Edge-Efficiency and Irradiation Studies for AFP Pixel Detectors using the DESY Test Beam

PRELIMINARY Results

Jörn Lange, Ivan López Paz, Andrea Micelli, Sebastian Grinstein

IFAE Barcelona

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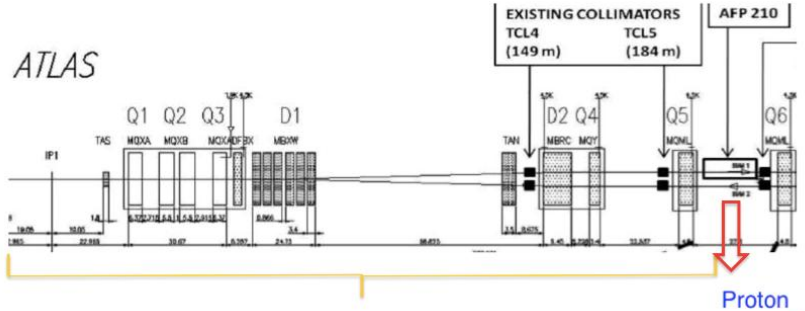
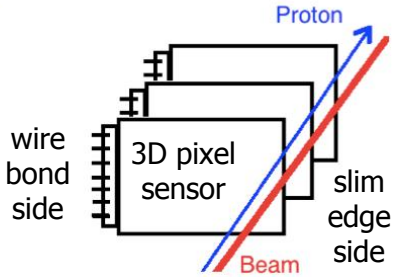
THANKS to:
The June and July test beam crews,
especially Igor Rubinskiy (DESY) and David Pohl (Bonn)

Introduction

- Atlas Forward Physics (AFP)
  - Diffractive physics: very forward protons
  - Combination of high-resolution pixel detector and fast timing detectors (pile-up removal)
  - Detectors close to the beam: 2-3 mm

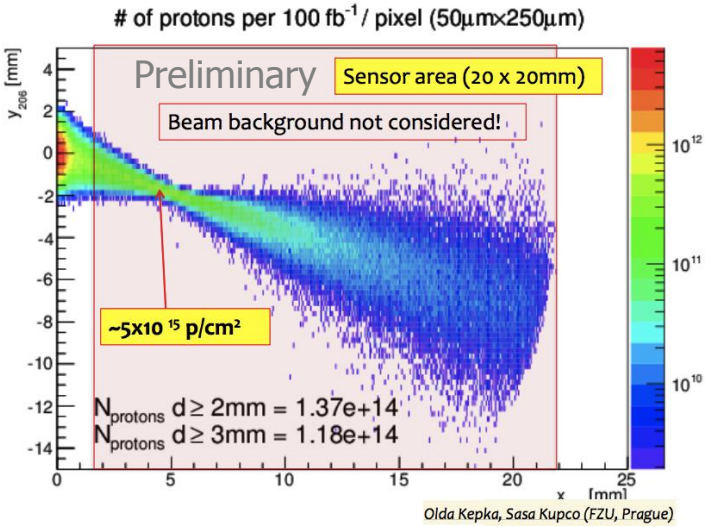




- Pixel detector requirements
  - Slim edge of side facing beam: ~100 µm
  - Highly non-uniform irradiation
    $5x10^{15}$ p/cm^2 (7 TeV p!) to several orders of magnitude lower on one sensor (preliminary, depends on final specs)

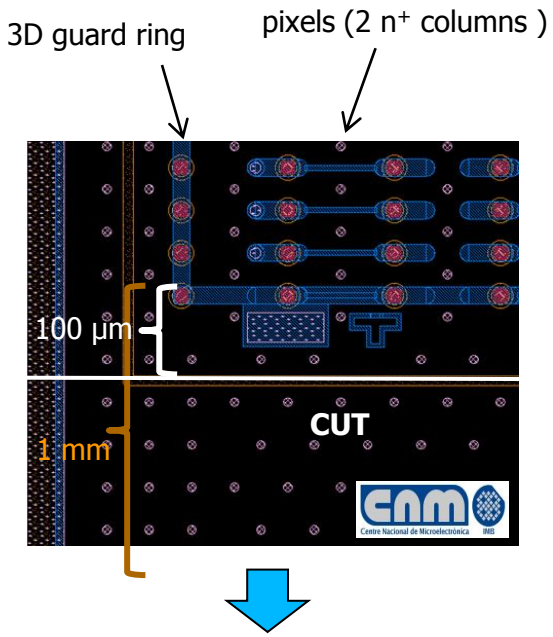
→ Baseline: *3D sensors with slimmed edge*

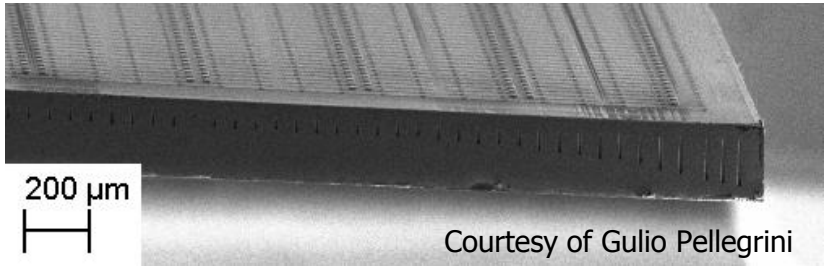
- This talk: test beam results and characterisation of
  1) unirradiated, slimmed-edge sensors
  2) non-uniformly irradiated sensor with standard edge



Sensors and Edge Slimming

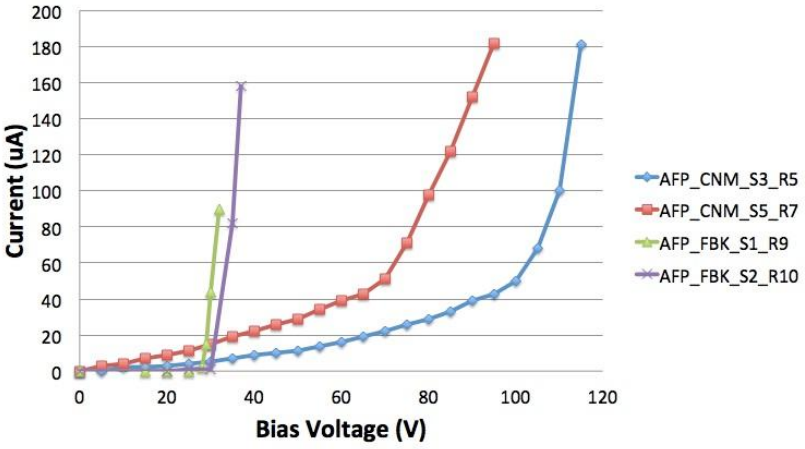
- FE-I4 3D sensors from CNM and FBK
  - 336x80 pixels of 50x250 μm^2
  - p-type bulk, 2 n^+ columns per pixel
  - Edge termination:
    - CNM: 3D guard ring of n^+ columns + p^+ ohmic-column fence
    - FBK: p^+ ohmic-column fence
  - IBL spares (not always best quality)
- Edge slimming:
  - Cut IBL sensors' inactive edge (~1 mm bias tab) down to ~100 µm (FE-I4 chip: 80 µm dead region)
  - Technique here: standard diamond-saw cut
  - Previously also investigated: sensors with SCP slimming with promising results
    see A. Micelli, 21st RD50 workshop Nov 2012;
    S. Grinstein, 8th Trento workshop 2013



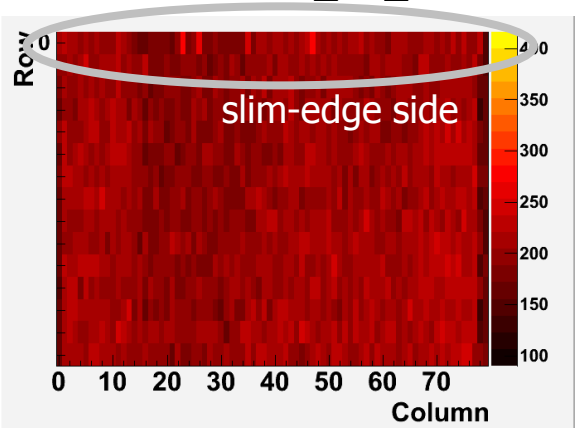


Current and Noise

IV of sensors used here (2 FBK, 2 CNM):
normal for used sensor-quality class

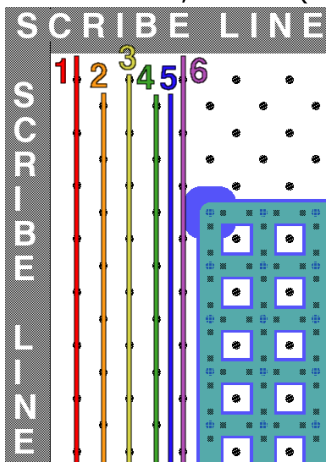


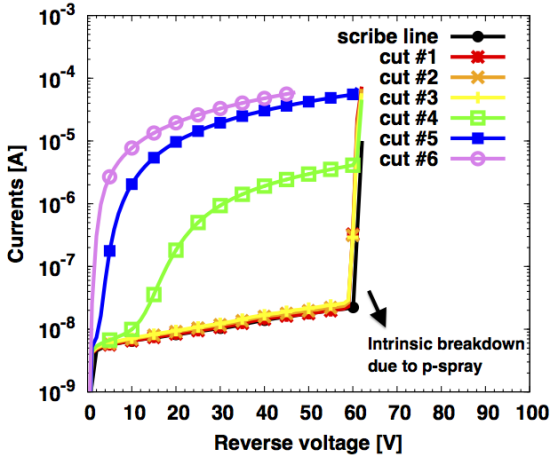
Noise of CNM_S3_R5



Previous study on FBK sensors:
IV unaffected up to 100 µm cut line

M. Povoli et al., JINST 7 (2012) C01015

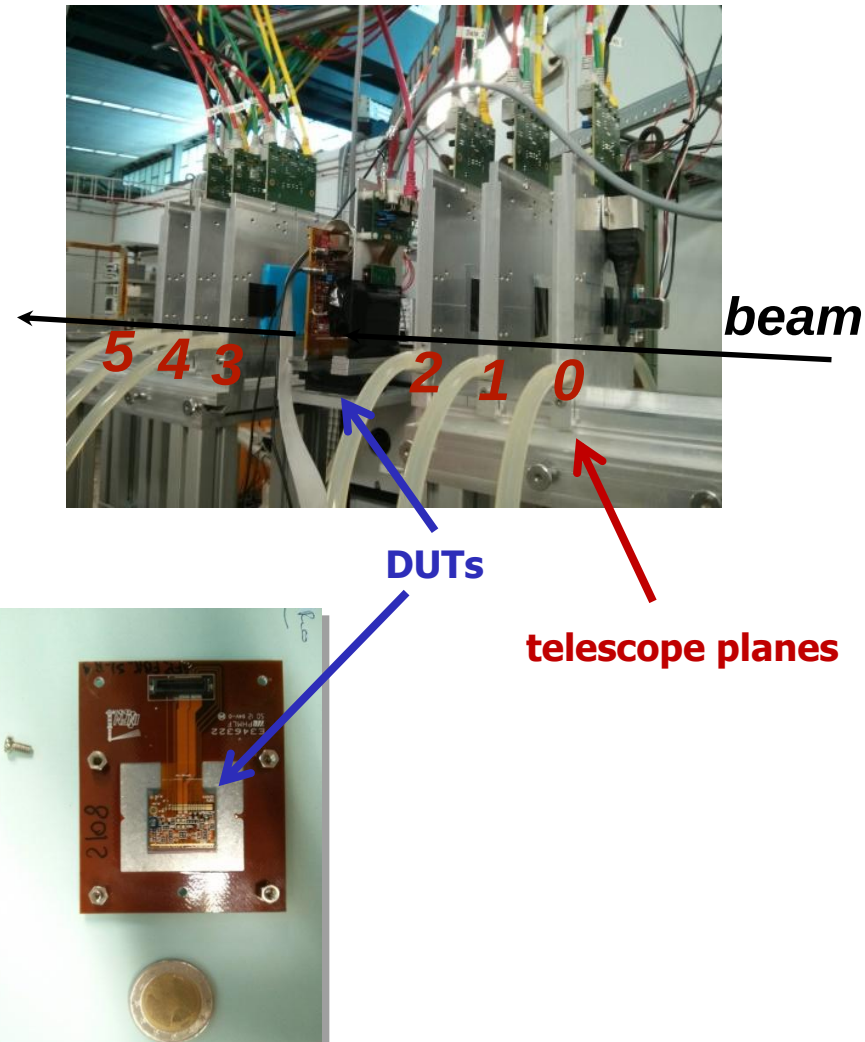


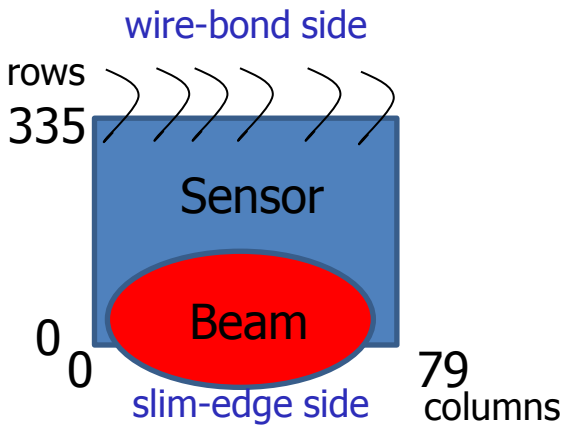


- No anomalous current and noise (also in first row) after edge-slimming to 100 µm

DESY Test Beam

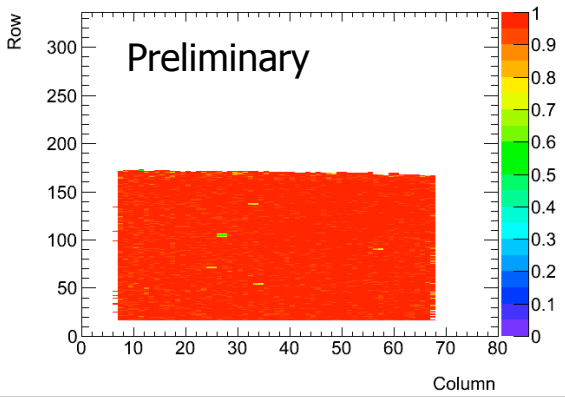
- Check performance in test beam
  - DESY II 5 GeV electrons
  - ACONITE telescope (EUDET type)
    - 6 planes of MIMOSA-26:
      660k Si pixels (18.4 µm pitch)
    - Trigger: 4 scintillators
  - June 2013:
    Special study of edge efficiency of first rows (slim-edge side)





Efficiency of Slim-Edge Sensors

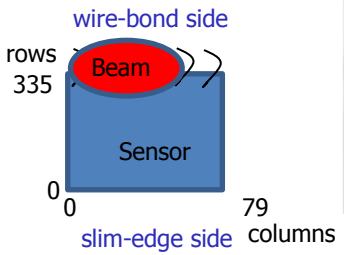
- 1 reference IBL sensor,
  4 slimmed-edge AFP sensors
- Normal incidence
- Efficiency in central region (97-98%) comparable to IBL reference (*)
  → what about edges?



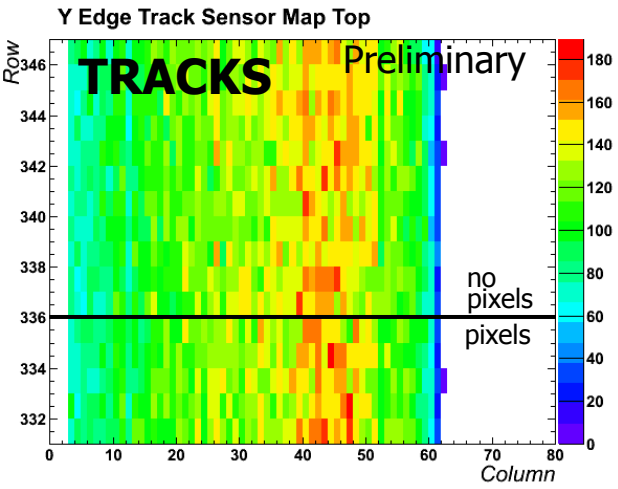
	DUTs				
Sample	CNM-55* (Reference)	AFP_CNM_S3_R5	AFP_FBK_S5_R10	AFP_CNM_S5_R7	AFP_FBK_S1_R9
Front-End	FE-I4A	FE-I4B	FE-I4B	FE-I4B	FE-I4B
Bias [V]	30	30	20	30	20
Threshold [e]	2800	1885	1969	1976	2000
#Tracks	5M	0.4M	1.5M	1.8M	0.6M
Efficiency (central region, mask applied)	98.2%	97.17%	97.99%	96.67%	97.2%

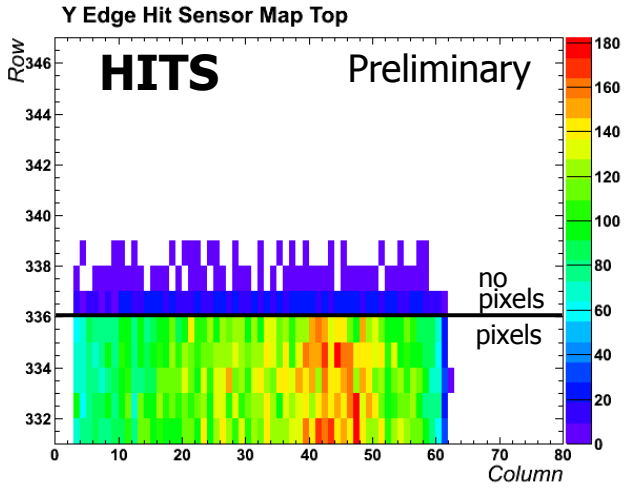
(*) In collaboration with O. Korchak (Prague), Sh. Hsu (UW)

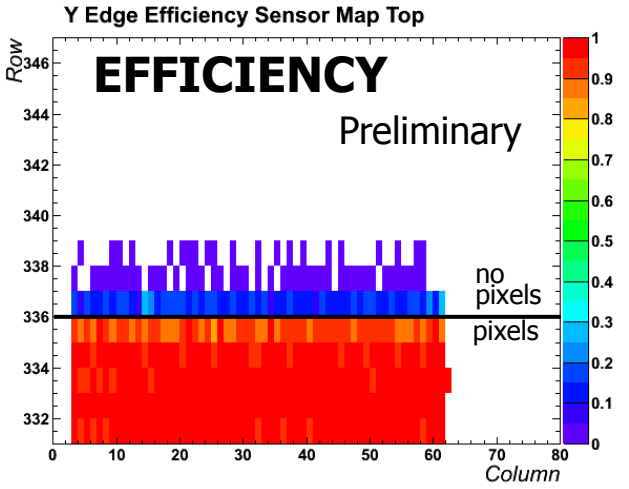
Reference: Regular Edge (Top Side)



Sensor: AFP_CNM_S5_R7

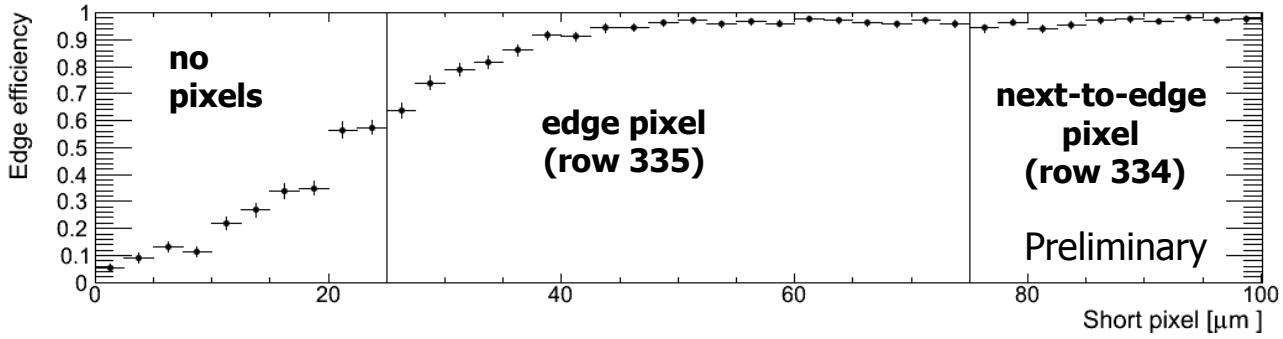






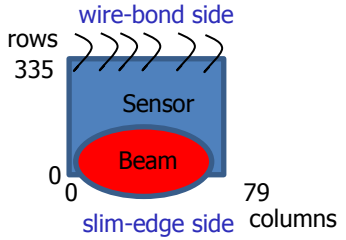
Note: position of tracks/hits according to tracks reco. by beam telescope

Efficiency projection



- Efficiency stable up to 15 µm away from edge
- S-curve around edge
  - Telescope resolution
  - Possibly also small sensitivity outside last pixel

Slim Edge (Bottom Side)



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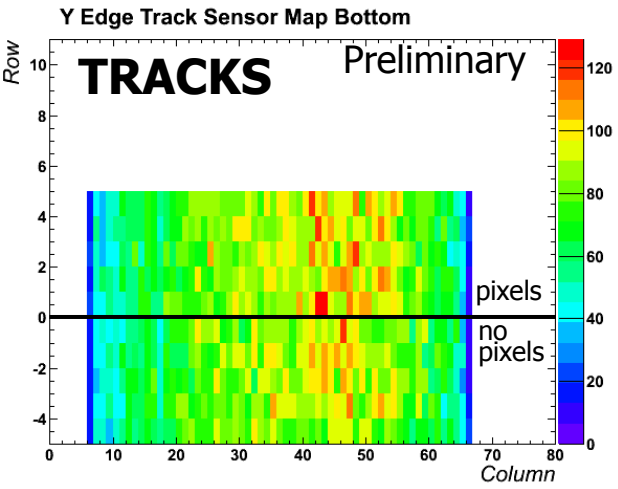

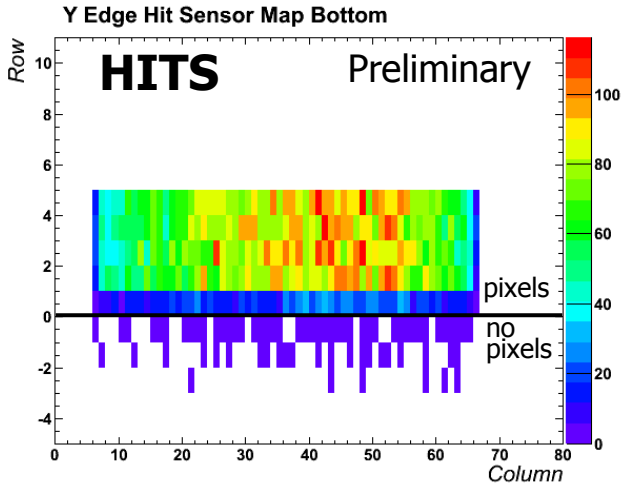

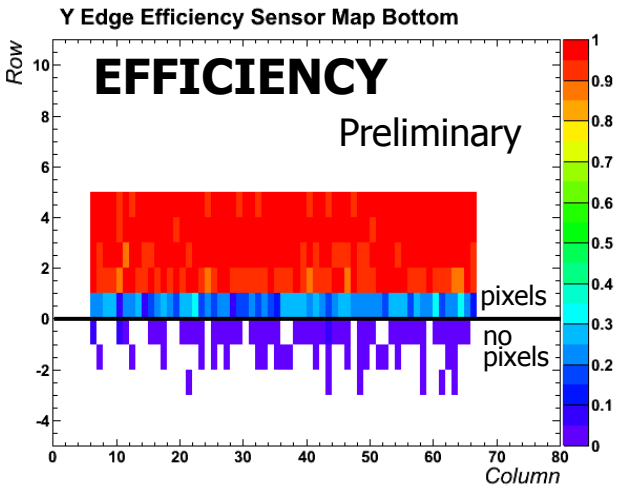

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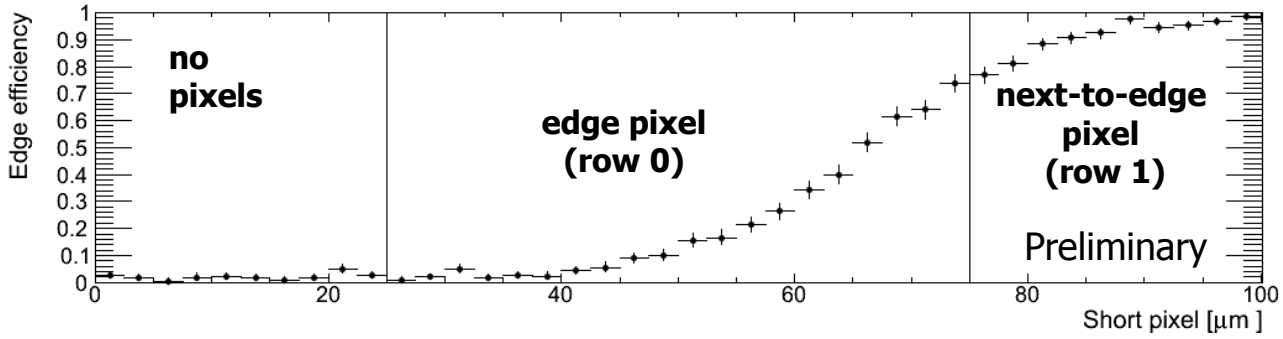


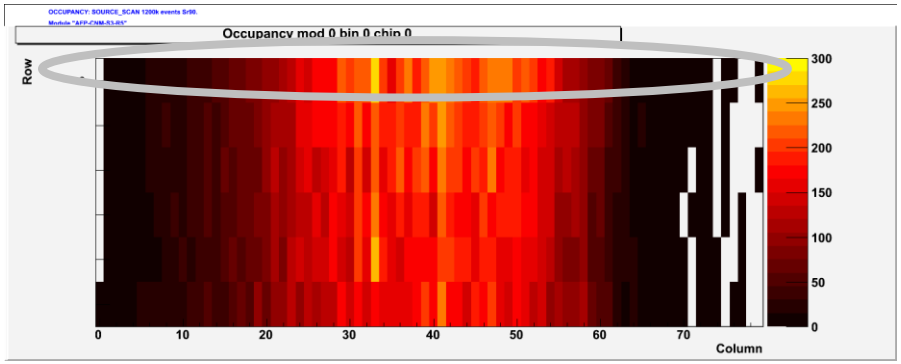
- Efficiency stable up to ~65 µm away from edge → seems to be "shifted" by one row compared to regular edge
- Good result as inactive region highly reduced: 1 mm → (100 + 50) µm
- In addition: low eff. in 1st row looks like artifact → further investigations

Further Investigations

- Source scan with Sr90 in IFAE lab
  - External trigger (scintillator)
  - 1st row (slim-edge side) is up here!

→ No deficiency of hits in 1st row!

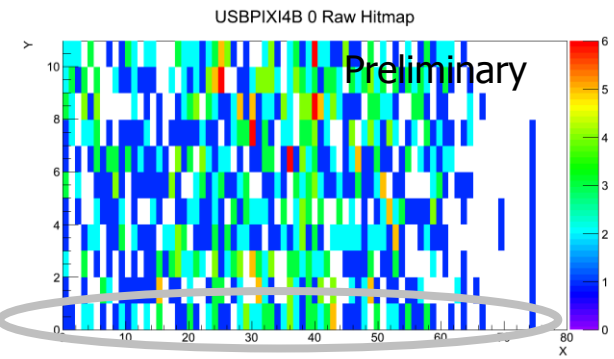
Sensor: AFP_CNM_S3_R5



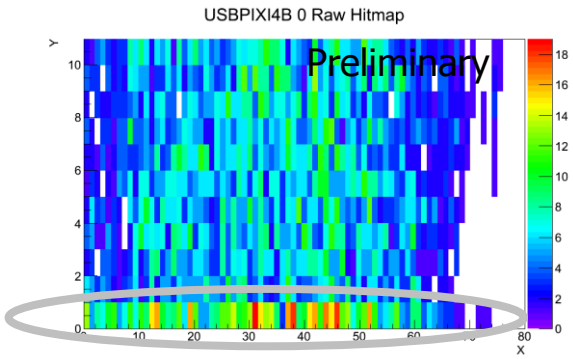
- Raw hitmap before offline reconstruction (reduced statistics)

→ No deficiency of hits in 1st row!

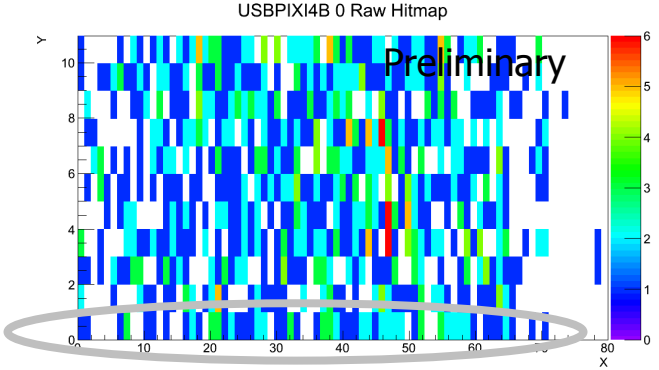
Sensor: AFP_CNM_S3_R5



Sensor: AFP_FBK_S5_R10

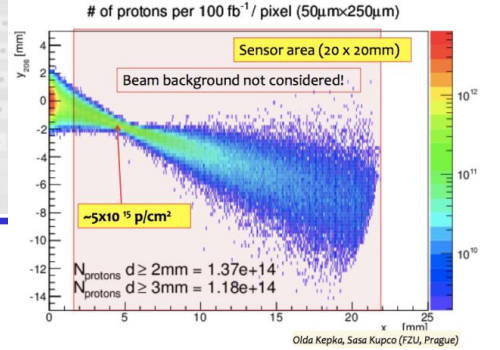


Sensor: AFP_CNM_S5_R7



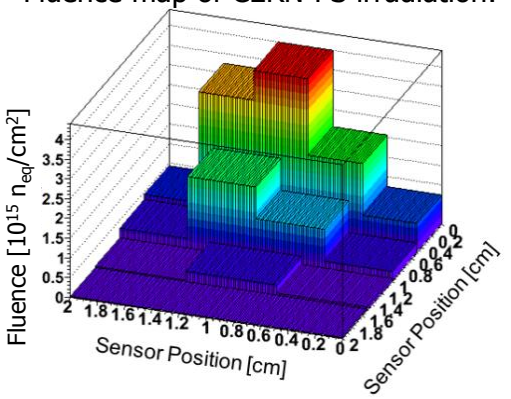
→ Inefficiency probably artifact in offline reconstruction

Non-Uniform Irradiation

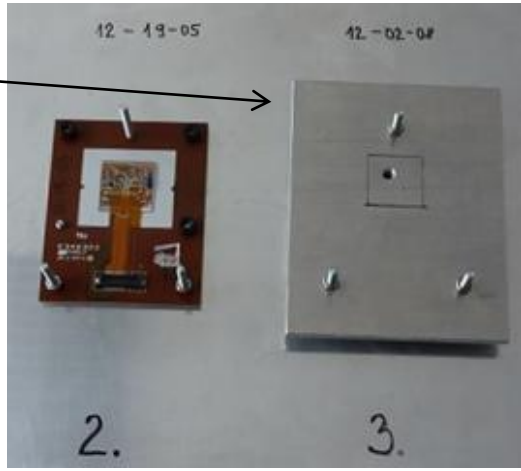


- Non-uniform irradiation:
  Can detector be operated to give high efficiency both in unirradiated region ($V<V_{BD}$ needed) and in irradiated region ($V>V_{dep,irr}$ needed)?
- First test beam study in 2012 with CERN-PS 23 GeV irradiation promising: 98% efficiency
  see A. Micelli, 21st RD50 workshop Nov 2012; S. Grinstein, 8th Trento workshop 2013
- But fluence spread was large
- New irradiation with more localised fluence:
  23 MeV protons (Karlsruhe), 1.8x10^{15} n_{eq}/cm^2 through 3 mm hole in Al plate (5 mm thick)
- Irradiated sensors:
  FBK and CNM 3D detector, standard-edge FE-I4

Fluence map of CERN-PS irradiation:



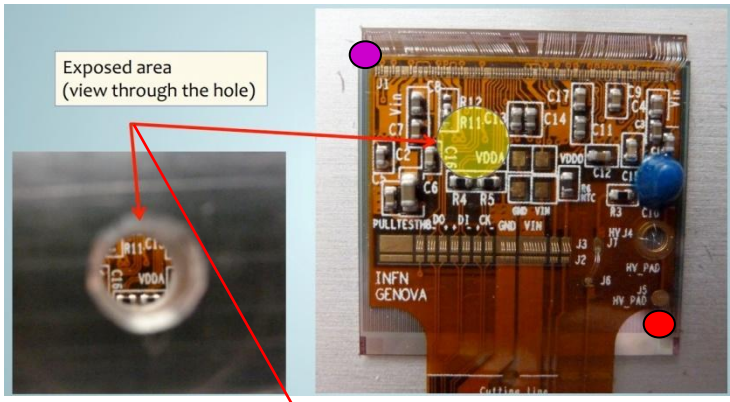
Al shield at Karlsruhe:



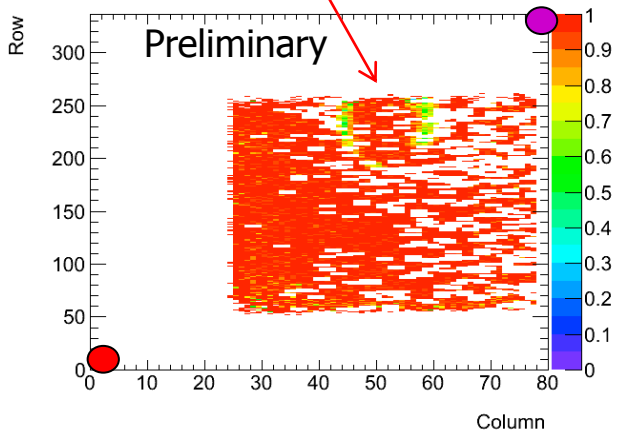
Thanks to Petr Sicho (CERN)/Felix Boegelspacher (KIT) for irradiation

Test Beam: Irradiation Studies

- July 2013 DESY test beam: only FBK sensor
- Not optimal sensor from beginning (IBL spare: merged/disconnected bump bonds; V_{BD}~40 V)
- T ~ -20 °C (dry ice)
- Different runs at different bias voltages of irradiated sample (20-58 V, limited by high I_{leak} for $V>V_{BD}$)
- Average efficiency of 96% (58 V) achievable, but regional dependence of efficiency observed



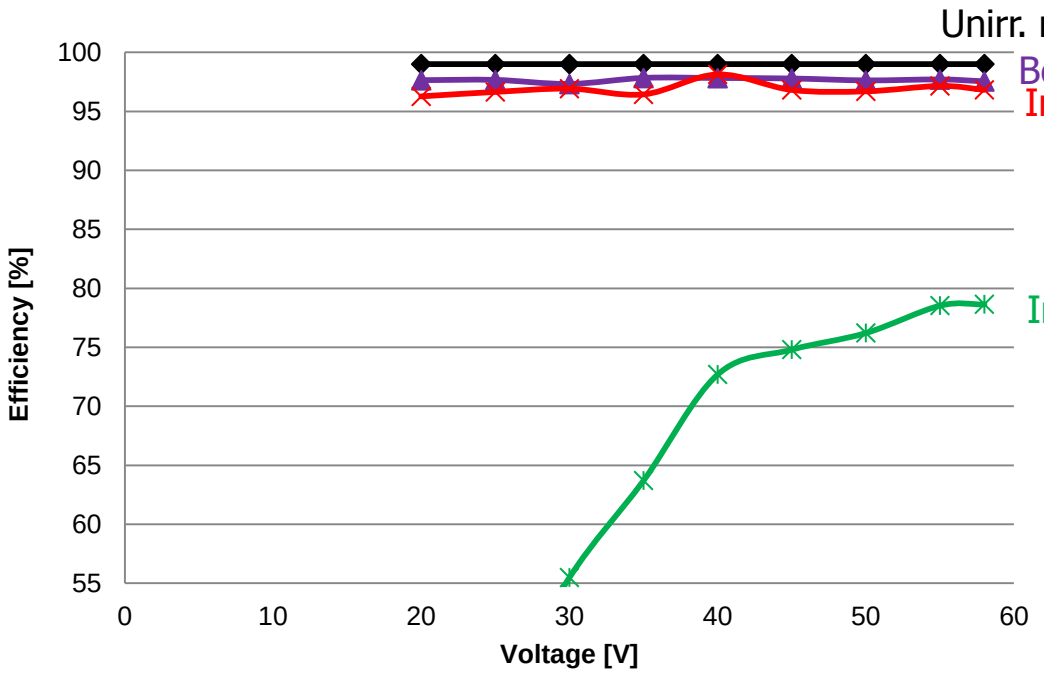
	DUTs	
Sample	CNM-55	FBK_12_02_08
Front-End	FE-I4A	FE-I4B
Fluence	unirrad.	1.8×10^{15} n_{eq}/cm^2
Bias [V]	30	20, 25, 30, 35, 40, 45, 50, 55, 58
Threshold	3500	2000
#Tracks	1.2M	2.1M
Overall Efficiency (average central region, mask applied)	99%	93% (20 V) - 96% (58 V)

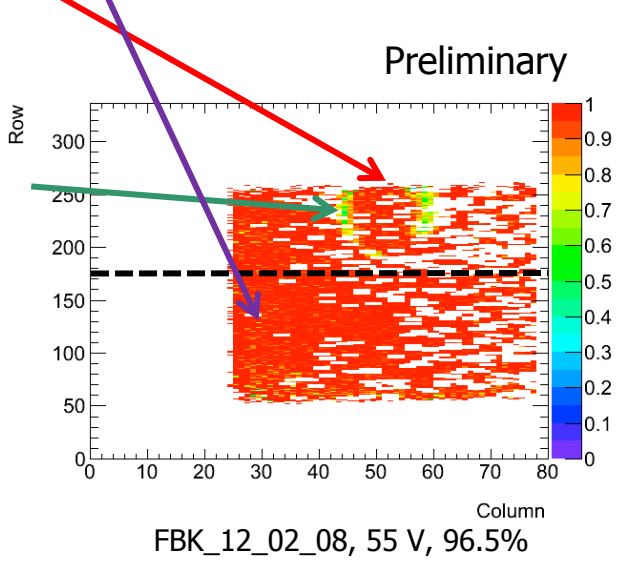


FBK_12_02_08, 55 V, 96.5%

Efficiency for Different Regions

- Irradiated hole (centre) almost as efficient as unirradiated bottom, starting already from 20 V
- Ring structure with much lower efficiency, increasing with voltage
  - higher fluence?
  - still under investigation

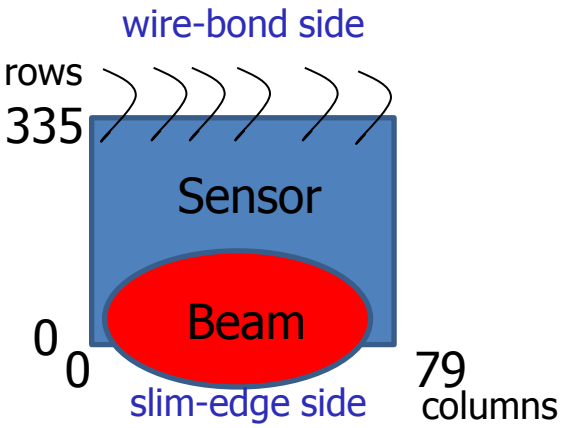


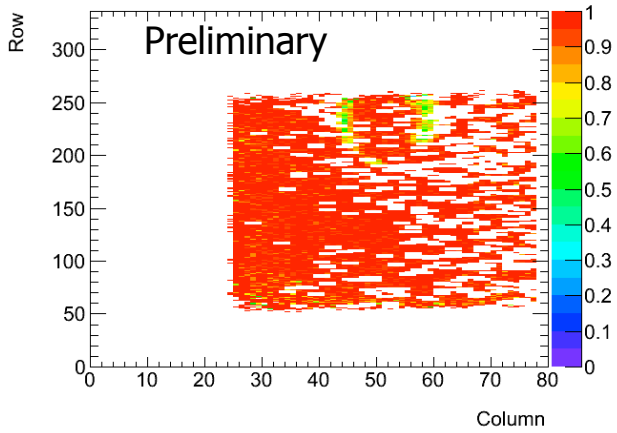


FBK_12_02_08, 55 V, 96.5%

Conclusions

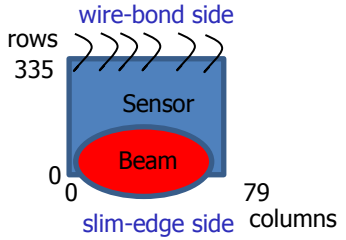
- Slim-edge and non-uniformly irradiated AFP sensors studied in test beam
- Slim edge:
  - Overall efficiency, IV and noise unaffected by edge-cutting
  - After offline reco. inefficiencies in 1st row observed
  - BUT: not visible in raw data and source scan!
  - In any case inactive pixel-sensor region highly reduced (from 1 mm to 100-150 µm)
- Non-uniform irradiation:
  - High efficiency of 97% achievable (in centre) despite low sensor quality
  - Lower efficiency in ring → higher fluence?
- Outlook:
  - Next test beam with non-uniformly irradiated CNM device in Jan. 2014 at DESY



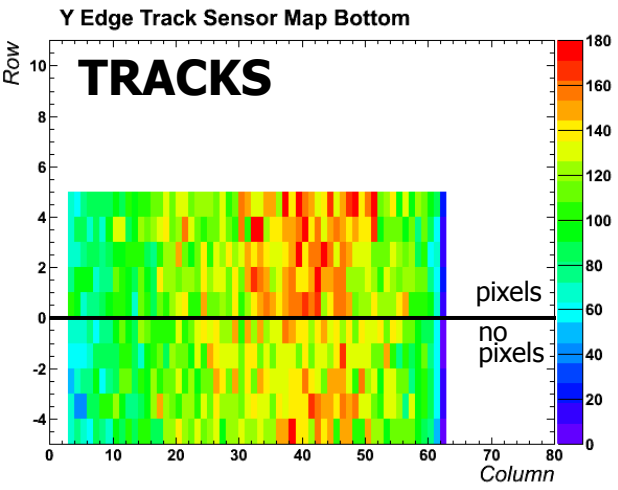


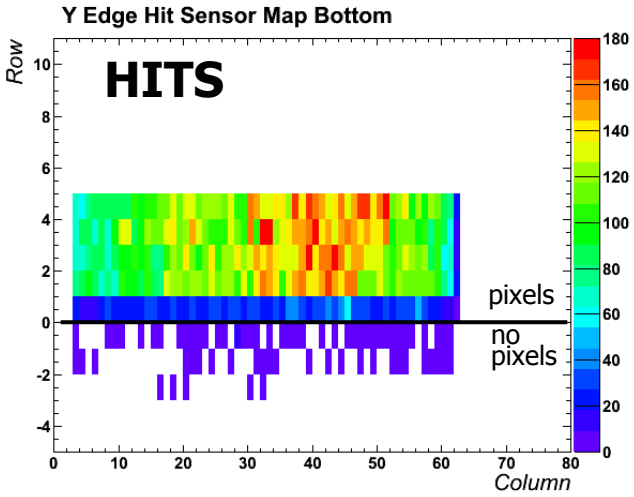
BACKUP

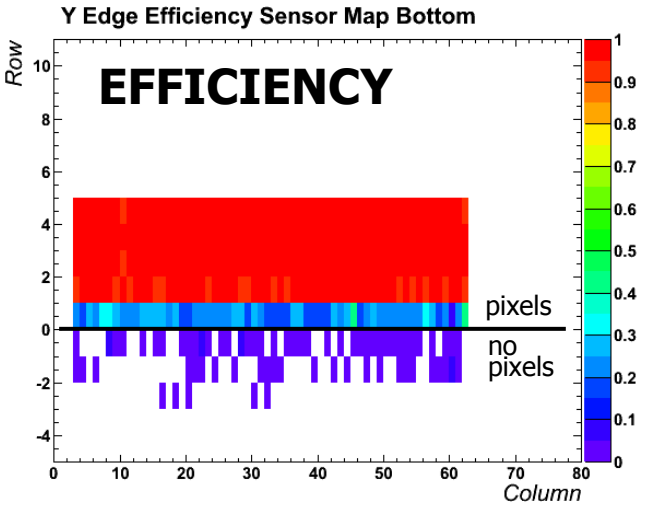
Slim Edge (Bottom Side)



Sensor: AFP_FBK_S5_R10

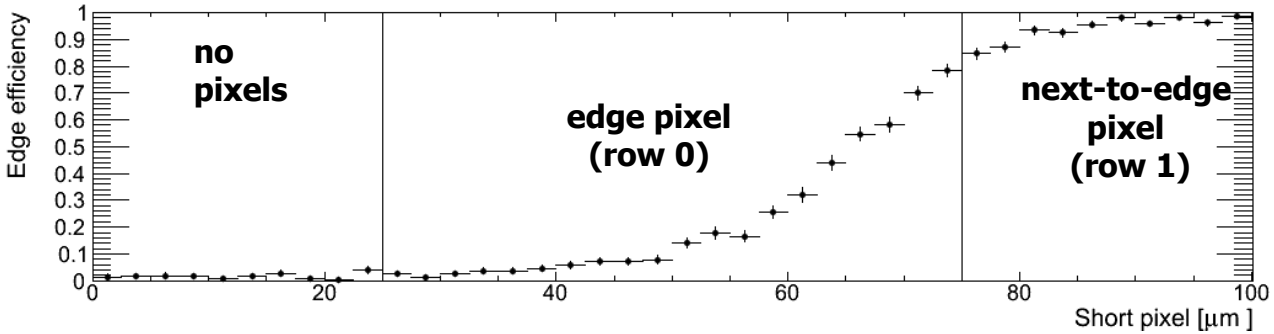






Note: position of tracks/hits according to tracks reco. by beam telescope

Efficiency projection



- Efficiency stable up to ~65 µm away from edge → seems to be "shifted" by one row compared to regular edge
- Good result as inactive region highly reduced: 1 mm → (100 + 65) µm
- In addition: low eff. in 1st row looks like artifact → further investigations

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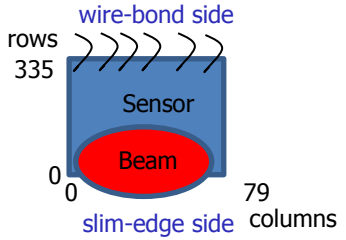
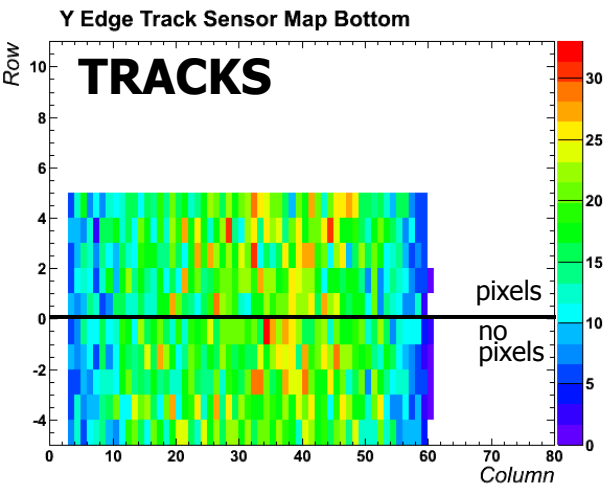
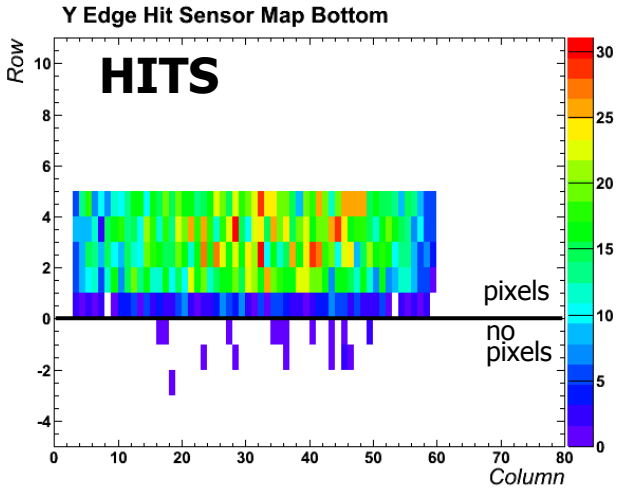
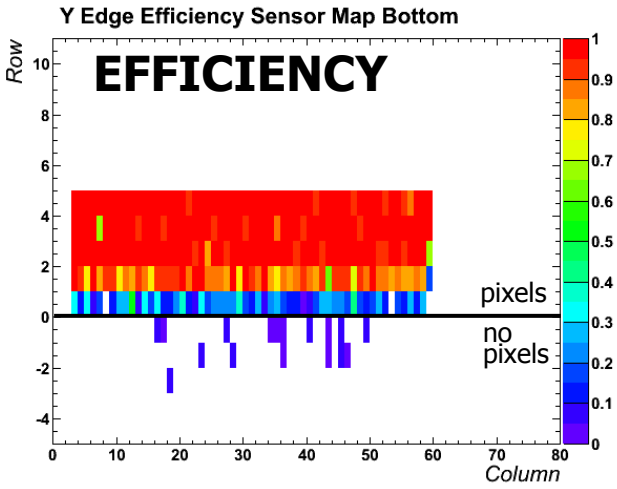


Sensor: AFP_CNM_S3_R5







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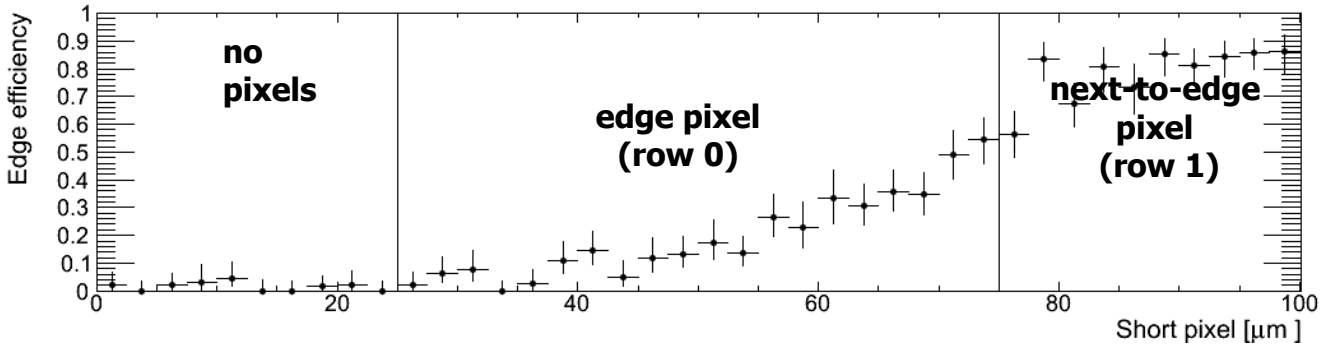
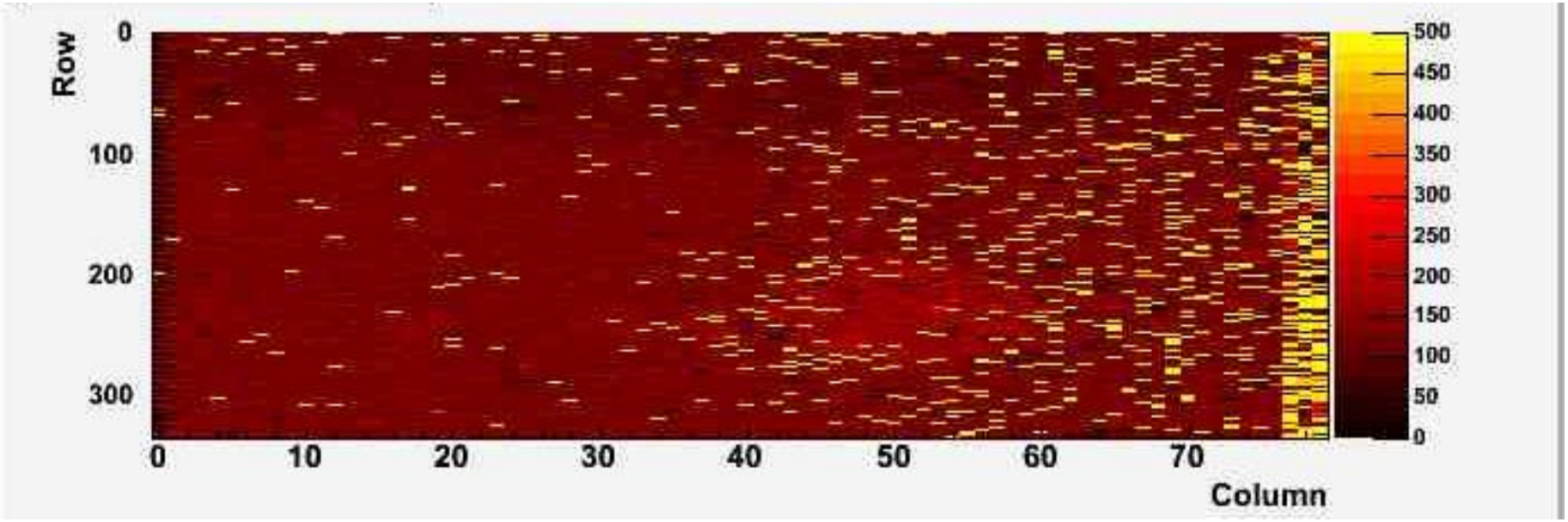


- Efficiency stable up to ~65 µm away from edge → seems to be "shifted" by one row compared to regular edge
- Good result as inactive region highly reduced: 1 mm → (100 + 65) µm
- In addition: low eff. in 1st row looks like artifact → further investigations

Noise of irradiated sensor

- Noise outside irradiated region ~ 130 e
- Noise inside irradiated region slightly higher (by about 10-20e)

FBK-12-02-08, 50 V



IV curve of non-uniformly irradiated sensor