High-resistivity CMOS pixel sensors and their application to the STAR PIXEL detector

Andrei DOROKHOV, on behalf of the IPHC-IRFU collaboration

Institut Pluridisciplinaire Hubert Curien,
23 rue du loess, BP 28, 67037 Strasbourg

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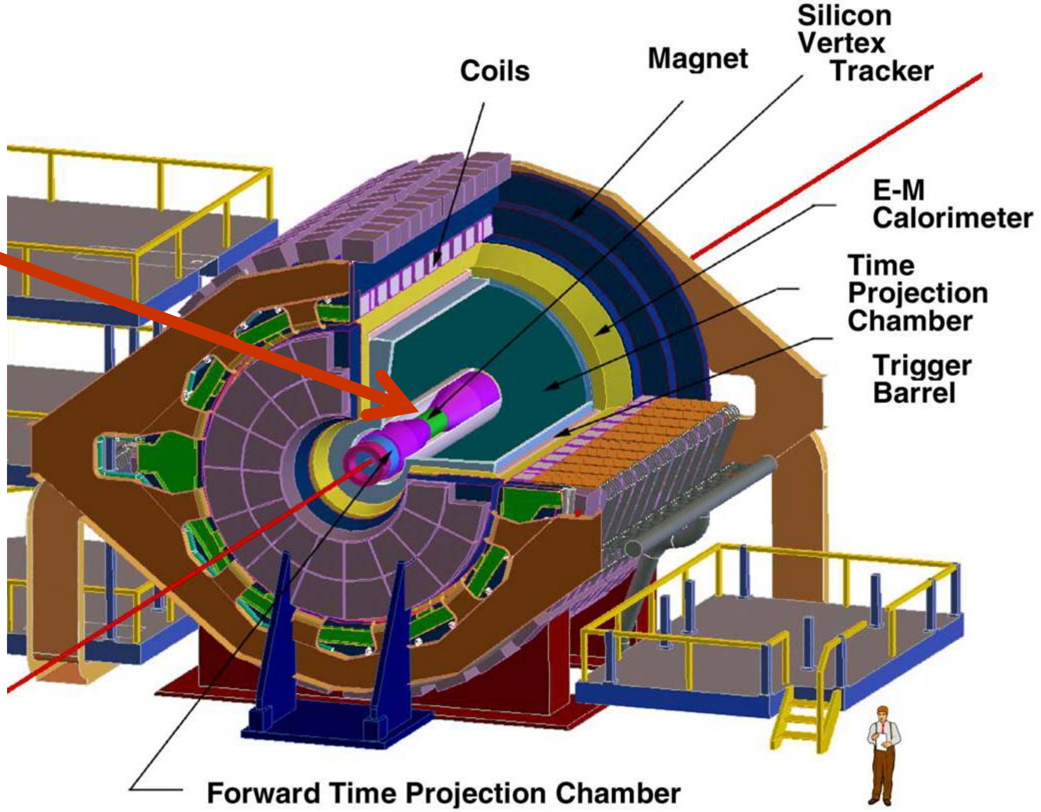
STAR experiment and Heavy Flavour Tracker

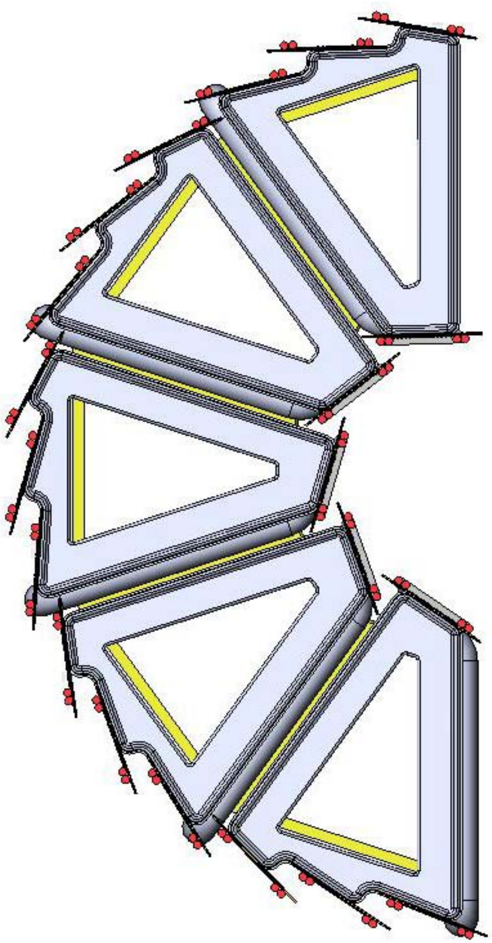
The STAR (**S**olenoidal **T**racker **A**t **R**HIC) experiment at the Relativistic Heavy Ion Collide (RHIC) studies the new state of matter produced in relativistic heavy ion collisions.

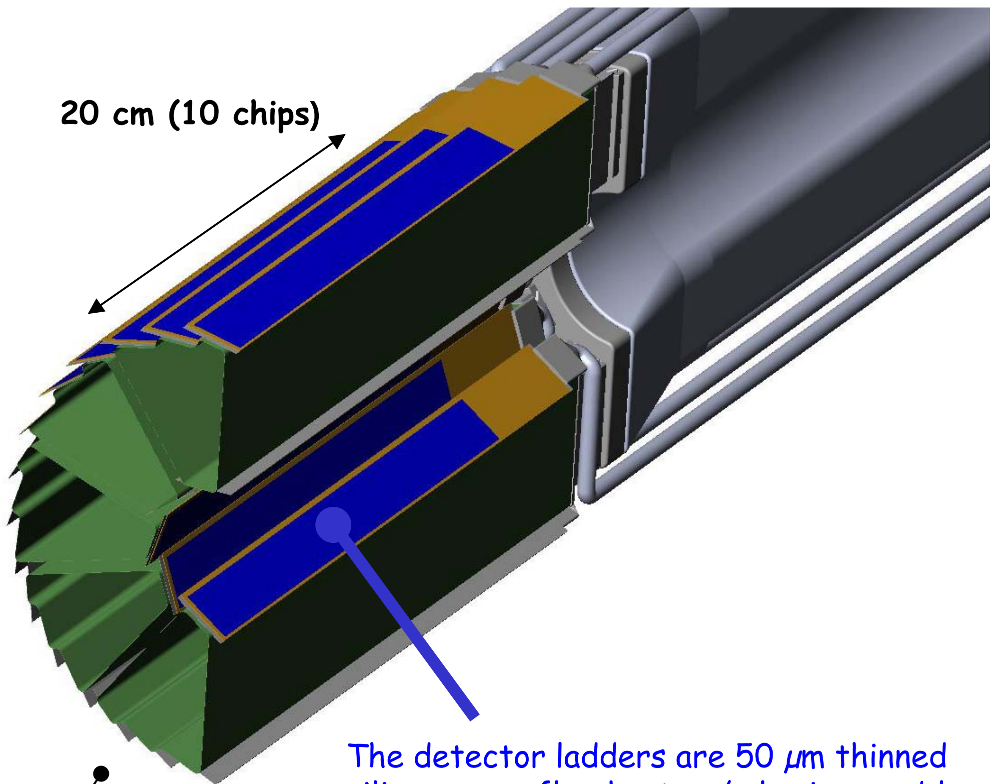
The Heavy Flavour Tracker (HFT) will use 2 cylindrical monolithic active pixel sensors (MAPS) layers for the vertex detector upgrade



- small radiation length: thinned to 50 um on a flex kapton/aluminium cable to minimize multiple scattering
- sensors positioned close (2.5 - 8 cm) to the interaction region (~ 150 kRad/yr and 3e12 Neq/cm^2)
- resolution sufficient to resolve the secondary decay vertices from the primary vertex (< 10 um)
- work at ambient (~ +35 C) temperature

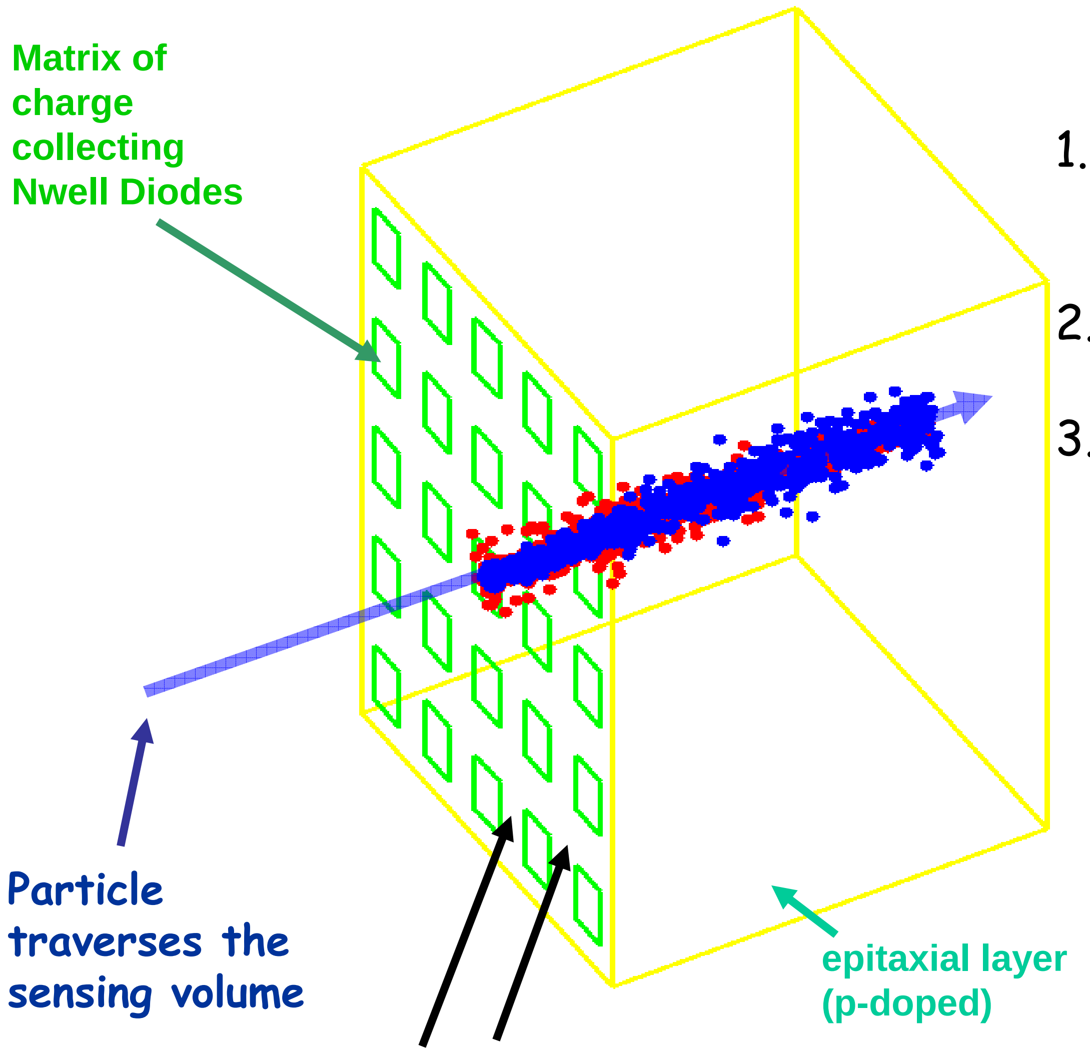
PIXEL detector geometry





Total: 40 ladders

Monolithic Active Pixel Sensors

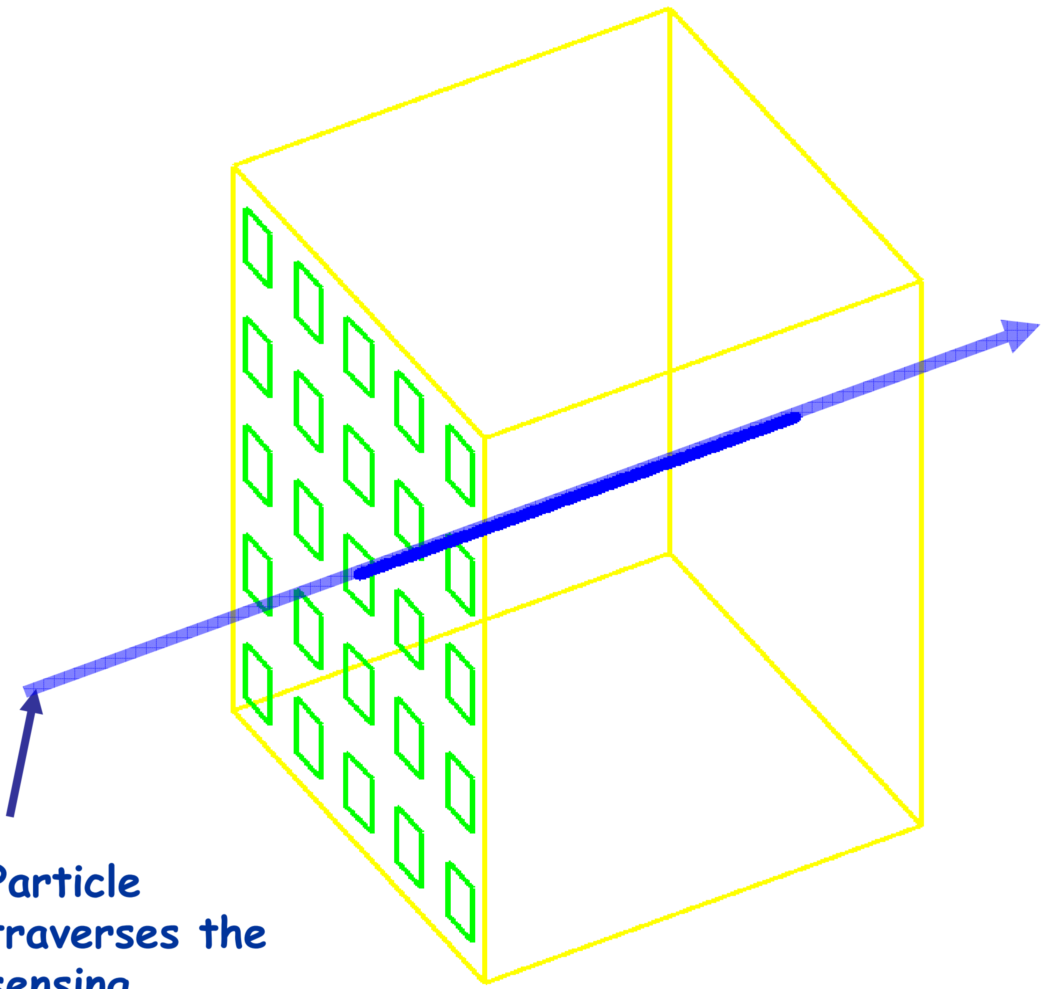


Under development since 1999 at IPHC (Strasbourg):

1. MAPS implemented in standard CMOS substrate with readout electronics
2. use p-epitaxial layer as sensing volume (~10-20 um)
3. Nwell Diodes collect e-h pair liberated by the particle

- low cost
- high granularity
- low material budget
- in-pixel signal amplification
- low noise
- integrated readout and signal processing

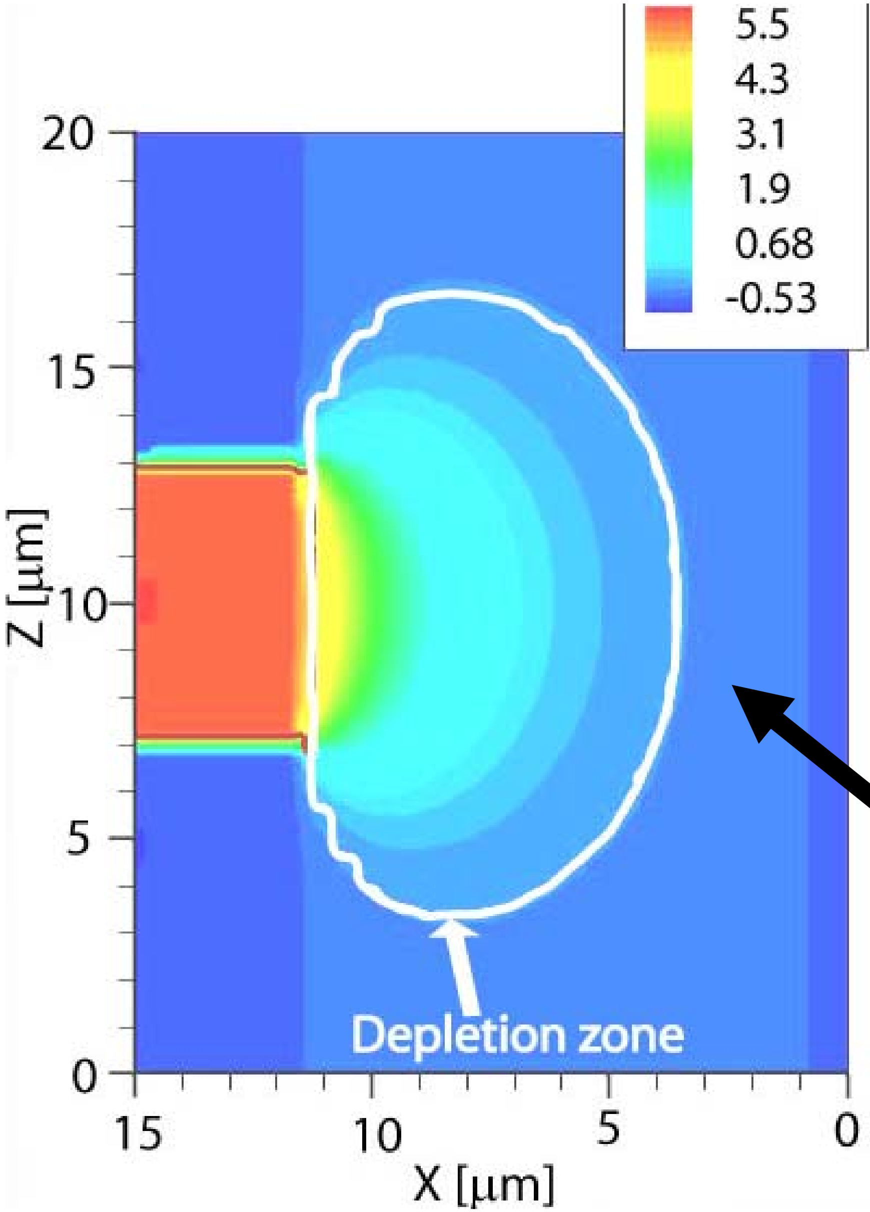
Monolithic Active Pixel Sensors: charge collection



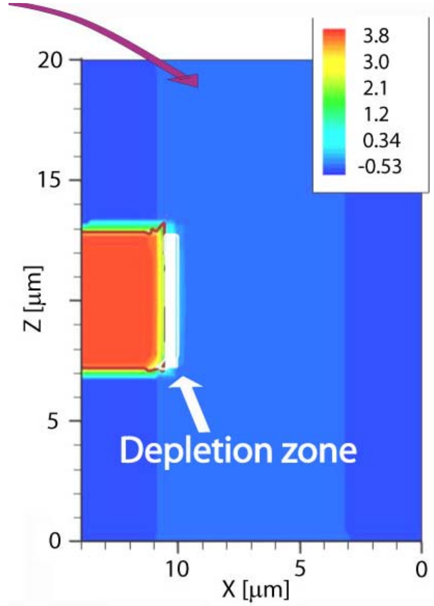
Blue: electrons
Red: holes

Particle traverses the sensing volume

MAPS in a high resistivity epitaxial layer



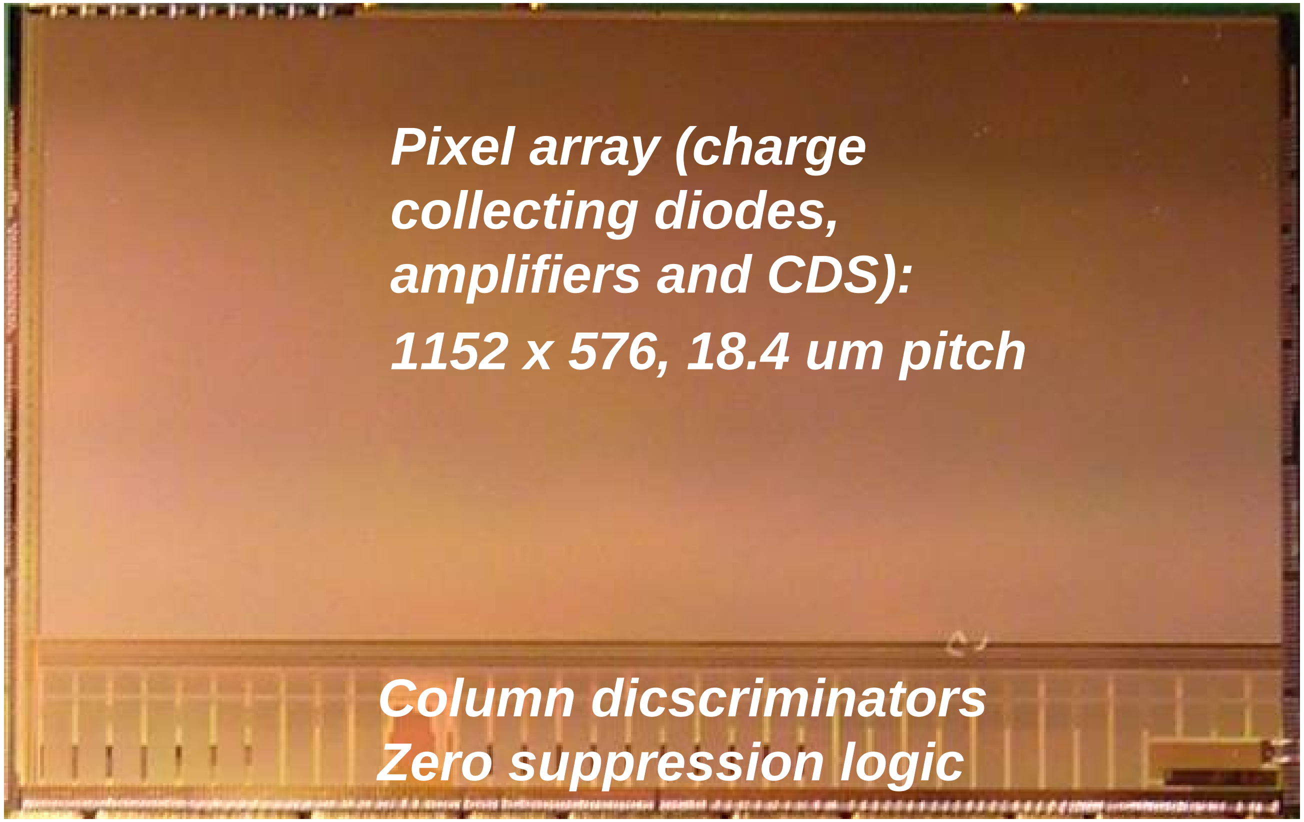
For comparison: standard CMOS technology, low resistivity P-epi



high resistivity (1kOhm*cm) P-epi: size of depletion zone size is comparable to the P-epi thickness!

Sensor (Mimosa26) for EUDET beam telescope

10.6 x 21.2 mm^2



CMOS AMS 0.35 um OPTO process, epi-layer 400 Ohm*cm

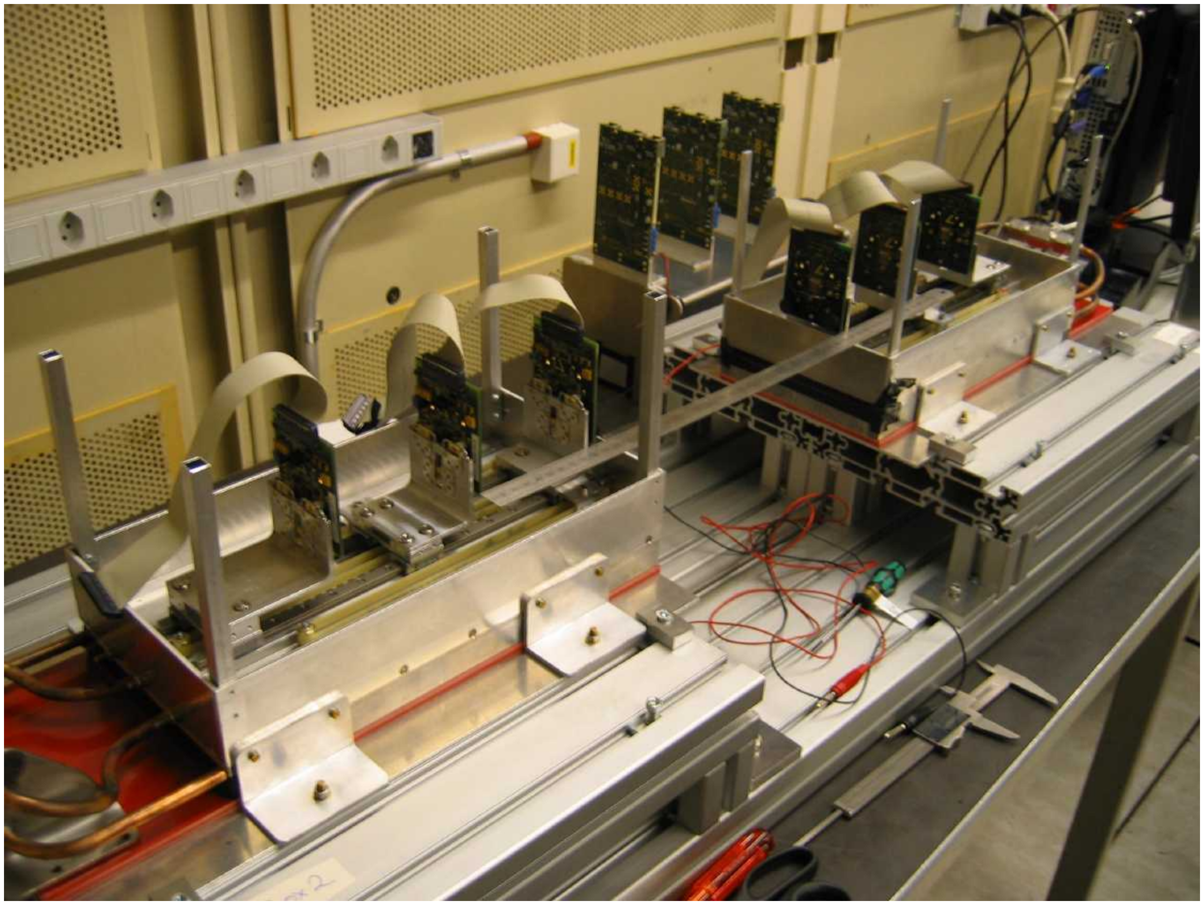
Read-out in rolling-shutter mode:
80 MHz clock (can work up to 115MHz),
115.2 us (down to ~85 us) integration time

binary signal readout

zero suppression in 18 groups of 64 columns allowing ≤ 9 "pixel strings" / row

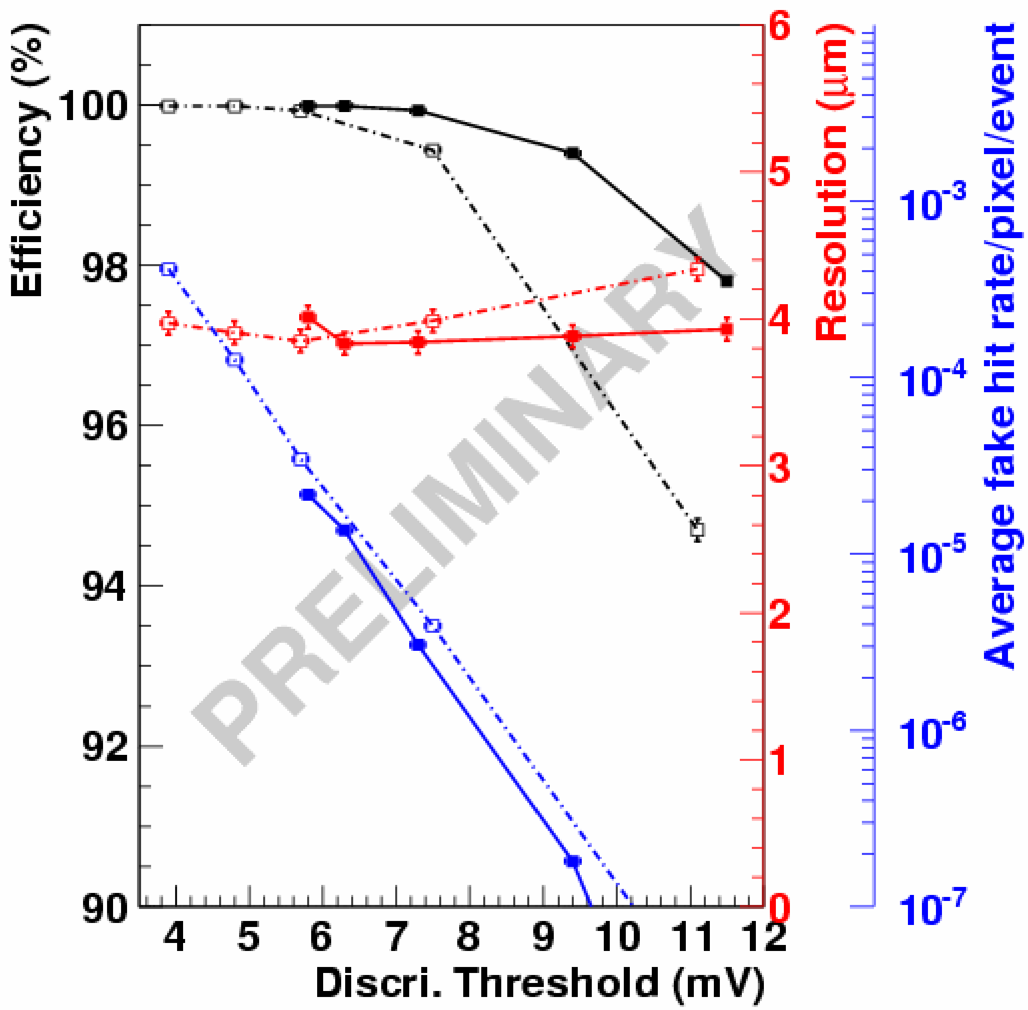
EUDET beam telescope

- 2 arms of 3 planes
- Mimosa26 thinned to 50 µm
- extrapolated 1-2 µm EVEN with e− (3 GeV, DESY)
- frame read-out frequency O(10^4) Hz
- running since '07 (demonstrator: analogues outputs) at CERN-SPS & DESY



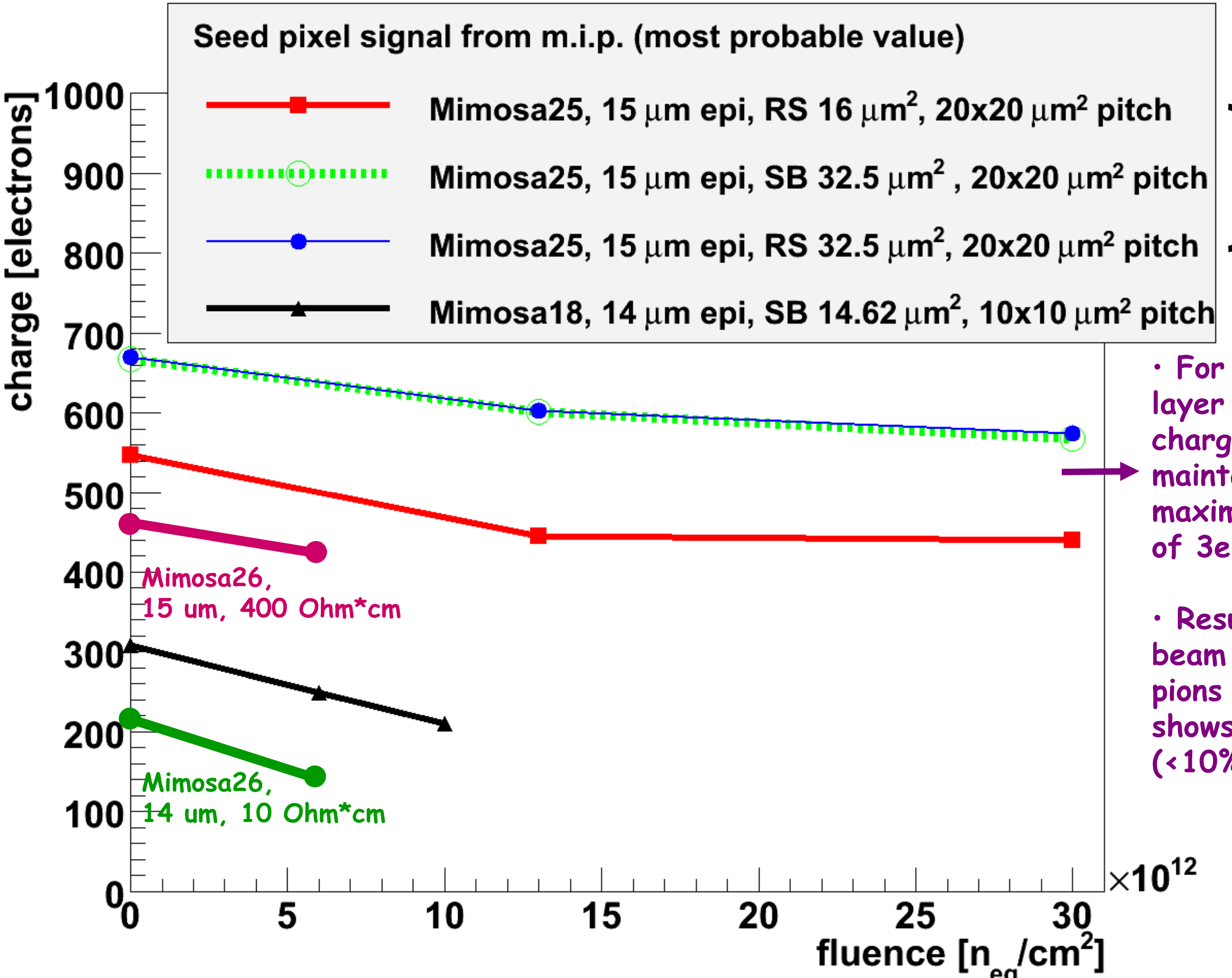
EUDET beam telescope sensor performance

Mi26 HR-15 and HR-10 Efficiency, Fake rate and Resolution



- non-irradiated
- thinned down to 50 um
- 20 C temperature
- 400 Ohm*cm epitaxial layer
- 15 um and 10 um thickness of epitaxial layer

Comparison of charge collection from Ru106 source for irradiated sensors



- For depleted epitaxial layer the excellent charge collection maintained up to the maximum tested value of 3e13 Neq
- Results from test beam at CERN with pions of 120 GeV/c shows similar values (<10% of difference)

Mimosa26 sensor as a prototype for the STAR HFT

Mimosa26 sensor

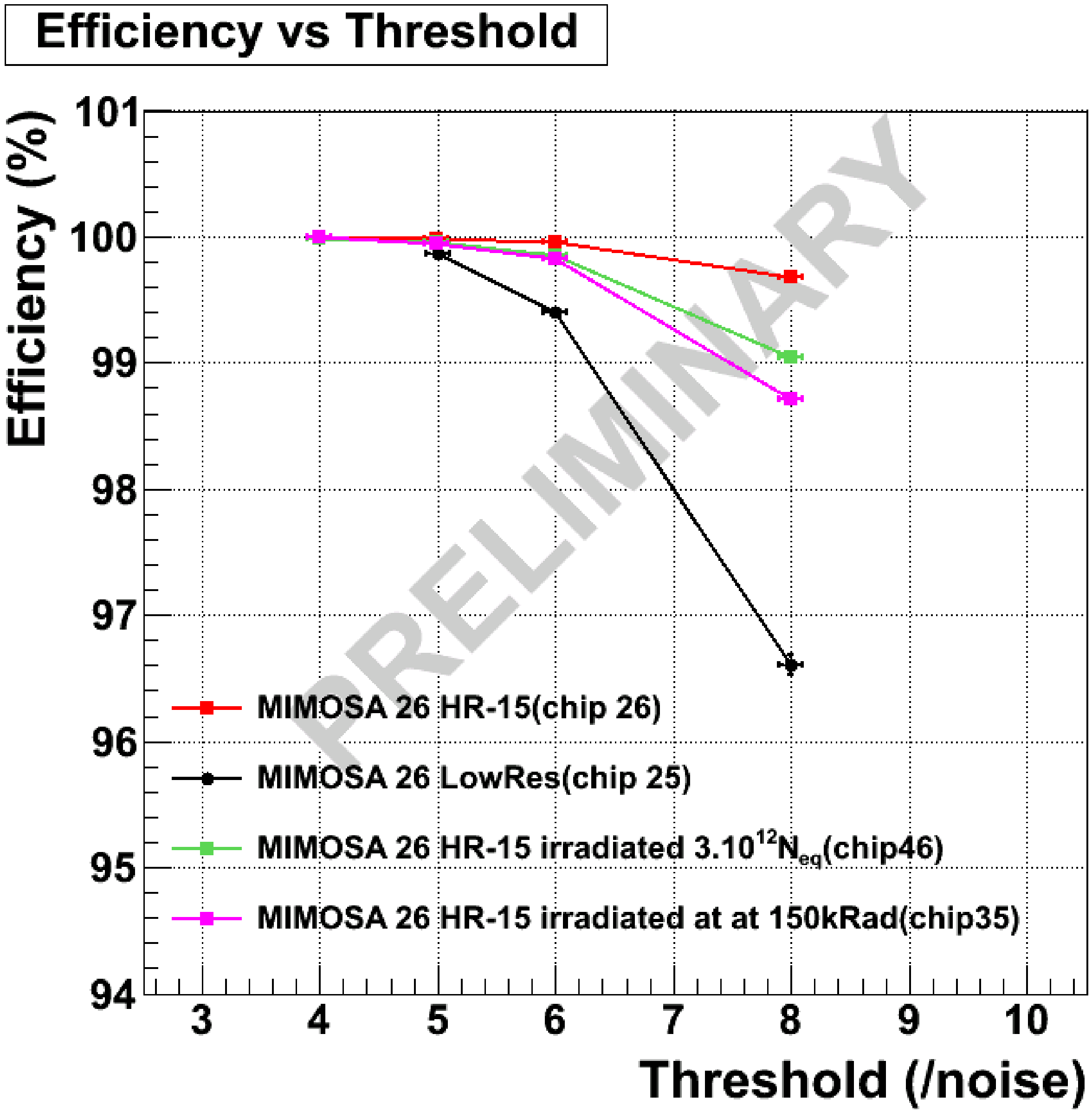
- 80 MHz
- 115.2 us integration time
- temperature ~ 20C
- 1152 x 576 pixels matrix
- 18.4 um pitch
- no constrains on radiation tolerance

ULTIMATE sensor (chip submission October 2010), design in progress

- larger matrix, integration time will be larger (<200 us)
- temperature +30 +35C
- 960 x 928 pixels matrix
- 20.7 um pitch, to fit power consumption constraints (< 135 mW/cm^2)
- 150 kRad ionizing radiation
- 3e12 Neq/cm^2 non-ionizing radiation

1. need to improve charge collection, radiation tolerance-> high resistivity epitaxial layer
2. improvement of radiation tolerance of pixel design

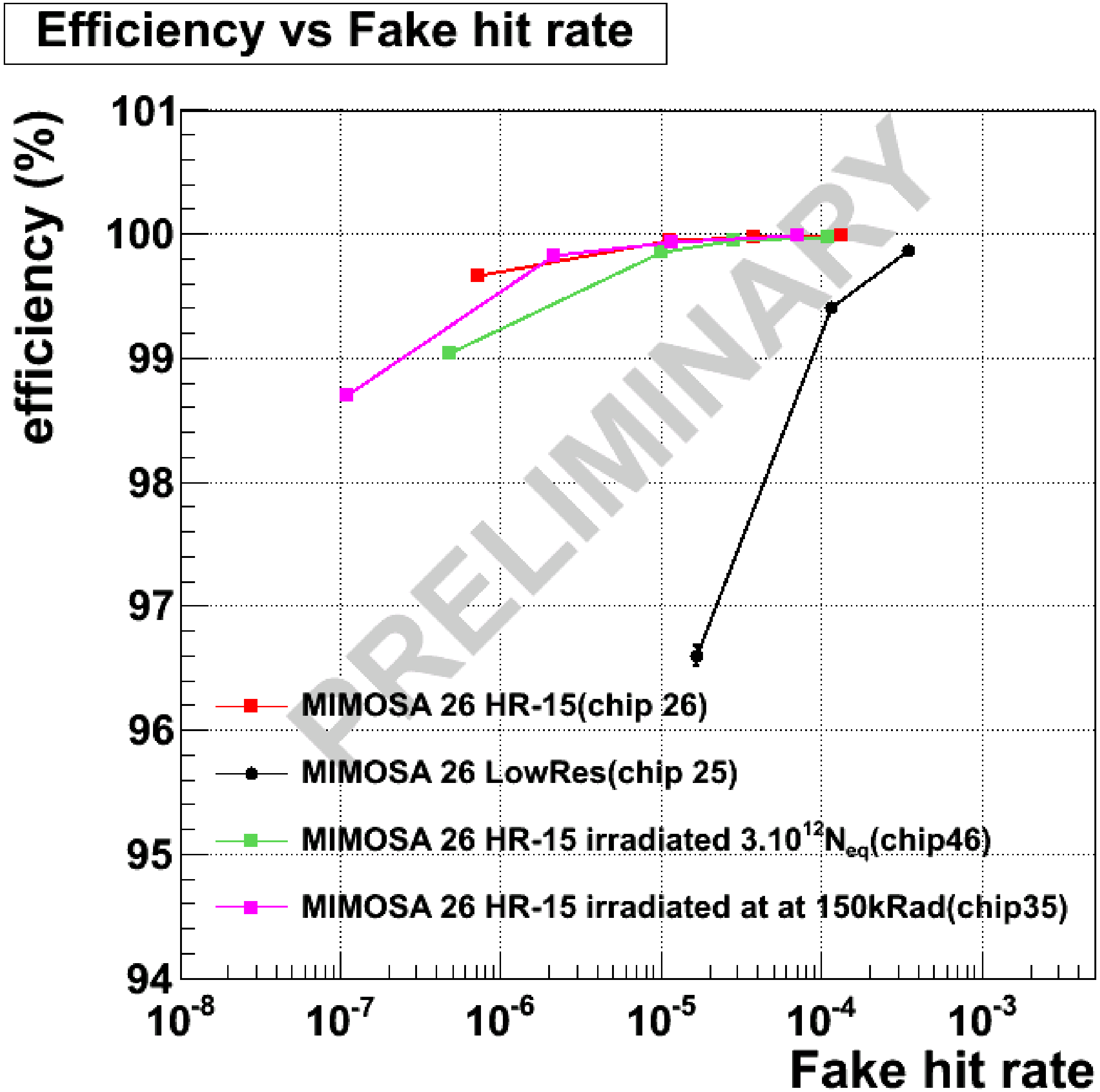
Mimosa26 sensor in a high-resistivity epitaxial layer



- 50 MHz to emulate longer integration time
- +35 C temperature!

resolution < 5um

Mimosa26 sensor in a high-resistivity epitaxial layer



- 50 MHz to emulate longer integration time
- +35 C temperature !

resolution < 5um

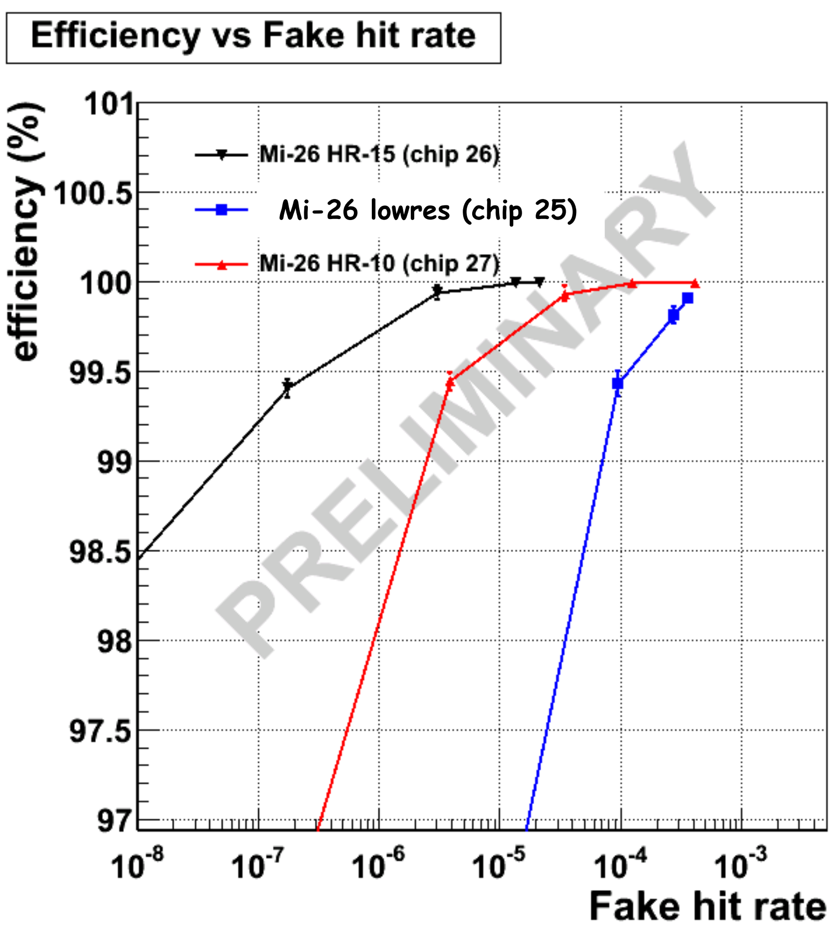
Prototyping for optimization: Mimosa22ahr - tests of several pixel variants

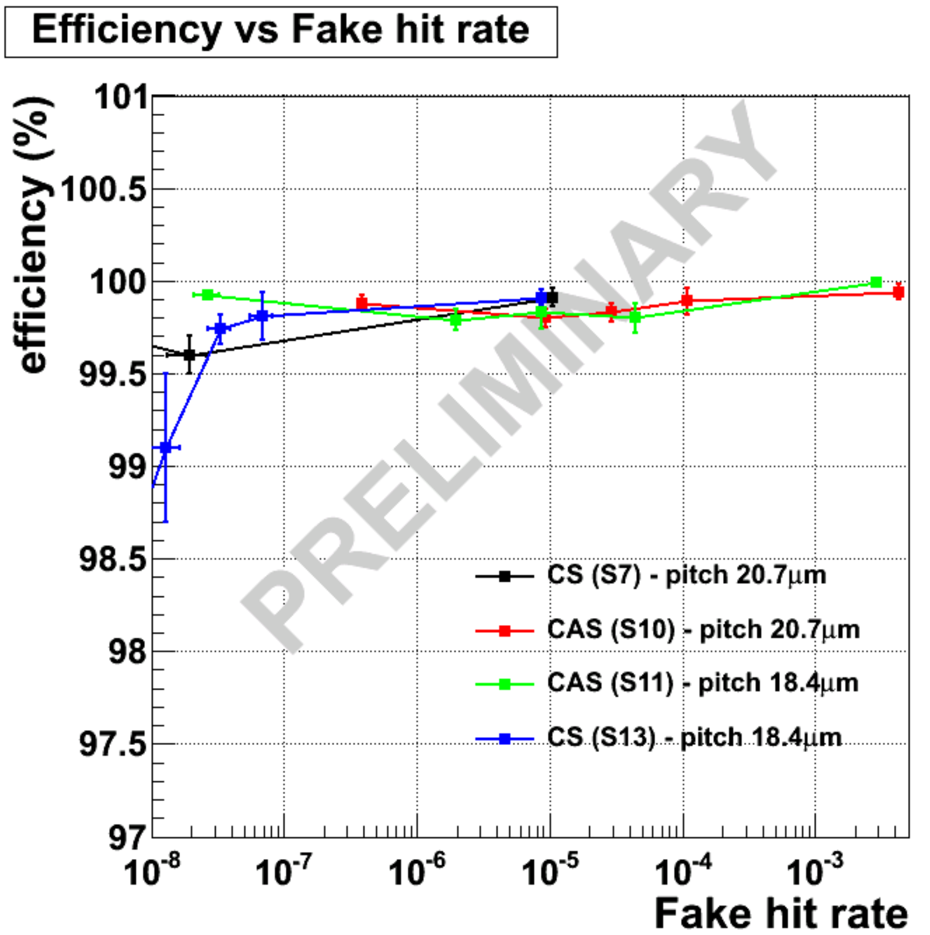
- pitch 20.7 um and 18.4 um
- few diode sizes , from 11 um^2 to 18 um^2
- radiation tolerant designs (ELT)
- diode bias voltage increase
- two stage amplifiers, AC coupling

Lab test with Fe55 at +35 C and integration time imposed by the STAR requirements shows:

- the conversion gain can be improved by factor of two
- noise before irradiation 10 to 13 e
- noise after irradiation with 150 kRad is from 13 to 23 e
- noise after irradiation with 3e12 Neq is from 16 to 23 e
- SNR up to 30 after irradiation
- for a low resistivity epitaxial layer ~30 before irradiation

Mimosa22ahr - beam tests (CERN-SPS)





- 100 MHz
- ~ 20 C temperature
- non-irradiated
- resolution < 5um

A. Dorokhov, IPHC, Strasbourg, France

Conclusions

• The high resistivity epitaxial layer improves signal-to-noise ratio of MAPS, confirmed in a beam test with Mimosa26 -> efficiency >99.8% (at 10e-5 fake hit rate)

-> In particular the radiation tolerance is highly improved (NIx100)

•The radiation hardness can still be improved by pixel design, first lab results of Mimosa22ahr + beam test measurements are in progress..

• PIXEL detector for the STAR experiment based on a modified version of Mimosa26 Sensors built in a high resistivity epitaxial layer will fulfill the STAR HFT requirement

-> ULTIMATE sensor is going to be submitted for fabrication autumn 2010