Simulation and study of current signals and plasma effects in Silicon detectors for Heavy Ions experiments

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- Motivations for a detailed study of silicon detector response
- Numerical simulation
- How does the simulated "plasma" look like?
- Quantitative comparison with experiments
  - reverse mount configuration
  - front mount configuration
- Conclusions

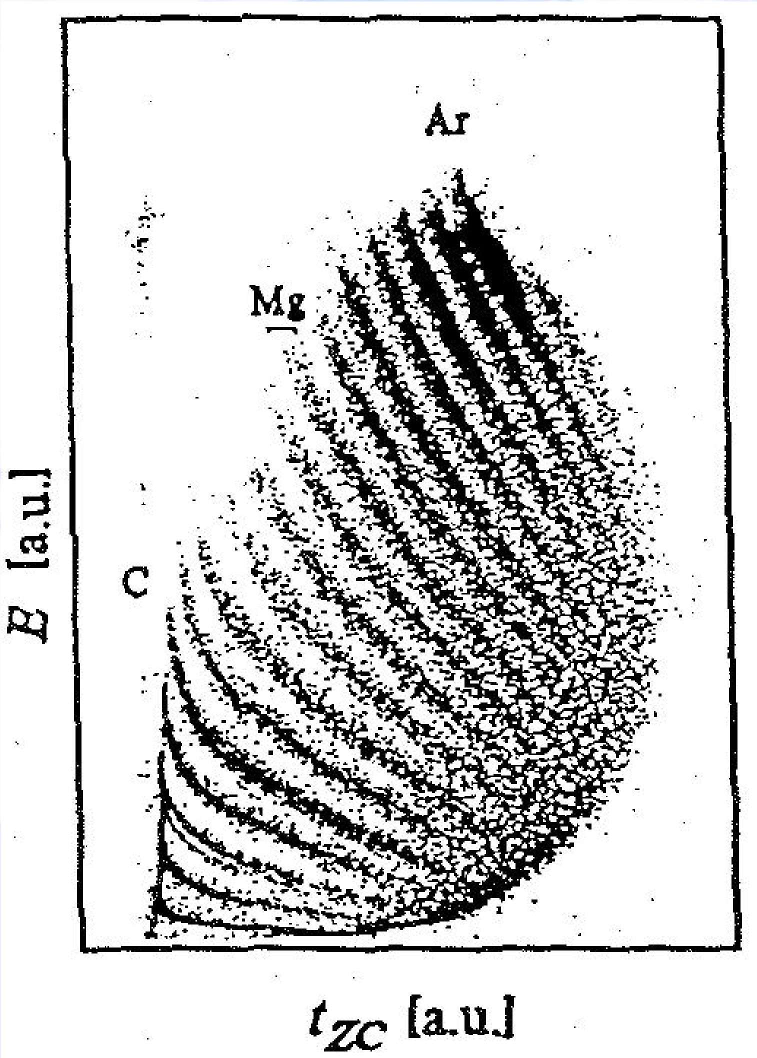
One of our purposes is the identification of nuclei in a (wide?) range of **charge** and **mass**

A possible experimental choice:
Pulse shape in **silicon detectors**

Great interest of the community towards
reverse mount silicon detectors

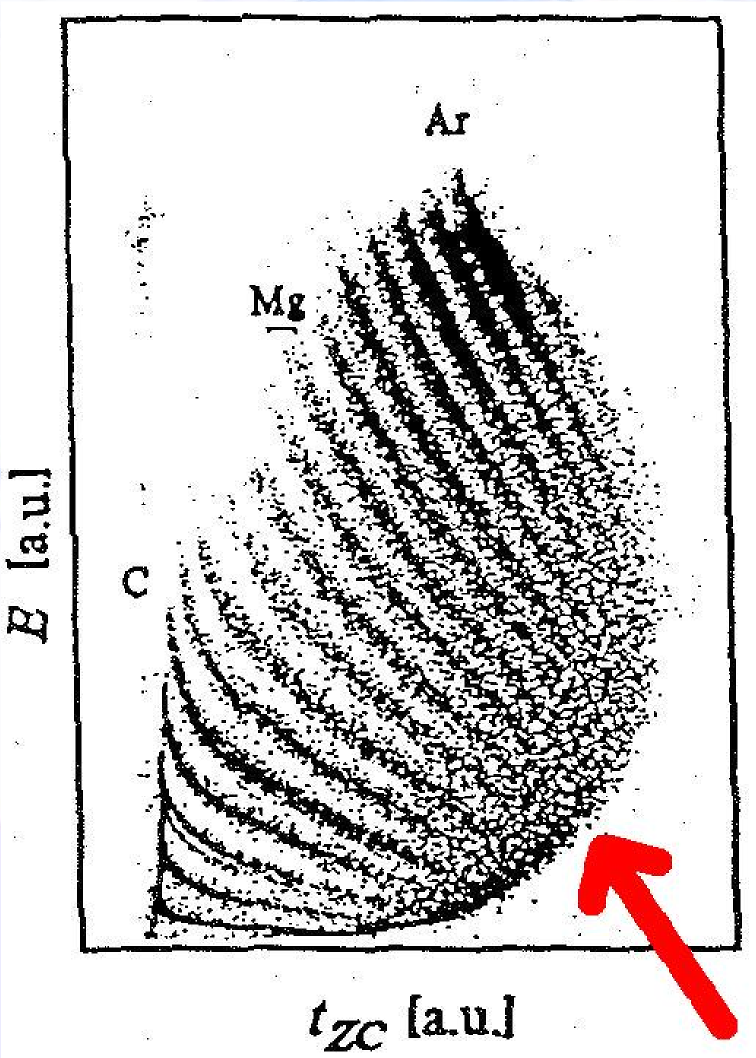
many theoretical and experimental studies.

Let's see just one. . .



[Swapped axes with respect to original]

G.Pausch et al., IEEE Trans. Nucl. Science, vol.44, no.3, June 1997



[Swapped axis with respect to original]

Experimental particle identification is possible but the **underlying physics is not fully understood**

"... We conclude that the decrease of t_{ZC} is caused by... However one would expect... This is in contradiction to our observations.

Further effort is necessary to understand the underlying physical effects. "

G.Pausch et al., IEEE Trans. Nucl. Science, vol.44, no.3, June 1997

In most theoretical works **plasma delay and erosion** are ignored or considered using simple semiempirical models.

Which are the underlying physical effects ?

Maybe the **simple electrostatic interaction** between electrons and holes? ("screening" of applied field)

- Simple explanation (if it works. . .)
- Analitic analysis difficult

How to test it?

Numerical computation

EXACT Coulomb interaction between electron and holes.

For **each** carrier k:

$$\vec{\mathbf{E}}^{k}_{\text{total}} = \vec{\mathbf{E}}^{k}_{\text{macro}} + \sum_{i=0}^{N} q_i \cdot \vec{F}\,(\Delta r_{ki})$$

(plus electrostatic boundary conditions).

Ramo's theorem to compute the current signal

- **No free/semi-empirical parameters!!!**

Numerical computation

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Ramo's theorem to compute the current signal

- **No free/semi-empirical parameters!!!**
- Too much microscopic information
- Computationally intensive i.e.:
  100 MeV ion ➡ $\sim 5 \cdot 10^7$ carriers
  ➡ $\sim$ **1 year/integration step** with 1 GHz processor

- **Carrier clustering** $\vec{E}$ and motion of charge clusters
- **Exact inter-cluster force** The electric field is computed considering the clusters as finite radius spheres.

Carrier clustering $\vec{\mathrm{E}}$ and motion of charge clusters

Exact inter-cluster force The electric field is computed considering the clusters as finite radius spheres.

Fully tridimensional We can follow erosion processes in 3D

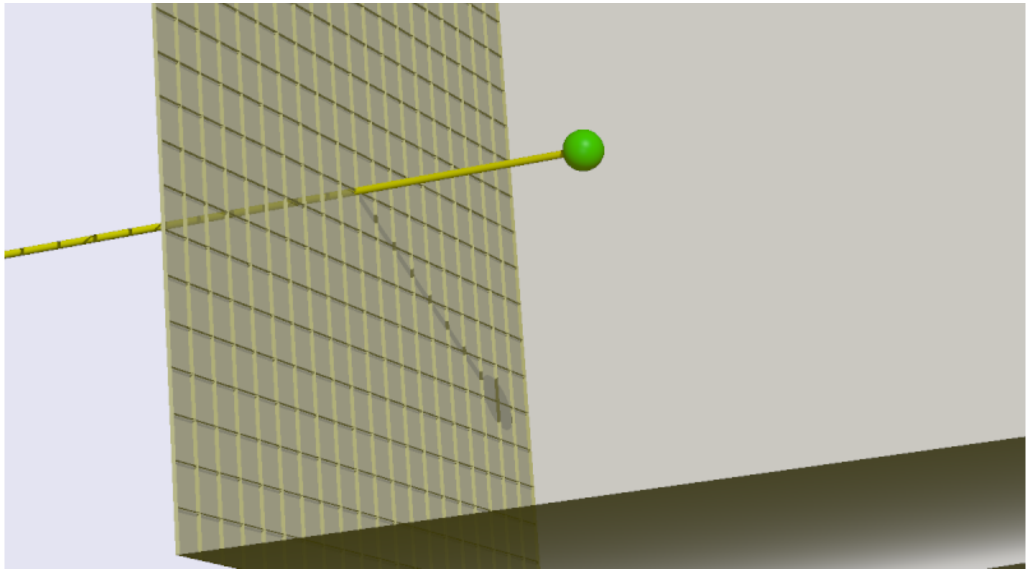
Silicon properties At each evolution step the saturation velocity and the dimension of each cluster is updated

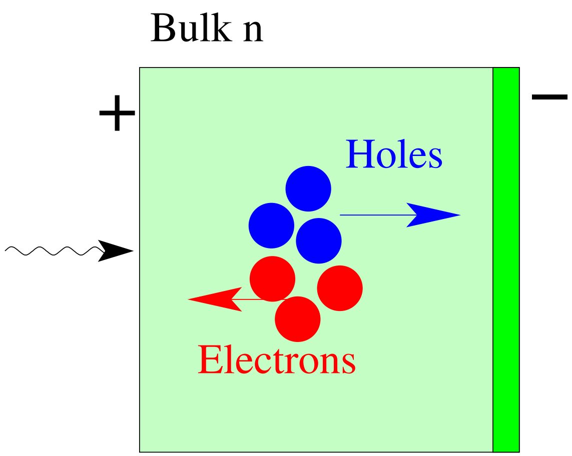
Boundary conditions are taken into account using a truncated mirror charges expansion of each cluster

Parallel computation Fully parallelized on a PC farm (Linux-based)

For example $N_{clusters} \simeq 10^4$, with 14 CPUs
→ 1 full current signal → 15 minutes.

Simulation of a 50 MeV ^{12}C ion:





(click the image to start the animation)

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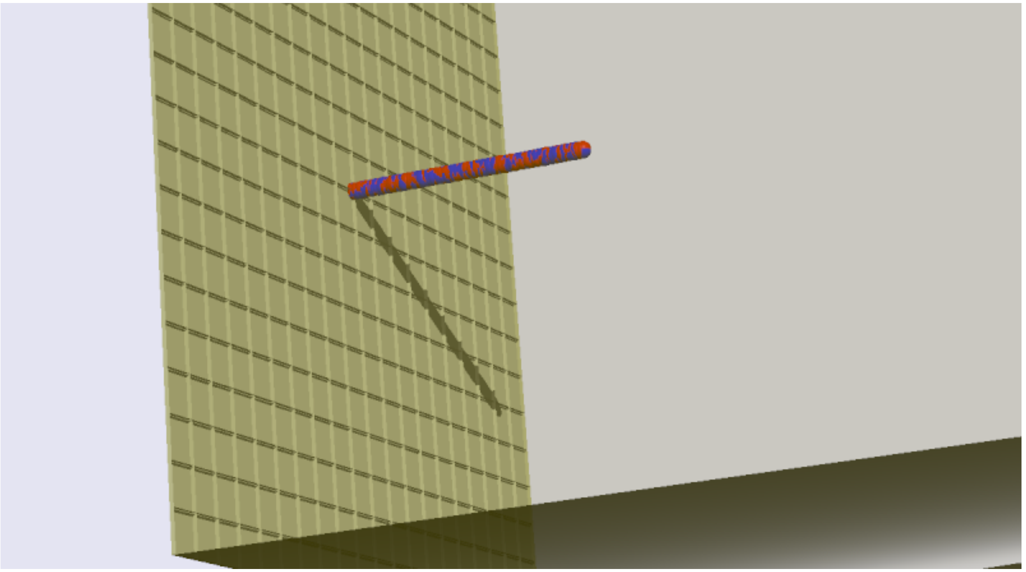

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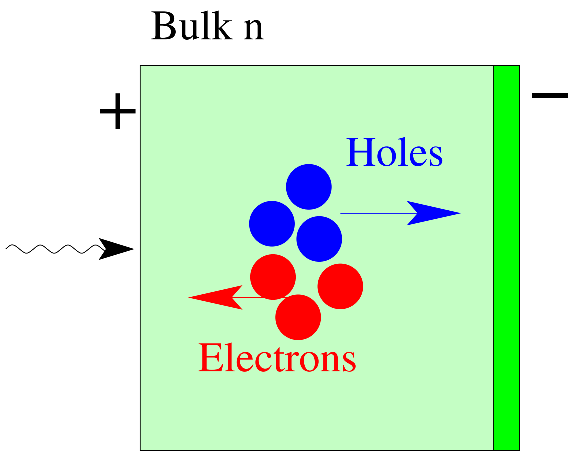
no e↔h interaction



cluster charge changes due to collection at electrodes

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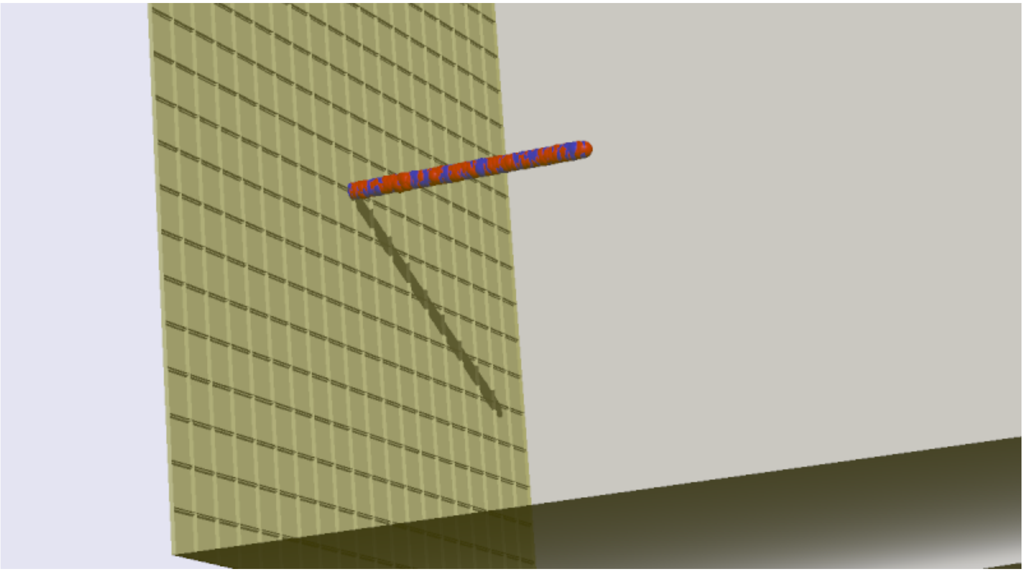

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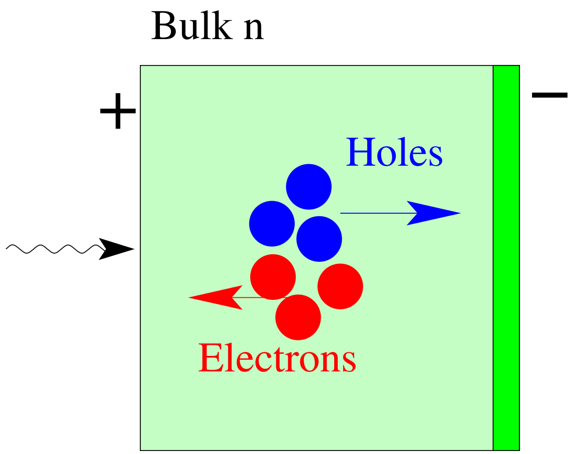
WITH e↔h interaction



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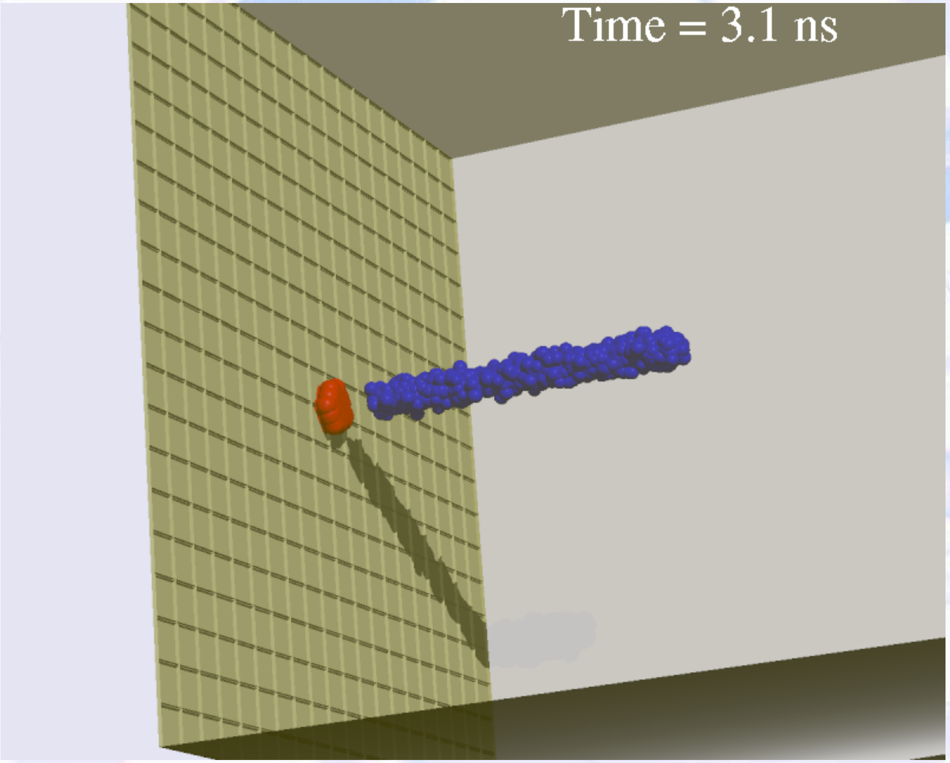

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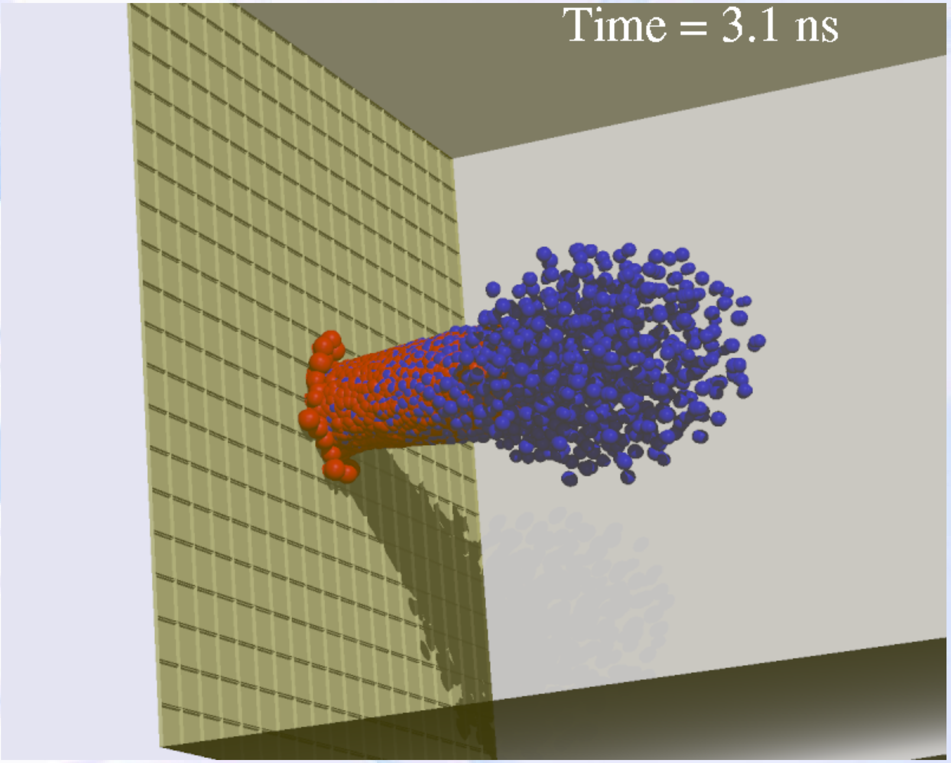

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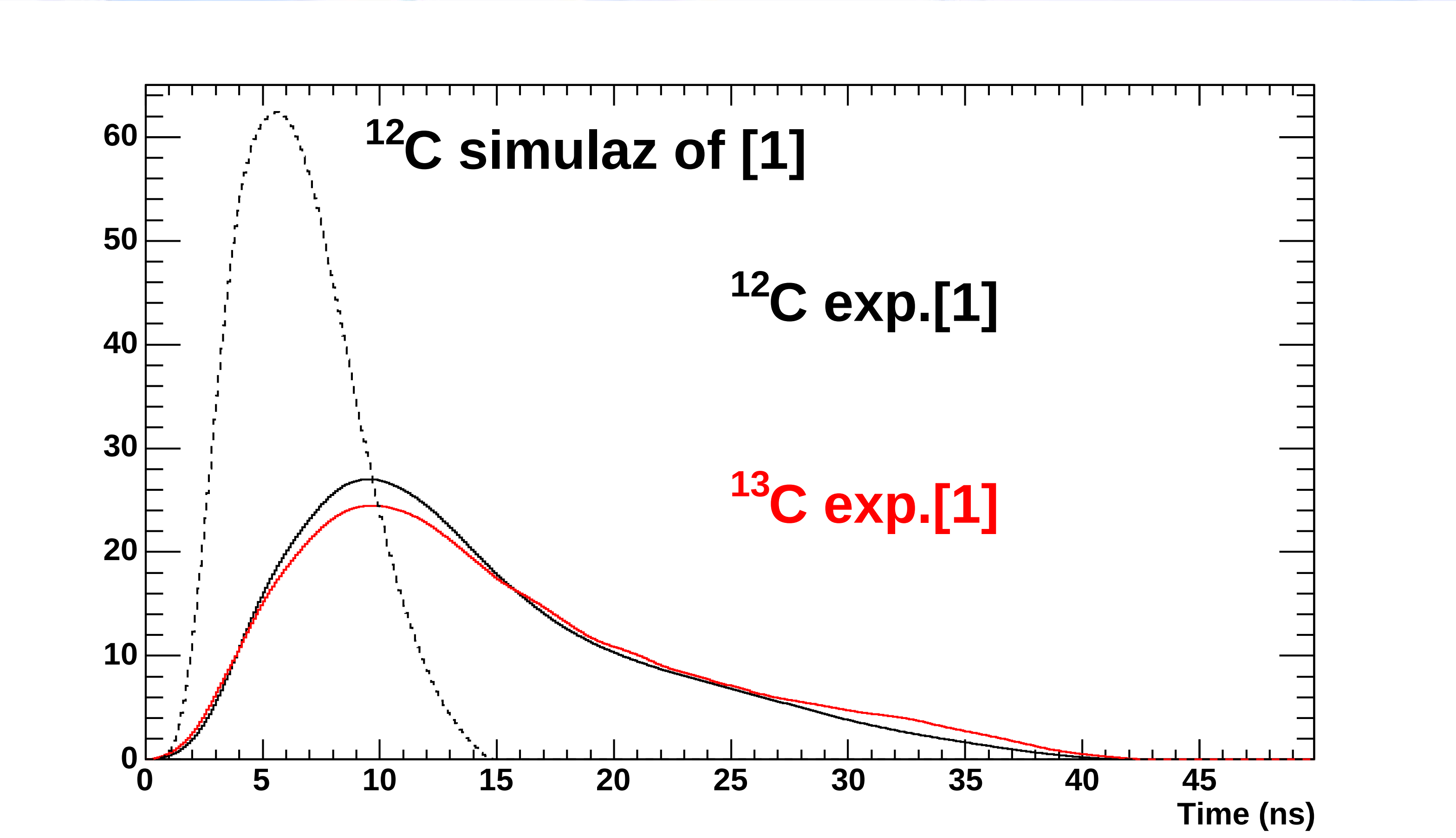
Comparison with experiment (1)

Data from: [1] H. Hamrita *et al*, NIM **A**531 (2004) 607:



80MeV Carbon: 190Vappl, depl.=128V

detailed knowledge of preamp. response needed!

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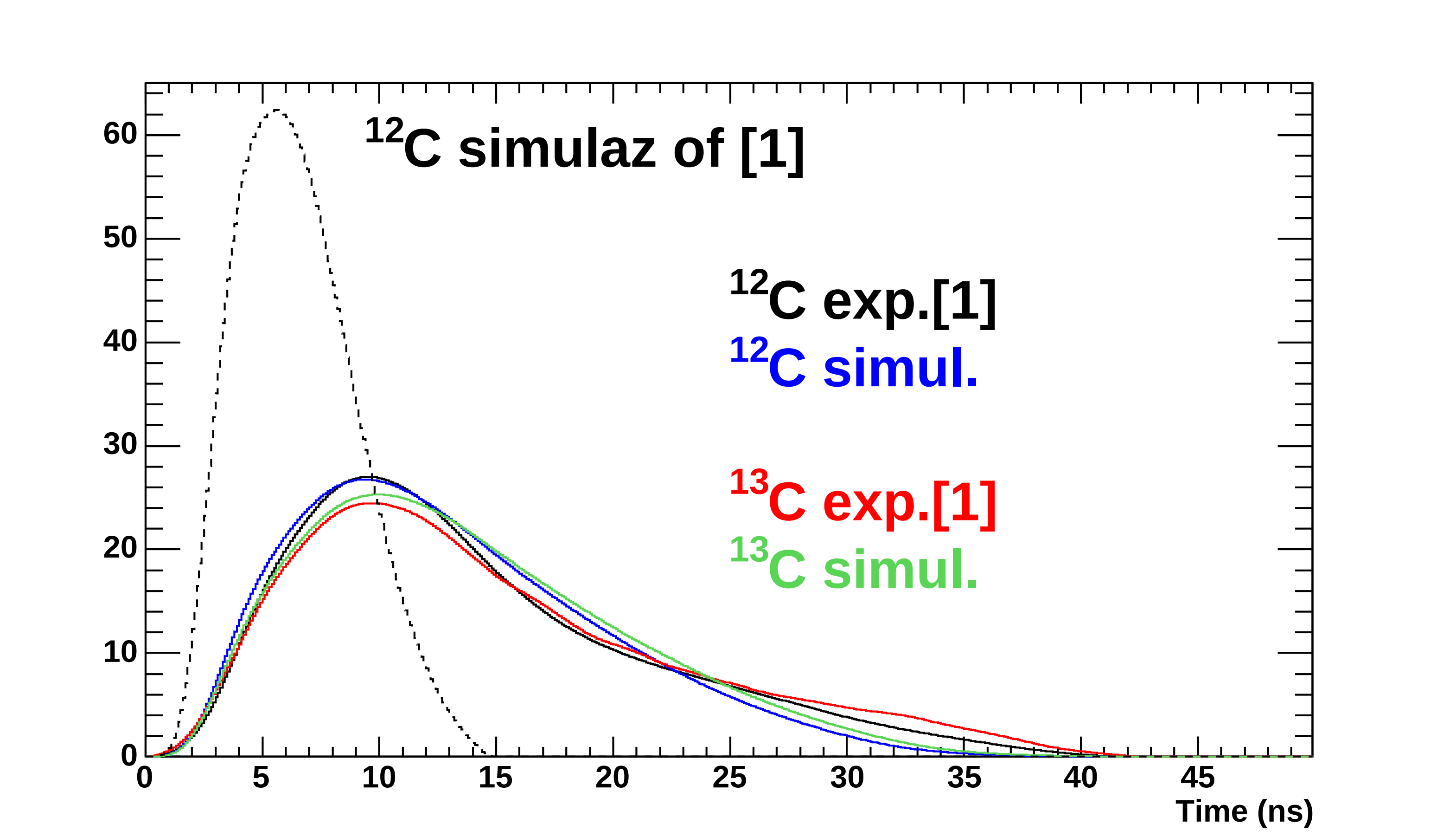

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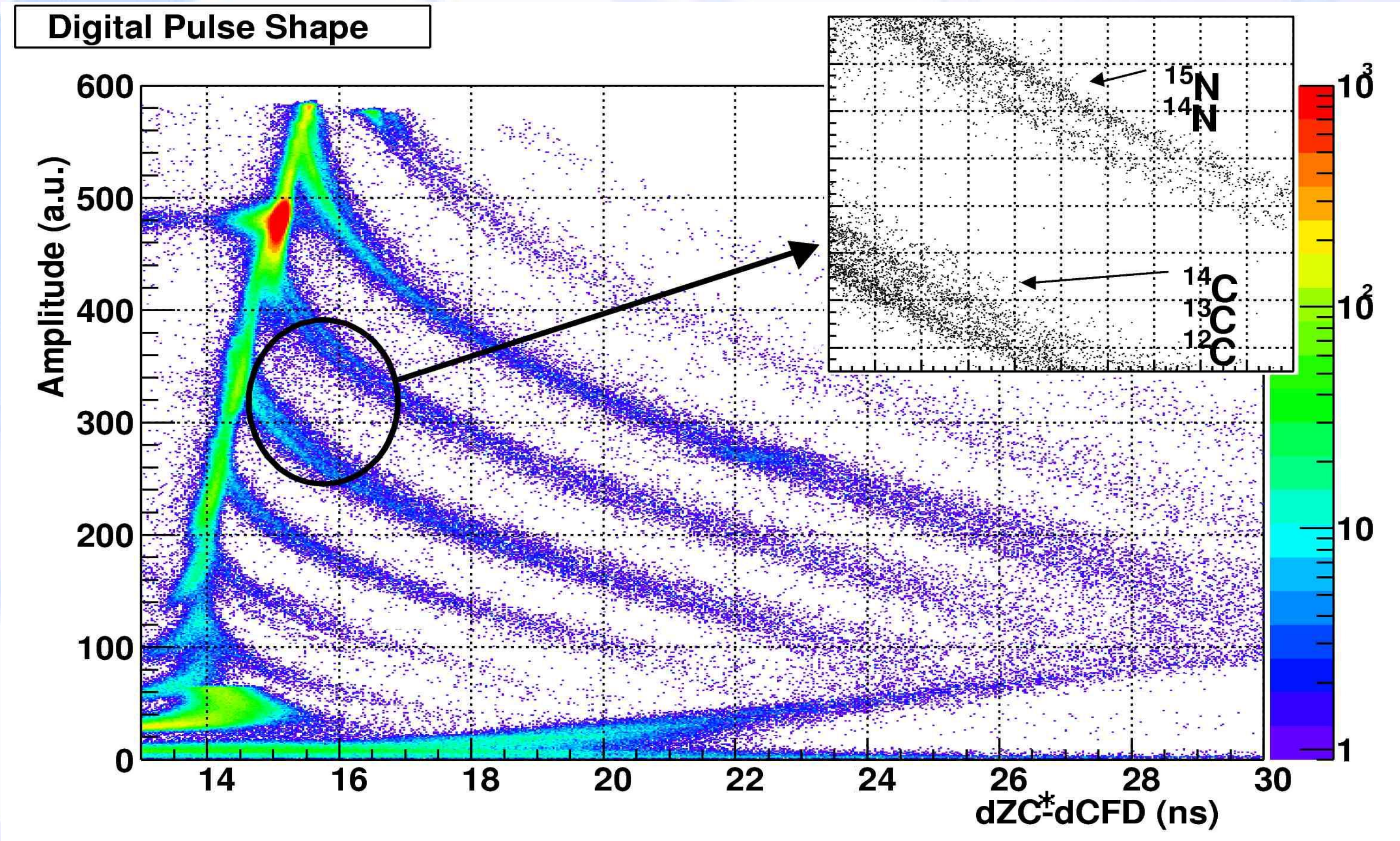
QUANTITATIVE comparison with experiment?

rev.mount NTD detector (L.Bardelli *et al* NIM A521 (2004) 580)



Vappl=140V, Vdepl=120V

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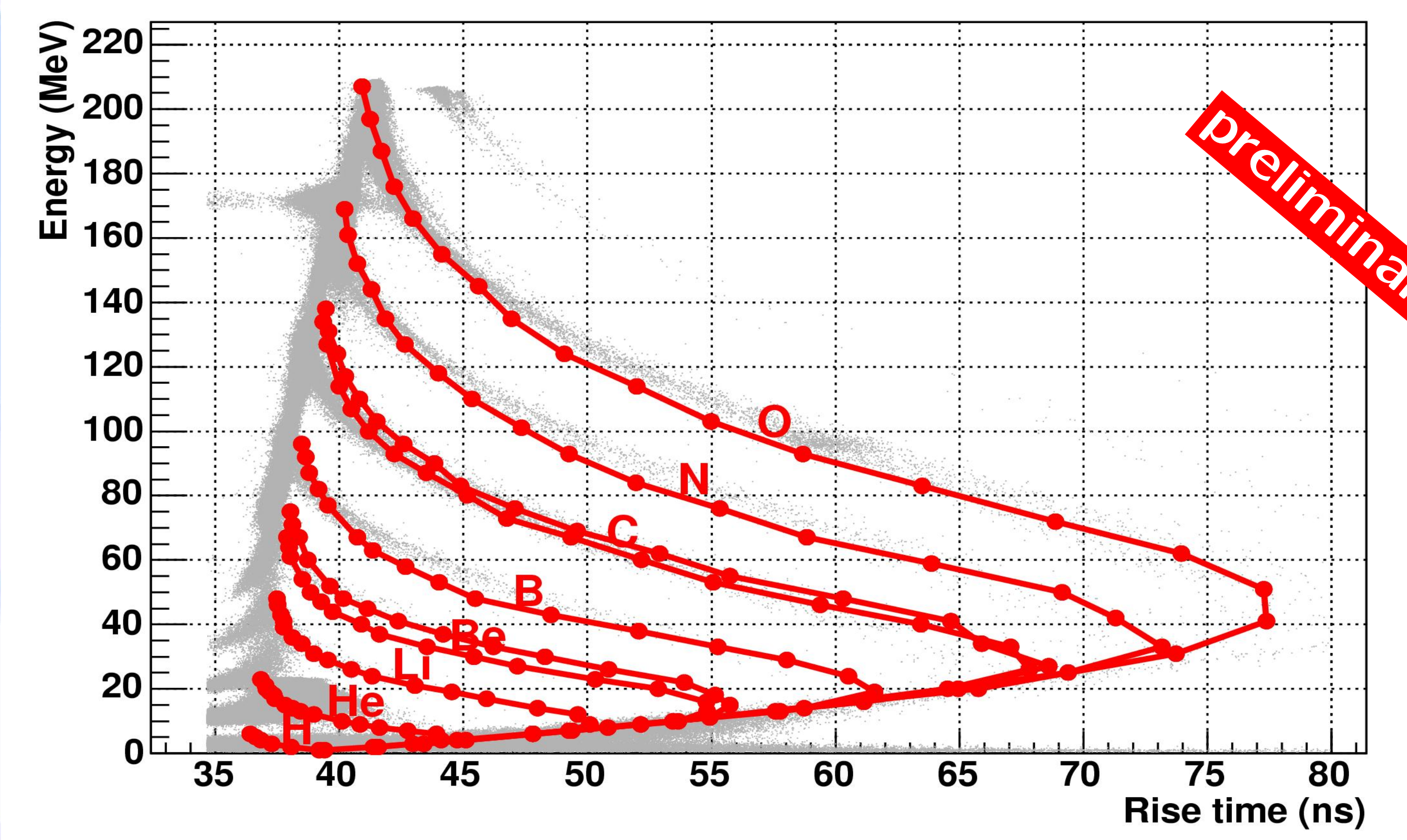

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• Simulated points.

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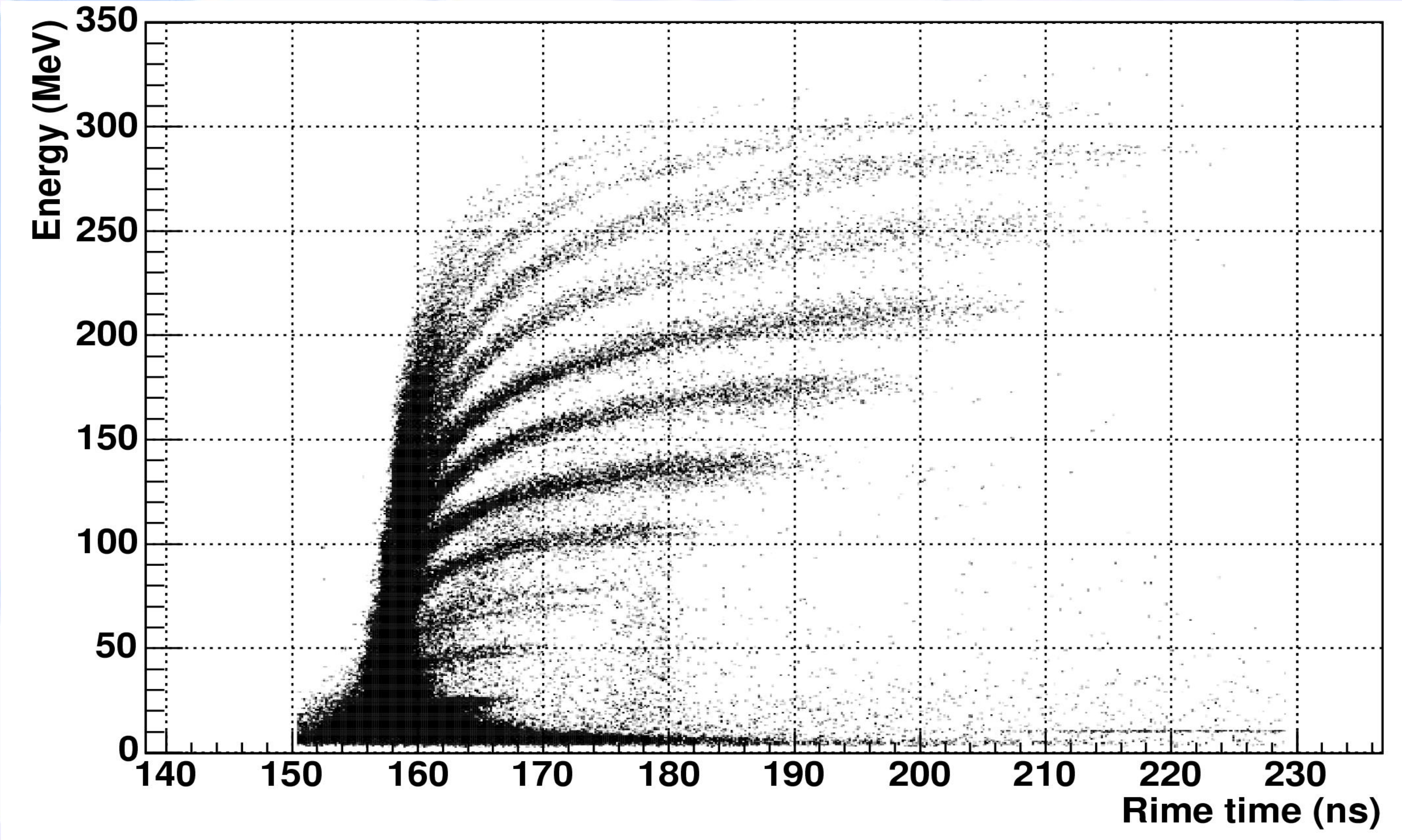
Data with **front mount** Si (CHIMERA, LNS Rep. 2004, p.129)



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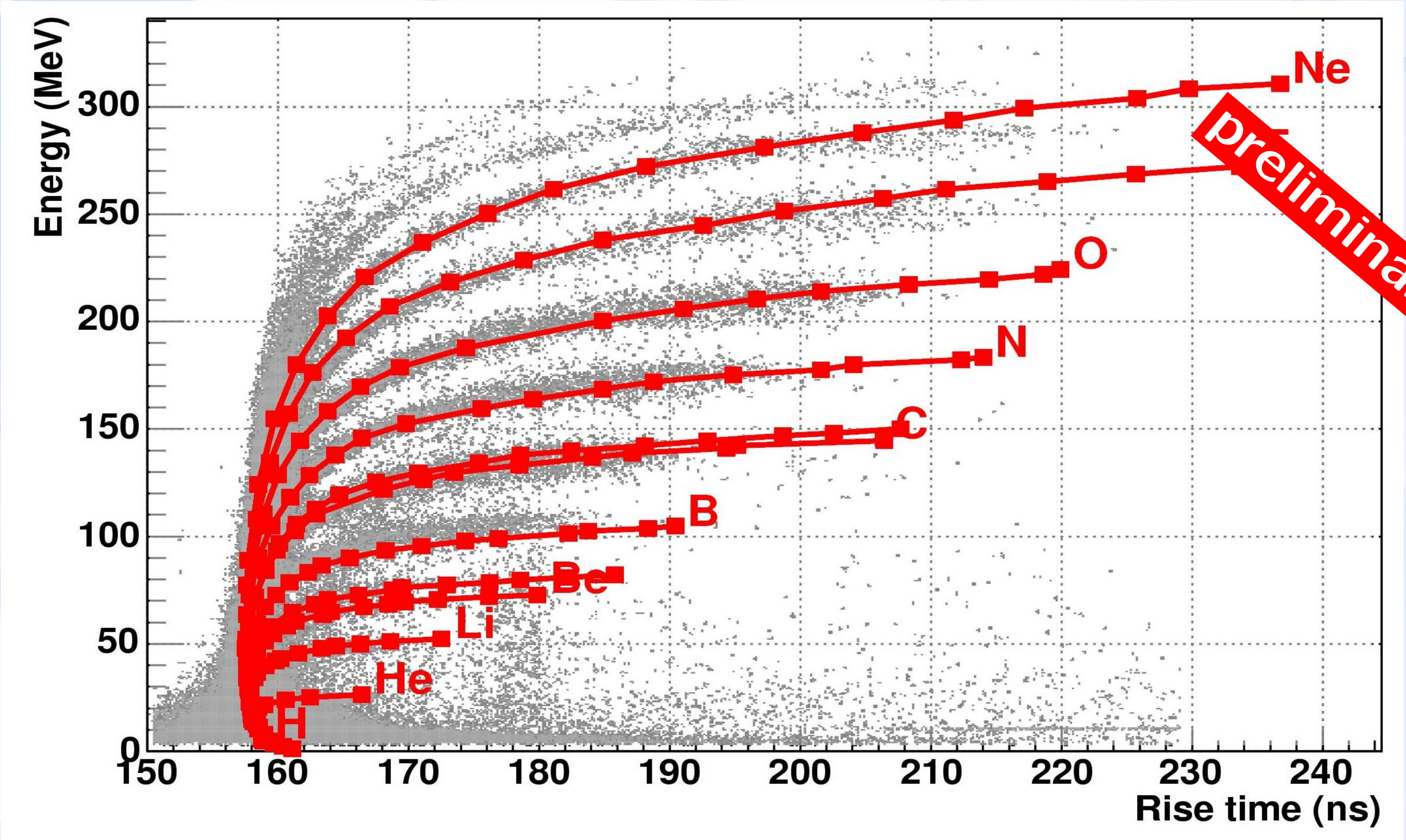


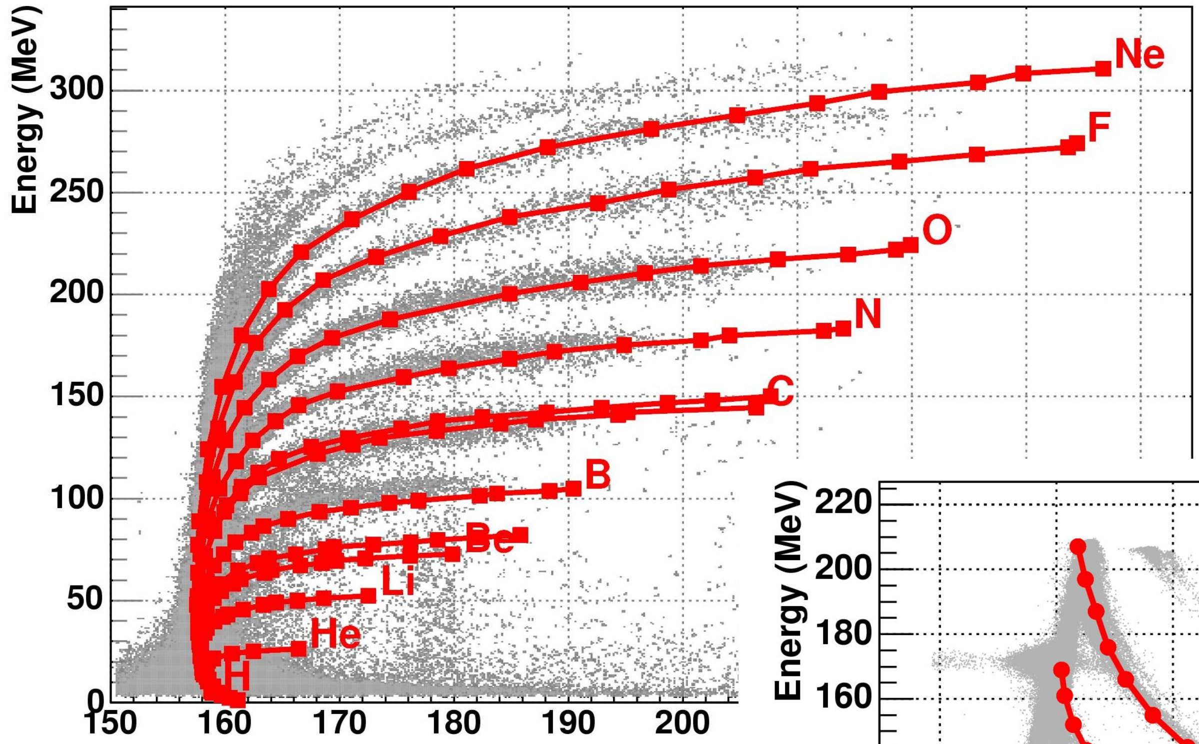
Vappl=55V, Vdepl=50V • Simulated points.

- A computationally intensive simulation for plasma effects in silicon and computation of current signals
- The simulation has no free/semi-empirical parameters
- Preliminay results have been shown
- Quantitative agreement with experiments, both rear- and front-mount silicon

The *exact* electrostatic of the silicon+carriers system, including e$\leftrightarrow$h interactions, accounts for the observed experimental features

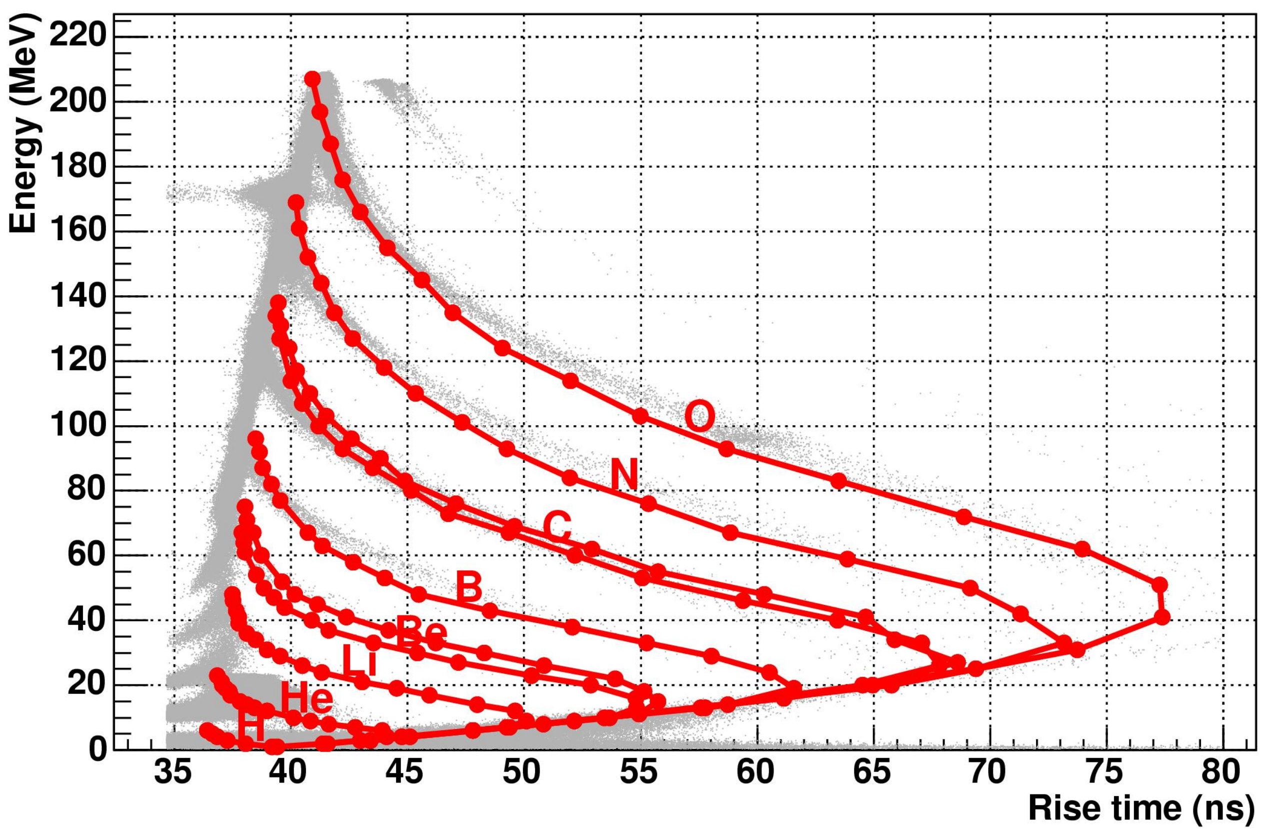
future:

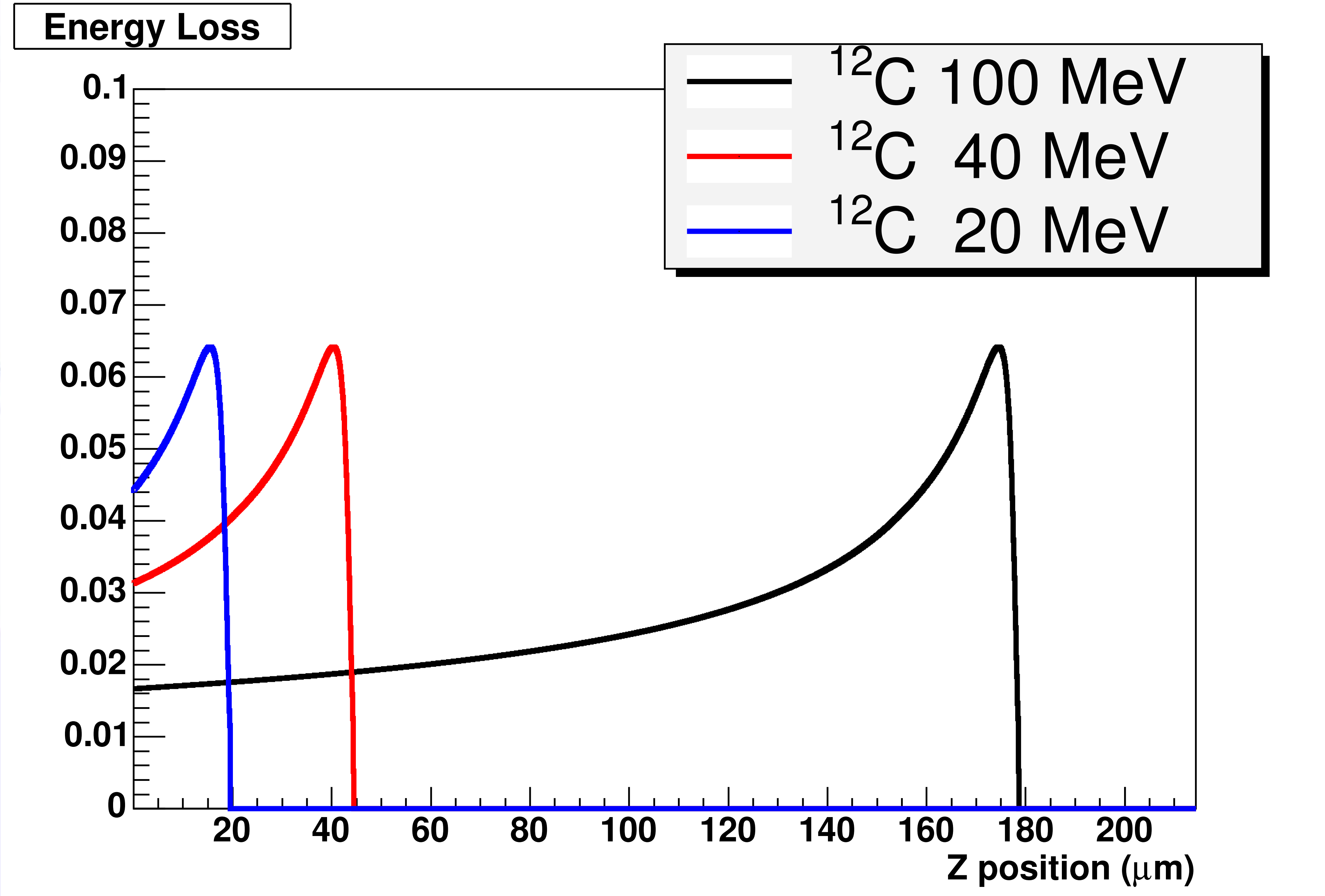
- test with exp. signals of heavier particles
- try to use the simulated signals to improve resolution in pulse shape measurements



REAR
140V (depl.=120V)
^{16}O+^{116}Sn, E=16 AMeV

FRONT
55 V (depl.=50 V)
^{20}Ne+^{12}C, E=21 AMeV




Energy Loss
^{12}C 100 MeV
^{12}C 40 MeV
^{12}C 20 MeV
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
20
40
60
80
100
120
140
160
180
200
Z position (μm)

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