



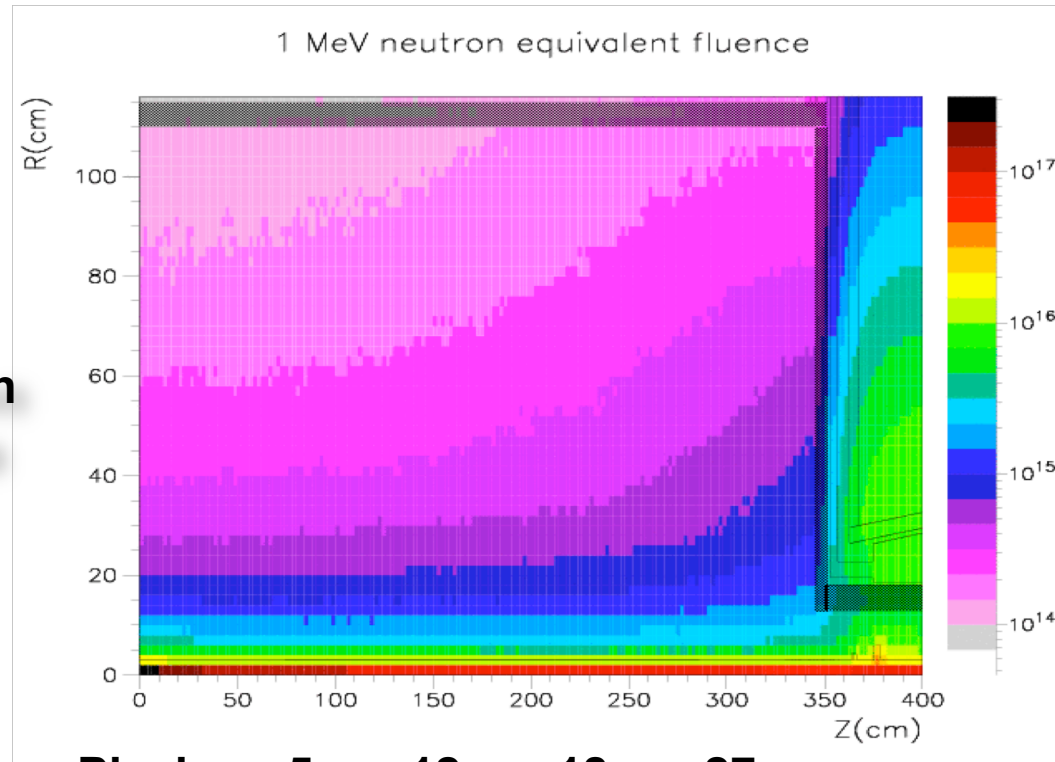
# The MCz Beam Testing Program

Lenny Spiegel, FNAL  
( on behalf of the CMS SiBT group)



# SLHC Radiation Environment

Early ATLAS straw man layout based on  $3000 \text{ fb}^{-1}$  with a 2X safety margin.



- Pixels  $r = 5\text{cm}, 12\text{cm}, 18\text{cm}, 27\text{cm}$ 
  - Need to survive  $10^{16} \text{ n}_{\text{eq}}/\text{cm}^2$
- Short (2.4 cm) strips  $r = 38\text{cm}, 49\text{cm}, 60\text{cm}$ 
  - $9 \times 10^{14} \text{ n}_{\text{eq}}/\text{cm}^2$  (50% neutrons)
- Long (9.6 cm) strips  $r = 75\text{cm}, 95\text{cm}$ 
  - $4 \times 10^{14} \text{ n}_{\text{eq}}/\text{cm}^2$  (mostly neutrons)

Strip/stixel region



# The CMS SiBT Group

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Burt Betchart, Regina Demina, Yuri Gotra, Doug Orbaker, Sergey Korjenevski  
(University of Rochester)

Both the Université catholique de Louvain and Università di Padova had collaborated in the past.

Sources of sensor irradiation:

<b>protons</b>	Karlsruhe	26 MeV
<b>neutrons</b>	Louvain-la-Neuve	3-45 MeV



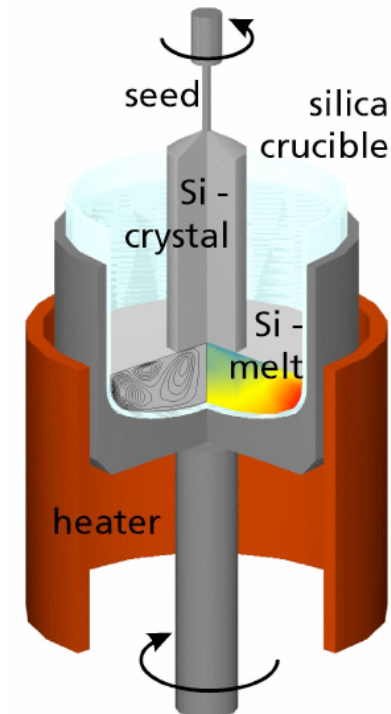
# Beam Studies

- Summer 2007 (Two beam periods)
  - Commissioning of converted CMS long-term (Vienna) system in CERN H2 beamline
  - Non-irradiated MCz and two irradiated sensors
  - 10-20 Hz DAQ rate
- Summer 2008
  - New n-type MCz sensors
  - FZ sensors (RD50 common order with Topsil)
  - Data acquisition rate increased to 100 Hz
  - Vienna box temperature lowered
  - Introduction of “cold finger” for CID studies
- Summer 2009
  - p-type MCz in addition to new nMCz, FZ
  - Biasing range extended from 600 to 1000 V



# Czochralski Process

- Commercially much more common than the Float Zone process traditionally used for HEP sensors.
  - Easier to produce large wafers
- The quartz crucible is a source of contaminants including oxygen. The latter was shown by the ROSE collaboration to mitigate the effects of radiation damage on charge collection efficiency.
- Compared with FZ silicon
  - Lower resistivity/higher depletion voltages
  - Higher leakage currents
  - No space charge inversion
- Introducing a magnetic field during growth *limits* the interstitial oxygen concentration and helps improve homogeneity
  - (M)Cz  $10^{17}$ - $10^{18}$  atoms/cm<sup>3</sup>
  - FZ  $<10^{16}$  atoms/cm<sup>3</sup>
  - DOFZ  $<10^{17}$  atoms/cm<sup>3</sup>





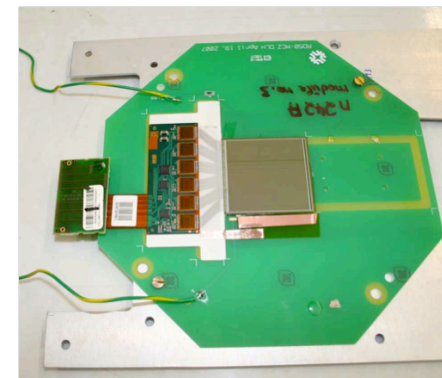
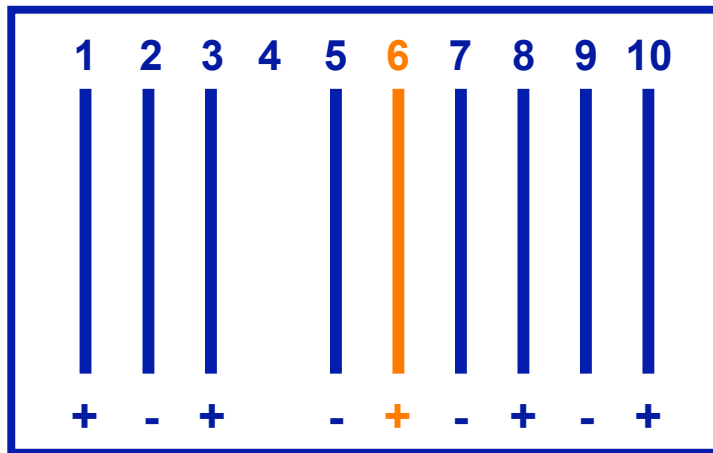
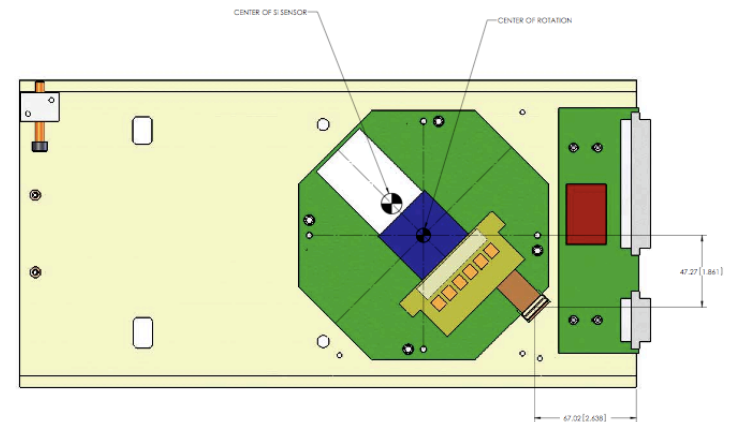
# Beam Telescope

- CERN North area SPS H2 beamline
  - 220 GeV muon, pion, and mixed beams
- 10 slot beam telescope based on CMS module test station
  - 8 reference modules and 1-2 DUTs in central slots
  - CMS DAQ electronics with early version of XDAQ
  - CMSSW used for track reconstruction
- Single slot external ultra-cold box



Originally provide by the Vienna HEP group to FNAL as part of CMS module long-term test system

## Vienna cold box (2007)





# MCz and Reference Sensors

## MCz

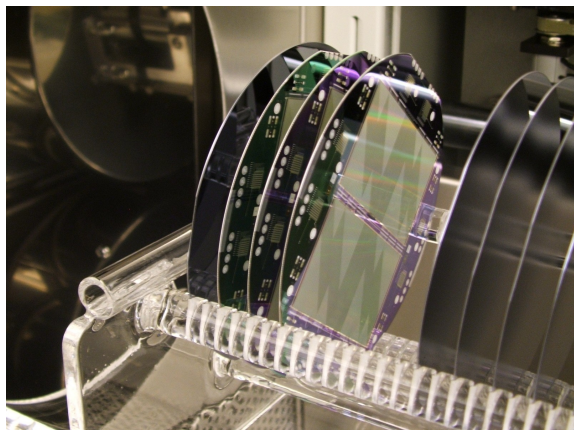
Processed at the Helsinki  
University of Technology  
Micronova Centre for Micro and  
Nanotechnology

Czochralski 4" silicon wafers  
from Okmetic Ltd

Two 4 cm x 4 cm detectors  
from one wafer

50  $\mu\text{m}$  pitch

768 strips per detector



## Reference

Provided by the D0 collaboration  
from unused Run IIb stock

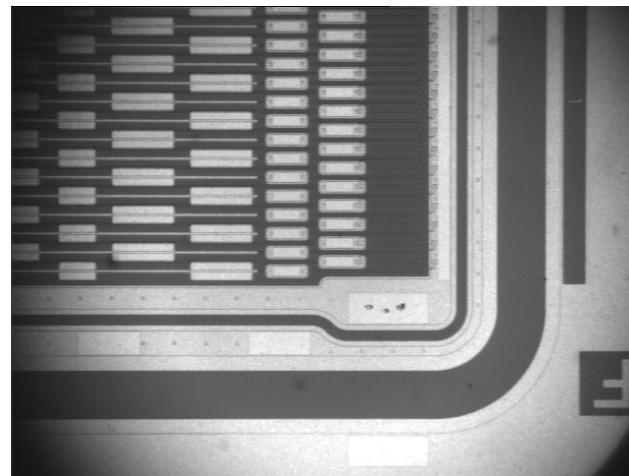
Hamamatsu FZ

4 cm x 10 cm

60  $\mu\text{m}$  pitch

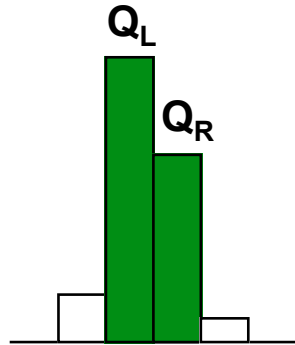
**Intermediate strips**

639 strips per detector

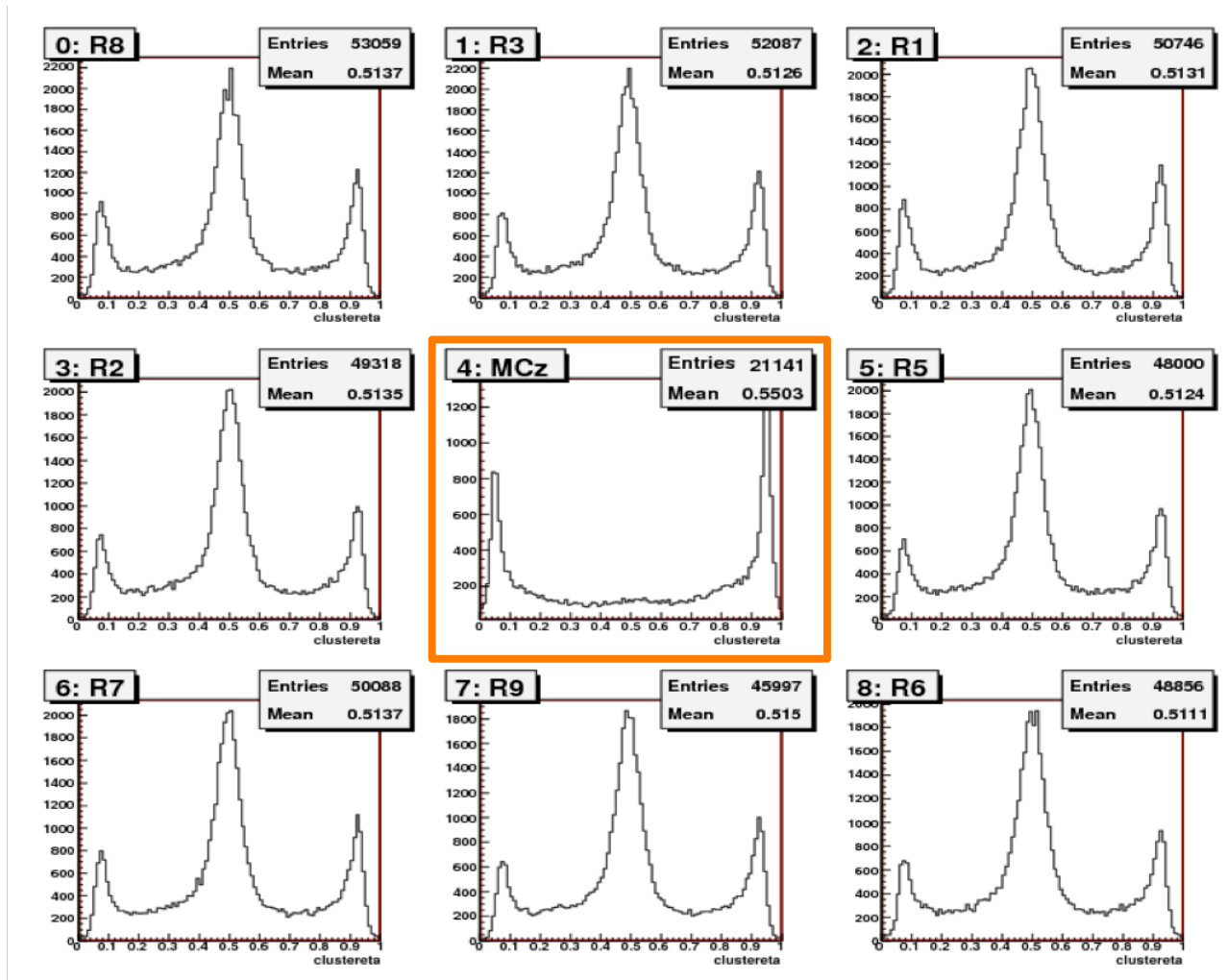




# Charge sharing (eta) distributions



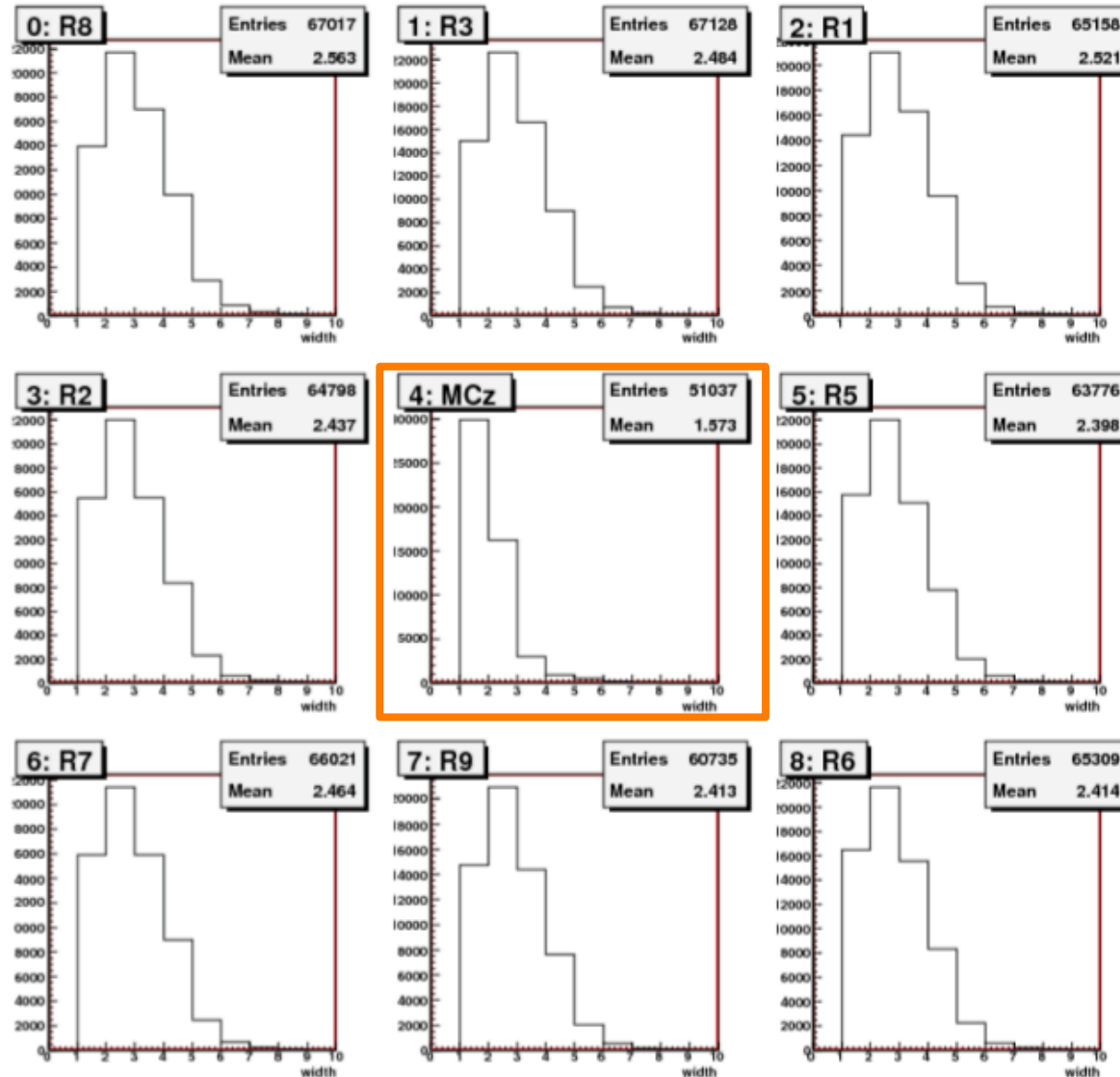
$$\eta = \frac{Q_L}{Q_L + Q_R}$$



Middle peak in reference planes is due to the intermediate strips.



# Cluster Size (number of strips)



**Beam tracks are largely perpendicular to the detectors.**



# Detector Under Test Results

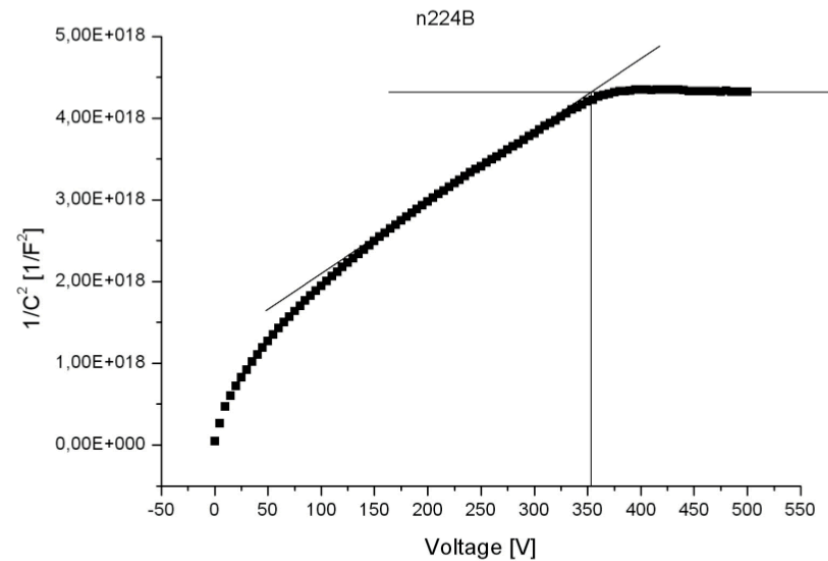
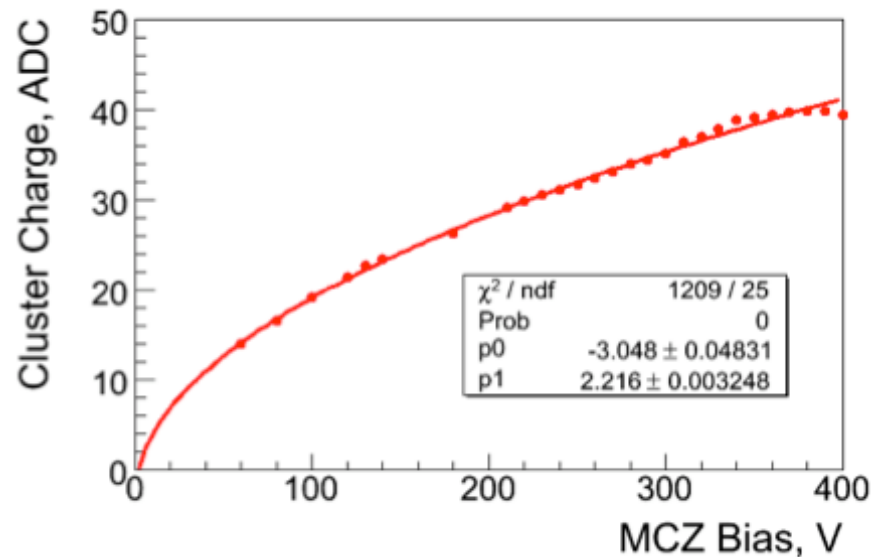


# Detectors Under Test

year	fluence [1 MeV n <sub>eq</sub> ]	proton [%]	tech.	bulk	thickness [μm]	box T [°C]	bias
2007	non-irrad.		MCz	n-type	300	-10	rev
2008	non-irrad.		FZ	n-type	285	3	rev
2007	$1.0 \times 10^{14}$	100	MCz	n-type	300	-10	rev
2009	$1.0 \times 10^{14}$	100	FZ	n-type	285	-24	rev
2008	$2.2 \times 10^{14}$	100	FZ	n-type	285	-18	rev
2009	$3.0 \times 10^{14}$	100	FZ	p-type	300	-24	rev
2007	$5.0 \times 10^{14}$	100	MCz	n-type	300	-10	rev
2008	$6.1 \times 10^{14}$	84	MCz	n-type	300	-18	rev
2009	$1.0 \times 10^{15}$	100	MCz	p-type	180	-24	rev
2008	$1.1 \times 10^{15}$	91	MCz	n-type	300	-18	rev
2008	$1.6 \times 10^{15}$	94	MCz	n-type	300	-18	rev
2009	$2.0 \times 10^{15}$	100	MCz	n-type	180	-24	rev
2009	$2.0 \times 10^{15}$	100	MCz	p-type	300	-53	rev/for
2008	$2.8 \times 10^{15}$	100	MCz	n-type	300	<-40	rev/for
2009	$5.0 \times 10^{15}$	100	MCz	n-type	300	-53	rev/for



# Non-irradiated MCz



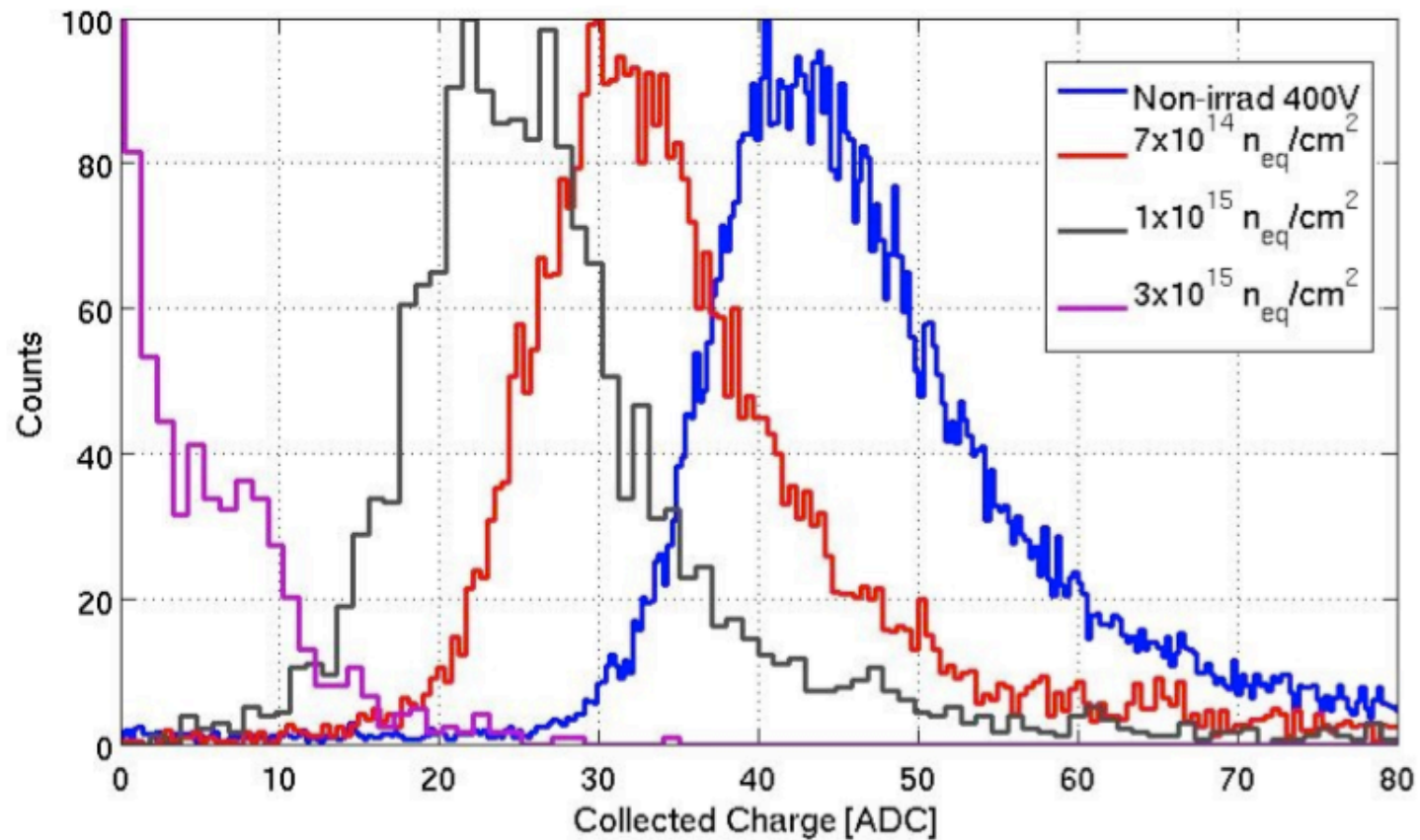
The non-irradiated MCz silicon fully depletes at around 350 V, both as shown from the test beam result and from an earlier probing study at Karlsruhe.

The HPK reference silicon depletes at around 130V and the Topsil FZ samples at ~10V.



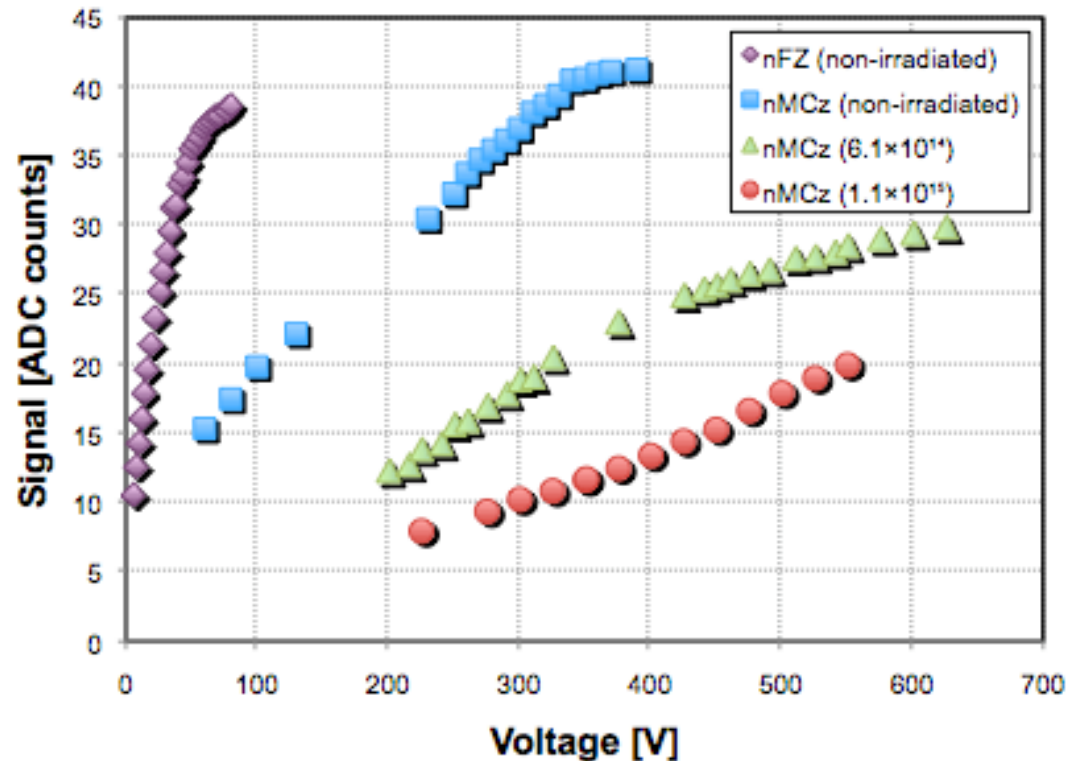
# Signal

## Results 2008





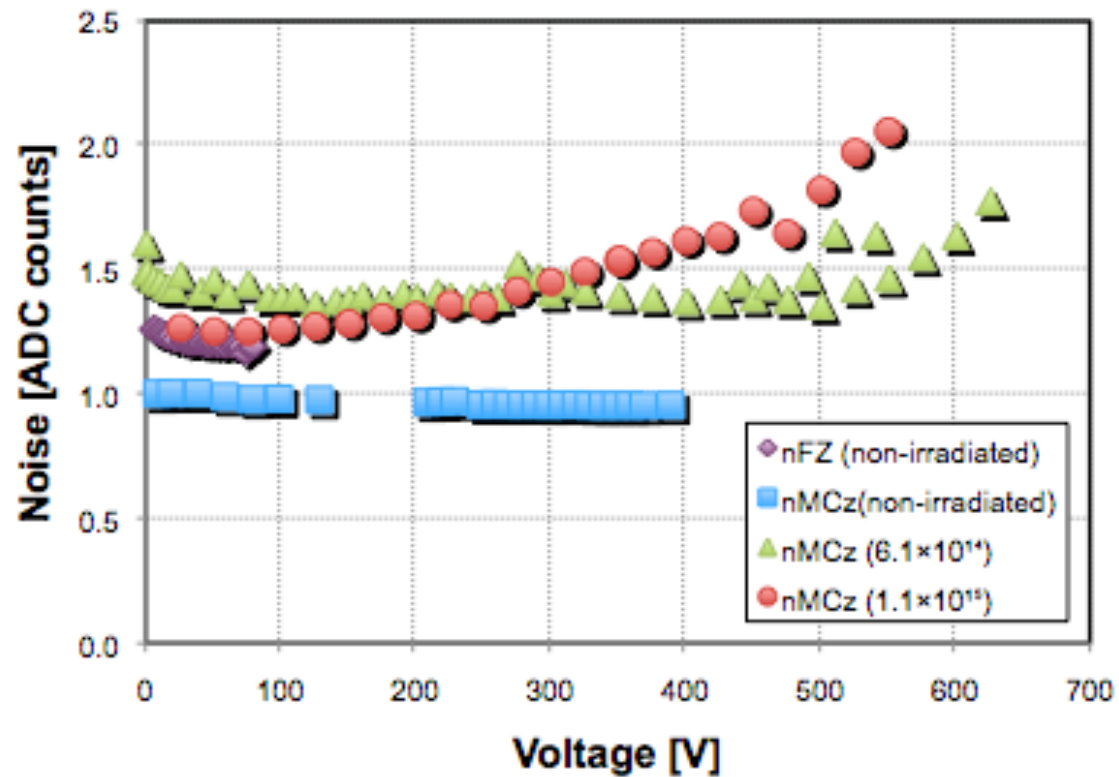
# Charge Collection Efficiency



**Full charge for non-irradiated sensors ~40 ADC counts**  
**At  $1 \times 10^{15}$  signal MPV ~ 20 (50% CCE), S/N > 10**

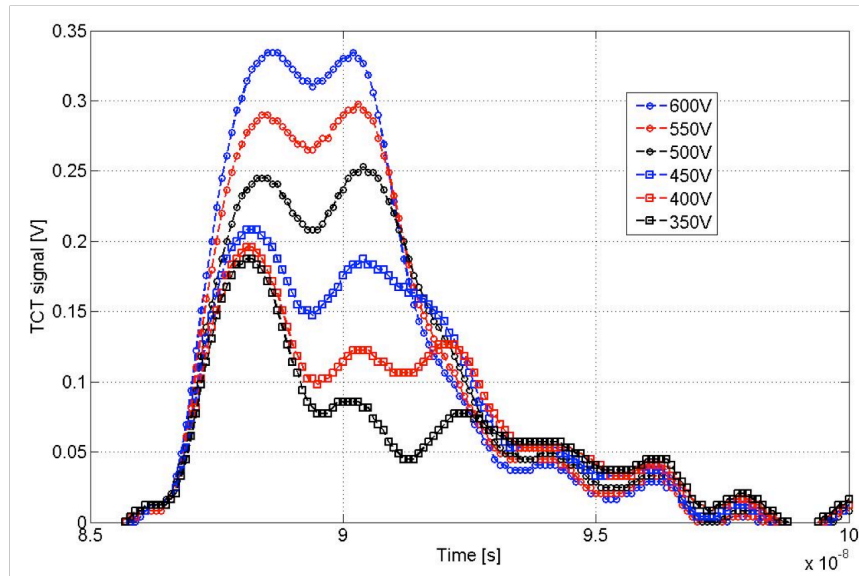


# Noise





# Electric Field after Irradiation

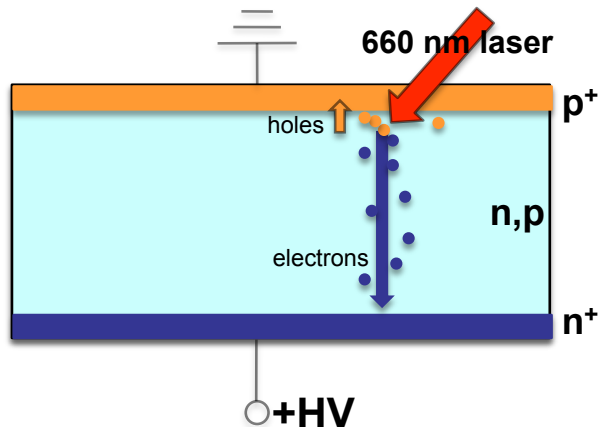


n-type MCz **diode** irradiated to  $1 \times 10^{15}$  neq (26 MeV protons)

**Transient Current Technique** red laser measurement by Helsinki group shows double peak E field (I(t) not trapping corrected).

Similar studies used to show type inversion in irradiated n-type FZ silicon.

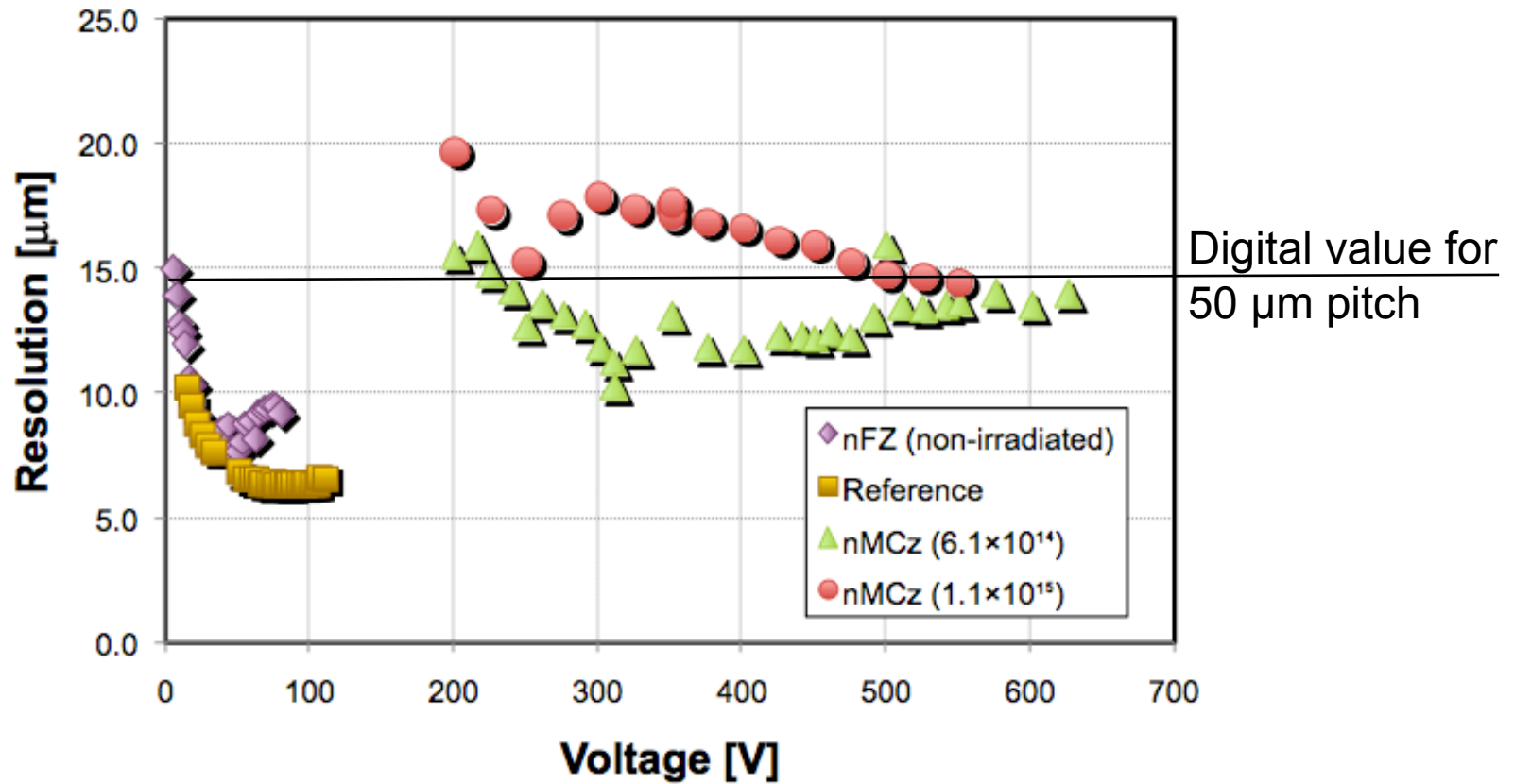
Close connection with the CERN **RD50** and **RD39** groups to understand the observed behavior.





# Position Resolution

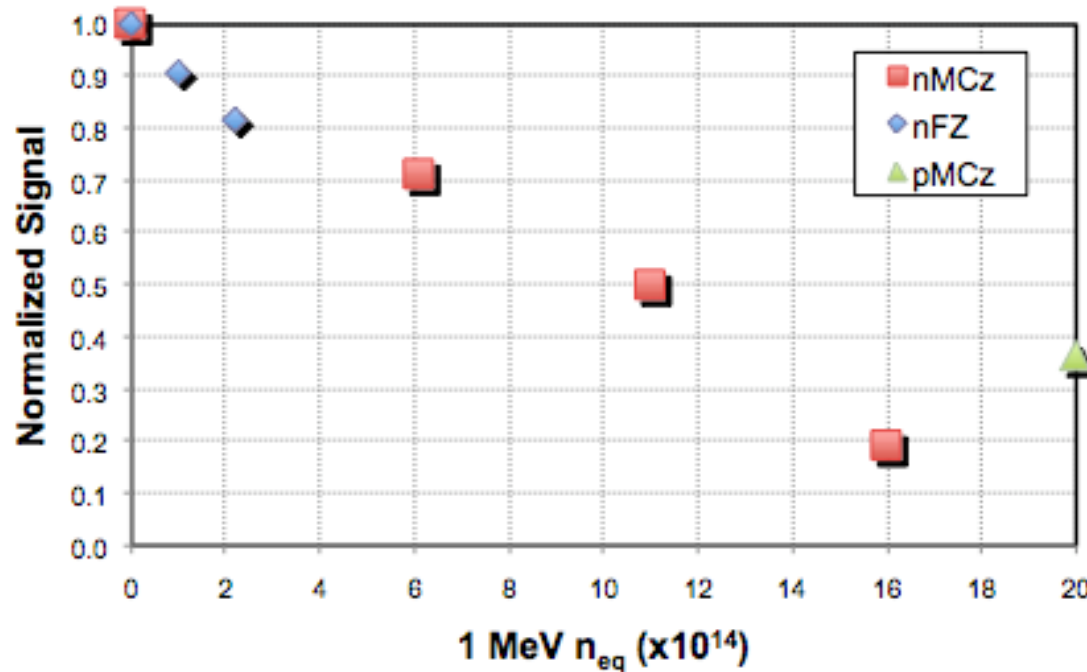
4  $\mu\text{m}$  beam uncertainty in slots 5 and 6





# Comparison of Technologies

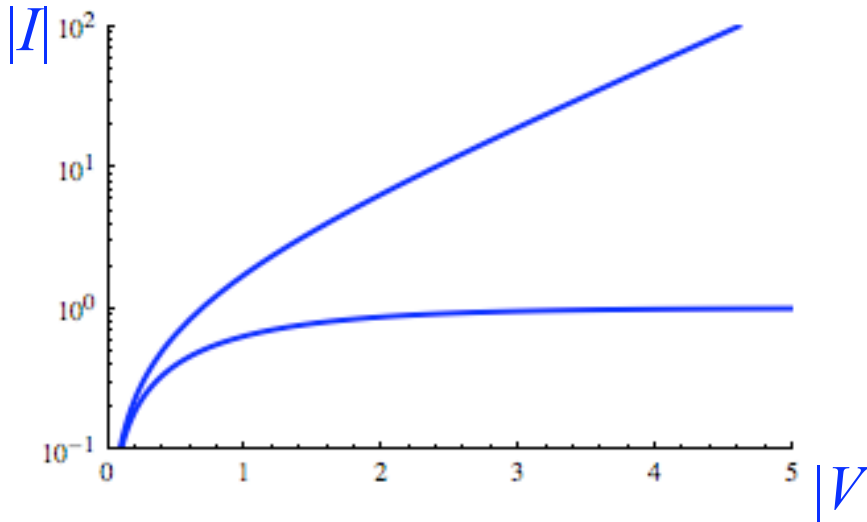
**Warning: 600 V  
limit for signal.  
Less than full  
depletion for  
high fluences!**



Although p-type MCz silicon has almost a factor of two CCE for the same fluence, as expected, our measurements indicated that n-type MCz silicon would be adequate for the S-LHC radiation environment. And given the need for extra processing to isolate n+ implants, this may weigh in favor of n-type MCz silicon for large scale production.



# Current Injected Detector (CID)



Forward and reverse bias diode curves



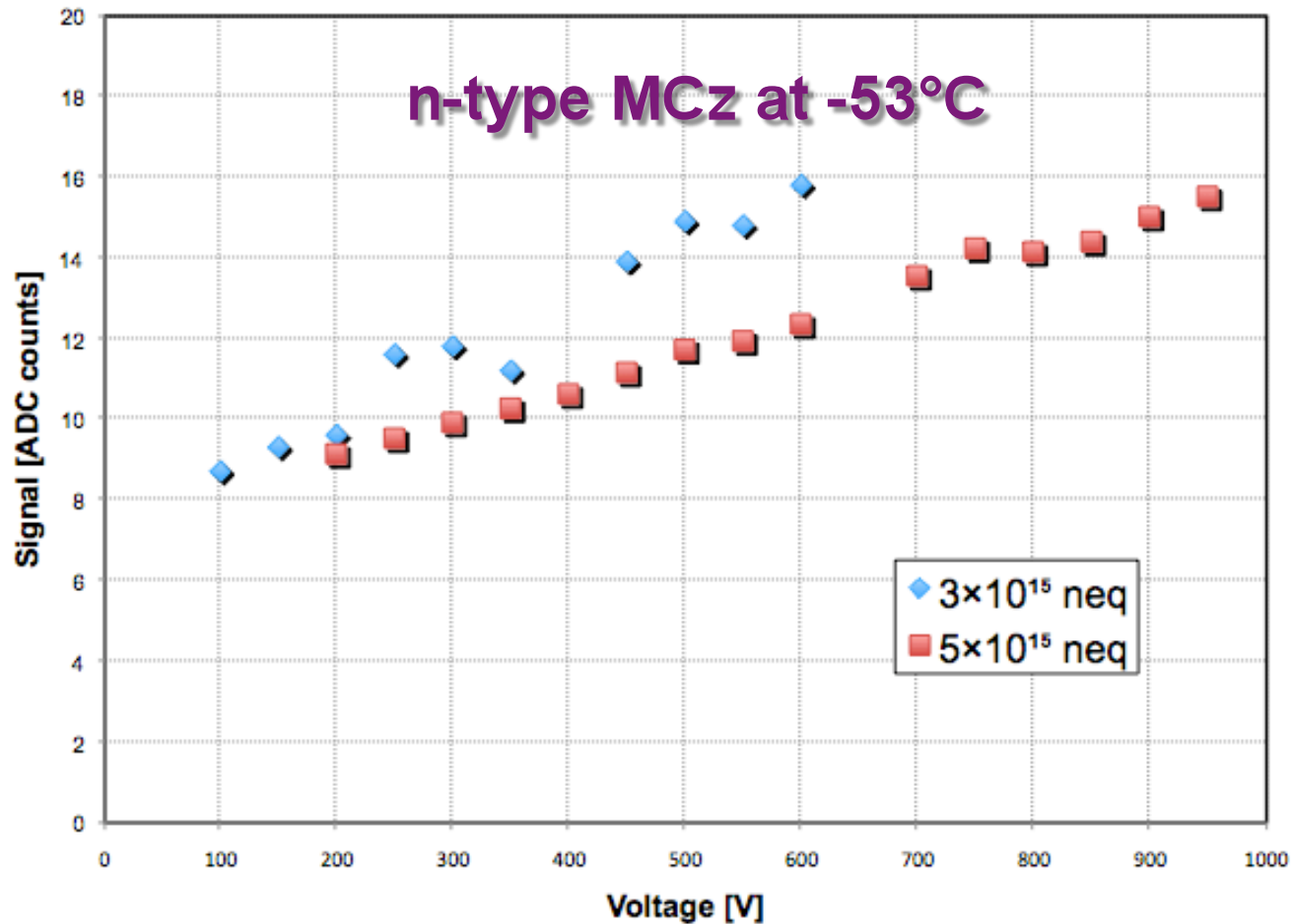
SiBT "cold finger"

Normally, HEP Si detectors are operated in a reverse bias mode. However, for highly irradiated sensors there exists the possibility of creating a balance between trapping and detrapping of forward injected charge carriers.

Leads to a square root dependence of  $E[x]$

Detrapping time constants increase exponentially with temperature, so very low temperatures are required.

# Current Injection Devices



**Changing from reverse to forward bias modes might prolong the lifetime of detectors IF one could provide the very low temperature required for trapping/detrapping balance.**



# Future Plans

- Will participate in a fourth beam test beginning in the fall of 2010
  - Work closely with the CMS Tracker Upgrade Sensor group to test a variety of MCz and FZ sensor types that have been ordered from HPK
  - Additional MCz n and p type sensors have been fabricated at Micronova
- Possible improvements to the beam telescope
  - “Vienna II” box
    - 12 slots (up to 4 DUTs)
    - Ability to tilt DUTs relative to beam
    - Improved low temperature performance
  - Standard CMS readout
    - Possible integration with CMS calorimeter beam setups in H2
  - Operation within a magnetic field?



# Backup Slides



# References

## ■ Web pages

- SiBT

<http://www.hip.fi/research/cms/tracker/SiBT/php/home.php>

- RD50

<http://rd50.web.cern.ch/rd50/>

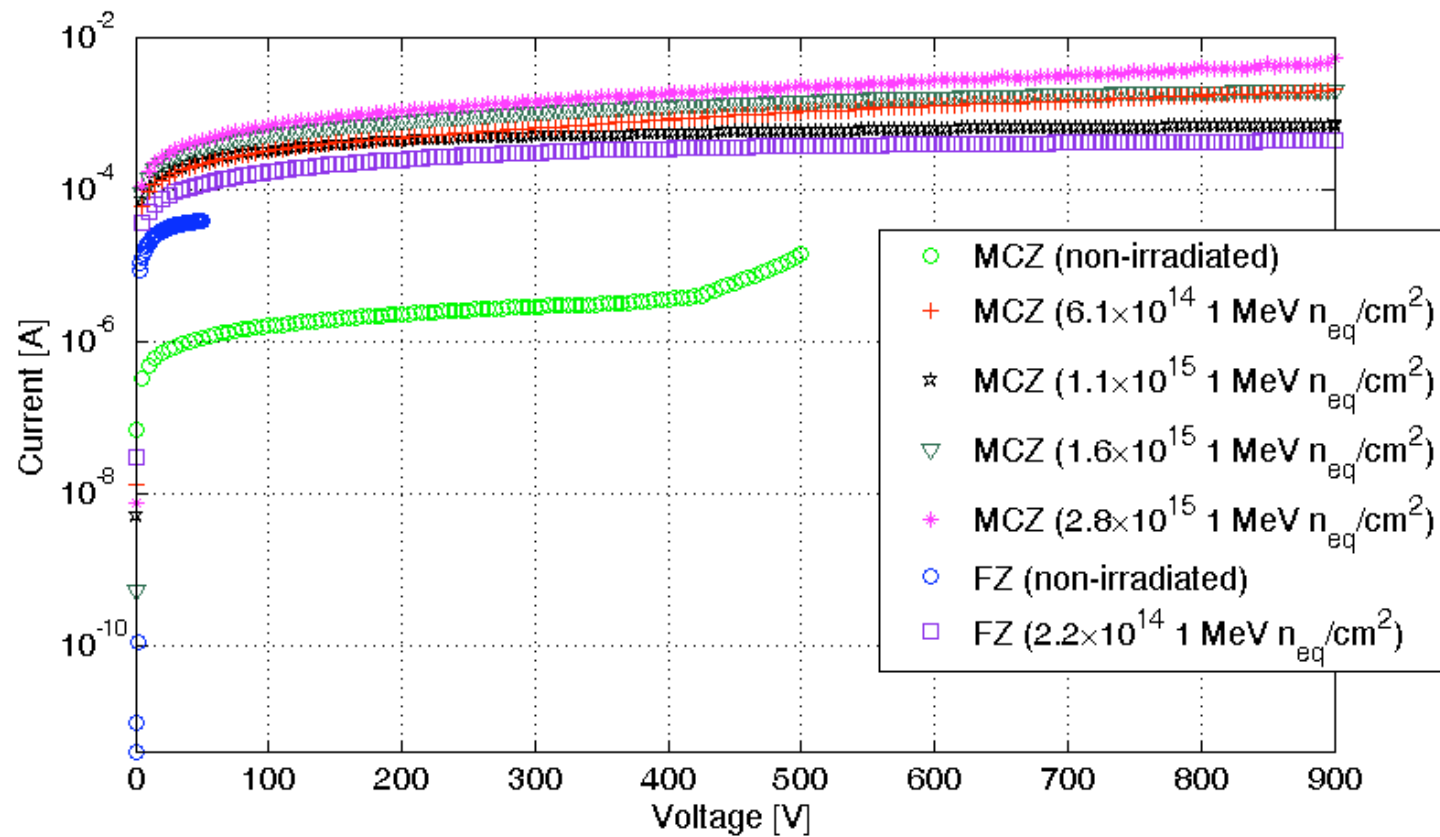
- RD39

<http://www.hip.fi/research/cms/tracker/RD39/php/home.php>

## ■ SiBT publications

- 1) Silicon Beam Telescope for LHC Upgrade Tests, Nuclear Inst. and Methods in Physics A, 593 (2008)
- 2) Off-line calibration and data analysis for the silicon beam telescope on the CERN H2 beam, Nuclear Inst. and Methods in Physics A, 602 (2009)
- 3) TCT and test beam results of irradiated magnetic Czochralski silicon (MCz-Si), Nuclear Inst. and Methods in Physics Research A, 604 (2009)
- 4) Test beam results of heavily irradiated magnetic Czochralski silicon (MCz-Si) strip detectors, Nuclear Inst. and Methods in Physics Research A, 612 (2010)
- 5) Test beam results of a heavily irradiated Current Injected Detector (CID), Nuclear Inst. and Methods in Physics Research A, 612 (2010)

# IV Measurements





# CMS Hamamatsu Program

- Goal is to identify a baseline sensor technology for the CMS Phase 2 upgrade
- Variations to be explored include
  - MCz vs FZ
  - p-on-n vs n-on-p
  - p-stop vs p-spray (for n-on-p)
- Sensor thicknesses include
  - 300  $\mu\text{m}$  FZ
  - 200 and 100  $\mu\text{m}$  FZ (carrier)
  - 200  $\mu\text{m}$  MCz (thinning)
  - 100 and 75  $\mu\text{m}$  epi
- And irradiation scenarios
  - proton
  - neutron
  - mixed

