Potential countermeasures against the very large SR heat load in FCC-hh.

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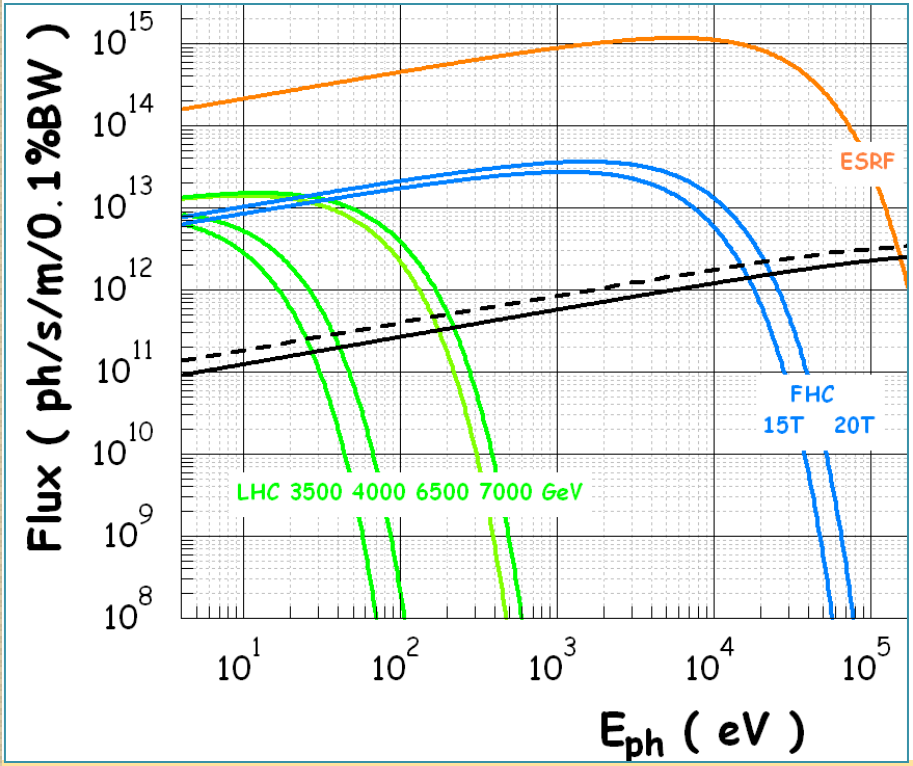
SR interacts with matter so that:

T(rasmission) + R(eflected) +A(absorbed) = 36 (68) W/m/Beam

Can we increase the Reflectivity of the Beamscreen (**RoB**) to (partially) reduce the average absorbed power (in LT sectors)?

Consider that the geometry of a 100 Km ring imply that SR light will impinge at an incredibly small angle:



- Θ ~0.62 mRad ~ 0.035°
- at ~ 21 m from source
- photon fan strip>2 mm
- Ph. energy spectrum where ε_c ~ 4-5 KeV

SR In the arcs:
28 W/m/Beam For 16T
44 W/m/Beam For 20T

The study of SR (R and PY) on accelerator walls has a longstanding tradition:

I.R. Collins, A.G. Mathewson and R. Cimino "VUV Synchrotron radiation photoemission investigation of proposed materials for the vacuum chambers of the Large Hadron Collider". *ECASIA'97*, Göteborg,

R. Cimino, V. Baglin and I. R. Collins "VUV Synchrotron radiation studies of candidate LHC vacuum chamber materials". *Vacuum* 52, 273-277 (1999).

R. Cimino, V. Baglin and I. R. Collins. "VUV photoemission of candidate LHC vacuum chambers materials". *Physical Review special topics -Accelerators and Beam* 2 063201 (1999).

. N.Mahne, V. Baglin, I. R. Collins, A.Giglia, L.Pasquali, M.Pedio, S.Nannarone and R. Cimino: "Photon reflectivity distributions from the LHC beam screen and their implications on the arc beam vacuum system" *Applied Surface Science* 235, 221-226, (2004).

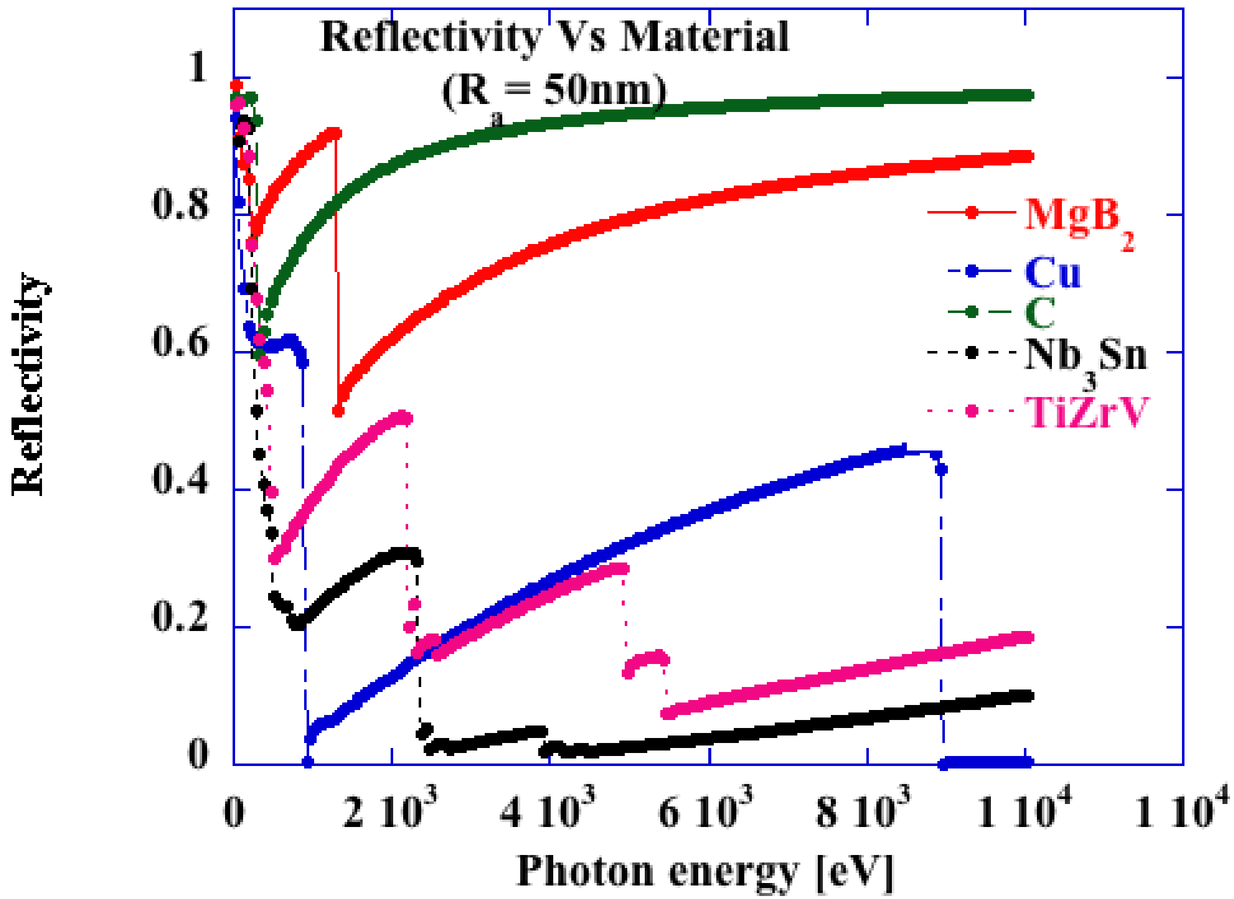
F. Schäfers, R. Cimino: "Soft X Ray reflectivity: From quasi-perfect mirrors to acceleretator walls". Proc. ECloud-12, Isola Elba, 2012

R. Cimino F. Schäfers: "Soft X-ray Reflectivity and Photoelectron Yield of Technical Materials: Experimental Input for Instability Simulations in High Intensity Accelerators" IPAC14.

G. F. Dugan, K. G. Sonnad, R. Cimino, T. Ishibashi, F. Schäfers: "Measurements of X-ray Scattering from Accelerator Vacuum Chamber Surfaces, and Comparison with an Analytical Model" under final review *Physical Review special topics -Accelerators and Beam* (2015).

See also : R. Cimino and T. Demma
"Electron cloud in Accelerators",
Int. J. Mod. Phys. A 29 (2014) 1430023 (pag. 65).

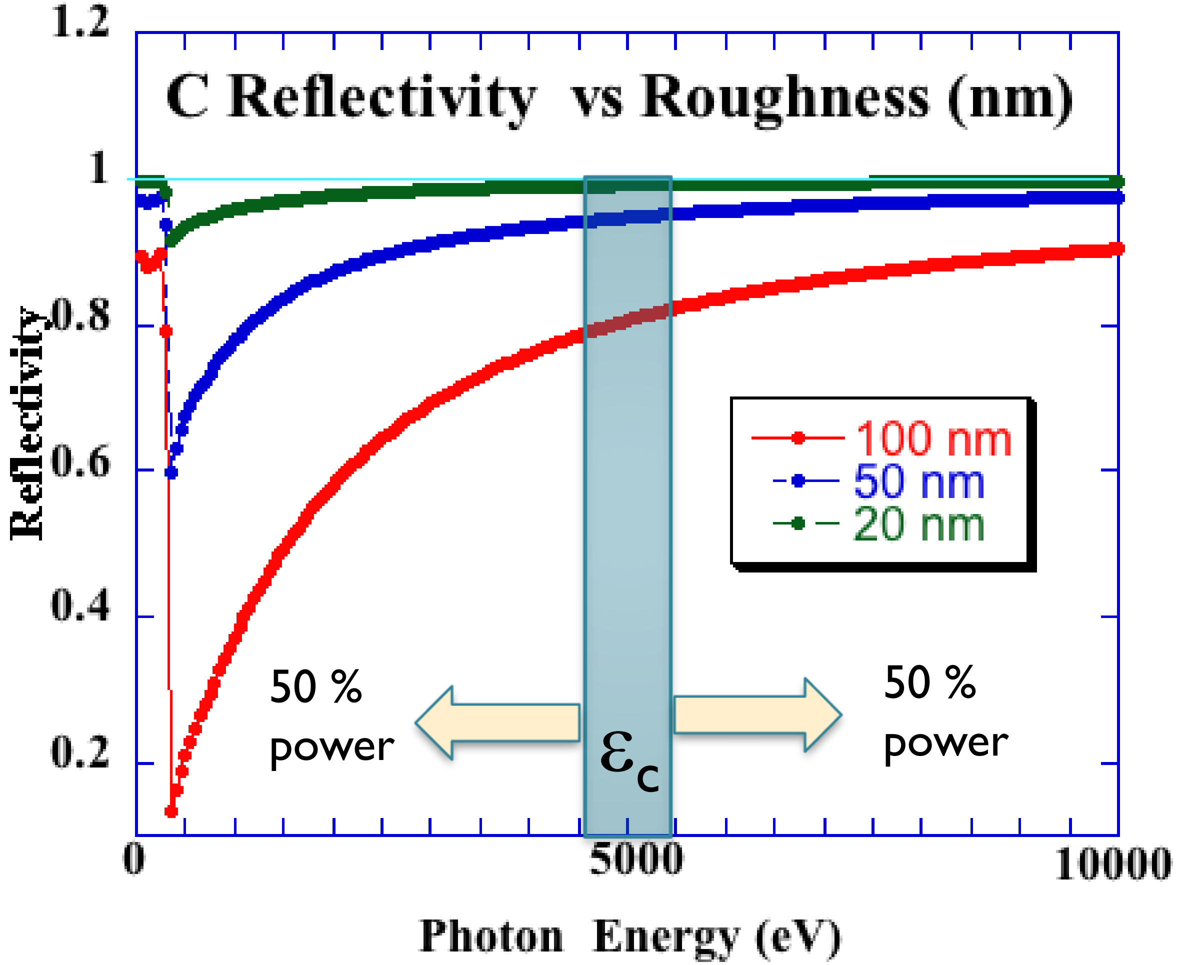
Reflectivity of Beamscreen (RoB) between 30 eV and 10 KeV at ~ 0.035° grazing incidence vs material (50 nm roughness)



http://henke.lbl.gov/optical_constants/ & RELFEC

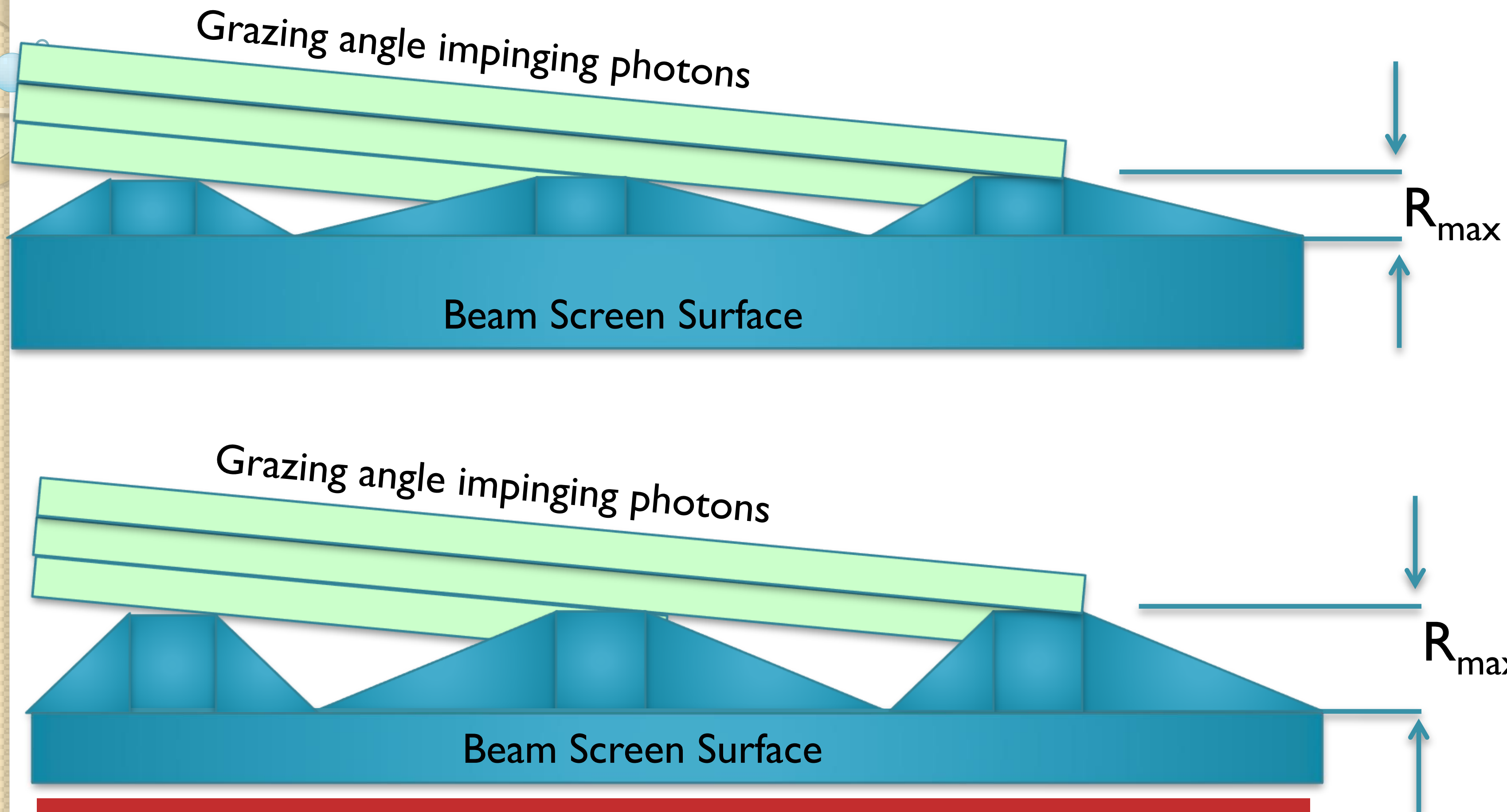
a-C RoB between 30 eV and 10 KeV at ~ 0.035° grazing incidence Vs roughness

(N. Kos, CERN TE-VSC: Ra of LHC copper layer was specified as <= 0.2 μm. Measured values were typically 0.05-0.1 μm for both arc and LSS beam screens.)



http://henke.lbl.gov/optical_constants/ & RELFEC

One can address if the calculations correctly consider roughness ($R_a = \frac{1}{4} R_{max}$) at such grazing incidences:



At very grazing incidence measured roughness can be overestimated in reflectivity calculations

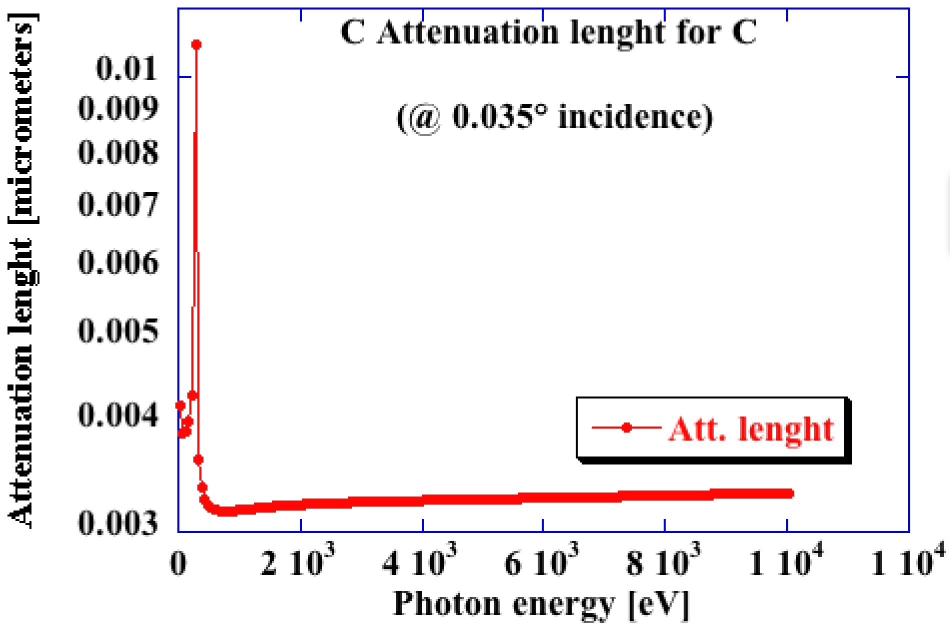
BUT will an a-C Layer cause Impedance problems?

Material	ρ (Ω m) at 20 °C
Silver	1.59×10−8
Copper	1.68×10−8
Annealed copper	1.72×10−8
Carbon (amorphous)	5.00×10−4 to 8.00×10−4
{Carbon (graphene) }	1.00×10−8

It is known that C (But in its Graphene form!!!) has high resistivity compared to Cu etc … But:
What is the thickness that we need to have most photons interacting with the topmost layer at our grazing incidence?

BUT will a C Layer cause Impedance problems?

Attenuation Length:
The depth into the material measured along the surface normal where the intensity of x-rays falls to 1/e of its value at the surface.



http://henke.lbl.gov/optical_constants/

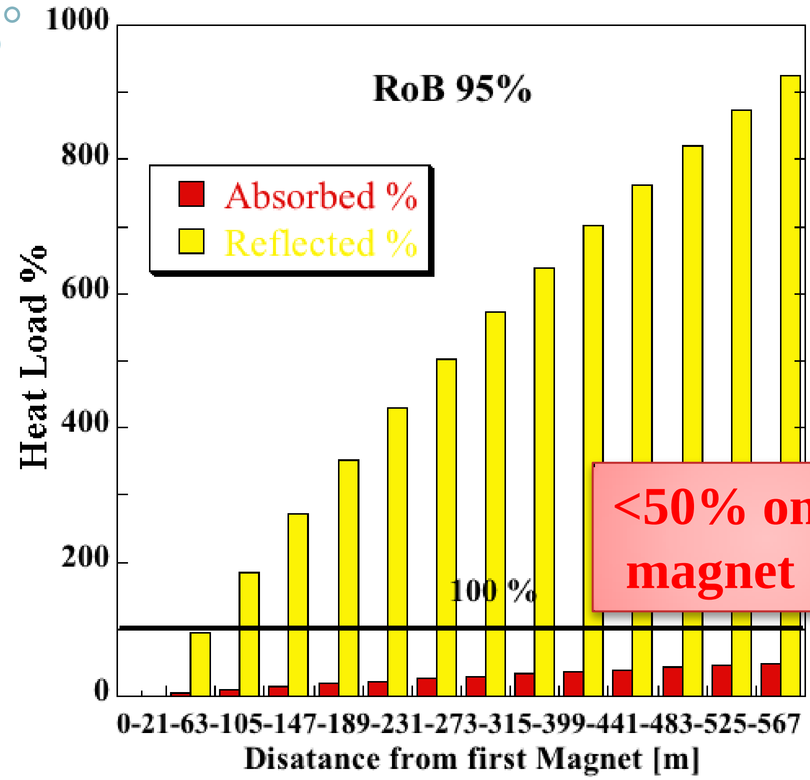
C thickness	T (%)
~ 3.5 nm	~ 37%
~ 7 nm	~ 13 %
~ 10 nm	~ 5 %
~ 14 nm	~ 2 %
~ 20 nm	~ 0.02 %

20 nm of a-C are enough!

Little or no effect on Impedance (which will be affected by the properties of at least few microns) (D.S.)

Heat Load Propagation Vs RoB

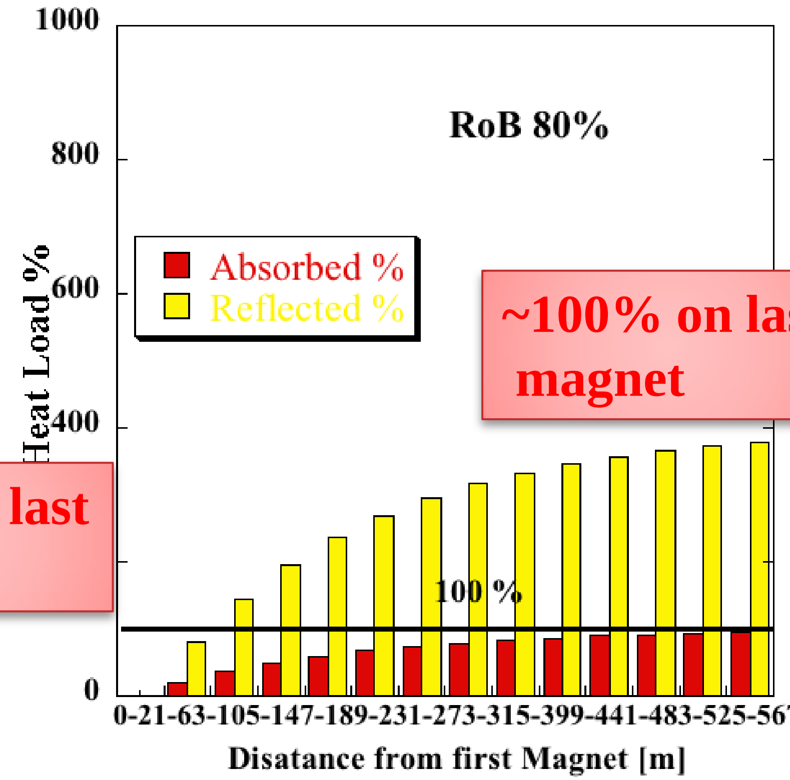
Optimized surface



<50% on last magnet

Within 500m ~ 30% of expected HL adsorbed @ LT

LHC standard surface finish



~100% on last magnet

Within 500m ~ 70% of expected HL adsorbed @ LT

✓ Considerations on Heat Load Propagation Vs RoB

Total heat load to be absorbed @ LT:

✓ **decrease with the obtainable RoB (%)**

✓ **increase with the distance between RT absorbers.**

Potential savings!

since adsorbing HL at RT is cheaper and easier!

✓ RoB need to be studied and controlled in any proposed design, to estimate HL distribution, thermal loads, photoelectron productions, gas desorbtion, etc.

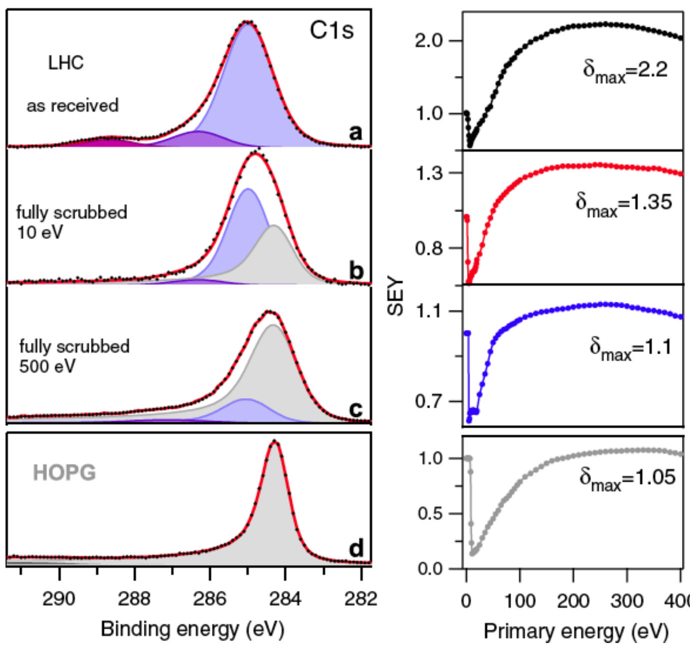
✓ Surface Reflectivity must be studied, controlled, understood, and "measured"!

One can absorb reflected HL in "ad hoc" designed RT Absorbers!

Obtaining low RoB is as difficult (or more) than high RoB since:

- ✓ Low grazing incidence (high reflectivity)
- ✓ Roughness not too efficient to reduce RoB (to be studied).
- ✓ High absorbing material choice could be irrelevant due to the natural ease at which C layers grow on surfaces upon electron (or) photon irradiation: the chemical origin of "scrubbing"

R. Cimino, et al PRL. 109 (2012) 064801



- ✓ at LT: A. Kuzucan, et al JVAC. A 30, 051401 (2012)
- ✓ Photon distribution along the beam pipe depends on the curvature of the tube (Optical ray tracing)

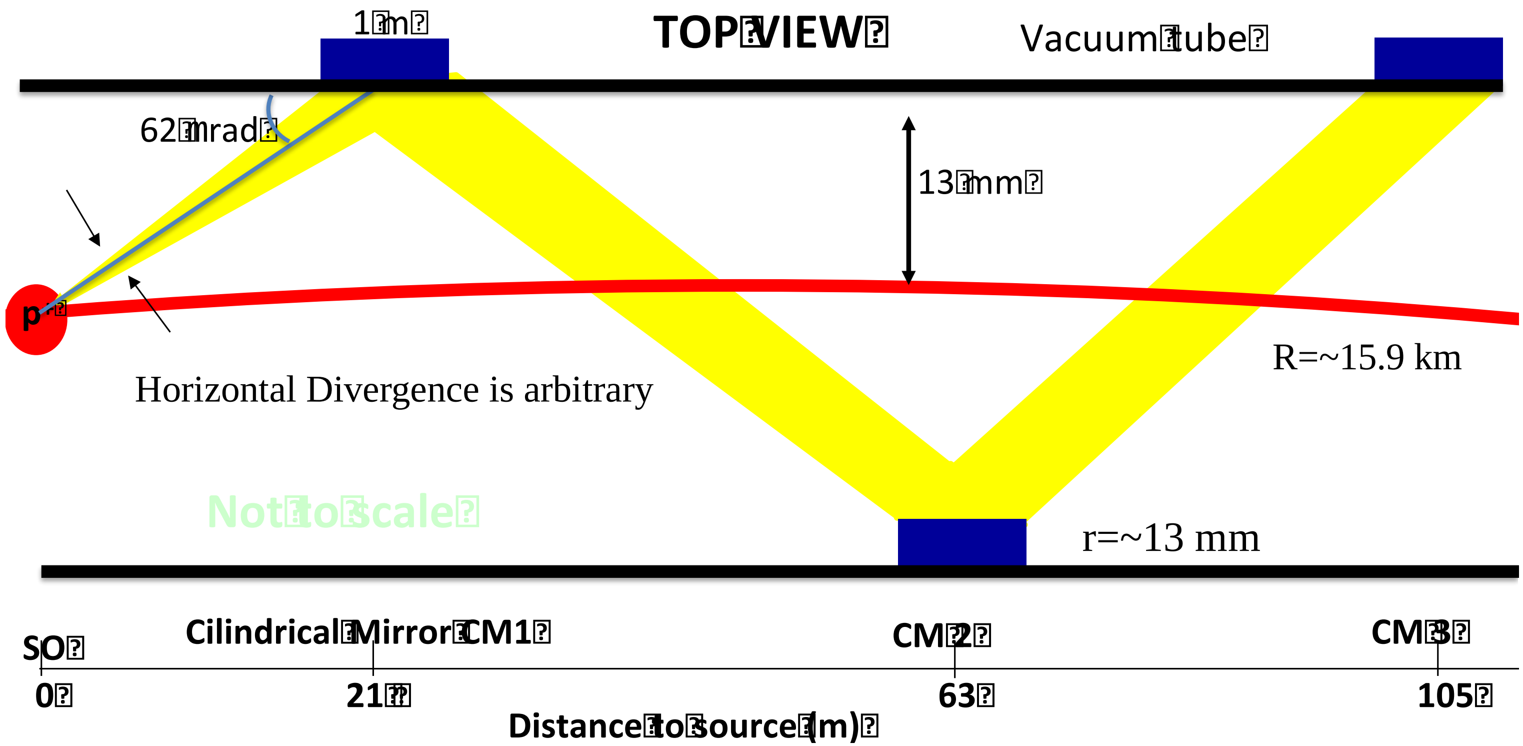
Optical RAY tracing:

It instructive to push to the limit and calculate the X-Ray transmission trough a perfectly reflecting and Cylindrical in shape beam pipe.

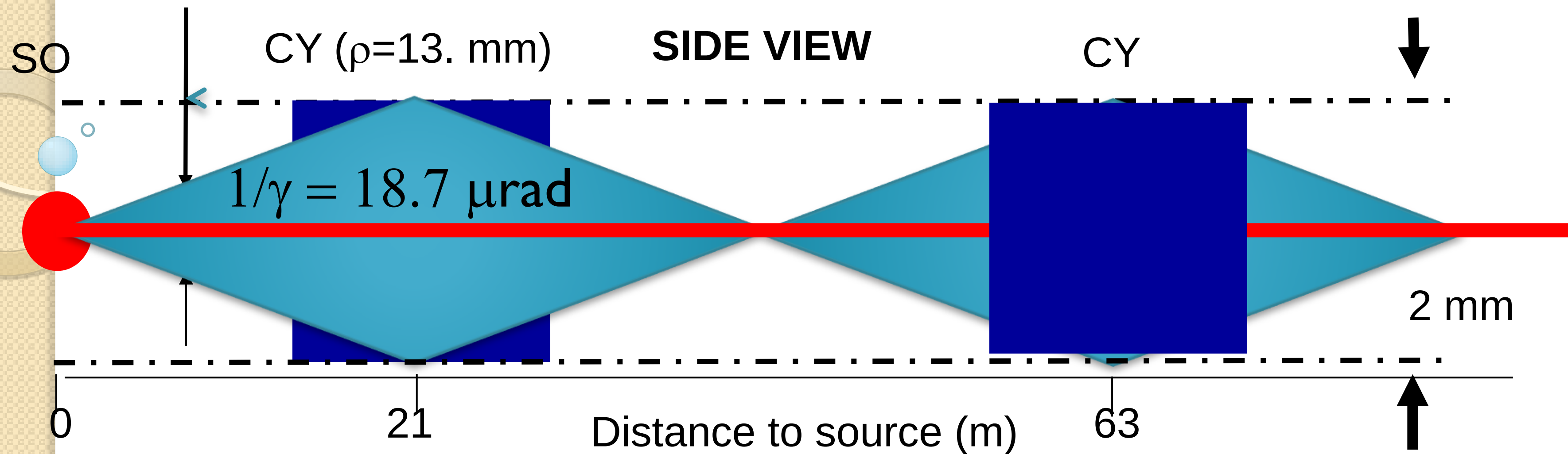
- **Optical raytracing for an X-ray at Ɛc (hν=4.5 KeV)**

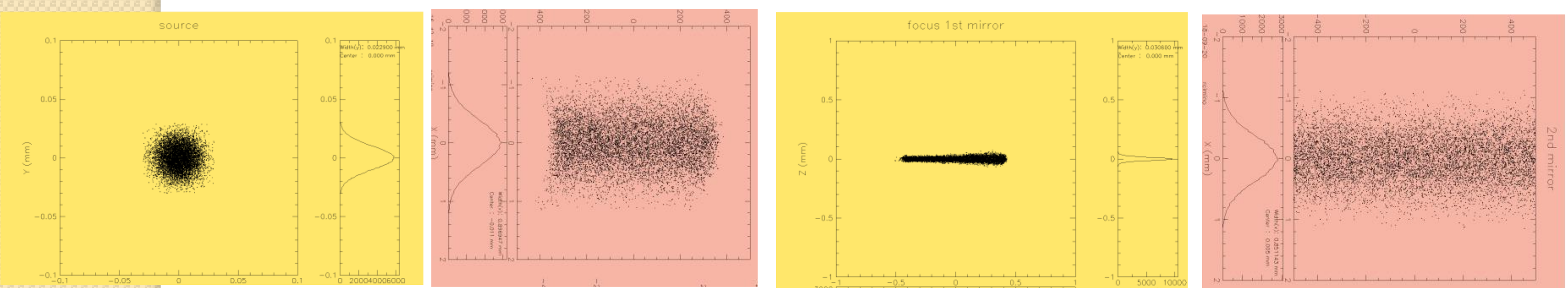
Source:10x10μm 1 mm long.

Photon Beam divergence: hor = arbitrary ; Vert. = 1/γ



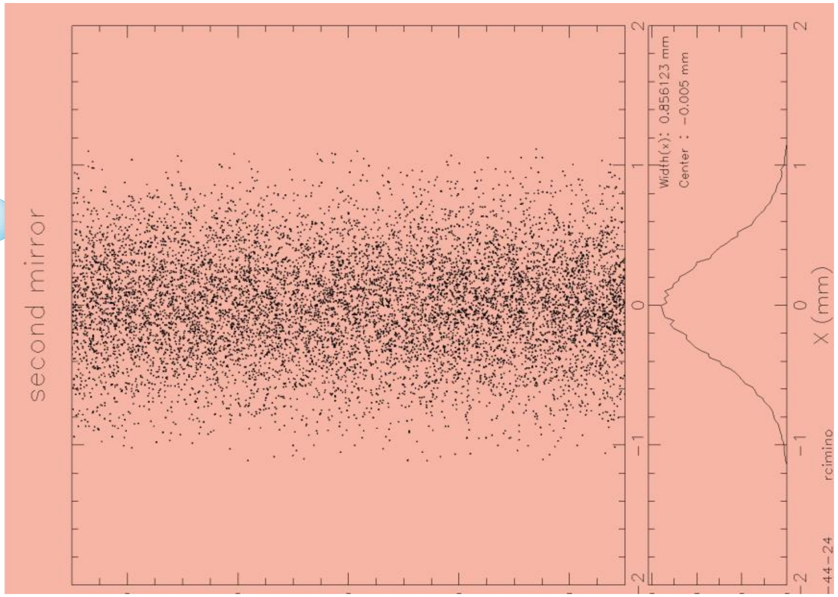
Ray tracing calculations with perfect optics:



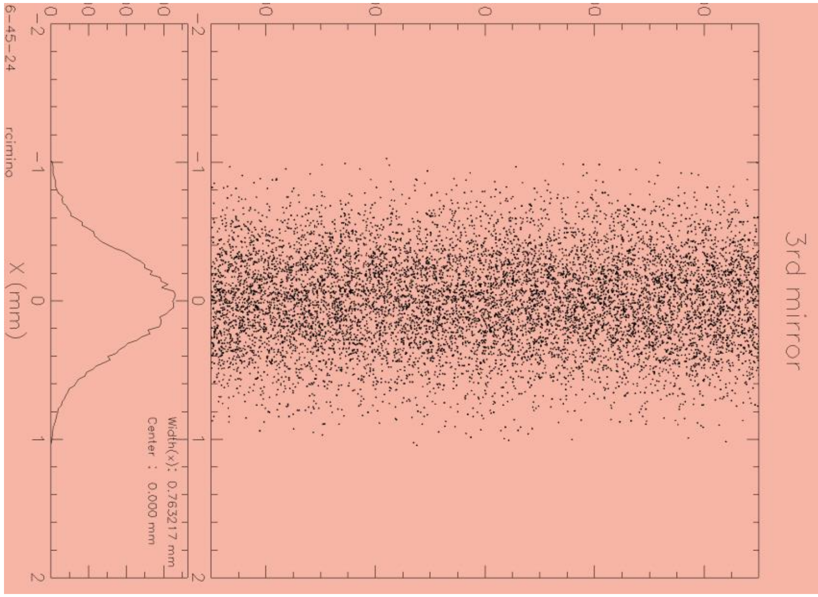


Source	@ 21m	First focus	@ 63 m
10x10 μm	<2 mm vertical	Verical~13 μm	<2 mm vertical

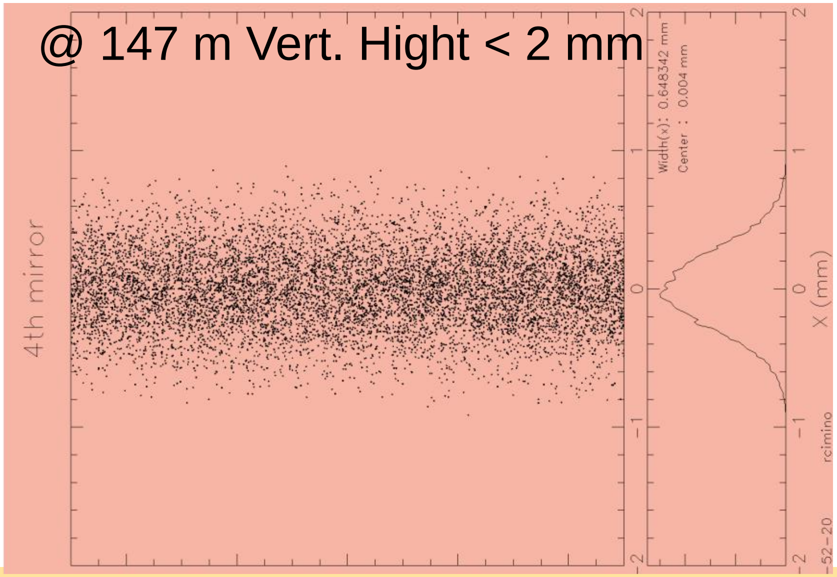
@ 63 m Vert. Hight < 2 mm



@ 105 m Vert. Hight < 2 mm



@ 147 m Vert. Hight < 2 mm

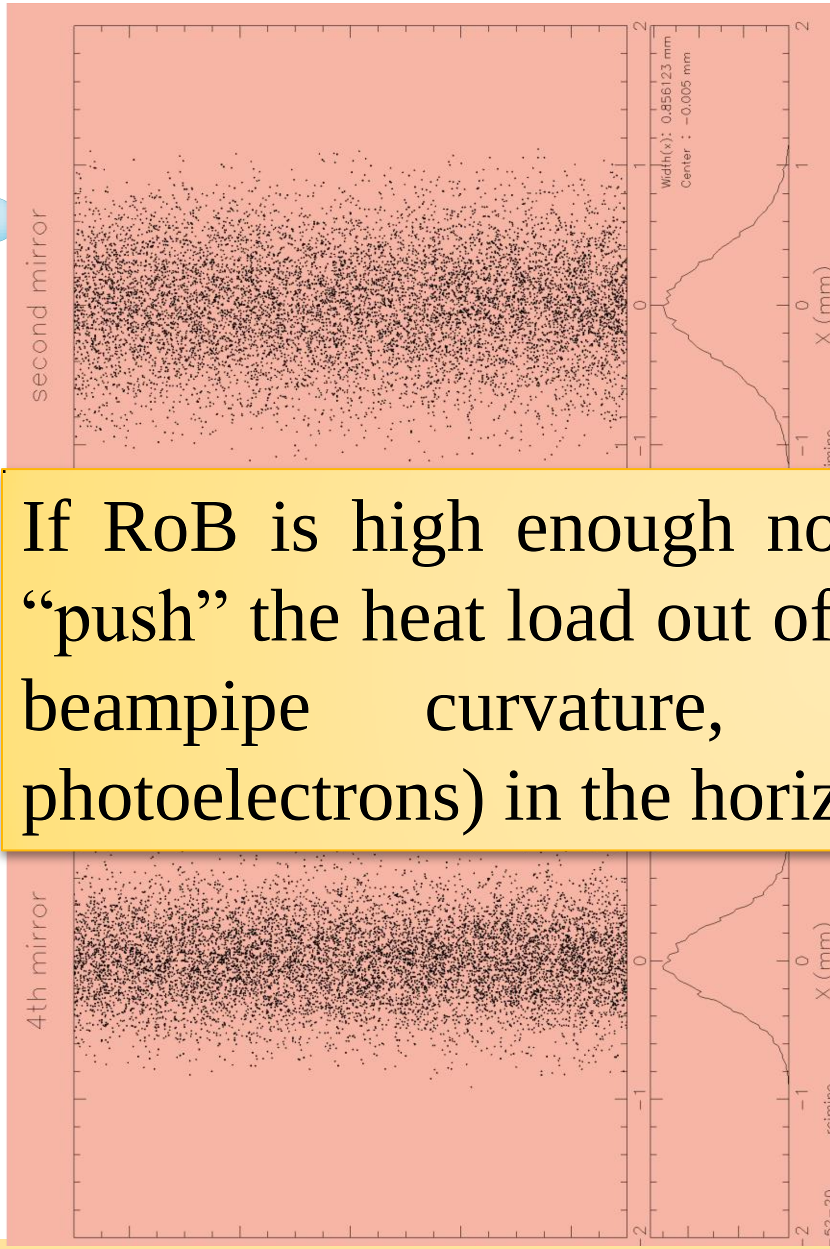


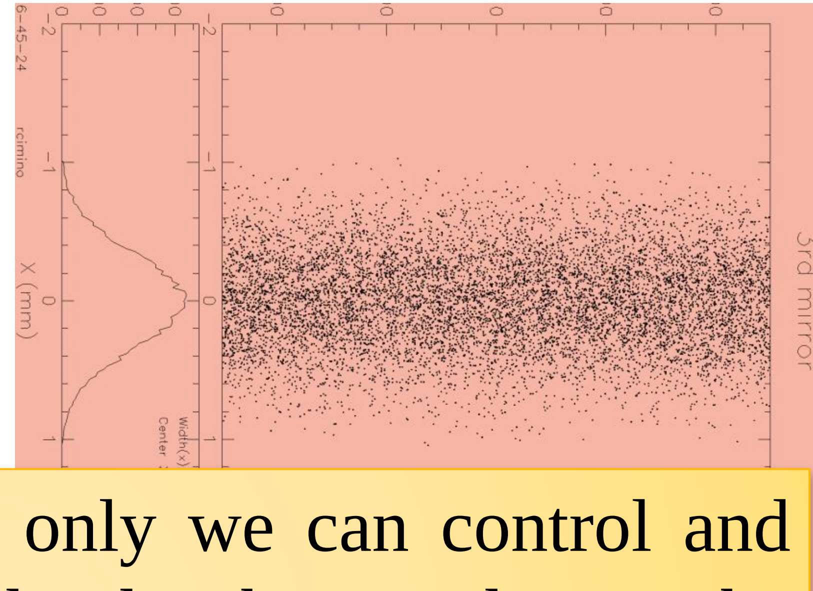
Calculation done with:
RAY & Reflec codes developed for X-ray optics at BESSY 2

See: "The BESSY Raytrace Program RAY", By F. Schäfers in: "Modern Developments in X-Ray and Neutron Optics" Springher.

@ 63 m Vert. Hight < 2 mm

@ 105 m Vert. Hight < 2 mm



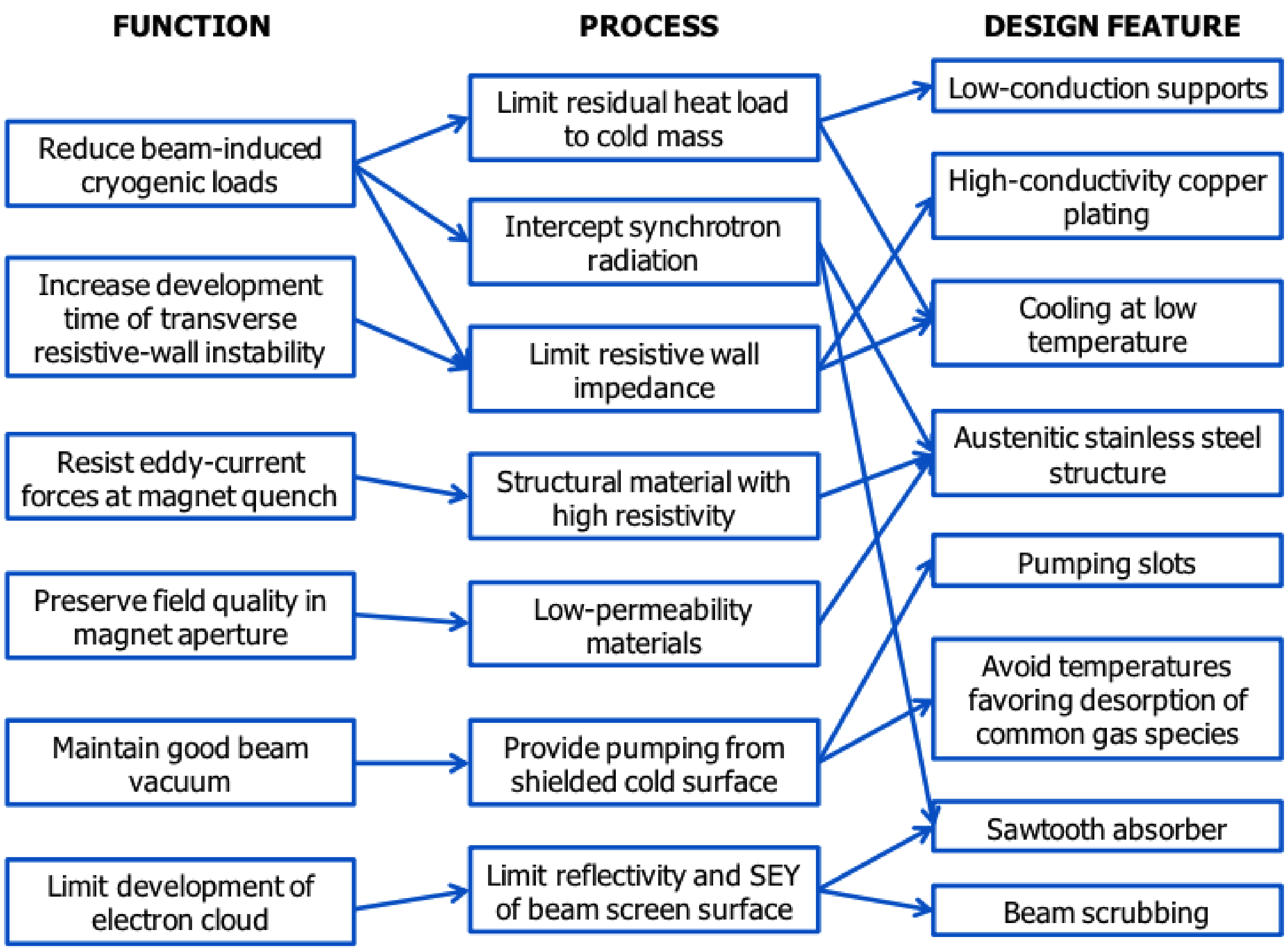


If RoB is high enough not only we can control and "push" the heat load out of dipoles, but, exploiting the beampipe curvature, confine photons (and photoelectrons) in the horizontal plane!

for X-ray optics at BESSY 2

See: "The BESSY Raytrace Program RAY", By F. Schäfers in: "Modern Developments in X-Ray and Neutron Optics" Springher.

Any adopted solution forthe Beam screen has to compel with many other requirements and boundary conditions.



From:
Cryogenic Beam Screens for High-Energy Particle Accelerators
By:
V. Baglin , Ph. Lebrun, L. Tavian, R. van Weelderen
CERN-ATS-2013-006

Presented at ICEC24-ICMC2012.

This study must consider all aspects!!!

In conclusion:

RoB seems to be an extremely important parameter to be controlled and (eventually) beneficially utilized. In all cases:

- **Validate reflectivity simulations and refine models.**
- **Developing and study smooth surfaces and high quality low C coverages (~ 20 nm).**
- **Since RoB depends on the first 20 nm… carefully analyze interaction of LT surfaces with residual gas, (physisorbtion), photo-desorbtion (and photochemistry) electron-desorbtion (and induced chemistry)**
- **Identify absorbers type and locations.**
- **Study and measure realistic Photoelectron Yield and reflectivity, essential ingredients to single bunch and/or e^- cloud related instabilities.**

A lot of resources needed for a most exciting study!!!