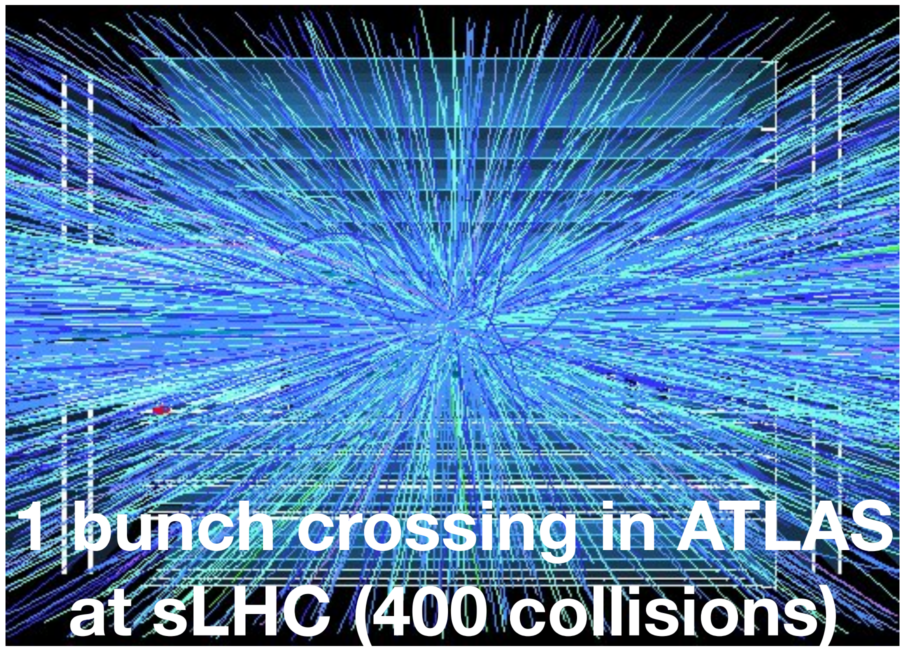
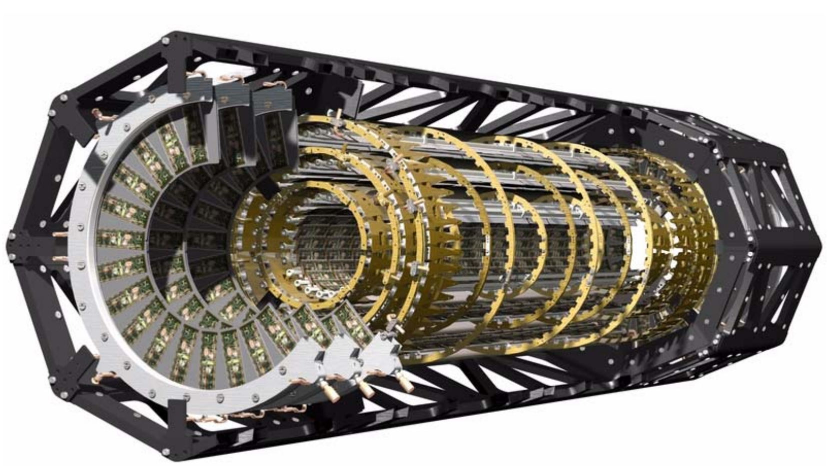
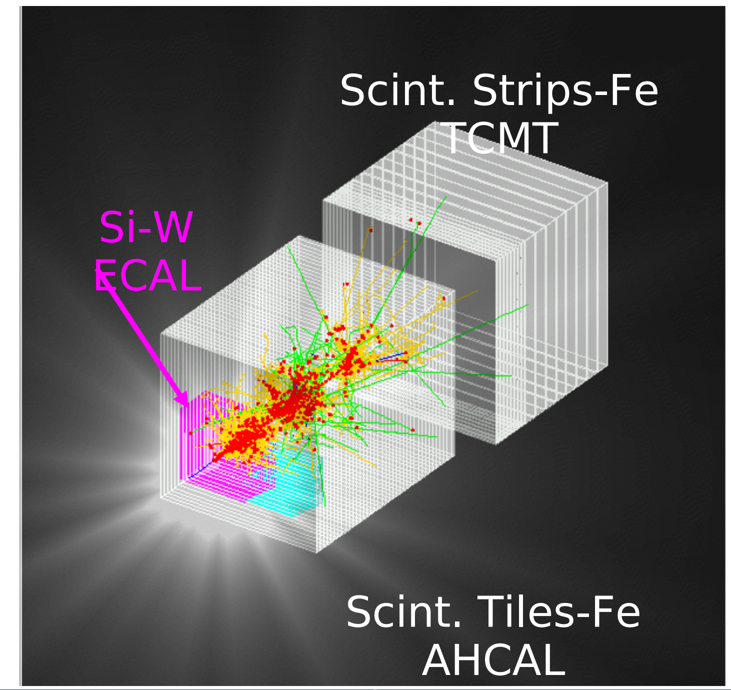
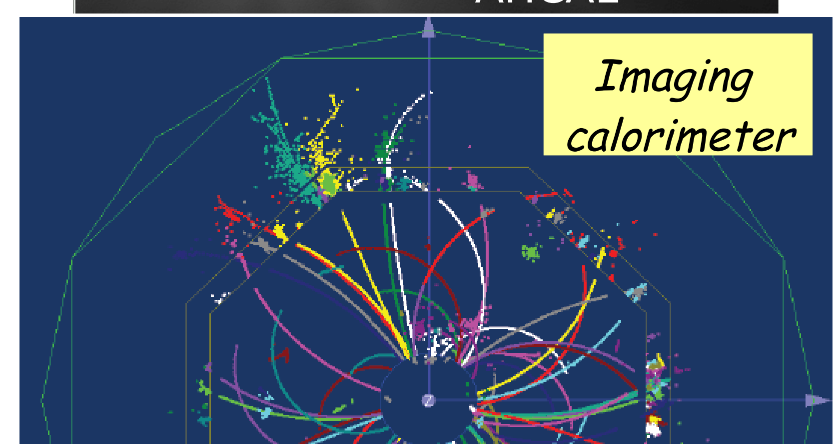
R&D on silicon detectors: ATLAS sLHC upgrade and Calice-ILD project





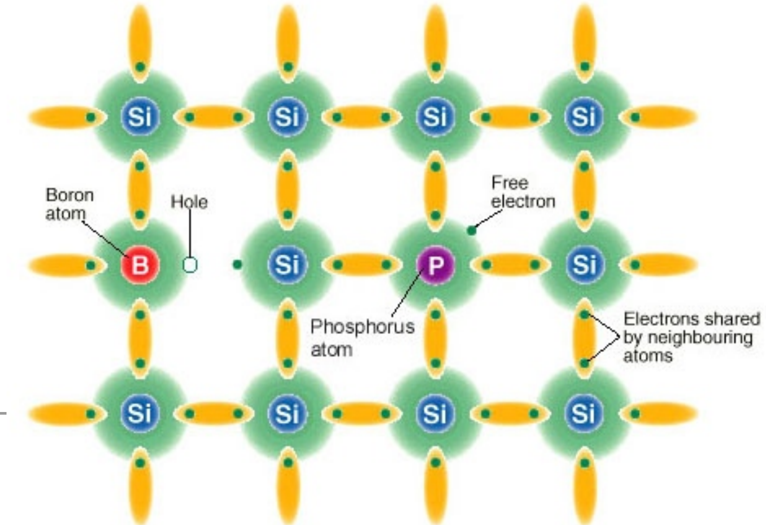


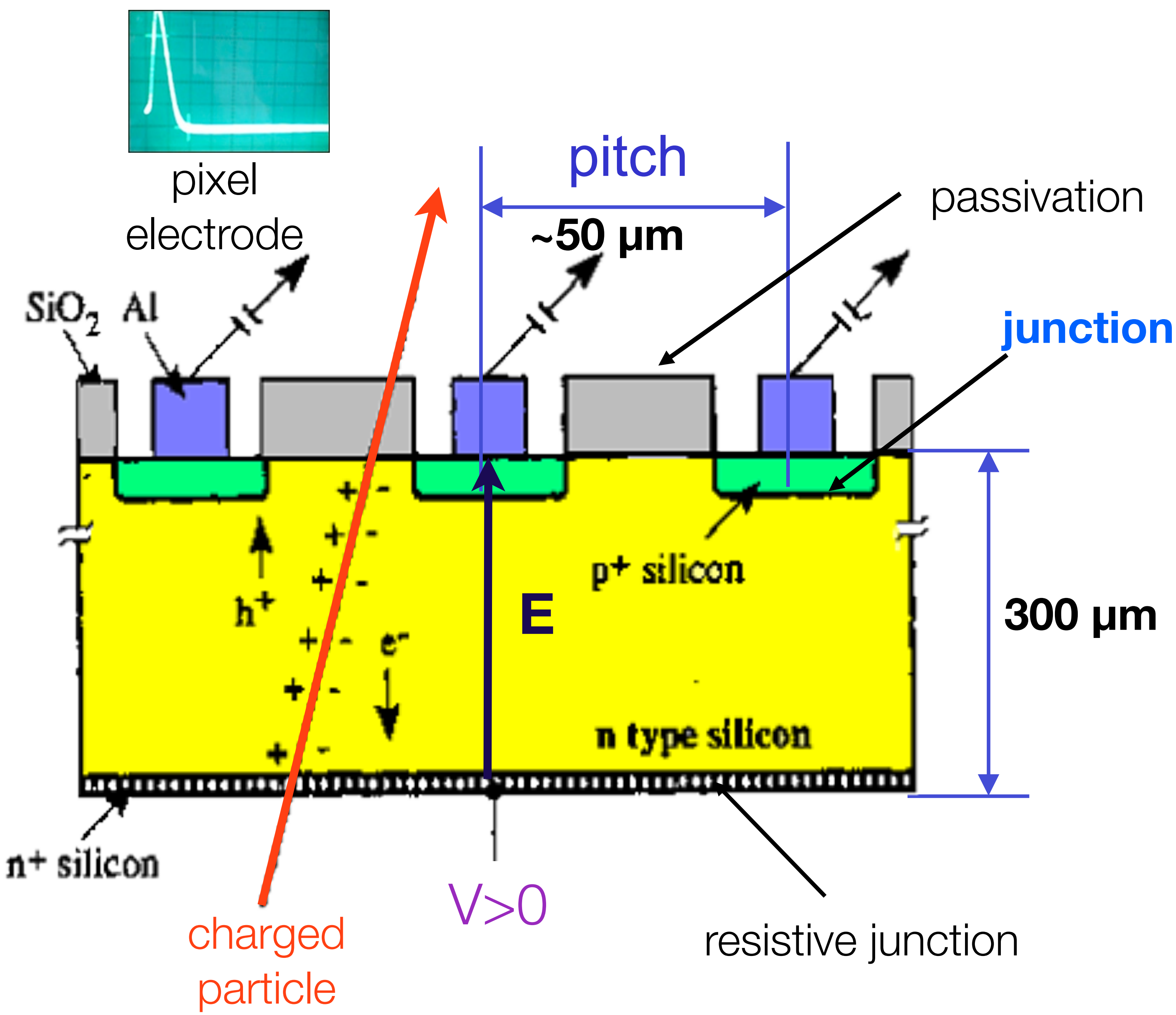


G. Marchiori

21/09/2011 - Biennale du LPNHE

Detecting particles with silicon

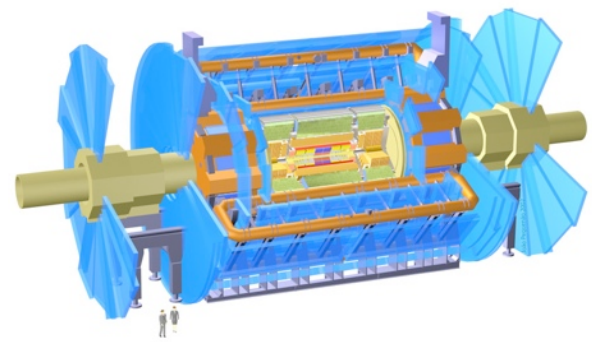


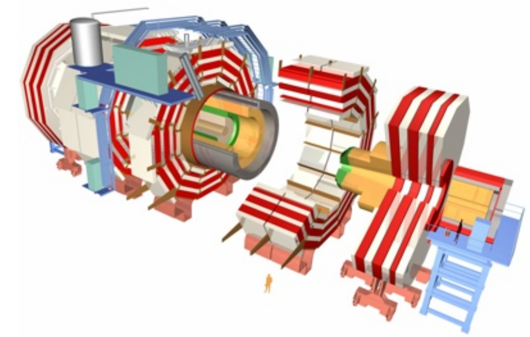


- charged particles crossing silicon "use" part of their energy to create multiple pairs of electric charges
- "junction" between 2 "types" of silicon (Si):
  - $p^{(+)}$: Si with some atoms of B ("dopant") in crystal lattice
  - $n^{(+)}$: Si doped with P, As
- with an external potential V applied ("bias")
  - **electric field E** is formed inside silicon "bulk"
  - charges migrate towards electrodes ⇒ electric signal
- **fast**: O(few ns)
- **precise**: spatial resolution O(10 µm)
- **compact**

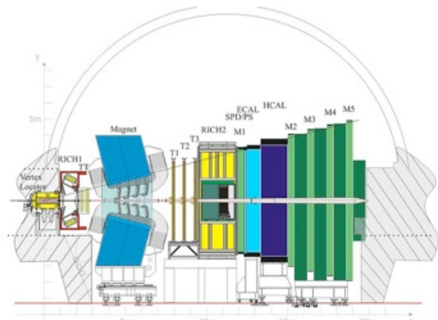
Silicon detectors in collider experiments

- recent/present experiments
  - ATLAS & CMS (LHC)

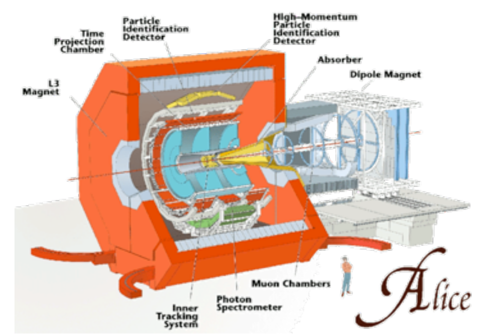




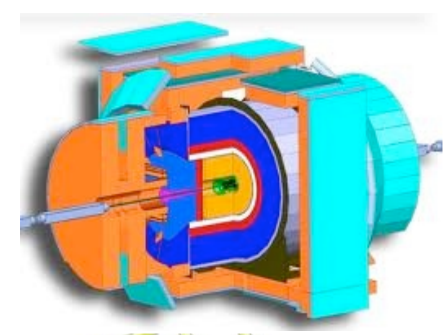
  - LHCb (LHC)

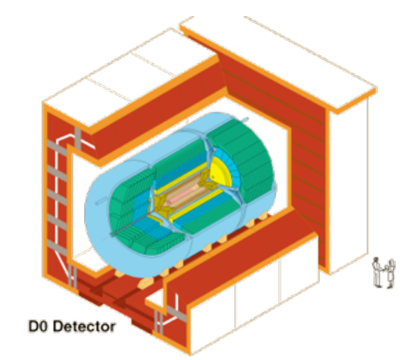


  - ALICE (LHC)

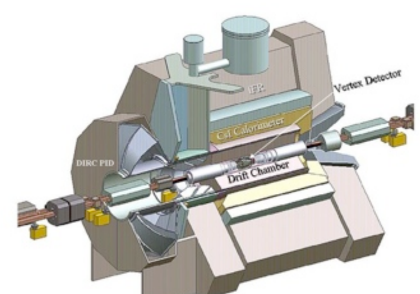


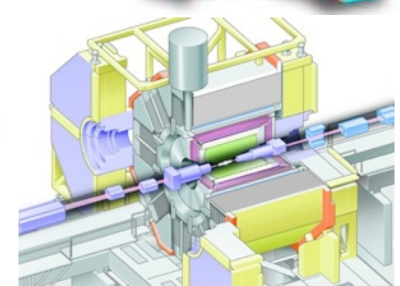
  - CDF & D0 (TeVatron)



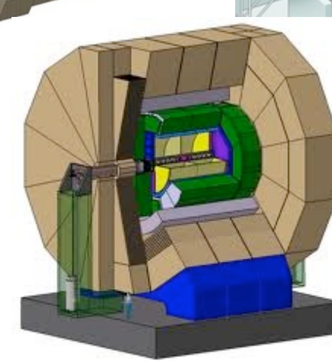


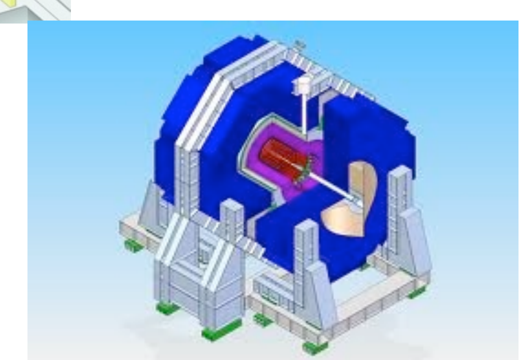
  - BaBar & Belle (SLAC & KEKB)





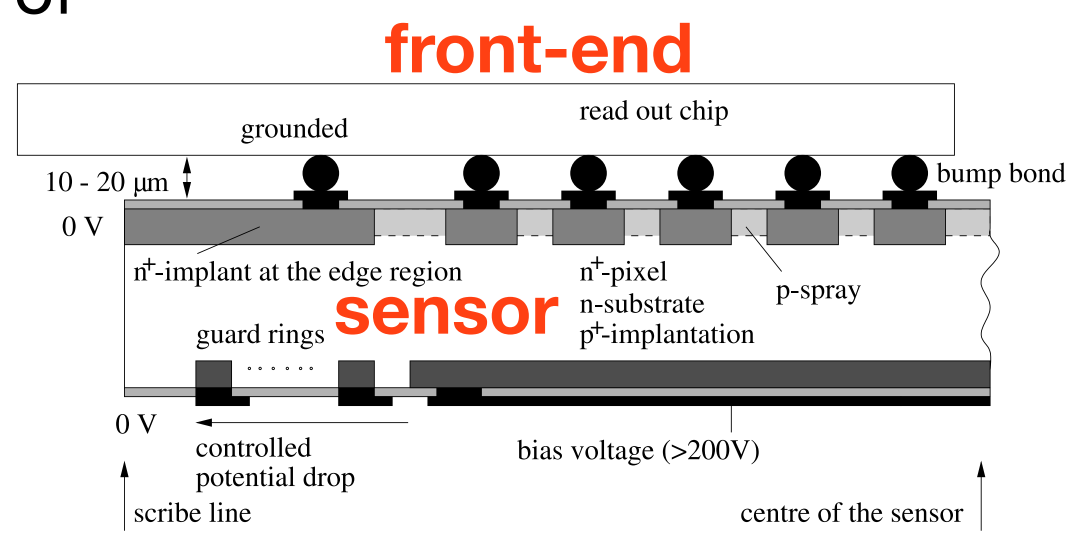
  - LEP (Delphi, ...)
- future (?): ILD & SiD (linear collider)





Key parts of a silicon detector

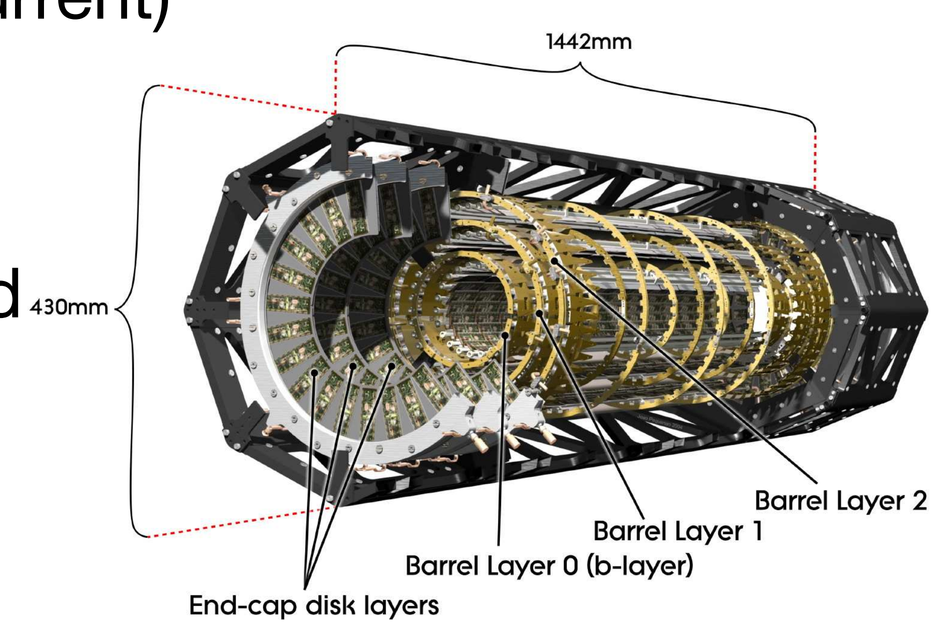
- Silicon sensors: where charge is generated by particles, drifts towards the electrodes because of the electric field, and is collected



- Front-end electronic: amplify and read out the signal at the electrodes, removing small "fake" signals (noise)

- Cooling: dissipate heat generated by electronics (also beneficial for sensors: reduce leakage current)

- Mechanical structure: everything has to be mounted on a supporting structure and placed around the interaction point of the experiment



Challenges and R&D directions

- Sensors: radiation hardness (see later), cost, reduction of inactive area at sensor's edge (efficiency) ..

- Electronics: faster chips (dead time), reduced power consumption (cooling), lower capacitance (noise), cost, ...

- Cooling/supporting structure: keep material to a minimum level while guaranteeing sufficient support and efficient cooling

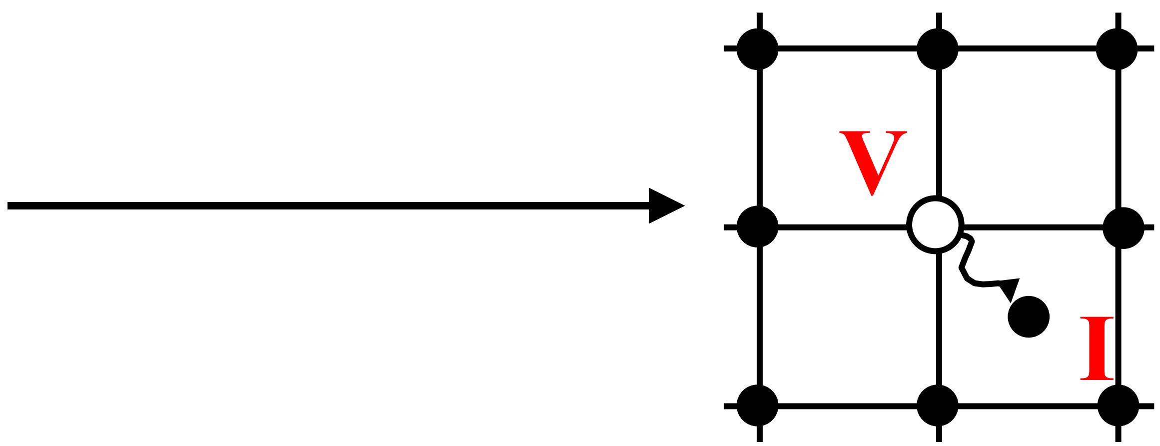
    - detector spatial resolution affected by amount of material (x)

$$\theta_0 = \frac{13.6\ \mathrm{MeV}}{\beta c p}\, z \sqrt{x/X_0}\Big[1 + 0.038 \ln(x/X_0)\Big]$$

Main problem for sensors: radiation damage

- performance of Si detectors depend on crystal lattice
  - leakage current (noise)
  - trapping time (charge collection efficiency)
  - effective doping (full depletion voltage)

- particles crossing Si detectors can displace atoms and create “defects”, changing the properties of the lattice and therefore the detector performance



Vacancy (lattice point not filled)

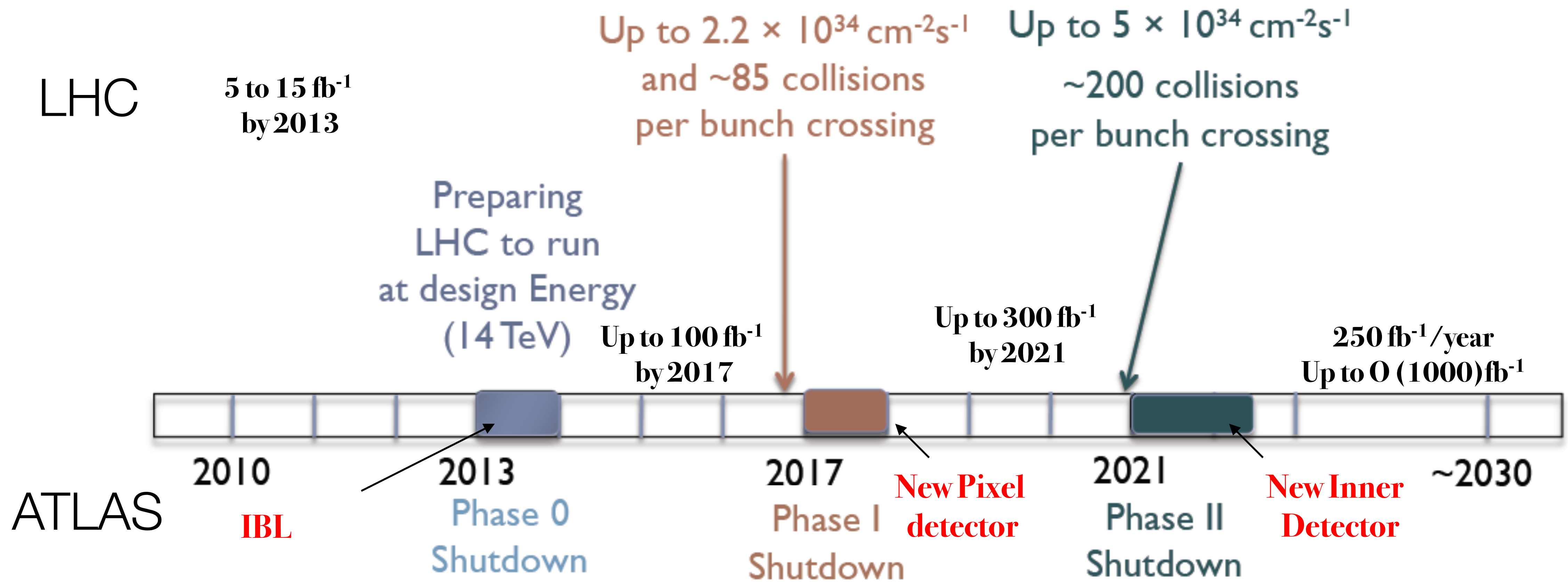
+

Interstitial (displaced atom)

- This can be a problem in experiments where a lot of particles are produced that cross the detector (inner layer of ATLAS at sLHC: > 10^{15}/cm^2)

Future colliders: timelines

- sLHC: upgrade (in 2 phases) of existing LHC (pp collider) to obtain 10x higher "intensity" (*luminosity*) - needs replacement of ATLAS Si detectors



- ILC/CLIC: future linear e^+e^- collider - needs new Si detectors
  - construction: this decade; run: next decade (2021-2030)?

Future colliders: physics case

- Improve measurements of new phenomena seen at LHC (should know more next year...)
  - SM Higgs found? Higgs boson couplings and self-energy potential
  - Many Higgs bosons found (SUSY/Little Higgs theories)?
    - precise exploration of Higgs sector (masses, mixing, couplings)
  - SUSY? properties of SUSY particles (mass, decay BRs)
- Detect/search phenomena inaccessible at the LHC
  - low rate processes: $H \rightarrow \mu\mu$, $H \rightarrow Z\gamma$, top quark FCNCs
  - high-mass scales phenomena: new forces (Z'..), quark substructure
  - SUSY light non-colored sparticles
  - Higgs not found? search for EWSB by new strong interactions at low scales in scattering of W,Z bosons in clean lepton-collider environment

R&D for sLHC

1. sensors
2. support and cooling
3. electronics

funding from: LPNHE, ATLAS, EU (AIDA/Eudet), UPMC (emergence)

Personnel

- 6 physicists:
    - Tristan Beau, Marco Bomben, Giovanni Calderini, Jacques Chauveau, Giovanni Marchiori, Philippe Schwemling
- 1 mechanical engineer:
    - Didier Laporte
- 1 assistant engineer:
    - Yann Orain
- 2 (+1) electronics engineers:
    - Jean-Francois Genat, Olivier Le Dortz (+ previous work by Yixian Guo)

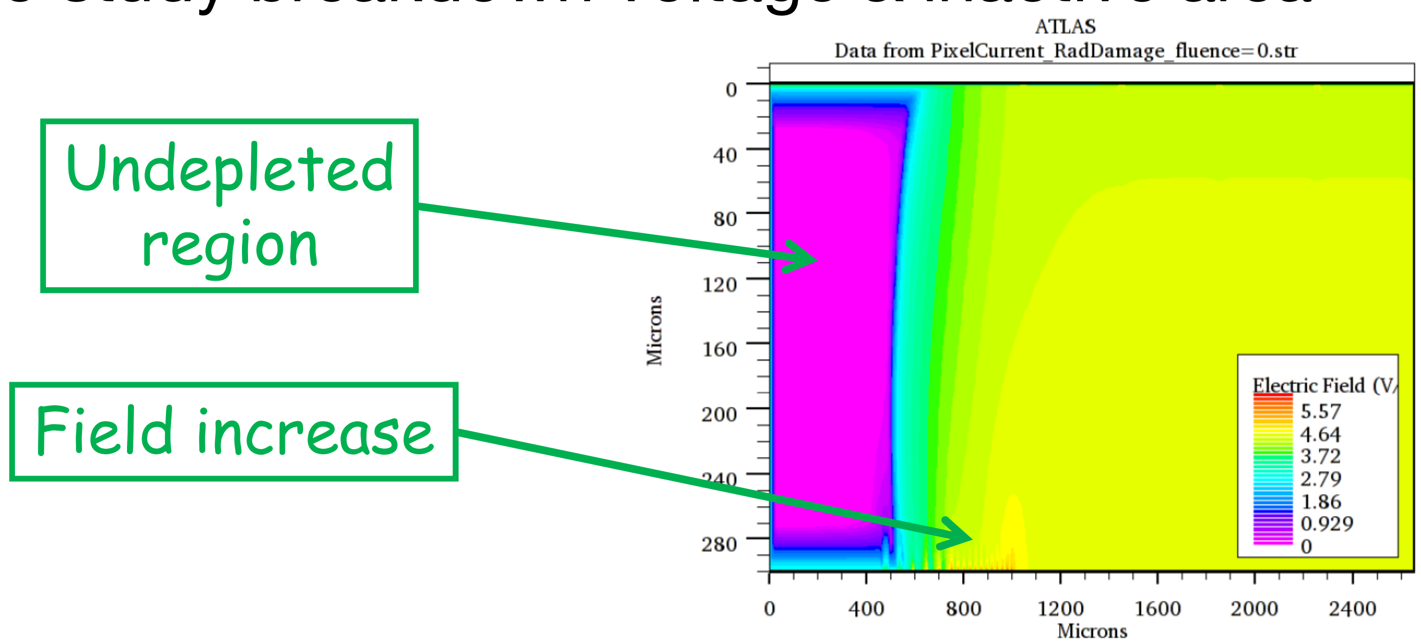
1. Sensor R&D for sLHC phase I (IBL) & II (HL-LHC)

- Activities (within the Planar Pixer Sensors ATLAS upgrade group):
  - sensor simulation (LPNHE) and production (CiS, Germany)
  - sensor electrical qualification (LPNHE cleanroom)
  - sensor irradiation to study radiation damage (CERN, Ljubljana)
  - module (sensor + electronics) performance (CERN and DESY testbeams: online data taking + offline analysis at LPNHE)
  - future sensor R&D (active edge sensor production at IRST)

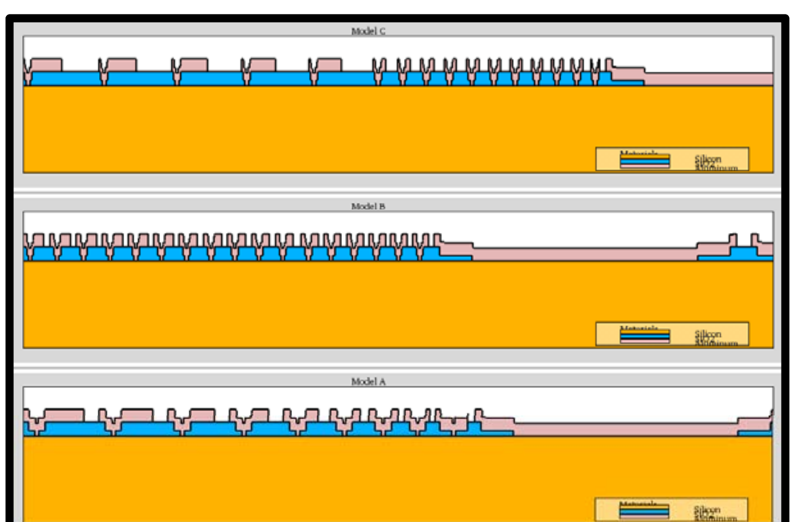
The PPS Upgrade Collaboration

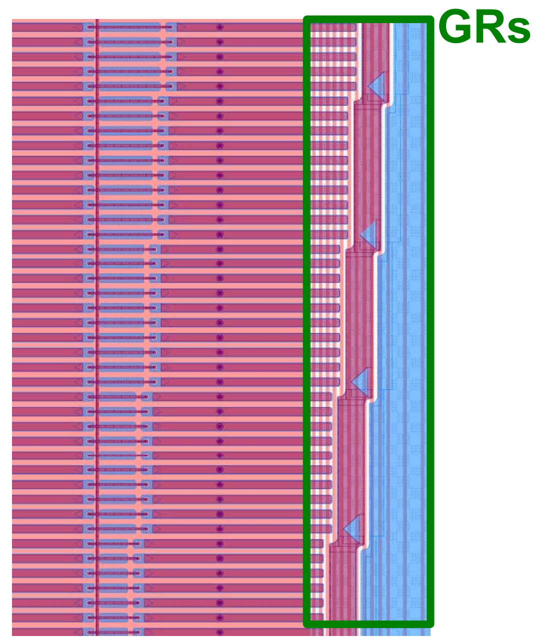
Sensor simulation

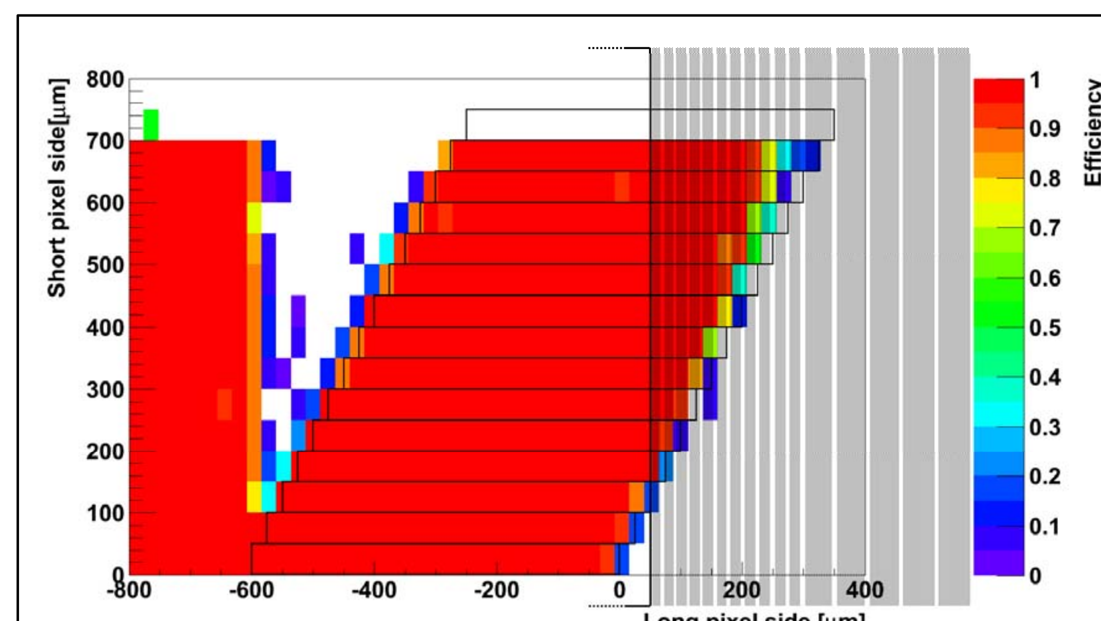
- Electrical simulation of different layouts at different doses with TCAD software (Silvaco) to study breakdown voltage & inactive area



- various configuration considered with different # of guard rings, distances, ..



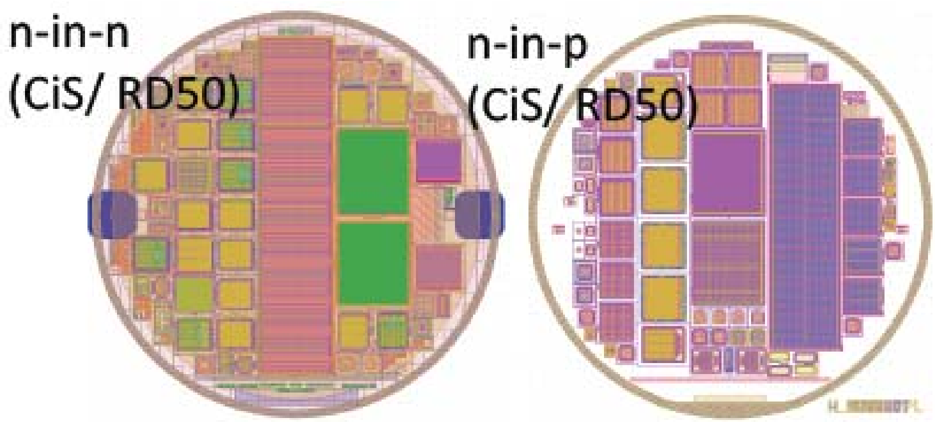




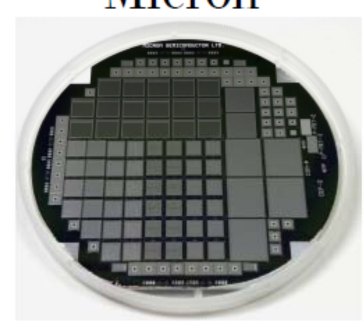
simulation, layout *simulation, layout* *hit efficiency measured in testbeam*

Sensor production and qualification

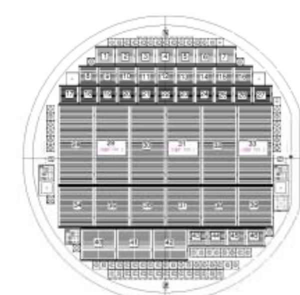
- Contributed to sensor production at CiS (2010, 2011), design aided by simulation results
- Sensor tests: I-V, C-V, Vguard-V curves measured using SUSS PA200 probe-station in LPNHE cleanroom



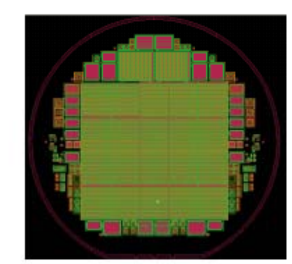
Micron

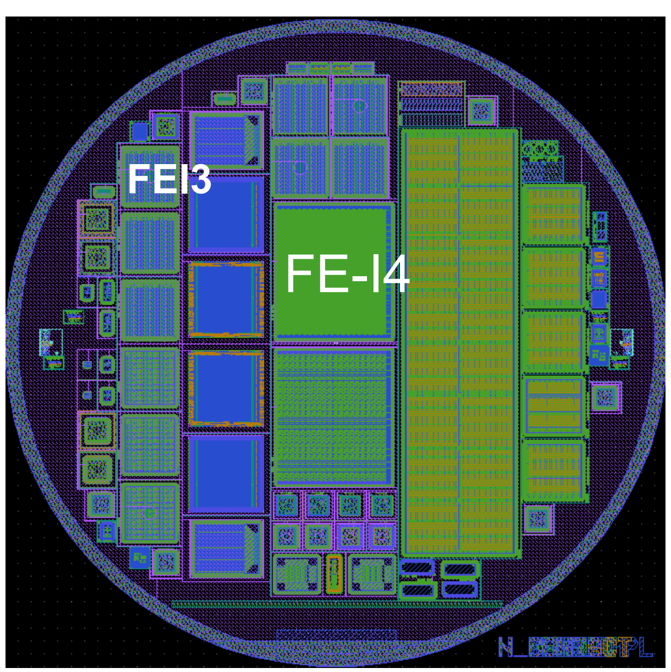


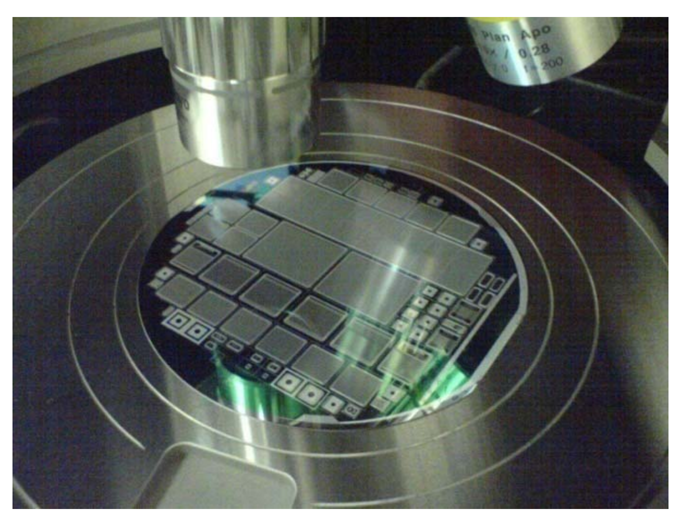
HPK

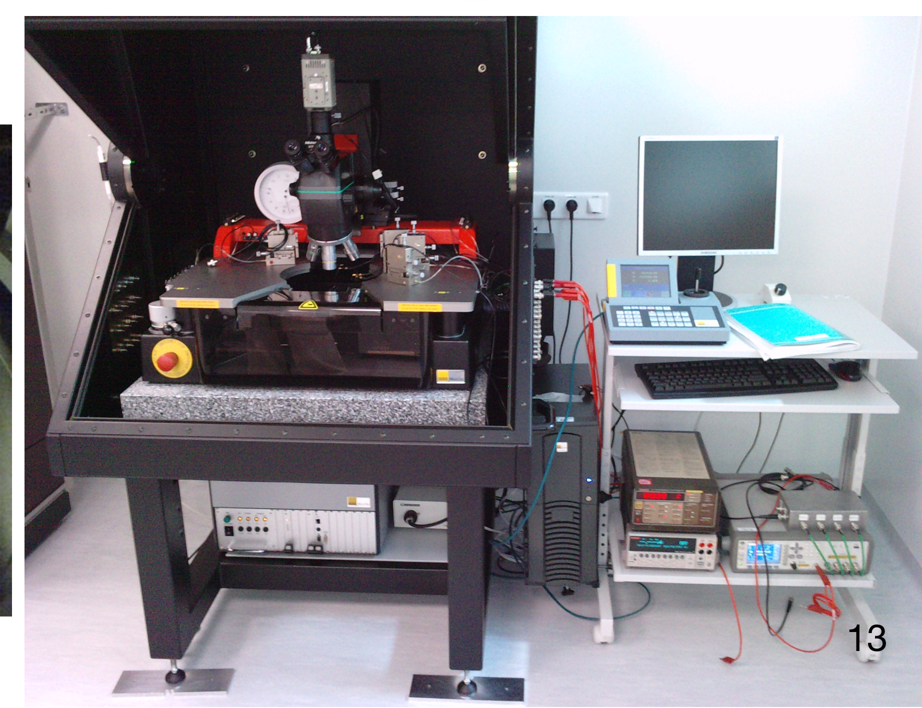


MPI-HLL



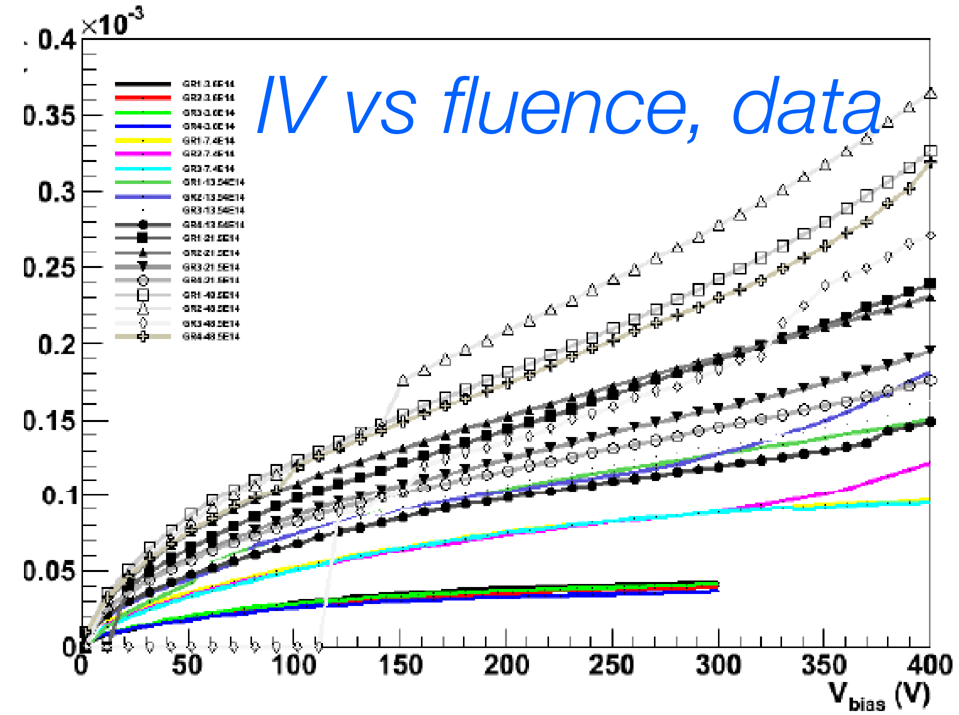




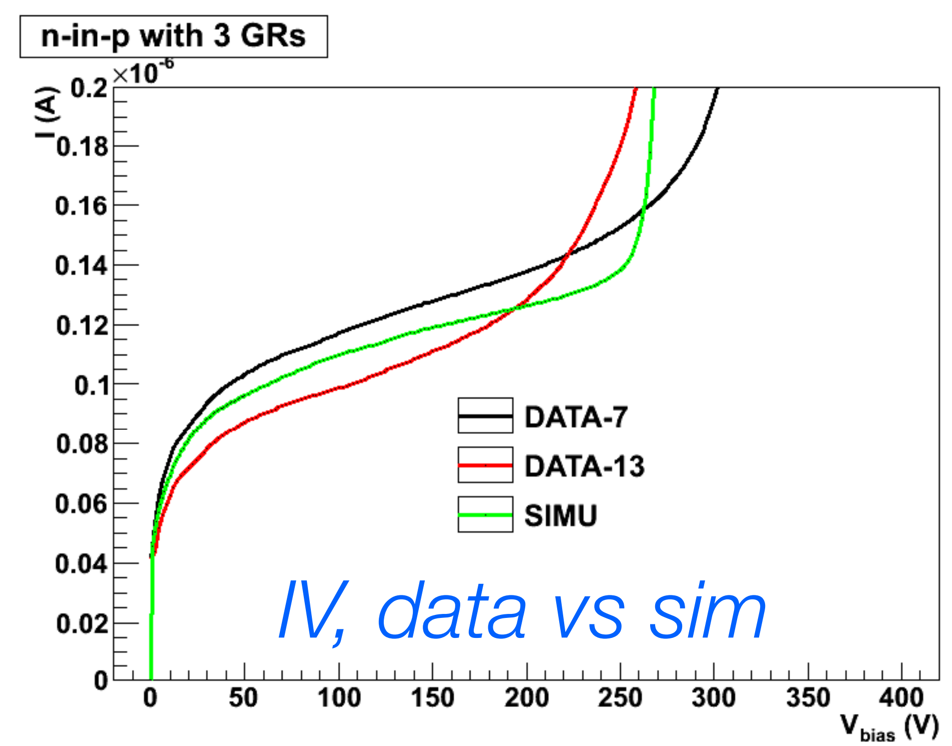


Electrical characterization of sensors (II)

- Irradiations of test structures in collaboration w/ CERN (proton beam) and Ljubljiana (neutron reactor), measurements after each step



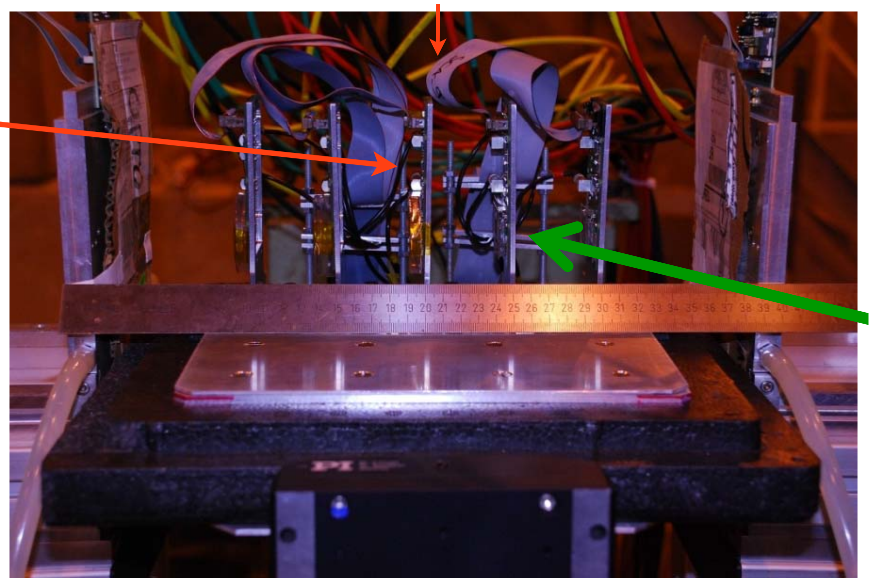
- Electrical device simulations performed at LPNHE and compared with data
  - simulation tuned to data: good agreement

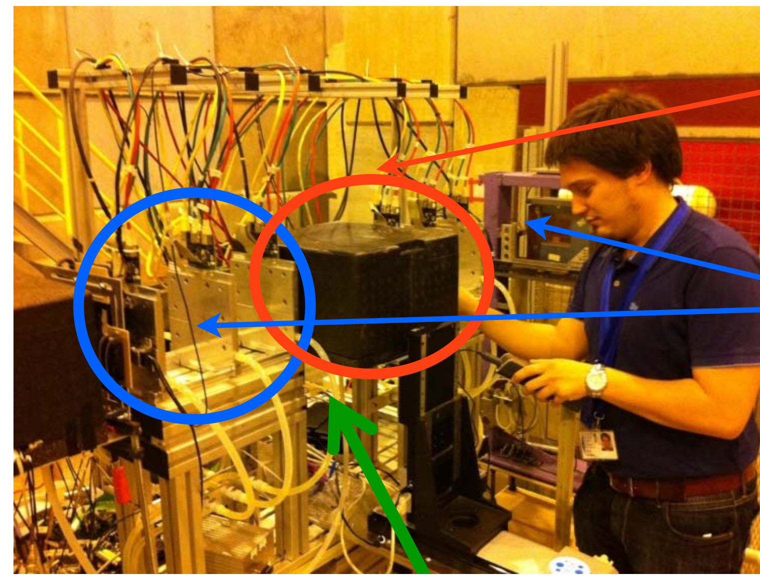


- "Cold" setup for measurements at low T in preparation (funds from AIDA)

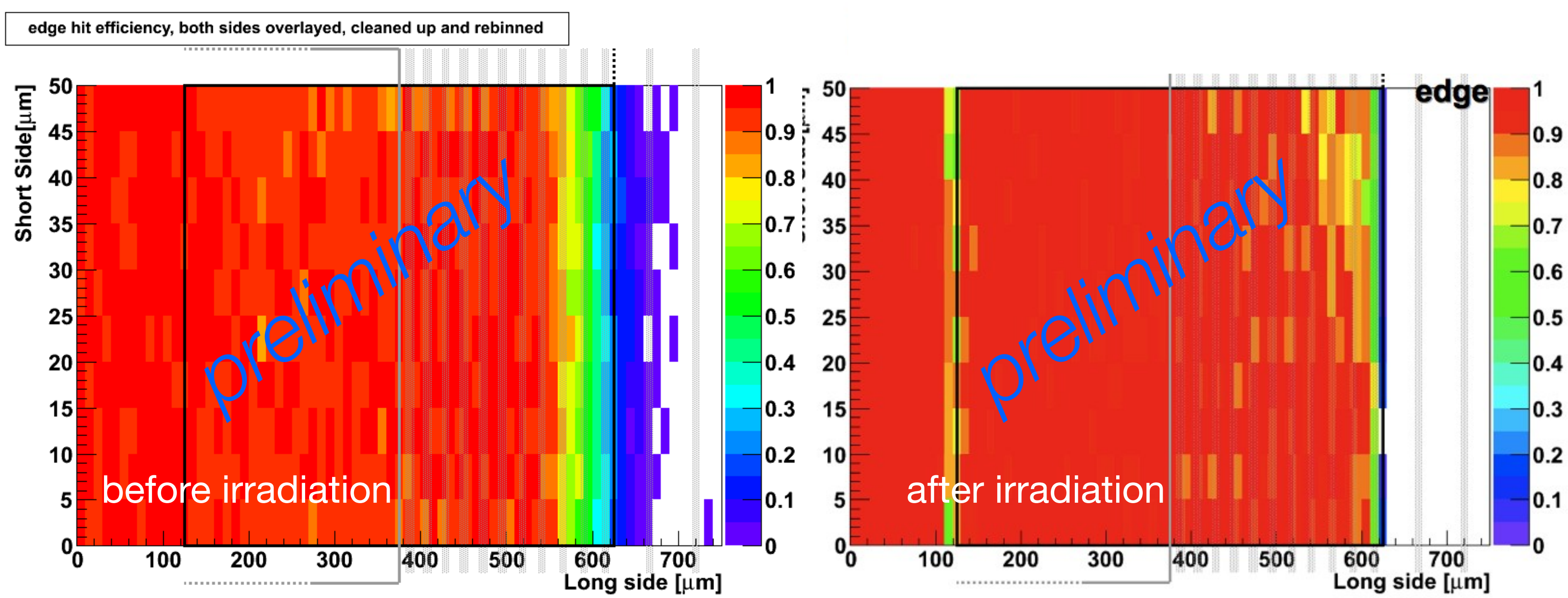
Module (sensor+electronics) performance studies

- Testbeam data taking + analysis: CERN 2010, DESY 2011 (x2), CERN 2011 (x3)





- Testbeam results used to choose planar sensor as candidate pixel technology for IBL (ATLAS upgrade for sLHC phase I)

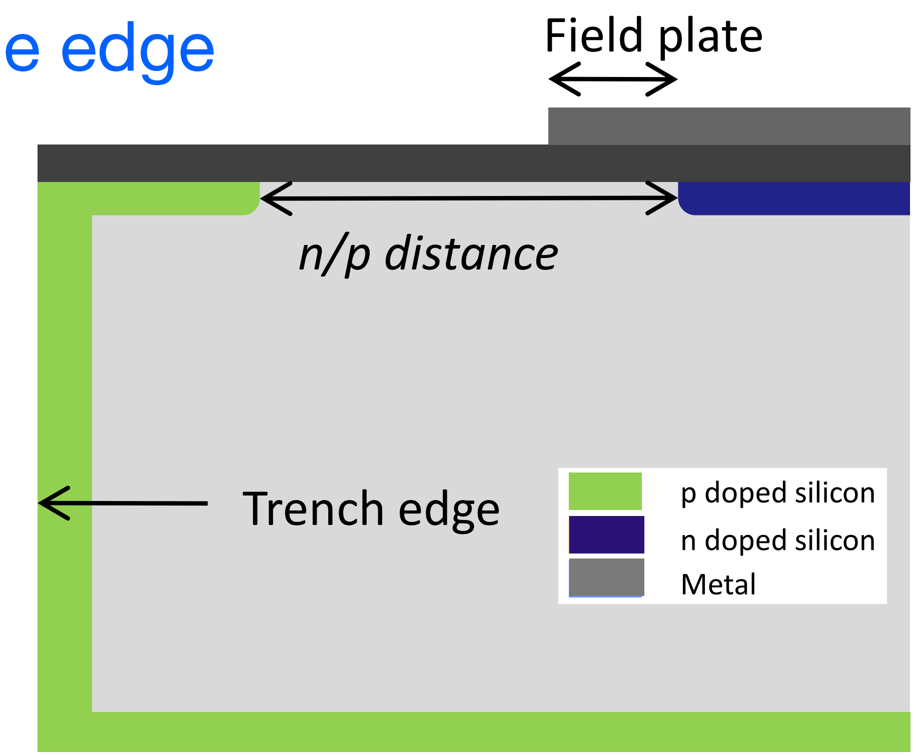


250 μm inactive edge achieved using better etching + shifted GRs (1.1 mm in current ATLAS pixels)

- Marco = PPS testbeam coordinator since Sep. 2011

R&D on future active edge detectors

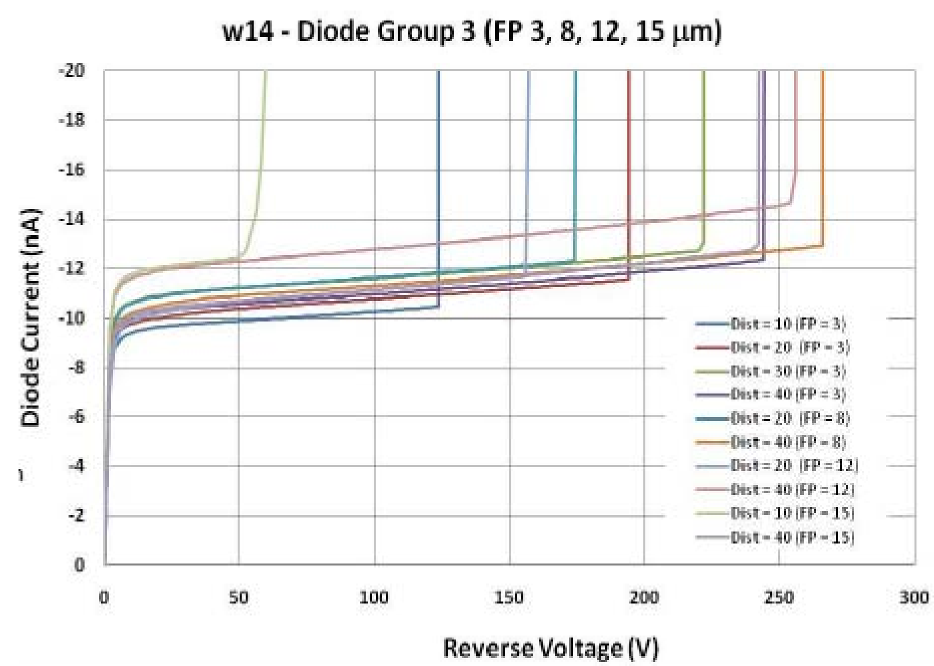
- long-term sensor development for phase-II: reduce even further (~0 um) the inactive lateral area using an active implant on the edge



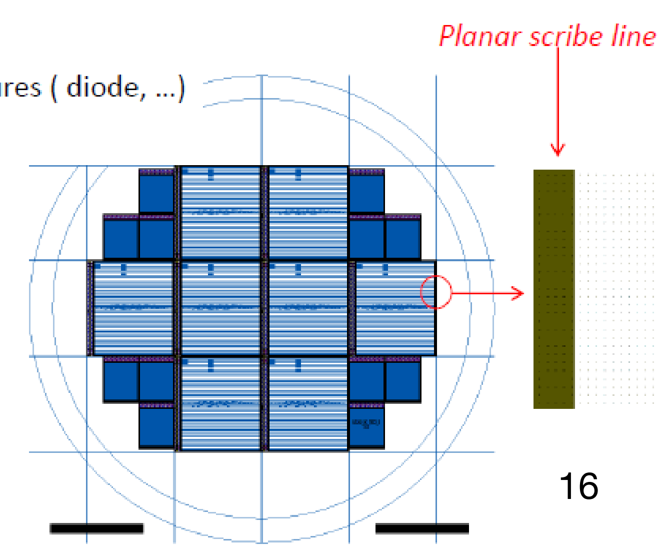
  - IRST-FBK (Trento)/LPNHE collaboration

- preliminary test diodes produced at IRST give promising results

  yields,
  leakage current,
  breakdown



On 4 inch wafer:
- 8 FE I4
- 12 FE I3
- Test structures (diode, ...)



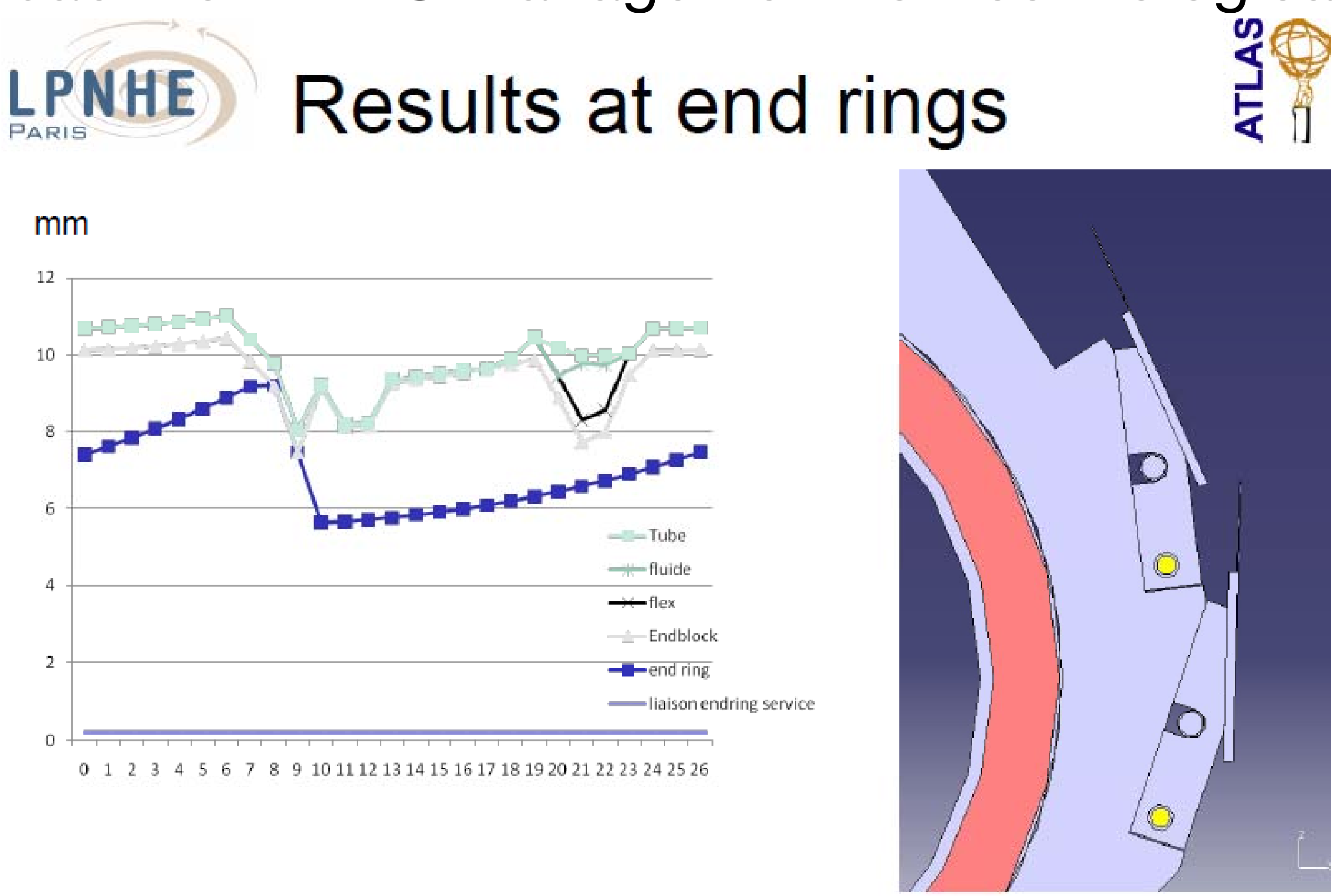
- 20 wafers to be produced for LPNHE (already funded thanks to collaboration with INFN and regione Trentino)

2. IBL/sLHC mechanical support and cooling R&D

- Activities:
  - material reduction
  - mechanical design
  - thermal simulations
  - thermal characterization

Mechanical studies: material reduction

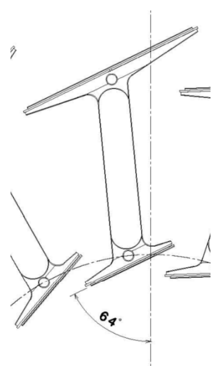
- Developed a method (CAD + catia plugin by IBM) to quickly evaluate material thickness (X/X0) from CAD drawings
- Coordination of task force to evaluate and trim the IBL material budget
  - precise evaluation of X/X_0 every time a new system layout is available
  - provide feedback to ATLAS management for technological choices



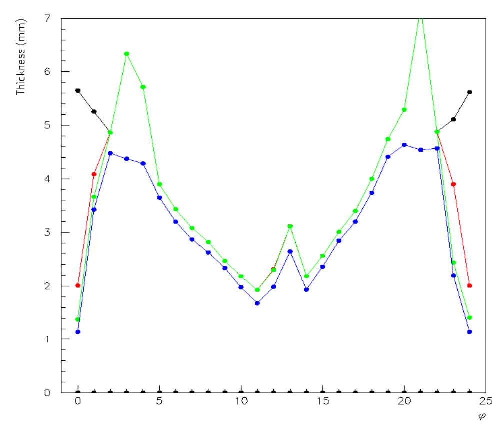
Mechanical studies: material reduction & design

- Evaluated X/X0 of I-beam “staves” (support+cooling structure) for sLHC

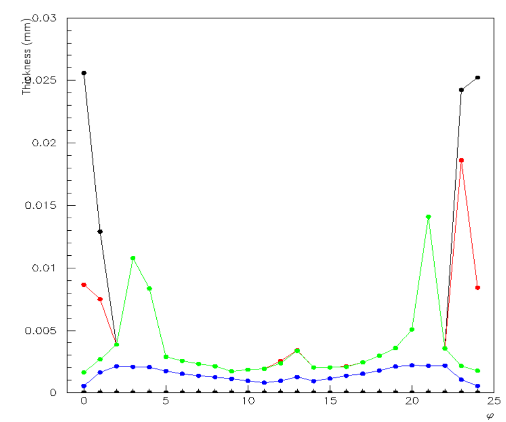
LBNL design



Distance



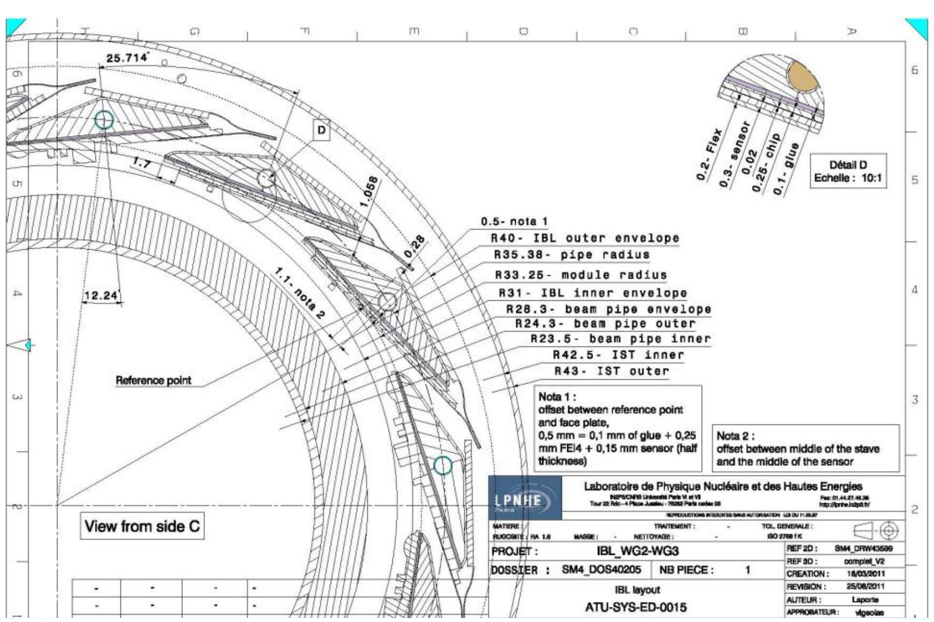
Xo



ATLAS upgrade week, 22/03/2011

Blue : Carbon foam (X0=2130 mm)
Green : Face sheet +I-shaped structural beam (X0=224 mm)
Red : cooling pipe (Al, X0=88.97 mm)
Black : cooling fluid (C3F8, X0=215.25 mm)

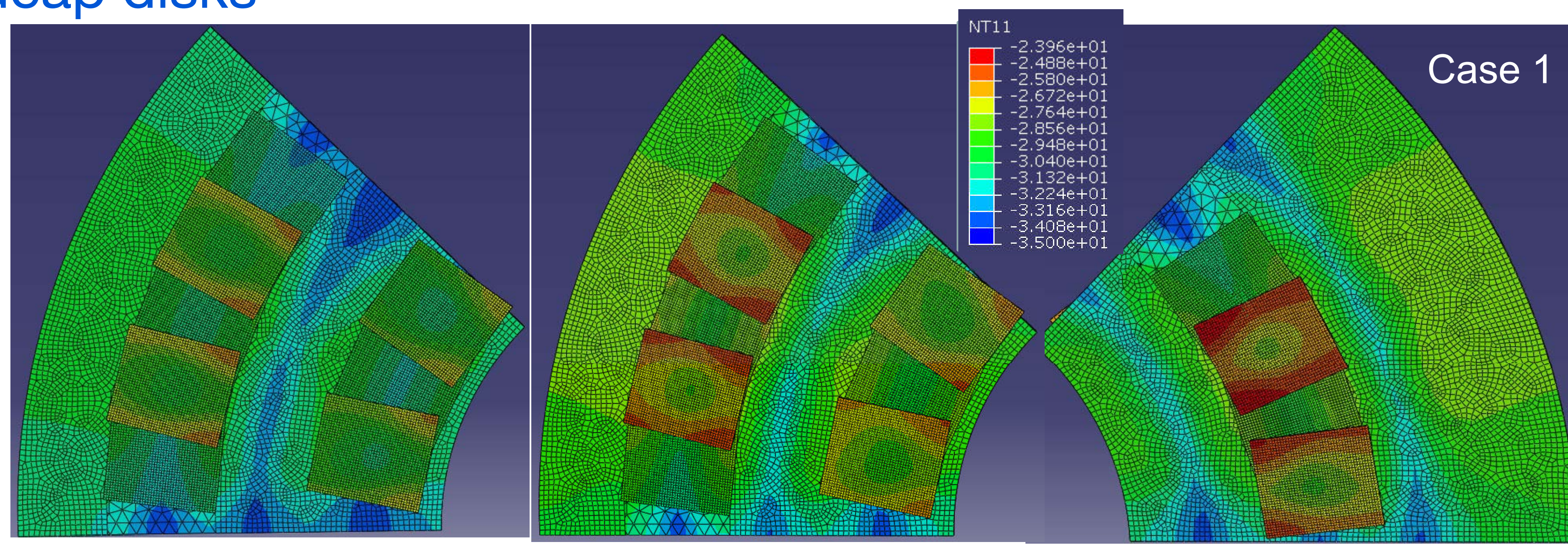
- Currently working on staves design and production for IBL support (including central + end rings) and on final assembly of 14 staves



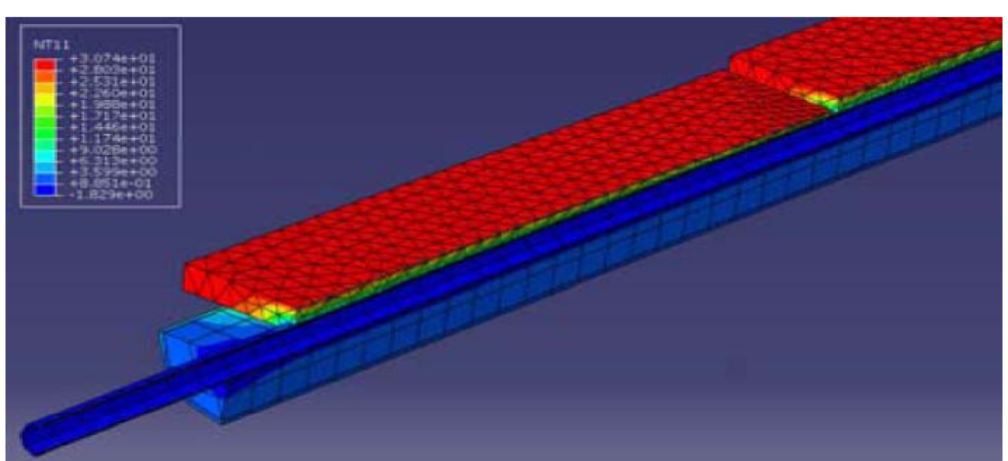
IBL integration stave review, 31/08/2011

Thermal studies

- simulation of different cooling configurations and pipe/support materials for sLHC pixel endcap disks



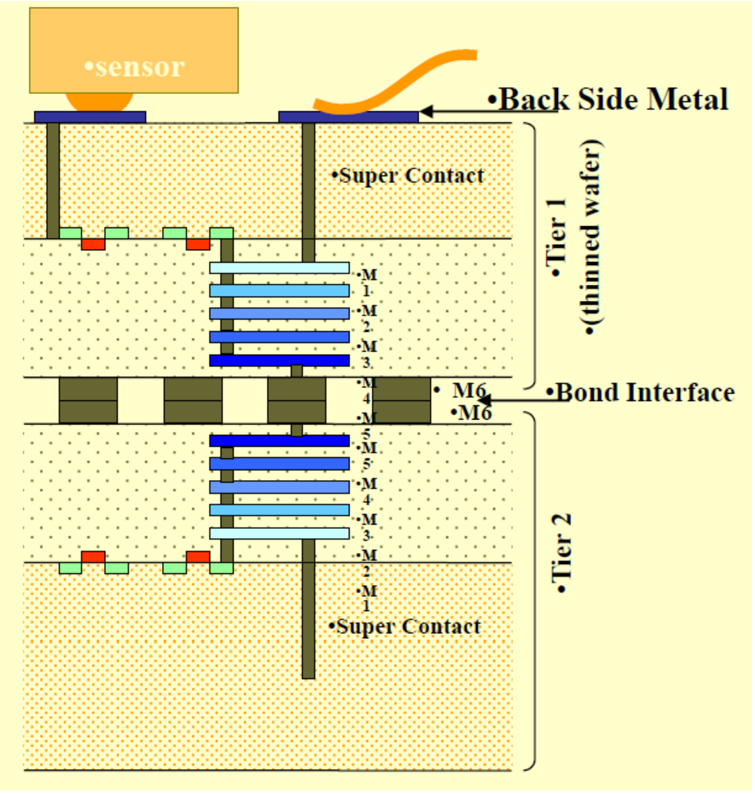
- simulation of staves for IBL and comparison with measurements @ LPNHE thermal bench



3. sLHC electronics R&D

- Activities:
  - development of a new front-end chip for phase-II sLHC (OmegaPix)
  - radiation damage studies: test and irradiation of (part of) OmegaPix chip (MemDyn)

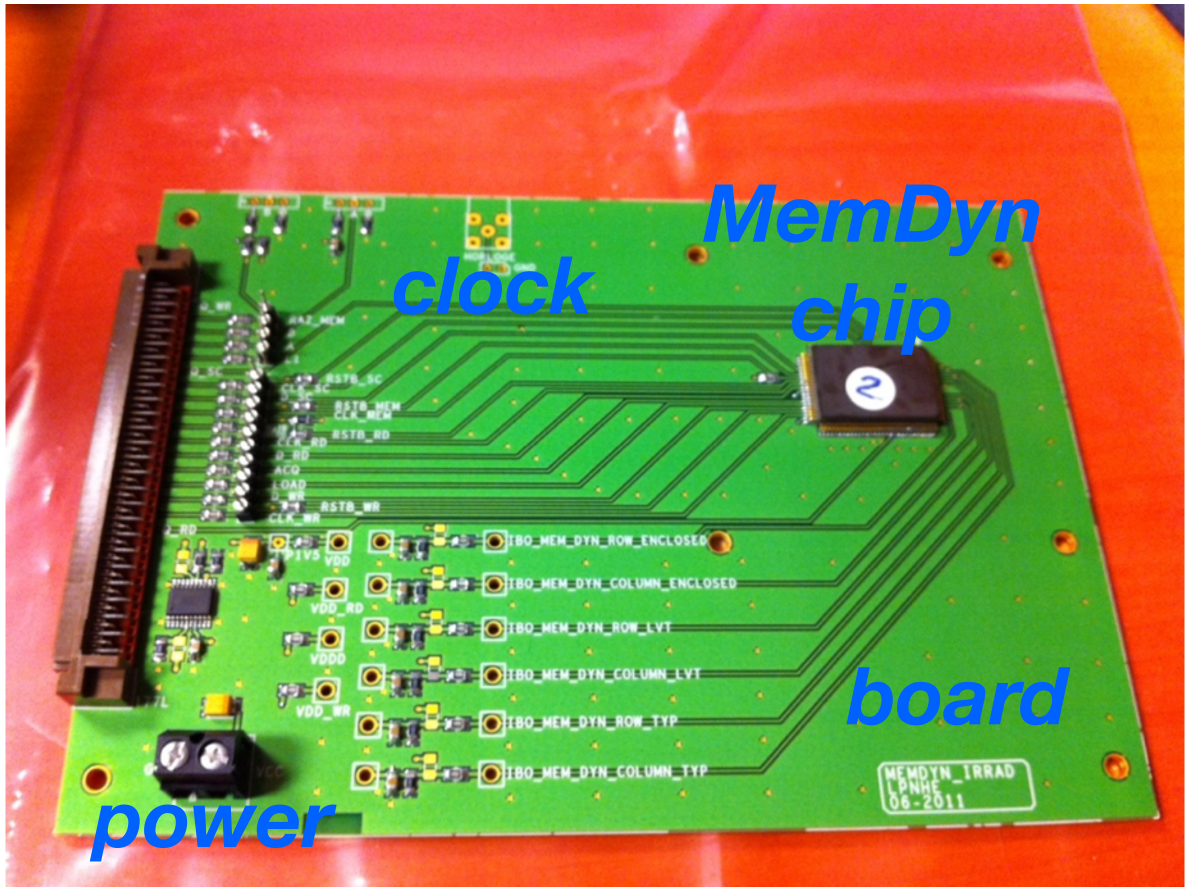
OmegaPix chip design



- Development of front-end chip for sLHC pixels using vertical integration (several layers stacked)
  - higher density at reasonable price
- In collaboration with LAL, using Tezzaron/Chartered 130 nm process
  - significant support from IN2P3 / ANR / AIDA
- Goals: low threshold (1000 e), low noise (100 e) low consumption (3 μW/pixel)
- Contributed to design of exploratory OmegaPix-I chip (LAL, LPNHE) with small pixel size (50x50 μm^2), matrix of 24x64 pixels
- Now working on digital part of OmegaPix-II chip (realistic pixel size, 35x200 μm^2), 1st submission in October

MemDyn

- Prototype chip with circular buffer memory for OmegaPix
- Radiation hardness has to be investigated with proton beam at CERN
- Board to provide power and clock during irradiation produced at LPNHE
- Irradiation to be performed in October, compare chip before/after irradiation



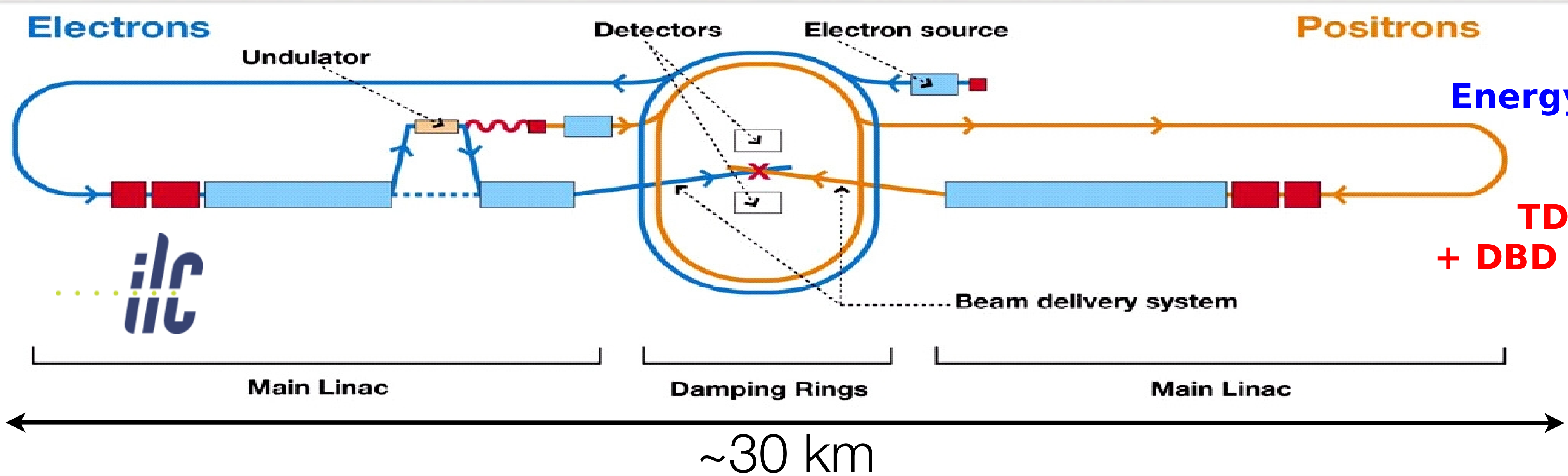
Outreach

- 3 talks at conferences: Hiroshima ’09 (GC), TIPP ’11 (MB), RD ’11 (GM)
- Publications/documents:
    - planar pixel sensor R&D proposal for sLHC: https://edms.cern.ch/document/966140
    - IBL TDR: CERN-LHCC-2010-013 ; ATLAS-TDR-019
    - GC, GM et al, Nucl Instrum Meth A (636) S37.
    - ATLAS-upgrade note (simulation): ATL-UPGRADE-PUB-2010-001 (GC+GM+LAL)
- 4 Internships: 1 M1+1 M2+1 ecole d’ingenieur (2010), 1 ecole d’ingenieur (2011)

R&D on ILC sensors

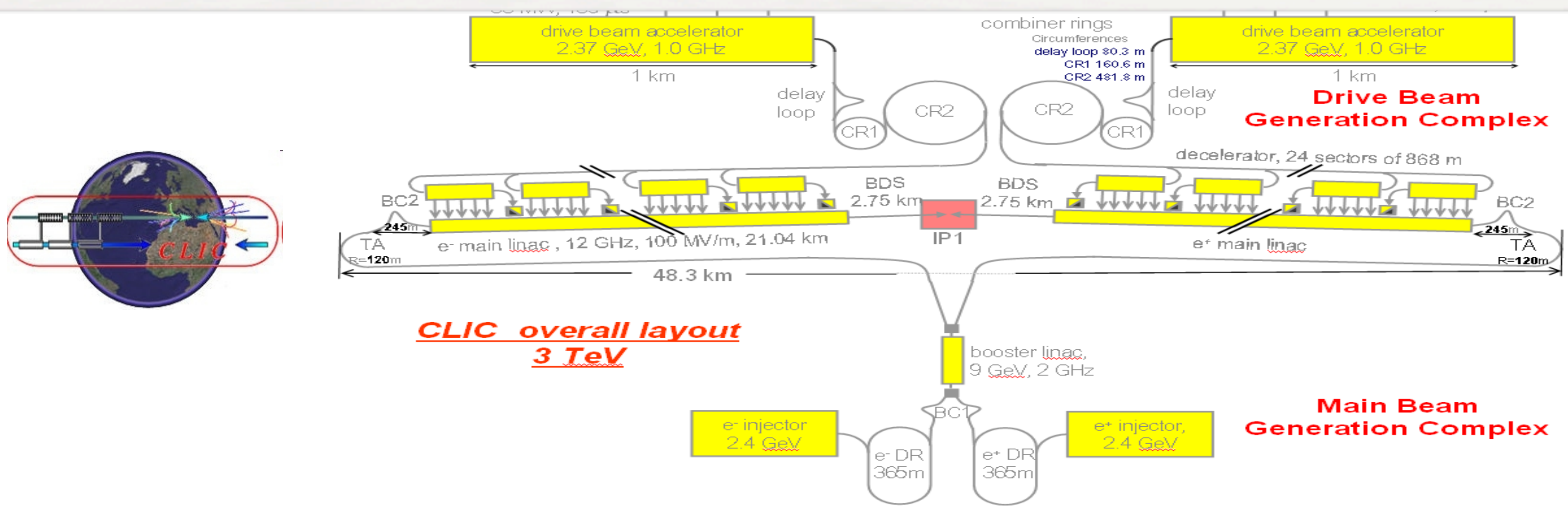
funding from: LPNHE

e^+e^- Linear Collider projects: ILC, CLIC



Energy: 0.1 - 1 TeV

TDR in 2012
+ DBD for detectors



Energy: 0.5 - 3 TeV

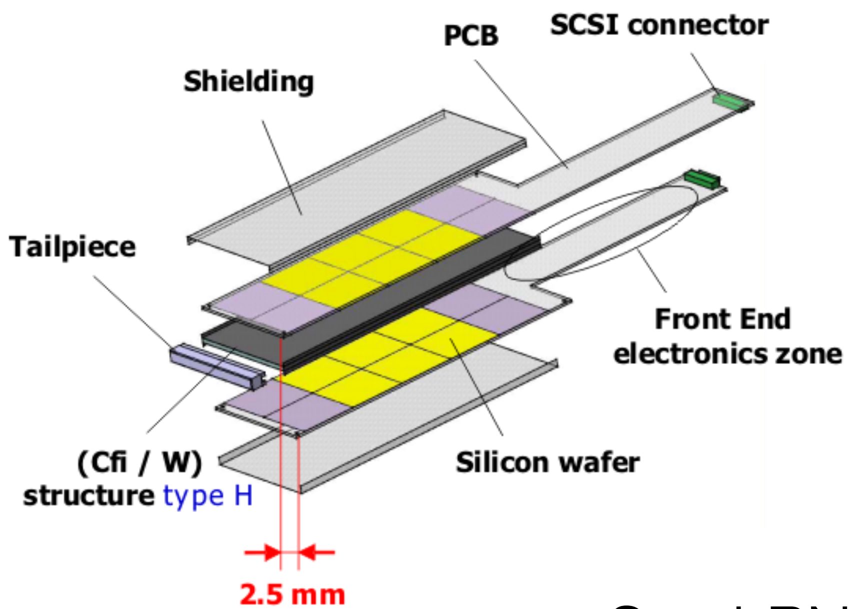
CDR in 2011

Linear collider is integral part of European Strategy beyond 2012

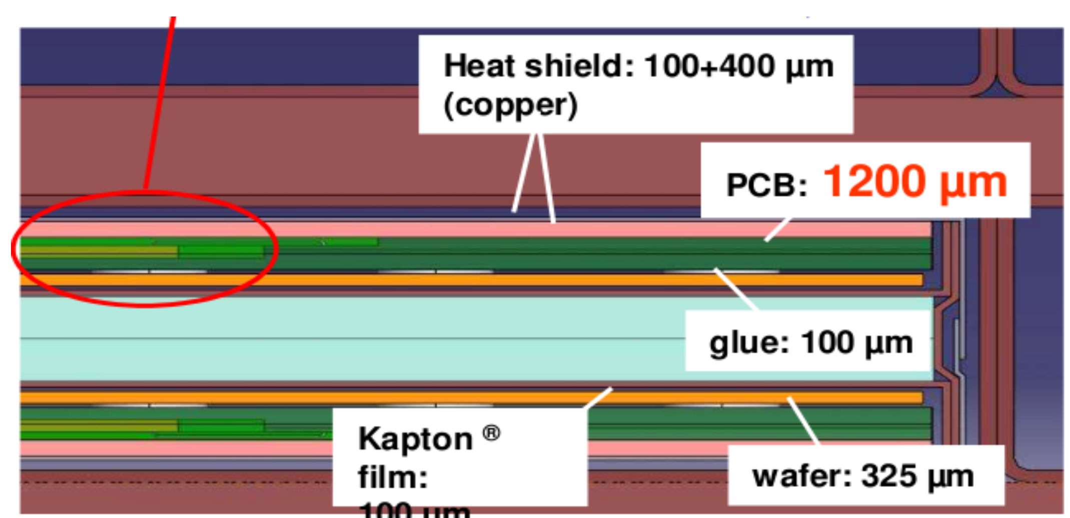
Calorimeter for ILC: Calice R&D project

- High granularity calorimeter system optimised for particle flow measurement of multi-jet final states at ILC, centre-of-mass energy between 90 GeV and ~1 TeV
- Three main calorimetric subsystems: ECAL, HCAL, tail catcher/muon tracker
- Silicon tungsten ECAL:

30 layers (23 X0) SiW sampling calorimeter
10^8 readout channels
Transverse granularity 5 X 5 mm^2
Energy resolution $(16.6\pm0.1)/\sqrt{E(GeV)} \oplus (1.1\pm0.1)\%$



One layer with the tungsten part and the silicon sensor glued onto the PCB



See LPNHE seminar by R. Poeschl:
http://indico.in2p3.fr/getFile.py/access?resId=0&materialId=slides&confId=4711

LPNHE contribution

- People involved at LPNHE: Jean-Eudes Augustin, Jacques David, Patrick Ghislain, Didier Imbault, Didier Lacour, Laurence Lavergne

- taking part to: silicon sensors R&D

An active layer is placed on each side of the layer of the tungsten absorber.

Active layer: a chain of identical Active Sensors Units (ASUs).

ASU: a Printed Circuit Board (PCB) integrating the silicon sensors, Front-End electronics and electrical infrastructure.

Sensors: high resistivity silicon (5KΩ.cm), single-sided process, individual pin-diodes of 5x5 mm^2

- planning to work on:

mechanical assembly: gluing of silicon sensors onto the PCB using a controlled technique

electrical tests: characterisation of the wafers (Leakage current and capacitance versus voltage)

Activities in details

A part of the gluing system: positioning system and gluing machine

- Gluing in LPNHE clean room:
  - Use robotic machine (tests ongoing)
  - Glue tests also being performed
  - Process to be automatized for series production (2500 m^2 of wafers!)
- Electrical tests under probe station on sensors during both R&D phase and series production (wafer qualification)
  - IV curves, CV curves
  - expertise and software already available at the lab in the sLHC group

Conclusions

- R&D activities on silicon detectors for future collider experiments gaining momentum at LPNHE
  - sLHC activity now established, various funding sources exploited, international collaborations developed
  - ILC activities in the ramp-up phase, enthusiasm for a new enterprise
- Increasing expertise on silicon detector R&D being acquired at the lab
- Infrastructure partly already available, missing pieces of equipment being bought thanks to several funding sources/collaborations (IN2P3/UPMC/EU)