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Recent RD50 Developments on Radiation Tolerant Silicon Sensors

Michael Moll (CERN-PH-DT)

OUTLINE

- Motivation, RD50 work program
- Radiation Damage in Silicon Sensors (1 slide)
- Silicon Materials (MCZ, EPI, FZ) (2 slides)
- Recent results and future plans on
    - Pad detectors (diode structures)
    - Strip detectors (segmented structures)
    - 3D detectors
- Summary

Motivation for R&D on Radiation Tolerant Detectors: Super - LHC

- **LHC upgrade**

⇨ **LHC (2008)** **L = 10^{34}cm^{-2}s^{-1}**

10 years → ϕ(r=4cm) ~ $3\cdot10^{15}$cm^{-2}
500 fb^{-1}

× 5

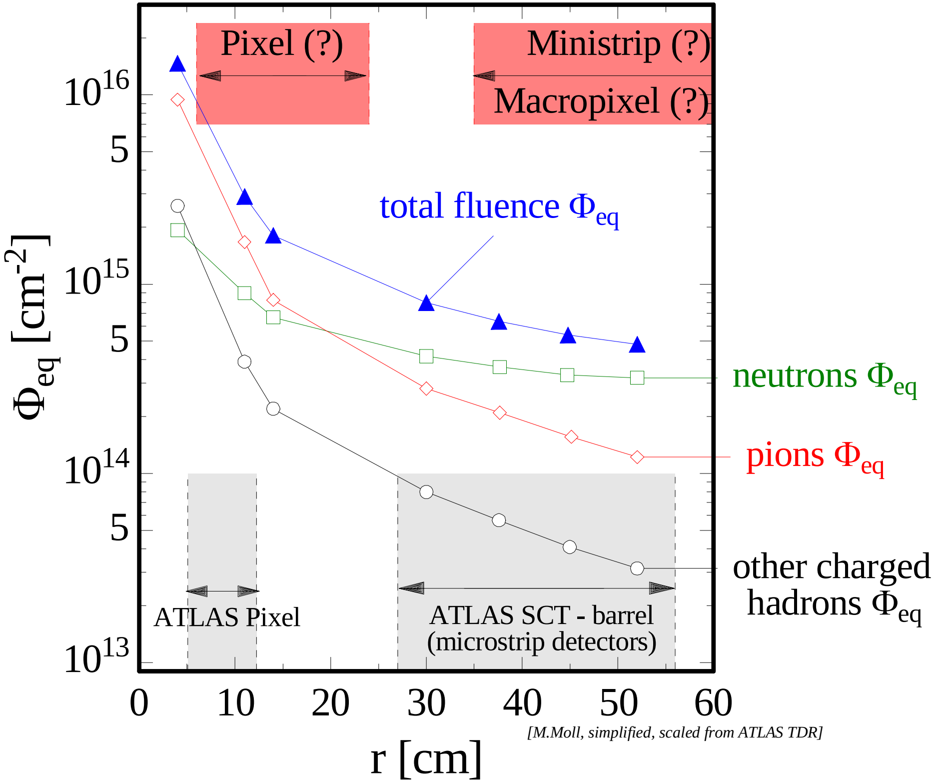
⇨ **Super-LHC (2018 ?)** **L = 10^{35}cm^{-2}s^{-1}**

5 years → ϕ(r=4cm) ~ $1.6\cdot10^{16}$cm^{-2}
2500 fb^{-1}

- **LHC (Replacement of components)**

e.g. - LHCb Velo detectors
- ATLAS Pixel B-layer

SUPER - LHC (5 years, 2500 fb^{-1})



[M.Moll, simplified, scaled from ATLAS TDR]

SLHC compared to LHC:

- **Higher radiation levels ⇨ Higher radiation tolerance needed!**
- **Higher multiplicity ⇨ Higher granularity needed!**

⇔

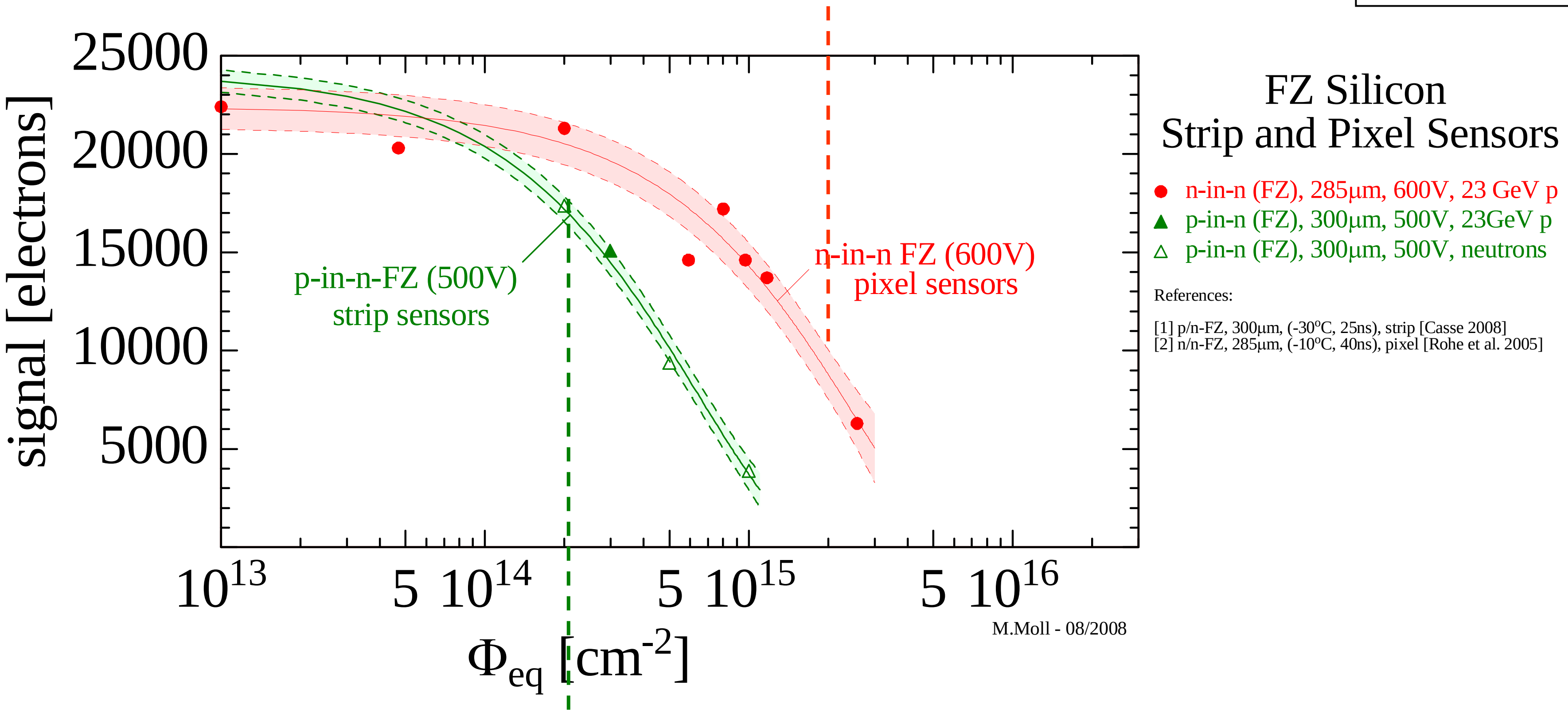
Power Consumption ?
Cooling ?
Connectivity
Low mass ?
Costs ?

⇨ Need for new detectors & detector technologies

RD50 Signal degradation for LHC Silicon Sensors

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

Pixel sensors:
max. cumulated fluence for LHC

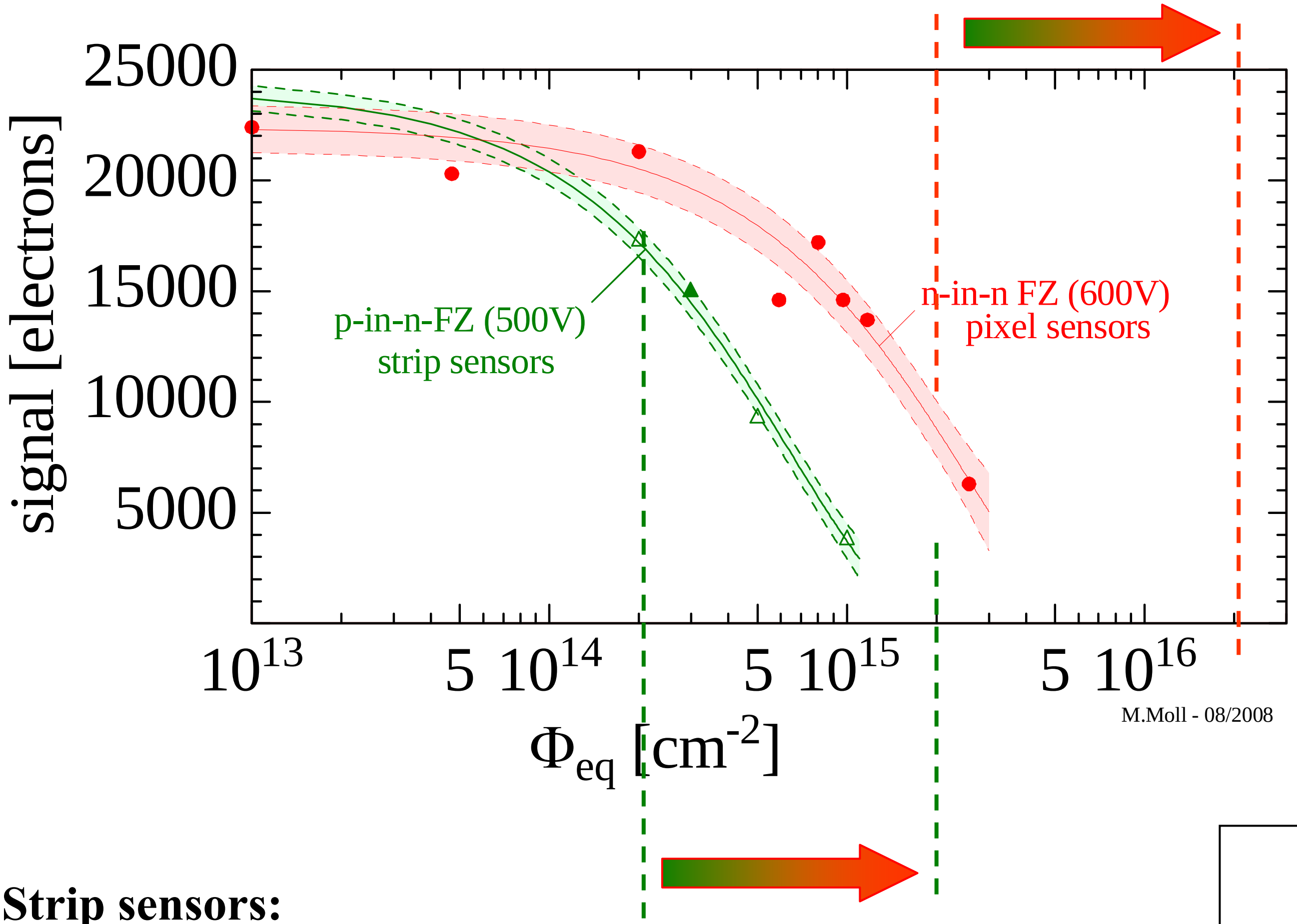


Strip sensors:
max. cumulated fluence for LHC

RD50 Signal degradation for LHC Silicon Sensors

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

Pixel sensors:
max. cumulated fluence for LHC and SLHC



FZ Silicon
Strip and Pixel Sensors

- ● n-in-n (FZ), 285µm, 600V, 23 GeV p
- ▲ p-in-n (FZ), 300µm, 500V, 23GeV p
- △ p-in-n (FZ), 300µm, 500V, neutrons

References:

[1] p/n-FZ, 300µm, (-30°C, 25ns), strip [Casse 2008]
[2] n/n-FZ, 285µm, (-10°C, 40ns), pixel [Rohe et al. 2005]

Strip sensors:
max. cumulated fluence for LHC and SLHC

SLHC will need more radiation tolerant tracking detector concepts!

Radiation Damage in Silicon Sensors

- **Two general types of radiation damage:**

- **Bulk (Crystal) damage due to Non Ionizing Energy Loss (NIEL)**
  - displacement damage, built up of crystal defects –

Influenced by impurities in Si – Defect Engineering is possible!

I. Change of effective doping concentration

⇒ type inversion, higher depletion voltage, under-depletion

⇒ loss of active volume ⇒ decrease of signal, increase of noise

II. Increase of leakage current

⇒ increase of shot noise, thermal runaway, power consumption…

III. Increase of charge carrier trapping

⇒ loss of charge

Same for all tested Silicon materials!

- **Surface damage due to Ionizing Energy Loss (IEL)**
  - accumulation of positive in the oxide (SiO_2) and the Si/SiO_2 interface –

⇒ interstrip capacitance, breakdown behavior, …

- **Impact on detector performance and Charge Collection Efficiency**

(depending on detector type and geometry and readout electronics!)

Can be optimized!

⇒ **Signal/noise ratio is the quantity to watch**

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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**

- **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**

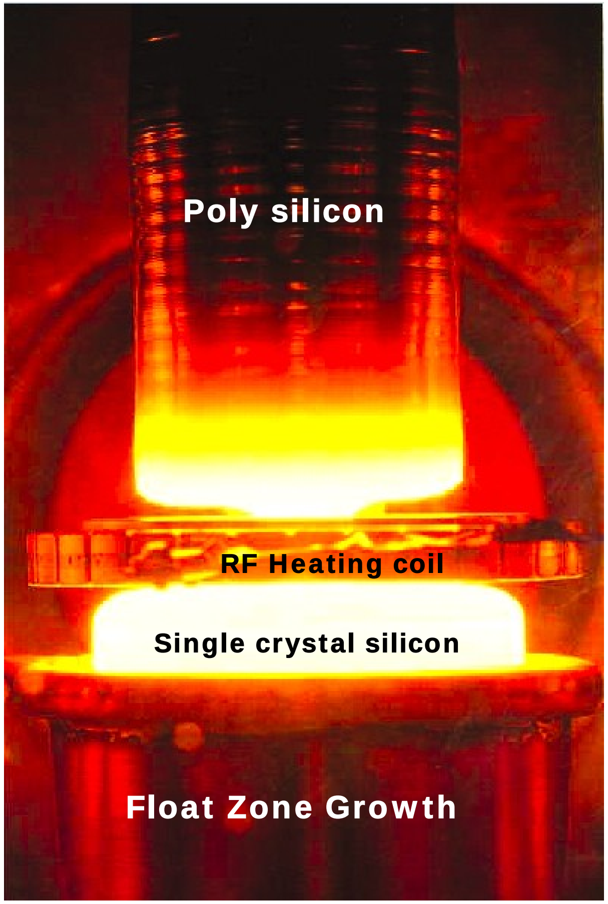
- **Development of test equipment and measurement recommendations**

Related Works – Not conducted by RD50

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

Silicon Growth Processes

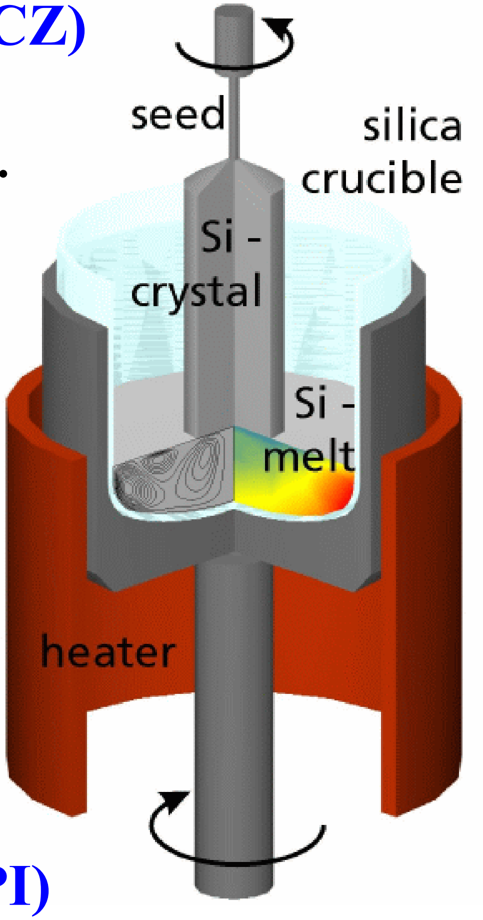
• Floating Zone Silicon (FZ)



- **Basically all silicon detectors made out of high resistivity FZ silicon**

• Czochralski Silicon (CZ)

- **The growth method used by the IC industry.**
- **Difficult to produce very high resistivity**



• Epitaxial Silicon (EPI)

- **Chemical-Vapor Deposition (CVD) of Si**
- **up to 150 µm thick layers produced**
- **growth rate about 1µm/min**

Silicon Materials under Investigation

standard for particle detectors

used for LHC Pixel detectors

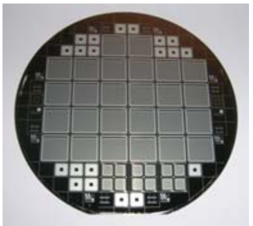
“new” silicon material

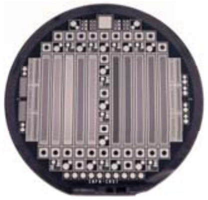
Material	Thickness [μm]	Symbol	ρ (Ωcm)	$[O_i]$ (cm^{-3})
Standard FZ (n- and p-type)	50,100,150, 300	FZ	$1-30\times10^{3}$	$< 5\times10^{16}$
Diffusion oxygenated FZ (n- and p-type)	300	DOFZ	$1-7\times10^{3}$	$\sim 1-2\times10^{17}$
Magnetic Czochralski Si, Okmetic, Finland (n- and p-type)	100, 300	MCz	$\sim 1\times10^{3}$	$\sim 5\times10^{17}$
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	$\sim 7\times10^{17}$

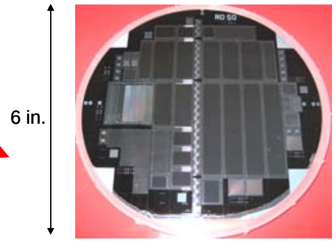
• **DOFZ silicon**	- Enriched with oxygen on wafer level, inhomogeneous distribution of oxygen
• **CZ/MCZ silicon**	- high Oi (oxygen) and O_{2i} (oxygen dimer) concentration (homogeneous) - formation of shallow Thermal Donors possible
• **Epi silicon**	- high O_i, O_{2i} content due to out-diffusion 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 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)







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

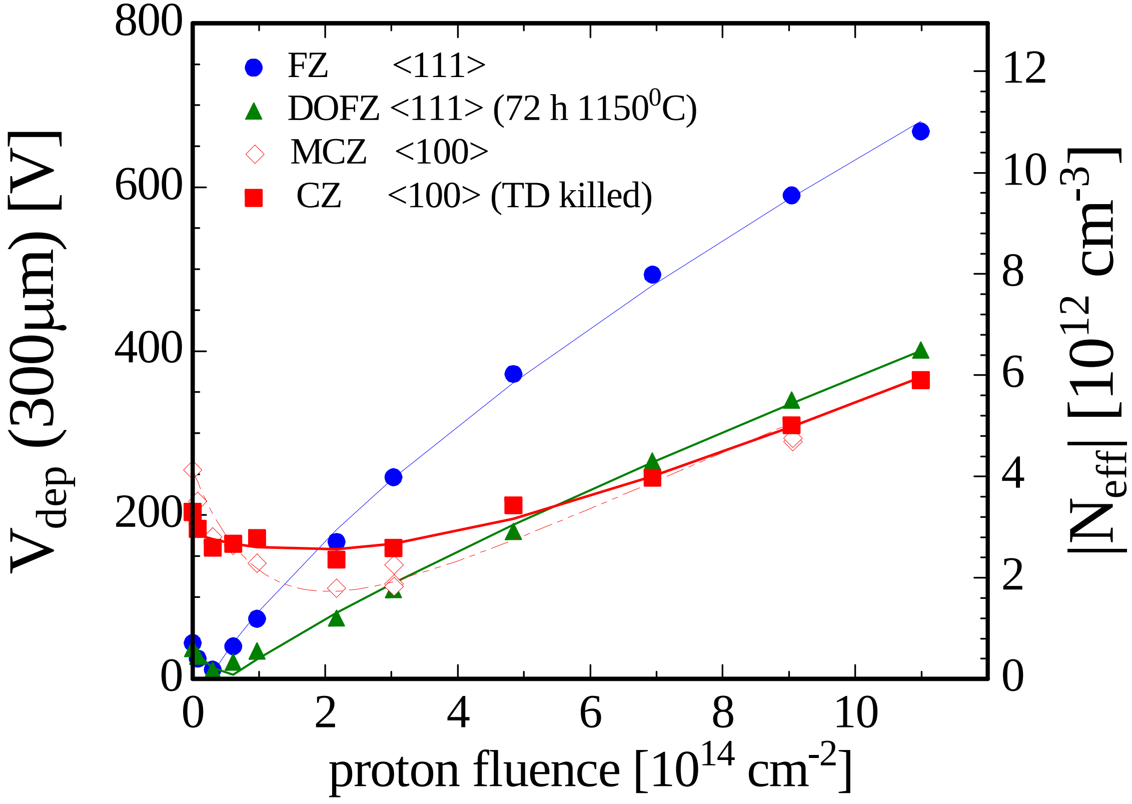
- M.Lozano, 8th RD50 Workshop, Prague, June 2006
- A.Pozza, 2nd Trento Meeting, February 2006
- G.Casse, 2nd Trento Meeting, February 2006
- D. Bortoletto, 6th RD50 Workshop, Helsinki, June 2005
- N.Zorzi, Trento Workshop, February 2005
- H. Sadrozinski, rd50 Workshop, Nov. 2007

FZ, DOFZ, Cz and MCz Silicon

- **Strong differences in V_{dep}**
  - **Standard FZ silicon**
  - **Oxygenated FZ (DOFZ)**
  - **CZ silicon and MCZ silicon**
- **Strong differences in internal electric field shape**

  (type inversion in FZ, no type inversion in MCZ silicon, double junction effects,…)
- **Different impact on pad and strip detector operation!**
  - **e.g.: a lower V_{dep} or $|N_{eff}|$ does not necessarily correspond to a higher CCE for strip detectors (see later)!**

24 GeV/c proton irradiation (n-type silicon)



- **Common to all materials (after hadron irradiation):**
  - **reverse current increase**
  - **increase of trapping (electrons and holes) within ~ 20%**

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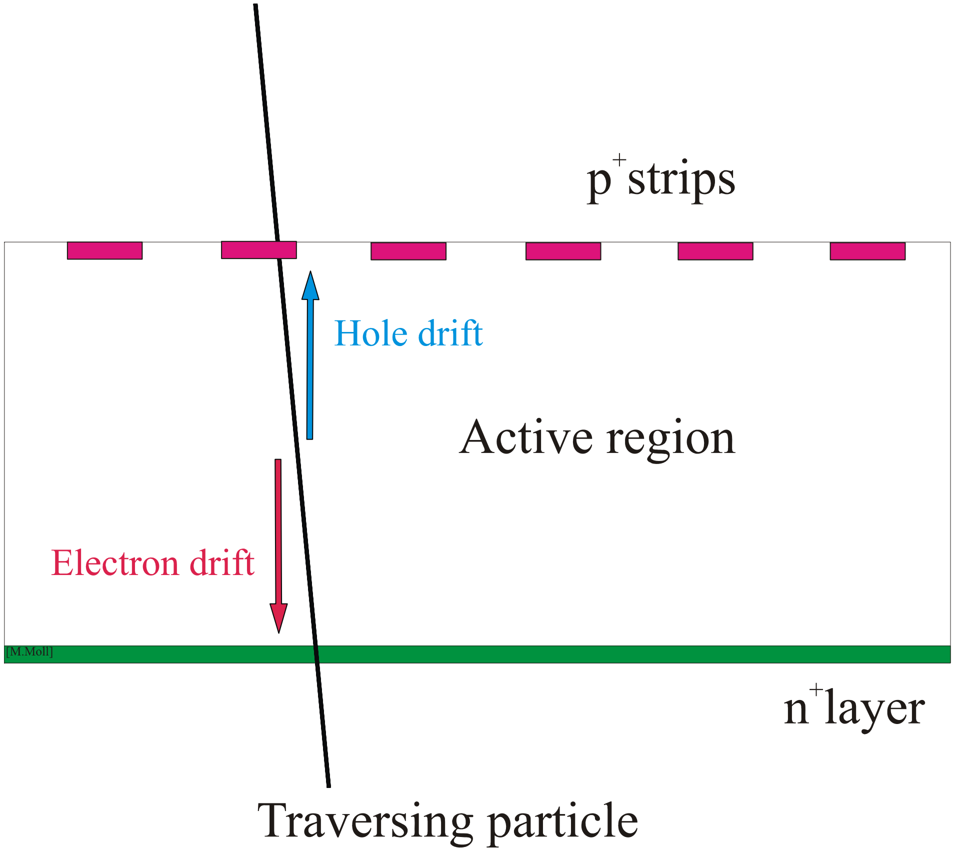
Advantage of non-inverting material

p-in-n detectors (schematic figures!)

Fully depleted detector
(non – irradiated):



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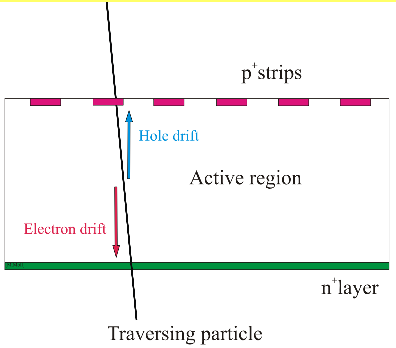
Advantage of non-inverting material

p-in-n detectors (schematic figures!)

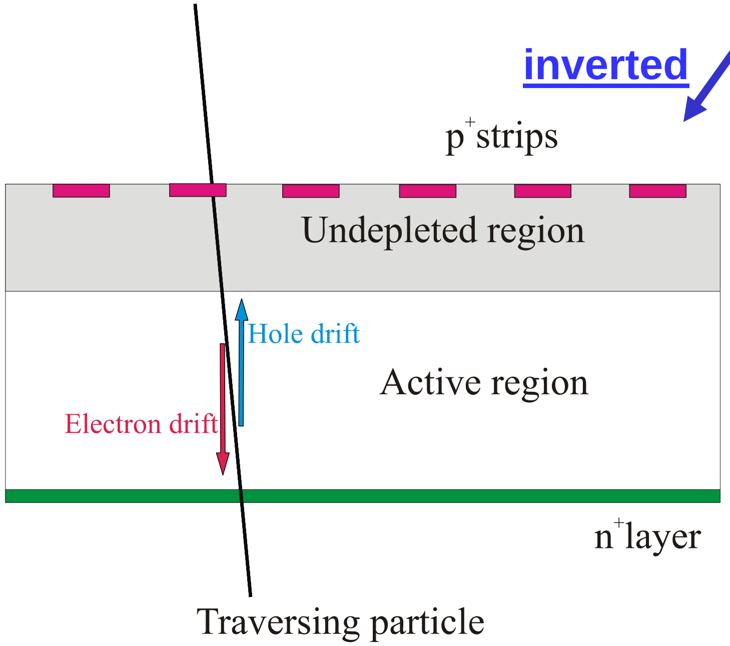
Be careful, this is a very schematic explanation, reality is more complex !

Fully depleted detector (non – irradiated):

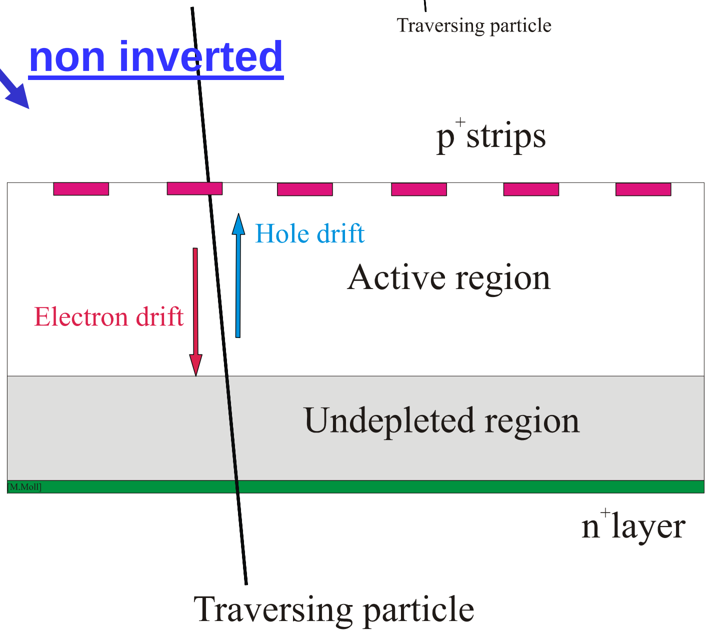


heavy irradiation

inverted



non inverted



inverted to “p-type”, under-depleted:

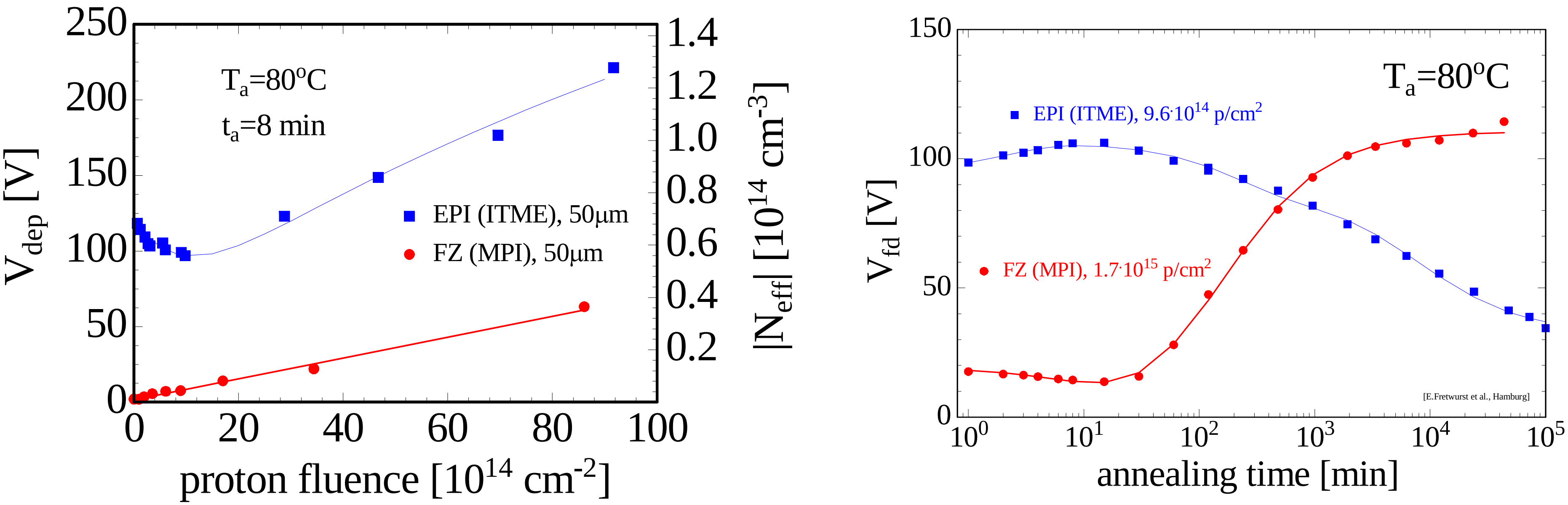
- **Charge spread – degraded resolution**
- **Charge loss – reduced CCE**

non-inverted, under-depleted:

- **Limited loss in CCE**
- **Less degradation with under-depletion**

Epitaxial silicon - Annealing

- **50 μm thick silicon detectors:**
  - Epitaxial silicon (50Ωcm on CZ substrate, ITME & CiS)
  - Thin FZ silicon (4KΩcm, MPI Munich, wafer bonding technique)



[E.Fretwurst et al.,RESMDD - October 2004]

- **Thin FZ silicon: Type inverted, increase of depletion voltage with time**
- **Epitaxial silicon: No type inversion, decrease of depletion voltage with time**

⇒ No need for low temperature during maintenance of SLHC detectors!

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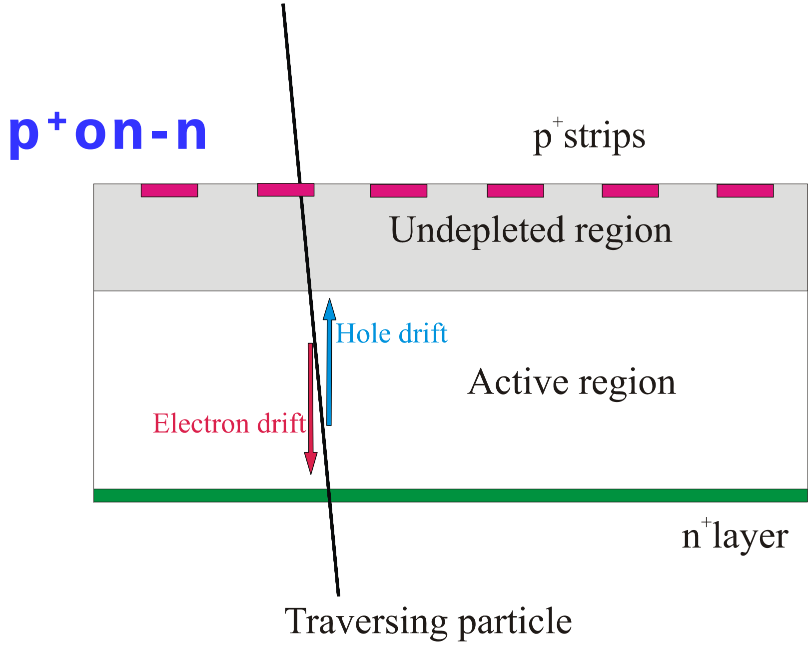
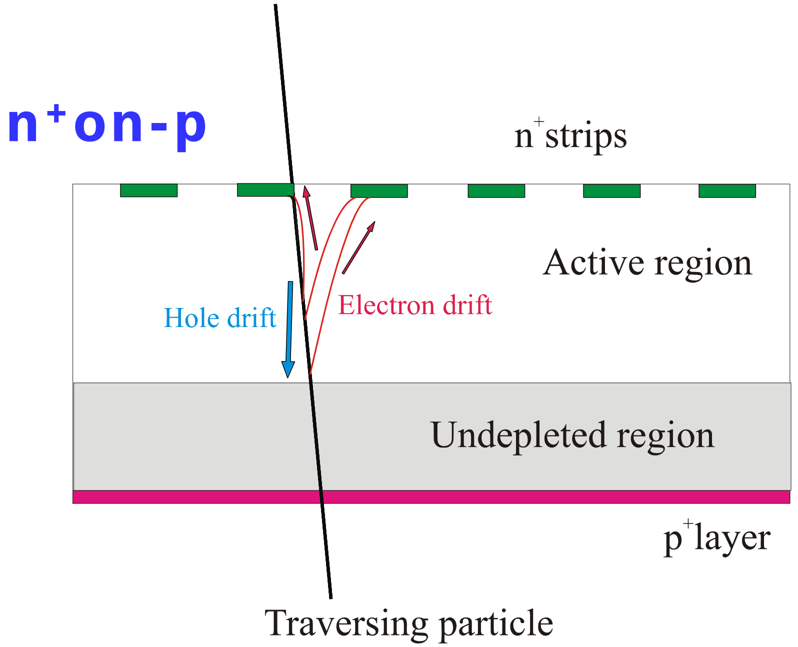
Device engineering (p-type silicon)

p-in-n versus n-in-p (or n-in-n) detectors

p+ strip readout (p-in-n) after high fluences:



n+ strip readout (n-in-p or n-in-n) after high fluences:



p-on-n silicon, under-depleted:

- **Charge spread – degraded resolution**
- **Charge loss – reduced CCE**

Be careful, this is a very schematic explanation, reality is more complex !

n-on-p silicon, under-depleted:

- **Limited loss in CCE**
- **Less degradation with under-depletion**
- **Collect electrons (fast)**

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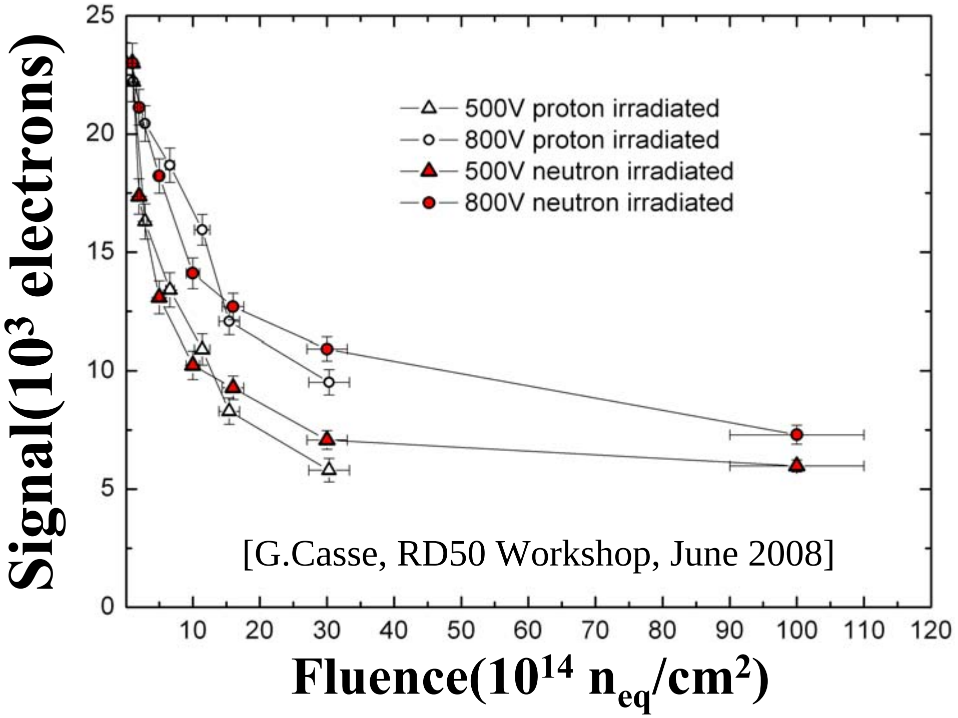
n-in-p microstrip detectors

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



[G.Casse, RD50 Workshop, June 2008]

- **CCE: ~7300e (~30%)**
  after ~ 1×$10^{16}$$cm^{-2}$ 800V
- **n-in-p sensors are strongly considered for ATLAS upgrade** (previously p-in-n used)

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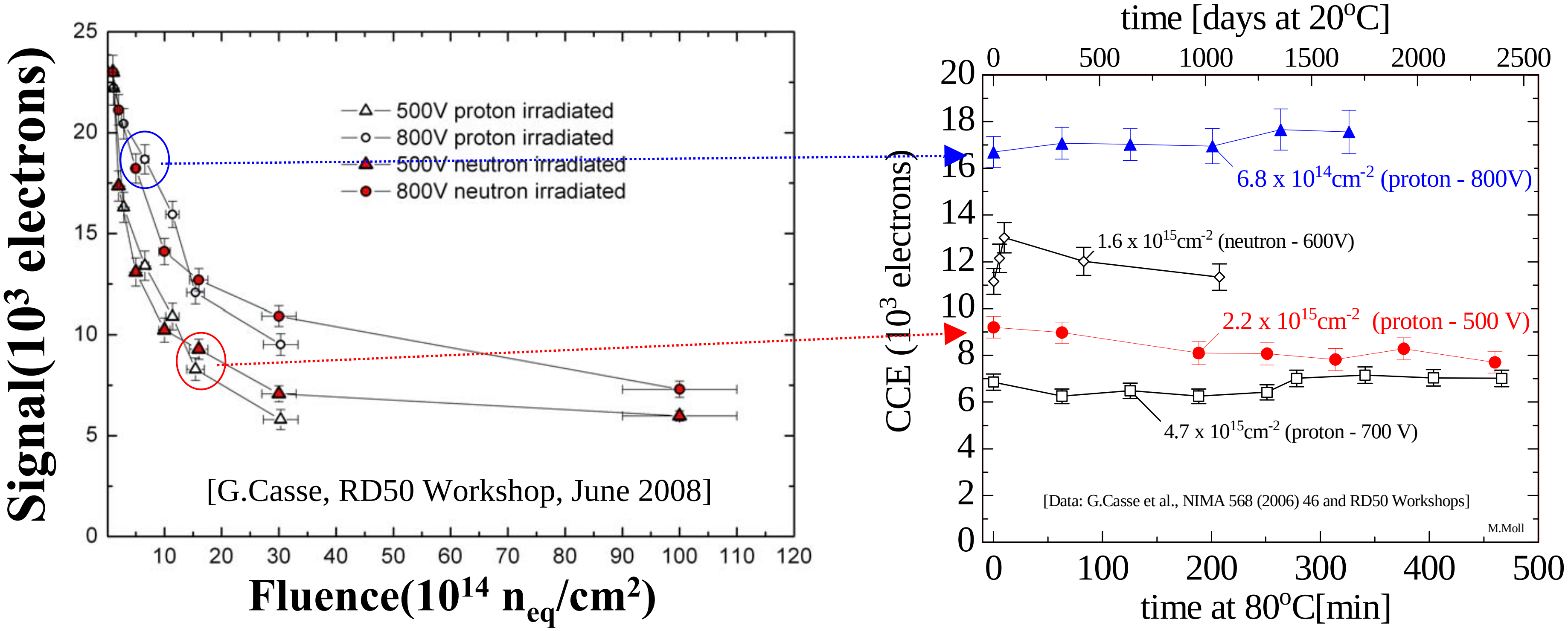


[G.Casse, RD50 Workshop, June 2008]

[Data: G.Casse et al., NIMA 568 (2006) 46 and RD50 Workshops]

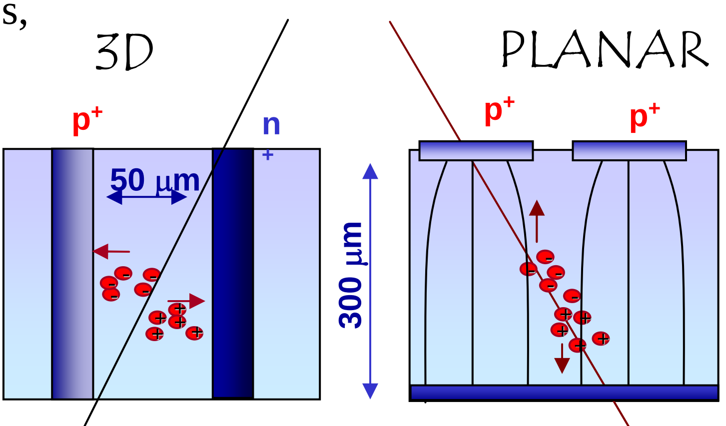
- **CCE: ~7300e (~30%)**
  after ~ 1×10^{16}cm^{-2} 800V
- **n-in-p sensors are strongly considered for ATLAS upgrade** (previously p-in-n used)

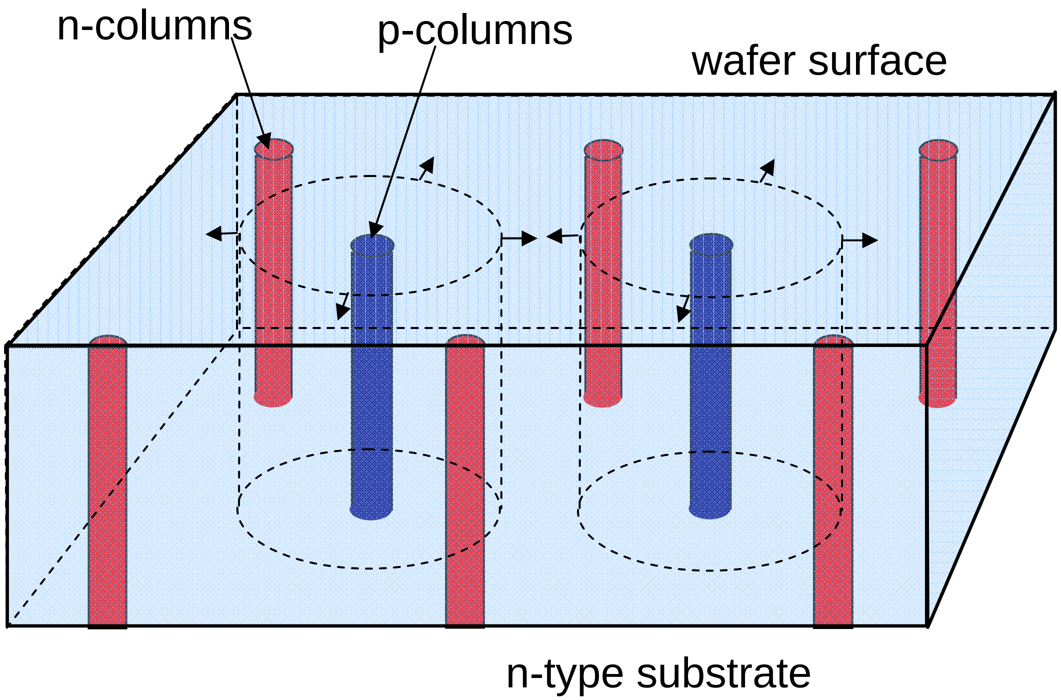
- **no reverse annealing in CCE measurements for neutron and proton irradiated detectors**

3D detector - concept

Introduced by: S.I. Parker et al., NIMA 395 (1997) 328

- **“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

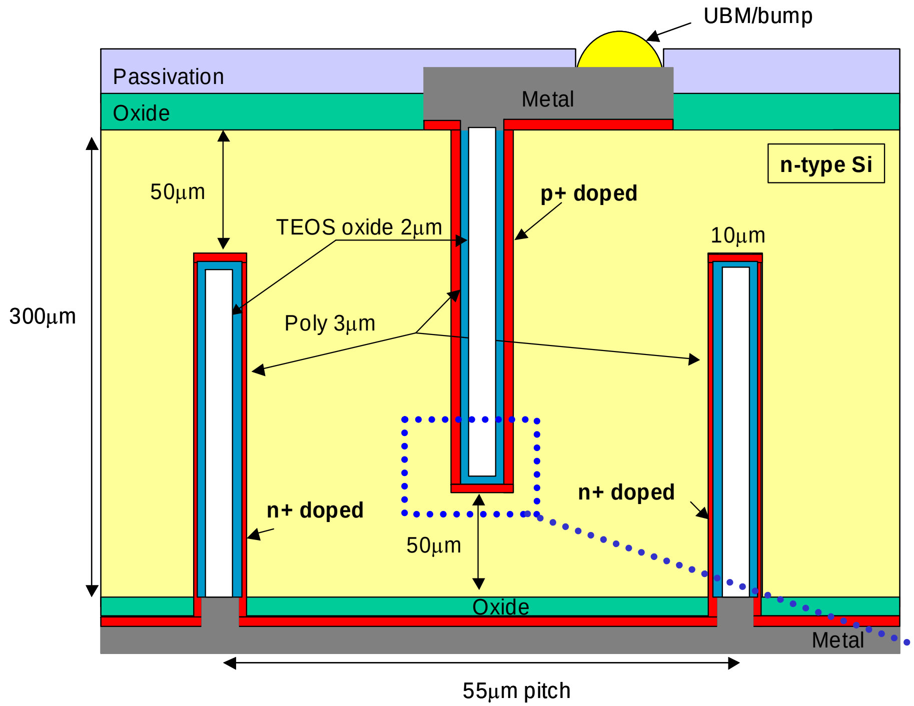




Double-Sided 3D detectors

- **Under processing at CNM, Barcelona**

  RD50 collaborative work (CNM, Glasgow, Valencia, …)



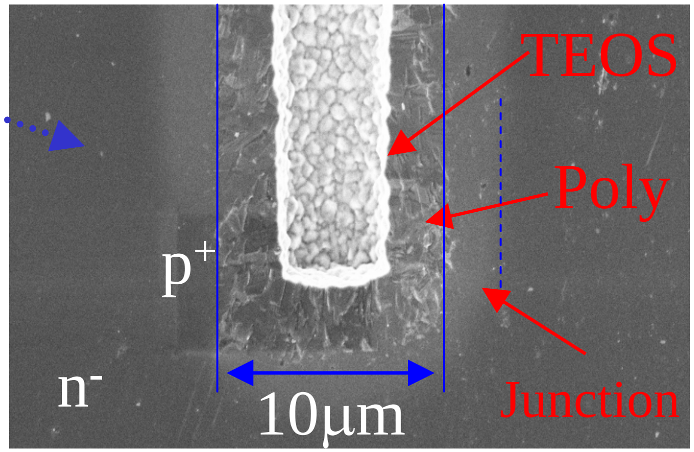
[G.Fleta, RD50 Workshop, June 2007]

- **4” wafer with Pad, Strip** (short and long, 80µm pitch) **and Pixel** (ATLAS, Medipix2, Pilatus) **structures processed at CNM, Barcelona**
  - p-in-n and n-in-p wafers under test now

- **Further processing at FBK, Trento and IceMOS, Belfast**

- **Advantages against standard 3D:**
  - Less complicated (expensive) process (??)
    - No wafer bonding
    - p^+ and n^+ columns accessed from opposite surfaces
- **Disadvantages (?) :**
  - lower field region below/above columns

- **Successful process evaluation runs:**
  - etching of holes with aspect ratio 25:1 (10 µm diameter, 250 µm depth)
  - polysilicon deposit, doping, TEOS, ..



Comparison of measured collected charge on different radiation-hard materials and devices

- **In the following:**

  Comparison of collected charge as published in literature

- **Be careful:**

  Values obtained partly under different conditions !!

  - **irradiation**
  - **temperature of measurement**
  - **electronics used (shaping time, noise)**
  - **voltage applied to sensor**
  - **type of device – strip detectors or pad detectors**

  ⇒ This comparison gives only an indication of which material/technology could be used,
  to be more specific, the exact application should be looked at!

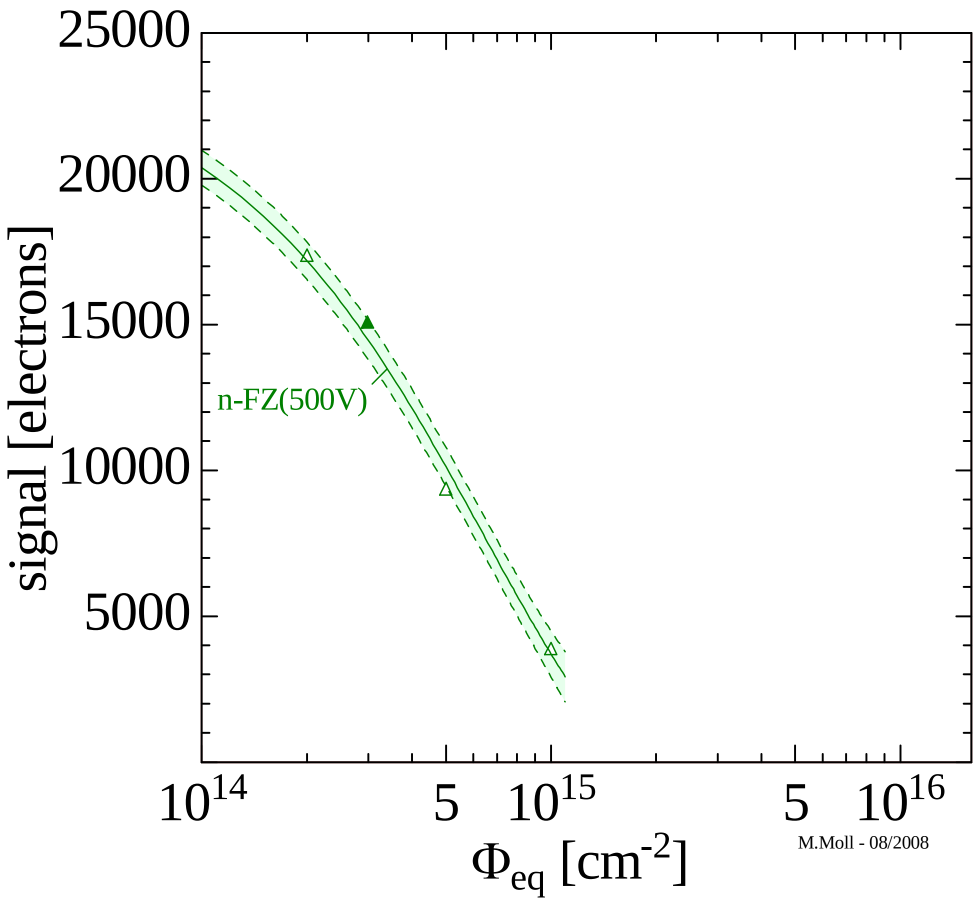
- **Remember:**

  The obtained signal has still to be compared to the noise !!

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 (FZ), 300µm, 500V, 23GeV p [1]

△ p-in-n (FZ), 300µm, 500V, neutrons [1]

Other materials

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**

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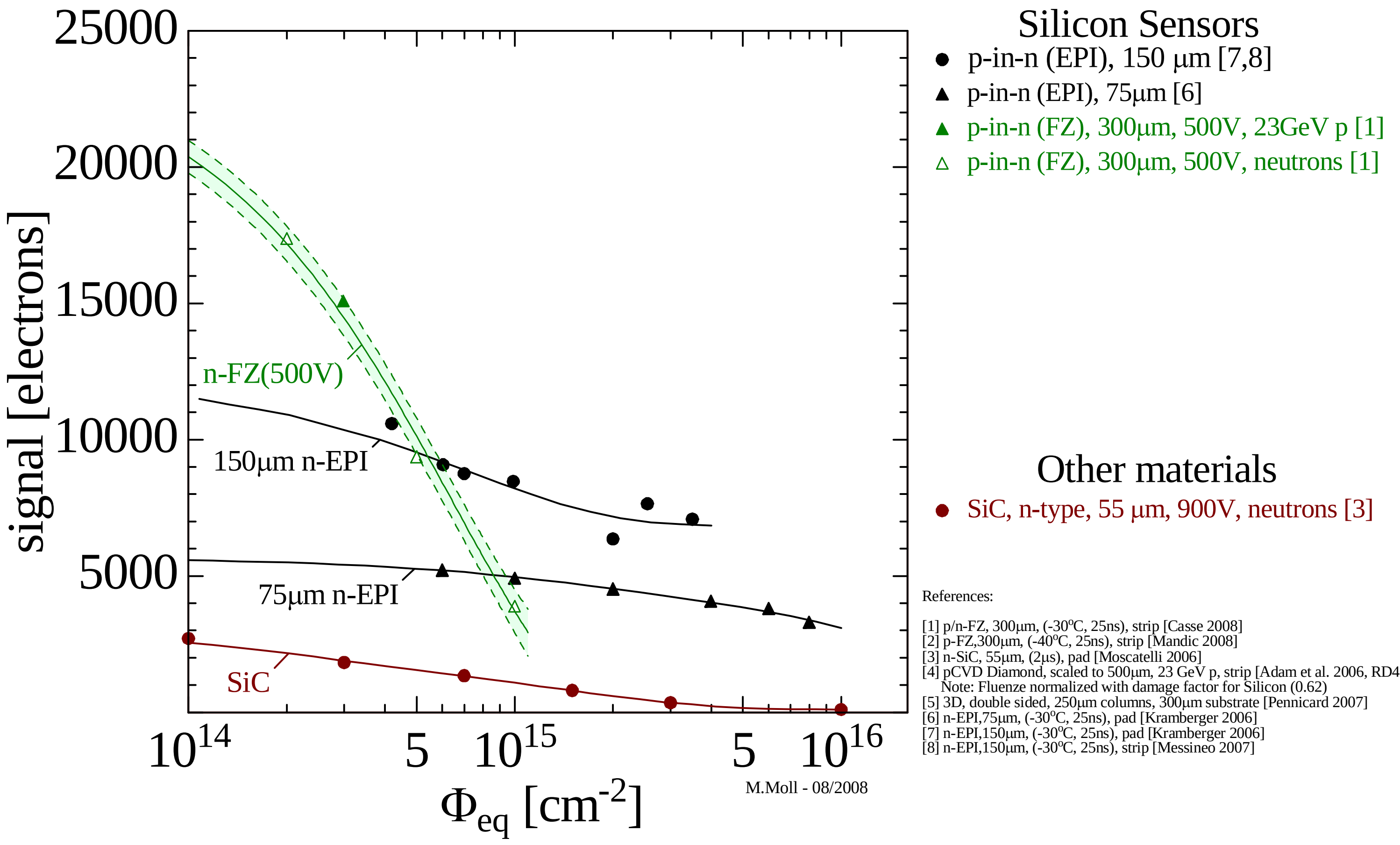

M.Moll - 08/2008

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- Signal comparison for various Silicon sensors

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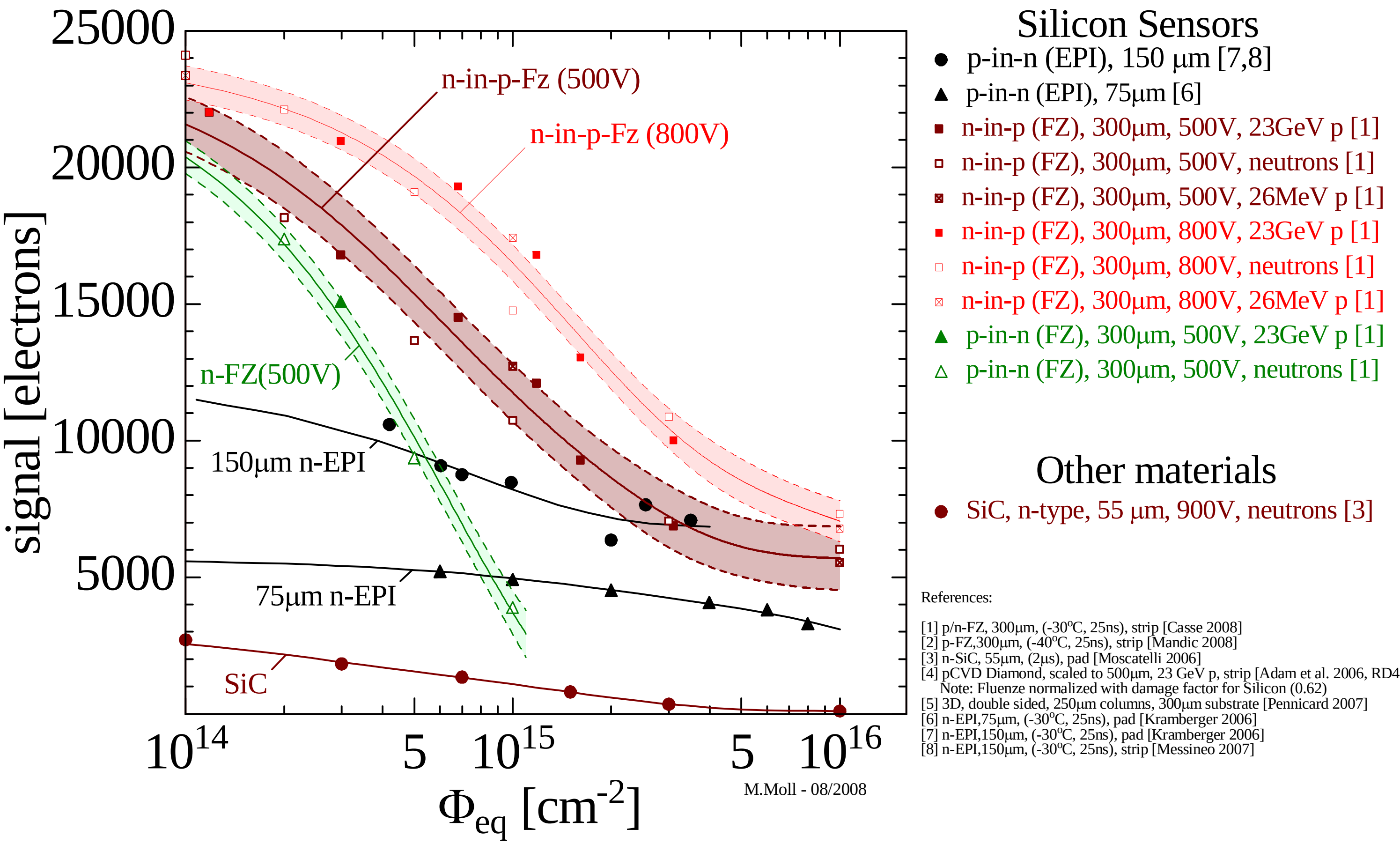

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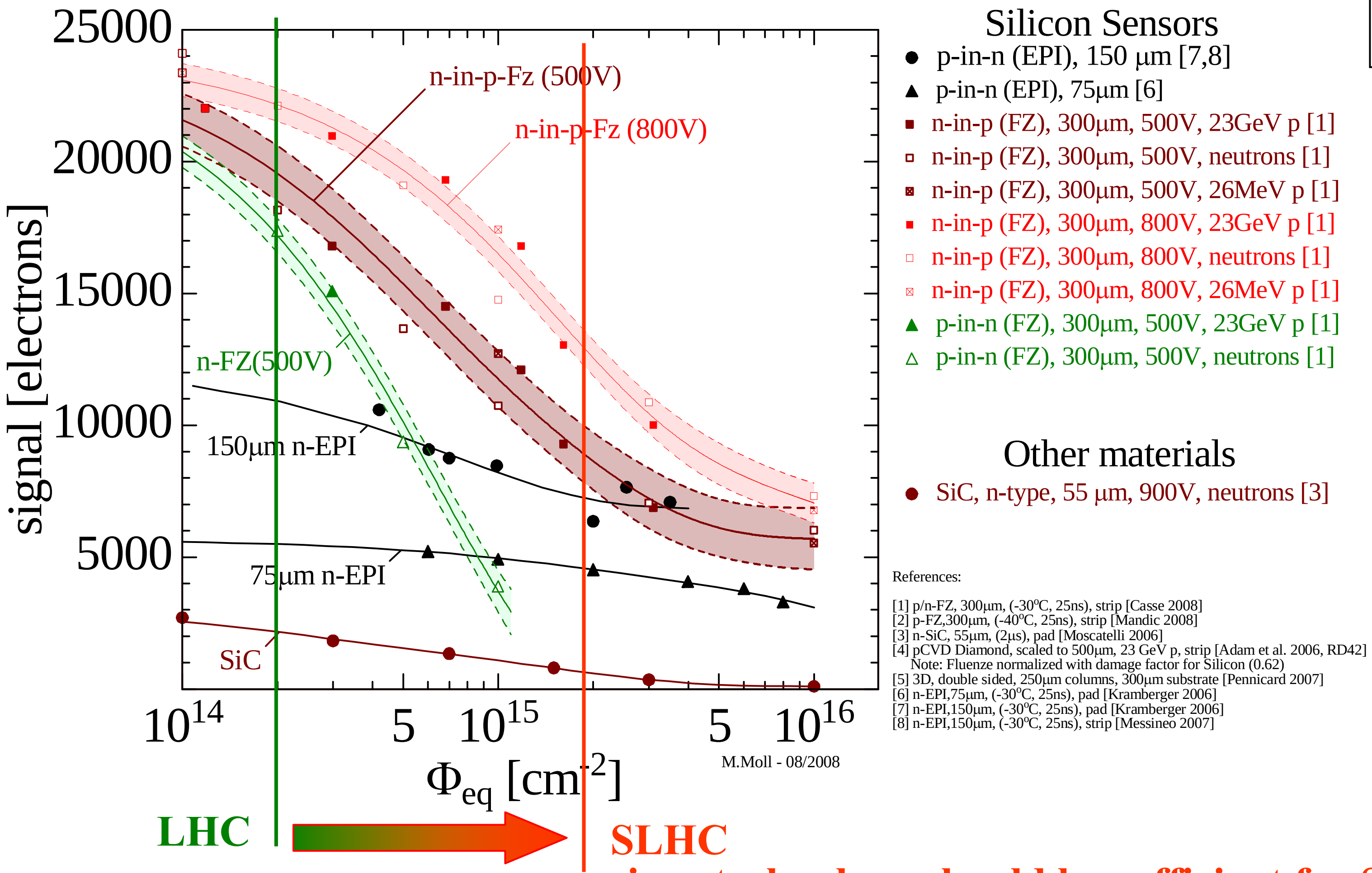

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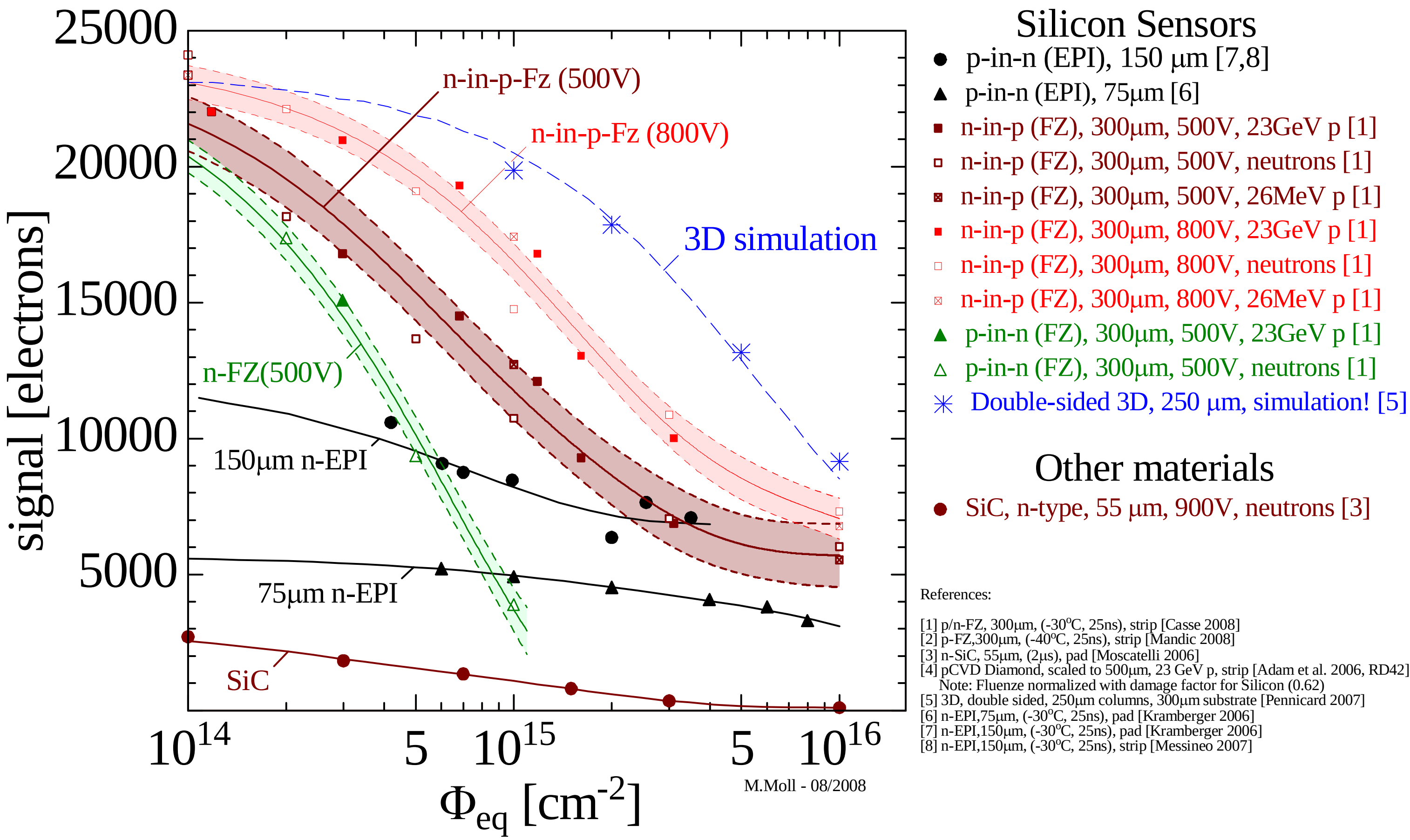
highest fluence for strip detectors in LHC: The used p-in-n technology is sufficient

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

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)!



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]
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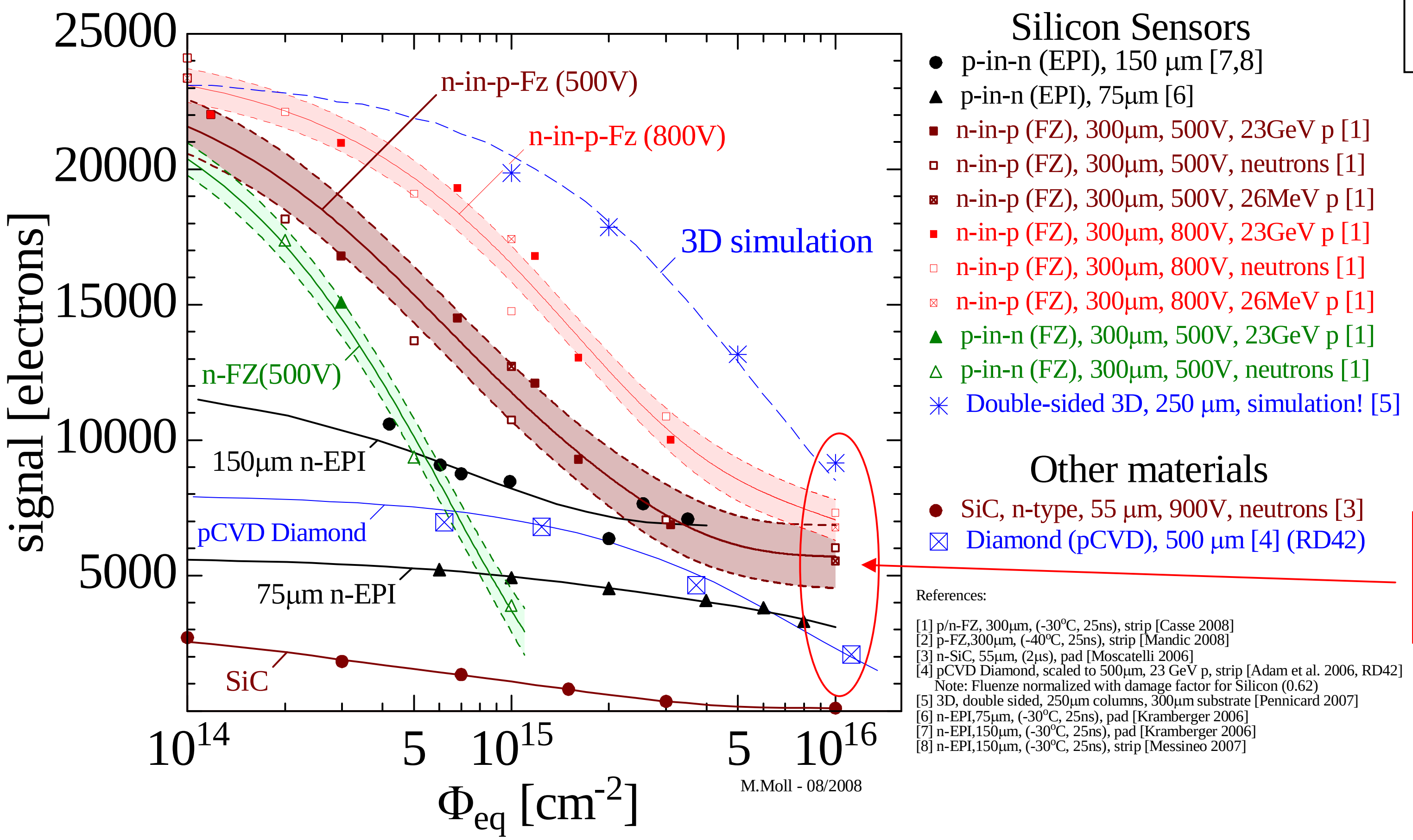
- **At a fluence of ~ 10^{15} n_{eq}/cm^2 all planar sensors loose sensitivity: on-set of trapping !**
- **No obvious material for innermost pixel layers:**
  - **Are 3-D sensors an option ??** (decoupling drift distance from active depth)
  - **Develop detectors that can live with very small signals ?? or regularly replace inner layers ??**

RD50 Silicon materials for Tracking Sensors

- **Signal comparison for various Silicon sensors**



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

See talk of Norbert Wermes for S/N scaling

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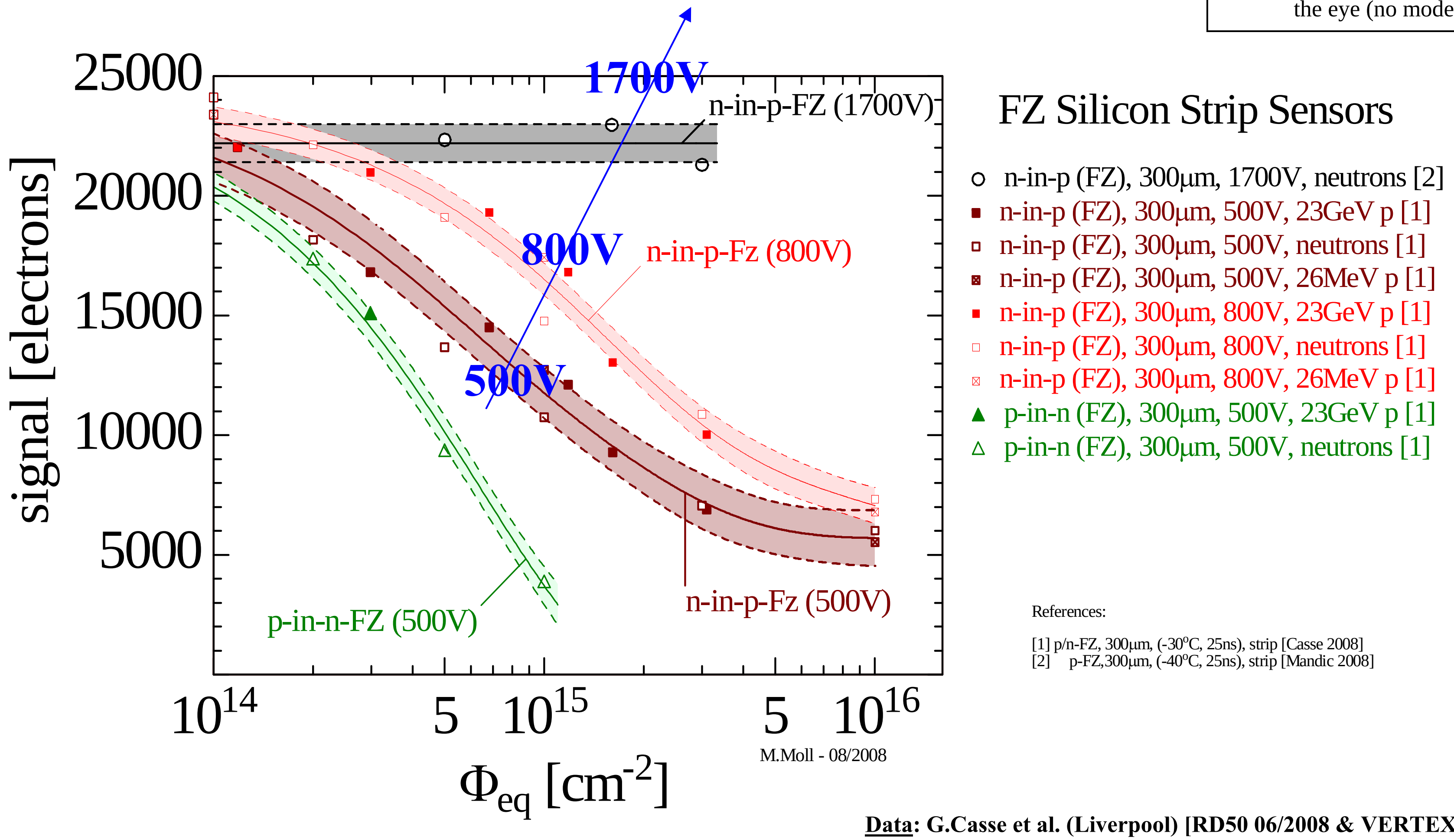
RD50

p-type FZ Silicon Sensors

- **Higher voltage helps!**

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



References:

[1] p/n-FZ, 300µm, (-30°C, 25ns), strip [Casse 2008]
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Data: G.Casse et al. (Liverpool) [RD50 06/2008 & VERTEX 2008] and I.Mandic et al. (Ljubljana) [RD50 06/2008]

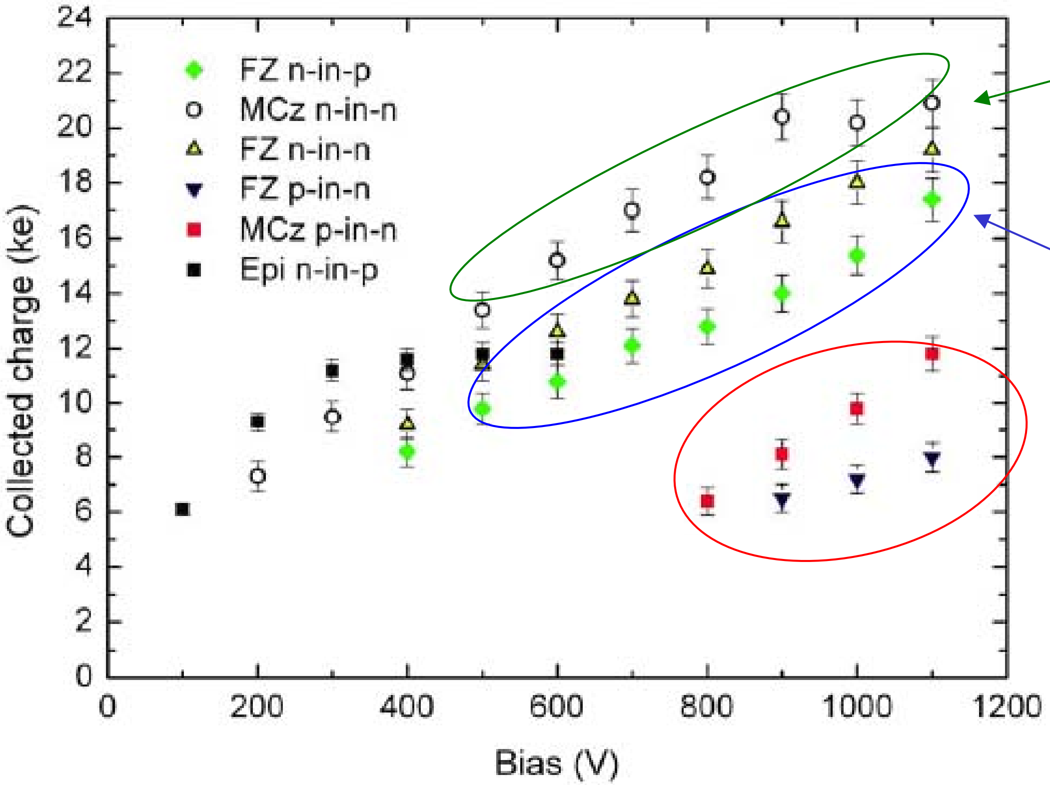
- **Which voltage can be applied?**

RD50

Strip detectors – MCZ silicon

- **Gianluigi Casse (Liverpool) [RD50 Workshop – June 2008]:**
  “Charge Collection Measurements on MICRON RD50 sensors”

Neutron irradiations: medium doses (1x10^{15} n cm^{-2})



MCZ
n-in-n

FZ sensors
n-in-n
and
n-in-p

p-in-n sensors
(MCZ, FZ)

RD50 “Mixed Irradiations” n-type MCZ

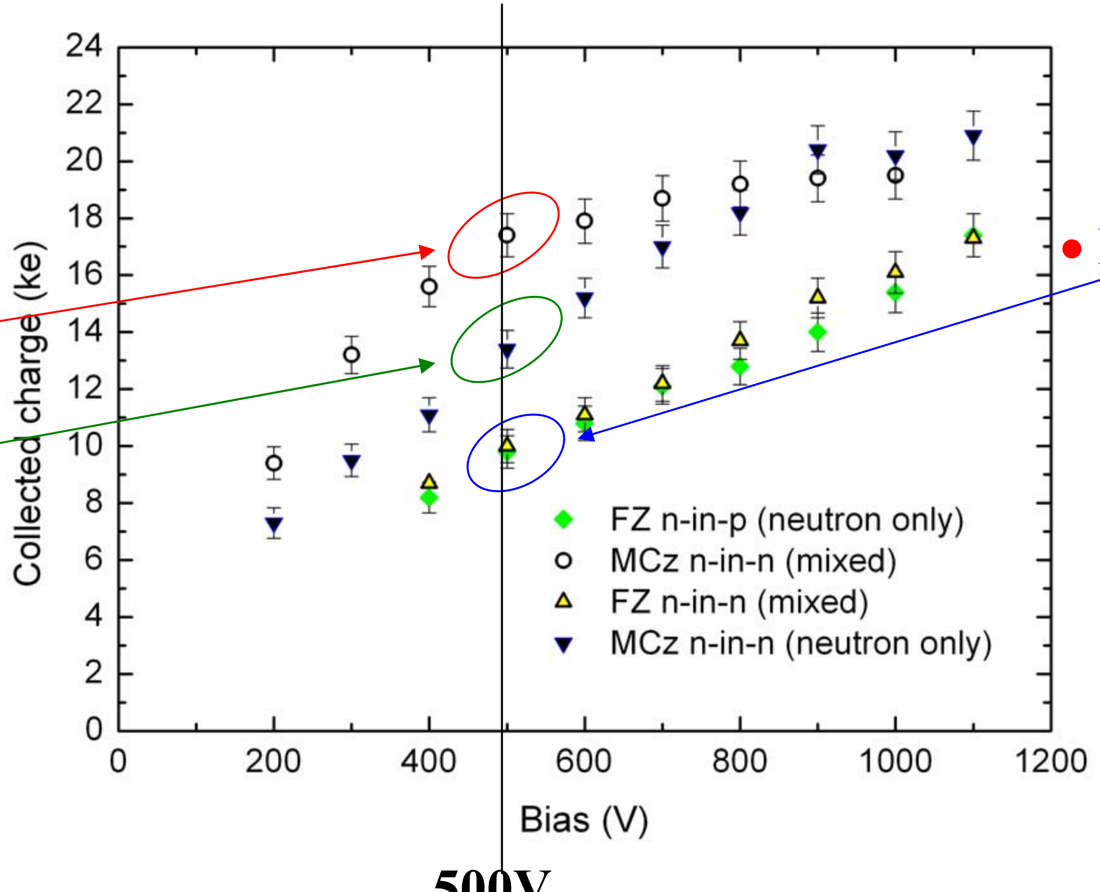
Gianluigi Casse (Liverpool) [VERTEX 2008]

- **Mixed irradiations performed with**
  - (neutrons only) up to 1x10^{15} neutrons
  - (mixed) 5x10^{14} neutrons plus 5x10^{14} protons (1 MeV equivalent fluence)

- **MCZ (n-in-n)**

Mixed Irradiation:
Proton damage
“compensates” part of
neutron damage (N_{eff})
➔ Excellent performance!

Neutron Irradiation:
Higher CCE than FZ silicon



- **FZ (n-in-n)**
  FZ (n-in-p)

Comment: NIEL scaling very strongly violated !

500V

Summary

- **Wide range of silicon materials under investigation within RD50**
  - **Floating Zone (FZ), Magnetic Czochralski (MCZ), Epitaxial (EPI) silicon**
  - **n- and p-type silicon with different thickness ranging from 25 to 300 µm**
  - **Some materials do not 'type-invert' under proton irradiation (n-type MCZ, EPI)**
    Very complex internal electric field structure (double junction effects)
- **Segmented detectors at high fluences ($\Phi > 10^{15}$cm^{-2}):**
  - **Collection of electrons at electrodes essential: Use n-in-p or n-in-n detectors!**
  - **Good radiation tolerance of n-in-p detectors and 'CCE immunity' against reverse annealing**
  - **MCZ and FZ p-type show similar results**
  - **MCZ n-type (n-in-n) shows excellent results (would need double sided processing)**
- **3D detectors**
  - **Single type column 3D – processed, irradiated, analyzed : Not radiation tolerant (as expected) – However, 'paved the way' for double column 3D detectors**
  - **Production of Double Sided and Full 3D detectors under way in several facilities (IRST, CNM, Sintef, IceMOS,…). First unirradiated devices characterized.**
- **Not reported on:**
  - **Defect studies: "WODEAN"** - Massive work program under way using C-DLTS, I-DLTS, TSC, PITS, TCT, FTIR, EPR, PL, PC, CV, IV, .. methods – (~10 RD50 Institutes) – about 250 detectors irradiated with neutrons for a first experiment.

Further information: http://cern.ch/rd50/

Spare

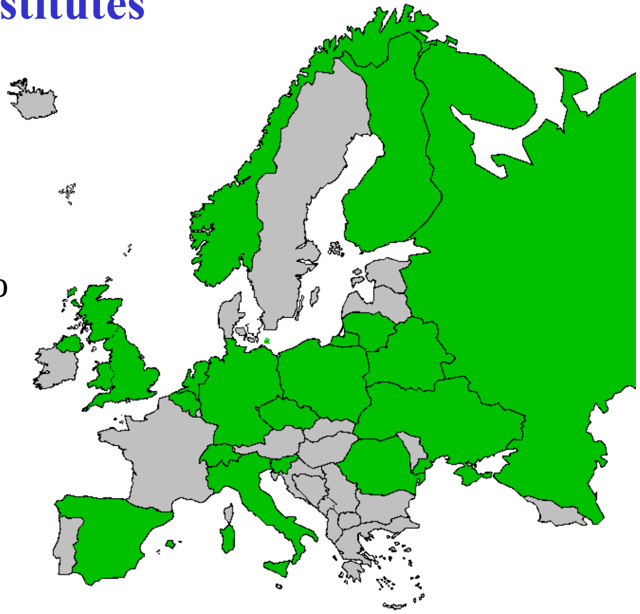
RD50 Development of Radiation Hard Semiconductor Devices for High Luminosity Colliders

Approved as CERN R&D project "RD50" in June 2002

Presently :257 Members from 49 Institutes

40 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** (Exeter, 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

Epitaxial SiC

“A material between Silicon and Diamond”

Property	Diamond	GaN	4H SiC	Si
E_g [eV]	**5.5**	**3.39**	**3.3**	**1.12**
$E_{breakdown}$ [V/cm]	10^7	$4 \cdot 10^6$	$2.2 \cdot 10^6$	$3 \cdot 10^5$
μ_e [cm^2/Vs]	1800	1000	800	1450
μ_h [cm^2/Vs]	1200	30	115	450
v_{sat} [cm/s]	$2.2 \cdot 10^7$	-	$2 \cdot 10^7$	$0.8 \cdot 10^7$
Z	6	31/7	14/6	14
ε_r	5.7	9.6	9.7	11.9
e-h energy [eV]	**13**	**8.9**	**7.6-8.4**	**3.6**
Density [g/cm3]	3.515	6.15	3.22	2.33
Displacem. [eV]	**43**	**≥15**	**25**	**13-20**

- **Wide bandgap (3.3eV)**

⇒ **lower leakage current than silicon**

- **Signal:**

Diamond	**36 e/μm**
SiC	**51 e/μm**
Si	**89 e/μm**

⇒ **more charge than diamond**

- **Higher displacement threshold than silicon**

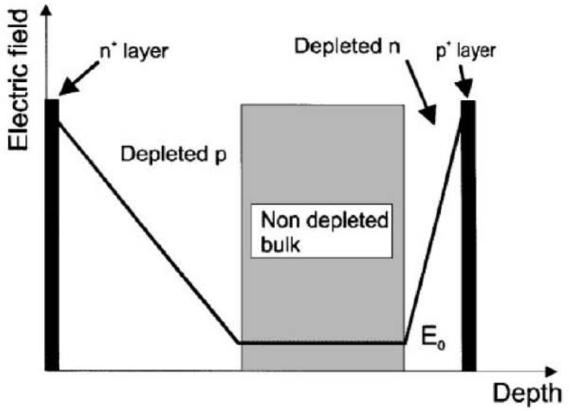
⇒ **radiation harder than silicon (?)**

RD50 The electric field after irradiation

Segmented detectors: side matters!!

N-side read-out for tracking in high radiation environments?

Schematic changes of Electric field after irradiation



Effect of trapping on the Charge Collection Efficiency (CCE)

$Q_{tc} \cong Q_0 \exp(-t_c/\tau_{tr}),\ 1/\tau_{tr} = \beta\Phi.$

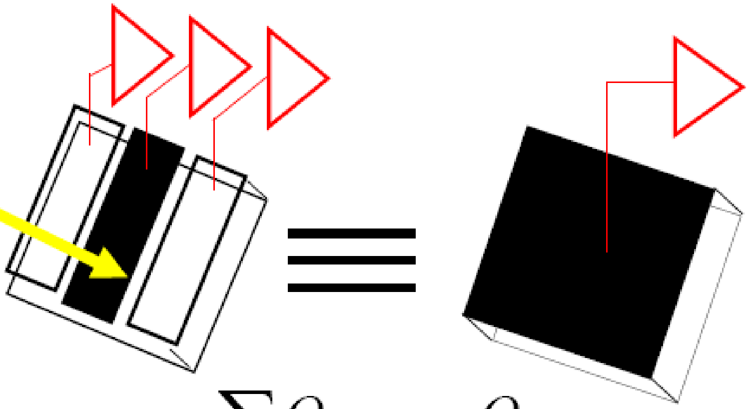
Collecting electrons provide a sensitive advantage with respect to holes due to a much shorter t_c. P-type detectors are the most natural solution for *e* collection on the segmented side.

N-side read out to keep lower t_c

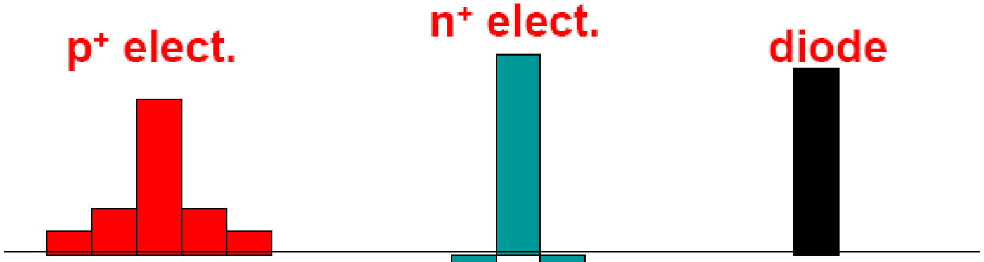
from G.Casse

RD50 The electric field after irradiation

Trapping induced charge sharing (G. Kramberger)


electrode hit in the center by ionizing particle

$$\sum_{\substack{\text{all electrodes}\\ (pitch-implant\,width)\to 0}} Q_i \equiv Q_{diode}$$



same polarity

$Q_{hit} < Q_{diode}$

↓

wider clusters

opposite polarity

$Q_{hit} > Q_{diode}$

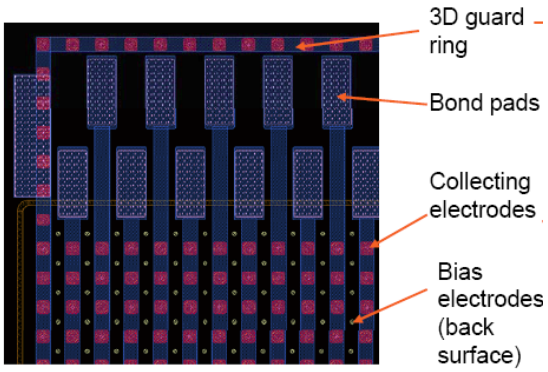
↓

larger signals

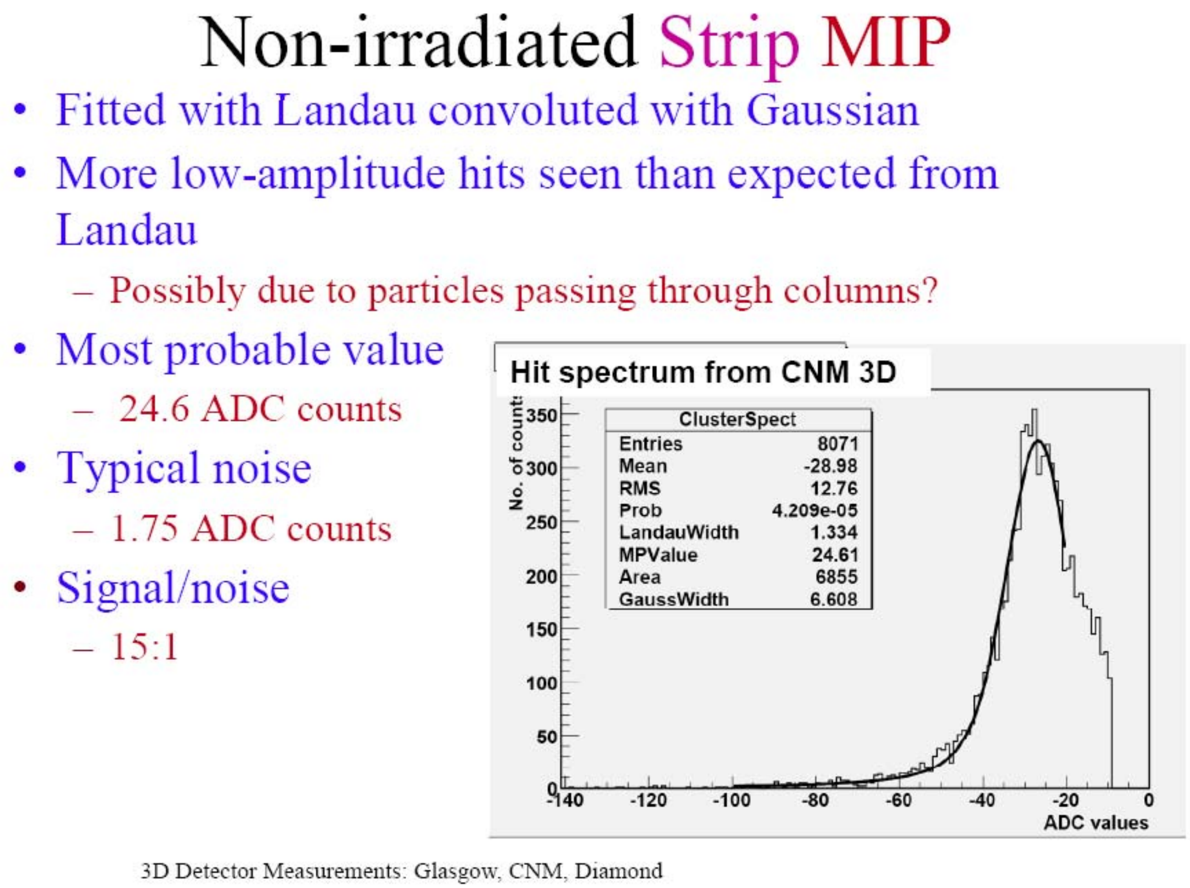
CNM – 3D devices

- **Chris Parkes (Glasgow University): “3D detector testing”**

Typical device layout – Strip detector, 80µm pitch



- **CNM 3D devices (strip)**
- **Glasgow MIP test setup**
  (Sr90, Beetle Chip, analogue,25ns)
- **Sensor DC coupled to chip**
- **100pA/strip (2pA/hole)**
- **10 pF/strip**
- **less charge sharing than in planar observed**
  - **planar 38% single strip**
  - **3D 84% single strip**



Non-irradiated Strip MIP

- Fitted with Landau convoluted with Gaussian
- More low-amplitude hits seen than expected from Landau
  - Possibly due to particles passing through columns?
- Most probable value
  - 24.6 ADC counts
- Typical noise
  - 1.75 ADC counts
- Signal/noise
  - 15:1

Hit spectrum from CNM 3D

ClusterSpect	
Entries	8071
Mean	-28.98
RMS	12.76
Prob	4.209e-05
LandauWidth	1.334
MPValue	24.61
Area	6855
GaussWidth	6.608

3D Detector Measurements: Glasgow, CNM, Diamond