

Diamond Beam Loss Monitors

oPAC Workshop, Barcelona, 15.9.2016

Erich Griesmayer, CIVIDEC Instrumentation



oPAC Workshop Barcelona



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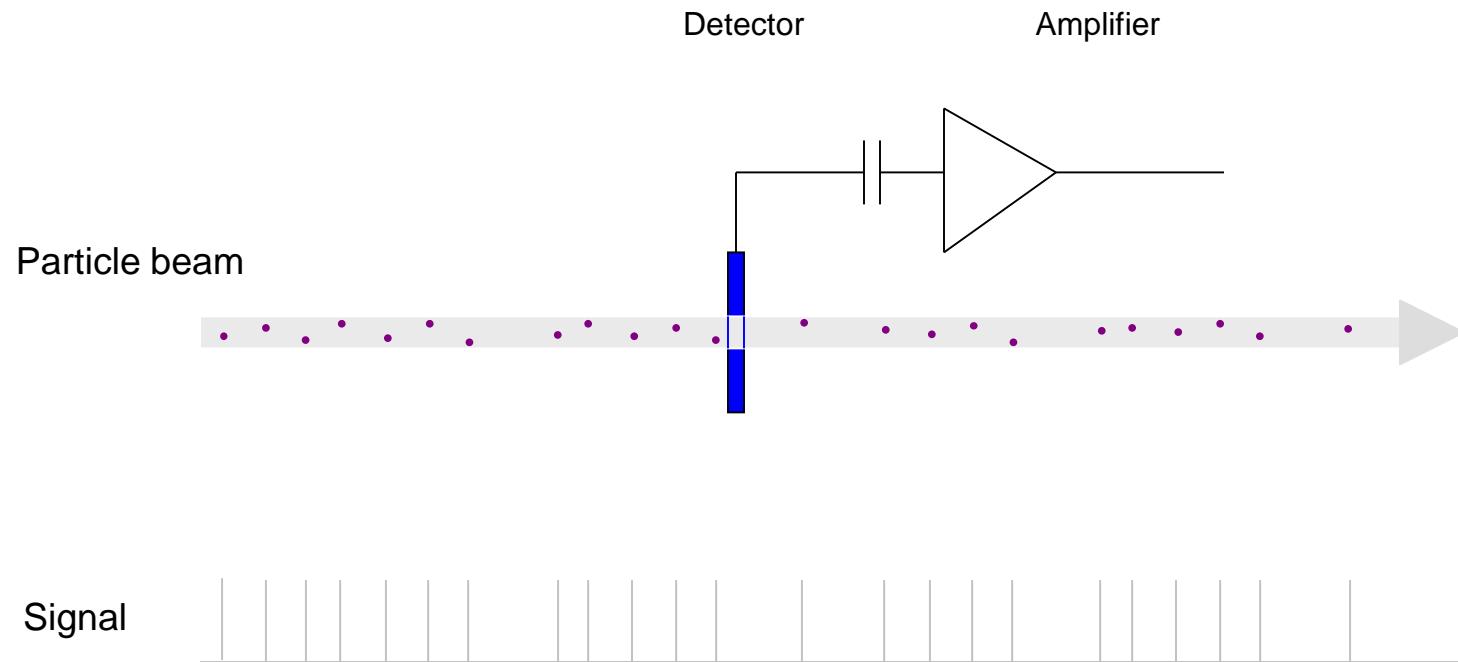
Content

- Principles
- Beam Loss Diagnostics
- Neutron Diagnostics
- X-Ray Diagnostics

Content

- Principles
- Beam Loss Diagnostics
- Neutron Diagnostics

Principle of a solid-state detector



Substrate



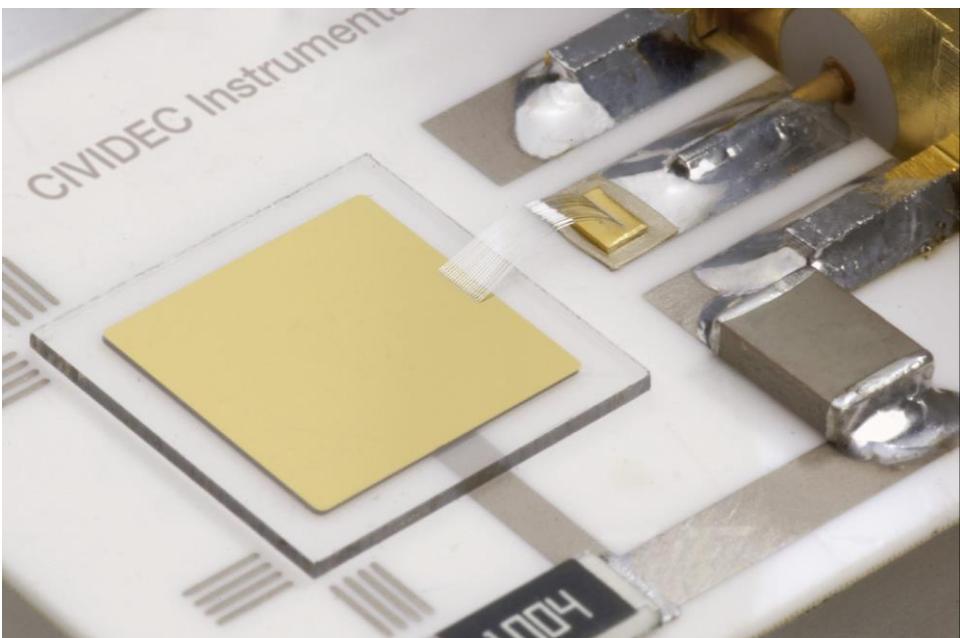
Diamond Substrate:

pCVD = 10 mm x 10 mm

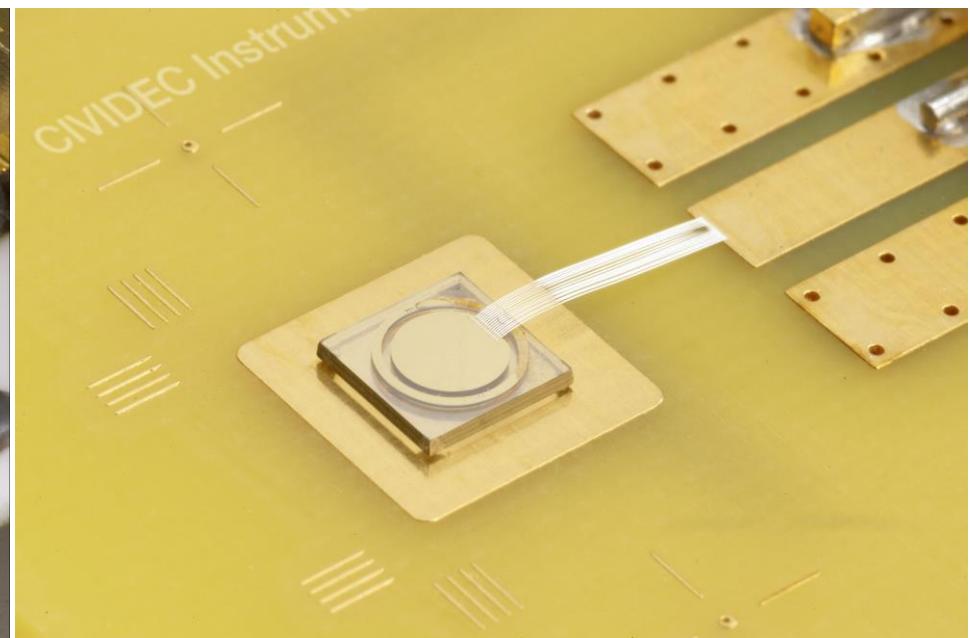
sCVD = 5 mm x 5 mm

Thickness = 500 um

Diamond detectors



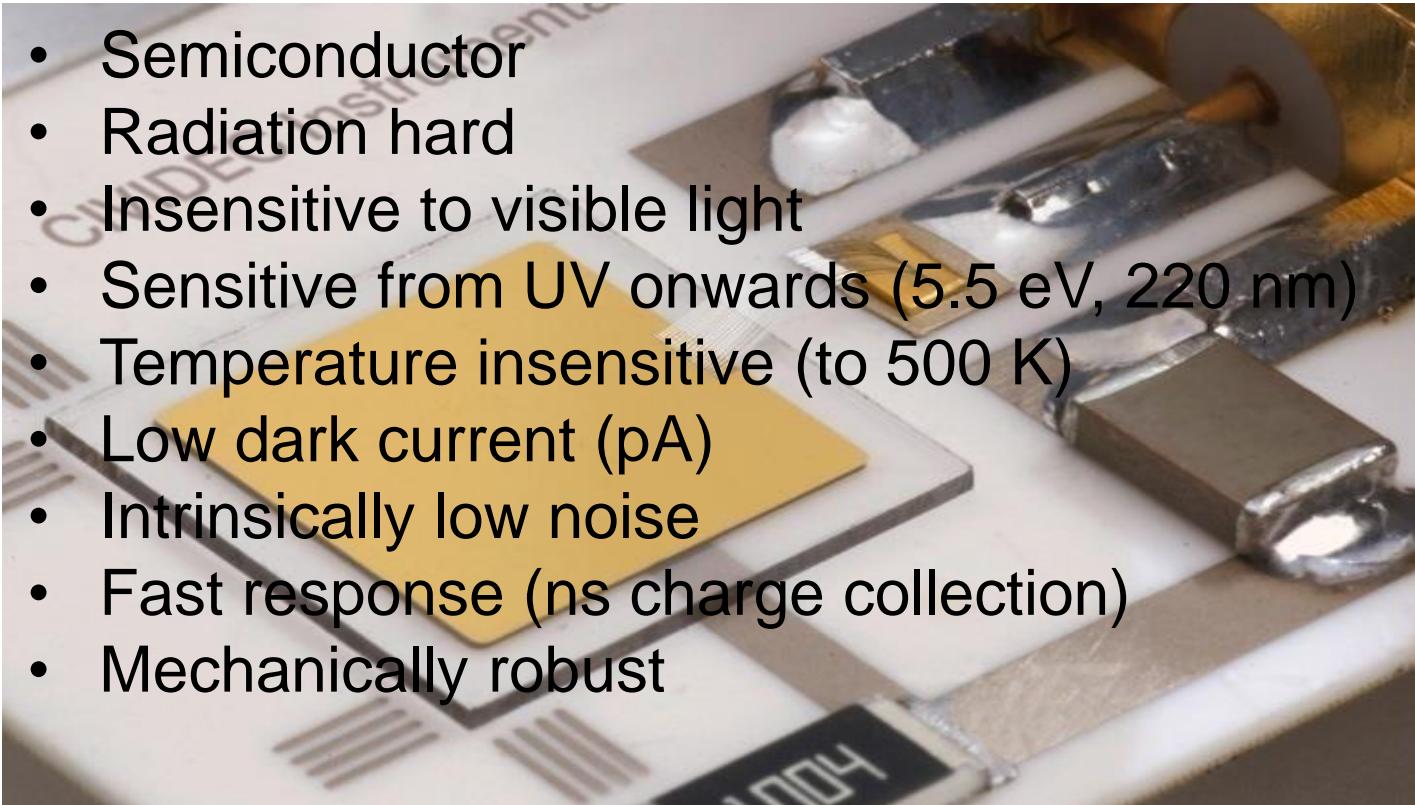
pCVD



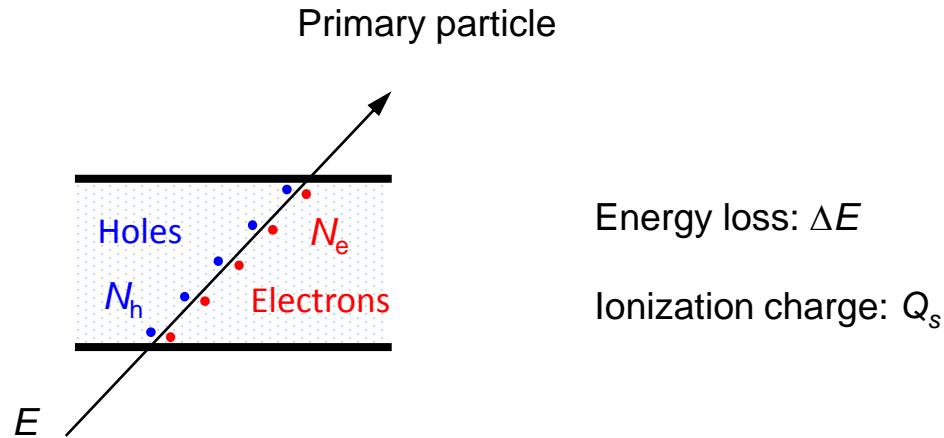
sCVD

Diamond sensor

- Semiconductor
- Radiation hard
- Insensitive to visible light
- Sensitive from UV onwards (5.5 eV, 220 nm)
- Temperature insensitive (to 500 K)
- Low dark current (pA)
- Intrinsically low noise
- Fast response (ns charge collection)
- Mechanically robust



Principle of ionization

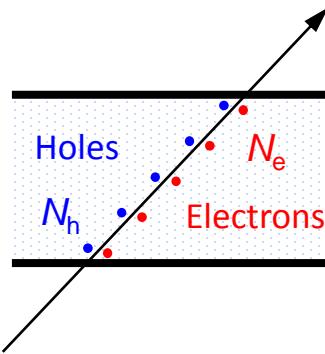


Ionization:

$$Q_s = (N_e + N_h) \cdot e = \frac{\Delta E}{e_i}$$

Ionization energy: $e_i = 13 \text{ eV/eh-pair}$

Principle of ionization



Recombination:

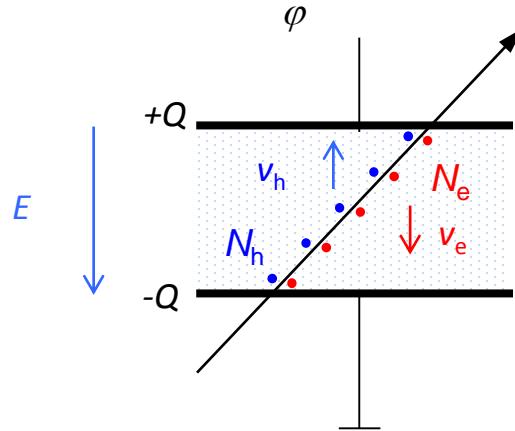
$$Q = Q_s \times \left(1 - e^{-t/t_r}\right)$$

Time constant = dielectric relaxation time constant:

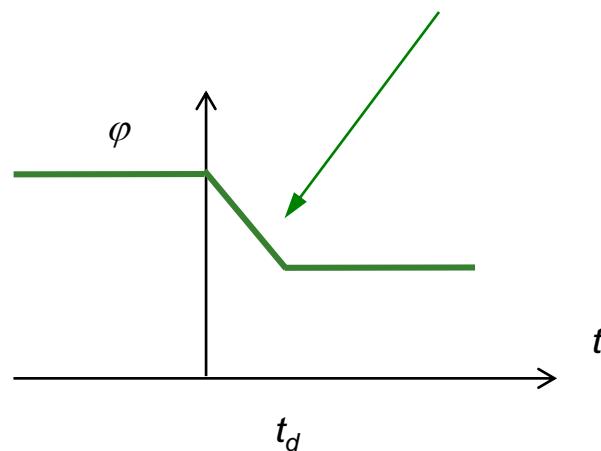
$$t_r = \epsilon \times k$$

ϵ ... Permittivity, κ ... Resistivity

Detector potential



$$Dj = \frac{Q_s}{C_{Det}}$$



$$V = m \times E$$

μ ... Mobility

m_e @ m_h

V_e @ V_h

Example

$$C_{Det} = 10 \text{ pF}$$

5 MeV α -particle:

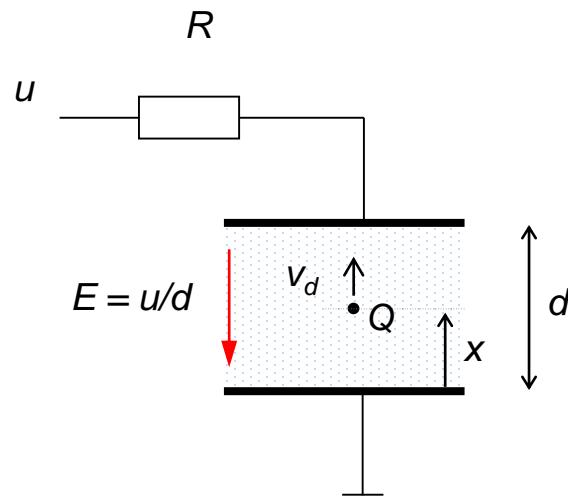
$$Q_s = 60 \text{ fC}$$
$$\Delta\varphi = 60 \text{ fC} / 10 \text{ pF} = 6 \text{ mV}$$

MIP particle:

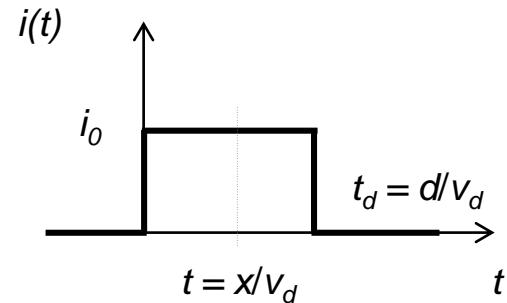
$$Q_s = 3 \text{ fC}$$
$$\Delta\varphi = 3 \text{ fC} / 10 \text{ pF} = 0.3 \text{ mV}$$

Shockley-Ramo Theorem

Ionization current:

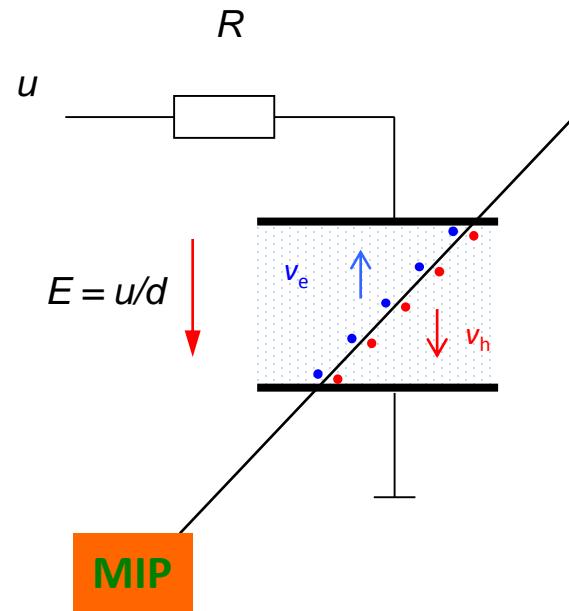


$$i_0 = \frac{Q_s \times v_d}{d}$$

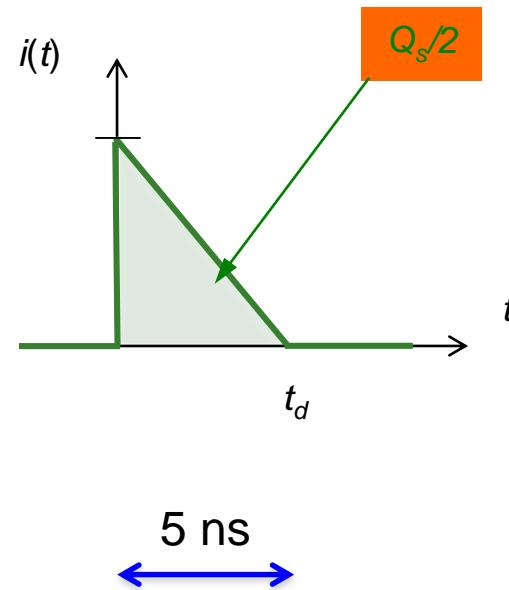


Charge collection

1. Homogenous ionization:

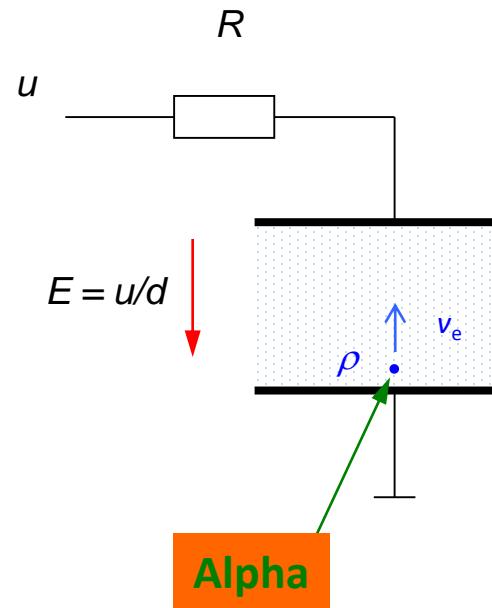


$$i_0 = \frac{Q_s \times v_d}{d}$$

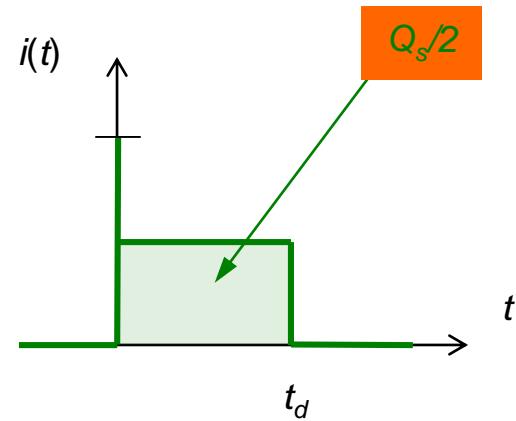


Charge collection

2. Point-like ionization:

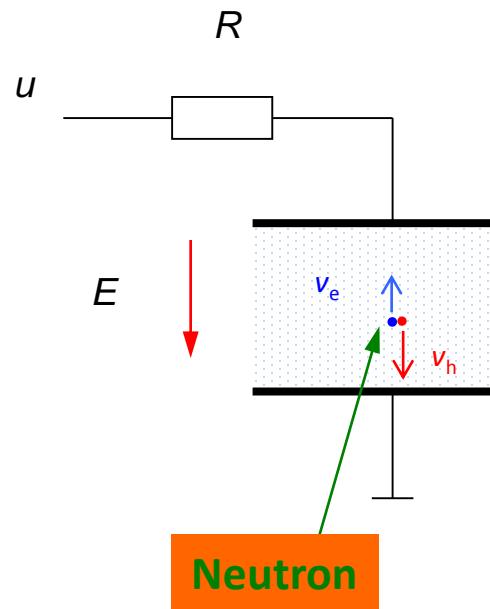


$$i_0 = \frac{Q_s \times v_d}{d}$$

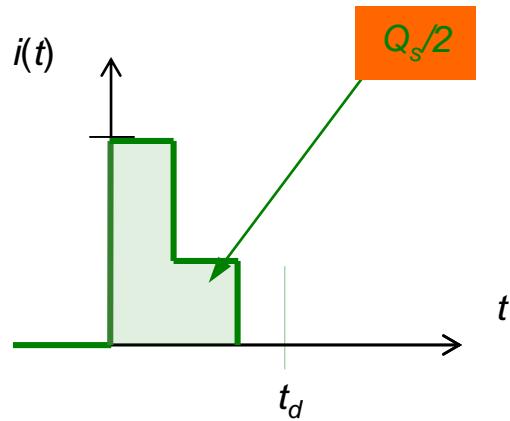


Example

3. Neutron ionization:

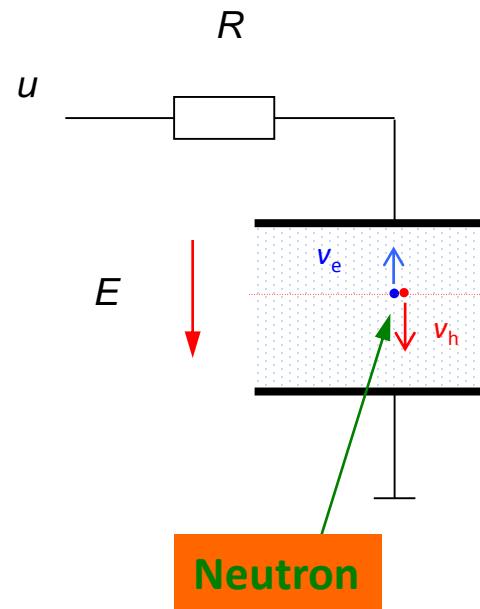


$$i_0 = \frac{Q_s \times v_d}{d}$$

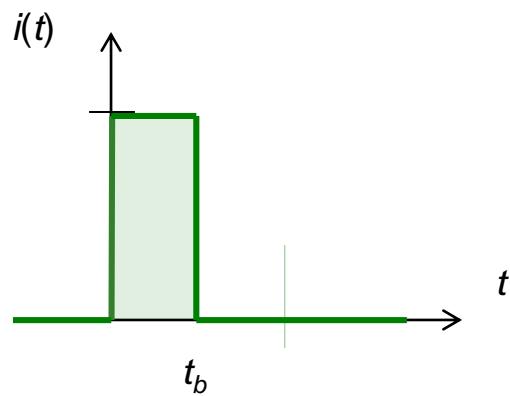


Example

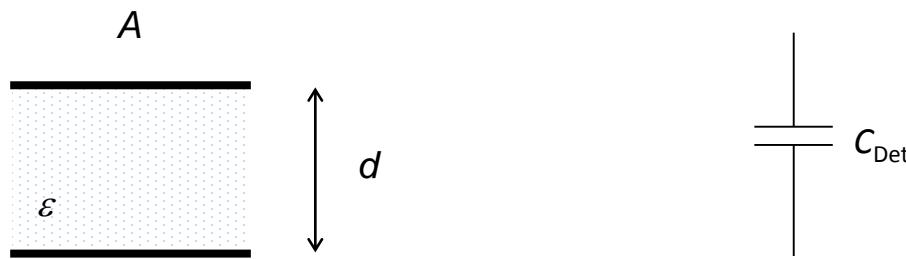
4. Neutron ionization:



Ballistic centre

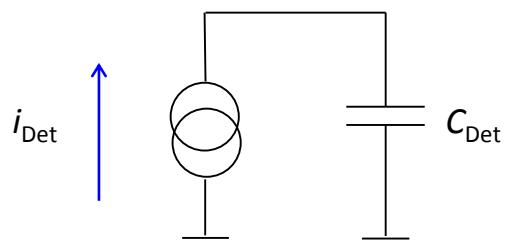


Electrical equivalent

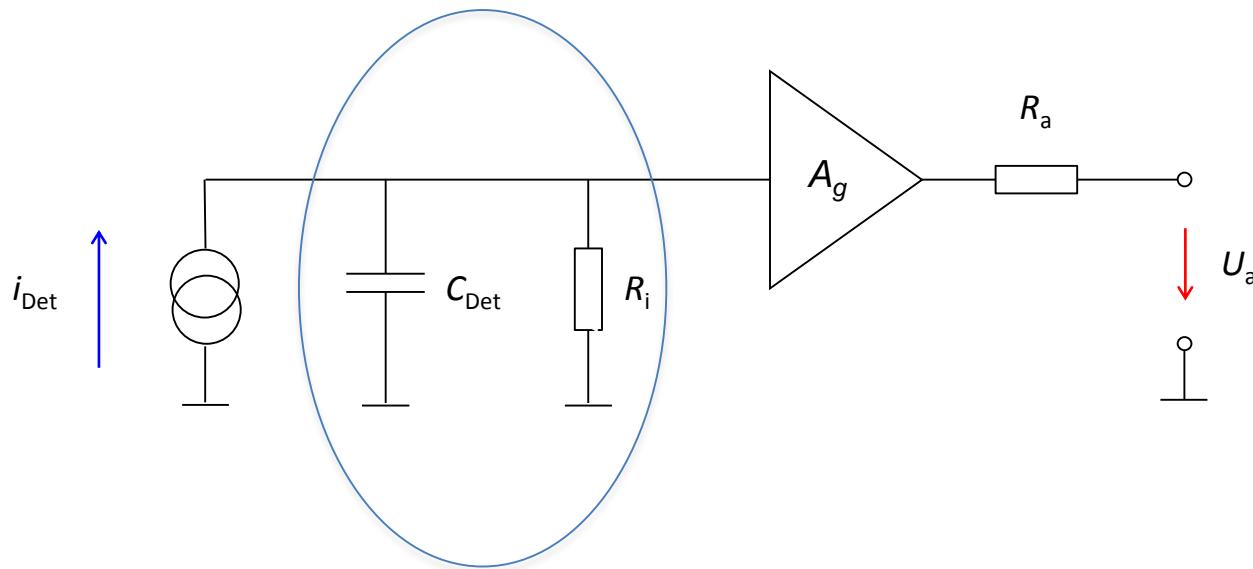


$$C_{\text{Det}} = \epsilon \times \frac{A}{d}$$

Electrical equivalent diagram

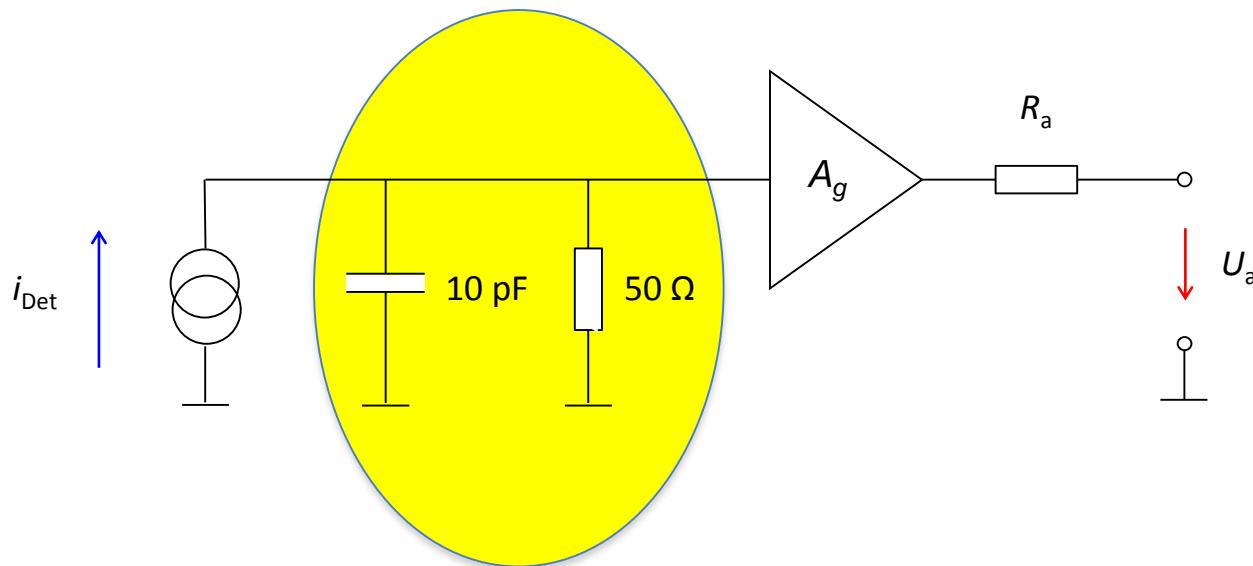


Electrical equivalent diagram



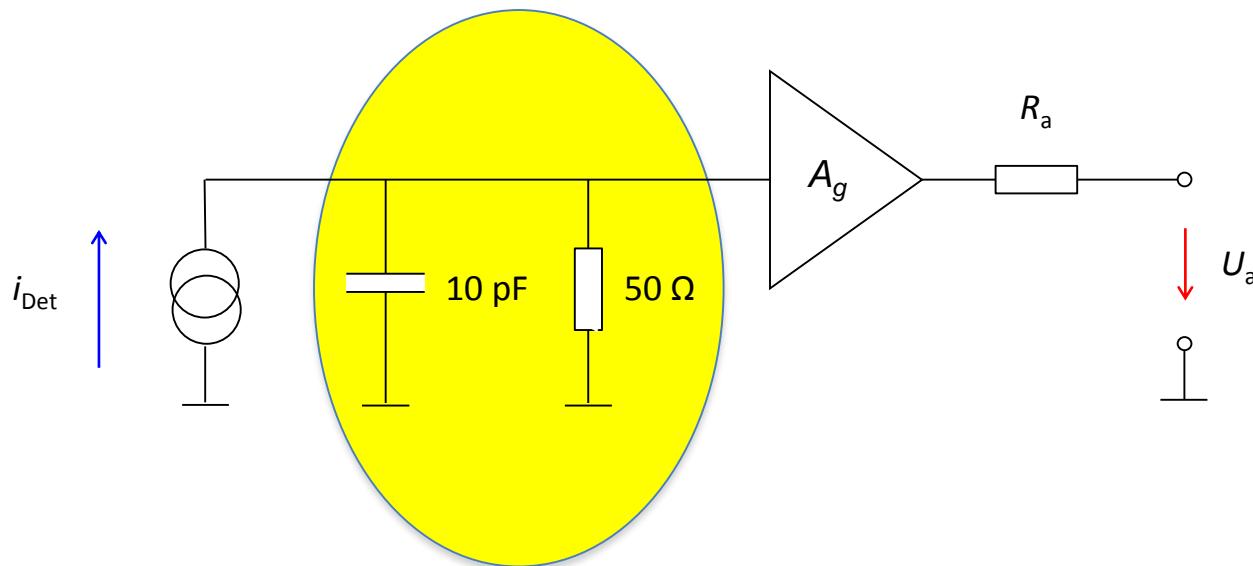
Electric time constant: $t = R_i \times C_{\text{Det}}$

Example



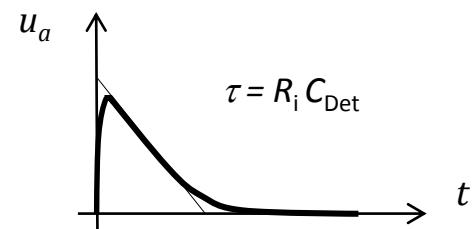
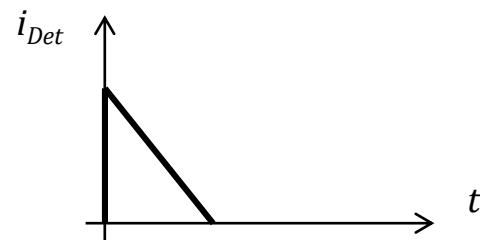
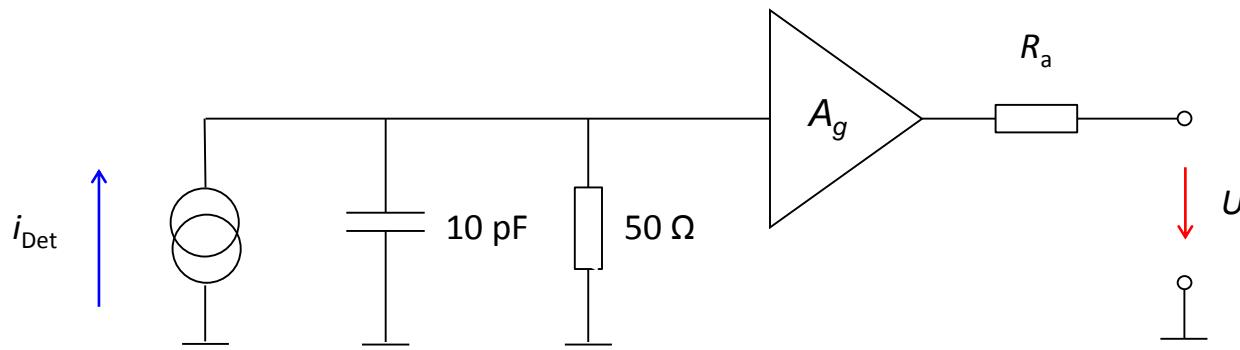
Electric time constant: $t = R_i \times C_{\text{Det}}$ $t = 500 \text{ ps}$

Example

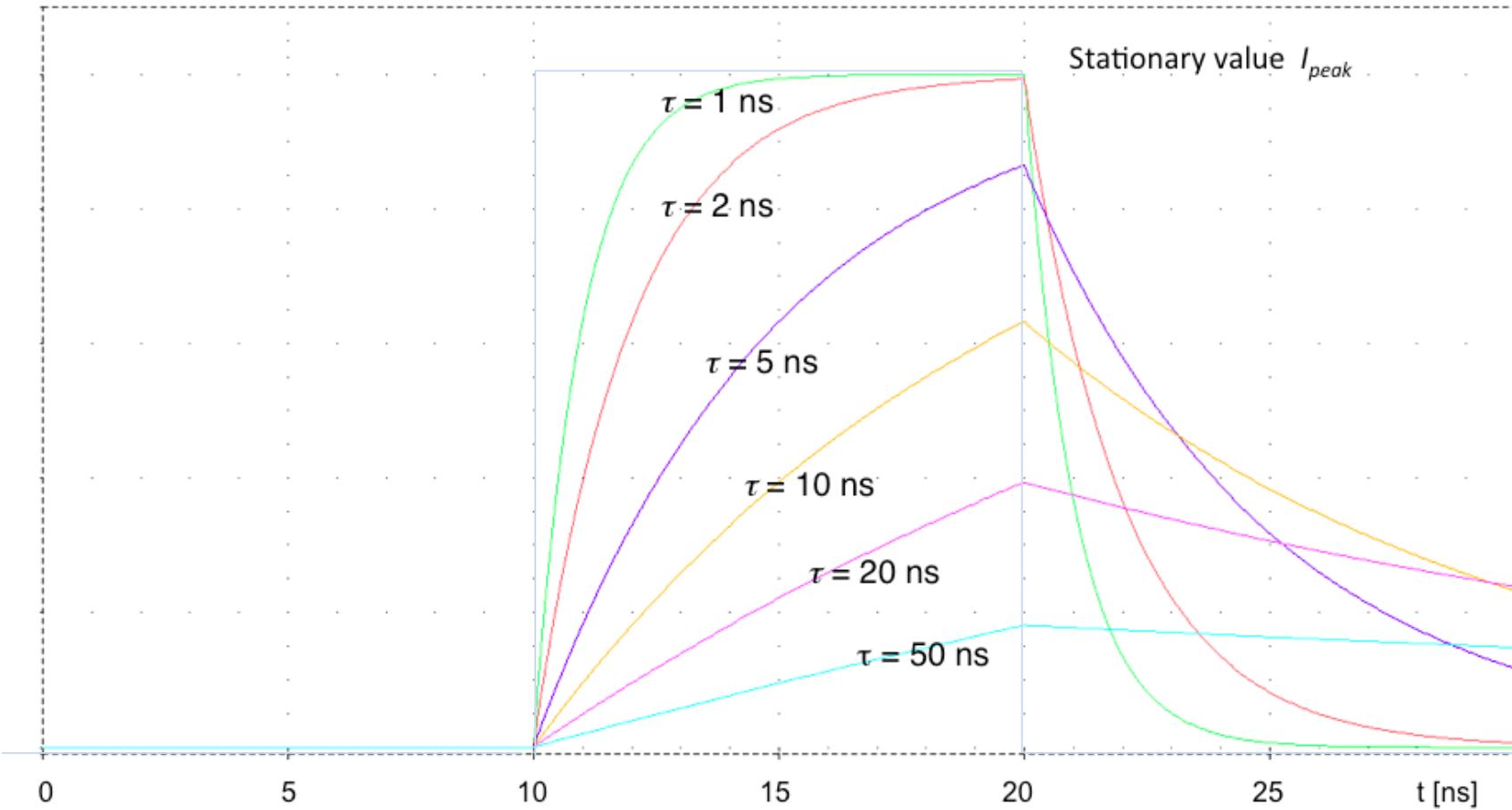


Electric time constant: $t = R_i \times C_{Det}$ $t = 500 \text{ ps}$ $f_L = 320 \text{ MHz}$

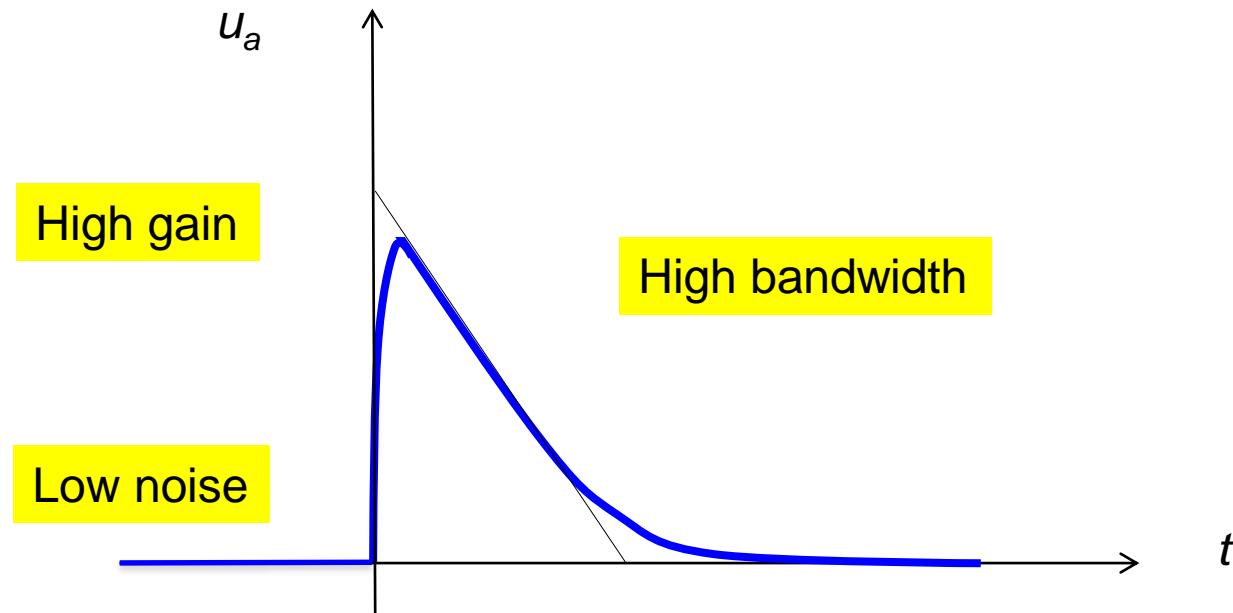
Example



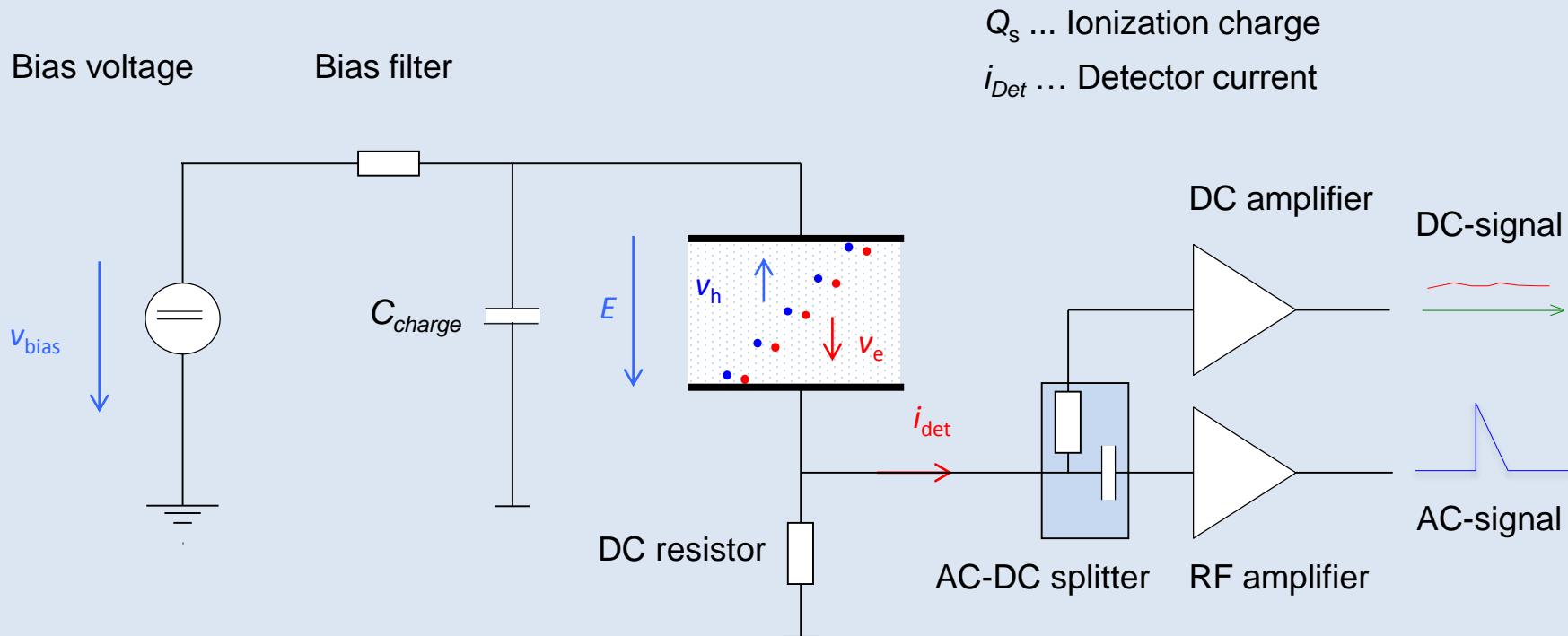
Time constant



Amplifier properties



DC-readout

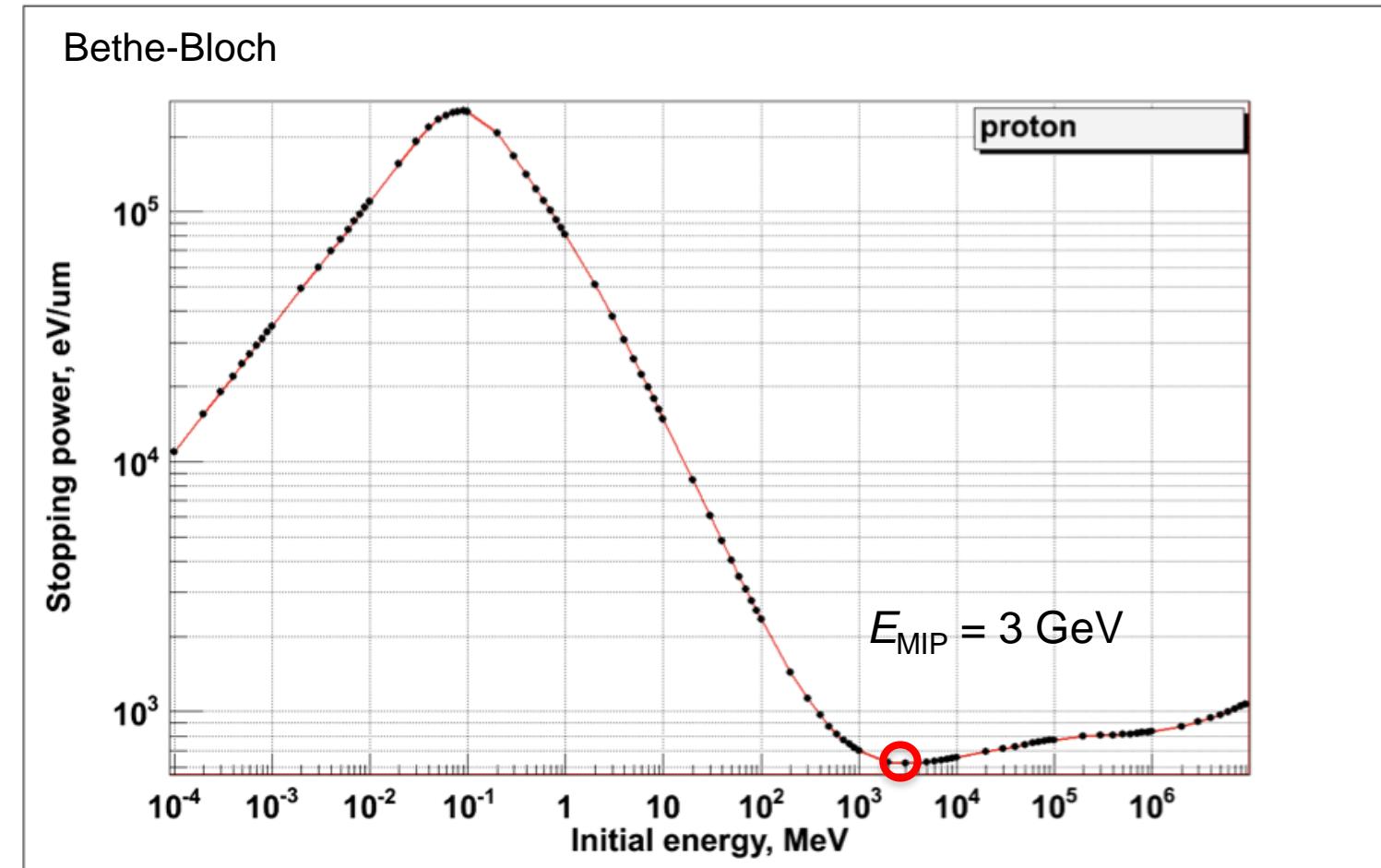


LHC DBLM

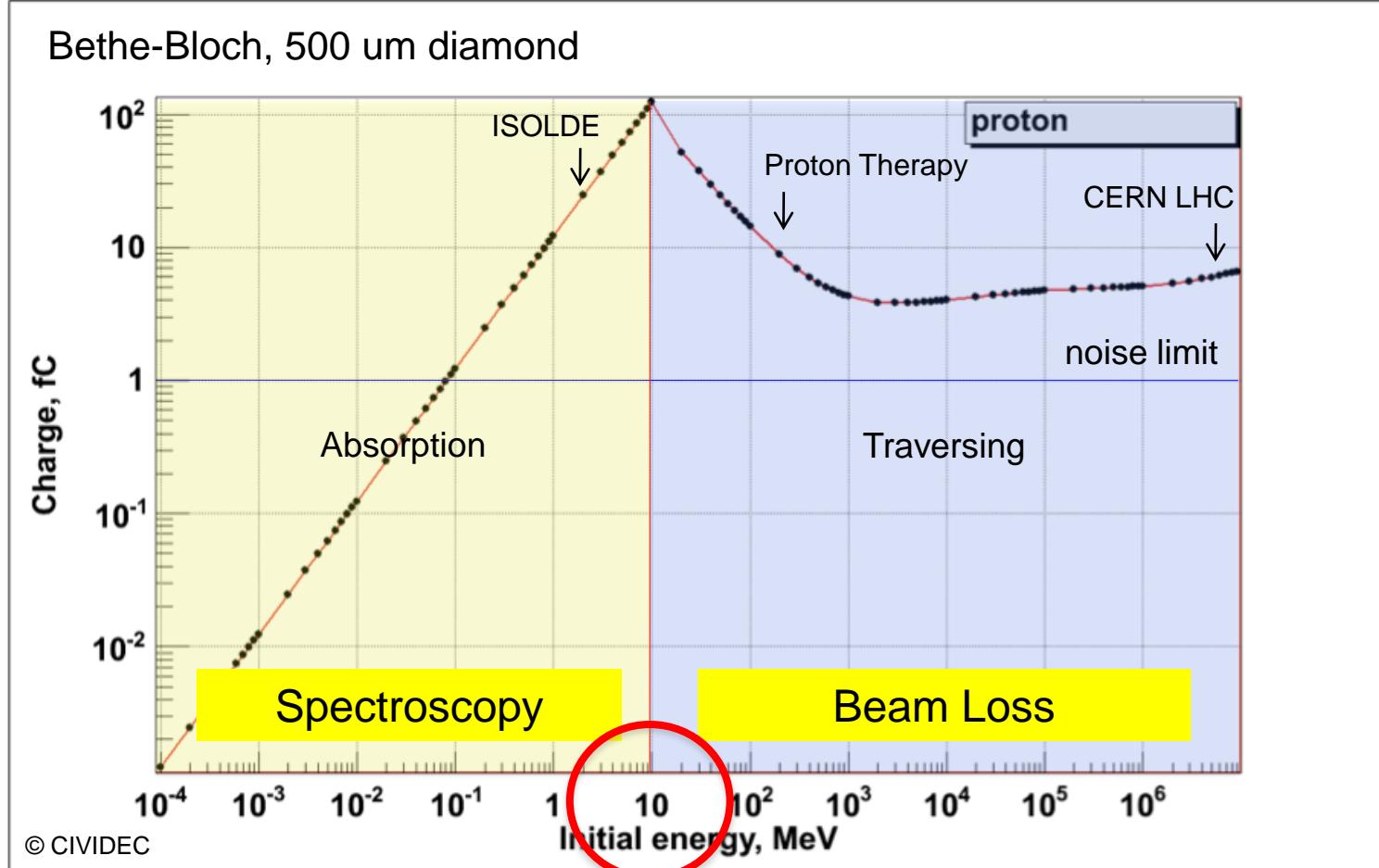


Interaction Mechanisms

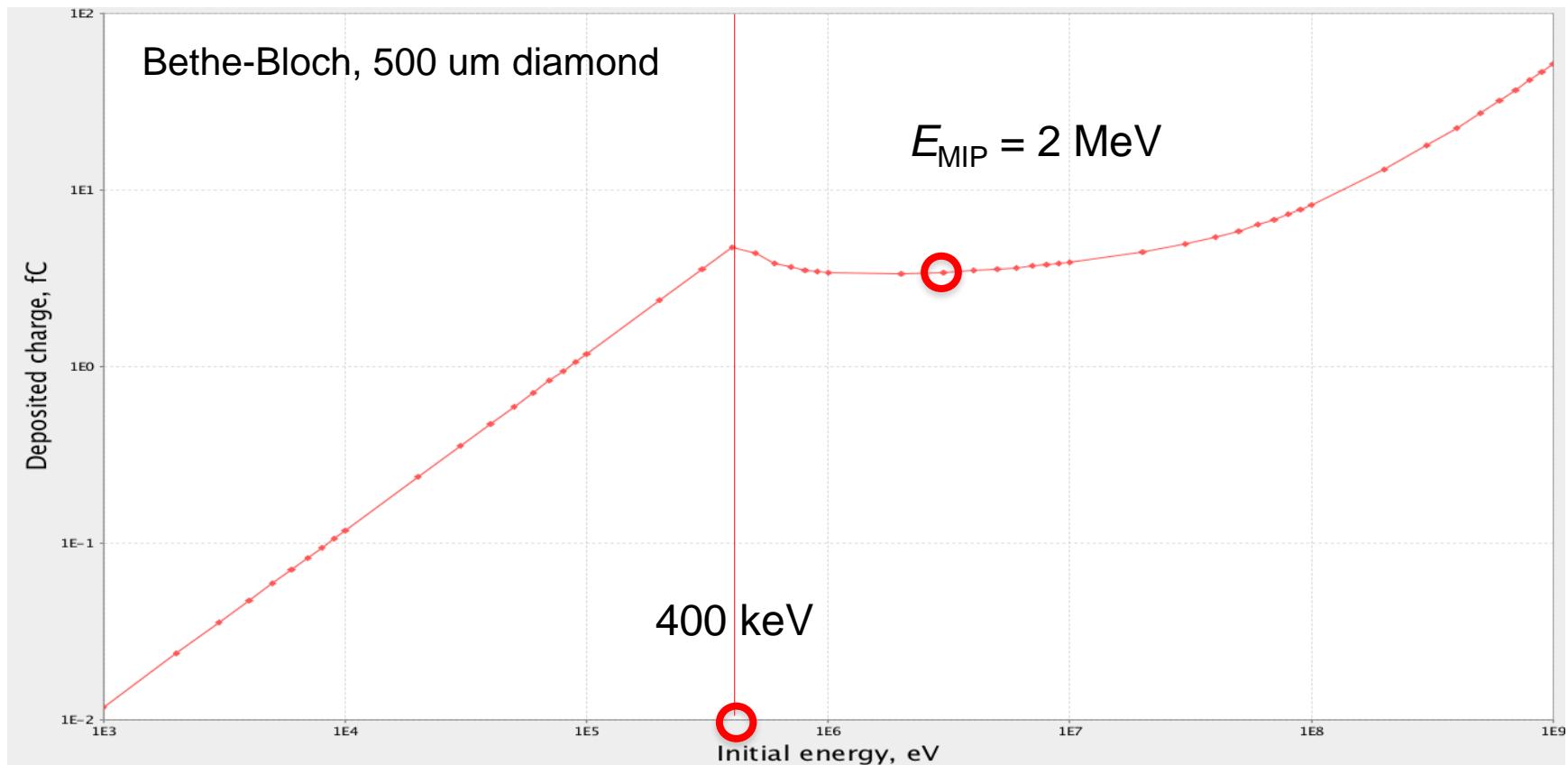
Proton interaction



Proton interaction

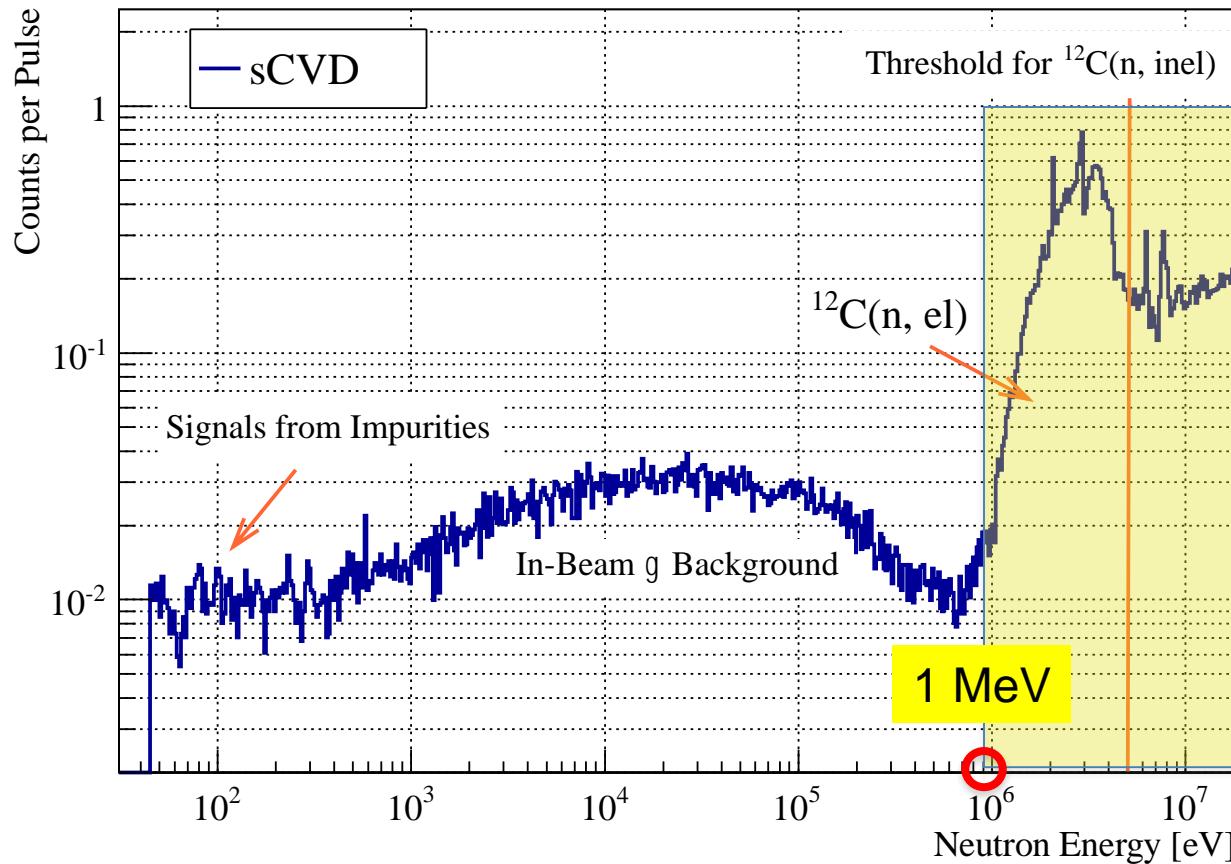


Electrons

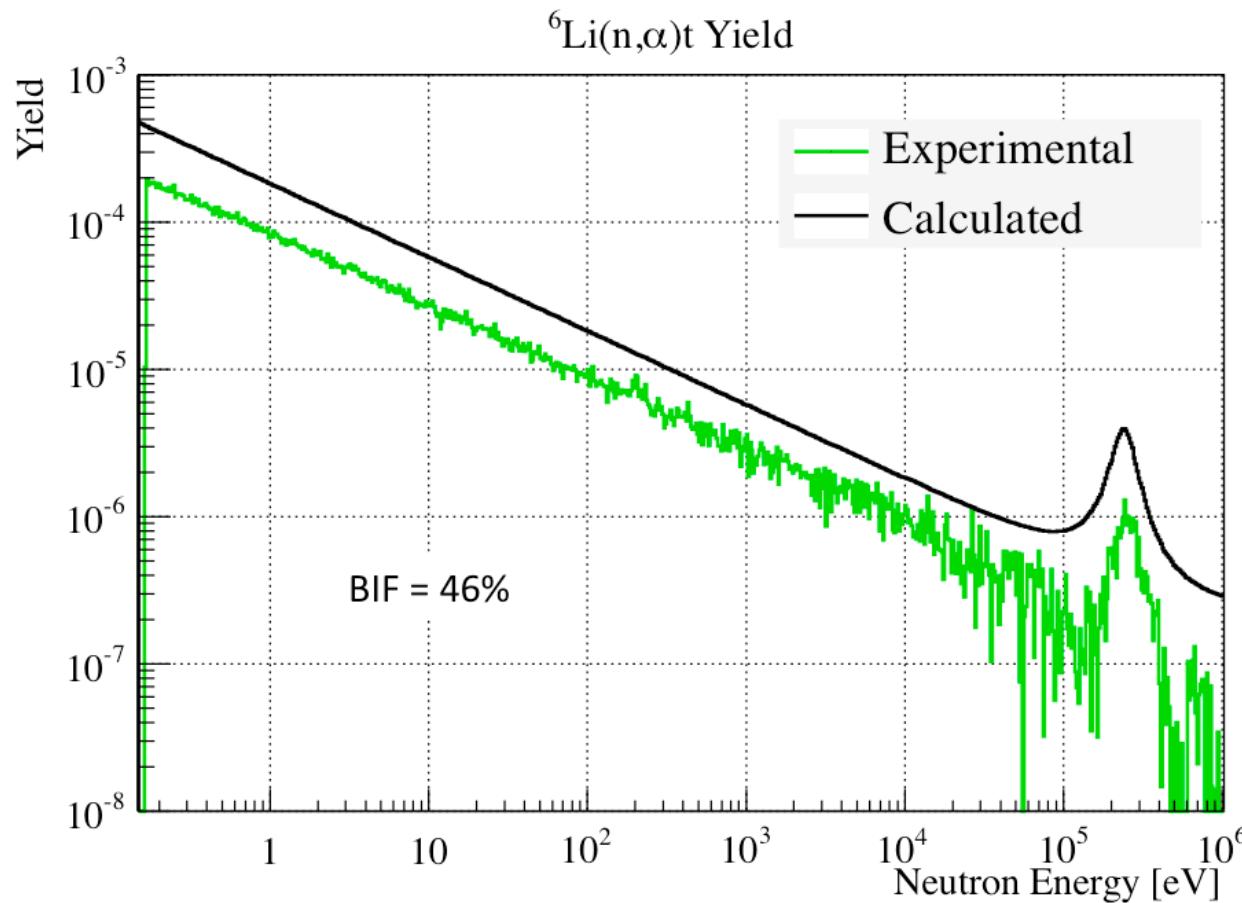


Neutron Spectrum

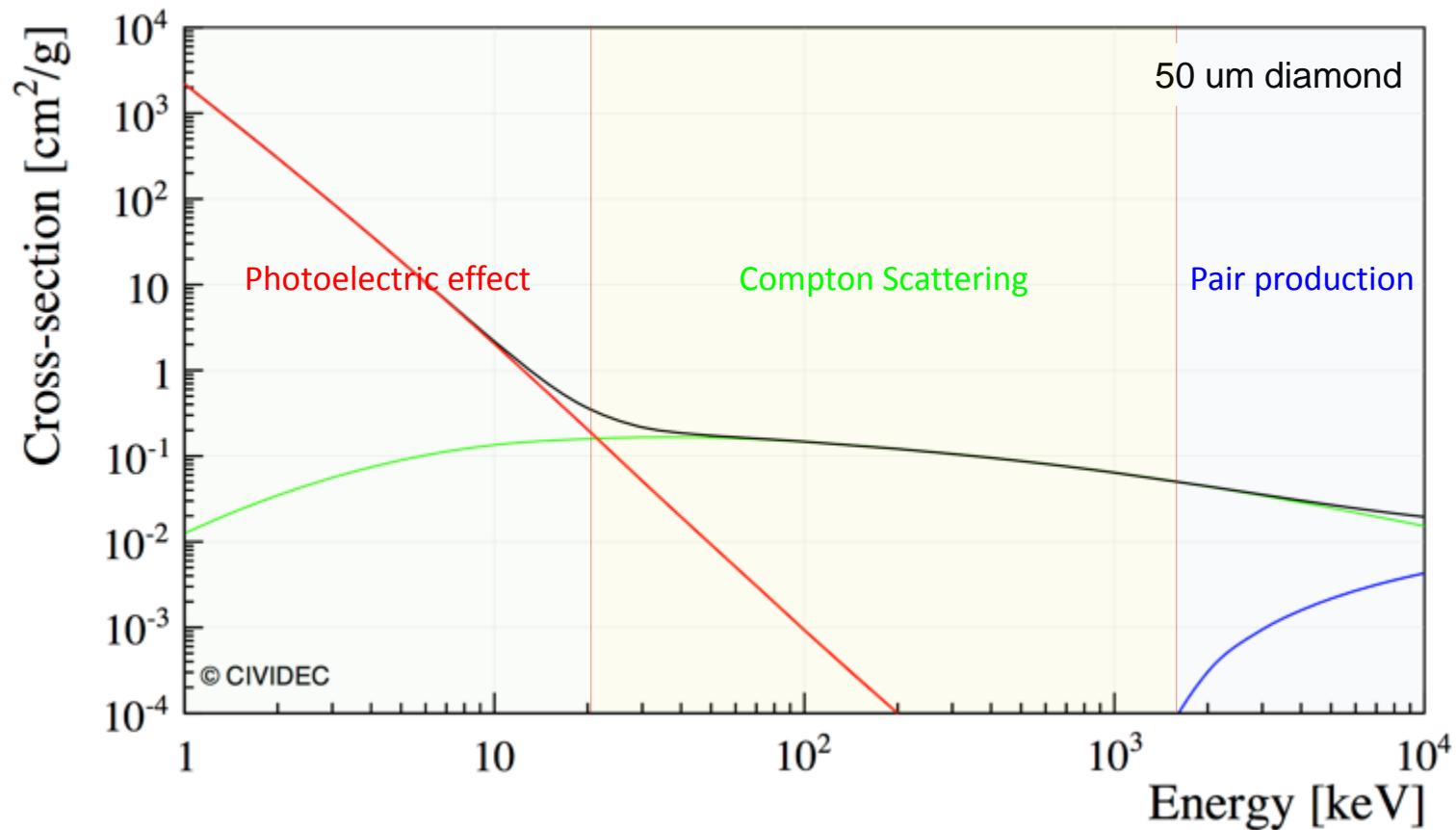
Background Measurement, n_TOF October 2010



Thermal neutrons with ${}^6\text{Li}(\text{n},\alpha)\text{t}$



Photon interaction



Content

- Principles
- Beam Loss Diagnostics
- Neutron Diagnostics

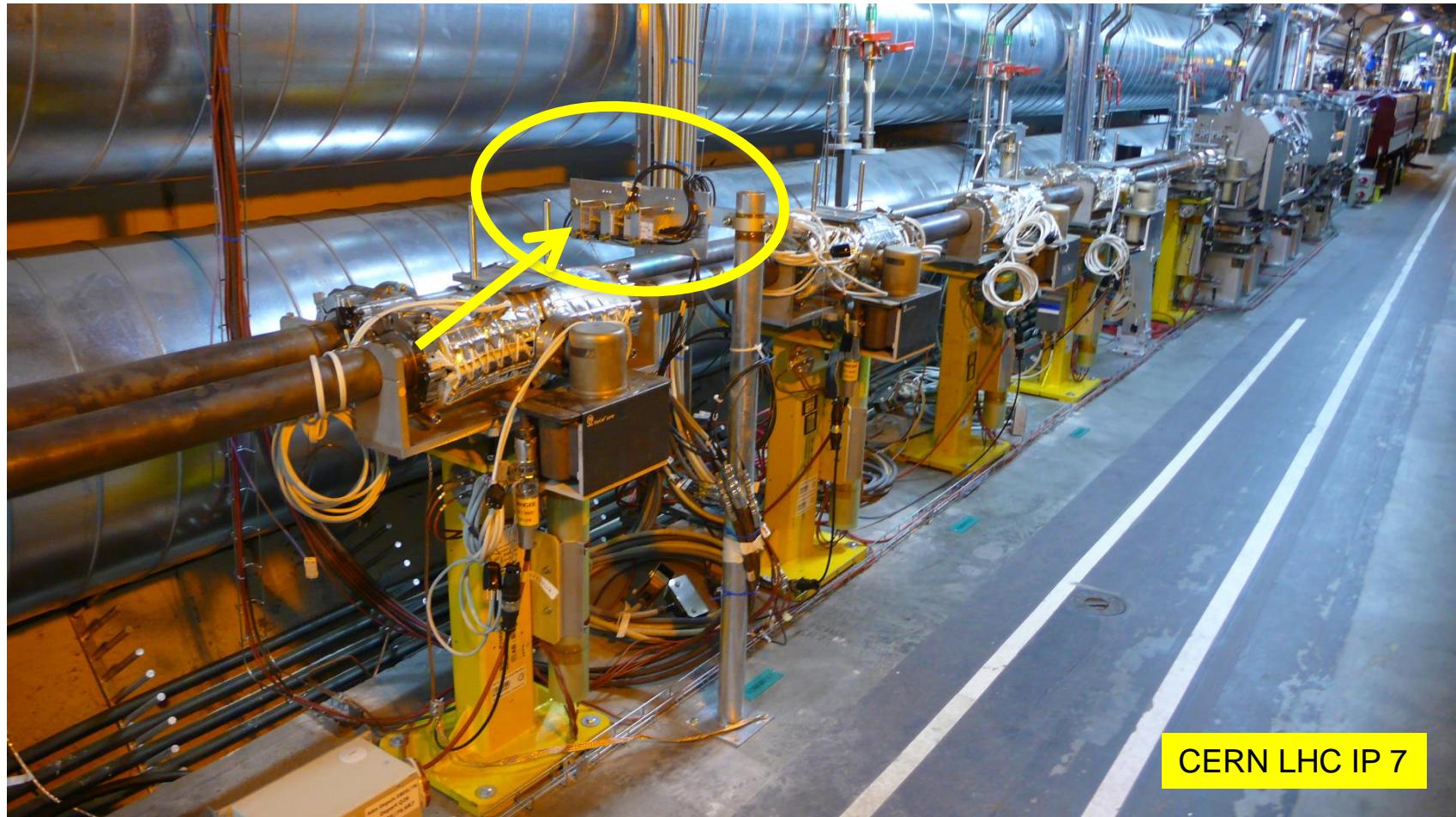
Four measurement examples:

- 1. LHC Beam Loss Monitoring**
- 2. High Radiation Detector**
- 3. Beam Position Monitor**
- 4. Phase Measurements**

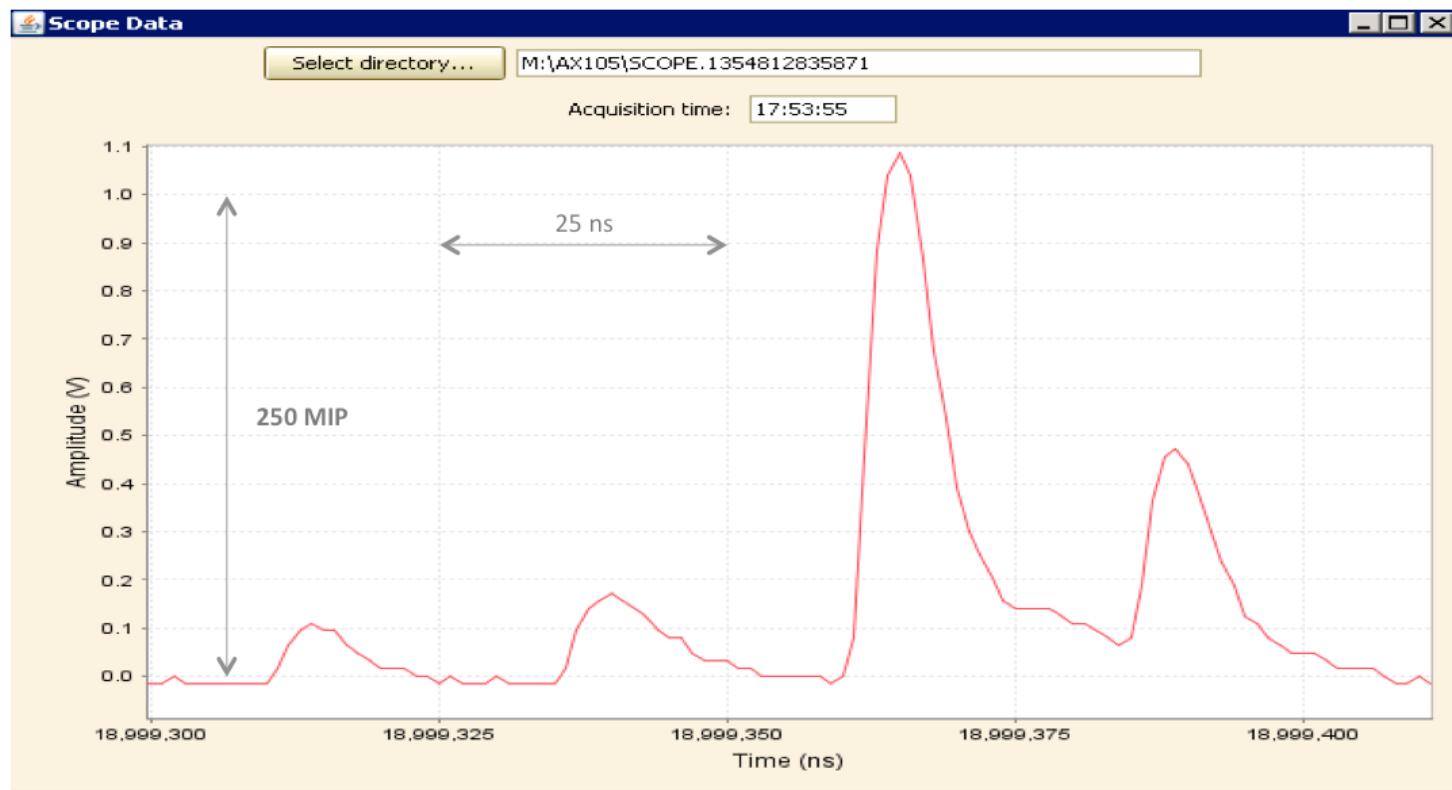
Example 1:

LHC Beam Loss Monitor

LHC DBLM

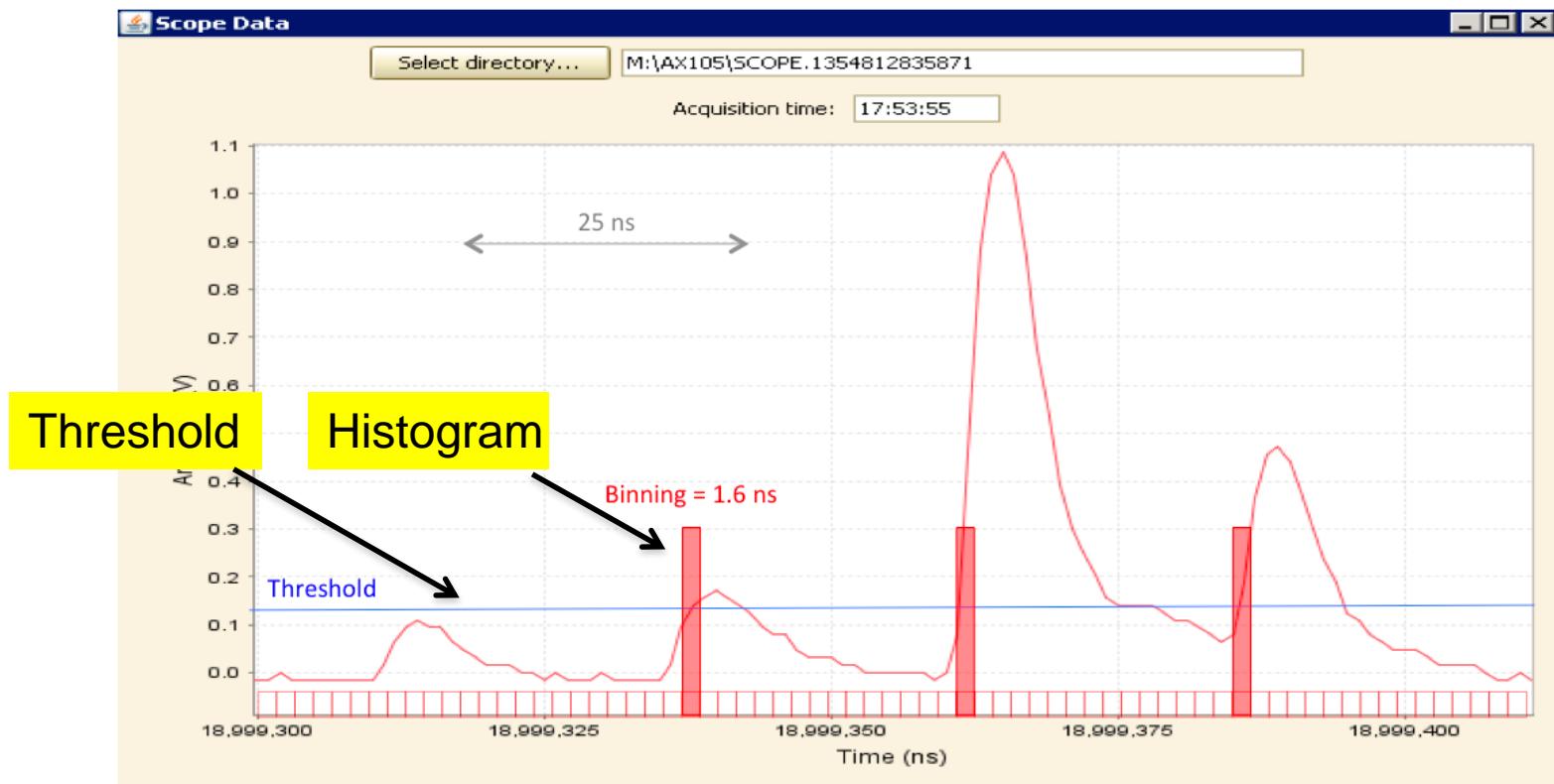


Bunch-by-bunch losses



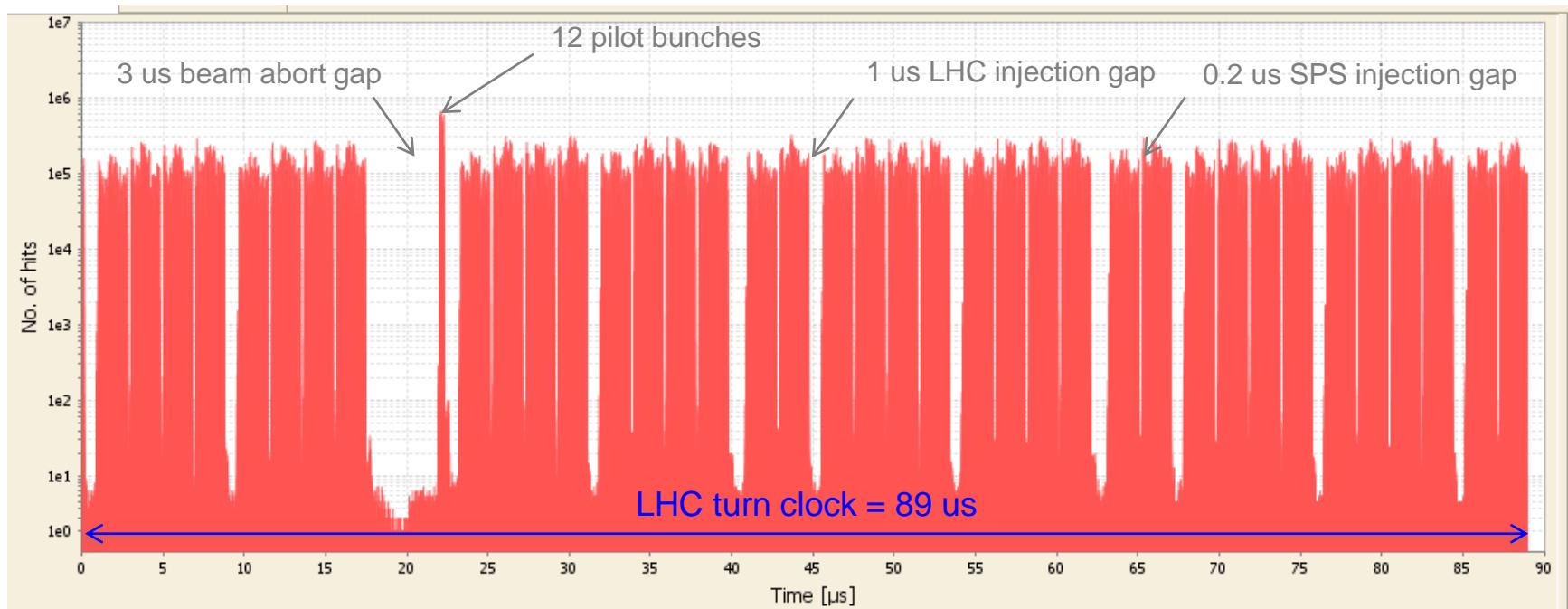
Pulse shape of losses, 25 ns bunch separation, 0.8 ns sampling period.

Loss Histogram



Pulse shape of losses, 25 ns per unit, 1.6 ns per bin

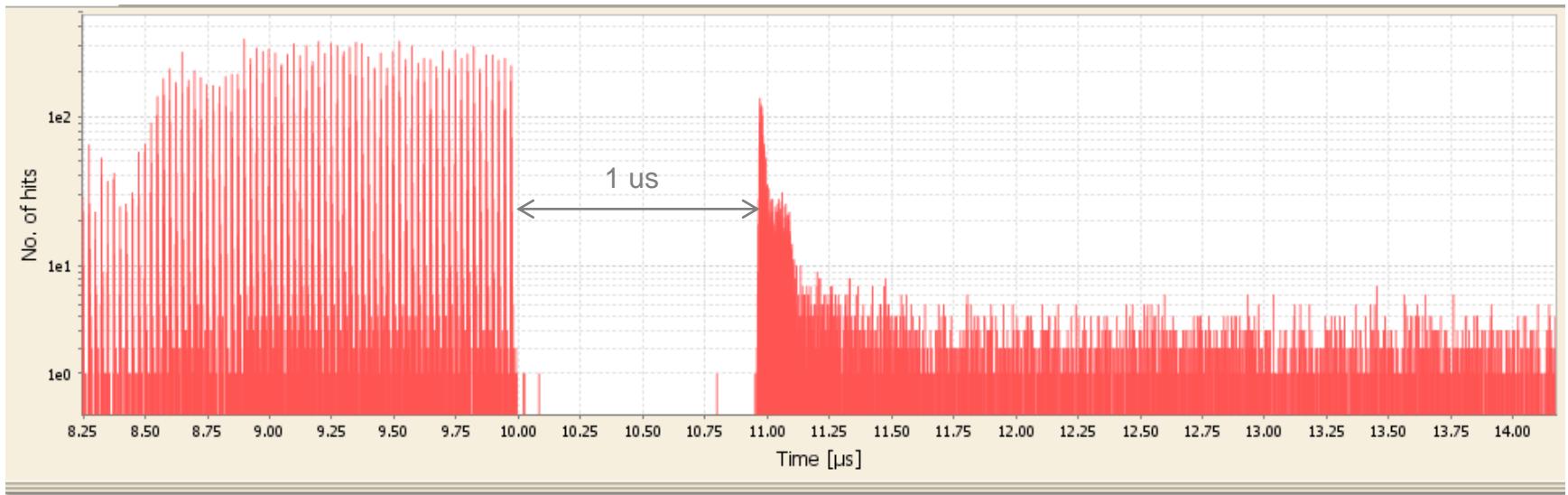
Static operation



Static losses after ramp - 89 us turn period

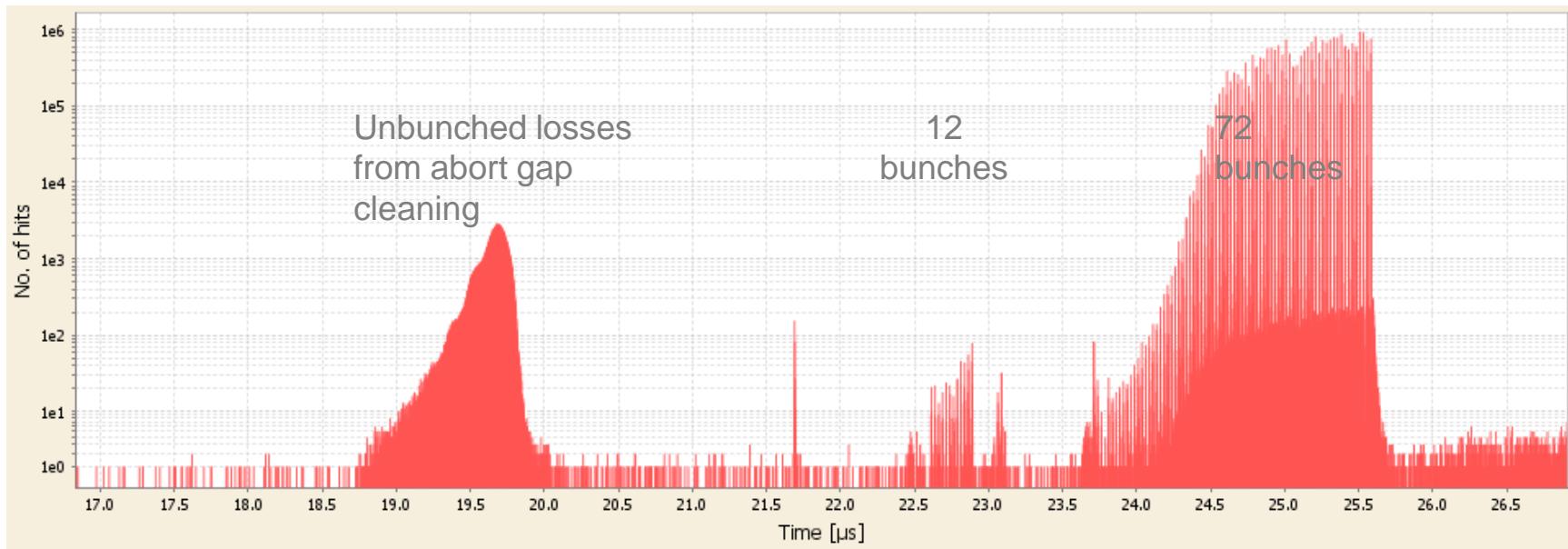
Batches of 4x36 bunches, 3 us beam abort gap, injection gaps: LHC = 1 us, SPS = 0.2 us
12 pilot bunches

Injection cleaning

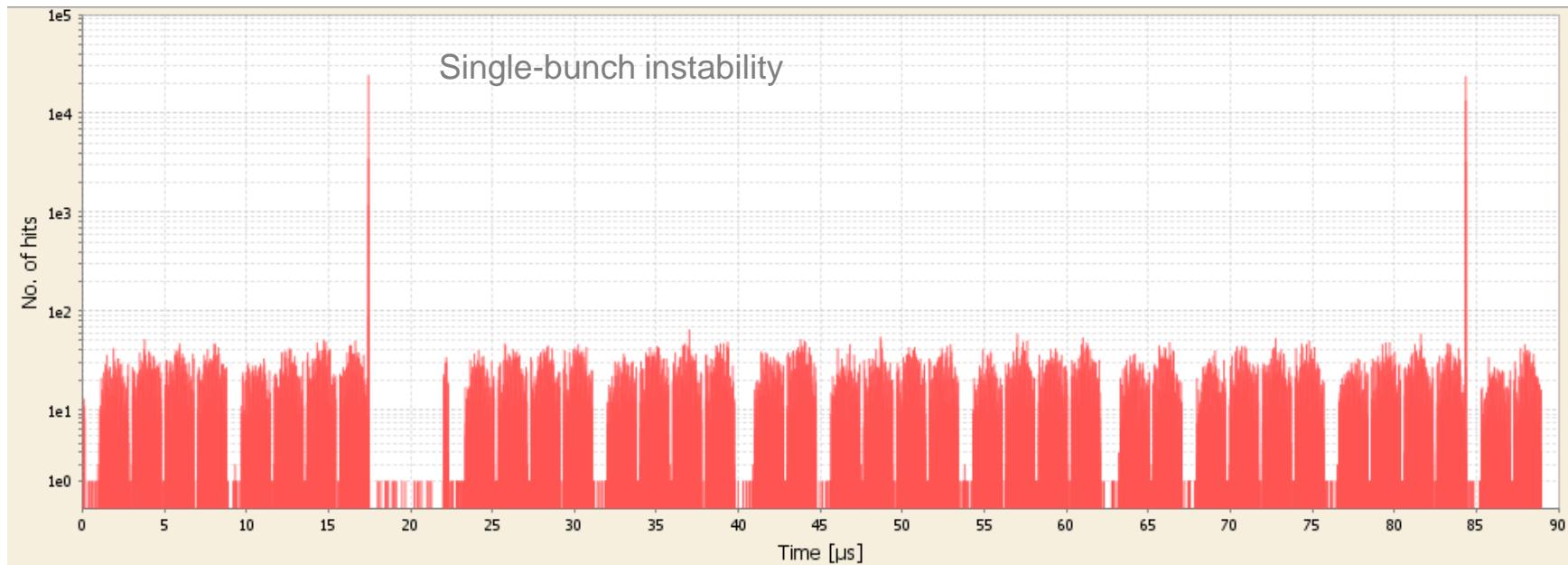


Injection cleaning, synchronous losses before and asynchronous losses after the beam abort gap

Beam abort gap cleaning

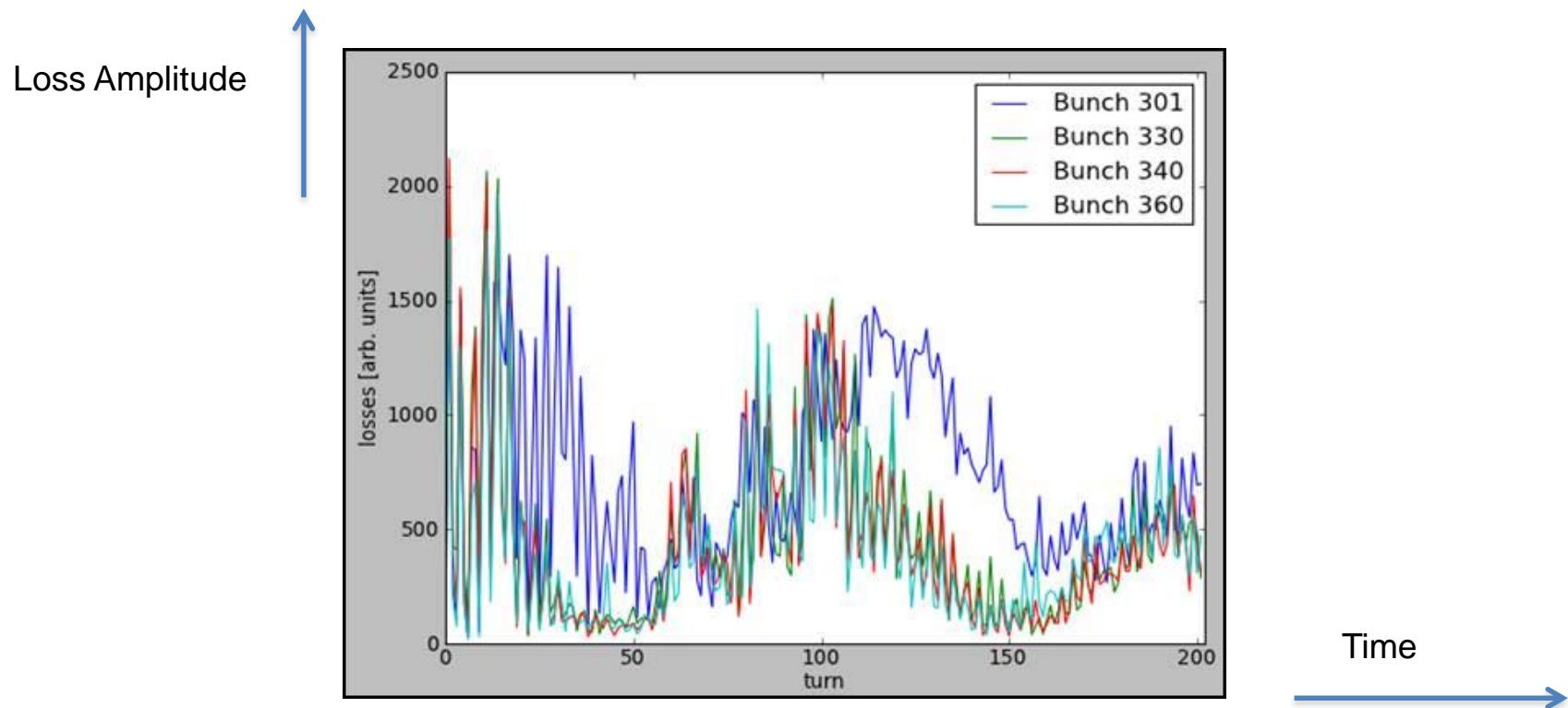


Single-Bunch Instability



Single-bunch instabilities at the end of a squeeze.

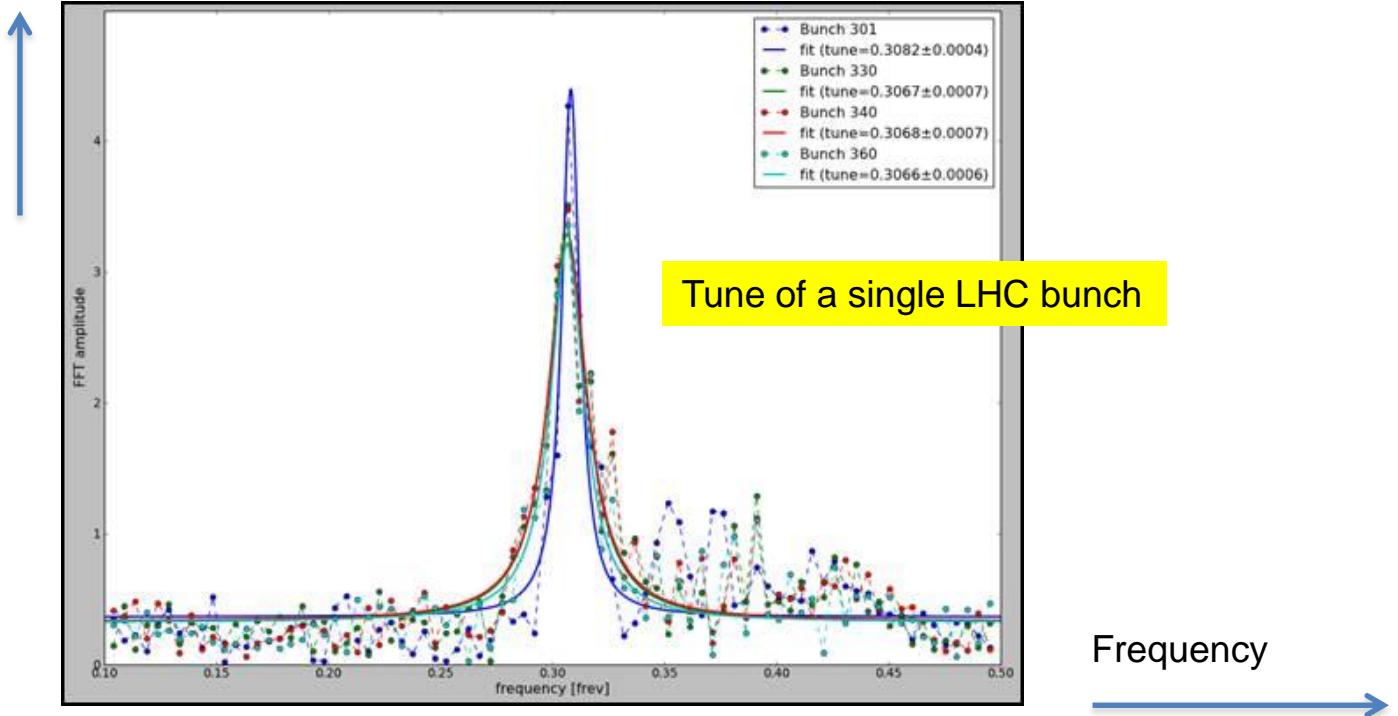
Tune measurement



Losses of 4 individual bunches over 200 turns.

Tune measurement

Spectral Amplitude



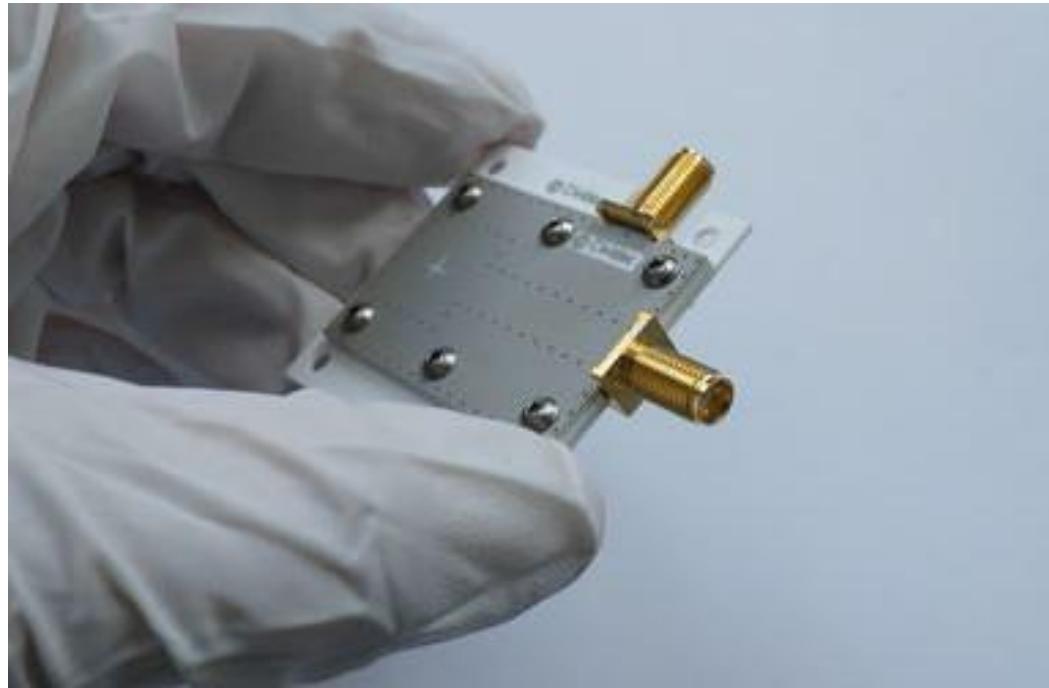
Horizontal tune = 0.307.

Reference tune: BBQ = 0.307.

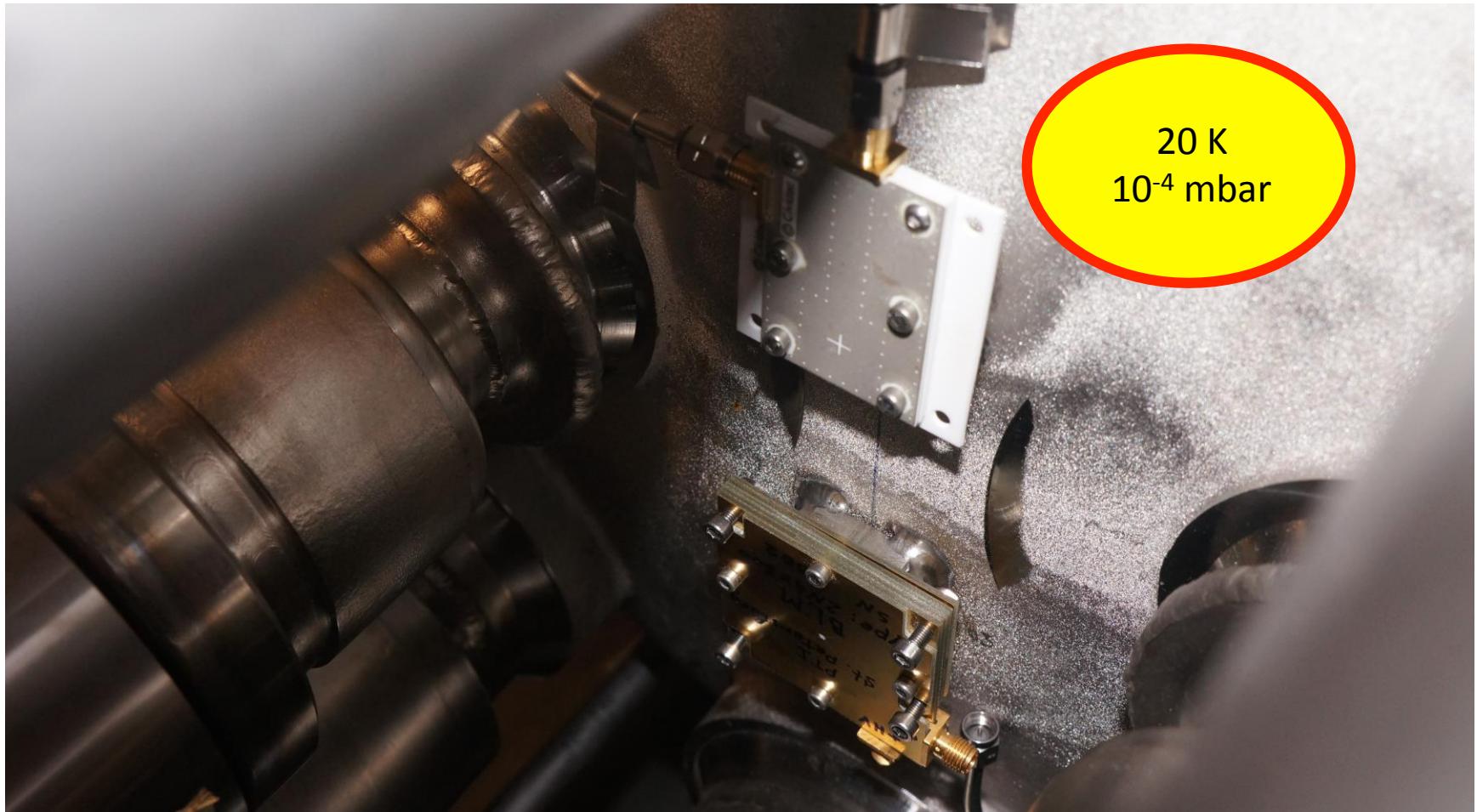
Kryogenic Application



Cryogenic Diamond Detector



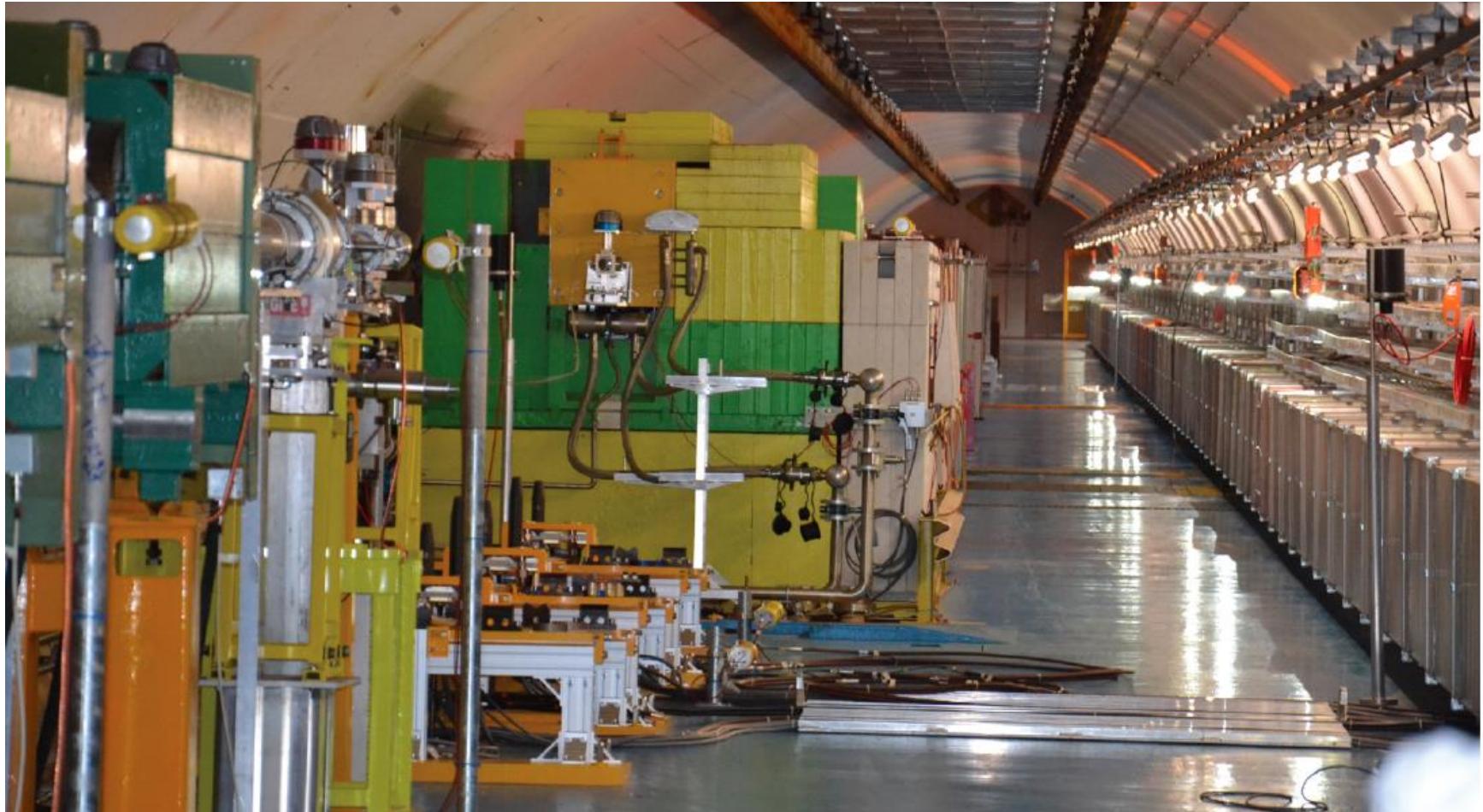
LHC Quadrupole



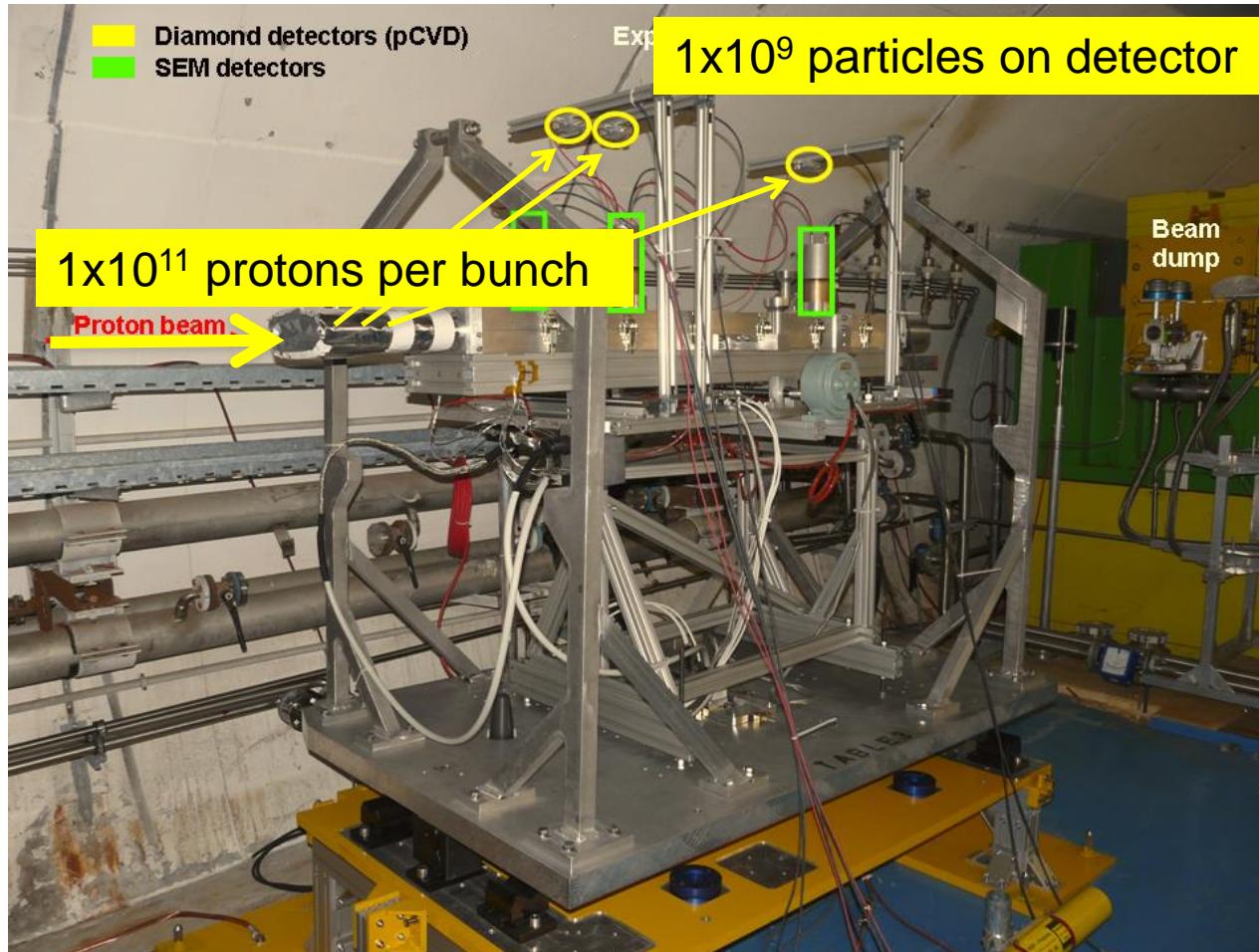
Example 2:

High-Radiation Detector

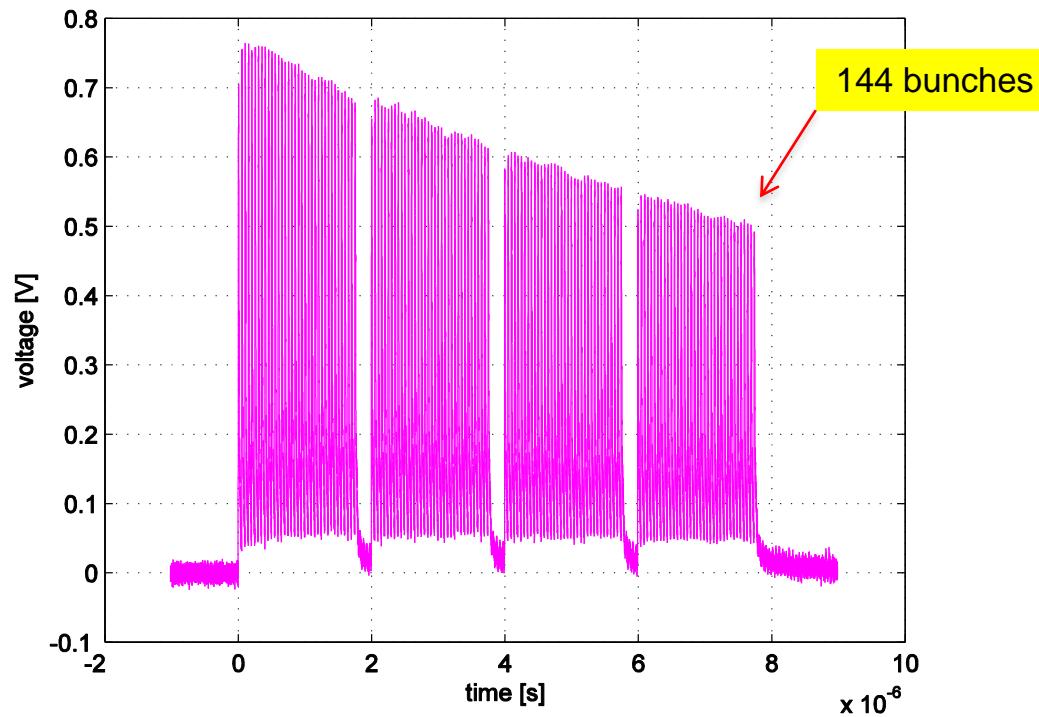
HiRadMat



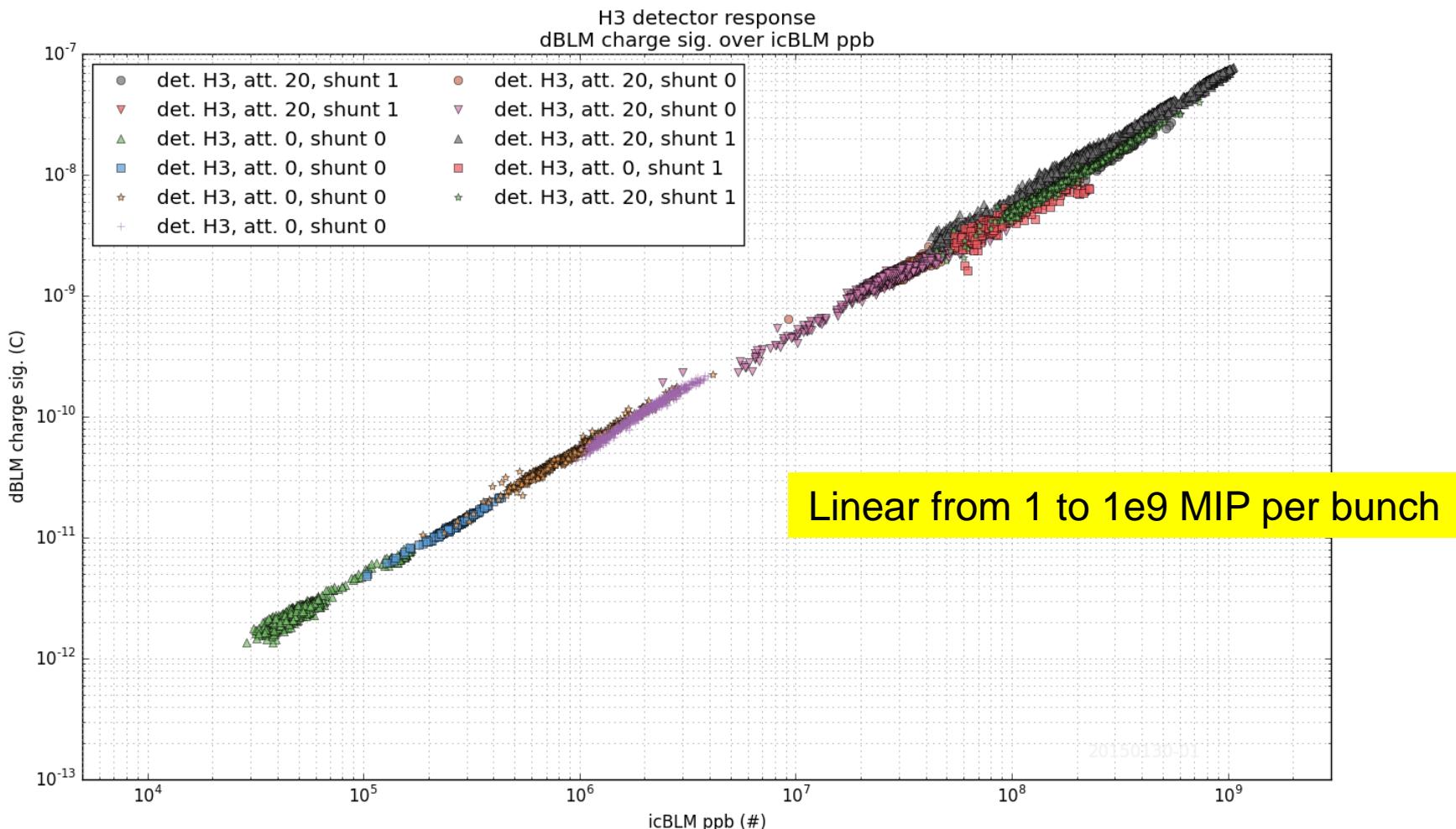
HiRadMat



Detector Response

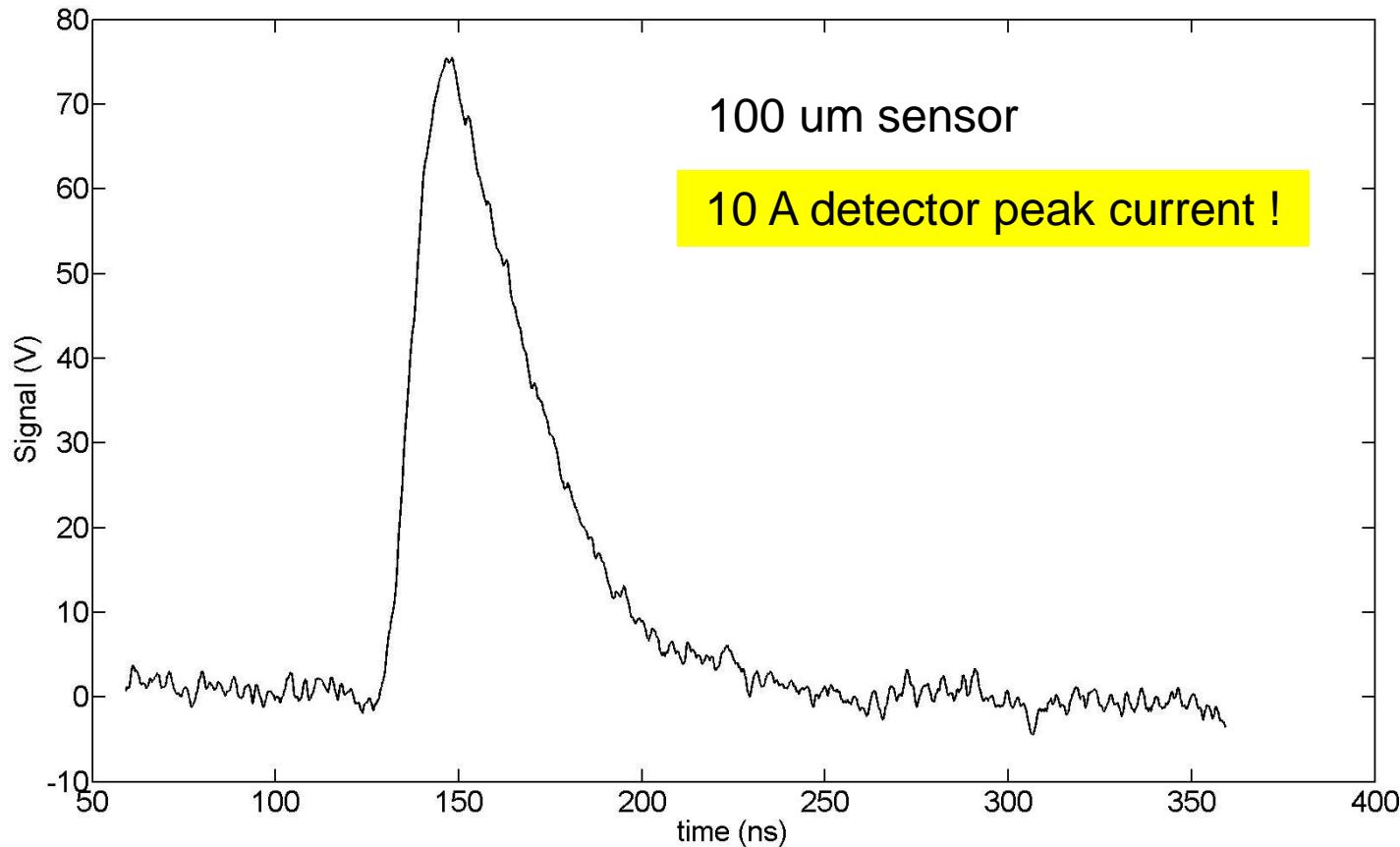


Linearity



Courtesy: BTF group Frascati - Luca Foggetta, Paolo Valente, Bruno Buonomo, Claudio di Giulio; F. Burkart, O. Stein, CERN, Shan Liu, Université Paris-Sud

Single bunch of $1\text{e}9$

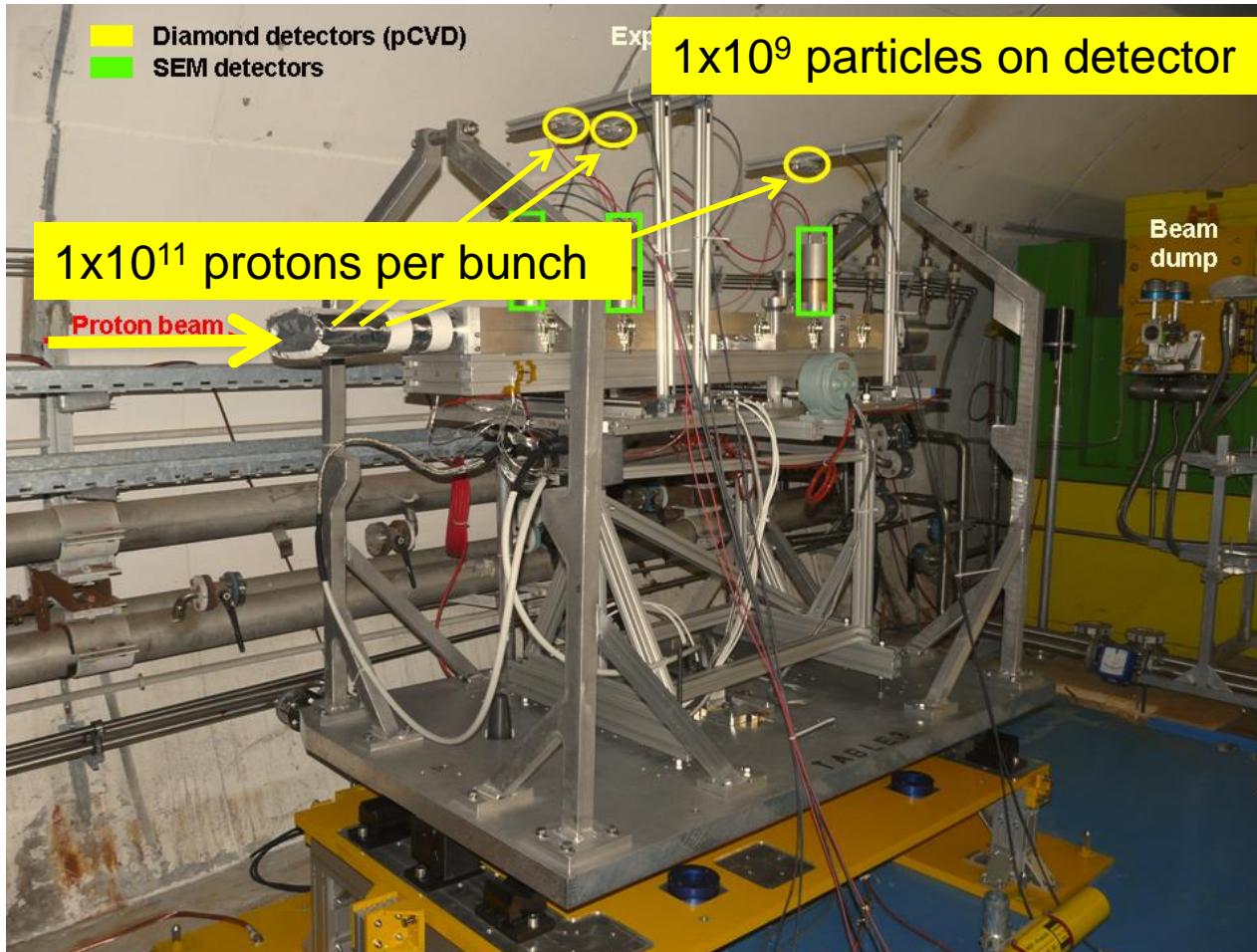


Courtesy: BTF group Frascati - Luca Foggetta, Paolo Valente, Bruno Buonomo, Claudio di Giulio;
F. Burkart, O. Stein, CERN

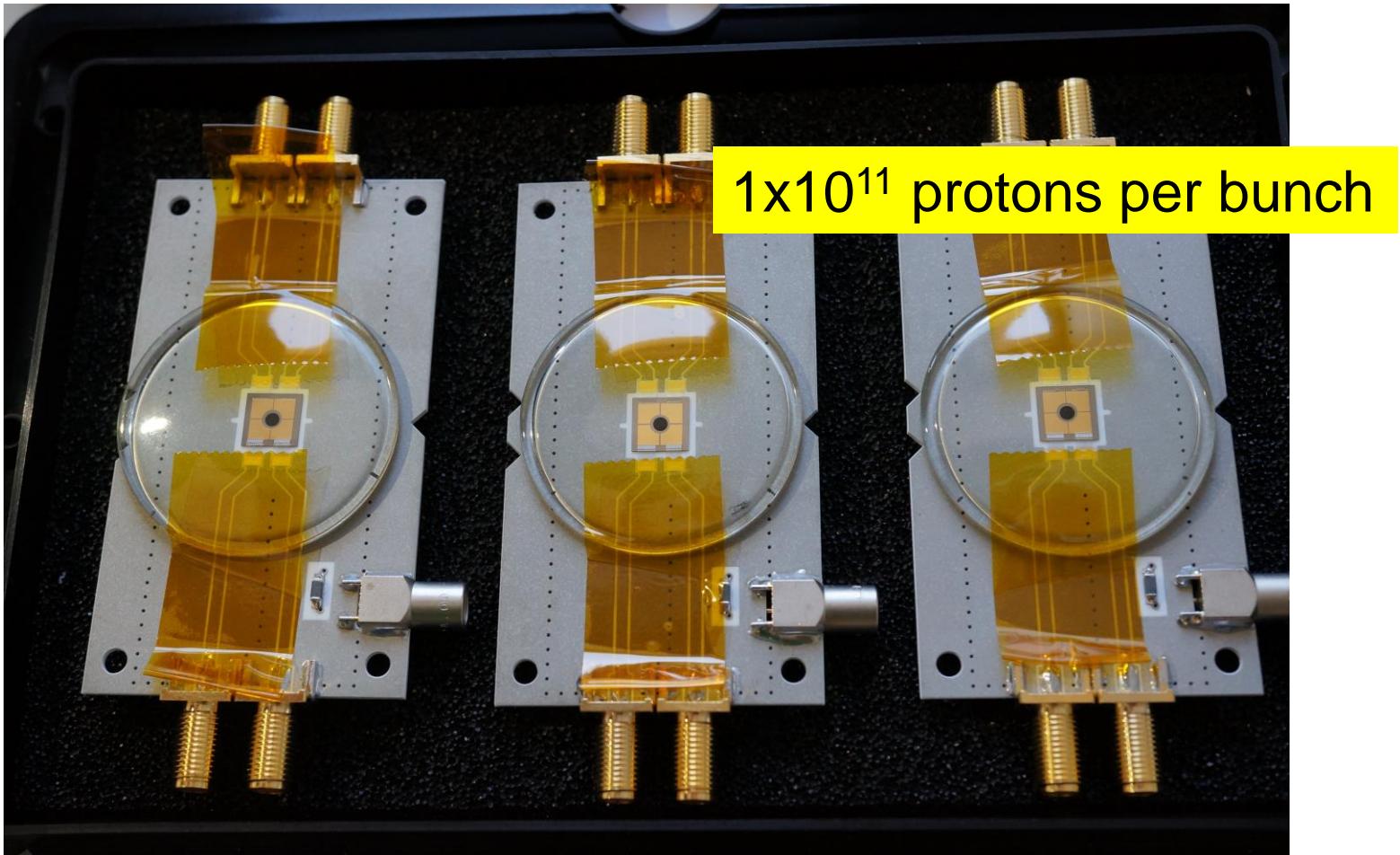
Example 3:

Beam Position Monitor

HiRadMat

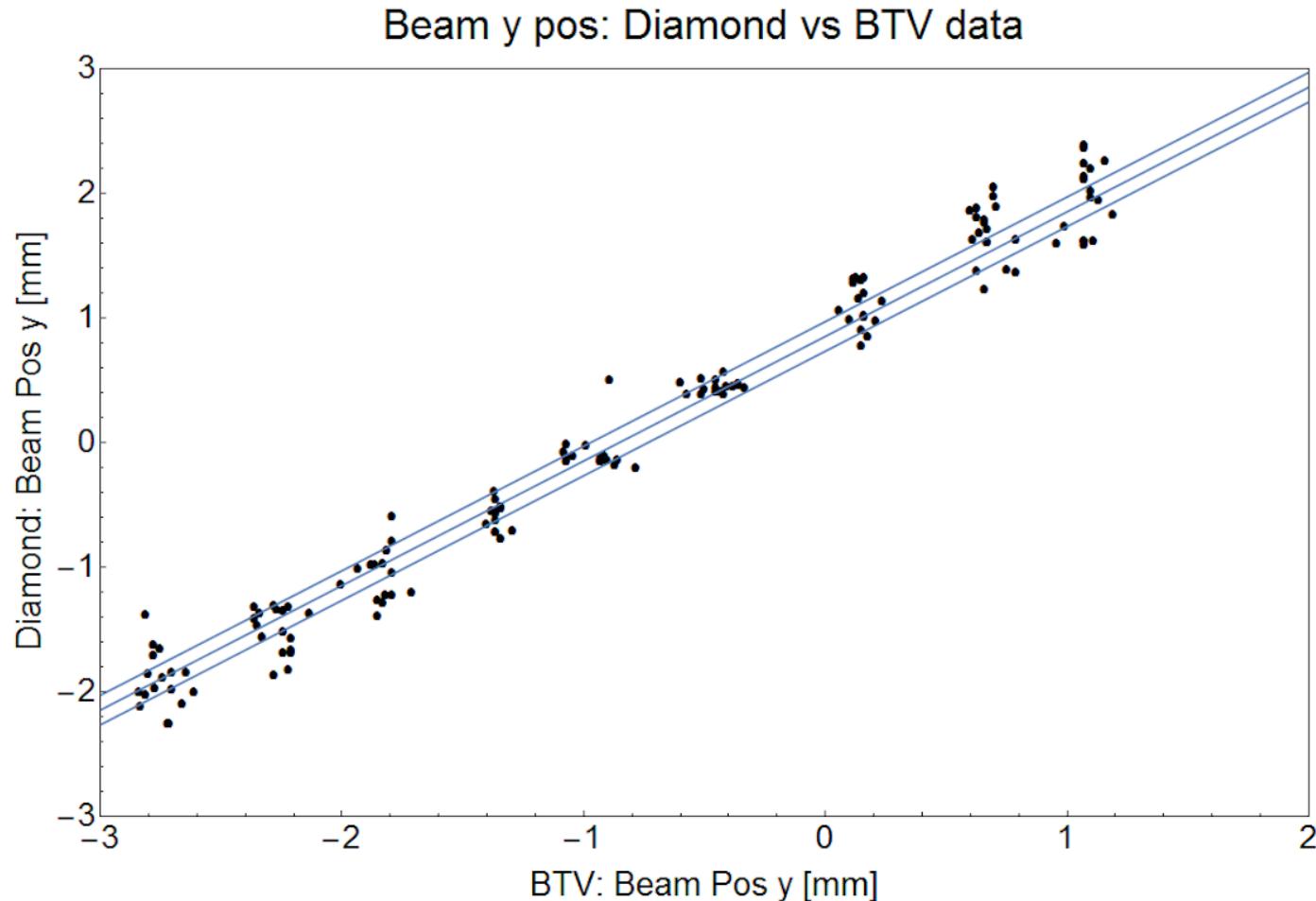


HiRadMat



Courtesy: Bjorn Hans Filip, CERN

Result: 100 um precision



Courtesy: Bjorn Hans Filip, CERN

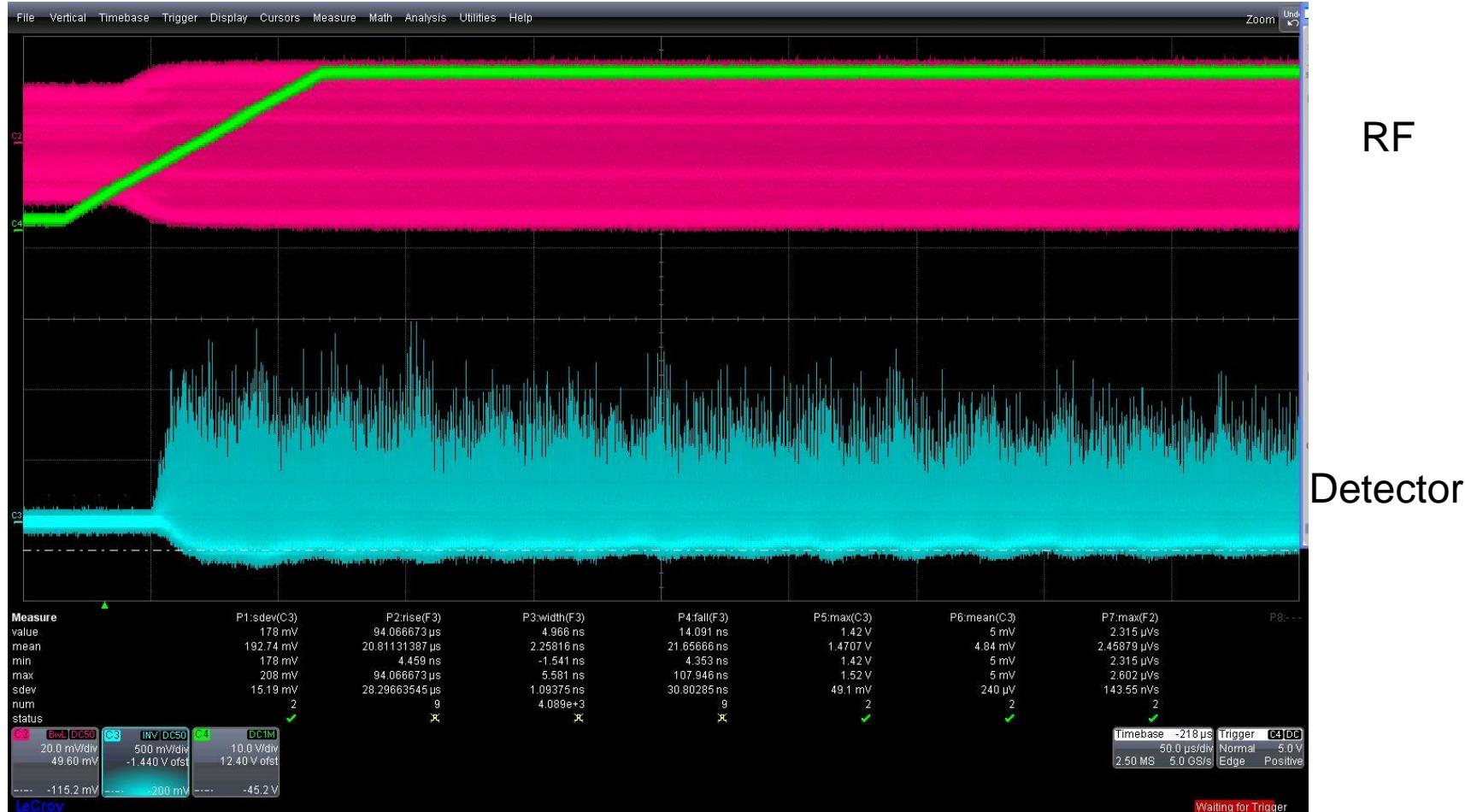
Example 4:

Phase Measurements

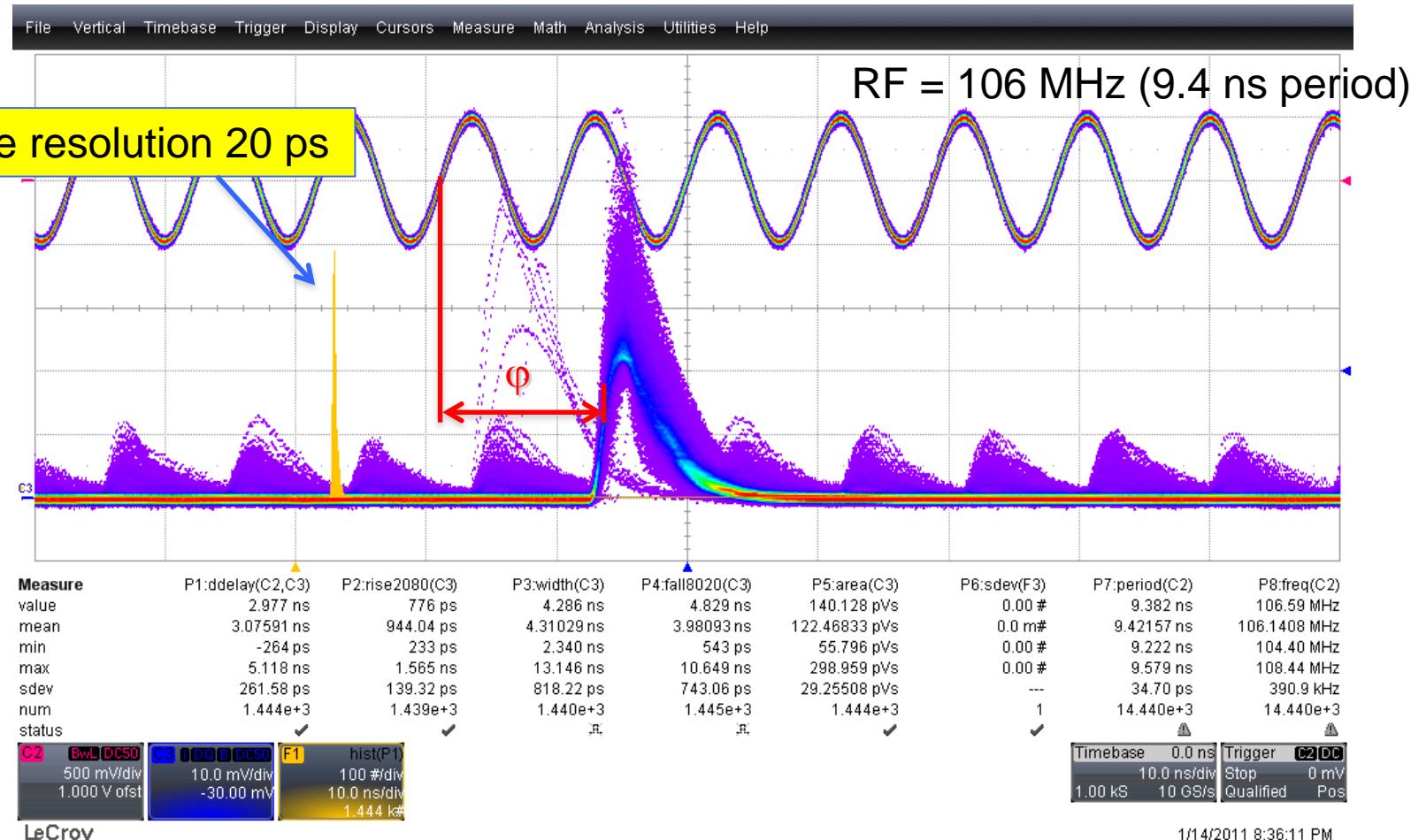
IBA - Cyclotron



One Extraction



Phase measurement



Content

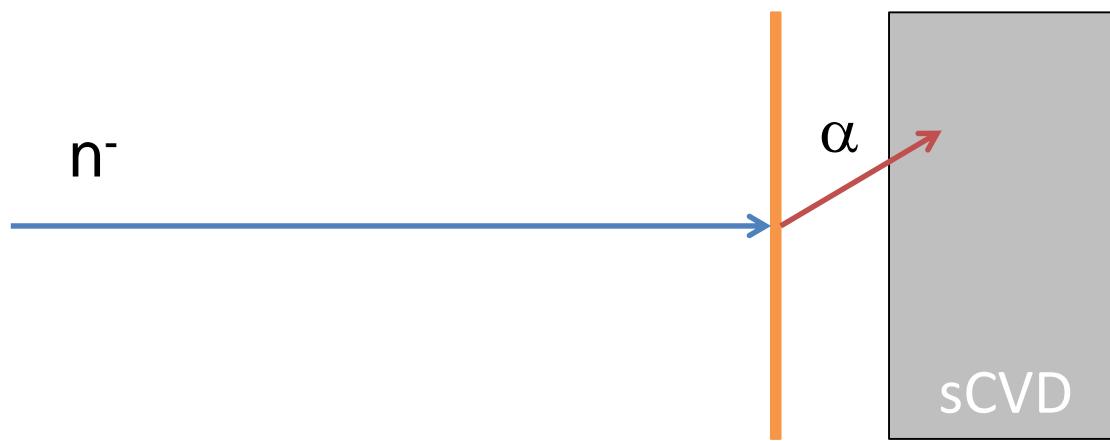
- Principles
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- Neutron Diagnostics

Detecting neutrons with diamond detectors

Courtesy Christina Weiss, ND16 Conference, Brugge, 14.9.2016

Thermal neutrons

${}^6\text{Li}$ converter

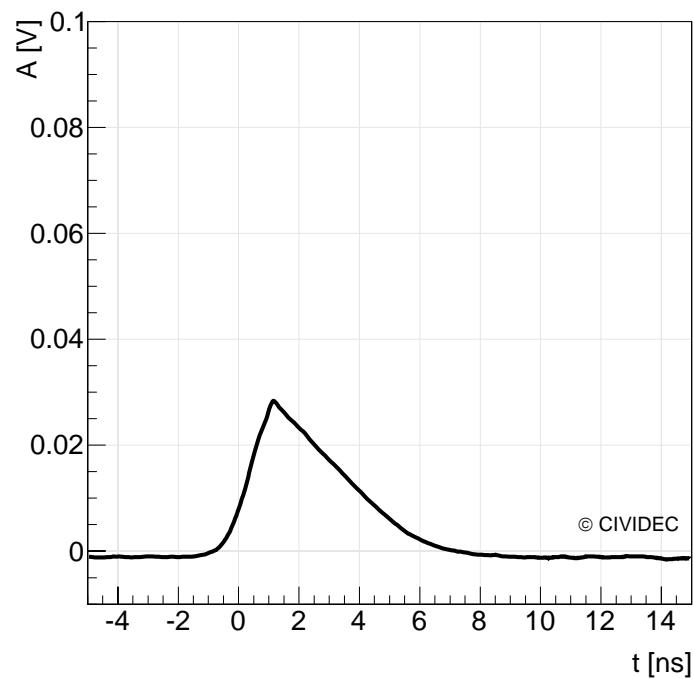
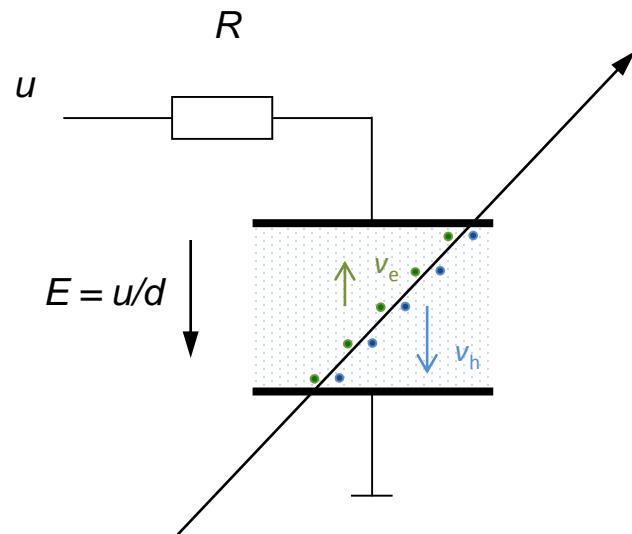


Fast neutrons



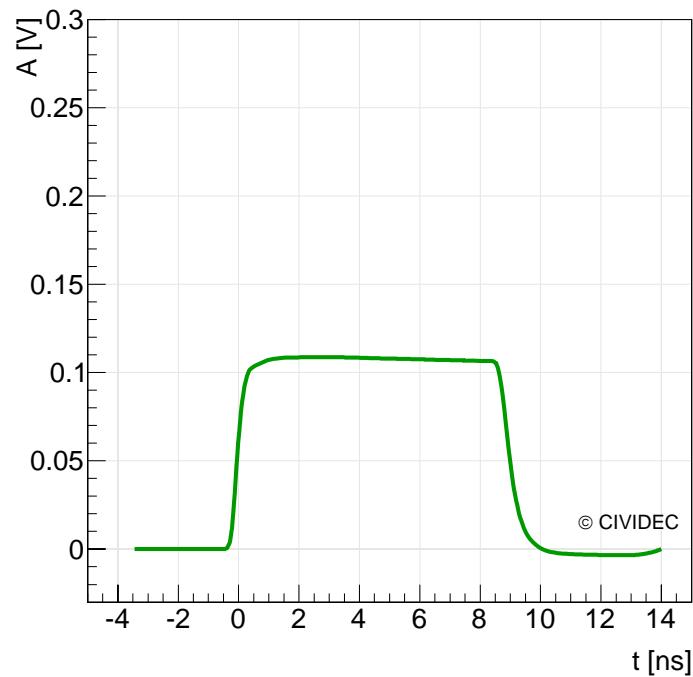
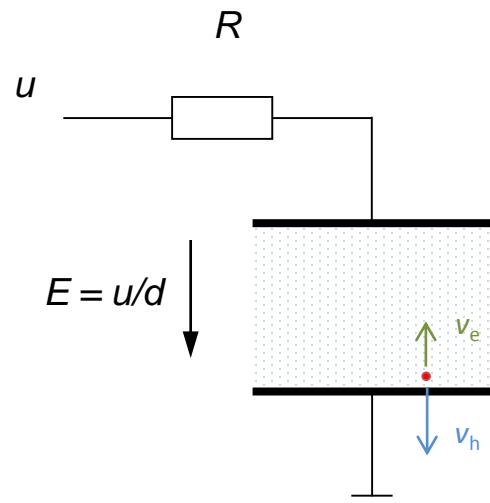
Signal shapes in sCVD

Homogeneous ionization (MIP, γ):



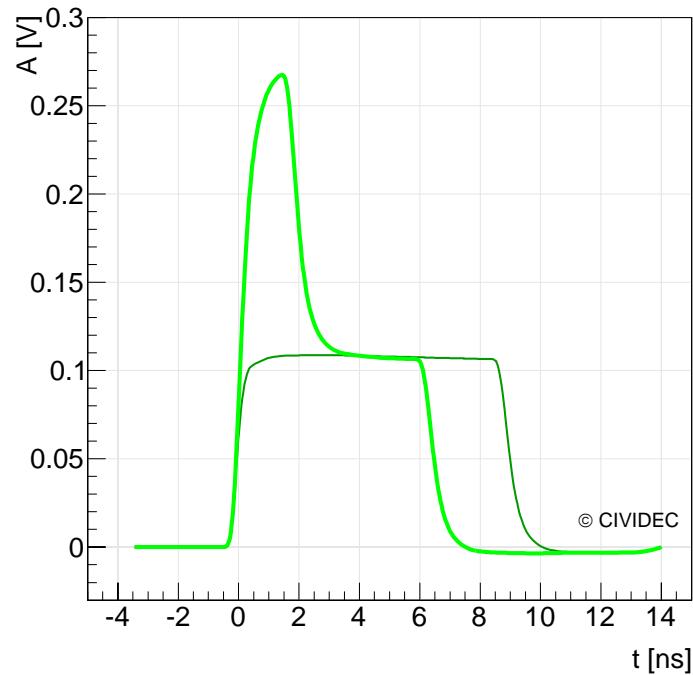
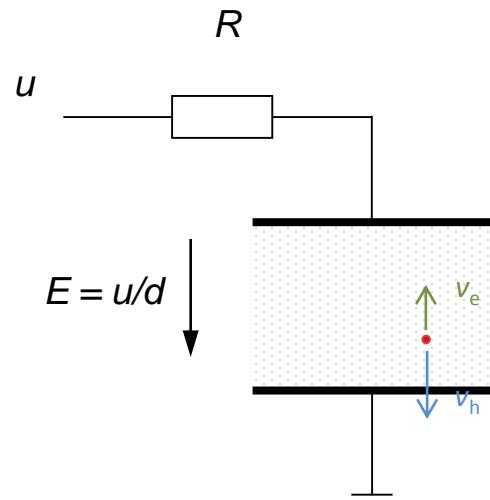
Signal shapes in sCVD

Point-like ionization:



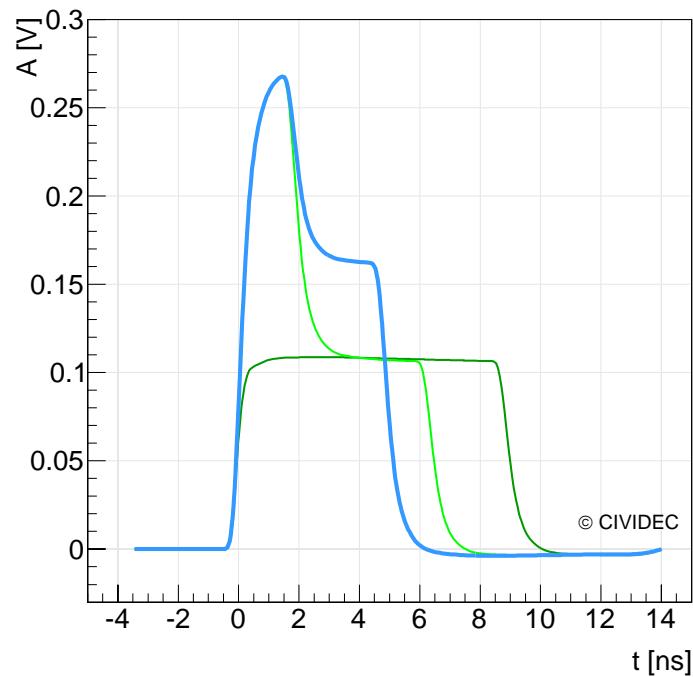
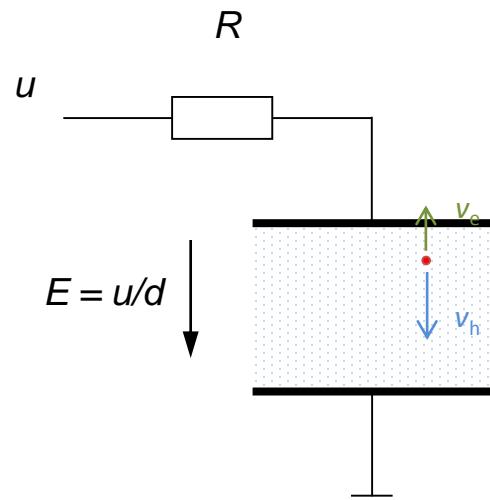
Signal shapes in sCVD

Point-like ionization:



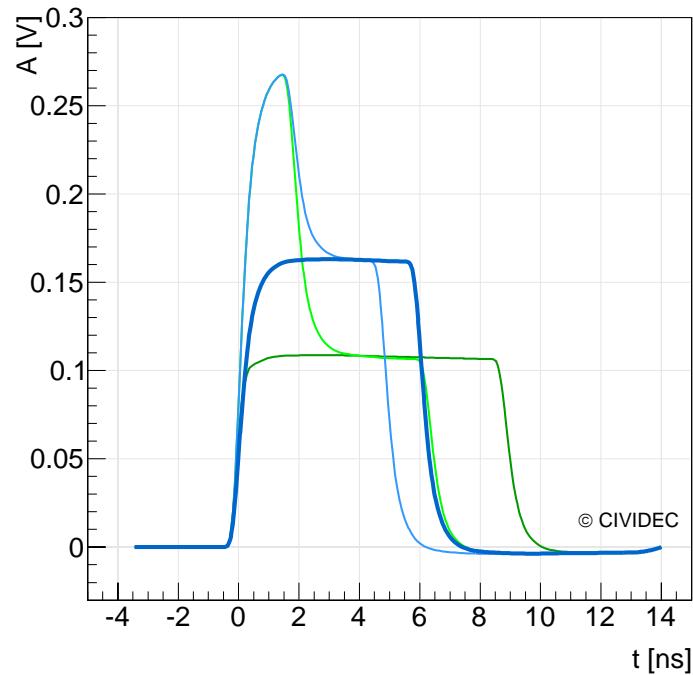
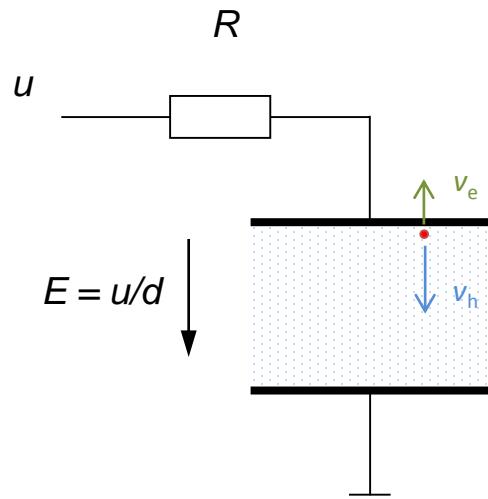
Signal shapes in sCVD

Point-like ionization:



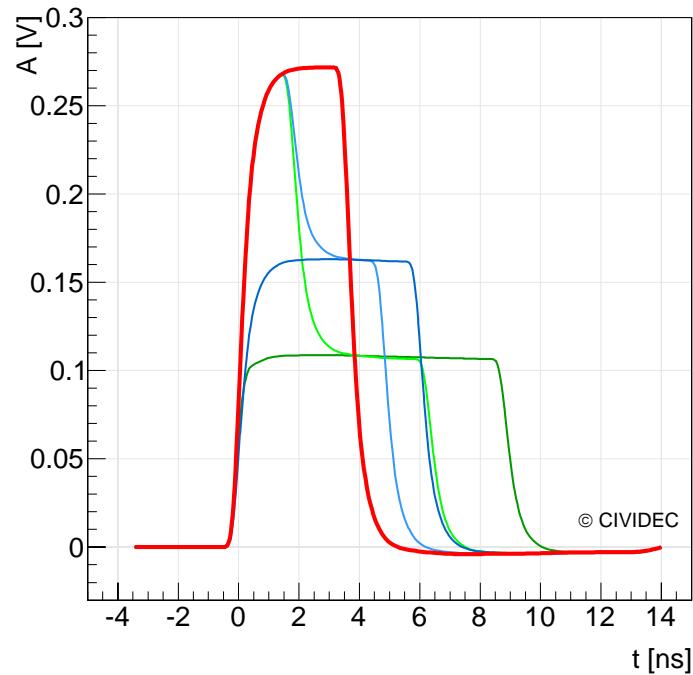
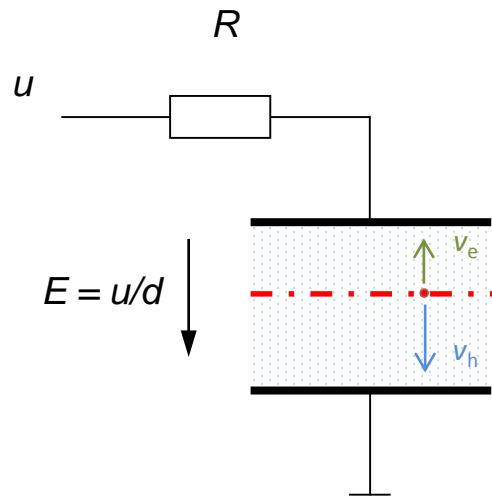
Signal shapes in sCVD

Point-like ionization:



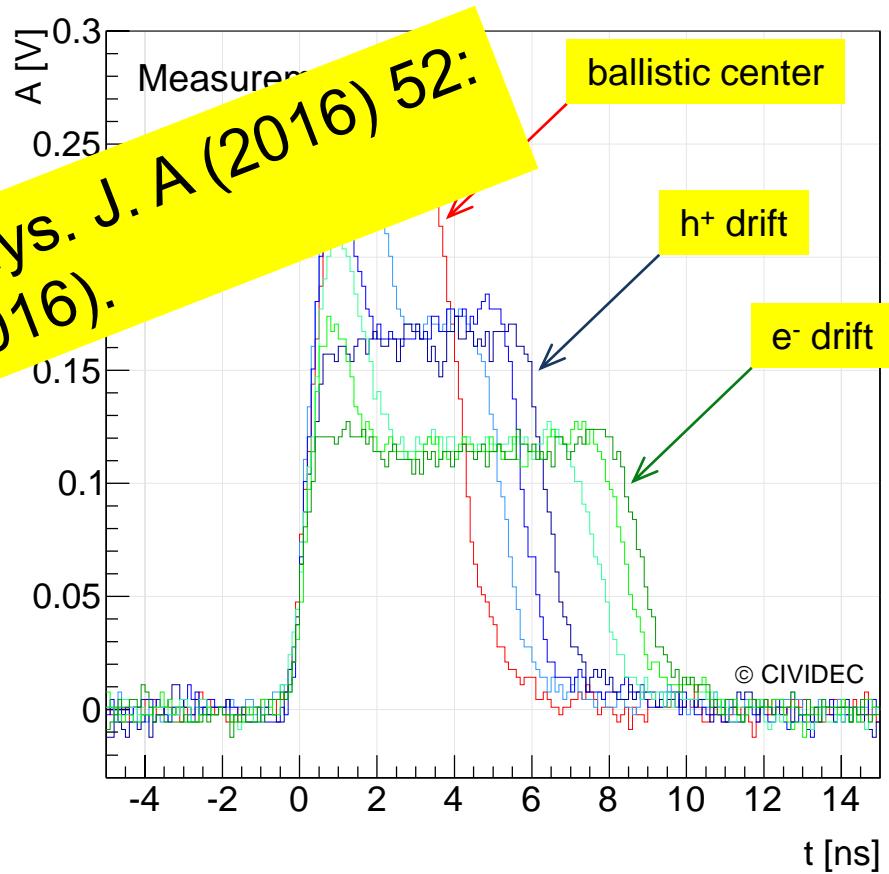
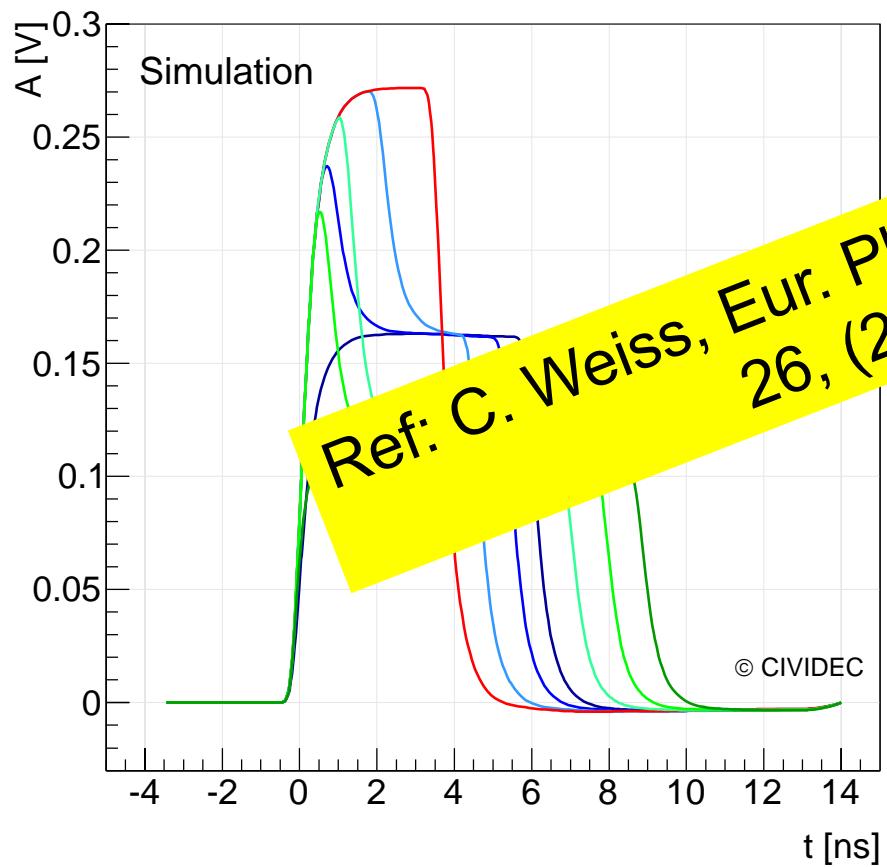
Signal shapes in sCVD

Point-like ionization:



New definition: ballistic center, $t_{d,h} = t_{d,e}$

Point-like ionization



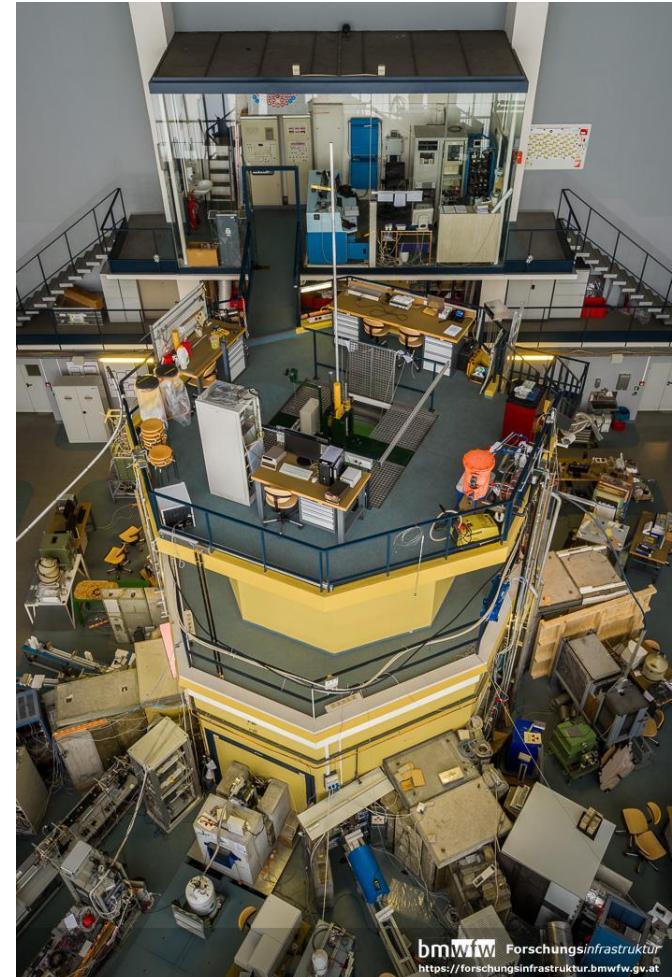
Three application examples:

1. Thermal neutrons
2. Fast neutrons
3. Mixed field

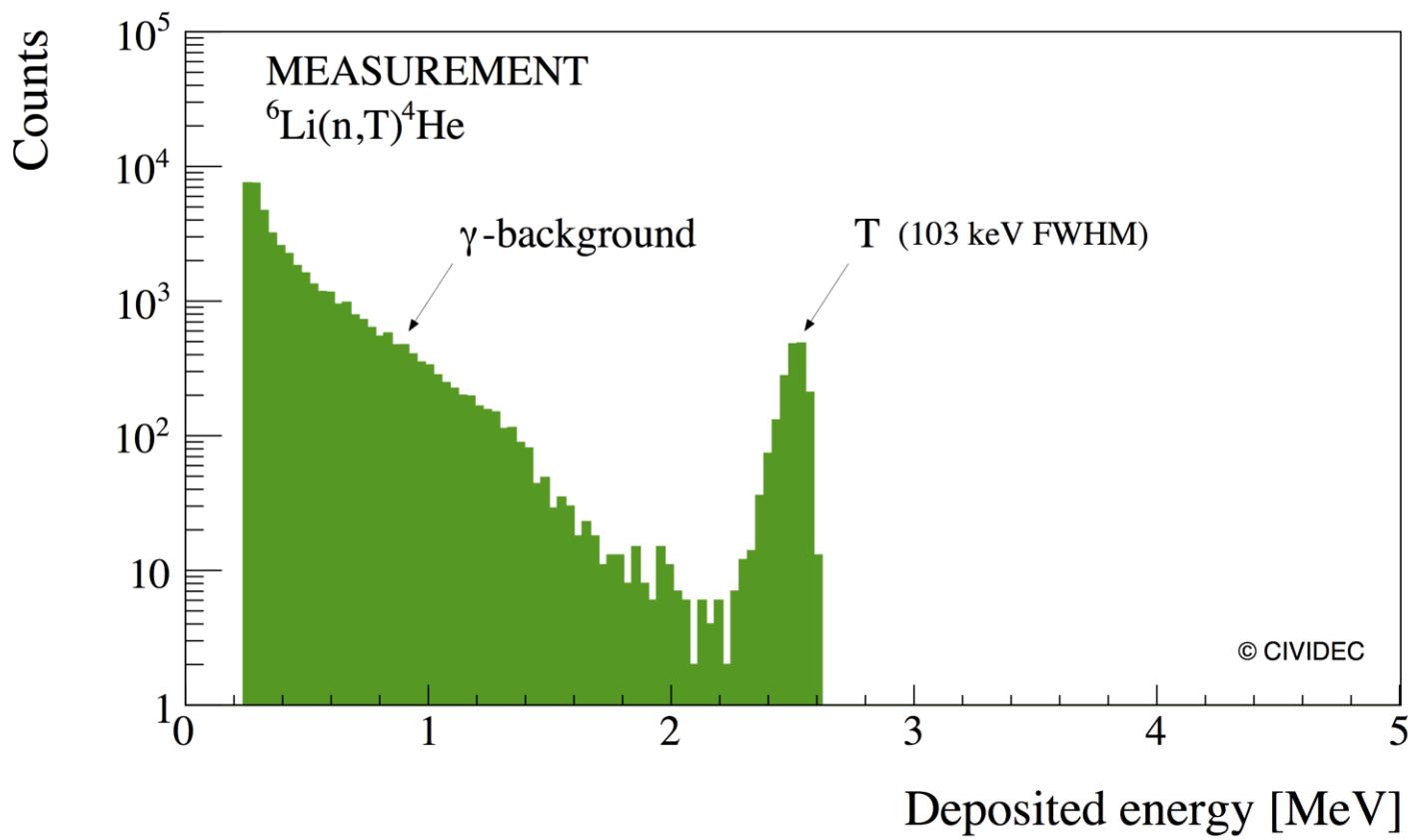
Thermal neutrons

ATI, Vienna, Austria

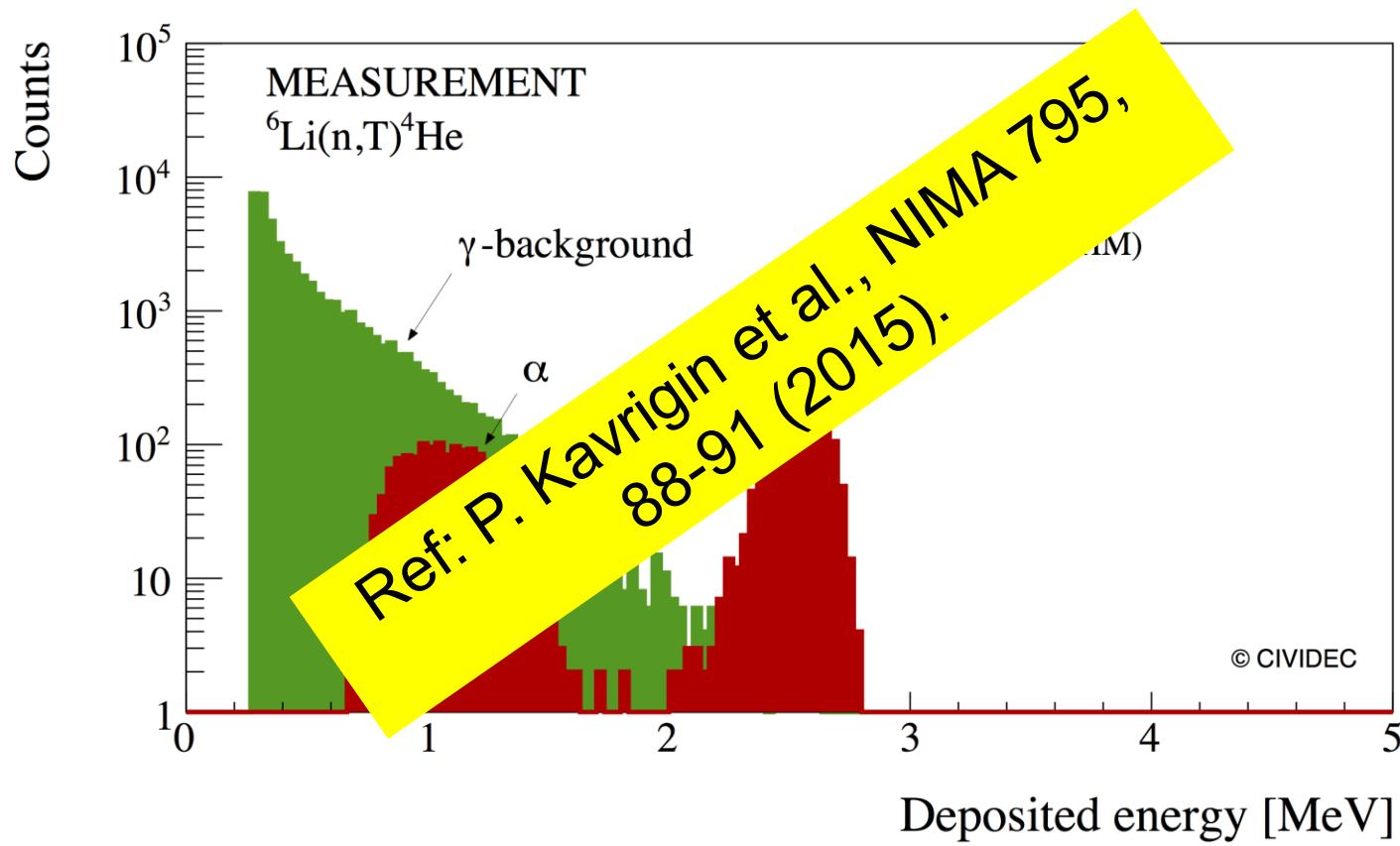
- Thermal neutron beam line at the TRIGA Mark-II reaction.



Recorded spectrum



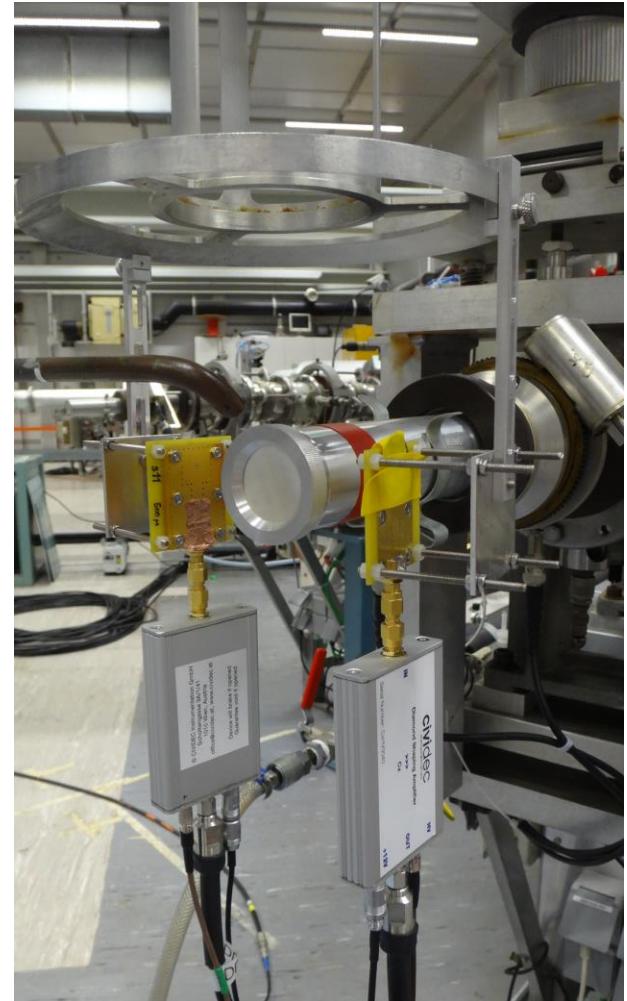
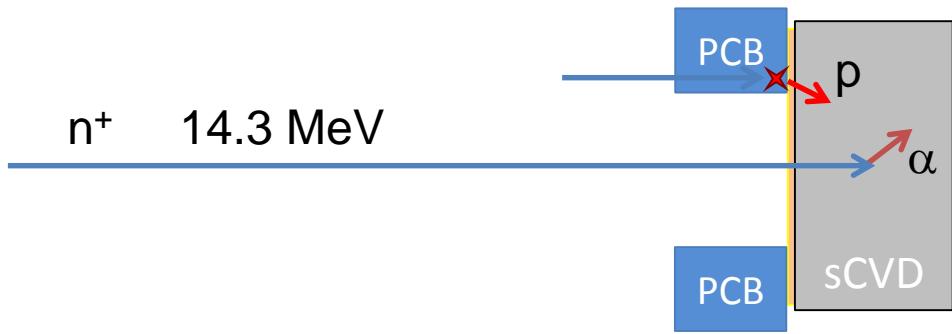
Selective spectroscopy



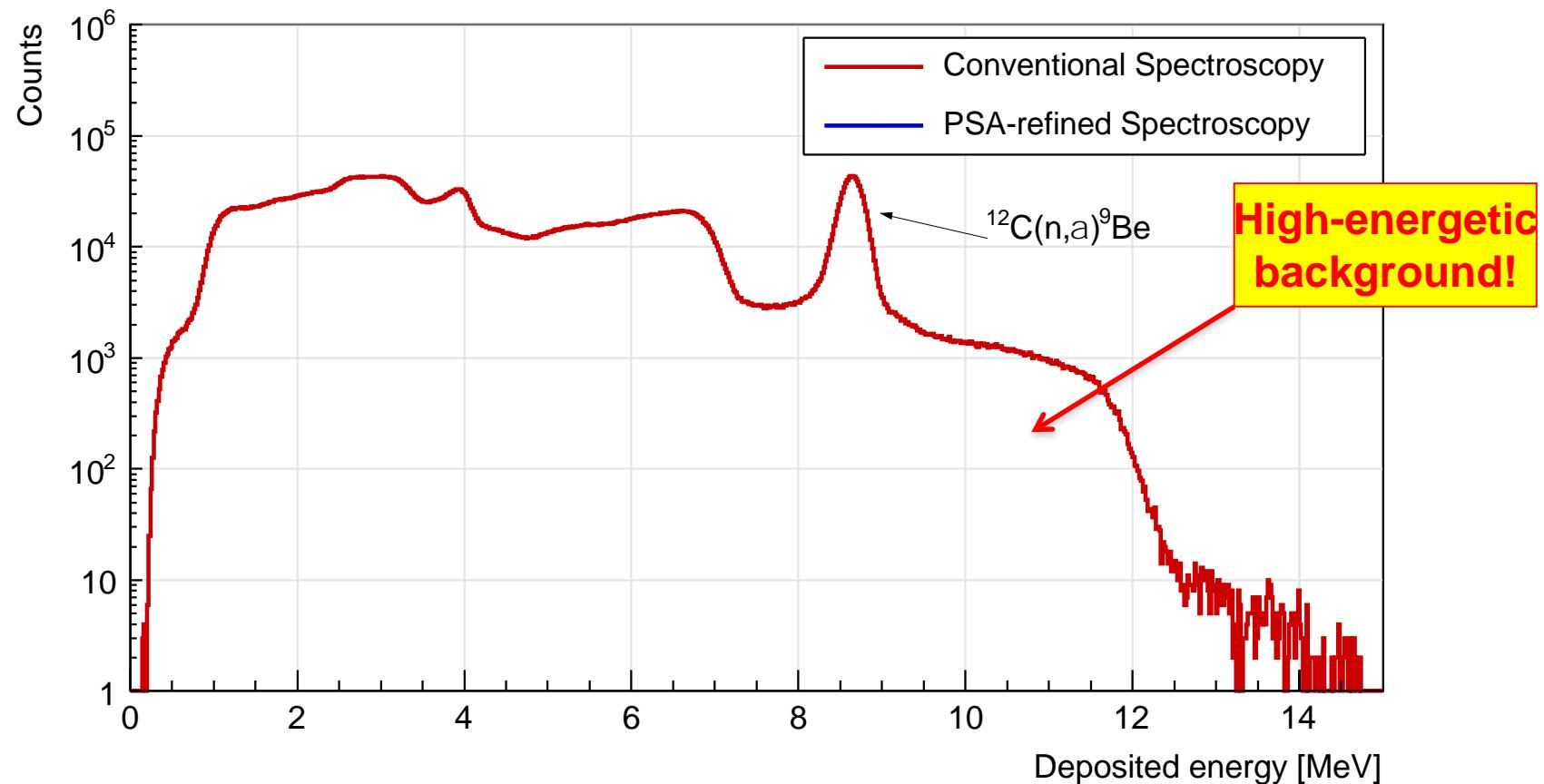
High-energy neutrons

EC-JRC, Geel, Belgium

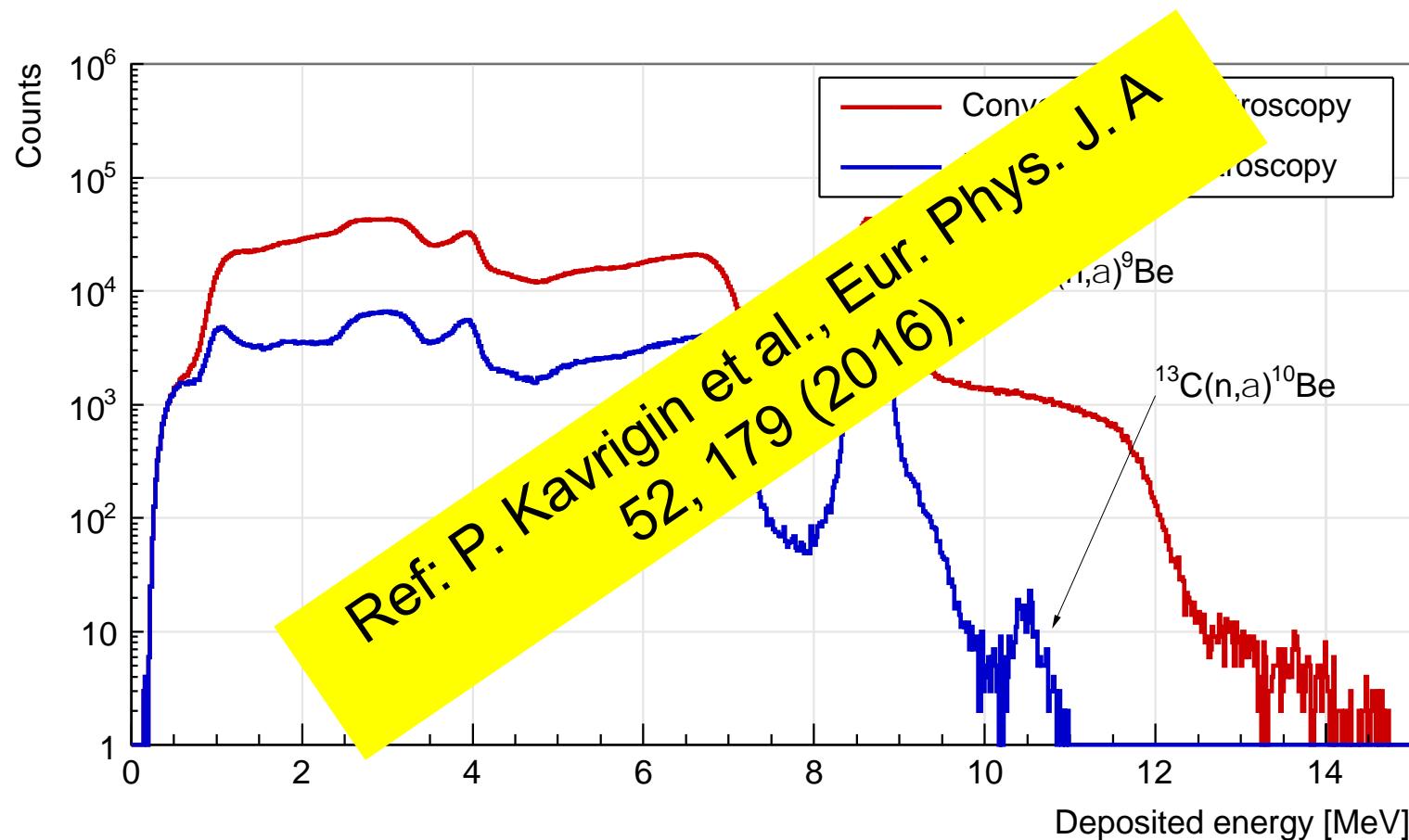
- Van de Graaff accelerator of EC-JRC, mono-energetic neutron beam.



Measurement of 14.3 MeV neutrons



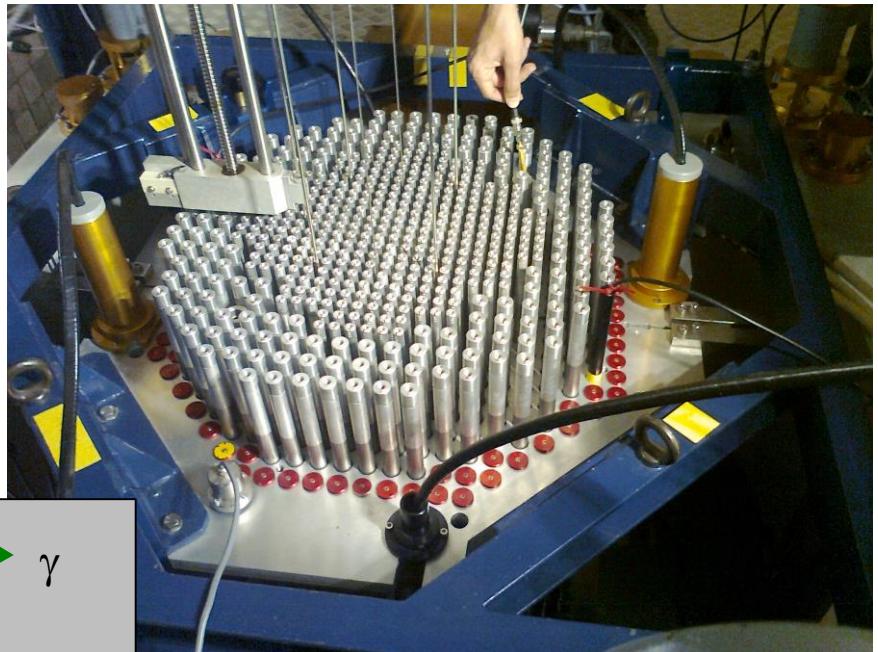
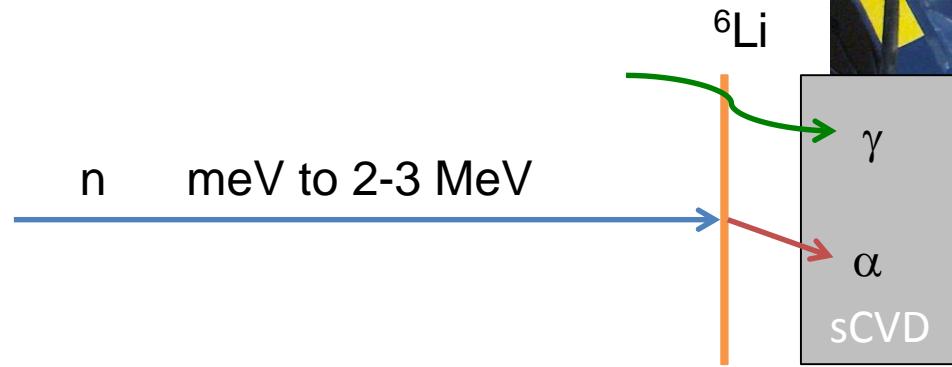
Selective spectroscopy



Mixed reactor field

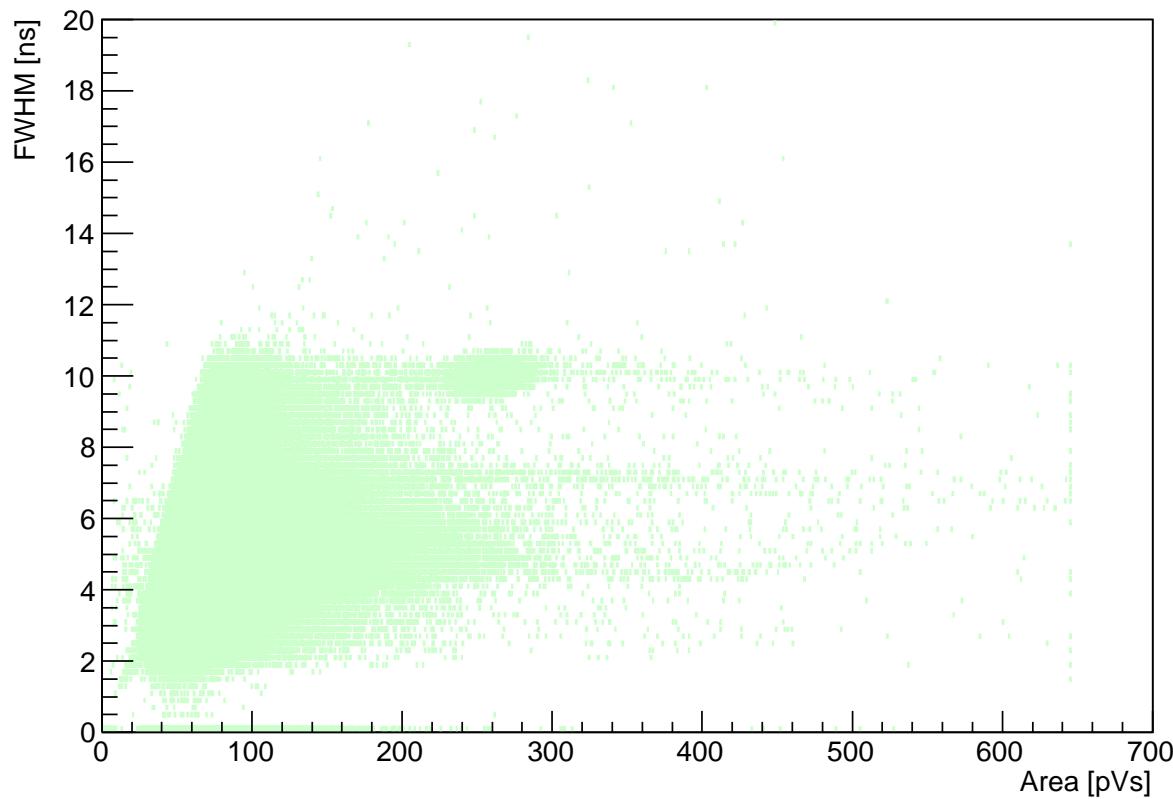
EPFL Lausanne, Switzerland

- In the core of the thermal reactor CROCUS.

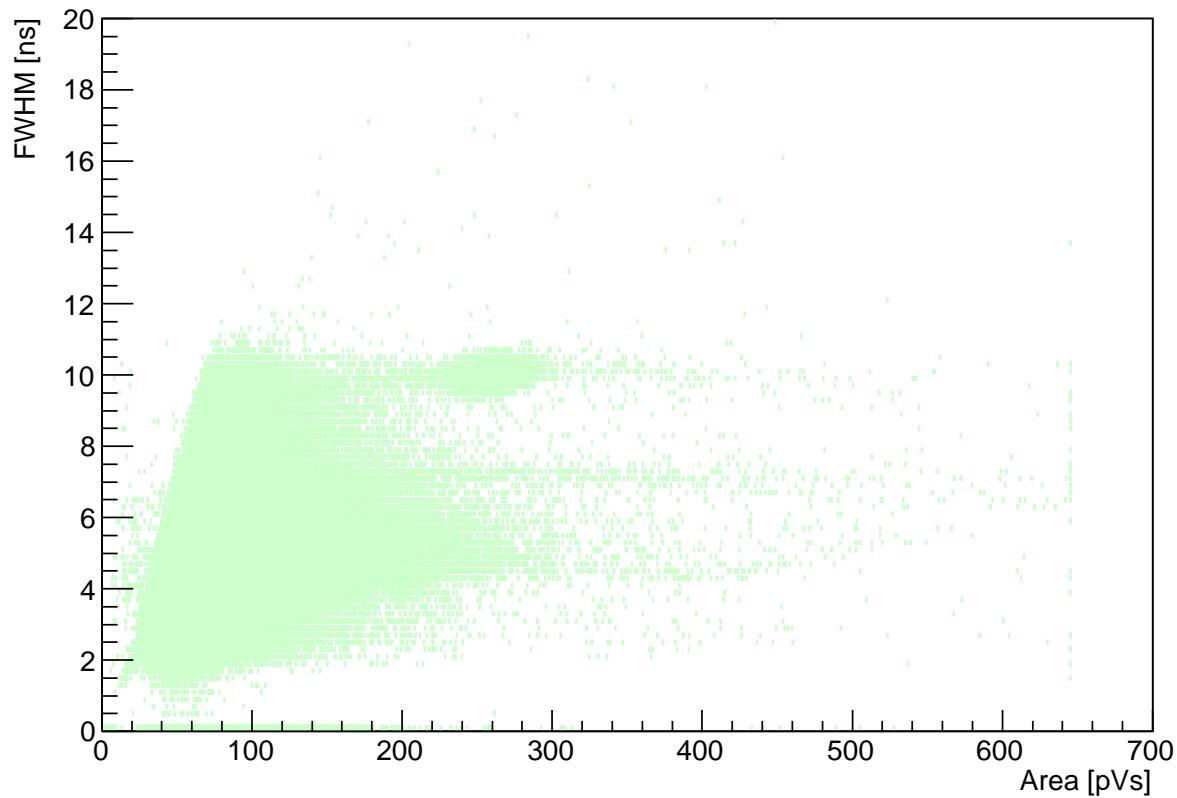


Courtesy M. Hursin, EPFL

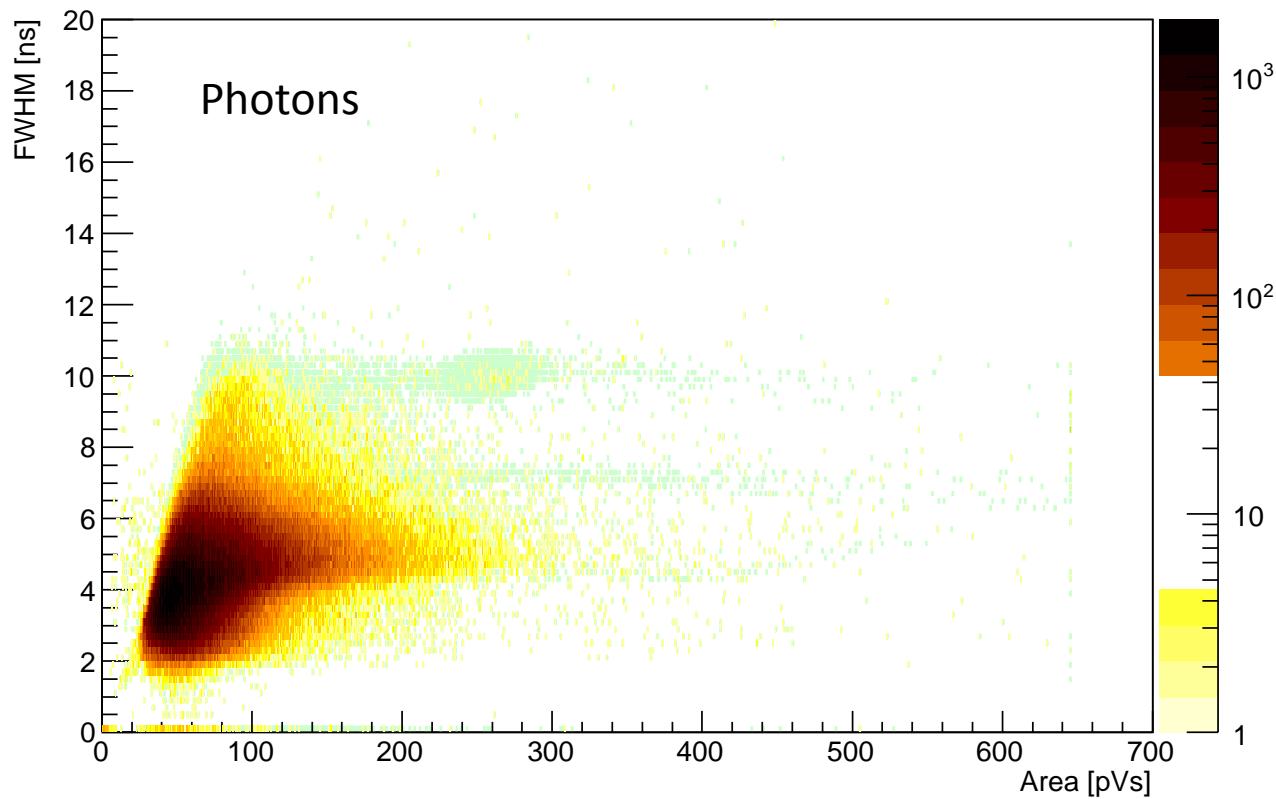
Spectrum



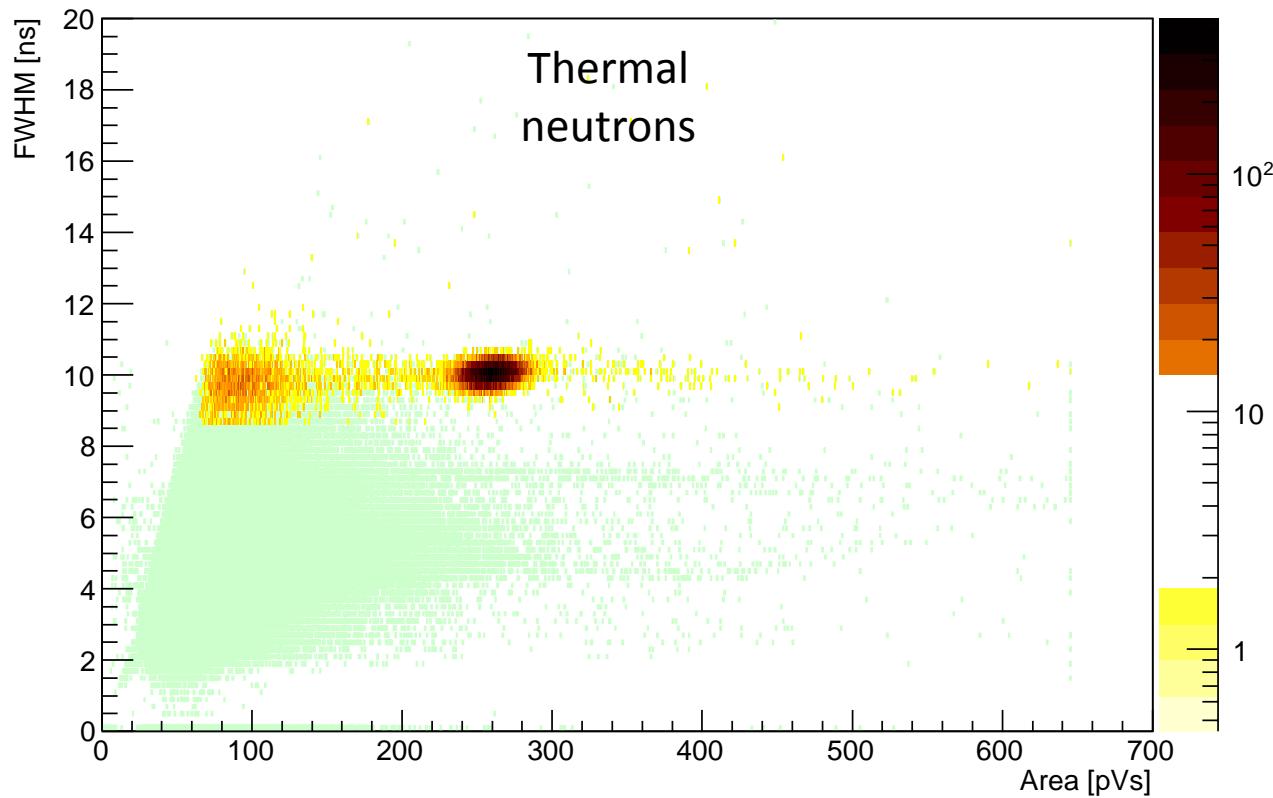
Selective spectroscopy



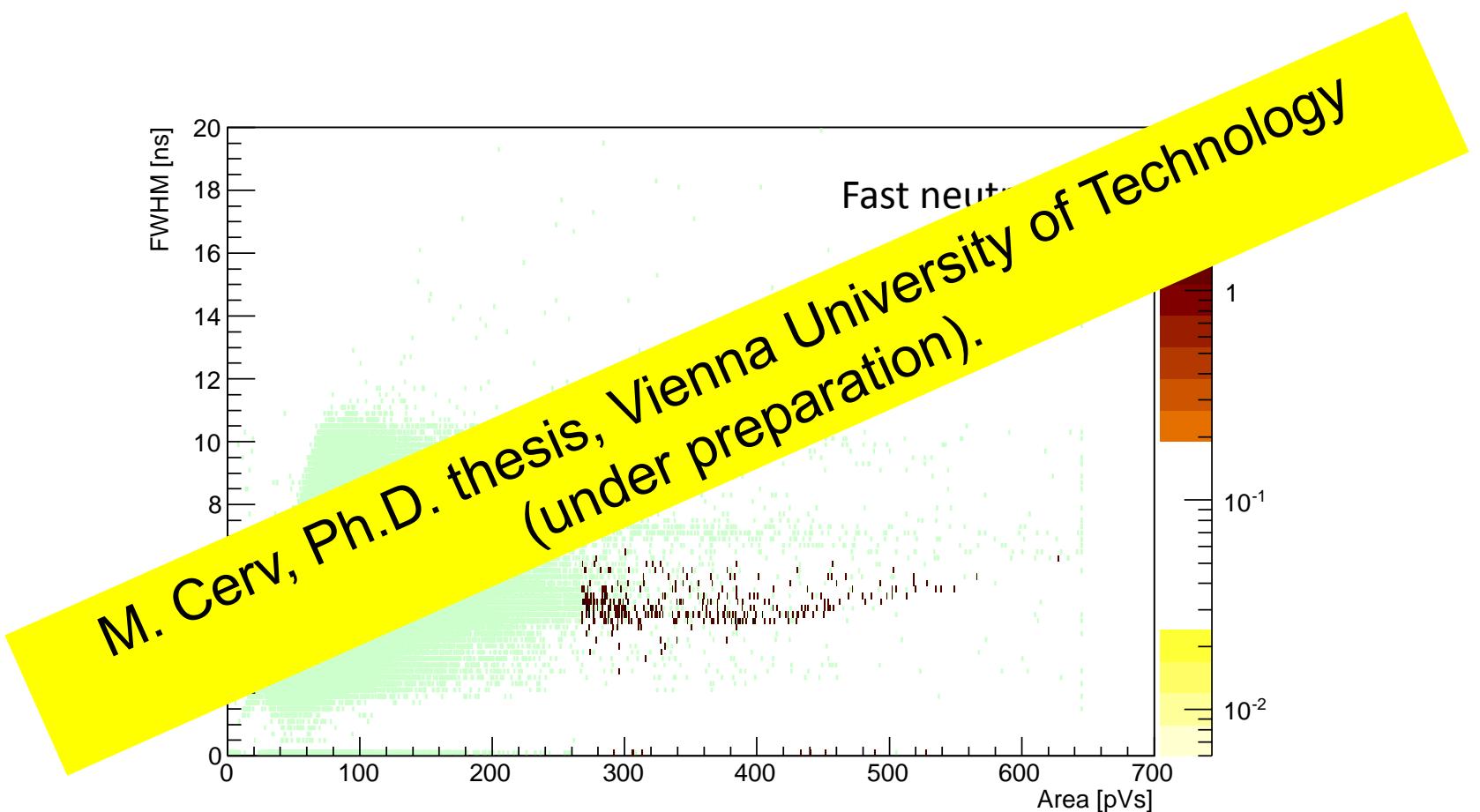
Selective spectroscopy



Selective spectroscopy



Selective spectroscopy



Thank you for your attention!



TU WIEN, 2016



Erich Griesmayer



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