Università di Pisa
Pre-tesi di dottorato
XXVIII ciclo

Controlled dose irradiation with pulsed beams of different ion species

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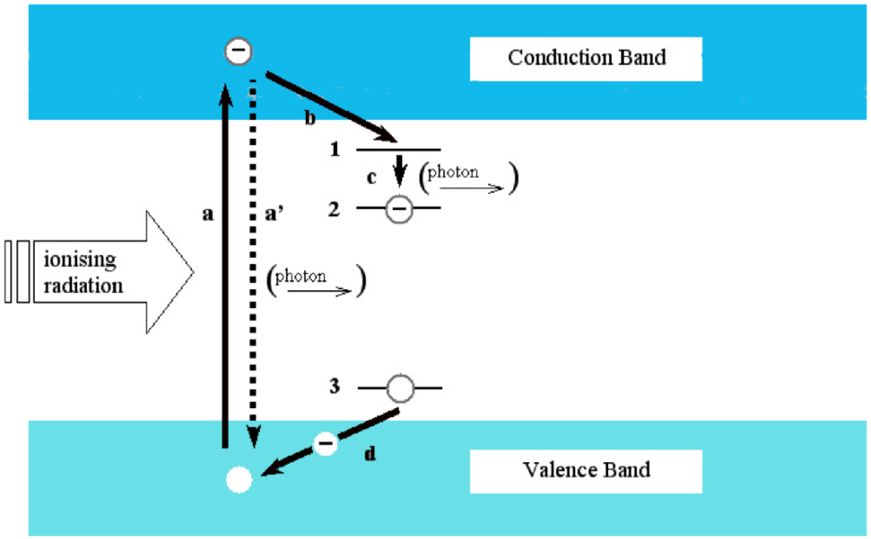
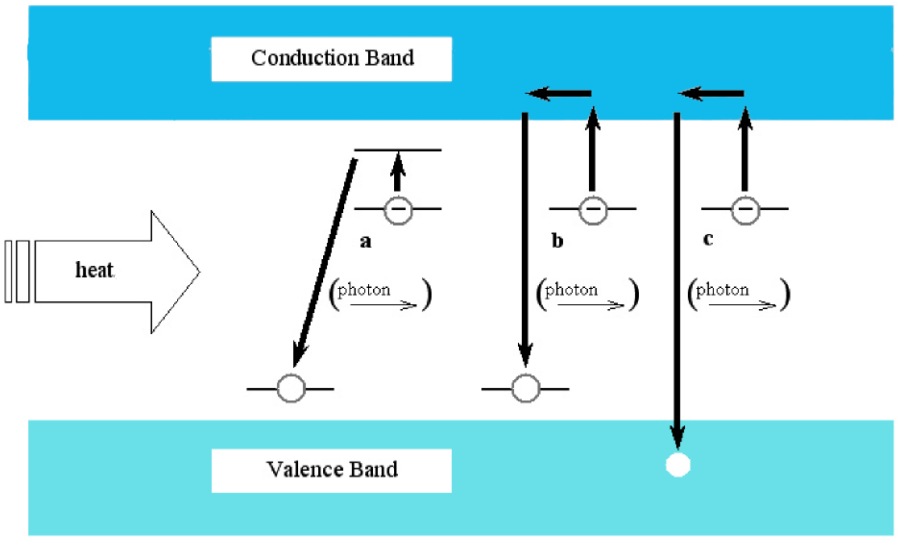
23/10/2014

Overview

- Thermoluminescence (TL)
- TL dating principles
- The 3 MV Tandem accelerator system
- The pulsed beam line DEFEL
- Detector system setup
- Preliminary measurements results

Thermoluminescence





a) Excitation of a valence electron by ionizing radiation

a') prompt recombination with a hole in the valence band

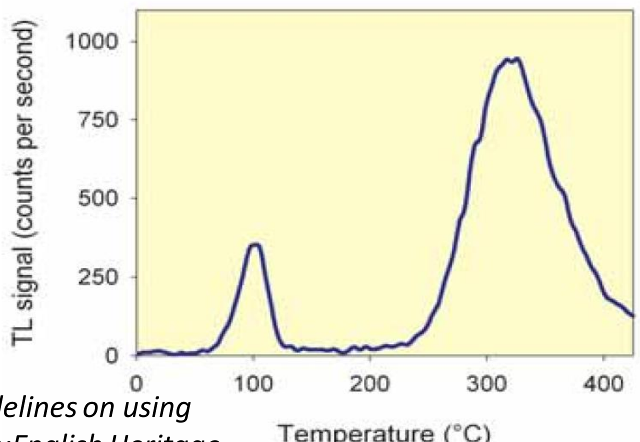
b,c) trapping in a metastable level near conduction band

d) trapping of a hole in a localized level near the valence band

a, b) Recombination with a hole at luminescent centre

c) Recombination with a hole in the valence band

Glow curve



Duller,G A T 2008 *Luminescence Dating:guidelines on using luminescence dating inarchaeology.Swindon:English Heritage*

Thermoluminescence: applications

Medical sciences, radiation dosimetry

Different kinds of dosimetric materials

LiF:Mg,Ti,
LiF:Mg,Cu,P
$Li_2B_4O_7$:Mn

Tissue equivalent

$CaSO_4$:Dy
Al_2O_3:C
CaF_2:Mn

TLDs are available in various forms: powder, chips, rods and ribbons

Archaeology: TL dating

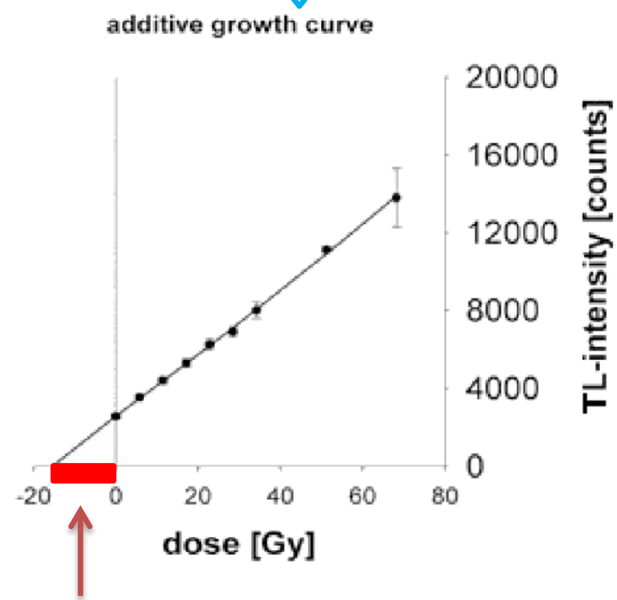
Natural TL materials present in clay and soil: quartzs, feldspars

Thermoluminescence Dating

Dating of inorganic materials (ceramics, pottery, sediments, lava, meteorites…)
Autyhentication of works of art

Dating range: 10-500000 years . Clock is set at time **t_0** (when all traps were emptied)

$$A(y) = \frac{D_e\,(Gy)}{D_r\,(Gy/y)}$$



Different contributions:

From surrounding soil

From within the sample $\quad {}^{238}_{92}U \ {}^{235}_{92}U \ {}^{232}_{90}Th \ {}^{40}_{19}K$

From space **Cosmic rays**

Aitken M. J., Thermoluminescence Dating, Academic Press, London,(1985)

Thermoluminescence Dating

Dr evaluation

Cosmic rays contribution → ≈150 μGy/year (1-2 m underground)

Radioactive nuclides contribution

→ Quartz inclusion technique (≈100 μm quartz grains cores)

Main contribution: β and γ radiation from soil

2 mGy/year

→ Fine Grain technique (≈1-8 μm quartz grains)

Main contribution: α radiation from within the sample

5 mGy/year

Controlled dose irradiation

The mechanisms at the basis of TL are not yet well known

The properties of TL materials are still under study: TL efficiency for different incident particles (particular interest in α particles for TL dating), radiation damage, dose rate effects.

Sample irradiations with known doses at the 3 MV Tandem accelerator of LABEC

p, Li, C, O, …

Energy: <1-6 MeV for protons
1-few tens of MeV for heavier ions

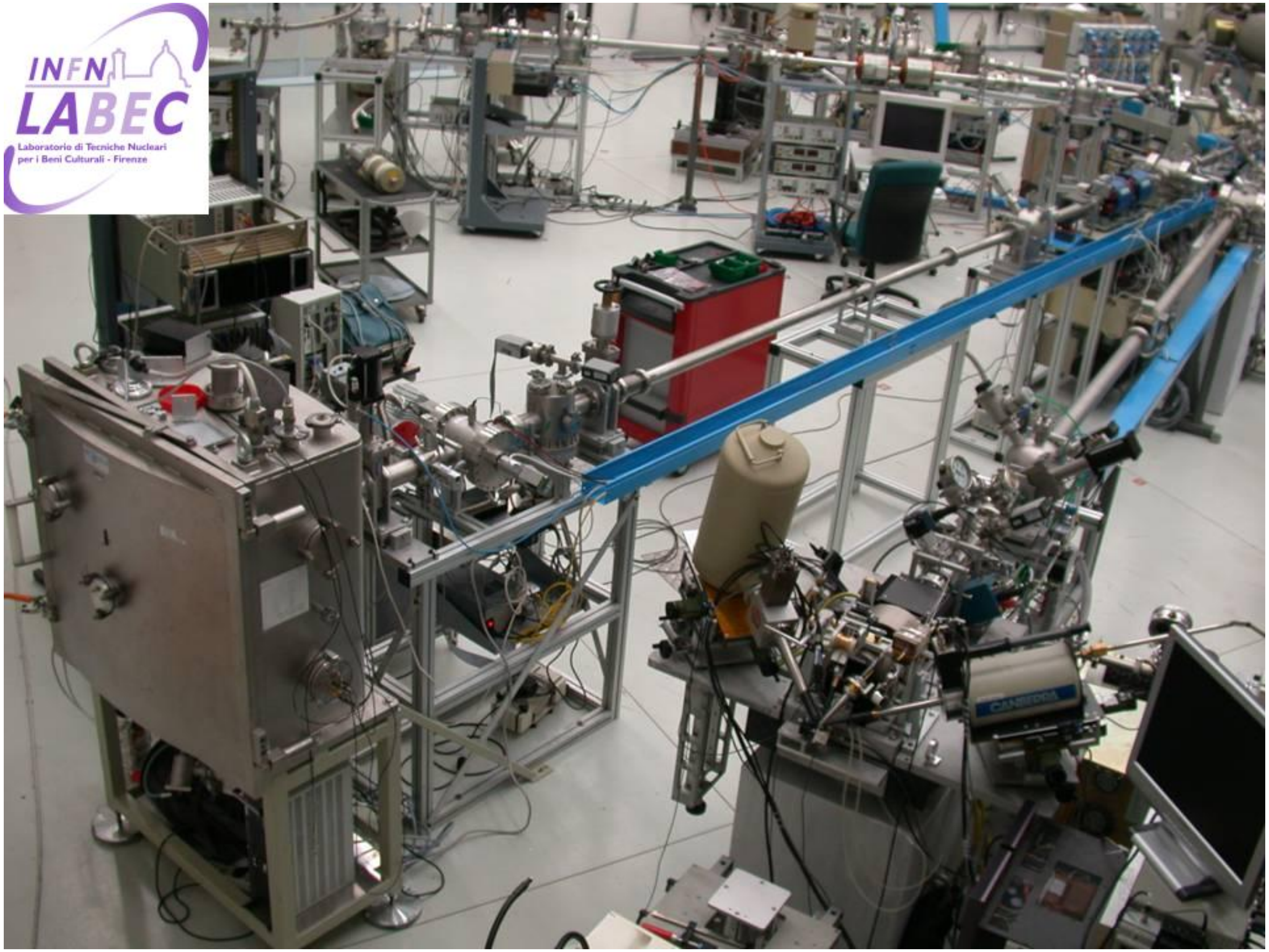
Dose <<1 mGy - 1000 Gy
Fluence 10^5- 10^{11} cm^{-2}

Very low beam currents

Example: quartz sample of 1 cm^2 → 2 Gy with 5 MeV α particles → 10^7 cm^{-2} → 1 pA for 1s

Use of pulsed beams

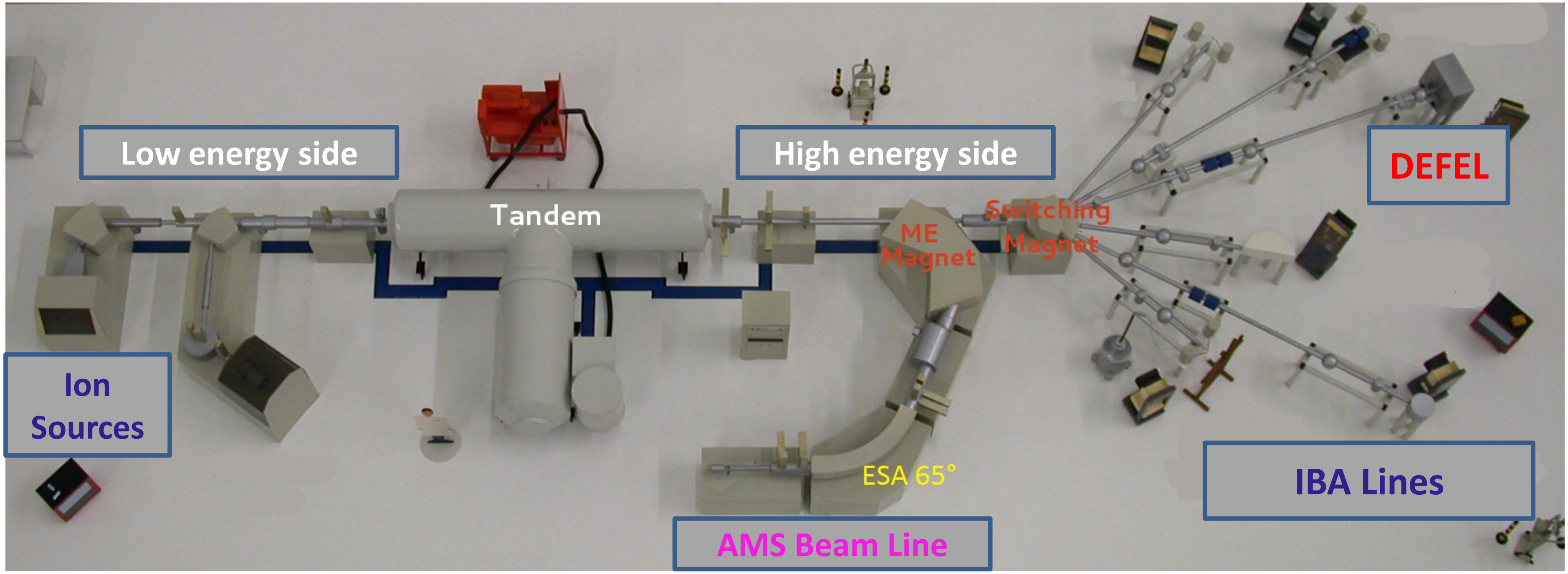
The pulsed beam line DEFEL



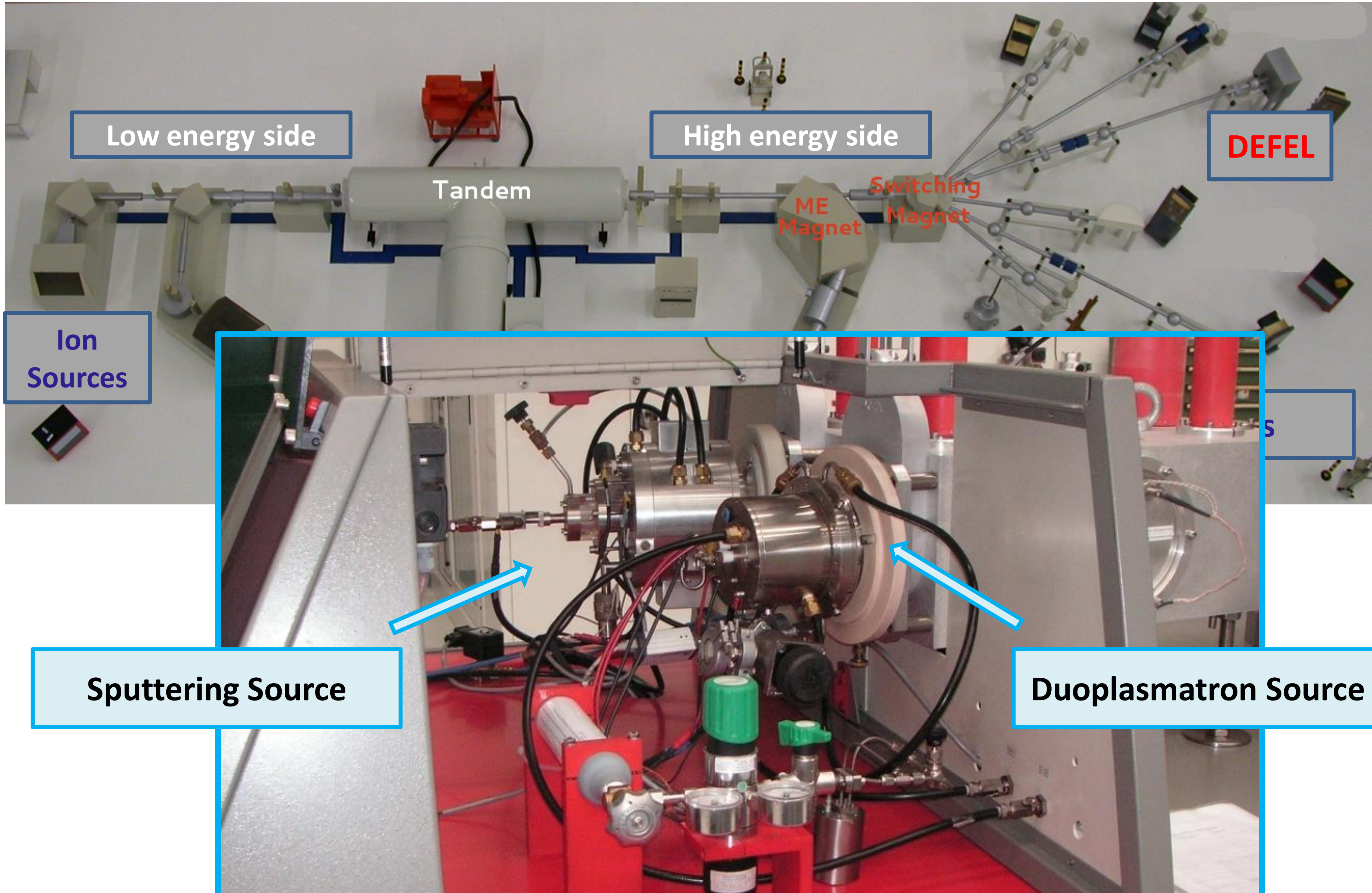
Bunch multiplicity:
1 – few hundreds

Bunch frequency:
single pulse-1 kHz

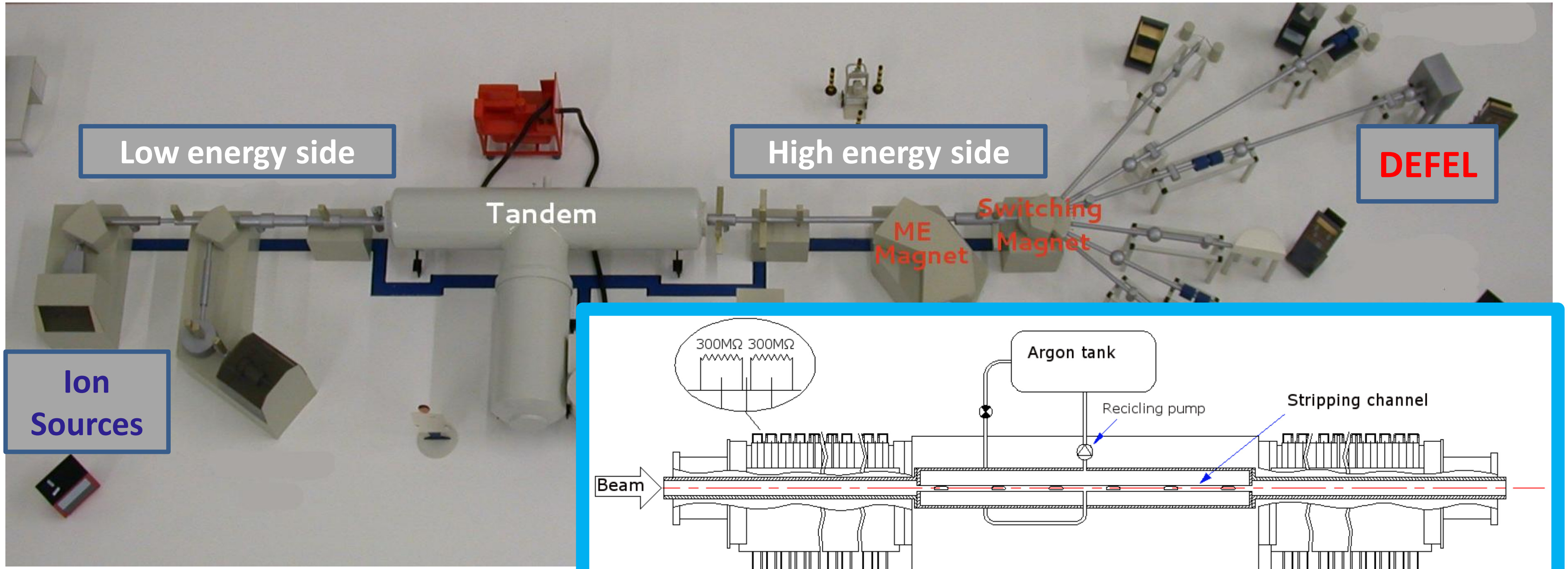
The accelerator system

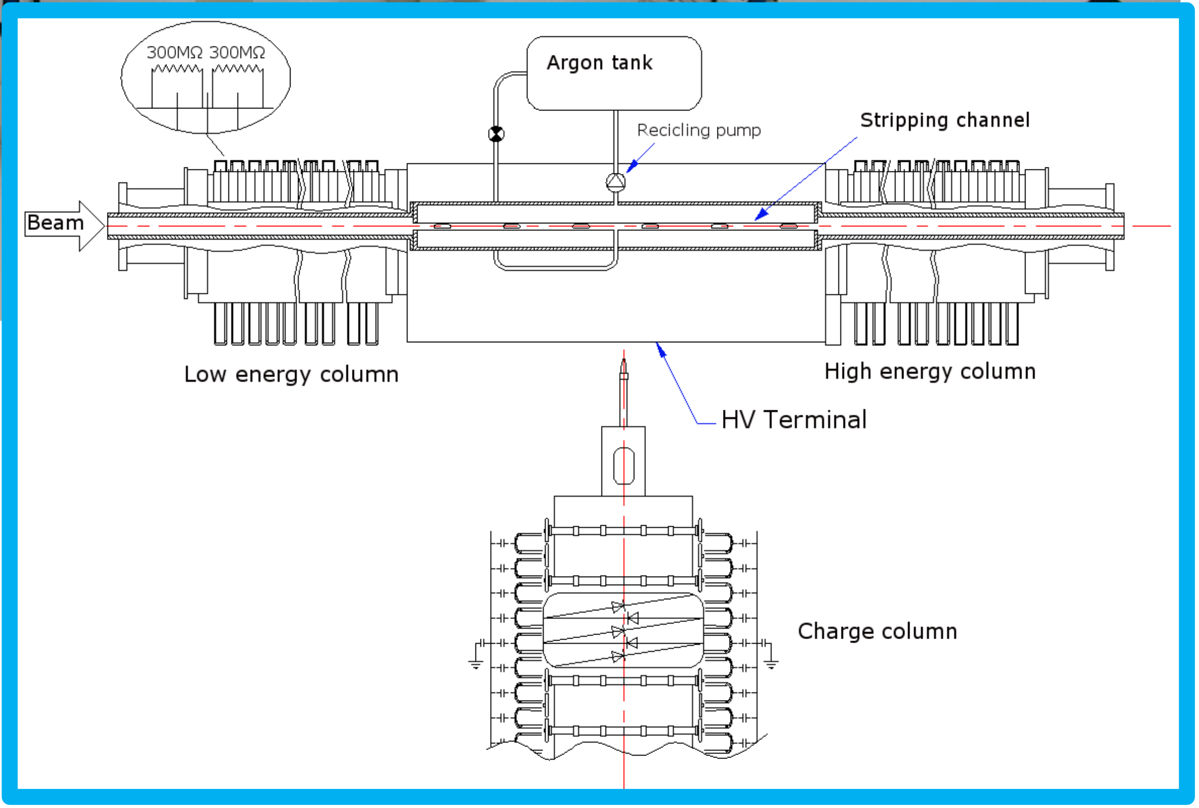


The accelerator system: ion sources

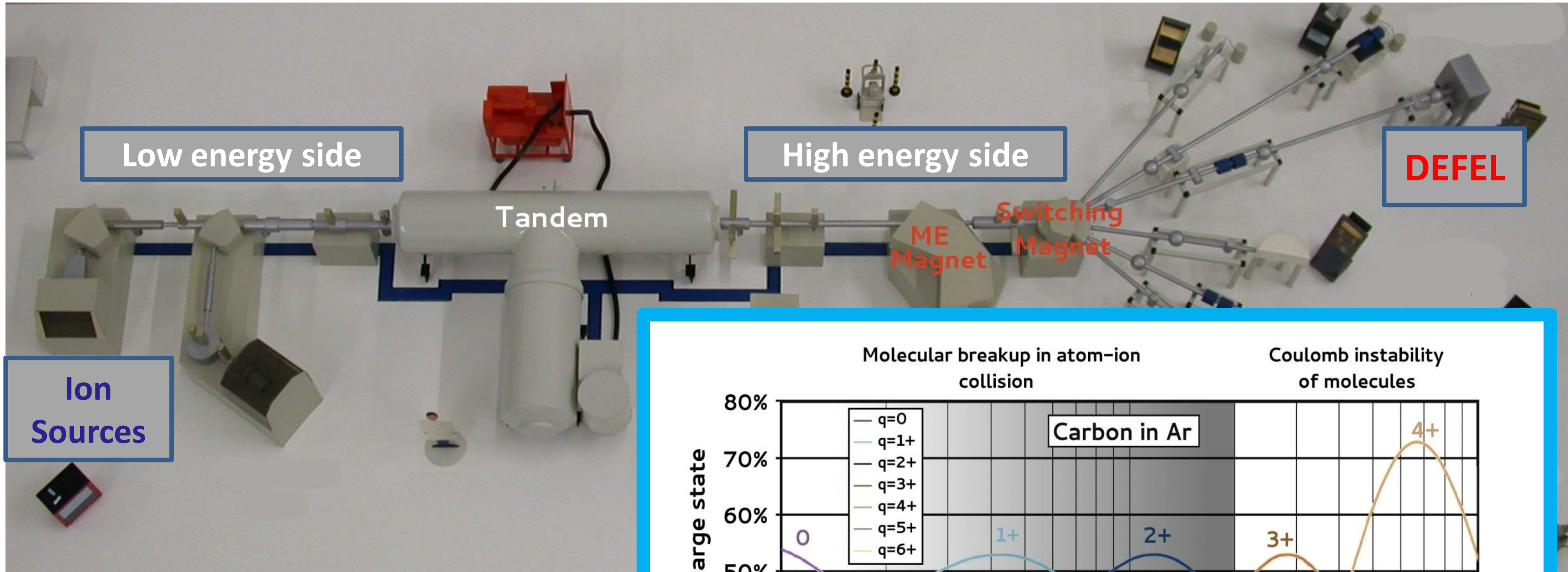


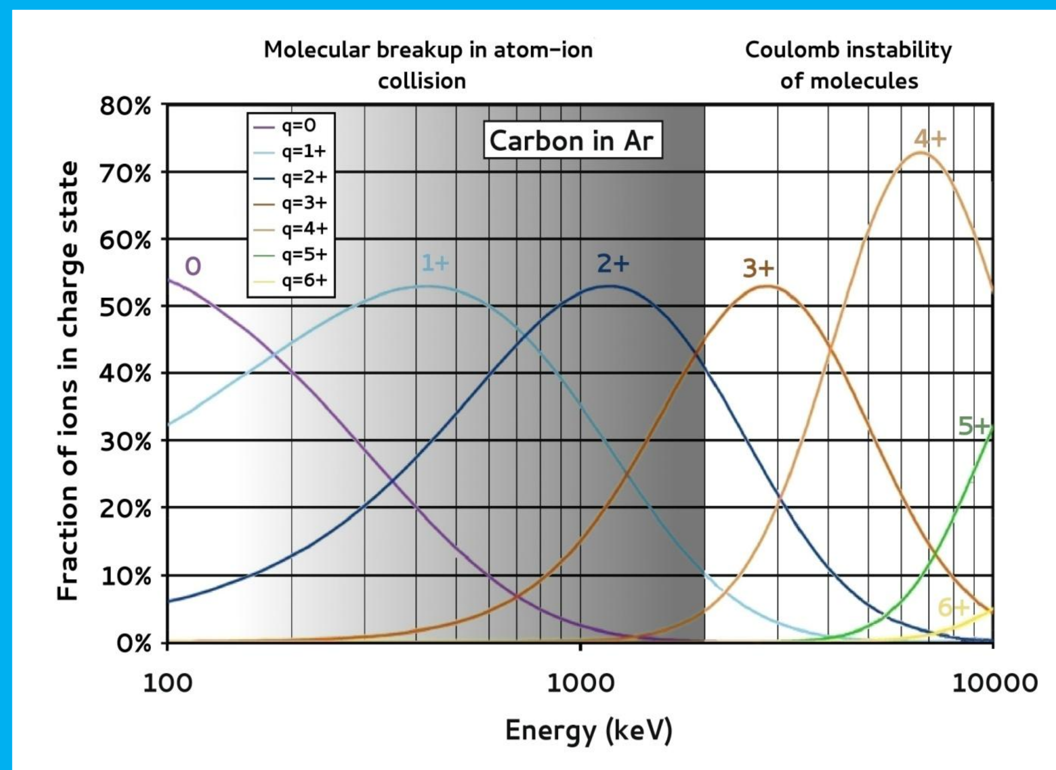
The accelerator system: the acceleration





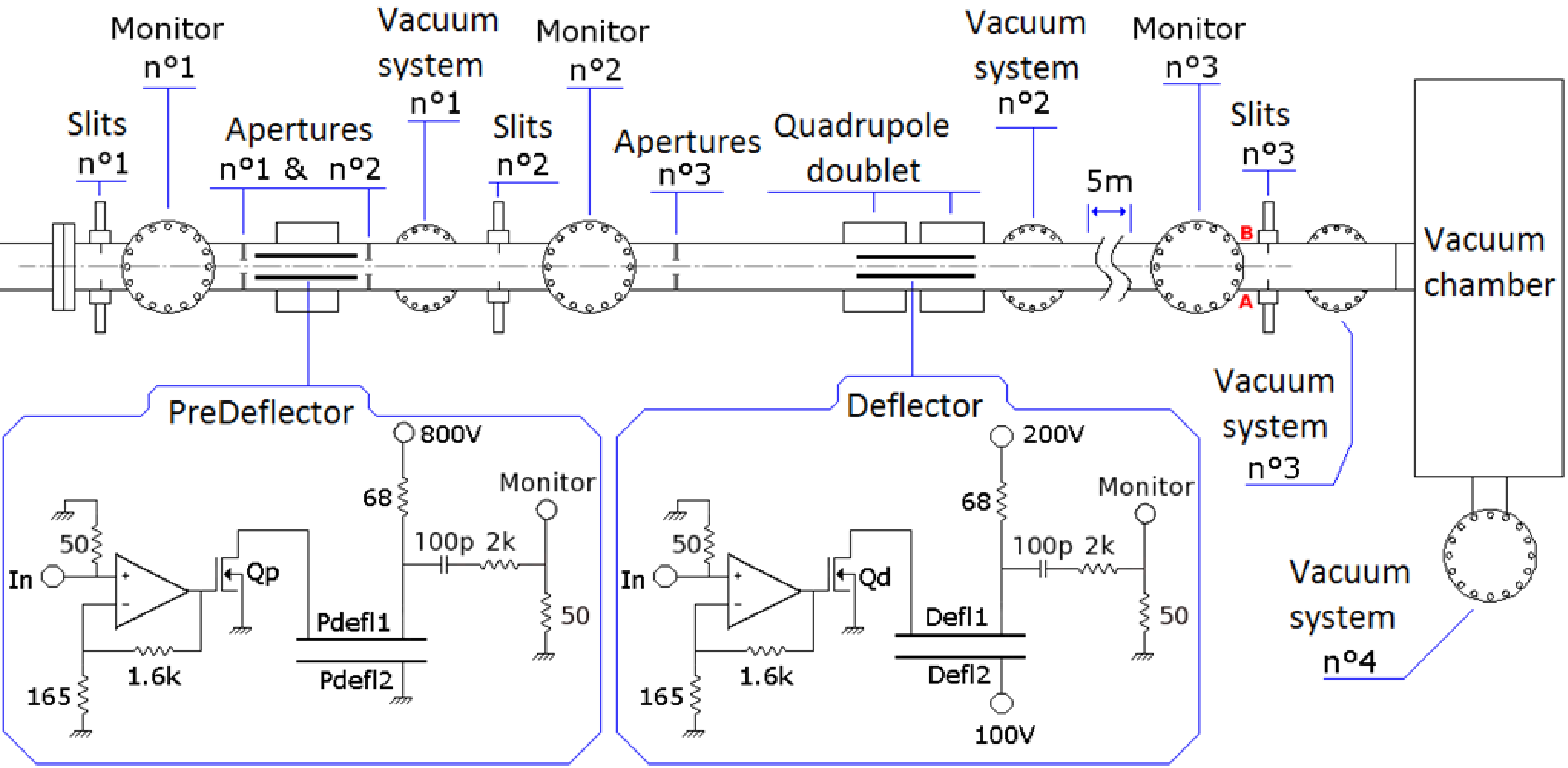
The accelerator system: the acceleration



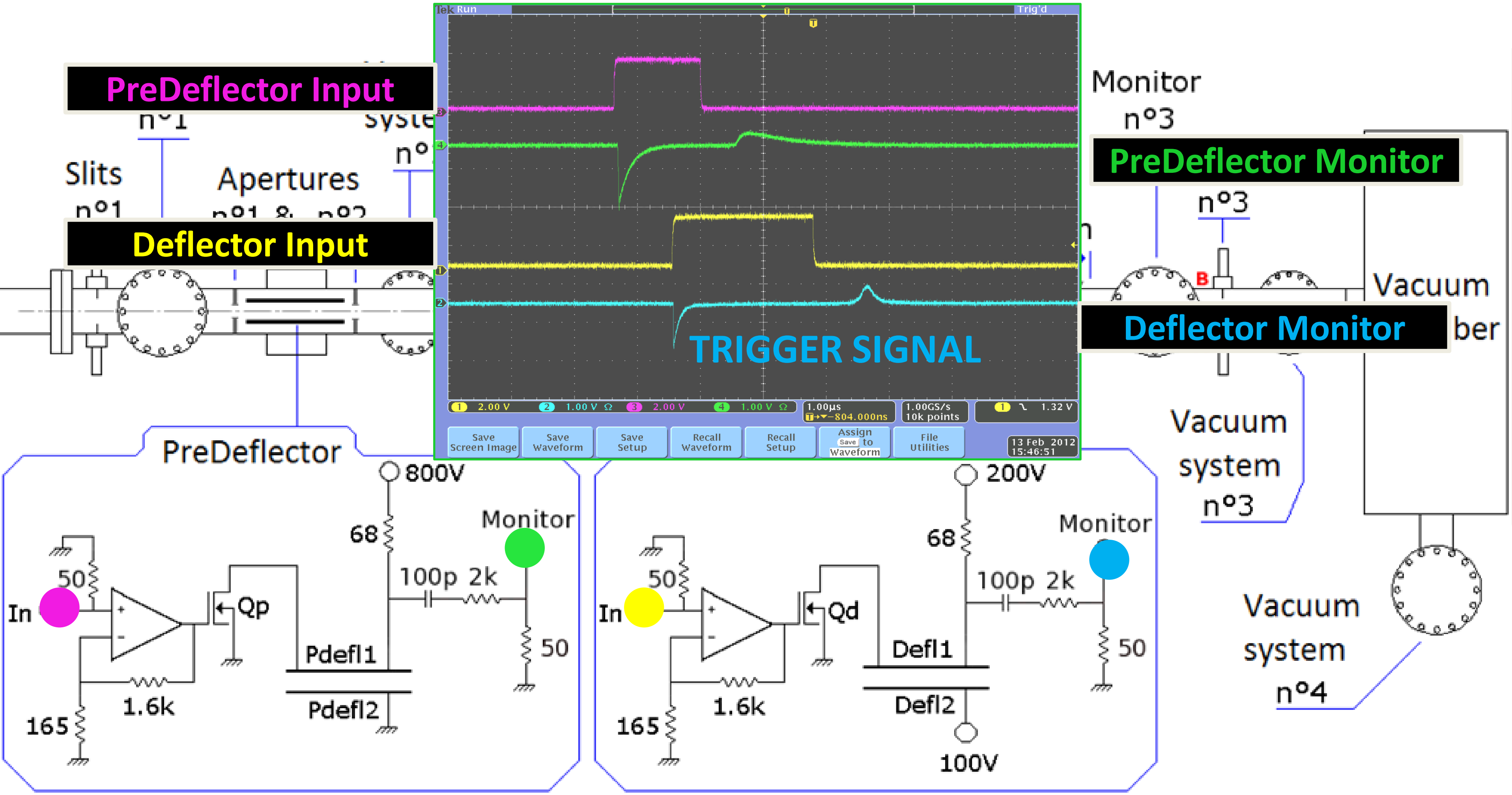


$$E_f = (E_i + qV_T)\frac{m_f}{m_i} + QV_T$$

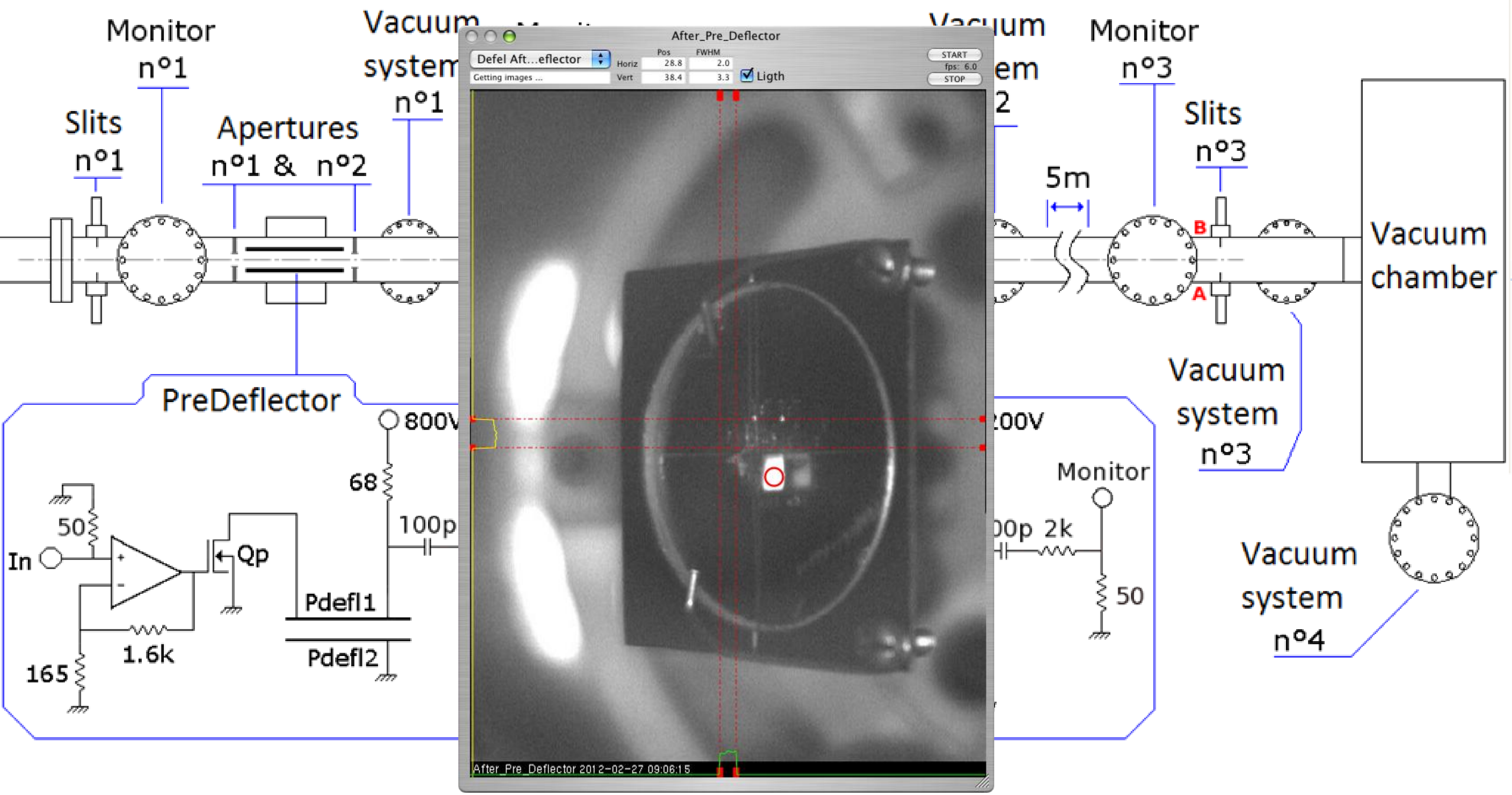
DEFEL: the creation of ion bunches



DEFEL: the creation of ion bunches



DEFEL: the creation of ion bunches

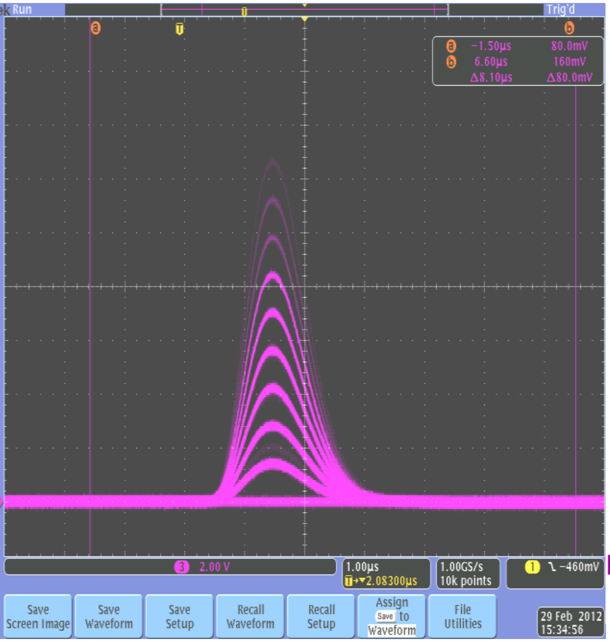


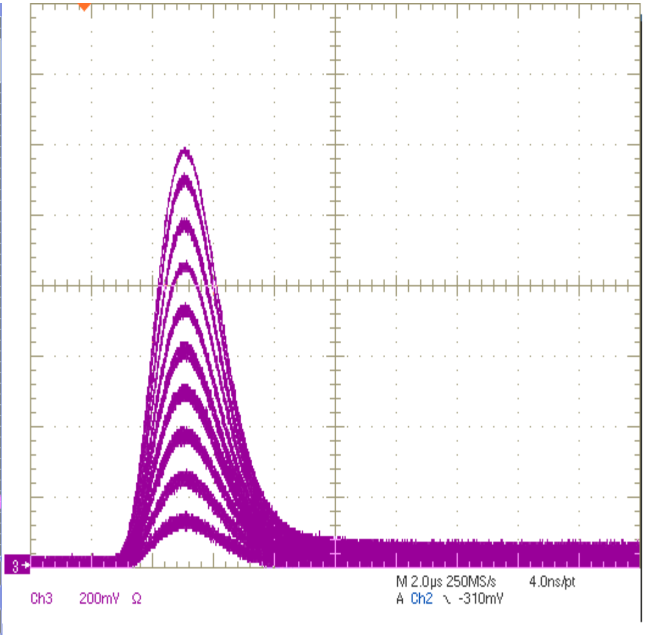
DEFEL: bunch characteristics

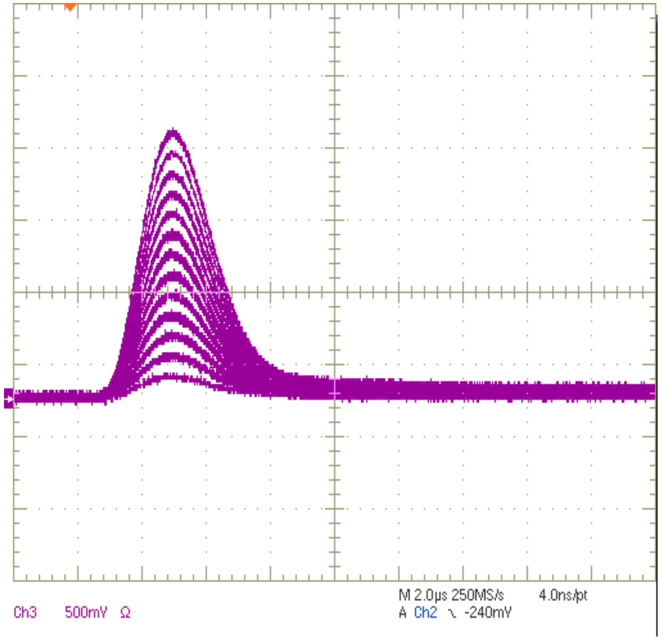
The bunch multiplicity follows a Poisson statistics

mean value μ depends on

- Initial beam current intensity
- Final apertures width
- Beam spot dimensions
- Deflecting fields intensity



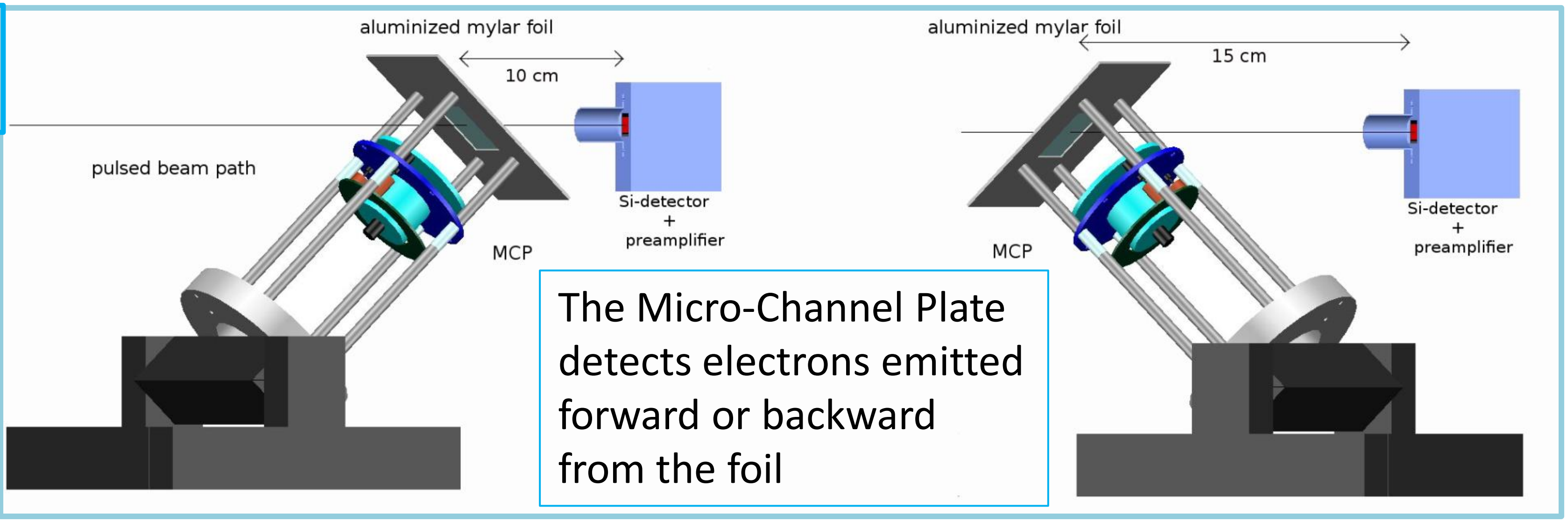




The detector system: configurations

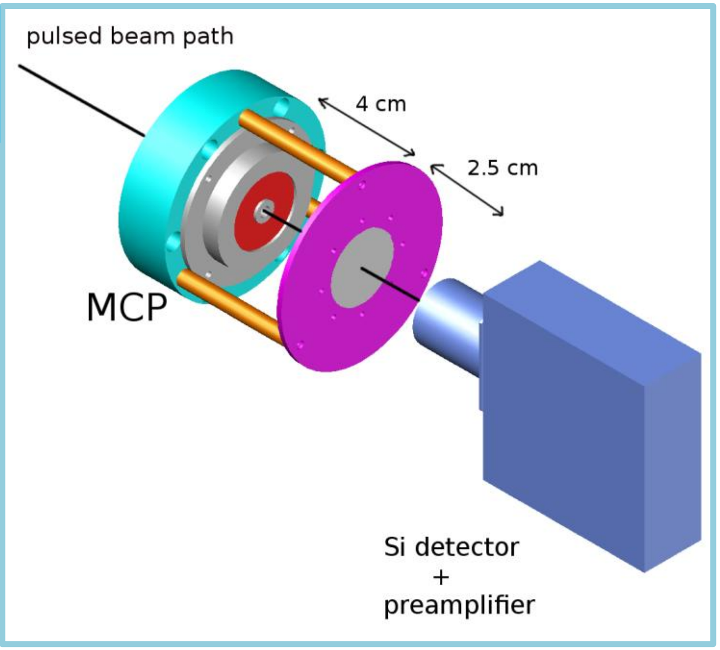
Counting of the ions inside the DEFEL bunches that hit the sample

1



The Micro-Channel Plate detects electrons emitted forward or backward from the foil

2



The detector system: the MCP

Model F9892-12

Effective area diam. 4 cm

Channel diam. 6 µm

PHR 150 %

Model F4655-12

Effective area diam. 1.5 cm

Channel diam. 12 µm

PHR 50 %

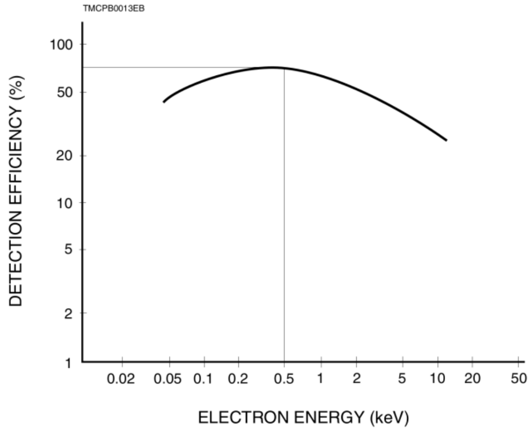
Model F2223-21SH

Effective area diam. 3 cm

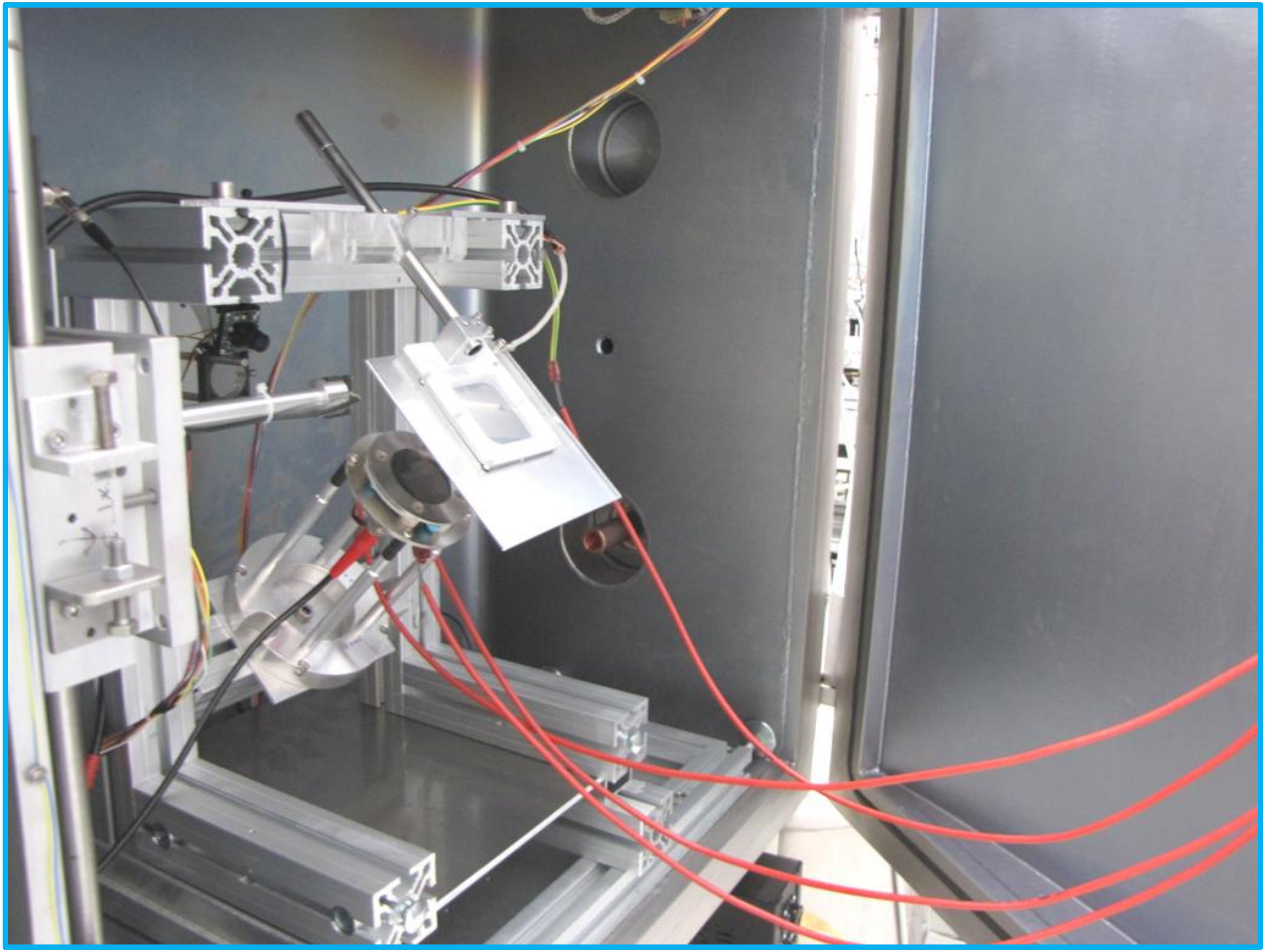
Channel diam. 12 µm

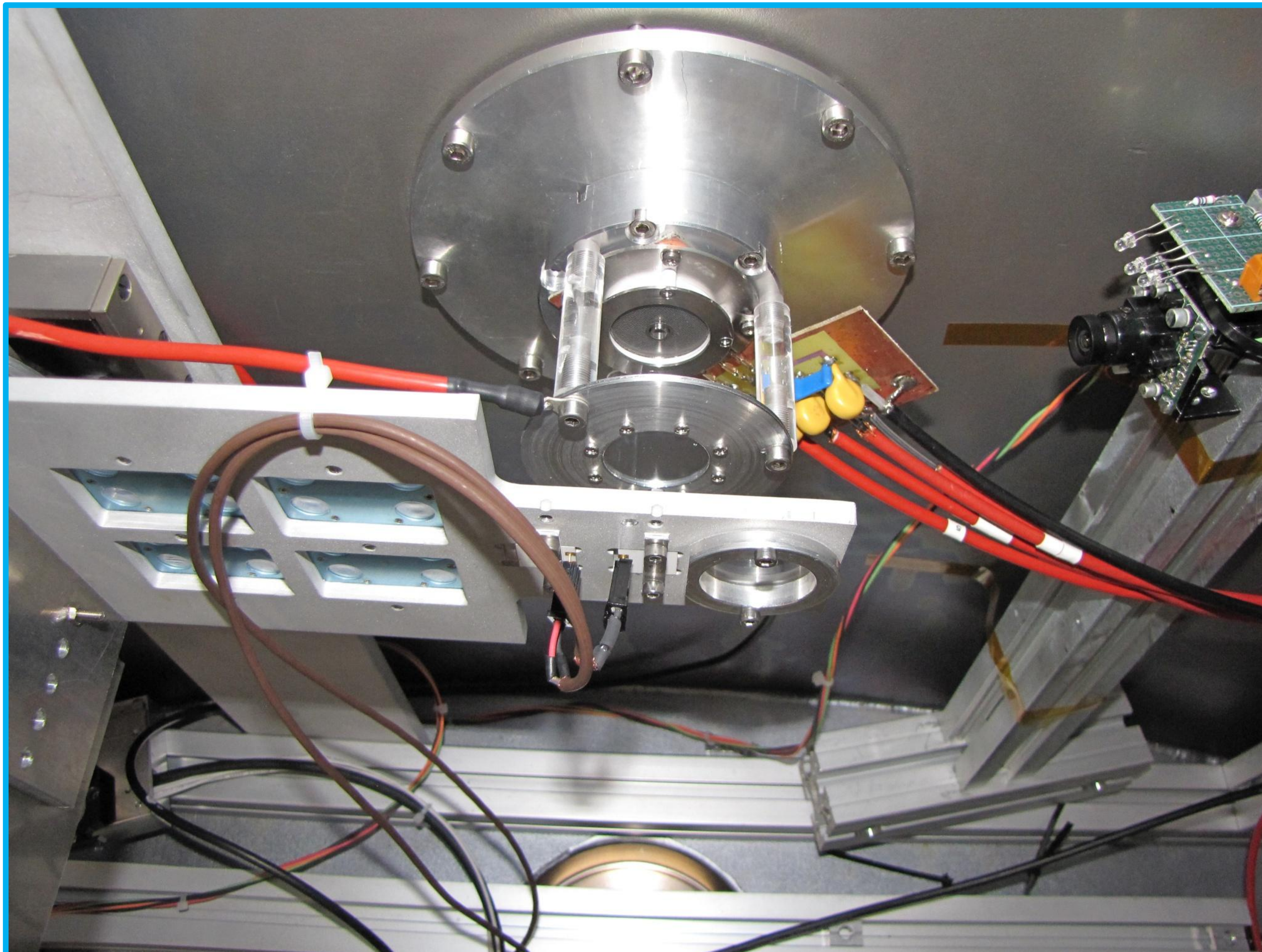
Hole diam. 4 mm

PHR 150 %



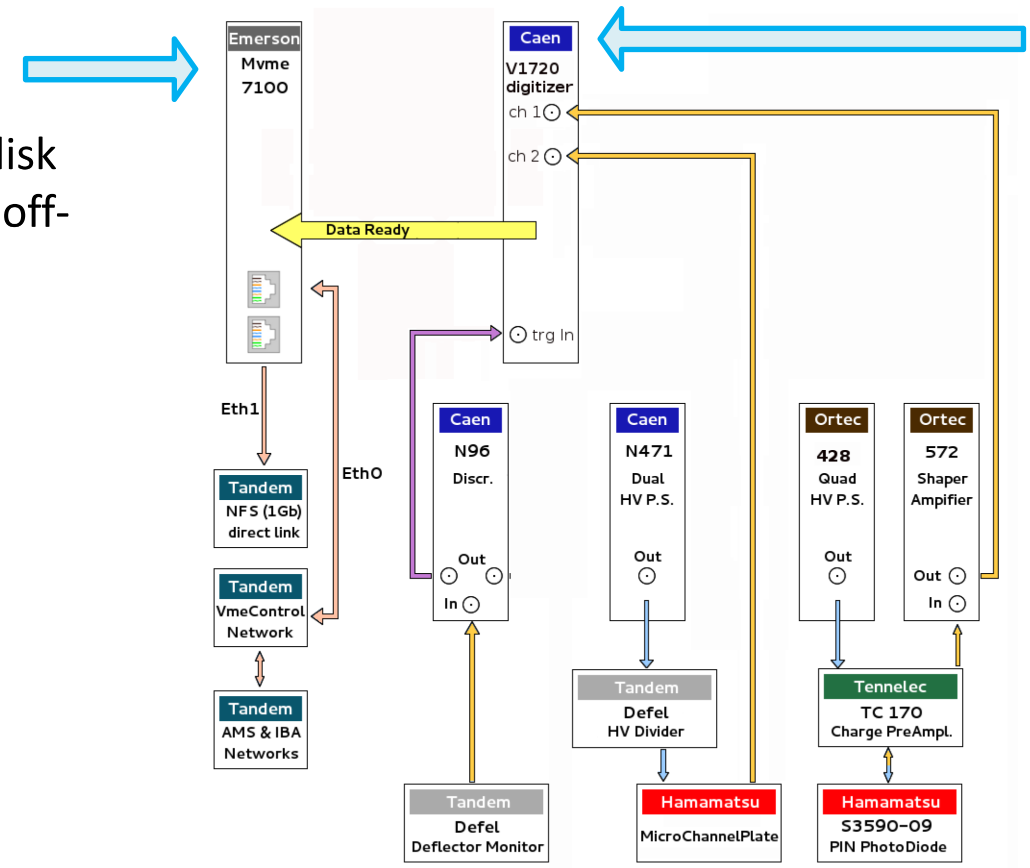
Detection efficiency for electrons





The detector system: electronics

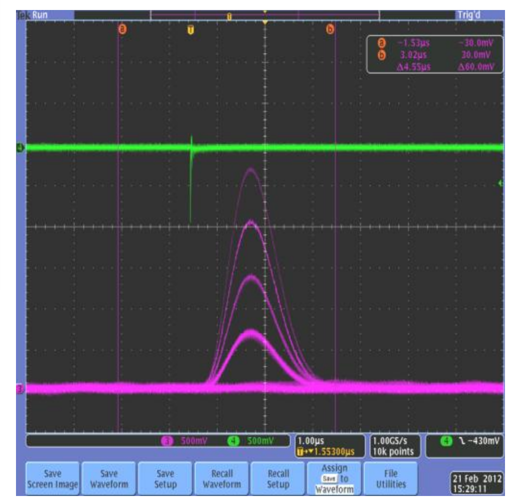
Data stored on disk (binary files) for off-line analysis



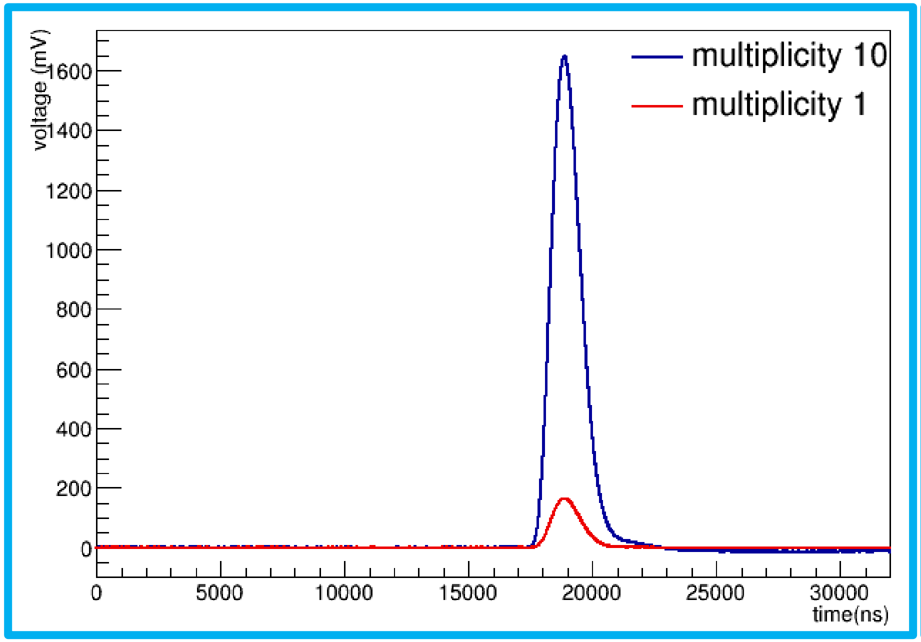
12 bit resolution

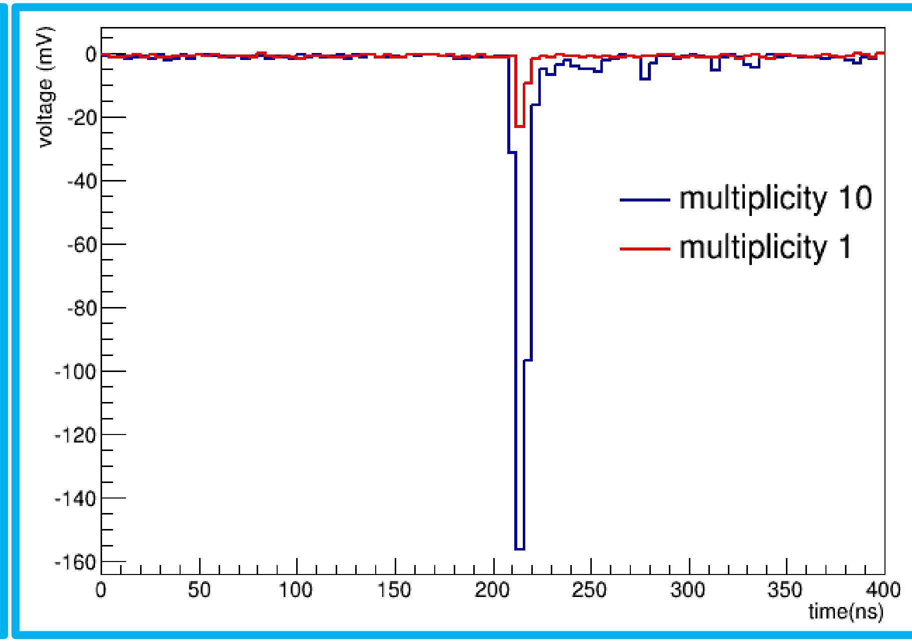
250 MS/s

Input range 2Vpp max

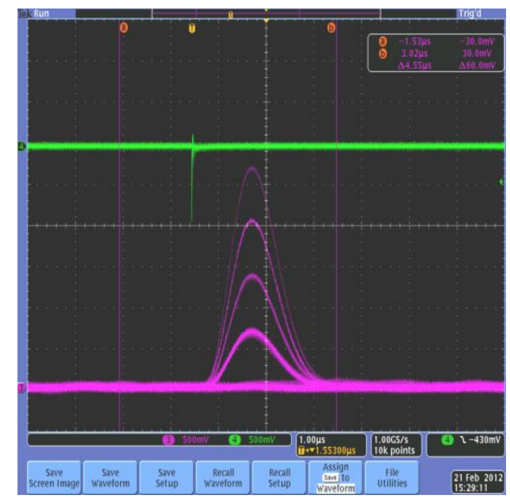


The detector system: electronics



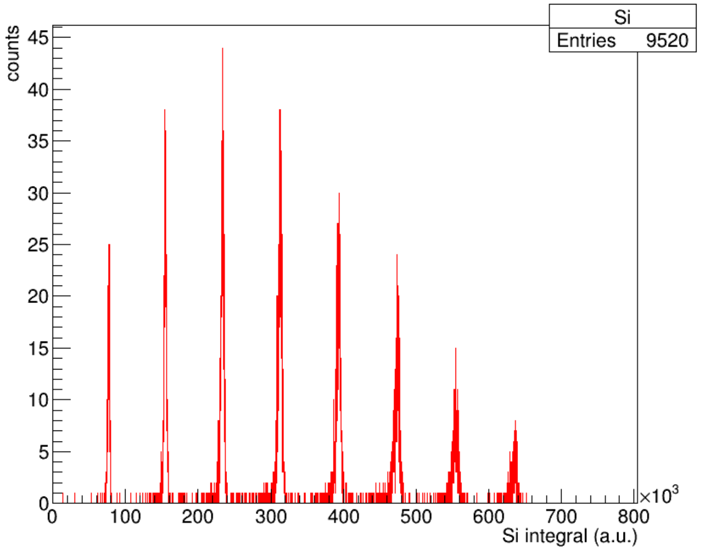


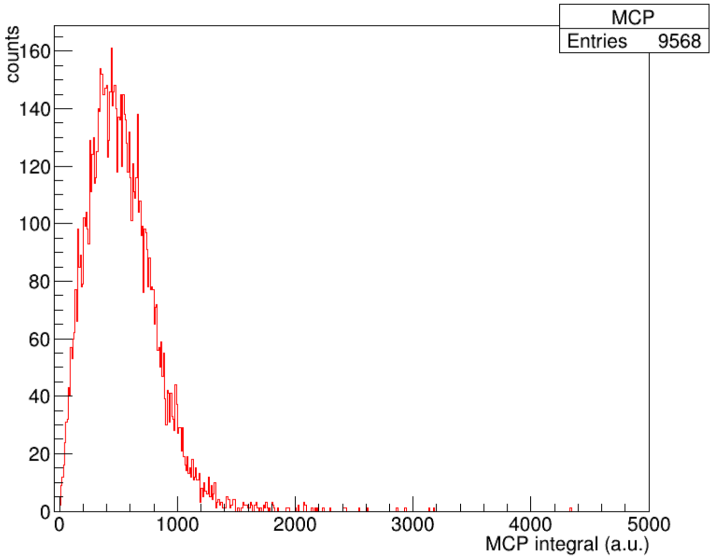
Digitized signals

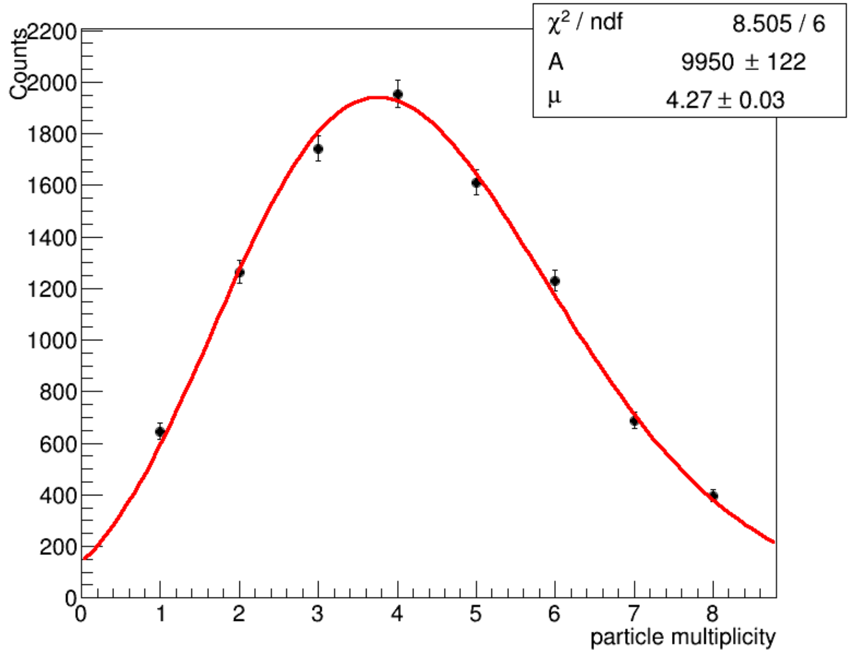


Preliminary measurements with different ions

10 MeV $^{12}C^{3+}$
10000 events @ 20 Hz

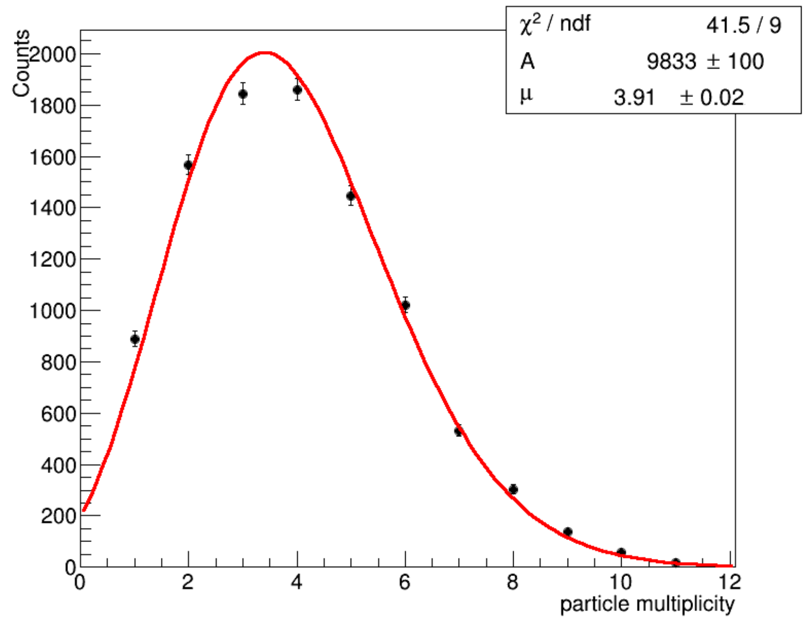


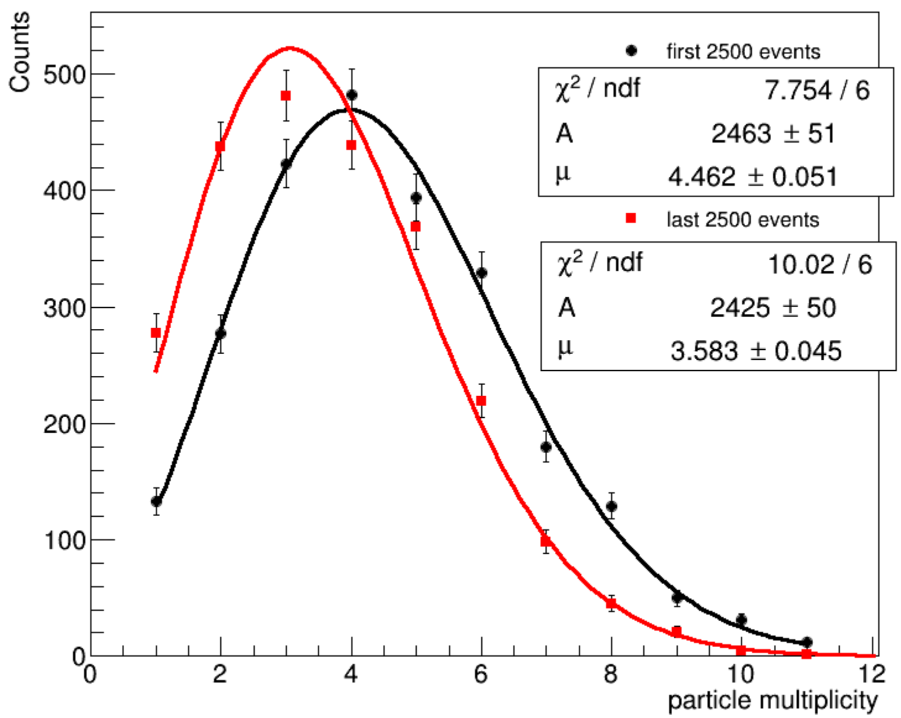


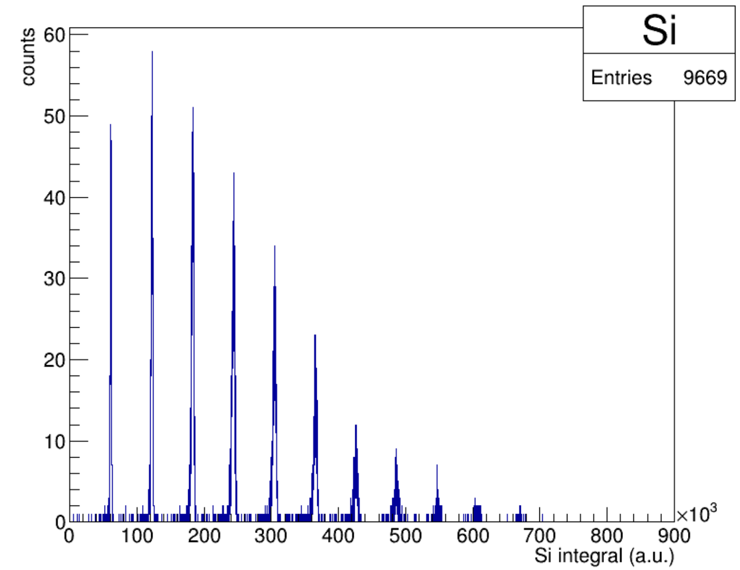


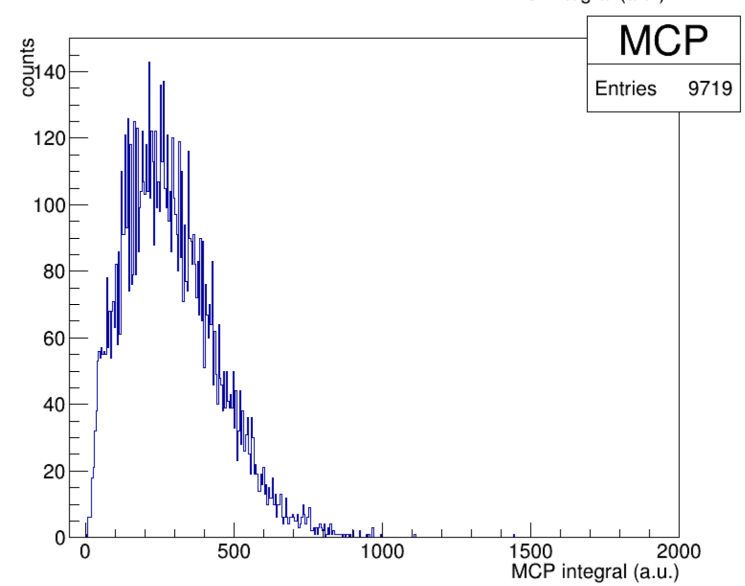
10 MeV $^{16}O^{4+}$

10000 events @ 20 Hz



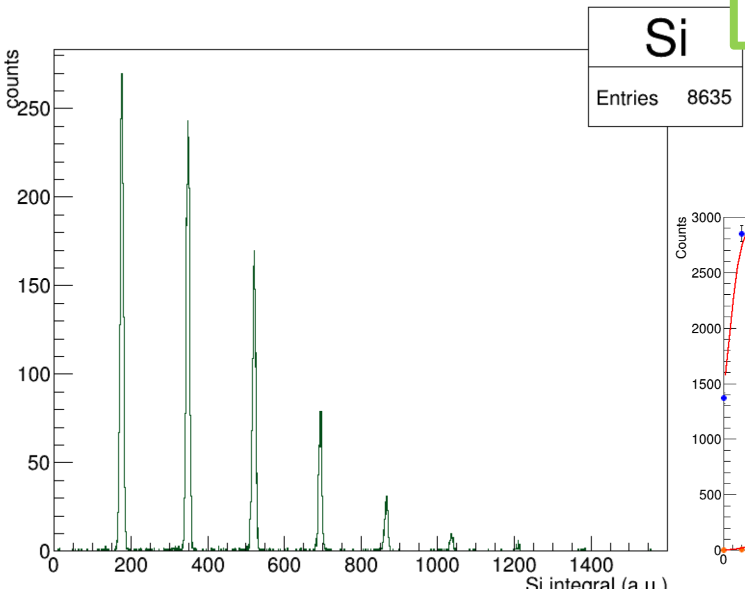


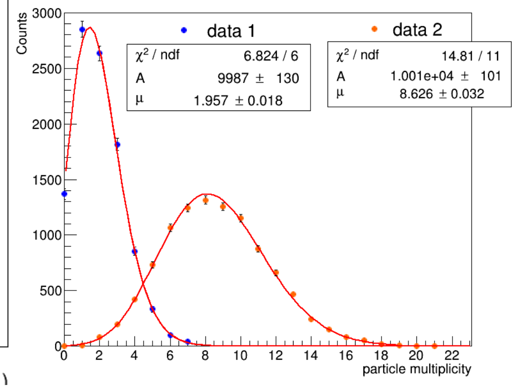


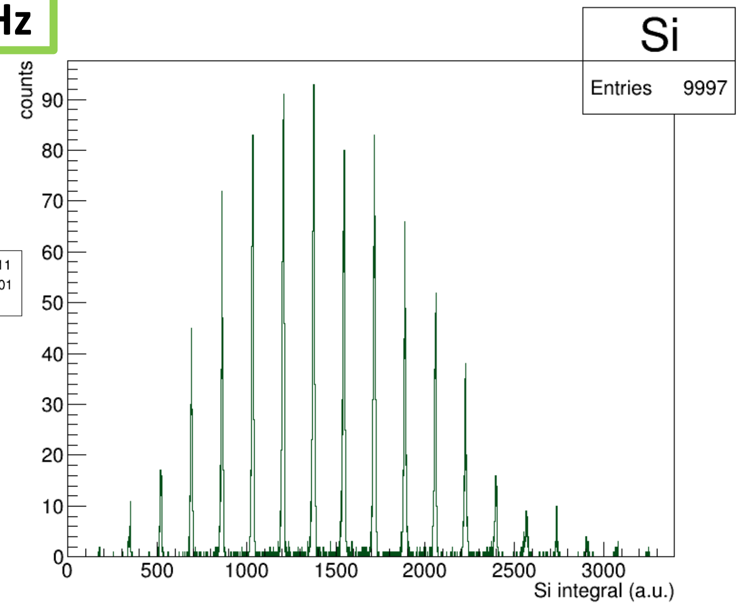


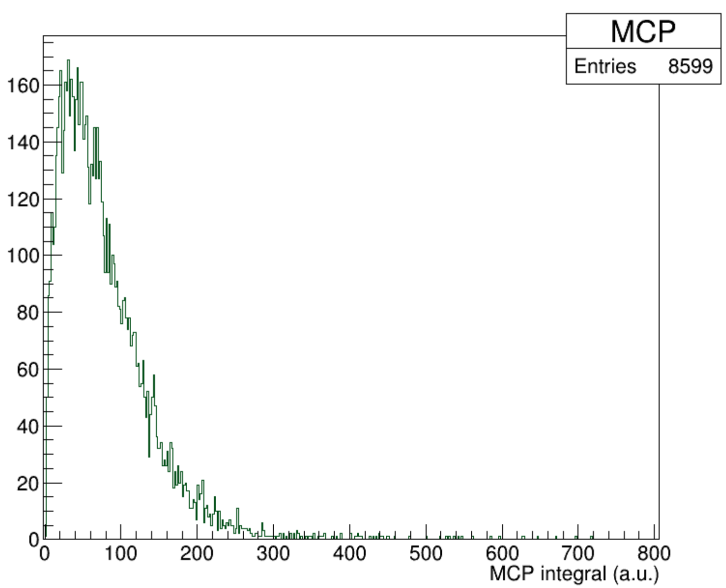
Preliminary measurements with different ions

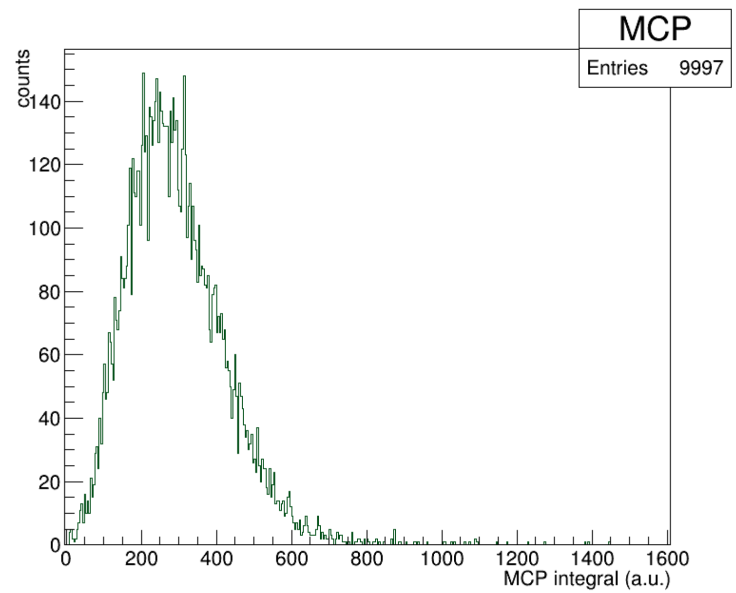
7.5 MeV $^{7}Li^{2+}$
10000 events @ 20Hz







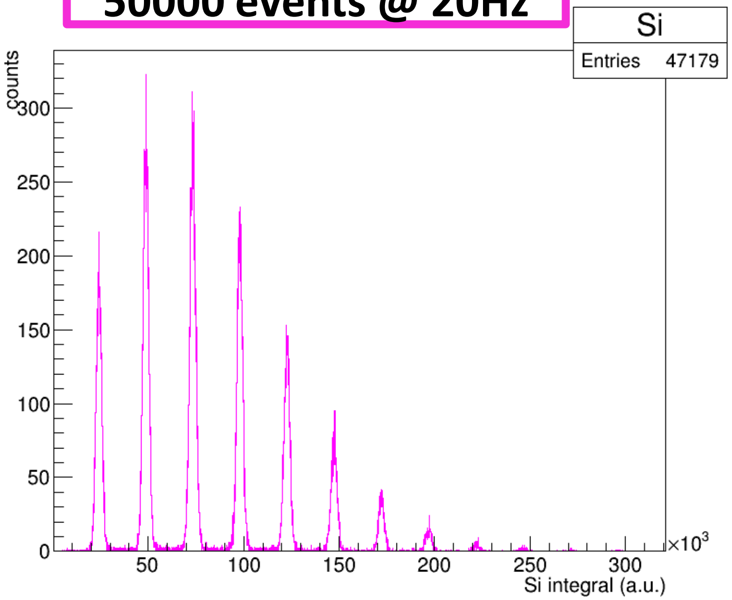


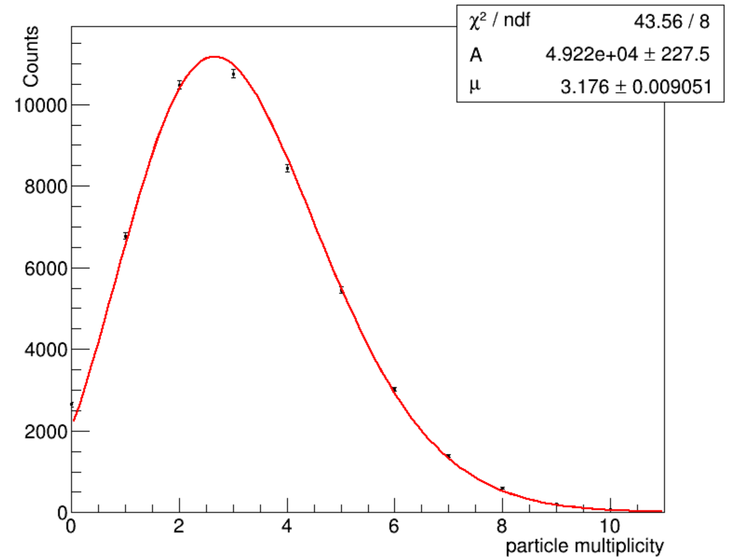


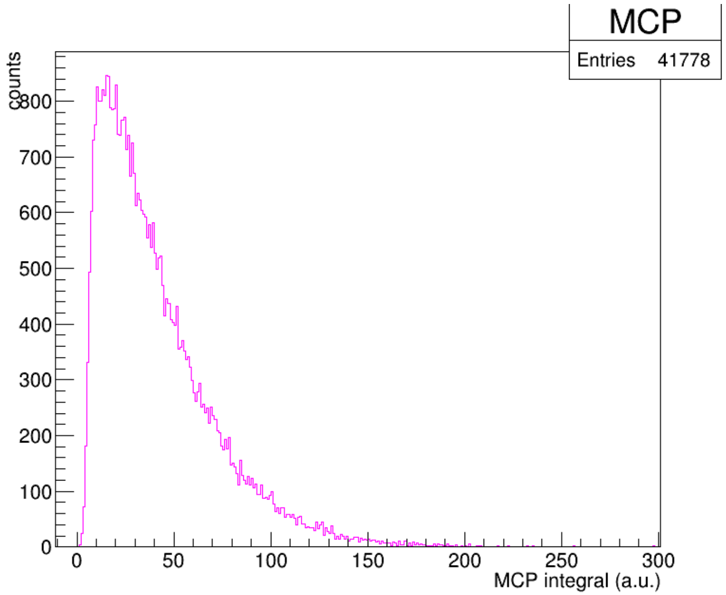
Preliminary measurements with different ions

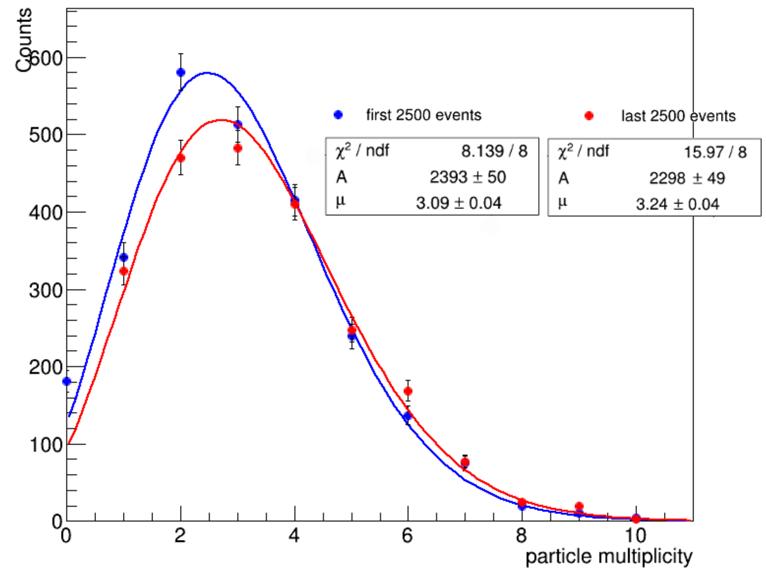
1.2 MeV H^+

50000 events @ 20Hz



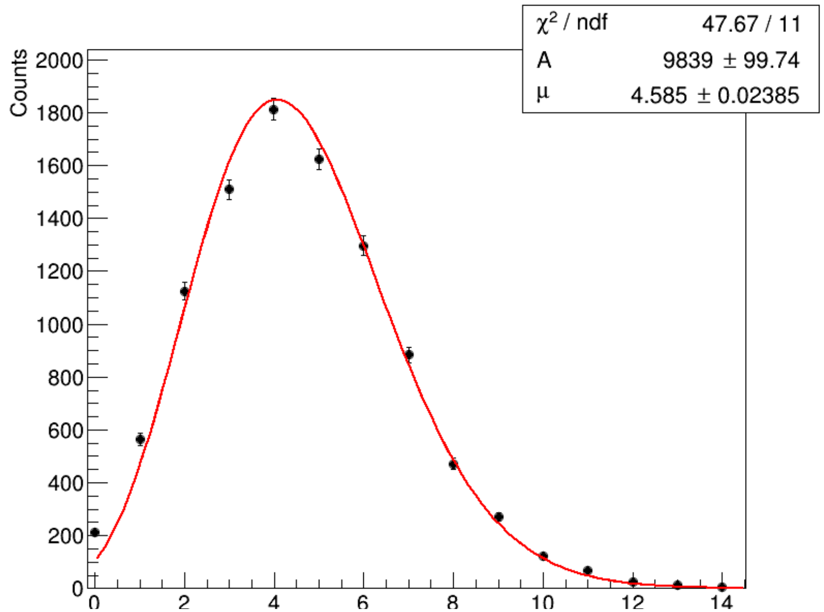


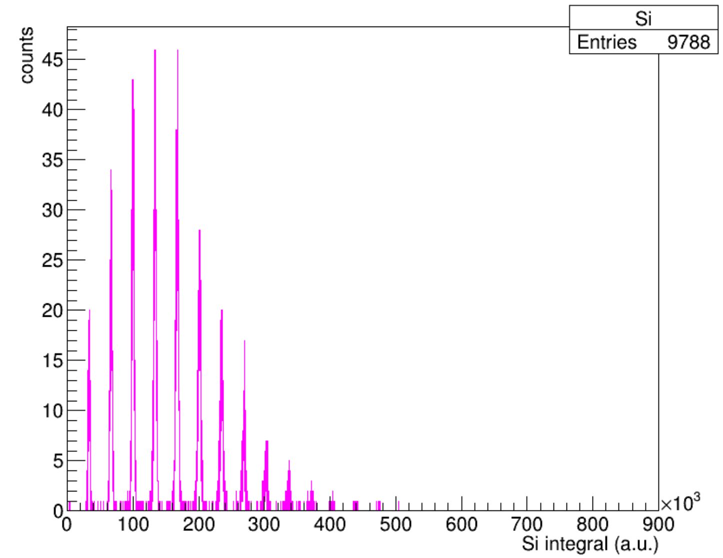


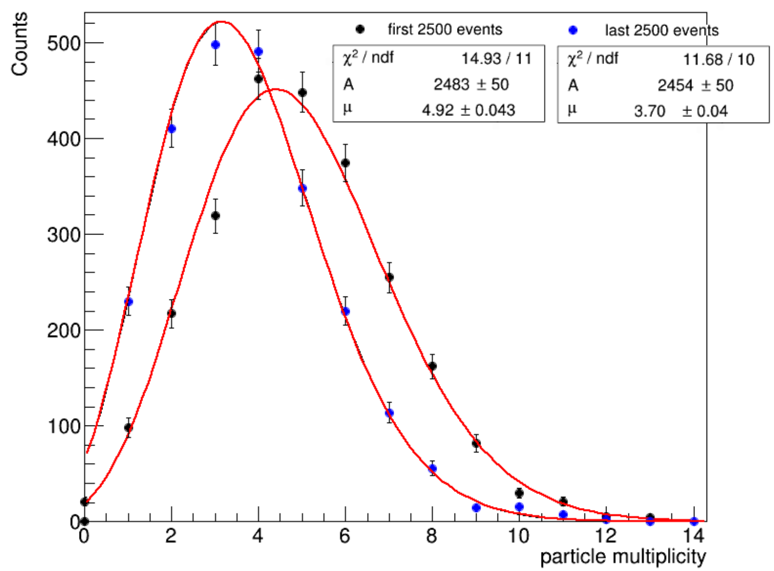


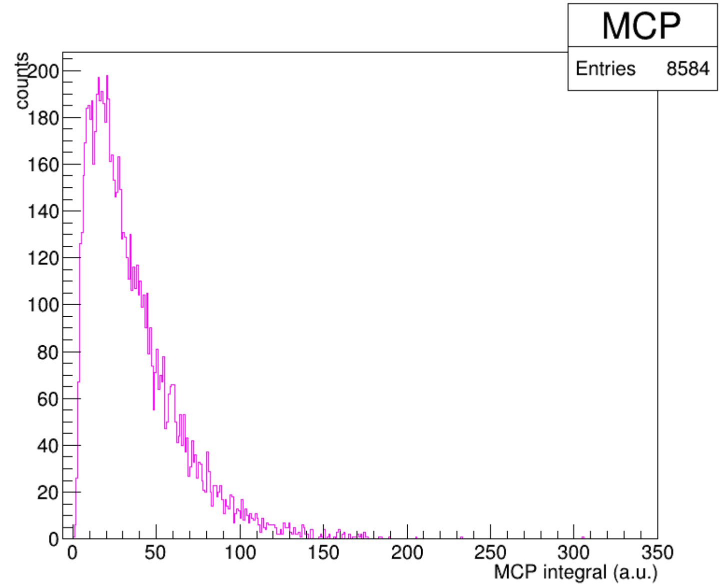
Preliminary measurements with different ions

2 MeV H^+
10000 events @ 20Hz



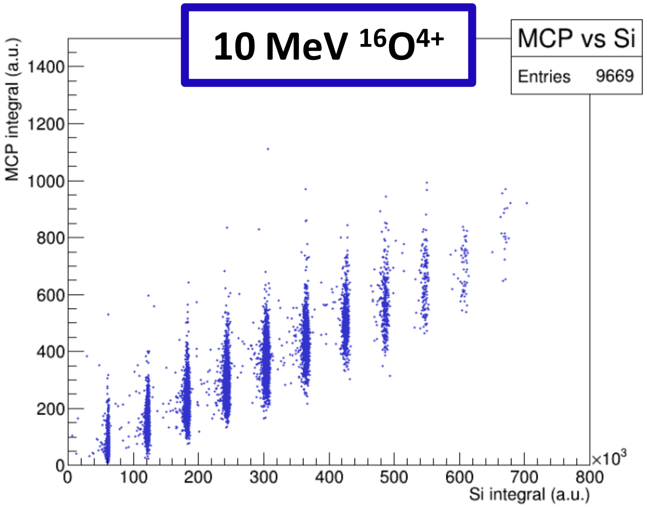


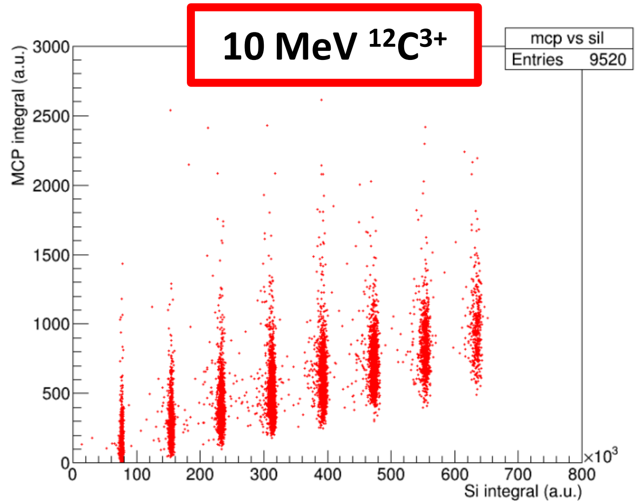


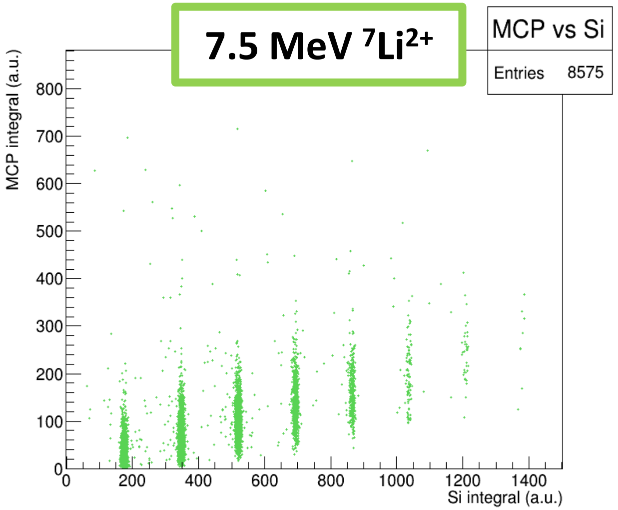


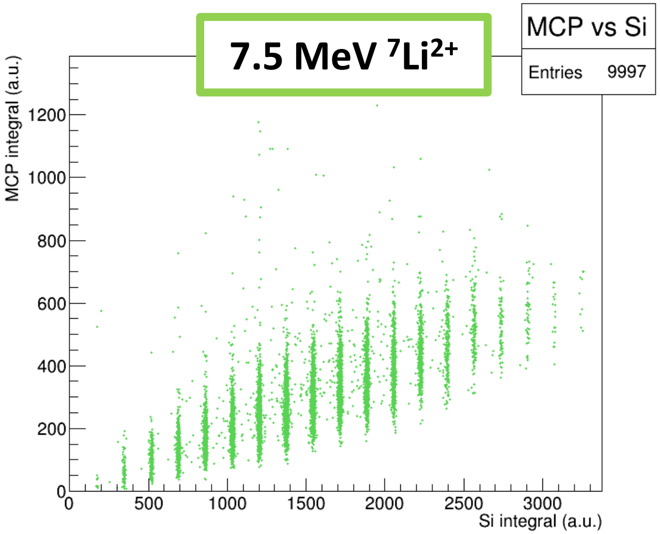
Detector system: calibration

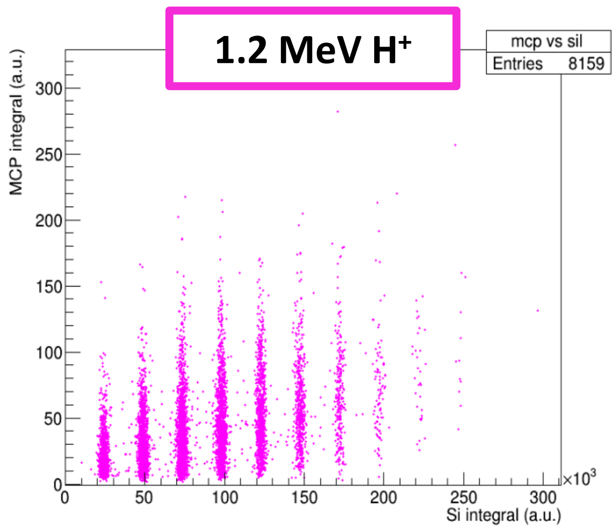
MCP Integrals as a function of Si Integrals

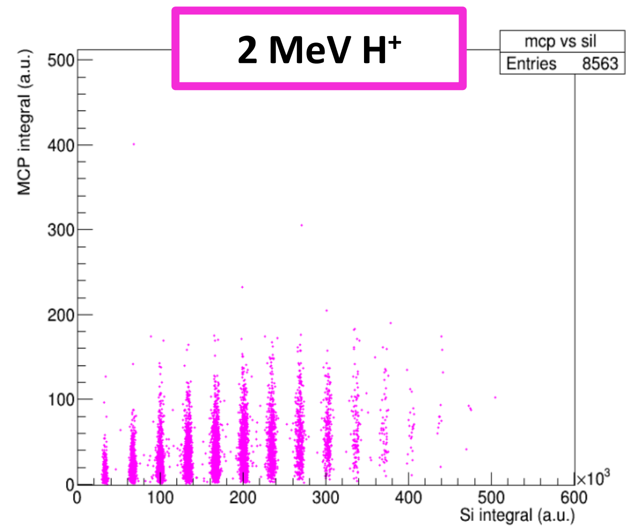






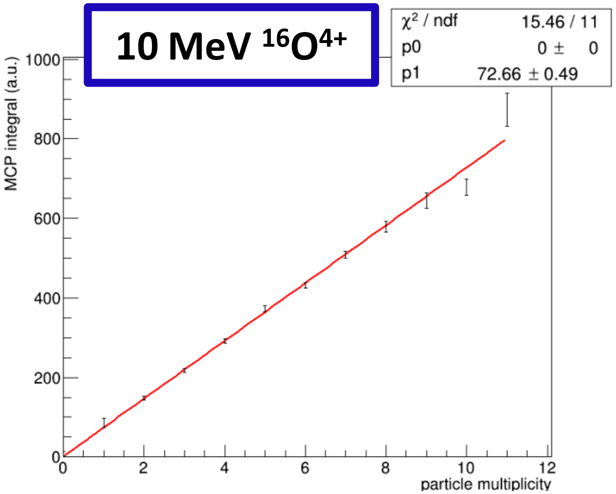


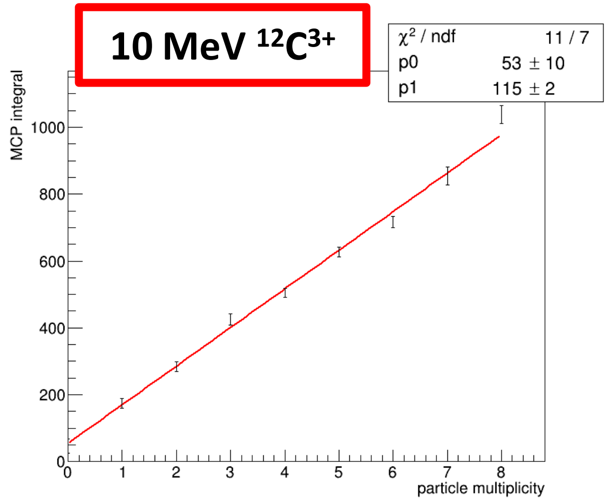


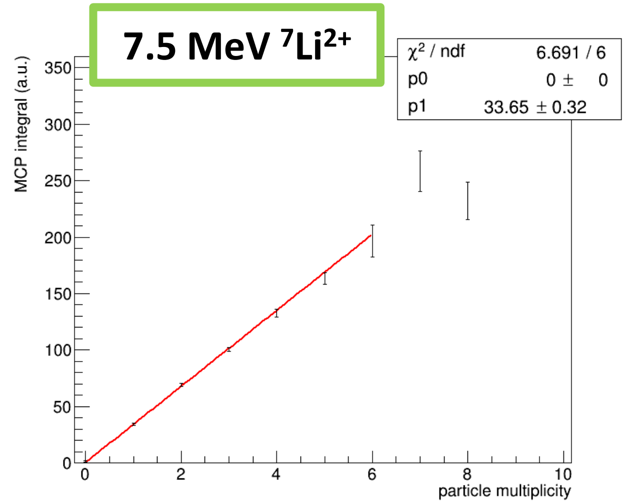


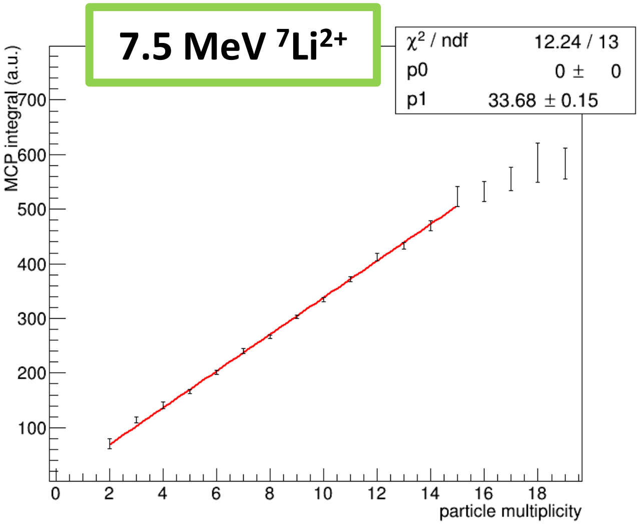
Detector system: calibration

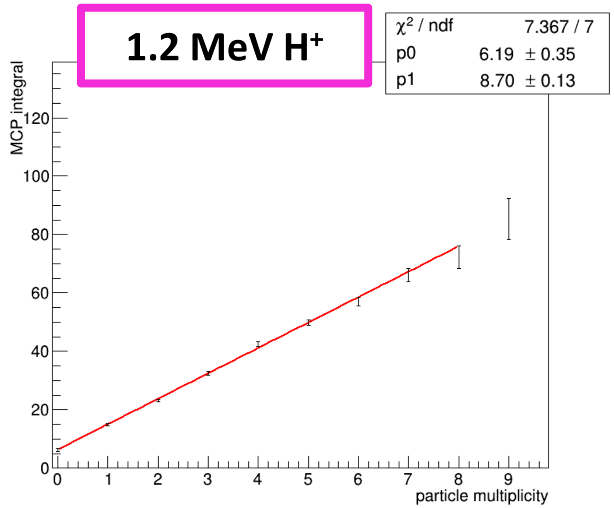
Calibration curves

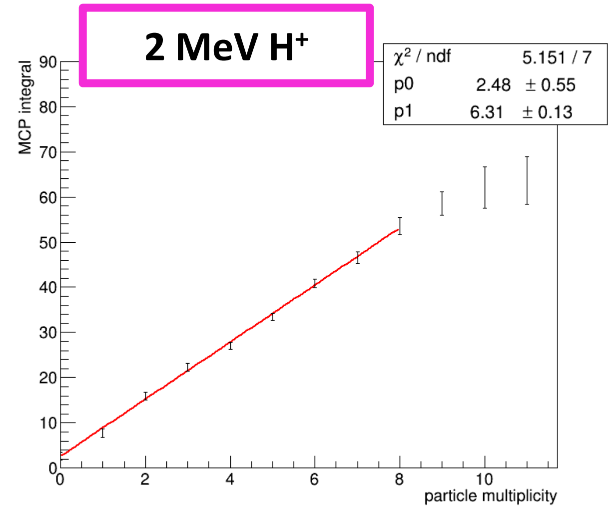












Average value of total MCP integral spectra ⇨ average multiplicity

Detector system: calibration results

10 MeV $^{16}O^{4+}$	μSi	μMCP	$\frac{(\mu MCP-\mu Si)}{\mu Si}$
evts 0-2500(CAL)	4.46(21) $\pm$ 0.05	4.46(24) $\pm$ 0.08	+0.007%
evts 2500-5000	3.76 $\pm$ 0.05	3.79 $\pm$ 0.07	+0.8%
evts 5000-7500	3.73 $\pm$ 0.05	3.71 $\pm$ 0.07	-0.5%
evts 7500-10000	3.58 $\pm$ 0.05	3.54 $\pm$ 0.06	-1.1%
10 MeV $^{12}C^{3+}$			
evts 0-2500(CAL)	4.38(0) $\pm$ 0.05	4.37(8) $\pm$ 0.095	-0.05%
evts 2500-5000	4.39(3) $\pm$ 0.05	4.3(91) $\pm$ 0.1	-0.035%
evts 5000-7500	4.17(2) $\pm$ 0.05	4.1(96) $\pm$ 0.1	+0.6%
evts 7500-10000	4.09(8) $\pm$ 0.05	4.0(76) $\pm$ 0.1	-0.54%
TEST	1.64(7) $\pm$ 0.04	1.3(68) $\pm$ 0.1	-17%
7.5 MeV $^{7}Li^{2+}$ **(data 1)**			
evts 0-2500(CAL)	1.95(1) $\pm$ 0.03	1.96(5) $\pm$ 0.05	+0.7%
evts 2500-5000	2.00 $\pm$ 0.02	2.04 $\pm$ 0.05	+2%
evts 5000-7500	1.99 $\pm$ 0.02	2.03(6) $\pm$ 0.05	+2%
evts 7500-10000	1.88 $\pm$ 0.02	1.93(0) $\pm$ 0.05	+2.7%
7.5 MeV $^{7}Li^{2+}$ **(data 2)**			
evts 0-2500(CAL)	8.81(3) $\pm$ 0.07	8.8(53) $\pm$ 0.1	+0.45%
evts 2500-5000	8.72(6) $\pm$ 0.07	8.8(65) $\pm$ 0.1	+1.6%
evts 5000-7500	8.63(8) $\pm$ 0.07	8.6(37) $\pm$ 0.1	-0.013%
evts 7500-10000	8.32(8) $\pm$ 0.06	8.4(48) $\pm$ 0.1	+1.4%

μSi from Poisson fit

μMCP from integral spectra after calibration

(Delivered dose = (μMCPxN°events)xE)

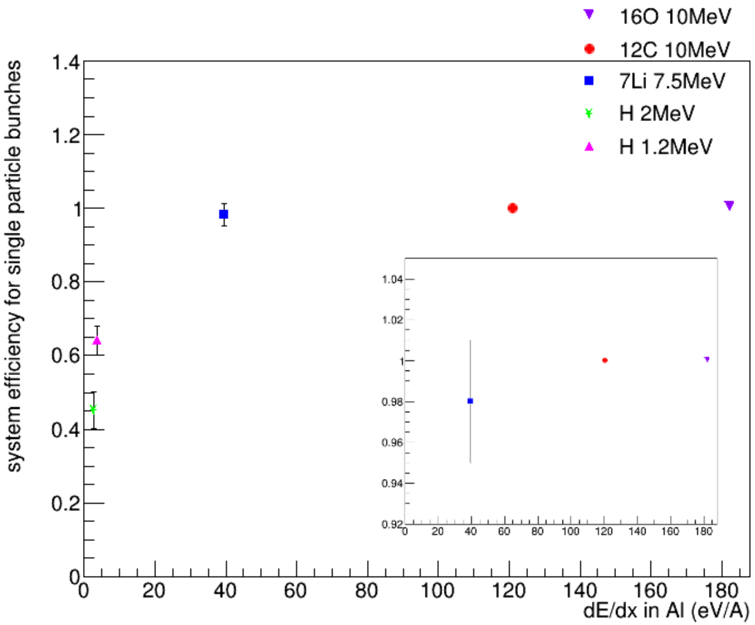
TEST: 60% decrease in average multiplicity with respect to the first dat set

2 MeV H^{+}	μSi	μMCP	$\frac{(\mu MCP-\mu Si)}{\mu Si}$
evts 0-2500(CAL)	4.92(0) $\pm$ 0.03	4.9(06) $\pm$ 0.1	-0.3%
evts 2500-5000	4.96(7) $\pm$ 0.03	4.9(36) $\pm$ 0.1	-0.6%
evts 5000-7500	4.63(9) $\pm$ 0.03	4.6(28) $\pm$ 0.1	-0.2%
evts 7500-10000	3.67 $\pm$ 0.04	3.48(7) $\pm$ 0.09	-5%
1.2 MeV H^{+}			
evts 0-10000(CAL)	3.05(8) $\pm$ 0.03	3.04(3) $\pm$ 0.05	-0.5%
evts 10000-20000	3.10(2) $\pm$ 0.02	3.11 $\pm$ 0.06	-0.27%
evts 20000-30000	3.23(9) $\pm$ 0.02	3.34(8) $\pm$ 0.06	+3%
evts 30000-40000	3.24(3) $\pm$ 0.03	3.26(1) $\pm$ 0.05	+0.55%
evts 40000-50000	3.20(9) $\pm$ 0.02	3.29(7) $\pm$ 0.07	+2.8%

25% decrease in average multiplicity with respect to the first dat set

Possible problems

With protons and with Li ions the foil-MCP system detection efficiency is reduced



Work with bunches of multiplicity ≥5

Some ion may not hit the Si detector if it leaves the foil with a large angle

Ion	$P_loss(distance10cm)$	$P_loss(distance15cm)$	$P_loss(distance2.5cm)$
^{16}O (10 MeV)	2.54%	7.63%	0.0009%
^{12}C (10 MeV)	1%	2.6%	0.0005%
^{7}Li (7.5 MeV)	0.3%	0.6%	0.0002%
H (1.2 MeV)	0.8%	2.2%	0.001%
H (2 MeV)	0.4%	0.7%	0.0002%

Reduce foil thickness
Minimize foil-Si distance

Conclusions and future work

- New series of test measurements will be performed to test and optimize the calibration procedure

- Upgrade of the system to allow for on-line determination of particle fluence and for monitoring possible beam current variations.

- The first irradiations with quartz samples will be carried out with the new system. Samples must be irradiated with known and uniform doses