CERN

Vacuum Systems

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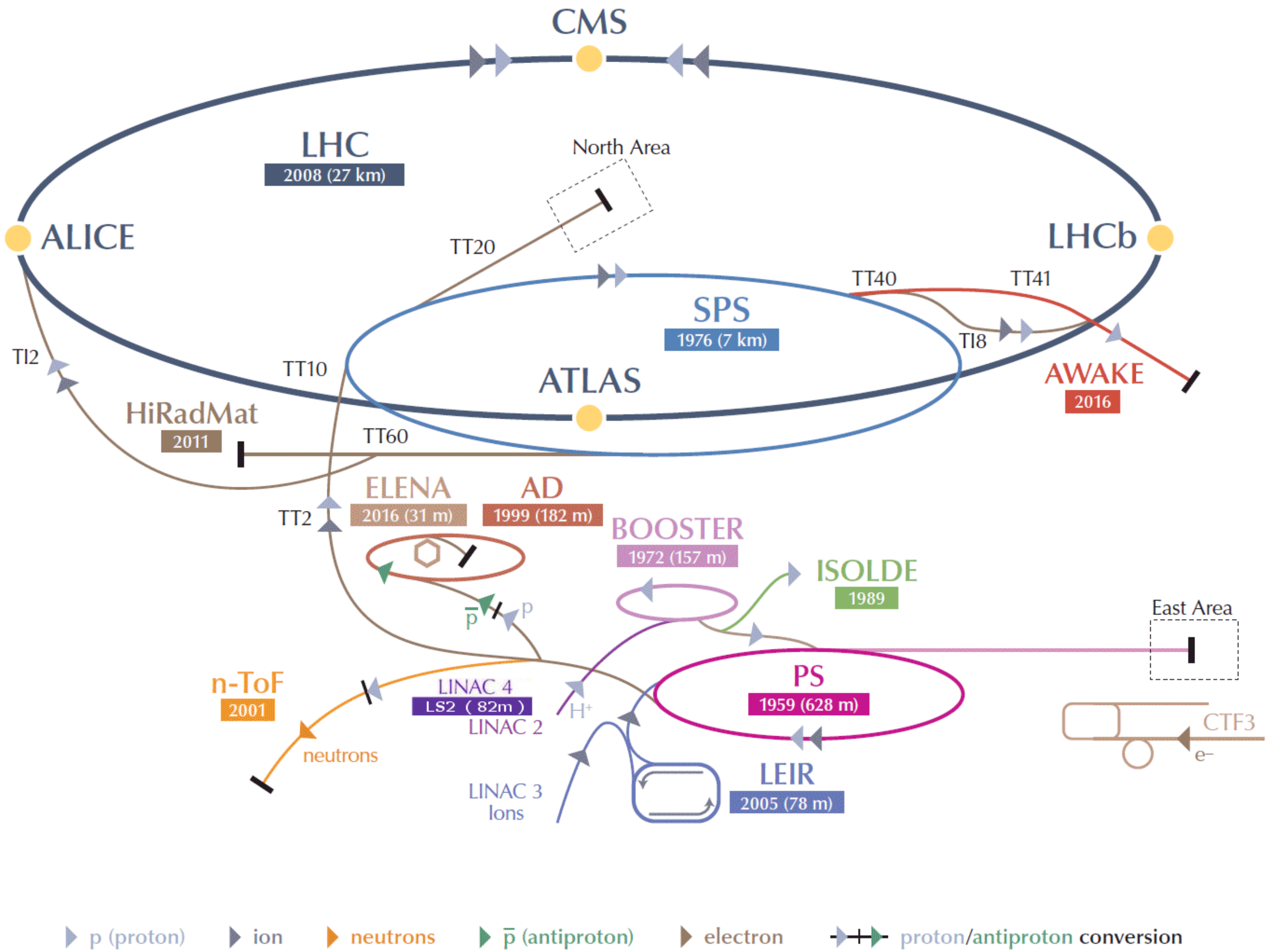
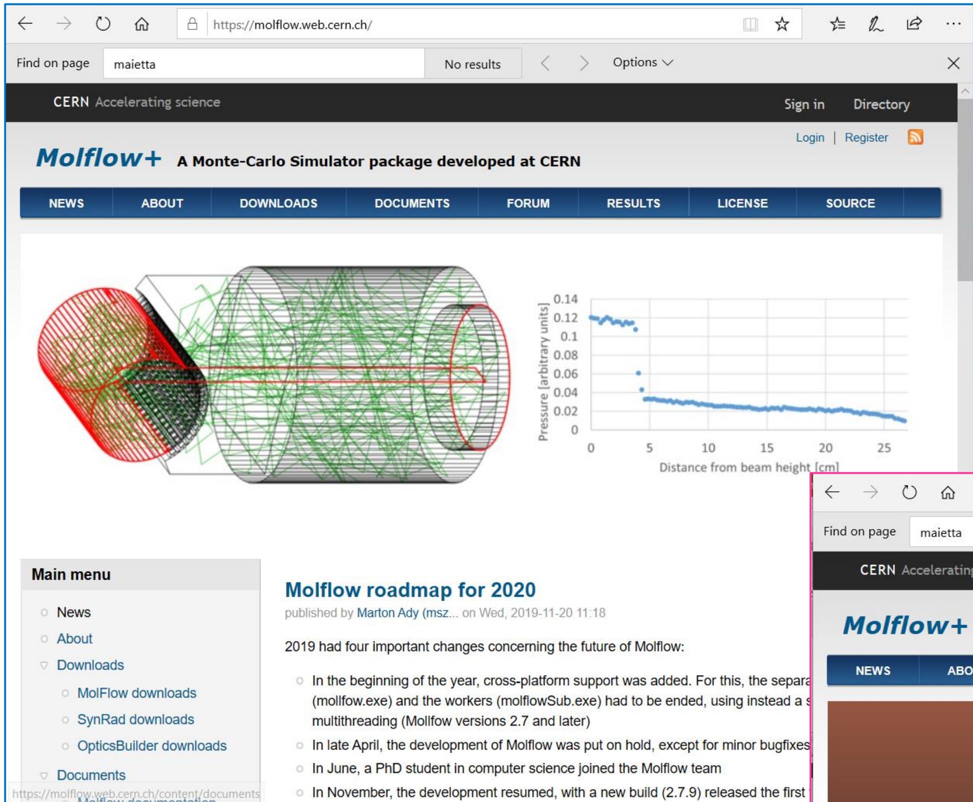
CERN accelerators complex



Montecarlo Simulation Codes:
Molflow+ (molecular flow), and SYNRAD+ (synchrotron radiation)



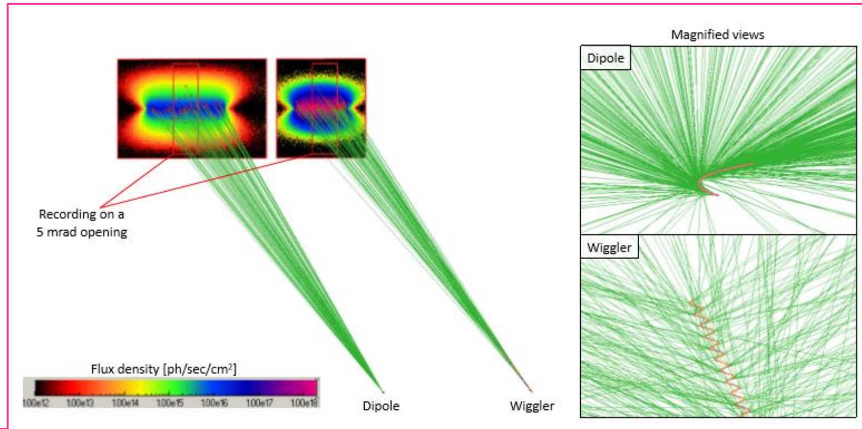
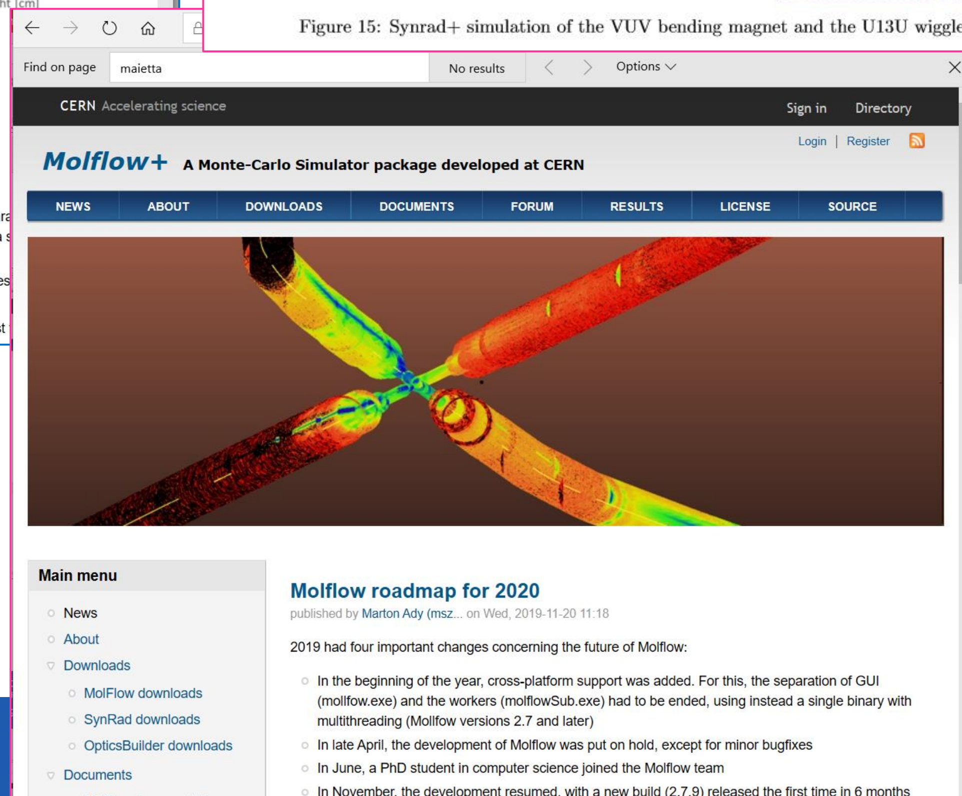


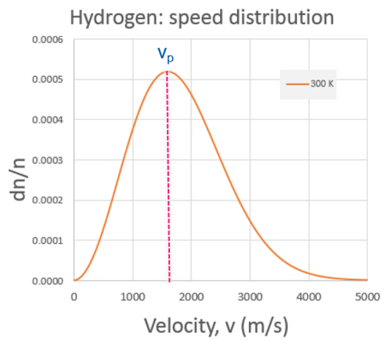
Figure 15: Synrad+ simulation of the VUV bending magnet and the U13U wiggler



Maxwell Boltzmann Distribution

- Assume a pure gas, in thermal equilibrium and enclosed in an isothermal volume
- In this case:
  - The molecule density is constant in the volume and do not vary in time
  - The direction of the molecule's speed is uniform
  - The speed distribution is stationary

$$\frac{dn}{n} = \frac{4}{\sqrt{\pi}}\left(\frac{m}{2kT}\right)^{3/2} v^2 \, e^{-\frac{mv^2}{2kT}} \, dv$$



- The speed of the molecules follows a Maxwell-Boltzmann distribution
- Most of the molecules have a speed around the maximum, v_p
- Less than 1/1000 of molecules have speed:
  $v<0.1\ v_p$ or $v>3\ v_p$

Maxwell Boltzmann Distribution

- The most probable speed is given at the maximum of the distribution: d(dn/n)/dv =0. It equals

$$v_p = \sqrt{\frac{2kT}{m}}$$

- The mean thermal speed equals:

$$\bar{v} = \frac{1}{n}\int_0^\infty v\,\frac{dn}{dv}\,dv = \sqrt{\frac{8kT}{\pi\, m}}$$

- The average quadratic speed equals:

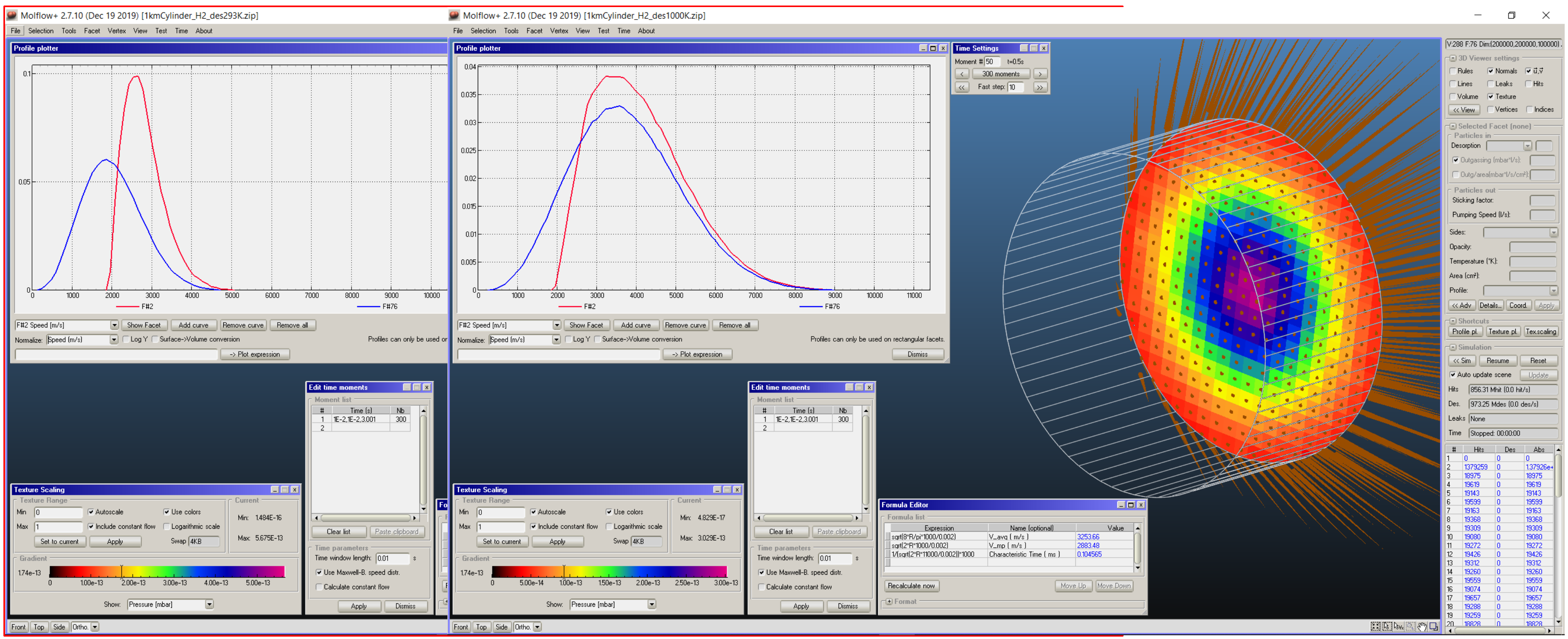
$$v_q{}^2 = \overline{v^2} = \frac{1}{n}\int_0^\infty v^2\frac{dn}{dv}\,dv$$

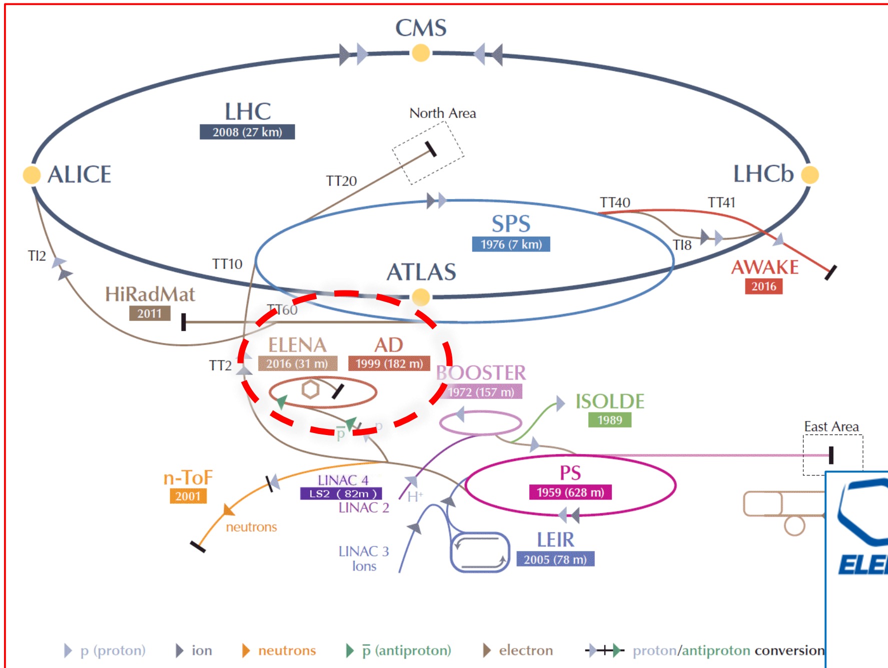
$$v_q = \sqrt{\frac{3kT}{m}}$$

- The corresponding kinetic energy is:

$$\frac{1}{2} m\, v_q{}^2 = \frac{3}{2} kT$$

All the molecular speeds scales like ~ $\sqrt{(T/m)}$





ELENA

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Vacuum Considerations:

How to Protect the Ring and the Experimental Beamlines from Accidental Loss-of-Vacuum Accidents

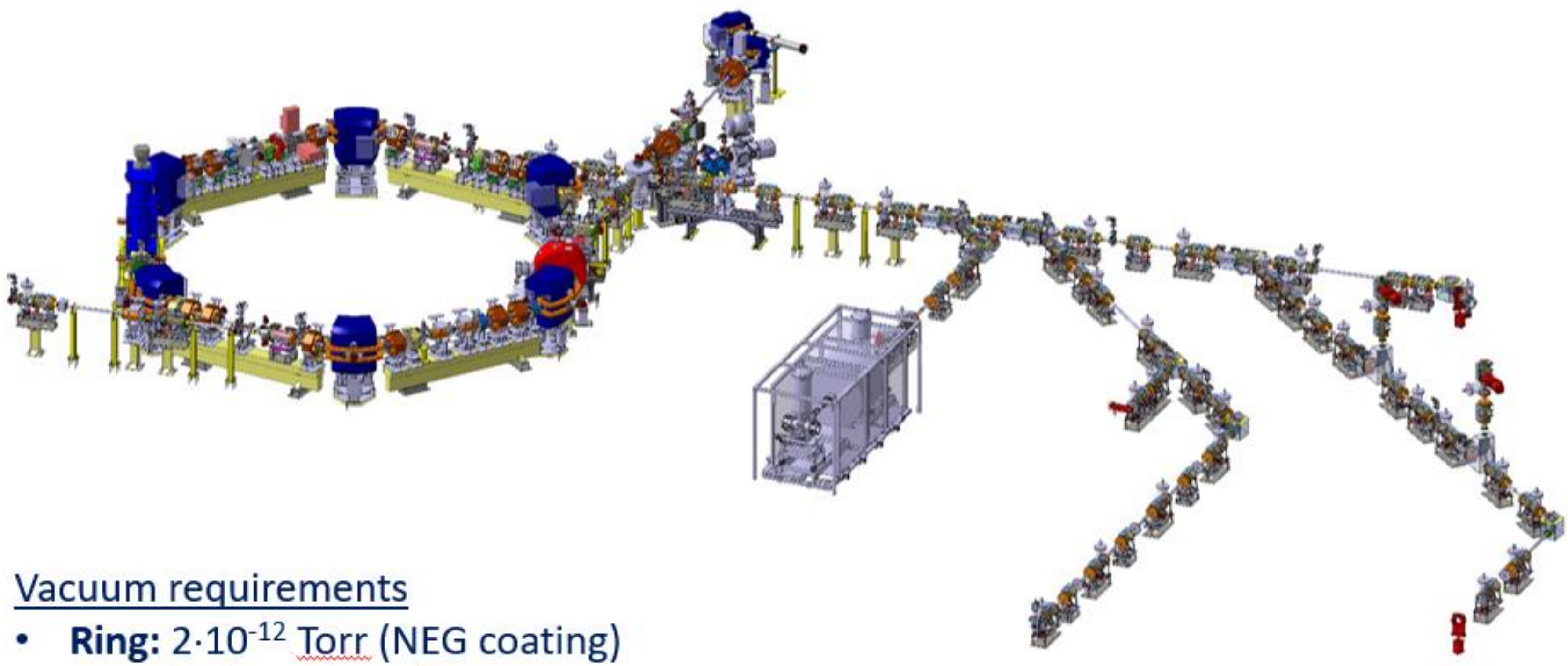
R. Kersevan, TE-VSC-VSM

ADUC and ELENA Meeting, 19 Jan 2016

ELENA: Extra-Low Energy Antiproton decelerator

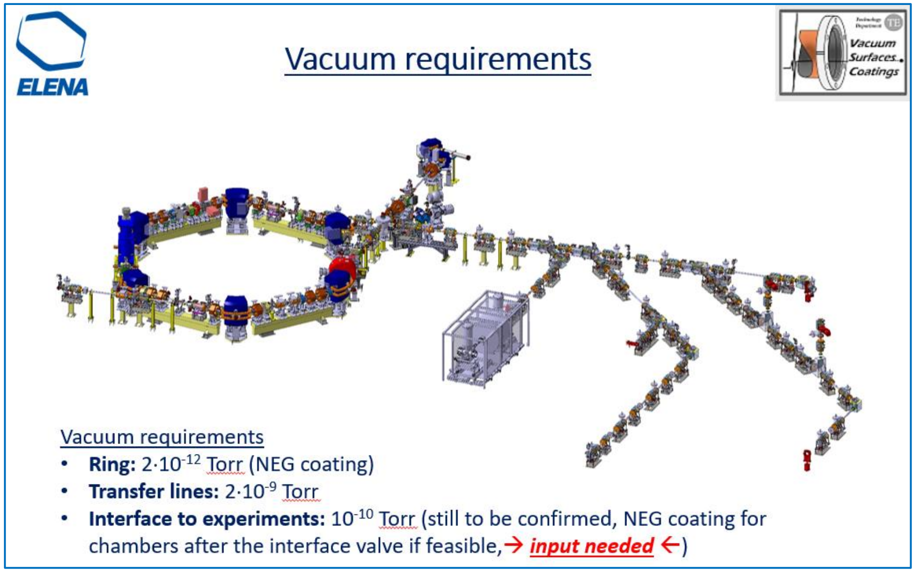
ELENA

Vacuum requirements

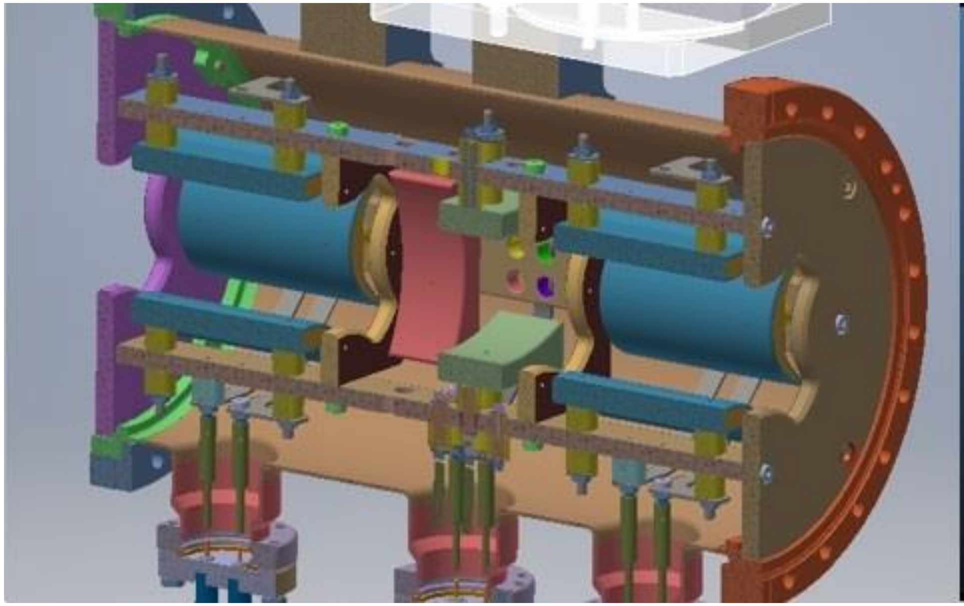


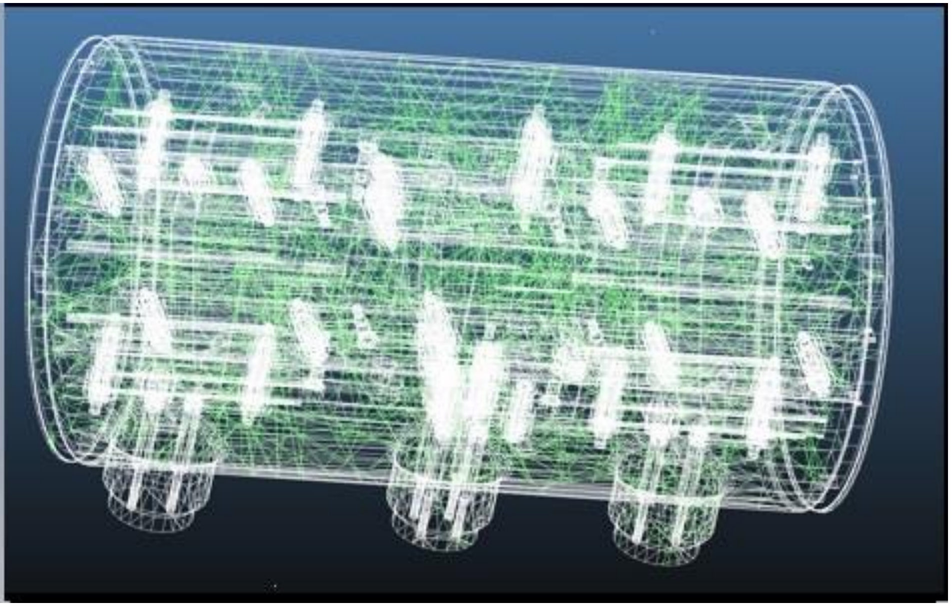
Vacuum requirements

- **Ring:** $2 \cdot 10^{-12}$ Torr (NEG coating)
- **Transfer lines:** $2 \cdot 10^{-9}$ Torr
- **Interface to experiments:** 10^{-10} Torr (still to be confirmed, NEG coating for chambers after the interface valve if feasible,→ ***input needed*** ←)

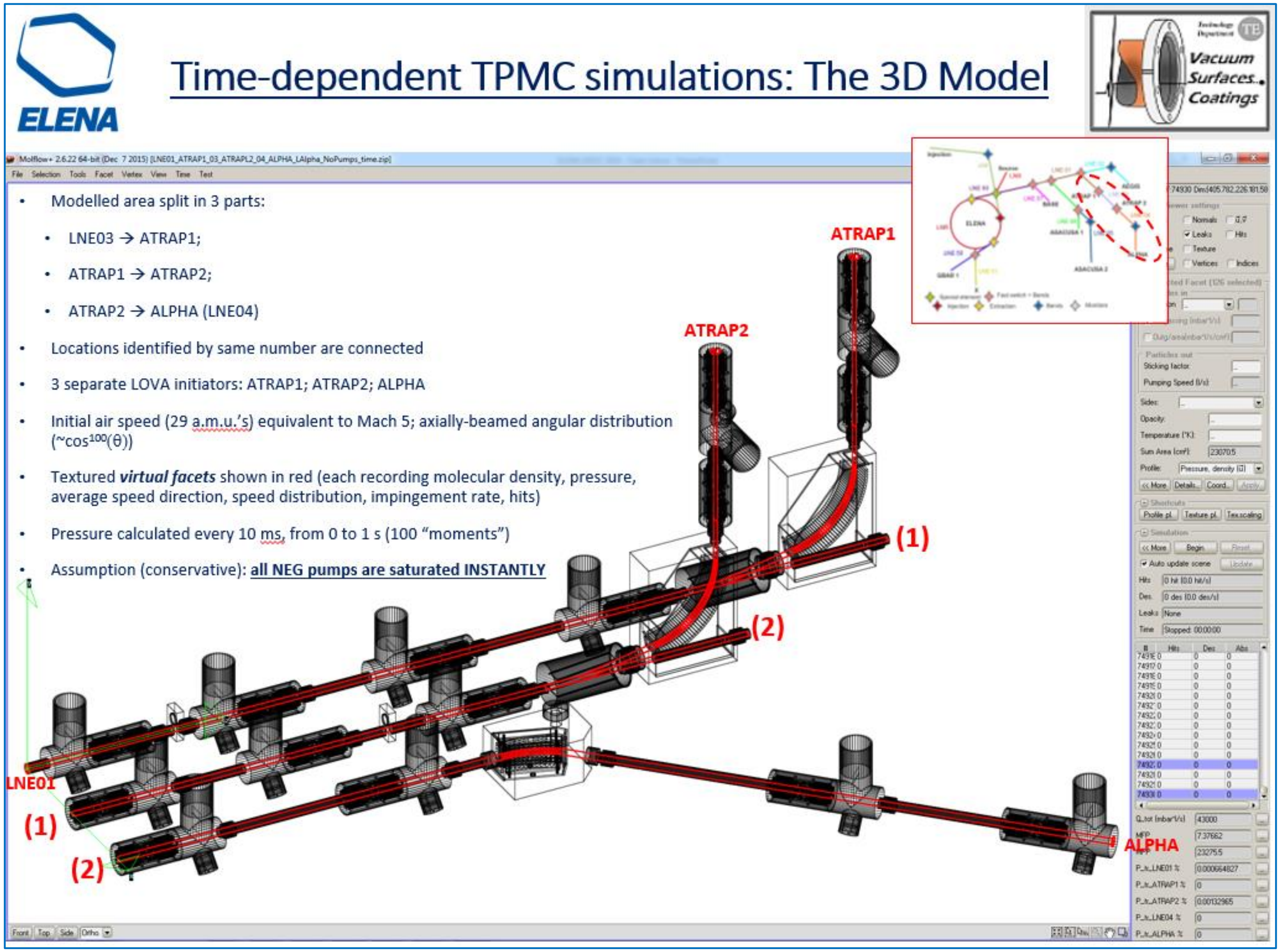


- **ELENA: Extra-Low Energy Antiproton decelerator**
- **Typical electrostatic quadrupole/corrector package (FODO)**
- **Molflow+ model imported from CAD**

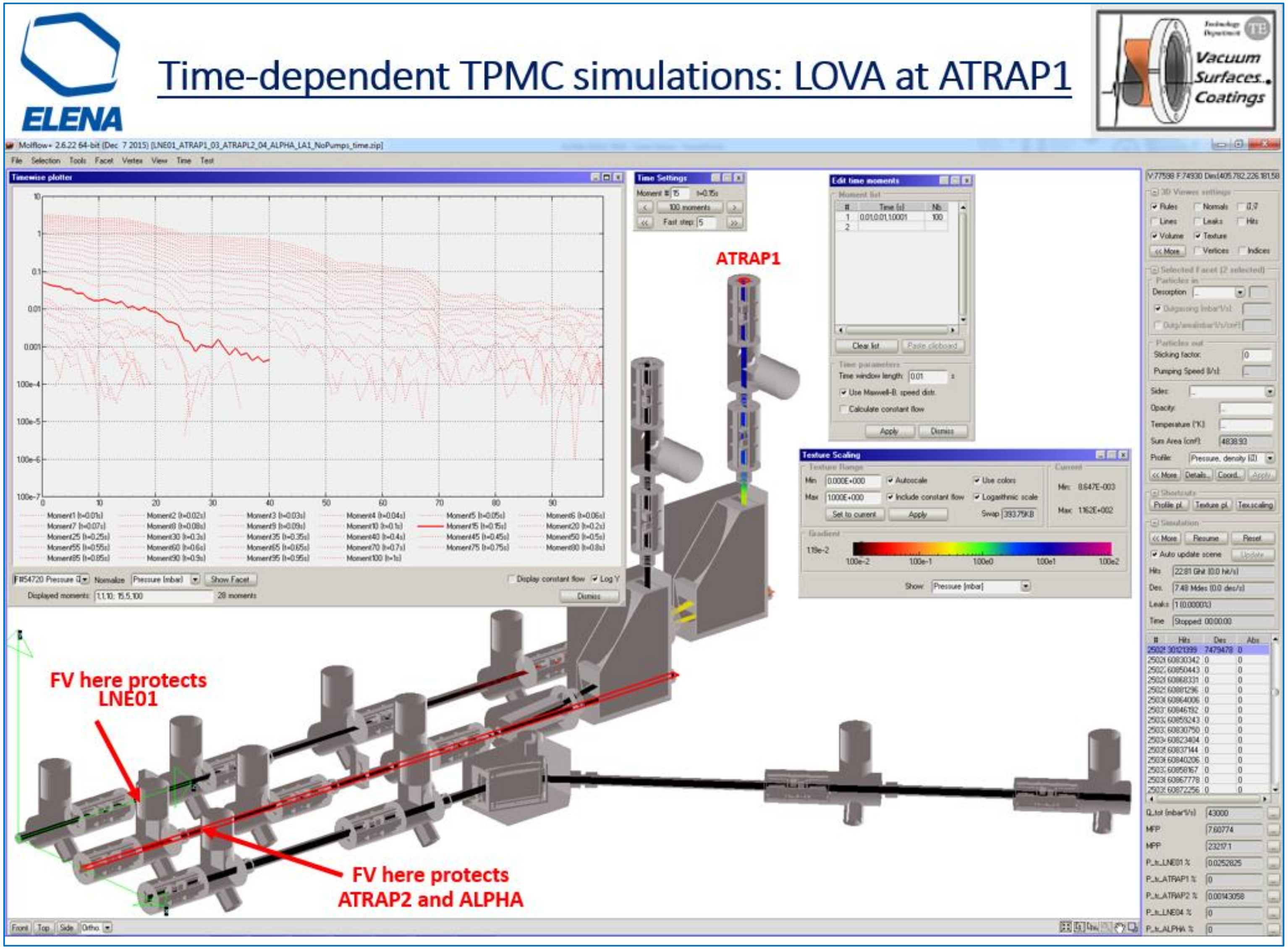


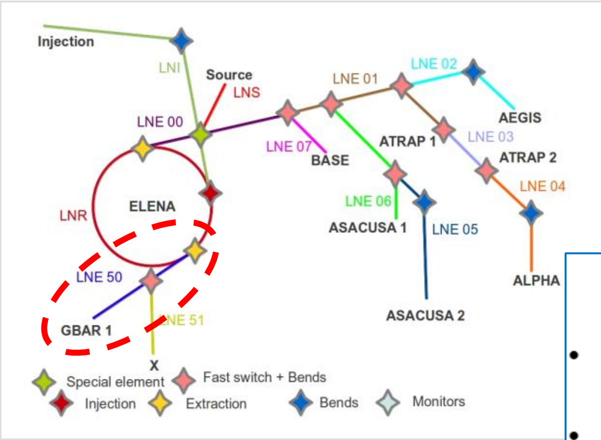


- Electrostatic beamline components: electrodes are under vacuum
- All internal surfaces are NEG-coated
- Need to protect all NEG-coated surface in case of air-inrush
- Montecarlo simulation, time-dependent, is used to determine best position of fast gate valves (20 msec closure time)



- **Generate molecules with velocities distributed as per Maxwell-Boltzmann, and initial temperature corresponding to "hot" supersonic gas jet**

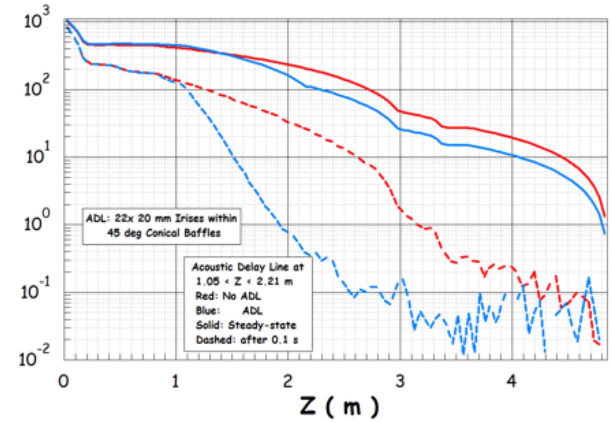


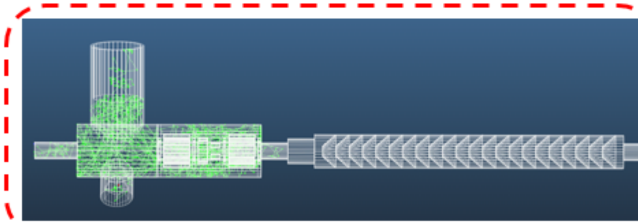


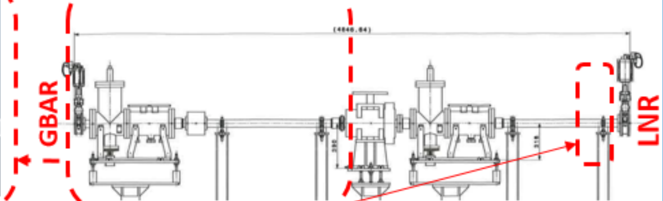
- **Gbar beamline, short distance from ELENA ring**
- **Need for an acoustic delay line, to slow down the air inrush**
- **Determination of the position of the fast gate valve**

TPMC simulation of air-inrush from Gbar towards LNR:

- A mass 29 a.m.u. (air) gas flow is simulated at the GV connecting to the Gbar beamline
- The gas flow is normalized to a pressure of 1 atmosphere at Gbar (at steady-state, solid curves)
- It is shown that even after only 0.1 s the other GV connected to the electrostatic deflector on LNR reaches the 1.0E-2 mbar range
- The beneficial effect of introducing a ~ 1m-long acoustic delay-line (ADL) is not sufficient to protect LNR (blue curves)
- ADL: 22x 5 cm-long cones, 20 mm ID iris, 45 deg baffles







- **CONCLUSION: LNR cannot be protected from air-inrush without using a fast-acting valve (FV), possibly installed here...**

Closing time of FV: ~ < 20 ms
(including trigger via dedicated board)

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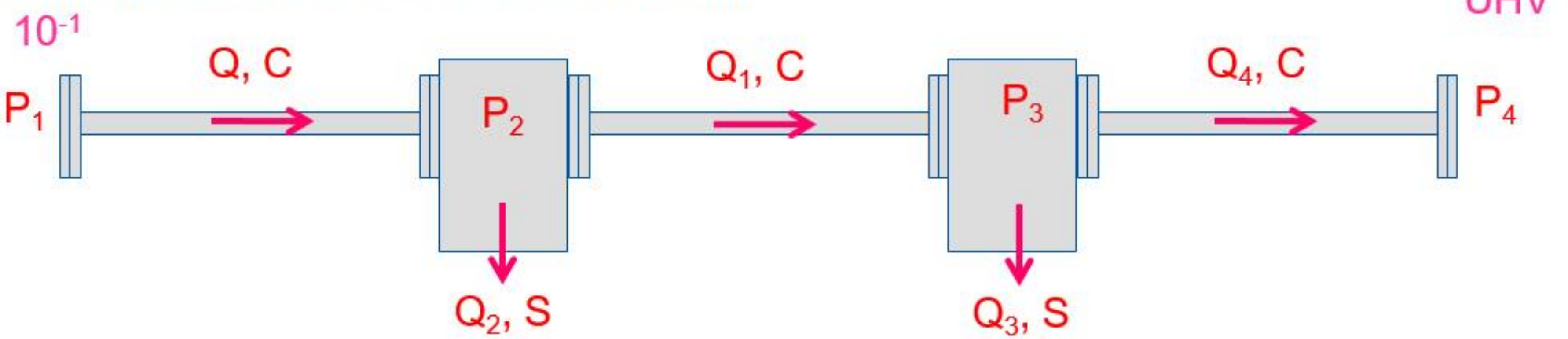
Differential pumping system

- This system allows to decouple a vacuum system from another one (*e.g.* in Linac source, between baked and unbaked vacuum system)

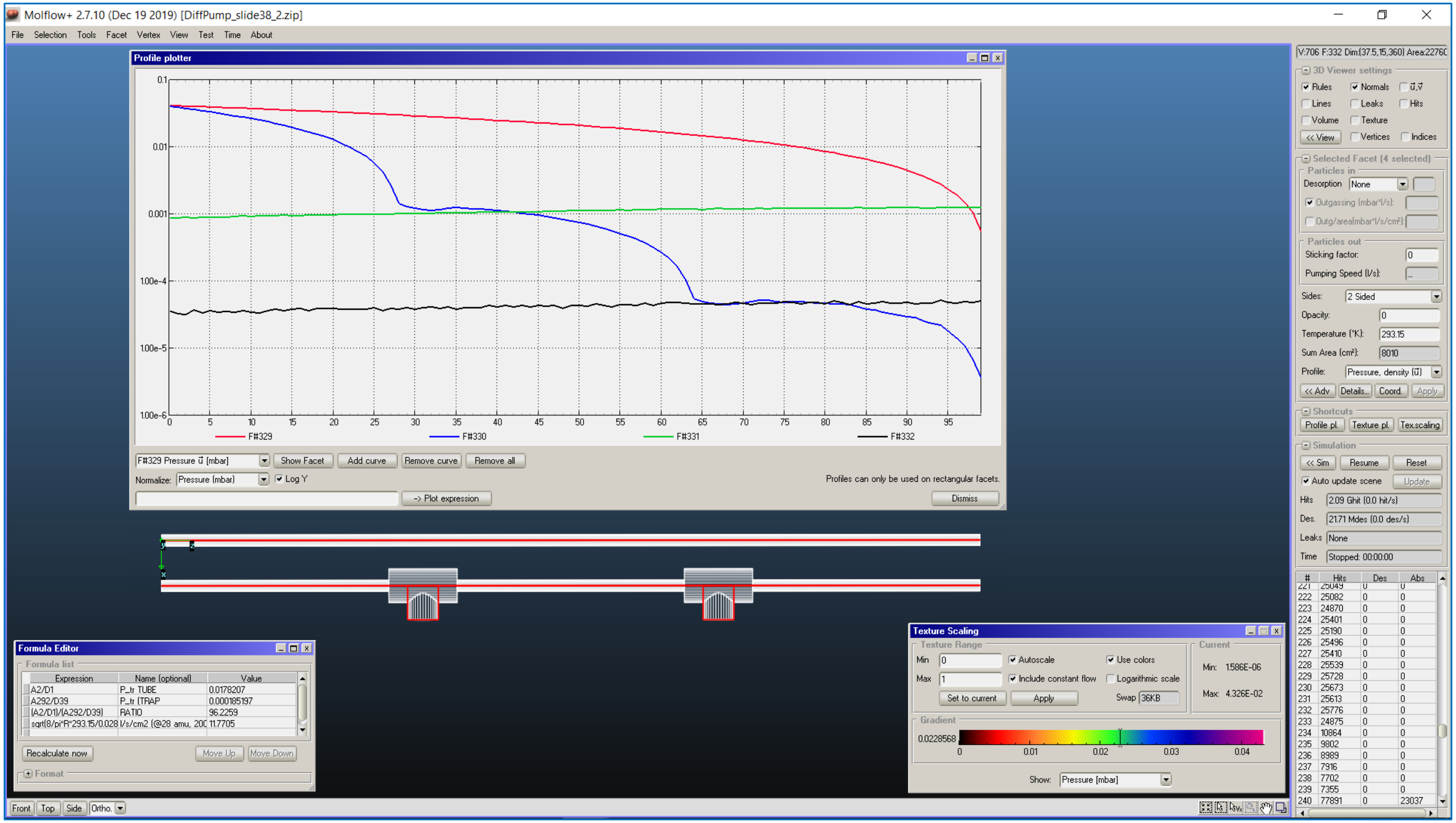


- Commercial differential pumps

Pictures Edwards

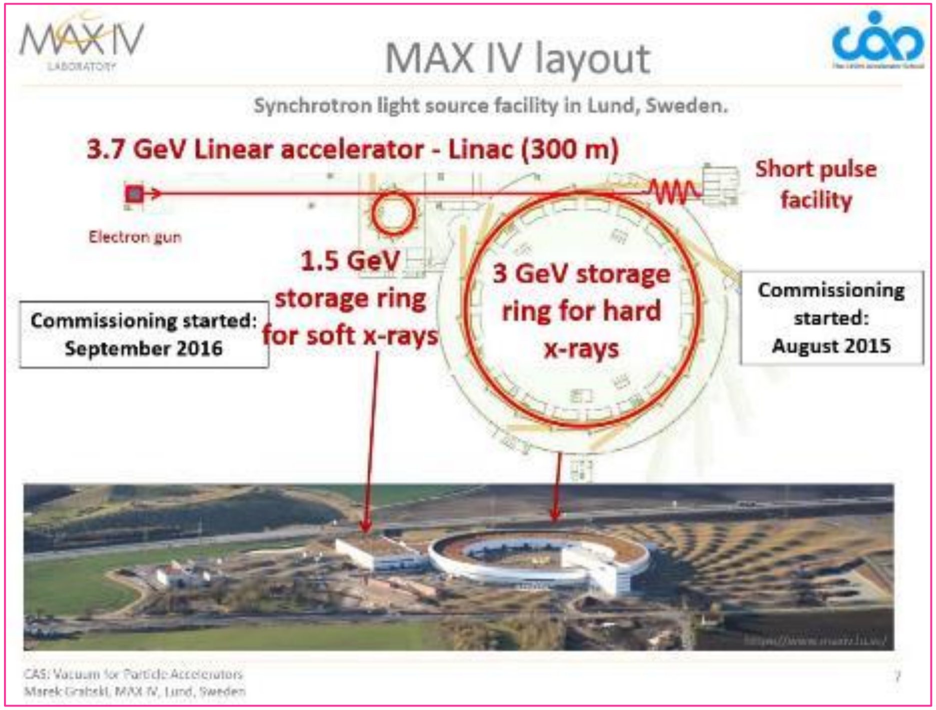
Transmission probability, P_{TR} calculation for:

- **3.6 m-long, 5 cm diameter tube**
- **Same made up of 3x 1 m-long tubes separated by 30 cm-long 10 cm diameter pumping domes (with 500 l/s pump each)**
- **P_{TR} (tube) = 1.782E-2; P_{TR} (Diff.Pumping) = 1.852E-4; RATIO=96.2x**

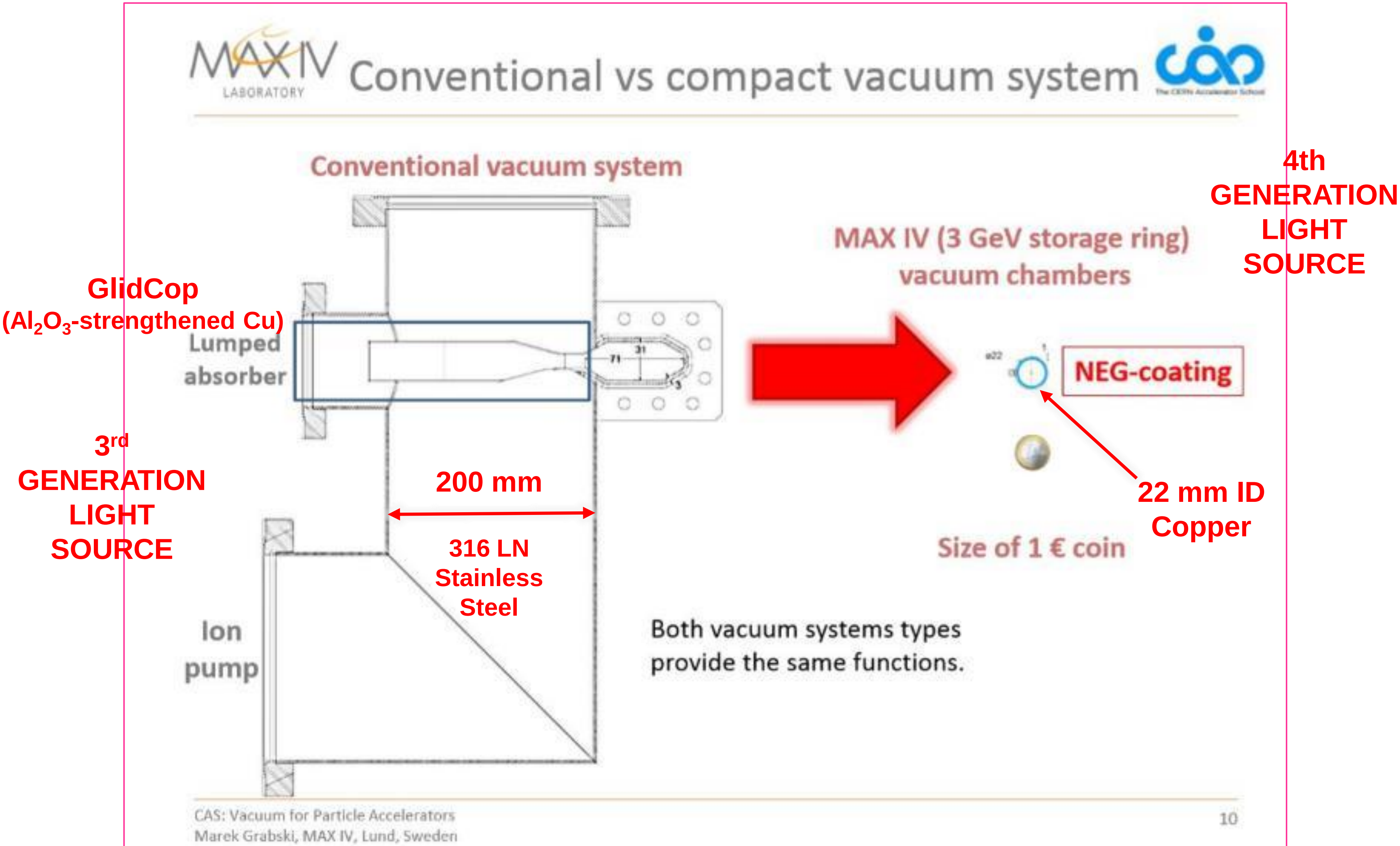


Comparison of vacuum system of two 4th generation light sources, Max-IV and ESRF-EBS

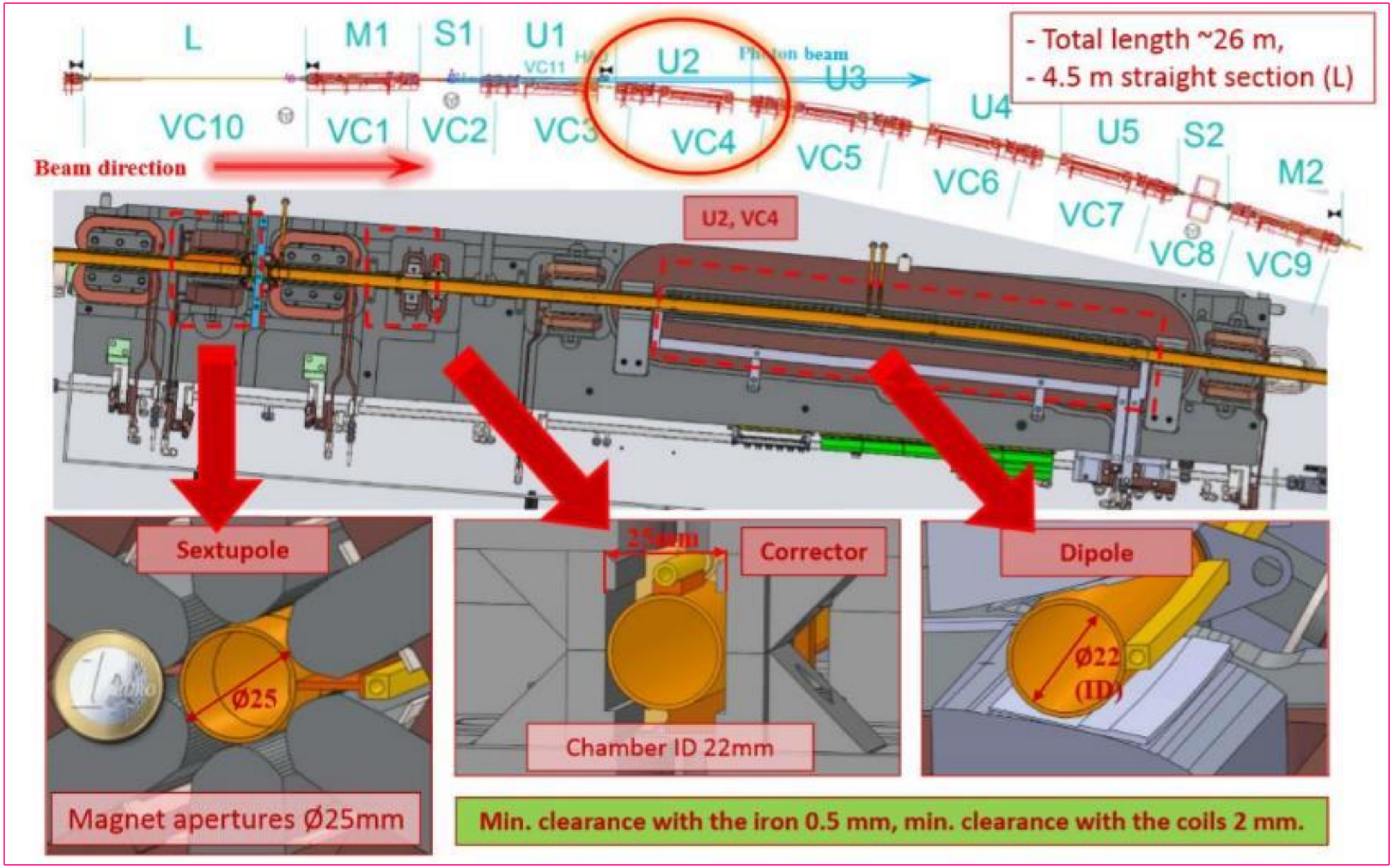
- **Max-IV: 3 GeV, 500 mA, ¬ 500 m circumference**
- **ESRF-EBS: 6 GeV, 200 mA, ¬ 850 m circumference**



Max-IV: comparison of its 22 mm ID circular chamber with ALBA light source; Max-IV: fully NEG-coated Cu; ALBA: SS

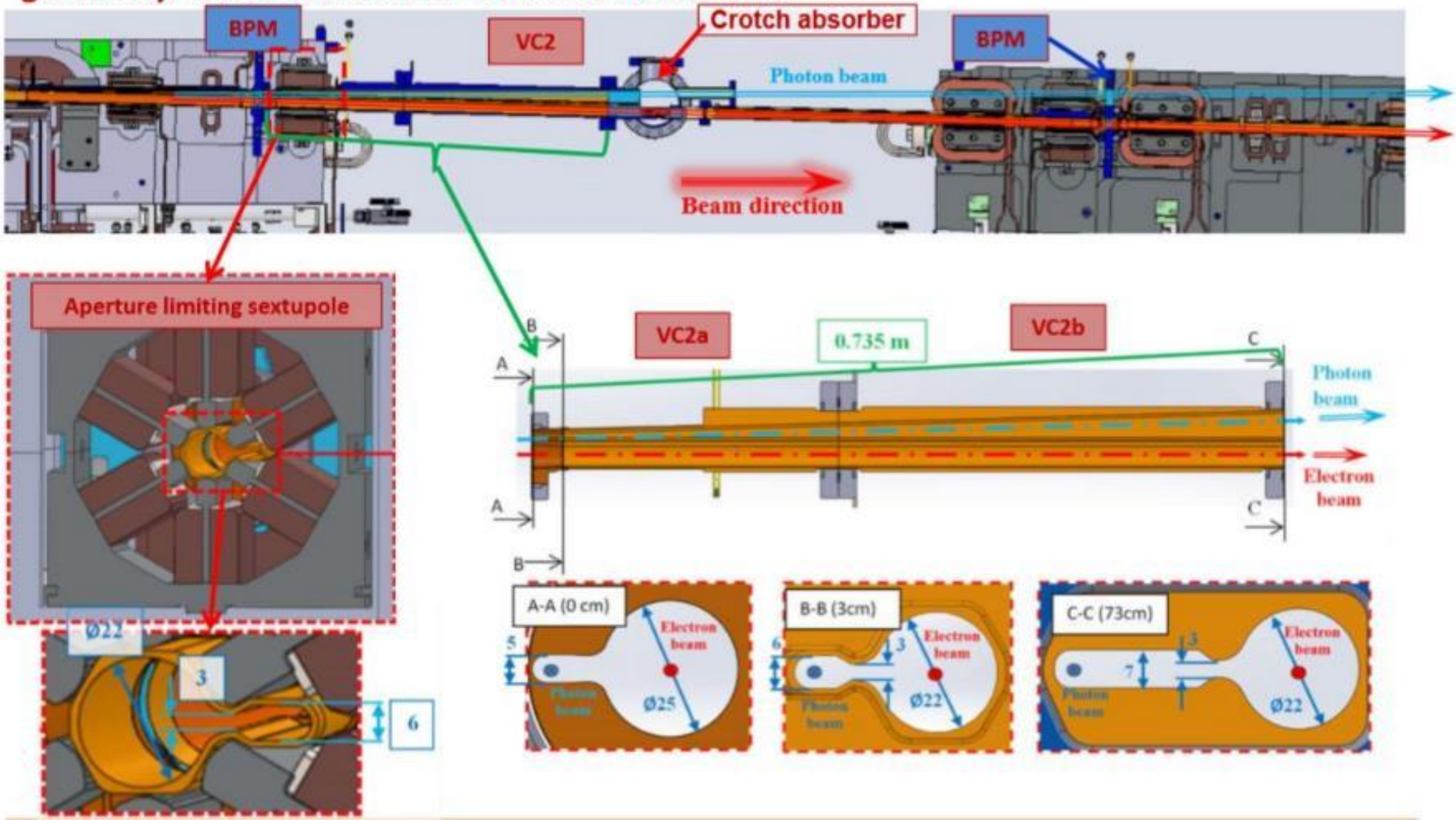


Very tight space between vacuum chambers and magnetic poles

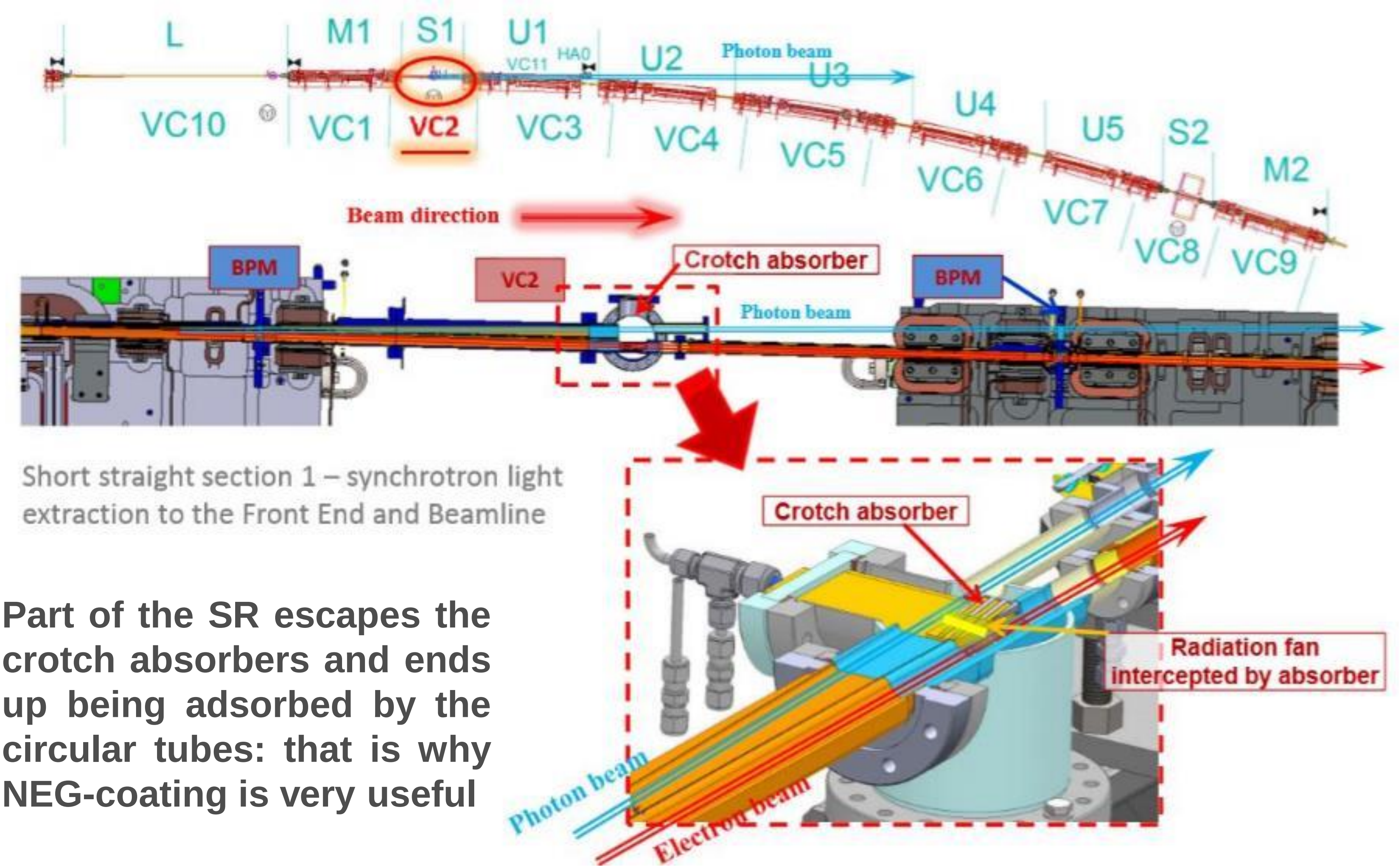


Variable cross sections at dipoles with SR extraction port

3 b). Establish coating procedure/technology and produce chambers of complex geometry: Vacuum chamber for beam extraction.



Crotch absorbers are used to intercept the fraction of the SR fan which doesn't reach the beamlines

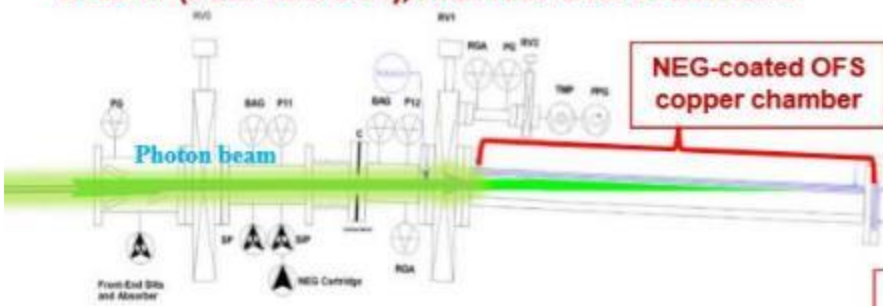


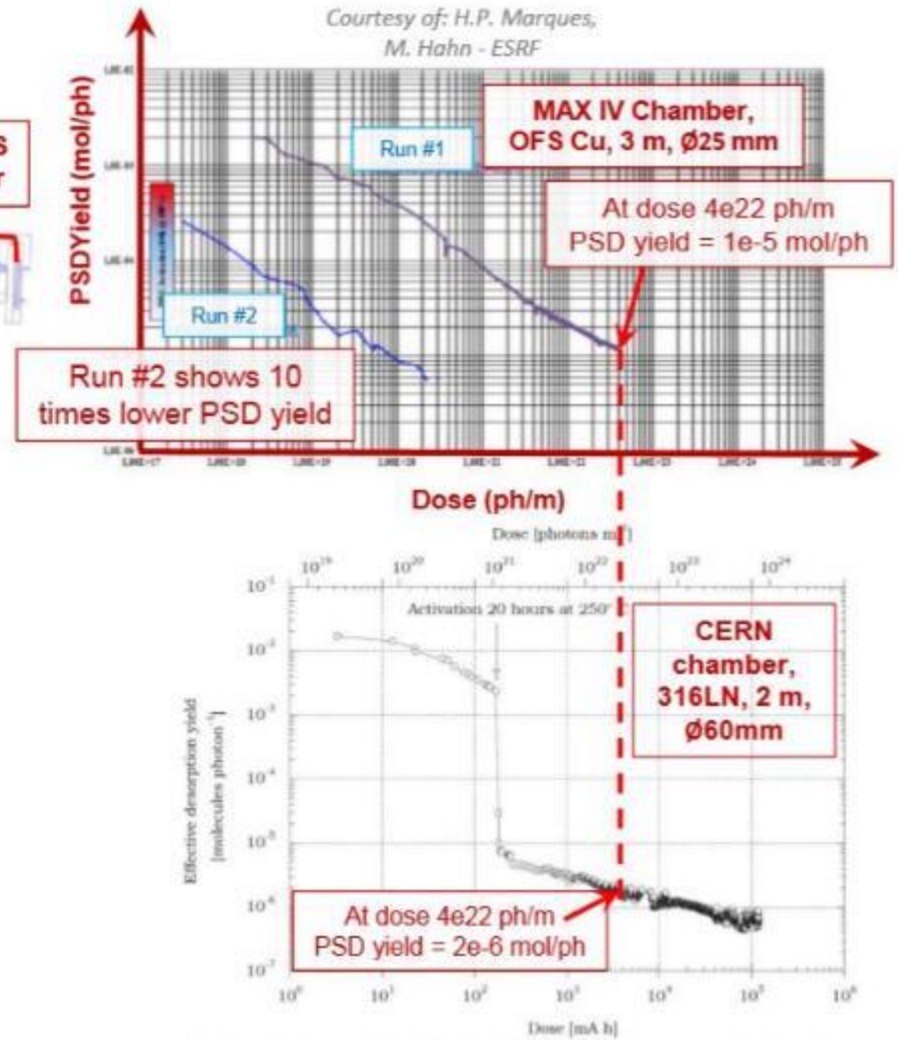
Short straight section 1 – synchrotron light extraction to the Front End and Beamline

Part of the SR escapes the crotch absorbers and ends up being adsorbed by the circular tubes: that is why NEG-coating is very useful

Feasibility of fully NEG-coated solution had been checked at ESRF on a dedicated photodesorption beamline (D31)

Photon stimulated desorption (PSD) measurements at ESRF (beamline D31), chamber after activation.

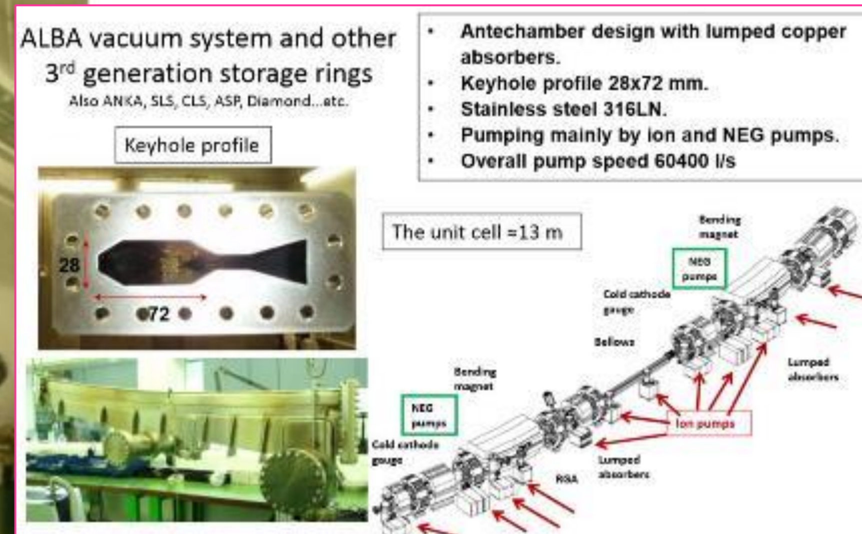


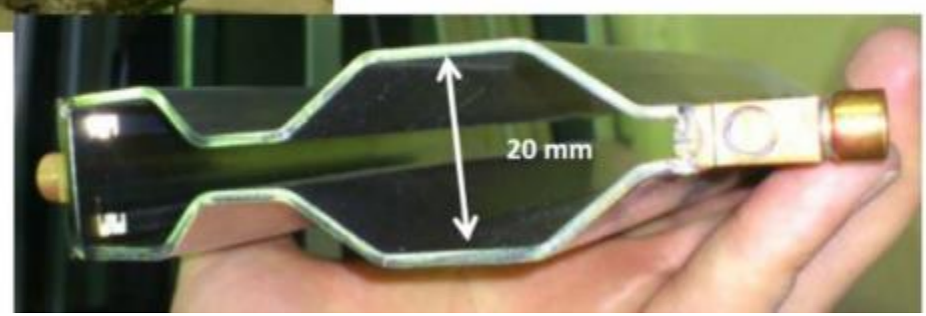


'Synchrotron Radiation-Induced Desorption from a NEG-Coated Vacuum Chamber', *P. Chiggiato, R. Kersevan*

Measured PSD yield from Run #2 similar to what was measured before.

1.5 GeV low-energy ring is not NEG-coated, and has vacuum chambers made of stainless steel, a “conventional” machine, with more relaxed dimensions and bigger conductance, copied from ALBA light source (Barcelona)



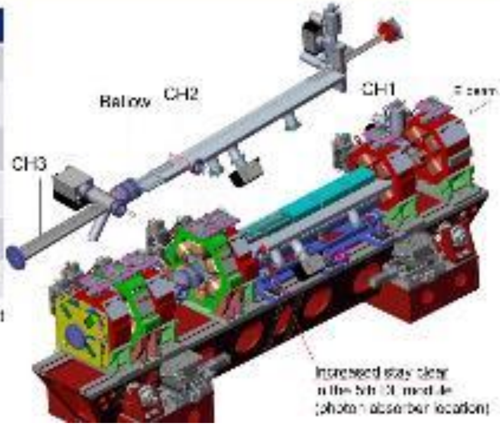


The ESRF upgrade, EBS (Extremely Bright Source), adopts a different design: very little NEG-coating, and use of machined SS and aluminium chambers, welded longitudinally

GIRDER 1

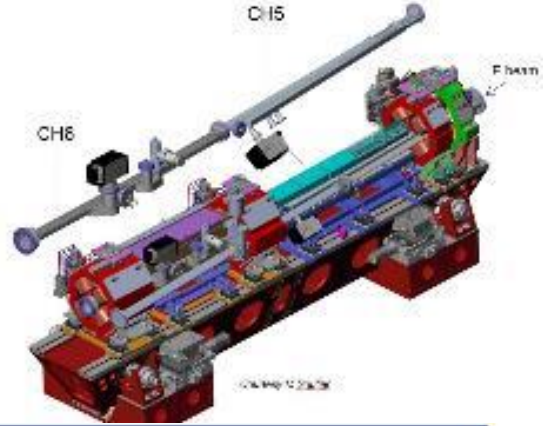
	CH1	CH2	CH3
Length [mm]	750.9	2927	1120.8
Material	316LN sheet	AL	316LN sheet
Bellow/RF fingers	1		-
Absorber	-	CH2 1-1	Crotch 1 CH3 1-1
BPM	BMP1		BFM2 BFM3

Red: fixed point



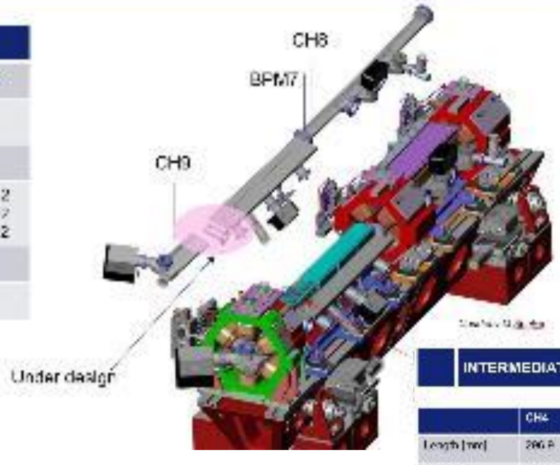
GIRDER 2

	CH5	CH6
Length [mm]	2408	2360
Material	AL	316LN sheet
Bellow/RF fingers	-	1
Absorber	CH5 1-1	CH6 1-1
BPM	-	BPM4



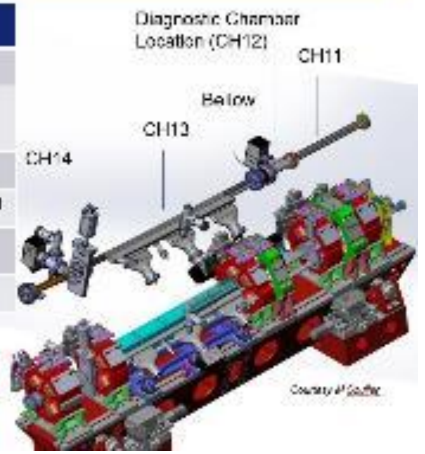
GIRDER 3

	CH8	CH9
Length [mm]	2311	2678.9
Material	316LN sheet	Al
Bellow/RF fingers	1	-
Absorber	CH8 1-2 CH8 2-2	Crotch 2 CH9 1-2 CH9 2 2
BPM	BPM7	-



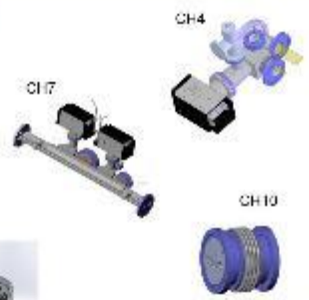
GIRDER 4

	CH11	CH12	CH13	CH14
Length [mm]	1071	418.9	2627	750.9
Material	316LN sheet	AL		316LN OFE
Bellow/RF fingers	-	-	-	1
Absorber			CH13 1 1	CH14 1 1
BPM	BPM8 BPM9	-	-	BPM10



INTERMEDIATE CHAMBERS

	CH4	CH7	CH10
Length [mm]	286.8	186	1-3
Material	316L sheet	[illegible] sheet	[illegible] sheet
Bellow/RF fingers	1	-	1
Absorber	[illegible]	CH7 1-2 CH7 2-2	-
BPM	-	BPM5 BPM6	-

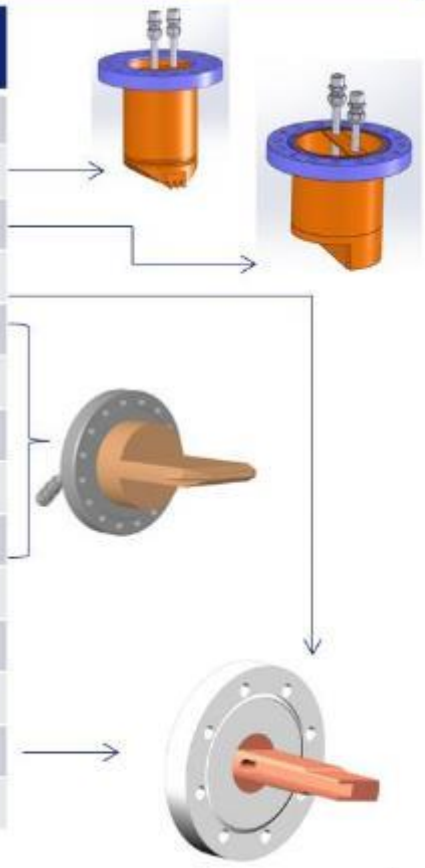


Diagnostic chambers (Girder 4)

At the ESRF-EBS 100% of the SR generated by the dipoles is intercepted by lumped absorbers

ABSORBERS POWER DISTRIBUTION

Chamber	Abs name	T Power [W]	Power dens max [W/mm2]
Chamber 2	CH2 1-1	196	1.4 * (≠ for Helical)
Chamber 3	Crotch 1	1103	90(@ normal incidence)
Chamber 4	CH4 1-1	393.4	13
Chamber 5	CH5 1-1	325.5	8.6
Chamber 6	CH6 1-1	968.5	14
Chamber 7	CH7 1-7	986.5	12.9
Chamber 7	CH7 2-2	522.5	14.2
Chamber 8	CH8 1-2	1160.9	11.6
Chamber 8	CH8 2-2	1261.2	11.9
Chamber 9	Crotch 2 part 1	1883.4	70 (@ normal incidence)
Chamber 9	Crotch 2 part 2	1262	12.6
Chamber 9	CH9 3-3	1871	54
Chamber 13	CH13 1-1	562.4	12.7
Chamber 14	CH14 1-1	631.7	2.2



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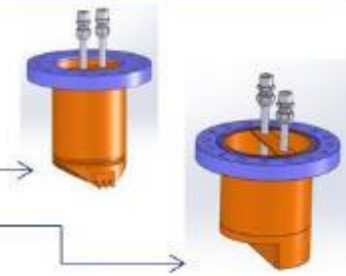

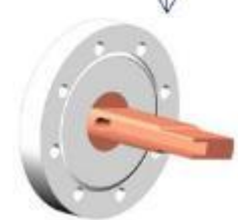

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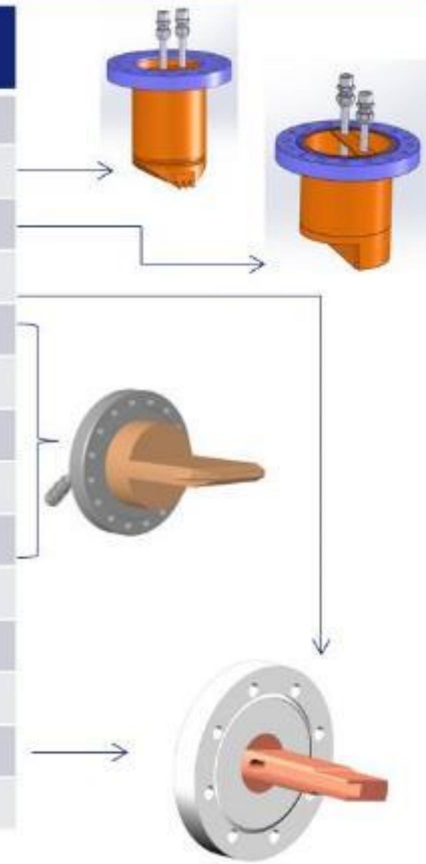
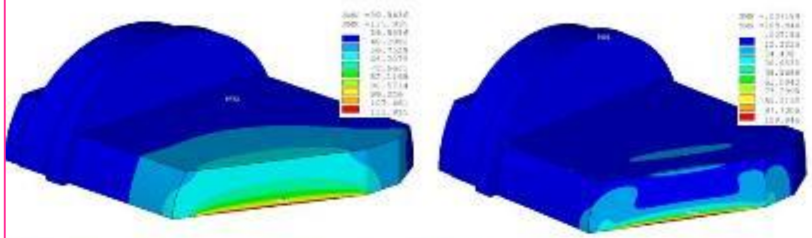


All photon absorbers have been carefully analysed and designed: Ray-tracing, followed by Finite-Elements thermo-mechanical analysis

PHOTON ABSORBERS CHAMBERS 6,7,8



FEA results: temperature distribution (left) and von mises stress distribution (right), the maximum values are T_{max}=115.9°C and S_{max}=109.9MPa, respectively.

T_{max}/S_{max}	h_{cv}=0.005 W/mm²/°C	h_{cv}=0.01 W/mm²/°C	h_{cv}=0.02 W/mm²/°C
Pa=10 W/mm²	83.0°C / 54.8MPa	70.5°C / 55.0MPa	63.5°C / 55.2MPa
Pa=20 W/mm²	141.0°C / 109.6MPa	115.9°C / 109.9MPa	102.0°C / 110.4MPa

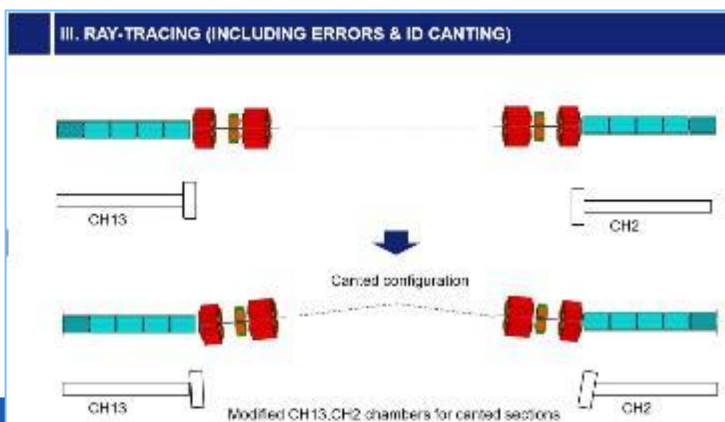
h_{cv} ↑ T_{max} ↓

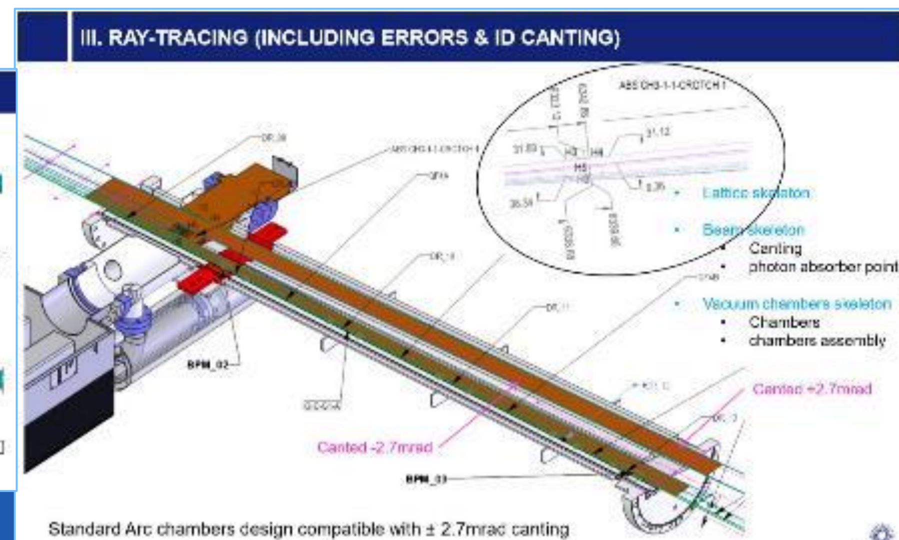
S_{max} ~ Pa

For OFHC, the Yield strength YS=70MPa

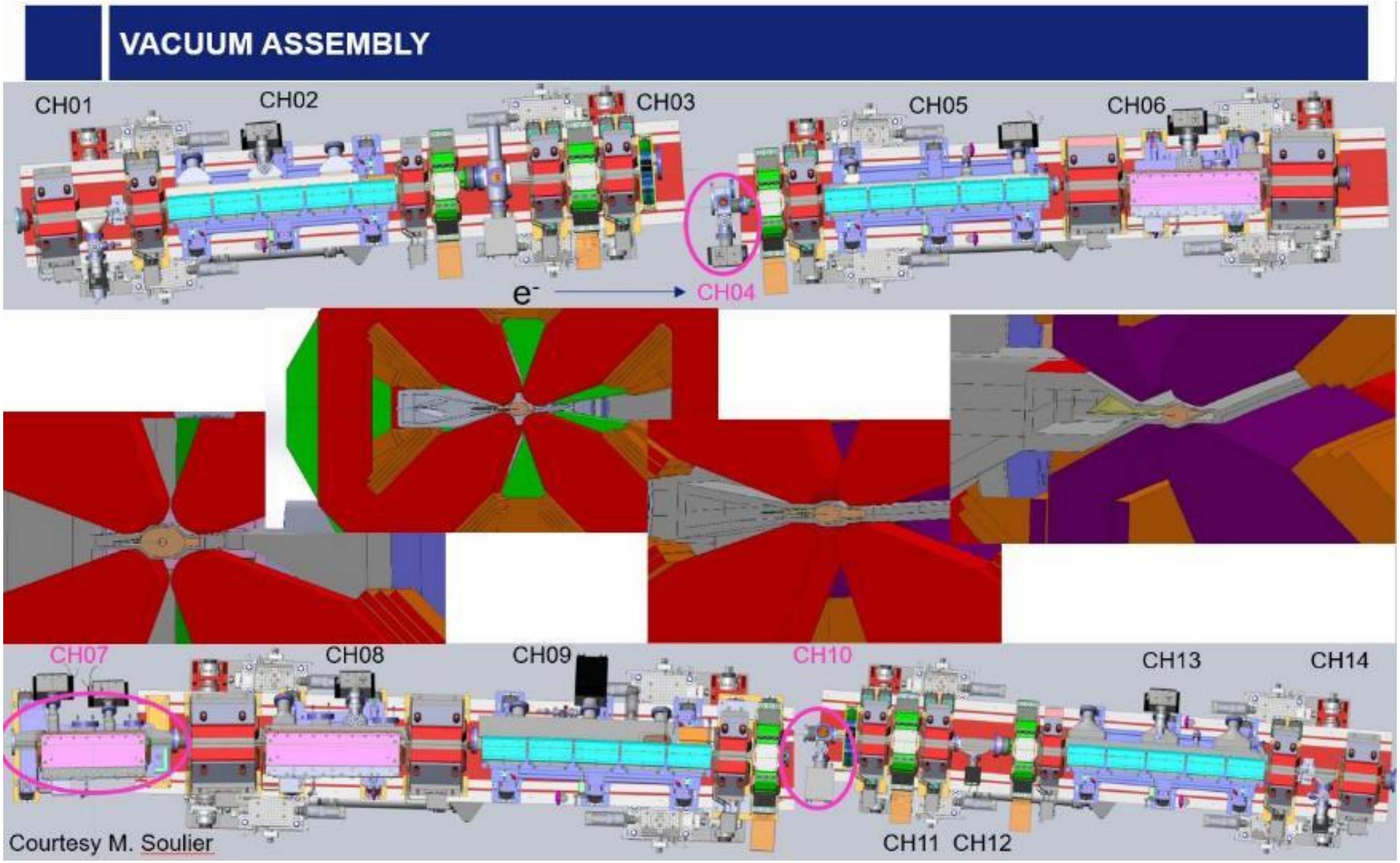
σ_{Pa}=(Pa/10)×$\sigma_{Pa=10}$<YS

Power density limit Pa_{cr}=12.8 W/mm²





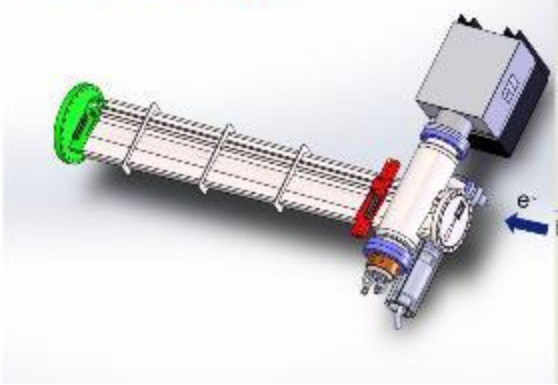
Contrary to the simple one circular tube of Max-IV, the ESRF-EBS team has designed basically a different cross-section for each chamber, to follow the many magnets' pole profiles

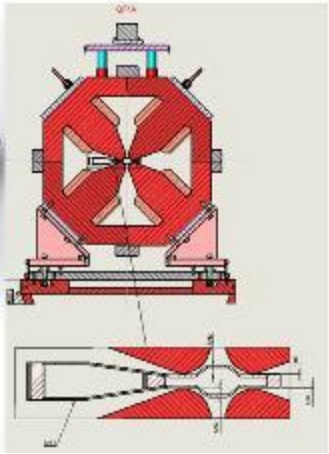


VACUUM CHAMBER LAYOUT

Ch3

- 150 l/s SIP replaced by 75 l/s

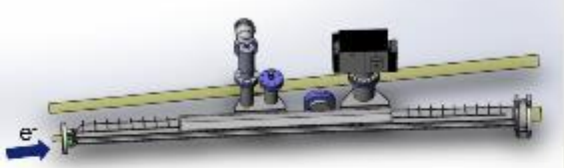


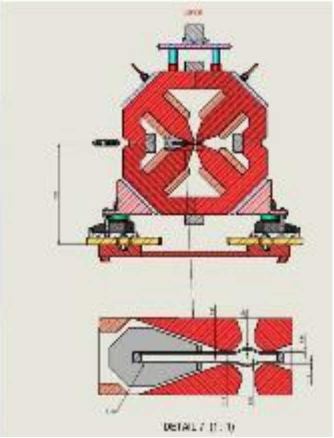


VACUUM CHAMBER LAYOUT

Ch6 (low profile 13v x 20h)

- e-beam welding
- 1.5mm 316LN sheets
- cup-welded bellow (space constraints)
- middle section curved



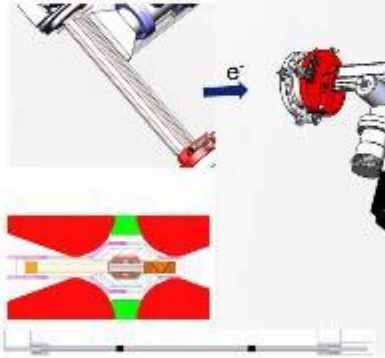


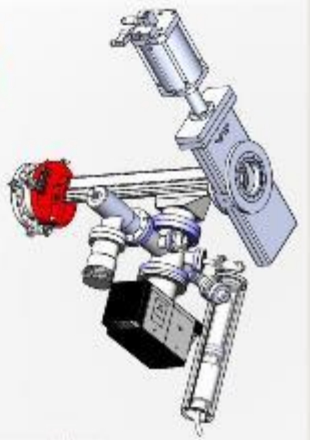
VACUUM CHAMBER LAYOUT

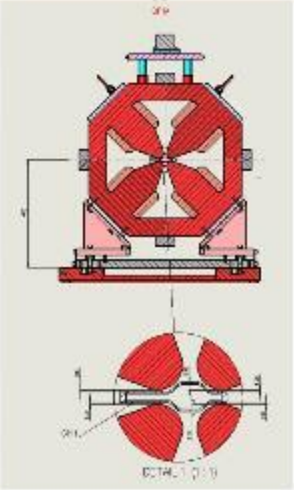
Ch1

-Stainless steel sheets 316LN

-Presumably e-beam welding



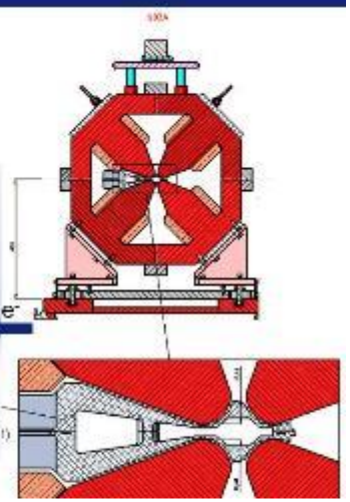


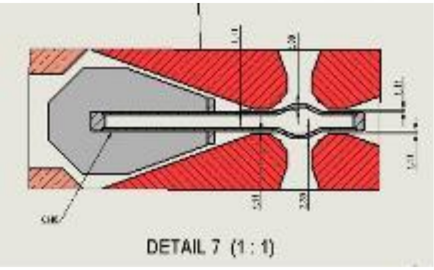


VACUUM CHAMBER LAYOUT

Ch2 – 2 half of Al TIG welded

View below, routing of heater channel





Summary

- We have seen a few examples of calculations of gas dynamics in molecular flow regime
- The transmission probability, speed distribution, and the pressure profiles have been calculated with the code Molflow+
- We have also seen that two modern 4th generation light sources have chosen completely different design philosophies, fully NEG-coated with a constant cross-section for Max-IV vs the un-coated with variable cross-section for ESRF-EBS
- Both designs working successfully: the choice among the two is based on cost analysis, design of magnetic lattice, and other choices concerning vacuum (like in-situ bakeability, for instance)

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