University of Padova

Department of Physics

Signal simulations in silicon detectors

A simplified approach

GASPARD-HYDE-TRACE workshop 10/29-31/2012

Leonardo Pigatto – *leonardo.pigatto@studenti.unipd.it*

Introduction

- improve spatial resolution using transient signals
- better measure of the ion-γ angle
- improve Doppler correction
- improve detection overall efficiency by discriminating particles

OBJECTIVE

Simulate signals and extrapolate useful information for particle identification

Framework

AGATA Detector Library - ADL3

Applying to plane silicon detectors the techniques used for AGATA's Ge crystals

- Building the new geometry -> SIMION instruments
- Material characteristics *
- Particle interaction points -> trace discretization
- Running the simulation

*Jacoboni et al Solid State Electron. 20, 2(1977) 77-89

The model and its limits

Assumed equation for electron/hole currents:

->Drift only – diffusion to be included in future developments?

$$J = q\mu nE$$

Neither interactions between charges nor trapping phenomena considered

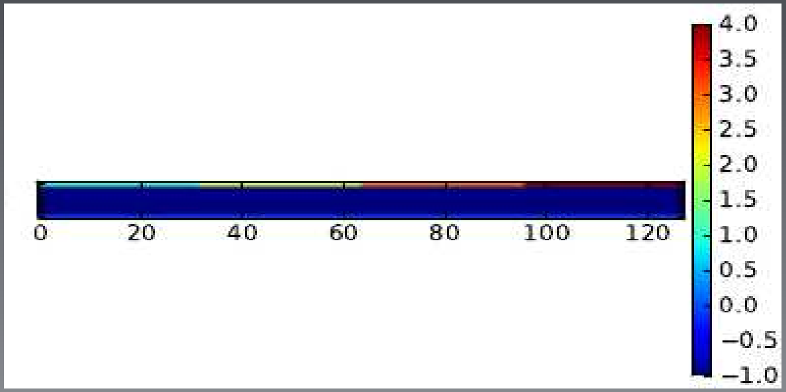
No interstrip is present between electrodes

The current in the k^{th} electrode is given by the weighting field through Ramo's theorem

$$I_k = -qvF_k$$

Geometry

Planar detector with 4 electrodes + core

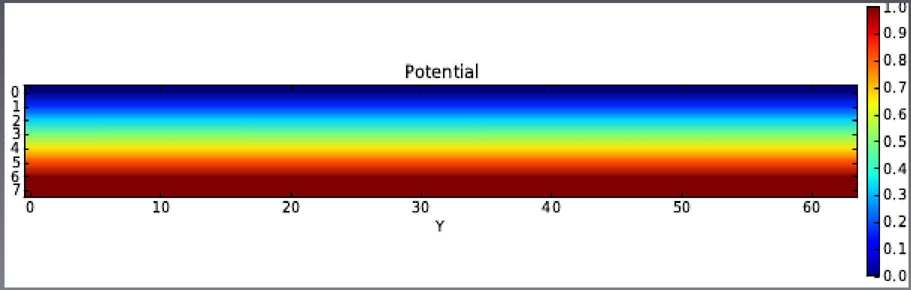


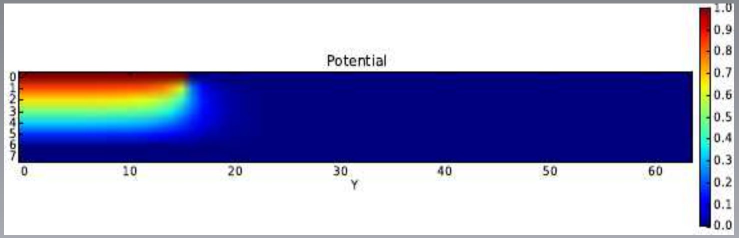
The weighting fields are calculated by applying a unitary potential on the k^{th} electrode and a zero potential to all the others

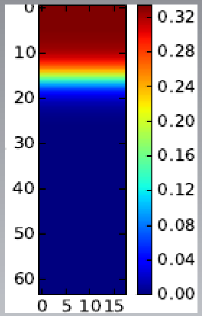
In the bulk the space charge distribution is calculated starting from a constant density (doping concentration)

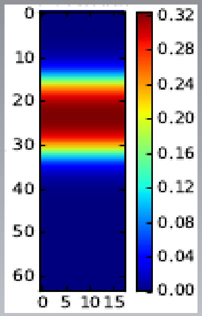
Weighting potentials obtained as solutions of the Laplace equation with the overrelaxation method

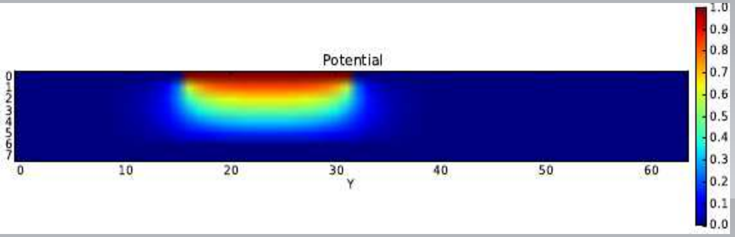
Scaling the potentials with a given factor the fields are calculated



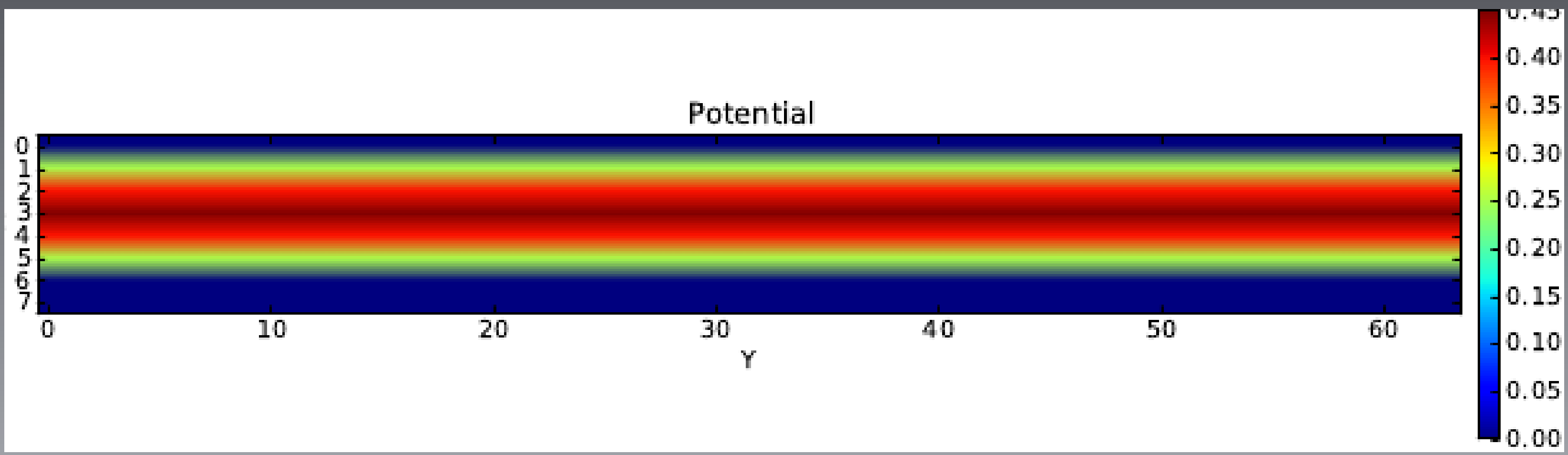






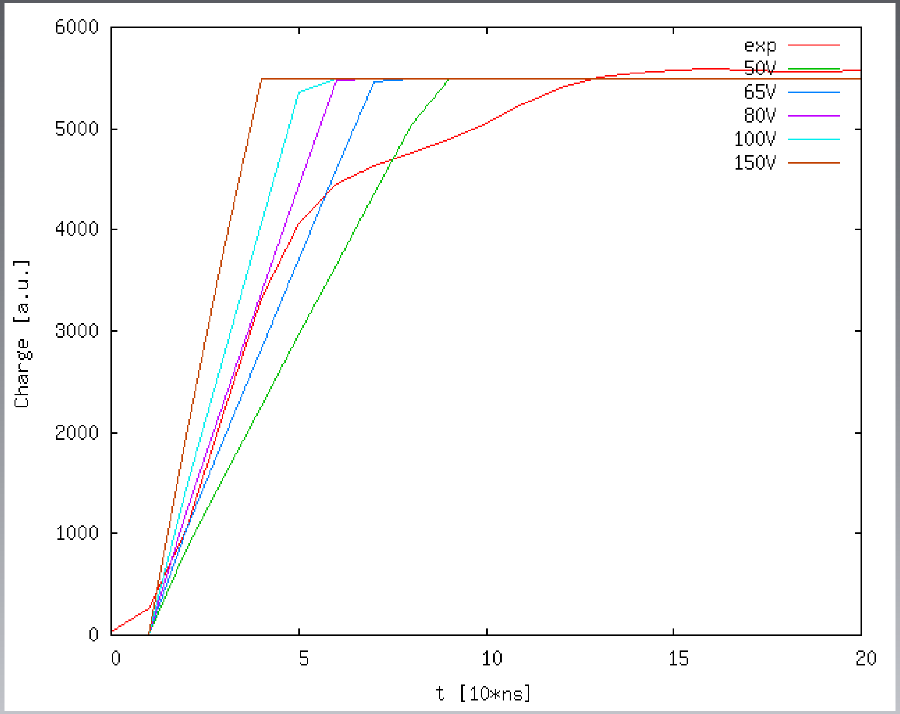


In the bulk the Poisson equation is solved through overrelaxation and a small electric field is obtained from the space charge distribution



First simulations

Comparison with experimental signal (5485 keV α) to find best voltage



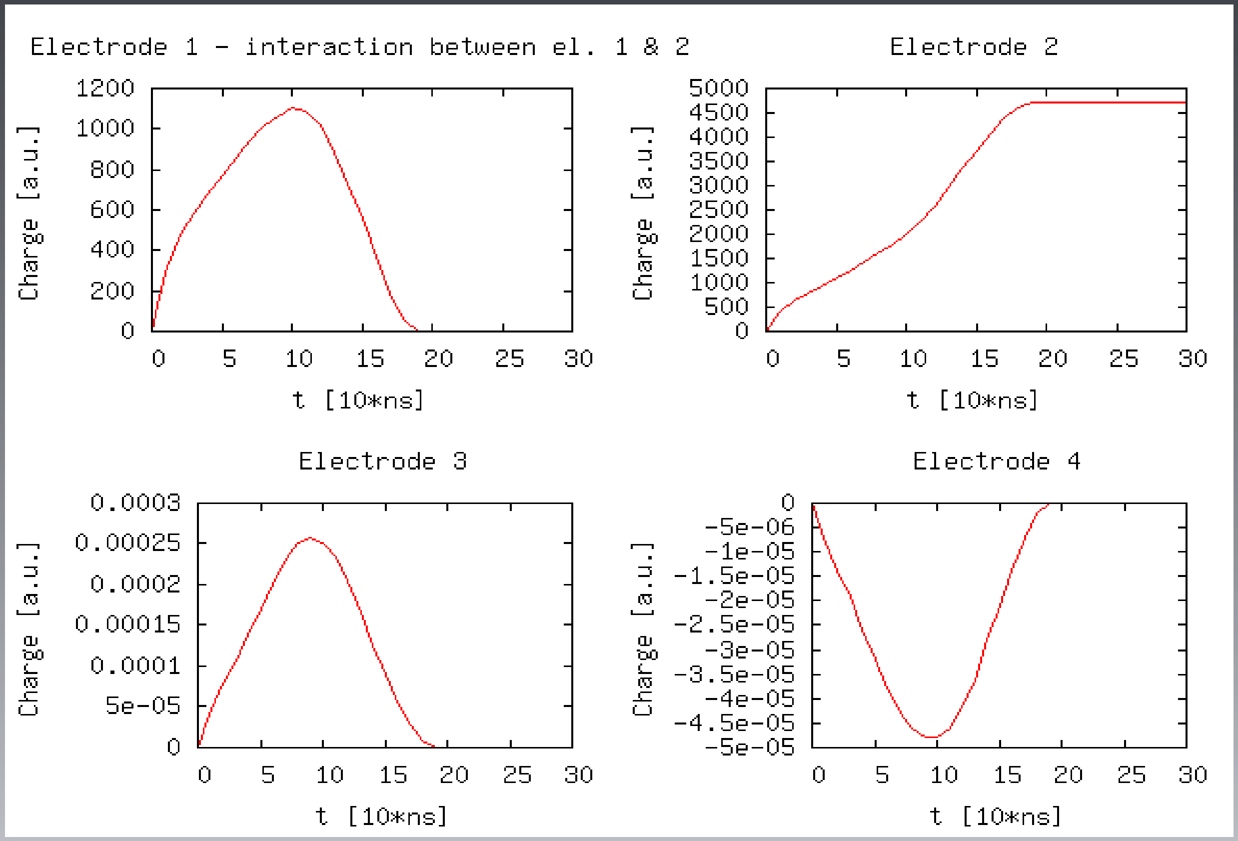
1mm thick detector @ 80V with 1×10^{10} atoms/cm^3

A few warnings…

The simulated signal fits well enough the reference case in the middle but important discrepancies are clear at the head and tail of the signal

- In the simulation no pre-amplification effetcs are considered (infinite bandwidth)
- The simulated event is located in the exact middle of the segment while in the experimental case some charge sharing might be present

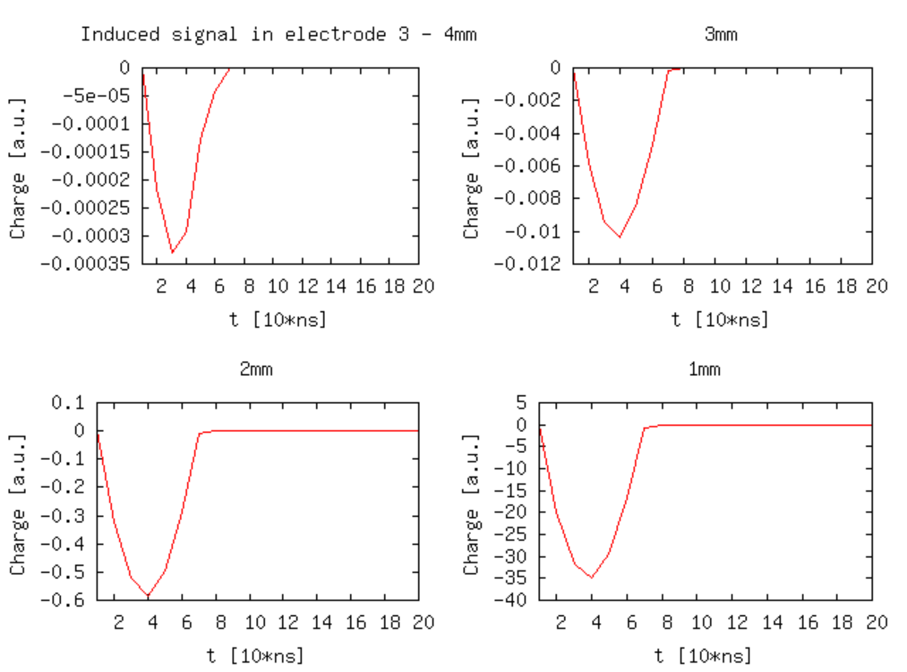
Charge sharing

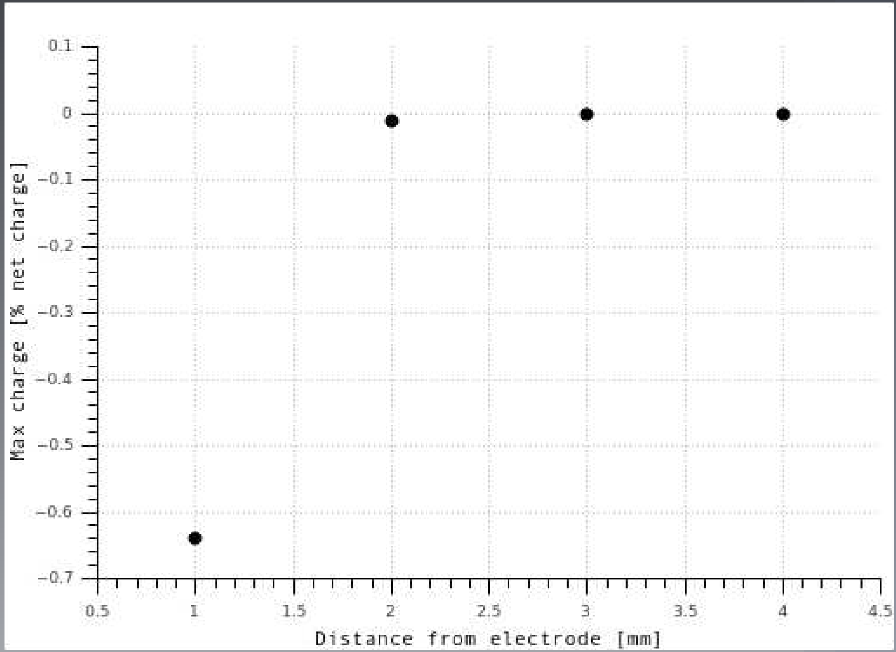


Interaction in the 2nd electrode but very close to the 1st

Charge sharing takes place when the interaction is deep inside the bulk and between two electrodes

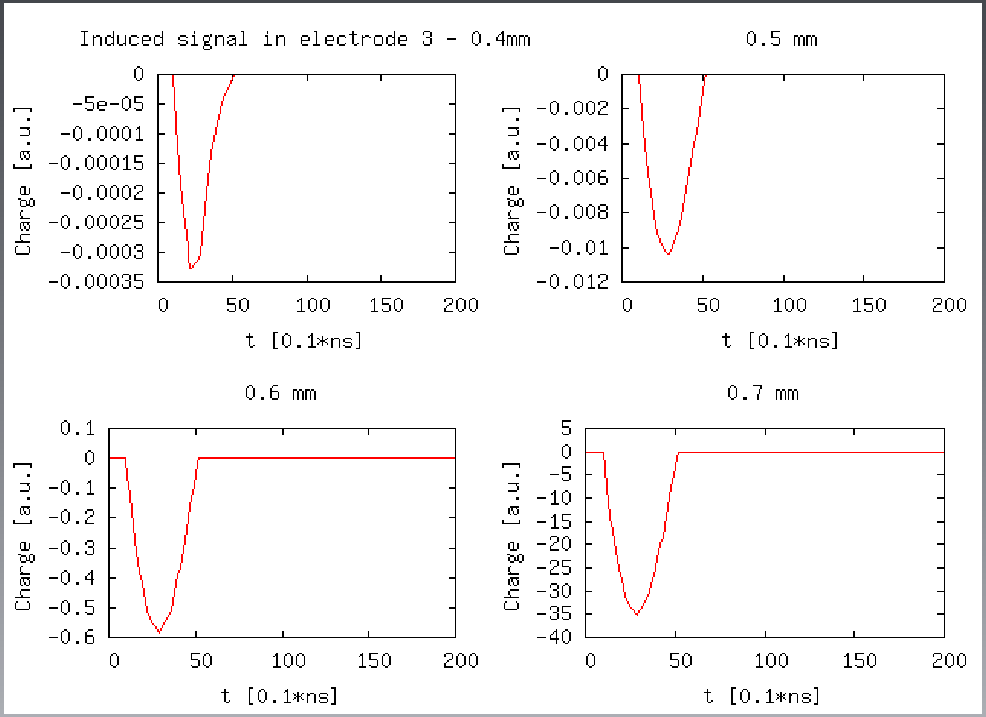
Position and transients



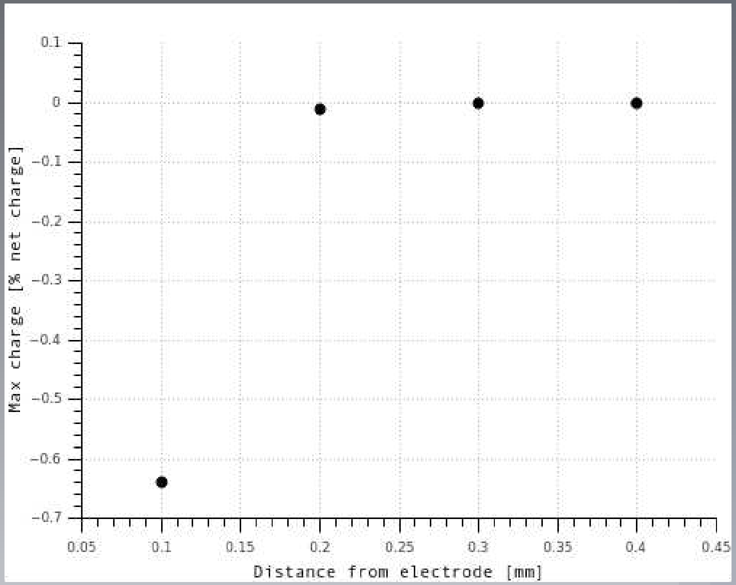


Interaction in the 2nd electrode changing its position towards the 3rd, the transient signal varies with position and becomes significant only close to the electrode

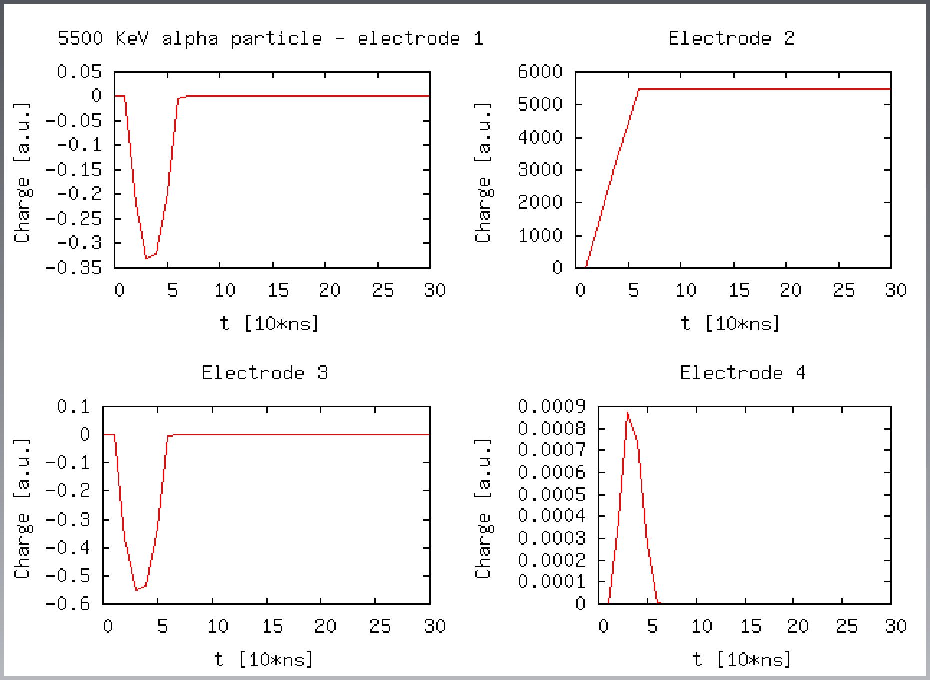
The same simulations have been made for a 0.1 mm thick detector at 10V. As expected the transient signals show the same pattern as before



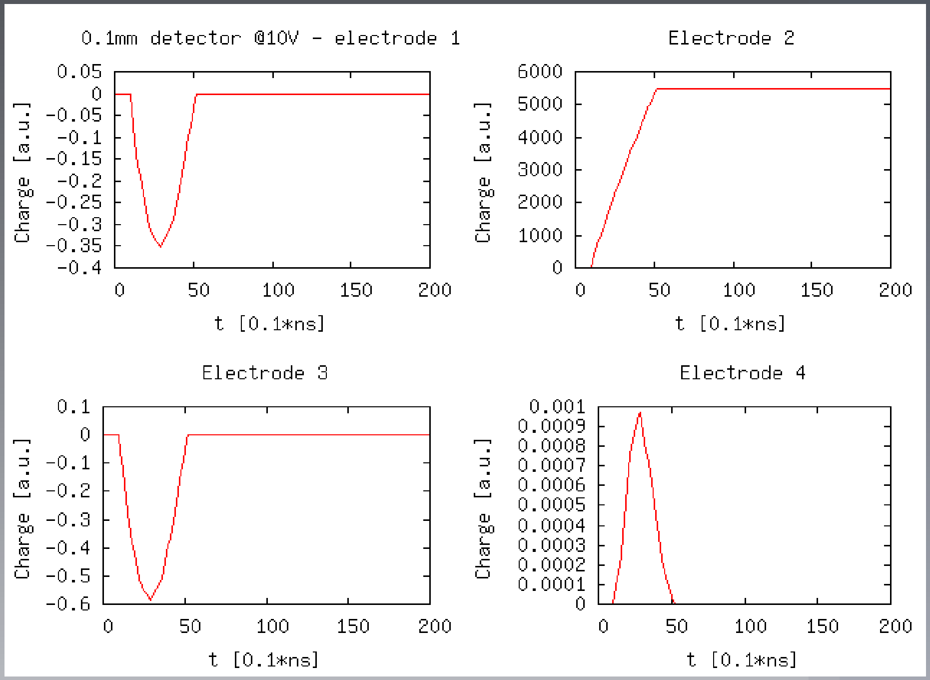
Next step? Simulate signal from different particles, pick observables that allow the extrapolation of useful information



α-particle

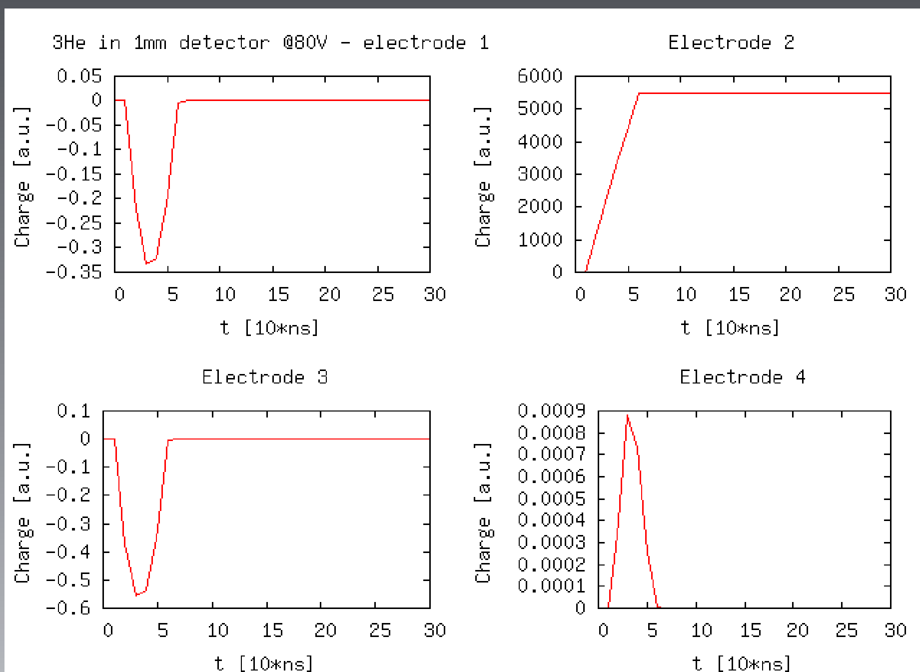


5500 KeV alpha particle - electrode 1
Electrode 2
Electrode 3
Electrode 4
Charge [a.u.]
t [10*ns]

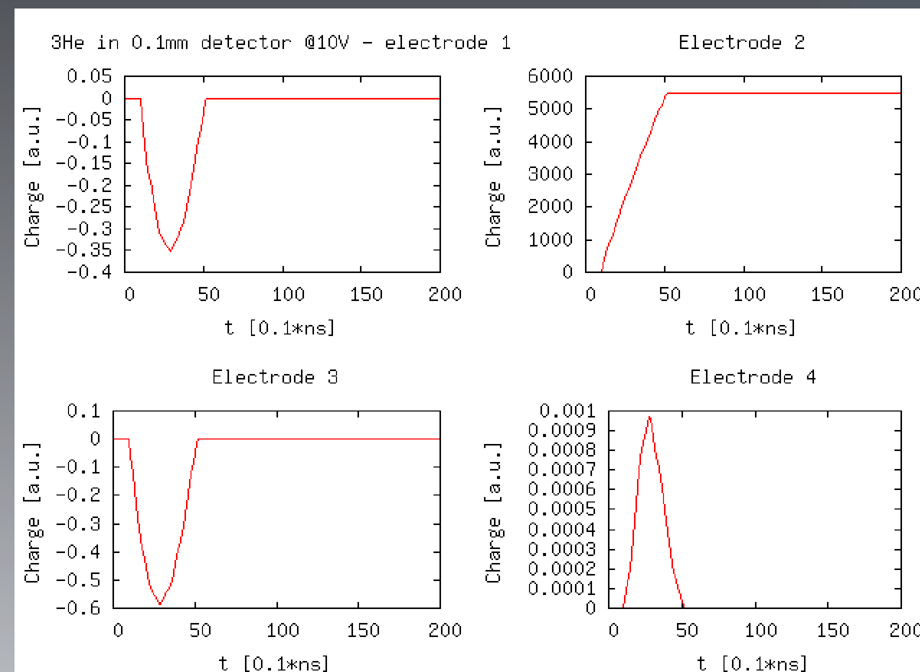


0.1mm detector @10V - electrode 1
Electrode 2
Electrode 3
Electrode 4
Charge [a.u.]
t [0.1*ns]

^{3}He

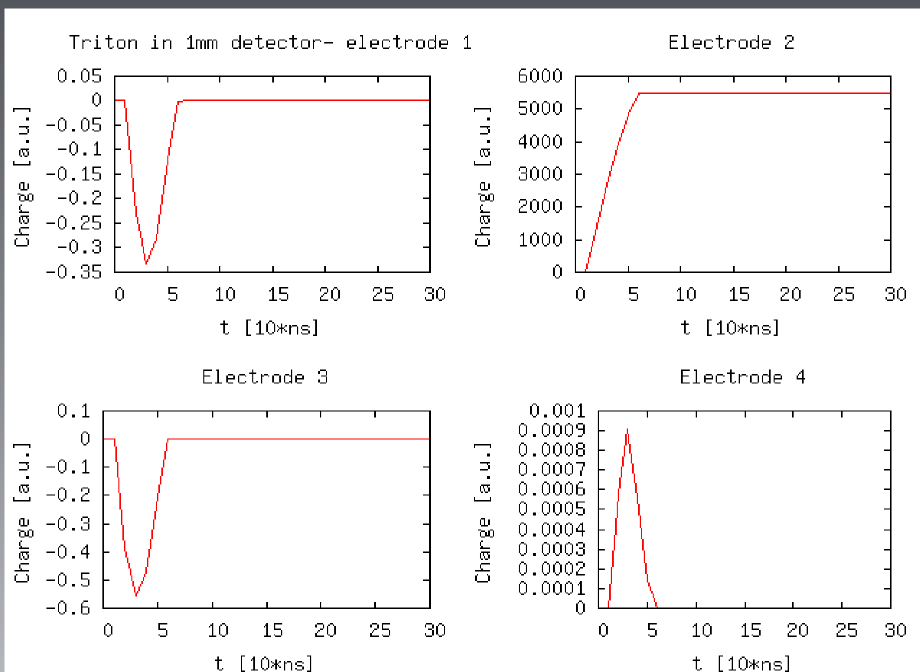


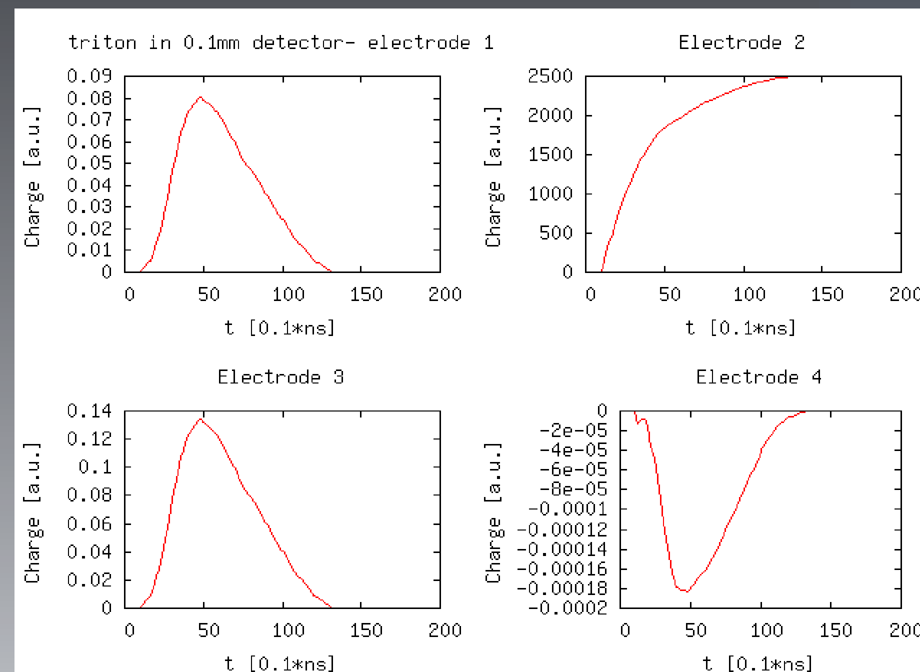
3He in 1mm detector @80V - electrode 1
Electrode 2
Electrode 3
Electrode 4
Charge [a.u.]
t [10*ns]
0.05 0 -0.05 -0.1 -0.15 -0.2 -0.25 -0.3 -0.35
6000 5000 4000 3000 2000 1000 0
0.1 0 -0.1 -0.2 -0.3 -0.4 -0.5 -0.6
0.0009 0.0008 0.0007 0.0006 0.0005 0.0004 0.0003 0.0002 0.0001 0
0 5 10 15 20 25 30



3He in 0.1mm detector @10V - electrode 1
Electrode 2
Electrode 3
Electrode 4
Charge [a.u.]
t [0.1*ns]
0.05 0 -0.05 -0.1 -0.15 -0.2 -0.25 -0.3 -0.35 -0.4
6000 5000 4000 3000 2000 1000 0
0.1 0 -0.1 -0.2 -0.3 -0.4 -0.5 -0.6
0.001 0.0009 0.0008 0.0007 0.0006 0.0005 0.0004 0.0003 0.0002 0.0001 0
0 50 100 150 200

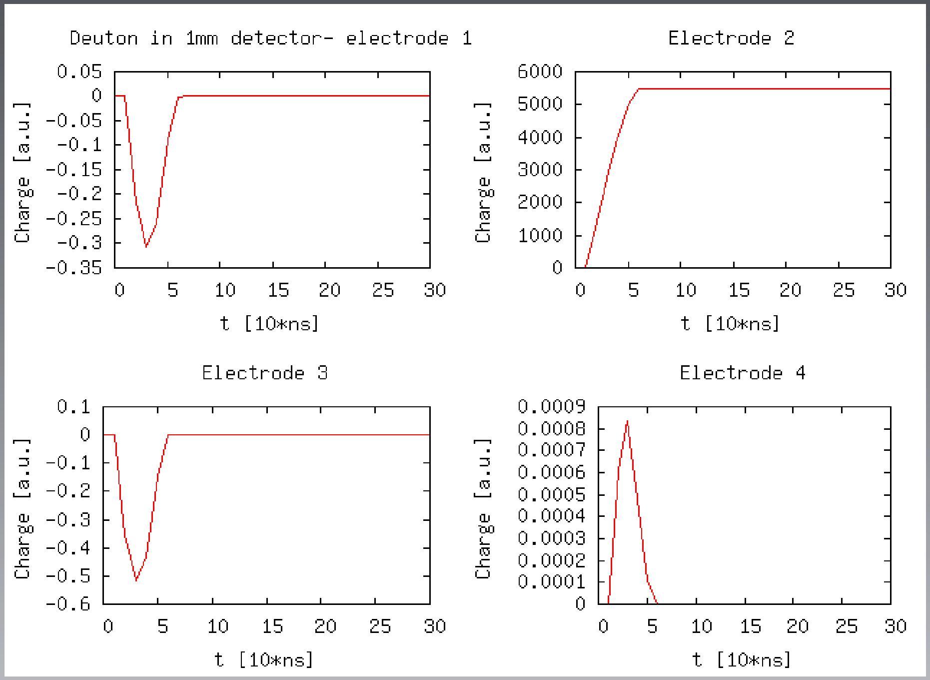
Triton



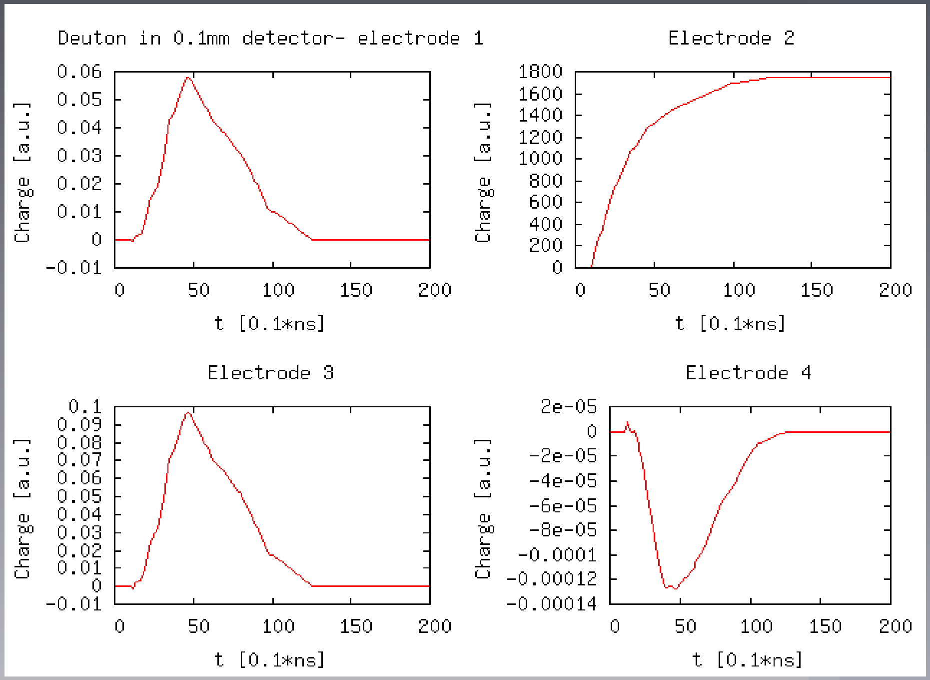


The net charge signal in 0.1mm detector does not reach the total energy because the particle punches through and loses only a fraction of its energy

Deuton

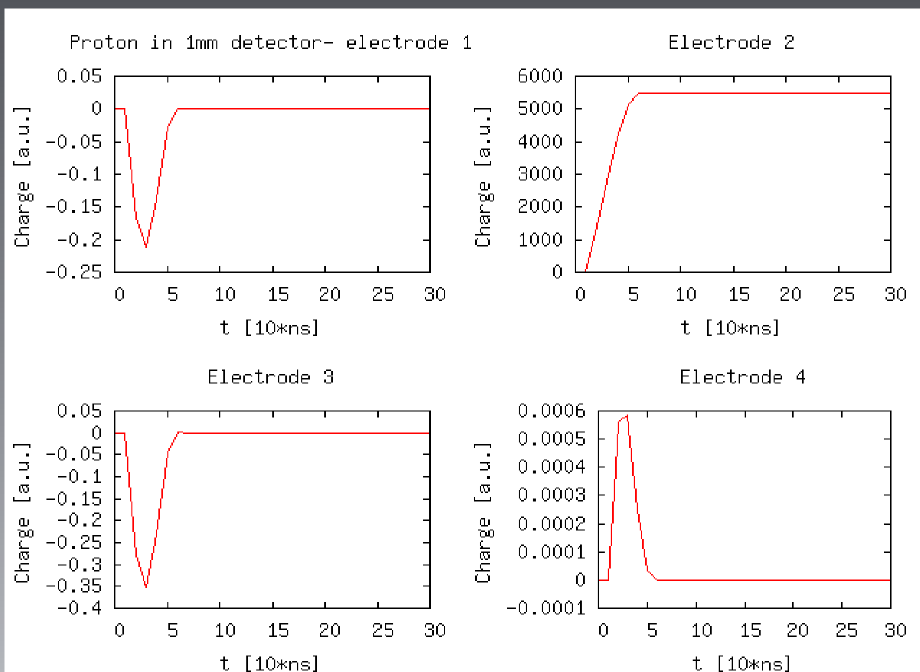


Deuton in 1mm detector- electrode 1
Electrode 2
Electrode 3
Electrode 4
Charge [a.u.]
t [10*ns]

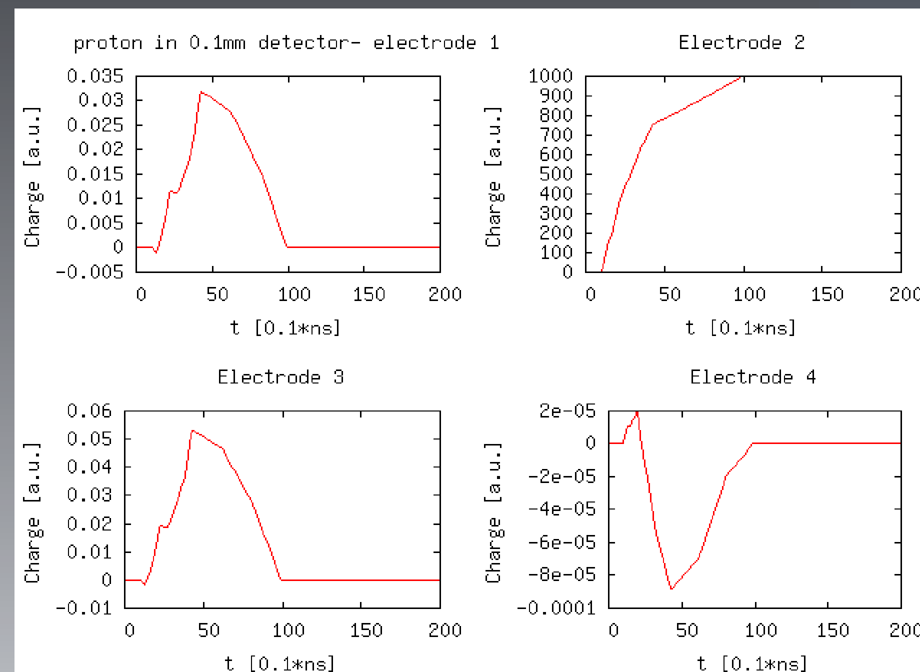


Deuton in 0.1mm detector- electrode 1
Electrode 2
Electrode 3
Electrode 4
Charge [a.u.]
t [0.1*ns]

Proton



Proton in 1mm detector- electrode 1
Charge [a.u.]
0.05 0 -0.05 -0.1 -0.15 -0.2 -0.25
0 5 10 15 20 25 30
t [10*ns]
Electrode 2
Charge [a.u.]
6000 5000 4000 3000 2000 1000 0
0 5 10 15 20 25 30
t [10*ns]
Electrode 3
Charge [a.u.]
0.05 0 -0.05 -0.1 -0.15 -0.2 -0.25 -0.3 -0.35 -0.4
0 5 10 15 20 25 30
t [10*ns]
Electrode 4
Charge [a.u.]
0.0006 0.0005 0.0004 0.0003 0.0002 0.0001 0 -0.0001
0 5 10 15 20 25 30
t [10*ns]



proton in 0.1mm detector- electrode 1
Charge [a.u.]
0.035 0.03 0.025 0.02 0.015 0.01 0.005 0 -0.005
0 50 100 150 200
t [0.1*ns]
Electrode 2
Charge [a.u.]
1000 900 800 700 600 500 400 300 200 100 0
0 50 100 150 200
t [0.1*ns]
Electrode 3
Charge [a.u.]
0.06 0.05 0.04 0.03 0.02 0.01 0 -0.01
0 50 100 150 200
t [0.1*ns]
Electrode 4
Charge [a.u.]
2e-05 0 -2e-05 -4e-05 -6e-05 -8e-05 -0.0001
0 50 100 150 200
t [0.1*ns]

Nice pictures but…

We have to chose the right particle identifiers (PI):

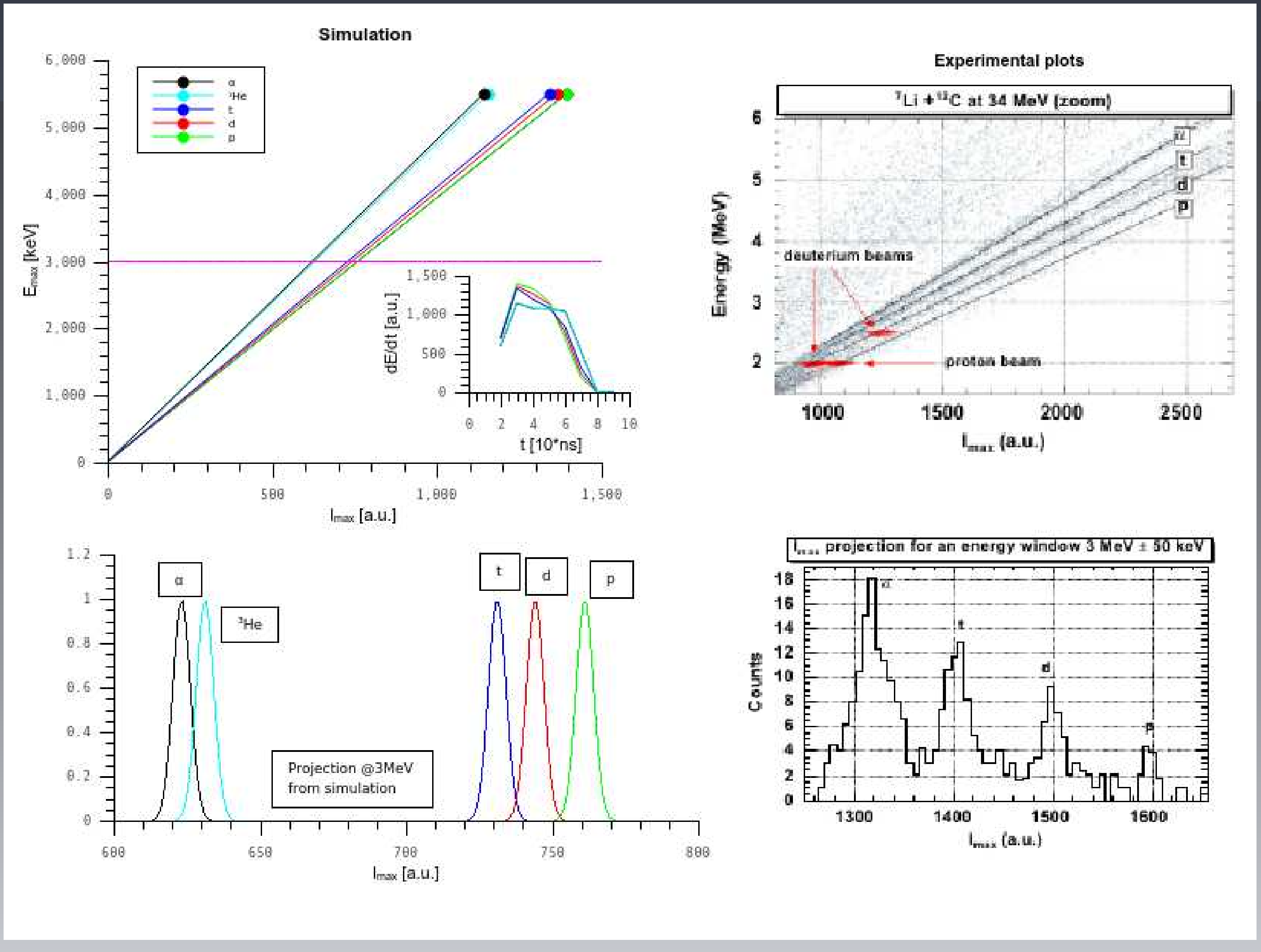
$$E_{max}$$

$$I_{max} = max\left(\frac{dQ}{dt}\right) \rightarrow \propto max\left(\frac{dE}{dt}\right)$$

For every particle we take the derivative of the net charge signal and plot its maximum against the corresponding energy

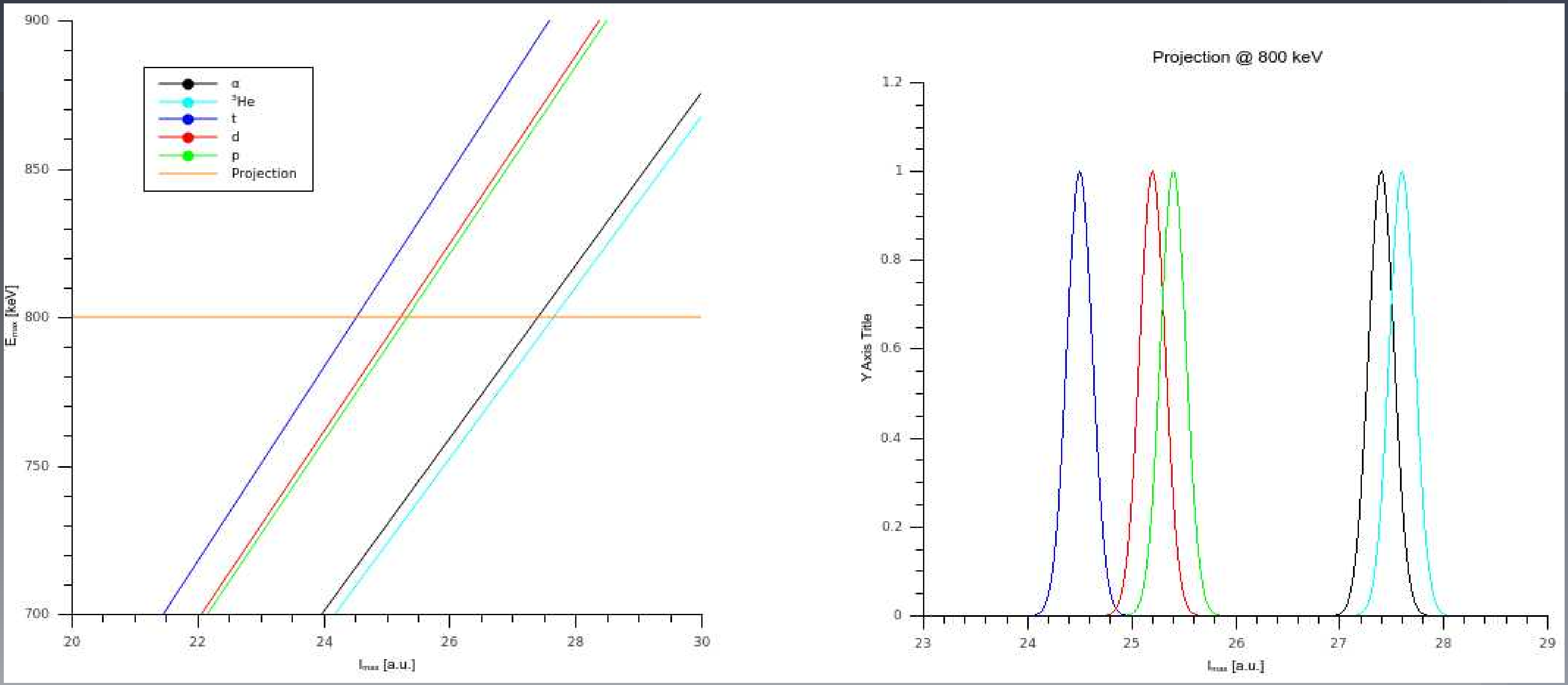
→ What happens for 1mm and 0.1 mm detectors?

1mm detector → the results can be compared to the study of particles produced in the reaction $^{7}Li+^{12}C$ @ 34 MeV*



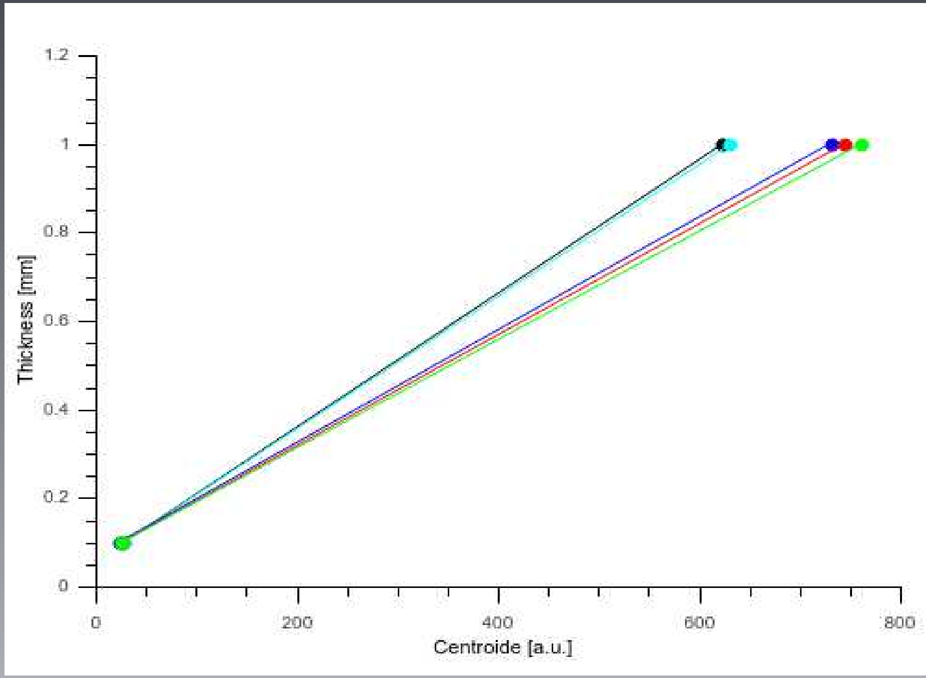
*J.A. Dueñas et al. Nuclear Instruments and Methods in Physics Research A 676 (2012) 70-73

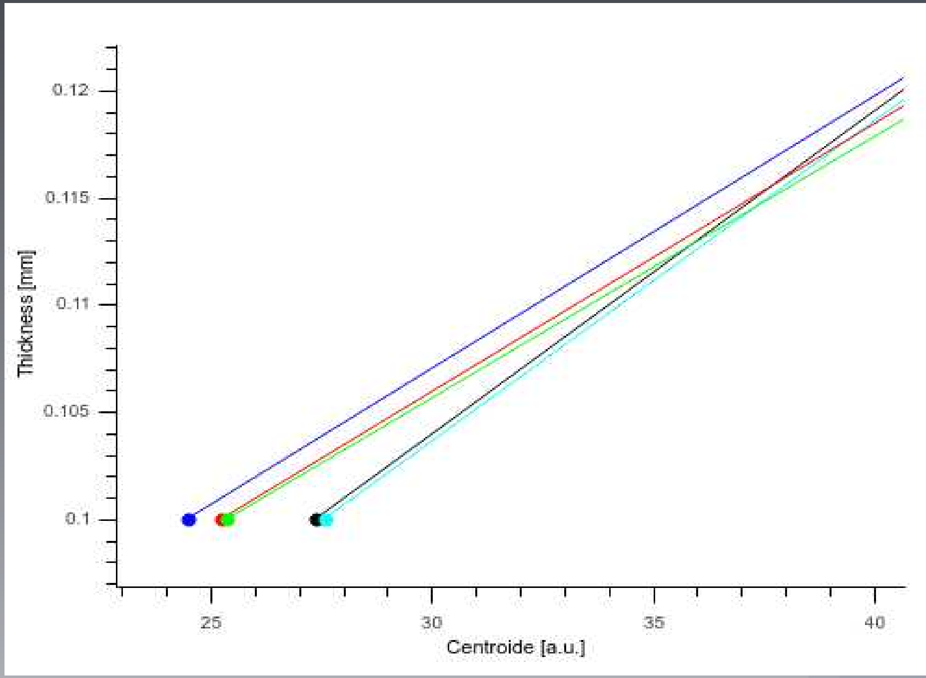
0.1mm detector → a characteristic pattern is found in the case of punch through!



- I_{max} for t,d,p is now lower than α and ^{3}He
- At low energy the peaks (particles) might not be fully resolved

Very light particles have long ranges and can pass through the detector without releasing their whole energy, this can compromise their identification!





→ How the projections' centroids vary with thickness, on the right the picture is zoomed to see the points corresponding to 0.1mm

Conclusions and further developments

- ✓ Simulations successfully compared with experimental results
- ✓ ADL tools applicable to different geometries and materials
- ✓ Studying transients signals can improve spatial resolution, depending on experimental noise
- ✓ PSA efficiency: detector thickness, particle energy and type
- ✗ Including diffusion and trapping for more realistic results
- ✗ New simulations with commercial products