Status overview & Recent Achievements of the ATLAS Upgrade Planar Pixel Sensors R&D Project

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on behalf of the ATLAS PPS collaboration

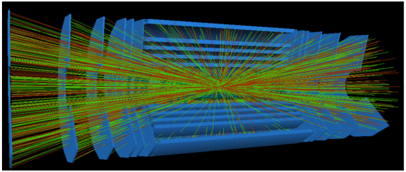
17.02.2014

LHC Program

$L=6\times10^{33}$ cm^{-2} s^{-1} √s=7-8 TeV		$L\sim1\times10^{34}$ cm^{-2} s^{-1} √s=13-14 TeV		$L\sim2\times10^{34}$ cm^{-2} s^{-1} √s=14 TeV		$L\sim5\times10^{34}$ cm^{-2} s^{-1} √s=14 TeV

2009 2013 (IBL) 2018 2022 (HL-LHC)

- Large peak luminosity $1-5\times10^{34}$ cm^{-2}s^{-1}
  - → Improved triggers
- Multiple interactions per BC up to $<200>$
  - → Coping with higher occupancy
- Huge fluences for innermost layer $2-3\times10^{16}$ $n_{\mathrm{eq}}/\mathrm{cm}^2$
  - → Radiation hard detectors
- Large area $\mathcal{O}(10\ \mathrm{m}^2)$
  - → Cost effective detectors



PPS R&D Project

Aim

Towards the development of improved silicon pixel sensors based on planar technology for the high-luminosity ATLAS Inner Detector Upgrade.

19 institutes, more than 90 people

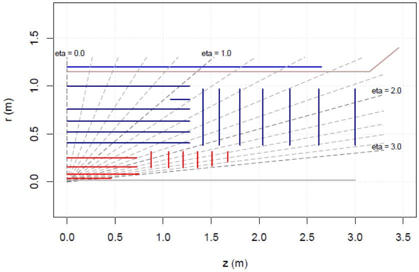
Research Directions

- Choice of bulk material and radiation damage related studies
- R&D on low-cost planar silicon pixel detectors
- R&D related to active edges / slim edges and/or overlapping sensors

Tracker Requirements

Requirements depend on distance to interaction point.

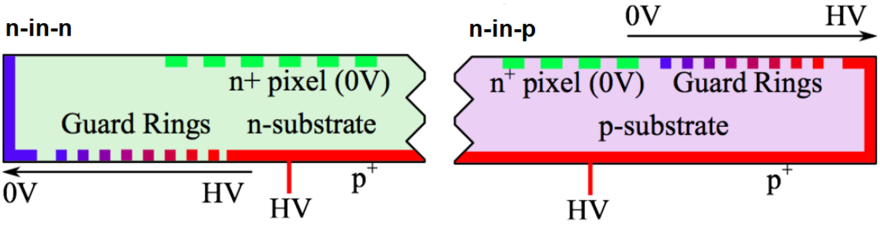
- Inner layers
  - → Very high fluence
  - → High bandwidth
  - → Small pixels (high occupancy)
  - → Small inactive region
  - → Small material budget
- Outer layers
  - → High fluence
  - → Smaller bandwidth (FE-I4)
  - → Large area



Research Activities

- Bulk material
- Thin sensors
- Slim edge
- Active edge
- Biasing system
- Much much more

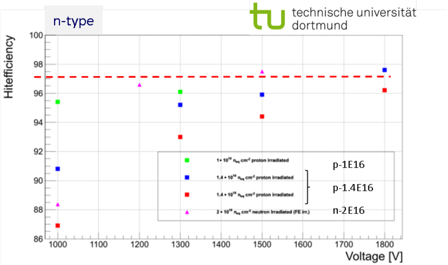
Bulk Material

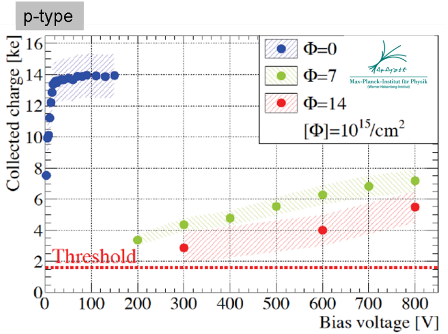


- Read out chip side at ground potential
- Double-sided processing
- Type inversion
- Partly depleted operable
- Well proven design

- Voltage drop on read out chip side
- Single-side processing
- Presumably lower production costs
- No type inversion

Radiation hardness





200 μm, IBL style, FE-I3

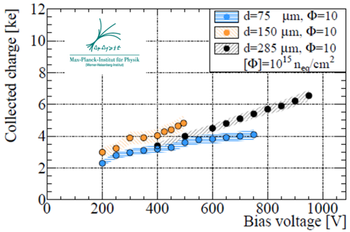
200 μm, CiS production, FE-I4

Further investigation:

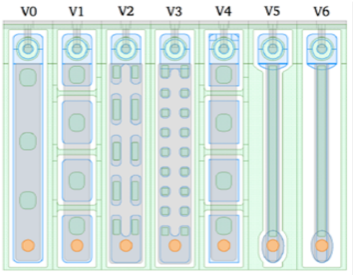
- Different bulk materials (DOFZ, MCz)

Thin Sensors

- Small material budget (less multiple-scattering, better track resolution)
- Higher electrical field at same voltage (better charge collection efficiency at highest irradiation)
- Lower collection time decreases possibility for trapping (larger signal)
- Charge multiplication effects can amplify signal (larger signal)

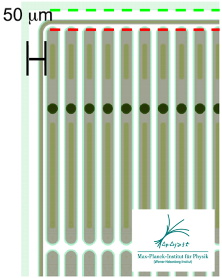


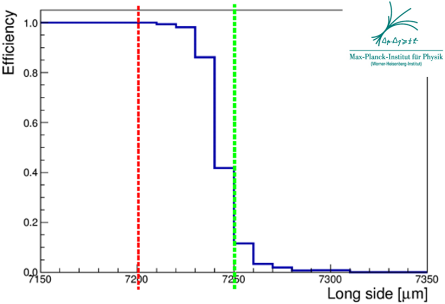
Different thicknesses, Irr. Los Alamos



Control charge multiplication (Reiner structures)

Reduce size of dead region ⇒ Reduce number of guard rings



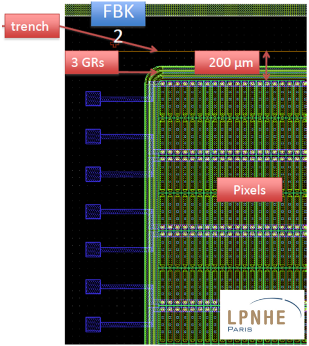


100 μm, VTT production, FE-I3

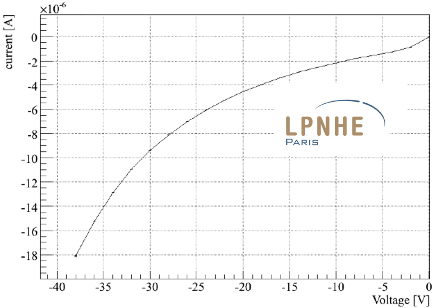
Efficiency between last pixel implant and edge of module: $\approx (85 \pm 1)\%$

Reduce size of dead region ⇒ Block edge current

→ DRIE (Deep Reactive Ion Etching): Doped edge thus equipotential region



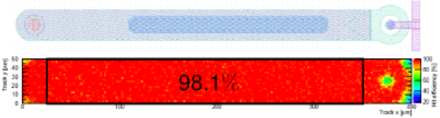
Test beam this week



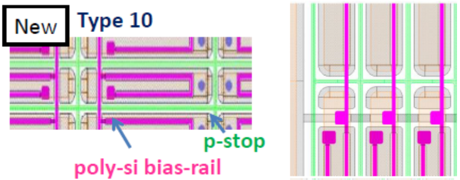
IV-Characteristic

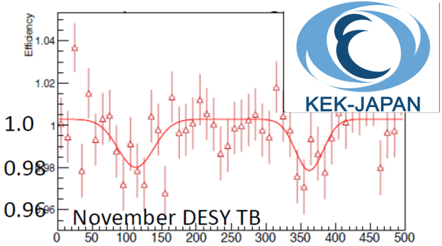
Best possible performance (even after heavy irradiation)

- Punch-trough structure of biasing system (low efficiency in dot region)
- Different biasing schemes



KEK: Increase efficiency → New bias path with poly-silicon





Different Pixel Size

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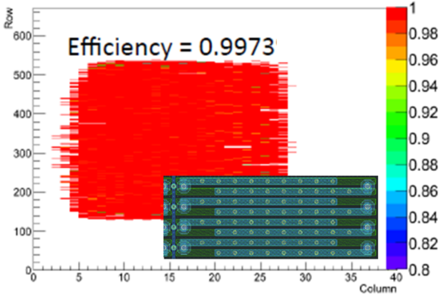
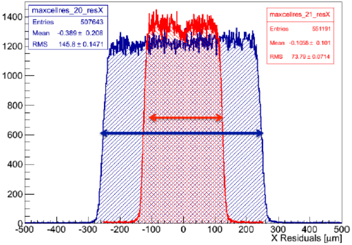
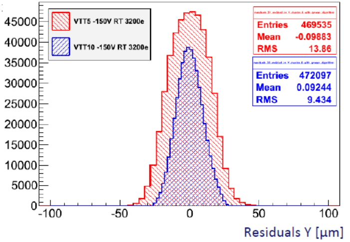
UK:

- Pixel size: $25 \times 500\ \mu m^2$
- Staggered bias lines to use FE-I4







Measured efficiency: 99.73%

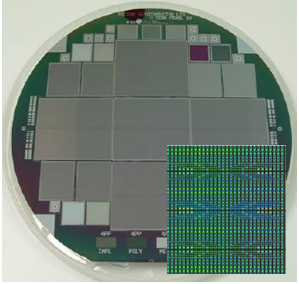
Wafers with similar approach: MPP, Japan

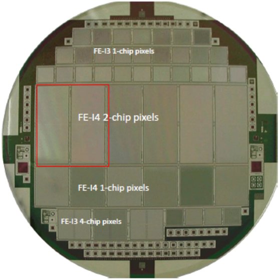
All vendors changed to 6" wafer

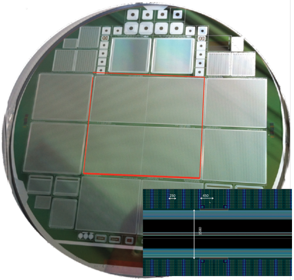
UK (Micron 6")
n-in-p ganged pixels

KEK (HPK 6")
n-in-p 2DC

MPP
(CiS 4") n-in-p 2DC







Caution: Different geometries in test beam analysis

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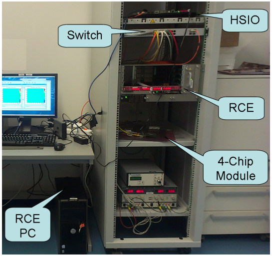
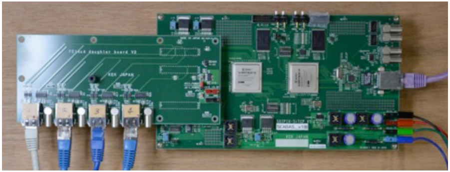
RCE System



- Handles 4-chip module like 4 single chip modules
- Calibration Scans, Source Scan
- Test Beam (up to 8 modules technically possible)

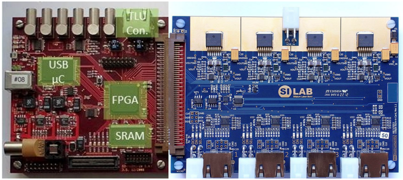
SEABAS DAQ



- Parallel scanning of 4 single chip modules possible
- Calibration Scans

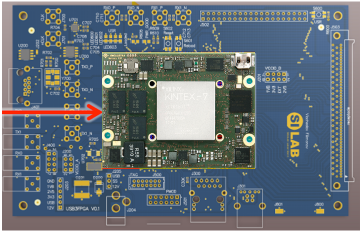
Readout System

USBpix system (with Burn-In Card)



- Handles 4-chip module like 1 module
- Calibration Scans, Source Scan
- Team beam support under development

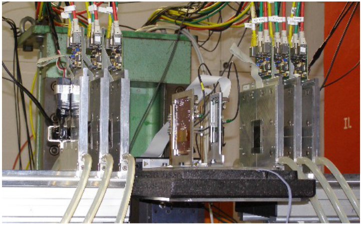
USBPix 3.0



- Downward compatible to USBpix adapter cards and SW
- Commercial FPGA Module: Enclustra Mercury KX-1
- USB 3.0: >200 MByte/sec transfer rate measured

DESY Test Beam 2013

- 3 periods (March, August, November)
- 4 GeV electrons
- Readout:
  - → USBpix
  - → RCE (from Göttingen)
- Very high rate (≈1 MHz) and stable system
- 160 different configurations

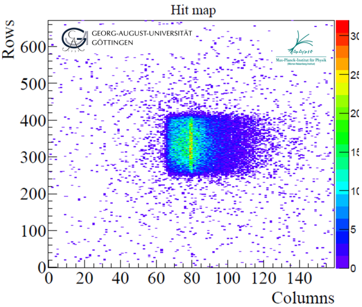


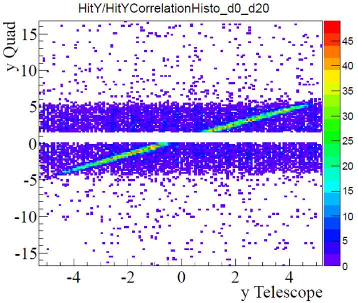
DESY CERN SLAC NATIONAL ACCELERATOR LABORATORY

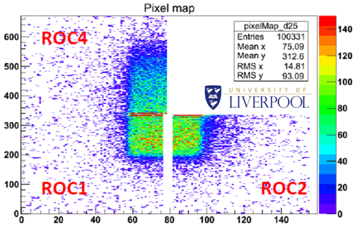
Plans for 2014

- DESY test beam ongoing right now
- May: time at SLAC
- Autumn: DESY and CERN

Results 4-Chip Module







- Problem: Only very simple DUT geometry description in reconstruction and analysis existing.

From telescope data to data analysis:
Reconstruction

- Task: New clustering for arbitrary pixel shapes
  $\Rightarrow$ Needs new geometry description
- Gö MSc student implementing new clustering and geometry description (full DUT description with different pixel types etc)

Future

- Clusters are output of reconstruction (no more clustering in analysis)
- Reconstruction and analysis use same coordinate system

Status

- FE-I4 geometry library exists

TBmon II

Test version available since November 2013

- More user friendly (no recompiling)
- All analyses ported to TBmon II
- Transparent and cleaned up code
  - Config file to easily access parameters per DUT individually
  - DUT description able to handle different pixel types

Next steps

- Analyse more than one track per event
- Use ToT Calibration for charge conversion
- Include TBmon II config file in root output file (easy repro. of analysis)

- Validation of test version (Liverpool and Göttingen).
- Open beta version available in a few weeks!

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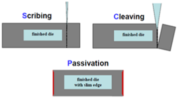
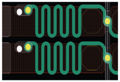
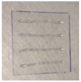
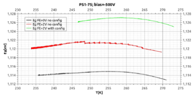
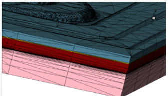
- Active edge: SCP (Scribe, Cleave, Passivate)
- AC coupled sensors
- Temperature dependence studies
- TCAD simulations
- Irradiation
- New interconnection technologies
- Other things that I forgot :-)











Conclusion

Planar pixel sensor is well-established technology and new areas are explored. Among those are:

- Radiation hard and thin sensors
- Reduce inactive area (slim/active edge)
- Best performance (reduce inefficiencies)
- New pixel sizes
- 4-chip modules

Thank you for your attention!

Special thanks to

AIDA and DESY Test Beam

PPS Collaboration Members

- CERN
- AS CR, Prague (Czech Rep.)
- LAL Orsay (France)
- LPNHE / Paris VI (France)
- University of Bonn (Germany)
- HU Berlin (Germany)
- DESY (Germany)
- TU Dortmund (Germany)
- Georg-August-Universität Göttingen (Germany)
- MPP und HLL Munich (Germany)
- Università degli Studi di Udine - INFN (Italy)
- KEK (Japan)
- Tokyo Institute of Technology (Japan)
- IFAE-CNM, Barcelona (Spain)
- Université de Genève (Switzerland)
- University of Liverpool (UK)
- UC Berkeley/LBNL (USA)
- UNM, Albuquerque (USA)
- UCSC, Santa Cruz (USA)