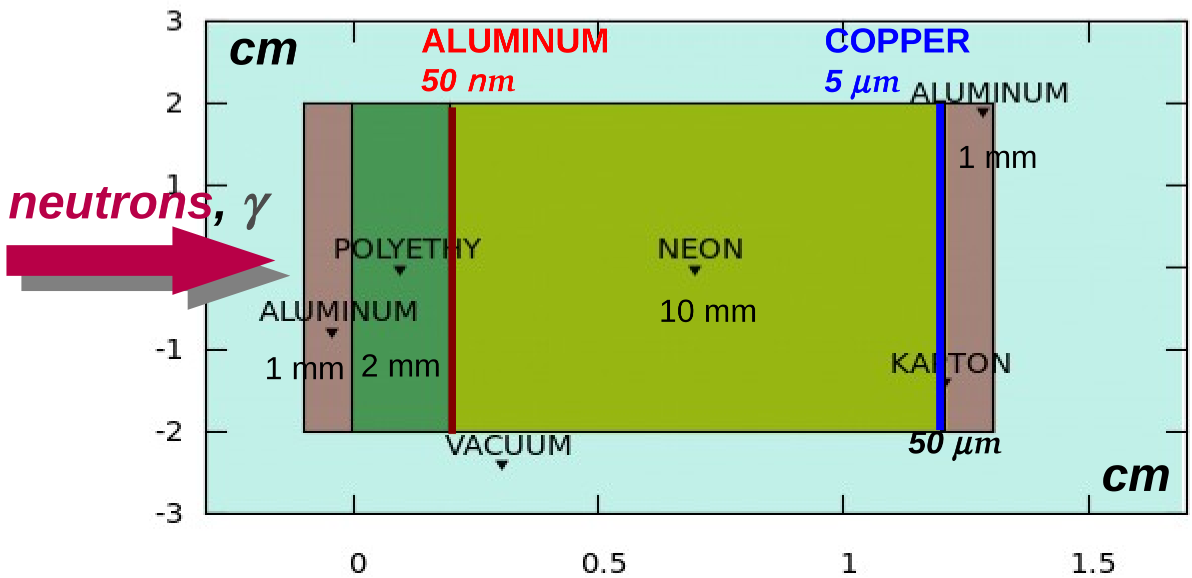
Simulations for micromegas used as BLM based on FLUKA MC / GEANT

- Detector design: 2 detector modules: MM + polyethylene, MM + B_4C
- FLUKA MC is used to model the BLM set-up and calculate the energy deposited in the gas by the incident particles (n and γ)
- Response to neutrons of energy: $(10^{-7} – 10^{2})$ MeV
- Optimizing geometrical parameters for maximum neutron detection efficiency
- Response to thermal neutrons / Estimation of the gamma contamination

- Validation + crosscheck using GEANT4
- Repetition of simulations and comparison with FLUKA
- Time response of the detector

A. Delbart, J. Marroncle, T. Papaevangelou, L. Segui, G. Tsiledakis

MM + polyethylene: A module for very high En& very high flux



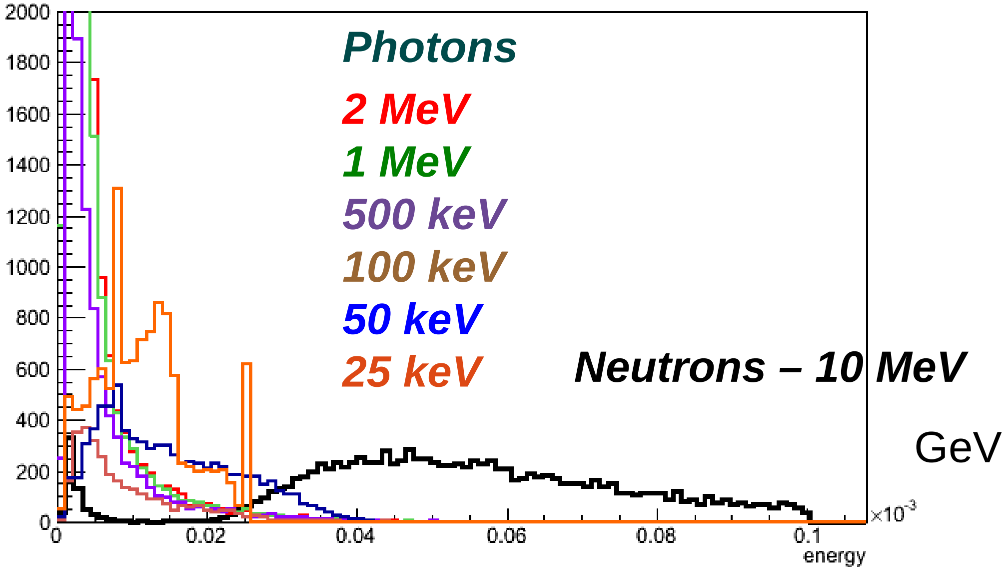
- 1 aluminum plate (1 mm) for the detector body
- 2 mm of polyethylene for "neutron conversion" to proton recoils
- 50 nm aluminum foil or deposition on the Polyethylene, Adjusting the thickness → set the neutron energy threshold
- 0.1 - 10 mm gas (neon/helium) to produce electrons by ionization processes induced by the recoil proton.

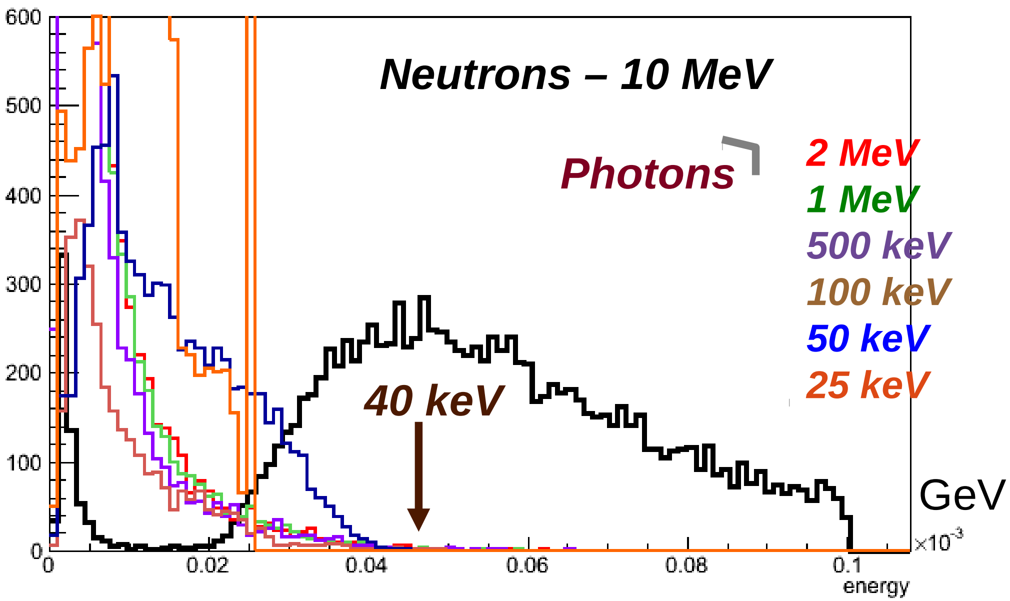
→ Directional detection of fast neutrons (En > ~0.5 MeV)

→ Strong gamma rejection

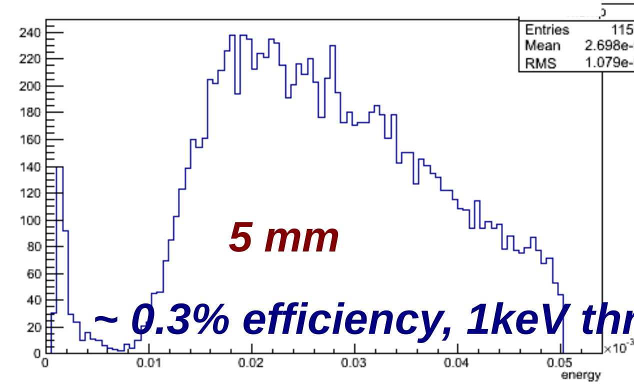
→ High rate capability

Simulated response

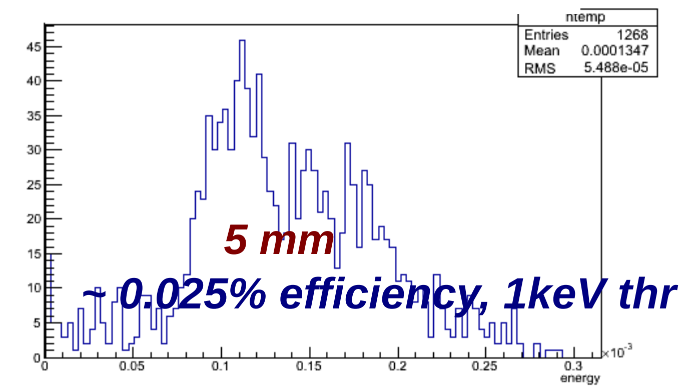




neutrons of 10 MeV



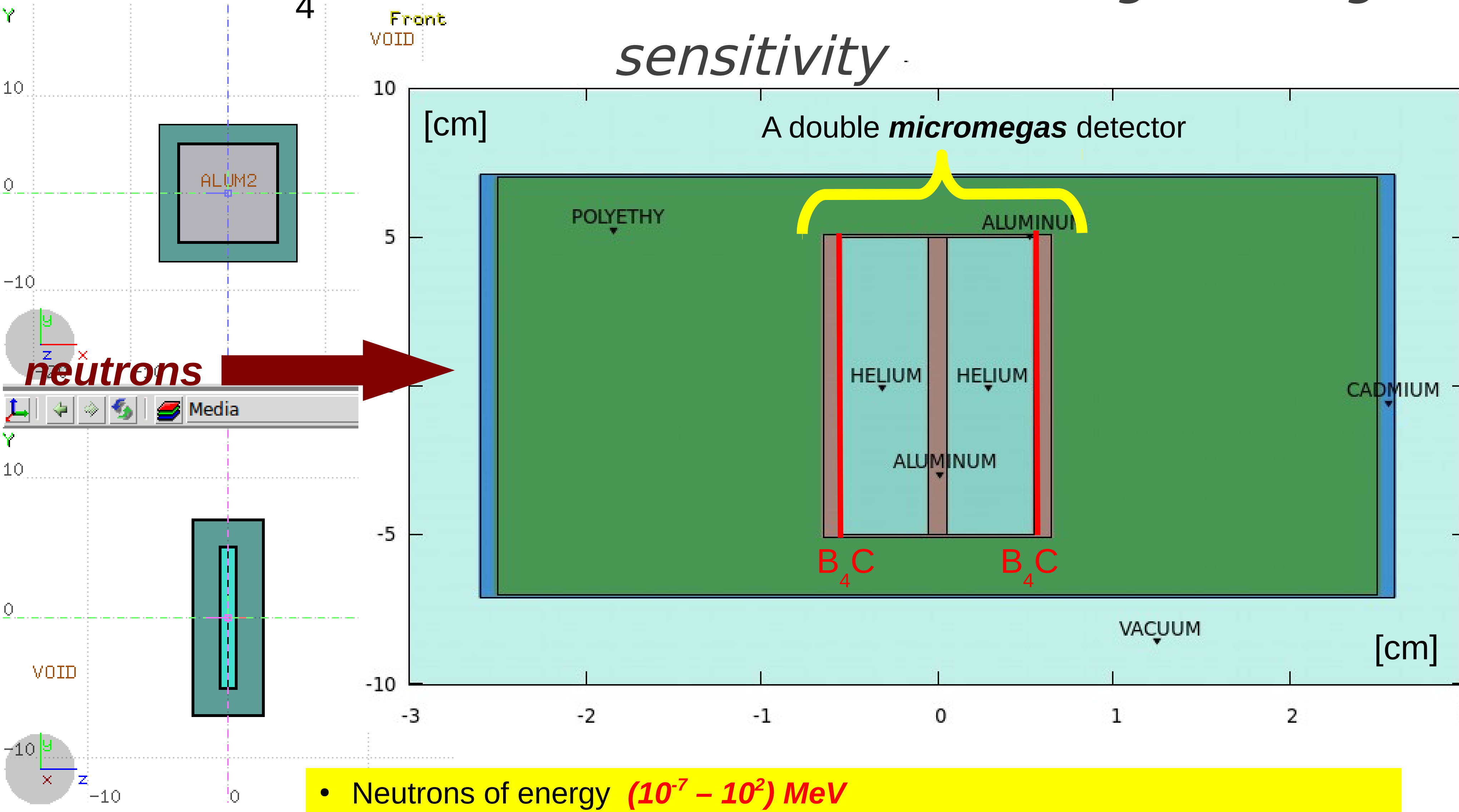
neutrons of 1 MeV



Efficiency × 10^{-5}

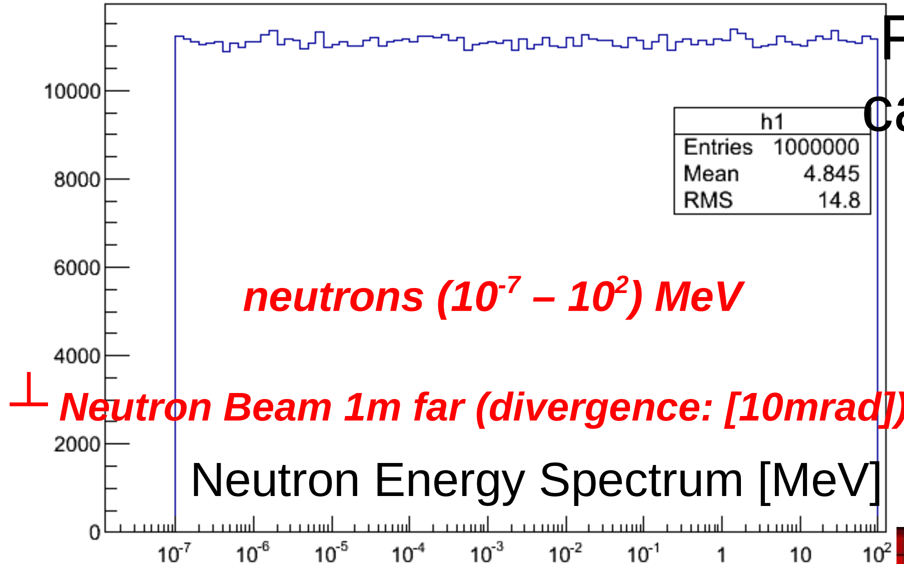
$E_{neutron}$ (MeV)	Threshold (keV)			
	1	10	20	50
0.1	5	4	3	1
0.3	9	9	8	6
0.5	13	13	12	11
1.0	25	24	24	23
10.0	300	287	287	192

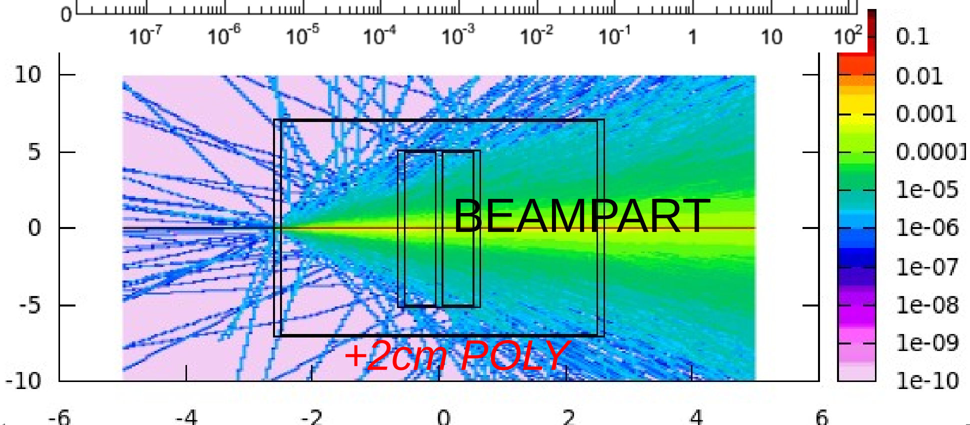
MM + B_4C: *Fast neutron flux monitoring with high sensitivity*

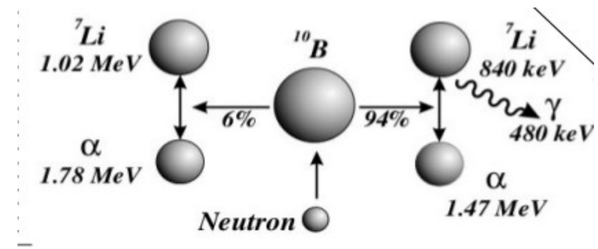


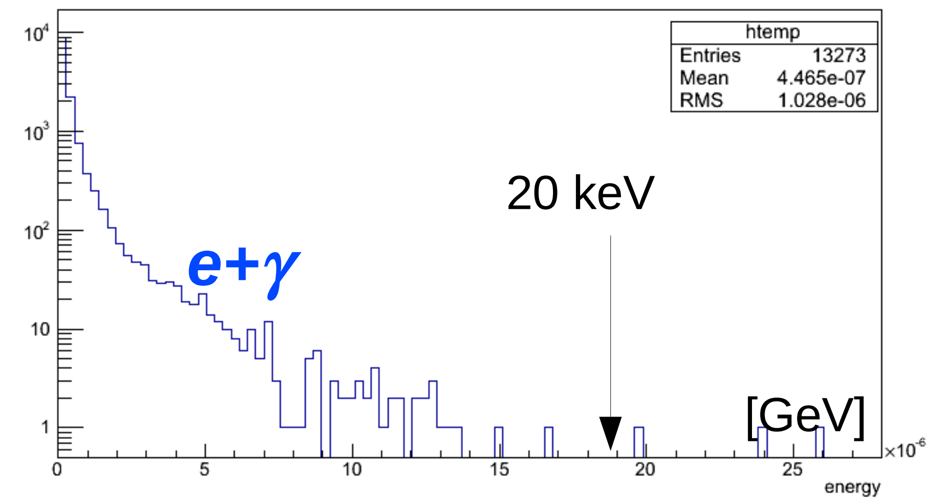
- Neutrons of energy ***$(10^{-7} – 10^{2})$ MeV***
- Cadmium (1mm) to eliminate incoming thermal neutrons
- Polyethylene (2, 4, 6 cm) to thermalize beam neutrons
- 2 layers of a ***B_4C*** converter (***2 µm*** thick) to capture thermal neutrons
- A double ***micromegas*** detector filled with **Helium**
- Detector size (4 cm thick Poly.) ~ ***20 x 20 x 10 cm^3***

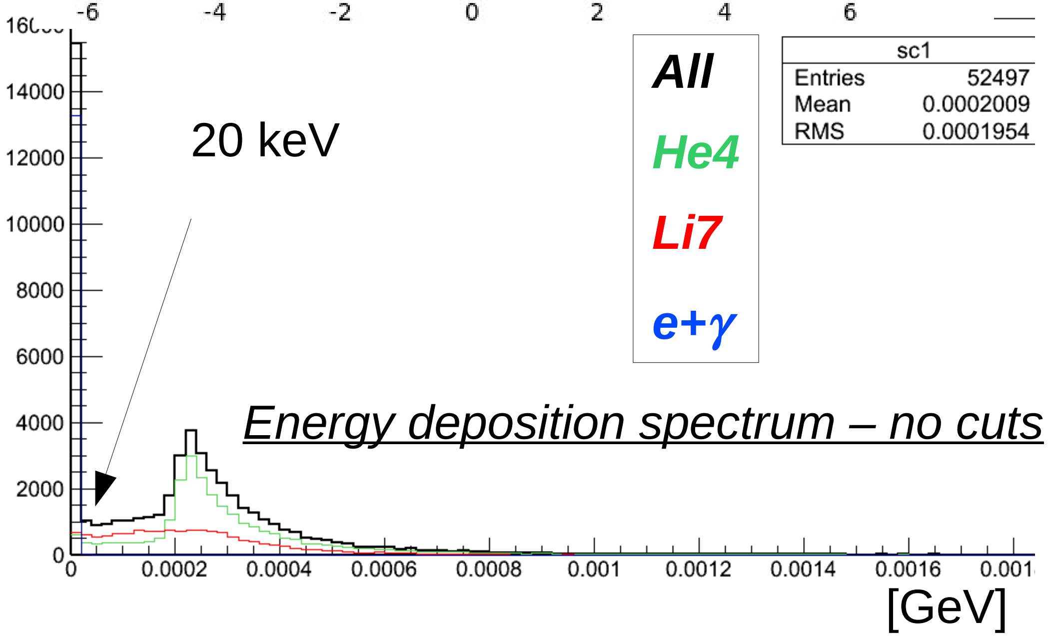
FLUKA MC: modeling the BLM set-up and calculating the energy deposition in the gas

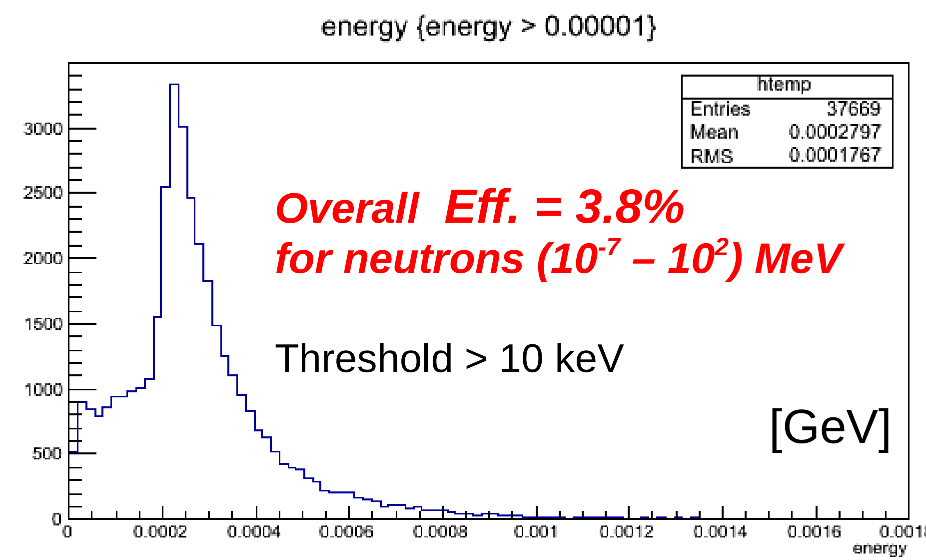




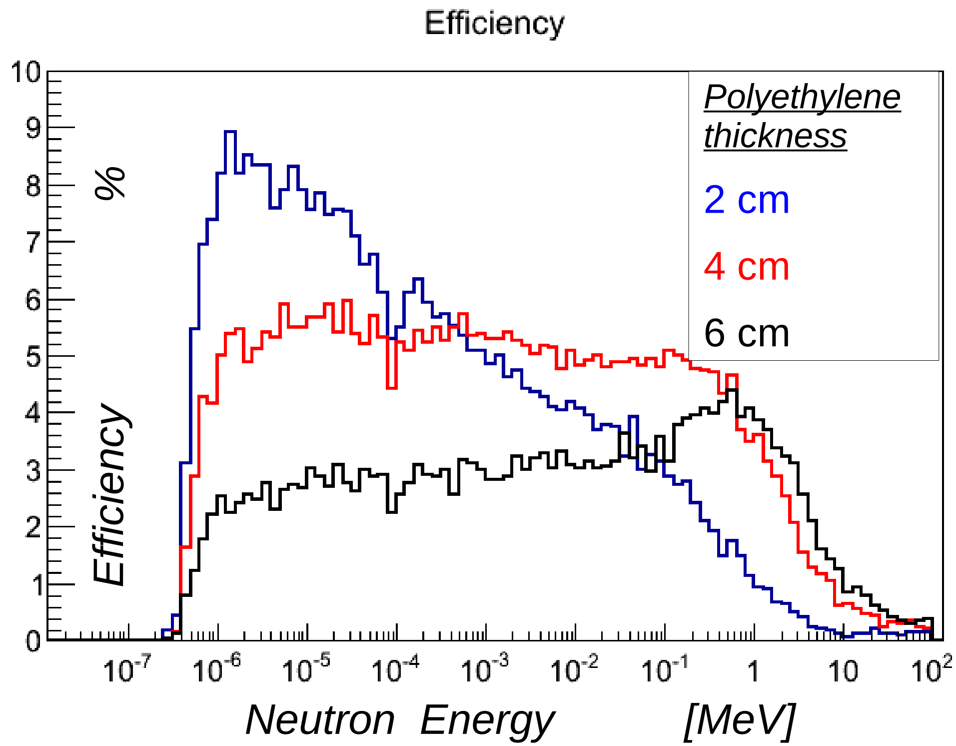


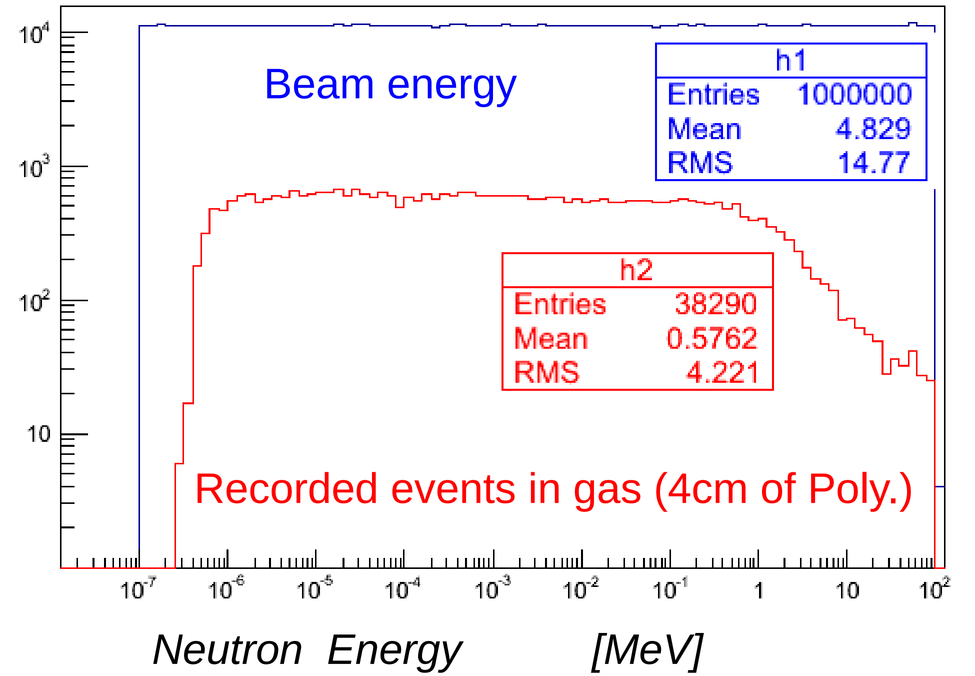


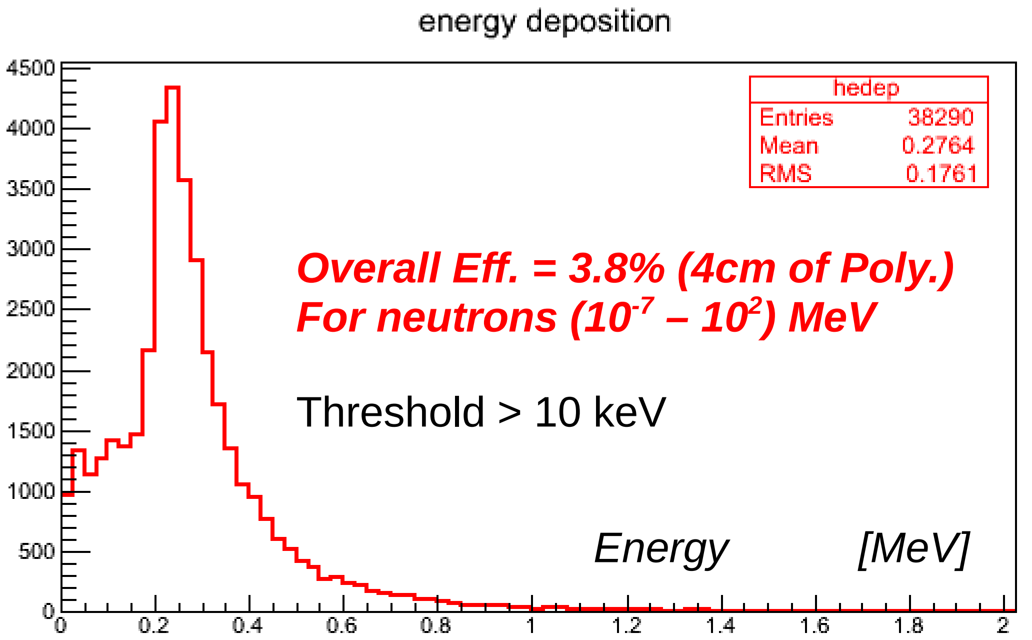




Varying the Polyethylene thickness

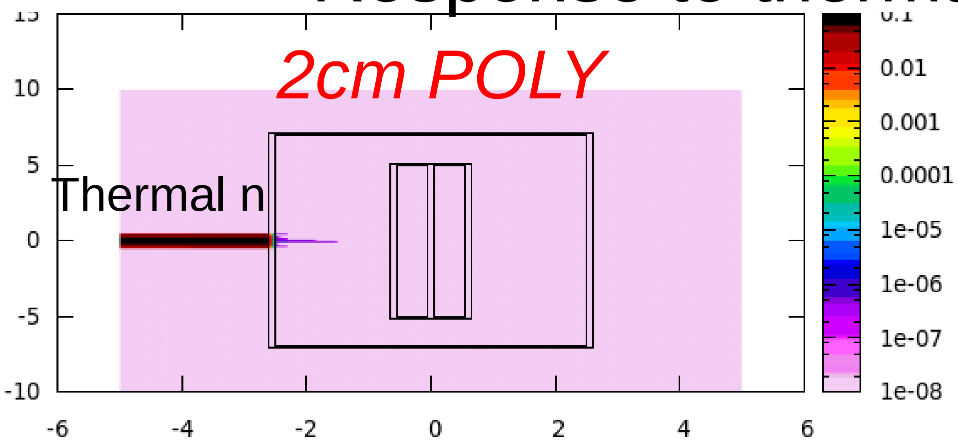




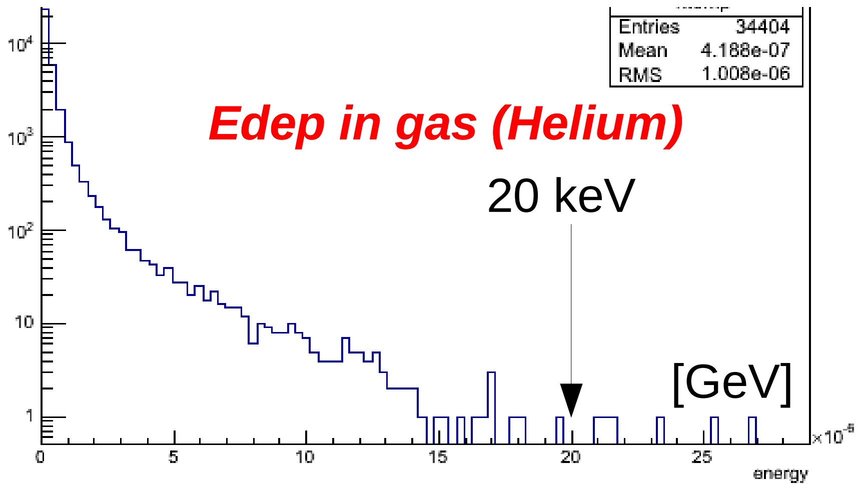


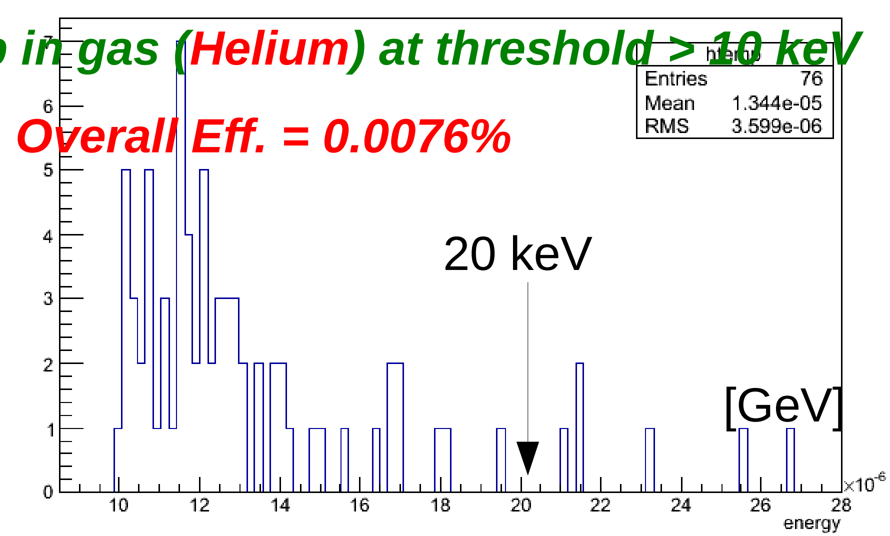
- *For neutrons with energy: (**1 eV – 1 MeV**), the recorded efficiency for a 2xB_4C layer double micromegas detector is **> 5%** (4cm of Poly.).*

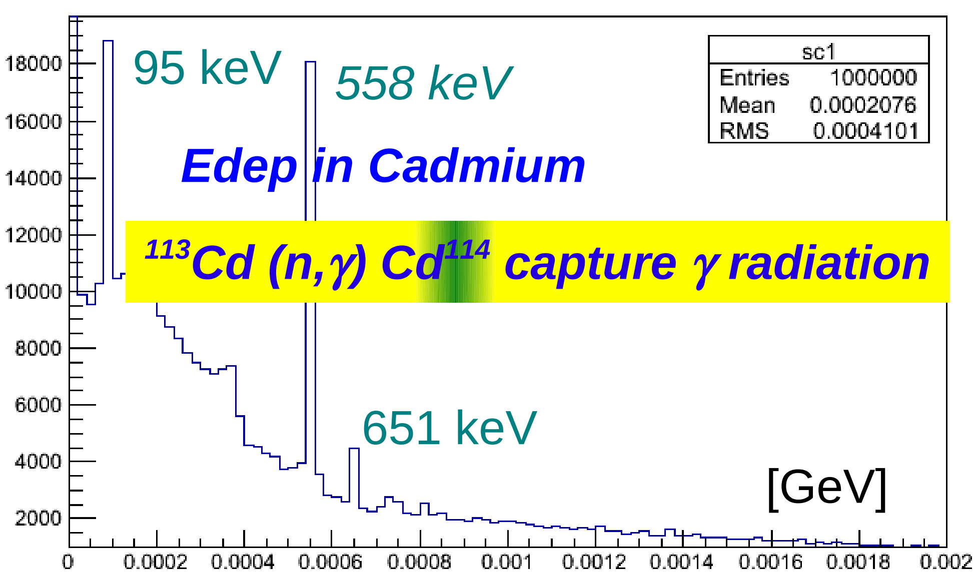
Response to thermal neutrons (E = 0.025 eV)

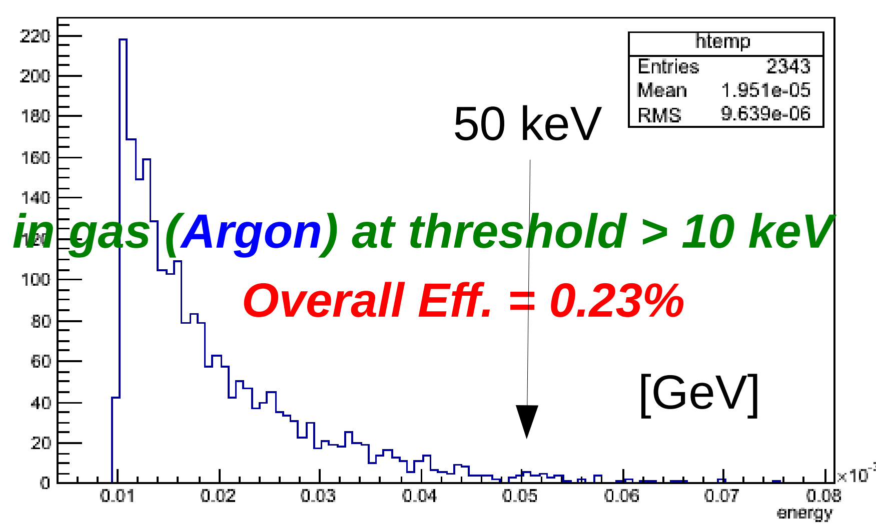


- *BEAM: n with Energy: 0.025 eV*
- *1M events*
- *Thermal n are captured by Cd*
- *Using Helium and a threshold > 20 keV ==> "BLIND" to external thermal n*

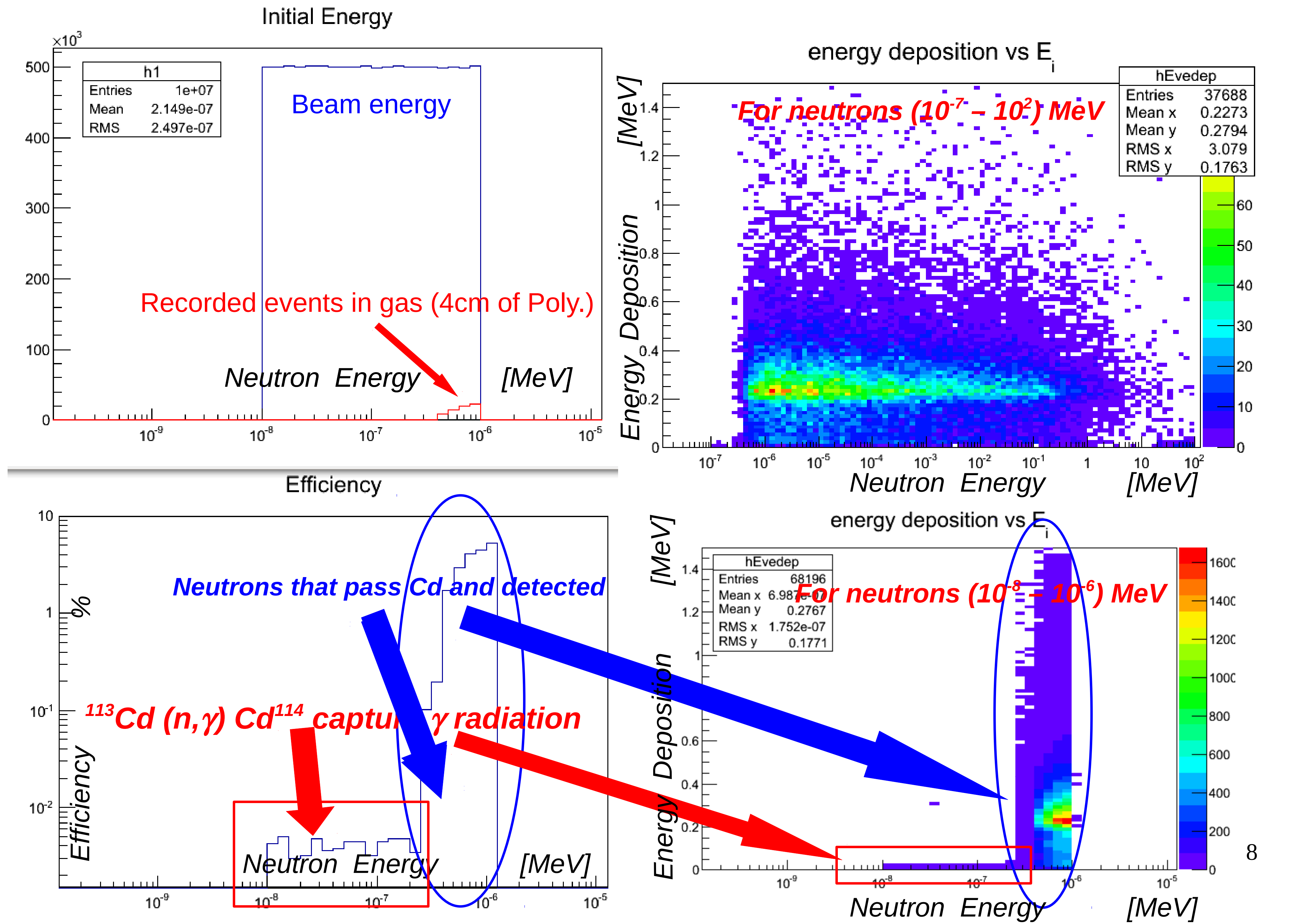




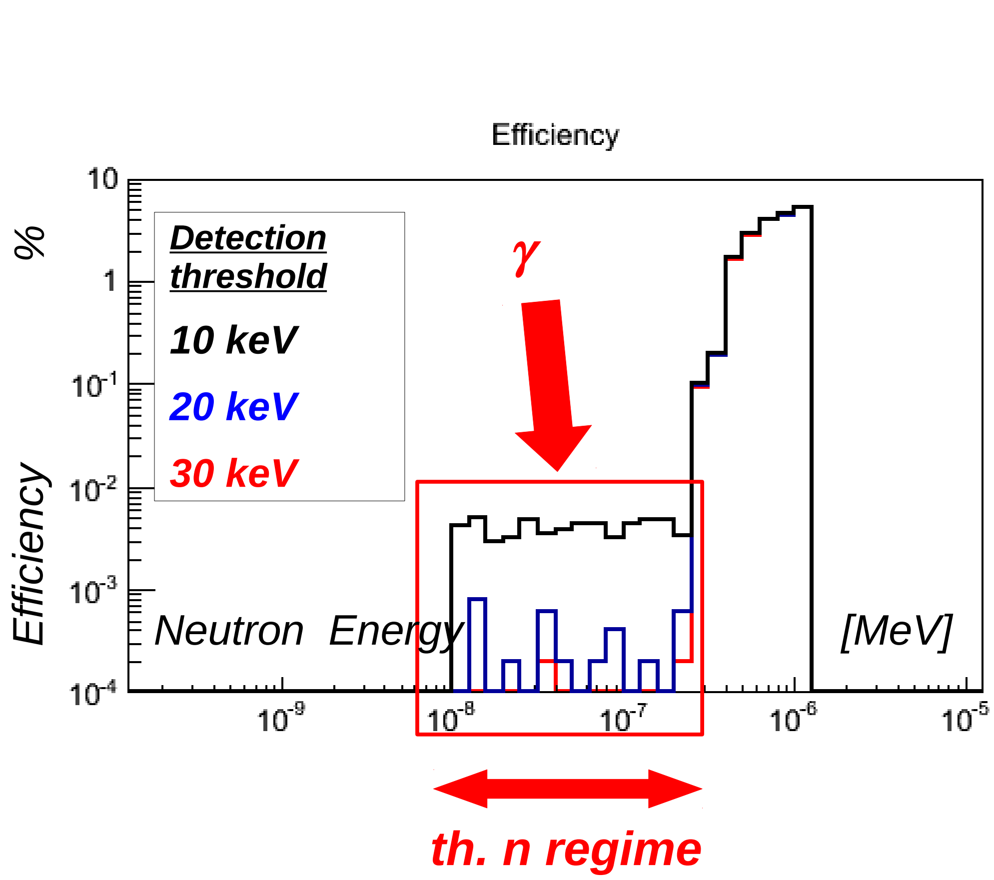


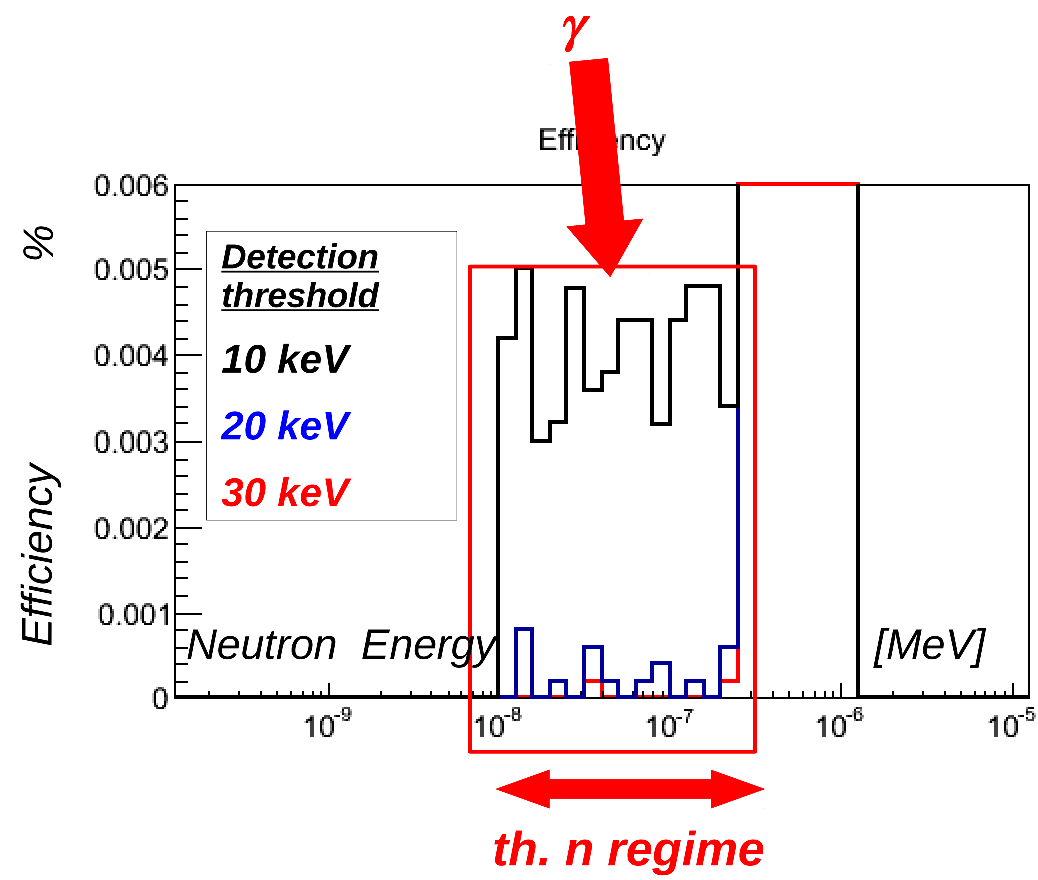


Response to neutrons with Energy: $(10^{-8} – 10^{-6})$ MeV *4cm POLY*



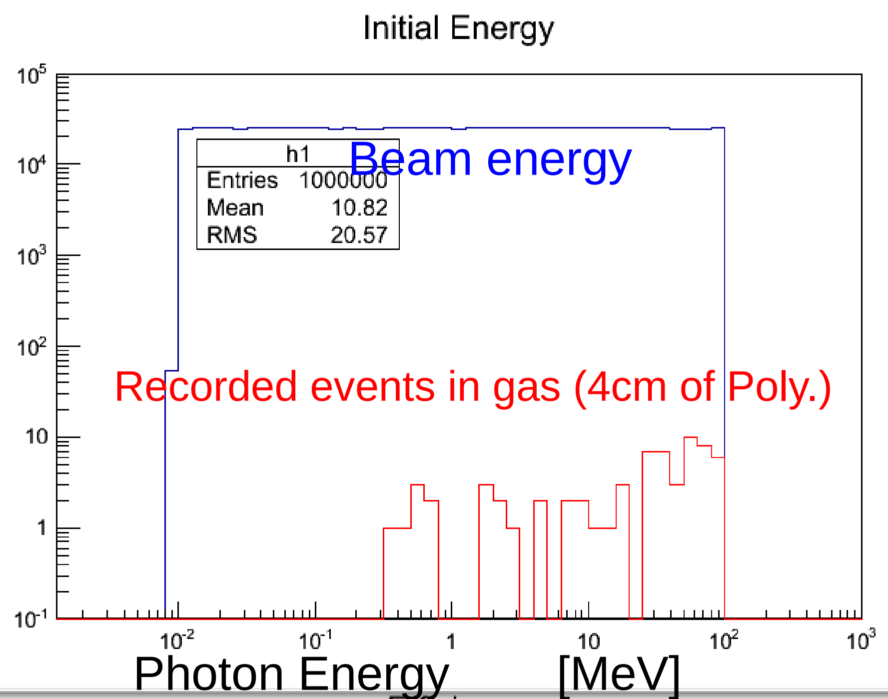
Response to neutrons with Energy: (10^{-8} – 10^{-6}) MeV 4cm POLY

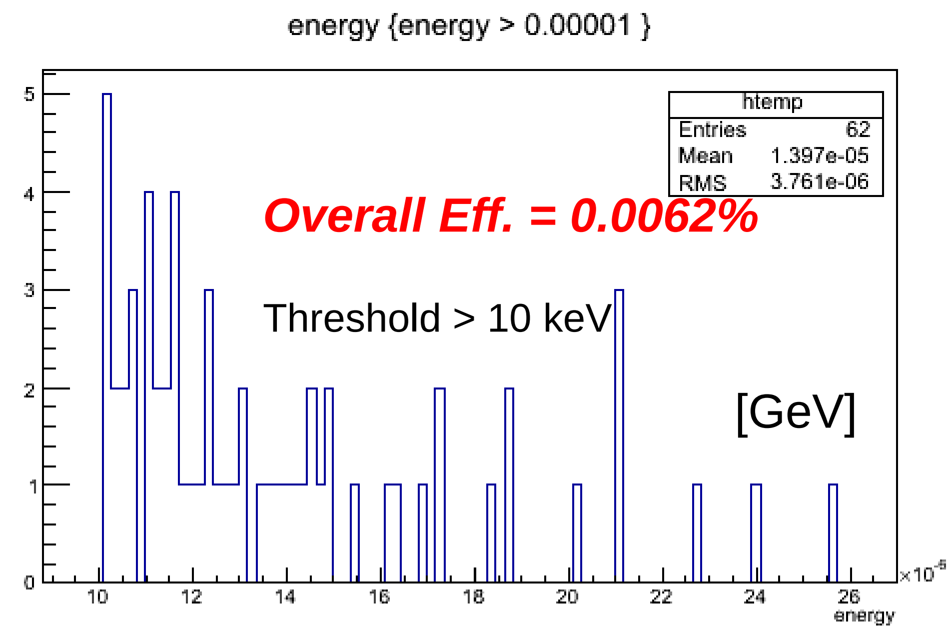


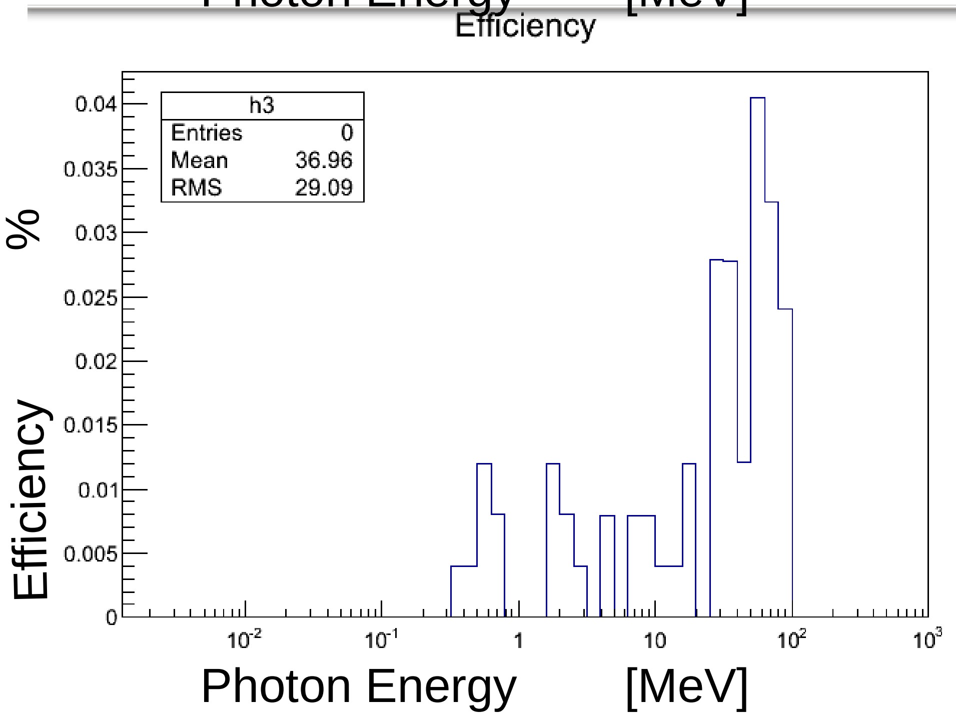


- Adjusting the detector parameters (gas, gain, threshold etc...) this BLM set-up can be "***blind***" to external thermal neutrons
- With a threshold > 10 keV, the detection efficiency in the thermal neutron regime is < 0.007% (using Helium)
- With a threshold > 30 keV, the detector becomes "***blind***"

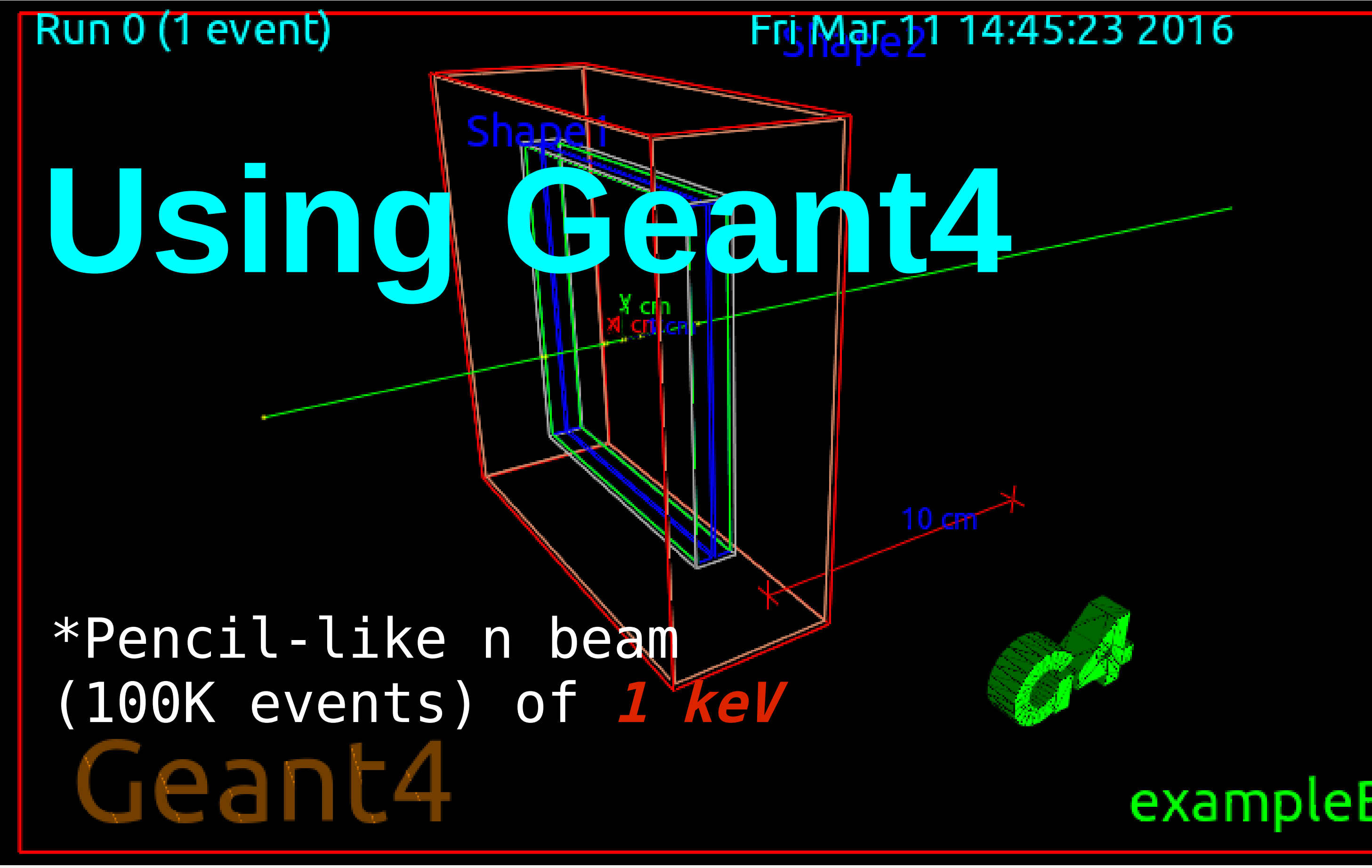
Response to photons with Energy: $(10^{-2} – 10^{2})$ MeV *4cm POLY*





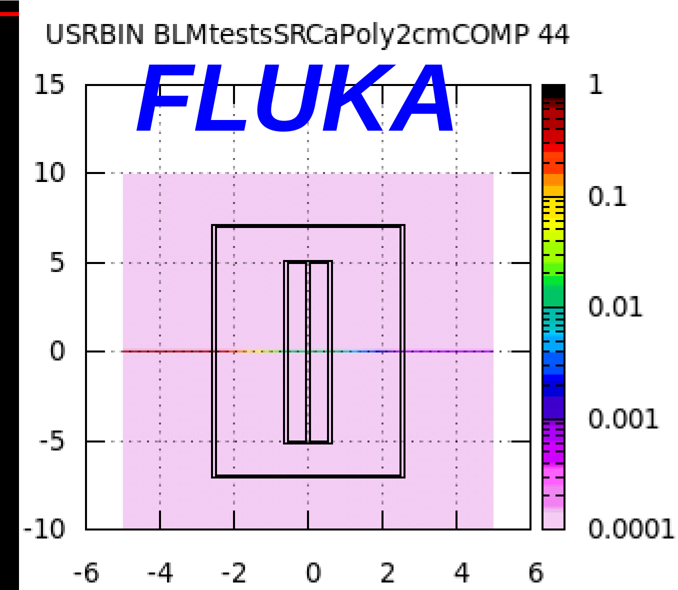


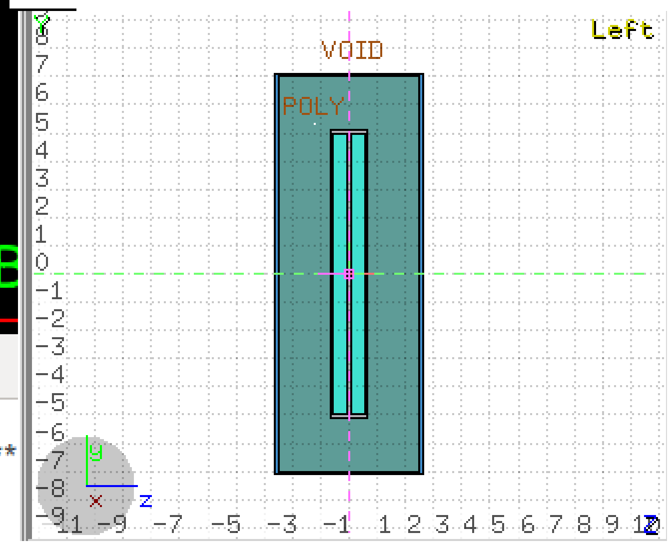
- With a threshold > 10 keV, photons from 10 keV to 100 MeV could create a very small background with a detection efficiency of ~ 0.006%
- A threshold of ~ 30 keV cuts almost all the photons



Using Geant4

*Pencil-like n beam (100K events) of *1 keV*

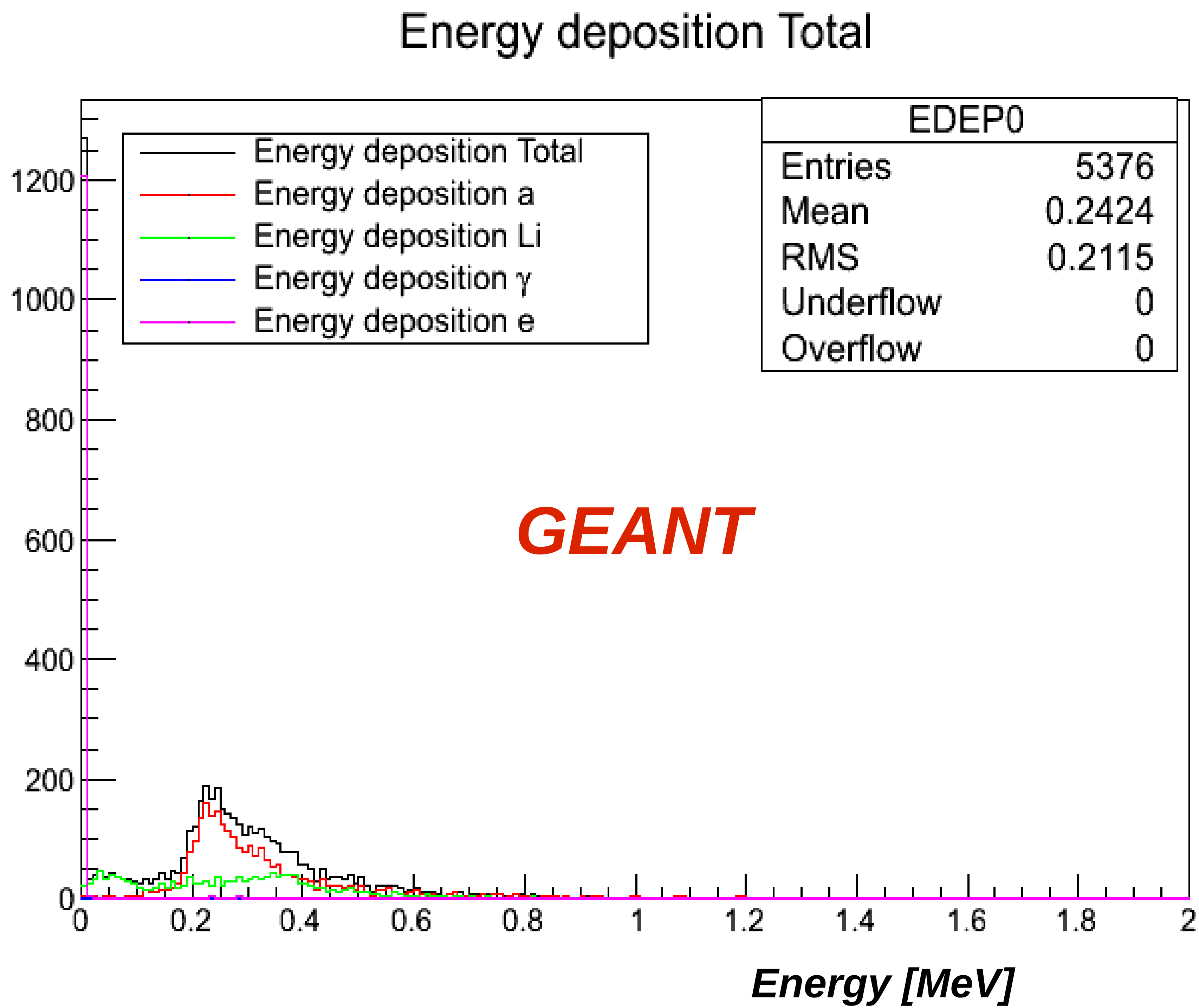


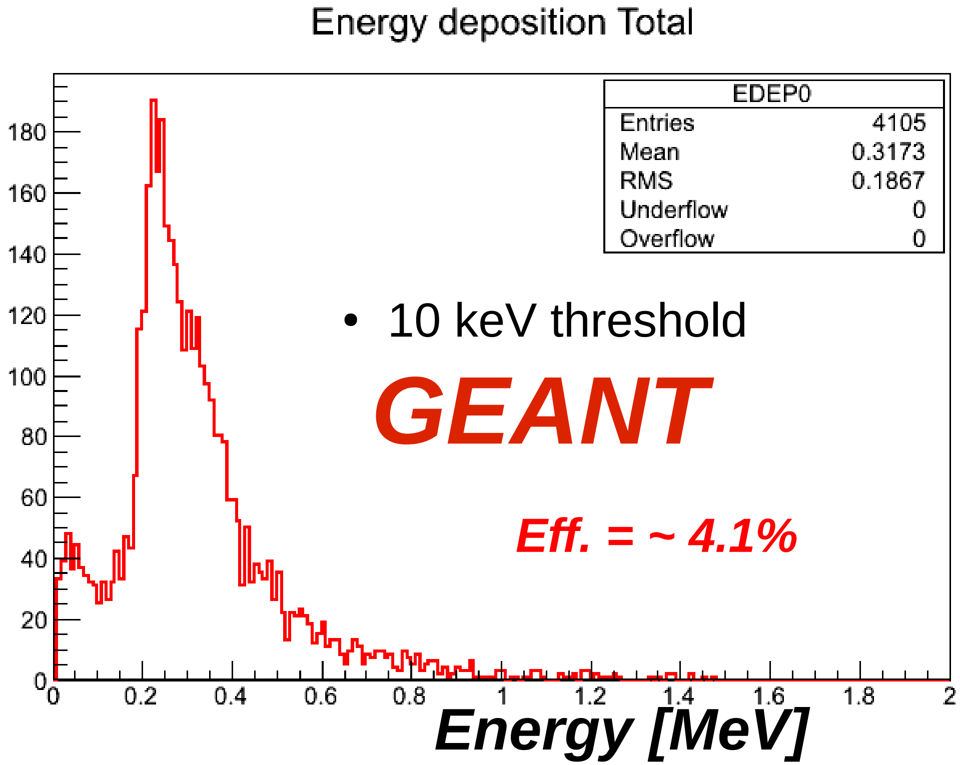


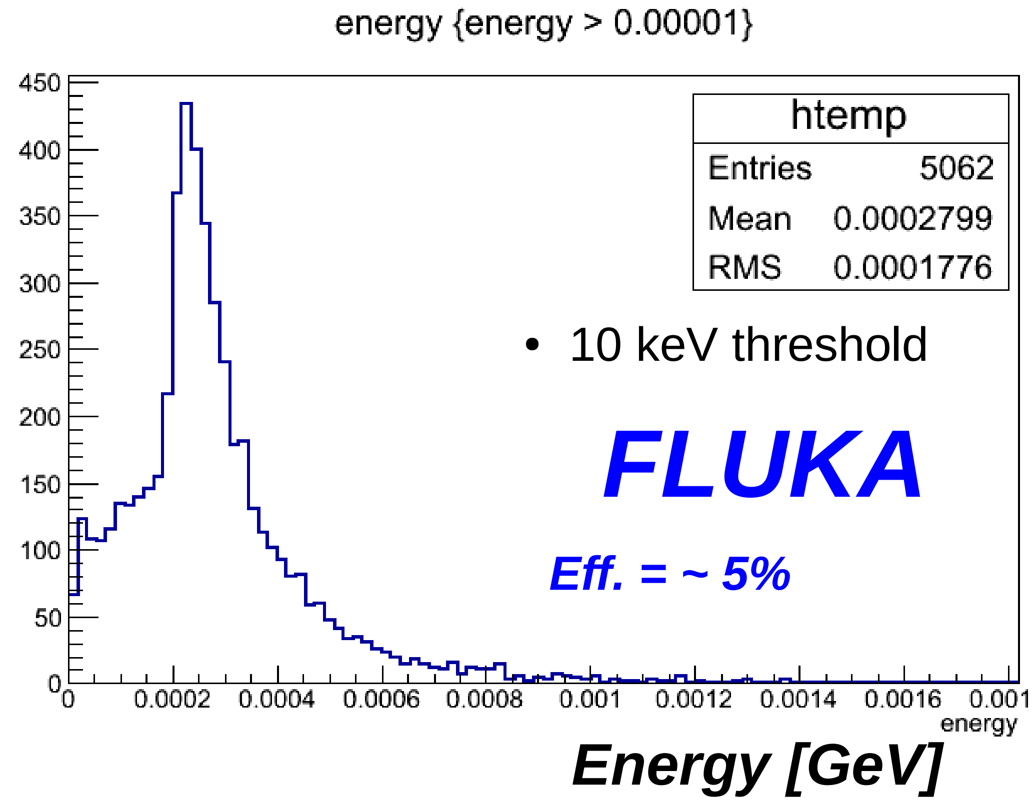
Output

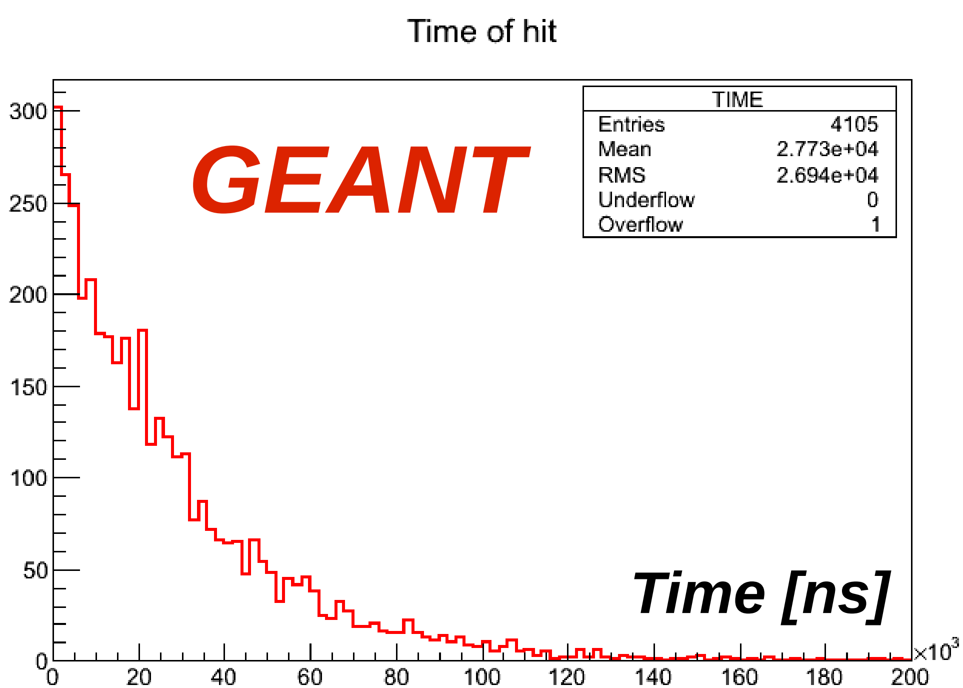
```
* G4Track Information:   Particle = gamma,   Track ID = 1,   Parent ID = 0
************************************************************************************
Step#   X(mm)   Y(mm)   Z(mm) KinE(MeV)  dE(MeV) StepLeng TrackLeng  NextVolume ProcName
0       0       0    -100    1e+04      0       0       0     World initStep
1       0       0     -26    1e+04      0      74      74        Cd Transportation
2       0       0     -25    1e+04      0       1      75  Pethylene Transportation
3       0       0    -6.5    1e+04      0    18.5    93.5        Al Transportation
4       0       0    -5.5    1e+04      0       1    94.5      B4C Transportation
5       0       0    -5.5    1e+04      0   0.002    94.5        He Transportation
6       0       0    -0.5    1e+04      0       5    99.5        Al Transportation
7       0       0     0.5    1e+04      0       1     100        He Transportation
8       0       0     5.5    1e+04      0       5     106      B4C Transportation
9       0       0     5.5    1e+04      0   0.002     106        Al Transportation
10      0       0     6.5    1e+04      0       1     107  Pethylene Transportation
11      0       0      25    1e+04      0    18.5     125        Cd Transportation
12      0       0      26    1e+04      0       1     126     World Transportation
13      0       0   2e+03    1e+04      0 1.97e+03  2.1e+03 OutOfWorld Transportation
Run terminated.
```

RPP	Cadmi	Xmin: -7.10 Ymin: -7.10 Zmin: -2.6	Xmax: 7.10 Ymax: 7.10 Zmax: 2.6
RPP	Poly	Xmin: -7.00 Ymin: -7.00 Zmin: -2.5	Xmax: 7.00 Ymax: 7.00 Zmax: 2.5
RPP	Alum1	Xmin: -5.10 Ymin: -5.10 Zmin: -0.6502	Xmax: 5.10 Ymax: 5.10 Zmax: 0.6502
RPP	Conv1	Xmin: -5.00 Ymin: -5.00 Zmin: -0.5502	Xmax: 5.00 Ymax: 5.00 Zmax: -0.55
RPP	Gas1	Xmin: -5.00 Ymin: -5.00 Zmin: -0.55	Xmax: 5.00 Ymax: 5.00 Zmax: -0.05
RPP	Alum2	Xmin: -5.00 Ymin: -5.00 Zmin: -0.05	Xmax: 5.00 Ymax: 5.00 Zmax: 0.05
RPP	Gas2	Xmin: -5.00 Ymin: -5.00 Zmin: 0.05	Xmax: 5.00 Ymax: 5.00 Zmax: 0.55
RPP	Conv2	Xmin: -5.00 Ymin: -5.00 Zmin: 0.55	Xmax: 5.00 Ymax: 5.00 Zmax: 0.5502


Energy deposition Total
Energy deposition Total
Energy deposition a
Energy deposition Li
Energy deposition γ
Energy deposition e
EDEP0
Entries 5376
Mean 0.2424
RMS 0.2115
Underflow 0
Overflow 0
GEANT
1200
1000
800
600
400
200
0
0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2
Energy [MeV]



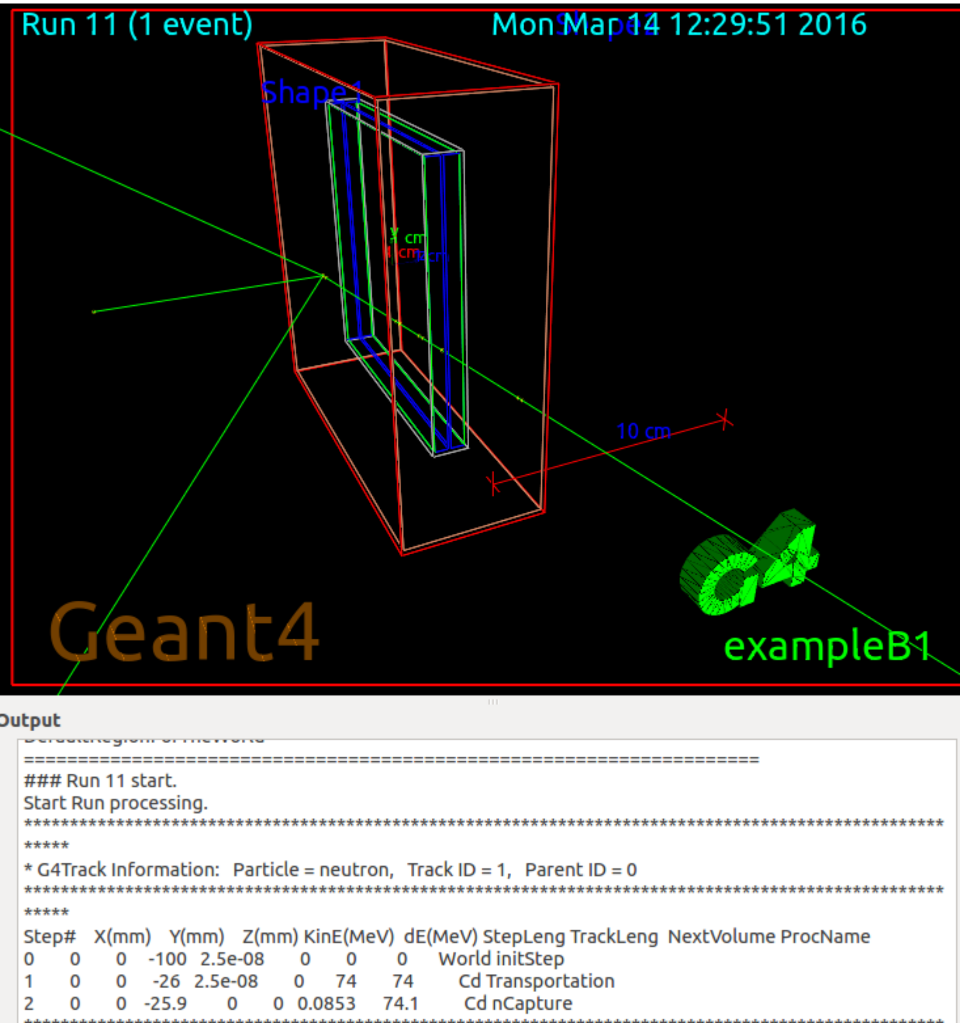


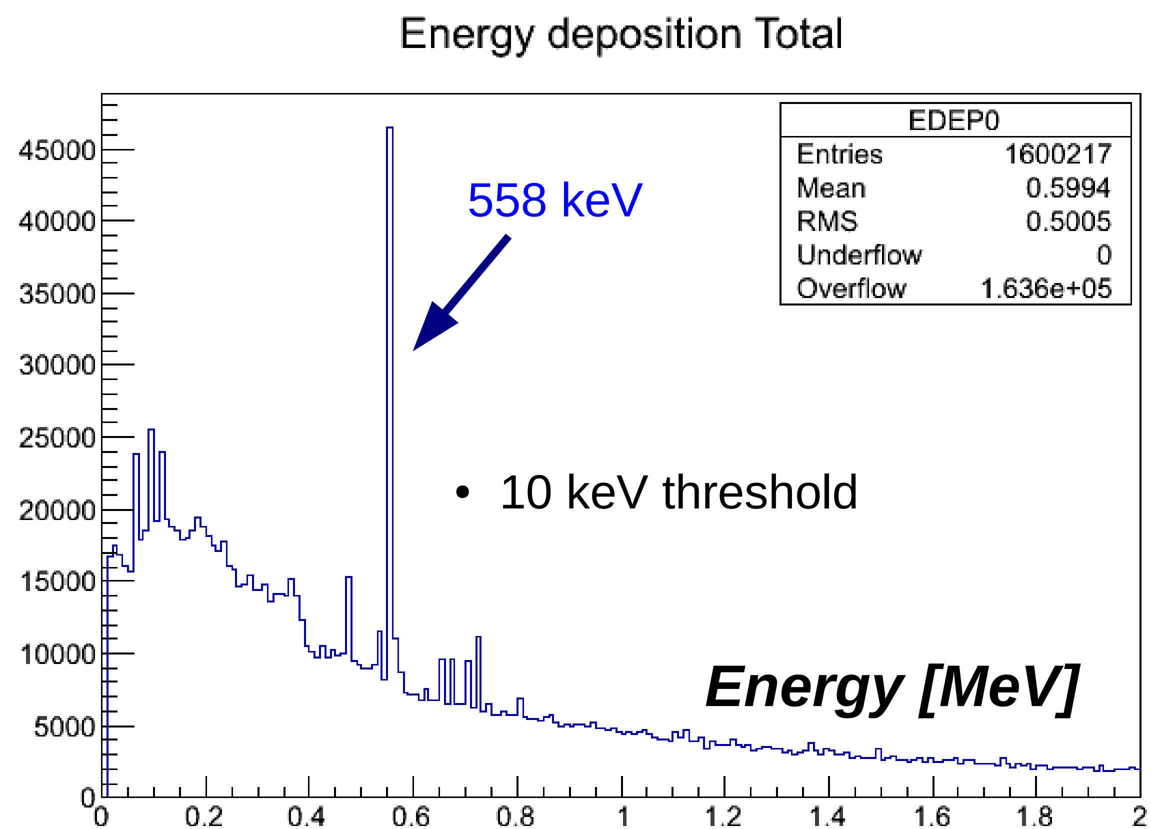


- ***FLUKA*** is NOT a toolkit like ***Geant4***! Its physical models are fully integrated
- Results obtained with both codes agree...

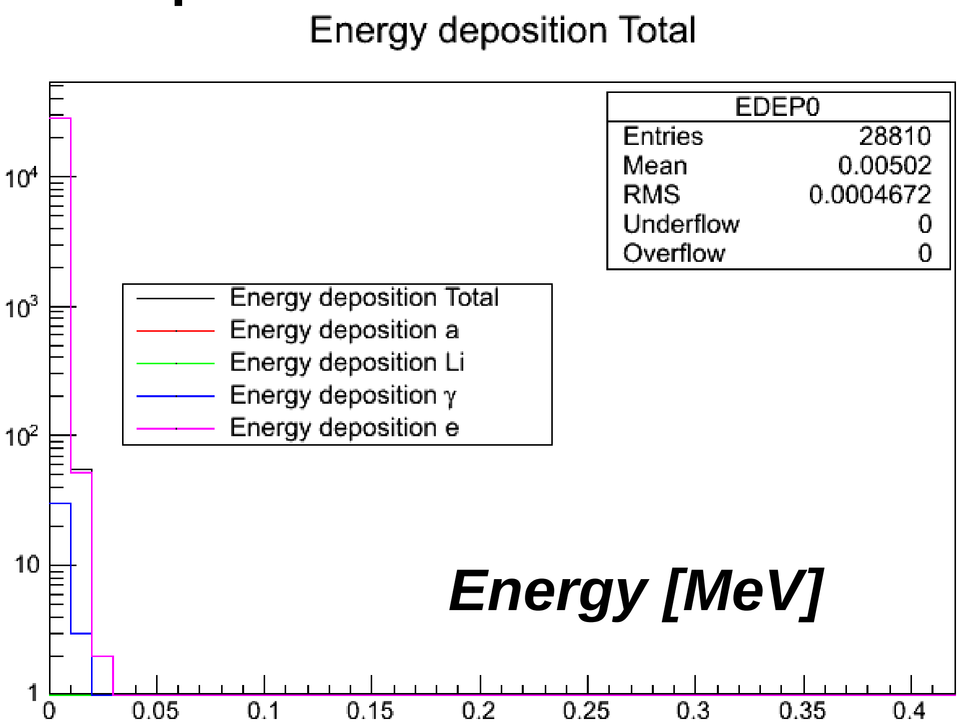
Response to Thermal neutrons – 0.025 eV (1M events)

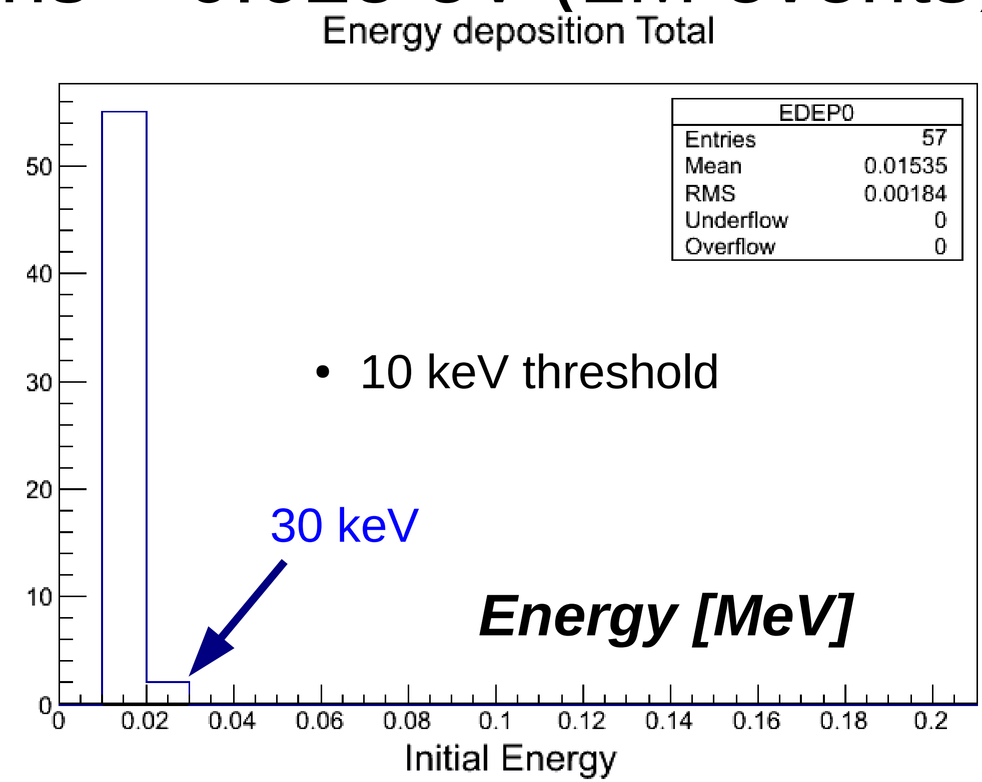
In Cd (thermal n capture)

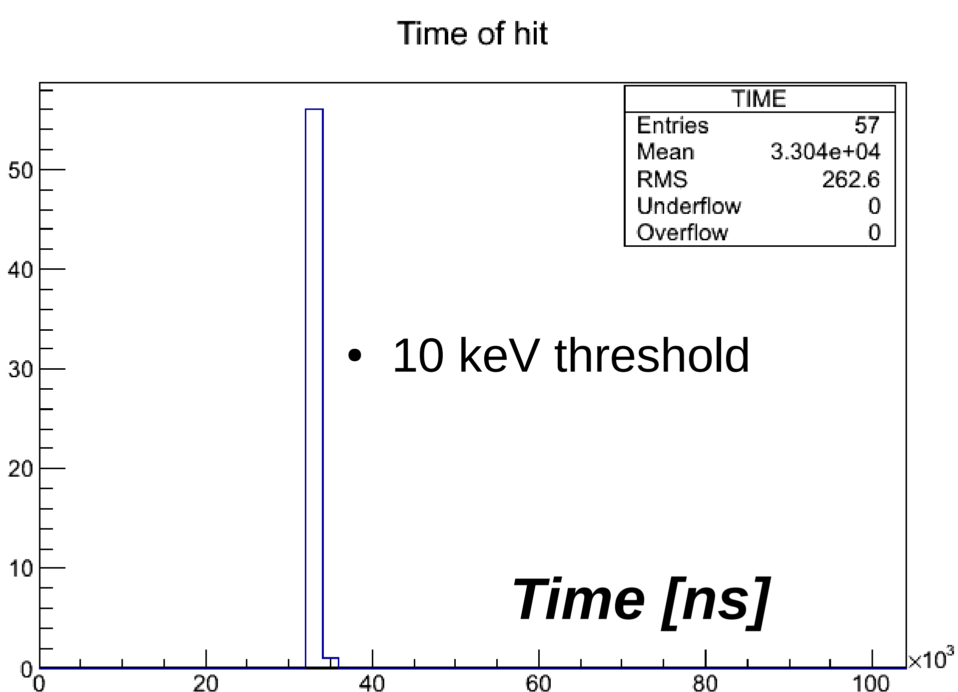


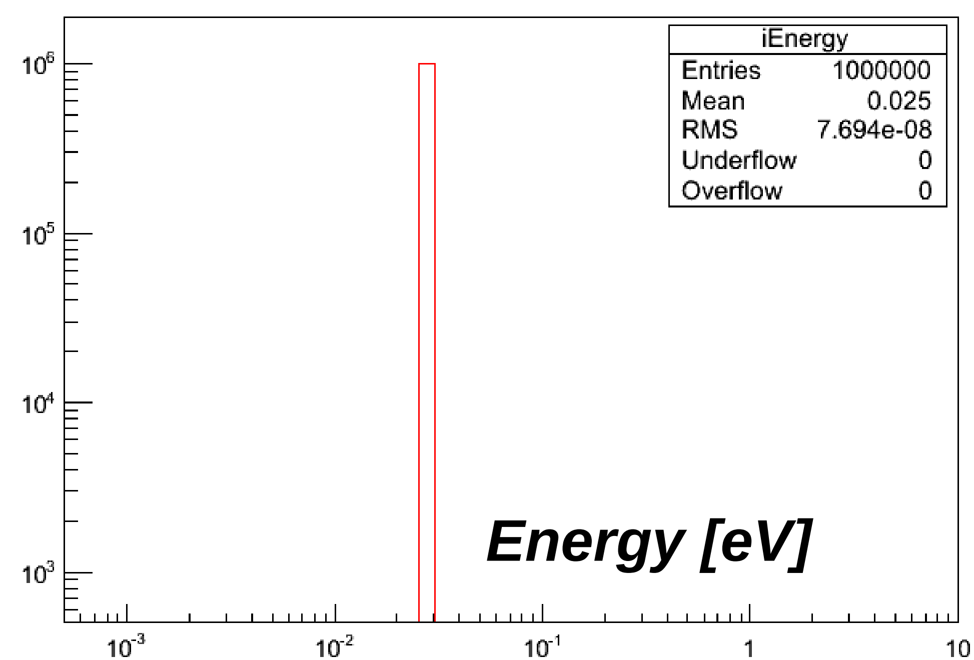


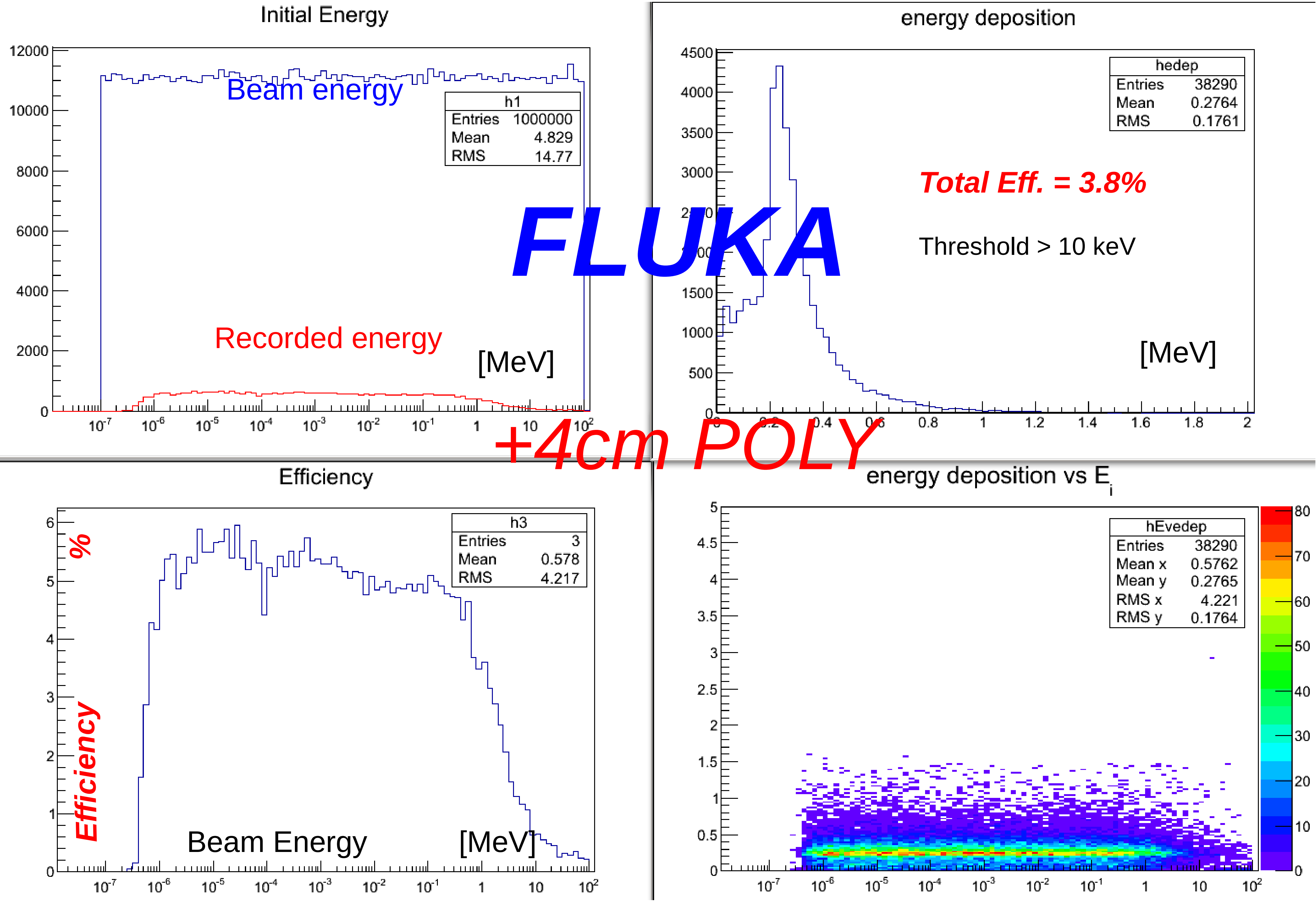
Response to Thermal neutrons – 0.025 eV (1M events)

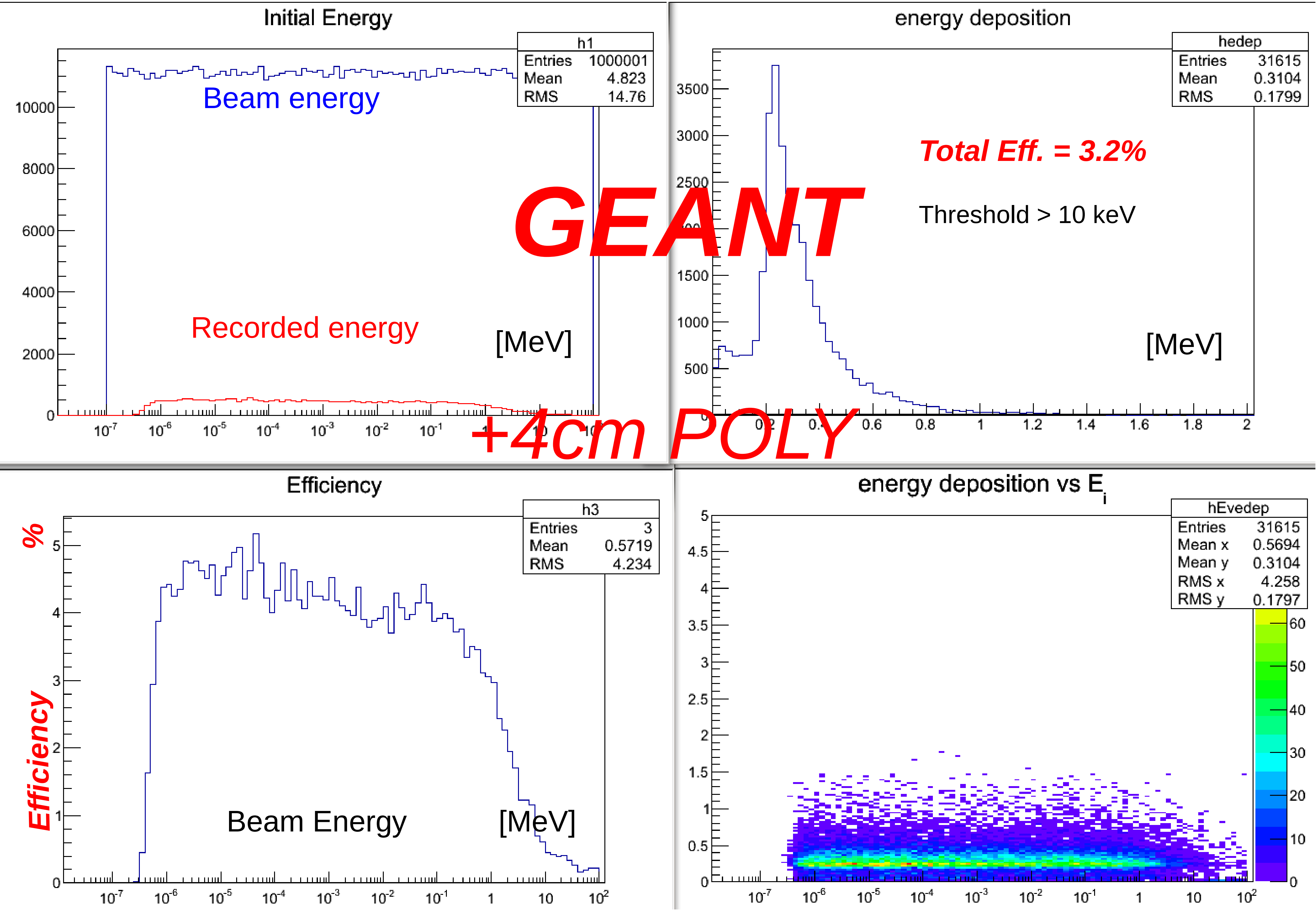








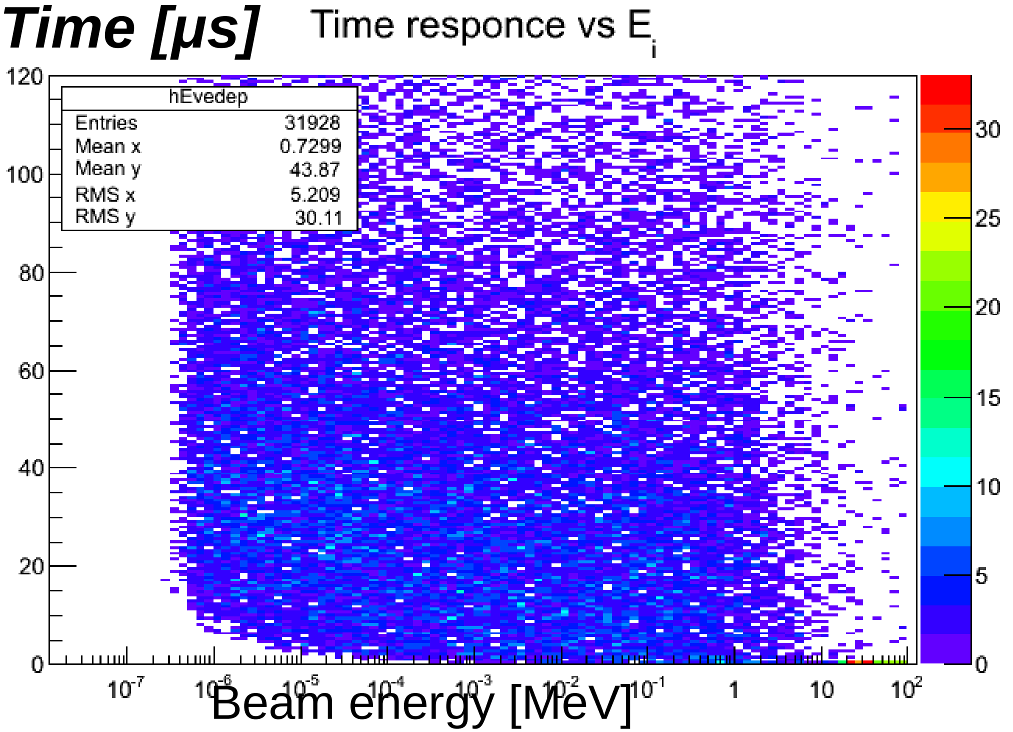

FLUKA
+4cm POLY
Initial Energy
Beam energy
h1
Entries 1000000
Mean 4.829
RMS 14.77
Recorded energy
[MeV]
energy deposition
hedep
Entries 38290
Mean 0.2764
RMS 0.1761
Total Eff. = 3.8%
Threshold > 10 keV
[MeV]
Efficiency
h3
Entries 3
Mean 0.578
RMS 4.217
% Efficiency
Beam Energy
[MeV]
energy deposition vs E_i
hEvedep
Entries 38290
Mean x 0.5762
Mean y 0.2765
RMS x 4.221
RMS y 0.1764

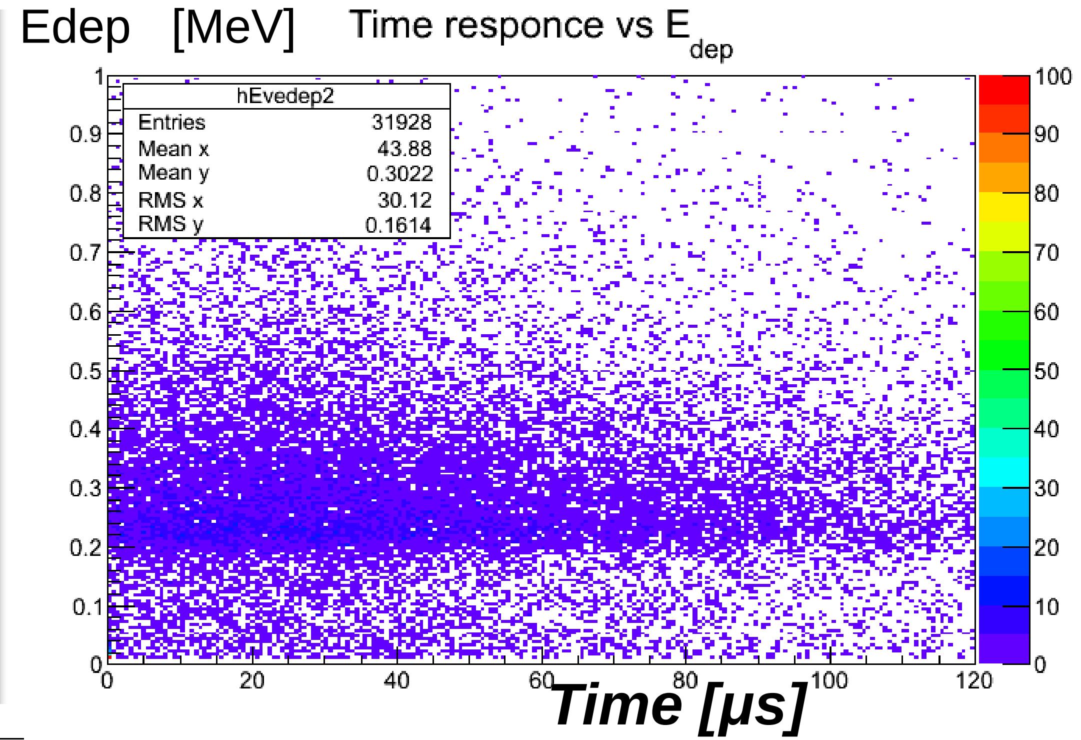


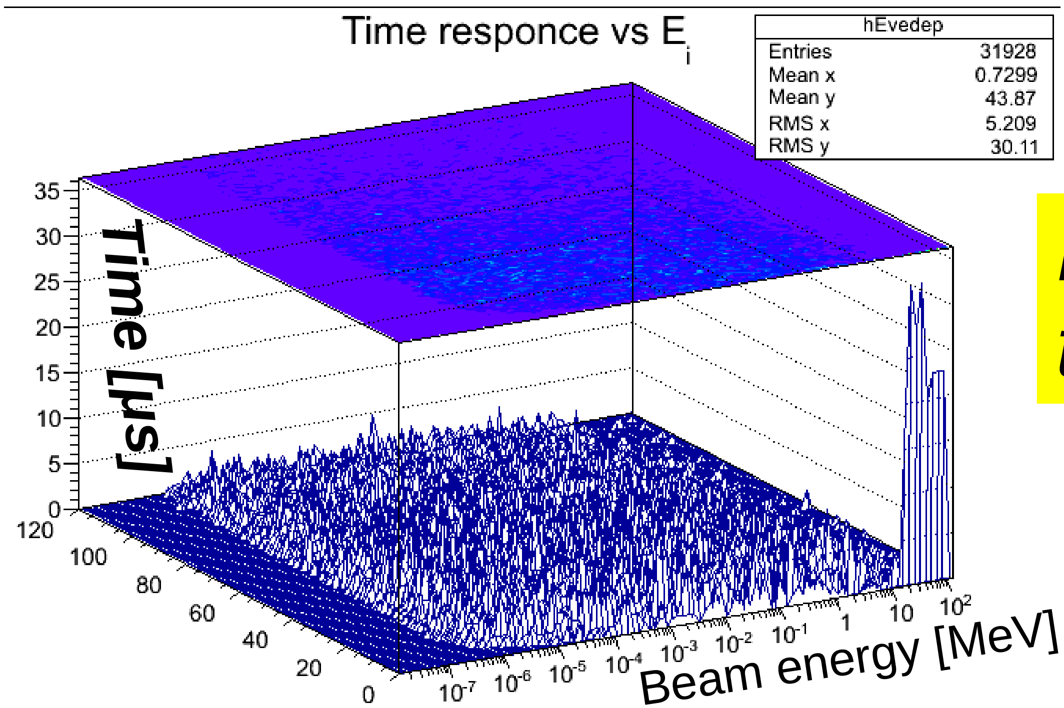
Initial Energy
h1
Entries 1000001
Mean 4.823
RMS 14.76
Beam energy
Recorded energy
[MeV]
energy deposition
hedep
Entries 31615
Mean 0.3104
RMS 0.1799
Total Eff. = 3.2%
Threshold > 10 keV
[MeV]
GEANT
+4cm POLY
Efficiency
h3
Entries 3
Mean 0.5719
RMS 4.234
Efficiency %
Beam Energy
[MeV]
energy deposition vs E_i
hEvedep
Entries 31615
Mean x 0.5694
Mean y 0.3104
RMS x 4.258
RMS y 0.1797

+4cm POLY

- ***Threshold > 10 keV***

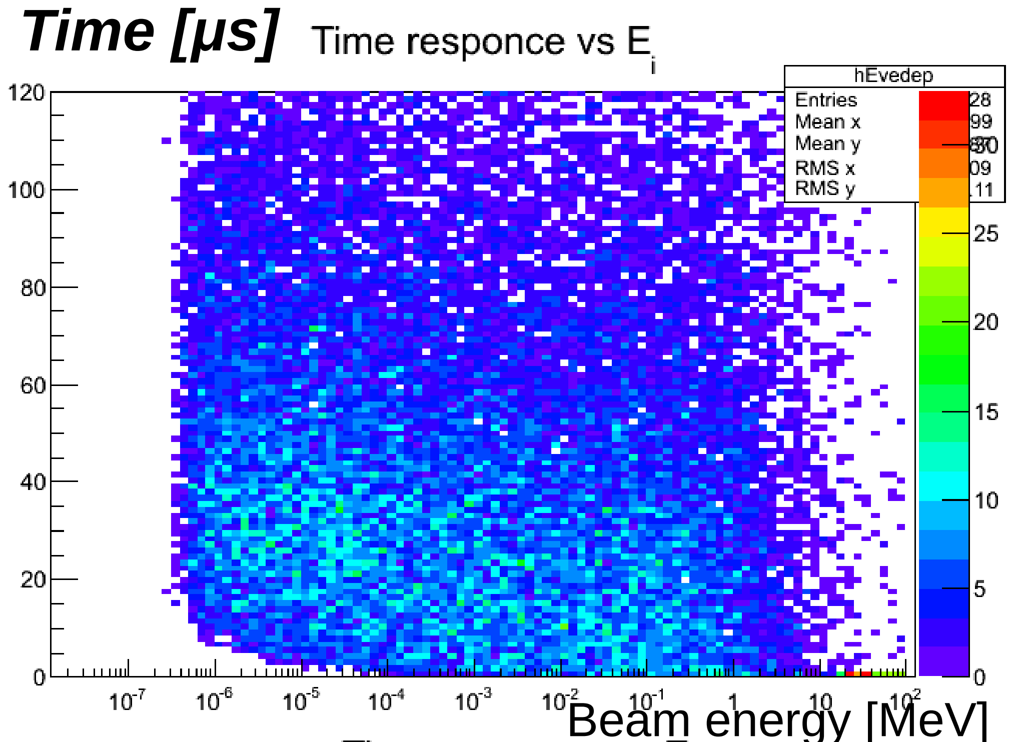


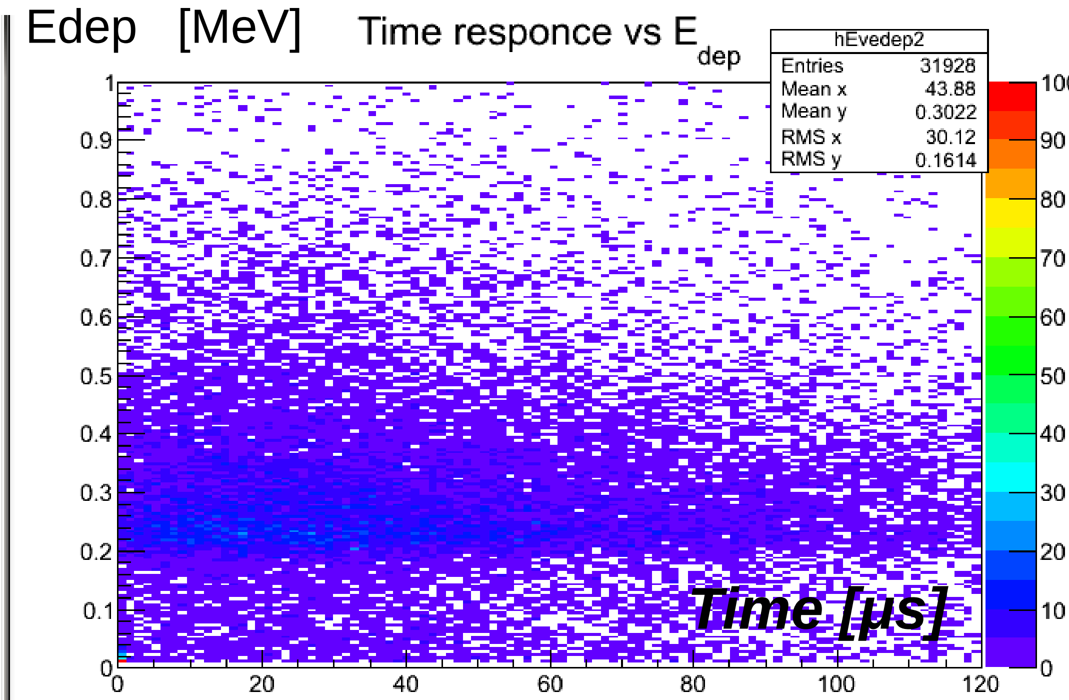


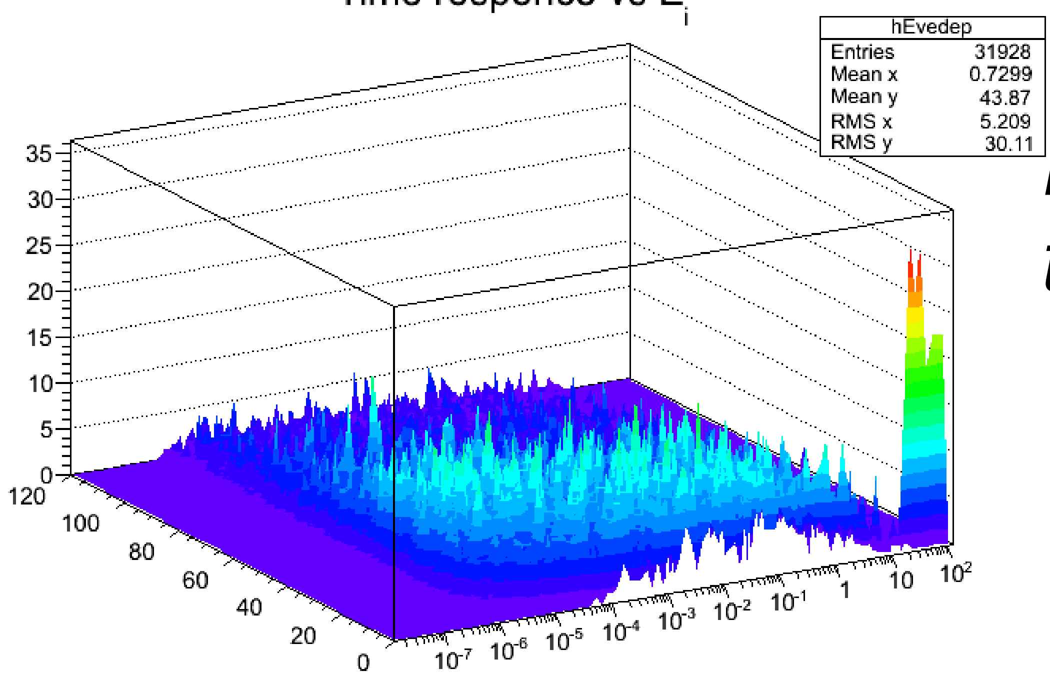


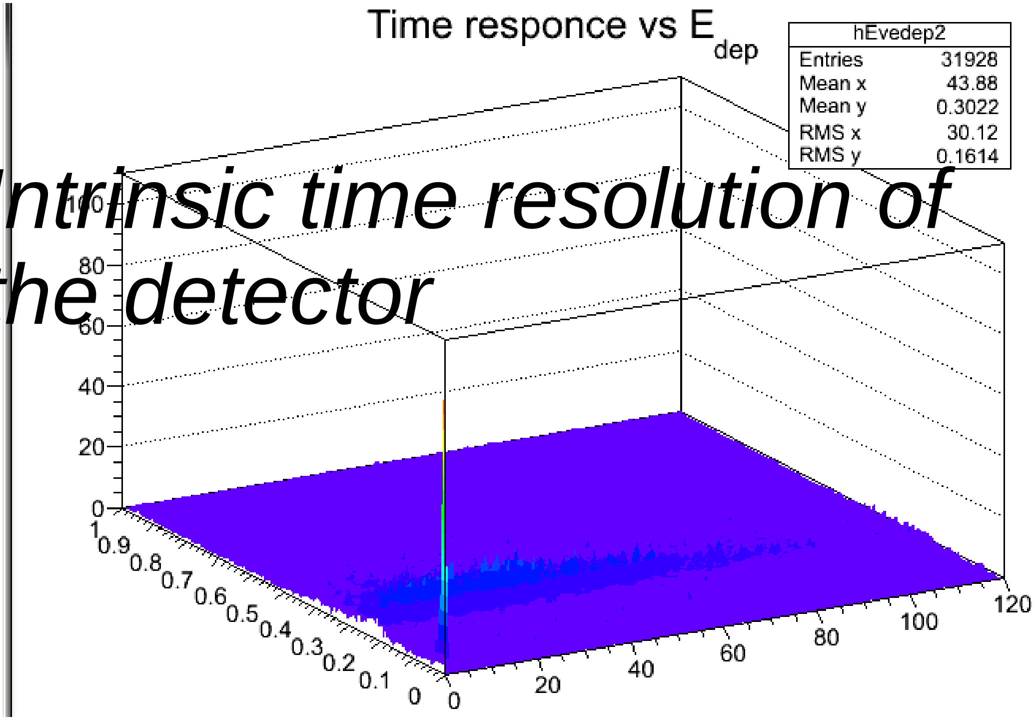
Intrinsic time resolution of the detector

- ***Threshold > 10 keV***



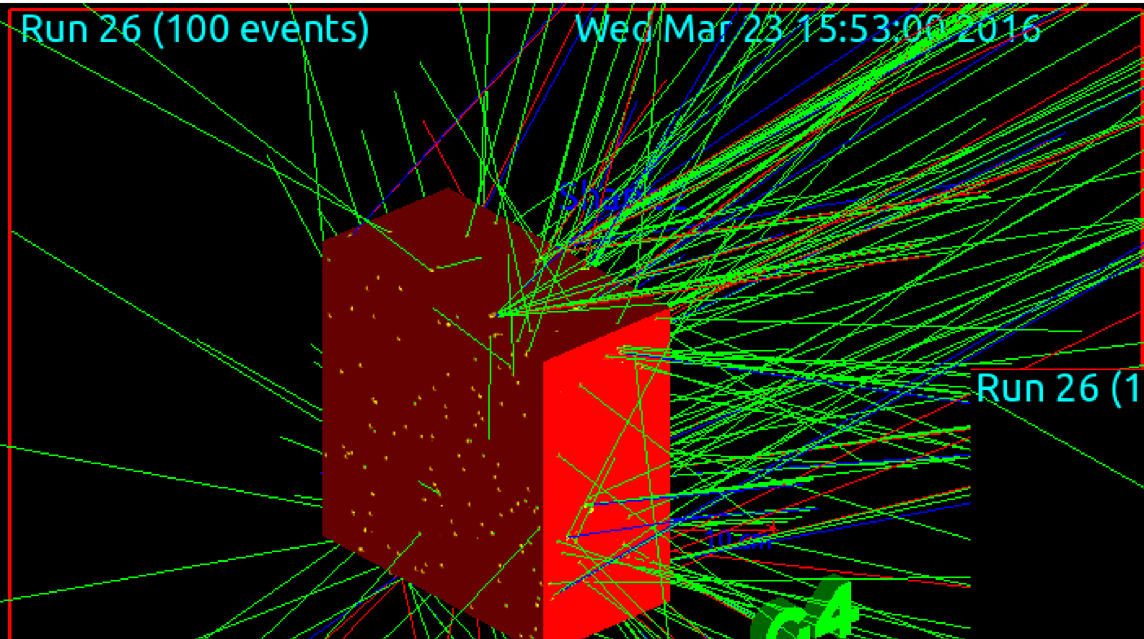


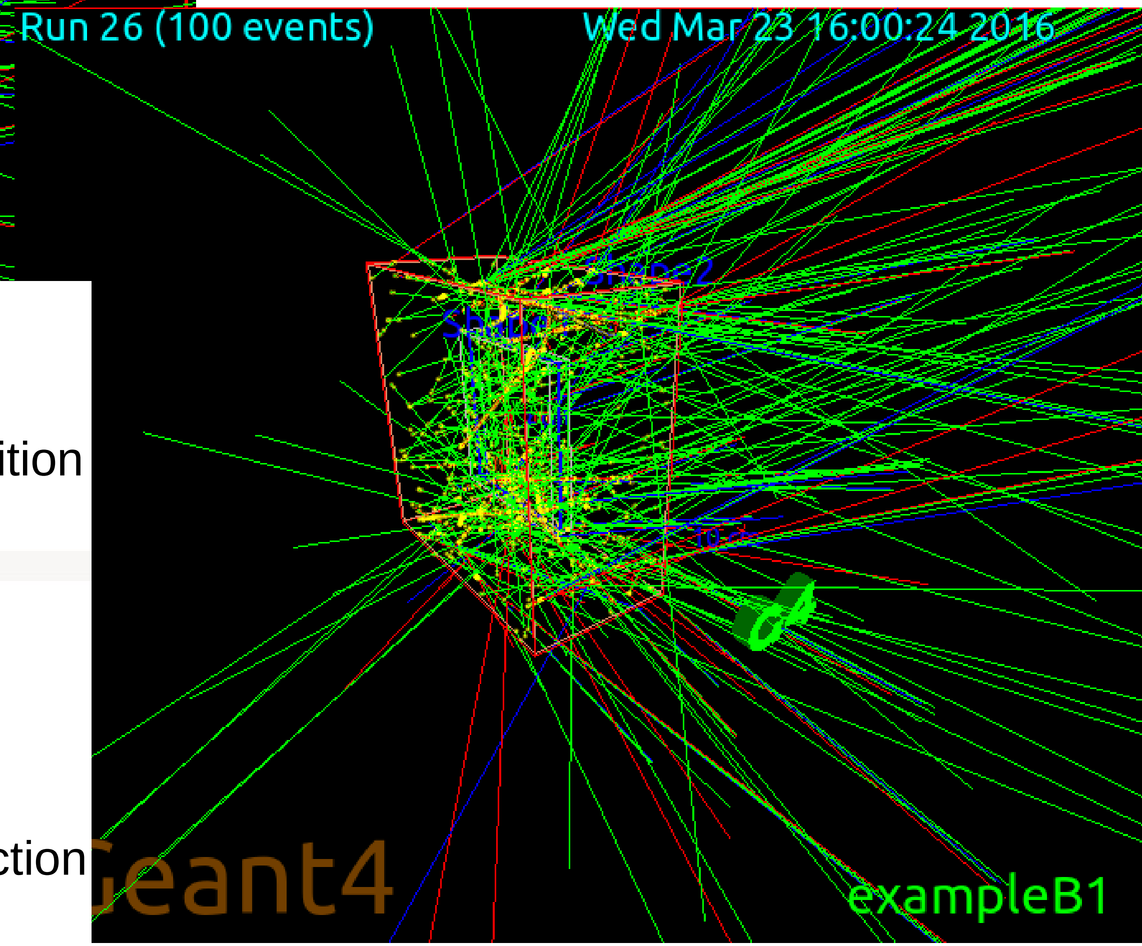




Intrinsic time resolution of the detector

100 gamma ~ 1GeV random isotropic for visualization – test!





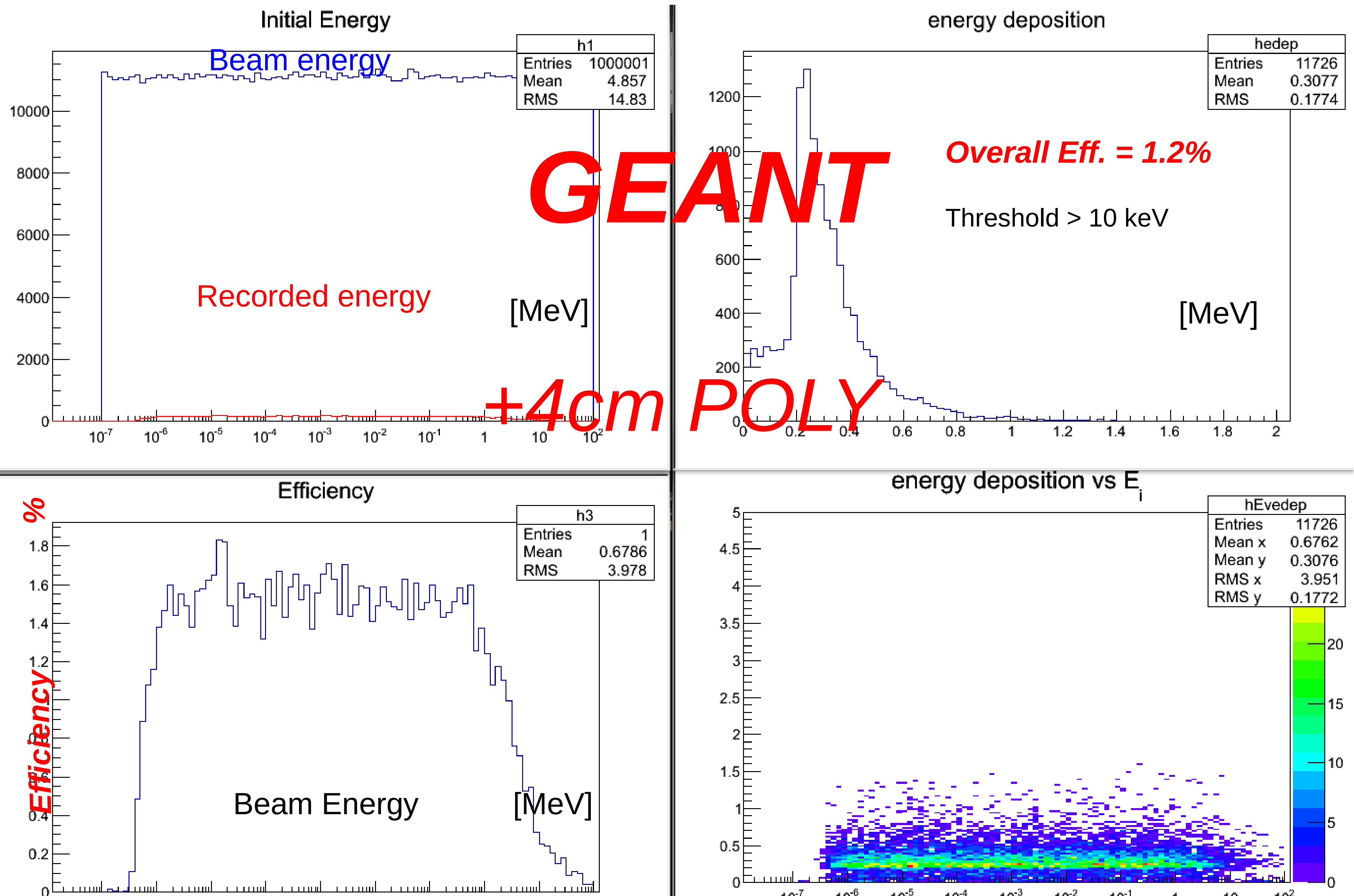

```
double x=0.,y=0.,z=0.;

double sourceL= -91.0*mm;
double zdist = -46.01*mm;

    x= (G4UniformRand()-0.5) * 2.* sourceL;
    y= (G4UniformRand()-0.5) * 2.* sourceL;
    z= zdist;
```

Source position

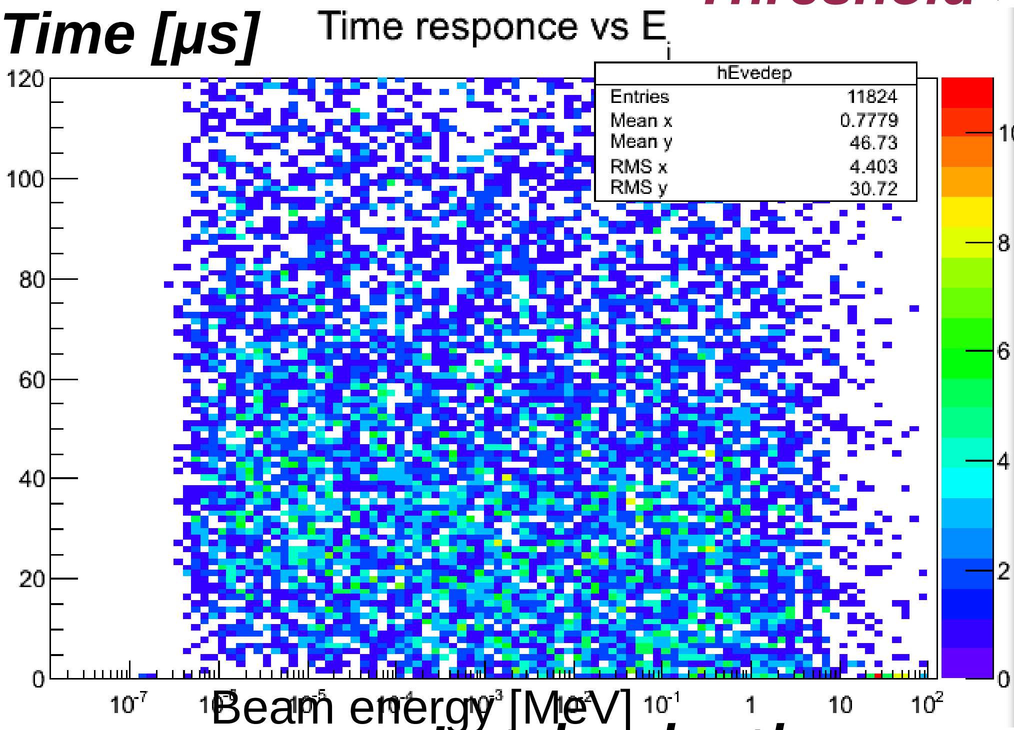
```
  G4ThreeVector position = G4ThreeVector(x,y,z);
  particleGun->SetParticlePosition(position);


G4double phi = G4UniformRand() * 2.*CLHEP::pi;
G4double sintheta = 2.*(G4UniformRand()-0.5);

double   px = sintheta*cos(phi);
double   py = sintheta*sin(phi);
double   pz = sqrt(1.-sintheta*sintheta);
```

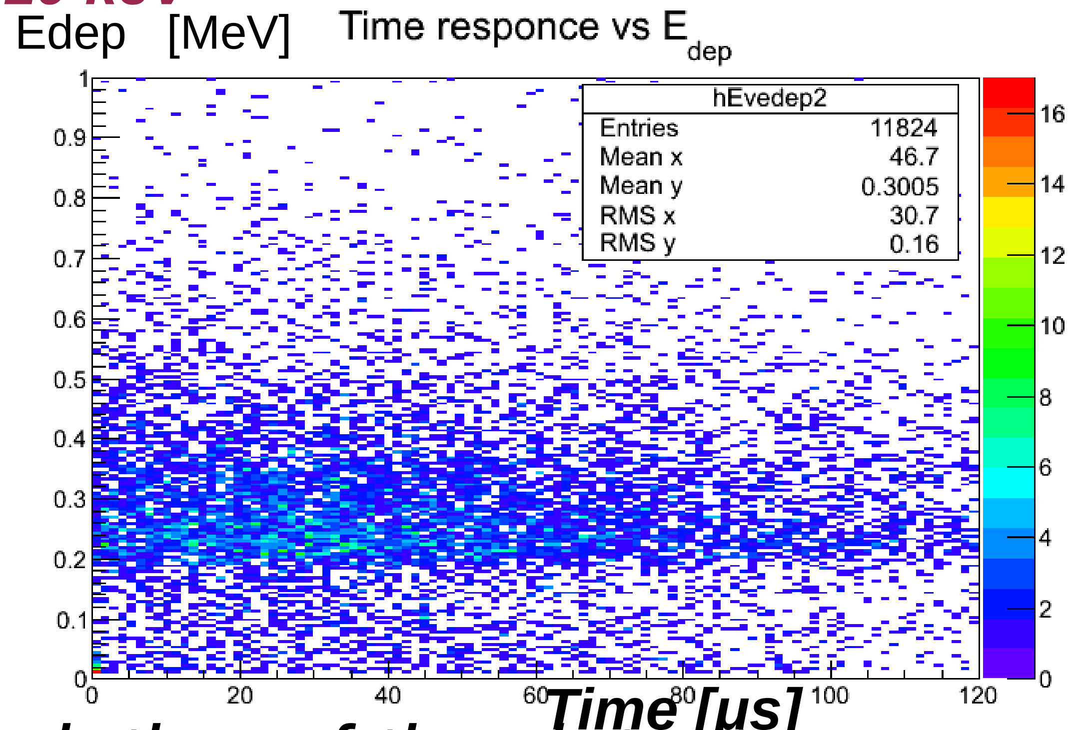
Mom. direction

```
  //   double px = (G4UniformRand()-0.5)*mm;
//   double py = (G4UniformRand()-0.5)*mm;
 //  double pz = 10.*mm;

   particleGun->SetParticleMomentumDirection(G4ThreeVector(px,py,pz));
```

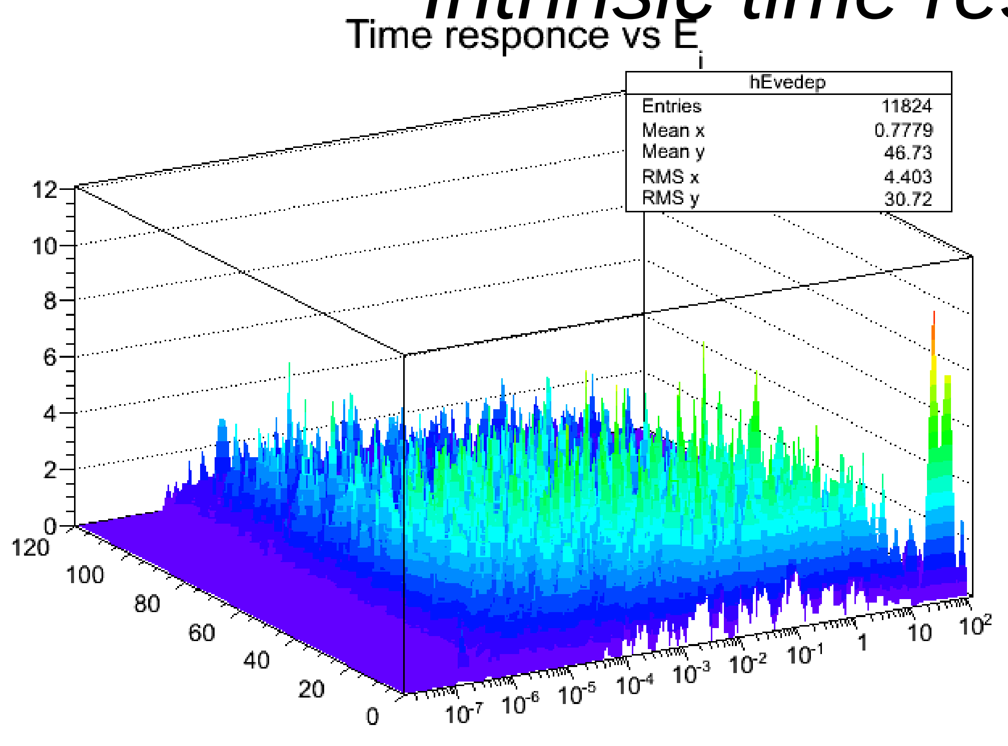

GEANT
+4cm POLY
Initial Energy
Beam energy
Recorded energy
[MeV]
h1
Entries 1000001
Mean 4.857
RMS 14.83
energy deposition
hedep
Entries 11726
Mean 0.3077
RMS 0.1774
Overall Eff. = 1.2%
Threshold > 10 keV
[MeV]
Efficiency
%
Efficiency
Beam Energy
[MeV]
h3
Entries 1
Mean 0.6786
RMS 3.978
energy deposition vs E_i
hEvedep
Entries 11726
Mean x 0.6762
Mean y 0.3076
RMS x 3.951
RMS y 0.1772

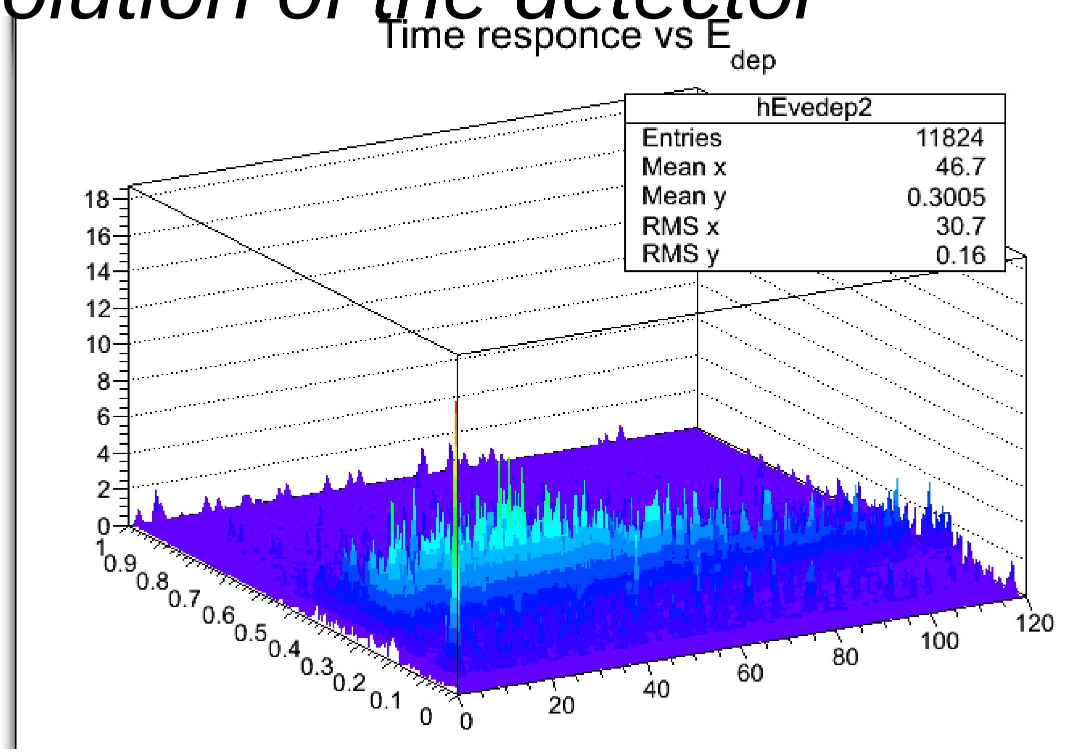
- ***Threshold > 10 keV***





Intrinsic time resolution of the detector



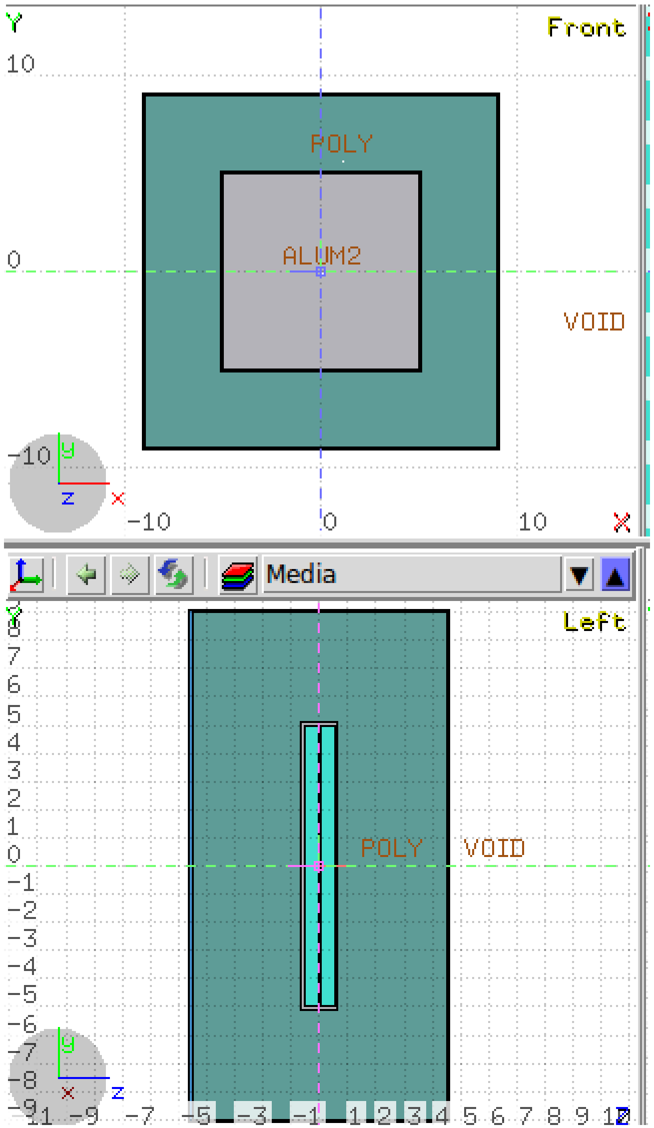


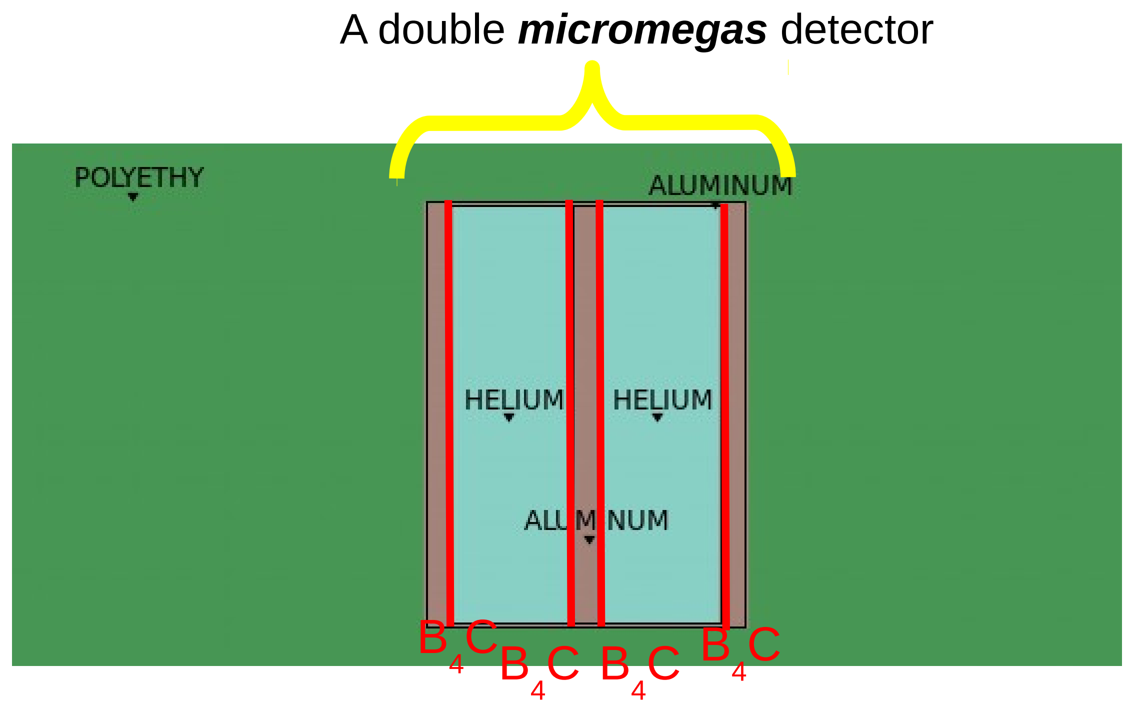
Summary

- A new type of BLM based on a double Micromegas readout is proposed equipped with 2 x B_4C layers, 2 gas drift volumes (Helium)
- Simulations show that we could record detection efficiencies ~ 5-6% for neutrons *(1 eV – 1 MeV)*
- This detection set-up, is completely insensitive to thermal neutrons and gammas (10 keV – 10 MeV)
- Both codes FLUKA / Geant4 agree...
- Time response of this BLM is estimated: ~20µs at low energies

Back-up slides

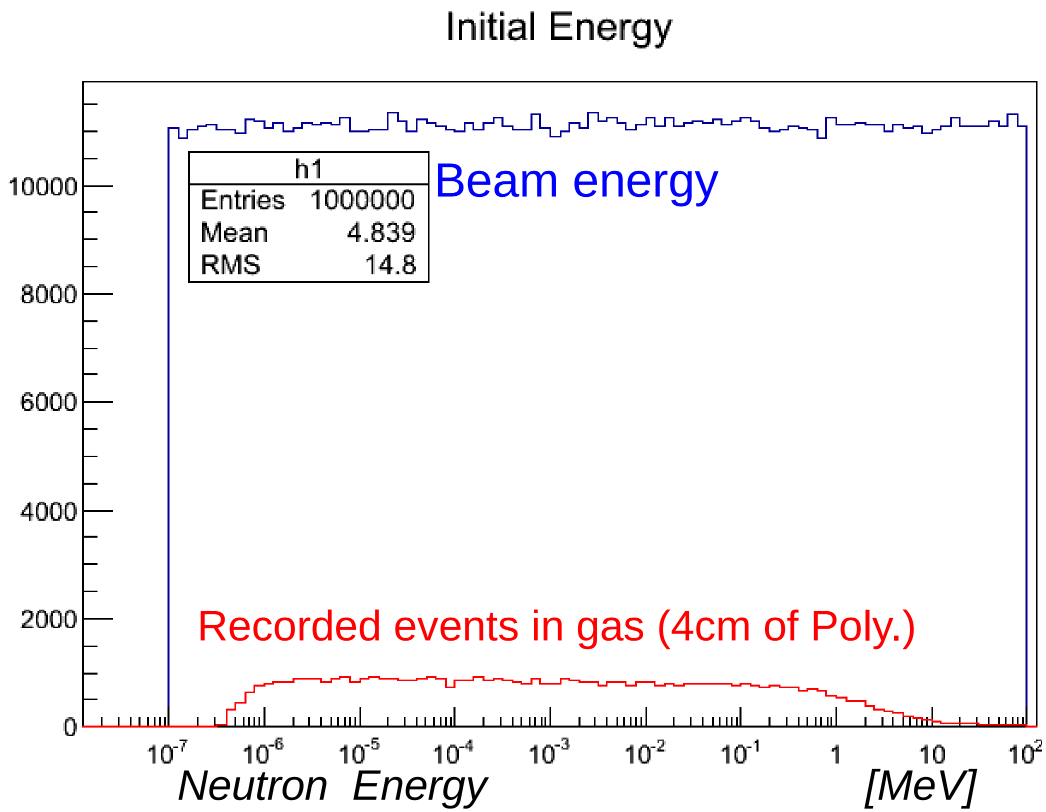
Model with 4 x B_4C layers + 4cm POLY

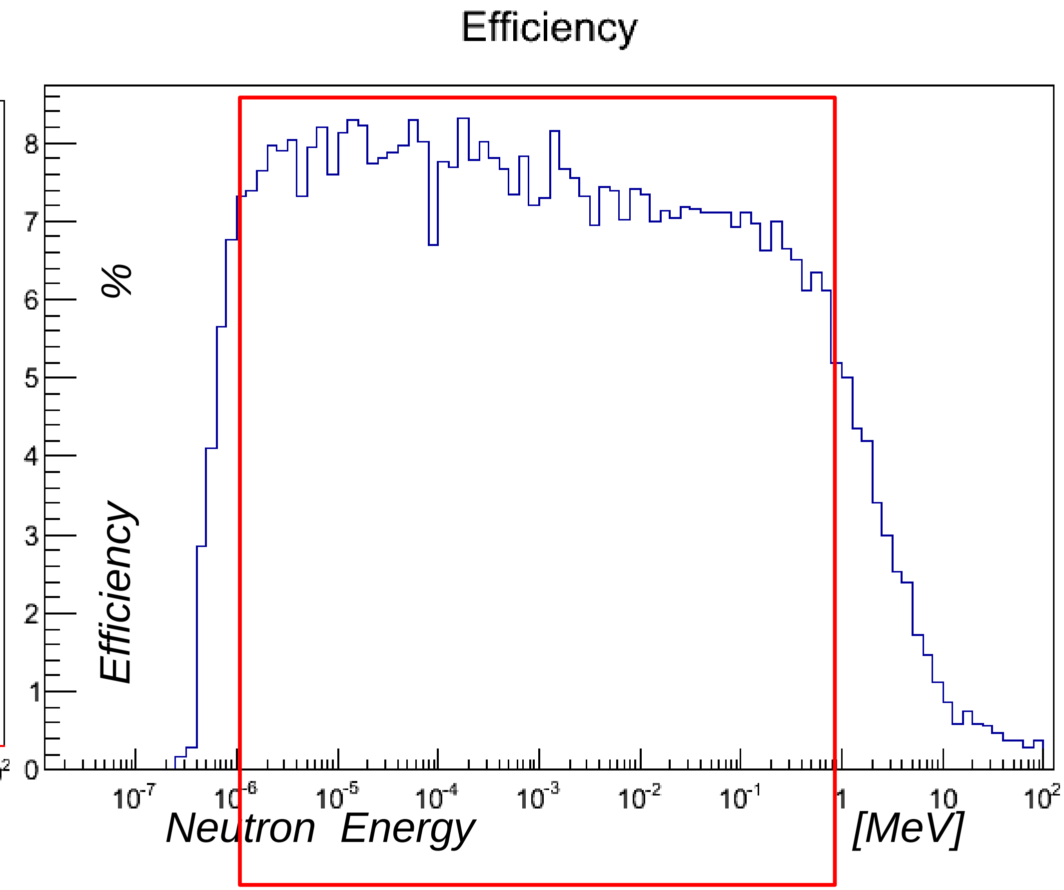


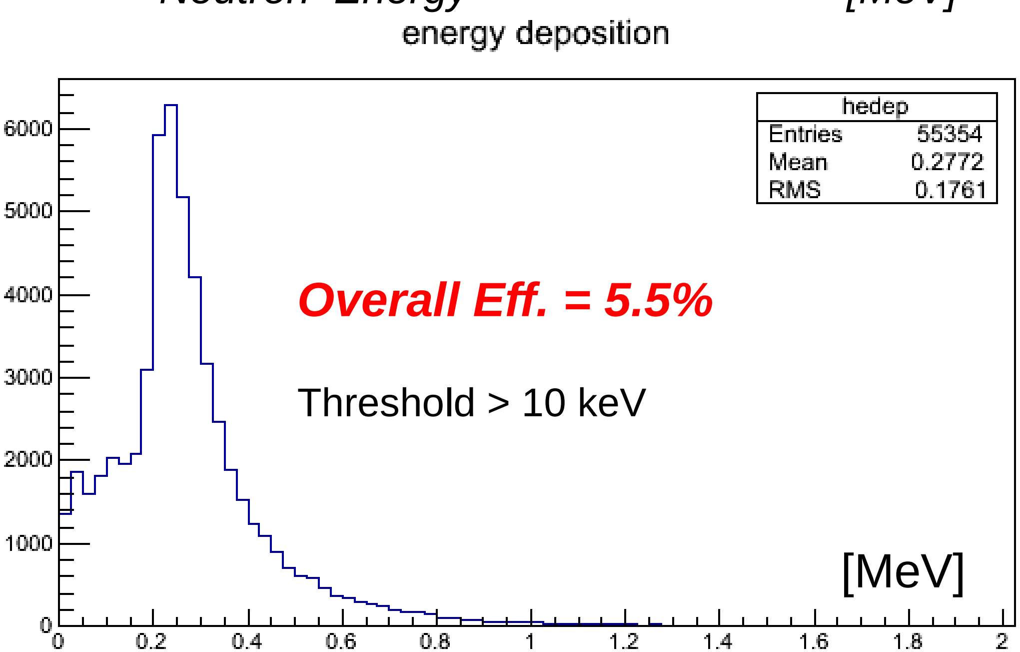


- Adding 2 more layers of B_4C (2µ thick each) in order to increase the neutron detection efficiency

Model with 4 x B_4C layers + 4cm POLY

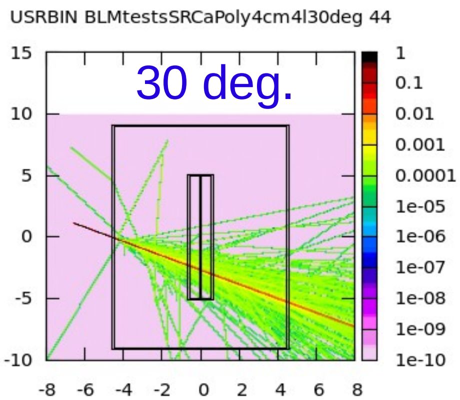


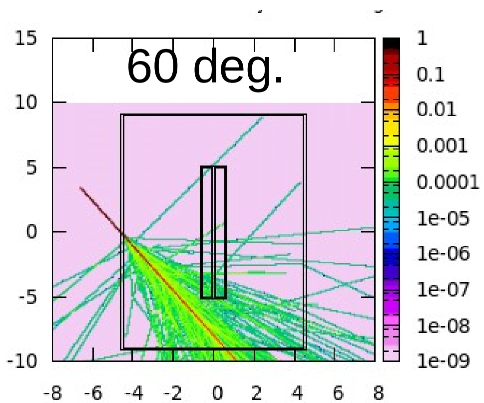


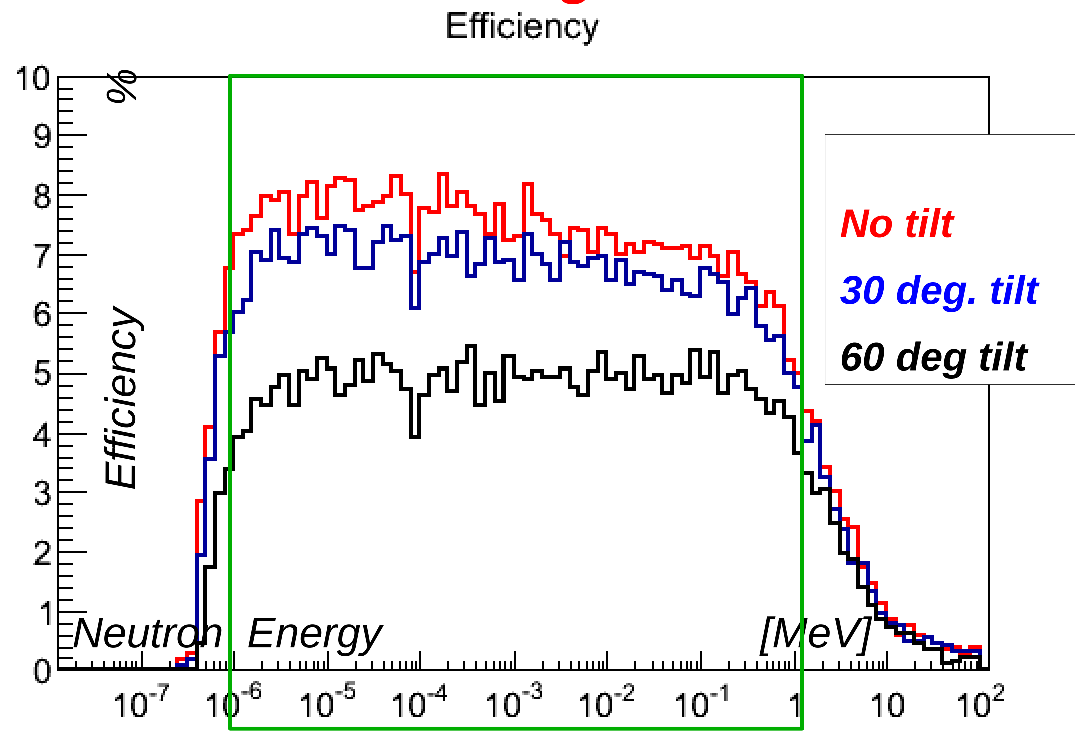


- *For neutrons with energy: (**1 eV – 1 MeV**), the recorded efficiency for a 4xB_4C layer double micromegas detector is **7-8%** (4cm of Poly.).*

Model with 4 x B_4C layers + 4cm POLY + 30/60 deg. tilt of beam

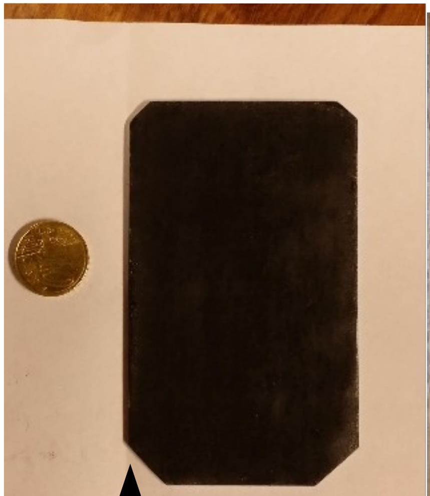




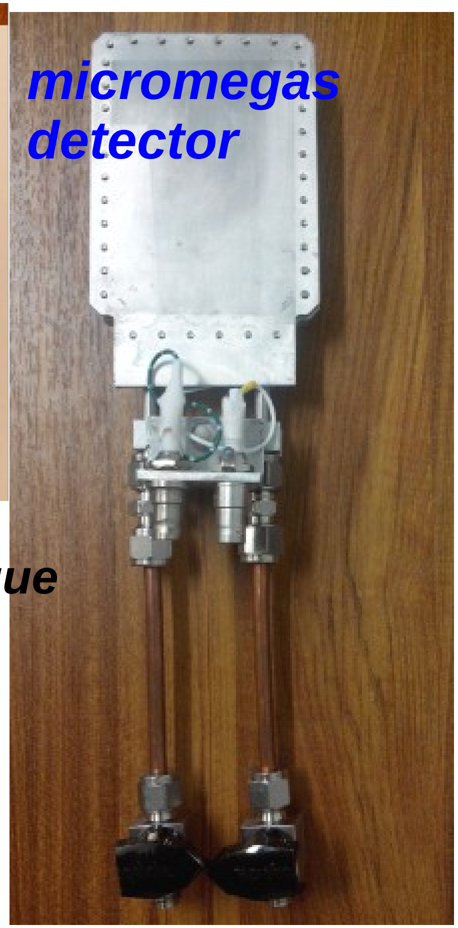


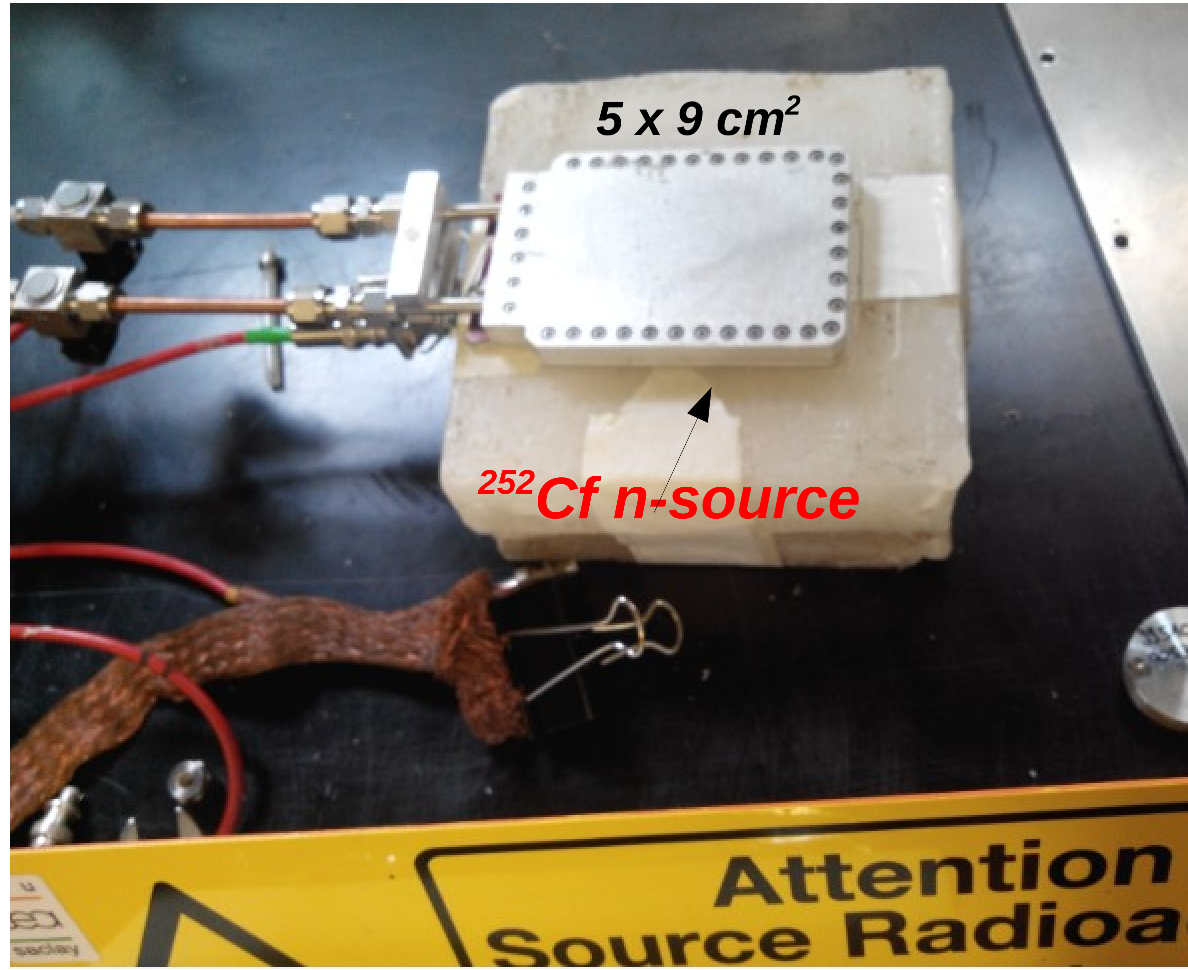
- *For neutrons with energy: (**1 eV – 1 MeV**), the recorded efficiency for a 4xB_4C layer double micromegas detector is **7-8%** (4cm of Poly.) for a perpendicular n beam*
- ***6-7%** for a perpendicular n beam at 30 degrees direction*
- ***4-5%** for a perpendicular n beam at 60 degrees direction*

Tests at CEA – simplified reference geometry
Benchmark for simulations



B_4C coated Al plaque at CEA





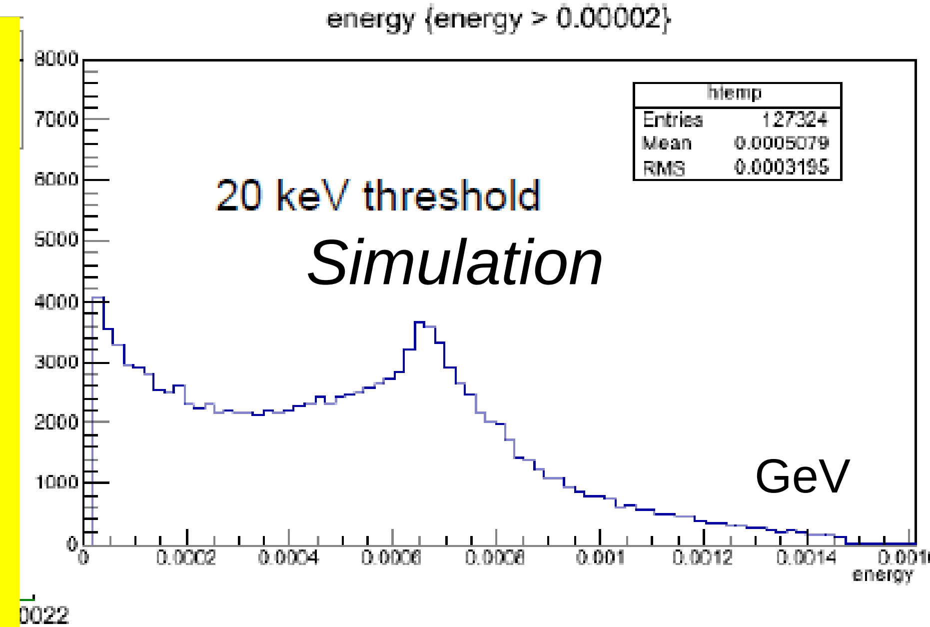
Ne-C_2H_6 (90-10%)

- ***Anode Voltage: +480V***
- ***Mesh Voltage: +200V***
- ***Drift (B_4C plate) Voltage: at ground***

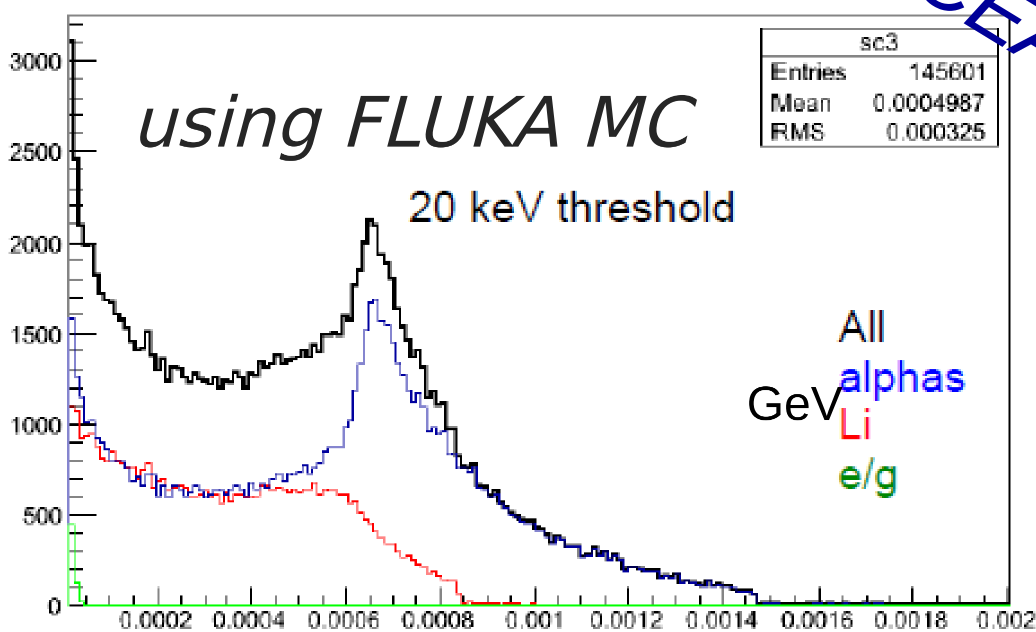
- ***Seal mode operation > 2months! (No gas circulation...)***

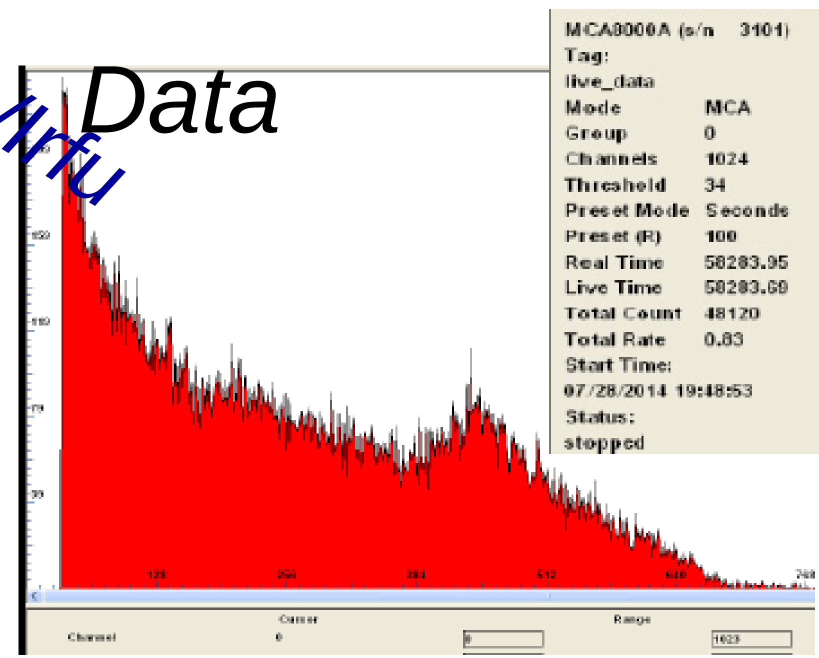
Simulation vs Data

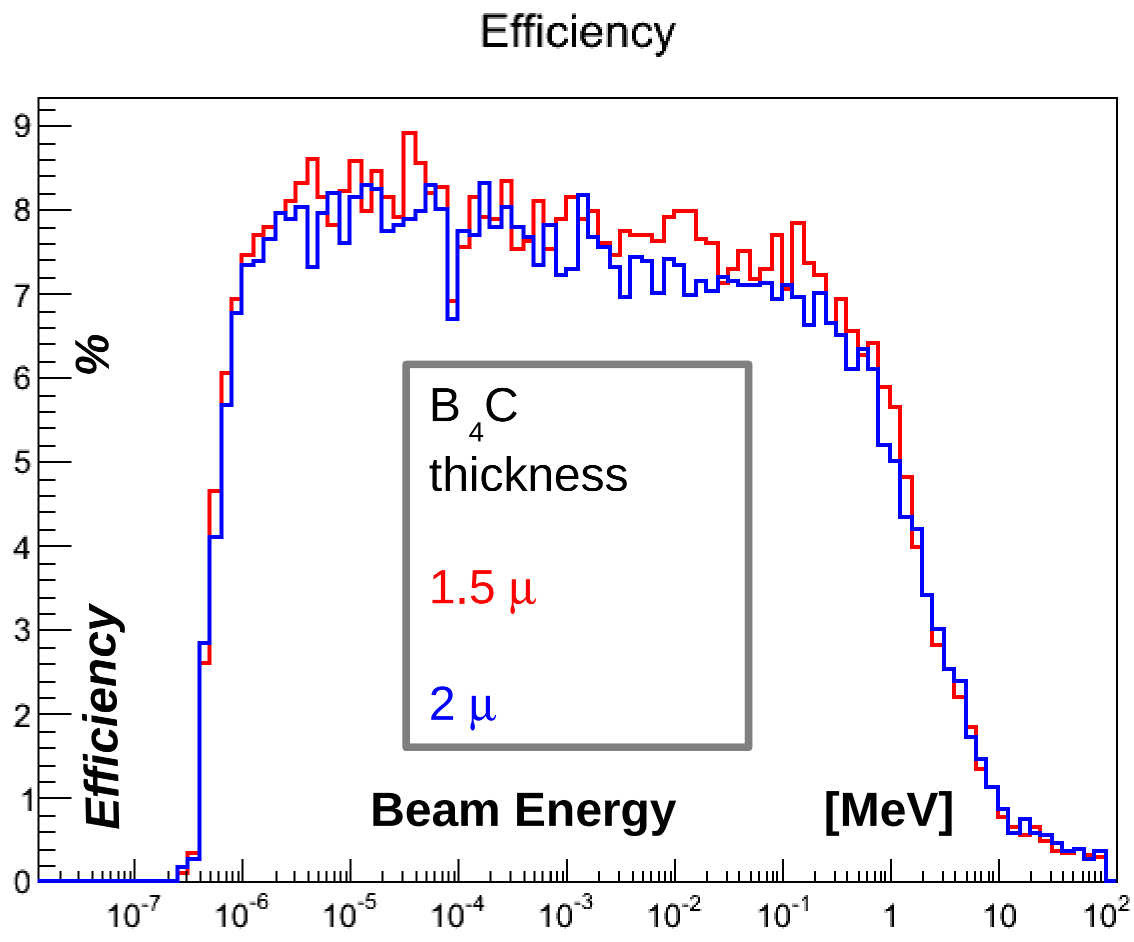
- With the calibrated window (1in.x1in.) made of Boron, the efficiency of micromegas compared to He3 tube is : ***5.05%*** (AmBe source).
- With micromegas directly in a neutron generator, the efficiency of micromegas compared to He3 tube is : ***4.3% (At Schumberger lab)***.
- Good agreement with simulations



At CEA/Irfu





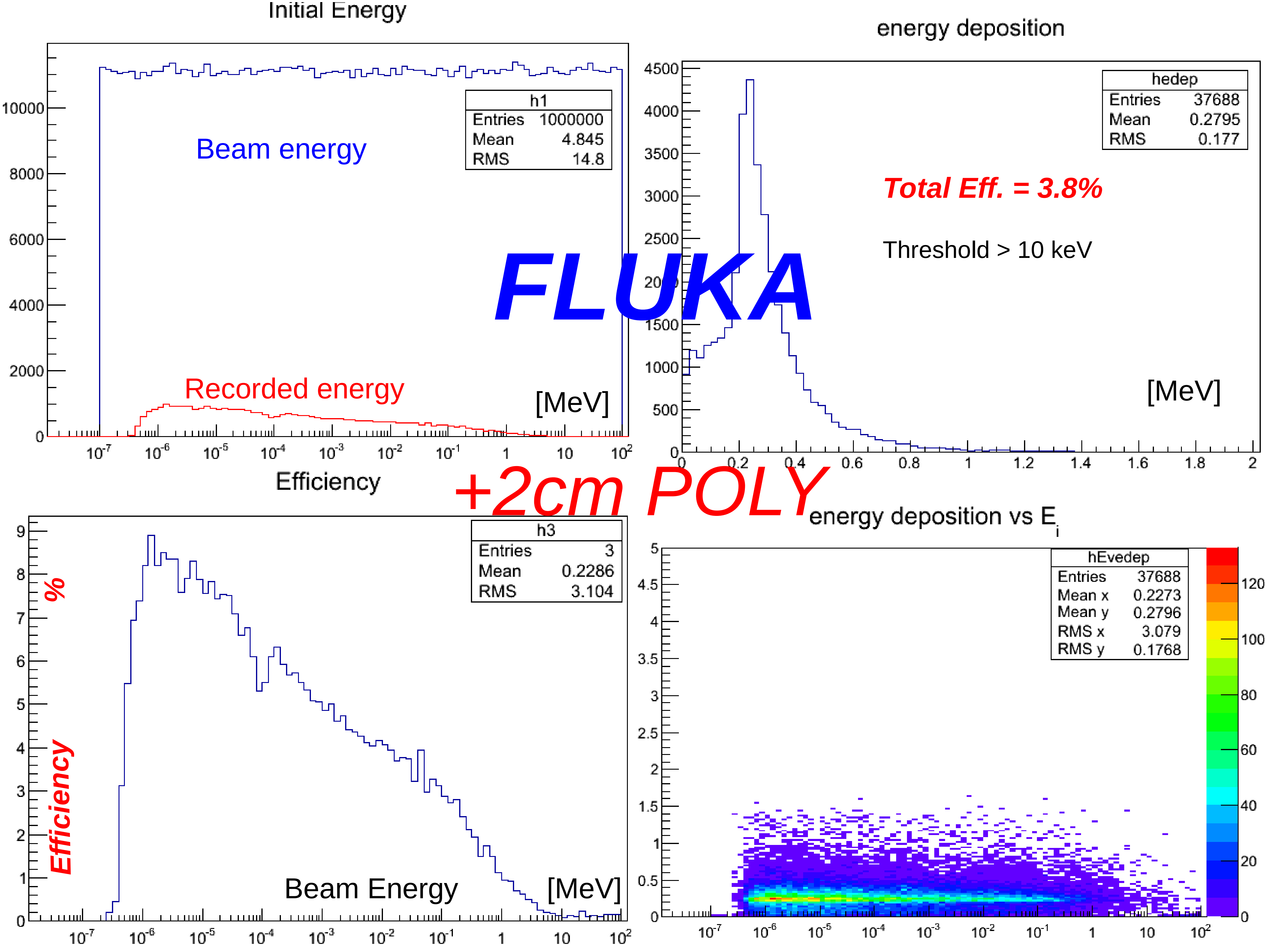


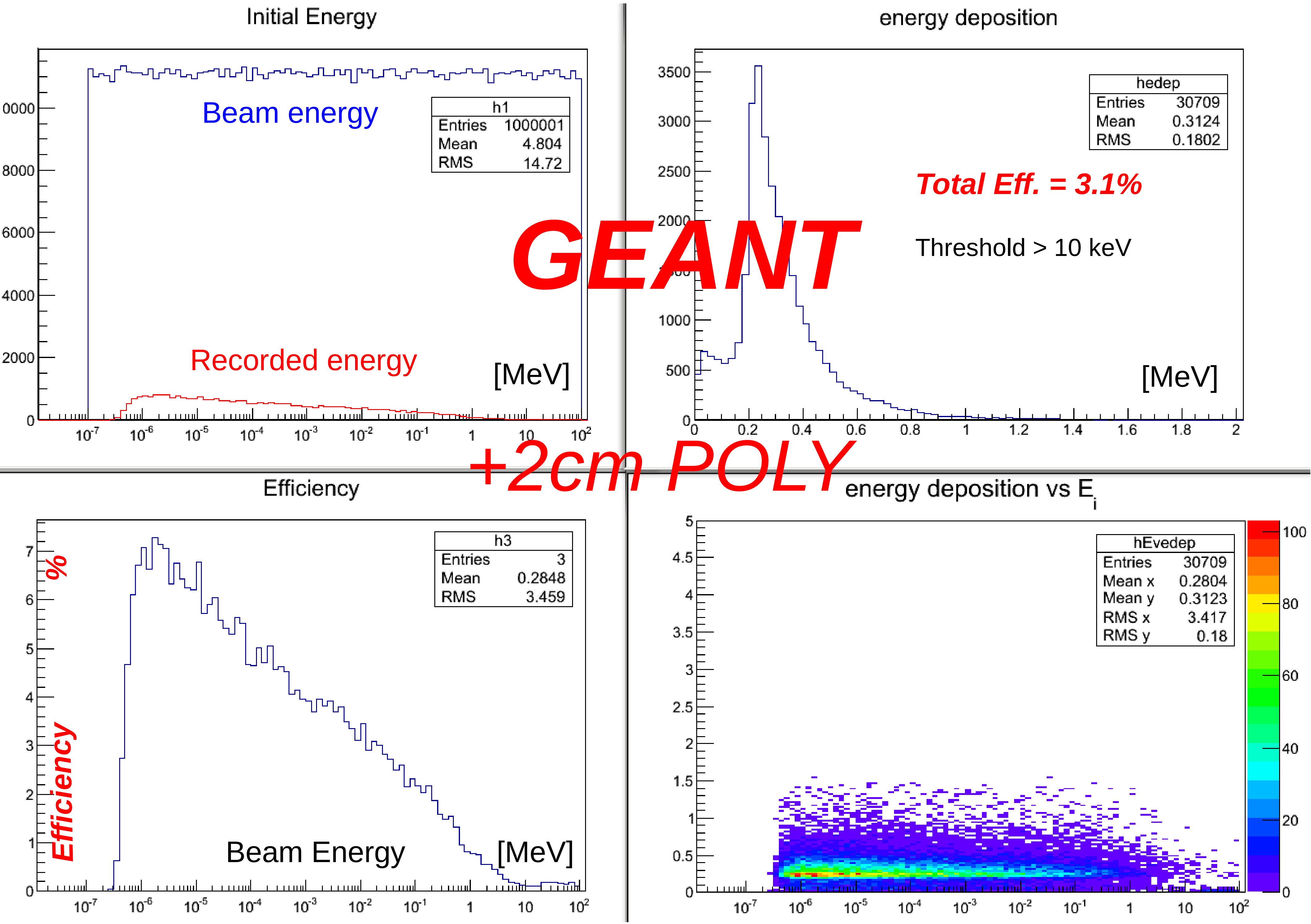
Efficiency
Efficiency %
B4C thickness
1.5 μ
2 μ
Beam Energy [MeV]
0
1
2
3
4
5
6
7
8
9
10-7
10-6
10-5
10-4
10-3
10-2
10-1
1
10
102

4 B_4C layers

FLUKA geometry

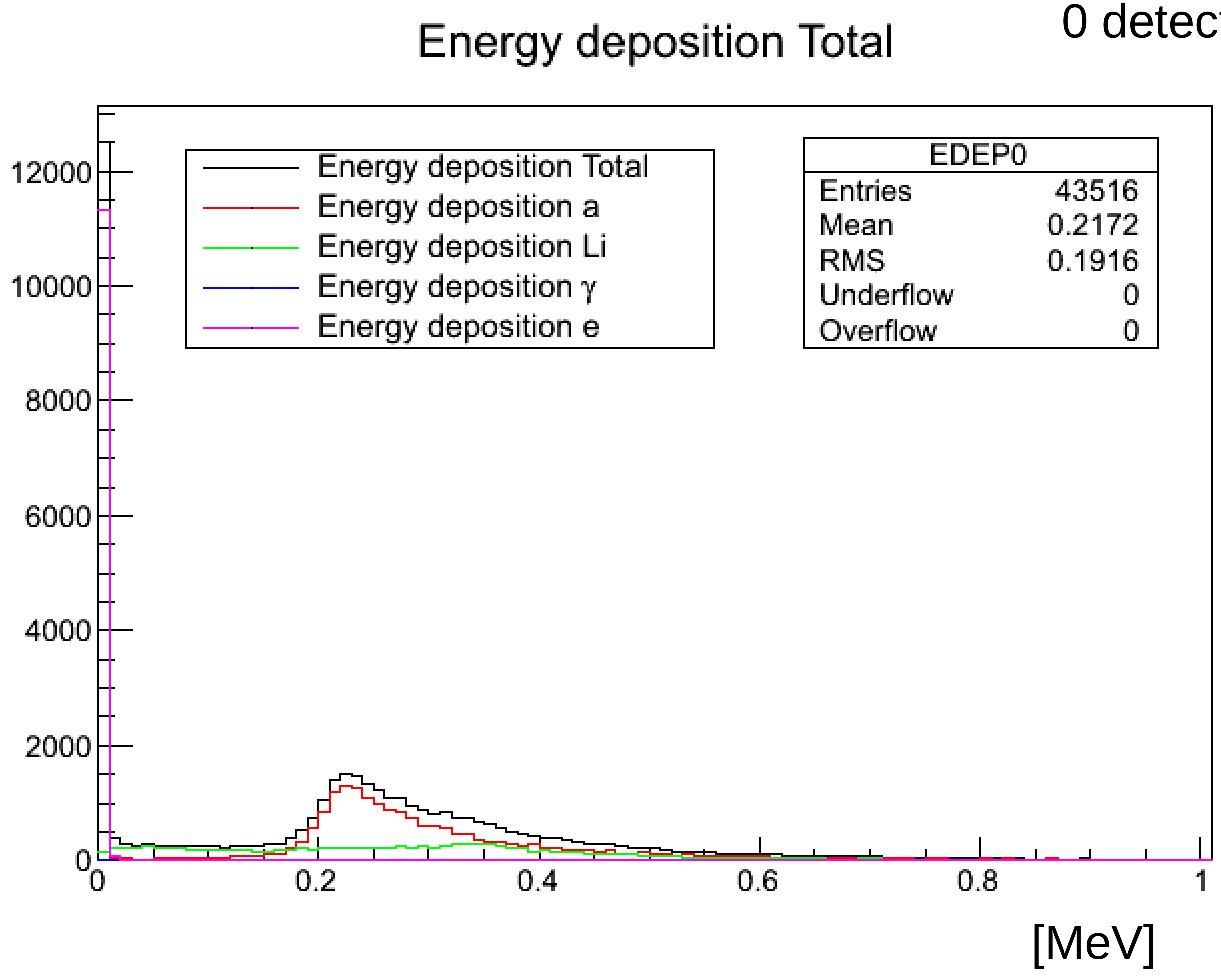
SPH	blkbody	x: 0.0 R: 100000.0	y: 0.0
SPH	void	x: 0.0 R: 10000.0	y: 0.0
RPP	Cadmi	Xmin: -9.10 Ymin: -9.10 Zmin: -4.6	Xmax: 9.10 Ymax: 9.10 Zmax: 4.6
RPP	Poly	Xmin: -9.00 Ymin: -9.00 Zmin: -4.5	Xmax: 9.00 Ymax: 9.00 Zmax: 4.5
RPP	Alum1	Xmin: -5.10 Ymin: -5.10 Zmin: -0.6502	Xmax: 5.10 Ymax: 5.10 Zmax: 0.6502
RPP	Conv1	Xmin: -5.00 Ymin: -5.00 Zmin: -0.5502	Xmax: 5.00 Ymax: 5.00 Zmax: -0.55
RPP	Gas1	Xmin: -5.00 Ymin: -5.00 Zmin: -0.55	Xmax: 5.00 Ymax: 5.00 Zmax: -0.05
RPP	Alum2	Xmin: -5.00 Ymin: -5.00 Zmin: -0.05	Xmax: 5.00 Ymax: 5.00 Zmax: 0.05
RPP	Gas2	Xmin: -5.00 Ymin: -5.00 Zmin: 0.05	Xmax: 5.00 Ymax: 5.00 Zmax: 0.55
RPP	Conv2	Xmin: -5.00 Ymin: -5.00 Zmin: 0.55	Xmax: 5.00 Ymax: 5.00 Zmax: 0.5502


Initial Energy
h1
Entries 1000000
Mean 4.845
RMS 14.8
Beam energy
Recorded energy
[MeV]
energy deposition
hedep
Entries 37688
Mean 0.2795
RMS 0.177
Total Eff. = 3.8%
Threshold > 10 keV
[MeV]
FLUKA
+2cm POLY
Efficiency
h3
Entries 3
Mean 0.2286
RMS 3.104
%
Efficiency
Beam Energy
[MeV]
energy deposition vs E_i
hEvedep
Entries 37688
Mean x 0.2273
Mean y 0.2796
RMS x 3.079
RMS y 0.1768

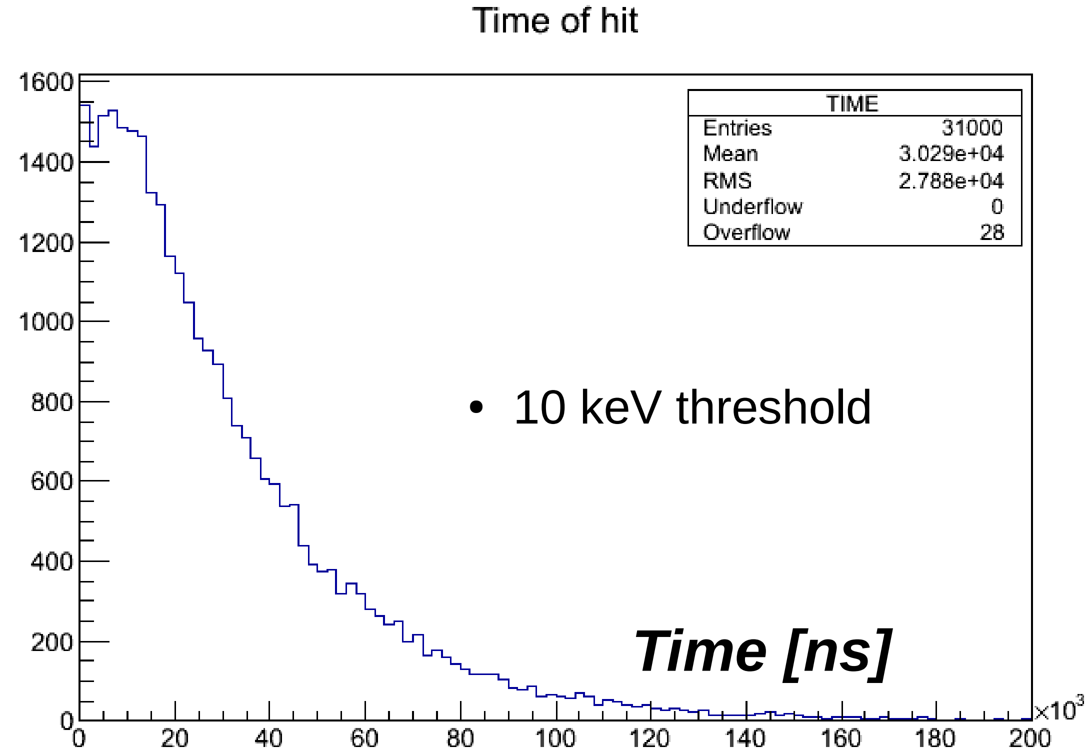


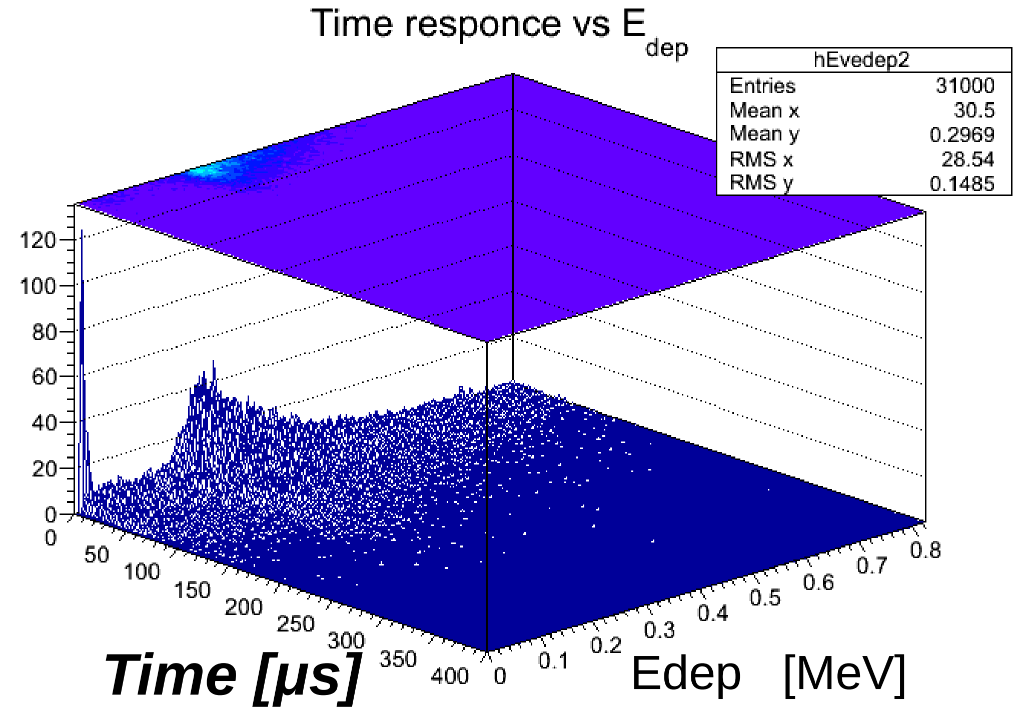
Initial Energy
Beam energy
h1
Entries 1000001
Mean 4.804
RMS 14.72
Recorded energy
[MeV]
energy deposition
hedep
Entries 30709
Mean 0.3124
RMS 0.1802
Total Eff. = 3.1%
Threshold > 10 keV
[MeV]
GEANT
+2cm POLY
Efficiency
h3
Entries 3
Mean 0.2848
RMS 3.459
%
Efficiency
Beam Energy
[MeV]
energy deposition vs E_i
hEvedep
Entries 30709
Mean x 0.2804
Mean y 0.3123
RMS x 3.417
RMS y 0.18

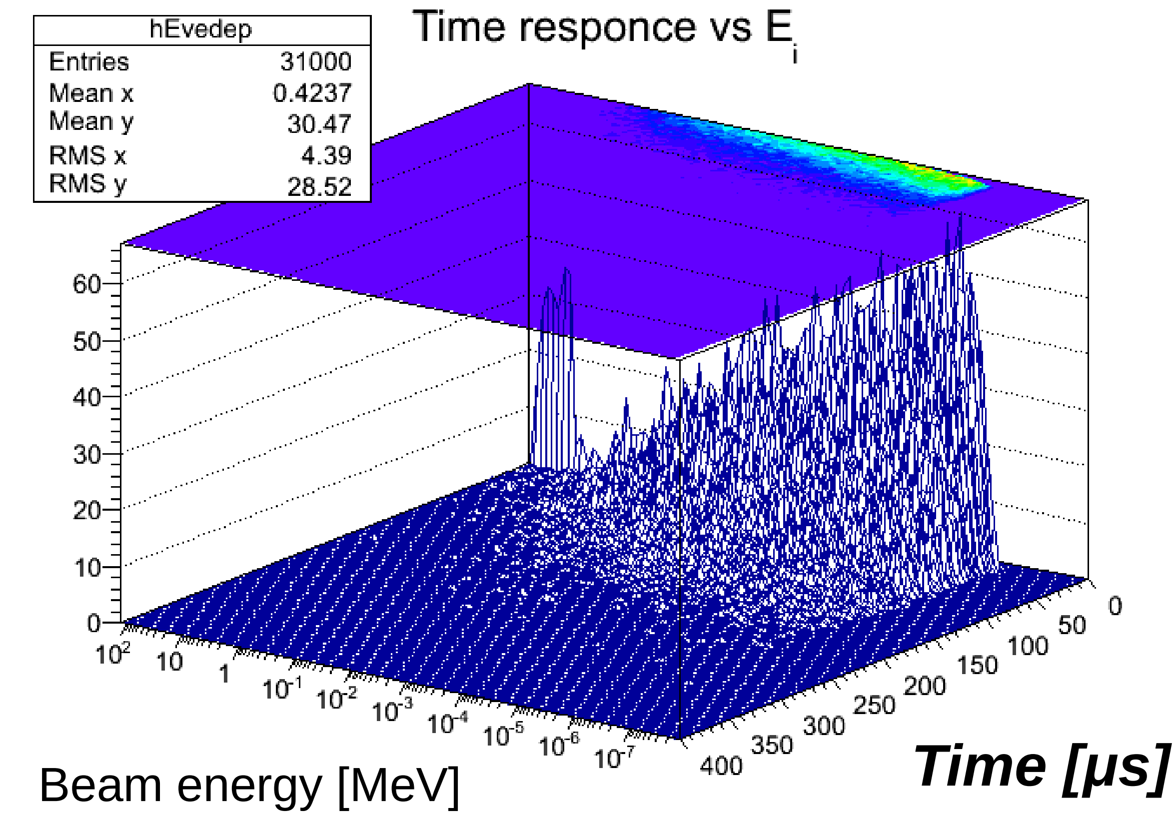
0 detection threshold



- ***Threshold > 10 keV***







- ***Threshold > 10 keV***