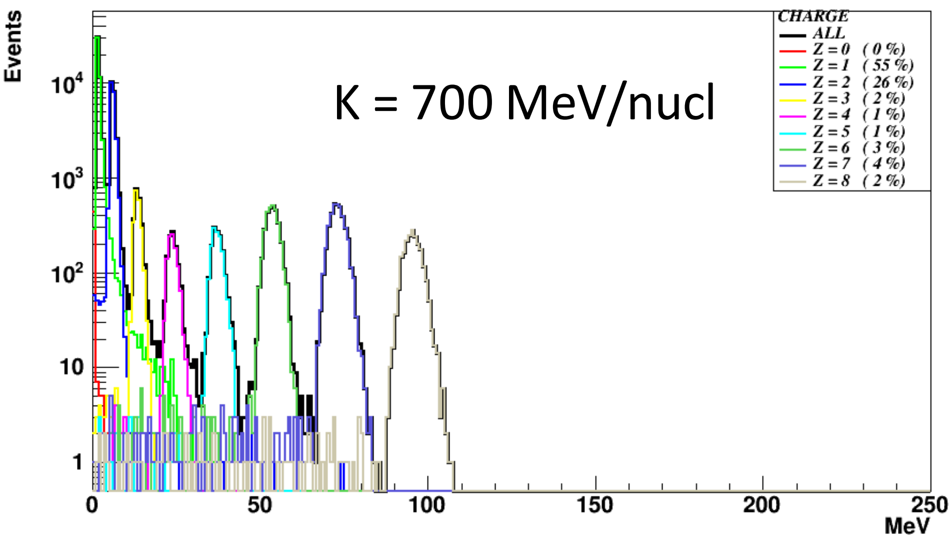
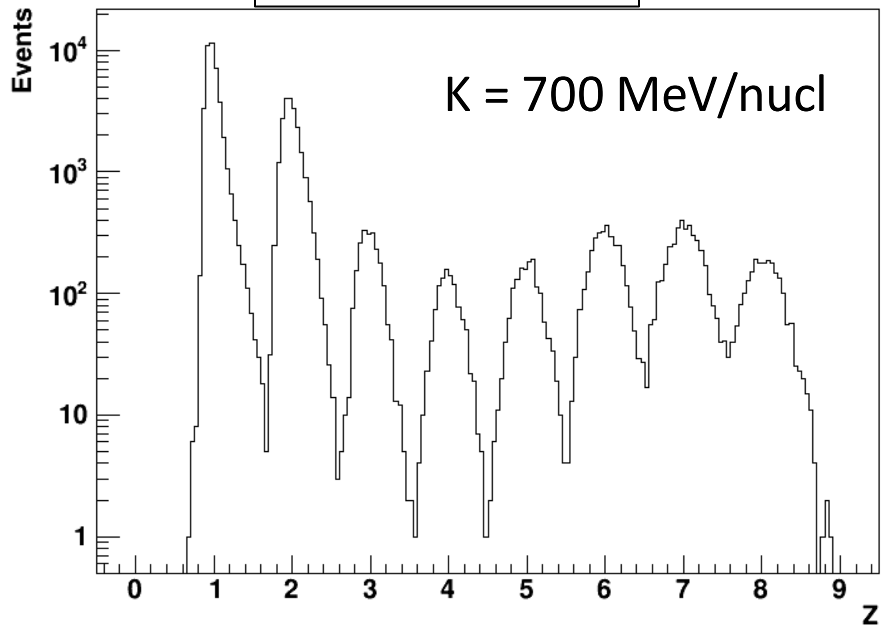
^{16}O (200-700 MeV/nucl) → C_2H_4 : Z reconstruction

energy deposited in SCN





reconstructed Z



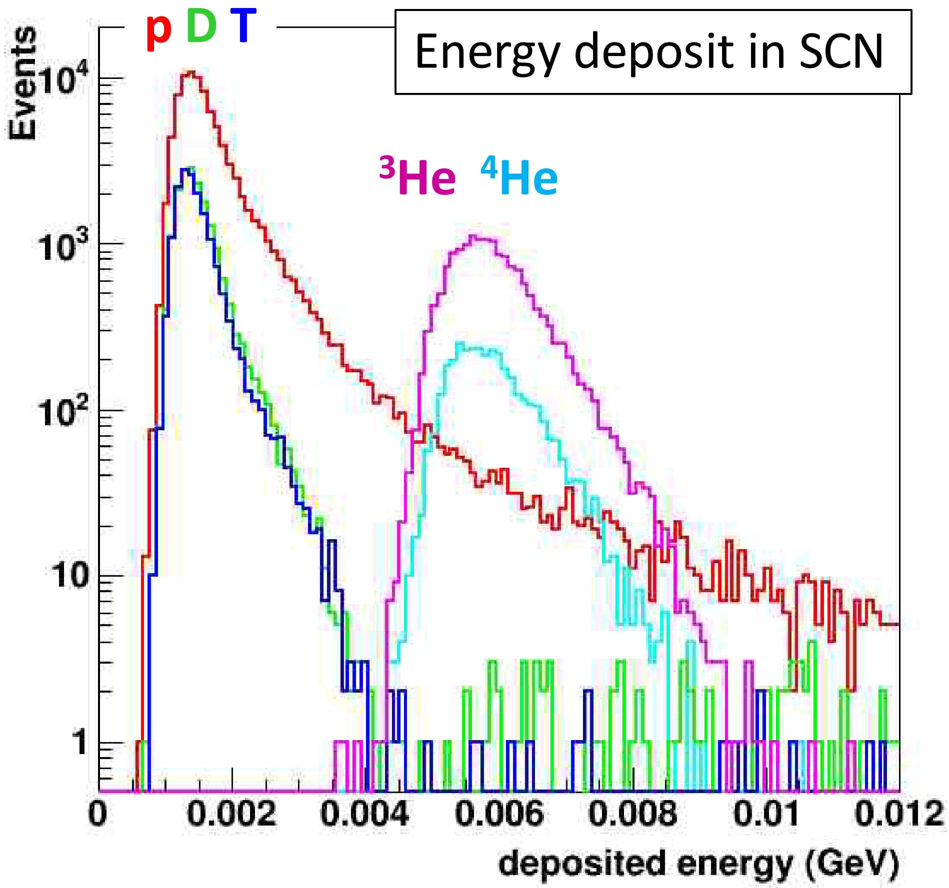
Z:	1	2	8
Resol (200 MeV):	5%	3%	2.2%
Resol (700 MeV):	6%	3%	2.8%

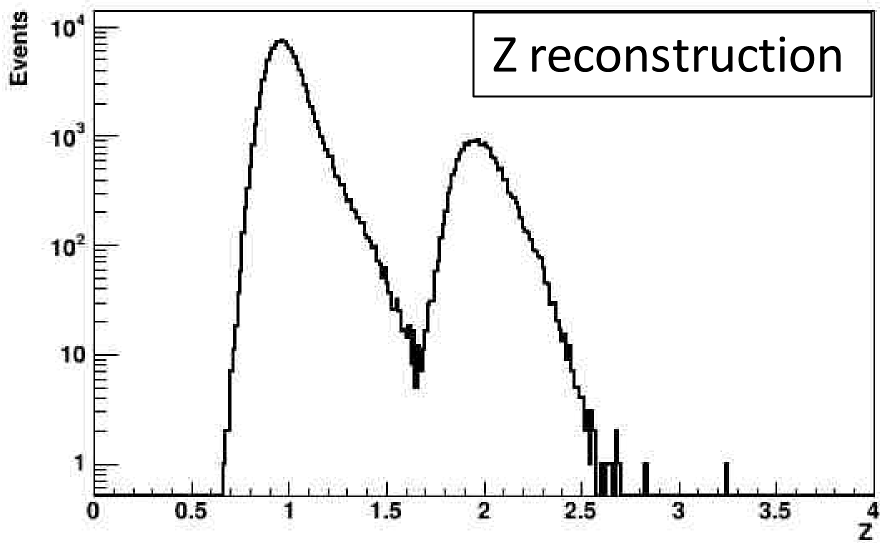
- **Front-end not simulated**
- **Performances decrease**
- **Investigate the MSD**

Radio-Protection → range mainly depends on Z

^4He (700 MeV/u): Z Reconstruction

Studied both $^4He \rightarrow C_2H_4$ and $\rightarrow$ C: Same results (here C target)





Electric charges completely separated

Z misedintification ~1%

Fragment identification: A

- Reconstruction

TRACKER

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

TOF

TOF

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

CALO

TRACKER

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

CALO

E_{kin} → Energy deposited by track in CALO (till now)
→All Energy deposition inside 2 cm (in x,y): test with low statistics

- Standard Fit χ^2 Methods

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

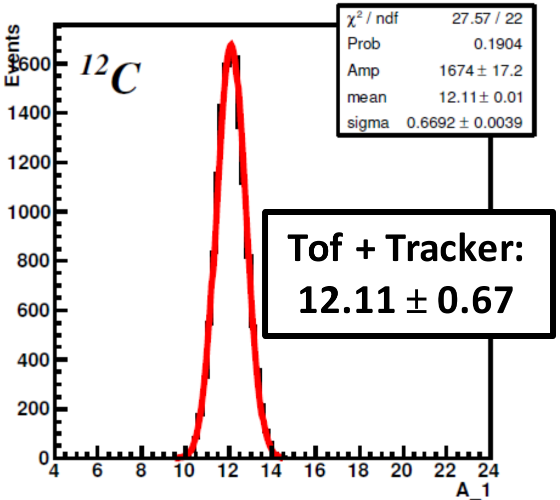
$$C = (A \cdot A^T)^{-1} \qquad A = \begin{pmatrix} \frac{\partial A_1}{\partial t}dt & \frac{\partial A_1}{\partial p}dp & 0 \\ \frac{\partial A_2}{\partial t}dt & 0 & \frac{\partial A_2}{\partial T}dT \\ 0 & \frac{\partial A_3}{\partial p}dp & \frac{\partial A_3}{\partial T}dT \end{pmatrix}$$

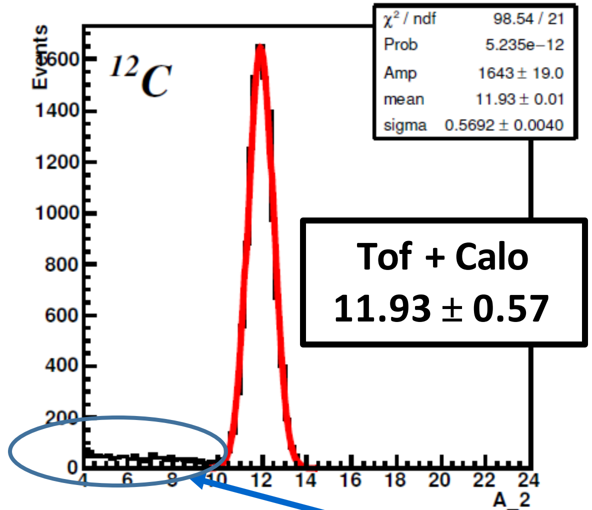
- Augmented Lagrangian Method (ALM) Fit

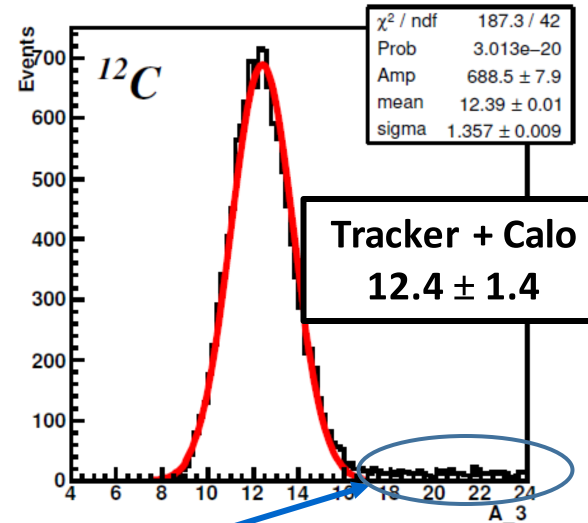
$$L(\vec{x}, \lambda, \mu) \equiv f(\vec{x}) - \sum_a \lambda_a c_a(\vec{x}) + \frac{1}{2\mu}\sum_a c_a^2(\vec{x})$$

^{16}O (200 MeV/nucl) → C_2H_4 : A of ^{12}C

Reconstruction methods

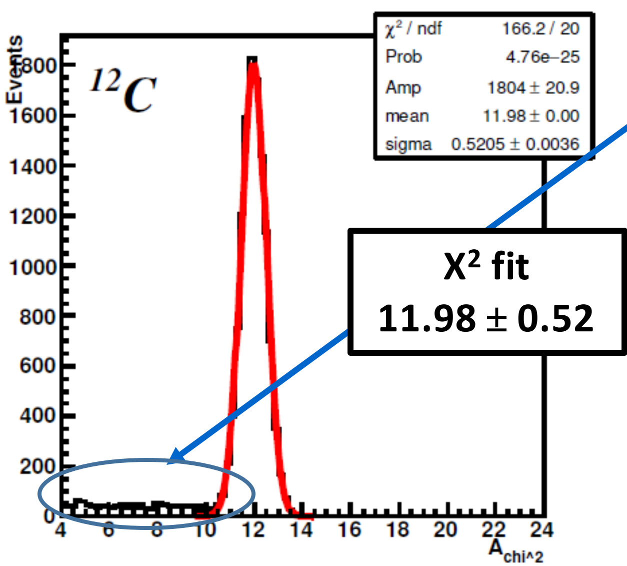


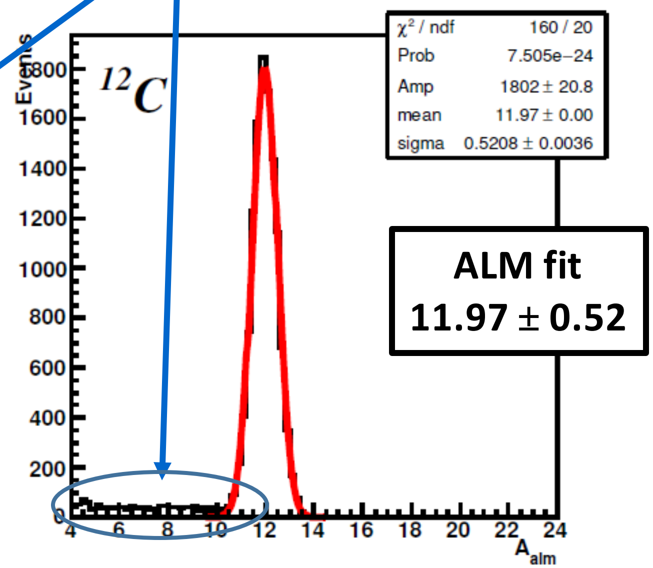


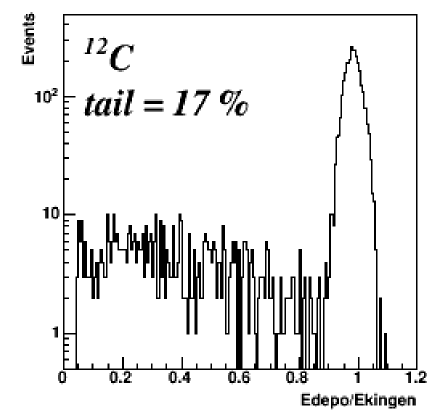


Tail for neutron emission in Calo

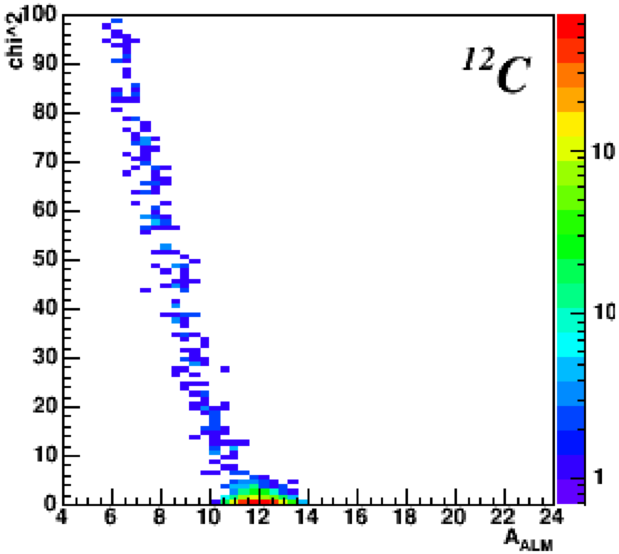
Fit methods



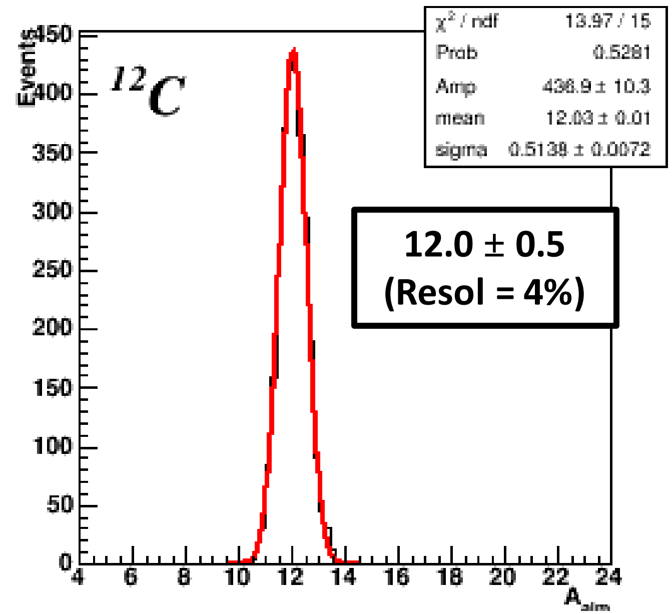




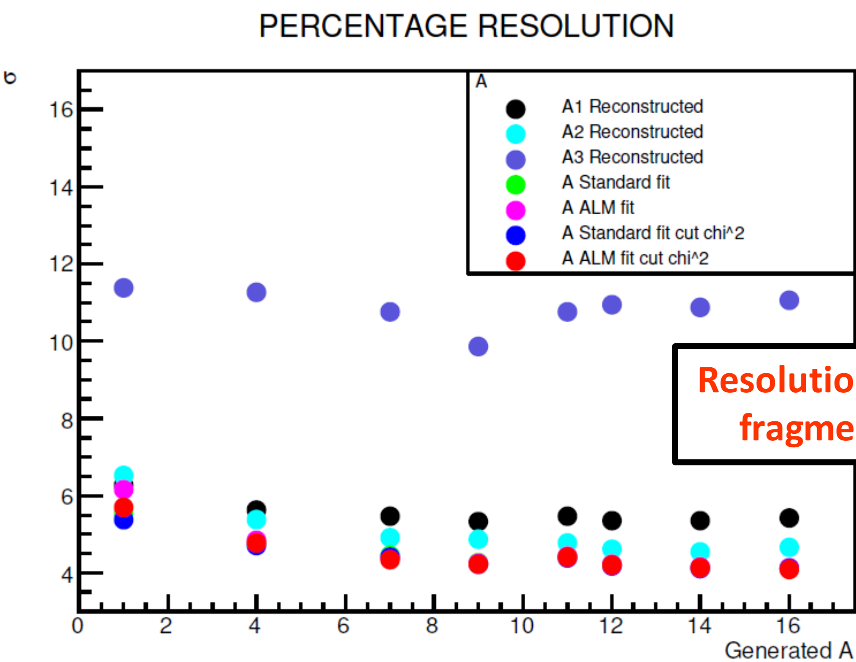
Request on χ^2



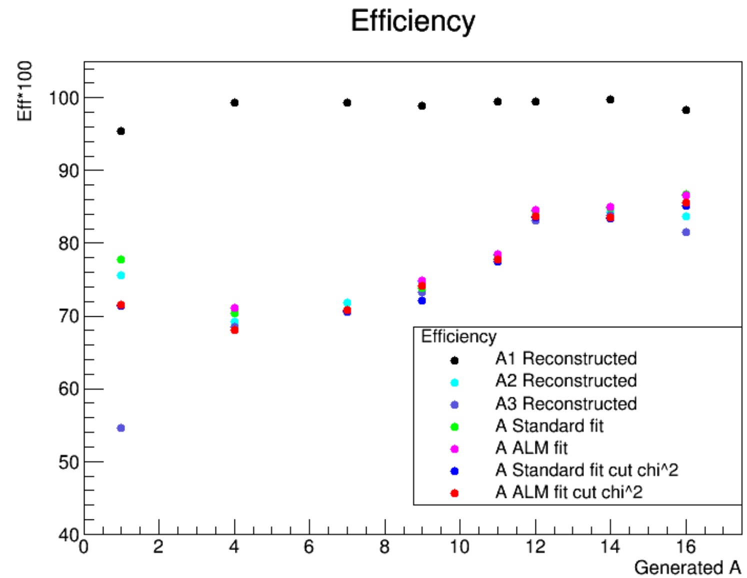
Beam: ^{16}O (200 MeV/u), target : C_2H_4



12.0 ± 0.5 (Resol = 4%)



Resolution for heavy fragments ~ 4%



Elimination of bad reconstructed mass, ε~ 70-80%

Resolution at 4% is enought to disentangle the different isotopes?

^{16}O (200 MeV/nucl) → C_2H_4: 2 different Energy reconstructions

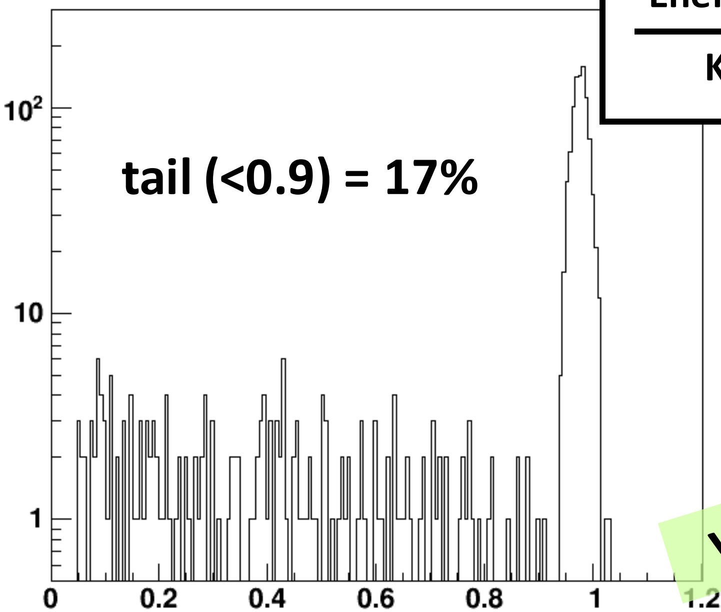
Till now:

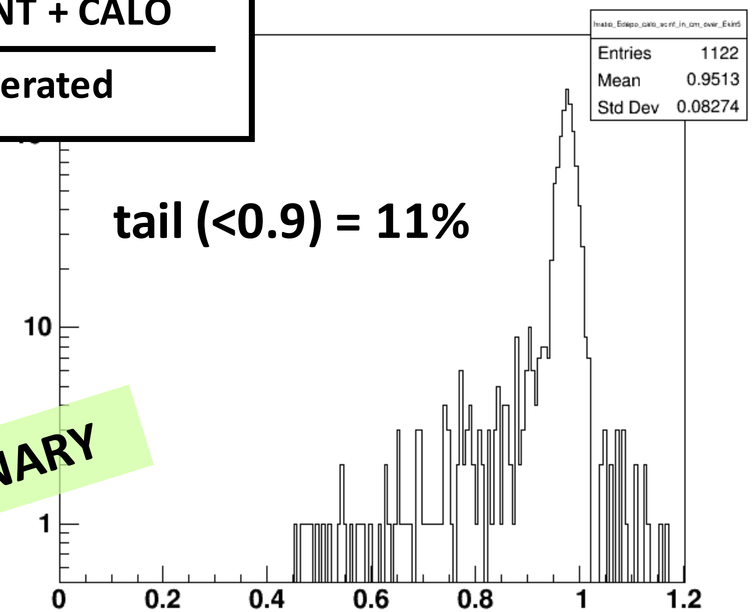
E_{kin} → Energy depo by track in CALO

To investigate

E_{kin} →All Energies depo in 2 cm (in x,y)

$$\frac{\text{Energy deposited SCINT + CALO}}{\text{Kinetic Energy generated}}$$





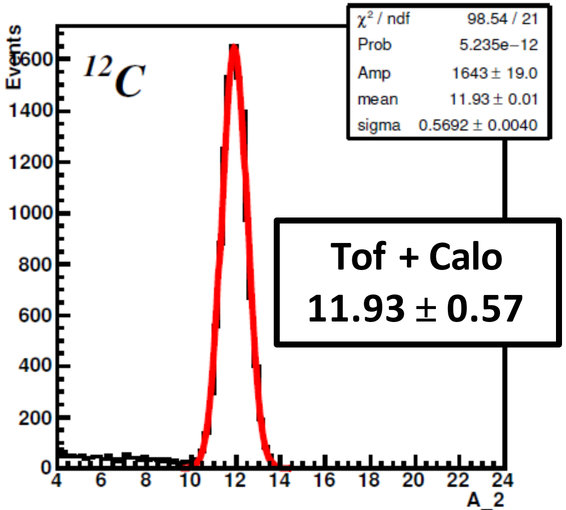
VERY PRELIMINARY

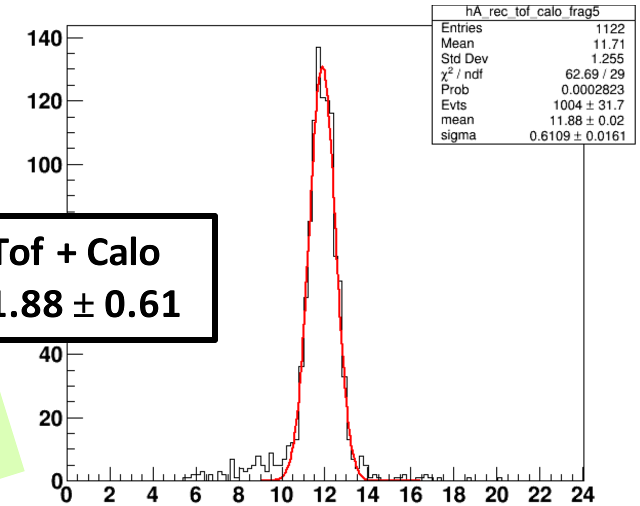
Less tail but the peak position is the same

Consequence on A (example of ^{12}C)

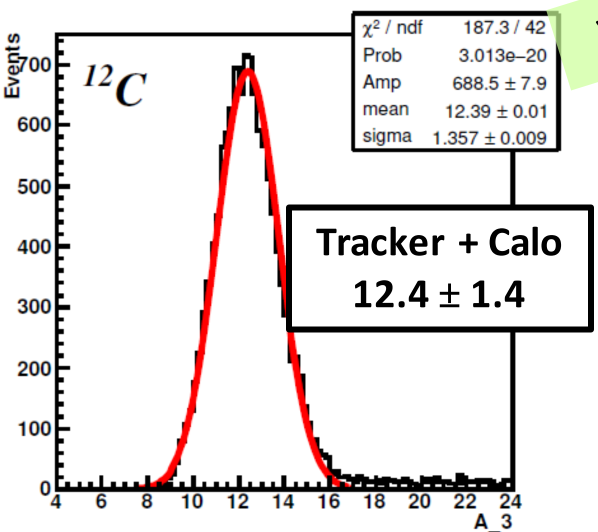
E_{kin} → Energy depo by track in CALO

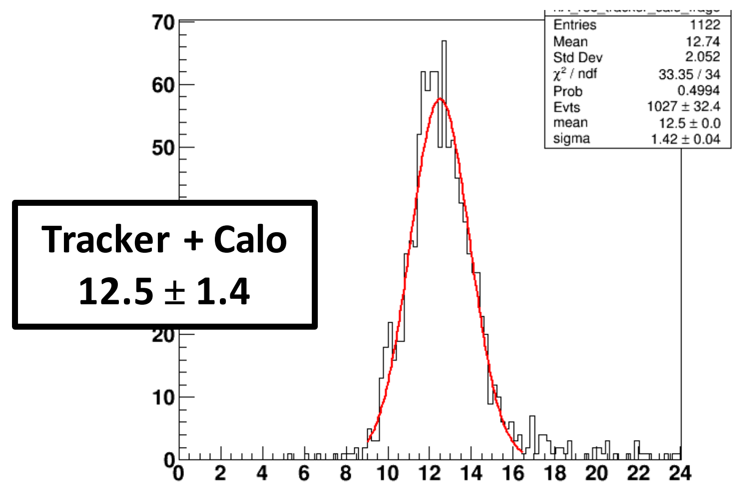
E_{kin} →All Energies depo in 2 cm (in x,y)





VERY PRELIMINARY

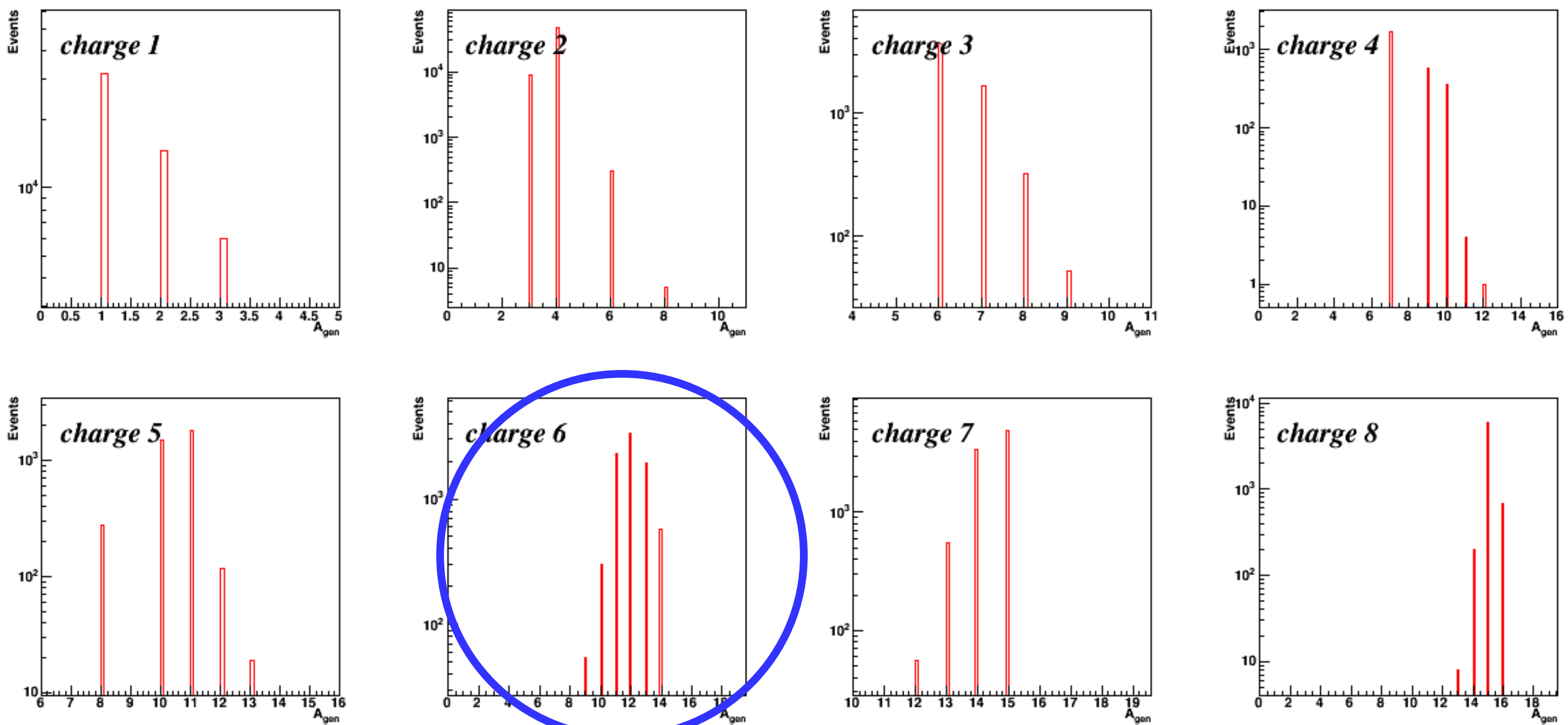




Seems that nothing change → to investigate better

ALL tracks produced by $^{16}O \rightarrow C_2H_4$

From 3 – 6 isotopes for each charge

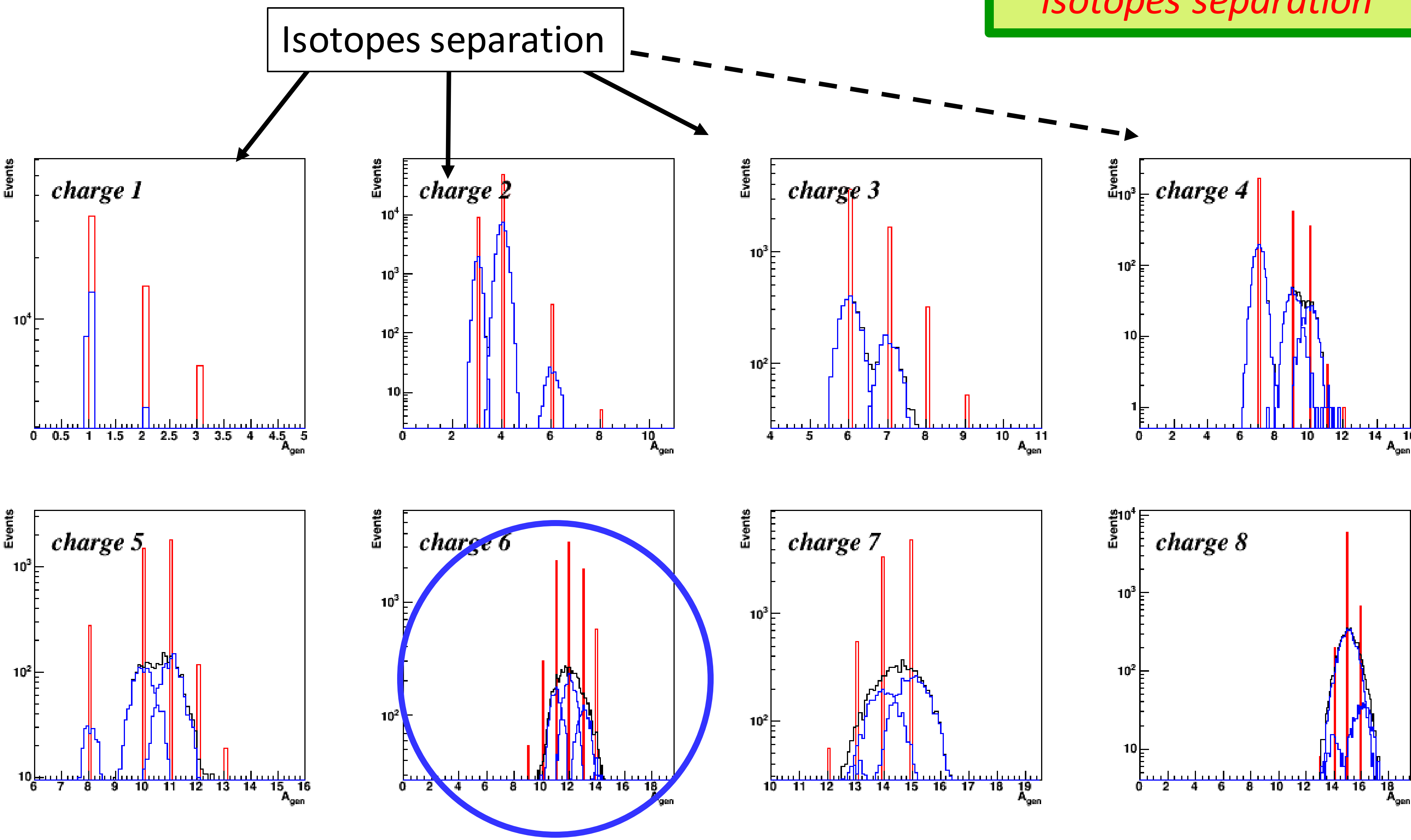


Z resolution is [2-5%] << minimum distance between charges

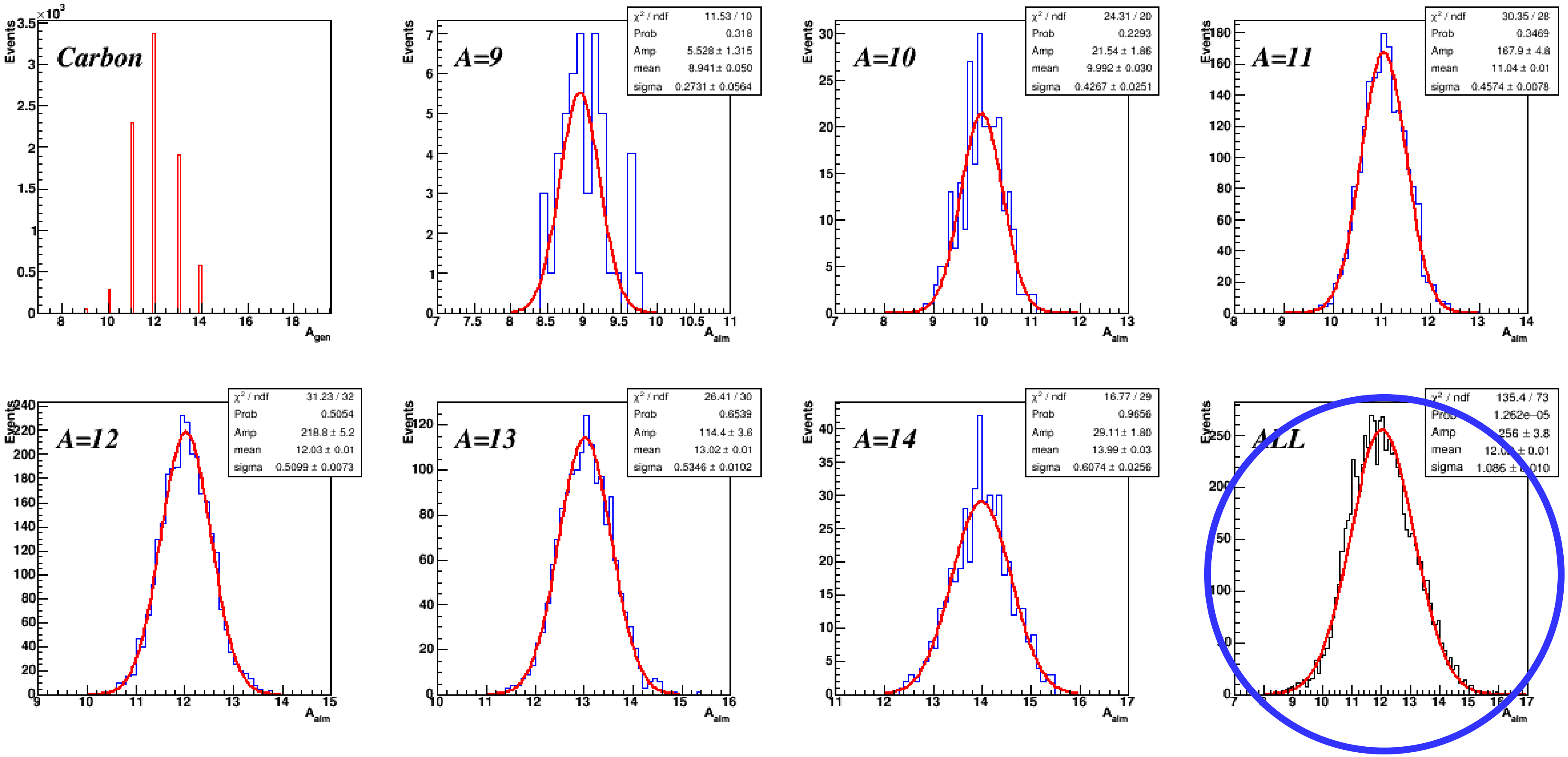
Separation is easier at low A and hard for heavy fragments (A distance for 2 isotopes is 6-10%)

Isotopes separation

Isotopes separation



^{16}O (200 MeV/nucl) → C_2H_4: Isotopes separation: Carbon

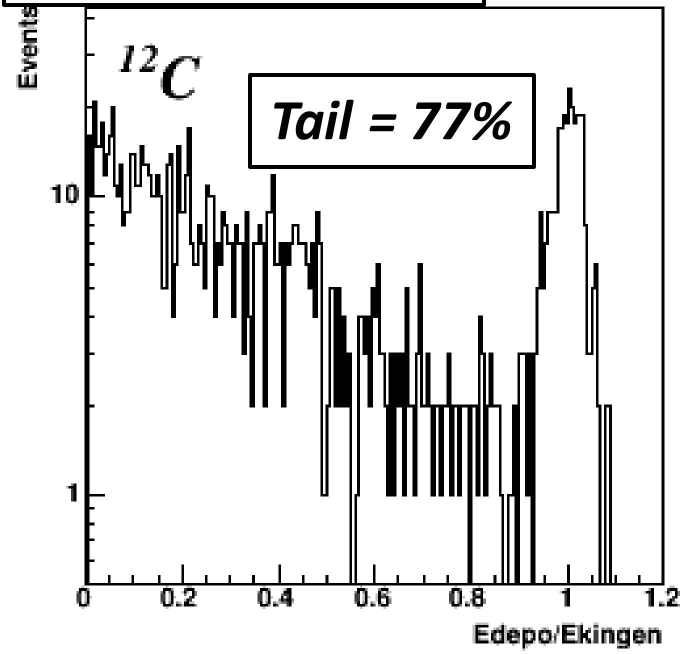


Single isotopes well reconstructed, but the overall peak is (at the moment) NOT resolved

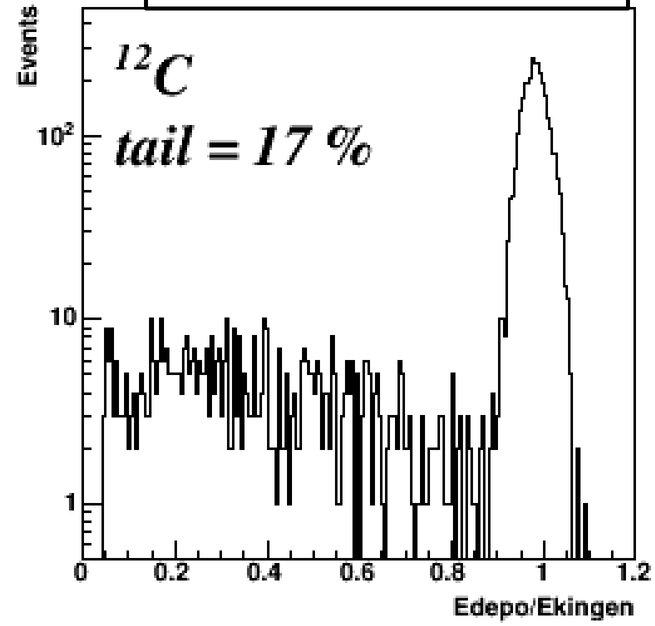
High Energy, $^{16}O \rightarrow C_2H_4$ with 700 MeV/nucleon

$$\frac{\text{Energy deposit SCINT + CALO}}{\text{Kinetic Energy generated}}$$

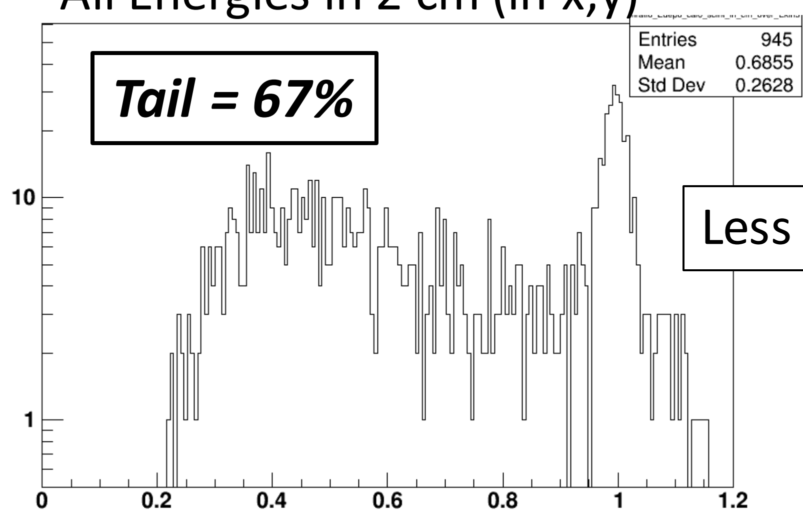
^{16}O (700 MeV/nucl)



^{16}O (200 MeV/nucl)



All Energies in 2 cm (in x,y)

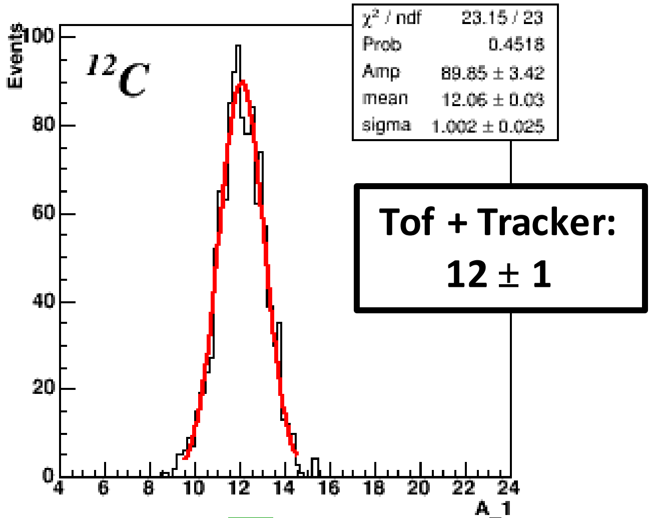


Less tail

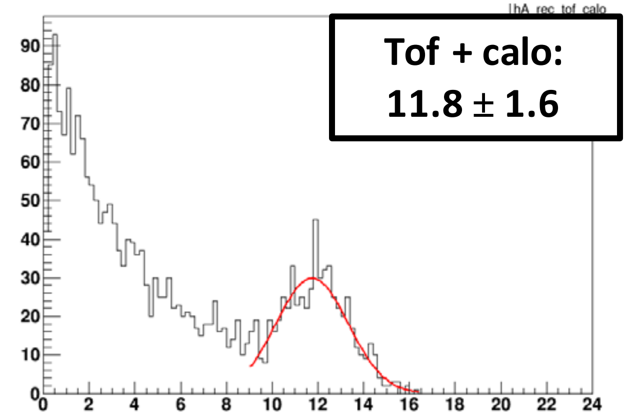
A lot of energy loose in Calo

A reconstruction with TOF and TRACKER

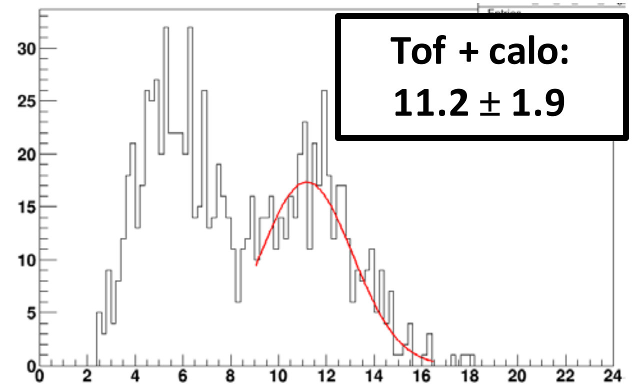
High Energy, $^{16}O \rightarrow C_2H_4$ with 700 MeV/u



standard



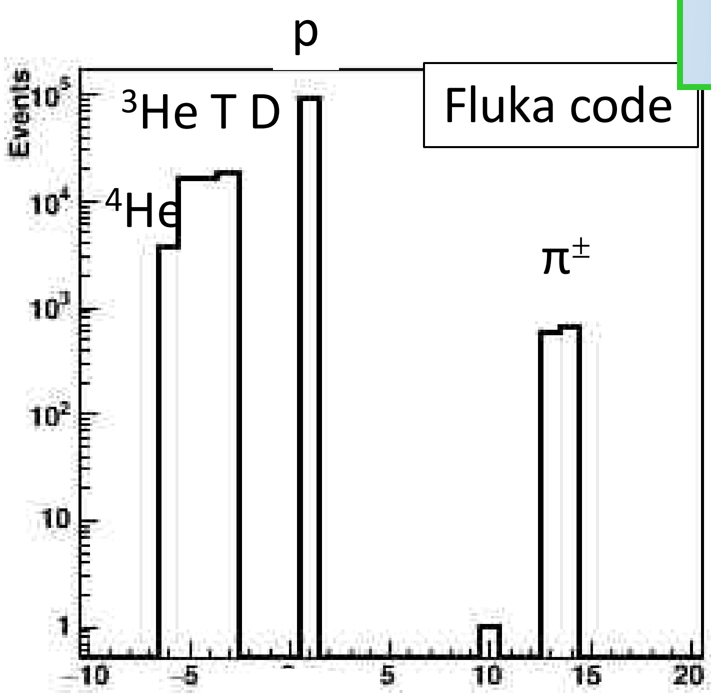
All Energies in 2 cm



Incident Energy and Method	Resolution on ^{12}C
^{16}O (700 MeV/u) on C_2H_4 → Tof + Tracker method	12 ± 1
^{16}O (200 MeV/u) on C_2H_4 → Tof + Tracker method	12.11 ± 0.67
^{16}O (200 MeV/u) on C_2H_4 → ALM fit	11.98 ± 0.52

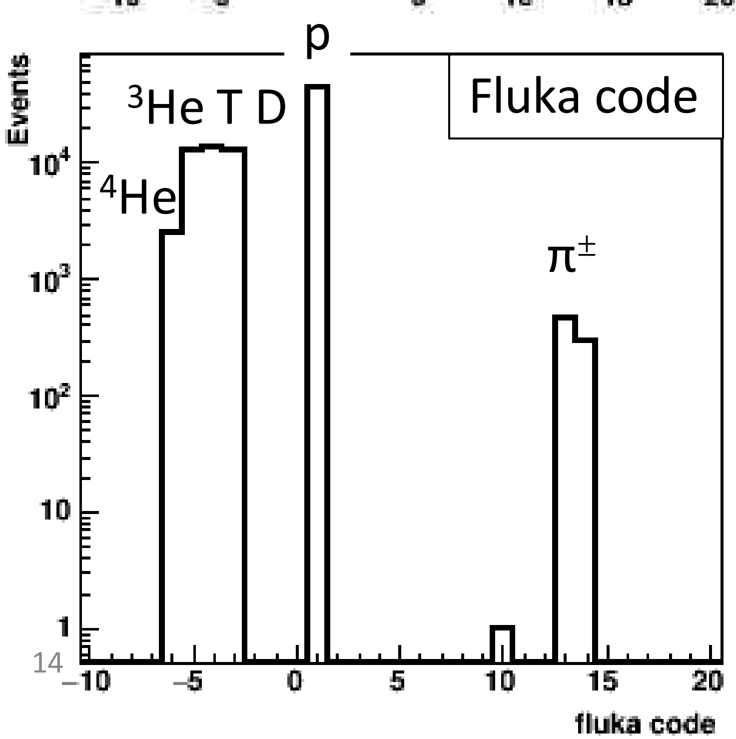
- **Radio-Protection → range mainly depends on Z**
- **important the Energy measurement for the differential cross section**
- **A Resolution decreases by a factor 2 (also for other fragments)**
- **Fundamental role of the Tof-Tracker for the better A Resolution**

^4He (700 MeV/u) → C or C_2H_4 : generation



Carbon Target

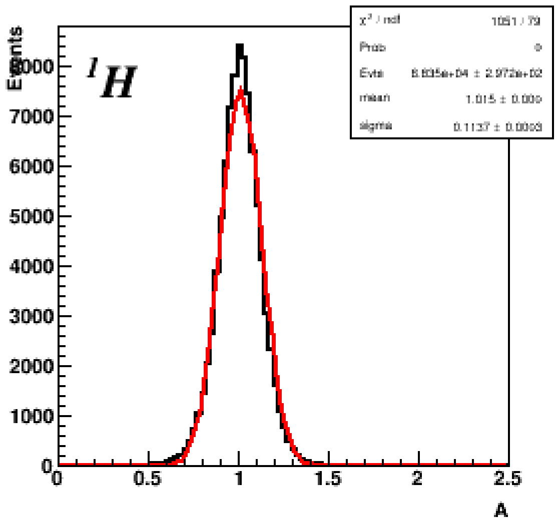
Fragments in FOOT (%)	
p	61.7
D	12.6
T	11.3
^3He	11.2
^4He	2.5
$\pi^\pm$	0.7

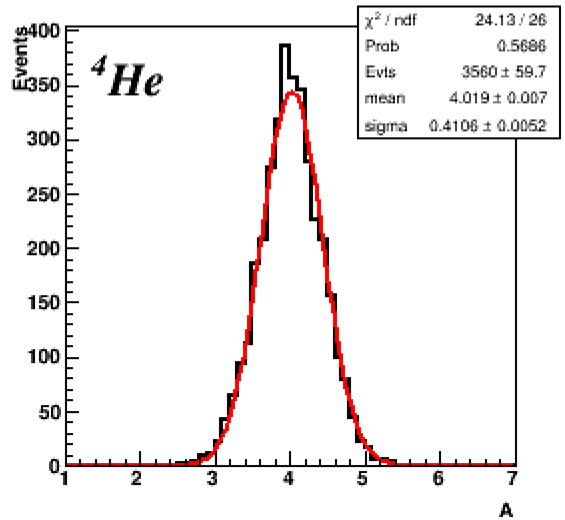


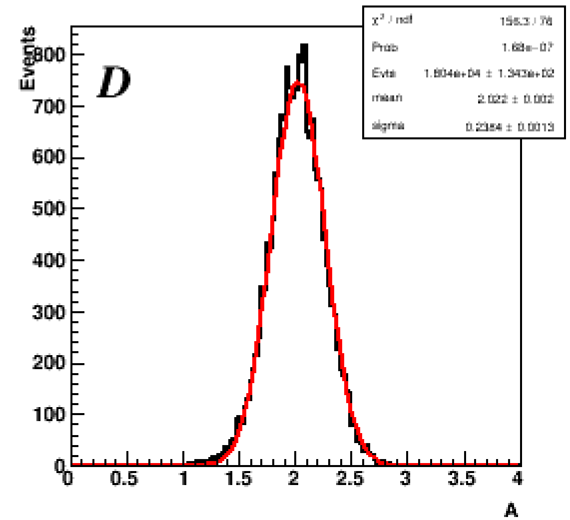
C2H4 Target

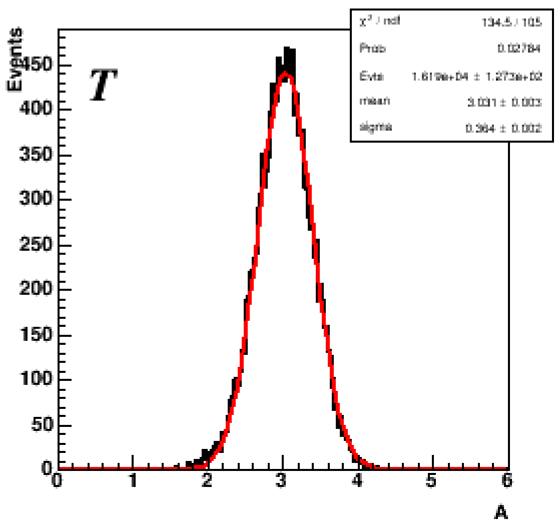
Fragments in FOOT (%)	
p	51.3
D	14.7
T	15.4
^3He	15.0
^4He	2.8
$\pi^\pm$	0.8

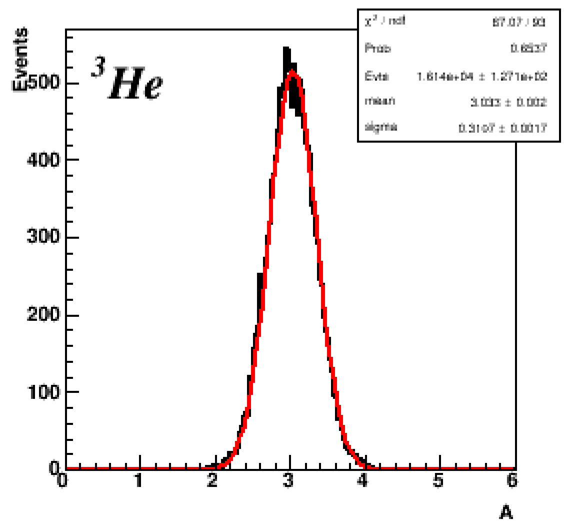
^{4}He (700 MeV/u) → C or C_2H_4 : A(Tof + Tracker) in C Target







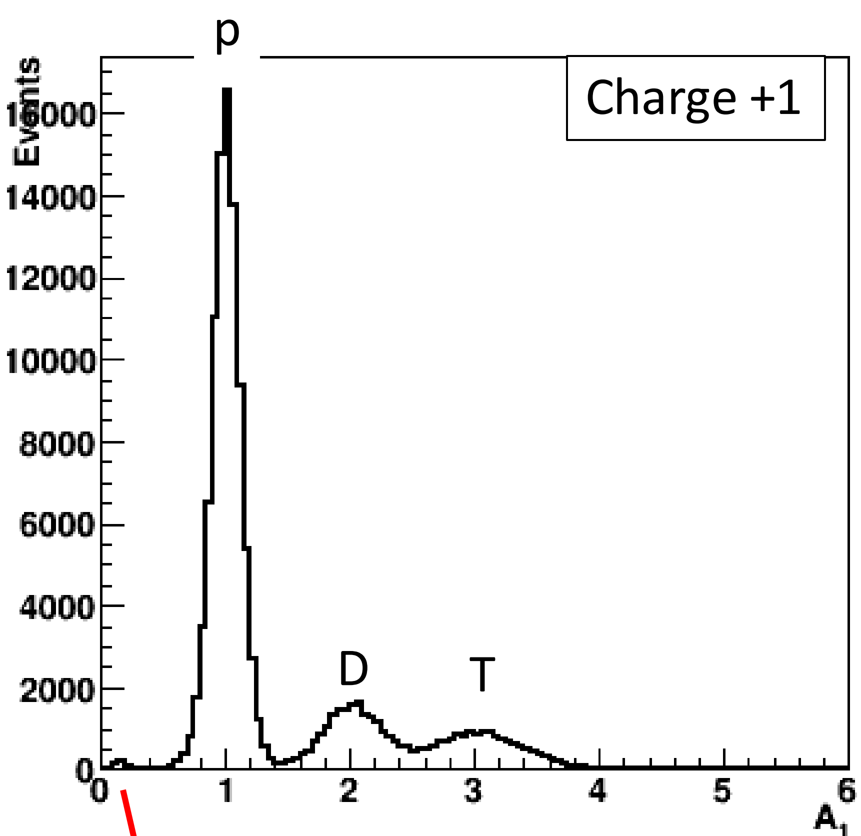




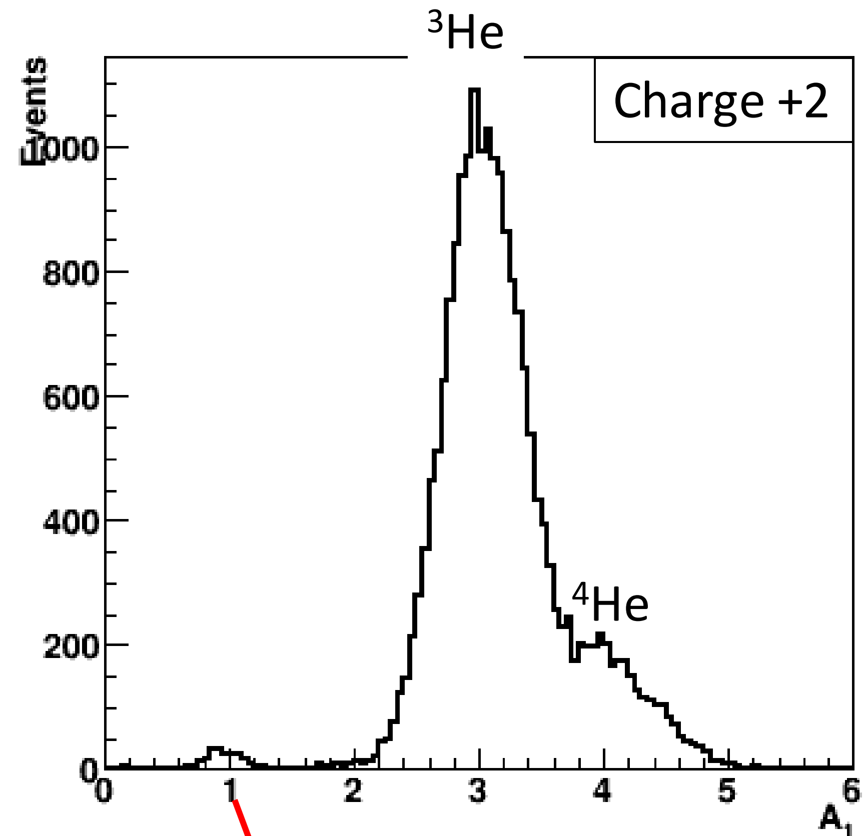
A determination	
p	1.02 ± 0.11
D	2.02 ± 0.24
T	3.03 ± 0.36
^{3}He	3.03 ± 0.31
^{4}He	4.02 ± 0.41

Precision at level of 10% →possibility to identify (with the charge) the fragments

Fragment identification: C Target



Pion identification



Charge misidentification at level of ~1%

capability to identify fragments for ^{4}He beam @ 700 MeV/u

New possible method for a Particle Identification

NIMA 490 (2002) 251-262 “Mass and charge identification of fragments detected with the Chimera Silicon-CsI(Tl) telescopes” suggested by Cardella G.

Bethe-Block

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

Kinetic Energy E

$$E = \frac{1}{2}Mv^2$$

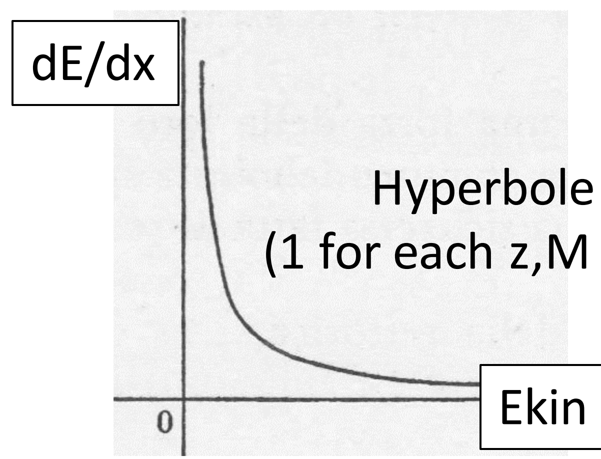
$$\frac{dE}{dx} \propto K\frac{z^2}{v^2}$$

$$E \propto Mv^2$$

not relativistic

$$\frac{dE}{dx}\cdot E \propto Kz^2 M \rightarrow$$

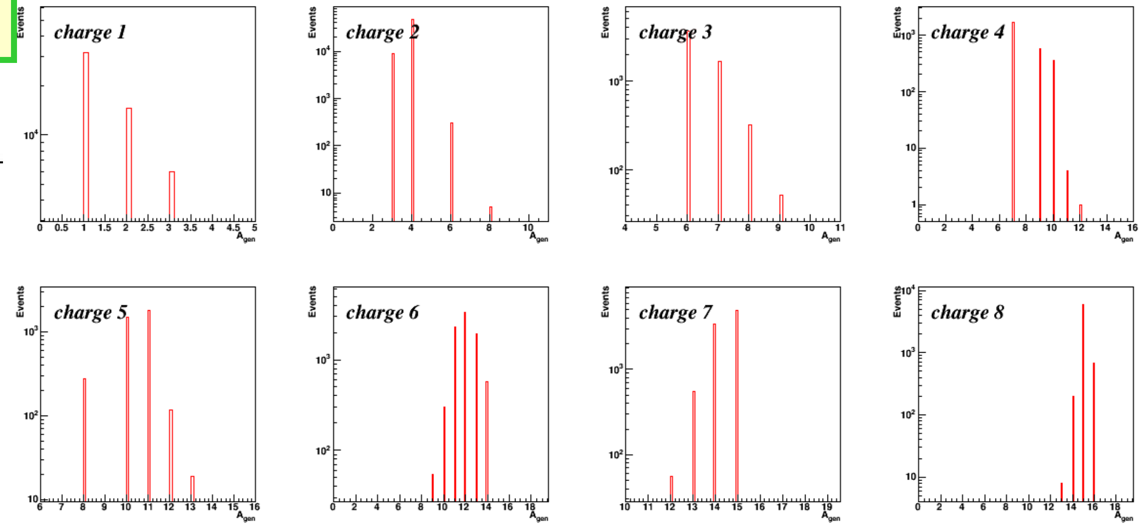
constant depending on charge and mass

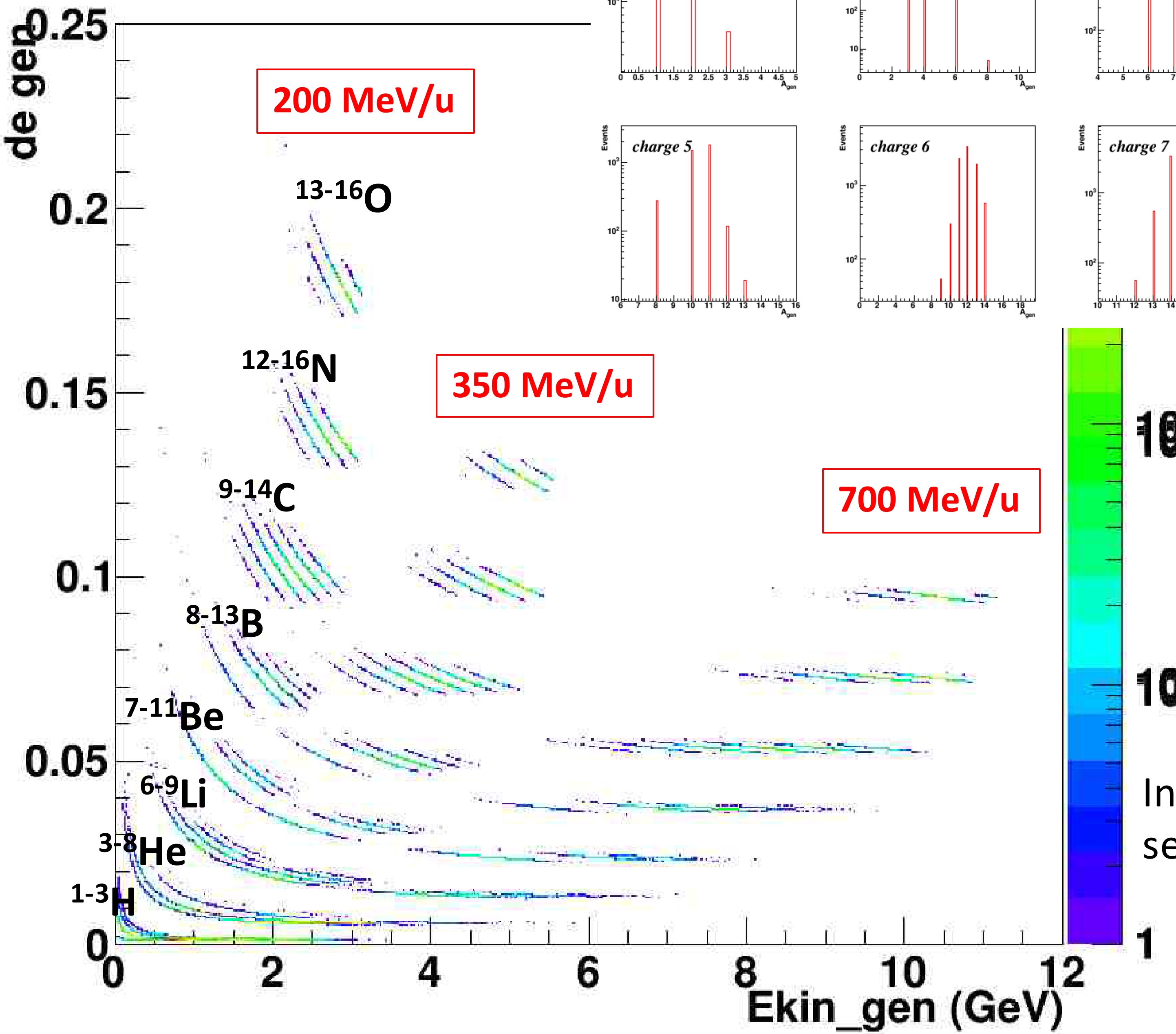


Involved subdetectors:

- dE/dx → **MSD, SCN**
- Ekin → **CALO**

dE/dx vs E @ generation level, 2

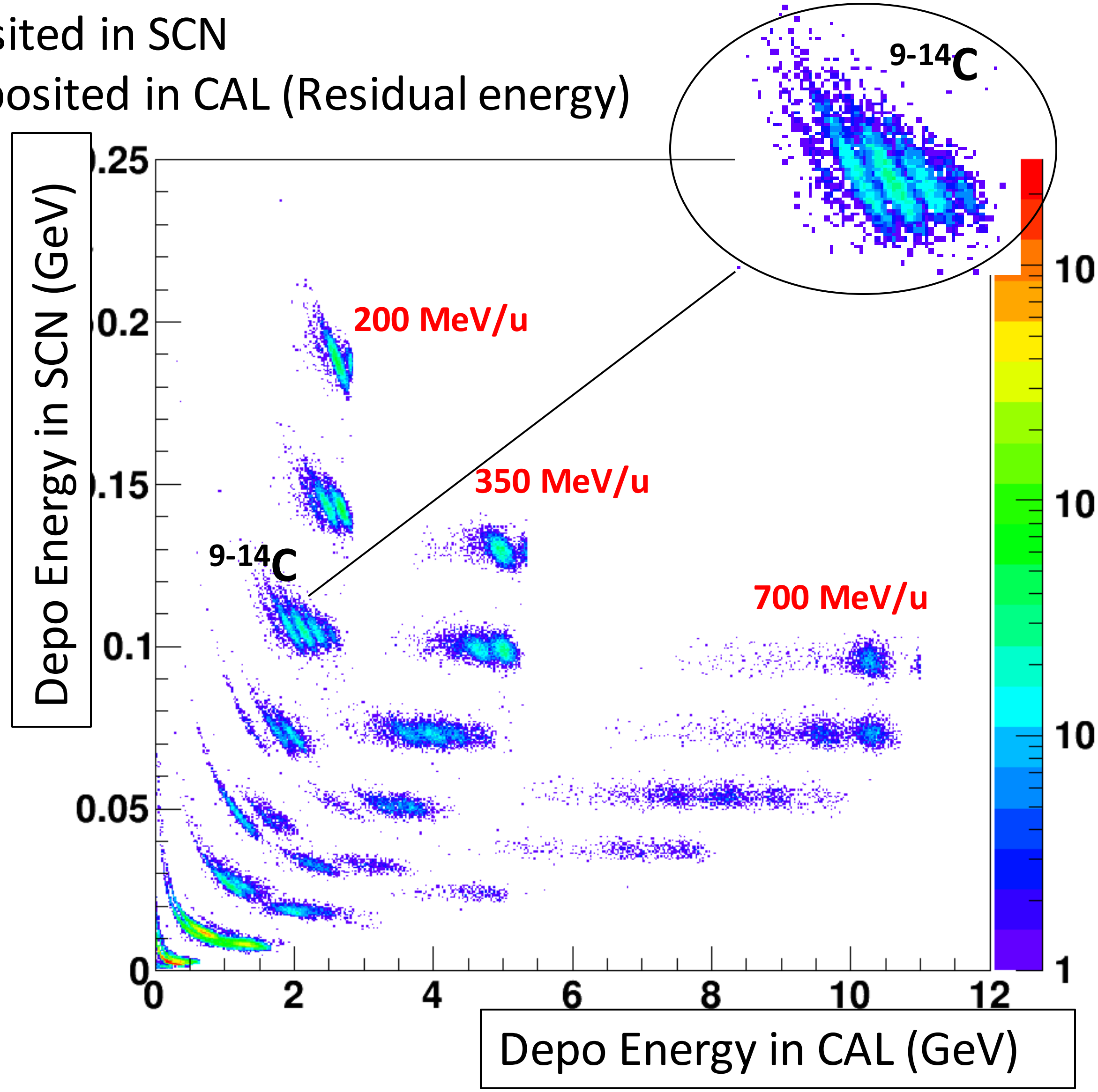




In principle the separation is possible

Generation level: Energy in SCN vs Energy in CAL

Bethe-block → Energy deposited in SCN
Kinetic Energy → Energy deposited in CAL (Residual energy)



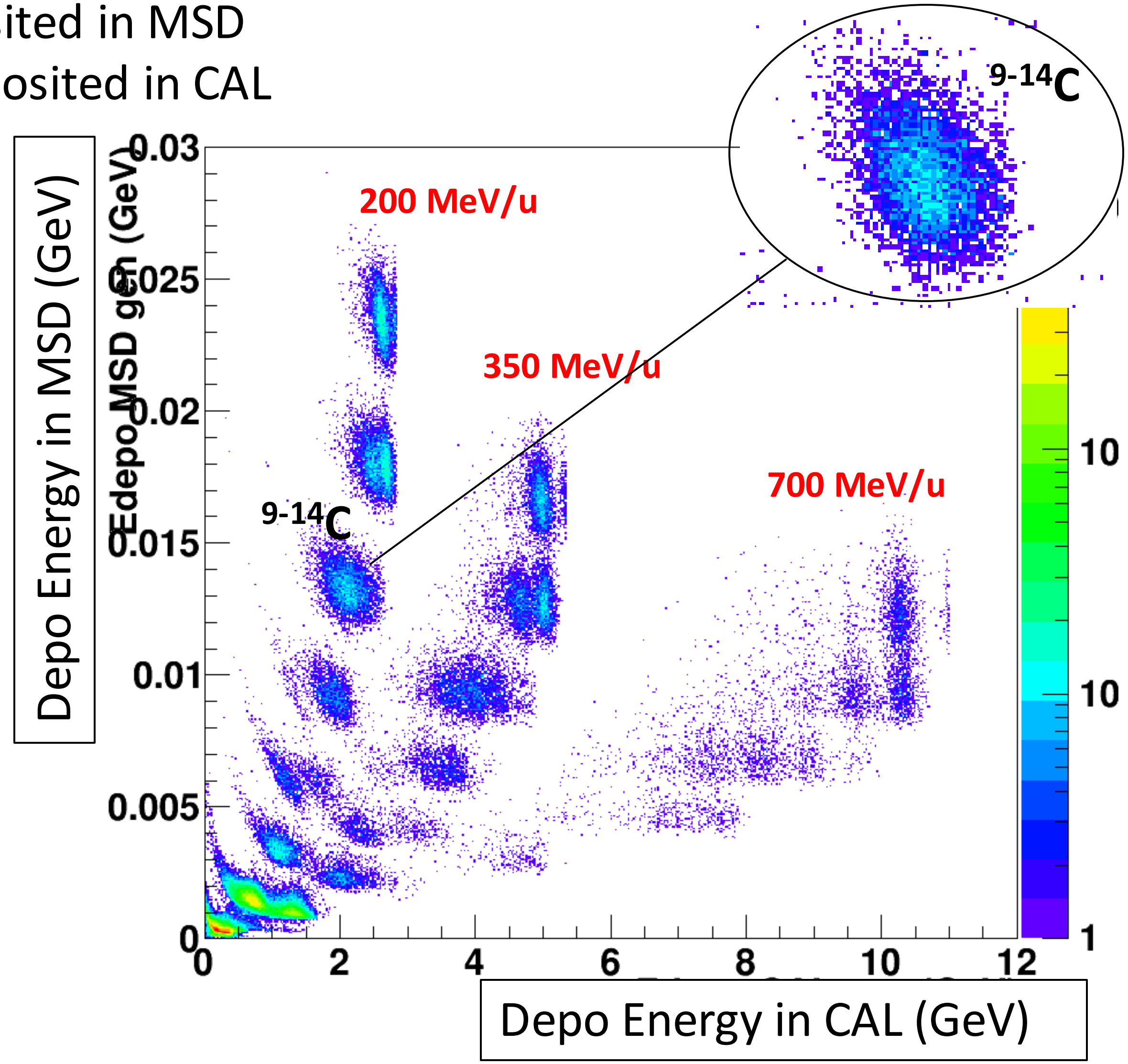
PERFECT RESOLUTION
on the deposited Energy
(extracted by Fluka),
only statistical fluctuation

SCN:
6 mm of plastic scintillator

Separation **IS POSSIBLE**, but worst than before due to the statistical fluctuations

Depo Energy in MSD vs Depo Energy in CAL @ generation level

Bethe-block → Energy deposited in MSD
Kinetic Energy → Energy deposited in CAL



PERFECT RESOLUTION
on the deposited Energy
(extracted by Fluka),
only statistical fluctuation

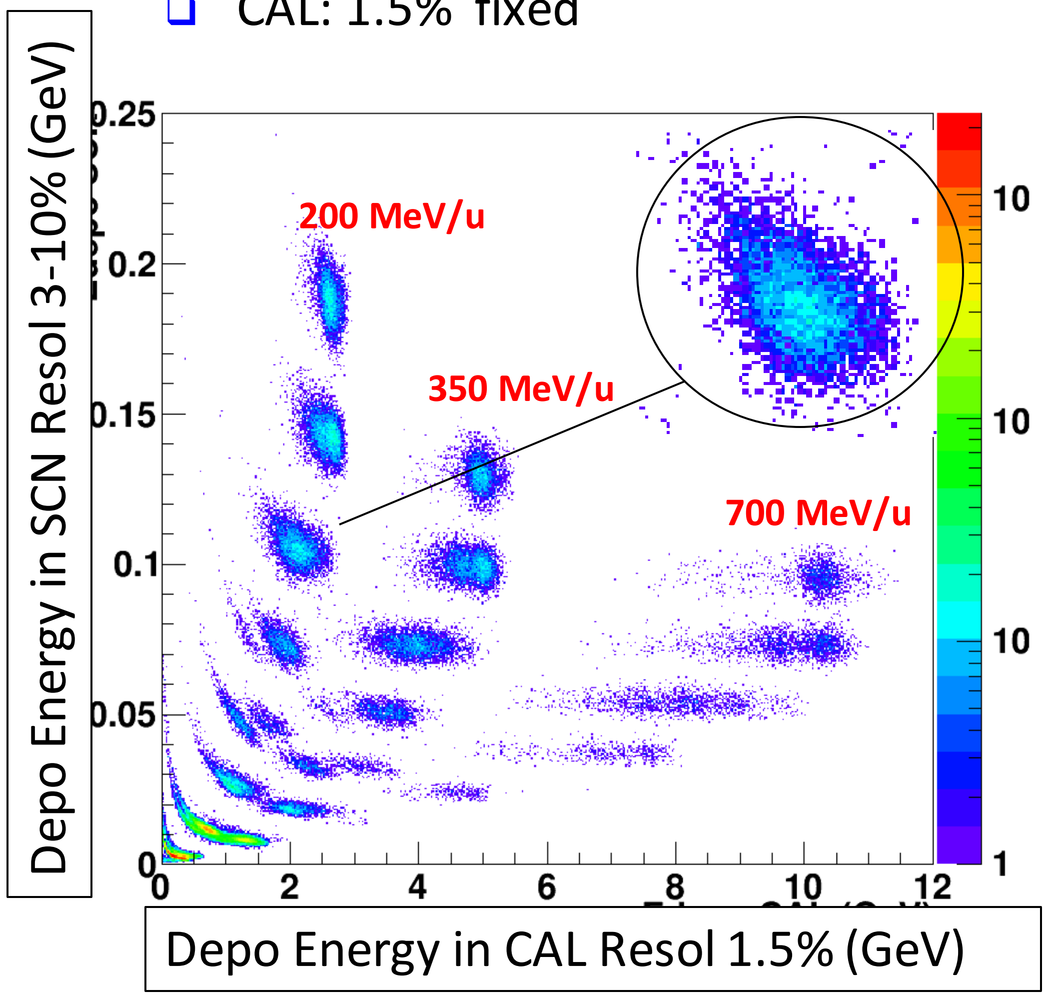
MSD: 420 μm of Silicon
energy deposited is 1/8 wrt SCN

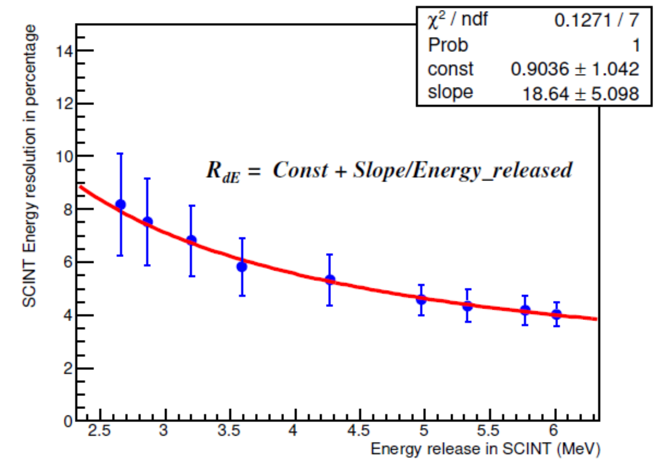
Separation is **NOT possible**: the deposited energy on MSD is 1/8 wrt the SCN → statistical fluctuations prevent the isotope identification with MSD

Reconstruction level: Energy in SCN vs Energy in CAL

Deposited Energy with a smearing to simulate the detector resolution

- SCN: 3-10% depending on the deposited energy
- CAL: 1.5% fixed





SCN: 6 mm of plastic scintillator

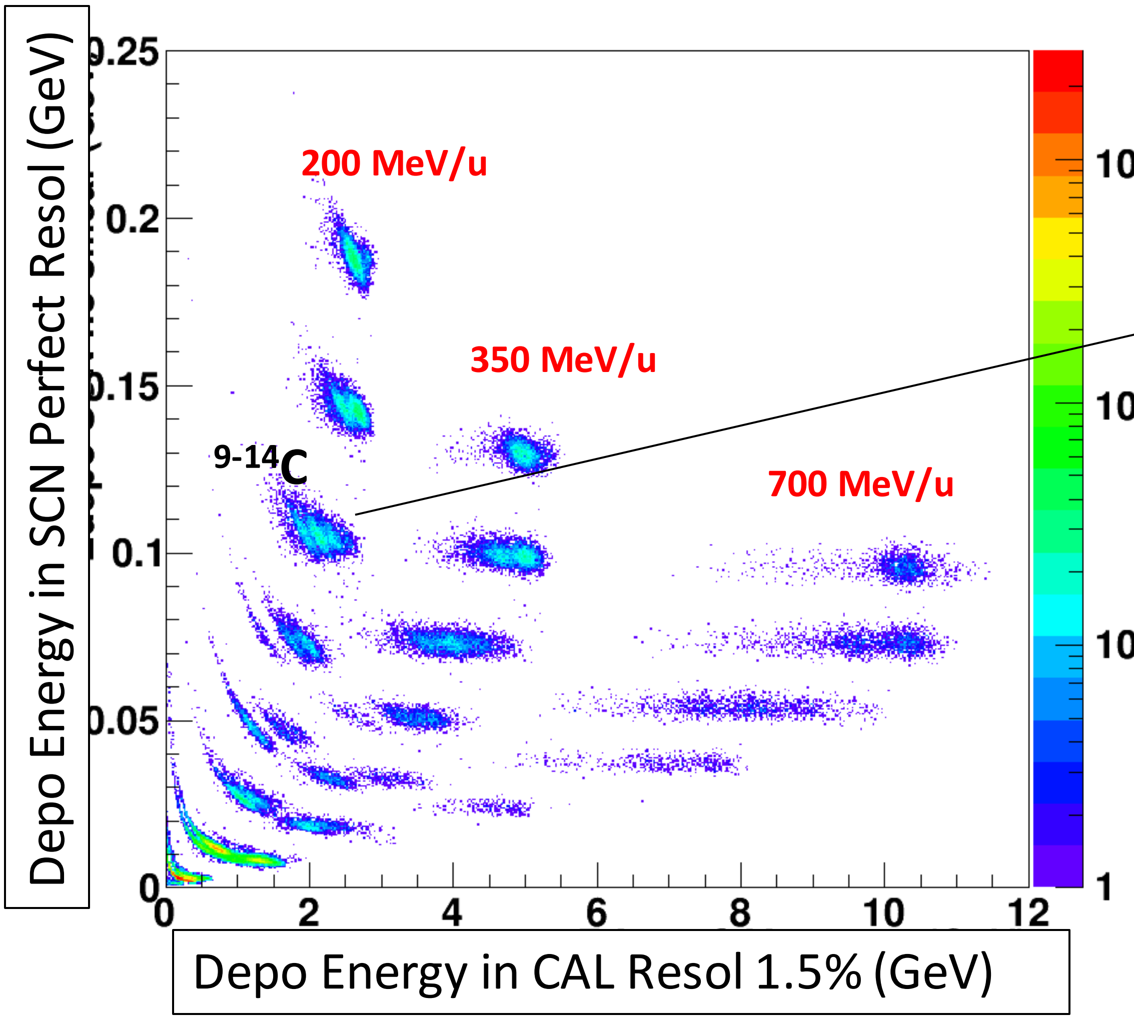
CAL: 21 cm of BGO

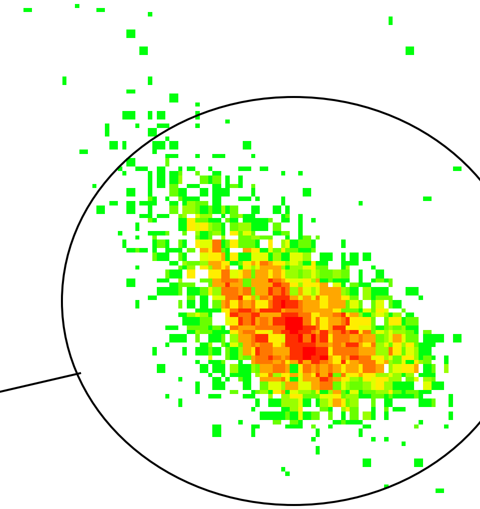
Separation is **NOT possible**: problem on SCN or CAL?

Depo Energy in SCN vs Depo Energy in CAL @ reconstruction level

Deposited Energy with a smearing to simulate the detector resolution

- SCN: perfect resolution
- CAL: 1.5% fixed





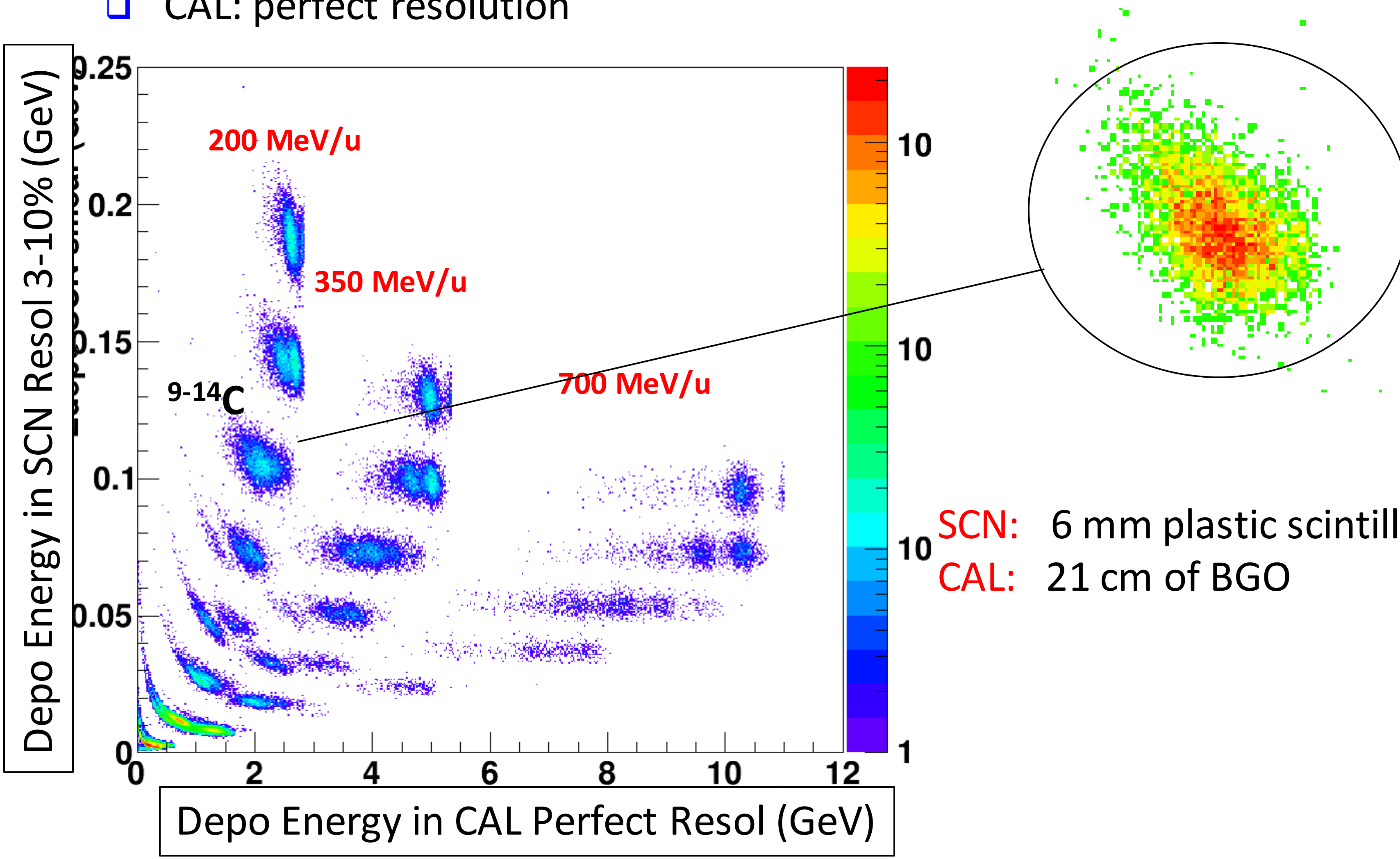
SCN: 6 mm plastic scintillator
CAL: 21 cm of BGO

Separation **IS POSSIBLE** →if the SCN resolution improve

Depo Energy in SCN vs Depo Energy in CAL @ reconstruction level

Deposited Energy with a smearing to simulate the detector resolution

- SCN: 3-10% depending on Z
- CAL: perfect resolution



SCN: 6 mm plastic scintillator
CAL: 21 cm of BGO

Separation is **NOT POSSIBLE** independent on the CAL resolution

Summary

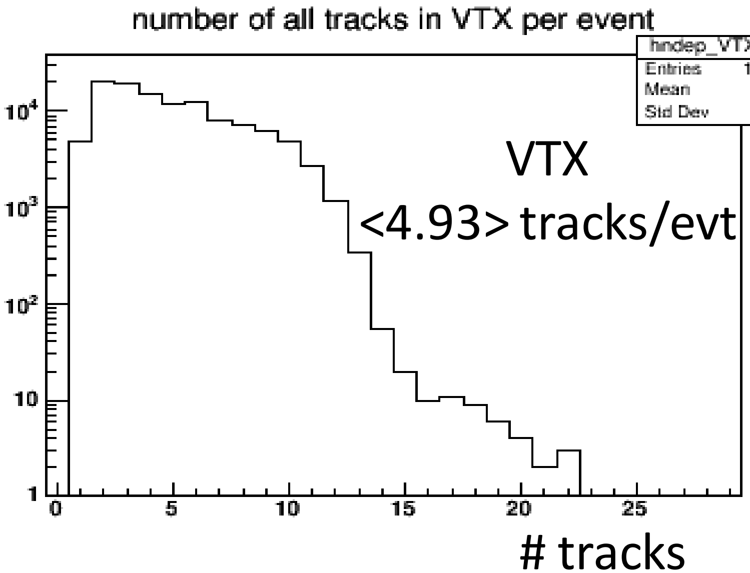
- **Z RECONSTRUCTION:**
  - Beam @ 200 MeV: Resolution in the range **[2-5]%**
  - Beam @ 700 MeV (^{16}O or ^{4}He): Resolution in the range **[3-6]%**
  - **Charge Misidentification ~1%**

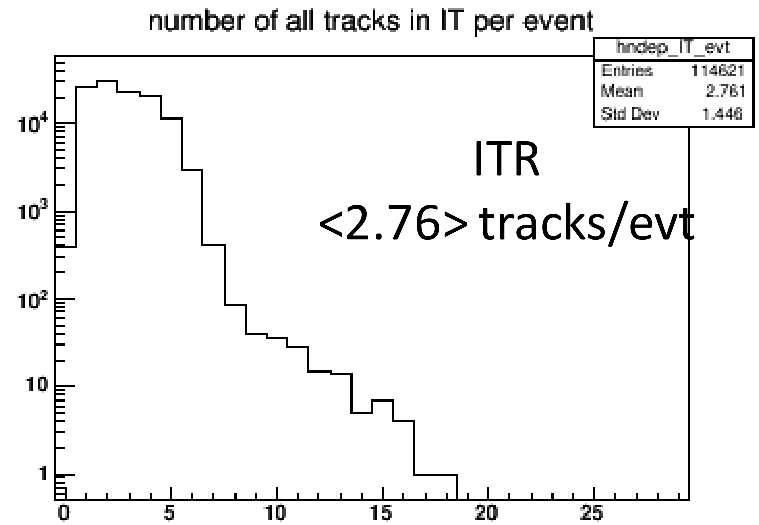
- **A RECONSTRUCTION**
  - Beam @ 200 MeV: Resolution **~ 4%**
  - Beam @ 700 MeV: Resolution **~ 10%**
  - **Not possible to disentangle the heavier isotopes**

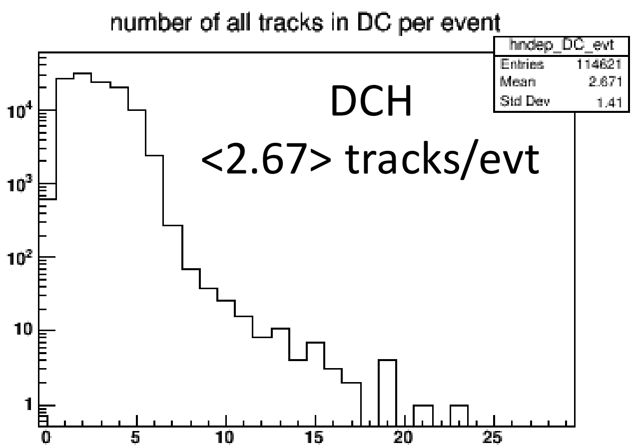
- **FRAGMENTS IDENTIFICATION WITH A $\Delta E/dx \bullet E$ METHOD**
  - **SCN: possible if the resolution increase**
  - **MSD: to few energy deposited → to high statistical fluctuation**

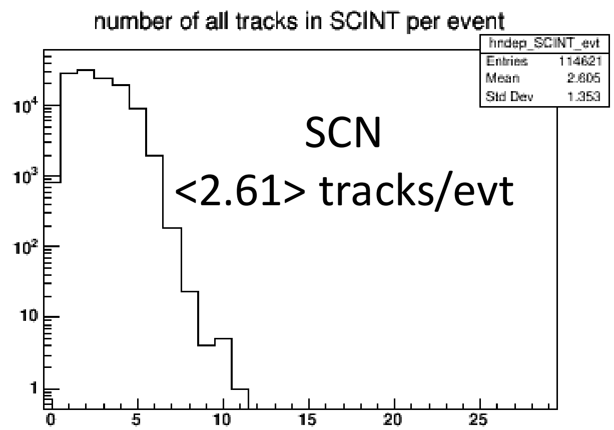
- **FUTURE** → investigate new E_{kin} reconstruction

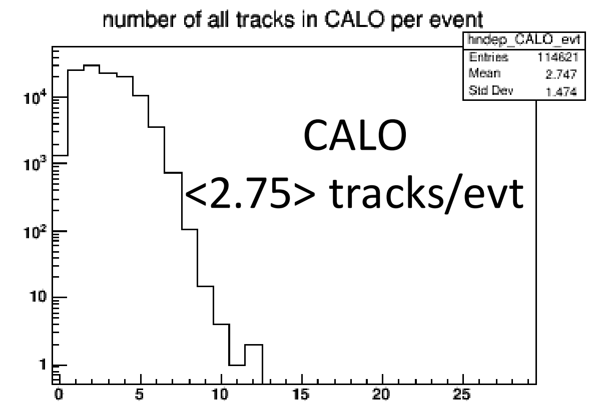
Number of tracks in the subdetectors (-3 < Trzin < 80 cm)



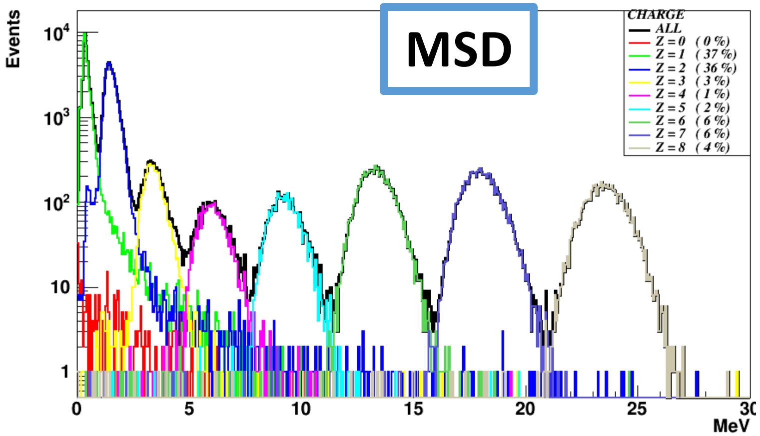




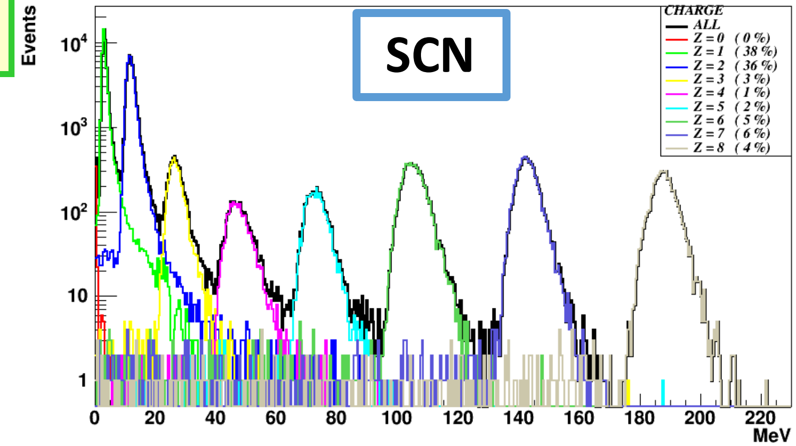


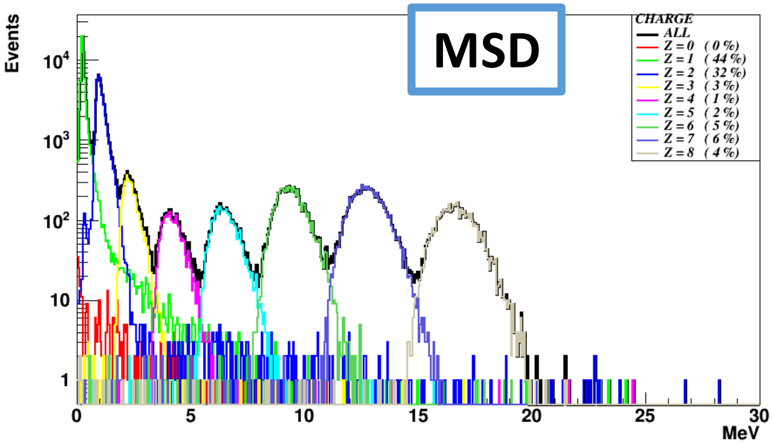


MSD - SCN

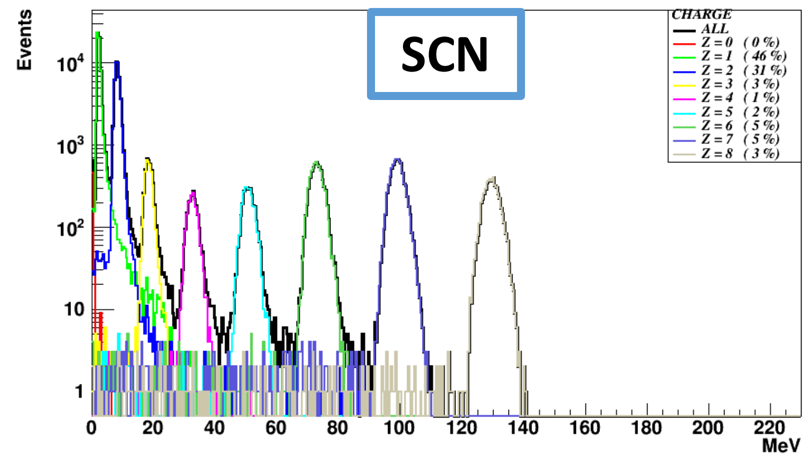


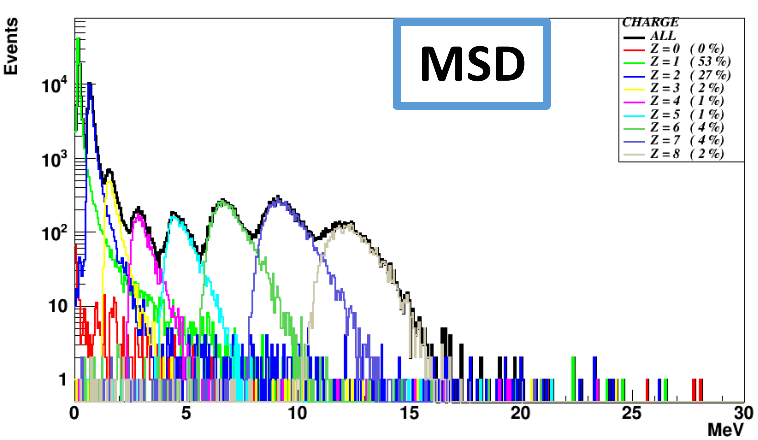
200 MeV/u



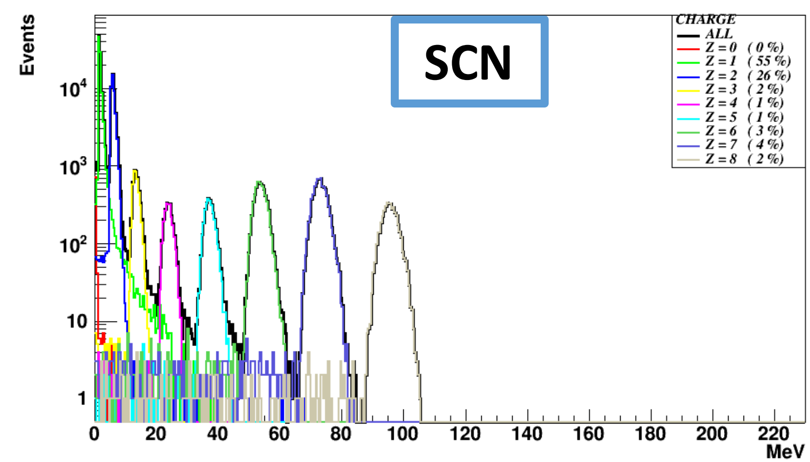


350 MeV/u

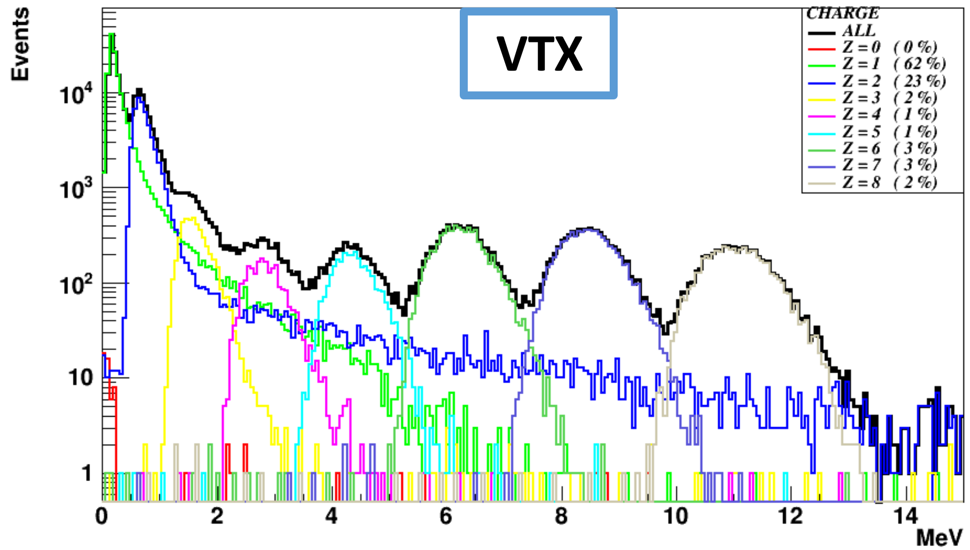




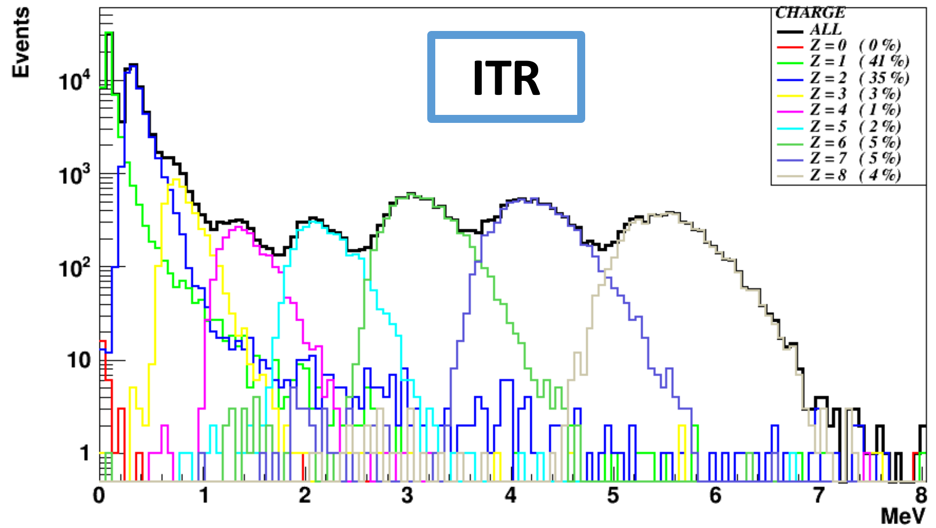
700 MeV/u

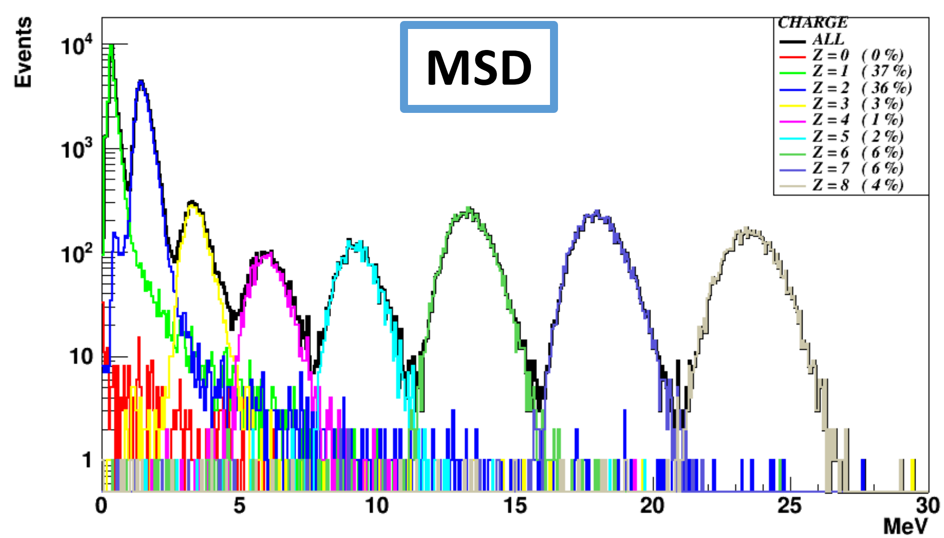


Silicon Detectors



200 MeV/u





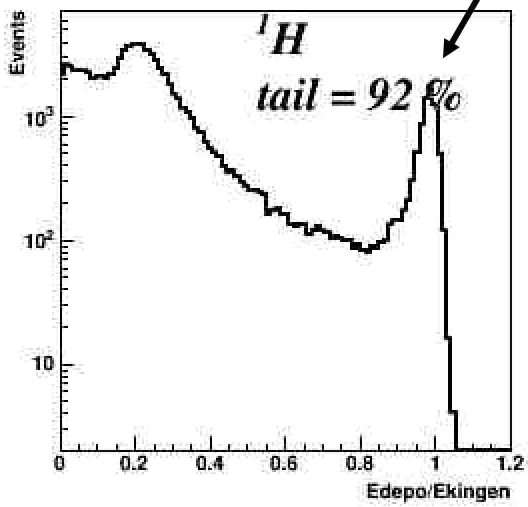
Deposited energy scales as Silicon thickness

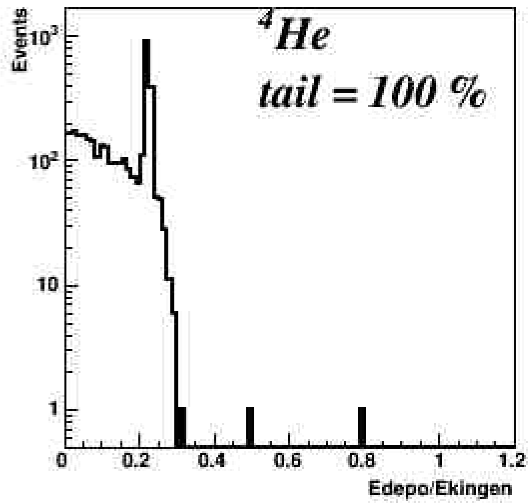
- VTX 200 μm
- ITR 100 μm
- MSD 420 μm

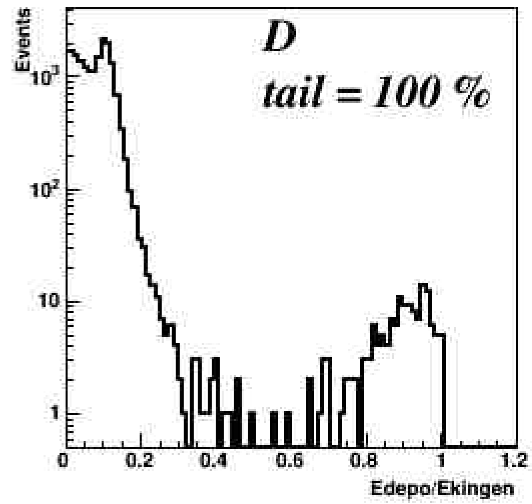
Energy Fraction in SCN + CAL: C Target

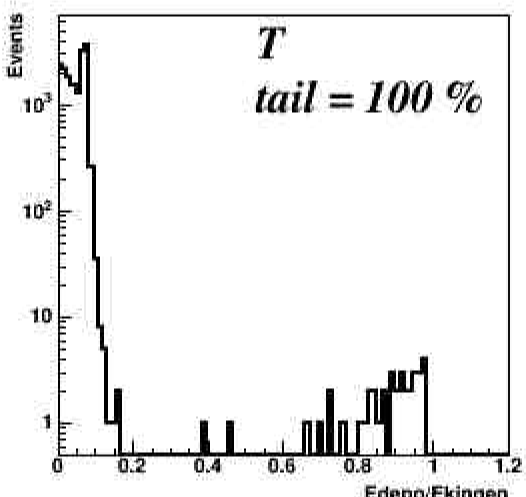
$$\frac{\text{Energy deposited SCINT + CALO}}{\text{Kinetic Energy generated}}$$

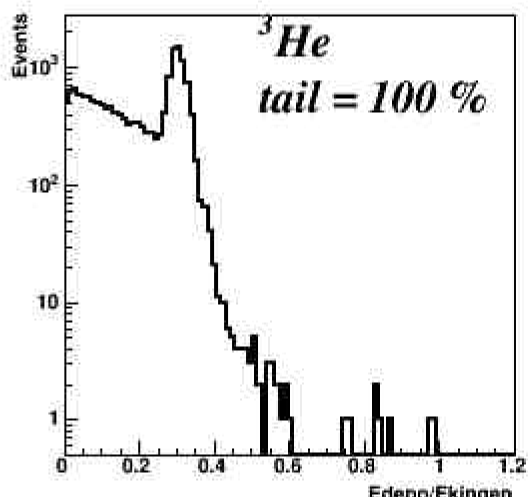
% Events outside peak (ratio<0.9)









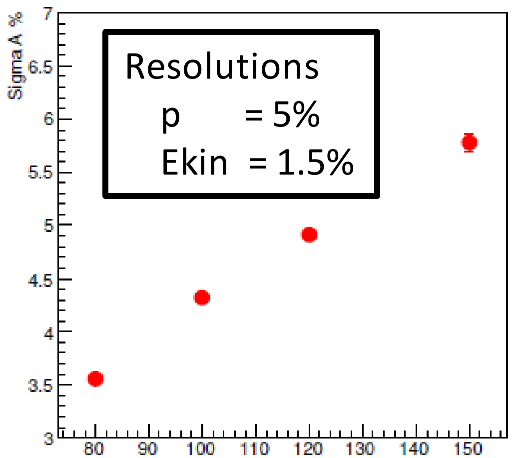


released only a little part of the kinetic energy

- P,D,T ≤ 20%
- ^{3}He and ^{4}He ~ 30%

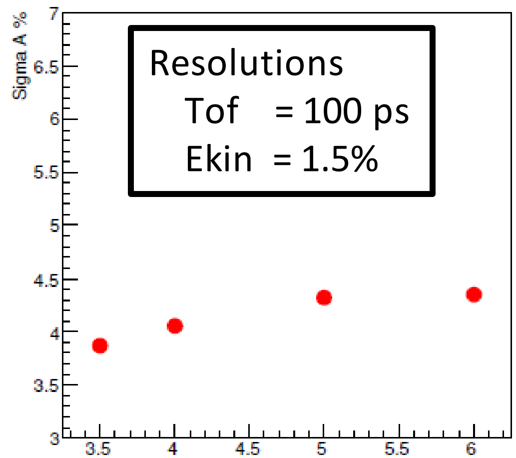
^{16}O (200 MeV/nucl) → C_2H_4 : Systematic on A resolution (example ^{12}C)

σ_A (%) vs Tof precision



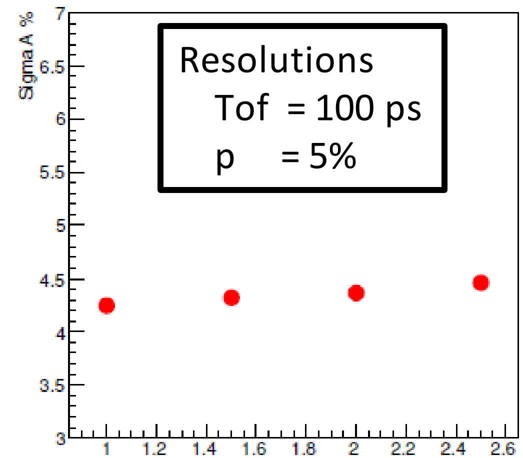
Tof precision (ps)

σ_A (%) vs p precision



p precision (%)

σ_A (%) vs E_{kin} precision



E_{kin} precision (%)

All the systematic values and plots have been included in the CDR

- **A Resolution**
  - **Large dependence on the Tof Resolution**
  - **Week dependence on the p and E_{kin} resolution**

High Energy, ^4He (700 MeV/u) → C or C_2H_4 : Energy fraction

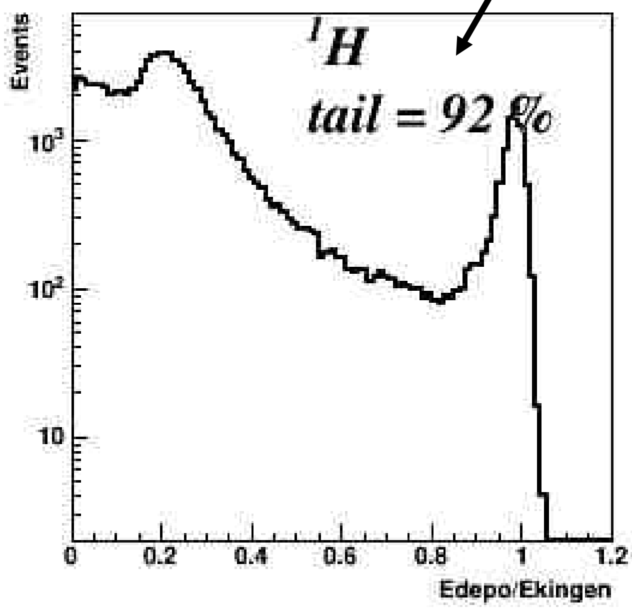
Till now:

E_{kin} → Energy depo by track in CALO

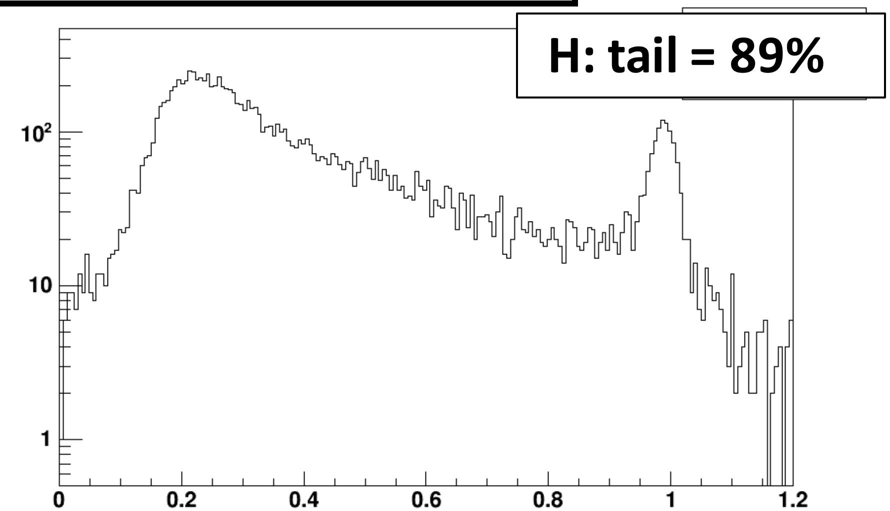
To investigate

E_{kin} →All Energies depo in 2 cm (in x,y)

% Events outside peak (ratio<0.9)



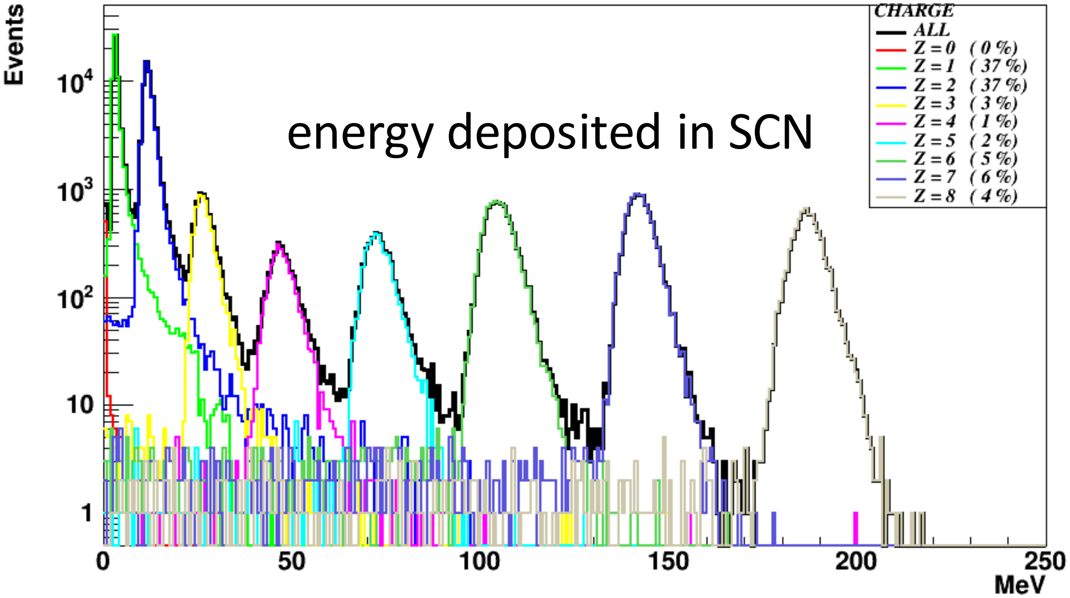
$$\frac{\textbf{Energy deposited SCINT + CALO}}{\textbf{Kinetic Energy generated}}$$



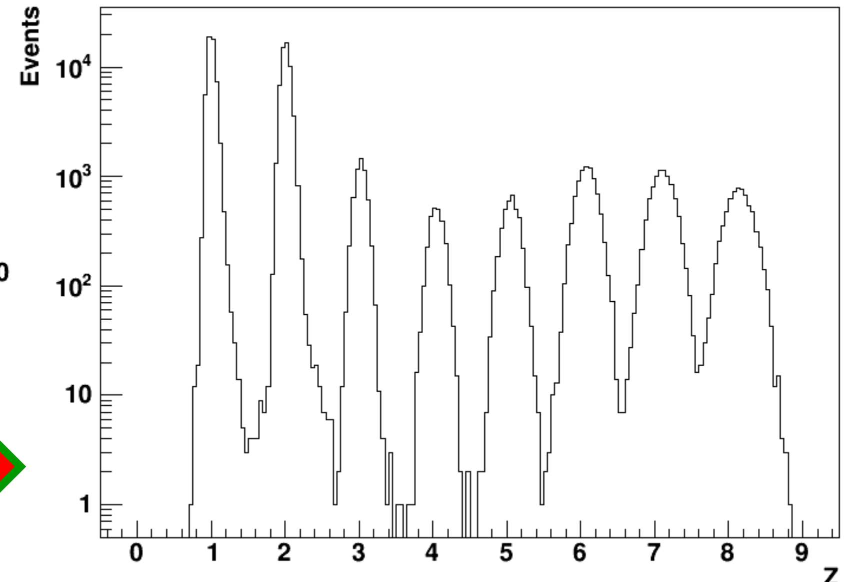
The 2 methods give similar results

Same results with C_2H_4 and C targets

Z reconstruction: 200 MeV



reconstructed Z



Using the Bethe formula → energy deposited in scintillator + β measurement

^{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 ± 0.05	2.02 ± 0.06	3.03 ± 0.08	4.05 ± 0.10	5.07 ± 0.11	6.09 ± 0.14	7.11 ± 0.16	8.15 ± 0.18

Resol: 5% 3% 2.2%

Z Resolution: [2-5%] << minimum distance between charges (~10% between 7 and 8)

Remember: the front-end is not simulated