First investigation of silicon microstrips for the CMS tracker upgrade using edge-TCT

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On behalf of the CMS tracker collaboration

♦

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CERN

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→ eTCT intro

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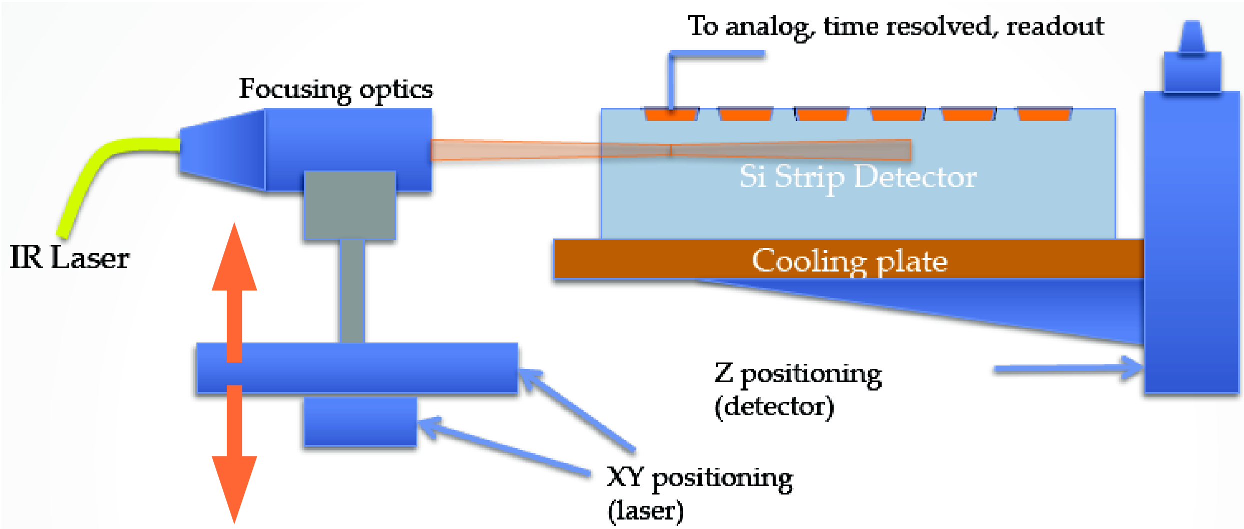
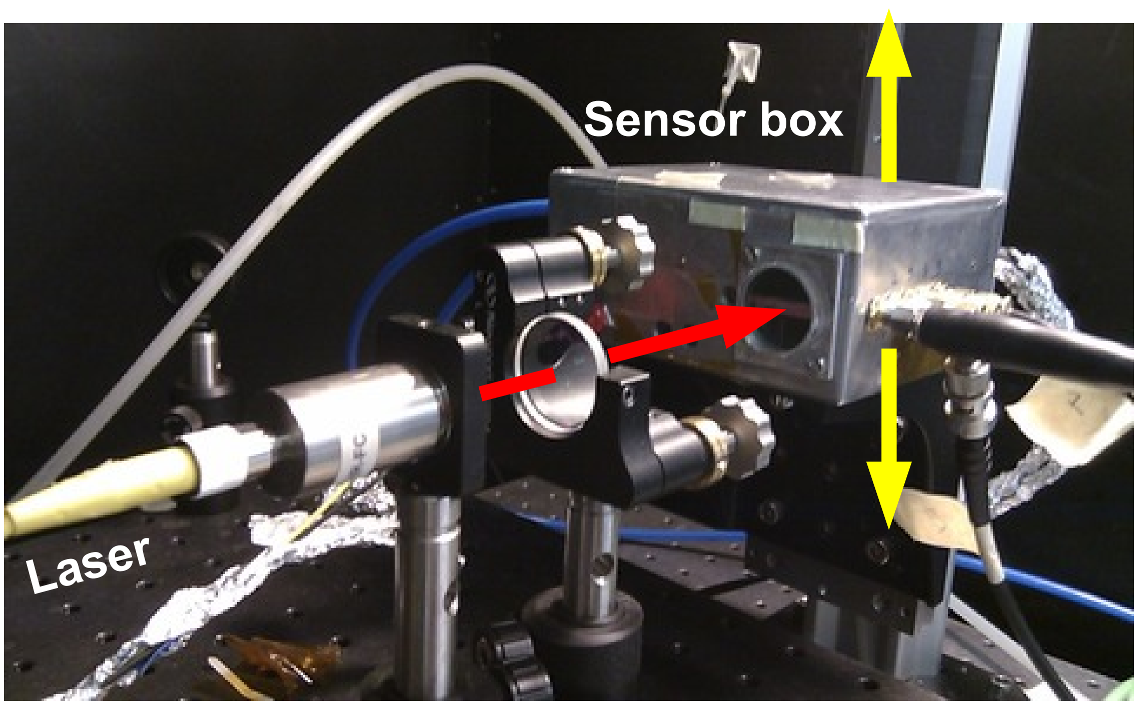
21st RD50 Workshop, CERN, Geneva

Edge-TCT setup





- Charge carriers created at **selected depth** with respect to strips.
- Sensor properties can be studied **as a function of depth**.
- **Spatial resolution** given by laser width (vertical). Measure-ments averaged over strip width.
- **One strip** readout only.

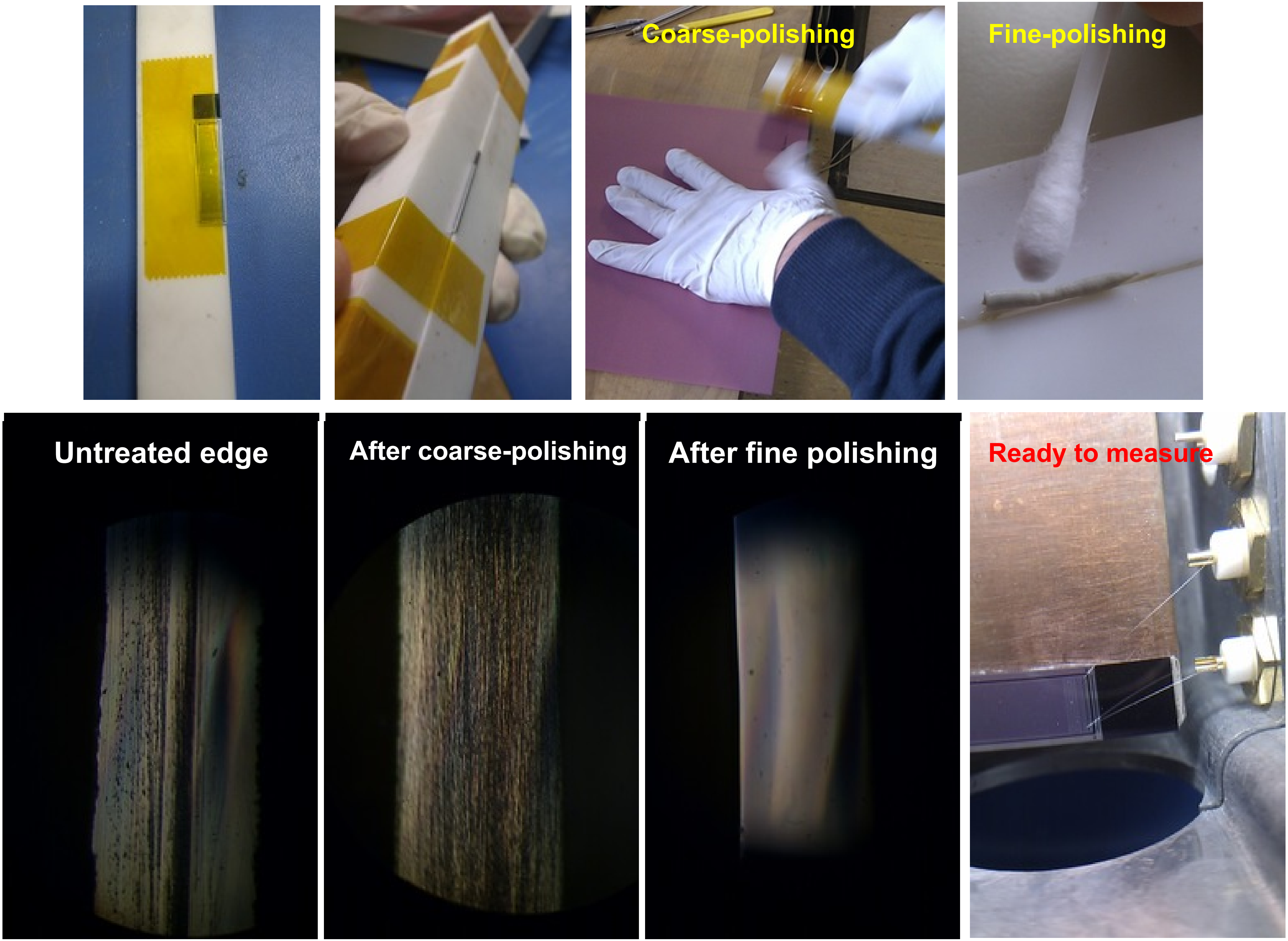
- Setup@CERN was built by N. Pacifico during his PhD.

Featuring:

→ 80 ps FWHM laser 1060 nm
→ XYZ motion
→ T controlled measurements
→ In-situ annealing

- DAQ by CERN SSD (N.Pacifico, M.Gabrysch, I.Dolenc)

ETCT method: G. Kramberger et al., IEE TNS, VOL. 57, NO. 4, August 2010, p. 2294


Coarse-polishing
Fine-polishing
Untreated edge
After coarse-polishing
After fine polishing
Ready to measure

Motivation of this study

- Study **baby** strip detectors (320 μm physical thickness) from **CMS HPK campaign** using eTCT:

  → Very useful to evaluate detector properties as a function of depth
  → Very useful to picture how radiation damage develops in the bulk

- **Trapping** can be different at different depths: $\tau=\tau(z)$ (for instance because $N_{eff}=N_{eff}(z)$). A **combined TCT + eTCT method** has been proposed within the CMS HPK campaign to obtain the trapping time profile $\tau(z)$ for irradiated detectors:

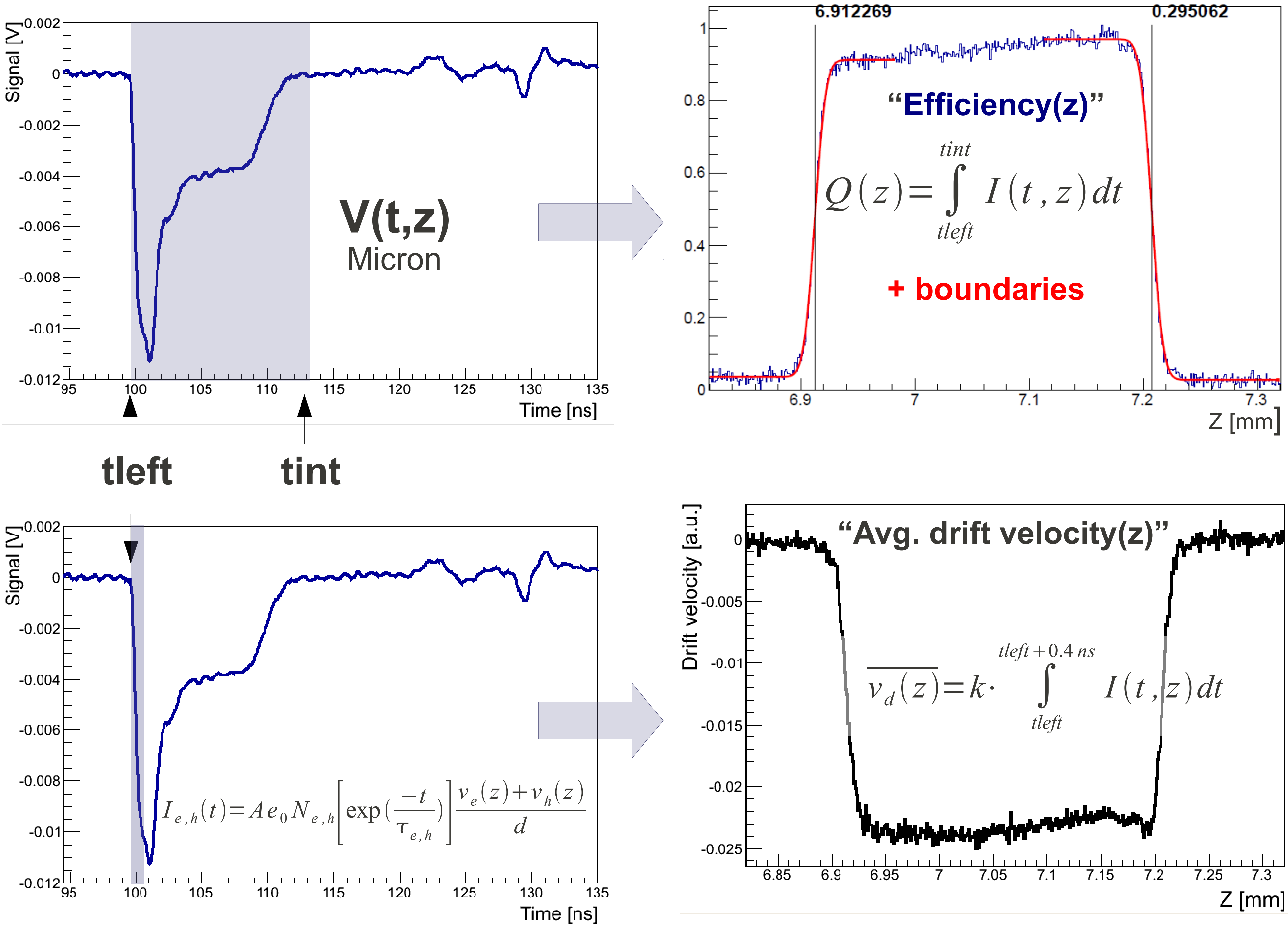
  → eTCT is used to **measure the drift velocity profile** in a **strip** detector

  → Drift velocity profile **fed into red TCT simulation** (see T. Pöhlsen, RD50 Bari 2012), convoluted with electronics transfer function.

  → **Diode** from same family as strip detector is **TCT measured**. Trapping is **tuned in** the simulation and result compared to measurement.

- **Fluences** to be addressed:
  → Unirradiated (← This work)
  → 3e14 n_{eq}/cm^2 protons
  → 1e15 n_{eq}/cm^2 protons

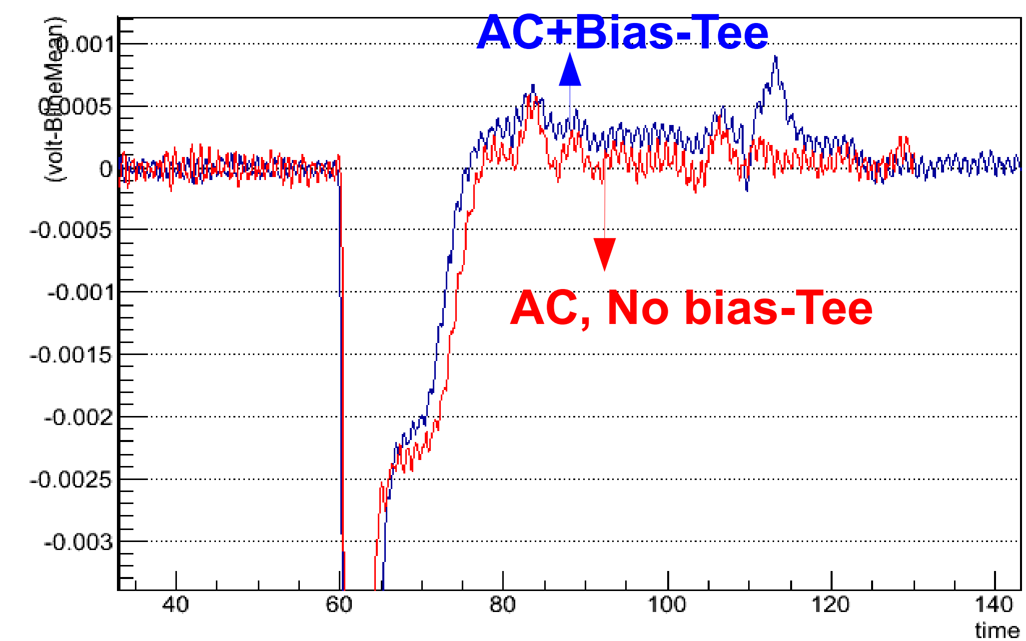
Analysis of eTCT pulses



Common considerations to all measurements:

- AC or DC coupling
- What laser power ?

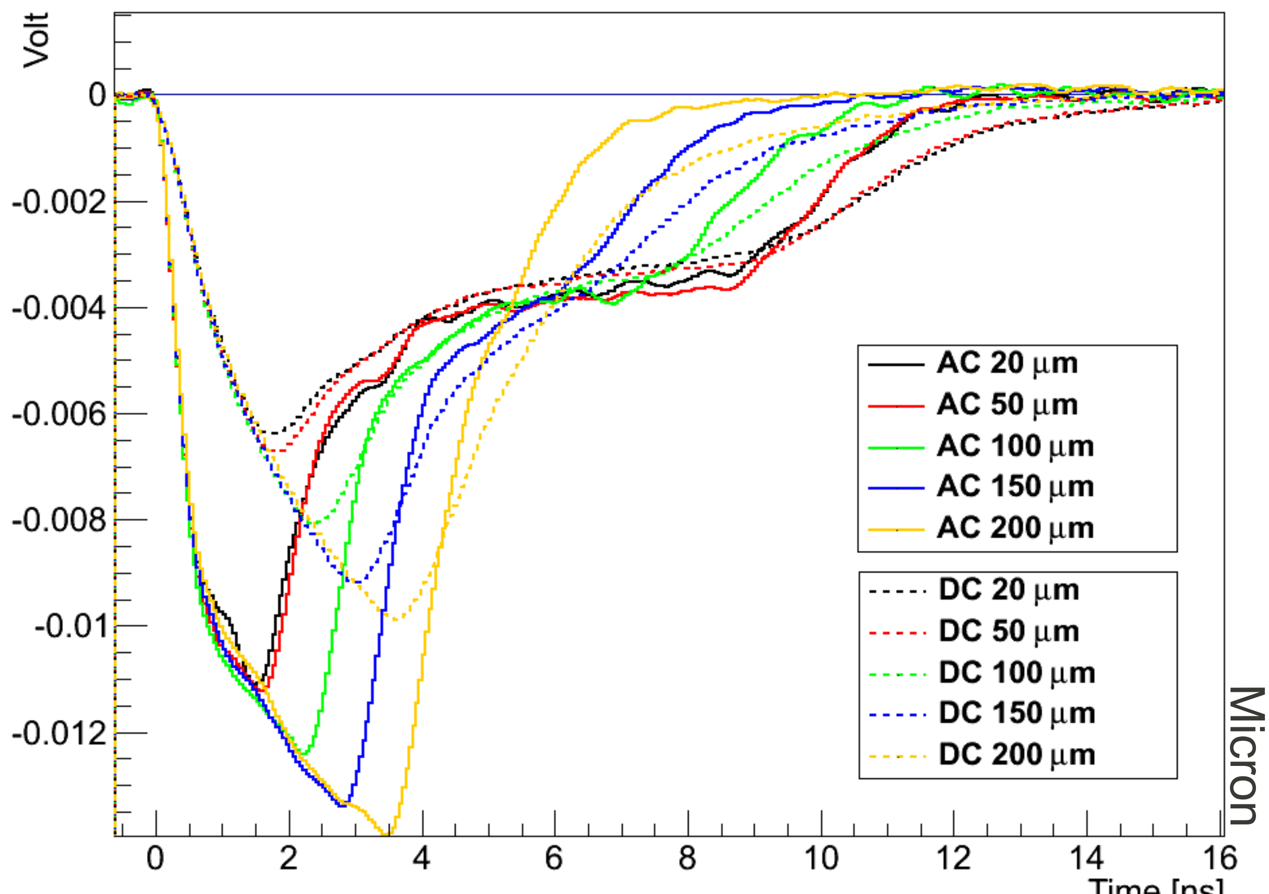
AC coupled detectors



DC coupling ⇒ Bias-Tee (Cc=2.2 nF) needed

Compared AC-coupled detector **with Bias-T (redundant)** with AC-coupled **without it .**

With **Bias-T**, undershoot is more noticeable.



Same detector AC or DC coupled

DC has Bias-tee in between the sensor and the amplifier. No undershoot.

AC risetime is faster

Laser power: drift velocity

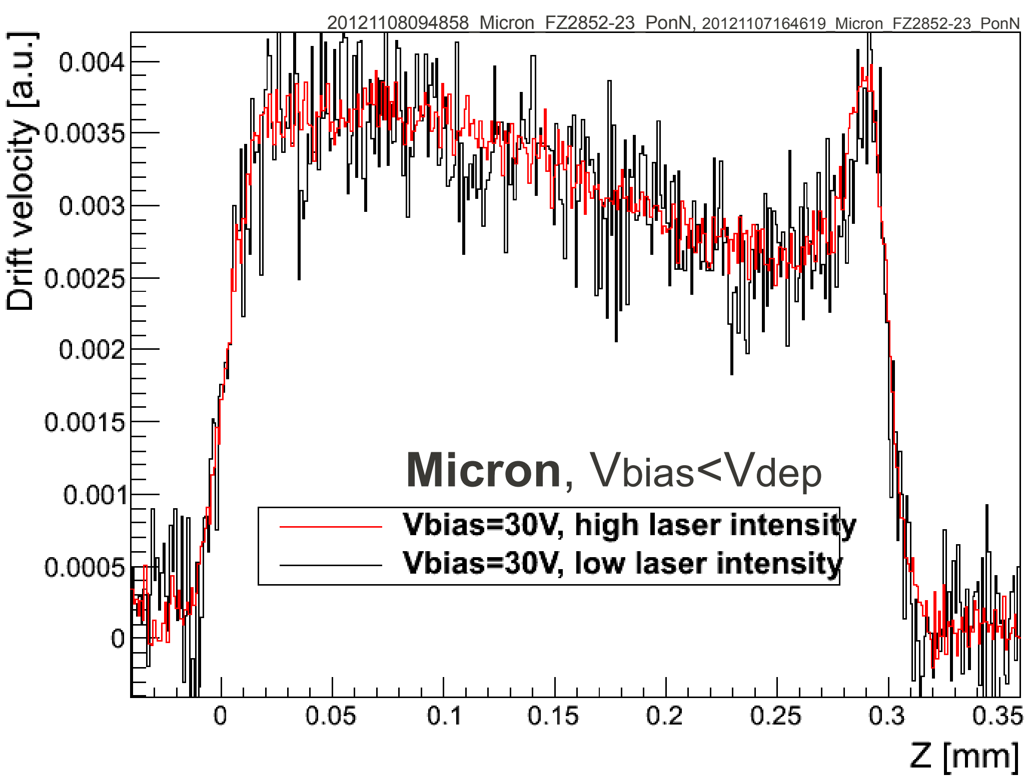
Drift velocity must be independent of laser intensity.

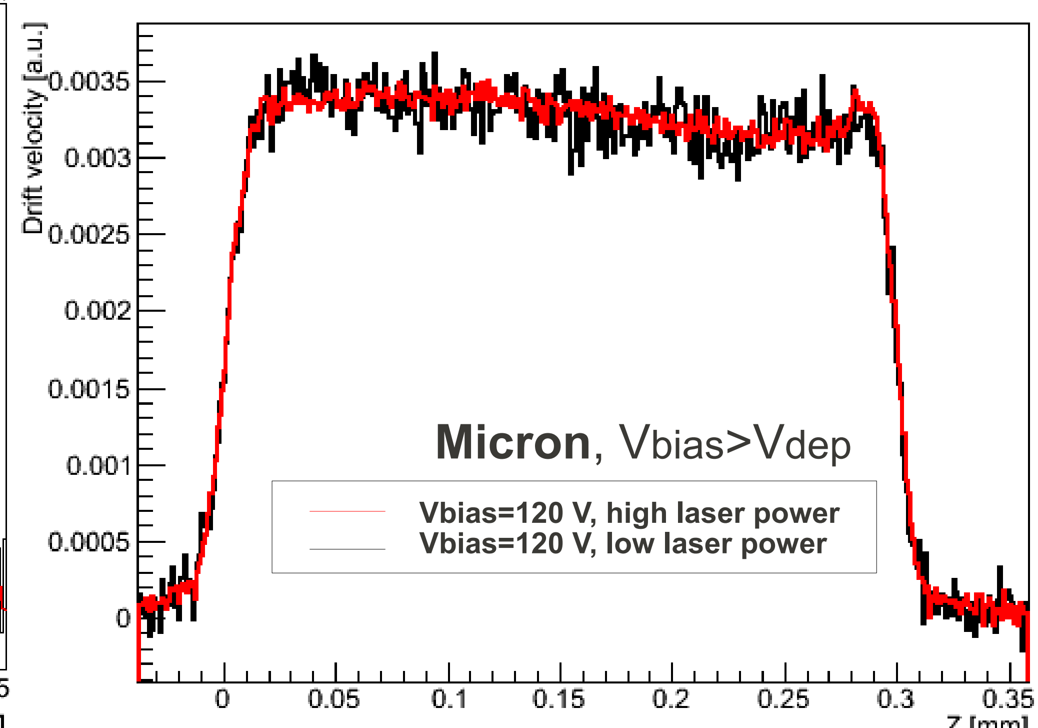
$$I_{e,h}(t) \approx A\, e_0\, N_{e,h} \frac{v_e(z)+v_h(z)}{d}$$

We do not measure the number of injected photons N ⇒ Plots are still given in arbitrary units.

Higher laser intensity → better S/N ratio

Normalized drift velocity identical for **high** and **low** laser intensity

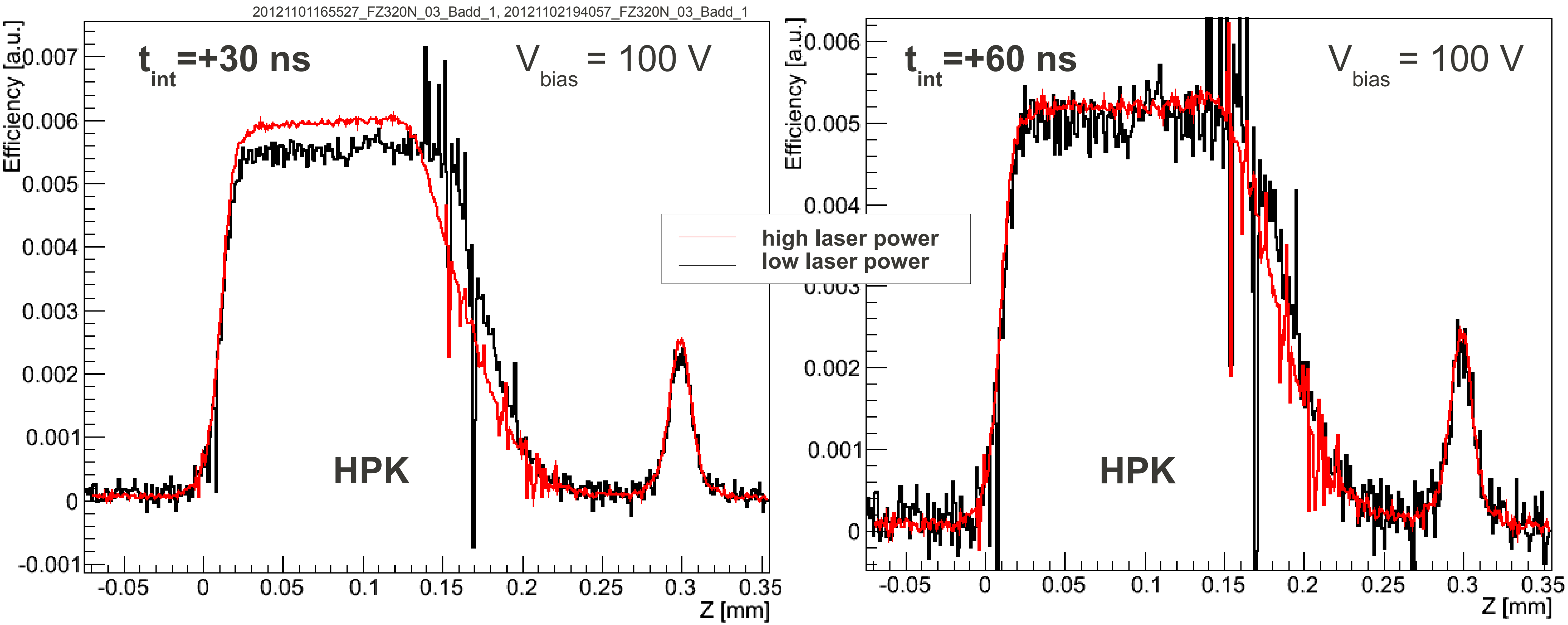




Laser power: efficiency

Efficiency defined as $Q(z) = \int_{tleft}^{+tint} I(t,z)\,dt$ depends on laser intensity (and integration time)

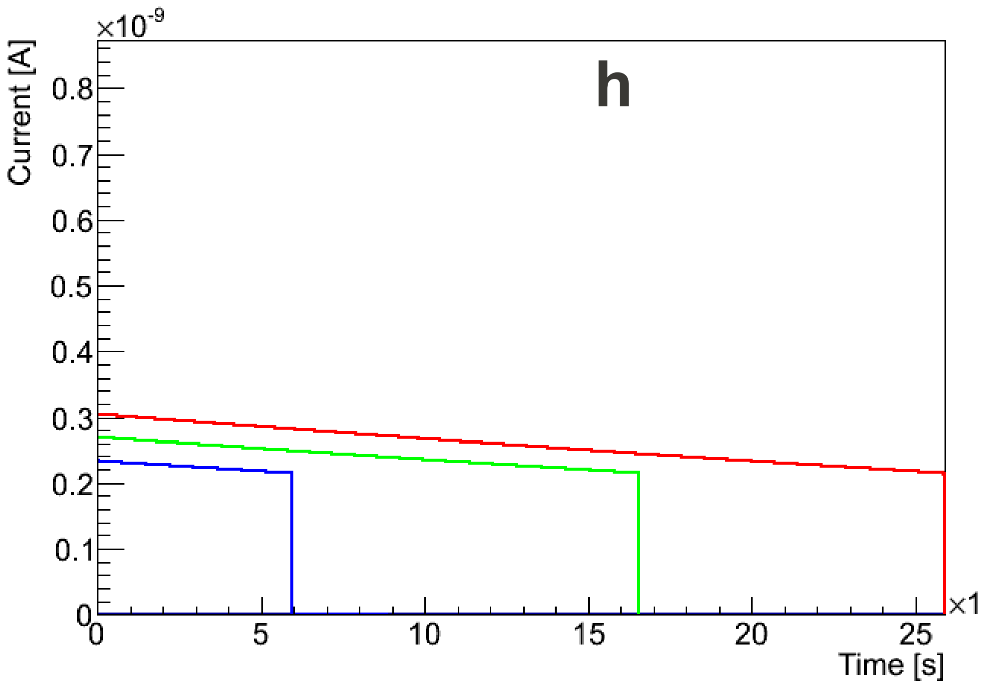
Normalized efficiency at high and low laser power coincides (for long integration time)

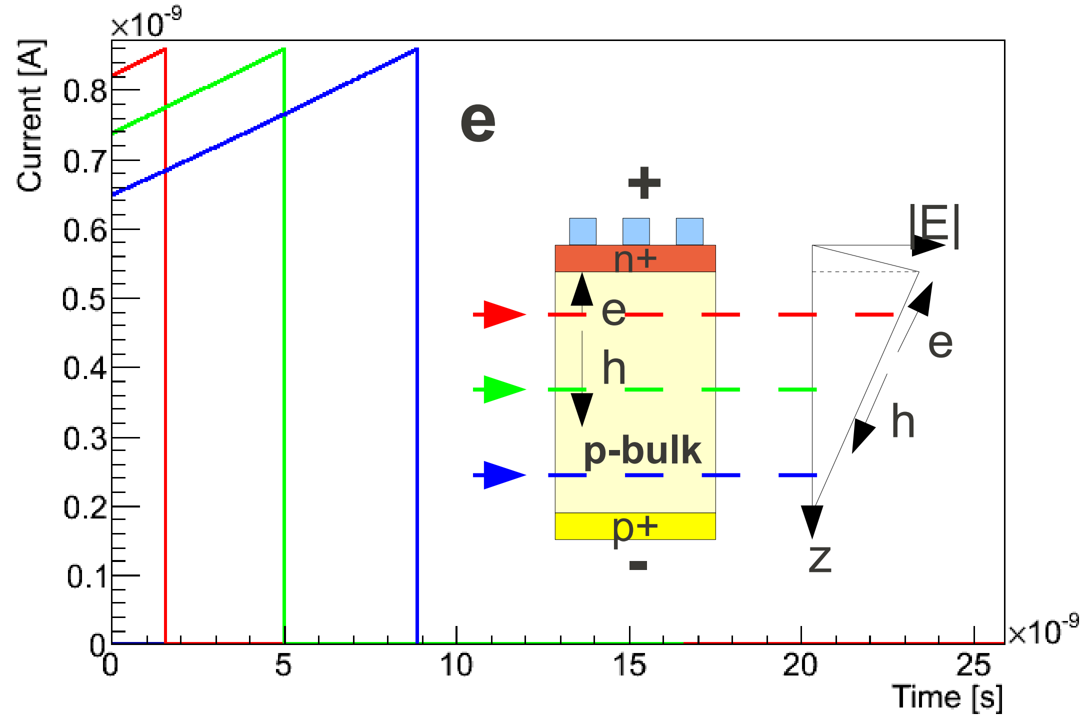


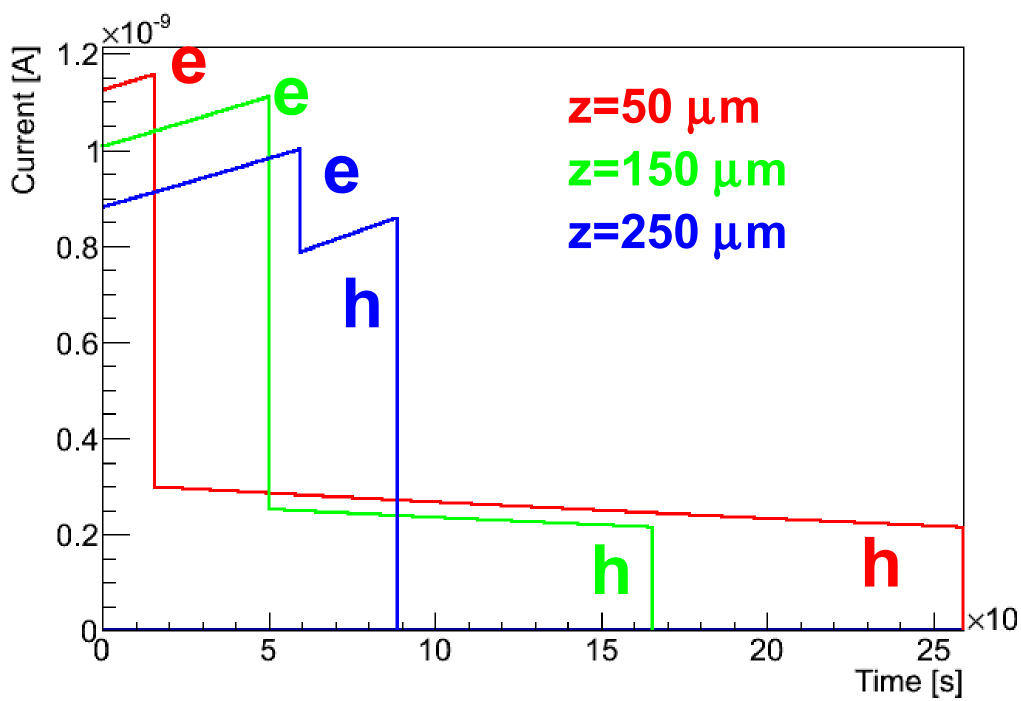
Since calculated efficiencies at low and high laser power coincide, this indicates we are very likely **not in plasma regime**

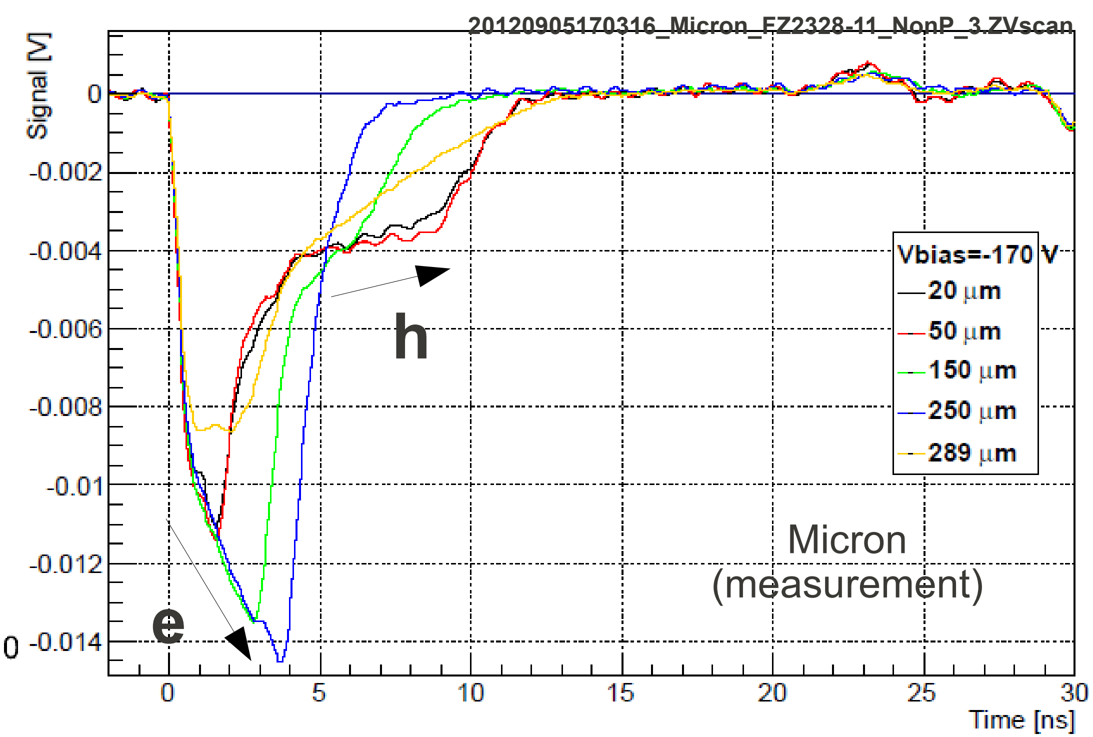
Photodiode will be added to estimate number of injected photons

Naïve 300 μm p-bulk diode simulation

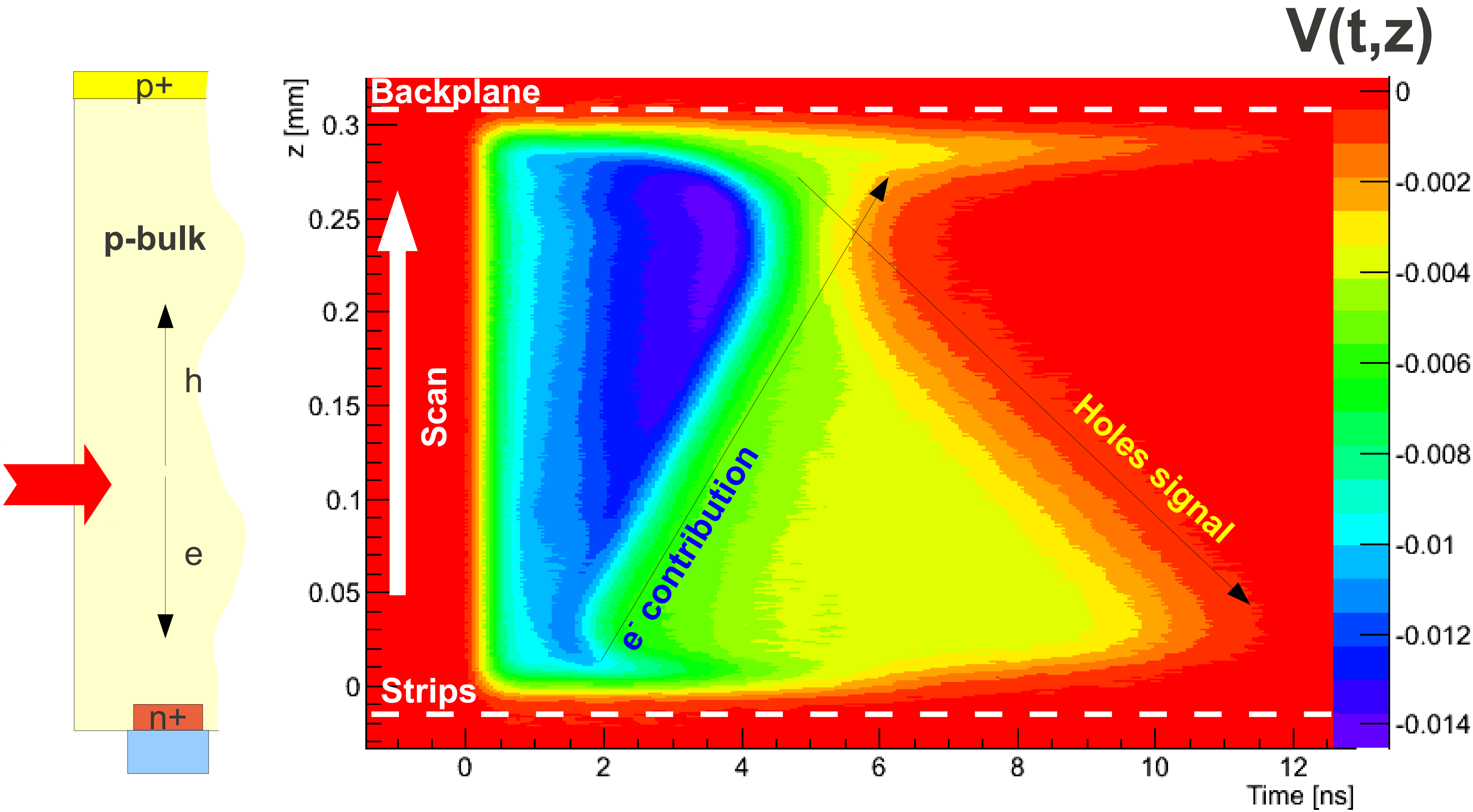






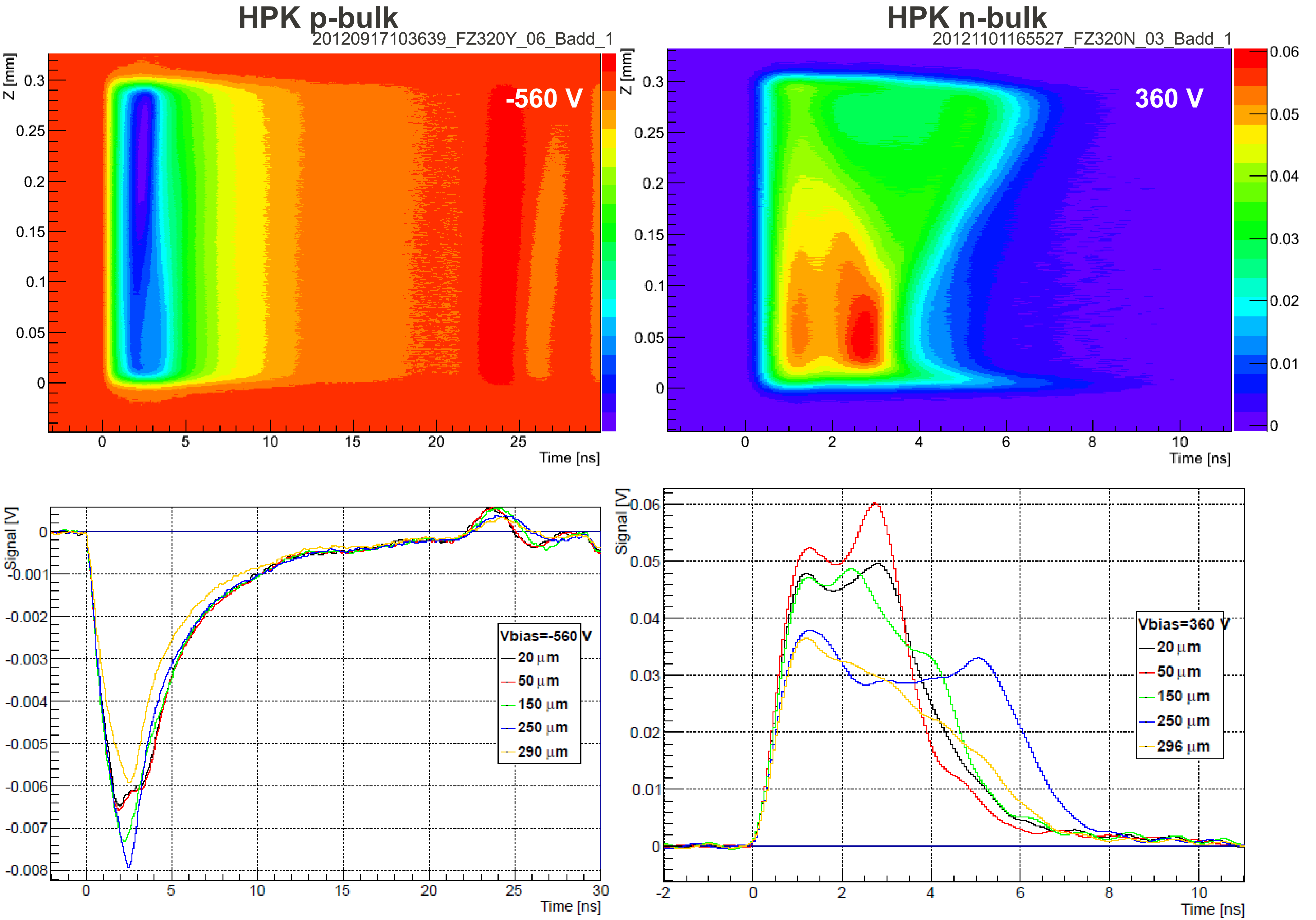


Micron: V(t,z) for a full Z scan (p bulk)

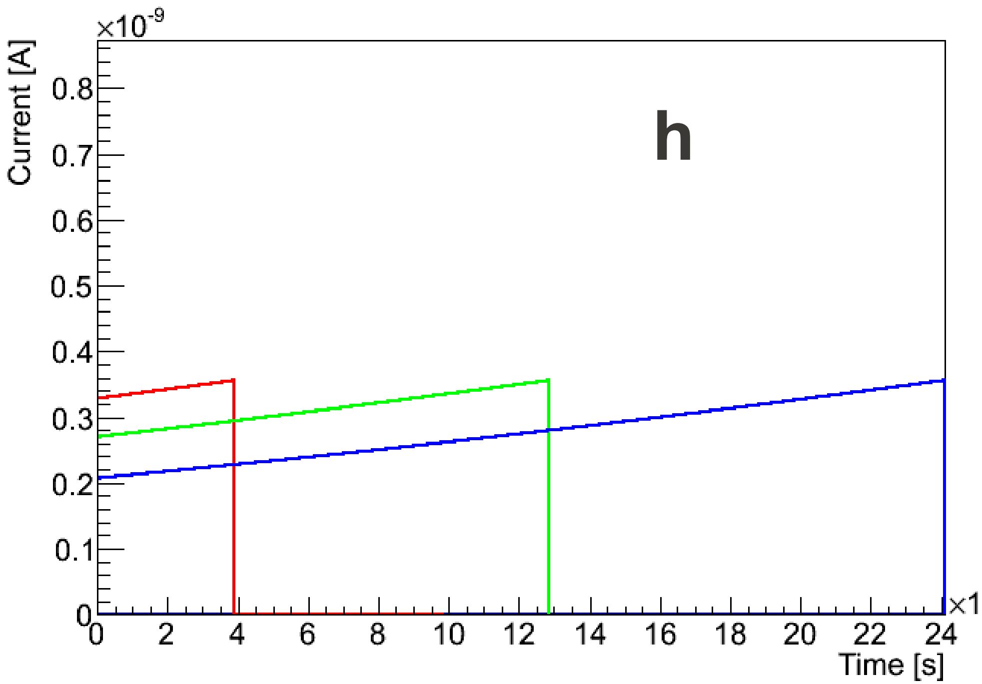


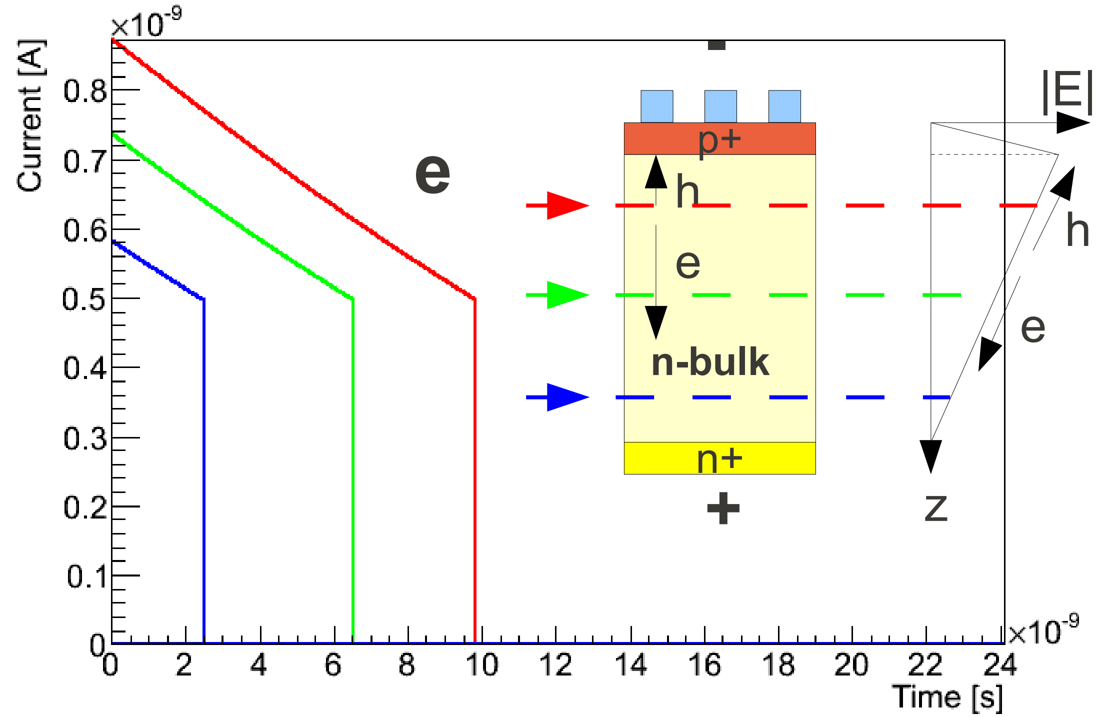
Contribution of electrons and holes clearly seen

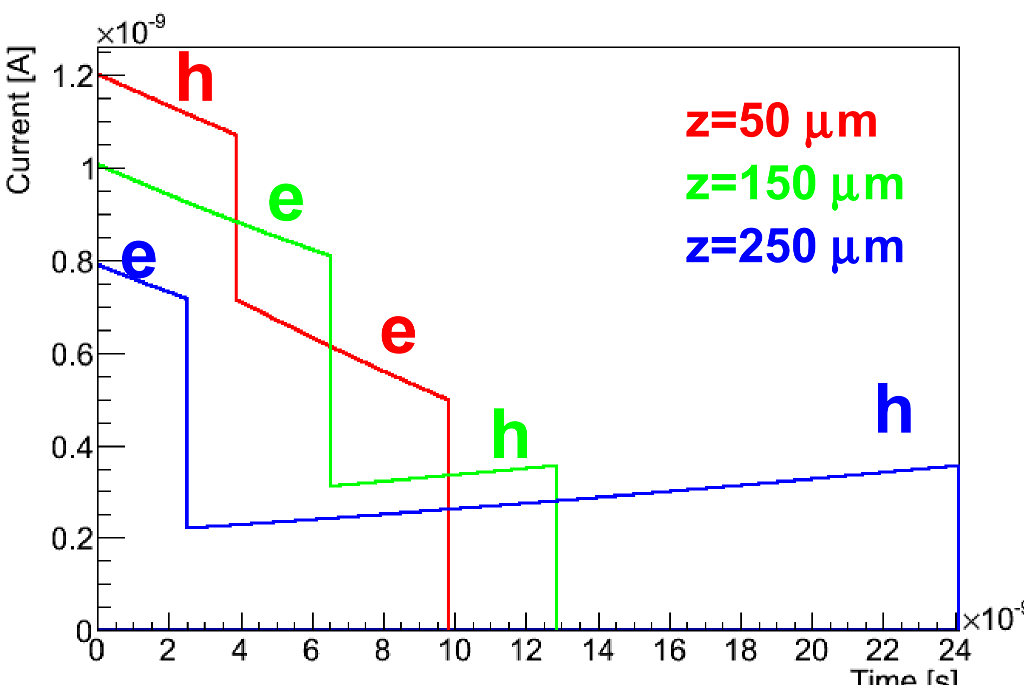
Measurements of unirradiated p-bulk and n-bulk Hamamatsu detectors for CMS upgrade

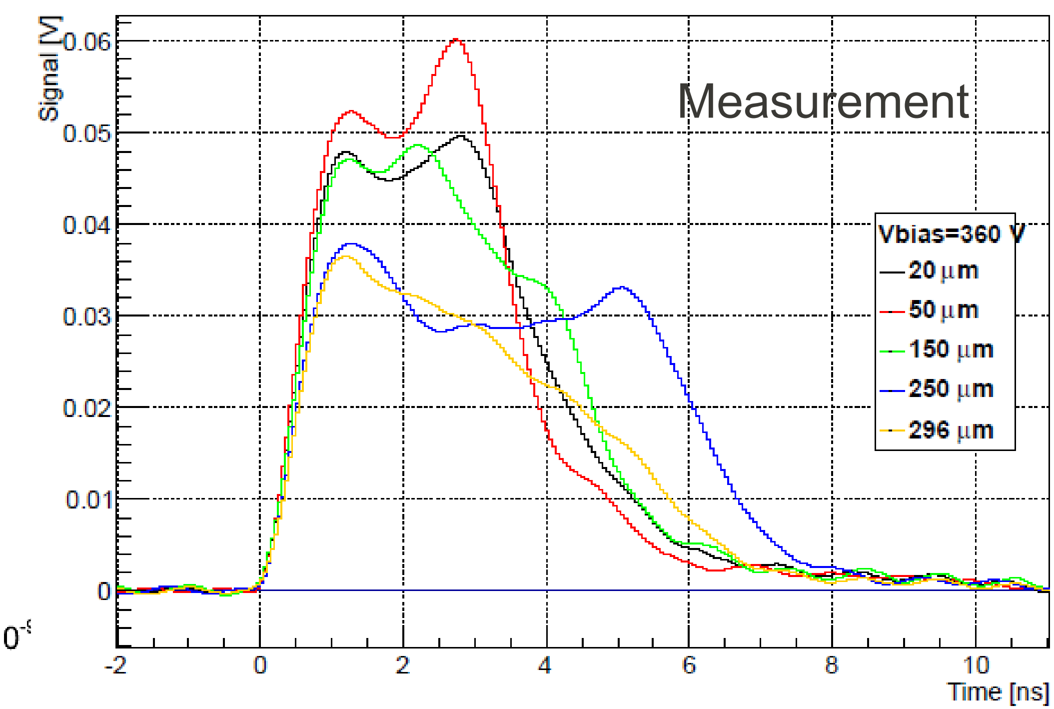

HPK p-bulk
20120917103639_FZ320Y_06_Badd_1
-560 V
Z [mm]
Time [ns]
HPK n-bulk
20121101165527_FZ320N_03_Badd_1
360 V
Z [mm]
Time [ns]
Signal [V]
Time [ns]
Vbias=-560 V
20 µm
50 µm
150 µm
250 µm
290 µm
Signal [V]
Time [ns]
Vbias=360 V
20 µm
50 µm
150 µm
250 µm
296 µm

Naïve 300 µm n-bulk diode simulation



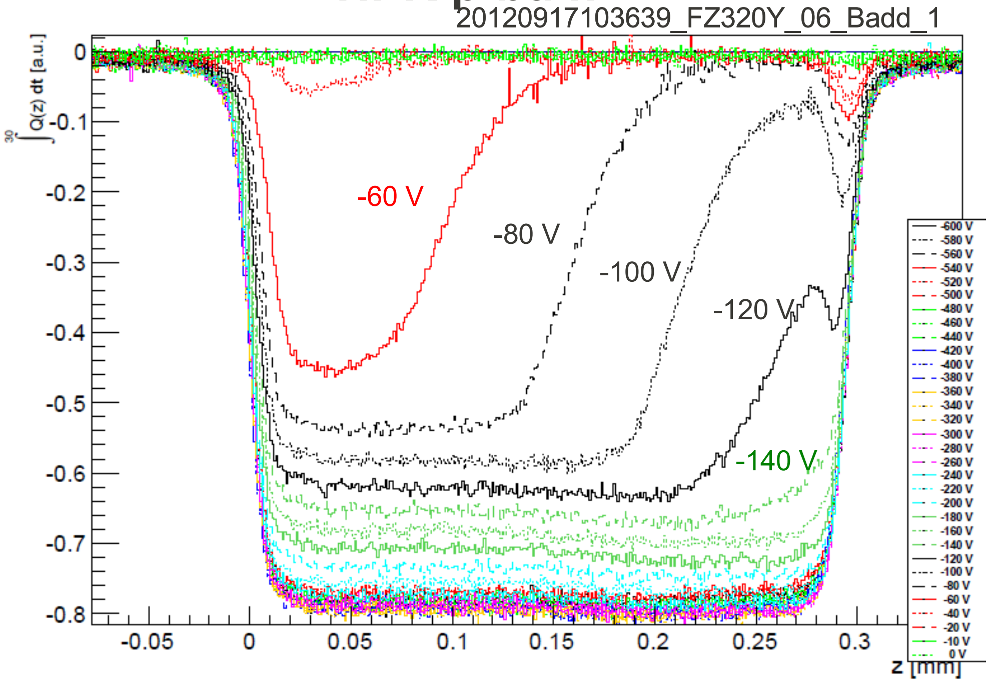


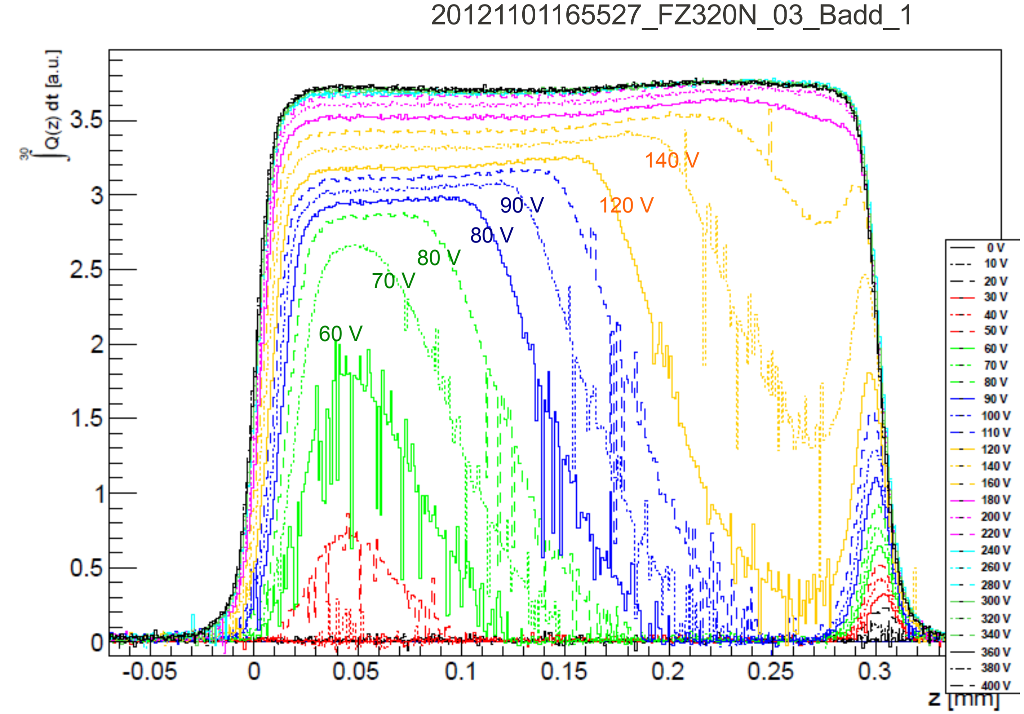


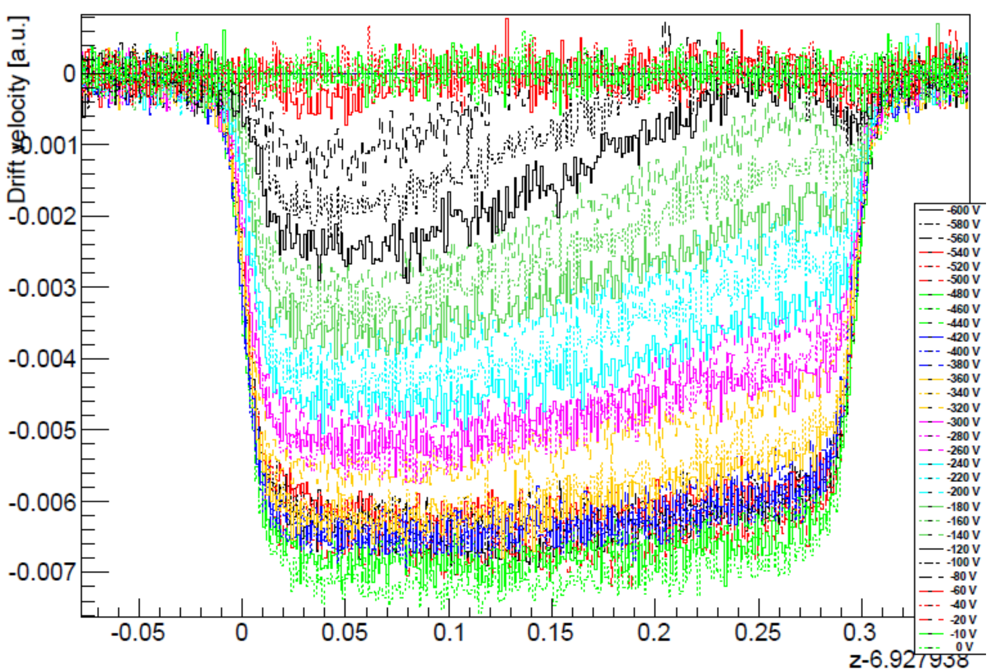


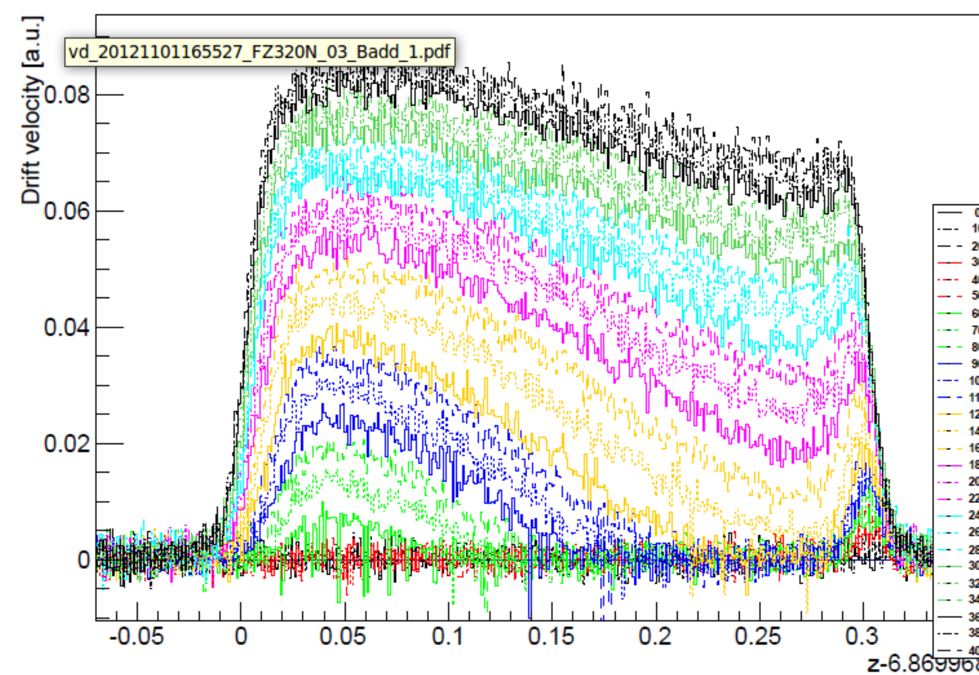
HPK p-bulk

HPK n-bulk









Conclusions

- Mini-strip sensors from CMS HPK campaign are being measured using eTCT.
  - Measurements done at SSD lab at CERN

- Former published work on eTCT Micron detectors taken as guideline:
  - CERN setup validated measuring p-bulk micron detectors

- Detectors are AC coupled

- Normalized drift velocity & efficiency used to compare measurements at different laser powers

- e-h contributions to I(t):

Micron:

p-bulk	clear e-h contribution.
n-bulk	less direct to interpret, but visible

HPK:

p-bulk	e-h contribution washed out
n-bulk	visible

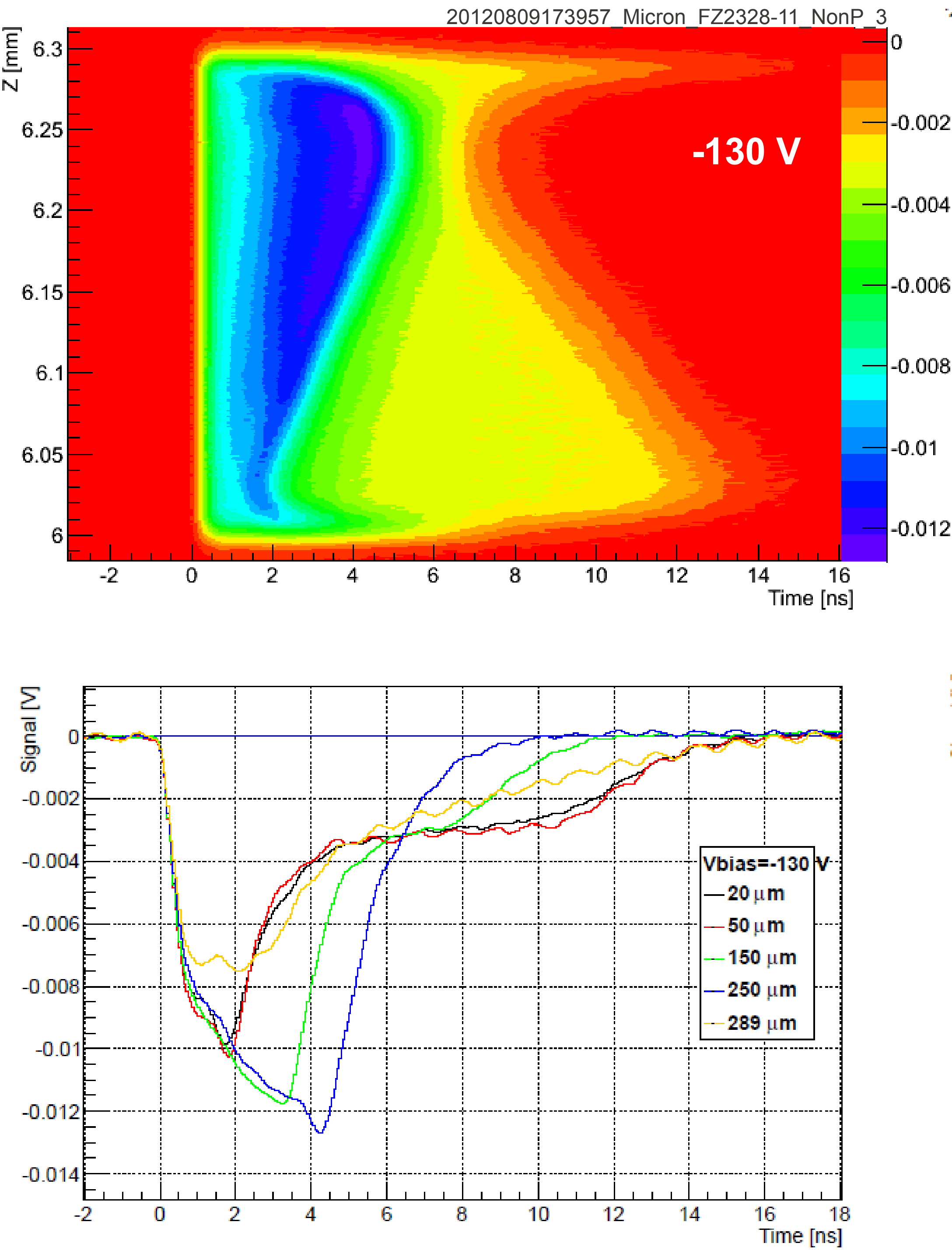
- HPK detectors show flat efficiency profiles after depletion. Effect of deep diffusion seen as double junction. Only 3 detectors measured for the moment.

- Next steps: measure (and irradiate) more detectors and extend study to other materials within the scope of CMS HPK campaign.

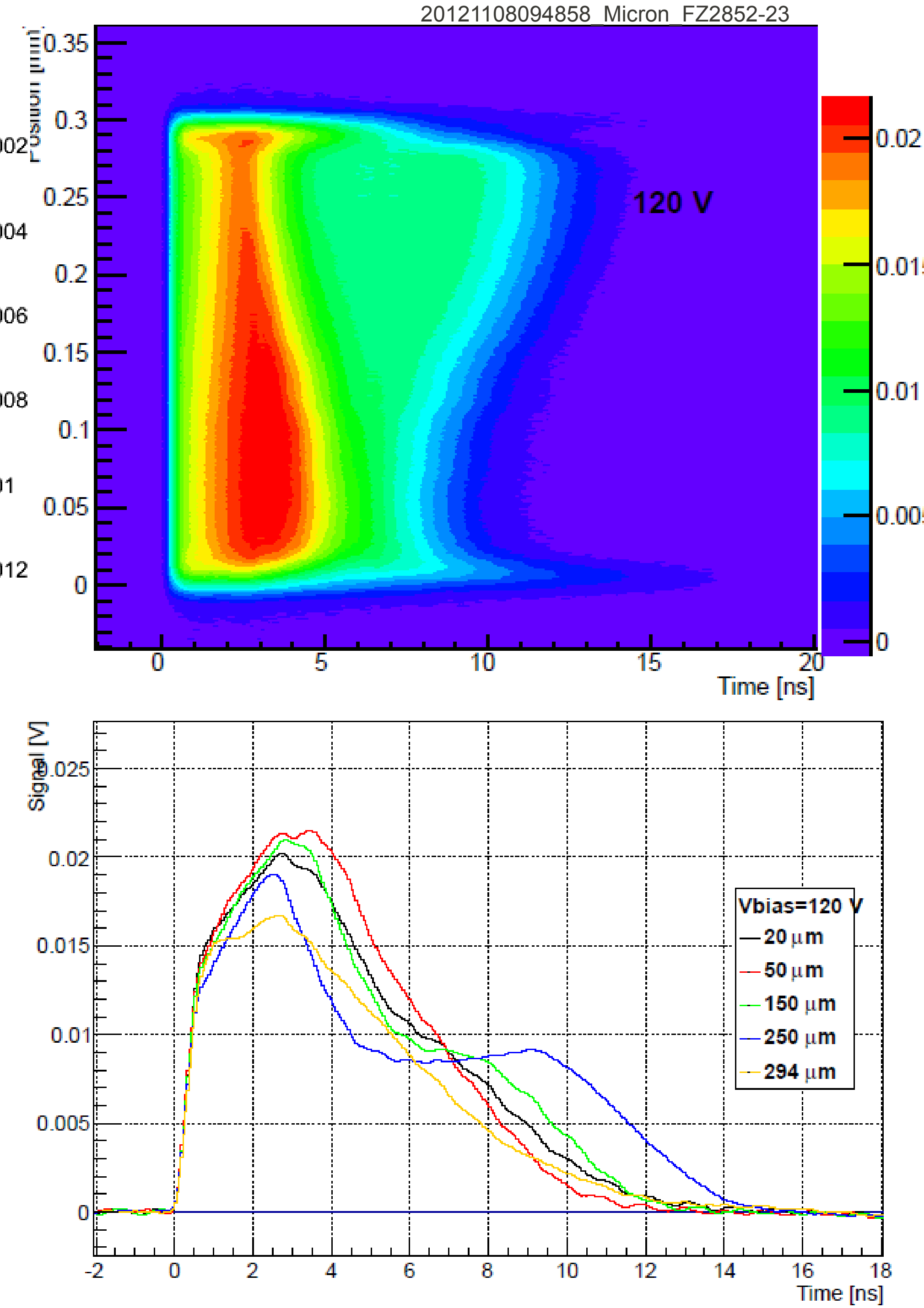
Thanks to I. Dolenc for help at the beginning of this work
Thanks to I. McGill & F. Manolescu (bonding lab) for bonding of detectors here presented

BACKUPS

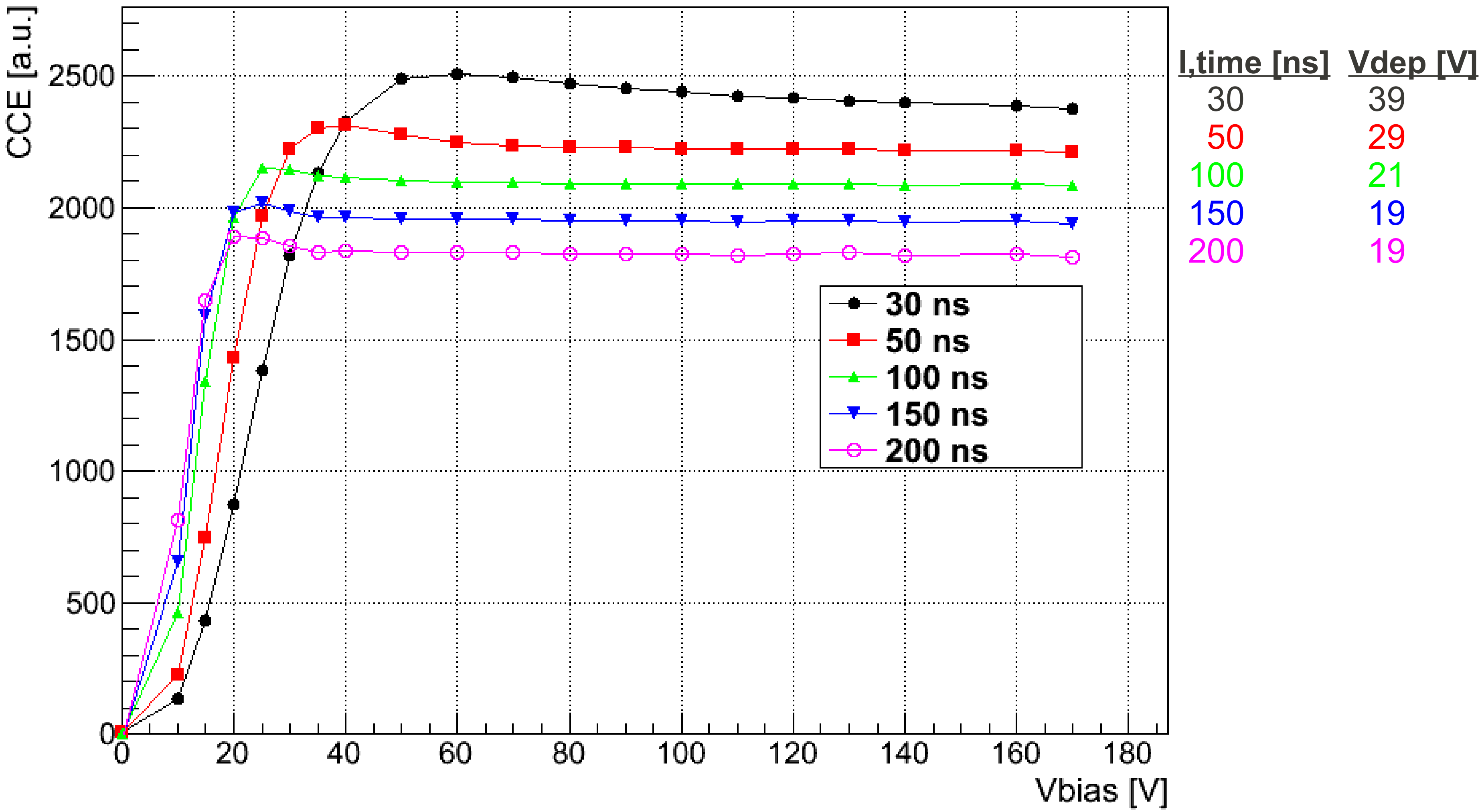
Micron P-bulk



Micron N-bulk



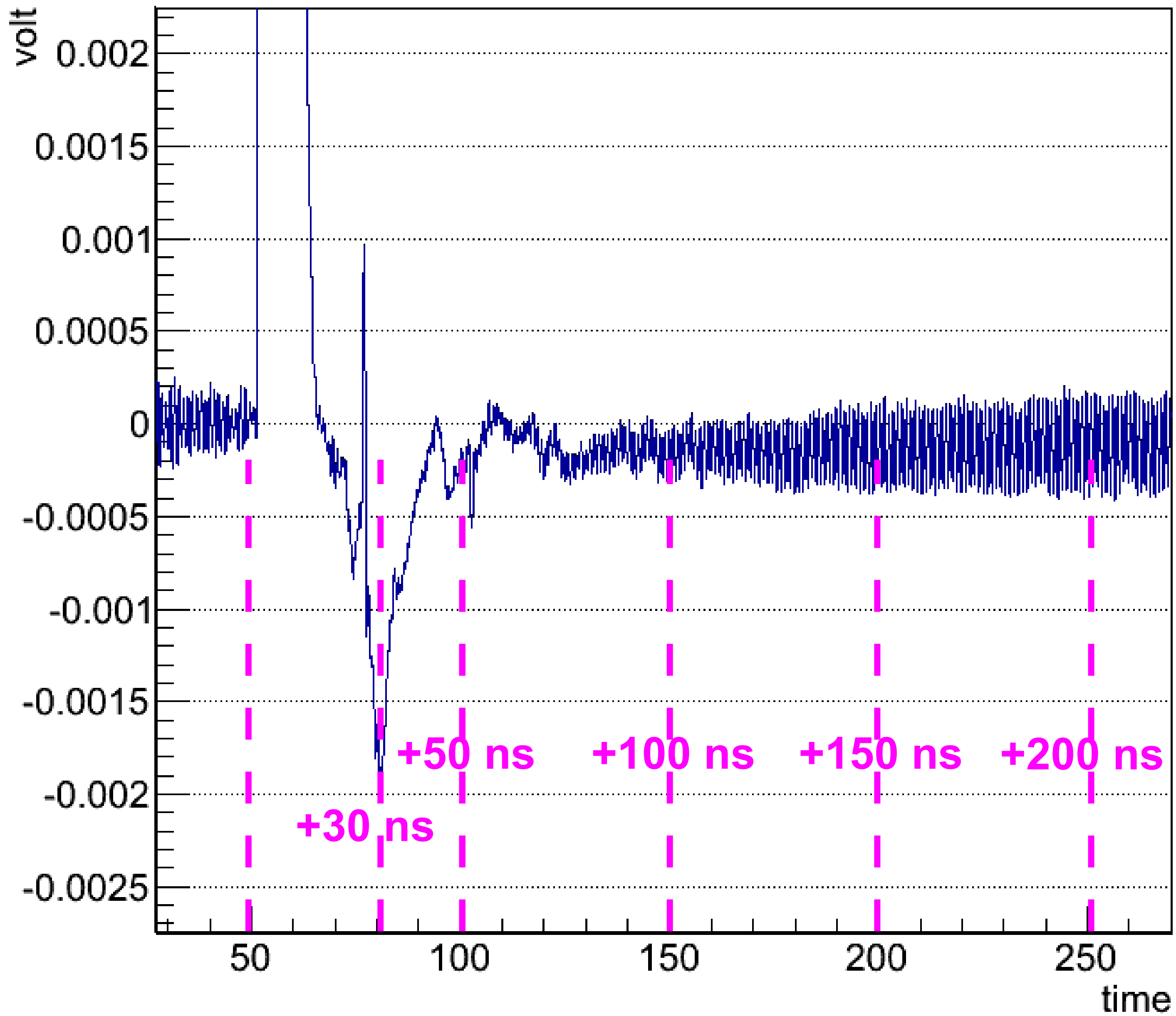
20121110210502_Micron_FZ2852-23_PonN



Up to 500 ns recorded in scope.
Studying effect of integration time on CCE.

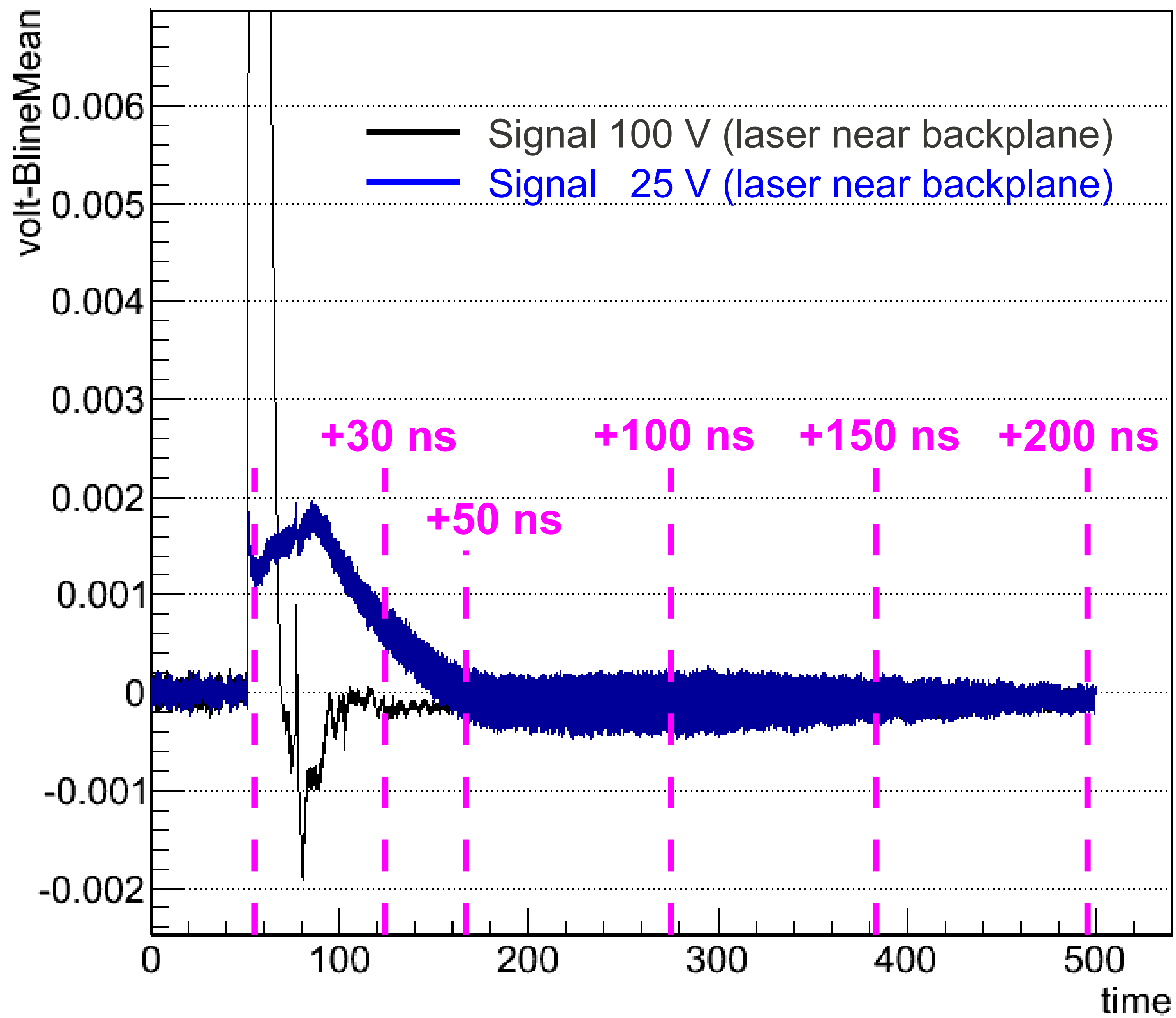
Longer integration time → more undershoot is integrated → less charge collected
Longer integration time → more signal can be collected at lower bias → plateau reached before

20121110210502_Micron_FZ2852-23_PonN



Longer integration time → more undershoot is integrated → less charge collected

20121110210502_Micron_FZ2852-23_PonN



Longer integration time → more signal can be collected at lower bias → plateau reached before

Detectors studied

Micron (taken as “reference”):
256 strips, 80 μm pitch, 1x1 cm^2

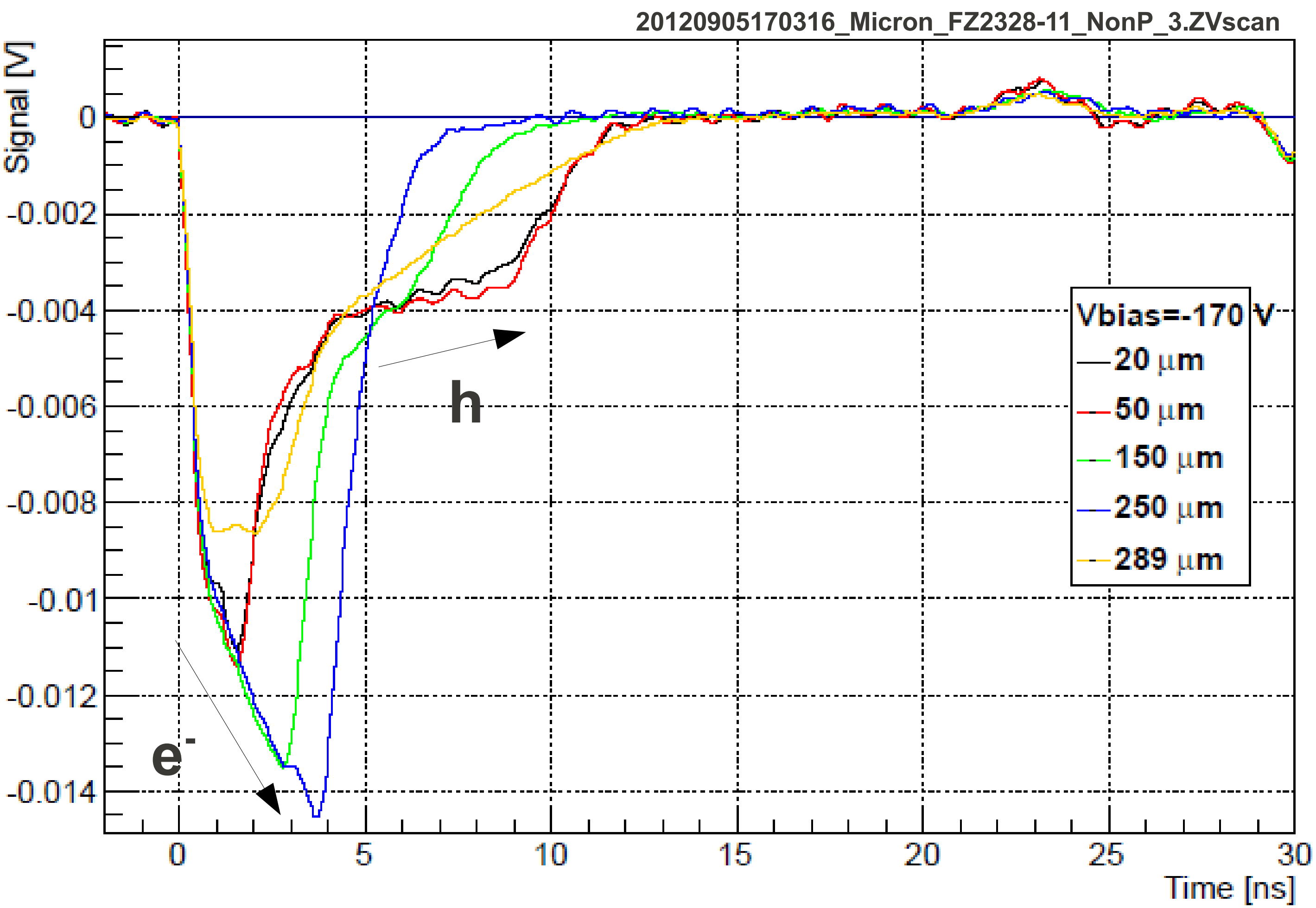
2x N-on-P: FZ2328-11
1x P-on-N: FZ2852-23

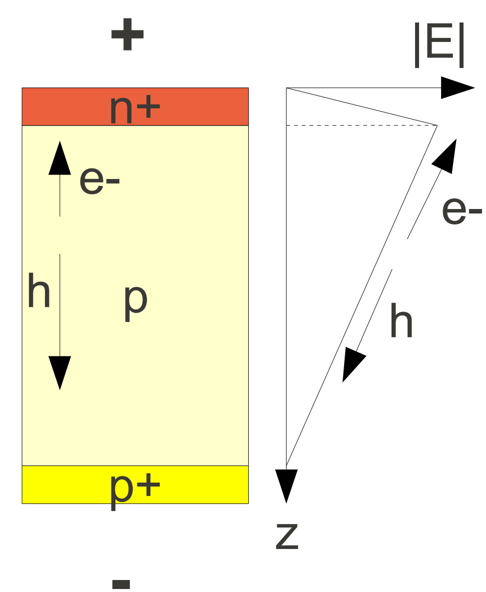
Hamamatsu (CMS HPK campaign)
Badd: 64 strips, 80 μm pitch, ~2.2x7 mm2

Time resolved pulses at different depths (P bulk)

- AC coupling (no bias-T), using Miteq (0.3Mhz-2 Ghz) amplifier, signal measured on digital scope (2.5 Ghz, 20 GSa/s).

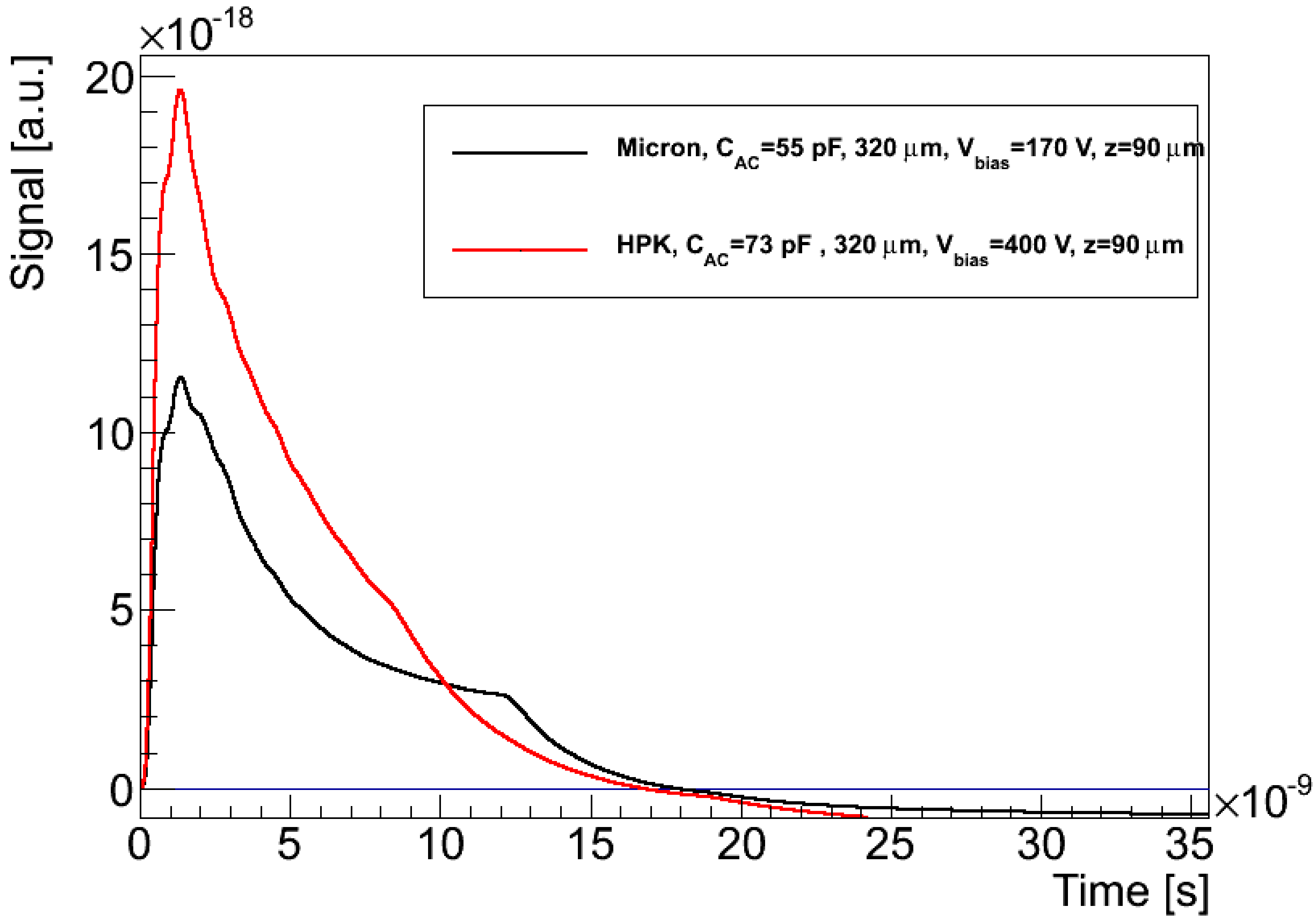
- Clearly seen electrons travelling “against” the increasing electric field, and holes “along” it.



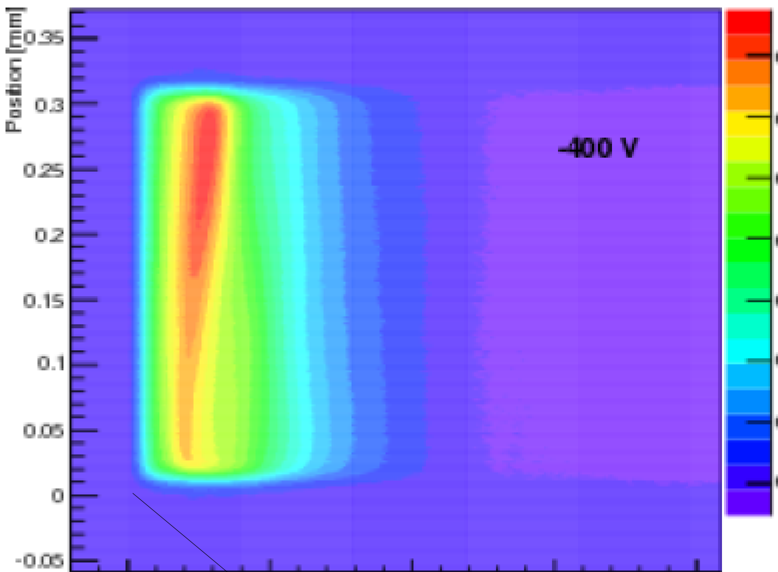


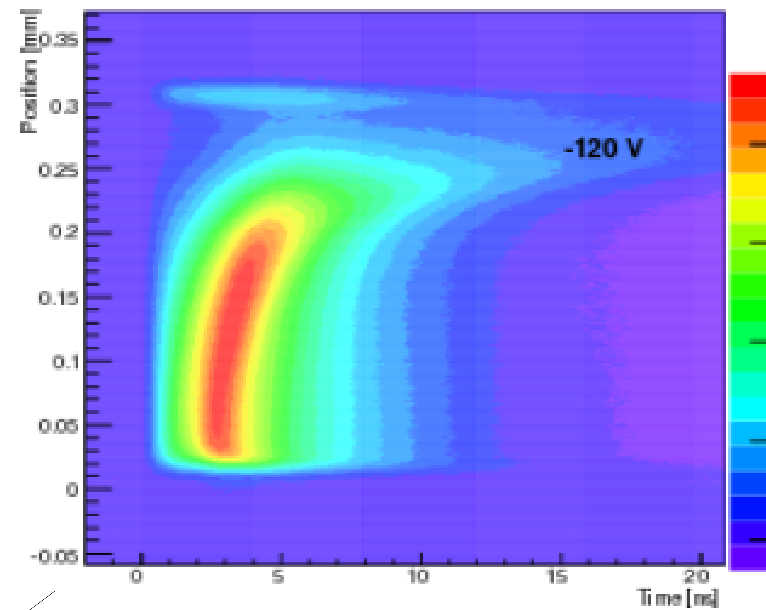
Effect of sensor coupling capacitance

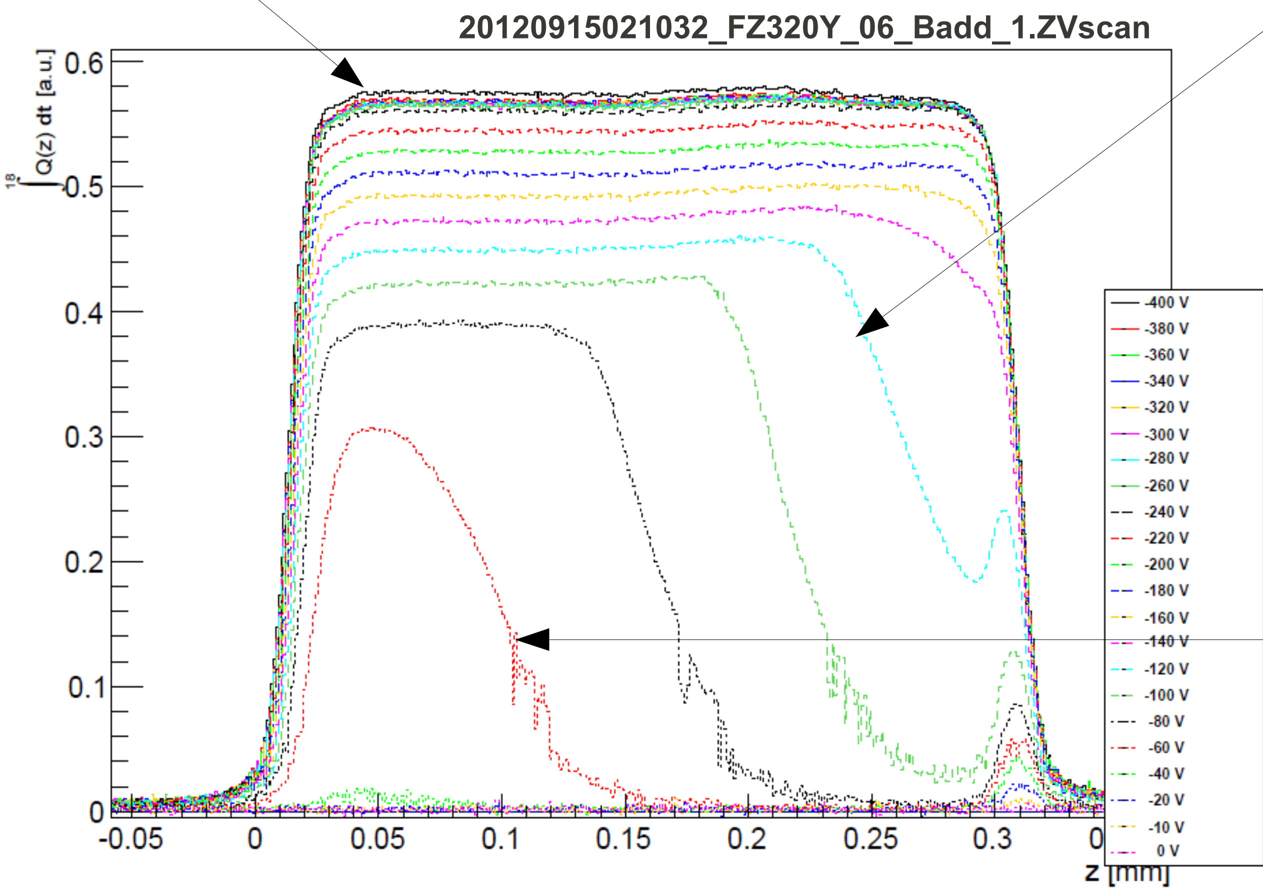
Naïve simulation including detector capacitance and convolution of ideal signal with amplifier response



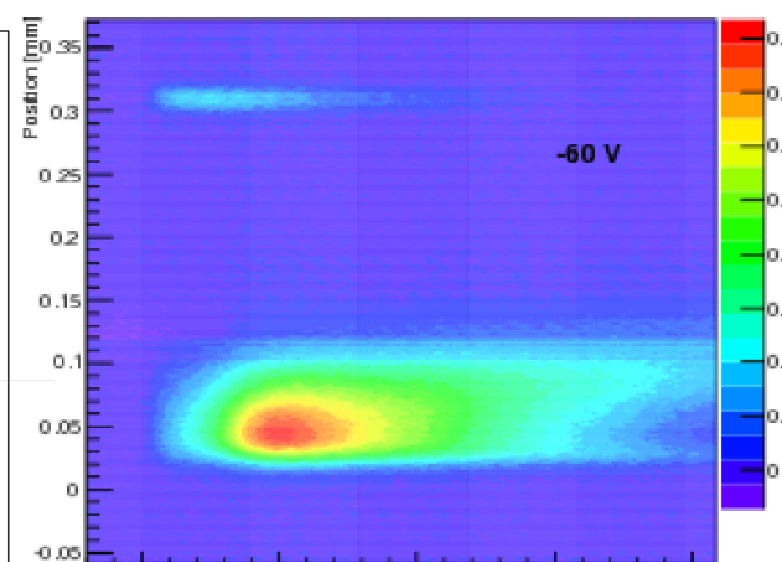
Inverting amplif.

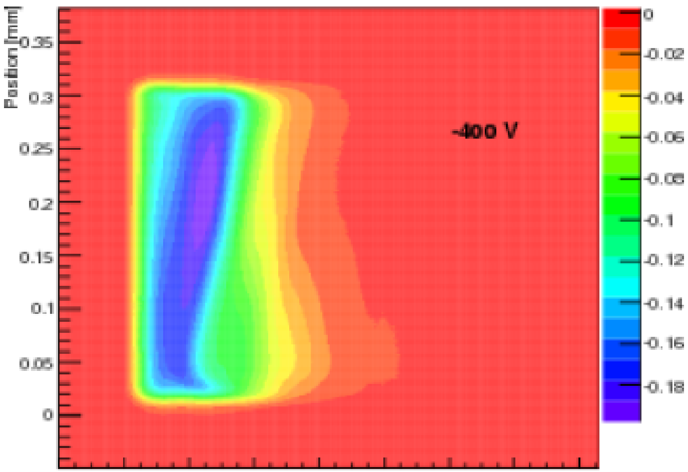


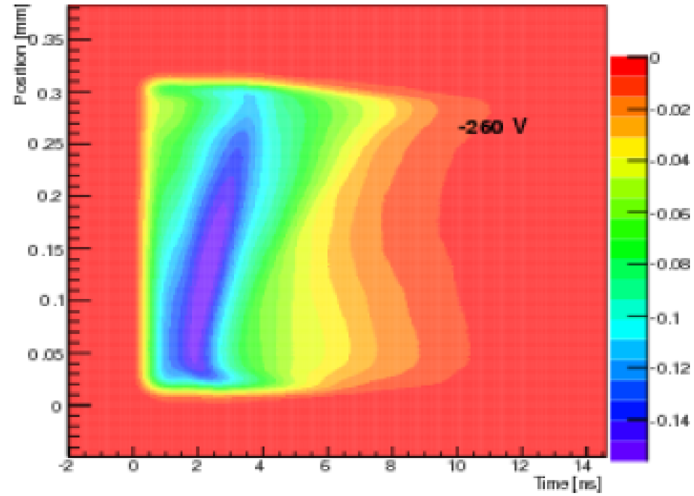


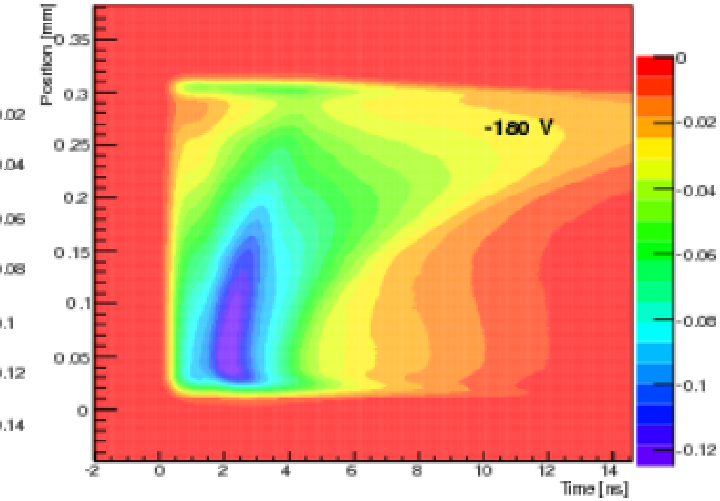


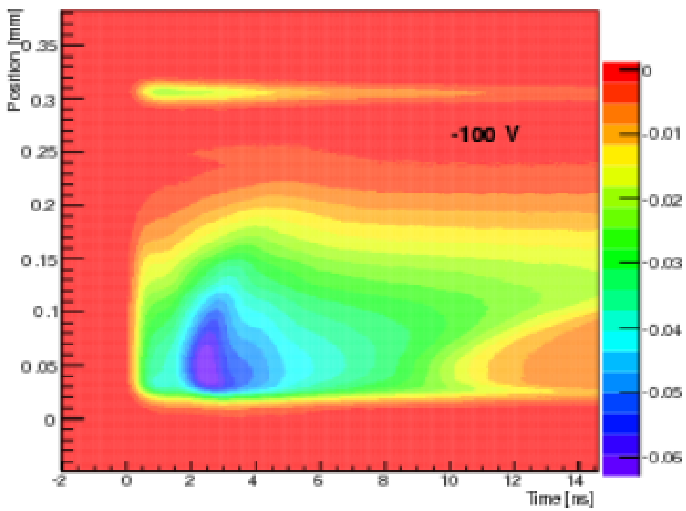
FZ320Y_06_Badd_1

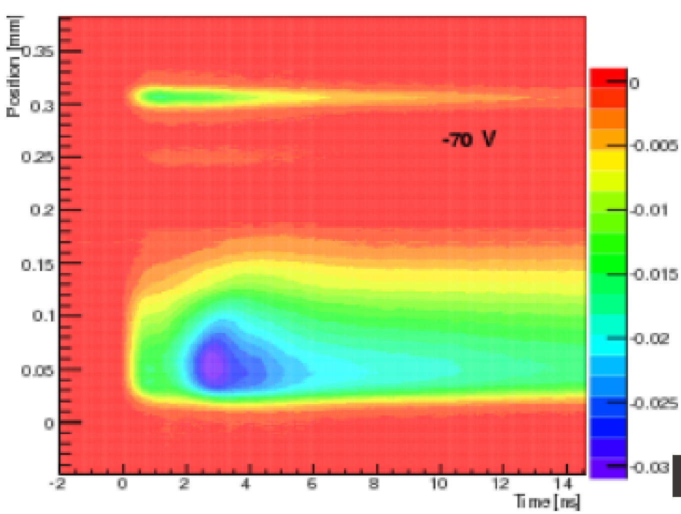


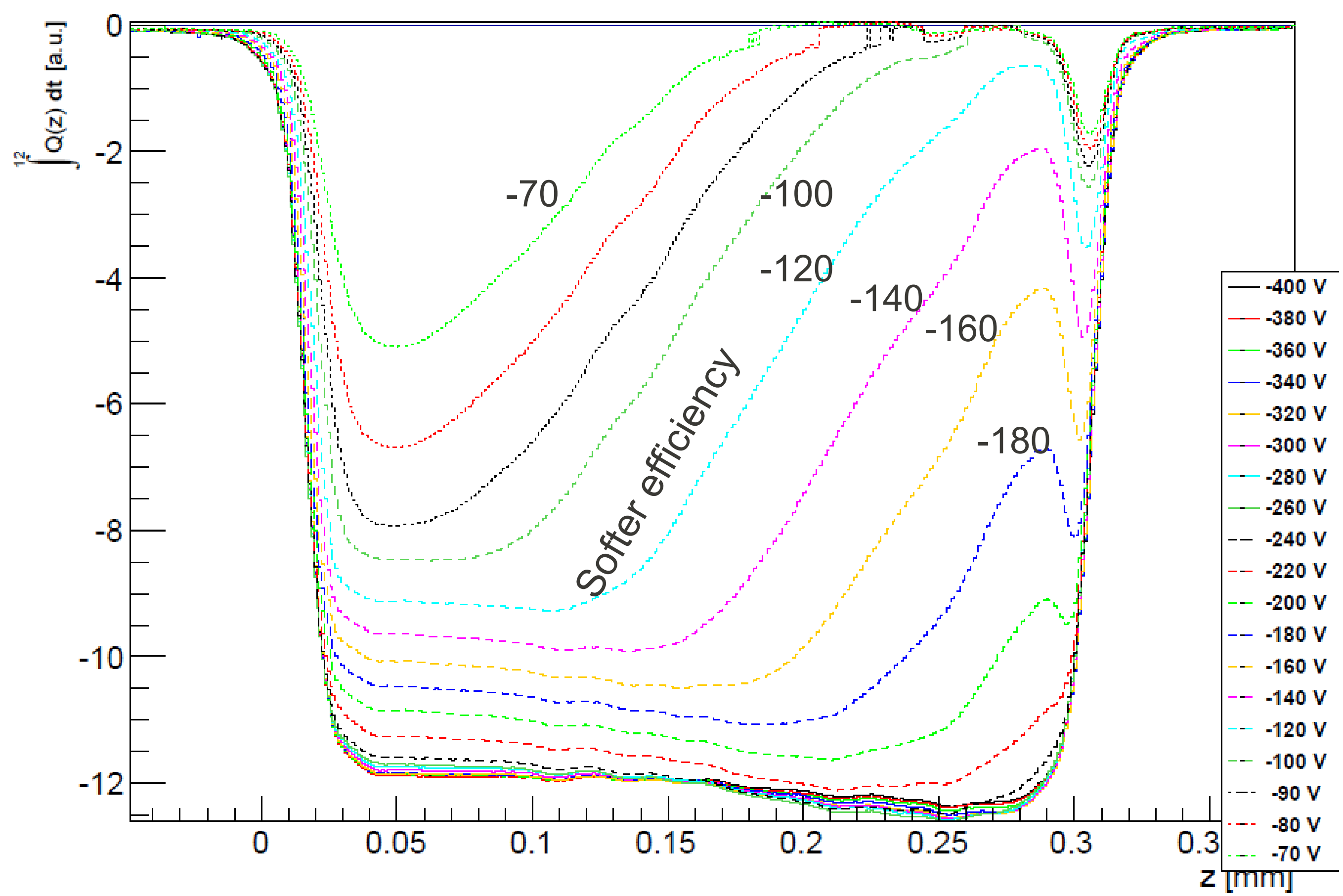












HIGH INTENSITY - FZ320Y_04_Badd_2 20120925171204

E-TCT formulae

$$I_{e,h}(t) = A e_0 N_{e,h} \exp\left(-\frac{t}{\tau_{\mathrm{eff},e,h}}\right) \vec{v}_{e,h}(t) \cdot \vec{E}_w, \quad (1)$$

E_W=1/W

$$I(y,t) = I_e(y,t) + I_h(y,t). \quad (2)$$

$$I(y,t \sim 0) \approx e_0 A N_{e,h} \frac{v_e(y) + v_h(y)}{W}. \quad (3)$$

Prompt current method

$$I(y,t \sim 0) \approx \frac{e_0 A N_{e,h}}{W} [\mu_e(E) + \mu_h(E)] E(y). \quad (4)$$

$$V_{\mathrm{bias}} = \int_0^W E(y) dy \quad (5)$$

Constrain to fix E(y)

$$Q(y) = \int_0^{t_{\mathrm{int}}} I(y,t) dt \quad (7)$$

Efficiency scan: Q=Q(y)

$$\langle Q \rangle = \frac{1}{W} \int_0^W Q(y) dy. \quad (8)$$

CCE

From G. Kramberger et al., IEEE Trans. Nucl. Scien., Vol 57, No. 4, August 2010