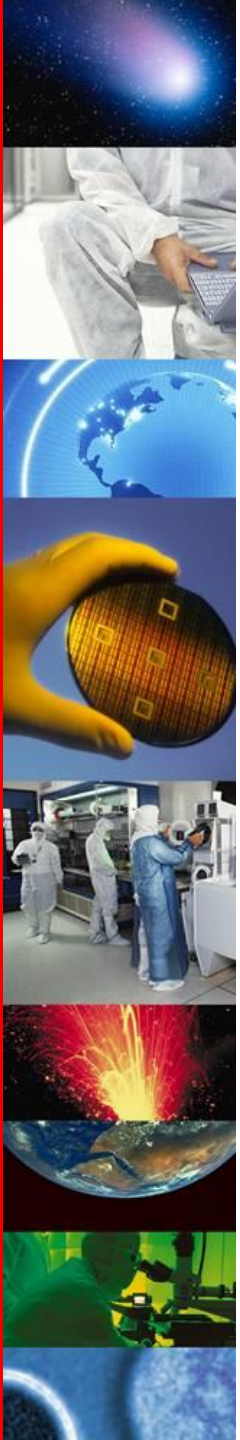

NanoSIMS 50: Optics and practical aspects of Tuning

F. Hillion
Cameca France

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N50 Optics and practical aspects of Tuning

1/ Primary column and secondary transfer optic.

- Chromatic compensation: L3
- Probe size
- Cross over and Images positions.
- Dynamic transfer and E0S.
- Practical rules for E0S tuning

2/ Mass spectrometer and Mass Resolving Power.

- Mass spectrometer: how it works?
- MRP and aberrations
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- Second order aperture aberrations
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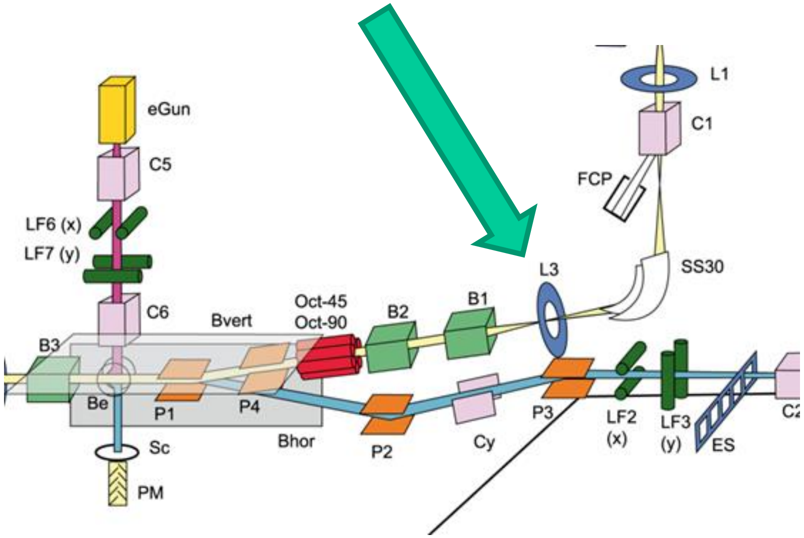
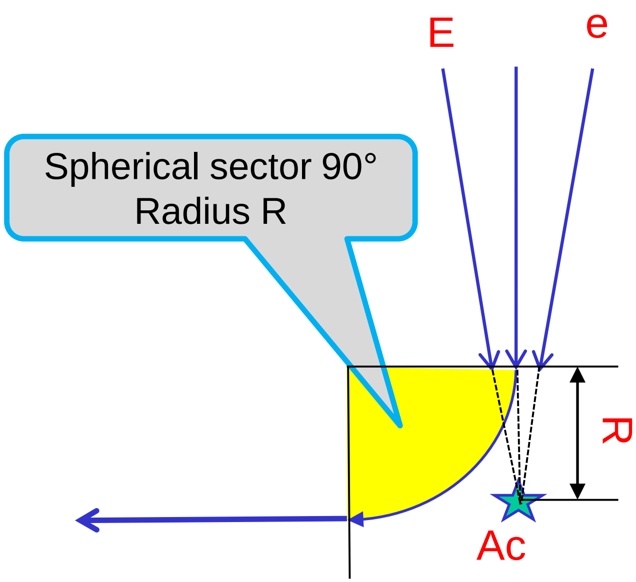
3/ New O^- ion source

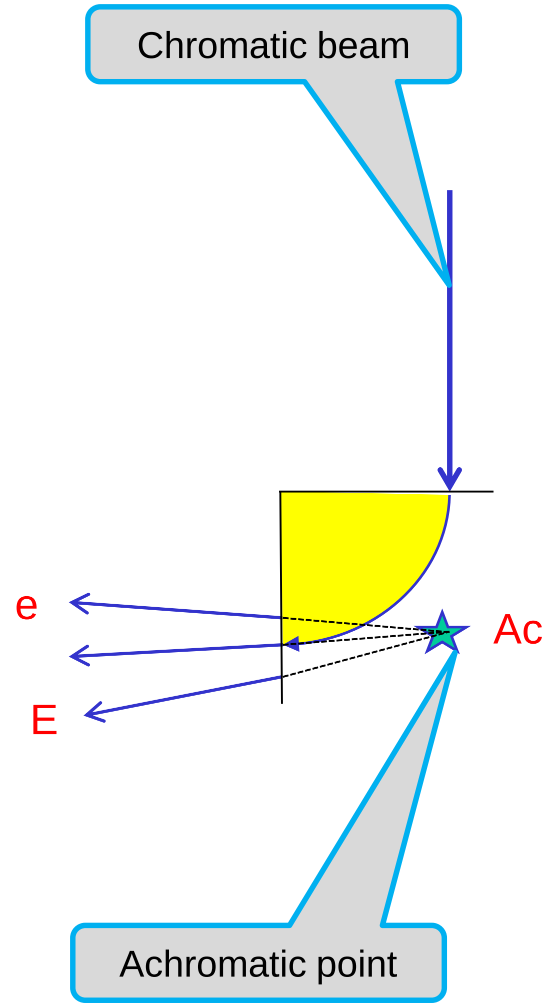
- How it works?
- Preliminary performances

Chromatic compensation: L3



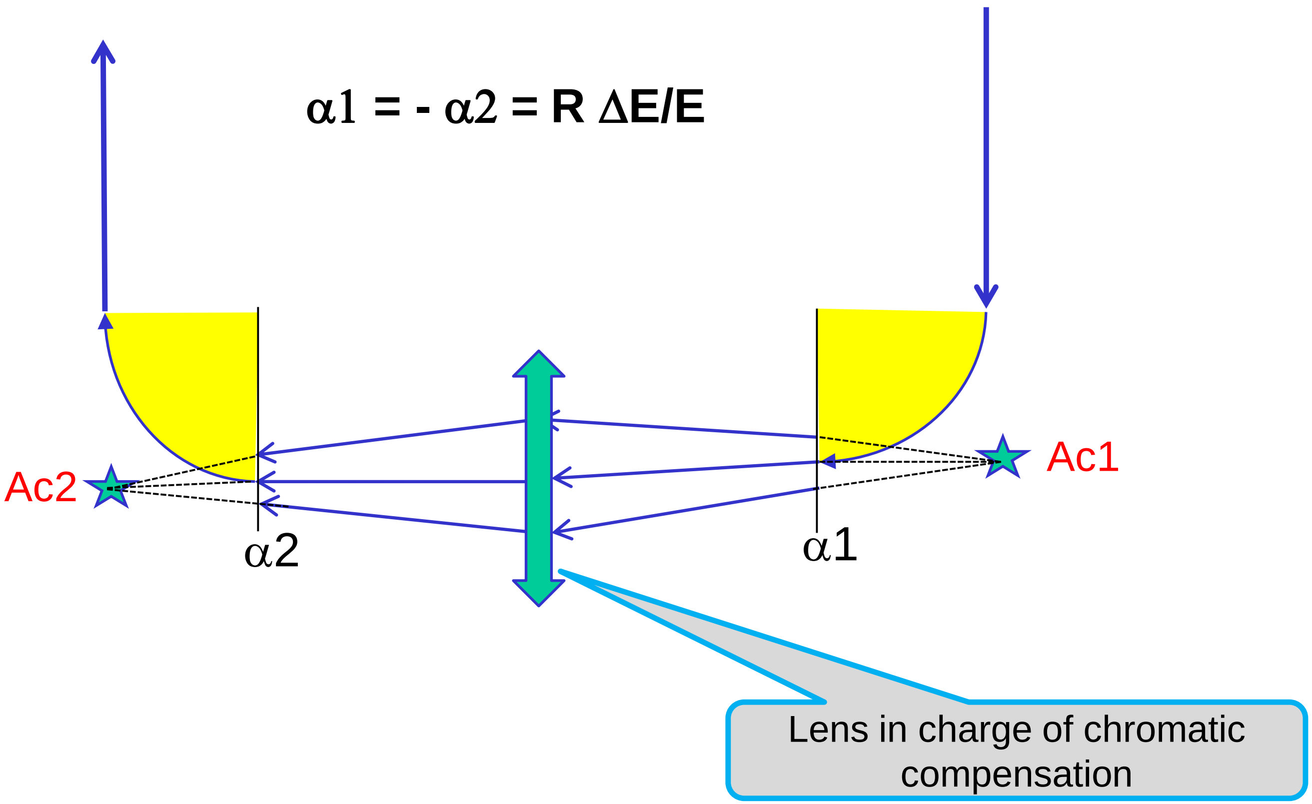


$\alpha = R\ \Delta E/E$



Chromatic compensation: L3

- Two spherical electrostatic sectors, radius = R
- Chromatic compensation of a polychromatic beam.
- Ac2 is the image of Ac1.



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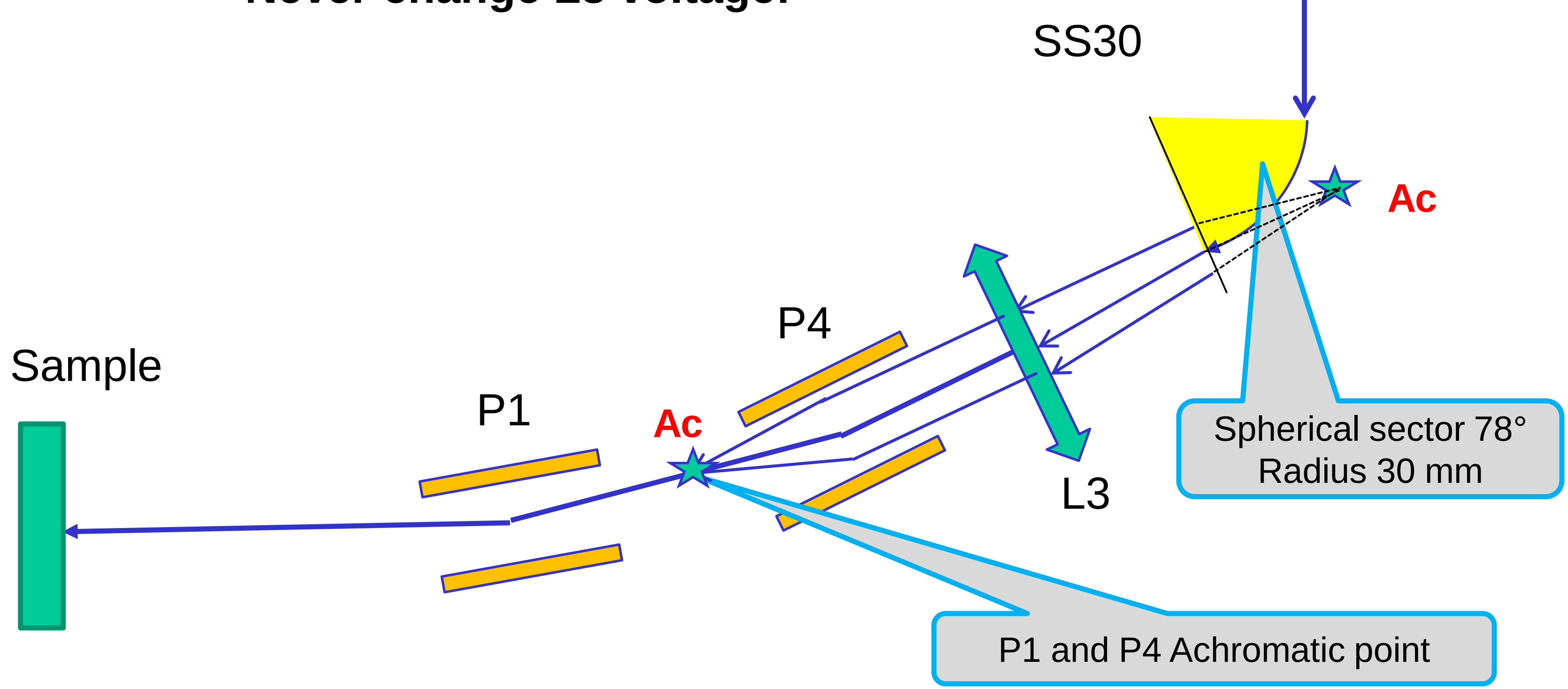
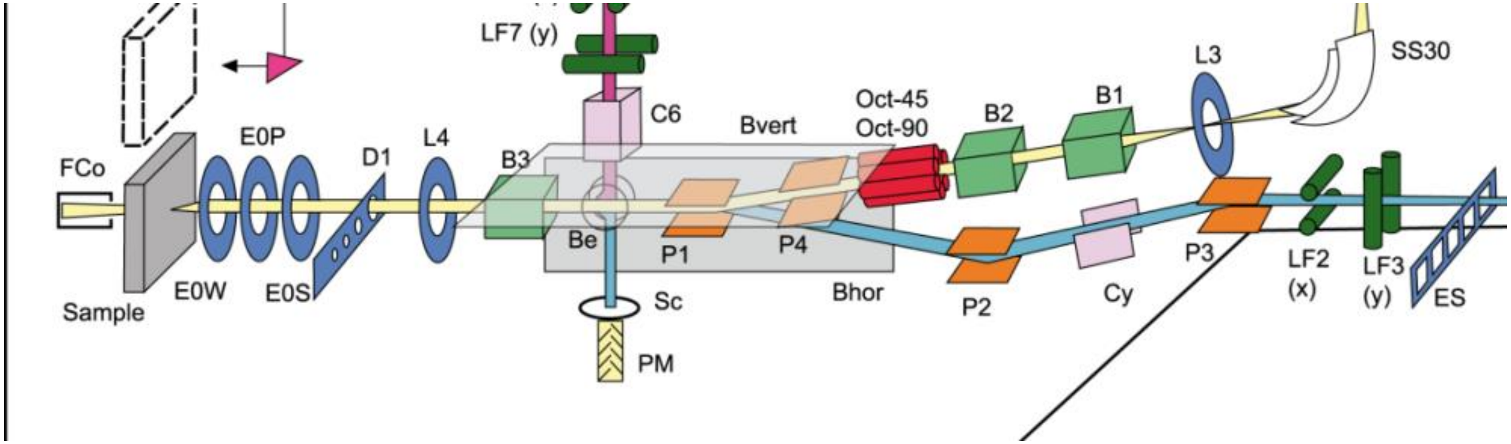
Chromatic compensation: L3

L3 position and voltage (6043 Volts @ 8 keV) have been chosen in order to compensate the chromatic dispersion due to SS30, P4 and P1.

Never change L3 voltage!



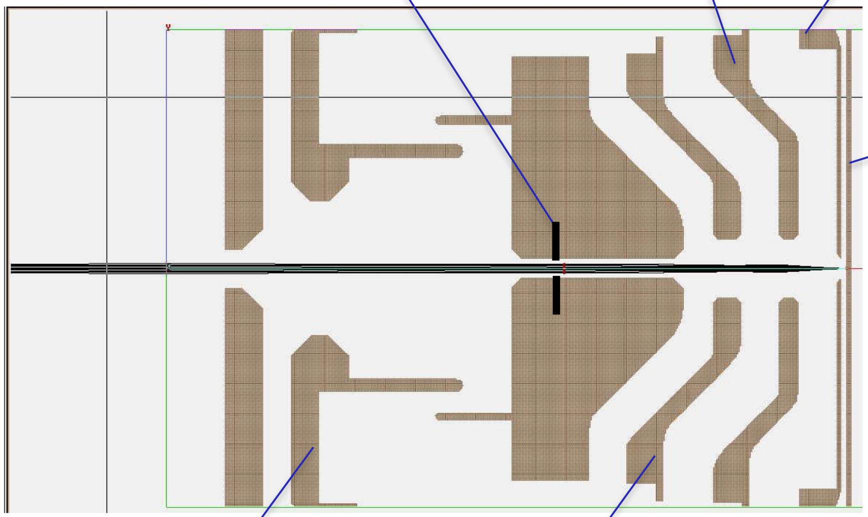
Secondary optics and dynamic transfer



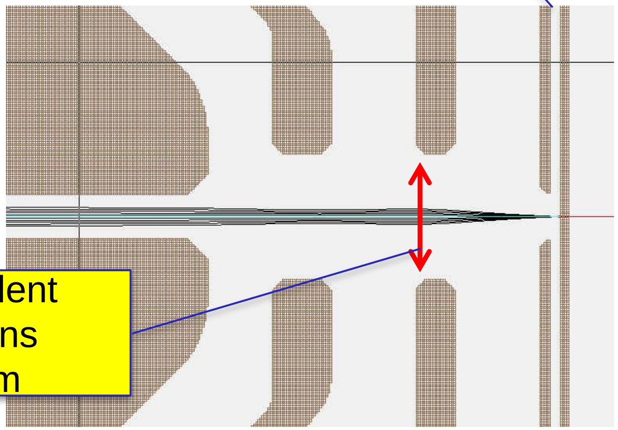
- P1, P2, P3, P4: Static plates. Value of angular deviation defined only by space considerations. 6° for P1, P3, P4 and 12° for P2.

- B1, B2, B3: scanning plates, 2 functions:
    - Scanning the primary ion beam on the sample
    - Maintaining the collection efficiency and the mass resolving power while the primary ion beam is scanned on the sample.

N50L Lateral Resolution
Immersion lens E0



Cs+ mode



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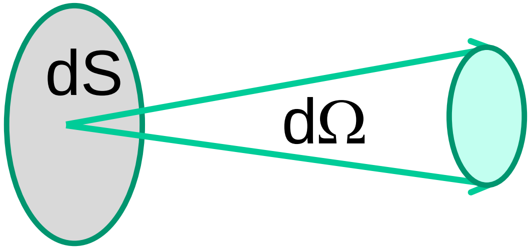
N50L Lateral Resolution
Aberrations and Brightness

Probe size = Σ (gaussian part + aberrations)

Main aberrations :

- Aperture aberration : **Cs α^3**
- Chromatic aberration : **Cc α ΔE/E**
- α being the primary ion beam aperture at the sample and **ΔE/E**
- the relative energy dispersion.
- Aberration coefficients Cs and Cc are linked to the optical properties of the immersion lens. Respective values are 62 mm and 15 mm.
- Gaussian part is linked to the **Brightness**

$$I(A) = \mathbf{B}\ dS_{(cm^2)}\ d\Omega_{(sr)}$$



B : A m^{-2} sr^{-1} V^{-1} or A cm^{-2} sr^{-1} @ 10 kV

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N50L Lateral Resolution
Probe size estimation

$$D_p = \sqrt{(D_{Br}^{1,3} + D_s^{1,3})^{2/1,3} + D_c^2}$$

With:

- $D_c = 0{,}6\ Cc\ \alpha_s\ \Delta E/E$ Chromatic
- $D_s = 0{,}18\ Cs\ \alpha_s^3$ Aperture
- $D_{Br} = (Ip/B\alpha_s^2\ 4/\pi^2)^{1/2}$ Brightness
- Dp = FWHM ⟶ D68 (+30%)

[1] J. E. Barth and P. Kruit, Optik, n°3 (1996) 101-109

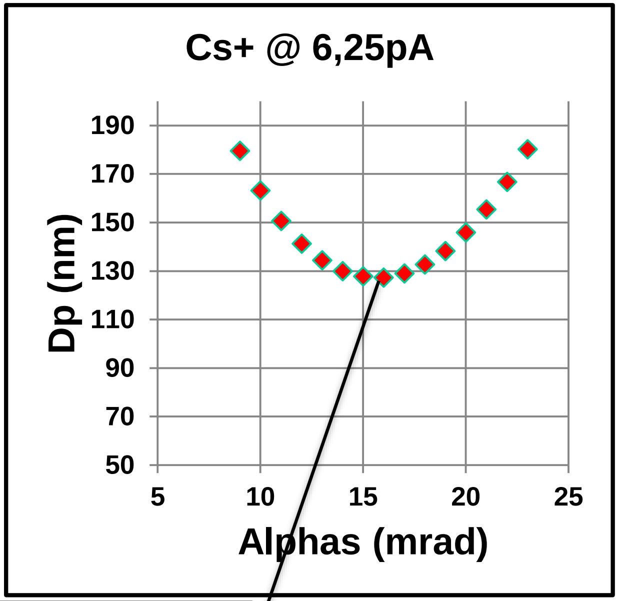
[2] M. S. Bronsgeest, J. E. Barth, L.W. Swanson and P. Kruit, J. Vac. Sci. Technol. B 26(3) May/June 2008, 949-955

N50L Lateral Resolution
Probe size estimation

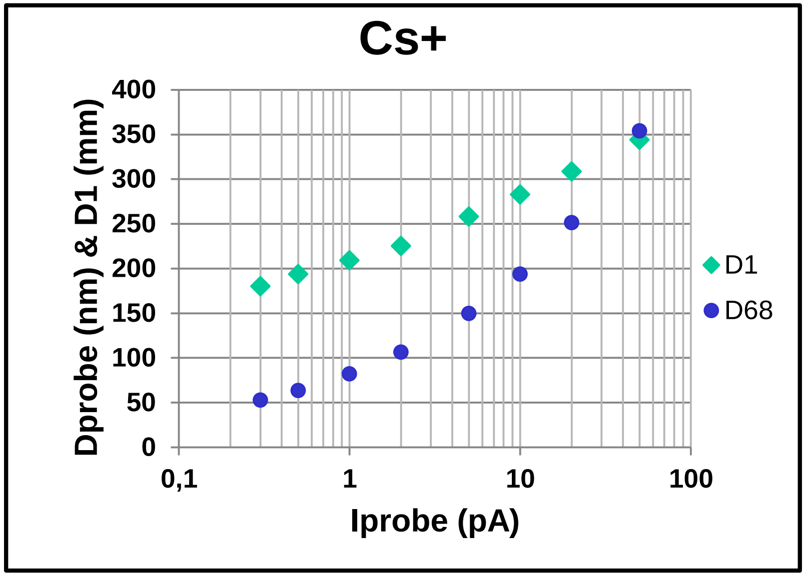
$$D_p = \sqrt{\left(D_{Br}^{\,1,3} + D_s^{\,1,3}\right)^{2/1,3} + D_c^{\,2}}$$

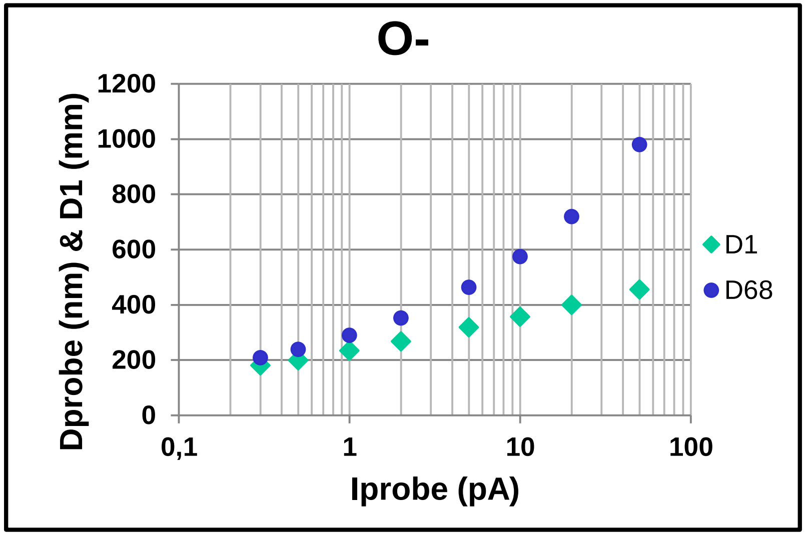
For each set of parameters one can find one α_s which minimizes Dp.

Cs+ : 100 A cm^{-2} sr^{-1} – 1eV
O- : 10 A cm^{-2} sr^{-1} – 15eV



D1 = 265 µm





N50L Lateral Resolution
Future developments

How could we increase the lateral resolution?

1/ Acting on the source by increasing the brightness and decreasing the energy dispersion.

2/ Acting on the immersion lens by decreasing aberrations coefficients

N50L Lateral Resolution Future developments

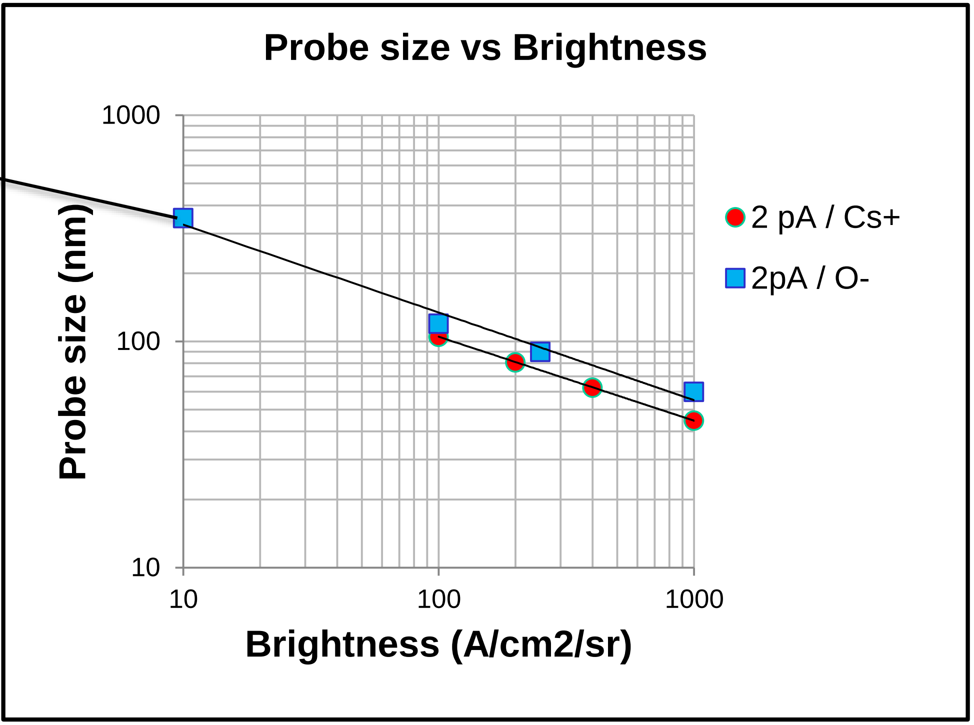
Acting on the source by increasing the brightness and decreasing the energy dispersion.

$\Delta E/E = 15/8000$ (Duo source)

Cs = 63 mm and Cc = 16 mm

Cs+ : $\Delta E/E = 1/8000$

O- : $\Delta E/E = 5/8000$ (RF source)

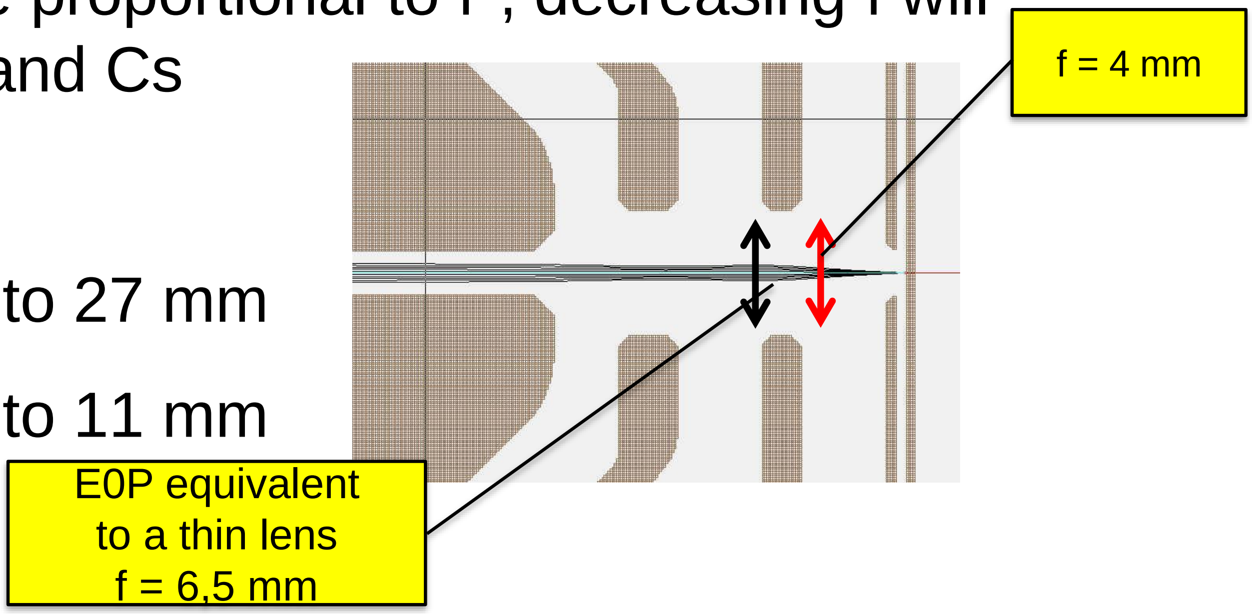


$$D_p \propto B^{-0,39}$$

N50L Lateral Resolution Future developments

Acting on the immersion lens by decreasing aberrations coefficients?

Cs and Cc are proportional to f^n, decreasing f will decrease Cc and Cs



- Cs: 63 mm to 27 mm
- Cc: 16 mm to 11 mm

1 pA – 82 nm to 1 pA – 66 nm for B = 100 A cm^{-2} sr^{-1}

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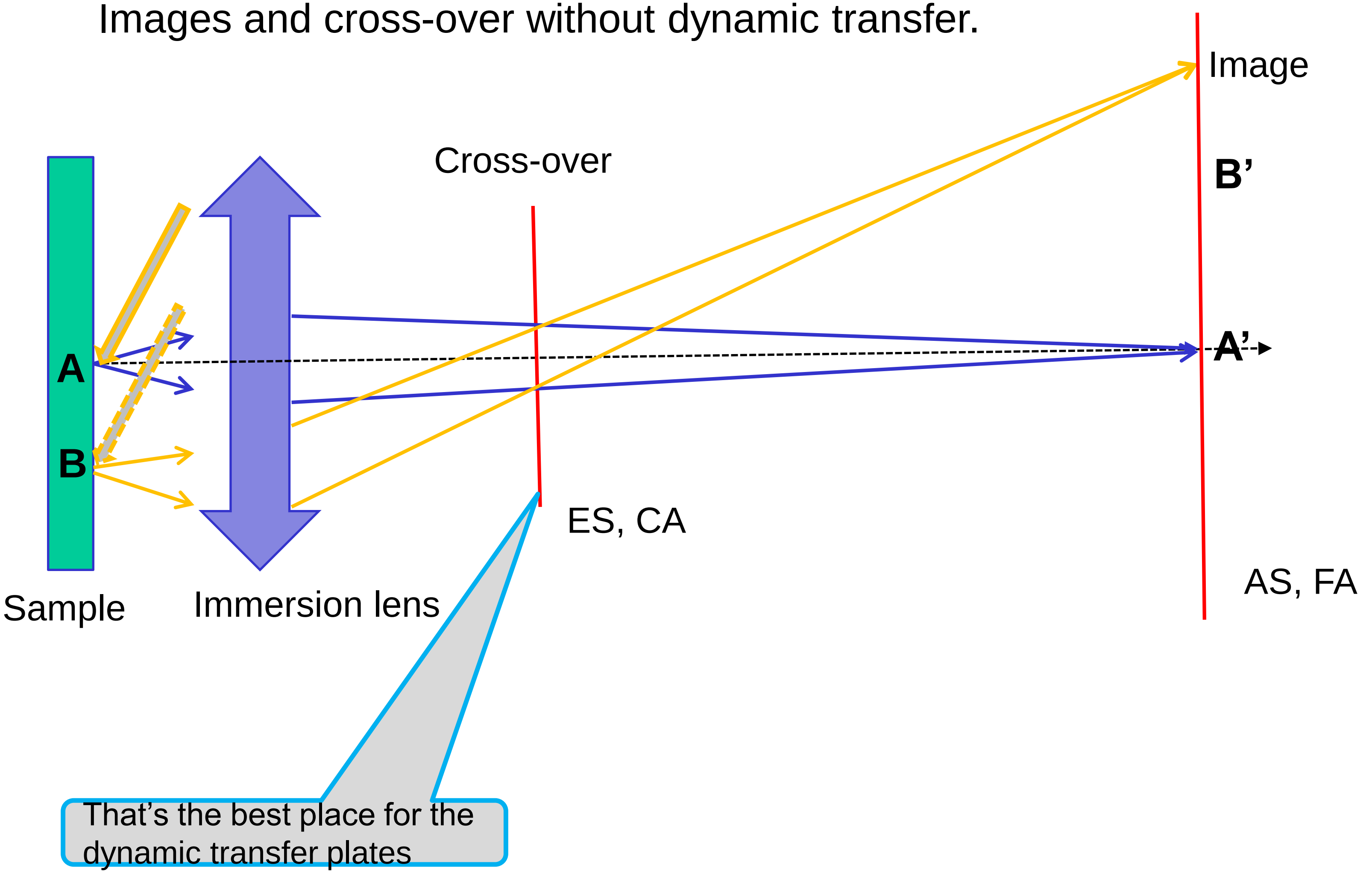
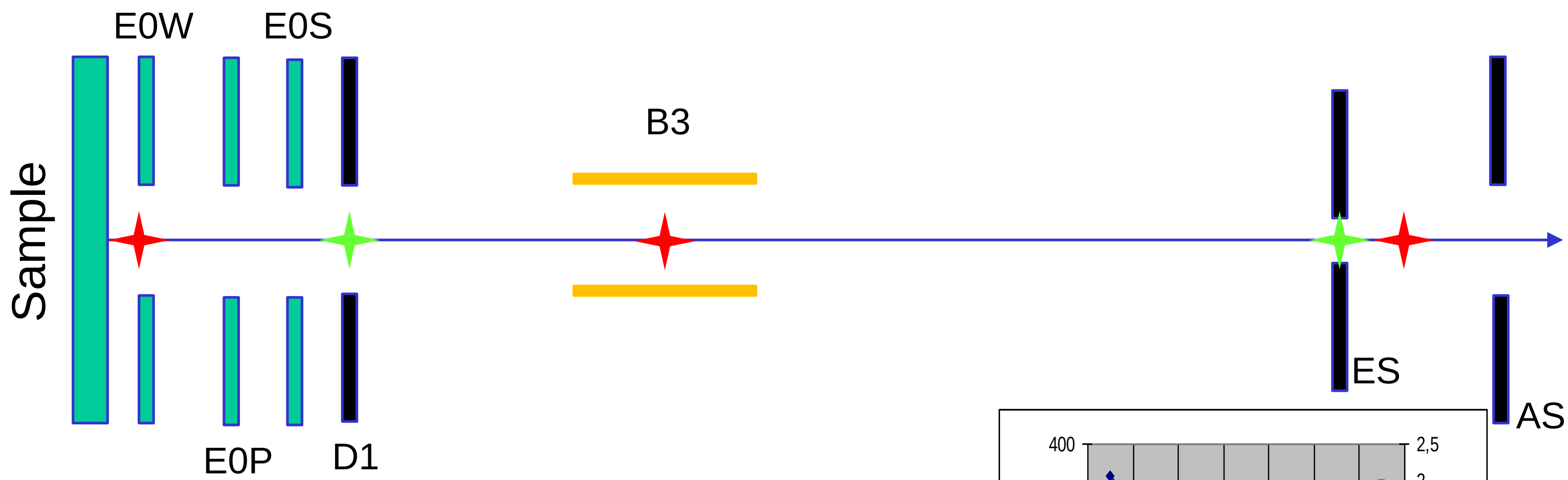
Secondary optics and dynamic transfer

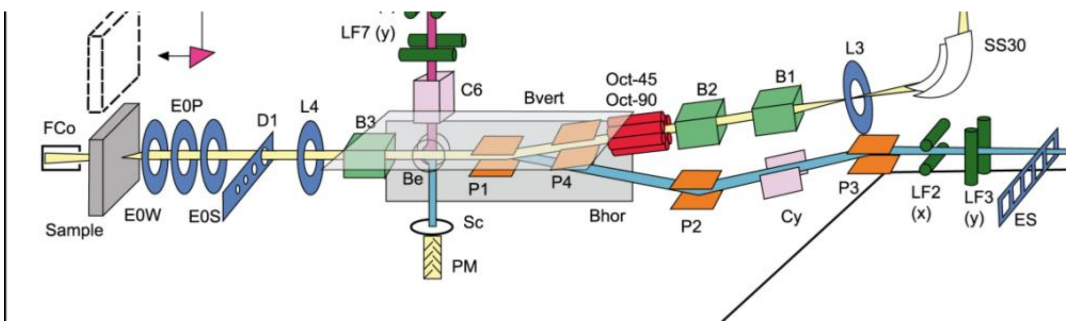
Classical optical schematic IMS XF and IMS1280.
Images and cross-over without dynamic transfer.

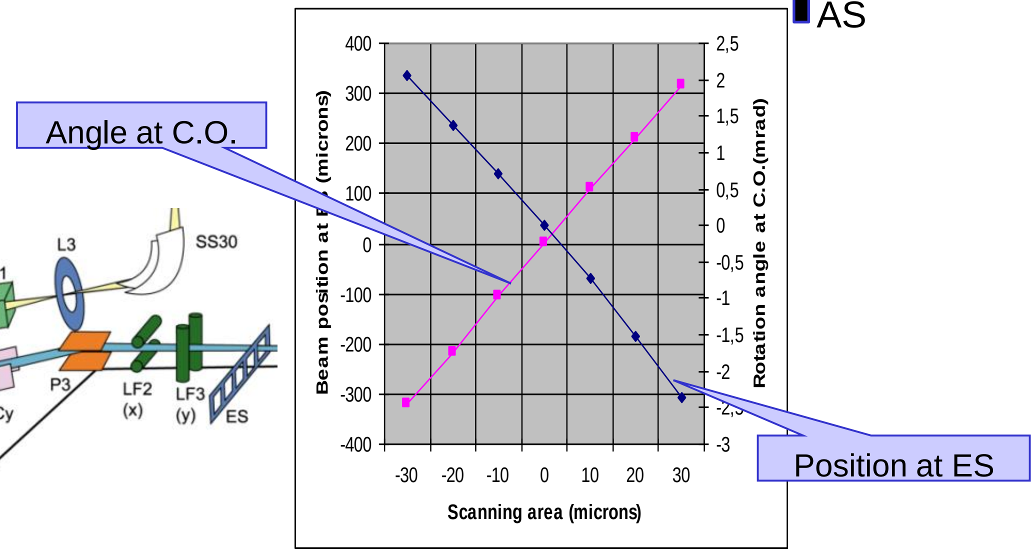


Secondary optics and dynamic transfer

NanoSims 50 optical schematic (horizontal plane)
Images and cross-over positions.







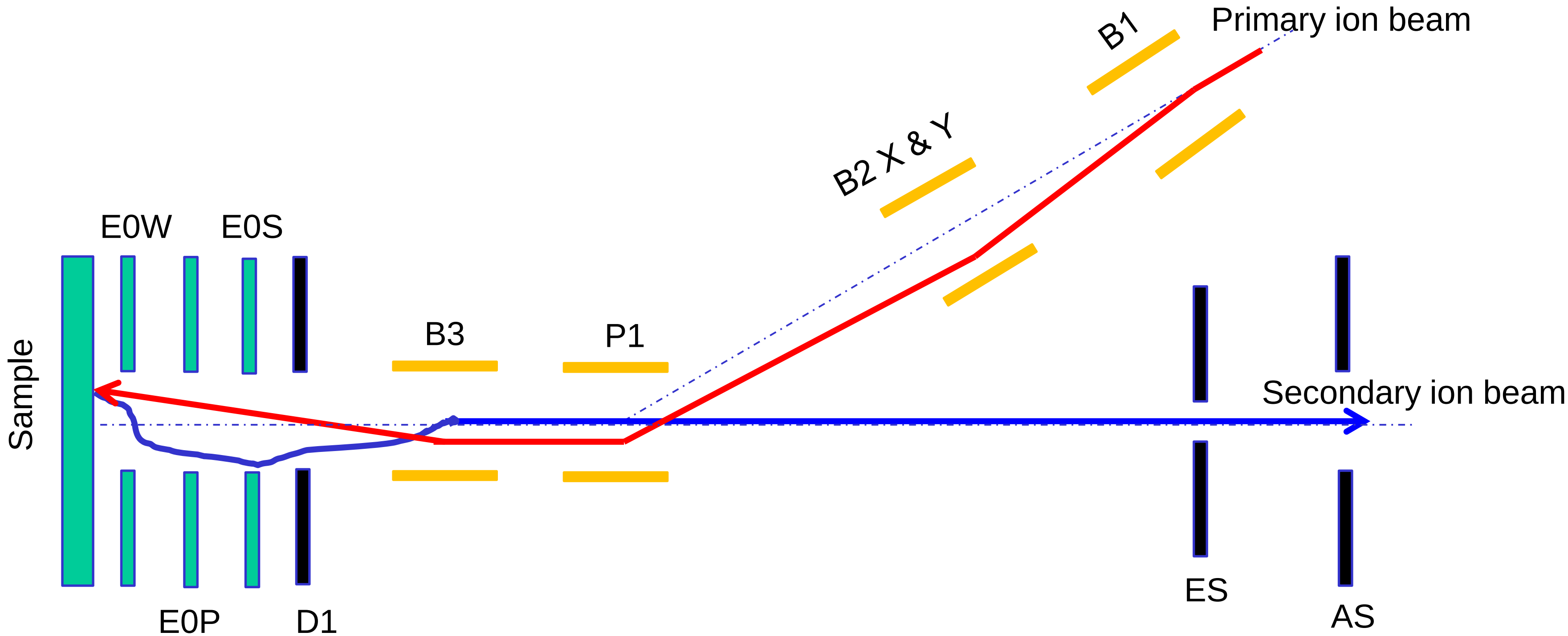
Secondary optics and dynamic transfer

How does it work?

•B1, B2 and B3 rotate the primary ion beam around the center of D1.

•B3 in addition to its action on the primary ion beam is in charge of the “Dynamic transfer”. B3 is powered so as to cancel the secondary ion beam motion

• B2X and B2Y could be set to different values to take in account the difference between the horizontal and vertical planes



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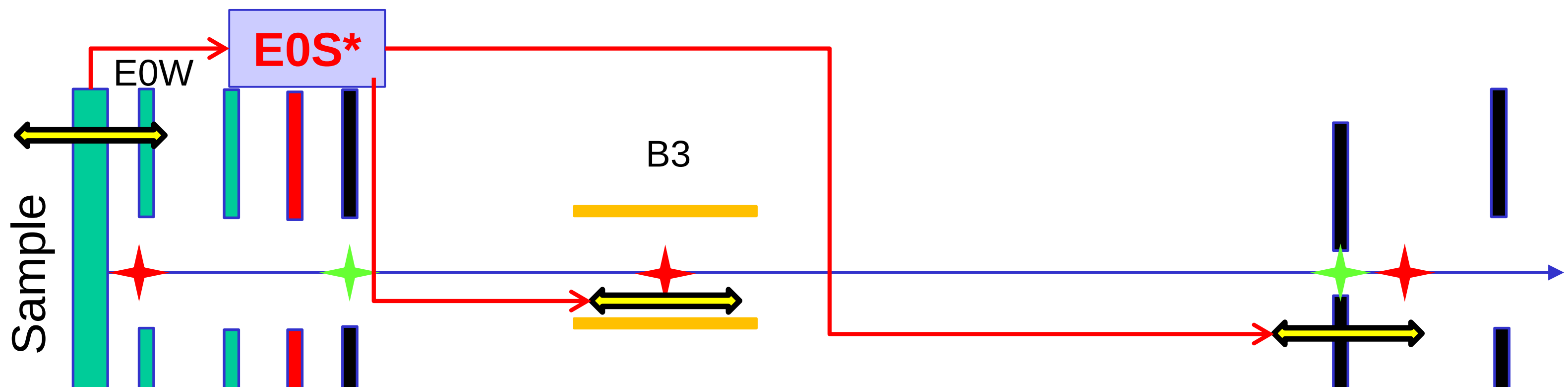
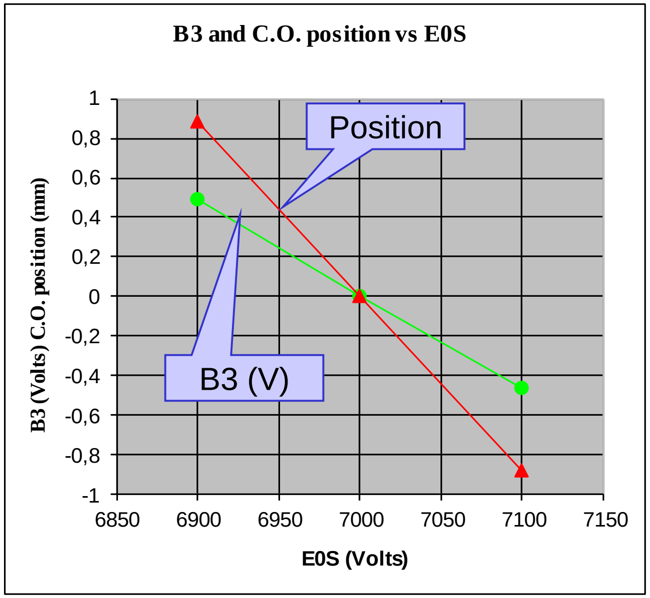
Secondary optics and dynamic transfer

While the sample is moving in Z, EOS has to be modified to keep the beam waist position at ES plane, leading to a slight movement of the C.O. in B3.





Simulation conditions :

- B3 = 10 Volts
- Sec. Ions emitted at 30 microns.
- E0S reference : 7000 Volts

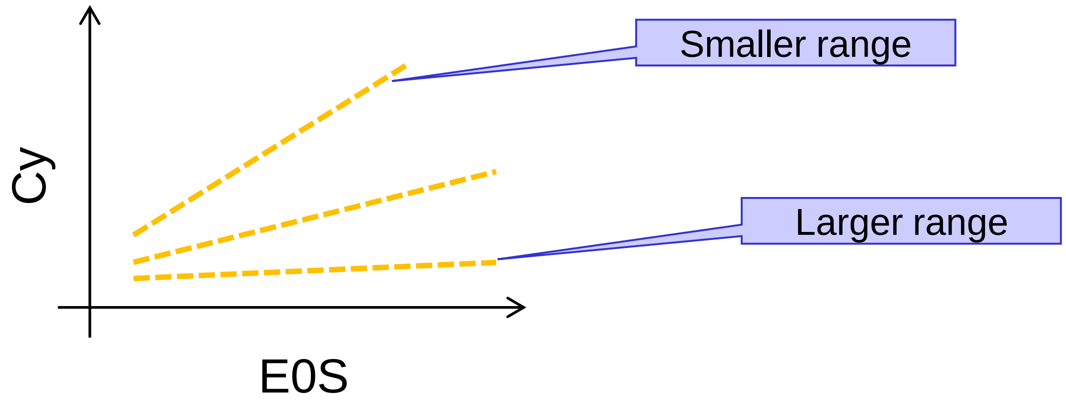
Secondary optics and dynamic transfer

Practical rules for E0S:

Keep E0S as constant as possible!

- Elemental imaging without isotopic ratios measurements: E0S* +/- 30 bits. (1 bit is 1,5 micron and 2,5 Volts)
- Low reproducibility Isotopic ratios measurements (by imaging or not) (Sigma > 2-3 permil) : E0S*+/- 20 bits.
- High reproducibility Isotopic ratios measurements (by imaging or not) (Sigma < 1 permil) : E0S* +/- 10 bits.

These ranges of value for E0S are varying from instrument to instrument depending of the relationship between E0S and Cy.



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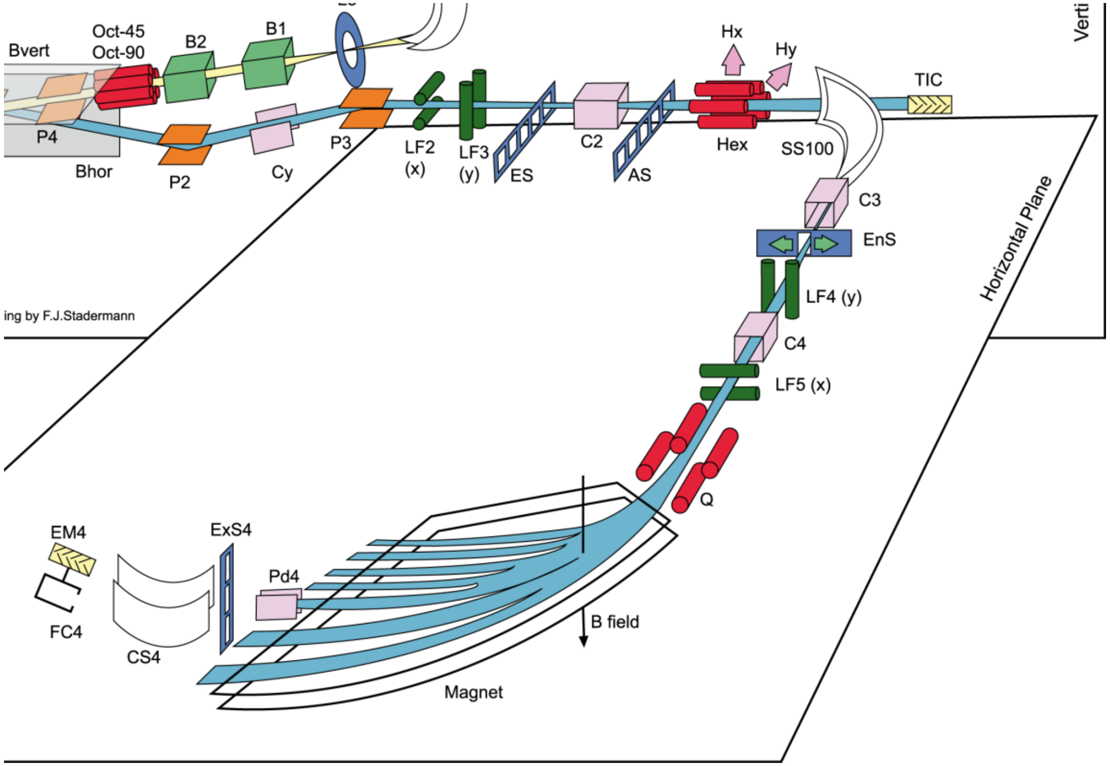
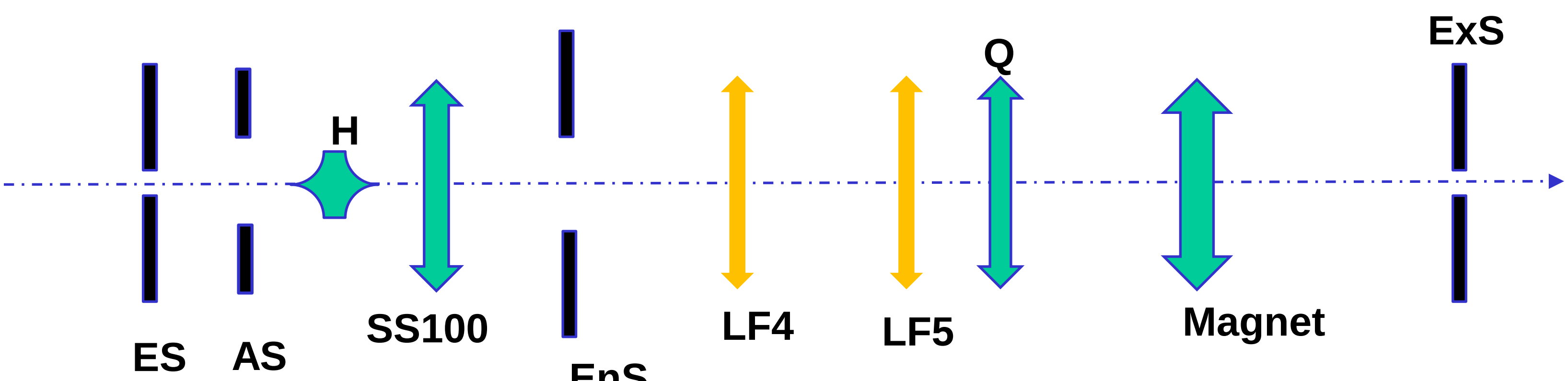
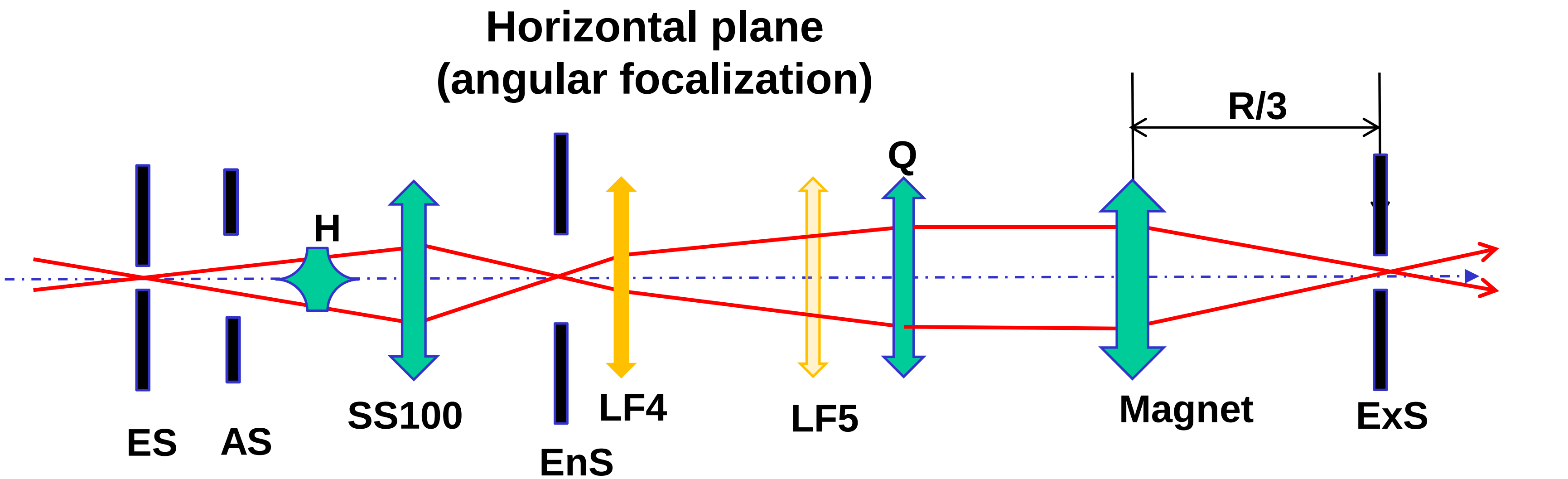
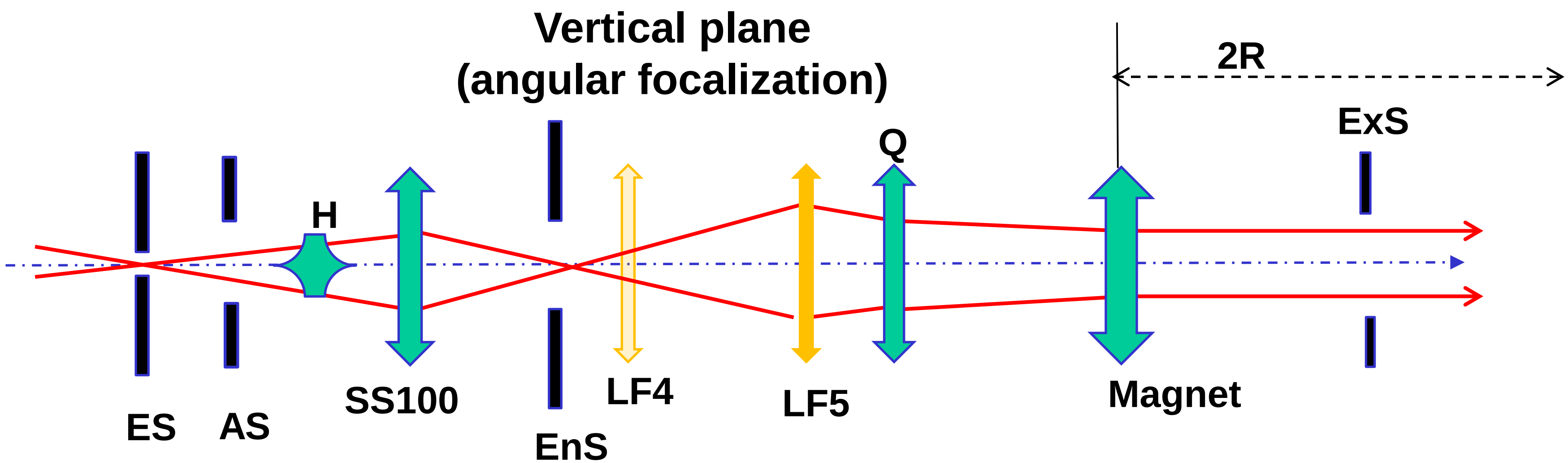
Mass spectrometer and Mass Resolving Power





Mass spectrometer and Mass Resolving Power





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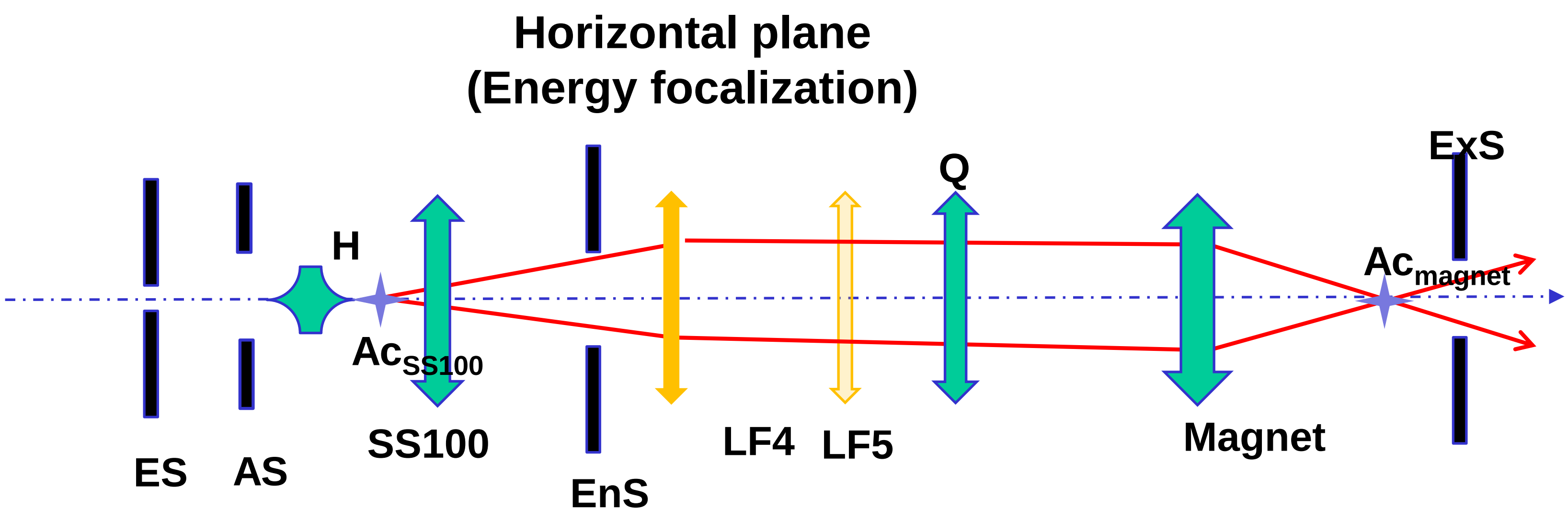
Mass spectrometer and Mass Resolving Power



Two conditions.

- Angular focalization and energy focalization.
- Two lenses Q and LF4.

- Q fulfilled both conditions (angular and energy) at 90%.
- LF4 is in charge of fine energy focusing. Theoretically any LF4 change needs to be compensate by a slight change of Q.

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Mass spectrometer and Mass Resolving Power

EnS, LF4, ES, AS

$$\Delta M/M = F(G\, W_{ES},\ K_{\alpha}\, \alpha^2,\ K_E\, \alpha\, \Delta E/E,\ (K_{\beta}\, \beta^2 + \text{higher order terms.....}))$$

H, LF2, LF5

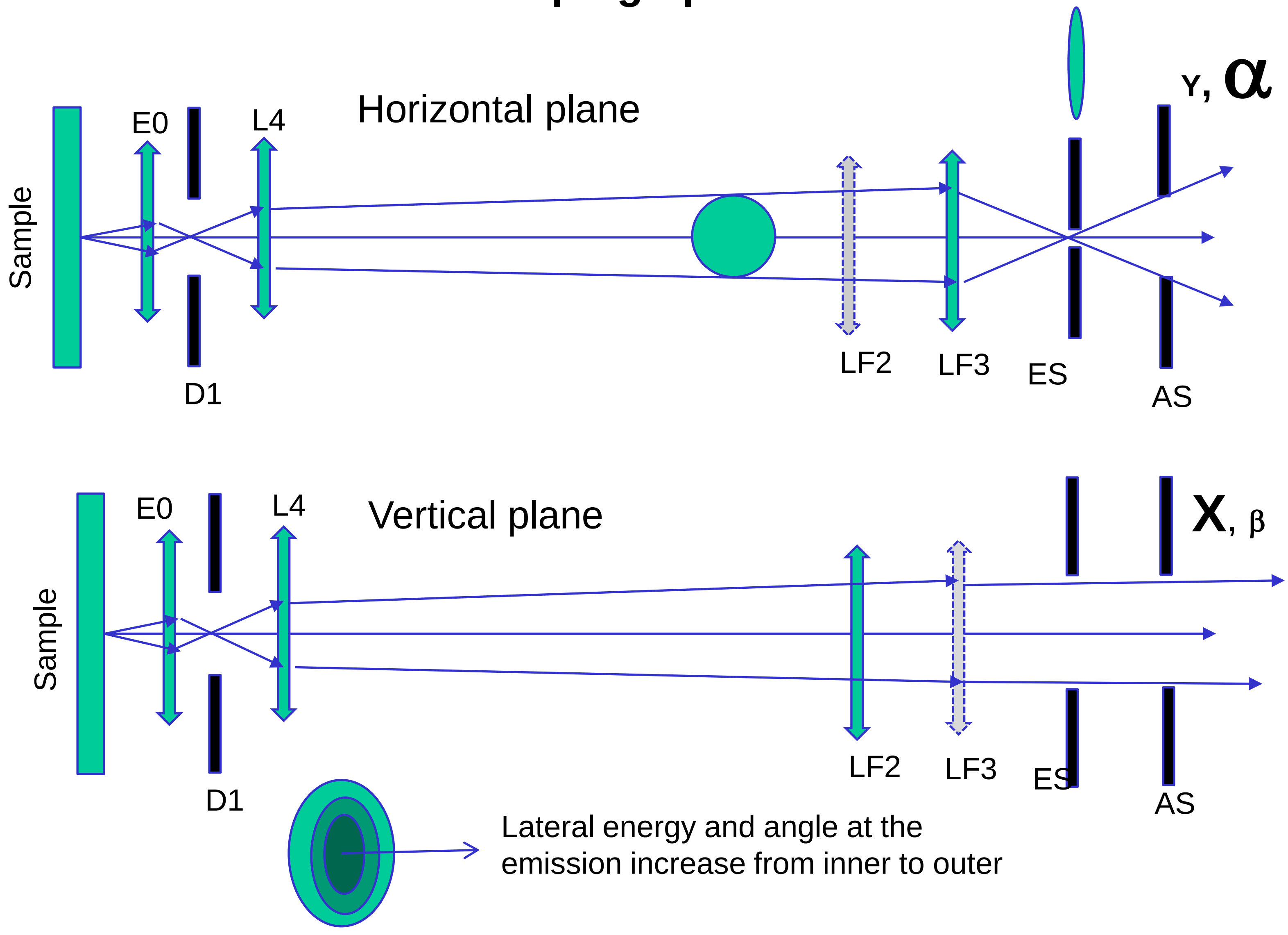
H, AS, ES, LF2 & LF3

- W_{ES} : Entrance slit width (or beam waist)
- G : magnification of the spectrometer. G = R/537; as the mass dispersion is R/2, MRP is independent of R.
- $K_a\, \alpha^2$: main second order aperture aberration term,
- $K_E\, \alpha\, \Delta E/E$: main chromatic aberration term,

with α and β being the half aperture angle in the radial plane and in the vertical plane and $\Delta E/E$ the relative energy spread of the secondary beam.

Mass spectrometer and Mass Resolving Power

Shaping optic



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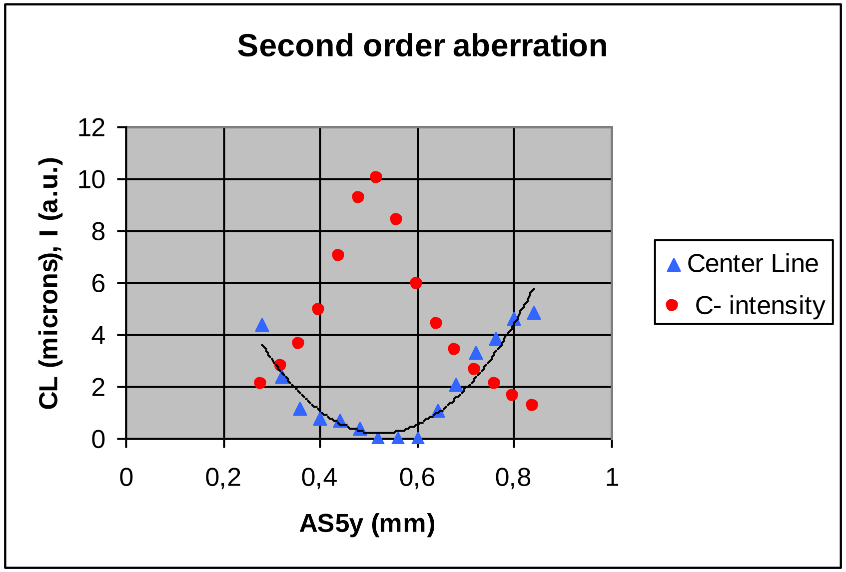
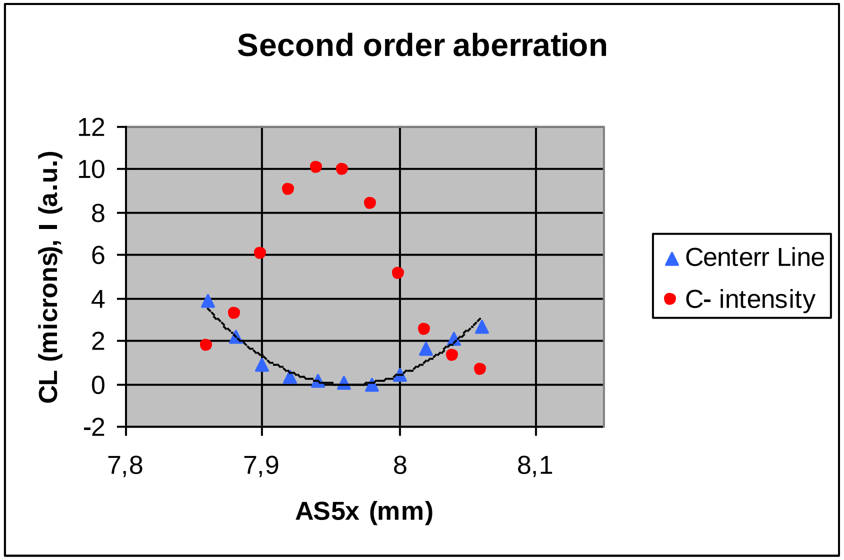
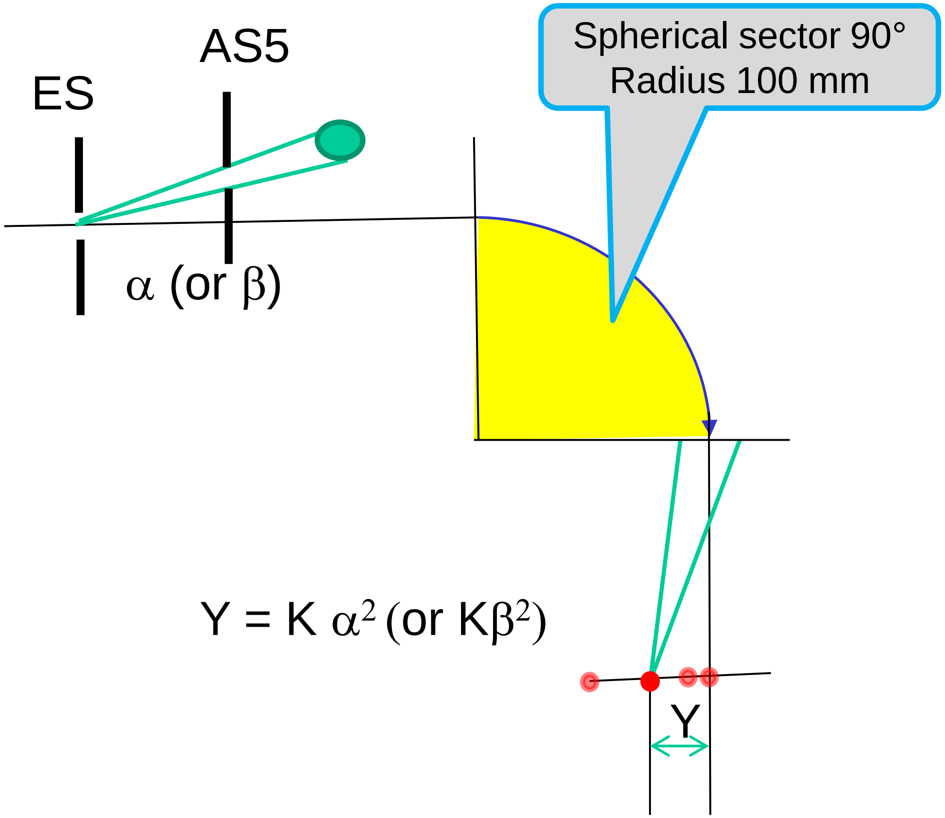
Mass spectrometer and Mass Resolving Power

Second order aperture aberrations

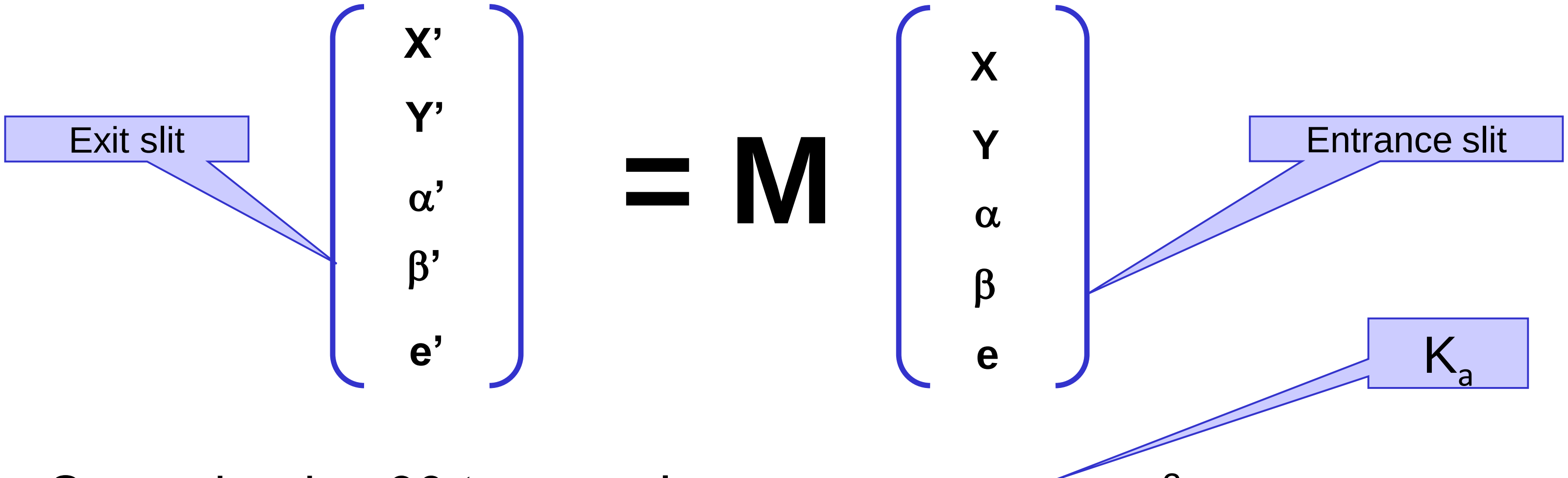






Mass spectrometer and Mass Resolving Power

$\Delta M/M = F(G\ W_{ES},\ K_{\alpha}\ \alpha^2\ ,\ K_E\ \alpha\ \Delta E/E\ ,\ (K_{\beta}\ \beta^2 + \text{higher order terms.....})\ )$



Second order, 30 terms: $x' = \langle xe\rangle\ x.e + \langle\alpha\alpha\rangle\ \alpha^2 + \langle\alpha e\rangle\ \alpha e$ ...

Third order, 70 terms: $x' = \langle xee\rangle\ x.e^2 + \langle\alpha\beta\beta\rangle\ \alpha.\beta^2 + $ ….

W_{ES} : Entrance slit width, G : magnification of the spectrometer, K_a, K_b : second order aperture aberration term, K_E chromatic aberration term, with α and β being the half aperture angle in the radial plane and in the vertical plane and $\Delta E/E$ the relative energy spread of the secondary beam.

Mass spectrometer and Mass Resolving Power

Practical rules for MRP tuning:

- Choose ES according to the MRP range and tune Q.

ES #	1	2	3	4	5
MRP	< 4500	< 6000	<8000	<10000	>10000

- Check which kind of aberration are the most dominating (energy or angular):

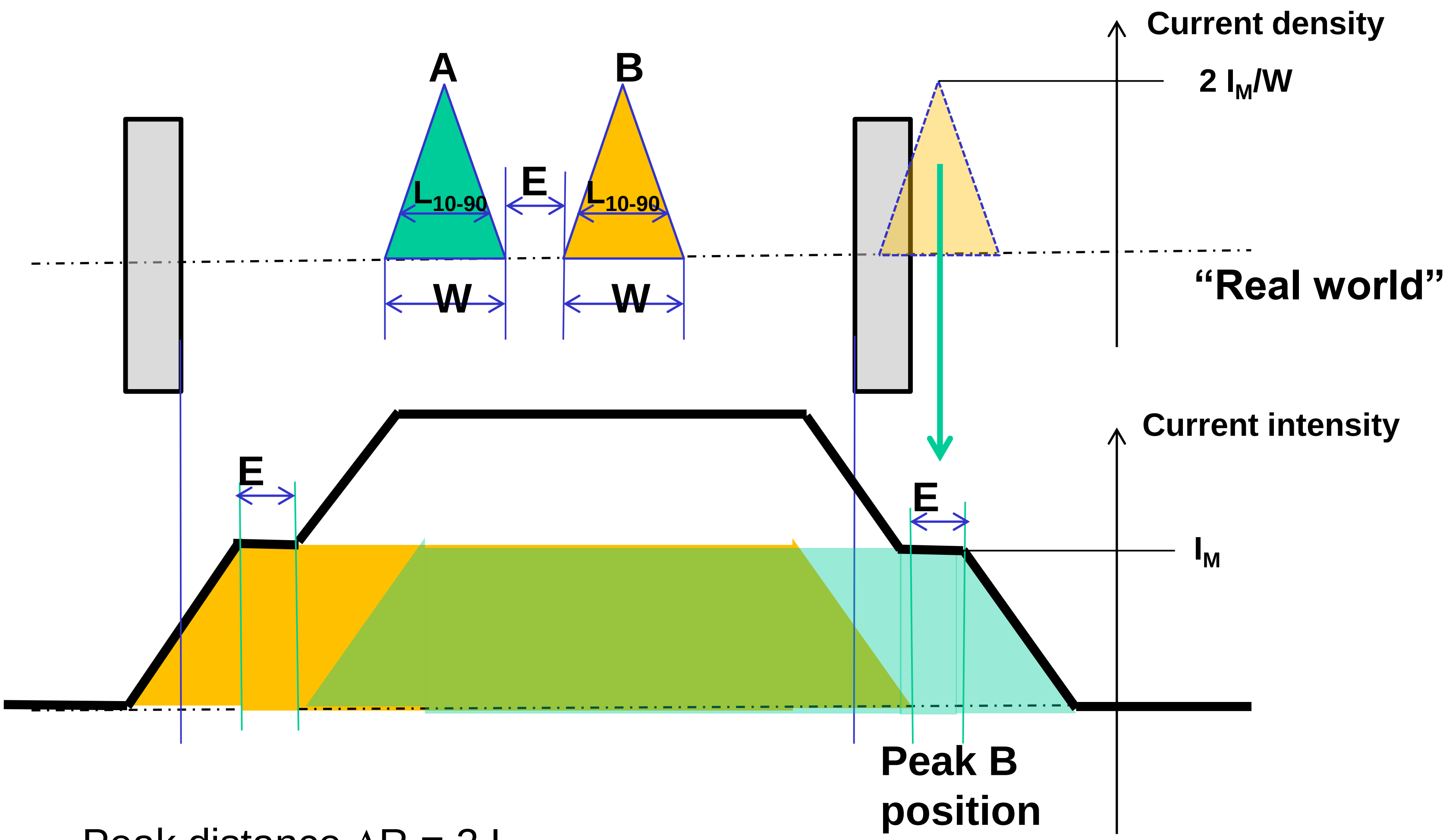
1) set EnS (-10%), if MRP increases a lot (more than 10-15%) and/or it changes the peak shape, check LF4 (wo EnS).
2) set ASn, if MRP increases a lot (more than 10-15%) and/or it changes the peak shape, check H (X, Y not the value) (wo AS).

- Set ASn and EnS (in this order) to improve MRP and the peak shape.

ES #	1	2	3	4	5
AS#	1 - 2	2-3	2-3	3-4	4-5

- Check C3x (and LF5) to get a C4x scan as flat as possible.

Mass spectrometer and Mass Resolving Power



Peak distance $\Delta R = 2\, L_{10\text{-}90}$

MRP = M/DM = R /2 ΔR = **R / 4 $L_{10\text{-}90}$**

$E = 0{,}9\, L_{10\text{-}90}$ with $L_{10\text{-}90} = 0{,}9\, W$

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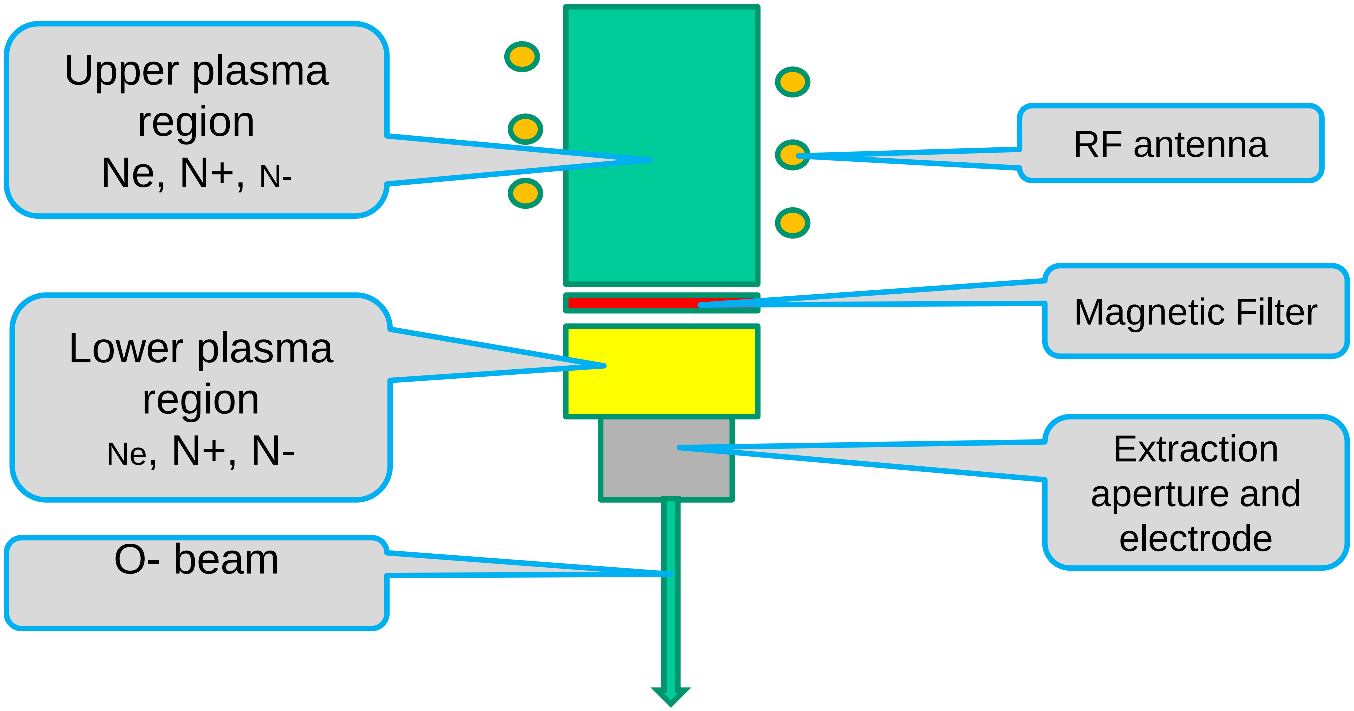
A new brighter O^- RF plasma ion source

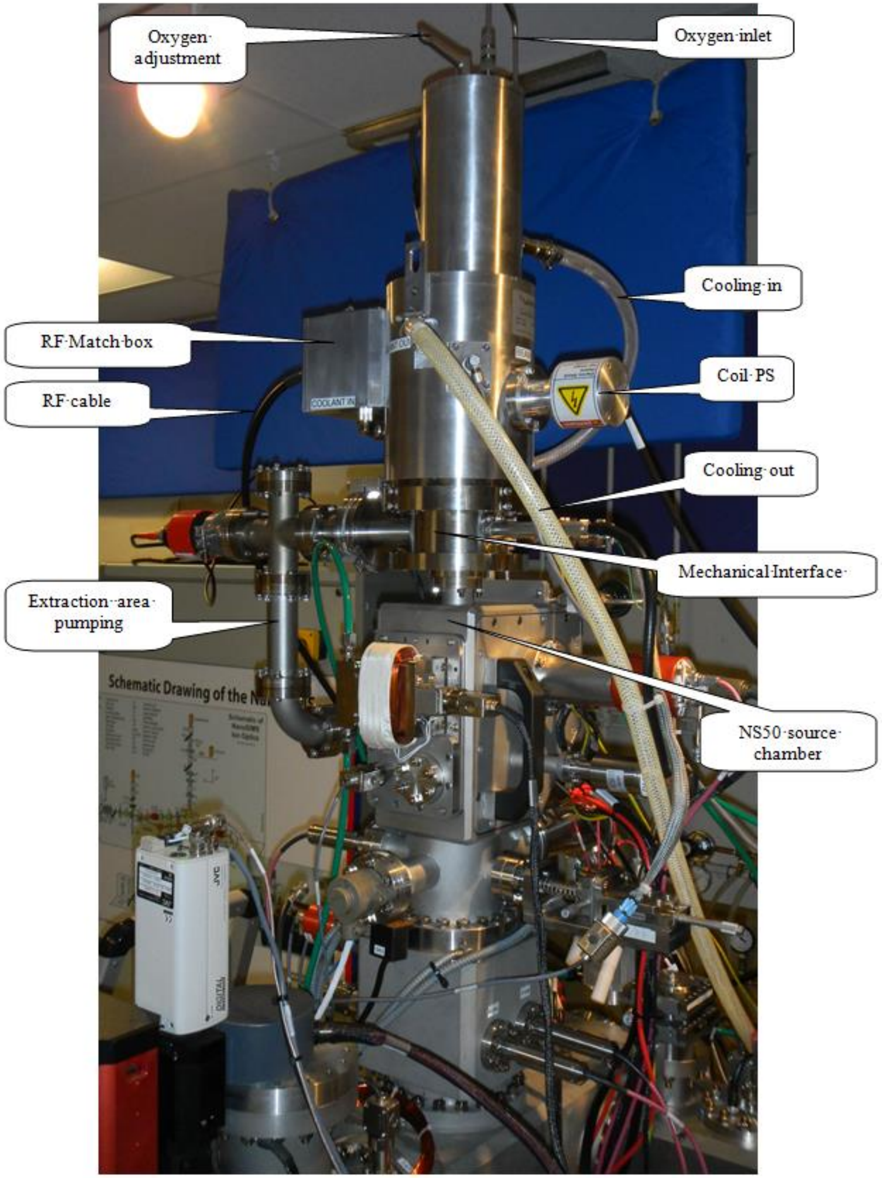
Source schematic



Duoplasmatron
Source diameter: 300 microns
Brightness: **10-20 mA cm^{-2} sr^{-1}**
Energy dispersion: < 15 eV FWHM

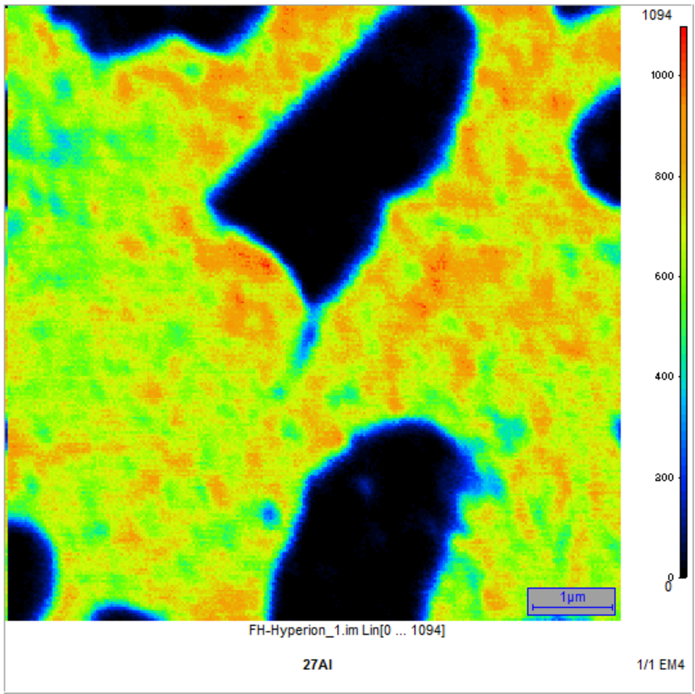
Oregon Physics
Source diameter: 35-50 microns
Brightness: **160 mA cm^{-2} sr^{-1}**
Energy dispersion: < 5 eV FWHM

A new brighter O^- RF plasma ion source

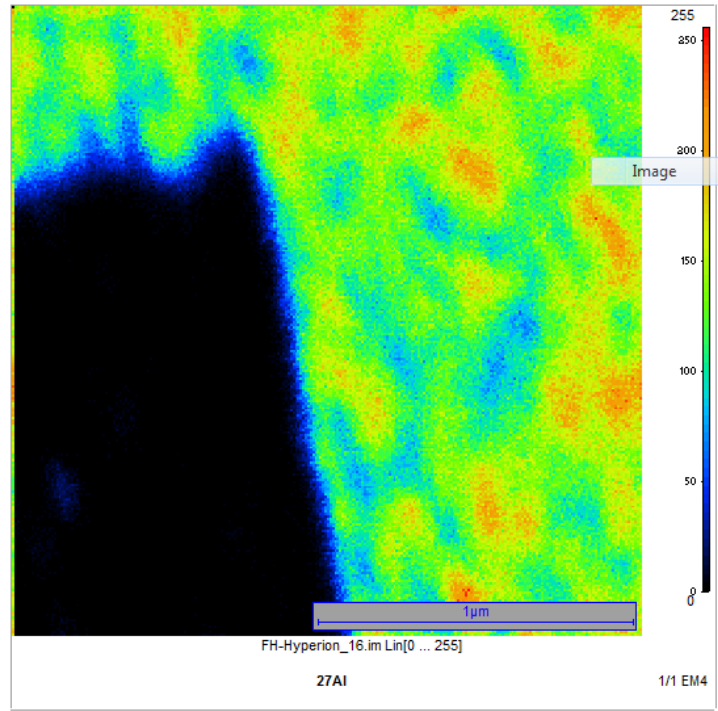


Prototype of the O- source tested on the NanoSIMS of LLNL, CA, USA

O- RF plasma ion source: preliminary tests

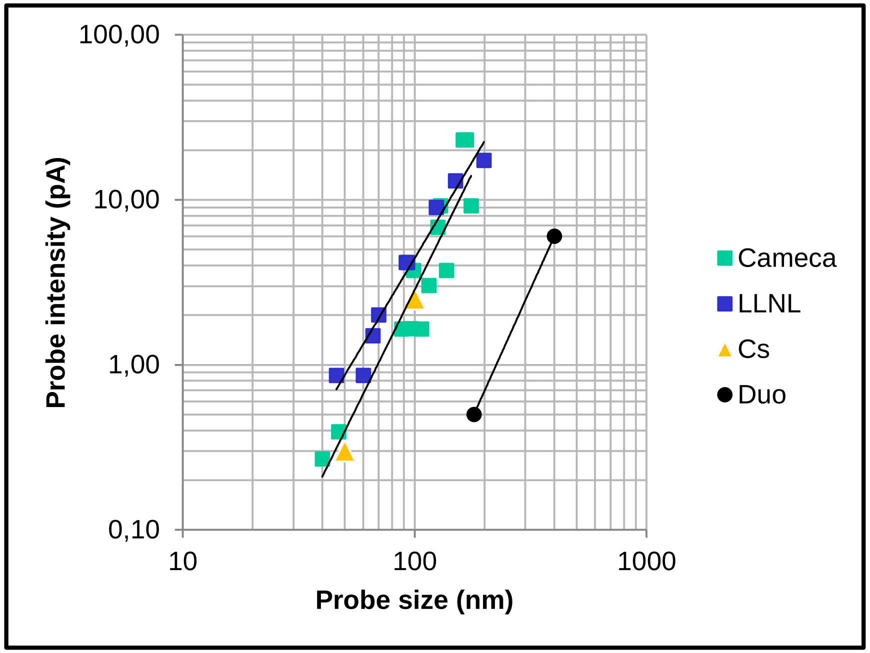


FOV 8 x 8 microns, 200 nm 17.3 pA



FOV 2 x 2 microns, 46 nm 0.86 pA

A new O^- RF plasma ion source



Source performances

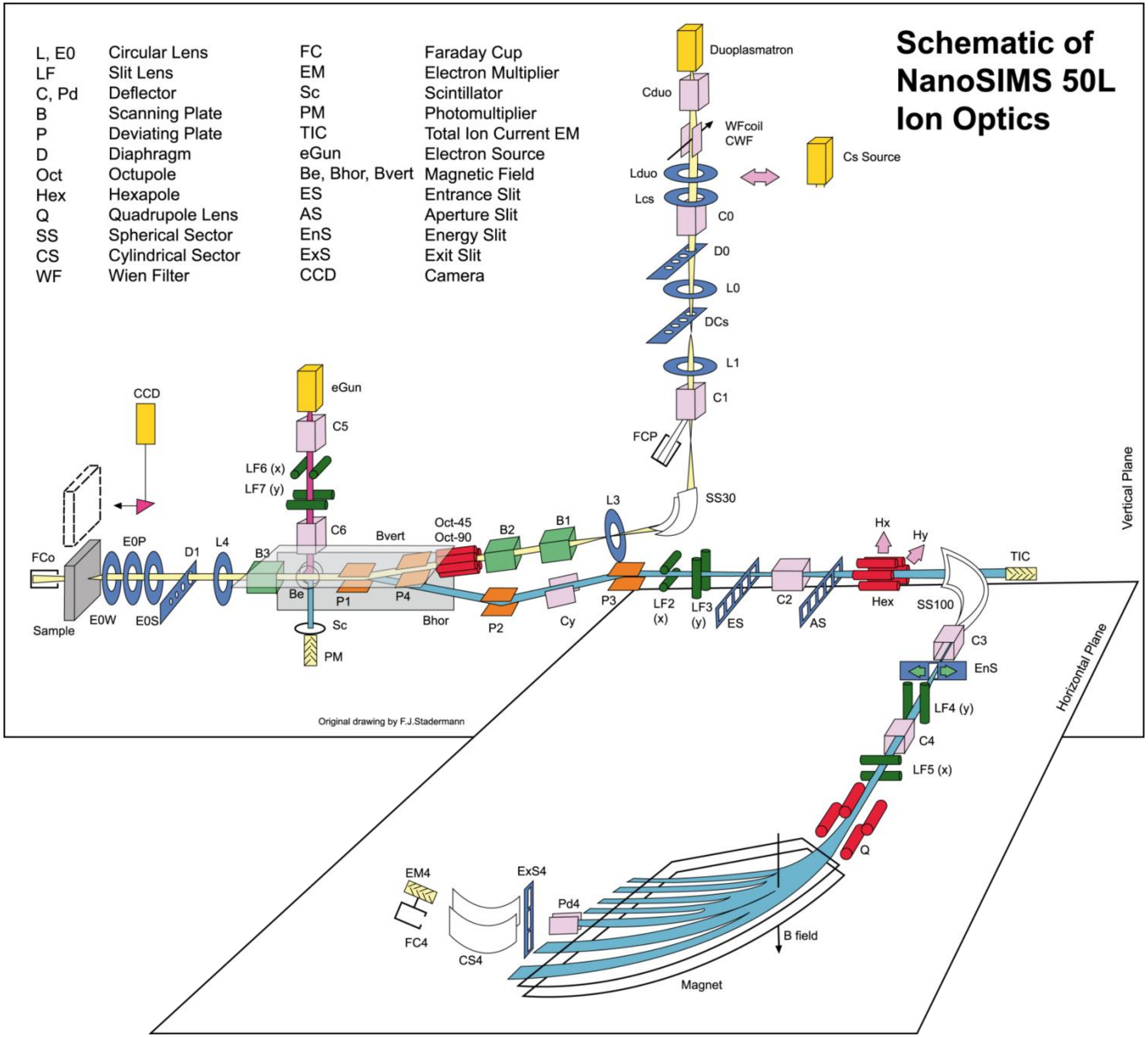
Source diameter: 70-80 microns

Brightness: **100 mA cm^{-2} sr^{-1}**

Energy dispersion: NA

Stability: < 1,6 % over 14h

Lifetime: > 500h on May 20th


Schematic of NanoSIMS 50L Ion Optics
L, E0 Circular Lens
LF Slit Lens
C, Pd Deflector
B Scanning Plate
P Deviating Plate
D Diaphragm
Oct Octupole
Hex Hexapole
Q Quadrupole Lens
SS Spherical Sector
CS Cylindrical Sector
WF Wien Filter
FC Faraday Cup
EM Electron Multiplier
Sc Scintillator
PM Photomultiplier
TIC Total Ion Current EM
eGun Electron Source
Be, Bhor, Bvert Magnetic Field
ES Entrance Slit
AS Aperture Slit
EnS Energy Slit
ExS Exit Slit
CCD Camera
Duoplasmatron
Cduo
WFcoil
CWF
Cs Source
Lduo
Lcs
C0
D0
L0
DCs
L1
C1
FCP
SS30
L3
B1
B2
Oct-45
Oct-90
Bvert
eGun
C5
LF6 (x)
LF7 (y)
C6
CCD
FCo
E0P
D1
L4
B3
Be
P1
P4
Sample
E0W
E0S
Sc
PM
Bhor
P2
Cy
P3
LF2 (x)
LF3 (y)
ES
C2
AS
Hex
Hx
Hy
SS100
TIC
Vertical Plane
Horizontal Plane
C3
EnS
LF4 (y)
C4
LF5 (x)
Q
B field
Magnet
EM4
FC4
CS4
ExS4
Pd4
Original drawing by F.J.Stadermann