Upgrade of BCM1F for fast beam background and luminosity measurement at CMS

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CERN & DESY & BTU

On behalf of BRIL

Adamas workshop Nov. 2014, Trento

Luminosity and machine induced background

The luminosity is a key parameter of a collider experiment

- It defines the physics potential
- Its measurement is necessary for cross section determination
- Its uncertainty is also the uncertainty of the cross section

Machine induced background is a nuisance for each collider experiment

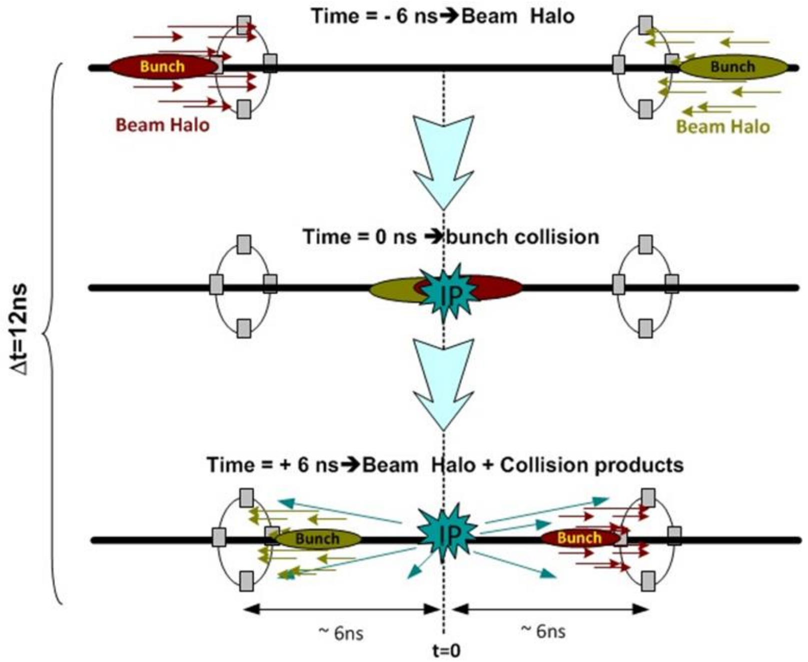
- Radiation damage of detectors
- Fake hits in detectors
    - Degradation of the performance
    - Spurious trigger

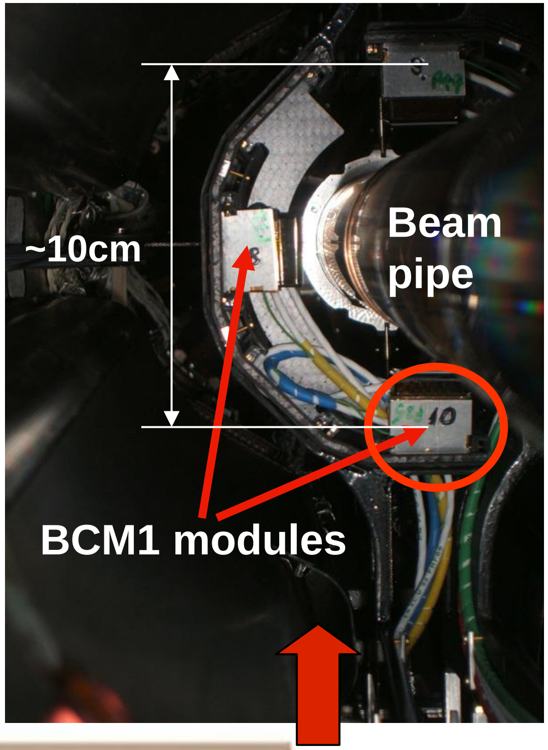
Dedicated detectors needed !

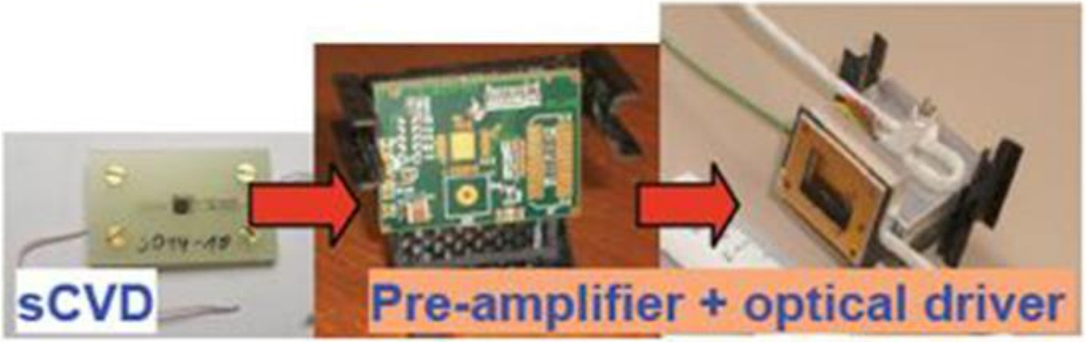
Luminosity and machine induced background

- Measurement of machine induced background whenever beam might be in LHC
- DAQ and power independent of CMS, robust.
- Real-time feedback to CMS and LHC on the background in the CMS detector
- On-line monitoring of the radiation environment in the CMS cavern

PAST BCM1F


Time = - 6 ns→Beam Halo
Bunch
Beam Halo
Bunch
Beam Halo
Time = 0 ns →bunch collision
IP
Time = + 6 ns→Beam Halo + Collision products
Bunch
IP
Bunch
~ 6ns
t=0
~ 6ns
Δt=12ns

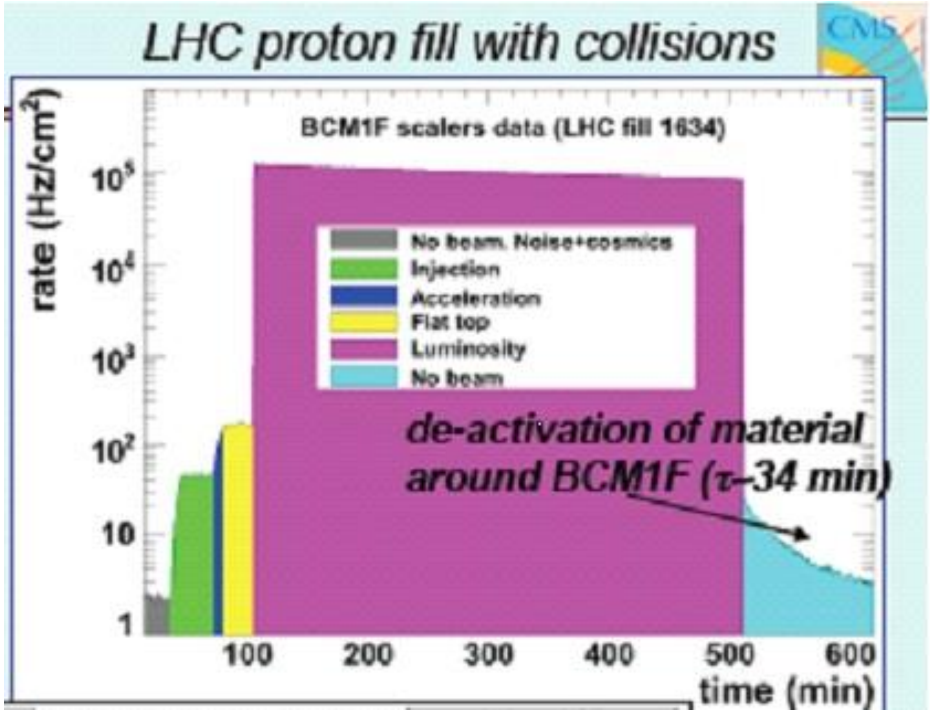

~10cm
Beam pipe
BCM1 modules

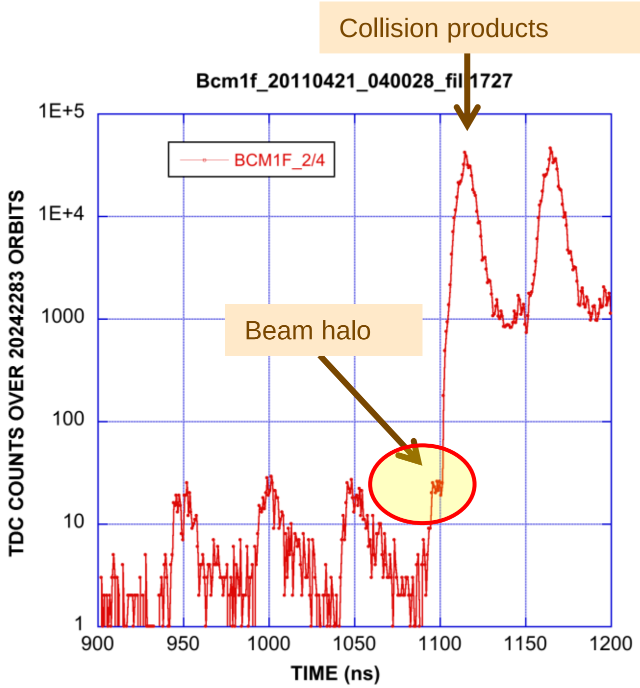

sCVD
Pre-amplifier + optical driver

PAST BCM1F

Example plots 2010-2012

rate of particles at different phases of LHC





Arrival time distribution of MIB and collision products
(ratio of collisions to MIB: ~10^3)

Time resolution is essential !

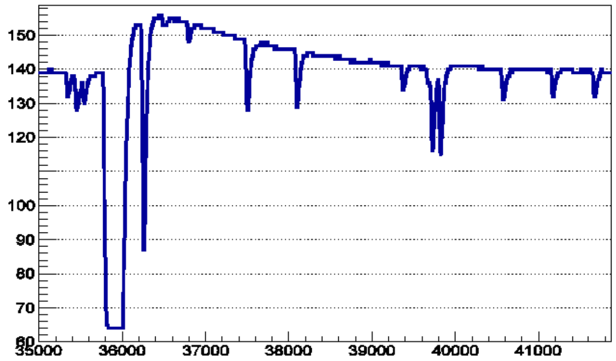
NEED for BCM1F upgrade

LHC after 2014

- Peak luminosity from 7.7 x10^{33} to 2x10^{34} $cm^{-2}s^{-1}$
- Cms-energy from 8 to ≥13 TeV
- Time between two bunch crossings from 50ns to 25 ns

→ higher rates, less average time between signals

Limits of the 2012 system:

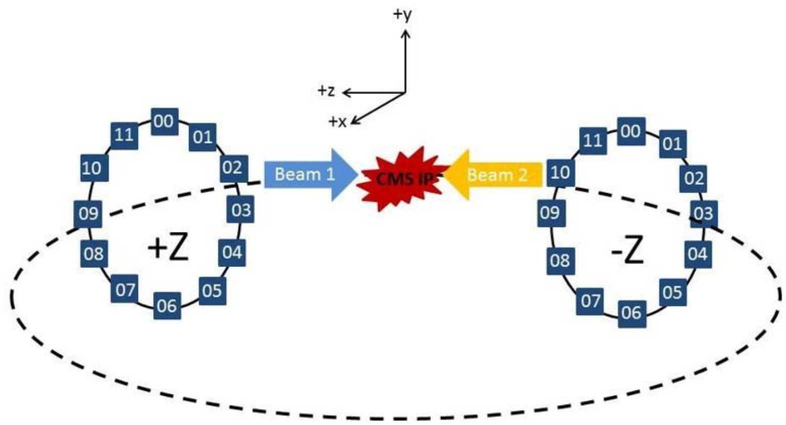


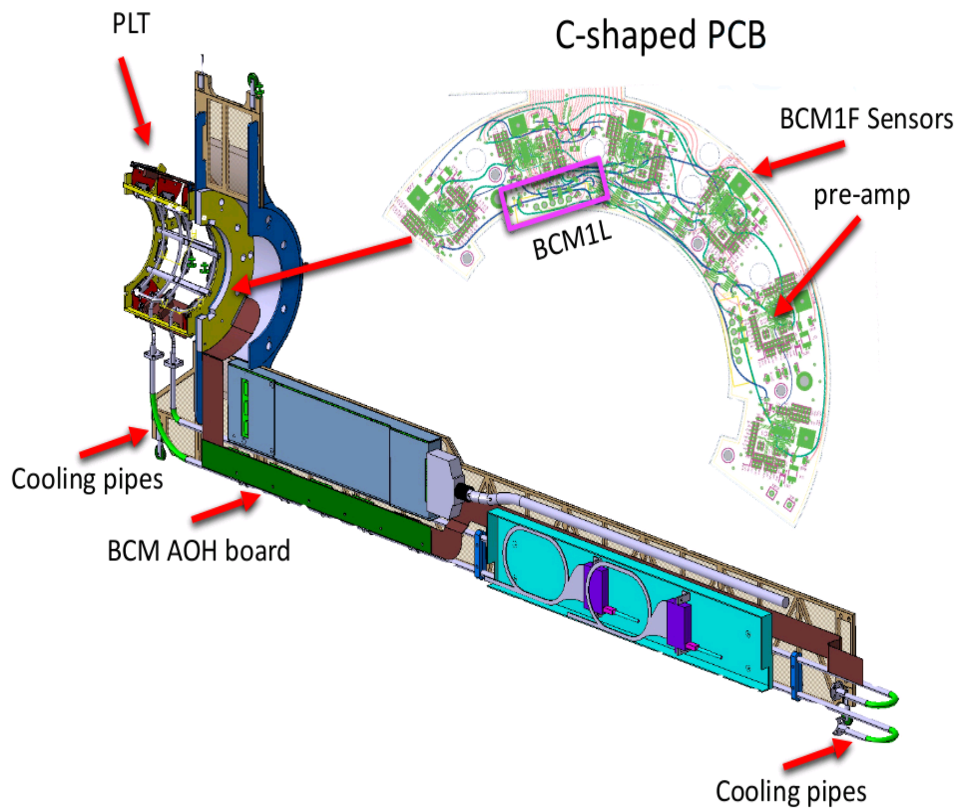
- Shaping time of the FE 25 ns
- ‘monster signals‘ with large and long overshoot
- Radiation damage of the laser diode
- Performance loss of sensors

BCM1F upgrade

R = 5cm, z= ±1.8 m

- two pad sensors, each pad 2.25x4.5 mm^2 → reduce count rate
- more sensors → redundancy





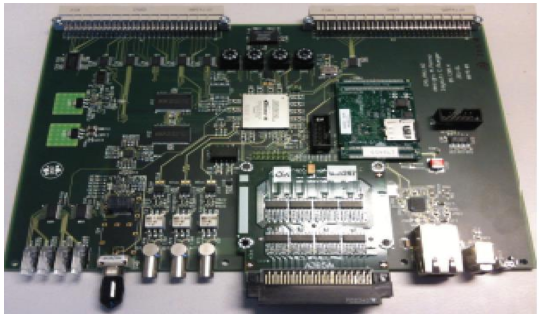
- higher voltage → compensate for radiation damage
- dedicated FE ASICs → time resolution and rate capability
- dedicated backend → no dead-time, integrated in the LHC trigger and timing

BCM1F upgrade

VME Backend:

similar principles as in LHC Run I for monitoring the perfomance :

- NEW Realtime Histogram Unit (RHU) v2 developed at DESY
- Bunch-by-bunch analysis (6.25 ns binning); for luminosity & backgrounds
- Redundant buffering
- TTC compliant, firmware tested
- Production complete, Commissioning ongoing



µTCA Backend:

New concept

Same functionality as VME, more flexibility

- ADC FMC125 1.25 Gs/s/ch
- FMC GLIB from CERN
  - Peak finding, logic, histograms
- AMC13 TTC information
- Triggerless, deadtime-free data throughput

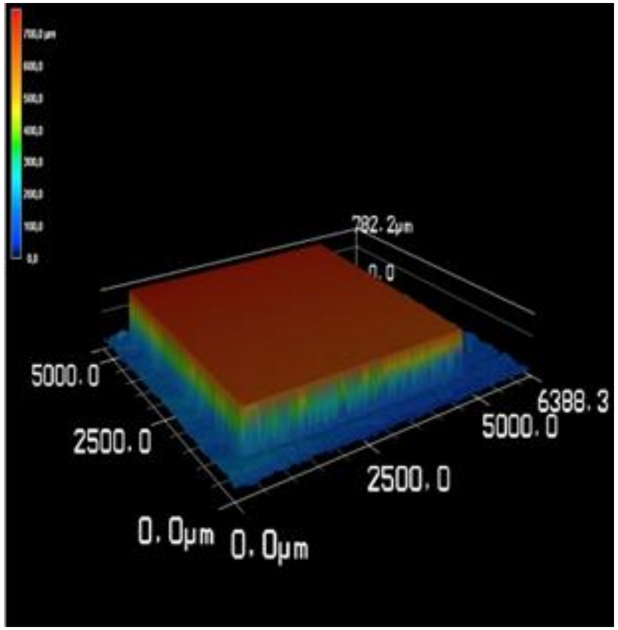
4DSP FMC125 ADC

GLIB

Diamond sensors

Optical inspection and size measurement (> 50 sensors)

- Thickness about 500 µm, variations over the surface small
- Size rougly 4.5x4.5 mm^2, edges sometimes fuzzy and spotty

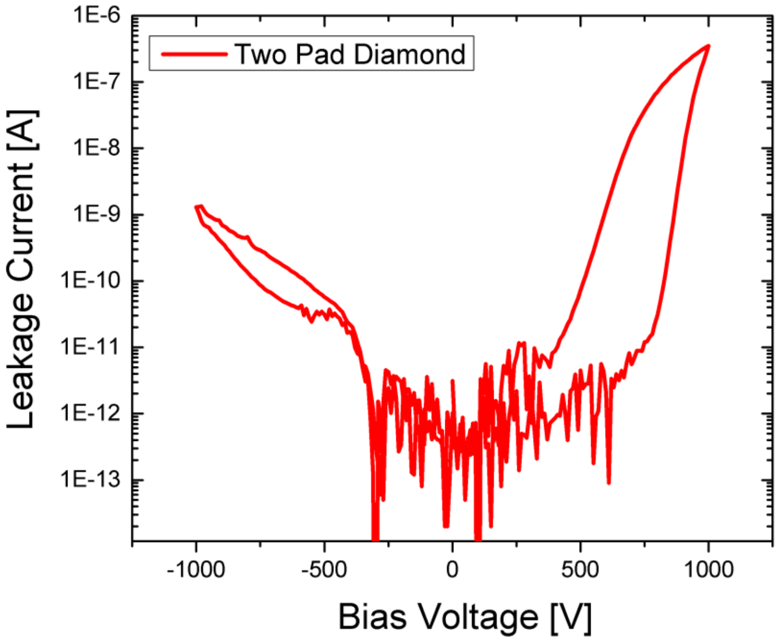


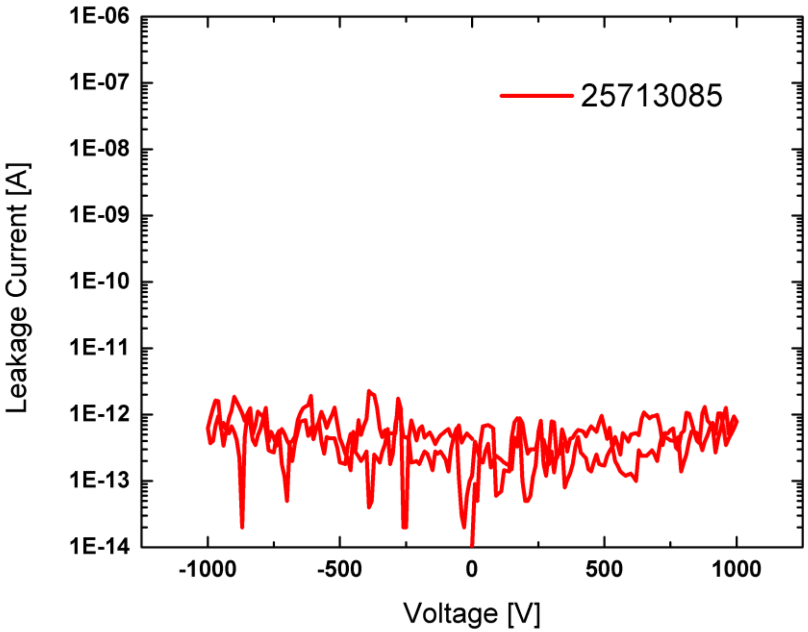
Surface treatment and metallisation

- Polished by element6
- Reactive ion etching/chemical etching
- Two pads 2.25x4.5 mm2
  W/Ti alloy, 100 nm (Princeton)
  Cr/Au, 50/150 nm (GSI)
- Gap width 25 µm

Electrical characterisation

- Leakage current as a function of the applied voltage





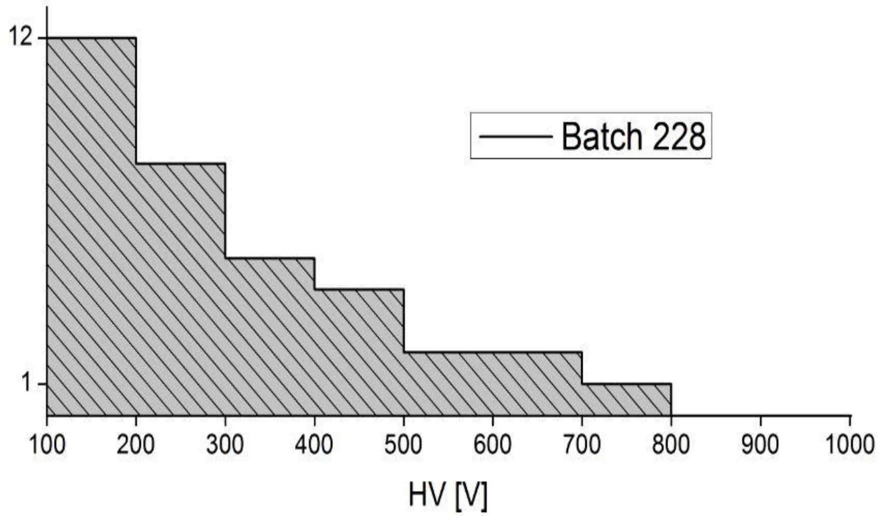
Not accepted

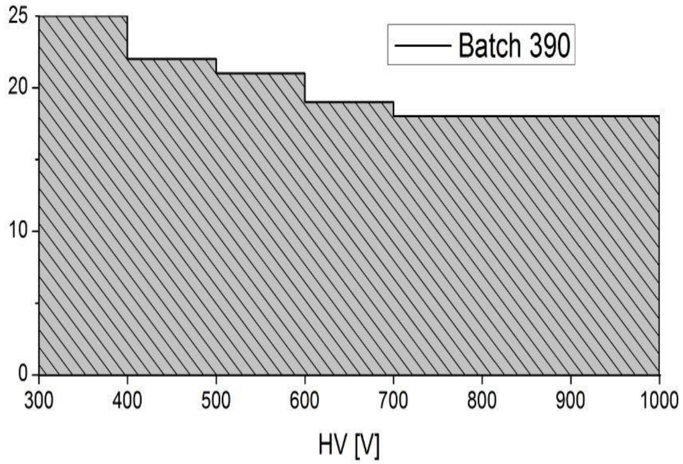
accepted

Electrical characterisation

Surviving sensors as a function of the applied voltage

Requirement: leakage current below a predefind threshold

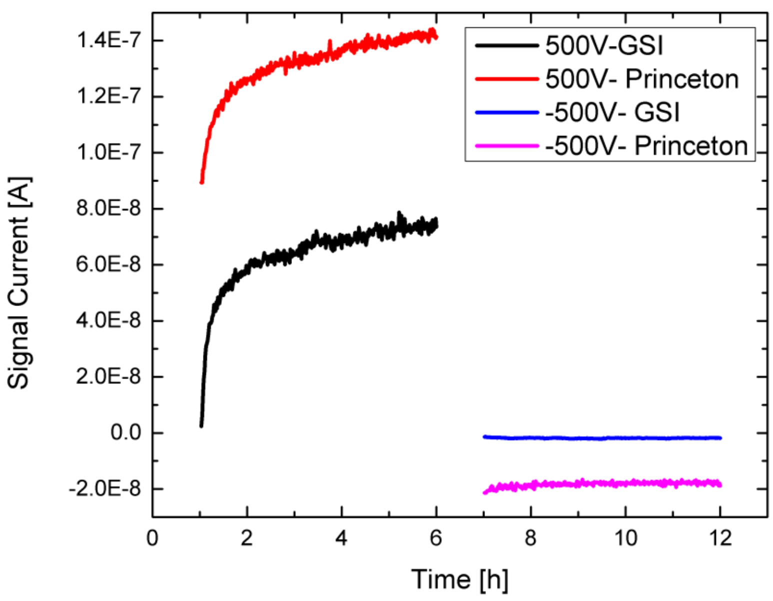




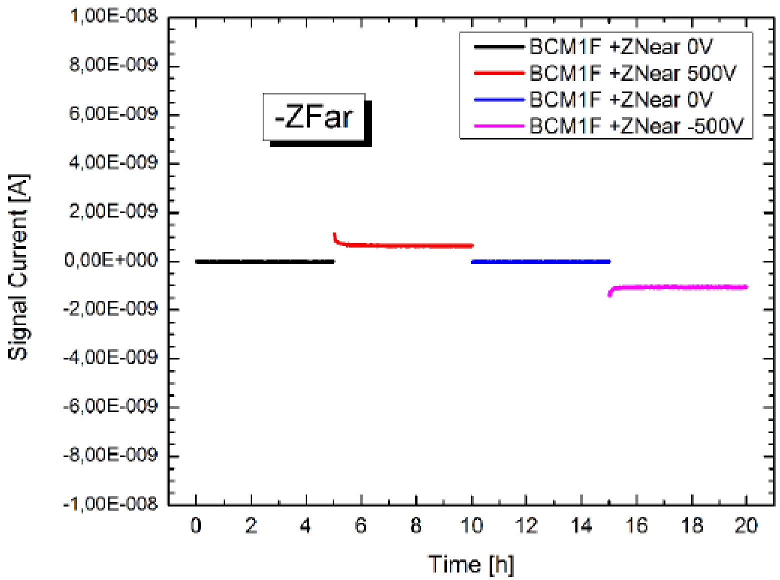
Signal as a function of time

Irradiation with a ^{90}Sr source

Measurement of the signal current as a function of time, ± 500 V



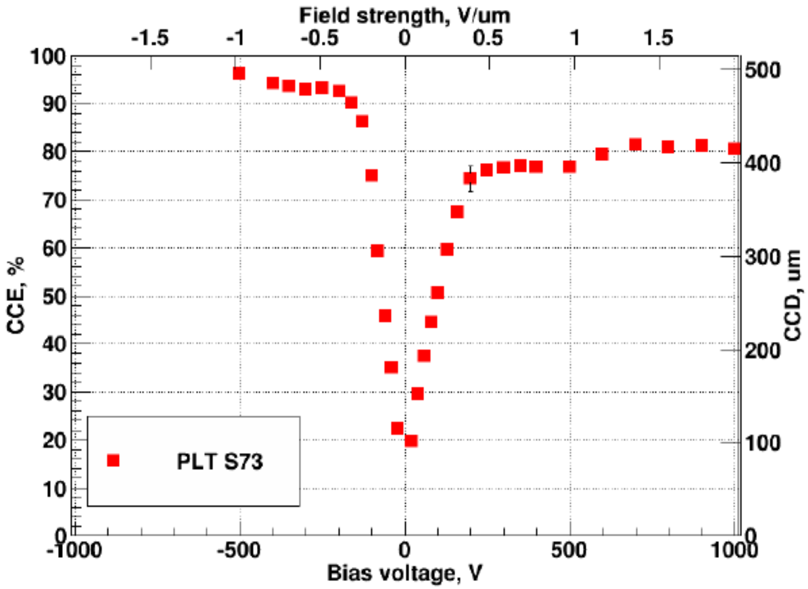
Not accepted for one polarity



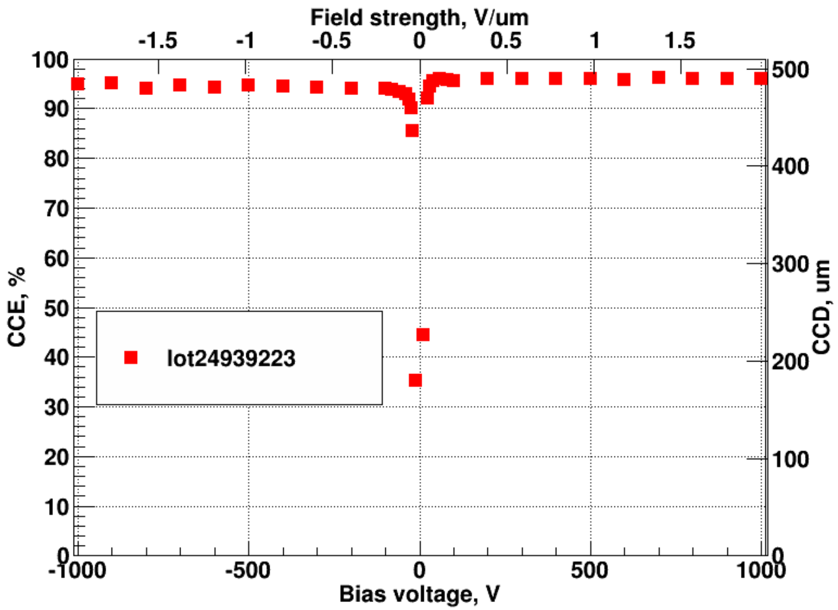
accepted

Diamond sensors

Signal as a function of HV (expressed as CCE)



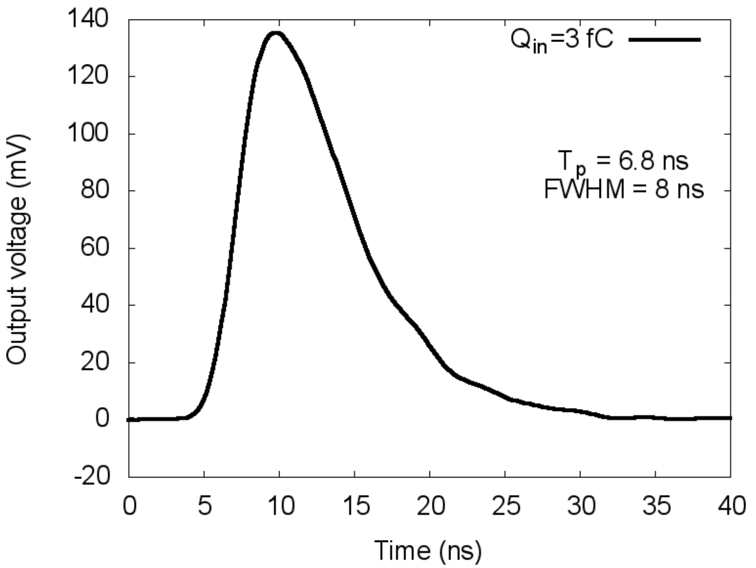
Not accepted

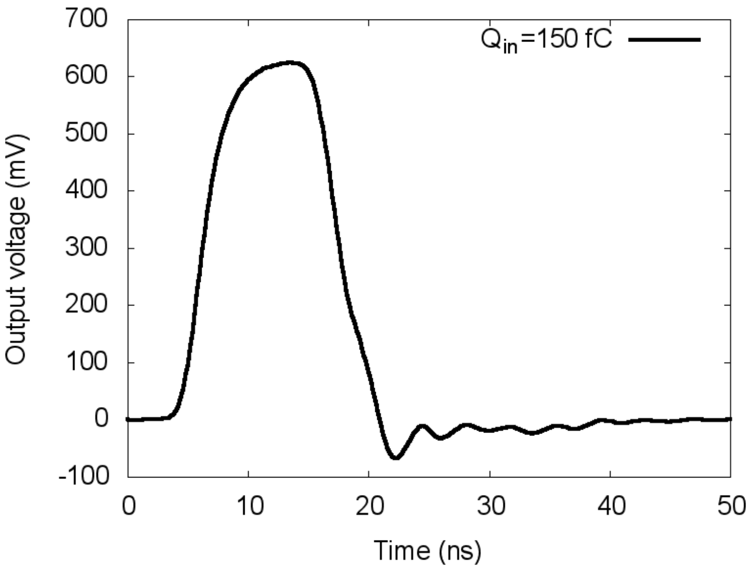


accepted

Dedicated charge sensitive FE ASIC in 130 nm CMOS

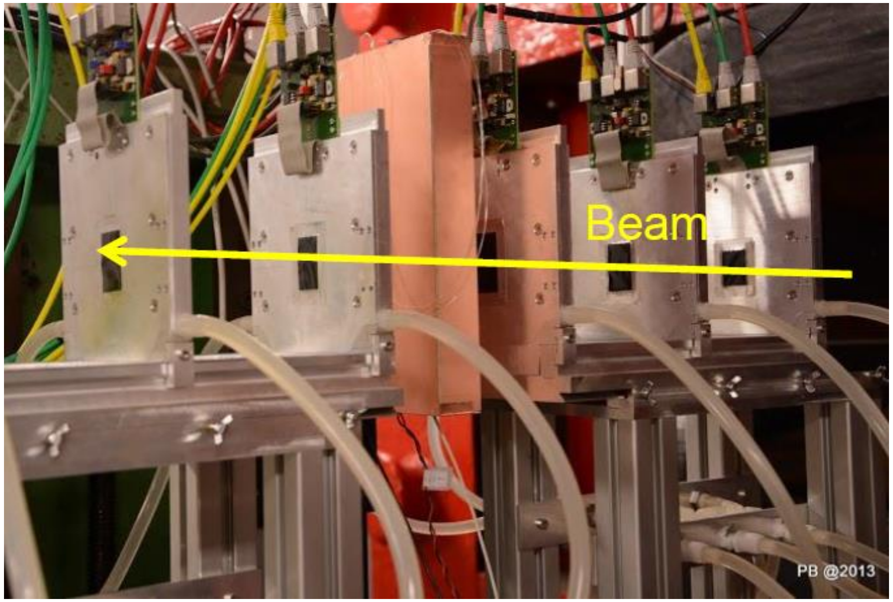
- Output signal FWHM 8 ns
- Fast recovery after large signals
- 50 mV/fC gain
- 400 e- equivalent noise (2pF sensor capacitance)

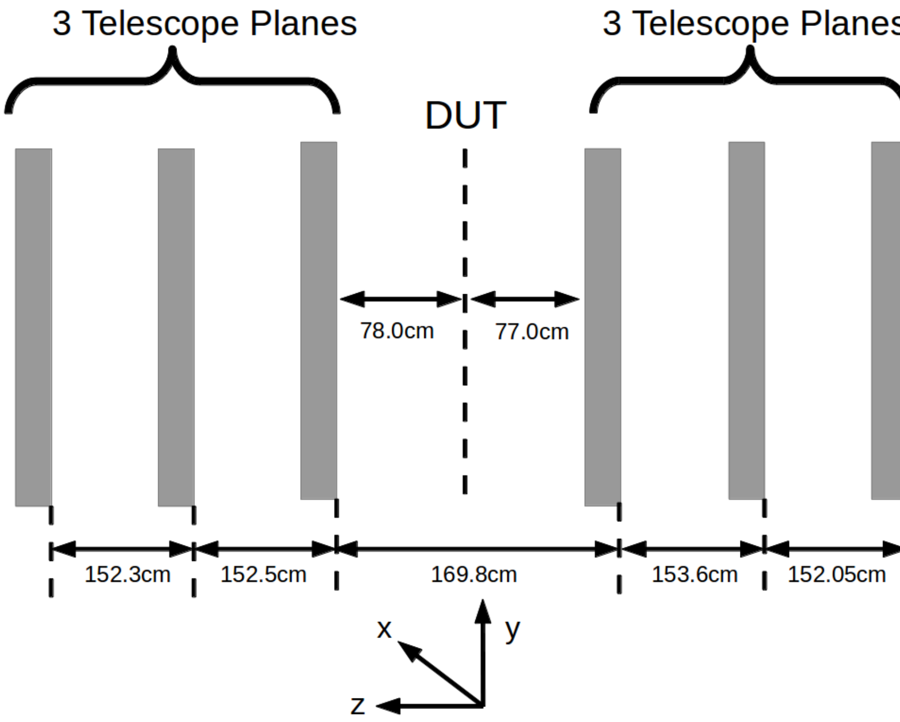




Testbeam

5 GeV electron beam at DESYII



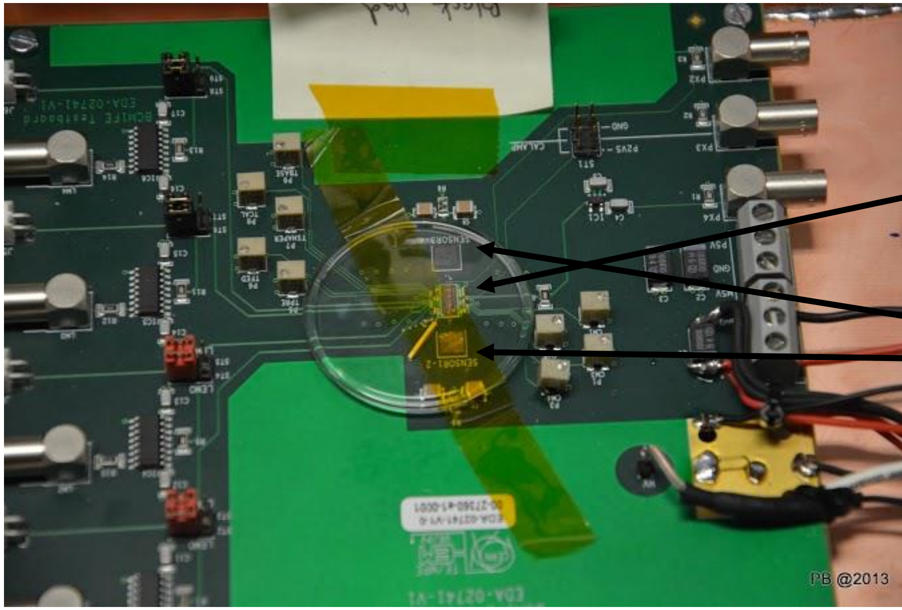


Beam Telecope, 4 planes of pixel sensors up- and downstream of the sensor box

After alignment: residual 2 μm

Testbeam

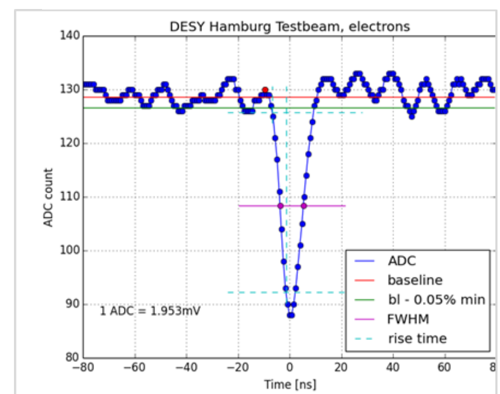
BCM1F prototype



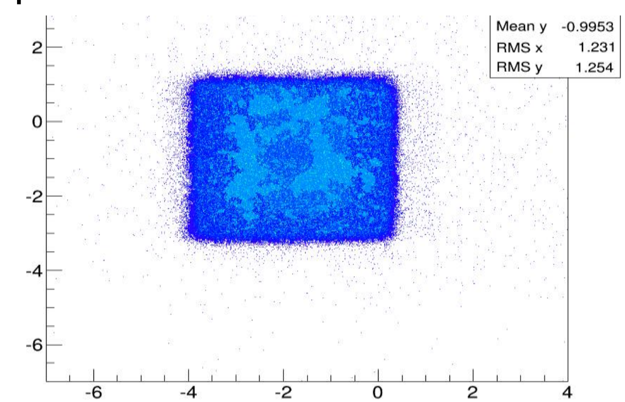
FE-ASIC

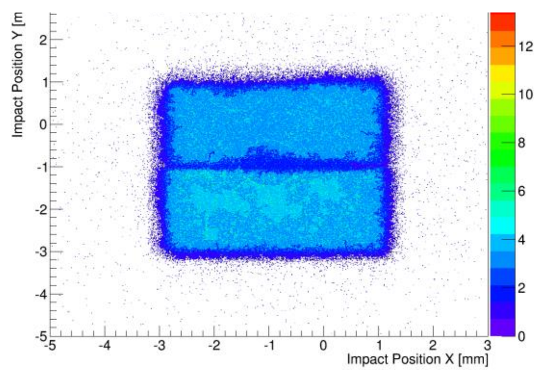
one and two pad sensor

MIP signal digitised by FMC125



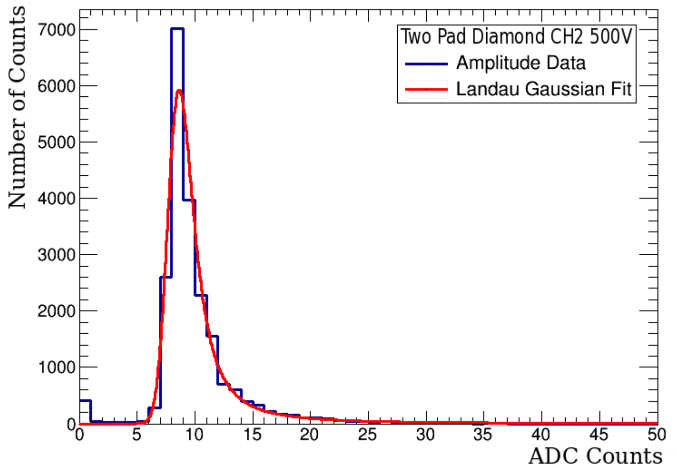
Distributions of the predicted hit positions with signals above a predefined threshold



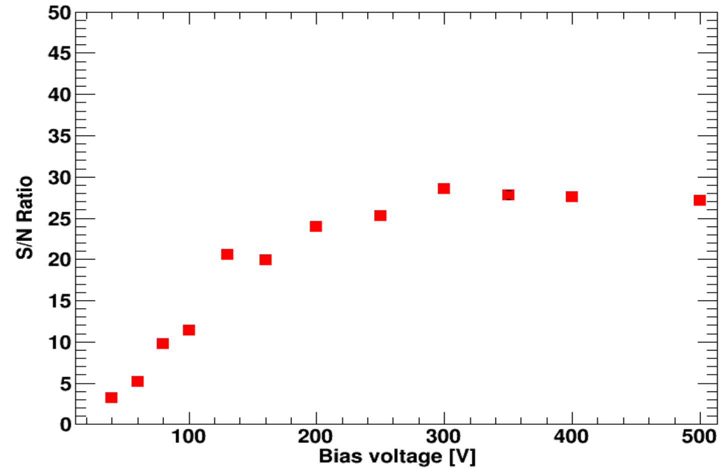


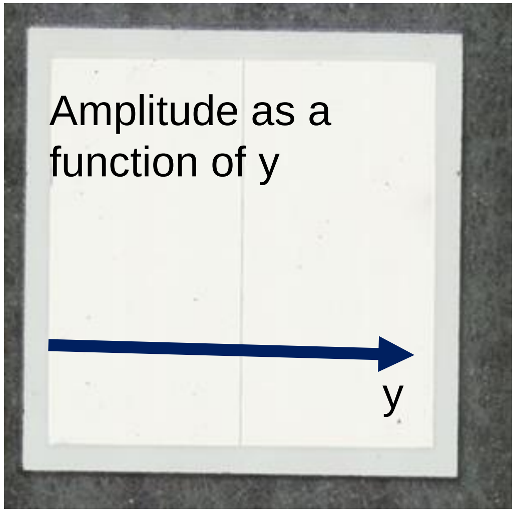
Testbeam results

Amplitude spectrum

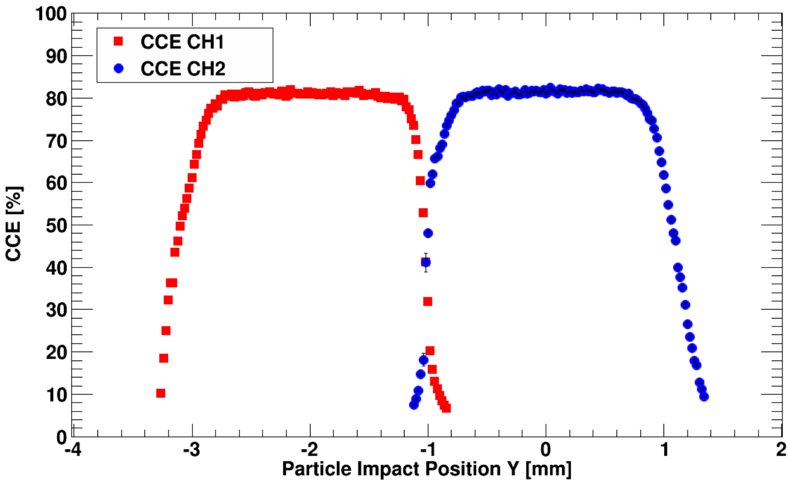


Signal-to-noise

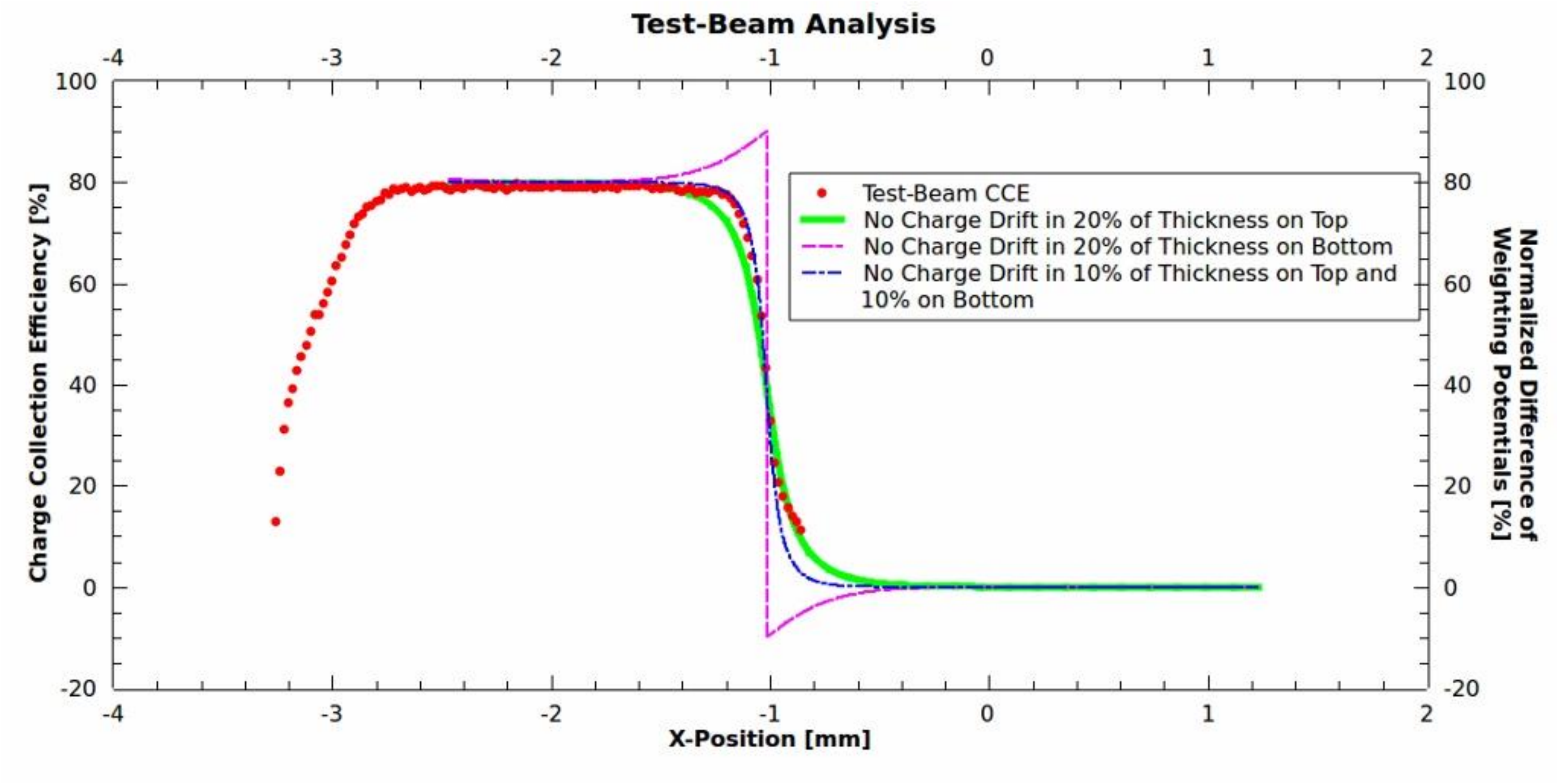




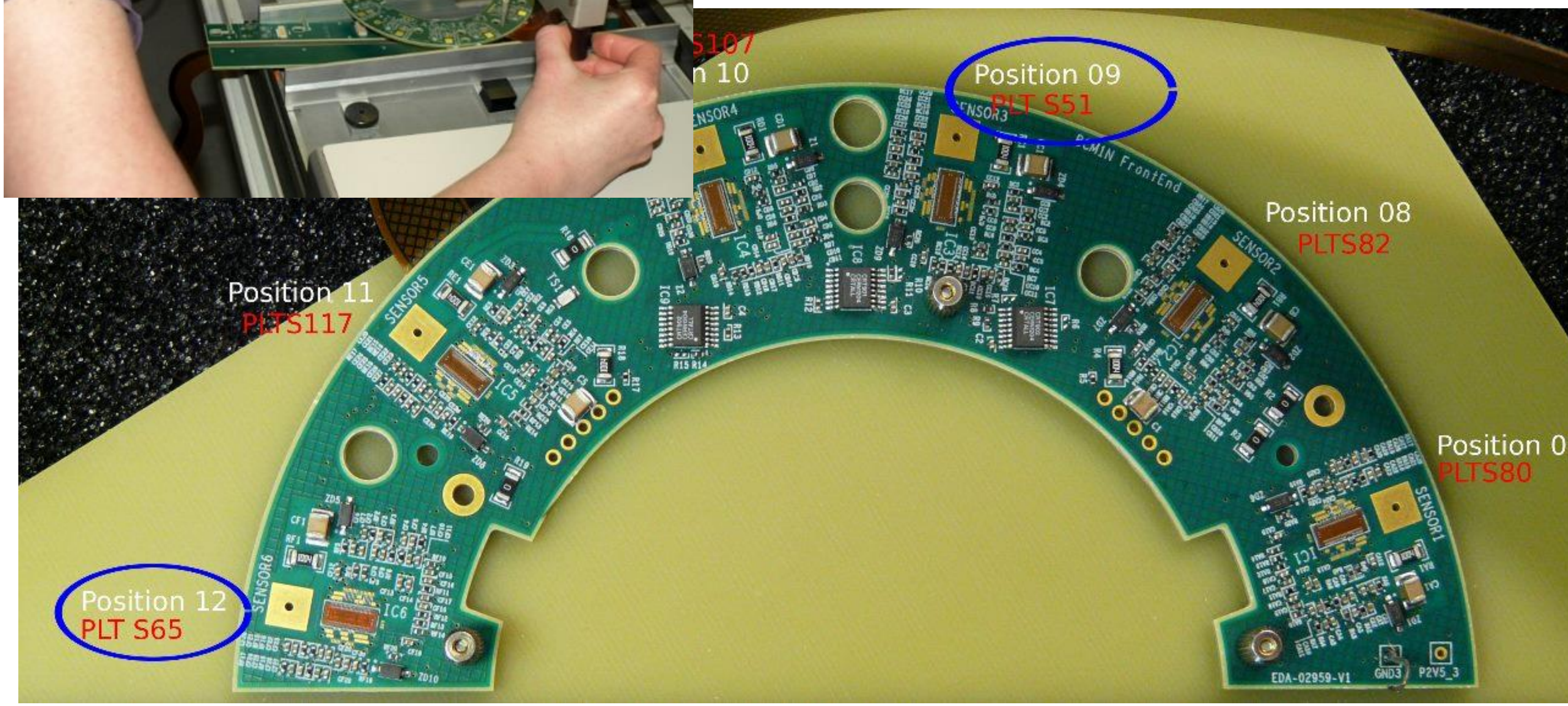
response as a function of the position



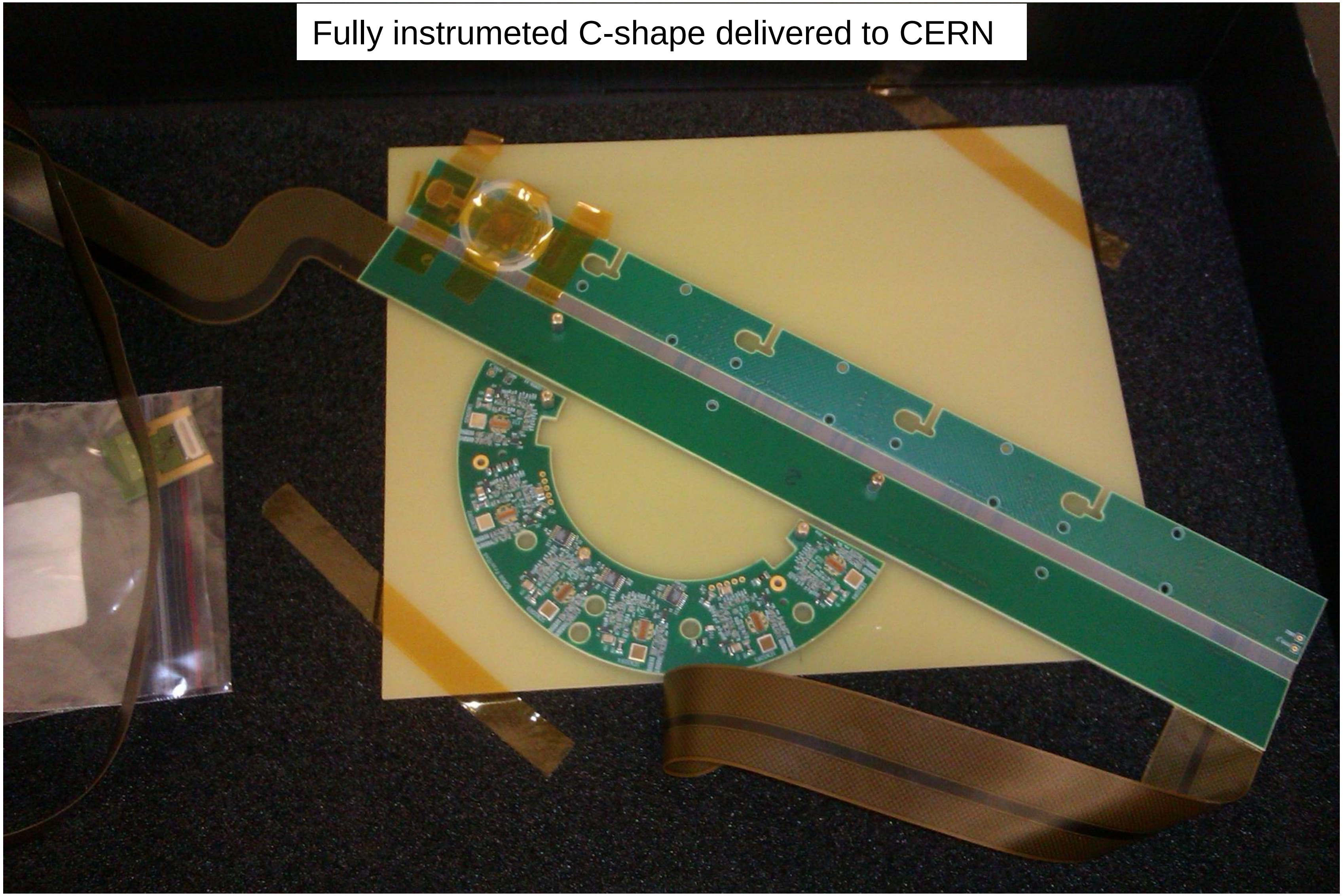
Simulation using superfish package



Integration



Integration



Higl Luminosity LHC

Expected rates

$L = 5x10^{34}$ cm^{-2}s^{-1} — 2.5×10^{7} s^{-1} for the current pad size

Possible solutions:

- smaller pads → pixel
- dedicated FE ASICs

Question: how to approach the necessary radiation hardness of the system

R&D necessary !!!!

Summary

- The upgraded BCM1F will comprise 24 sc CVD diamond sensors with two pads
- Quality criteria are defined on the basis of laboratory measurements
- Dedicated charge integrated ASIC in 130 nm CMOS technology designed, produced and tested
- Successful beam test, full characterisation of a prototype detector
- All detectors (C-shapes) produced, currently commisioning and integration
- HL-LHC will be a challenge due to high count rates and radiation field, R&D needed

Acknowledgements

Maria Hempel – who did most of the sensor characteristics

Dominik Przyborowski – ASIC developent

The GSI group for pad metallisation

The BRIL group at CERN

The electronics workshop in DESY (Zeuthen)