Electrostatic analyser as alternative electrons detector

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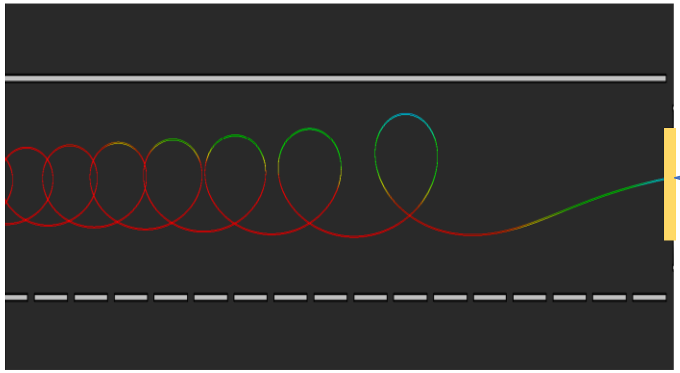
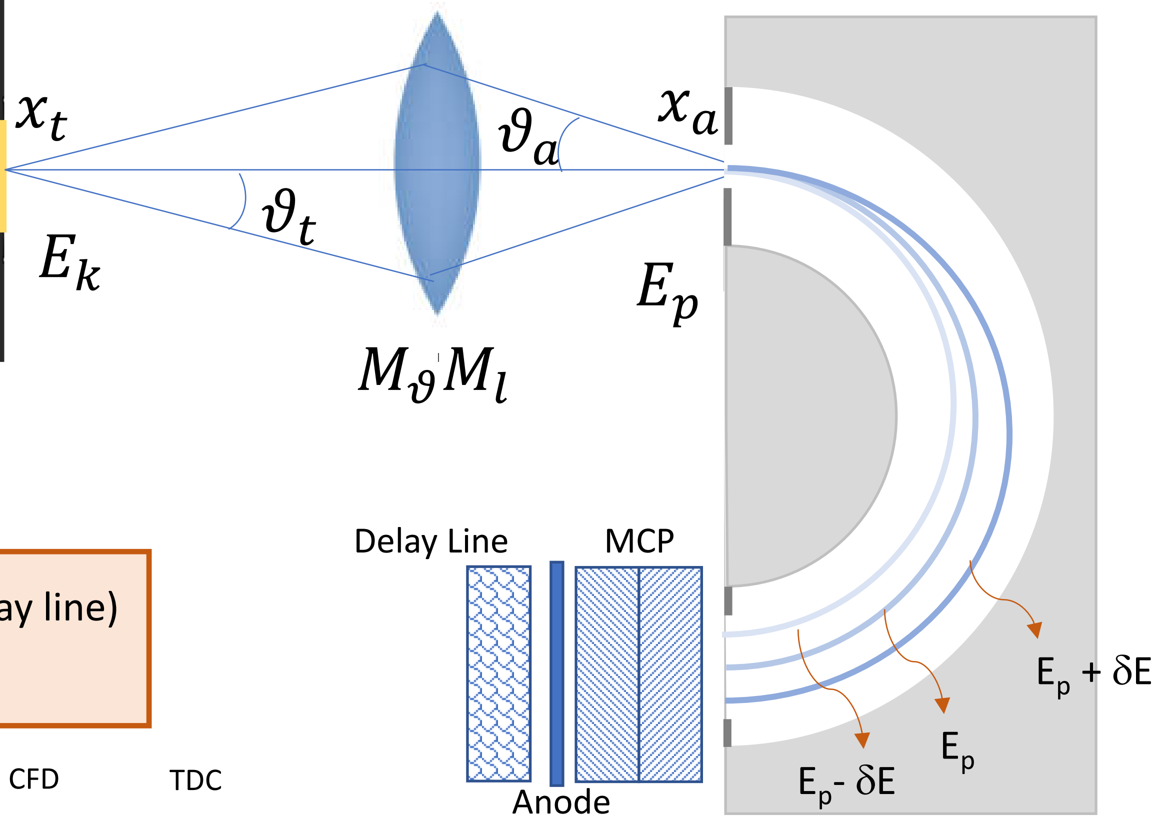
PTOLEMY meeting   Sapienza 19-2-2025

Electrostatic analyser as alternative electrons detector



Ptolemy e.m. filter



Electron optic basic equation

Helmholtz – Lagrange law

$$x_t \vartheta_t \sqrt{E_k} = x_a \vartheta_a \sqrt{E_p}$$

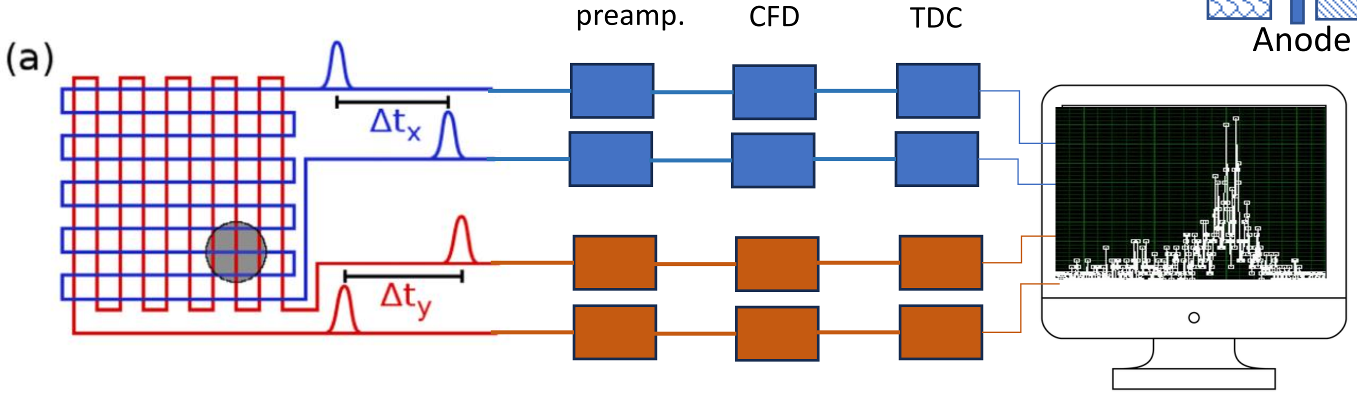
Two concentric hemispheres for the energy selection

Energy resolution (bandpass energy)

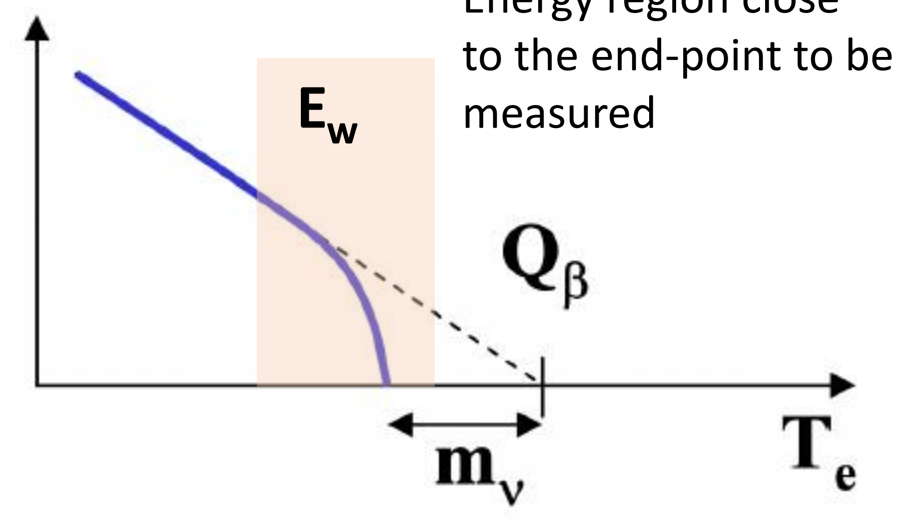
$$\frac{\Delta E}{E_p} = \frac{x}{2R_0} + \frac{\vartheta^2}{4}$$

ΔE: energy resolution
E_p : pass energy
x: slit width
R_0: mean radius
θ: accepted angle

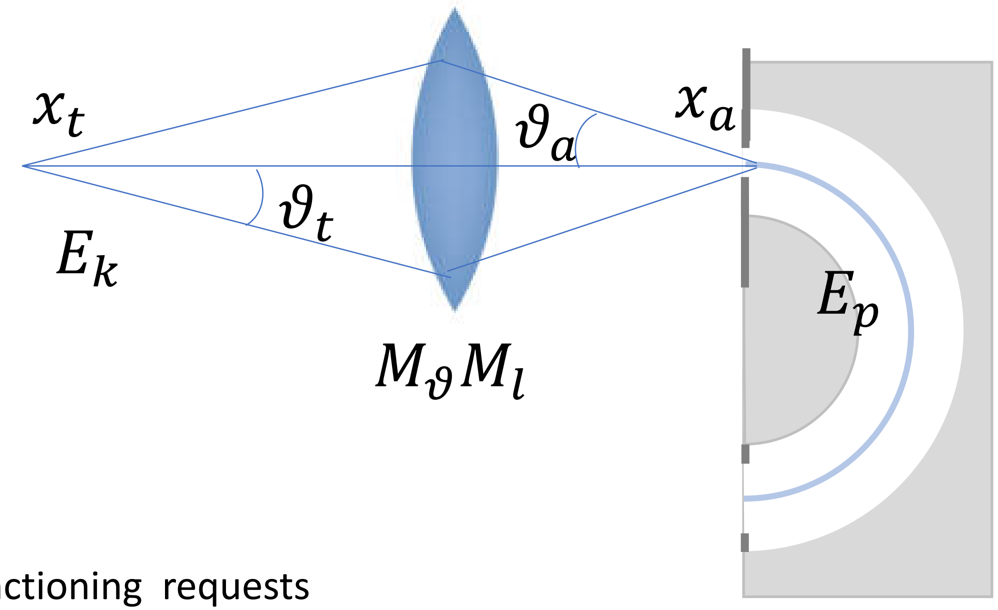
Position sensitive detector (MCP+delay line) allows parallel acquisition



Electrostatic analyser as alternative electrons detector



Energy region close to the end-point to be measured



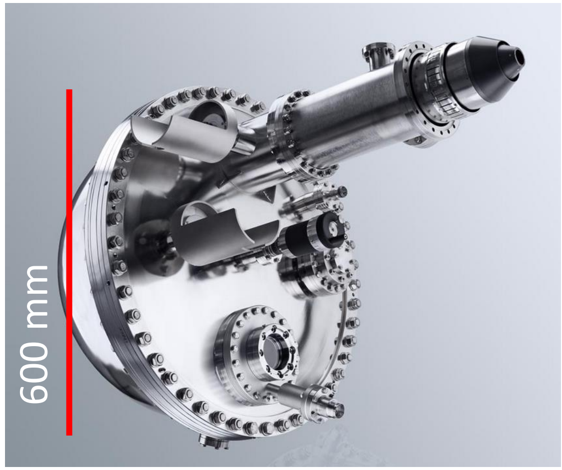
An example of Electron Analyser Project

E_w(eV)	E_p(eV)	ΔE (meV)	R_0(mm)	x_a(mm)	ϑ_t(°)
5	50	50	250	0.5	33
5	50	100	250	1	16

Functioning requests

Magnetic field	< 5 mG
Operating temperature	T ambient
Surface stability vs time	Stable (graphite)
Max rate	2 MHz

Specs Phoibos 225



Update of Application of Electron Energy Analysers in the Ptolemy Project

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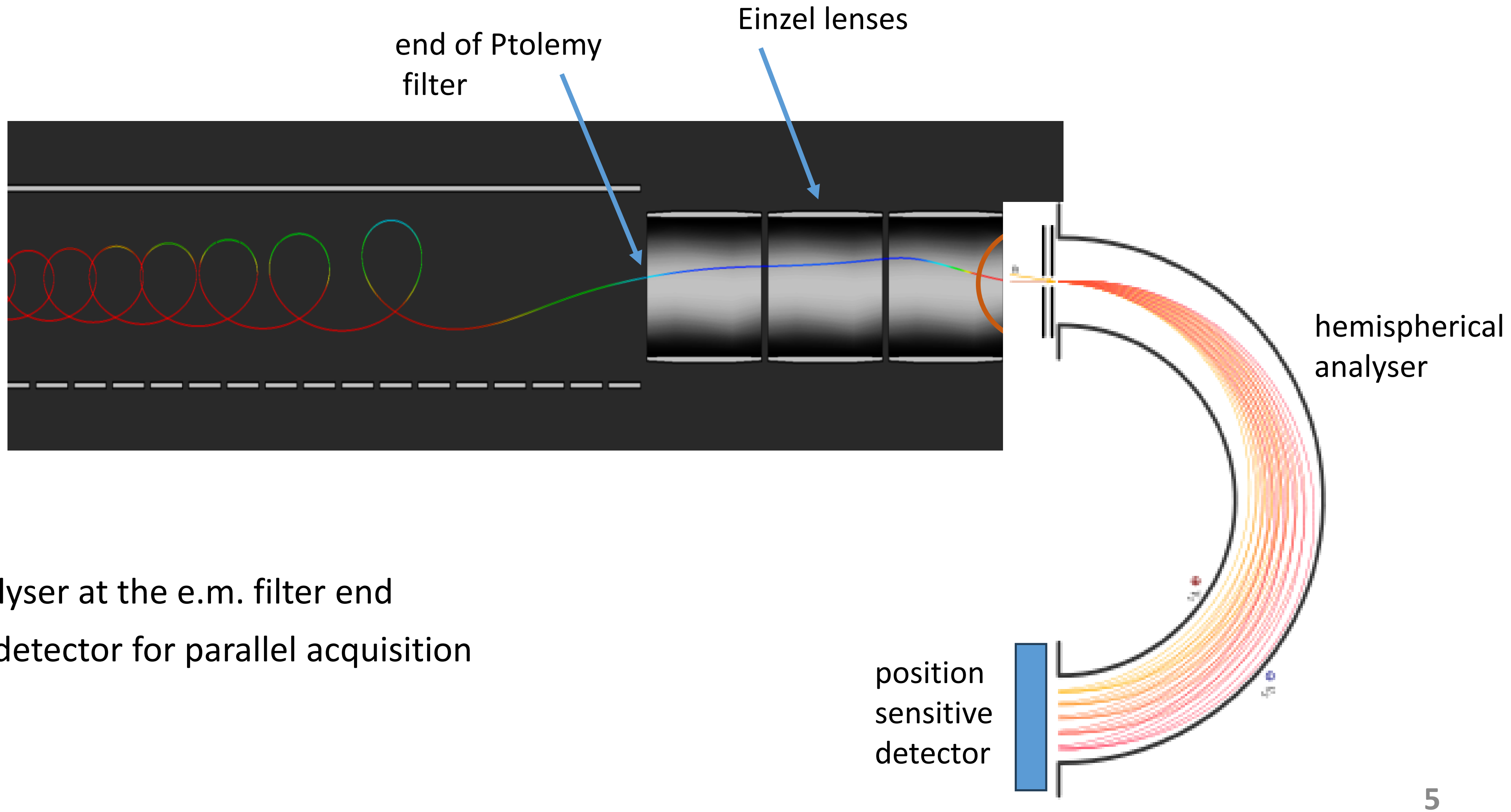
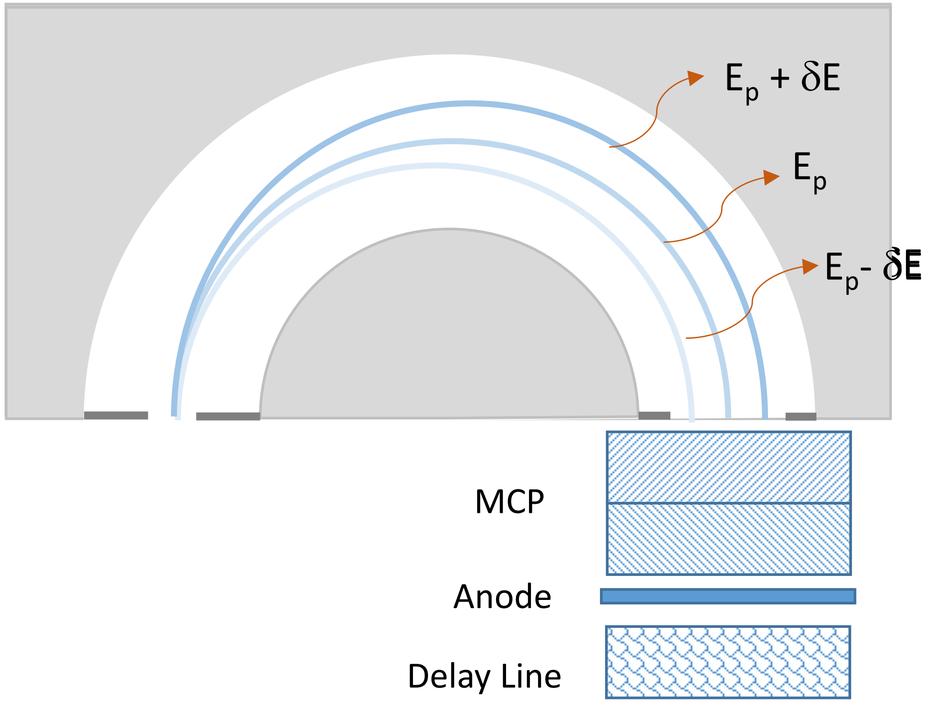
Electrostatic Electron Analyser: a possible alternative to TES

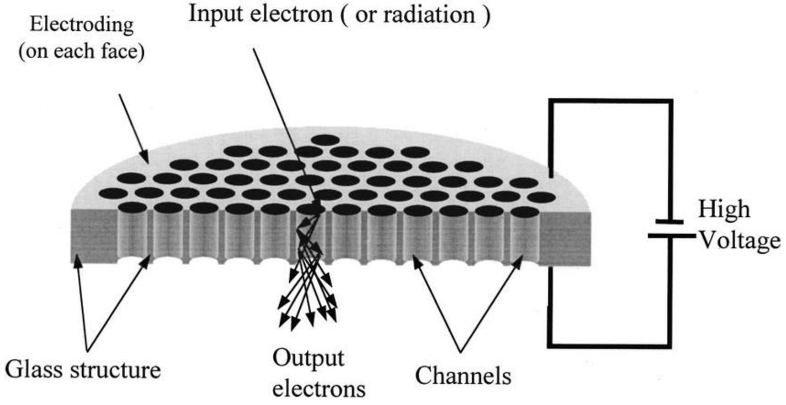


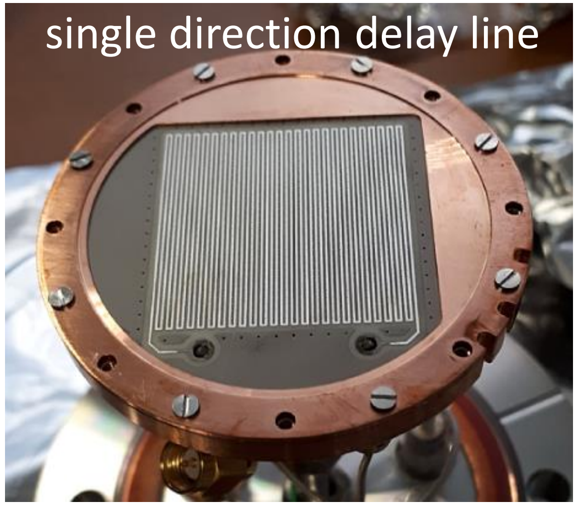
- hemispherical analyser at the e.m. filter end
- position sensitive detector for parallel acquisition

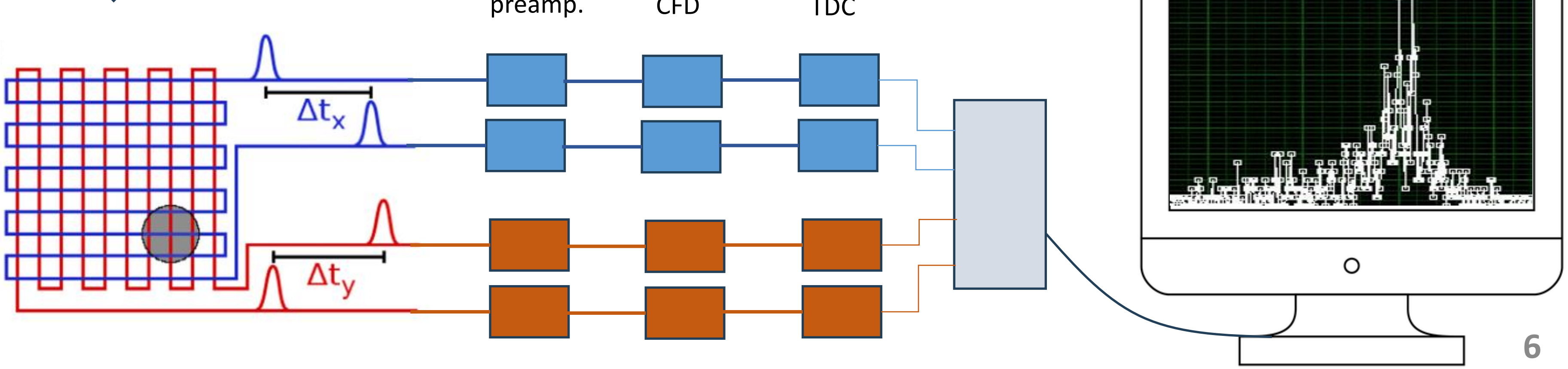
Position sensitive detector for parallel acquisition



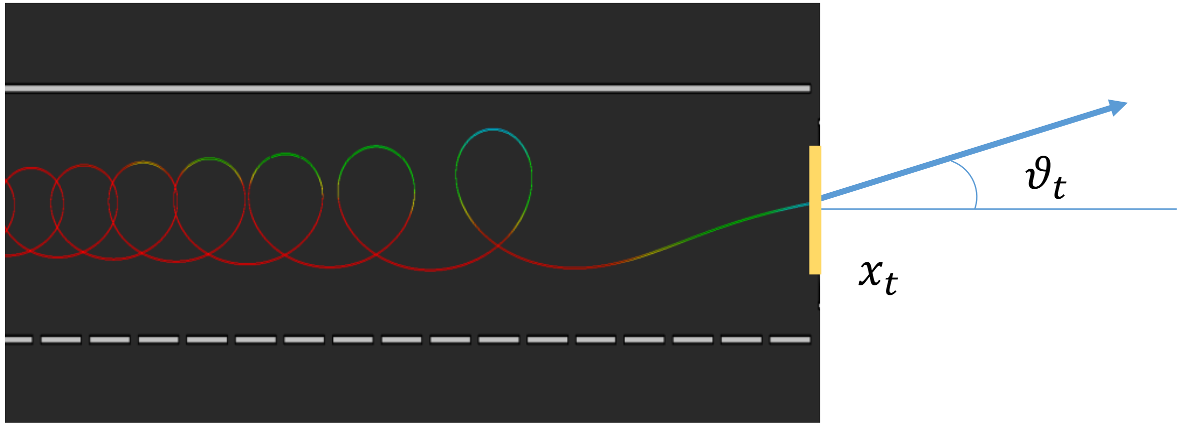
Micro Channel Plate





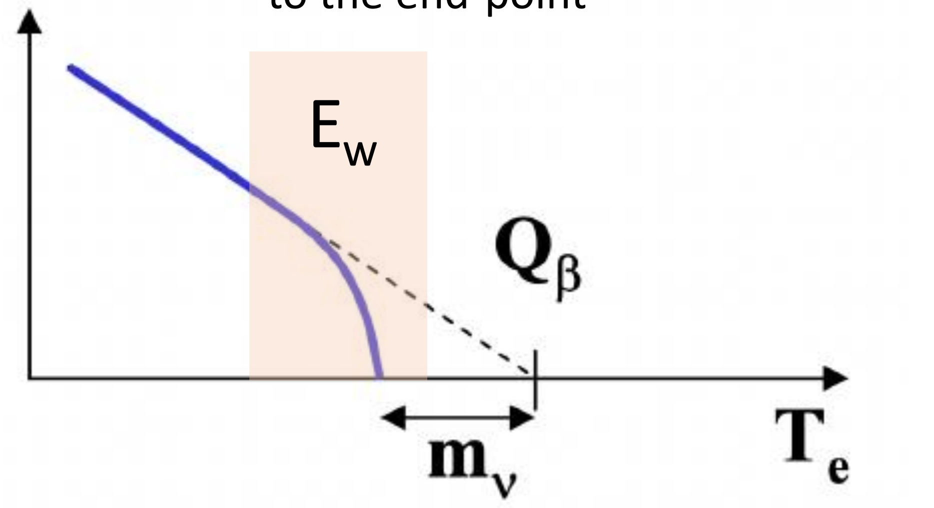


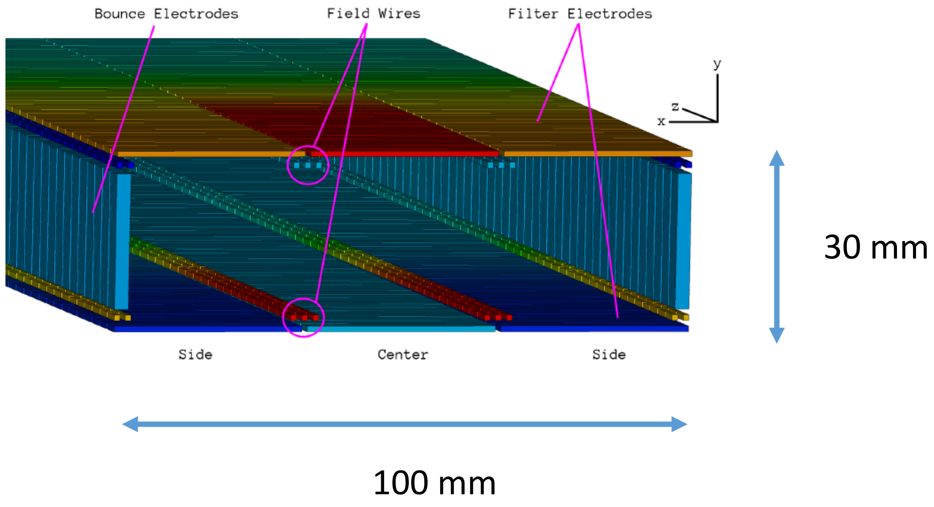
The Ptolemy exercise: input parameters



Ptolemy e.m. filter

Energy region close to the end-point





resolution requested	50 meV
kinetic energy at the exit point of e.m. filter	10 eV
dimension of electron beam at the exit of e.m. filter	(??)
Energy region (E_w) close to the end-point	10 eV

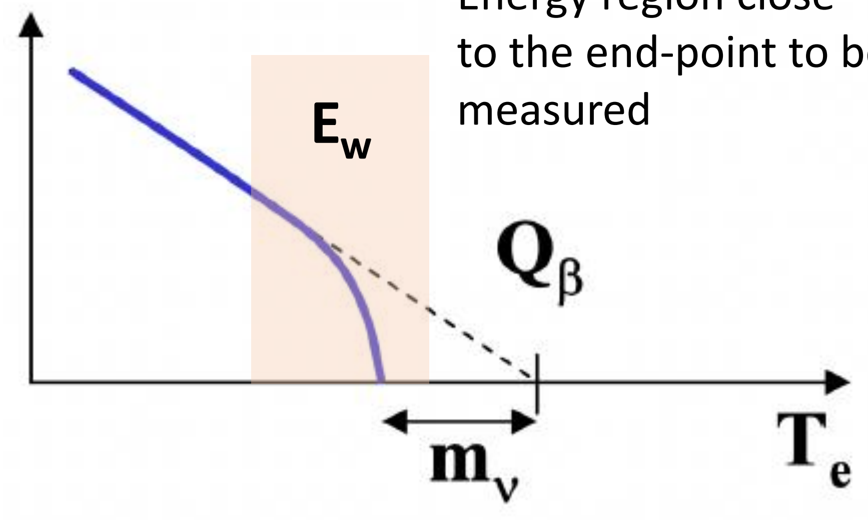
The Ptolemy exercise: the hemisphere project

E_w = 10 eV parallel acquisition: E_w = 10% E_p → E_p= 100 eV

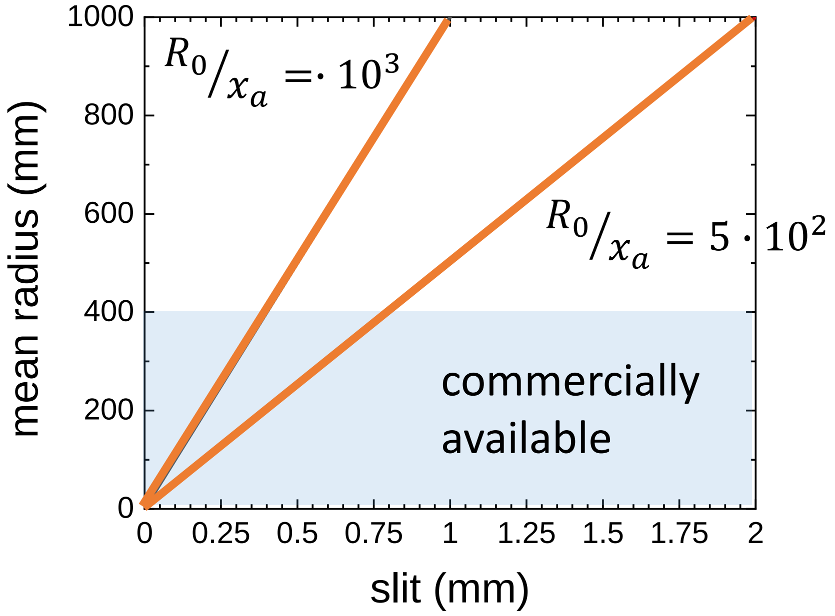
$$\Delta E = E_p \frac{x_a}{2R_0} \rightarrow \frac{0.05}{100} = \frac{x_a}{2R_0} \rightarrow R_0/x_a = 10^3$$

E_w = 5 eV parallel acquisition: E_w = 10% E_p → E_p= 50 eV

$$\Delta E = E_p \frac{x_a}{2R_0} \rightarrow \frac{0.05}{50} = \frac{x_a}{2R_0} \rightarrow R_0/x_a = 5 \cdot 10^2$$



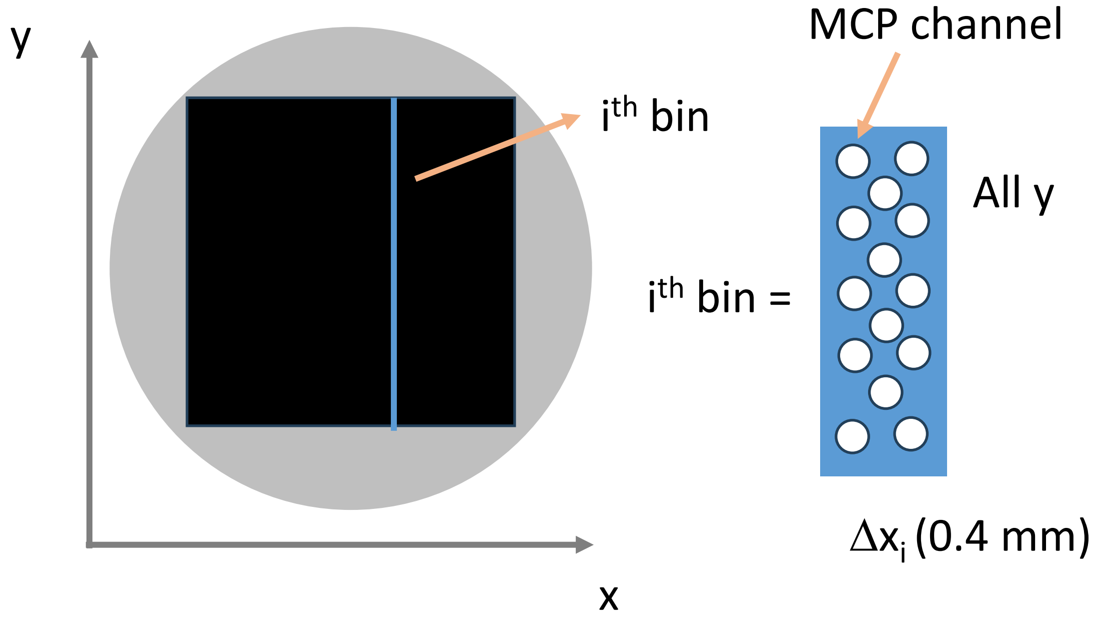
Energy region close to the end-point to be measured



E_w(eV)	E_p(eV)	ΔE (meV)	R_0(mm)	x_a(mm)
10	100	50	250	0.25
10	100	100	250	0.5
5	50	50	250	0.5
5	50	100	250	1

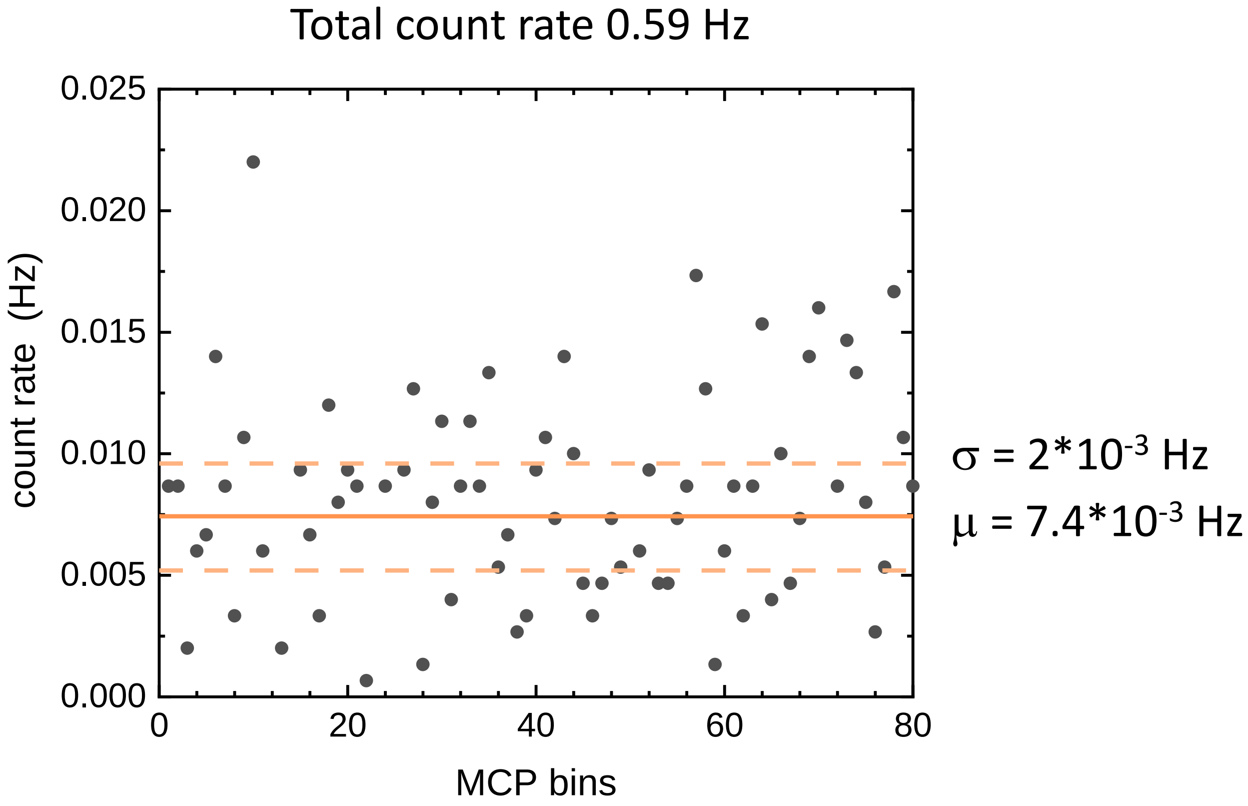
Dark noise from MCP in the electron analyser at LASEC

Model	Hamamatsu F1217-01
Dimension (Ø)	50 mm
Channel diameter	12 μm
Channel pitch	15 μm
Bias angle	8°

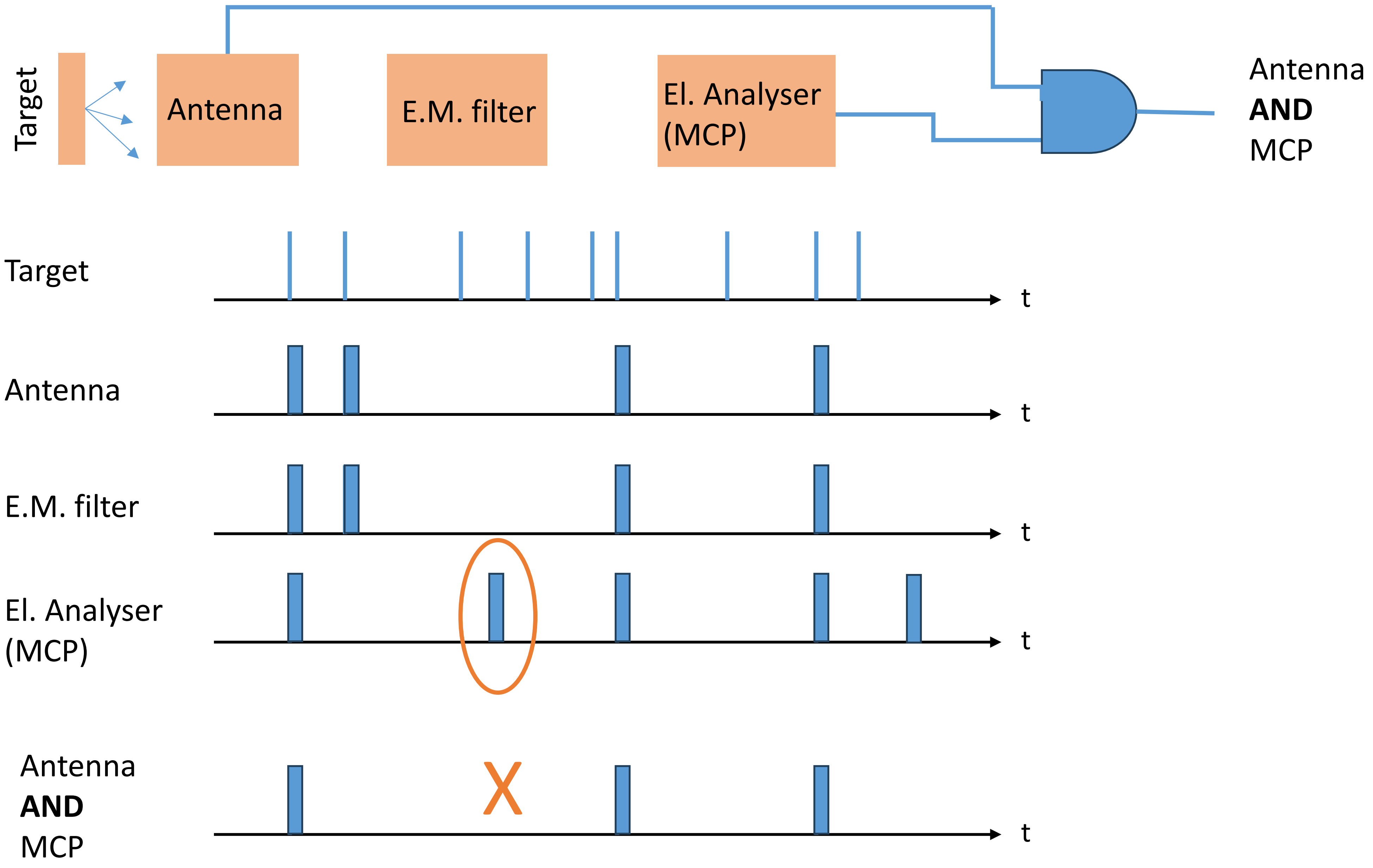


x: energy dispersion direction
y: integrated along this direction

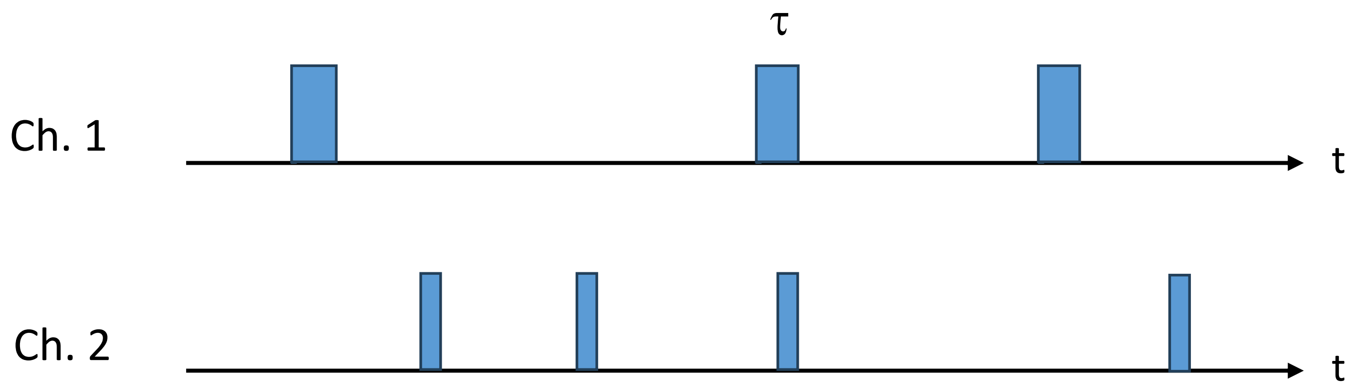
Measured dark noise – total acquisition time 1500 s

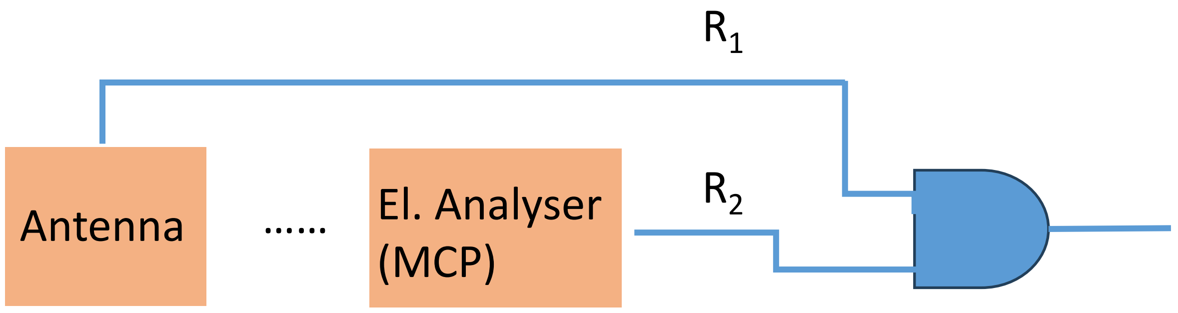


Dark noise from MCP can be electronically managed



Accidental coincidence is not an issue





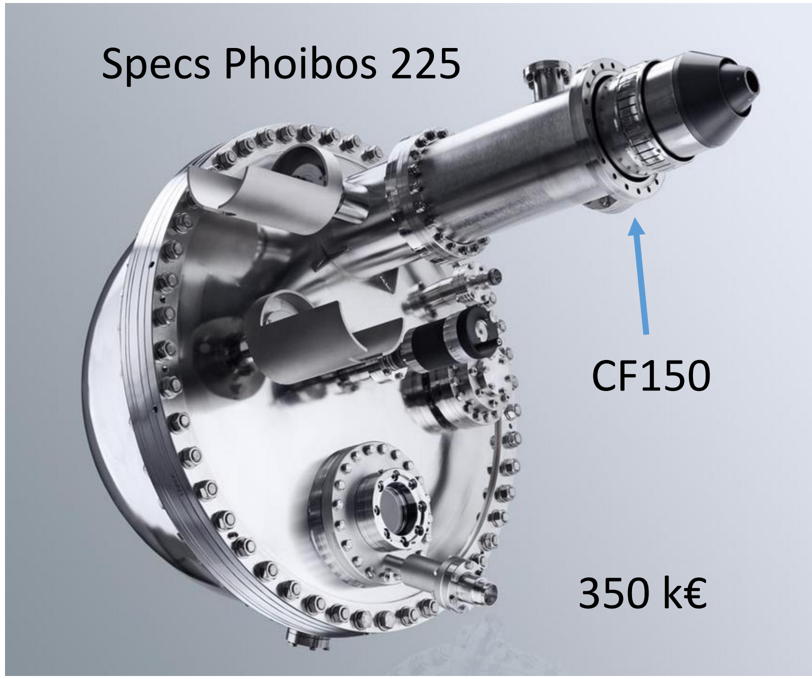
Rate of accidental coincidences at AND exit
(R_1 and R_2 are the rates in the single channels)

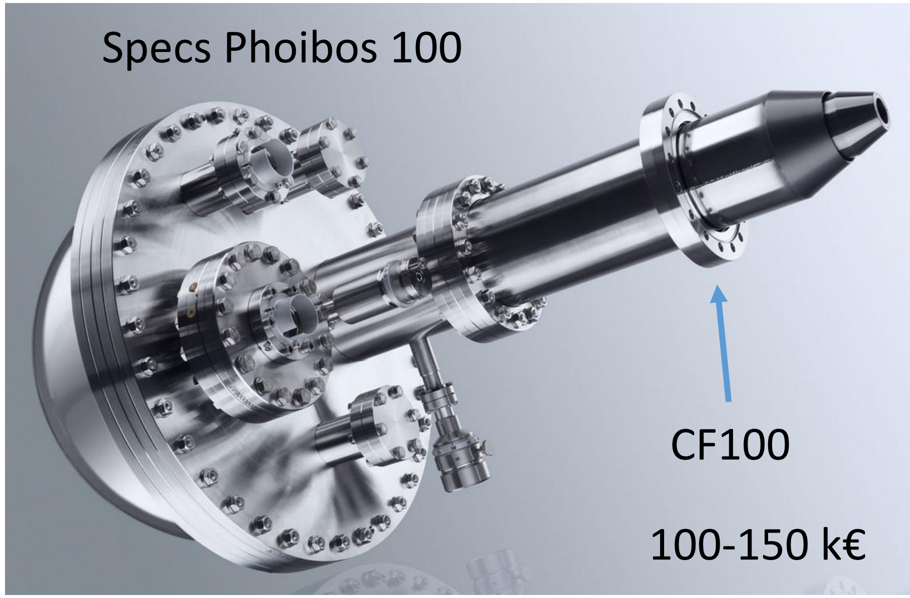
$$R_A = R_1 R_2 \tau$$

Can be accidental coincidences an issue?
with this number, no

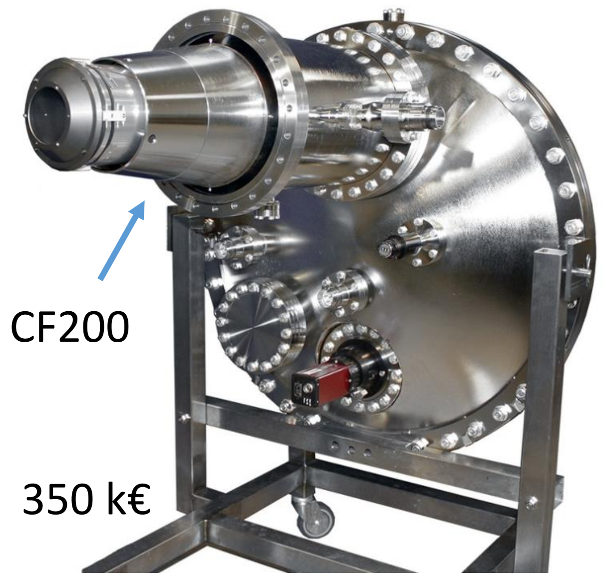
$R_1 = 30$ Hz/mg Trizio (4 m^2); $R_2 = 0.6$ Hz; $\tau = 10^{-6}$ s → $R_A = 2*10^{-5}$ Hz/mg T

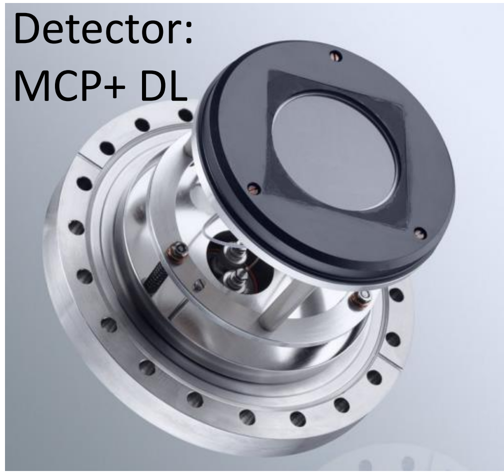
Commercial Electron analysers





Omicron EW-4000

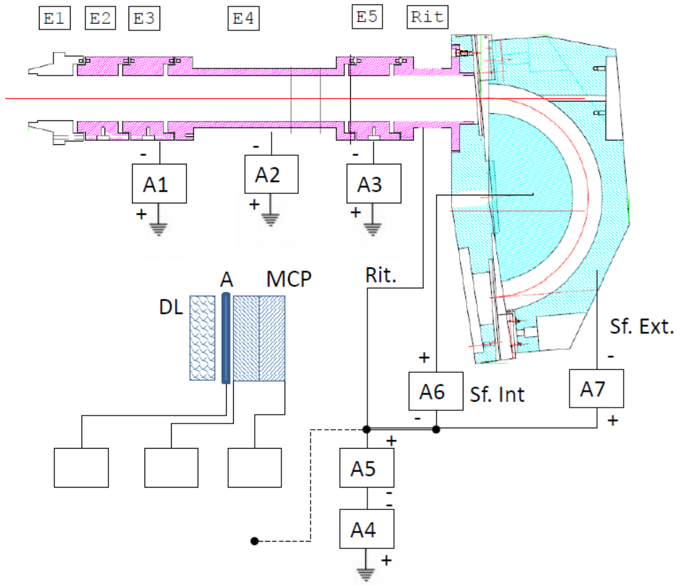




	Phoibos 225	Phoibos 100	EW-4000
Mean radius (mm)	225	100	200
Detector type	2D DLD	2D DLD	2D DLD
Pass energy (eV)	Up to 500	Up to 500	Up to 500
Energy window	9% of P.E.	20% of P.E.	
Resolution	< 1meV	< 3 meV	< 2 meV
Acceptance angle	±15°	±15°	±30°

Custom Electron analyser: the Lasec experience

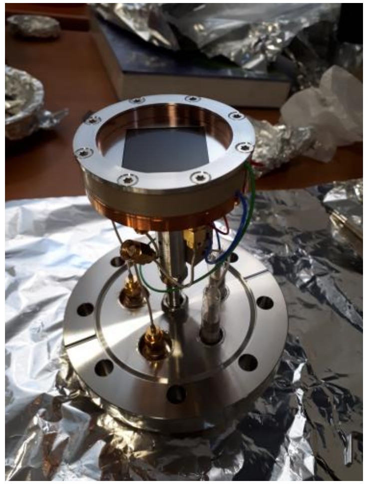
Electron analyser



acceptangle angle= ±1°
R_0 = 66 mm

Power supply

2D-detector + electronics

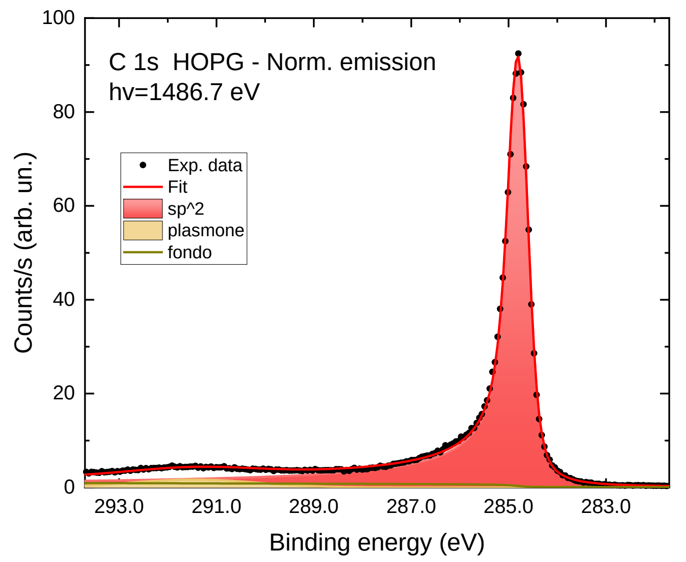


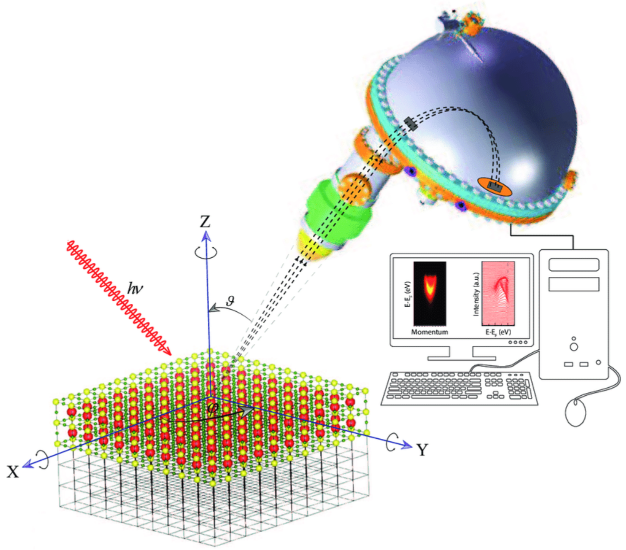
Mechanical	20 k€
Power supply (10 ch)	30 k€
2D detector	40 k€
Accessory	10 k€
Personnel	15 k€
	115 k€

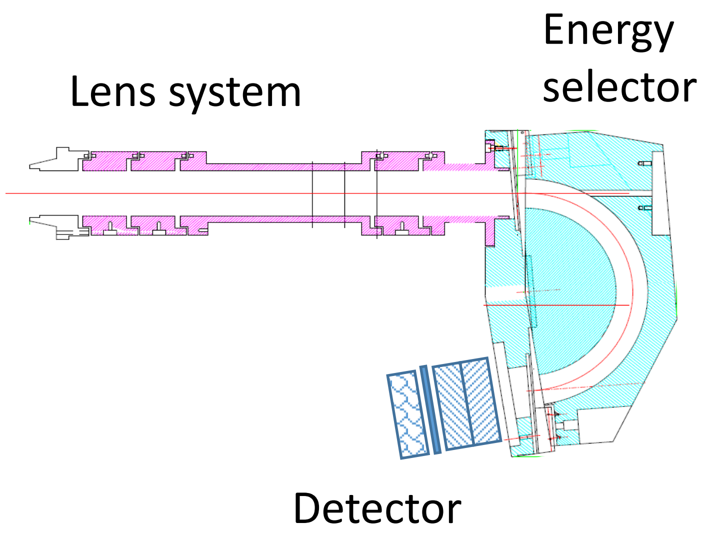
Conclusions

- It seems possible to use an **electron analyser** at the end of the e.m. filter
- Dark noise from the MCP seems manageable
- Technology already **available**
- It works at **room temperature**
- High flexibility even at fixed applied potential
- Fundamental requirement:
  - the **exact dimension** of e-beam at the e.m. exit
  - compensation of any magnetic field in the detection region

Electrostatic Electron Analyser





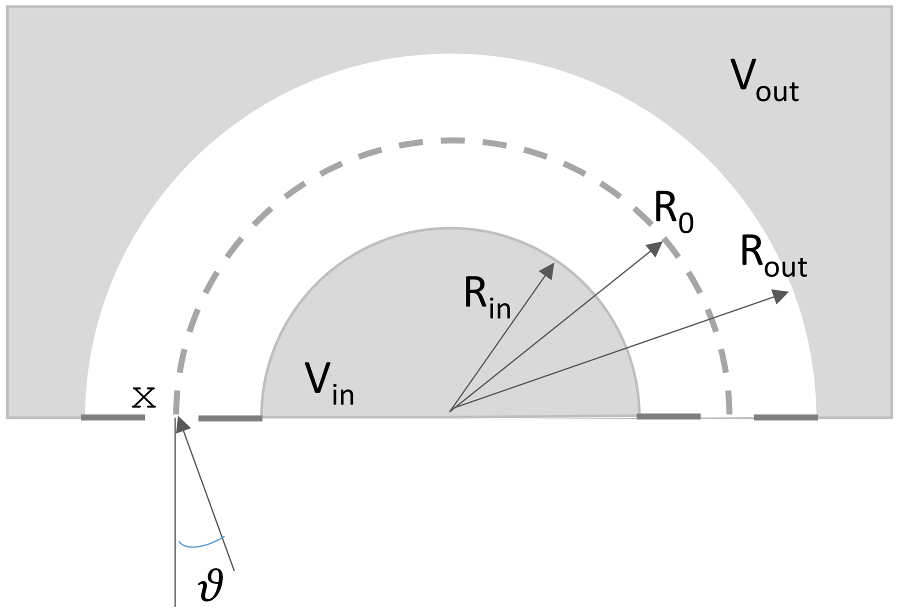


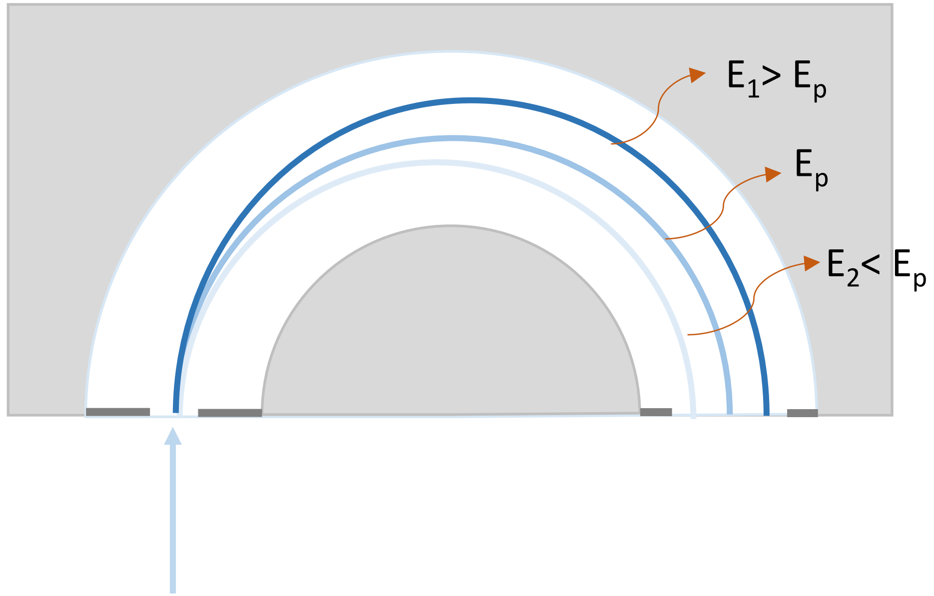
- standard in photoemission spectroscopy

An electron analyser is made of three parts:

- Lens system: collect a specific solid angle, (de)accelerate e^-
- Energy selector (pass band filter)
- Detector (single or multichannel)

Two concentric hemispheres for the energy selection





- Analytical solution of the trajectory
- Electron with kinetic energy **Ep** travel along the central orbit
- select a band of energy around E_p

Applied potential to hemispheres

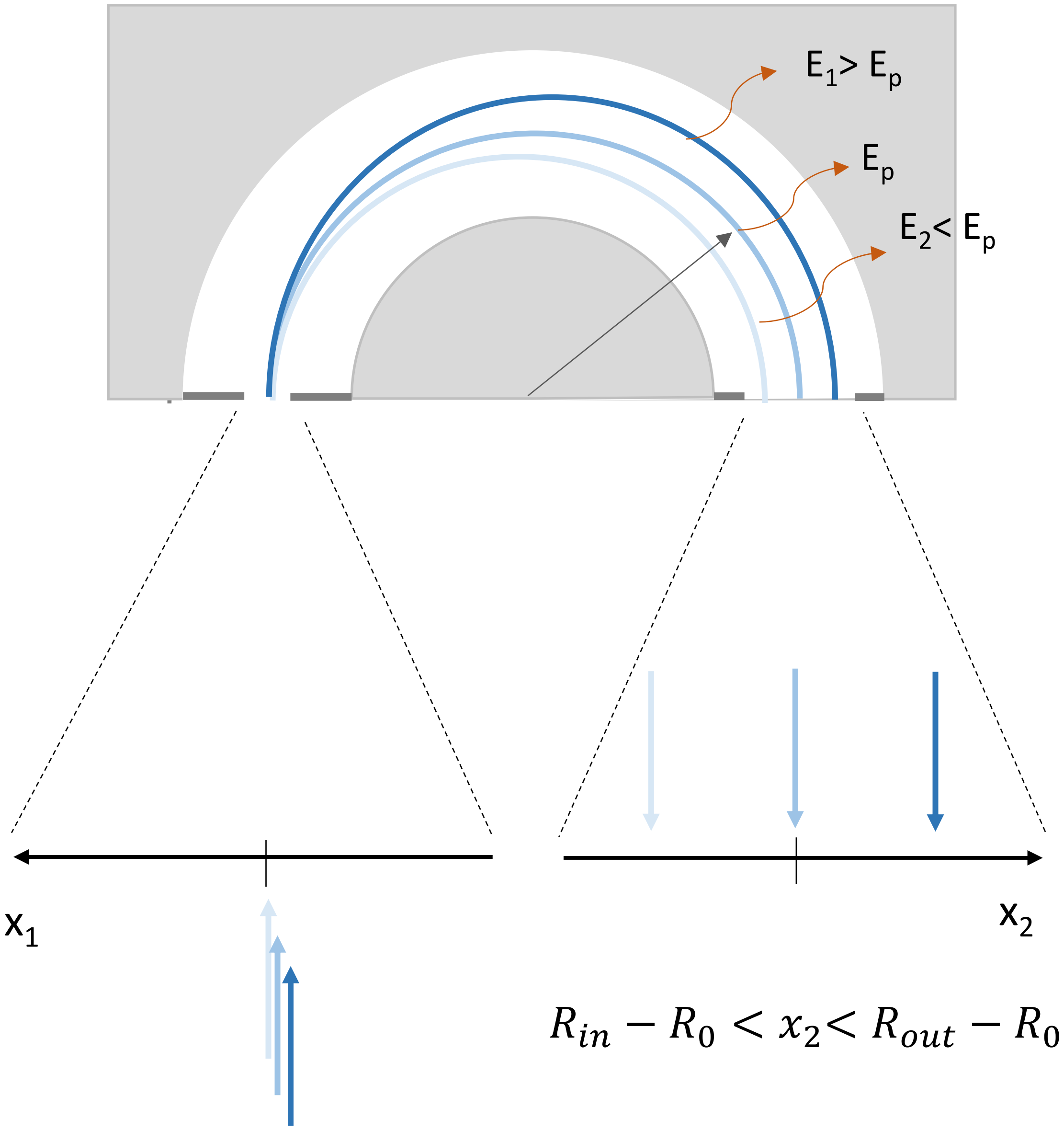
$$V_{in} = 2E_p\left(\frac{R_0}{R_{in}} - 1\right) > 0 \qquad V_{out} = 2E_p\left(\frac{R_0}{R_{out}} - 1\right) < 0$$

Energy resolution
(bandpass energy)

$$\frac{\Delta E}{E_p} = \frac{x}{2R_0} + \frac{\vartheta^2}{4}$$

ΔE: energy resolution
E_p : pass energy
x: slit width
R_0: mean radius
θ: accepted angle

Linear energy dispersion at exit slits



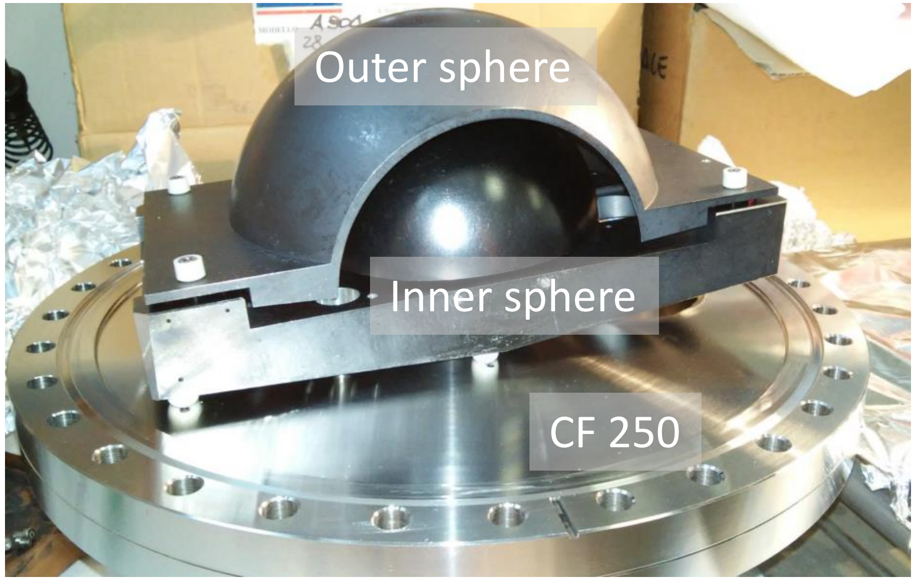
$$R_{in} - R_0 < x_2 < R_{out} - R_0$$

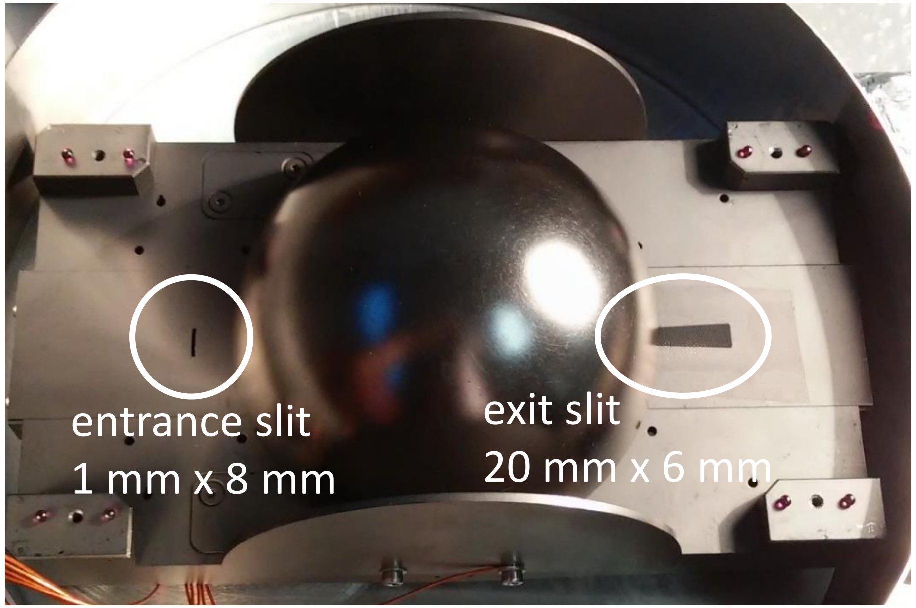
$$\frac{x_2}{R_0} = 2\left(\frac{E - E_p}{E_p}\right) - \left(\frac{x_1}{R_0}\right) - 2\vartheta^2$$

- $\mathbf{x_2}$ position at the **exit** slit as a function of:
  - $\mathbf{x_1}$ position at **entrance** slit
  - **E** kinetic energy of incoming electron
  - **θ** incidence angle at entrance slit

- linear energy dispersion at the exit slits
- entrance angle and position give a minor contribution with respect to the electron energy

The analyser at LASEC (Roma Tre)





Example: Analyser at Lasec, Roma Tre

$$R_{in} = 56.1\ mm$$
$$R_0 = 66\ mm$$
$$R_{out} = 75.9\ mm$$

$$-9.9\ mm < x_2 < 9.9\ \mathrm{mm}$$

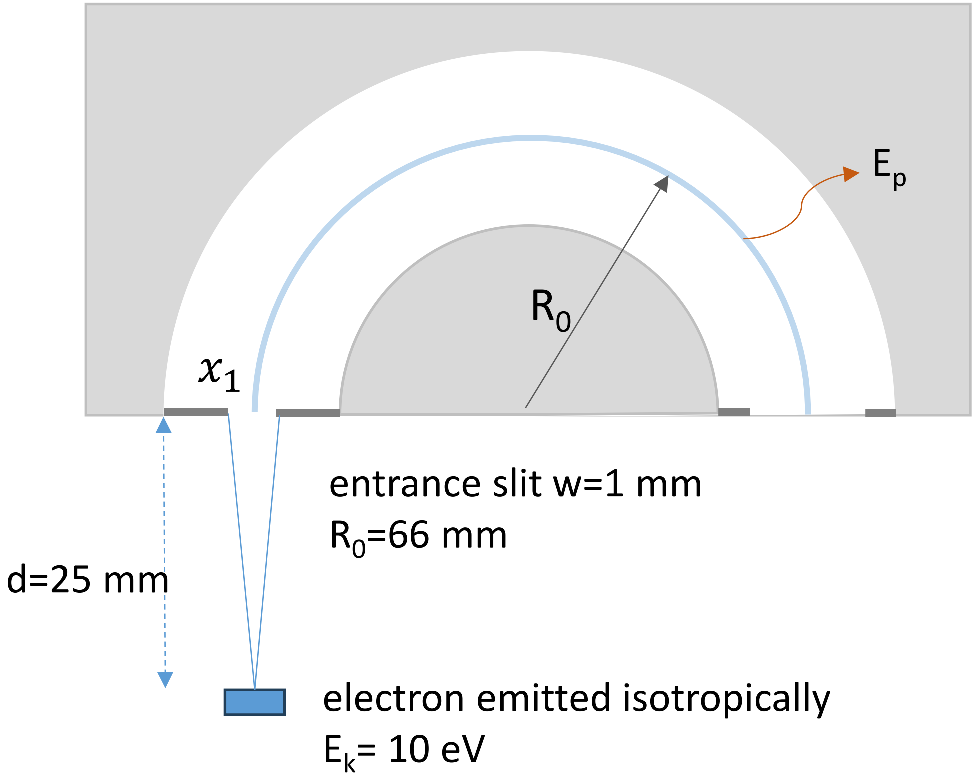
$$\frac{x_2}{R_0} = 2\left(\frac{E - E_p}{E_p}\right)$$

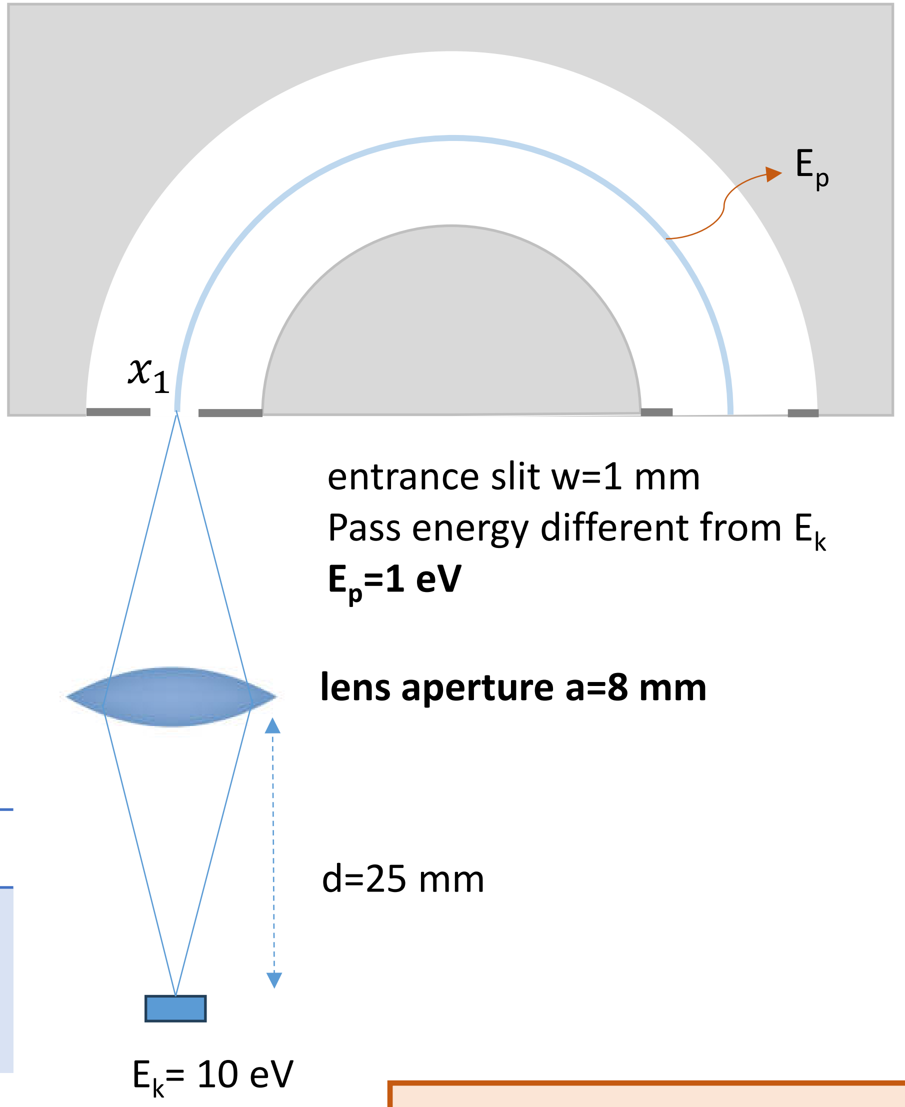
$$E_p - 7.5\%E_p < E < E_p + 7.5\%E_p$$

To avoid aberration, parallel acquisition 10% of E_p

$$E_p - 5\%E_p < E < E_p + 5\%E_p$$

Electrostatic lenses increase flux and resolution

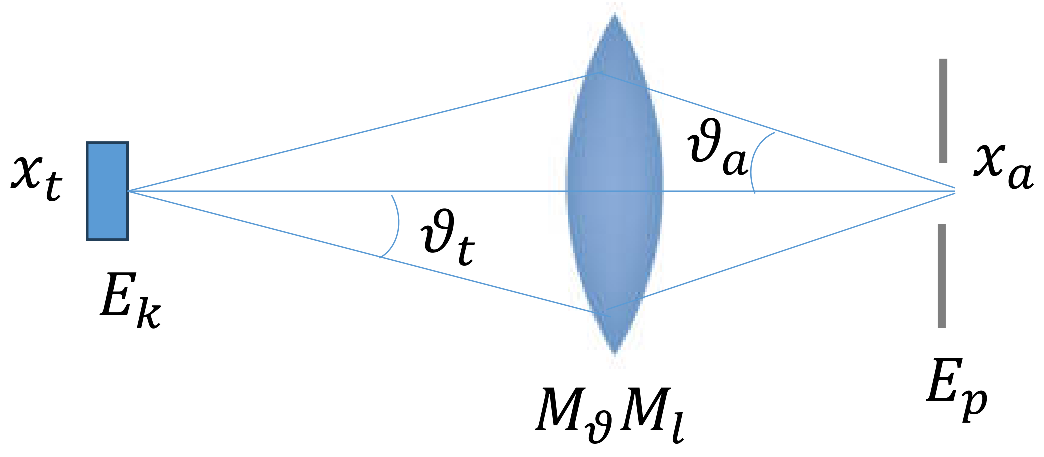




	Without Lens	With lens
Resolution $\Delta E = E_p \frac{x_1}{2R_0}$	$76\ meV$	$7.6\ meV$ 10 times better!!
Flux $\phi \propto \Omega = \left({}^{x_1}/_{2d}\right)^2 \pi$	$1.8 * 10^{-4} sr$	$1.2 * 10^{-2} sr$ 64 times bigger!!

- Focussing
- Freedom to choose the pass energy

Intrinsic characteristic of electrostatic lenses



Helmholtz – Lagrange (HL) law

$$x_t \vartheta_t \sqrt{E_k} = x_a \vartheta_a \sqrt{E_p}$$

By defining the angular and linear magnification

$$M_\alpha = \frac{\vartheta_a}{\vartheta_t} \qquad M_l = \frac{x_a}{x_t}$$

$$\sqrt{R} = \sqrt{\frac{E_k}{E_p}} = M_\vartheta M_l$$

- Angular and linear (de)magnification are correlated
- Source and hemisphere entrance slit must satisfy the HL law

The Ptolemy exercise: the electrostatic lenses

Helmholtz – Lagrange (HL) law

$$x_t \vartheta_t \sqrt{E_k} = x_a \vartheta_a \sqrt{E_p}$$

Energy at end of e.m. filter

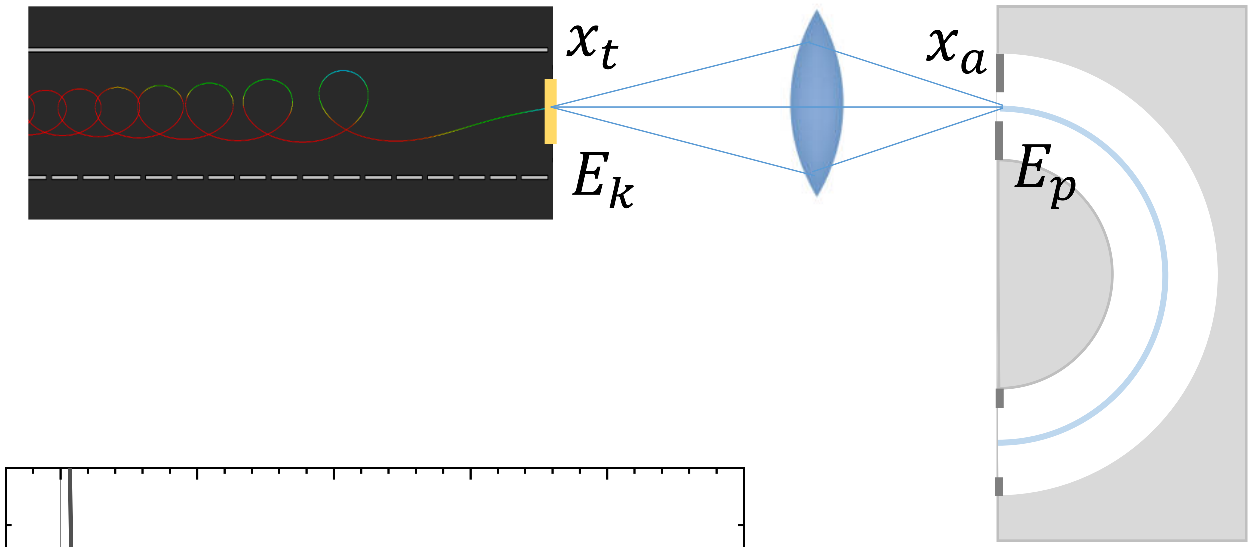
E_k= 5 eV

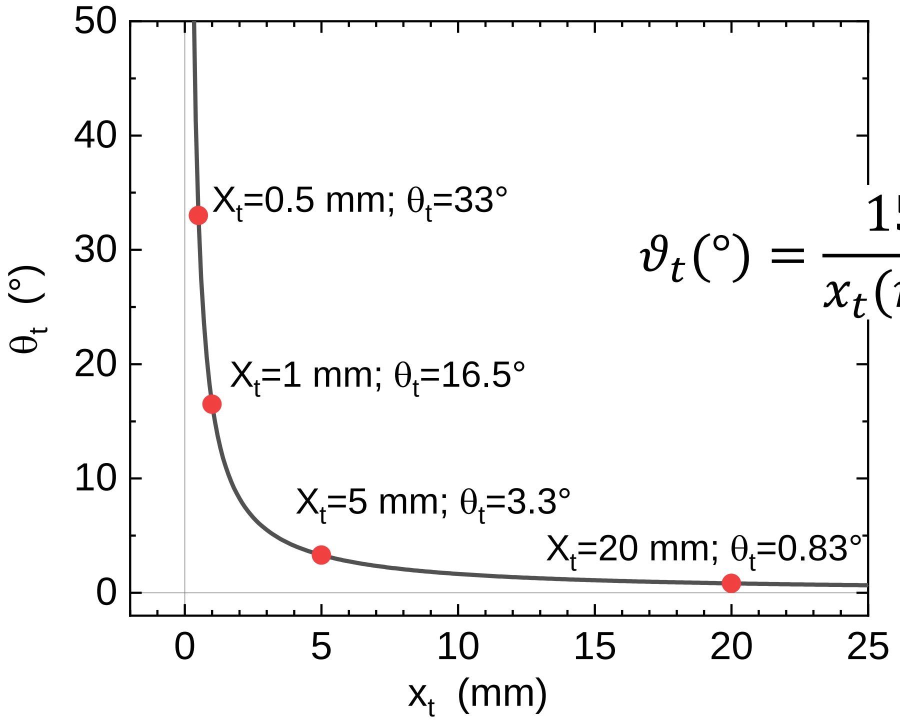
From hemisphere exercise

E_p= 50 eV $\quad x_a = 1\,mm \quad \vartheta_a = 5°$

$$M_\alpha = \frac{\vartheta_a}{\vartheta_t} \qquad M_l = \frac{x_a}{x_t}$$

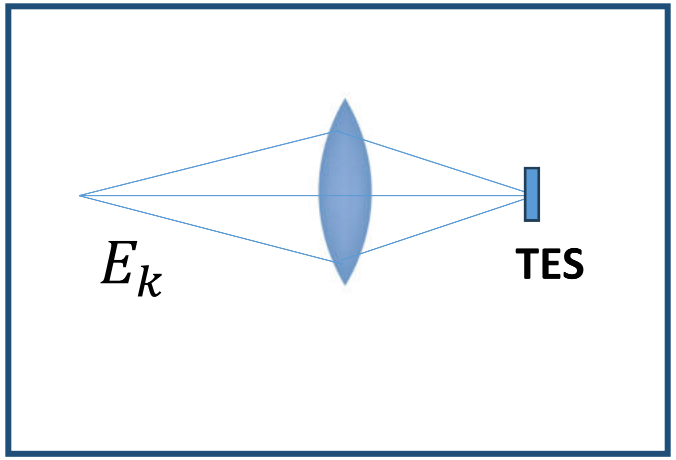
$$\sqrt{\frac{E_k}{E_p}} = 0.32 = M_\alpha M_l$$

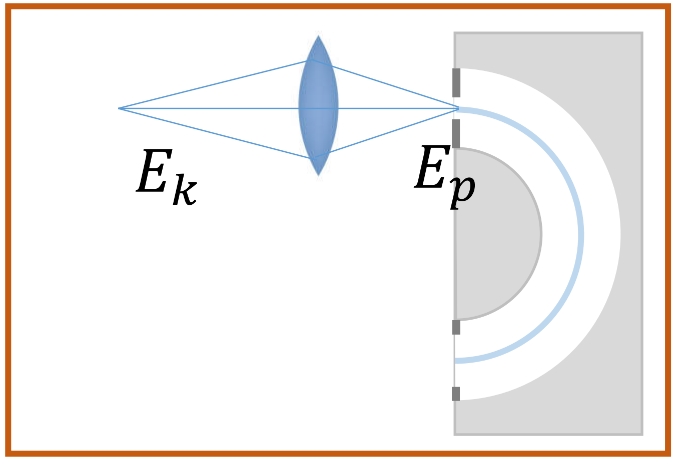




$$\vartheta_t(°) = \frac{15.6}{x_t(mm)}$$

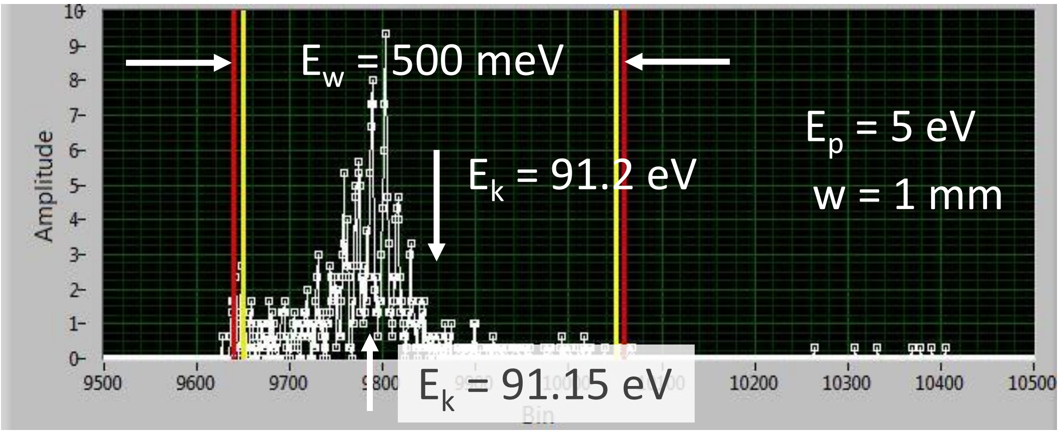
TES and Electron Analyser comparison

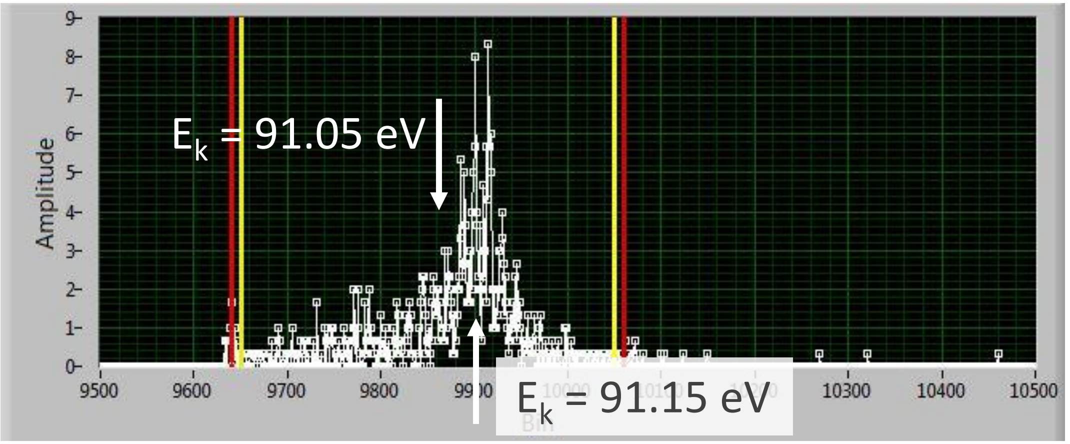


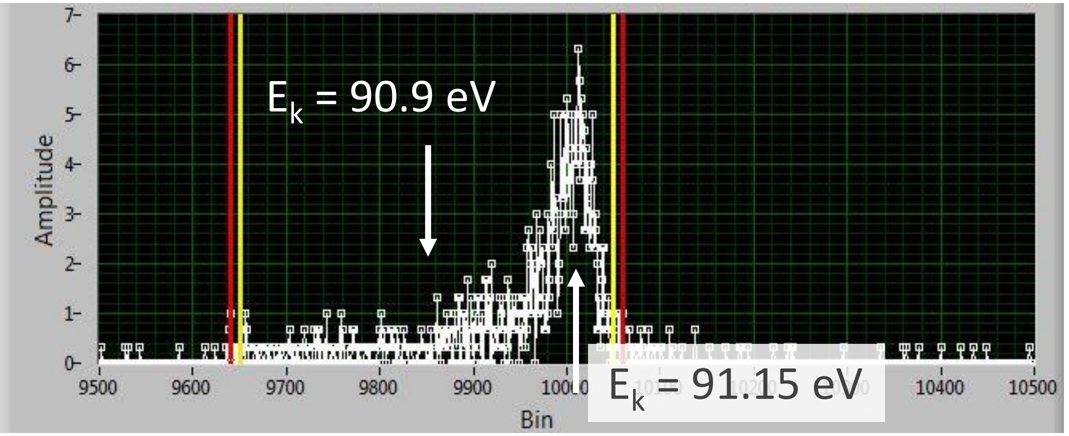


	TES	2000 x TES	Electron An.
Magnetic field	< 5 mG	< 5 mG	< 5 mG
Operating temperature	Cryogenic	Cryogenic	T ambient
Surface stability vs time	Stable (Au) ?	Stable (Au) ?	Stable (graphite)
Size	50 μm x 50 μm	1 mm x 5 mm	1 mm x 8 mm
Max rate	1 kHz	2 MHz	2 MHz

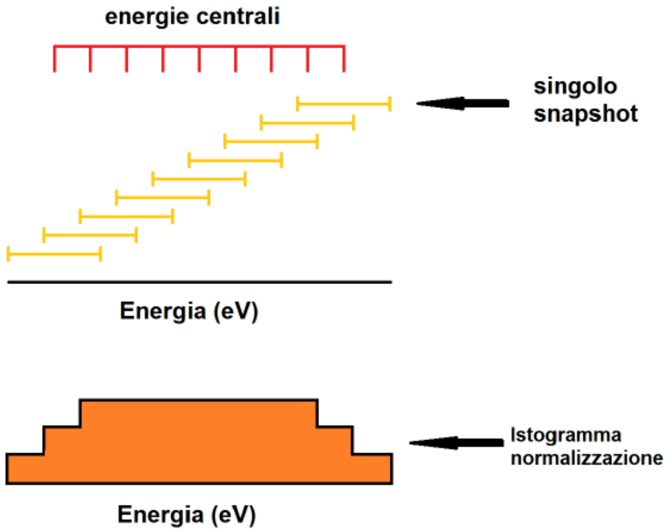
How to build an energy scan with a PSD

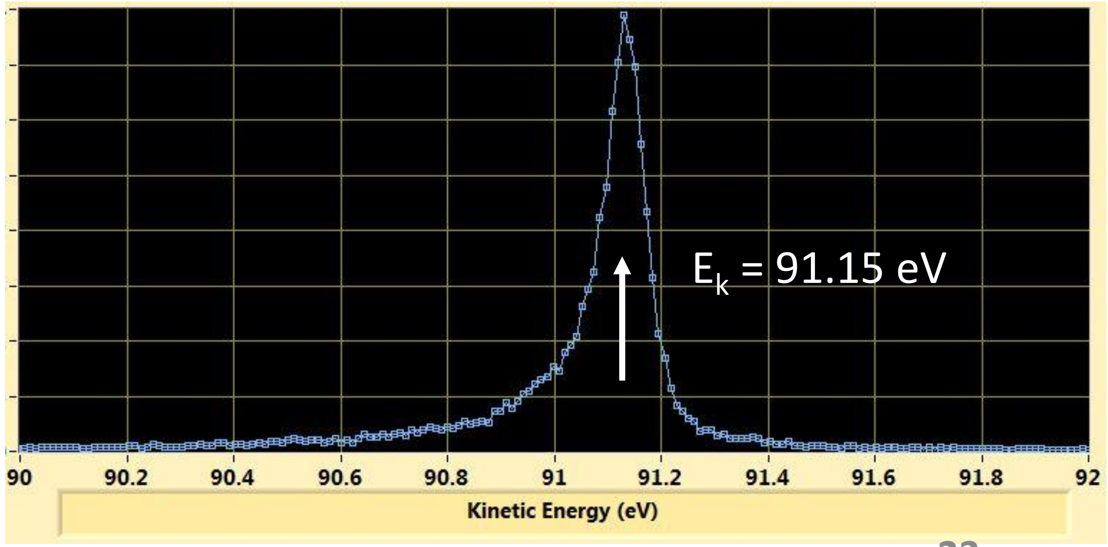


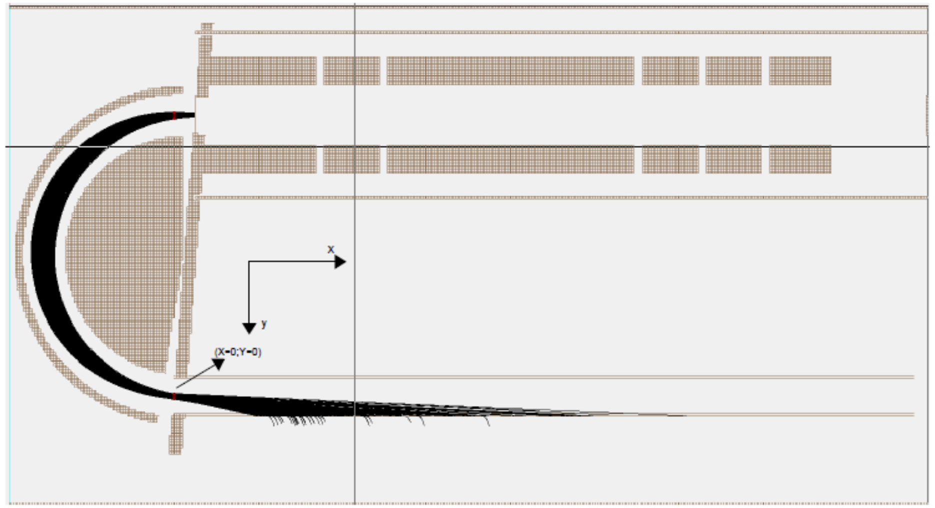


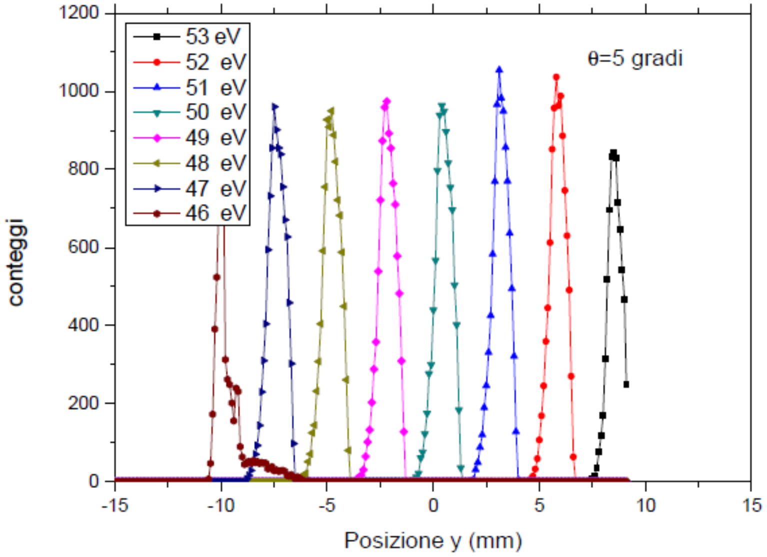


- measuring the elastic peak (Ek = 91.15 eV) with PSD

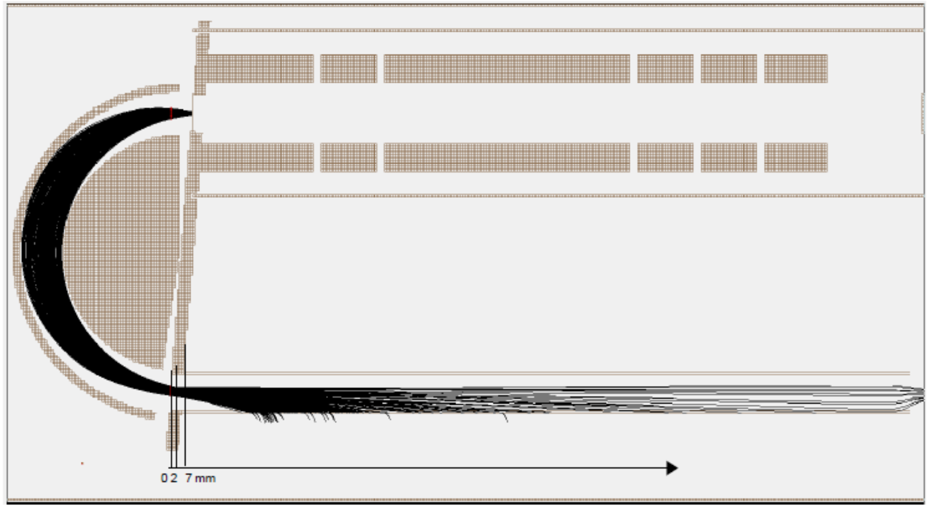


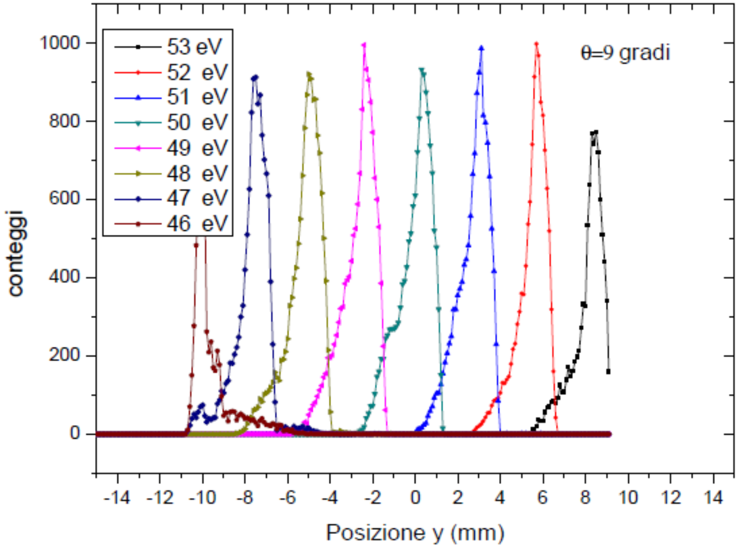


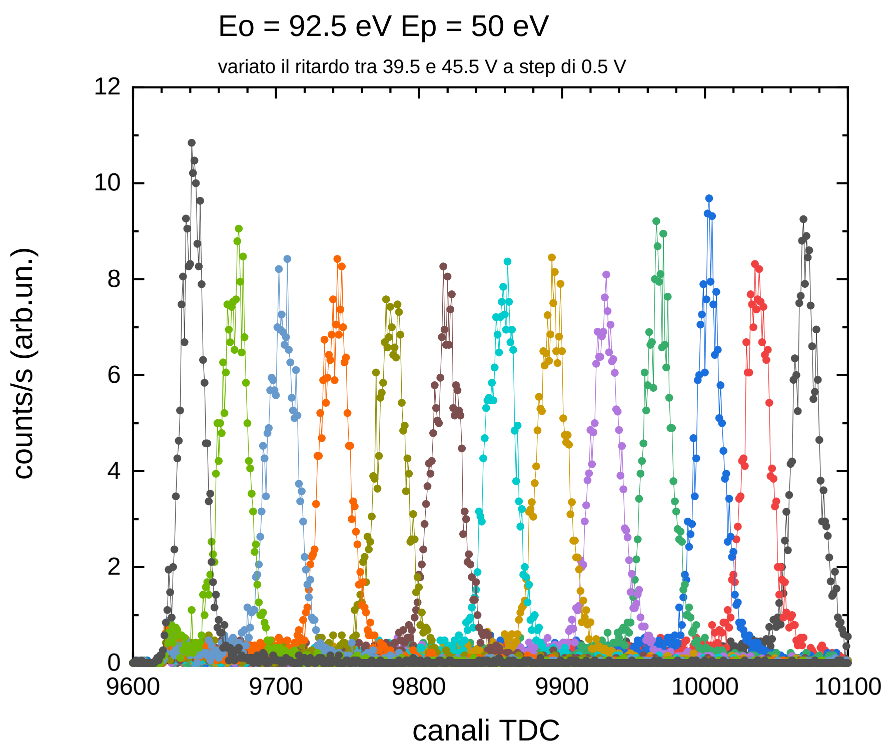

x
y
(X=0;Y=0)

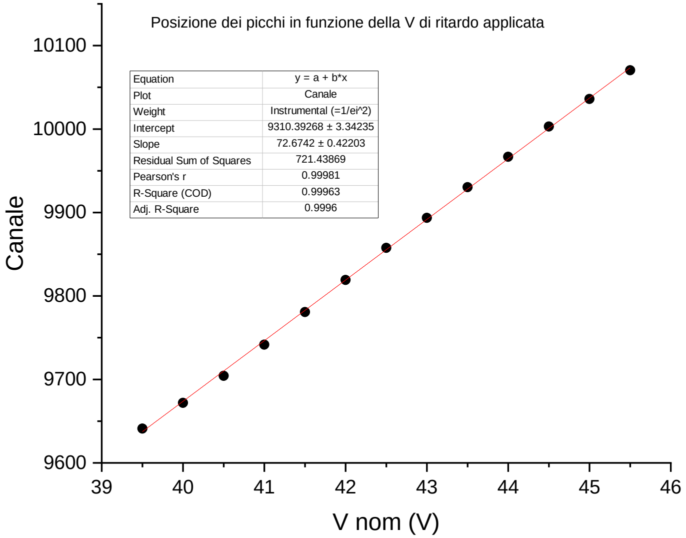


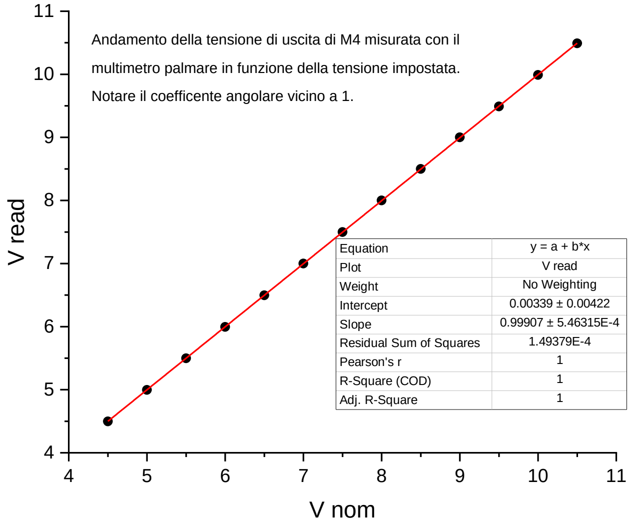
1200
1000
800
600
400
200
0
conteggi
-15
-10
-5
0
5
10
15
Posizione y (mm)
53 eV
52 eV
51 eV
50 eV
49 eV
48 eV
47 eV
46 eV
θ=5 gradi


0 2 7 mm


1000
800
600
400
200
0
conteggi
-14
-12
-10
-8
-6
-4
-2
0
2
4
6
8
10
12
14
Posizione y (mm)
53 eV
52 eV
51 eV
50 eV
49 eV
48 eV
47 eV
46 eV
θ=9 gradi







Dal fit della posizione dei picchi si trova che il fattore di conversione è a Ep = 50 eV   72.67 ± 0.42 ovvero **3633 ± 21** a Ep = 1 eV