Preliminary results on irradiated micro-strip detectors

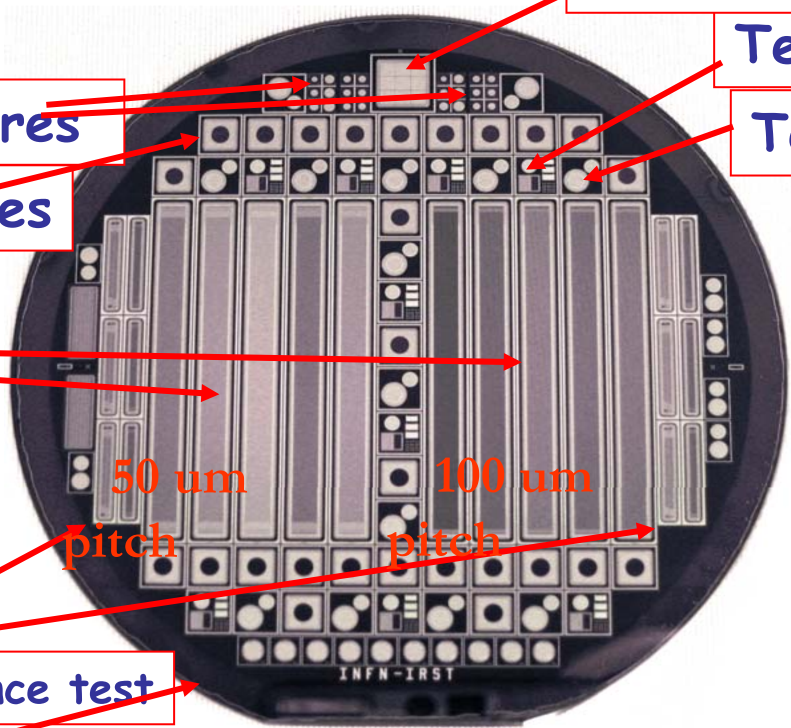
Comparison of micro-strips detectors processed with different materials

Talk Outline

- *Sensors and set-up*
- *Pre irradiation measurement*
- *Radiation hardness study up to 3,5 10^{15} 1 MeV n eq./cm^2*
- *Conclusion and plans*

Radiation hardness study made by the SMART collaboration
CCE measurement performed by the Pisa Team:
J.Bernardini, L.Borrello, F. Fiori, A. Messineo

SMART : Wafer layout, 4"



- ✓RD50 common wafers procurement
- ✓Wafer Layout designed by SMART collaboration
- ✓Masks and process by ITC-IRST (Trento)

RUN I p-on-n

22 wafers Fz, MCz, Cz, Epi

March 04

MCz Samples
<100> ρ>500 Ω*cm thickn.=300μm

Fz Samples
<111> ρ>6 kΩ*cm thickn.=300μm

Epitaxial Samples
<100> ρ>500 Ω*cm thickn.=150μm

RUN II n-on-p

24 wafers Fz, MCz

September 04

MCz Samples
<100> ρ>1.8 kΩ*cm thickn.=300μm

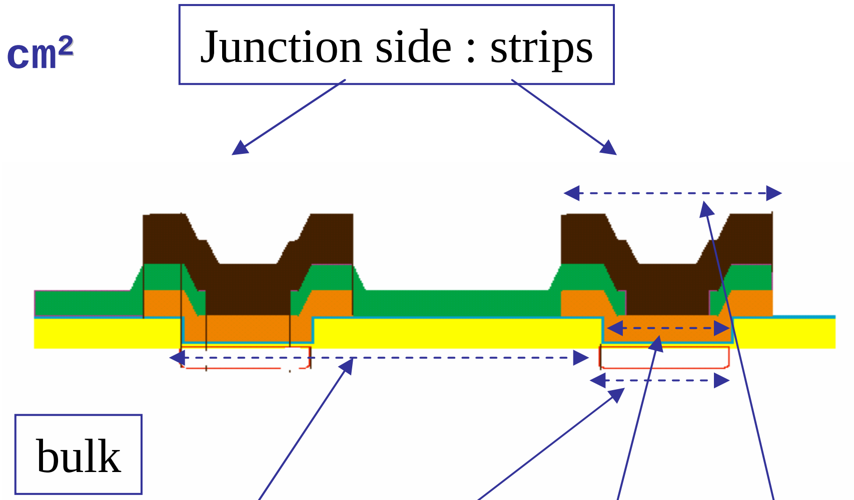
Fz Samples
<100> ρ>5 kΩ*cm thickn.=200 μm

✓Low dose p-spray (3.0E12 cm^{-2})

✓ High dose p-spray (5.0E12 cm^{-2})

Sensors design features

Mini-sensor active area ~0.32 x 4.5 cm²



a) *Pitches 50, 100 μm to match active thickness (EPI) and for a low occupancy level*

b) *Strips length ~45 mm to exploit tracking detector performances (noise)*

c) *Implants geometry to investigate leakage current level, breakdown performances and strip capacitance effects*

μ-strip #	pitch (μm)	p+ width (μm)	Poly width (μm)	Metal width (μm)
S1	50	15	10	23
S2	50	20	15	28
S3	50	25	20	33
S4	50	15	10	19
S5	50	15	10	27
S6	100	15	10	23
S7	100	25	20	33
S8	100	35	30	43
S9	100	25	20	37
S10	100	25	20	41

Main goal : to study Material (Fz (n,p) MCz (n,p) Epi(n) and device processing

Irradiation campaigns

Source: 24 Gev/c protons at CERN SPS

3 fluences: $6.0x10^{13}$ $3.0x10^{14}$ $3.4x10^{15}$ n_{eq}/cm^2

27 mini-sensors, 90 diodes

75 % n-type, 25 % p-type (MCz, SFZ)

Thanks to M. Glaser, M. Moll,...

Irradiation set-up at CERN SPS

Source: 26 MeV protons at the

Cyclotron of the Forschungszentrum Karlsruhe

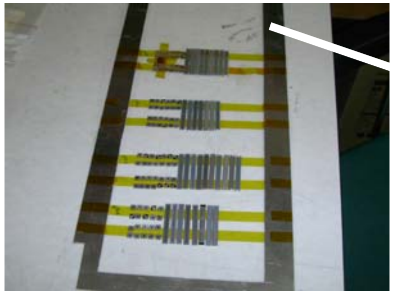
11 fluences: $1.4x10^{13}$ - $2.0x10^{15}$ n_{eq}/cm^2

62 mini-sensors, 100 diodes

38 % n-type, 62 % p-type (MCz, SFZ)

Thanks to A. Furgeri

Irradiation set-up at FZK(Karlsruhe)



Source : fast neutron from Lijubliana Nuclear reactor

12 fluences: $5.5x10^{13}$ – $8.5x10^{15}$ n_{eq}/cm^2

27 mini-sensors, 11 test structure (capts),100 diodes

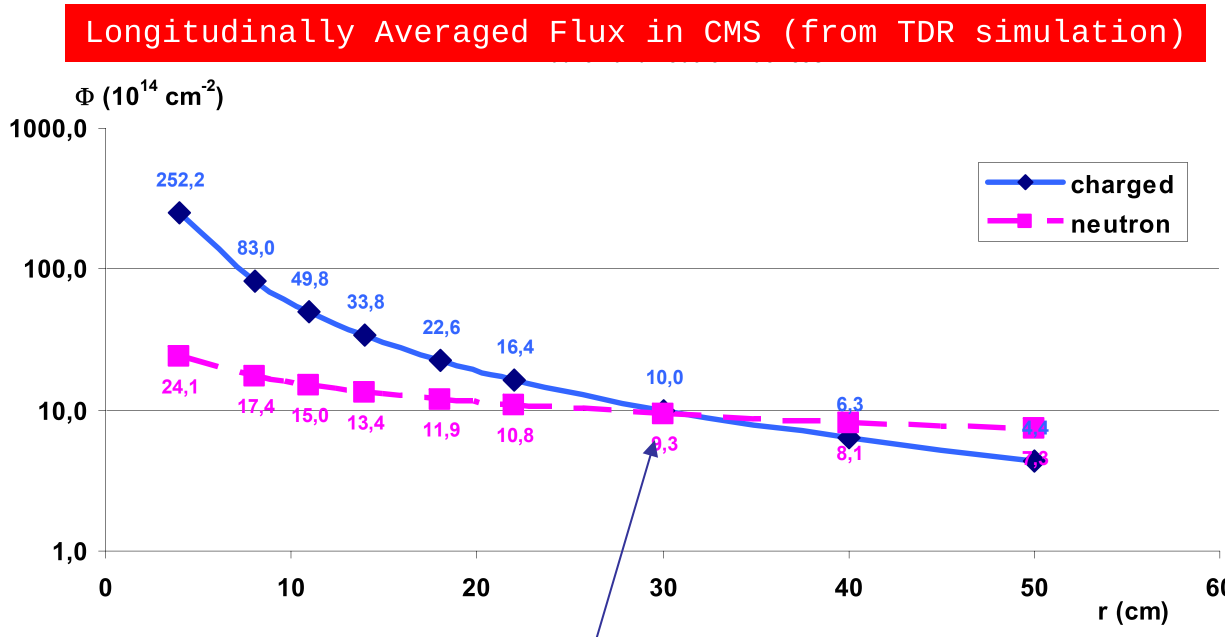
60 % n-type, 40 % p-type, Fz, MCz, Epi

Thanks to V.Cindro and G.Kramberger

Irradiation set-up at JSI(Ljubljana)

Fluence and Investigated Sample

Fluence axpected for 5 years SLHC (X 2 s. f.)



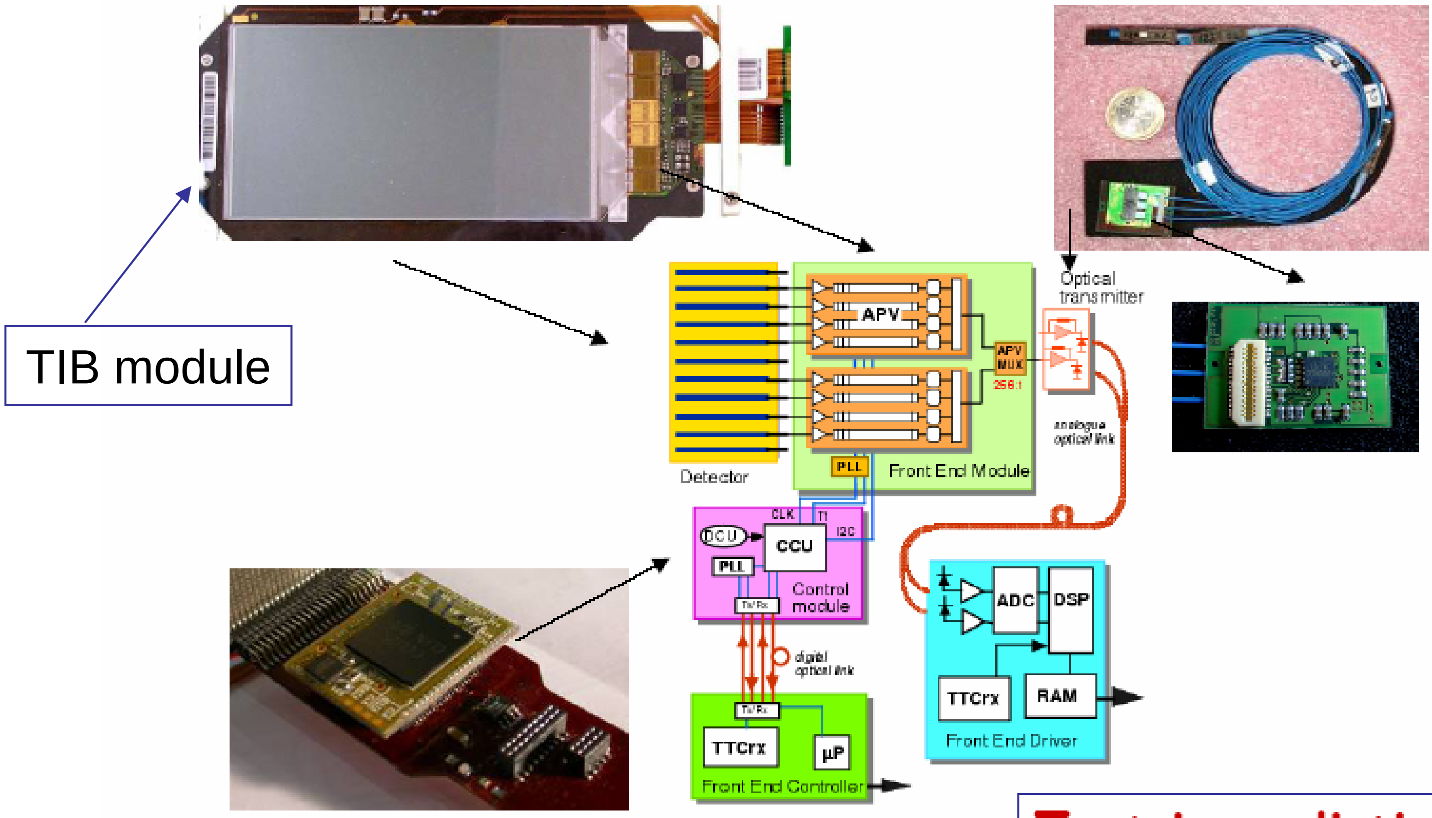
For |z|<50 cm (small Pixel)
***x-point* moved at r ~55 cm**

- **Preliminary study of the charged component damage (π,p)**
- **Minisensors irradiated – Karlsruhe (most of the sample)**

  -Liubliana (high fluence)

- **Study of performance of micro strip assembled in detectors with LHC-like read-out and DAQ (CMS):**
  - Signal
  - S/N
  - CCE

CMS DAQ system

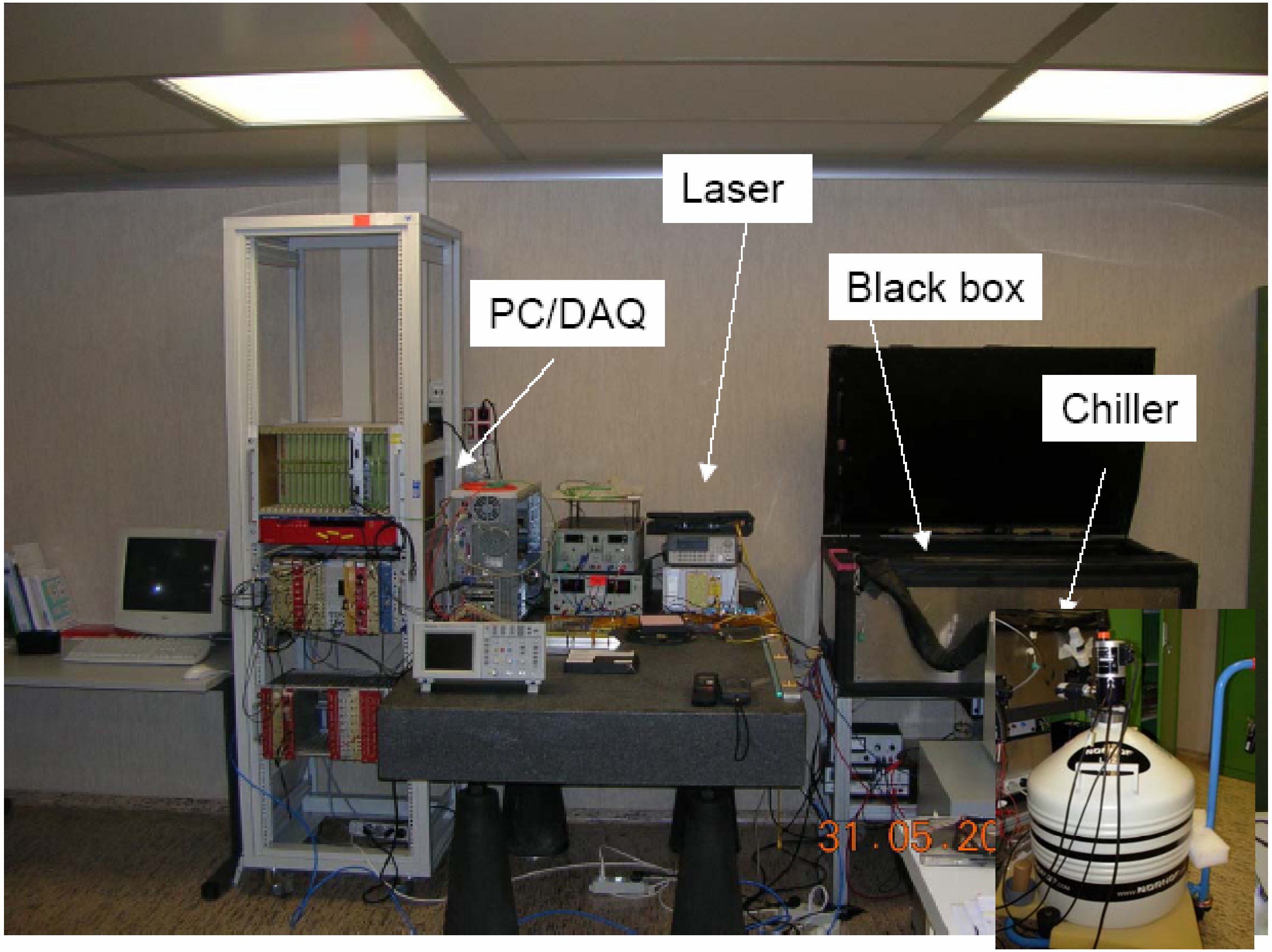


Test in realistic LHC-like conditions

Helsinki 2-4 June 2005 — 6th RD 50 Workshop

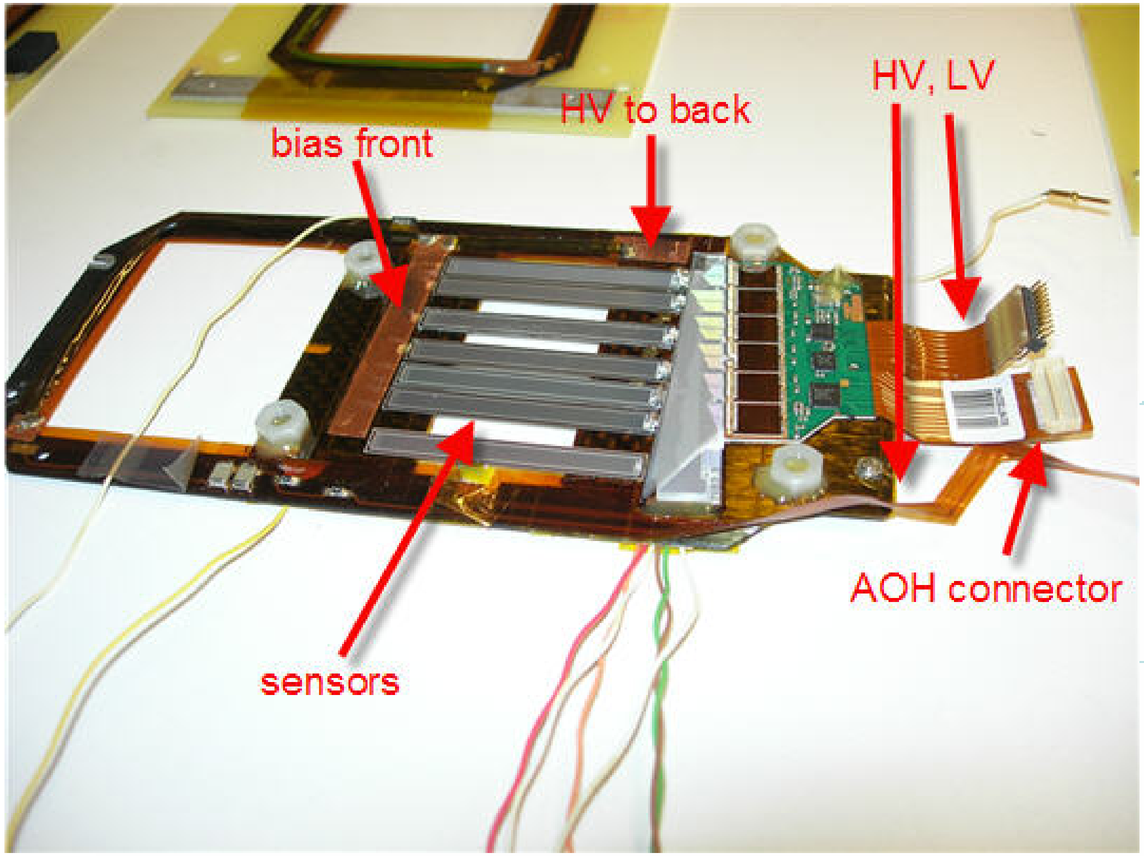
Few non standard components in the set-up: FED + FEC PCI (instead of VME) and Opto/Electrical Converter.
All components designed and used for the CMS tracker integration and sub-detector commissioning
Software for control/diagnosis tools and analysis from CMS

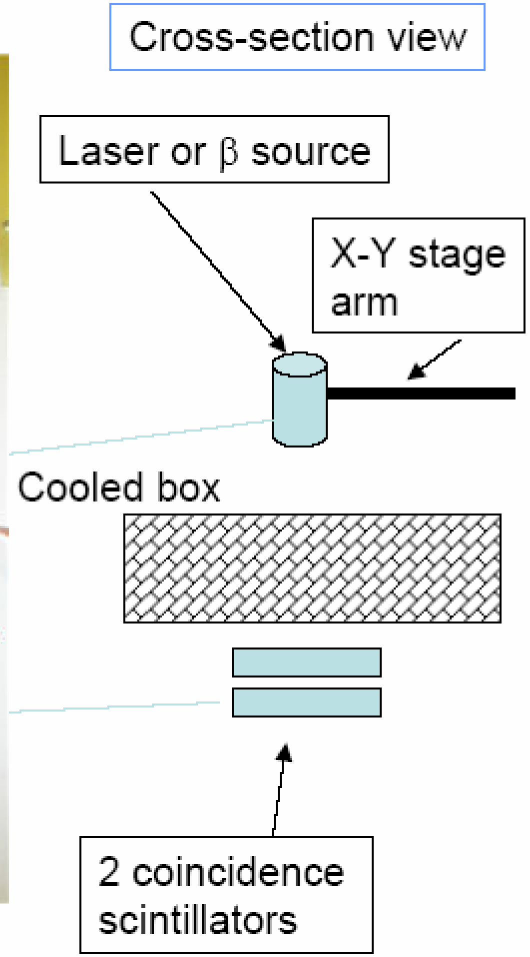
Test stand with Laser and β source



Detectors and F.E are cooled with N_2 cold gas extracted from liquid with a pump
Temperature range [20 ^{o}C to -50 ^{o}C].
Standard DAQ operation for irradiated detectors at T=-30 ^{o}C

Detector set-up





Helsinki 2-4 June 2005 6th RD 50 Workshop

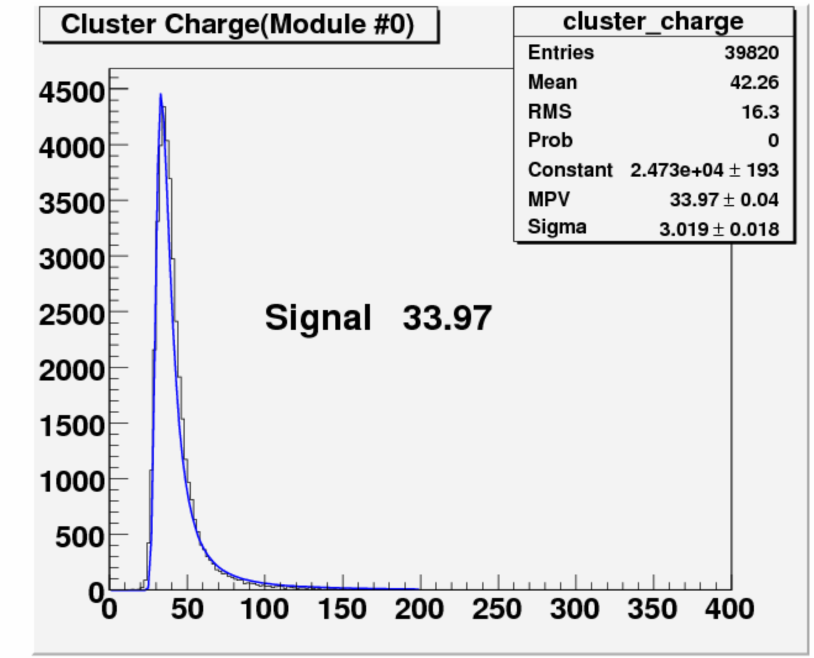
Laser source used to set-up the system (timing,..)
Results showed in the following are achieved with Beta source

Module operation

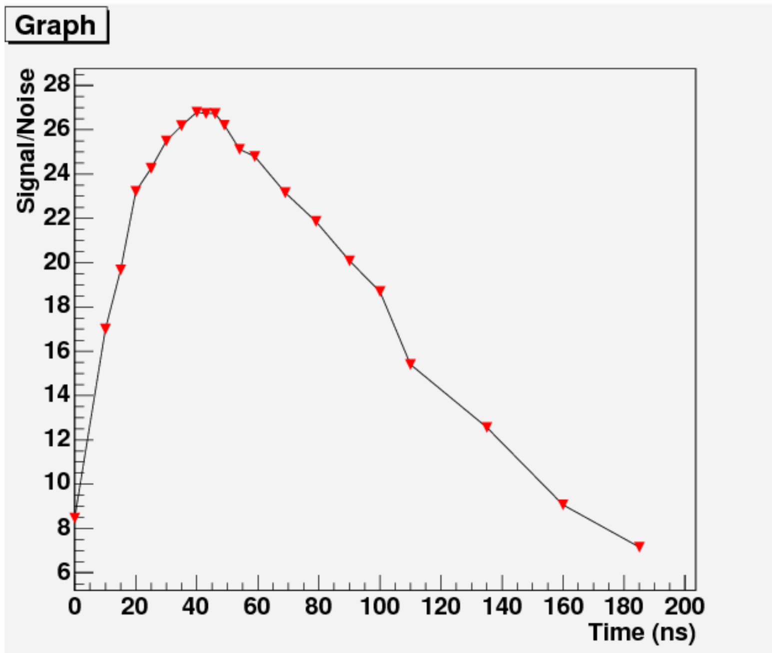
- 6 modules assembled: 4 to 7 micro-strips/module
  - n-type and p-type
  - Fz , MCz and Epitaxial
- CMS F.E. (APV25) has feature (Inverter) to read signal from both sources (*e-*, *h*)
  - Analog operation with no loss in integration dynamical range
  - Peak mode operation
- Performance Bench mark with CMS TIB detector (before/after irradiation)
- Same clustering and analysis for irradiated and not irradiated devices
  - 3 threshold clustering: 4 seed, 3 neigh. and 5 total
- Operation
  - Bias up to 600 V, compatibility with present CMS p.s.
  - Measurement performed up to the highest bias allowed

Reference detector (CMS-TIB): S & S/N

- All studies shown are in Peak Mode
  - smaller noise compared to De-convolution
  - signal sampled each 25 ns (40 MHz speed)



Synchronization with trigger/DAQ pipeline



TIB Module :
Pitch 80 um length 9,4 cm
S ~ 34 N ~ 1.26
S/N ~ 27

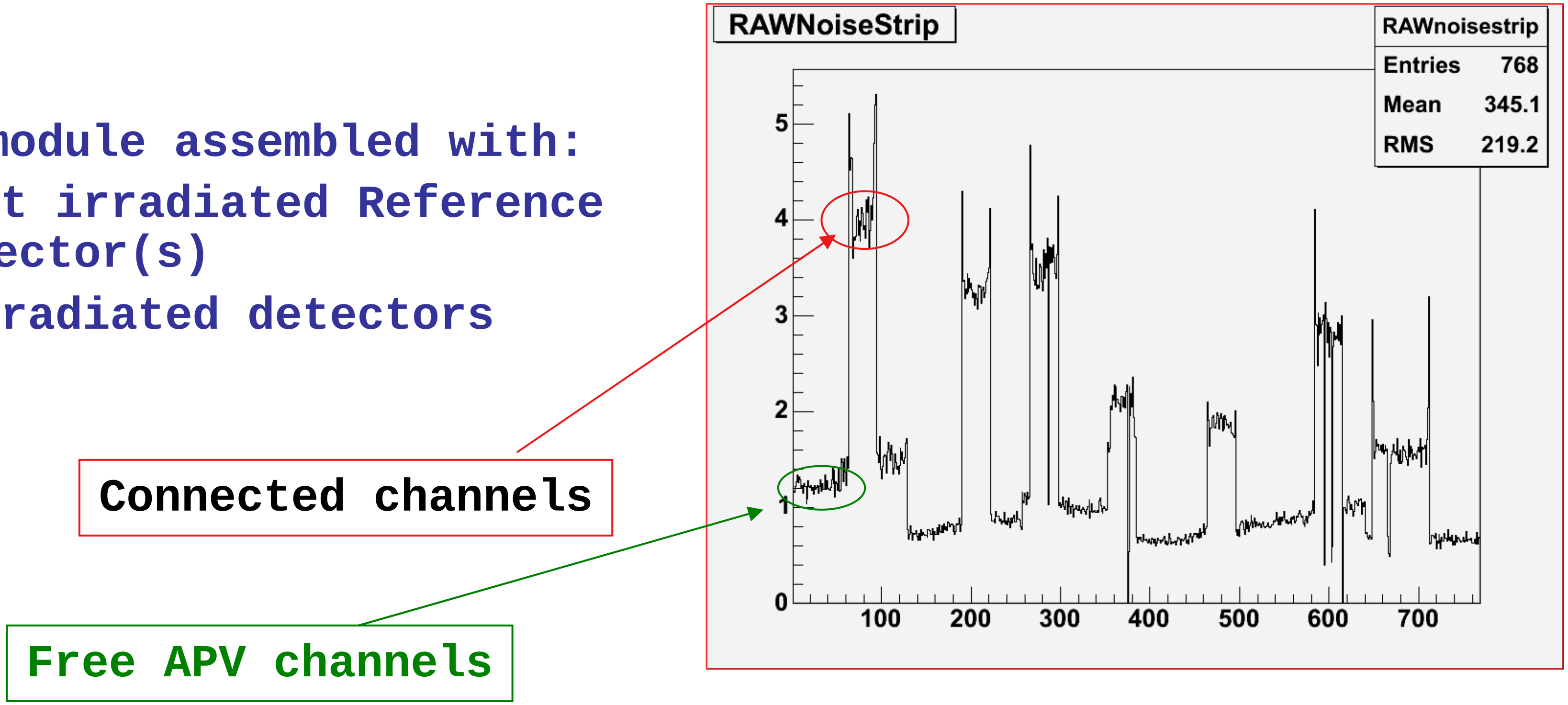
Set-up has been validated :

1)comparing noise performance with theory

2)evaluating electron eq./ADC calibration

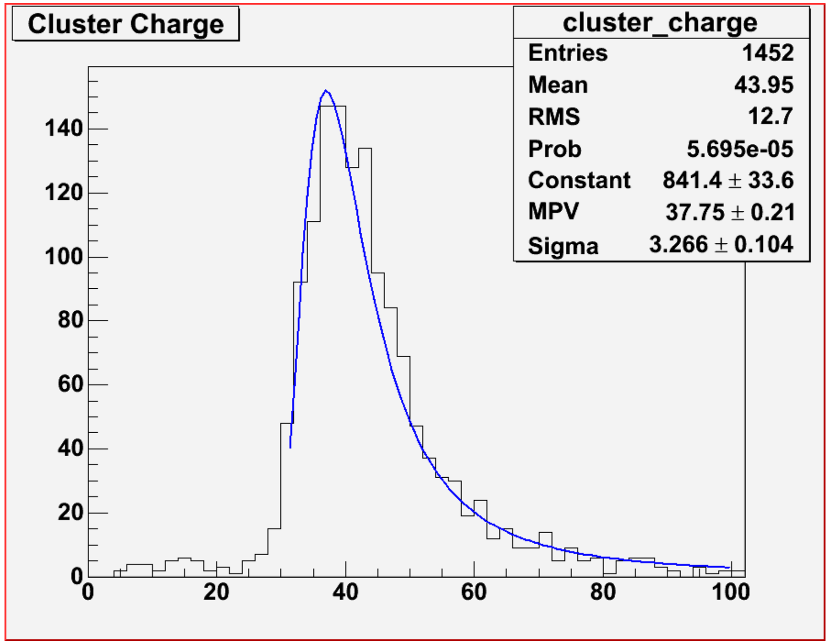
Fz(n,300 um) Reference micro-strips:

- Each module assembled with:
  - Not irradiated Reference detector(s)
  - Irradiated detectors

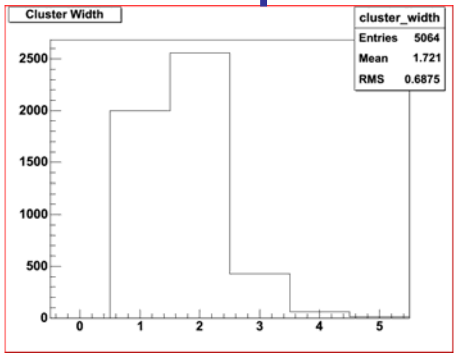


Raw Noise figure with 0 V bias applied
Module with 6 APV used
Micro-strips sensors: 32 or 64 strips

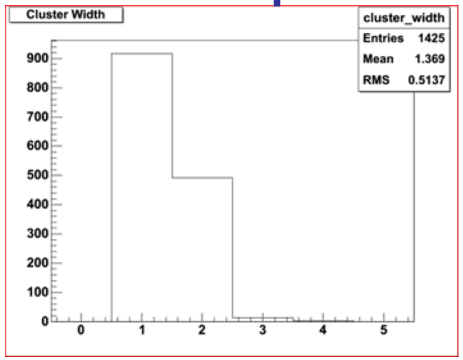
Fz(n,300 um) Reference micro-strips: S & S/N



50 um pitch



100 um pitch



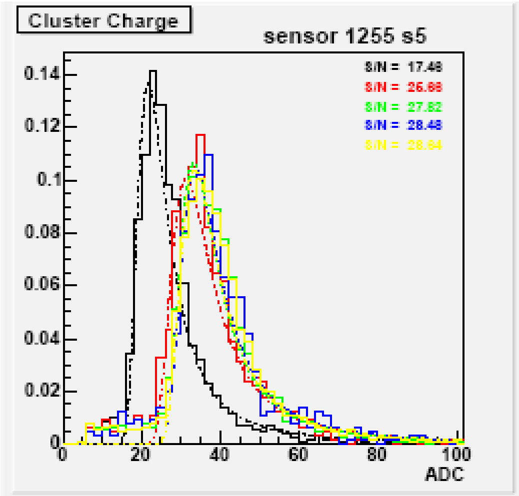
Strips cluster shape as expected

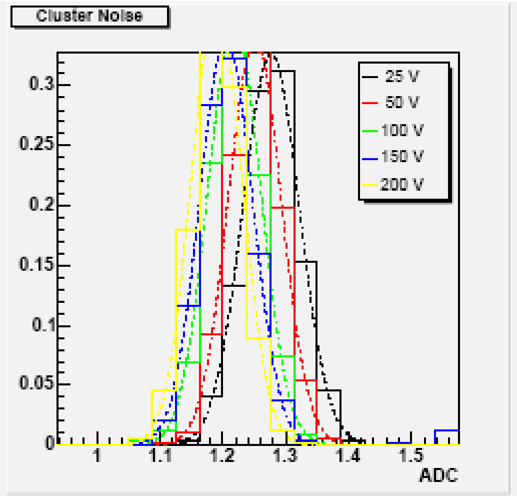
Measurement performed at 25 deg C
Signal extracted with (Landau ⊗ gauss) fit

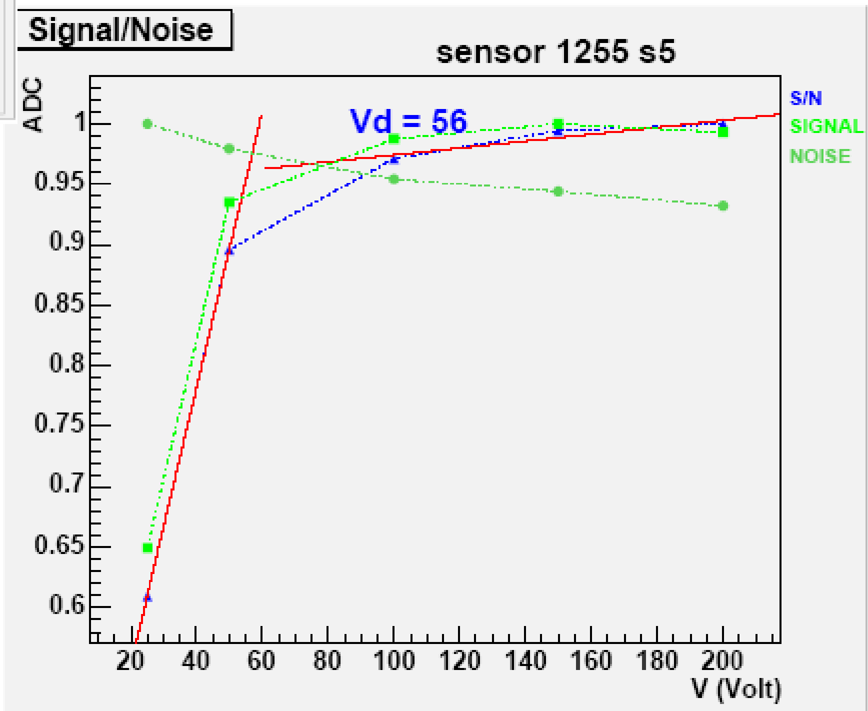
Device	Type	w/p	p(um)	Vbias (V)	S	S/N
1255-s4	Fz-n (300 um)	0,3	50	250	32,2	34,1
1255-s5	Fz-n (300 um)	0,3	50	200	35,8	33,5
1255-s6	Fz-n (300 um)	0,25	100	200	37,6	36
1255-s7	Fz-n (300 um)	0,15	100	200	34,3	34,4

Performance comparable with CMS-TIB detector
After correction for:
- *<111> to <100>*
- *Strip length*
- *Wafer thickness*

Fz(n,300 um) Reference micro-strips: Voltage Bias scan



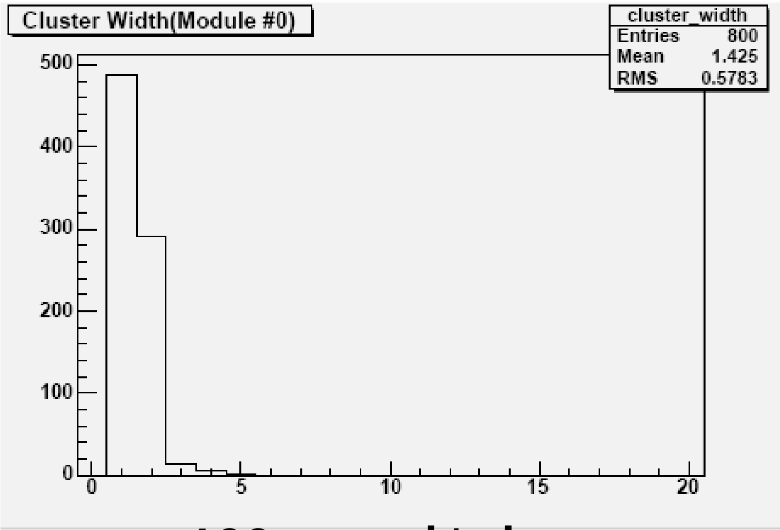




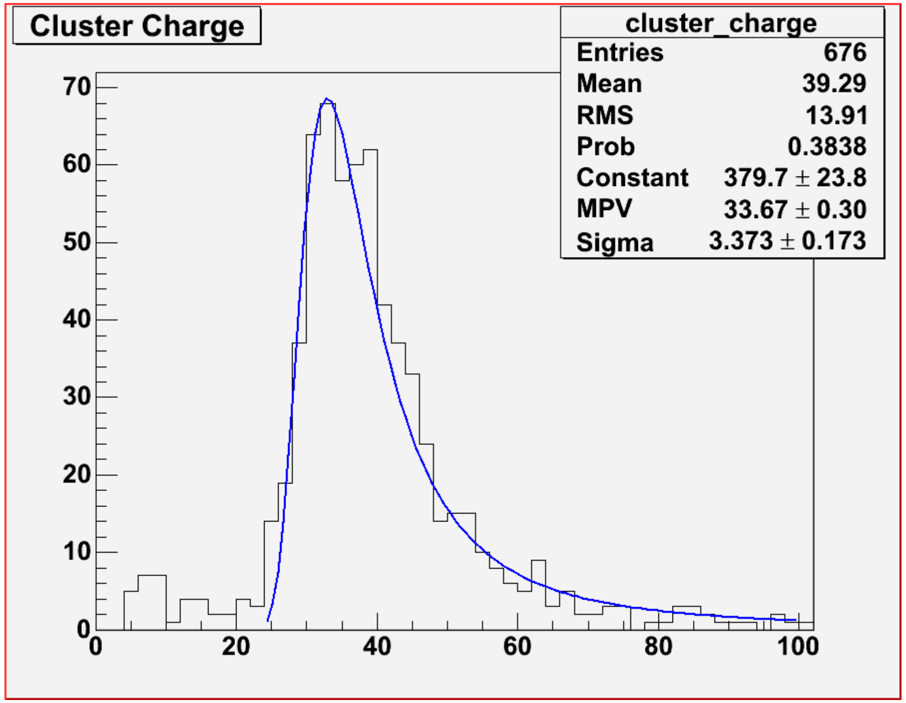
Signal and noise performance improve with bias voltage.

To be compared with bulk diodes depletion voltage measured at wafer level : V_{depl}= 23-33 V

MCz(n,300 um) Reference micro-strips: S & S/N



100 um pitch

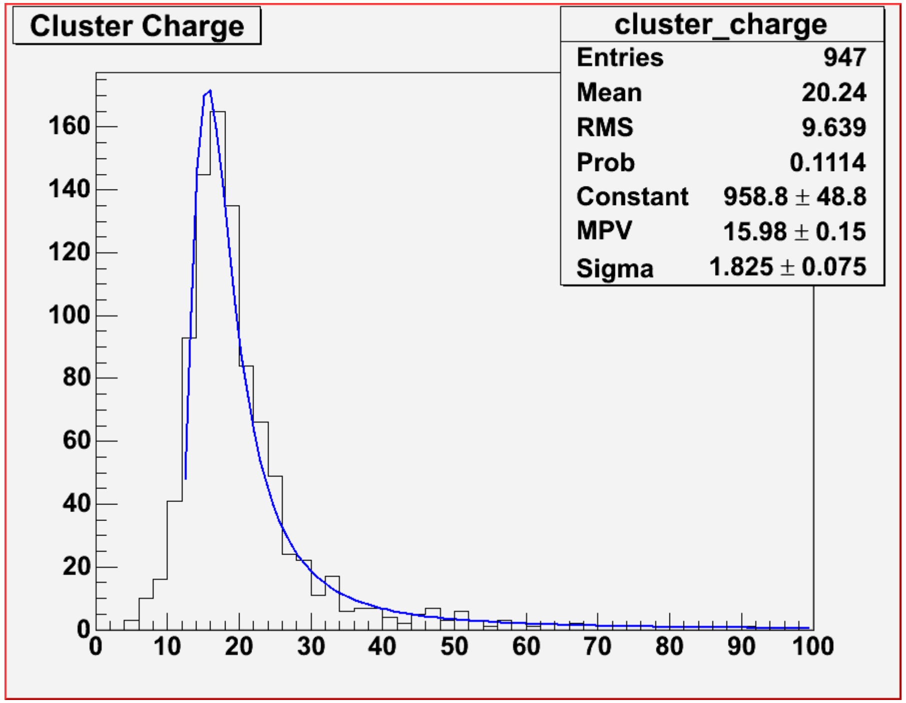


Device	Type	w/p	p(um)	Vbias (V)	S	S/N
130-s5	MCz-n (300um)	0,25	100	600	32,76	36
160-s7	MCz-n (300um)	0,3	50	600	33,41	38,7

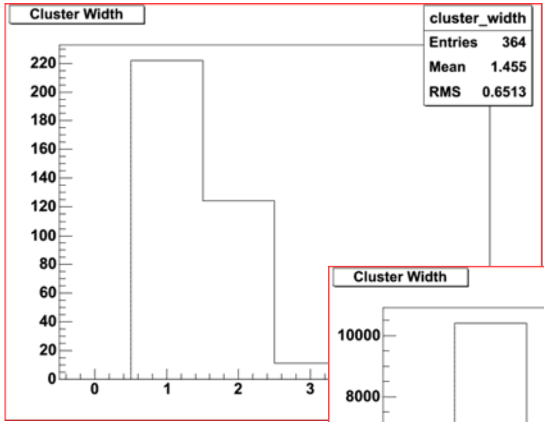
Bulk depletion from diodes CV:
(130) 399-497V (160) 370-414 V

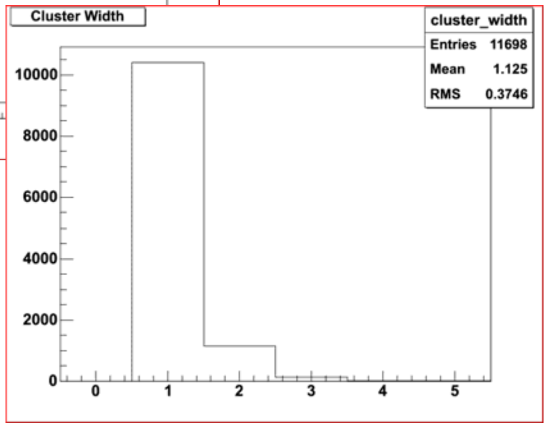
Performance of MCz-n comparable to Fz-n

Epi(n,150 um) Reference micro-strips: S & S/N



50 um pitch





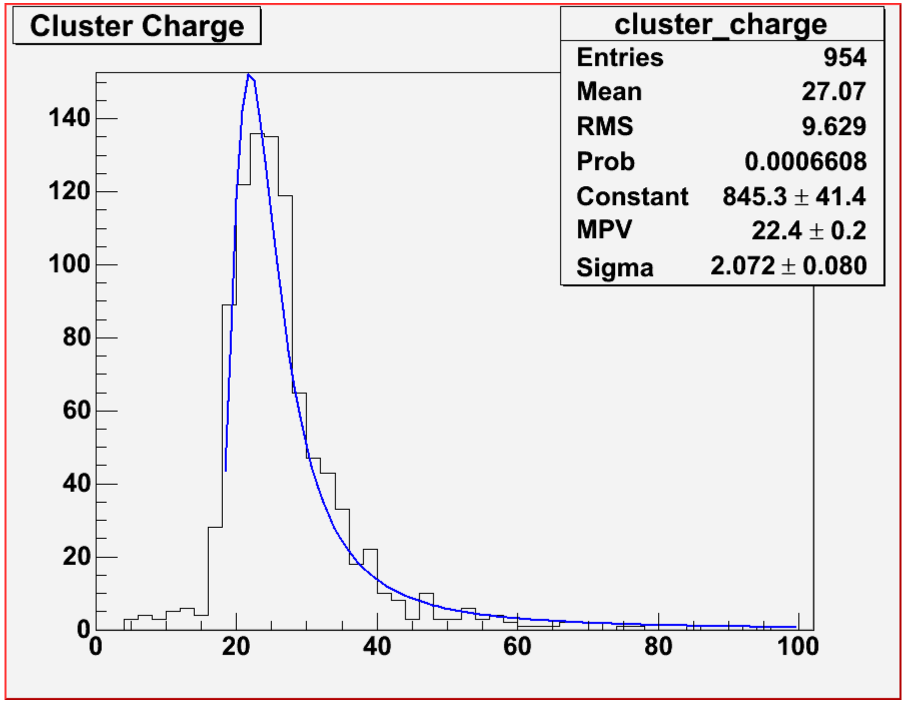
100 um pitch

Device	Type	w/p	p(um)	Vbias (V)	S	S/N
13-s3	Epi-n (150 um)	0,5	50	200	15,5	15,8

Bulk depletion voltage from diodes CV ~150V

Signal scales with thickness
Performance similar to Fz-n
Noise a bit higher: maybe strip Capacitive load

Fz(p,200 um) Reference micro-strips: S & S/N

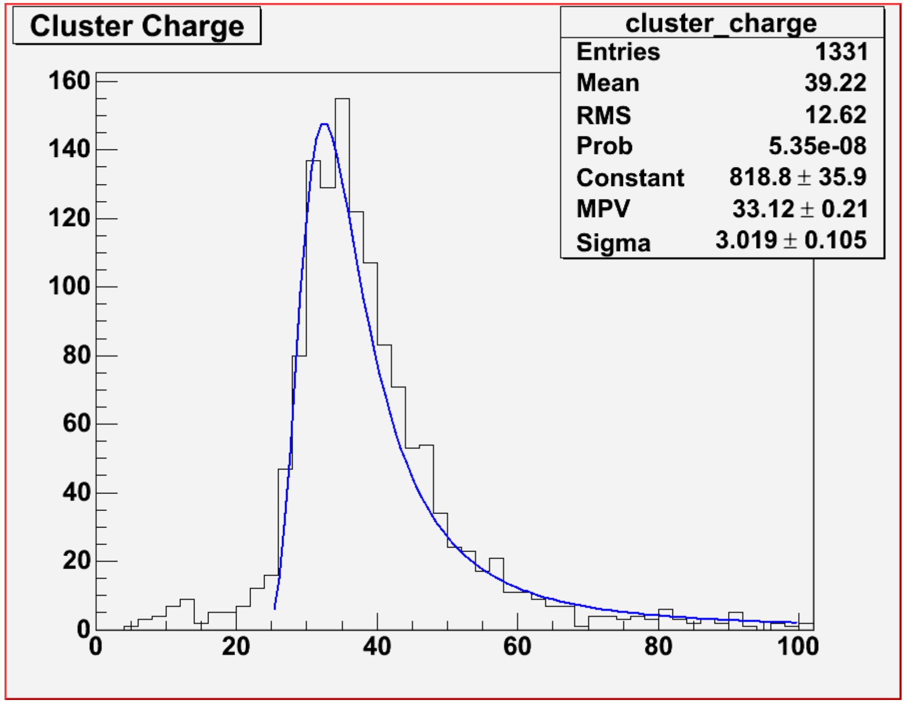


Device	Type	w/p	p(um)	Vbias (V)	S	S/N
14-s7	Fz-p (200 um)	0,25	100	250	22,3	23,1

Bulk depletion voltage from diodes CV ~75V

Signal scales with thickness
Performance similar to Fz-n

MCz(p,300 um) Reference micro-strips: S & S/N



Device	Type	w/p	p(um)	Vbias (V)	S	S/N
66-s7	MCz-p (300 um)	0,25	100	250	33,2	34,3

Bulk depletion voltage from diodes CV ~100V

Performance similar to Fz-p (n)

Measurements after irradiation

Micro-strips irradiated

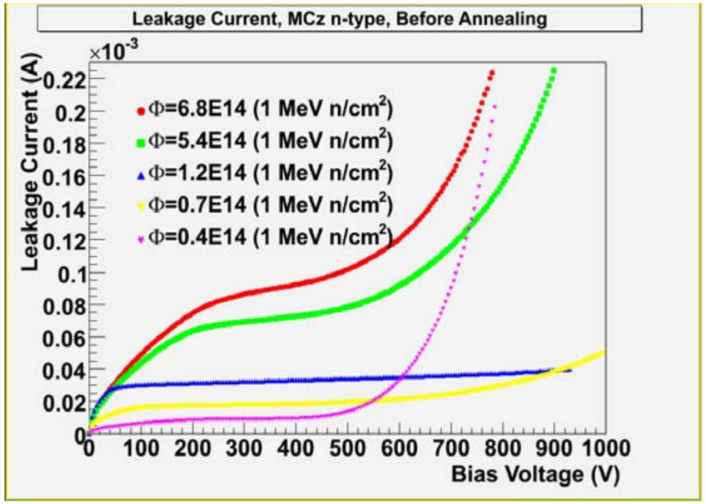
device	□ 1 MeV n eq/cm^2	irrad-facility	wafer type
12-s9	4,20E+14	karlsruhe	Epi-n
12-s5	7,00E+14	karlsruhe	Epi-n
12-s4	2,55E+15	ljubljana	Epi-n
12-s10	3,50E+15	karlsruhe	Epi-n
24-s2 lps	8,50E+14	ljubljana	Fz-p
127-s8	4,20E+14	karlsruhe	MCz-n
127-s9	5,53E+14	karlsruhe	MCz-n
160-s4	7,00E+14	karlsruhe	MCz-n
127-s4	1,70E+15	ljubljana	MCz-n
102_s4 lps	1,23E+14	karlsruhe	MCz-p
130-s7 hps	2,71E+14	karlsruhe	MCz-p
102-s2 lps	4,13E+14	karlsruhe	MCz-p
9-s9 lps	5,53E+14	karlsruhe	MCz-p
66_s4 lps	7,00E+14	karlsruhe	MCz-p
253-s10 hps	3,50E+15	karlsruhe	MCz-p

Fluence correction
1)Source hardness Factor
2)Diode study of annealing
fit to expected α

Micro-strips have different annealing time
< 30 min. @ 80 deg C
(far from annealing induced Type inversion)

I_{leak} performance of proton irr. microstrip sensors

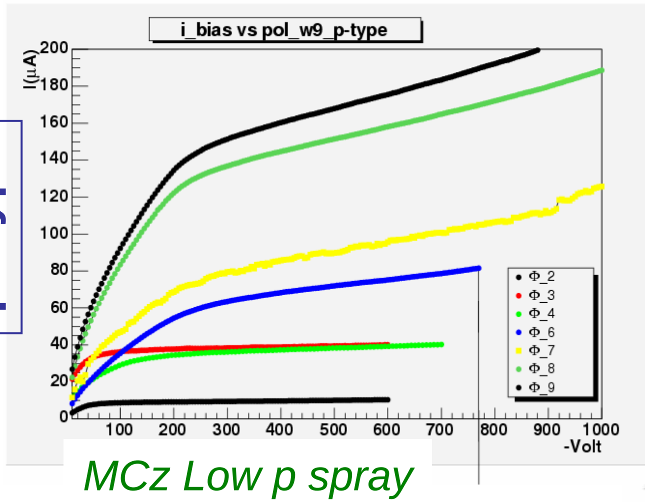
n-type



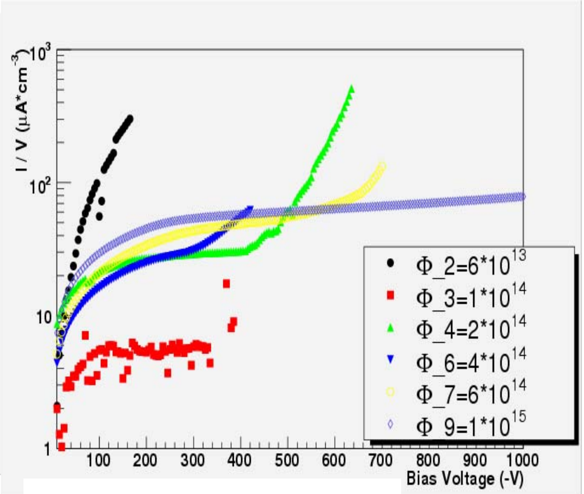
IV curves of n-type detectors for the full fluence range before annealing (measured at 0ºC):

- ✓ Current levels in MCz detectors are comparable with Fz at a given fluence
- ✓ Leakage currents measured at V_{depl} scale as the received fluences.

p-type



MCz Low p spray



MCz High p spray

The performance of p-type Fz and MCz .detectors are much improved after irradiation

- ✓ Sensors with low p-spray have IV performance comparable with n-type detectors.
- ✓ Detectors with a high p-spray show improved IV performance at fluence > 4.0 10^{14} n_{eq}/cm^2

Similar effect of damage on reverse current on all materials Fz , MCp Epi

Epitaxial devices irradiated with 26 MeV protons

✓ *The annealing curves suggest that the SCSI takes place around 50 minutes at 80°C except for the lower fluence → confirmed by TCT measurements.*

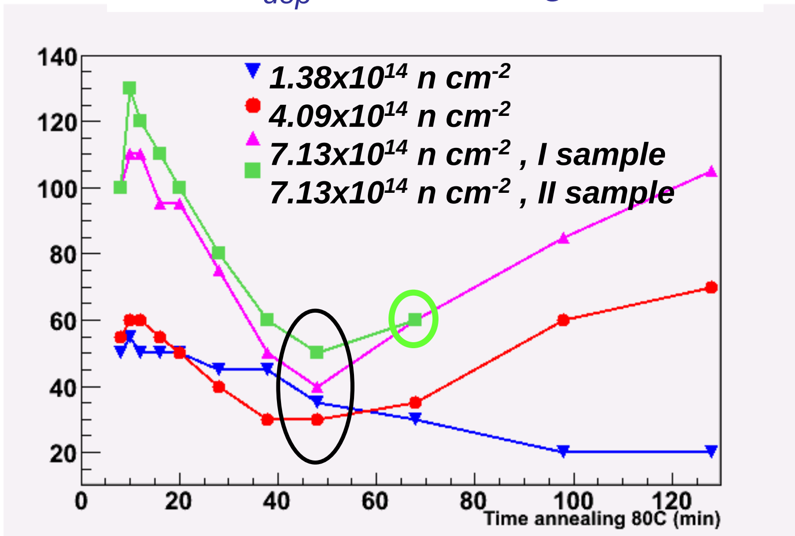
✓ *Pulse shape measured (red) and predicted (blue) from the field distribution extracted from the fit: $\Phi = 7.1 \times 10^{14}\ n_{eq} cm^{-2}$.*

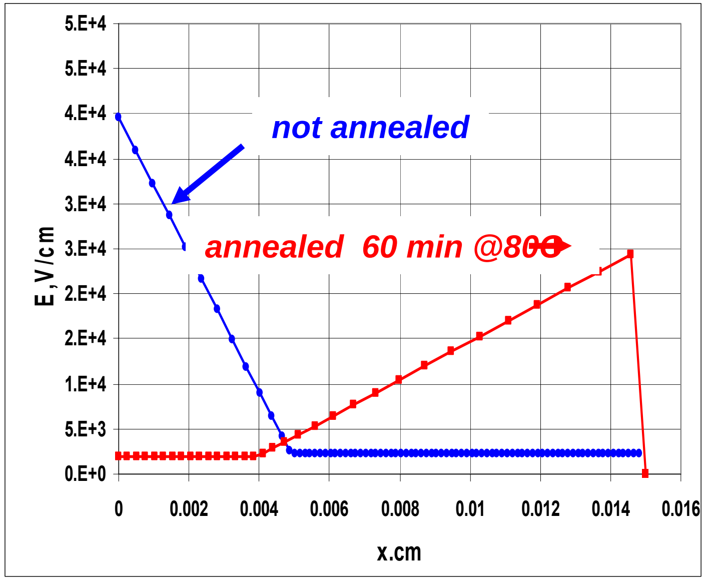
✓ *The 150 μm epitaxial samples show a type-inverted behaviour after neutron irradiation (already at the lowest fluence analysed $8.5 \times 10^{14}\ n_{eq}\ cm^{-2}$)*

✓ *Before annealing the dominant junction is still on the front side with a wide neutral base on the back.*

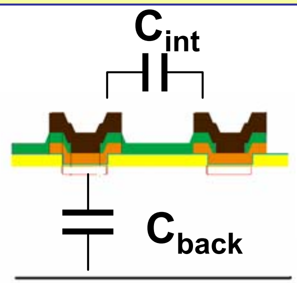
✓ *After a long reversal annealing the dominant junction has moved from the front to the back side.*

V_{dep} vs Annealing Time





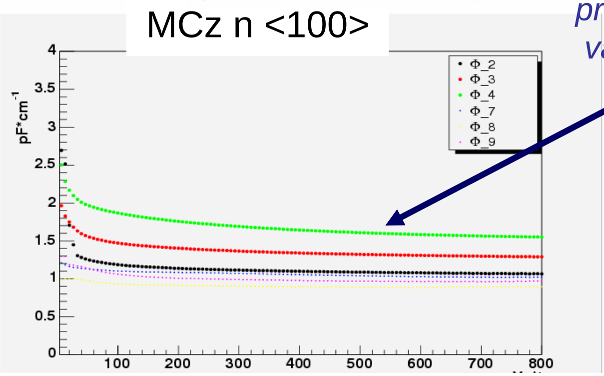
Inter-strip Capacitance after proton irradiation



$C_{tot} = C_{back} + 2(C_{int}\ 1^{st} + C_{in}\ 2^{nd} + \ldots)$

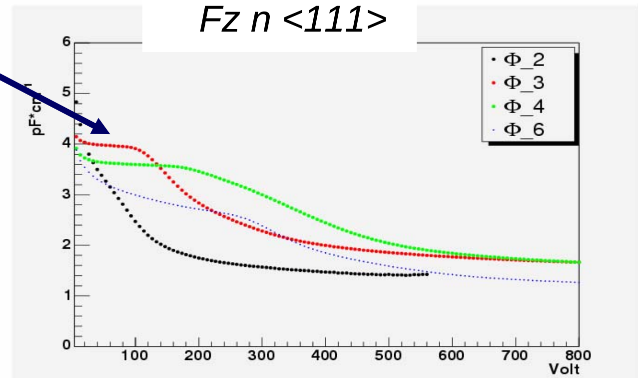
Total capacitance to input amplifier

n-type



pre irradiation values recovered

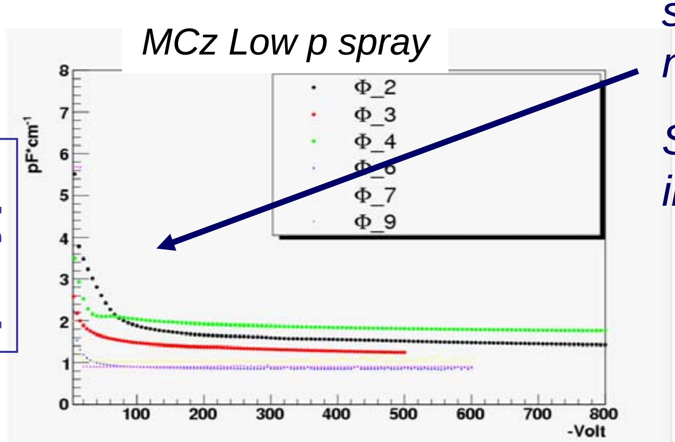
Typical of <111> Si

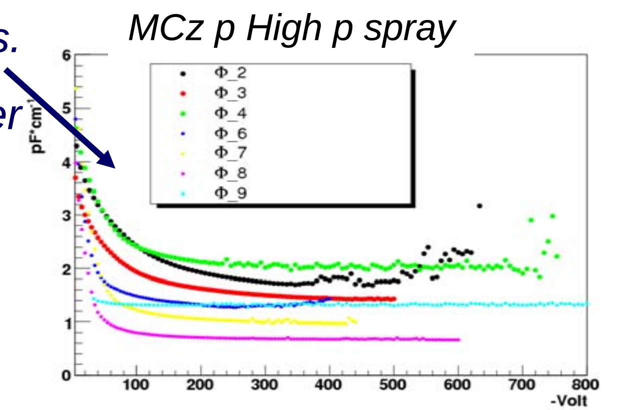


Same problem (slow saturation) found for not irradiated sensors.

Slightly improved after irradiation.

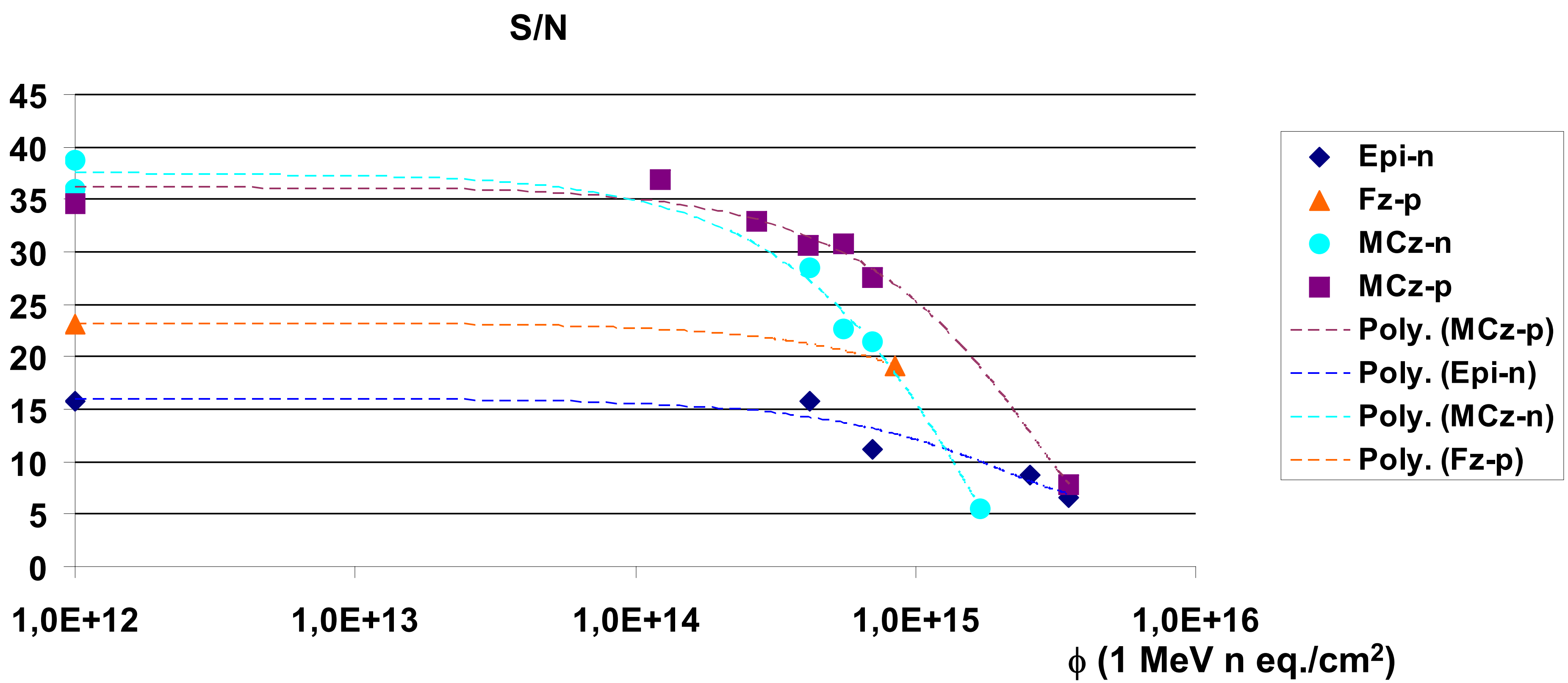
p-type





Devices simulation results (ITC-IRST) have shown good agreement with data: step forward in understanding strips geometry & isolation scheme

Summary: S/N for irradiated SMART micro-strips detectors



Detector operation limit S/N= 10 (safe value)

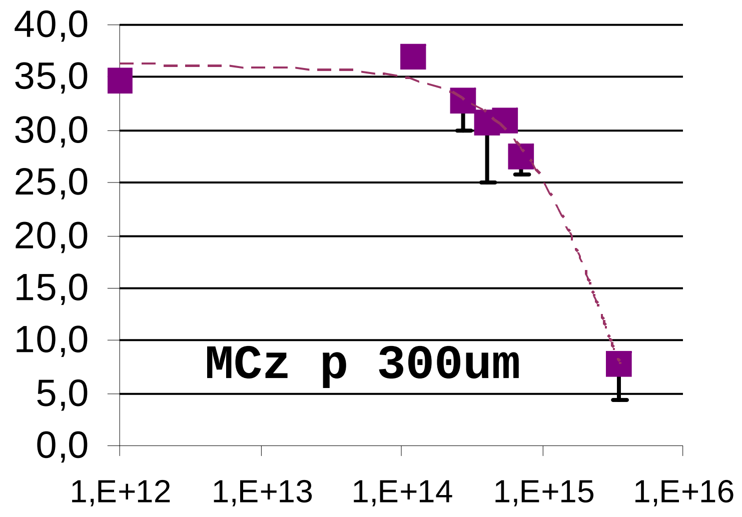
MCz(p) up to ϕ =3,1 10^{15} | **Epi(n) up to ϕ = 1,8 10^{15}**

Fz(p) up to ϕ= 2,6 10^{15}(extrapol) | **MCz(n) ϕ = 1,3 10^{15}(guess)**

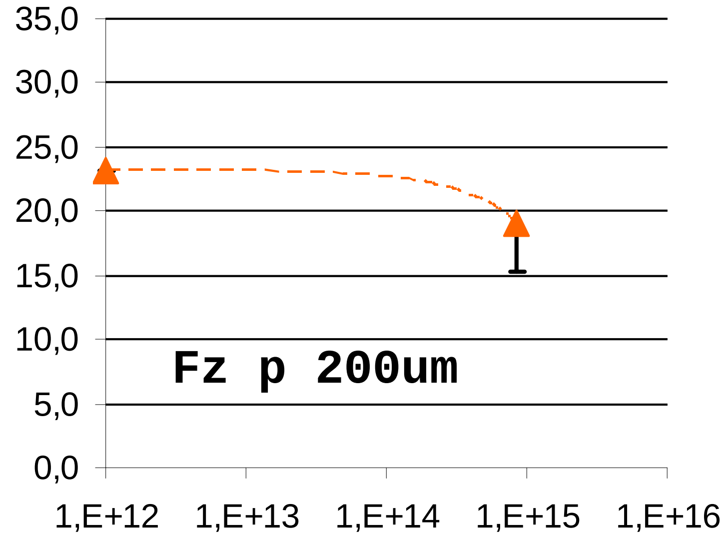
Measurements: SMART devices

S/N

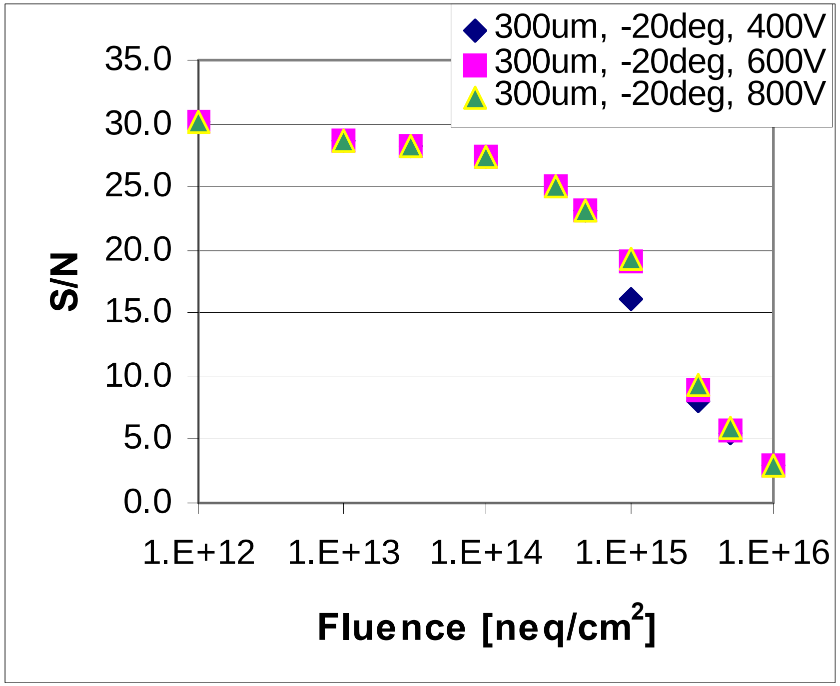
Error bar correspond to 400-600 V difference

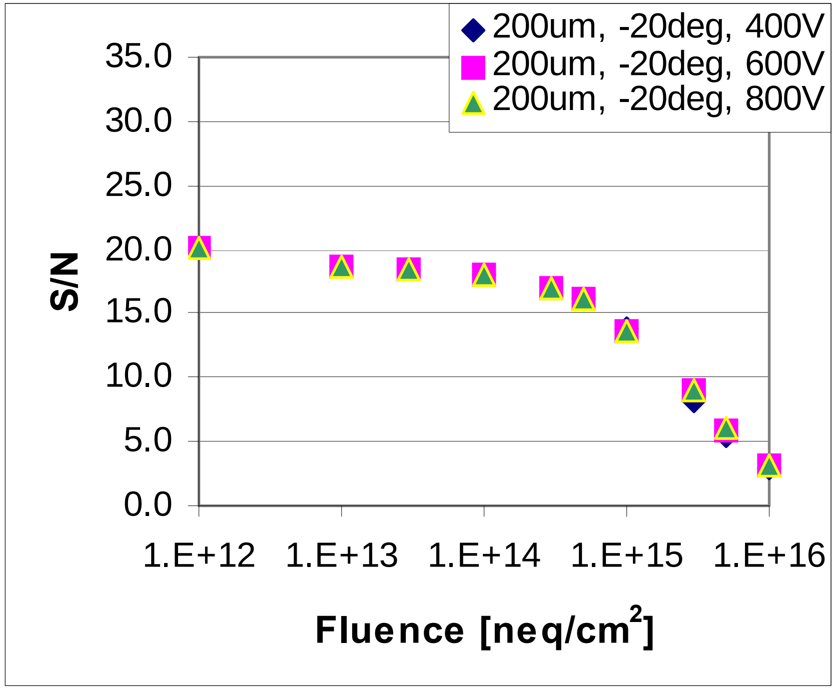


S/N

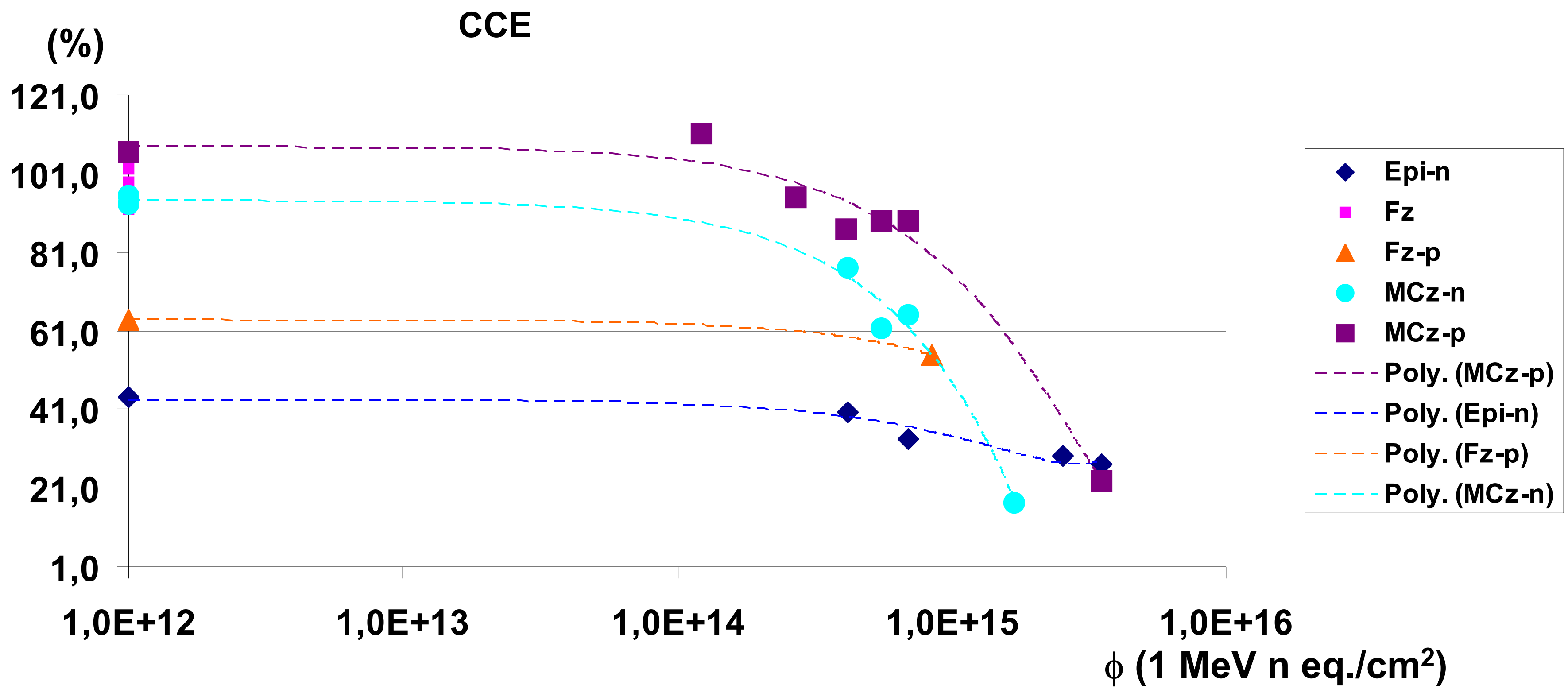


(From H.F.W. Sadrozinski et al. SCIPP report 05/09)



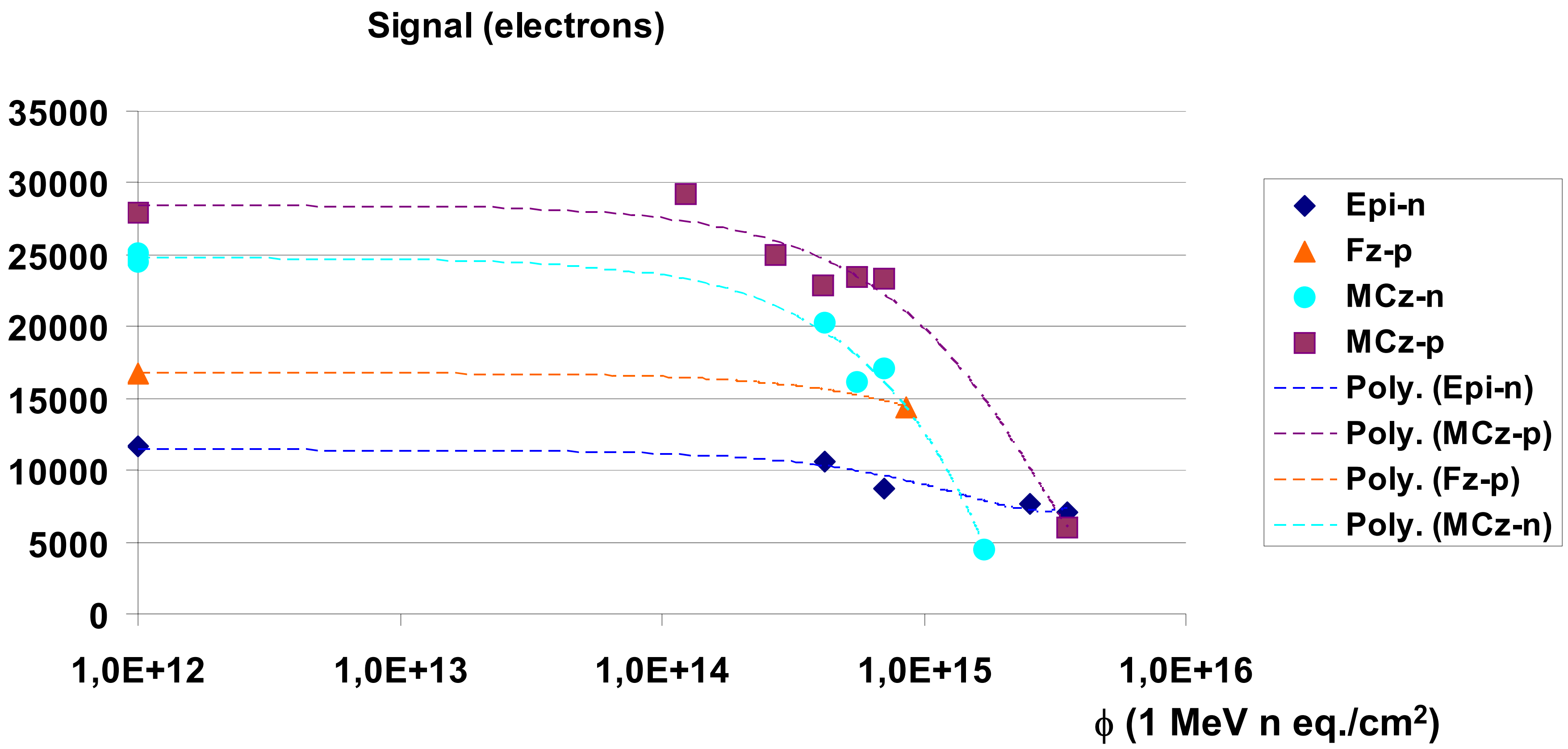


Summary: CCE for irradiated SMART micro-strips detectors



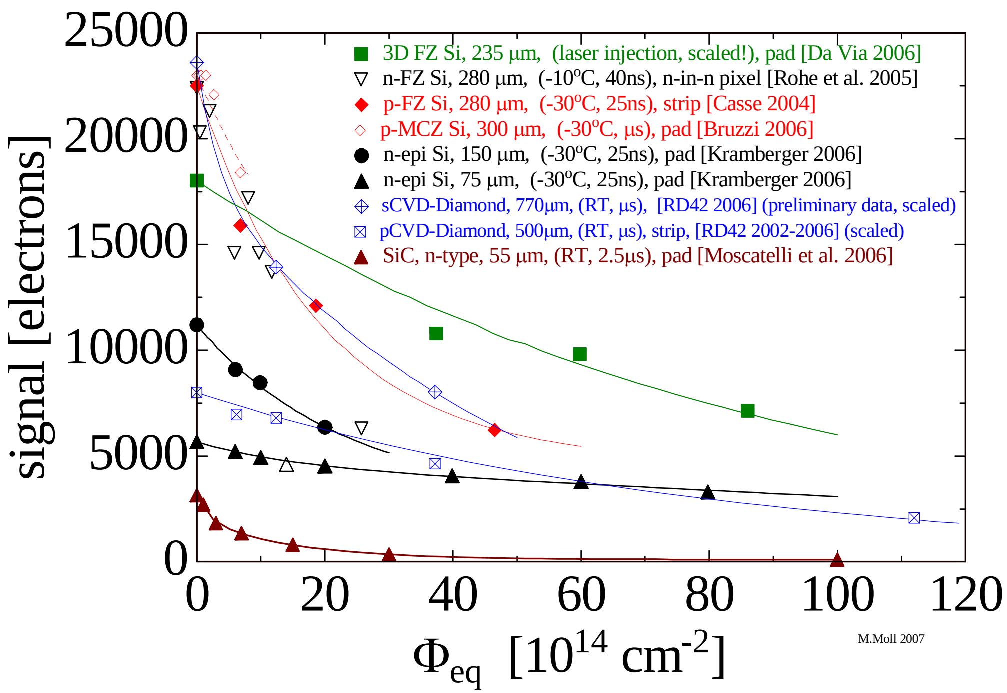
CCE normalized to Fz(n,300 um) micro-strip.
TIB CMS module: CCE ~65% at 1,9 10^{14} 1 MeV n eq./cm^2

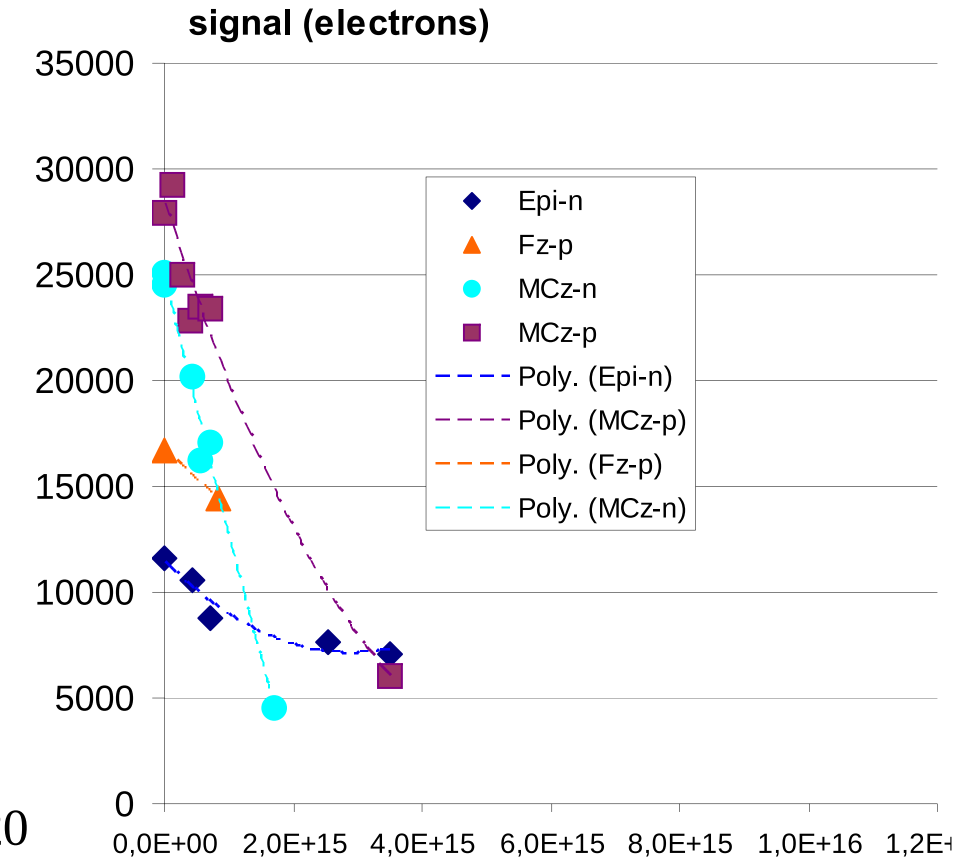
Summary: Collected signal for irradiated SMART micro-strips detectors



At S/N=10 we collect 8000-9000 electrons

Micro-strip signal compared to pad





Conclusion

- Micro-strips performances investigated up to 3,5 10^{15} 1 MeV n eq.
- S and S/N :
  - MCz(n/p,300 um):
    - n-type cannot be used at high fluence (signal disappear and clustering efficiency strongly decrease), maybe performances enhanced in the medium fluence range by D.J. effect
    - p-type have acceptable performance up to a few 10^{15}
  - Epitaxial(n,150 um) moderate decrease with fluence
  - Fz(p, 200um) seems competitive (more measurement needed)
- S/N for MCz(300,p) and Fz(200,p) is in agreement with simulation, and compatible pad CCE measurements
- Safe detector operation limit (S/N=10) up to ϕ =3,1 10^{15} 1 MeV n eq./cm^2 for MCz(p) (fluence expected for ~9 cm at SLHC)

Future plans

- Assembly of new modules with SMART sensors to have :
  - More fluence points
  - Cross check of results
- Analysis of performance vs Vdepl, quantitative comparison with diodes
- Study of optimized clustering after high level irradiation

- Assembly of new sensors from 6 inch and 4 inch production with improved design and process.
- Study of power detector stability
  - Increase of detector CM noise
  - Run away and early breakdown effects
  - Optimization of cooling