Stato della produzione, installazione e test diamanti

Belle II - Italia
Pisa - November 22, 2017

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Diamond sensor status

Phase 2: 8 “PXD” diamond sensors

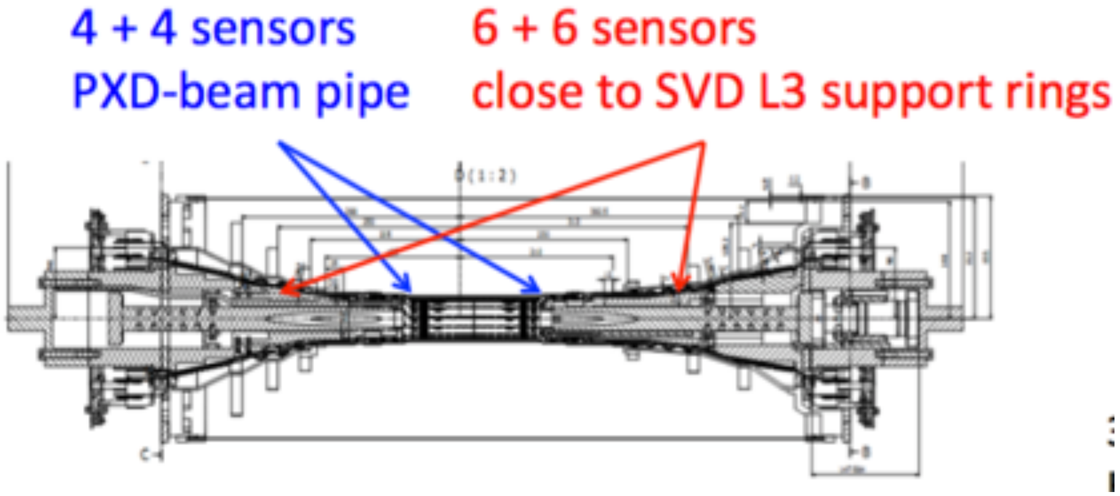
Phase 3: 8 “PXD” + 12 “SVD” diamond sensors

} in parallel

Diamonds assembly and testing

24 diamonds mounted on the final support.
23 fully tested:

- 14 already installed
- 9 almost ready for next installations


4 + 4 sensors
PXD-beam pipe

6 + 6 sensors
close to SVD L3 support rings

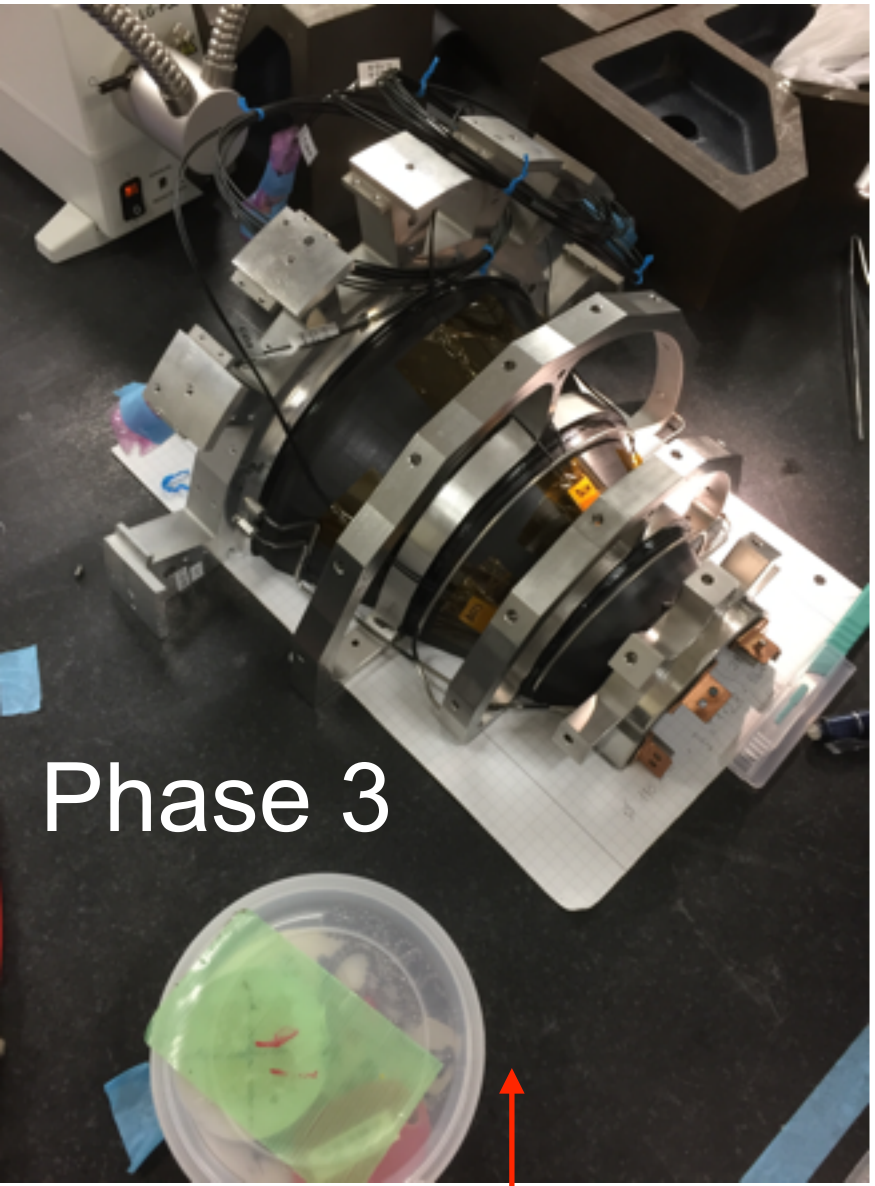
Schedule (only phase 3)

- 6 diamonds are needed for -X SVD half Ladder Mount and will be installed on December 01-16
- 8 more needed for Phase 3 for next year

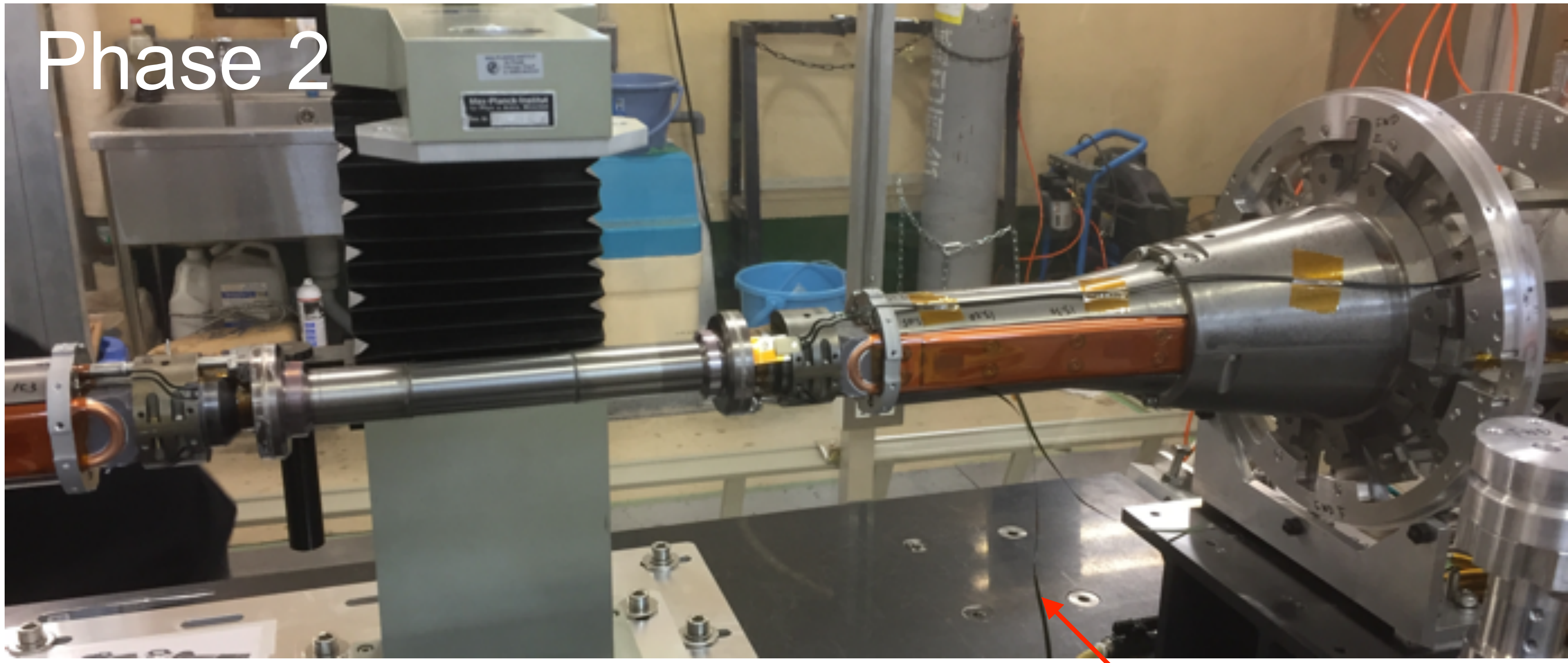
Other activity

- Irradiation tests of diamond sensors for a calibration with γ from ^{60}Co

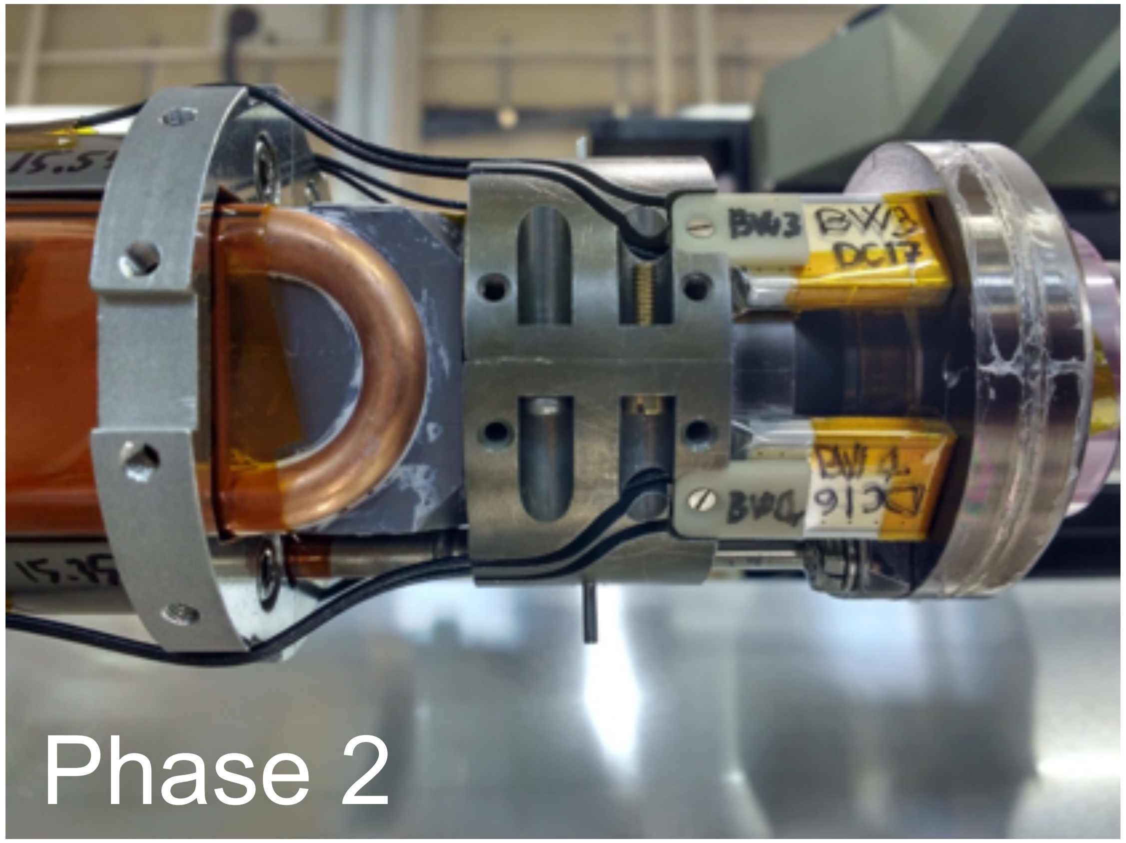
Already installed

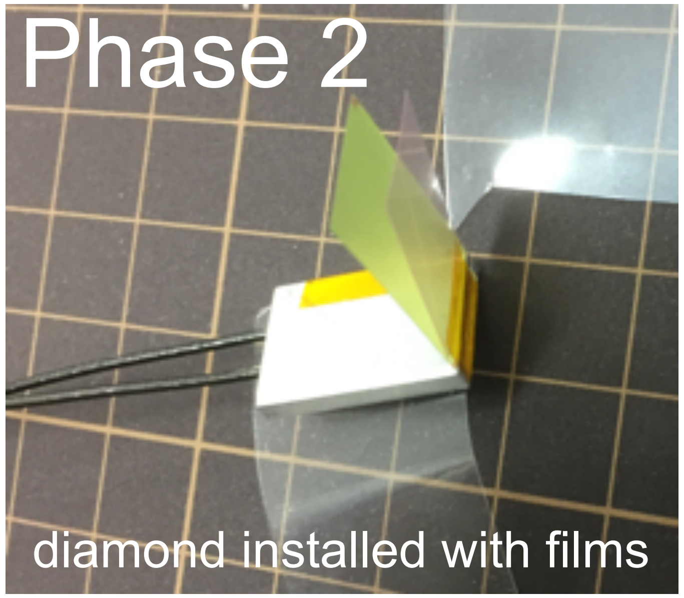


6 diamonds for +X SVD
(June 2017)

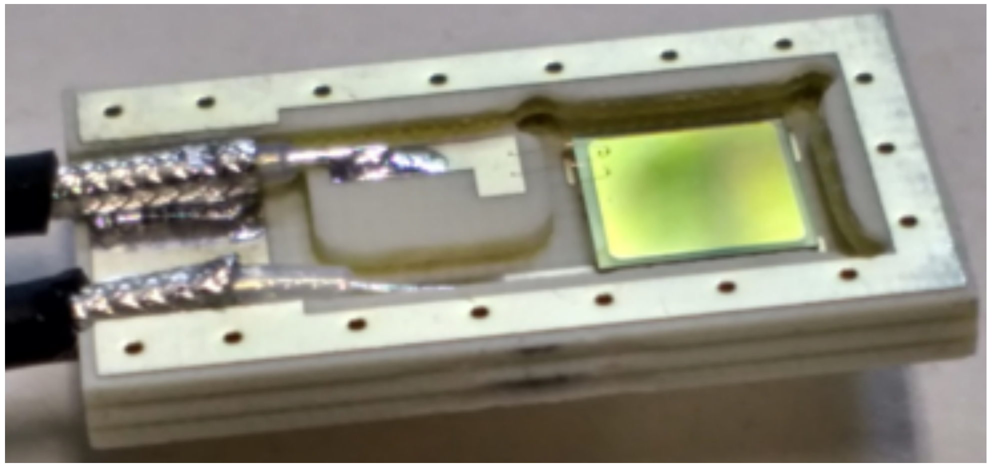


8 diamonds on the beam pipe (Sept 2017)



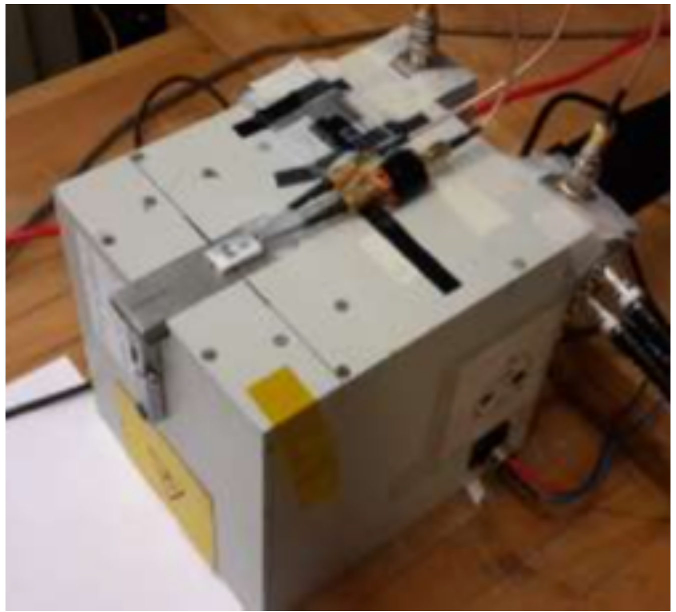


Tests and calibrations



- the metallized diamond crystal is first glued on the printed circuit support

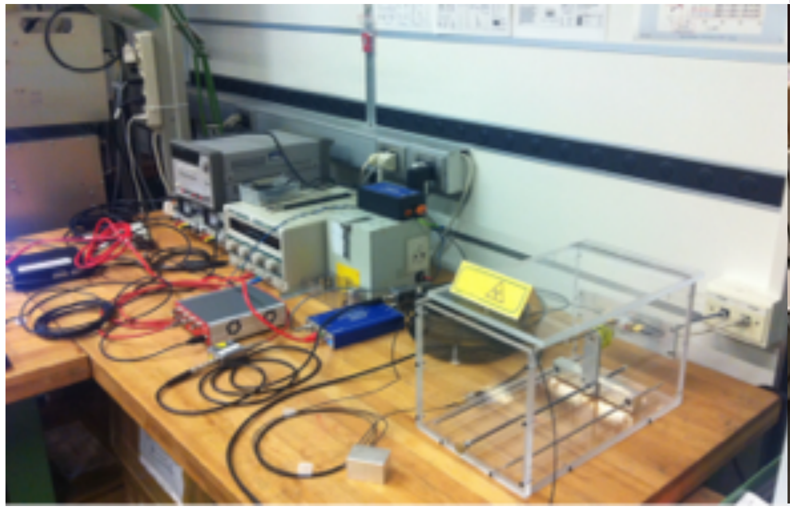
- the upper electrode is wire bonded

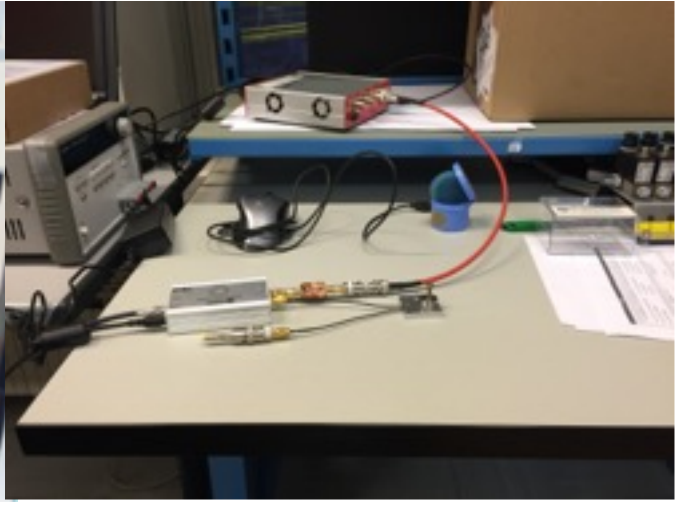


(0) Preliminary test: dark I-V characteristic:

Dark currents below the pA range at typical O(100V) operation voltage

- uniformity of electric field
- charge collection efficiency
- stability with time
- conversion from current to dose rate

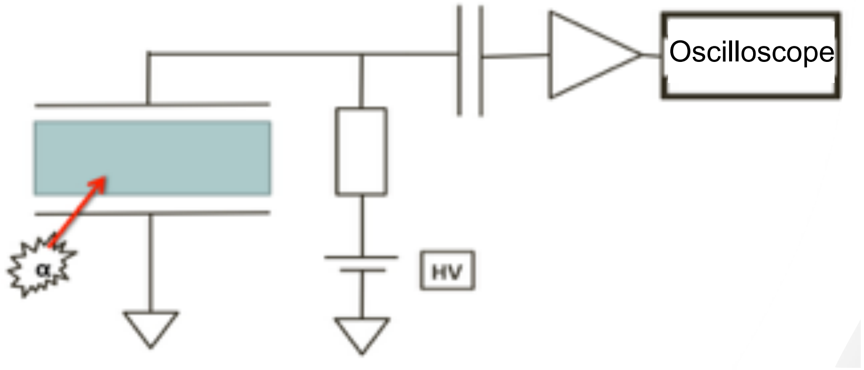




TCT with Alpha source

(TCT = Transient Current Technique)

α source: 241-Am, 55kBq

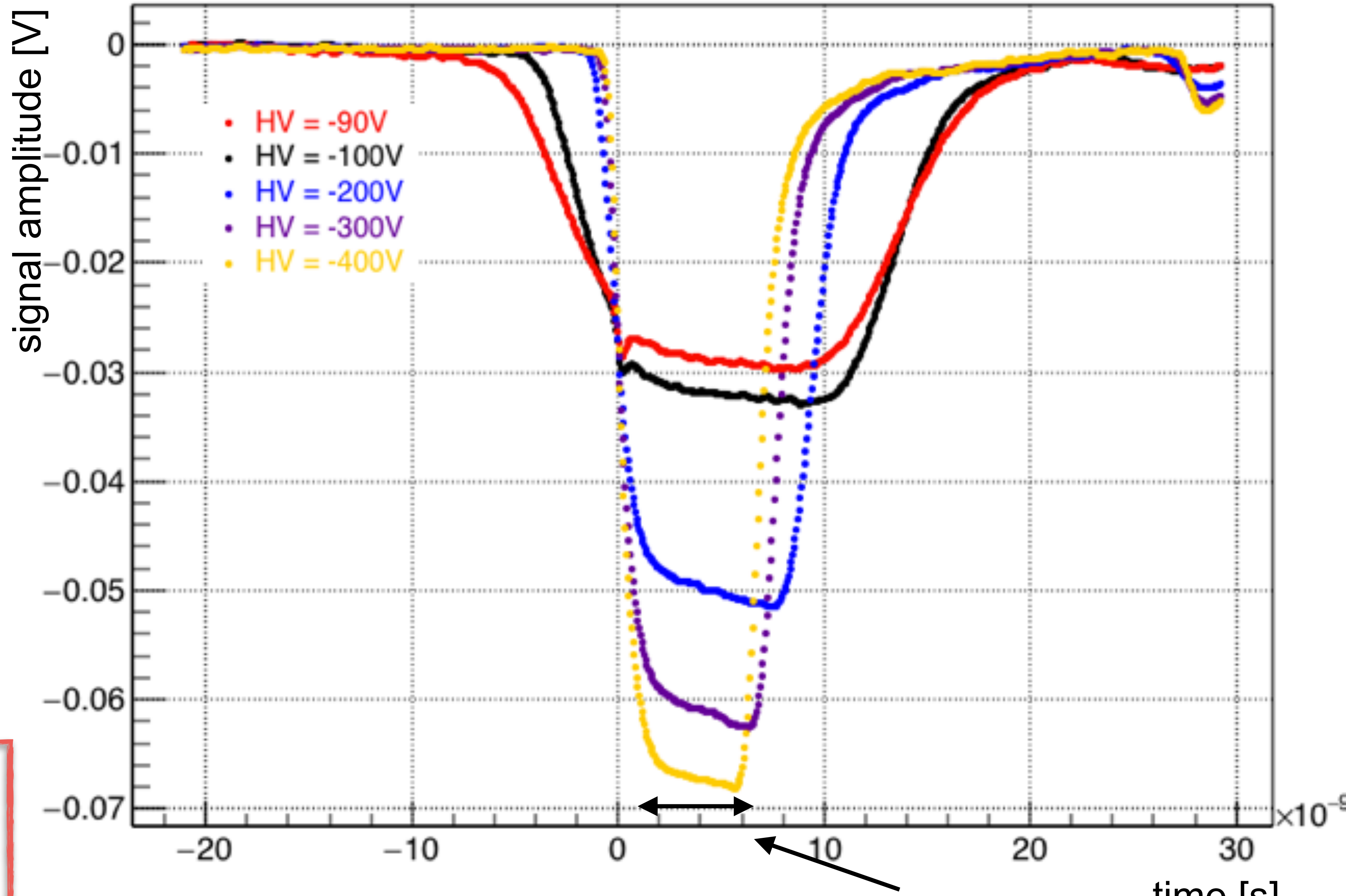


square pulse →

check of the uniformity of the electric field in the diamond bulk

pulse area constant from -90V up to -400V

→ Fully efficient from -90V (CCE ~ 100%)



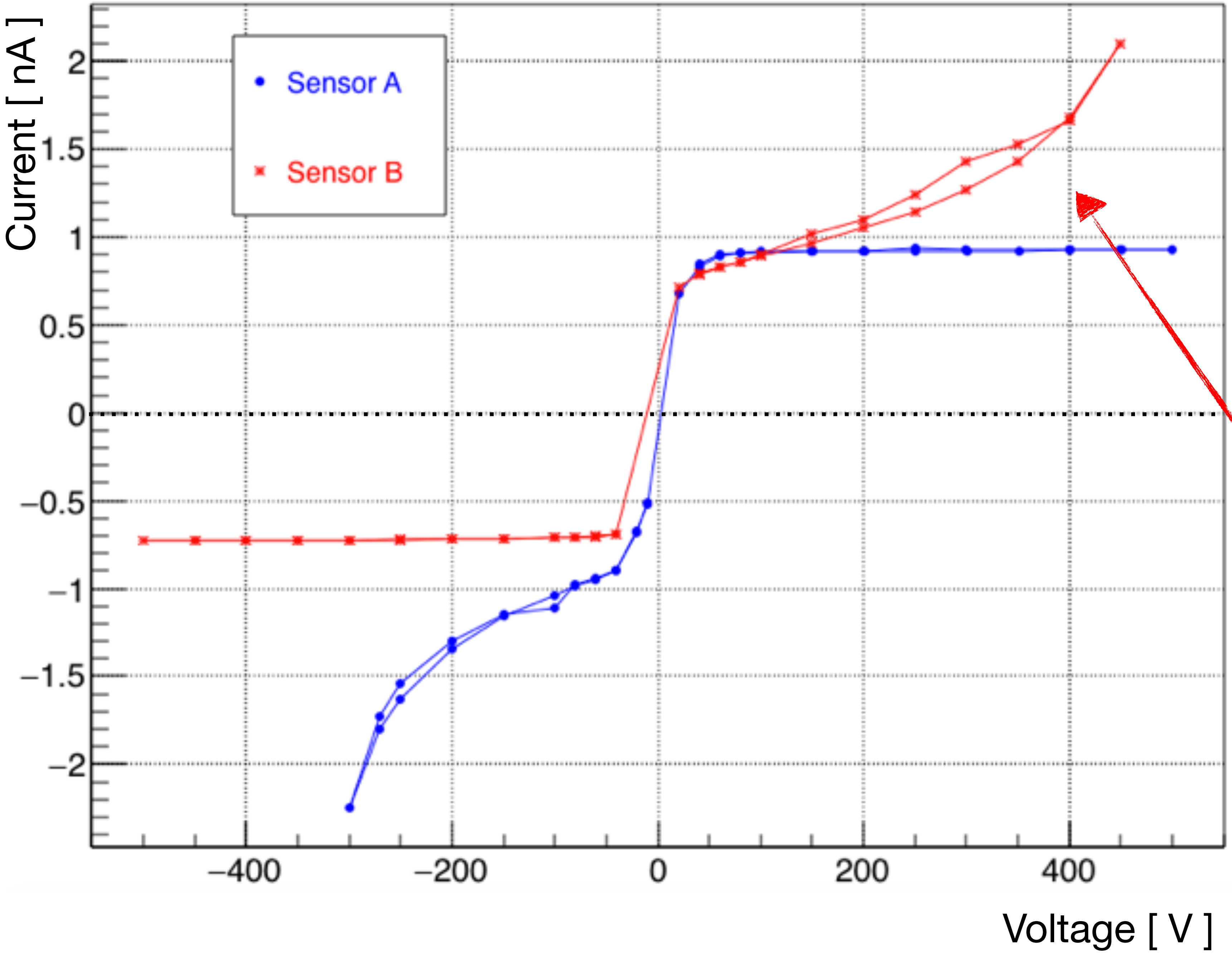
the width of the signal is the drift time (about 10ns) of charge carrier

it decreases consistently with the bias applied

I-V with β ^{90}Sr source

I-V characteristic (just an example - typical behaviour)

2 single crystal CVD diamonds with metalization (Ti + Pt + Au)



source-sensor distance fixed at 2mm

Different behaviour observed for each diamond sensor

hysteresis loop in some sensors

deep levels act as centres to capture or emit carriers during the charging or discharging process

I-V with β ^{90}Sr source

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I-V characteristic (just an example - different behaviour)

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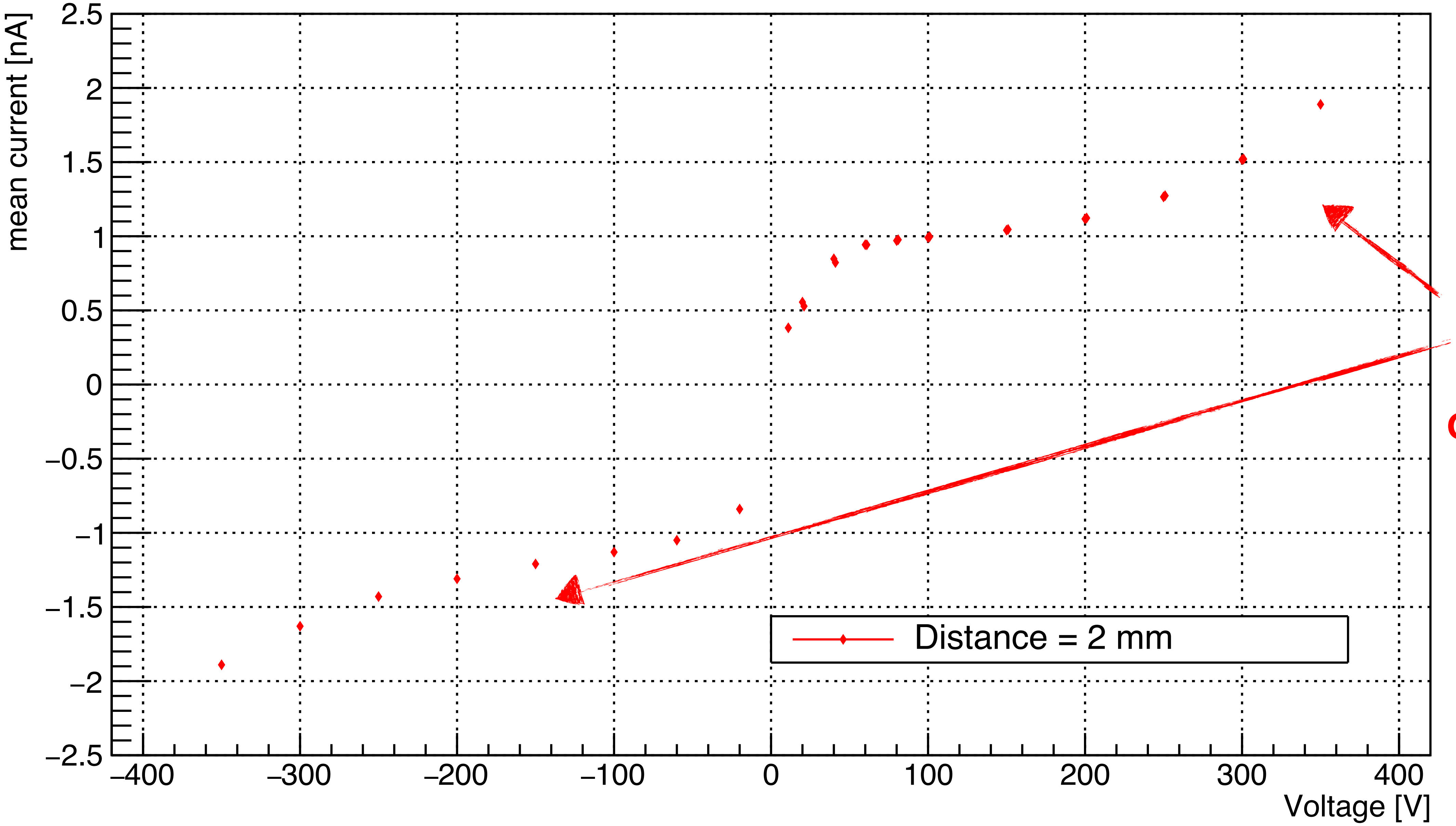
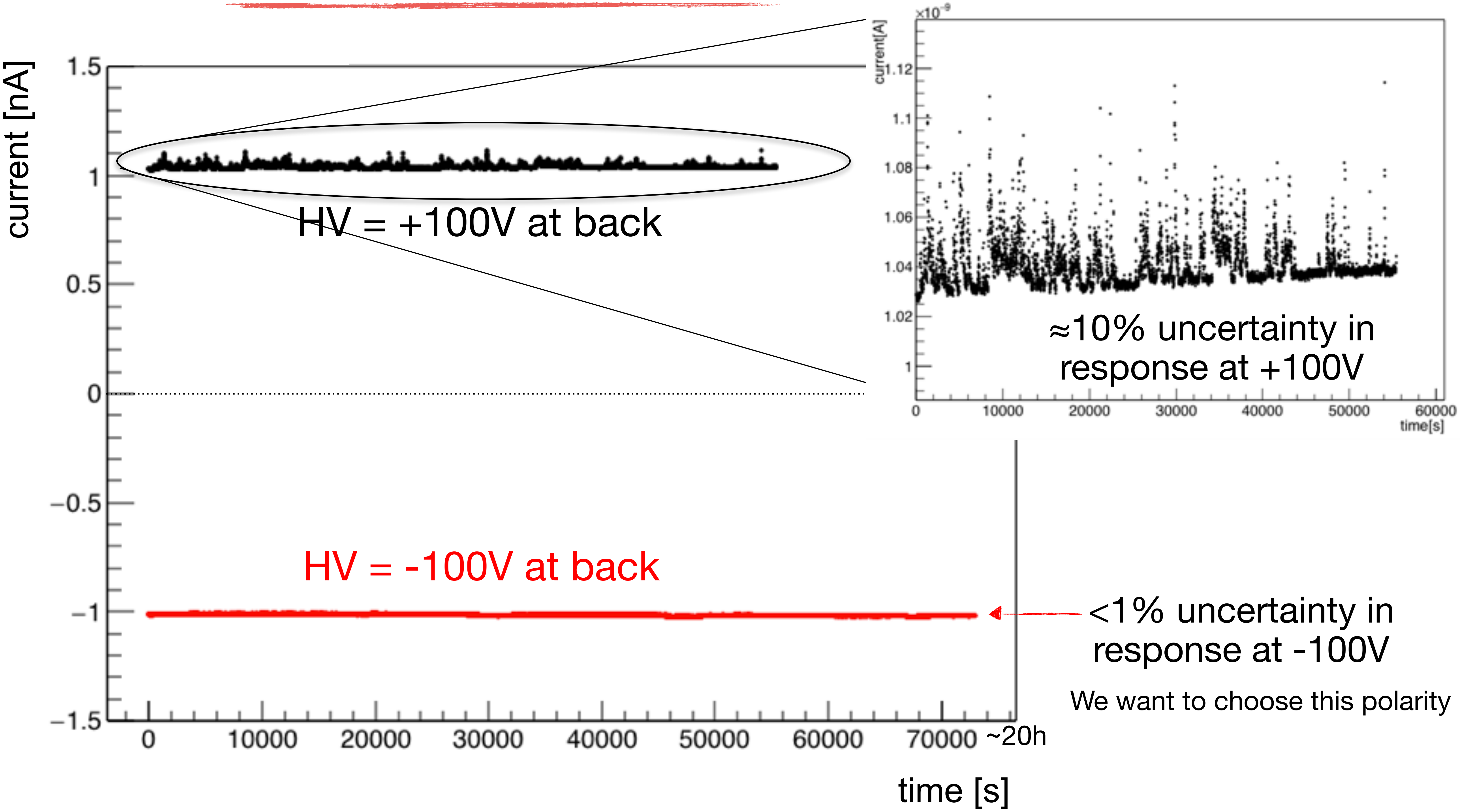


more symmetric trend, only short plateau

Stability

Check stability as diamonds will record dose for years

same diamond with different polarity

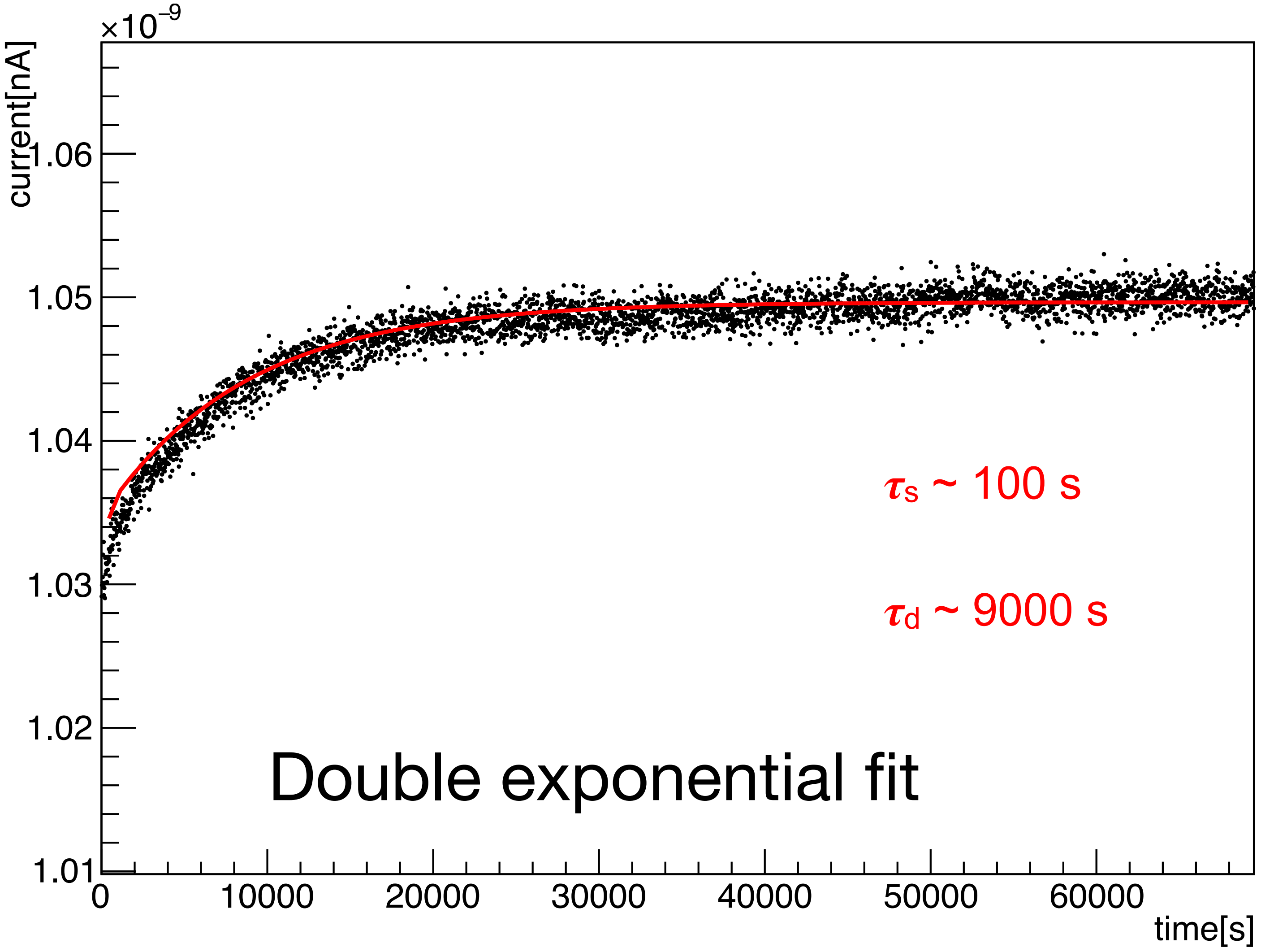


≈10% uncertainty in response at +100V

<1% uncertainty in response at -100V

We want to choose this polarity

Transient



τ_s ~ 100 s

τ_d ~ 9000 s

Double exponential fit

stability is reached after a transient

→ presumably due to traps in the crystal

Asymptotic state: both shallow and deep levels completely filled

Shockley-Hall-Read theory for impurity levels as trapping centres.

Two different types of traps:

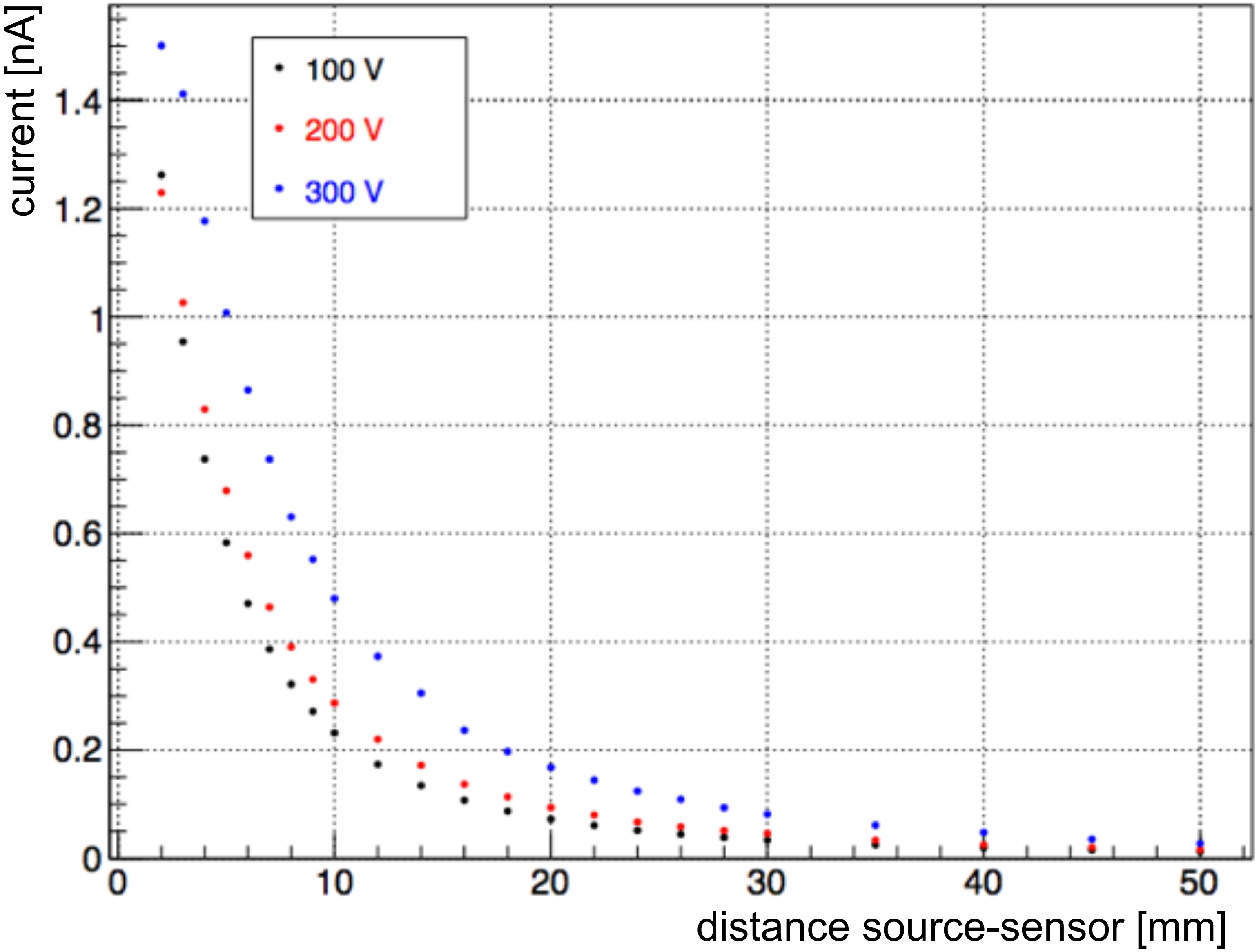
- shallow traps
- deep traps

τ_s → time constant associated to shallow traps

τ_d → time constant associated to deep traps

inferred from the fit

Dependence on β source distance



Response as a function of the distance between the source and the sensor depends on HV bias

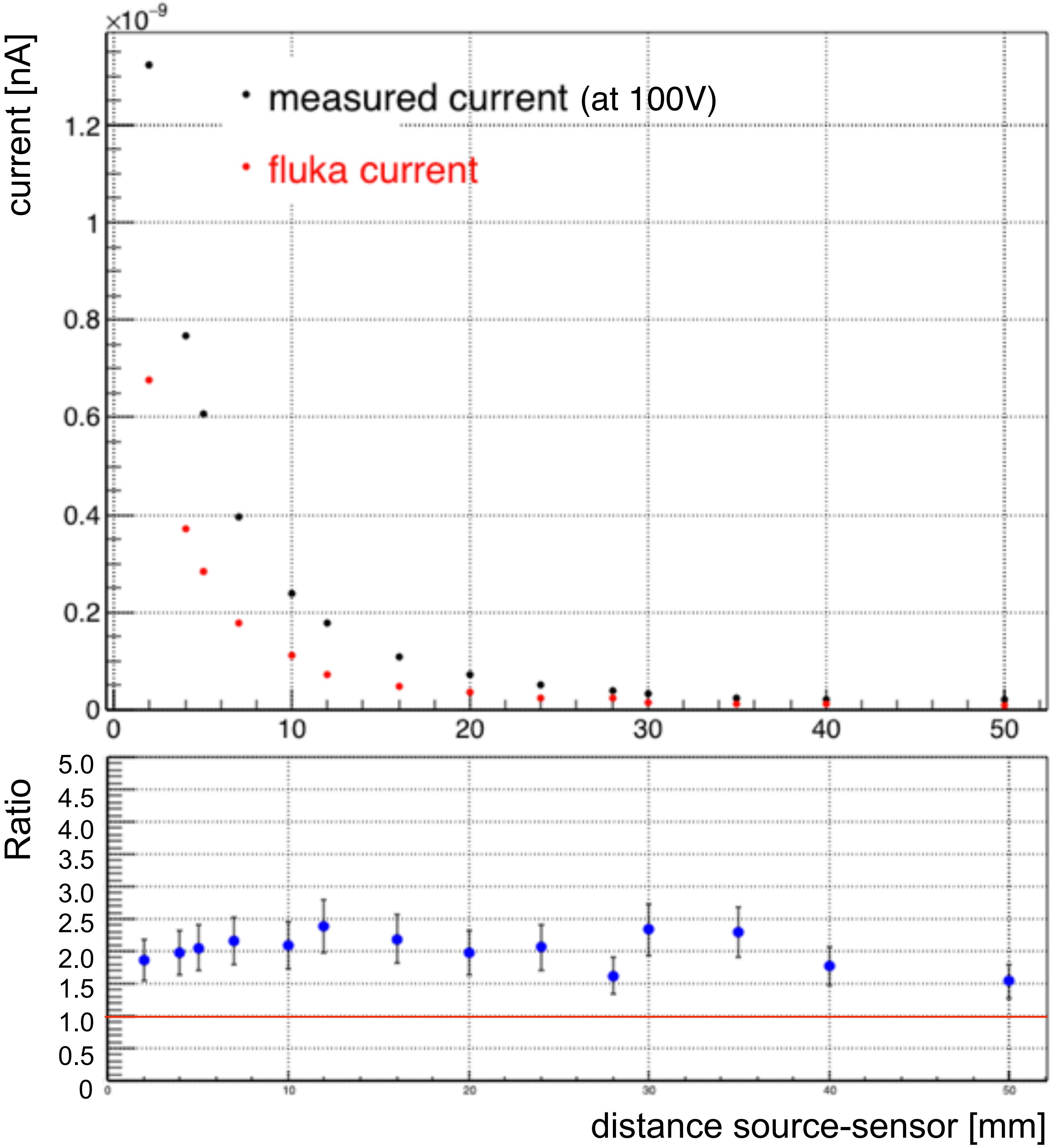
→ photoconductive gain

due to ohmic contact between electrodes and diamond → charge injected from the electrode

current-to-dose conversion requires knowledge of the photoconductive gain

Use FLUKA to compare with measurement and infer the gain for each diamond

Comparison with FLUKA



current decreases approximately with the inverse square of the distance

→ agreement with simulation

measured current > simulated current

→ photoconductive gain (at 100V)

photoconductive gain

$= I_{meas}/I_{FLUKA}$

Systematic Uncertainty (phase 1)	***δG/G [%]***
Source - Diamond sensor distance	10
Diamond sensor active volume	10
Diamond sensor priming or pumping	5
Source activity	7
FLUKA simulation statistics	1
HV reproducibility	1
Combination in quadrature	**17**

Summary

DONE

- Installation of 8 diamond sensors for phase 2
- Installation of 6 +X SVD diamond sensors for phase 3

- Installation of 6 -X SVD diamond sensors for phase 3

  → December 2017

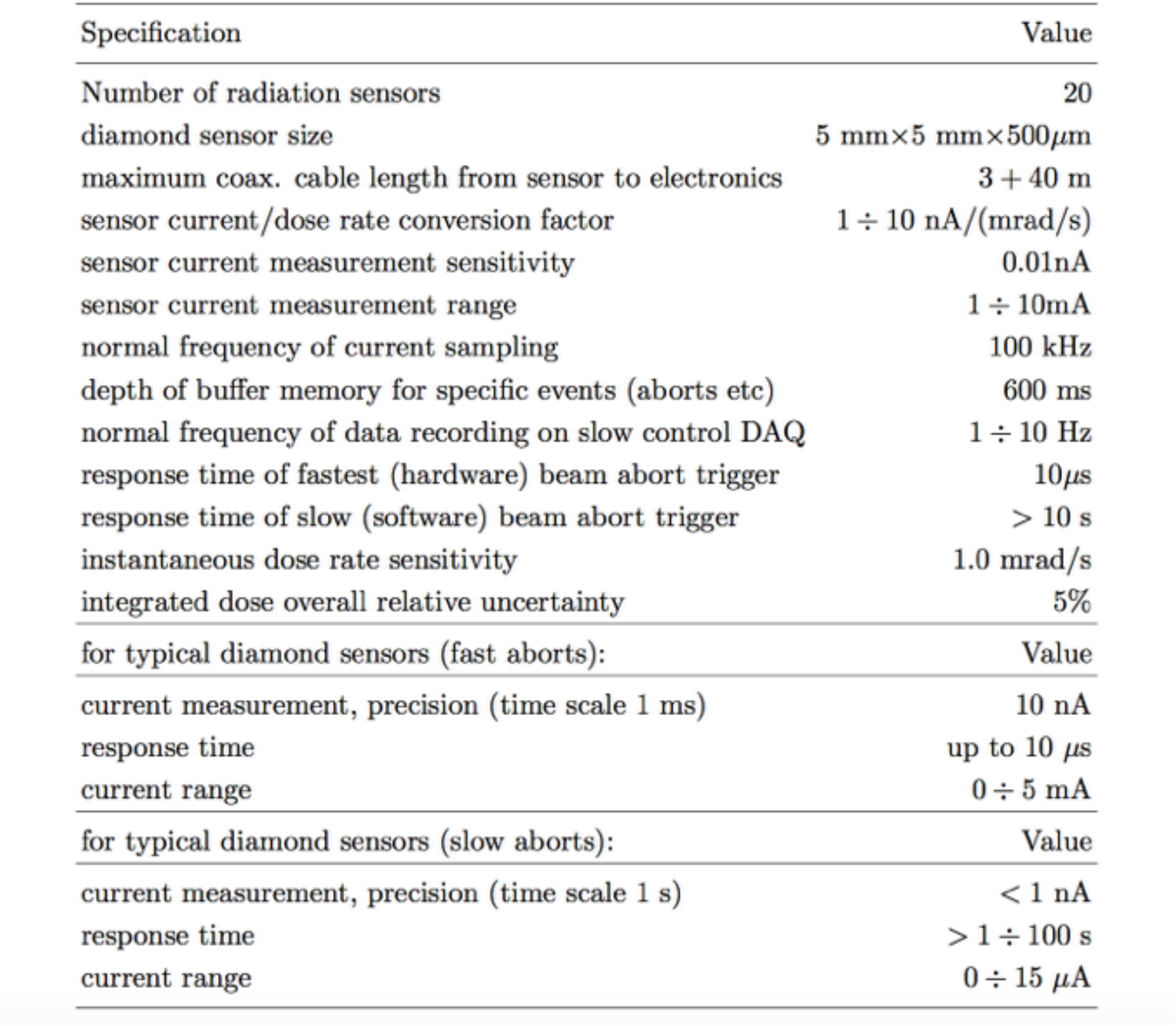
- Installation of 8 “PXD” diamond sensors for phase 3

  → next year

- Tests on diamond sensors go on, the last 8 diamonds calibrated ready for the beginning of the next year

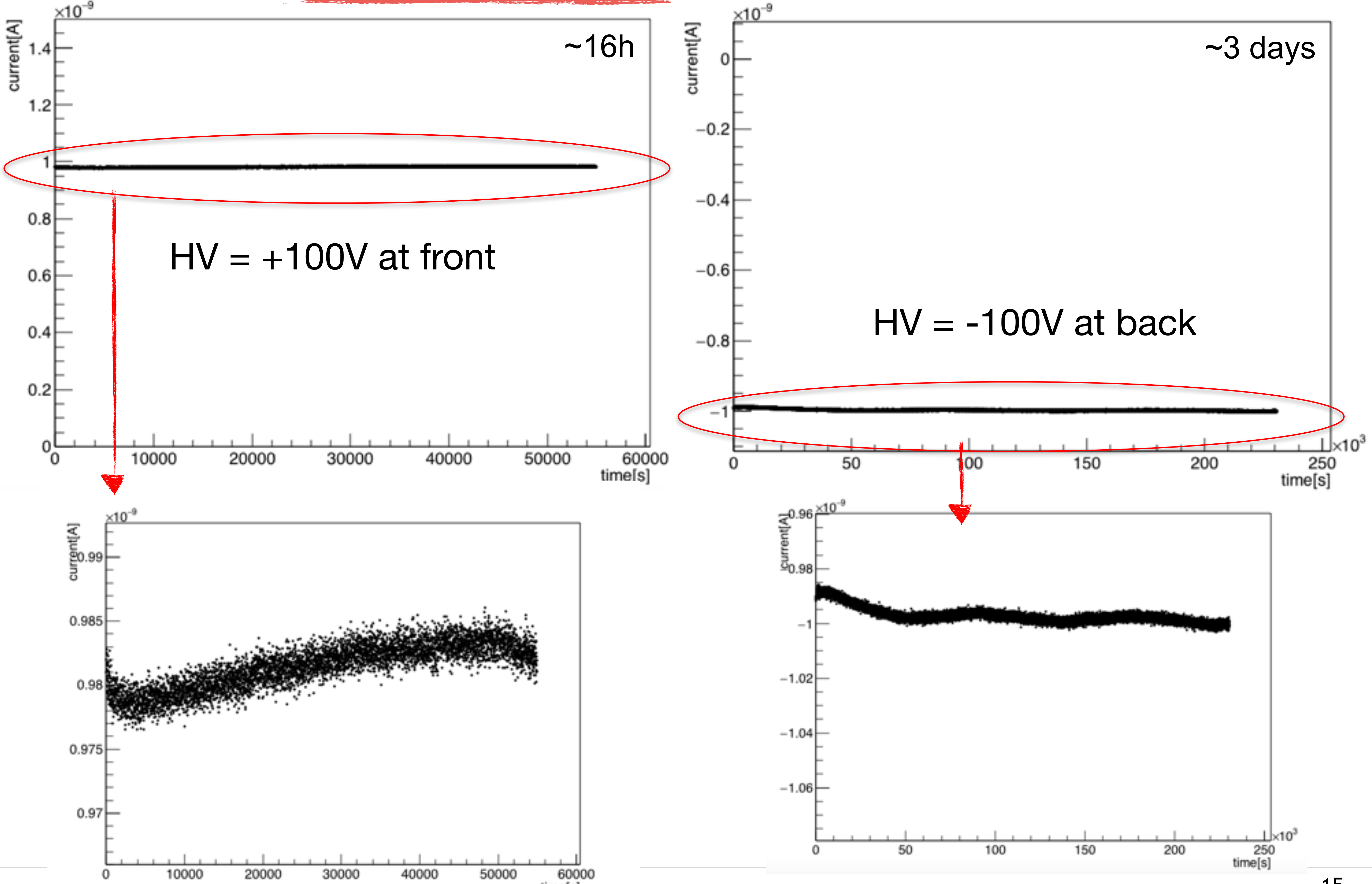
- Irradiation tests: first next week.

BACKUP



Specification	Value
Number of radiation sensors	20
diamond sensor size	5 mm×5 mm×500μm
maximum coax. cable length from sensor to electronics	$3 + 40$ m
sensor current/dose rate conversion factor	$1 \div 10$ nA/(mrad/s)
sensor current measurement sensitivity	0.01nA
sensor current measurement range	$1 \div 10$mA
normal frequency of current sampling	100 kHz
depth of buffer memory for specific events (aborts etc)	600 ms
normal frequency of data recording on slow control DAQ	$1 \div 10$ Hz
response time of fastest (hardware) beam abort trigger	10μs
response time of slow (software) beam abort trigger	> 10 s
instantaneous dose rate sensitivity	1.0 mrad/s
integrated dose overall relative uncertainty	5%
for typical diamond sensors (fast aborts):	**Value**
current measurement, precision (time scale 1 ms)	10 nA
response time	up to 10 μs
current range	$0 \div 5$ mA
for typical diamond sensors (slow aborts):	**Value**
current measurement, precision (time scale 1 s)	< 1 nA
response time	$> 1 \div 100$ s
current range	$0 \div 15$ μA

Stability



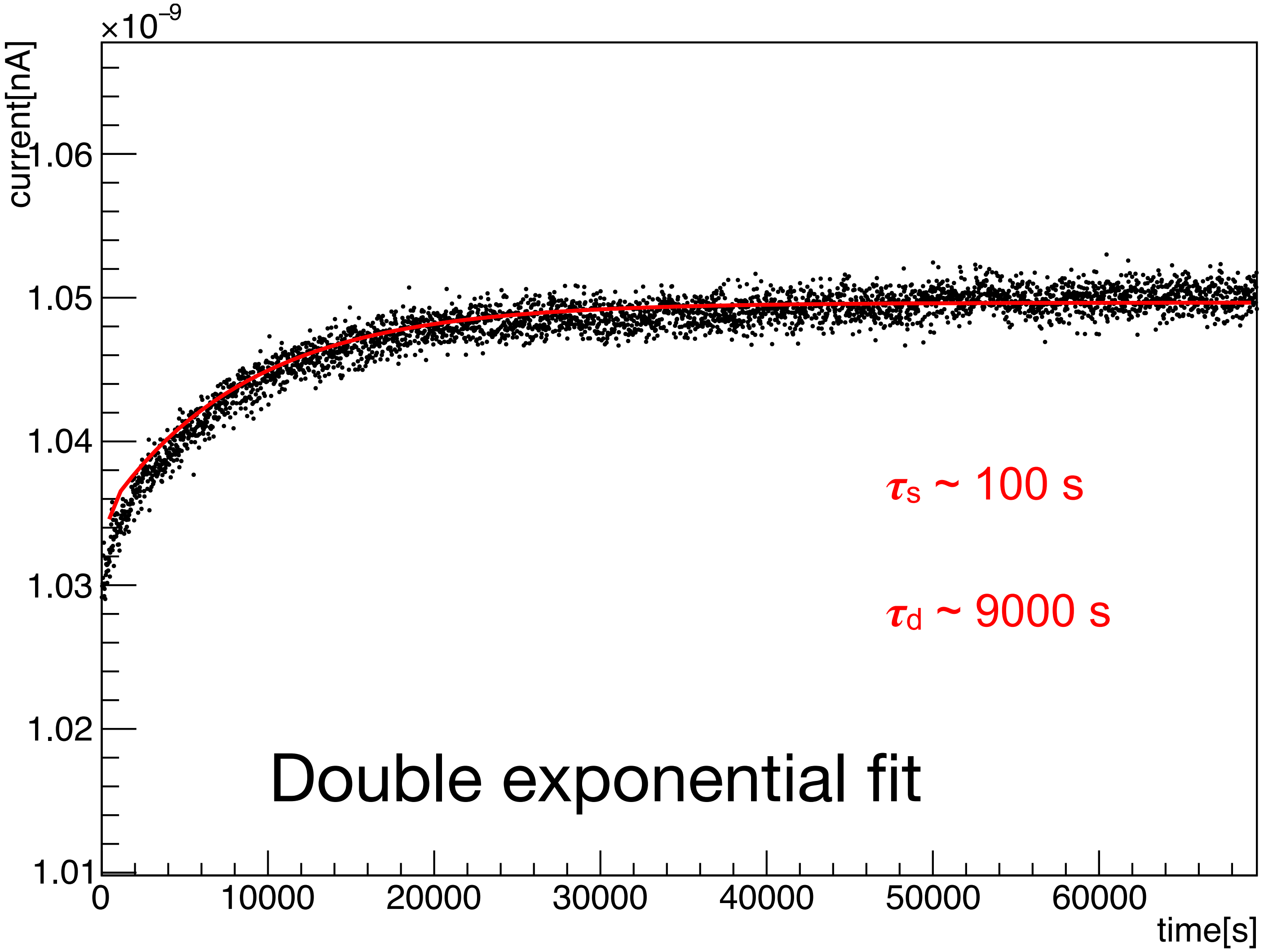
~16h

HV = +100V at front

~3 days

HV = -100V at back

Transient



stability is reached after a transient

→ presumably due to traps in the crystal

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Two different types of traps:

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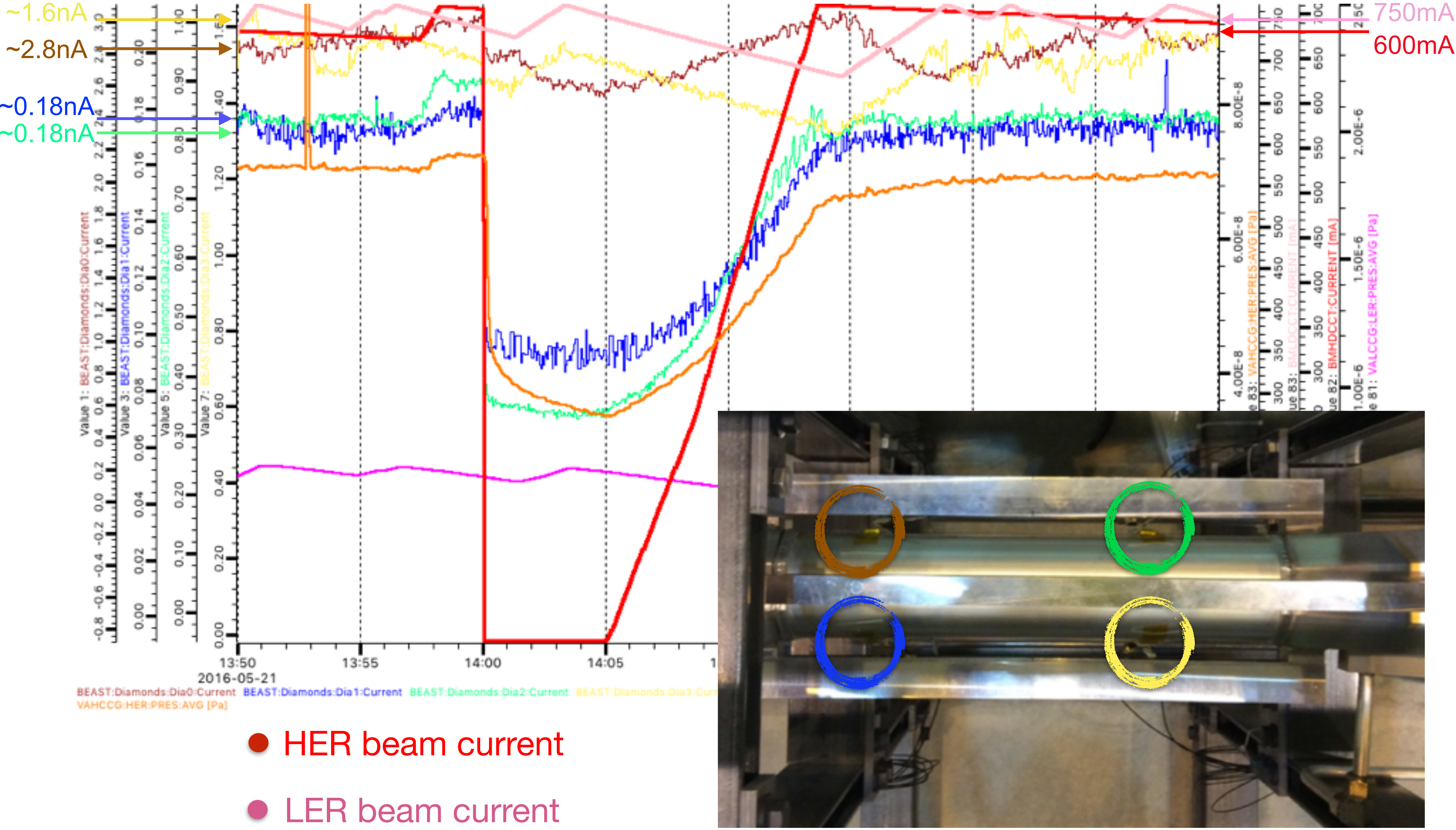
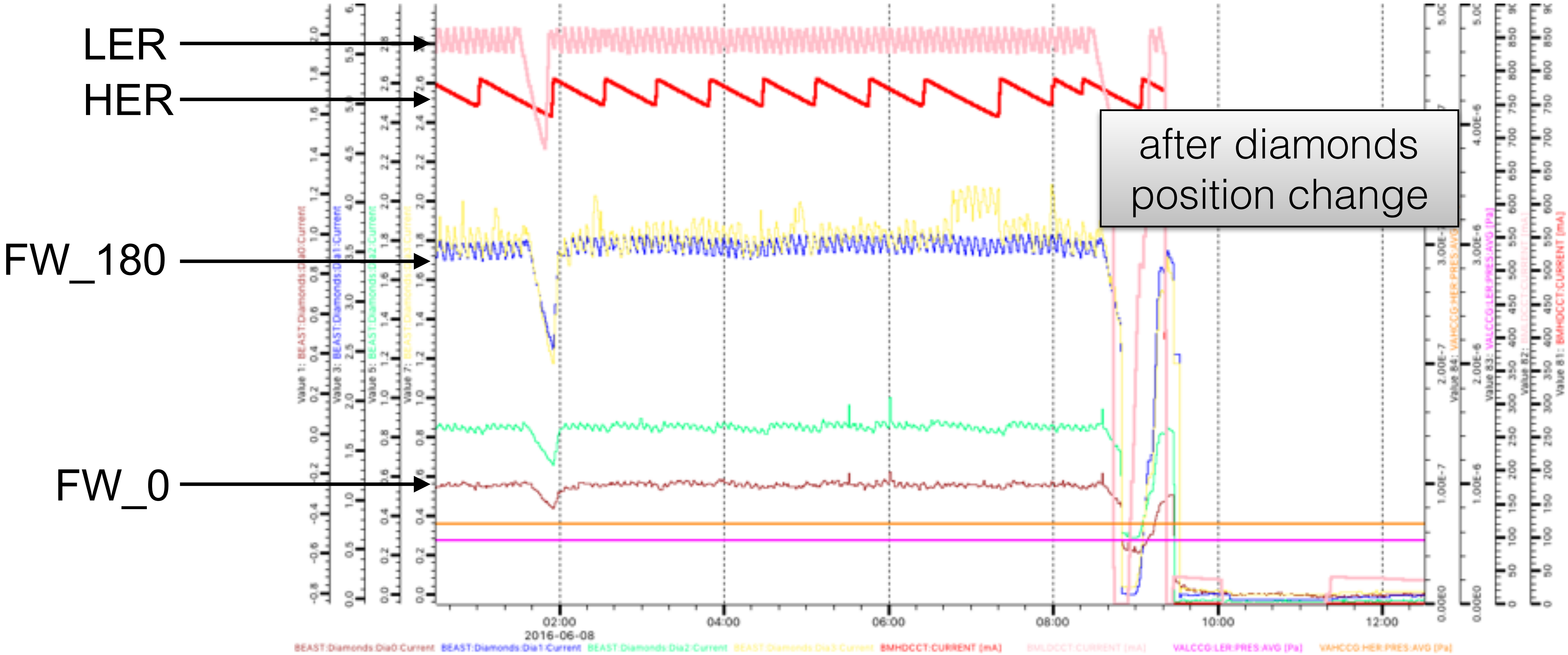
inferred from the fit

Diamond sensor response



- HER beam current
- LER beam current

Sensor response after exchange



after diamonds position change

before diamonds position change:

I_{HER} ~ 700mA I_{LER} ~ 750 mA

I_{FW_0} ~ 0.16 nA (DC3)

I_{FW_180} ~ 2.6 nA (DM7)

DM7 ⟷ DC3

after diamonds position change:

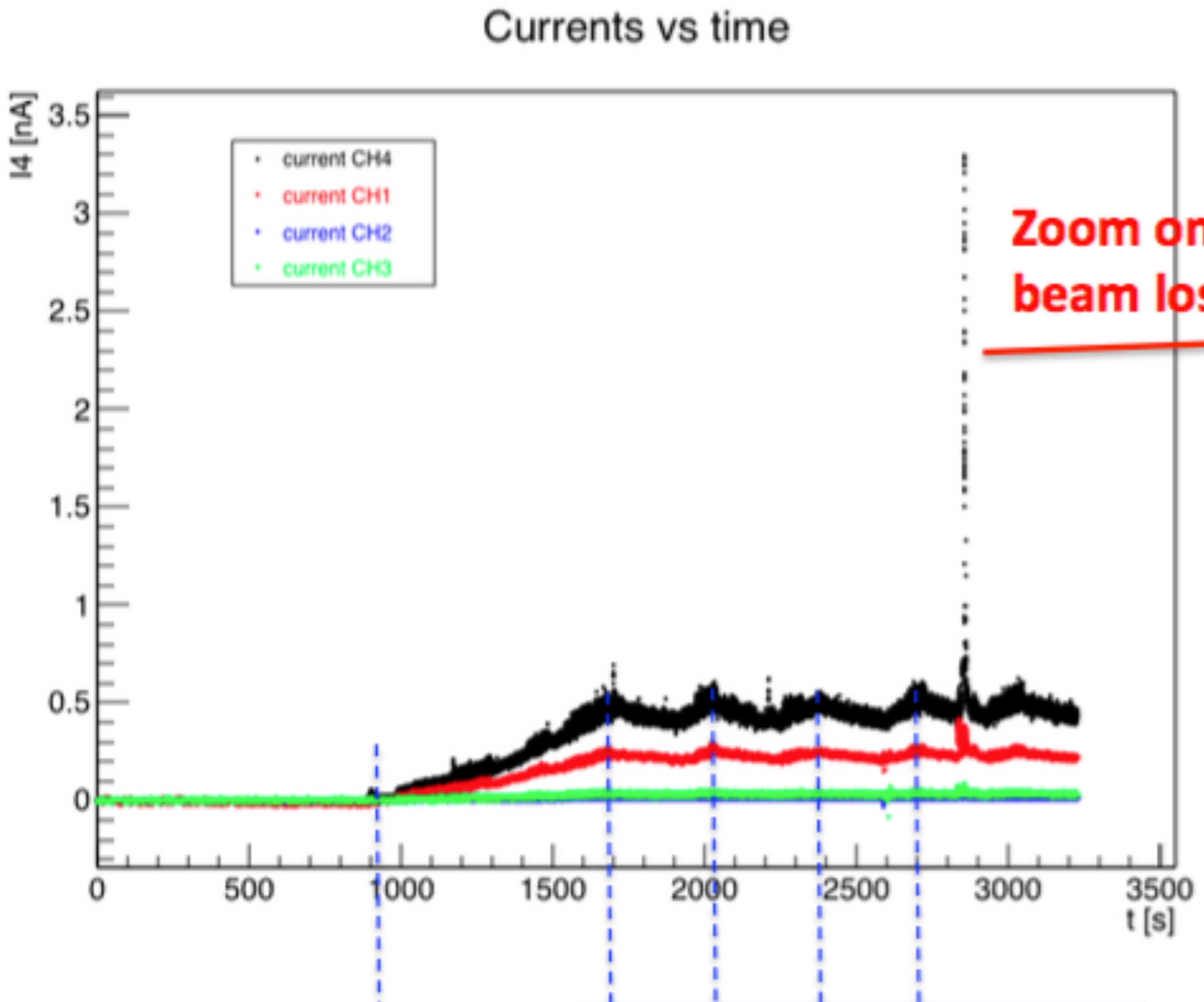
I_{HER} ~ 750 mA I_{LER} ~ 850 mA

I_{FW_0} ~ 0.4 nA (DM7)

I_{FW_180} ~ 3.5 nA (DC3)

Diamonds currents well correlated to their position on the beam pipe

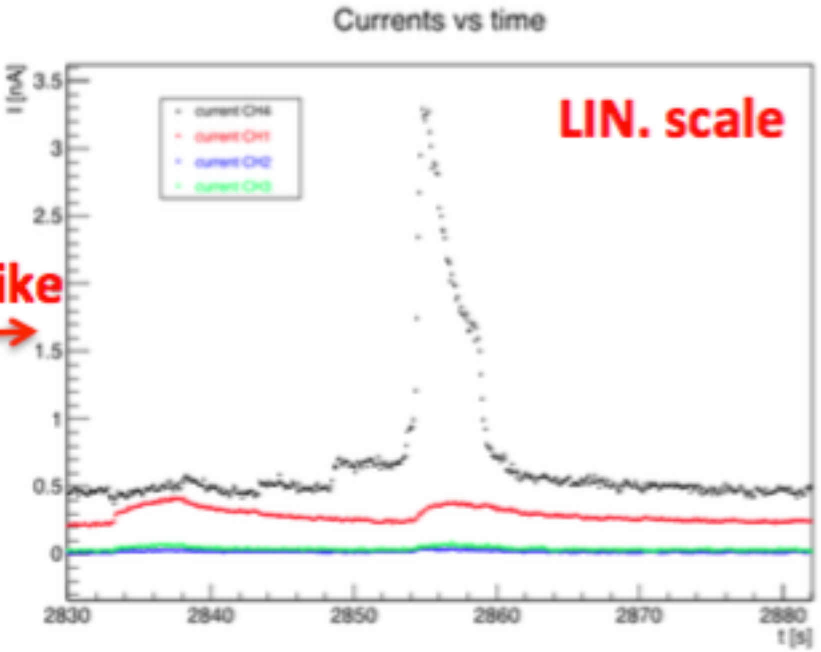
First signals



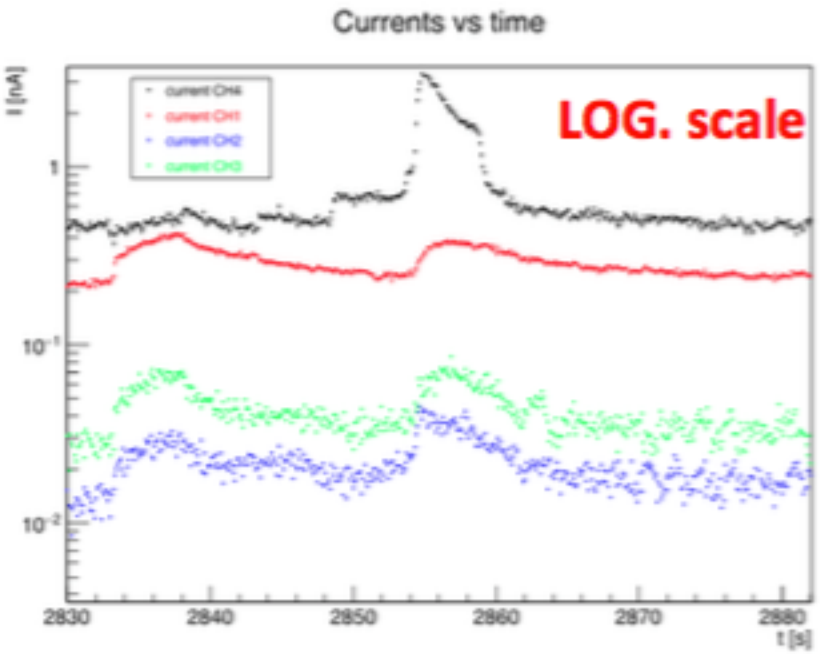
Zoom on beam loss spike

Top-off every 4 min.

Start filling



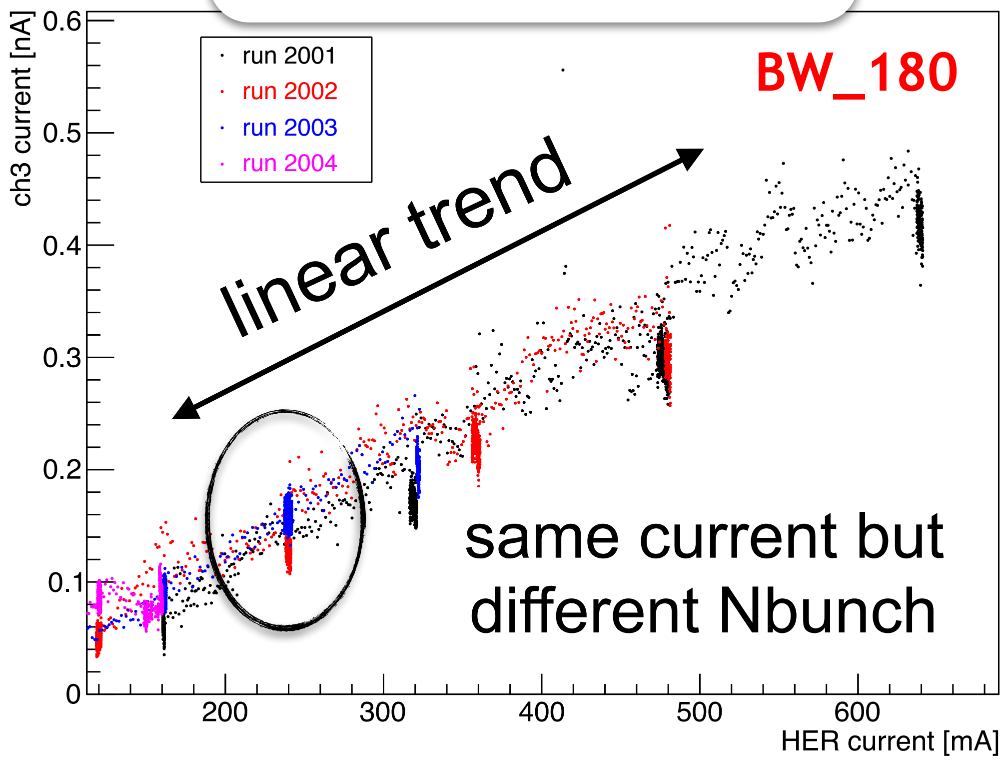
LIN. scale



LOG. scale

Background Studies

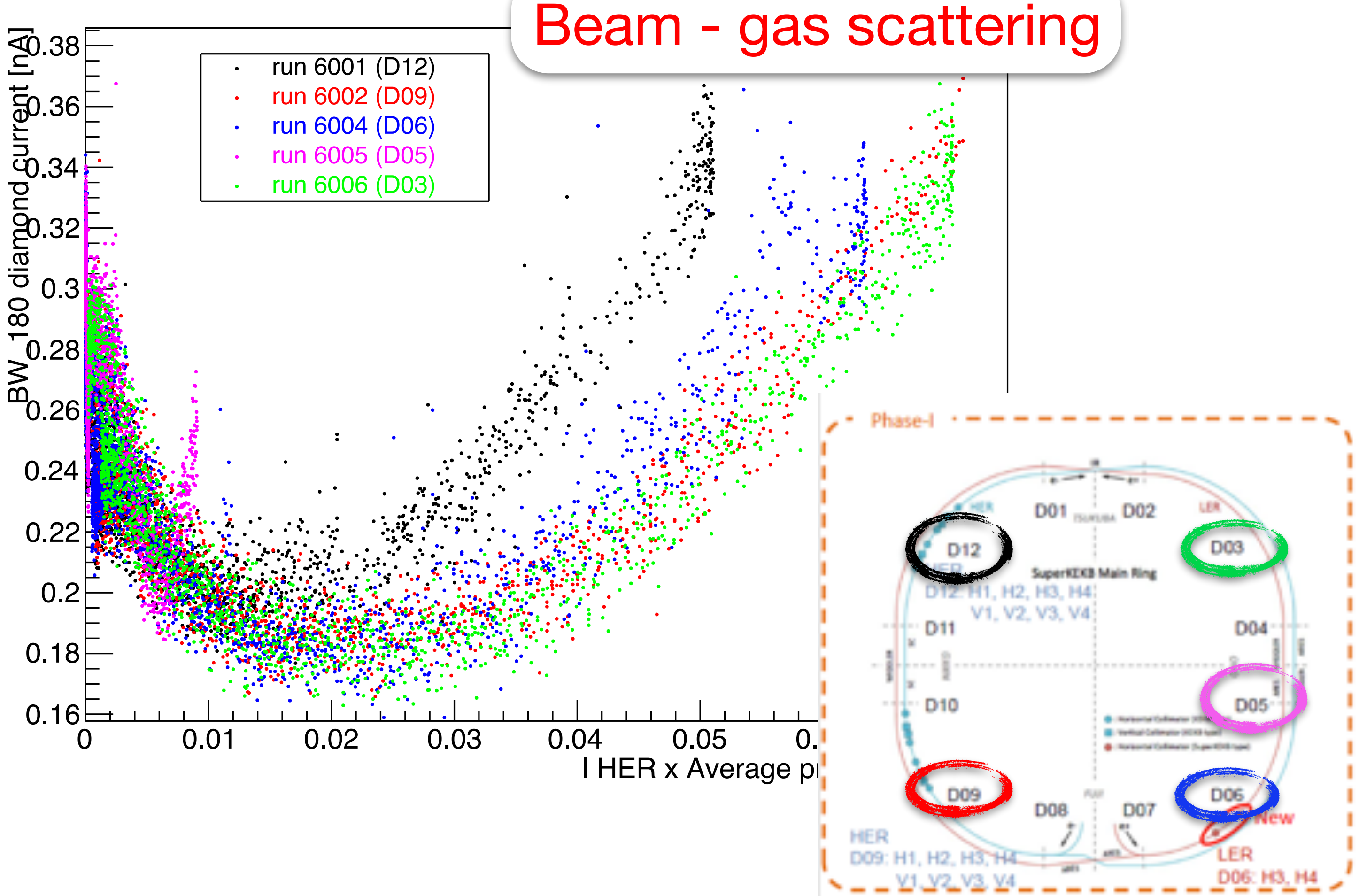
Current scan



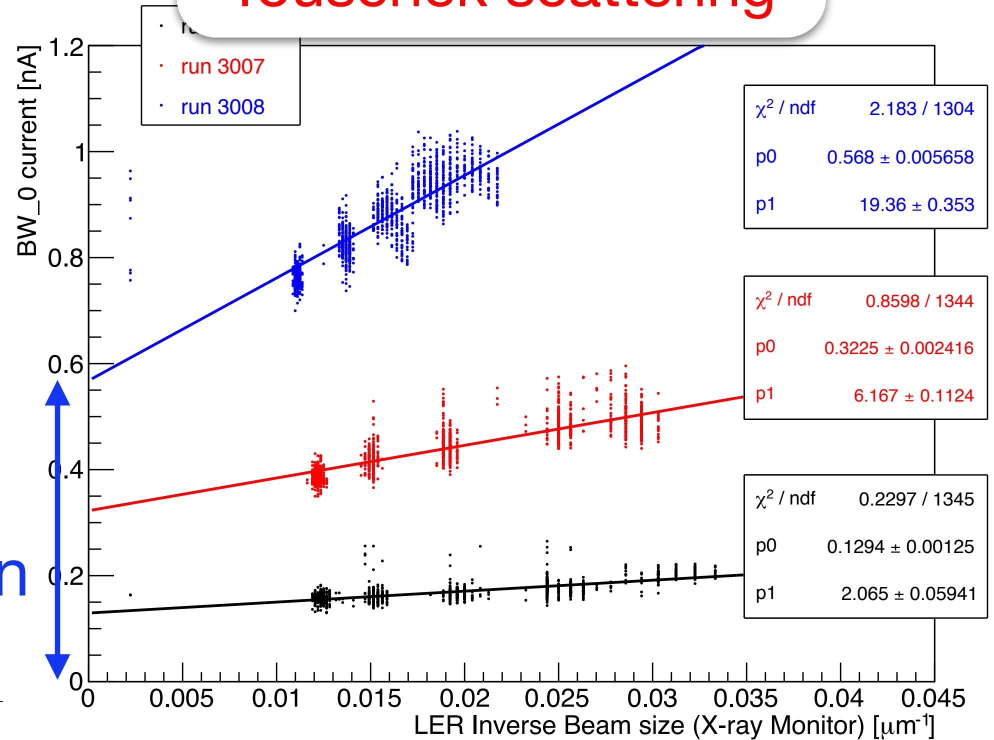
linear trend

same current but different Nbunch

Beam - gas scattering



Touschek scattering



beam gas contribution

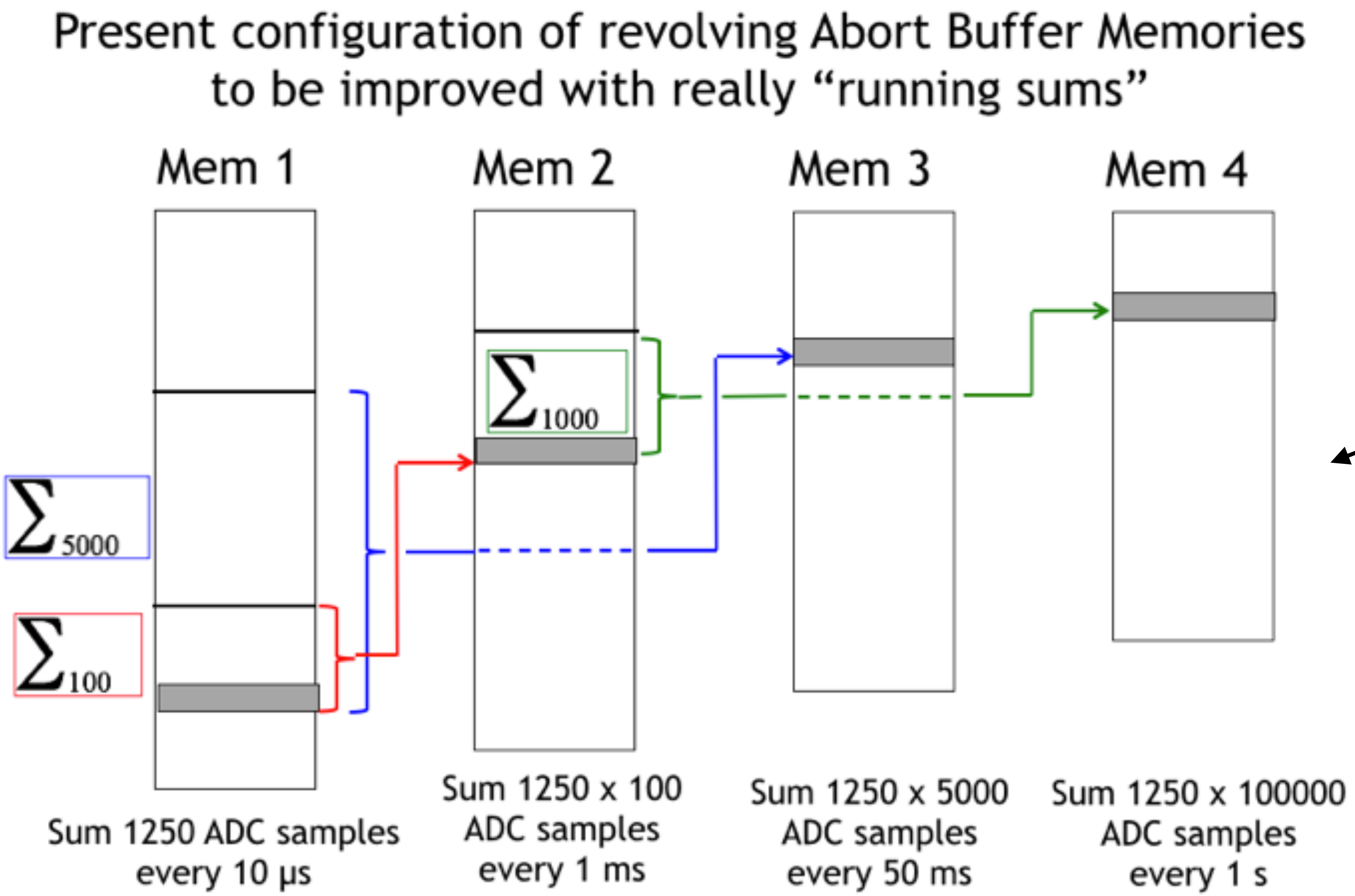
Diamond current vs inverse beam size:
Linear fit, intercept
→ extrapolation to pure beam-gas contribution

Beam abort thresholds (1/2)

Preliminary study from diamond sensors

Diamonds: Abort Buffer Memories

- diamond current will be sampled and digitized at 100kHz
- several levels of running averages are computed providing an effective digital filter



data buffered in memories of different depth

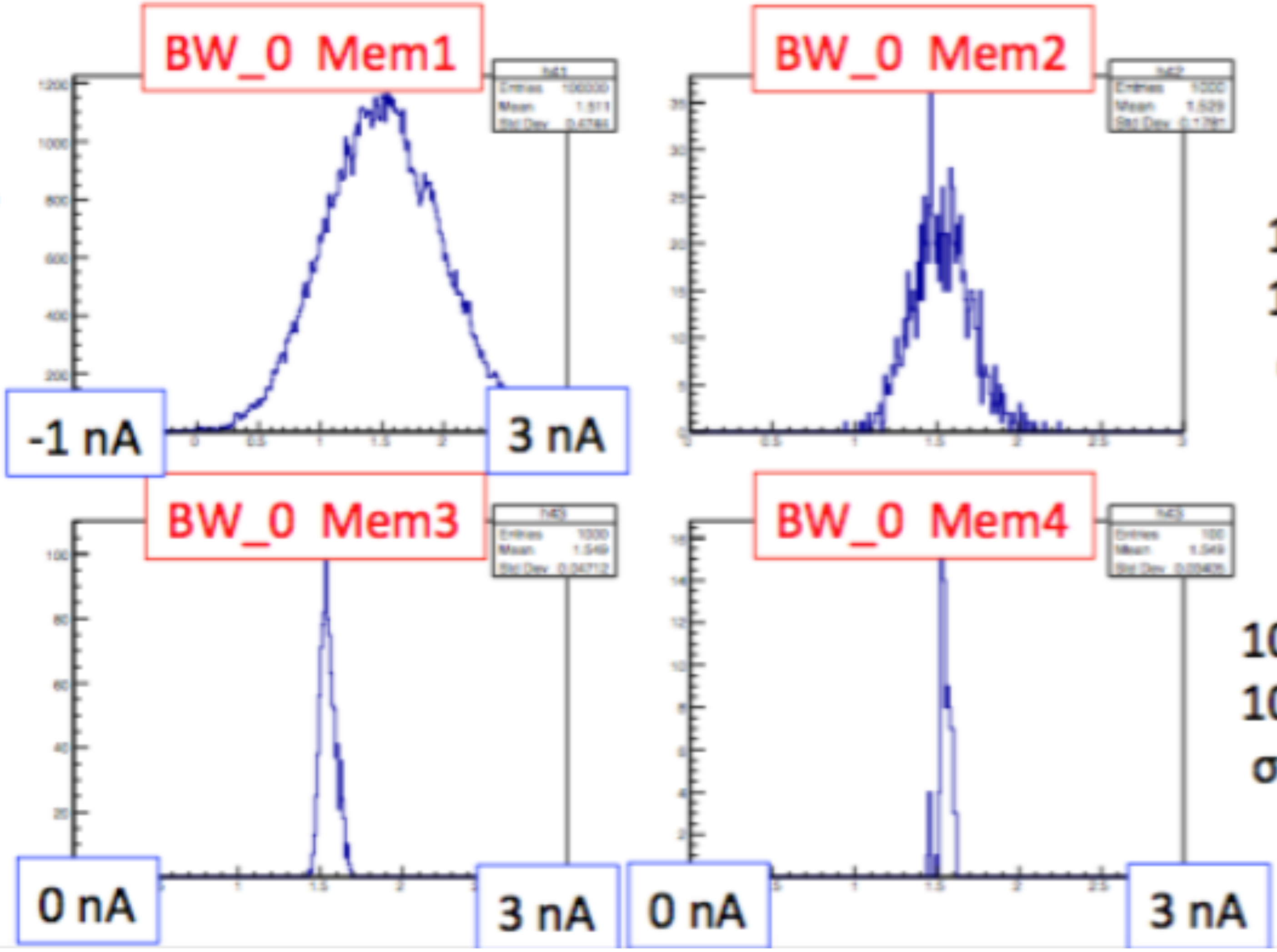
Beam abort thresholds (2/2)

Buffer memories: snapshot example

Example of snapshot of Buffer Memories (Mem1 to Mem4) for Dia3 = BW_0 in stable beam conditions, with average I(BW_0) = 1.5 nA

Noise decreases with increased averaging, from about 0.47 nA to < 0.04 nA

OK both for fast (10 μs) and slow (> 1 s) beam aborts with appropriate thresholds



100000 entries
1 s history
σ = 0.47 nA

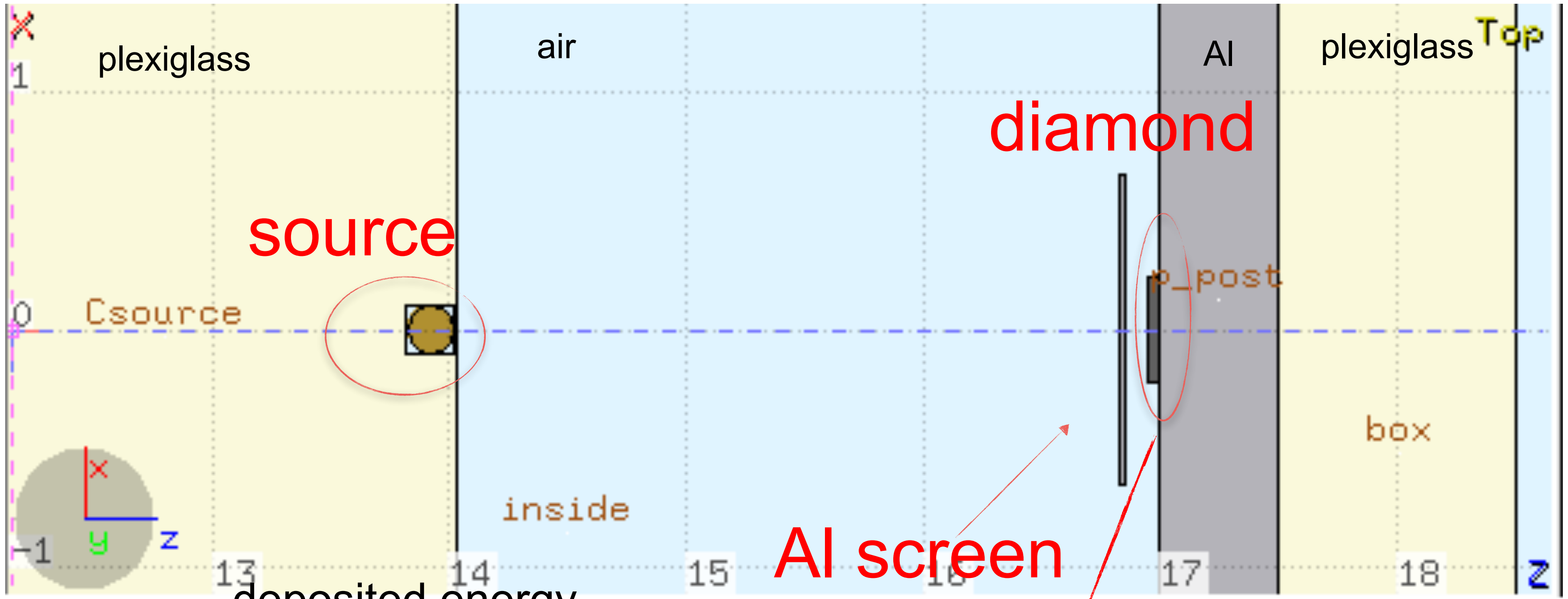
1000 entries
1 s history
σ = 0.18 nA

1000 entries
50 s history
σ = 0.047 nA

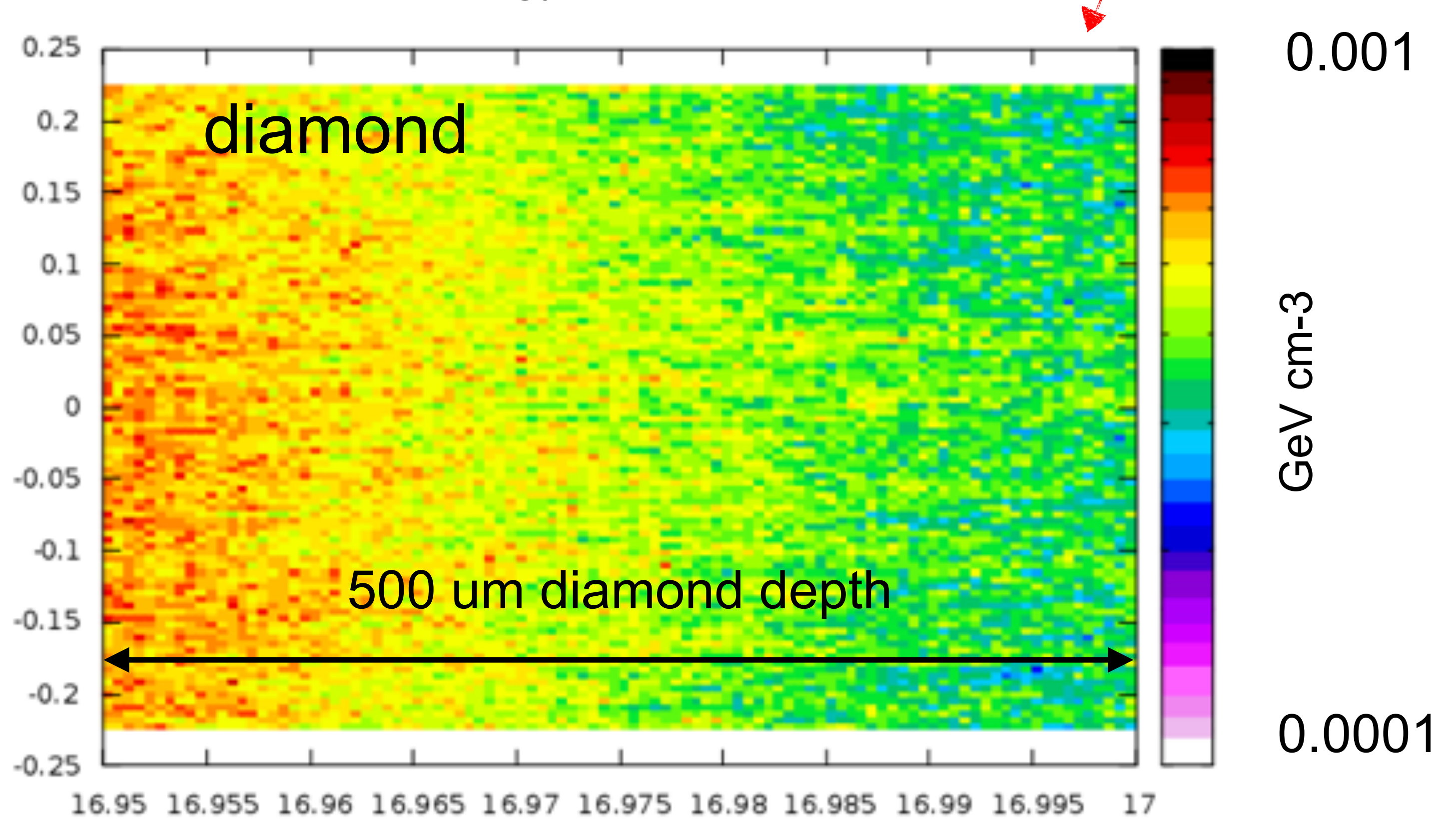
100 entries
100 s history
σ = 0.034 nA

FLUKA

simplified geometry:



deposited energy

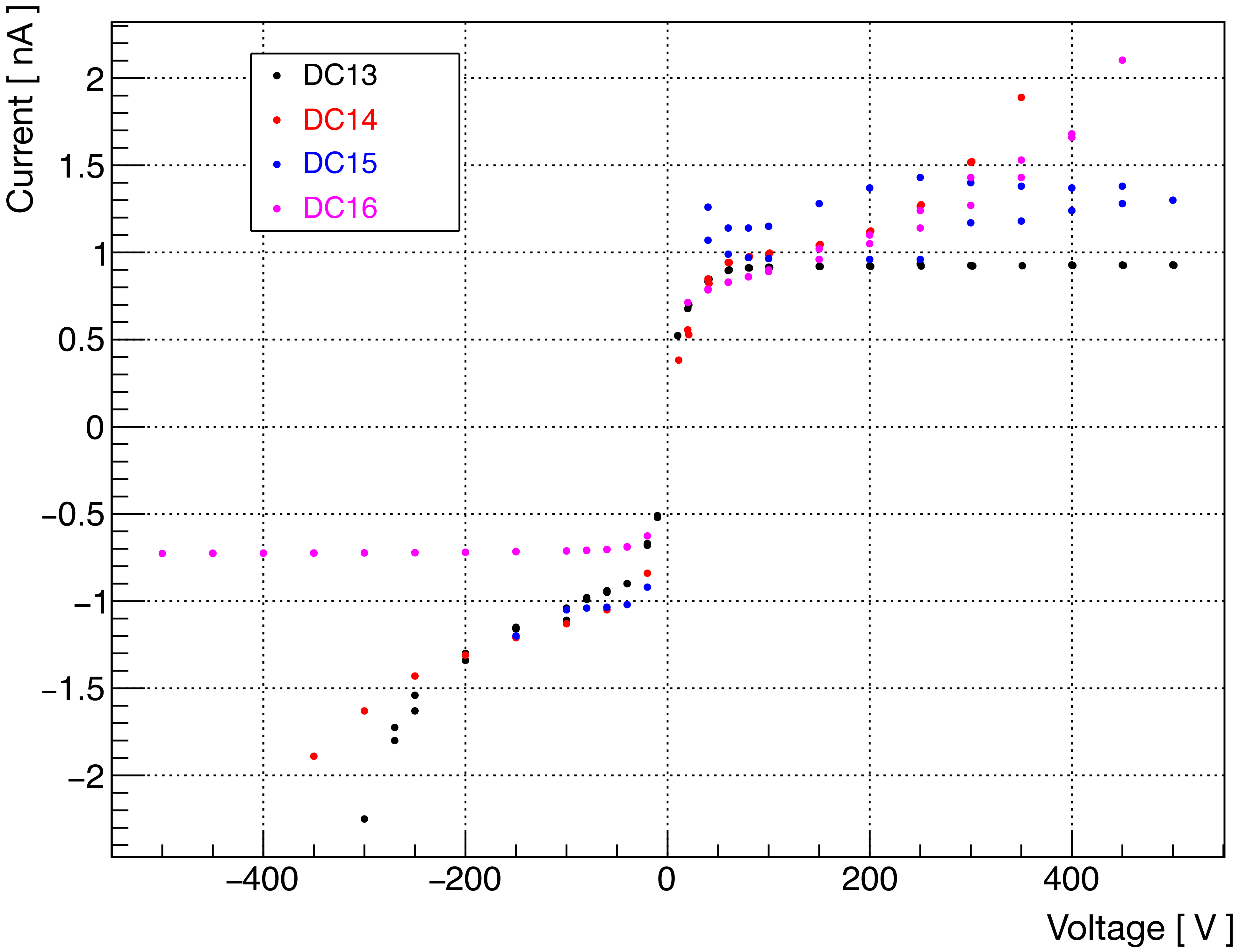


photoconductive gain = I_{meas}/I_{FLUKA}

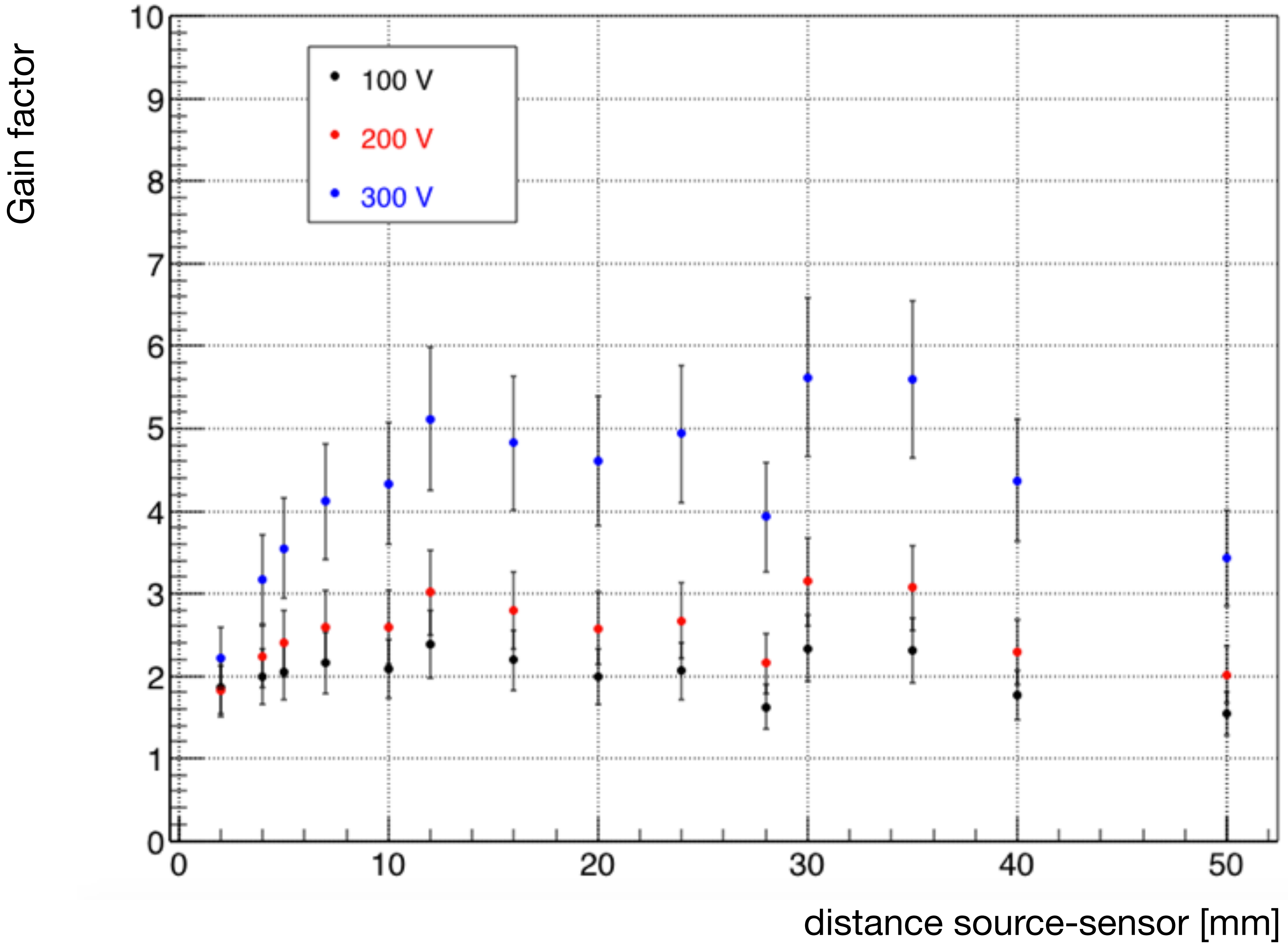
assuming:

- deposited energy equal in simulation and measurement
- $CCE_{FLUKA} = 1$, $CCE_{meas} = 1$
- no photoconductive gain in simulation

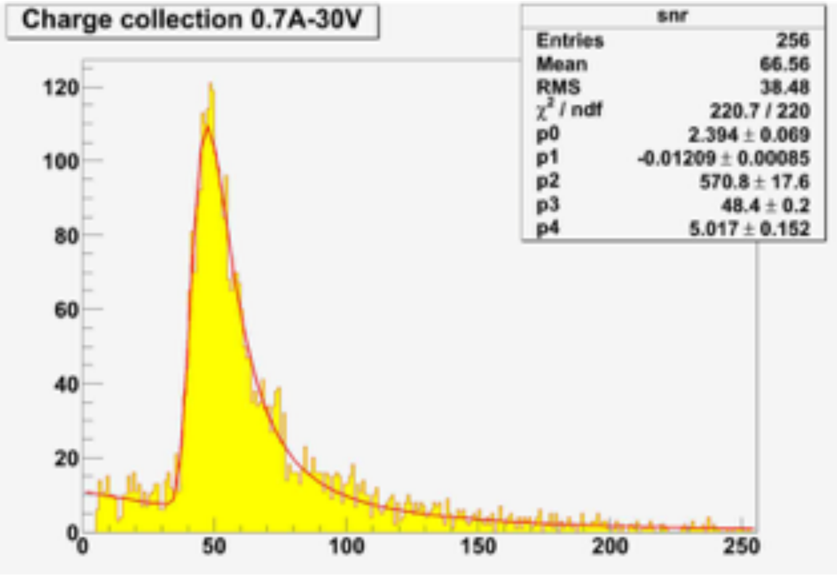
IV characteristic



Photoconductive gain



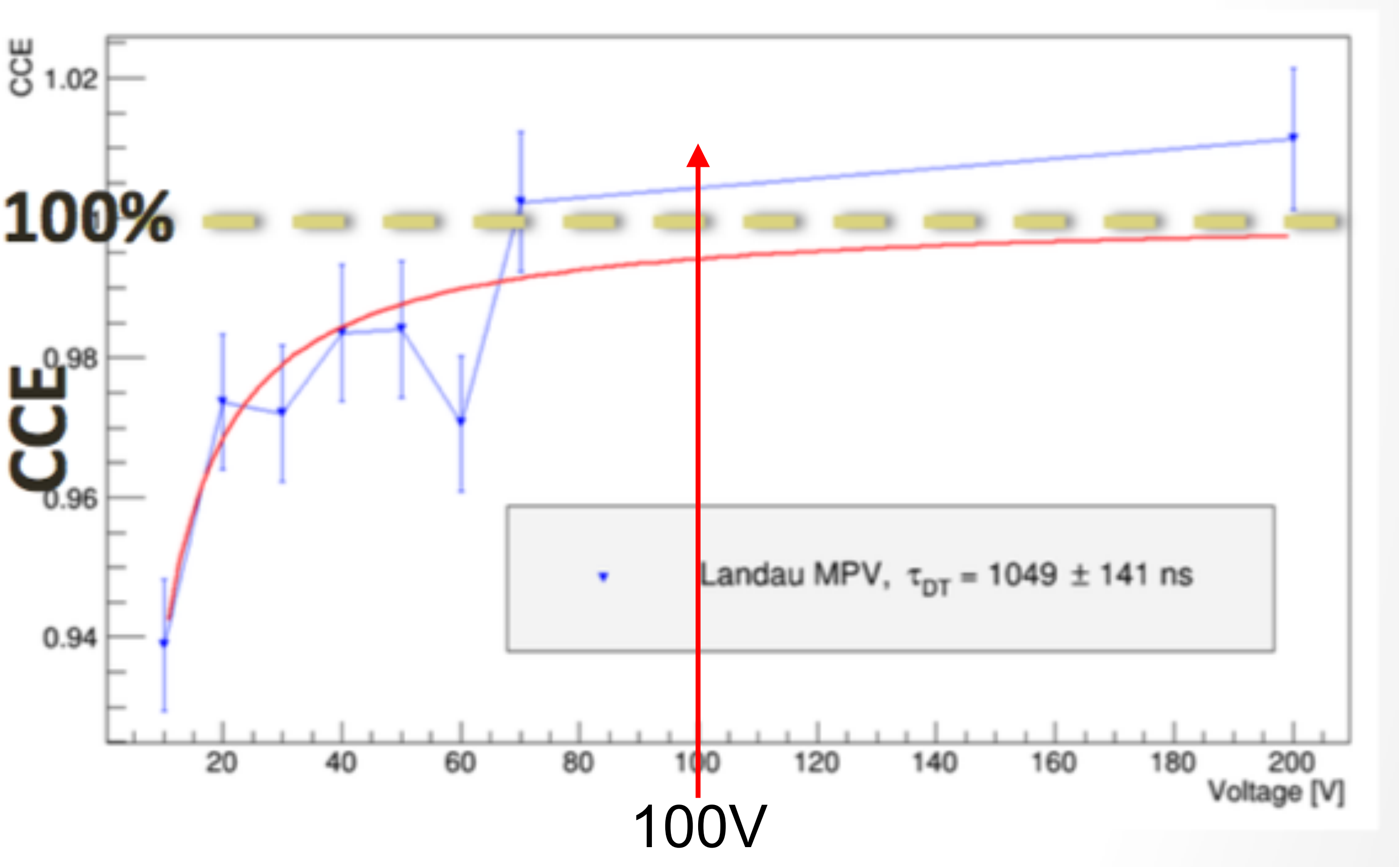
Charge Collection Efficiency

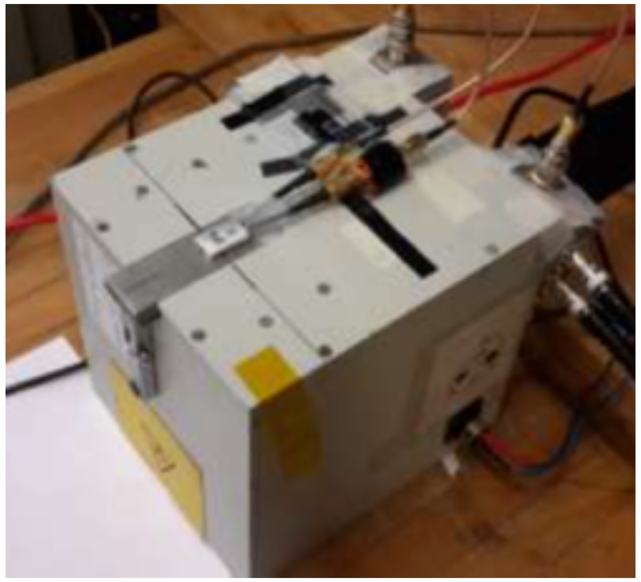


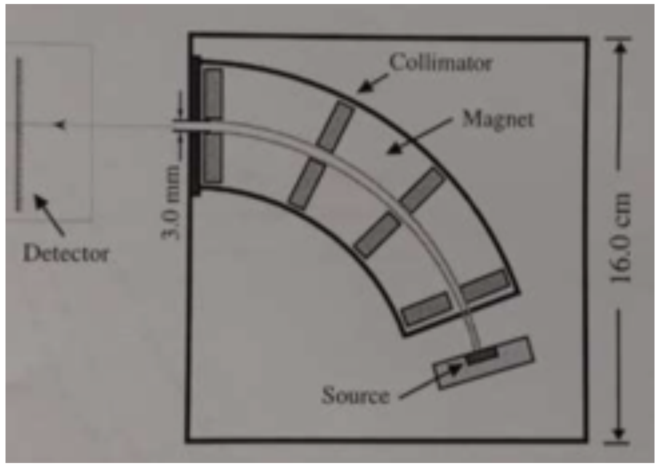
Example: DM5, CCE ≈ 100%

Landau Most Probable Value (MPV) vs HV ➔ Charge Collection Efficiency

$$CCE = \frac{Q_{raccolta}}{Q_{generata}} = \frac{v_{dr}\tau}{d}\left(1 - e^{-\frac{d}{v_{dr}\tau}}\right), \text{con } v_{dr} = \mu\frac{V}{d}$$







Current-dose calibration factor (1/2)

Reference: With β ^{90}Sr source at 18 mm distance -> FLUKA vs measurement

We measure currents -> we need a conversion factor from current to dose

FLUKA

- RE (Released Energy) = 3.25 GeV/s
- Assuming:
  - $CCE_{FLUKA}=1$
  - $E_{e-h} = 13$ eV

predicted current

=1

$$I_{FLUKA} = \frac{RE_{FLUKA} * q_e}{E_{e-h}} \; CCE_{FLUKA} * (G_{PC})_{FLUKA} = 40\ \text{pA}$$

generated charge

conversion factor eV->J

$$\text{Dose} = \frac{RE * 1.6\ 10^{-19}}{M} = 1.47\ \text{mrad/s}$$

mass (Kg)

predicted dose rate

$$\boxed{(\text{Dose/I}) = \frac{1.47\ \text{mrad/s}}{0.04\ \text{nA}} = \frac{37\ \text{mrad/s}}{\text{nA}}}$$

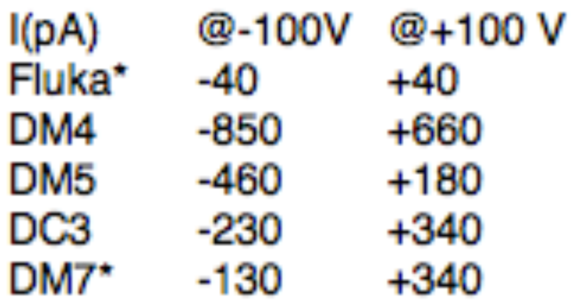
dose - current conversion factor

Current-dose calibration factor (2/2)

We measure currents -> we need a conversion factor from current to dose

Measurements

Photoconductive gain = I_m/I_{FLUKA}



I(pA)	@-100V	@+100 V	G_{PC-}	G_{PC+}
Fluka*	-40	+40		
DM4	-850	+660	21.25	16.5
DM5	-460	+180	11.5	4.5
DC3	-230	+340	5.75	8.5
DM7*	-130	+340	3.25	8.5

measured current

=1

I_m = generated charge CCE_{exp} $G_{PC,exp}$

assumption: equal to generated charge FLUKA

$$\text{Dose (mrad/s)} = \frac{I_m\text{(nA)* 37 mrad/s/nA}}{G_{PC}}$$

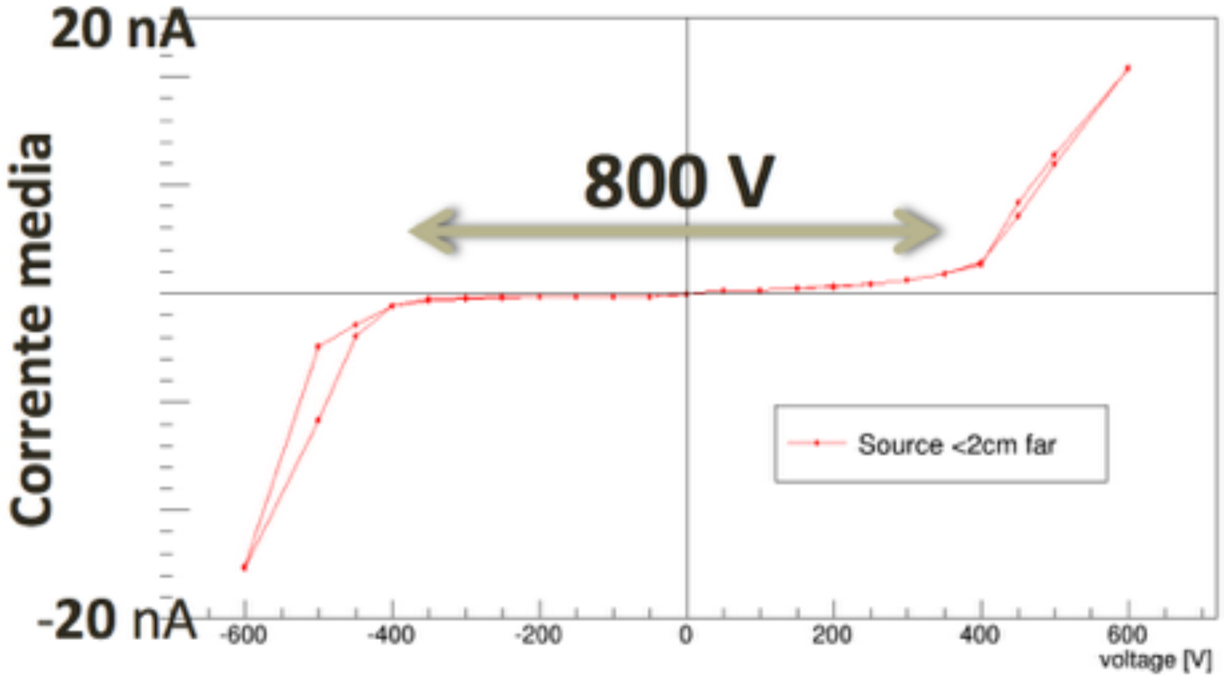
DOSE RATE

Systematics

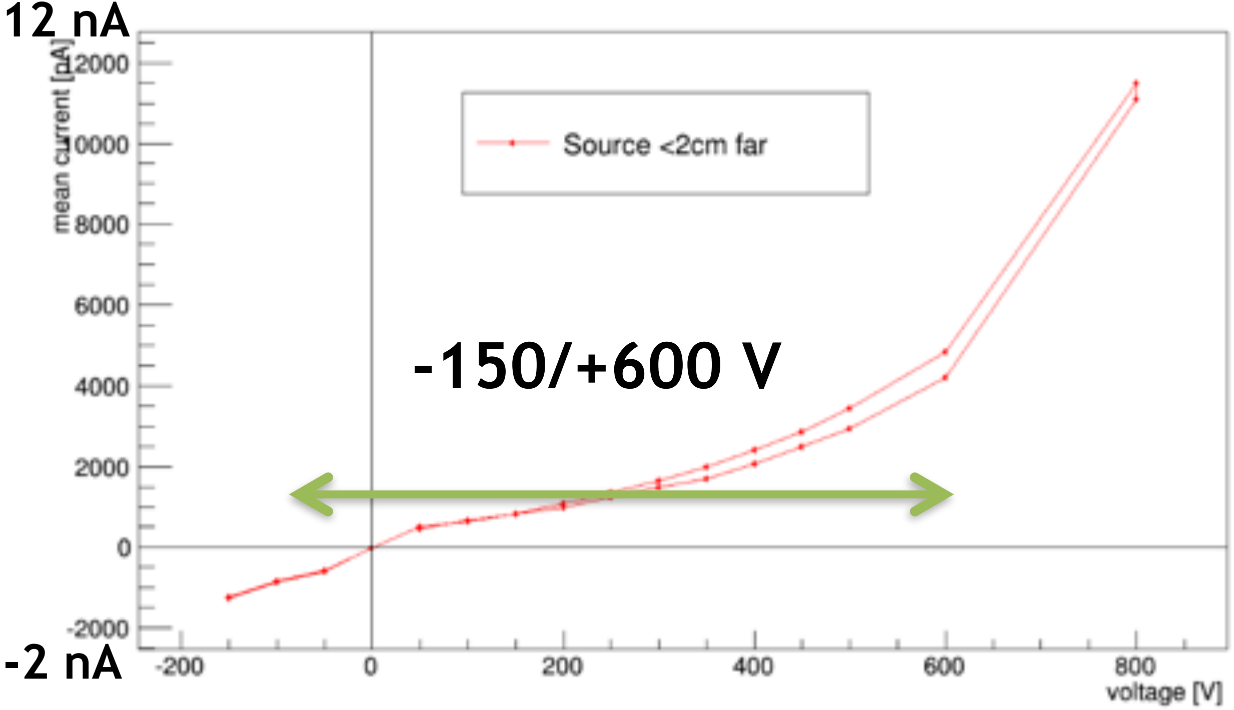
- Source distance -> 11%
- Diamond Active Volume-> 10%
- Source activity -> 7%
- Electronics Offset drift ~ 2%
- HV effects order 1%
- Priming/pumping effects (initial stability)<10%
  (long term < 1%)
- FLUKA simulation -> 1 %

I-V with β ^{90}Sr source (d=18mm)

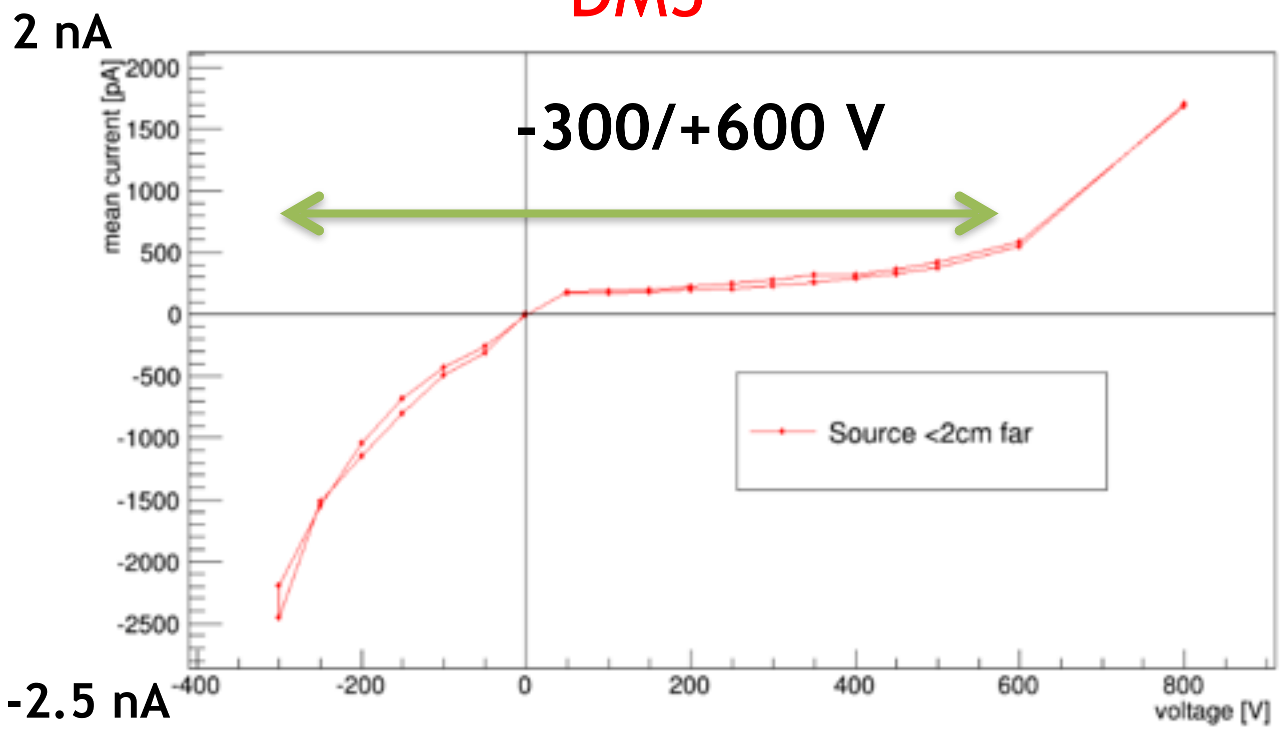
DC3



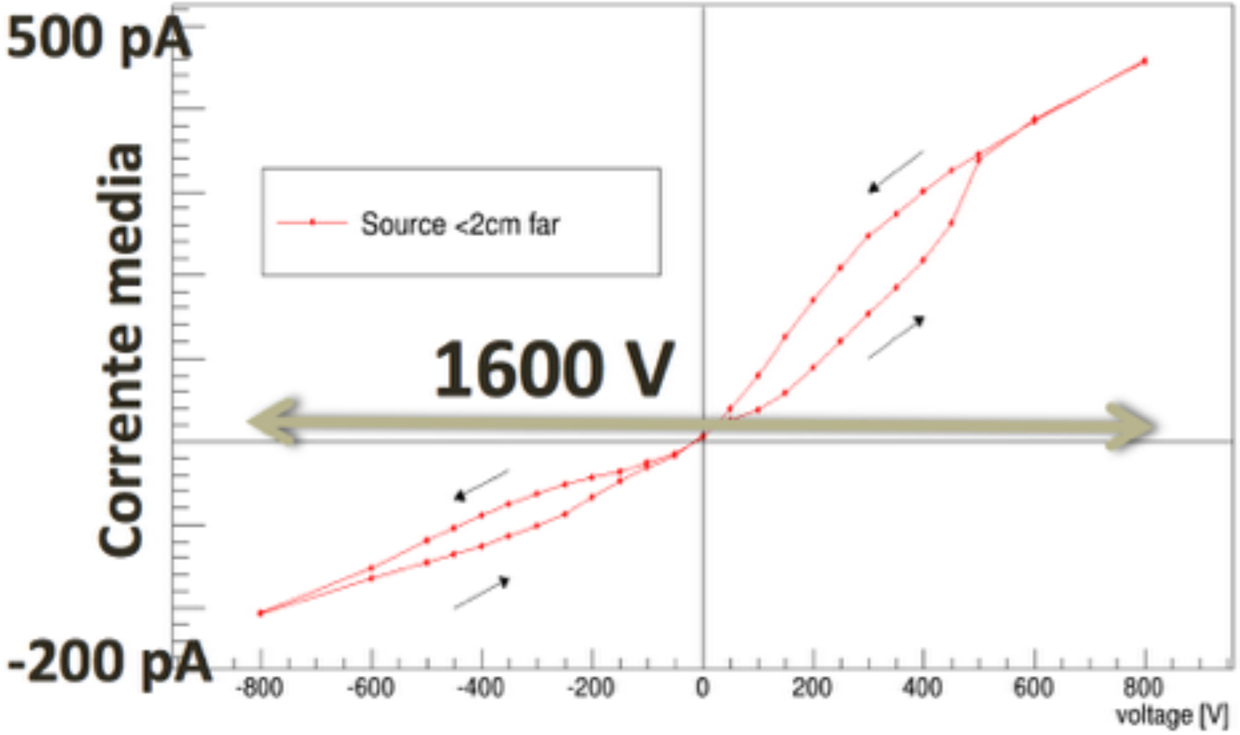
DM4



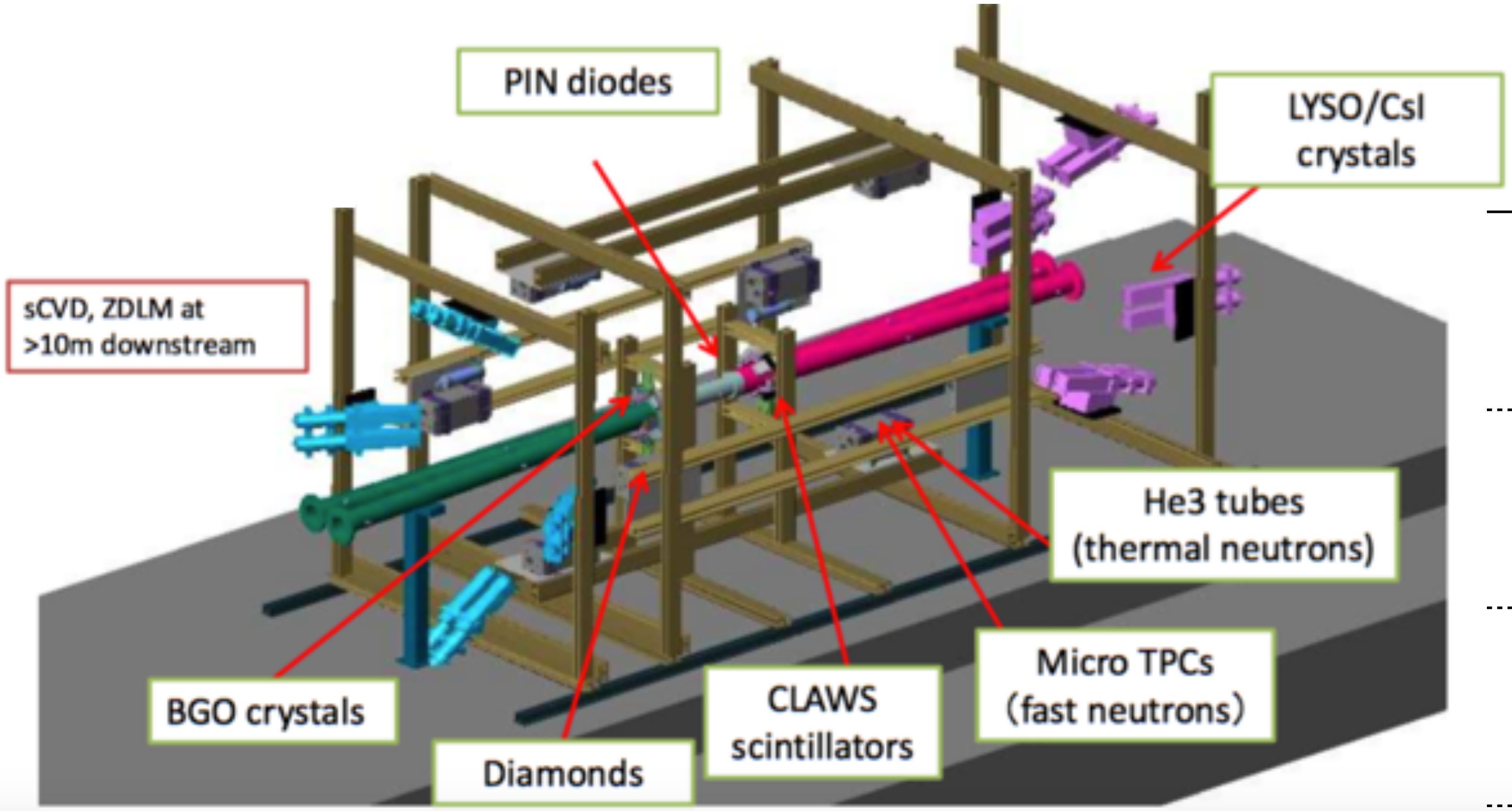
DM5



DM7



BEAST sensors



System	Detectors installed	Measurement
"CLAWS" scintillator	8	injection backgrounds
Diamonds	4	ionization dose
BGO	8	luminosity
Crystals	6 CsI(Tl) 6 CsI 6 LYSO	EM energy spectrum
He-3 tubes	4	thermal neutron flux
Micro-TPCs	2	fast neutron
PIN diodes	64	neutral vs charged radiation dose