Radiation hardness of silicon sensors for the ATLAS upgrade

Claudia Merlassino
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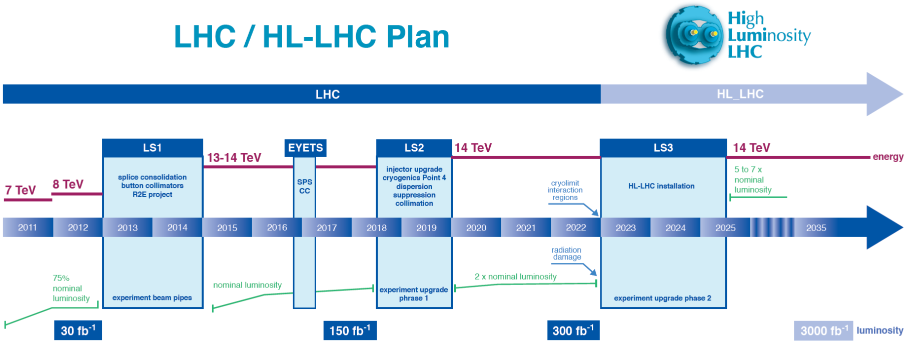
ATLAS EXPERIMENT

Present and future of the LHC



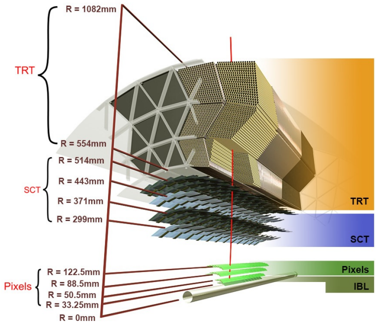
ATLAS Inner Detector now

The Inner Detector provides the reconstruction of charged particle tracks:

- transverse momentum measurement
- collision and decay vertex identification

$\rightarrow$

- high segmentation
- long lever arm
- as close as possible to the interaction point



Pixel Detector + IBL

Silicon sensors

highly segmentated, close to te beam pipe

SCT

Larger silicon strips

TRT

Gaseous detector, covers a large area

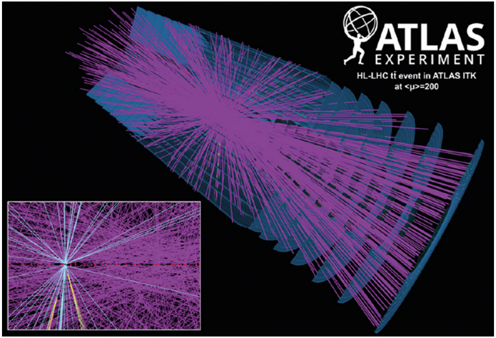
ITk - the ATLAS Inner Detector upgrade

Goals:

- separation of primary vertices in a busy environment
- efficient readout
- tolerance to high radiation doses

Plans for the upgrade:

- substitution of the whole system
- all silicon detector
- layout and technologies under study



Radiation effects on silicon sensors

High luminosity $\rightarrow$ High level of radiation!

Two different kind of radiation damage:

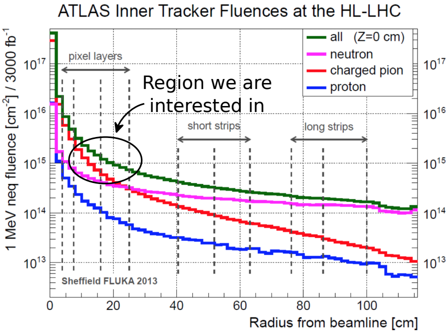
- $\propto$ ionising dose
  (fully recovered in the silicon bulk,
  important for the front-hand electronics)
- nuclear collisions
  (called fluence and expressed in $1\,\text{MeV}\ n_{\text{eq}}/\text{cm}^2$)

Effects:

- increase of the dark current
- higher operation voltage to obtain the same performances
- defects in the lattice $\rightarrow$ charge trapping

Qualification of radiation-hard technology

Target: 10^{15} 1 MeV n_{eq}/cm^2 for ITk outer pixel layer



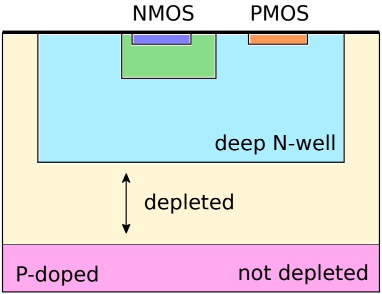
Strategy:

- different steps of irradiation of the sensors
- characterisation in lab with radioactive sources
- test beam studies at CERN

Goal:

- parametrise sensors response in different conditions

New monolithic sensors proposed for the outer pixel layers



- CMOS technology embedded in each pixel
- shielded by a deep n-doped region

$\downarrow$

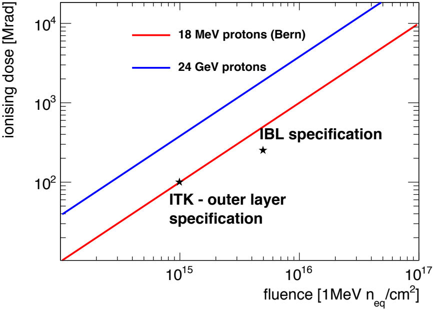
possibility to operate at high voltage (HV)

Pros:

- possibility of industrial production
  $\rightarrow$ lower cost
- small depletion zone
  $\rightarrow$ radiation hardness

Irradiations at the Bern University Cyclotron

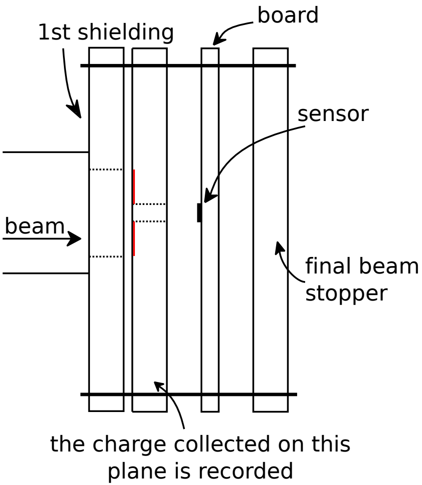
Separate beam-line for multi-disciplinary research: 18 MeV proton



On-line dose monitoring

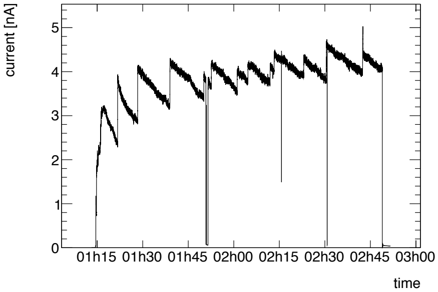
Current read on the new beam dump, designed for these irradiations

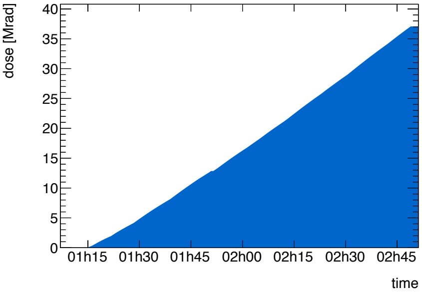
- material: aluminium
- covered in kapton
- charge collected in the sensor evaluated through the proportion of the areas



On-line dose monitoring

$$\text{dose} = \frac{Q}{q_e}\frac{dE}{d\rho x}\frac{1}{A}$$





Fresh results from the first irradiations

The first two steps are done:

- 10 Mrad
- 50 Mrad

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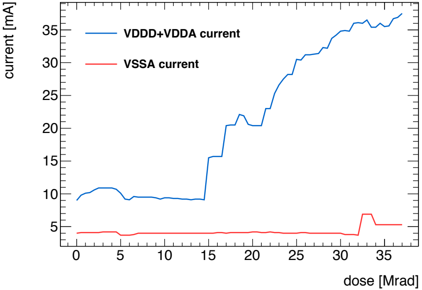
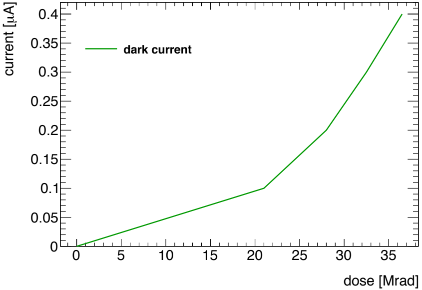
From the online monitoring:

- increasing power consumption
- increasing dark current





Conclusions

Upgrade for HL-LHC:

- ATLAS inner detector fully made of silicon
- understanding of the behaviour of the sensors in extreme environment
- study of the performance after different steps of dose
- irradiation performed at the Bern Cyclotron

Next steps:

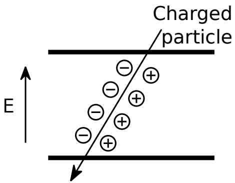
- analysis of test beam data after each irradiation
- accurate simulation of the precesses observed
    - to be integrated in the ATLAS reconstruction software

Backup slides

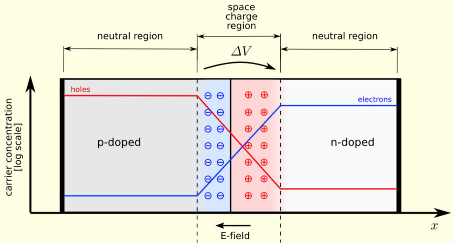
Detecting particles with silicon

Silicon is a semicontductor

- energy released by charged particle creates electron-hole pairs
- small band gap
  hard to discriminate from thermal excitation



Solution: p-n junction



- created by joining n-type and p-type doped silicon
- charge migration creates a region without free charges (depletion zone)
- the depletion zone can be enlarged by applying a reverse bias voltage