# Update on simulations for scintillator bars

# Outline

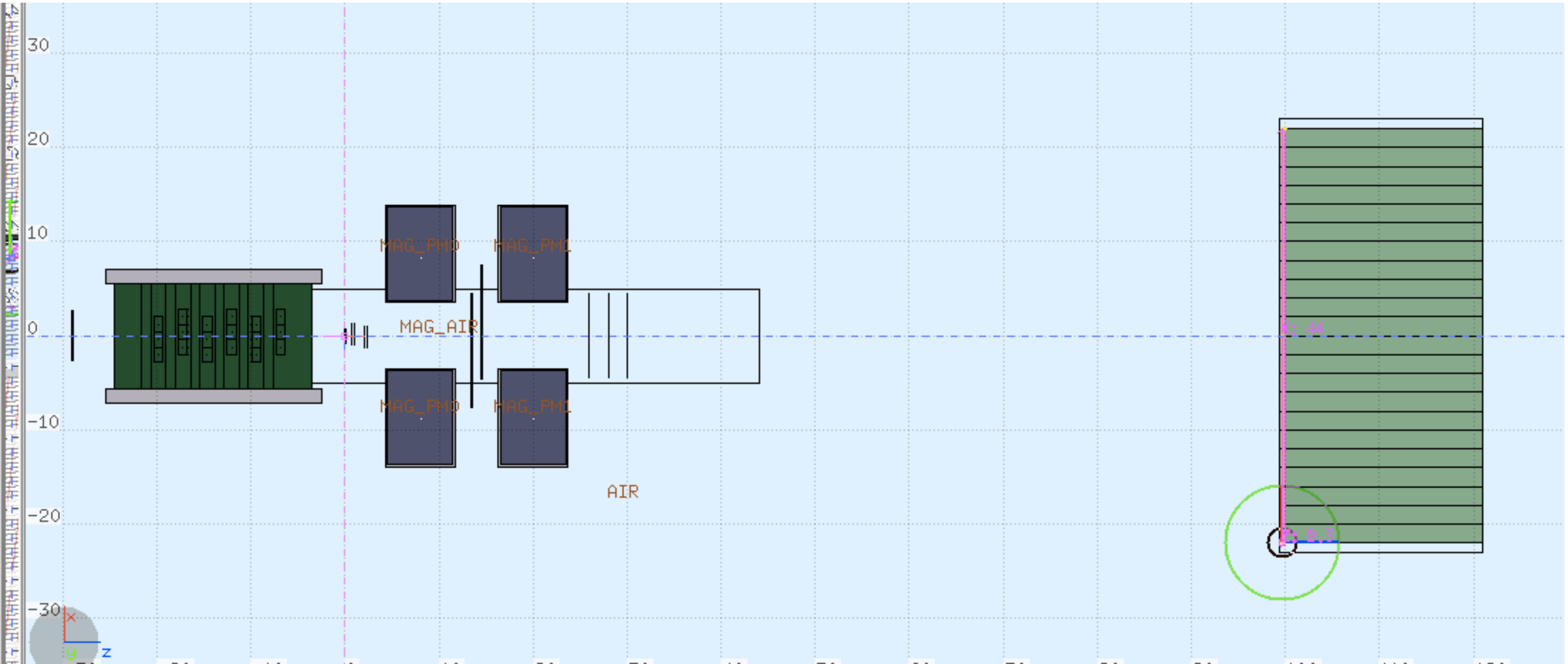
- Introduction
- Setup
- Results
- Plans

# Introduction

- Goal: understand better how various parameters have influence on fragmentation and scintillator energy resolution
  - **Z of particle**
  - **Thickness of scintillator**
  - **Energy of passing particle**
- Comparison with experimental results (not included today)
- Today: results of first studies (work in progress!!)

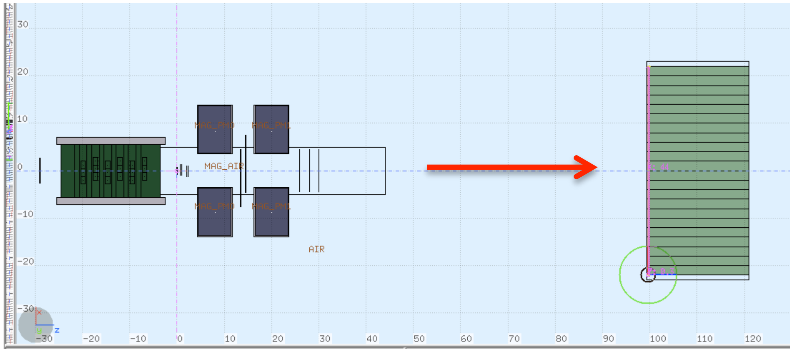
# FLUKA simulations

- Introduced to FOOT software related to FLUKA by Giuseppe **Version: FOOT V13.1.1**
- 5 steps (mostly automized to simulate different Z, A, E, z, scint thickness, etc … ):
  1. Creation of FLUKA input file
  2. Run FLUKA simulations (already available):
  3. Convert FLUKA txt output → Rootfiles (already available)
  4. Creation of analysis histogram file ("AnaFOOT", added a few lines up to now)
  5. Plots/analysis (my analysis)



# Fragmentation and energy resolution vs Z

**How does Z influence the fragmentation probability?**



- 1M particles shot **directly on scintillator** with fixed energy and 8 different Z-values
- No detector effects included for the moment!

| Z | A | E [GeV] | SCN thickness [cm] |
|---|---|---|---|
| **1** | 1 | 0.2 | 0.3 |
| **2** | 4 | 0.2 | 0.3 |
| **3** | 7 | 0.2 | 0.3 |
| **4** | 9 | 0.2 | 0.3 |
| **5** | 11 | 0.2 | 0.3 |
| **6** | 12 | 0.2 | 0.3 |
| **7** | 14 | 0.2 | 0.3 |
| **8** | 16 | 0.2 | 0.3 |

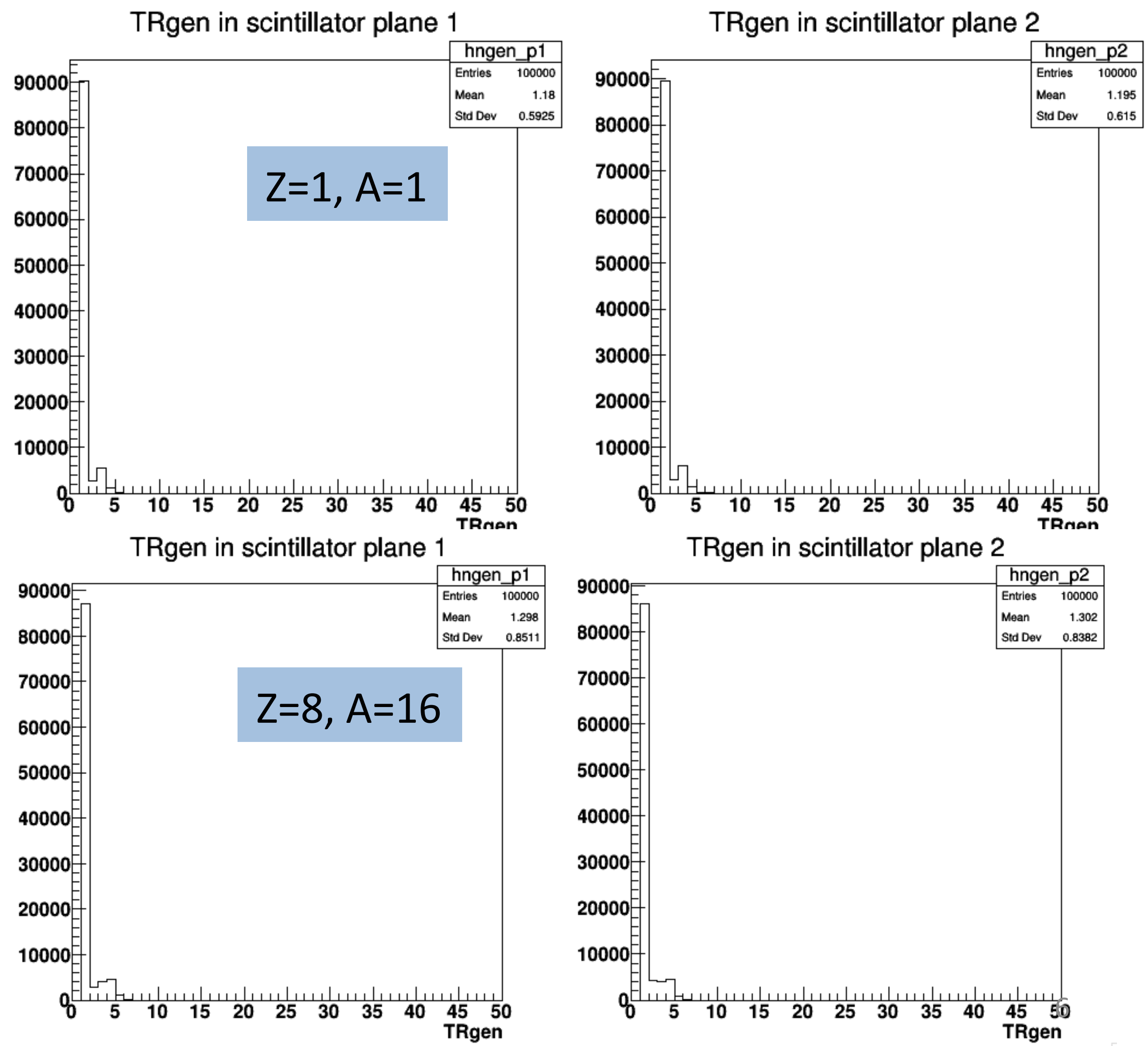
# Fragmentation vs Z

- In scintillator loop(over SCNn deposits):
  - check the generation number of associated TR particle:
  
  trid1=pevstr->TRgen[ipart];
- For **each event** fill the histogram

**$N_{gen}$=1 → not fragmented**
Otherwise it was fragmented

Fragmentation probability =

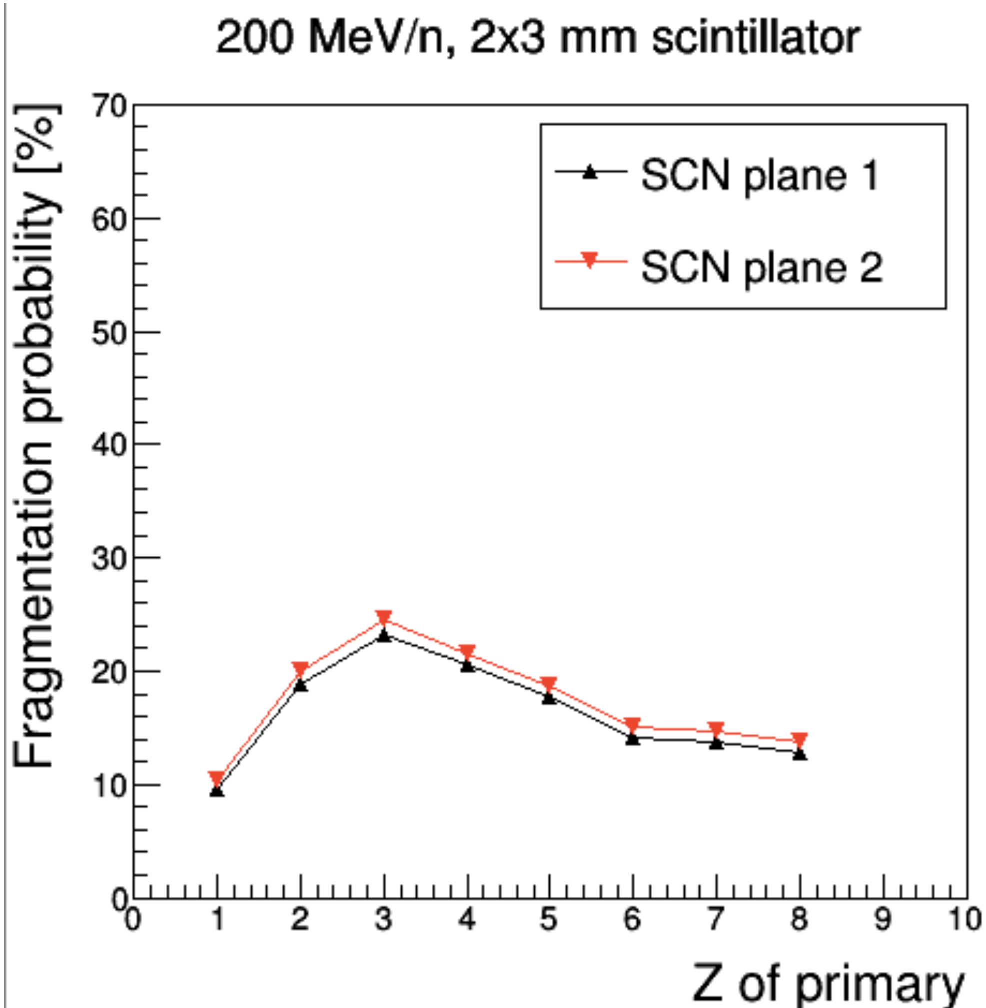
$$1 - \frac{N_{events}\ \text{with}\ N_{gen}=1}{N_{events}}$$



# Fragmentation vs Z

- Stat error is included (small)

- 1M particles
- Thickness of 1 bar=0.3 cm (so 0.6 cm for 2 bars)
- Energy=200 MeV/n
- **Z varied**

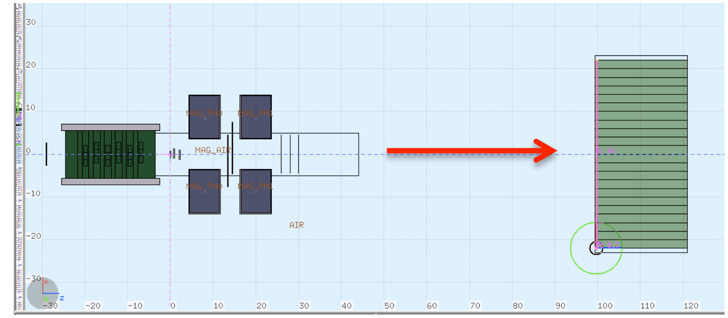


# FOOT Fluka simulations

- Introduction
- Setup
- Results
  - Study as function of Z:
    - Fragmentation probability
  - **Study as function of bar thickness:**
    - **Fragmentation**
    - **Energy resolution**
  - Study as function of energy:
    - Fragmentation
    - Energy resolution
  - 2-D plot calorimeter energy vs scintillator energy
- Plans

# Samples with varying bar thickness

**How does bar thickness influence the fragmentation probability and energy resolution??**

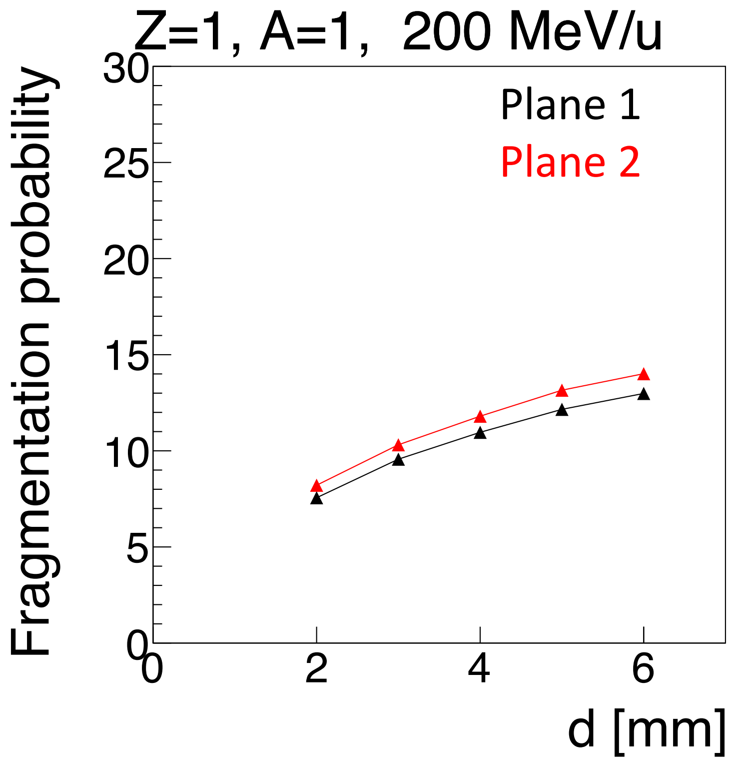


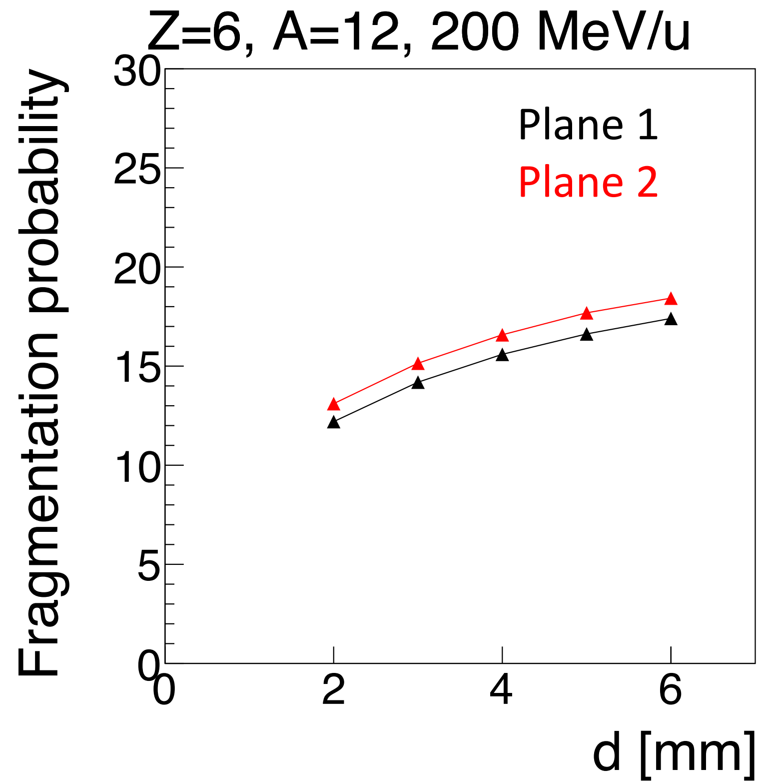
- 1M particles shot **directly on scintillator** with fixed energy and 8 different Z-values
- No detector effects included for the moment!

| Z | A | E [GeV] | SCN thickness [cm] |
|---|---|---|---|
| 1 | 1 | 0.2 | **0.2** |
| 1 | 1 | 0.2 | **0.3** |
| 1 | 1 | 0.2 | **0.4** |
| 1 | 1 | 0.2 | **0.5** |
| 1 | 1 | 0.2 | **0.6** |

| Z | A | E [GeV] | SCN thickness [cm] |
|---|---|---|---|
| 6 | 12 | 0.2 | **0.2** |
| 6 | 12 | 0.2 | **0.3** |
| 6 | 12 | 0.2 | **0.4** |
| 6 | 12 | 0.2 | **0.5** |
| 6 | 12 | 0.2 | **0.6** |

# Fragmentation vs bar thickness

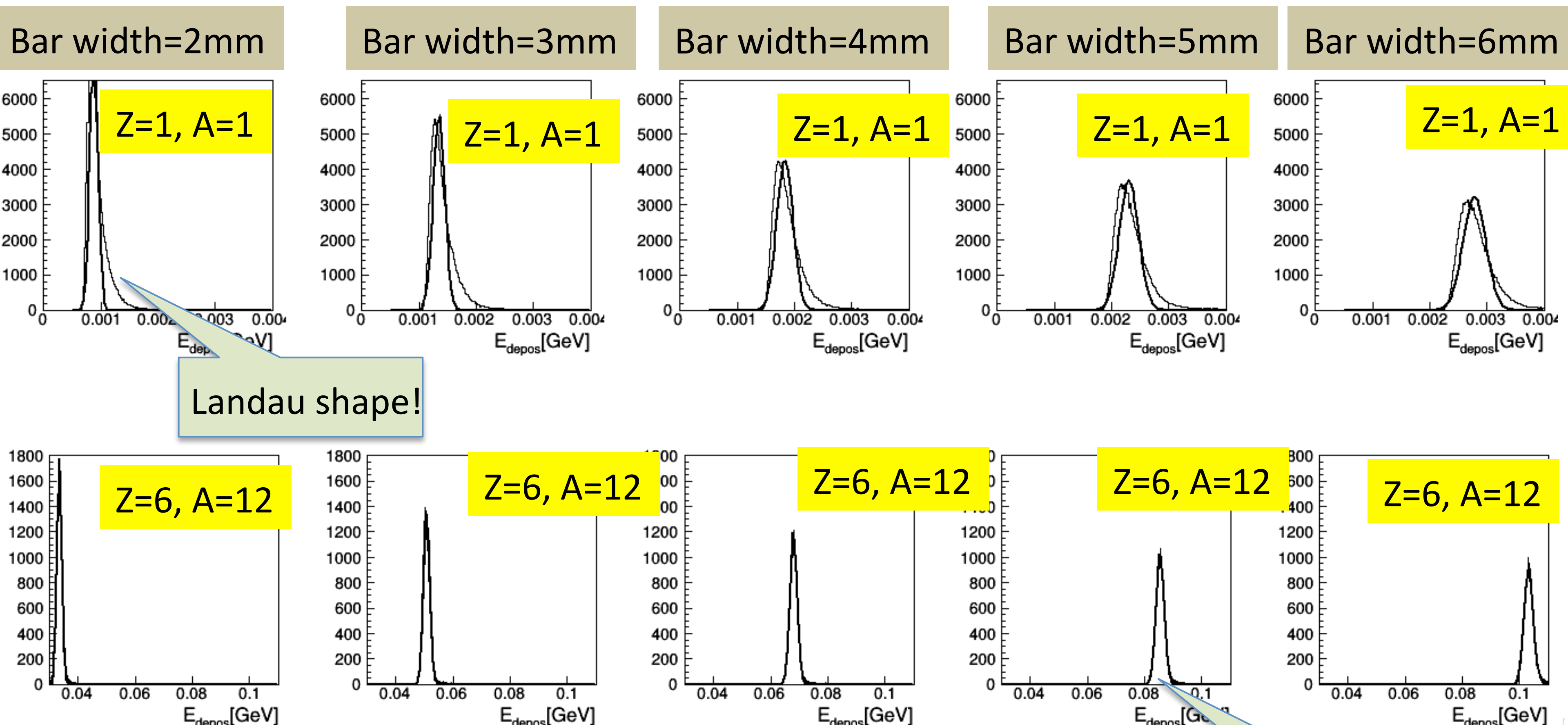



What about energy resolution?

# Energy deposit vs bar thickness

Energy deposit in 1 bar




Evaluate:

- $<E_{depos}>$: mean energy deposit in bar
- FWHM of distribution
- Max: value of maximum probability
- Sigma and mu of gaussian fit

# Energy deposit vs bar thickness

- Energy loss increases linearly with bar thickness

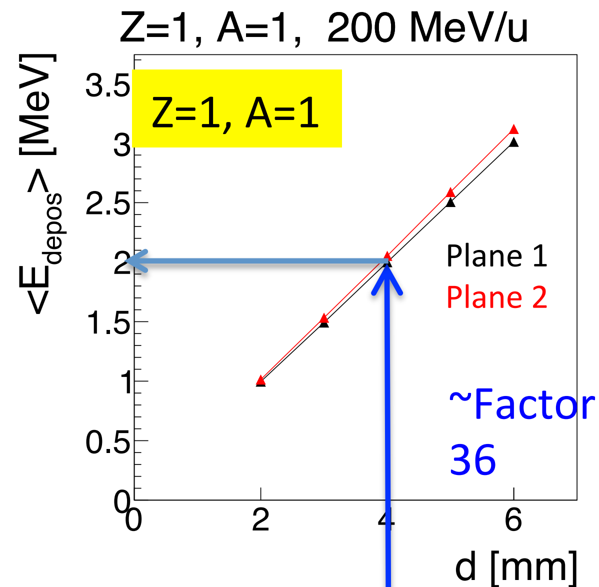
- Apart from $1/\beta^2$, Bethe Bloch depends mainly on $Z^2$

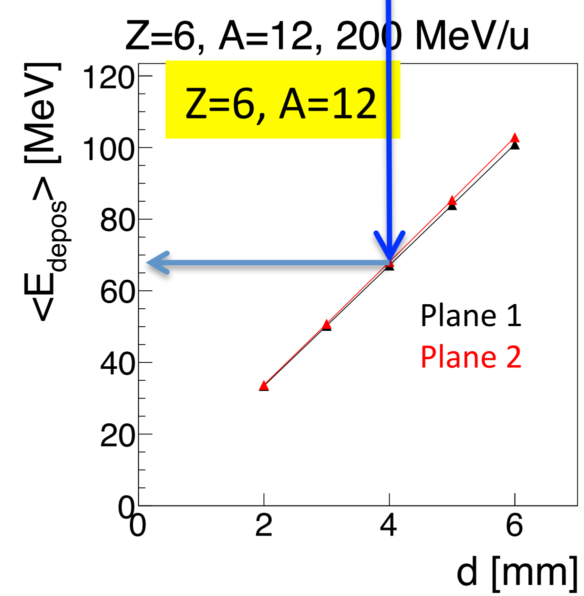
$$\frac{dE}{dx} = K\rho \frac{Z_p^2}{\beta^2}\frac{Z_t}{A_t}\left[\frac{1}{2}ln\left(\frac{2m_e c^2\beta^2\gamma^2 T_{max}}{I_e^2}\right) - \beta^2 - \frac{\delta}{2} - \frac{C}{Z_t}\right]$$

- Remember that the value for β is the same given the kinetic energy is given in energy per nucleon

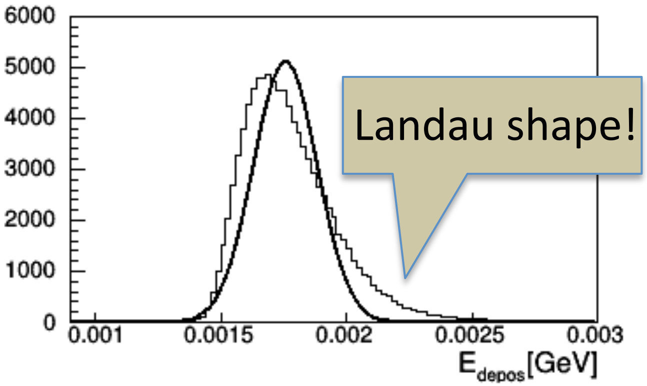
$$\beta = \frac{p}{E} = \frac{\sqrt{E^2 - m^2}}{E} = \frac{\sqrt{(E_{kin}+m)^2 - m^2}}{E_{kin}+m} = \frac{\sqrt{(\frac{E_{kin}}{m}+1)^2 - 1^2}}{\frac{E_{kin}}{m}+1}$$

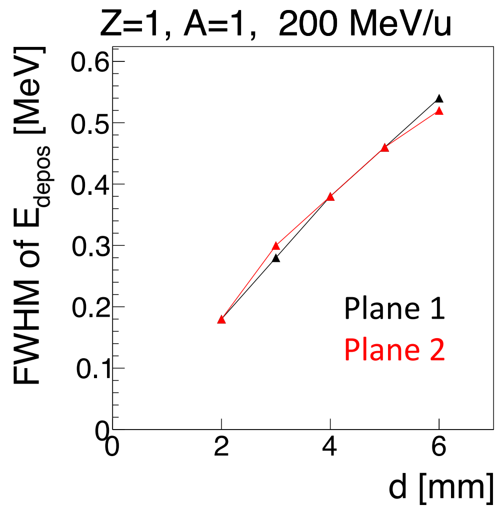
What about the energy resolution?

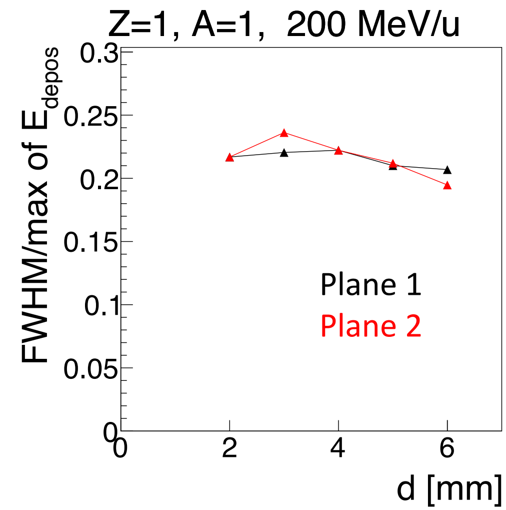


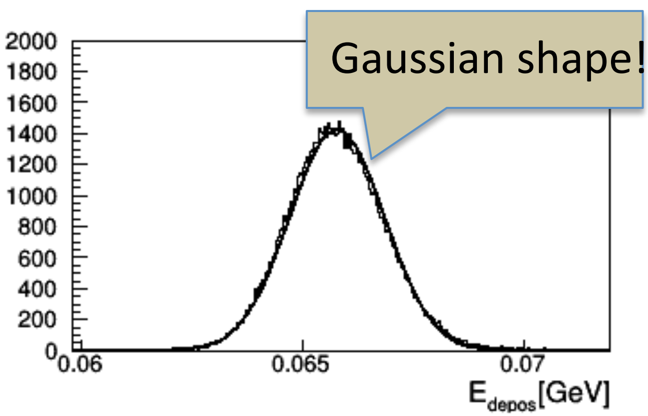



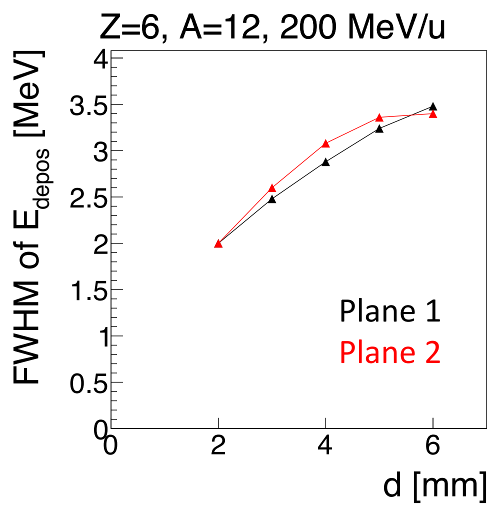
# Energy resolution vs bar thickness

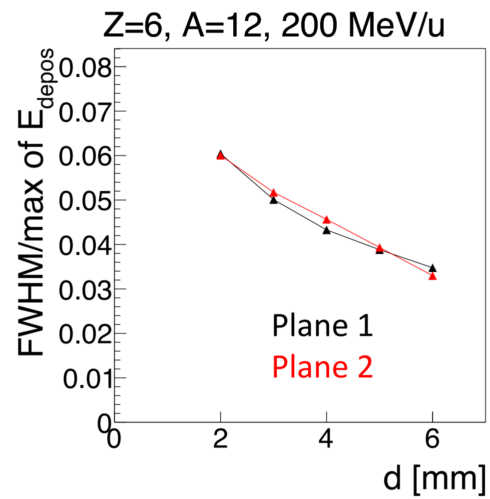


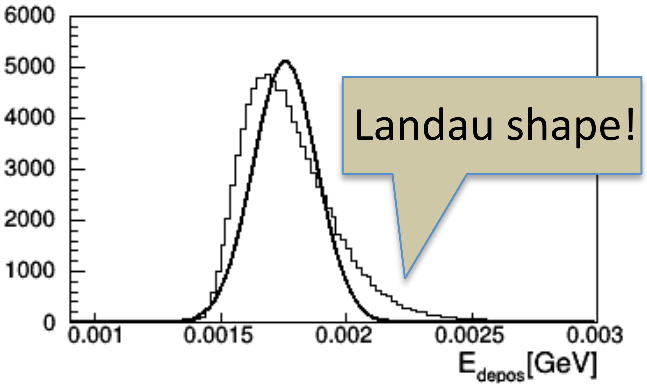



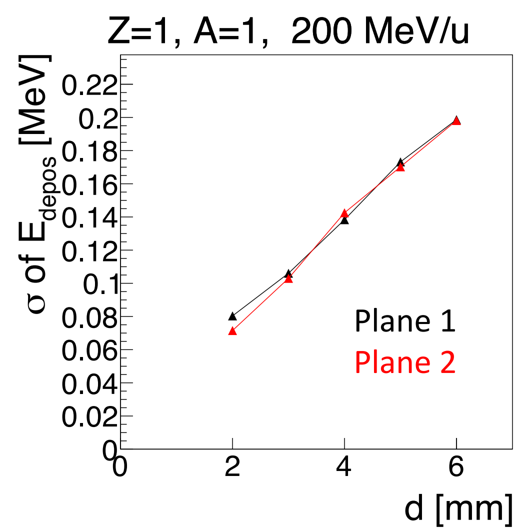



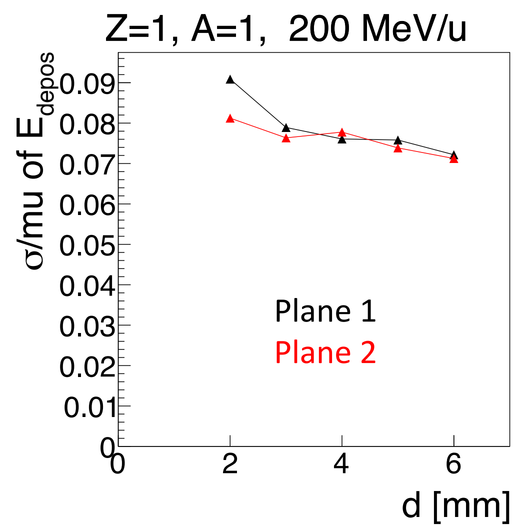



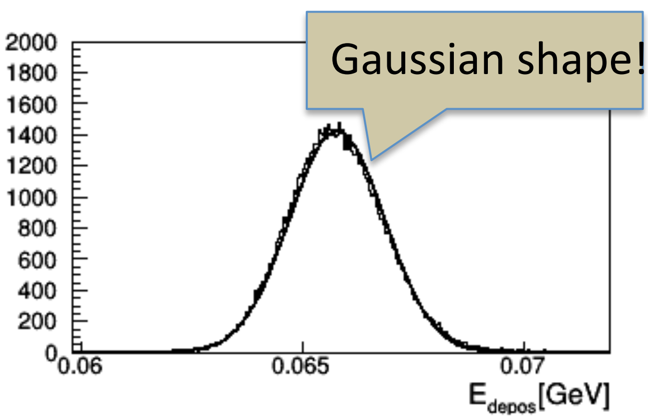

- Z=1, A=1: FWHM/max varies between 20%-25%, no strong dependence on thickness!
- Z=6, A=12: FWHM/max varies from 6% (d=2 mm) to 3.5% (d=6 mm): resolution decreases with thickness d

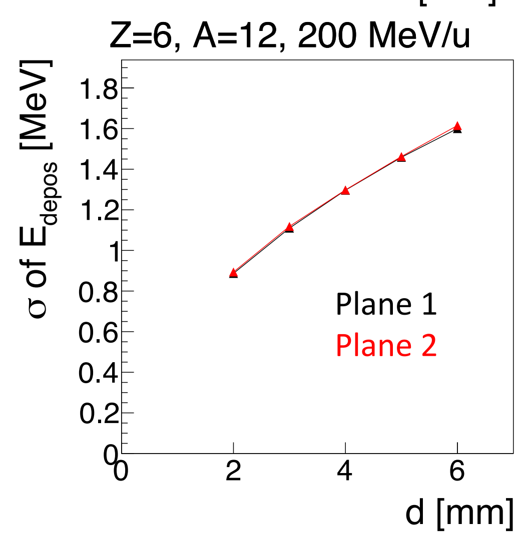
# Energy resolution vs bar thickness

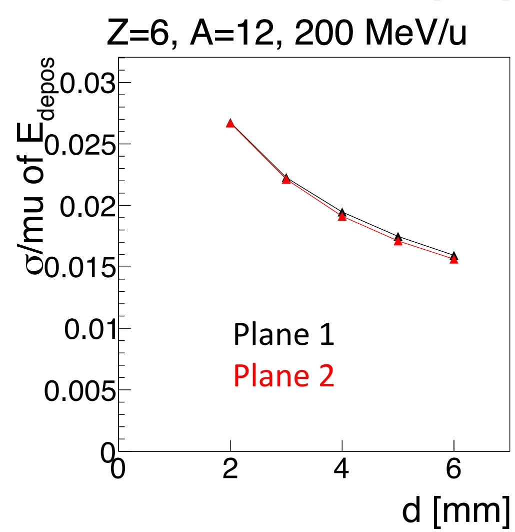


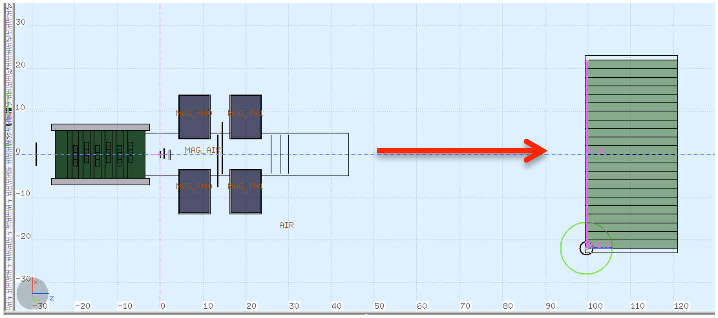

- Z=1, A=1: σ/μ varies between 9% (2 mm) and 7% (6 mm), weak dependence on d
- Z=6, A=12: σ/μ varies from 2.5% (d=2 mm) to 1.5% (d=6 mm): resolution decreases with thickness d

# FOOT Fluka simulations

- Setup
- Results
  - Study as function of Z:
    - Fragmentation probability
  - Study as function of bar thickness:
    - Fragmentation
    - Energy resolution
  - **Study as function of energy:**
    - **Fragmentation**
    - **Energy resolution**
  - 2-D plot calorimeter energy vs scintillator energy
- Plans

# Samples with varying energy

**How does energy influence the fragmentation probability and energy resolution??**

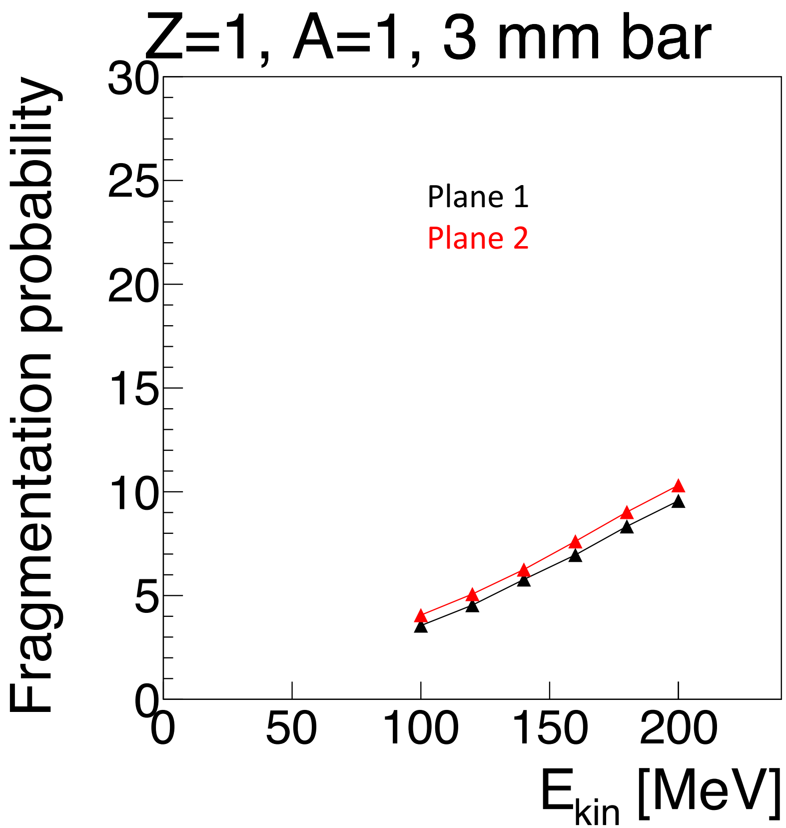


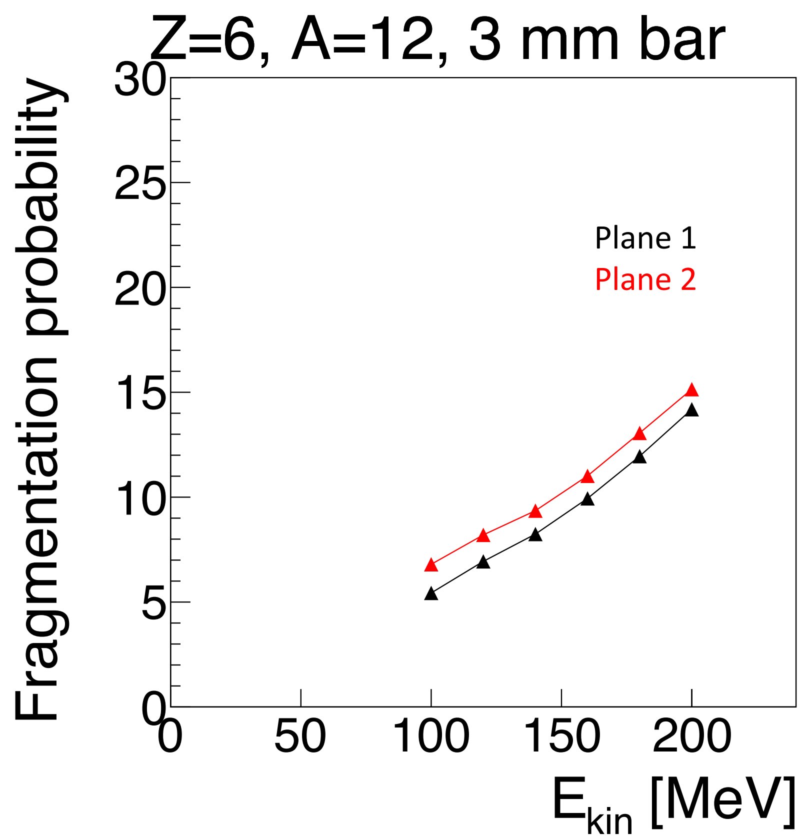
- 1M particles shot **directly on scintillator** with fixed energy and 8 different Z-values
- No detector effects included for the moment!

| Z | A | E [GeV] | SCN thickness [cm] |
|---|---|---|---|
| 6 | 12 | **0.10** | 0.3 |
| 6 | 12 | **0.12** | 0.3 |
| 6 | 12 | **0.14** | 0.3 |
| 6 | 12 | **0.16** | 0.3 |
| 6 | 12 | **0.18** | 0.3 |
| 6 | 12 | **0.20** | 0.3 |

| Z | A | E [GeV] | SCN thickness [cm] |
|---|---|---|---|
| 1 | 1 | **0.10** | 0.3 |
| 1 | 1 | **0.12** | 0.3 |
| 1 | 1 | **0.14** | 0.3 |
| 1 | 1 | **0.16** | 0.3 |
| 1 | 1 | **0.18** | 0.3 |
| 1 | 1 | **0.20** | 0.3 |

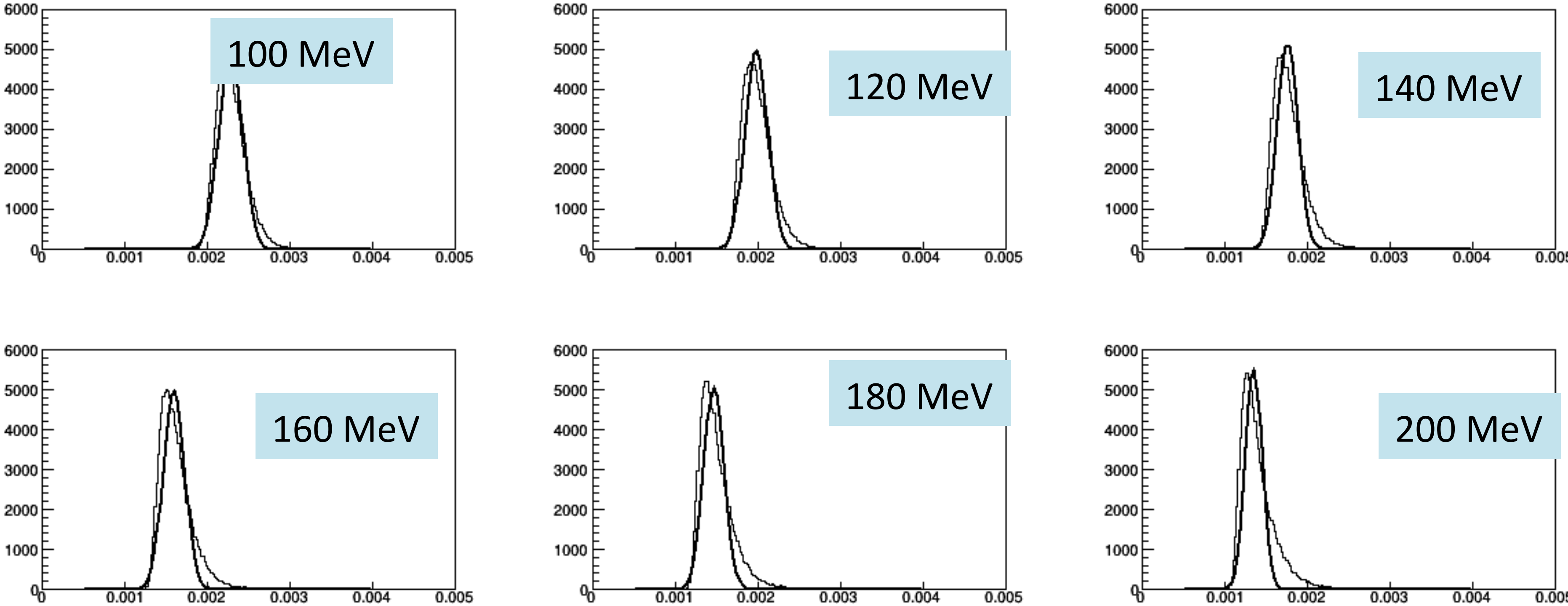
# Fragmentation vs energy




What about energy resolution?

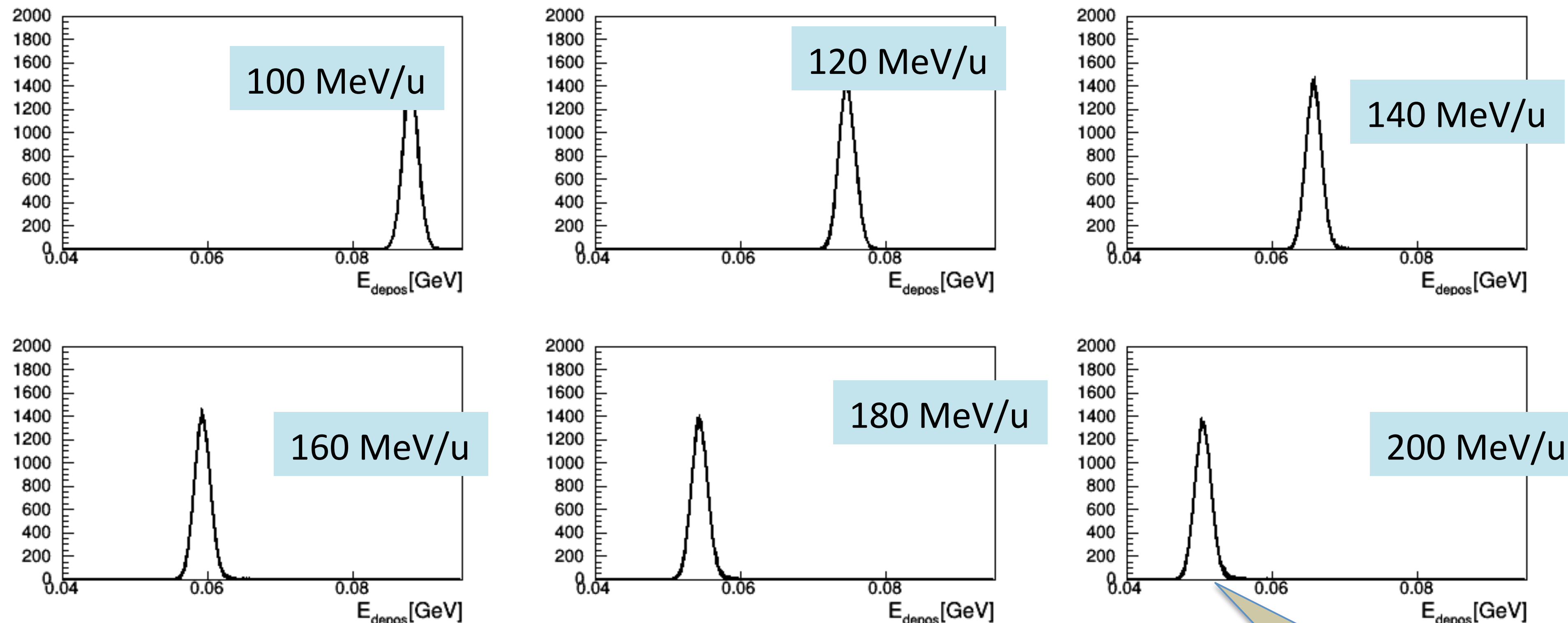
# Example $^{1}$H energy deposits




Landau shape!

- Energy deposits in 3 mm bar: between 1 and 3 MeV
- Landau shape worsens with increasing energy (decreasing deposit)

# Example $^{12}C$ energy deposits

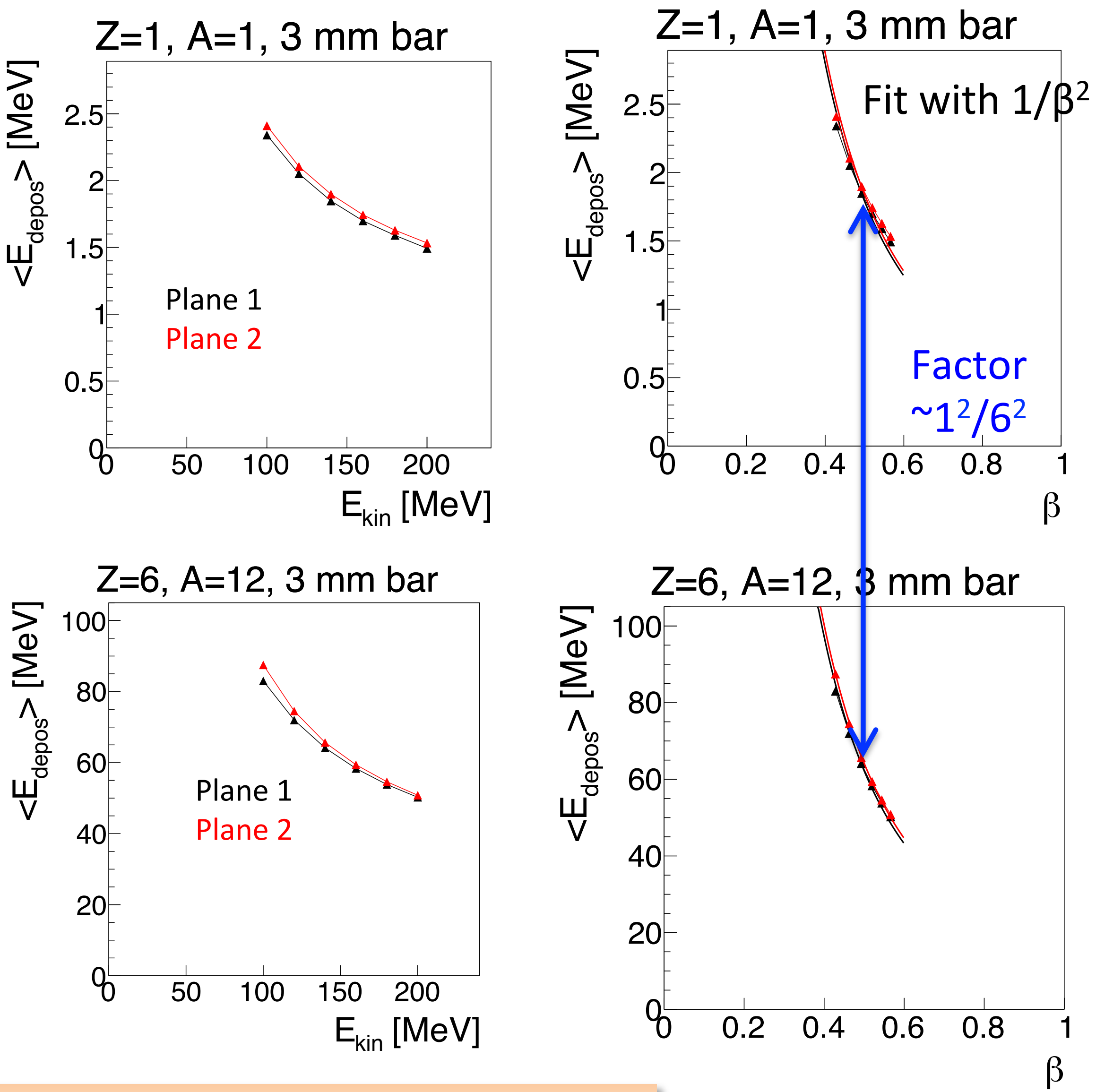



Gaussian shape!

- Energy deposits in 3 mm bar: between 50 and 90 MeV
- Nicely gaussian over whole energy range

Evaluate:
- $\langle E_{depos} \rangle$: mean energy deposit in bar
- FWHM of distribution
- Max: value of maximum probability
- Sigma and mu of gaussian fit

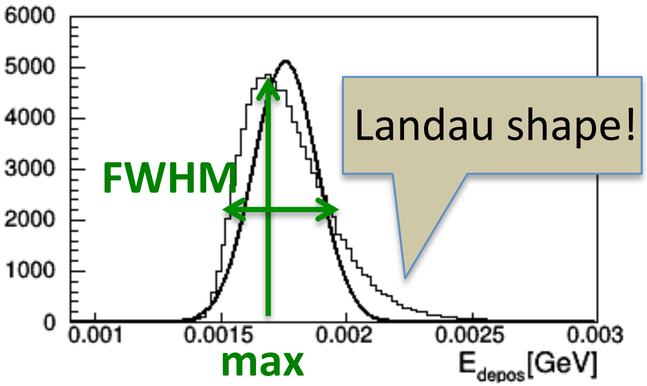
# Energy deposit vs energy

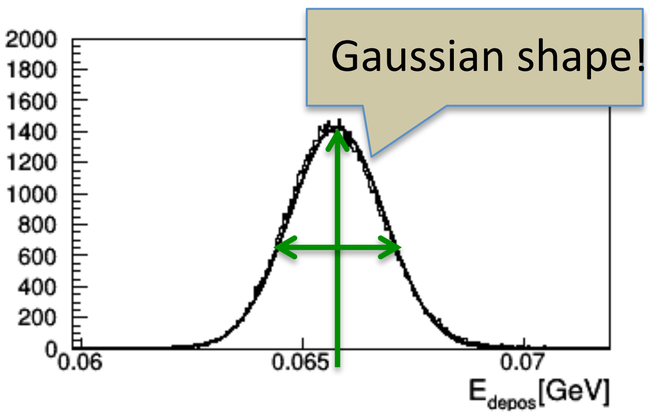


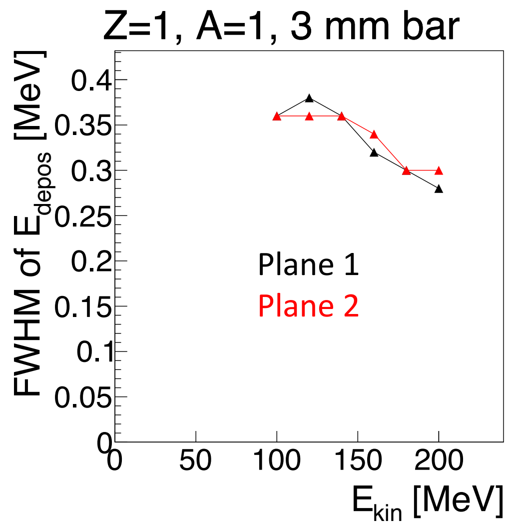

Energy deposit follows Bethe Bloch!

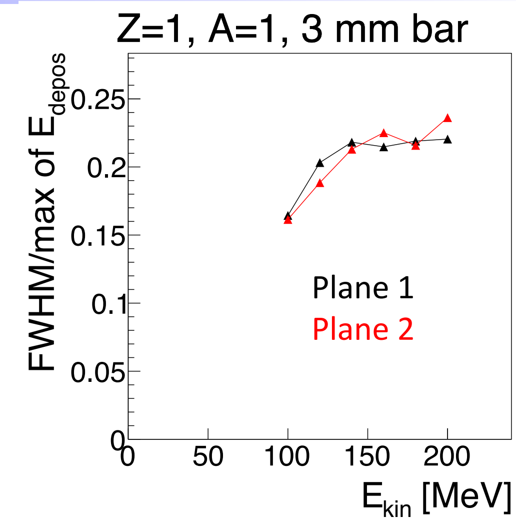
# Energy resolution vs energy

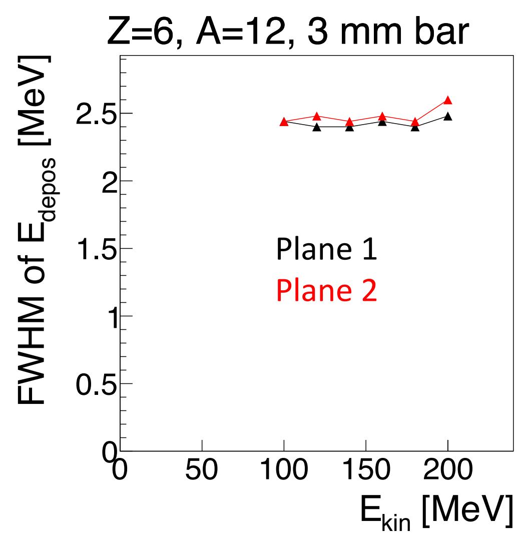
Energy deposit in 1 bar
E=140 MeV, Z=1, A=11 bar

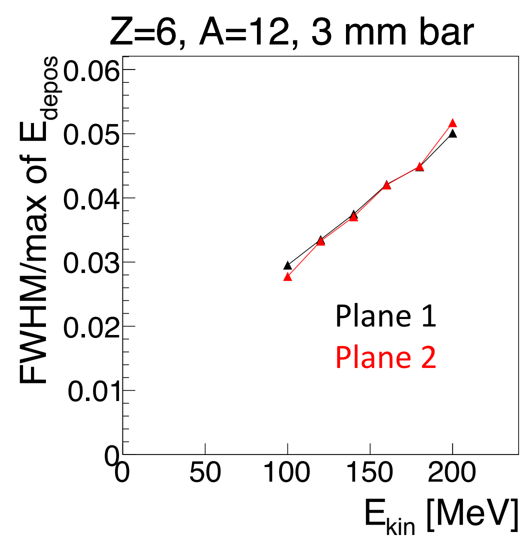


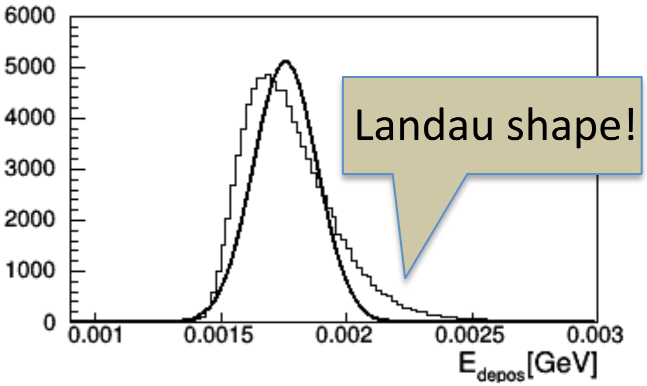



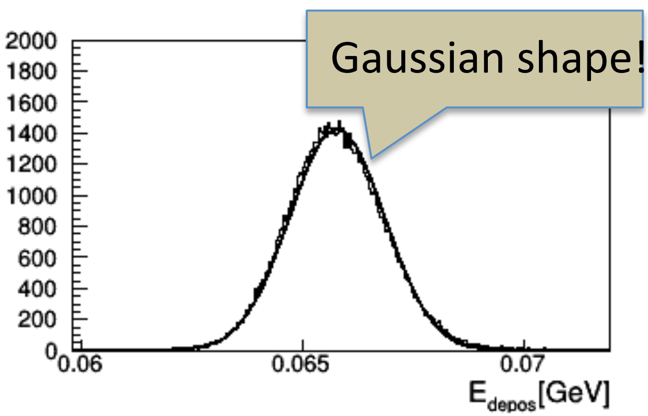



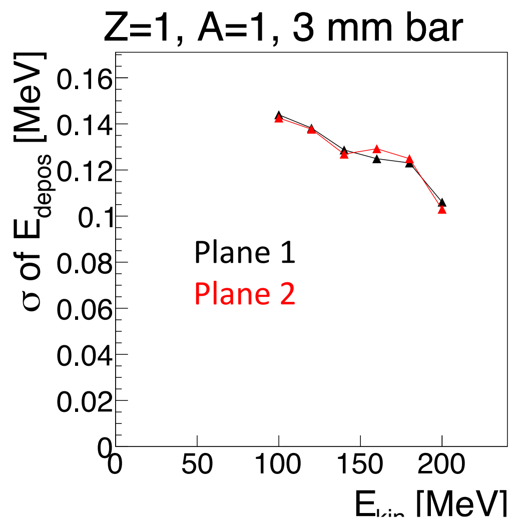

- Z=1, A=1: SCN resolution defined as FWHM/Emax: 15-25%
- Z=6, A=12: SCN resolution defined as FWHM/Emax: 3-5%
- Relative energy resolution of scintillator bar increases with energy

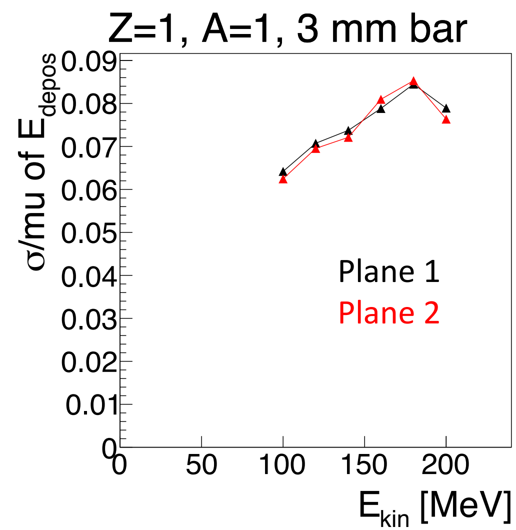
# Energy resolution vs energy

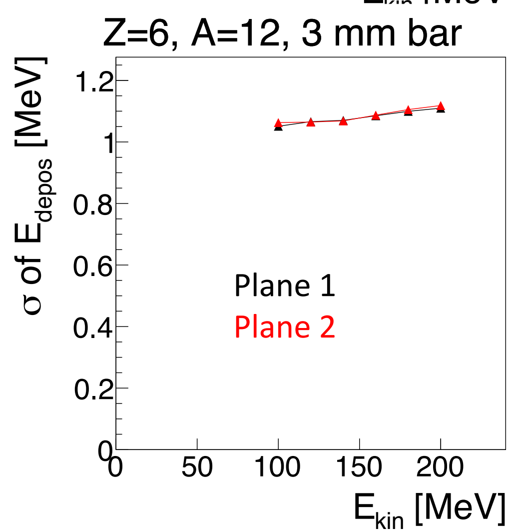
Energy deposit in 1 bar
E=140 MeV, Z=1, A=11 bar

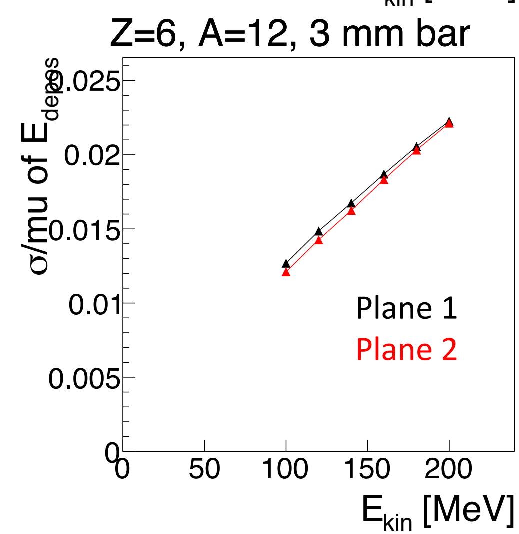



- Z=1, A=1: SCN resolution defined as sigma/mu = 6% (100 MeV)-8% (200 MeV)
- Z=6, A=12: SCN resolution defined as sigma/mu= 1% (100 MeV/u)-2% (200 MeV/u)
- Relative energy resolution of scintillator bar increases with energy

# FOOT Fluka simulations

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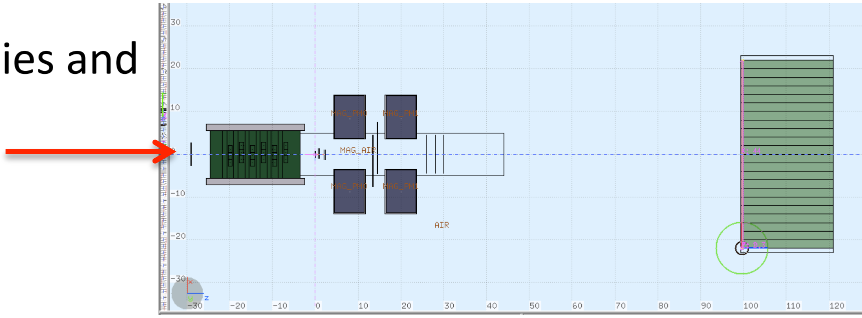
  - Study as function of bar thickness:
    - Fragmentation
    - Energy resolution
  - Study as function of energy:
    - Fragmentation
    - Energy resolution
  - **2-D plot calorimeter energy vs scintillator energy**
- Plans

# 2-D plots scintillator vs calorimeter

- Need to check scintillator bar performance in context of other systems: calorimeter
- Separation of different isotopes possible?



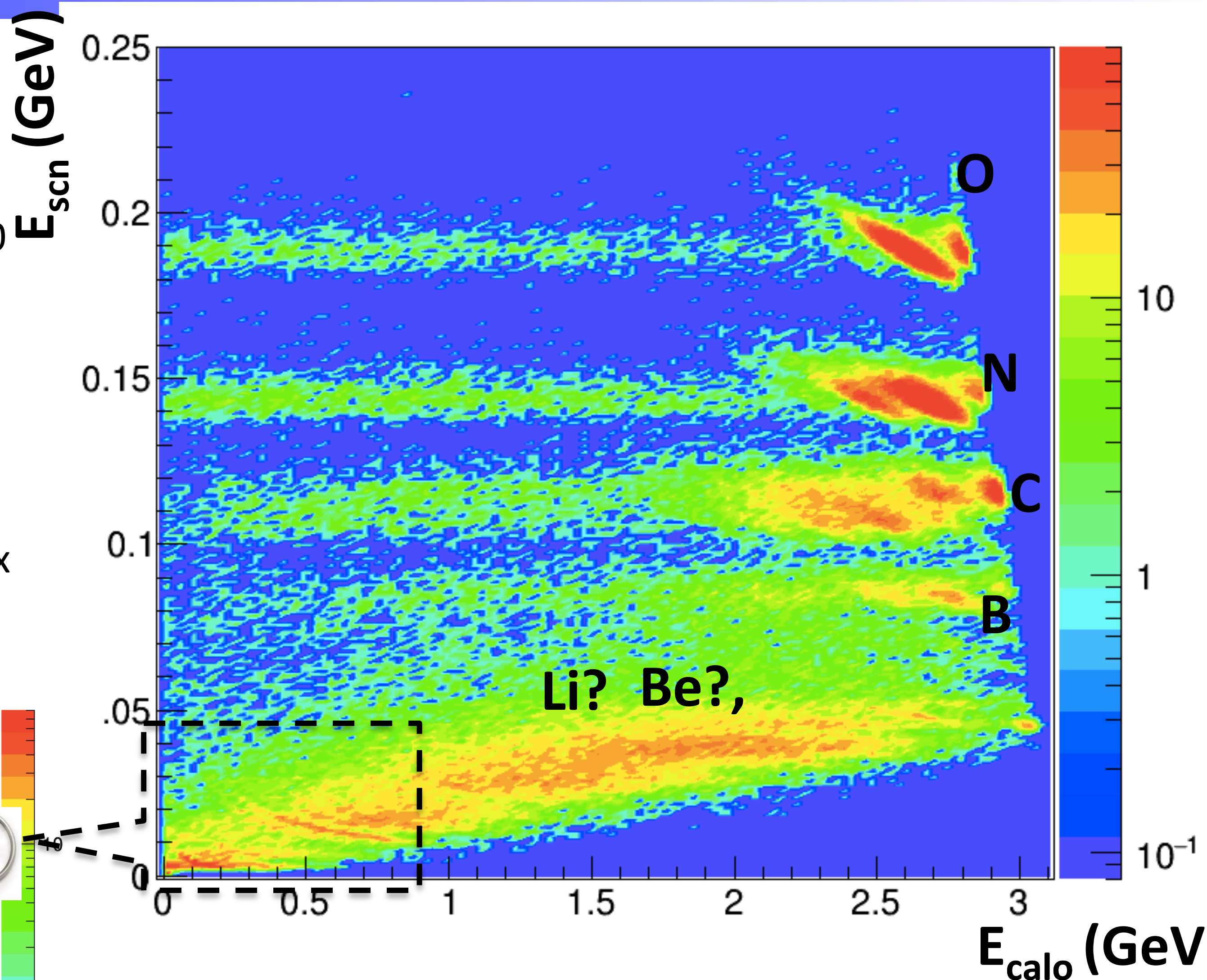
- 5 M particles shot **on start counter** with 3 energies and 2 thicknesses
- Chosen as

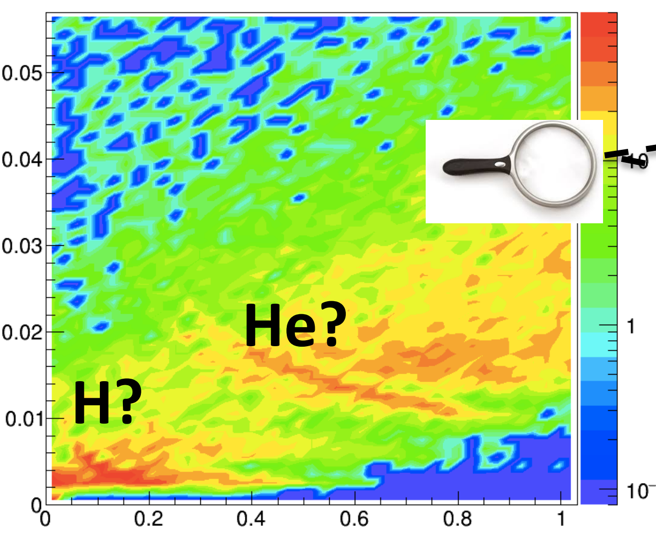
| Z | A | E [GeV] | SCN bar thickness [cm] |
|---|---|---|---|
| 8 | 16 | 0.2 | 0.3 |
| 8 | 16 | 0.35 | 0.3 |
| 8 | 16 | 0.7 | 0.3 |

| Z | A | E [GeV] | SCN bar thickness [cm] |
|---|---|---|---|
| 8 | 16 | 0.2 | 0.6 |
| 8 | 16 | 0.35 | 0.6 |
| 8 | 16 | 0.7 | 0.6 |

# 2-D plots scintillator vs calorimeter

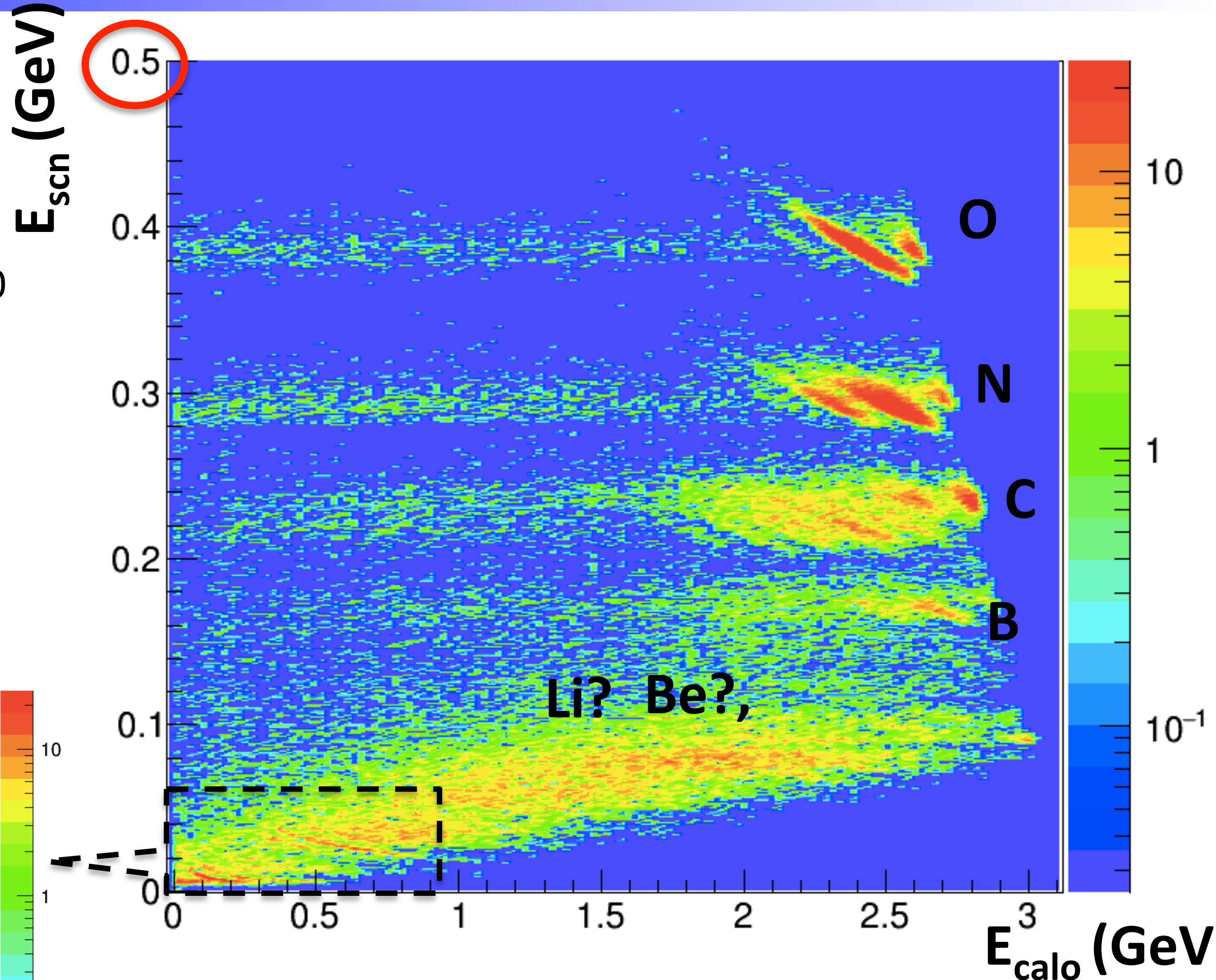
- Deposits in scintillator vs deposits in calorimeter
- No detector effects!
- 5M $^{16}O$ nuclei with E= 200 MeV (low stat)
- **2 bars 3 mm**
- Average energy of 2 bars
- Need to understand the fragments better…
- Cont4z drawoption, z-max set to 70

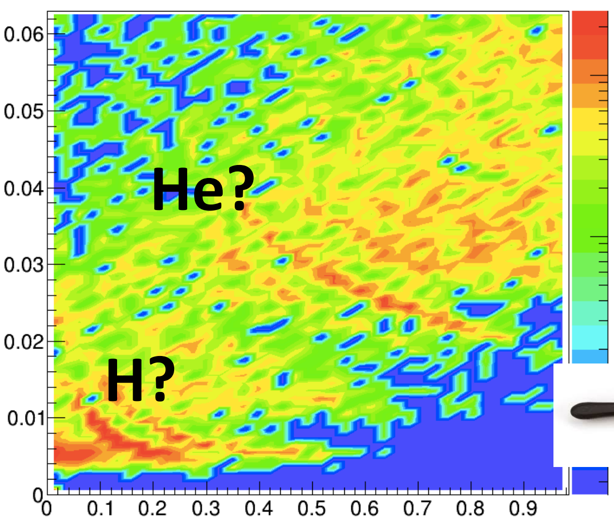


# 2-D plots scintillator vs calorimeter

- Depositions in scintillator vs depositions in calorimeter
- No detector effects!
- 5M $^{16}O$ nuclei with E= 200 MeV (low stat)
- **2 bars 6 mm**
- Average energy of 2 bars
- Need to understand the fragments better…
- Cont4z drawoption,z-max set to 30



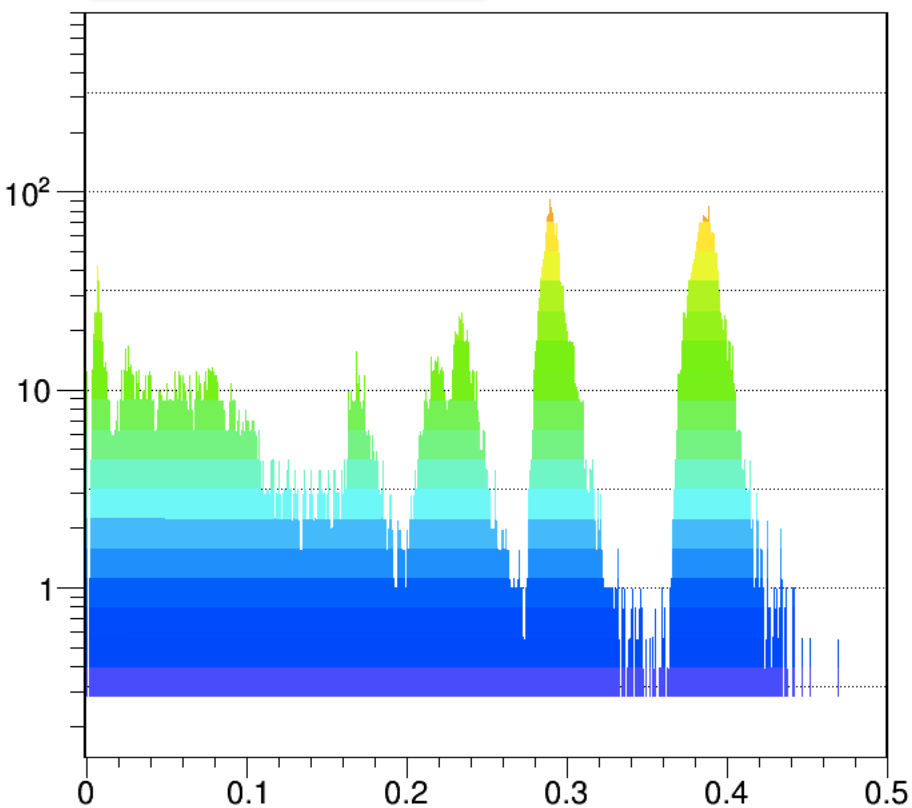

These 2-d plots are just visual… need a better way to quantify the difference between 3 and 6 mm bars… Seems that low Z nuclei profit from thicker bar (as before!)

# Conclusions

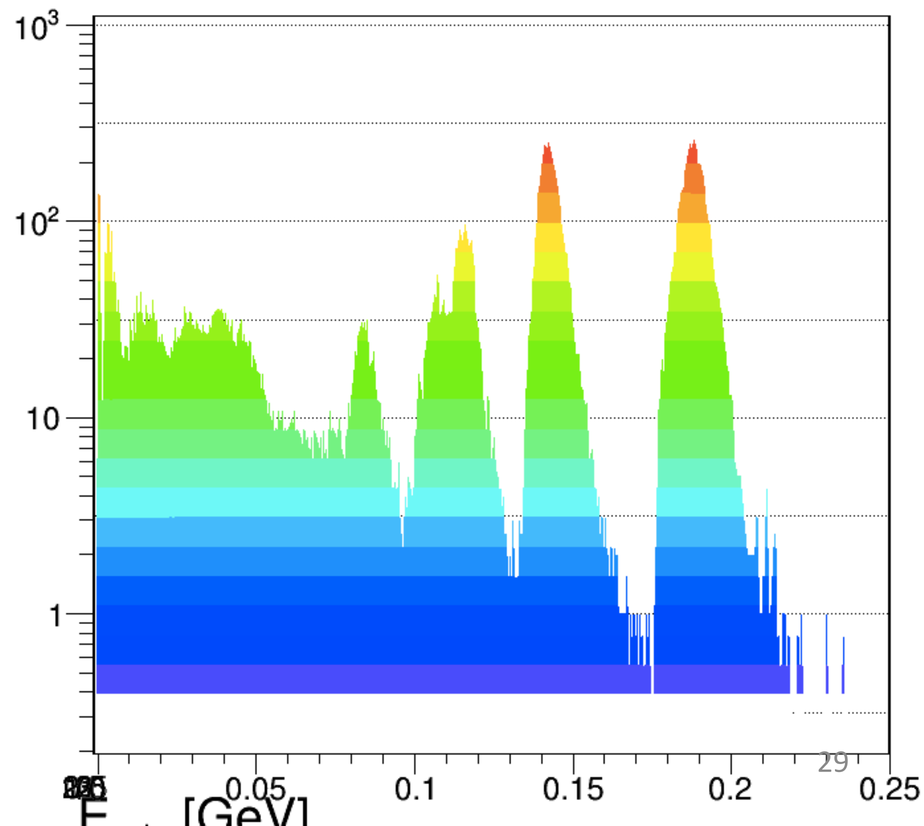
- First tests performed for fragmentation and energy resolution as function of
  - Z
  - bar thickness: with 6 mm better resolution is obtained, but more fragmentation. More studies needed!
  - Energy

# BACKUP

6 mm



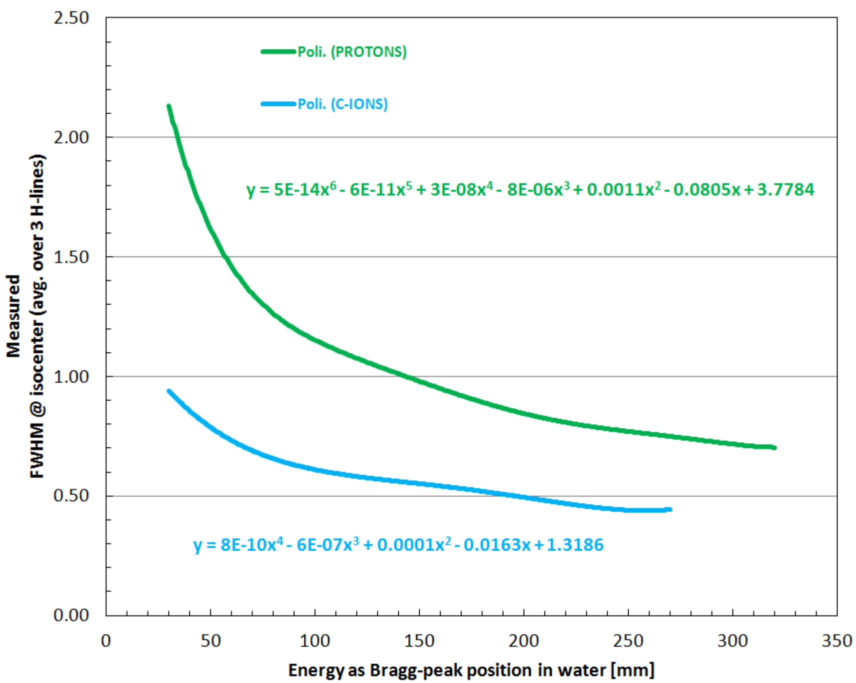

3 mm

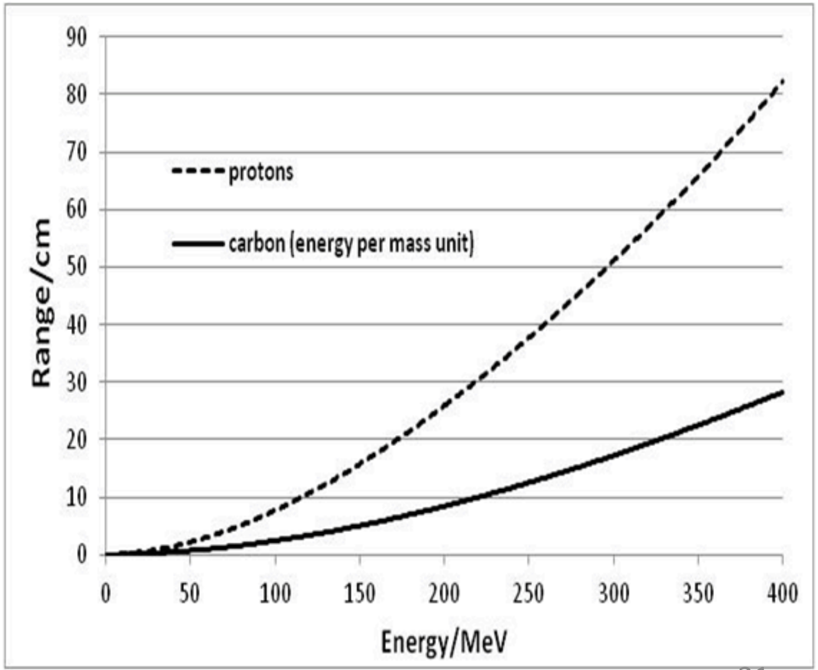


- Polyvinyltoluene

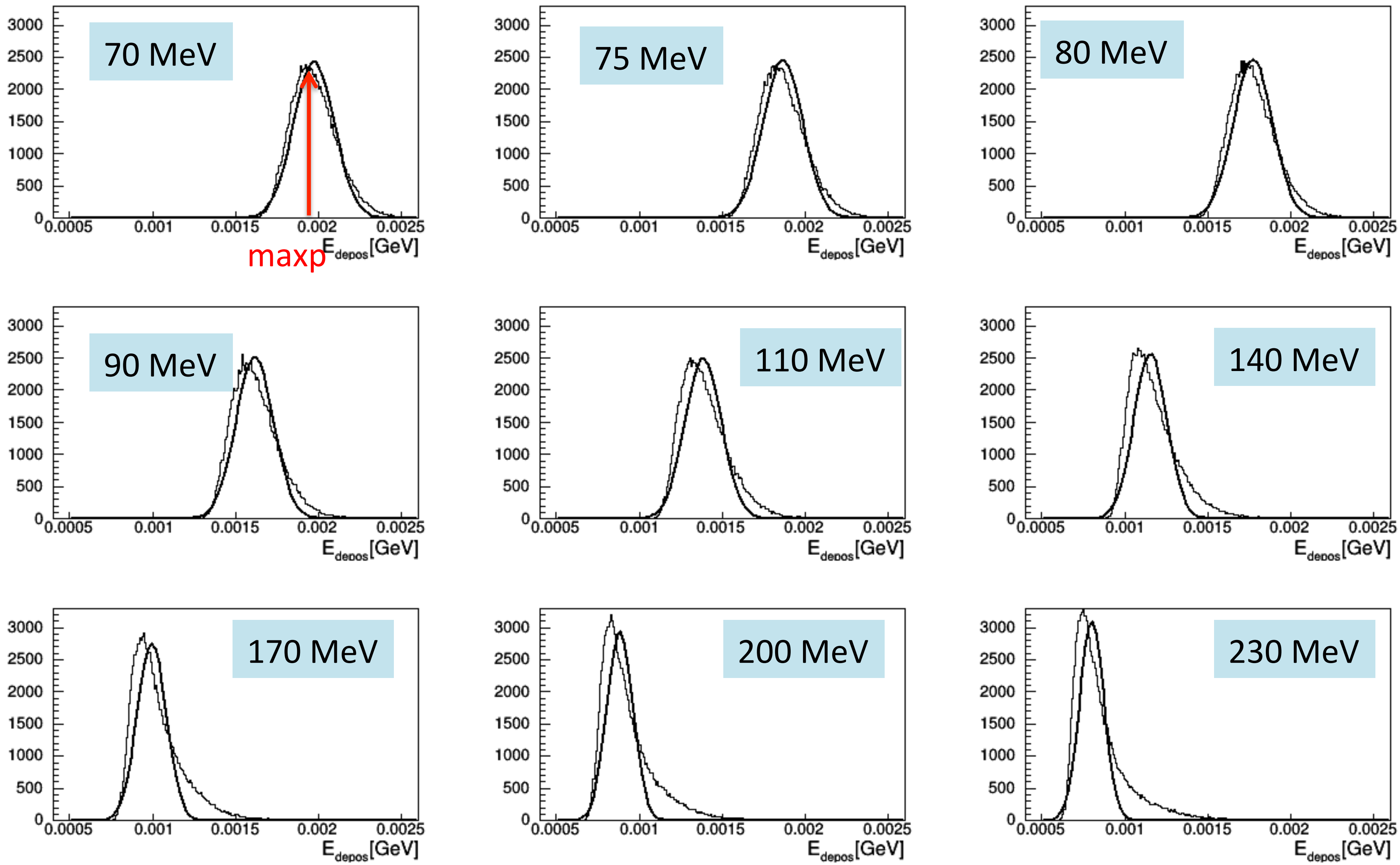
# Simulations for 2 mm

- Momentum spread included:
  - CNAO: have dP/P
  - FLUKA: Ekin of particle
  - Included dP/P (energy spread in beam) as function of beam energy
- FWM of beam
  - CNAO beam included: have FWHM as function of range in water
  - FLUKA: kin energy
  - Translate kin energy into range, and get FWHM
- Study energy resolution



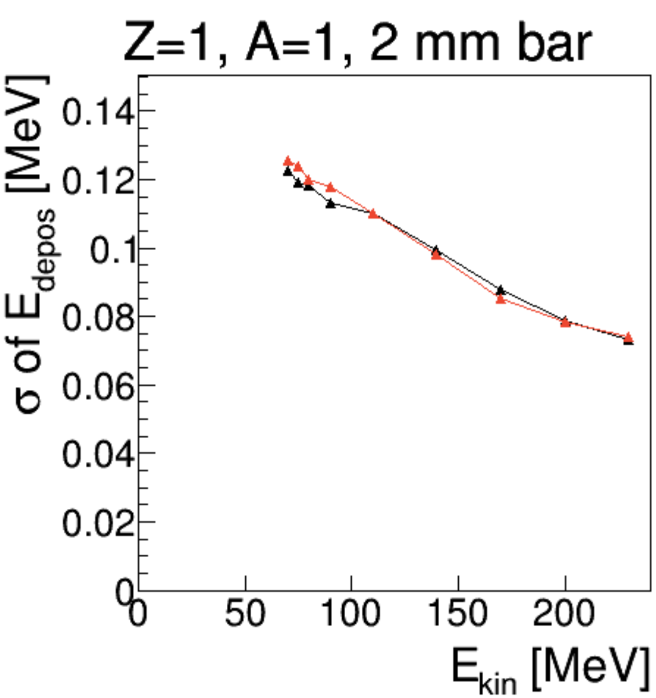
# Simulations for 2 mm

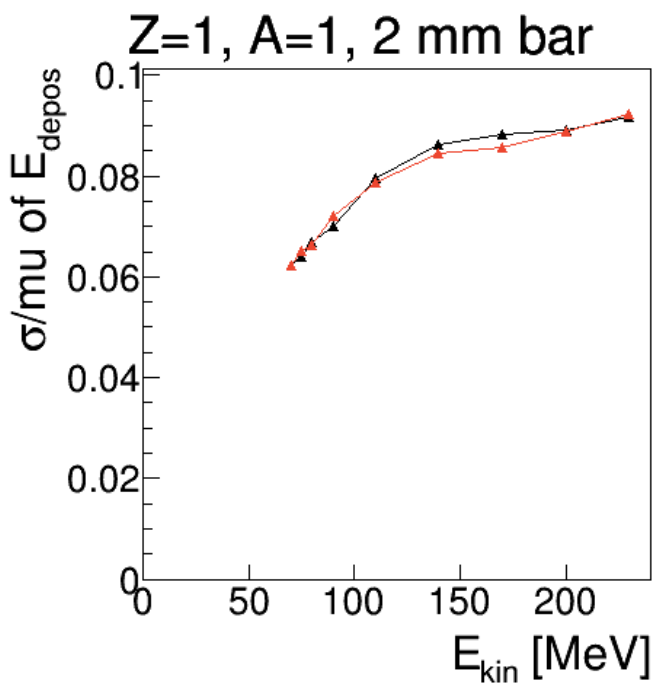


# Simulations for 2 mm

| Ekin[MeV] | <Edep>[MeV] | maxp(Edep)[MeV] | FWHM[MeV] | FWHM/maxp | #mu[MeV] | #sigma[MeV] | #sigma/#mu |
|---|---|---|---|---|---|---|---|
| 70.000 | 2.094 | 1.956 | 0.304 | 0.155 | 2.016 | 0.125 | 0.062 |
| 75.000 | 1.976 | 1.868 | 0.312 | 0.167 | 1.903 | 0.124 | 0.065 |
| 80.000 | 1.876 | 1.772 | 0.312 | 0.176 | 1.803 | 0.120 | 0.066 |
| 90.000 | 1.707 | 1.572 | 0.296 | 0.188 | 1.639 | 0.118 | 0.072 |
| 110.000 | 1.469 | 1.332 | 0.280 | 0.210 | 1.399 | 0.110 | 0.079 |
| 140.000 | 1.253 | 1.100 | 0.248 | 0.225 | 1.160 | 0.098 | 0.084 |
| 170.000 | 1.114 | 0.932 | 0.224 | 0.240 | 0.997 | 0.085 | 0.086 |
| 200.000 | 1.017 | 0.812 | 0.200 | 0.246 | 0.884 | 0.078 | 0.089 |
| 230.000 | 0.944 | 0.740 | 0.176 | 0.238 | 0.802 | 0.074 | 0.092 |

6-9%

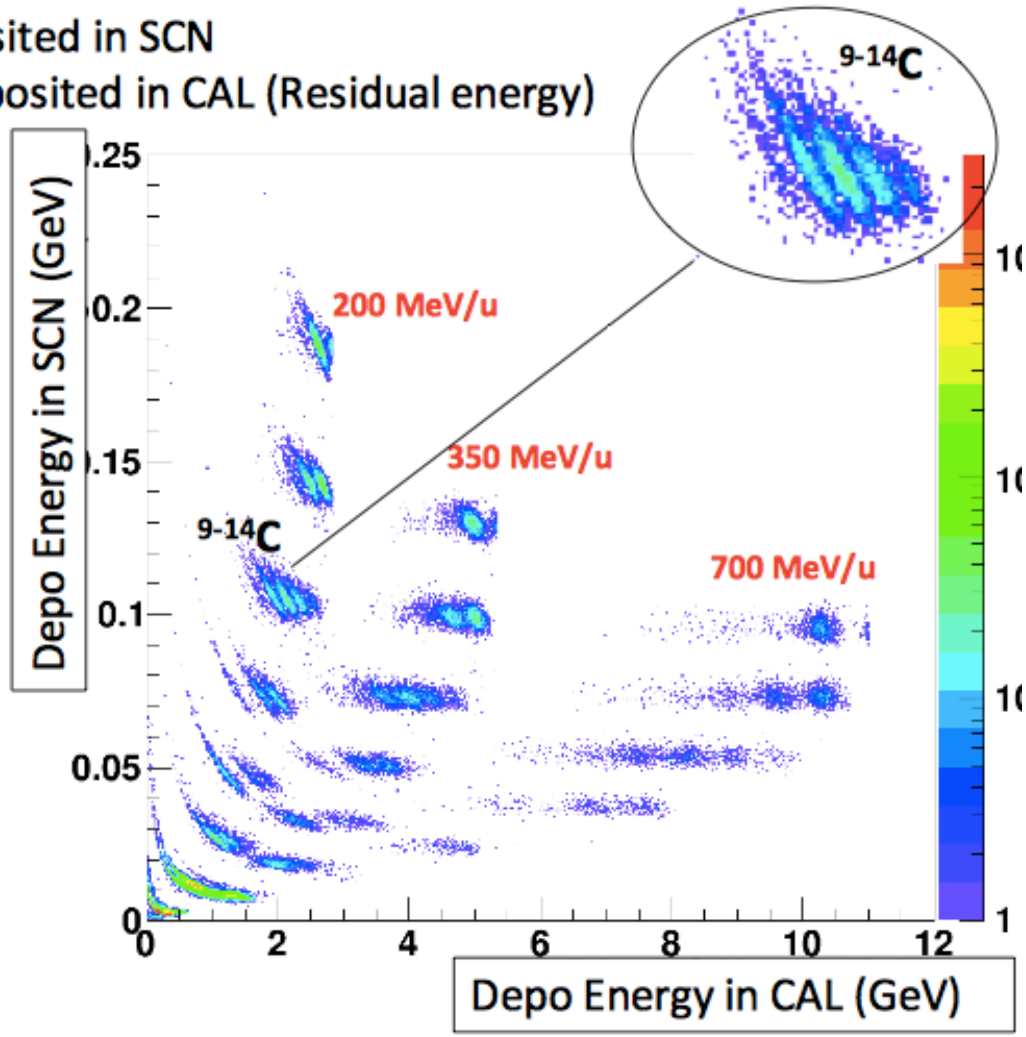


# Reproduction Roberto Spighi's plot (1)

***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