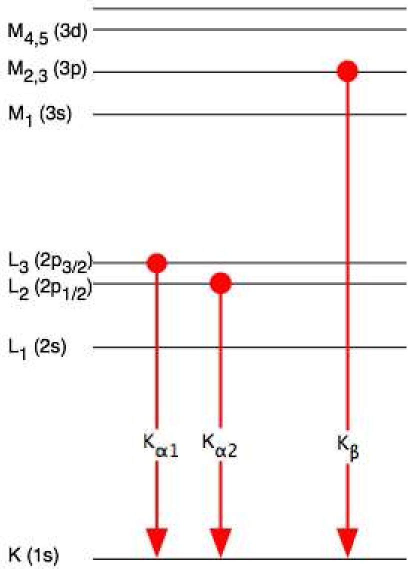
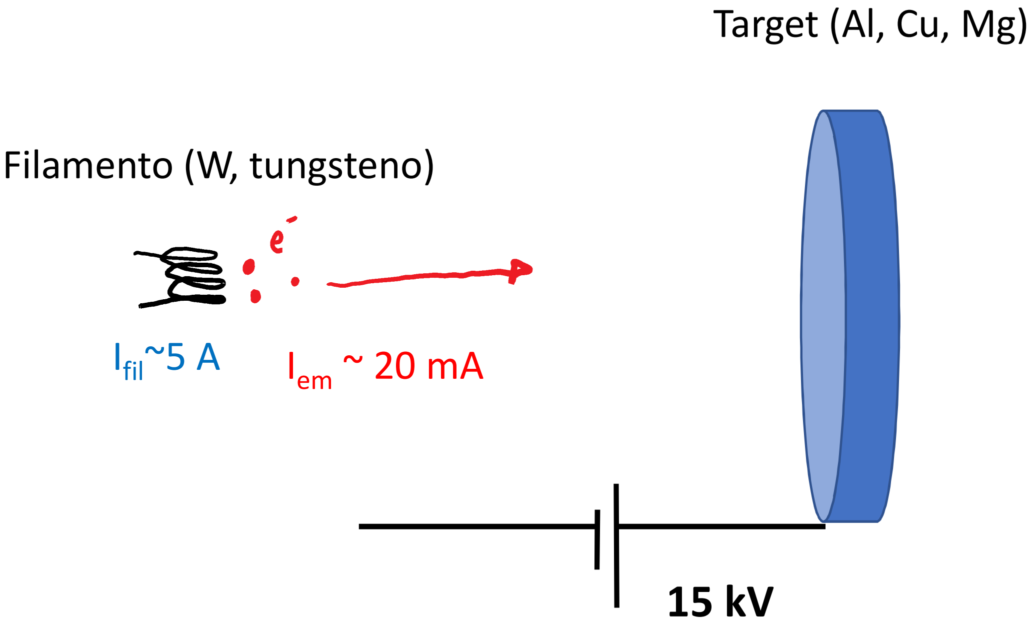
Sorgente X di laboratorio





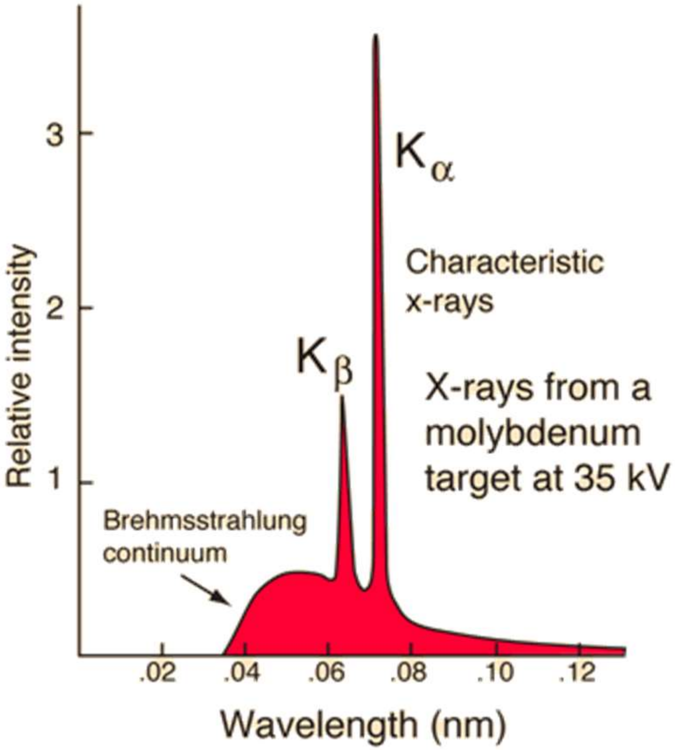
Target (Al, Cu, Mg)

Filamento (W, tungsteno)

I_{fil}~5 A

I_{em} ~ 20 mA

15 kV


3
2
1
Relative intensity
Kα
Kβ
Characteristic
x-rays
X-rays from a
molybdenum
target at 35 kV
Brehmsstrahlung
continuum
.02
.04
.06
.08
.10
.12
Wavelength (nm)

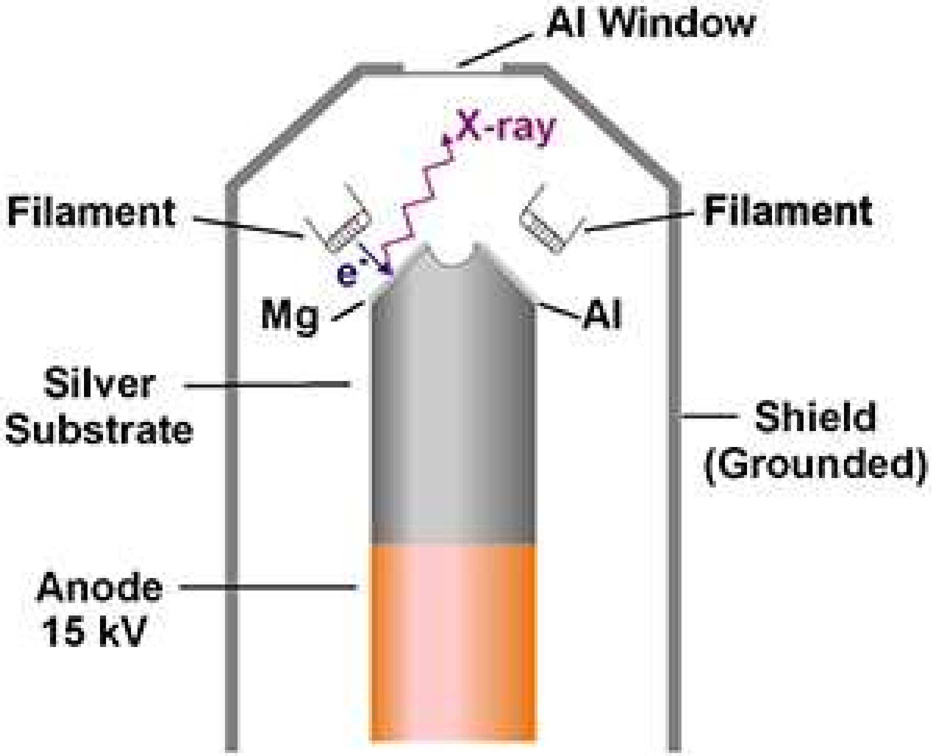
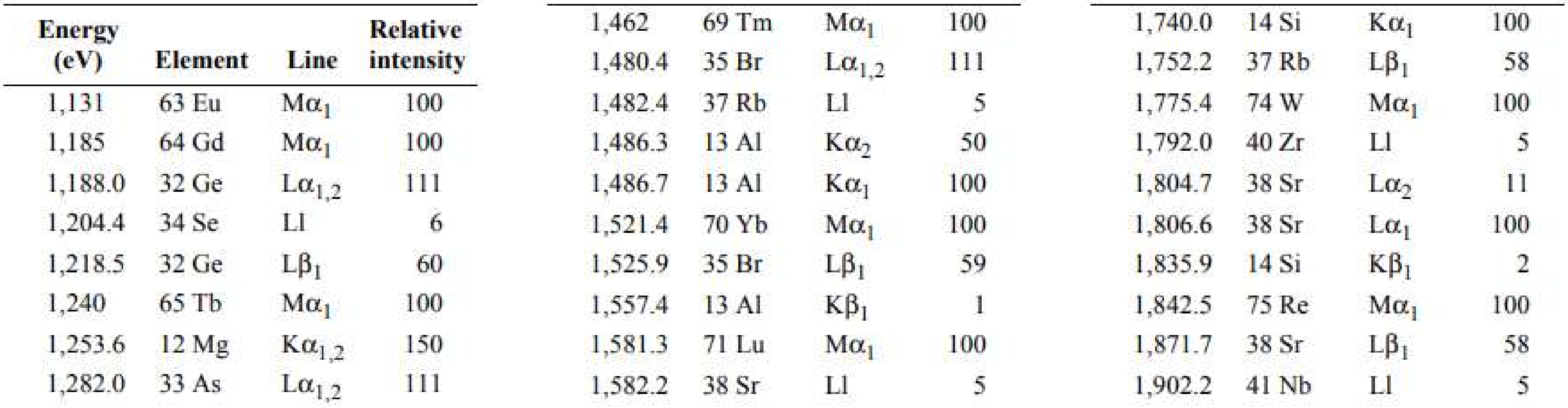

Al Window
X-ray
Filament
Filament
e⁻
Mg
Al
Silver
Substrate
Shield
(Grounded)
Anode
15 kV

Table 1-3. *Energies and intensities of x-ray emission lines (continued).*



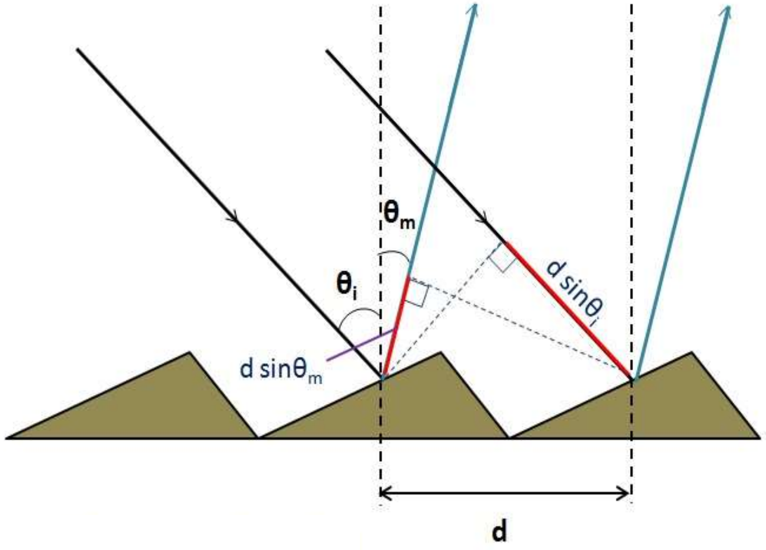
Energy (eV)	Element	Line	Relative intensity
1,131	63 Eu	$M\alpha_1$	100
1,185	64 Gd	$M\alpha_1$	100
1,188.0	32 Ge	$L\alpha_{1,2}$	111
1,204.4	34 Se	Ll	6
1,218.5	32 Ge	$L\beta_1$	60
1,240	65 Tb	$M\alpha_1$	100
1,253.6	12 Mg	$K\alpha_{1,2}$	150
1,282.0	33 As	$L\alpha_{1,2}$	111
1,462	69 Tm	$M\alpha_1$	100
1,480.4	35 Br	$L\alpha_{1,2}$	111
1,482.4	37 Rb	Ll	5
1,486.3	13 Al	$K\alpha_2$	50
1,486.7	13 Al	$K\alpha_1$	100
1,521.4	70 Yb	$M\alpha_1$	100
1,525.9	35 Br	$L\beta_1$	59
1,557.4	13 Al	$K\beta_1$	1
1,581.3	71 Lu	$M\alpha_1$	100
1,582.2	38 Sr	Ll	5
1,740.0	14 Si	$K\alpha_1$	100
1,752.2	37 Rb	$L\beta_1$	58
1,775.4	74 W	$M\alpha_1$	100
1,792.0	40 Zr	Ll	5
1,804.7	38 Sr	$L\alpha_2$	11
1,806.6	38 Sr	$L\alpha_1$	100
1,835.9	14 Si	$K\beta_1$	2
1,842.5	75 Re	$M\alpha_1$	100
1,871.7	38 Sr	$L\beta_1$	58
1,902.2	41 Nb	Ll	5

https://xdb.lbl.gov/

Reticolo di diffrazione

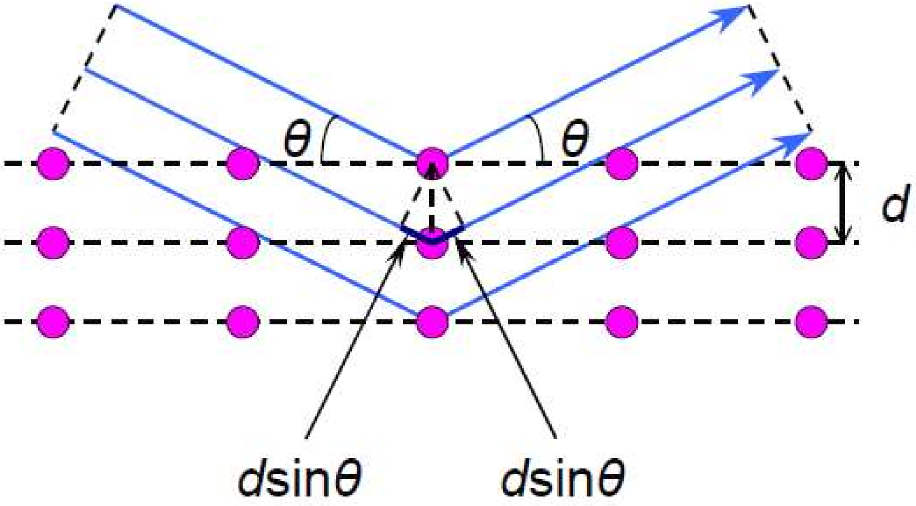
Ogni gradino del reticolo diventa una sorgente che riflette il fronte d'onda incidente. La differenza di cammino ottico tra il fascio riflesso da due gradini adiacenti è, dalla figura, $d(\sin\theta_m - \sin\theta_i)$. Per lunghezze d'onda tali che $n\lambda = d(\sin\theta_m - \sin\theta_i)$ avrò interferenza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

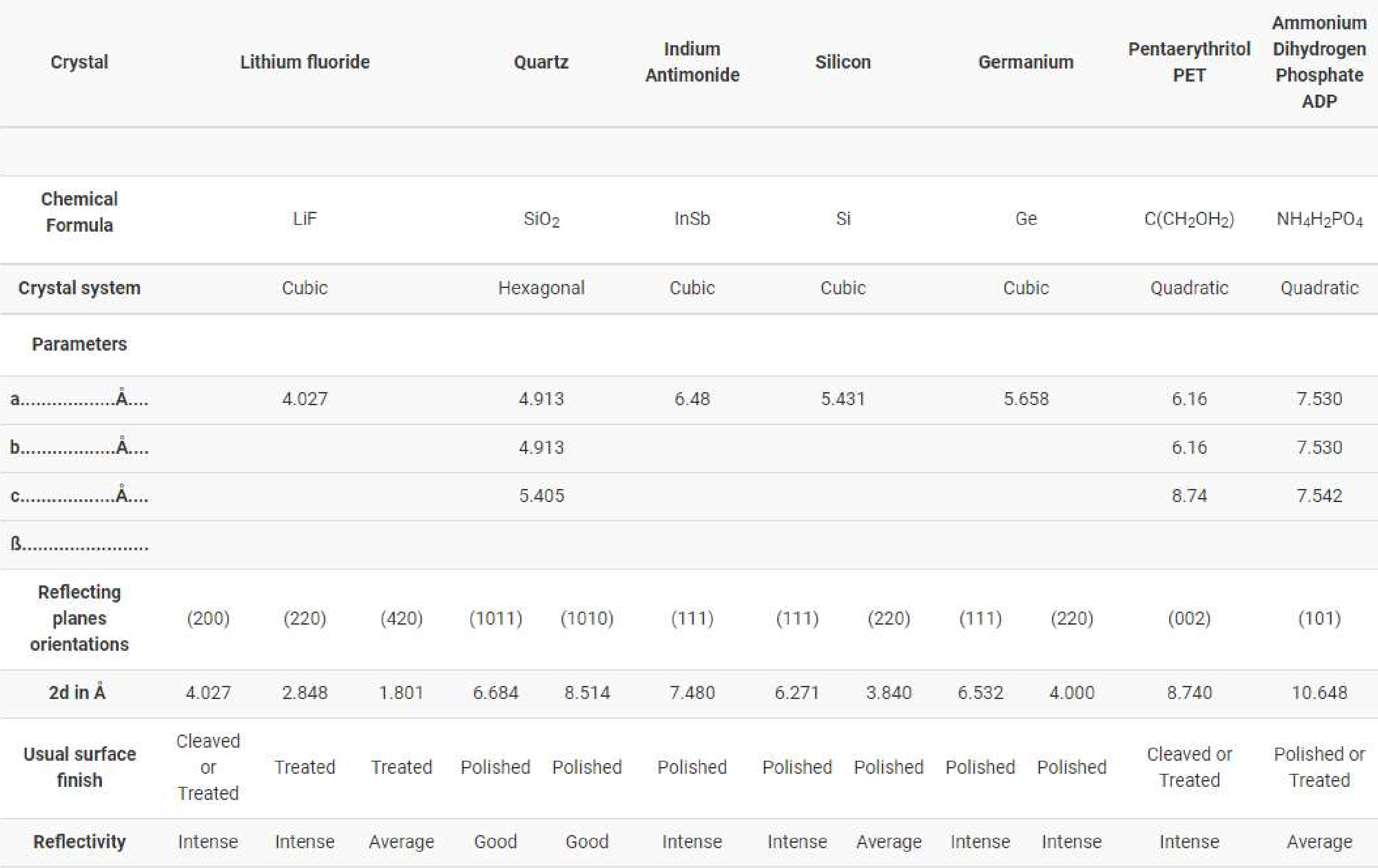


Come monocromatizzare i raggi X?

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



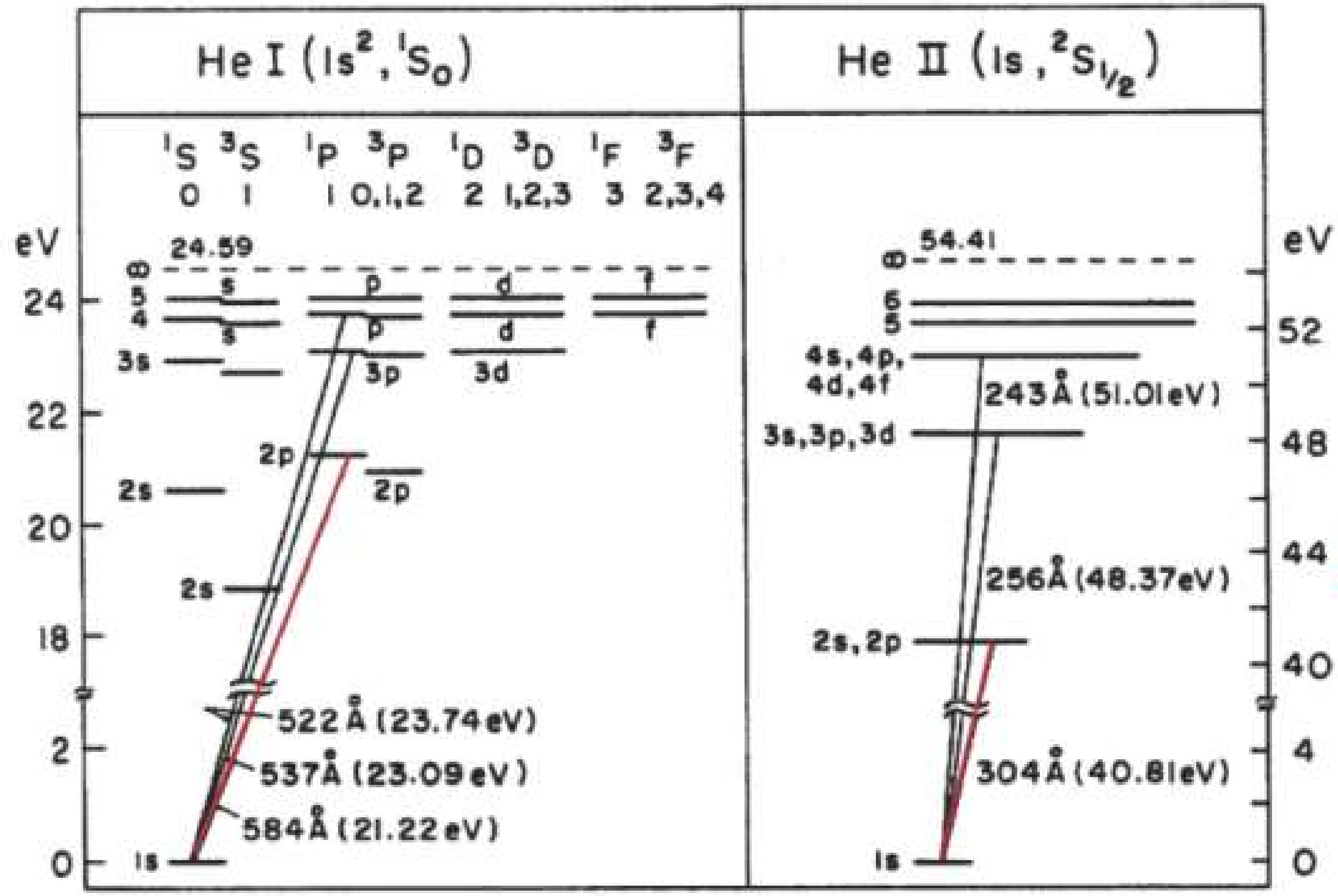
$$\boxed{2d(\text{Å})\sin(\theta) = n\lambda(\text{Å}) = n\frac{12.4}{E(keV)}}$$



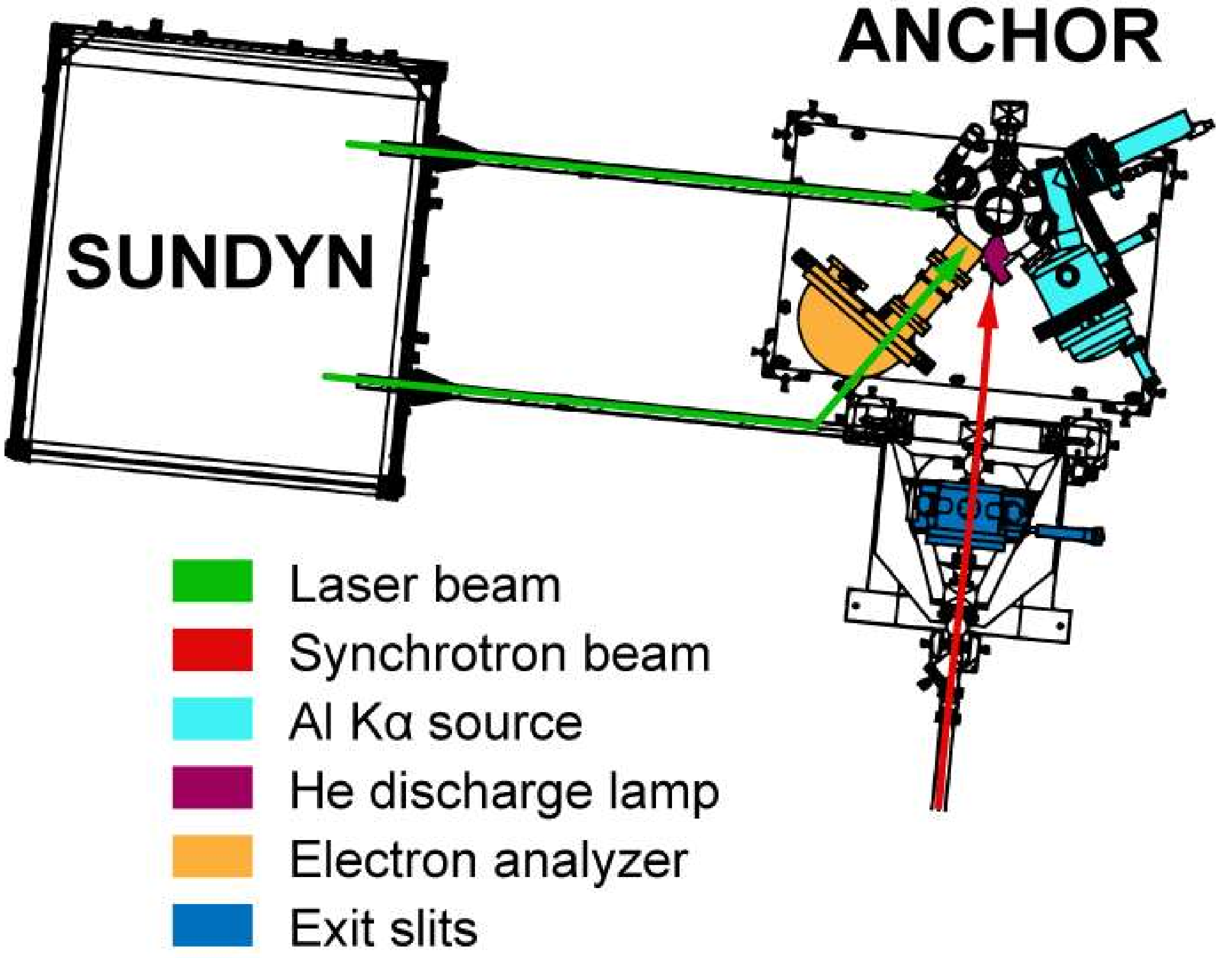
Crystal	Lithium fluoride			Quartz		Indium Antimonide	Silicon		Germanium		Pentaerythritol PET	Ammonium Dihydrogen Phosphate ADP
Chemical Formula	LiF			SiO_2		InSb	Si		Ge		$C(CH_2OH_2)$	$NH_4H_2PO_4$
Crystal system	Cubic			Hexagonal		Cubic	Cubic		Cubic		Quadratic	Quadratic
Parameters												
a.................Å....	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	7.542
ß.......................												
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)

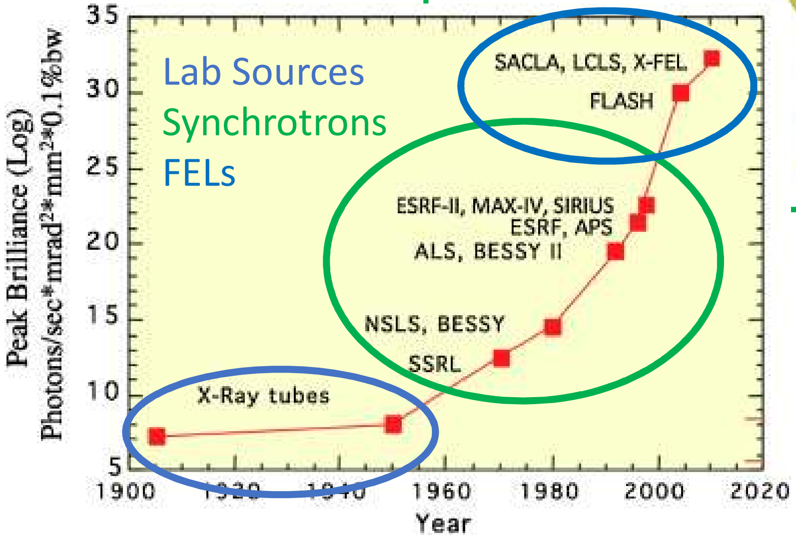

He I (1s², ¹S₀)
He II (1s, ²S₁/₂)
¹S ³S ¹P ³P ¹D ³D ¹F ³F
0 1 1 0,1,2 2 1,2,3 3 2,3,4
eV
24.59
∞
24
22
20
18
2
0
5
4
3s
2s
1s
s
p
d
f
3p
3d
2p
2s
2p
522Å (23.74eV)
537Å (23.09eV)
584Å (21.22eV)
54.41
∞
6
5
4s,4p,
4d,4f
3s,3p,3d
2s,2p
1s
243Å (51.01eV)
256Å (48.37eV)
304Å (40.81eV)
eV
52
48
44
40
4
0

	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


ANCHOR
SUNDYN
Laser beam
Synchrotron beam
Al Kα source
He discharge lamp
Electron analyzer
Exit slits

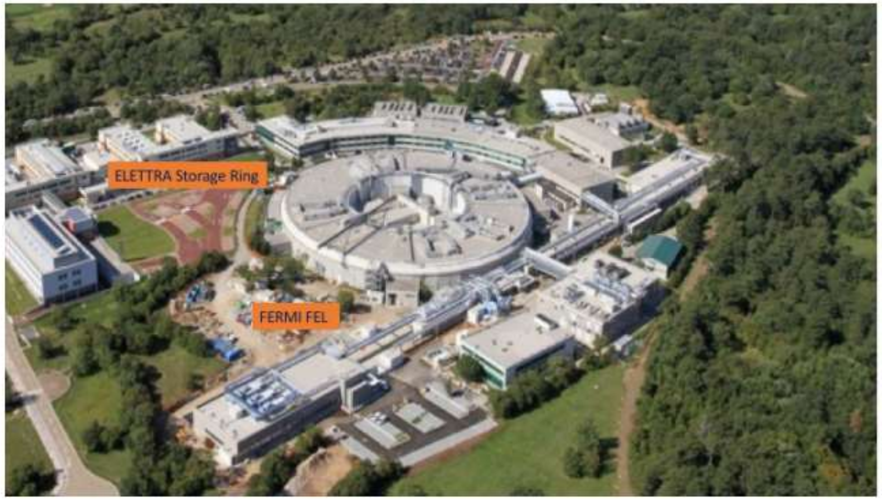
X-Ray Sources

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



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

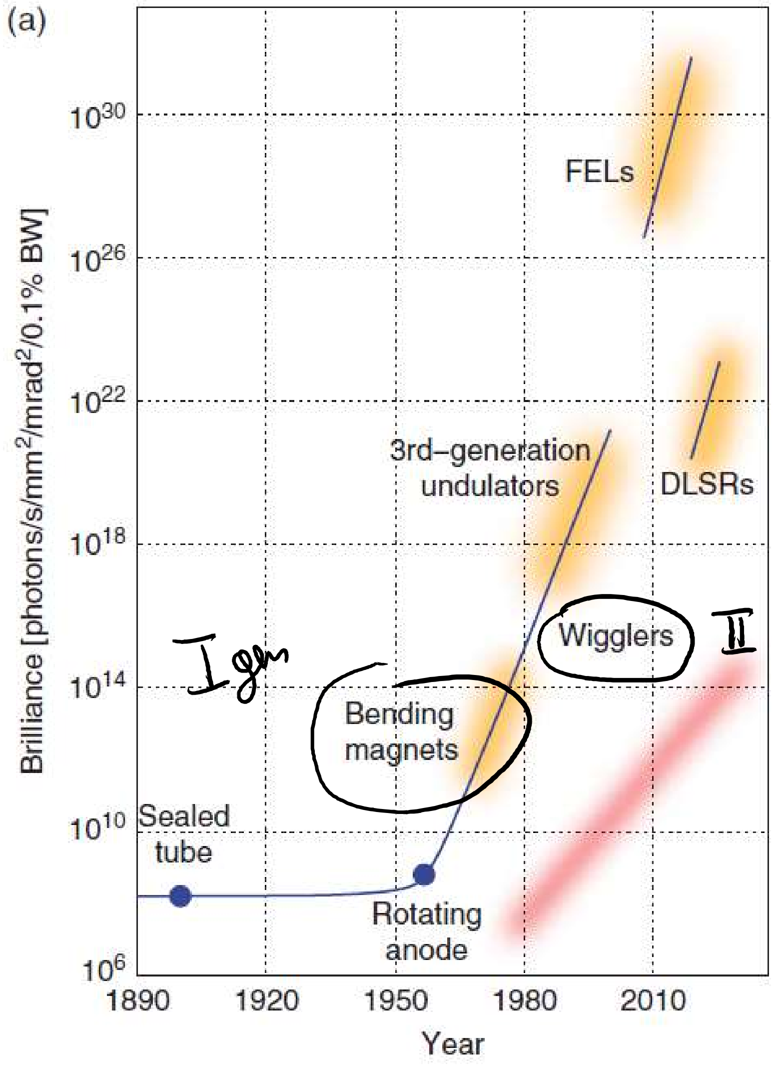
Elettra Synchrotron



USER FACILITY

Elettra Sincrotrone Trieste

ELETTRA: 28 beamlines in cooperation with national and international institutions



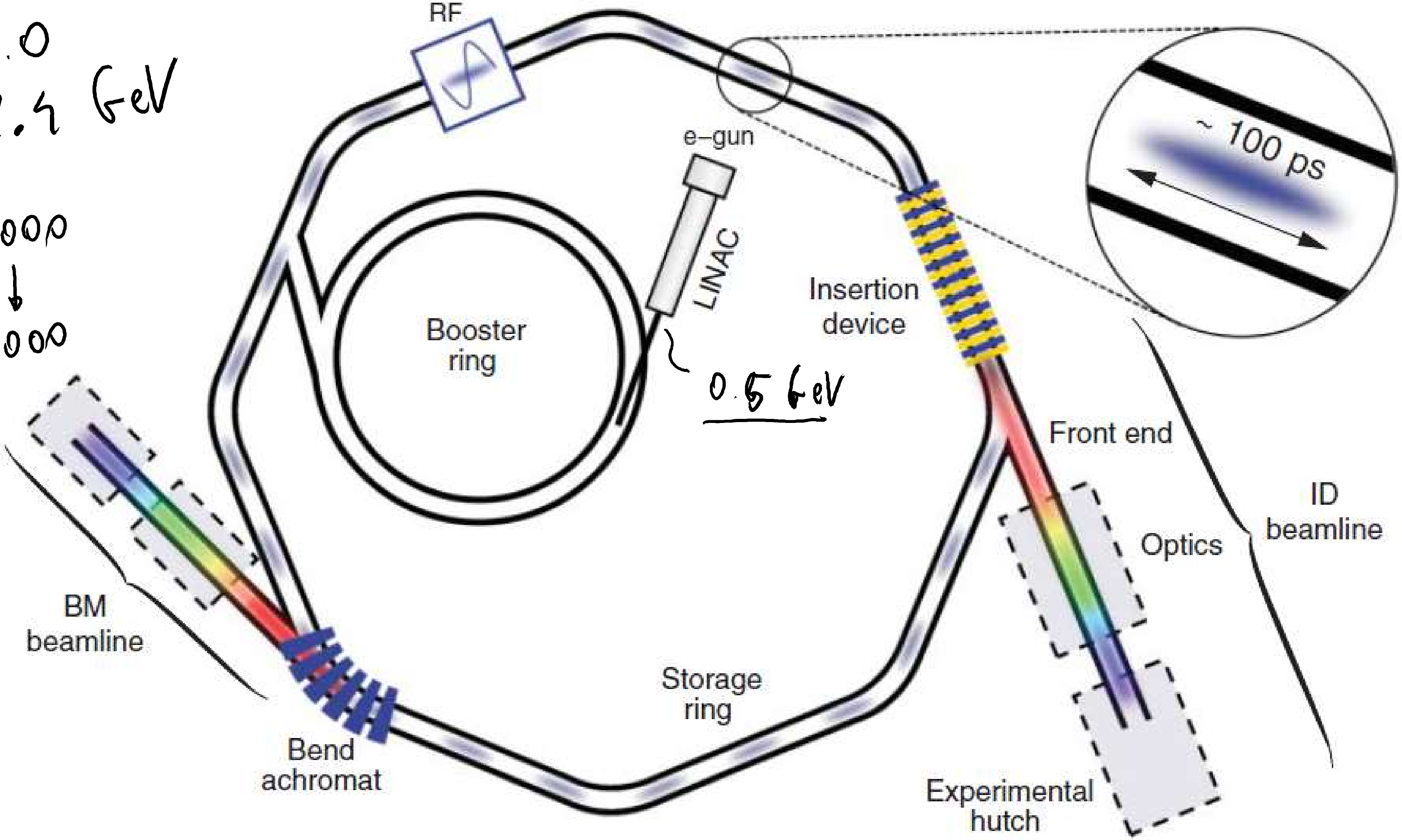
Free Electron Laser

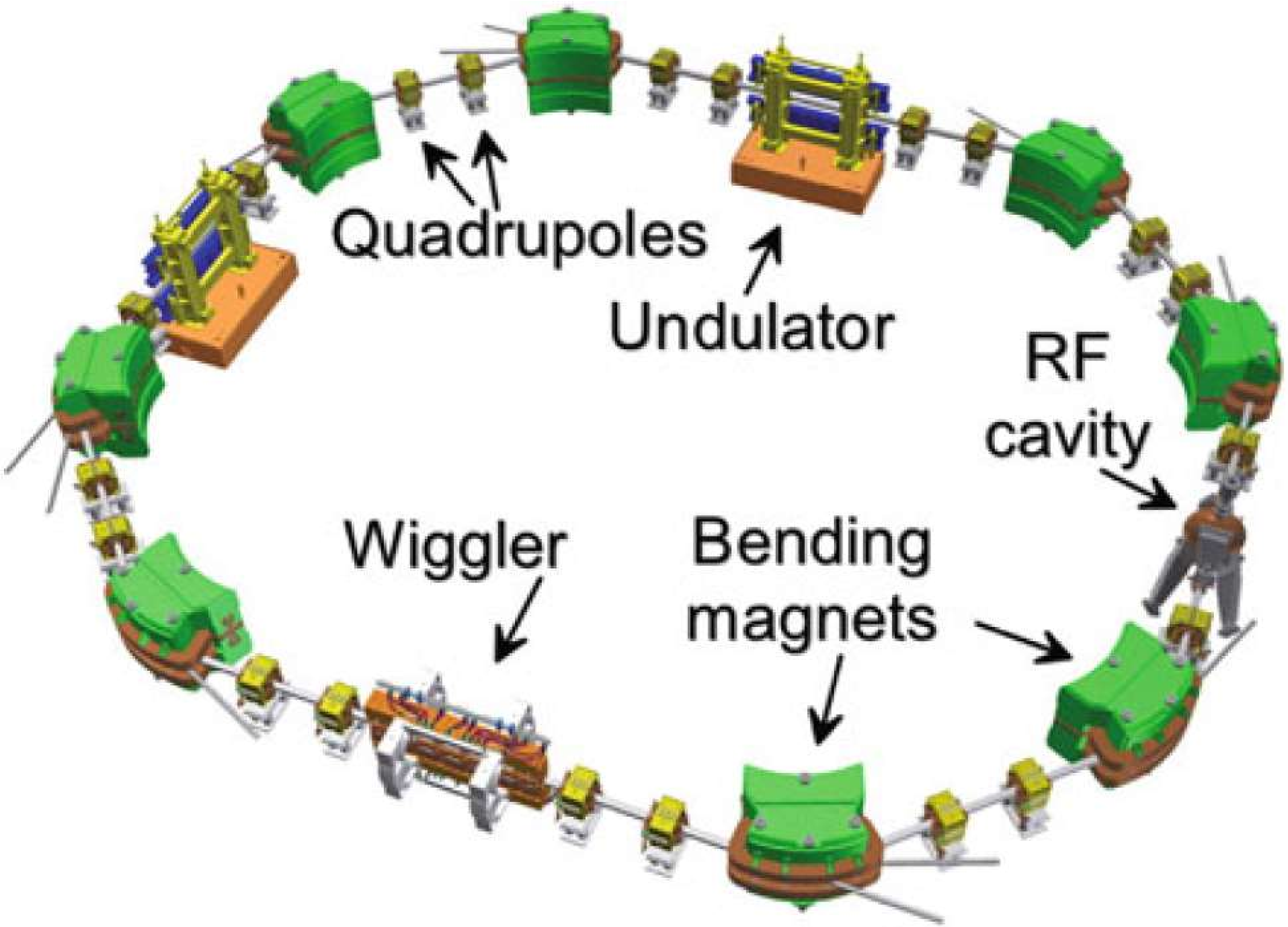
Diffraction Limited Storage Ring

energia e⁻ nell'anello

Elettra : 2.0
2.4 GeV

$$\gamma = \frac{E}{mc^2} \simeq \begin{matrix} 4000 \\ \downarrow \\ 10000 \end{matrix}$$

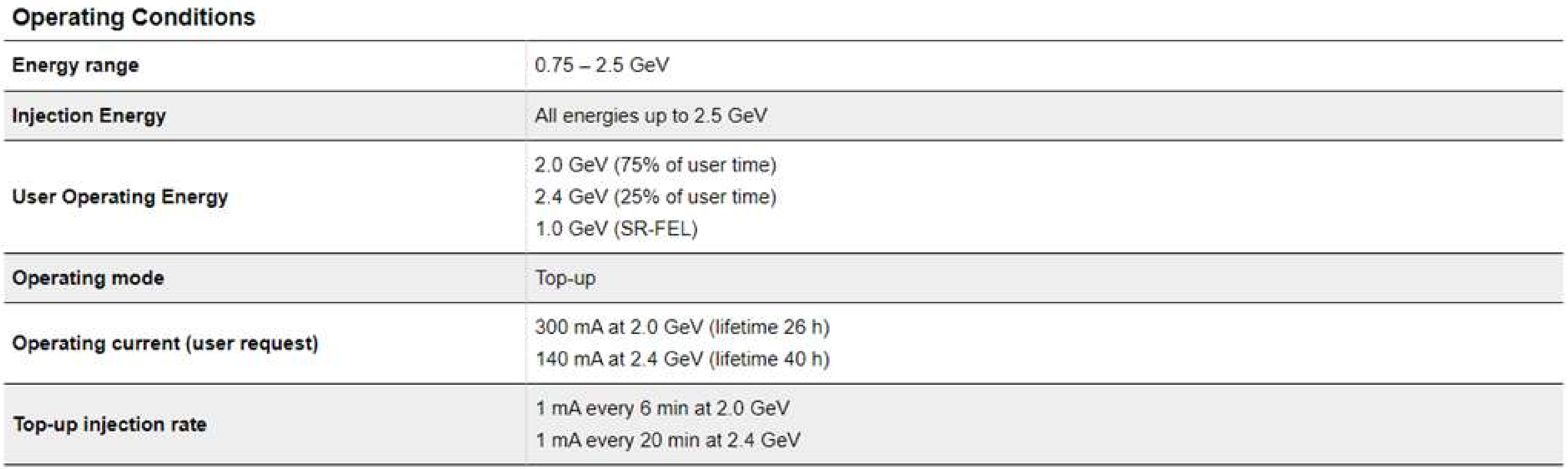




Mobilio-Boscherini-Meneghini,
Synchrotron Radiation, Springer 2015

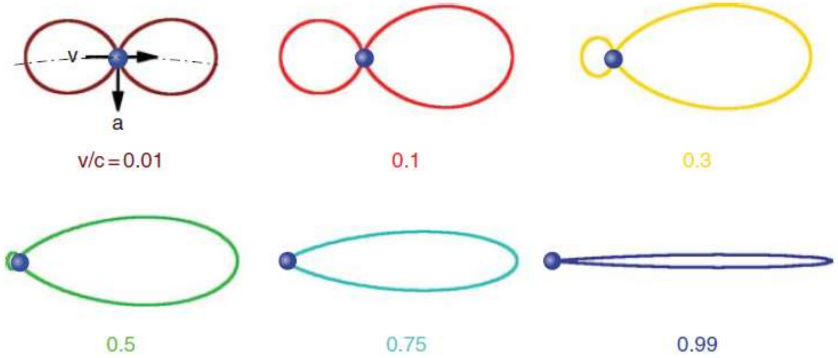
Insertion Devices
- wiggler
- ondulatori

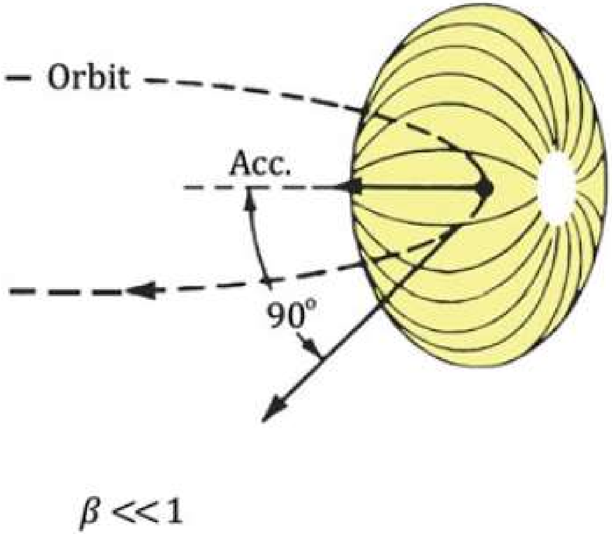
Elettra

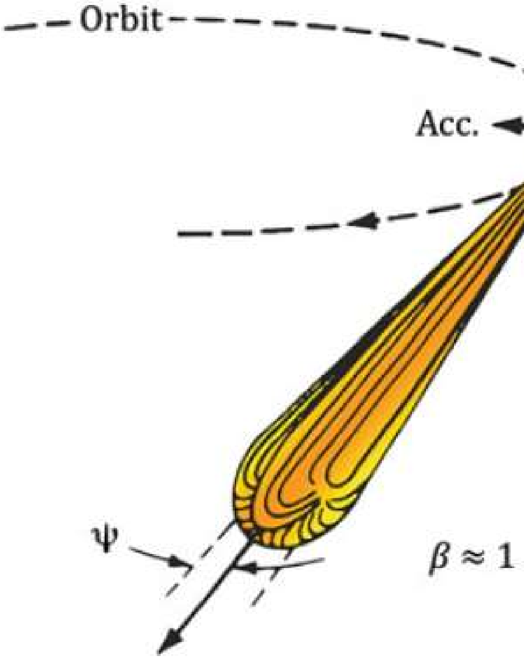


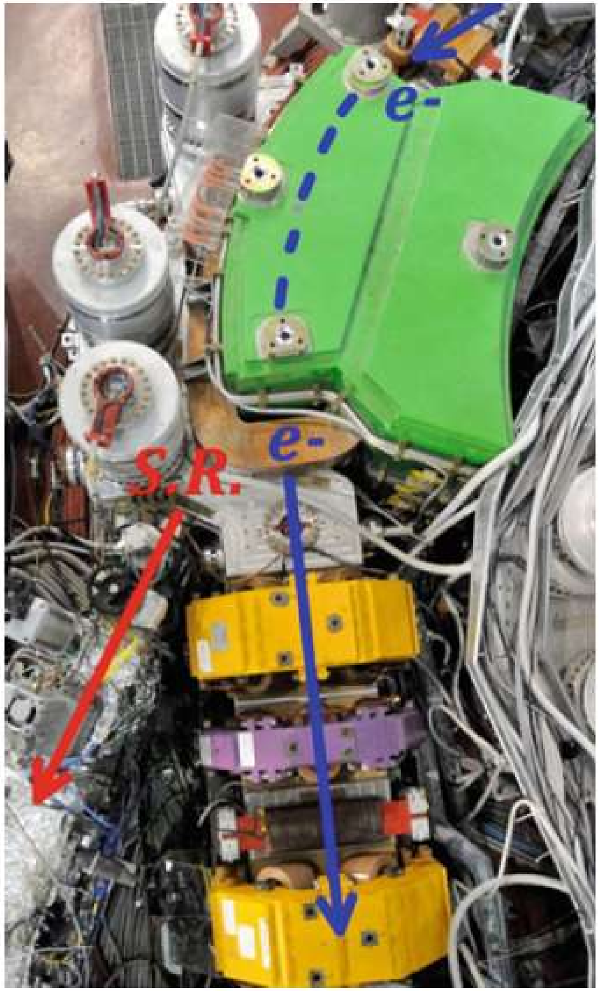
Operating Conditions

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


v
a
v/c = 0.01
0.1
0.3
0.5
0.75
0.99


Orbit
Acc.
90°
$\beta << 1$


Orbit
Acc.
ψ
$\beta \approx 1$

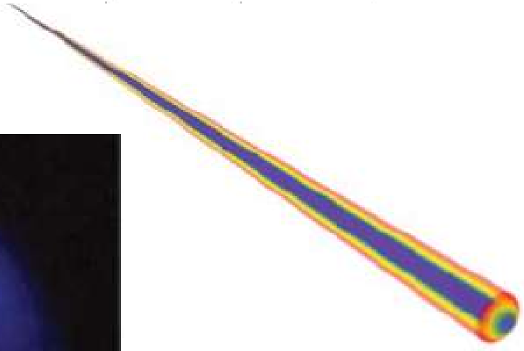

e-
e-
S.R.

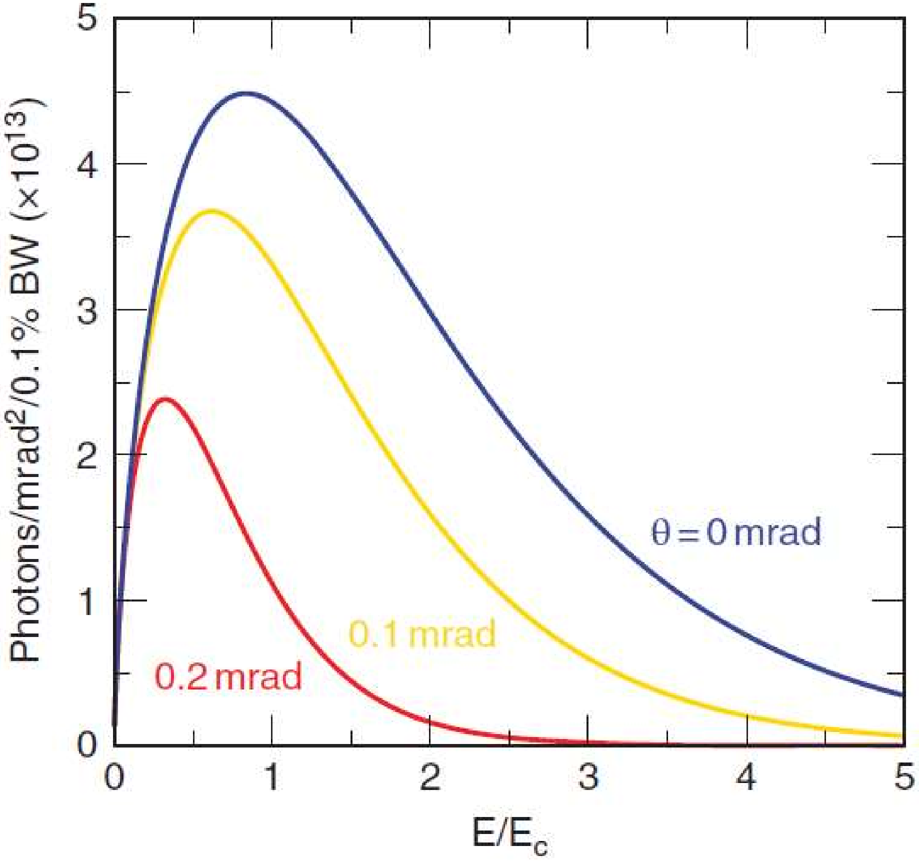
Energia critica del magnete curvante

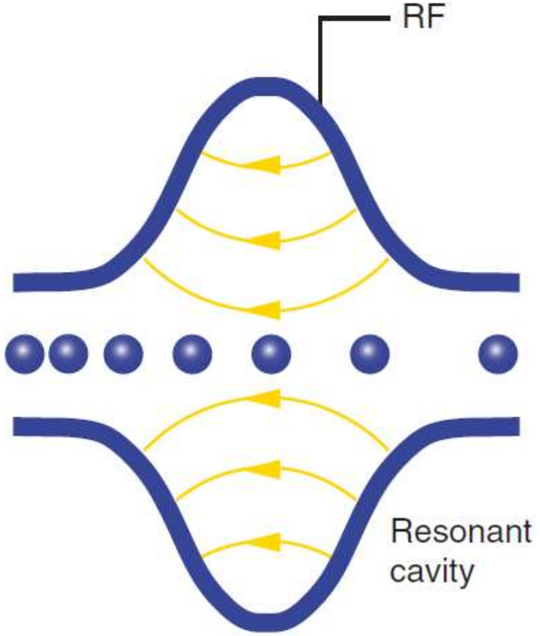
Elettra

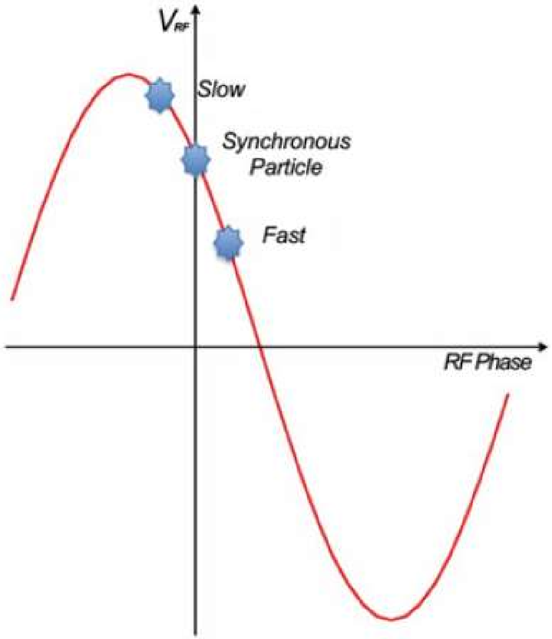
Critical energy [keV]		3.2	5.5
Bending magnet field [T]		1.2	1.45

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

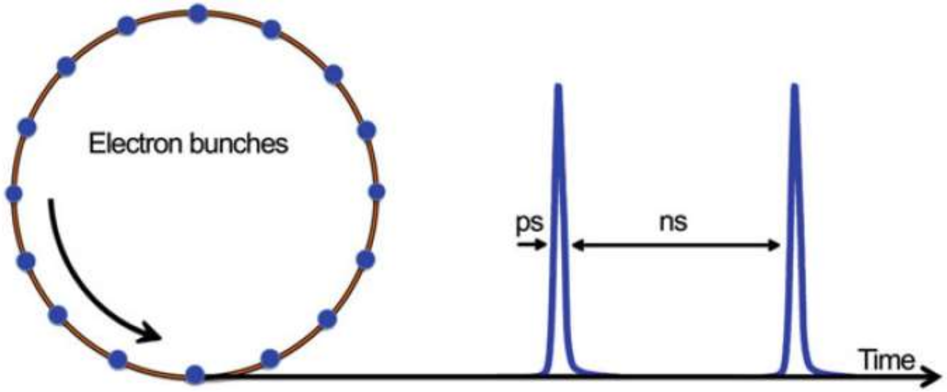


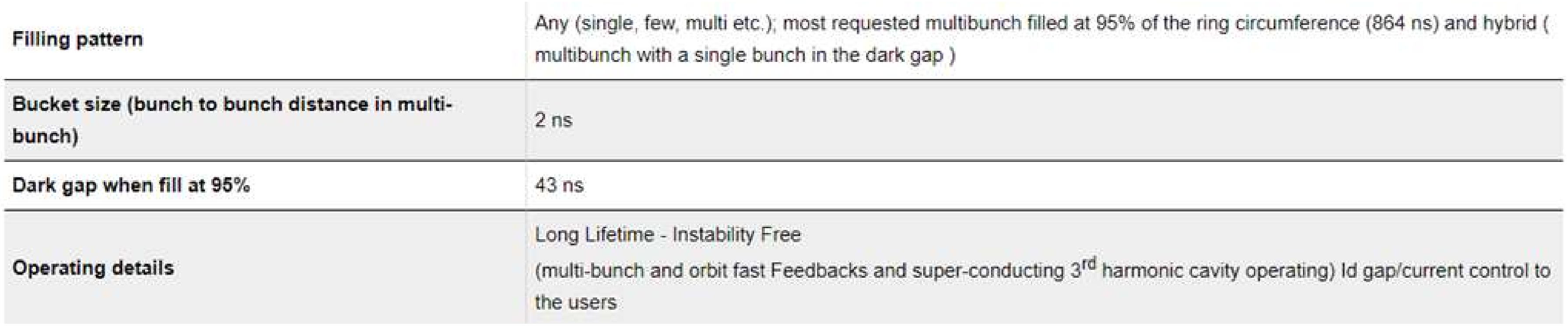






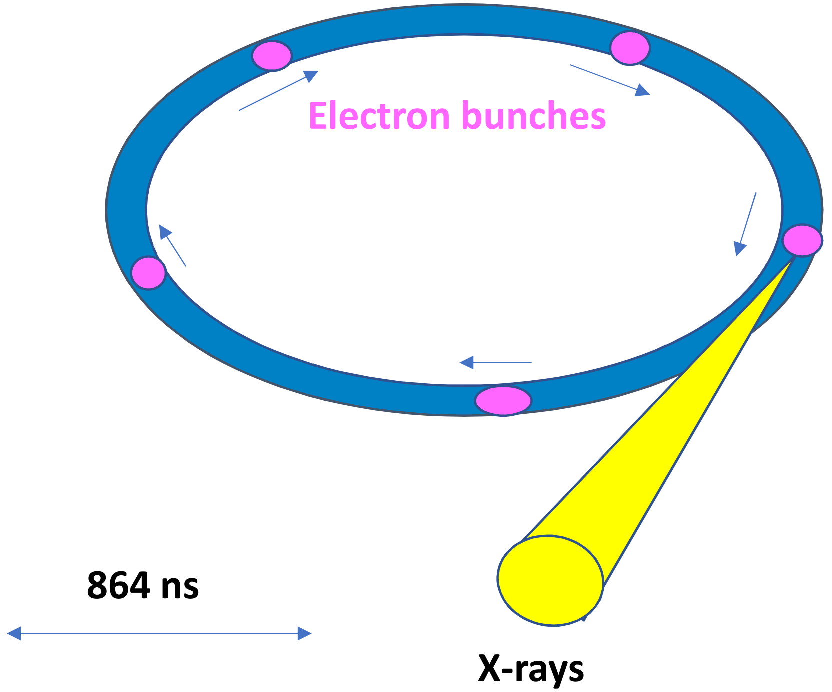
Mobilio-Boscherini-Meneghini,
Synchrotron Radiation, Springer 2015





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 3rd harmonic cavity operating) Id gap/current control to the users

Synchrotron X-ray pulses



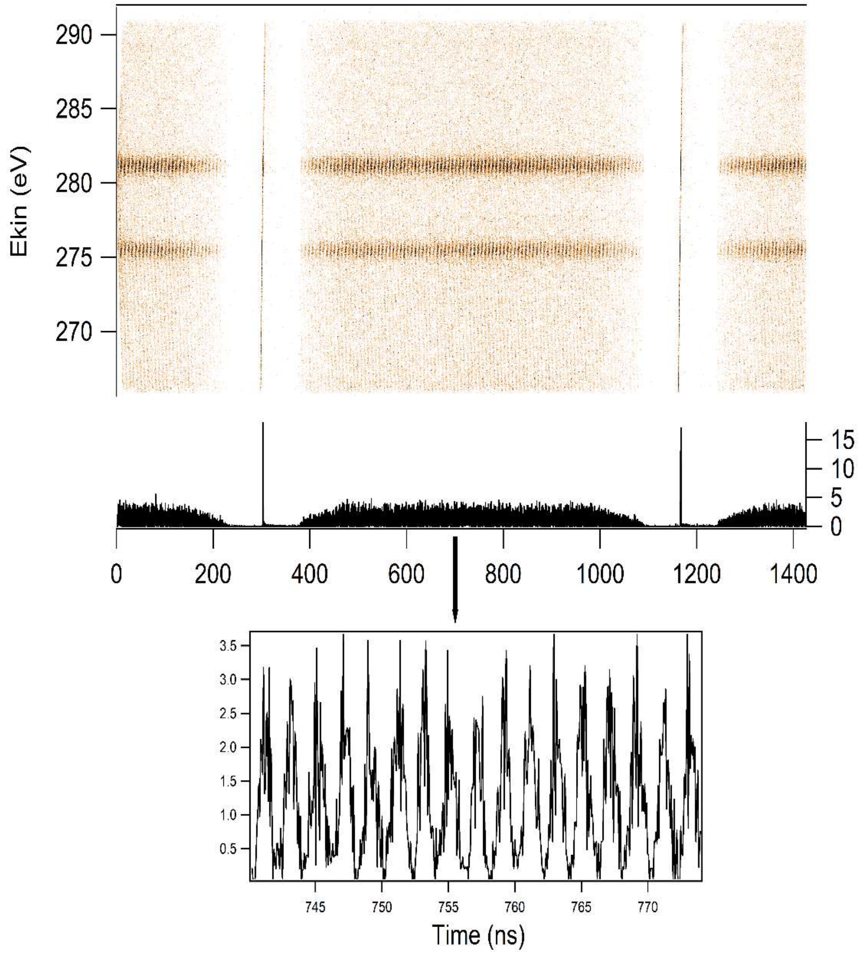
Electron bunches

864 ns

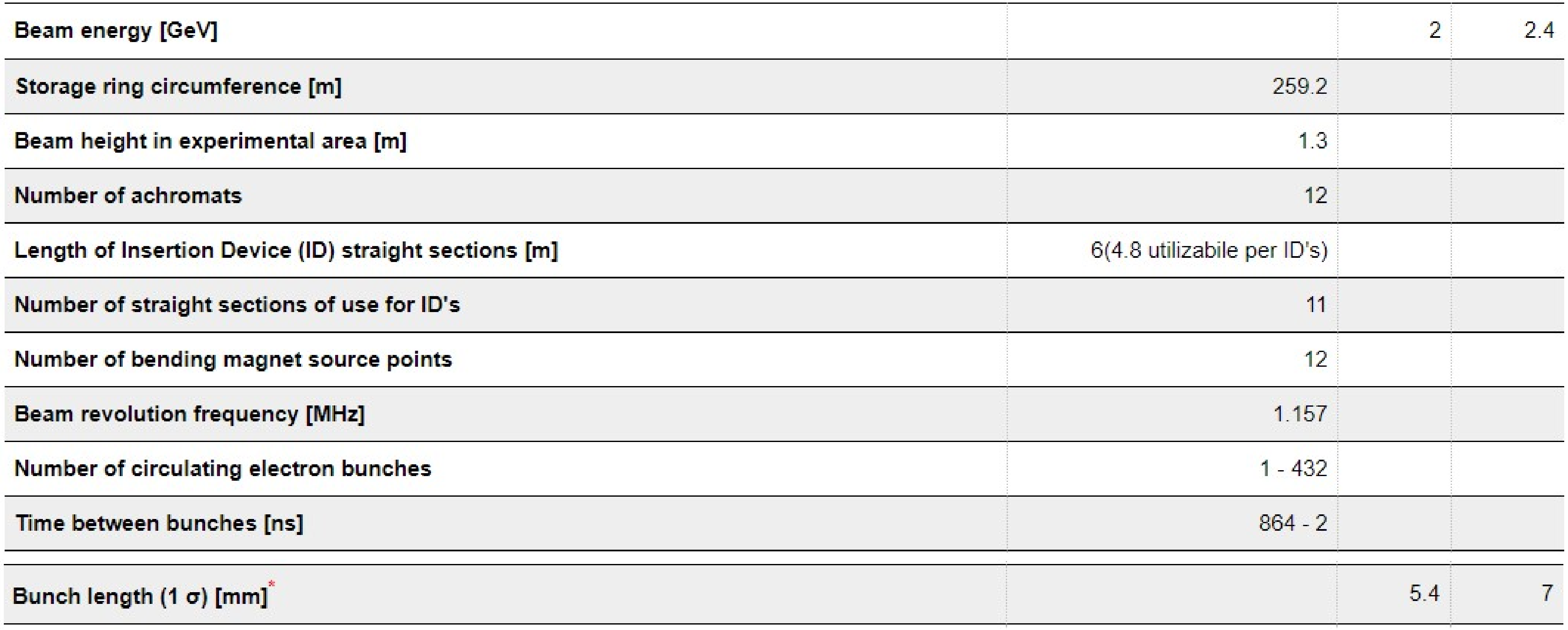
X-rays

100 ps X-ray pulses

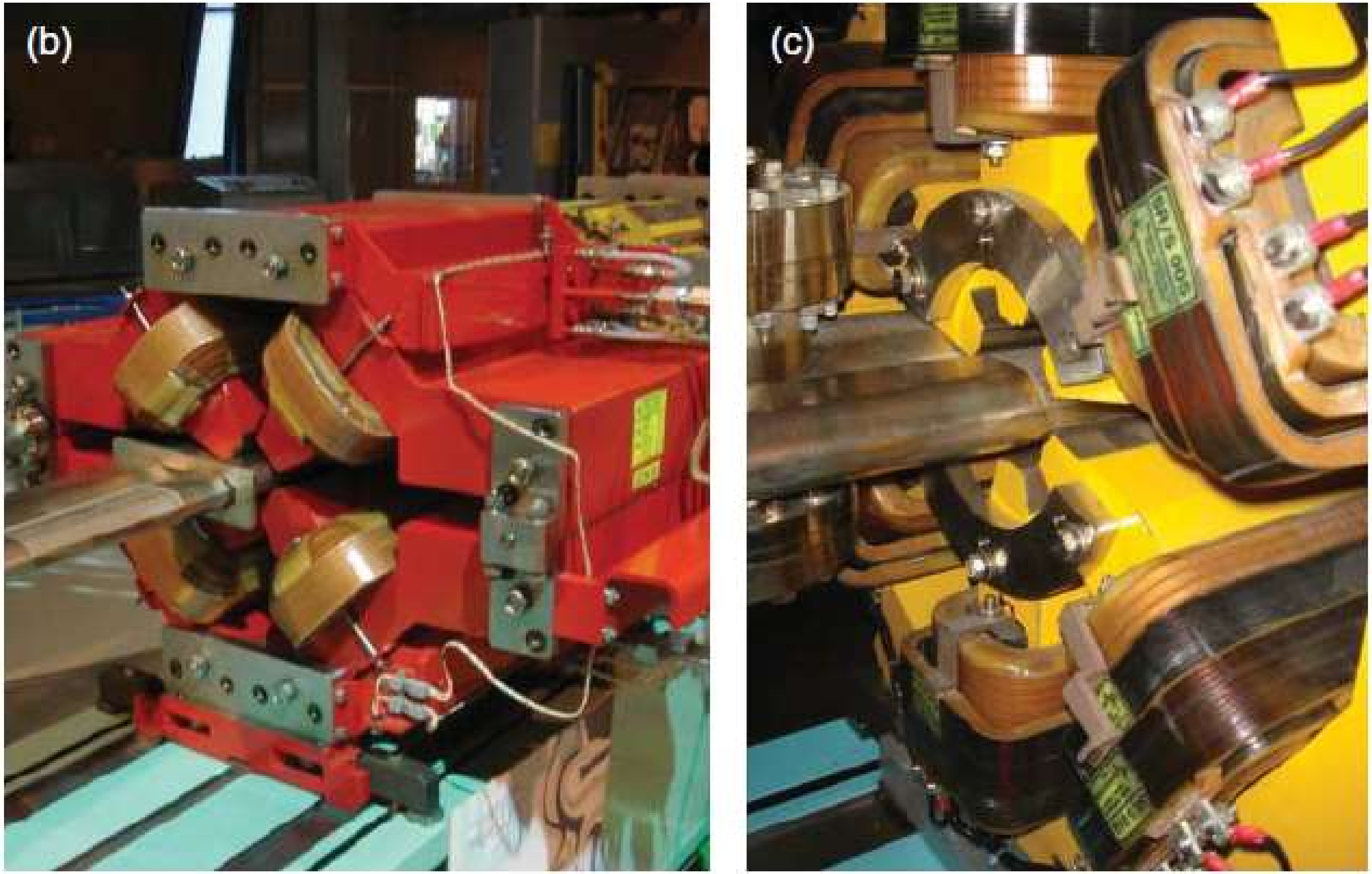
Elettra filling pattern



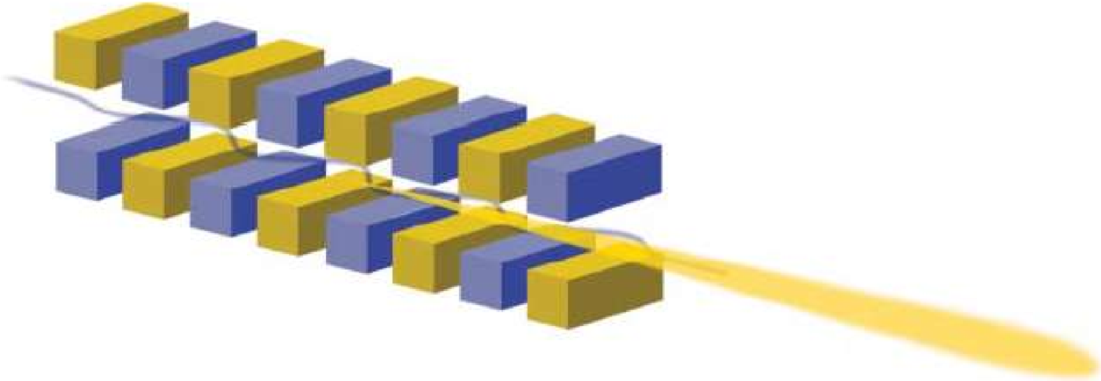
Elettra



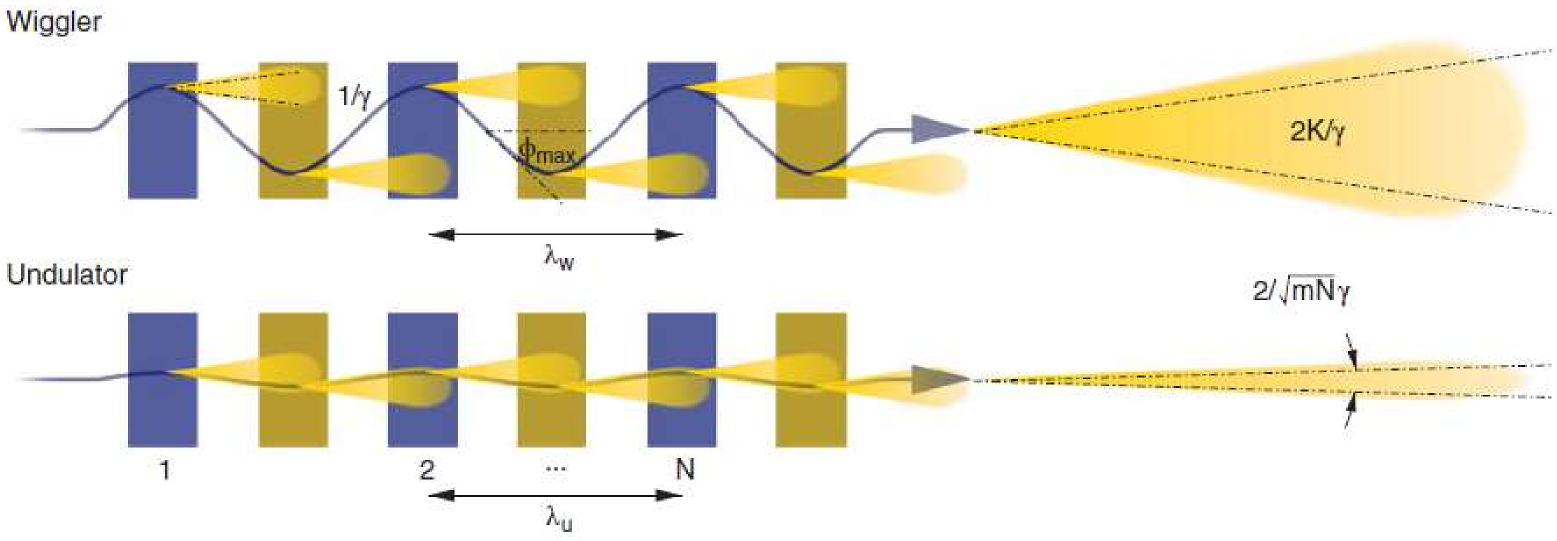
Beam energy [GeV]		2	2.4
Storage ring circumference [m]	259.2		
Beam height in experimental area [m]	1.3		
Number of achromats	12		
Length of Insertion Device (ID) straight sections [m]	6(4.8 utilizabile per ID's)		
Number of straight sections of use for ID's	11		
Number of bending magnet source points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



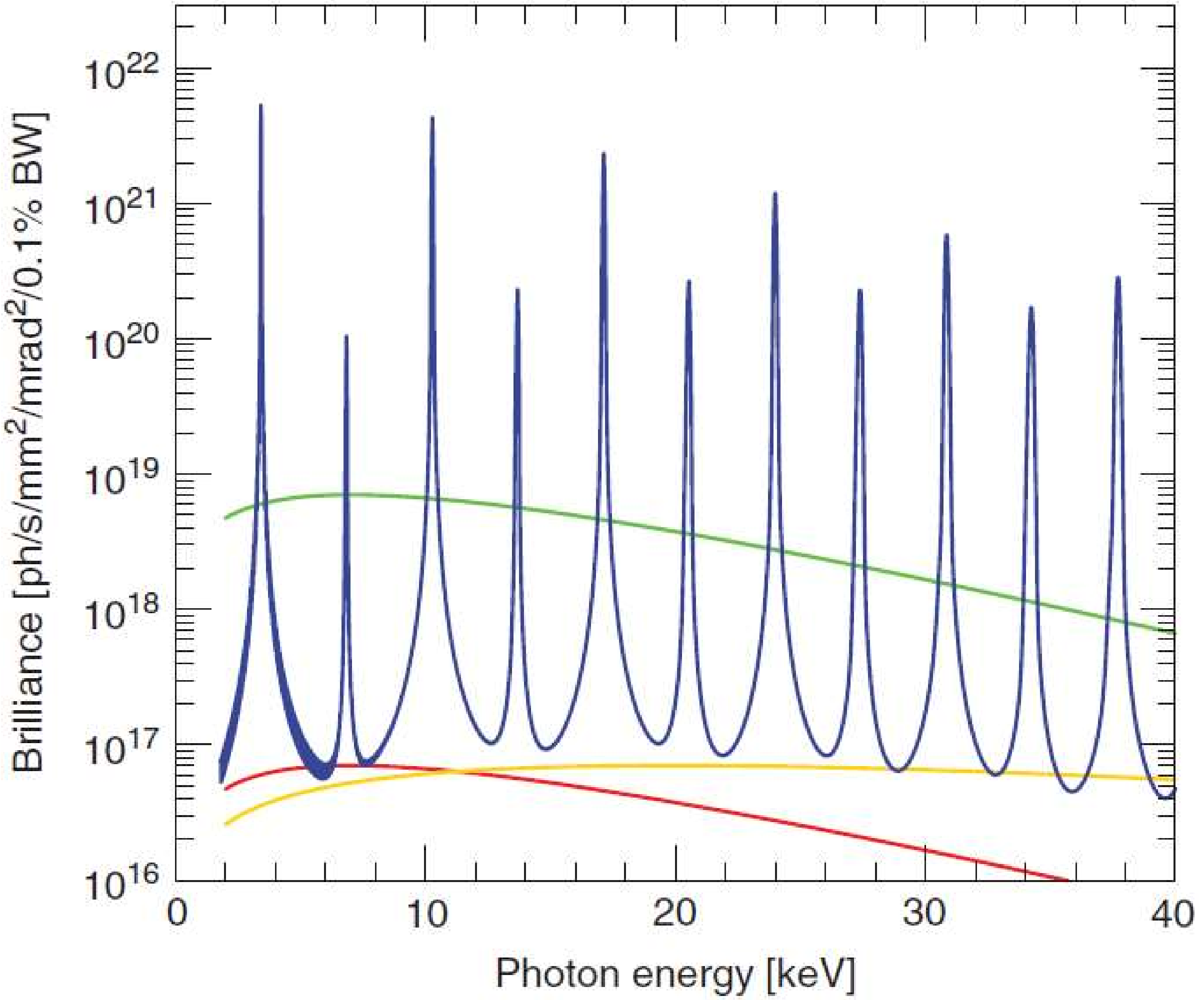
(b)
(c)




(b)



$$K = \frac{eB_0}{m_e c k_{u,w}} = 0.934\ \lambda_{u,w}[\text{cm}]\ B_0[\text{T}]$$



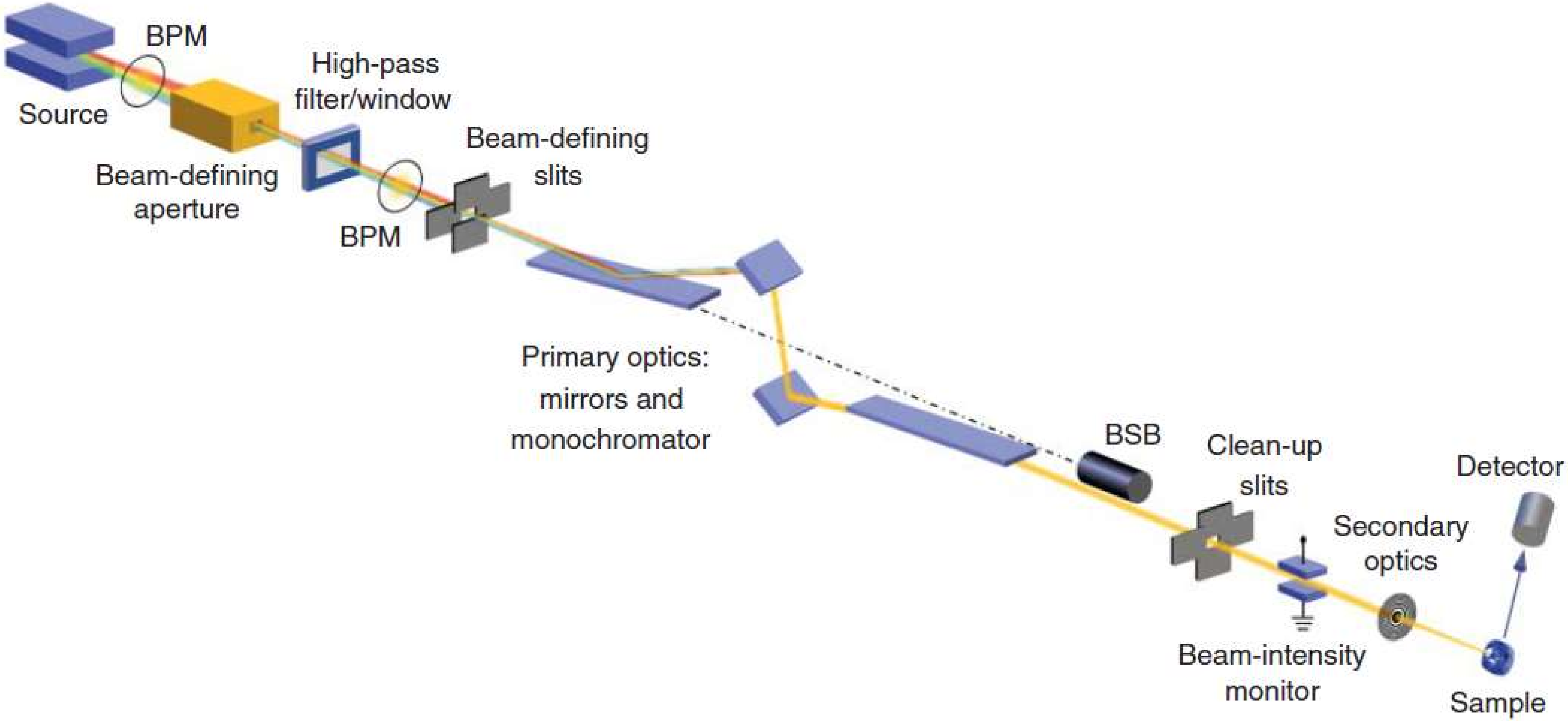
🟦 ondulatore

🟩 wiggler

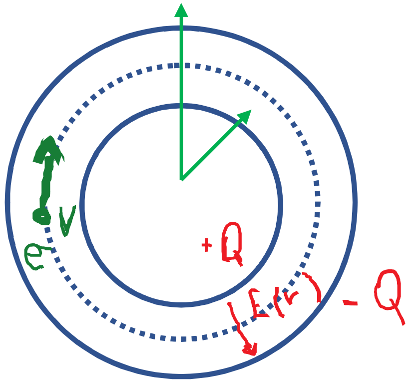
🟨 Bending 4 gen (superbend)

🟥 Bending

Beamlines


BPM
Source
High-pass filter/window
Beam-defining aperture
Beam-defining slits
BPM
Primary optics: mirrors and monochromator
BSB
Clean-up slits
Detector
Secondary optics
Beam-intensity monitor
Sample

L’analizzatore di elettroni emisferico



Condensatore sferico

Raggio interno: R_1

Raggio interno: R_2

$$E(r) = \frac{Q}{4\pi\varepsilon_0}\frac{1}{r^2}$$

$$\Delta V = \int_{R_1}^{R_2} E(r)\,dr = \frac{Q}{4\pi\varepsilon_0}\left[\frac{1}{r}\right]_{R_1}^{R_2} = \frac{Q}{4\pi\varepsilon_0}\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Consideriamo la traiettoria circolare di raggio intermedio.
In che condizioni un elettrone può percorrerla senza precipitare sula 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 pari alla forza centripeta

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

$\boxed{m\frac{v^2}{r} = eE}$ $\boxed{E(r) = \frac{Q}{4\pi\varepsilon_0}\frac{1}{r^2}}$ $\boxed{\Delta V = \frac{Q}{4\pi\varepsilon_0}\left(\frac{1}{R_1}-\frac{1}{R_2}\right)}$

$$\frac{mv^2}{\cancel{r}} = e\frac{Q}{4\pi\varepsilon_0}\frac{1}{r^{\cancel{2}}}$$

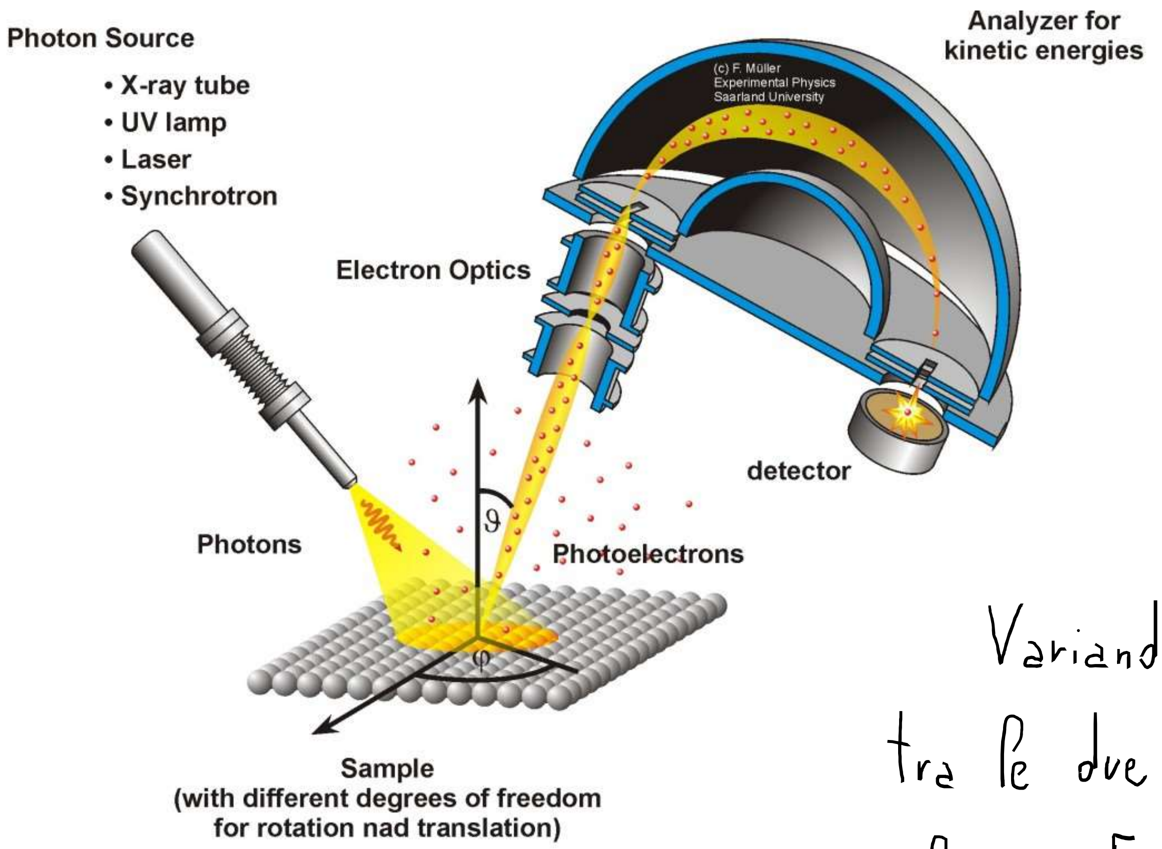
$$r = \frac{R_1+R_2}{2}$$ (raggio intermedio)

$$Q = \Delta V\, 4\pi\varepsilon_0\frac{R_1\cdot R_2}{R_2-R_1}$$

$$= 2e\Delta V\frac{R_1R_2}{R_2^2-R_1^2}$$

$$\boxed{\frac{1}{2}mv^2 = e\Delta V\frac{R_1R_2}{R_2^2-R_1^2}} = E_p$$

pass energy

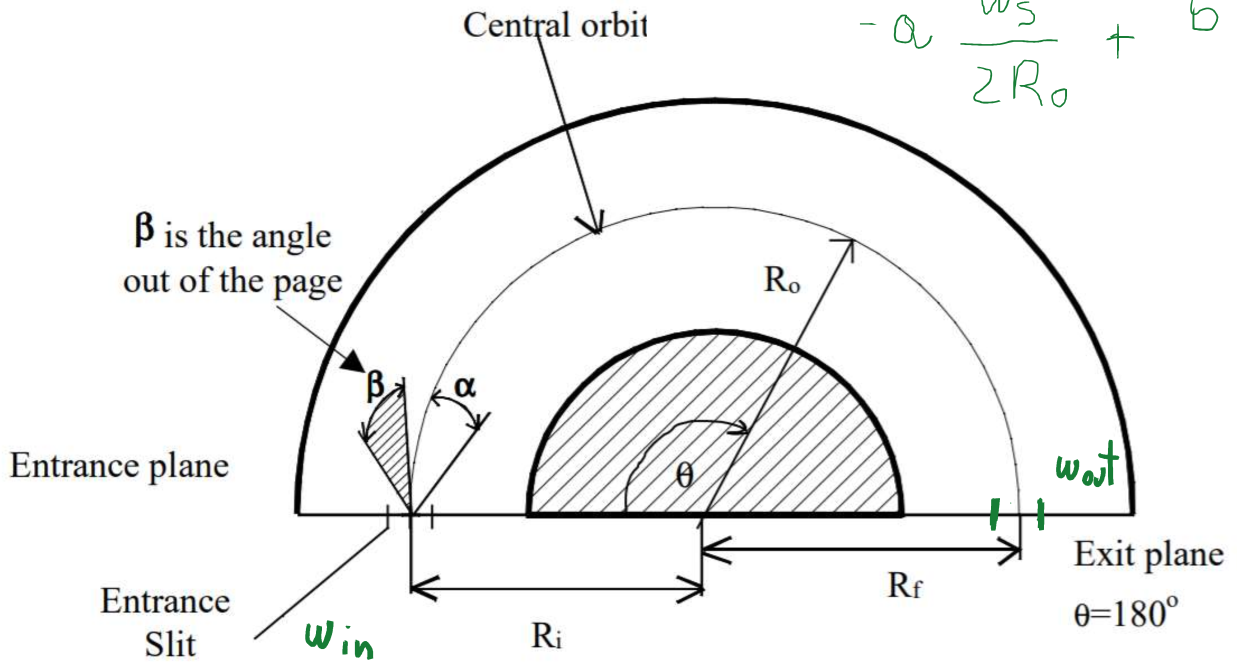


https://jacobs.physik.uni-saarland.de/

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

Risoluzione energetica

$$-a\,\frac{w_s}{2R_0} + b\,\alpha^2$$



$$\frac{\Delta E_p}{E_p} = -a\,\frac{w_s}{2R_0} + b\,\alpha^2$$

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

a, b parametri dell'analizzatore

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

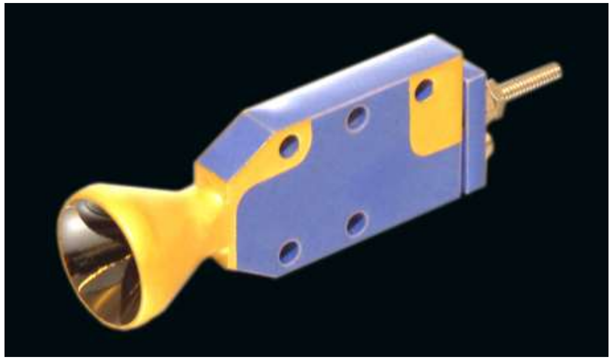
10 elettroni al secondo corrispondono ad una corrente di:

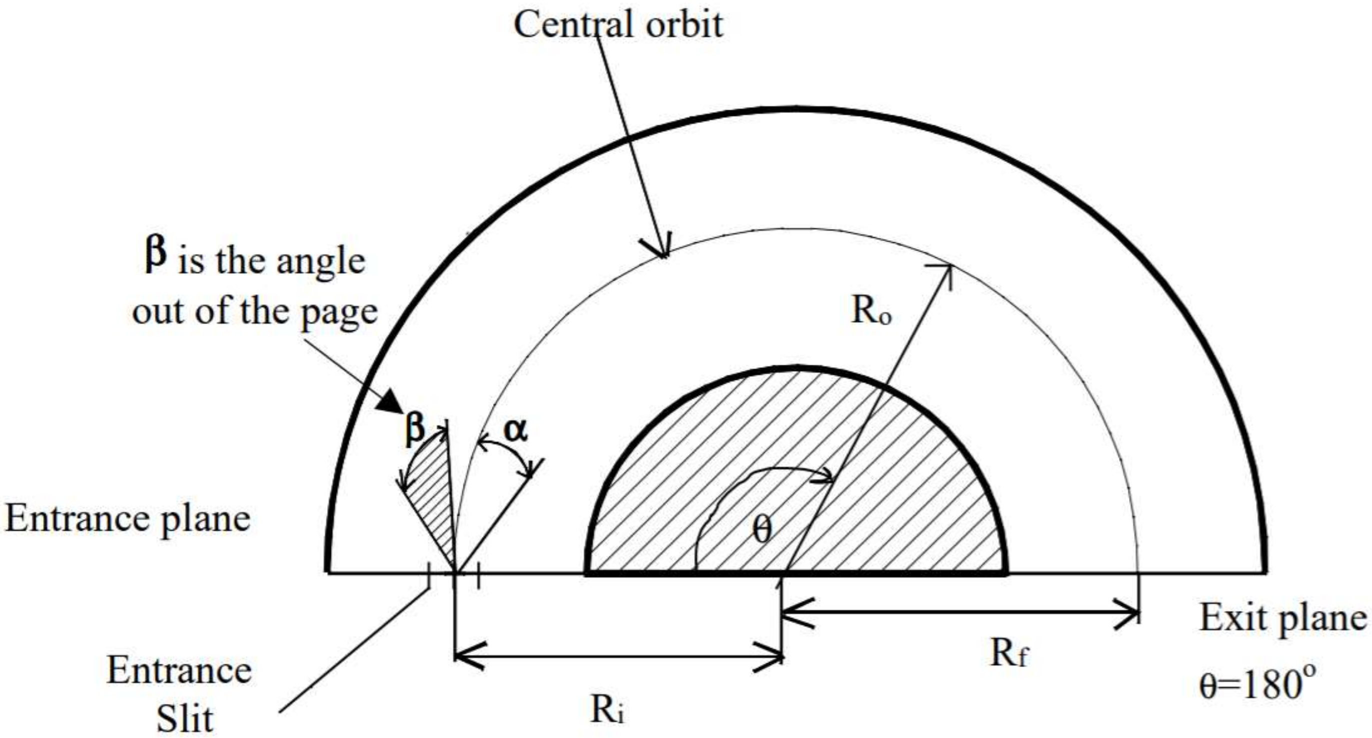
$$10 \times 1.6 \times 10^{-19} \, C/s \sim 10^{-18} \, A$$

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

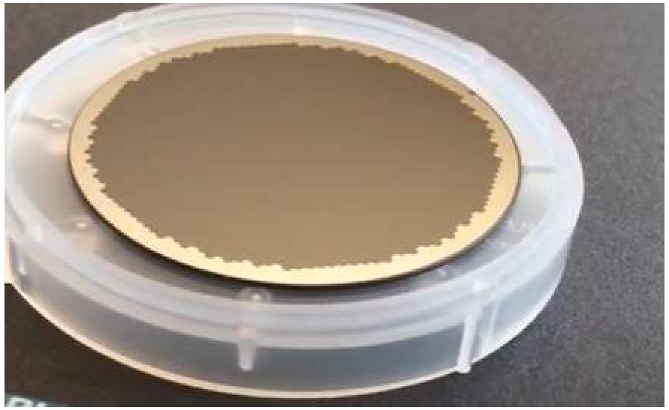
→ Serve amplificare il segnale

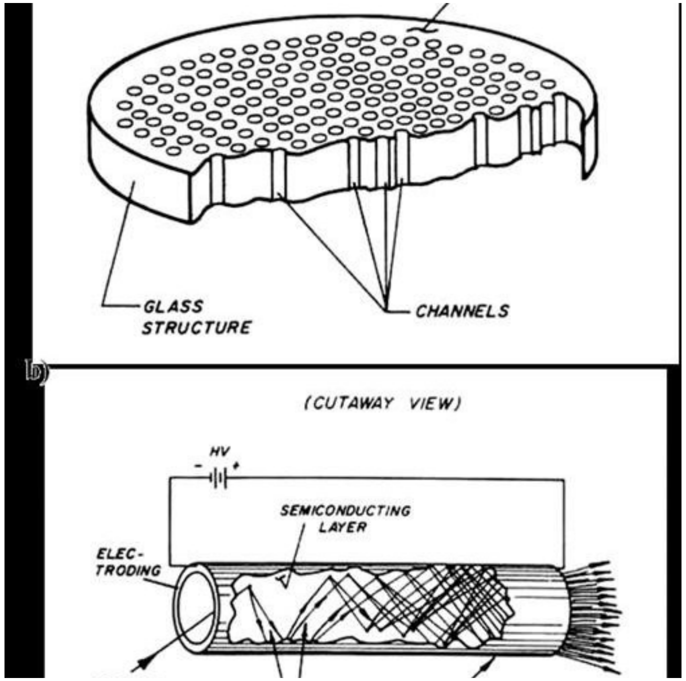
Channeltron



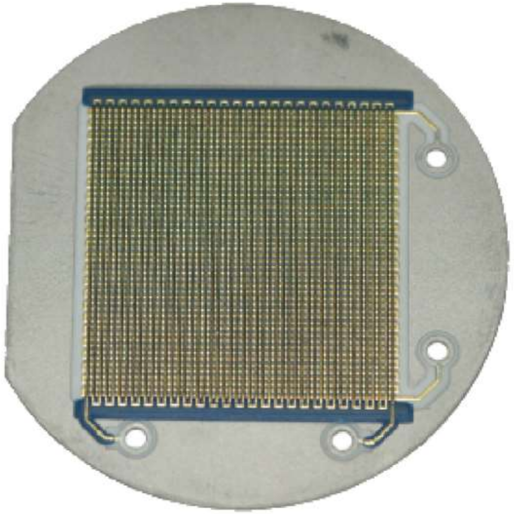

Central orbit
β is the angle out of the page
β
α
R_o
θ
Entrance plane
Exit plane
θ=180°
R_f
R_i
Entrance Slit

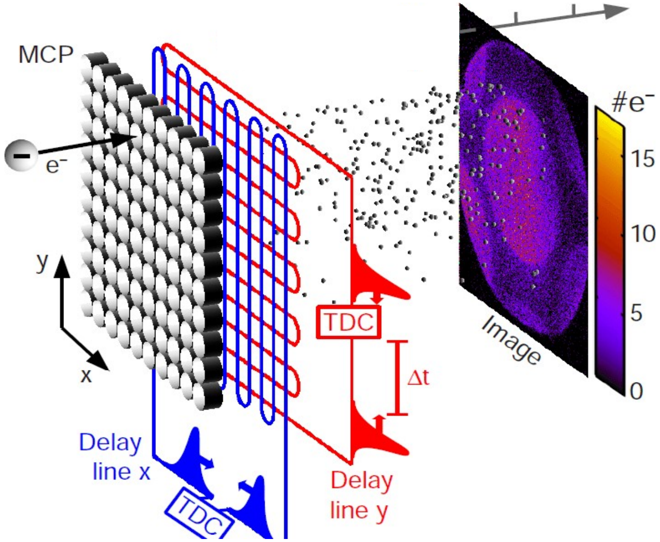
Microchannelplate (MCP)

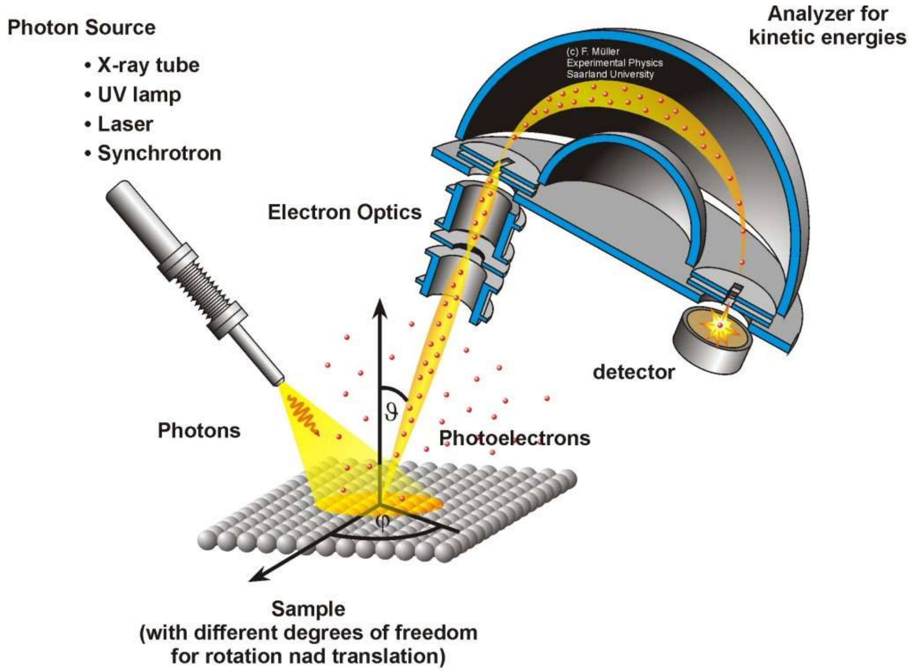


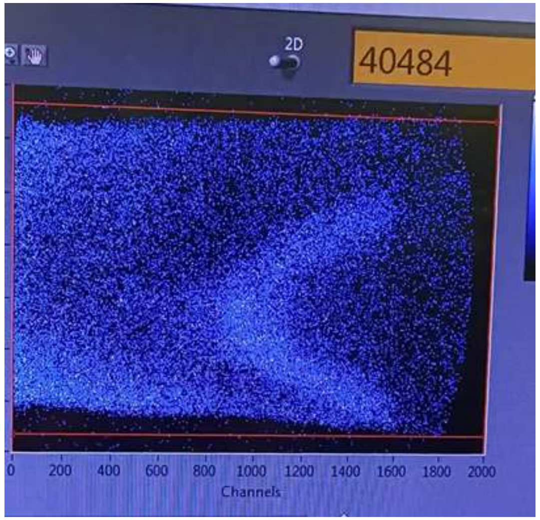


Delay line






Photon Source
• X-ray tube
• UV lamp
• Laser
• Synchrotron
Analyzer for kinetic energies
(c) F. Müller
Experimental Physics
Saarland University
Electron Optics
detector
Photons
ϑ
Photoelectrons
φ
Sample
(with different degrees of freedom
for rotation nad translation)


2D
40484
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Channels