Pulse Shape Simulation for Segmented Detectors

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GERDA

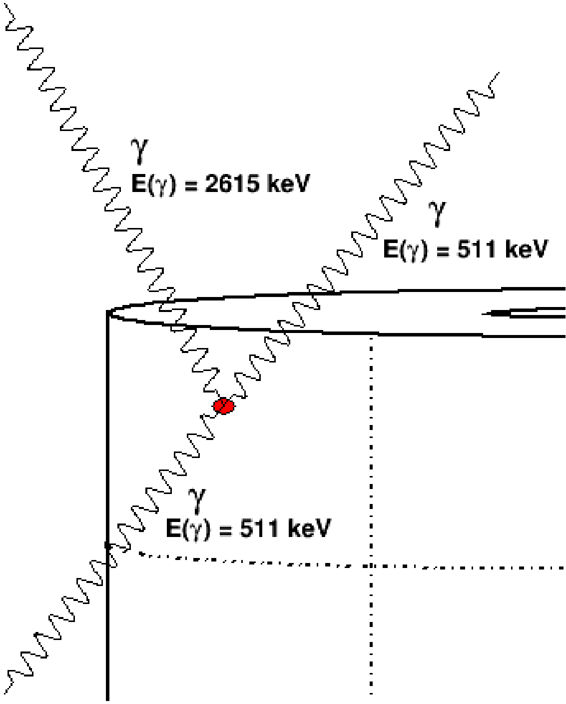
Outline:

- Motivation
- Electric Field
- Charge Carrier Drift
- Evaluation I + II
- Summary and Outlook

Pulse Shape Simulation - Why?

➡ samples of SSE and MSE are needed to understand efficiencies of PSA

- MSE can be easily extracted from data (MeV photon peaks)
- SSE can be also be extracted from data (Double Escape Peak)



BUT:

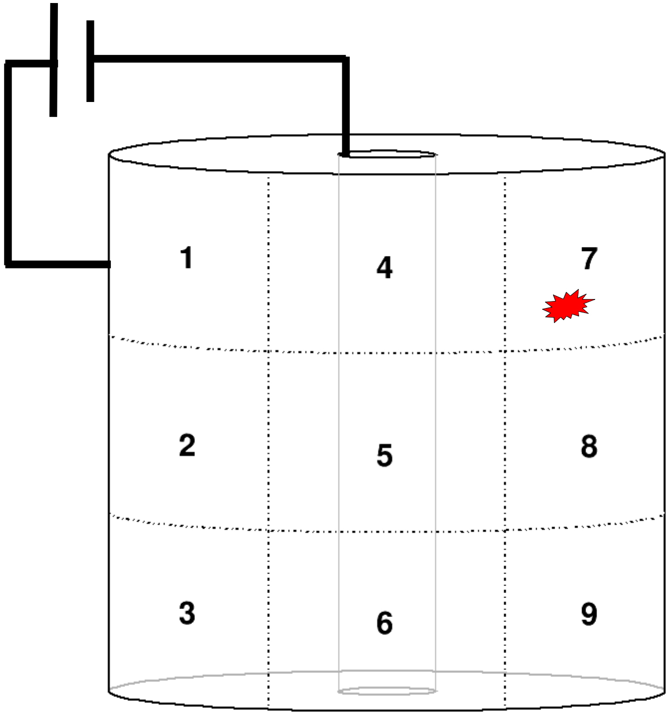
- samples are not pure SSE or MSE
- events are not homogeniously distributed throughout the detector

can be overcome

BUT takes long time to record samples

- Data should be supplemented by simulated pulses
- PSS can give insights into crystal properties
- helps reconstructing interaction positions

Basic Principle



- **energy deposit** ⇒ electrons holes created
- charges **drift** under influence of external **E-Field**
- drifting charges **induce pulses** on electrodes

1. simulate energy deposit using MaGe
2. group hits according to position bandwidth and sampling frequency
3. determine number of electron hole pairs
4. **calculate E-Field** inside detector
5. **calculate drift** of charge carriers
   ⇒ **calculate induced charges** using **weighting potentials**
6. take into account electronics effect, i.e noise, bandwidth...

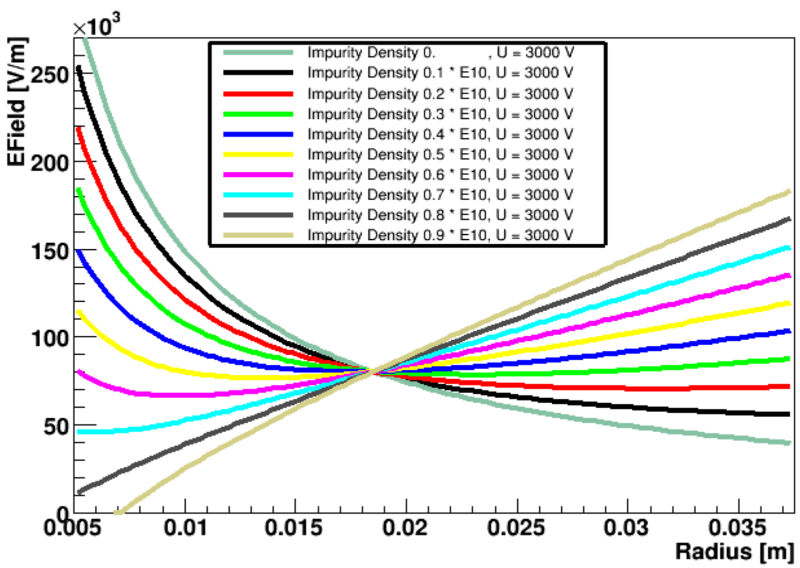
Electric Field

Solve Poisson-equation: $\nabla^2 \varphi(\vec{r}) = \frac{1}{(\epsilon_0 \cdot \epsilon_R)} \cdot \rho(\vec{r})$

numerical procedure: **Successive Overrelaxation (SOR)**

agreement
numerical and analytical solution
better than 1%

numerical calculation works



- impurity density ρ dominates the electric field
- ρ changes with radius, height and maybe with azimuthal angle ϕ

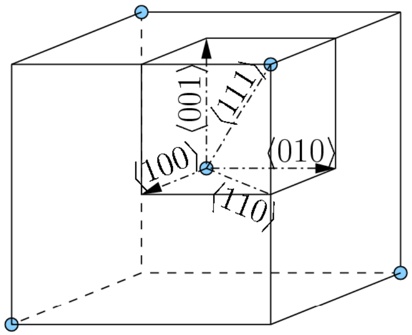
Drift:

$$\vec{v}(\vec{r}) = \mu_{e,h} \vec{E}(\vec{r})$$

with $\mu_{e,h}$ depends on temperature, electric Field and **structure** of **germanium crystal**

Transverse anisotropy:

- in direction ⟨100⟩, ⟨110⟩ and ⟨111⟩ $\mu_{e,h}$ **parallel** to E-Field **otherwise not**!



Longitudinal anisotropy:

- along crystal axes ⟨100⟩, ⟨110⟩ and ⟨111⟩ $\mu_{e,h}$ has different magnitude

- Charge carrier drift in **any** direction can be computed using mobilities along ⟨100⟩ and ⟨111⟩ directions

- experimental data along axes exists ⇒ mobility can extracted along axes

$$v = \frac{\mu_0 E}{\left[1 + \left(\frac{E}{E_0}\right)^{\beta}\right]^{1/\beta}} - \mu_n E$$

Drift Parameters

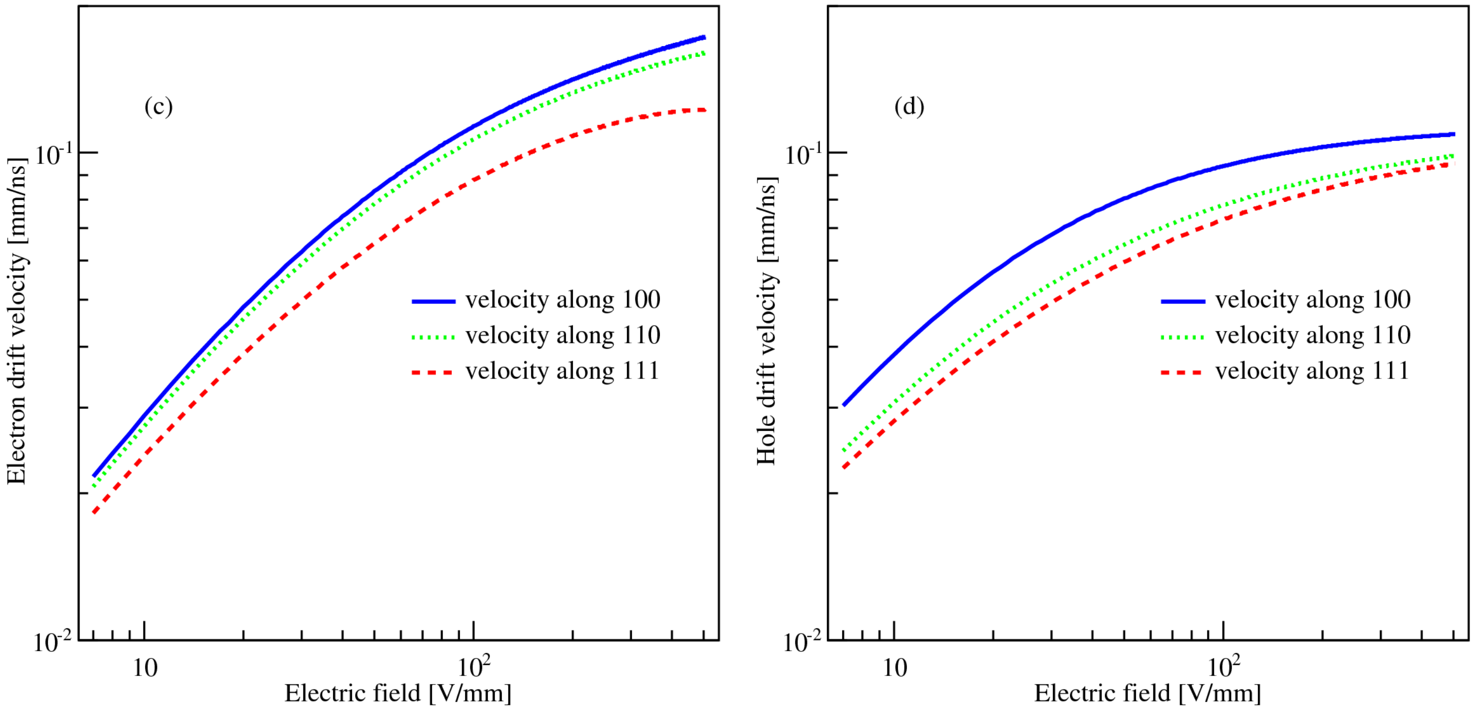
Reference	Carrier	Direction	μ_0 $\left[\frac{cm^2}{V\cdot s}\right]$	E_0 $\left[\frac{V}{cm}\right]$	β	μ_n $\left[\frac{cm^2}{V\cdot s}\right]$
Ref. [102]:	Electron	⟨111⟩	42420	251	0.87	62
		⟨100⟩	40180	493	0.72	589
Ref. [103]:	Hole	⟨111⟩	107270	100	0.58	0
		⟨100⟩	66333	181	0.744	0
Ref. [104]:	Electron	⟨111⟩	38536	538	0.641	510
		⟨100⟩	38609	511	0.805	-171
	Hole	⟨111⟩	61215	182	0.662	-
		⟨100⟩	61824	185	0.942	-

$$v = \frac{\mu_0 E}{\left[1 + \left(\frac{E}{E_0}\right)^{\beta}\right]^{1/\beta}} - \mu_n E$$

[102]:Mihailescu *et al.* NIM A 447: 350

[103]:Reggiani *et al.*, Phys. Rev. B 16: 2781

[104]:Bruyneel *et al.*, NIM A569:764



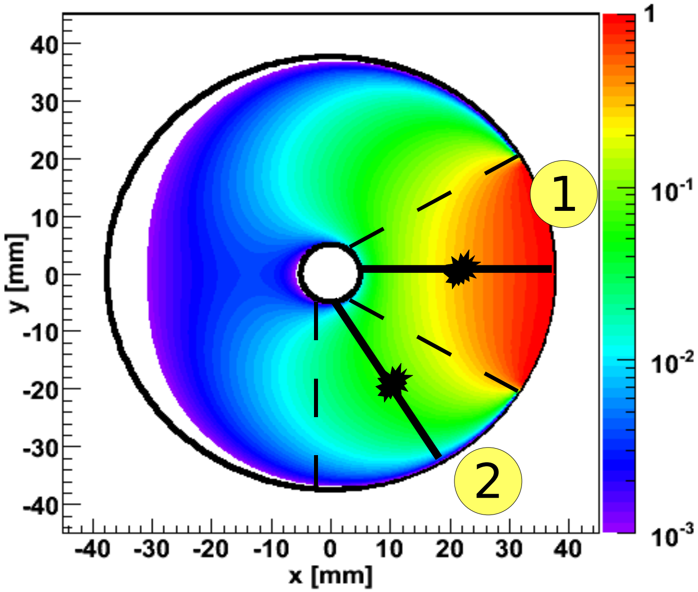
Shockley-Ramos Theorem:

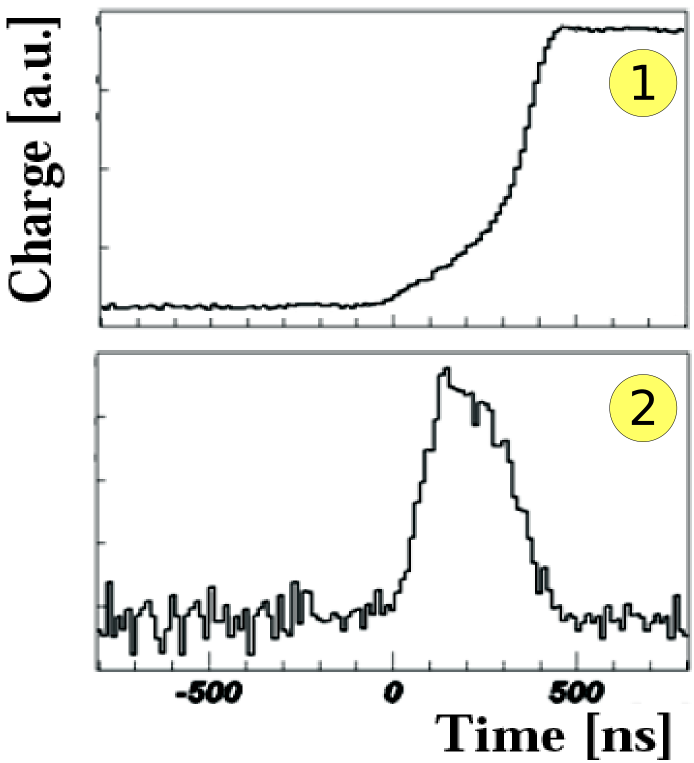
$$Q^{i}_{induced}(t) = q_e \cdot \phi^{i}_{W}(\vec{r}(t)) + q_h \cdot \phi^{i}_{W}(\vec{r}\,'(t))$$

Weighting Potential: **no** analytical solution in 3D for 18 segments

calculated solving Laplace equation
BC WP on electrode 1, otherwise 0

Need numerical calculation (SOR)





Segment Pulse

Mirror Pulse

Connection to MaGe

Virtual base classes:

MGVCrystalFields ◄—— MGSORCrystalFields

MGVFieldCalculation ◄—— MGSORFieldCalculation

MGVWaveformGenerator ◄—— MGWFGenFromDrift

- MaGe/waveform
  - **MGVCrystalFields**

```
//Set and access the MGCrystalData
  inline void SetCrystalData(MGCrystalData* crystal){fCrystalData = crystal;};
  inline const MGCrystalData* GetCrystalData() const {return fCrystalData;};

  //Methods to save, load and draw(?) the electric and weighting fields
  virtual void SaveFields() =0;
  virtual void LoadFields() =0;
  //  virtual void DrawFields();

  //Methods to access the electric and weighting field
  virtual CLHEP::Hep3Vector GetEField(CLHEP::Hep3Vector coordinates)const =0;
  virtual CLHEP::Hep3Vector GetWField(CLHEP::Hep3Vector coordinates, size_t segment) const =0;
  virtual double GetWPotential(CLHEP::Hep3Vector coordinates, size_t segment) const =0;

protected:
  MGCrystalData* fCrystalData;
```

- MaGe/waveform
  - **MGVFieldCalculation**

```
MGVFieldCalculation(){;};
MGVFieldCalculation(MGVCrystalFields* crystalFields){fCrystalFields = crystalFields;};
//  virtual ~MGVFieldCalculation();


//Methods to access MGVCrystalFields
inline void SetCrystalFields(MGVCrystalFields* crystalFields){fCrystalFields = crystalFields;};
inline MGVCrystalFields* GetCrystalFields(){return fCrystalFields;};

//Methods to calculate efield and weighting fields
virtual void CalculateFields() = 0;


protected:
  MGVCrystalFields* fCrystalFields;
```

Open files, show how it works!

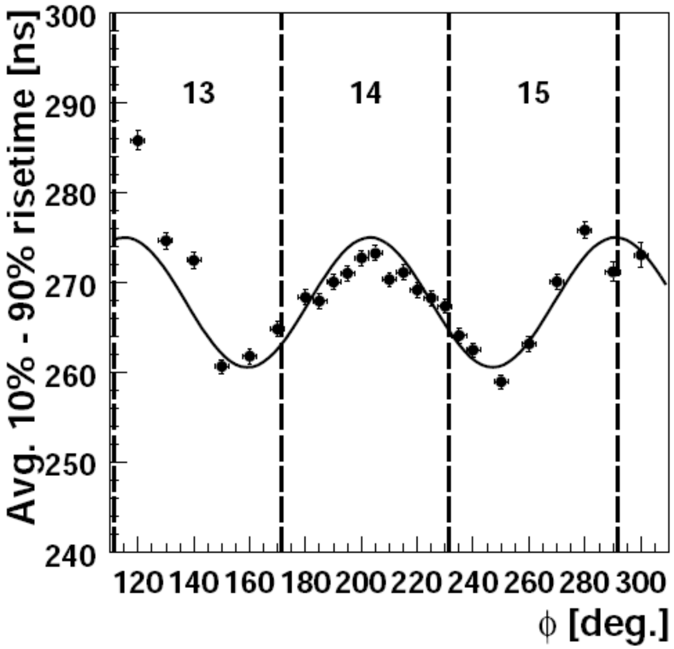
Files can be found in **MaGe/sandbox**

Evaluation I

Data:

- 18-fold seg. n-type HPGe detector
- 121.78 keV line from 75kBq collimated ^{152}Eu source
- rise time 10%-90% calculated:

Abt *et al.* NIM A 577: 574



Simulation:

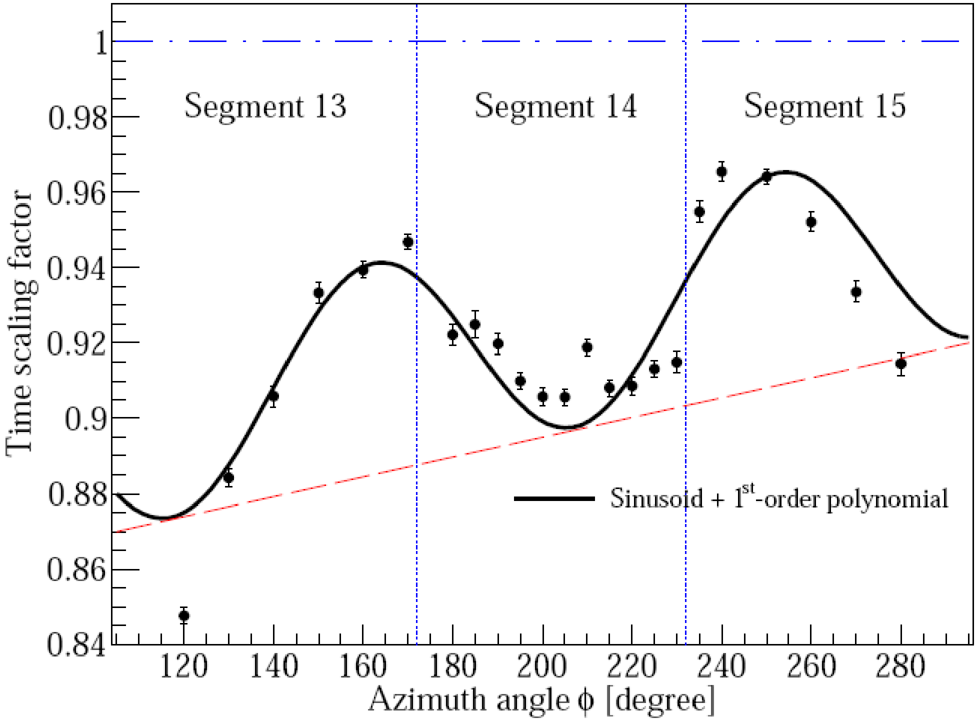
- ρ_t = 0.70 10^{10} cm^{-3}
  ρ_b = 1.35 10^{10} cm^{-3}
- single pulse on ⟨110⟩ axis at r=37.5mm (max radius)
- ⟨110⟩ axis at 290 degree
- added 50 μs decay time from preamp
- 37.5 MHz bandwidth of electronics

Evaluation I

- each data pulse fitted with simulated pulse;
  3 parameter: time offset, amplitude scale factor, time scale factor

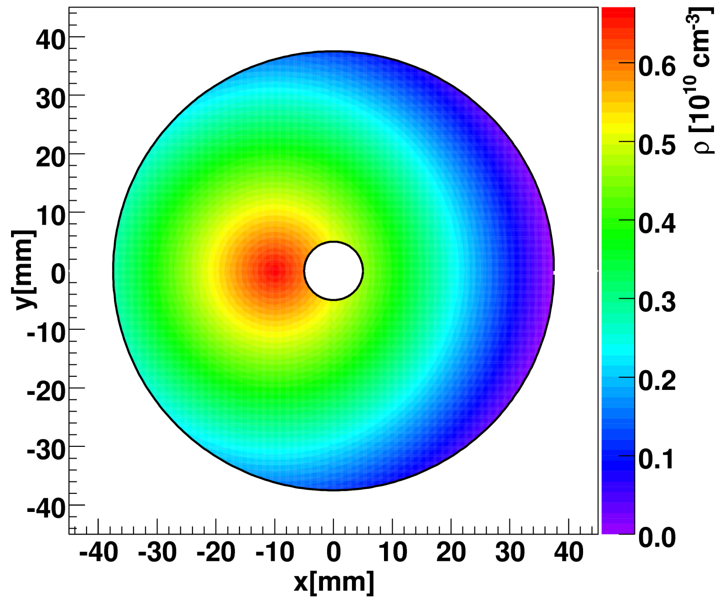
- pulse with $\chi^2 > 200$ removed; background event

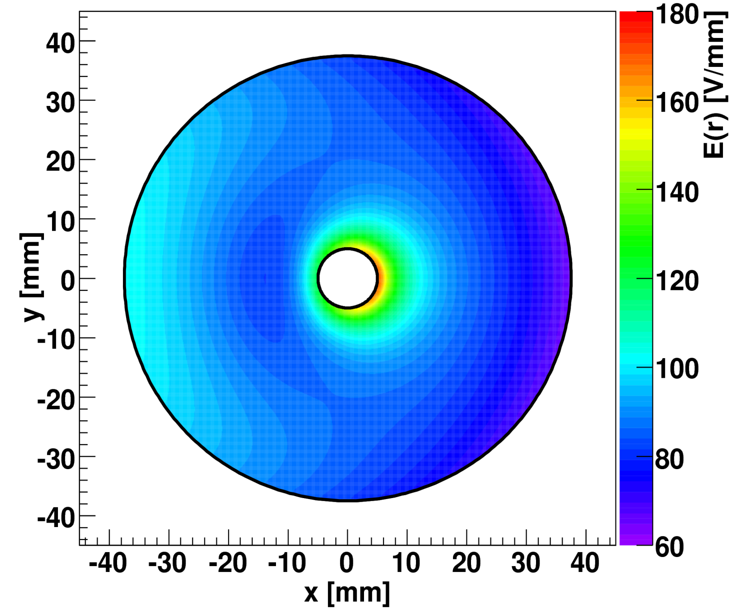
- Time scaling factor histogrammed and fitted with Gaussain

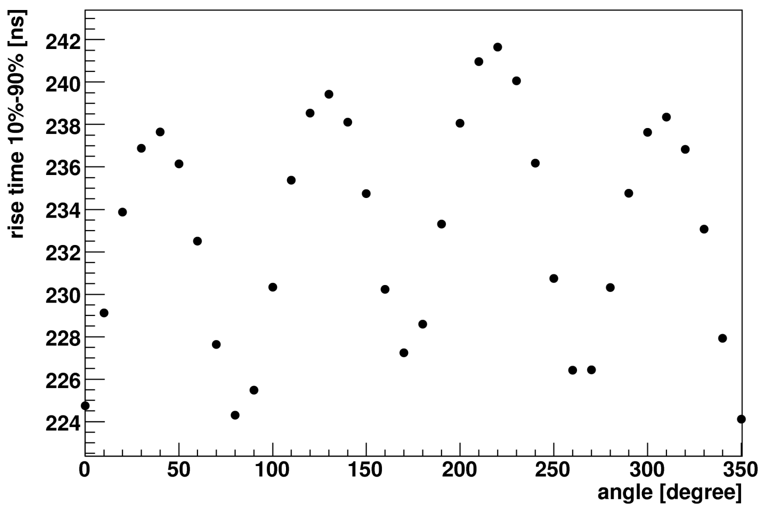


- overall shift of about 10 %

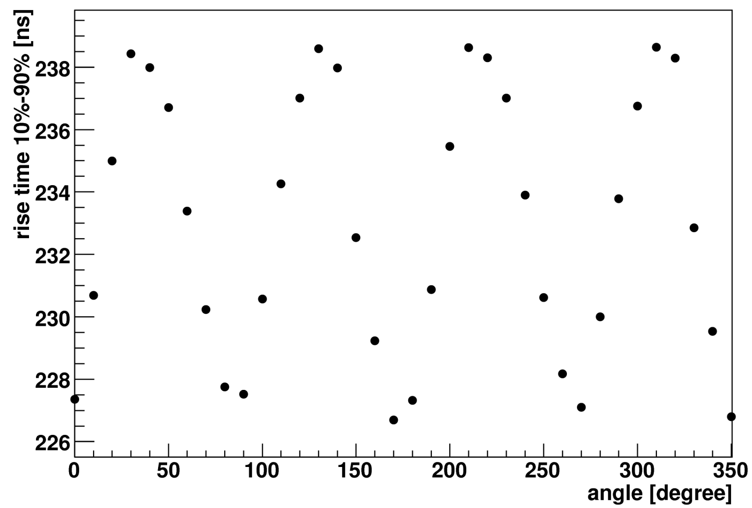
- azimuthal shift about 3%
  - detector effect?
  - temperature effect?







single charge on outside



full simulation 122keV

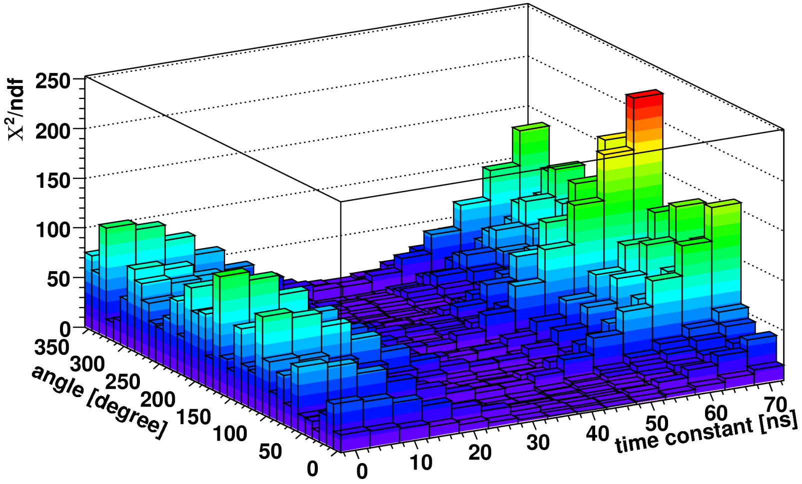
Evaluation II

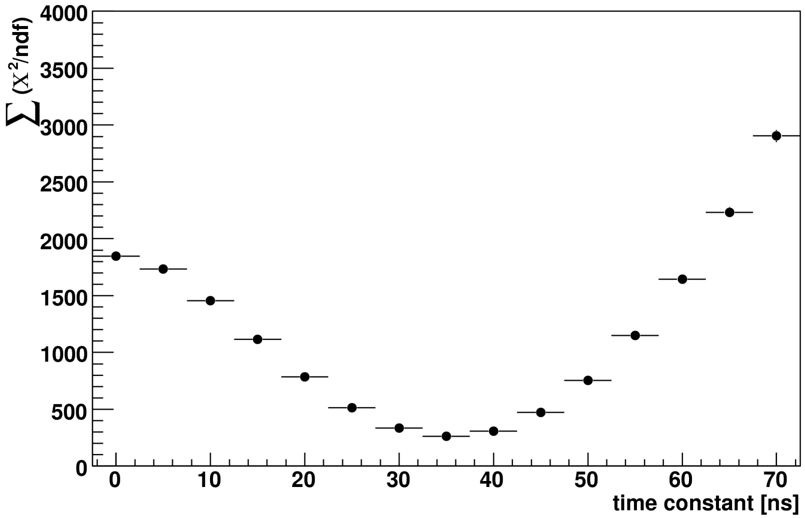
Data:

- 19-fold seg. n-type HPGe detector
- 121.78 keV line from 42kBq collimated ^{152}Eu source
- all pulses added and normalized

Simulation:

- 121.78 keV photons collimated
- all pulses added and normalized
- added 50 μs decay time from preamp
- several bandwidths simulated; χ^2 fit determined best bandwidth





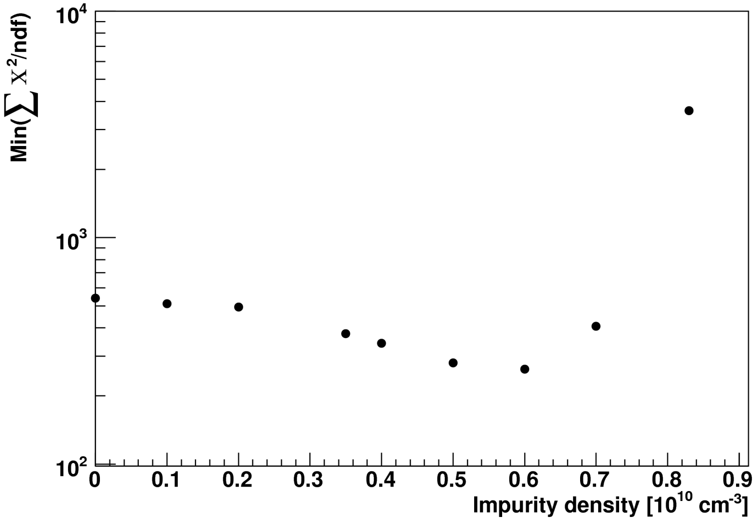
Evaluation II

Vary impurity densities ρ:

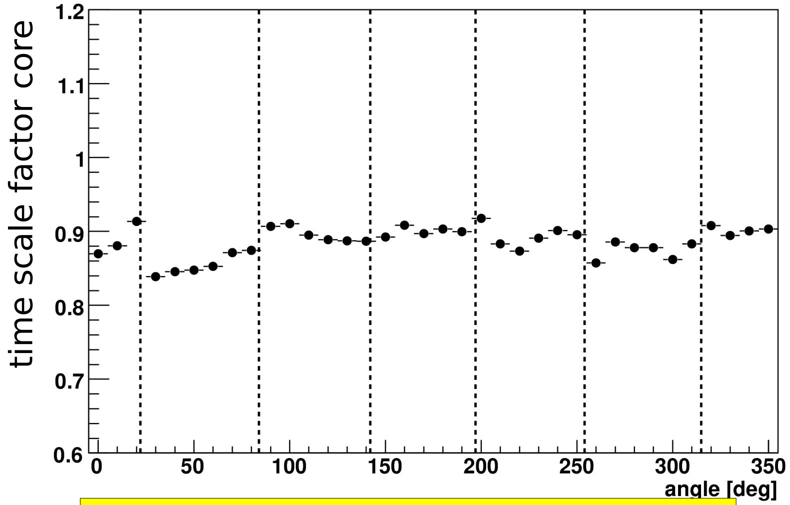
lowest χ^2 at ρ=0.6 10^{10} cm^{-3}

coincides with ρ calculated from depletion voltage 2250V

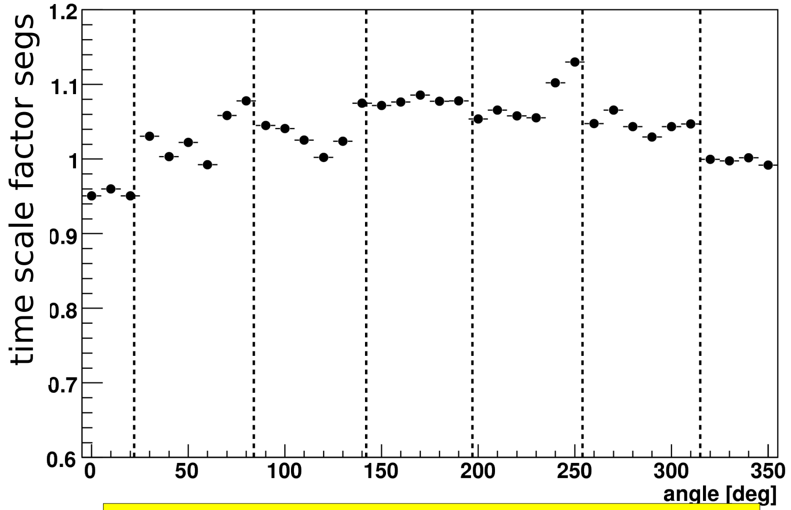
in the middle of given ρ range for that detector:
0.44 10^{10} cm^{-3} - 1.30 10^{10} cm^{-3}



average χ^2/ndf = 6.9
individuals much better



~10% scaling needed



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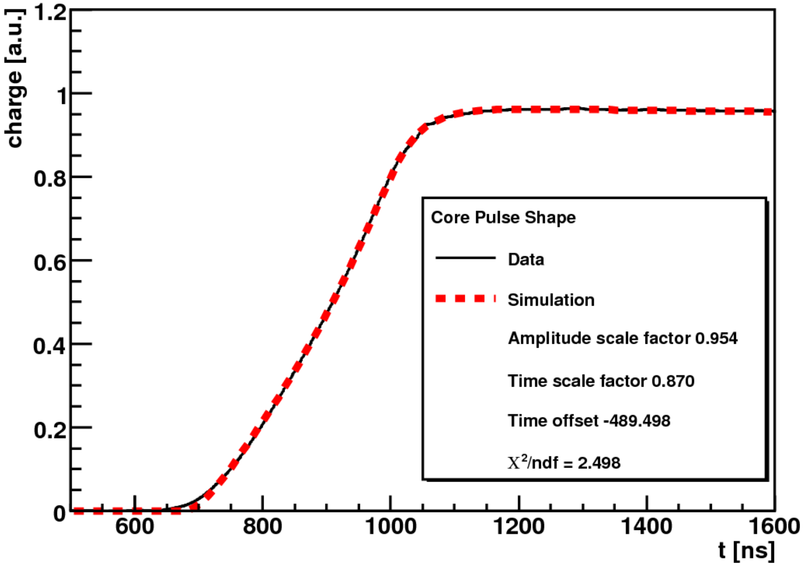
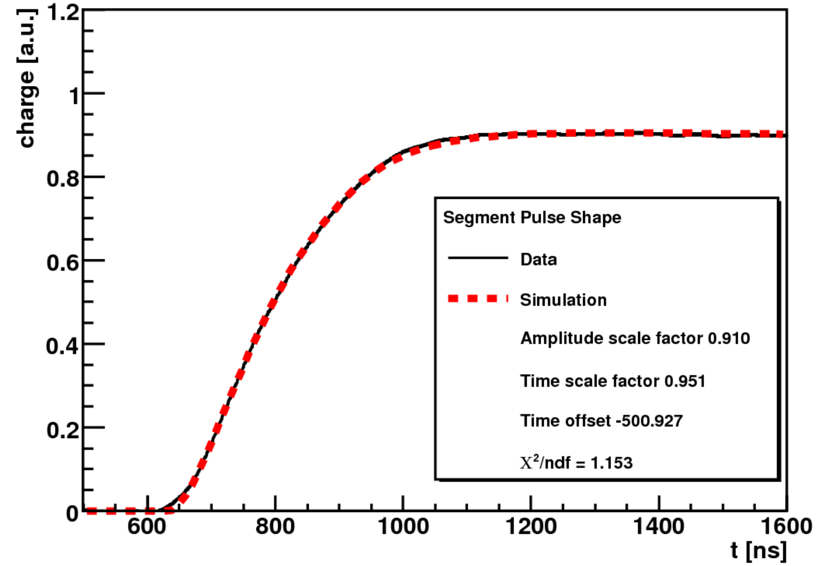
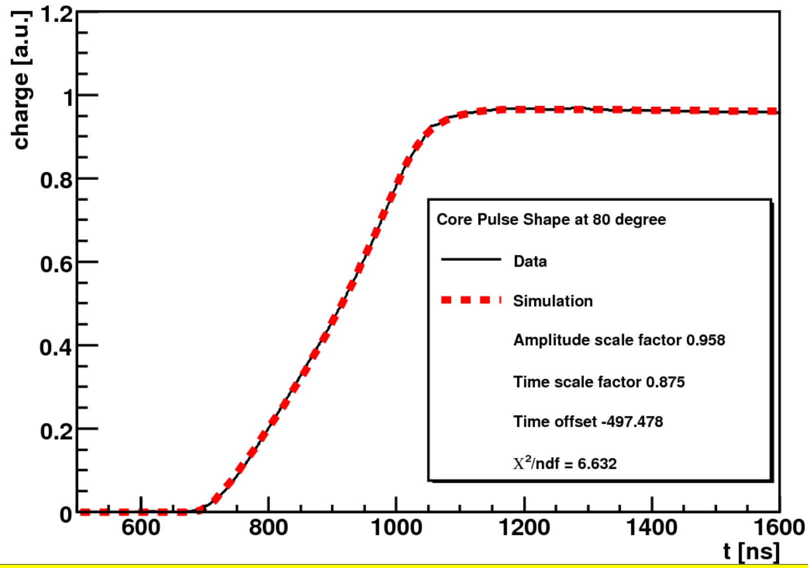
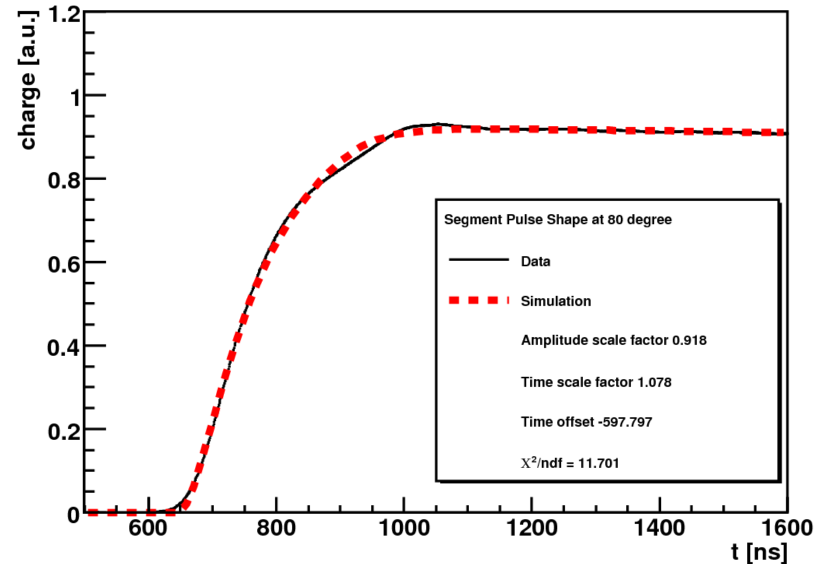
Evaluation II









- core shape well matched
- uncertainty not properly estimated?

- shape for some preamps good
- transfer function needed!

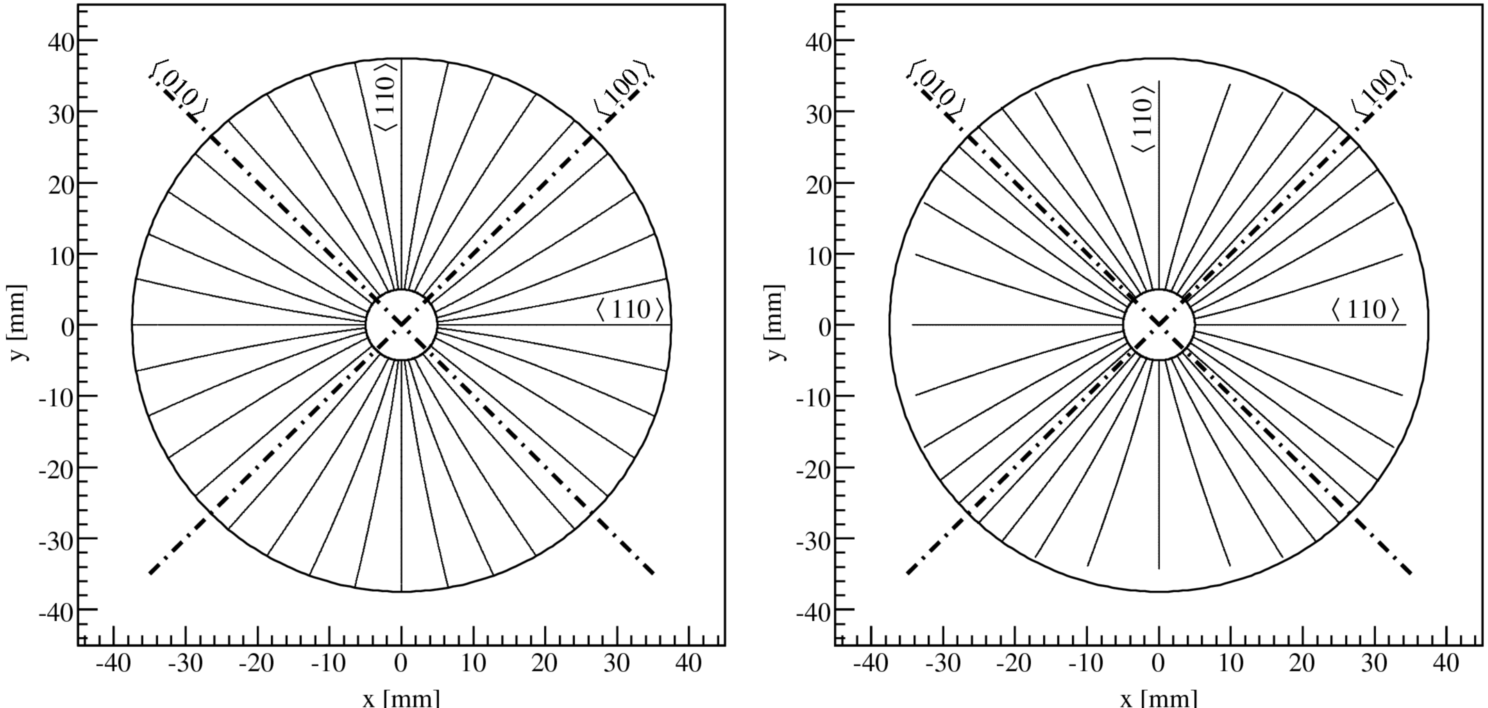
Summary and Outlook

- PSS **needed** to **fully understand** PSA
- **Numerical simulation** of electric field **better** than **1%**
  Weighting potential calculated with **same algorithm**
- Drift implemented taking into account **longitudinal** and **transverse anisotropy**
- Correct impurity density can be extracted
  azimuthal change in rise time can hardly be explained by impurities
- **Agreement** of shape **good** after **scaling** of about **10% core**
  5% segments
- Replace electronics simulation by measured transfer function

Extras

Drift

- drift charges in **fixed time intervall** Δt
- start position **equally spaced** on outer/inner surface



e⁻ drift from outside in

h⁺ drift from inside out

- holes drift slower than electrons
- drift along ⟨100⟩ axis faster than ⟨110⟩