Latest results of RD50 collaboration

Development of radiation hard sensors for very high luminosity colliders

Panja Luukka

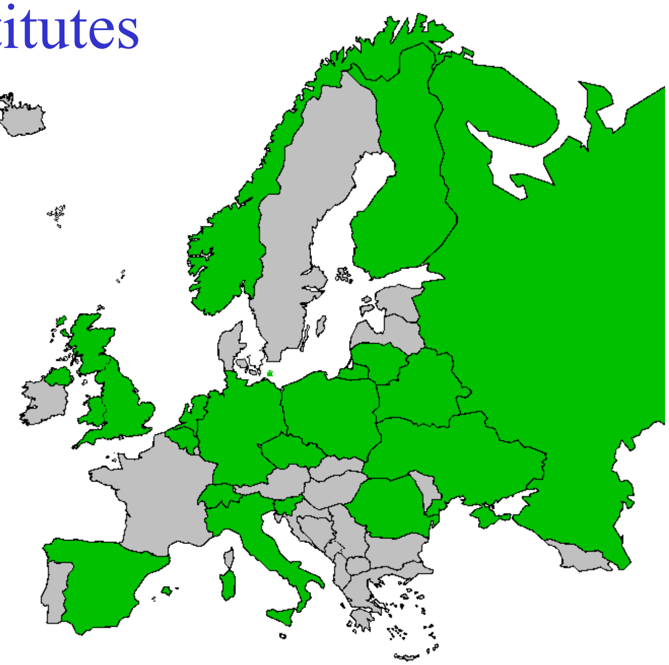
Helsinki Institute of Physics

on behalf of RD50 collaboration

http://www.cern.ch/rd50

RD50 **Development of Radiation Hard Semiconductor Devices for High Luminosity Colliders**

250 Members from 48 Institutes



41 European and Asian institutes

Belarus (Minsk), **Belgium** (Louvain), **Czech Republic** (Prague (3x)), **Finland** (Helsinki), **Germany** (Dortmund, Erfurt, Freiburg, Hamburg, Karlsruhe, Munich), **Italy** (Bari, Bologna, Florence, Padova, Perugia, Pisa, Torino, Trento), **Lithuania** (Vilnius), **Netherlands** (NIKHEF), **Norway** (Oslo (2x)), **Poland** (Warsaw(2x)), **Romania** (Bucharest (2x)), **Russia** (Moscow, St.Petersburg), **Slovenia** (Ljubljana), **Spain** (Barcelona, Valencia), **Switzerland** (CERN, PSI), **Ukraine** (Kiev), **United Kingdom** (Glasgow, Lancaster, Liverpool)

8 North-American institutes

Canada (Montreal), **USA** (BNL, Fermilab, New Mexico, Purdue, Rochester, Santa Cruz, Syracuse)

1 Middle East institute

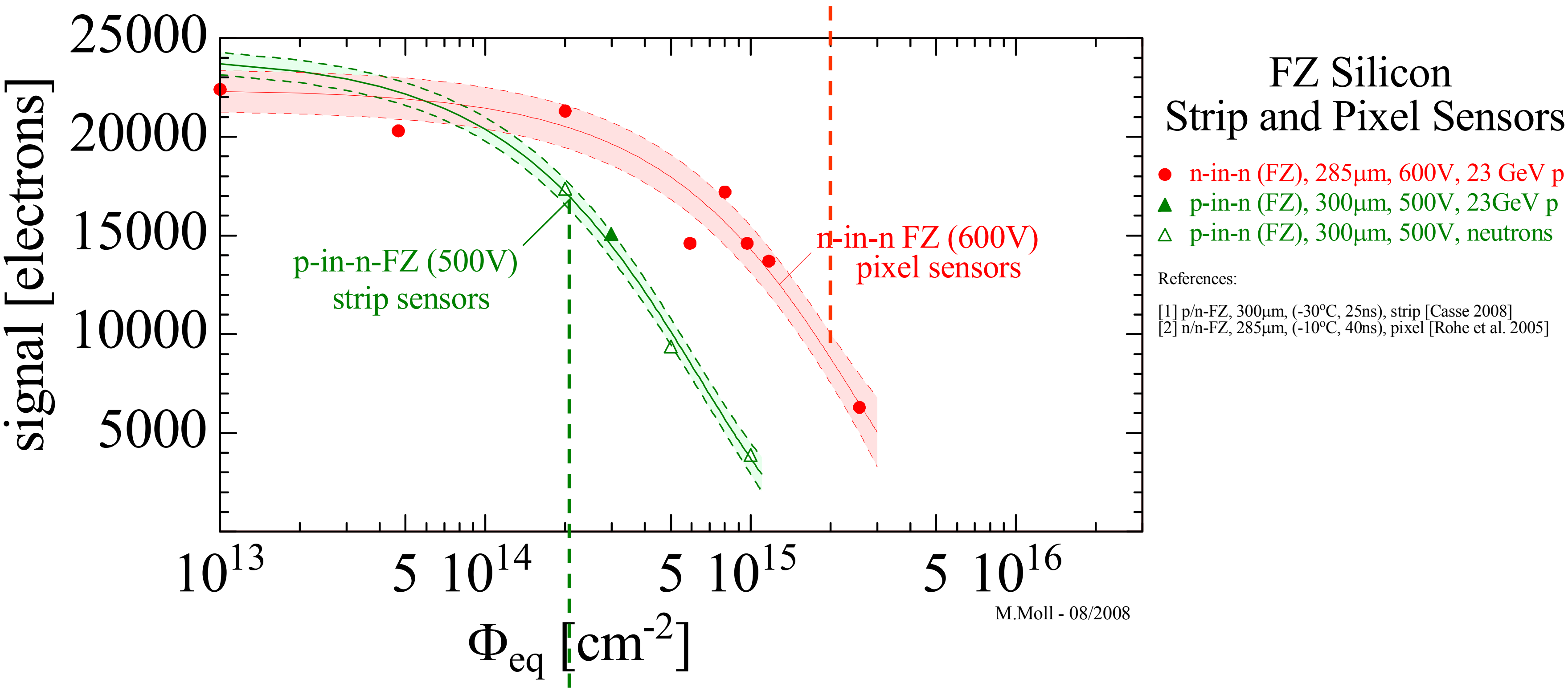
Israel (Tel Aviv)

Detailed member list: http://cern.ch/rd50

RD50 Motivation: Signal degradation for LHC Silicon Sensors

Pixel sensors:

max. cumulated fluence for LHC



Strip sensors:

max. cumulated fluence for LHC

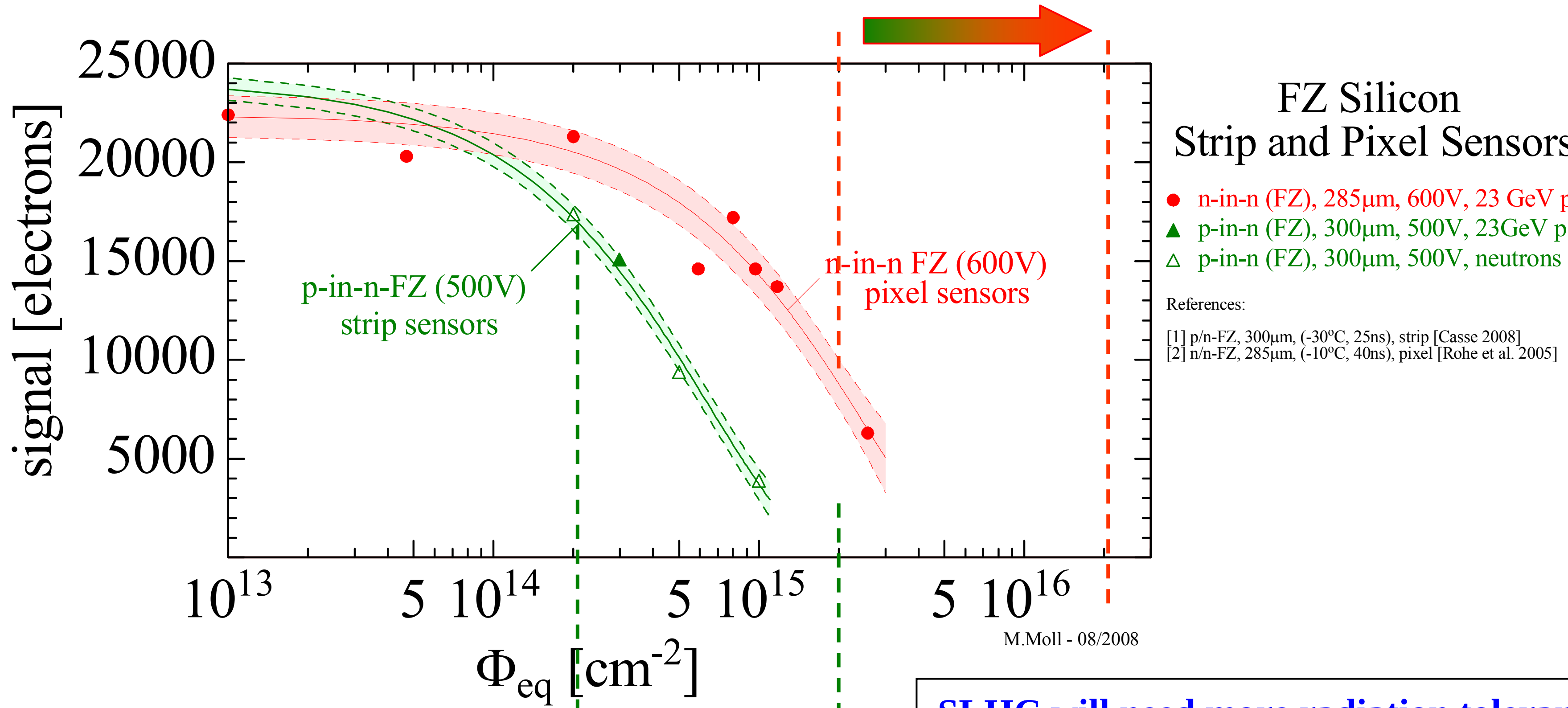
RD50

Motivation:

Signal degradation for LHC Silicon Sensors

Pixel sensors:

max. cumulated fluence for LHC and SLHC



Strip sensors:

max. cumulated fluence for LHC and SLHC

SLHC will need more radiation tolerant tracking detector concepts!

Boundary conditions & other challenges:

Granularity, Powering, Cooling, Connectivity, Triggering, Low mass, Low cost !

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RD50 approaches to develop radiation harder tracking detectors

- **Material Engineering -- Defect Engineering of Silicon**
  - **Understanding radiation damage**
    - **Macroscopic effects and Microscopic defects**
    - **Simulation of defect properties & kinetics**
    - **Irradiation with different particles & energies**
  - **Oxygen rich Silicon**
    - **DOFZ, Cz, MCZ, EPI**
  - **Oxygen dimer & hydrogen enriched Silicon**
  - **Influence of processing technology**

Radiation Damage to Sensors:

- **Bulk damage due to NIEL**
  - **Change of effective doping concentration**
  - **Increase of leakage current**
  - **Increase of charge carrier trapping**
- **Surface damage due to IEL**

(accumulation of positive charge in oxide & interface charges)

- **Material Engineering-New Materials** (work concluded)
  - **Silicon Carbide (SiC), Gallium Nitride (GaN)**
- **Device Engineering (New Detector Designs)**
  - **p-type silicon detectors (n-in-p)**
  - **thin detectors**
  - **3D detectors**
  - **Simulation of highly irradiated detectors**
  - **Semi 3D detectors and Stripixels**
  - **Cost effective detectors**
- **Development of test equipment and measurement recommendations**

Related Works – Not conducted by RD50

- **"Cryogenic Tracking Detectors"** (CERN RD39)
- **"Diamond detectors"** (CERN RD42)
- **Monolithic silicon detectors**
- **Detector electronics**

RD50 Reminder: Silicon Materials under Investigation

standard for particle detectors

used for LHC Pixel detectors

"new" silicon material

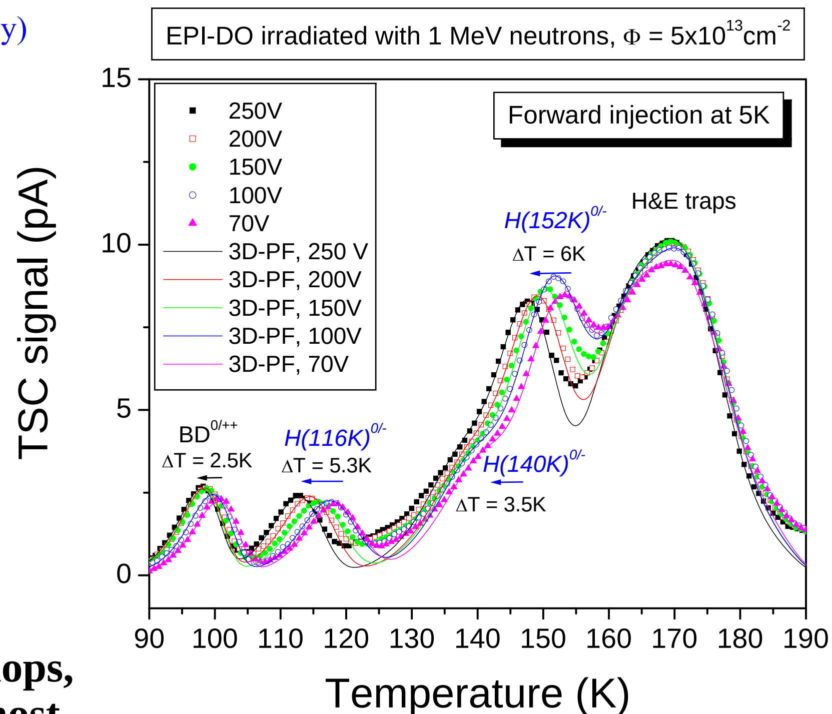
Material	Thickness [µm]	Symbol	ρ (Ωcm)	$[O_i]$ (cm^{-3})
Standard FZ (n- and p-type)	50,100,150, 300	FZ	$1–30\times10^3$	$< 5\times10^{16}$
Diffusion oxygenated FZ (n- and p-type)	300	DOFZ	$1–7\times10^3$	$\sim 1–2\times10^{17}$
Magnetic Czochralski Si, Okmetic, Finland (n- and p-type)	100, 300	MCz	$\sim 1\times10^3$	$\sim 5\times10^{17}$
Czochralski Si, Sumitomo, Japan (n-type)	300	Cz	$\sim 1\times10^3$	$\sim 8\text{-}9\times10^{17}$
Epitaxial layers on Cz-substrates, ITME, Poland (n- and p-type)	25, 50, 75, 100,150	EPI	50 – 100	$< 1\times10^{17}$
Diffusion oxyg. Epitaxial layers on CZ	75	EPI–DO	50 – 100	$\sim 7\times10^{17}$

- **DOFZ silicon** - Enriched with oxygen on wafer level, inhomogeneous distribution of oxygen
- **CZ/MCZ silicon** - high Oi (oxygen) and O_{2i} (oxygen dimer) concentration (homogeneous)
  - formation of shallow Thermal Donors possible
- **Epi silicon** - high O_i , O_{2i} content due to out-diffusion from the CZ substrate (inhomogeneous)
  - thin layers: high doping possible (low starting resistivity)
- **Epi-Do silicon** - as EPI, however additional O_i diffused reaching homogeneous O_i content

RD50 Defect Characterization - WODEAN

- **WODEAN project** (initiated in 2006, 10 RD50 institutes, guided by G.Lindstroem, Hamburg)
  - **Aim:** **Identify defects responsible for Trapping, Leakage Current, Change of N_{eff}**
  - **Method:** **Defect Analysis on identical samples performed with the various tools available inside the RD50 network:**
    - **C-DLTS** (Capacitance Deep Level Transient Spectroscopy)
    - **I-DLTS** (Current Deep Level Transient Spectroscopy)
    - **TSC** (Thermally Stimulated Currents)
    - **PITS** (Photo Induced Transient Spectroscopy)
    - **FTIR** (Fourier Transform Infrared Spectroscopy)
    - **RL** (Recombination Lifetime Measurements)
    - **PC** (Photo Conductivity Measurements)
    - **EPR** (Electron Paramagnetic Resonance)
    - **TCT** (Transient Charge Technique)
    - **CV/IV**
  - **~ 240 samples irradiated with protons and neutrons**
  - **first results presented on 2007 RD50 Workshops, further analyses in 2008 and publication of most important results in in Applied Physics Letters**

… significant impact of RD50 results on silicon solid state physics – defect identification



Example: TSC measurement on defects (acceptors) responsible for the reverse annealing

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Summary – defects with strong impact on the device properties at operating temperature

Point defects

- $E_i^{BD} = E_c - 0.225$ eV
- $\sigma_n^{BD} = 2.3\cdot10^{-14}$ cm^2

- $E_i^{I} = E_c - 0.545$ eV
  - $\sigma_n^{I} = 2.3\cdot10^{-14}$ cm^2
  - $\sigma p^{I} = 2.3\cdot10^{-14}$ cm^2

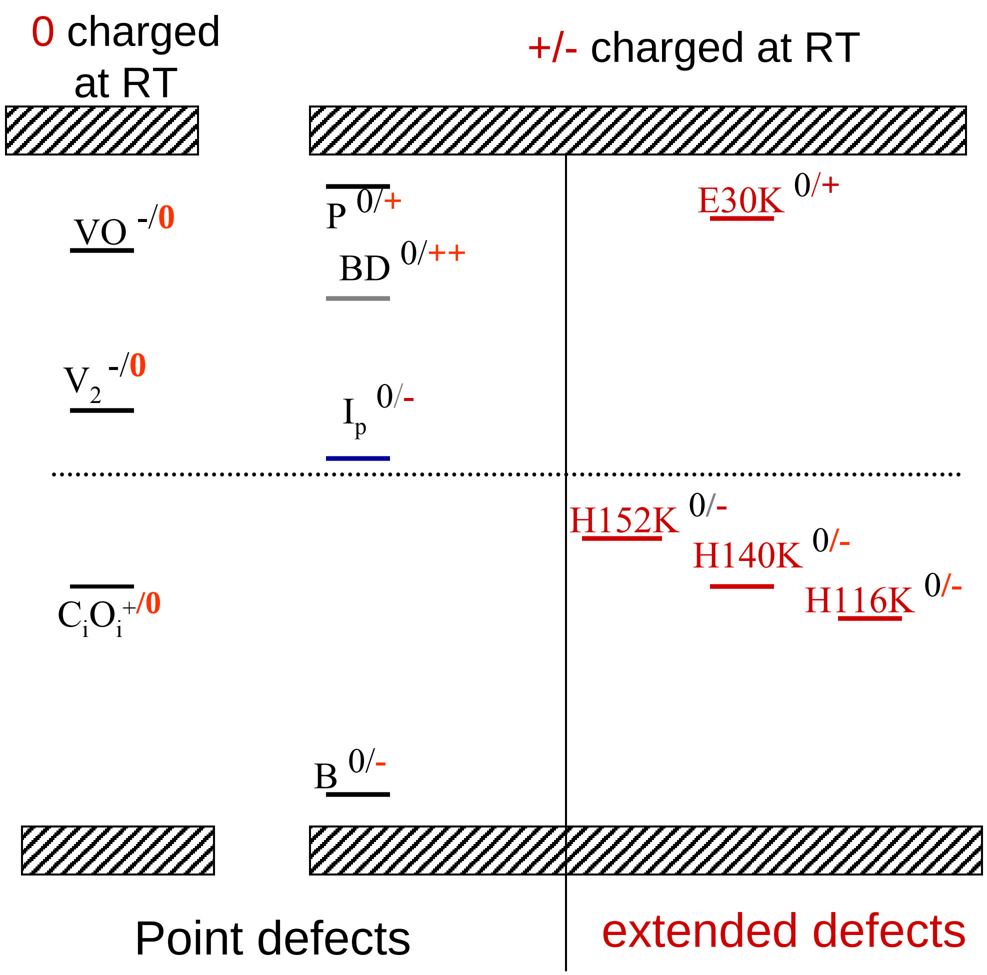
Cluster related centers

- $E_i^{116K} = E_v + 0.33$eV
- $\sigma_p^{116K} = 4\cdot10^{-14}$ cm^2

- $E_i^{140K} = E_v + 0.36$eV
- $\sigma_p^{140K} = 2.5\cdot10^{-15}$ cm^2

- $E_i^{152K} = E_v + 0.42$eV
- $\sigma_p^{152K} = 2.3\cdot10^{-14}$ cm^2

- $E_i^{30K} = E_c - 0.1$eV
- $\sigma_n^{30K} = 2.3\cdot10^{-14}$ cm^2



Summary – defects with strong impact on the device properties at operating temperature

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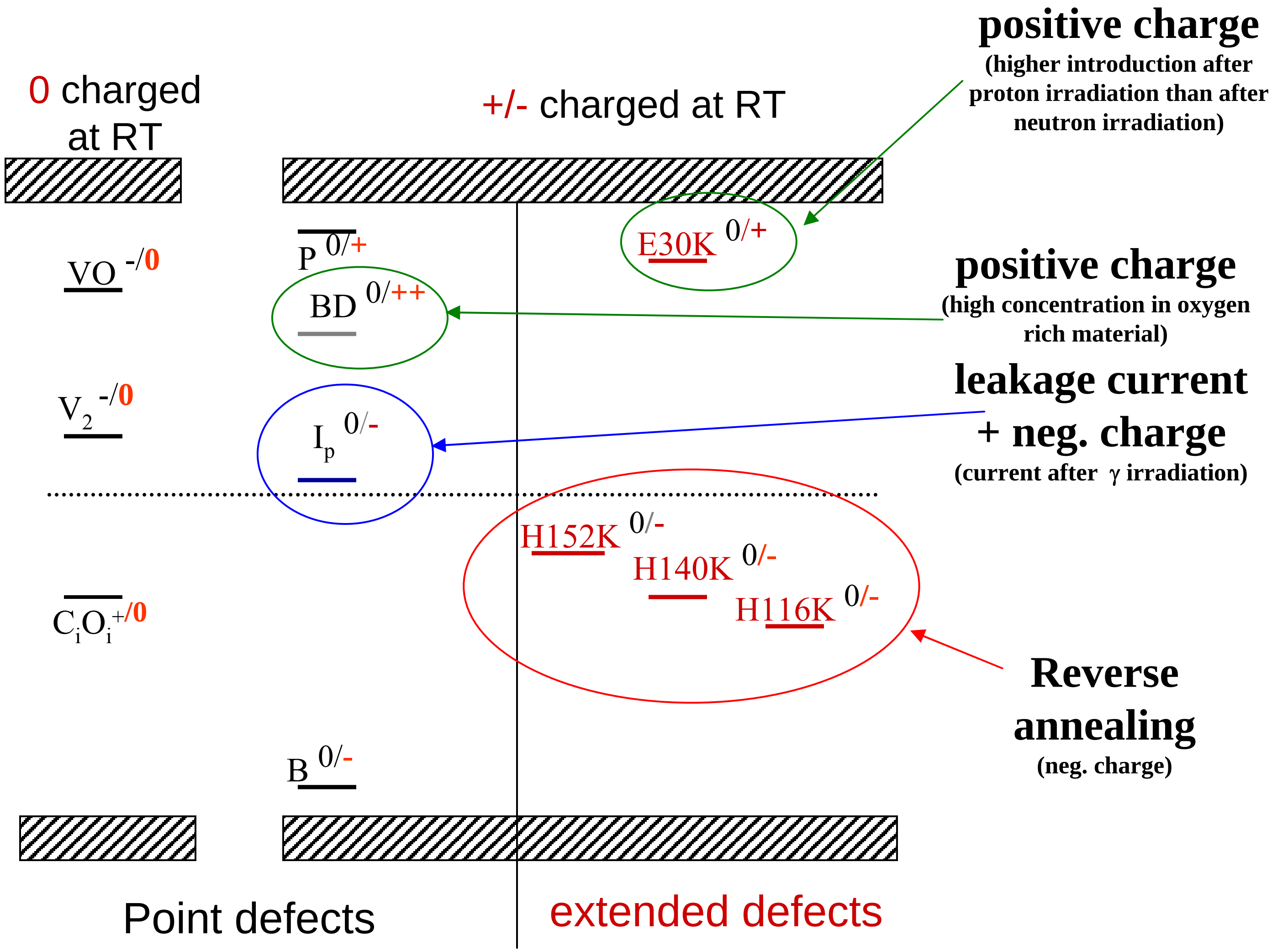
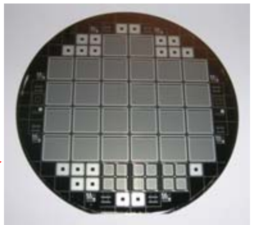
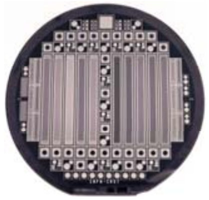


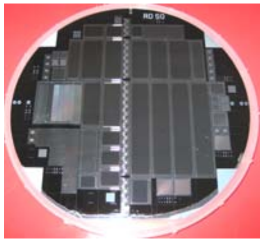
RD50 RD50 Test Sensor Production Runs (2005-2008)

- **Recent production of Silicon Strip, Pixel and Pad detectors (non exclusive list):**
  - **CIS Erfurt, Germany**
    - **2005/2006/2007 (RD50): Several runs with various epi 4" wafers only pad detectors**
  - **CNM Barcelona, Spain**
    - **2006 (RD50): 22 wafers (4"), (20 pad, 26 strip, 12 pixel),(p- and n-type),(MCZ, EPI, FZ)**
    - **2006 (RD50/RADMON): several wafers (4"), (100 pad), (p- and n-type),(MCZ, EPI, FZ)**
  - **HIP, Helsinki, Finland**
    - **2006 (RD50/RADMON): several wafers (4"), only pad devices, (n-type),(MCZ, EPI, FZ)**
    - **2006 (RD50) : pad devices, p-type MCz-Si wafers, 5 p-spray doses, Thermal Donor compensation**
    - **2006 (RD50) : full size strip detectors with 768 channels, n-type MCz-Si wafers**
  - **IRST, Trento, Italy**
    - **2004 (RD50/SMART): 20 wafers 4" (n-type), (MCZ, FZ, EPI), mini-strip, pad 200-500μm**
    - **2004 (RD50/SMART): 23 wafers 4" (p-type), (MCZ, FZ), two p-spray doses 3E12 amd 5E12 cm^{-2}**
    - **2005 (RD50/SMART): 4" p-type EPI**
    - **2008 (RD50/SMART): new 4" run**
  - **Micron Semiconductor L.t.d (UK)**
    - **2006 (RD50): 4", microstrip detectors on 140 and 300μm thick p-type FZ and DOFZ Si.**
    - **2006/2007 (RD50): 93 wafers, 6 inch wafers, (p- and n-type), (MCZ and FZ), (strip, pixel, pad)**
  - **Sintef, Oslo, Norway**
    - **2005 (RD50/US CMS Pixel) n-type MCZ and FZ Si Wafers**
  - **Hamamatsu, Japan [ATLAS ID project – not RD50]**
    - **In 2005 Hamamatsu started to work on p-type silicon in collaboration with ATLAS upgrade groups (surely influenced by RD50 results on this material)**





6 in.

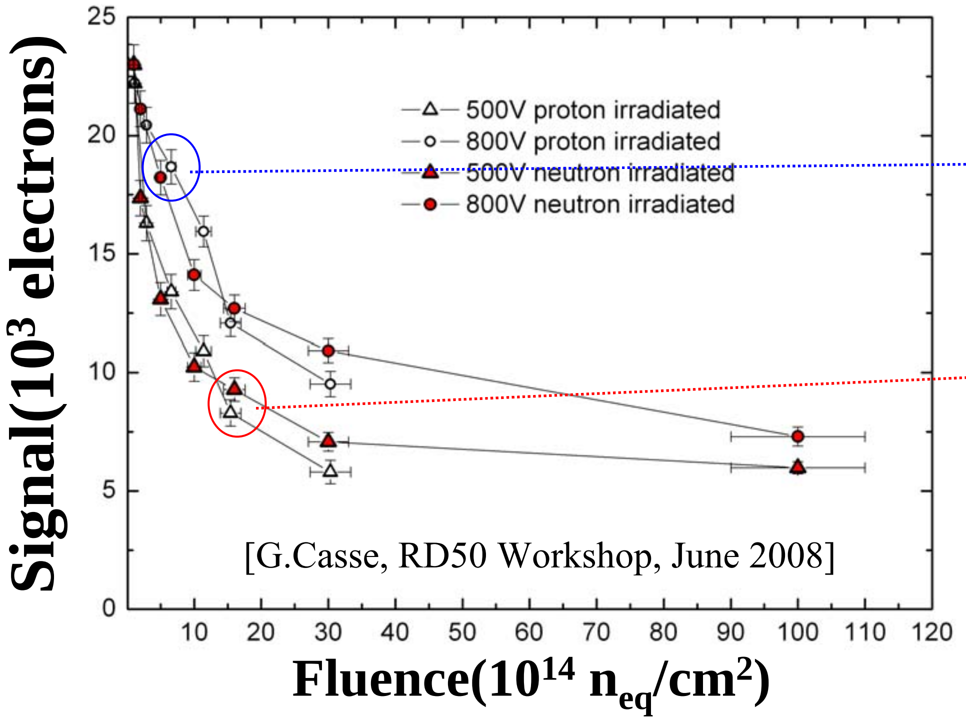


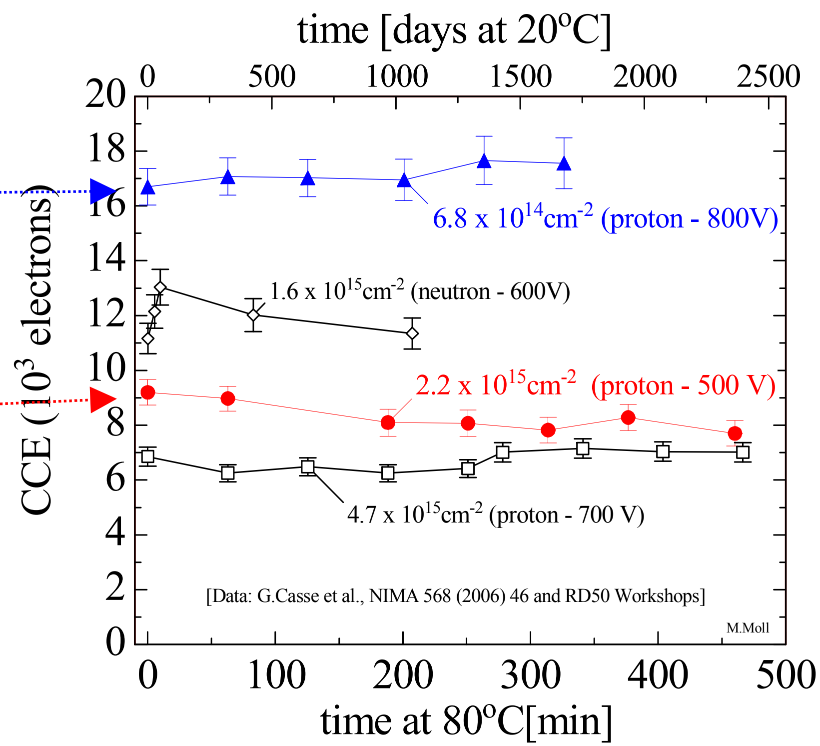
Hundreds of samples (pad/strip/pixel) recently produced on various materials (n- and p-type).

- M.Lozano, 8th RD50 Workshop, Prague, June 2006
- A.Pozza, 2nd Trento Meeting, February 2006
- G.Casse, 2nd Trento Meeting, February 2006
- D. Bortoletto, 6th RD50 Workshop, Helsinki, June 2005
- N.Zorzi, Trento Workshop, February 2005
- H. Sadrozinski, rd50 Workshop, Nov. 2007

RD50 n-in-p microstrip detectors

- n-in-p microstrip p-type FZ detectors (Micron, 280 or 300µm thick, 80µm pitch, 18µm implant)
- Detectors read-out with 40MHz (SCT 128A)



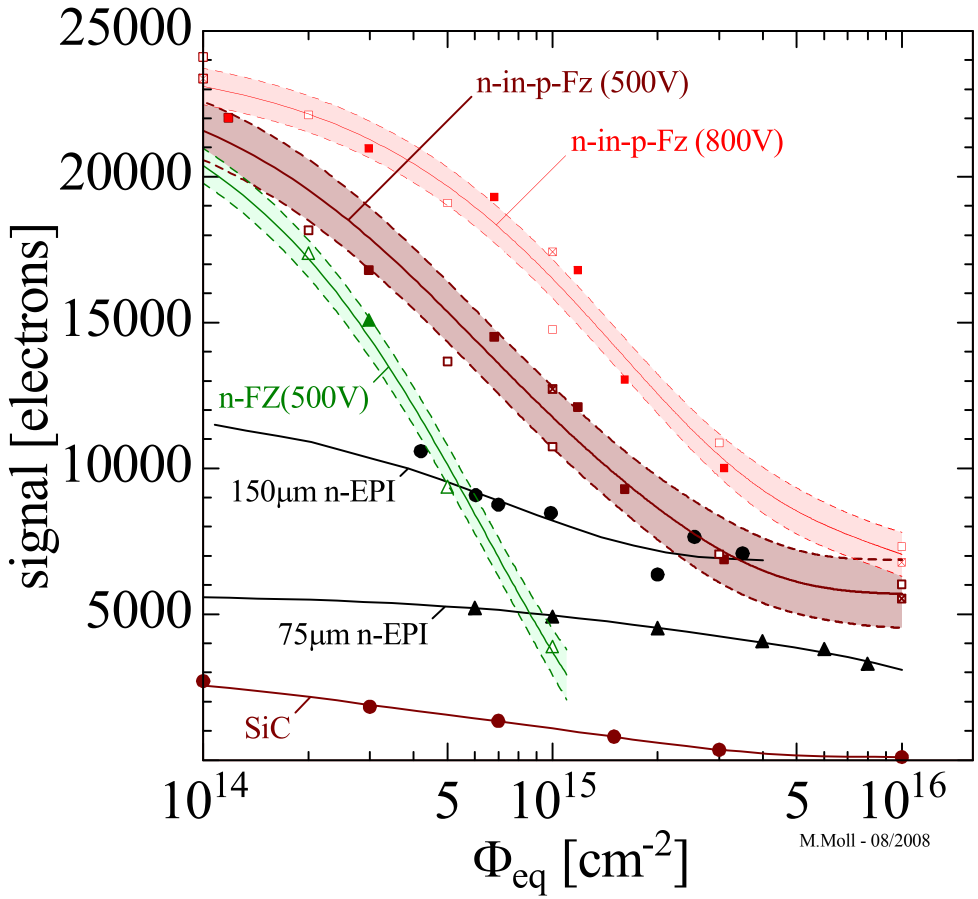


- **CCE: ~7300e (~30%)**
  after ~ $1\times10^{16}cm^{-2}$ 800V
- **n-in-p sensors are strongly considered for ATLAS upgrade** (previously p-in-n used)

- **no reverse annealing in CCE measurements for neutron and proton irradiated detectors**

RD50 Silicon materials for Tracking Sensors

- **Signal comparison for various Silicon sensors**



Note: Measured partly under different conditions! Lines to guide the eye (no modeling)!

Silicon Sensors

- ● p-in-n (EPI), 150 µm [7,8]
- ▲ p-in-n (EPI), 75µm [6]
- ■ n-in-p (FZ), 300µm, 500V, 23GeV p [1]
- □ n-in-p (FZ), 300µm, 500V, neutrons [1]
- ⊠ n-in-p (FZ), 300µm, 500V, 26MeV p [1]
- ■ n-in-p (FZ), 300µm, 800V, 23GeV p [1]
- □ n-in-p (FZ), 300µm, 800V, neutrons [1]
- ⊠ n-in-p (FZ), 300µm, 800V, 26MeV p [1]
- ▲ p-in-n (FZ), 300µm, 500V, 23GeV p [1]
- △ p-in-n (FZ), 300µm, 500V, neutrons [1]

Other materials

- ● SiC, n-type, 55 µm, 900V, neutrons [3]

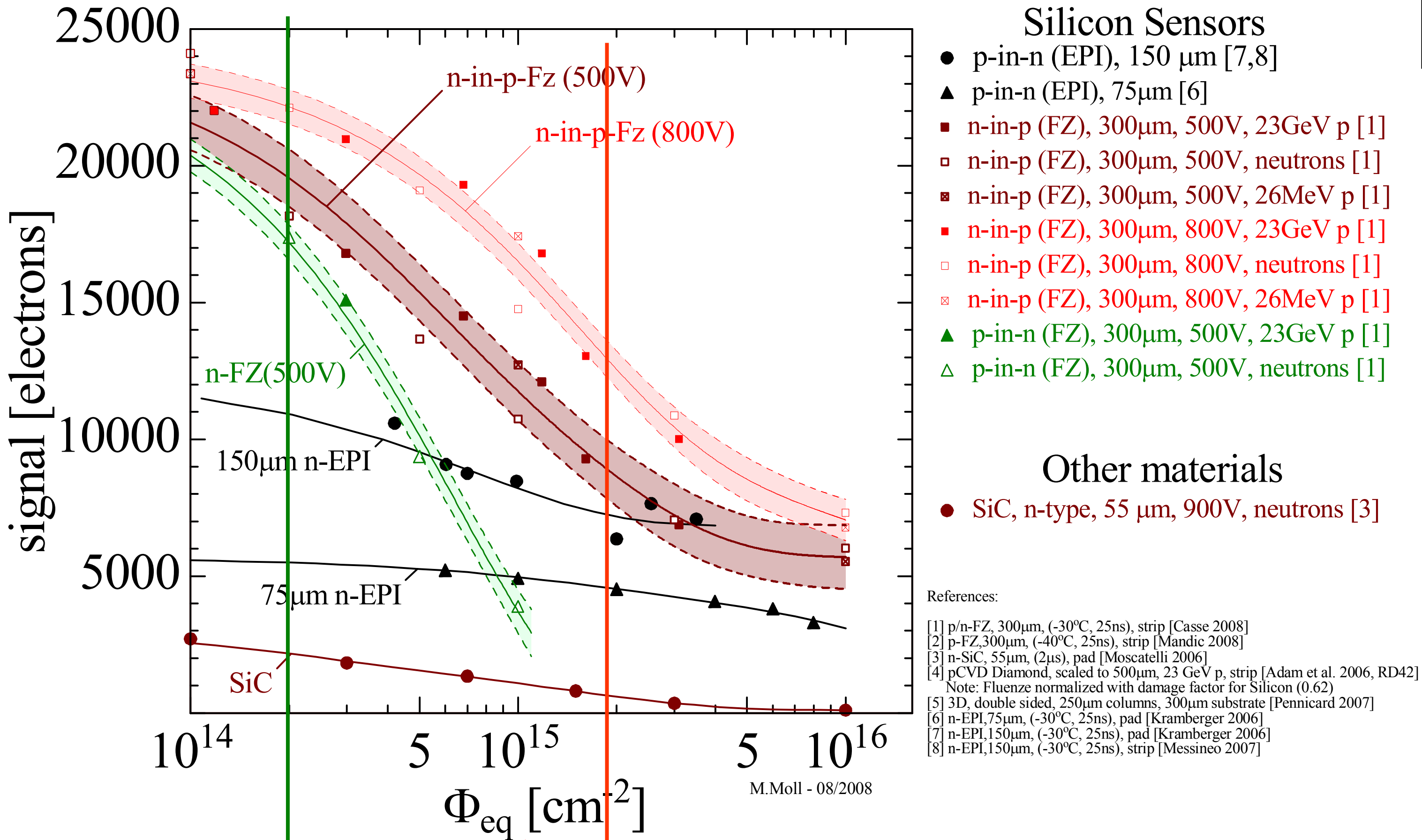
References:

[1] p/n-FZ, 300µm, (-30°C, 25ns), strip [Casse 2008]
[2] p-FZ,300µm, (-40°C, 25ns), strip [Mandic 2008]
[3] n-SiC, 55µm, (2µs), pad [Moscatelli 2006]
[4] pCVD Diamond, scaled to 500µm, 23 GeV p, strip [Adam et al. 2006, RD42]
Note: Fluenze normalized with damage factor for Silicon (0.62)
[5] 3D, double sided, 250µm columns, 300µm substrate [Pennicard 2007]
[6] n-EPI,75µm, (-30°C, 25ns), pad [Kramberger 2006]
[7] n-EPI,150µm, (-30°C, 25ns), pad [Kramberger 2006]
[8] n-EPI,150µm, (-30°C, 25ns), strip [Messineo 2007]

RD50 Silicon materials for Tracking Sensors

- **Signal comparison for various Silicon sensors**

Note: Measured partly under different conditions! Lines to guide the eye (no modeling)!



LHC → **SLHC**

highest fluence for strip detectors in LHC: The used p-in-n technology is sufficient

n-in-p technology should be sufficient for Super-LHC at radii presently (LHC) occupied by strip sensors

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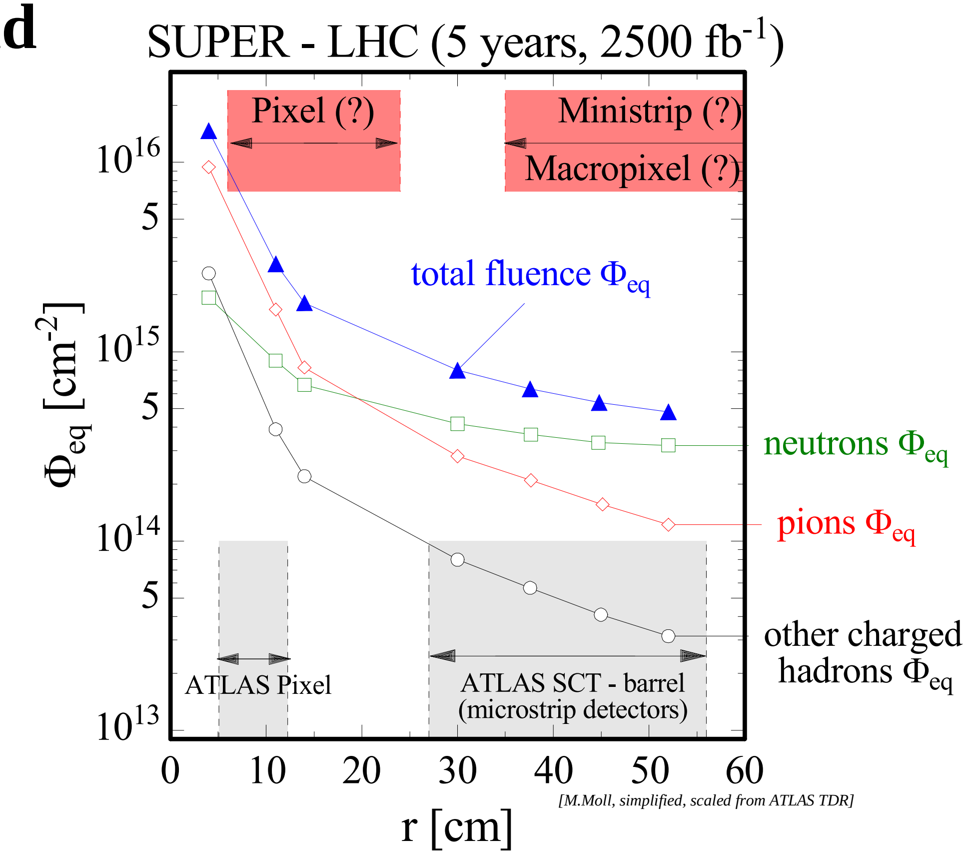
"Mixed Irradiations"

- **LHC Experiments radiation field is a mix of different particles**

  (in particular: charged hadrons ⇔ neutrons)

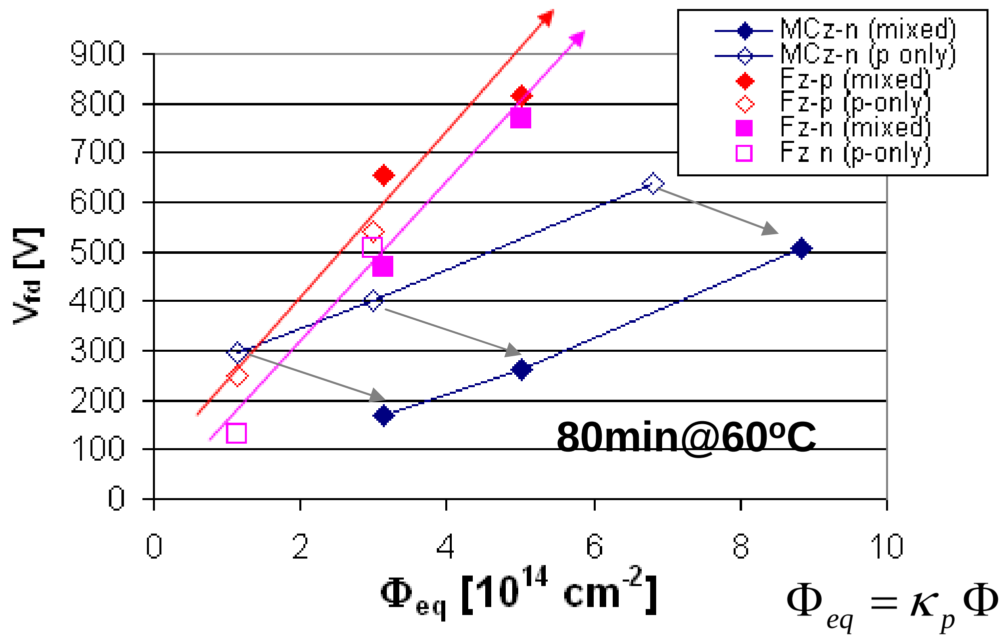
- **MCZ silicon has shown an interesting behavior:**
  - **build up of net negative space charge after neutron irradiation**
  - **build up of net positive space charge after proton irradiation**

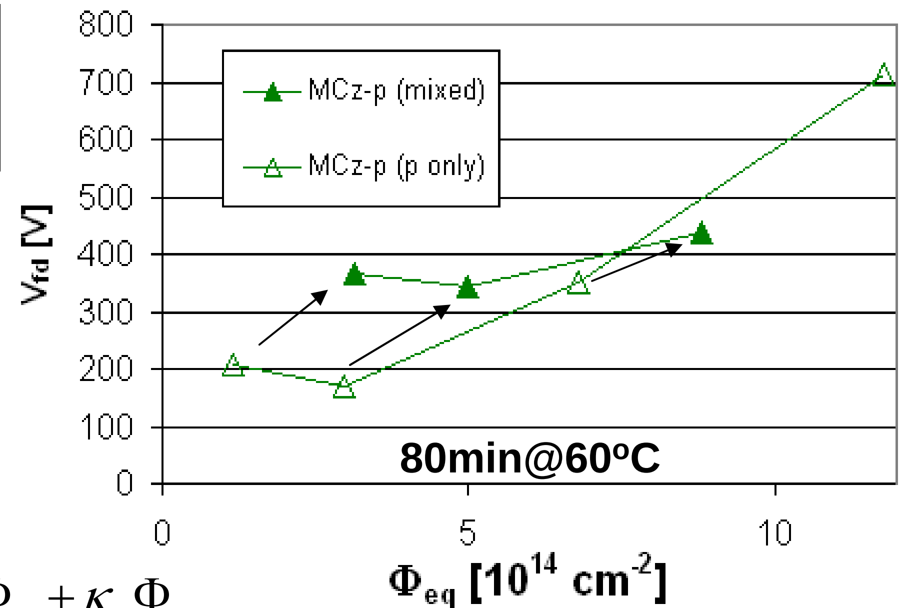


- **Question:**
  - **What happens when (MCZ) detectors are exposed to a 'mixed' radiation field?**

RD50 Mixed irradiations: 23 GeV protons+neutrons

Micron diodes irradiated with protons first and then with 2e14 n cm^{-2} (control samples p-only, open marker)





$$\Phi_{eq} = \kappa_p \Phi_p + \kappa_n \Phi_n$$

$$N_C = g_{c,p} \Phi_{eq,p} + g_{c,n} \Phi_{eq,n}$$

g_c can be + or -

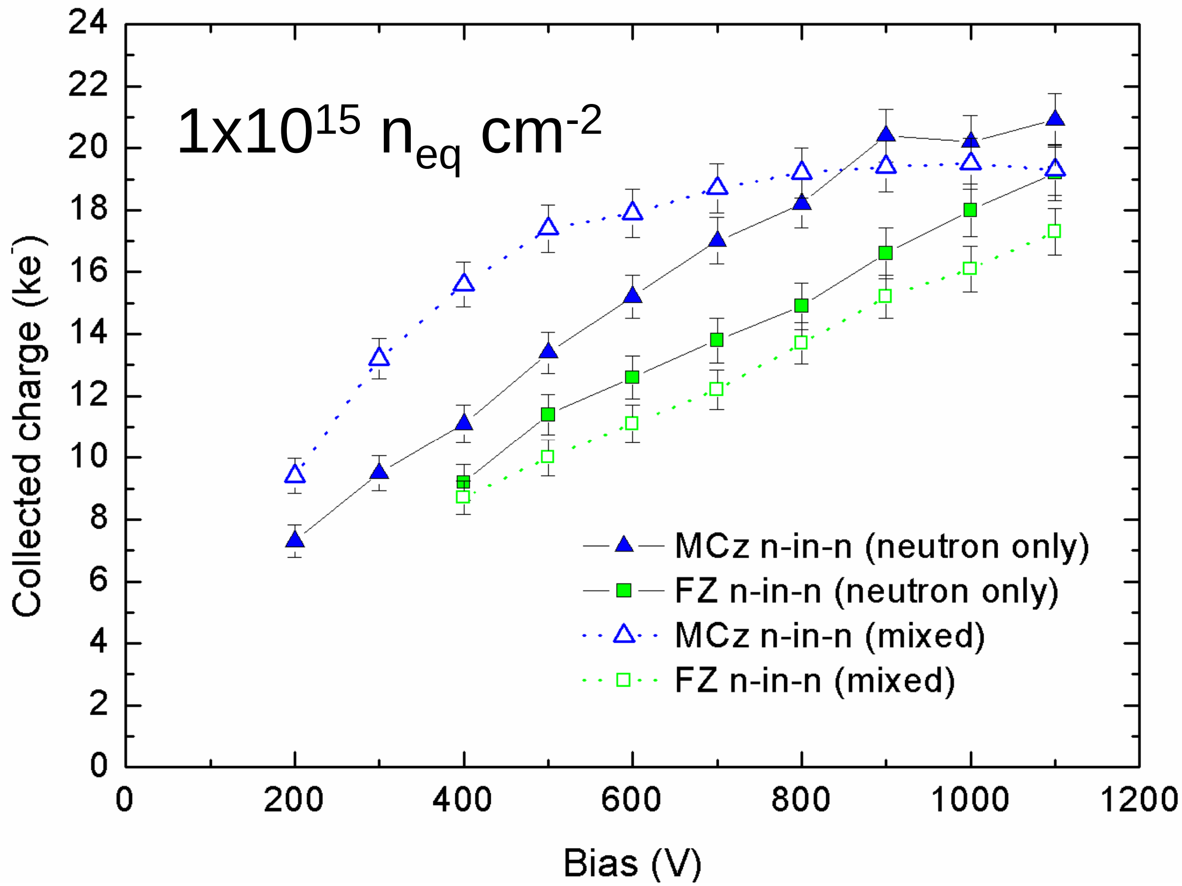
always +

- FZ-p,n: increase of V_{fd} proportional to Φ_{eq}
- MCz-n: decrease of V_{fd} , due to different signs of $g_{c,n}$ and $g_{c,p}$
- **MCz-p at larger fluences the increase of V_{fd} is not proportional to the added fluence –as if material becomes more "n-like" with fluence – same as observed in annealing plots**

RD50 Mixed Irradiations (Neutrons+Protons)

- **Both FZ and MCz show "predicted" behaviour with mixed irradiation**

  - **FZ doses add**
    - $|N_{eff}|$ increases
  - **MCz doses compensate**
    - $|N_{eff}|$ decreases



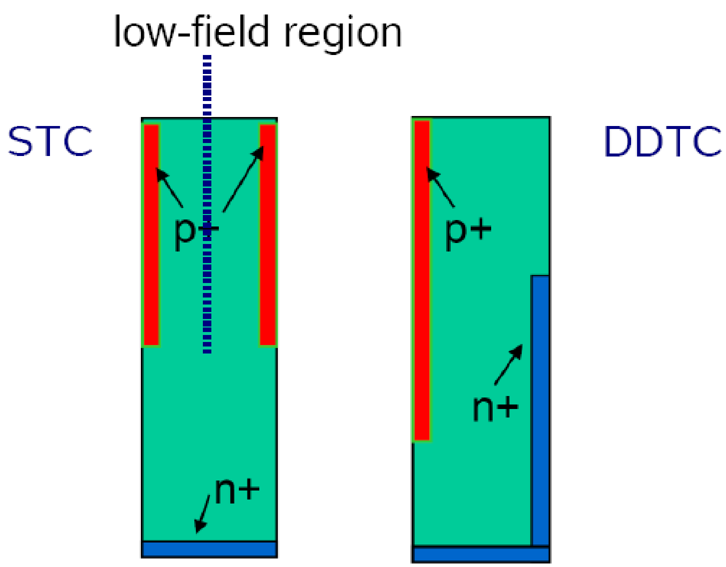
Needs further study with both nMCz and pMCz substrates and differing mixed doses

[T.Affolder 13th RD50 Workshop, Nov.2008]

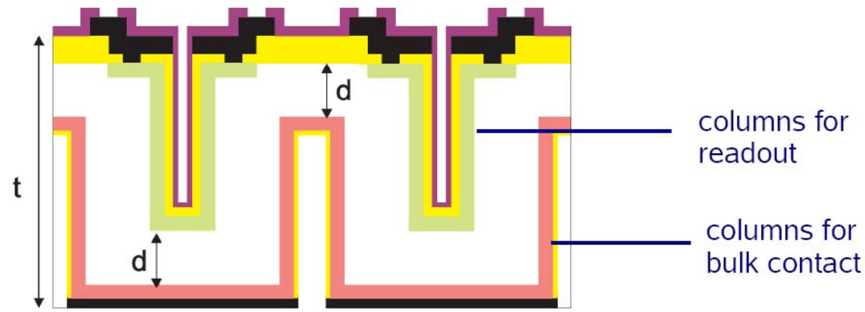
Development of 3D detectors

- **"3D" electrodes:** **- narrow columns along detector thickness,**
  - diameter: 10µm, distance: 50 - 100µm
- **Lateral depletion:** **- lower depletion voltage needed**
  - thicker detectors possible
  - fast signal
  - radiation hard

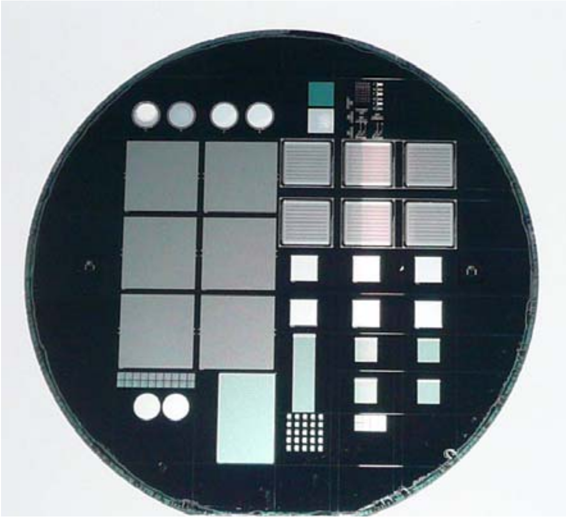
From STC to DTC

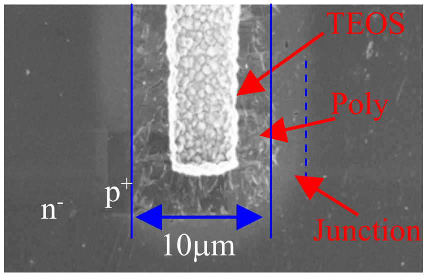


- DDTC: "double-sided double type columns"
- Columnar electrodes of both doping types are etched into the detector from both wafer sides
- Columns are not etched through the entire detector
  - Charge collection expected to be similar to "full 3D" detectors, but the fabrication process is much simpler



Processing of Double-Column 3D detectors





1. CNM Barcelona (2 wafers fabricated in Nov. 2007)

- **Double side processing with holes not all the way through**
- **n-type bulk**
- **Next step: - dice and test 1 wafer**
  - bump bond 1 wafer to Medipix2 chips
- **Further production (n and p-type) to follow)**

2. FBK (IRST-Trento)

- **very similar design to CNM**
- **2 batches under production (n-type and p-type)**

- **First tests on irradiated devices performed (CNM devices, strip sensors, 90Sr , Beetle chip, $5*10^{15} n_{eq}/cm^2$ with reactor neutrons) : 12800 electrons**

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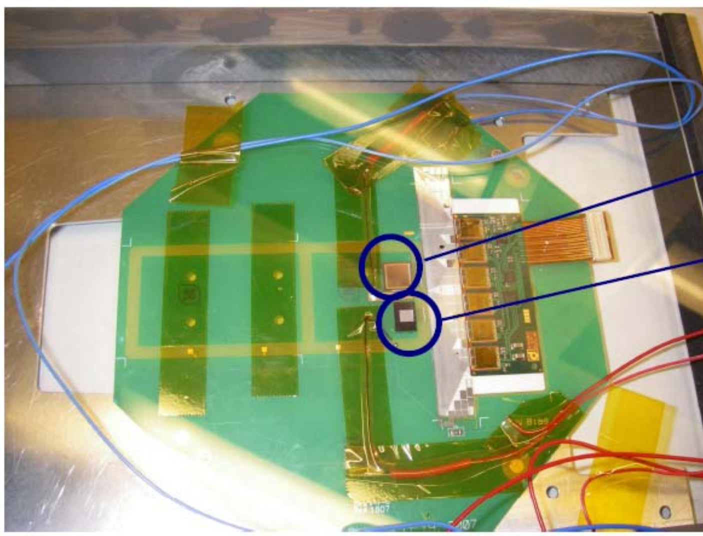
2008 test beam with 3D sensors

- Two microstrip 3D DDTC detectors tested in testbeam (CMS/RD50)
  - One produced by CNM (Barcelona), studied by Glasgow
  - One produced by FBK-IRST (Trento), studied by Freiburg

- Readout: APV25, as used in CMS tracker
  - Analogue readout (40 MHz), 50 ns shaping time
  - Trigger accepted during the entire 25 ns clock window (no TDC), but sampling of the signal always at the same time

    → Average detected signal expected to be ≈ 10% lower



[M.Koehler 13th RD50 Workshop, Nov.2008]

RD50 3DDTC sensors (test beam – first data)

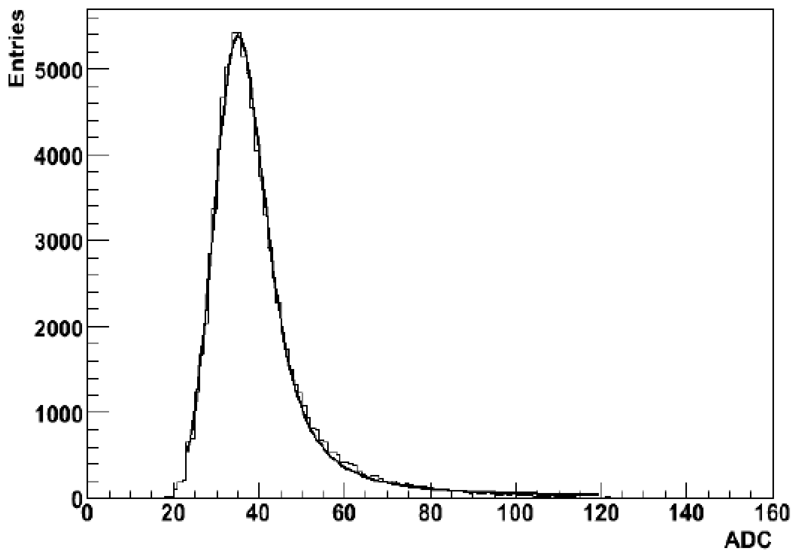
Landau distribution

- ADC distribution with fit of a convoluted Landau and Gaussian

- Bias voltage: 40 V, SNR ≥ 10
- Result:

Landau MP= (33.32±0.02) ADC counts

- Calibration ADC counts → charge so far not available
- Histogram contains data from all bonded strips (not position resolved)



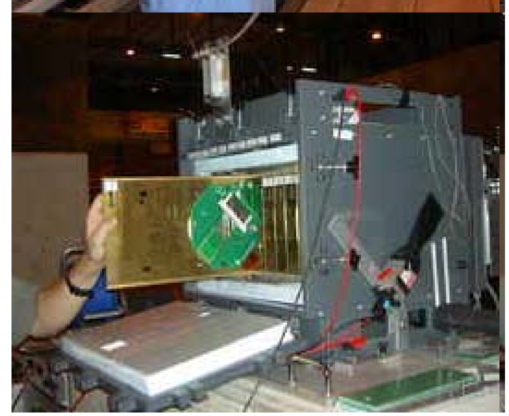
[M.Koehler 13th RD50 Workshop, Nov.2008]

Test beam results of heavily irradiated magnetic Czochralski silicon (MCz-Si) strip detectors

P. Luukka, J. Härkönen, T. Mäenpää, B. Betchart, S. Bhattacharya, S. Czellar, R. Demina, A. Dierlamm, Y. Gotra, M. Frey, F. Hartmann, A. Kaminskiy, V. Karimäki, T. Keutgen, S. Korjenevski, M.J. Kortelainen, T. Lampén, V. Lemaitre, M. Maksimow, O. Militaru, H. Moilanen, M. Neuland, H.J. Simonis, L. Spiegel, E. Tuominen, J. Tuominiemi, E. Tuovinen, H. Viljanen

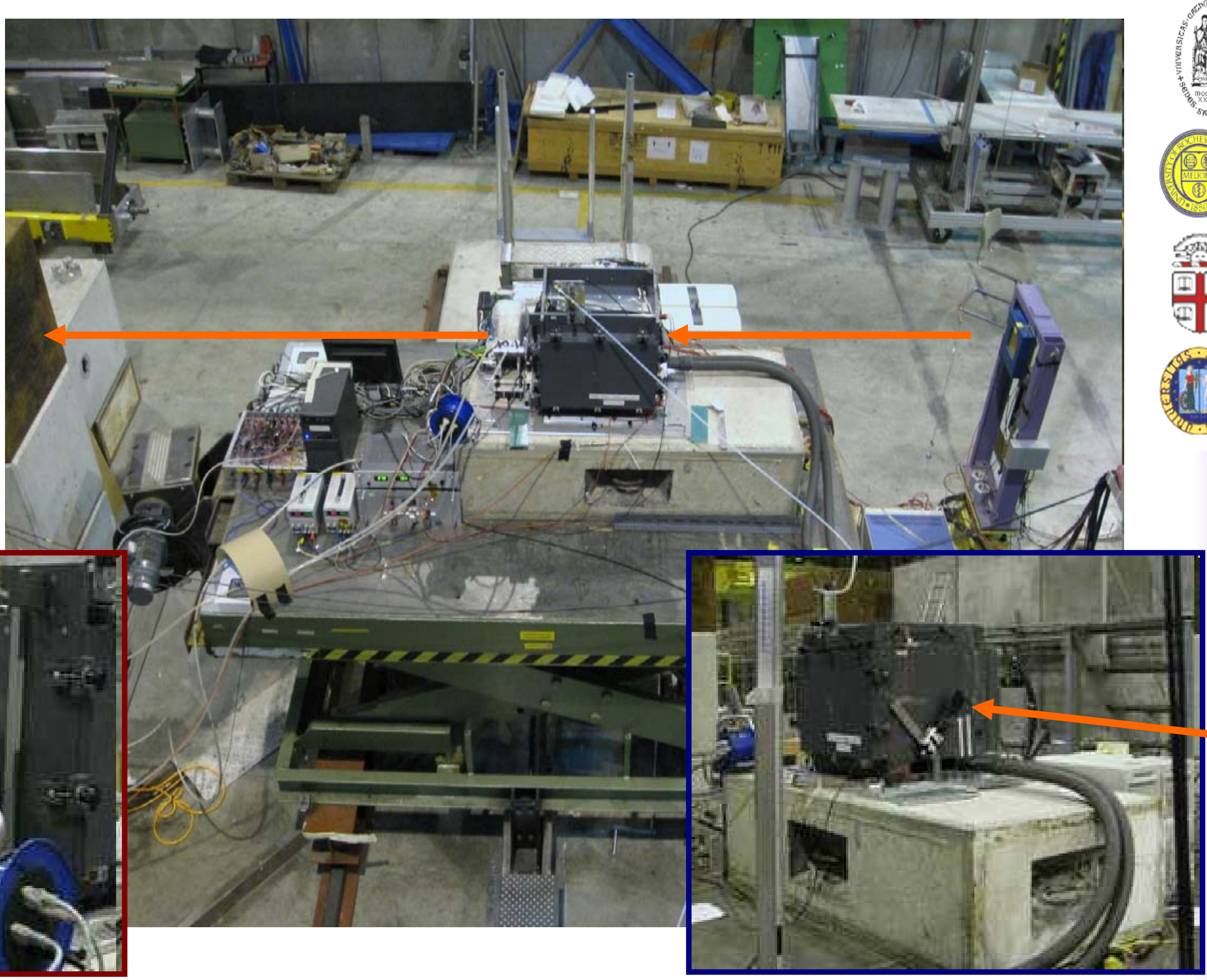
Telescope setup

- The telescope reference planes + detectors under test are housed inside a cold chamber, in which the temperature can be adjusted by two water cooled 350 W Peltier elements.
- Reference planes are installed to ±45 degrees (due to the height limitation)
- Reference detectors are D0 Run IIb HPK sensors with:
  - 60 micron pitch and intermediate strips
  - size 4 cm x 9 cm
  - 639 channels
- Readout electronics: CMS 6-APV chip Tracker Outer Barrel hybrids (5 chips bonded)
- DAQ software: a modified version of the CMS Tracker data acquisition software XDAQ

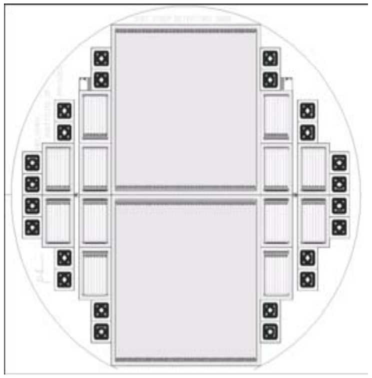


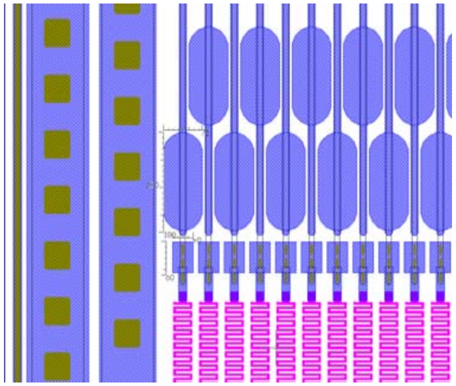
Telescope setup

- An additional cold box was designed for operating very heavily irradiated detectros in cold temperature
- The box can reach a temperature of -52°C.

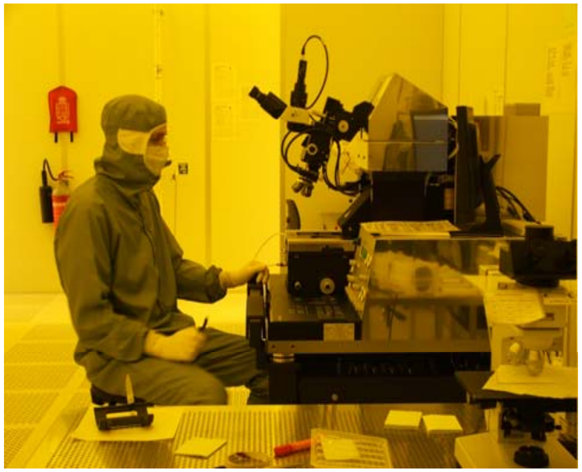


MCz-Si detectors



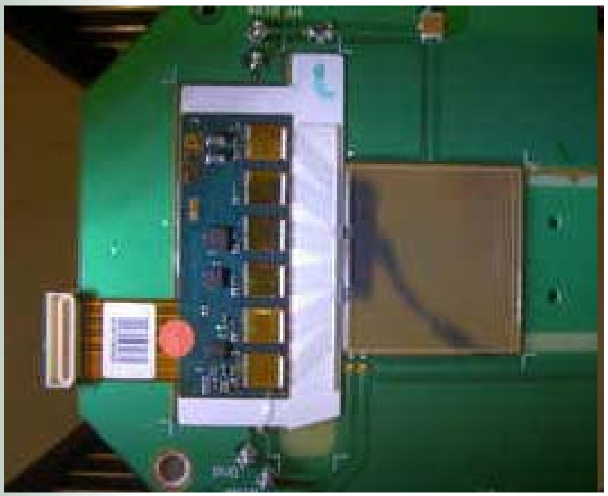


- Detector processing was done at the clean room of Helsinki University of Technology (TKK) Micro and Nanofabrication Centre (MINFAB)
  - Materials: n-type Magnetic Czochralski (Okmetic Ltd., Finland) wafers and n-type Float Zone wafers (Topsil, RD50 common order)
  - Detector characteristics:
    - AC-coupled
    - 4.1×4.1 cm^2 area
    - 50 µm pitch
    - strip width 10 µm, strip length 3.9 cm
    - 768 strips per detector (=6*128)
    - Designed for CMS (APV) readout
  - MCz detectors depleted with 330 V, Fz sensors with 10 V prior to the irradiation.



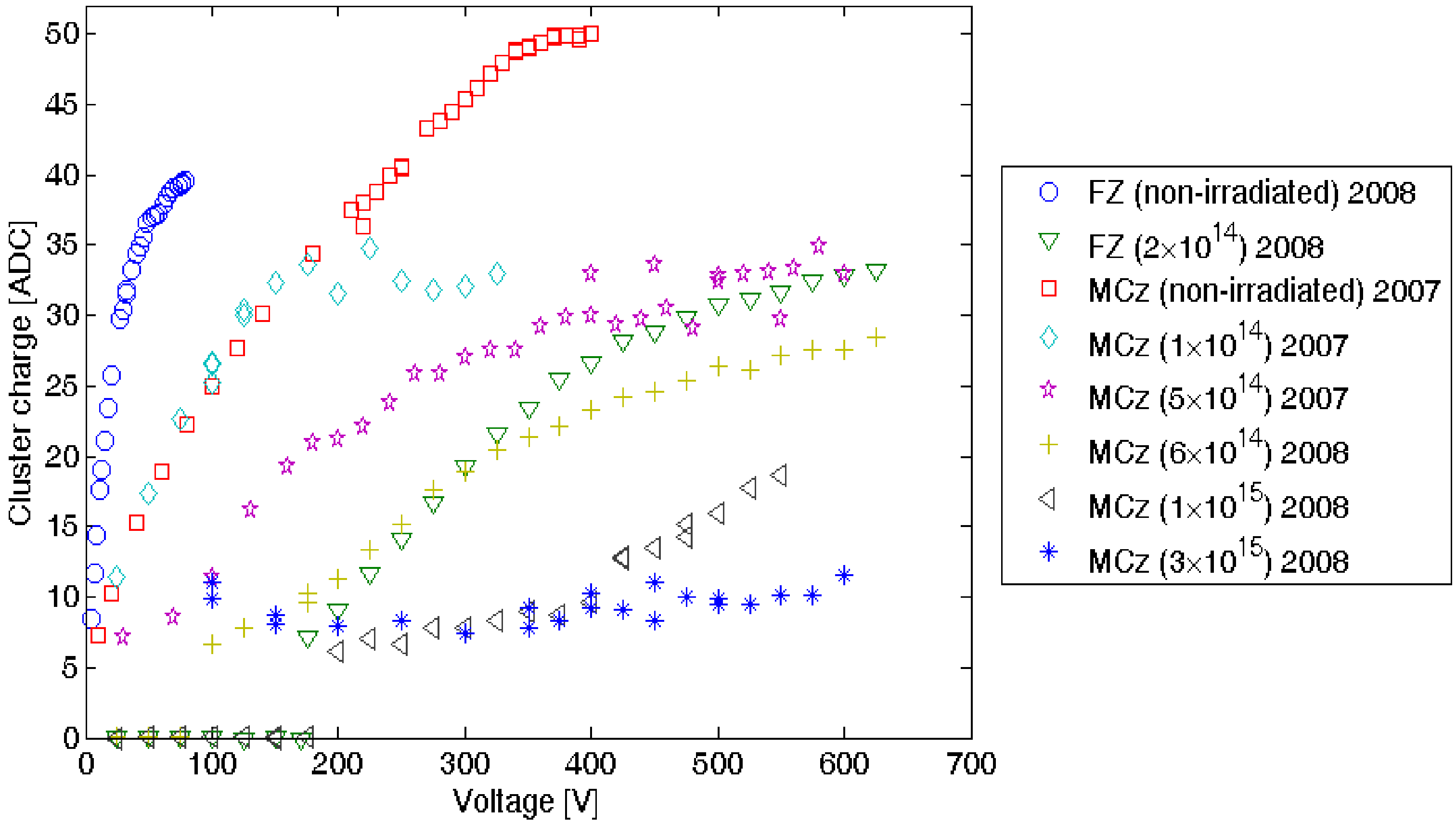
Irradiations

- The detectors were irradiated to the fluences ranging from 2×10^{14} to 3×10^{15} 1 MeV n_{eq}/cm^2 with 26 MeV protons in Karlsruhe and 3 MeV – 45 MeV neutrons (average spectrum 20 MeV) in Louvain.

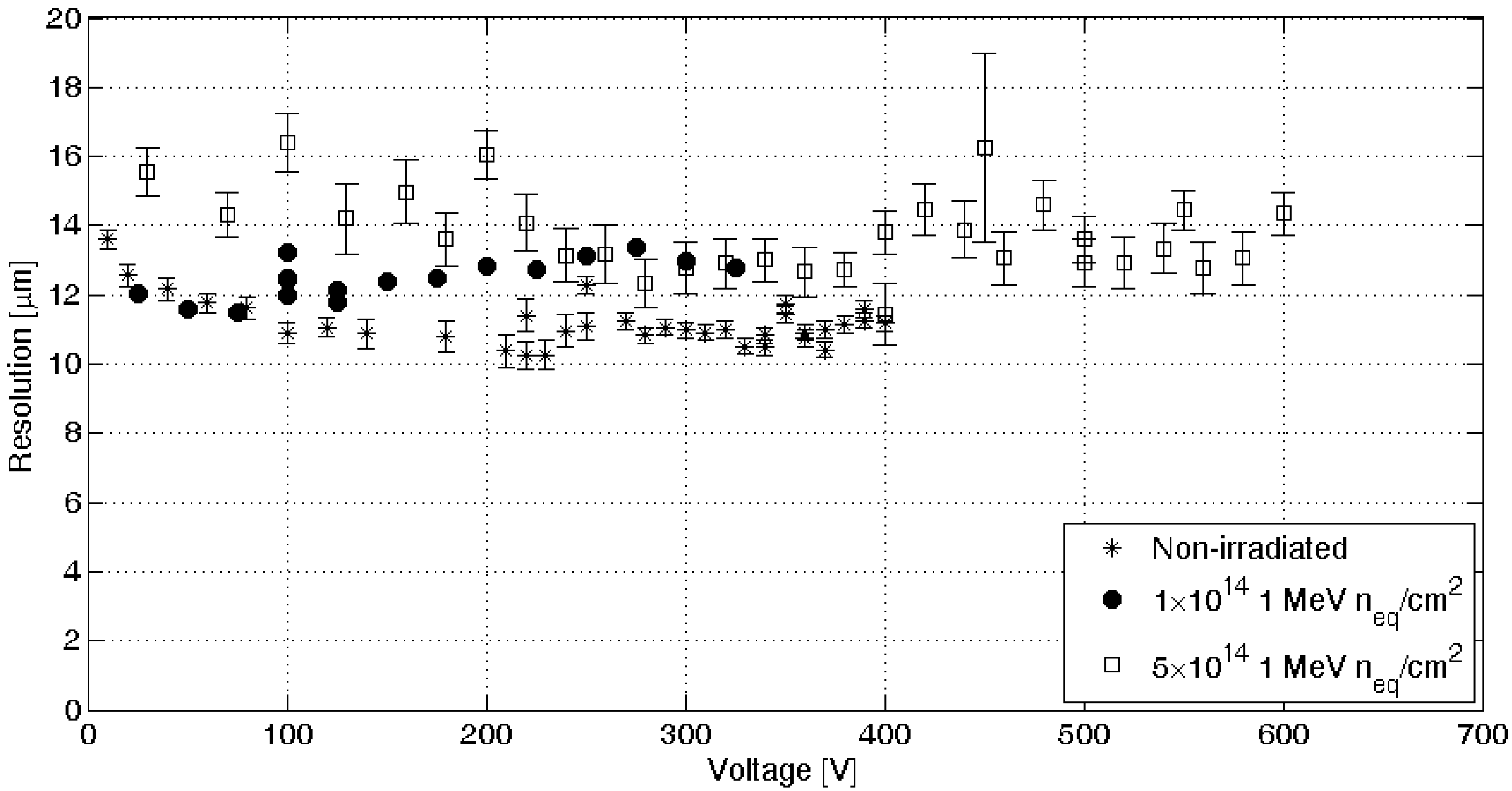


Irradiation fluences		
Material	Fluence	n/p
MCz	$6.1\times10^{14}\pm20\%$	n/p mix
MCz	$1.1\times10^{15}\pm20\%$	n/p mix
MCz	$1.6\times10^{15}\pm20\%$	n/p mix
MCz	$2.8\times10^{15}\pm20\%$	p
MCz	non-irradiated	
Fz	$2.4\times10^{14}\pm20\%$	p
Fz	non-iradiated	

Test beam results (results from 2007 included)



Detector resolutions (2007 data)



- The resolution doesn't seem to change much with the irradiation.
- This is most probably due to so-called double junction effect.

Conclusions

- N-type MCz-Si strip detectors have an acceptable S/N at least up to the fluence of 1×10^{15} 1 MeV n_{eq}/cm^2.

- Thus, n-type MCz-Si detectors are a feasible option for the outer strip layers of the SLHC CMS tracker.
- After the fluence of 3×10^{15} 1 MeV n_{eq}/cm^2 the collected signal is approximately 20 % of the signal of a non-irradiated device.

Latest results of RD39 collaboration

1. Trapping effect on Charge Collection Efficiency (CCE) in Super-LHC
2. Operation of current-injected-detectors (CID)
4. Beam test results of CID strip detectors
5. Summary

http://rd39.web.cern.ch/RD39/

Trapping effect on CCE in S-LHC

$$CCE = \frac{Q}{Q_0} = CCE_{GF} \times CCE_t = \frac{w}{d} \times [\frac{\tau_t}{t_{dr}} \cdot (1 - e^{-t_{dr}/\tau_t})]$$

Depletion term → $\frac{w}{d}$

Trapping term → $\frac{\tau_t}{t_{dr}} \cdot (1 - e^{-t_{dr}/\tau_t})$

Overall CCE is product of
- CCE_t is trapping factor
- CCE_{GF} is geometrical factor

$$w = \sqrt{\frac{2\varepsilon\varepsilon_0 V}{eN_{eff}}} \text{ and } \frac{w}{d} = \sqrt{\frac{V}{V_{fd}}}$$

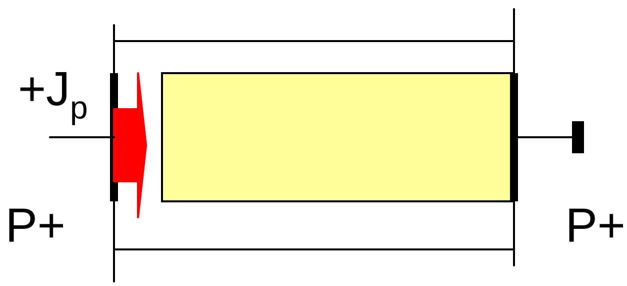
For fluence less than 10^{15} n_{eq}/cm^2, the trapping term CCE_t is not significant

For fluence 10^{16} n_{eq}/cm^2, $\frac{\tau_t}{t_{dr}} << 1$ the trapping term CCE_t is a limiting factor of detector operation !

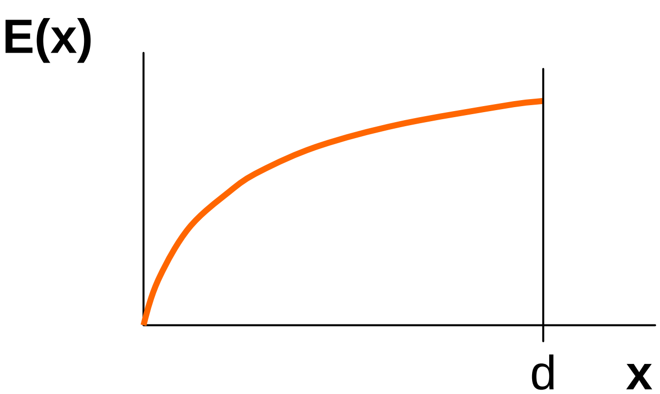
$$Q = Q_0 \cdot CCE \cong Q_0 \cdot \frac{w}{d} \cdot \frac{\tau_t}{t_{dr}} = q_{MIP} \cdot d \cdot \frac{w}{d} \cdot \frac{v_{dr} \cdot \tau_t}{v_{dr} \cdot t_{dr}} = q_{MIP} \cdot v_{dr} \cdot \tau_t = q_{MIP} \cdot d_t$$

- d_t is trapping distance, and it is about 20 μm at 10^{16} n_{eq}/cm^2 for non-CID detectors
- q_{MIP} is unit charge/ μm for MIP in Si = 80 e's/ μm

Current injected detector
(principle of operation)



$J_p = ep\mu E$
$divJ=0$
$divE=p_{tr}$
$E(x=0) = 0$ (SCLC mode)



$$j = \theta \varepsilon \varepsilon_0 \mu \frac{V^2}{d^3}$$

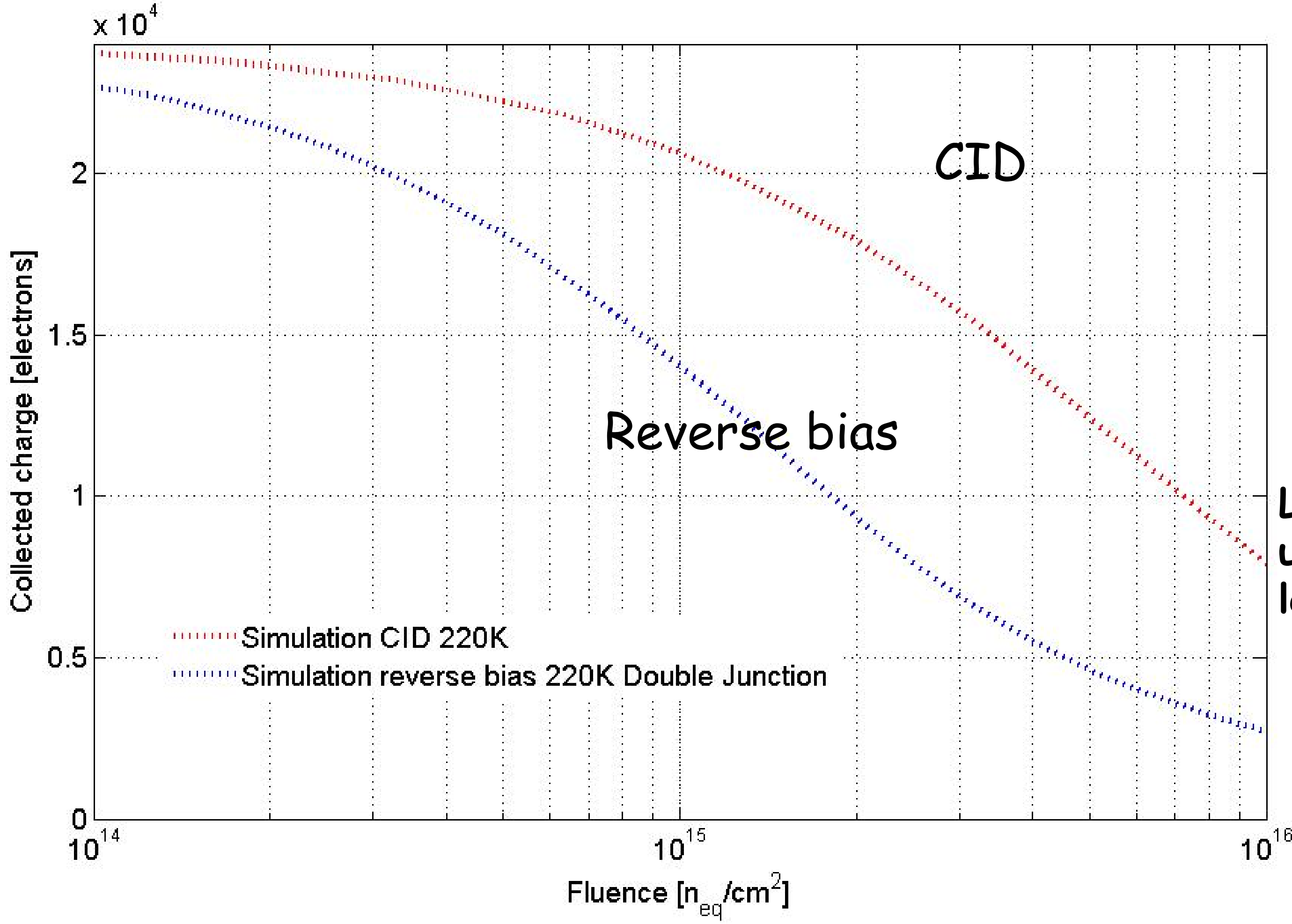
$$E = \sqrt{\frac{2j}{\varepsilon \varepsilon_0 \mu}} x^{1/2}$$

The key advantage:

The shape of ***E(x)*** is ***not affected*** by N_{mgl}, and ***stable*** at any fluence

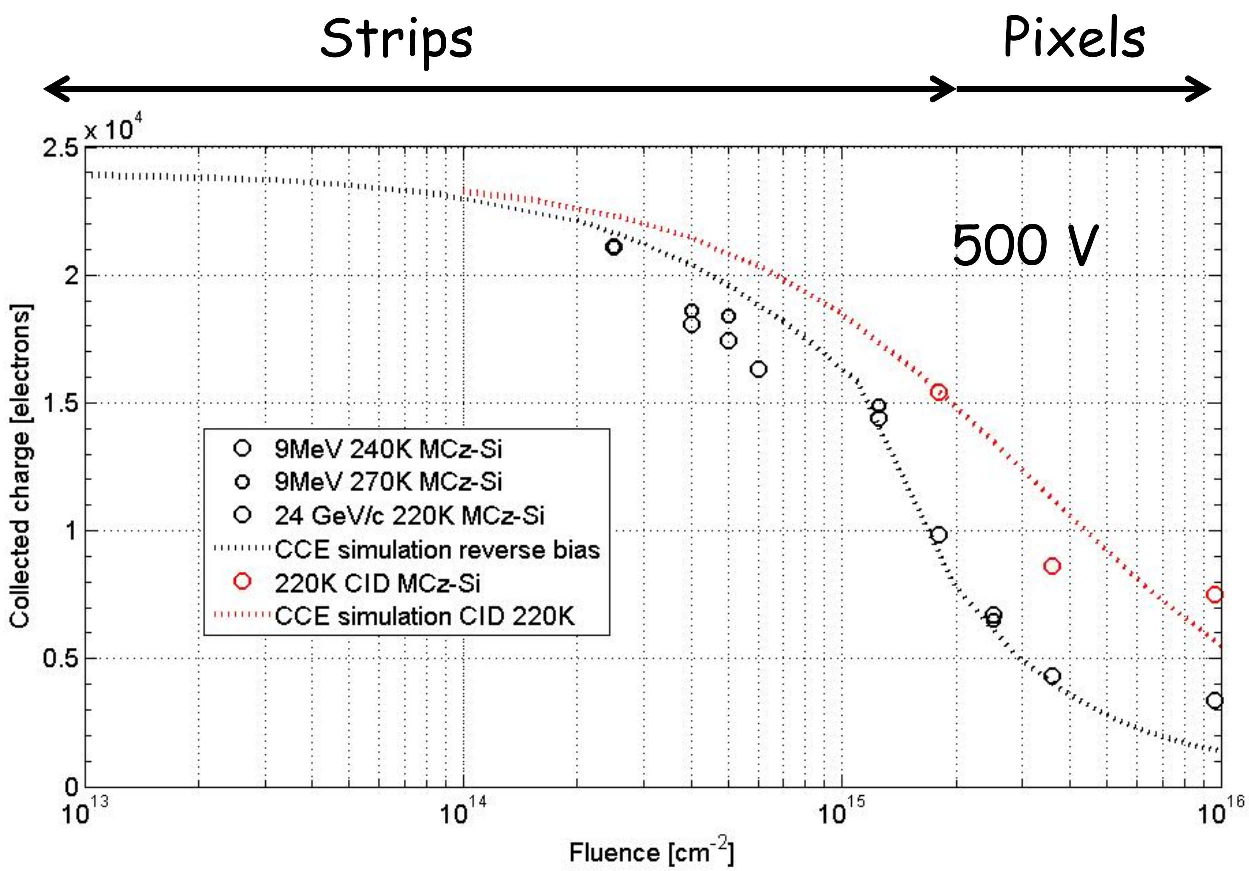
CCE of strip detectors as a function of fluence

Pitch =80 μm, width =20 μm



Larger τ_t
used to fit CID data
less trapping in CID

Expected CCE of CID at -50°C

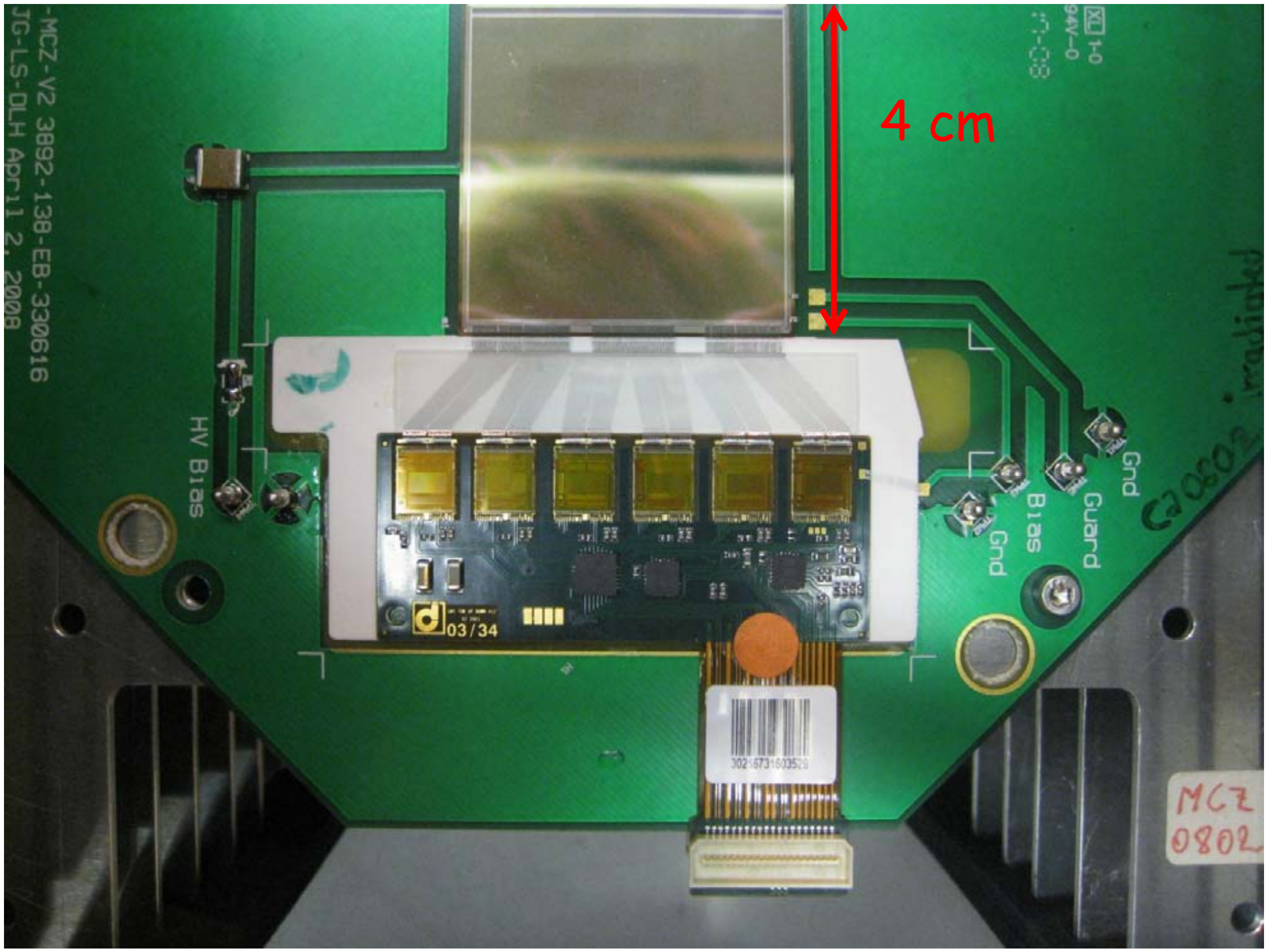


- Simulation takes into account linear dependence of trapping probability on fluence
- β=0.01 cm^{-1}
- √x E-field distribution is assumed

$$E_{pin} \propto \left(1 - \frac{x}{w}\right)$$

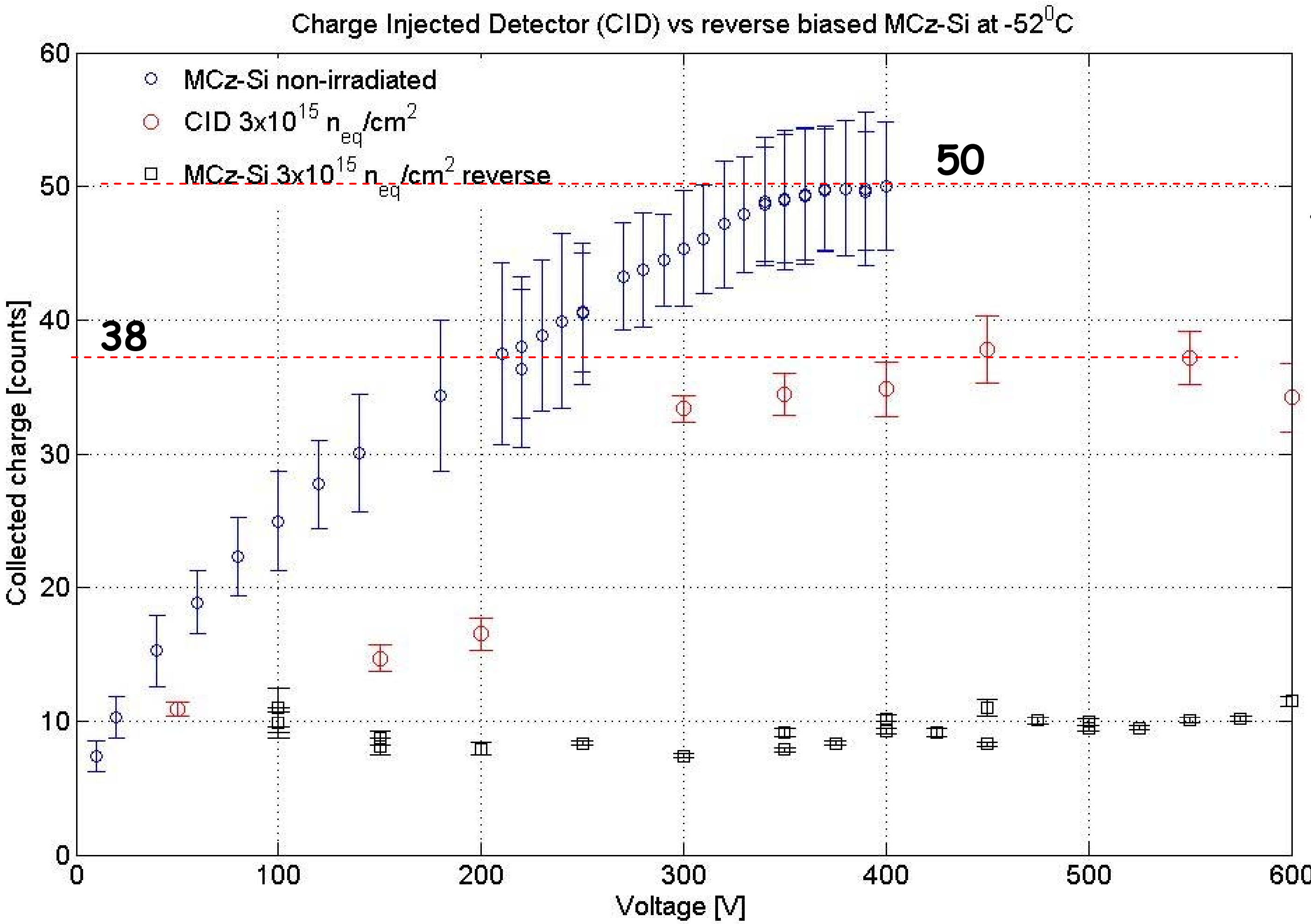
$$E_{CID} \propto \sqrt{x}$$

CID, irradiated up to $3 \times 10^{15}\ n_{eq}/cm^2$



- MCz-Si AC-coupled strip detector with 768 channels
- APV25 readout
- Fabrication of detector and pitch adapter by HIP @ Helsinki University of Technology, Micronova
- Irradiation with 26 MeV protons @ University of Karlsruhe
- Bonding @ University of Karlsruhe

CID strip detector test beam results –CCE at -52⁰C



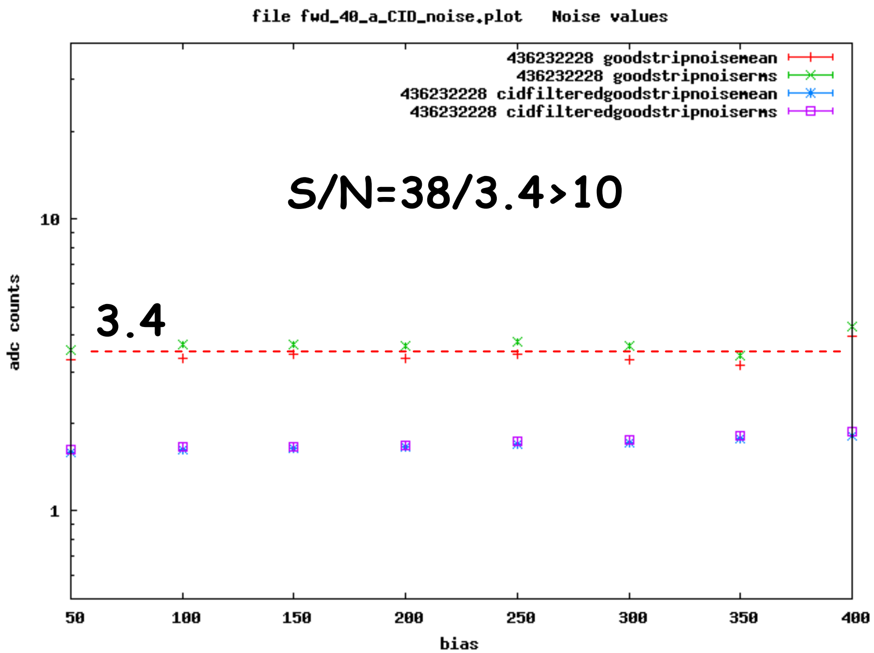
fluence (n_{eq}/cm^2)

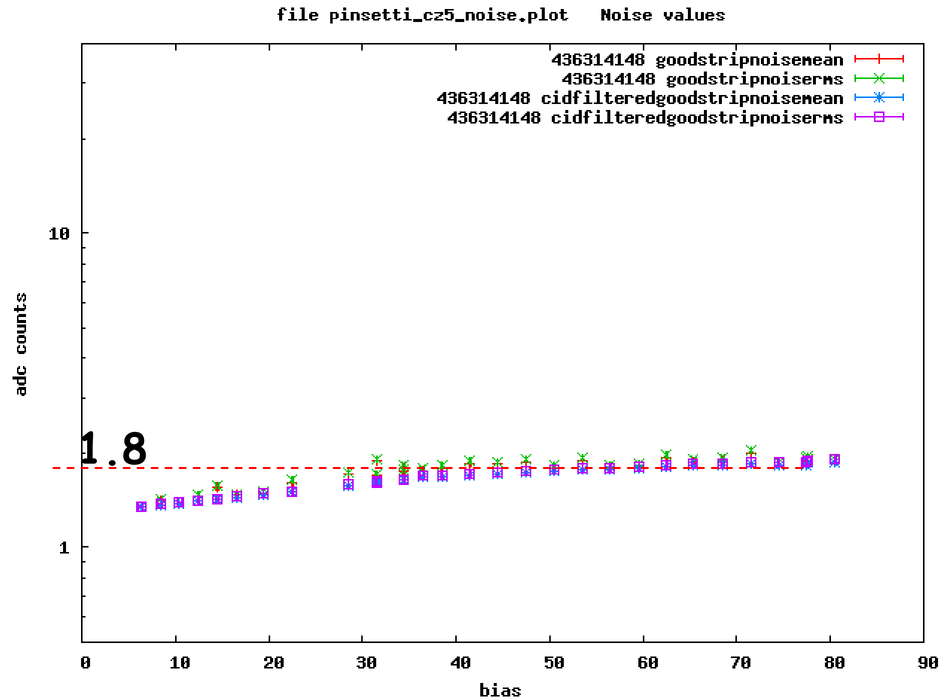
$3x10^{15}$ → $1x10^{16}$

75% → 22.5% (5400 e's)

20% → 6% (1440 e's)

Noise of CID and non-irradiated detector



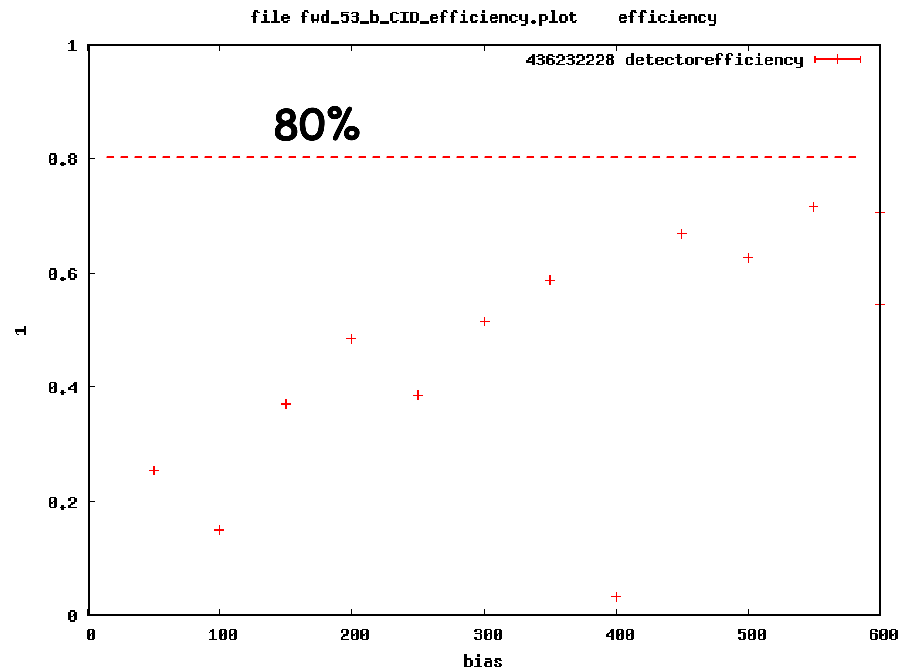


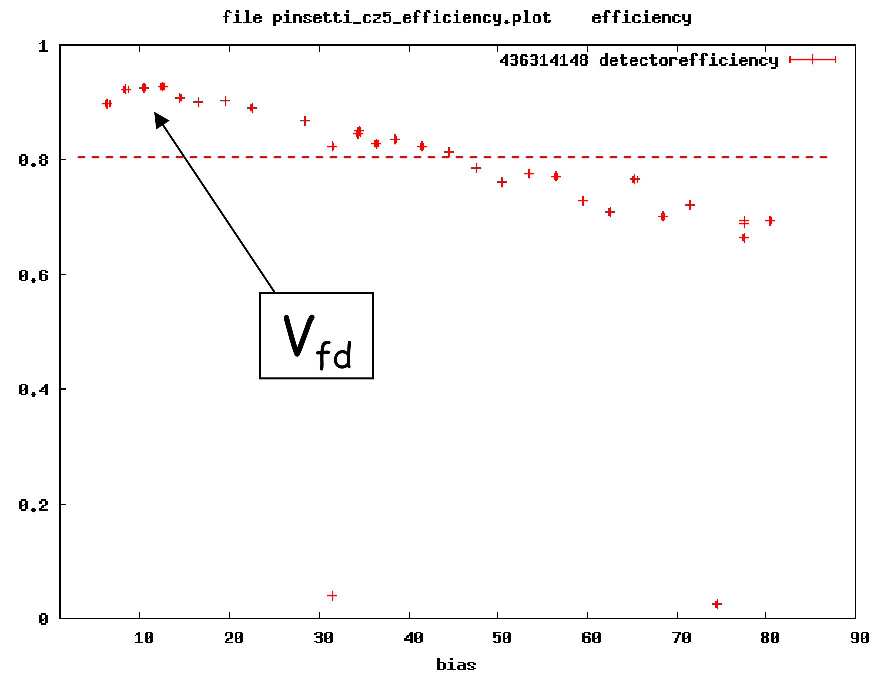
CID noise at -40 °C
Little change with T (-53 to -40 ° C)

Reference detector noise at -20°C

Fz-Si $p^+/n^-/n^+$, same design, same processing, V_{fd}~10V

Tracking efficiency of CID vs reference





CID at -53°C

Reference Fz-Si at -20°C

Tracking efficiency = probability that DUT measures the same track as the reference telescope

Conclusions

- CID offers: full depletion and less trapping
- At least two times greater CCE is expected from CID than in reverse biased detectors according to measurements and simulations.
- Normal detector operation possible with 300μm MCz-Si up to 1-2×10^{15} n_{eq}/cm^2 fluence, i.e. strip layers in Super-LHC trackers.
- CID was measured at -40°C, -45°C and -53°C (768 channels AC-coupled MCz-Si strip detector) in test beam.
- Test beam results reveal >70% CCE, and S/N >10 after 3×10^{15} n_{eq}/cm^2 irradiation.
- Test beam was performed with CMS electronics and DAQ (SiBT).
- CID operation possible up to 1×10^{16} n_{eq}/cm^2 fluence.
- Collected charge equals ≈7000e^- and 30% at this fluence.