Geant4 simulation of the ionisation energy loss fluctuation in the GaAs and Si sensors

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Outline

- ❑ PAI model in Geant4
- ❑ Energy loss fluctuations in GaAs sensors
- ❑ e – h pairs distributions
- ❑ Energy loss fluctuations in Si sensors
- ❑ e – h pairs distributions
- ❑ Conclusions

PAI model

$$\frac{d\sigma_i}{d\omega} = \frac{\alpha}{\pi\beta^2}\left\{\frac{\widetilde{\sigma_\gamma}}{\omega|\varepsilon(\omega)|^2}\left[ln\frac{2mv^2}{\omega|1-\beta^2\varepsilon|} - \frac{\varepsilon_1-\beta^2|\varepsilon|^2}{\varepsilon_2}\arg(1-\beta^2\varepsilon^*)\right] + \frac{1}{\omega^2}\int_{I_1}^{\omega}\frac{\widetilde{\sigma_\gamma}(\omega')}{|\varepsilon(\omega')|^2}d\omega\right\}$$

$\sigma_i = cross\ section\ of\ ionising\ collision$
$\omega = energy\ transfer$

V. M. Grichine at al, NIM A 453, 2000

$$\varepsilon_1(\omega) = \frac{N\hbar c}{\omega}\widetilde{\sigma_\gamma}(\omega)$$

$\varepsilon = \varepsilon_1 + i\varepsilon_2$ - dielectric constant of the medium
$\widetilde{\sigma_\gamma}(\omega)$ the normalised photo absorption cross section

$$\int_{I_1}^{\omega_{max}}\widetilde{\sigma_\gamma}(\omega')d\omega' = \frac{2\pi^2\hbar e^2 Z}{mc}$$

m, e – electron mass, charge
$\hbar$ - Planck constant
$\beta = v/c$ ratio of particle velocity and speed of light
Z – effective atomic number
N – number of atoms in unit volume
$\propto$ - electromagnetic strength constant
I_1 - the first ionisation potential

GEANT4

- Parameterization of the photo-absorption cross section

$$\sigma_\gamma(\omega)=\sum_{k=1}^{4} a_k^i \omega^{-k}$$

on *i* energetic intervals from 0.01 eV to 500 eV. They are determined by fits with experimental data.

- MC generation of
  - number of ionisation interactions according to the Poisson distribution

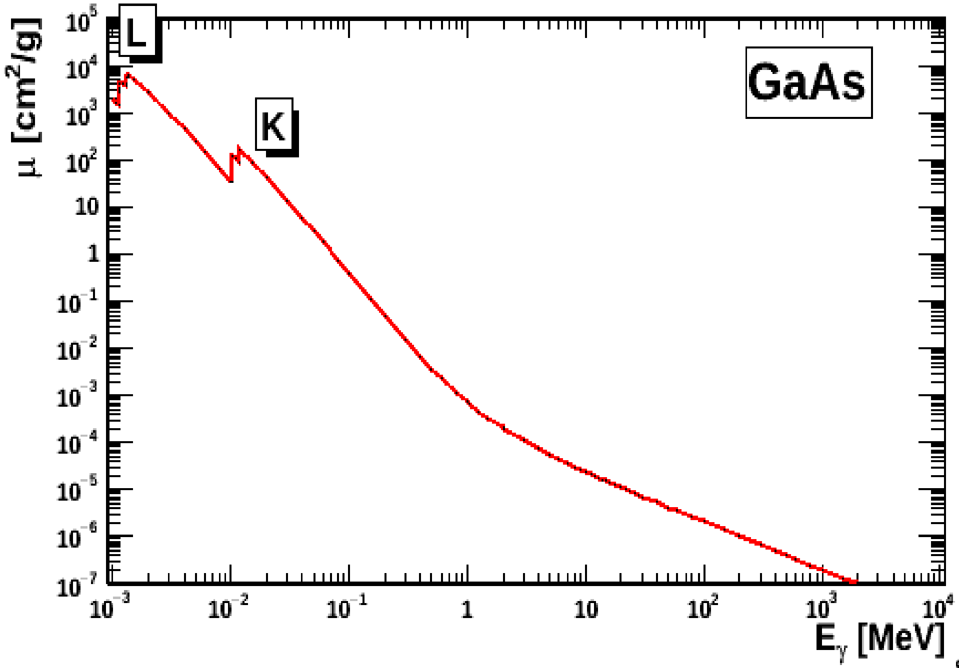
$$P_k^n = \frac{n^k}{k!}e^{-n}$$

$$n \sim \sigma_i(>\omega) = \int_{I_1}^{\omega_{max}}\frac{d\sigma_i(\omega')}{d\omega'}d\omega'$$

  - and energy transfer w according to the integral distribution

$$\sigma_i(>\omega) = \int_{\omega}^{\omega_{max}}\frac{d\sigma_i(\omega')}{d\omega'}d\omega'$$

Mass attenuation coefficient in GaAs and Si (NIST data)



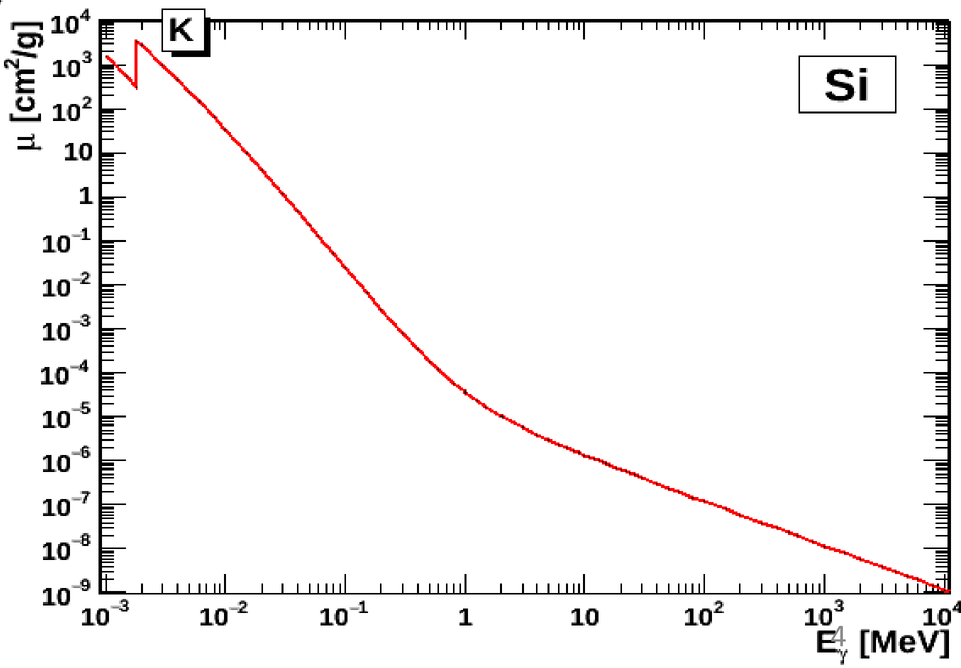
Landau model – „free electron"

$$\mathcal{P} = \left(\frac{2\pi N_A e^4 \rho}{m v^2}\right)(Z/A)(1/\omega^2)$$

m, e – electron mass and charge,
A - relative atomic mass of absorber
ρ density of the absorber
N_A – Avogadro number
ω - loses energy

$$\mu/\rho = \sigma_\gamma / uA$$

u atomic mass
A relative atomic mass of the target element



PAI Physics List

ClassName: DetectorConstruction

```
-------------------------------------------------------------
G4Region* aPad = new G4Region("aPad");
 aPad-AddRootLogicalVolume(pad3_log);
```

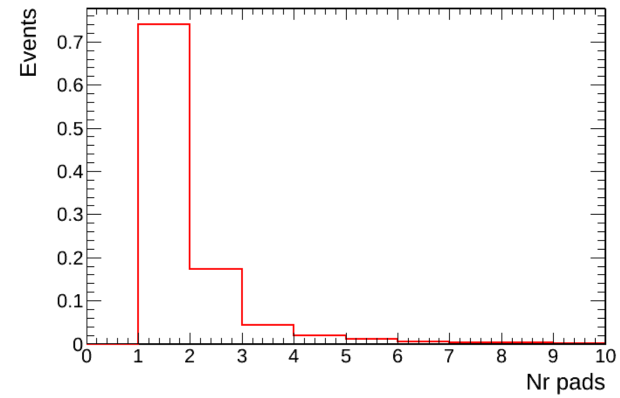
PAI aplies to $e^{\pm}, \gamma, p, \pi^{\pm}, \mu^{\pm}$

ClassName: PhysicsList

```
// Description: EM physics with a possibility to add PAI model
// Author: V.Ivanchenko
…………………………….
#include "G4PAIModel.hh"
#include "G4PAIPhotonModel.hh"
……………………………..
------------------------------------------------------------------------------
//Get the Region
 G4Region* aPad = G4RegionStore::GetInstance()->GetRegion("aPad");
//Define cuts object for the aPad region and set values
 G4ProductionCuts* cuts = new G4ProductionCuts;
 cuts->SetProductionCut(0.01*mm); //same for e+, e- and gamma
……………………………..
------------------------------------------------------------------------------------
void PhysicsList::NewPAIModel(const G4ParticleDefinition* part,
                              const G4String& modname,
                              const G4String& procname)
{
 G4String partname = part->GetParticleName();
 if(modname == "pai") {
  G4PAIModel* pai = new G4PAIModel(part,"PAIModel");
  fConfig->SetExtraEmModel(partname,procname,pai,"aPad",0.0,100.*TeV,pai);
 } else if(modname == "pai_photon") {
  G4PAIPhotonModel* pai = new G4PAIPhotonModel(part,"PAIPhotModel");
  fConfig->SetExtraEmModel(partname,procname,pai,"aPad",0.0,100.*TeV,pai);
 }
……………………………..
```

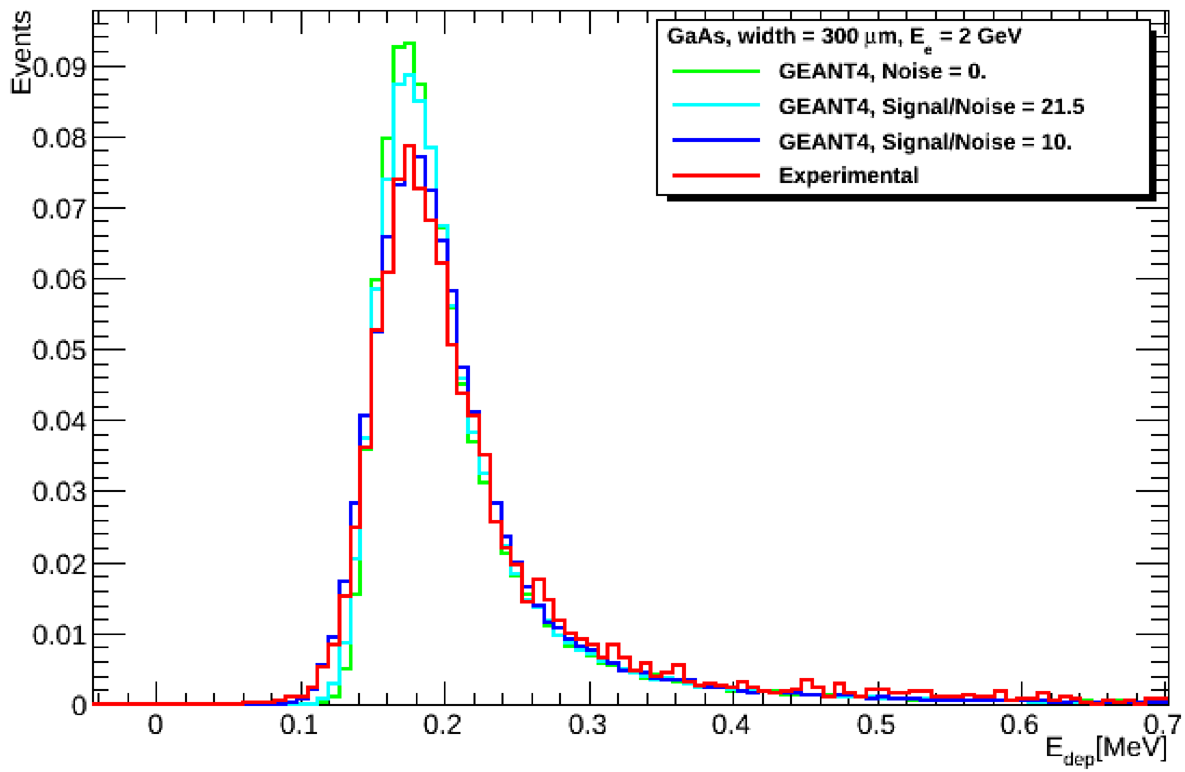
Energy loss fluctuation in GaAs

Testbeam 2011 experimental data

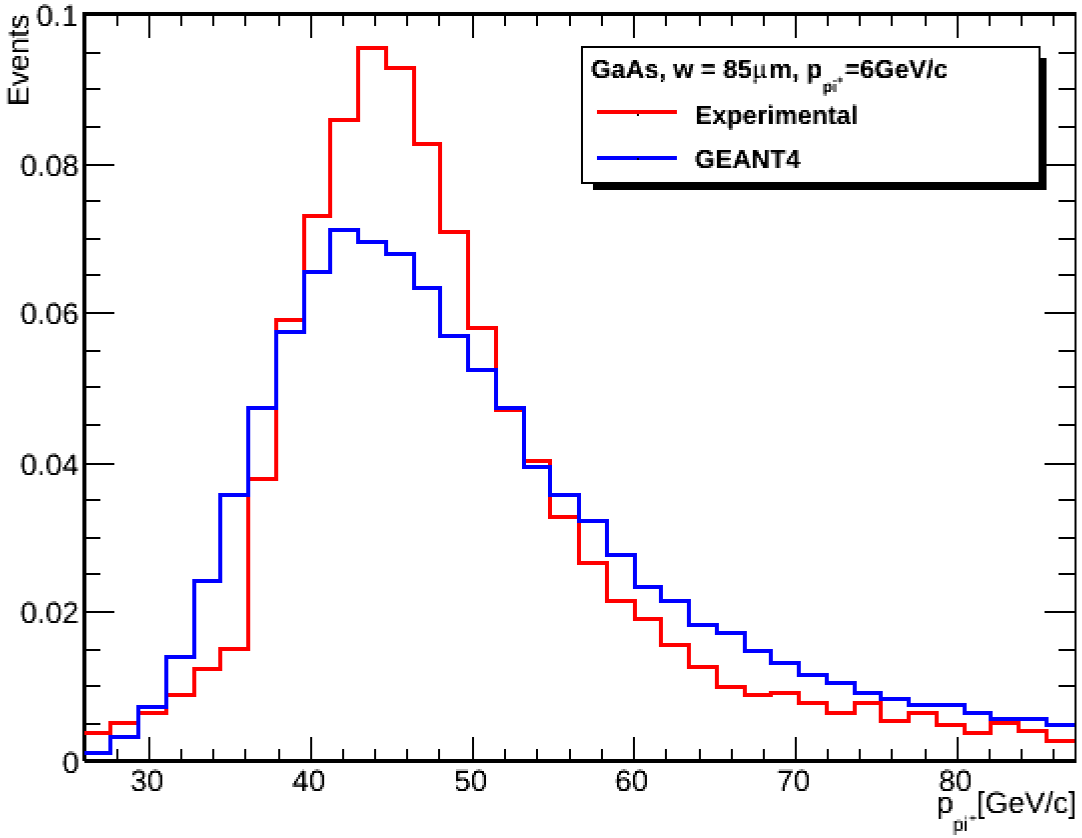


GaAs 300 μm
E_{e^-} = 2 GeV

$$S = \sum_{i=1}^{N_{cluster}} S_i$$

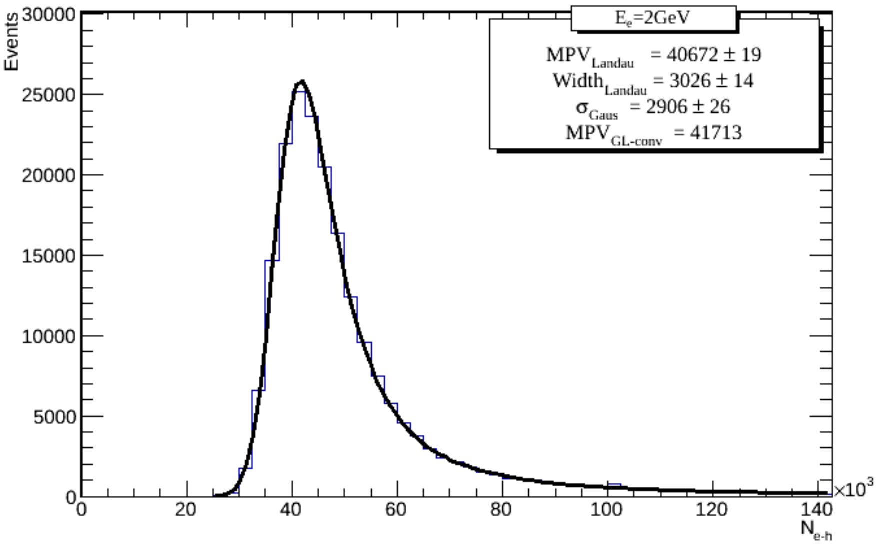


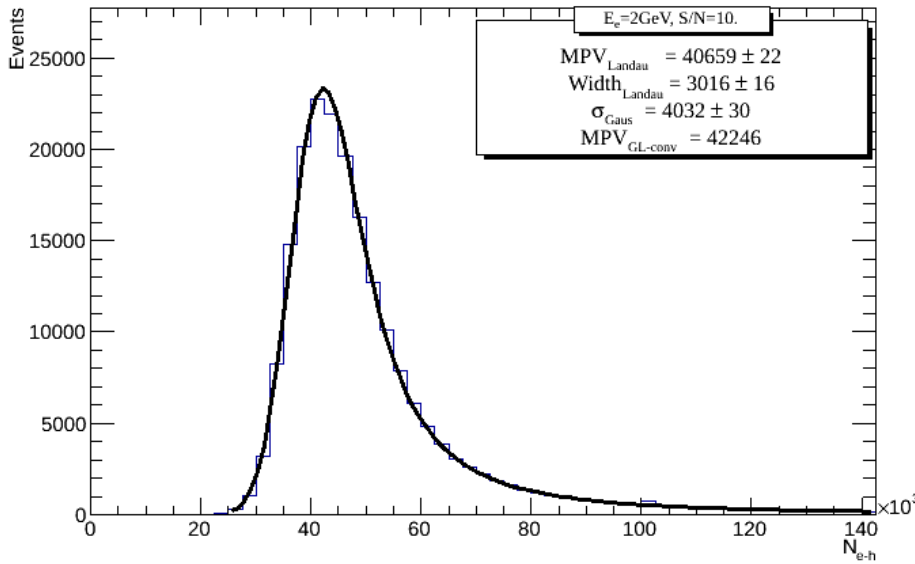
Energy loss fluctuation in Ga As



- Experimental data from
J. Apostolakis, …, V.M. Grichine
NIM A45(2000)597
- Original experimental data without calibration in:
R. Bertin, S. D'Auria, C. Del Para et al., Nucl. Instr. and Meth. A 294 (1990) 211

Number of e-h pairs created in GaAs sensor



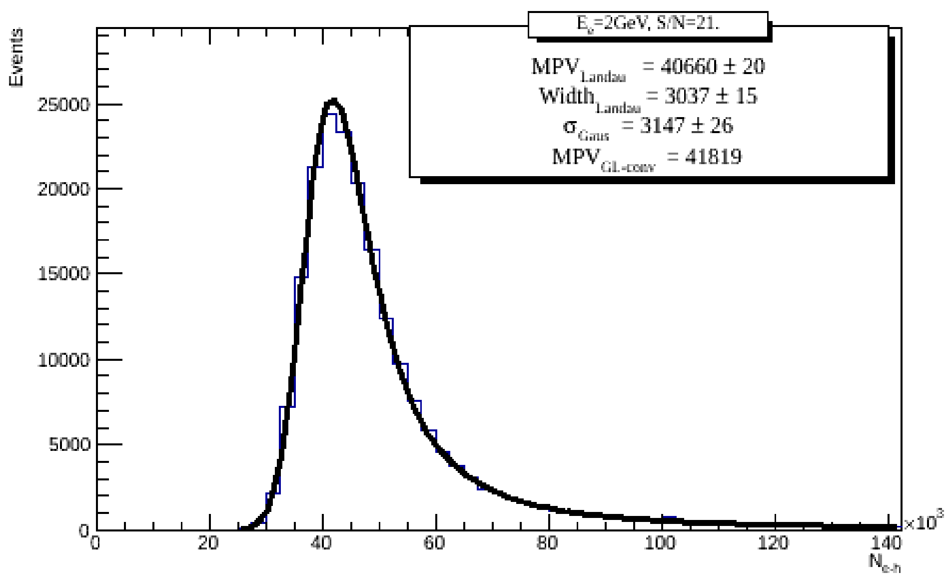


Thickness = 300 μm

E_{e^-} = 2 GeV

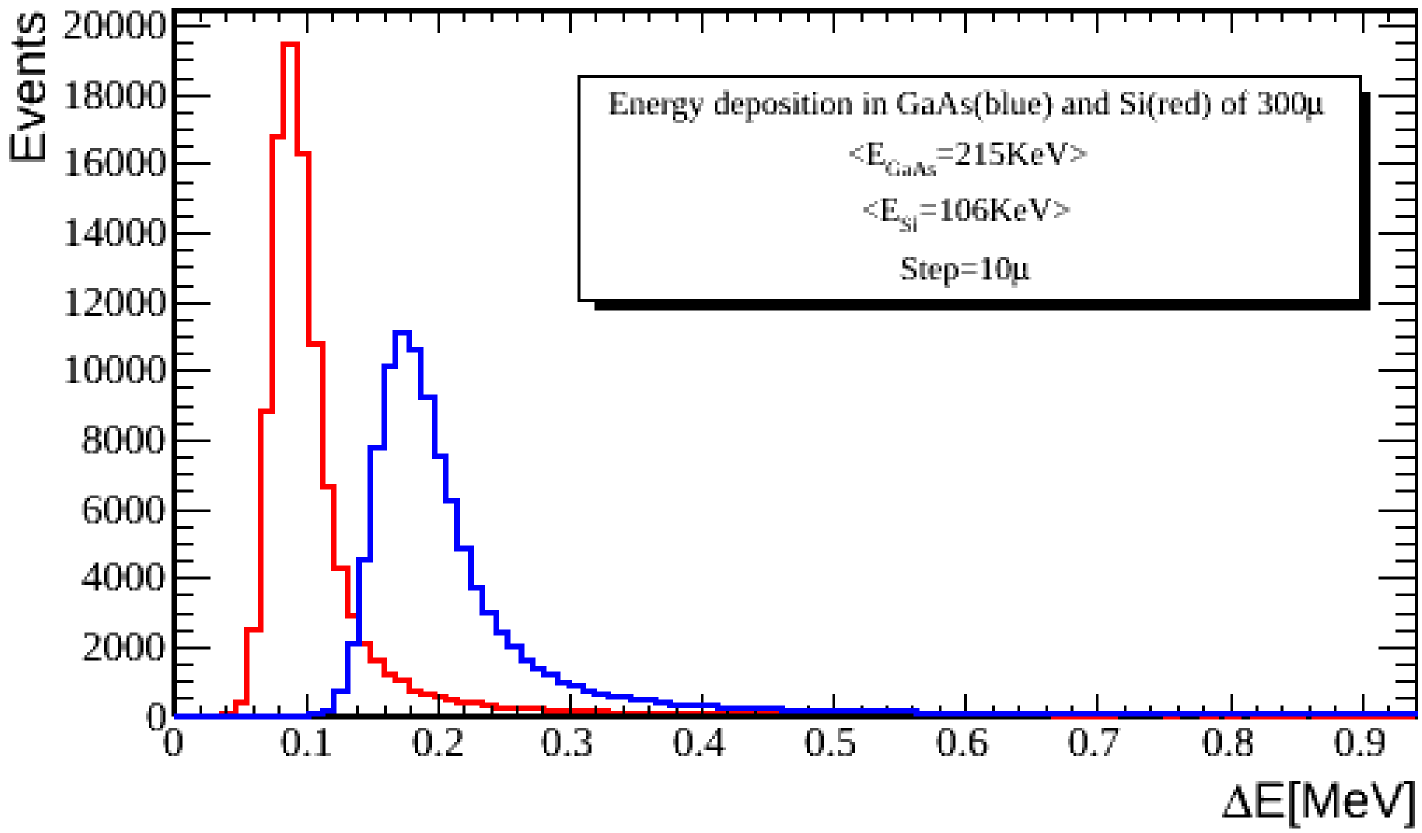
$$n = \frac{E_{dep}}{E_i}$$

E_i =4.2 eV

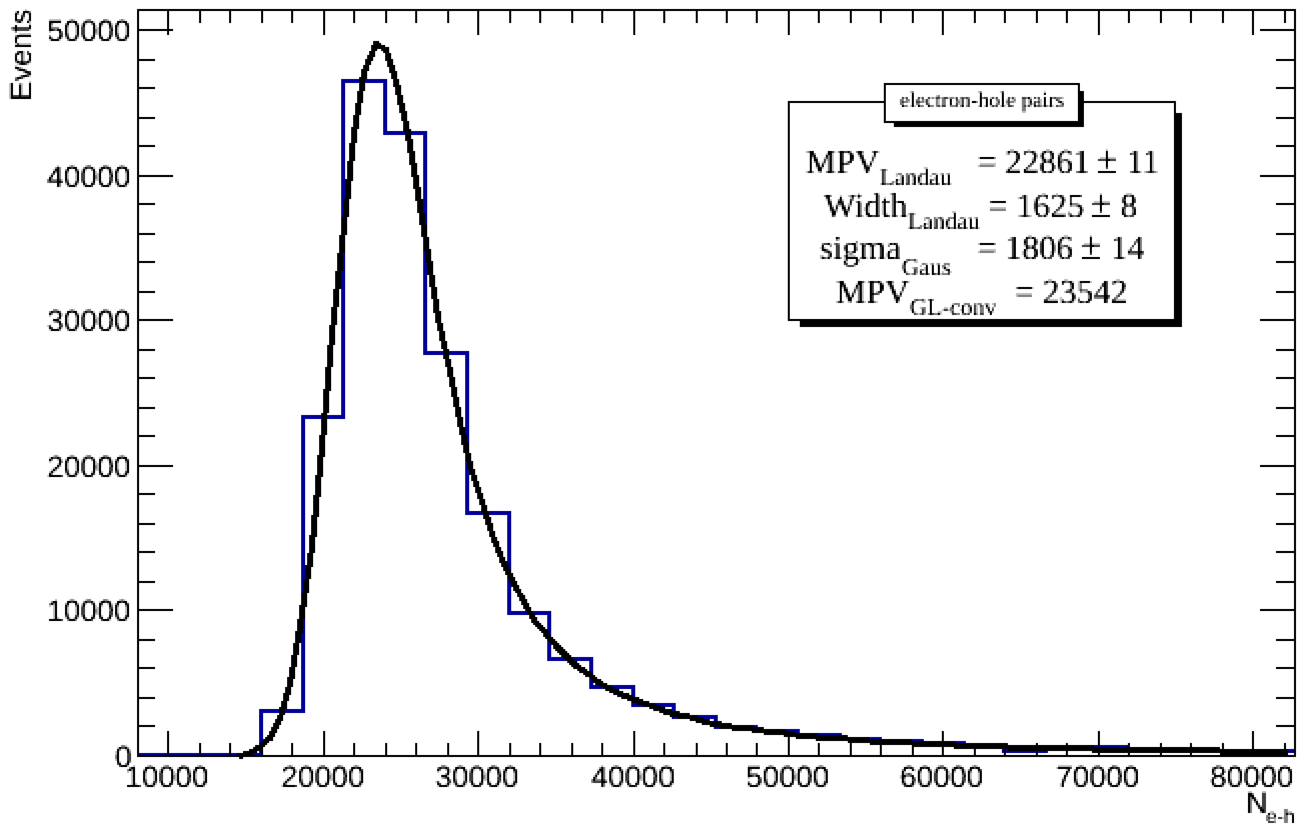


Energy deposited

material	E_i(eV)	μ_e	μ_h	ρ	<Z>
Si	3,6	1350	450	2,33	14
Ga As	4,2	8000	400	5,32	31,5



Number of e-h pairs in Si sensor



Thickness = 300 μm
E_{e^-} = 2 GeV
$$n = \frac{E_{dep}}{E_i}$$
E_i =3,6 eV

Similar value obtained for π at minimum ionisation
MPV $_{GL\text{-}conv}$ = 23512

Conclusions

- Simulations of the GaAs & Si sensors were performed using PAI model
- Very good agreement between simulations and experimental data, even for very thin sensors
- PAI could be used successfully for thin sensitive materials in electromagnetic and hadronic calorimeters.

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