MC simulations of silicon strip detector response to the laser and high energy particles

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Contents

Motivation

- Obtain an instrument allowing us to simulate the response of the detector and the electronics to a particle and a laserbeam
- Compare beam test data of ATLAS SCT with simulated ones and verify functionality of the program
- Simulate the response of the detector to the laser beam and reproduce basic charac-teristics – S-curves, η-plots, efficiency plots ...

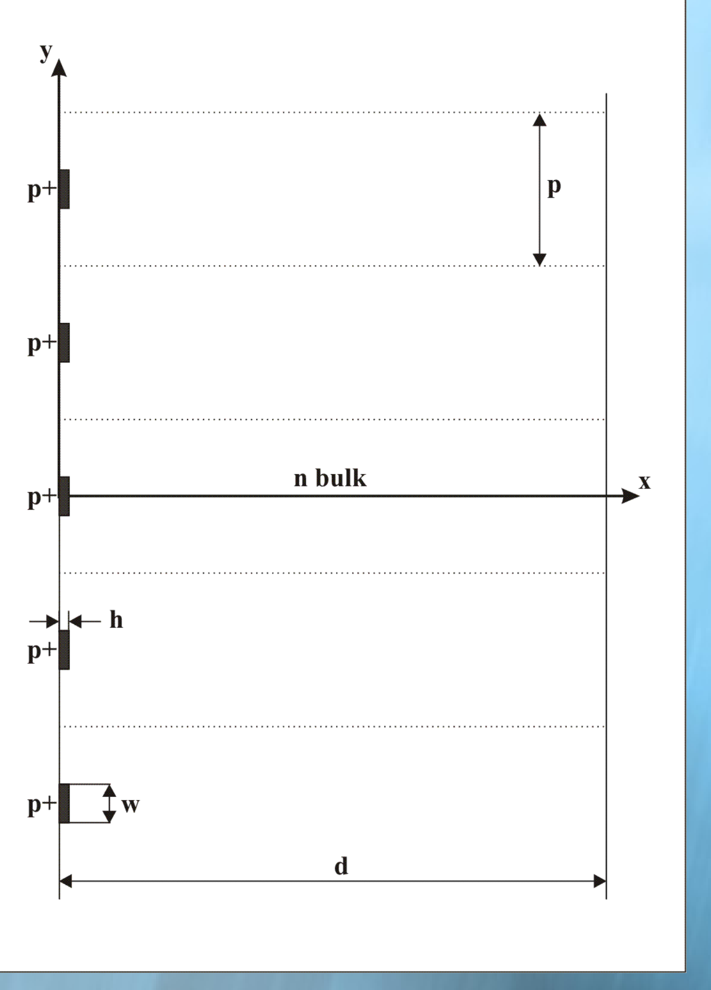
Concept of the simulation

- Calculation of electric and weighting field in MAXWELL 2D and conversion into hbook format
- MC simulation
  - Generation of e-h pairs
    - by a laser beam incident at a certain angle
    - by a minimum ionizing particle (180 GeV pion) (Geant3) incident at a certain angle
  - e-h pairs propagation in a silicon bulk
    (Many thanks to N.Mazziotta, F.Loparco INFN Bari for valuable advice and for a fortran code of e-h pairs propagation, more information in NIMA 533 (2004))
  - Calculation of the current induced at time *t* by a moving carrier (e,h) on the k^{th} electrode (strip) via Shockley-Ramo theorem
  - Results (histograms, graphs or ntuples) saved in hbook format

Detector parameters

Parameters:

- **Depth = 285 μm**
- **Pitch = 80 μm**
- **p^+ width = 16 μm**
- **p^+ height = 1 μm**
- **$N_{donors} = 10^{12}$ cm^{-3}**
- **$N_{acceptors} = 3.10^{19}$ cm^{-3}**
- **Refraction index = 3.5**
- **Backside reflectance = 90%**
- **Frontside reflectance = 35%**
- **Bias voltage = 150 V**



Laser parameters

Parameters:

Wavelength: $\lambda_1 = $ **1060 nm, i.e. 1.17 eV**

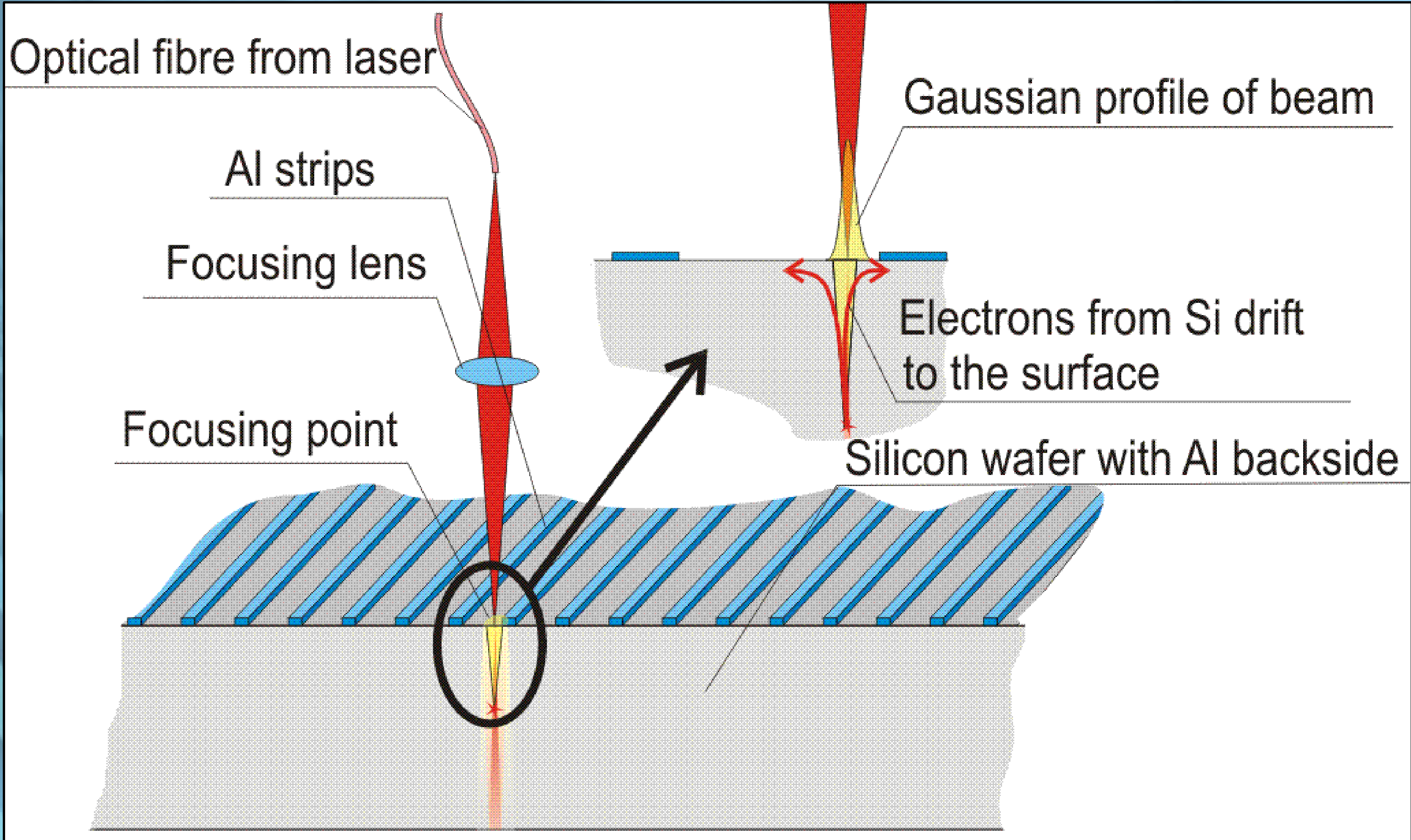
$\lambda_2 = $ **650 nm, i.e. 1.91 eV**

Attenuation length: $\lambda_{att1} = $ **900 μm**

$\lambda_{att2} = $ **4 μm**

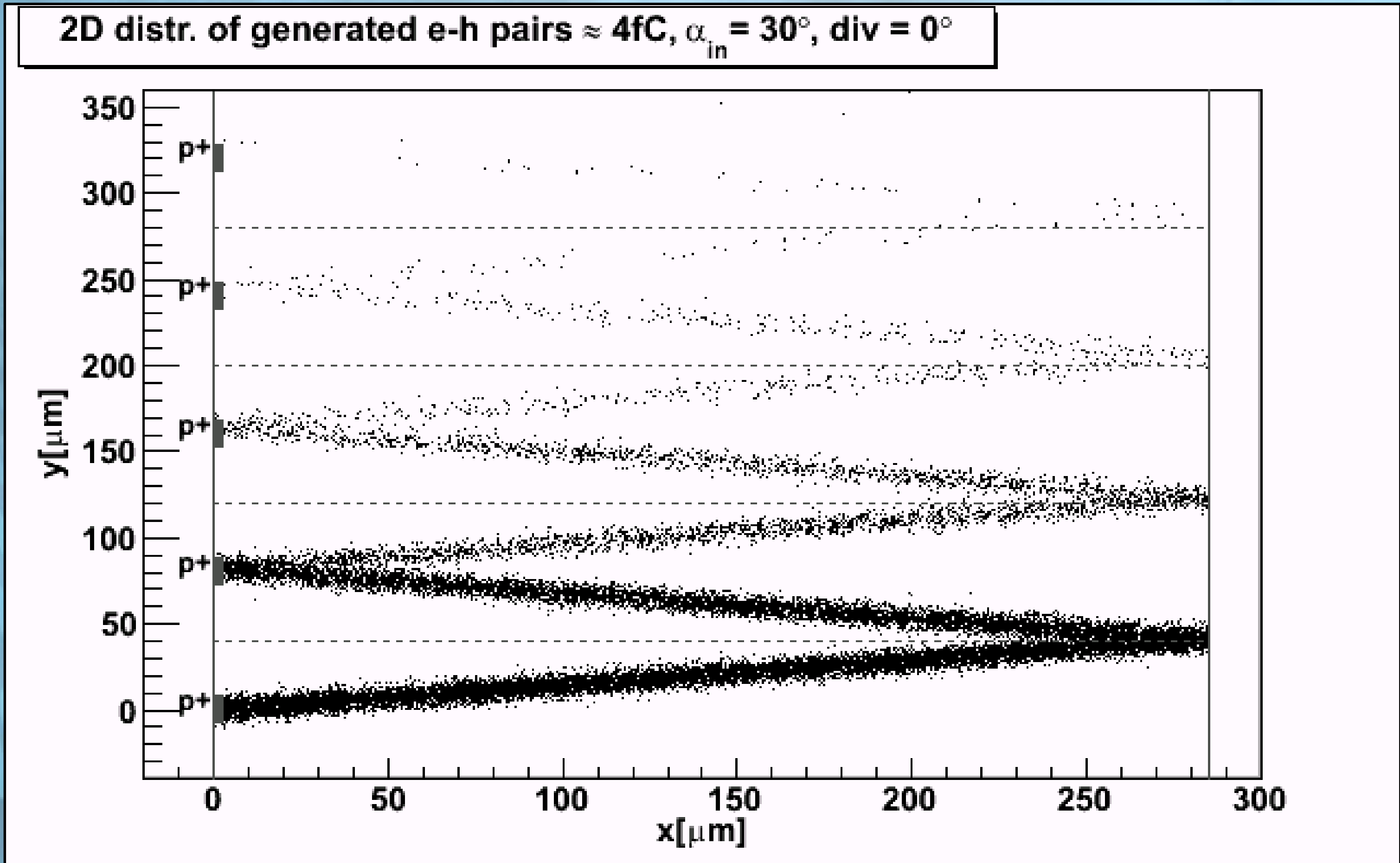
Transverse gaussian distribution sigma $\sigma = $ **3.3 μm**

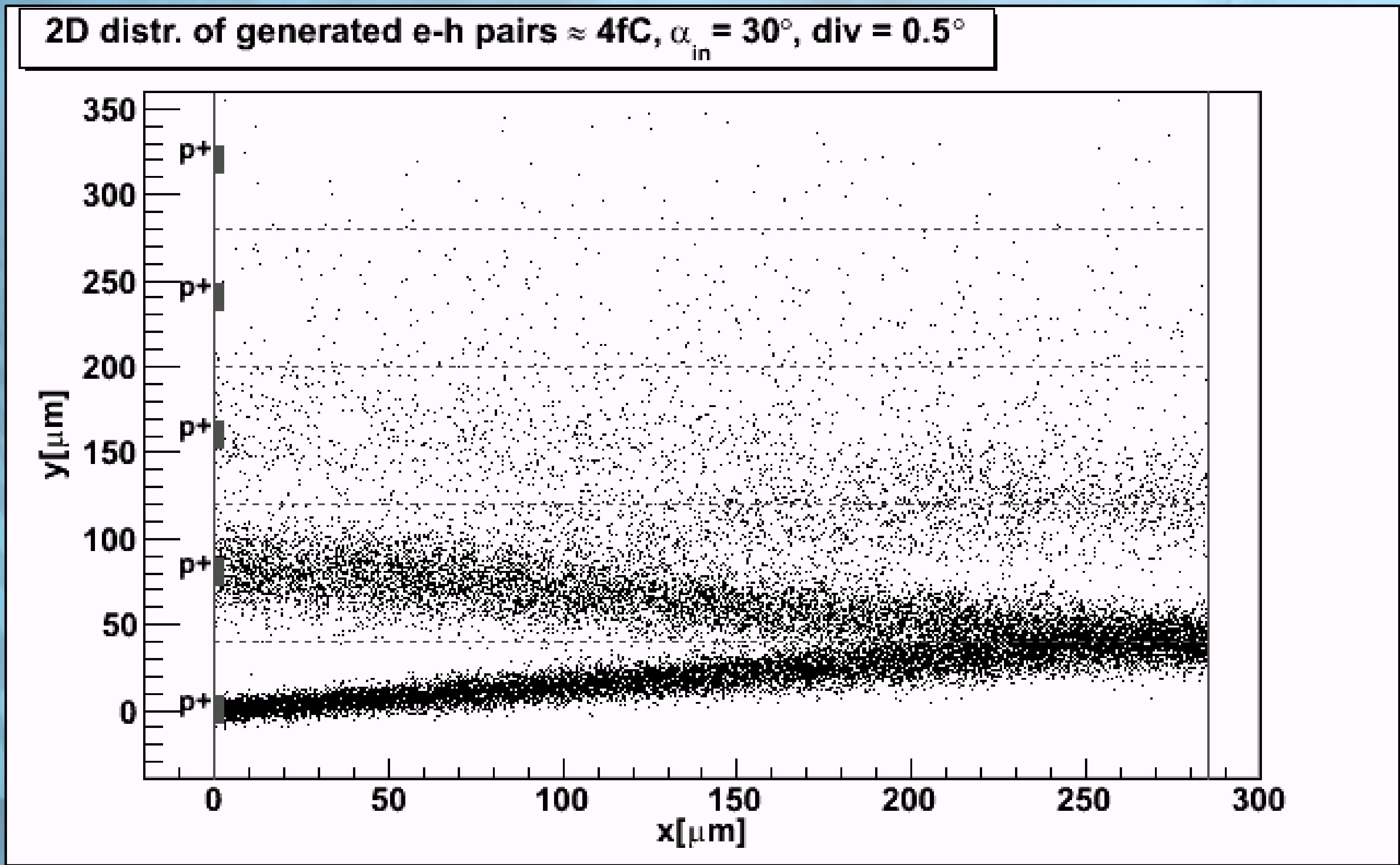
Divergence of laserbeam in direction of motion $=$ **0.5°**


Optical fibre from laser
Al strips
Focusing lens
Focusing point
Gaussian profile of beam
Electrons from Si drift
to the surface
Silicon wafer with Al backside

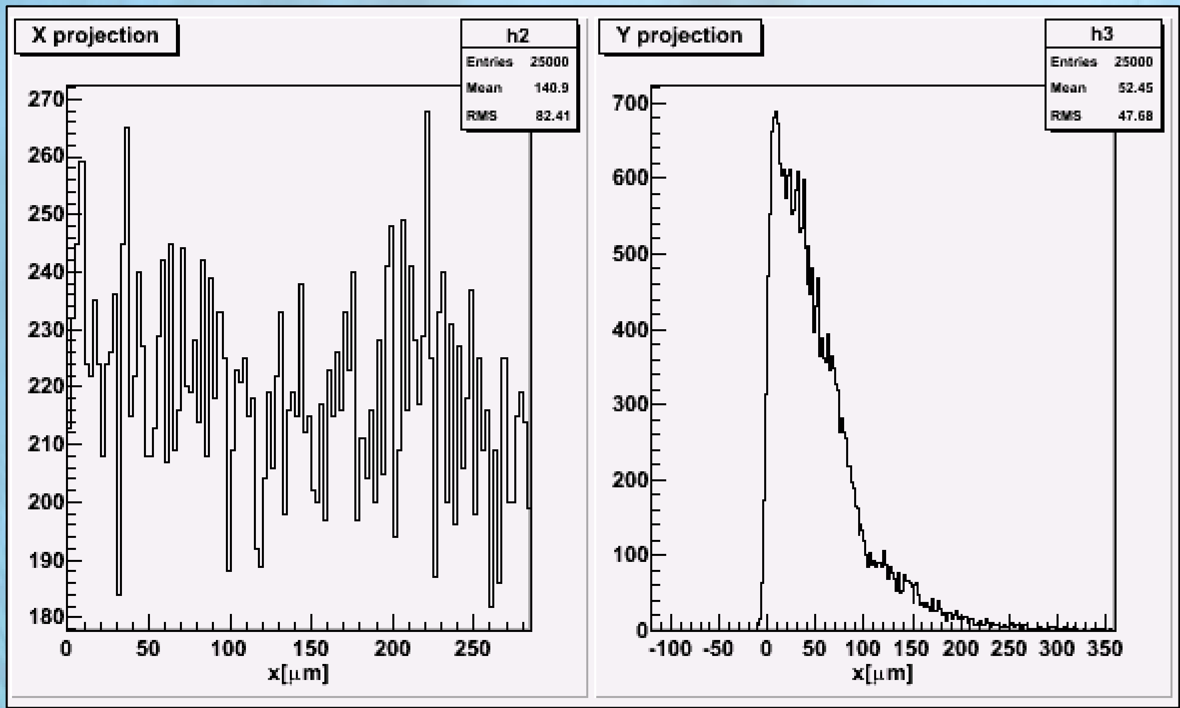
Generation of e-h pairs

- Laser beam incident at a certain angle is refracted on the edge of the detector and then exponentially attenuated and reflected untill the intensity decreases to 3% of the initial value
  - each photon generates e-h pair
  - in direction of motion e-h pairs are generated using exponential distribution
  - in direction perpendicular to motion e-h pairs are generated via Gaussian distr.
  - moreover, in direction of motion, there is possibility to switch on the divergence of the beam
- MIP (180 GeV pion) incident at a certain angle generates e-h pairs uniformly along the track with step 5μm
  - energy necesarry for e-h pair creation = 3.65 eV
  - Landau distribution generated in GEANT3 using PAI model, δ electrons off


2D distr. of generated e-h pairs ≈ 4fC, α_{in} = 30°, div = 0°
y[μm]
x[μm]
p+
p+
p+
p+
p+
350
300
250
200
150
100
50
0
0
50
100
150
200
250
300



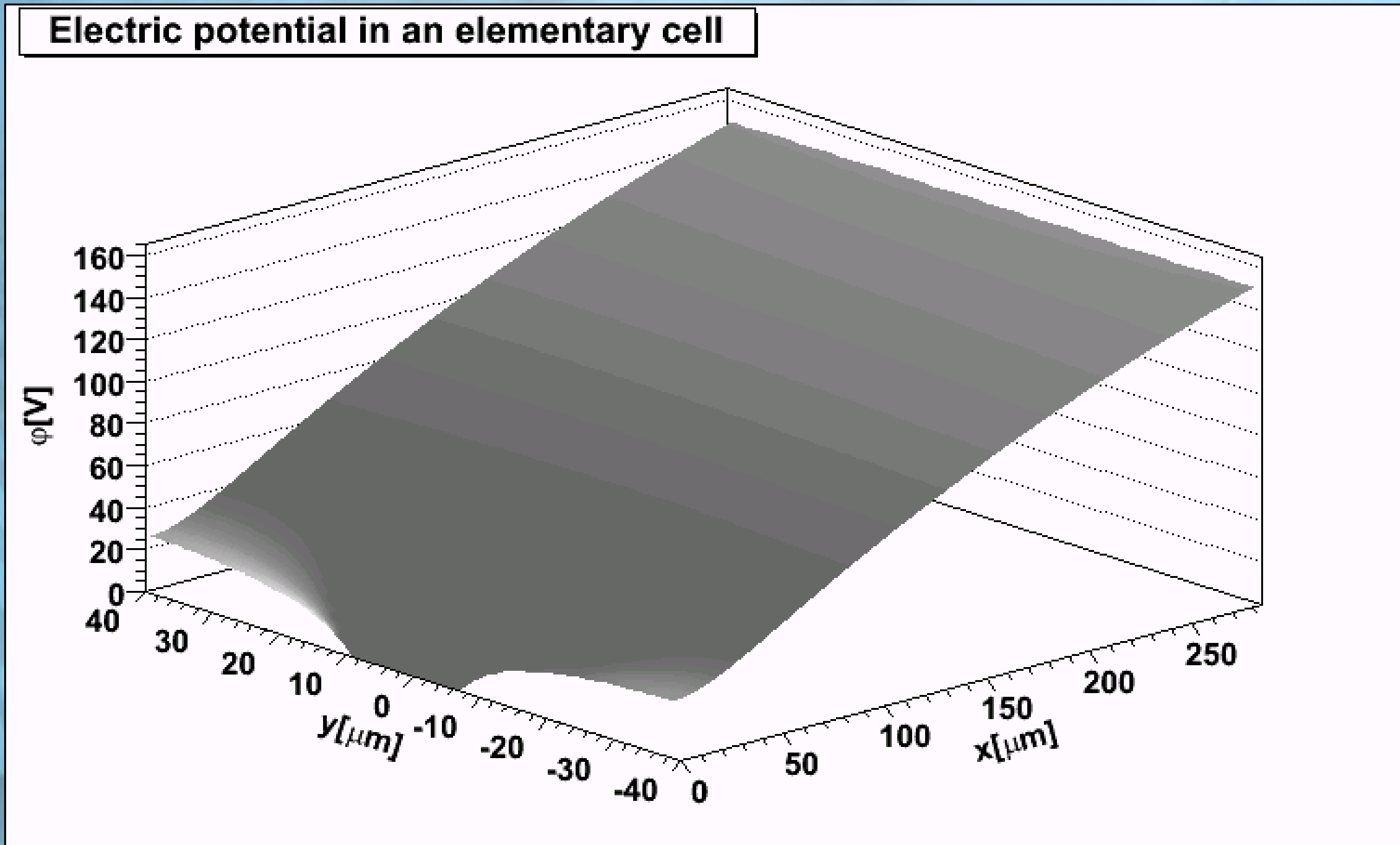
2D distr. of generated e-h pairs ≈ 4fC, α_{in} = 30°, div = 0.5°
p+
p+
p+
p+
p+
y[μm]
x[μm]
0
50
100
150
200
250
300
350


X projection
h2
Entries 25000
Mean 140.9
RMS 82.41
x[μm]
Y projection
h3
Entries 25000
Mean 52.45
RMS 47.68
x[μm]

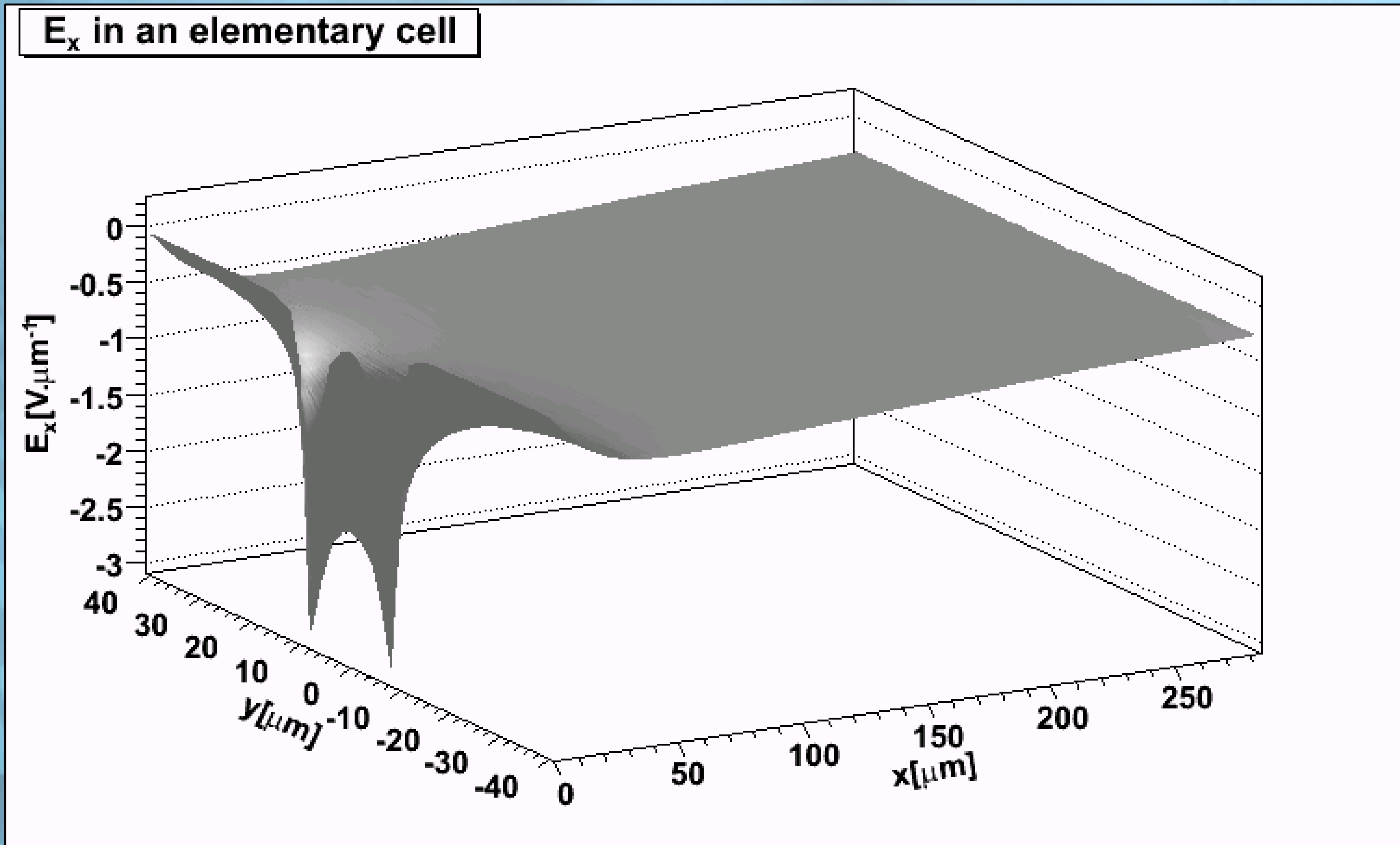
Calculation of electric field

- In order to simulate the motion of charge, it's necessary to evaluate the electric field
- This was done by dividing detector volume into elementary cells and solving Laplace equation with the following boundary conditions:

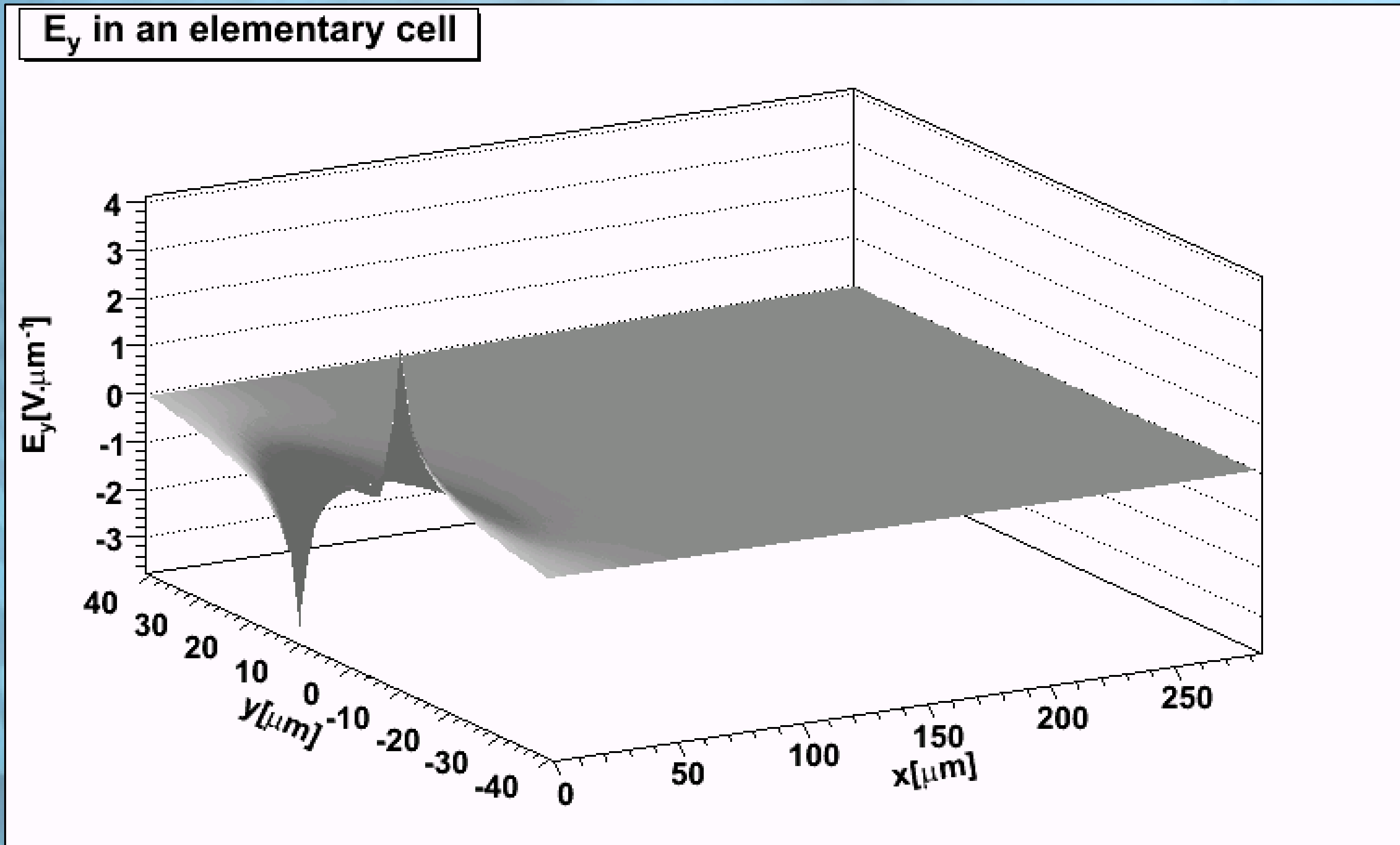
  - $\varphi(x = 0) = 150 \text{ V}$
  - $\varphi(x = d, -w/2 \le y \le +w/2) = 0 \text{ V}$
  - $\varphi(y = -p/2) = \varphi(y = +p/2)$



Electric potential in an elementary cell
φ[V]
160
140
120
100
80
60
40
20
0
40
30
20
10
0
-10
-20
-30
-40
y[μm]
0
50
100
150
200
250
x[μm]



E$_x$ in an elementary cell
E$_x$[V.μm^{-1}]
0
-0.5
-1
-1.5
-2
-2.5
-3
40
30
20
10
0
-10
-20
-30
-40
y[μm]
0
50
100
150
200
250
x[μm]

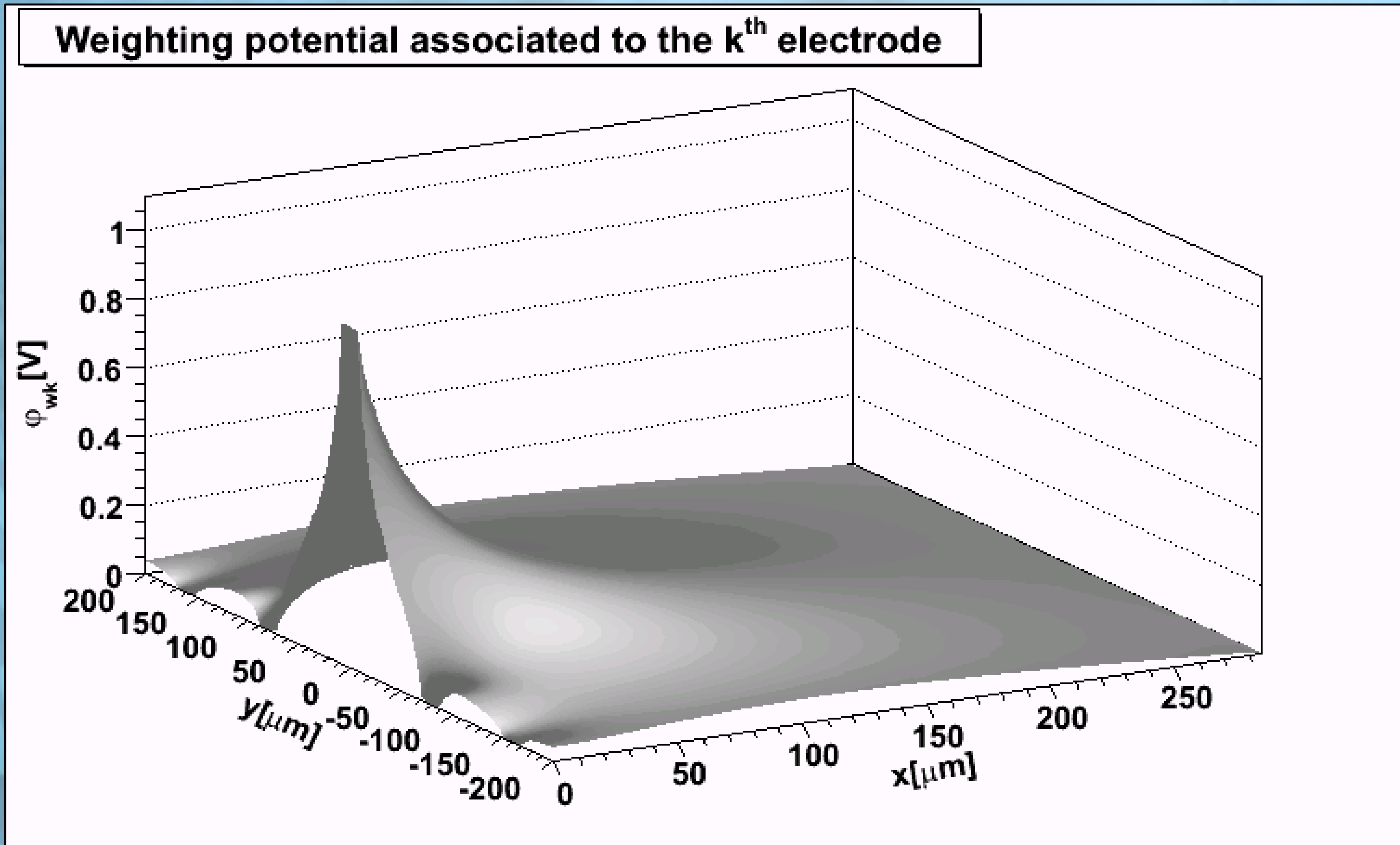

E$_y$ in an elementary cell
E$_y$[V.μm^{-1}]
4
3
2
1
0
-1
-2
-3
40
30
20
10
0
-10
-20
-30
-40
y[μm]
0
50
100
150
200
250
x[μm]

Propagation of e-h

- Under the action of el. field electrons and holes will drift
- The motion of carriers is given by: $v(\vec{r}(t)) = \mu . \vec{E}(\vec{r})$, where $\mu = \mu(v_m(T), E_C(T), \beta(T))$ is different for electrons and holes
- The ODF is solved numerically, using Runge-Kutta method, in which the time stepsize δt is adjusted that the overall space accuracy ε increases: $\delta t = \varepsilon / v(\vec{r}(t))$
- After each step new position is evaluated and diffusion effect is added to it (during the drift electrons and holes are diffused by multiple collisions and their distribution follows Gaussian law), i.e. : $\delta \vec{r} = \delta \vec{r}_E + \delta \vec{r}_D$

- The current induced at time *t* by a moving carrier on the k^{th} electrode can be evaluated with the Shockley-Ramo theorem, as: $i_k(t) = -q \cdot v(\vec{r}(t)) \cdot \vec{E}_{wk}(\vec{r})$
- Where $\vec{E}_{wk}(\vec{r})$, representing weighting field associated to the k^{th} electrode, describes the geometrical coupling between a charge and k^{th} electrode and can be evaluated by solving the same Laplace equation as for the true electric field and potential, but with following boundary conditions:

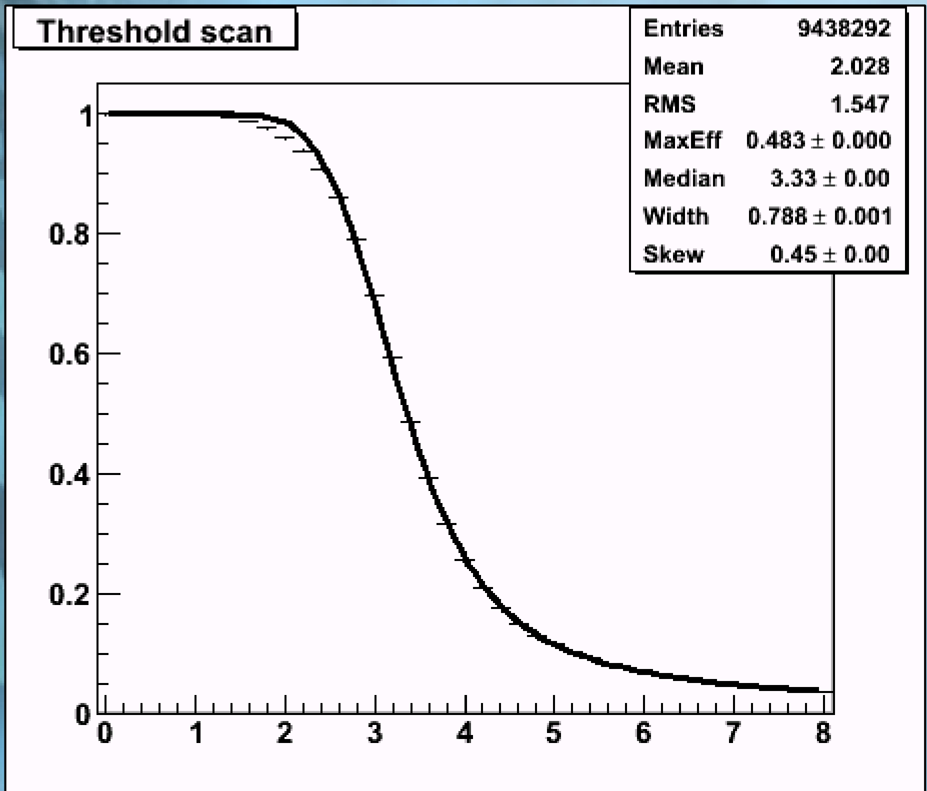
  - $\varphi_k = 1\ V$
  - $\varphi_i = 0\ V,\ i \neq k$
  - $\rho = 0$

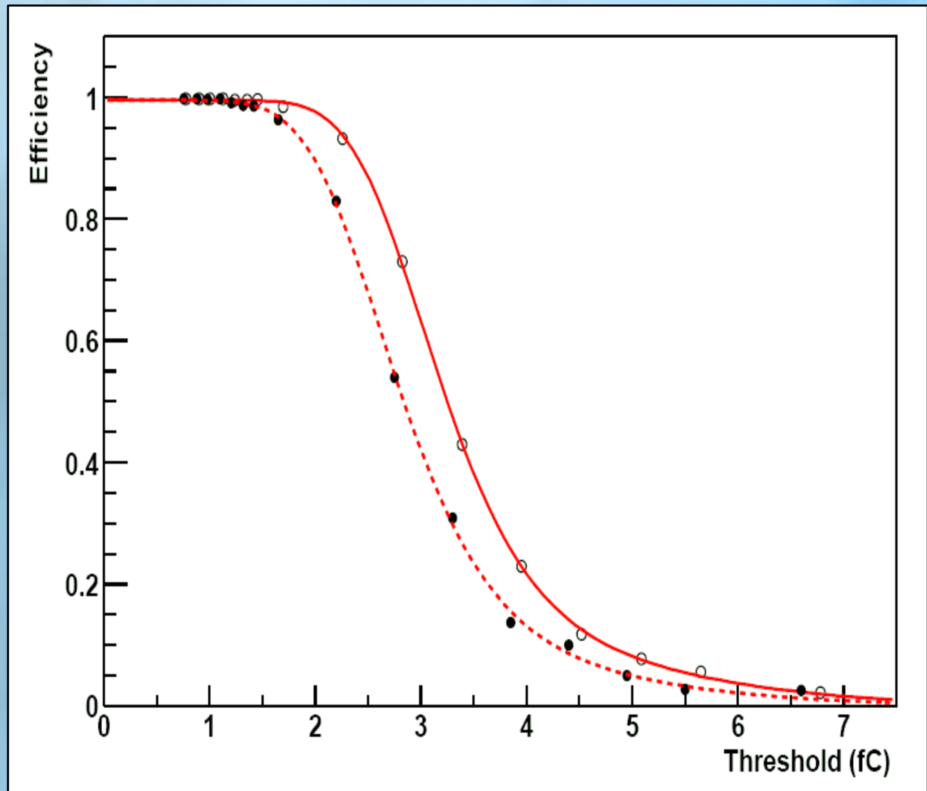

Weighting potential associated to the k^th electrode
φwk [V]
1
0.8
0.6
0.4
0.2
0
200
150
100
50
0
-50
-100
-150
-200
y[μm]
0
50
100
150
200
250
x[μm]

Test beam data simulation

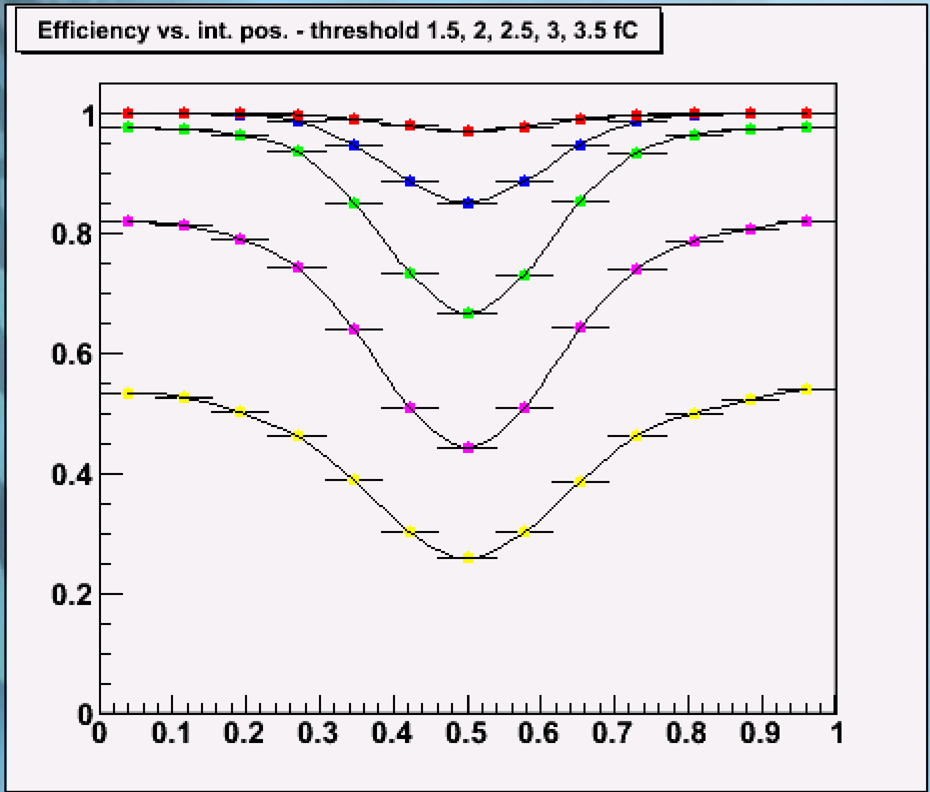
- Simulation of beam test data of ATLAS strip modules at CERN 2000 – 2003 and comparison with the measured ones
  - for barrel module
  - noise set to 1500 e ≈ 0.24fC
  - multiple scattering resolution $\sigma = 6\ \mu m$
  - ***telescope resolution*** $\sigma = 5\ \mu m$

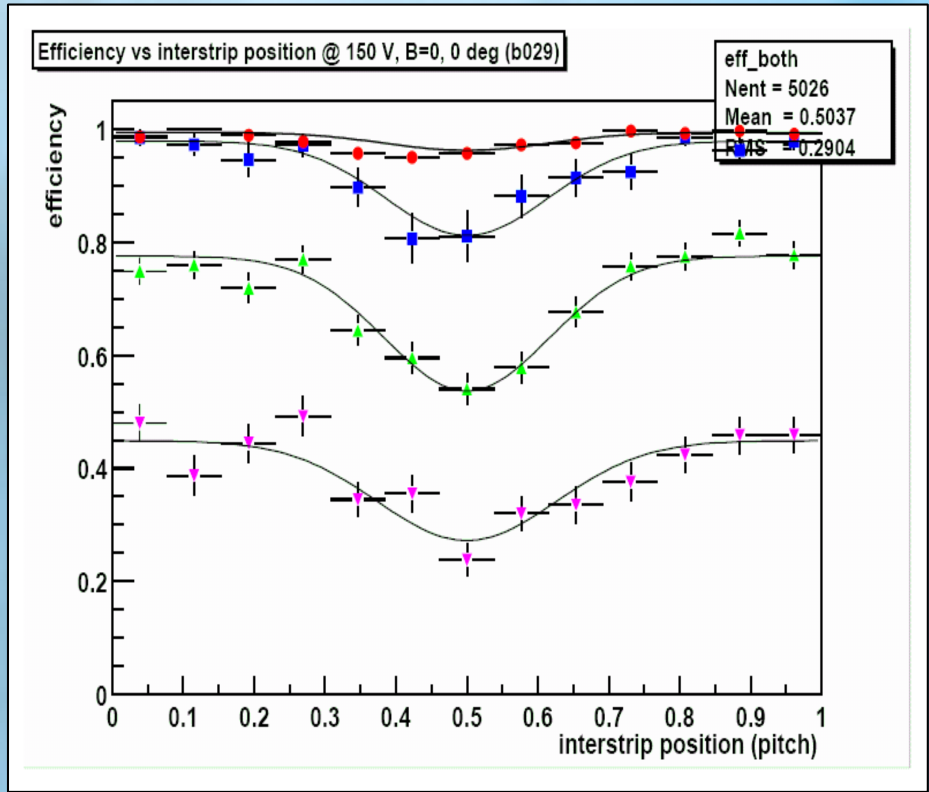
- Threshold scan (simulation x testbeam)



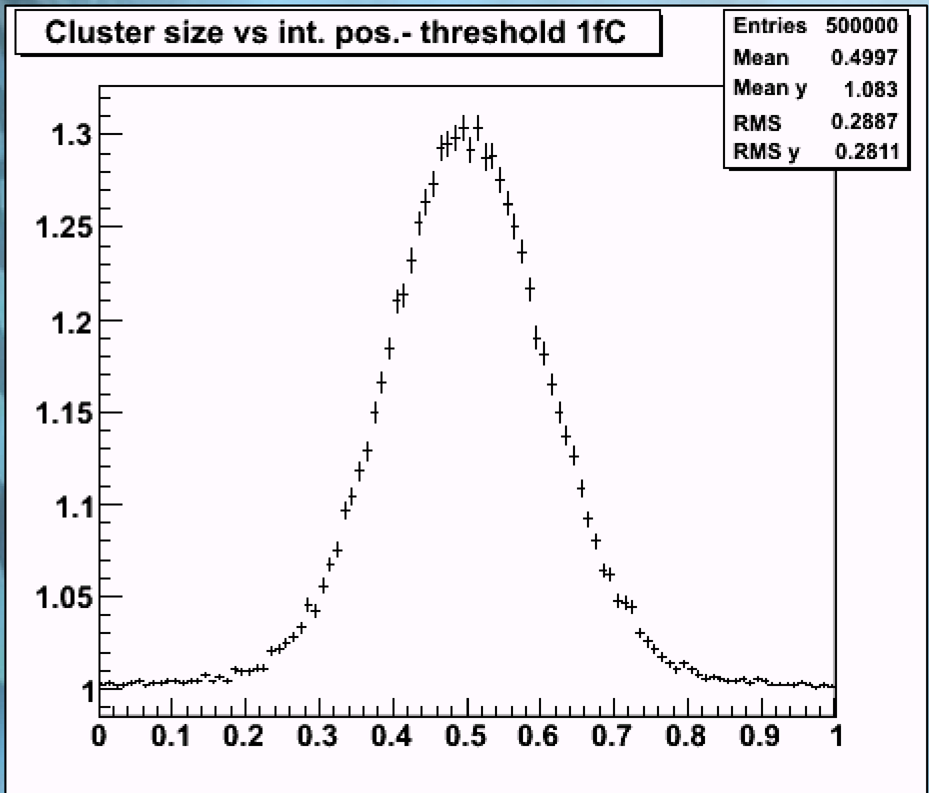


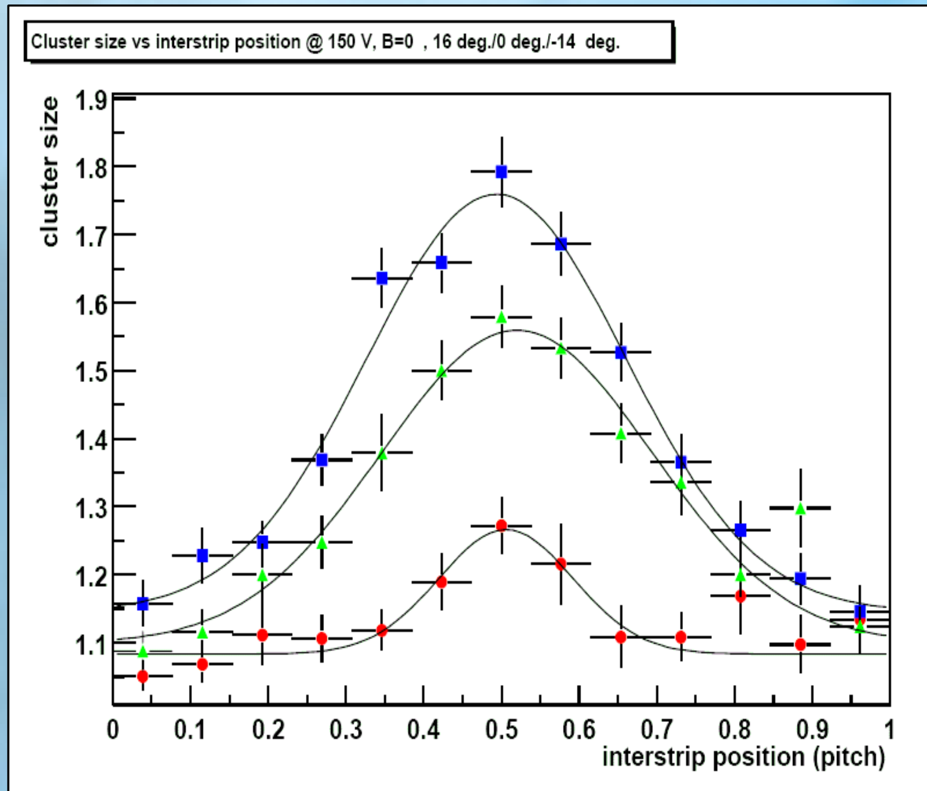
- Efficiency vs interstrip position (simulation x testbeam)



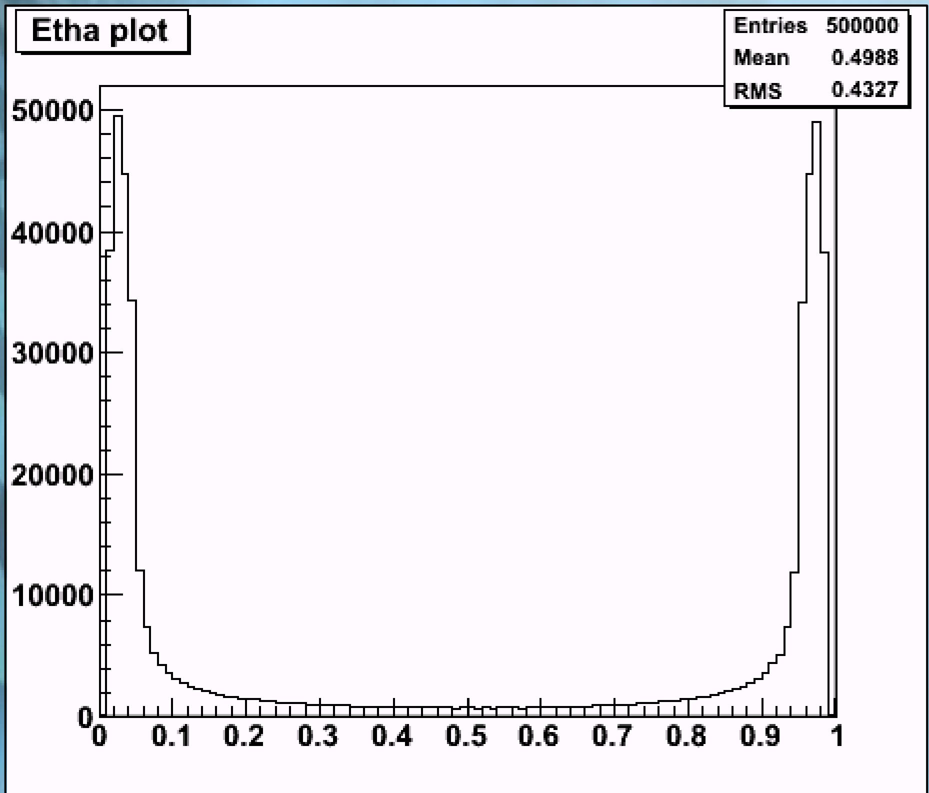


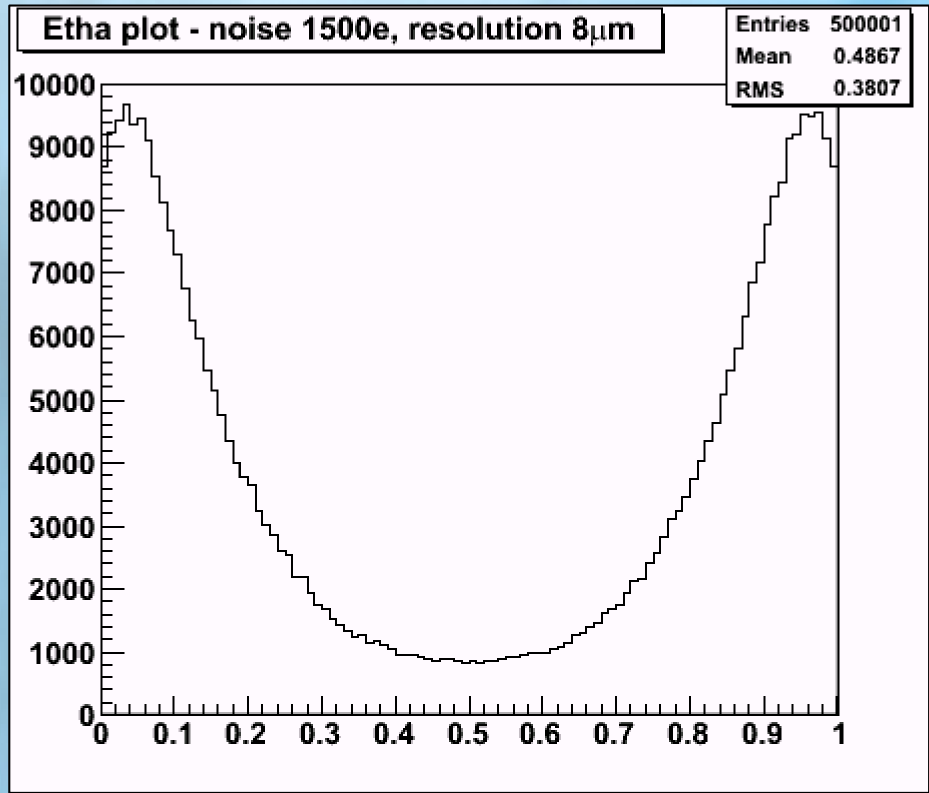
- Cluster size vs interstrip position (simulation x testbeam)





Distribution of particles across the strips - Eta plot (simulation)





Conclusions

- Code for strip detector response simulation created and validated for MIP
- Simulations of laser stimuli started
- Verifications with measurements planned
- Code can be modified for other detectors
- To be added:
  - Delta electrons
  - Electronics (expertise welcome)

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