Destructive detectors for low energy ion beams

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CERN BE-BI-EA

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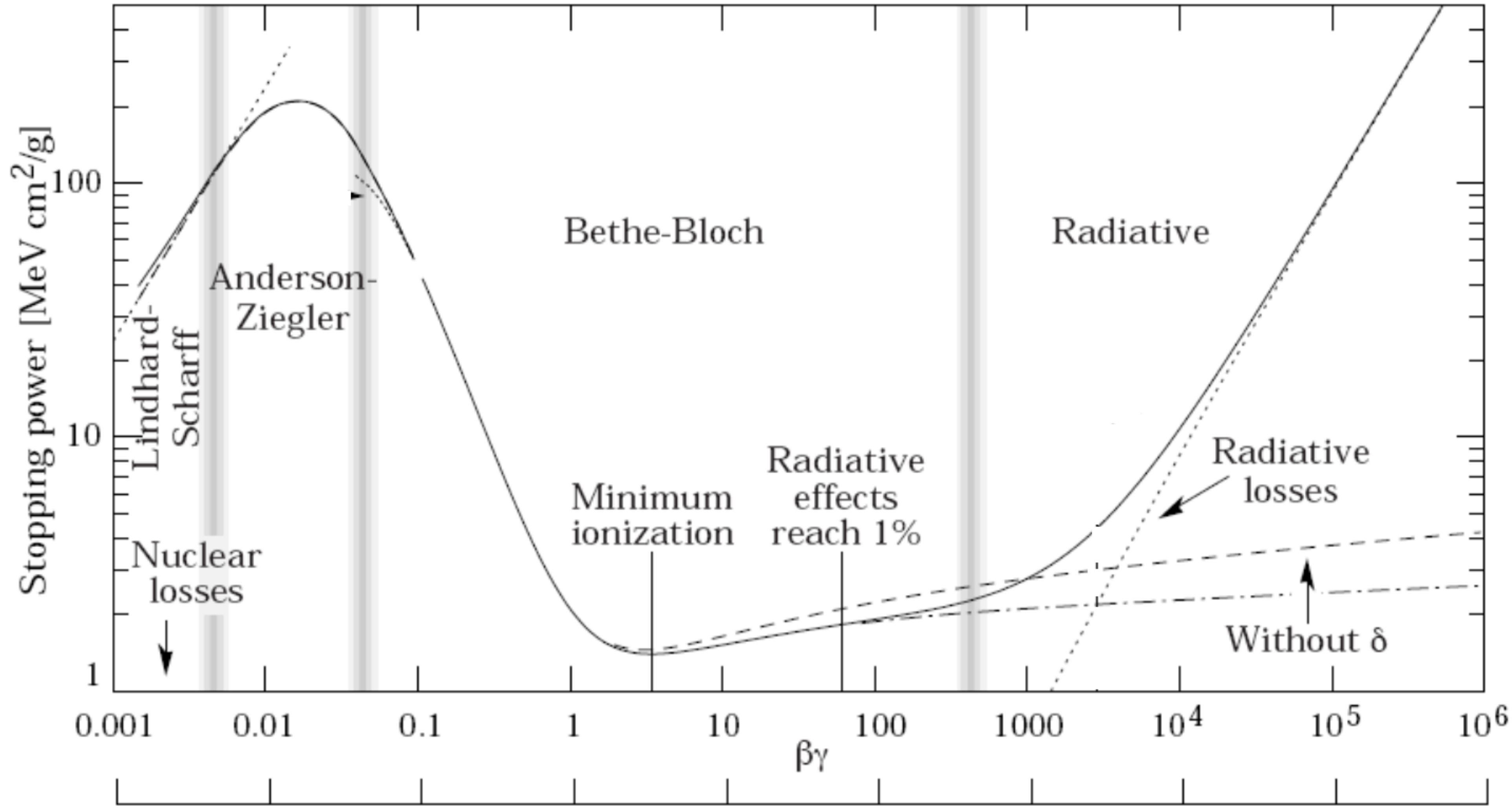
Outline

1. Interaction of particles with matter
2. Faraday Cup
3. Scicnillators/screen
4. Silicon detector

Interaction of particles with matter

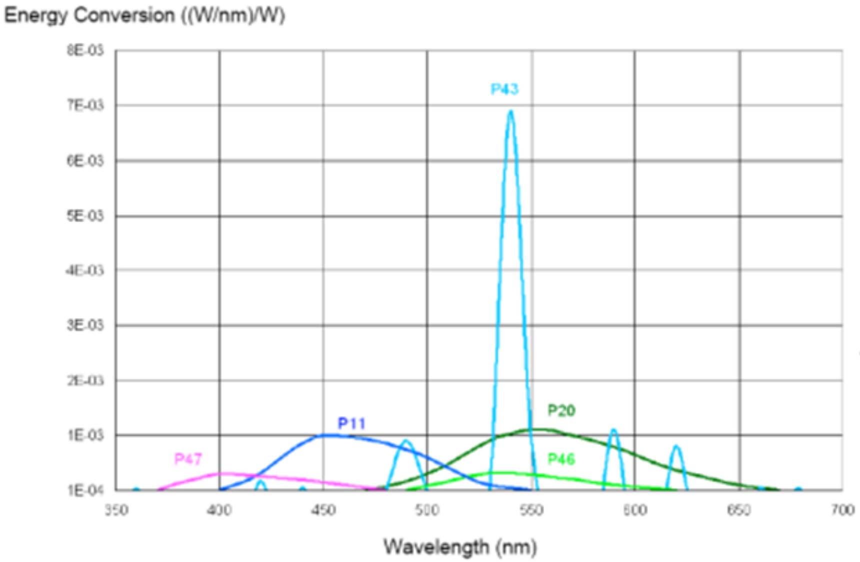
- Ionization
  - Creation of electrons/ions pairs
    - *Secondary electron emission (low energy electrons)*
    - *Emission of photons (decay of excited states)*
- Elastic and Inelastic scattering
  - Dislocations
  - Production of secondary particles (high energy particles)
- Radiation
  - Cherenkov radiation
  - Bremsstrahlung
  - Optical transition radiation

Energy deposition

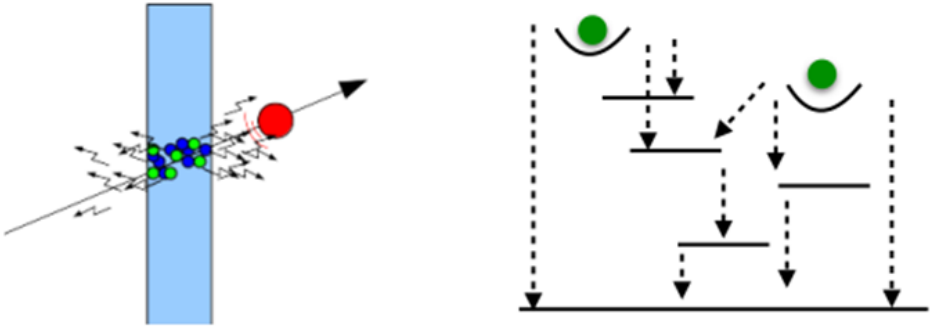


Scintillation

Type	Composition	Decay Time	
		Decay of Light Intensity	
		from 90 % to 10 % in	from 10 % to 1 % in
P 43	$Gd_2O_2S:Tb$	1 ms	1,6 ms
P 46	$Y_3Al_5O_{12}:Ce$	300 ns	90 µs
P 47	$Y_2SiO_5:Ce,Tb$	100 ns	2,9 µs
P 20	(Zn,Cd)S:Ag	4 ms	55 ms
P 11	ZnS:Ag	3 ms	37 ms

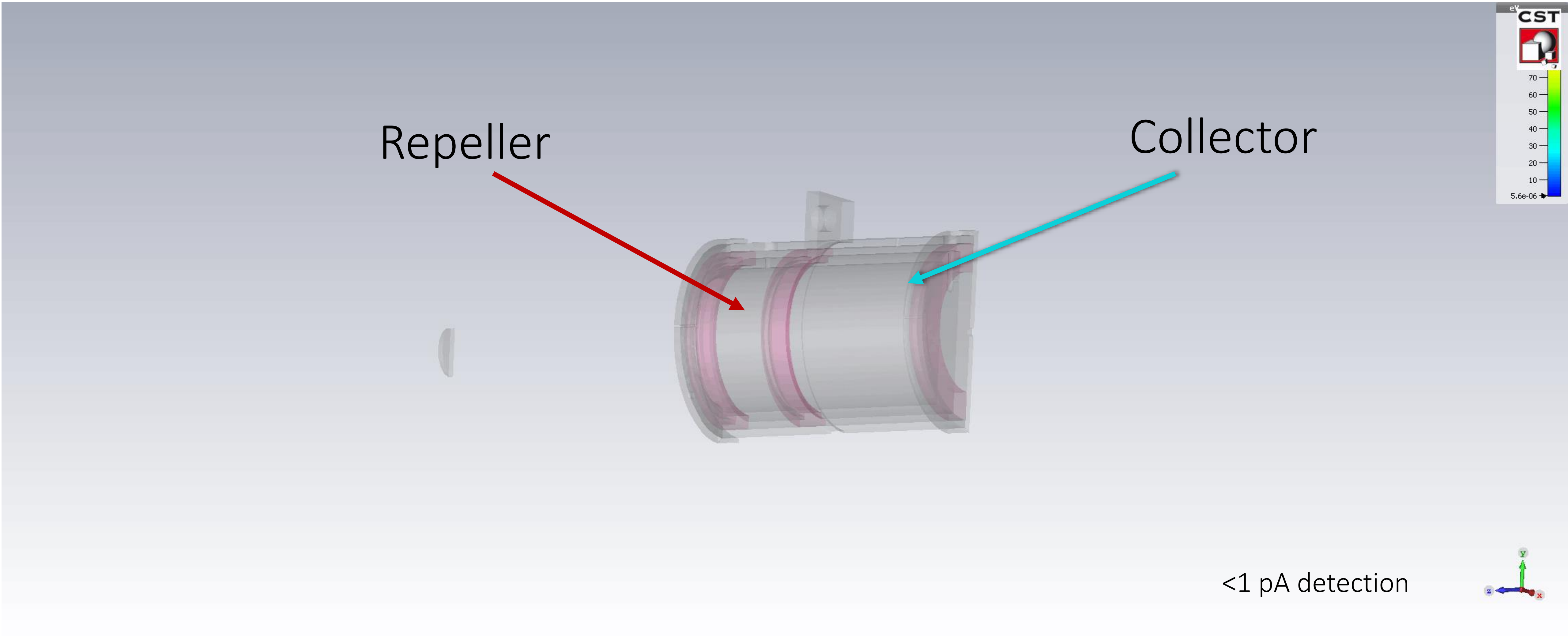


- Linked to ionisation
- Photons are emitted by the de-excitation of atomic states populated by the passage of the particle
- Emission time ns to hours



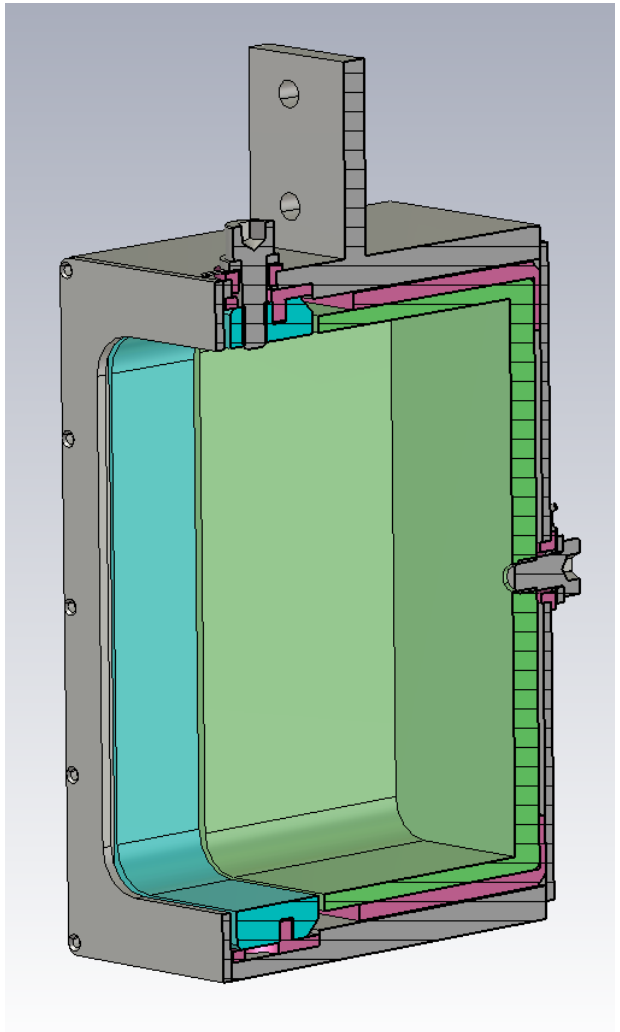
1MeV e⁻ on 5µm P43 yields ~ 60 ph.

Faraday Cup

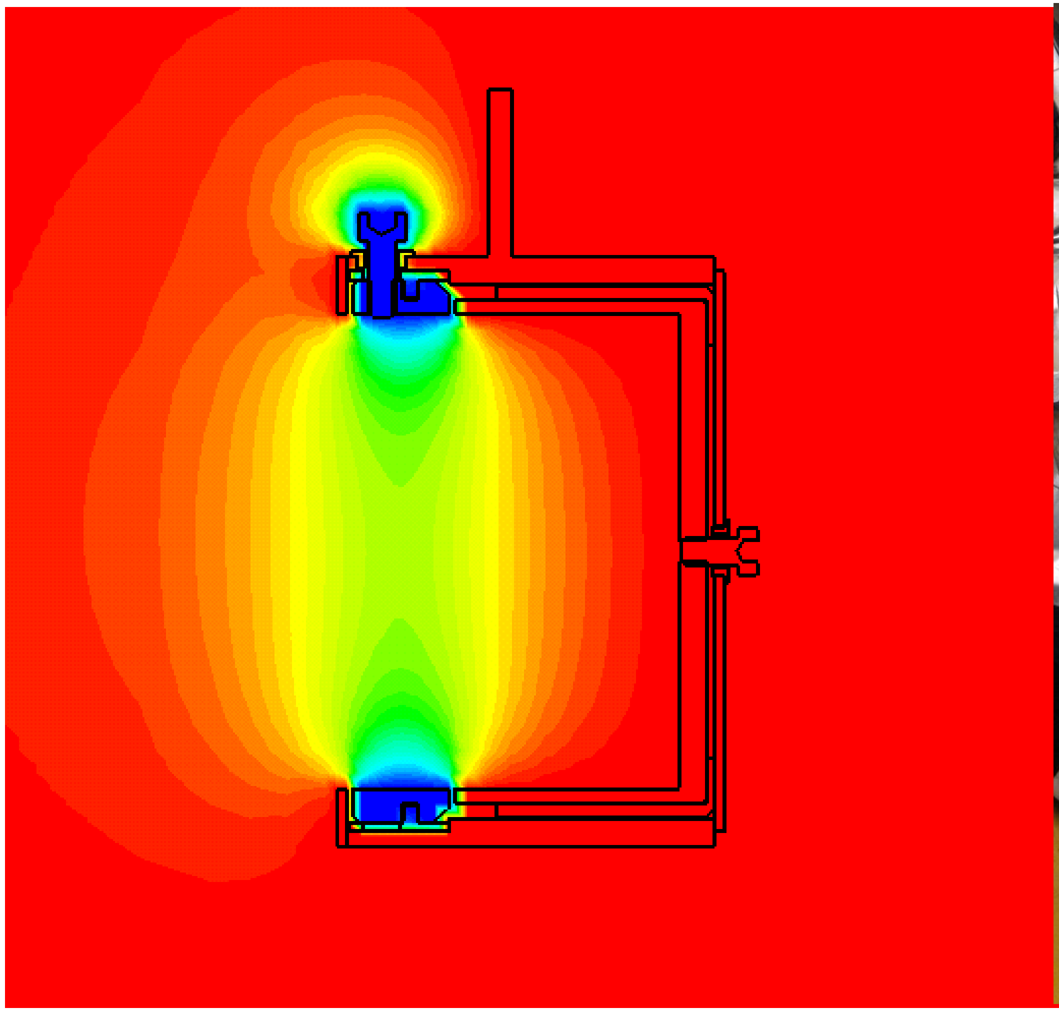


Repeller
Collector
CST
70
60
50
40
30
20
10
5.6e-06
<1 pA detection

FC: Example 1

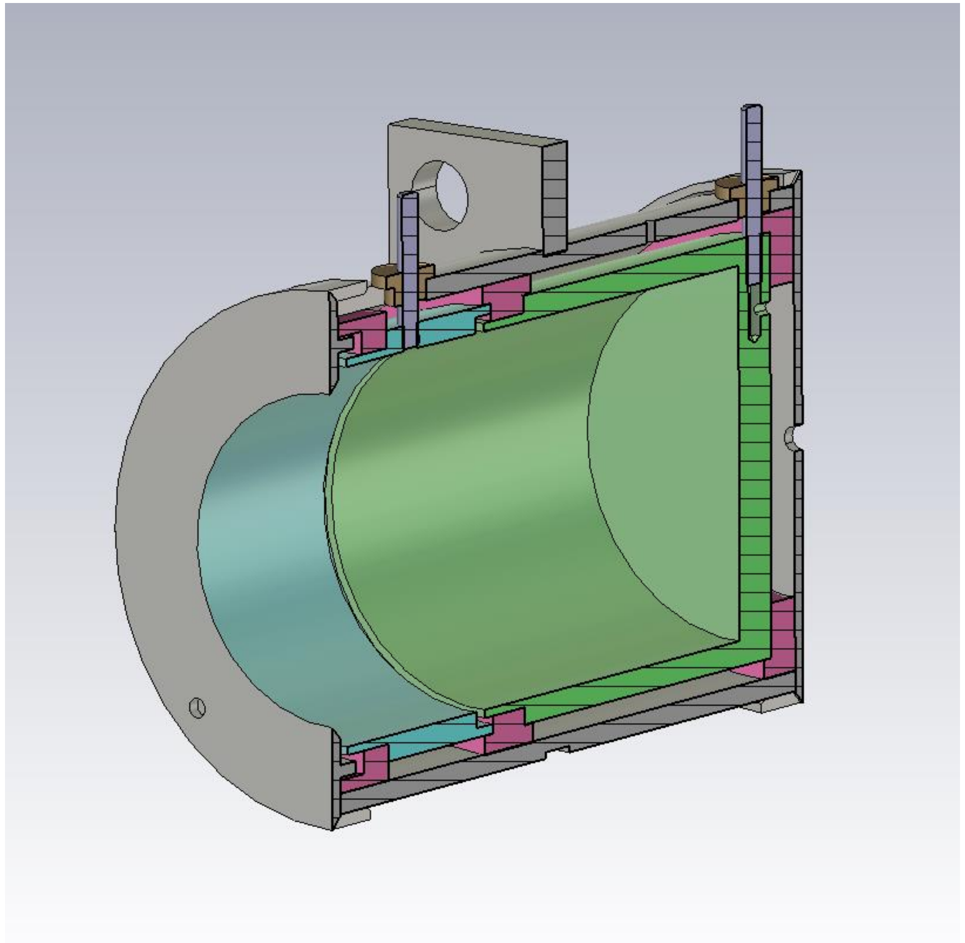


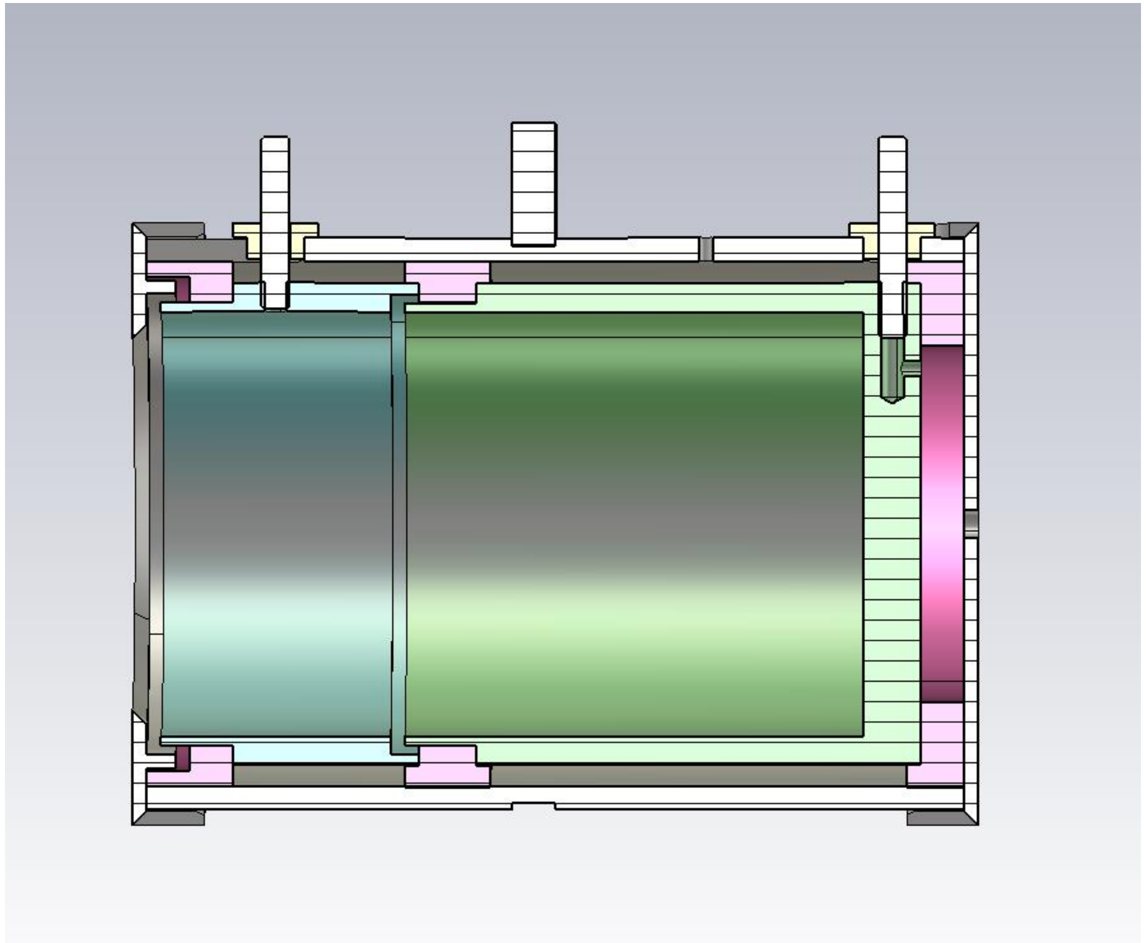
Aperture 60x100 mm



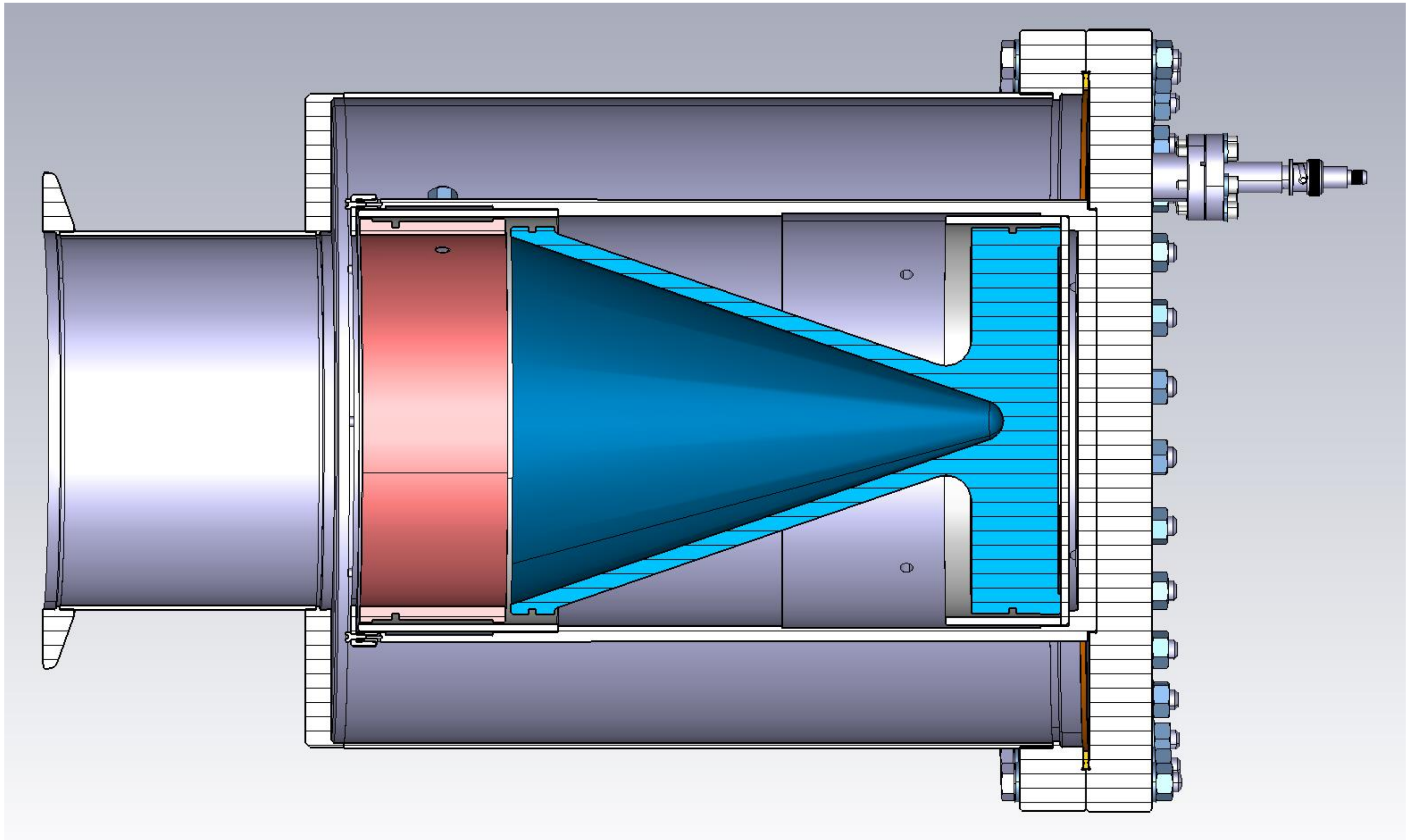
Large aperture – up to 1kV on repeller
Grounded shielding around repeller

FC: Example 2





FC: Example 3



Aperture 140mm

High current/density/energy:

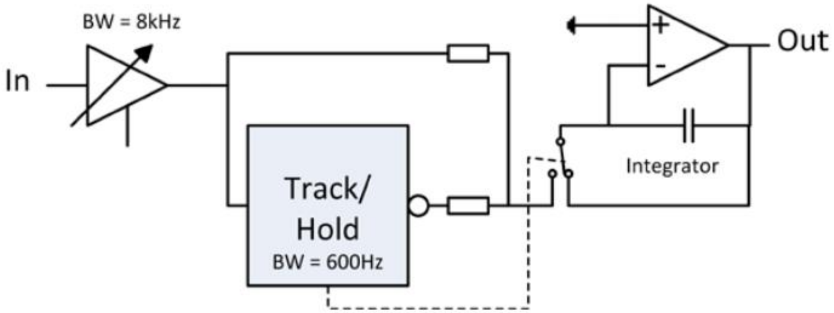
V shape of the FC collector

Coating of the FC collector with refractory metals

Water cooling

FC: Signal extraction

Microphonic/triboelectric effect /ground loops – proper cables/cabling/connectors are required



Preamplifier (low noise, changeable gain) + ADC

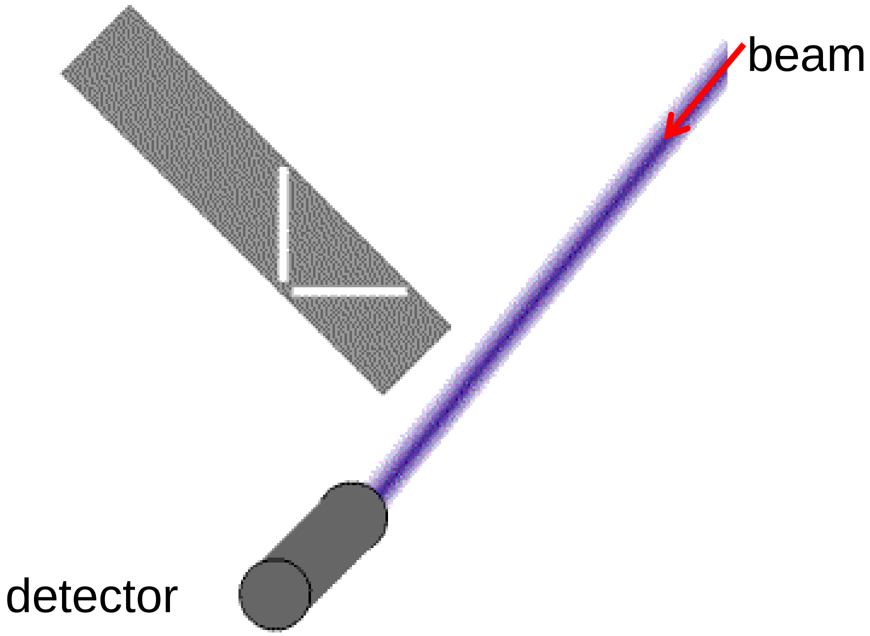
FC: application

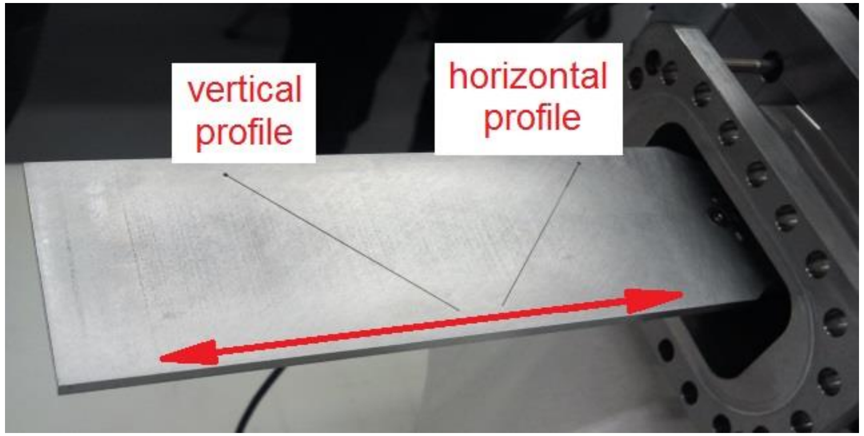
Current

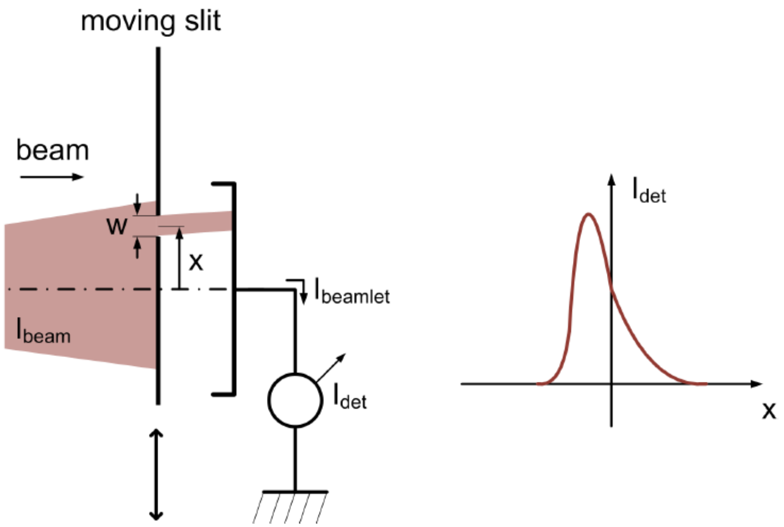
Profile/position

Emittance

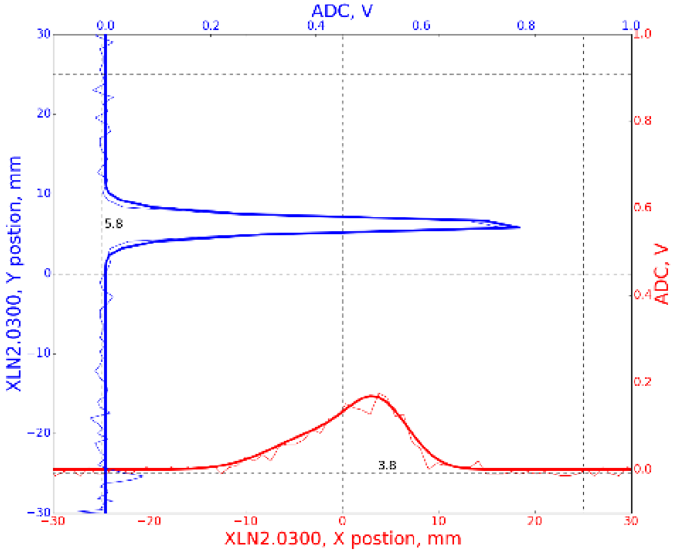
FC and Scanning slit (profile measurement)

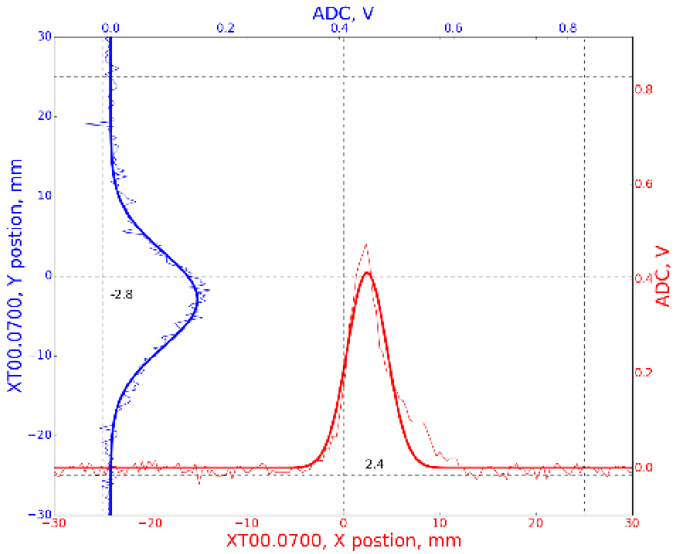


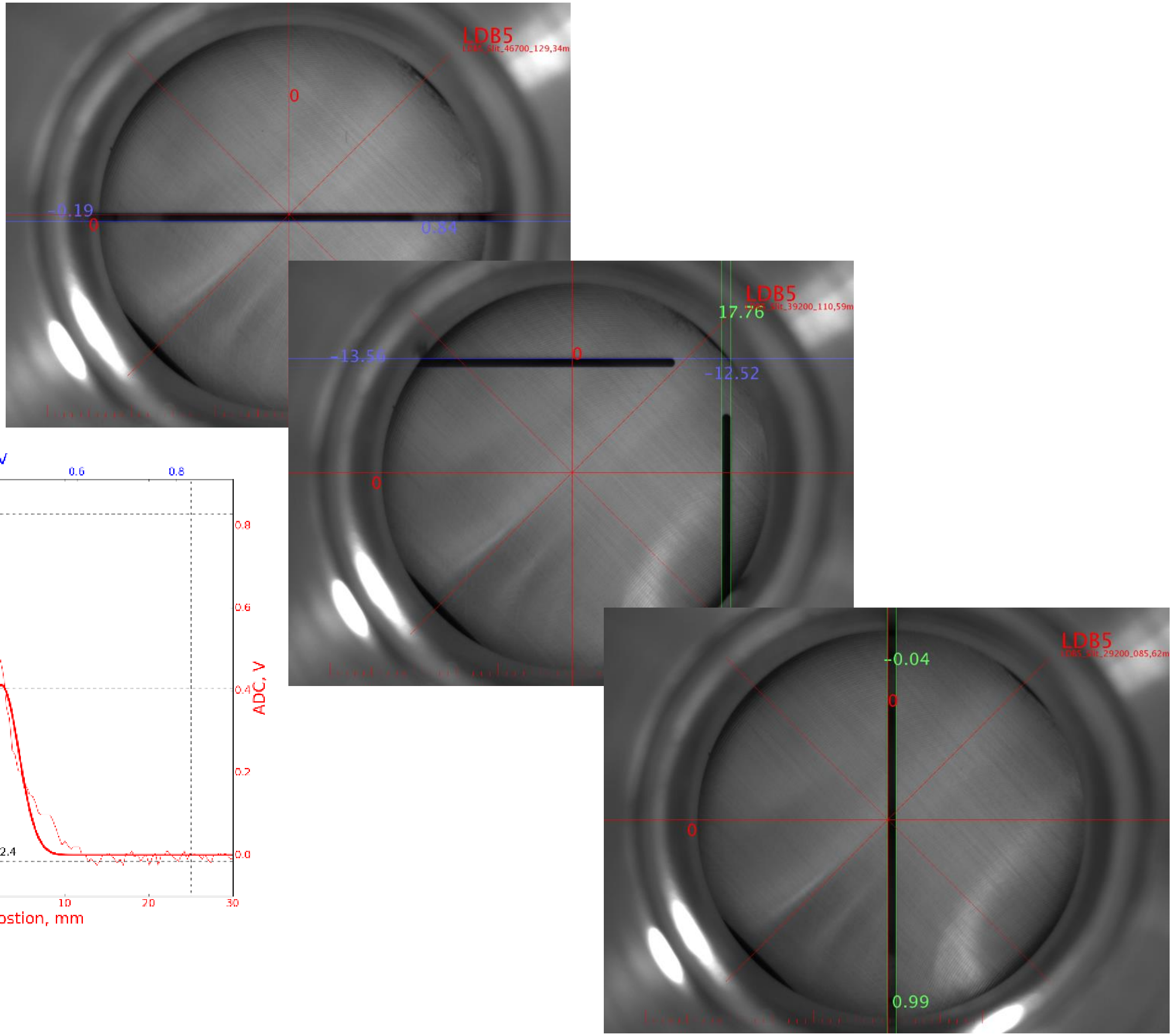




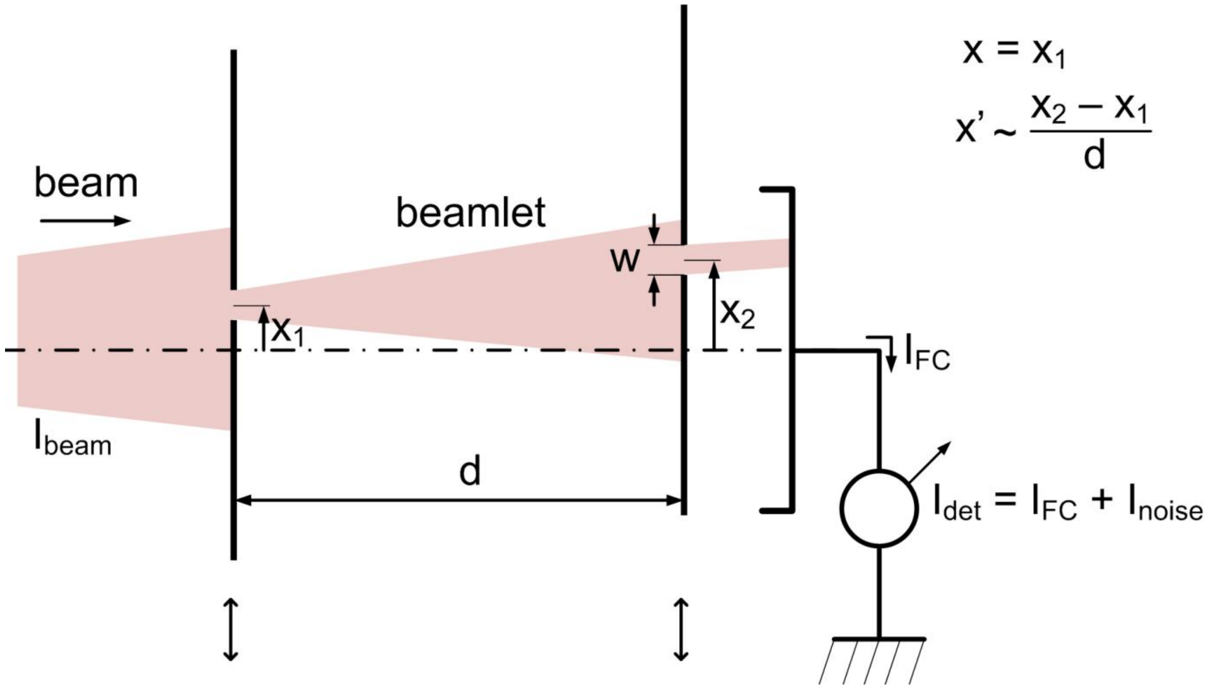
FC and Scanning slit (profile measurement)

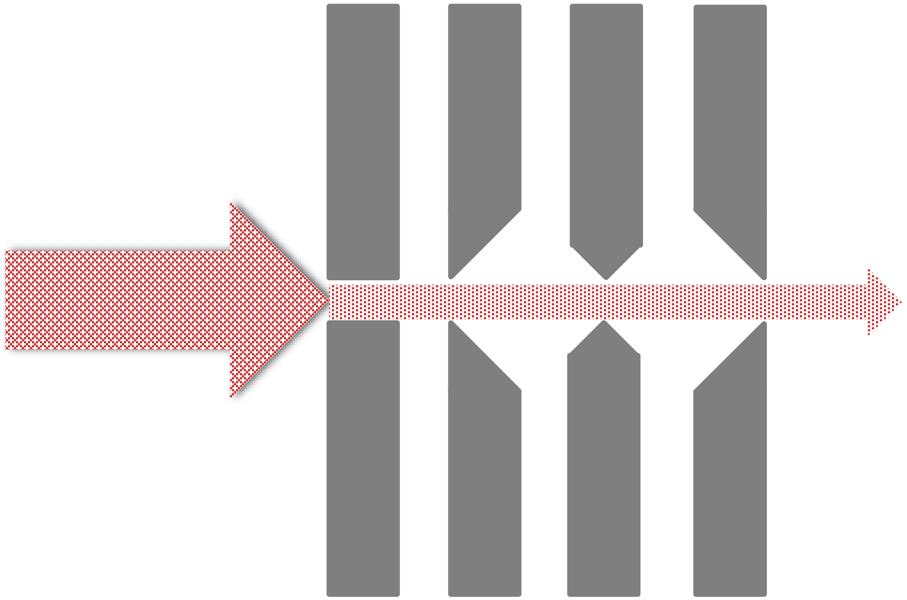






FC and 2 Scanning slits (transverse emittance)

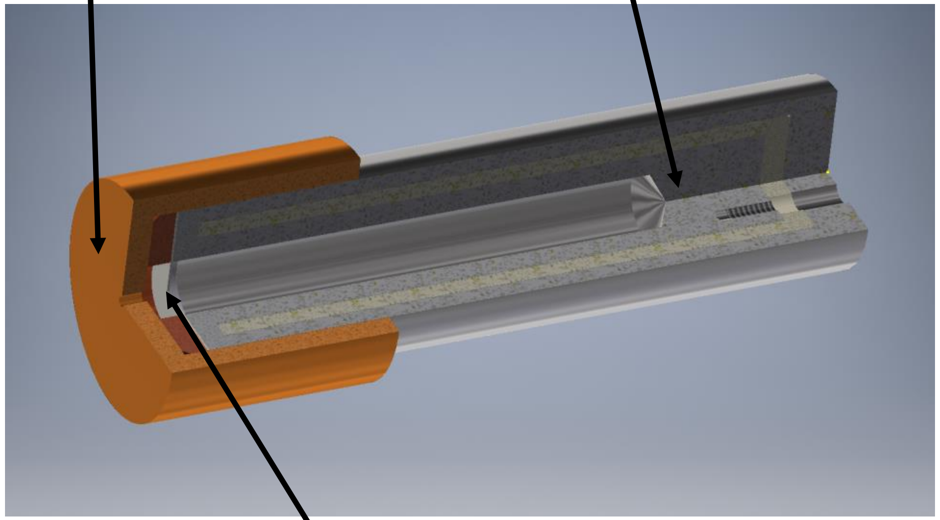




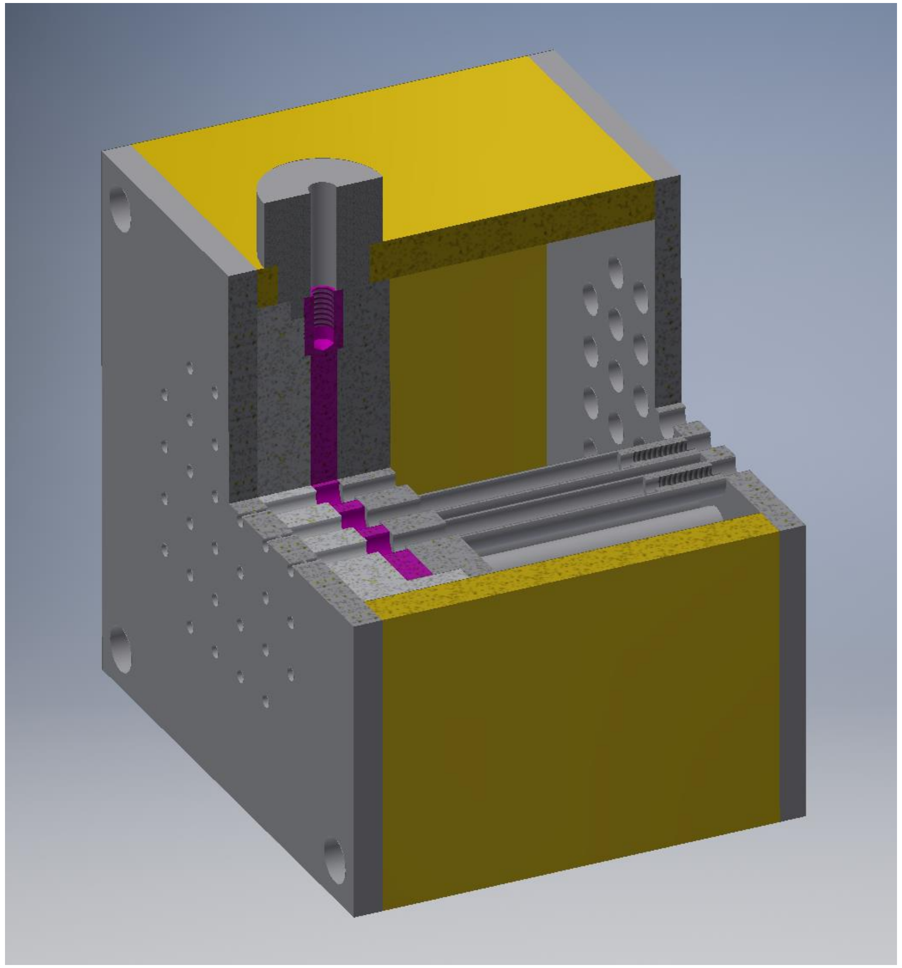
FC: pin-hole / array

1 mm aperture in molybdenum cup

Faraday Cup collector



0.2 mm aperture in tungsten foil



FC: summary

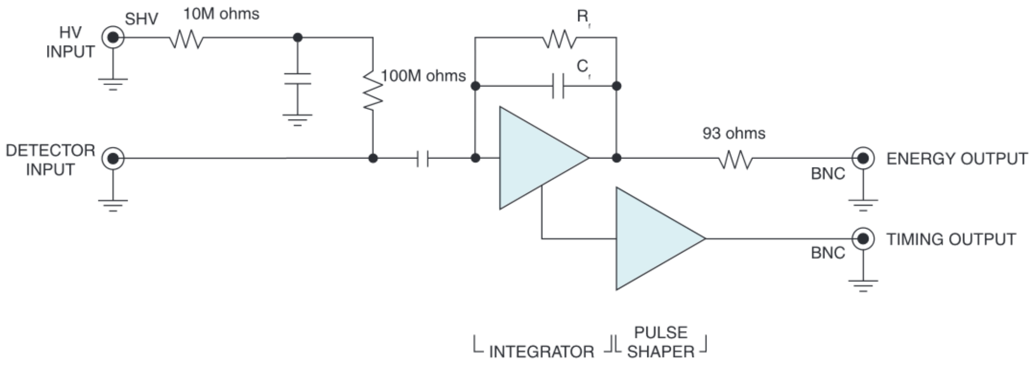
Cheap and robust device for current measurement (< 1 pA), for lower values magic with improving signal to noise ratio is required

Updated functionality with slit (profile and position measurement)

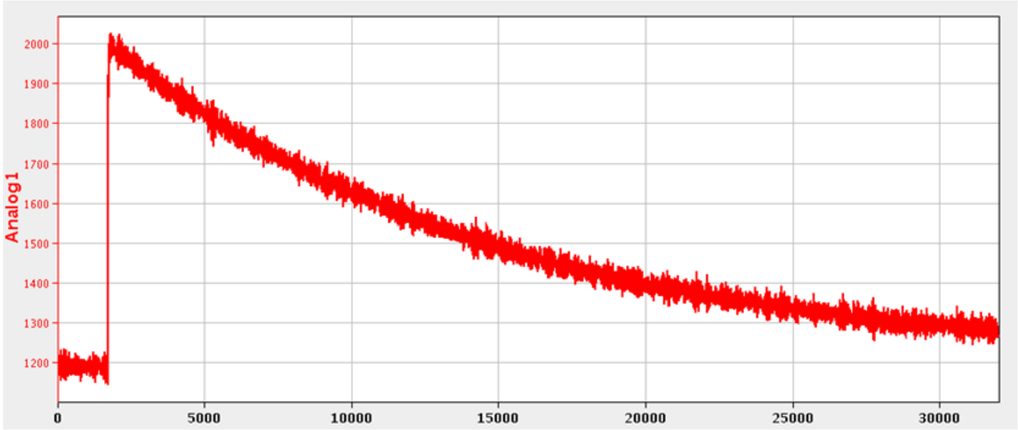
Beam stopper – energy absorption / dissipation

Silicon detector

Model 2003BT Silicon Detector Preamplifier



Functional Schematic



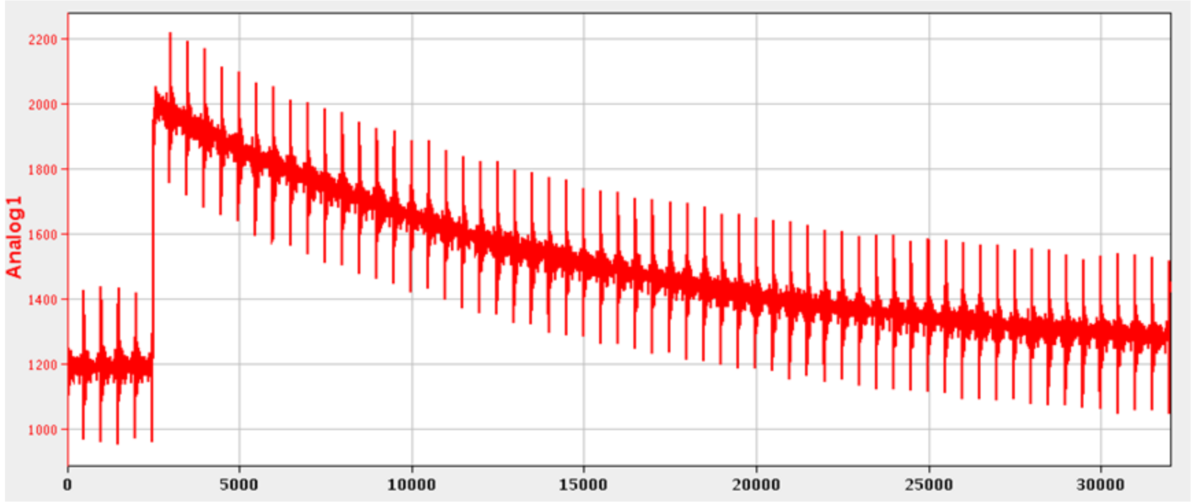
Preamplifier (Operating as a charge to voltage converter) (0.45V per pC -> 20mV per MeV)

500 MeV for 0…10V digitizer

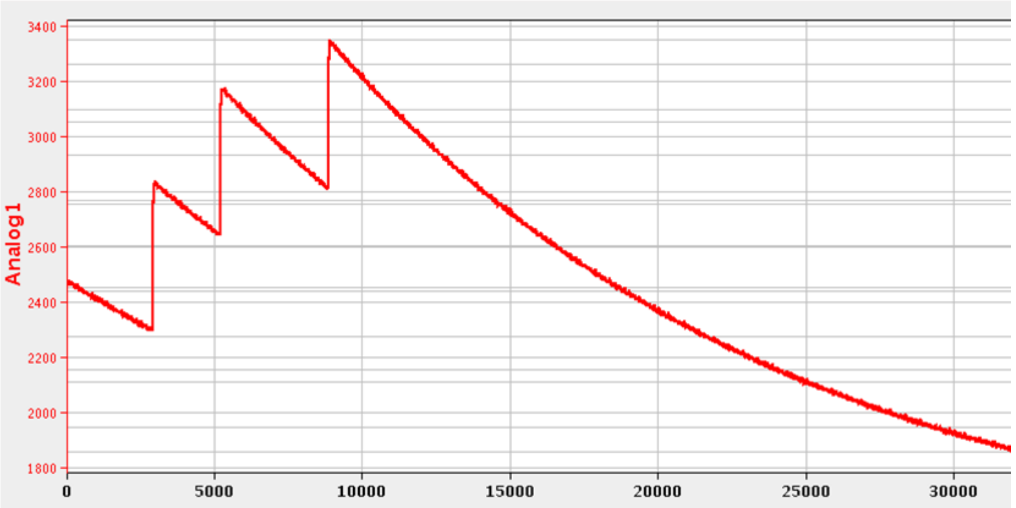
Single particle detection

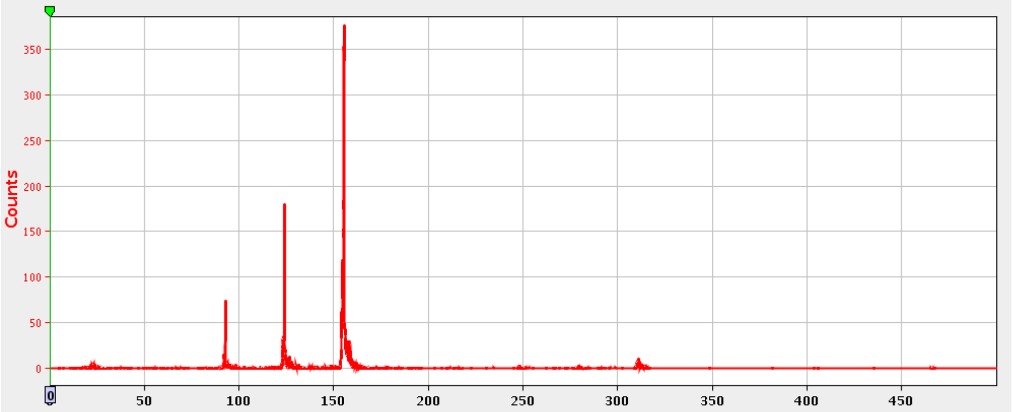
Fragile/degradation

Silicon detector



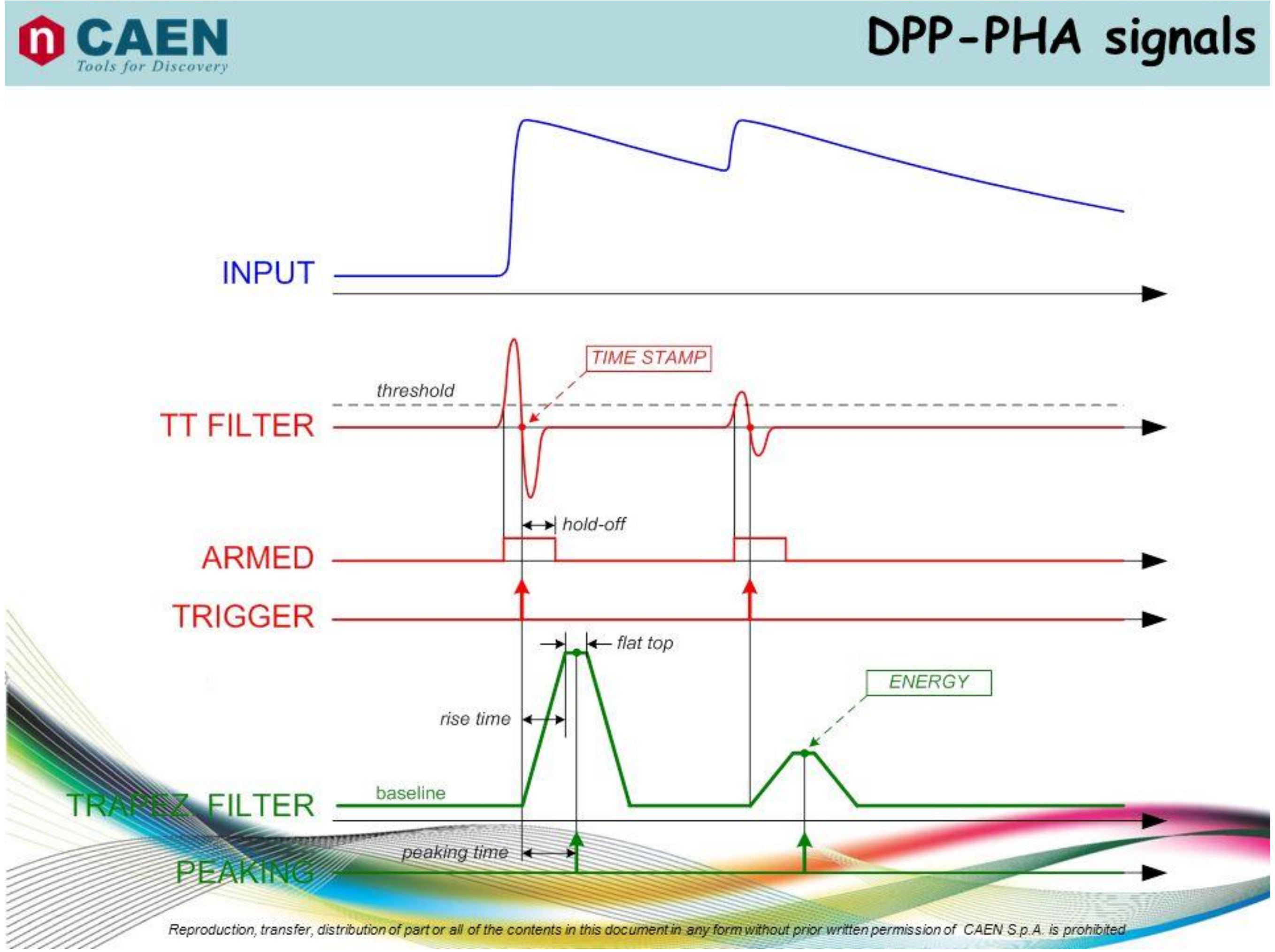
Silicon detector



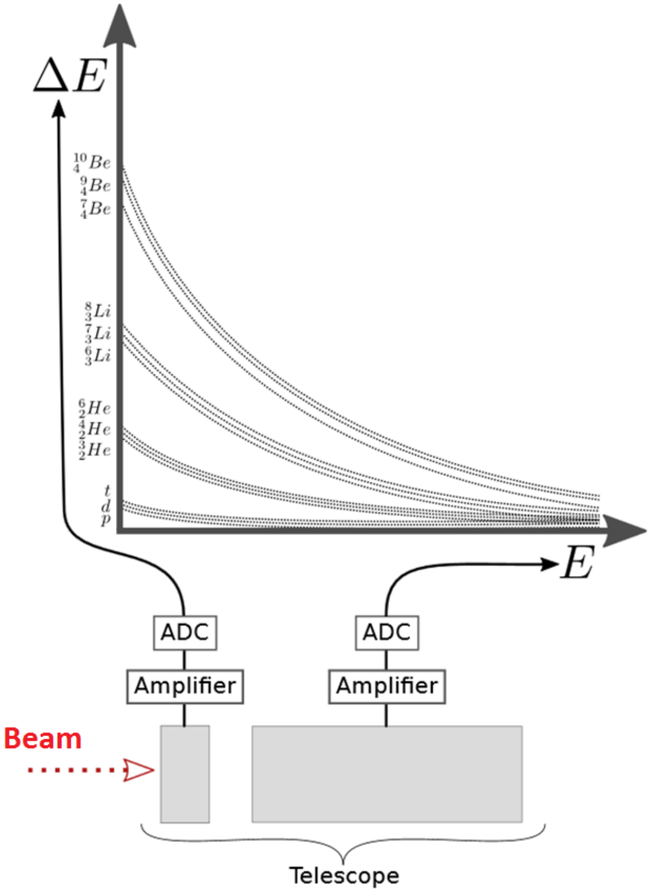


DPP-PHA

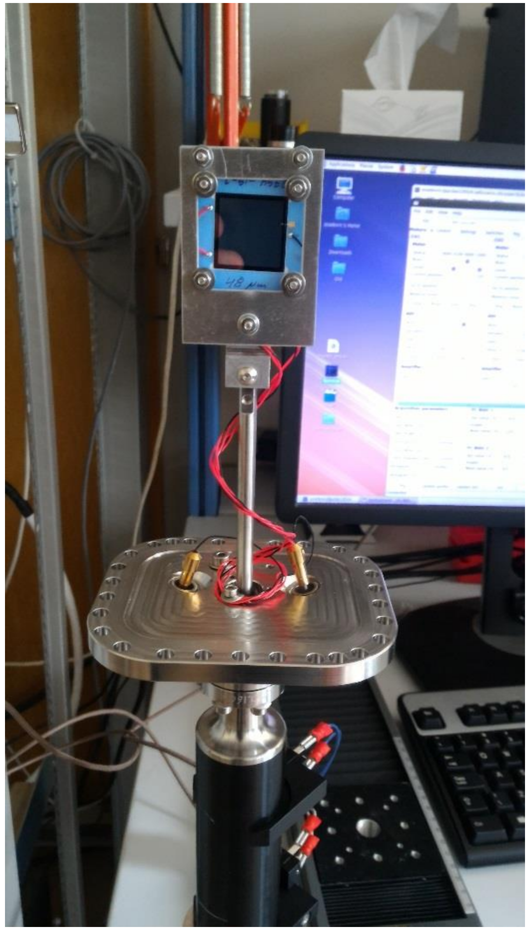
Digital Pulse Processing – Pulse Height Analysis



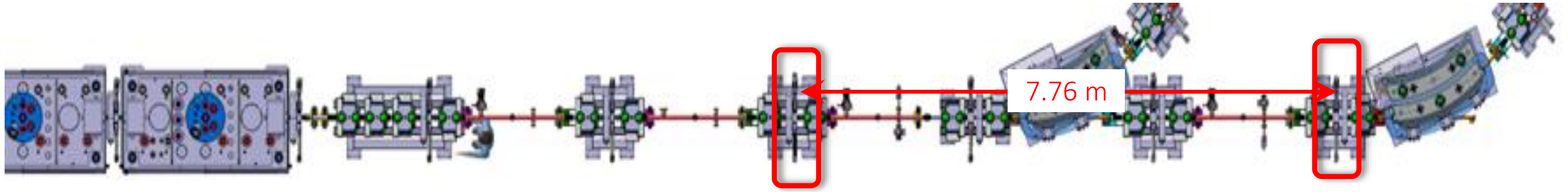
Silicon telescope



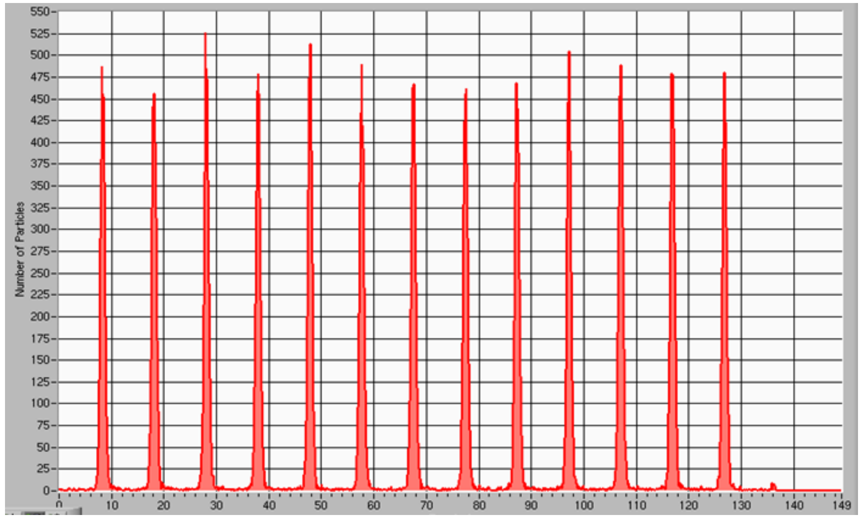
K.Schmidt and O.Wyszynski
An evolutionary strategy for ΔE-E identification

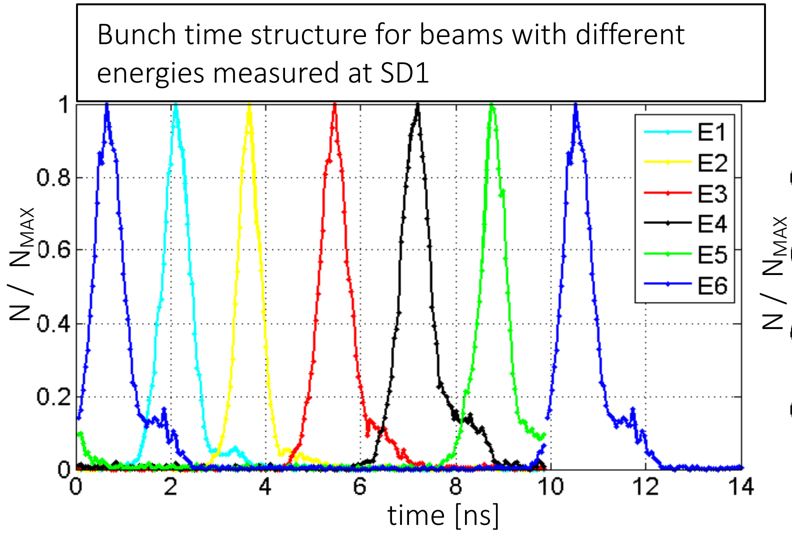


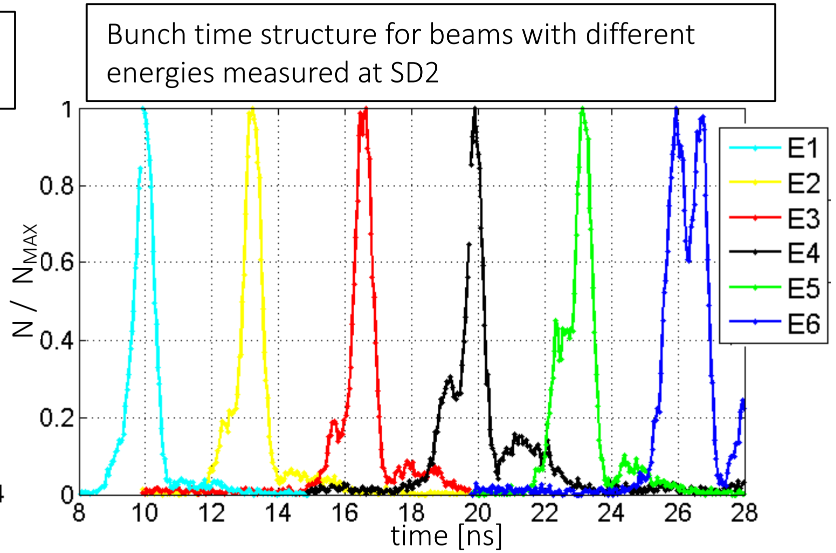
Silicon detector: TOF



Annular silicon detector

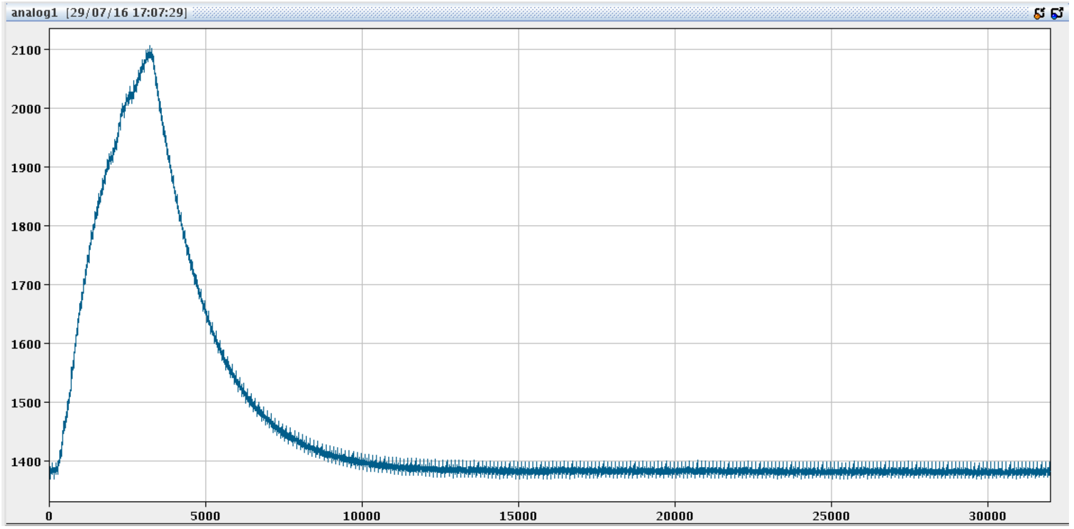






- The TOF system uses the time information provided by two silicon detectors separated 7.76 m from each other
- Energy changes smaller than 0.5 % could be easily resolved
- Bunch structure in second Si detector has partially degraded

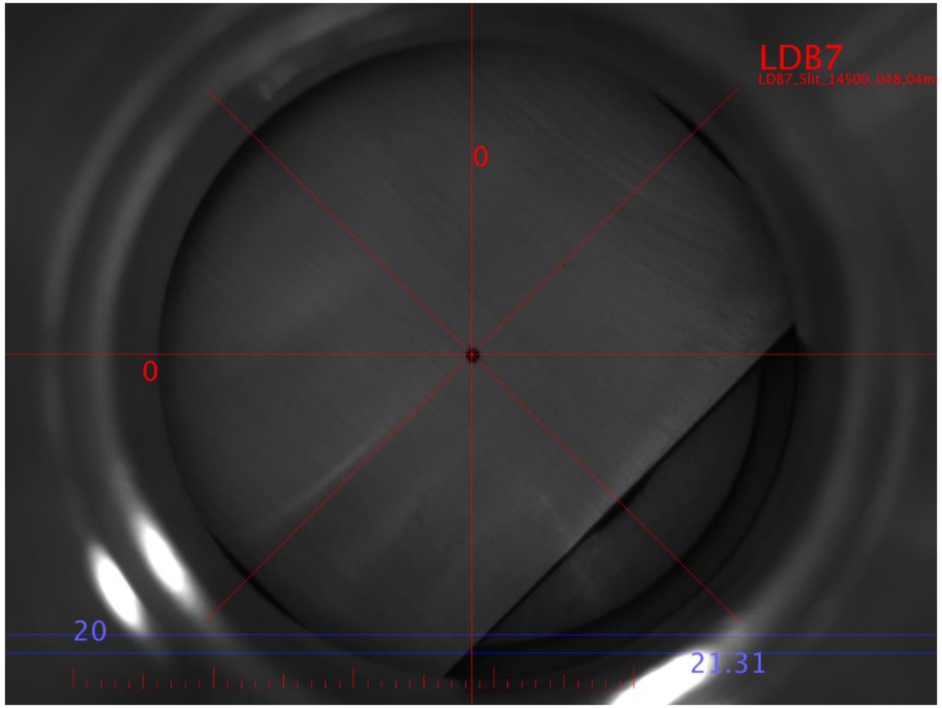
Degradation of SD

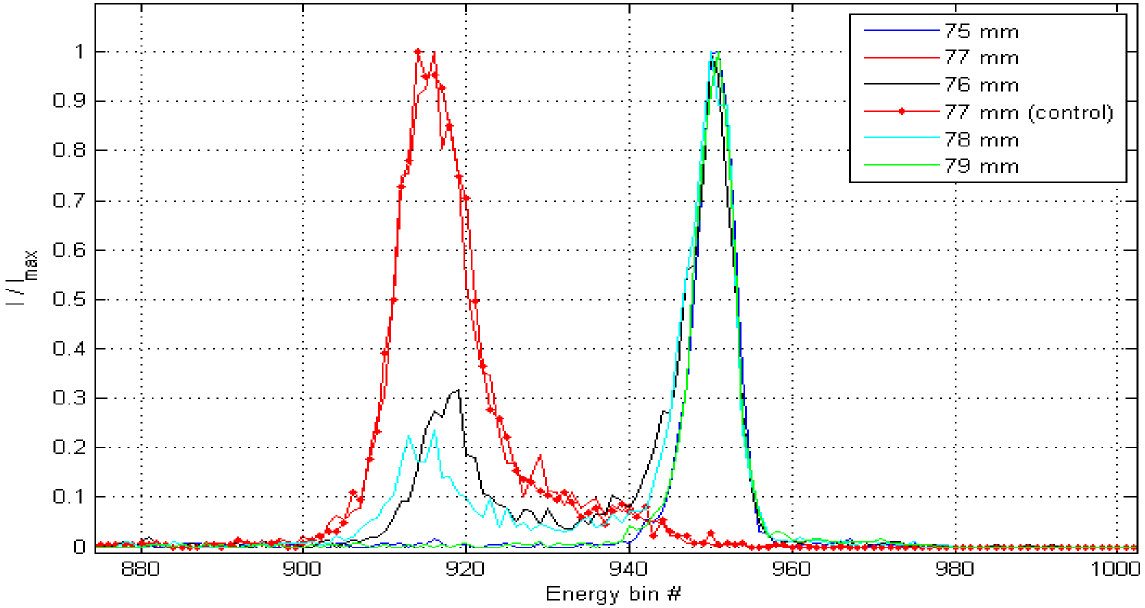


Typical leakage current: 2-5 nA

Leakage current increases during opration

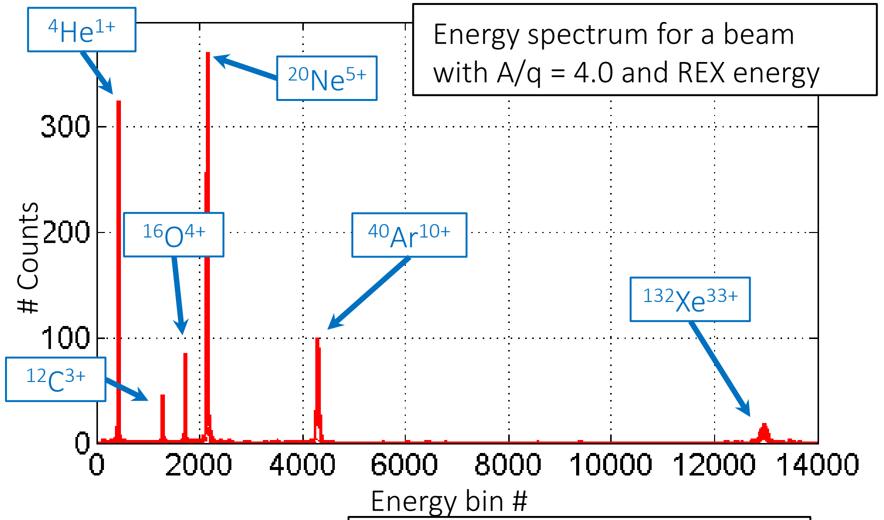
Degradation (not critical for relative measurement, can affect final measurements)

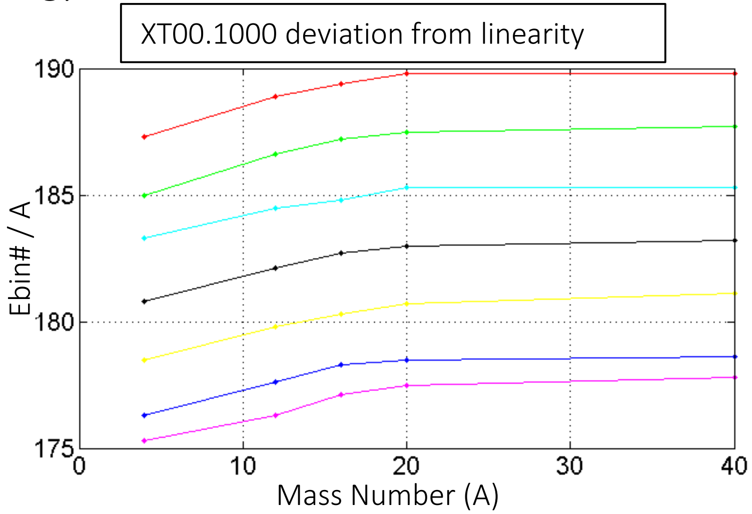


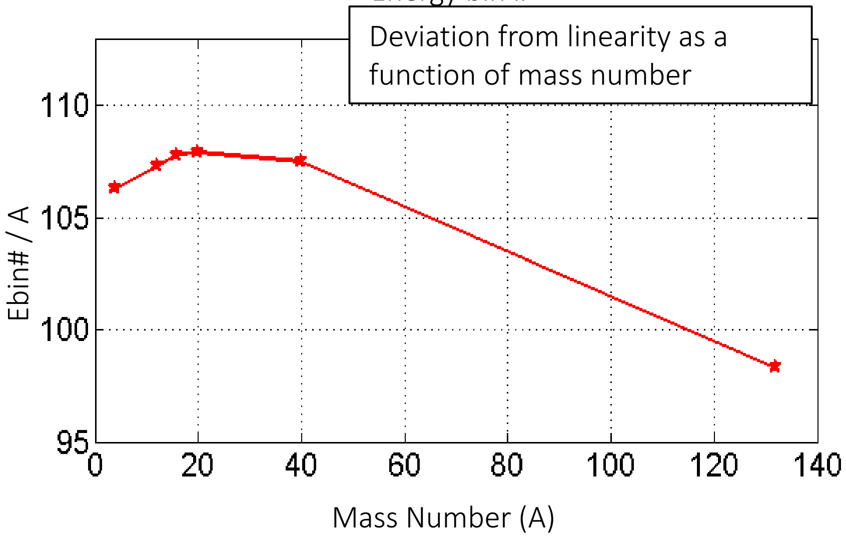


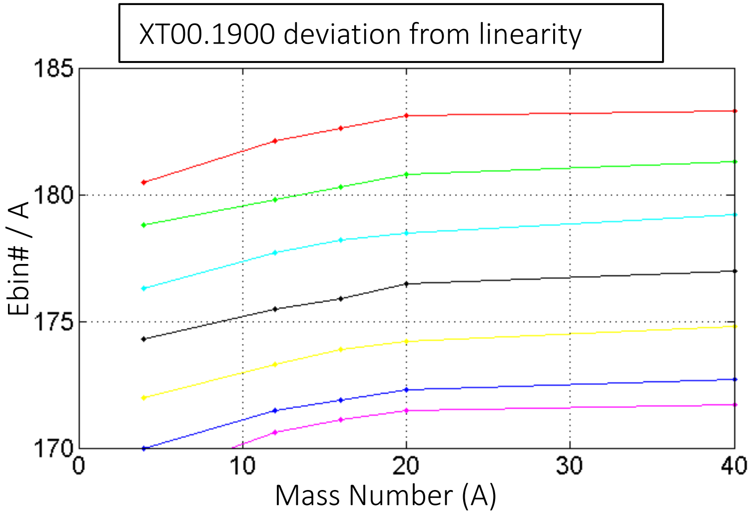
Energy measurement: Pulse Height Defect

- Cocktail of beams (EBIS and Xe from GPS target) was sent to silicon detector
- PHD is visible for heavy ions – time of flight technique should be used for energy measurement









Silicon detectors: summary

Absolute energy measurement of the beam (0.5%): roughly measurement using energy output and fine correction using timing output

Single particle detection

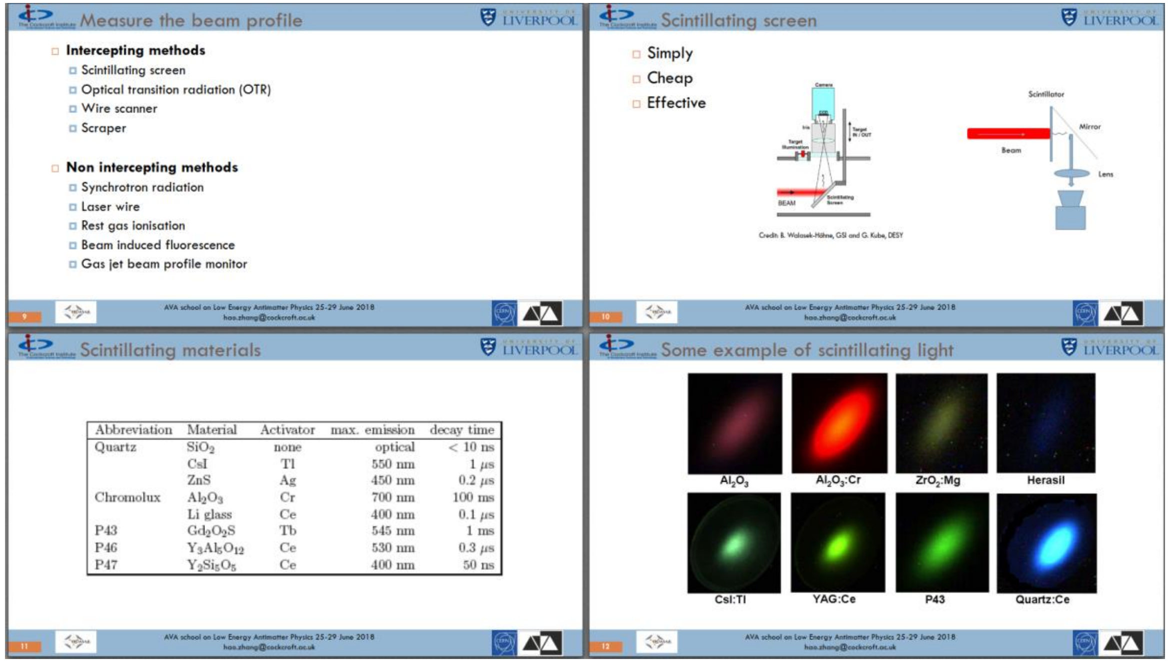
Fragile – can be destroyed in one direct pulse

Degradation during operation (corrections for data analysis are required / calibration using alpha source)

Corrections for PHD should be taken into account for data analysis

Scintillators

Widely used for beam profile measurements
- Decay time
- Radiation hardness



Hao Zhang - Beam Diagnostics I (Destructive monitors)

For chemical compound $A_m B_n$

$$(-dE/dx)_{A_m B_n} = m(-dE/dx)_A + n(-dE/dx)_B$$

Table 1: Properties of Scintillators

	τ_{decay} [ns]	λ_{max} [nm]	Relative output (NaI:Tl =100)	Radiation hardness [rad]
YAG:Ce	70	550	35	$>10^6$
LYSO:Ce	41	420	75	$>10^6$
BGO	300	480	21	$>10^{5-6}$
Al_2O_3:Cr_2O_3	> ms	690	Large	High

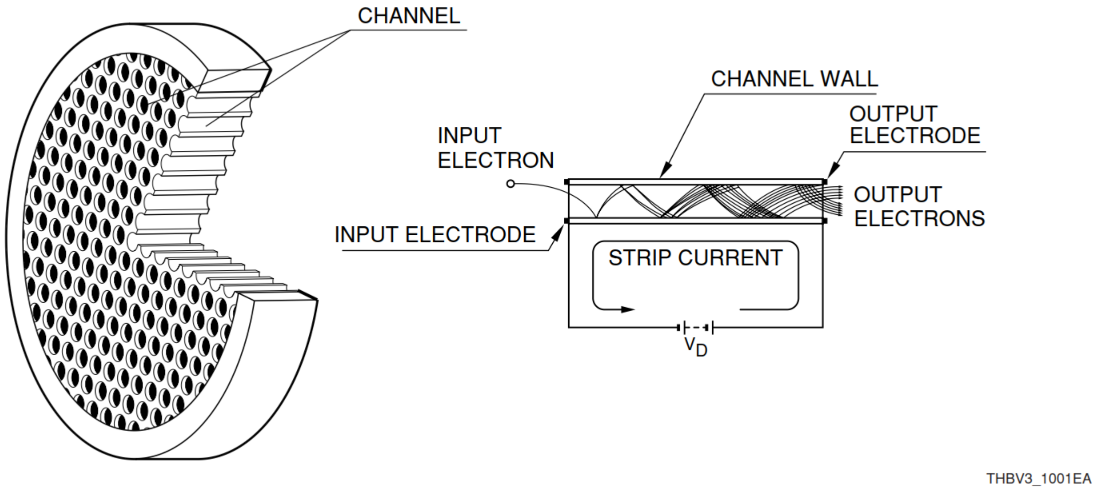
Saturation with very dense beam (pC/mm^2) is possible

F. Miyahara et all
Response of scintillating screens to high charge density electron beam

Scintillator: summary

- Phosphors have very high light yields, but can only be used as thin coating on a rigid support and get damaged very quickly (often used in MCP)
- Normally used for very low intensity beams
- CHROMOX (Al_2O_3:Cr, Aluminum Oxide) is a very common choice because it is a very robust ceramic
- ZZZ-doped YAG is also a very frequent choice (fast)

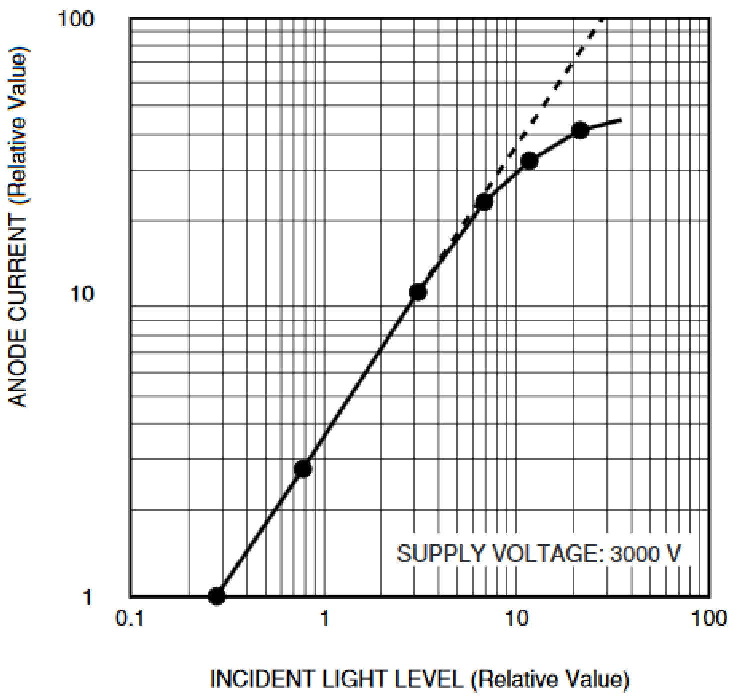
Micro Channel Plate



(a) Schematic structure of an MCP **(b) Principle of multiplication**

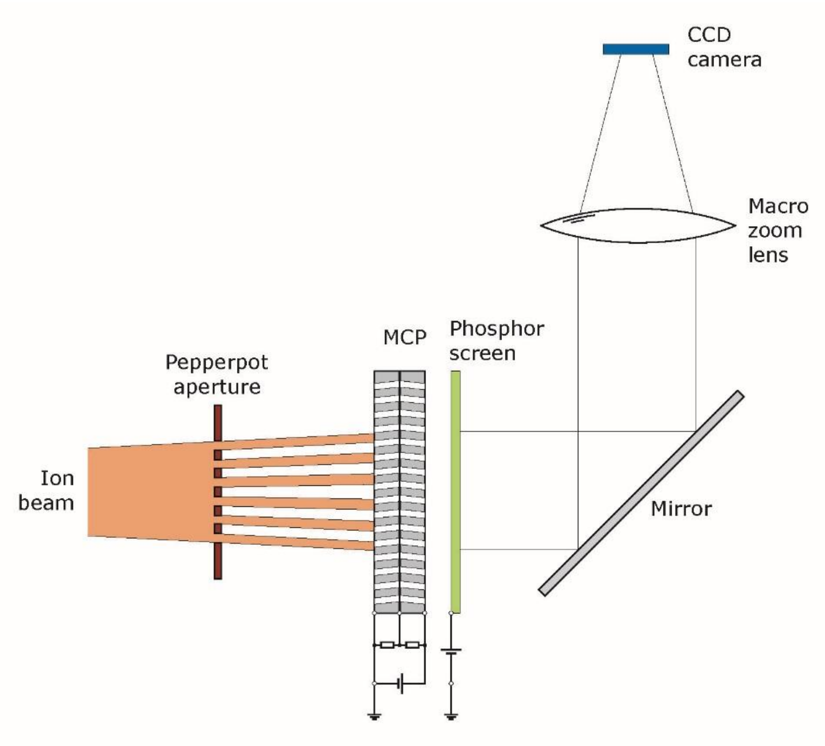
Parameter \ Type	F1551				F1094			F1552			F1208-01	F1217		F1942-04	F2395-04	Unit
	-01⑤	-06	-011	-074	-01⑤	-011	-074	-01⑤	-011	-074		-01⑤	-011			
Outer size A	ϕ17.9				ϕ24.8			ϕ32.8			ϕ38.4	ϕ49.9		ϕ86.7	ϕ113.9	mm
Electrode area B	ϕ17				ϕ23.9			ϕ31.8			ϕ36.5	ϕ49		ϕ84.7	ϕ112	mm
Effective area C	ϕ14.5				ϕ20			ϕ27			ϕ32	ϕ42		ϕ77	ϕ105	mm
Thickness D	0.48	0.2	0.48	0.3	0.48		0.3	0.48		0.3	0.48	0.48		1		mm
Channel diameter	12	4	12	6	12		6	12		6	12	12		25		µm
Channel pitch	15	5	15	7.5	15		7.5	15		7.5	15	15		31		µm
Bias angle θ	8	12			8	12		8	12		8	8	12	8		degrees

Saturation of the MCP (channels)

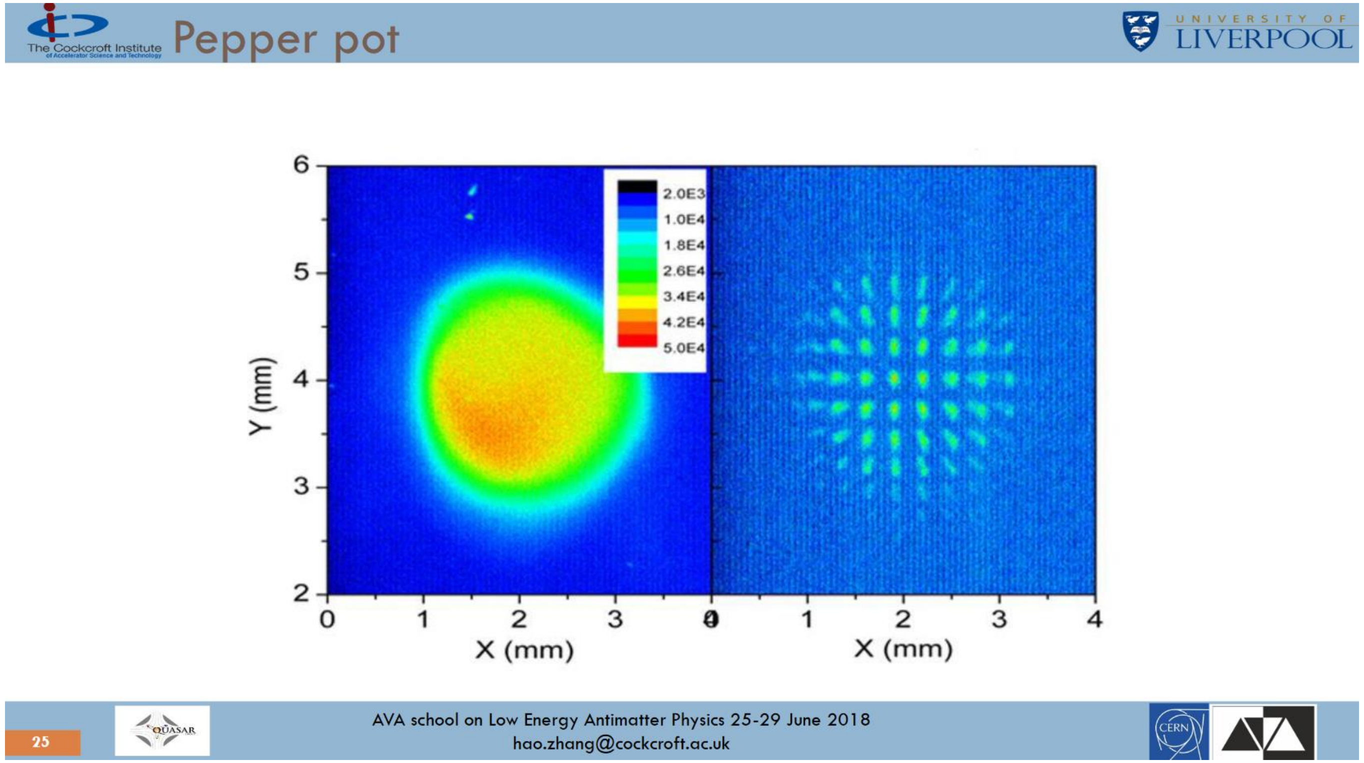


www.hamamatsu.com

PepperPot

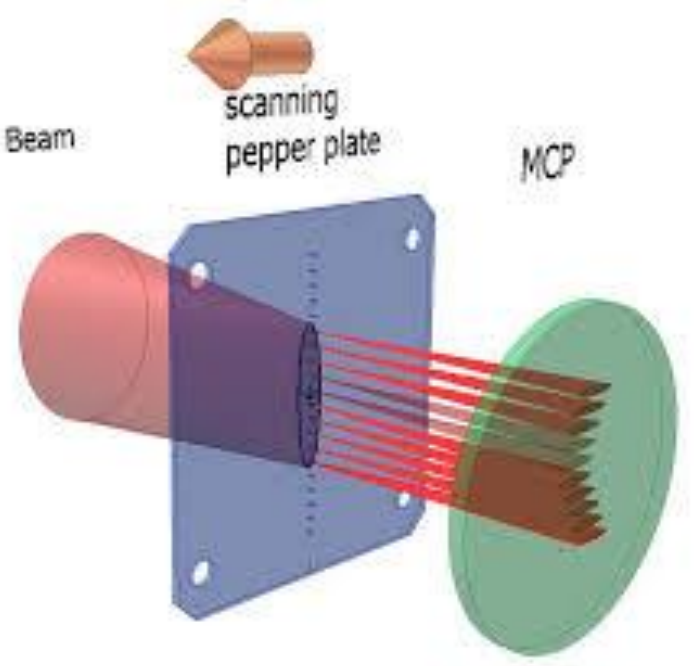


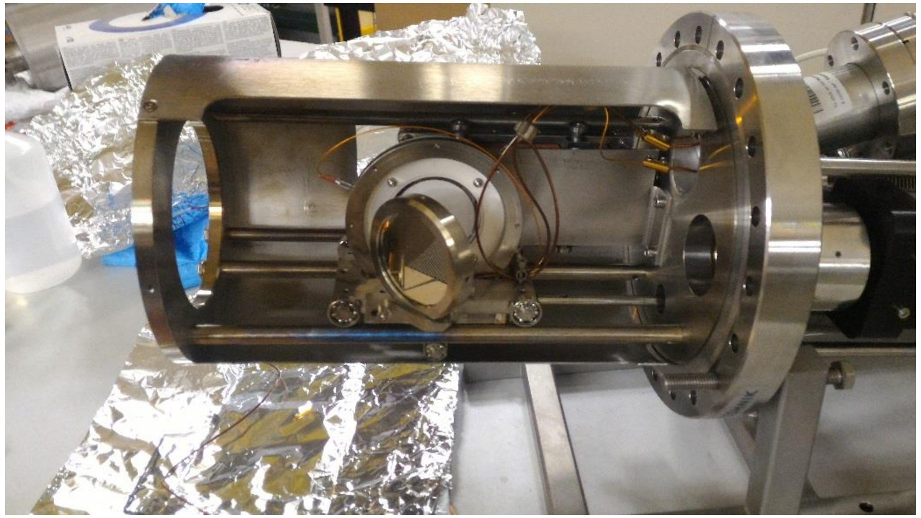
www.dreebit-ibt.com



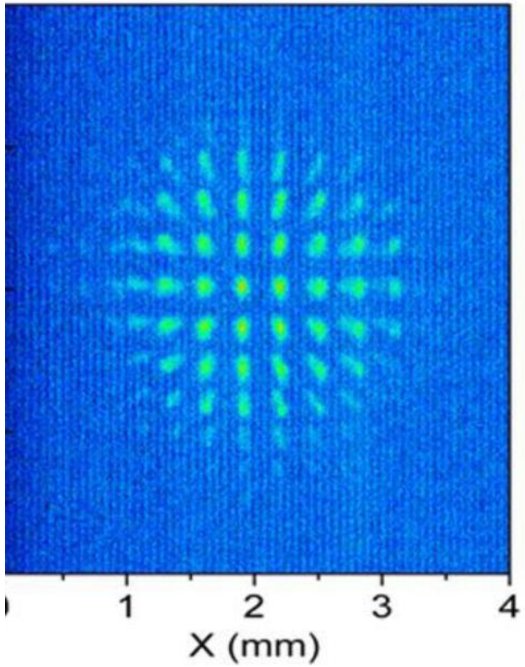
Hao Zhang - Beam Diagnostics I (Destructive monitors)

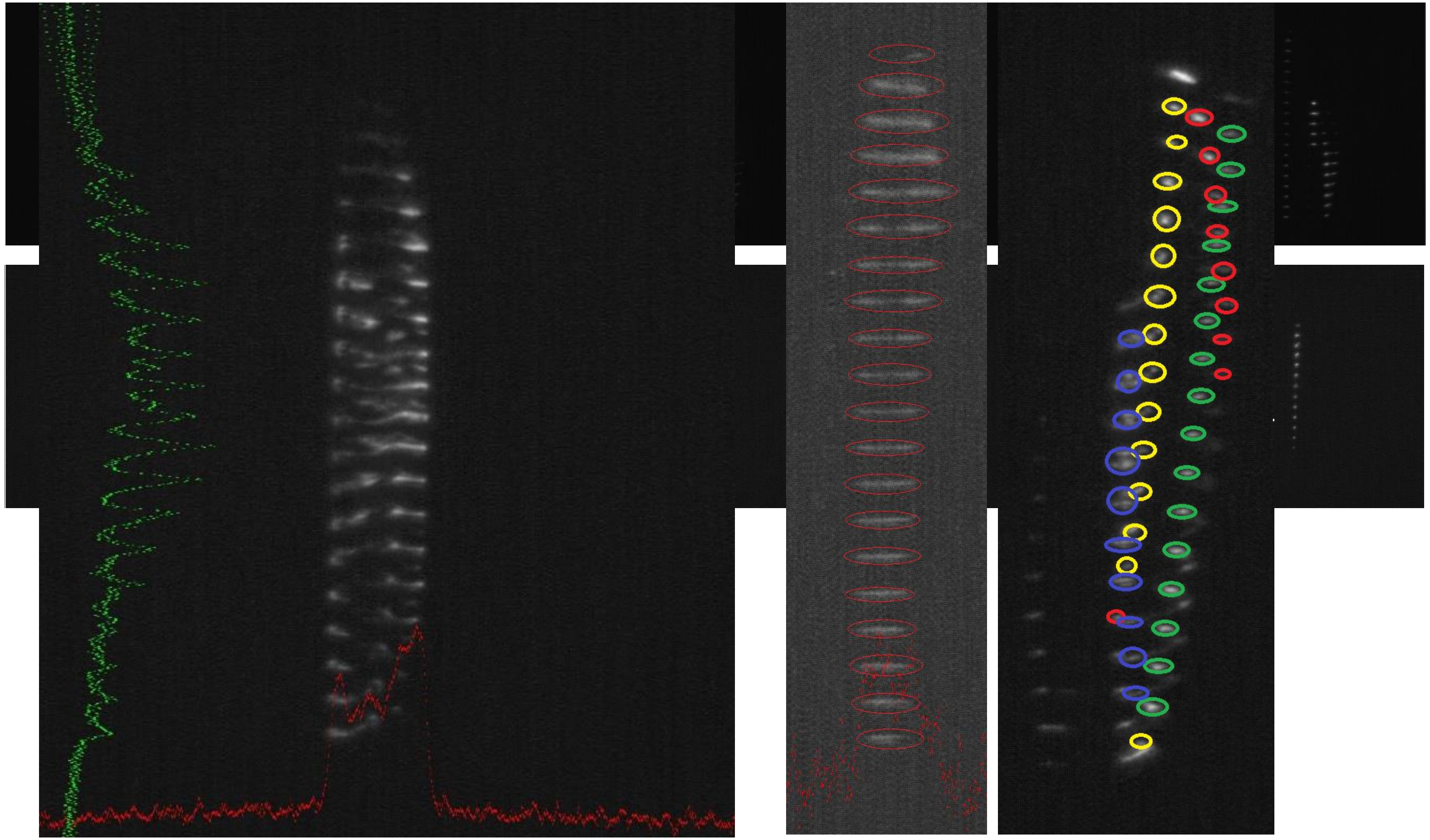
PepperPot: scanning plate



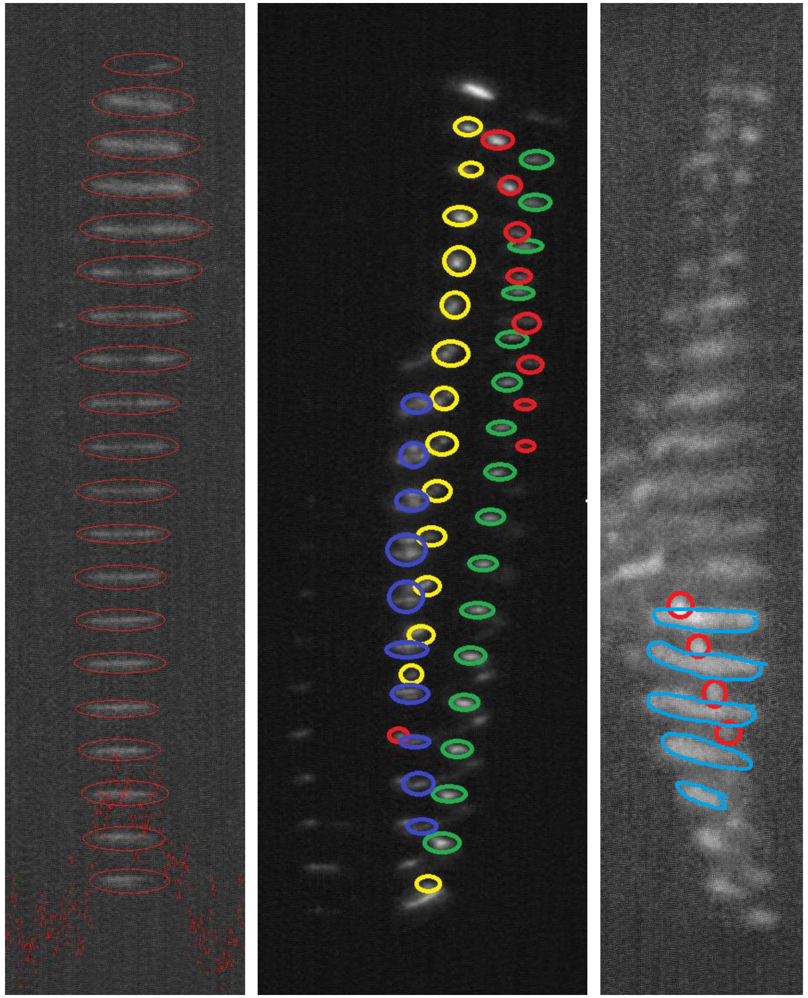


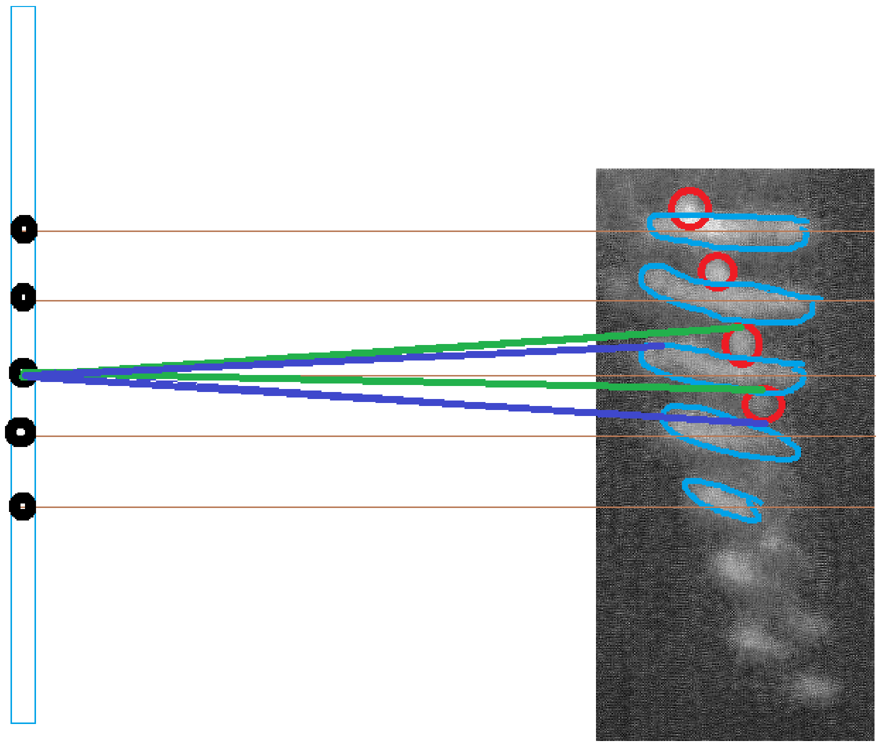
PepperPot: image processing





How to analyze images





MCP summary

Sensitive tool for particles detection

MCP-PMT with a single photon detection

Fragile

Linearity and working point (to avoid saturation)

Image processing can be non-trivial

The End