Non Uniform Irradiation of CNM 3D sensors for AFP

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IFAE - Barcelona

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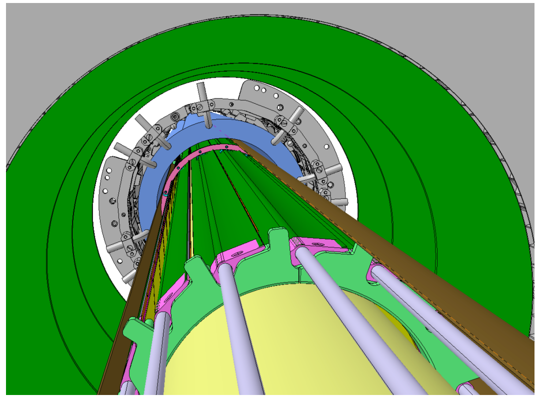
Work done in collaboration with:

- CNM/IBL (Giulio et al, samples)
- UCSC/NRL (device edge slimming - SCP)
- RD50 (RD50 funding of SCP slimming)
- AFP (P. Sicho, sample preparation/irradiation)
- IRRAD1 facility at CERN-PS (M. Glaser)
- ATLAS 3D R&D Collaboration (testbeam)

3D Pixel Sensors for ATLAS

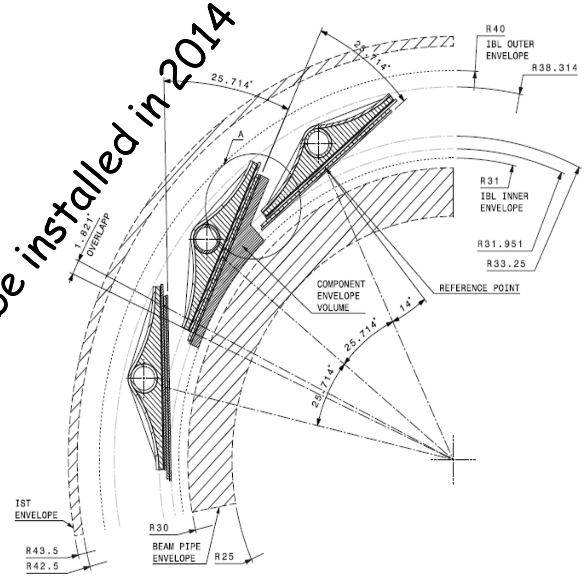


IBL: Insertable B-Layer

Fourth ATLAS pixel layer (improve physics, backup current inner layer)

- Layout:
  - 14 Staves, each with 32 front-end chips
  - No overlap on Z due to space restriction
- Front-end/Sensor Design:
  - NIEL dose = $5\times10^{15}\ n_{eq}\ cm^{-2}$ (w/ safety factor)
  - Small dead area (slim/active edge)
  - Max sensor power < 200 mW/cm^2 @ -15 C
  - Max bias voltage: 1000V
  - Sensor: 75% Planar and **25% 3D-DDTC pixels**:

To be installed in 2014

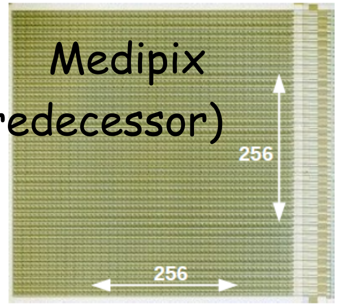


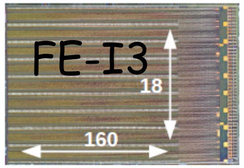
- Longer term:
  - AFP (ATLAS Forward Physics) pixel: **3D sensors** for tracking

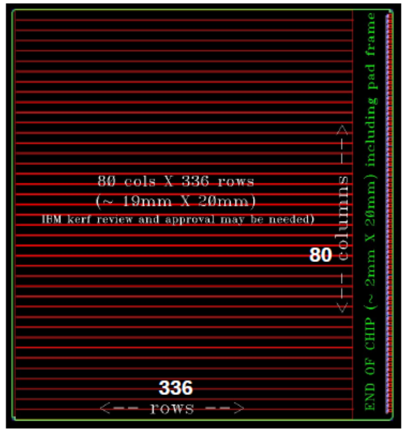
➢ Results shown here: using FEI3/FEI4 devices produced for IBL sensor R&D (some slim-edged for AFP)

IBL: Font End Chip: FE-I4

- Biggest chip in HEP to date
- Higher active fraction (x6) (than ATLAS predecessor)
- Higher data rate, lower power
- More radiation hard (130nm technology)

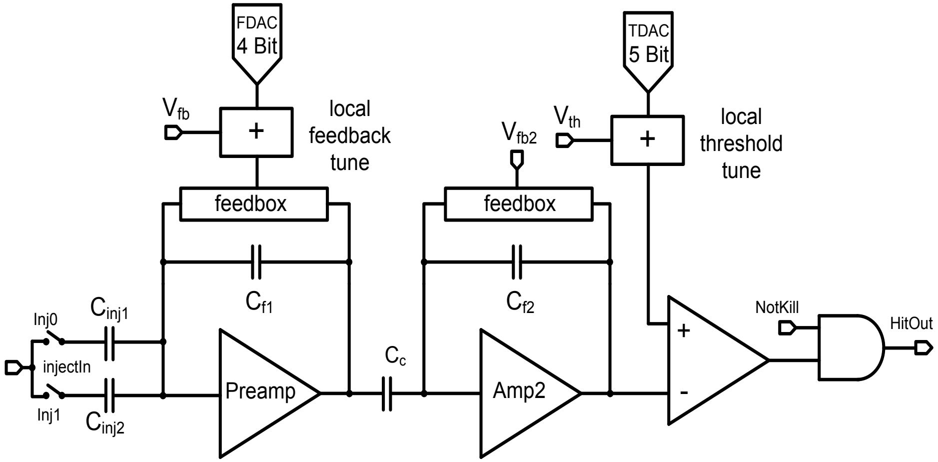


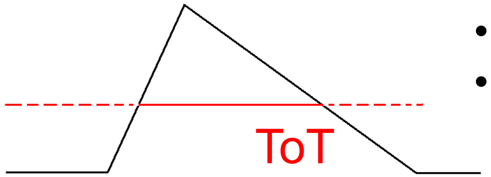




FE-I4

Size (um2)	50x250
Pixel array	80x336
Chip size (mm2)	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 sixe (um2)	50 x 250
ToT Resolution	4-bit



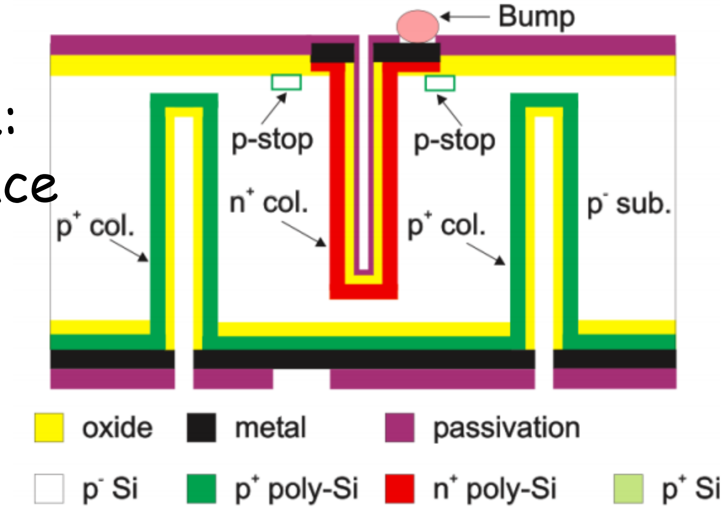


- FEI4-A: *NIM A 636, 1, Pages S155, 2011*
- FEI4-B: *2012 JINST 7 C02050*

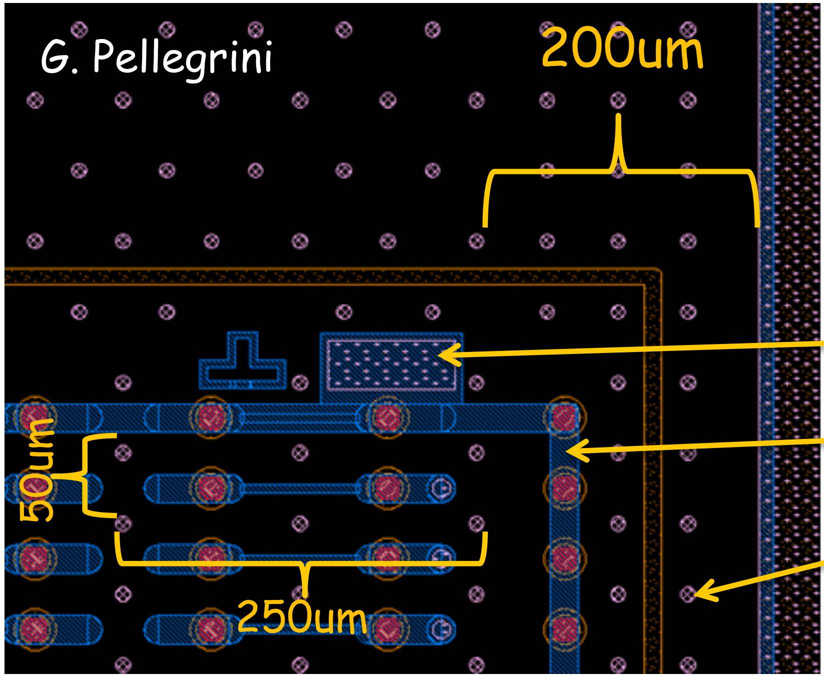
- Pixel above threshold
- Time over threshold (~collected charge)

IBL 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)



NIM A 694 (2012) 321-330



CNM 3D IBL sensors:
- 210um columns (2 electrodes/pixel)
- 3D Guard ring + fences (200um)
- Evaluate sensor quality on GR

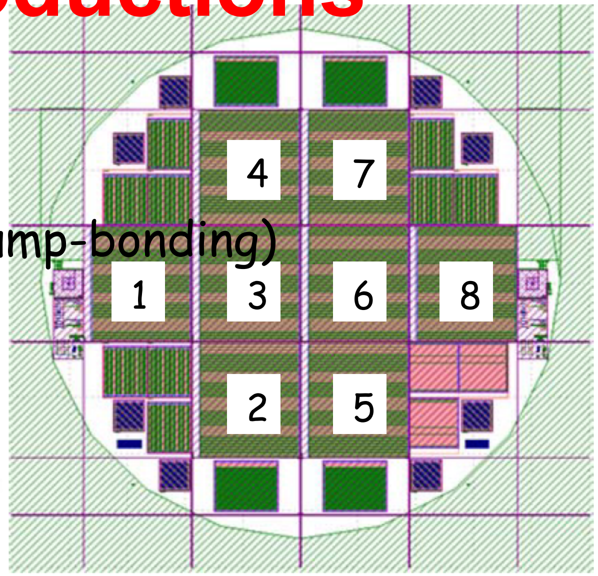
Probe pad for quality assurance

3D Guard ring

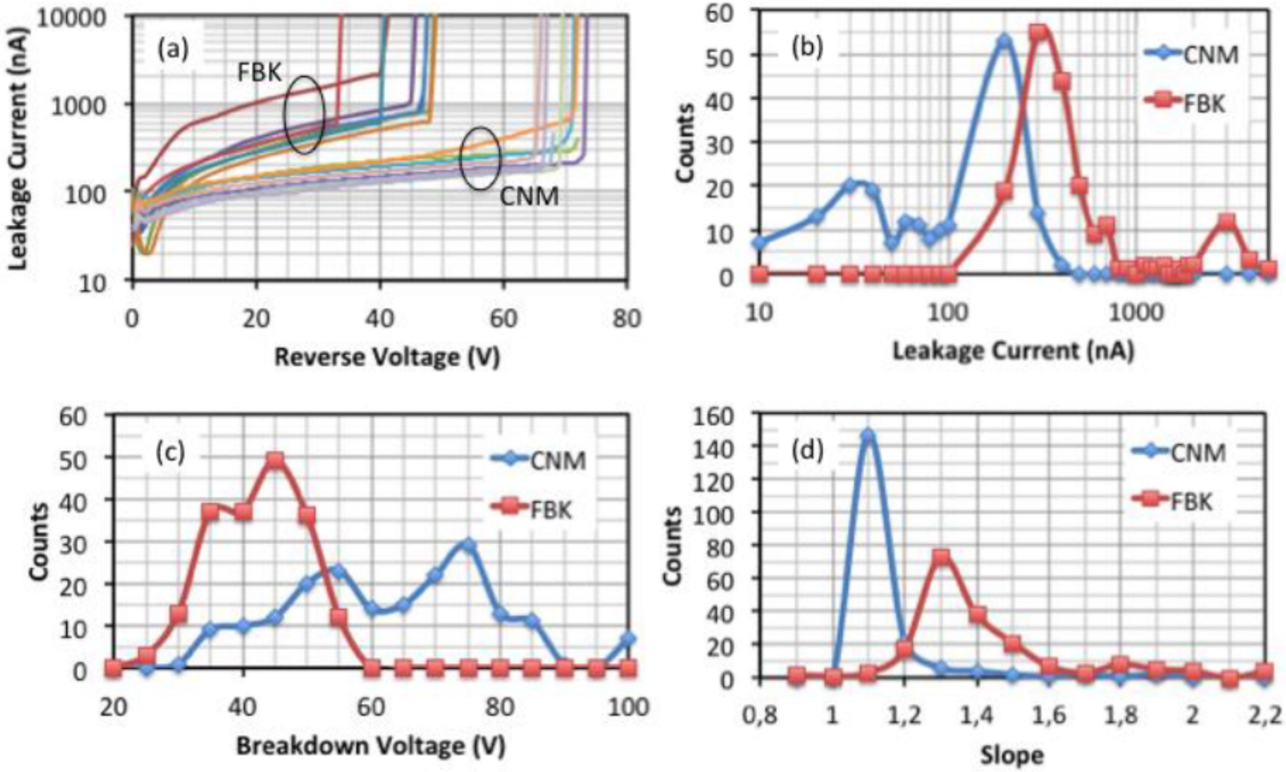
p+ implant (fences)

Status of IBL CNM 3D productions

- IBL 3D production status (as Oct 2012):
  Need: 224 (112 to be installed - 25% 3D)
  - CNM: 216 good sensors sent to IZM (for UBM+bump-bonding)
  - FBK: 135 good sensors sent to IZM
  - Already produced needed sensors for IBL



FBK/CNM common floor plan design

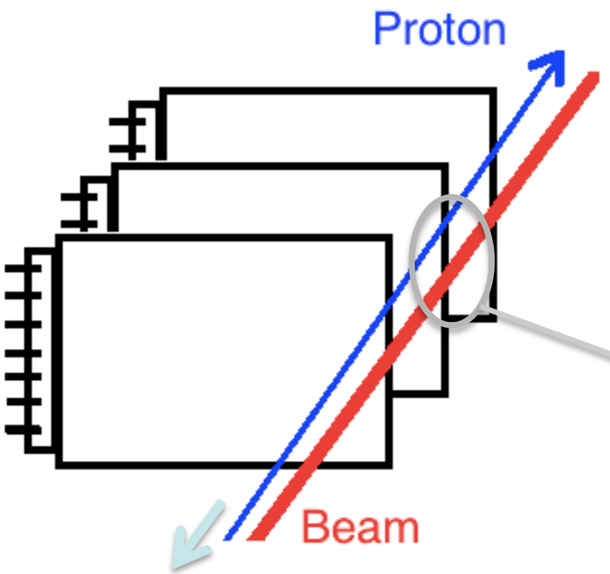


➢ CNM/FBK 3D sensor productions met IBL schedule with ~60% yield (excluding bad wafers)

[G-F Dalla Betta, IWORID 2012 proceedings]

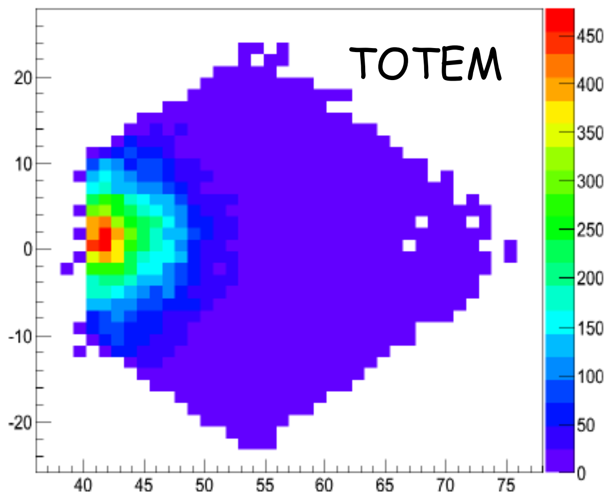
3D Sensor for Forward Physics Trackers

- Interest in 3D sensors for forward physics detectors
  - ✓ AFP (ATLAS), HSP (CMS), Totem…



220m to ATLAS P1

- AFP: detect very forward protons at 220m from IP, with pixel detectors for position resolution and timing detectors for removal of pile up protons.
- Both Si and timing detectors mounted very close to the beam

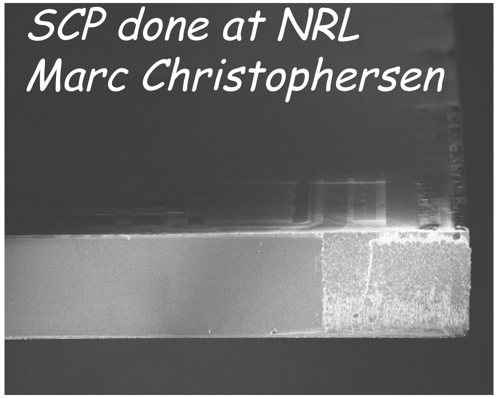


J. Baechler , 12th Pisa Meeting on Advanced Detectors, 20 May 2012, Isola d'Elba , Italy

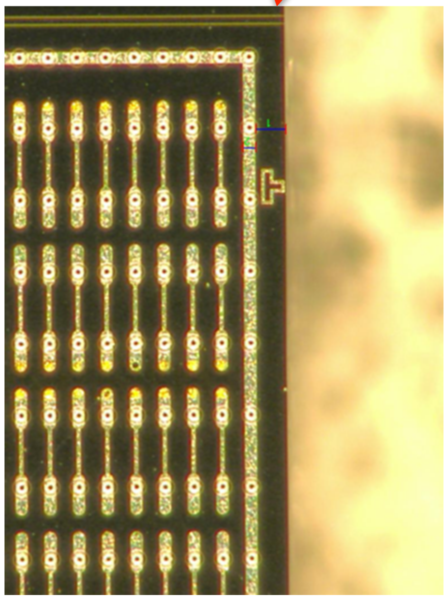
Key issues for Forward Si detectors:

- ➢ Silicon detector has to have small dead inactive region on side into beam
- ➢ Non-uniform irradiation of the detectors

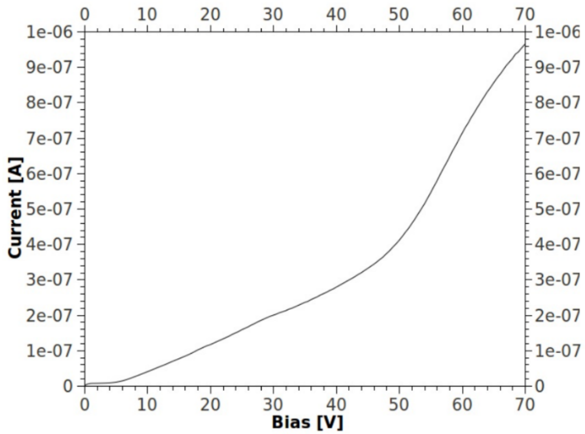
CNM Sensors for AFP



- Same IBL design, but slim-edge on side "facing" beam
- NRL: Laser-scribing, cleaving and Al_2O_3 sidewall passivation
- Coll. Between: CNM, IFAE, NRL and UCSC through RD50
    - Technique: V. Fadeyev, et al, Pixel 2012 proceedings

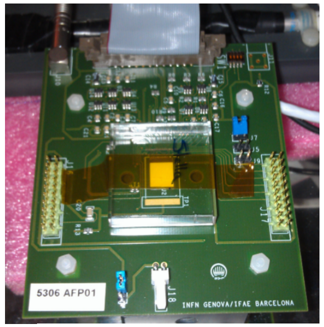


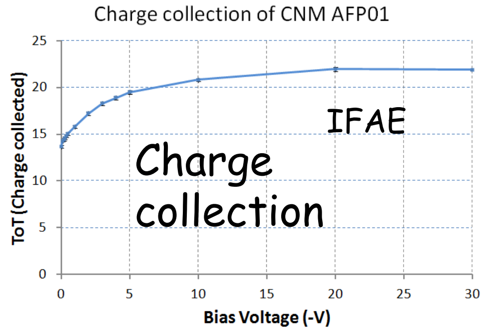
FEI4 AFP devices

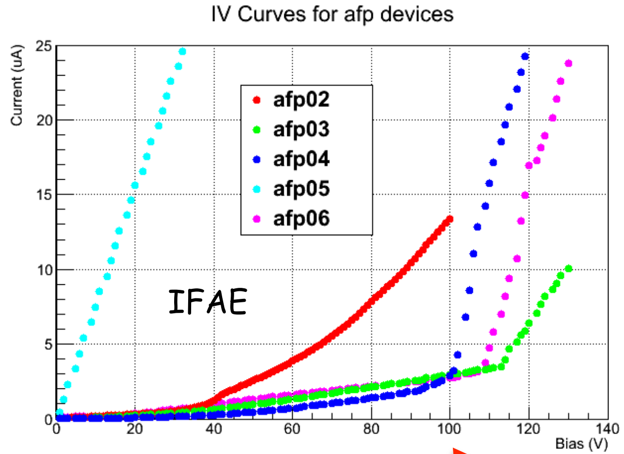


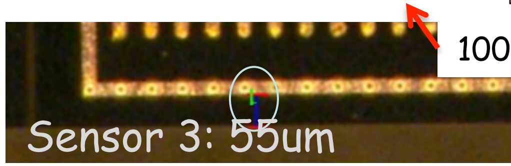
- CNM FEI4 slim-edged device
- 80um from active area
- Good IV after slim-edge

FEI3 AFP devices



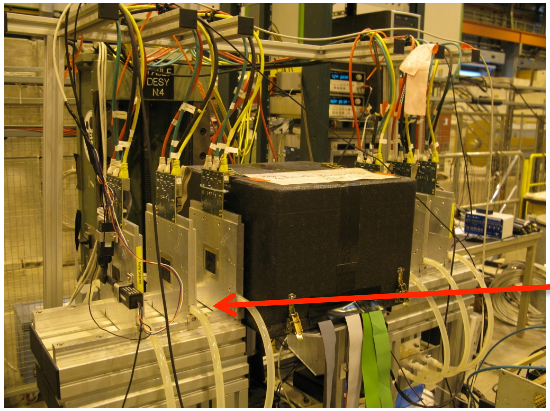


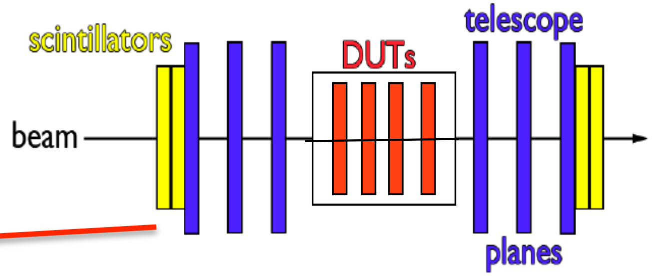


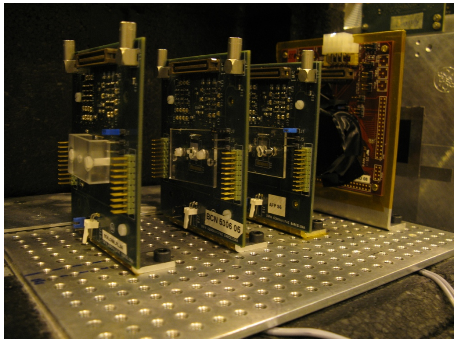


- ➢ Slim-edged detectors down to:
    - 80um FEI4 (limit of FEI4 ASIC)
    - ~50um FEI3

AFP 2012 Beam Tests Results





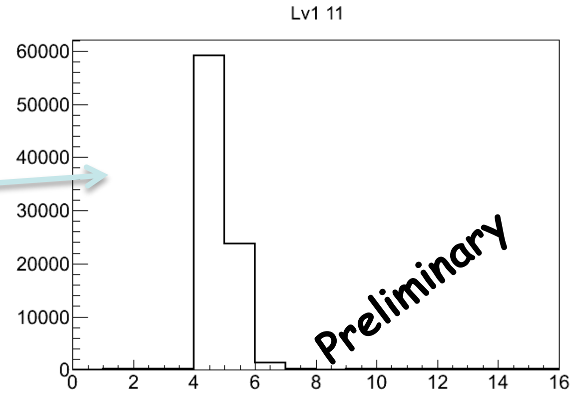


DUTs

- **EUDET Telescope August and October (together with AFP-Timing group):**
  - 120 GeV pions from CERN - SPS (point H6b)
  - 6 planes: 660k Si pixels (18.4 µm pitch)
  - trigger: four scintillators
  - 500k events per run to have enough statistics
- **DUTs:**
  - August: Irradiated FE-I4
    - CNM-87 ($6e15n_{eq}/cm^2$) CNM-83 ($1e16n_{eq}/cm^2$)
    - Reference: un-irradiated FEI4
  - October: Un-irradiated 3D and Planar FE-I3 devices
    - Four 3D FEI3 devices were slim-edged (SCP) for AFP
    - Reference: un-irradiated FEI4

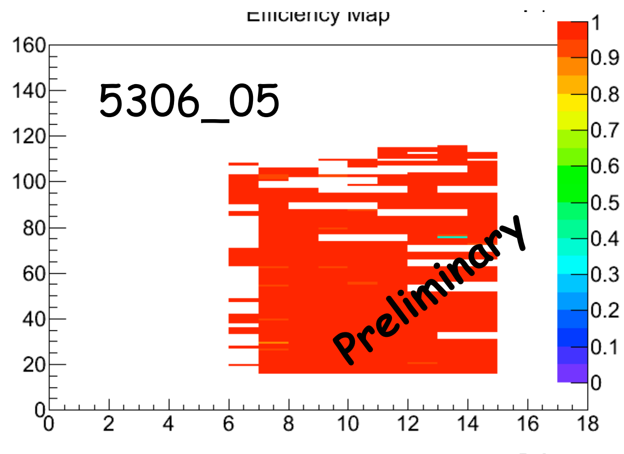
October Beam Tests Results

- On Line Monitoring to check the quality of the data taking
  - Level 1 distribution (ideally delta shape) to check the synchronization between DUTs and telescope



Preliminary efficiency results of Batch2m:

DUT	HV	Threshold	Tilt	Efficiency
CNM-55	30	2000	0	99.14
AFPs6	25	3200	0	96.72
5306_05	25	3200	0	96.06
Planar04	50	3200	0	99.98



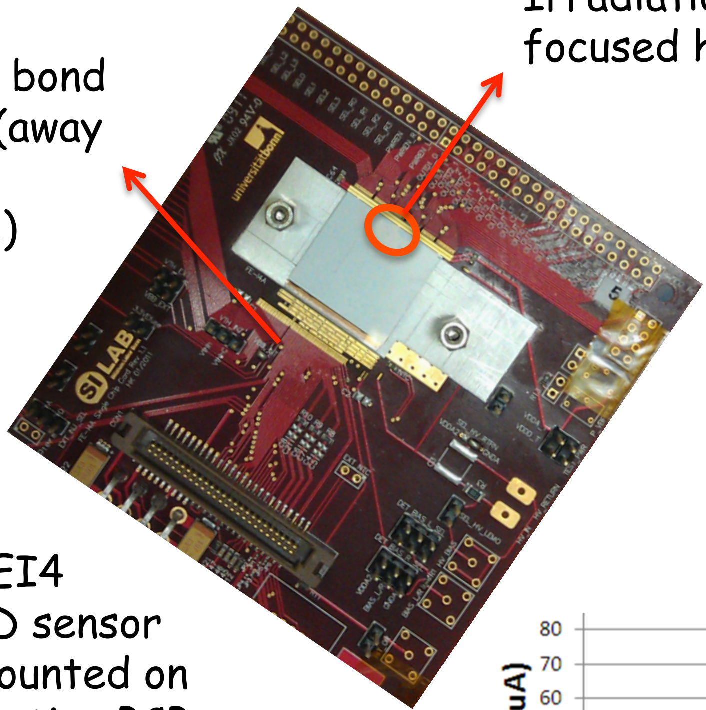
- **Very Preliminary Results:**
  - Further Analysis and Results will come (Test Beam over two weeks ago)
    - Edge efficiency studies planned

August TB: In-Homogeneous Irradiation of 3D samples

- Non-uniform irr. of **CNM 3D** devices done in IRRAD1 facility at CERN-PS
  - ➢ These CNM sensors were **not** slim-edged for AFP
  - ➢ Test in-homogeneous irradiation still valid

Wire bond side (away from beam)

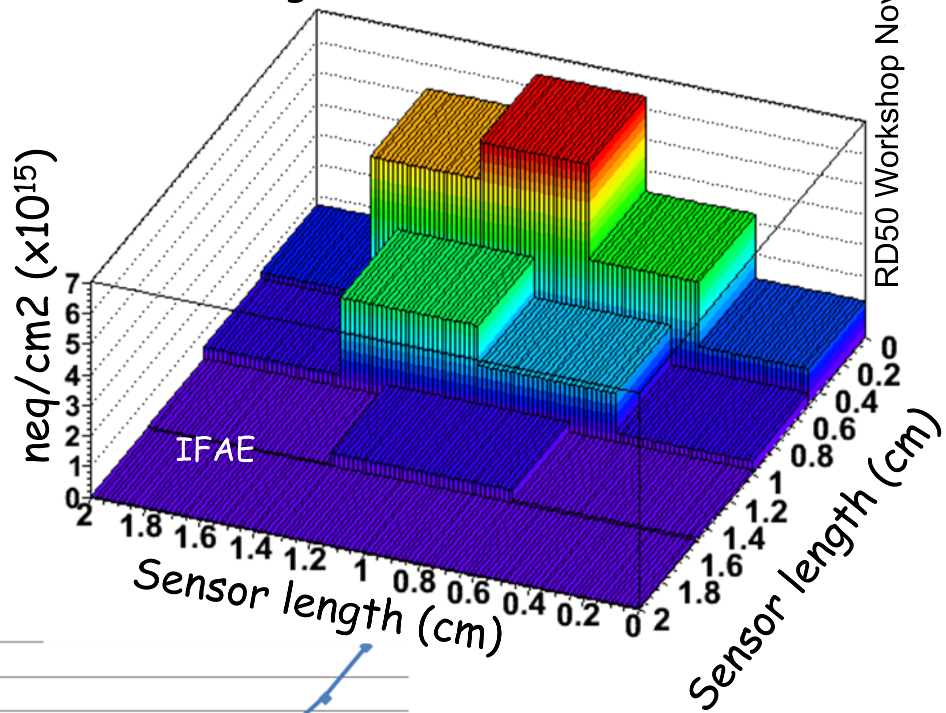
Irradiation focused here

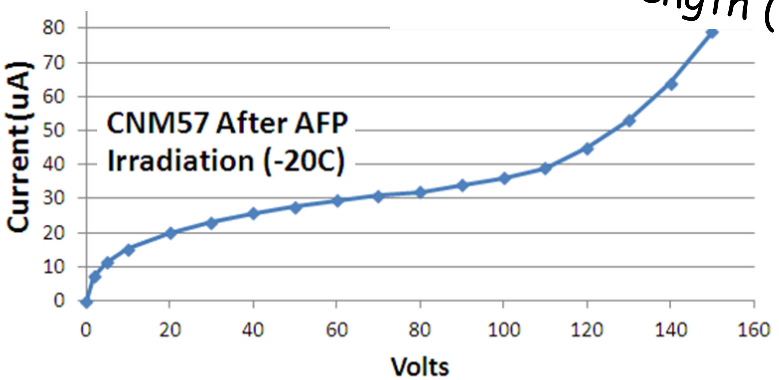


FEI4 3D sensor mounted on testing PCB

Can operate device so that there is high efficiency in irradiated area ?

In-homogeneous dose of CNM-57

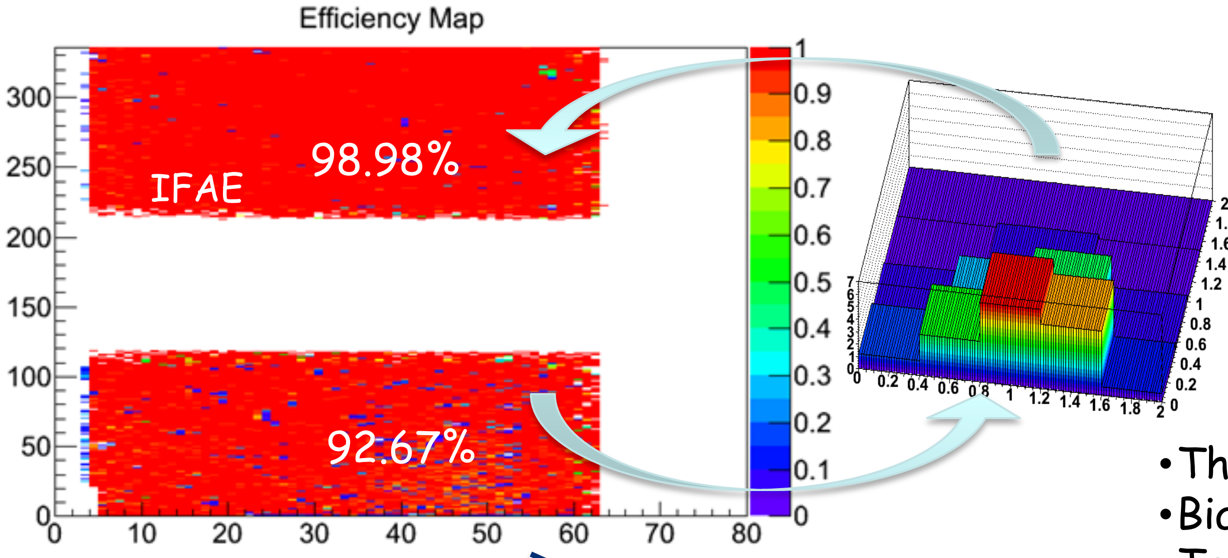


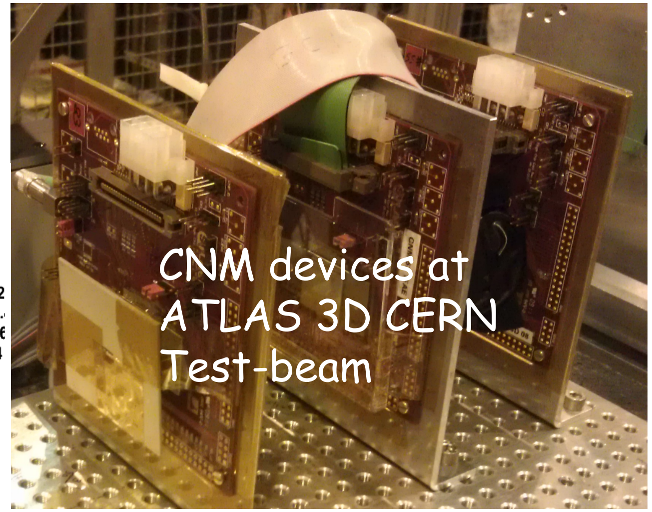


Good leakage after non-uniform irradiation

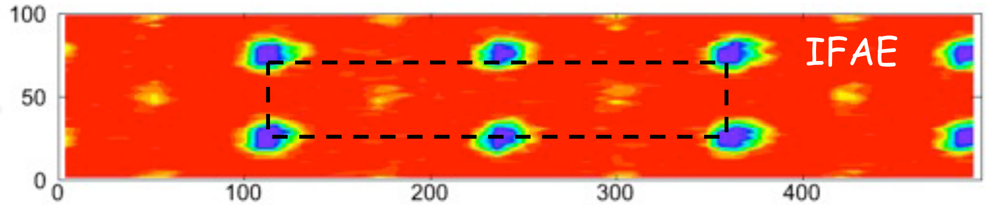
In-Homogeneous Irradiation and Test-beam Results of FEI4 samples

- Non uniformly irradiated device performance evaluated at CERN ATLAS 3D Aug 2012 test-beam





- Threshold: 1700e
- Bias voltage: 130V
- Temperature: -20C (approx.)



Efficiency: **98.0%** (irradiated side)
Masking out dead digital pixels

Encouraging results:
- After dicing IVs reasonable
- Good performance after non-uniform irradiation

Summary

- Big progress made recently on 3D sensor community, specially by the ATLAS 3D Sensor group: from R&D to industrialization
- Excellent results of IBL 3D sensors ➔ 25% of IBL will be 3D
- Promising results for Forward Physics
  - Obtained high efficiency for non-uniform irradiation (up to $7E15 n_{eq}/cm^2$)
  - Slim edged devices: good IVs after SCP'ed
  - Preliminary efficiencies look good (analysis on-going)
- Other experiments at LHC interested in 3D pixel technology