

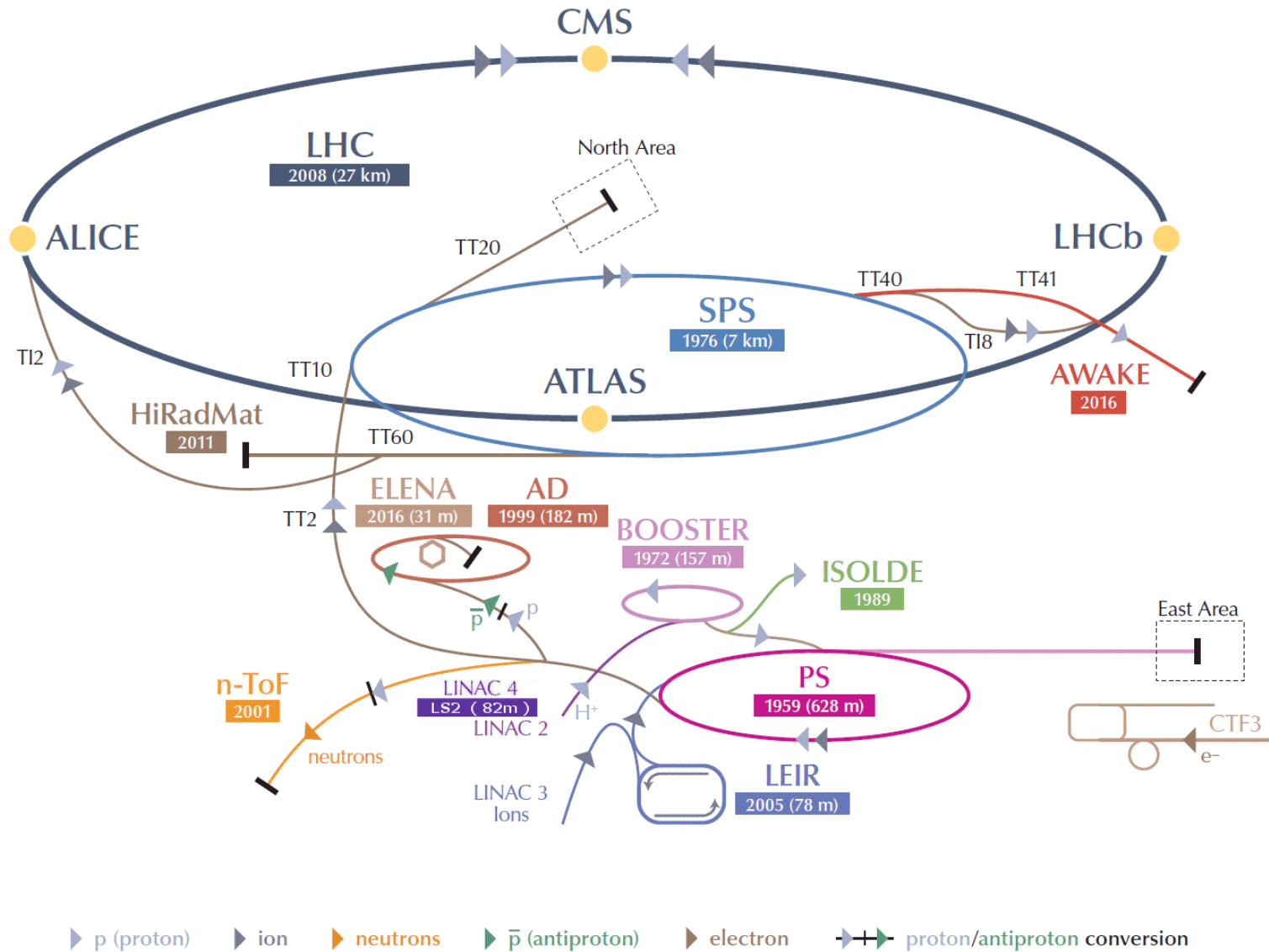
# Vacuum Systems

R. Kersevan

CERN TE-VSC, Geneva



# CERN accelerators complex



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

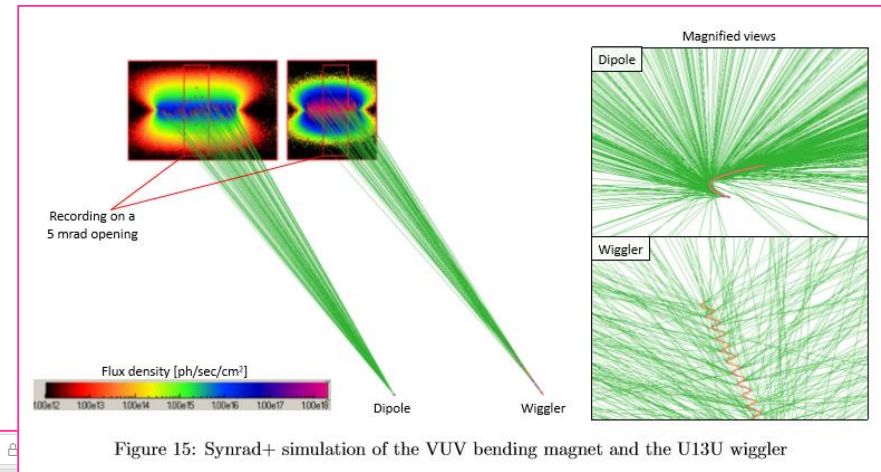
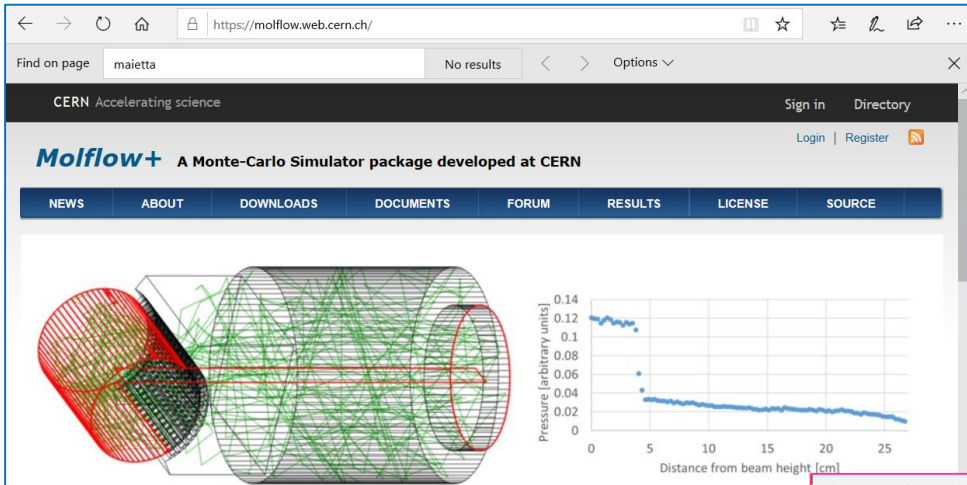


Figure 15: Synrad+ simulation of the VUV bending magnet and the U13U wiggler

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  - SynRad downloads
  - OpticsBuilder downloads
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[https://molflow.web.cern.ch/content/documents/Molflow\\_documentation](https://molflow.web.cern.ch/content/documents/Molflow_documentation)

**Molflow roadmap for 2020**  
published by Marton Ady (msz... on Wed, 2019-11-20 11:18)

2019 had four important changes concerning the future of Molflow:

- In the beginning of the year, cross-platform support was added. For this, the separation of GUI (molflow.exe) and the workers (molflowSub.exe) had to be ended, using instead a single binary with multithreading (Molflow versions 2.7 and later)
- In late April, the development of Molflow was put on hold, except for minor bugfixes
- In June, a PhD student in computer science joined the Molflow team
- In November, the development resumed, with a new build (2.7.9) released the first time

**Molflow+ A Monte-Carlo Simulator package developed at CERN**

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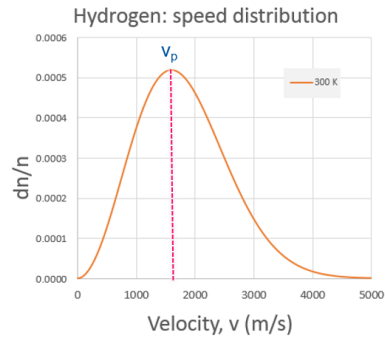
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## Maxwell Boltzmann Distribution

- 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:

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

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

- The corresponding kinetic energy is:

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

**All the molecular speeds scales like  $\sim \sqrt{T/m}$**

Molflow+ 2.7.10 (Dec 19 2019) [1kmCylinder\_H2\_des293k.zip]

Molflow+ 2.7.10 (Dec 19 2019) [1kmCylinder\_H2\_des1000k.zip]

Time Settings: Moment # 00, t=0.5, 300 moments, Fast step 10

Texture Scaling: Min 0, Max 1, Autocalc, Use colors, Logarithmic scale, Set to current, Apply, Swap, Max 5.675E-13

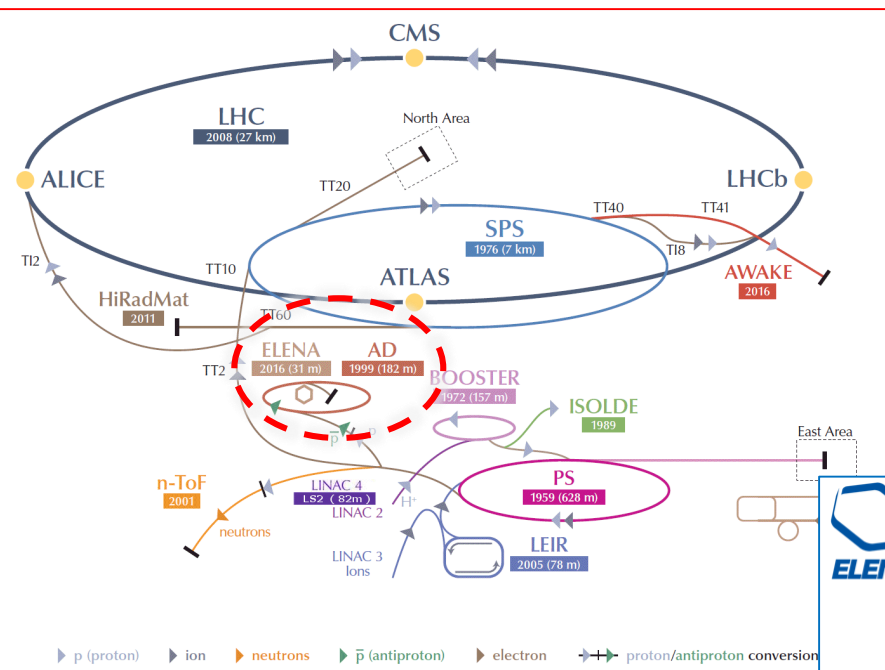
Texture Scaling: Min 0, Max 1, Autocalc, Use colors, Logarithmic scale, Set to current, Apply, Swap, Max 3.023E-13

Edit time moments: Moment list, Time (s), Nb. 1: 1E-2, 1E-2, 1001, 300; 2: 2

Formula Editor: Expression, Name (optional), Value. sqrt(2\*(1000/0.003)), V\_avg [m/s], 2983.48; sqrt(2\*(1000/0.003)\*1000), Characteristic Time (ms), 0.134565

Simulation: Profile pl., Texture pl., Tex scaling. Sim, Resume, Reset. Auto update scene. Hts: 656.31 Mic (0.0 h2), Des: 973.25 Mic (0.0 des/1), Leaks: None, Time: Stopped 00:00:00

#	Hts	Des	Abr
1	0	0	0
2	1379259	0	137926+
3	18375	0	18375
4	1573	0	1573
5	19143	0	19143
6	19939	0	19939
7	1963	0	1963
8	19368	0	19368
9	19309	0	19309
10	19880	0	19880
11	15272	0	15272
12	19426	0	19426
13	19312	0	19312
14	19360	0	19360
15	19959	0	19959
16	19714	0	19714
17	19857	0	19857
18	19388	0	19388
19	19259	0	19259
20	19828	0	19828



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

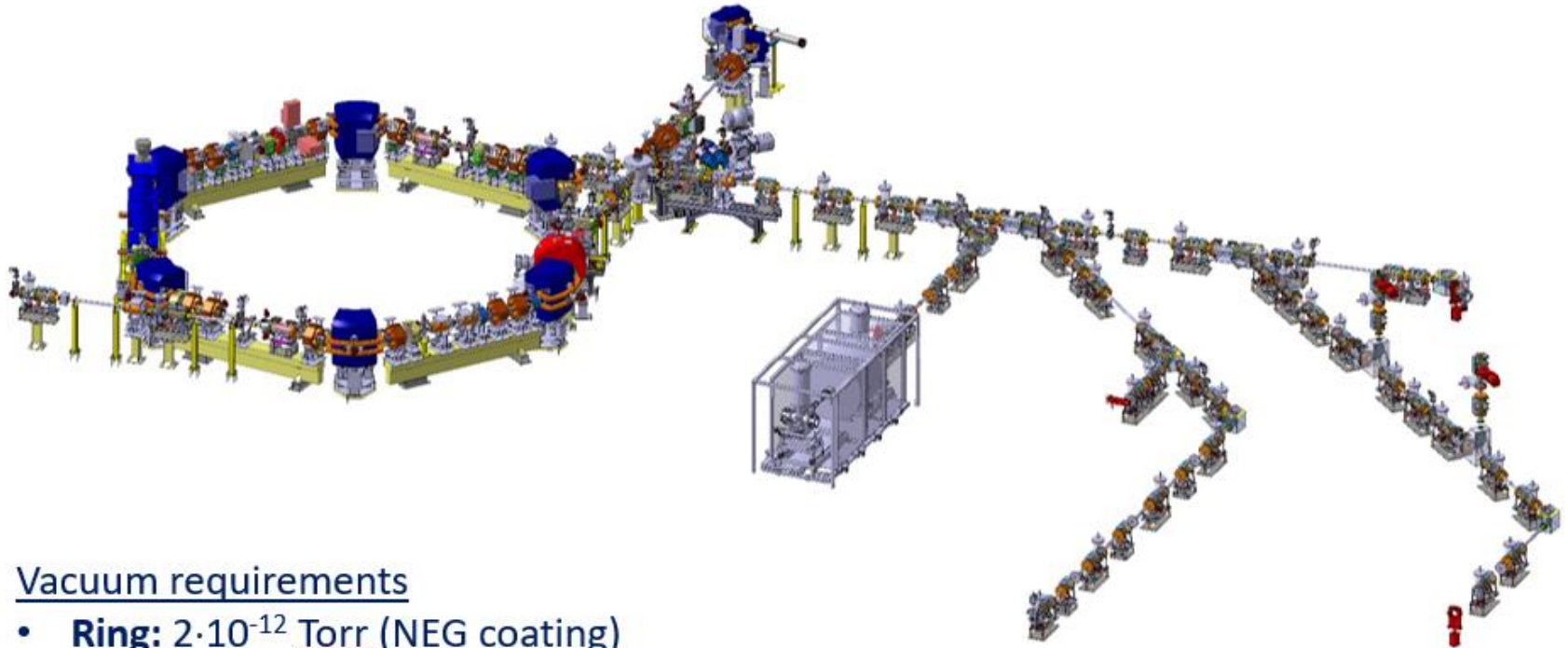
R. Kersevan, TE-VSC-VSM

ADUC and ELENA Meeting, 19 Jan 2016



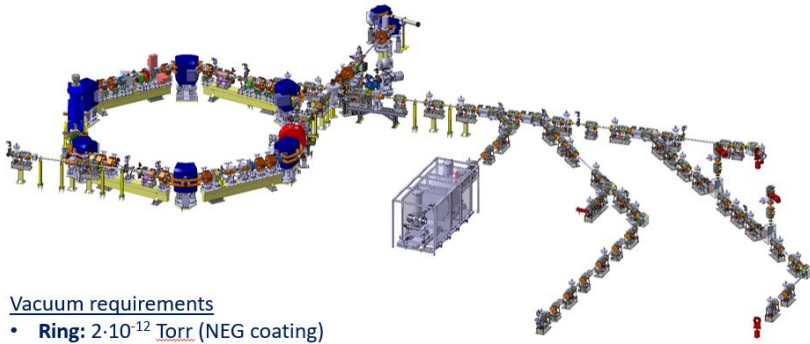


## Vacuum requirements



### Vacuum requirements

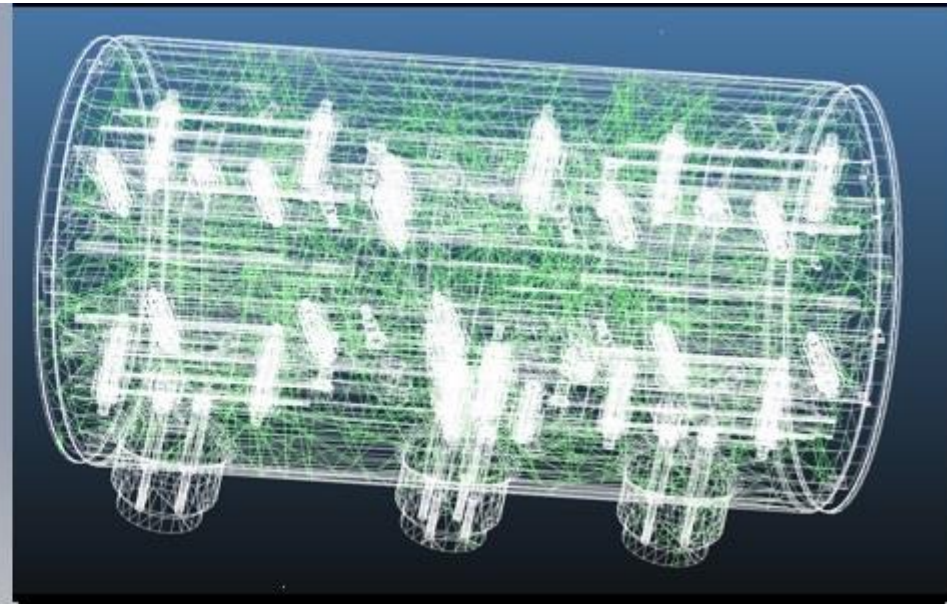
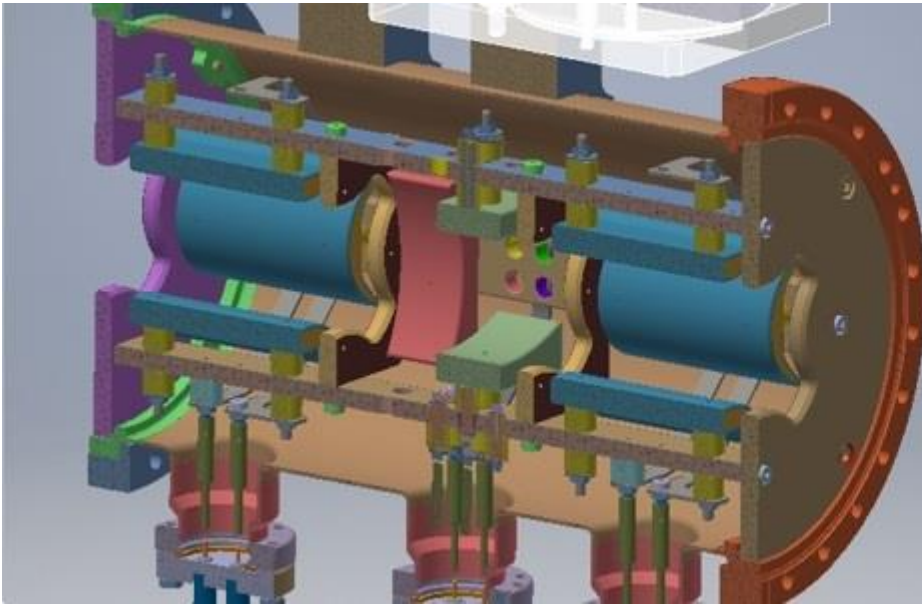
- **Ring:**  $2 \cdot 10^{-12}$  Torr (NEG coating)
- **Transfer lines:**  $2 \cdot 10^{-9}$  Torr
- **Interface to experiments:**  $10^{-10}$  Torr (still to be confirmed, NEG coating for chambers after the interface valve if feasible,  $\rightarrow$  **input needed**  $\leftarrow$ )



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- **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)



## Time-dependent TPMC simulations: The 3D Model



Modelled area split in 3 parts:

- LNE03 → ATRAP1;
- ATRAP1 → ATRAP2;
- ATRAP2 → ALPHA (LNE04)

Locations identified by same number are connected

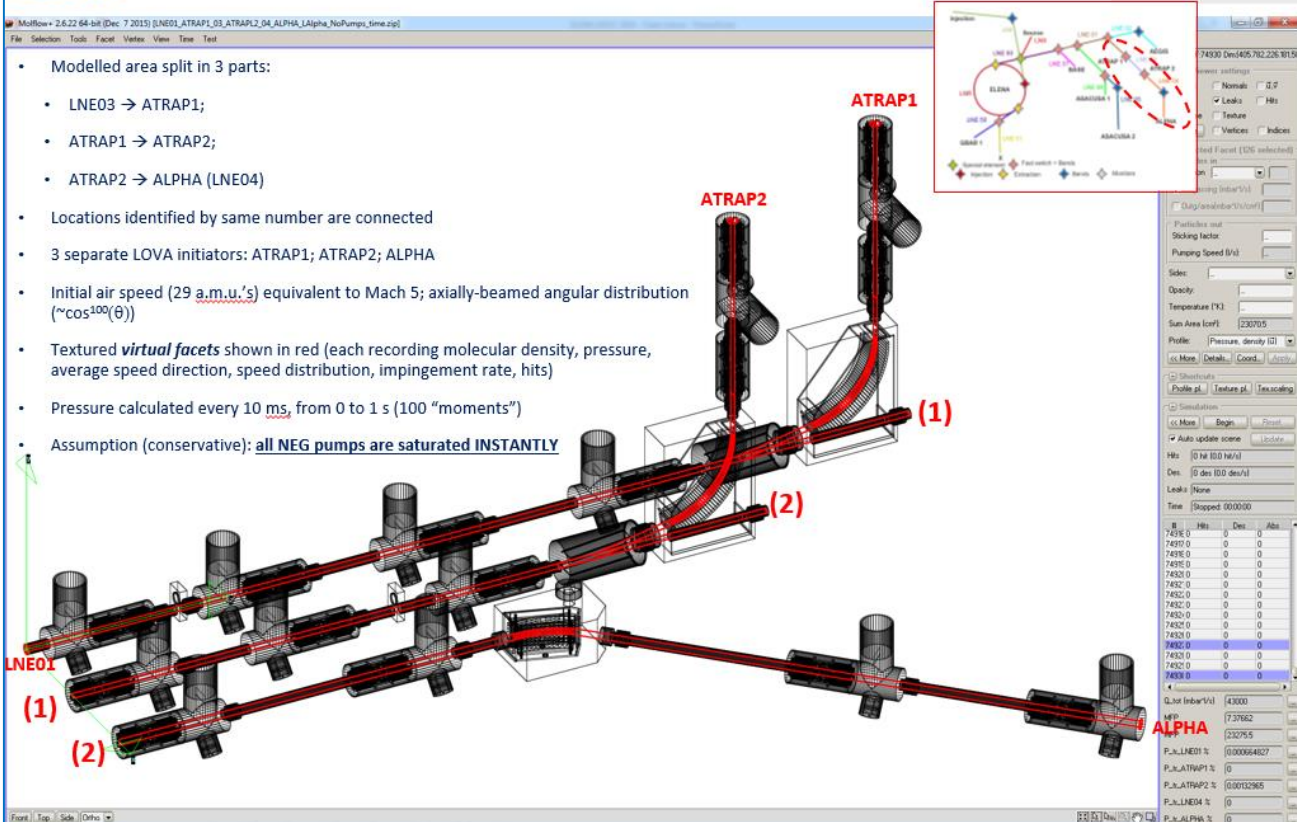
3 separate LOVA initiators: ATRAP1; ATRAP2; ALPHA

Initial air speed (29 a.m.u.'s) equivalent to Mach 5; axially-beamed angular distribution ( $\sim \cos^{100}(\theta)$ )

Textured *virtual facets* shown in red (each recording molecular density, pressure, average speed direction, speed distribution, impingement rate, hits)

Pressure calculated every 10 ms, from 0 to 1 s (100 "moments")

Assumption (conservative): all NEG pumps are saturated INSTANTLY



#	Hits	Des	Alts
74918	0	0	0
74919	0	0	0
74920	0	0	0
74921	0	0	0
74922	0	0	0
74923	0	0	0
74924	0	0	0
74925	0	0	0
74926	0	0	0
74927	0	0	0
74928	0	0	0
74929	0	0	0
74930	0	0	0
74931	0	0	0
74932	0	0	0
74933	0	0	0
74934	0	0	0
74935	0	0	0
74936	0	0	0
74937	0	0	0
74938	0	0	0

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

The screenshot displays the software interface for TPMC simulations. At the top left is the ELENA logo. The main title is "Time-dependent TPMC simulations: LOVA at ATRAP1". On the top right is the Vacuum Surfaces Coatings logo.

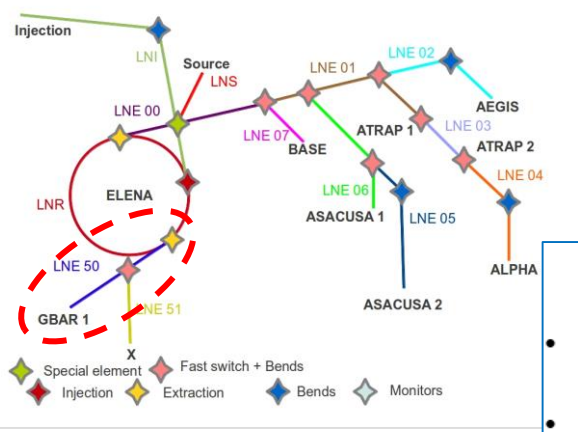
The interface includes several panels:

- Time-wise plotter:** A graph showing the evolution of various moments over time. The y-axis is logarithmic, ranging from  $10^{-7}$  to 10. The x-axis represents time from 0 to 90. A legend below the plot lists moments from 1 to 100, with Moment 5 highlighted in red.
- Time Settings:** A panel with "Moment 5" selected and "Fast step" set to 5.
- Add time moments:** A table with columns for "Moment list", "Time list", and "Nb". It shows two entries: 1 (0.010.01.10001) with Nb 100, and 2.
- Texture Scaling:** A panel with "Autocalc" and "Use colors" checked. It shows a color gradient bar from  $10^{-2}$  to  $10^2$ .
- 3D Viewport:** A 3D model of the vacuum chamber with a red laser line passing through it. Red arrows point to specific locations with the text "FV here protects LNE01" and "FV here protects ATRAP2 and ALPHA".
- Right Panel:** A control panel with various simulation parameters such as "Pumping Speed", "Temperature", "Sun Area", and "Leak". It also includes a table for simulation results.

The simulation results table at the bottom right shows the following data:

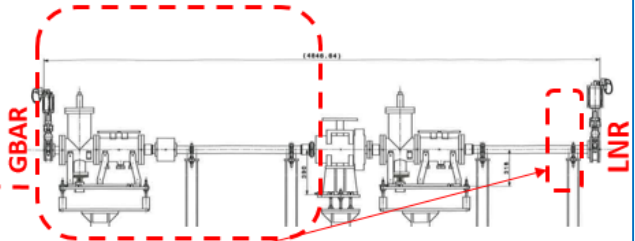
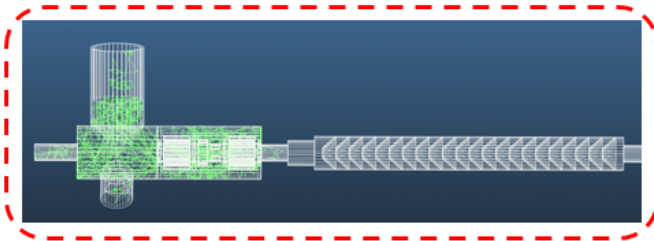
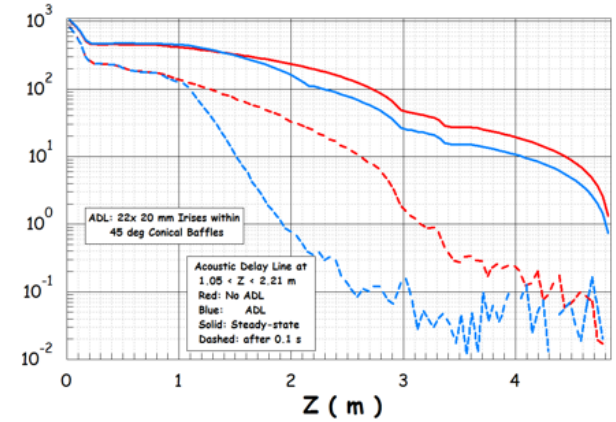
#	Nb	Des	Abn
2502	302339	7479478	0
2501	6083042	0	0
2502	6085043	0	0
2502	6086031	0	0
2502	6088126	0	0
2503	6086406	0	0
2503	6085543	0	0
2503	60830750	0	0
2503	6082304	0	0
2503	60846762	0	0
2503	60846206	0	0
2503	60859167	0	0
2503	60867778	0	0
2503	60872258	0	0

- **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:**

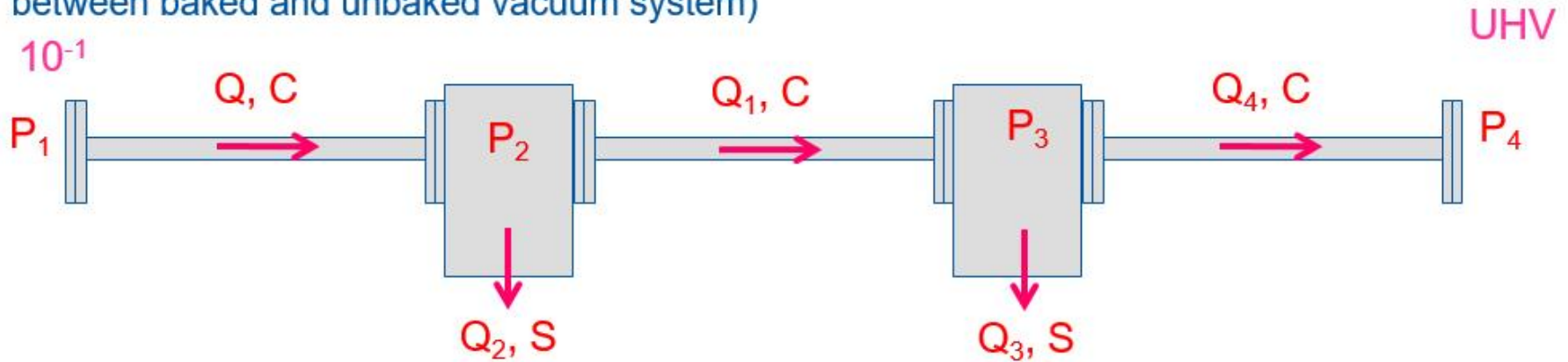
- A mass 29 a.m.u. (air) gas flow is simulated at the GV connecting to the Gbar beamline
- The gas flow is normalized to a pressure of 1 atmosphere at Gbar (at steady-state, solid curves)
- It is shown that even after only 0.1 s the other GV connected to the electrostatic deflector on LNR reaches the 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...](#)**

# 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)



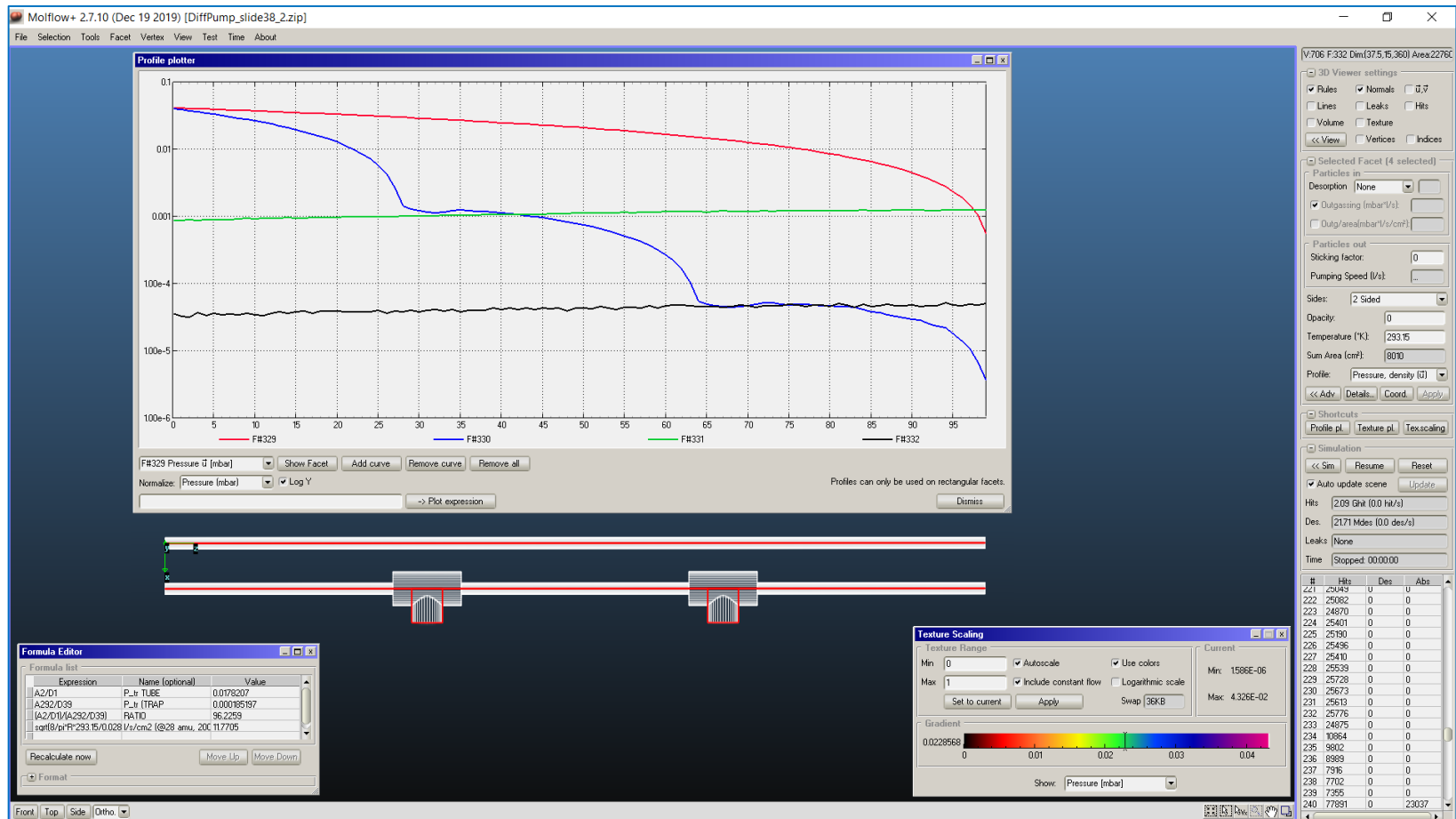
- Commercial differential pumps



Pictures Edwards

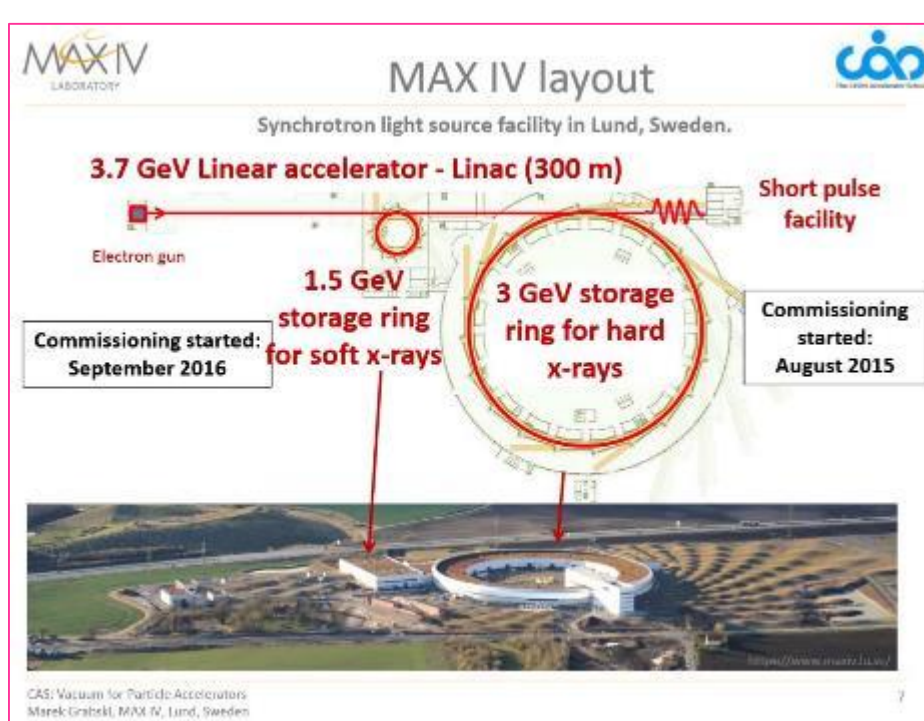
# Transmission probability, $P_{TR}$ calculation for:

- 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 4<sup>th</sup> generation light sources, Max-IV and ESRF-EBS

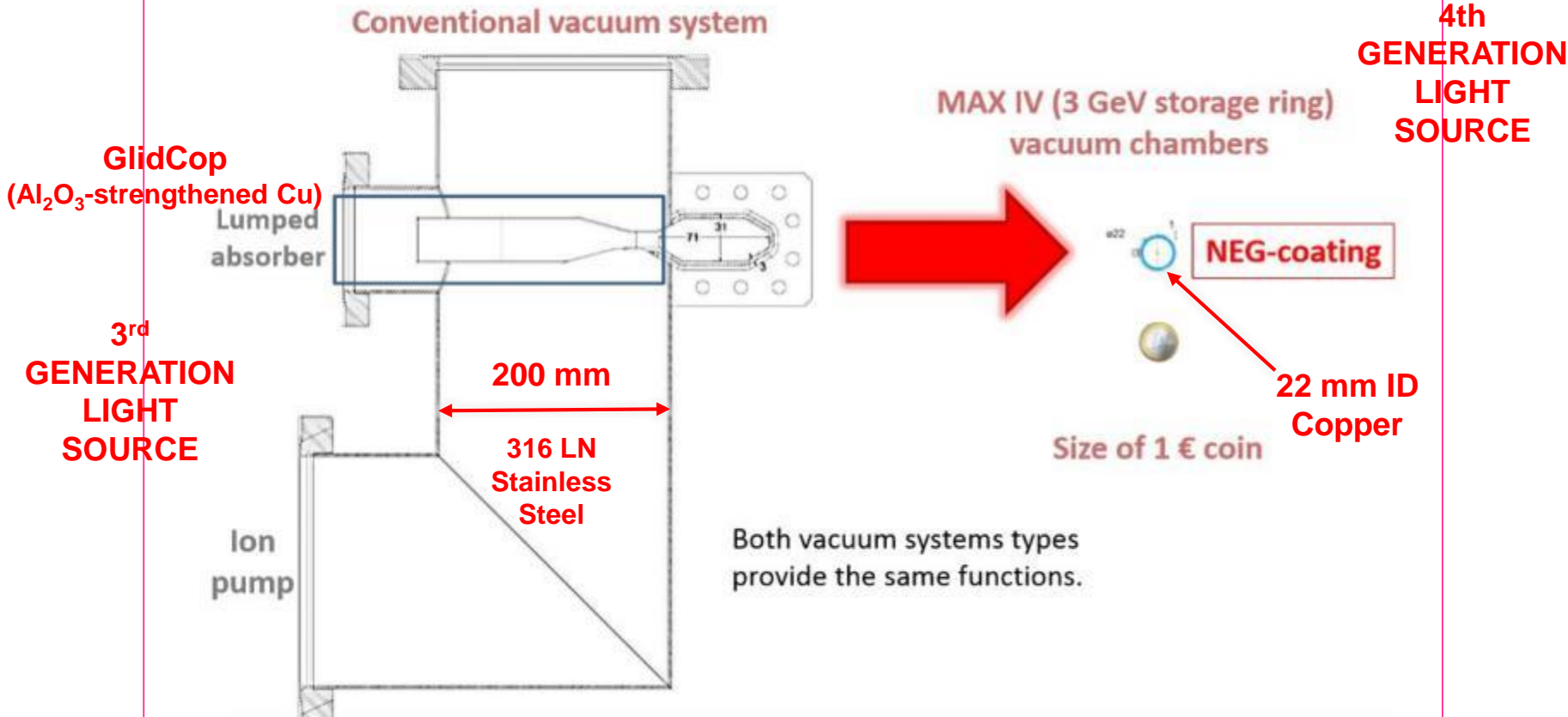
- Max-IV: 3 GeV, 500 mA,  $\approx$  500 m circumference
- ESRF-EBS: 6 GeV, 200 mA,  $\approx$  850 m circumference



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



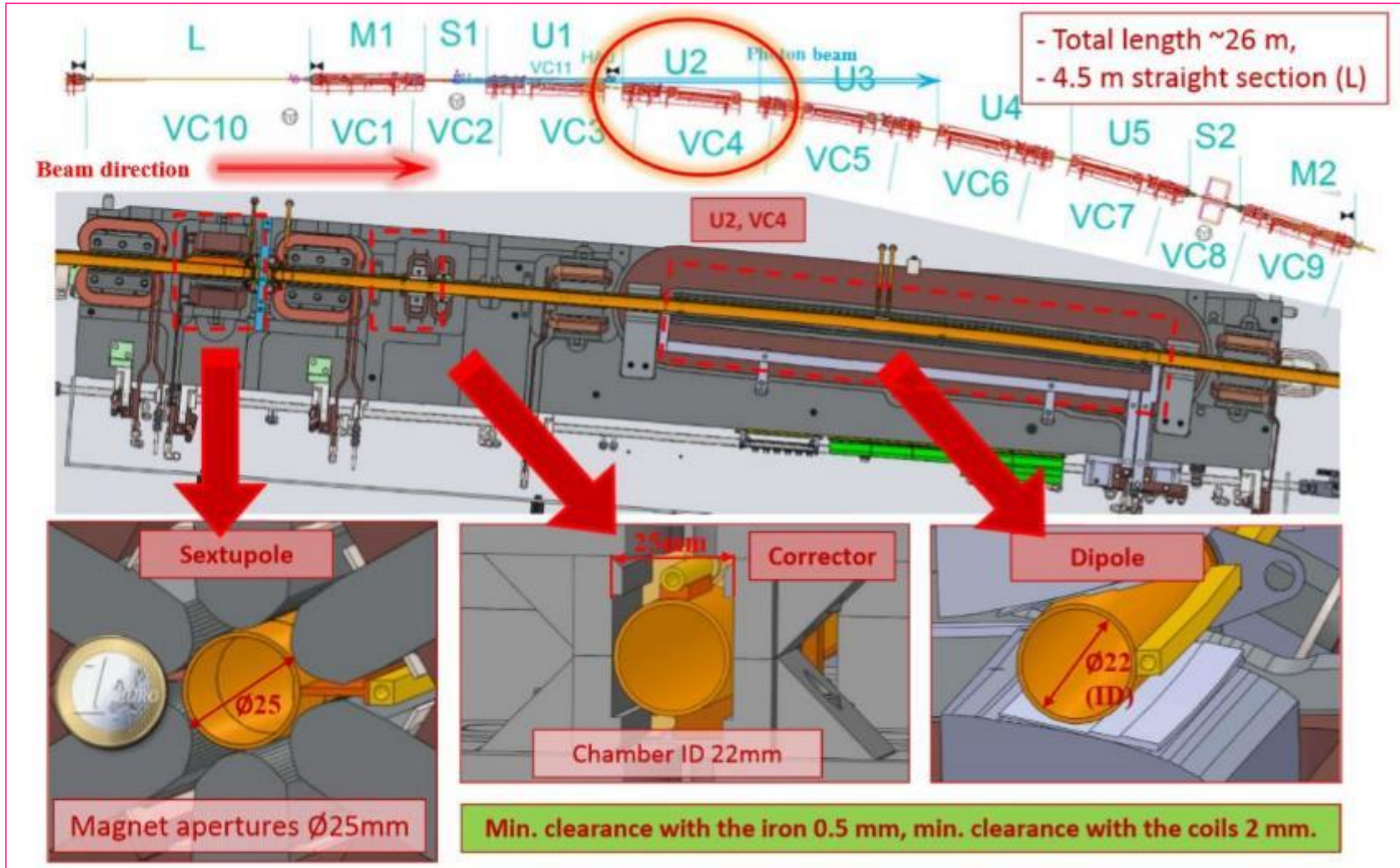
## Conventional vs compact vacuum system



CAS: Vacuum for Particle Accelerators  
Marek Grabski, MAX IV, Lund, Sweden

10

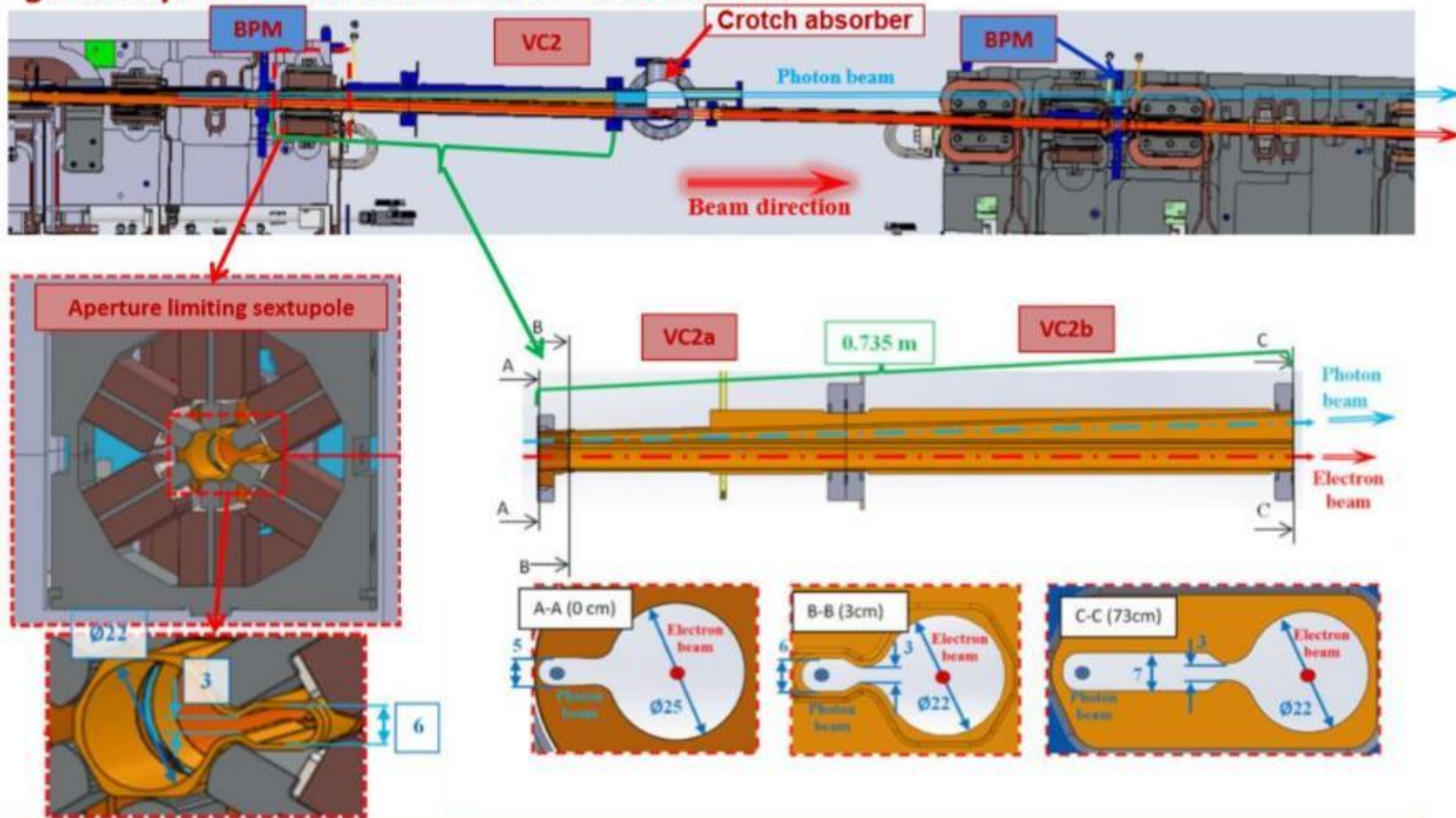
# Very tight space between vacuum chambers and magnetic poles



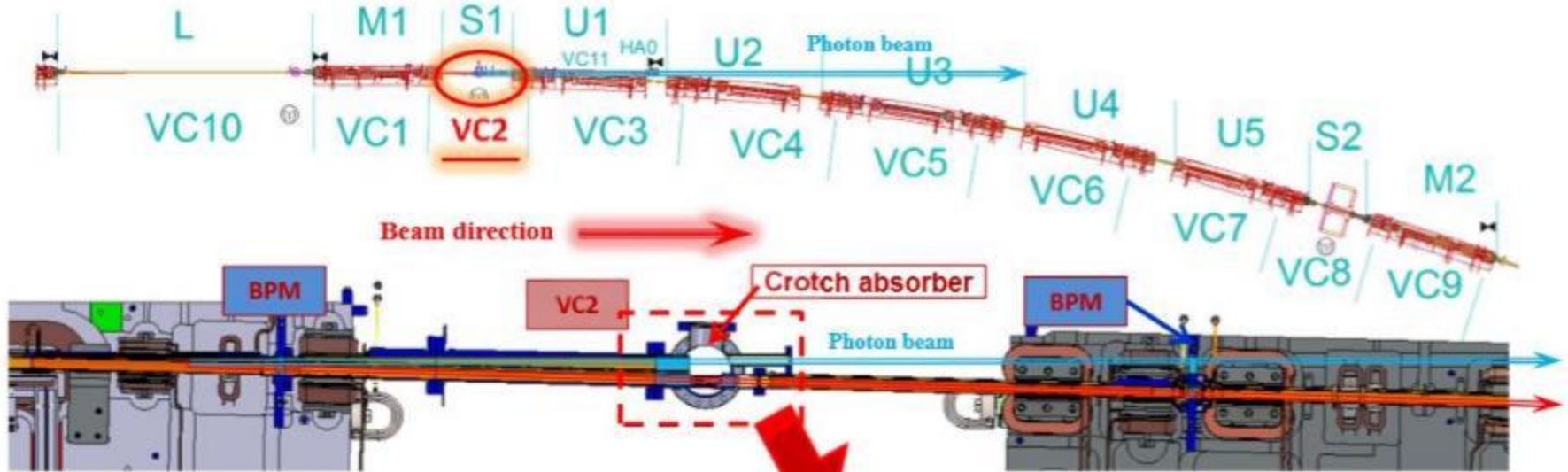


# Variable cross sections at dipoles with SR extraction port

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

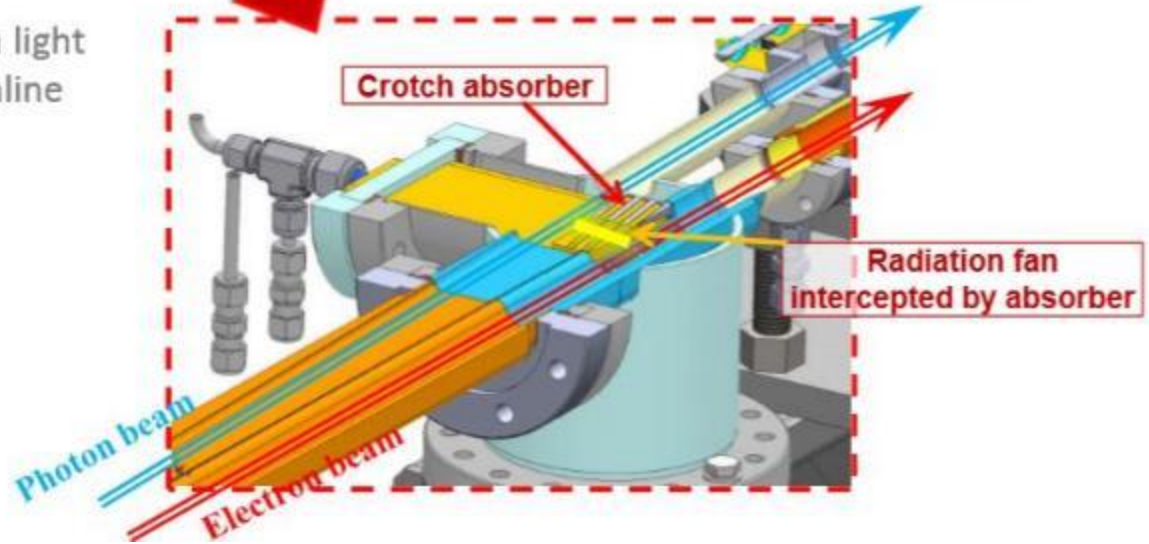


Crotch absorbers are used to intercept the fraction of the SR fan which doesn't reach the beamlines



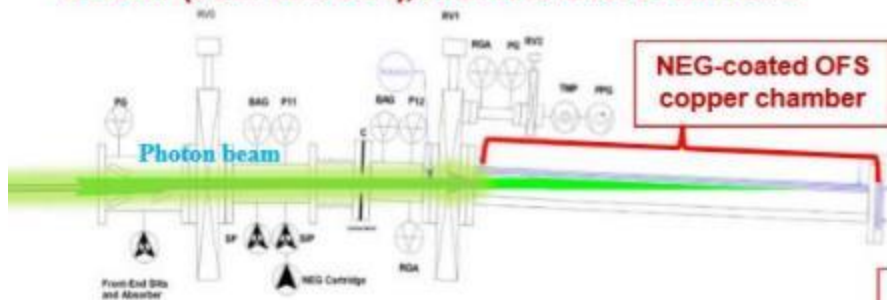
Short straight section 1 – synchrotron light extraction to the Front End and Beamline

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

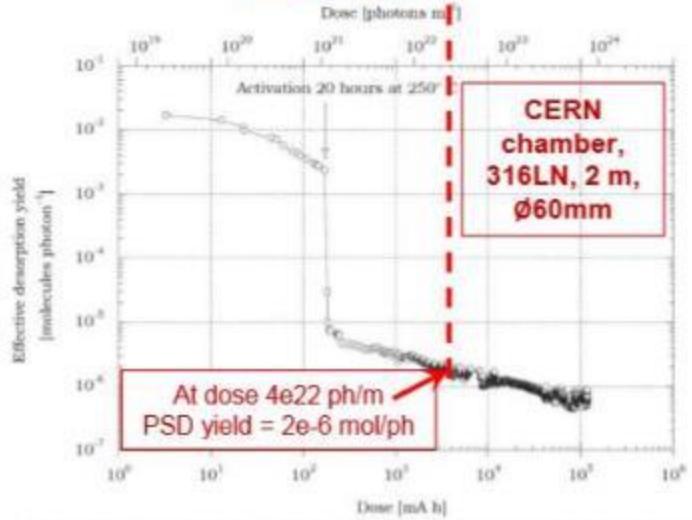
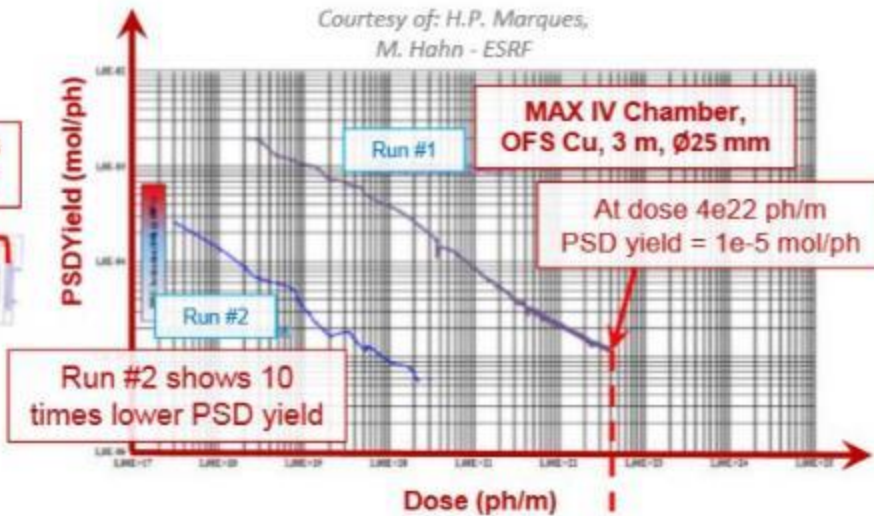


# Feasibility of fully NEG-coated solution had been checked at ESRF on a dedicated photodesorption beamline (D31)

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



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



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

# 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)

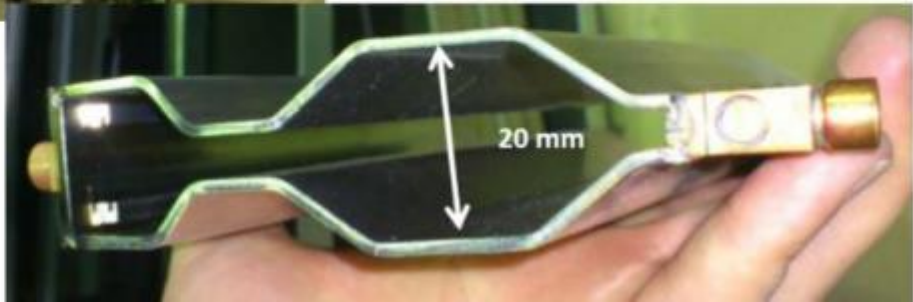


ALBA vacuum system and other 3<sup>rd</sup> generation storage rings  
Also ANKA, SLS, CLS, ASP, Diamond...etc.

Keyhole profile

The unit cell = 13 m

- Antechamber design with lumped copper absorbers.
- Keyhole profile 28x72 mm.
- Stainless steel 316LN.
- Pumping mainly by Ion and NEG pumps.
- Overall pump speed 60400 l/s



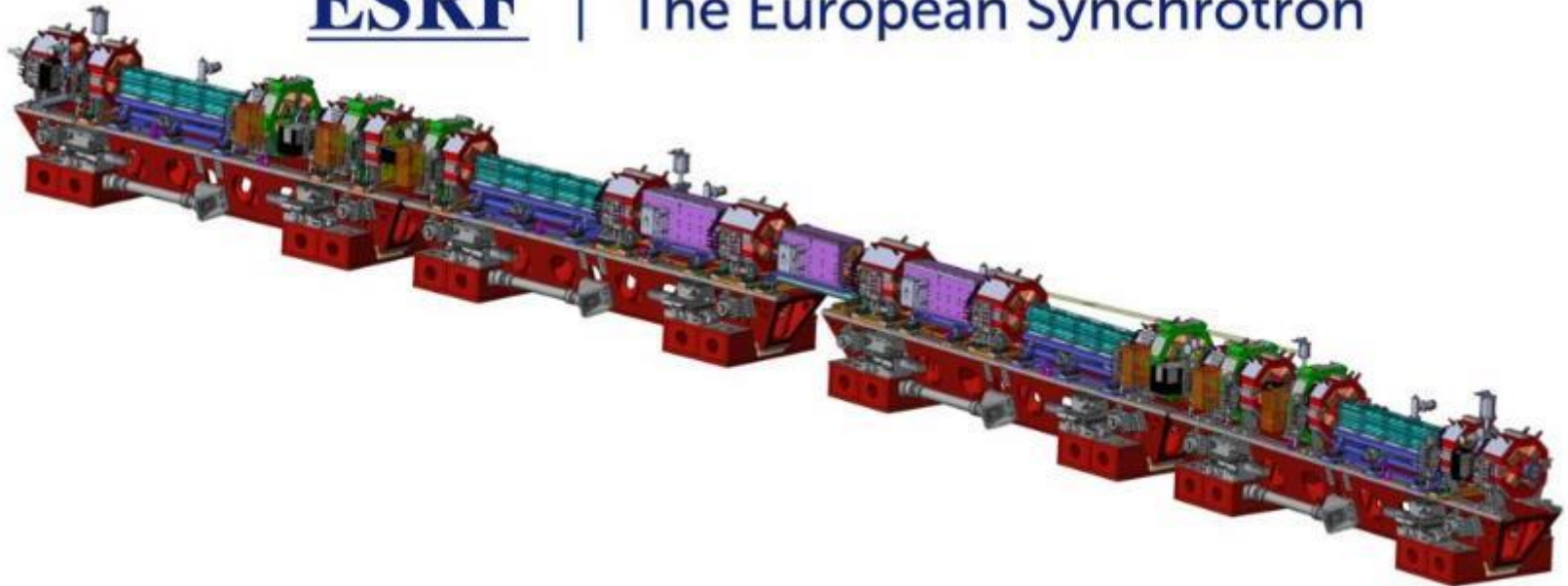
The ESRF upgrade, EBS (Extremely Bright Source), adopts a different design: very little NEG-coating, and use of machined SS and aluminium chambers, welded longitudinally

**WP-3 – Vacuum Vessels Design – JC Biasci**

*On behalf of the Accelerator Project Phase II Team*



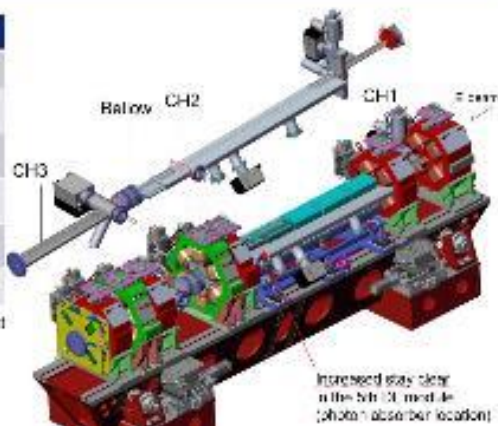
The European Synchrotron



## GIRDER 1

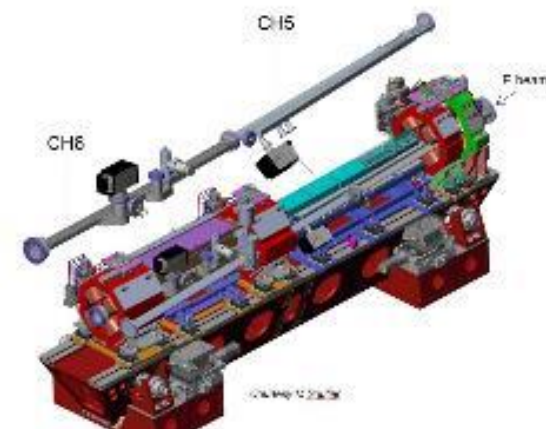
	CH1	CH2	CH3
Length [mm]	750.9	2527.7	1120.8
Material	316LN sheet	AL	316LN sheet
Bellow/RF fingers	1	-	-
Absorber	-	CH2 1-1	Crutch 1 CH3 1-1
BPM	BPM1	-	BPM2 BPM3

Res: face point



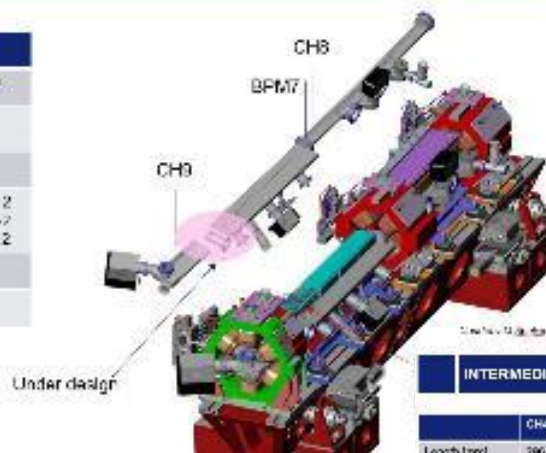
## GIRDER 2

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



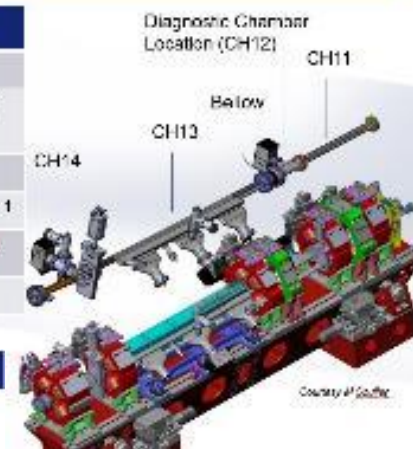
## GIRDER 3

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



## GIRDER 4

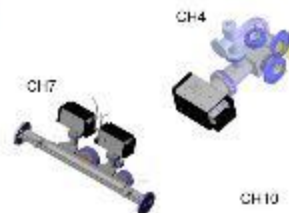
	CH11	CH12	CH13	CH14
Length [mm]	1071	418.9	2627	750.9
Material	316LN sheet	AL	-	316LN OFF
Bellow/RF fingers	-	-	-	1
Absorber	-	-	CH13 1-1	CH14 1-1
BPM	BPV8 BPV9	-	-	BPM10



### INTERMEDIATE CHAMBERS

	CH4	CH7	CH10
Length [mm]	286.8	161	113
Material	316LN sheet	316LN sheet	316LN sheet
Bellow/RF fingers	1	-	1
Absorber	CH4 1-1	CH7 1-2 CH7 2-2	-
BPM	-	BPM5 BPM6	-

Diagnostic chambers (Girder 4):



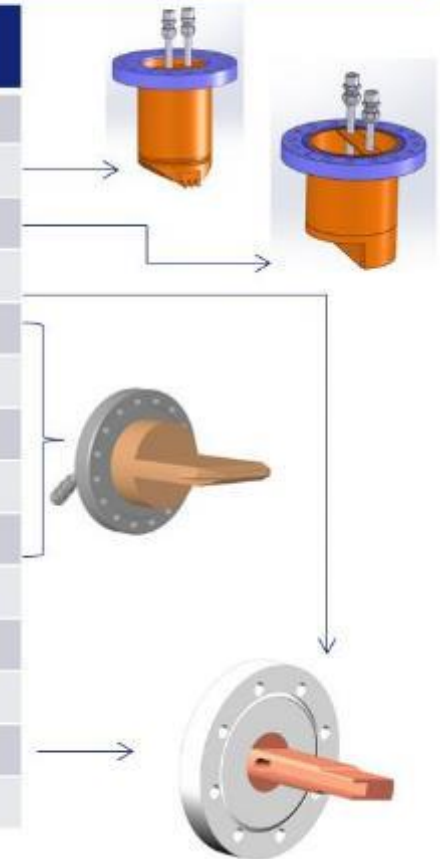
CH10



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

## ABSORBERS POWER DISTRIBUTION

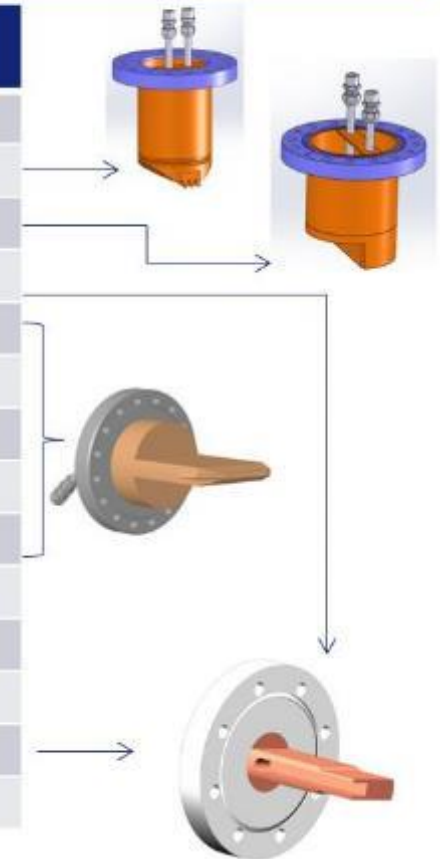
Chamber	Abs name	T Power [W]	Power dens max [W/mm <sup>2</sup> ]
Chamber 2	CH2 1-1	196	1.4 * (≠ for Helical)
Chamber 3	Crotch 1	1103	90(@ normal incidence)
Chamber 4	CH4 1-1	393.4	13
Chamber 5	CH5 1-1	325.5	8.6
Chamber 6	CH6 1-1	968.5	14
Chamber 7	CH7 1-7	986.5	12.9
Chamber 7	CH7 2-2	522.5	14.2
Chamber 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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Chamber	Abs name	T Power [W]	Power dens max [W/mm <sup>2</sup> ]
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Chamber 14	CH14 1-1	631.7	2.2

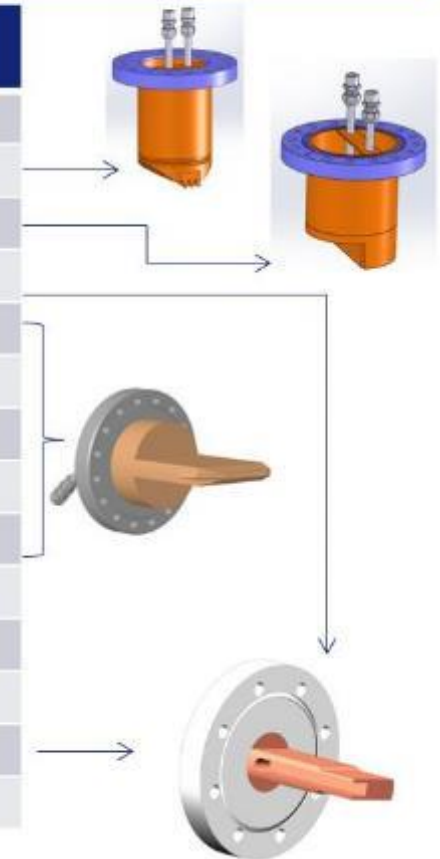




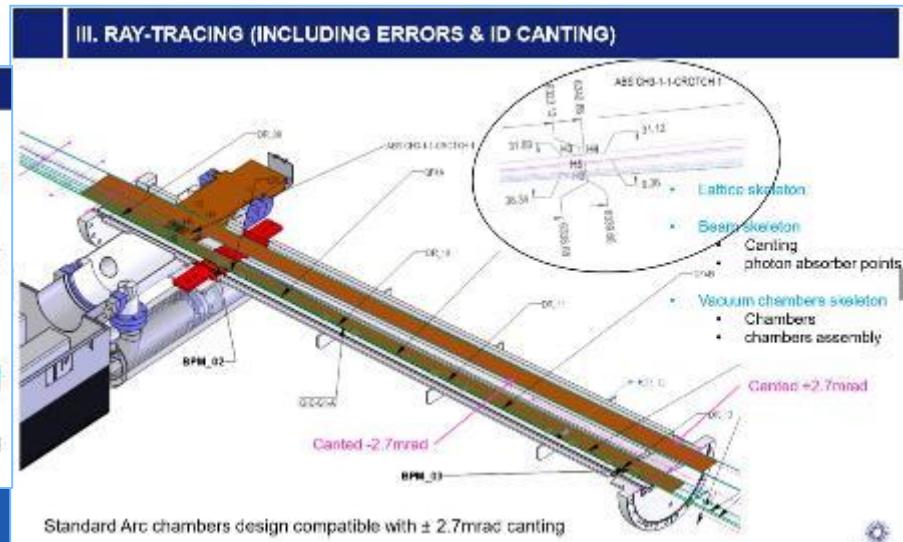
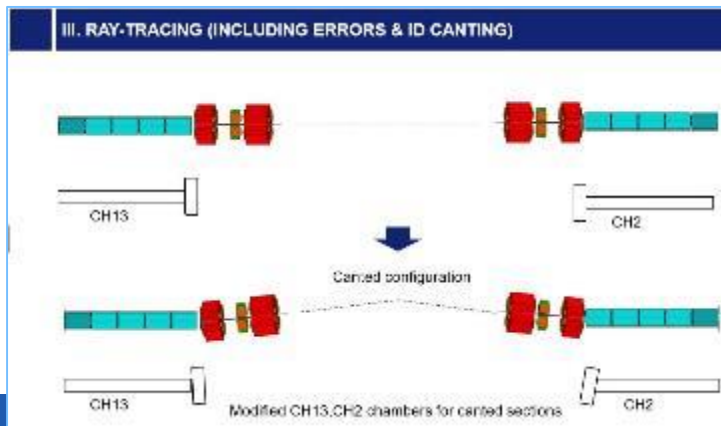
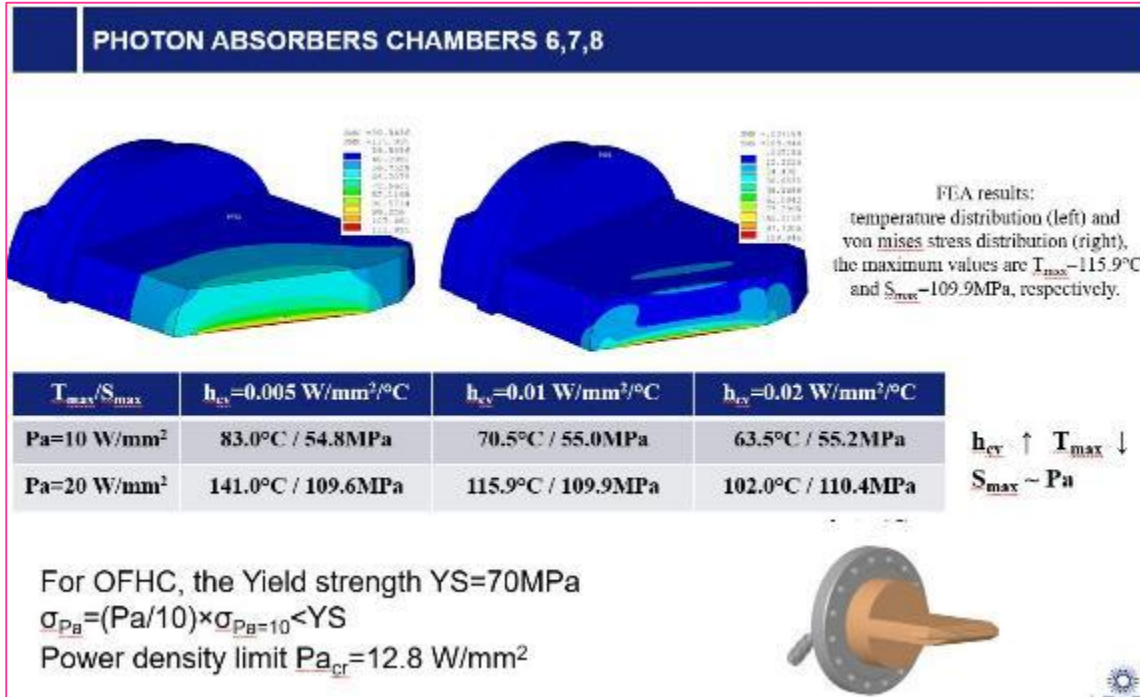
# At the ESRF-EBS 100% of the SR generated by the dipoles is intercepted by lumped absorbers

## ABSORBERS POWER DISTRIBUTION

Chamber	Abs name	T Power [W]	Power dens max [W/mm <sup>2</sup> ]
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

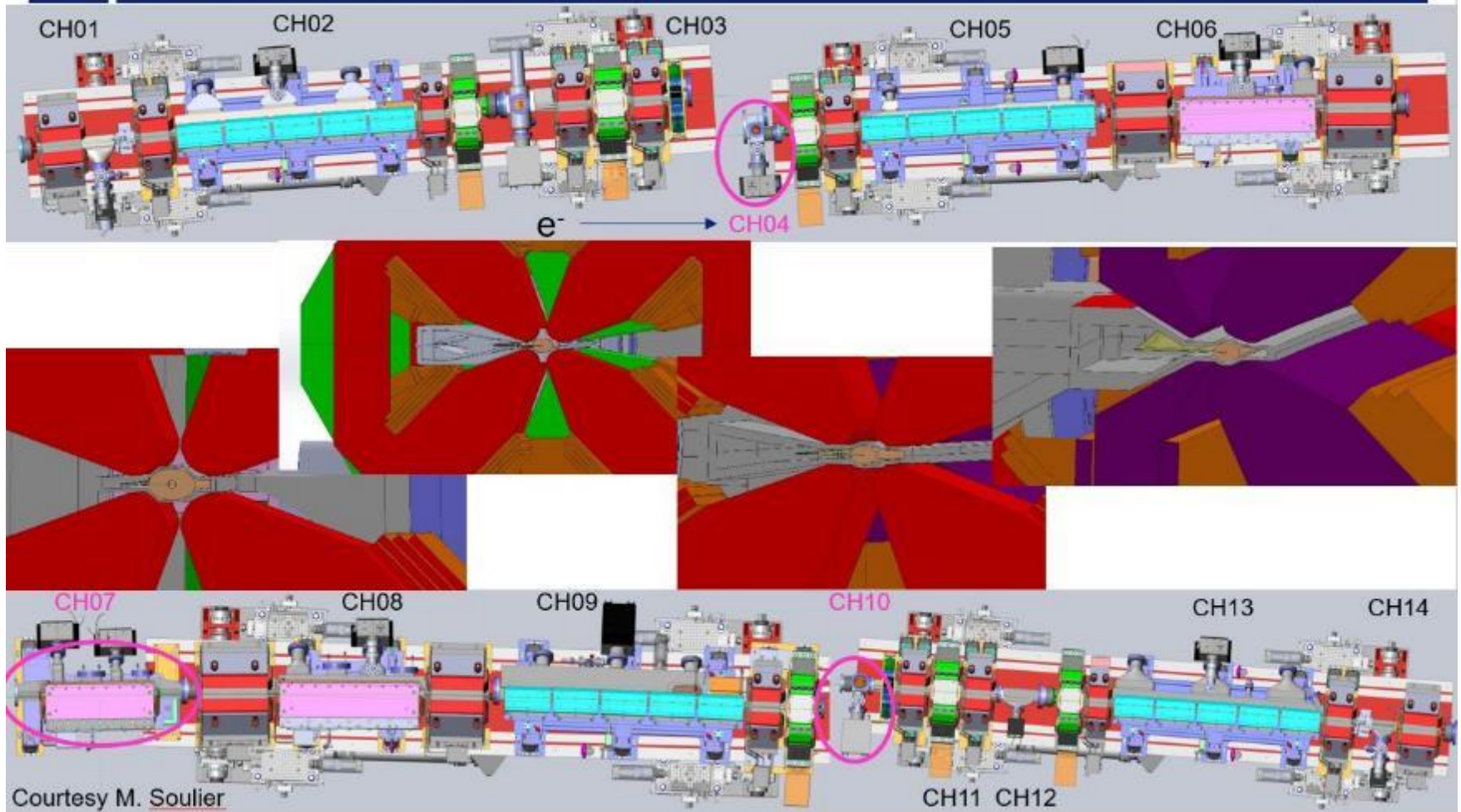


# All photon absorbers have been carefully analysed and designed: Ray-tracing, followed by Finite-Elements thermo-mechanical analysis



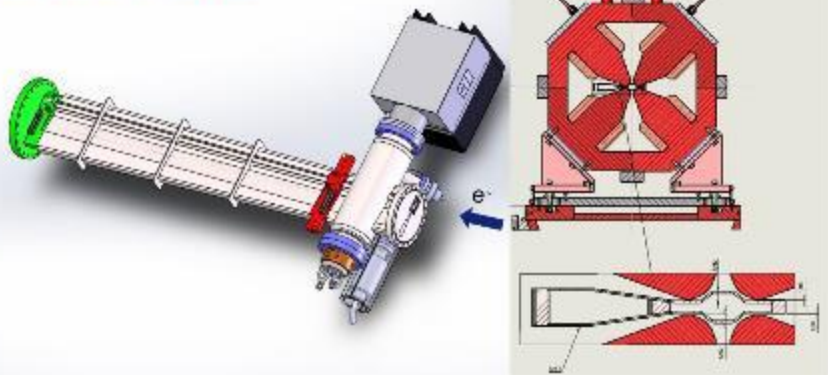
Contrary to the simple one circular tube of Max-IV, the ESRF-EBS team has designed basically a different cross-section for each chamber, to follow the many magnets' pole profiles

## VACUUM ASSEMBLY



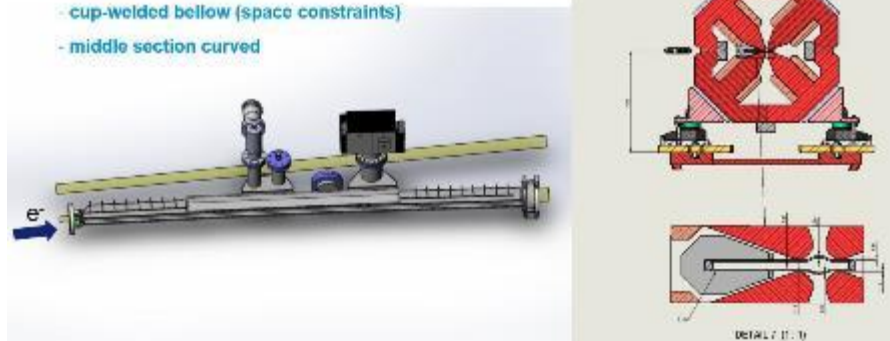
Ch3

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



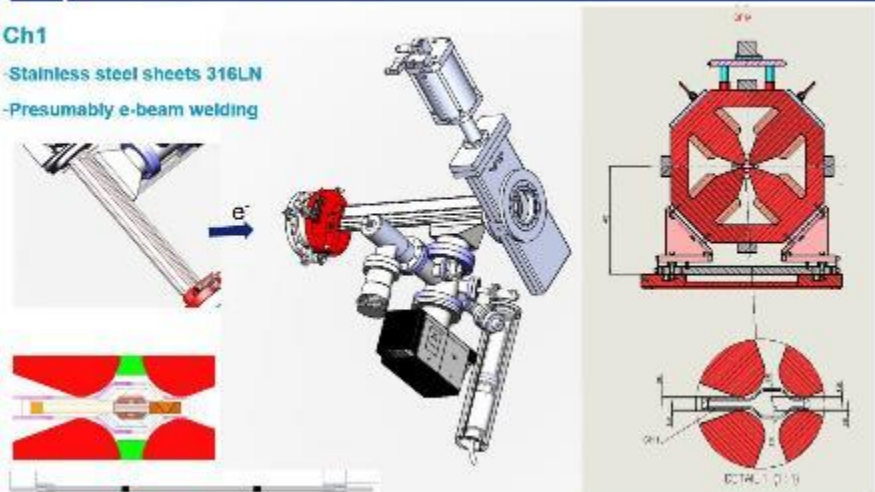
Ch6 (low profile 13v x 20h)

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

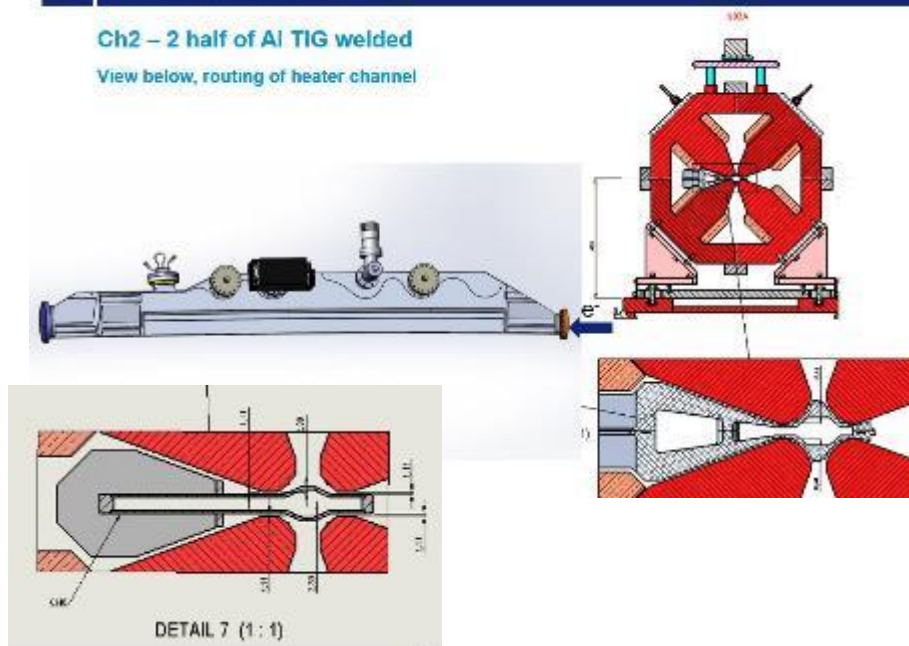


Ch1

- Stainless steel sheets 316LN
- Presumably e-beam welding



- 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 4<sup>th</sup> generation light sources have chosen completely different design philosophies, fully NEG-coated with a constant cross-section for Max-IV vs the uncoated 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)**

