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Status of ATLAS Pixel Test beam simulation

Status of the validation studies with test-beam data of the Geant4 simulation and Pixel digitization code in ATHENA

Simulation 1

- I am currently playing with two Geant4 simulations of the pixel test beam.
- The goal of the first simulation is to validate the code which will be used for the ATLAS detector simulation, so that code was used as much as possible.
- The simulation runs within the ATHENA framework, using the same SensitiveDetector class, hit definition, pixel module layout and digitization classes used for the ATLAS simulation. Only the geometry is different.
- Currently working with ATLAS release 6.4.0 (Geant 4.5.1.ref02)
- No simulation of radiation damage yet
- Only the geometry (material) of the Test Beam tracking system is described

Data set, parameters

- Comparison with a not-irradiated detector (production sensor + first version of rad-hard electronics chip, FE-I1) without magnetic field
- Accept 16 consecutive LVL1 triggers (no in-time requirement applied)

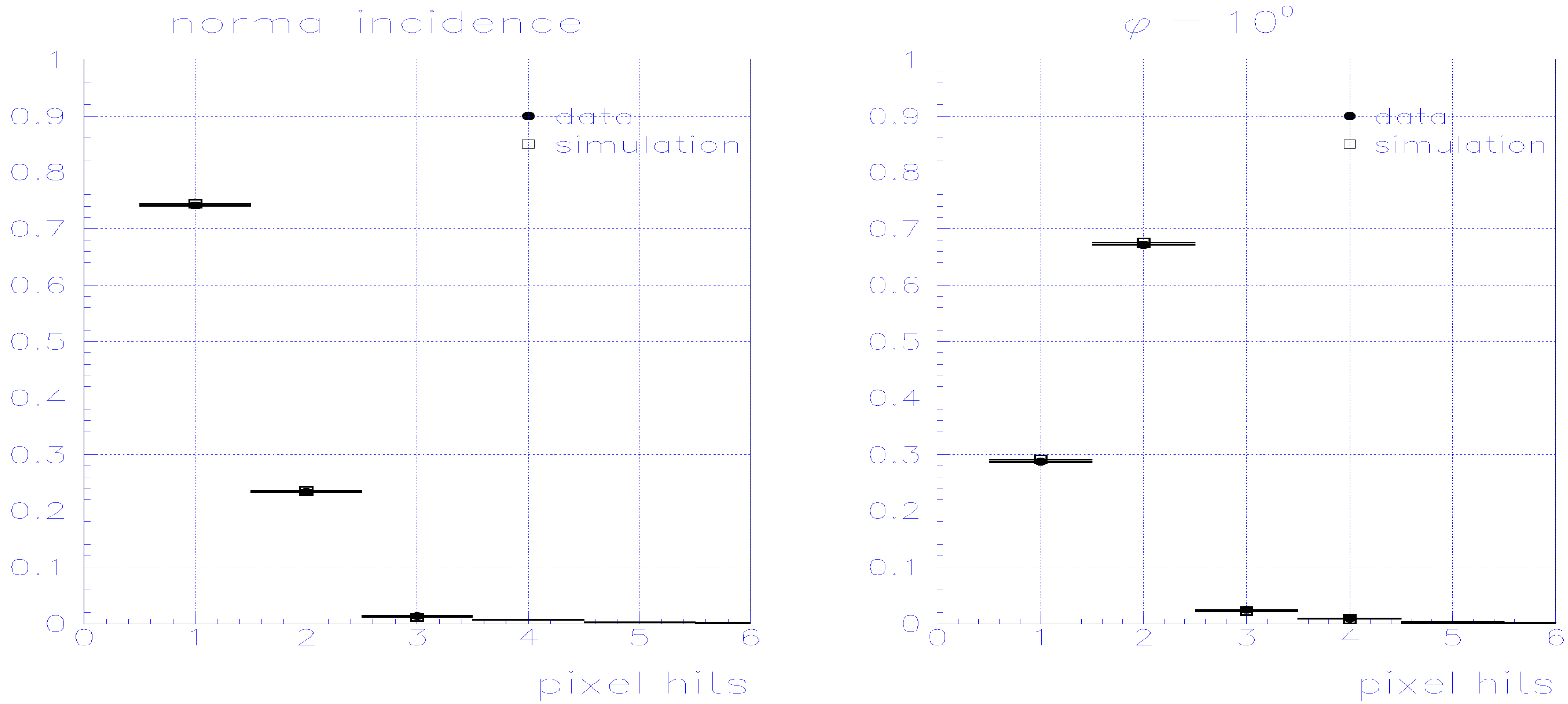
Tilt Angles = 0^0 to 30^0 in Rϕ, 0^0 in zR

Threshold = (3000 ± 10%) e, Thresh. dispersion = 100 e, Noise = 270 e

Thickness = (257 ± 3) μm

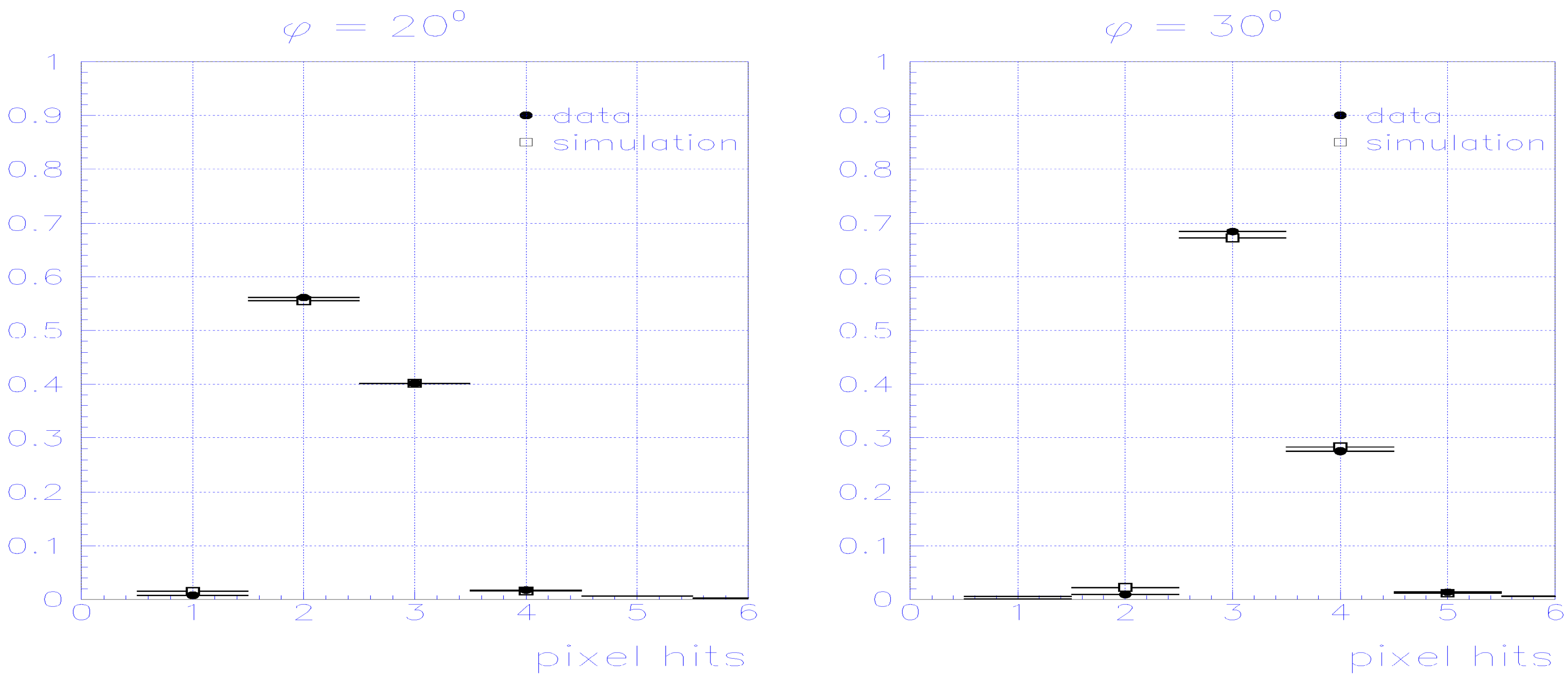
- Using thickness = 260 μm and threshold = 2700 e in simulation (is consistent with measured values and give better agreement with data)
- G4 parameters: ExN04PhysicsList, DefaultPhysicsCut = 5 μm, 5 steps in silicon sensor

Cluster size comparison



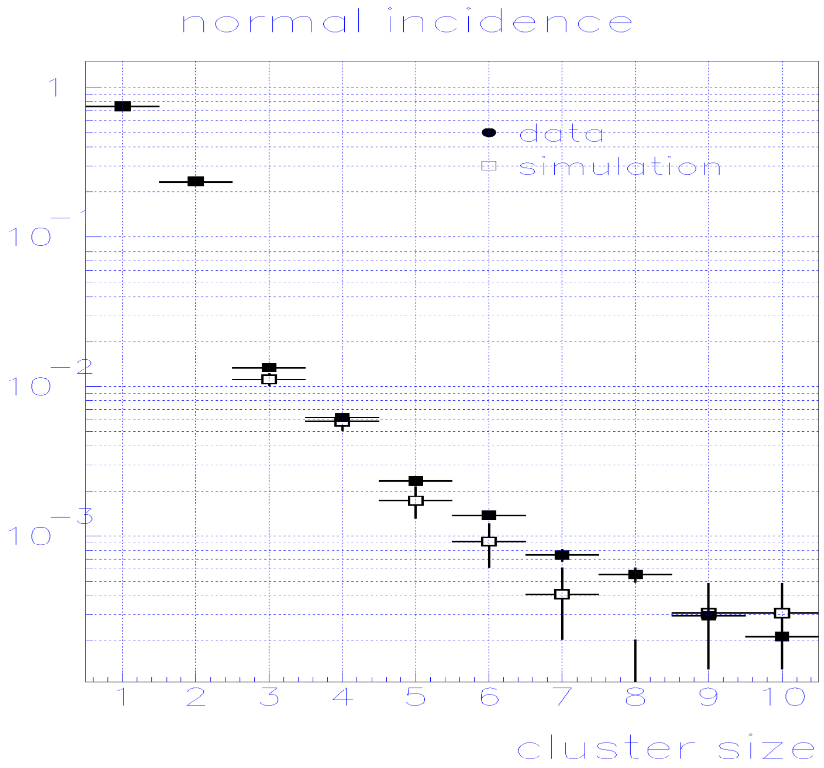
Very good agreement at 0^0 and 10^0

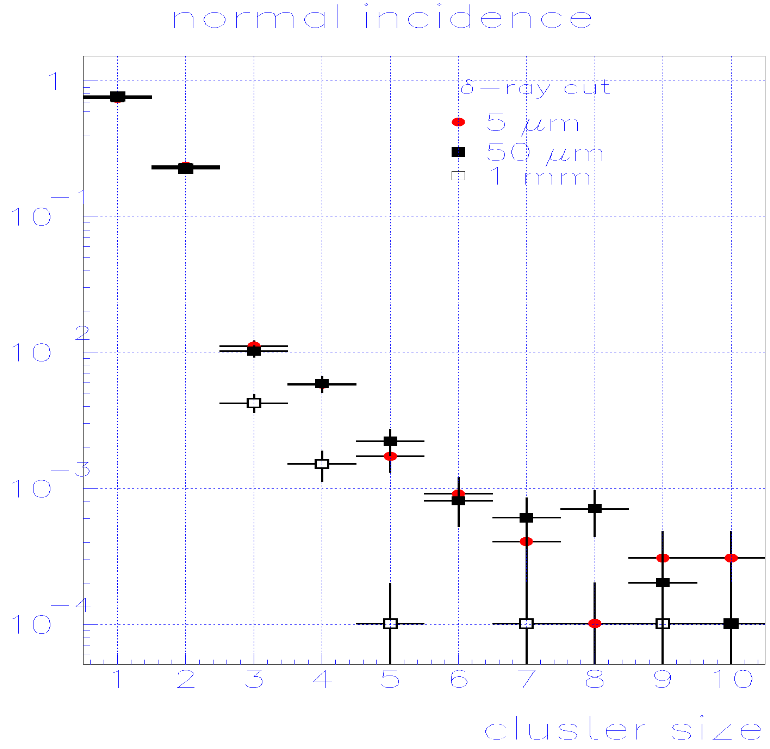
Cluster size comparison



Very good agreement at 20^0 and 30^0

δ Rays simulation





- Log-scale plots show a somewhat low number of simulated knock-out electrons. The process range cut can be as large as 50 μm

Pixel ToT

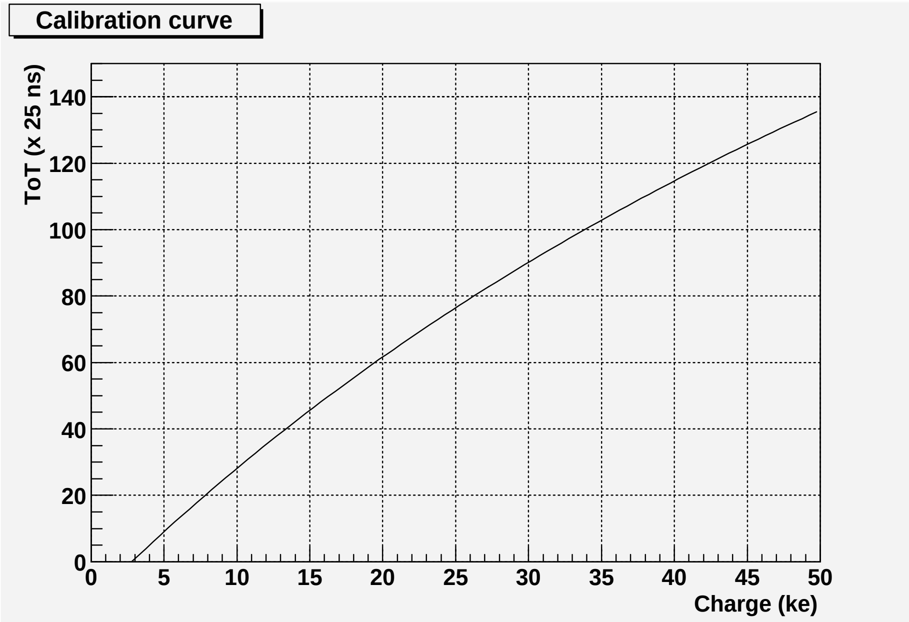
Simulation

- The charge collected by a pixel is converted to an integer (Time over Threshold of the signal, in bunch crossing units) according to a calibration curve (the same for all pixels, settable via jobOptions)
- A gaussian smearing can be applied to simulated ToT
- Final ToT (plus random between 0 and 1) converted back to charge to compare with calibrated data

Measurement

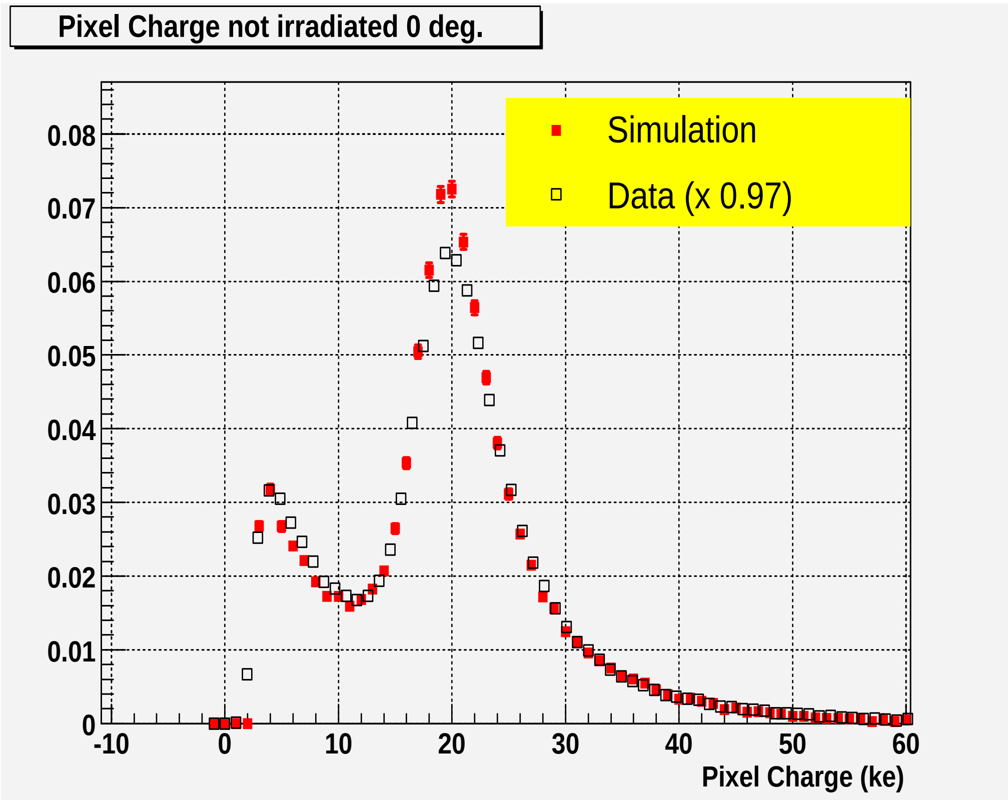
- The ToT is converted to a charge according to calibration curves determined separately for each pixel.
- There is an uncertainty of the order of 10% on the absolute scale provided by calibrations

Calibration Curve



- This is how the average calibration curve looks like for the pixel detector under study (note the 3 ke threshold, and the good linearity)
- ToT = A/(Q+B)+C   (A < 0)

Pixel Charge distribution



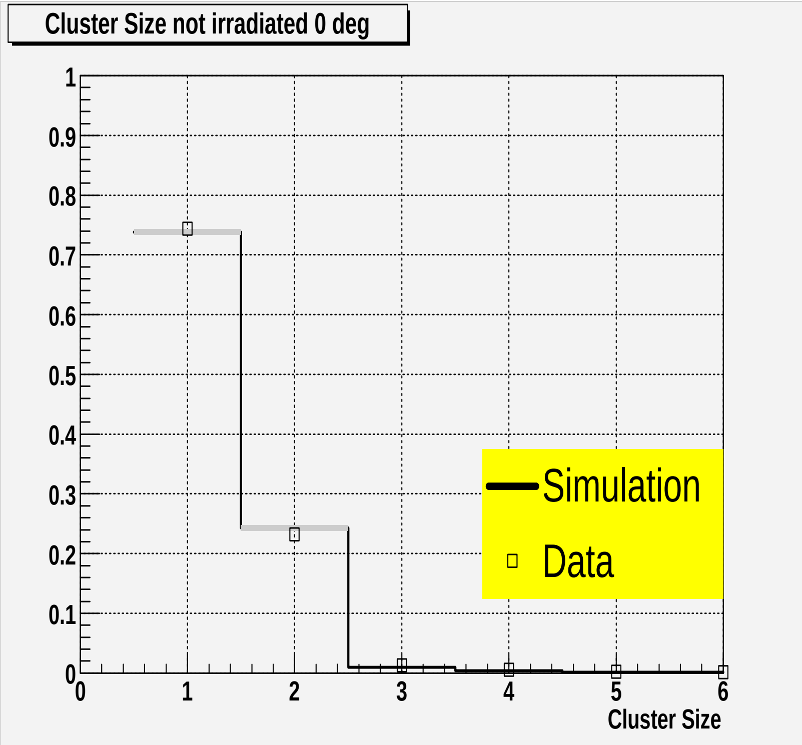
- Here, no ToT smearing was used - the simulated charge is basically the MC truth (the error associated to ToT digitization, i.e. the conversion to an integer, is small).
- Good agreement with measured charge (with 0.95 scale factor,within calibrations uncertainty)
- Some ToT smearing still needed.

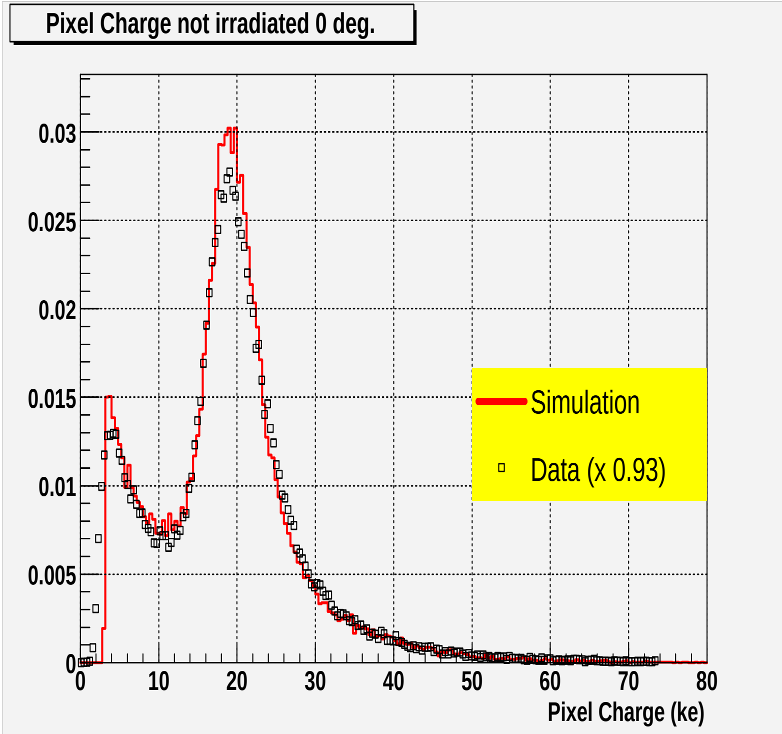
Simulation2

- The second simulation is a stand-alone package, pre-dating the ATHENA simulation, intended to provide a detailed description of charge drift in silicon and radiation damage effects
- Follows charge drift in silicon step-by-step, simulates diffusion, charge trapping from radiation-induced defects, signal induction on the pixel electrodes from a moving charge which can be trapped before reaching the pixels
- Consumes CPU! ATHENA simulation must use fast parameterizations but the detailed simulation can be provide guidance to develop them (and a cross-check…)
- Documented in ATL-INDET-2003-015
- Used to measure charge trapping constants in silicon from comparison with test-beam data (ATL-INDET-2003-014).
- Uses Geant4.5.0

Sim2: not irradiated detectors

- Very much the same results obtained later with ATHENA simulation

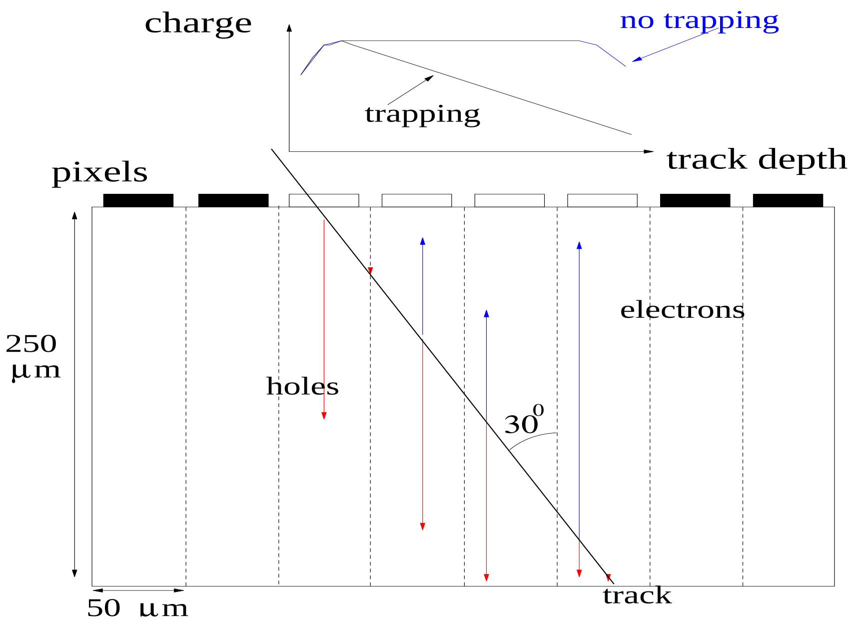


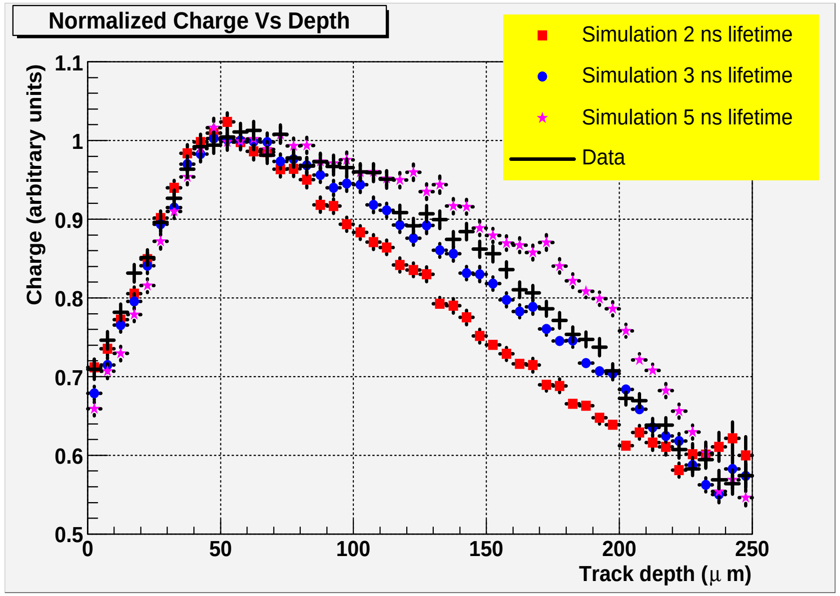


irradiated detectors

- Comparison with detectors (sensor+electronics) irradiated to the maximum ATLAS fluence/dose
- Good agreement simulation/data using full depletion (charge is collected from whole silicon thickness) and 3.5 ns electron/hole lifetime before trapping (2-300 μm mean free path)
- The lifetime can be extracted by comparing the simulation with test-beam distribution (next slide). This was the purpose of the detailed description of charge drift processes in irradiated silicon.

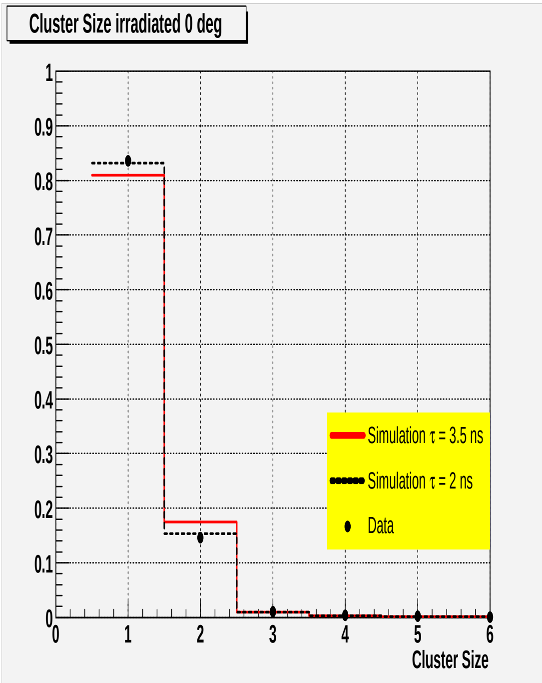
Charge trapping measurement

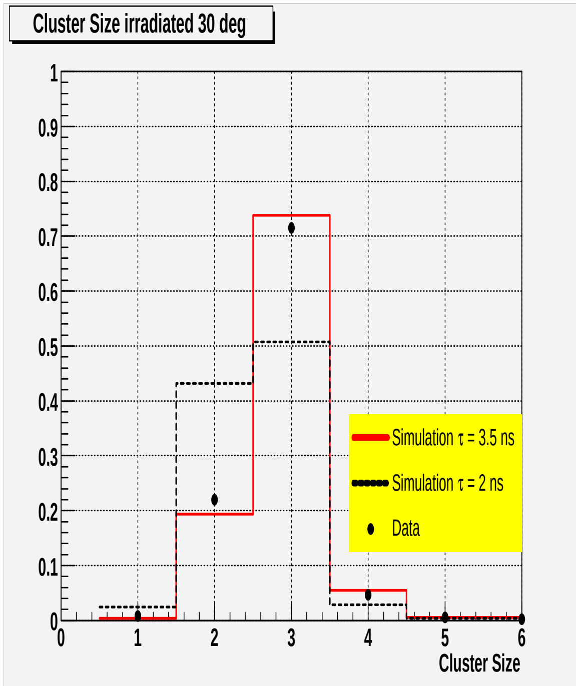


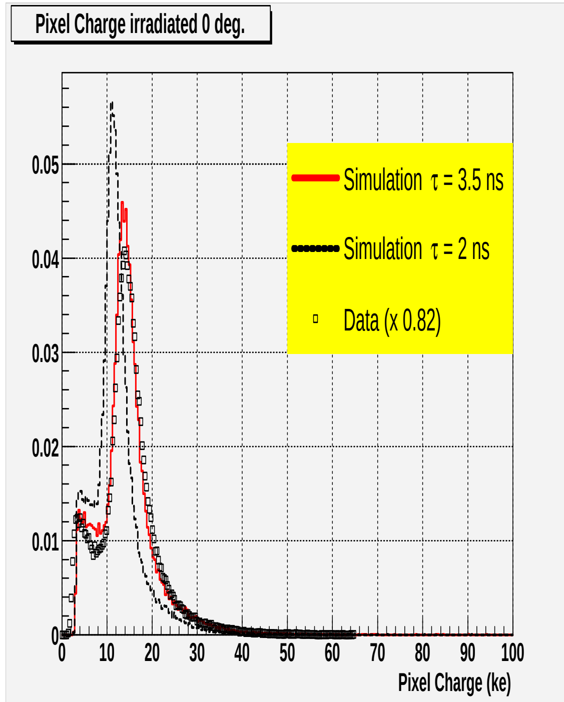


Data are taken with non-zero incidence angle. In irradiated detectors the pixel charge decreases as the depth of the track segment under the pixel increases, because of finite charge Lifetime. Lifetime can be obtained by comparison with data.

Irradiated normal incidence

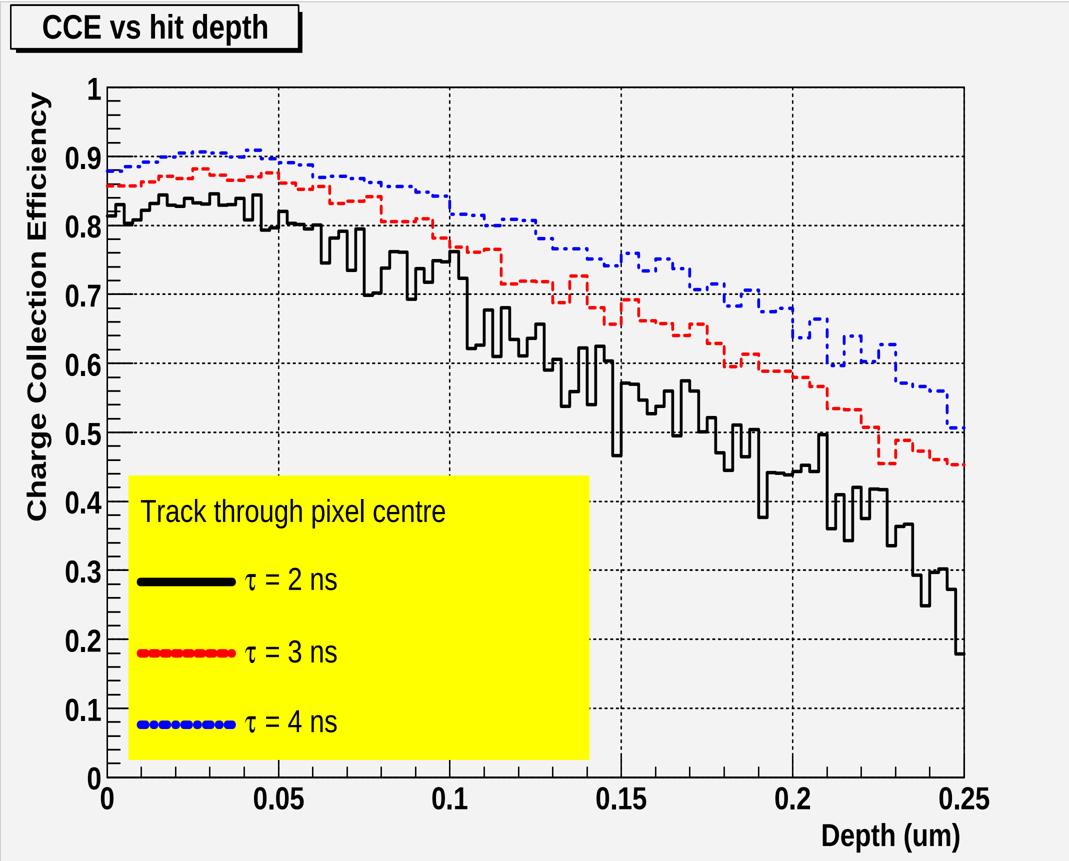






- The simulation can reproduce the cluster size and charge of irradiated detectors, after fitting radiation damage parameters (lifetime and depletion) on other experimental distributions

Charge Collection efficiency



- For ATLAS simulation, use parameterization of charge collection efficiency as a function of depth in the sensor?
- Lifetime as a theoretical function of fluence and temperature (radiation defects thermal annealing) or fitted from data
- Will probably end up in the conditions DB.

Conclusions

- Validation of the ATLAS Pixel Geant4 Simulation and Digitization against test-beam data has started
- First results on hit multiplicity and pixel charge show a good agreement with data (G4 seems ok for mips interactions in silicon detectors)
- To do: timing studies, data with new FE-I2 (FE-I3) electronics chip, radiation effects, magnetic field (more digitization than simulation however)
- Compare with Geant3 (energy deposited in silicon is in good agreement – see talk of A. Salzburger at semptember software week).
- A stand-alone simulation is available which describes both not-irradiated and irradiated detectors. It is too detailed for use in ATLAS, but can be used to derive parameterisations (for example, of radiation damage effects)