**RD50**

# TCT measurements on MCz n- and p-type after proton and neutron irradiation

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**CERN-PH**

# Common RD50 project

- ## What?
  - Investigation of type inversion problem in MCz

- ## Who?
  - **Ljubljana**
  - **CERN**
  - **HIP**
  - **Bari**
  - **BNL**

- ## How?
  - Common irradiations with protons at CERN and reactor neutrons in Ljubljana
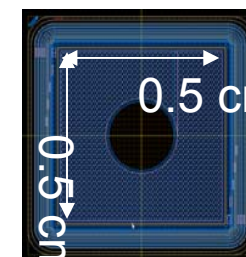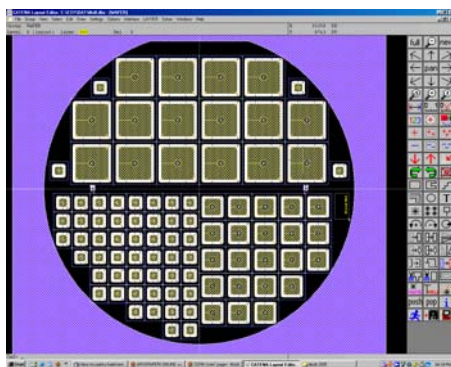  - sets of MCz-n, MCz-p and Fz-n reference distributed

# MCz: Material and measurements

## MCz n-type

- **HIP-MCz-01-n**  0.5 x 0.5 cm$^2$  $V_{fd}$ ~320V (ρ ~ 1 kΩcm) (back & front illumination)
- **SMG**  0.5 x 0.5 cm$^2$  $V_{fd}$ ~310V (ρ ~ 1 kΩcm) no TCT done
- **CNM-01-M**  0.5 x 0.5 cm$^2$  $V_{fd}$ ~370V (ρ ~ 0.8 kΩcm) (front illumination)
- **8556-3 (CiS)**  0.5 x 0.5 cm$^2$  $V_{fd}$ ~100V (ρ ~ 2.9 kΩcm) (back & front illumination)

## MCz p-type (ρ ~ 7.4 kΩcm)

- **p069/8**  0.5 x 0.5 cm$^2$  $V_{fd}$ ~115V



0.5 cm

0.5 cm

# Experimental procedure

## Irradiation
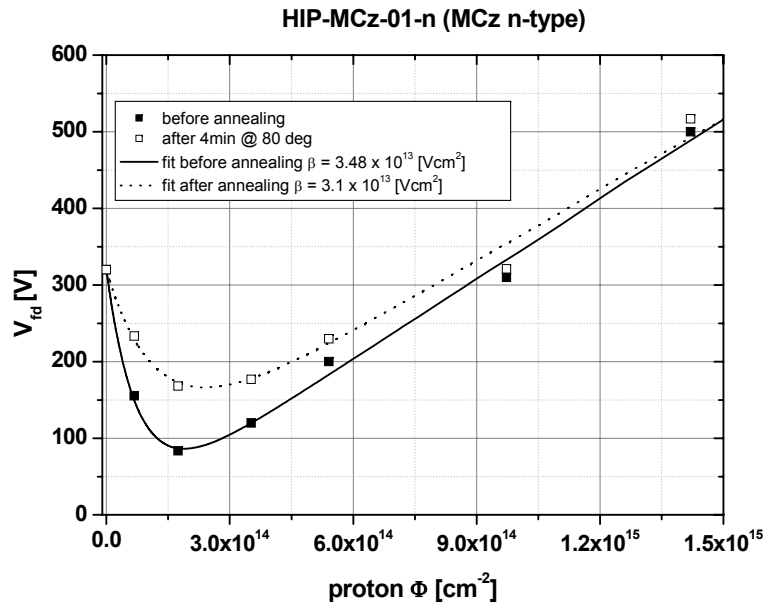
• proton irradiation at CERN (24 GeV/c, 27 °C)
    between $6.8 \times 10^{13}$ cm$^{-2}$ and $2.5 \times 10^{15}$ cm$^{-2}$ proton fluence

• neutron irradiation in Ljubljana (1 MeV)
    between $5 \times 10^{13}$ cm$^{-2}$ and $1 \times 10^{15}$ cm$^{-2}$ neutron fluence

## CV/IV

– Measured at room temperature in parallel mode at 10kHz

## TCT

– 660nm laser, measured at -5°C

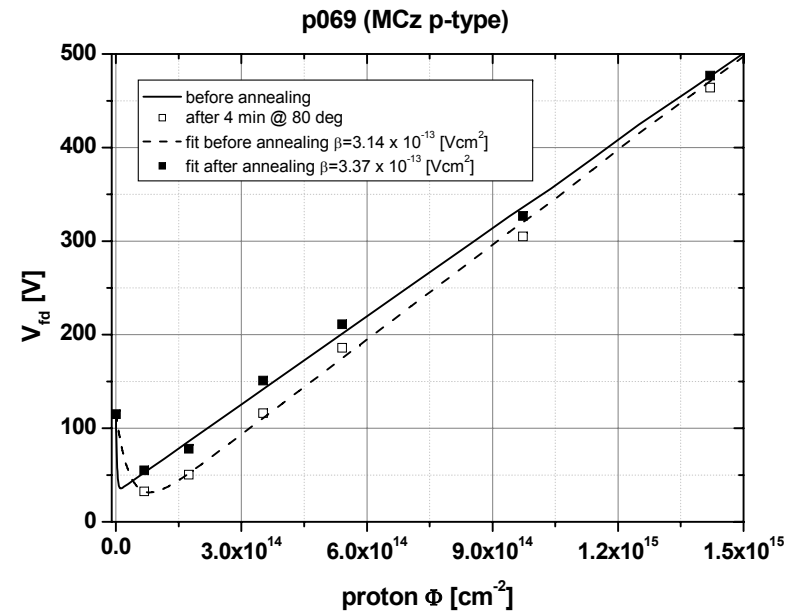# MCz: Depletion voltage (CV)

**HIP-MCz-01-n (MCz n-type)**



- ■ before annealing
- □ after 4min @ 80 deg
- — fit before annealing β = 3.48 x 10$^{13}$ [Vcm$^2$]
- ···· fit after annealing β = 3.1 x 10$^{13}$ [Vcm$^2$]

$V_{fd}$ [V]

proton Φ [cm$^{-2}$]

**p069 (MCz p-type)**



- — before annealing
- □ after 4 min @ 80 deg
- – – fit before annealing β=3.14 x 10$^{13}$ [Vcm$^2$]
- ■ fit after annealing β=3.37 x 10$^{13}$ [Vcm$^2$]

$V_{fd}$ [V]

proton Φ [cm$^{-2}$]

before annealing:  β = 5.1 x 10$^{-3}$ cm$^{-1}$

after 4 min @ 80 °C : β = 4.5 x 10$^{-3}$ cm$^{-1}$

**MCz n-type:**

depletion voltage goes up after annealing for 4 min @ 80 °C => indicates n-type (i.e. no type inversion)

before annealing:  β = 4.6 x 10$^{-3}$ cm$^{-1}$

after 4 min @ 80 °C : β = 4.9 x 10$^{-3}$ cm$^{-1}$

**MCz p-type:**

depletion voltage goes down after annealing for 4 min @ 80 °C => indicates p-type (i.e. no type inversion)

**BUT…**
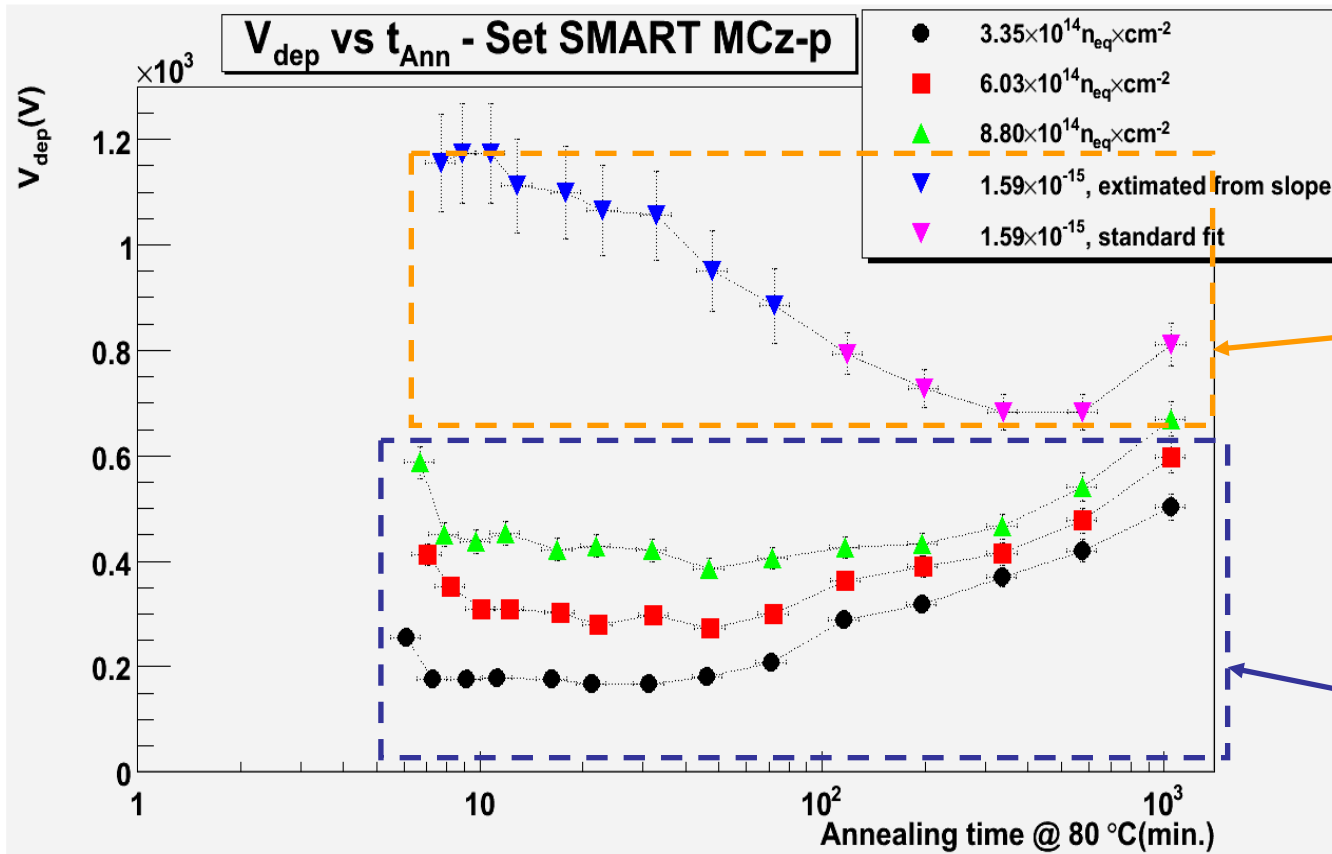
# Annealing results from Bari



12th RD50 Workshop, Ljubljana, Slovenia 2-4. June 2008 (D. Creanza)

## Presented so far

**24 GeV/c proton** irradiation (irradiated together):

- **Bari\*:** MCz n- and p-type, front illumination only (SMART samples)

  "TCT measurements (for p-type MCz), corrected for trapping, shows a junction on the back that is clearly dominant at a fluence of 6.03 $\cdot 10^{14}$ $n_{eq}$/cm$^{2}$"

- **BNL/HIP\*\*:** MCz n- and p-type, front and back illumination (HIP samples)

  "the two peaks/junction are almost the same (for n- and p-type MCz) (after trapping corrections), indicating half +SC and half –SC in the detector, especially at higher fluences than 3x10$^{14}$ p/cm$^{2}$, regardless of bias voltages"

## Some new data:      **???**

**CERN**: MCz n- and p-type, front and back (not all) illumination

proton and neutron irradiation

12th RD50 Workshop, Ljubljana, Slovenia 2-4. June 2008
\* D. Creanza, \*\*J. Haerkoenen

# TCT setup

- voltage applied with Cu/Be needle
- floating guard ring

- $N_2$ atmosphere
- Peltier cooling

- 660nm red laser
- 1060nm IR laser

• all detectors were measured at -5$\pm$0.1°C
• humidity in the box was around 15%

# MCz n-type
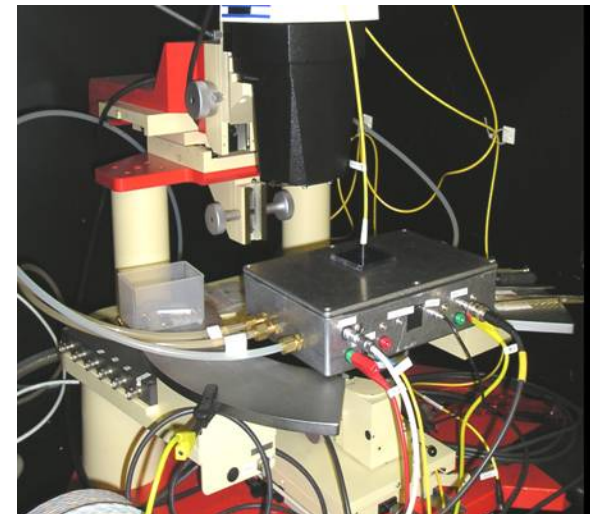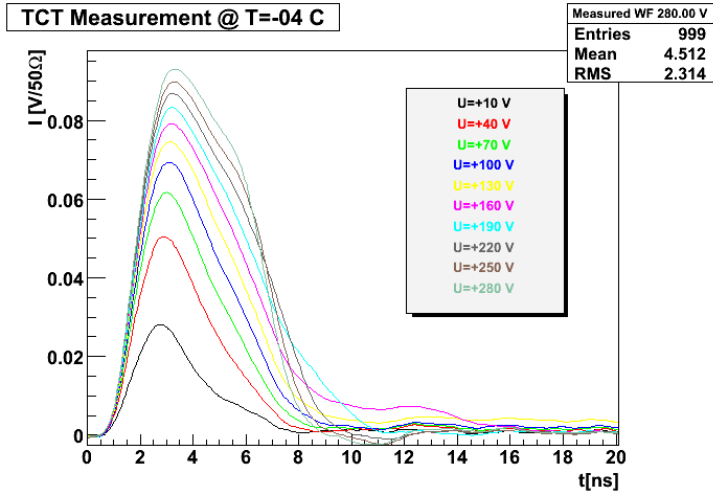
**proton**

HIP-MCz-01-n-26
$1.08 \times 10^{14}$ $n_{eq}$ cm$^{-2}$
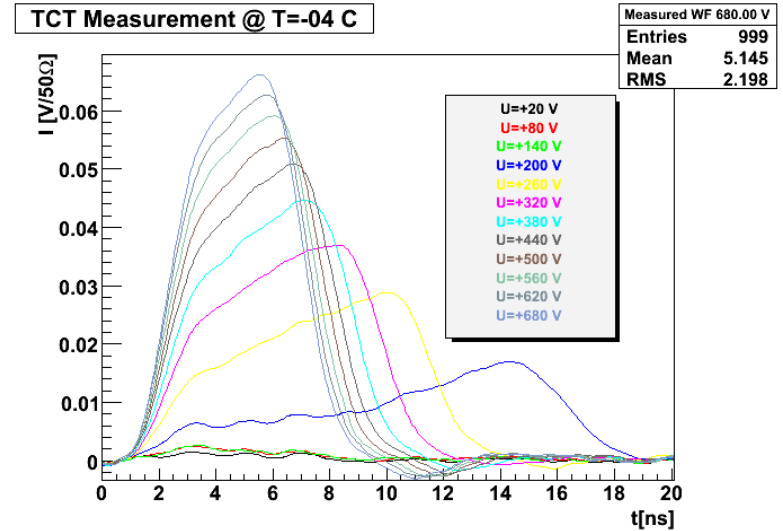
front (electrons)
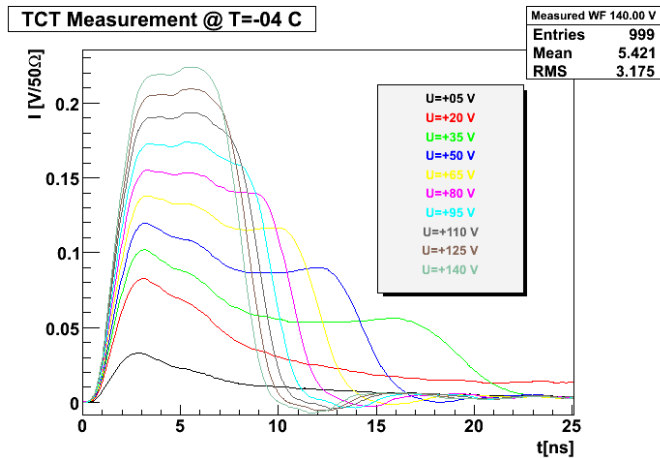
back (holes)

**neutron**

CNM-01-S93
$1 \times 10^{14}$ n cm$^{-2}$

back side not possible
no grid
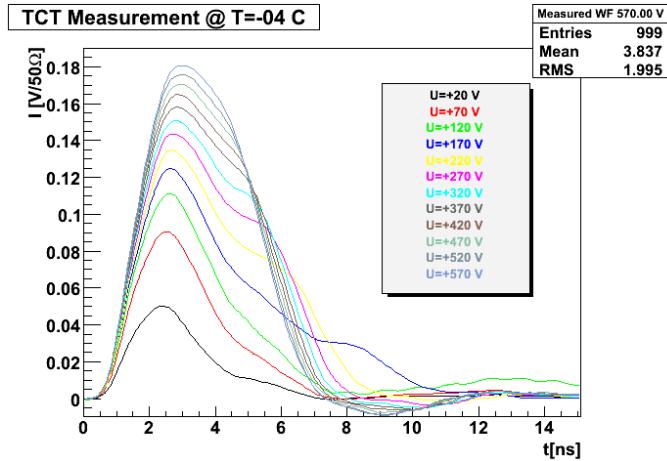
**proton**

HIP-MCz-01-n-24
$3.35 \times 10^{14}$ $n_{eq}$ cm$^{-2}$
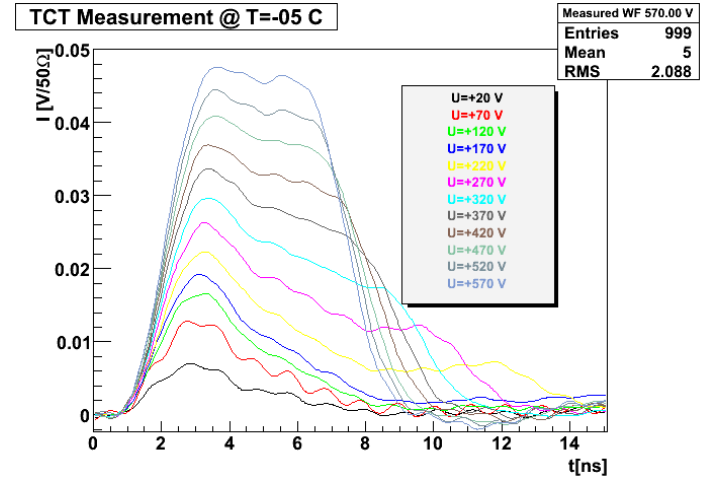
front (electrons)

back (holes)
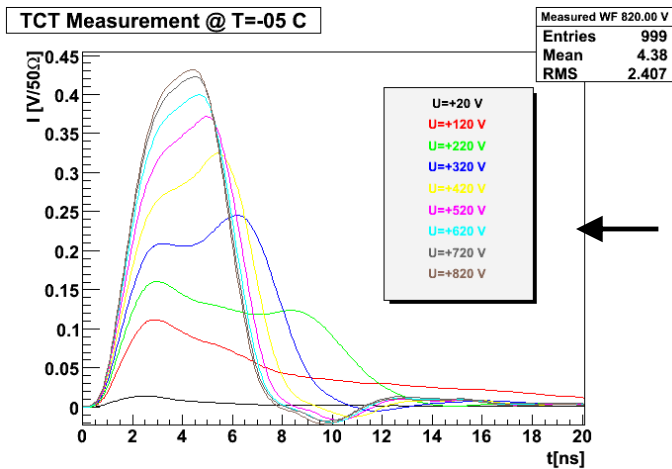
**neutron**

CNM-01-S83
$3 \times 10^{14}$ n cm$^{-2}$

8556-3-S11
$2 \times 10^{14}$ n cm$^{-2}$
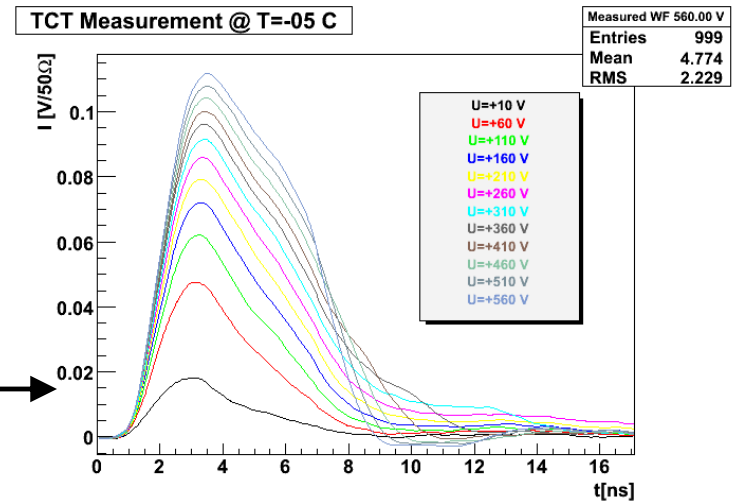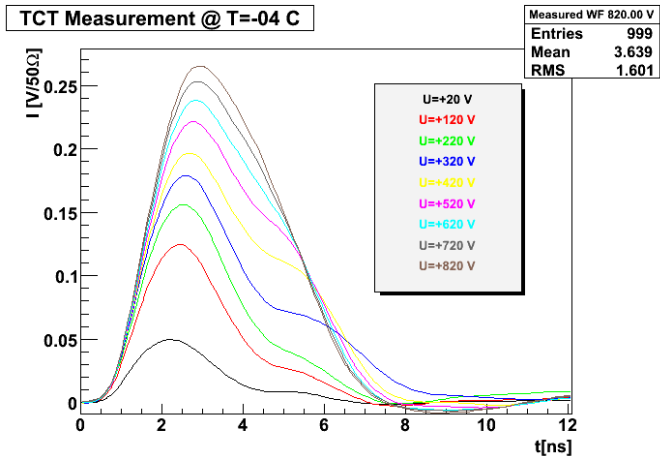
**proton**

CERN
HIP-MCz-01-n-22
$8.8 \times 10^{14}$ $n_{eq}$ cm$^{-2}$
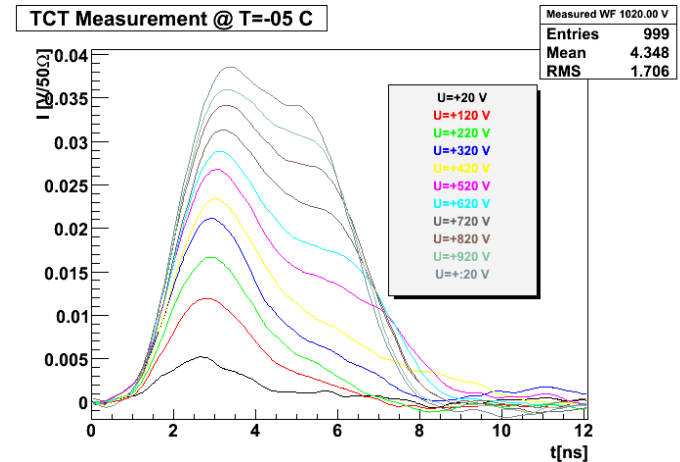
front (electrons)

BNL
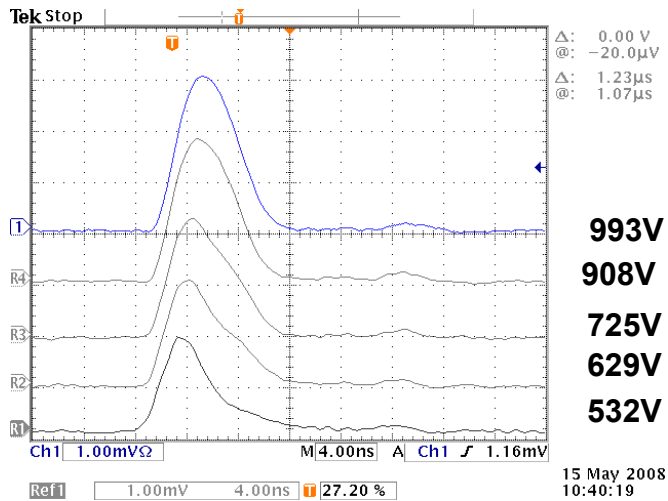
back (holes)

**MCZ-n, #01-N-20, $1.3 \times 10^{15}$ p/cm$^2$
double junction/peak clearly seen**
**Nearly identical TCT curves for
both e and h**
**Equal-Double-Junction**
**+SC dominates near p$^+$ contact, -
SC dominates
near n$^+$ contact**

993V
908V
725V
629V
532V

900V
720V
629V
532V

# MCz p-type
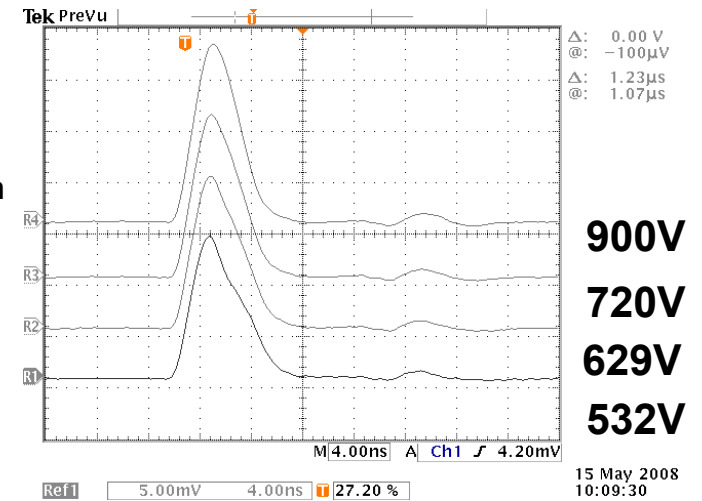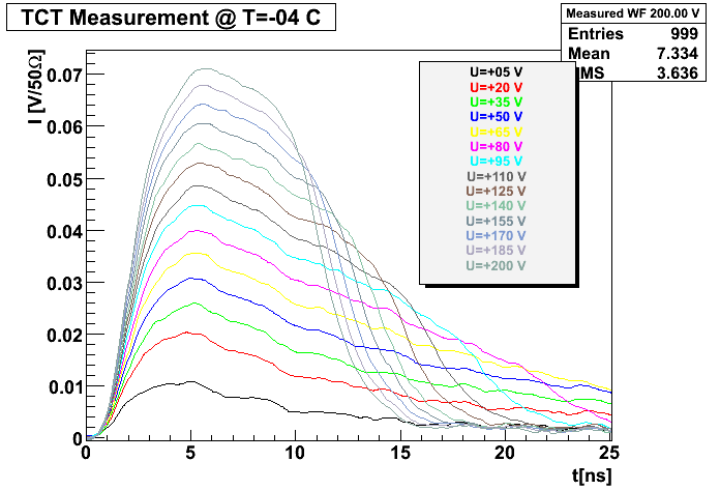


## proton

p069-51
$4.2 \times 10^{13} \, n_{eq} \, cm^{-2}$

$V_d$ (CV) = 33V
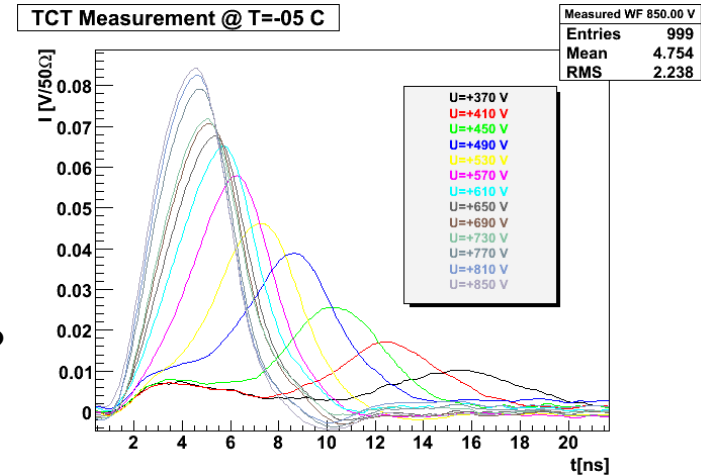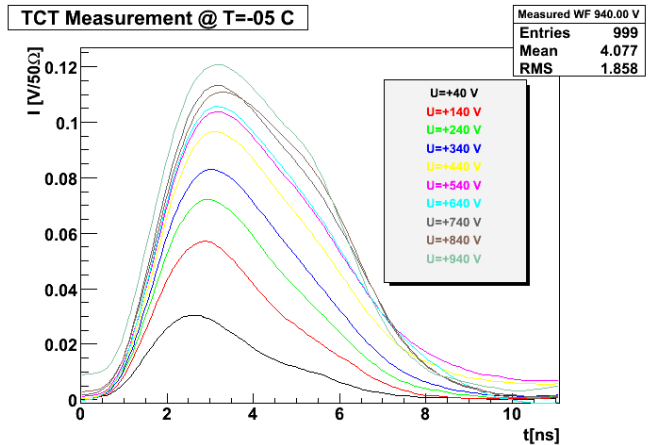$V_d$ (front) = 60V
$V_d$ (back) = 60V
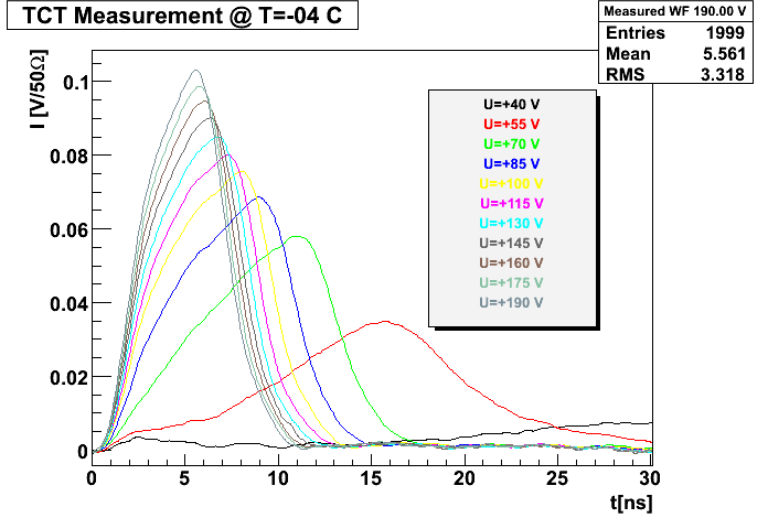
front (holes)
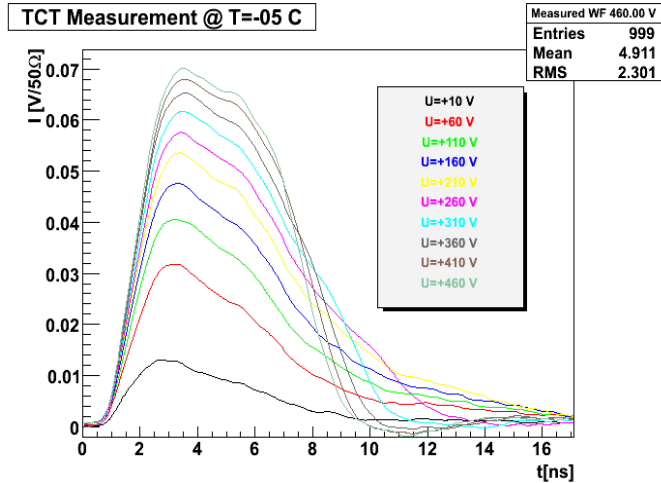
back (electrons)

## neutron

p068-60
$5 \times 10^{13} \, n \, cm^{-2}$

$V_d$ (CV) = 243V
$V_d$ (front) = 200V
$V_d$ (back) = 270V

# MCz p-type
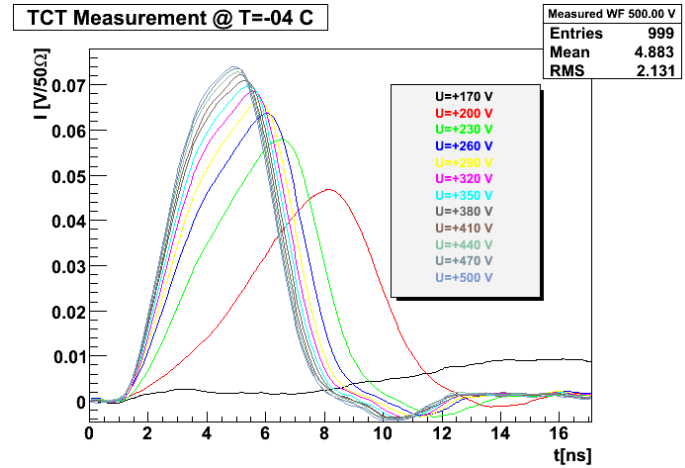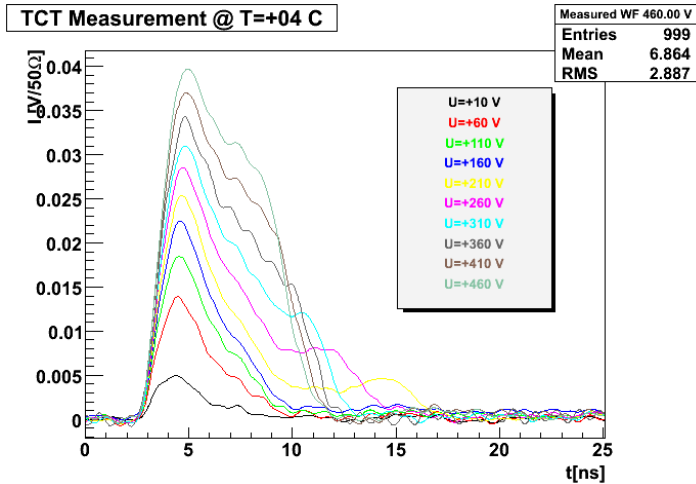


**proton**

p069-44
$3.35 \times 10^{14}$ $n_{eq}$ cm$^{-2}$

$V_d$ (CV) ~ 186V
$V_d$ (front) = 60V
$V_d$ (back) = 60V
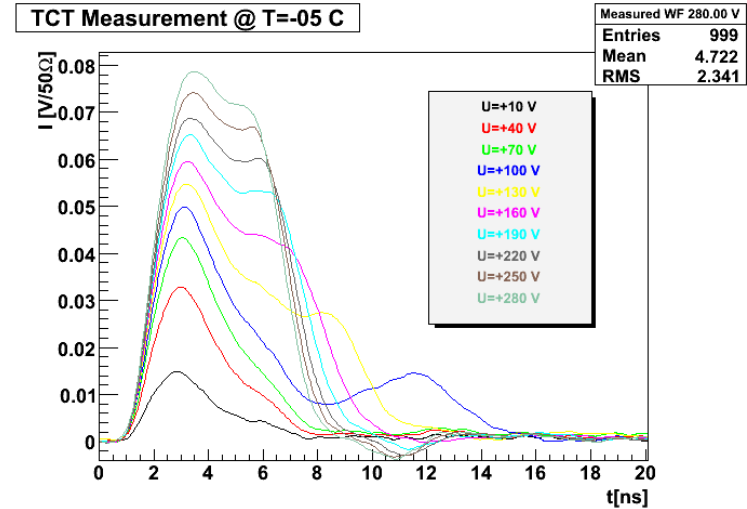
front (holes)

back (electrons)

**neutron**

p068-64
$3 \times 10^{14}$ n cm$^{-2}$
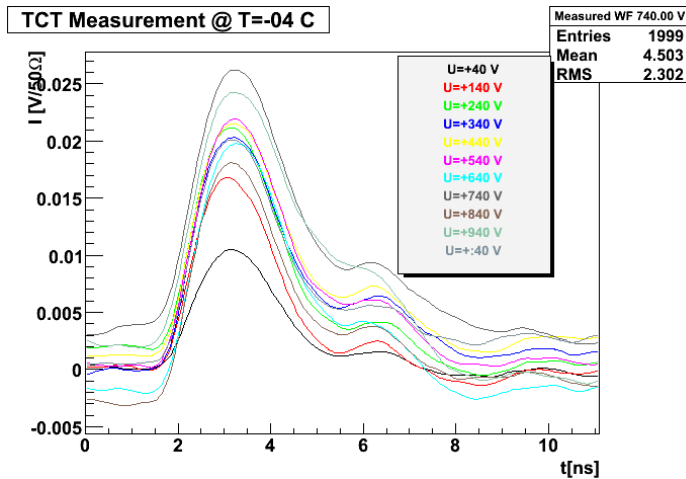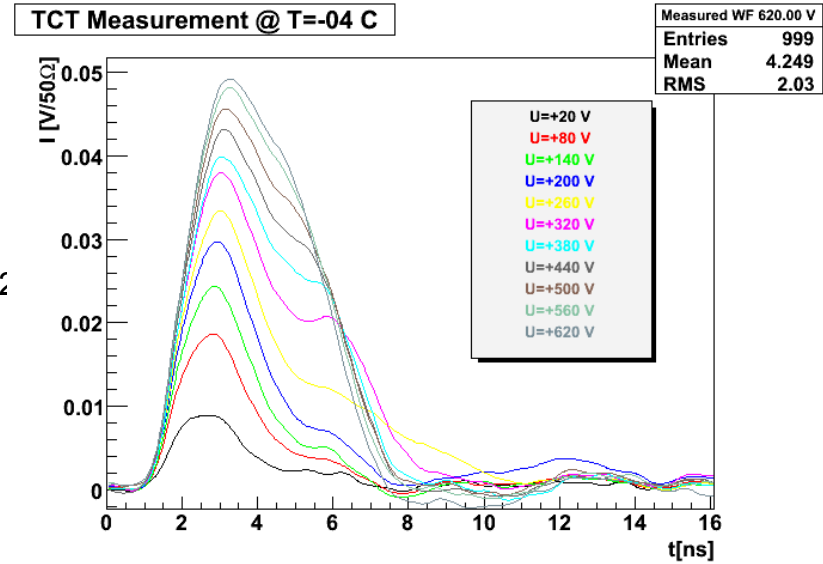
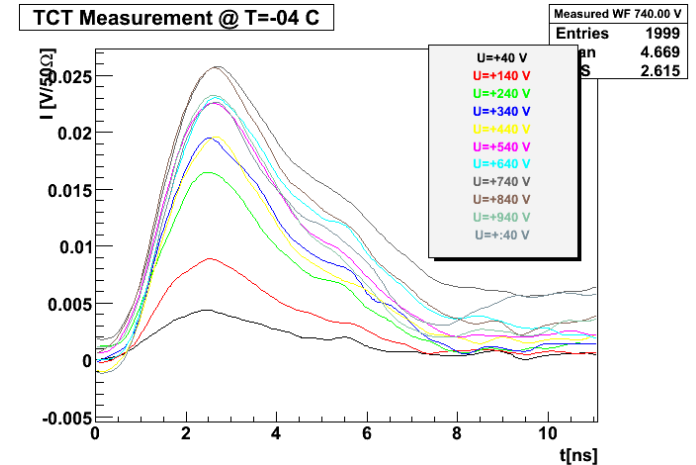$V_d$ (CV) ~ 730V
$V_d$ (front) ~440V ?
$V_d$ (back) = ?

# MCz p-type
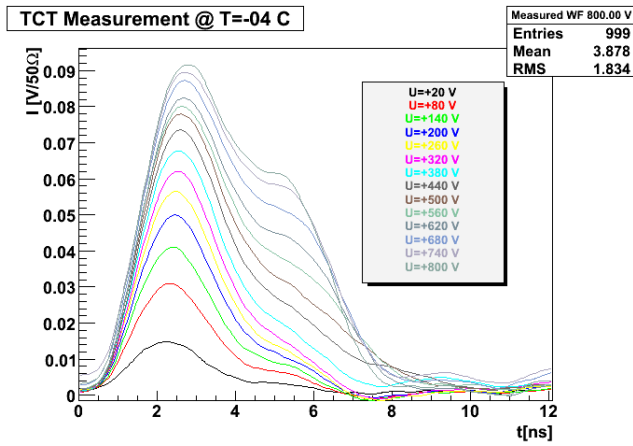
**proton**

p069-46
$8.8 \times 10^{14} \; n_{eq} \; cm^{-2}$

$V_d$ (CV) ~ 480V
$V_d$ (front) = ?
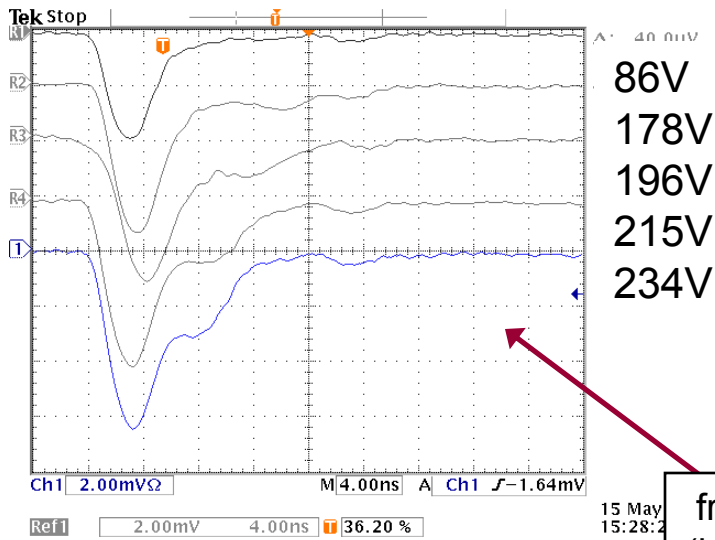$V_d$ (back) ~ 340V

**front (holes)**

**neutron**

p068-66
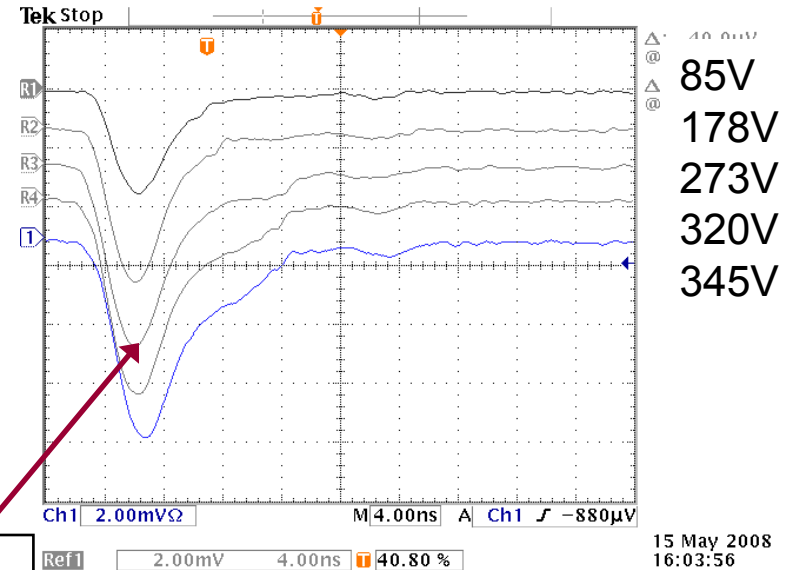$8 \times 10^{14} \; n \; cm^{-2}$

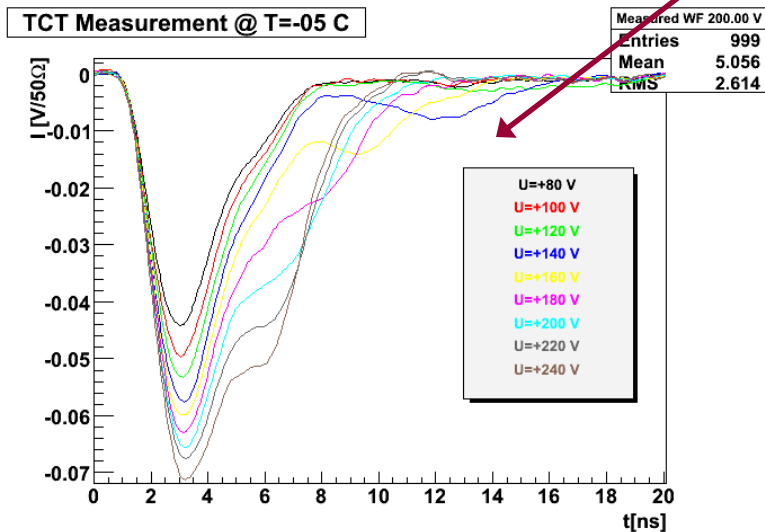above depletion not possible

# Comparison as measured

86V
178V
196V
215V
234V

**BNL**
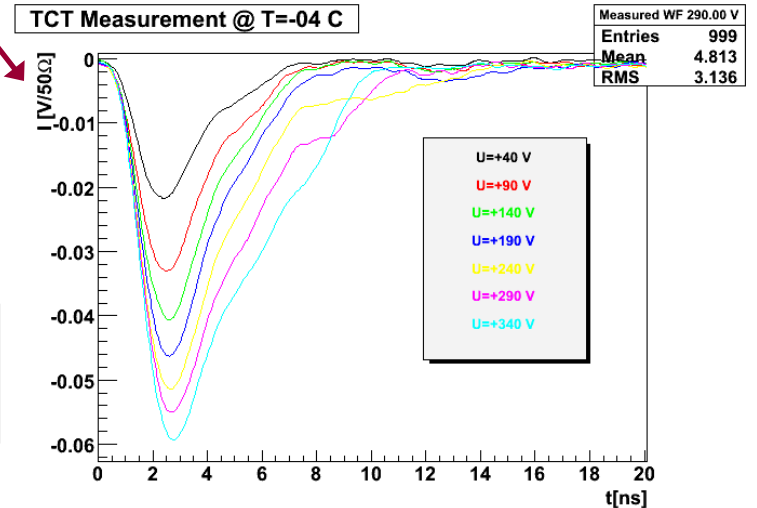p069-72
$9.7 \times 10^{14} p/cm^2$

85V
178V
273V
320V
345V

front
(hole)

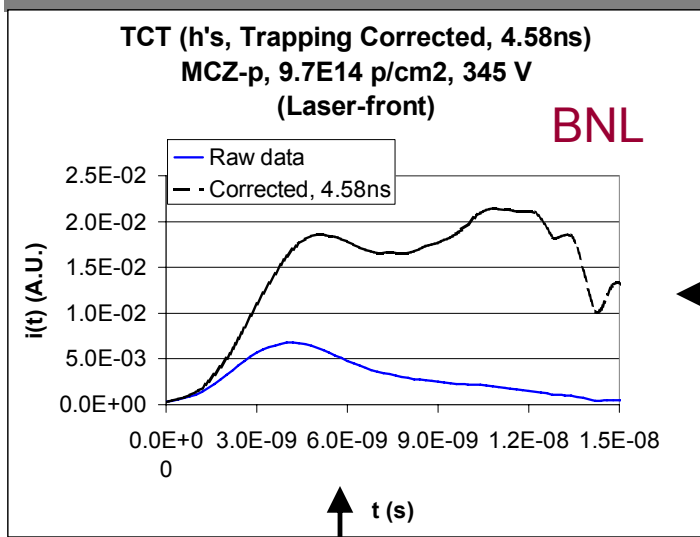back
(electron)

**CERN**
p069-45
$9.7 \times 10^{14} p/cm^2$

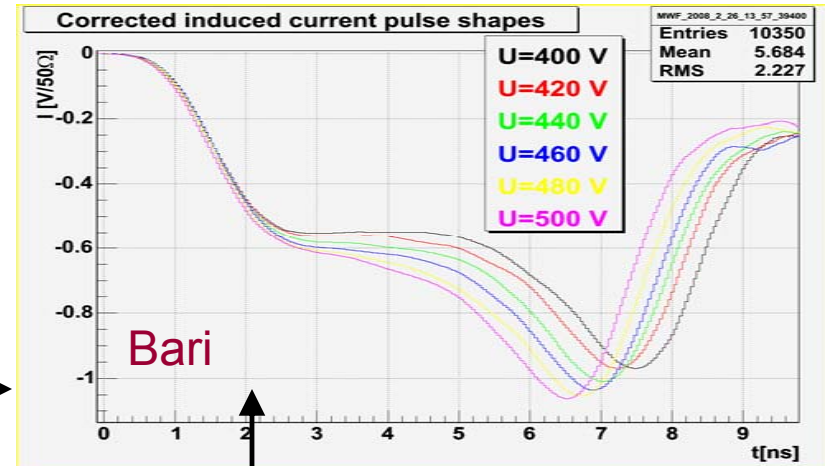**Raw data looks the same!**

Katharina Kaska

TCT Measurement @ T=-05 C

| Measured WF 200.00 V | |
|---|---|
| Entries | 999 |
| Mean | 5.056 |
| RMS | 2.614 |

U=+80 V
U=+100 V
U=+120 V
U=+140 V
U=+160 V
U=+180 V
U=+200 V
U=+220 V
U=+240 V

TCT Measurement @ T=-04 C

| Measured WF 290.00 V | |
|---|---|
| Entries | 999 |
| Mean | 4.813 |
| RMS | 3.136 |

U=+40 V
U=+90 V
U=+140 V
U=+190 V
U=+240 V
U=+290 V
U=+340 V

# trapping corrected pulses



TCT (h's, Trapping Corrected, 4.58ns)
MCZ-p, 9.7E14 p/cm2, 345 V
(Laser-front)

BNL

MCz p-type
9.7 x $10^{14}$ p/cm$^2$

p069-72

SMART

Bari

Corrected induced current pulse shapes

U=400 V
U=420 V
U=440 V
U=460 V
U=480 V
U=500 V

**4.58 ns**
345V

**Difference in correction**

**3 ns**
>400V

Corrected induced current pulse shapes

CERN

U=340 V
U=350 V
U=360 V

p069-45
9.7x$10^{14}$p/cm$^2$

Corrected induced current pulse shapes

U=410 V
U=420 V
U=430 V
U=440 V
U=450 V
U=460 V
U=470 V
U=480 V
U=490 V
U=500 V

CERN

Katharina Kaska

# Conclusions
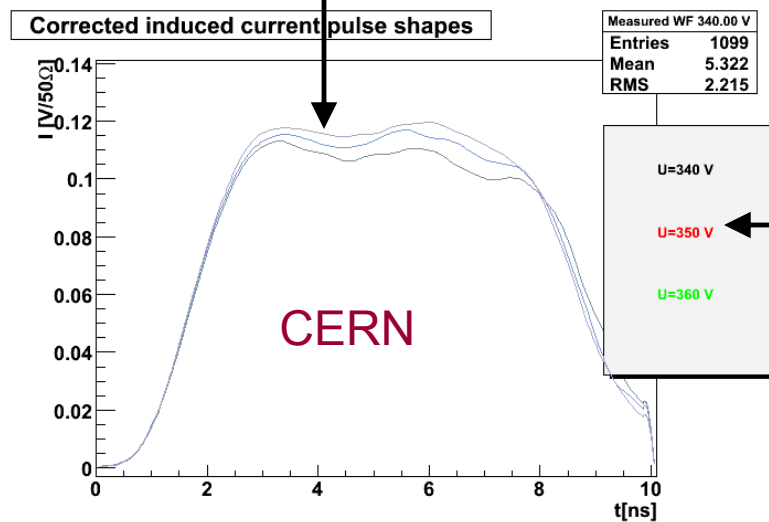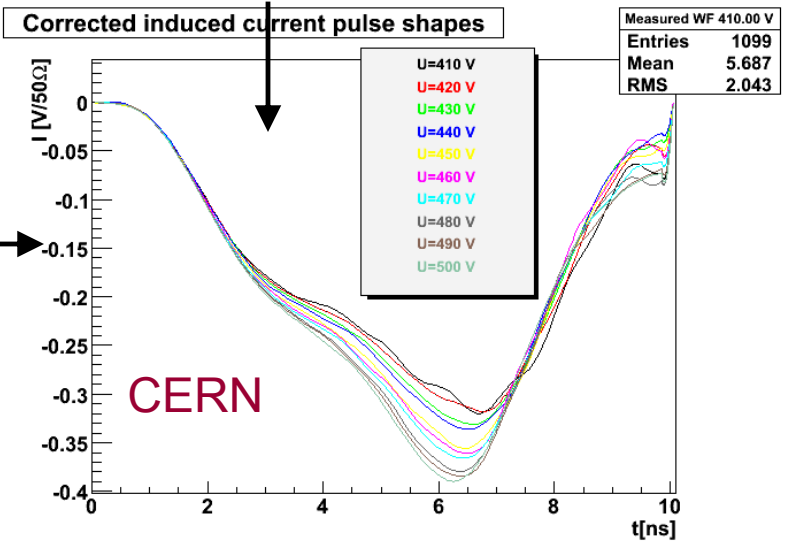
- MCz n- and p-type detectors were measured in TCT after neutron and proton irradiation, up to $8 \times 10^{14}$ and $8.8 \times 10^{14}$ cm$^{-2}$ respectively.

- After neutron irradiation, negative space charge in MCz-n and p. After proton irradiation picture more complex: Pulse shapes for holes and electrons similar.

**Comparison of RD50 data (common project)**

- CERN data compared to Bari and BNL results: Very good agreement in measured TCT data for most diodes arriving from identical material and irradiations. (Few inconsistencies for diodes irradiated to highest fluence.)

- Differences in interpretation of data by different groups arising from different trapping times used to correct the TCT curves for trapping!

- Same raw data can lead to different interpretations: e.g. equally strong fields in front and back versus dominating field in front or back side.

**Conclusion**: Raw and corrected data should be presented and not only corrected data. Interpretation of data should contain an evaluation on the impact of varying trapping time used for the data correction.

# •SPARES

# •N type
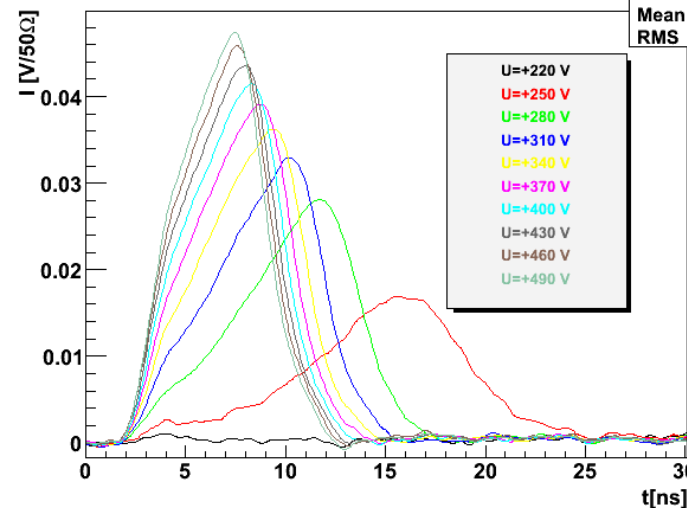
**proton**

HIP-MCz-01-n-60

$4.2 \times 10^{13}$ $n_{eq}$ cm$^{-2}$

front (electrons)                    back (electrons)

# MCz n-type
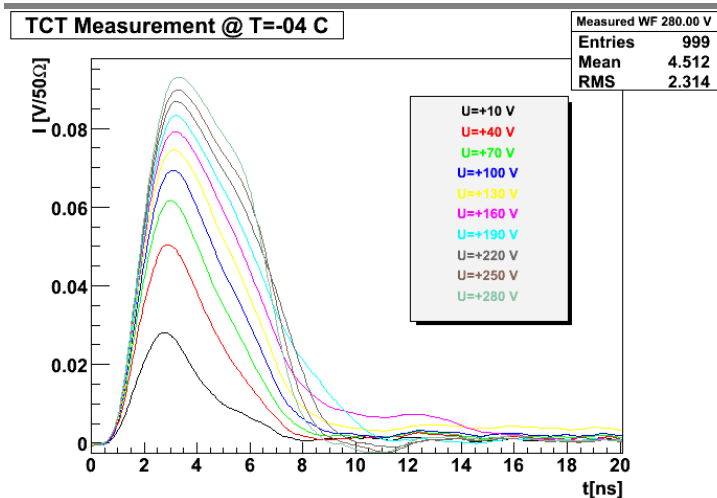
**proton**

HIP-MCz-01-n-26
$1.1 \times 10^{14}$ $n_{eq}$ cm$^{-2}$
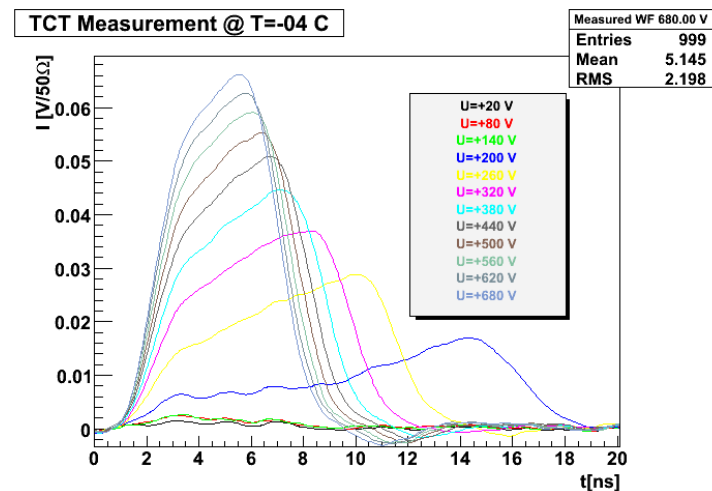
front (electrons)

back (electrons)

**neutron**

CNM-01-S93
$1 \times 10^{14}$ n cm$^{-2}$

# MCz n-type
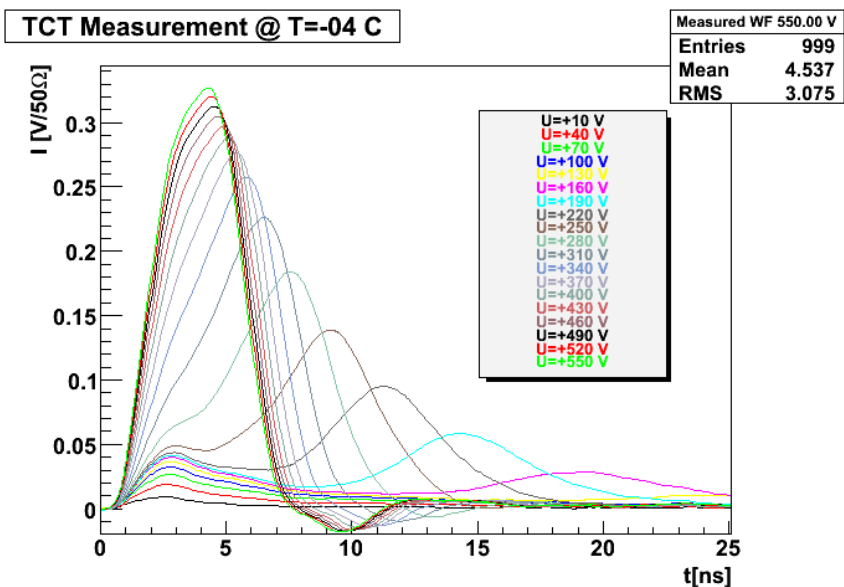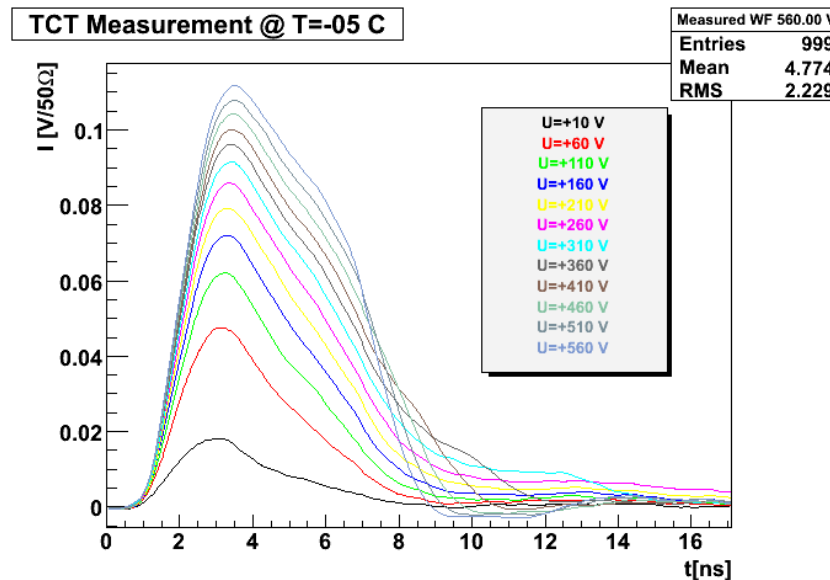


front (electrons)

back (electrons)

**neutron**

8665-3-S11
$2 \times 10^{14}$ n cm$^{-2}$

front (electrons)

**proton**

HIP-MCz-01-n-24
$3.3 \times 10^{14}$ $n_{eq}$ $cm^{-2}$



back (electrons)



**neutron**
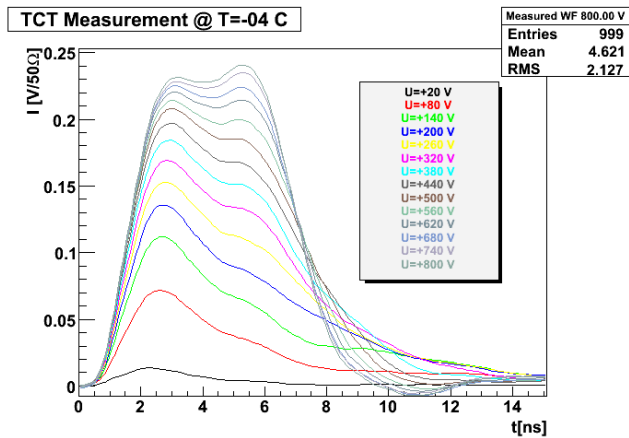
CNM-01-S83
$3 \times 10^{14}$ n $cm^{-2}$

front (electrons)

back (electrons)

**neutron**

8665-3-S12
$4 \times 10^{14}$ n cm$^{-2}$

**TCT Measurement @ T=-04 C**

| Measured WF 570.00 V | |
|---|---|
| Entries | 999 |
| Mean | 3.769 |
| RMS | 1.917 |

$I [V/50\Omega]$

U=+20 V
U=+70 V
U=+120 V
U=+170 V
U=+220 V
U=+270 V
U=+320 V
U=+370 V
U=+420 V
U=+470 V
U=+520 V
U=+570 V

t[ns]

**proton**

HIP-MCz-01-n-23
$6.03 \times 10^{14}\ n_{eq}\ cm^{-2}$

**TCT Measurement @ T=-05 C**

| Measured WF 570.00 V | |
|---|---|
| Entries | 999 |
| Mean | 4.817 |
| RMS | 2.091 |

$I [V/50\Omega]$

U=+20 V
U=+70 V
U=+120 V
U=+170 V
U=+220 V
U=+270 V
U=+320 V
U=+370 V
U=+420 V
U=+520 V
U=+570 V

t[ns]
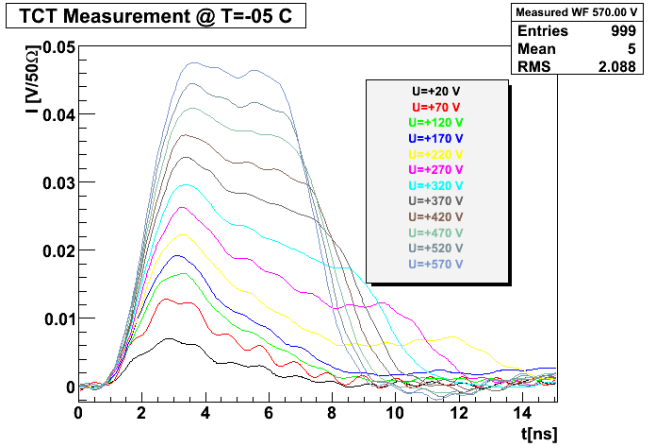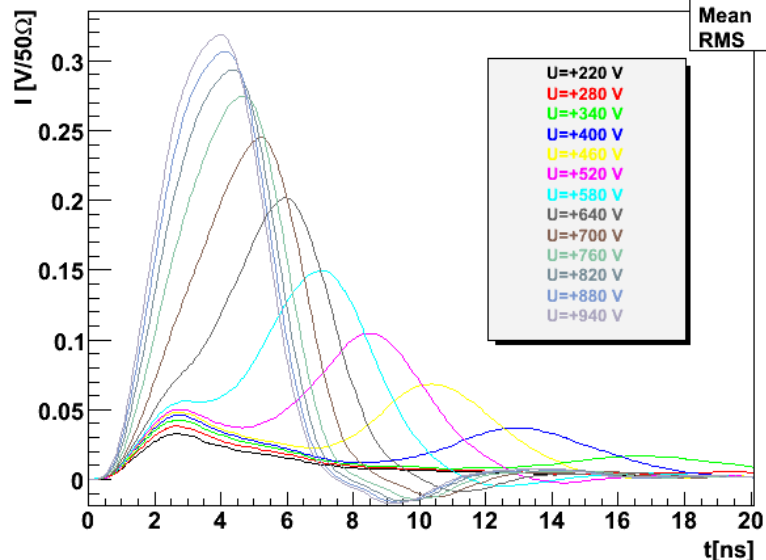
front (electrons)

back (electrons)

**TCT Measurement @ T=-04 C**

| Measured WF 800.00 V | |
|---|---|
| Entries | 999 |
| Mean | 4.621 |
| RMS | 2.127 |

$I [V/50\Omega]$

U=+20 V
U=+80 V
U=+140 V
U=+200 V
U=+260 V
U=+320 V
U=+380 V
U=+440 V
U=+500 V
U=+560 V
U=+620 V
U=+680 V
U=+740 V
U=+800 V

t[ns]

**neutron**

CNM-01-S73
$5 \times 10^{14}\ n\ cm^{-2}$

# MCz n-type
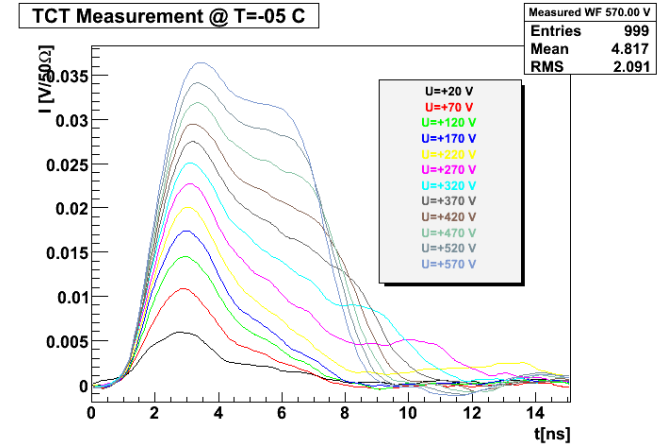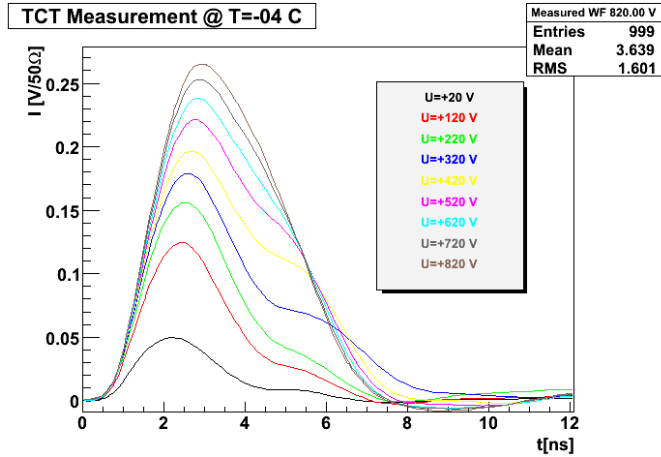


**proton**

HIP-MCz-01-n-22
$8.8 \times 10^{15}$ $n_{eq}$ cm$^{-2}$
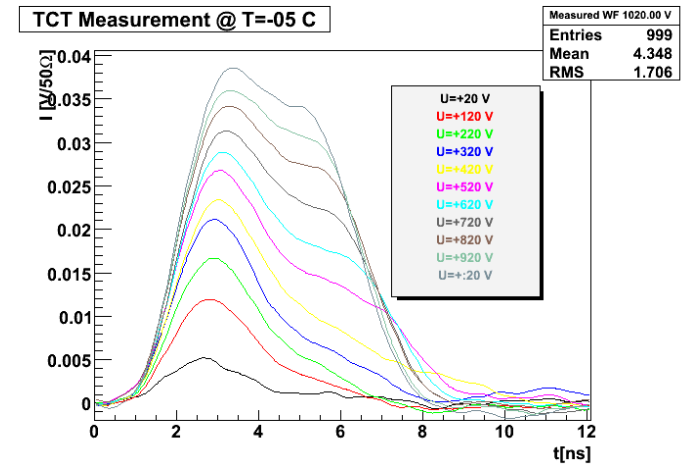
front (electrons)
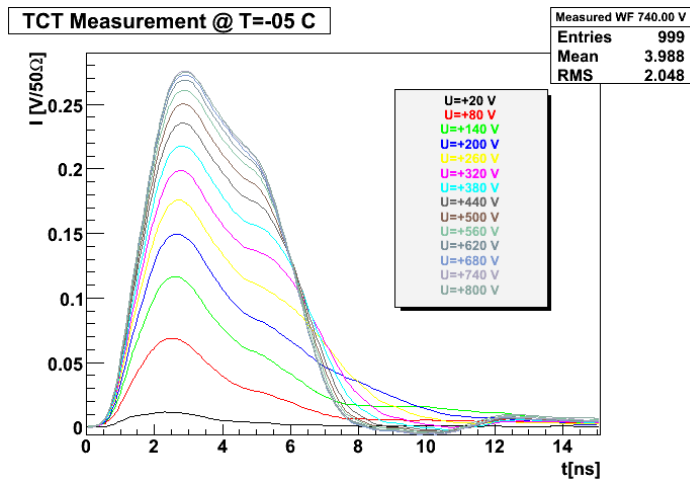
back (electrons)



**neutron**

CNM-01-S63
$8 \times 10^{14}$ n cm$^{-2}$
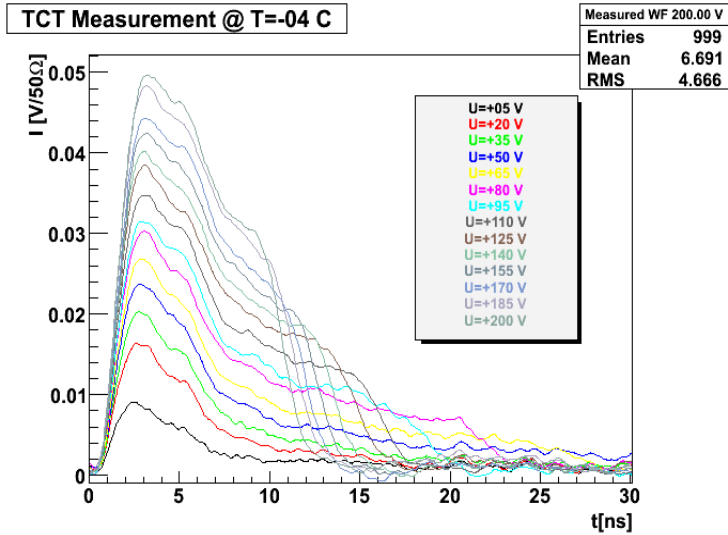
# MCz n-type
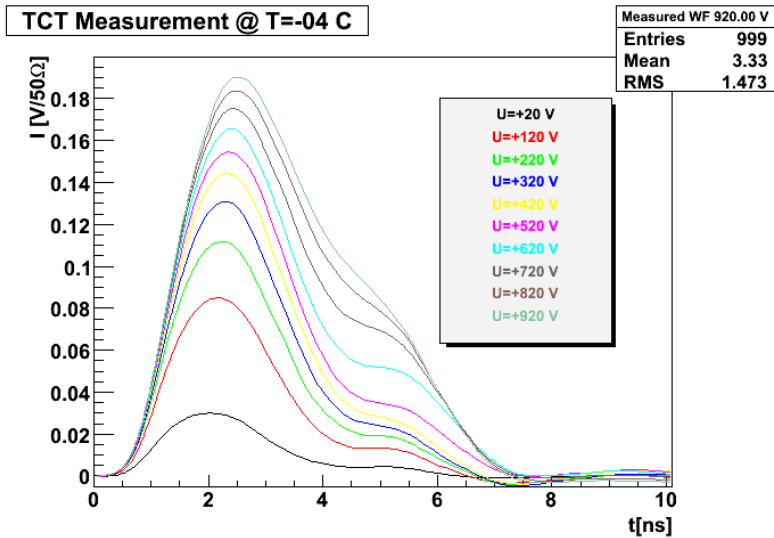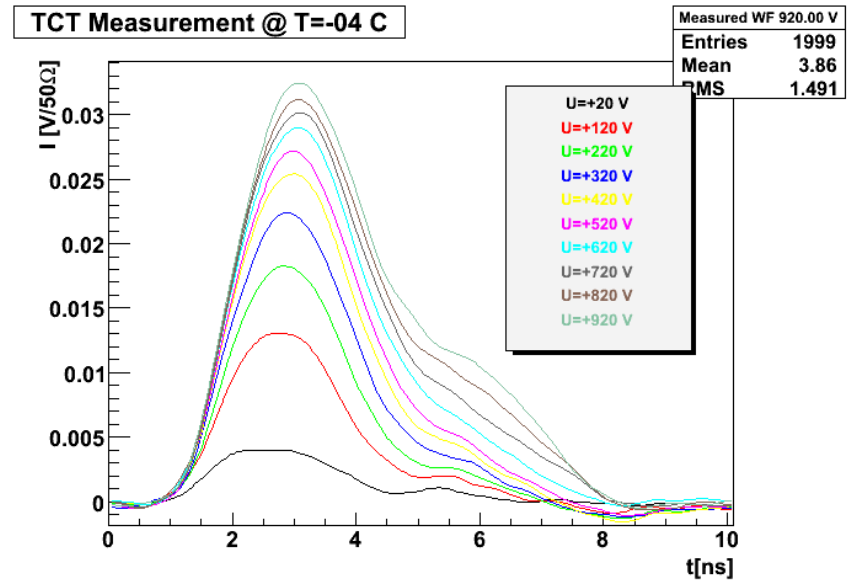


front (electrons)



back (electrons)

**proton**

HIP-MCz-01-n-21
$1.6 \times 10^{15}$ $n_{eq}$ cm$^{-2}$

# •p type

# MCz p-type



**proton**

p069-42
$1.07 \times 10^{14}$ $n_{eq}$ $cm^{-2}$
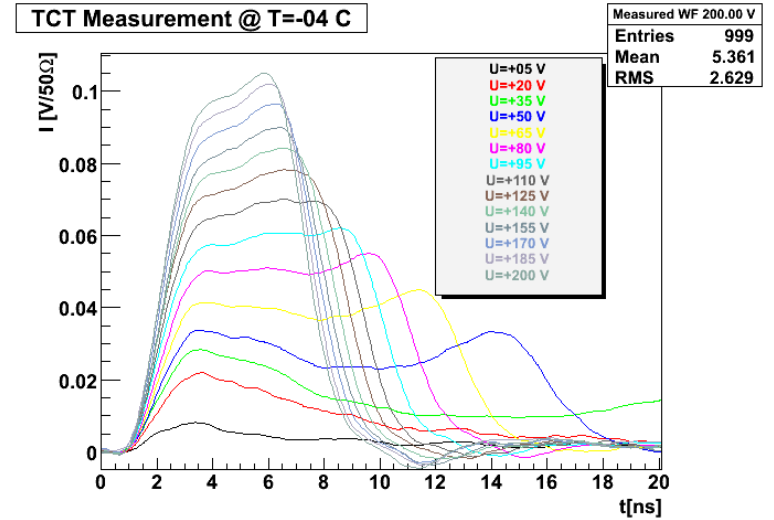
front (holes)

back (electrons)

**neutron**

p068-61
$1 \times 10^{14}$ n $cm^{-2}$

# MCz p-type



neutron

front (holes)

back (electrons)

p068-62
$2\times10^{14}$ n cm$^{-2}$

# MCz p-type



**proton**

p069-44
$3.35 \times 10^{14}$ $n_{eq}$ $cm^{-2}$

front (holes)

back (electrons)

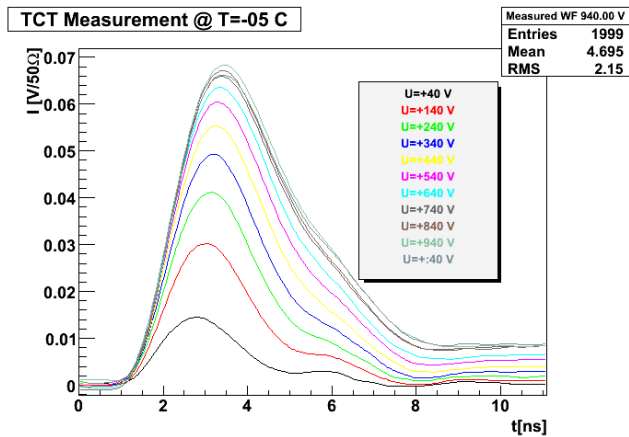**neutron**

p068-64
$3 \times 10^{14}$ n $cm^{-2}$

Katharina Kaska
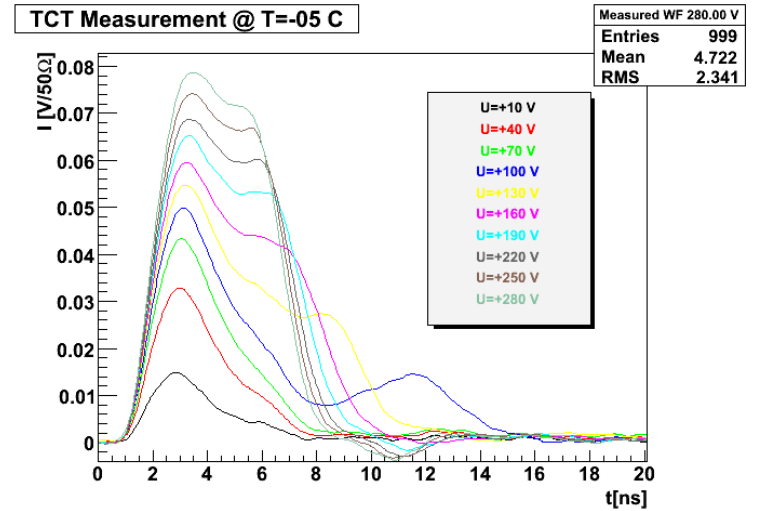
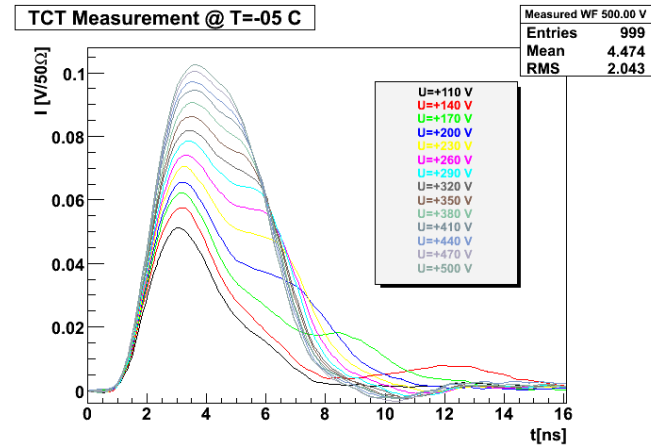**proton**
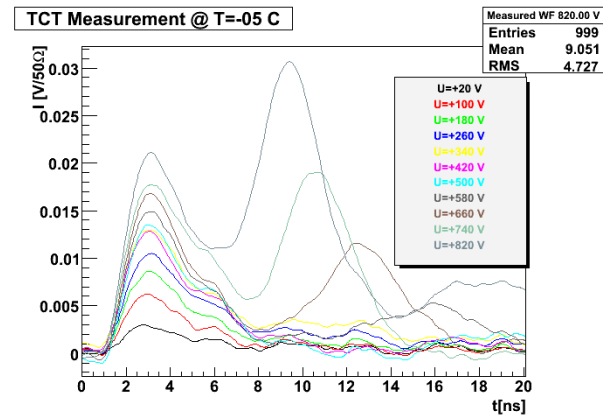
p069-45
$6.2 \times 10^{14} \; n_{eq} \; cm^{-2}$

$V_d$ (CV) = 33V
$V_d$ (front) = 60V
$V_d$ (back) = 60V

**neutron**

p068-65
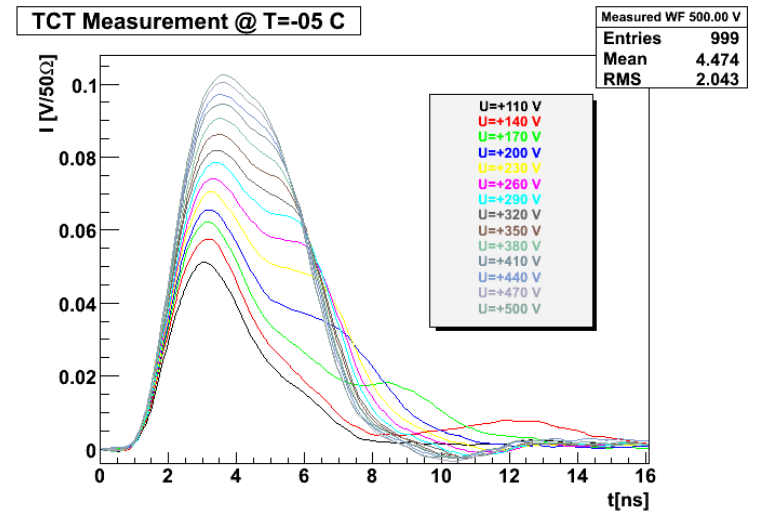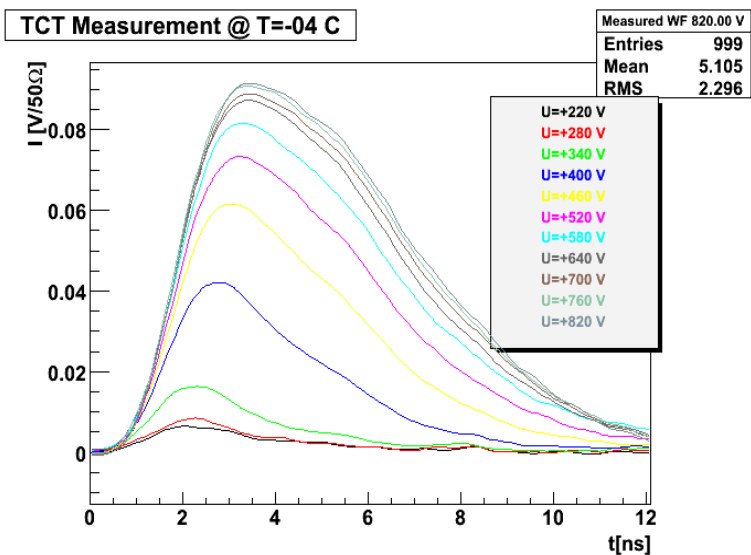$5 \times 10^{14} \; n \; cm^{-2}$

strange

# MCz p-type
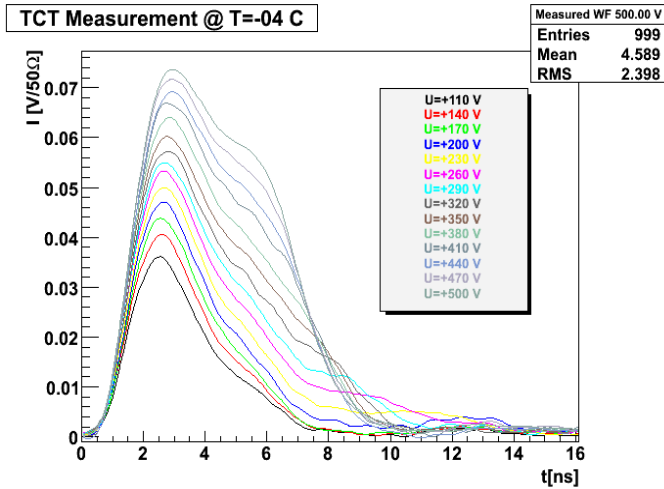


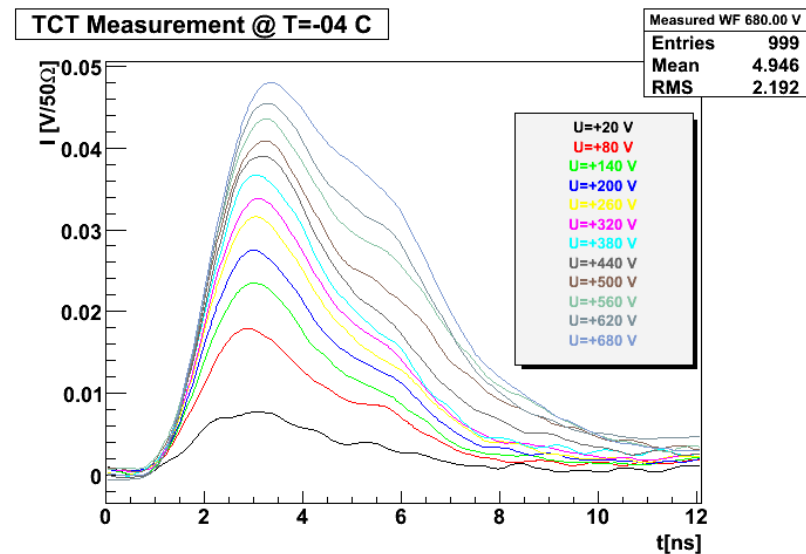p069-45
$6.03 \times 10^{14}$ n$_{eq}$ cm$^{-2}$
**proton**

$V_d$ (CV) = 327V
$V_d$ (front) ~ 500V
$V_d$ (back) ~ 210V

proton

front (holes)                back (electrons)

p069-47
$1.6 \times 10^{15}$ $n_{eq}$ cm$^{-2}$