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for FAZIA Collaboration

Modeling of the signal from silicon detectors in nuclear reactions

Verification and extensions of the Gaussian cloud dynamics model for the induced current signal in silicon detectors are presented.

The approach is based on Ramo-Shockley theorem where, in addition to electrodes field, Coulomb interactions between electron and hole clouds are taken into account.

The preliminary results provide good description of experimental observations gathered by FAZIA collaboration concerning Pulse Shape Analysis (PSA).

Focus is put on ion identification and on the factors impacting the PSA. The results of model calculations deliver suggestions for possible optimizations.

Joint LIA COLL-AGAIN, COPIGAL, and POLITA Workshop
French-Italian-Polish Collaborations
April 26-29, 2016
LNS Catania

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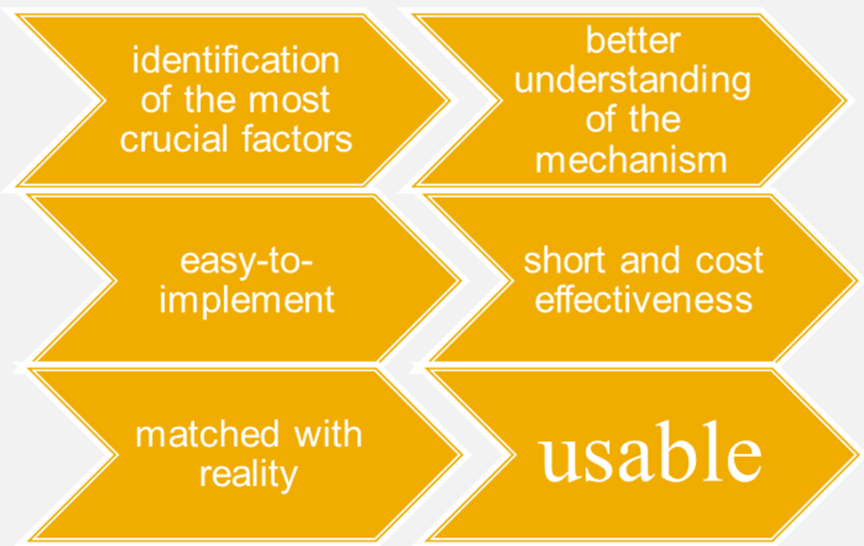
OUTLINE

- Introduction
- ΔE-E vs. Pulse Shape Discrimination (PSD)
- Model assumptions
- The outcome and outlook
- Summary

Introduction

- Identification of particles and fragments is of critical importance for nuclear physics
- ΔE-E method still widely used and well proven
- Pulse Shape Discrimination (PSD) in rapid and extensive development
- why to model? how to model?



- **FAZIA**

- investigating of silicon detectors properties
- tuning detector characteristics that influence their performance for particles identification
- using both: ΔE-E and PSD

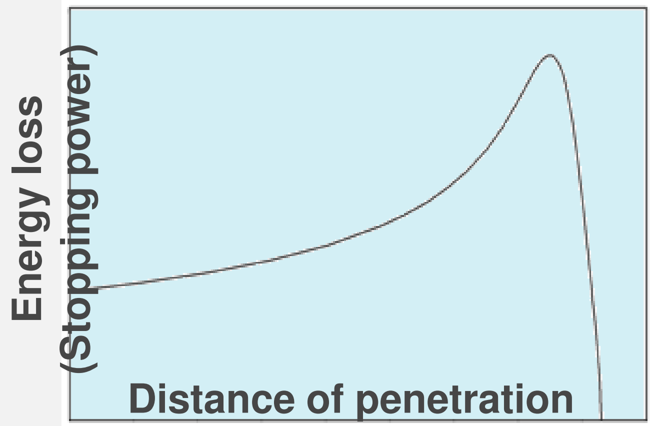
>10 institutions from 6 countries
(France, Italy, Poland, Spain, Romania, India)

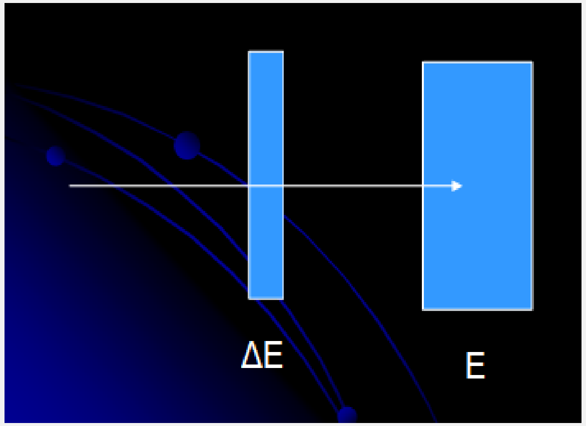
- main target is to design a new detector with enhanced capabilities in the detection and charge and mass identification of particles

ΔE-E vs. PSD

- ΔE-E is a classical method of charged particles identification

- driven mainly by energy loss shown by Bragg curve (W. Bragg – 1903)





- theory given in 1930/1933 by Hans **Bethe**

$$-\frac{dE}{dx} = \frac{4\pi e^4 z^2 \rho N_A Z}{m_e v^2 A} \ln\left(\frac{2 m_e v^2}{I}\right)$$

z particle charge
ρ material density
N_A Avogadro number
Z material atomic number
m_e rest mass of electrone
V velocity of particle
I - mean excitation potential

- identification function

$$TMz^2 \sim (E_T + k_0 + k_1 \Delta E)\Delta E$$

T detector thickness
E_T particle total energy
$k_{0,1}$ const values

ΔE-E vs. **PSD**

- proposed in the1963 (C. Ammerlaan), attempts to describe formally in 1968 (e.g. A. Quaranta); paid attention to importance of collection times of carriers

- in general that time in semiconductor depends on:

$$\tau = f(\tau_E, \tau_P, \tau_{RC}, \tau_A)$$

factors related to:

τ_E carriers collection time in detector field
τ_P ionization across particle trajectory
τ_R detector area resistancy
τ_A amplifier and cabling resistancy

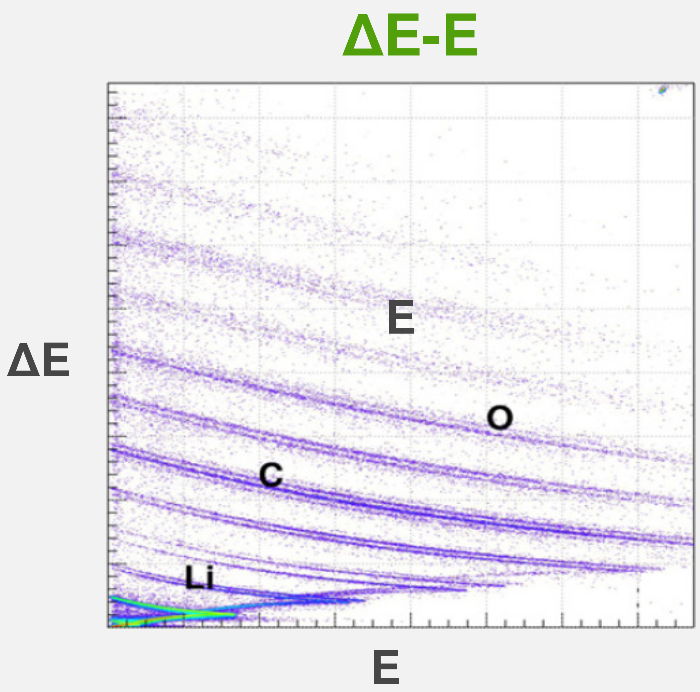
- charged particles enter silicon detector and create plasma column which length is related to charge density and mass

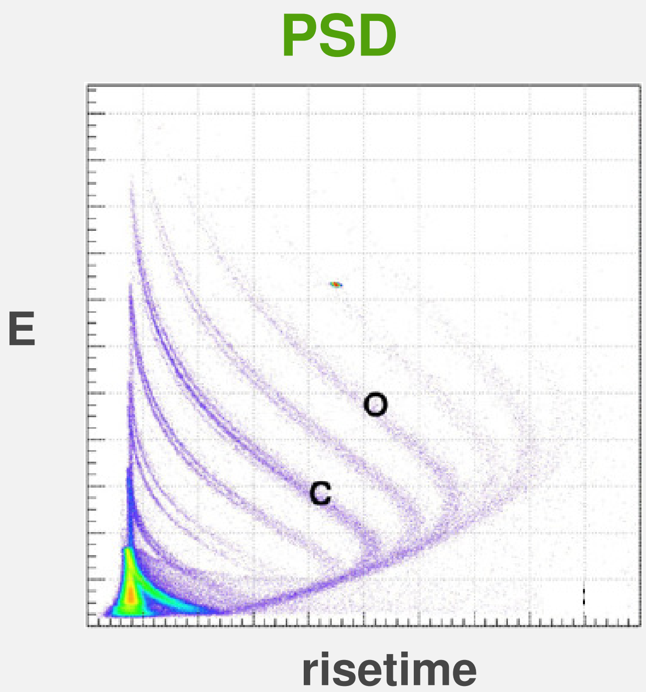
\- **pulse rise time** (correlated via preamplifier factor to collection time) depends on **mutual interactions of carriers**

- described approach is governed by Plasma Delay Effect (PDE) which in silicon detectors case can be observed as shortening of pulse rise time when Z decreases

ΔE-E vs. PSD

particle identification





Why to consider PSD as an alternative to ΔE-E?

- less space
- cheaper
- one electronic channel

Model assumptions

Based on Z. Sosin, Nuc. Instr. and Meth. in Phys. Res. A 693, 170-178 (2012).

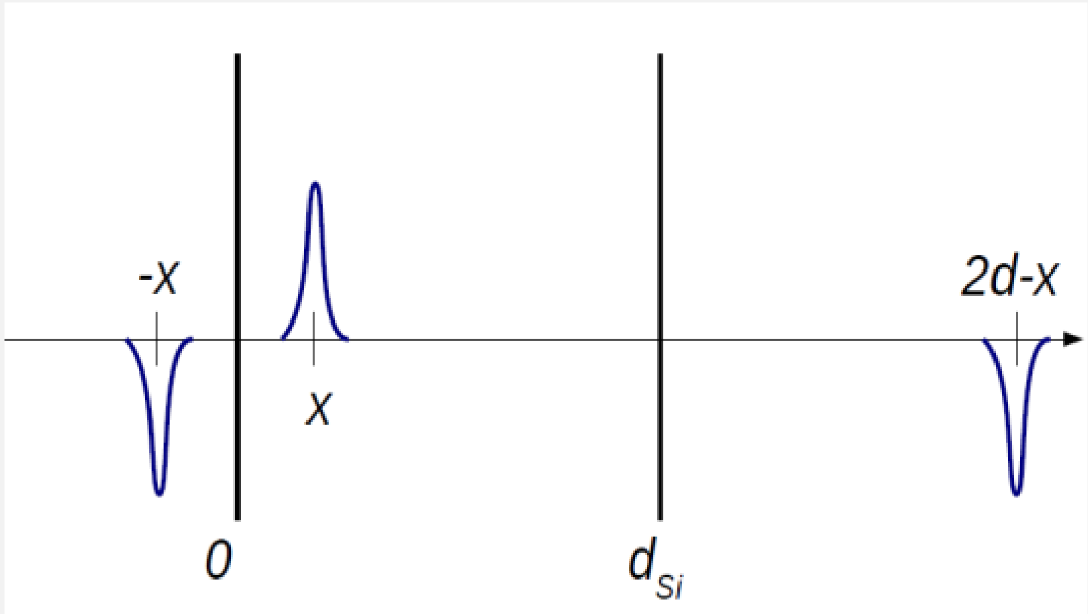
- propagation of electrons and holes induced in detector is represented by Gaussian clouds

- centroids and variances are calculated separately

- Gaussian centroids are ruled by drift

- Gaussian variances are ruled by diffusion and drift

- only the nearest mirror reflections in the electrodes are considered



Model assumptions

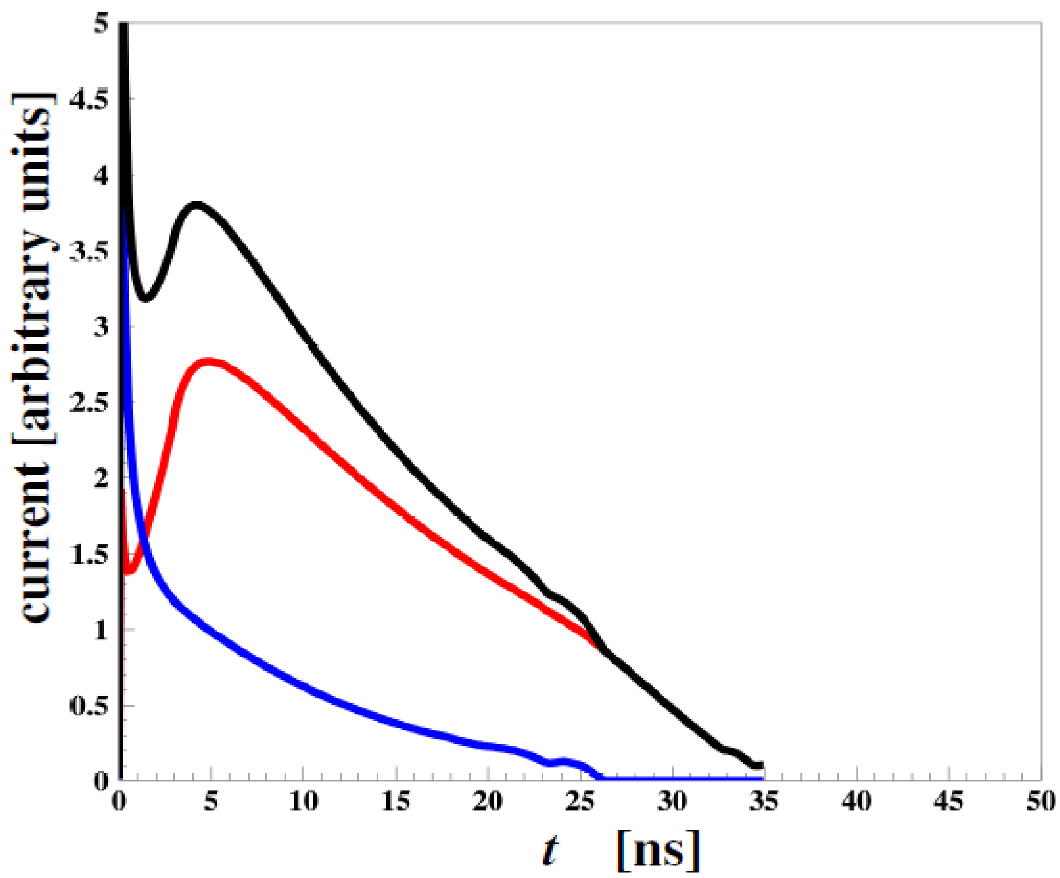
- model parameters

feature	symbol	value	remarks
energy per e–h pair creation	w	$3.6\ \left[\frac{eV}{pair}\right]$	material constant
silicon dielectric, permittivity	ε_r	11.7	material constant
electrons mobility	μ_{xe}	$135\ \left[\frac{\mu m^2}{Vns}\right]$	material constant
holes mobility	μ_{xh}	$47.5\ \left[\frac{\mu m^2}{Vns}\right]$	material constant
electrons variance mobility	$\mu_{\sigma e}$	$2\ \left[\frac{\mu m^2}{Vns}\right]$	free parameter
holes variance mobility	$\mu_{\sigma h}$	$\mu_{\sigma h} = \mu_{\sigma e}\frac{\mu_{xh}}{\mu_{xe}}$	model assumption
diffusion coefficient for electrons	D_e	$3.49\ \left[\frac{\mu m^2}{ns}\right]$	material constant
diffusion coefficient for holes	D_h	$1.228\ \left[\frac{\mu m^2}{ns}\right]$	material constant

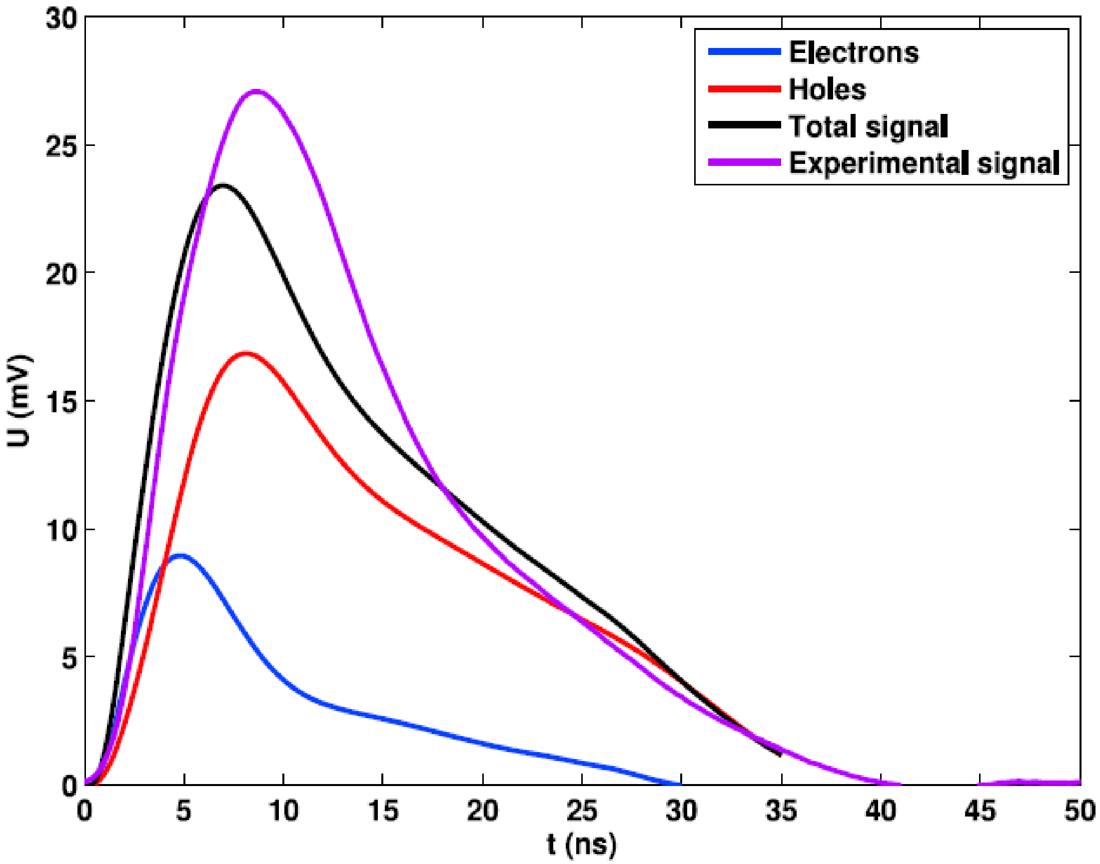
The outcome and outlook

^{10}C at 80MeV

pulses

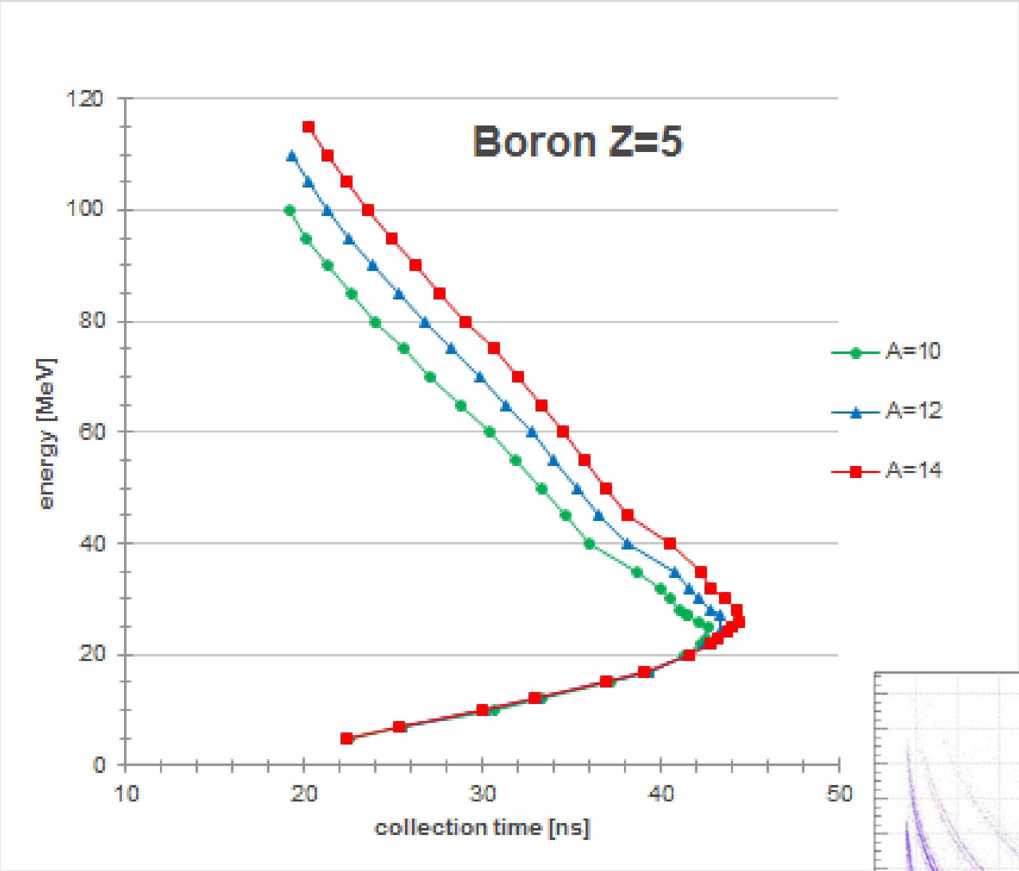


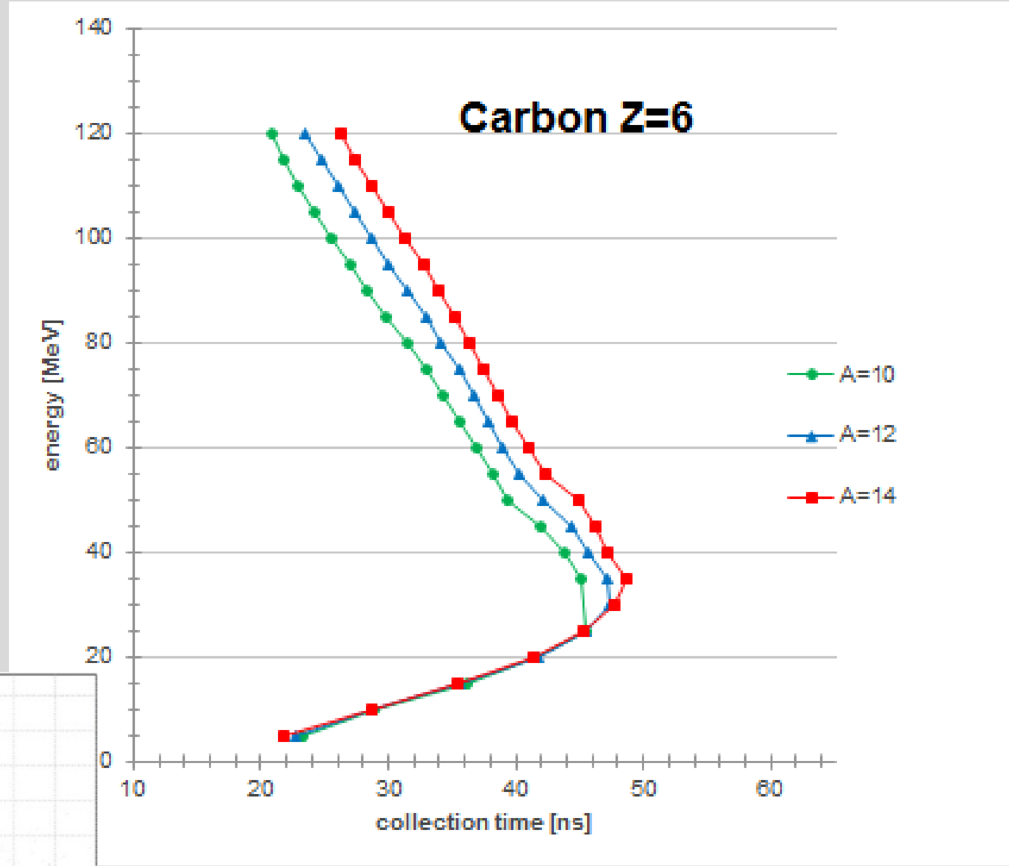
+ preamplifier correction

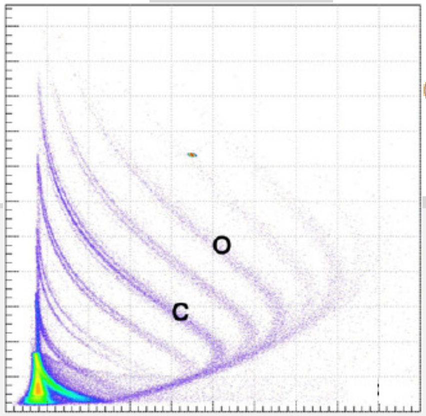


The outcome and outlook

Correlation between collection time and particles energy

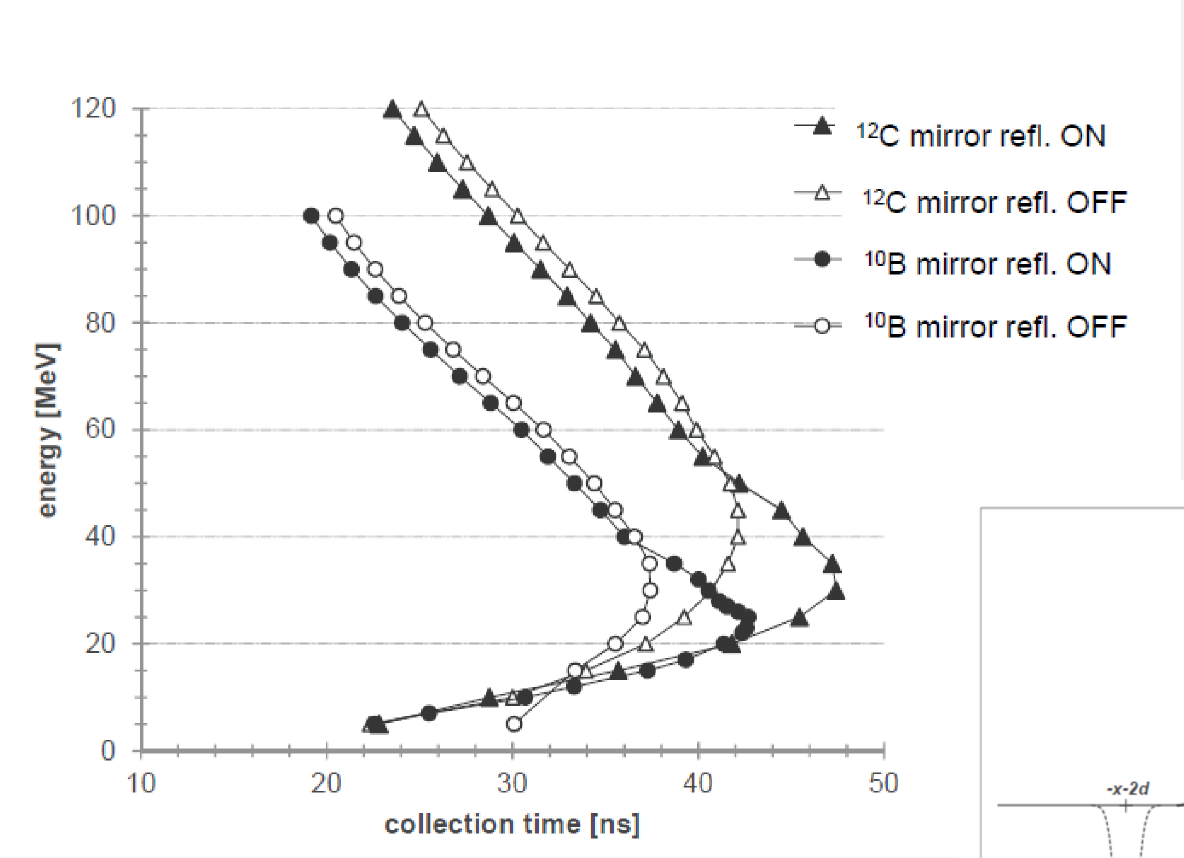


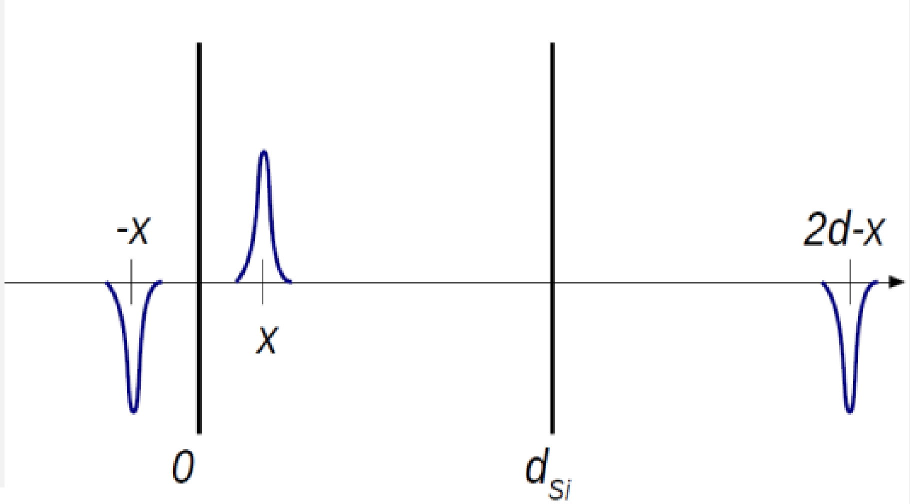


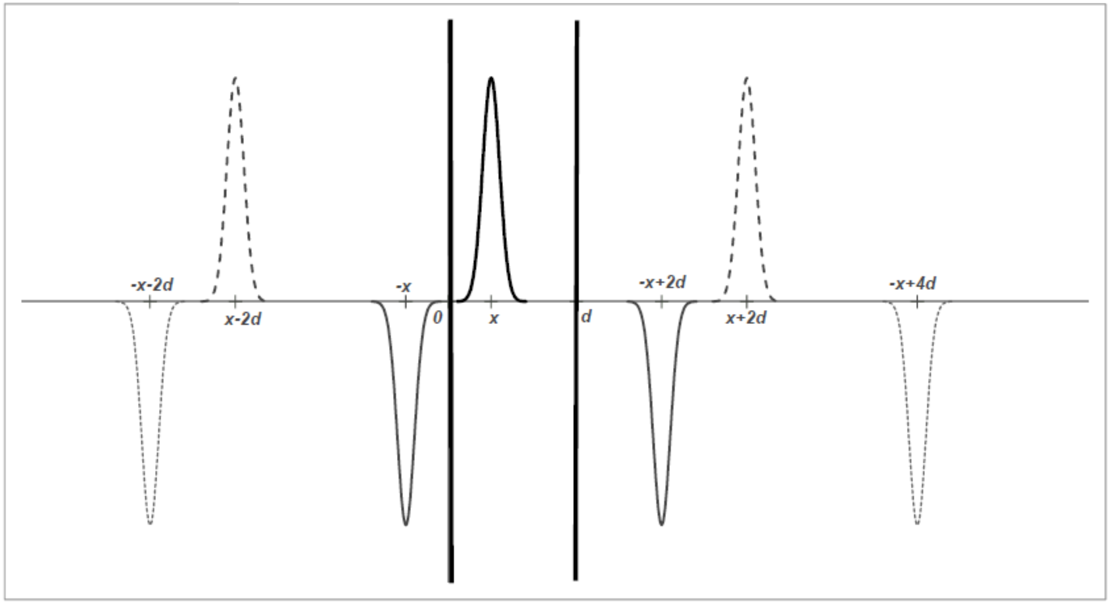


The outcome and outlook

Importance of mirror charges





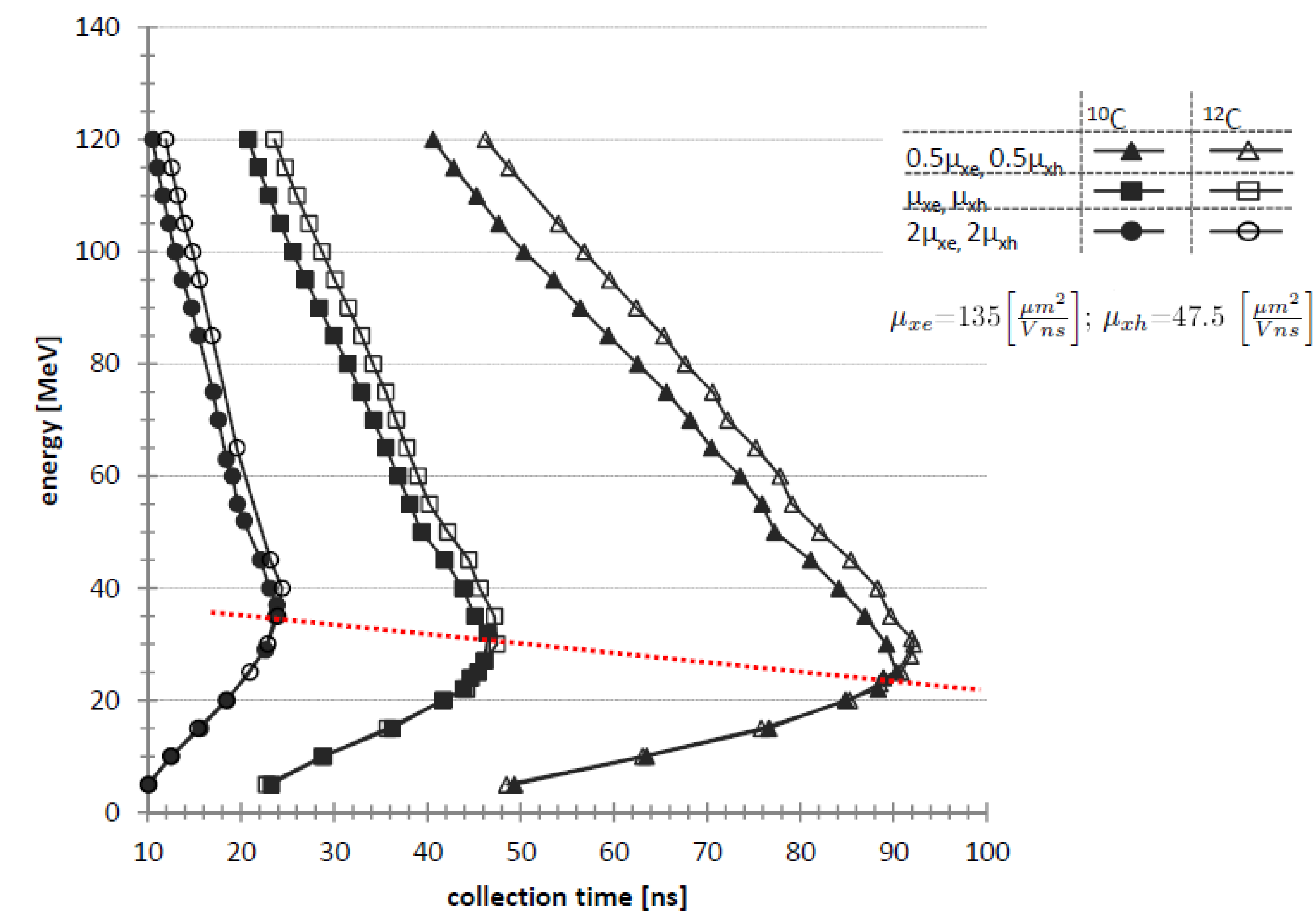


thin detector may require second/third reflection considerations

The outcome and outlook

Correlation collection time - particles energy may be influenced by

electron/holes mobility

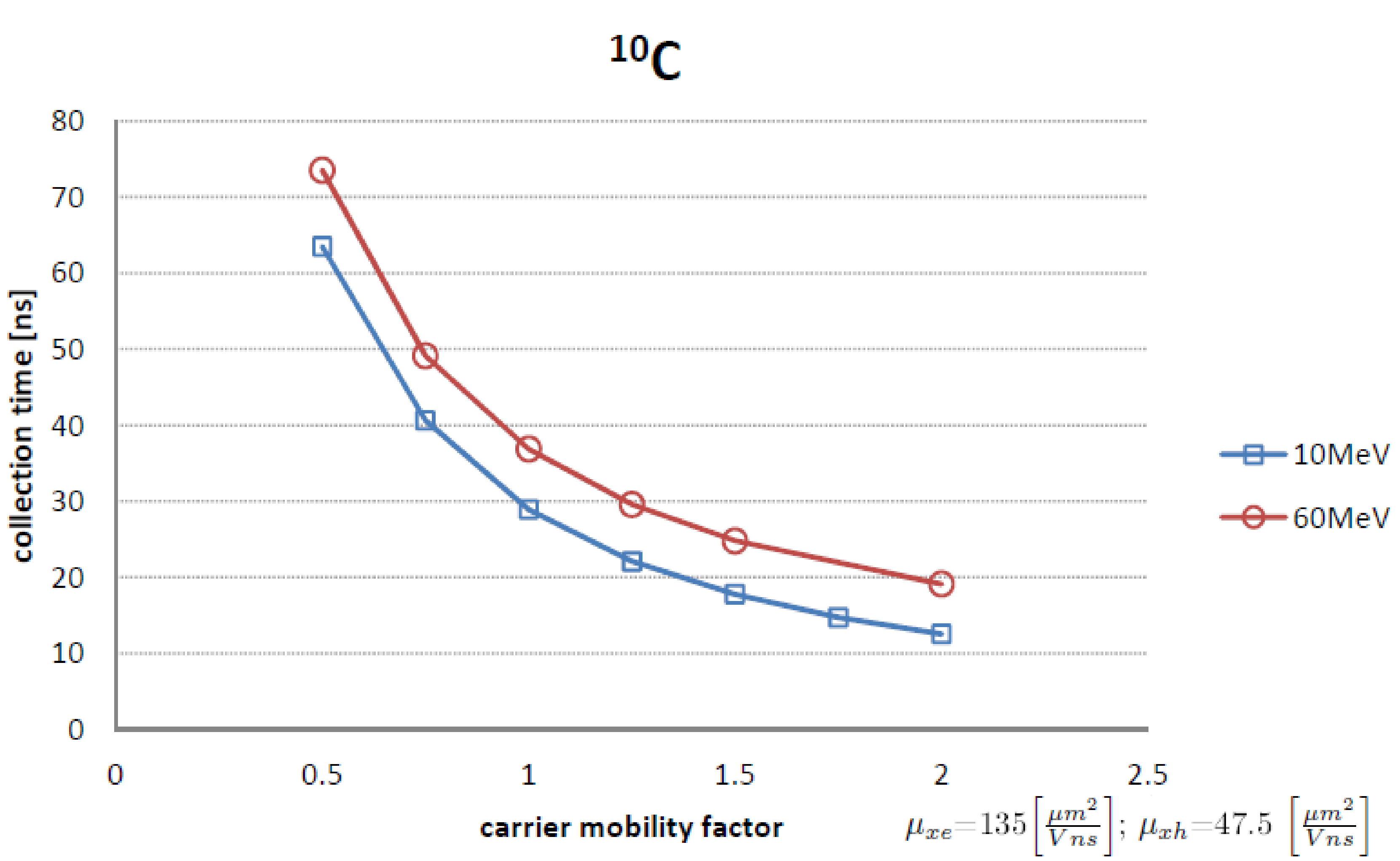


$d_{Si}=310$ μm, $V = 190$V, $V_d=128$V

The outcome and outlook

Correlation collection time - particles energy may be influenced by

electron/hole mobility



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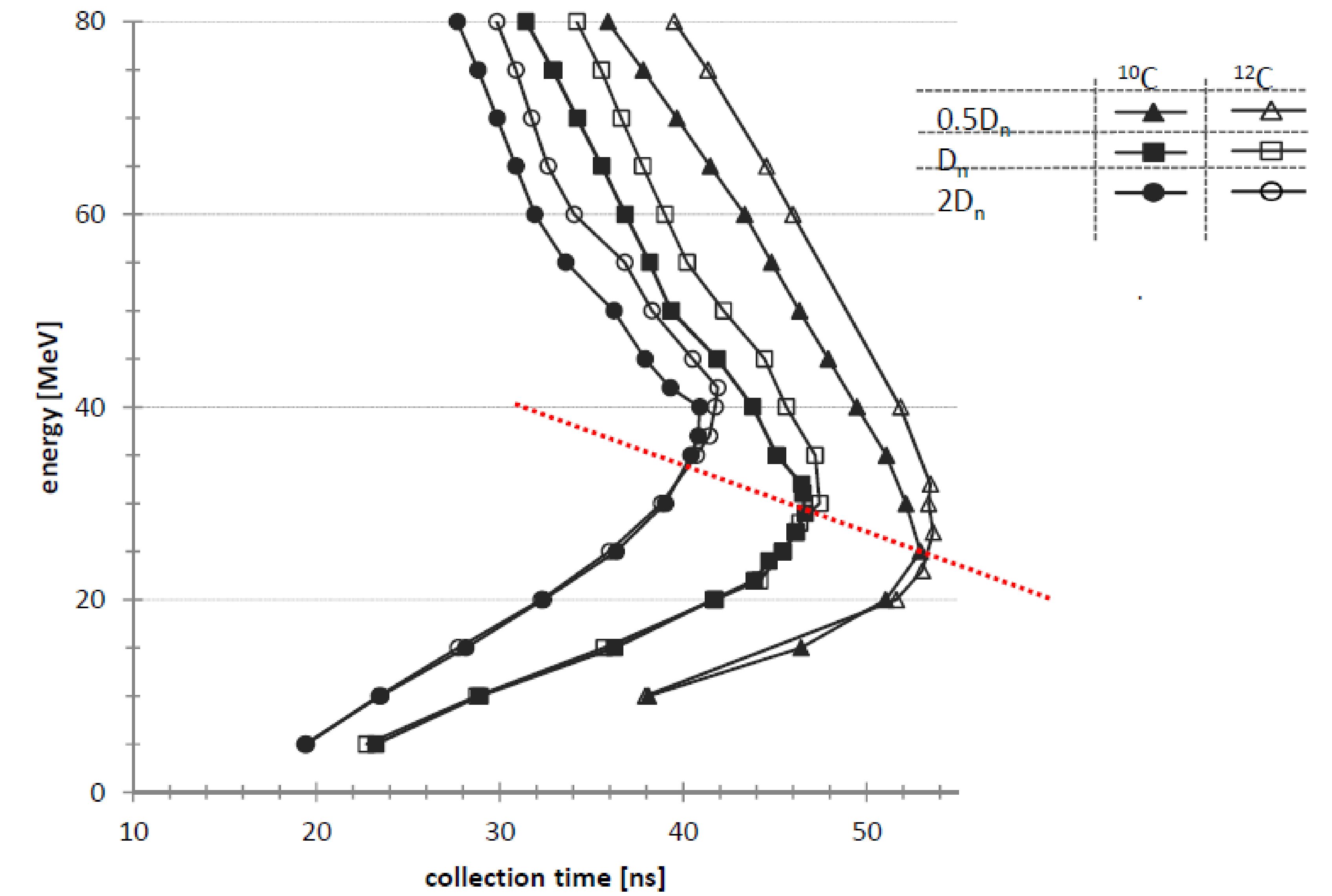
The outcome and outlook

Correlation collection time - particles energy may be influenced by

diffusion coefficient

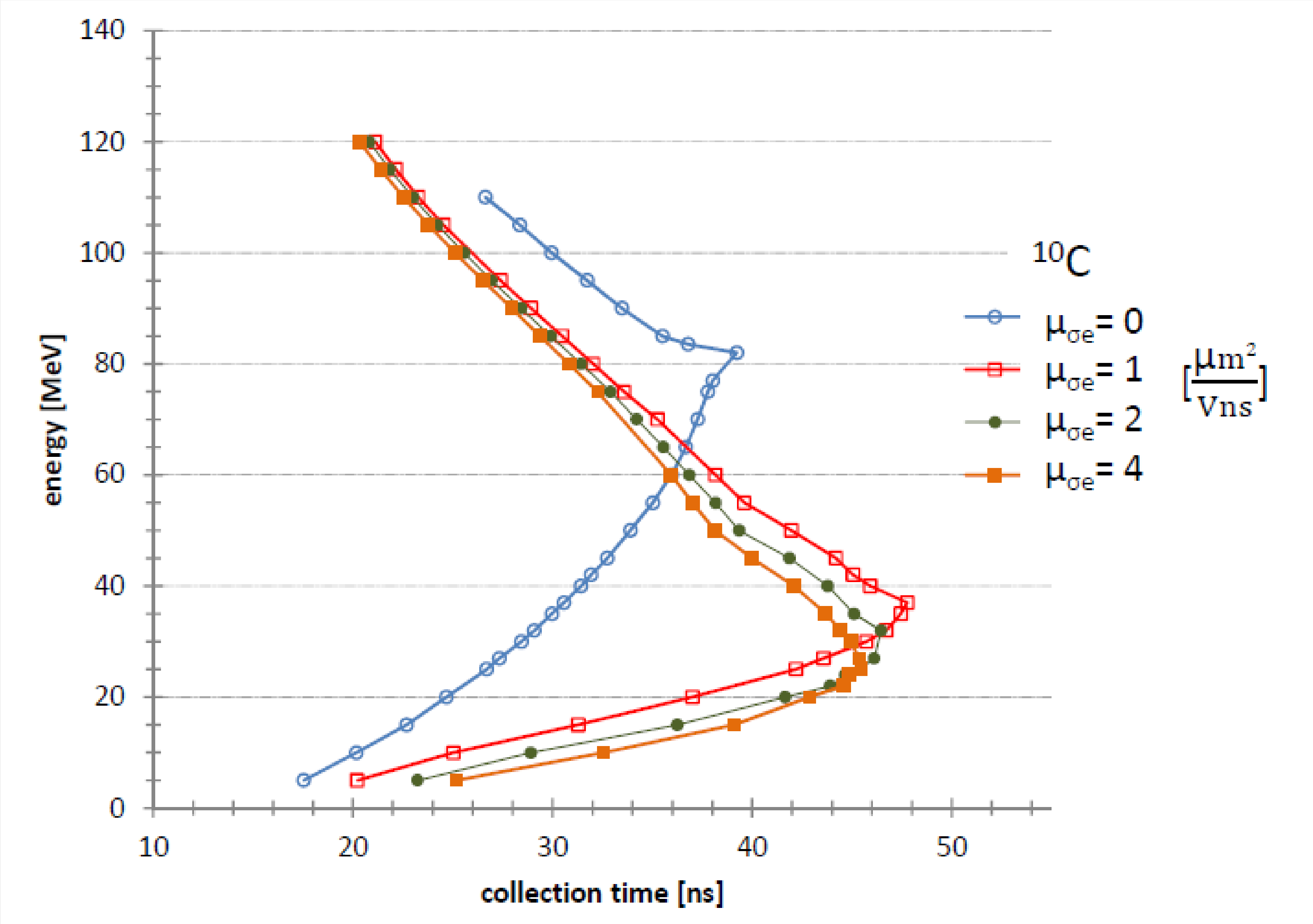


d_{Si}=310 µm, V = 190V, V_d=128V

The outcome and outlook

Correlation collection time - particles energy may be influenced by

carriers variance mobility



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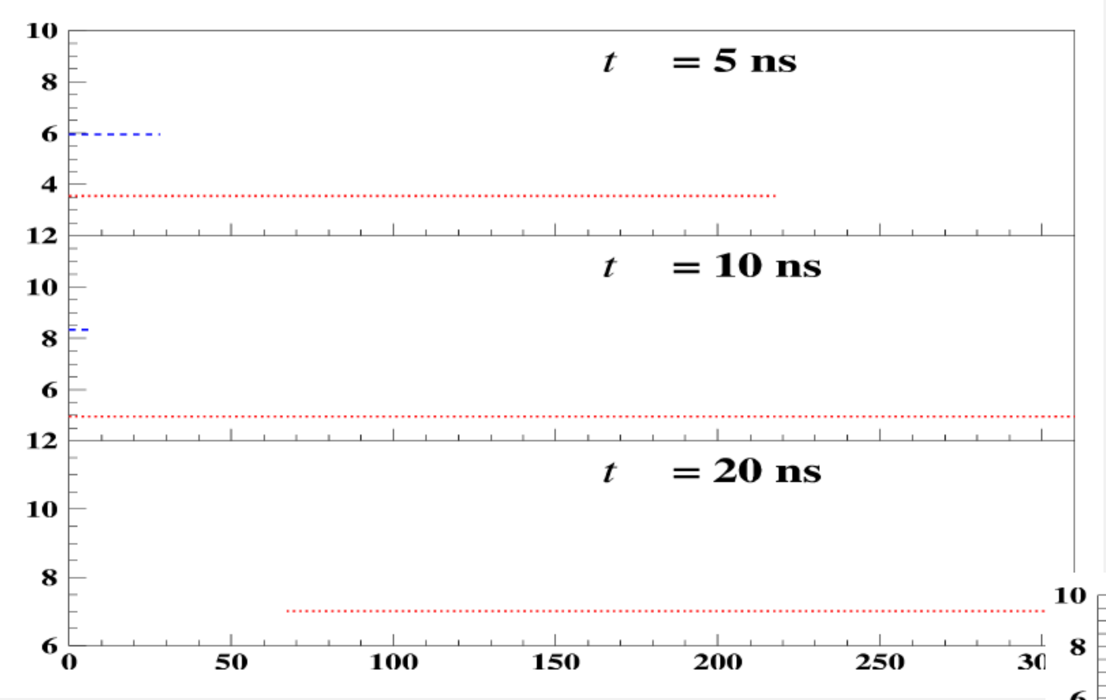
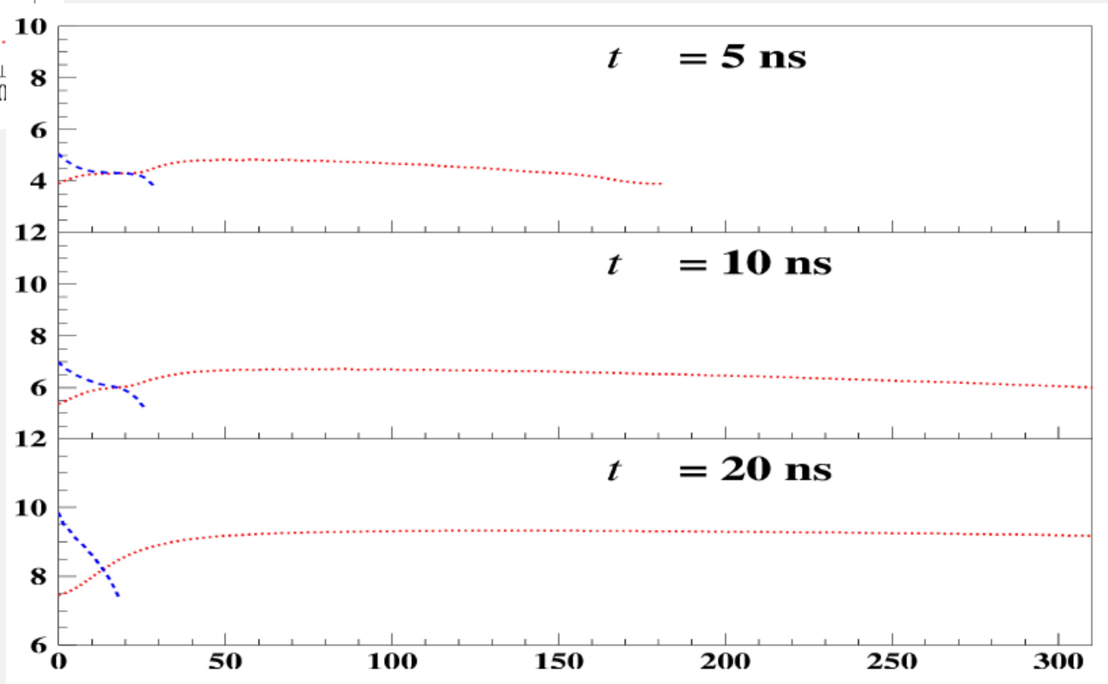
The outcome and outlook



The evolution of the width of
the charge distributions
in the perpendicular direction

$\mu_{\sigma e} = 0$

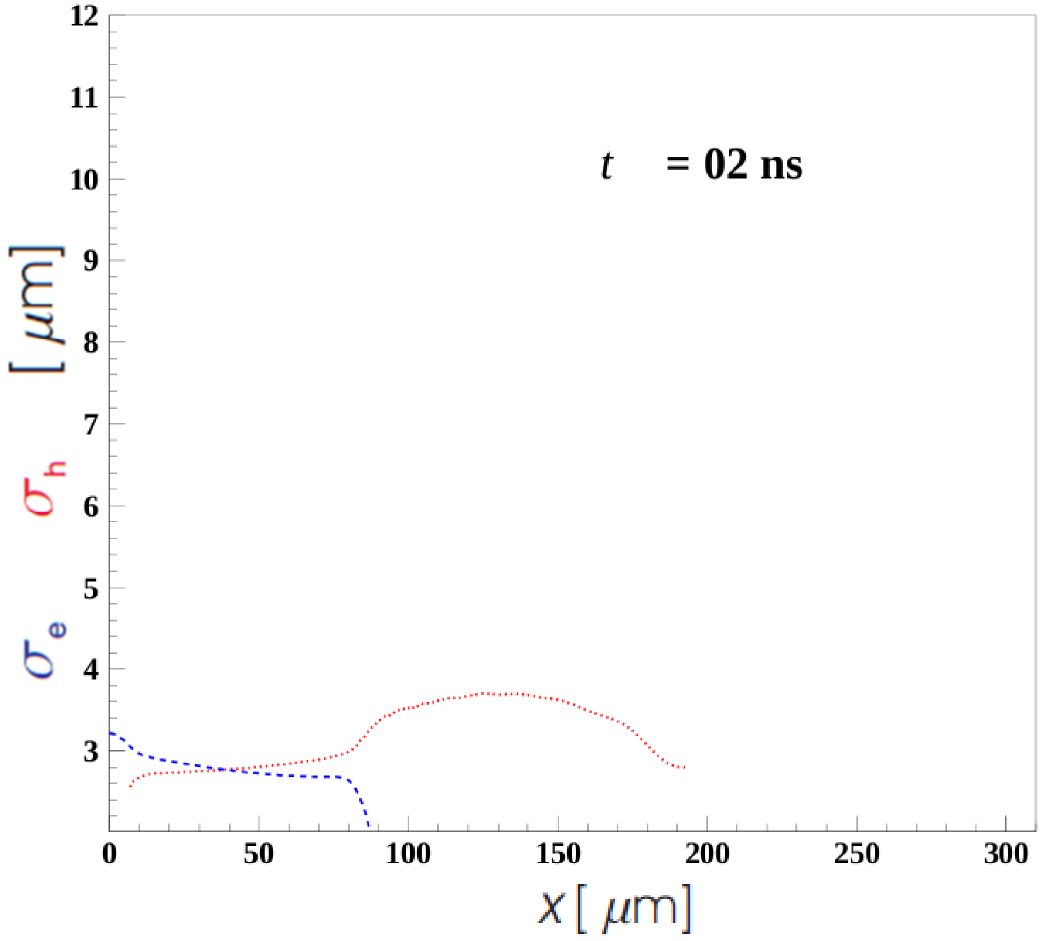
$\mu_{\sigma e} = 2$



The evolution of the width of the charge distributions: 60MeV, ^{10}C

σ_e σ_h

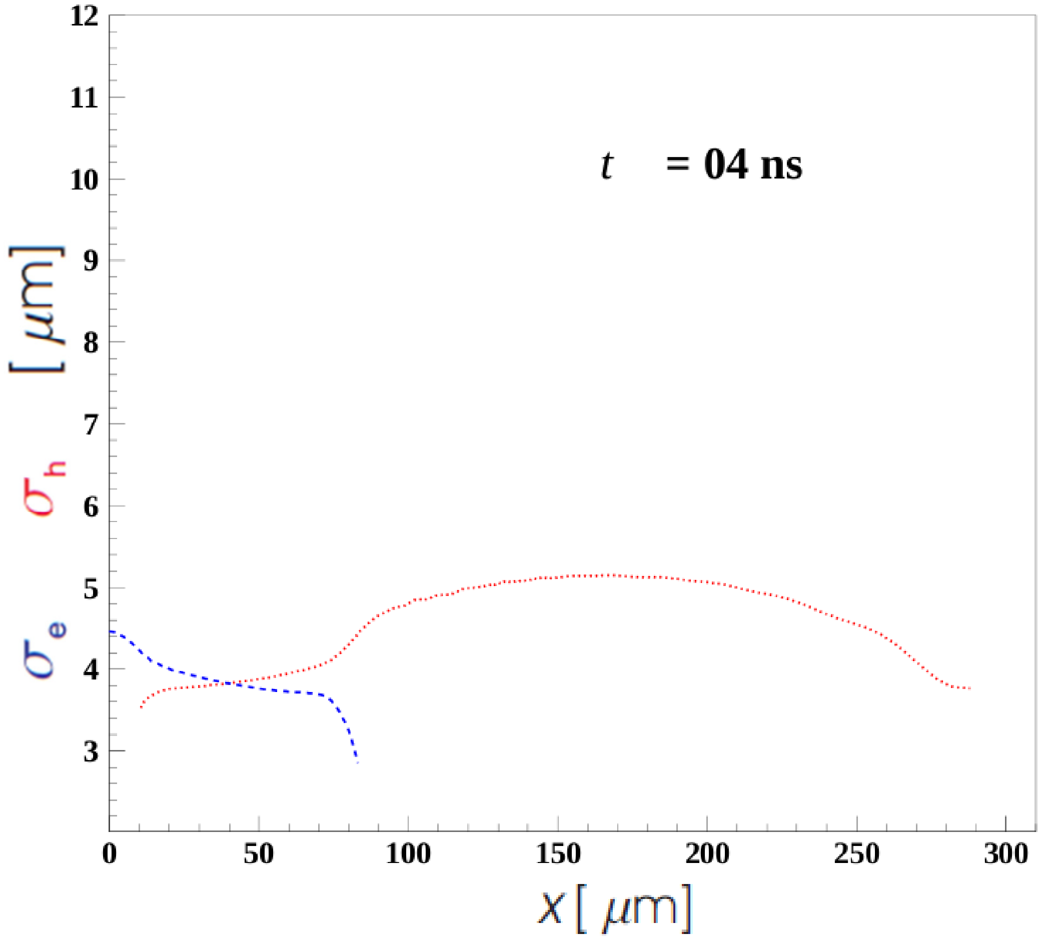
$\mu_{\sigma e} = 2$ [$\mu m^2/Vns$]



The evolution of the width of the charge distributions: 60MeV, ^{10}C

σ_e σ_h

$$\mu_{\sigma e} = 2\ [\mu m^2/Vns]$$



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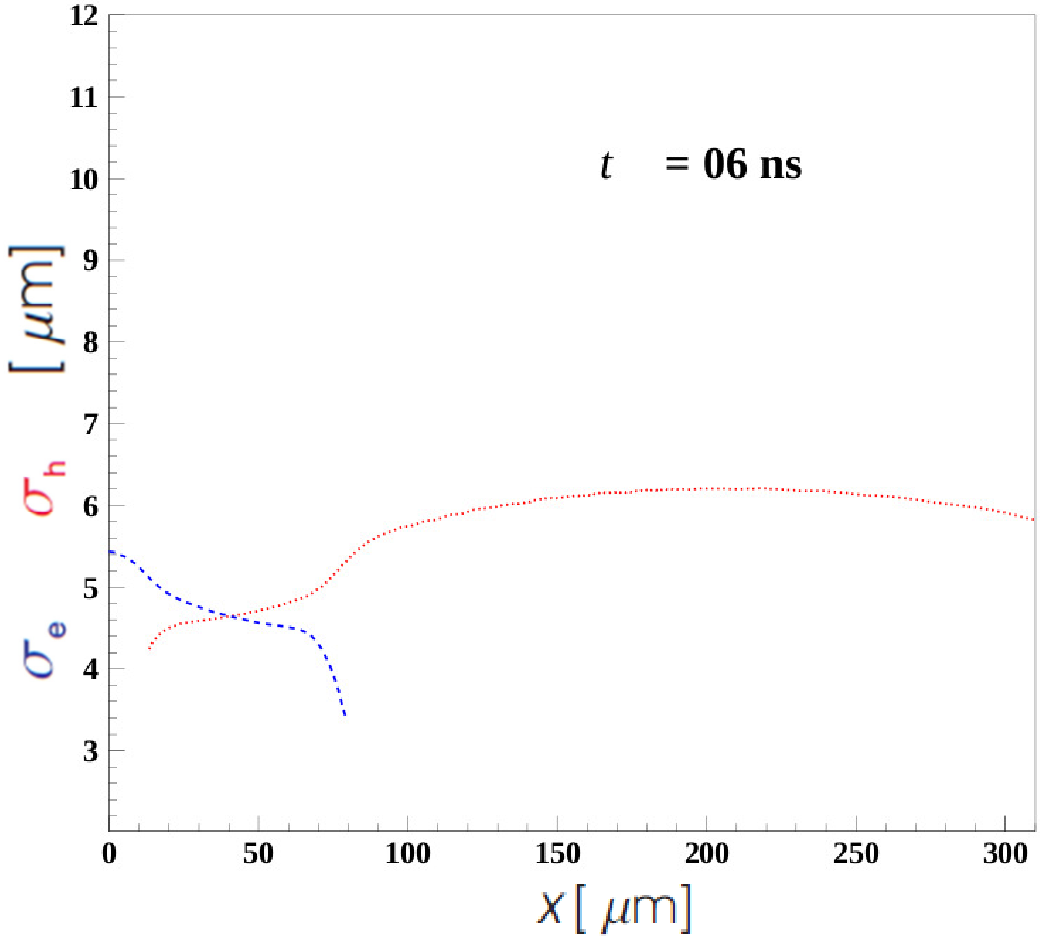

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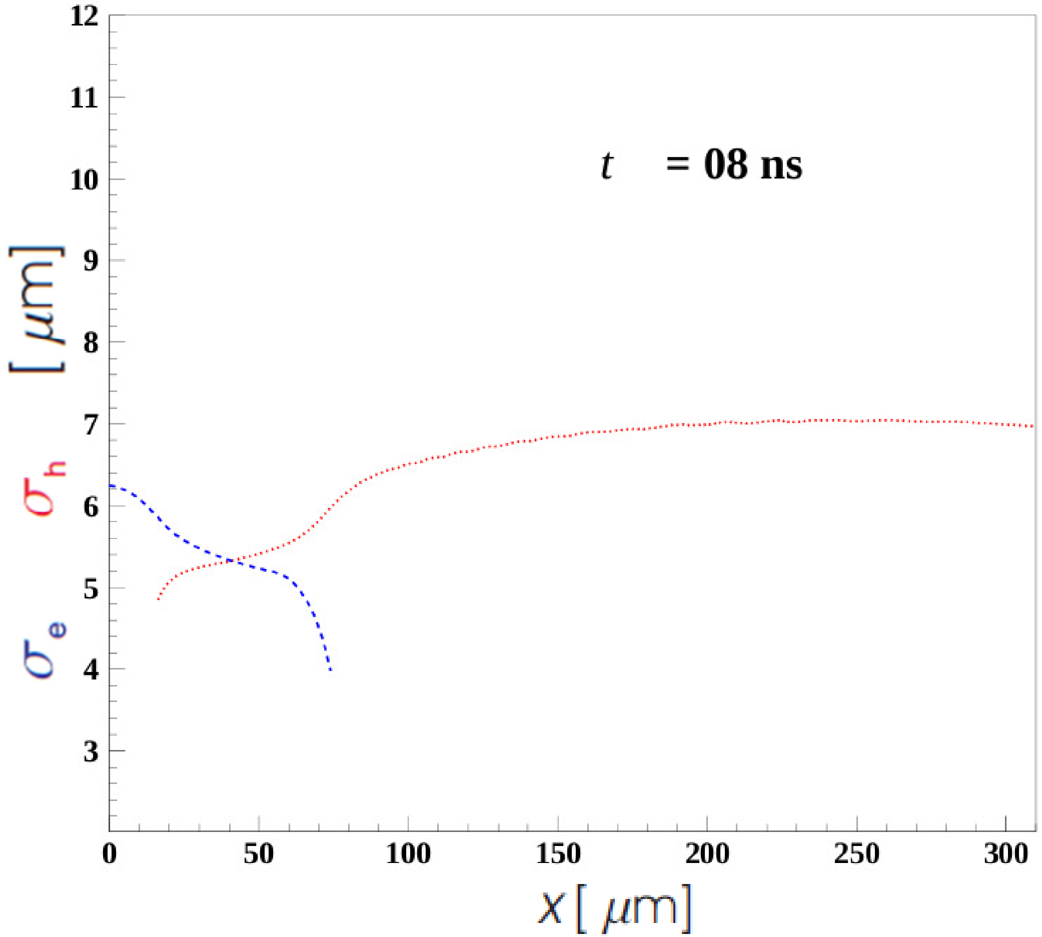

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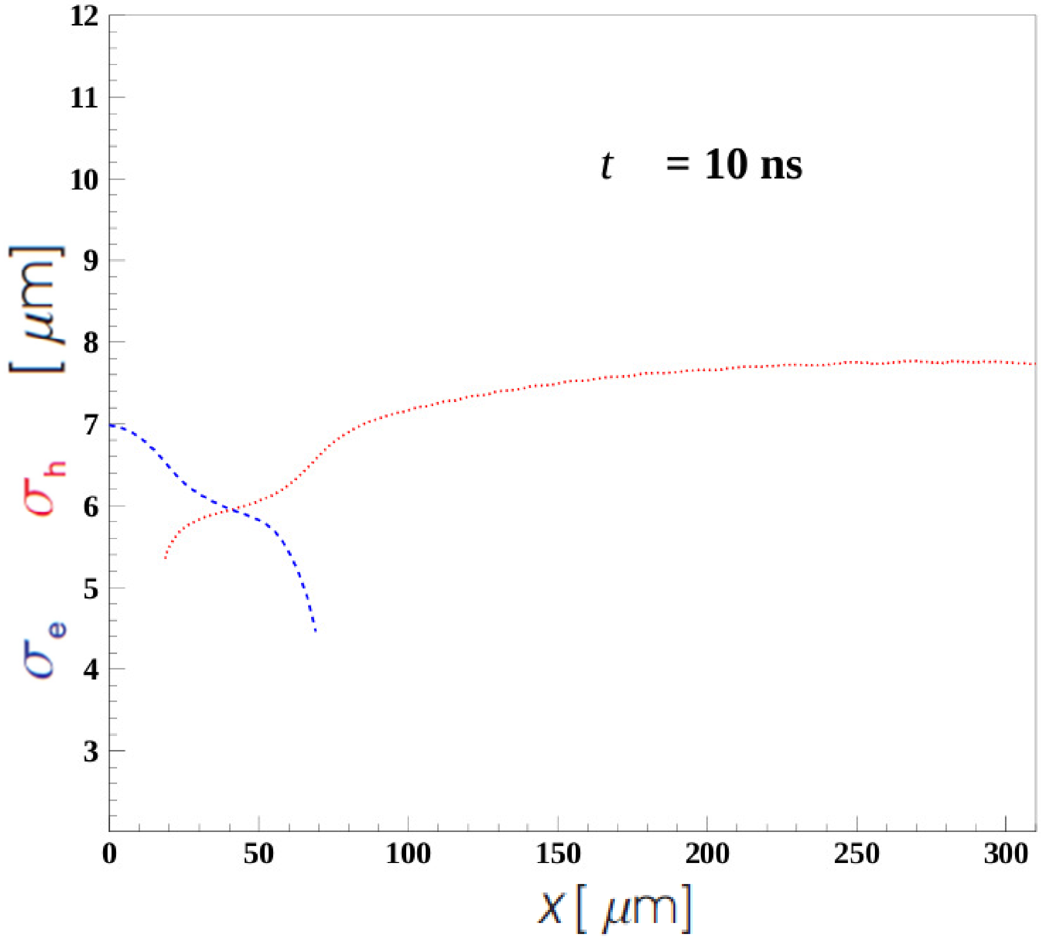

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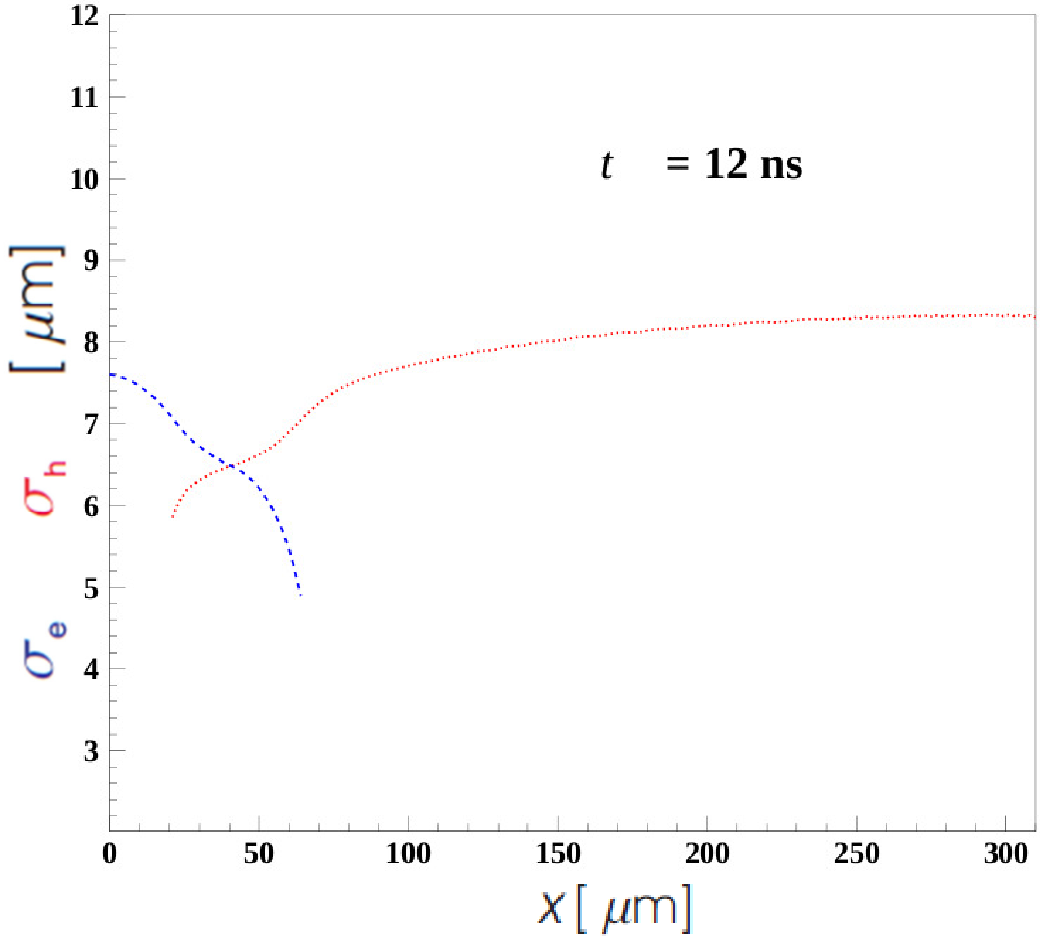

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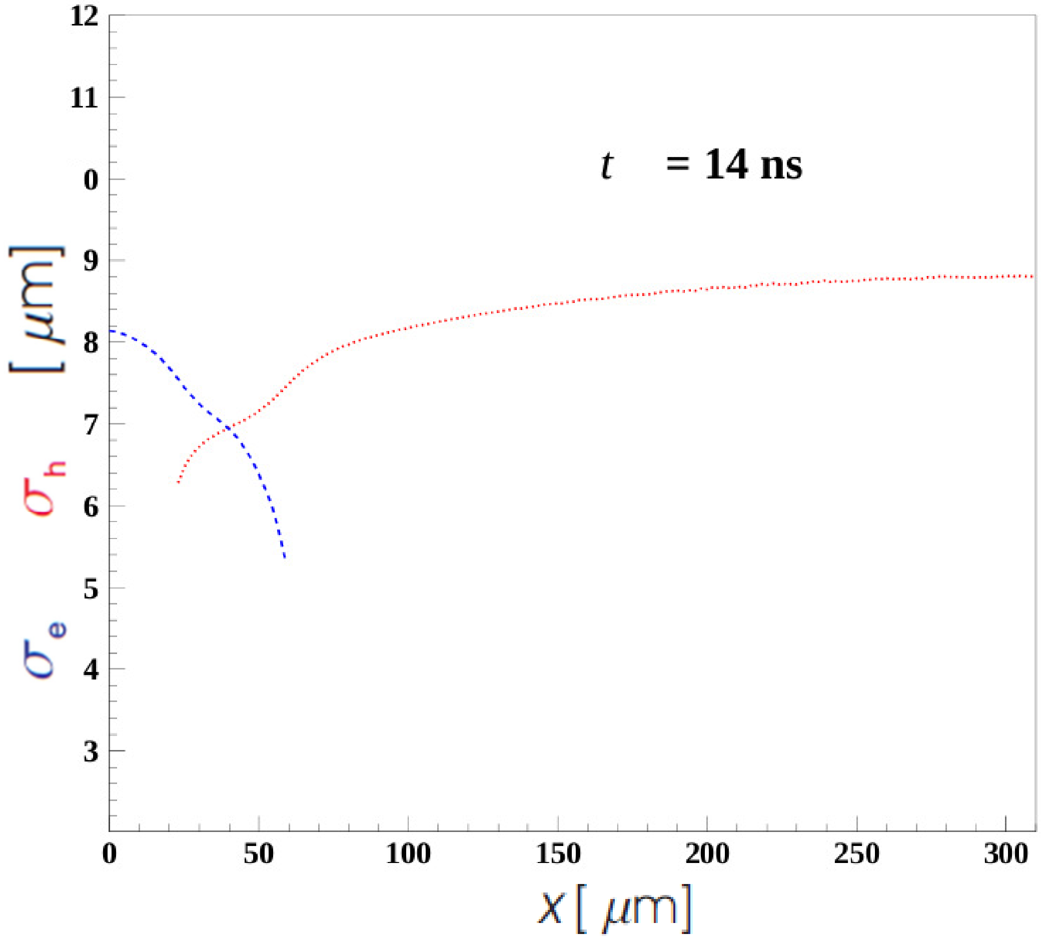

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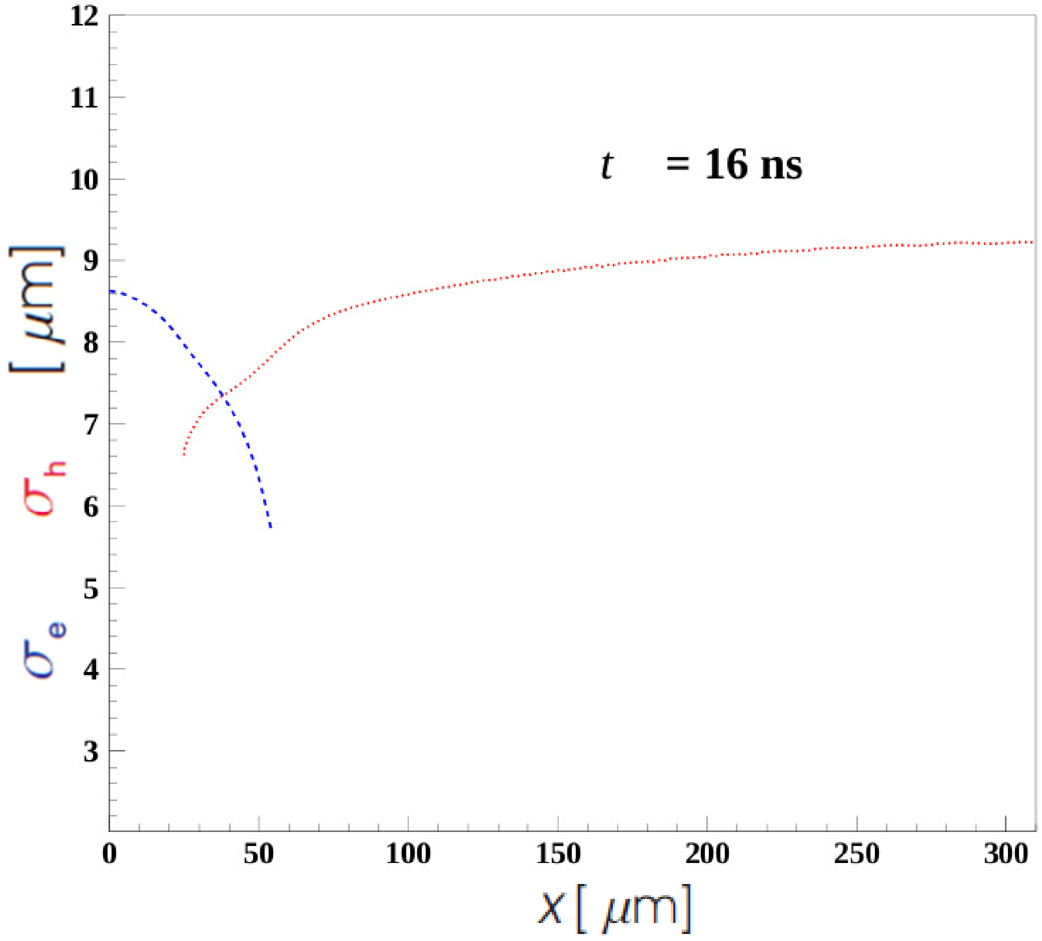

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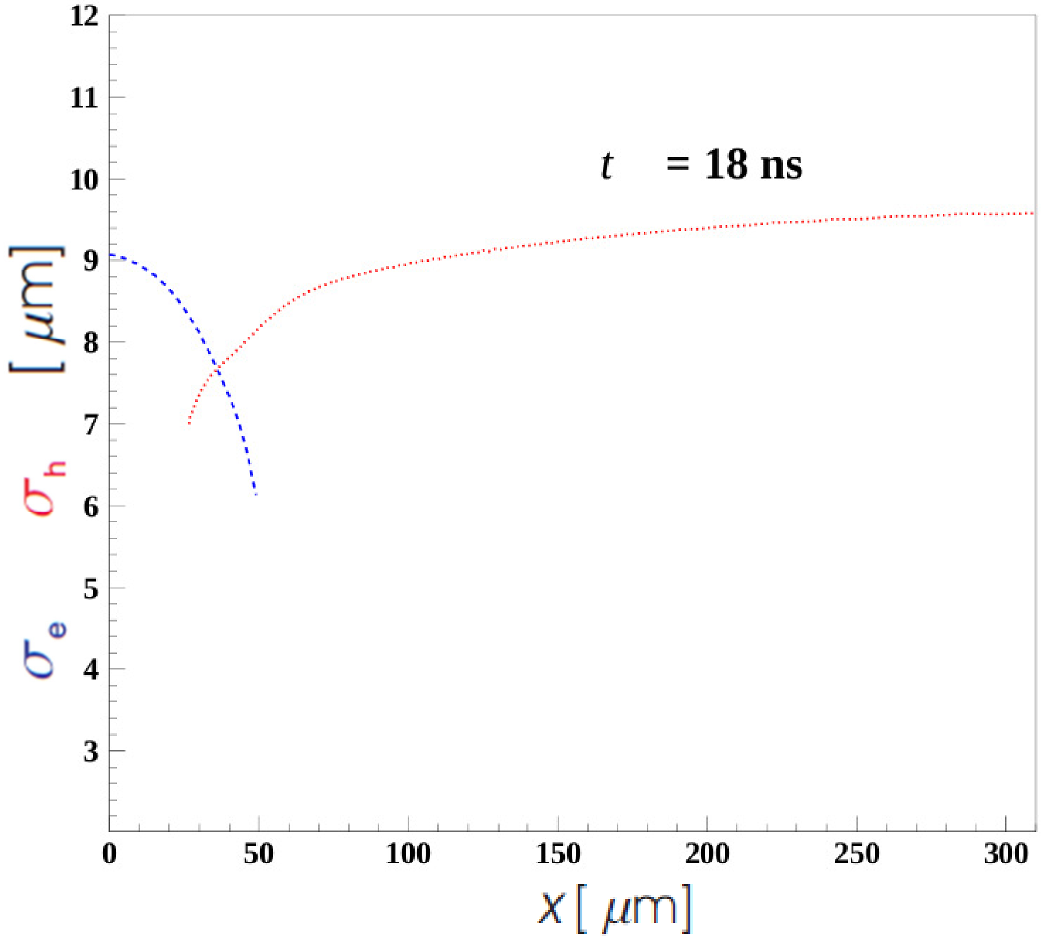

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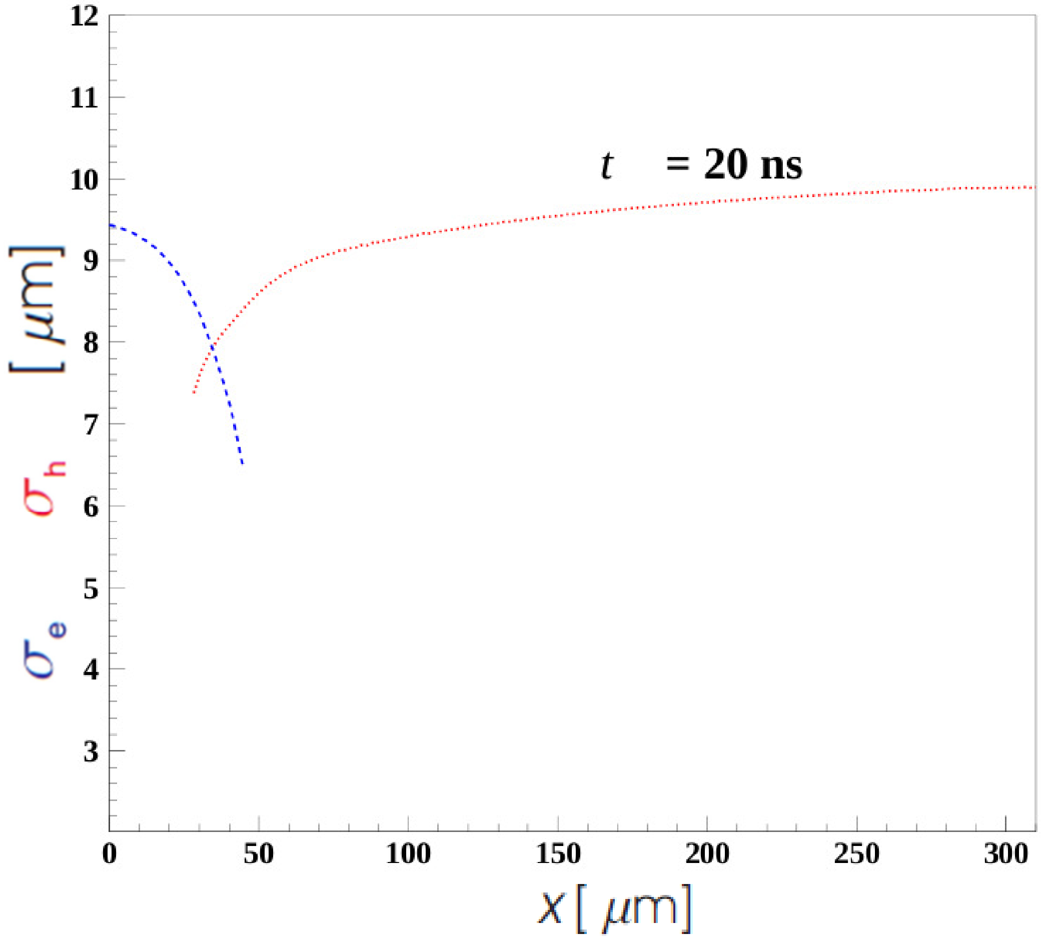

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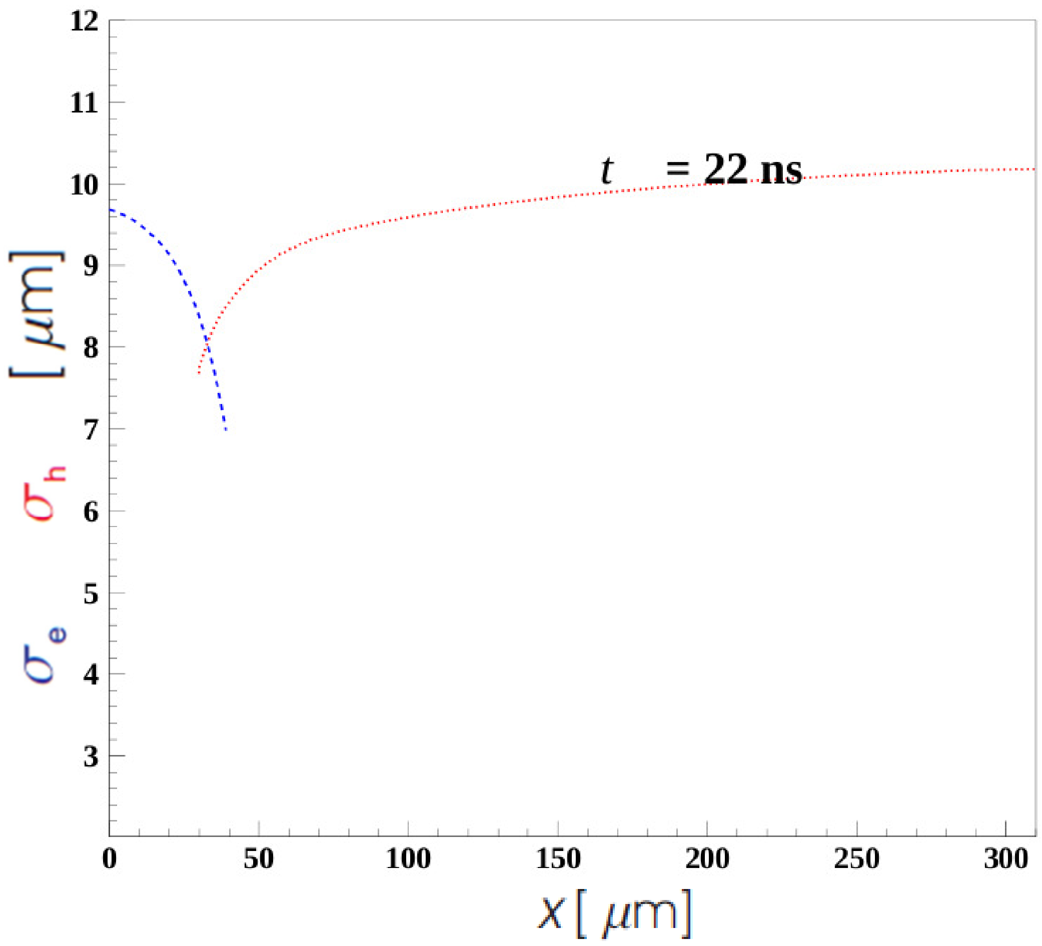

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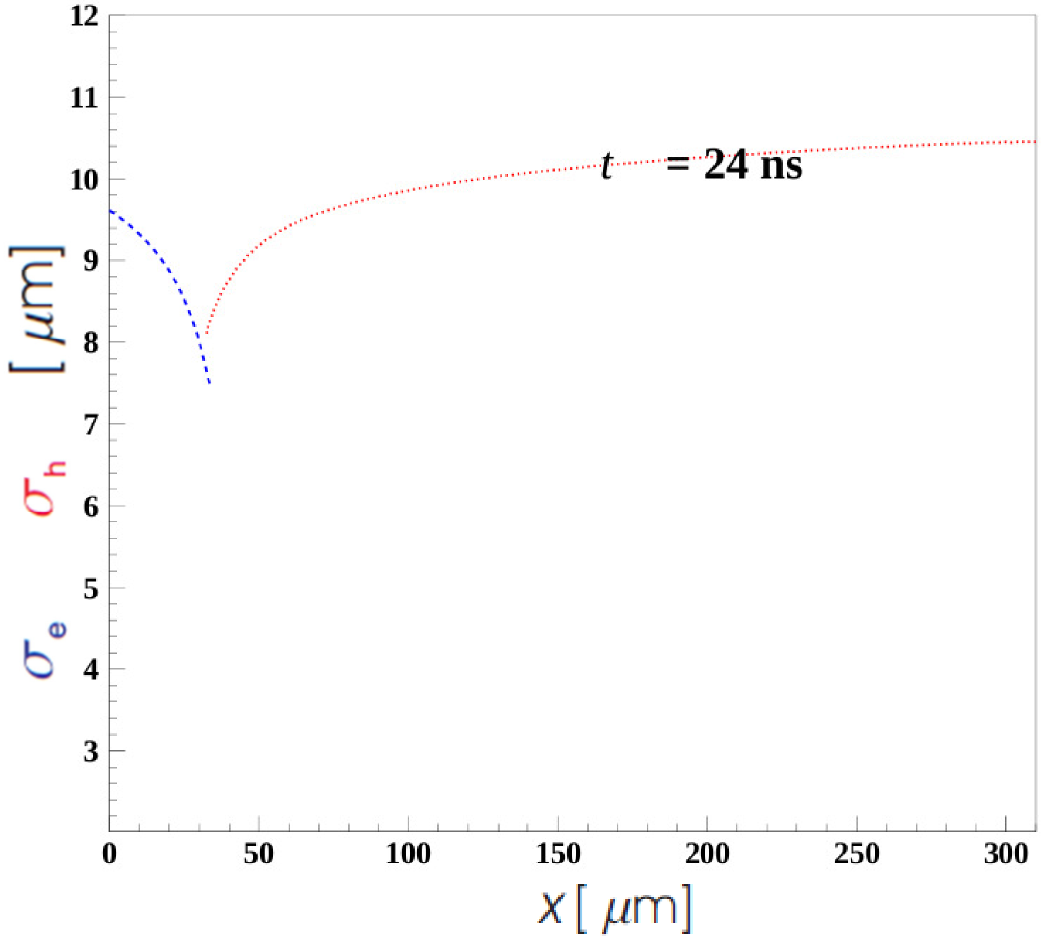

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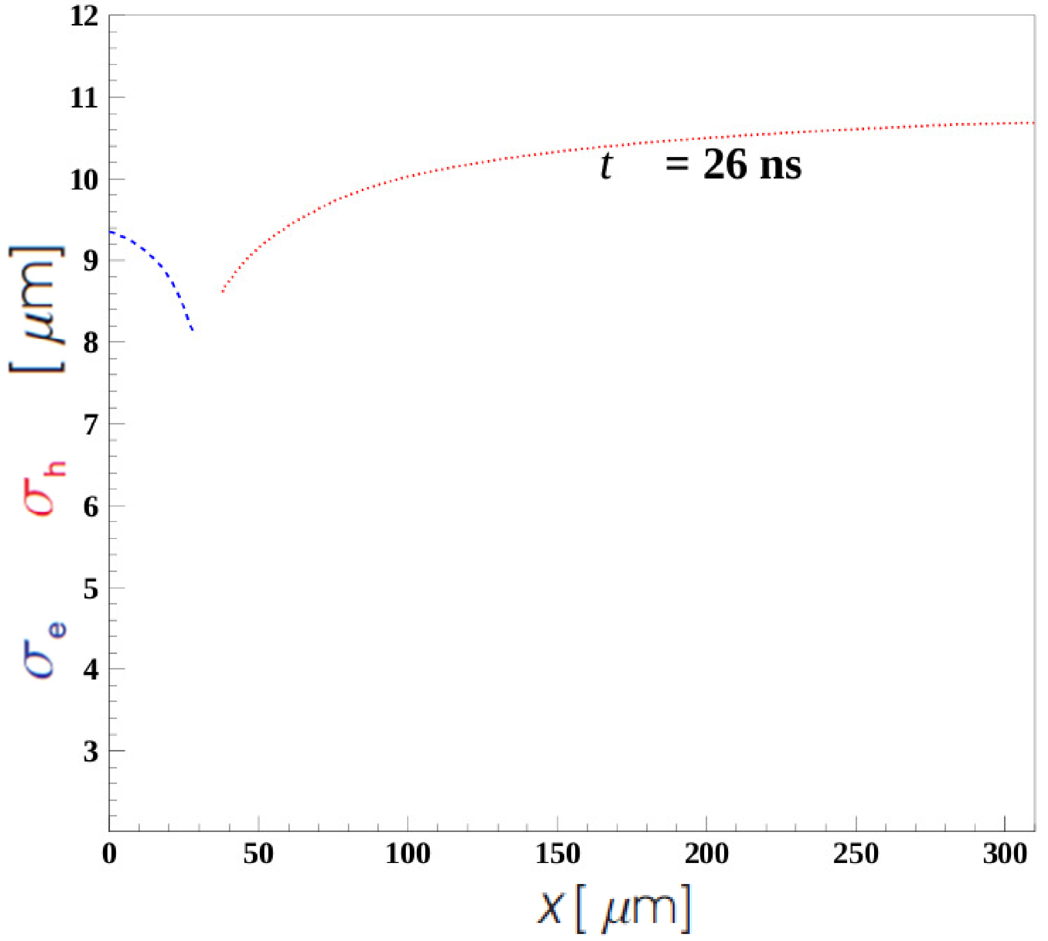

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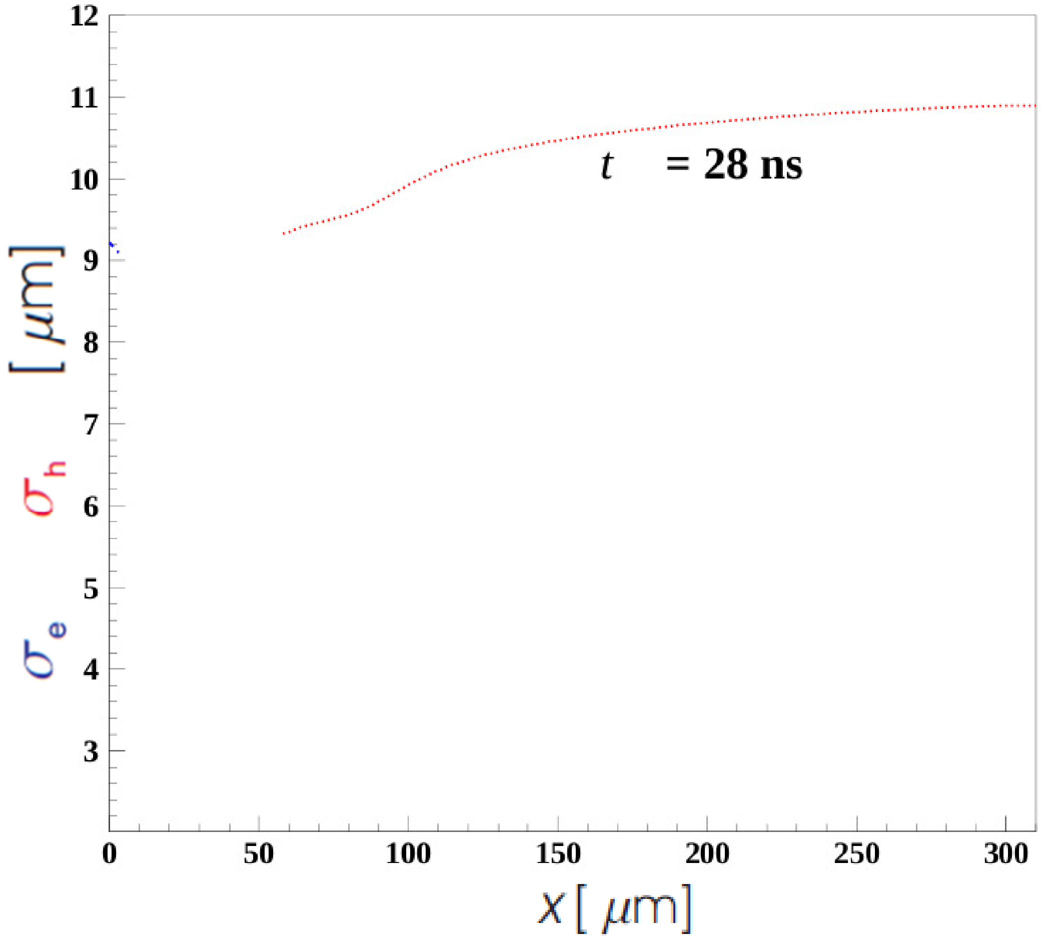

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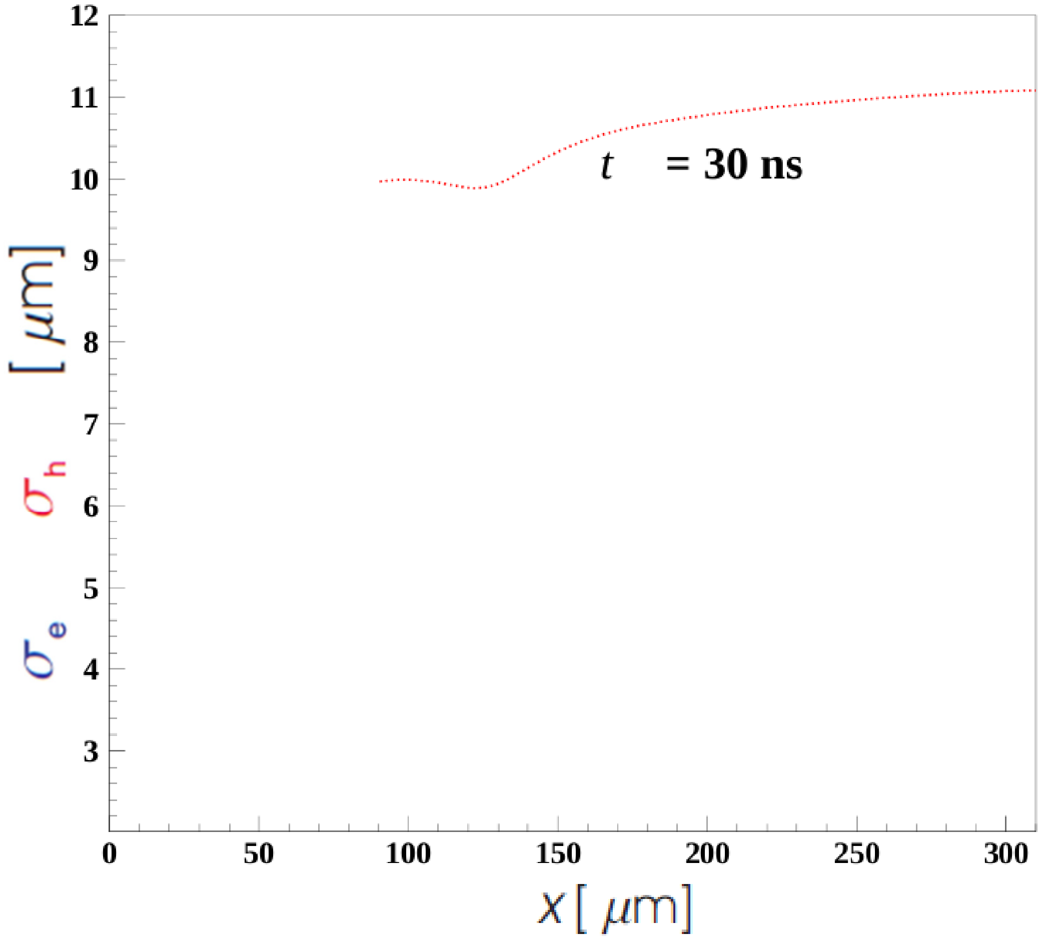

Summary / Next steps

- robust model for carriers propagation in semiconductor detectors has been introduced
- identification matrix „collection time – energy” has been verified using model calculations – it does reproduce shapes known from the experiments
- the research to find the best carriers variance mobility (free parameter) needed
- slowing down the detectors characteristics may be the way to improve isotopic resolution
- the research to create materials of lowest possible carriers mobility may give a major improvement
- carrier mobilities are not fixed... doping, temperature, depletion... model needs developments...
- both diffusion and drift matters
- thin detectors may require model enhancements as mirror charges affect plasma stability

References

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