LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

French Task force for Phase 2 ATLAS Tracker construction

Future Contributions of LPNHE & LAL and IRFU

Giovanni Calderini – LPNHE, Paris
Abdenour Lounis- LAL, Orsay

Overview of the presentation

- Introduction to the ATLAS context
- Contributions to the development of the Inner Tracker system
- Future plans for ATLAS ITK construction
- Infrastructures to contribute as an ATLAS pixel production center
- Conclusions

Pixel sensors R&D groups (Almost 10 yea rs)- People involved

LAL:

A. Lounis,

Phd Students : T. Rashid+ Dmytro Hohov (Kiev)

Past contributions: C. Nellist (PostDoc), E. Gkougkousis (P... A. Bassalat (PhD), M. Benoit (PhD), J. Idarraga (PostDoc), Vladimir Linhard (PostDoc)

For the Construction: D. Varouchas, L. Fayard, C.A. Bourdarios, R.Tanaka

LPNHE:

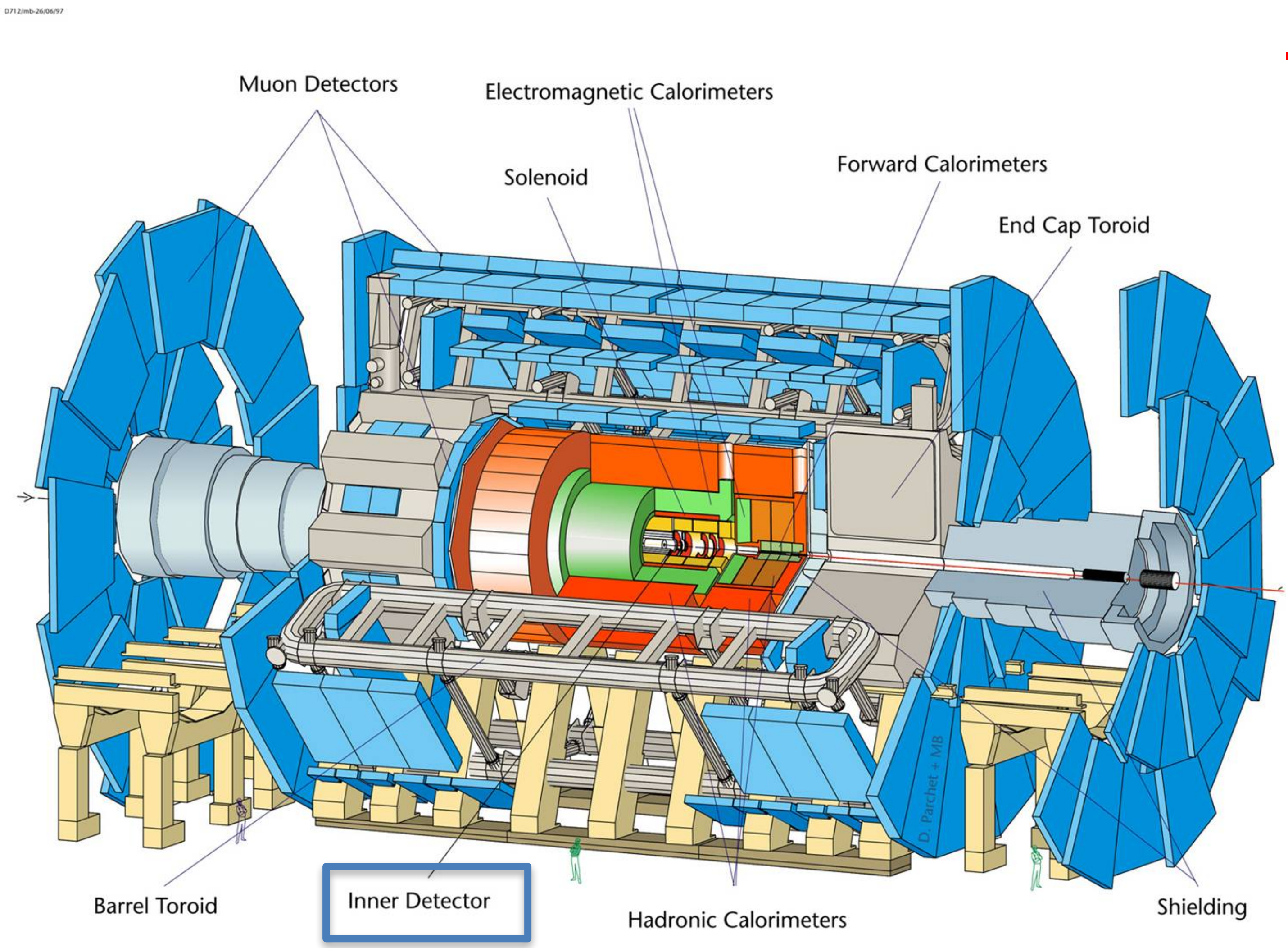
G. Calderini

M. Bomben, G. Marchiori, F. Cresoli,

PhD student : A. Ducourthial , J. Chauveau

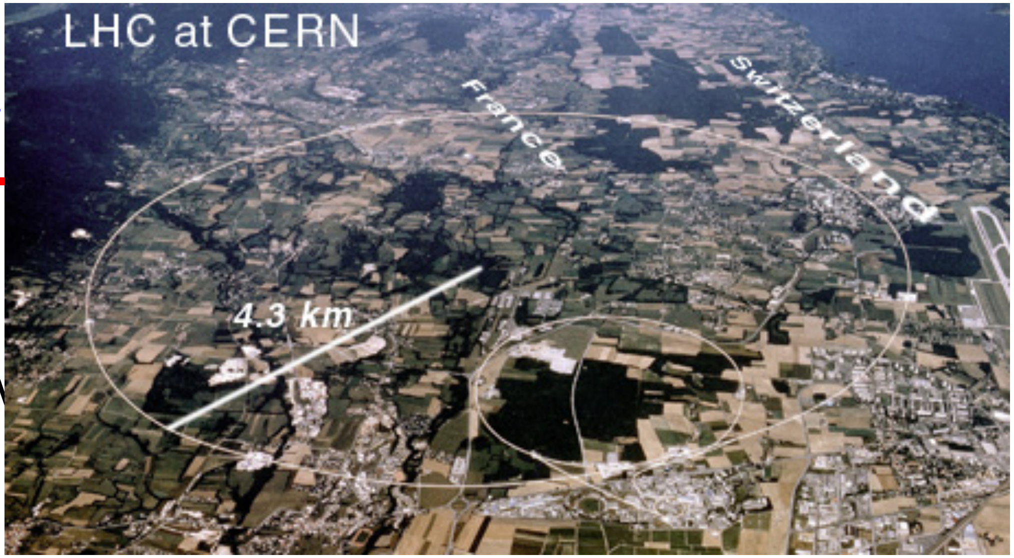
Yourii Piadyk, Mykyta Haranko (Kiev)

ATLAS detector



- Huge multi-purpose detector; 46 m long; diameter 22 m; weight 7000 t
- Tracking system: 7 m long; diameter 2.3 m; 2 T field

ATLAS Tracker at LHC



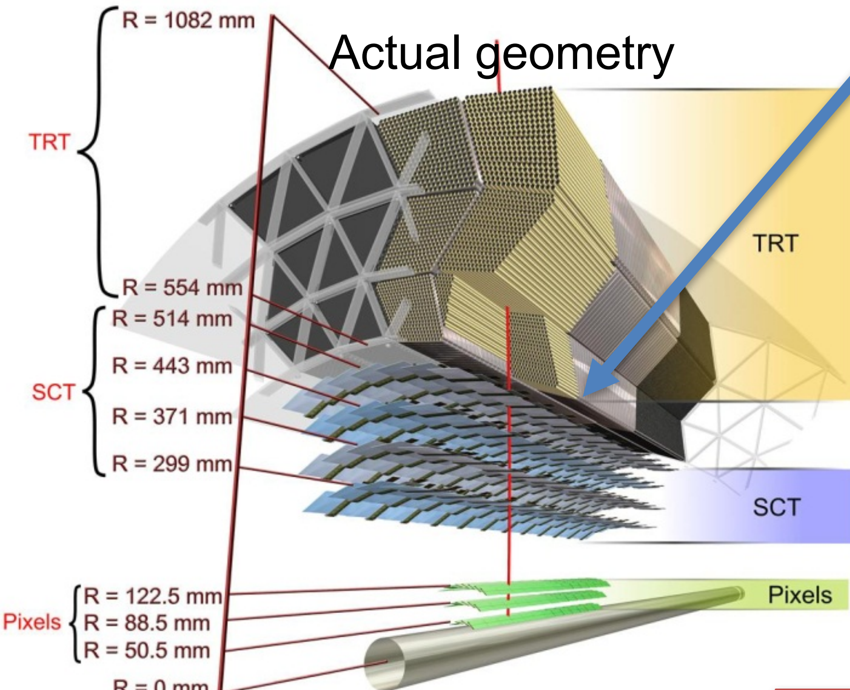
- **L**arge **H**adron **C**ollider in ~27km, E=14 TeV, L=10^{34} $cm^{-2}s^{-}$ Beam-crossing: 40M
  - 1 GHz interaction rate, 10^3 particles each 25 ns.
- Tracking detectors must fulfill the conditions:
  - Fast (40MHz), Rad-Hard (10-100kGy), high granularity & good pattern recognition capabilities (10^3 tracks/25 ns).
- Environment is very radiation hostile: Accuracy and we should be able to measure tracks!
  - To measure momenta (→dynamics, invariant masses)
  - To measure vertices
    - » Primary → improve on p and E measurements
    - » Secondary → tag ps living particles (b,τ)→ markers of events with significant physics content
  - To help identifying photons

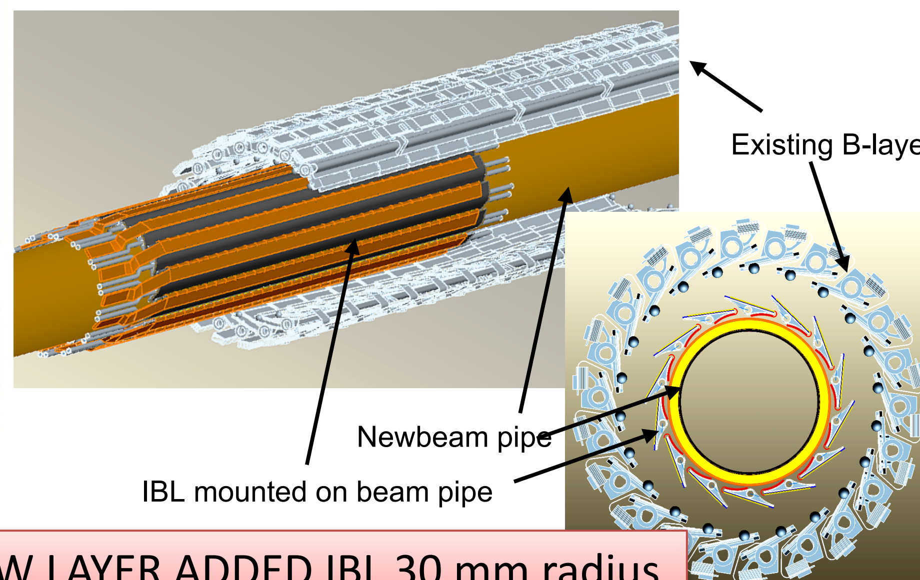
Bref summary of what has been acheived

Focus on the actual pixel system

Detector:	Silicon area [m^2]	Channels [10^6]
Pixel barrel	5.1	445
Pixel end-cap	3.1	193
Pixel total	**8.2**	**638**
Strip barrel	122	47
Strip end-cap	71	27
Strip total	**193**	**74**

Table 6.6: Inner tracker active area and channel count.





NEW LAYER ADDED IBL 30 mm radius

Past important contributions

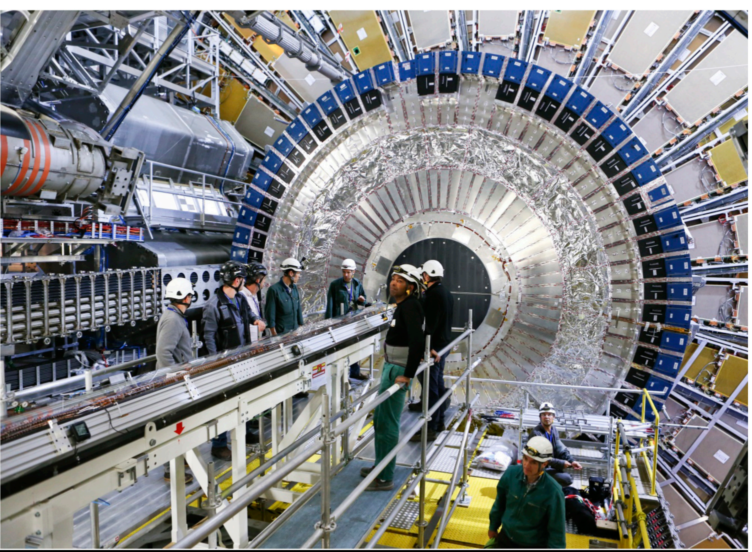
- IN2P3 important contributions

(2010-2015) for the Insertable B Layer project :

- Sensors
- Cooling
- Mechanics
- Integration

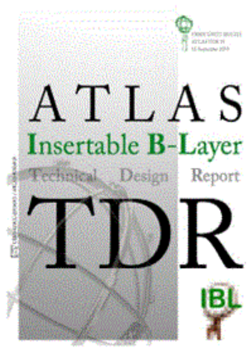
Work in Labs & manpower

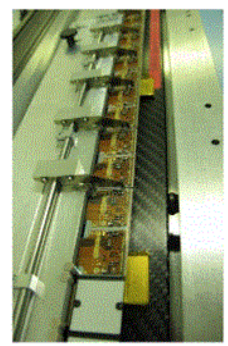
(1 LAL-PhD student @CERN)

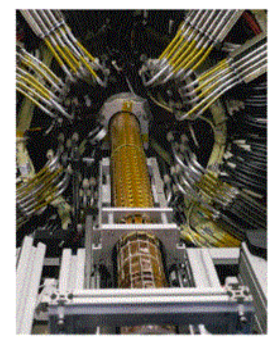


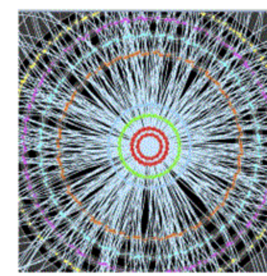
History of construction and operation

September 2010	Mid 2012	May 2014	May~ 2015









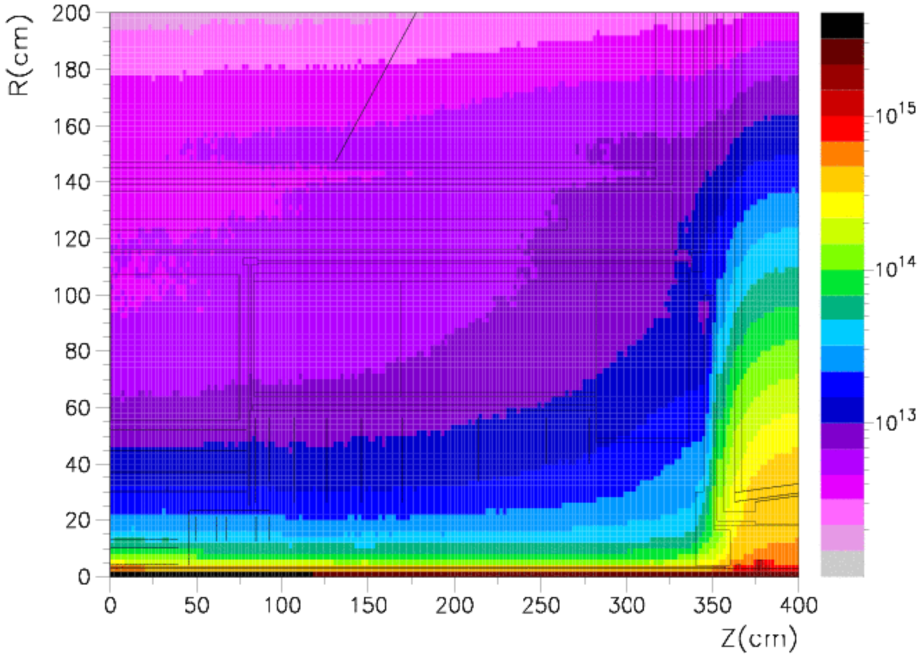
Preparation: ~2years Construction: ~2years Commissioning: ~1years

- IBL was proposed as the first detector upgrade activity in ATLAS experiment and was installed only in 4 years after TDR!
- Each part of the groups collaborates efficiently to finalize the construction in the limited time of 2 years.

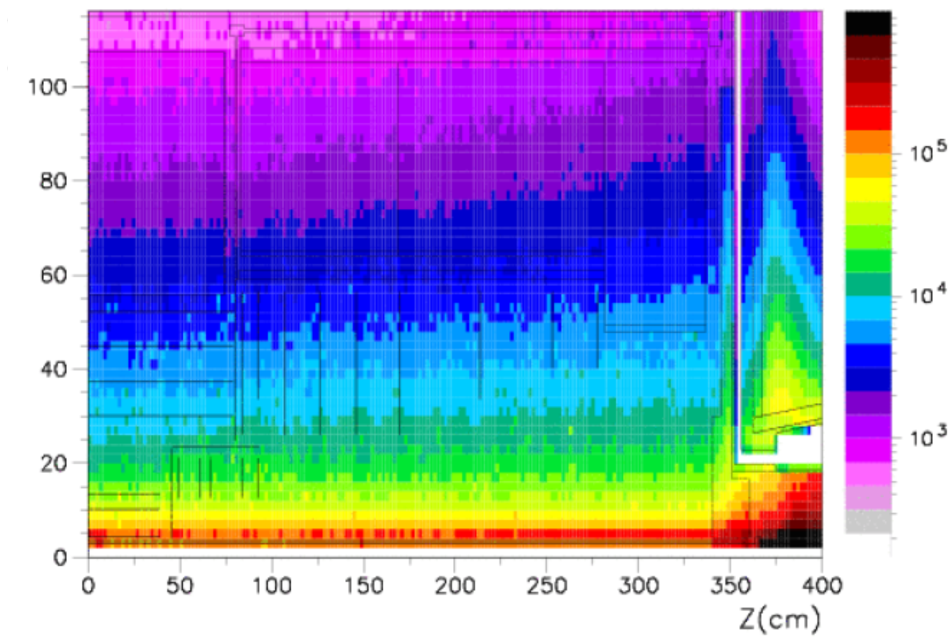
One important issue at LHC: Extreme radiation levels !

Plots show radiation dose and fluence per high luminosity LHC year for ATLAS (assuming 10^7 s of collisions; source: ATL-Gen-2005-001)

Fluence [1 MeV eq. neutrons/cm^2]



Radiation dose [Gray/year]



"Uniform thermal neutron gas"

Put your cell phone into ATLAS !
It stops working after 1 s to 1 min.

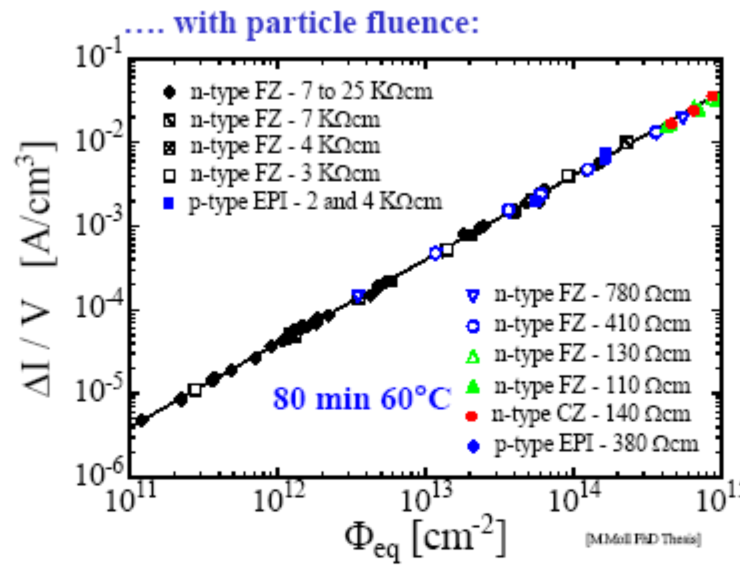
- Neutrons are everywhere and cannot easily be suppressed

Radiation-hard sensors

1. Radiation induced leakage current

independent of impurities; every 7°C of temperature reduction halves current

⇔ cool sensors to ≈ -25°C (SCT = -7°C)



2. "type inversion" from n to p-bulk

⇔ increased depletion voltage

oxygenated silicon helps (for protons);

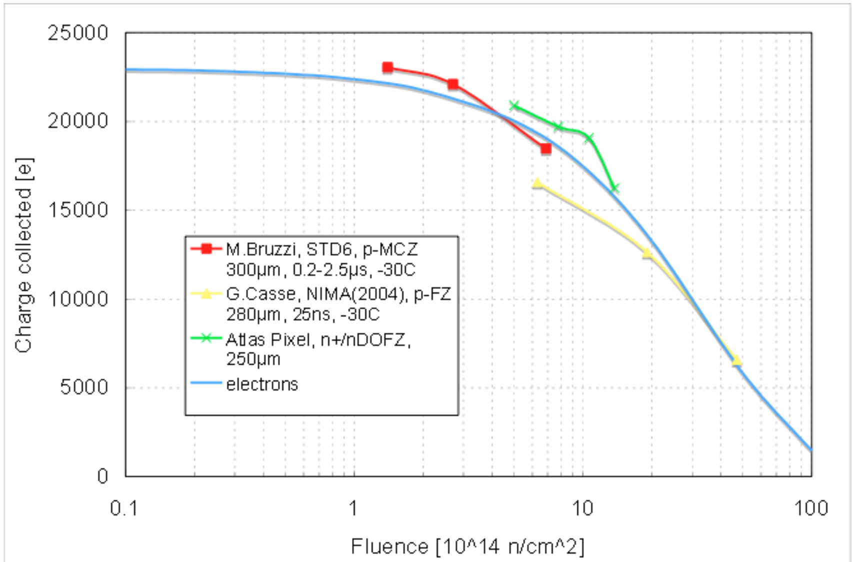
n+-in-n-bulk or n+-in-p-bulk helps

3. Charge trapping

the most dangerous effect at high fluences

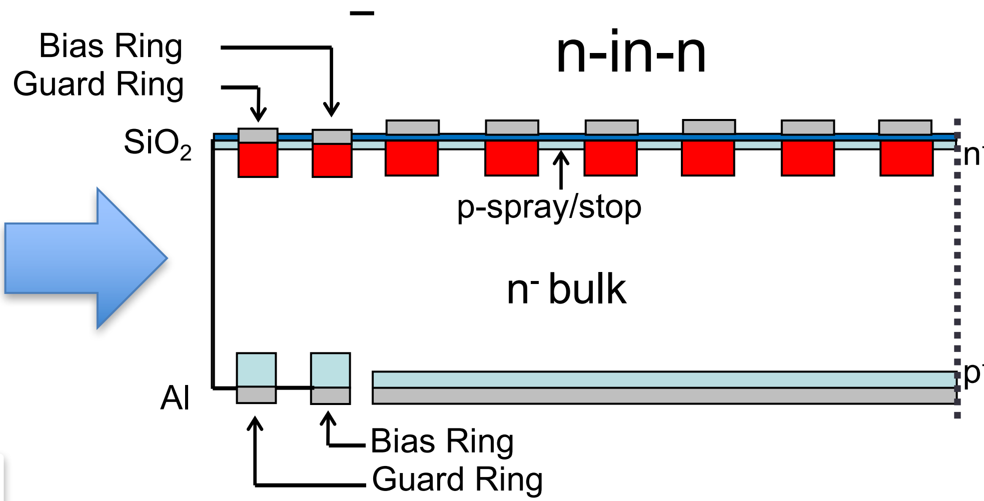
⇔ collect electrons rather than holes

⇔ reduce drift distances



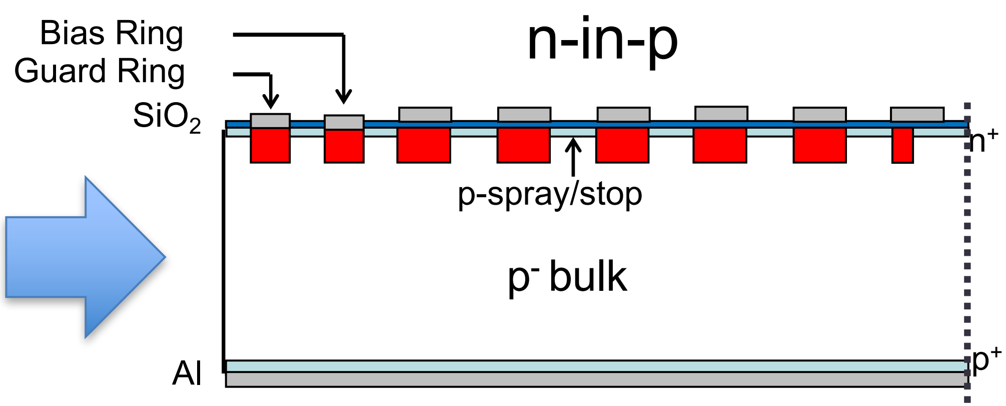
Alternatives for Planar pixel technology

- n-in-n
  - More expensive
  - Double-sided processing
  - Limited suppliers
  - Some experience with “large” scale production
    - CMS/ATLAS pixels, LHCb VELO



Present

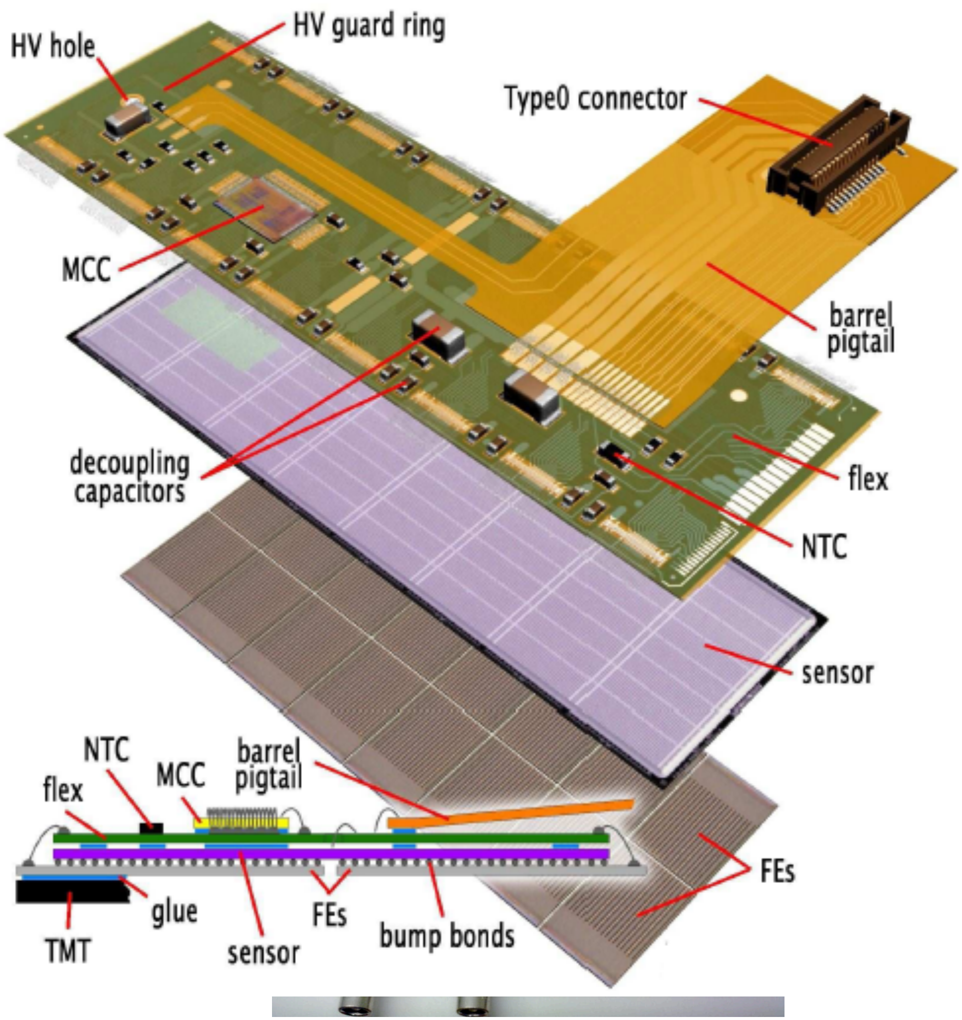
- n-in-p
  - ~50% less expensive than n-in-n
  - Single-sided processing
  - More suppliers (Japan, EU)
  - Limited production experience
  - Better radiation hard tolerance
  - n^+ R/O kept

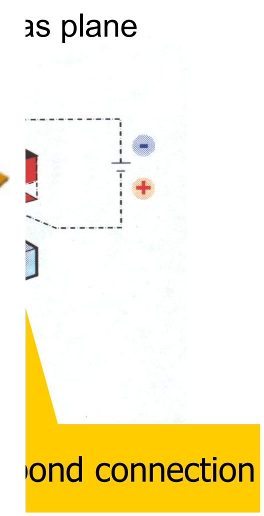


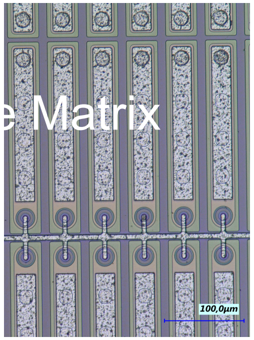
Future

Pixel Module Detection Unit

- Intrinsic Module Detection device
  - Hybrid pixel d
    - The sensor and the r
      electronic are realize
      semiconductor substr
    - Size of the electronic
      pixels is equal to the
      sensor pixels
    - The connection betw
      electronic and the se
      via bump bond conne

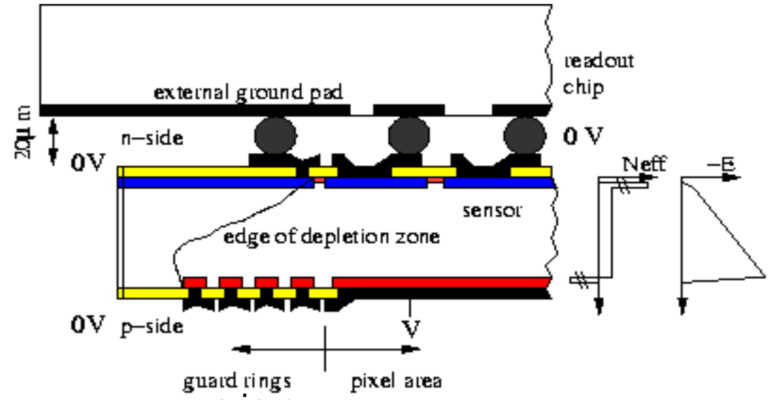






R&D :Towards (n-in-p) Edgless Sensors for the future

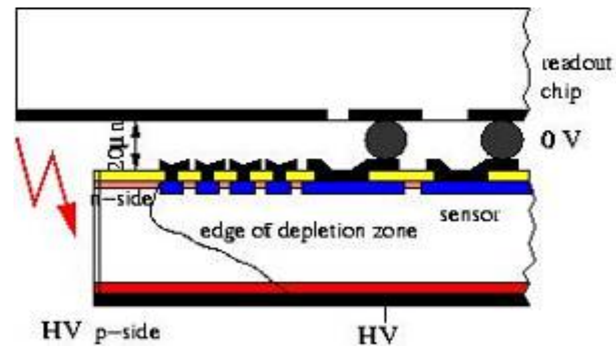
n-in-n



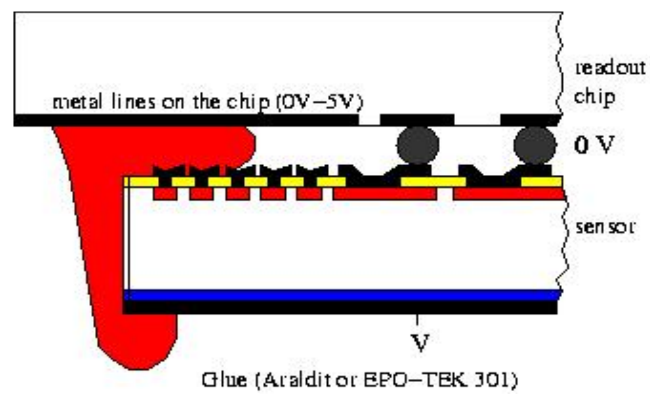
ATLAS pixel detector uses n-in-n-sensors

- double sided processing (back side is structured)
- all sensor edges at ground
- most expensive part of the module

n-in-p



- Exploring n-in-p sensors as alternative
- Studies show radiation hardness *(LAL&LPNHE Member of RD50 coll.)*
- single sided process ~ price benefit of factor 2-3
  - Develop Active Edge Technology
- Absence of guard rings on back side lead to risk of (destructive) sparking to the ROC



LPNHE & LAL: Active contributions within ATLAS Pixel R&D

– Tasks to improve the Planar Pixel Silicon detector for the ATLAS upgrade

Goals

– Performance : evaluate & improve sensor design for radiation tolerance up to $3\times10^{15} n_{eq}/cm^2$ fluence.

– Productions : work on various wafer productions (Cis, VTT Advacam & FBK)

Active Edge

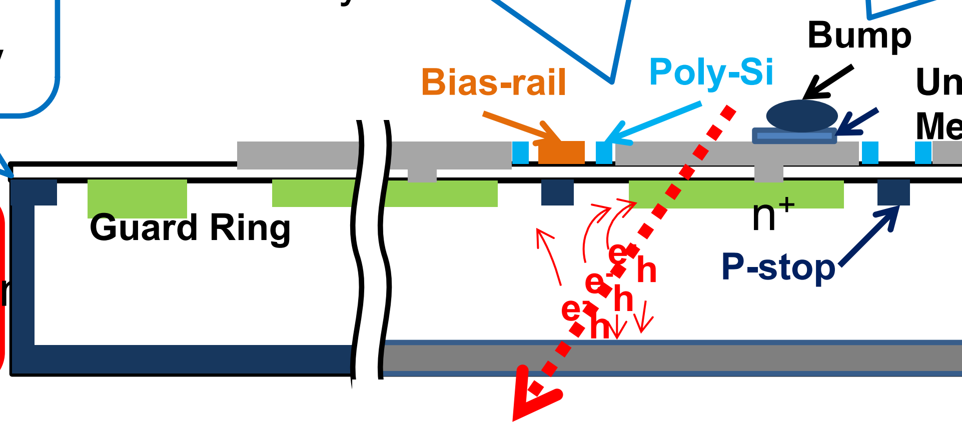
- Smaller Edge size
- Higher Efficiency at Edge region

Biasing Structure

- Optimize Biasing structure
- Higher Efficiency at Pixel boundary

Bumpbonding

- Better UBM material
- Higher Flip-Chip Yield



Simulation

- Doping concentration
- Charge collection

Radiation Tolerance
Assembly
Production…

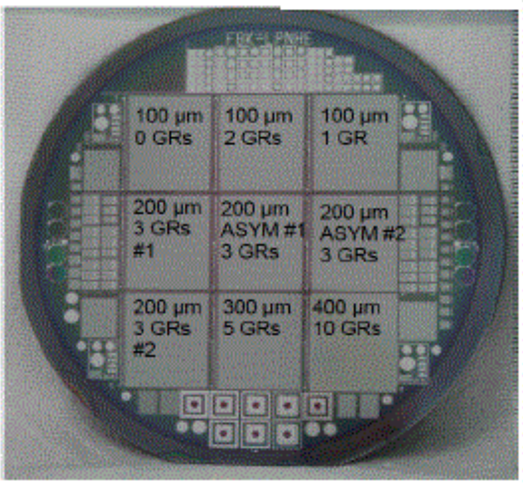
Edgless & Slim edge Pixels for Phase 2

Recent LPNHE planar pixel productions

FONDAZIONE BRUNO KESSLER

PAE1

LPNHE PARIS



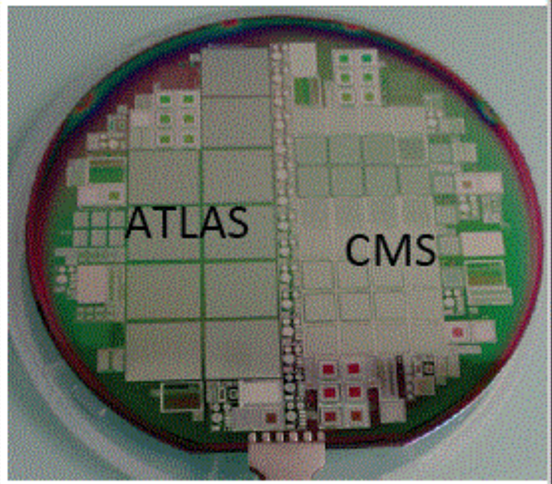
4” 200 µm thick n-on-p
Active Edge technology
Pixel-to-edge down to 100 µm
Tested extensively on beam

NIM A 712 (2013) 41–47
NIM A 730 (2013) 215

JINST 12 P05006 (2017)

P2

INFN Istituto Nazionale di Fisica Nucleare

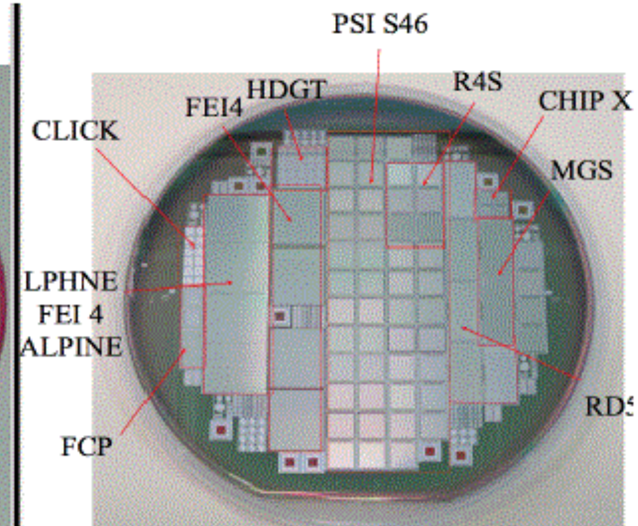


6” 100-130 µm thick n-on-p
INFN ATLAS/CMS project
Tested extensively on beam, after irradiation too

12th Trento Workshop

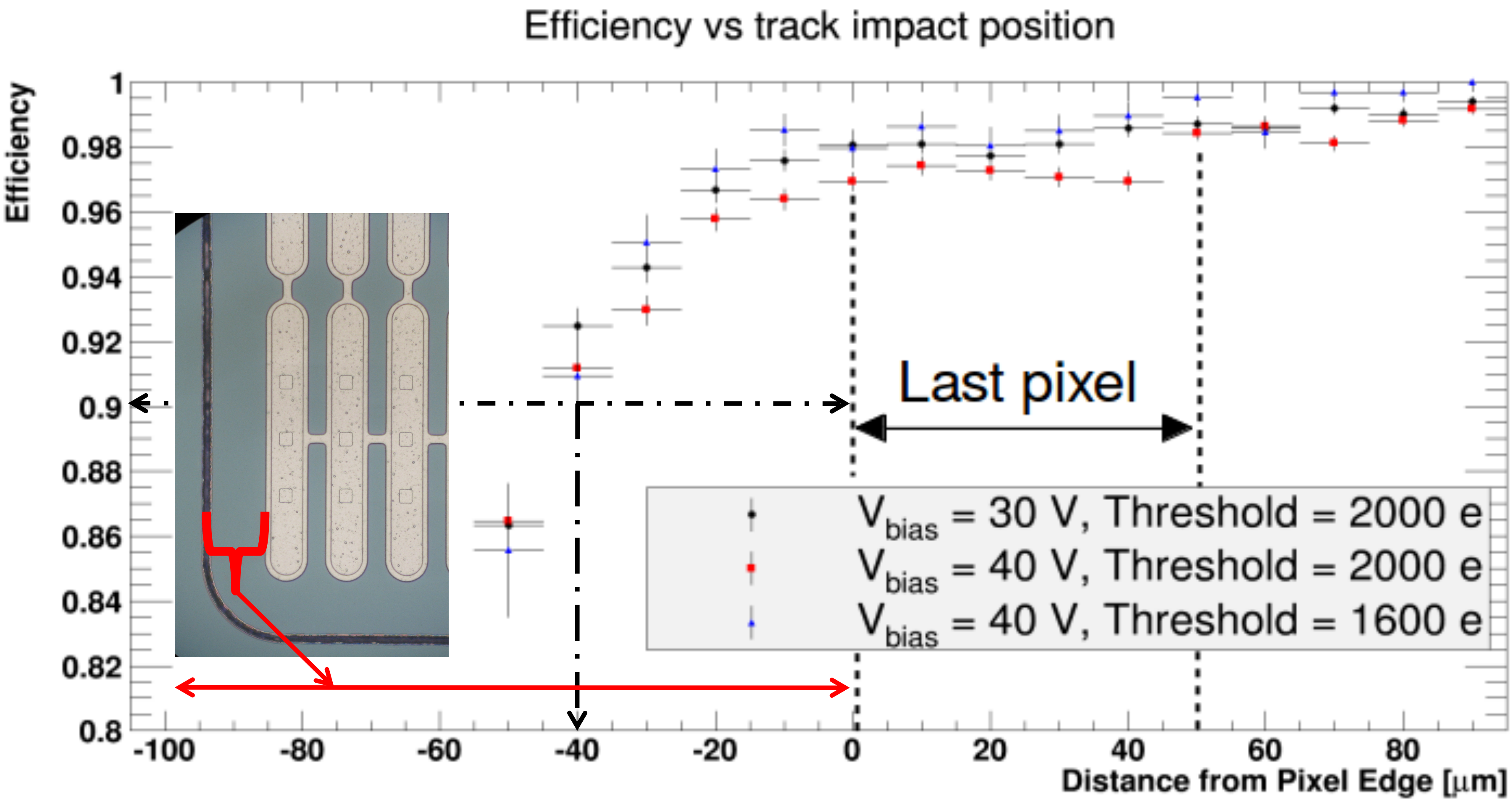
PAE3

LPNHE PARIS



6” 100 130 µm thick n-on-p
INFN ATLAS/CMS project
Active Edge technology
Pixel-to-edge down to 50 µm
RD53 compatible sensors
Samples at IZM for b.b-ing

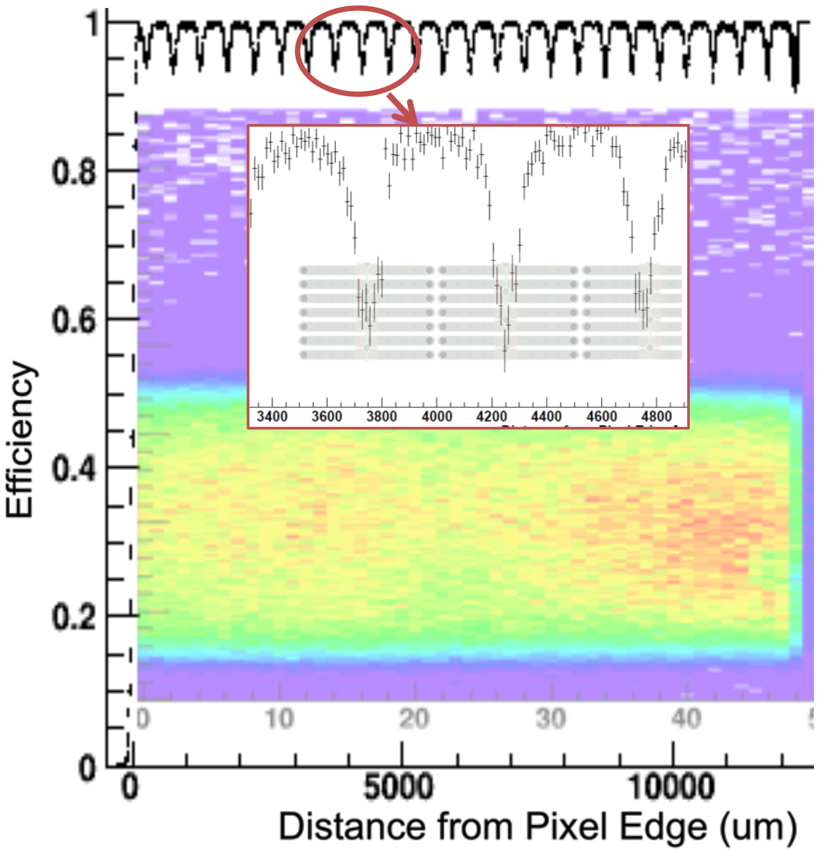
Hit-efficiency at the edge

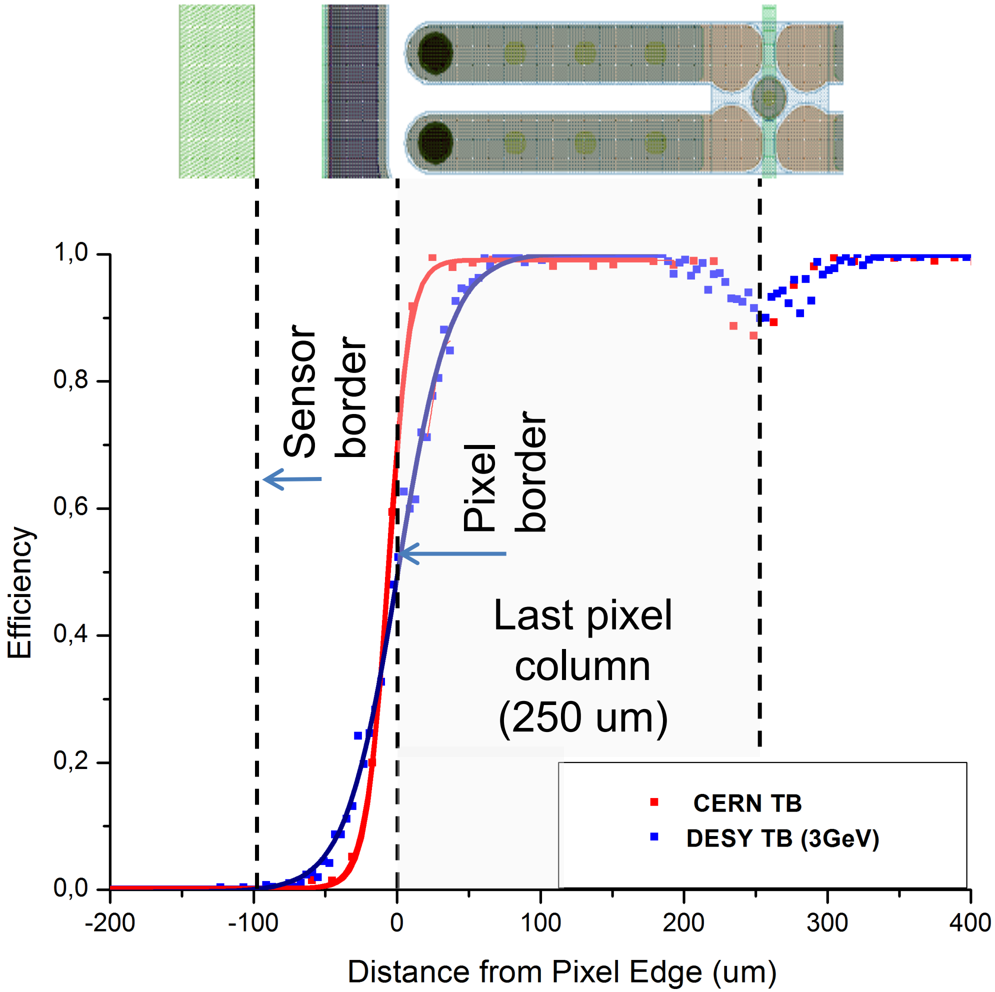


- Hit-efficiency above 90% up to 40 μm away from the last pixel
- No good tracks beyond -50 μm due to quality cuts

Efficiencies from beam tests

- *Efficiency vs track impact position DUT#22*

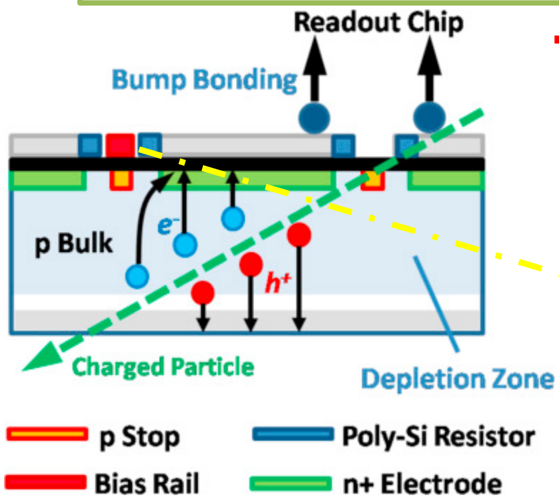


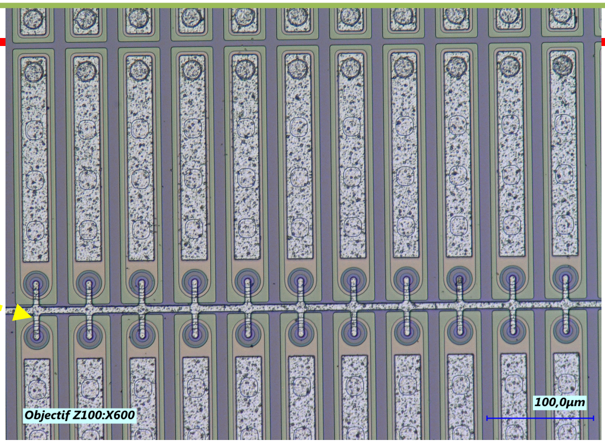


Analysis from Dmytro Hohov ATLAS@LAL

Irradiated pixel behavior at high fluen

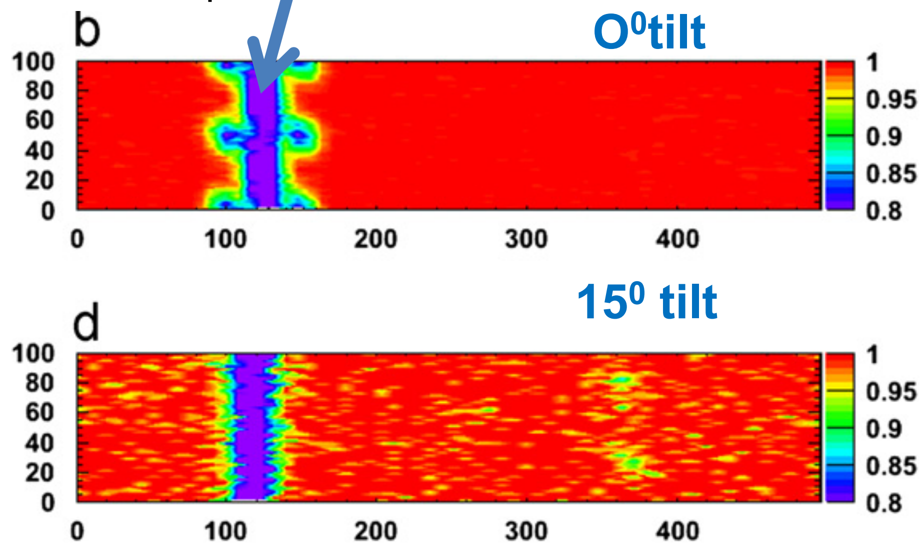
Beam-tests results





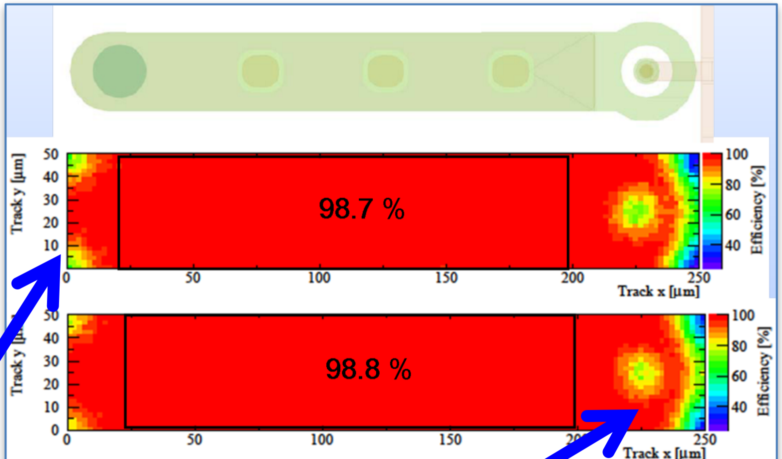
Bias Rail

Position of polarization rail



Pixel Matrix Hitmap at 5. 10^{15} neq/cm^2 and Temperature -15^{0}c.

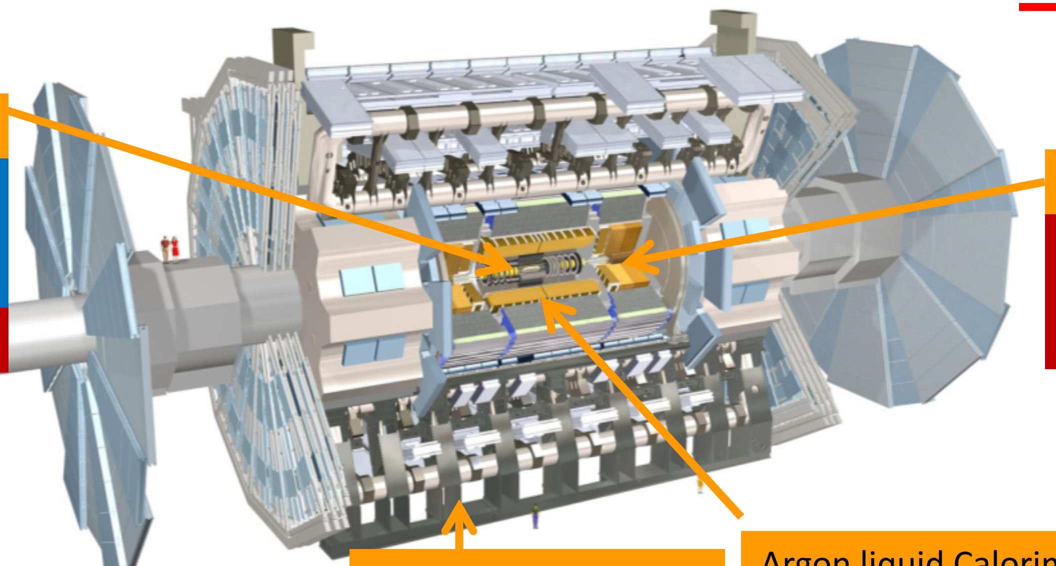
Eudet 120 GeV pions/ $\Phi=4\times10^{15}\ n_{eq}\ cm^{-2}$



Loss of Effiicency around Bias rails and implants

Future plans for ATLAS ITK construction

Roadmap for ATLAS phase 2



Internal Detector

- Installation IBL
- Fast track (FTK) for Trigger
- Full replacement

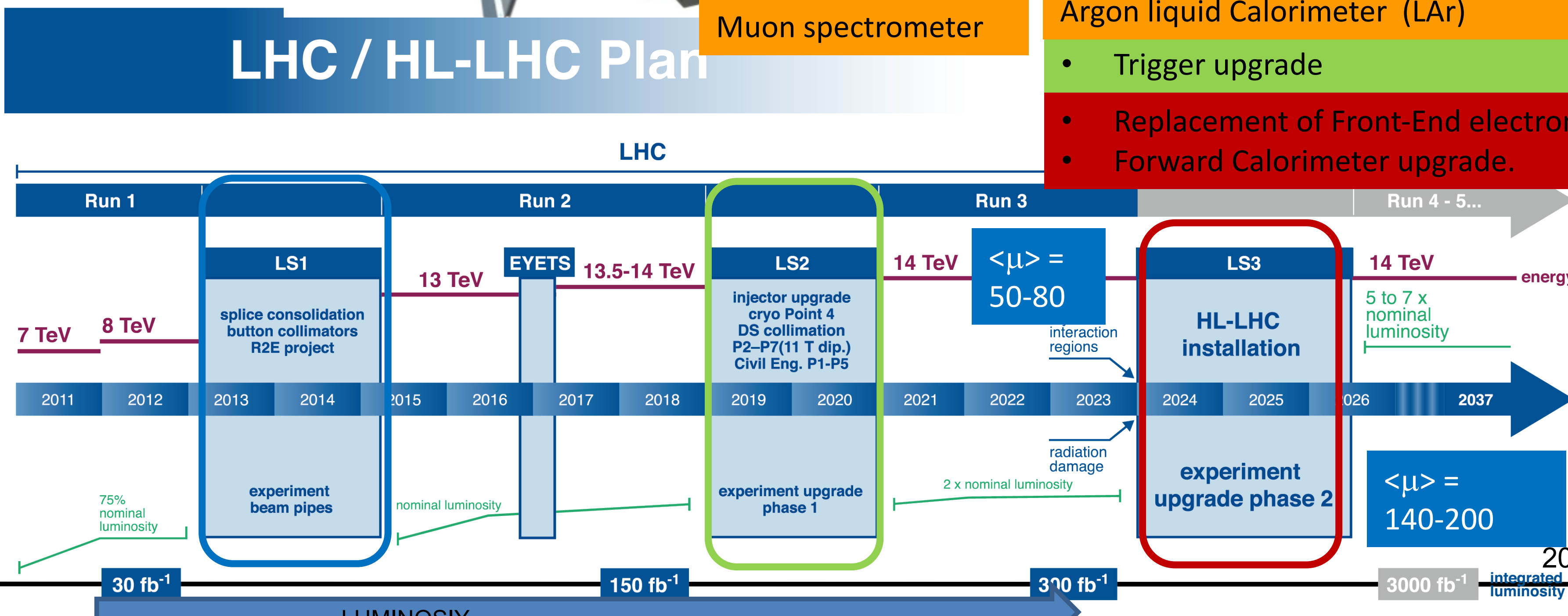
Tile calorimeter

- Front end Electronics replacement

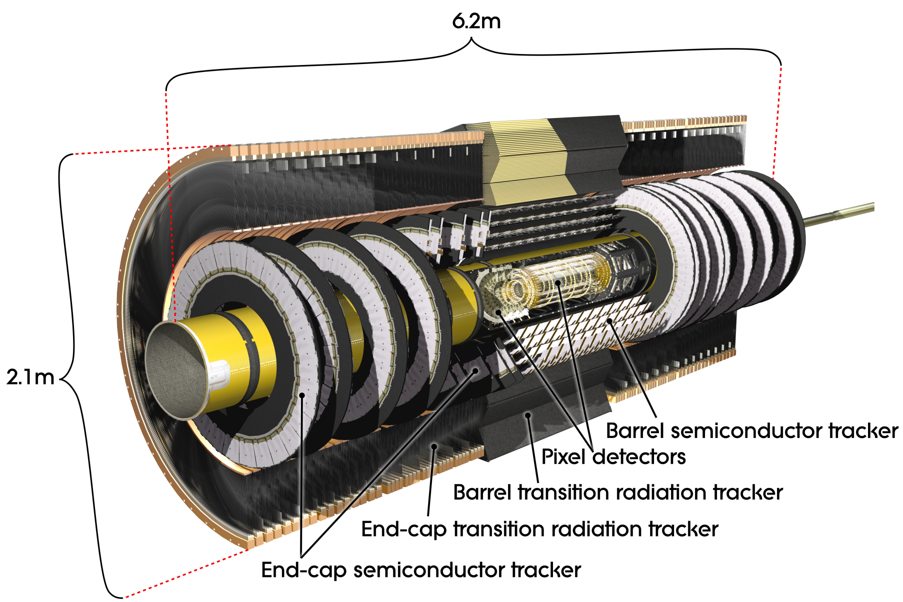
Muon spectrometer

Argon liquid Calorimeter (LAr)

- Trigger upgrade
- Replacement of Front-End electronics
- Forward Calorimeter upgrade.



Challenges for a new inner tracker

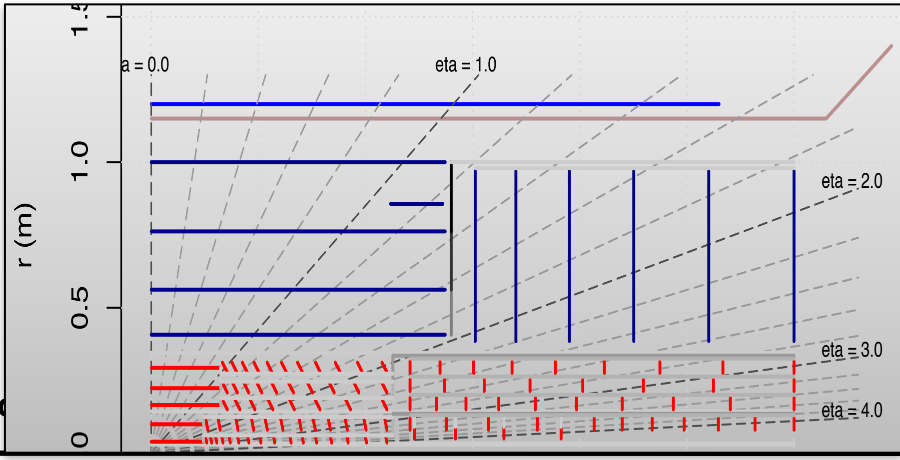


High Luminosity LHC conditions will affect Drastically the current design

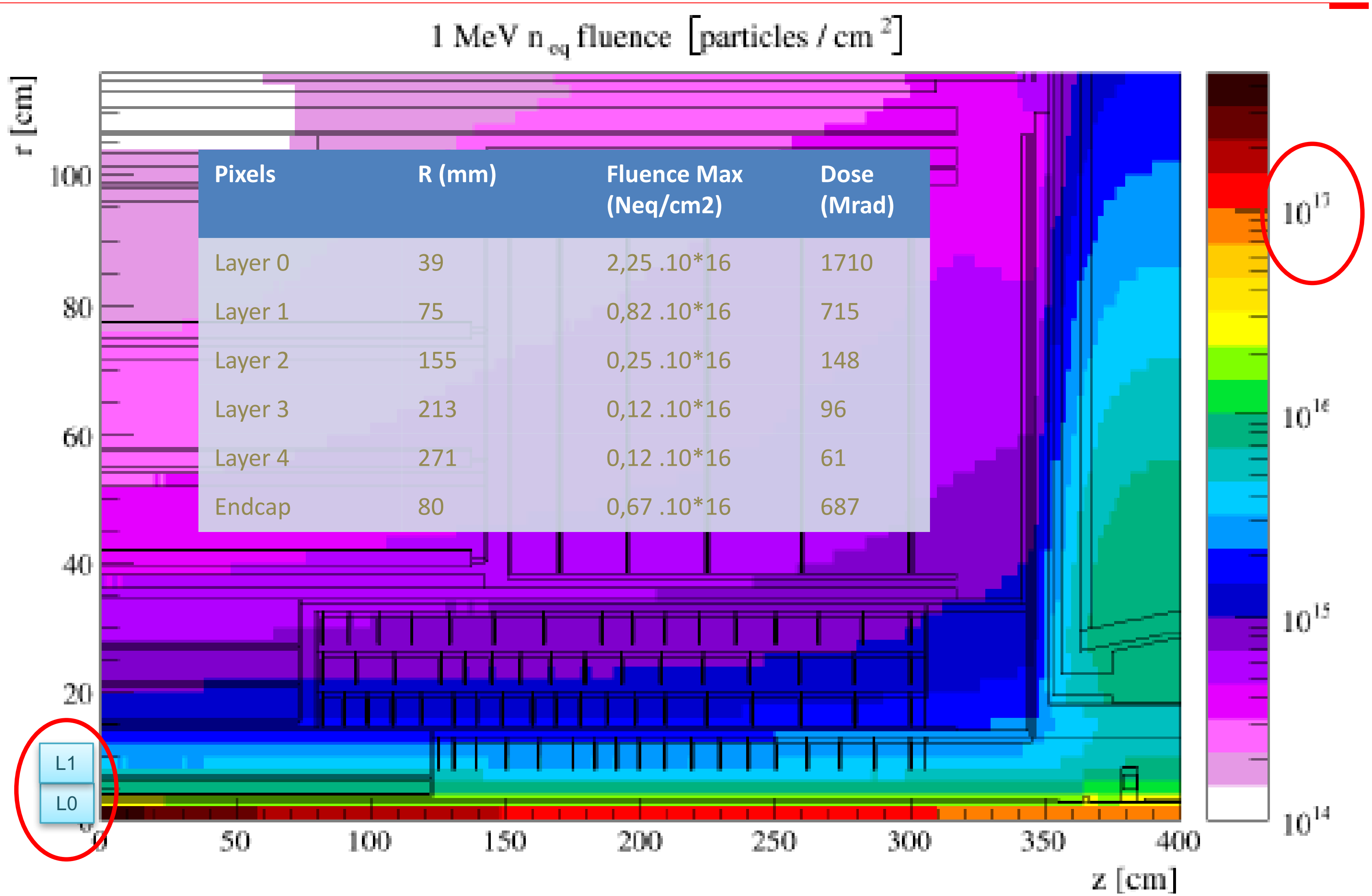
- ➢ **Peak Luminosity will increase by a factor 5-7 10**34**
- ➢ **Average Pileup : a factor of 8 <m> ~200**
- ➢ **Integrated luminosity : a factor 10 : 3000**
- ➢ **Radiation hardness : a factor 20 : 2x10 n$_{e}$**

But !

- Same or better performance required !
  - Use quite "transparent tracker" Low X0
  - Provide V. High granularity sensors
  - Go du deep submicron technologies
  - Raise the transfer data band-with (5Gps)
  - Improve the layout and mechanics



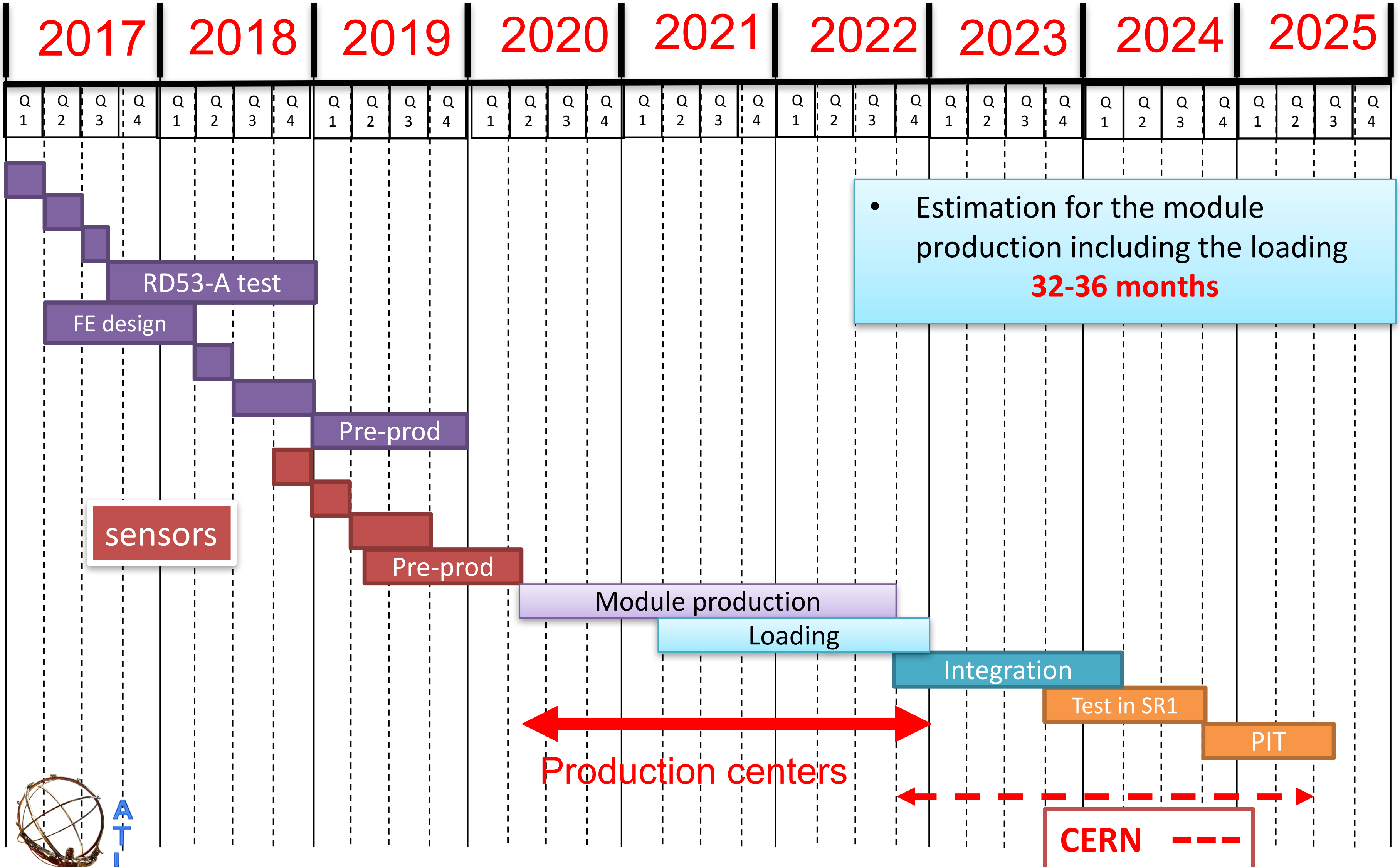
Expected fluences (1 MeV $n_{eq}.cm^{-2}$)



Pixels	R (mm)	Fluence Max (Neq/cm2)	Dose (Mrad)
Layer 0	39	2,25 .10*16	1710
Layer 1	75	0,82 .10*16	715
Layer 2	155	0,25 .10*16	148
Layer 3	213	0,12 .10*16	96
Layer 4	271	0,12 .10*16	61
Endcap	80	0,67 .10*16	687

ATLAS ITk Simulation, FLUKA to 3,000 fb^{-1}

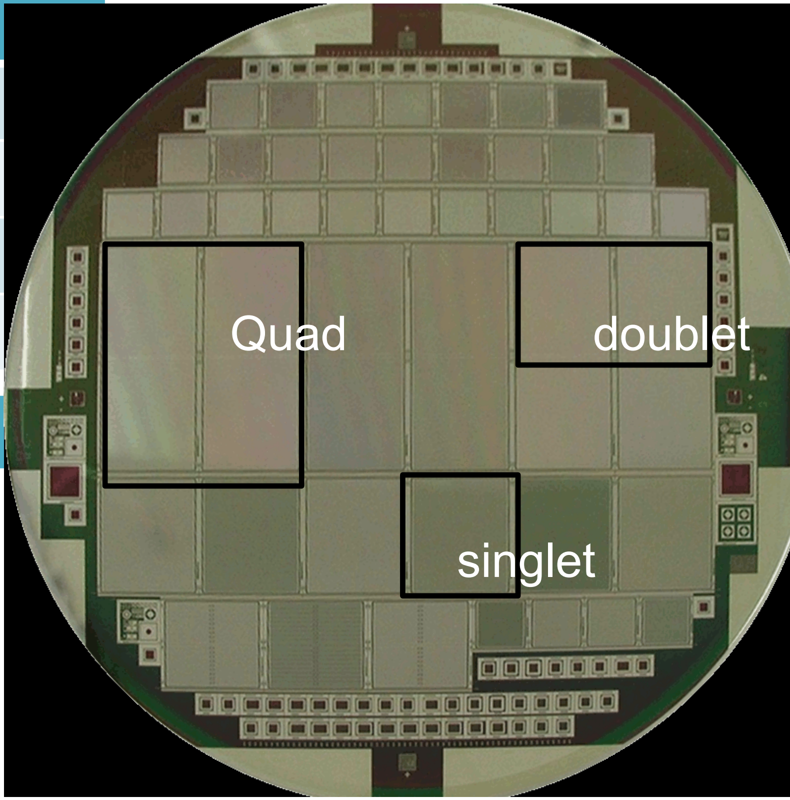
Production planning of the next Pixel Tracker : Planning 2017-2025



Estimation in terms of module construction

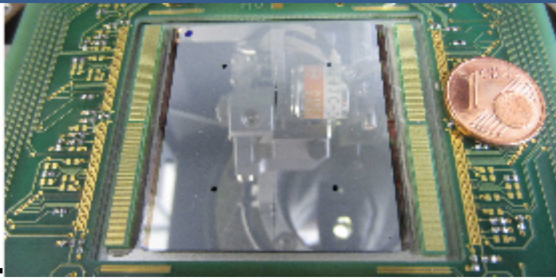
Fully inclined (Front-end)	
Layer 0	936 FE
Layer 1	2016 FE
Layer 2	3200 FE
Layer 3	4752 FE
Layer 4	6264 FE
Total	**17168 FE**

Rings	
Layer 0	3264 FE
Layer 1	5472 FE
Layer 2	6144 FE
Layer 3	7680 FE
Total	**22560 FE**



Supposing single chip for layer 0
double chip module Layer 1
Quads for Layers 3 et 4
Total Modules including rings ~ 12.000 Modules

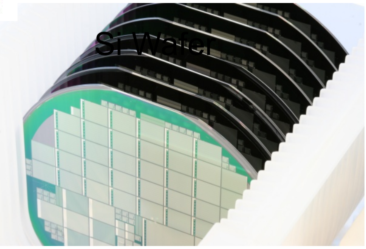
Quad FEI4 Module prototype



Major investment of IN2P3 for ITK
LAL-IN2P3-CPPM-LPSCG-LAPP

Contribution (LAL+ LPNHE)~ ~1000-2000 Modules

Strategy for module constructi



- RECEPTION-INSPECTION OPTICAL TESTS ONE WAFER SI -SENSORS INDIVIDUAL TESTING OR WAFER TESTINGS

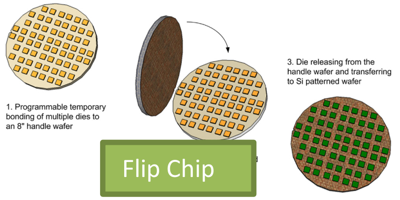
Probe tests

SITE : : LAL LPNHE

- INTERCONNECTION MATRICES PIXELS WITH INDIUM BUMPS / PIXEL SENSORS TO READOUT CHIP (FLIP-CHIP)

connexion

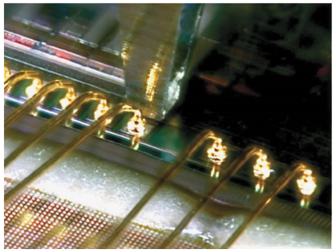
INDUSTRY



- CONNECTION OF MODULE ON READOUT CARD (WIRE BOND)

Module construction

LAL LPNHE+ IRFU



- GLUING OF FLEX CABLE AND WIRE BONDS OF SIGNAL, BIAS, TENSION, CLOCKS

Wire bonding

LAL LPNHE+ IRFU

Tests on modules with béta source , laser ...

DEBUG

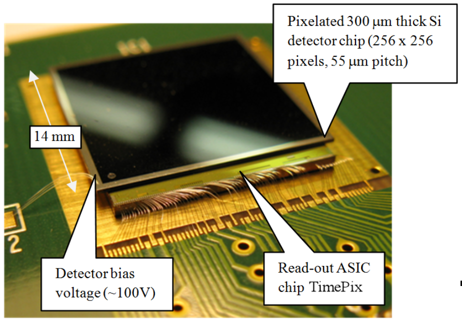
COMPLETE CHARACTERIZATION AND MODULE SELECTION ACCORDING TO GRADES ,DATABASE Classification

NO

LAL LPNHE

OK

EXPEDITION OF MODULES SELECTED TOWARS LOADING AND INTEGRATION CENTERS (CERN, CPPM, et.....)



Infrastructures to contribute as an ATLAS production center

Clean room (LAL, LPNHE, CEA-IRFU)

Modern and state of the art for Pixel development: Captinnov plateform

- High precision technology equipment for silicon devices characaterization & low noise electronics front end readout

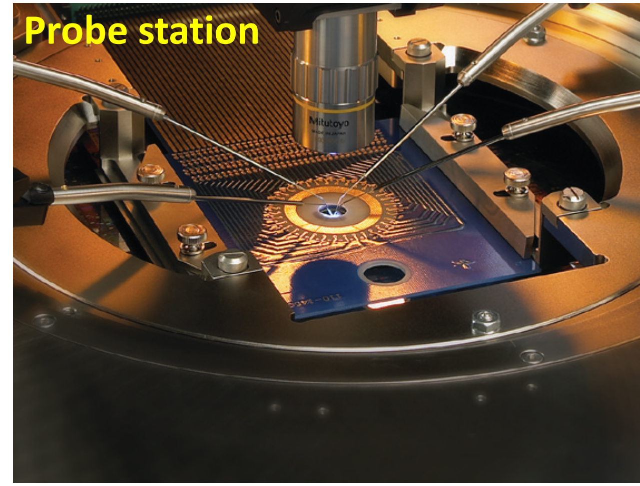
❑ Machine semi-automatic for probing devices

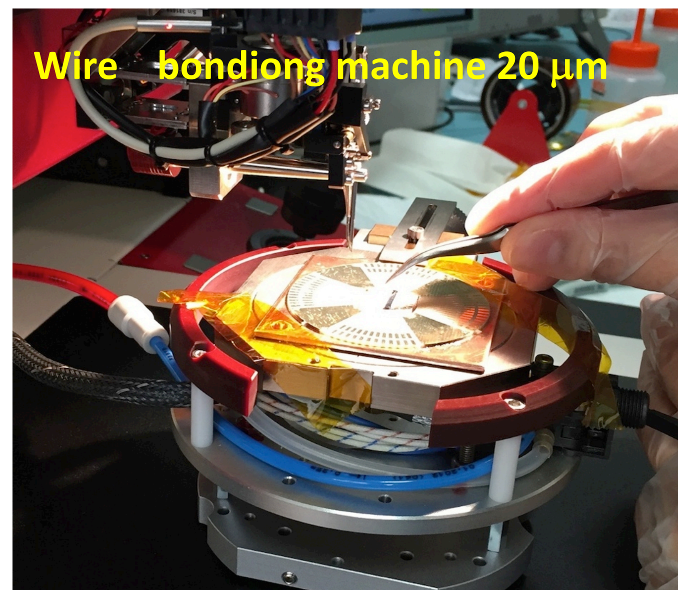
✓ Integrated Fraday Cage for low current detection

➢ *Performances in terms of low courants (0.1 fA) et capacités (A.Farads)*

➢ *Machine completely programmable*

➢ *Possibilité of probe card insertion (Test multi-variables)*

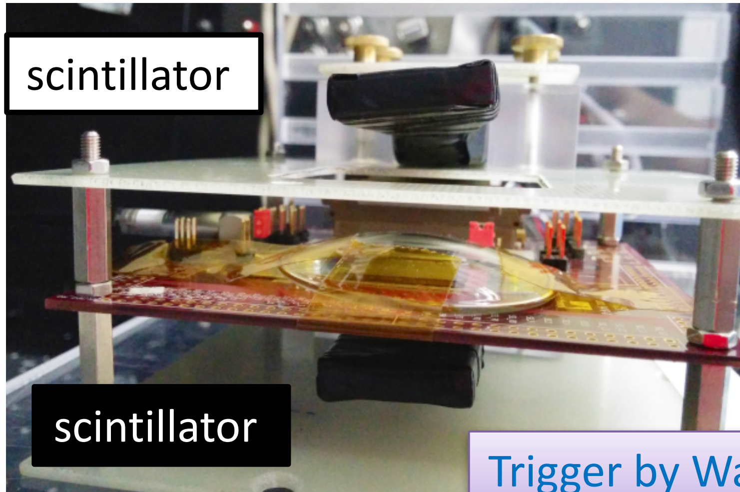




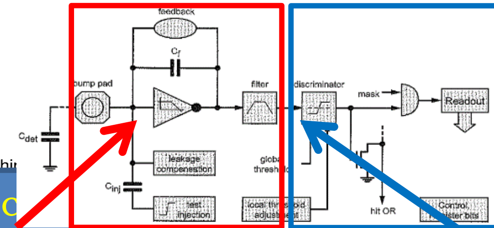
Semi automatic Karl Suss prober

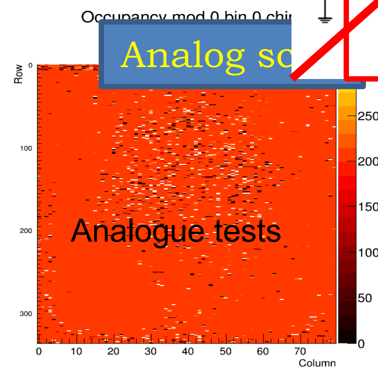
Cosmic and source for Pixel module testing

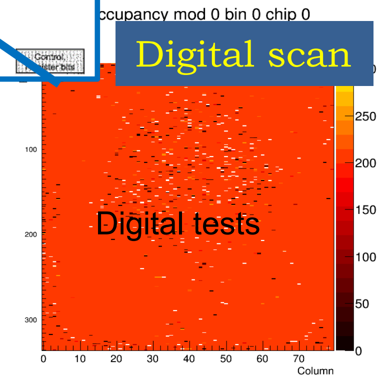
- Tests of modules before and after irradiation

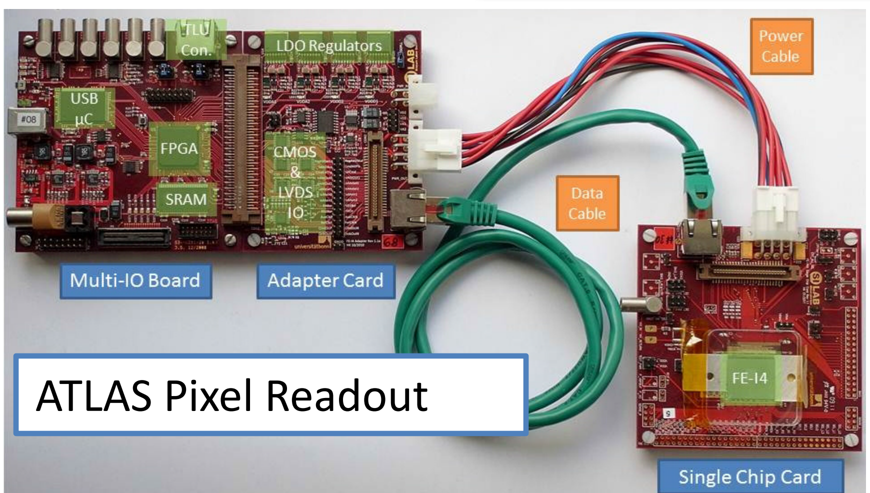


Trigger by Wave-catcher

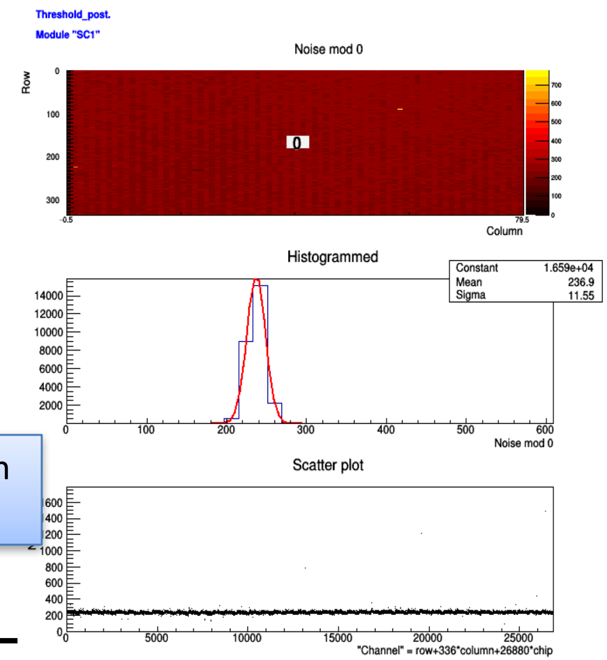








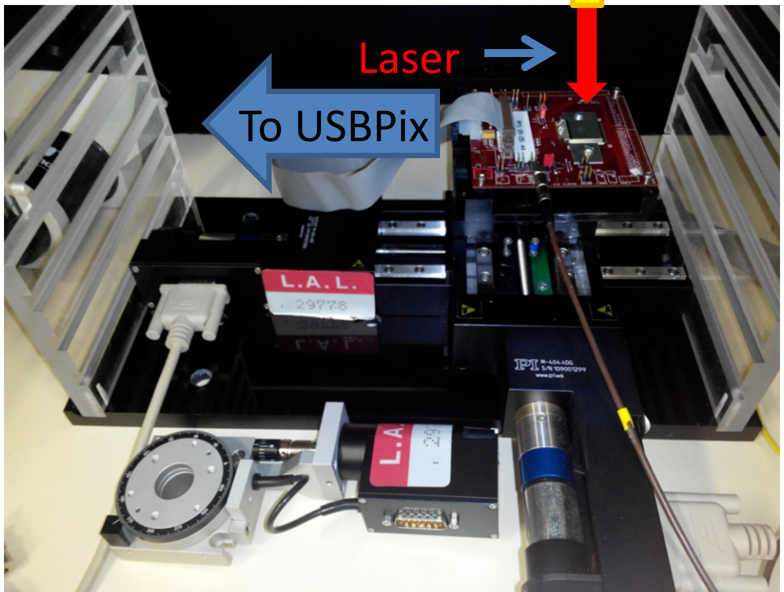
ATLAS Pixel Readout



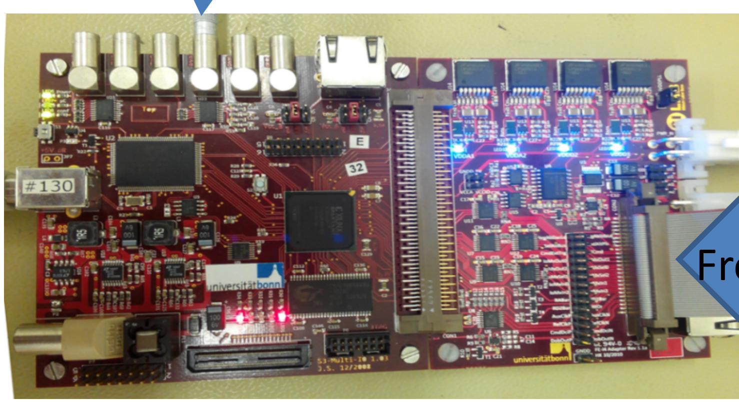
Noise and dispersion measurements

Construction of a Laser testbench

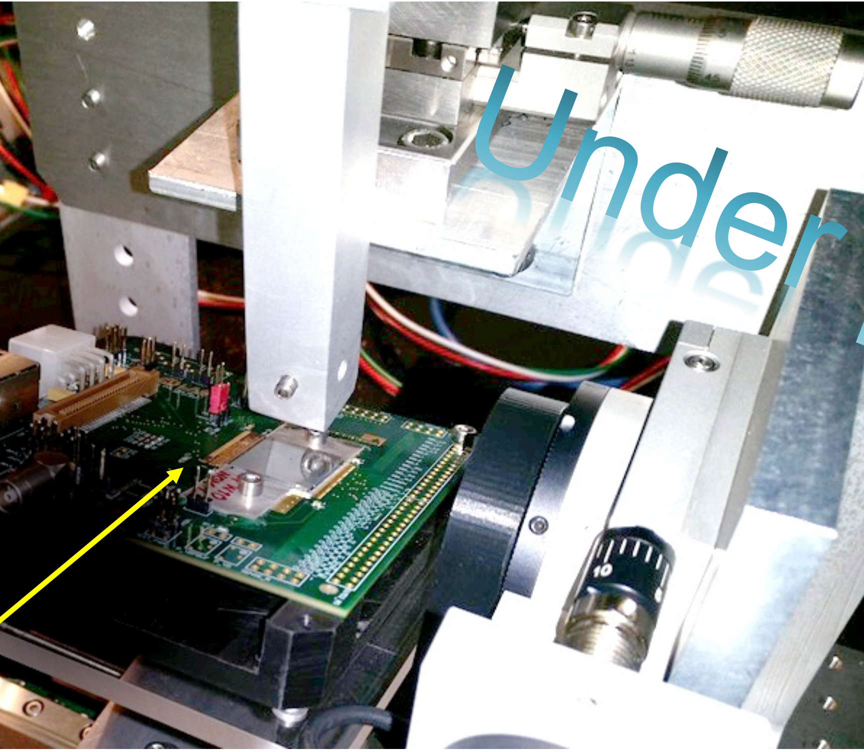
Scan des pixels , dead pixel detection, cross talk.

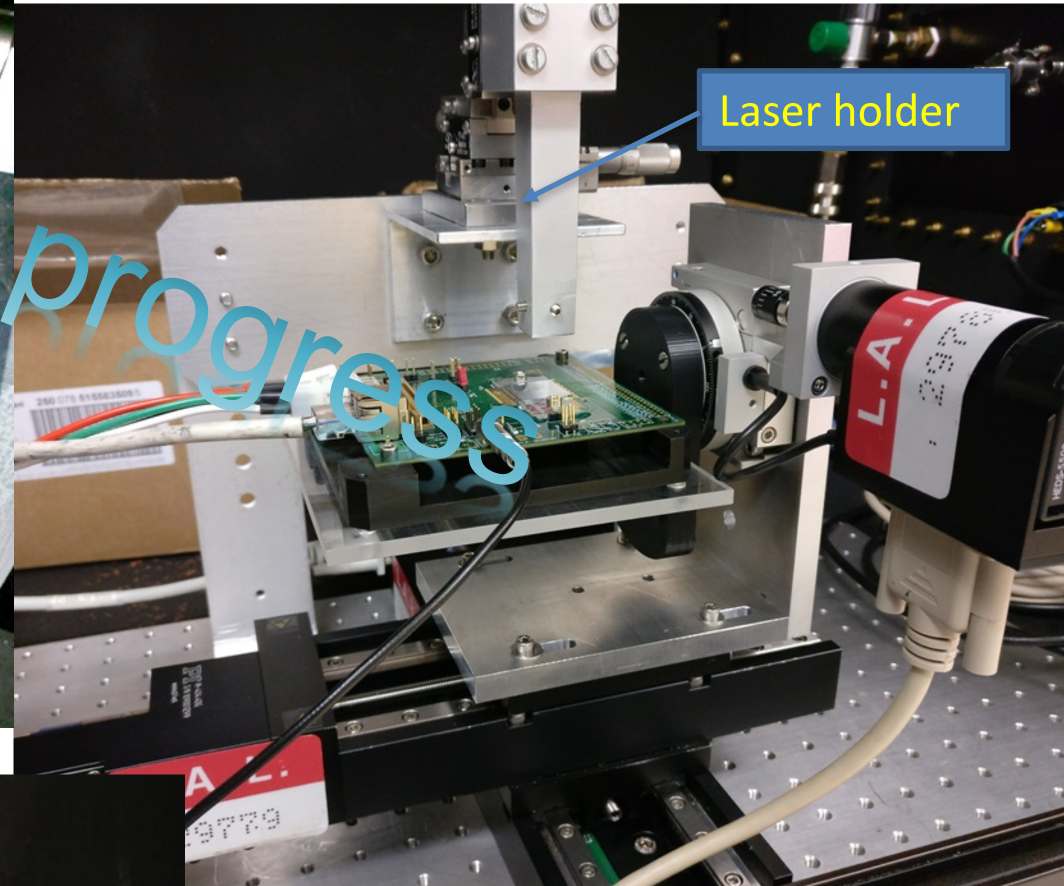


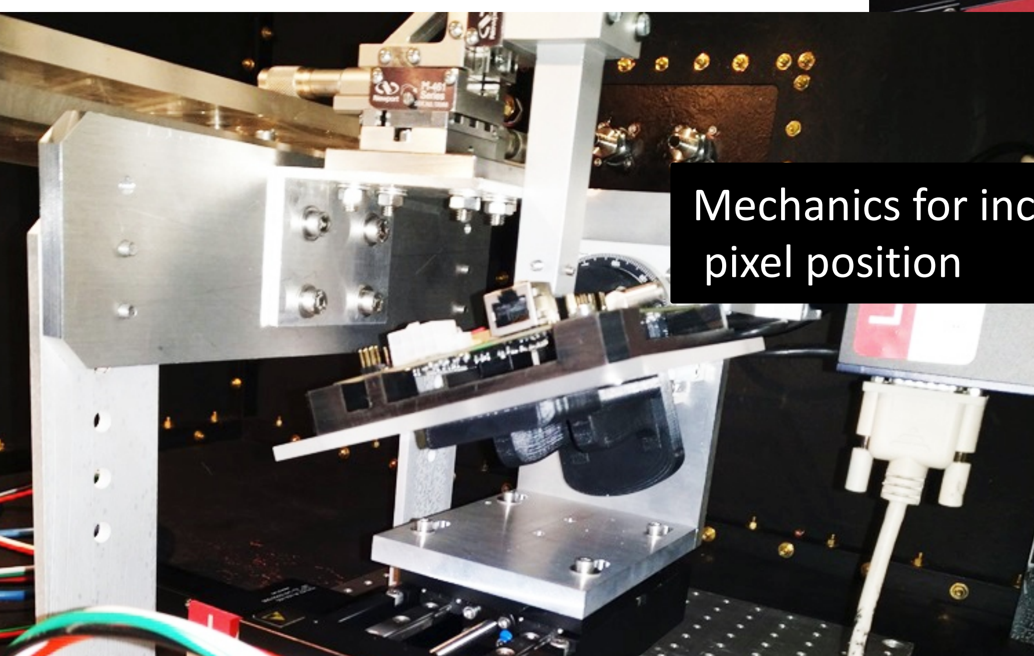
Trigger



USBPix system: ATLAS Standard device





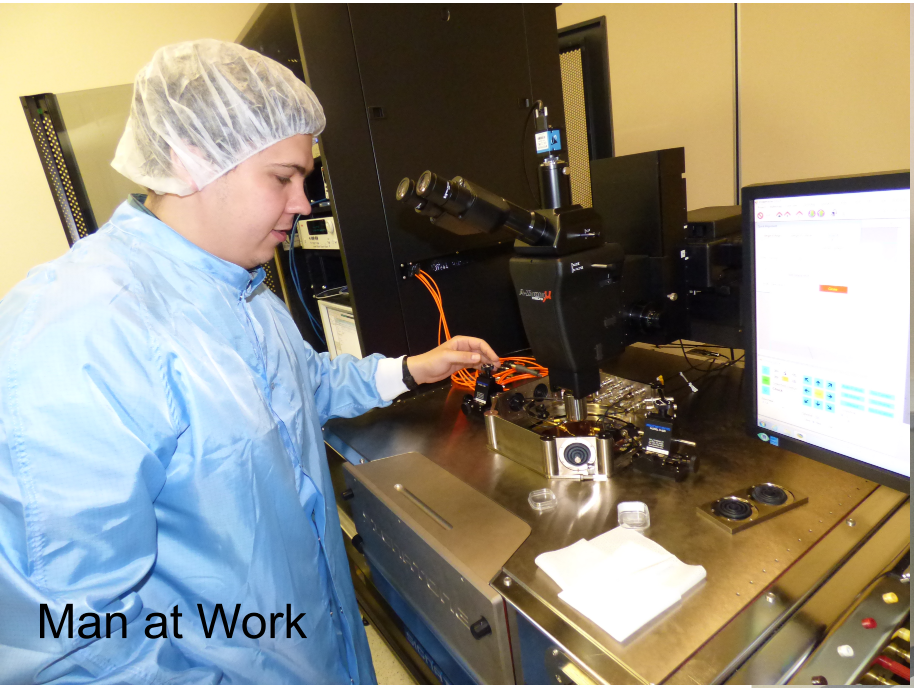


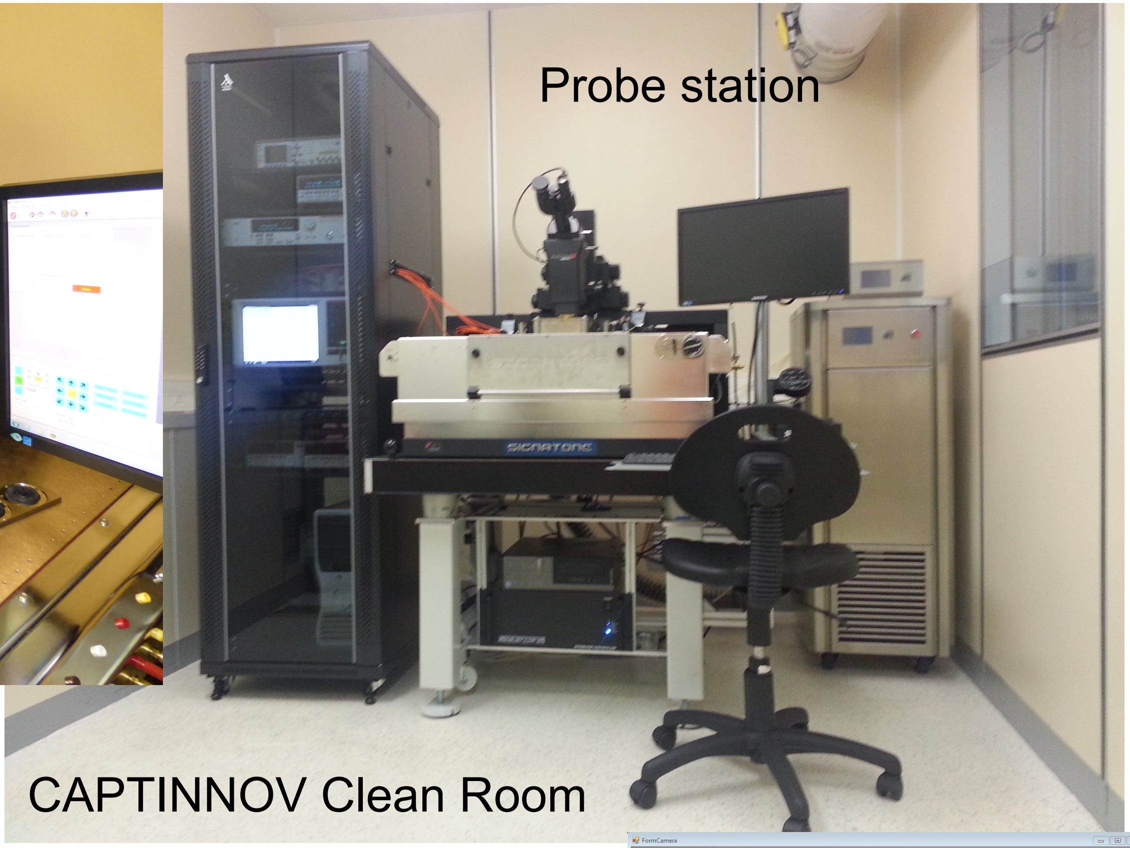
LABORATOIRE
DE L'ACCÉLÉRATEUR
LINÉAIRE

Improvement of Laser testbench
for pixel module Characterization
(PhD project- D. Hohov)

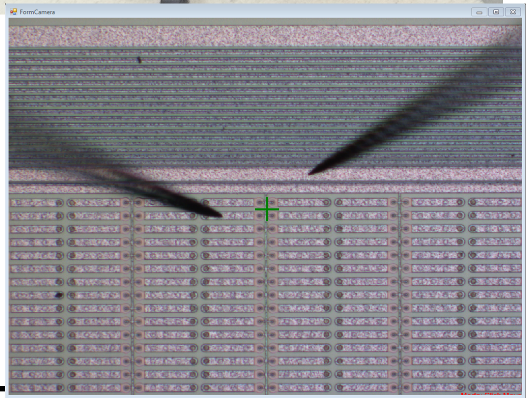
Captinnov Infrastructure

LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE





Pixel Matrix



Conclusions

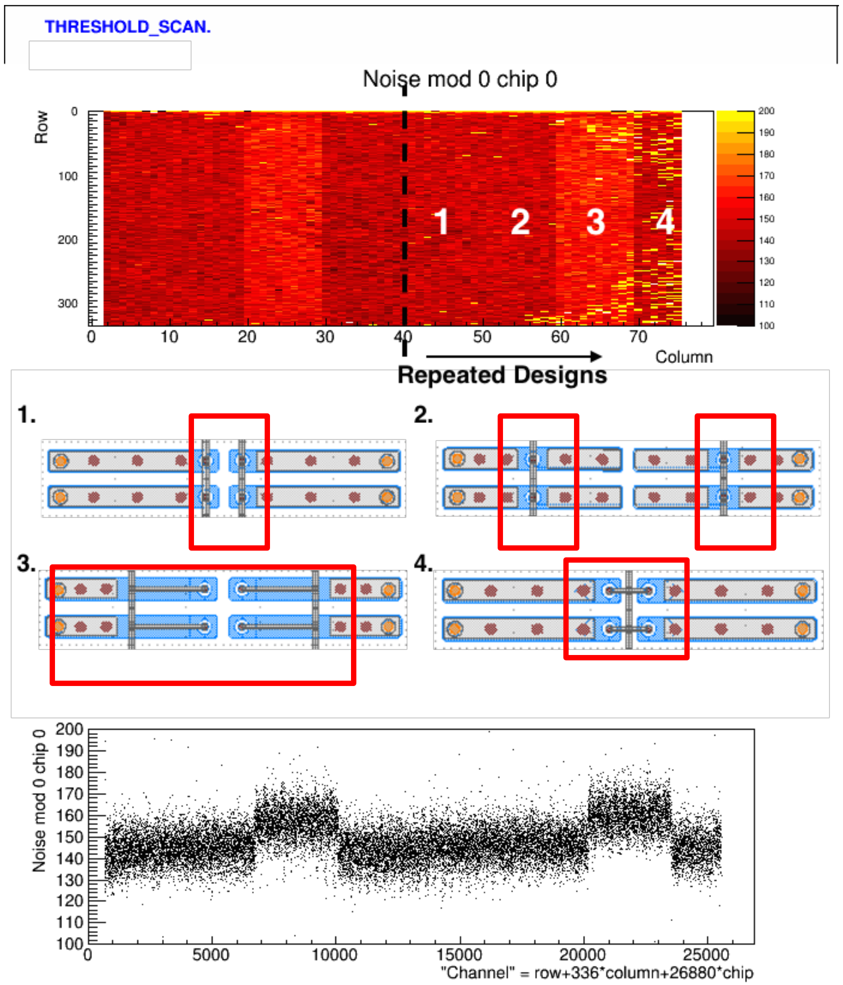
Comments & conclusions

- An IN2P3 task force has been set to gather their efforts to contribute in a significant way to the construction of the new tracker for ATLAS phase 2
- The ATLAS Phase 2 project is highly challenging requiring high level of technical expertise, for mastering precision silicon detectors, low noise electronics and many other aspects (mechanics, cooling, metrology…)
- LPNHE and LAL are key players in ATLAS project since a long time, in various fields from Technology Computed Aided simulation, pixel sensor design, high precision low noise silicon characterization, to module assembly
- Important technical infrastructures and skills have been accumulated
- it offers an excellent opportunity for students to embark in one of the most attractive project for students and young scientist so Welcome!!

Thank you for your attention and welcome on board !!

Improving efficiency: biasing solutions

Aim is to find a solution that reduces the inefficiencies in the biasing region within the pixel cell.



- CiS FE-I4 planar sensor, with four bias rail designs on the same sensor.
- Both show increased noise for one design

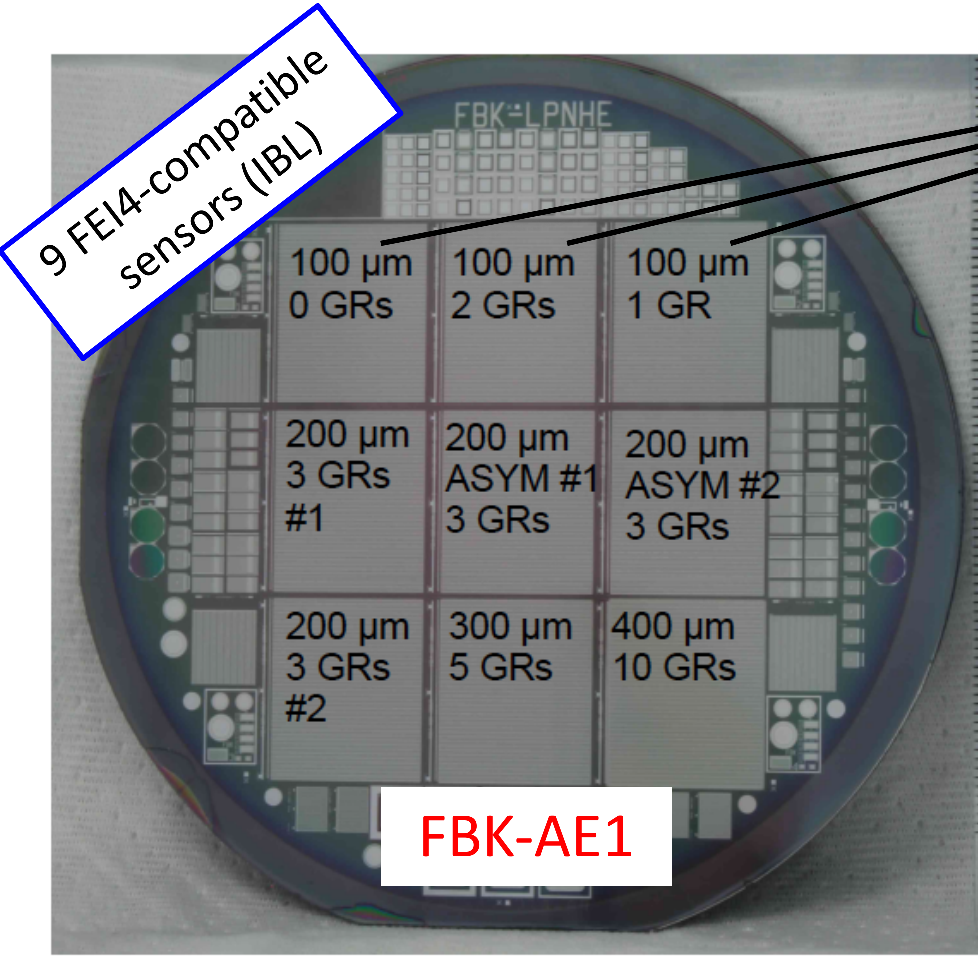
Test beams:

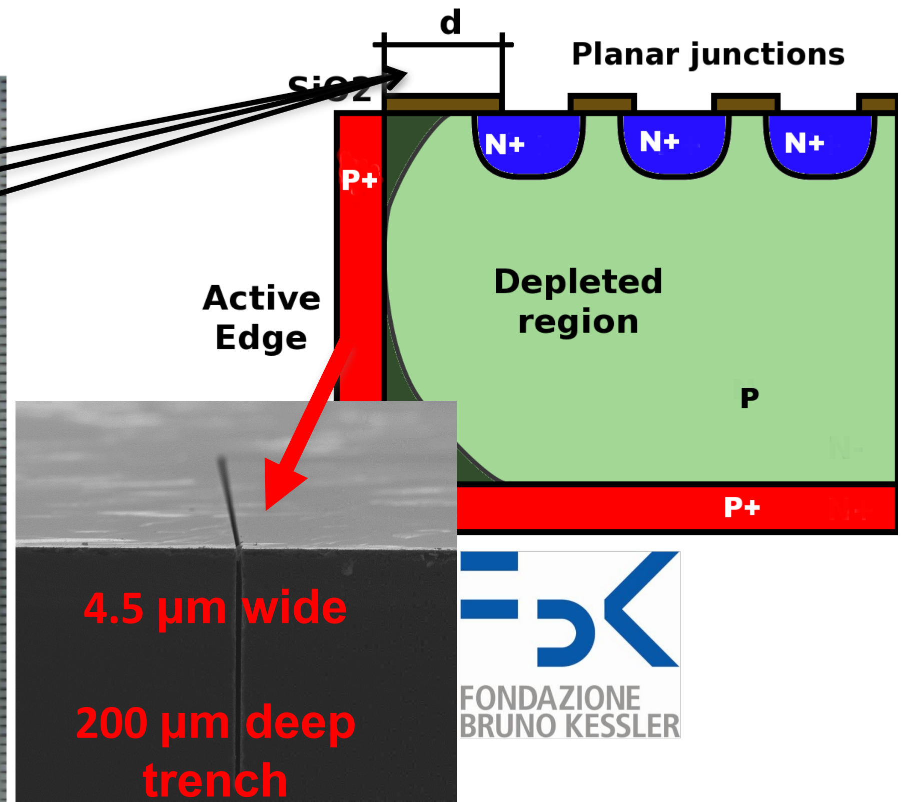
- A sample was tested in the CERN SPS test beam in July 2015.
  - Reconstruction and data analysis performed at LAL.
  - This device will be irradiated and tested in a future test beam.

Testbeam: LAL & LPNHE joint activity

The FBK/LPNHE Active Edge pixel 1 production

- 2013 4"n-on-p active edge production, on 200 µm FZ wafers
  - Plus: 500 µm support wafer

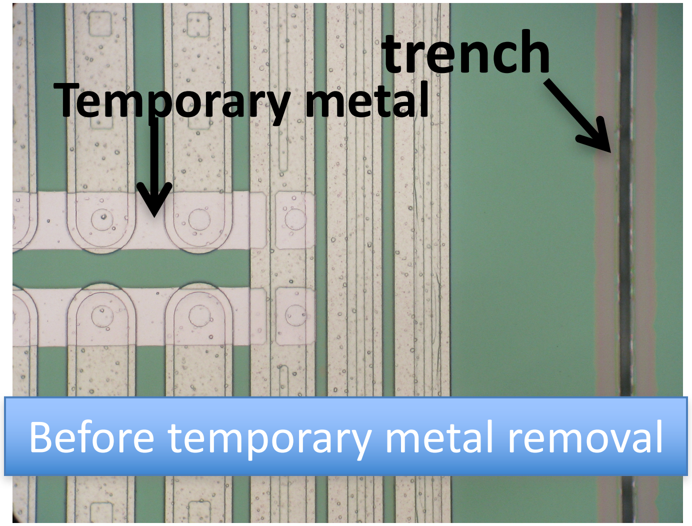


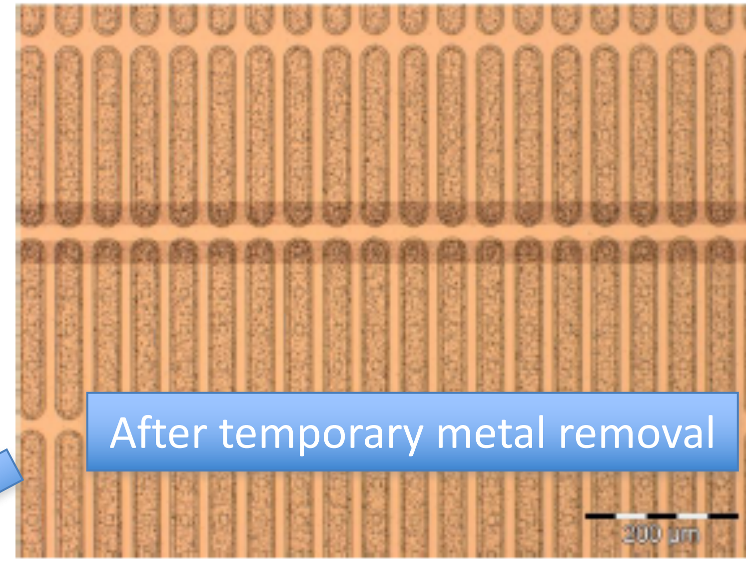


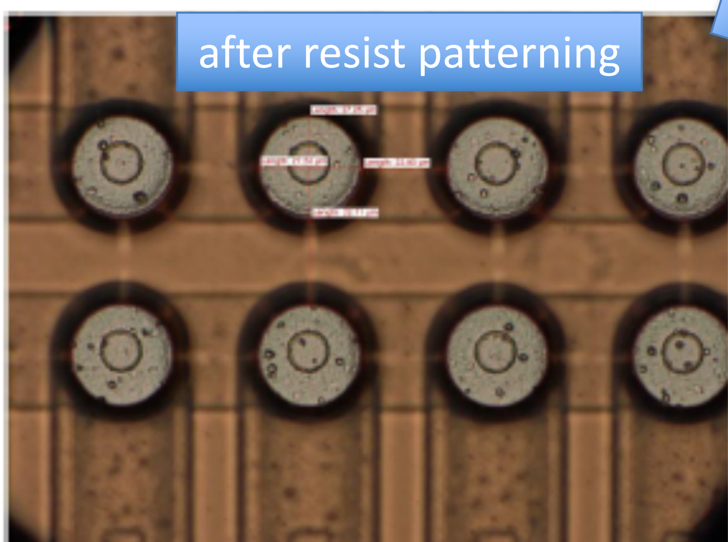
- Tested with radioactive source
- And now on beam

M. Bomben *et* al. Nucl. Instrum. Meth. A 712 (2013) 41

Temporary metal at FBK



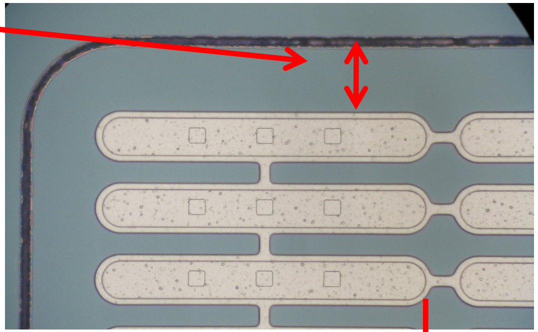




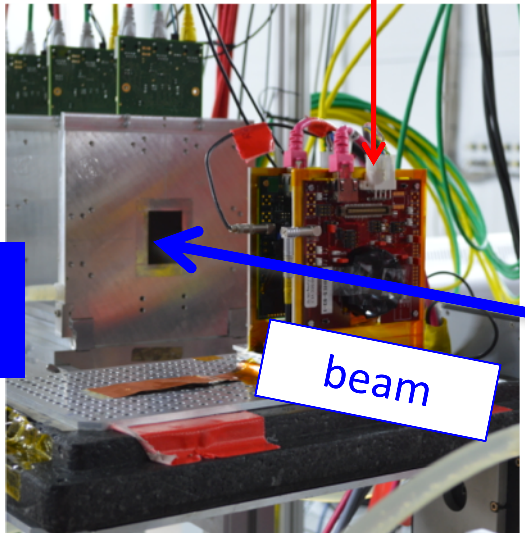
Technical solution allowing to remove the metal grid used to bias pixels during tests. After the metal removal, no inefficiency left due to bias network

DESY March testbeam

- The sample: LPNHE5, featuring 100 µm pixel-to-trench distance and no GRs
  - 2 samples more available; not enough time to measure them



- Several configurations tested



Testbeam: LAL & LPNHE joint activity

- Results – next slides

CONCLUSIONS AND OUTLOOK

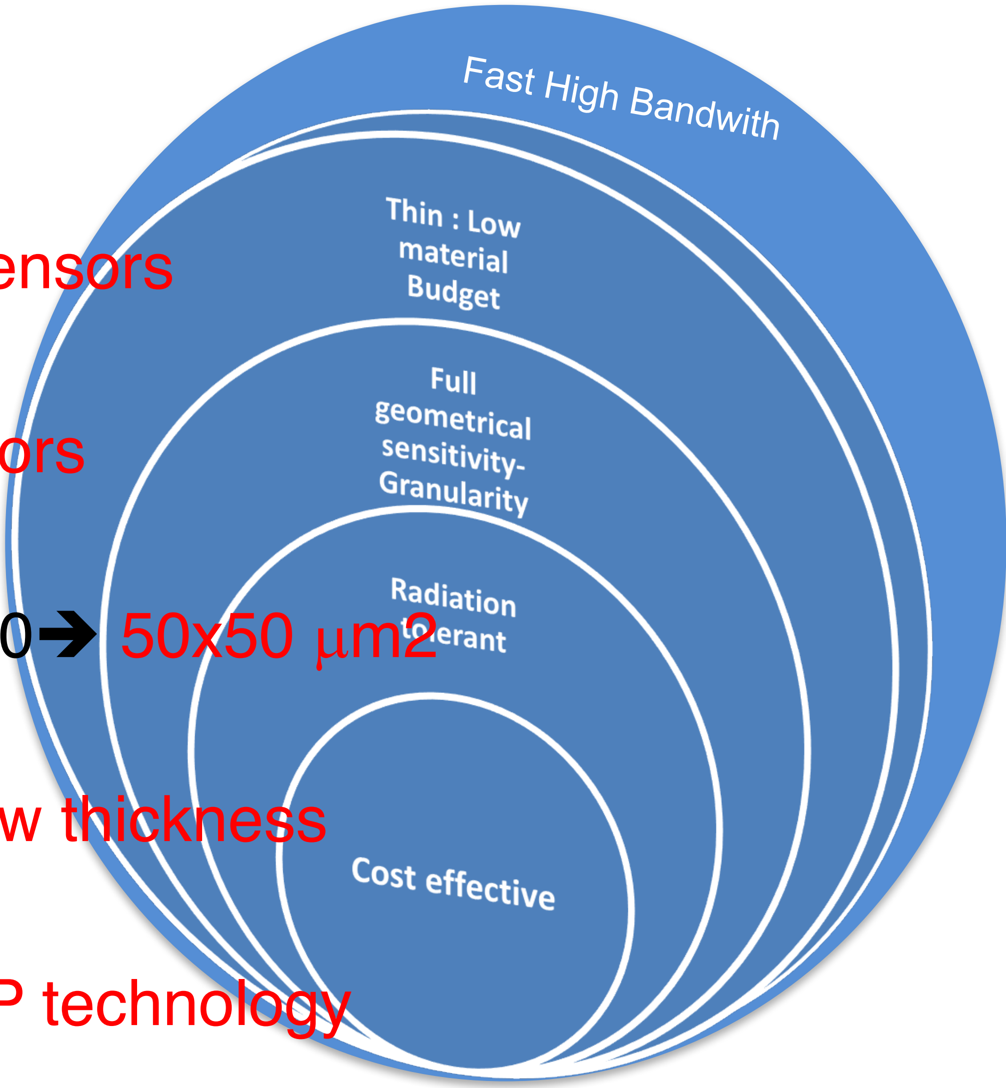
Comments & Conclusions

- The HL-LHC phase preparation is moving forward
- The new tracker demands new (pixel) readout chip, cooling, mechanics, trigger, and sensors
- The ATLAS IN2P3 R&D groups are involved in many of these activities playing a leading role in most of them
- The LAL and LPNHE are important actors in this field thanks to new pixel productions, simulation studies, modules assembly, characterization and measurement

BACKUP

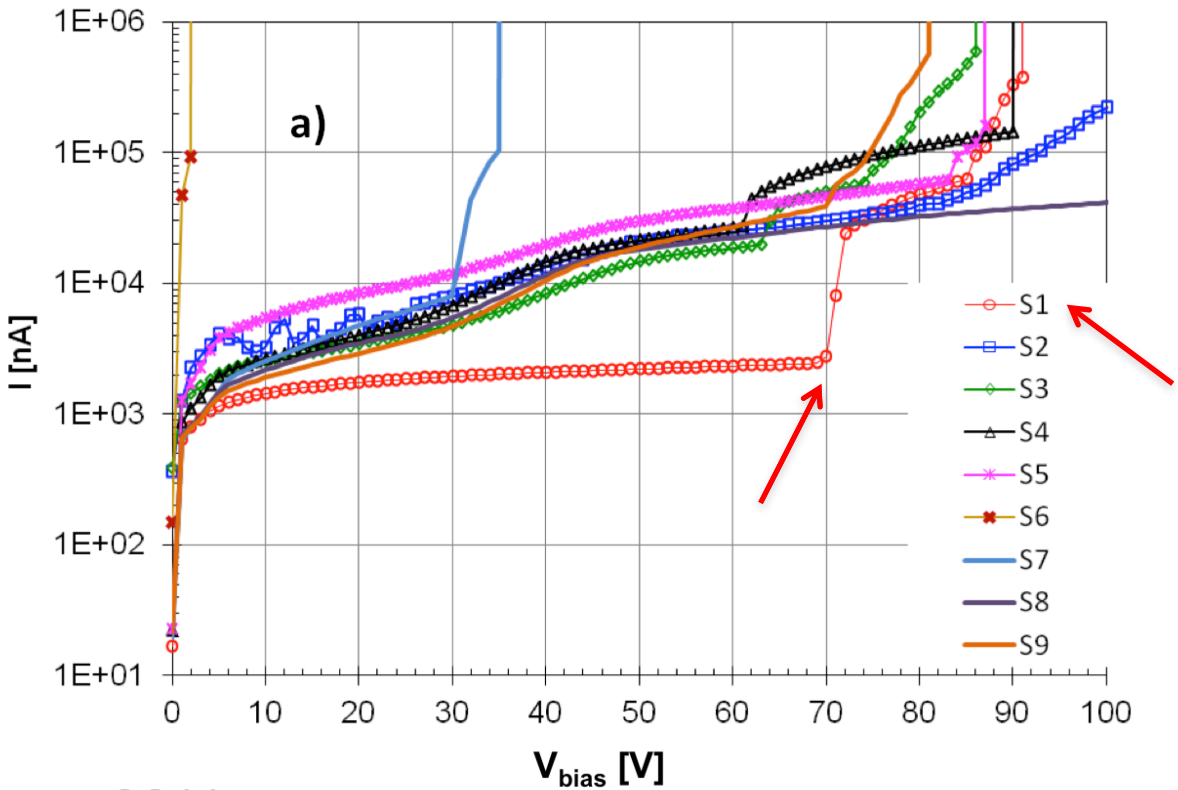
Tracker sensor design requirements

- Fast & High Bandwith
- Low Material budget : Thin sensors
- Full Sensitivity : Egless Sensors
- Granularity 50x450 ➔ 50x250➔ 50x50 μm2
- Radiation : use N-in-P and low thickness
- Cost : N-in-N actual to N-in-P technology



Breakdown voltage performance

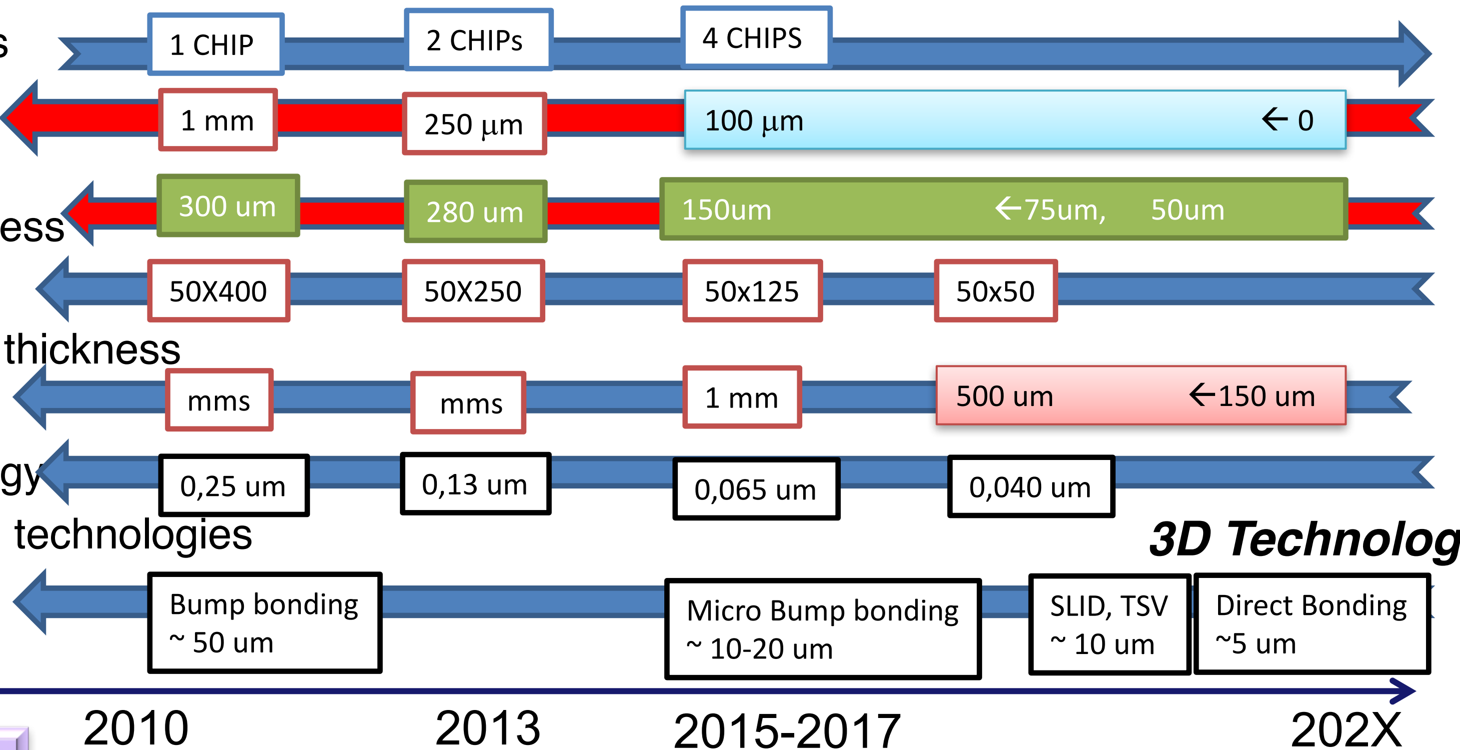
P-spray dose: $3x10^{12}/cm^2$



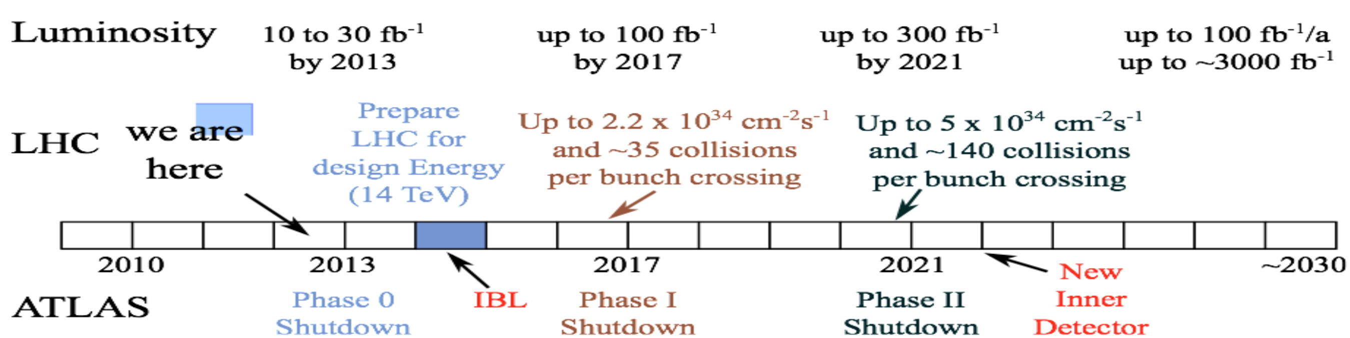
Depletion Voltage: 20 V

Large breakdown voltage values already with 100 µm pixel-to-edge distance!

- Chips/Modules
- Edges width
- Sensor Thickness
- Sensor pitch
- ASIC +sensor thickness
- ASIC technology
- Bump bonding technologies

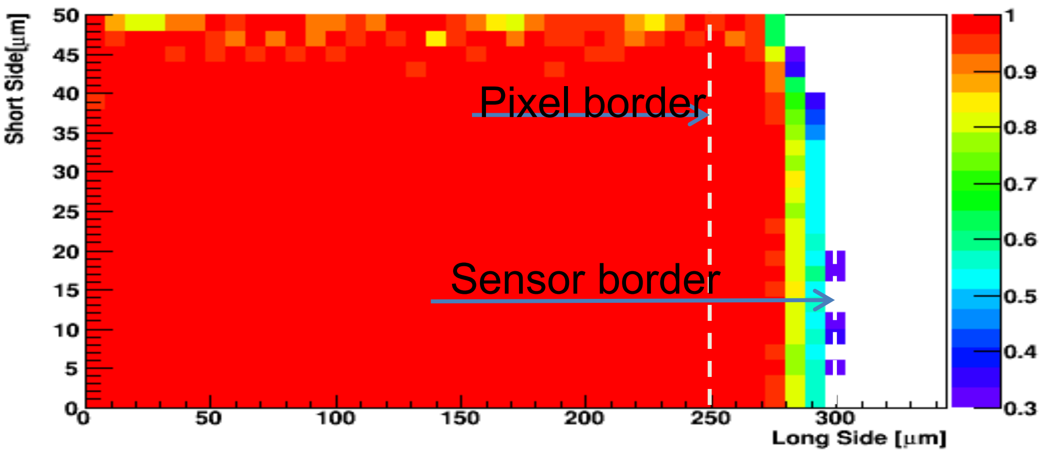


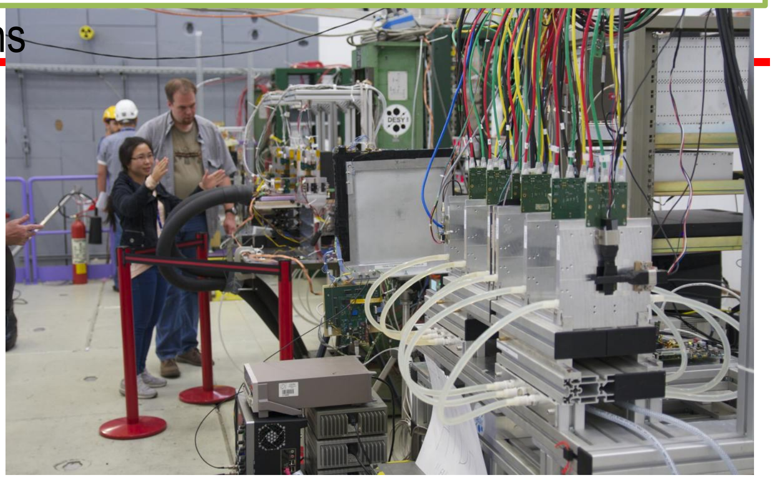
MICRON,ADVACAM ,VTT, IZM ,EMFT,TEZZARON,CIS, HAMAMATSU,TSMC,IBM, LETI



Testing the the performances at the borders to increase the overall surface efficiency

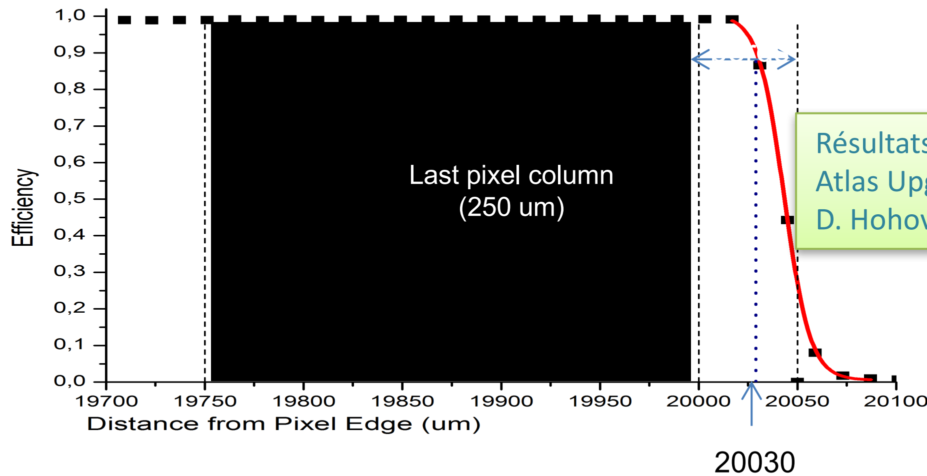
- Performances of pixels planaires under High energy Pions





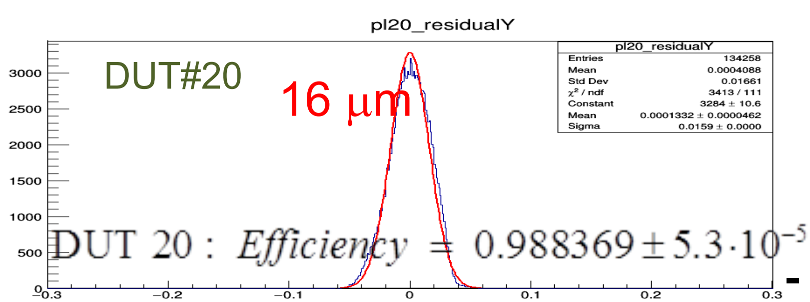
AIDA HIGH RESOLUTION PIXEL TELESCOPE

Active Edge 50 µm

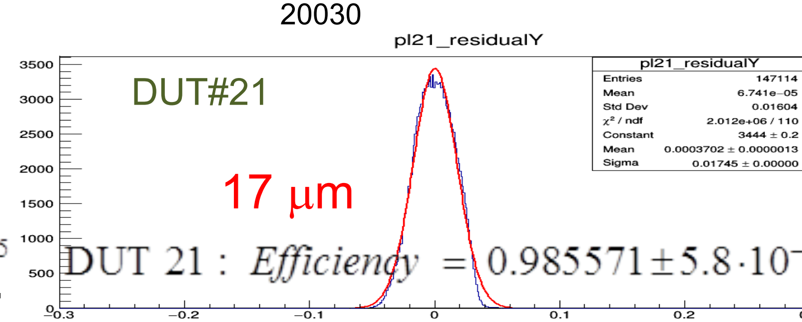


Résultats presented at CERN
Atlas Upgrade Week-27-31/03/2017
D. Hohov, LAL

Distribution of residuals



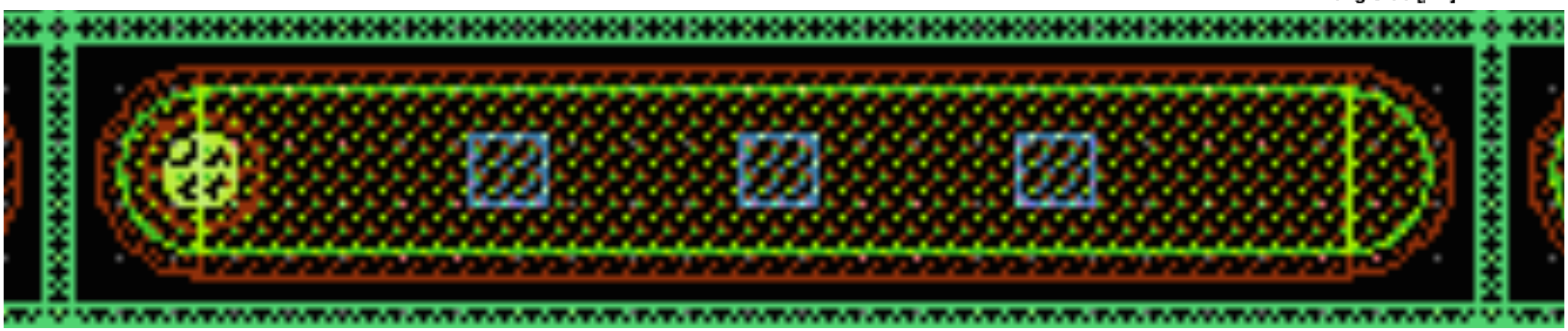
$$DUT\ 20:\ Efficiency = 0.988369 \pm 5.3 \cdot 10^{-5}$$



$$DUT\ 21:\ Efficiency = 0.985571 \pm 5.8 \cdot 10^{-5}$$

In-pixel efficiency

Thr 1600, V_{bias} = -40 V



- No biasing structure → (small) very uniform charge efficiency
  - effect due to charge sharing at the pixel's corners