Overview of the ATLAS Insertable B-Layer (IBL) Project

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For the **ATLAS Collaboration**

“8th International Hiroshima Symposium on the Development and Application of Semiconductor Tracking Detectors”

Academia Sinica, Nankang, Taipei -- 5th-8th December, 2011.

ATLAS Overview

- Central trackers in a solenoidal magnet
- EM + hadronic calorimeters
- Muon spectrometer in toroidal magnets

ATLAS Inner Detector

Straw tubes

Silicon strip

Silicon pixel

ATLAS Pixel Detector

- Why pixels? **Position resolution**

- Critical for physics program (Higgs, SUSY searches, top,...)

- ATLAS Pixel Detector

- 3 barrels + 6 disks
- inner layer radius: 50.5mm
- 1744 modules, 80M channels
- $\sim 1.8 \text{ m}^2$ active area, $|\eta| < 2.5$

- ATLAS Pixel Module

- 16 FE chips (FE-I3) + Controller Chip
- 2880 channels/chip; $50 \mu\text{m} \times 400 \mu\text{m}$ ($50 \mu\text{m} \times 600 \mu\text{m}$ between FEs)
- Planar n-on-n DOFZ silicon, $256 \mu\text{m}$ thick
- Designed for $1\text{E}15 \text{ 1MeV neq}$ fluence

Insertable B-Layer (IBL)

- New (4th) pixel layer mounted directly on beam-pipe
 - radius=33mm, $|\eta| < 2.5$, 0.2m^2
 - requires new (smaller) beam-pipe
- Reasons for IBL:
 - Back-up existing B-Layer (hard failures)
 - Improve physics performance
(Based on smaller radius and low mass)

Stringent requirements on sensor and front-end electronics

- Need of larger and faster font-end chip
- Better radiation hardness that current detector

Insertable B-Layer (IBL)

• Layout:

- 14 Staves, each with 32 front-end chips
- No overlap on Z due to space restriction
- Operate at -15 C, CO₂ cooling, Ti pipe

• Front-end/Sensor Design:

- NIEL dose = $5 \times 10^{15} n_{eq} \text{ cm}^{-2}$ (w/ safety factor)
- Ionizing dose $\geq 250 \text{ Mrad}$
- Small dead area (slim/active edge)
- Max sensor power $< 200 \text{ mW/cm}^2$ @ -15 C
- Max bias voltage: 1000V

• Sensor Technology:

- Planar n-on-n and 3D double sided being considered
- 75% Planar and 25% 3D sensor layout:

Sensor facing beam

IBL: Font End Chip: FE-I4 ("A")

- Biggest chip in HEP to date
- Higher active fraction (x6)
(than ATLAS predecessor)
- Local memory cells (bus activity only on readout) → Lower power
- Higher data rate
- More radiation hard (130nm technology)

FE-I4

Pixel array	80x336
Chip size (mm ²)	20.2x19.0
Active fraction (%)	89
Analog/Digital current (uA/pix)	10/10
Analog/Digital voltage (V)	1.5/1.2
LVDS output (Mb/s)	160
Pixel size (um ²)	50x250

Planar Pixel Sensors

- Proven technology current ATLAS detector: n-on-n pixels (DOFZ silicon)
- Bias grid to evaluate sensor quality before bump-bonding
- Thinner substrate (200um, was 250um)
- Slim edge design (~200um, was 1mm)
 - Guard rings on p-side shifted beneath outer pixels (longer outer pixels to keep tile length design)
 - Distorts electric field on the sensor edge, but charge collection after irradiation dominated by region directly beneath implant

Vendor:
CiS-Germany

Two FE-I4 chip IBL planar sensor tile

~200um inactive edge 500um long pixel 250um

3D Pixel Sensors

- Pixel electrodes penetrate into the substrate: depletion region grows parallel to wafer surface
- Double sided process, p-bulk 230um thick, (FZ high resistivity wafers)
- Two vendors producing IBL 3D sensors with same specifications:

CNM (Spain) and FBK (Italy)

CNM 3D IBL sensors:

- 210um columns
- 3D Guard ring + fences (200um)
- Evaluate sensor quality on GR

Probe pad for quality assurance

3D Guard ring

p+ implant (fences)

3D Pixel Sensors

FBK 3D IBL sensors:

- Pass-through columns
- 200um inactive edge fences
- Evaluate sensor quality with temporary metal on each row of pixels (strip)

IBL Sensor Selection

Planar and 3D sensors have to meet wafer quality (bow, thickness tolerance, etc) and electrical specifications (leakage current, V_{break})

CNM: leakage current along the GR region

Bump-Bonding

- To reduce the amount of inactive material, FE-I4 are thinned to 90 μm .
- Through the bump-bonding process the bowing of the thinned chip can cause unconnected pixels.

- At IZM (Germany) the thinned chip (90 μm) is attached to a glass support during the heating step of the bonding cycle

IBL Module

FBK 3D Device

Planar Module

- First single chip modules mounted
- Temporary pigtail will be cut and replaced by flex wing

Irradiated IBL Devices

Several planar and 3D IBL devices irradiated to IBL fluencies ($5E15$ neq/cm²)

- Planar devices irradiated to IBL fluencies comply with the power dissipation limits at 1000V bias

- For 3D devices (here FBK) irradiated to IBL fluencies power dissipation is not a constraint

Device Performance

- Irradiated and non-irradiated devices characterized before test-beams
- Study of lowest operational threshold of devices

Low threshold operation possible for irradiated devices:

➤ Operation at ~1500e threshold possible

Device Performance

Noise increase
with bias
voltage:

➤ So does charge collection: which is the optimal bias voltage for 3D devices?

Device Performance

- Optimal high voltage for 3D CNM devices ~160V (~150V for FBK)
- For planar devices limited by electrical constraints to 1000V

Test-beam Results

- Only part of the FE-I4 device covered by telescope planes
- Low threshold operation ($1500e^-$)
- Noisy, dead pixels masked out
- Efficiency determined from extrapolated track on devices

Efficiency = 97.5%

Planar

n-irr

$4E15 \text{ neq/cm}^2$

Summary

- ATLAS plans to insert a 4th layer (IBL) in 2013/14
- Planar and 3D pixel technologies being evaluated for IBL
 - 75% planar + 25% 3D layout being investigated
- Planar and 3D devices within the IBL requirements have been produced
 - Both technologies well developed
 - Inactive edges of $\sim 200 \text{ um}$
 - High efficiency ($>97\%$) after irradiation ($5E15 \text{ n}_{eq}/\text{cm}^2$) has been achieved (see also Igor R. talk)
- Final planar and 3D sensor productions underway

Back-up Slides

Irradiation of IBL Devices

- Several planar and 3D IBL devices irradiated to IBL fluencies ($5E15$ neq/cm²):
 - Proton irradiation at KIT (beam energy 23 MeV)
 - ✓ Estimated TID dose ~ 750 Mrad (IBL requirement: 250Mrad)
 - Neutron irradiation at Ljubljana
 - Devices annealed: 120min at 60C for test-beam

FE-I4 Assemblies for Sensor Review

Foundry	Technology	Batch ID	Thickness (μm)	Sensor EdgeType	Number of Assemblies			Target Fluence (neq/cm ²)
					Done	p-irradiated	n-irradiated	
CIS	Planar n-in-n	<n-in-n 150>	150	slim	2	1		2×10^{15}
				conservative	2			
		<n-in-n 200>	200	slim	12	3	2	5×10^{15}
				conservative	2		1	
		<n-in-n 250>	250	slim	9	1	2	5×10^{15}
				conservative	10		1	
CNM	3D, double side	5306	230	slim	16	1	2	2×10^{15}
FBK	3D, double side	ATLAS 07	230	slim	8			5×10^{15}
	3D, double side	ATLAS 09	230	slim	16	1		2×10^{15}
	3D, double side	ATLAS 09	230	slim		1		5×10^{15}
Total Planar					37		11	
Total 3D					40		8	
Grand Total					77		19	

Green: IBL Design

LHC and ATLAS Upgrade Plans

- LHC has plans upgrades (increasing luminosity) to ultimately collect ~3000/fb
- ATLAS needs to maintain excellent position resolution (vertexing, tracking)