# Vacuum and cryogenic design of the CW-final focus

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# Content

- Input conditions and parameters
- General assembly with detector
- Design and common assembly of IP, Y chambers and cryostat
- SR flux and power distribution
- Electron clouds
- Resistive wall loses.
- Temperature of vacuum chambers inside superconducting quadrupoles
- Conclusion

# Input conditions and parameters

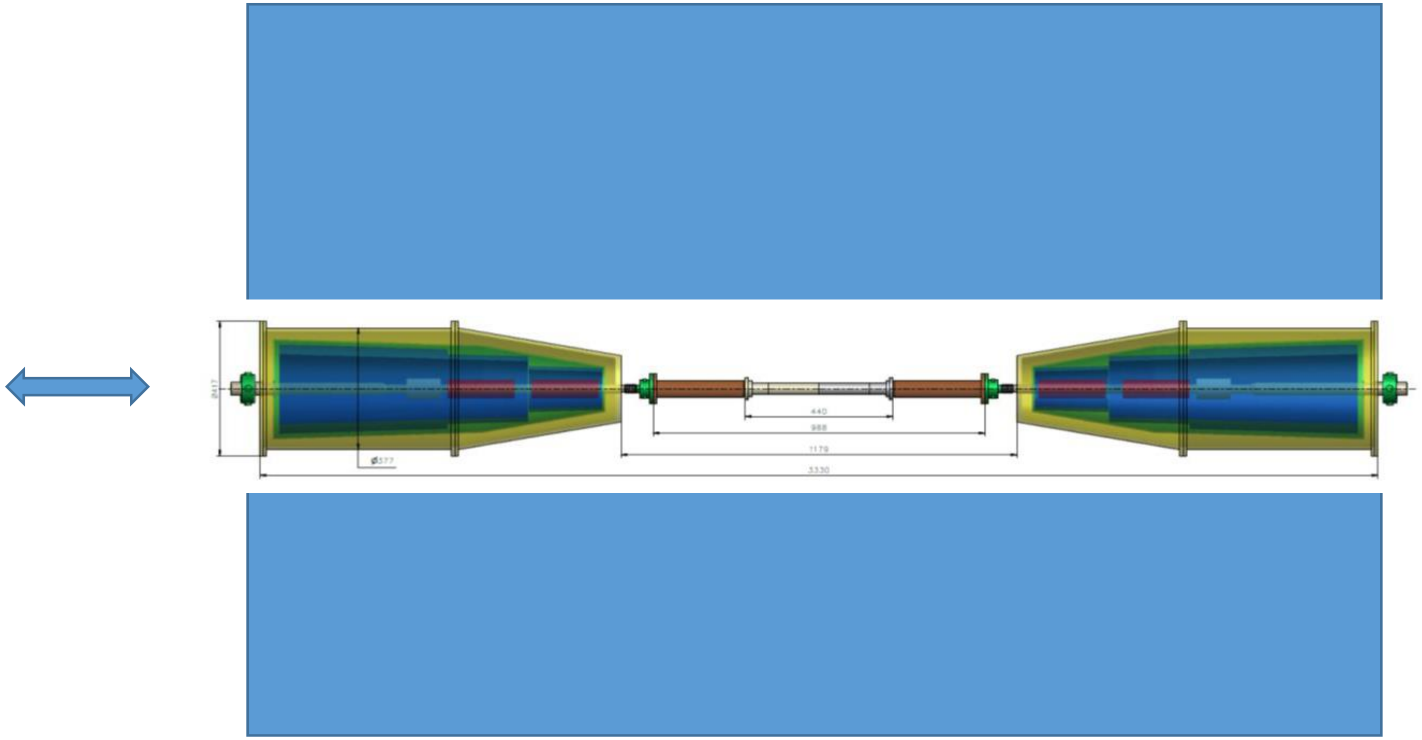
We are going to develop an universal design and technologies for FF elements, which can be used not at test facility in VAPP4 tunnel only but also at SCTF. It means we have to take into account proposed SCTF beam and SR parameters at highest energy:

| **E [GeV]** | **3.5** |
|---|---|
| **I(A)** | 2.9 |
| **Perimeter [m]** | 936 |
| $N_{e/bunch} \times 10^{-10}$ | 5.8 |
| $N_b$**/q** | 974/1093 |
| $\sigma_s$**(mm) (SR/IBS+WG)** | 8/14 |
| **SR power [W/mrad]** | 84 |
| **SR flux [Ph/mrad]** | 1,3E18 |
| **Distance from IP to SR source [m]** | 16.3 |

General requirements

1. The average residual gases pressure : < $3 \times 10^{-7} \times$ Perimeter/FF_length x 0.4 $\approx 3 \times 10^{-5}$ Pa (lower is better)
2. SR should not irradiate IP chamber (detector background)
3. All elements, with the exception of beryllium IP chamber, must be placed inside 10 degree cone with an apex at IP
4. To avoid RF cavity at IP (high mode capture), the diameter of vacuum chambers (in one direction at least) shall not be less that diameter of IP chamber
5. To minimize geometrical impedance, the vacuum chambers must be as smooth as possible (with smooth transitions between elements with deferent cross-section)

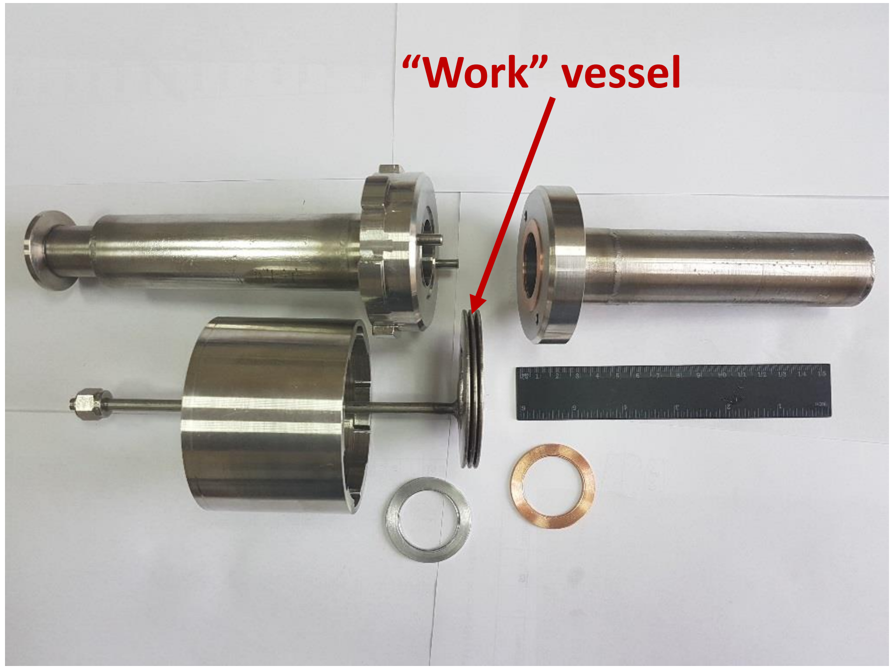
# General assembly with detector



We are going to install the both pre-assembled cryostat with IP chambers into detector from one side.

In principle, the assembly from both sides (Super KEKB variant) with the use remote control vacuum flange is also possible

# BINP Remote control flange prototype

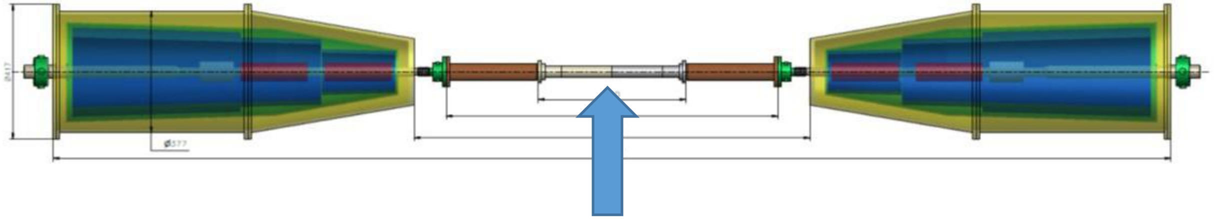


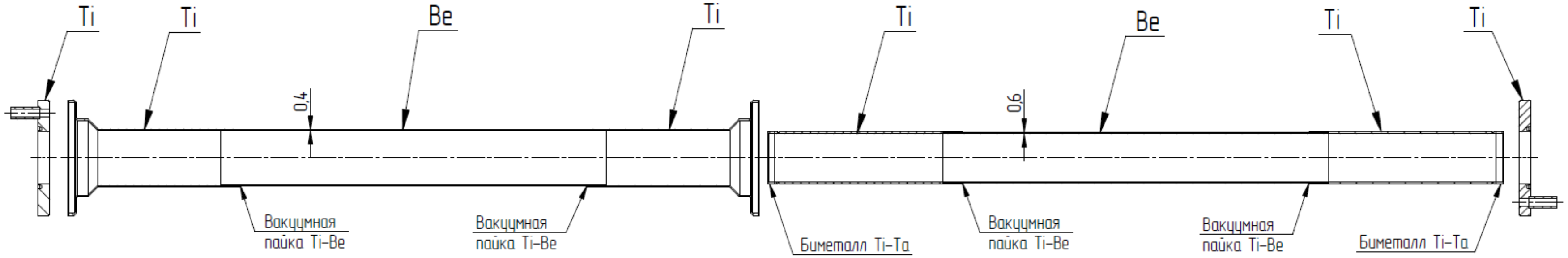

Parts of the flange connection

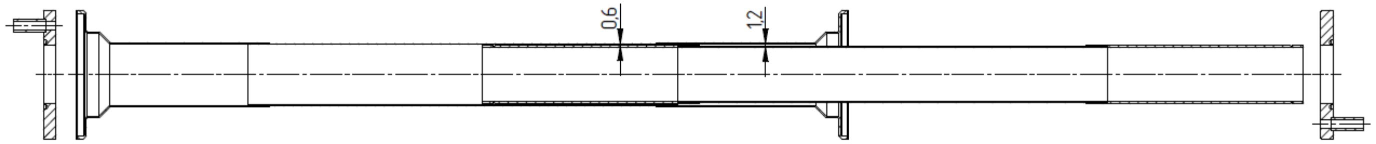
Assembled connection

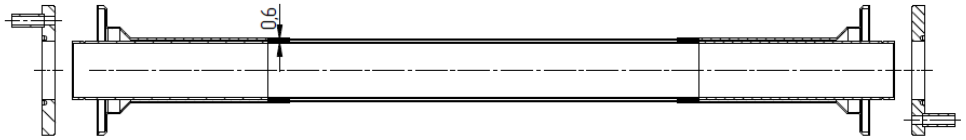
- We've got successful result with Cu and Al gaskets at pressure 150 atmosphere. Leak rate is less than 1E-10 mbar*L/s.
- Note, the connection keeps smoothness of internal surface along beam propagation

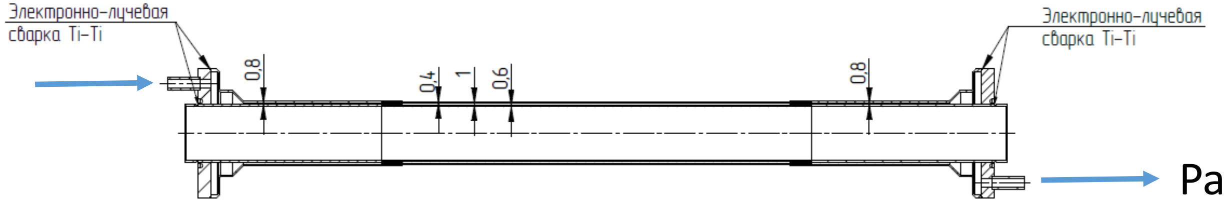
# IP double wall chamber






Paraffinic coolant

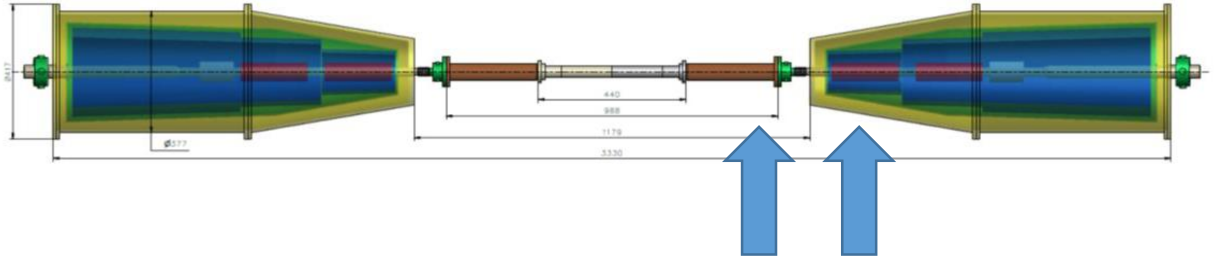
Mainly we are following to Supper KEKB solutions.

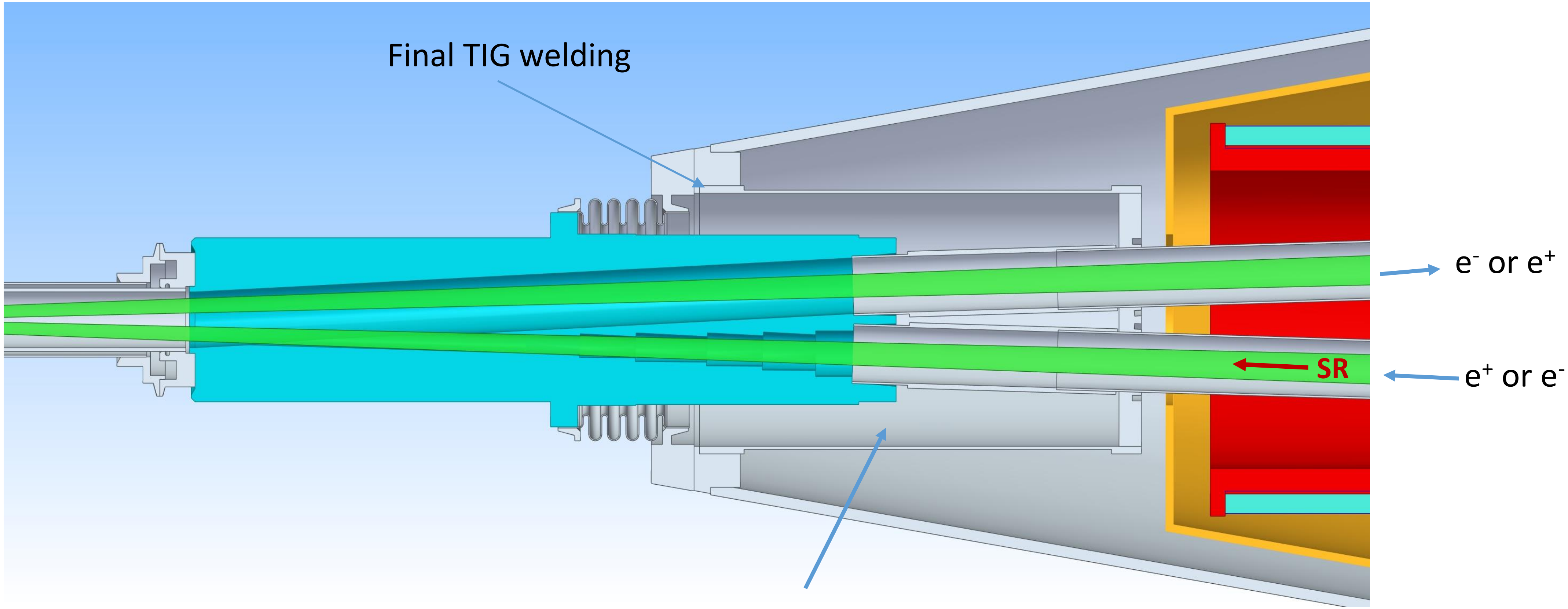
Preliminary choice:

ID of IP chamber is 15 mm

Internal coatings (Au or others) is under consideration

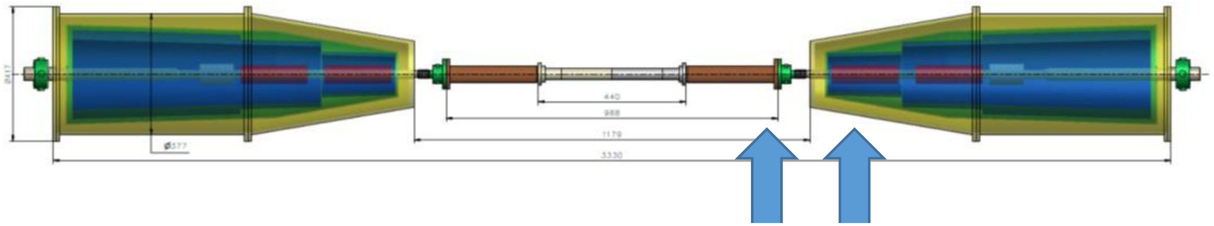
# Y chamber connection with cryostat

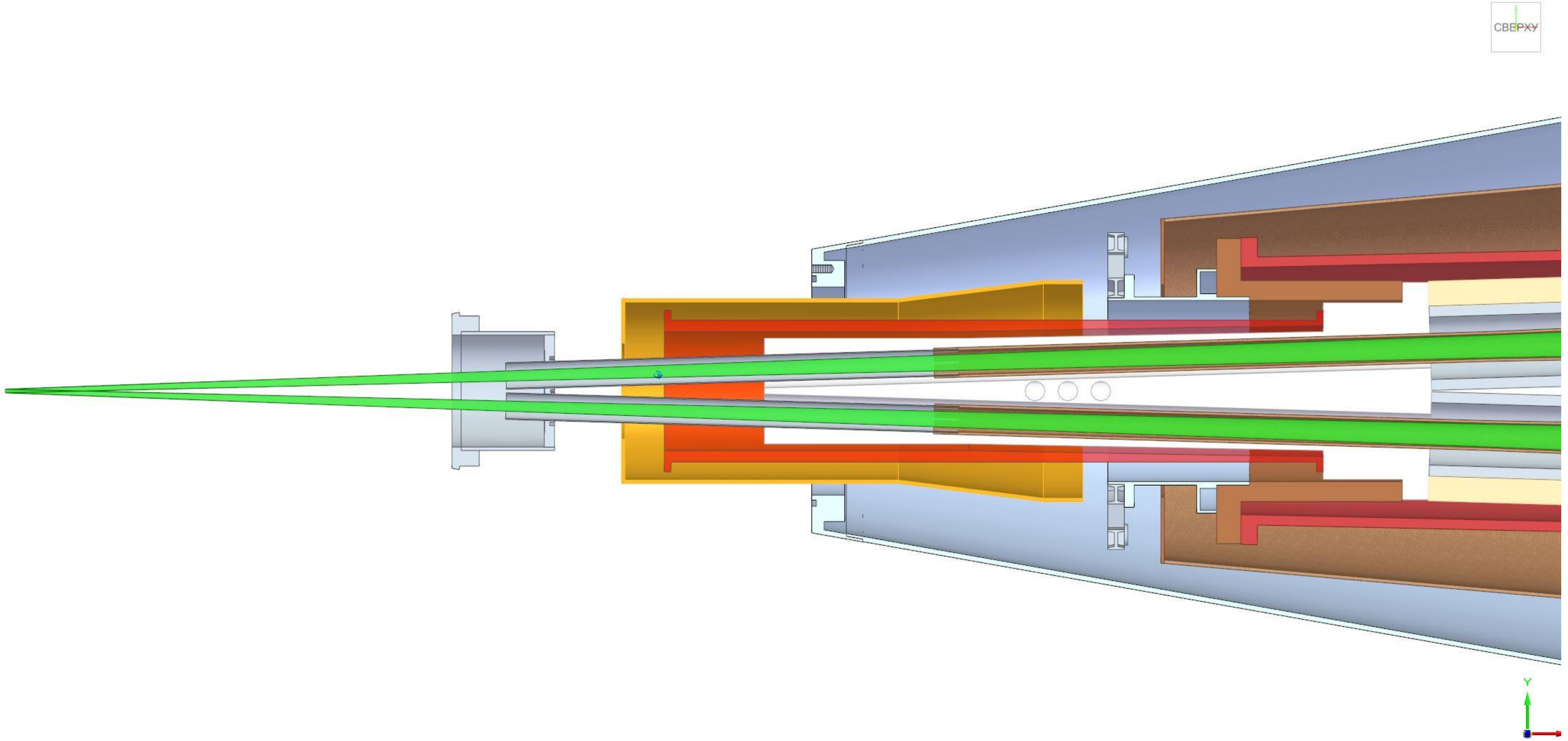




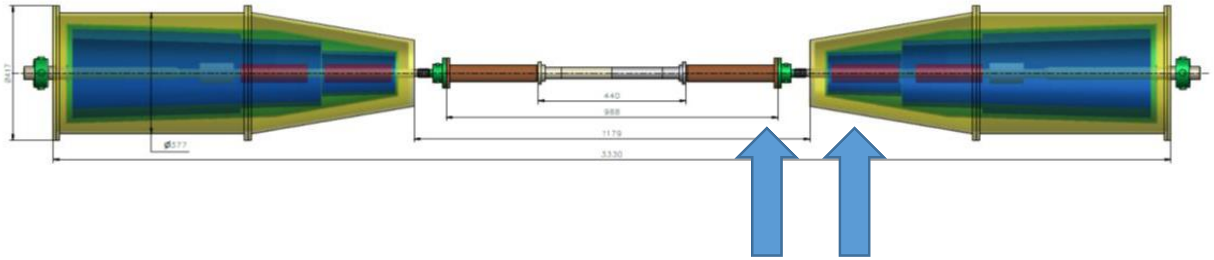

Free space for vacuum pump
A combined ion-getter + getter pump for example
BPMs can be install here also

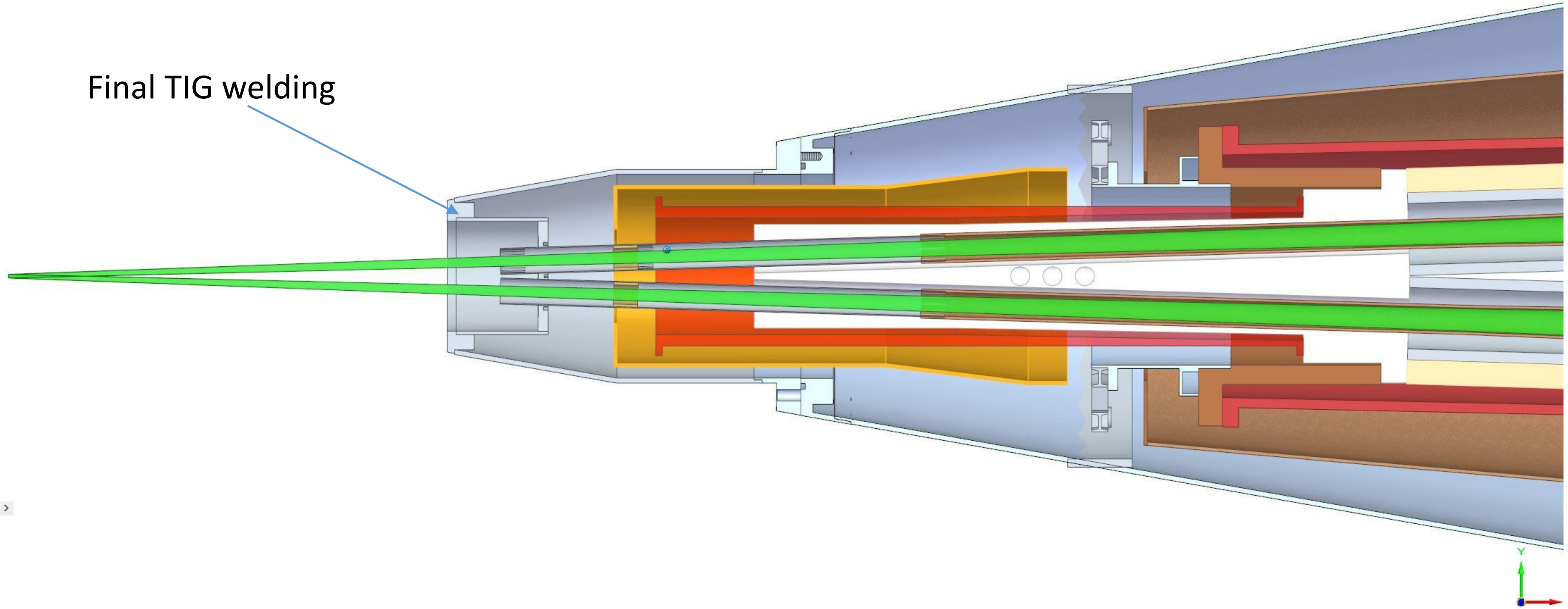
# Cryostat assembly



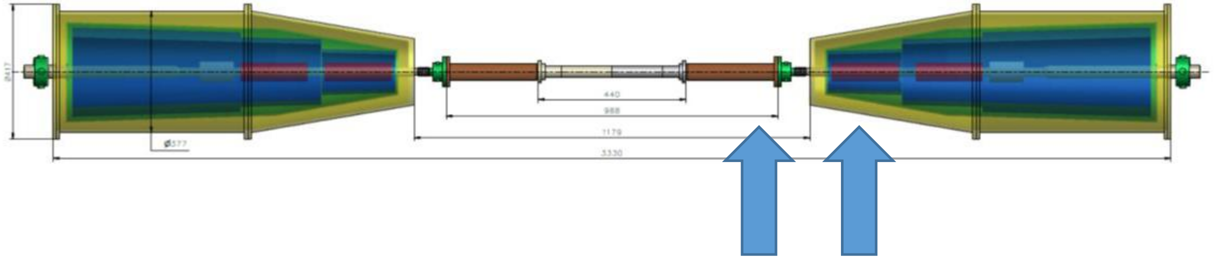


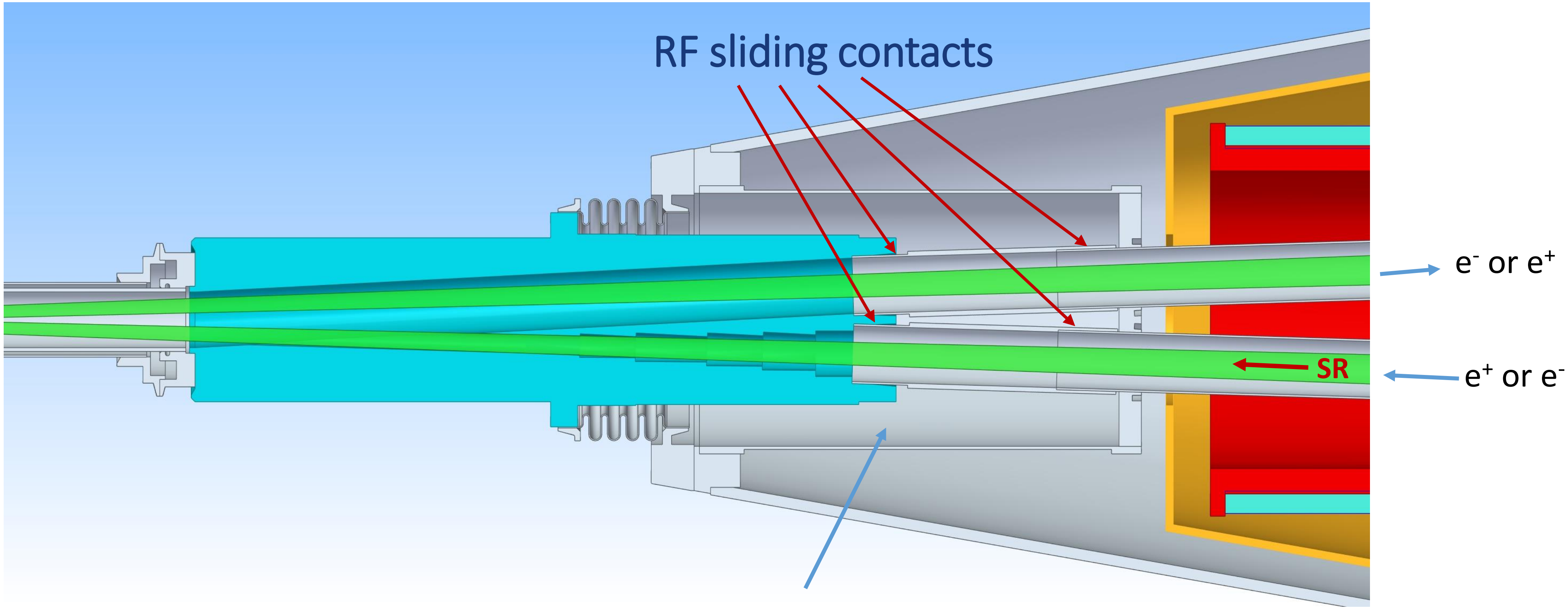
# Cryostat assembly





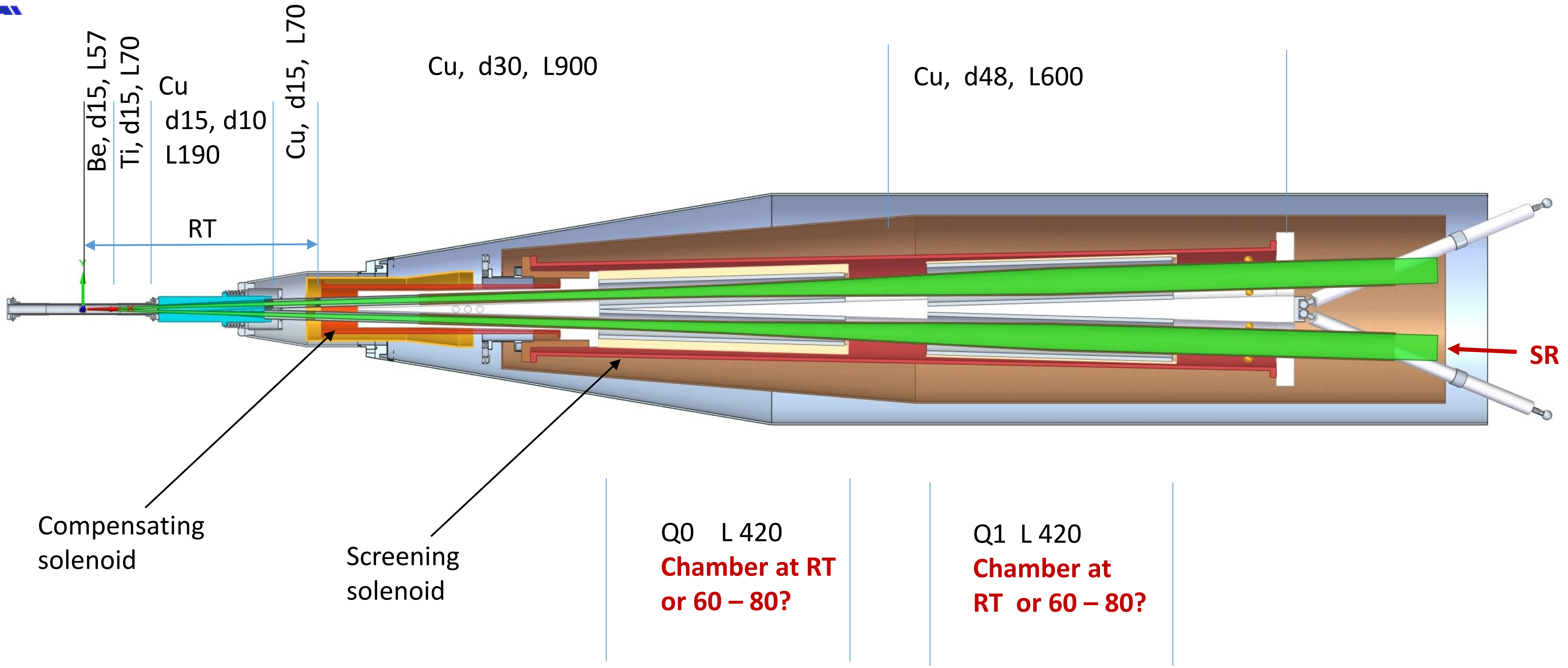
# Y chamber connection with cryostat





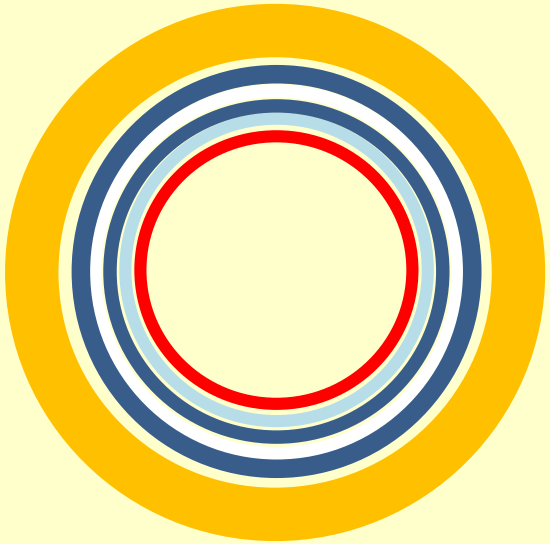

Free space for vacuum pump
A combined ion-getter + getter pump for example
BPMs can be install here also

# Heat loads


Be, d15, L57
Ti, d15, L70
Cu
d15, d10
L190
Cu, d15, L70
Cu, d30, L900
Cu, d48, L600
RT
SR
Compensating solenoid
Screening solenoid
Q0 L 420
Chamber at RT or 60 – 80?
Q1 L 420
Chamber at RT or 60 – 80?

# Vacuum chamber inside cryogenic magnets. Super KEKB case

BINP



Inner tube SS 0.7 mm with Cu coating

Gap 0.7 with water flow and spacers

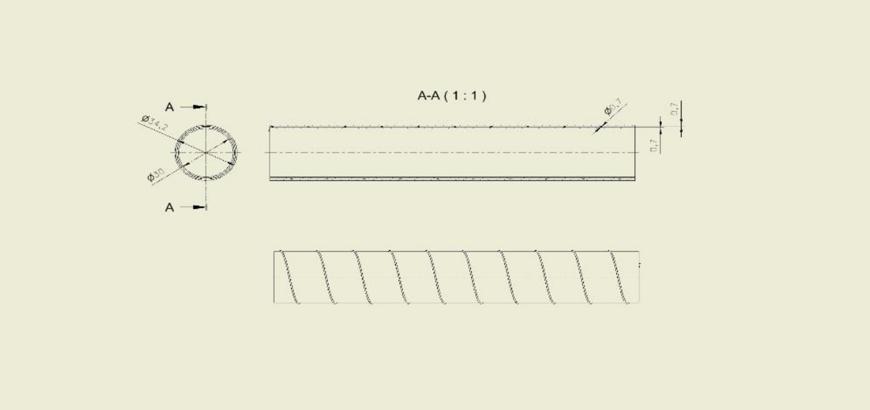
SS tube 0.7 mm

Vacuum gap 0.9 mm with spacers

Outer SS tube 1 mm

A coil

**If ID=30mm, OD=38mm**




Power load 100 W/m is not challenging for the design

But it looks too complex

# Resistive wall loses

При комнатной температуре с учетом нормального скин-эффекта:

$$P_{\text{NSE}} = \frac{\Gamma\left(\frac{3}{4}\right)c}{4\pi^2 b\sigma_s^{3/2}}\sqrt{\frac{Z_0}{2\sigma_c}} \cdot q_e N_e I$$

At high frequencies or at low temperatures, when the depth of field penetration becomes less than the mean free path of electrons, the theory of anomalous skin effect is used, which takes into account the scattering of electrons at the interface (surface). A more strict criterion for the region of the anomalous skin effect is written as follows:

$$\alpha = \frac{2}{3}\left(\frac{l}{\delta}\right)^2 = \frac{3}{4} \cdot \frac{\omega Z_0}{c}\left(\frac{l}{\sigma_c}\right)^2 \sigma_c^3 > 1$$

Borderline frequency between normal and anomalous skin effect:

$$f_t = \frac{2}{3\pi} \cdot \frac{c}{Z_0}\left(\frac{l}{\sigma_c}\right)^{-2} \sigma_c^{-3}$$

One of the best approach for surface impedance, which works well for wide frequency region is:

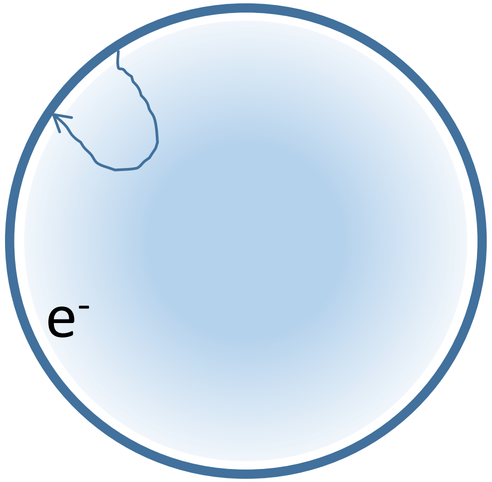
$$R_s(\omega) = \left(\frac{\sqrt{3}}{16\pi} \cdot \frac{l}{\sigma_c}\right)^{1/3} Z_0^{2/3} \frac{\omega^{2/3}}{c^{2/3}} \left(1 + 1.157\alpha^{-0.276}\right) = B\frac{\omega^{2/3}}{c^{2/3}}\left(1 + 1.157\alpha^{-0.276}\right)$$

Integration over beam frequency spectra for a circular beam pipe gives:

$$P_{\text{АСЭ}} = \frac{1}{\pi} \cdot \frac{q_e N_b I}{2\pi b}\int_0^\infty R_s(\omega) e^{-\sigma_s^2\frac{\omega^2}{c^2}} \partial\omega = \frac{B \cdot c \cdot \left(\Gamma\left(\frac{5}{6}\right) + 1.157 \cdot \left[\frac{3}{4} \cdot \frac{Z_0}{\sigma_s}\left(\frac{l}{\sigma_c}\right)^2 \sigma_c^3\right]^{-0,276} \Gamma(0.7)\right)}{4\pi^2 b\sigma_s^{5/3}} q_e N_e I$$

It makes good approach for Cu at temperature from LHe up to 60-80K and beam rms length up to 2 cm

# Electron Clouds (for e+ beam only)




$$\rho_{e,sat} \approx \frac{N_b}{\pi s_b b^2} \quad \text{for} \quad N_b \ll N_{trans}$$

$$\rho_{e,sat} \approx \frac{E_s}{m_e c^2 b^2 r_e} \quad \text{for} \quad N_b \gg N_{trans}$$

$$N_{trans} \approx \frac{E_s s_b}{m_e c^2 r_e}.$$

$E_s$ – average energy of secondary electrons (about 2 eV)

For SCTF parameters the saturations density of electron cloud is 5e6 1/cm$^3$ in the chamber with ID 30mm.

Taking into account average energy of the electrons 200 eV after bunch propagation and bunch spacing 1m, one can obtain heat load due to EC **40 W/m**

It looks like the mitigation of the EC with the use a coating (amorphous carbon for example) is necessary. Otherwise, the vacuum chamber operation inside quads is possible at RT only.

# Electron cloud formation
# at $\delta_{\max}$ <1

BINP

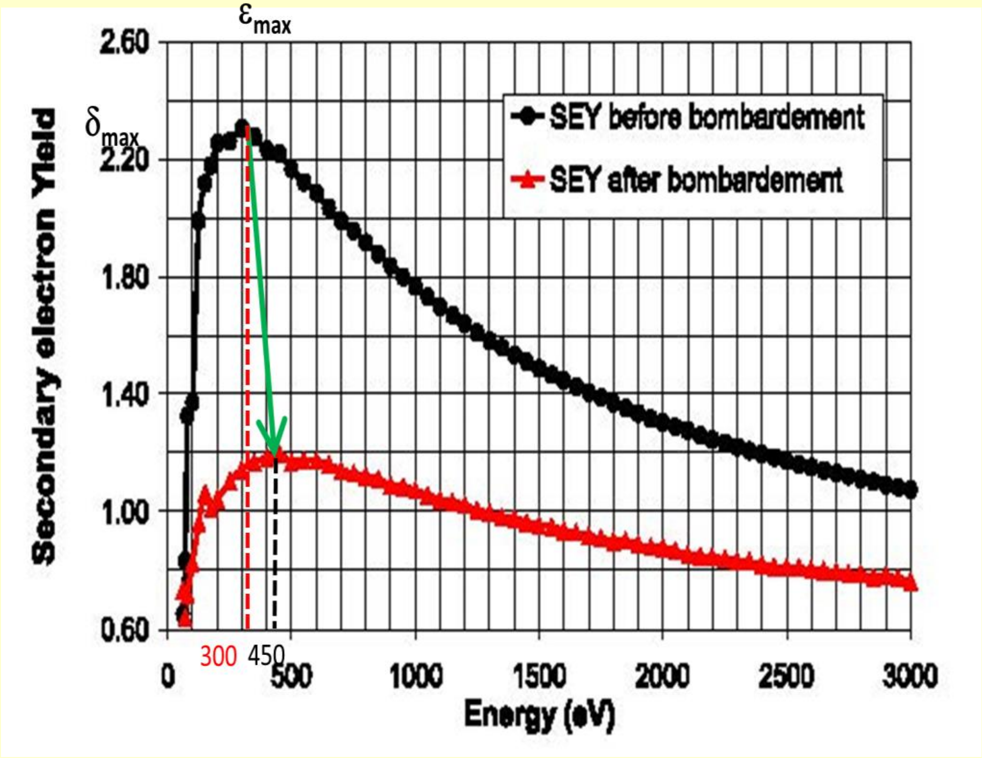
**Phenomenologically, neglecting space charge, electron density can be estimated as:**

$$\rho_e = \frac{Y \cdot g \cdot \dot{\gamma} \cdot \tau_b}{\pi r^2 (1-\delta_{eff})} < 5E5\ cm^{-3}$$

$$\delta_{eff} = \int_0^\infty \delta(E_e) n_e(E_e) dE_e$$

**- The problem is solved if s <0,1**
**and $\delta_{\max}$ < 0,9 One can obtain: $\rho_e \approx 4E5\ cm^{-3}$**

**And heat load ~ 3 W/m**

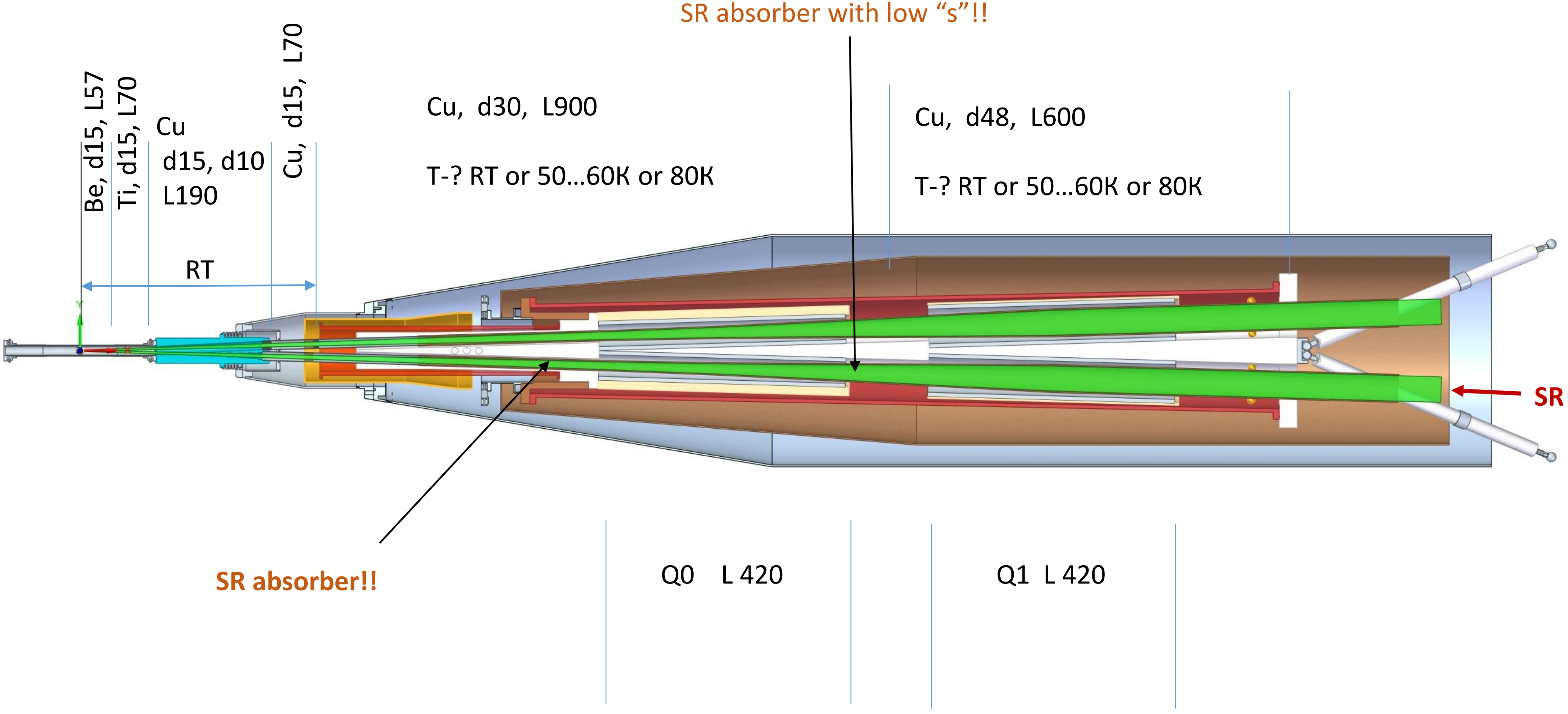



SEY of OFE Copper

**How to reach it:**
- **amorphous carbon coating**
- **High quality NEG (TiZrV)**
- **Laser treatment**
- **Or just Ti but deposited in-situ (!)**

**Geometrical solutions with low "g"?**

# Heat load



SR absorber with low “s”!!
Be, d15, L57
Ti, d15, L70
Cu
d15, d10
L190
Cu, d15, L70
Cu, d30, L900
T-? RT or 50…60K or 80K
Cu, d48, L600
T-? RT or 50…60K or 80K
RT
SR
SR absorber!!
Q0 L 420
Q1 L 420

# Heat load. Cu chambers inside Q at 60 – 70 K

IP and Y-chambers Total power (paraffinic coolant)

| Material | | b [мм] | Length [мм] | $\sigma_c$ [1/(Ом·м)] | P (RW) [W] | Total P (RW) [W] | P (SR) |
|---|---|---|---|---|---|---|---|
| Be | IP | 7.5 | 114 | 2.5E7 | 14 | 73 | 0 |
| Ti | | 7.5 | 140 | 2E6 | 59 | | |
| Au (coating) | | 7.5 | 254 | 4.35E7 | | 23 | 0 |
| Cu | Y | 5 | 190 | 5.7E7 | 23 | 38 | 37 |
| Cu | | 7,5 | 190 | 5.7E7 | 15 | | |

**Total power 150W or 100W in case Au coating**

For Cu chambers at 60-80K (for one cryostat)

| element | b [м] | Length [mm] | $\sigma_c$ [1/(Ом·м)] | P (RW) [W} | P (SR) [W] | P(EC) [W] s=0.1, $\sigma_{eff}$=0.9 | P total [W] |
|---|---|---|---|---|---|---|---|
| Q0 | 0.015 | 620 | 5,7E8 | 8 | 3.5 | 2 | 13.5 |
| Q1 | 0.024 | 620 | 5,7E8 | 5 | 6 | 2 | 13 |
| transition | 0,015 – 0,024 | - | - | - | 47 | ~4 | 51 |

Total heat load on cryogenic level **60 – 80K is 27W** if transition between Q0 and Q operates at RT

# Conclusion

- The first iteration of the FF elements layout has been completed
- Estimations of resistive, SR and EC heat loads have been carried out
- Operation at 60 – 80K of the chambers inside quads looks possible for SCTF
- All manufacturing technologies and assembly concepts can be tested at the VEPP-4CW stand.
- To simulate heat losses, it is necessary to build in resistive heating of vacuum chambers for the VEPP-4CW stand
- To make a decision on the temperature regime of the vacuum chambers inside quads, it is necessary to carry out numerical modeling of electron clouds and calculate the pressure of residual gases taking into account the SR and EC

# Thanks for your attention!