Test beam measurements of irradiated CVD diamond

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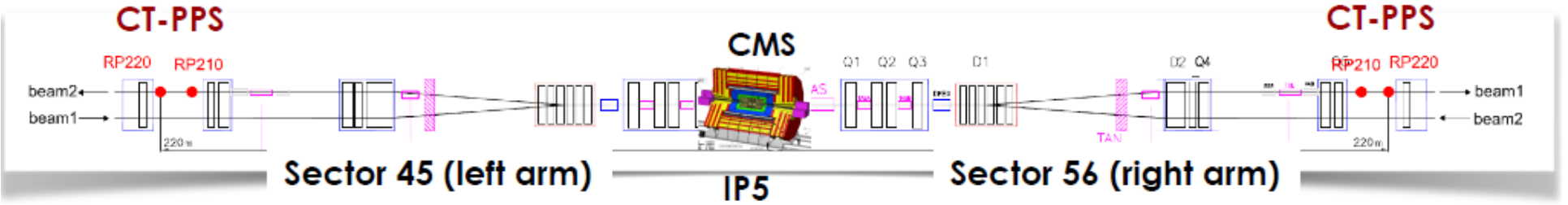
Outline

- ✓ Time resolution
- ✓ Radiation damage in diamond
- ✓ Set-up at the test beam
- ✓ Results

Motivation: CMS Precision Proton Spectrometer (PPS)



Measures forward protons, joint project between CMS and TOTEM

In each arm:

2 stations of tracking detectors: Precise measurement of proton trajectory

1 timing station: Time-of-Flight of proton

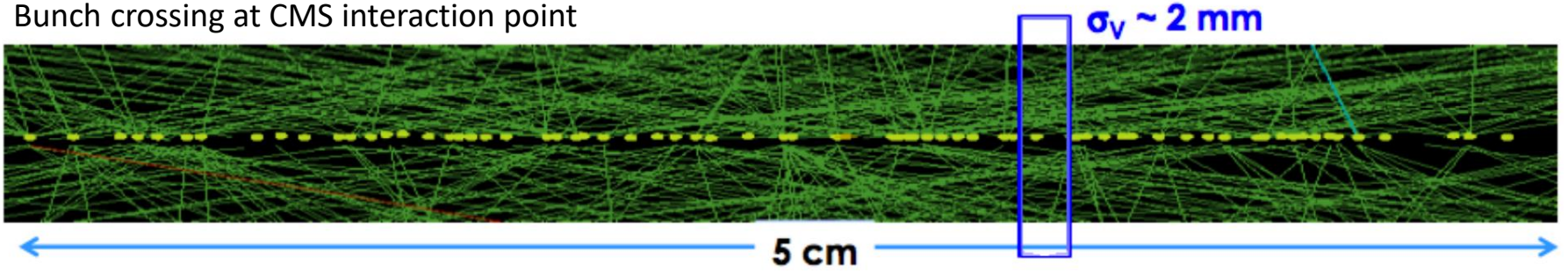
Vertex measurement by timing eg.: σ_t=10ps ⟶ σ_v=2mm

Needed time resolution depends on magnitude of **pile-up,**

Depending on beam optics needed resolution ranging from 10ps to 50ps

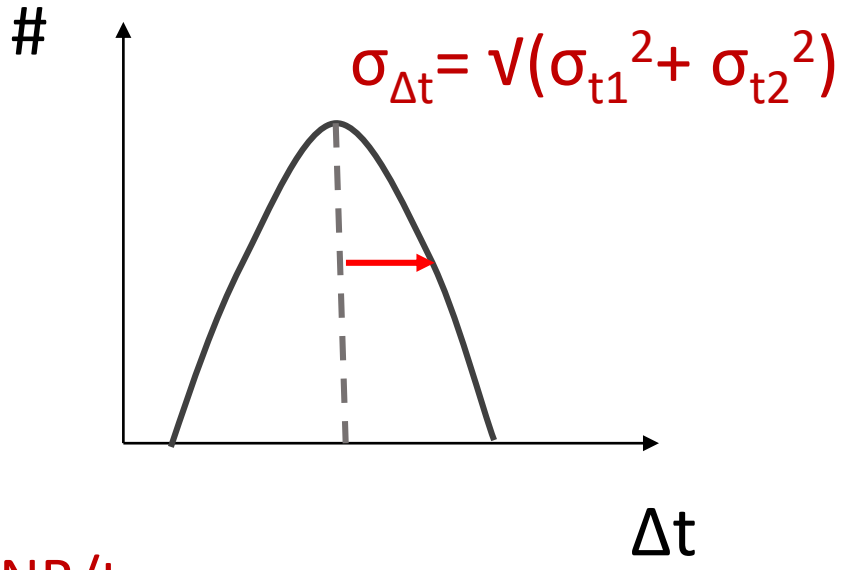
Note: Requirements for time precision are for detector package. Current timing detector package consists of 4 planes.

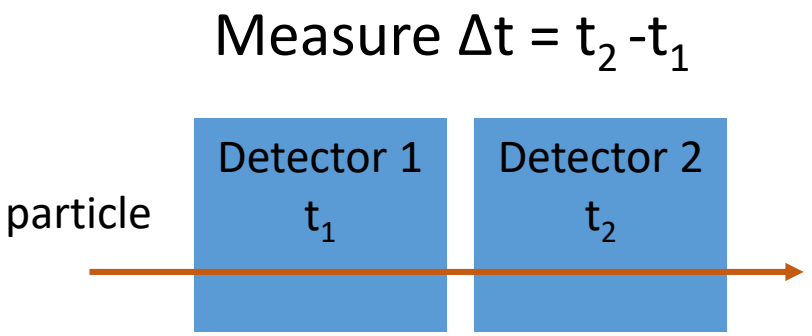
Bunch crossing at CMS interaction point



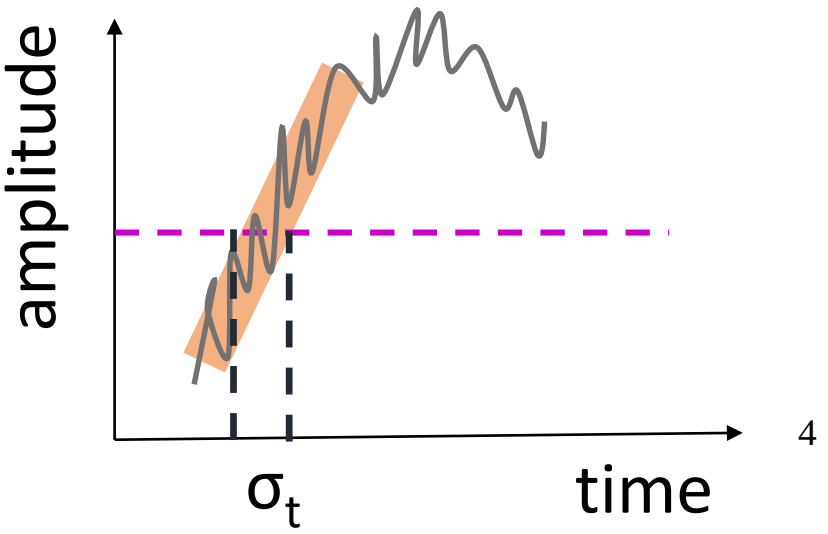
[LHCC-2014-021; TOTEM-TDR-003; CMS-TDR-13]

Time resolution





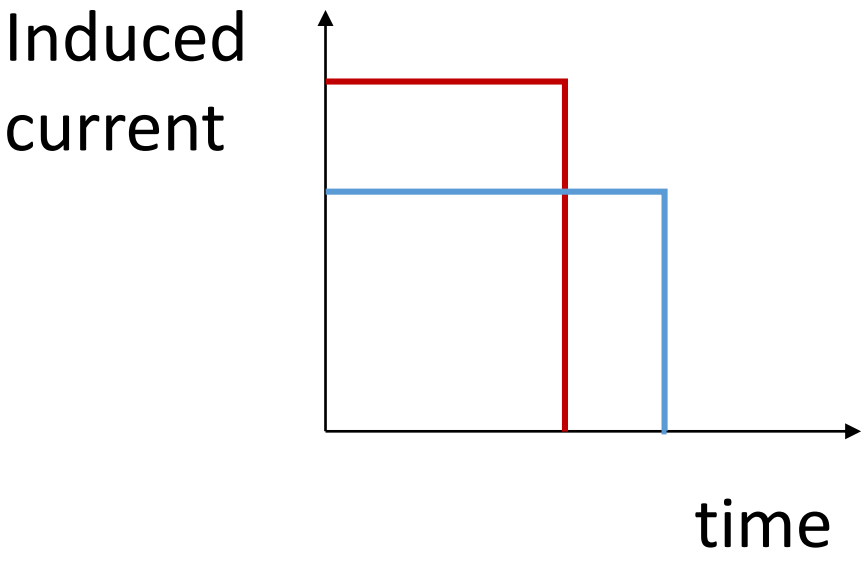
- ✓ $\sigma_t \sim SNR/t_{rise}$
- ✓ Stochastic signal generation
  -> Initial charge distribution
- ✓ Stochastics in signal transport
- ✓ Direct measurement not possible
  -> SNR & rise time characteristics



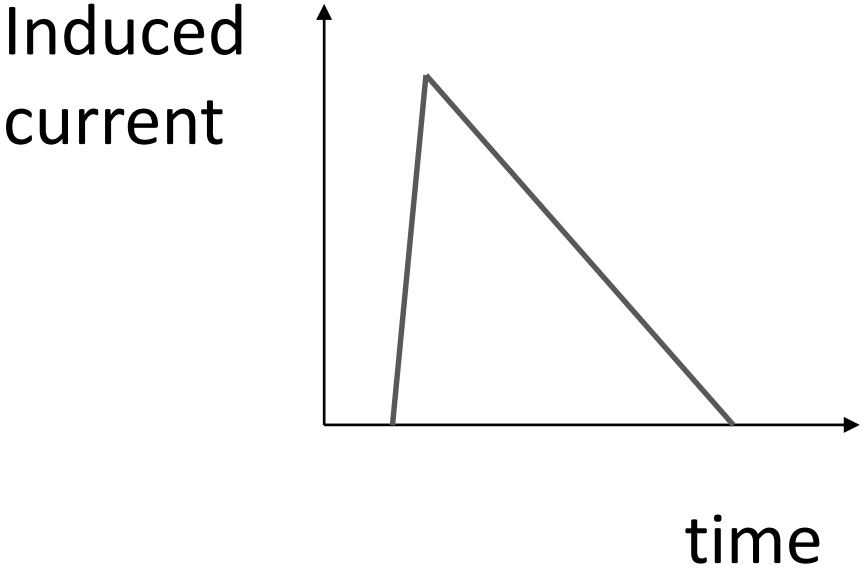
Radiation damage in high purity single crystal diamond

✓ Ideal pure diamond

Single charge carrier
traversing trough crystal



Several charge carriers
from MIP

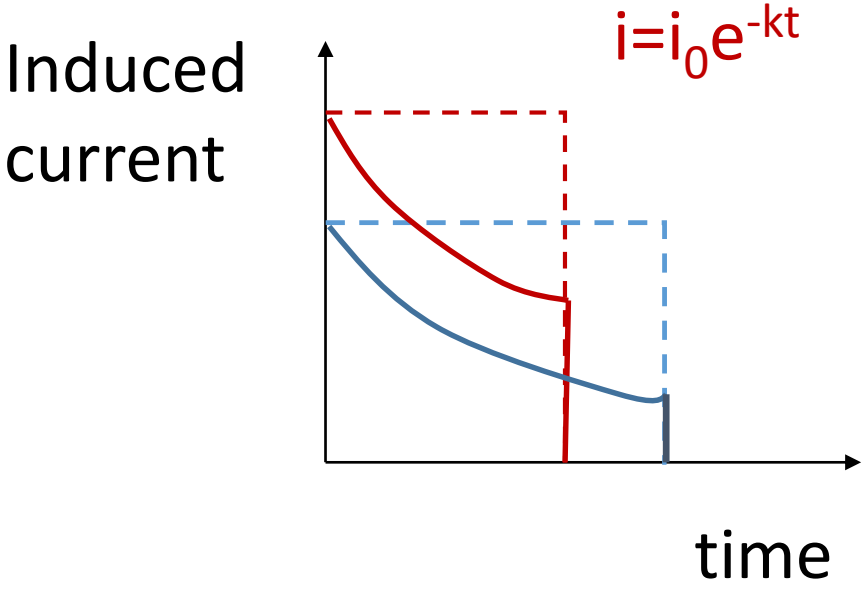


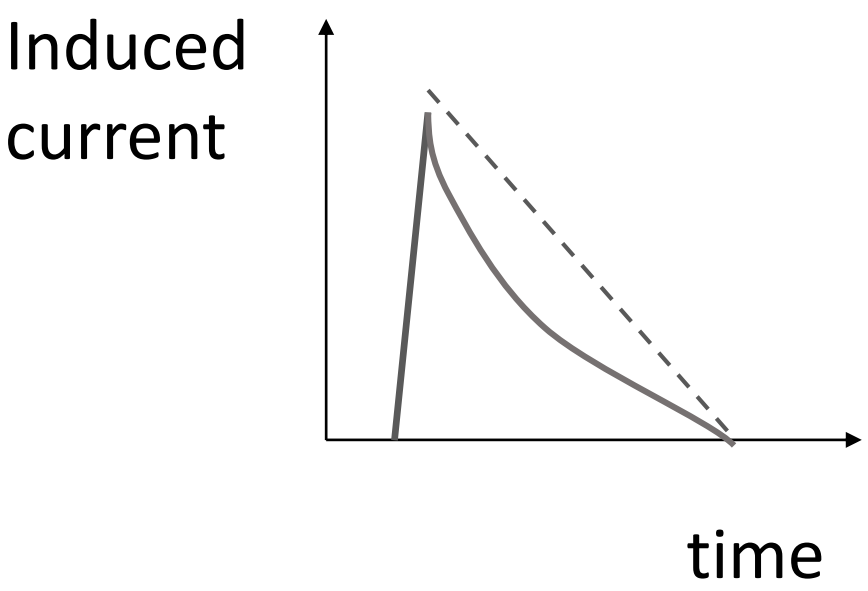
Radiation damage in high purity single crystal diamond

✓ Radiation damage: Mono vacancies & interstitials -> deep level traps

Single charge carrier
traversing trough crystal

Several charge carriers
from MIP



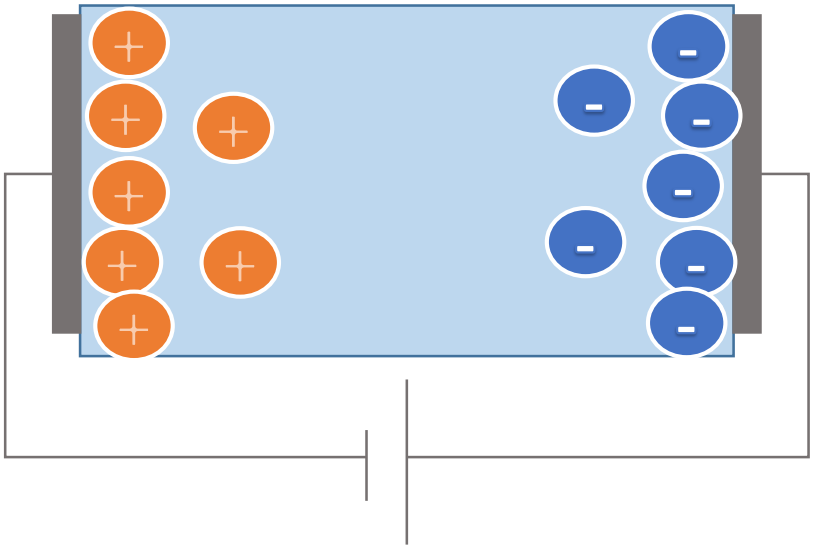


➢ Reduced charge collection, faster signal

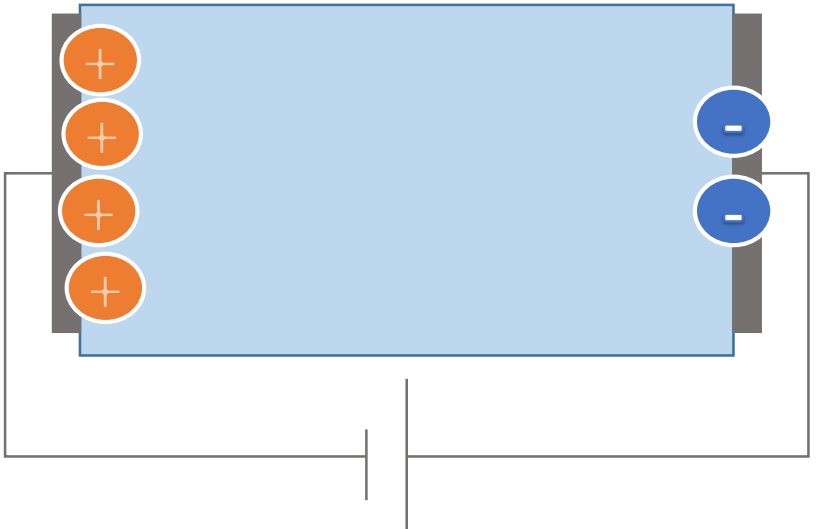
Radiation damage in high purity single crystal diamond: polarization

✓ Uneven charge density caused by trapped charge

Trapping in bulk

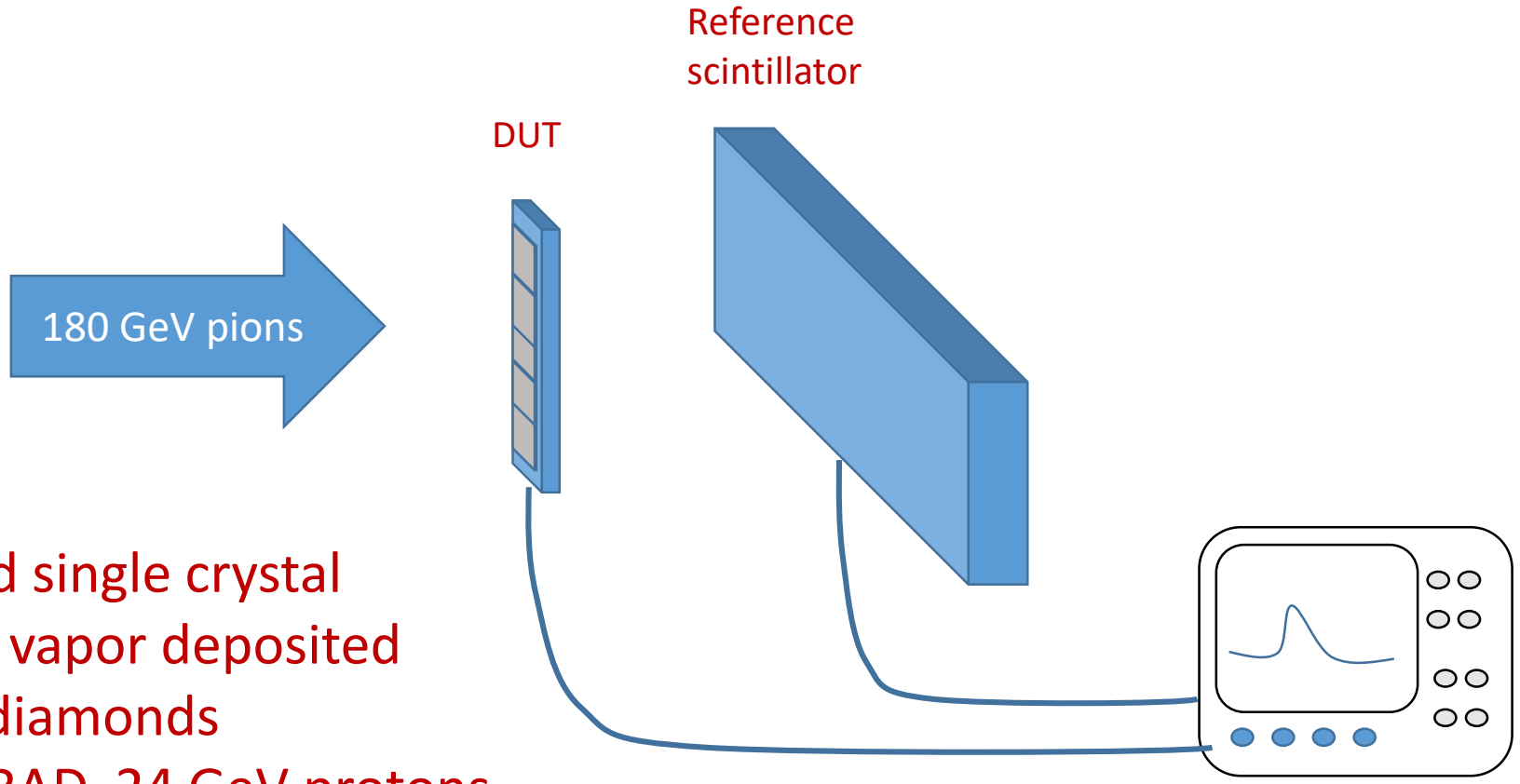


And interfaces



- ➢ Results in lower E-field
- ➢ Longer signals

Set-up at SPS Northern experimental area



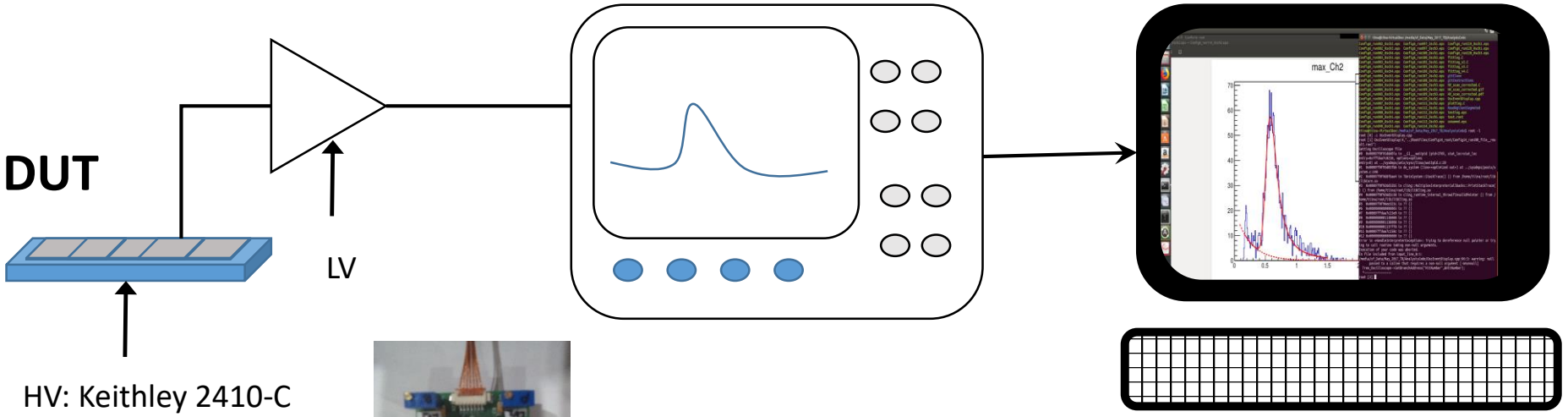
- ✓ Irradiated single crystal chemical vapor deposited (scCVD) diamonds
  - ✓ @ IRRAD, 24 GeV protons
- ✓ Fluence 0 p/cm^2, 10^{14} p/cm^2, $5*10^{15}$ p/cm^2
- ✓ Sensor size 4.5x4.5x0.5 mm^3

Set-up at SPS Northern experimental area

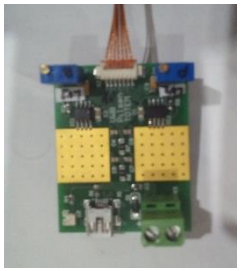
- ✓ Sensor mounted on TOTEM hybrid [2]
- ✓ Three stage amplification chain

- ✓ Signal readout with fast oscilloscope (Agilent DSO9254A, LeCroy WaveRunner8104)

- ✓ Signal processed offline using ROOT

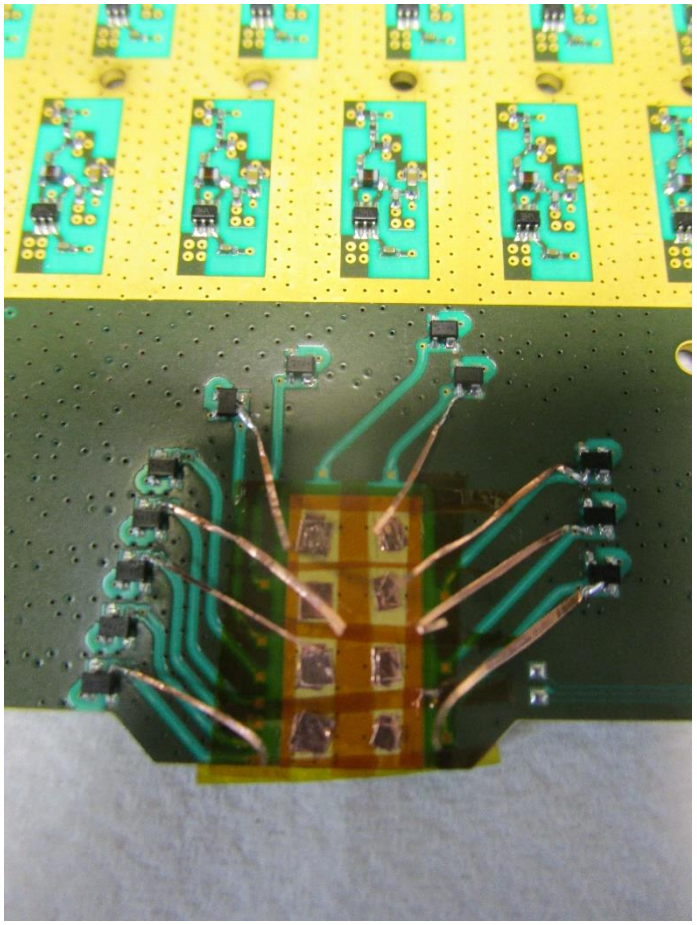


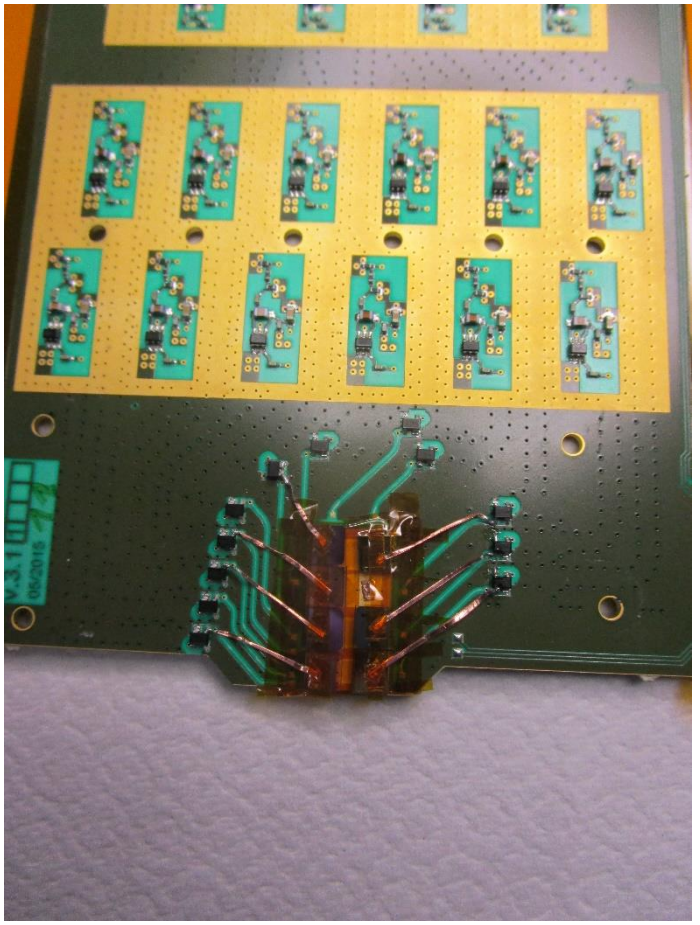
HV: Keithley 2410-C

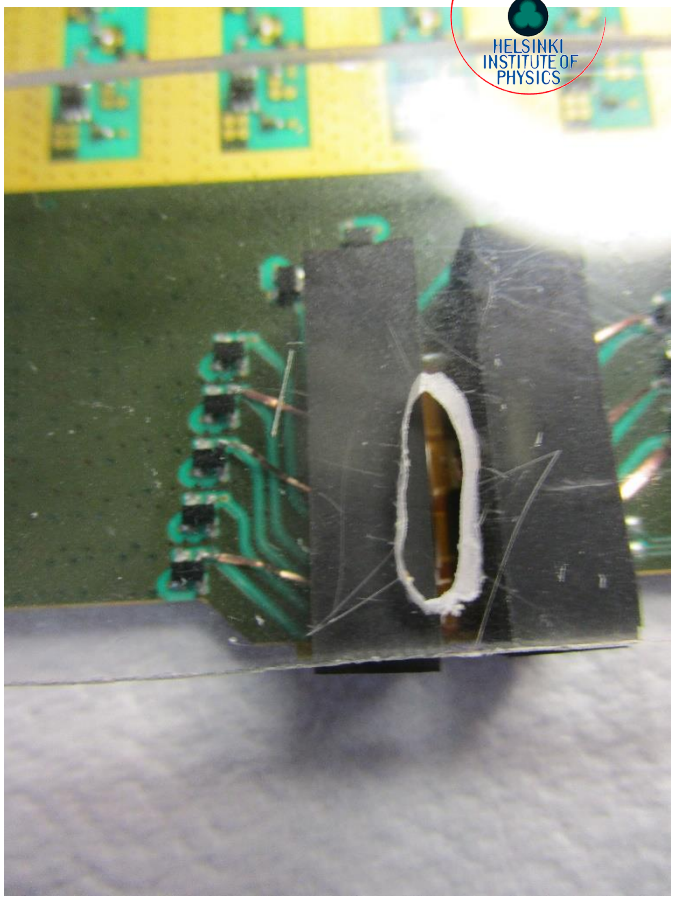


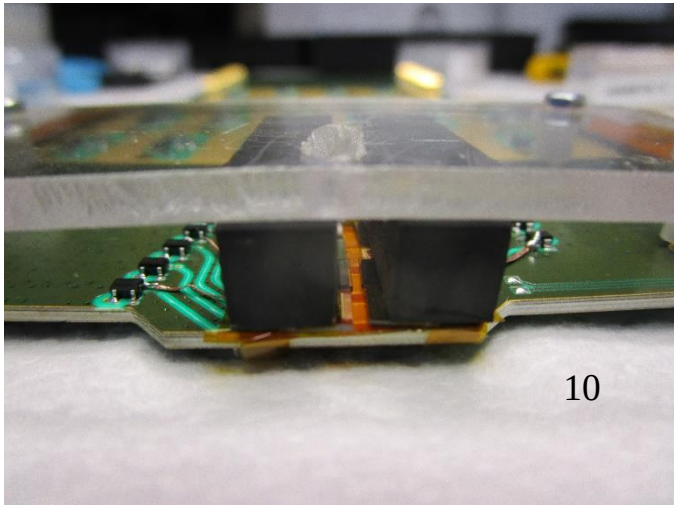
[2] 2017 JINST 12 P03007

Contact by pressure





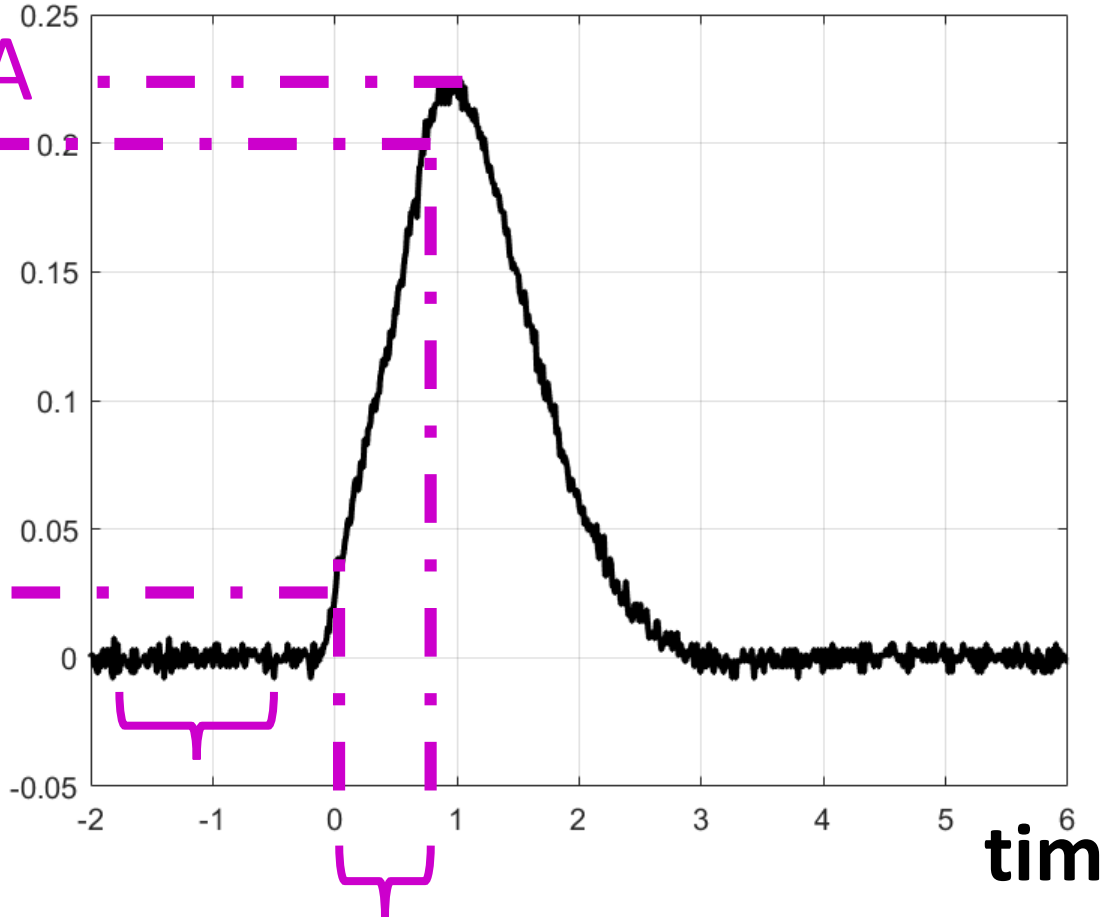




- Piece of copper tape soldered directly to pre-amplifier leg (thank you Georgui!!)
- Surface leakage stop with kapton tape, contact pad raised with copper tape stack
- Pressure applied with pieces of rubber and recycled plexiglass
- In practice:
  - Single channel works as well as bonding
  - several channels -> increased noise (pick off)

Signals attributes:
Signal amplitude, Signal rise time

Amplitude

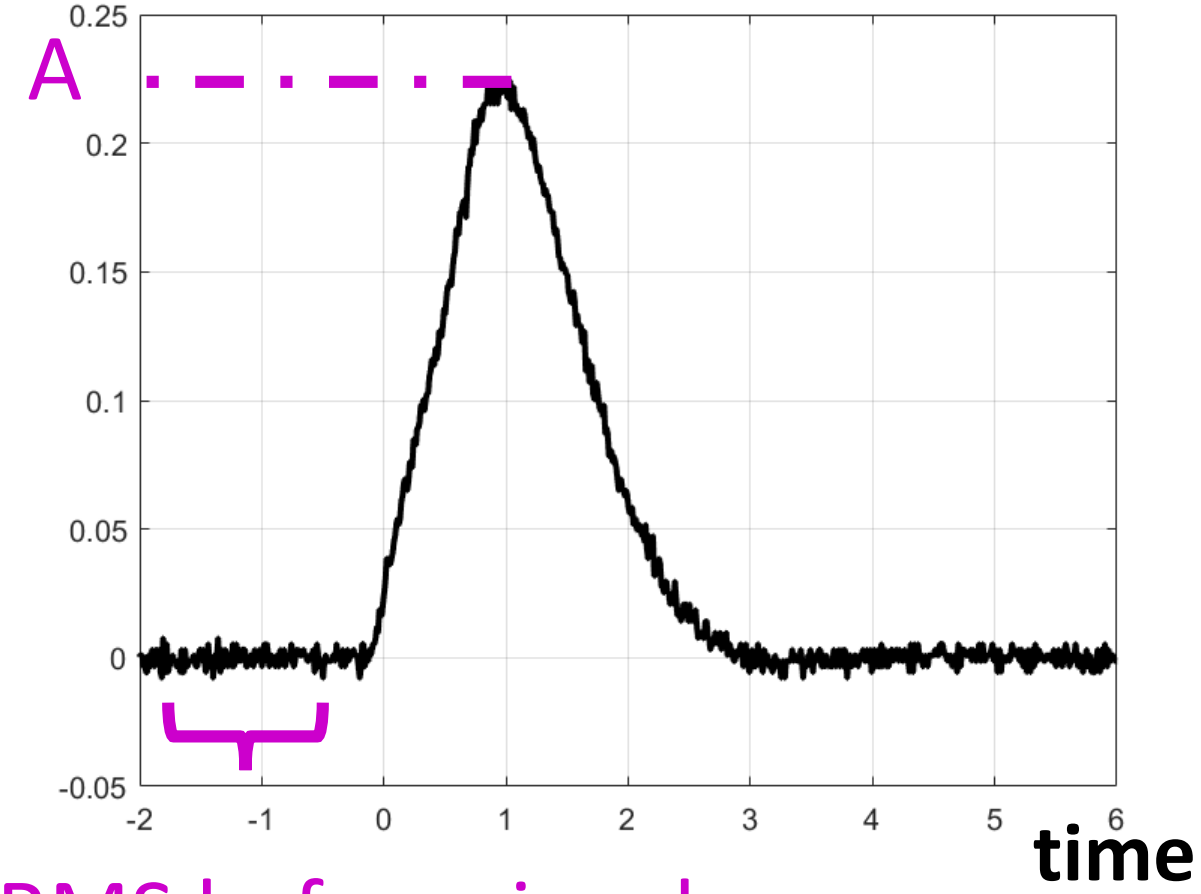


RMS = noise

Signal rise time

Signals attributes: Noise RMS

Amplitude

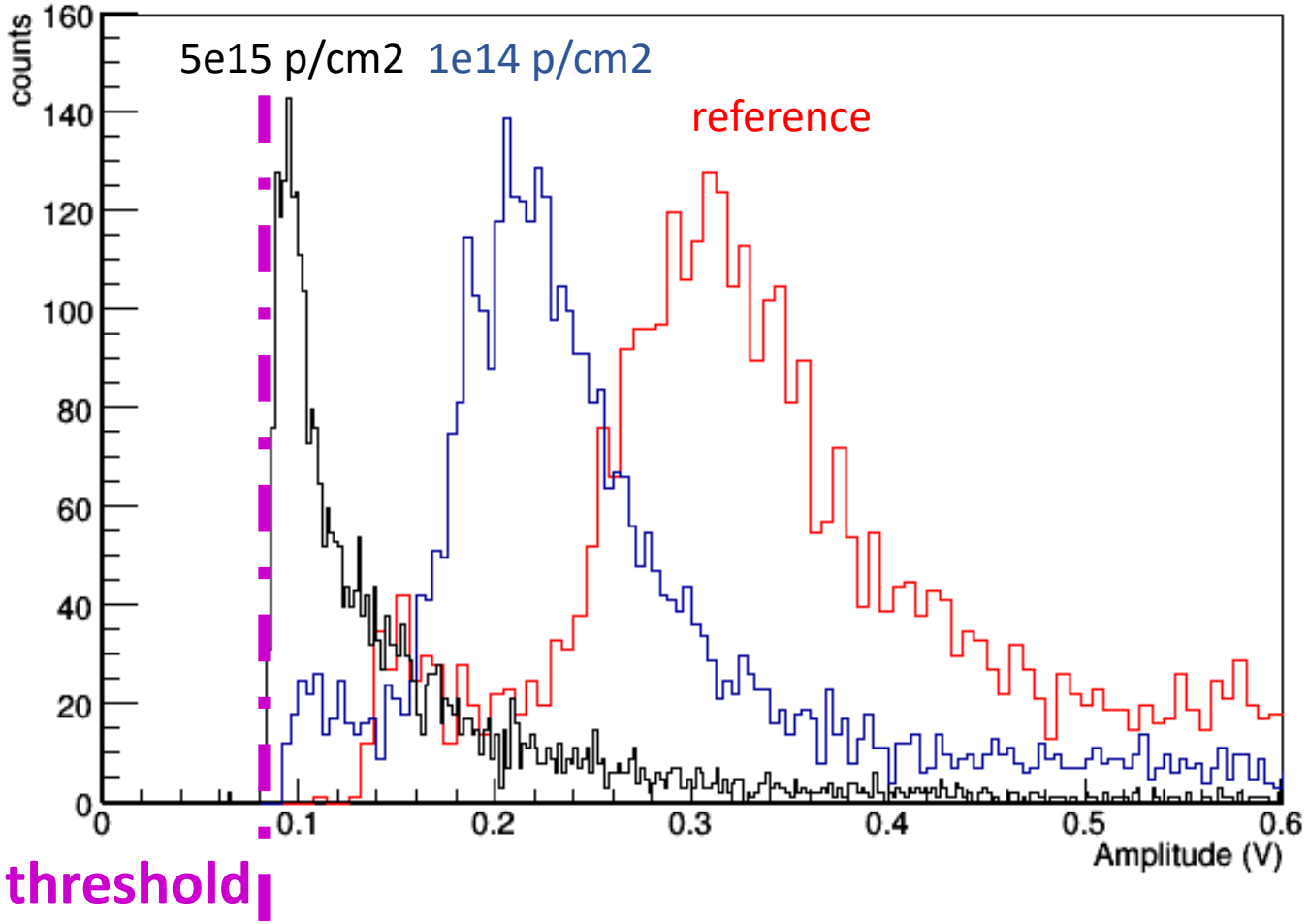


RMS before signal

= noise RMS

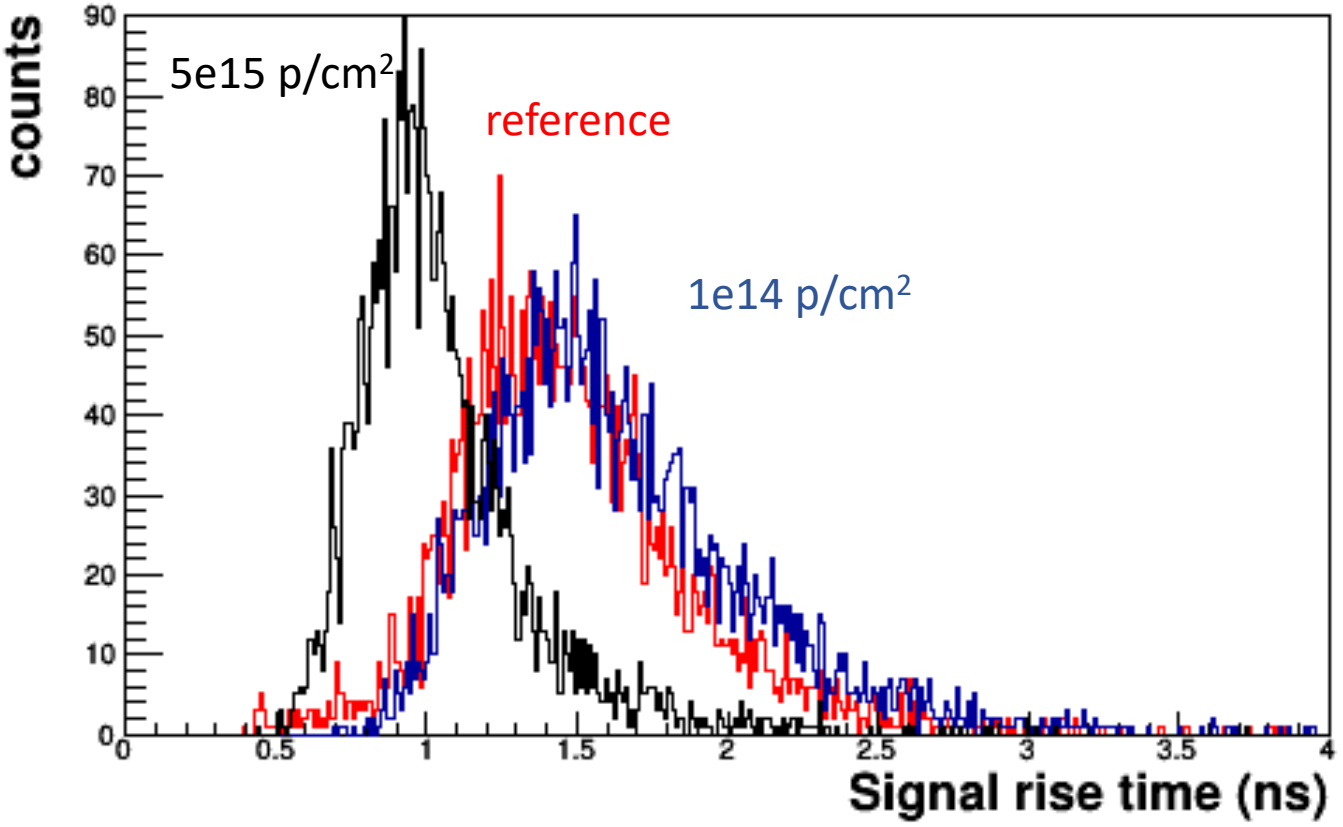
Raw amplitude spectrum of proton irradiated diamonds under pion beam

HV=1000V

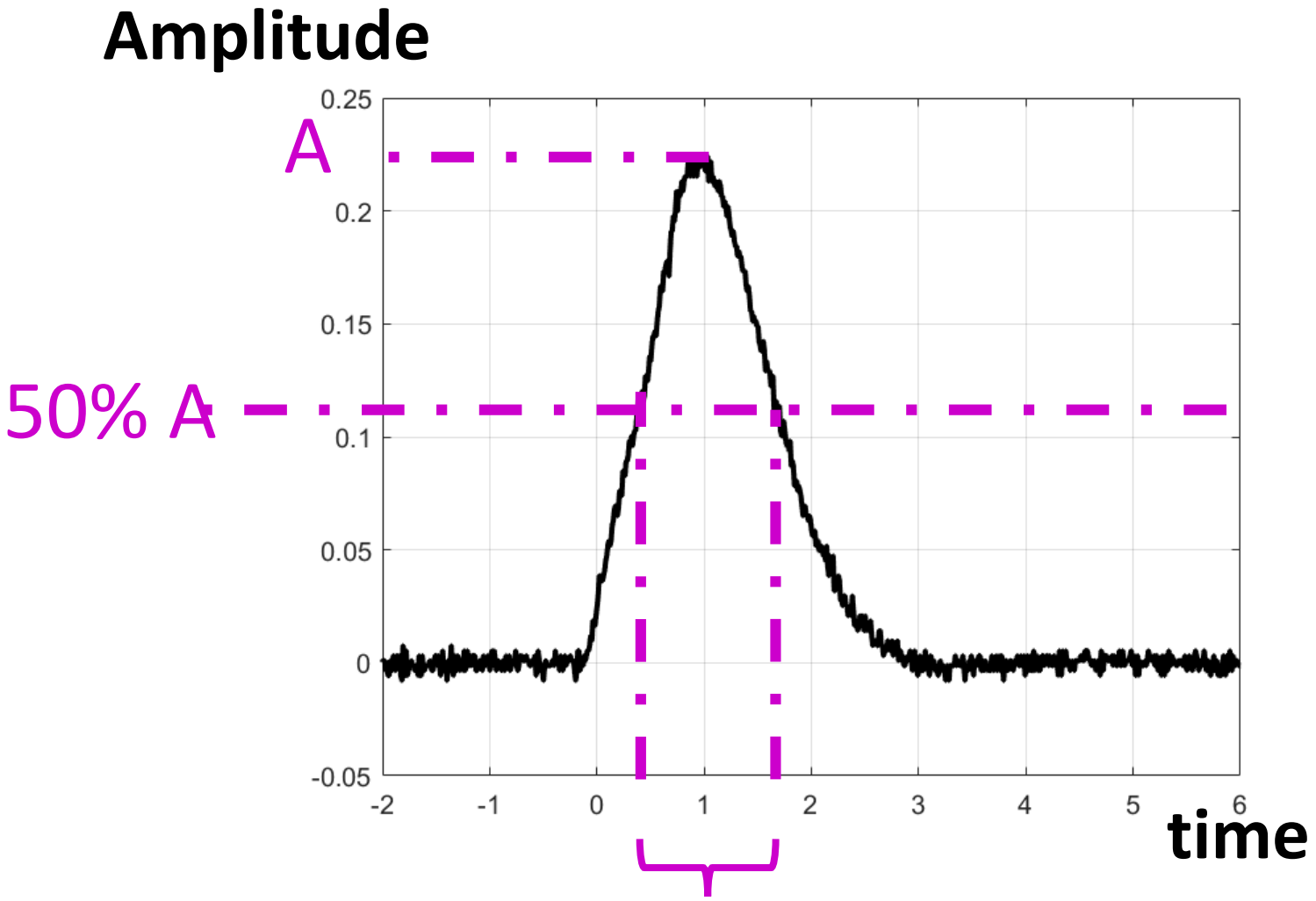


Signal rise time spectrum of proton irradiated diamonds under pion beam

HV=1000V

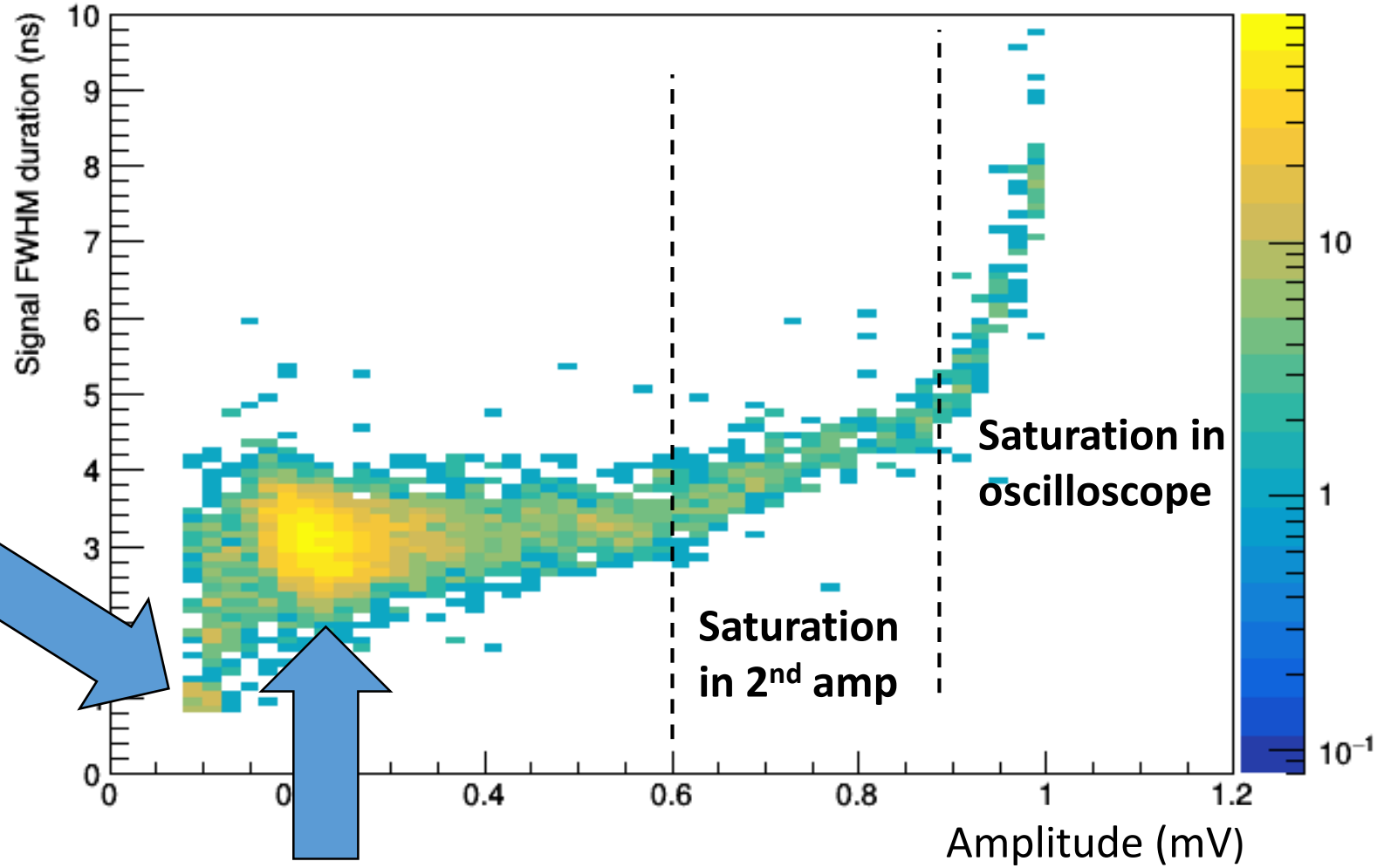


Signals attributes: Signal duration



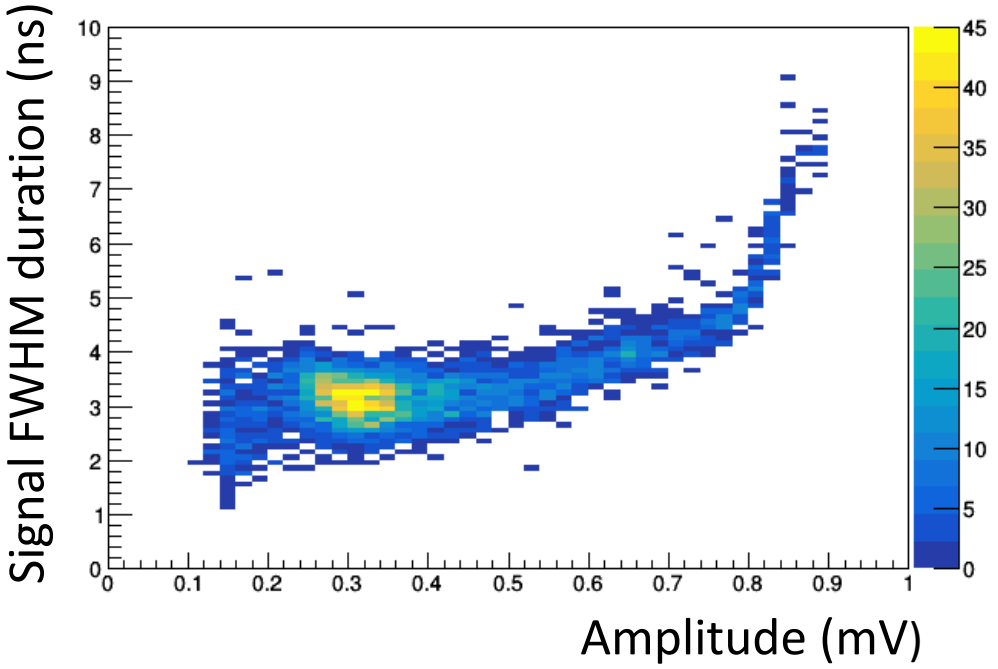
Signal FWHM duration

Signals in amplitude-signal duration plane, separation using signal shape



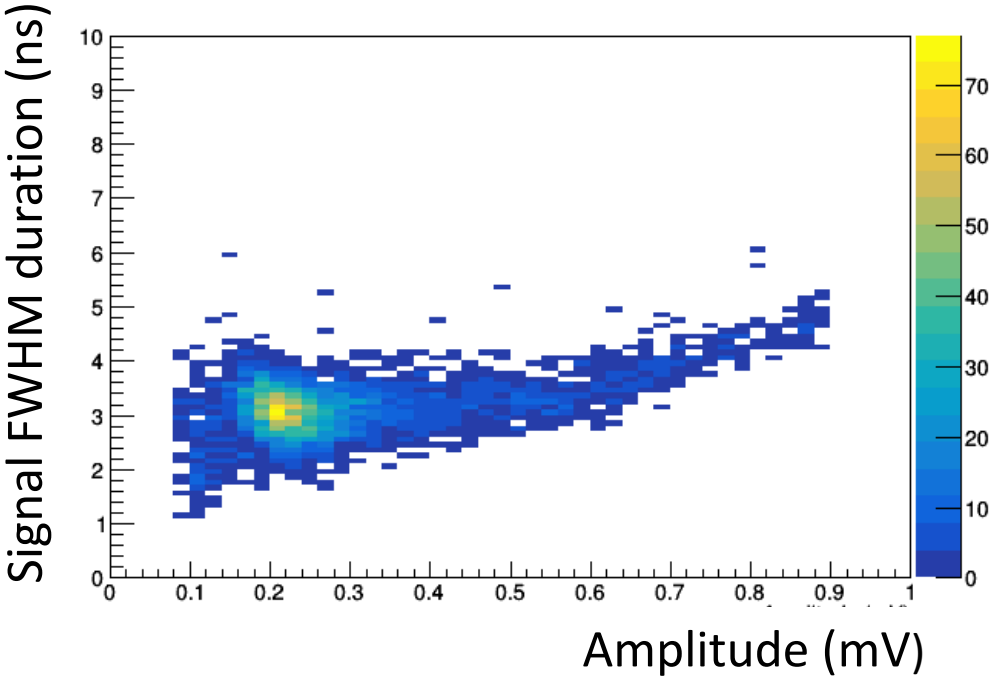
Signals in amplitude-signal duration plane, separation using signal shape

Non-irradiated reference



2D-gaussian fit:
Amplitude = 322 ± 1 mV
Duration = 3.144 ± 0.001 ns

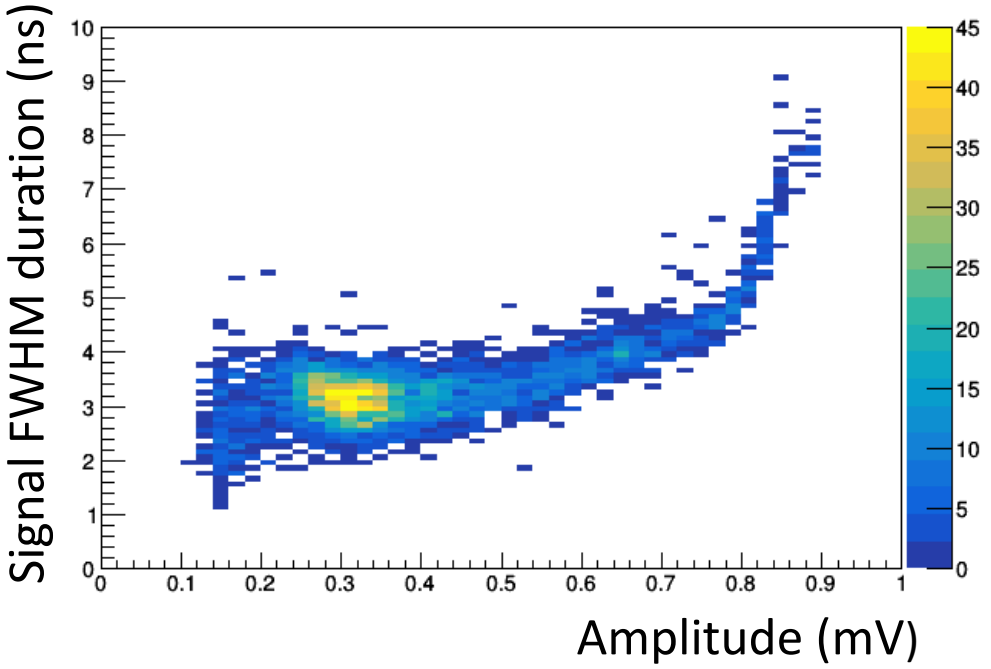
Irradiated to 10^{14} p/cm^2



2D-gaussian fit
Amplitude = 288 ± 1 mV
Duration = 3.048 ± 0.008 ns

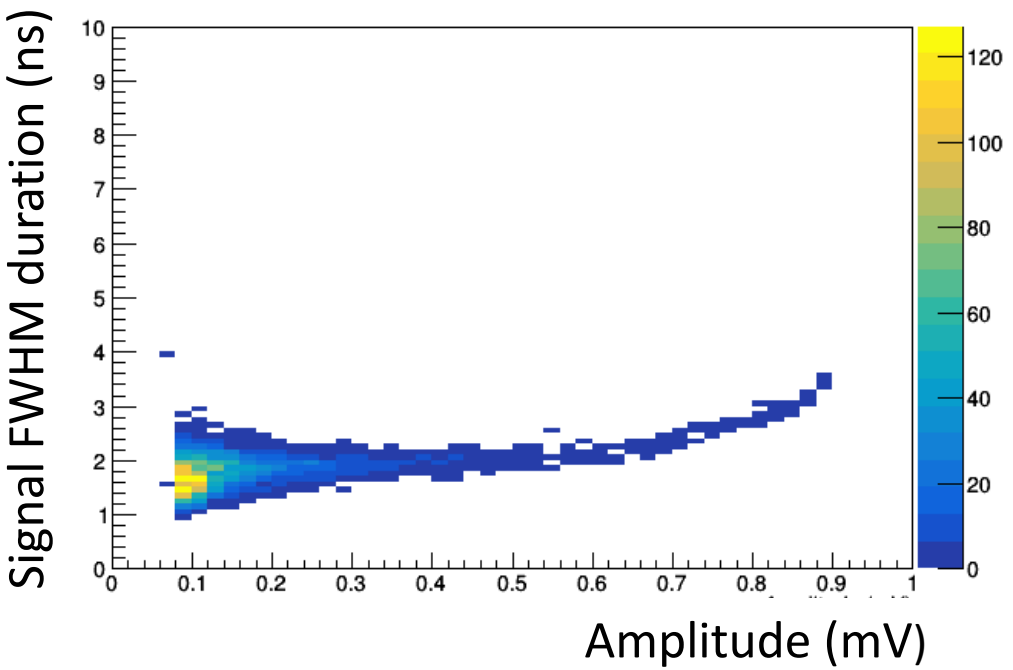
Signals in amplitude-signal duration plane, separation using signal shape

Non-irradiated reference



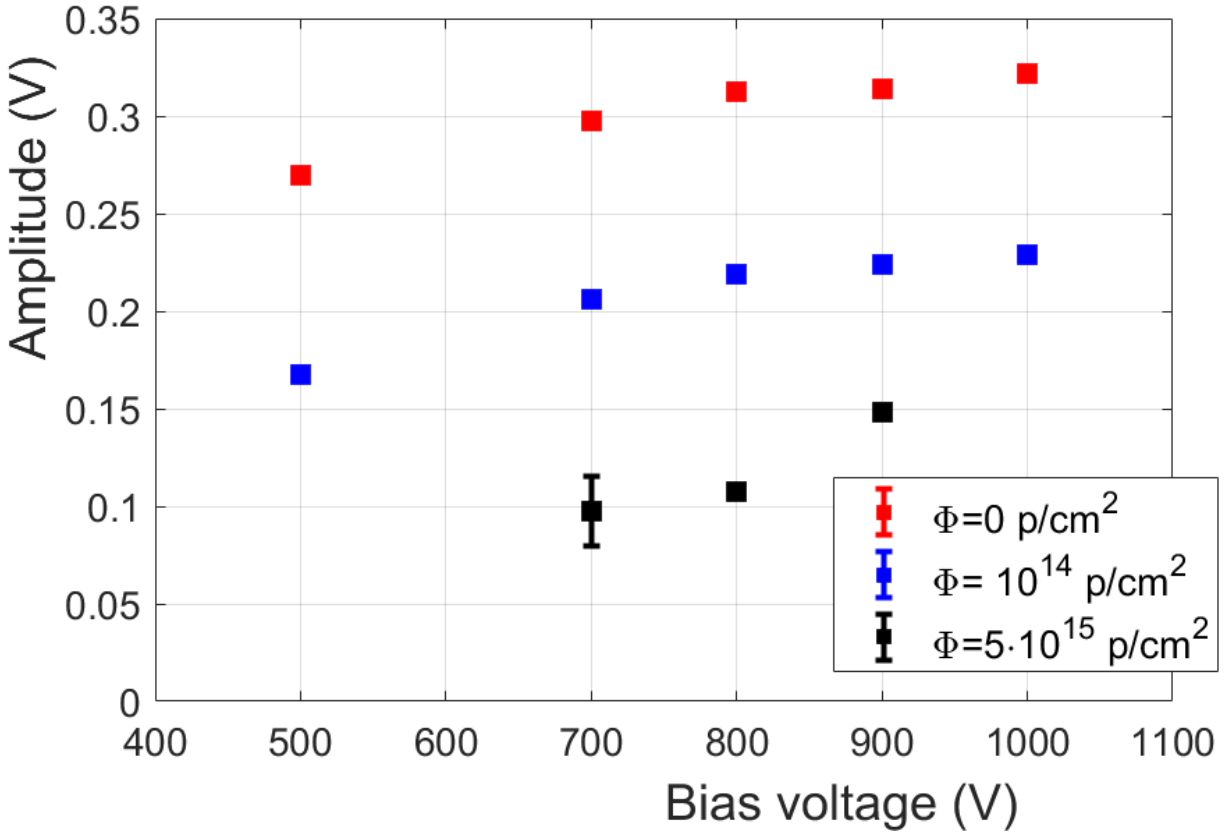
2D-gaussian fit:
Amplitude = 322 ± 1 mV
Duration = 3.144 ± 0.001 ns

Irradiated to $5*10^{15}$ p/cm^2

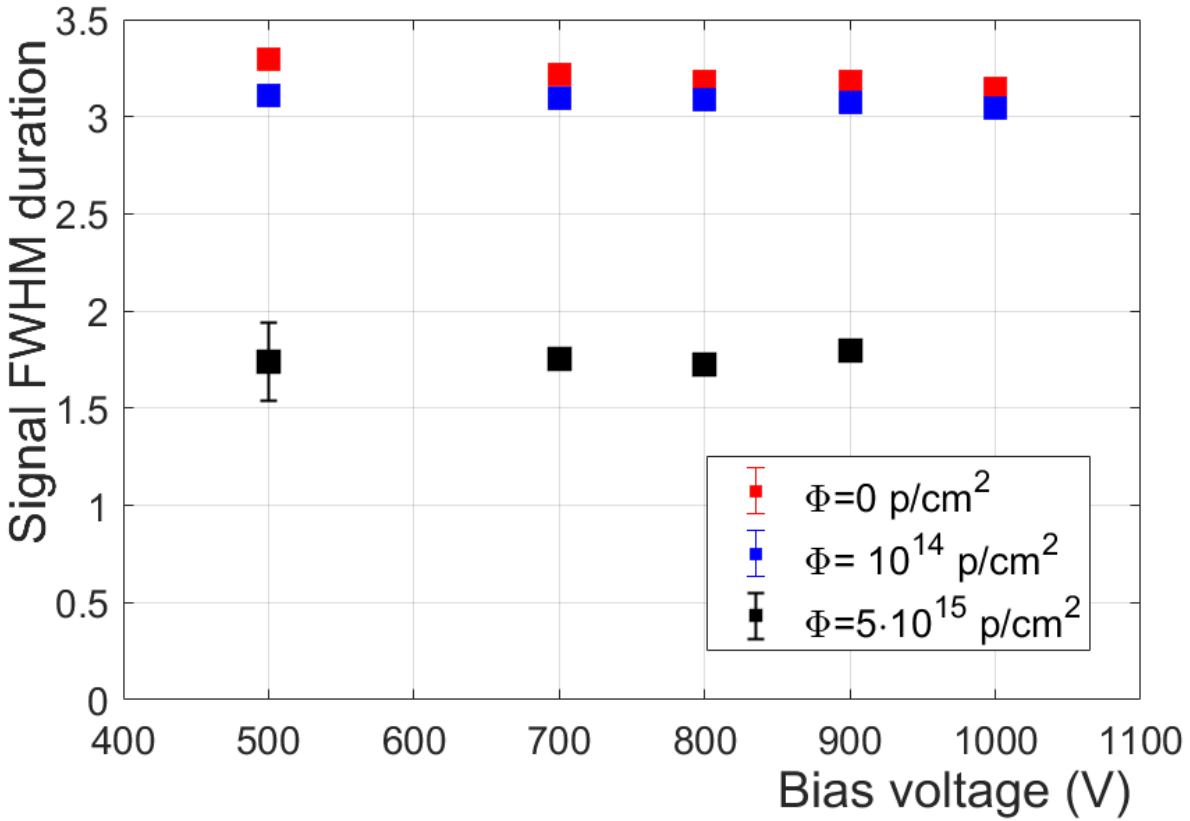


2D-gaussian fit:
Amplitude ≤ 100 mV
Duration = 1.761 ± 0.006 ns

Signal amplitude with different bias voltages



Signal FWHM duration vs bias voltages



Conclusions

- ✓Basic signal attributes from 180 GeV pions was investigated
- ✓Signal amplitude reduced with radiation damage
- ✓Signal duration & rise time reduced as well
  - ✓Helps with time resolution

Acknowledgements

- ✓HUGE thanks to the IRRAD team, Precision Proton Spectrometer community and my “home experiment” TOTEM
- ✓A. Gädda and J. Ott in Helsinki CMS upgrade group for processing the reference diamond
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  - Academy of Finland
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