Silicon Detector Simulation

KOALICE Workshop, January 5th 2020

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Activity in 2019

- Xic0 analysis
  - Electron decay channel
  - p+p 13 TeV (Jinjoo)
  - p+Pb 5 TeV
- Hardware contribution
  - Assymbly at Busan
- Simulation on silicon detector
  - Silvaco TCAD
  - Garfield++ simulation

Silicon detector simulation

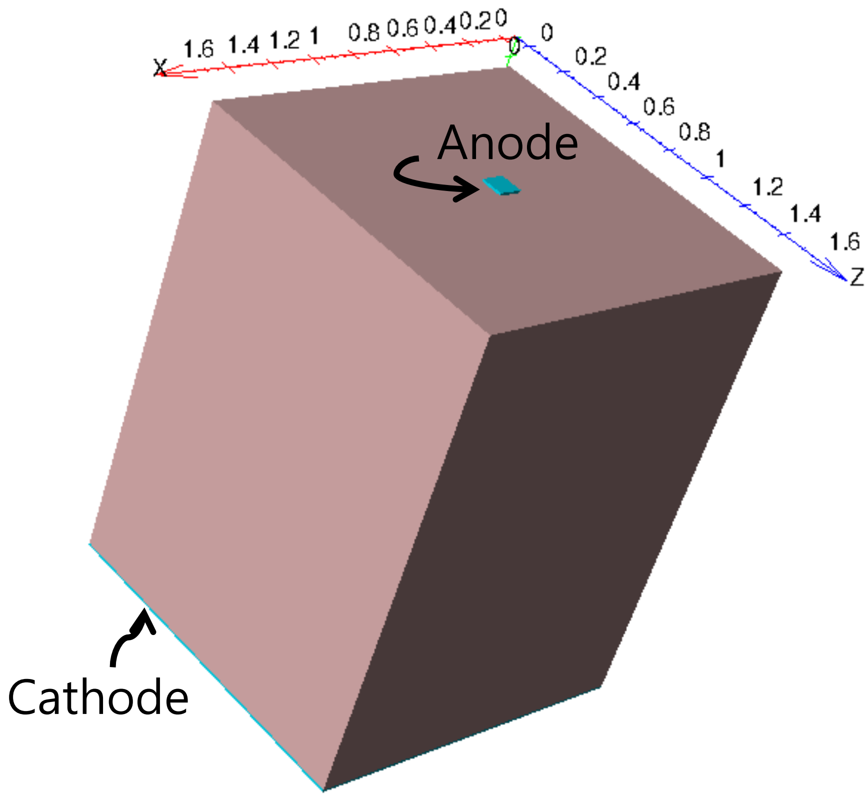
- TCAD (Technology computer-aided design)
  - modelling of process steps (such as diffusion and ion implantation)
  - modelling of the behavior of the electrical devices based on funda mental physics, such as the doping profiles of the devices
  - Silvaco is a physics-based simulator, which predicts electrical chara cteristics associated with specific physical structures and condition s
  - Extract Electric field (input of Garfield++ simulation)

- Garfield++ simulation
  - a toolkit for the detailed simulation of particle detectors that use g as and semi-conductors as sensitive medium.
  - up-to-date treatment of electron transport and the user interface, which is derived from ROOT
  - Extract signal, charge collection time, charge collection efficiency

Current Status and Goals

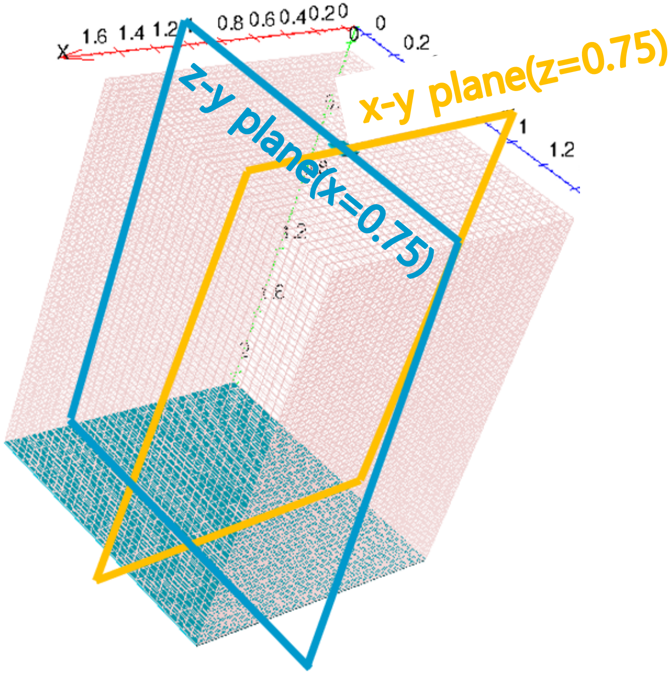
- Silvaco TCAD
  - Input : Doping concentration
  - Goals
    - calculate electric field
    - Compare electric field and resistivity with result using Synopsis(CERN)
- Garfield++ simulation
  - Compared charge collection time without weighting field
  - Goals
    - Compare simulation with data

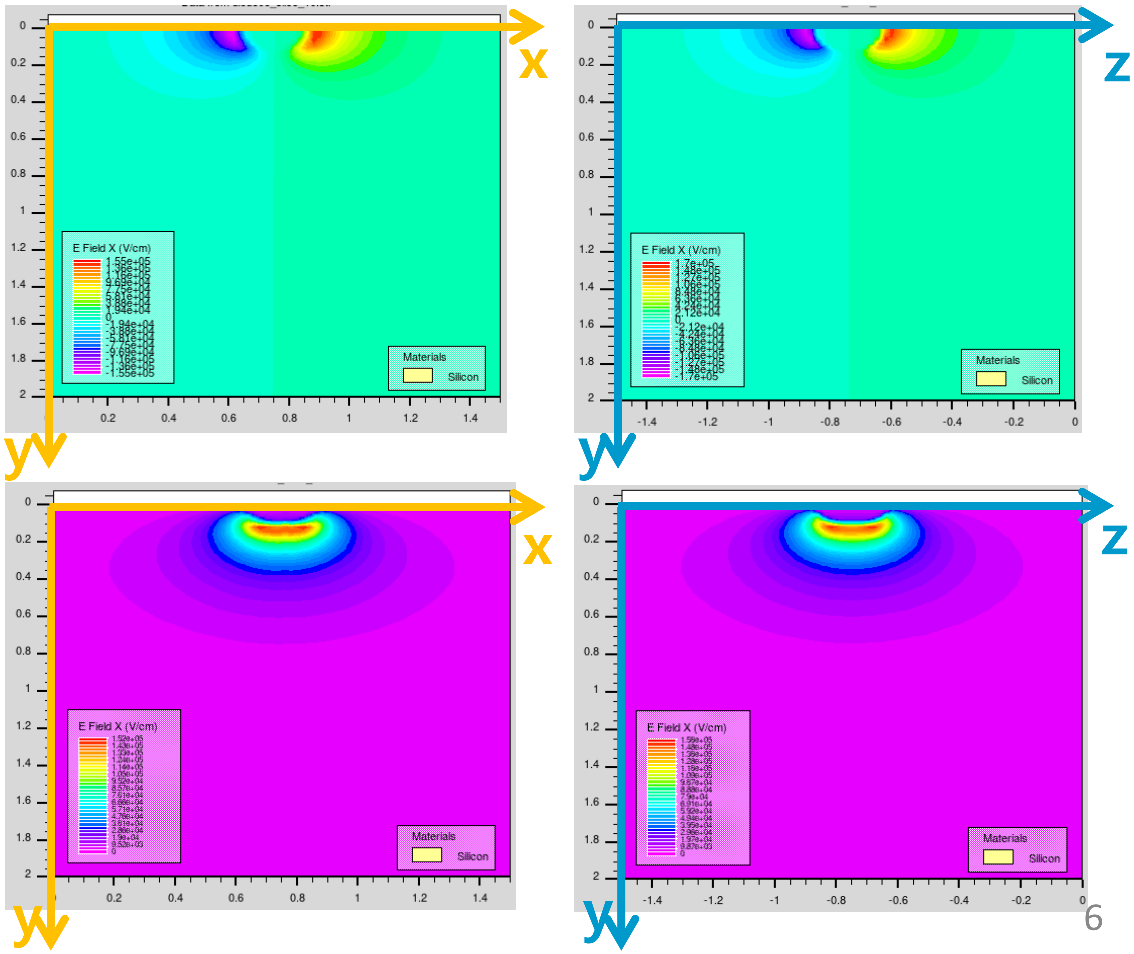
Silvaco TCAD : an example



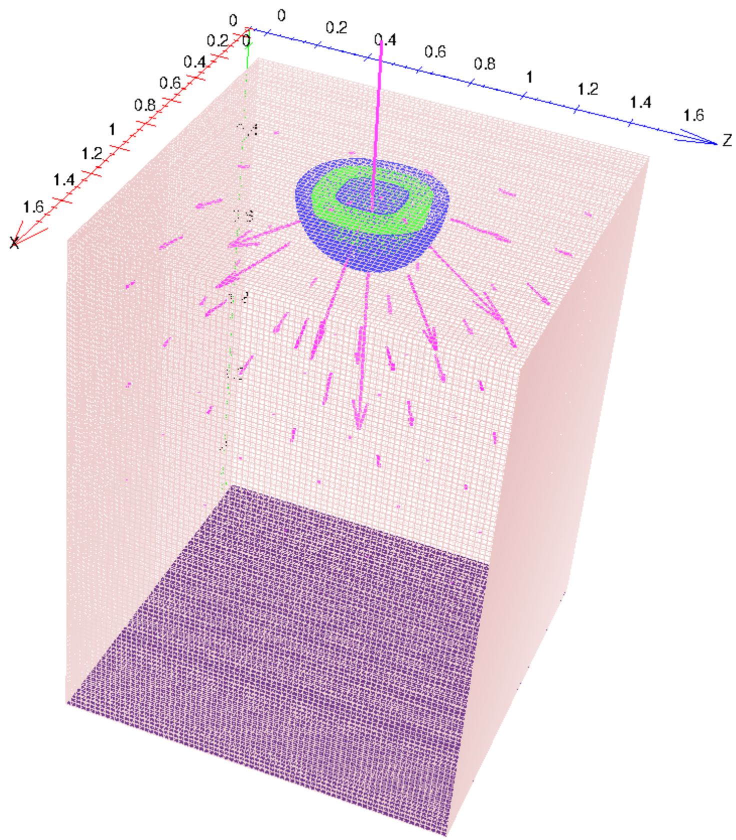
- Size(μm) :1.5×1.5×2.0
- Material
  - Silicon, Aluminum(Electrode)
- Doping concentration
  - n-type : 5e19
  - p-type : 1e15
- V(anode)=2.0V

Silvaco TCAD : an example : Efield



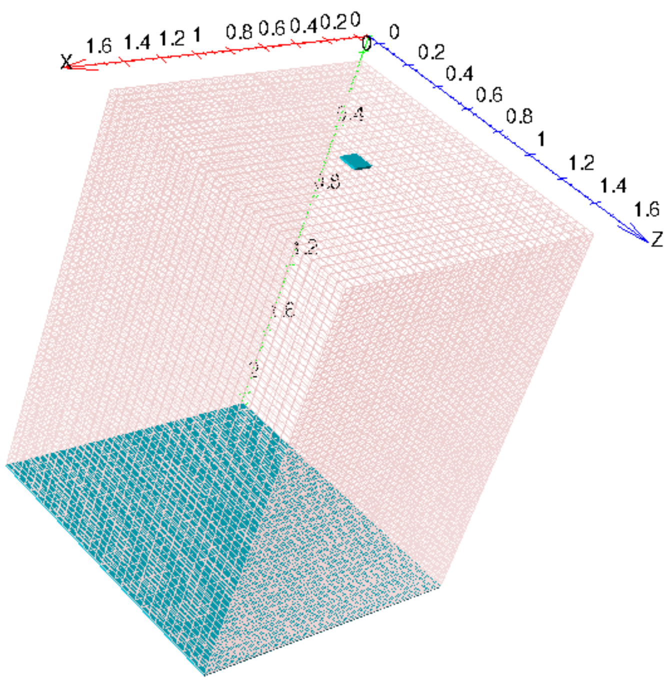


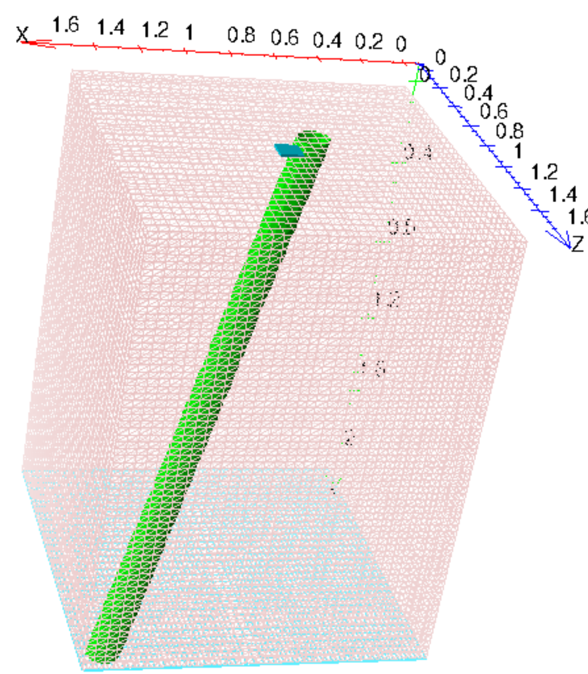
Silvaco TCAD : an example : Efield



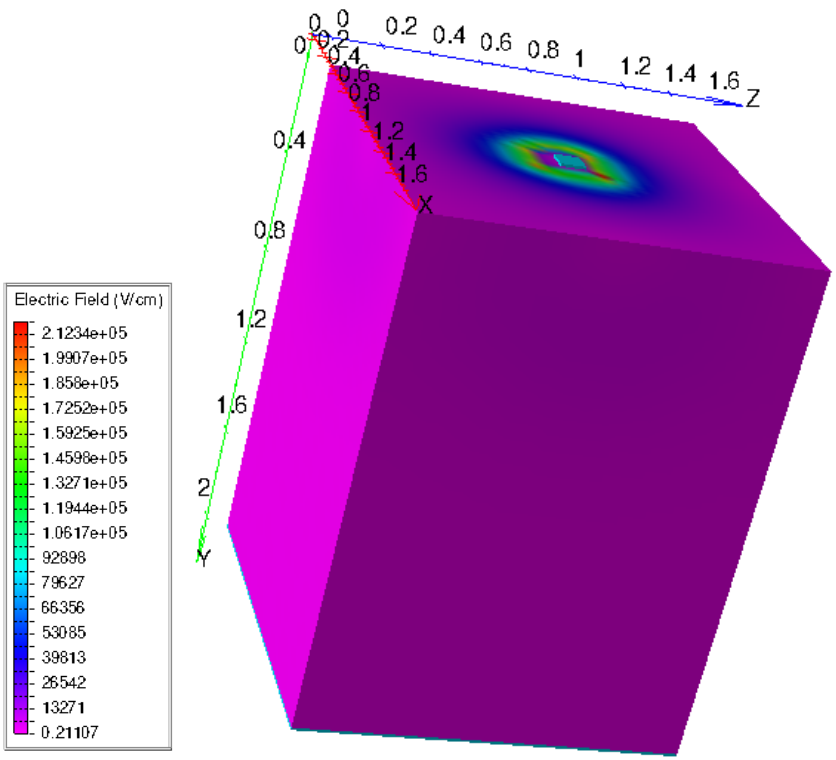
Silvaco TCAD : an example : SEU test

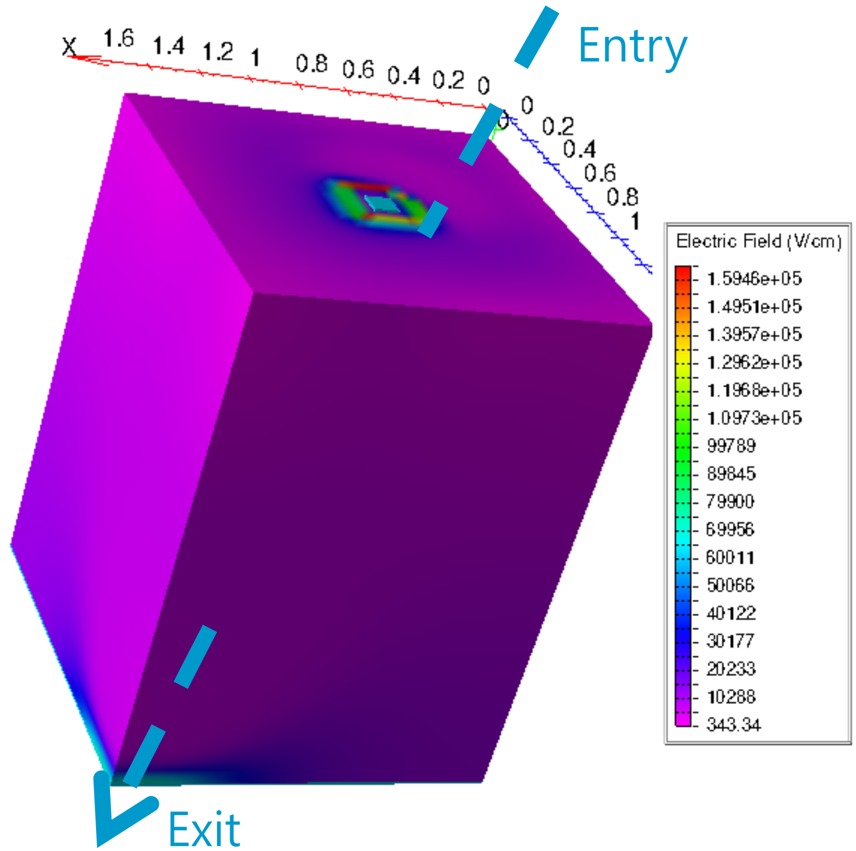
- SEU : a change of state caused by one single ionizing striking a sensitive node in a micro-electronic device
- Density : 1e18.   Radius : 0.05µm
- Entry : 0.6, 0.0, 0.6.   Exit : 1.4, 2.0, 1.4



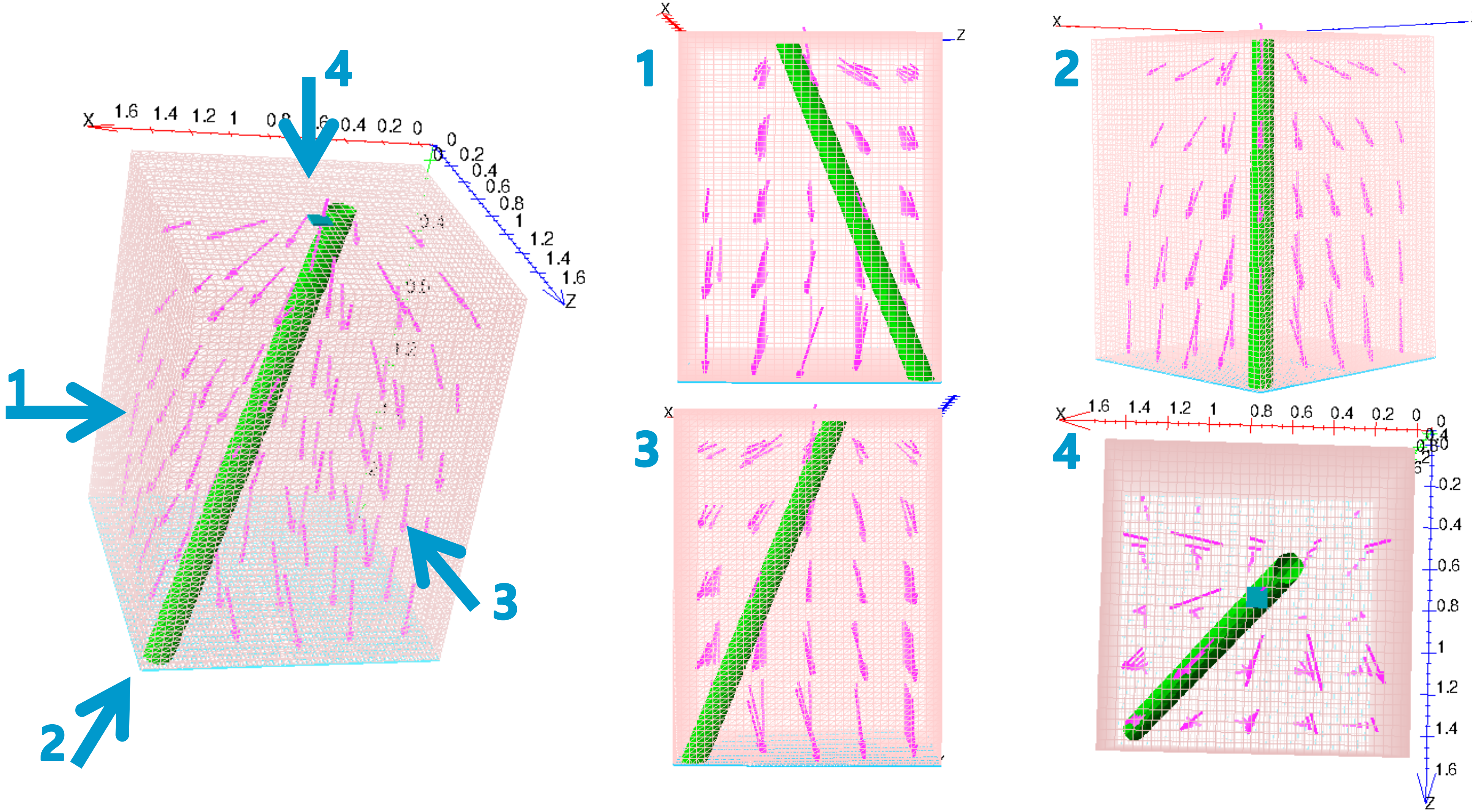


Silvaco TCAD : an example : Efield



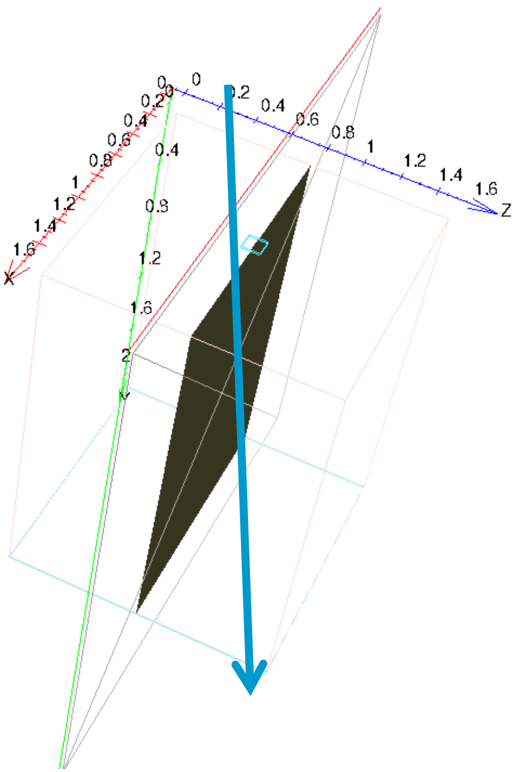


Silvaco TCAD : an example : Efield

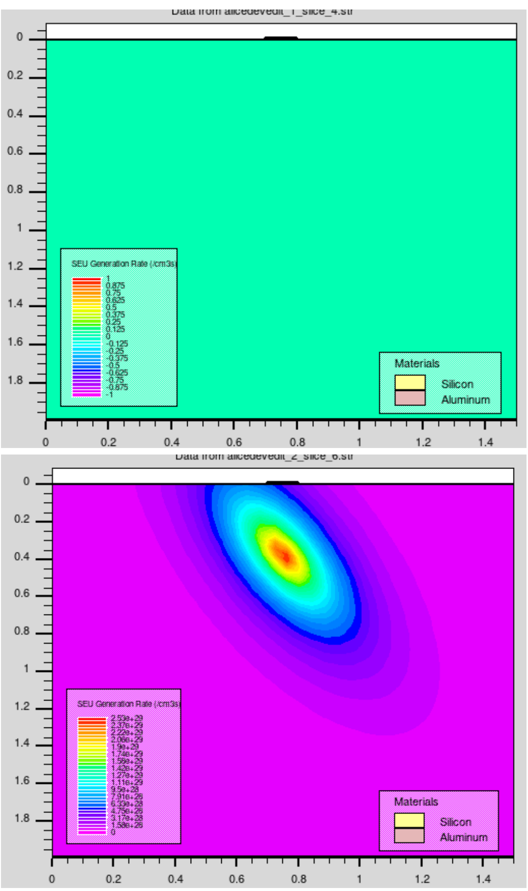


Silvaco TCAD : an example : Efield

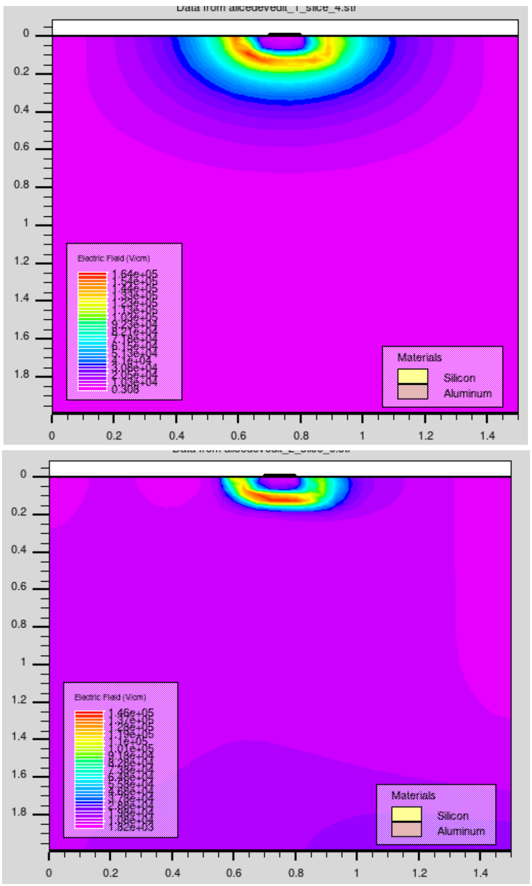
- X-Y plane (0.75)



SEU Generate rate



Electric field

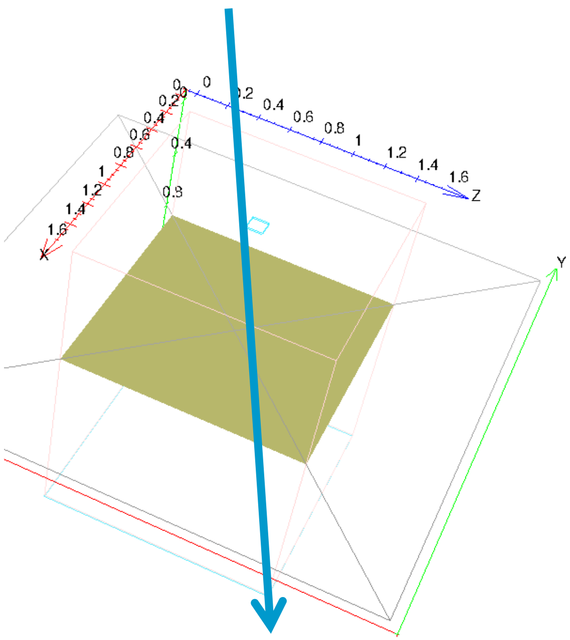


Before

After

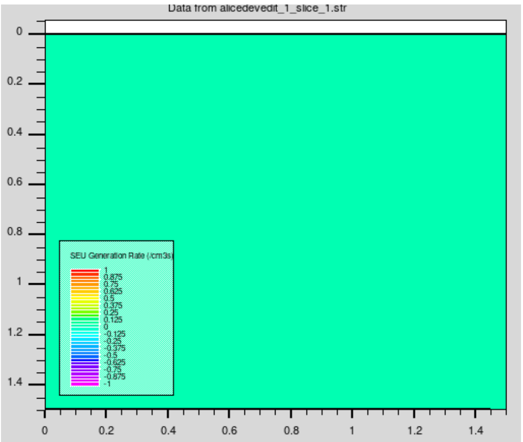
Silvaco TCAD : an example : Efield

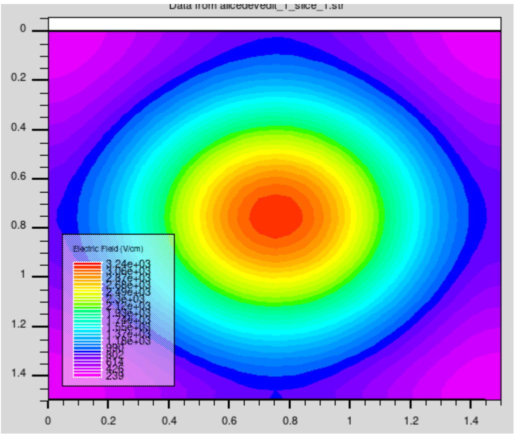
- X-Z plane (0.75)



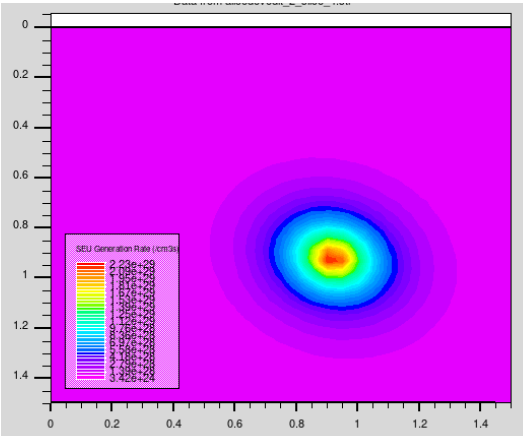
SEU Generate rate

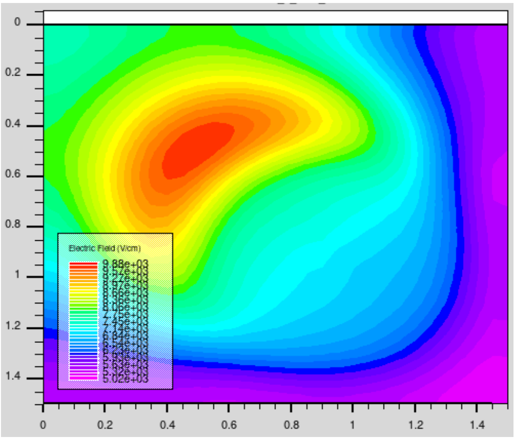
Electric field





Before

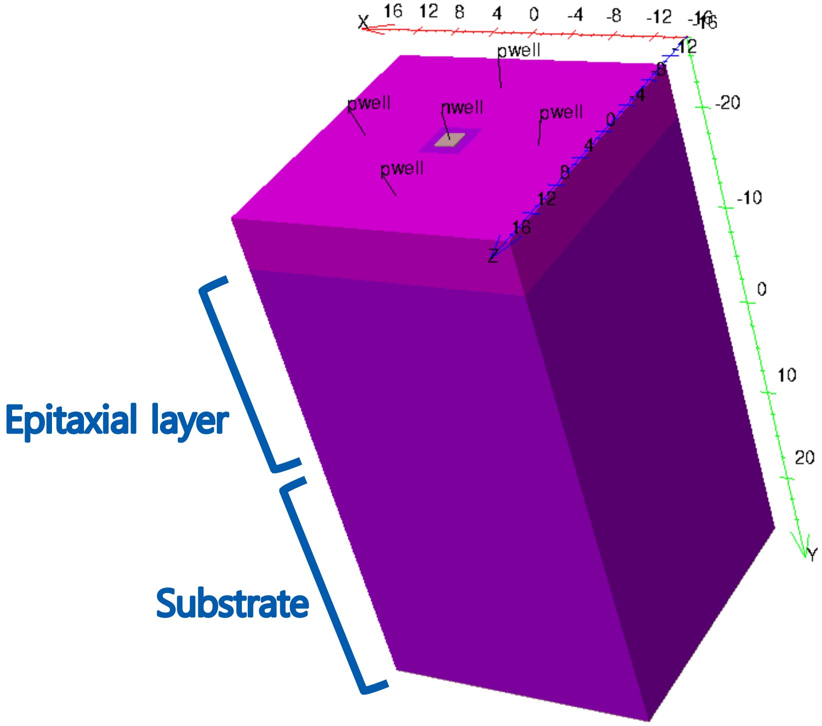




After

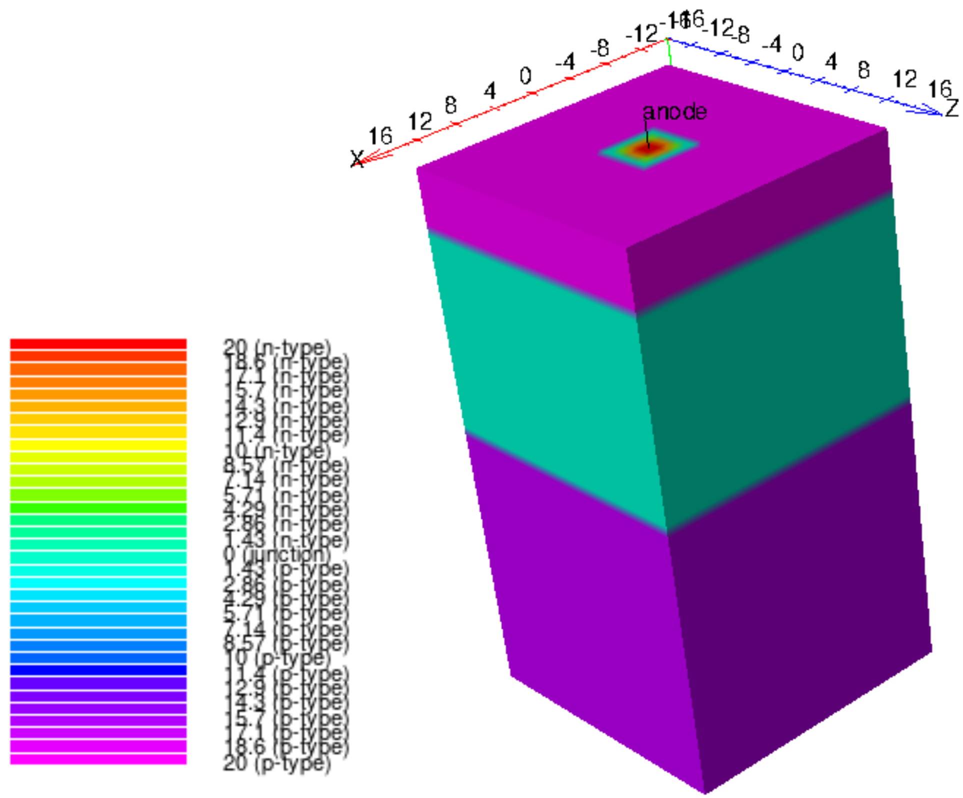
Test with ALPIDE design

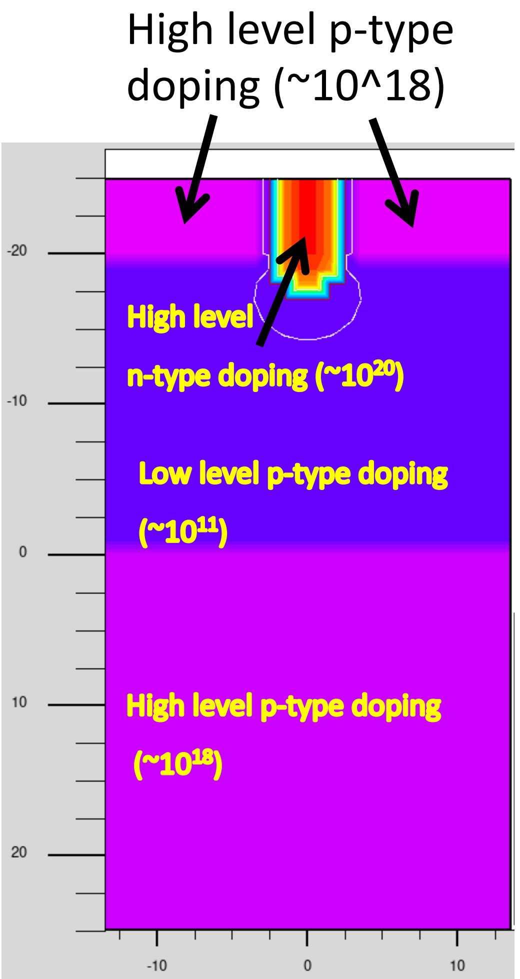
- 27x50x27 um
- Anode : 6V
- Resistivity of Epitaxial layer = 1kΩ



Test with ALPIDE design

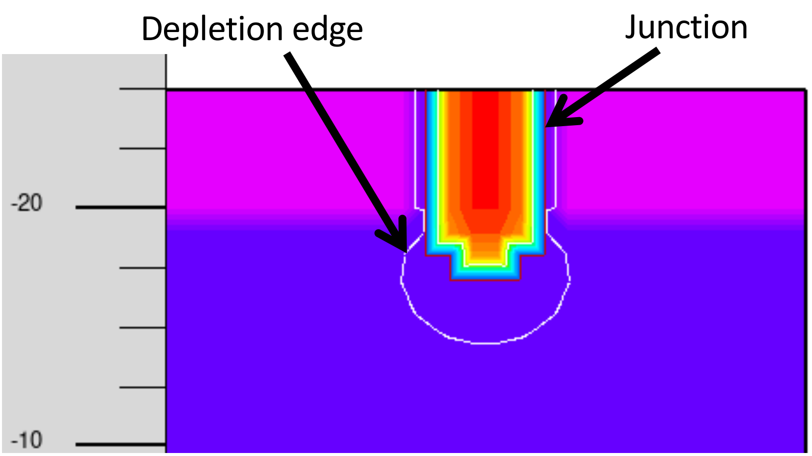
- Doping concentration



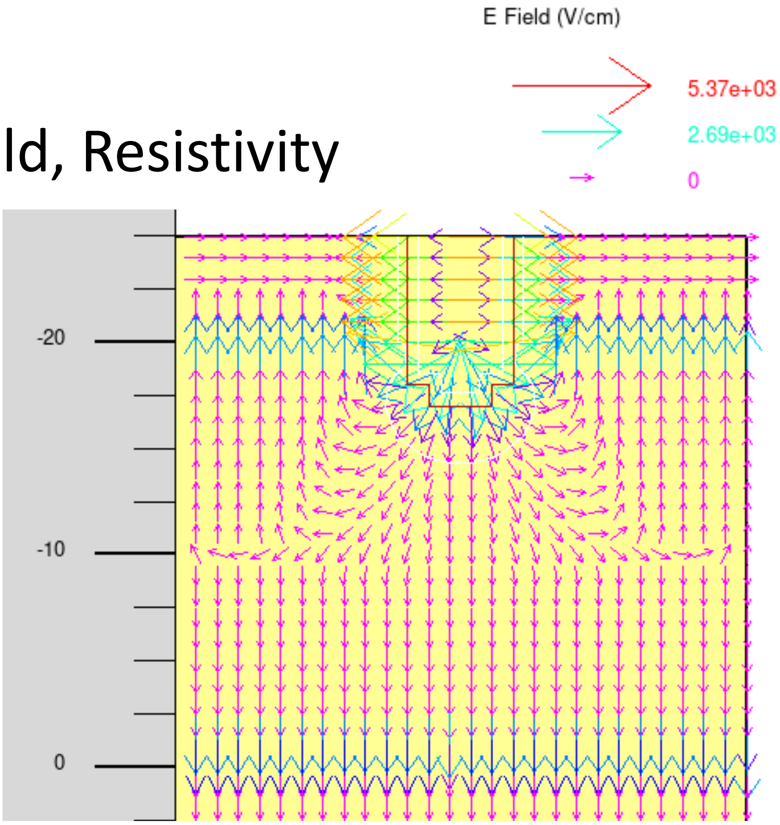


Test with ALPIDE design

- Doping Concentration and Electric field
  - Electric field, Depletion edge and Junction
- Current status
  - Obtained Efield plot
  - Working on extracting value of Efield, Resistivity



▲ Doping Concentration



▲ Electric Field

Garfield++ simulation

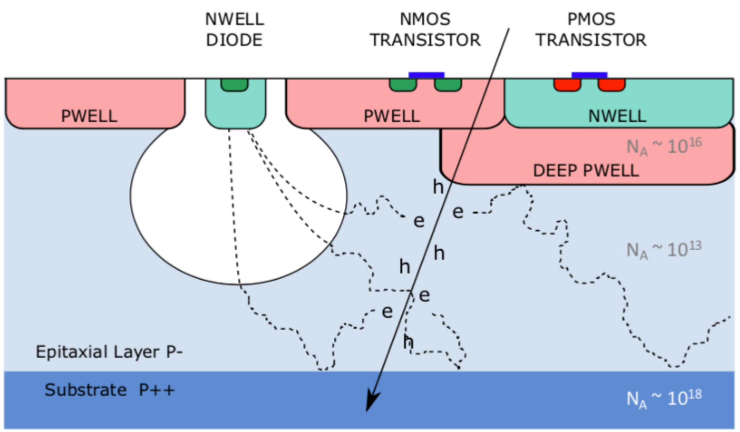
- History
  - originally written in Fortran by Rob Veenhof for gas detectors
  - ported to C++ by Heinrich Schindler
  - extended also for silicon detectors (still being developed)
- particle tracking
  - import of electric and weighting fields/potentials (TCAD, Ansys, etc .)
  - single point like electron hole pairs are tracked through the sensor using drift velocity and diffusion
  - induced current/charge is collected along the path
- charge collection time
  - defined as the time from 20% to 95% of the total induced charge
  - only on a sensor level without electronics

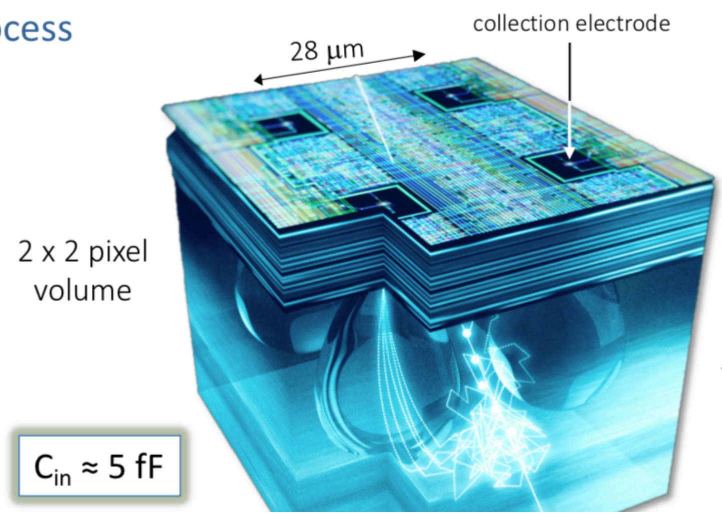
ALPIDE status and future development

- ALPIDE – process, dimensions, doping concentration
  - TowerJazz 180nm CMOS Imaging Process
  - 27x29µm pitch, 2µm n-well, 3µm spacing, 25µm epitaxial layer thickness
  - standard process with deep n/p-well with high resistive epitaxial layer
- switch to 65nm process node
  - smaller electronics in n/p-well free up space
  - shrinking the pixel pitch to 20µm, 15µm or even 10µm possible
  - shrinking the n-well for lower capacitance or more complex electronics within it
  - new combinations of n-well diameter and spacing possible
- no necessity of process modification for higher depletion
  - smaller pixel pitch or wider spacing could lead to stronger and more uniform de pletion
  - faster charge collection time and more radiation hardness

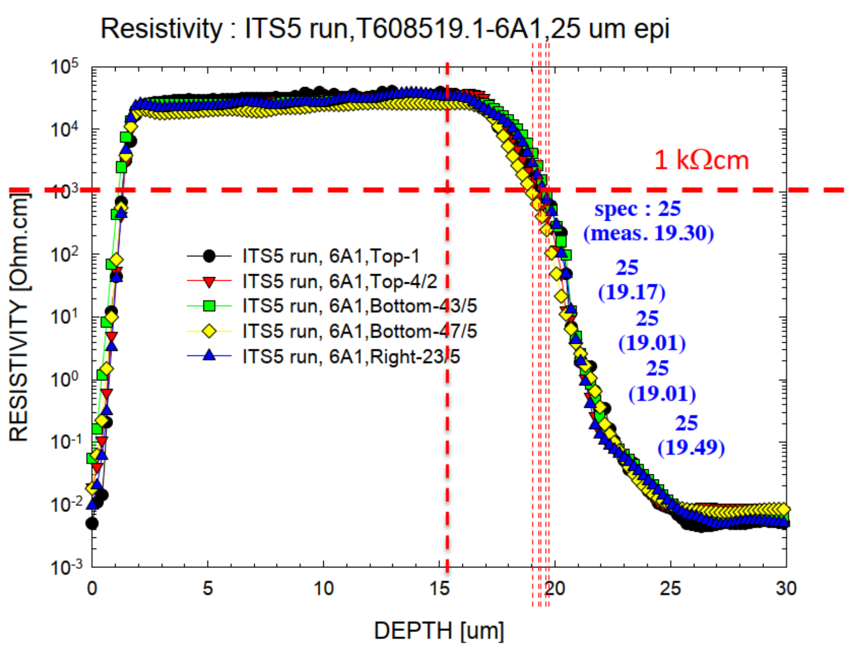
ALPIDE

CMOS Pixel Sensor using TJ 0.18µm CMOS Imaging Process

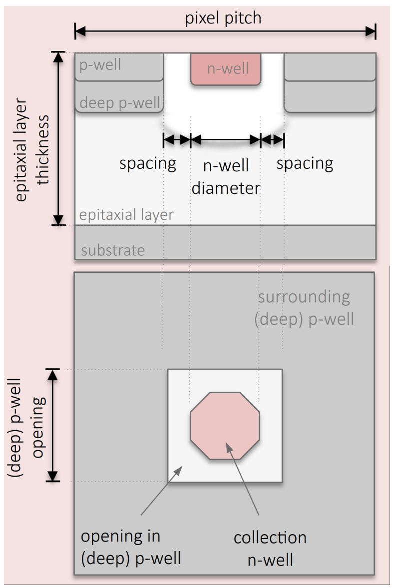




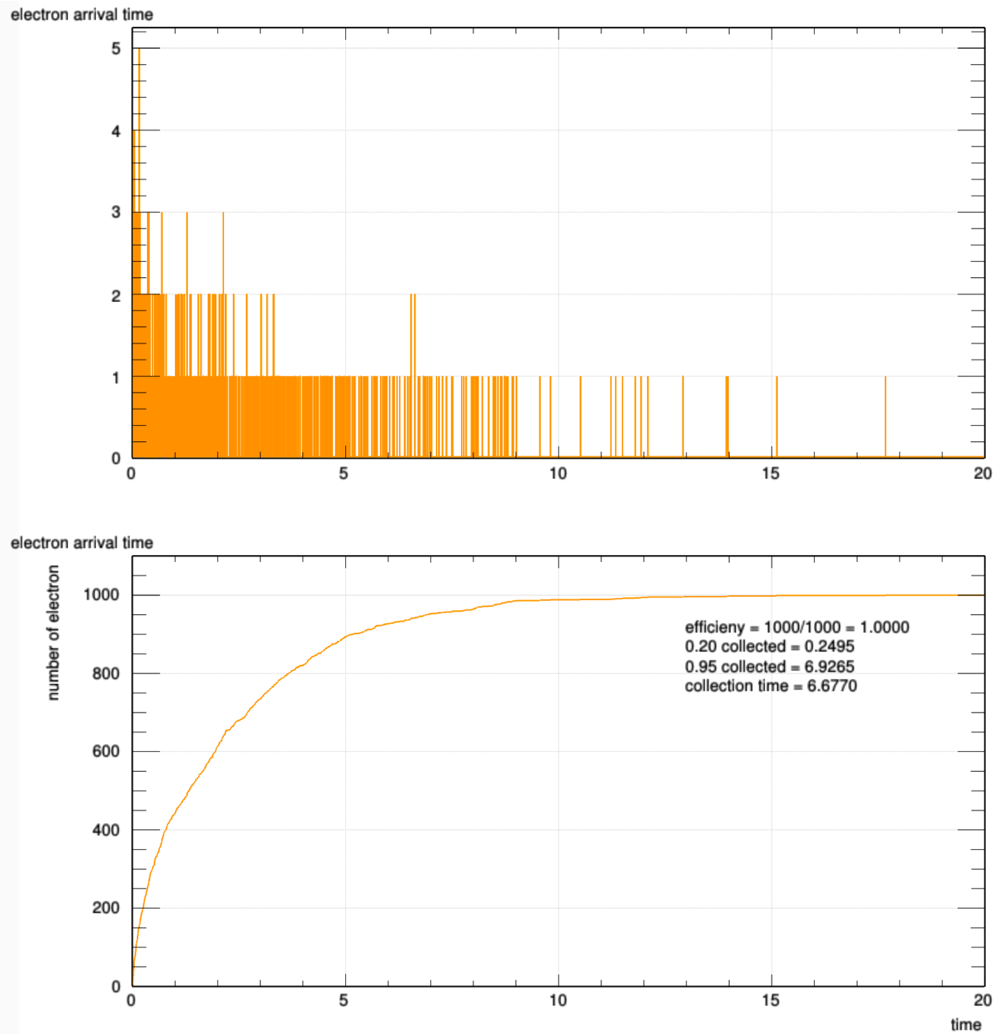
Artistic view of a SEM picture of ALPIDE cross section



Resistivity vs depth



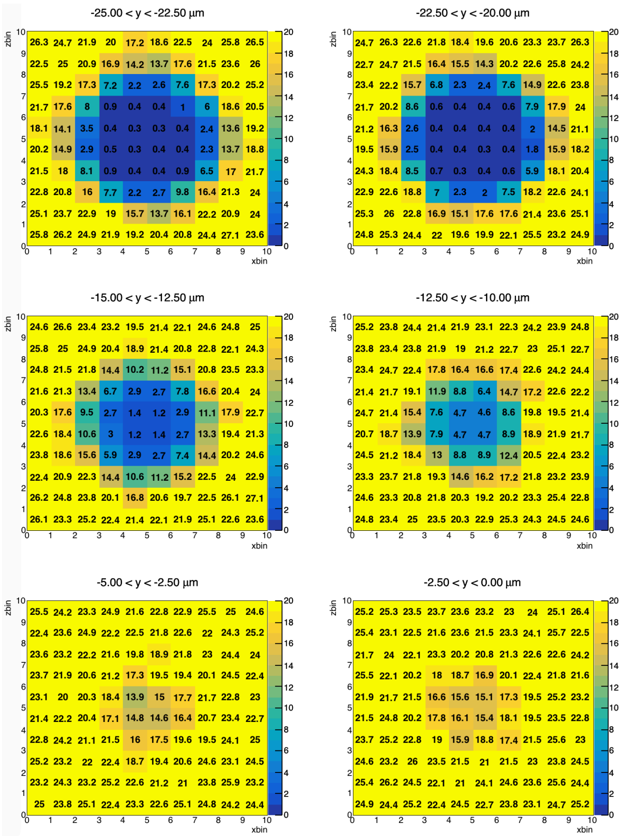
Charge collection time

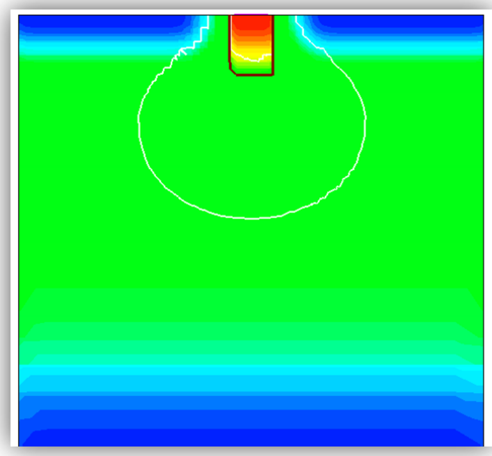


- Top : electron arrival time
- Bottom : cumulative
- Calculate 20%~95%
  - charge collection time
- 1000 electron located randomly in a pixel

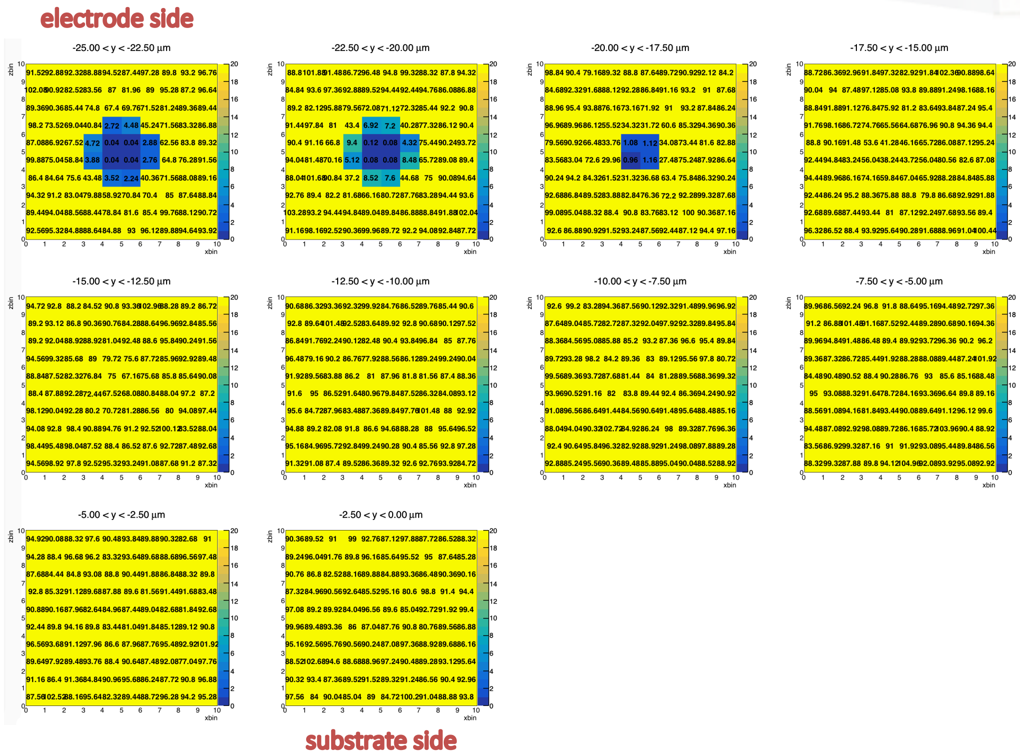
Charge collection time

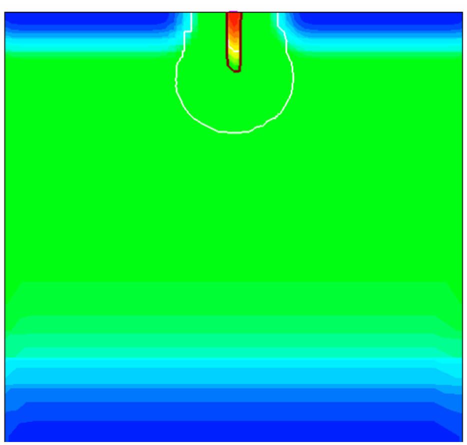
- 1000 electrons distributed randomly in a cell where a pixel has 10x10x10 cell s
- Efield from Synopsis TCAD
- Deep region shows slower charge collection time
- 27µm pitch - n-well 2µm, spacing 3µm, 6V back bias





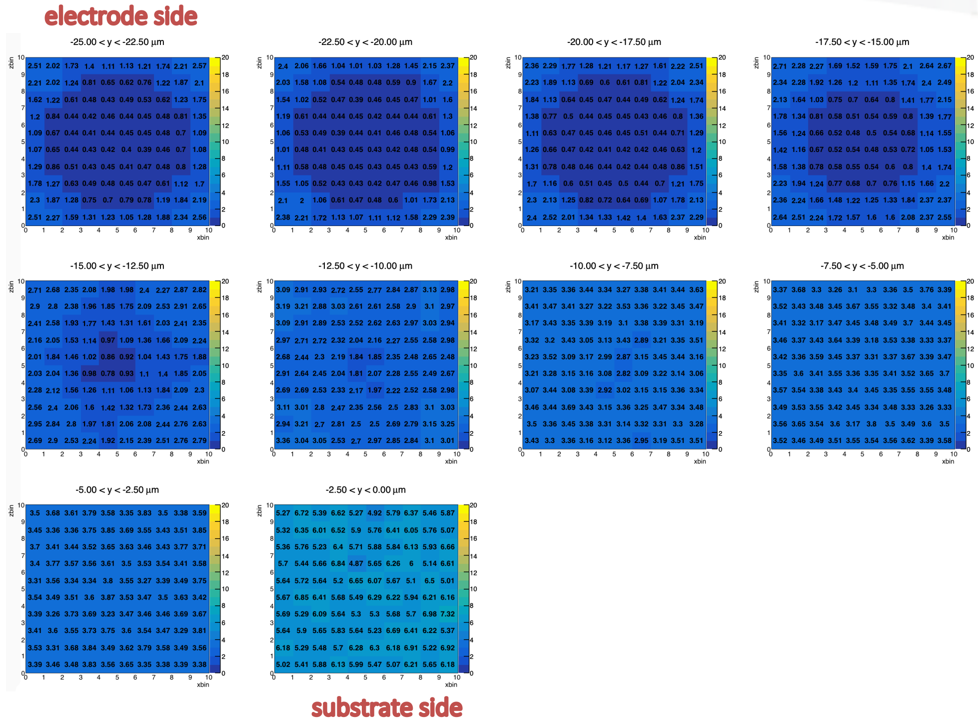
CCT n-well test 27μm pitch - n-well 0.5μm, spacing 3.75μm, 6V back bias

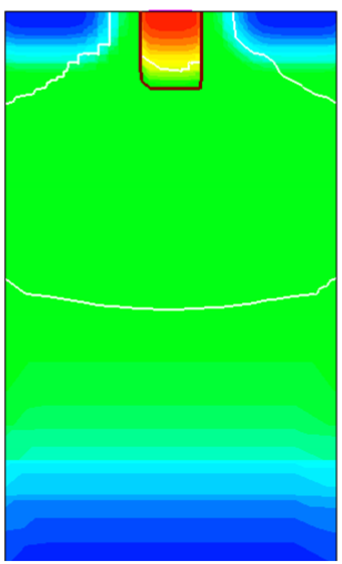




- Smaller n-well size

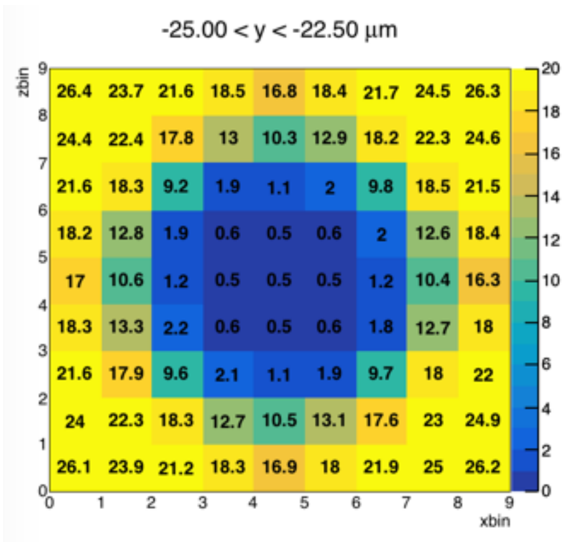
CCT n-well test 15μm pitch - n-well 2μm, spacing 3μm, 6V back bias

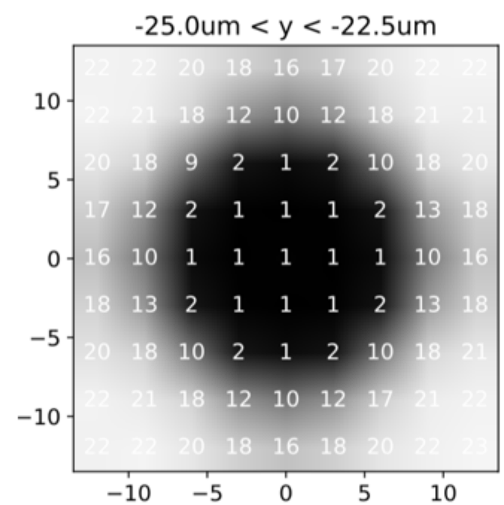




- smaller pixel size

Comparing two methods





Without weighting field　　　　With weighting field

- Two methods are consistent

- The Shockley–Ramo theorem allows one to easily calculate the instantaneous electri c current induced by a charge moving in the vicinity of an electrode
- $i = E_v qv$
  - q: charge v:velocity
  - E_v is the component of the electric field in the direction of v at the charge's instantaneou s position, under the following conditions: charge removed, given electrode raised to uni t potential, and all other conductors grounded.

Current status and plan

- Silivaco TCAD
  - Following current simulation with ALPIDE design
  - doping concentration looks reasonable
  - Obtained electric field plot
  - Plan
    - Extract the values
    - Compare resistivity
    - Once they turned out to be reasonable results, we can apply other geometry.
- Garfield++
  - two methods are consistent in terms of charge collection time
    - a reference to compare during development of simulation
  - Plan
    - Matching the simulation to the experimental results and once it works, perform studies on future geometries.

감사합니다

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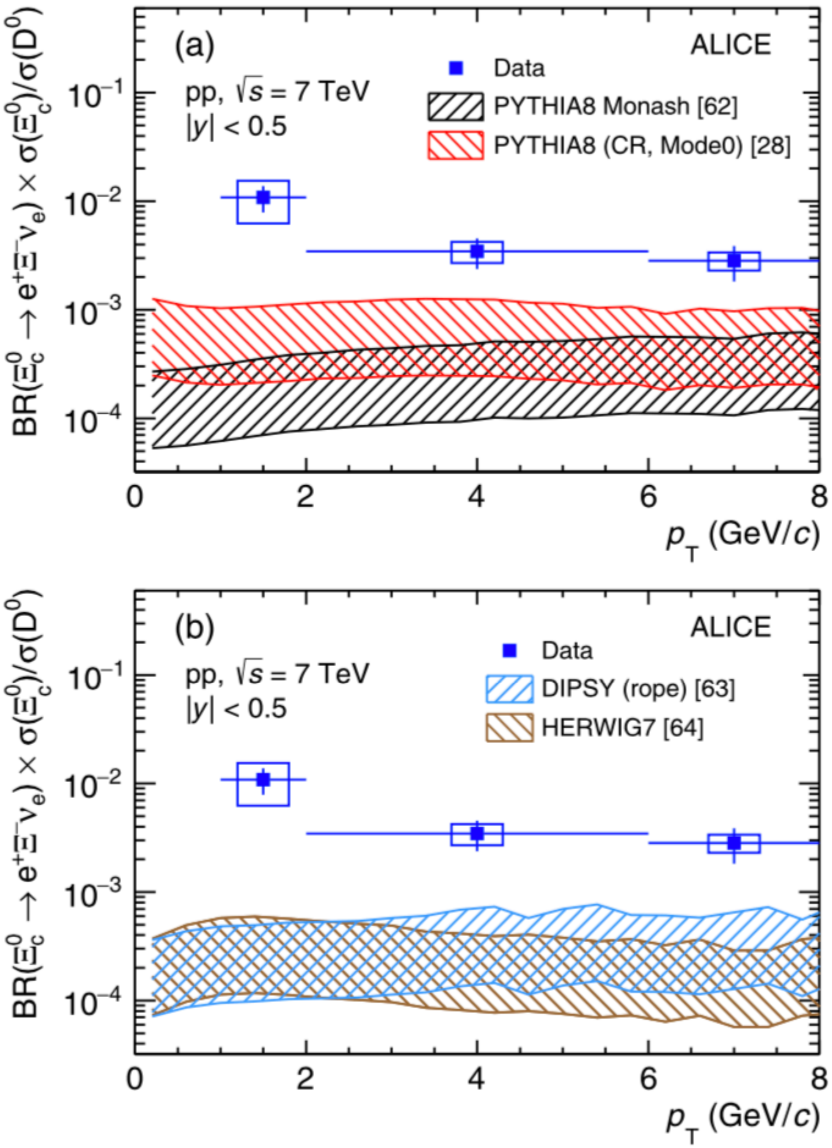
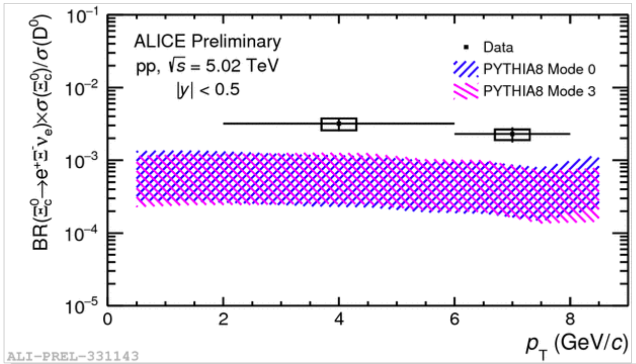
Backup : Activity in analysis : Xic0 in p+Pb

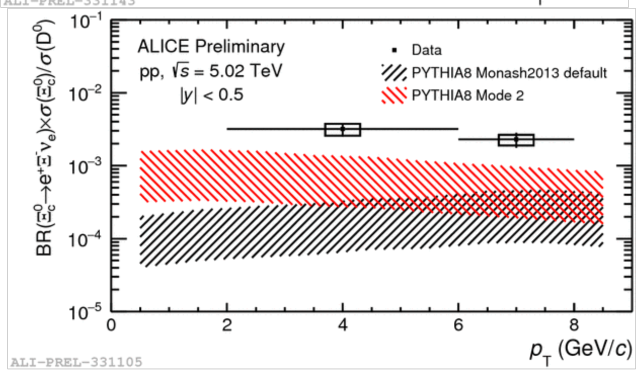
- Heavy quarks are
  - sensitive probes to study the Quark-Gluon Plasma in heavy-ion coll isions.
  - Due to their large masses, they are formed in initial hard scattering of parton before the timescale of QGP formation
    - →produced early in the collision, live long enough to sample QGP
  - experience the whole system evolution
- Baryon containing Heavy Quark
  - Charm-baryon measurements provide unique insight into hadroniz ation processes
  - Baryon-to-Meson ratio is expected to be higher in p+Pb and Pb+Pb
- Charmed baryon-to-meson ratio in p+p and p+Pb higher tha n than model calculations

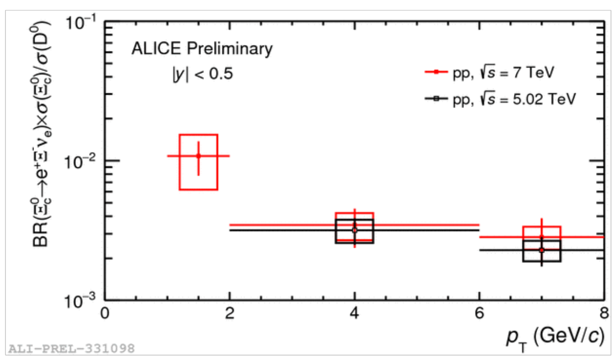
Ξ_c^0 / D^0

- Phys. Lett. B. 781 (2018) 8–19
- Theories underestimate it

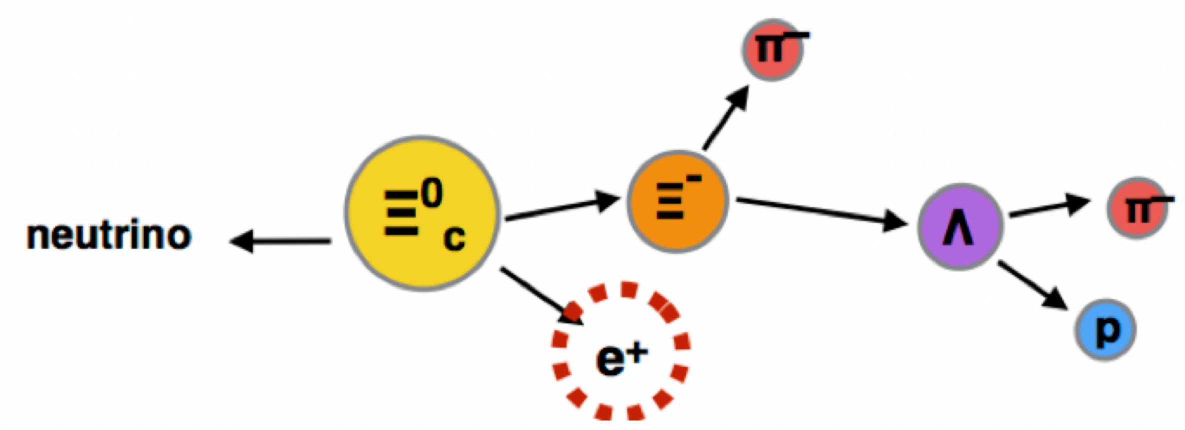








Studying Ξ_c^0 using semi-leptonic decay

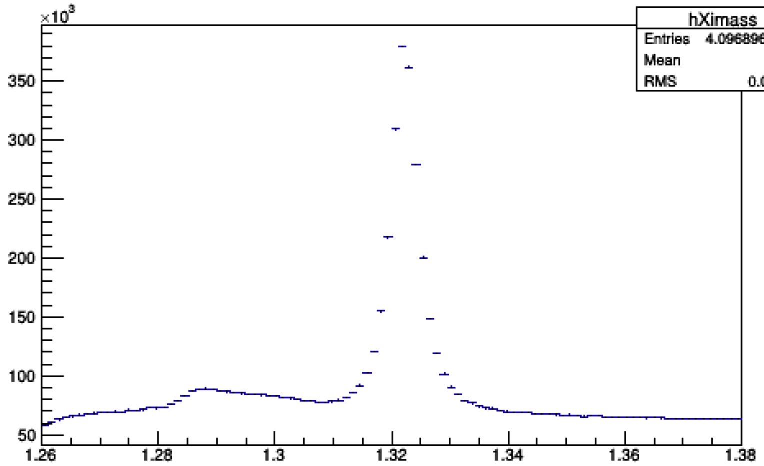


- Analysis procedure
  - Reconstruct Ξ-
  - Reconstruct electron
  - Subtract WS background
  - Unfold Ξ_c^0 pT spectra
- Dataset
  - p+Pb 5.02 TeV
  - Using LHC16q (32 runs) (LHC16t 4 runs)
  - MC : LHC17d2b_fast_new

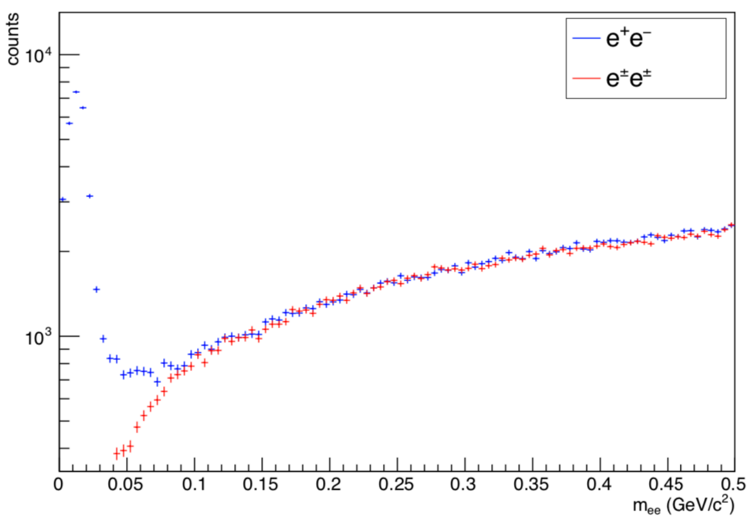
Hadronic decay channel:
$\Xi_c^0 \rightarrow \pi^+ \Xi^- \rightarrow \pi^+ \pi^- \Lambda \rightarrow \pi^+ \pi^- p \pi^-$

Backup : p+Pb plots

- Ξ- Mass

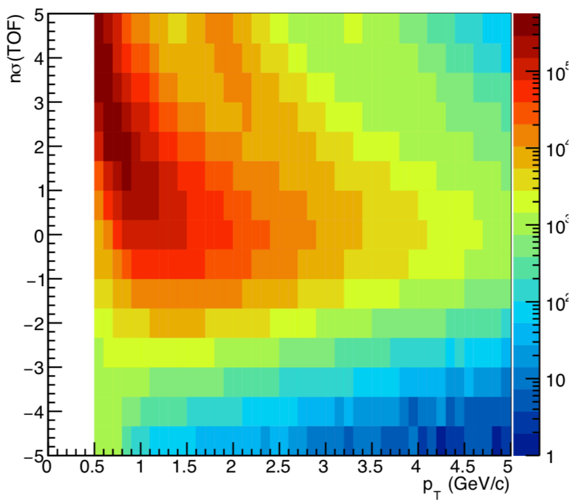


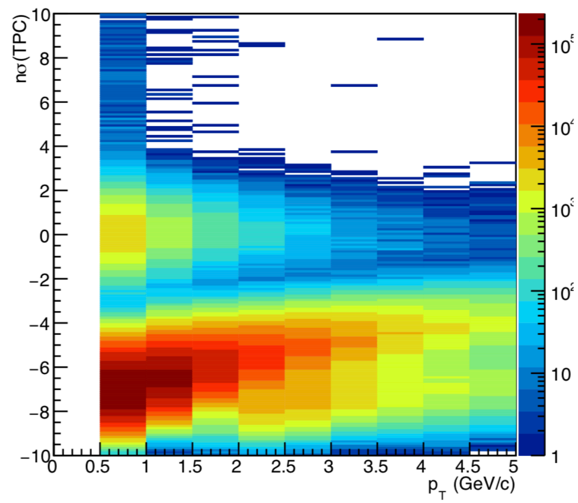
- Mass of Electron Pair



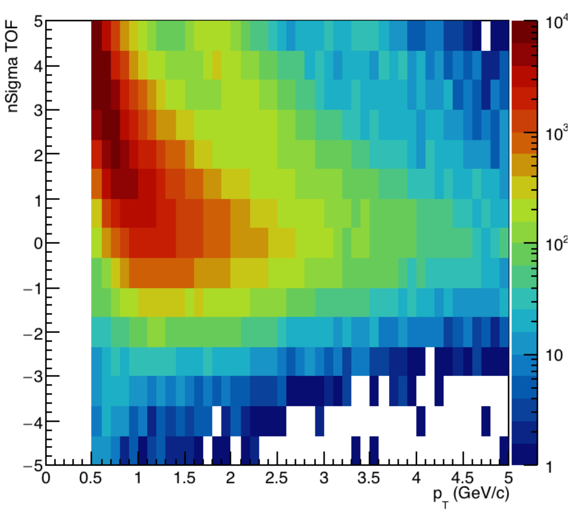
Backup : p+Pb plots

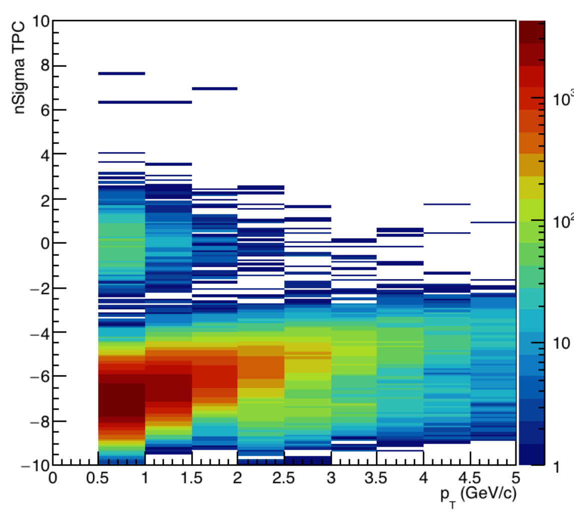
- Nsigma (TOF), nsigma (TPC) p+Pb 5 TeV





- p+p 13 TeV LHC16l





Weighting Field

- Ramo's theorem predicts the result of electrostatic inductio n produced by the moving charge in an arbitrary system of c onductive electrodes placed in a non-conductive medium.
- The charge q_0 generated by incident particles and drifting in the medium induces the current $i_i(t)$ on any electrode as

$$\mathrm{i}_i(t) = q_0 \vec{v}_{\mathrm{dr}}(t) \vec{E}_i^*(t)$$

  - where v_{dr} is the drift velocity and E_i* the weighting electric field, Δ Q the change of the charge Q induced on the readout electrode, a nd Δϕ∗ the change of the weighting potential ϕ∗
  - The weighting field is defined in the Ramo's theorem as the electri c field created by the unit potential (V ∗ = 1) applied to the readou t electrode while all the other electrodes of the device remain gro unded (V ∗ = 0)