SiLC Digitization Package

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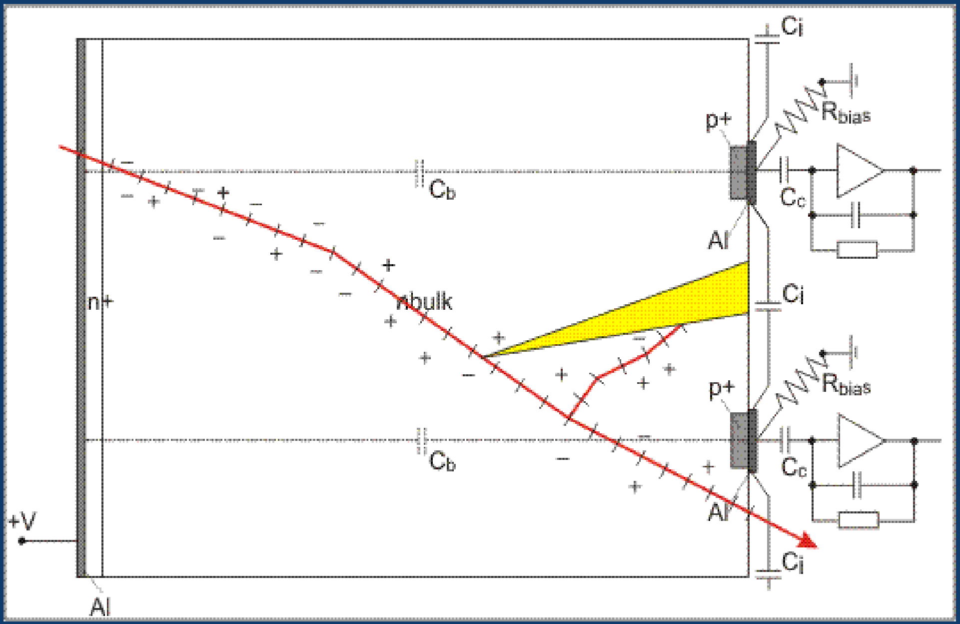
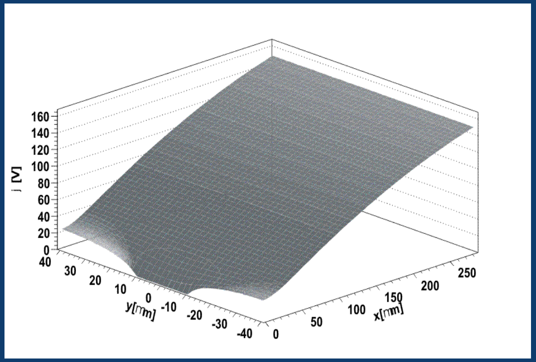
Introduction

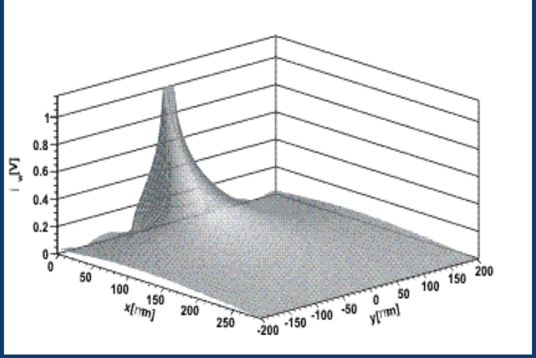


- Digitization (SiStripDigi) – geometry:
  - Geant4 hits transformation – from global to local reference system
- Digitization (SiStripDigi) – phys. processes:
  - Generation of e-h pairs (E_{eh}=3.65 eV)
  - Drift of e-h pairs in electric field
  - Diffusion of e-h due to multiple collisions
  - Lorentz shift of e-h pairs in magnetic field
  - Mutual microstrip cross talks (wrt. AC or DC coupling of individual microstrips)
  - Noise: sensor, electronics ...
  - Current type collected: e, h, both
- Clustering (SiStripClus):
  - Cluster finding (seed strips + neighbouring strips) – based on COG algorithm
  - Cluster transformation back to global ref. s.
  - Sensor hits calculation (wrt. single or double-sided structure of sensors)



Electric potential distribution

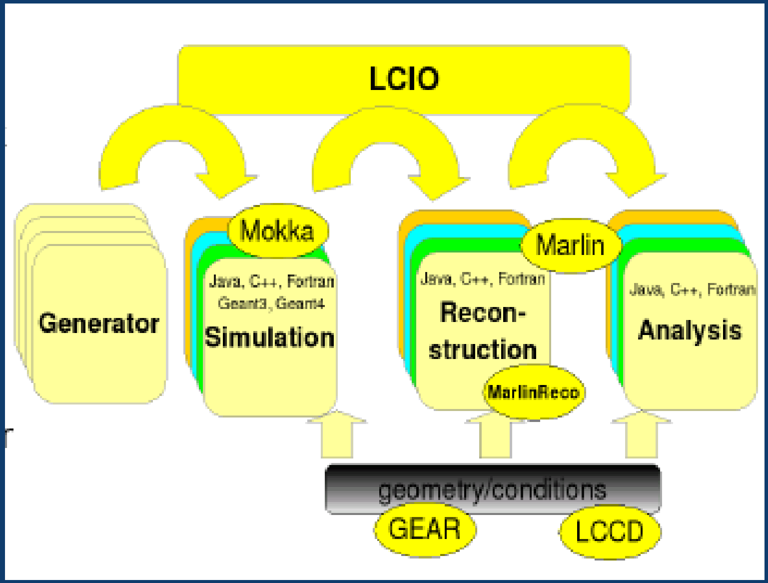
Weighting potential



Digitization & ILC Software Framework

- Digitization software fully based on ILC framework (input: LCIO collect. of SimTrackerHits):
  - **SiStripDigi** – Marlin processor performing digitization → output: LCIO collect. of TrackerPulses
  - **SiStripClus** – Marlin processor performing cluster finding → output: LCIO collect. of TrackerHits
  - Other classes:
    - SiStripGeom – helper class that provides geometry information obtained from Gear xml file + transformations from local to global or global to local reference systems
    - RombIntSolver – integration solver class utilizing Romberg integration method

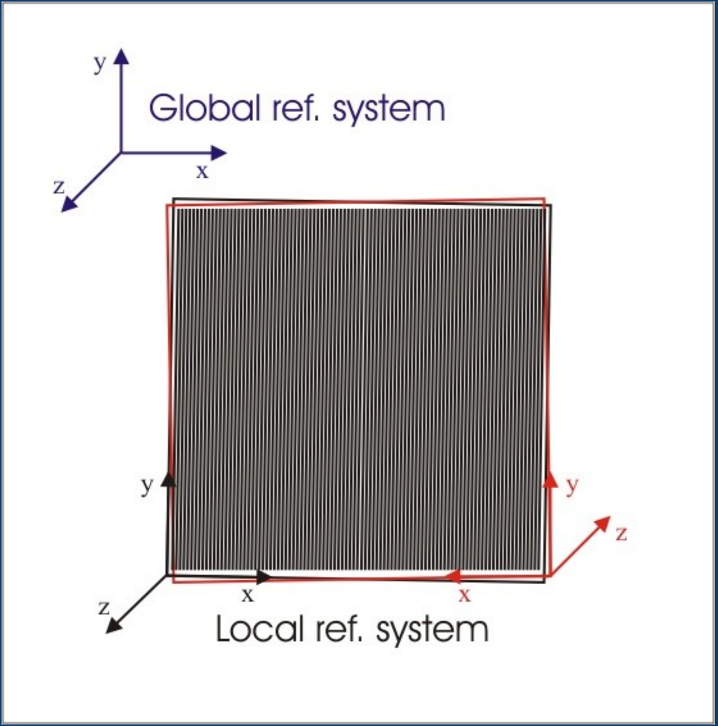
- ILC software framework:
  - **Mokka:** Geant 4 based, full simulation tool using a realistic det. geometry available via a MySQL database
  - **LCIO:** Linear Collider I/O framework, which defines a data model for ILC → output: ***.slcio** file
  - **GEAR:** Geometry description toolkit for ILC analysis and reconstruction software → output: ***.xml** file
  - **MARLIN:** ILC Modular Analysis&Reconstruction tool that enables modular approach (processors) to development of reconstruction and analysis code based on LCIO



Digitization & Geometry

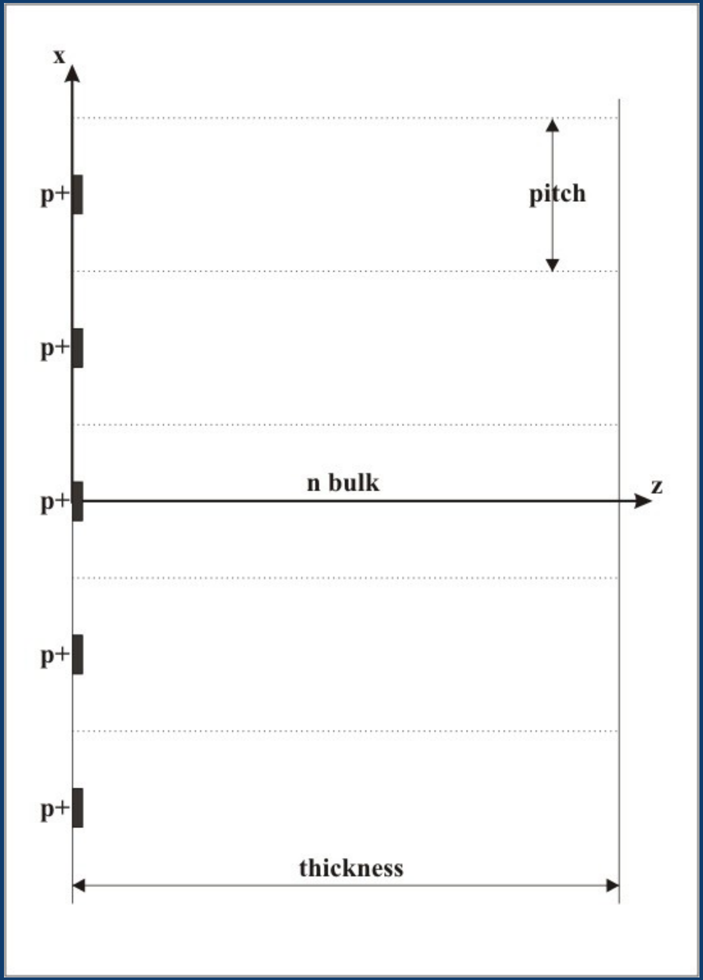
- Detector geometry – complex geometry approach; MySQL database → Mokka → GEAR interface
  - Geometry accessed via SiStripGeom interface class
  - Only barrel type detectors supported (right now)
  - Global ref. system defined in Mokka
  - Local ref. system defined as follows:
    - (0,0,0) position corresponds to the right down corner of each wafer
    - x, y, z coordinates are positive, z = 0 corresponds to the strip side
    - strips – parallel to y-axis, numbered in positive direction of x-axis
  - Detector system information:
    - Number of sensors + sensor type, resp. Gear type
    - Magnetic field
  - Sensor, resp. Si wafer (for double-sided), information:
    - Sensor – position in space
    - Sensor – rotation wrt. position point (axes: z, x´,z´´)
    - Sensor – number of wafers
    - Sensor – sizes + thickness
    - Wafer – mutual stereo angle – for double-sided sensors
    - Wafer – thickness
    - Wafer – pitch
    - Wafer – number of strips

Geometry of double-sided sensors



Digitization & Parameters

- SiStripDigi processor:
  - Geometry parameters:
    - sensor (wafer) thickness
    - sensor pitch
    - number of strips
  - Digitization parameters:
    - sensor bias voltage
    - sensor depletion voltage
    - sensor temperature
    - sensor capacitances: $C_{interstrip}$, $C_{backplane}$, $C_{coupling}$
    - CMS-like noise (common mode subtracted noise)
    - type of current collected by electrodes
  - Precision parameters:
    - space precision ≈ 5 – 50 μm
    - relative angle precision ≈ 0.001 – 0.01
    - relative drift time precision ≈ 0.001 – 0.01
- SiStripClus processor:
    - CMS-like noise (common mode subtracted noise)
    - S/N ratio for seed strips
    - S/N ratio for adjacent strips

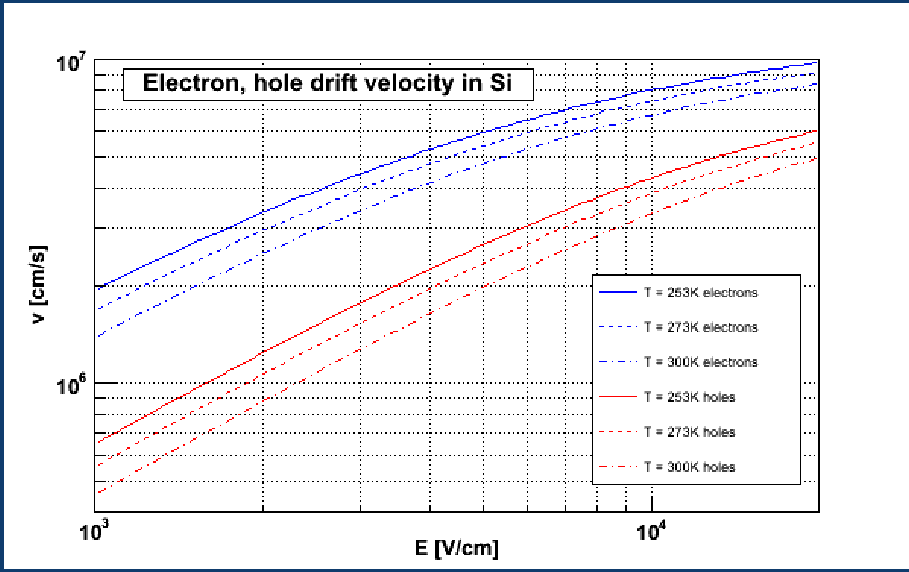


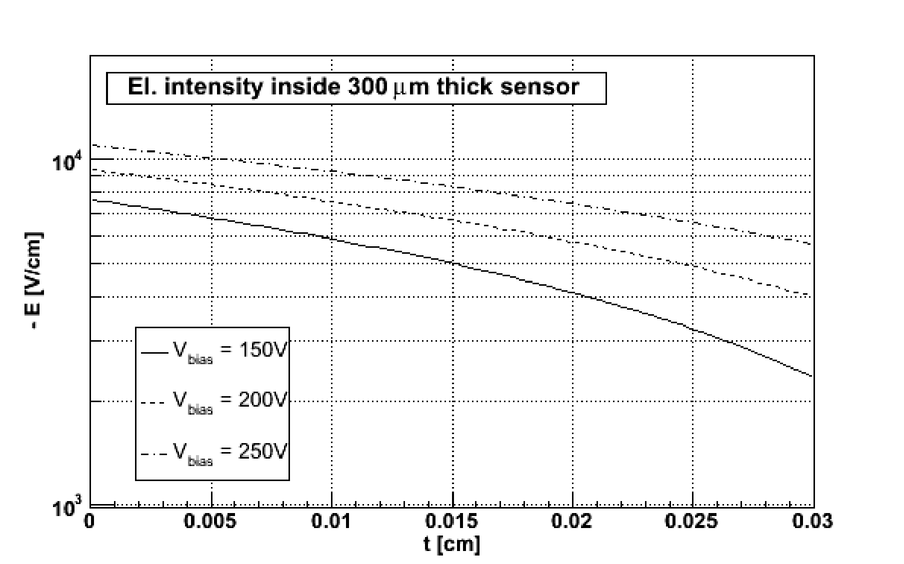
Digitization & El. Field, Drift

- Electric field of abrupt p-n junction:
  - Instead of areas around the strips, the analytically expressible field of p-n junction:

$$E(z) = -\left(\frac{V+V_{dep}}{d} - \frac{2z}{d^2} V_{dep}\right)$$

  is very similar to what one obtains when solving Poisson equation; moreover, the field is constant for given *z* and various *x* !
  - Parameters: $V_{dep} = 80$ V, $V_{bias} = 150, 200, 250$





- Drift of e-h pairs:
  - Represented by the eq. of motion (1st order ODE):

$$v(z) = \mu(E(z), T) . E(z)$$

  - where the mobility is strongly dependent on elec. field and sensor temperature:

$$\mu(E(z), T) = \left(\frac{\mu_s / E_c}{(1 + (E(z)/E_c)^{\beta})^{1/\beta}}\right)$$

  - Mobility parameters for Si oriented in <111> direction (different for e, h): $\mu_s(T)$, $E_c(T)$, $\beta(T)$
  - ODE integrated numerically using Romberg meth.

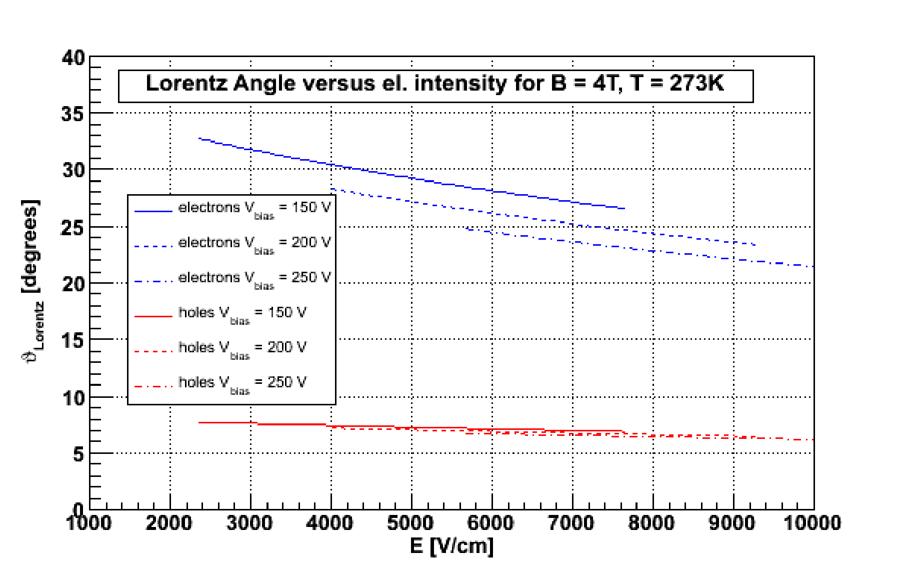
Digitization & Diffusion, Lorentz Shift

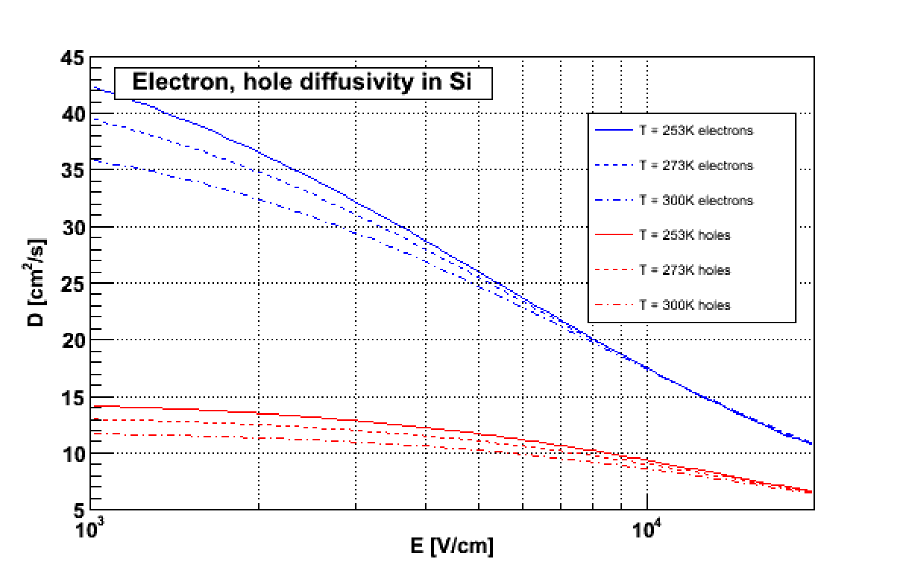
- Diffusion of e-h pairs:
  - ***e***, resp. ***h***, are during the drift diffused by multiple collisions
  - Distribution given by Gaussian law:

$$dN=\frac{N}{\sqrt{4\pi Dt(\vec{r})}}\exp(-\frac{\vec{r}^2}{4Dt(\vec{r})})d\vec{r}$$

$$D=\left(\frac{kT}{q}\mu(E,T)\right)$$

  - where ***D*** denotes diffusivity given by Einstein relation and ***t*** the drift time





- Lorentz shift of e-h pairs in mag. field:
  - ***e***, resp. ***h***, are during the drift deflected in magnetic field (Lorentz shift of charge carriers) :

$$\tan(\vartheta_L)=\frac{\int_z^d \mu(E(z))\, r\, B\, dz}{\int_z^d dz}$$

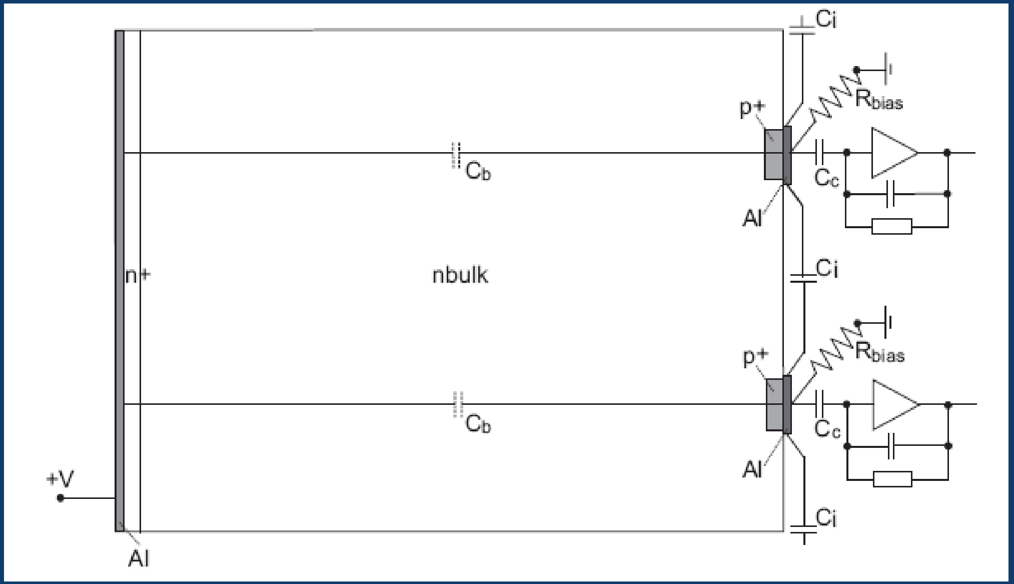
  - where ***r*** denotes so-called Hall scattering factor:
    - r = 1,13 + 0.0008.(T-273) for ***e***
    - r = 0,72 - 0.0005.(T-273) for ***h***
  - Solution obtained numerically using Romberg meth.

Digitization & Crosstalk, Current Type

- Cross talk effect:
  - The charge generated on each strip is for both DC and AC coupled sensors redistributed to the neighbours according to following relation:

$$i_{neighbour} = i_{strip} \frac{C_i}{C_i + C_c + C_b}$$

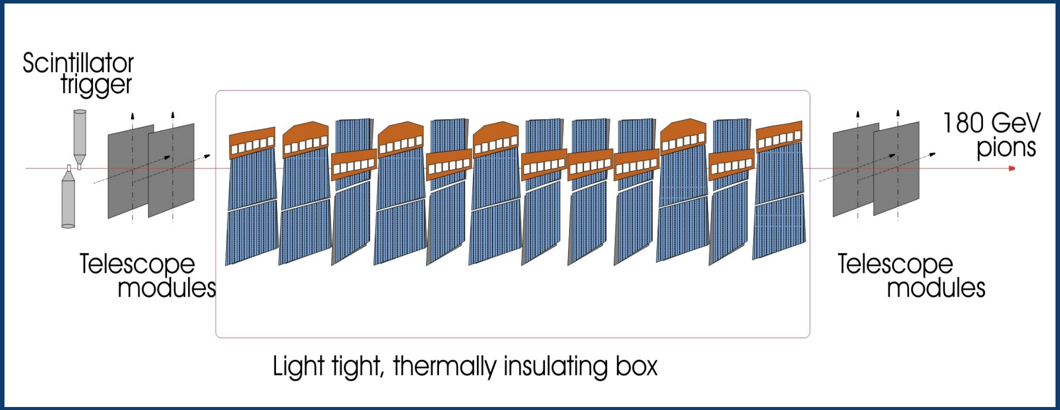
  - where C_i, resp. C_b, resp. C_C, denotes:
    - capacitive coupling between individual strips
    - resp. strip-to-backplane coupling
    - resp. load capacitance (for AC coupling only)



- Current type:
  - In contrast to full simulation (using weighting field approach to calculate the current induced on each strip), here, either ***e*** component or ***h*** component is taken as a signal (resp. as a collected charge) or both weigthed by a weighting potential of a p-n junction

SiStripDigi & TB Results

- Simulation of SCT detector response to a beam of 180 GeV/c pions (ATLAS CERN 2000 – 2004), comparison with real experimental data and verification of SiStripDigi package reliability:
- Simulation parameters:
  - Hamamatsu barrel detector (with binary read-out) simaluted:
    - Sensor thickness = 285μm
    - Si wafer pitch = 80 μm
    - $C_{interstrip}$ = 6 pF
    - $C_{backplane}$ = 1.77 pF
    - $C_{coupling}$ = 120 pF
    - ENC 1500 e ≈ 0.24 fC
    - Discriminator threshold: 1 fC (detector efficiency higher than 99 %)
  - Multiple scattering resolution $\sigma = 6\ \mu$m
  - Telescope resolution $\sigma\ = 5\ \mu$m



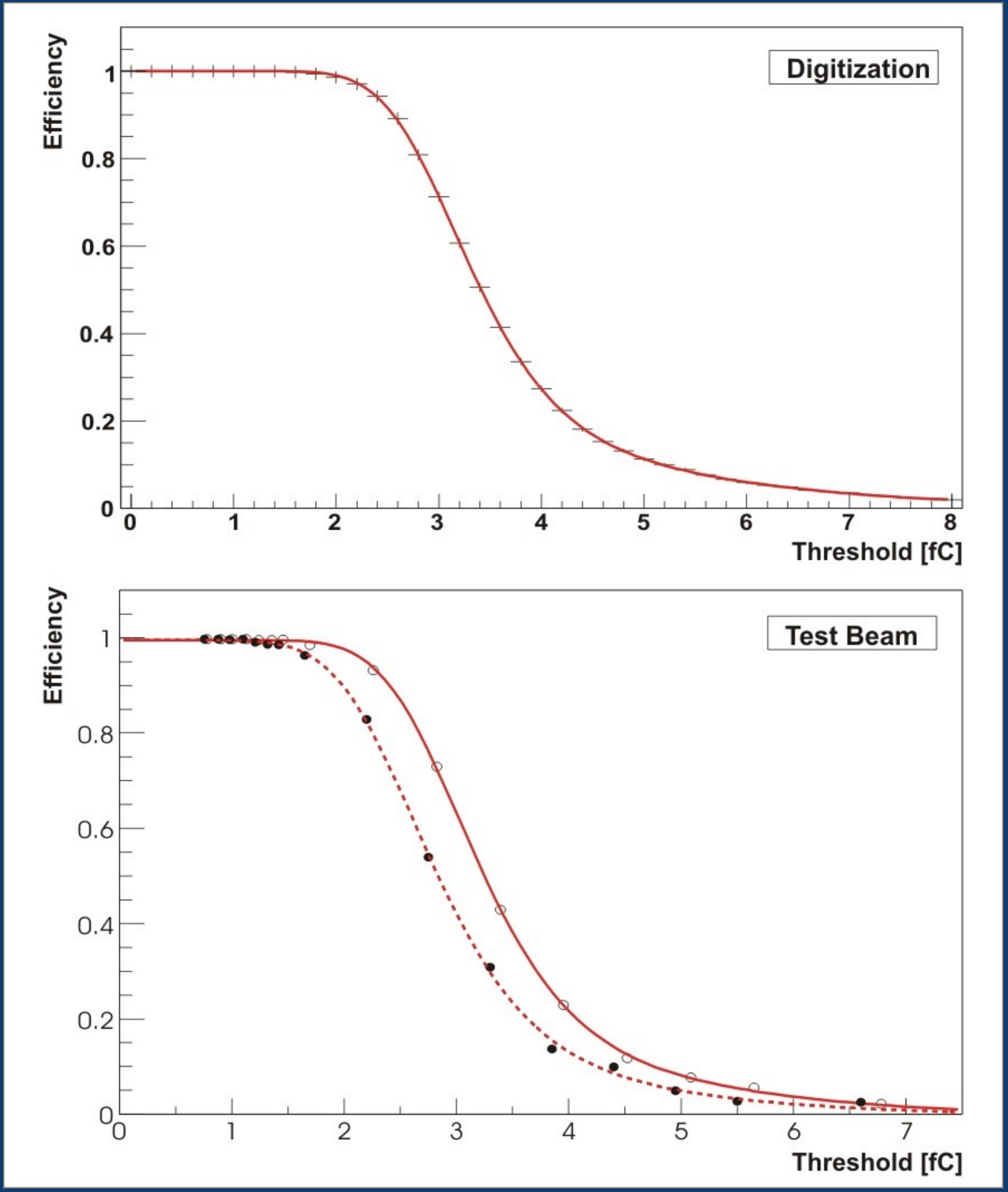
SiStripDigi & TB Median Charge

- S-curve measurement:
  - Fit with a skewed error function:

$$\varepsilon = \varepsilon_{max}\, f\left(x\left[1+0.6\frac{e^{-\xi x}-e^{\xi x}}{e^{-\xi x}+e^{\xi x}}\right]\right)$$

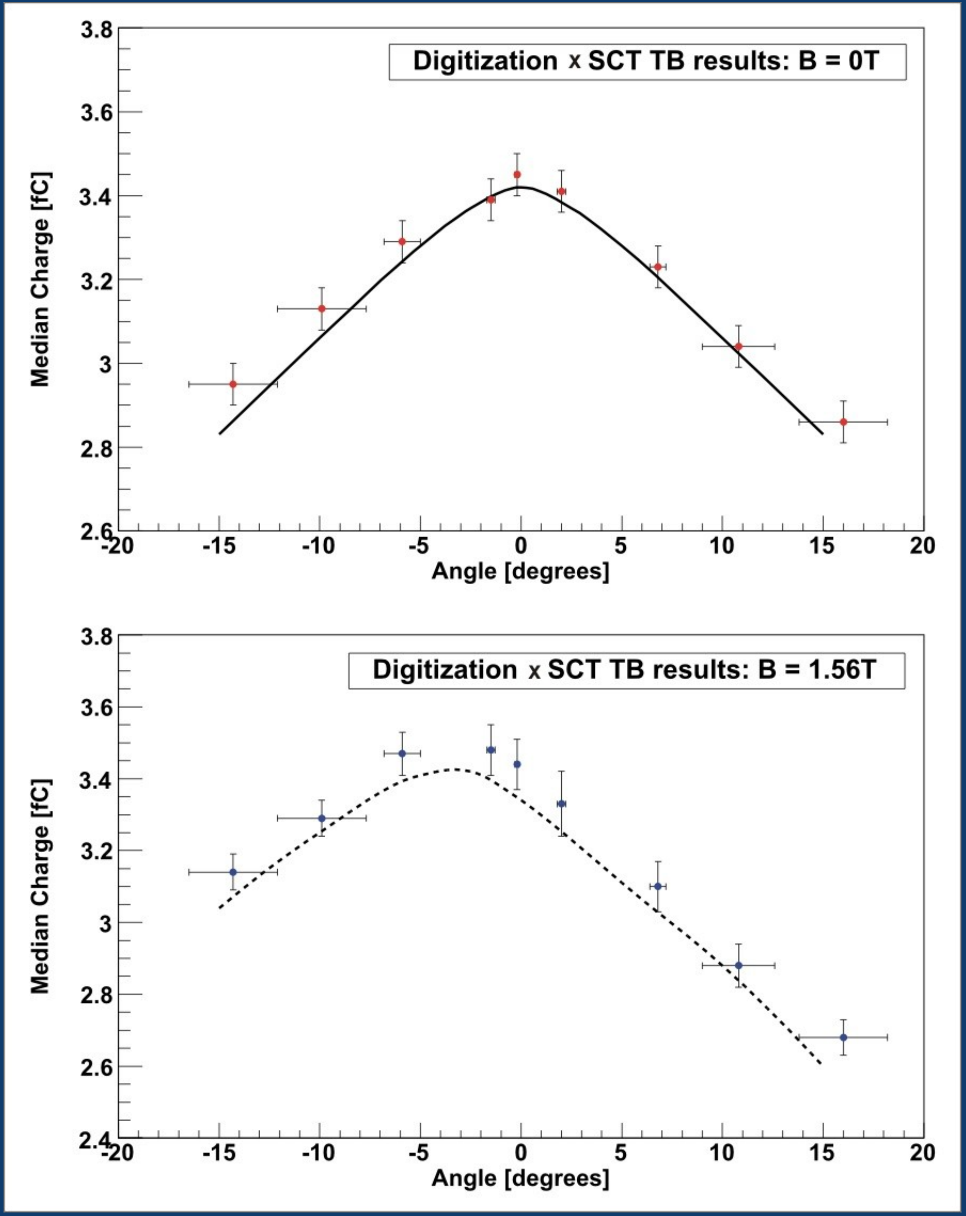
$$x = (q_{thresh}-\mu)/\sqrt{2}\sigma$$

  - Experiment: (3.5 ± 0.1) fC
  - SiStripDigi: (3.41 ± 0.04) fC



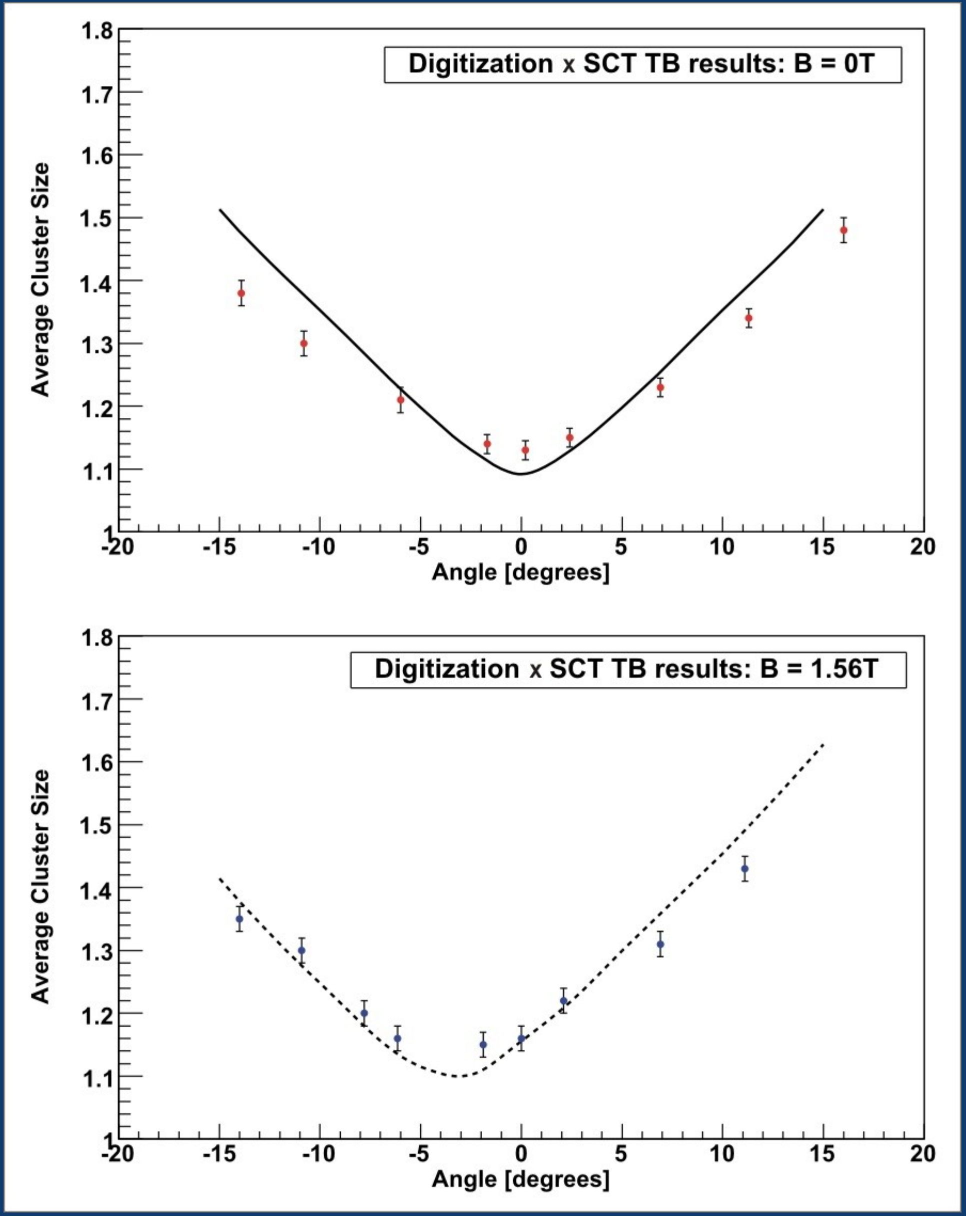
SiStripDigi & TB Incidence Angle

- Median charge versus inc. angle – with or without magnetic field:
  - 2 mutually opposite effects:
    - path length ≈ 1/cos(α)
    - charge sharing effect
  - Experiment:
    - Red markers: B = 0 T
    - Blue markers: B = 1.56 T



SiStripDigi & TB Cluster Size

- Cluster size = the median number of strips that collect charge (the charge at each strip in cluster must be above threshold set)
  - Experiment:
    - Red markers: B = 0 T
    - Blue markers: B = 1.56 T



Conclusion & Status

- New MARLIN processors – **SiStripDigi** (v. 00-02) + **SiStripClus** (v. 00-00) available:
  - SiStripDigi: represents detailed digitizer with all relevant physical processes included
  - SiStripClus: represents cluster finder
  - Functionality verified on real data (SCT TB)
    - still interesting to verify the same measurements with analog read-out sensors (SiLC TB 2008)
  - Input: Marlin config file: *.steer file; Gear geometry file: *.xml file; data file: *.slcio file
  - Output: SiStripDigi: *.slcio file (TrackerPulse) → SiStripClus: *.slcio file (TrackerHit)
  - Software documentation available → use Doxygen to generate it
  - To ease the building process CMAKE configuration files written → use CMAKE to build it
    - linking – dependent on following libraries: CLHEP, GEAR, LCIO, MARLIN (SiStripClus depends on SiStripDigi)
  - CPU time consumption:
    - AMD Athlon 64 3200+ → 1.2 ms per event (1 event ≈ 3 hits approximately)

Digitization & Backup Slides

TBSiDet & Mokka Status

- New testbeam geometry (TBSiDetectors) available:
  - classes created for TB simulations and for digitization package development
  - **TBSiDetectors03**: geometry driver (defines a number of sensors being tested, which one is DUT, if double or single-sided detectors being used, sensor positions, alignment parameters: rotation, shift ...)
  - **TBSiSensitive03**: redefines a sensitive detector class
  - **TBSiHit03**: redefines a tracker hit class – when saving in LCIO format the SimTrackerHitImpl class used
    - SimTrackerHitImpl parameters: *MCParticle* *, *prestep position*, *step length*, *particle momentum* defined at prestep position, *deposited energy*, *time stamp*, *cellID* (for double-sided wafers: 1.wafer cell ID corresponds to sensor ID, 2.wafer cell ID corresponds to sensor ID + 100)
  - **MySQL configuration files**: when using a local copy of central database, these files can be used to configure the testbeam geometry ...

TBSiDet & ILC GEAR status

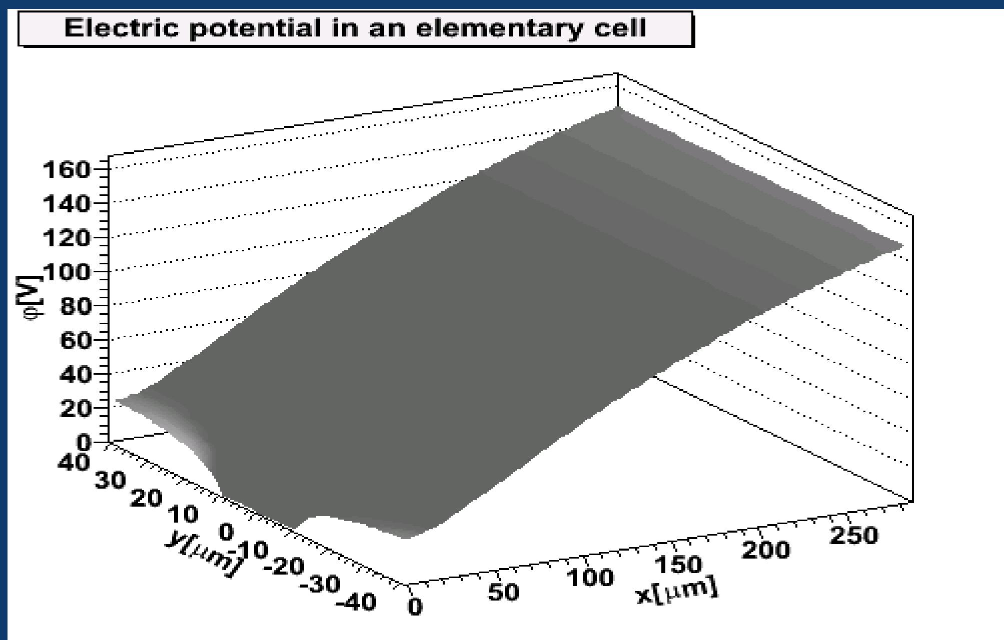
- New testbeam Gear description (TBSiDet) available:
  - classes created for TB simplified geometry description; used by Marlin processors
  - **TBSiDetParameters(Impl)**: describes main parameters of test beam setup of silicon detectors: TB *name*, *TB type* (with or without DUT), *number of sensors*, DUT *ID*, *testbeam layout* (returns sensors layout to read or write new sensors)
  - **TBSiLayout(Impl)**: describes sensor parameters – position, rotation, number of wafers, rad. length ..., and except reading info, enables adding a new sensor

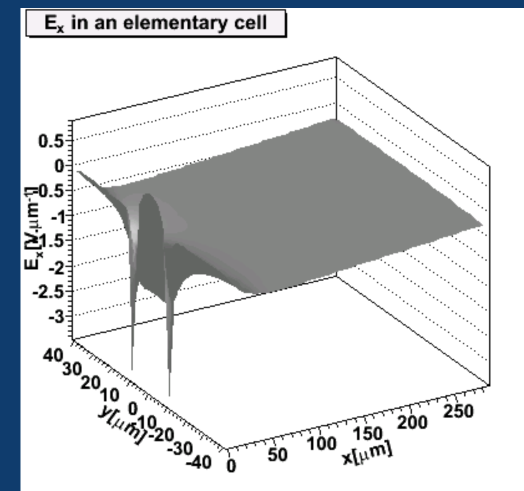
*.xml output example

```
- <gear>
  - <!--
     Gear XML file automatically created with GearXML::createXMLFile ....
    -->
  - <detectors>
    - <detector name="TBSiDet" geartype="TBSiDetParameters">
      - <setup name="TestSetup" type="WithDut">
        - <sensors number="1" idDut="0">
          - <sensor name="Dut" id="0" sensitivity="yes">
            - <wafers number="1" stereoAngle="1.000000000e+01" pitch="1.000000000e+02" nStrips="256"
              radLength="9.366073396e+00">
                <dimensions sizeX="5.000000000e+00" sizeY="5.000000000e+00" sizeZ="3.000000000e-02"/>
              </wafers>
              <dimensions thickness="3.000000000e-02"/>
              <position posX="0.000000000e+00" posY="0.000000000e+00" posZ="0.000000000e+00"/>
              <rotation theta="0.000000000e+00" phi="0.000000000e+00" psi="0.000000000e+00"/>
            </sensor>
          </sensors>
        </setup>
      </detector>
    </detectors>
  </gear>
```

Full Simulation & Electric Field

- Numerical solution – obtained from MAXWEL 2D; detector volume has been divided into so-called elementary cells and the Poisson equation with the following boundary conditions has been solved:

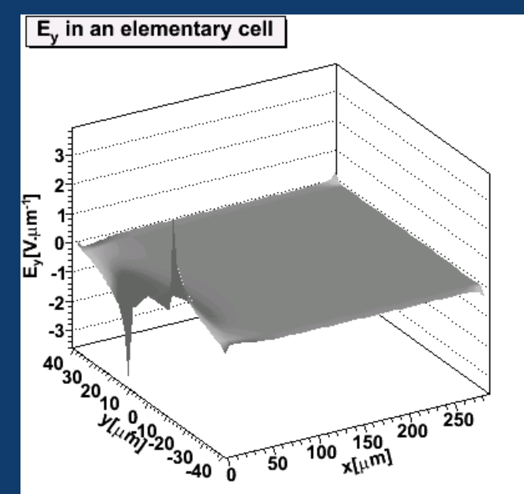




$$\varphi(x=d)=150\,V$$

$$\varphi(x=0,-w/2\leqslant y\leqslant+w/2)=0\,V$$

$$\varphi(y=-p/2)=\varphi(y=+p/2)$$



Full Simulation & Signals

- Each ***e***, resp. ***h***, when drifting to the electrode, generates a relevant signal on each strip
- The current induced at time ***t*** on ***k^th^*** electrode is evaluated by a Shockley-Ramo theorem:

$i_k(t) = -q\,\vec{v}\cdot\vec{E}_{wk}$, where $\boldsymbol{E}_{wk}$ represents the weighting field associated to the $\boldsymbol{k^{th}}$ electrode and **v** the drift velocity; it describes the geometrical coupling between ***e***, resp. ***h***, and the electrode