ATLAS pixels
- sensors & instrumentation -

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On behalf of the LAL ATLAS pixels group

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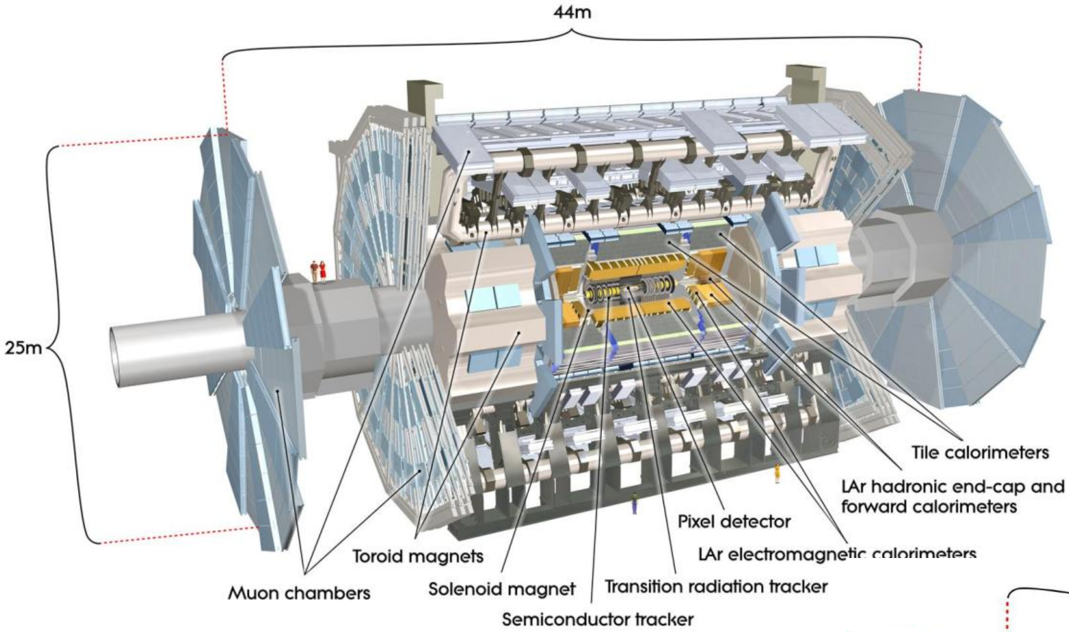
Outline

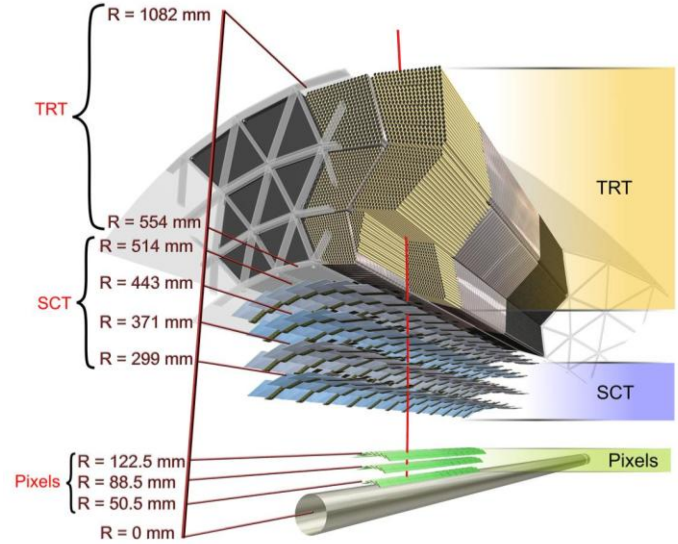
- Introduction
  - Motivation of ATLAS pixel detector upgrade
- LAL ATLAS pixel group activities
  - R&D for pixels design using TCAD simulations
  - Development of experimental tools for pixels characterization
  - Test-beams
  - IBL commissioning
- Conclusions and future activities

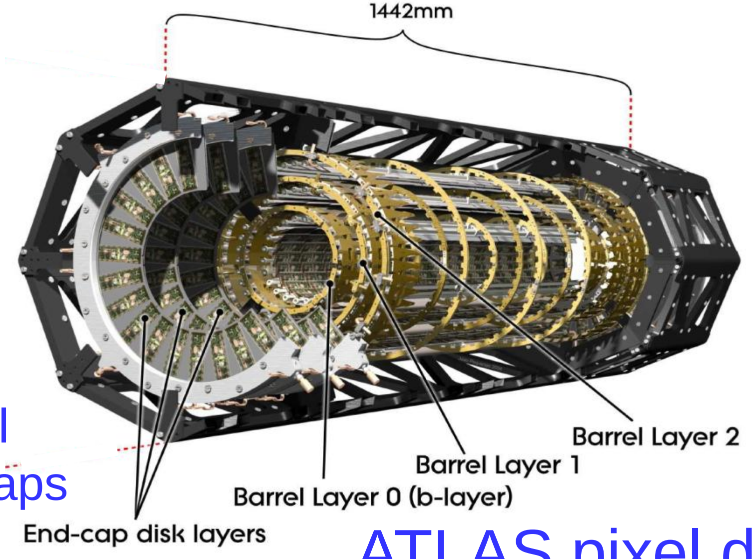
ATLAS detector and his components

ATLAS detector



ATLAS inner detector



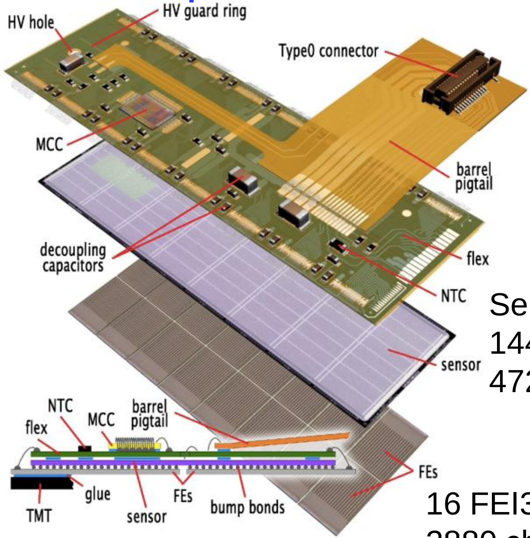


1.7 m^2 total active area
67 million pixels in the barrel
13 million pixels in the endcaps

ATLAS pixel detector

ATLAS pixel detector

barrel pixel module

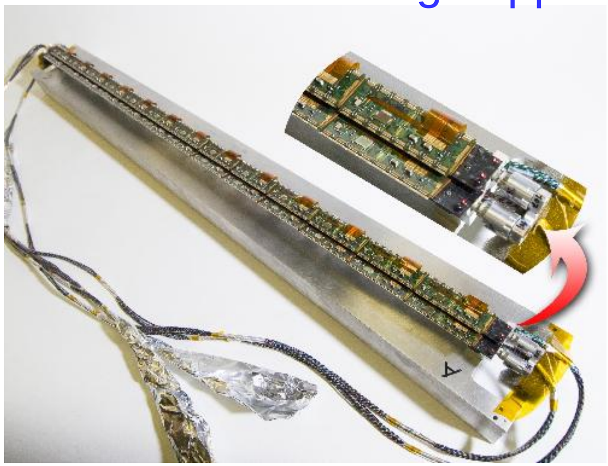


Sensor tile
144 col x 328 rows
47232 pixels

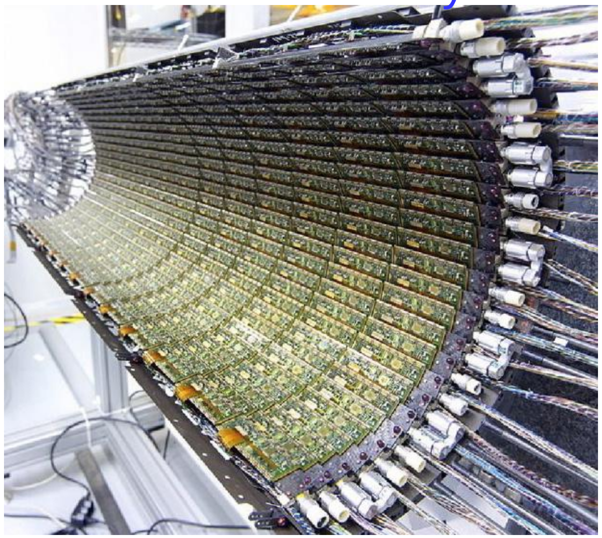
16 FEI3 chips
2880 channels/chip

1

stave mechanical/cooling support



Half shell assembly



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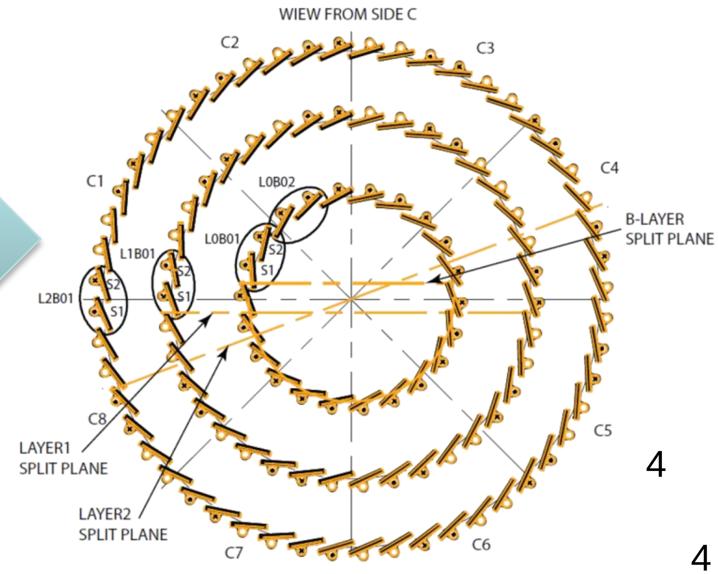
r-ϕ barrels plane view



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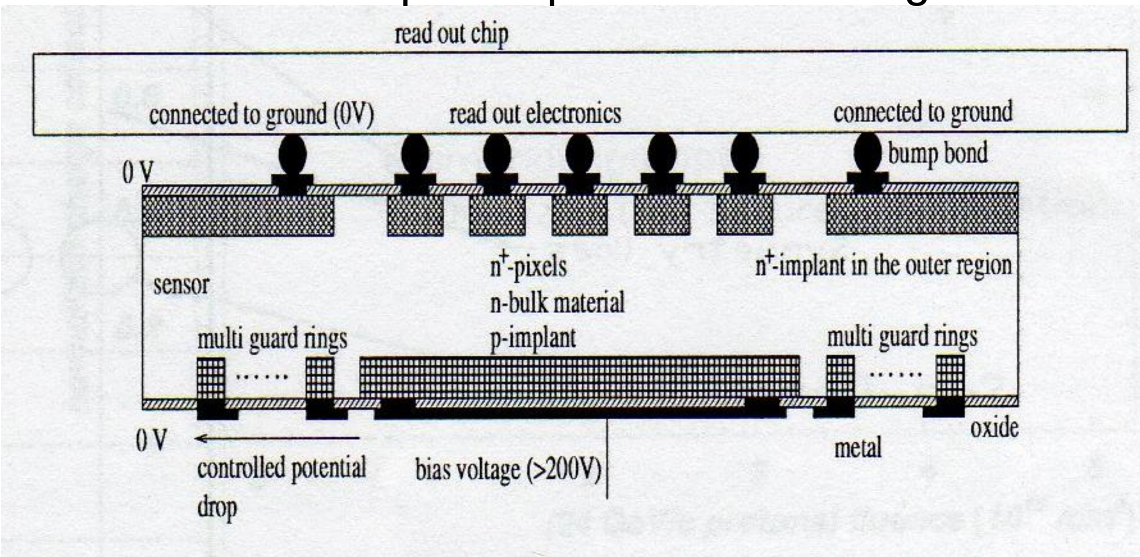
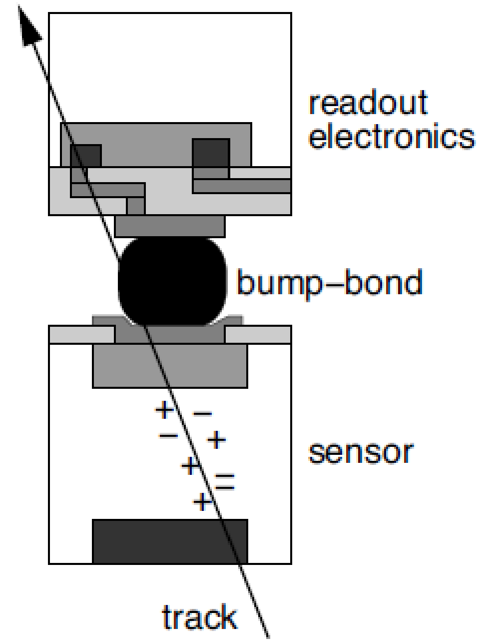
The actual ATLAS pixel detector uses planar sensors

n-in-n planar pixel sensor design





Connection between
- one sensor pixel cell
- the electronics pixel cell

- Characteristics of FEI3 n-in-n planar pixel sensor
  - n-type silicon substrate (2-5kΩ cm, 250µm thickness)
  - junction side (back contact):
    - uniform p+/n junction
    - surrounded by a structure of 16 guard-rings
  - pixel side (front side):
    - each pixel: n+ implant: 30µm wide, 380µm long
    - 2880 pixels: 18 columns x 160 rows
    - pixel cell dimensions (pitch): 50x400µm^2
    - p-spray isolation technology

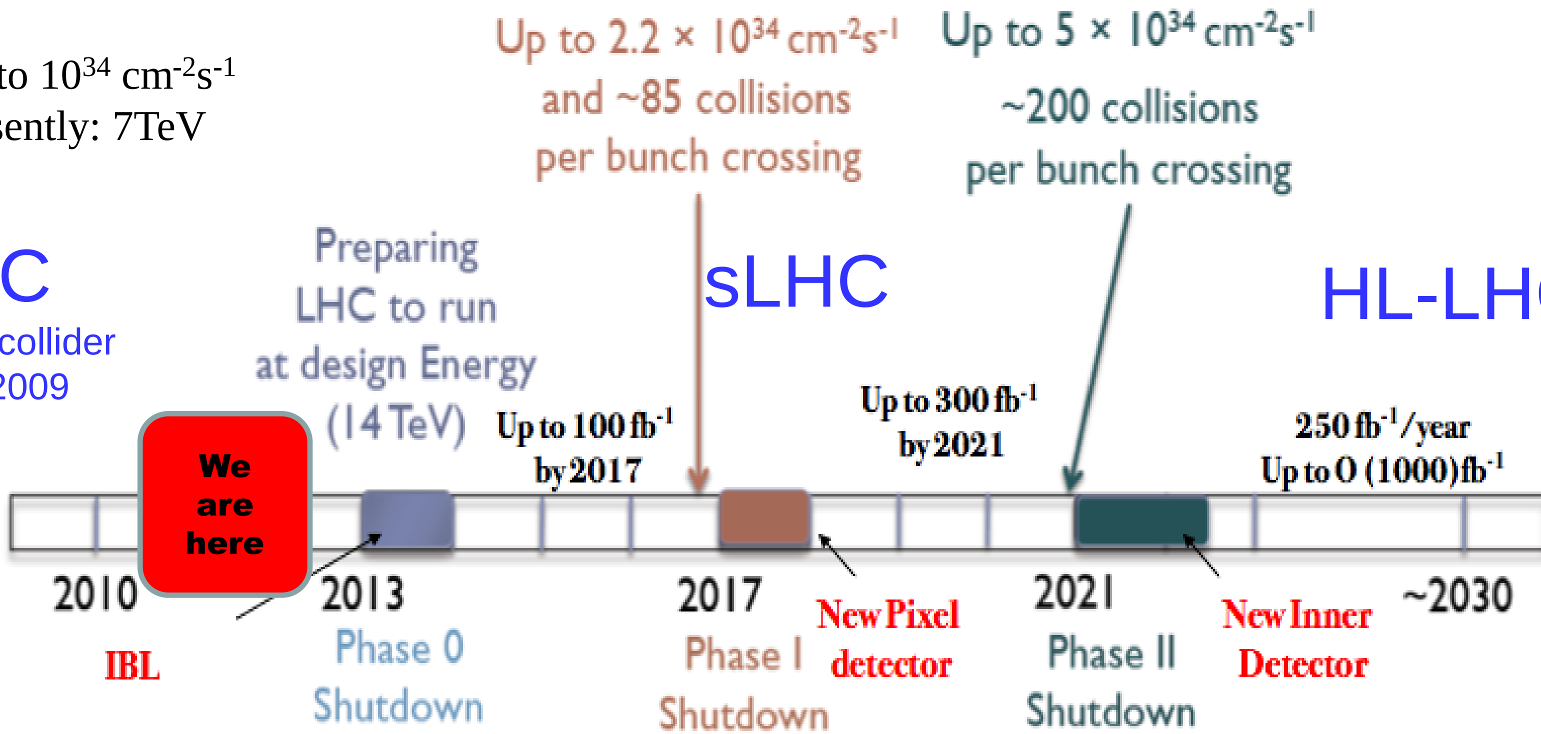
LHC and ATLAS inner detector upgrade scenario

Up to 10^{34} $cm^{-2}s^{-1}$
presently: 7TeV

LHC
p+p+ collider
Nov. 2009

sLHC

HL-LHC

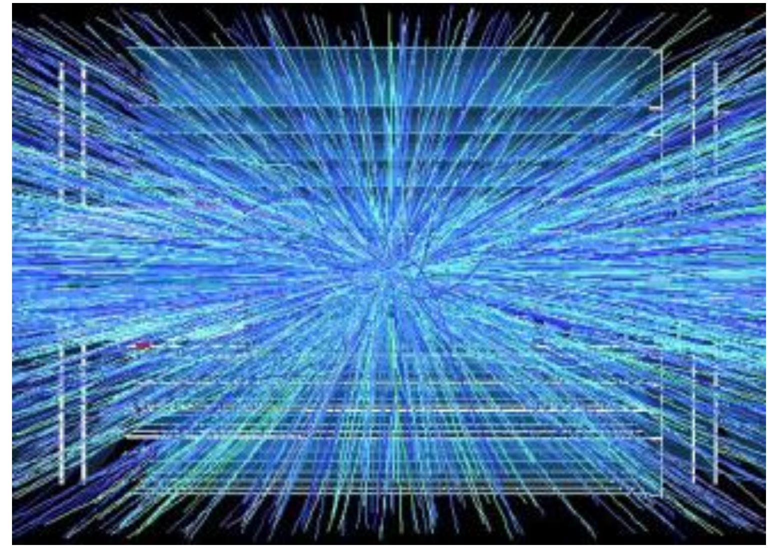


ATLAS
inner detector

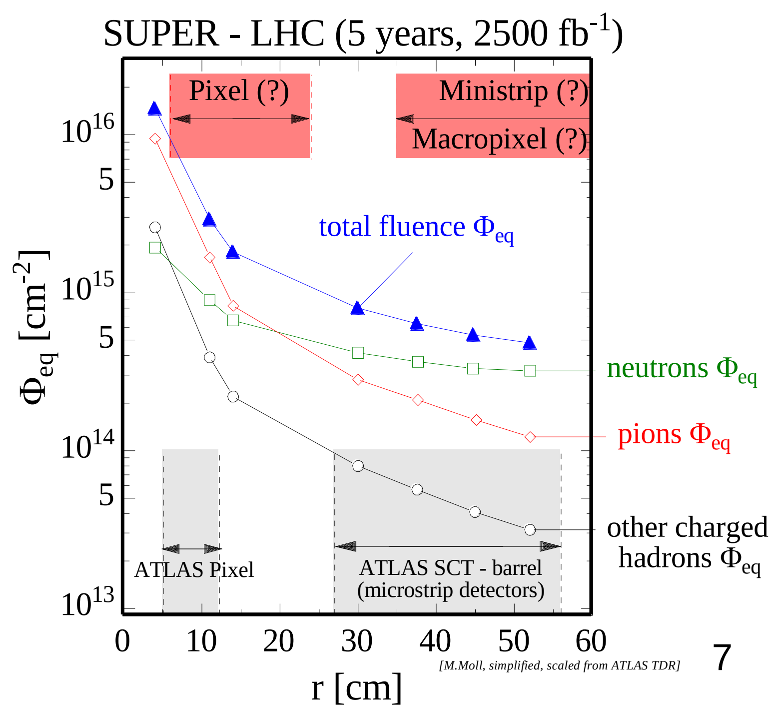
ATLAS
inner detector upgrade

Challenges at high luminosity

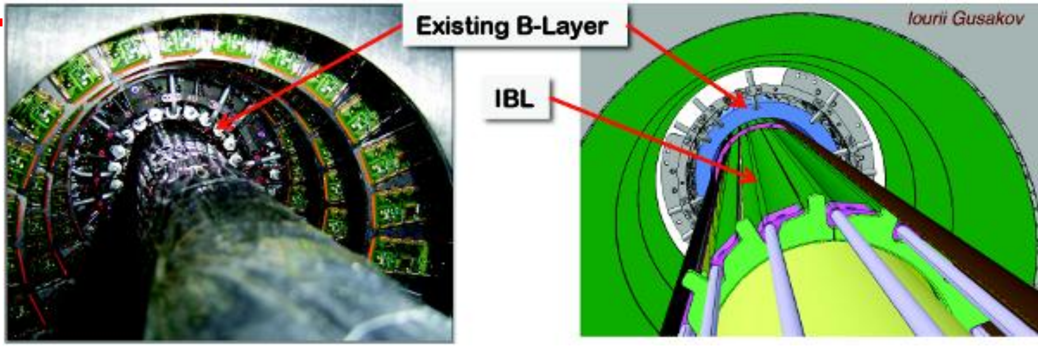
- Increased occupancy & event rate
  - $O(10^2)$ events/BC
  - events pile-up will render the reconstruction more difficult
  - higher pixel granularity is required
    - 400 ⇒ 250 μm on long pixel side
    - FEI3 ⇒ FEI4



- Radiation damage (CCE, depletion)
  - 1e15 ⇒ 2e16 1MeV n_{eq} cm^{-2} - B layer
  - induce loss in efficiency and eventually lead to data loss of the inner pixel layer
    (deteriorates the impact parameter resolution)
  - New inner layer is required:
    - Radiation hard material



IBL (ATLAS inner detector phase 0 upgrade)



- For the Phase 0, new b-layer (Insertable b-Layer, IBL) between the interaction point and the actual b-layer is planned:
  - Increases tracking robustness
  - Limits loss in efficiency at high luminosity
  - Increases reconstruction accuracy
  - Copes with increased radiation damage
- The IBL will be located at 3.325cm of interaction point
- Reduced beam-pipe to a radius of 2.5 cm

Sensors requirements for IBL:

Radiation hard sensor:

- sufficient charge collection efficiency after 2e16 1MeV n_{eq} cm^{-2} ;
- leakage current < 100nA/pixel

The small space available for the IBL imposes a limit on the inactive area of the sensor to allows the placement of the sensors, chips, cooling and other services within the actual pixel detector radius

- inactive edges < 450 μm (actual 1 mm)

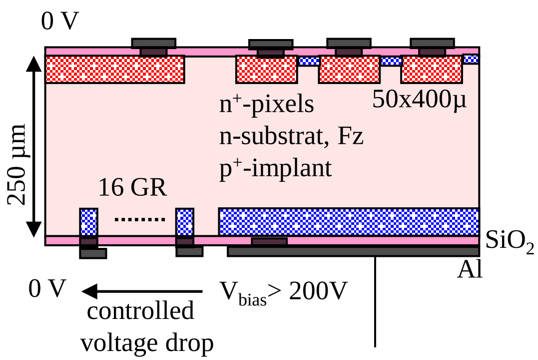
Material budget needs to be minimized to reduce the unwanted photon conversion associated with additional mass between the interaction point and the calorimeter system

- sensor thickness between 150 et 250 μm (actual 250 μm)

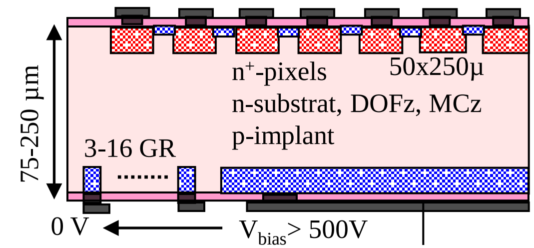
- Sensor operation voltage: max 1KV (actual 600V)
- Operation temperature: -15°C (actual -10°C)

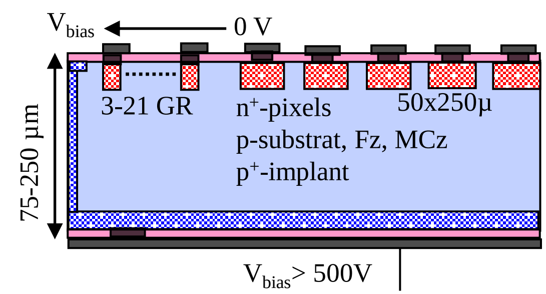
Planar Pixel Sensor R&D for the ATLAS upgrade

- 17 institutes, > 80 scientists (full list in the appendix), official ATLAS R&D project started in 2008
- Goals
  - Evaluate/improve performances of PPS at high fluences
  - Geometry optimization
  - Cost reduction at large areas for sLHC&HL-LHC



Pixels optimization
LHC ⇒⇒ HL-LHC





- Tools
  - available sensors: CiS / HLL-MPI / Micron / HPK/ VTT
  - n&p irradiations (Ljubliana/CERN/Karlsruhe/Los Alamos) up to 2e16 1MeV n_{eq}/cm^2
  - characterisation in testbeams (CERN/DESY),
  - lab tests (Dortmund, MPI, LAL, LPNHE, Liverpool, KEK)
  - *TCAD simulations, dopant profile measurements, fabrication process control: LAL*

LAL ATLAS pixel group activities

Few parallel activities:

1. Sensor design and simulations using TCAD (Technology Computed-Aided Design) tools (M.Benoit thesis):
   - Development of planar pixel sensor model able to predict the pixel behavior during HL-LHC conditions:
     - optimized geometry (e.g. less inactive area)
     - improved radiation hardness

2. Development of experimental tools (hardware/software) for:
   - measurement of real pixel structures characteristics
   - comparison of measured parameters with TCAD simulation results
   - validation of pixel sensor model developed using TCAD

SERDI involvement

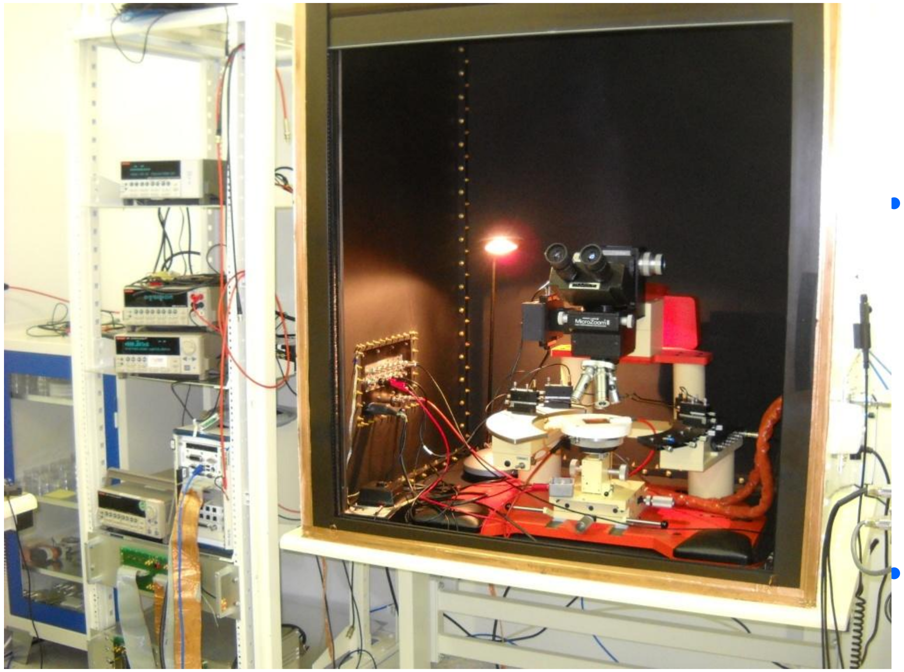
3. Measurements & simulations of irradiated pixel modules in test-beam:
   - CERN SPS, 120 GeV pions; Desy, 1-4 GeV electrons

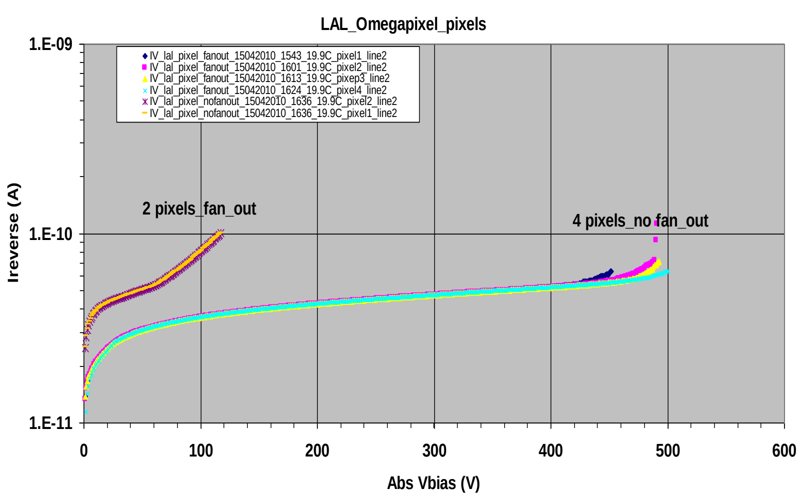
4. IBL commissioning at CERN (mechanics, cooling system, sensors test on staves)

5. Development of 3D electronics (not included in this talk)

Experimental tools for ATLAS pixels characterisation (1)

LAL clean-room (1)





- Clean-room:
  - 14 m^2 + 3 m^2 entrance
  - class 100000 (Building 208, room 117a)
  - temperature (~20°C) and humidity (< 50%) control
- Manual Karl-Suss test-station for DC tests
  - home-made Faraday cage (JF.Vagnucci)
  - connections using triaxial cables
  - room temperature measurements
  - new chuck in development for lower temperature measurements (~0°C) (T.Vanderberghe & A.Falou, JF.Vagnucci)
- Instruments for semiconductor characterization
  - Keithley electrometer 6517B
  - Keithley source-meter 2410 & 2612
  - Agilent LCR meter E4980A
  - Very low noise DC measurements (fA currents, fF capacitances)
- PC running programs
  - automatic measurements of IV, CV, GR potential, interpixel capacitances
  - New software package assuring the instruments interchangeability – C. Cheikali

Experimental tools for ATLAS pixels characterisation (2)

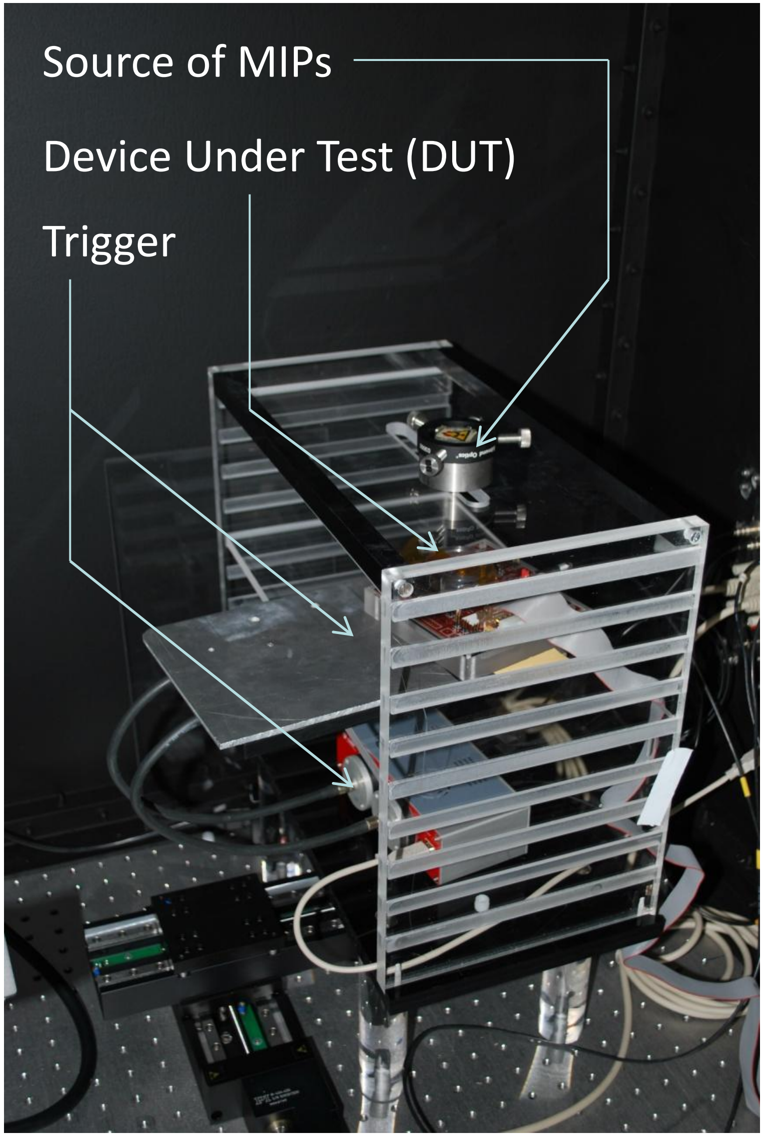
LAL clean-room (2)

- Climatic chamber + refrigerating system
  - Mechanical group development for Plank experiment
  - Allows thermal cycling tests for pixels modules (-170°C ÷100°C)

- Vacuum pumps
  - Primary vacuum VARIAN SH6110
  - Turbo pump TMH261

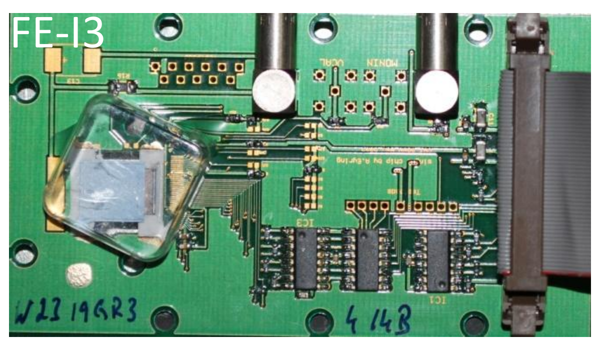
Experimental tools for ATLAS pixels characterisation (3)

LAL clean-room (3)



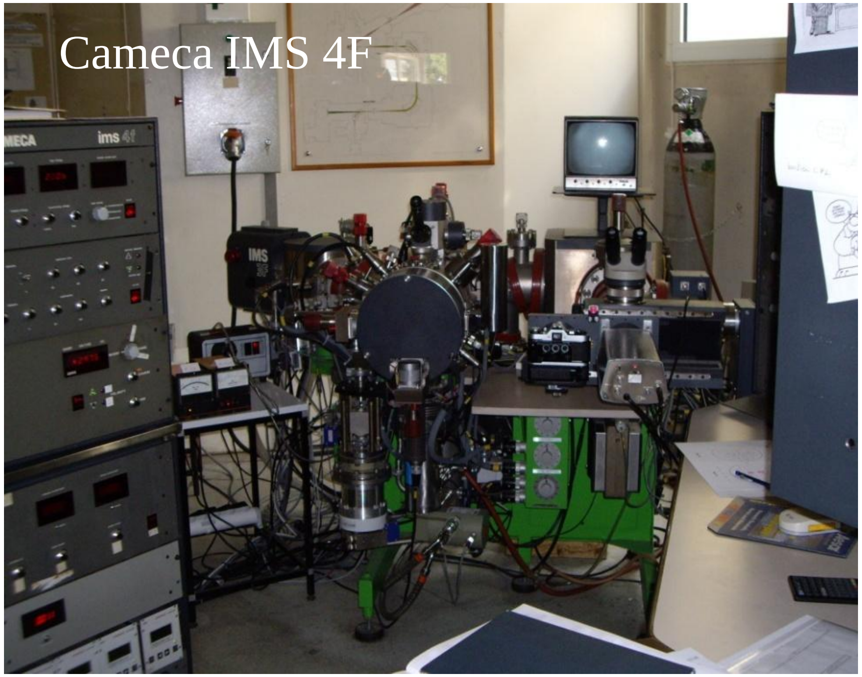
Charge collection efficiency set-up

- Sources of MIPs
  - radioactive source of beta particles: ^{90}Sr (1.3MBq; rate of 50000 betta/s)
  - Laser: 1060 nm (infrared); $E\gamma$=1.17eV ($E_{gap\ Si}$ =1.12eV; penetration depth ~800µm)
- Optical bench; µm precision translation tables
- Device Under Tests (irradiated diodes, FEI3, FEI4 pixels structures)
- Trigger system
  - Plastic scintillator with wave-length shifter in the form of a fiber collecting the scintillating photons
  - Two SiPM's + coincidence unit.
- FE-I3 and FE-I4 chips in our case

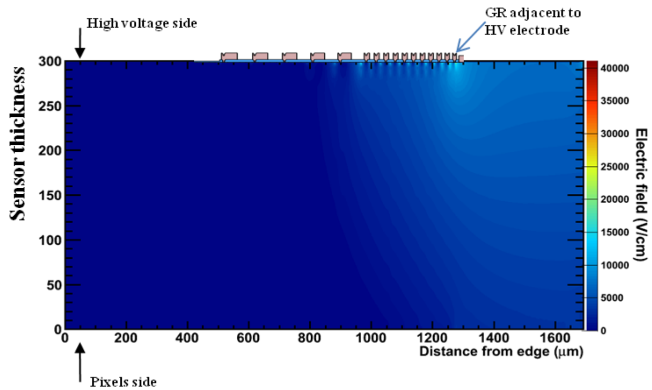


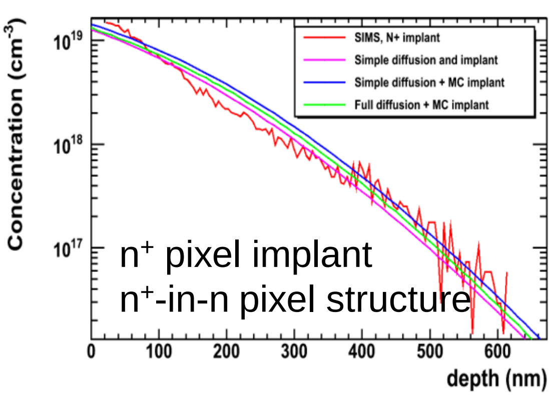
Experimental tools for ATLAS pixels characterisation (4)

- Experimental methods in collaboration with other laboratories
  - Secondary Ion Mass Spectrometry (SIMS) for total dopant density profile

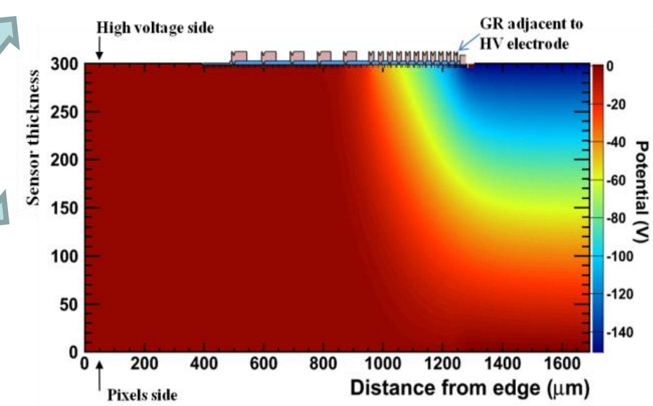


- Collaboration with GEMaC laboratory
- SIMS system @ CNRS, Meudon Bellevue
- *Accurate measurements performed thanks to the help of Eng. F. Jomard*



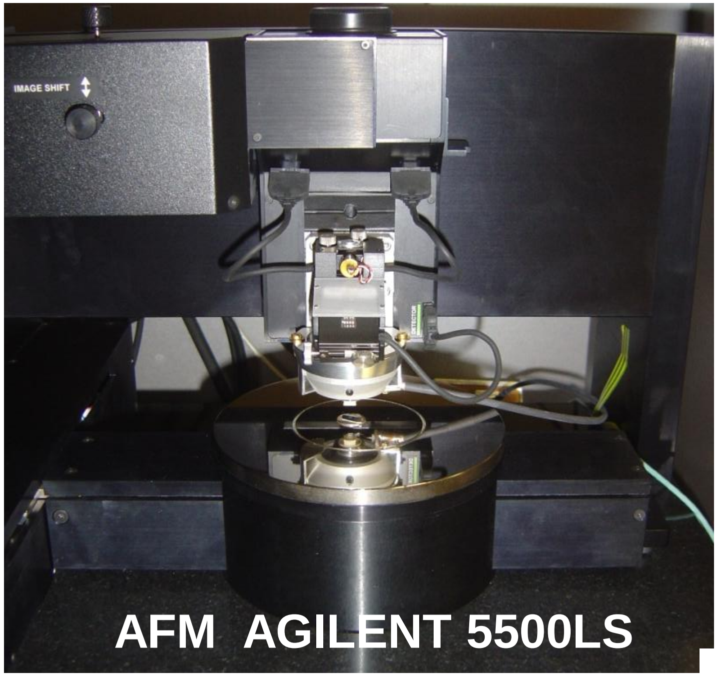


- TCAD tool
- dopant profiles as input
- simulation of sensors electrical behavior
- *prediction of optimized pixel geometry*



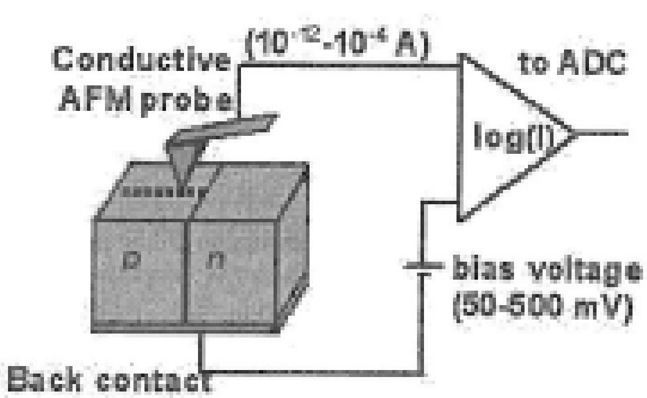
Experimental tools for ATLAS pixels characterisation (5)

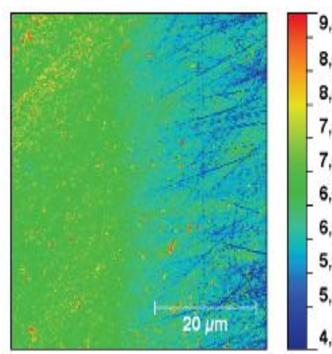
- Experimental methods in collaboration with other laboratories
  - Charge carrier density profile by Scanning Spreading Resistance Microscopy (AFM system with conductive probes)



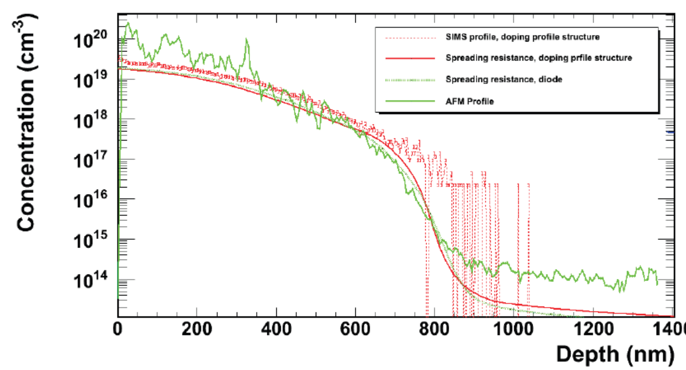
- *New method, developped in collaboration with Eng. JL. Perrosier, CTU-IEF*
- Sample preparation by polishing

Holder designed by T. Vanderberghe Fabricated at LAL





N+ implant



Conclusions and future activities

- The planar pixels sensors:
  - choice for the Phase 0 of ATLAS inner detector upgrade (IBL)

- The LAL activities had an important contribution to this choice:
  - Experimental tools contributed to validation of the TCAD simulations
  - Pixel sensor model with improved design has been predicted by TCAD simulations
    - Geometry optimization (edge dead area reduction, thickness reduction)
    - Improved radiation damage (99.5% efficiency for sensors irradiated up to 5xe15 1MeV n_{eq}/cm^2, Vbias = 1kV))

- IBL planar pixels sensor production already finished
- On going work on IBL commissioning and mechanical/cooling system

- Simulation/experimental tools development continue for the next ATLAS inner detector upgrades (2017, 2020)

Aditional slides

ATLAS PPS R&D project collaborators

CERN
D. Dobos, B. Di Girolamo, D. Muenstermann, H. Pernegger, S. Roe, A. La Rosa
AS CR, Prague (Czech Rep.)
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LPNHE / Paris VI (France)
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H. Lacker
DESY (Germany)
C. Hengler, I. M. Gregor, U. Husemann, V. Libov, I. Rubinsky
TU Dortmund (Germany)
S. Altenheiner, C. Gößling, J. Jentzsch, T. Lapsien, R. Klingenberg, A. Rummler, G. Troska, T. Wittig, R. Wunstorf
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Università degli Studi di Udine – INFN (Italy)
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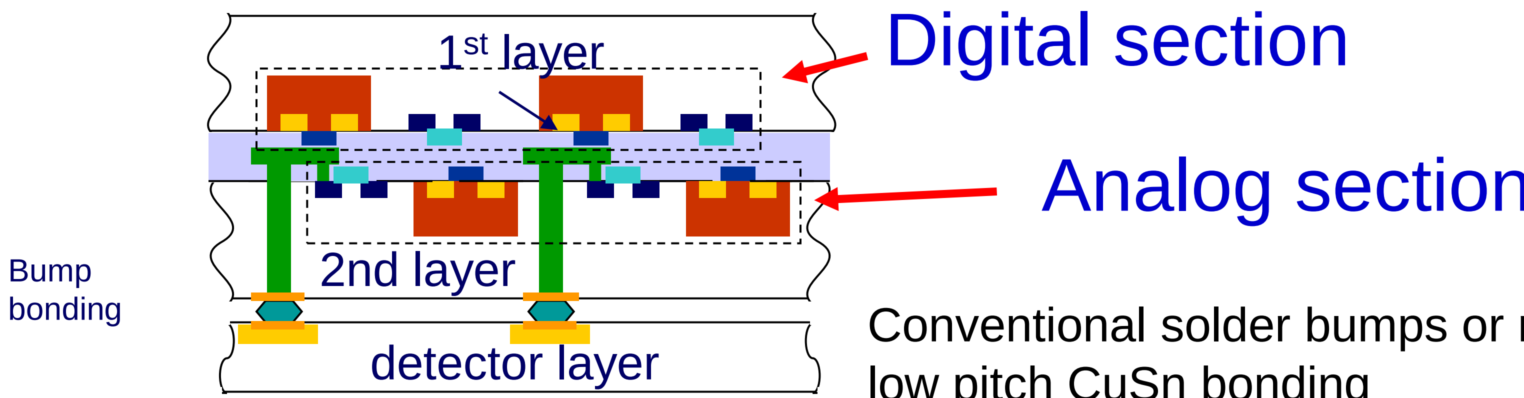
KEK (Japan)
Y. Unno, S. Terada, Y. Ikegami, Y. Takubo
IFAE-CNM, Barcelona (Spain)
M. Cavalli, S. Grinstein, Korolkov, M. Lozano, C. Padilla, G. Pellegrini, S. Tsiskaridze
University of Liverpool (UK)
T. Affolder, P. Allport, G. Casse, T. Greenshaw, I. Tsurin
UC Berkeley/LBNL (USA)
M. Battaglia, T. Kim, S. Zalusky
UNM, Albuquerque (USA)
I. Gorelov, M. Hoeferkamp, S. Seidel,K. Toms
UCSC, Santa Cruz (USA)
V. Fadeyev, A. Grillo, J. Nielsen, H. Sadrozinski, B. Schumm, A. Seiden

3D readout integrated circuits interconnected to high resistivity sensors overview

3D CONCEPT / THIN RAD HARD MONOLITHIC SENSOR + READOUT CHIP



Conventional solder bumps or more advanced, low pitch CuSn bonding

The 3D-IC consortium

Fermilab, Batavia
LBNL, Berkeley
BNL, Brookhaven
University at Bergamo
University at Pavia
University at Perugia
INFN Bologna
INFN at Pisa
INFN at Rome
University of Bonn, Germany

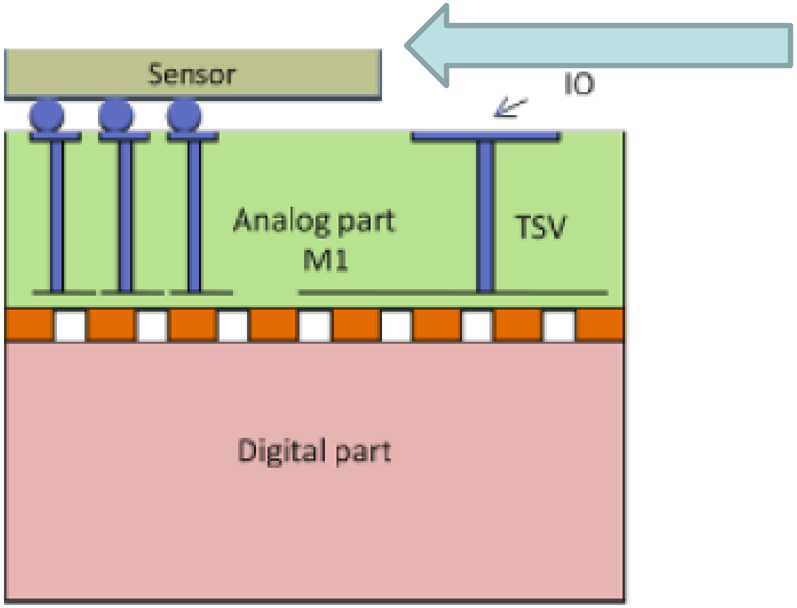
LAL, Orsay
CPPM, Marseille
IPHC, Strasbourg
IRFU Saclay
LPNHE, Paris
CMP, Grenoble
AGH University of Science &Technology, Poland

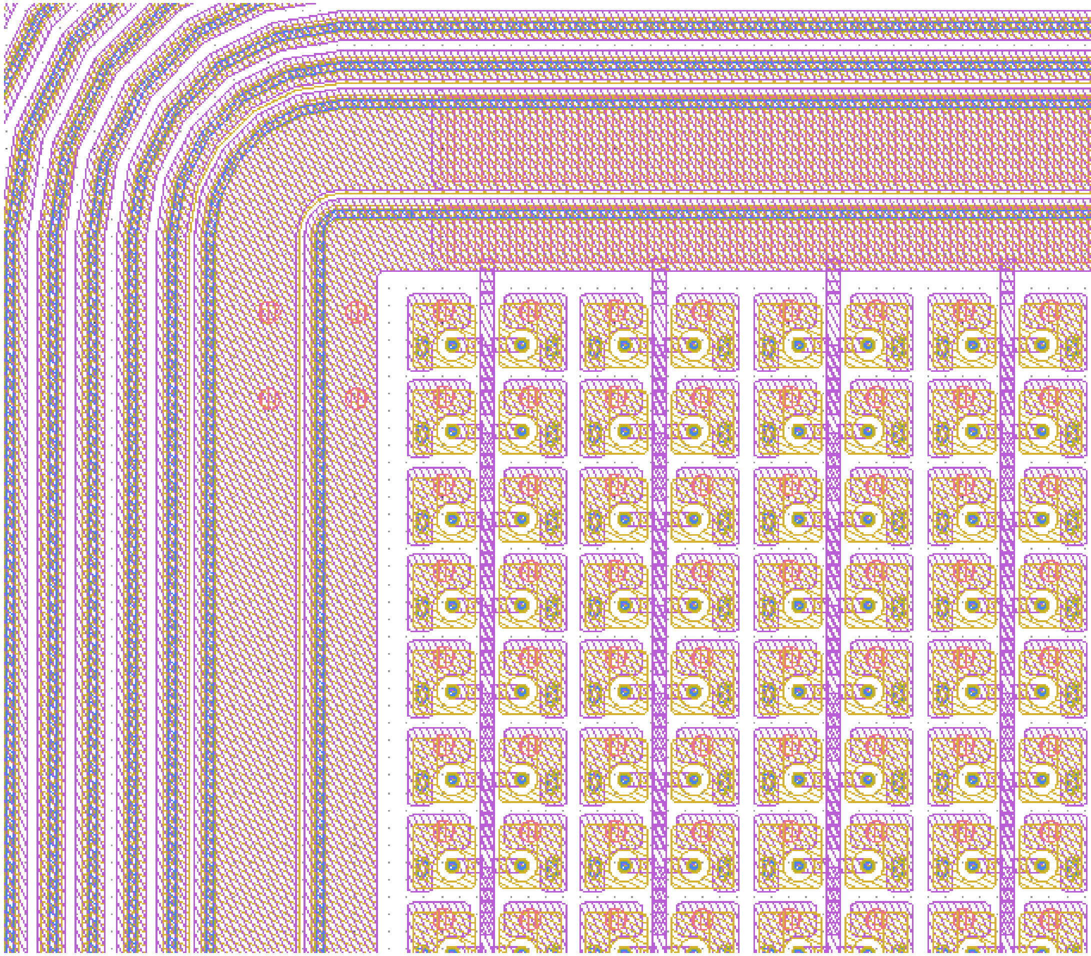
Project LAL/MPI

➢ Pixel matrix with 50x50 μm^2 pitch to be interfaced to a test chip from LAL:

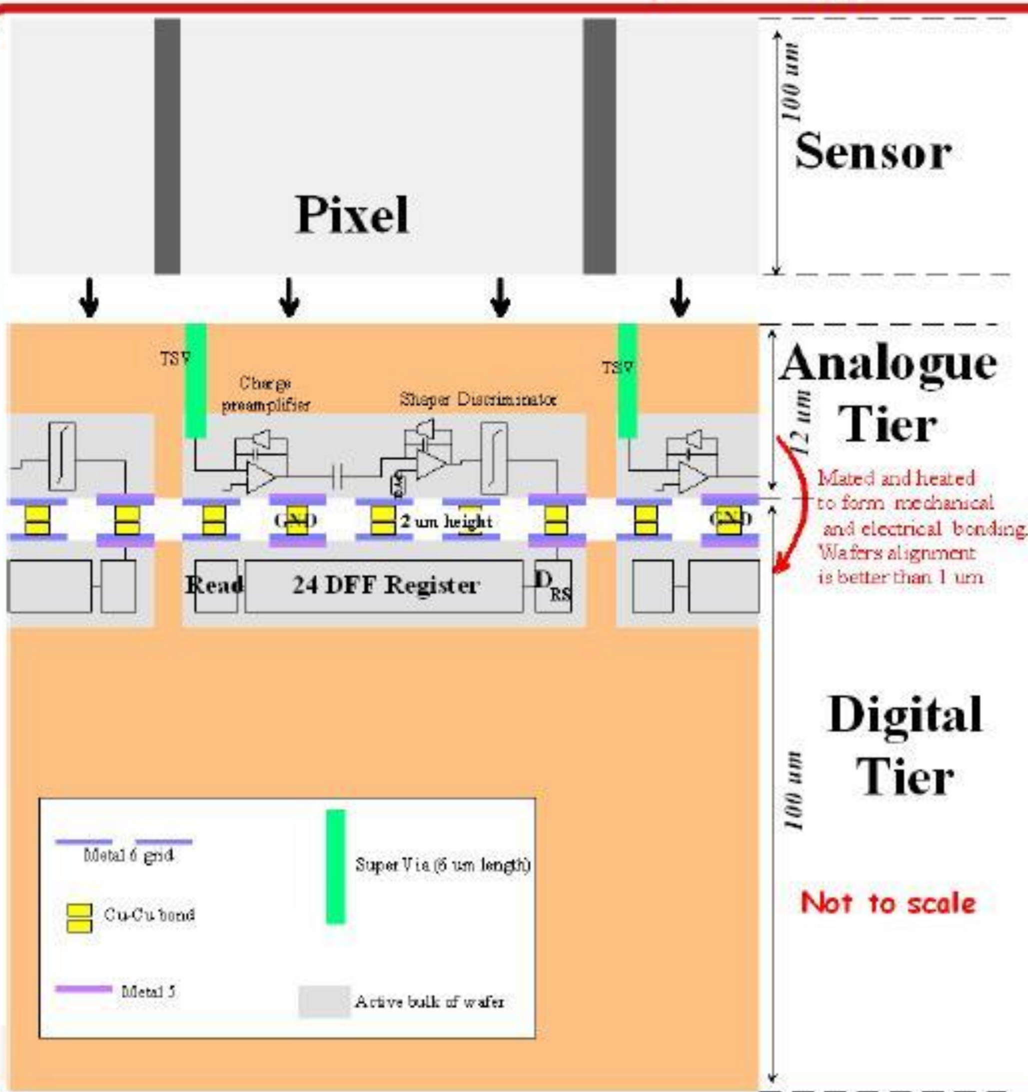
- study different functionalities of the two-tier chip

- minimize pixel pitch





OMEGAPIX: first 3D IC prototype



OMEGAPIX is the first 3D IC prototype for the ATLAS upgrade SLHC pixel project designed at LAL Orsay

It is a two stacks 3D chip: analogue tier + digital tier. Sensor will be bonded directly on the back side of the thinned analogue layer.

Analogue channel: preamplifier + shaper + discriminator + DAC to fix the threshold

Digital channel: one 24 DFlipflop register

OMEGAPIX includes 1536 channels divided in 24 columns and 64 ch/col.

Project forecast & Time scale

- A-operation: is to get slim edge Pixel sensors (IZM) with Omegapix2 130 nm chip- 05/2012
- B-operation is to get edgless pixel sensors (VTT) with Omegapix2 chip- 05/ 2012
- Third step is to have an Omegapix ASIC readout 130nm (end 2013) and later-on 65nm
- Deliver a 4 side abuttable monolithic edgless device where I/O signals are routed vertically through the readout chip (~2015)