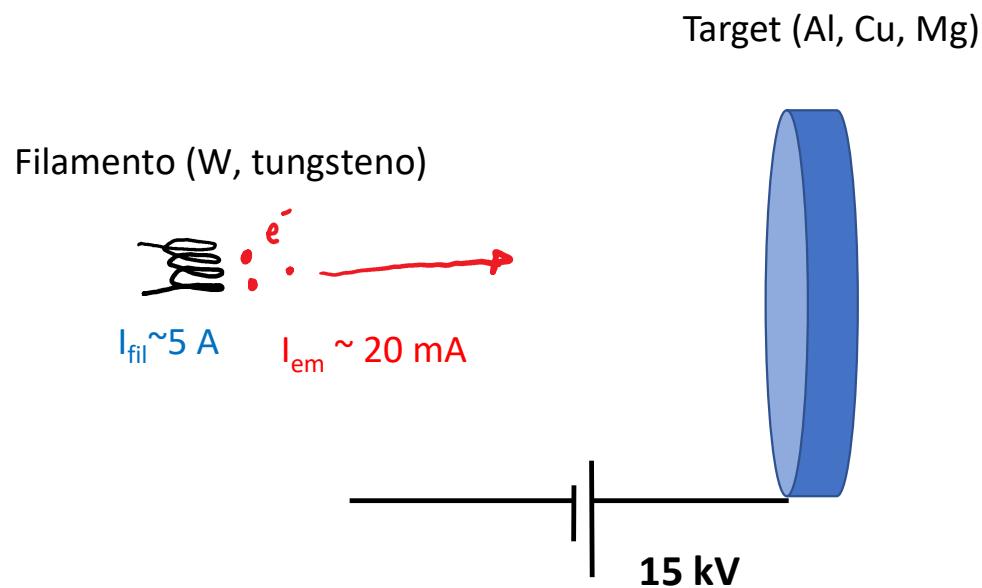
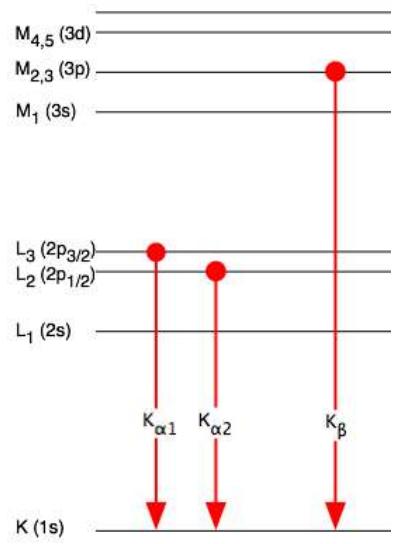


Sorgente X di laboratorio





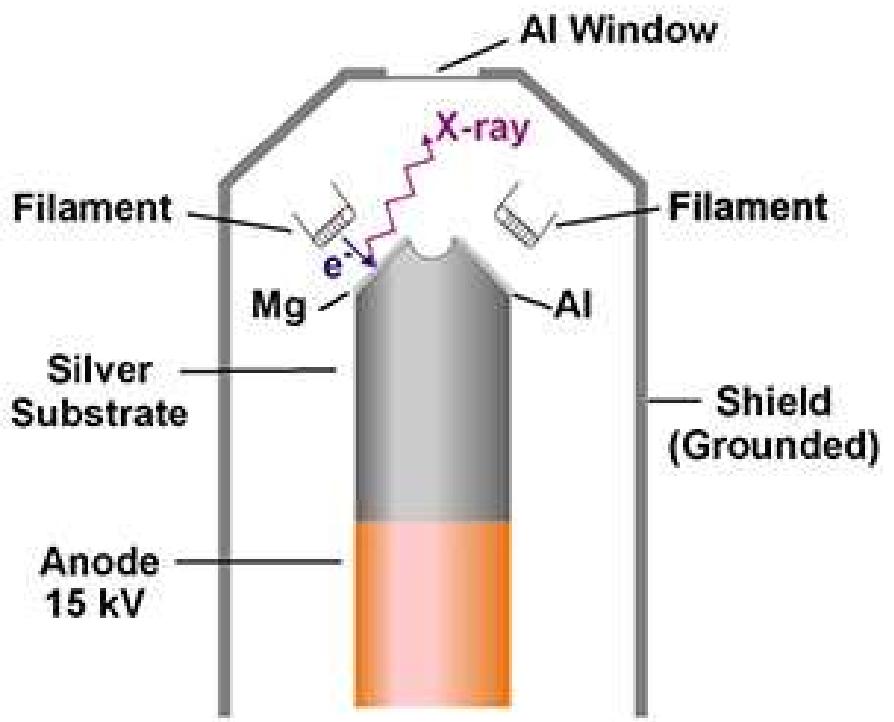
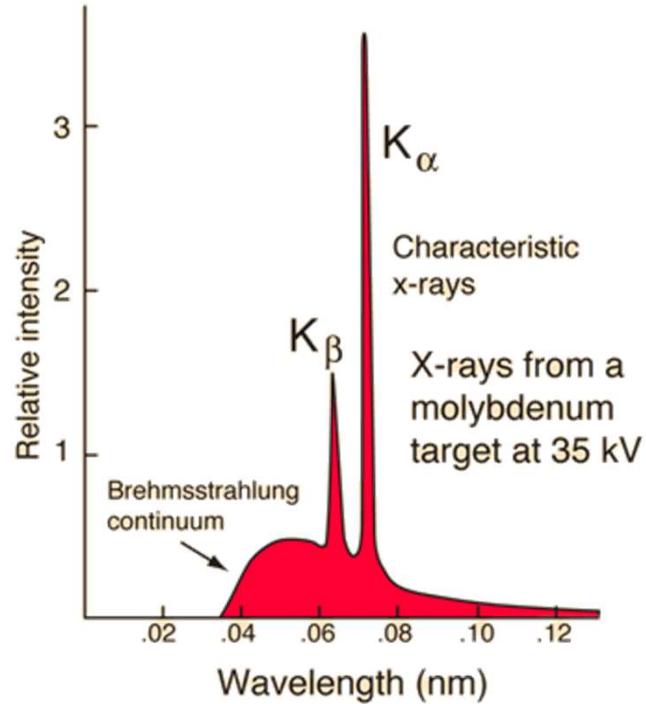


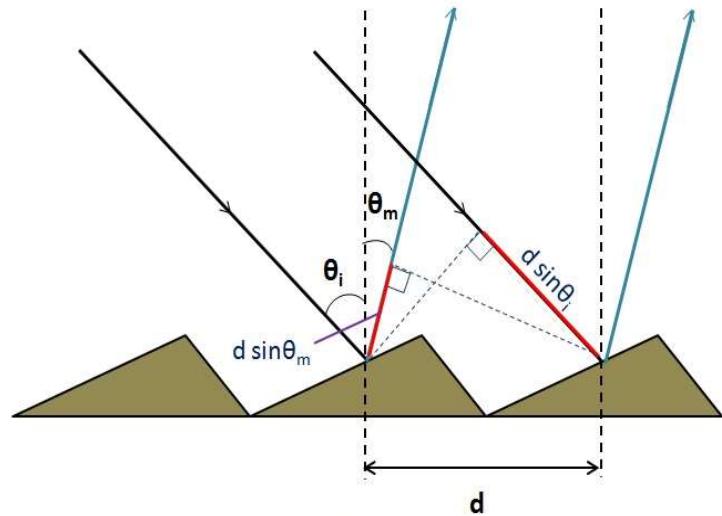
Table I-3. Energies and intensities of x-ray emission lines (continued).

Energy (eV)	Element	Line	Relative intensity	1,462	69 Tm	M α_1	100	1,740.0	14 Si	K α_1	100
				1,480.4	35 Br	L $\alpha_{1,2}$	111	1,752.2	37 Rb	L β_1	58
1,131	63 Eu	M α_1	100	1,482.4	37 Rb	Ll	5	1,775.4	74 W	M α_1	100
1,185	64 Gd	M α_1	100	1,486.3	13 Al	K α_2	50	1,792.0	40 Zr	Ll	5
1,188.0	32 Ge	L $\alpha_{1,2}$	111	1,486.7	13 Al	K α_1	100	1,804.7	38 Sr	L α_2	11
1,204.4	34 Se	Ll	6	1,521.4	70 Yb	M α_1	100	1,806.6	38 Sr	L α_1	100
1,218.5	32 Ge	L β_1	60	1,525.9	35 Br	L β_1	59	1,835.9	14 Si	K β_1	2
1,240	65 Tb	M α_1	100	1,557.4	13 Al	K β_1	1	1,842.5	75 Re	M α_1	100
1,253.6	12 Mg	K $\alpha_{1,2}$	150	1,581.3	71 Lu	M α_1	100	1,871.7	38 Sr	L β_1	58
1,282.0	33 As	L $\alpha_{1,2}$	111	1,582.2	38 Sr	Ll	5	1,902.2	41 Nb	Ll	5

Reticolo di diffrazione

Ogni gradino del reticolo diventa una sorgente che riflette il fronte d'onda incidente. La differenza di cammino ottico tra il fascio riflesso da due gradini adiacenti è, dalla figura, $d(\sin\theta_m - \sin\theta_i)$. Per lunghezze d'onda tali che $n\lambda = d(\sin\theta_m - \sin\theta_i)$ avrà interferenza costruttiva nella direzione individuata da θ_m .

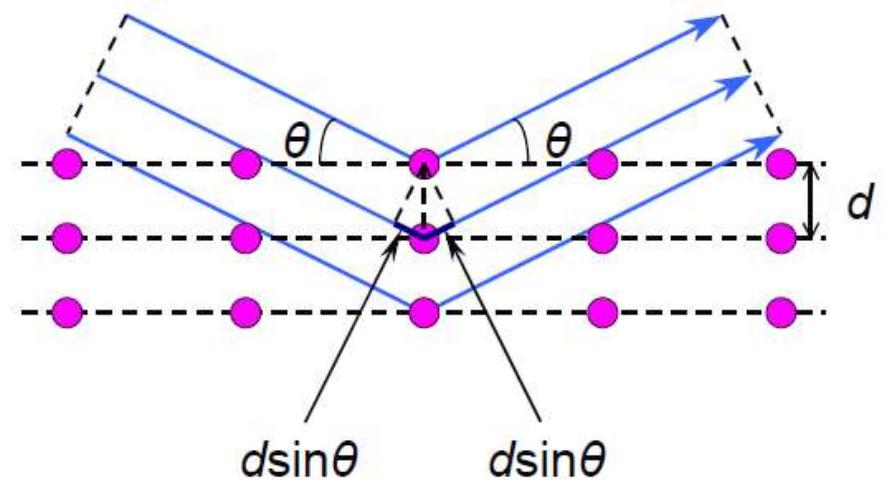
Questo sistema e' adatto a monocromatizzare luce nell'UV/soft X (fino ad energie di 1800-2000 eV).



Come monocromatizzare i raggi X?



Si utilizzano dei cristalli (ad esempio di Si, Ge...) e si sfrutta la diffrazione alla Bragg dai loro piani cristallini



$$2d(\text{\AA}) \sin(\theta) = n\lambda(\text{\AA}) = n \frac{12.4}{E(\text{keV})}$$

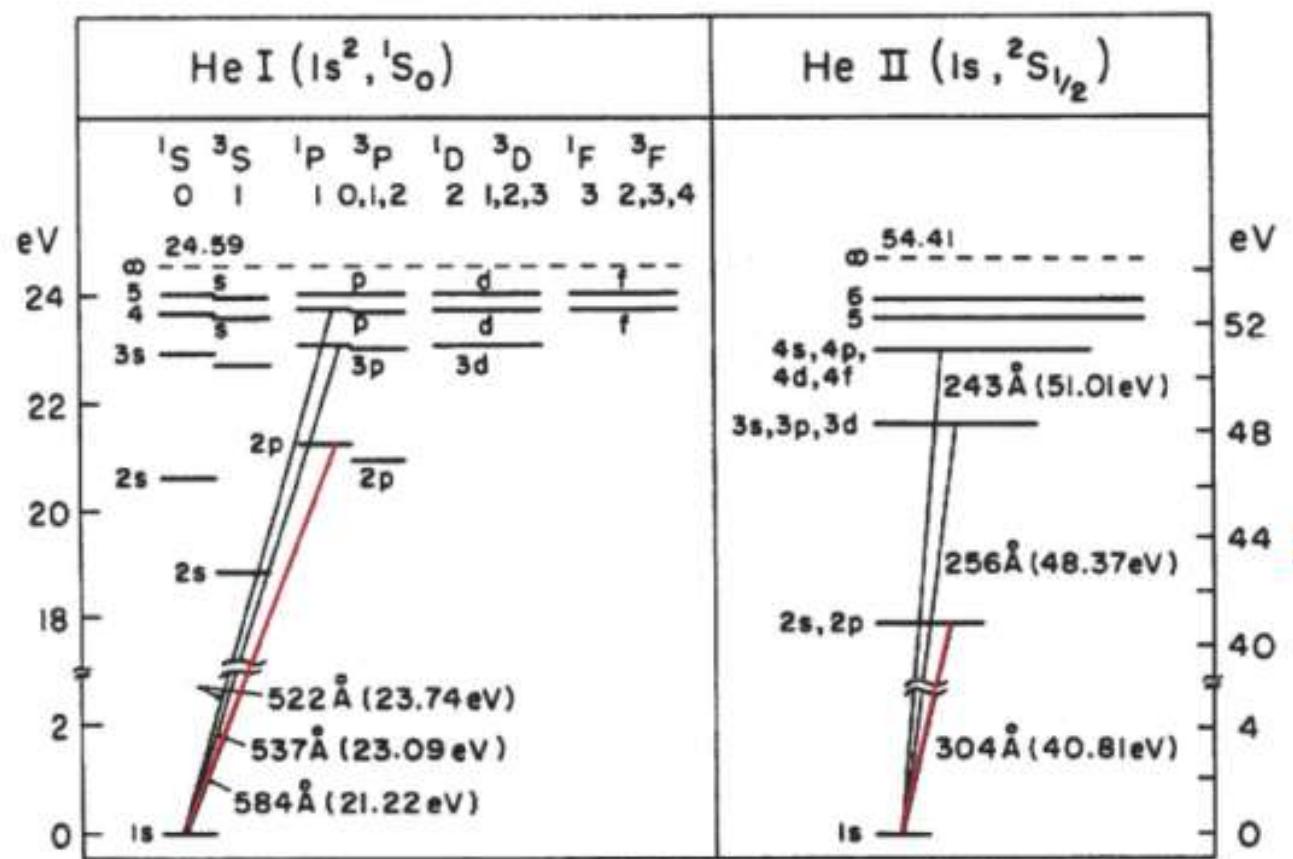
Crystal	Lithium fluoride		Quartz		Indium Antimonide		Silicon		Germanium		Pentaerythritol PET	Ammonium Dihydrogen Phosphate ADP
<hr/>												
Chemical Formula	LiF		SiO ₂		InSb		Si		Ge		C(CH ₂ OH) ₂	NH ₄ H ₂ PO ₄
Crystal system	Cubic		Hexagonal		Cubic		Cubic		Cubic		Quadratic	Quadratic
Parameters												
a.....Å...	4.027		4.913		6.48		5.431		5.658		6.16	7.530
b.....Å...			4.913								6.16	7.530
c.....Å...			5.405						8.74		8.74	7.542
β.....												
Reflecting planes orientations	(200)	(220)	(420)	(1011)	(1010)	(111)	(111)	(220)	(111)	(220)	(002)	(101)
2d in Å	4.027	2.848	1.801	6.684	8.514	7.480	6.271	3.840	6.532	4.000	8.740	10.648
Usual surface finish	Cleaved or Treated	Treated	Treated	Polished	Polished	Polished	Polished	Polished	Polished	Polished	Cleaved or Treated	Polished or Treated
Reflectivity	Intense	Intense	Average	Good	Good	Intense	Intense	Average	Intense	Intense	Intense	Average

<https://www.crystals.saint-gobain.com/products/x-ray-monochromators>

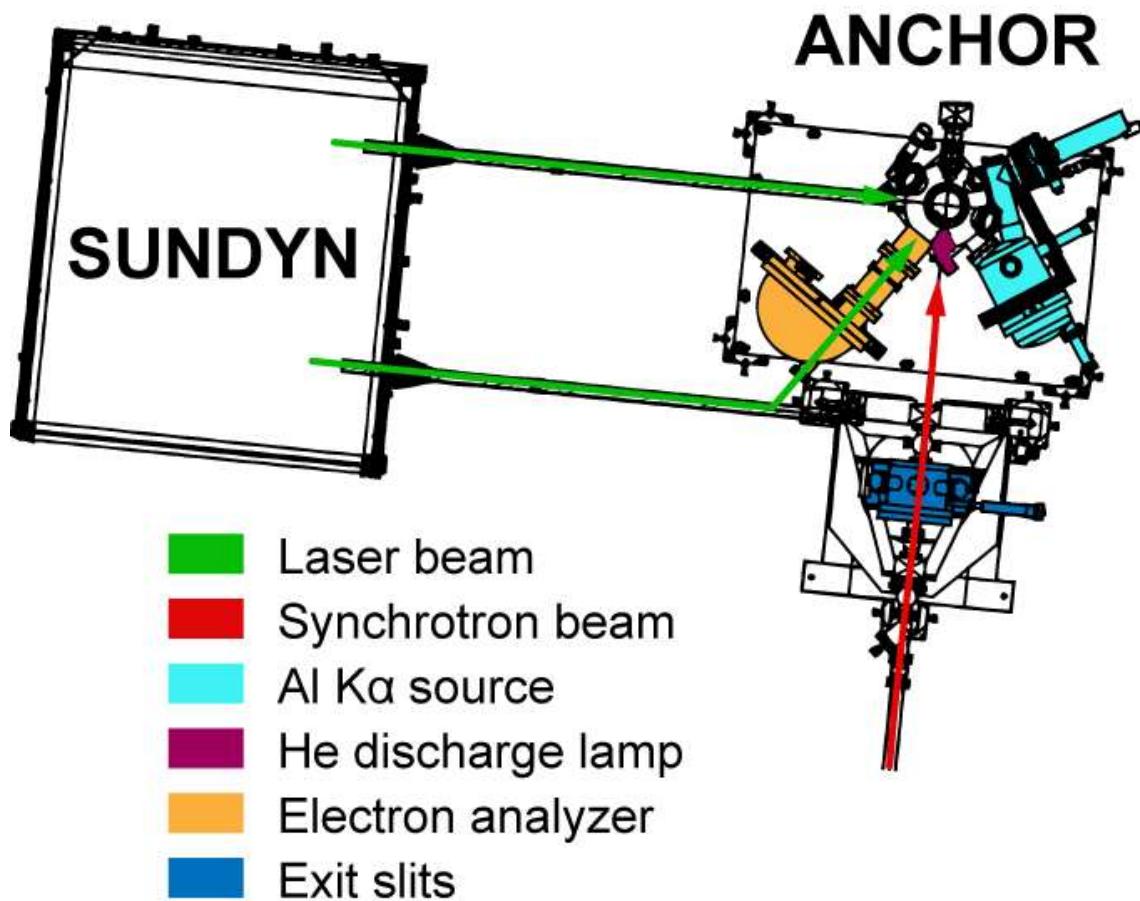


Lampada di Elio
(Discharge Helium Lamp)



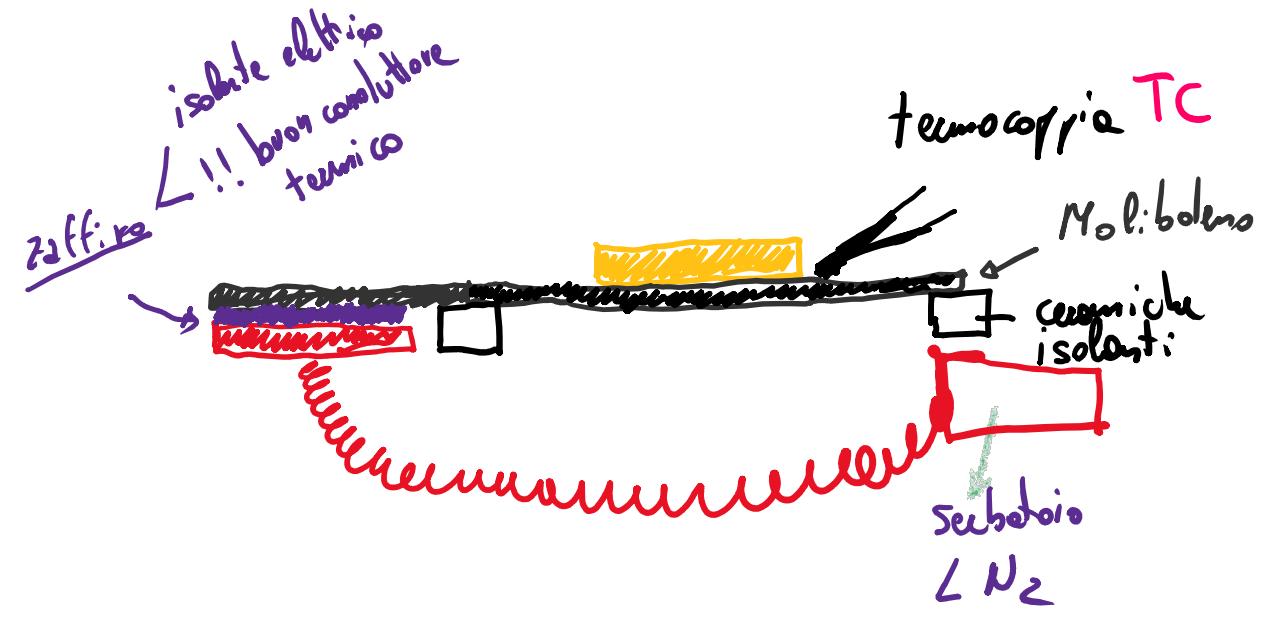


	Energy [eV]	Satellite shift [eV]	Relative Intensity [%]
He I α	21.22	0	100
He I β	23.09	1.87	1.5
He I γ	23.74	2.52	0.5
He II α	40.81	0	100
He II β	48.37	7.56	<10
He II γ	51.02	10.2	<1



Montaggio del campione





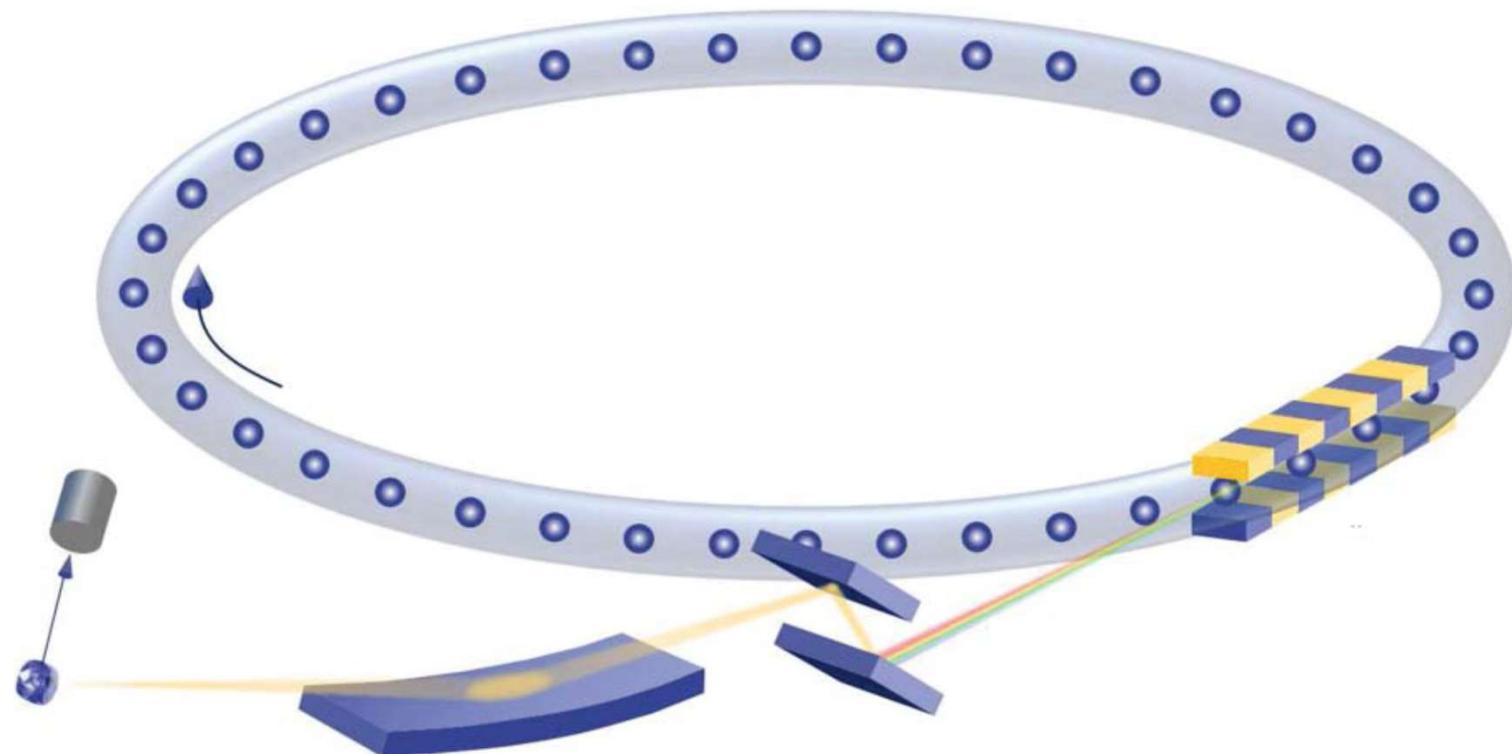
1. fotoluminescenza
 e^- estretti dal campione
 il campione si carica $+$

\Rightarrow devo sempre mettere e
mosse i P campione !!

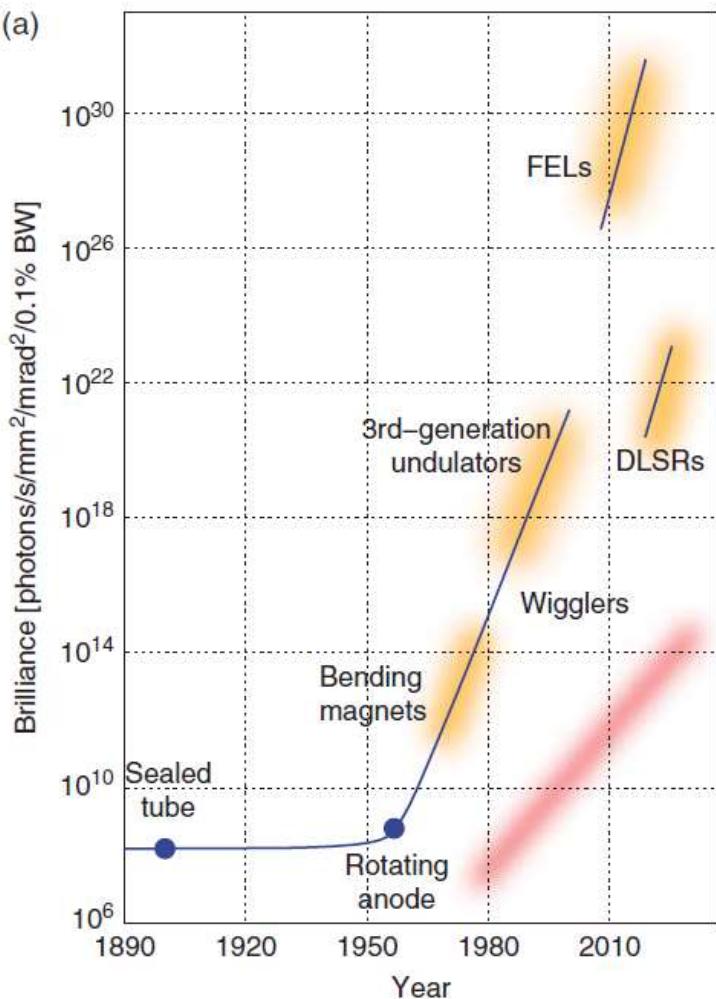
\rightarrow 1 delle terminazioni delle
TC e mossa

2. Sempre ottenermi TC
 posso mettere un potenziale
BIAS tra campione e anodizzatore

Il sincrotrone: principi di funzionamento



(a)

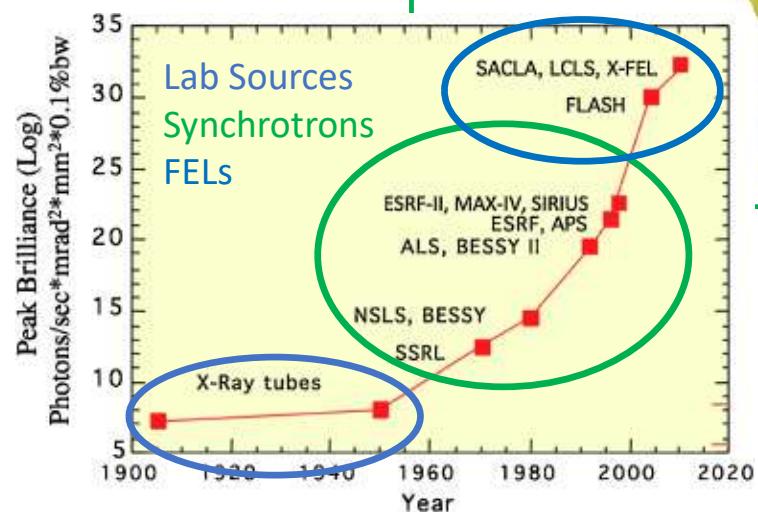


La brillanza di una sorgente è definita come il numero di fotoni emessi al secondo, per unità di superficie e di angolo solido, per millesimo della larghezza di banda emessa.

X-Ray Sources



M. E. Couplie, J. Elect. Spec. Rel. Phen. 196 (2014) 3



W. Eberhardt, J. Elect Spec. Rel Phen. 200 (2015) 31

Elettra Synchrotron



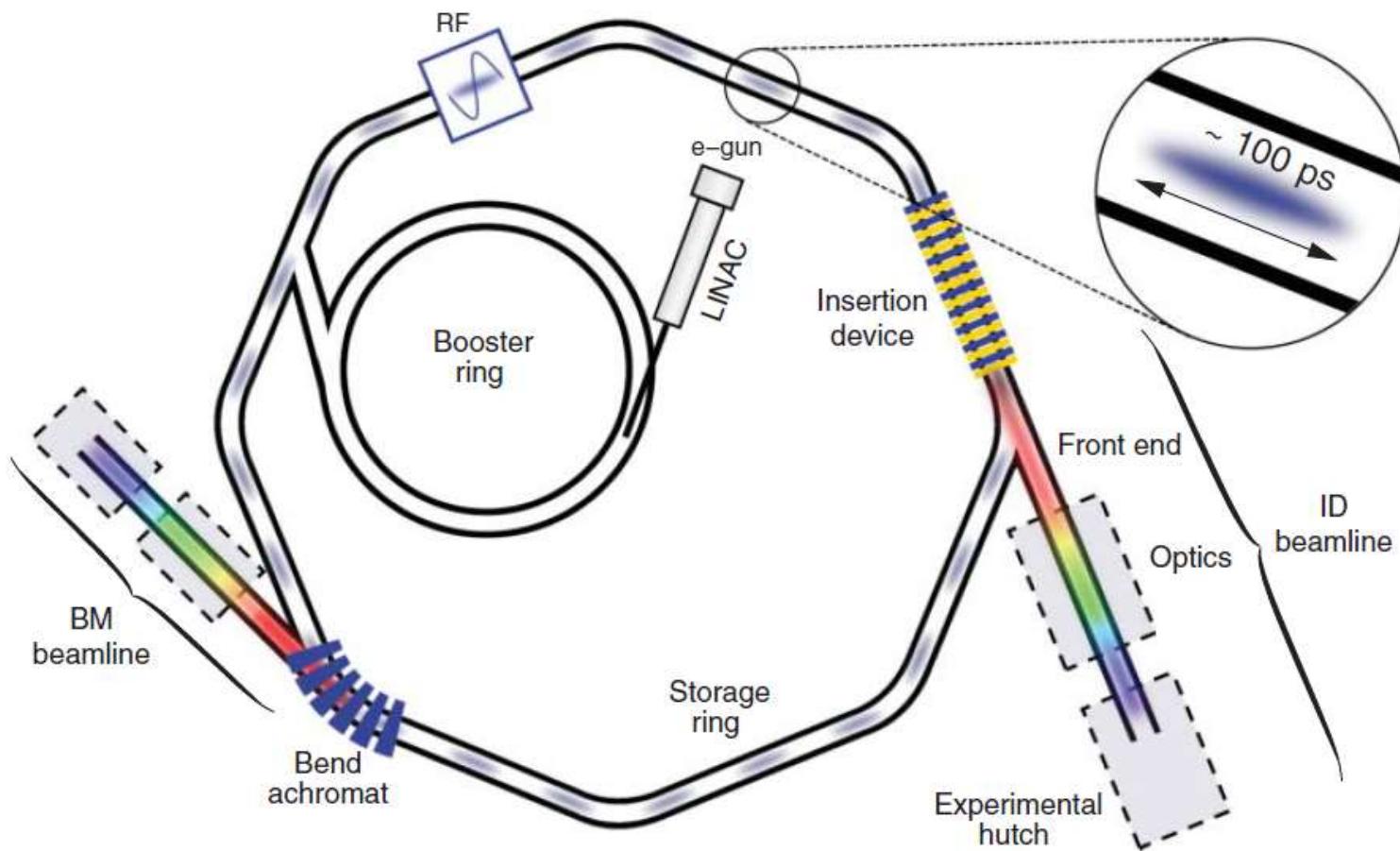
USER FACILITY

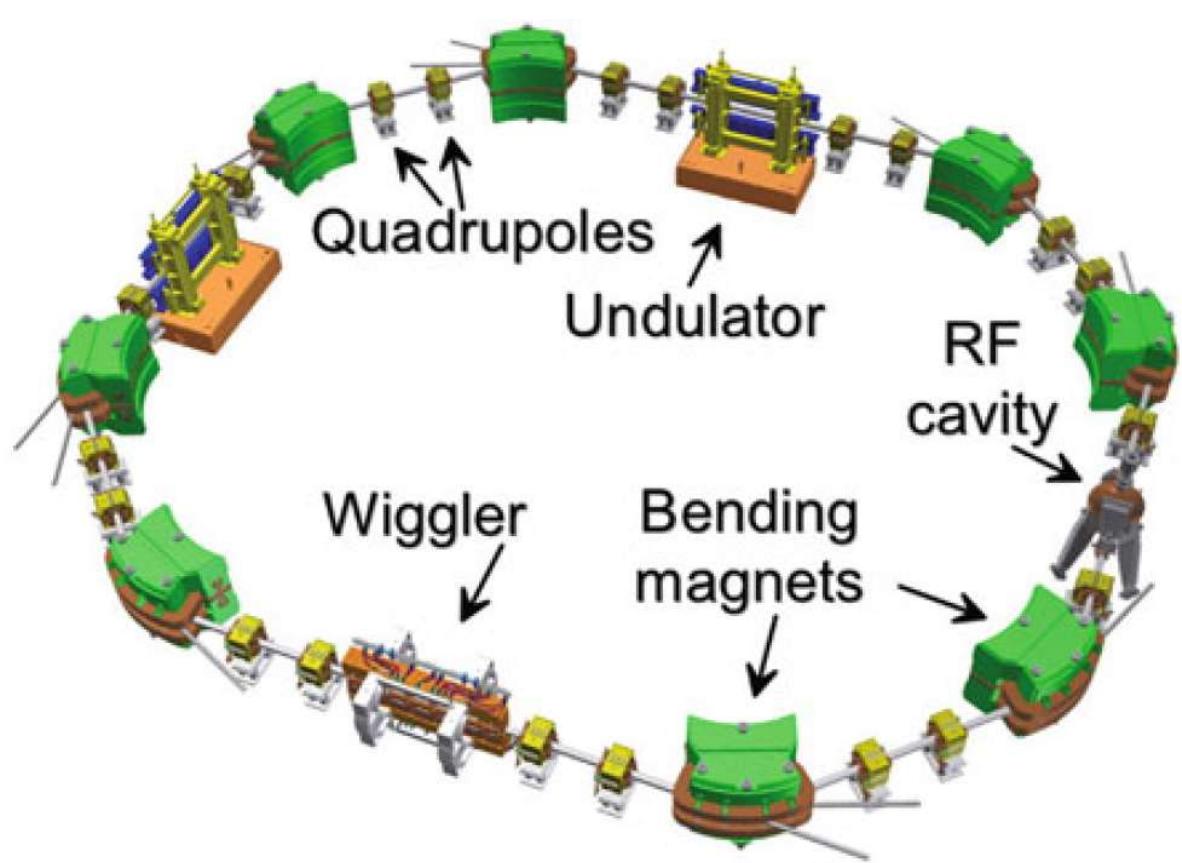


Elettra Sincrotrone Trieste



**ELETTRA: 28 beamlines in cooperation with
national and international institutions**





Insertion Devices

- wiggler
- undulator

Mobilio-Boscherini-Meneghini,
Synchrotron Radiation, Springer 2015

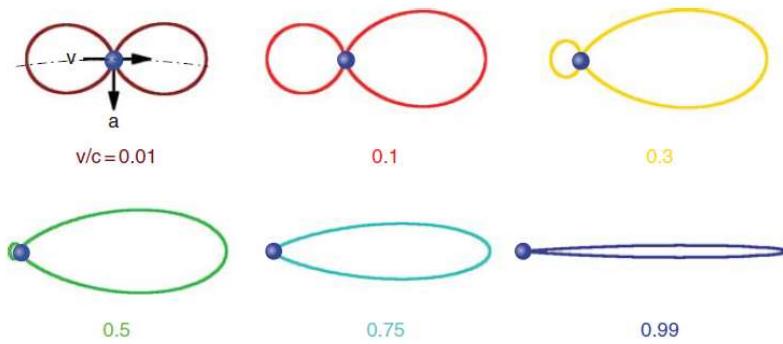
Quadrupoli e sestupoli disposti lungo l'orbita generano campi magnetici che ricompattano i bunch di elettroni



Elettra

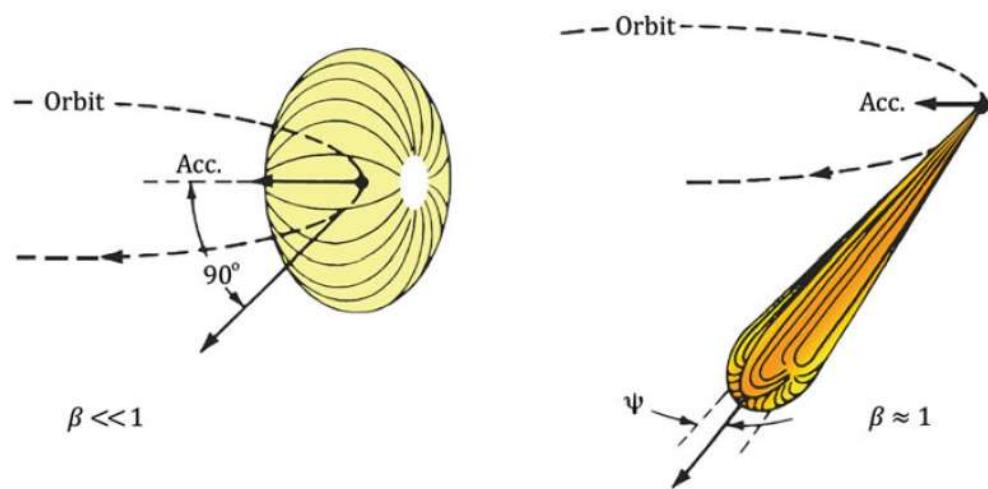
Operating Conditions

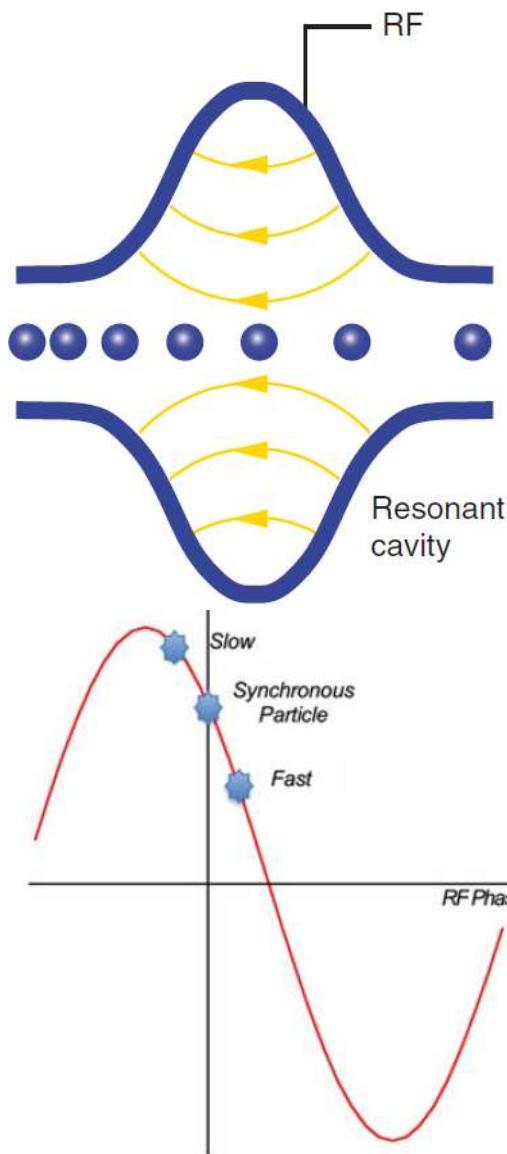
Energy range	0.75 – 2.5 GeV
Injection Energy	All energies up to 2.5 GeV
User Operating Energy	2.0 GeV (75% of user time) 2.4 GeV (25% of user time) 1.0 GeV (SR-FEL)
Operating mode	Top-up
Operating current (user request)	300 mA at 2.0 GeV (lifetime 26 h) 140 mA at 2.4 GeV (lifetime 40 h)
Top-up injection rate	1 mA every 6 min at 2.0 GeV 1 mA every 20 min at 2.4 GeV



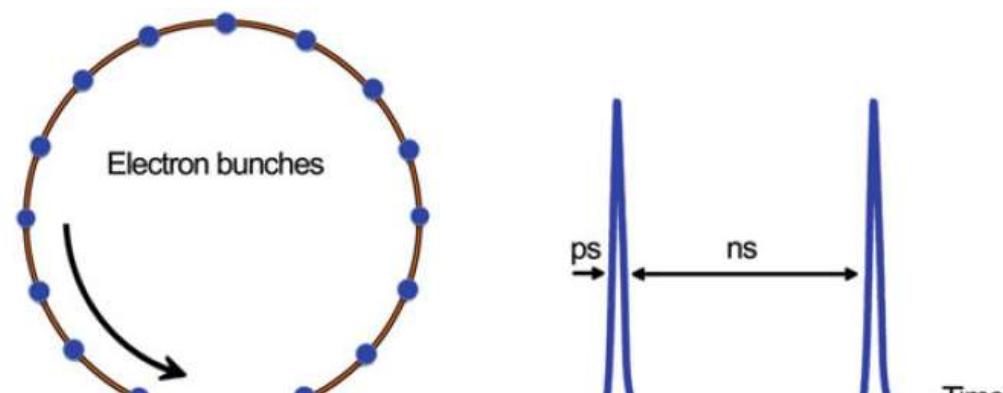
La radiazione di dipolo così come l'abbiamo trattata descrive l'onda e.m. prodotta da una carica accelerata quando la sua velocità è molto inferiore a c .

Nel caso di $v \sim c$ serve una trattazione relativistica. L'effetto relativistico principale è che man mano che la velocità aumenta il lobo di emissione gradualmente si protrae verso la direzione del moto; l'angolo di emissione inoltre si fa via via più stretto.



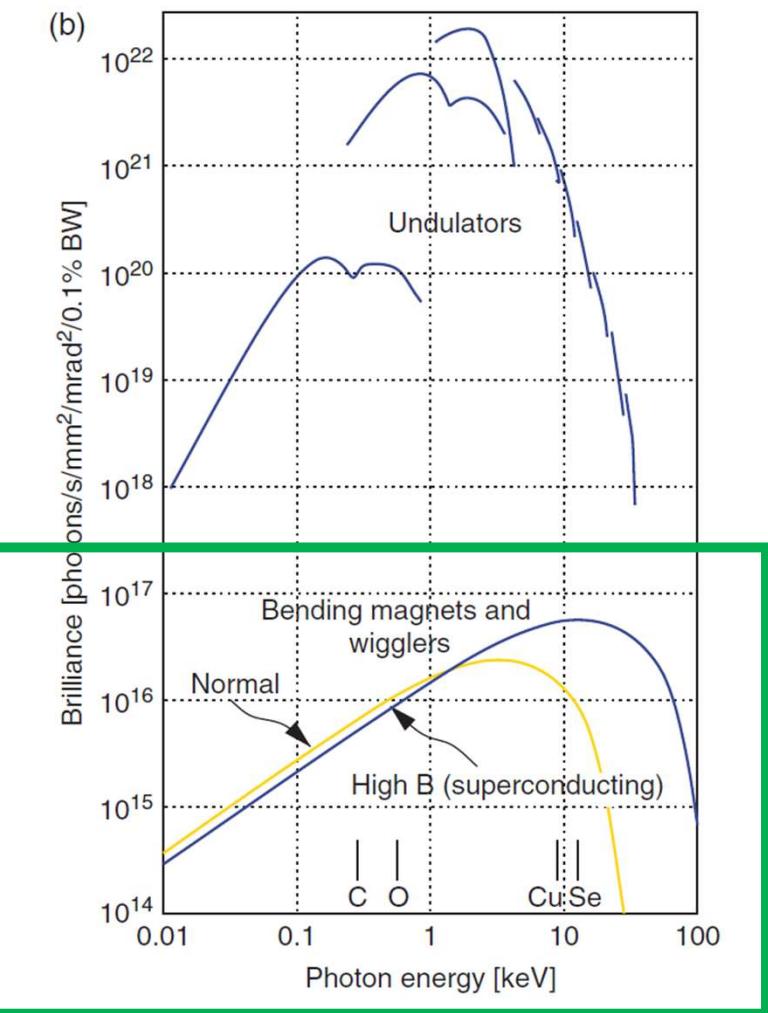
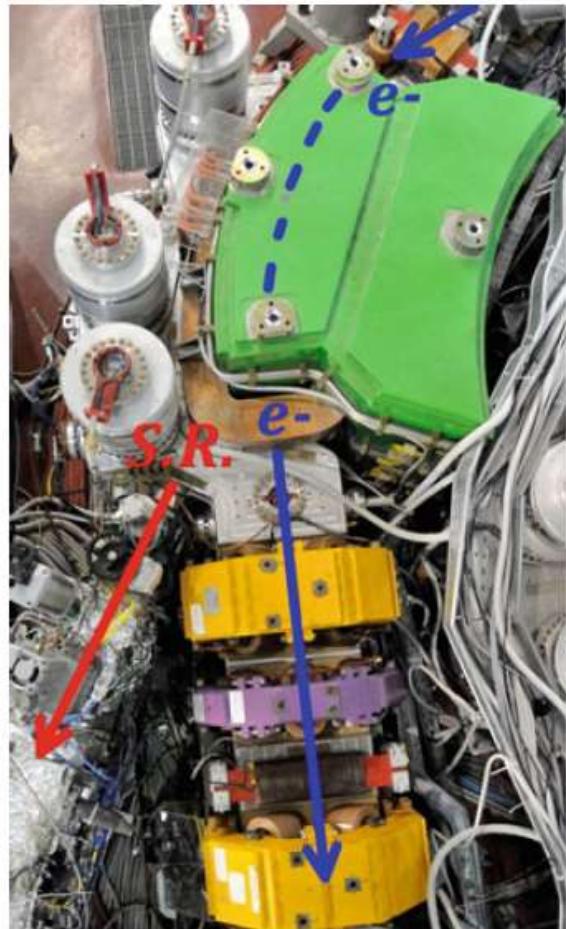


Ad ogni giro di anello, un elettrone perde energia in quando emette radiazione. L'energia viene ripristinata da una *cavità risonante a RF* (radio frequenza) posizionata lungo il percorso. Nella RF, un campo sinusoidale accelera/rallenta gli elettronni a seconda della fase. Solo una porzione del 10-15% della sinusoide della RF viene effettivamente utilizzate per ricompattare i bunch di elettroni. Elettroni che arrivano troppo lenti o troppo veloci sono destinati a perdere in collisioni con le pareti dell'anello.



Mobilio-Boscherini-Meneghini,
Synchrotron Radiation, Springer 2015

Magnete curvante



Energia critica del magnete curvante

Elettra

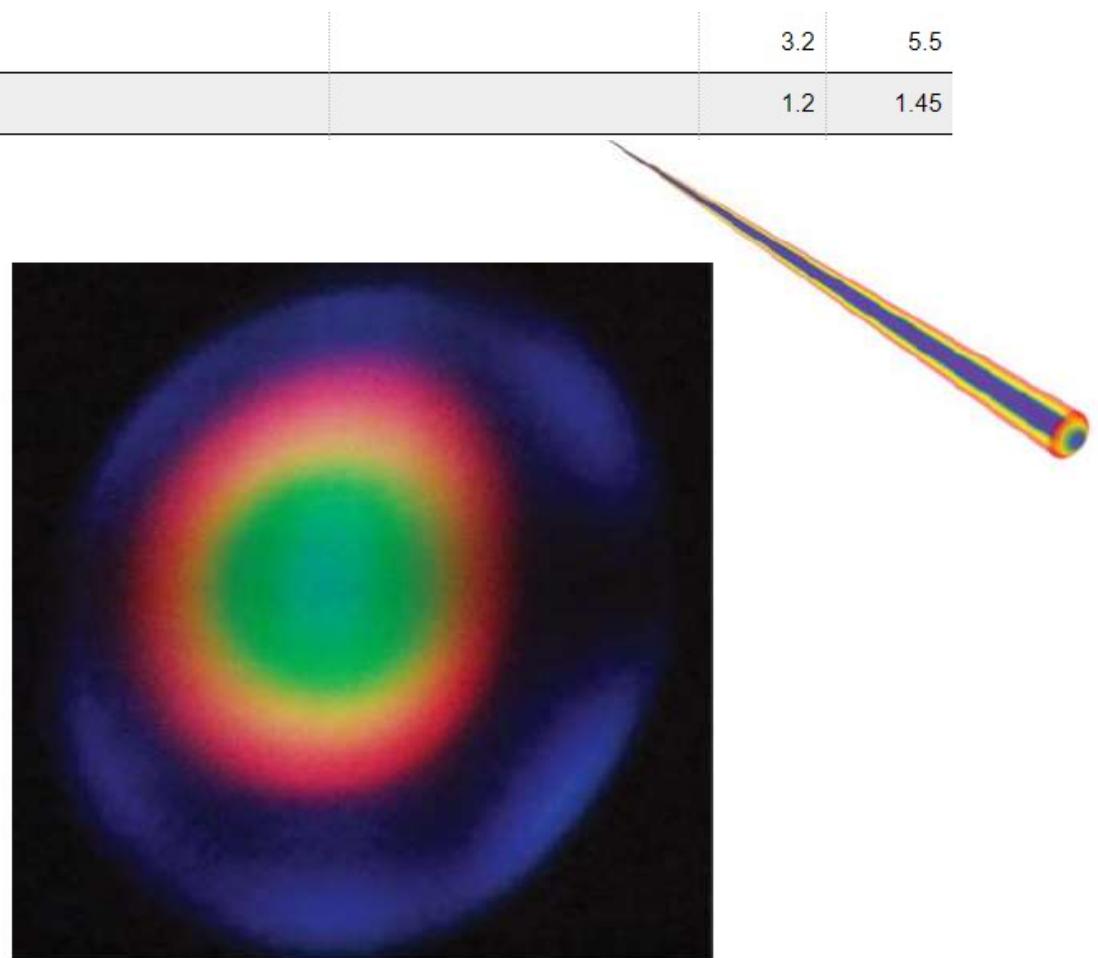
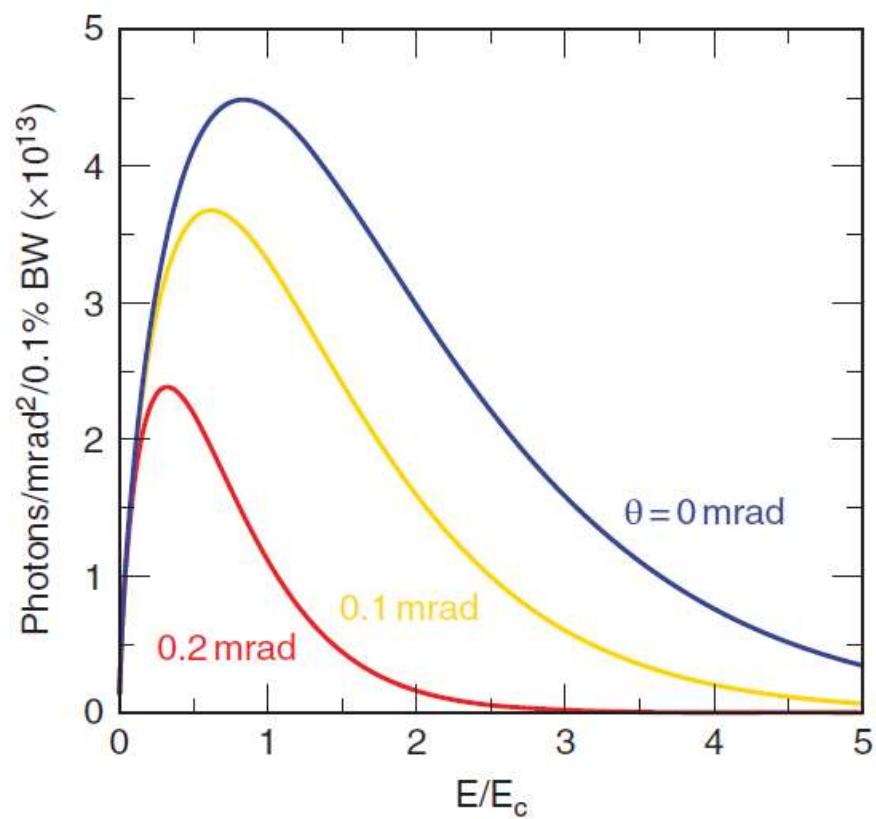
Critical energy [keV]

3.2 5.5

Bending magnet field [T]

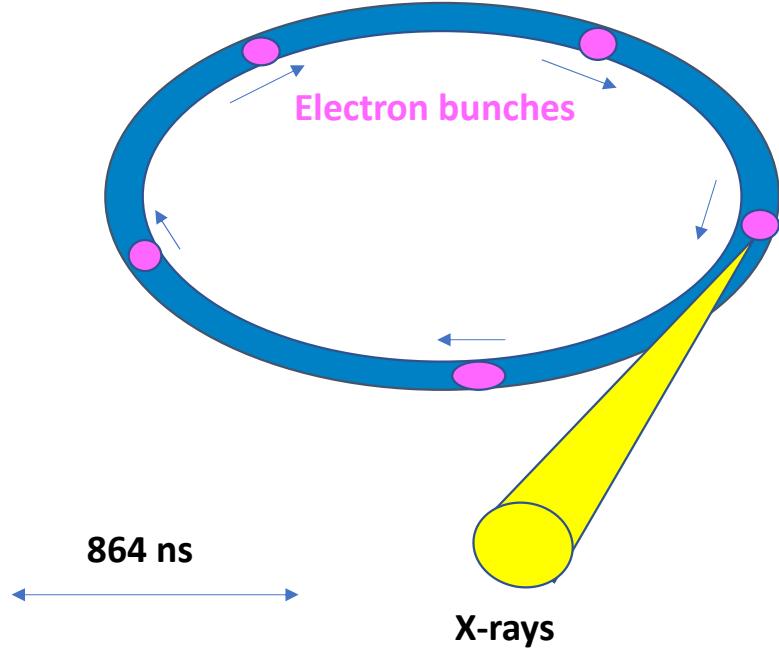
1.2 1.45

$$\hbar\omega_c[\text{keV}] = 0.665 \cdot \mathcal{E}^2[\text{GeV}] \cdot B[\text{T}]$$

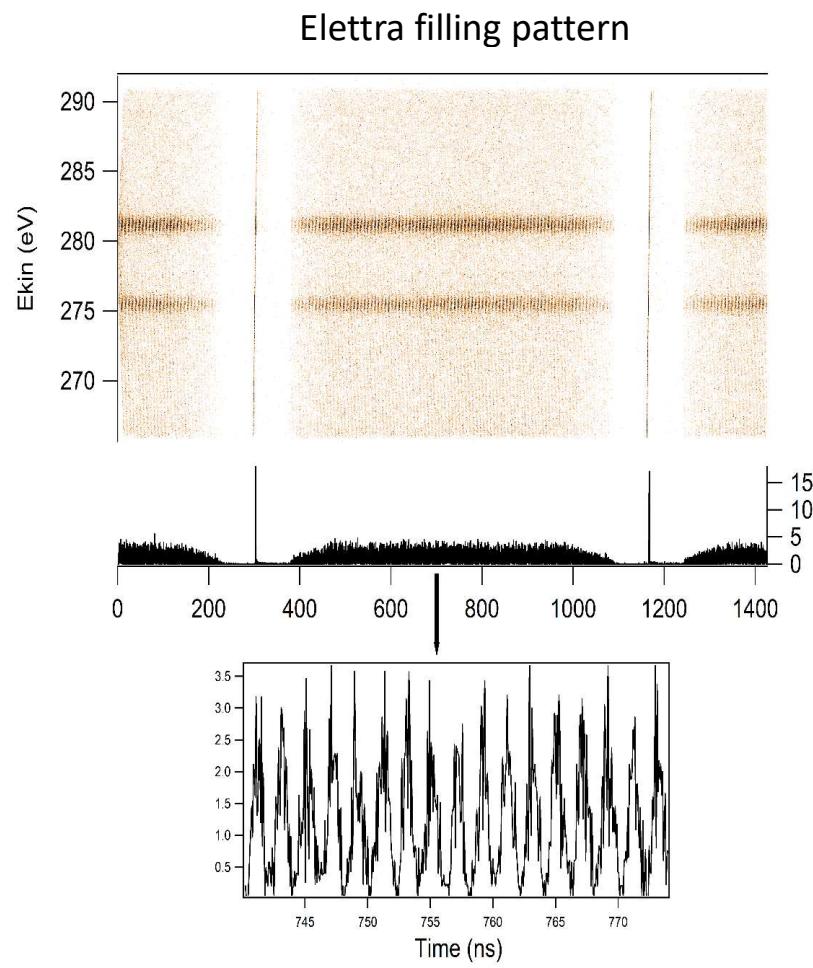


Filling pattern	Any (single, few, multi etc.); most requested multibunch filled at 95% of the ring circumference (864 ns) and hybrid (multibunch with a single bunch in the dark gap)
Bucket size (bunch to bunch distance in multi-bunch)	2 ns
Dark gap when fill at 95%	43 ns
Operating details	Long Lifetime - Instability Free (multi-bunch and orbit fast Feedbacks and super-conducting 3 rd harmonic cavity operating) Id gap/current control to the users

Synchrotron X-ray pulses



100 ps X-ray pulses

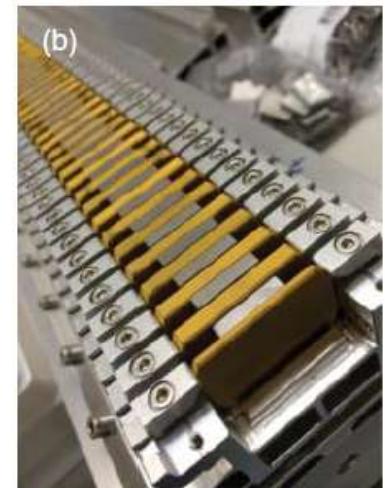
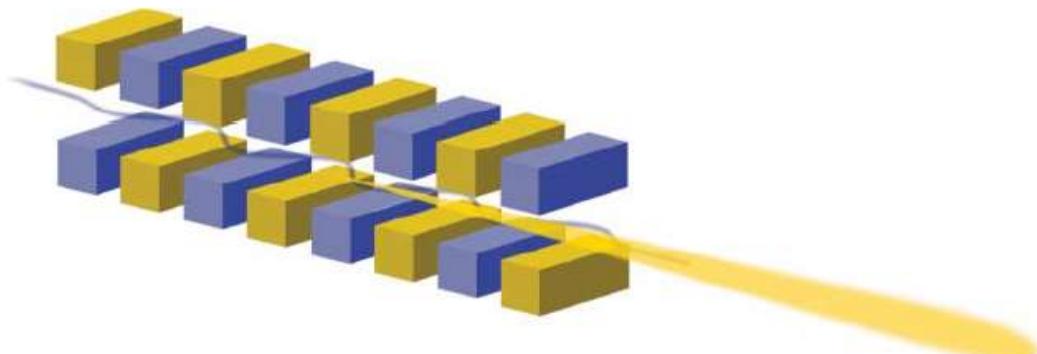


Elettra

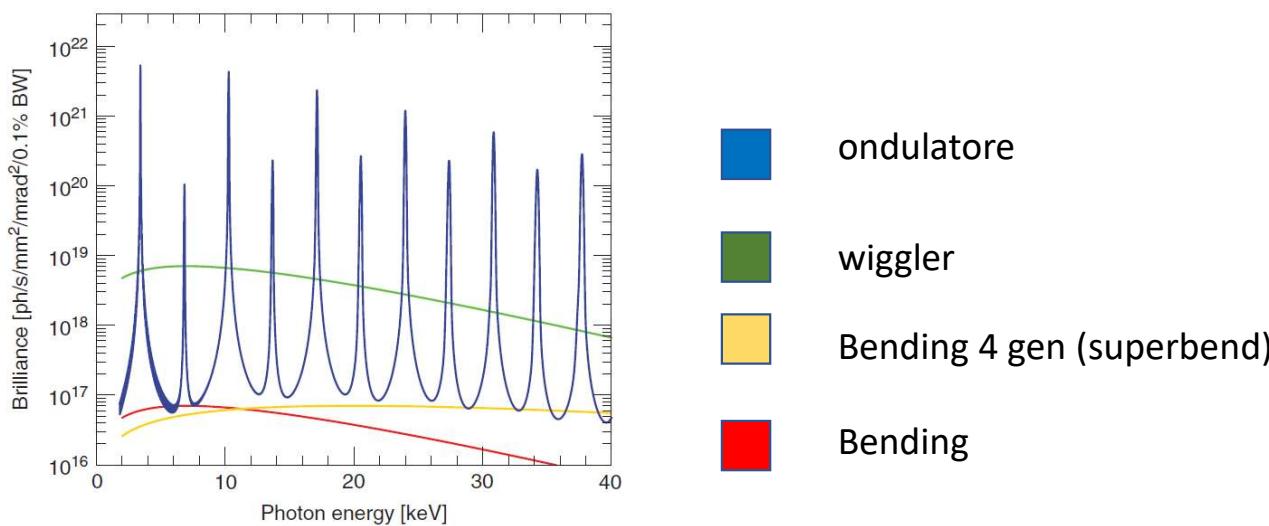
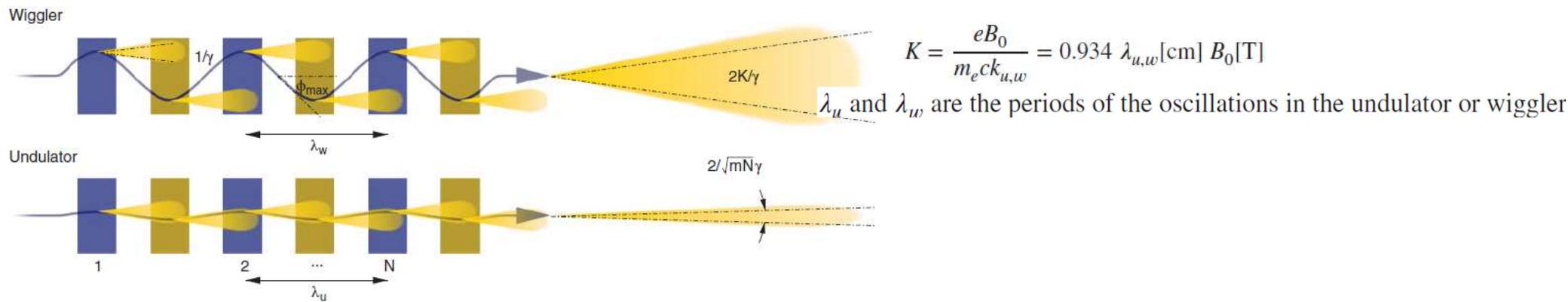
Beam energy [GeV]	2	2.4
Storage ring circumference [m]	259.2	
Beam height in experimental area [m]	1.3	
Number of achromats	12	
Length of Insertion Device (ID) straight sections [m]	6(4.8 utilizable per ID's)	
Number of straight sections of use for ID's	11	
Number of bending magnet source points	12	
Beam revolution frequency [MHz]	1.157	
Number of circulating electron bunches	1 - 432	
Time between bunches [ns]	864 - 2	
Bunch length ($1\ \sigma$) [mm] [*]	5.4	7

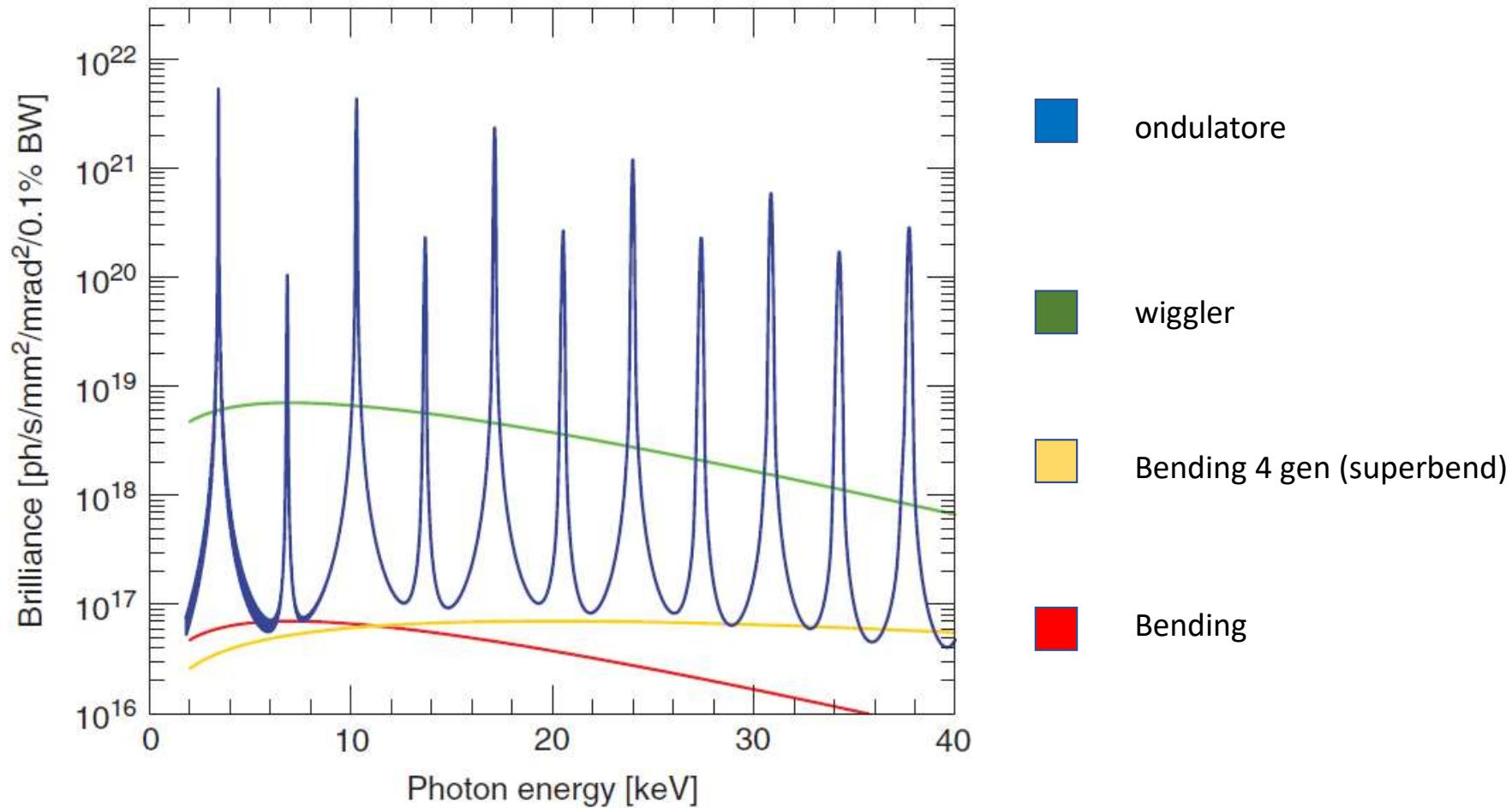
Dispositivo di inserzione (Insertion Device, ID)

Nei tratti rettilinei del percorso che gli elettroni fanno in un sincrotrone sono installati gli ID, array di elettromagneti che generano un campo magnetico che fa compiere agli elettroni un percorso a serpentina.

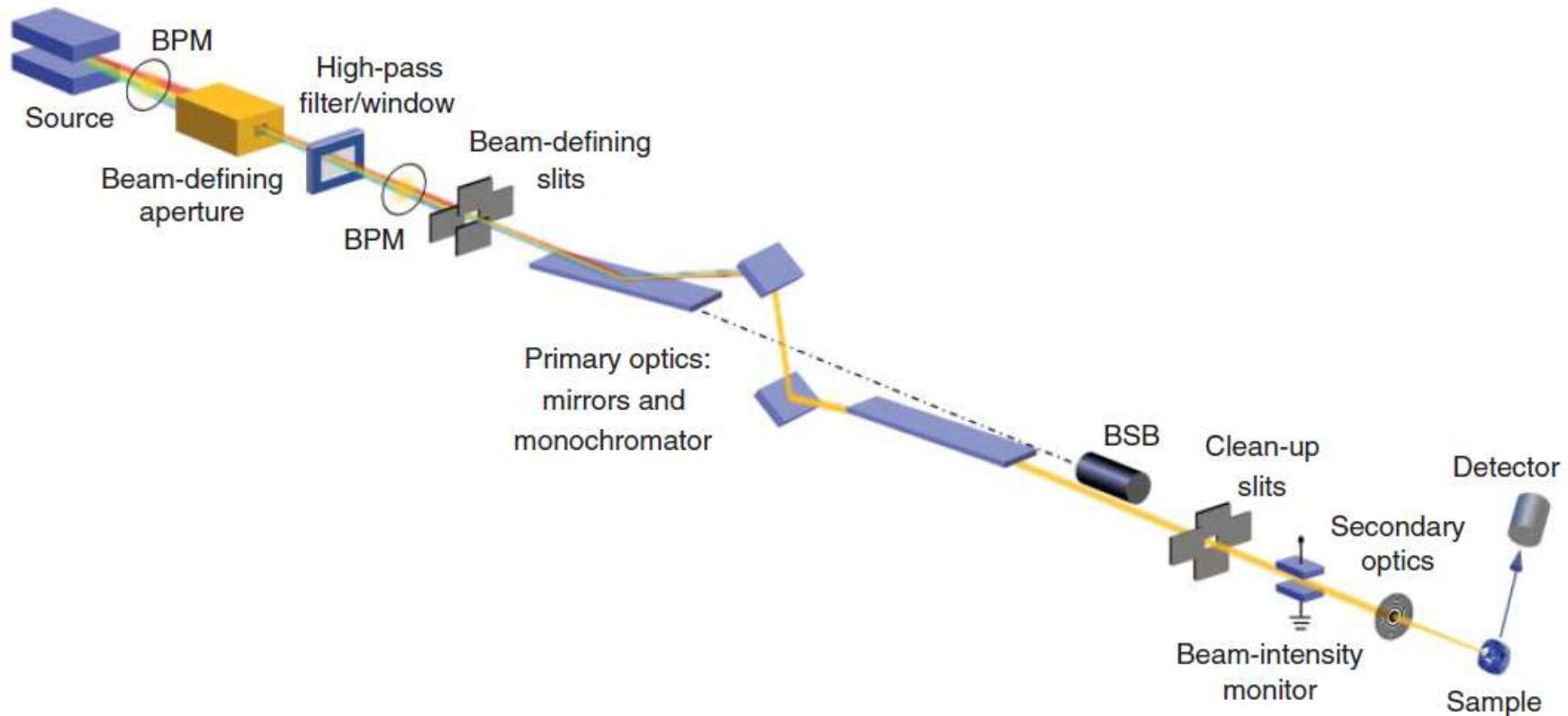


Gli ID possono operare in due modalità: wiggler e undulator. La differenza sostanziale è che in modalità undulator la radiazione emessa dalle diverse sezioni si somma in fase, dando origine a picchi di intensità molto elevata.





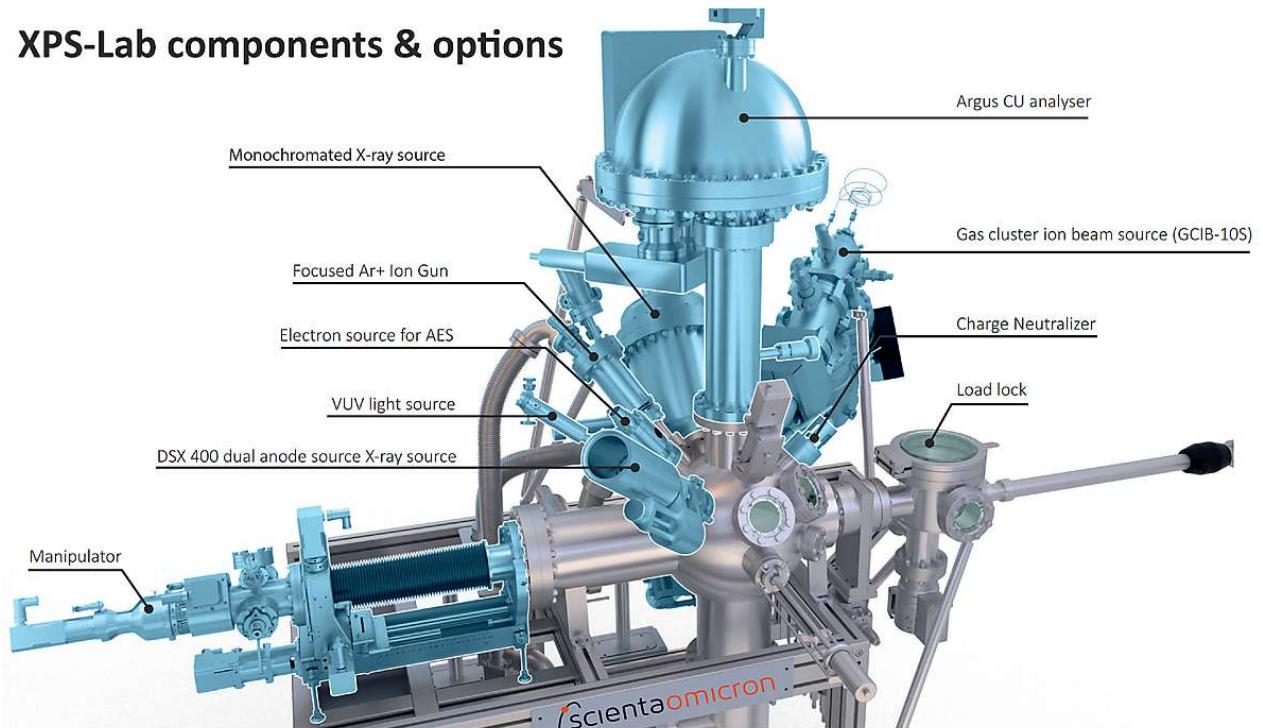
Beamlines

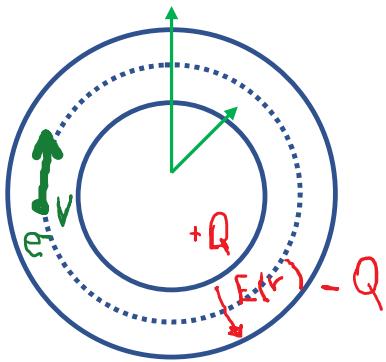


L'analizzatore di elettroni emisferico



XPS-Lab components & options





Condensatore sferico

Raggio interno: R_1

Raggio interno: R_2

$$E(r) = \frac{Q}{4\pi\epsilon_0} \frac{1}{r^2}$$

$$\Delta V = \int_{R_1}^{R_2} E(r) dr = \frac{Q}{4\pi\epsilon_0} \left[\frac{1}{r} \right]_{R_1}^{R_2} = \frac{Q}{4\pi\epsilon_0} \left(\frac{1}{R_1} - \frac{1}{R_2} \right)$$

Consideriamo la traiettoria circolare di raggio intermedio.

In che condizioni un elettrone può percorrerla senza precipitare sulla sfera interna?

Se e^- ha velocità v , tangente alla traiettoria, sente una forza verso il centro pari a: $F = eE$

Avrà traiettoria circolare se questa forza è par: alla forza centripeta

$$m \frac{v^2}{r} = eE$$

$$m \frac{v^2}{r} = eE$$

$$E(r) = \frac{Q}{4\pi\epsilon_0} \frac{1}{r^2}$$

$$\Delta V = \frac{Q}{4\pi\epsilon_0} \left(\frac{1}{R_1} - \frac{1}{R_2} \right)$$

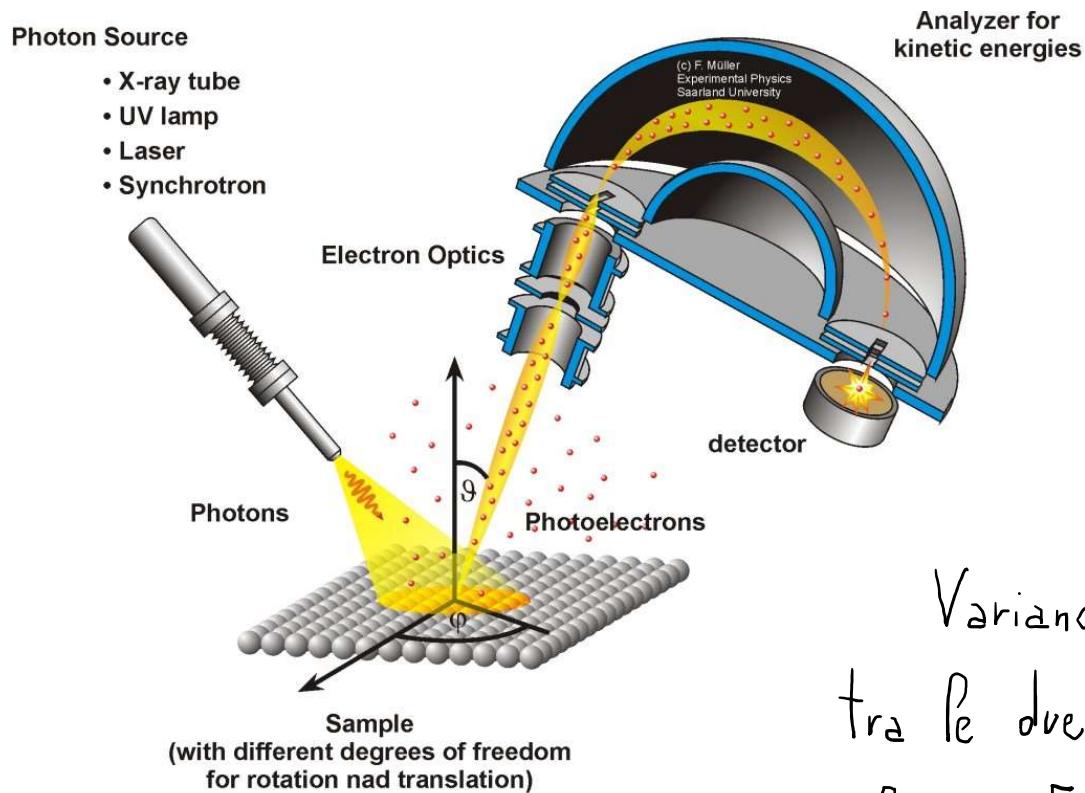
$$\frac{mv^2}{r} = e \frac{Q}{4\pi\epsilon_0} \frac{1}{r^2} \quad r = \frac{R_1 + R_2}{2} \quad (\text{reggio intermedio})$$

|

$$Q = \Delta V \cdot 4\pi\epsilon_0 \cdot \frac{R_1 \cdot R_2}{R_2 - R_1}$$

$$= 2e\Delta V \frac{R_1 R_2}{R_2^2 - R_1^2}$$

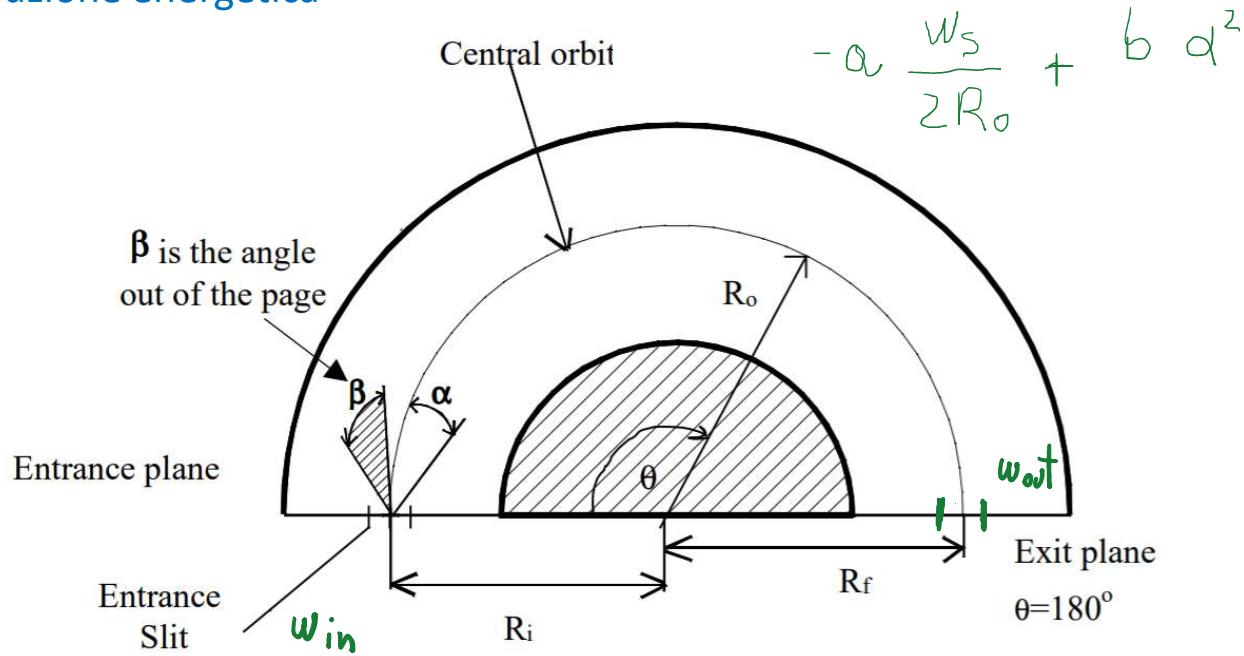
$$\frac{1}{2}mv^2 = e\Delta V \frac{R_1 R_2}{R_2^2 - R_1^2} = E_p \quad \text{pass energy}$$



<https://jacobs.physik.uni-saarland.de/>

Variando ΔV
tra le due emisfere
Seleziona E_{kin} degli elettroni
che raggiungono il detector

Risoluzione energetica



$$\frac{\Delta E_p}{E_p} = -a \frac{w_s}{2R_o} + b q^2$$

$w_s = w_{in} + w_{out}$

a, b parametri dell'analisatore

Read F.H, Comer J., Imhof R. E., Brunt J. N. and Harting E. Al. (1974), *Journal of Electron Spectroscopy and Related Phenomena*, 4, 293-312



Il detector

Come conto un elettrone?

In un esperimento posso avere l'esigenza di dover misurare flussi di elettroni molto bassi, di poche decine di elettroni al secondo

10 elettroni al secondo corrispondono ad una corrente di:

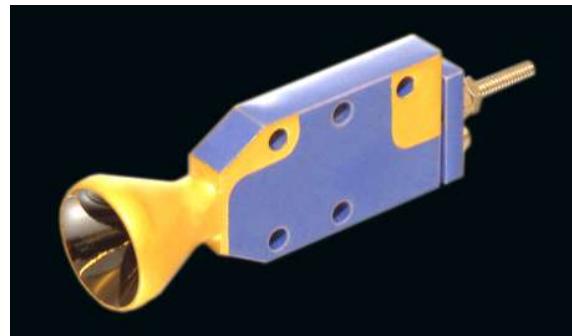
$$10 \times 1.6 \times 10^{-19} \text{ C/s} \sim 10^{-18} \text{ A}$$

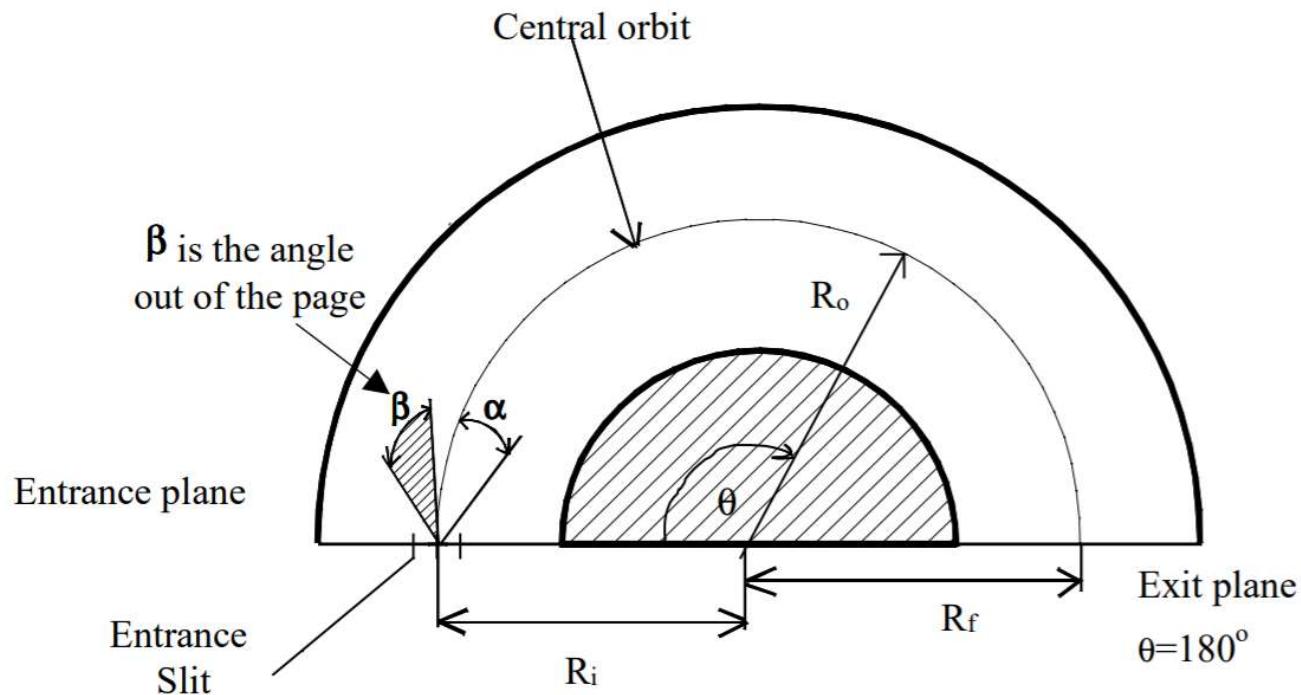
Misurare correnti dell'ordine del pA (10^{-15} A) è già molto complicato



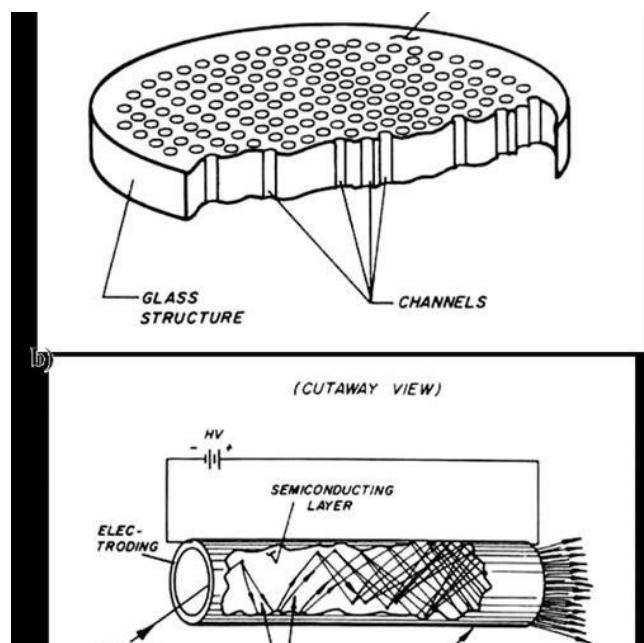
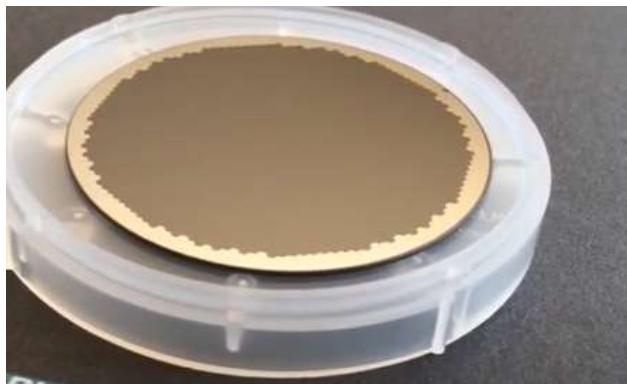
Serve amplificare il segnale

Channeltron





Microchannelplate (MCP)



Delay line

