# ATLAS - from LHC via IBL to sLHC

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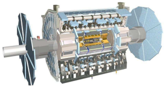
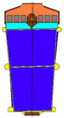
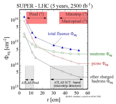
# The plan of this presentation



The ATLAS detector



The MPP/HLL envolvements and achievements

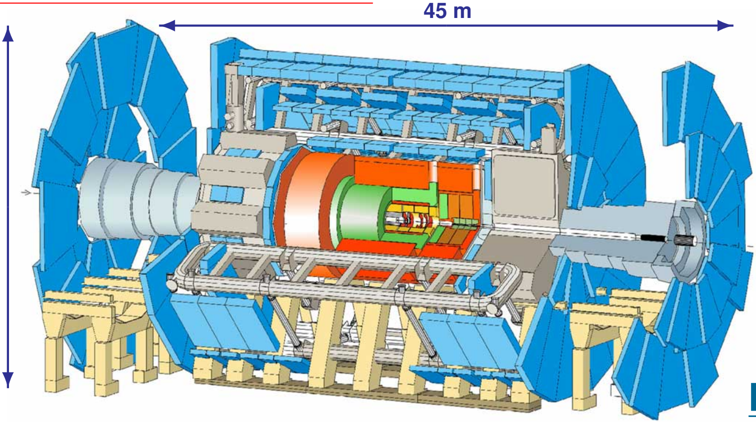



New silicon detectors for the IBL and sLHC

Conclusions and outlook

**Work by: L. Andricek, M. Beimforde, G. Liemann, H.G. Moser, R. Nisius, A. Macchiolo, A. Reiter, R.H. Richter and P. Weigell.**

# The ATLAS detector - general layout

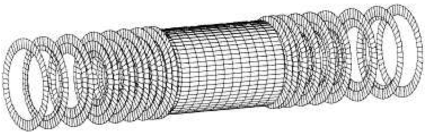



MPP

- — Silicon tracker (Pixel, SCT)
- — Transition radiation tracker (Xe)
- — Central solenoid ($B = 2$ T)
- — Electromagnetic calorimeter (Pb, LAr, 25 $X_0$)
- — Hadronic tile calorimeter (Fe, Szi, 11 $\lambda$)
- — Hadronic end cap (Cu, LAr, 11 $\lambda$)
- — Forward calorimeter (Cu/W, LAr, 11 $\lambda$)
- — Air toroid magnet ($B = 4$ T)
- — Muon spectrometer (MDT/CSC, RPC/TGC)

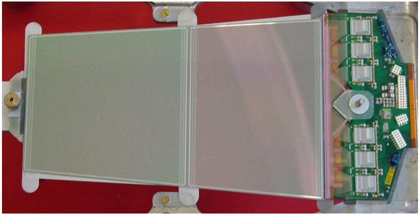
# The ATLAS SemiConductor Tracker (SCT)

## The Layout



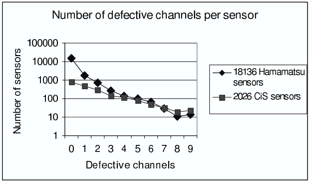
- Barrel: 4 layers.
- Endcaps: 2x9 discs.
- Modules: In total 4088, barrel 2112, endcaps 1976 (four types).
- Resolution: 16 $\mu m$ (perpendicular) und 580 $\mu m$ (parallel) to the strips.

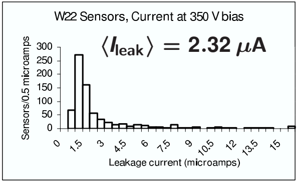
## An Endcap Module

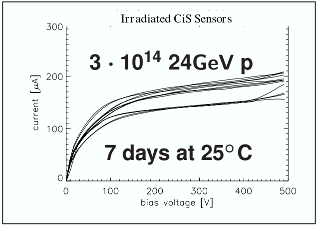


- 768 single sided p-in-n strips with 50-90 $\mu m$ pitch.
- Two sided hybrid with 6 chips per side, binary read-out.
- Mounting points with 20 $\mu$m precision.

# SCT - the HLL participation



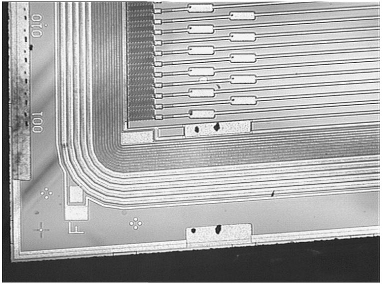




## The contributions

- Sensor design and technology transfer to CiS.
- Procurement of the CiS sensors.
- Performance tests of the CiS sensors.

## The specifications

- Number of defect channels below 10 / 768.
- $I_{leak}(20^\circ C) < 20\ \mu A$ at 350 V before irradiation.
- $I_{leak}(-18^\circ C) < 250\ \mu A$ at 450 V after irradiation.



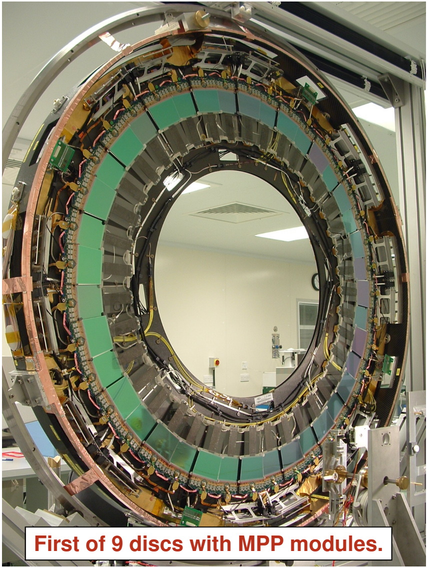

**The CiS wafers are successfully used in about 20% of the endcap modules.**

# SCT - from modules to superstructures

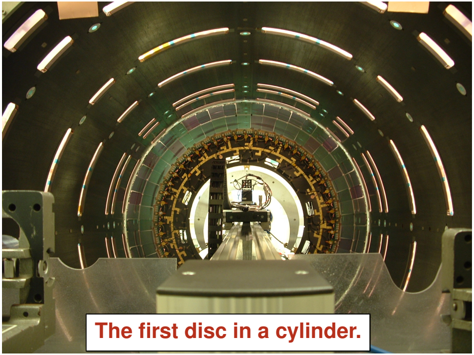
— At MPP we produced 96 *short middle* and 328 *long middle* modules.

— The MPP modules amount to all (50%) of the SCT short (long) middle modules.

— The efficiency for modules within all specs. was 93%, well above the 85% required by SCT.

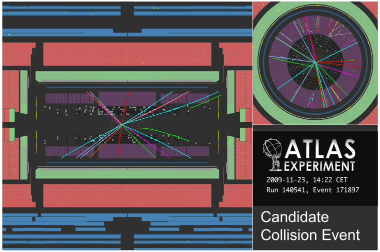


First of 9 discs with MPP modules.

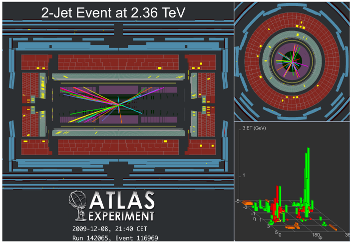


The first disc in a cylinder.

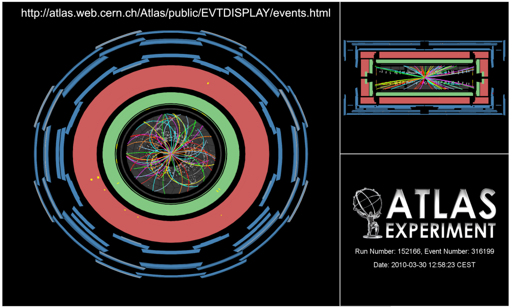
# Chronology after the LHC restart in 2009




http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html



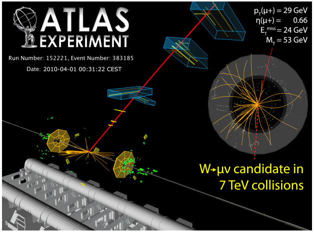

20.11.09 — Start of LHC.
23.11.09 — Collisions at 2x0.45 TeV.
08.12.09 — Collisions at 2x1.18 TeV.
22.03.10 — Collisions at 2x3.5 TeV
18.04.10 — $\mathcal{L}_{\text{int}} = 394\ \mu b^{-1}$.
2010 - 11 — Continous running up to 1 $\text{fb}^{-1}$.



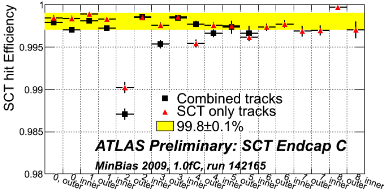

**Now the LHC is the world record holder for accelerator high energetic particle collisions.**

# Detector performance and first physics results

## The first $W \rightarrow \mu\nu$ Candidate

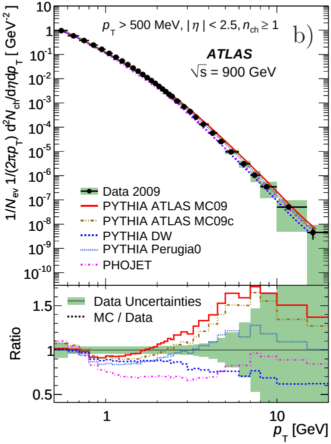



## The SCT runs at high hit efficiency




## First min bias physics results

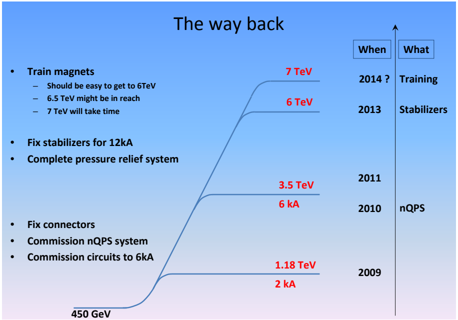
**(accepted by PLB)**



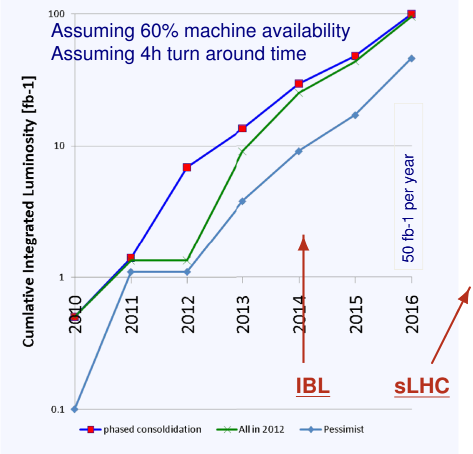

**The physics program has started, there is much more to come soon.**

# The expected path to high energy and high luminosity

## The way back to high energy




## The way to high luminosity




**The ID upgrade programme for the IBL (Insertable B-Layer) is already on its way.**

# The ID upgrade from now via IBL to sLHC

## The Insertable B-Layer (IBL)

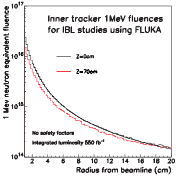



**Figure 2:** 1MeV fluences versus radius R from the beam line, for the cases z=0 cm and z=70 cm [4]. The parameterization is $\Phi(r) = (\frac{2.9}{r^2} + \frac{0.14}{r}) \cdot 10^{16}$

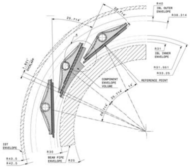
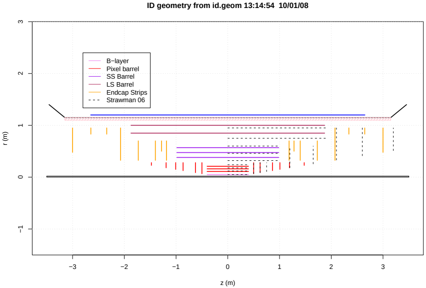


**Figure 3:** Radial dimensions in the IBL baseline layout.

| | |
|---|---|
| Staves | 14 |
| Length of stave | 80 cm |
| Width of stave | 2 cm |
| Inner radius | 3.2 cm |
| Outer radius | 3.835 cm |
| Tilt angular | 14° |

- A new read-out chip FEI4.
- Mechanics, cooling and all that is being worked out.
- Sensor candidates are: 3D-, planar- (n-in-n or n-in-p) and diamond sensors.
- The IBL is a worked out project that still this year is looking out for (MPP/HLL?) sensors.

## The ID for the super LHC (sLHC)

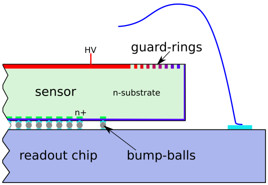



- The ID for the sLHC contains pixels, short strips (SS) and long strips(LS).
- It is still at a conceptual level, and the time planning is still rather vague.

**We are continously contributing to both projects.**

# The proposed novel pixel detector concept

## The present pixel module



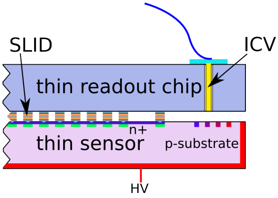

## Some expected improvements

- Live fraction of more than 90%
- No cantilever needed for read-out.
- Wider modules, i.e. less staves would be needed.
- Si-radiation length of only about 0.12% $X_0$.
- The challenge is the small? signal size.

## The key features

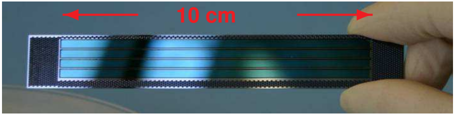
- Thin planar silicon sensors.
- SLID interconnection (IZM).
- Vertical integration with Inter-Chip Via (ICV) of the read-out electronics.

## The new module concept




**The concept needs very good, low noise electronics.**

# The production of thin sensors

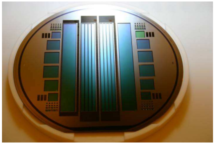




1. implant backside on sensor wafer
2. bond sensor wafer to handle wafer
3. thin sensor side to desired thickness
4. process on top side
5. structure resist, etch backside up to oxide/implant

HLL → Industry: TraciT, Grenoble → HLL main lab → HLL special lab

## Some details

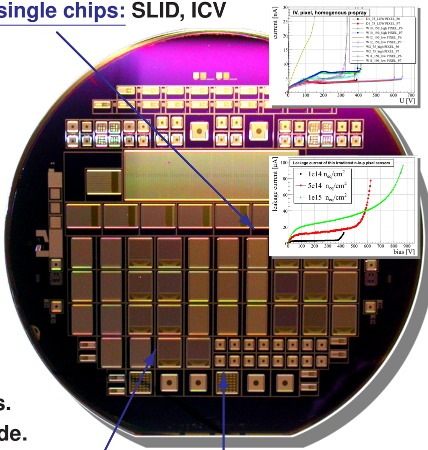


- In the past, the full process has been successfully applied to diodes.
- The gravitational bow of large mechanical samples is below 20 $\mu$m.
- The active thickness can be varied to achieve a specific signal size.
- The process leads to oxygen enriched sensors for free.
- Micro-strips and pixel sensors have been made, but the handle wafer is not yet thinned.
- Backside etching needs to be transferred to industry, or integrated into the HLL main Lab.

**The process is well established, but needs to be optimized.**

## Some achievements of our first thin sensor production

**ATLAS single chips:** SLID, ICV




— In total 12 n-in-n and n-in-p wafers with 75 $\mu$m and 150 $\mu$m active thickness were produced at HLL and in industry.

— A high pixel yield $\frac{79}{80}$, $V_{\text{break}} \gg V_{\text{dep}} =$ (20-80) $V$, and $I = \mathcal{O}(nA)$, are observed before irradiation.

— After p-irradiation at KA up to $\Phi_{\text{eq}} = 10^{16} \text{n}_{\text{eq}}/\text{cm}^2$ still acceptable $V_{\text{break}}$ are observed.

— Slim edges (standard, (610+300) $\mu$m) $\longrightarrow$ (slim, (225+685) $\mu$m) edges are possible.

— CCE measurements show encouraging (and surprising) results after large fluences.

— Investigations of radiation hardness of the BCB and HV stability will follow on single chip modules.

— The details will be shown tomorrow by M. Beimforde.

— The production of FEI4 compatible sensors for IBL qualification still this year are already underway at HLL.

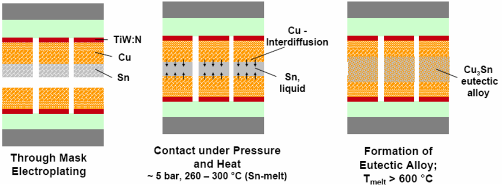
**Test structures:** Diodes, SLID

**Micro-strips:** pixel isol., IV, CCE

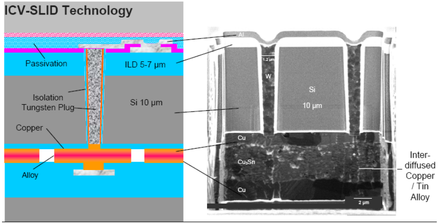
**The performance of the thin n-in-p sensors is very encouraging.**

# The IZM-München 3D-integration approach

## Fraunhofer IZM-München




## Fraunhofer IZM-München




### Solid Liquid Inter Diffusion (SLID)

(an alternative to bump bonding)

— TiW layer as diffusion barrier

— Cu + Sn layers $\longrightarrow$ formation of $Cu_3Sn$ alloy at $T = 300^\circ$C.

— The feature size is determined by the pick & place precision.

### Inter Chip Vias (ICV) + SLID

(the 3D integration concept)

— A TiW layer as diffusion barrier.

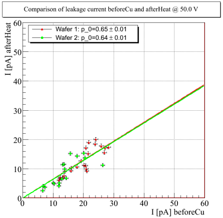
— W plugs of about $(3 \times 10)\ \mu m^2$.

— The pixel dimensions could be as small as $(30 \times 30)\ \mu m^2$.

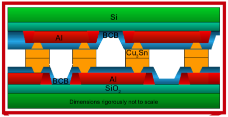
— Stacking of chips is possible, since the alloy is stable up to $T = 600^\circ$C.

**This IZM technology is being explored for potential use at the sLHC upgrade.**

# SLID performance - results so far

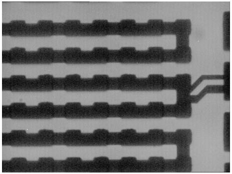



— Two wafers with diodes were treated with TiW, Cu and Sn, as needed for SLID. The currents, $I$, are small and $I^{\mathrm{before}} \approx I^{\mathrm{after}}$. $\Rightarrow$ no Cu diffusion into the silicon.




— Long daisy-chains with different pitches are used to investigate the SLID efficiency. The resistance measurements yield SLID inefficiencies of $\mathcal{O}(10^{-4})$ or less.

— Deliberate steps in height of up to 1 $\mu$m are non critical.



— Infrared pictures, e.g. for chains of $(30 \times 30)\ \mu\mathrm{m}^2$ pads show that the wafer-to-wafer SLID alignment accuracy is better than 5 $\mu$m.

— The chip-to-wafer results are not yet sufficient due to not precise enough chip placement caused by a) different size chips per wafer and b) different heights of chips taken from several wafers

**The w-to-w SLID works well on dummy structures, the c-to-w process needs more work.**

# Future steps for this R&D

## Sensors

— Produce thin n-in-p sensors for FEI3 and FEI4 chips, flip chip at IZM-B using bump balls, and compete with other sensors for IBL qualification.

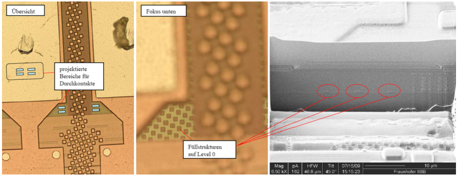
— Continue the investigations of the sensor behaviour at $\Phi_{eq} = 10^{16} n_{eq}/cm^2$, $I_{leak}$, $V_{dep}$, CCE.

— Perform testbeam measurements of FEI3 and FEI4 modules.

— Prove the HV stability of the modules.

## SLID and ICV etching

— Perform chip-to-wafer SLID (without ICV) on FEI3 sensors. The mask and the electro-plating (EP) are done. The assembly of the handle wafer and the SLID connections are tbd.




— The FEI2 are not designed for ICVs $\Rightarrow$ The only possible choice are the wire bond pads.

— The mask and the EP (sensors) are done.

— The vias etching, EP (chips), the assembly of the handle wafer, and finally the SLID connections will be performed.

**A clear but challenging road-map of this R&D is ahead of us.**

# Conclusions and Outlook

- The physics goals at the LHC, i.e. the investigation of electroweak symmetry breaking, demand a powerful detector.
- The MPP has made substantial contributions to the construction of the ATLAS experiment within the MDT, HEC and SCT groups.
- The expertise of the HLL staff and the good collaboration of MPP and HLL have been essential for the success of the SCT project.
- The LHC just started. In parallel, the upgrade of the machine and R&D work for an upgrade (IBL), and a completely new more radiation tolerant ID for sLHC are underway.
- Bringing to life the MPP/HLL concept for a novel pixel detector design has made very good progress. The R&D results on thin sensors and SLID are very promising.
- Our sensors will compete for the IBL still this year. If successfull, a production of the IBL sensors within HLL/MPP is foreseen.

**The exciting data taking period of ATLAS has just started, but intense preparations for the future detectors need to be performed in parallel.**