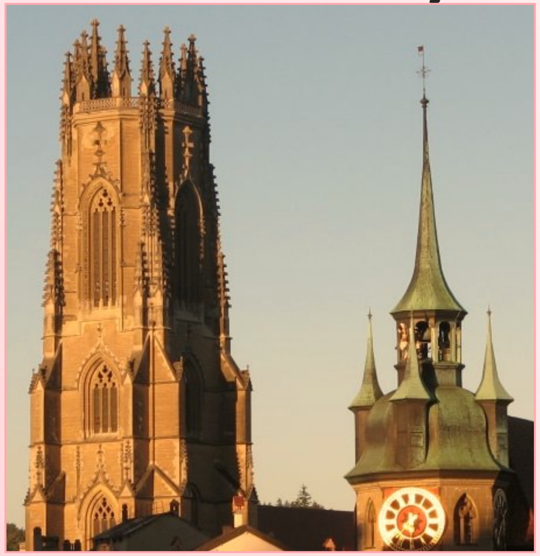
SPS/CHIPP Annual Meeting 2014

Uni Fribourg – Switzerland

June 30 – July 2



The Insertable B-Layer For The ATLAS Upgrade

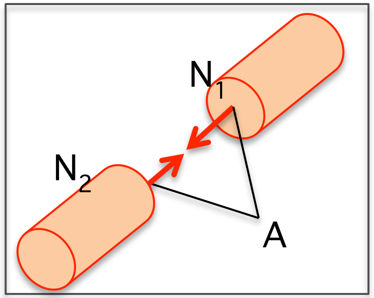
Maria Elena Stramaglia

(AEC/LHEP Uni Bern)

Why IBL?

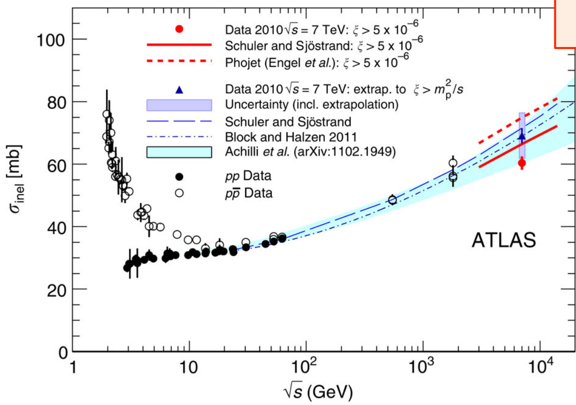
Higher Peak Luminosity & Higher energy!!!!

$$\mathcal{L} = \frac{1}{\sigma_r}\cdot\frac{dN_r}{dt} = \frac{N_1\cdot N_2}{A}\cdot f_i$$

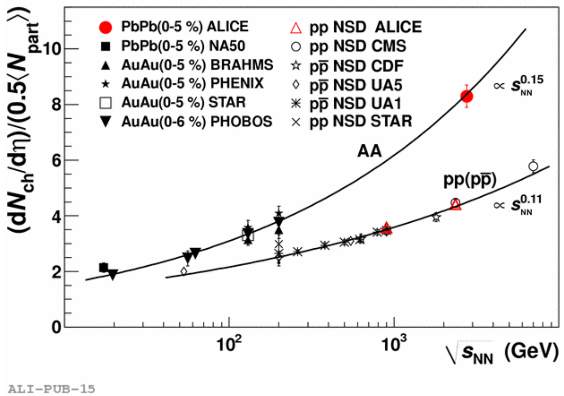


LHC: $8\cdot10^{33}\ s^{-1}\ cm^{-2} \rightarrow 2\cdot10^{34}\ s^{-1}\ cm^{-2}$

LHC: 8 → 14 TeV



p-p cross section increases with the center of mass energy increase.



Charged particles multiplicity increases with the center of mass energy increase.

- **Occupancy:**

  Number of hits per trigger for a given layer divided by the number of readout channels available for this layer.

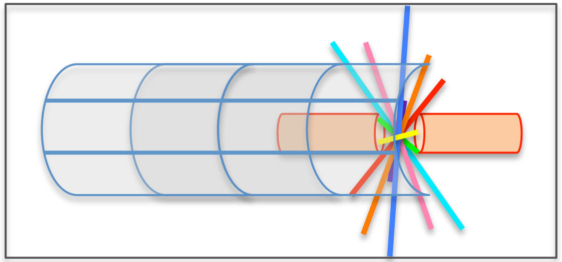
- **Pile-up:**

  Overlap of data collected coming from more collisions with respect to the ones we are sensitive.

Deal with Occupancy and Pile-up

- Higher segmentation

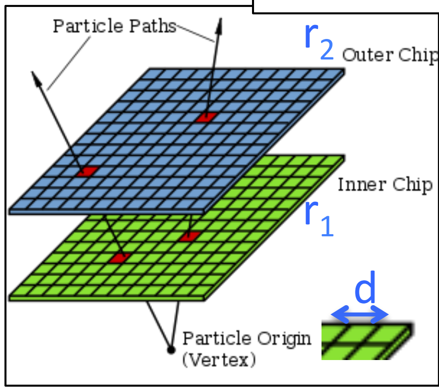
  To reduce the occupancy and pile-up (need of R&D for a faster readout)



- Closer to the beam

  To improve the **vertexing** (reconstruction of the primary and secondary vertexes) and **b-tagging** (identification or "tagging" of jets originating from bottom quarks)

Vertex extrapolation



$$\sigma = \frac{d}{\sqrt{12}}$$

$$\sigma_{vtx} = \frac{r_1}{r_1 - r_2}\sigma$$

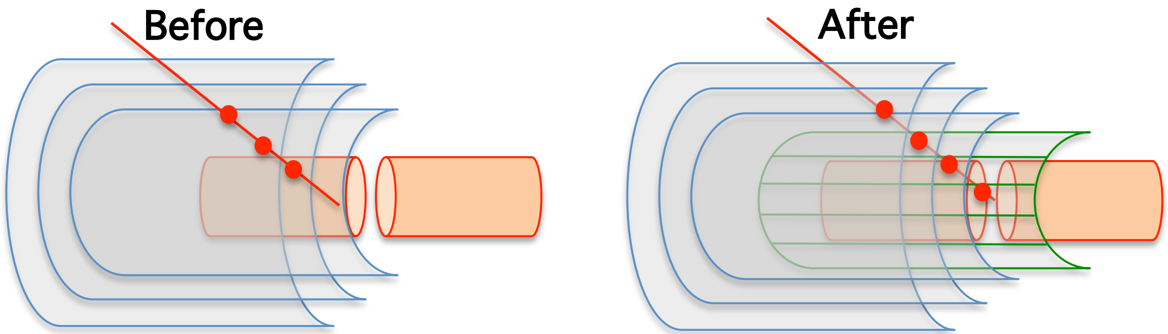
$$\sigma_{vtx} = \frac{r_2}{r_2 - r_1}\sigma$$

$$\sigma_{vtx} = \sigma_{vtx} \oplus \sigma_{vtx} = \sqrt{\left(\frac{d}{\sqrt{12}}\right)^2 \cdot \left(1 + \frac{r_1^2}{(r_2 - r_1)^2}\right)}$$

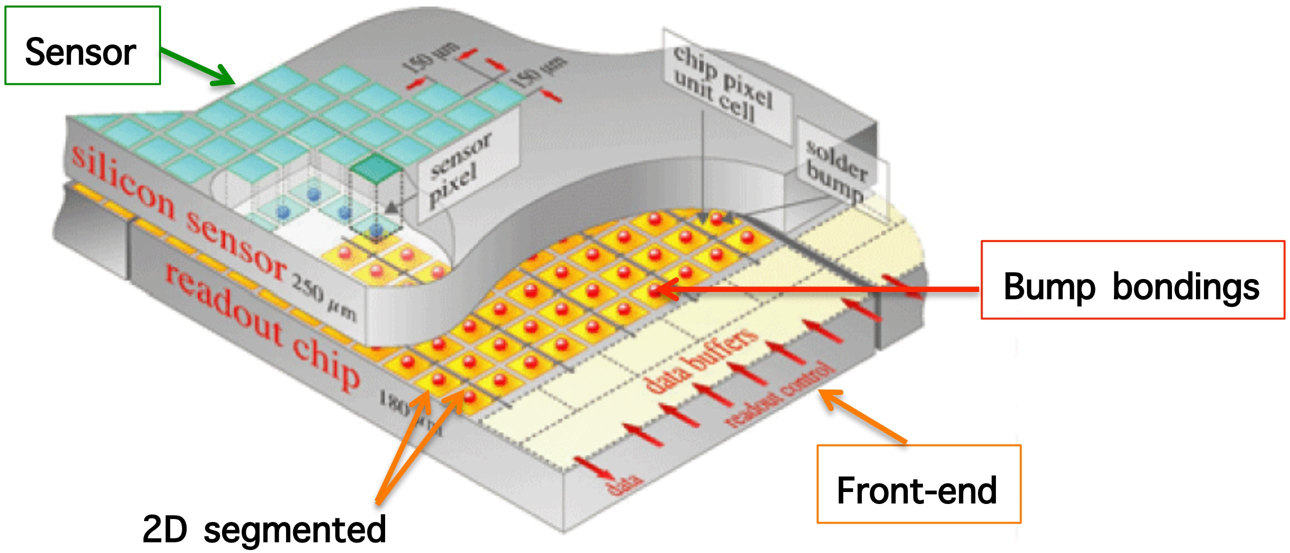
- More layers

  More tracks are better reconstructed with the help of more hits:

$$\frac{\sigma(p)}{p} \propto \frac{1}{\sqrt{N_{layers}}}$$



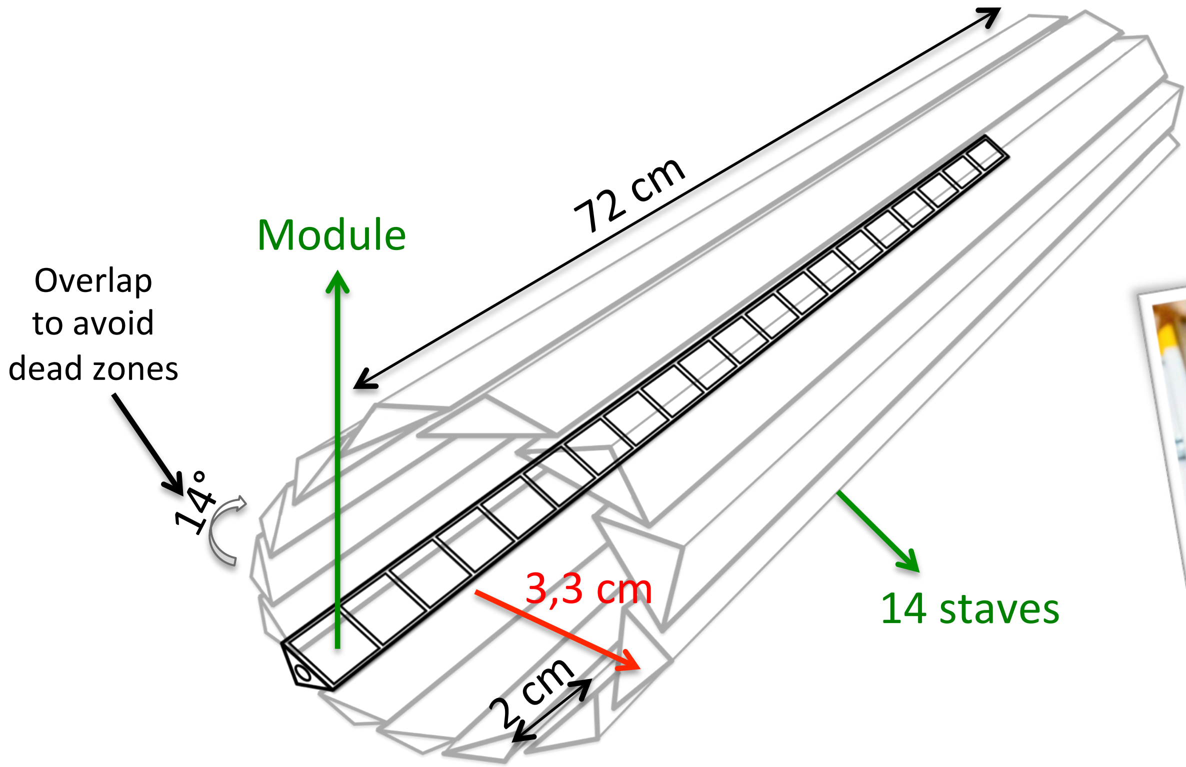
Silicon detector

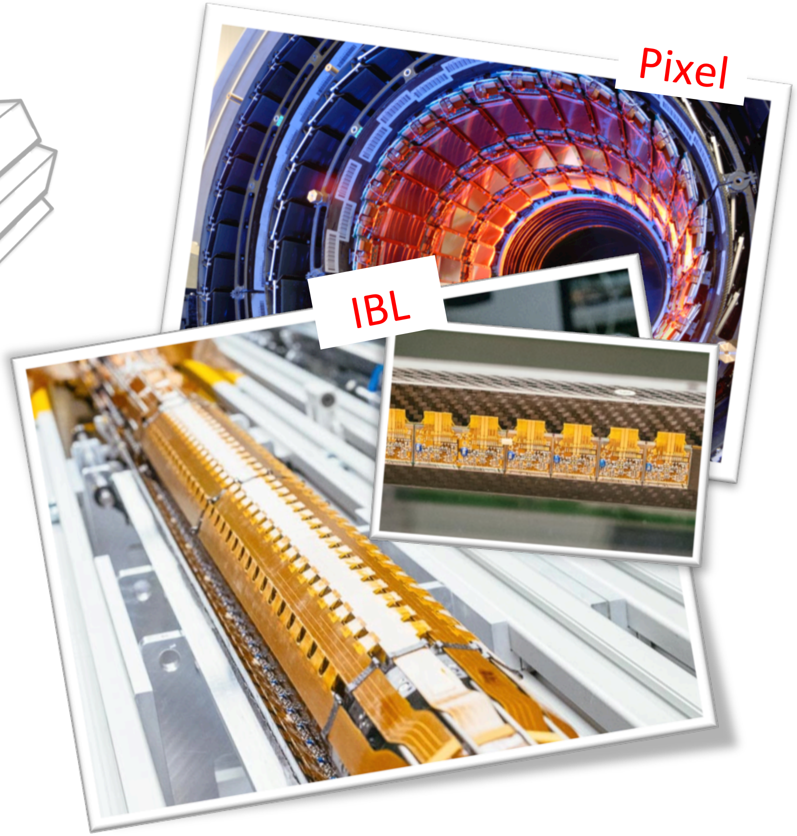


- Module segmentation defined by the electrodes segmentation
  - **Highly segmented:** Typical pixel dimensions: 50 × 400 µm
- **Compact:** Typical sensor thickness: 300 µm
- **Fast:** Typically 15-20 nsec
- **Radiation hard** (integrated luminosity increasing): until $10^{15}\ n_{eq}/cm^2$

IBL Insertable B-Layer

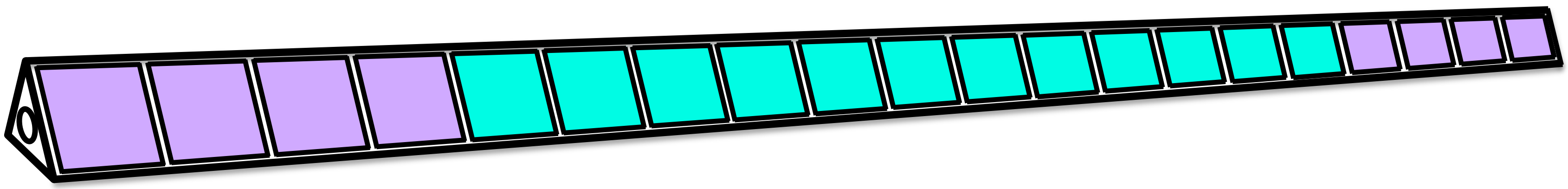
- Silicon detector: compact, highly segmented and radiation hard $10^{15}\ n_{eq}/cm^2$
- Higher segmentation: pixel dimensions: $50 \times 400\ \mu m \rightarrow 250 \times 50\ \mu m$
- One more faster layer: the fourth silicon layer (160 MHz)
- Closer to the beam: radius of 3,3 cm



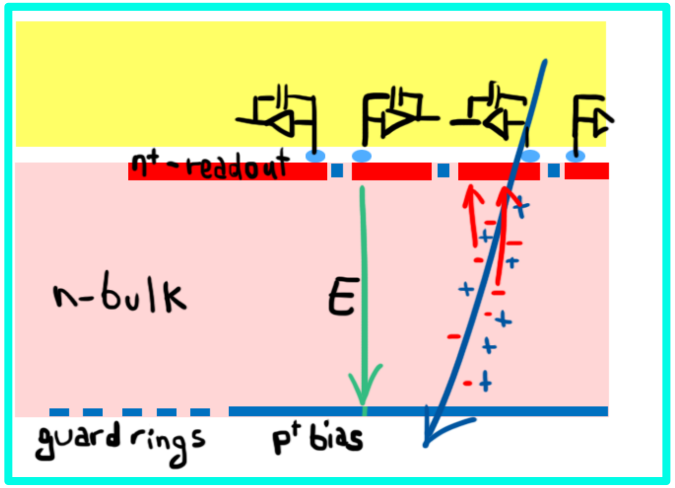


- Insertable: has been inserted in the existing detector with the new beam pipe
- B-layer: improvement for the existing B-Layer with vertexing and b-tagging

IBL Modules - Sensors

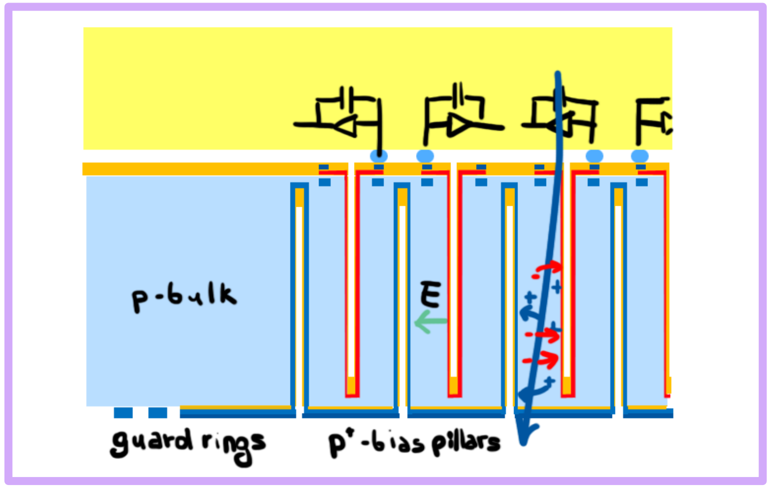


Planar Pixel Sensor (PPS)



- Technology as used in present pixel detector
- High production yield
- Large area sensors (double chip)
- Drift = ionization distance

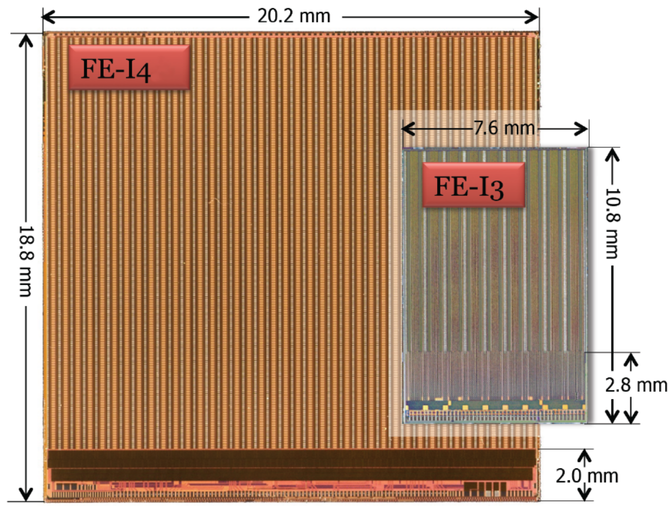
3D Silicon Sensor (3D)

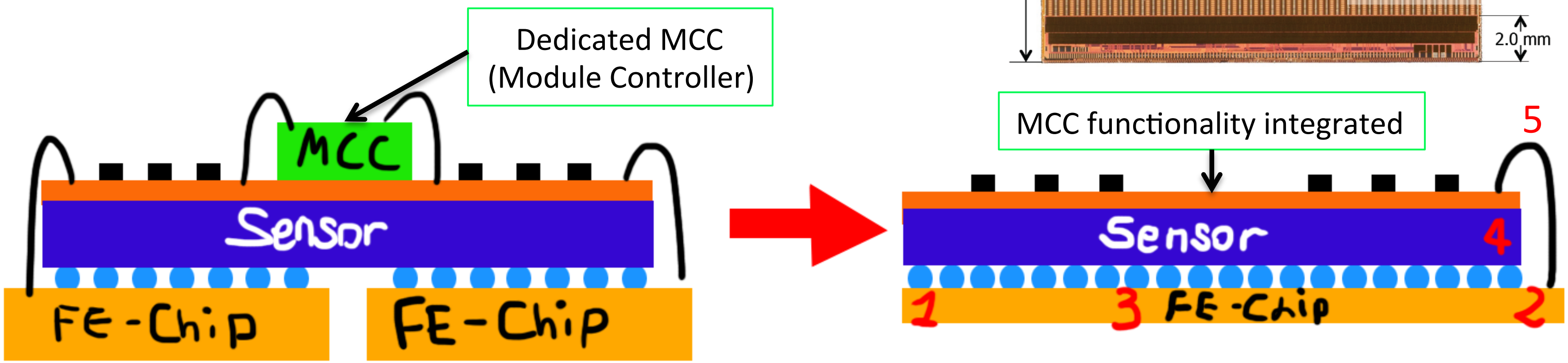


- New technology
- Lower yield
- Radiation hardness
- Smaller area sensors (single chip)
- Drift << ionisation distance

IBL Modules - Fe Chip

- Completely new readout chip developed
- ~ 6 times size of the present pixel chip
- Pixel size 50 x 250 µm (26.880 pixels)
  from: 50 x 400 µm
- Hits stored at pixel level





1.Big chip

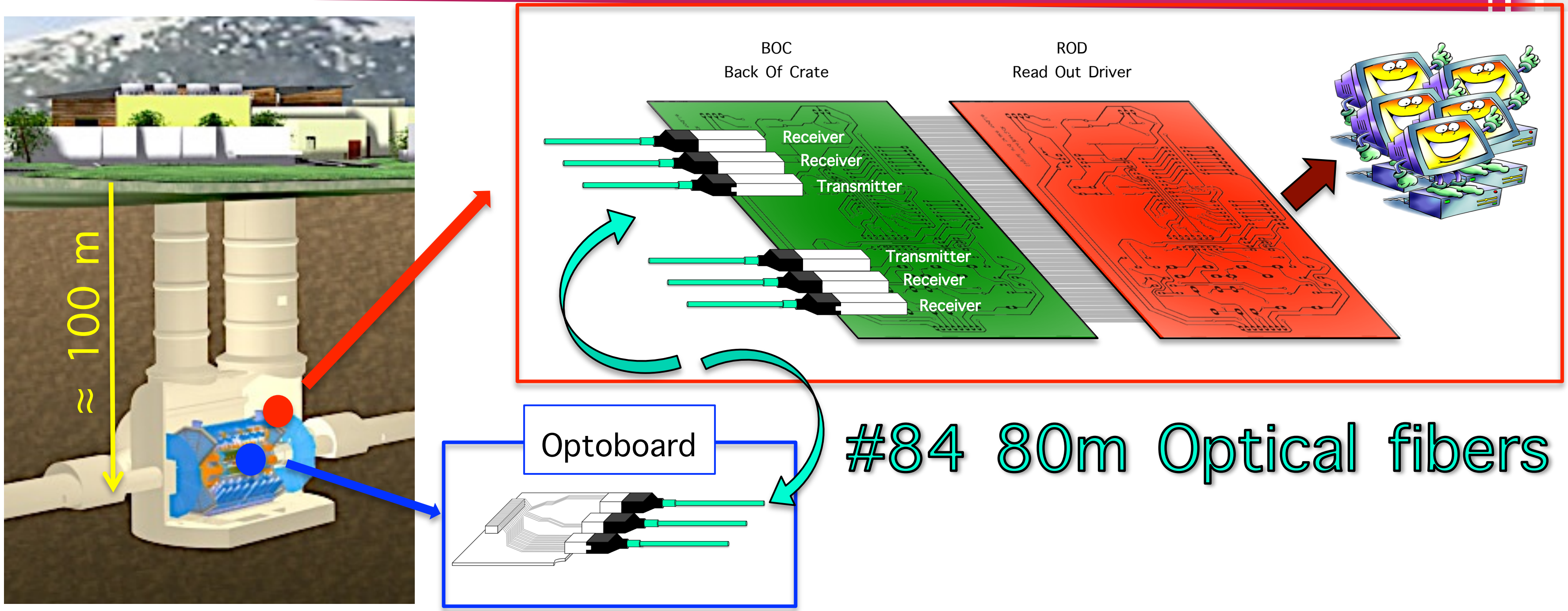
2.Reduce size of periphery (2.8 mm→2 mm)

3.Thin down FE chips (190 µm→150 µm)

4.Thin down the sensor (250 µm →200 µm)

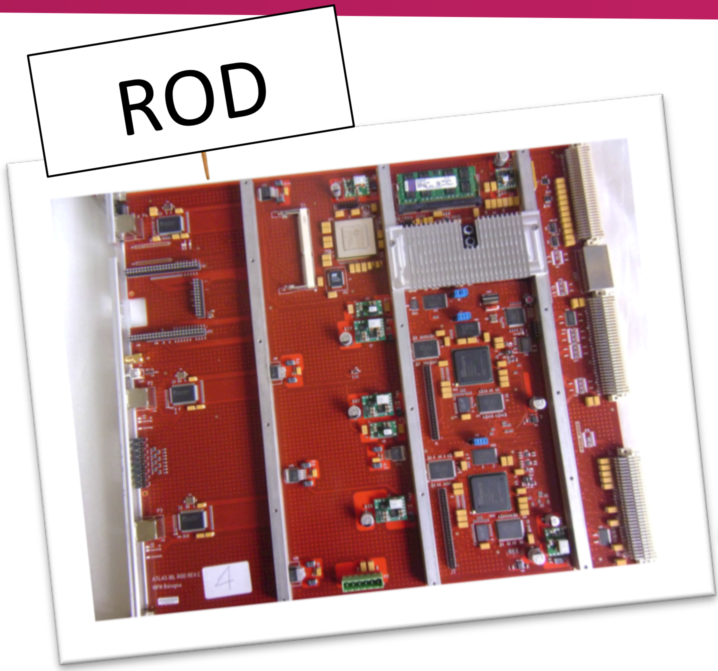
5.Less cables (powering scheme)

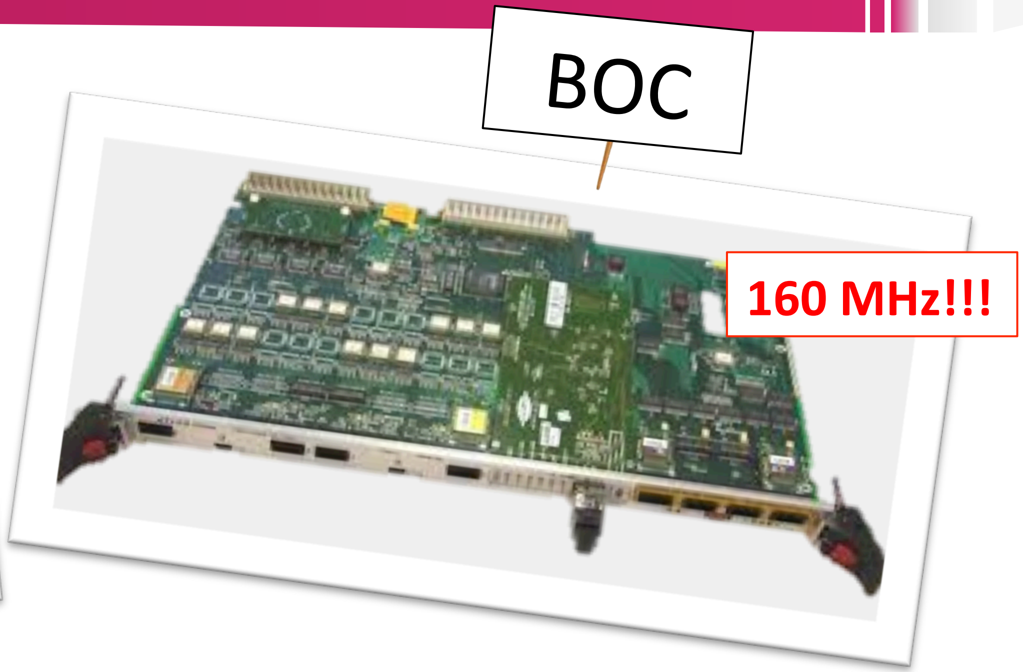
IBL Read-out chain



- Optical transmission: optical fibers improve the transmission
  reduce the volume of cables, eliminate cross-talk and electrical ground loops, wide bandwidth
- Optoboard: electrical ⇔ optical converter
- Read Out boards:
  - optical ⇔ electrical conversion (**Tx** transmitters and **Rx** receivers)
  - DAQ (data acquisition) and storage
  - histogramming
  - calibration and configuration

IBL Boards





ROD (Read Out Driver)

- Data formatting
- Event fragment building and routing
- Histogramming
- Fitting

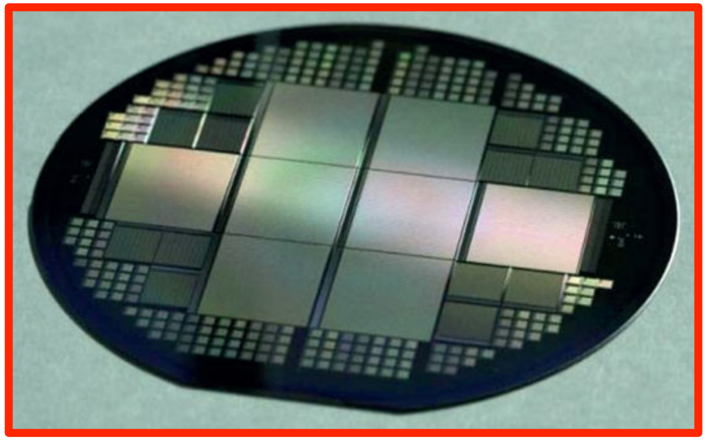
BOC (Back Of Crate)

- Hosts transmitters and receivers: 4 receivers and 2 transmitters for every stave
- Hosts the S-link (fast data link): level-1 accepted events pushed by ROD to higher levels of trigger and DAQ structure
- Clock

From Production Sites to IBL

Sensor production sites:
CNM (Valencia)
FBK (Trento)
CIS (Erfurt)

FE-I4 production site:
IBM



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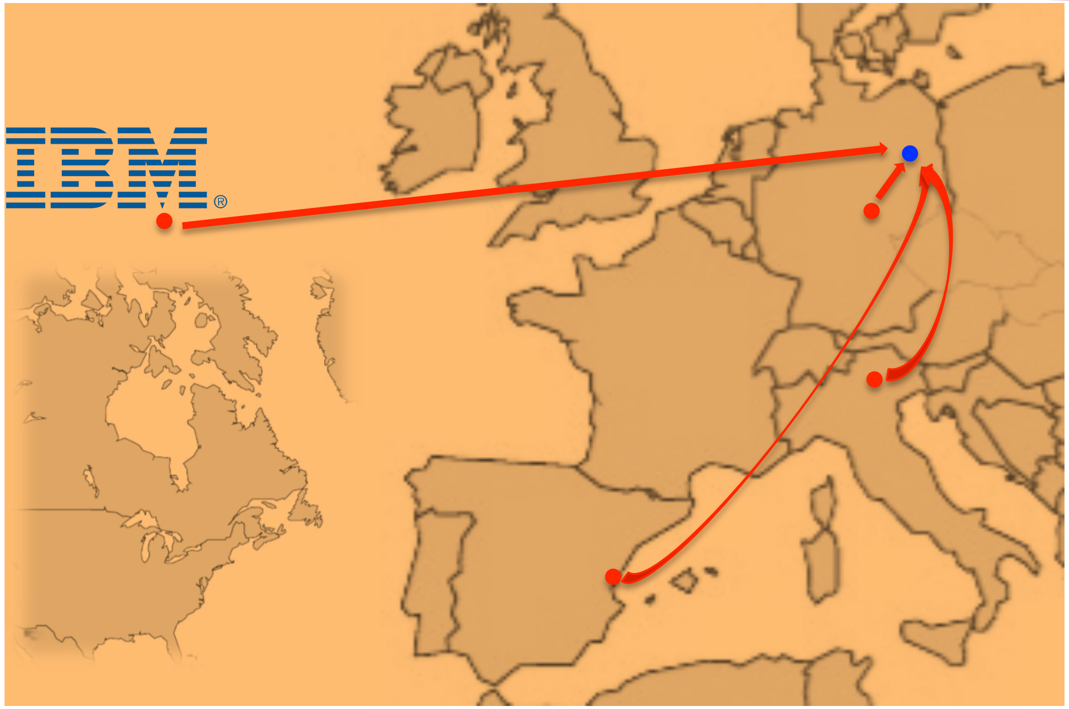

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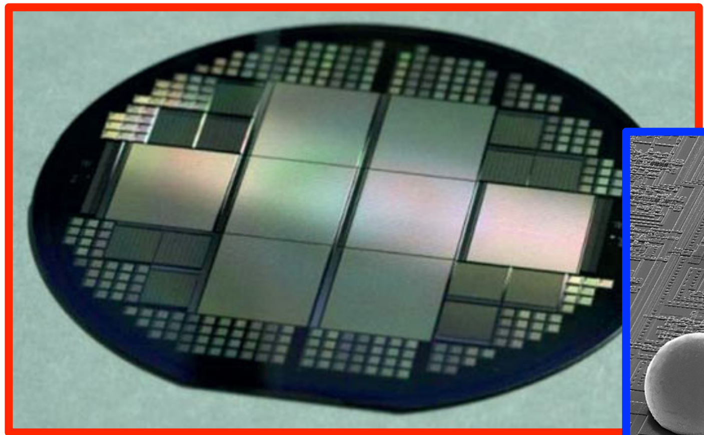
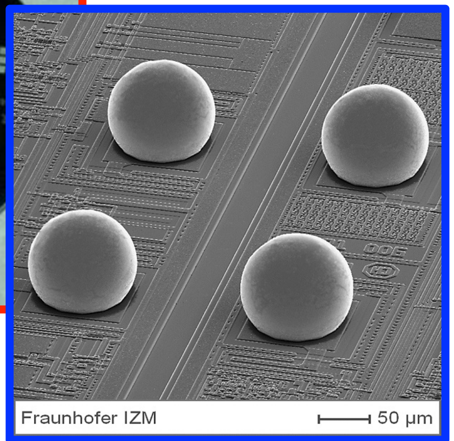
FE-I4 production site:
- IBM

Bump bonding:
- IZM (Berlin)





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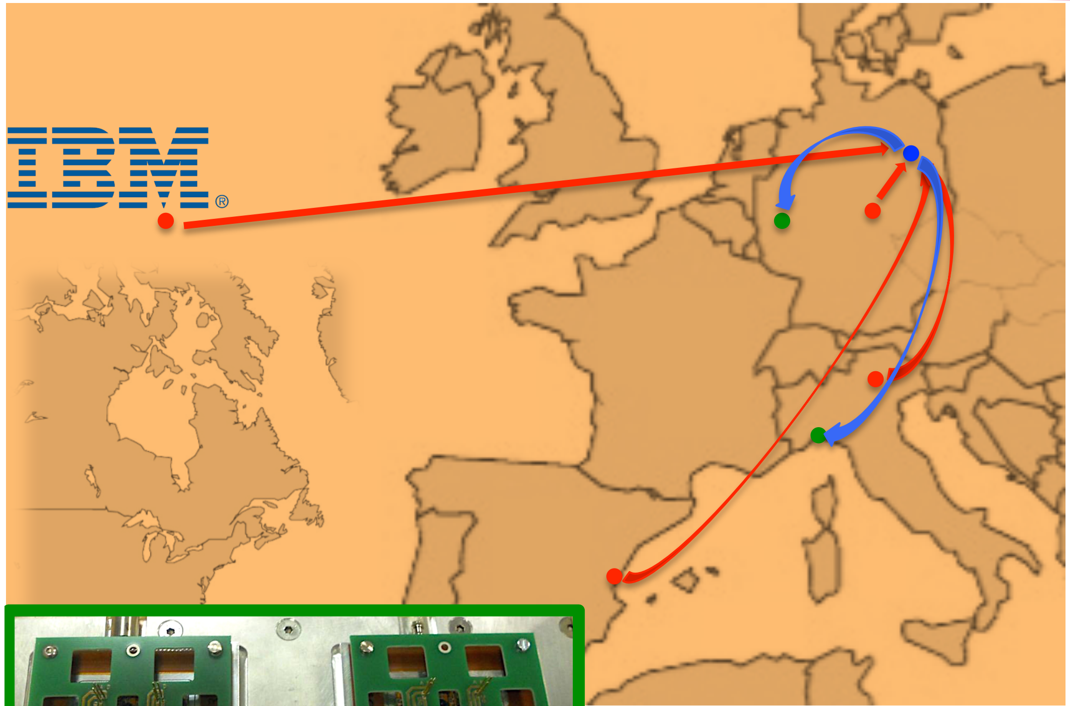

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Bump bonding:

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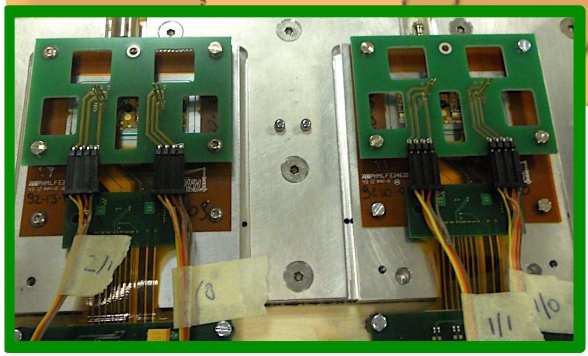
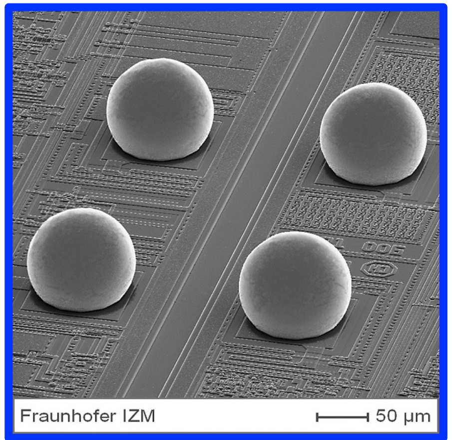
Module assembly:

INFN (Genova)
University of Bonn (Bonn)





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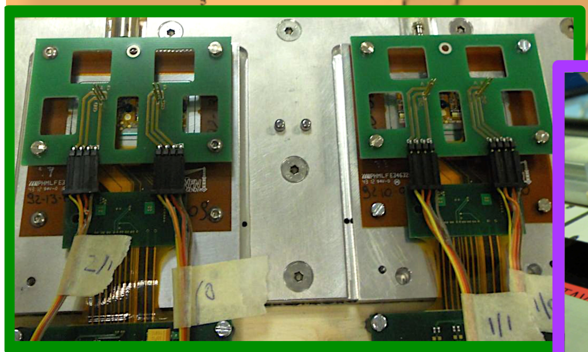

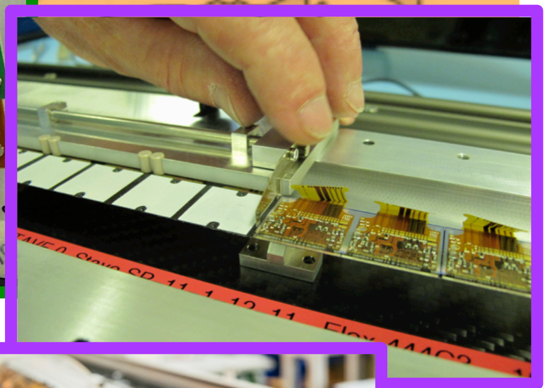

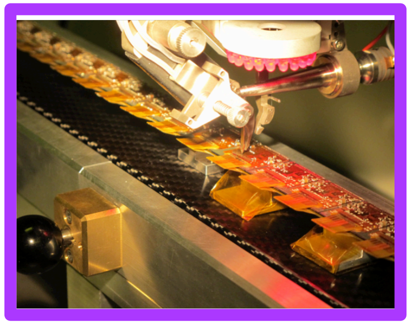

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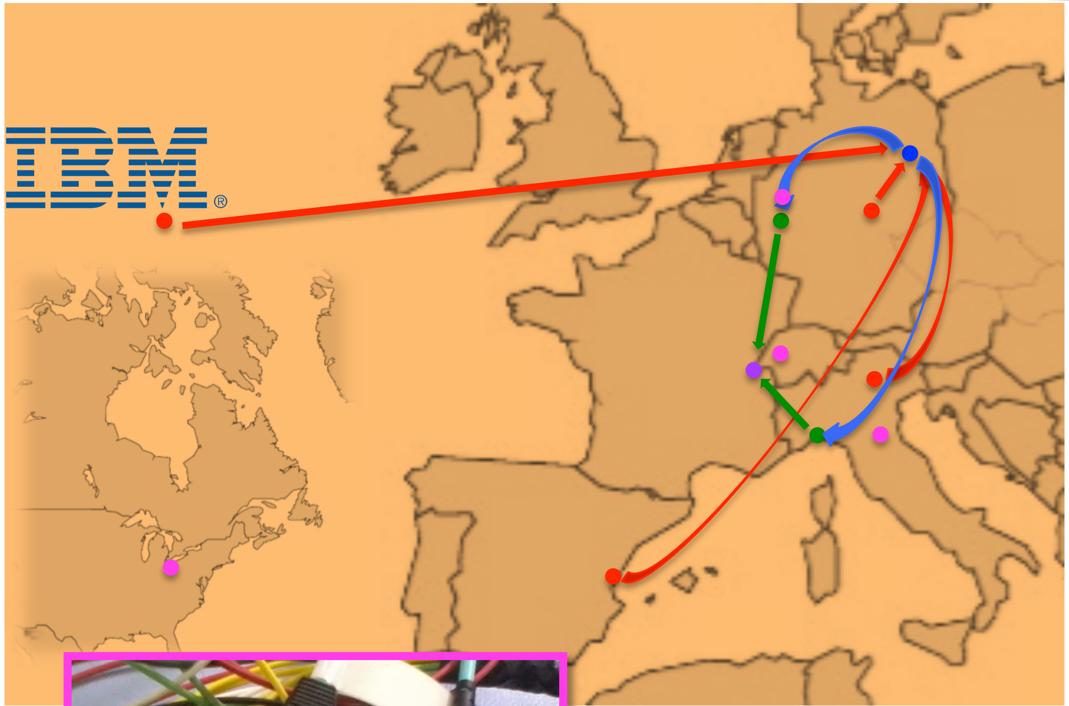
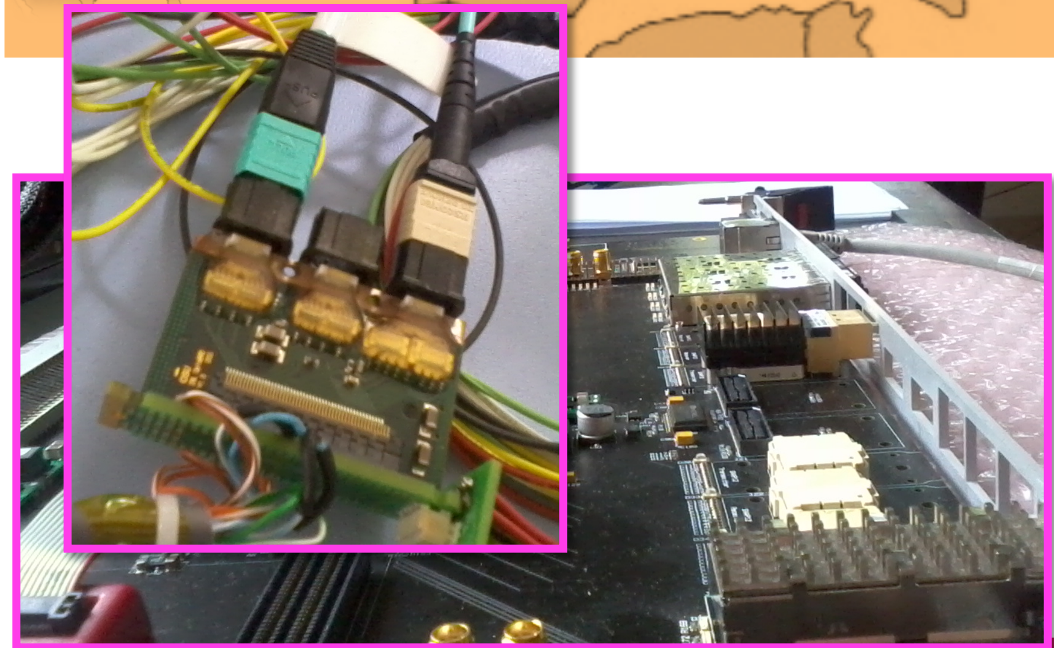
Reception test and Stave Loading
- University of Geneva (Geneva)

Quality Assurance, staves integration
- CERN (Geneva)

From Production Sites to IBL





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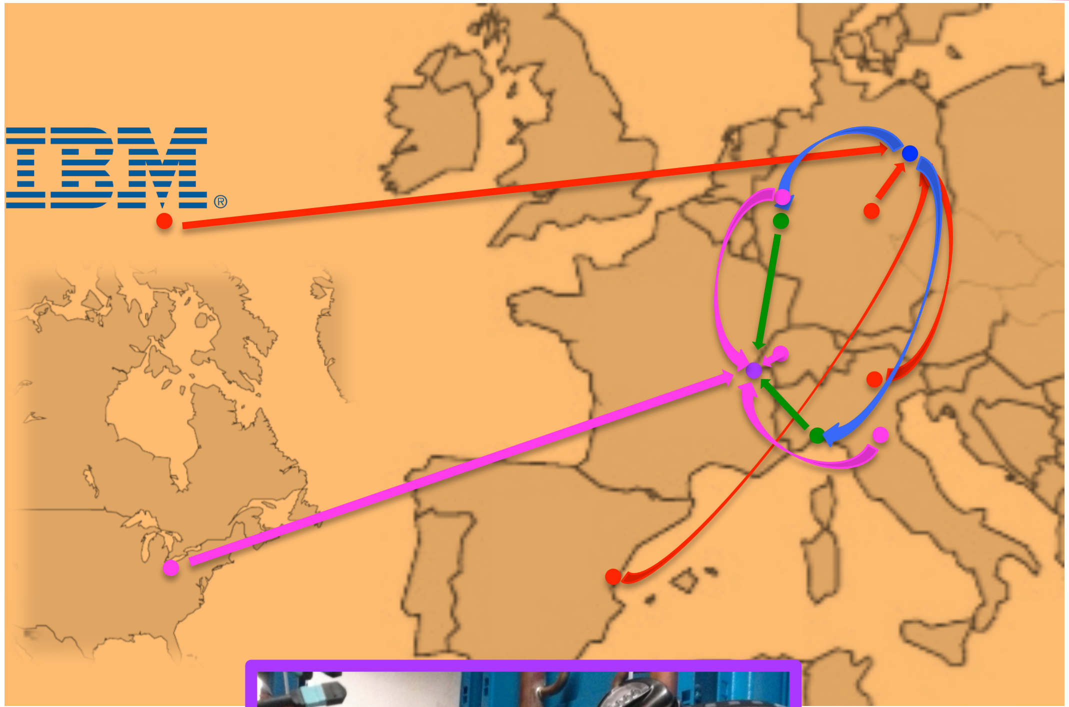
BOC production and firmware development
- University of Wuppertal (Wuppertal)

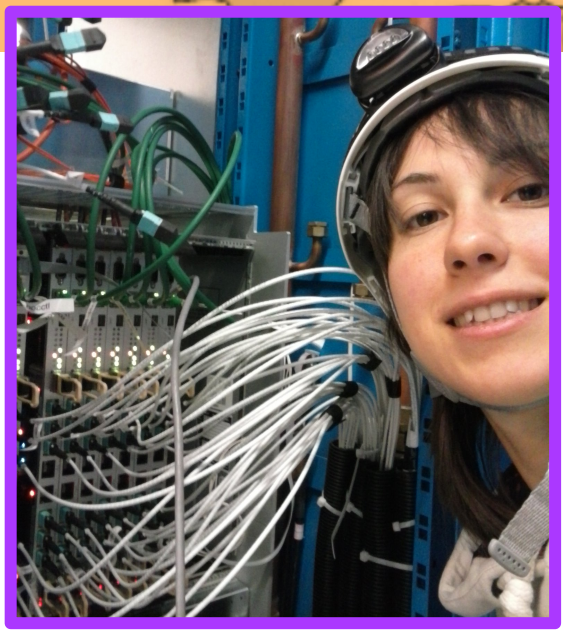
ROD production
- INFN Bologna (Bologna)

Optoboard production
- University of Ohio (Ohio – USA)

Tx and Rx tests
- University of Bern (Bern)

From Production Sites to IBL





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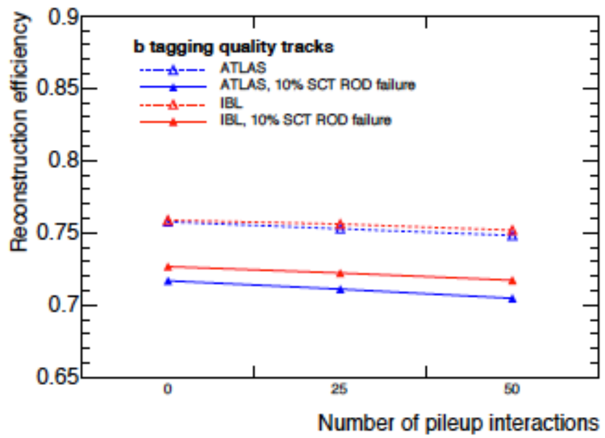
- University of Ohio (Ohio – USA)

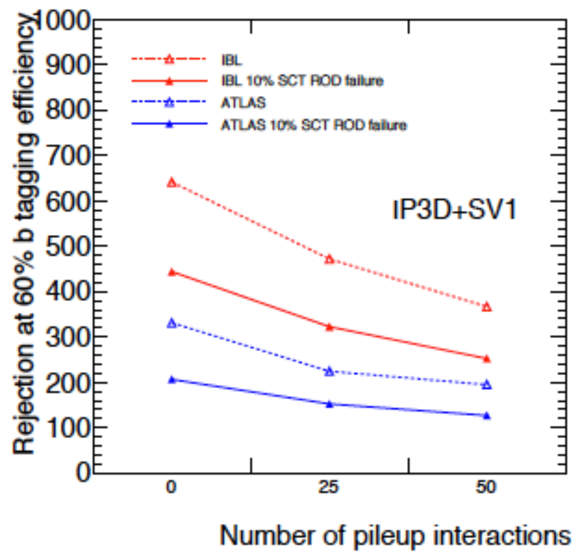
Tx and Rx tests
- University of Bern (Bern)

Read-out tests at CERN

Conclusions

- IBL project is the upgrade for the ATLAS Pixel Detector in LHC phase-I upgrade
- The 4th layer has been included into the Pixel system
- Radiation tolerance of electronics and sensors is 10^{15} n_{eq}/cm^2
- The detector passed a long and detailed quality assurance procedure
- IBL has been installed and it is ready for configuration and testing
- ATLAS simulation showed significant improvement in tracking, vertexing and b-tagging





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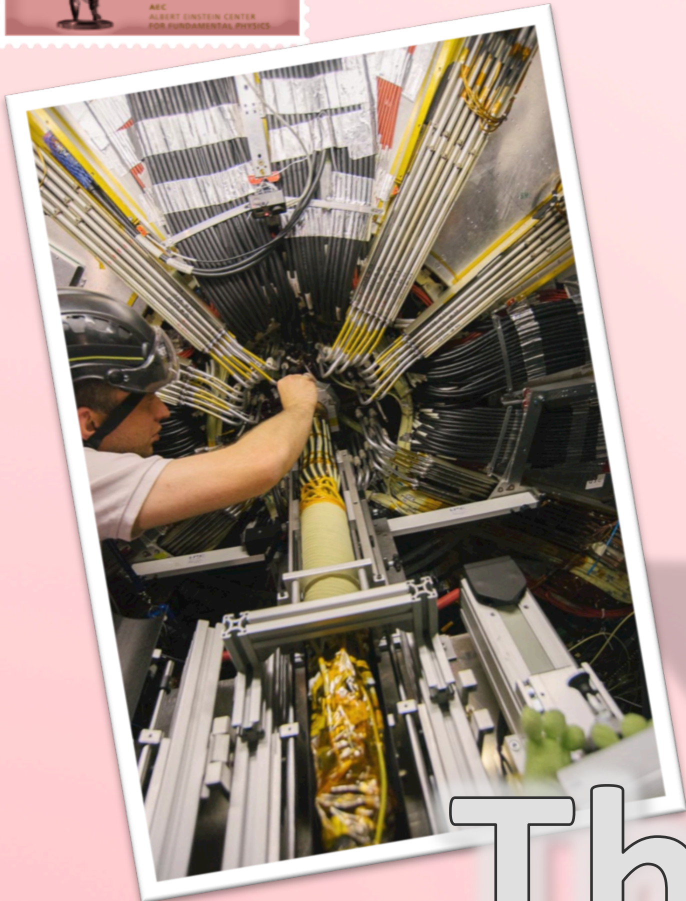
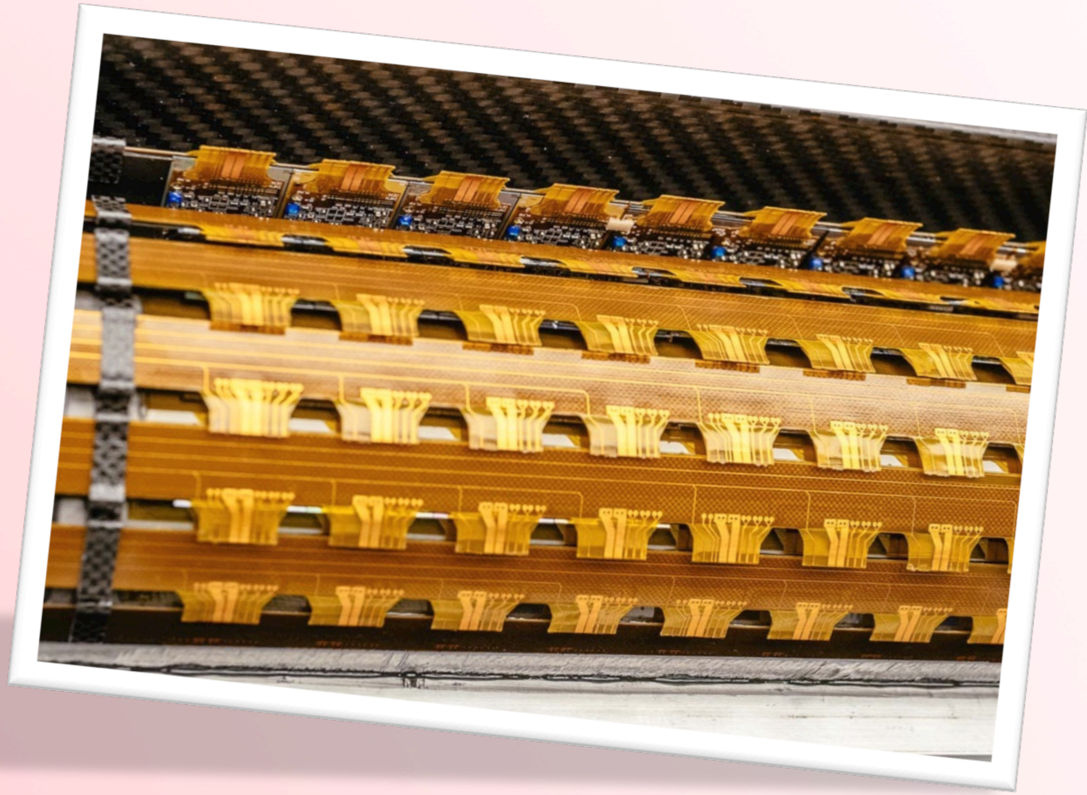
LHEP
UNIVERSITÄT BERN





Thank you !!!

Backup

Where IBL was born

Two-ring-superconducting hadron accelerator and collider

- Installed in the existing (26.7 Km) LEP tunnel
- Proton beams colliding with (7-8-**14 TeV**) centre-of-mass energy
- Pb ions colliding with an energy of **2.8 TeV** per nucleon-pair
- Crossing frequency: (every 50-**25 ns**)

>900, all peer reviewed

ATLAS Experiment

- Multi-purpose experiment
- Search for new discoveries after the Higgs Boson:
  - extra dimensions
  - fundamental forces unification
  - much more
- Shutdown for upgrades 2013-2014

ATLAS detector

Overall layout: shell structure with several specialized sub-detectors

Inner tracking system

- Silicon pixel detector
- Silicon strip detector (SCT): four barrel layers and nine disks on each side
- Straw tube tracking detector
- Transition Radiation Tracker (TRT): for the electron identification

Electromagnetic calorimeter

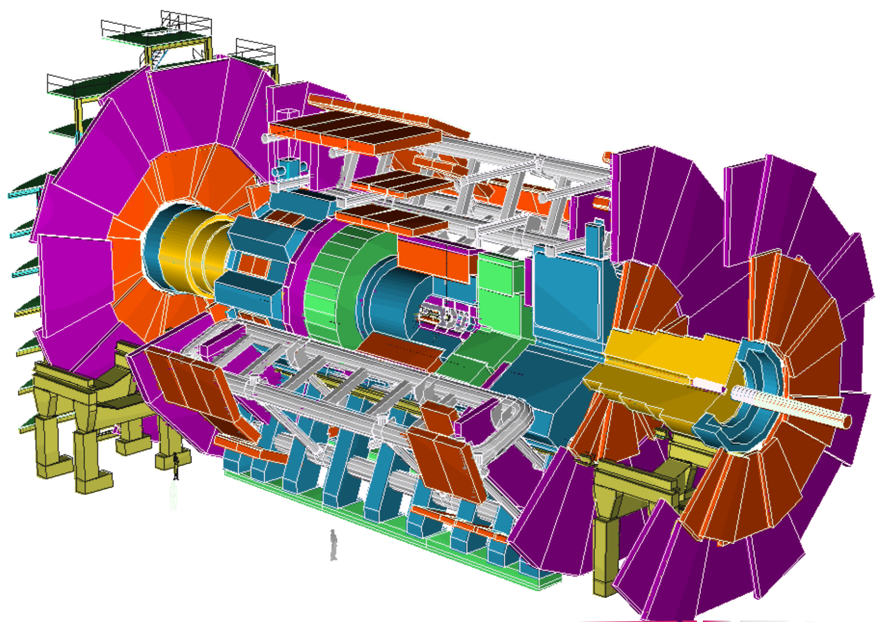
- Liquid-argon

Hadronic calorimeter

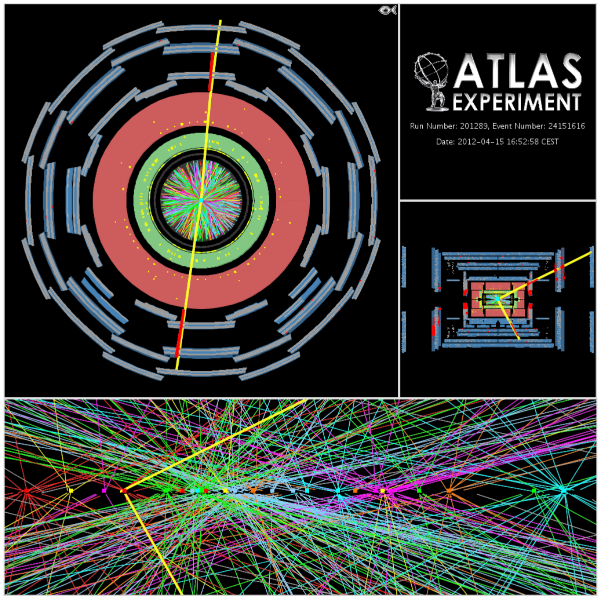
- Liquid-argon for the end-caps
- Scintillator-tiles for barrel

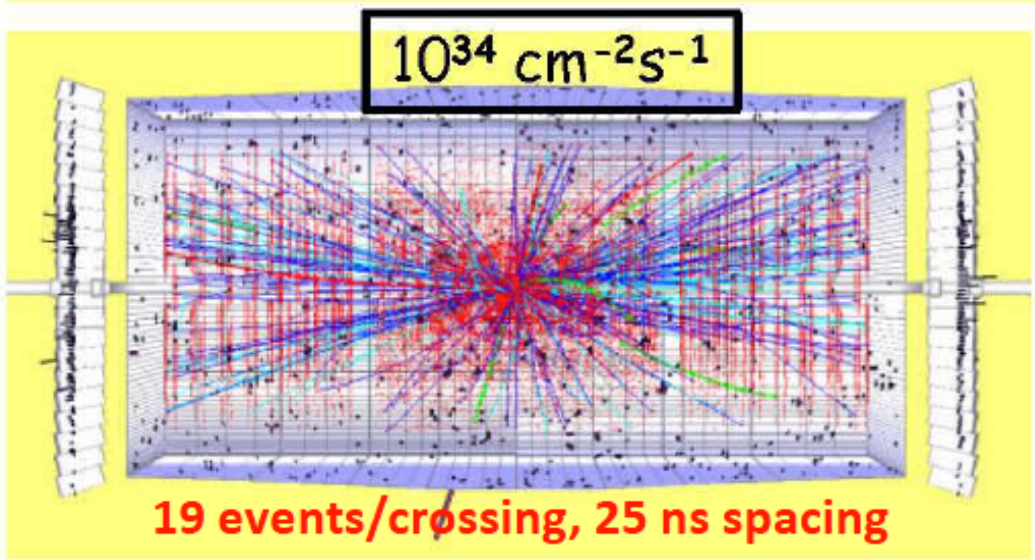
Monitored drift tubes

Air-core toroid magnet coils (2T)



Occupancy and Pile-up





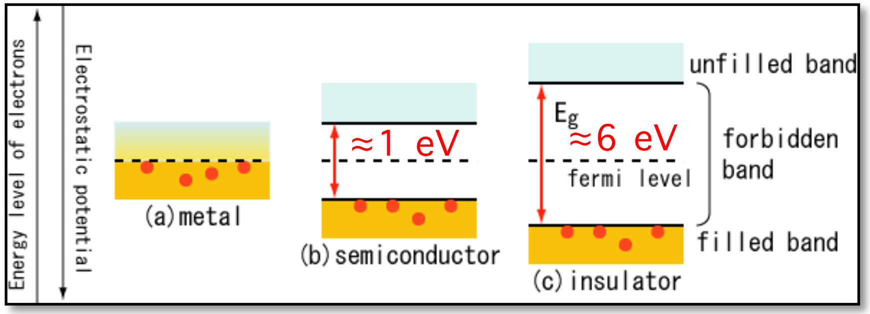
- Occupancy:

  Number of hits per trigger per a given layer divided by the number of readout channels available for this layer

- Pile-up:

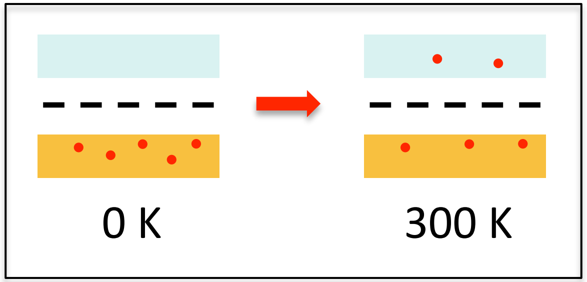
  Overlap of data collected coming from more collisions respect to the ones we are sensitive.

Silicon Detector working principle



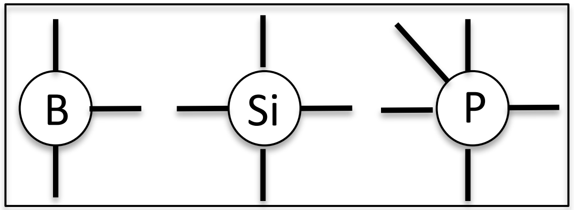
Solid state metal, semiconductor and insulator bands.

(T = 300 K: n_{fe} ~$1.45 \cdot 10^{10}$ cm^{-3})



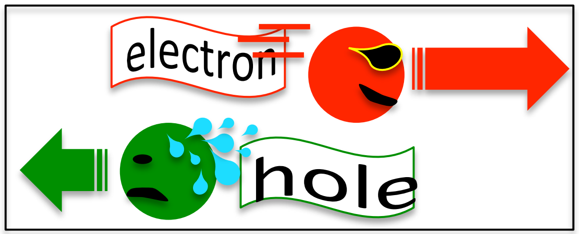
- At 0 K, all electrons are in valence band
- At higher temperature: electrons in conducting band, holes in the valence band

(for Si: B p-doping and P n-doping)

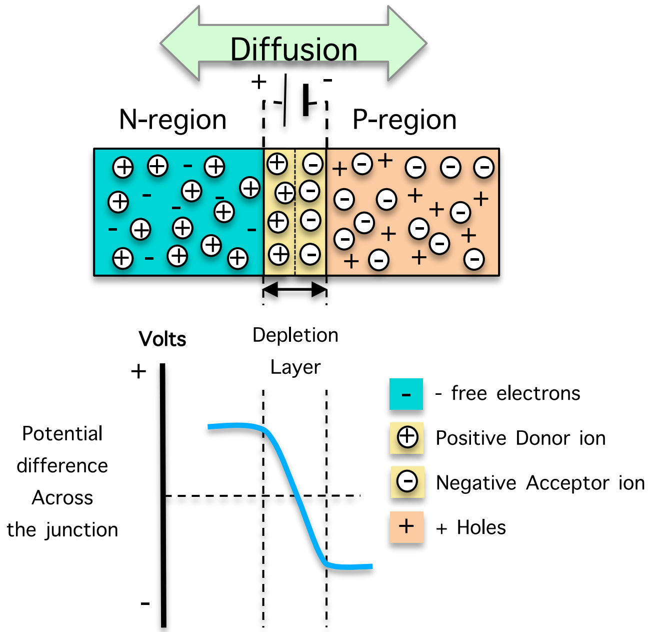


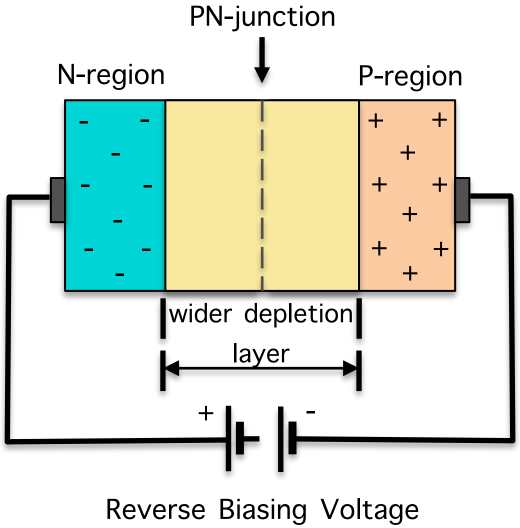
- The number of free charges can be increased "doping" the semiconductor

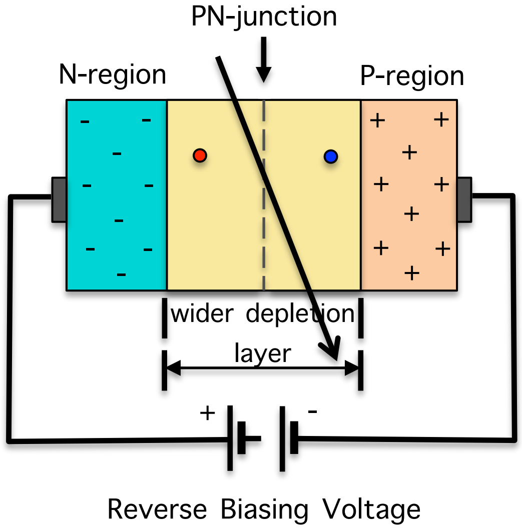
- If you then apply an electrical field the free charges will move:
  - $v^n_D = \mu_n E$ with μ_n = 1450 cm/Vs for electrons in Si
  - $v^p_D = \mu_p E$ with μ_p = 450 cm/Vs for holes in Si



Silicon Detector working principle







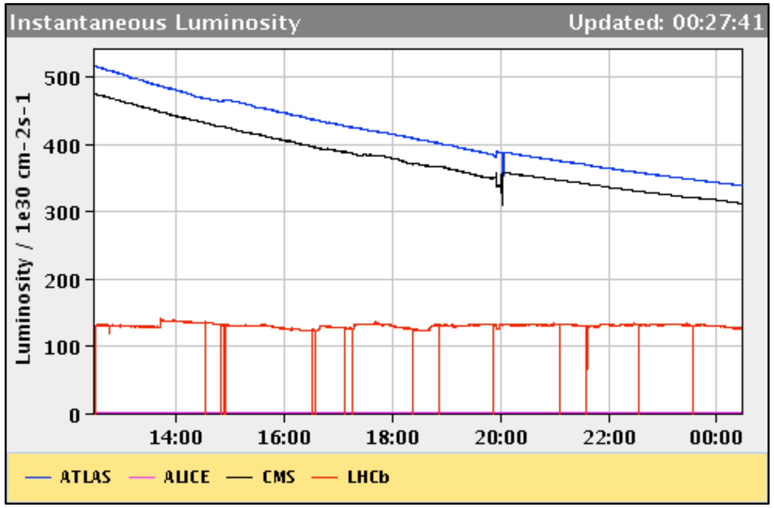
- Contact diffusion (gradient)
- Dinamic equilibrium with potential difference

- Reverse Bias voltage
- Electric field more intense

- Charged particles ionize
- The free charges are driven by the field
- A current is read proportional to the number of generated pairs

Higher Integrated luminosity

$$\int_{t_0}^{t_1} \mathcal{L} dt$$



- Increasing $\mathcal{L}$, the Integrated luminosity will grow faster
- Many particles run over the detector
- Not all can be detected
- Ageing of the sensors and of the readout chain
- Some kind of radiation may damage the sensoristic or the electronics
  - Not ionizing energy losses for Si detector (mostly present in hadronic collisions)
- Need of radiation hard detector

Radiation damages

- Bulk (crystal): due to Non Ionizing Energy Loss (NIEL)

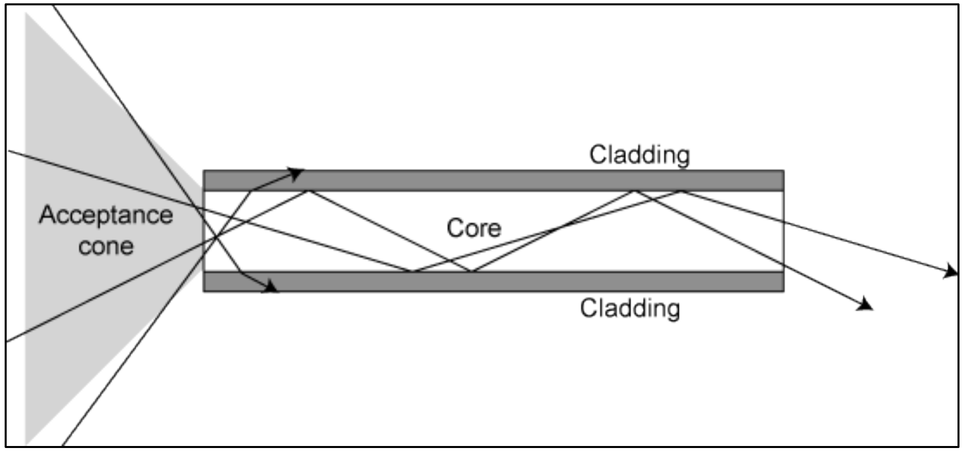
  displacement damage, crystal defects/microscopic defect

  - Change of effective doping concentration (higher depletion voltage)
  - Increase of leakage current (increase of shot noise, thermal runaway)
  - Increase of charge carrier trapping (reduced charge collection efficiency)

- Surface: due to Ionizing Energy Loss (IEL)
  - Charge build-up
  - Traps at the interface between bulk and electrodes)breakdown of critical corners)
  - Surface generation current (increase shot noise)

Optical fibers

- Cylindrical dielectric waveguide
- Transmits light along its axis
- Trasmission by **total internal reflection**
- A core surrounded by cladding layer



- Fibers with large core diameter (>10 µm) are called multi-mode fibers (more confined transverse modes)
- Multi-mode fibers may be analyzed by geometrical optics
- **Our fibers** are **multi-mode** fibers (50/125 µm)
- A larger core size simplifies connections and also allows the use of lower-cost electronics

FE Chips and signal processing

- Consider the rising edge
  - Fast
  - Proportional to the charge
- Shape the signal
  - To easier handle it
  - Slope tuning
- Amplify the signal
  - To have a clear information
- Compare it with a threshold
  - To be above the noise
- Digitalize the information
  - Easier to treat
  - Proportional to the original hight