Diamonds for Beam Instrumentation

TIPP 2011, Chicago, 9.6.2011

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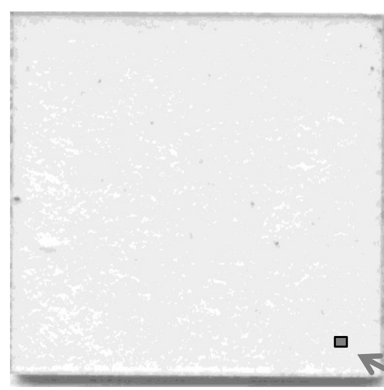
CERN and CIVIDEC Instrumentation

Overview

- Diamond Detectors
- Physics
- Application Examples
- Summary

The Diamond Detector

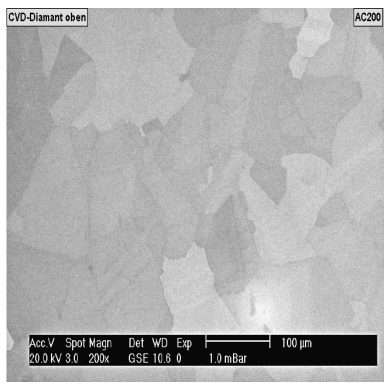
Substrate



Diamond Substrate:

pCVD = 10x10 mm^2 x 0.5 mm
sCVD = 5x5 mm^2 x 0.5 mm

pCVD Substrate



500 um

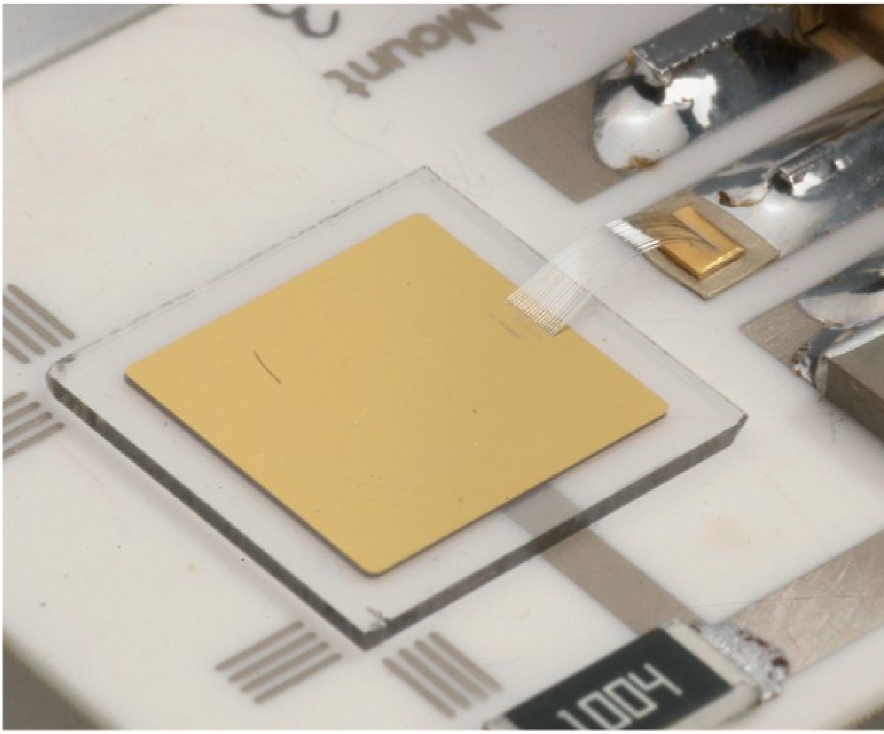
Crystal boundaries, 100 – 200 um

Charge-collection distance 200 um

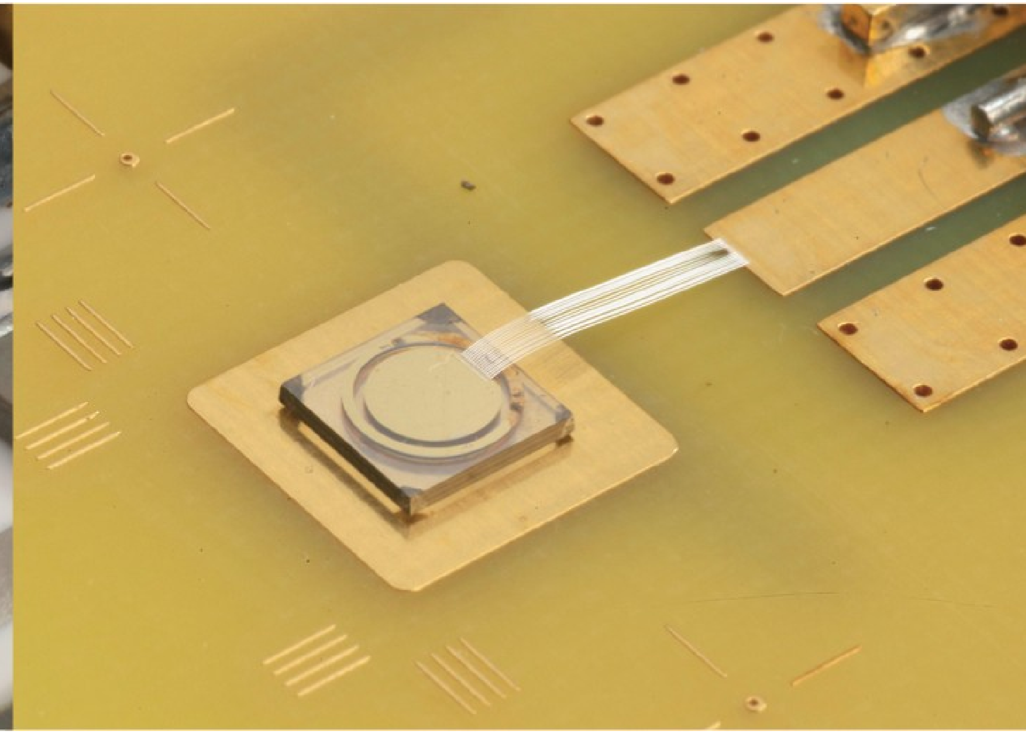
→ Trapping

→ Reduction of ionization charges

Diamond Detectors

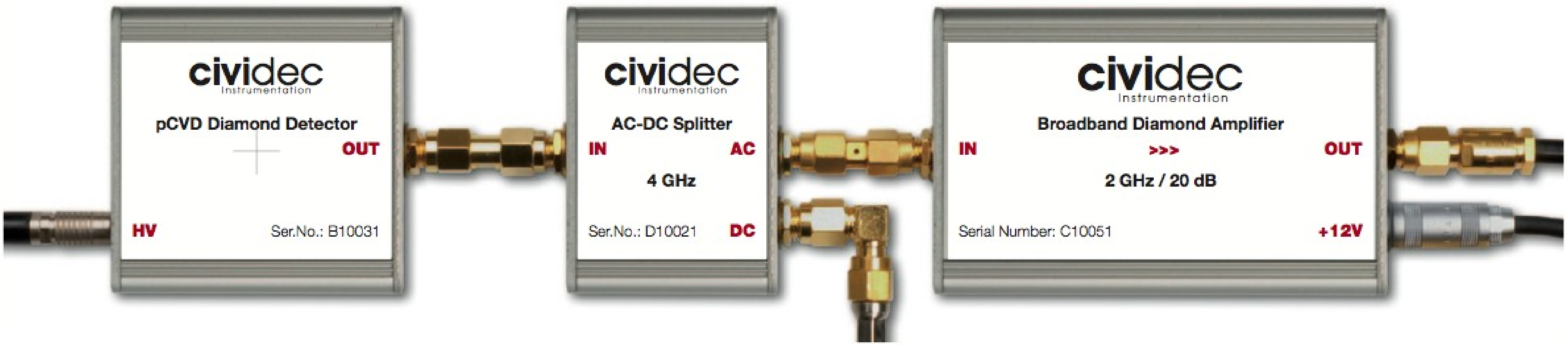


pCVD



sCVD

Diamond Beam Monitor



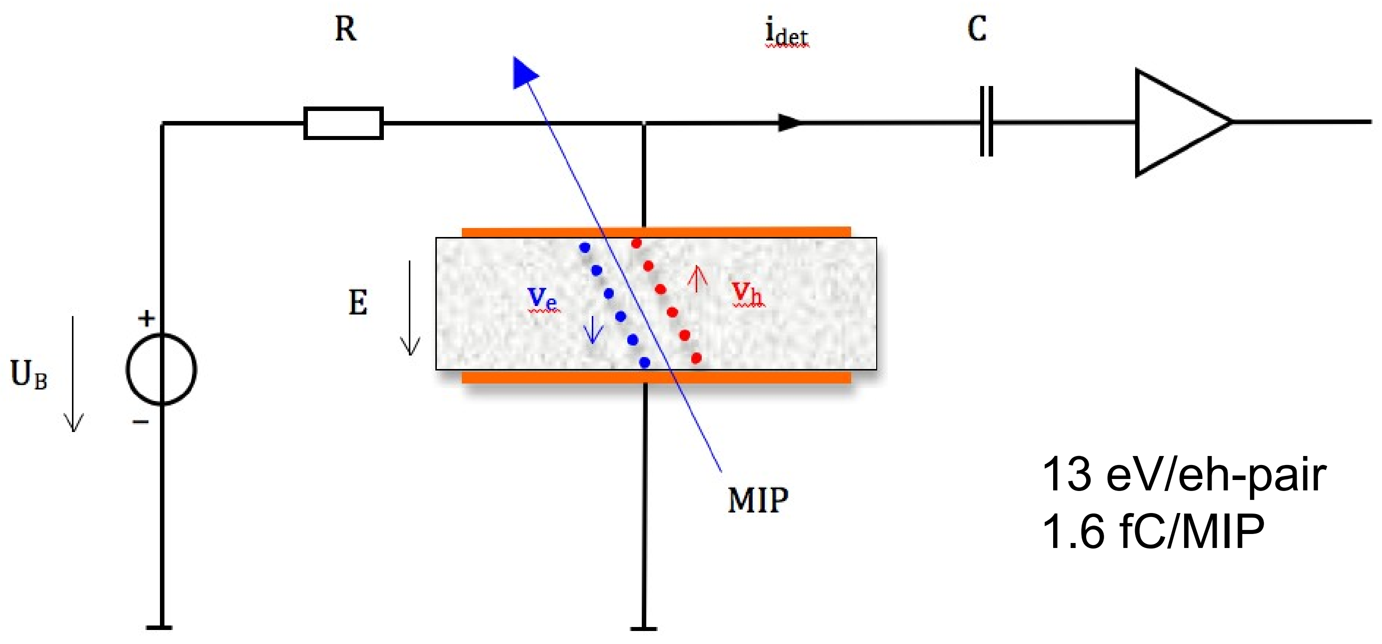
Detector

AC/DC Splitter

2 GHz Amplifier

Physics

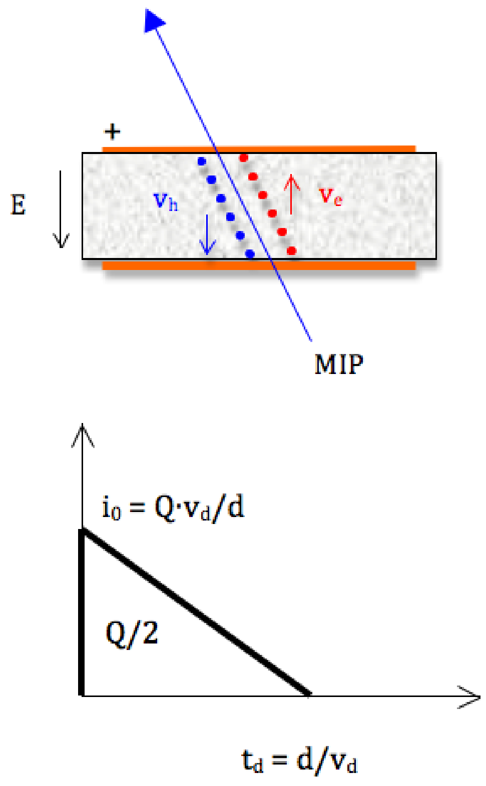
Principle of Ionization



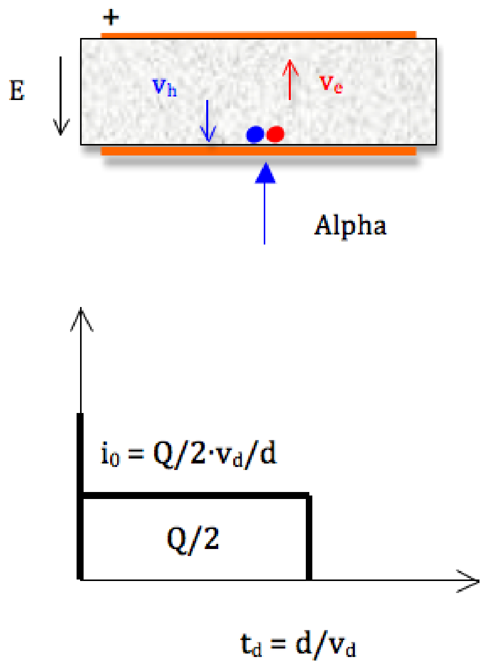
13 eV/eh-pair
1.6 fC/MIP

Modes of Operation

Counting Mode



Calorimetric Mode



Proton Interaction

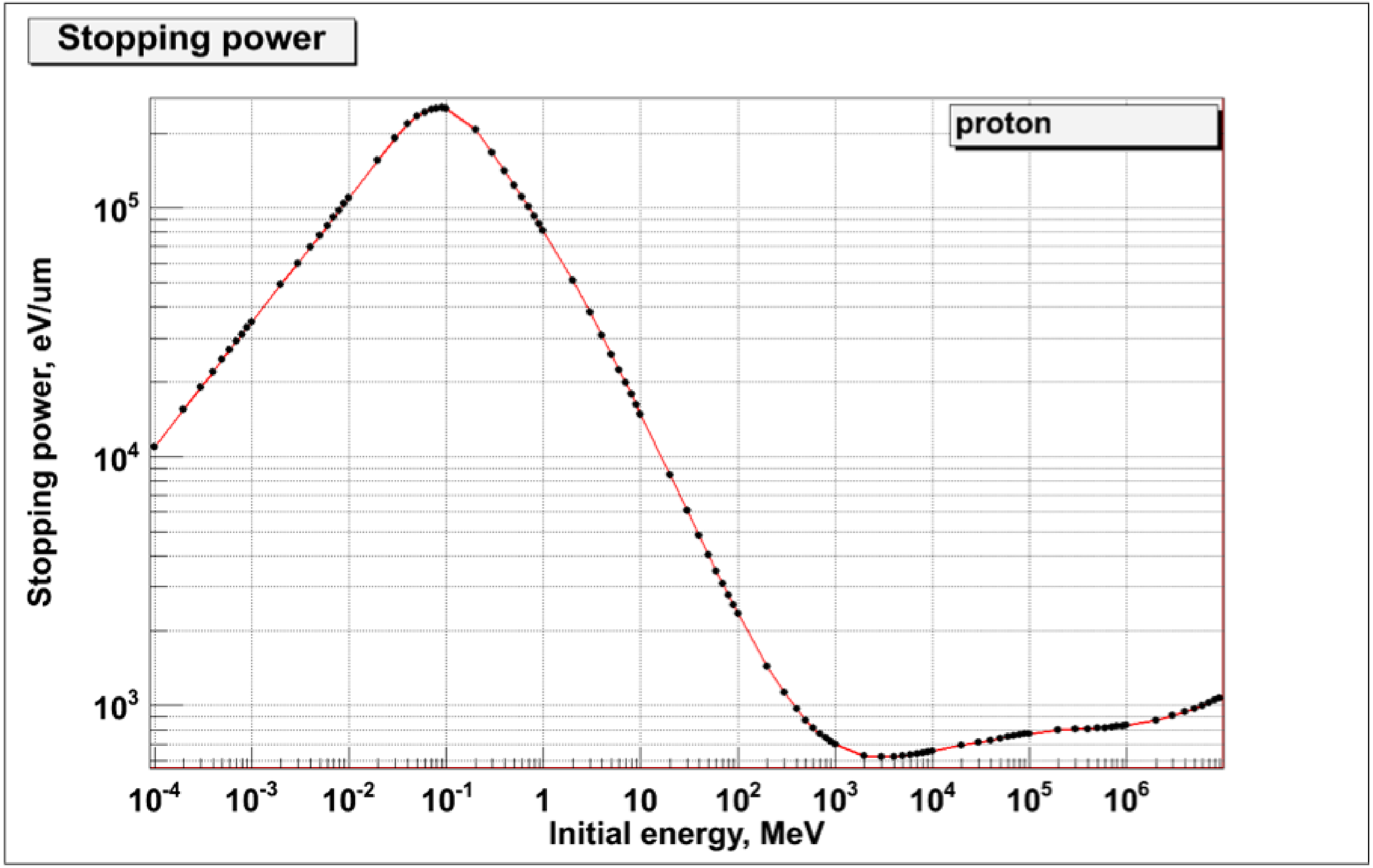
E > 10 MeV: protons traverse detector

E < 10 MeV: protons penetrate the detector (calorimetric mode)

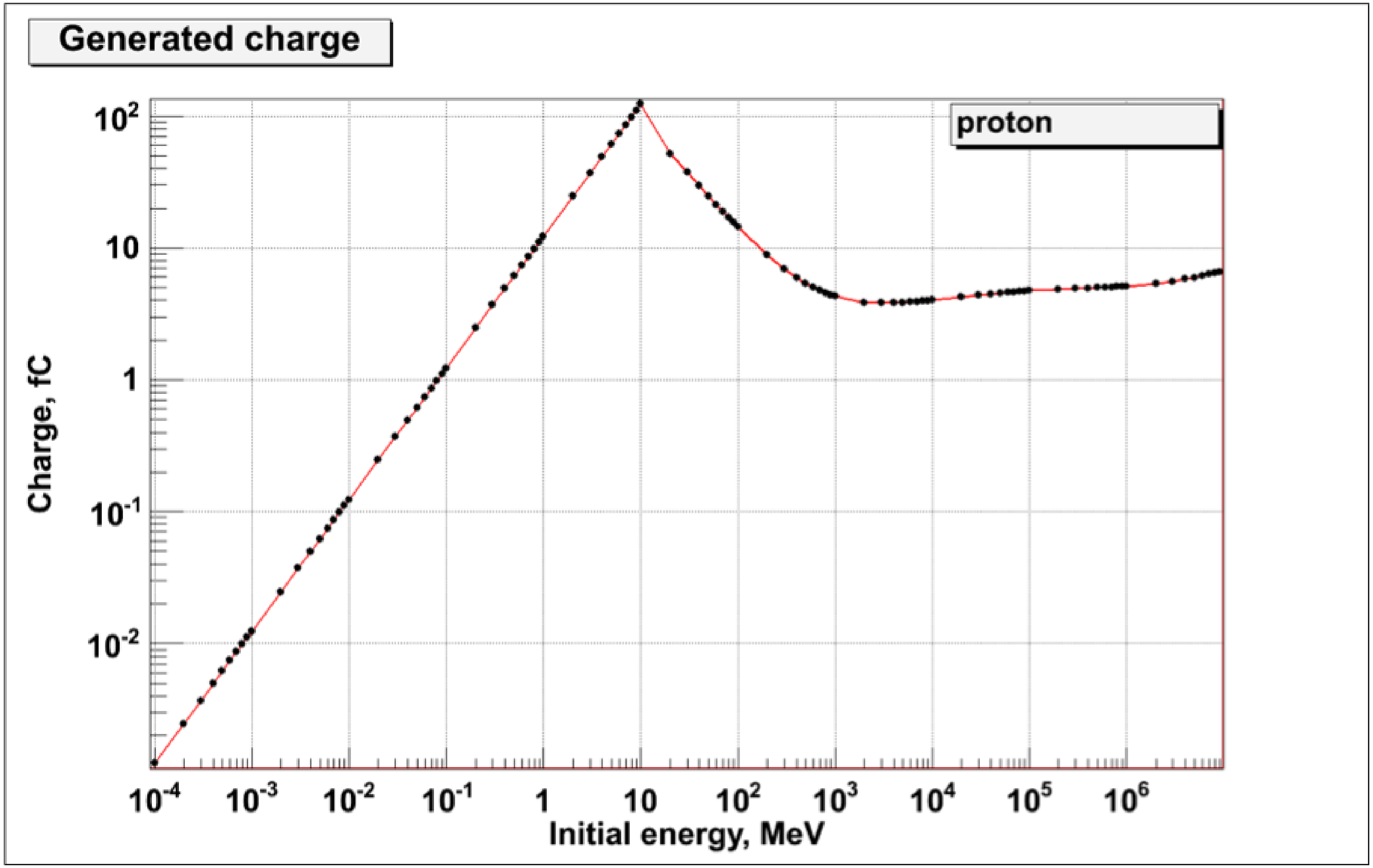
→ Direct measurement of the ionization charge.

→ Single protons, efficiency = 100%

Proton Interaction

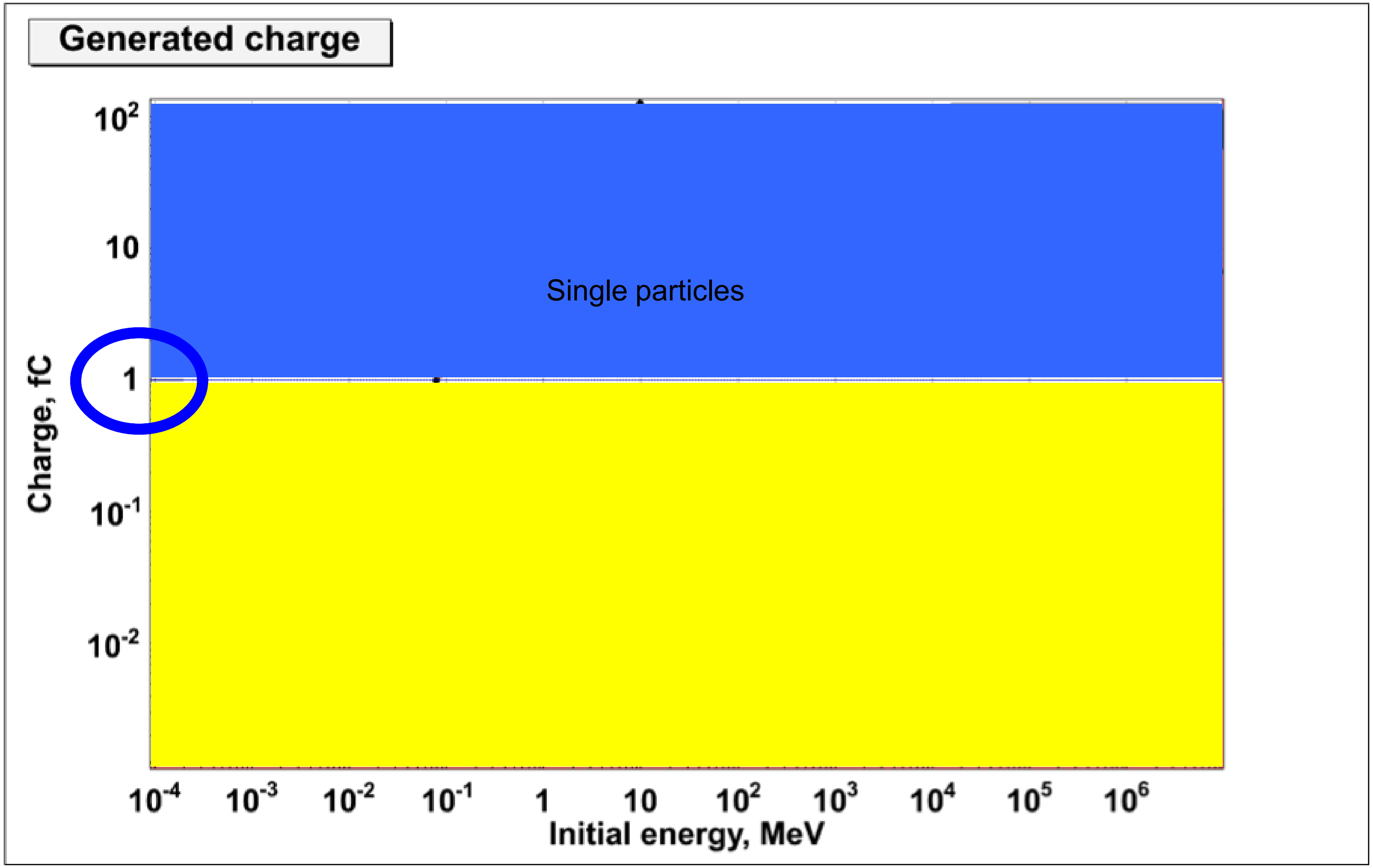


Proton Interaction

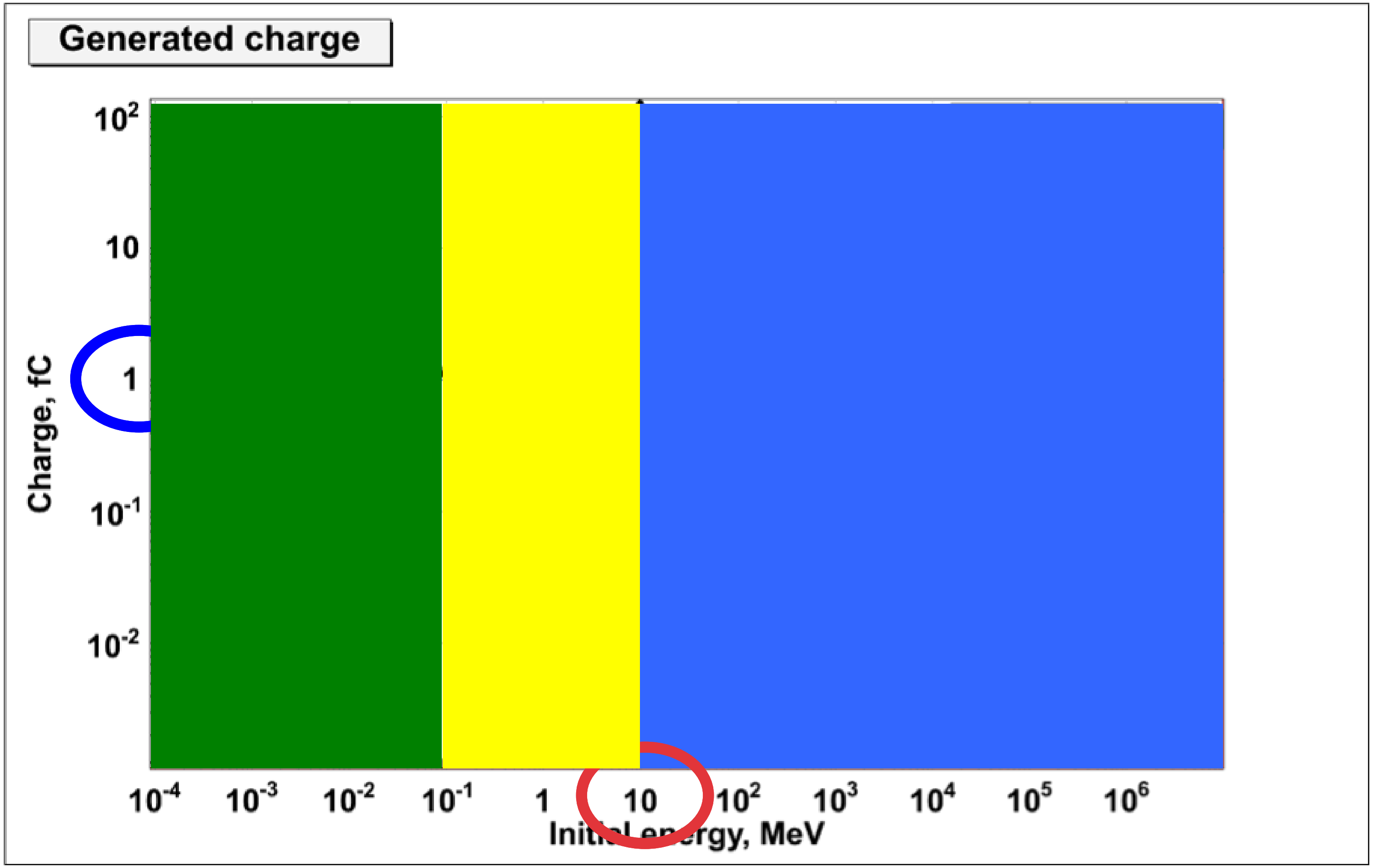


Proton Interaction

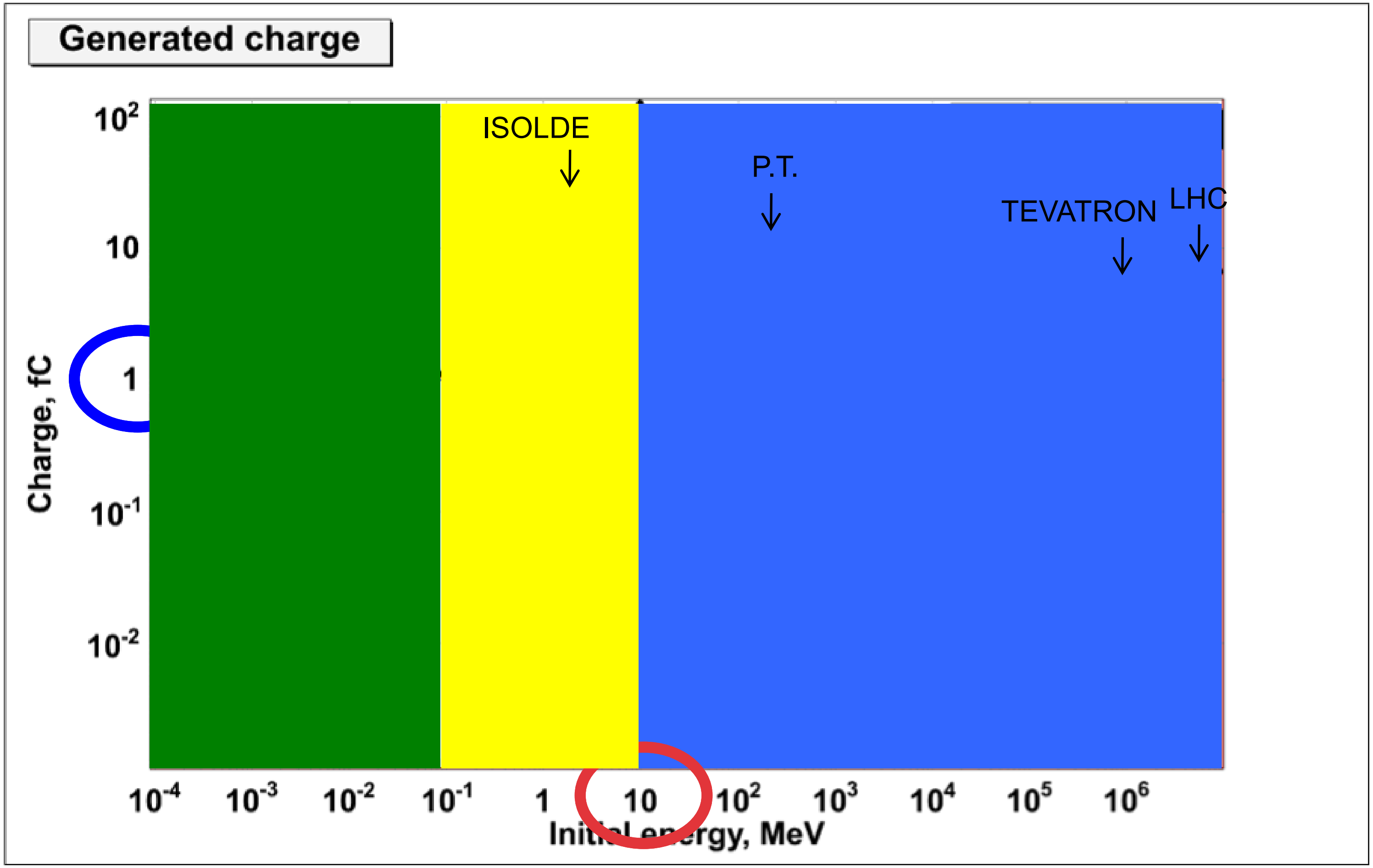
Proton Interaction



Proton Interaction



Proton Interaction



Electron Interaction

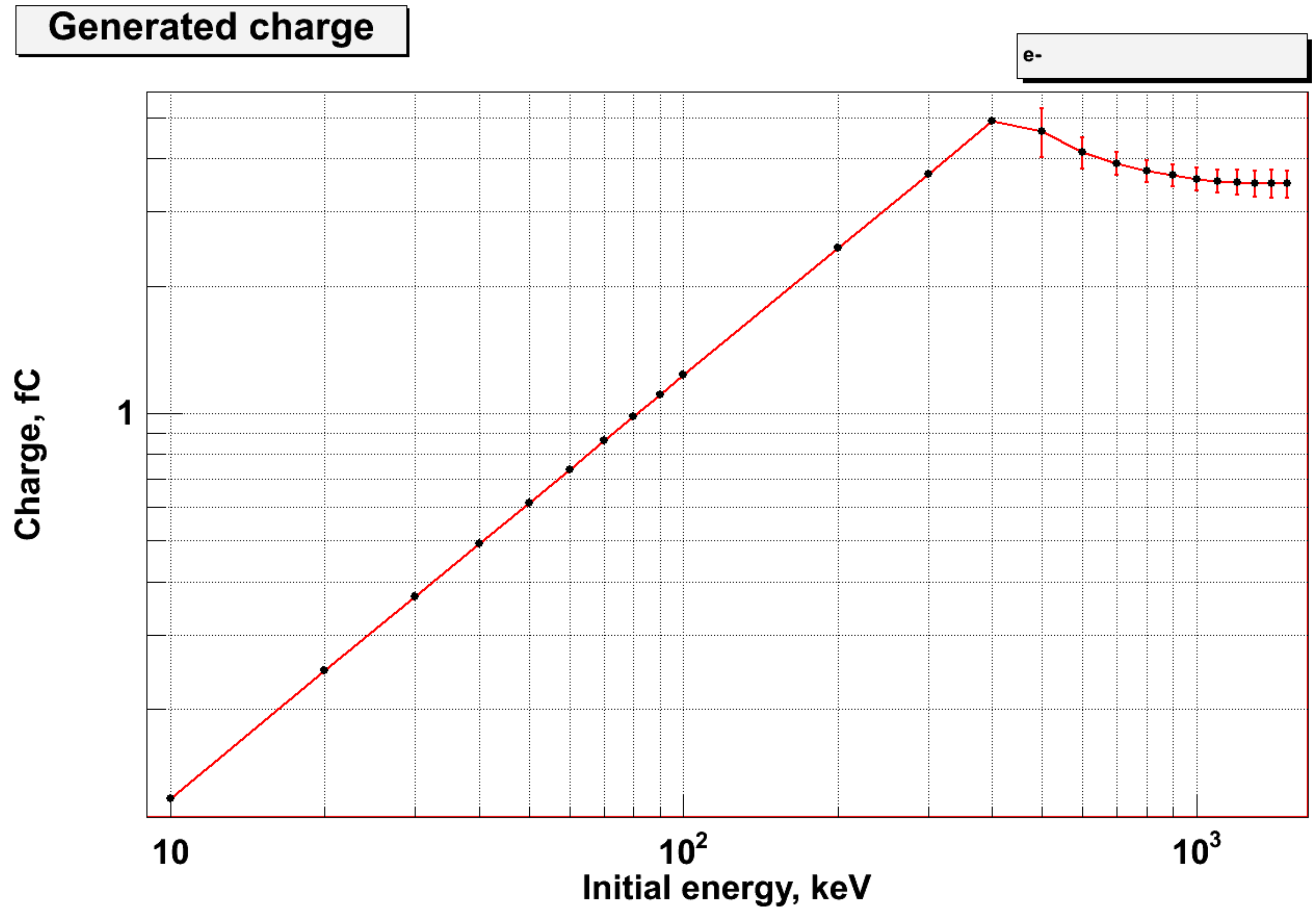
E > 400 keV: electrons traverse detector

E < 400 keV: electrons penetrate the detector (calorimetric mode)

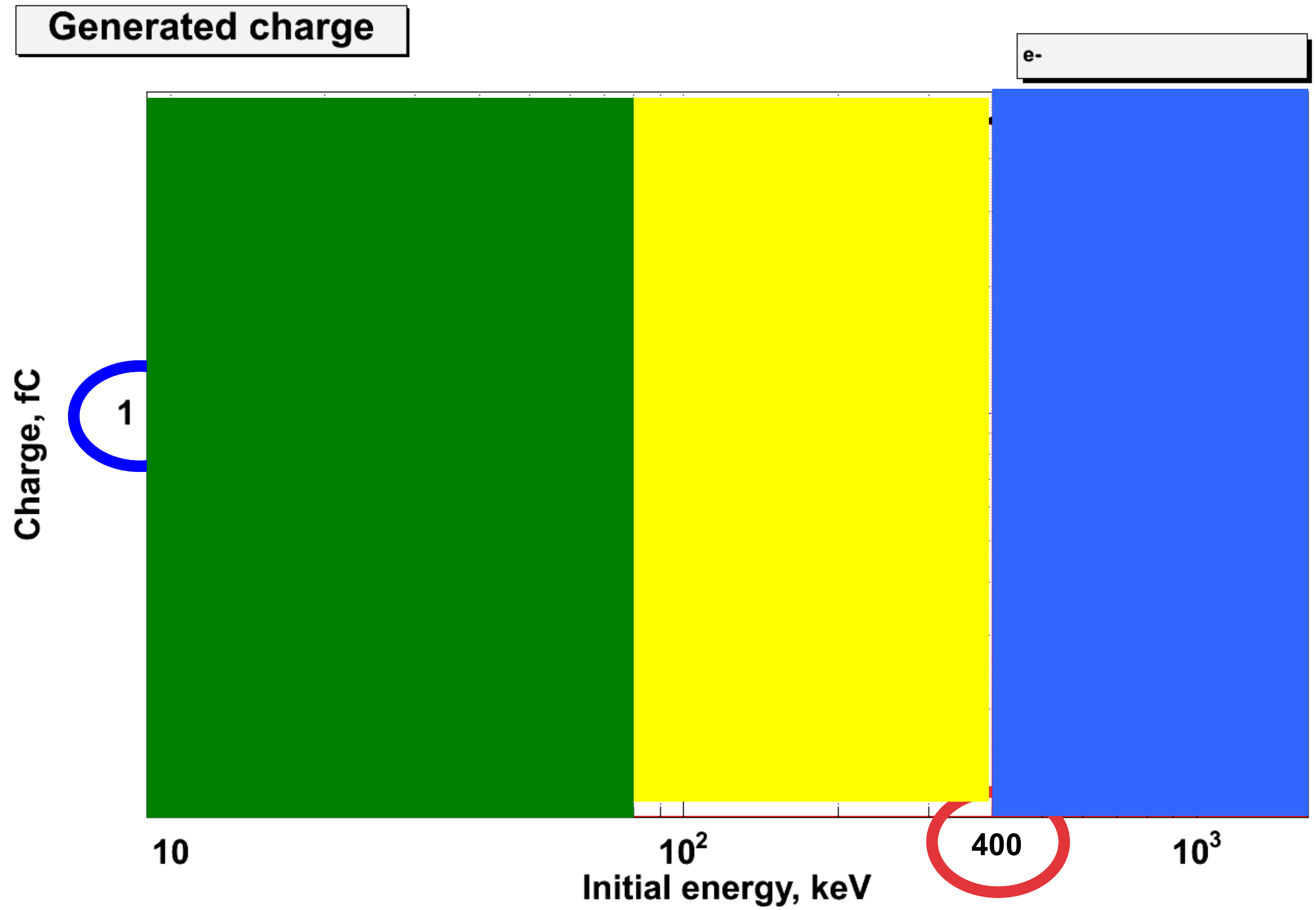
→ Direct measurement of the ionization charge.

→ Single electrons, efficiency = 100%

Electron Interaction



Electron Interaction



Neutron Interaction

E < 6 MeV: Converter foil (B, Gd) and measure n → α conversion products

E > 6 MeV: Direct measurement of n → α interaction of neutrons and detector

→ Direct and indirect measurement of the n → α ionization charge.

→ Single neutrons, efficiency << 100%
→ Neutron flux, efficiency = 100%

Photon Interaction

E > 5.5 eV: Photo excitation current

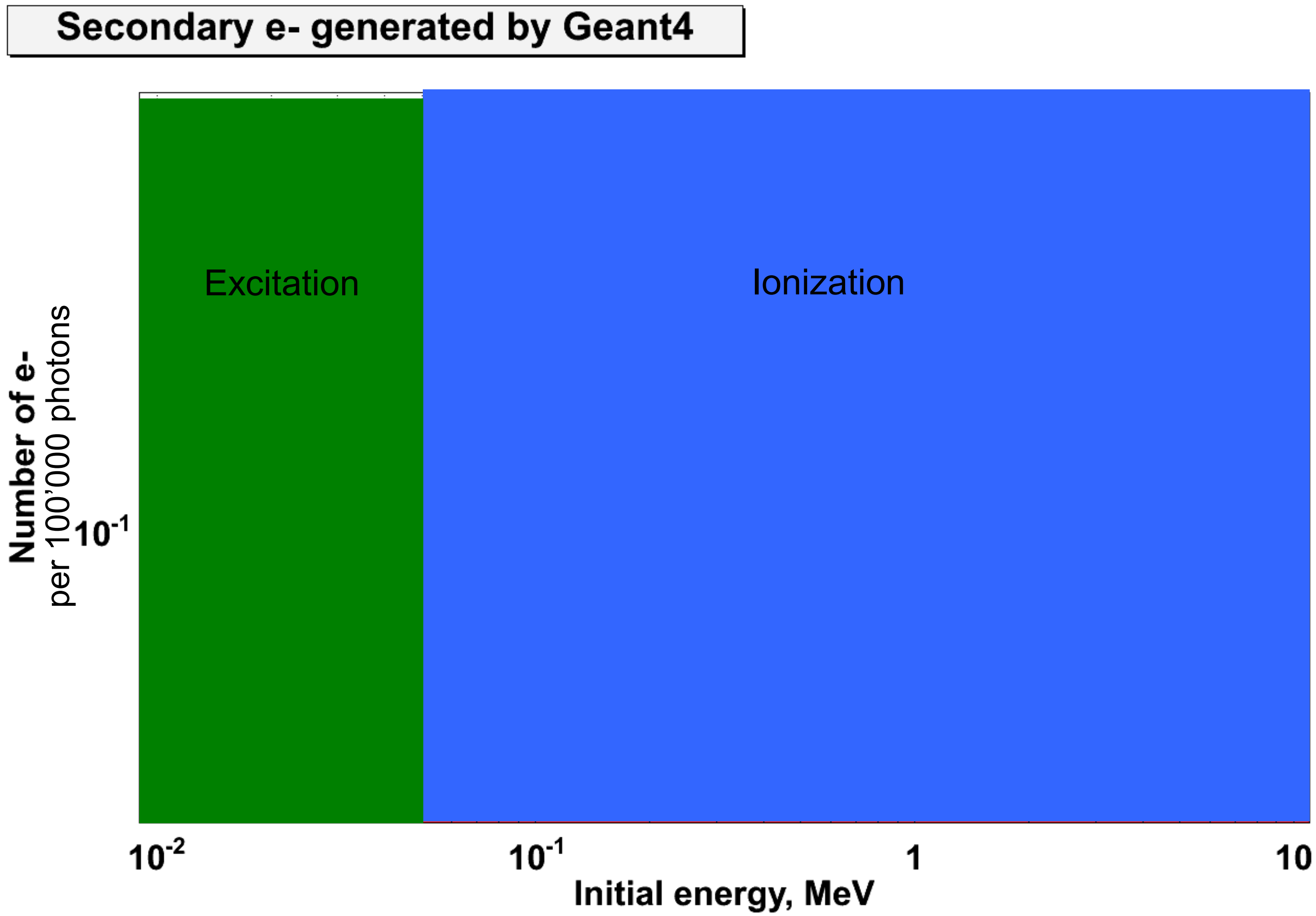
2 keV < E < 50 keV: Fluorescence monitors

E > 50 keV: Ionization → direct measurement, single photon detection

→ Direct and indirect measurement of the ionization
→ Direct measurement of the excitation

→ Single photons, efficiency << 100%
Photon flux, efficiency = 100%

Photon Interaction



Applications

Beam Instrumentation Detectors

Protons

- Beam Loss / Position / Profile Monitors

Electrons

- Beam Loss Monitors

Photons

- Beam Position Monitors (SLS, XFEL)

Neutrons

- Flux monitors (14 MeV fusion, radiation protection)

Application Example 1:

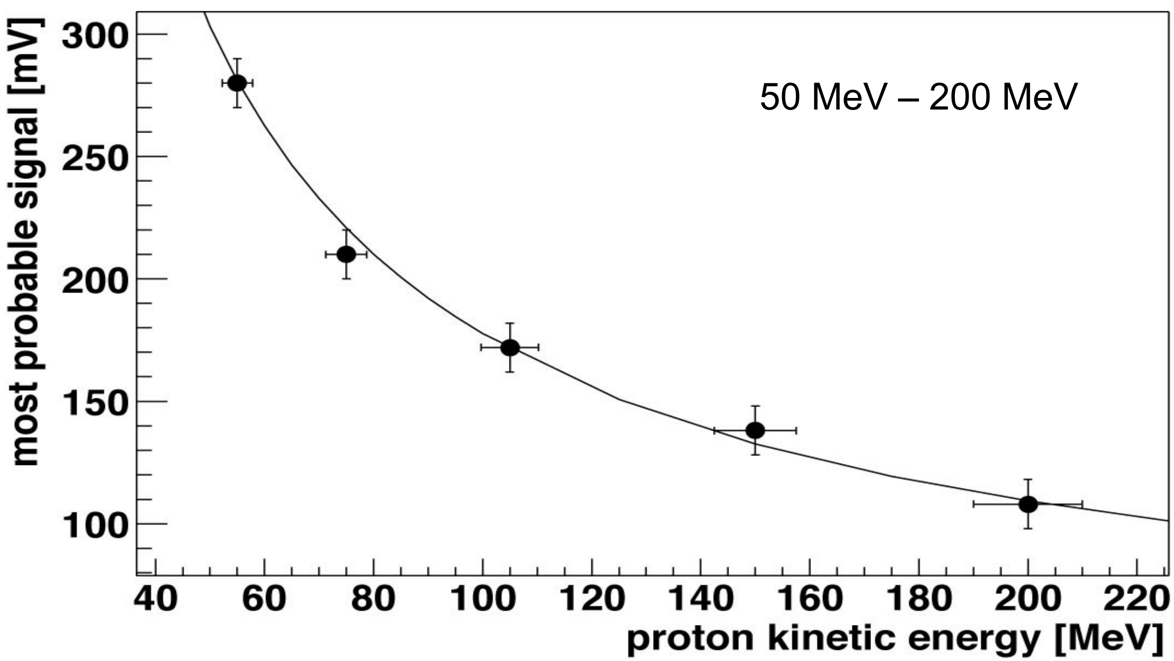
PROTONS

Proton Therapy


IBA Cyclotron in Orsay

Proton Therapy

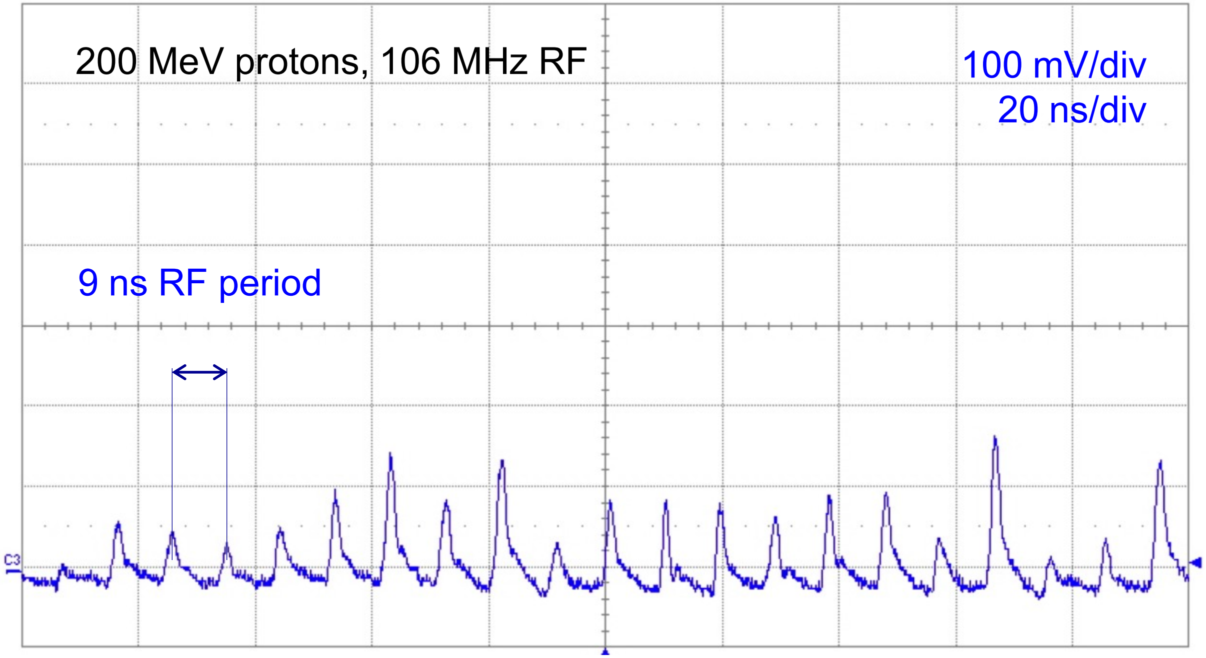
Energy calibration



IBA Cyclotron

Proton Therapy

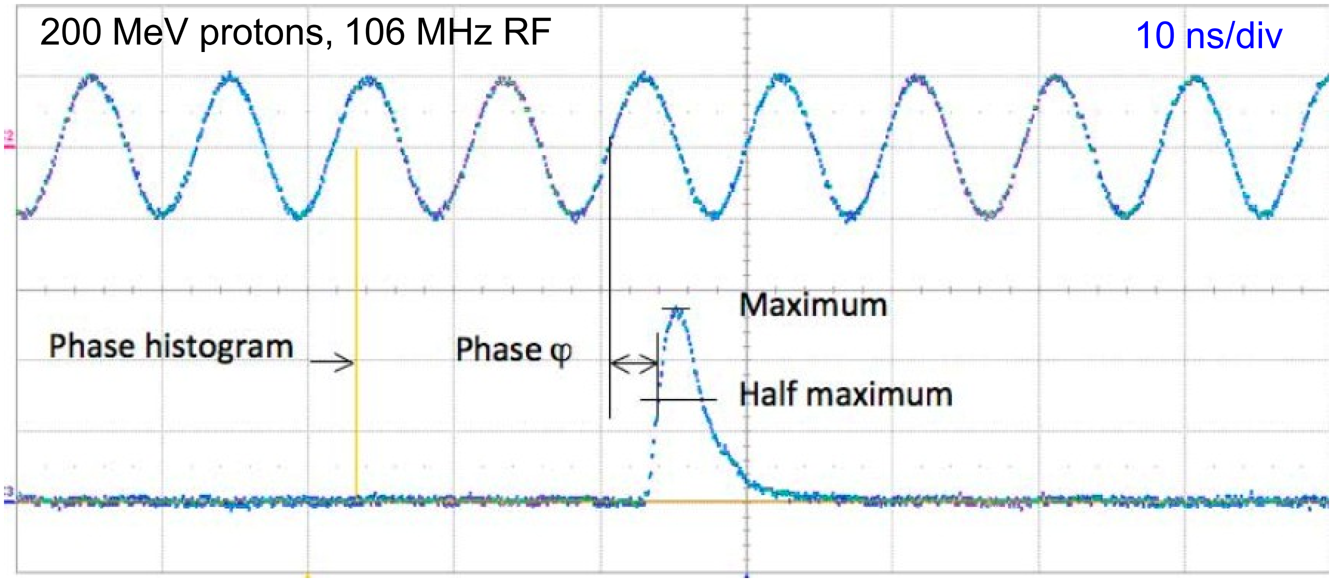
Beam structure



IBA Cyclotron

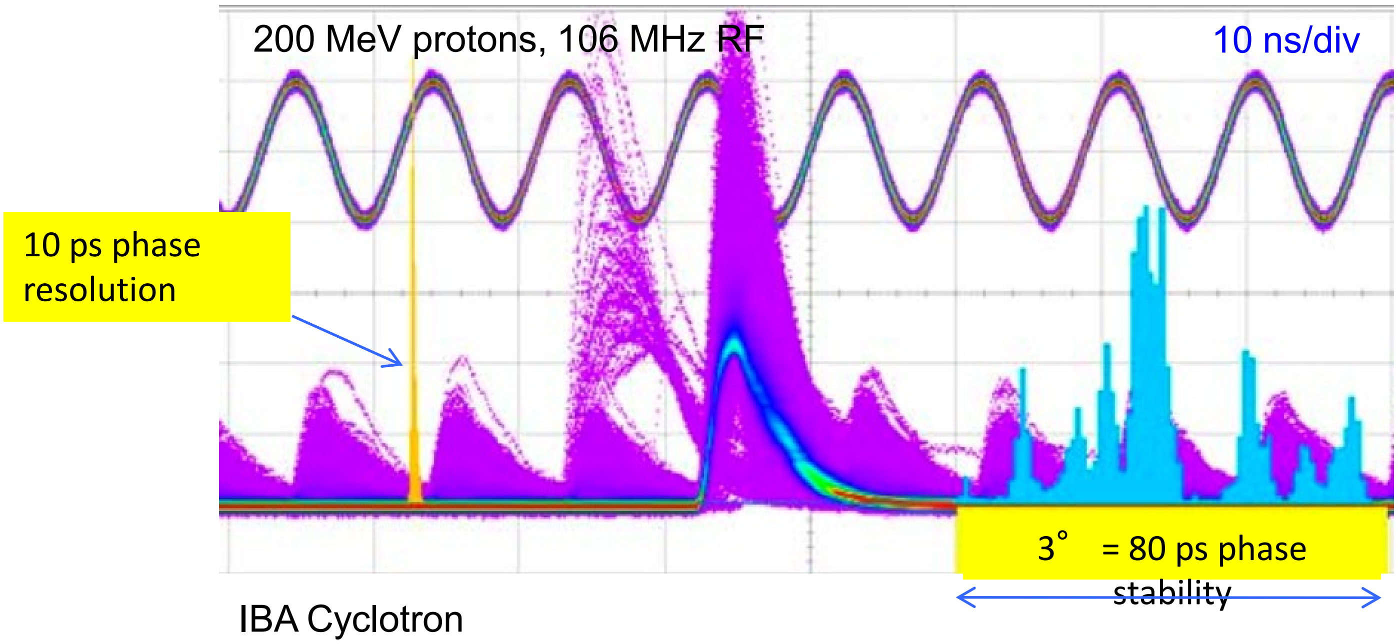
Proton Therapy

Phase measurement

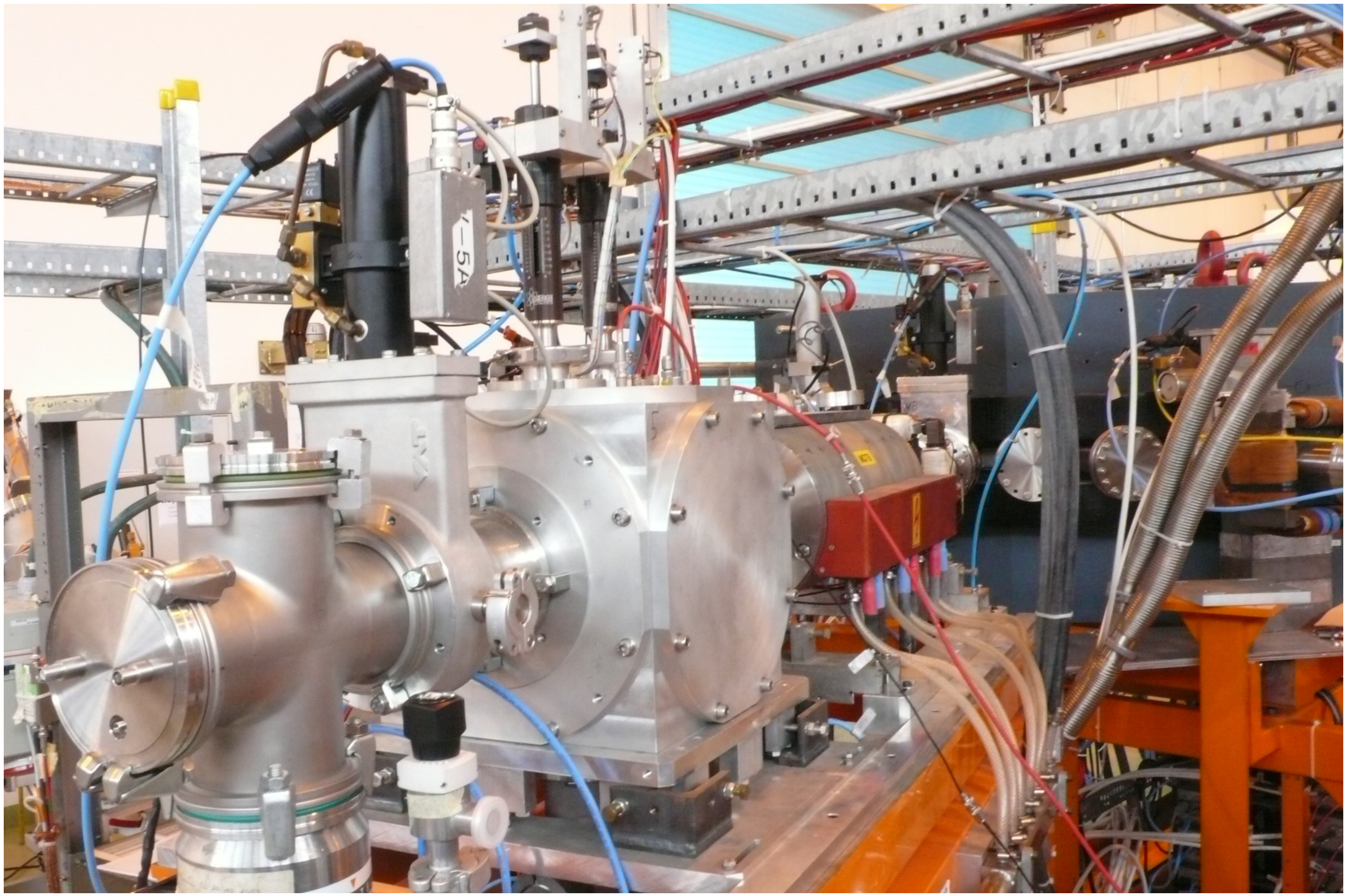


Proton Therapy

Phase measurement

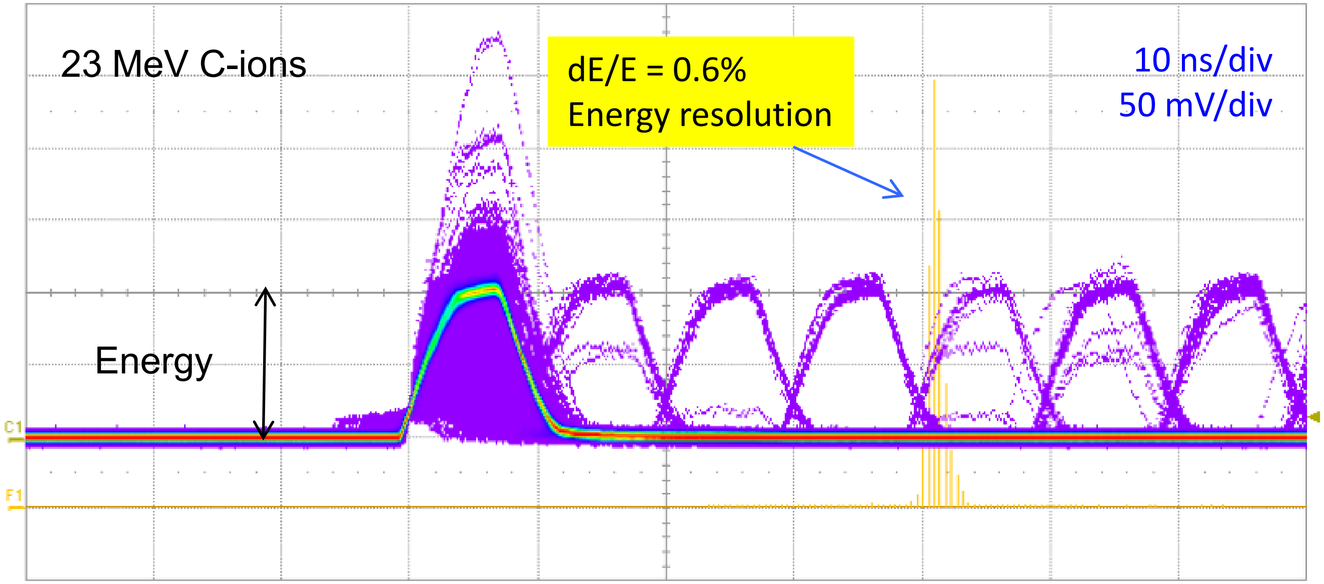


CERN ISOLDE – Heavy Ions



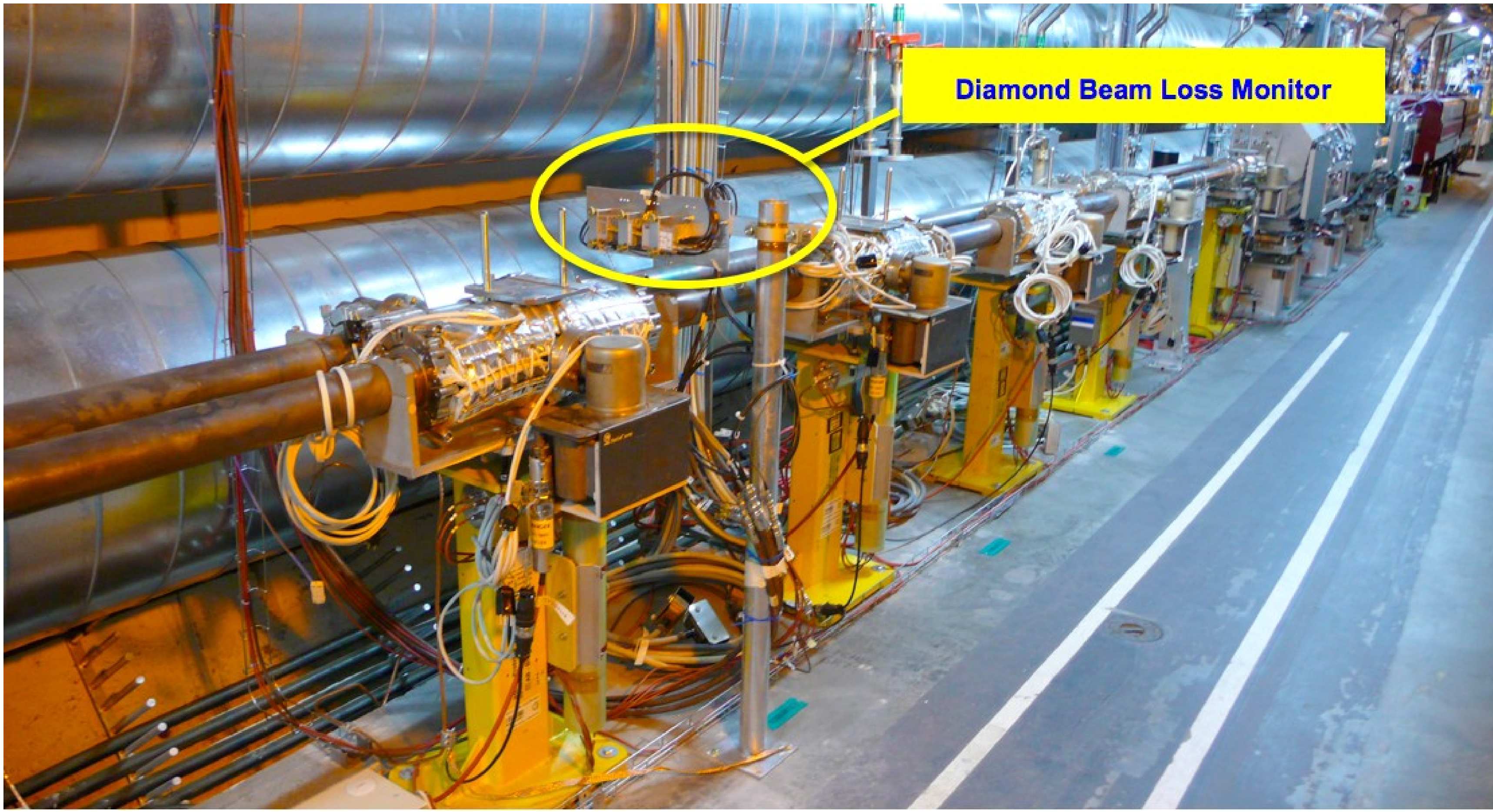
Heavy Ions

Calorimetric spectroscopy



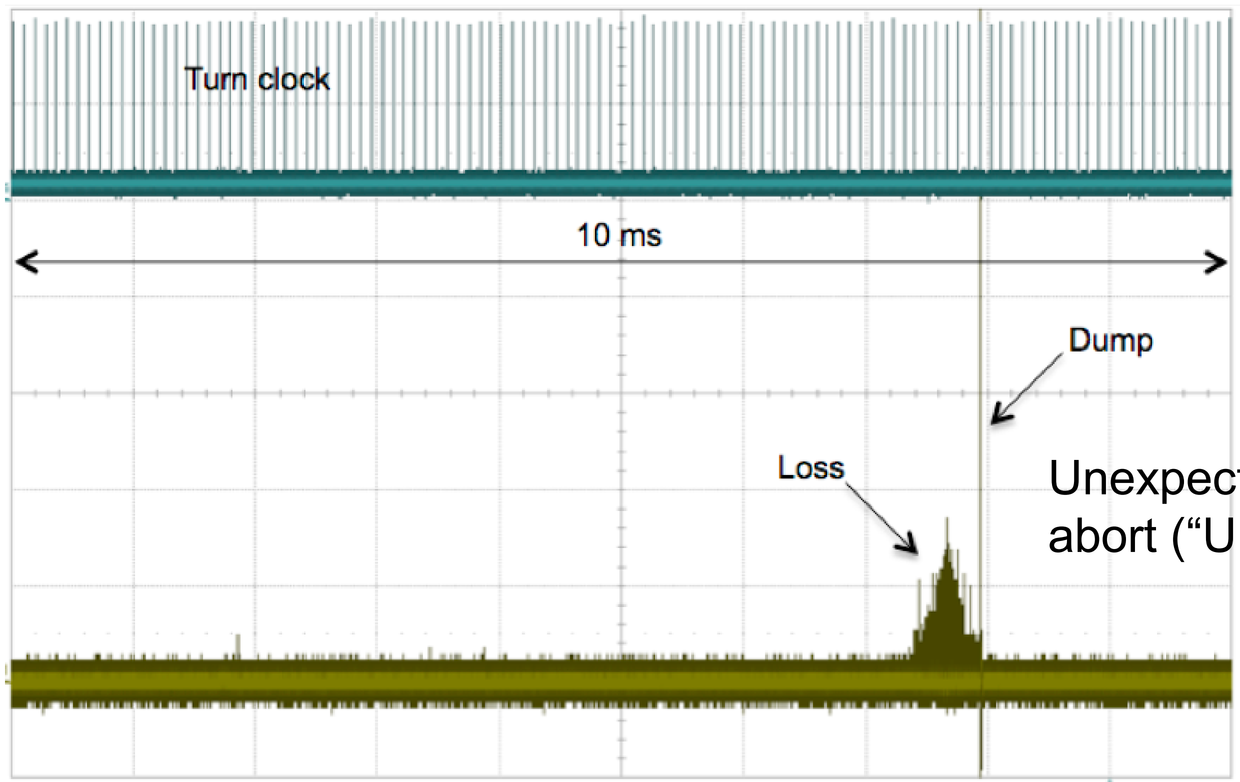
REX ISOLDE

LHC - Diamond Beam Loss Monitor



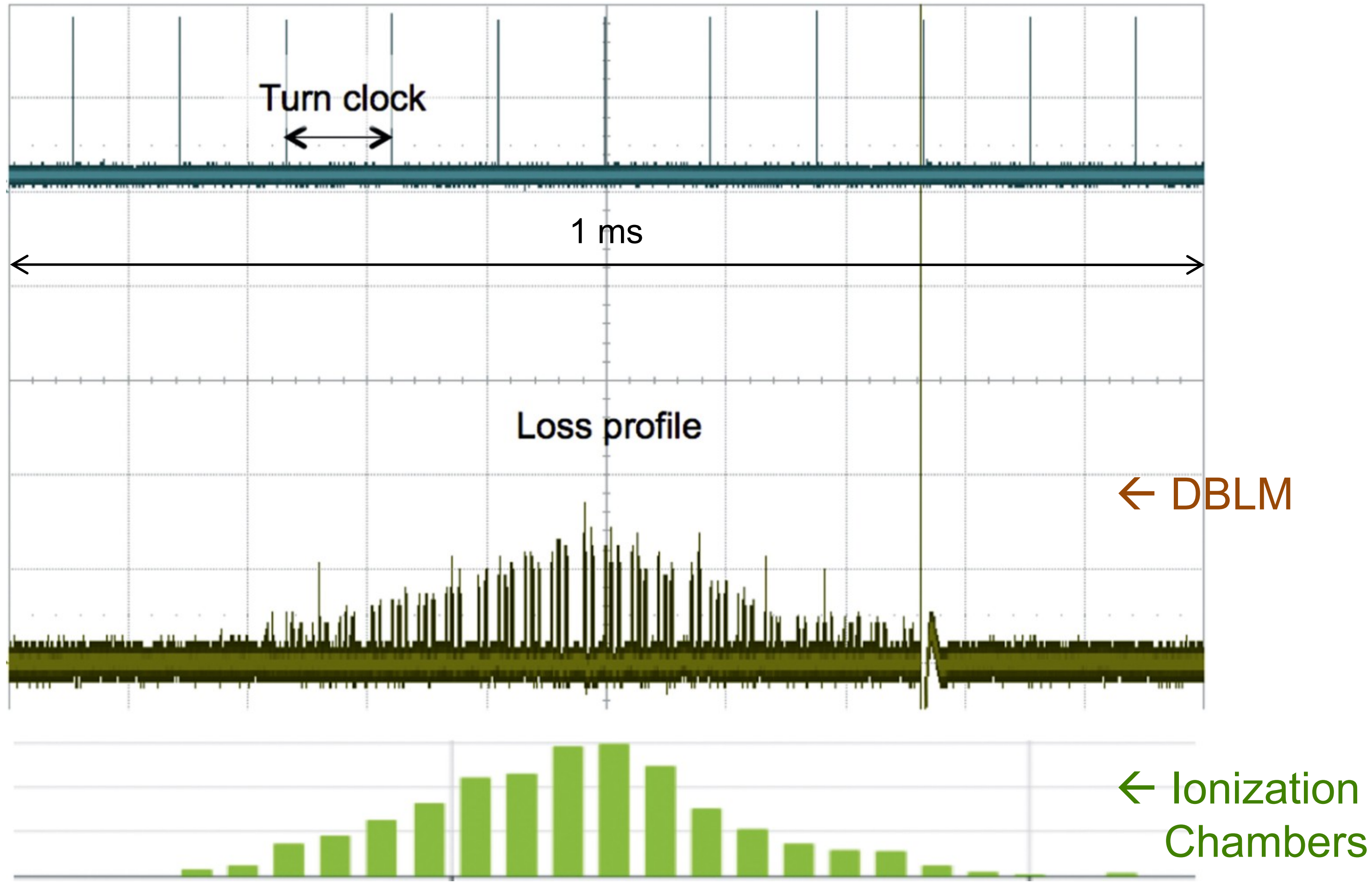
LHC – Collimation Area – IP7

LHC - DBLM

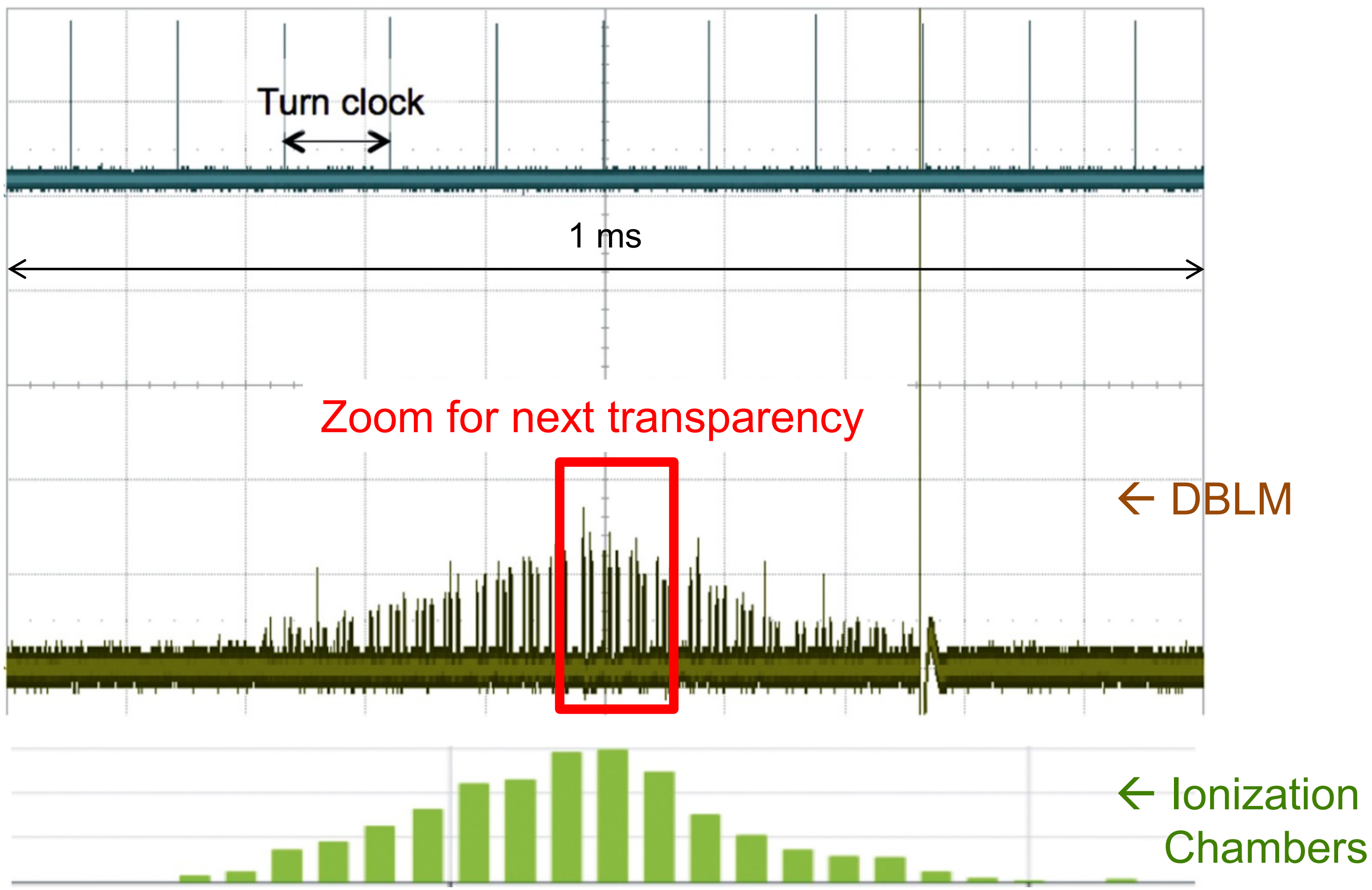


Unexpected beam abort ("UFO")

LHC - DBLM



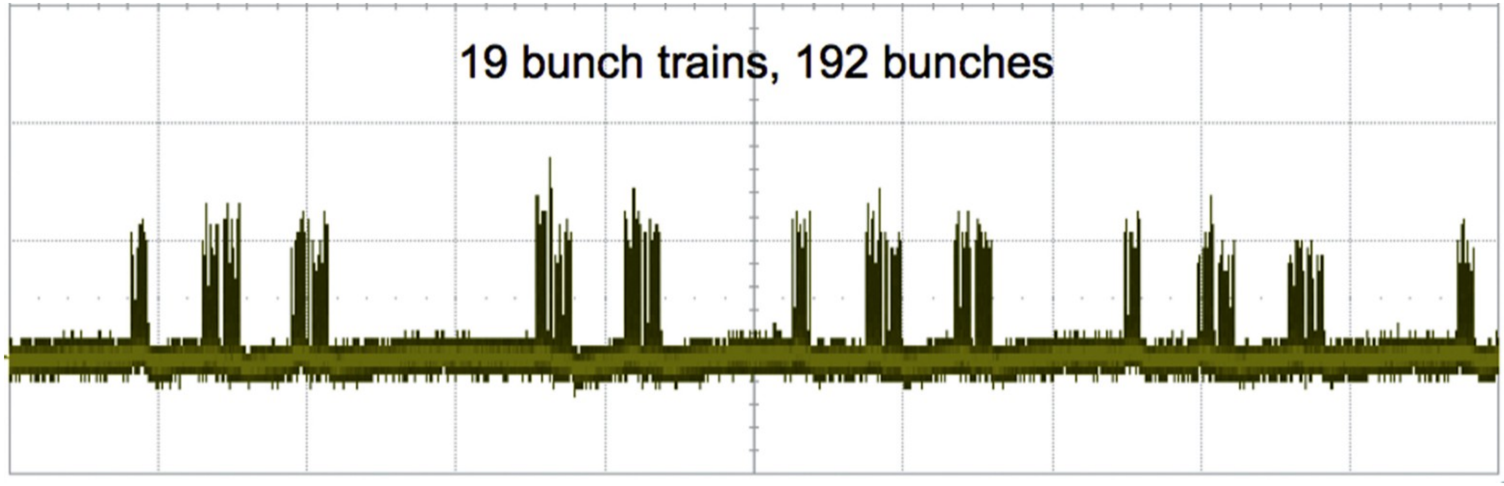
LHC - DBLM



Turn clock
1 ms
Zoom for next transparency
← DBLM
← Ionization Chambers

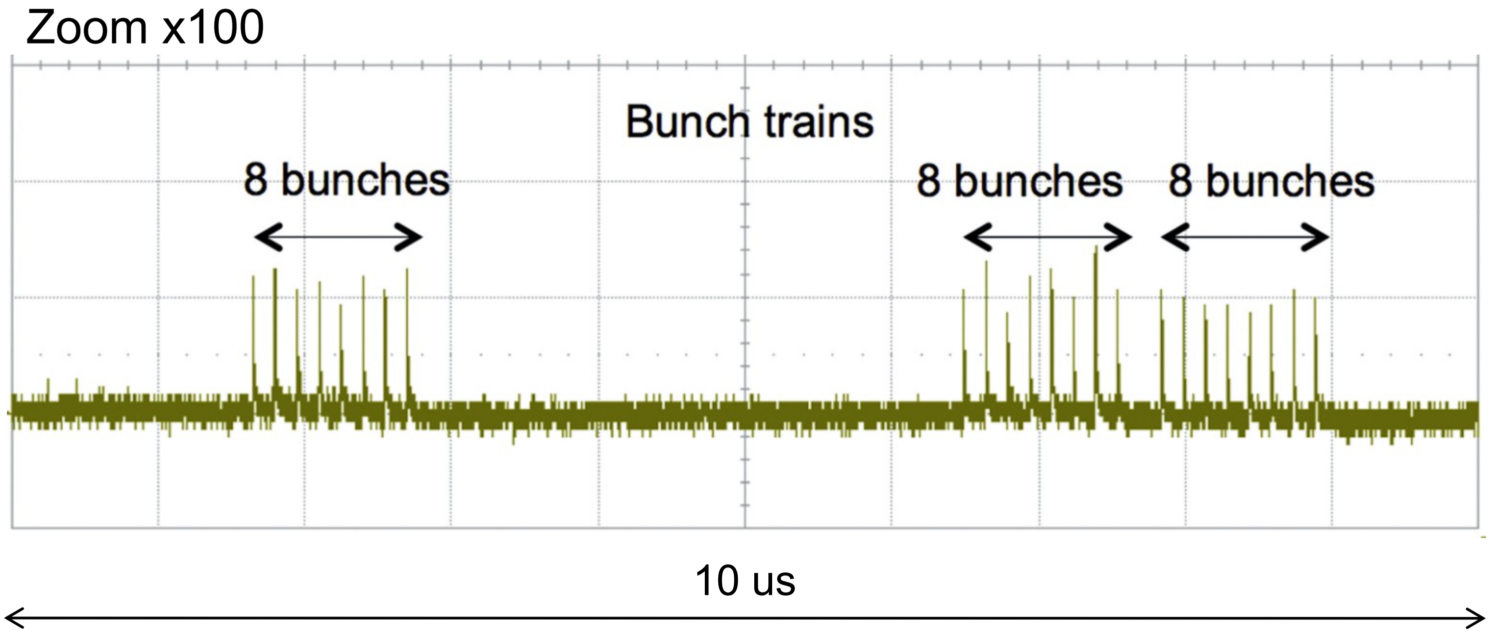
LHC - DBLM

Zoom x10



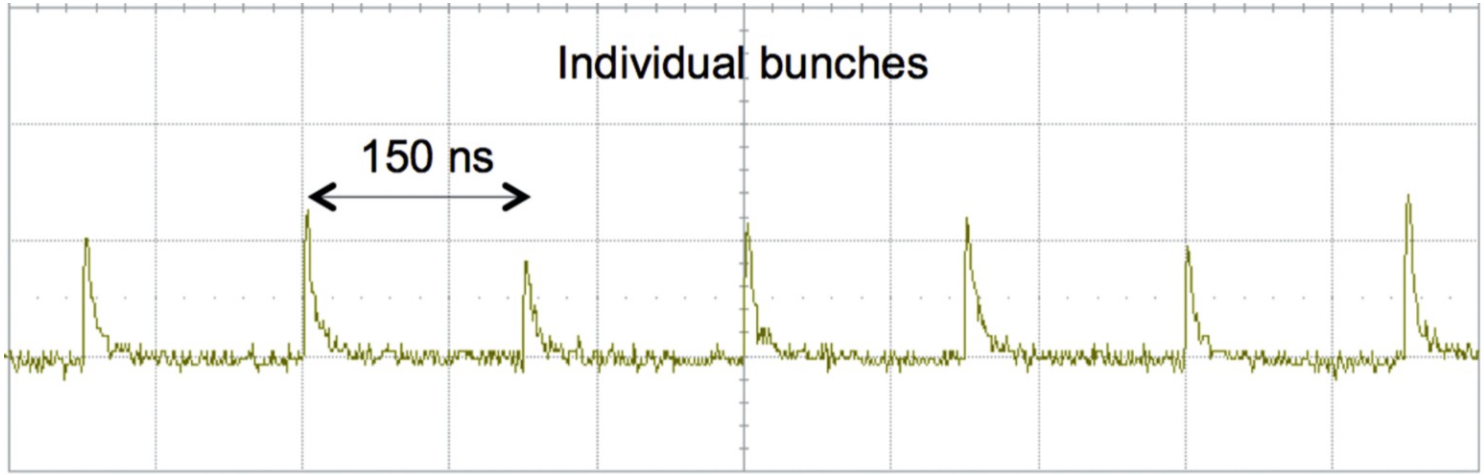
100 us

LHC - DBLM



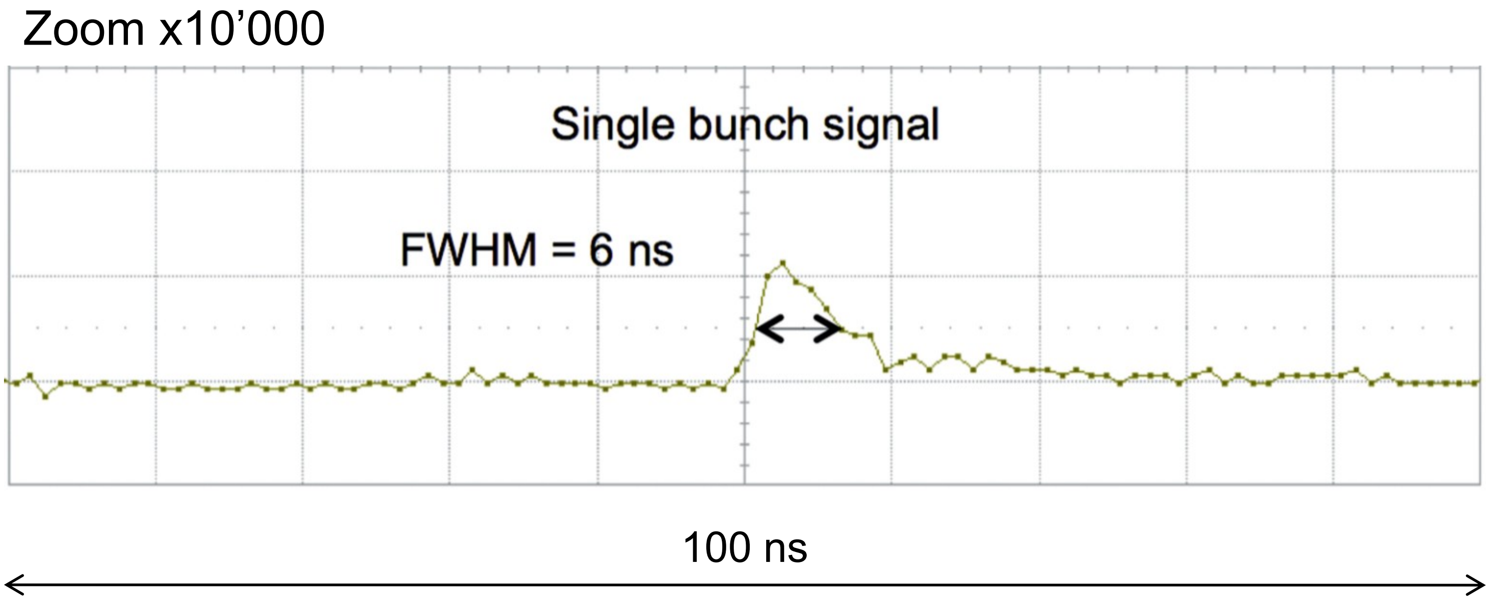
LHC - DBLM

Zoom x1000



1 us

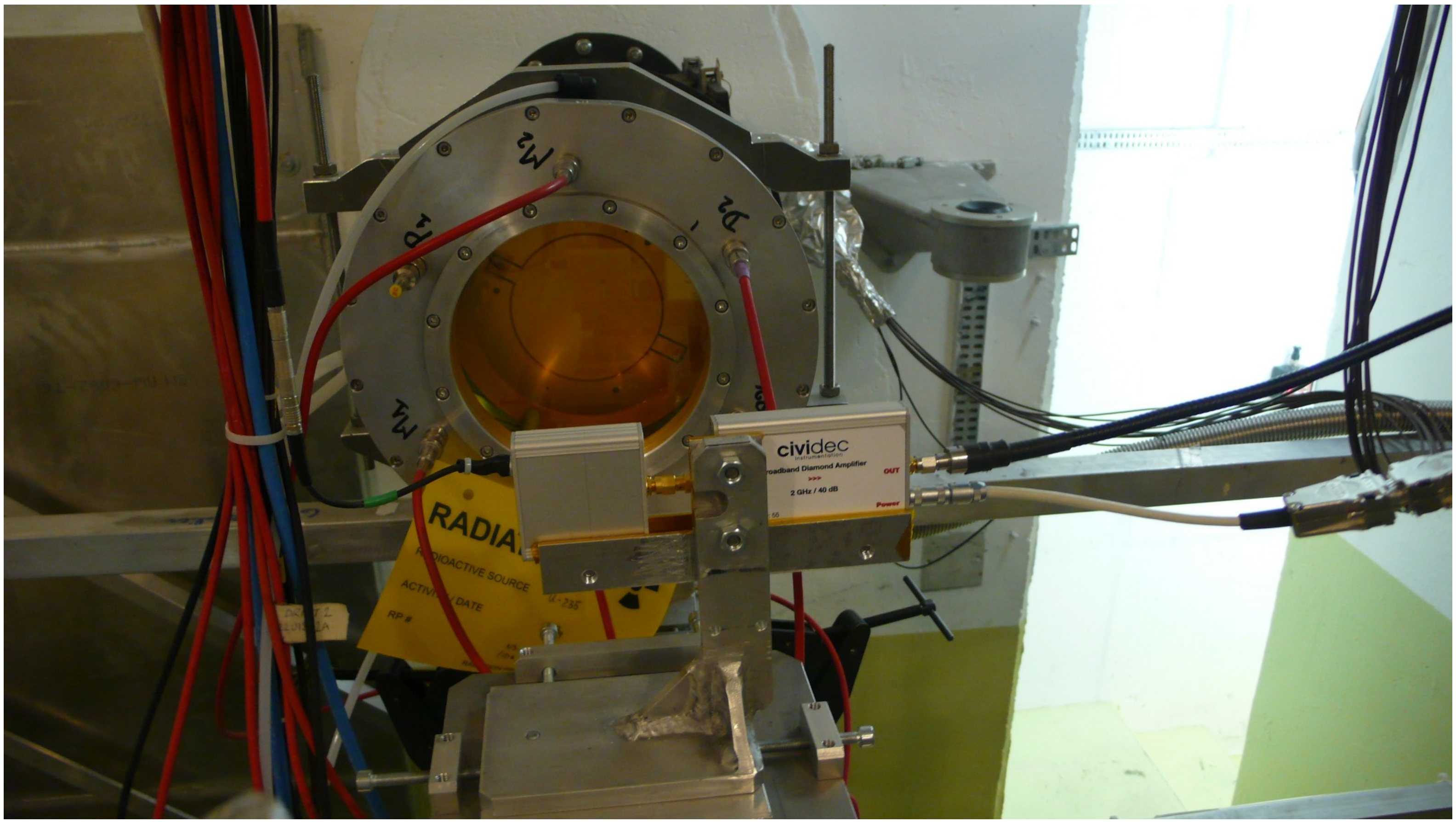
LHC - DBLM



Application Example 2:

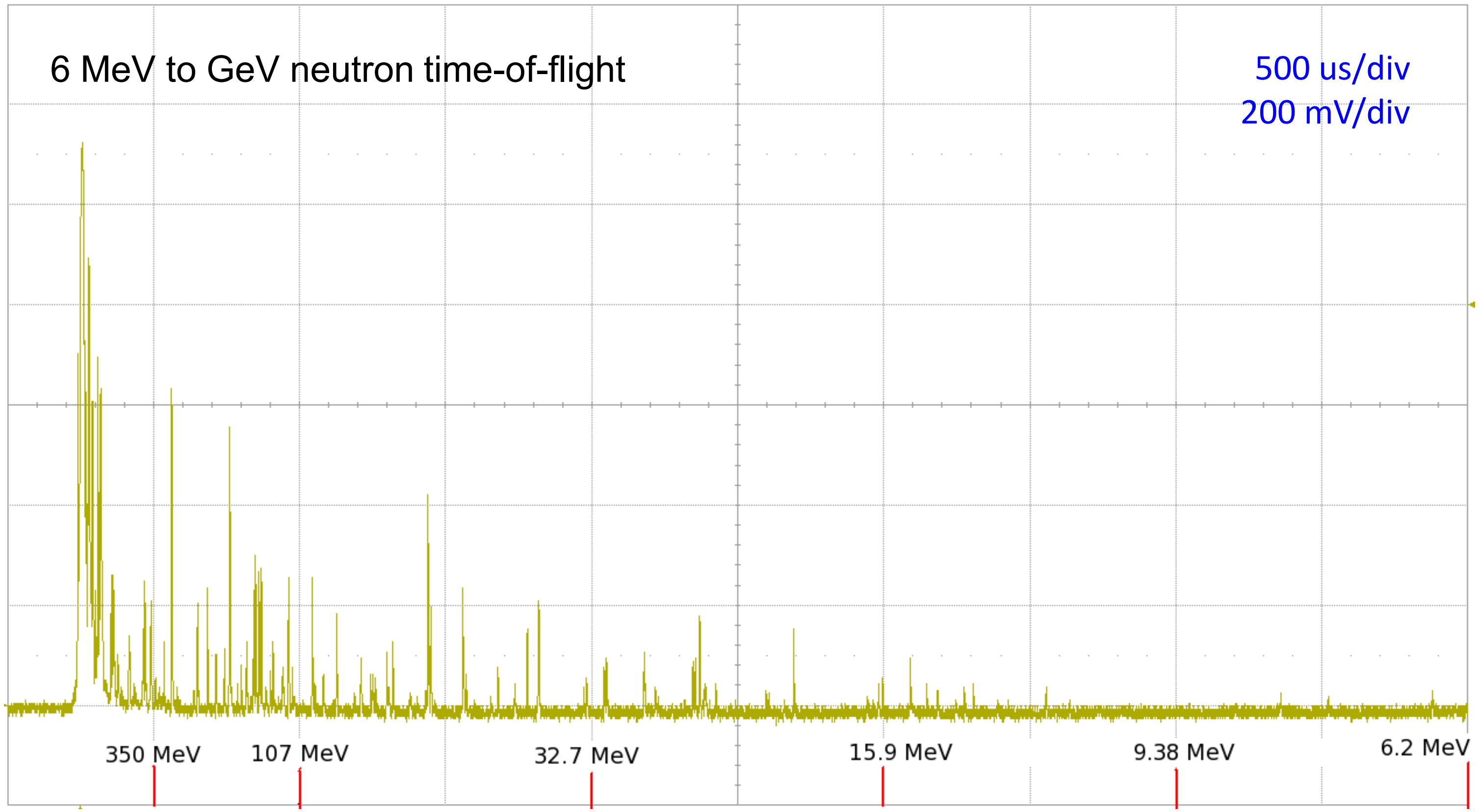
Neutrons

Neutron Measurement



n_TOF experiment at CERN: thermal to GeV neutrons

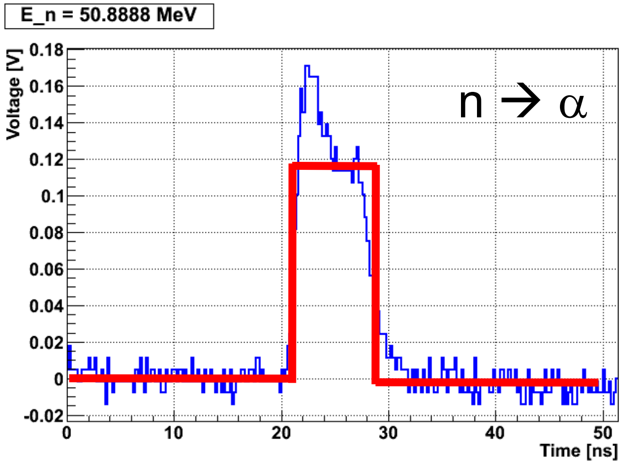
Neutron Measurement

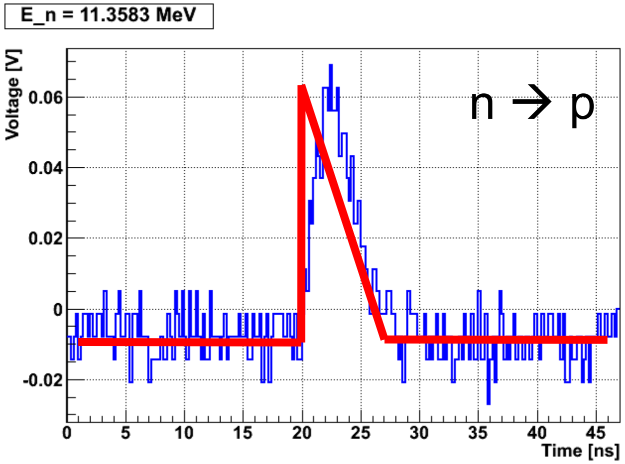


n_TOF at CERN

Neutron Measurement

Measurement of n → α and n → p interactions





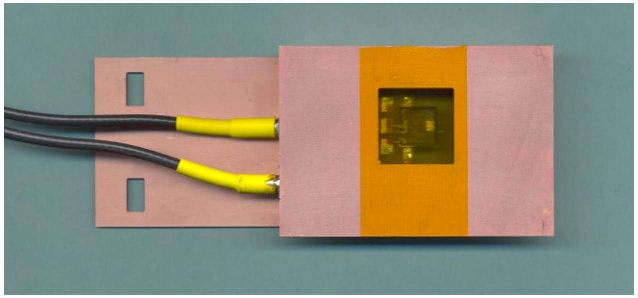
Pulse shapes of interactions

Application Example 3:

Photons

Medical LINAC

AKH Vienna
X-rays: 6 MV – 25 MV
Dose-rate: 4 Gy/min
Courtesy: D. Georg

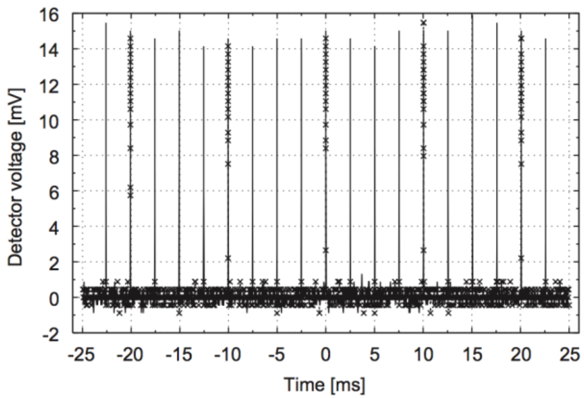


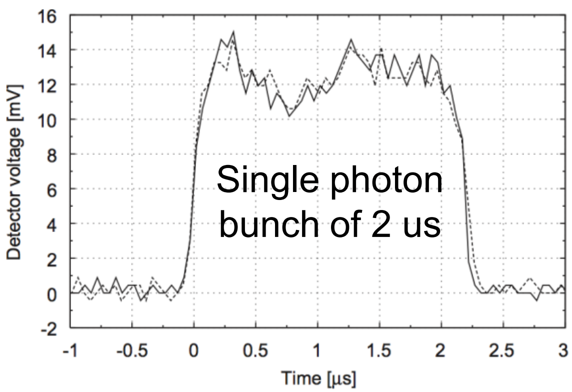
Diamond Detector

Water phantom

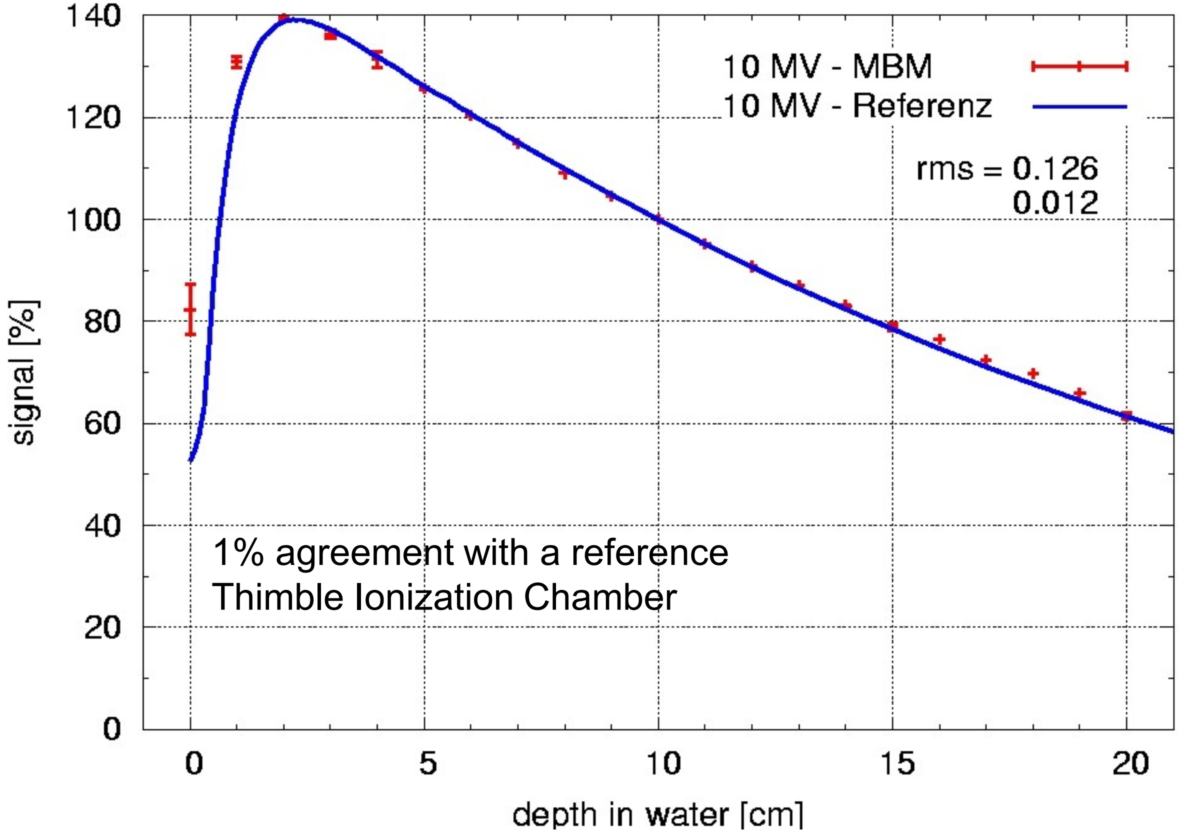
10 MeV Photons

2.5 ms bunch rate





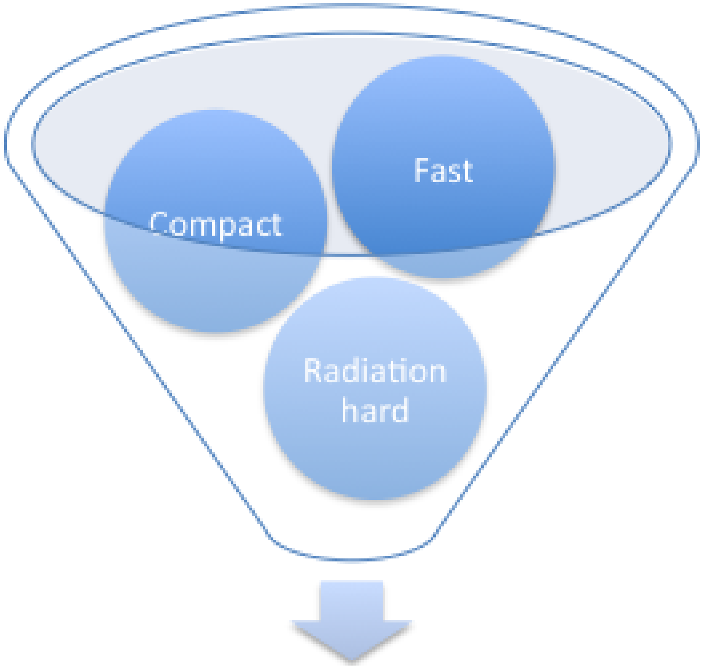
Depth-dose profile measurement



Summary

- Radiation resistance
- Fast → 10 ps time resolution, 360 ps for single particles
- High sensitivity → single particles with +40 dB
- High dynamic range → attenuation -40 dB
- Protons – electrons – neutrons – photons
- BLM, BPM, Counter, Spectroscopy, Phase
- Many other potential applications…..

Conclusion



DIAMONDS

Thank you for your attention !

CVD Parameter

Property	Diamond	Silicon	Advantage
Band gap [eV]	5.5	1.12	Low leakage
Breakdown field [V/cm]	10^7	$3 \cdot 10^5$	
Intrinsic resistivity @ R.T. [Ω cm]	$> 10^{11}$	$2.3 \cdot 10^5$	
Intrinsic carrier density [cm^{-3}]	$< 10^3$	$1.5 \cdot 10^10$	
Electron mobility [cm^2/Vs]	1900	1350	
Hole mobility [cm^2/Vs]	2300	480	
Saturation velocity [cm/s]	e^-: $0.9 \cdot 10^7$ holes: $1.4 \cdot 10^7$	$0.82 \cdot 10^7$	
Density [g/cm^3]	3.52	2.33	
Atomic number - Z	6	14	
Dielectric constant - ε	5.7	11.9	Low capacitance
Displacement energy [eV/atom]	43	13-20	Radiation hard
Thermal conductivity [W/m.K]	≈ 2000	150	Heat spreader
Energy to create e-h pair [eV]	13	3.61	
Radiation length [cm]	12.2	9.36	
Interaction length [cm]	24.5	45.5	
Spec. Ionization Loss [MeV/cm]	6.07	3.21	
Aver. Signal Created / 100 μm [e_0]	3602	8892	Low signal, Low Noise
Aver. Signal Created / 0.1 X0 [e_0]	4401	8323	

Radiation Hardness