Global Analysis for SHOE

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(with the crucial support of Roberto Spighi)

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What we have now

Analysis macro (by Roberto)

- Import the ROOTuple (from FLUKA simulation) and analyse the data

- Reconstruct all the needed quantities to identify the different fragments
  - Charge
  - Momentum and TOF
  - Energy deposition dE/dx
  - Mass with standard χ^2 fit and Augmented Lagrangian Method (ALM)

- Generate an *Out.root* file with all the interesting quantities

Cross Sections macro (by Roberto)

- Import the previous *Out.root* file and elaborate the information to get the different cross sections

What we have now

- They are two standalone macros
- If you are not familiar with them, it's not easy to understand where to get your hands "to change stuff"
- They have got bigger and bigger over time: some of the stuff inside are not really needed right now

What I did

- Rearrangement of the code in a SHOE friendly way: last goal is its **inclusion in SHOE** → Should be easier for the rest of the collaboration to access the global analysis in the future

- Double check with the previous results → I got the same results as with the previous codes

Organization of the code in different classes

Initialization

Set the experimental information about each detectors

Set information about the beam (Z, A, Energy)

Generation

It deals with all the quantities directly generated from Fluka (taken from the ROOTple) and fills the related plots

Reconstruction

It manipulates the information from Fluka (future: real data) to identify the different fragments and fills the related plots

Plots

Create all the plots that will be filled with the Generation and Reconstruction classes

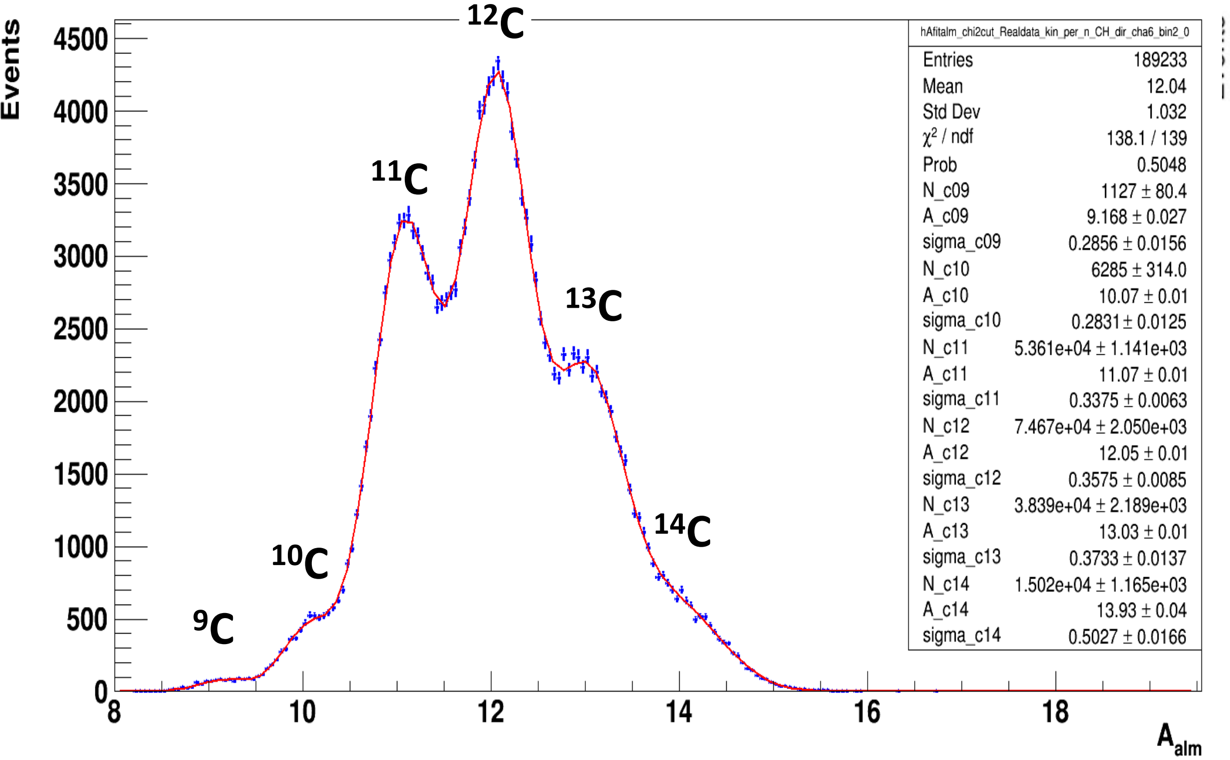
Out.root

Cross Section

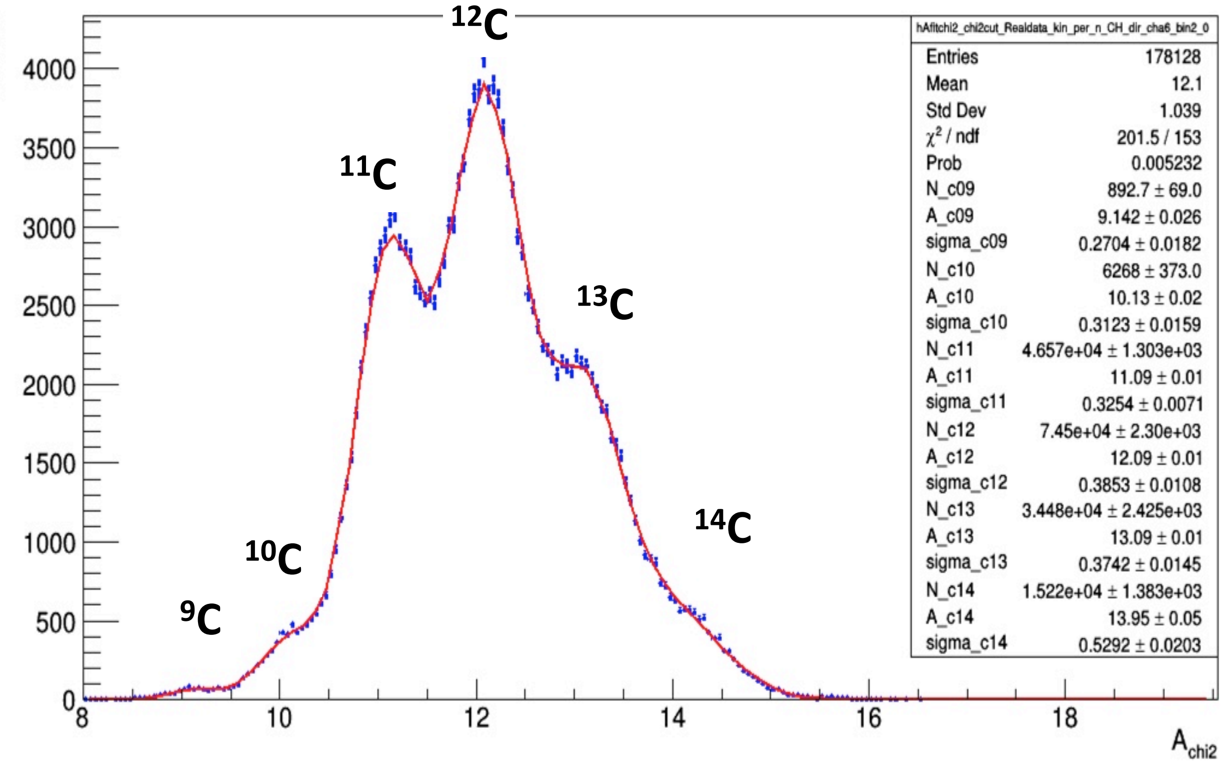
Take the Out.root and does all the machinery (see Roberto's presentation 4.12.2018) to get the cross sections

Just to show you that it works

Before



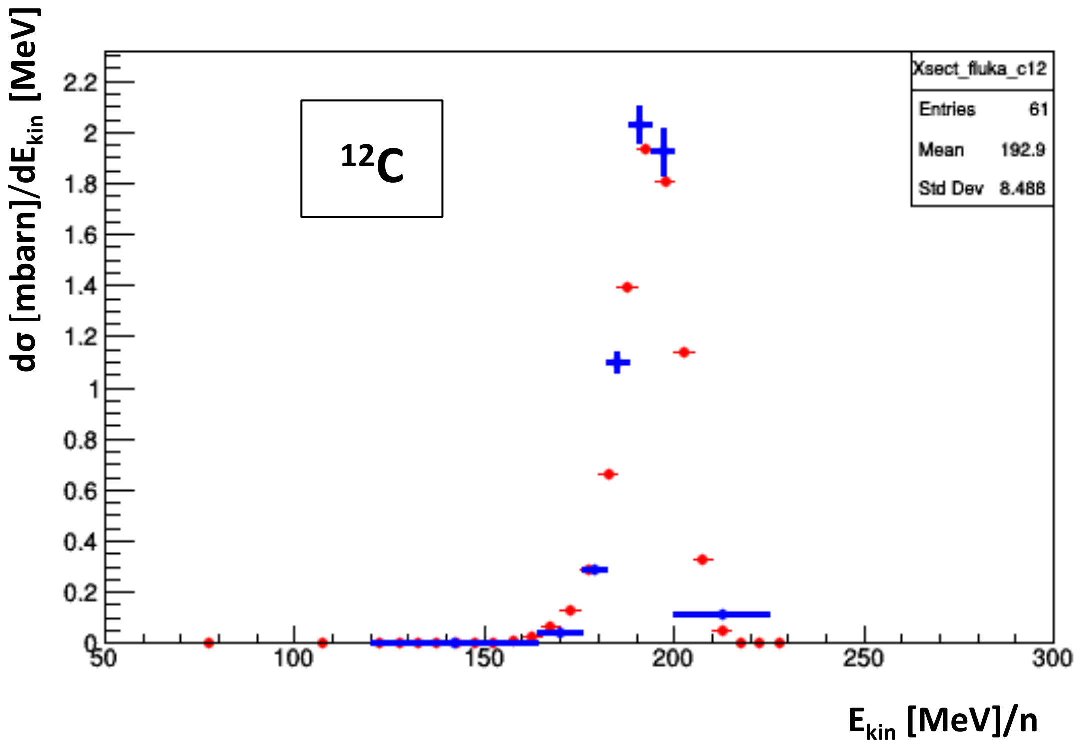
Now



Simulation:

- 2.5×10^8 primaries (2880551 interactions → 1.15%)
- Beam: ^{16}O (200 MeV/u)
- Geometry V15
- Target: C_2H_4 :ρ = 0.94 g/cm^3, A = 28.052, z = 0.2 cm

$d\sigma/d_{Ekin}$ and σ comparison with Fluka: 200 MeV/u $^{16}O + C_2H_4 \rightarrow {}^{12}C + X$



Total σ mbarn	FLUKA	OUR	DIFF %
$^{16}O + C_2H_4 \rightarrow {}^{9}C+X$	0.77 ± 1.7 %	0.34 ± 5%	55
$^{10}C+X$	3.62 ± 0.7%	2.83 ± 1.4%	21
$^{11}C+X$	24.24 ± 0.3%	22.76 ± 0.7%	6
$^{12}C+X$	39.29 ± 0.2%	35.52 ± 0.7%	9
$^{13}C+X$	26.52 ± 0.3%	20.79 ± 1%	21
$^{14}C+X$	8.38 ± 0.5%	6.17 ± 2%	26

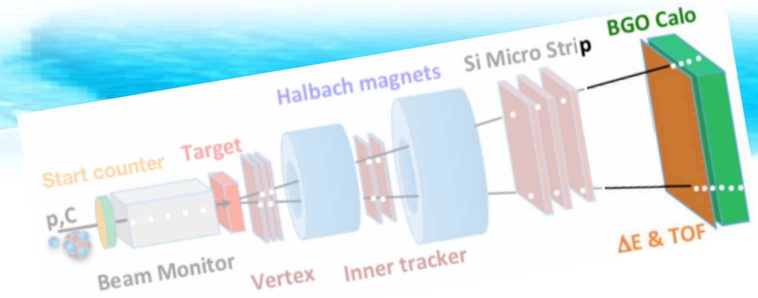
$$\frac{d\sigma_f}{dE_{kin}} = \frac{(Y_f - Bkg_f)^U}{N_{Prim} \, . \, N_t \, . \, \Omega_{Ekin} \, \epsilon_f} \Longrightarrow \text{total Cross Section } \sigma_f = \frac{(Y_f - Bkg_f)^U}{N_{Prim} \, . \, N_t \, . \, \epsilon_f}$$

(see Roberto's presentation 4.12.2018)

Next steps

- Finish the exercise with $^{16}O + C \rightarrow {}^{i}C + X$
    - Getting $^{16}O + H$ (by difference with the results of $^{16}O + C_2H_4$)
- Repeat the exercise to get the cross sections of different ions
- Estimate the effect of the resolution on the mass reconstruction in the cross section evaluation
- Use the code on the available experimental data from GSI
- FOOT in the space: repeat the cross section estimation and exercises with simulation of higher beam energy. Is FOOT able to see neutrons?

BACKUP SLIDES



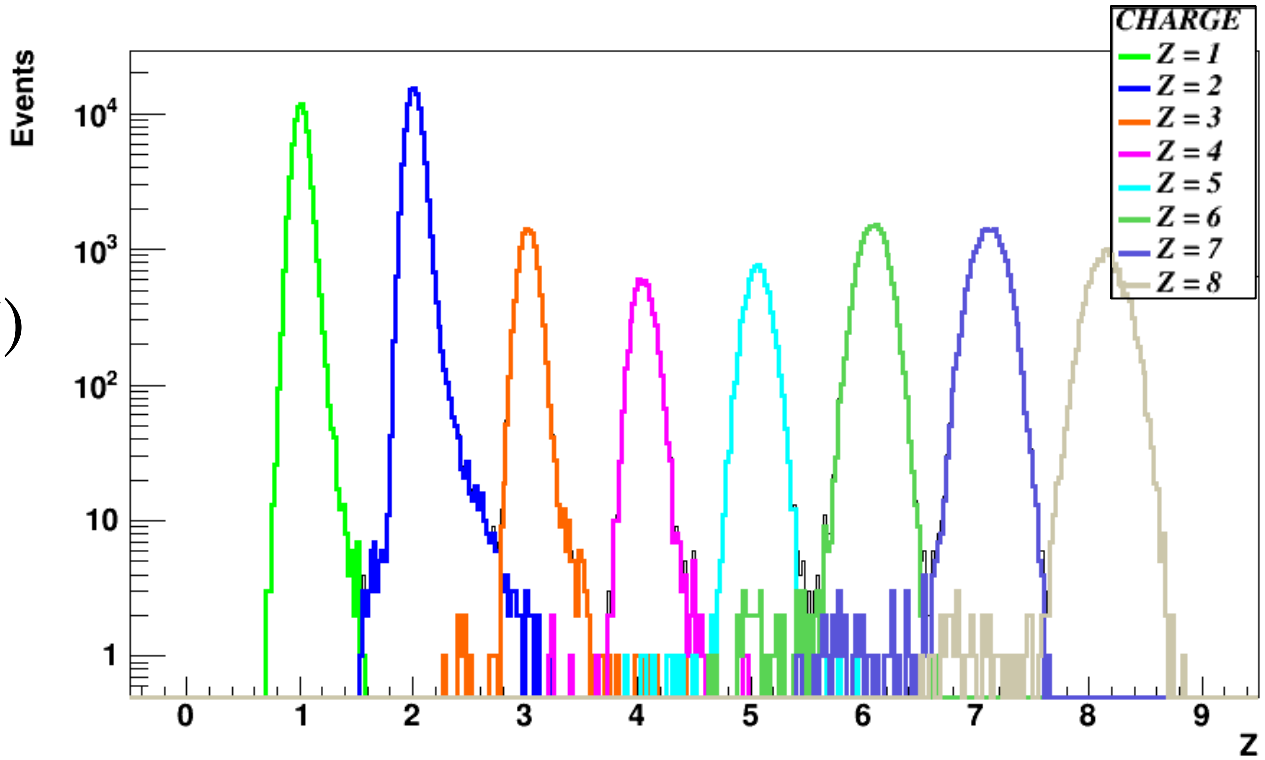
Charge identification

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)

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

Charge and velocity of the fragment (divided by c)

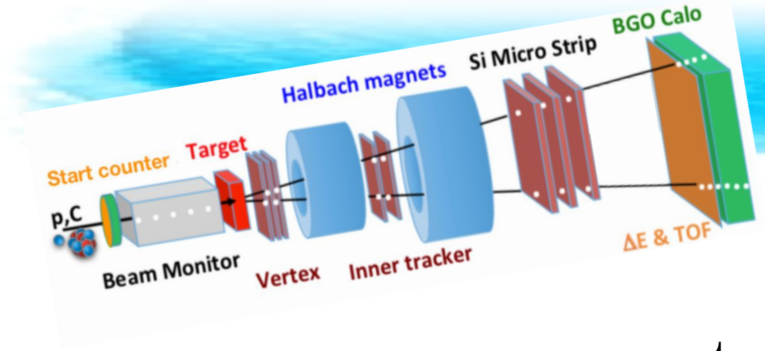
- Resolution: **2%** (^{16}O) – **6%** (^{1}H)
- Wrong charge assignment < 1%



Fluka simulation

^{16}O (200 MeV/u) → C_2H_4

Mass identification



Combination of reconstructed quantities:

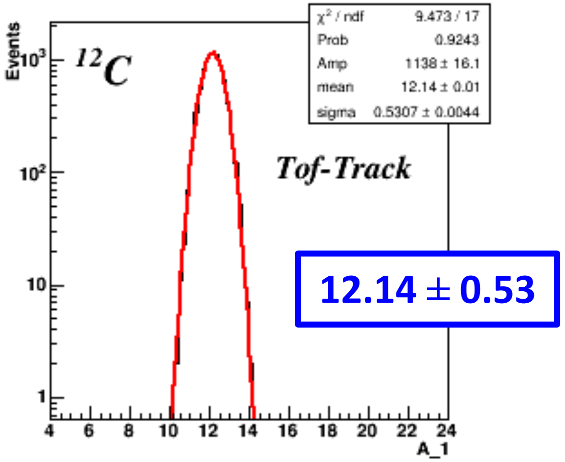
- Momentum (**magnetic spectrometer**)
- ToF (**scintillator**)
- Kinetic energy (**calorimeter**)

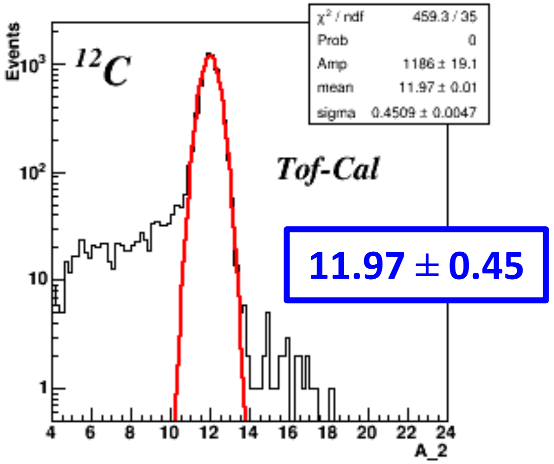
$$A_1 = \frac{p}{U\beta\gamma c} \qquad A_2 = \frac{E_k}{Uc^2(1-\gamma)} \qquad A_3 = \frac{pc^2 - E_k{}^2}{2Uc^2 E_k}$$

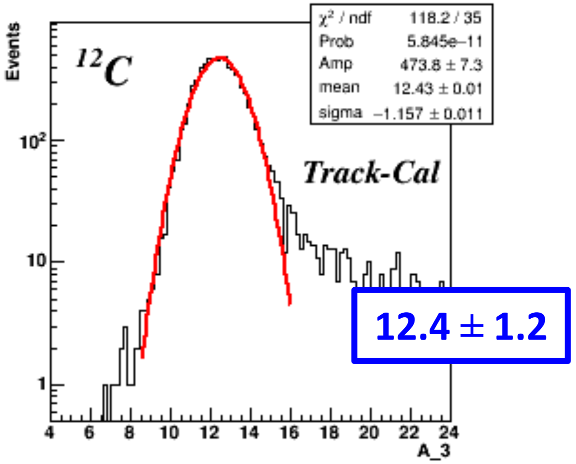
Fluka simulation

^{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:

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

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

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

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})

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

- **Augmented LagrangianFit (ALM)**
  - The method minimizes a Lagrangian function *L* expressed by:

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

  - f is the analog of χ^2 fit

$$f = \left(\frac{(tof_{reco} - t)}{\sigma tof_{reco}}\right)^2 + \left(\frac{(p_{reco} - p)}{\sigma p_{reco}}\right)^2 + \left(\frac{(E_{kin,reco} - E_{kin})}{\sigma E_{kin,reco}}\right)^2$$

  - Summations run over A_1, A_2 and A_3 with the relation

$$\sum_a \lambda_a c_a(\vec{x}) + \frac{1}{2\mu}\sum_a c_a^2(\vec{x}) = (\,\lambda_1(A_1 - \mathrm{A}) + \lambda_2(A_2 - \mathrm{A}) + \lambda_3(A_3 - \mathrm{A}) + \frac{1}{2\mu}\,((A_1 - \mathrm{A})^2 + (A_2 - \mathrm{A})^2 + \ (A_3 - \mathrm{A})^2)^2$$

λ = variable Lagrangian multiplier parameters

μ = penalty term fixed at 0.1 -> the lower is μ the greater is the effect of A_1, A_2 and A_3 (reconstructed quantities)

Machinery for the cross section evaluation of C fragments

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

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

- 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