RD39 Status Report 2006

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

Outline

Introduction

Trapping effect on Charge Collection efficiency (CCE) in S-LHC

CryogenicTCT setup

CCE at the low temperatures

Operation of current-injected-detectors (CID)

CCE measurements on CID

Simulation of noise in CID strip detectors

Cryogenic module of microstrip Si detectors

Milestones and Budget

Trapping effect on CCE in S-LHC

$$CCE = CCE_{GF} \times CCE_t = \frac{w}{d} \cdot e^{-t_{dr}/\tau_t}$$

Trapping term

Depletion term

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/cm^2, the trapping term CCE_t is significant

For fluence 10^{16} n/cm^2, the trapping term CCE_t is a limiting factor of detector operation !

TRAPPING

$$\tau_t = \frac{1}{\sigma v_{dr} N_t}$$

The drift velocity $v_{dr} \approx 10^7$cm/s

10^{16}cm^{-2} irradiation produces $N_T \approx 3\text{-}5 \times 10^{16}$ cm^{-3} with $\sigma \approx 10^{-14}$cm^2

On average (e and h) it gives a $\tau_t \approx 0.2$ ns!

Even in highest E-field (Saturation velocity, 10^7 cm/s), carrier drifts only 20-30 μm before it gets trapped regardless whether the detector is fully depleted or not !

In S-LHC conditions, about 90% of the volume of d=300μm detector is dead space !

DETRAPPING

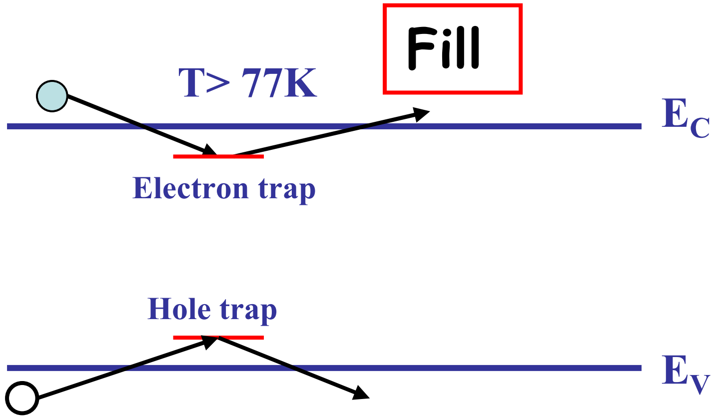
$$\tau_d = \frac{1}{\sigma v_{th} N_C e^{-E_t/kT}}$$

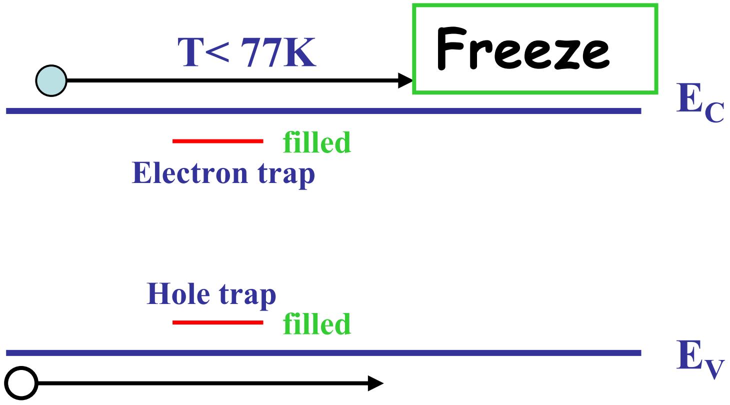
If a trap is filled (electrically non-active) the detrapping time-constant is crucial

The detrapping time-constant depends exponentially on T

For A-center (O-V at E_c-0.18 eV with $\sigma \approx 10^{-15}$ cm^2)

T(K)	300	150	100	77	60	55	50	48	47	46
τ_d	3.7 ns	3.9 µs	4 ms	2 s	1.22 hrs	1.2 days	53 days	302 days	2.1 years	5.47 years

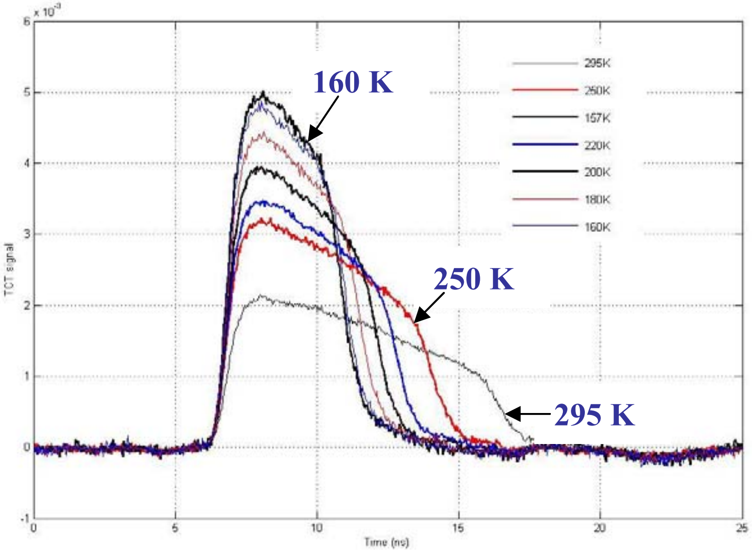


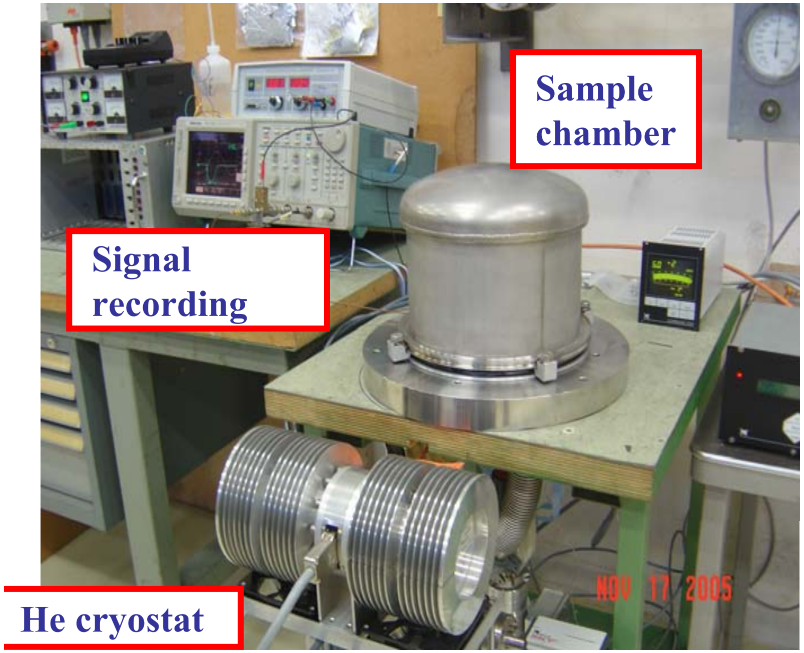


Cryogenic Transient Current Technique (C-TCT)

With C-TCT it is possible to measure and extract

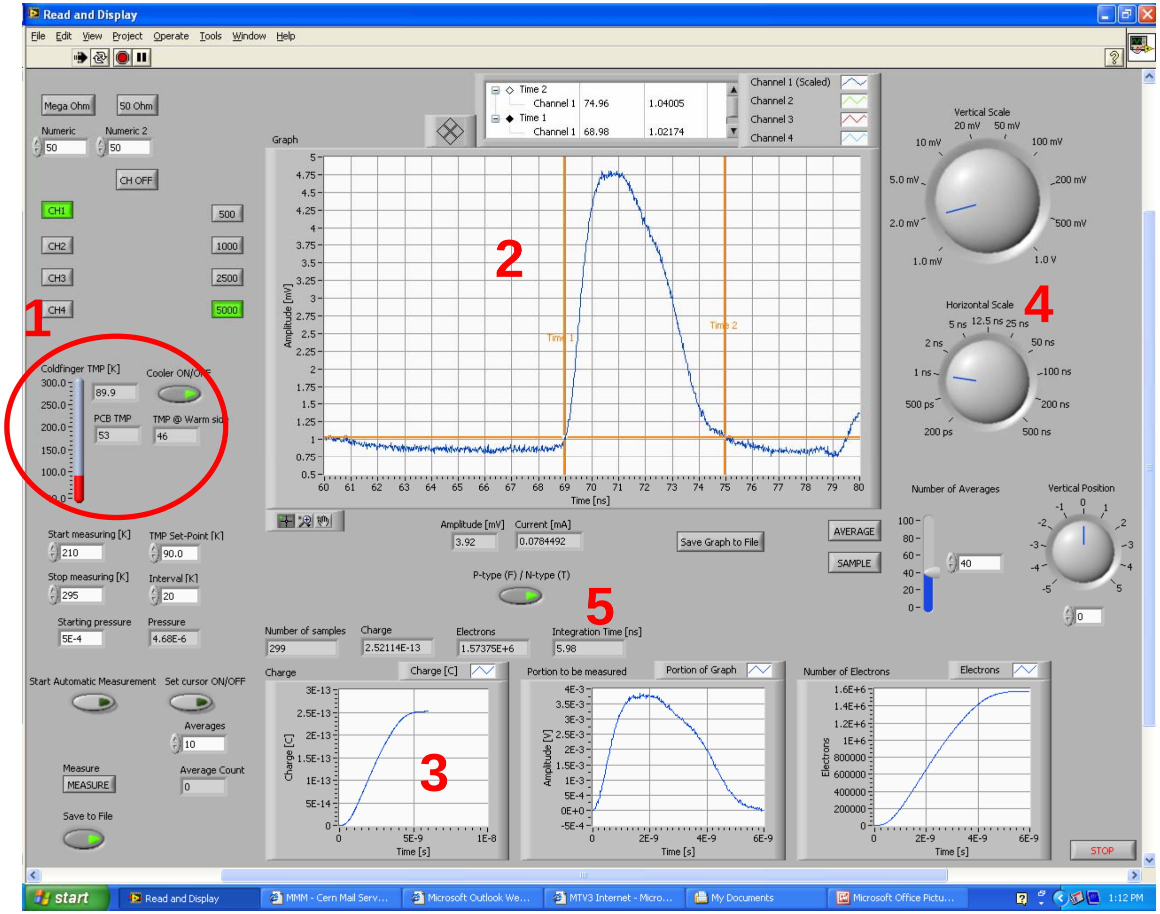
- -Full depletion voltage V_{fd}
- -Charge Collection Efficiency (CCE)
- -Type of the space charge (n or p)
- -Trapping time constant $\tau_{e,h}$
- -Electric field distibution $E(x)$





Improvements since Dec 2005

Fully computer controlled user interface



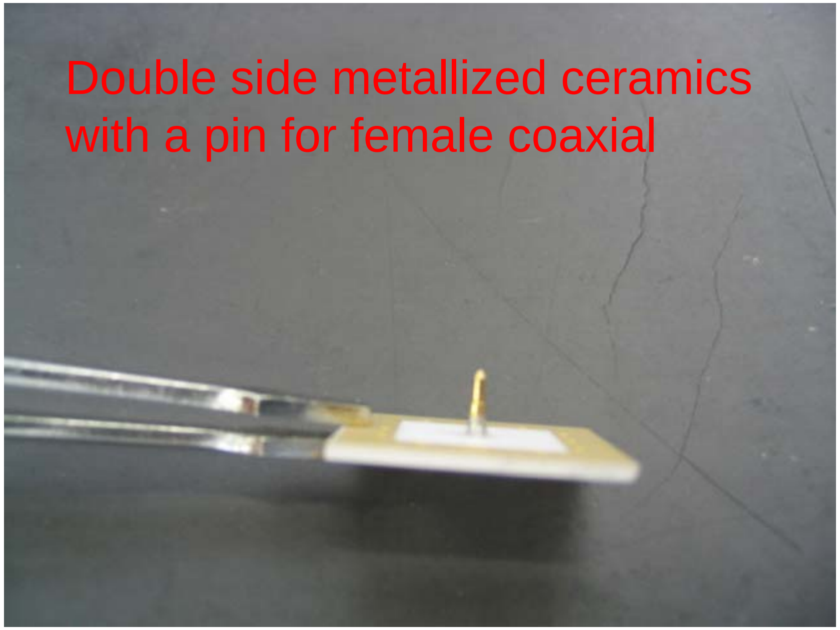
Time 2 — Channel 1: 74.96, 1.04005
Time 1 — Channel 1: 68.98, 1.02174

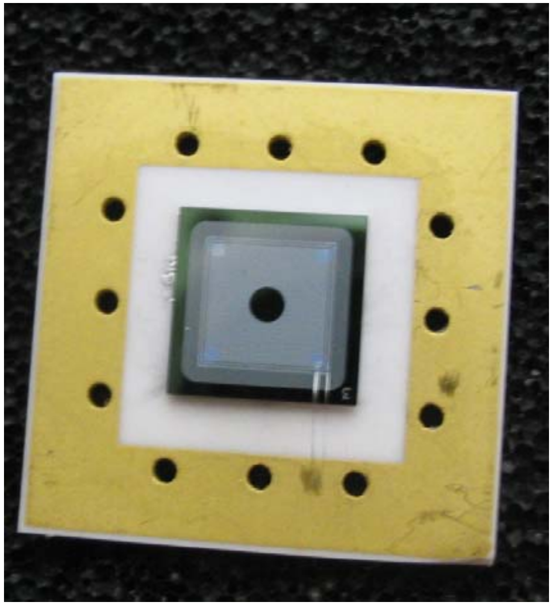
Numeric: 50
Numeric 2: 50
Coldfinger TMP [K]: 89.9
PCB TMP: 53
TMP @ Warm side: 46
Start measuring [K]: 210
TMP Set-Point [K]: 90.0
Stop measuring [K]: 295
Interval [K]: 20
Starting pressure: 5E-4
Pressure: 4.68E-6
Averages: 10
Average Count: 0
Amplitude [mV]: 3.92
Current [mA]: 0.0784492
Number of samples: 299
Charge: 2.52114E-13
Electrons: 1.57375E+6
Integration Time [ns]: 5.98
Number of Averages: 40
Vertical Position: 0

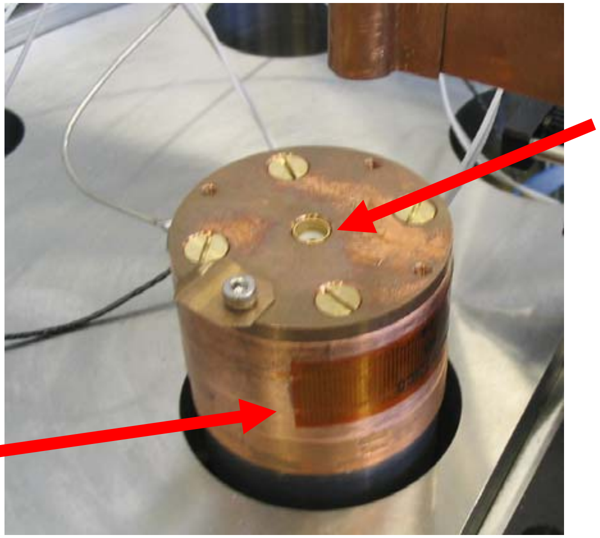
1. Temperature control
2. Adjustable cursors for data taking
3. CCE measurement screen
4. Oscilloscope control
5. N or P type sample

Improvements since Dec 2005

- Ceramic sample holders







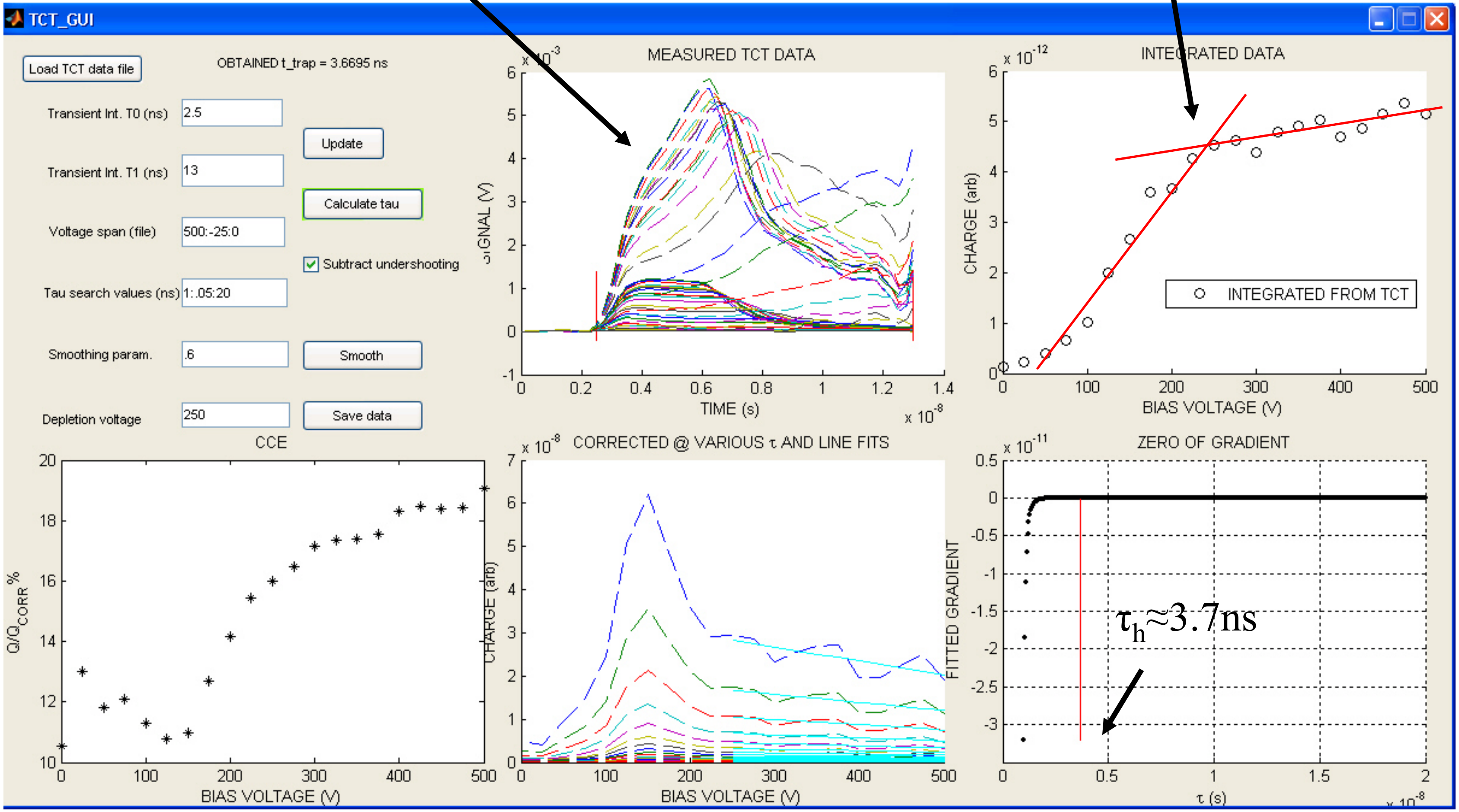
Cold finger and coaxial connector

Heating resistor provides faster temperature ramping

C-TCT data analysis

Trapping corrected transient

V_{fd}



OBTAINED t_trap = 3.6695 ns

Transient Int. T0 (ns): 2.5

Transient Int. T1 (ns): 13

Voltage span (file): 500:-25:0

☑ Subtract undershooting

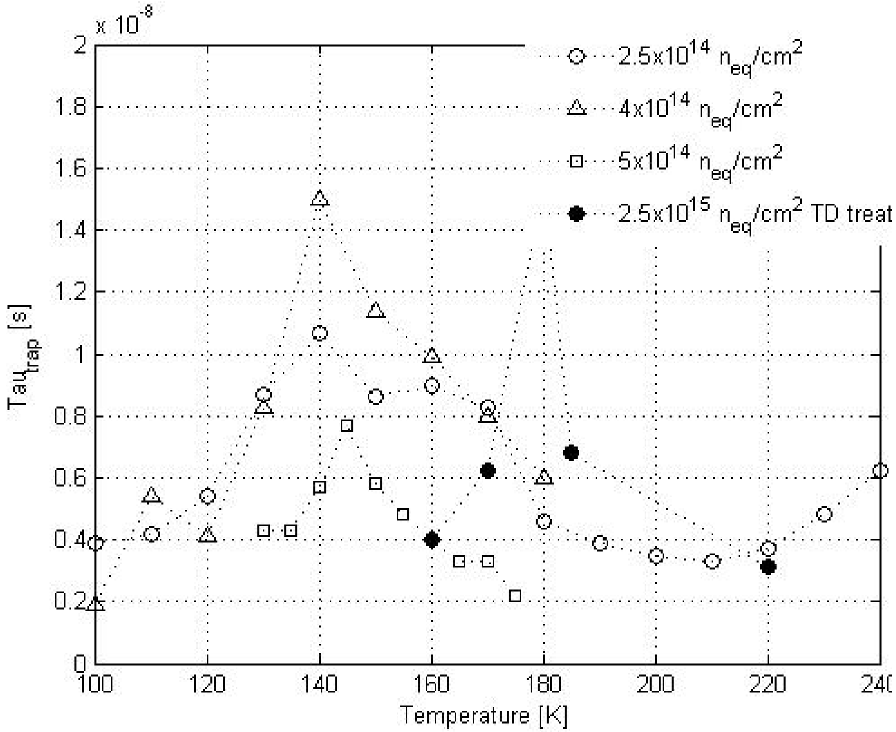
Tau search values (ns): 1:.05:20

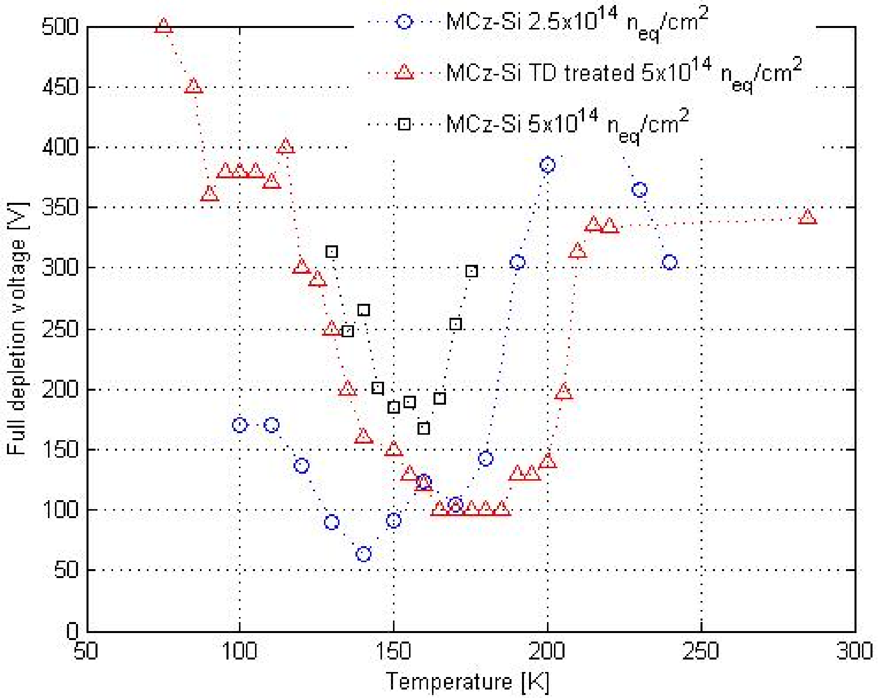
Smoothing param.: .6

Depletion voltage: 250

$\tau_h \approx 3.7$ns

Trapping time τ_{eff} and V_{fd} vs Temperature



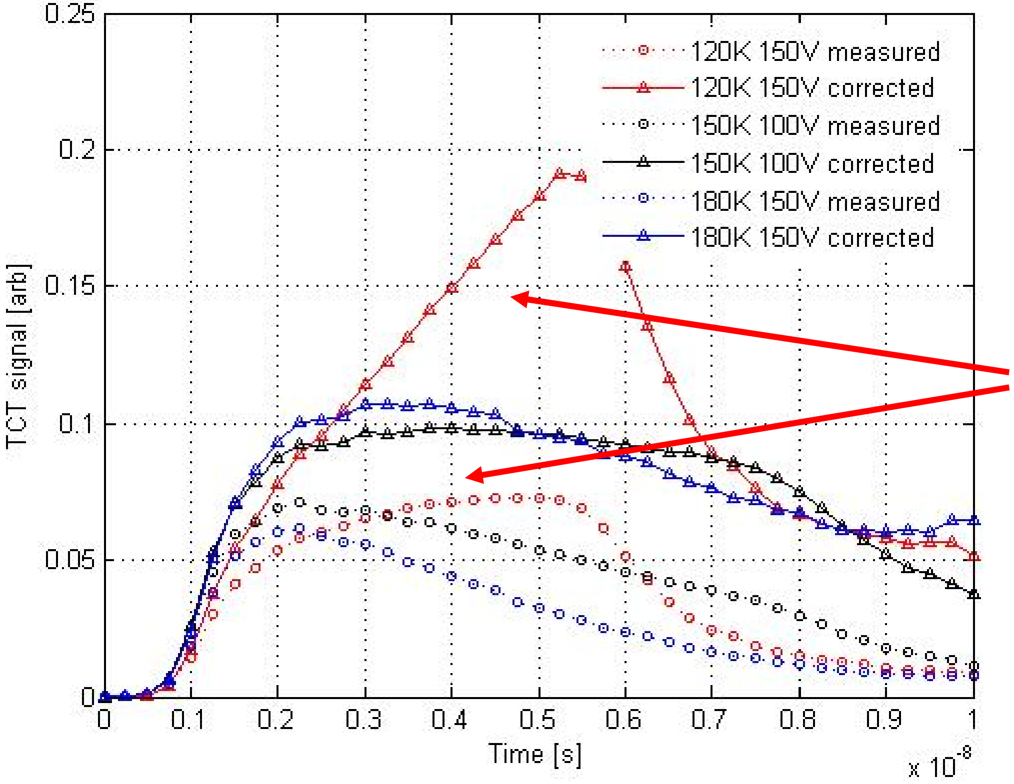


$$\tau_t = \frac{1}{\sigma v_{th} N_t}$$

Heavily irradiated $n^+/p^-/p^+$ Magnetic Cz-Si detector
At room temperature $V_{fd} > 500V$

$$\tau_d = \frac{1}{\sigma v_{th} N_C e^{-E_t/kT}}$$

Space Charge Sign Inversion at low T



Decreasing transient 150K & 180K

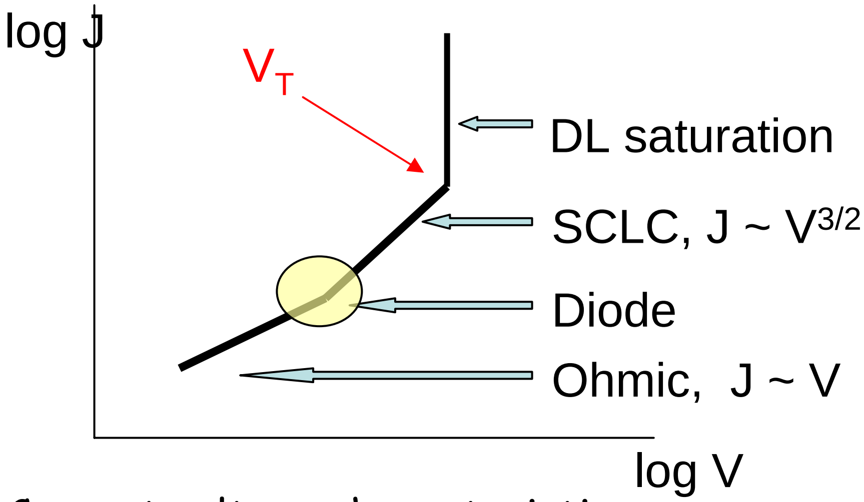
Increasing transient 120K

Space Charge is balanced by trapping and detrapping !

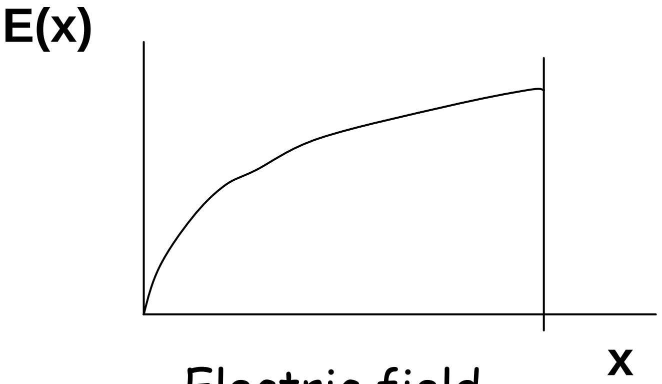
→ High E field → Low V_{fd}
→ Higher τ_{trap}

$$\tau_t = \frac{1}{\sigma v_{th} N_t} \qquad \tau_d = \frac{1}{\sigma v_{th} N_C e^{-E_t/kT}}$$

Charge Injected Detector CID



Current voltage characteristic



Electric field

Features of CID

*Electric field shape is not affected by fluence >> E-field exists at S-LHC conditions

*E field exists regardless of thickness

*Low temperature makes possible to keep forward current at µA range

*No breakdown problem due to self-adjusted electric field by space charge limited current feedback effect

*CID is quite insesisite on detectors material properties.

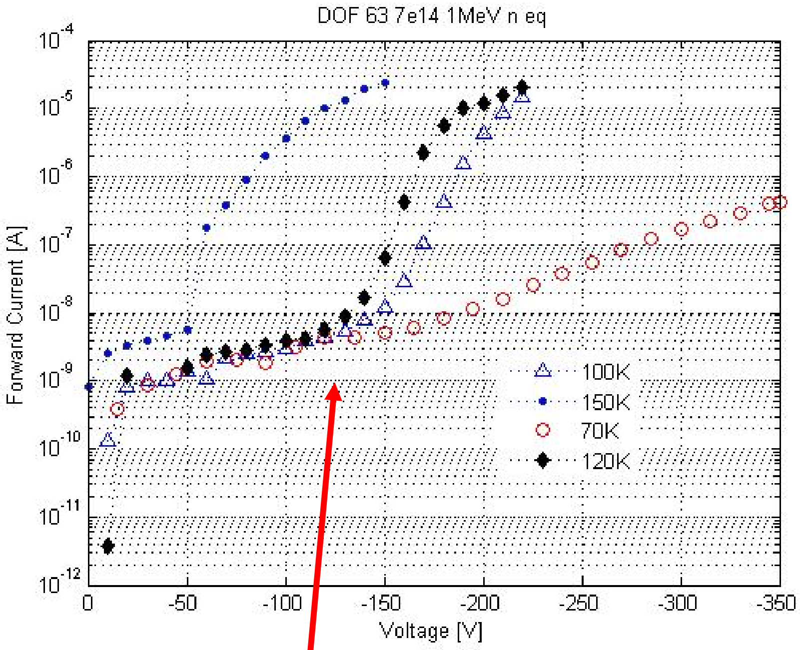
*CID is insensitive on type of irradiation.

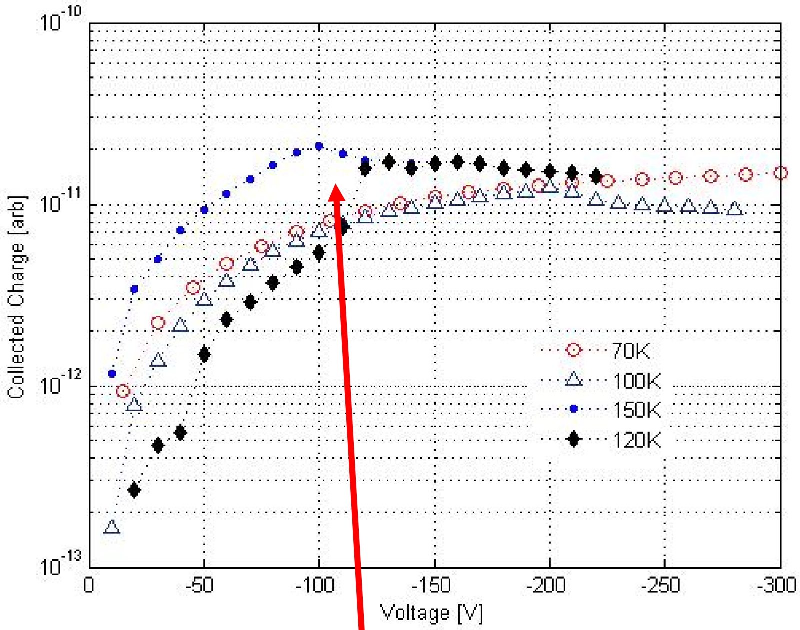
*CID is insensitive on reverse annealing of radiation defects >> importnant in HEP applications.

*Treshold for sharp current increase V_T increases with respect of fluence

*V_T can be affected by temperature

Charge Collection in CID





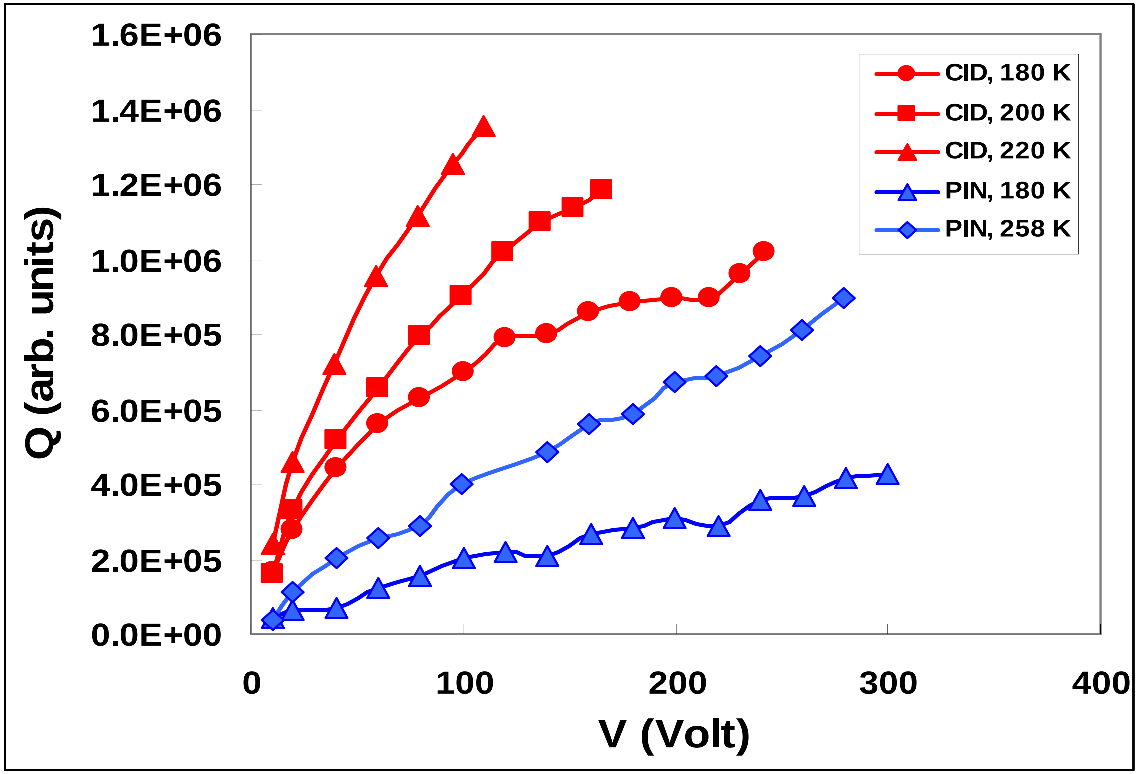
Space charge saturation treshold V_T

CCE plateau after V_T

Measurements done with 670nm laser

$$V_T = \frac{q}{\varepsilon\varepsilon_0} d^2 \left(N_{dl} - N_{dl}^{+}\right)$$

CCE of CID vs. “normal” detector PIN

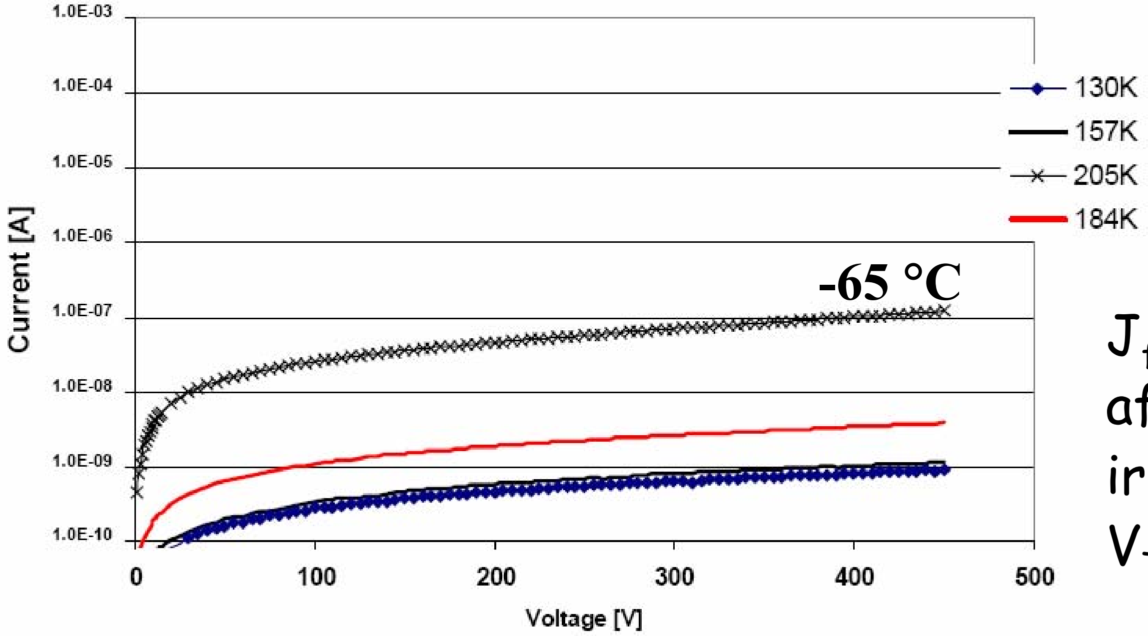


1060nm Infrared laser simulates MIPs

Fluence 1×10^{15} cm^{-2}

$V_{fd} \approx 1000$V in normal reverse biased operation

CID operation at S-LHC fluence



J_{forw}≈100nA/cm^2 at -65°C after 7x10^{15} 1MeV n_{eq}/cm^2 irradiation.

V_T> 450V

MCz-Si 9MeV proton irradiated 7x10^{15} 1MeV n_{eq}/cm^2

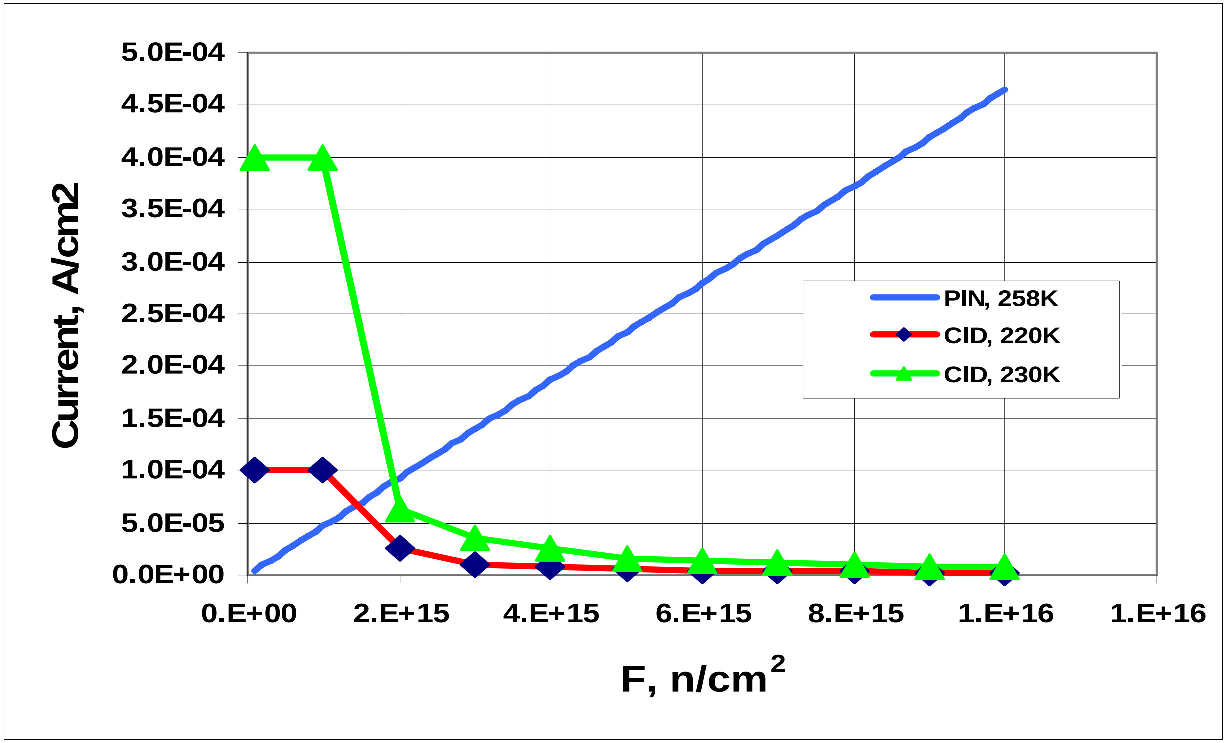
Current of CID and PIN

Simulation parameters:

-DL introduction rate – **4×10^{12}cm^{-3}** ***at*** **1×10^{15} n/cm2**

-V_{CID} =200V

-$V_{pin} > V_{fd}$



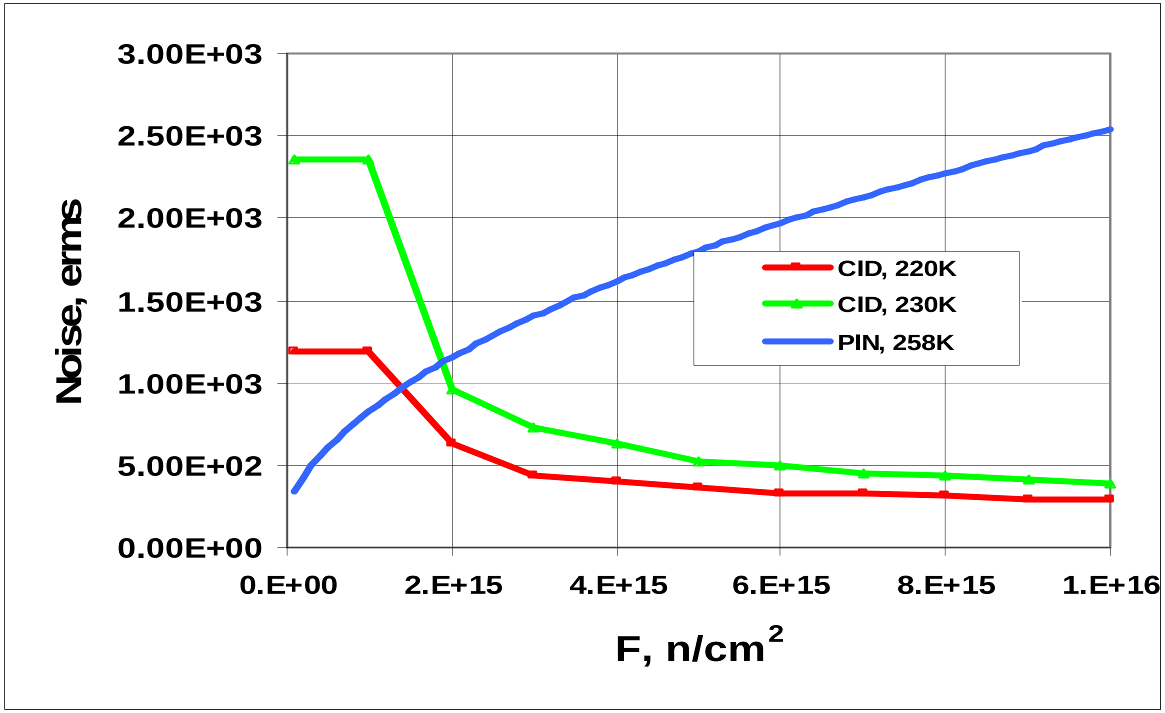
Noise in CID strip detector

Simulation parameters:

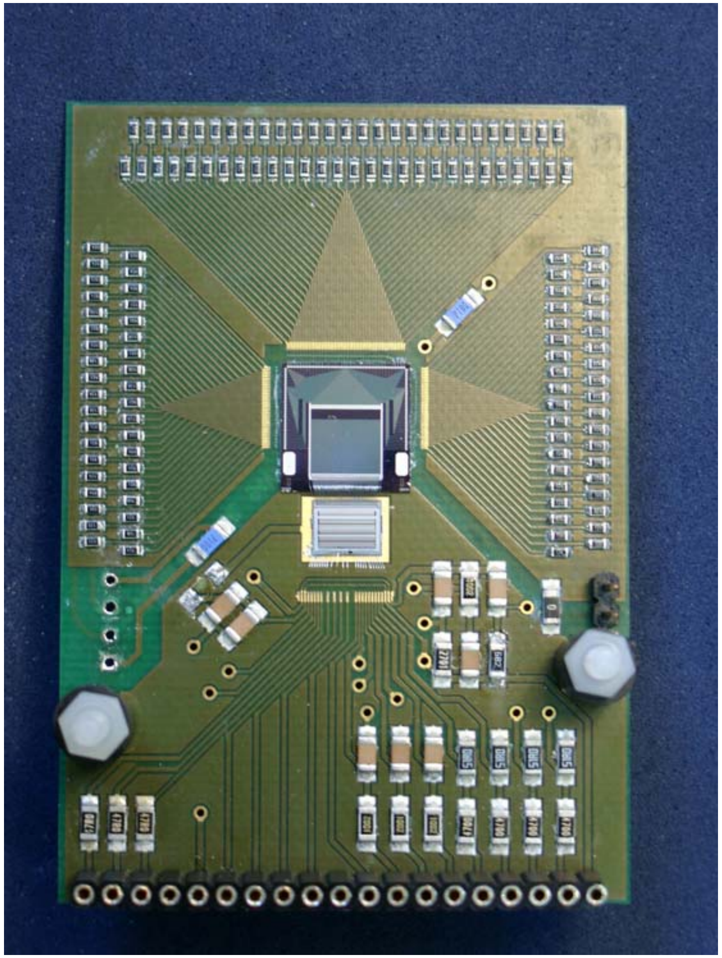
-ATLAS strip design, pitch 80μm, length 6cm, shaping time 25ns

-CID at 200V

-PIN at $V=V_{fd}$ and 258K



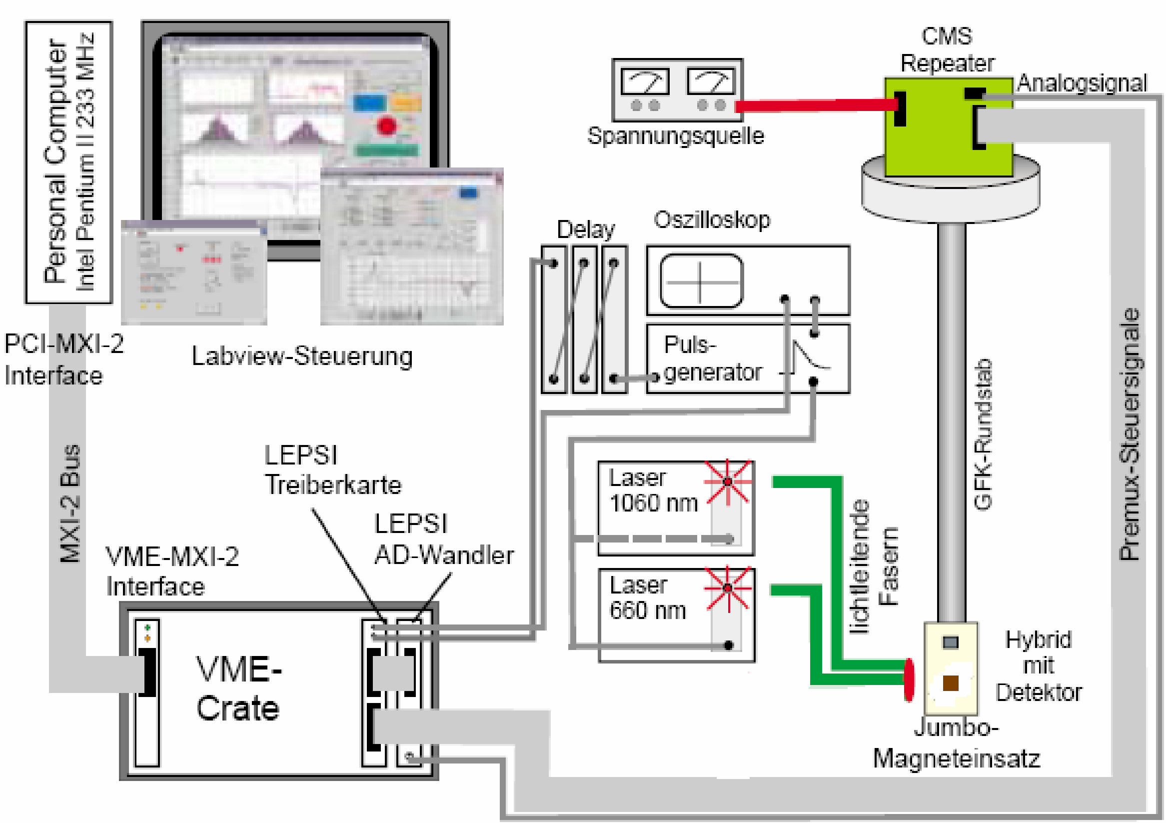
Hybrid with strip sensor

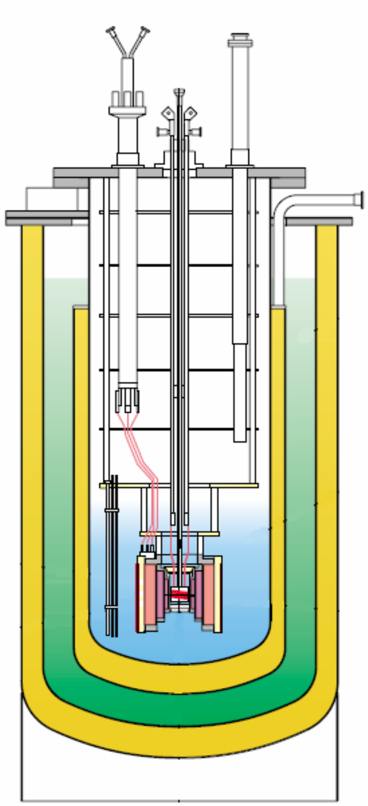


- Double sided sensor (~1cm²), 50µm pitch, 300µm thickness, strips on both sides parallel (former sensors had stripes crossed)
- bias resistors (10MΩ) on hybrid
- Premux128 Chip for data recording
- irradiated with 26MeV protons
- $\Phi=6 \times 10^{13}$ and $\Phi=1{,}2 \times 10^{14}$

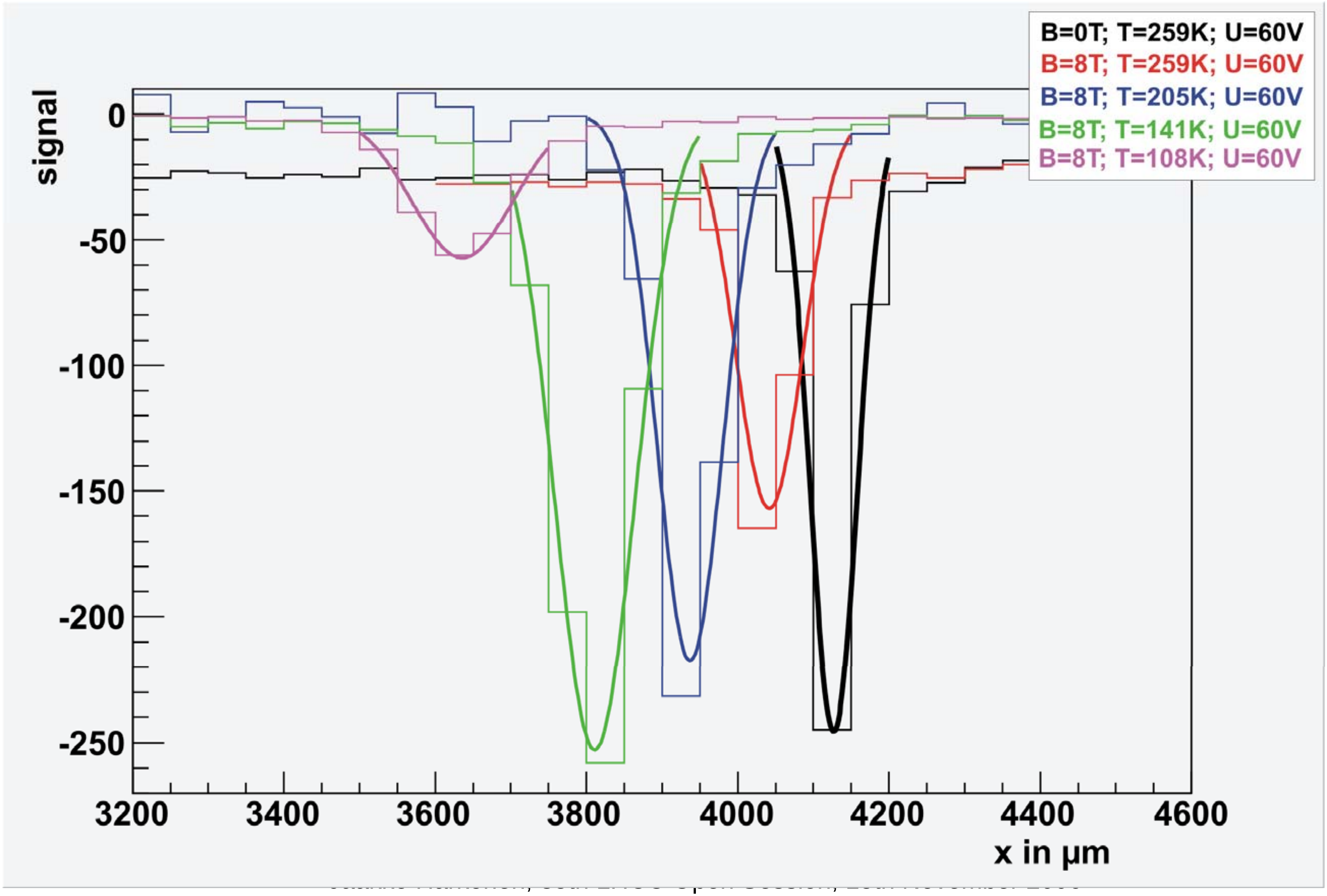
Karlsruhe Cryogenic TCT/CCE measurement setup

- The setup has extensively been used for Lorenzshift measurements
- Ongoing activity for CID measurements of strip detectors

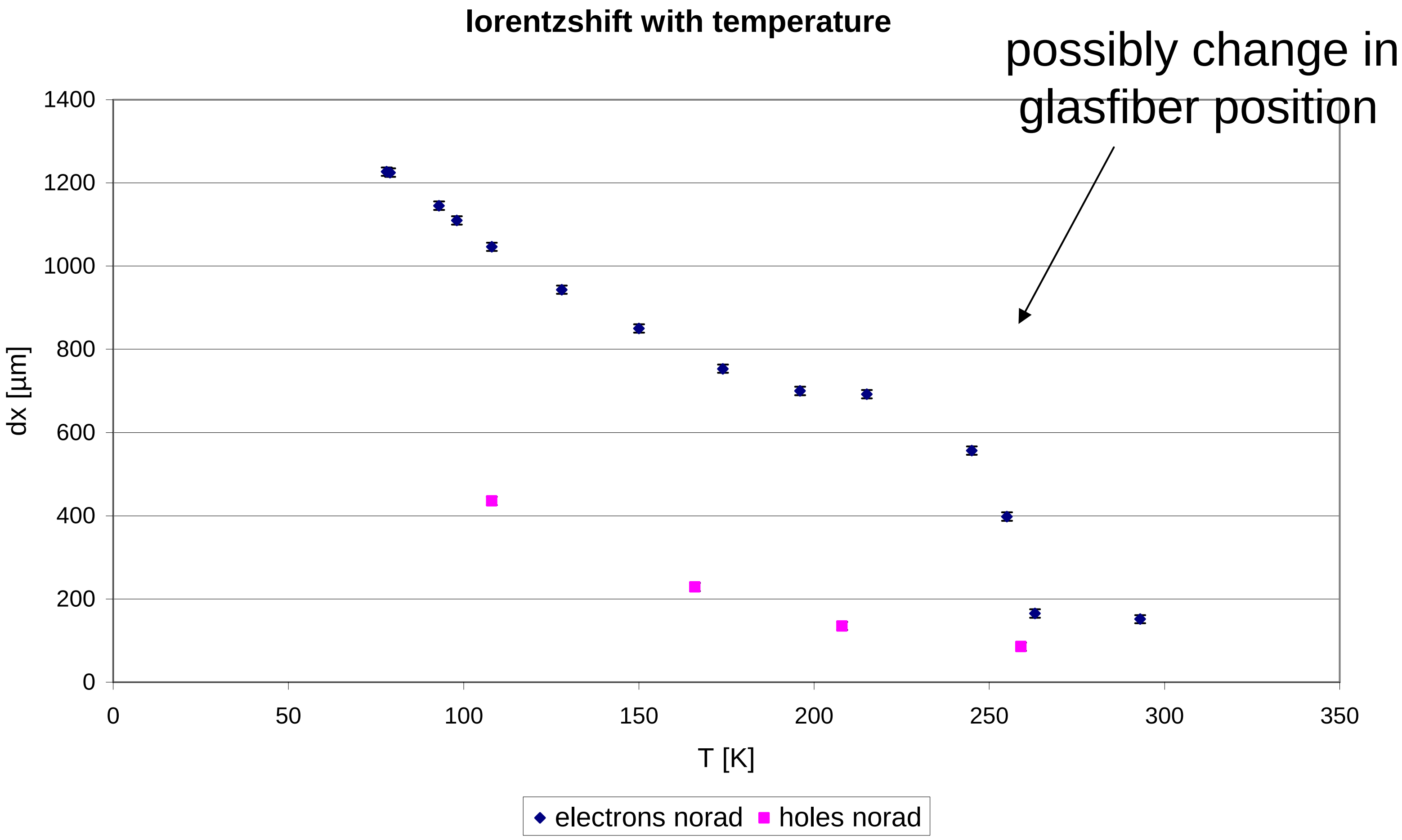




Lorentzshift of holes with different temperatures



Lorenzshift of electrons and holes vs temperature



possibly change in glasfiber position

Jaakko Härkönen, 85th LHCC Open Session, 15th November 2006

Summary

- The C-TCT project has been successfully completed
- The results show that at low temperatures the effective space charge is balanced by the trapping and detrapping.
- That results in

  1) Space Charge Sigh Inversion SCSI
  2) Low full depletion voltage (measured by QV)
  3) Increase of trapping time

- In CID detectors

  1) E-field exists at any bias and at any fluence. Detector is always “fully depleted”
  2) CCE measurements on CID at cryogenic temperatures with laser and forward current injection have shown significant increase in CCE
  3) Simulations on ERMS noise predict that noise in CID strip detectors could be significantly lower than reverse biased detector operating at -15°C

Schedule for the projects of RD39 in 2006 and 2007

Device physics

Task name	2006				2007			
	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4
Device Physics/ Basic Research								
Radiation of segmented (strip) Si detectors				X		XXX		
Improvements on the Cryo-TCT (C-TCT) by adding a floating power - Simulations of injection and E field.					XXX			
CID measurements at T<80 K for pad detectors by red and IR lasers				XX	XXXXXXXXXXX			
CID measurements at T<80 K for strip detectors by red and IR lasers						XXXXXXXXXXXX		
More detailed CID modeling				XX	XXXXXXXXXXXXXXXXX			
Simulations of injection and E field at cryogenic temperatures						XXXXXXXXXXXX		
Modeling of trapping at CID conditions at low temperatures					XXXXXXXXXXXXXXXXX			

Schedule for the projects of RD39 in 2006 and 2007 II

Full size systems

Cryogenic Modules		
Characterization of CID operation of irradiated strip detectors with read-out electronics	XXX	XXXXXXXXX
Laser cut and ICP Plasma etching of edgeless CMS baby strip detectors	XXX	X
Assembly of modules with edgeless CMS baby strip detectors		XXXXXXX
Electrical tests of modules at low temperatures		XXX
Irradiation of modules		XX
Source and beam tests of irradiated modules		XXXX
ICP Plasma etching of edgeless detectors	XXX	XX

Resources

Resources of the 15 institutes in RD39, planned for the projects of RD39 for 2007. For institutes involved also directly in the experiments, the resources for the construction of the final detectors are not included in the figures given for the budget and for the FTE manpower.

Institute	Authors	Device Physics	Basic Research	Cryogenic Modules	RD39 Budget (CHF/year)	FTE In RD39
U. Northeastern	5	x	x		5000	1.00
BNL	2	x	x	x	20000	1.00
CERN	2	x	x		2000	1.00
U. Florence	4	x	x		4000	1.00
U. Geneva	1	x		x	1000	0.15
U. Glasgow	2	x	x		2000	0.50
HIP Helsinki	4	x	x		20000	1.00
U. Helsinki	4	x	x		10000	2
U. Karlsruhe	7	x	x		5000	2.00
U. Louvain	3	x		x	20000	1.00
JSI Ljubljana	4	x	x		2000	0.50
U. Naples	3			x	2000	0.50
Ioffe PTI	3	x	x	x	10000	1.50
U. Turku	3	x	x		5000	0.60
U. Vilnius	7	x	x		10000	2.0
Total	54	14	12	5	113000	14.75