3rd ILSF Advanced School on Synchrotron Radiation and Its Applications

September 14-16, 2013

Vacuum System of Synchrotron radiation sources

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Institute of fundamental Sciences

September 14, 2013

outlines

- Why do synchrotrons need vacuum?
- Vacuum system of synchrotron
- Sources of Gas in a Vacuum System
- Linear Vacuum System
- Pressure profile calculation
- Ray tracing and photon absorbers
- Examples of Vacuum system

Why do synchrotrons need vacuum?

- The main reason is beam-gas interaction (Scattering)
  - Losses accelerated particles
  - Increases beam size
  - Reduces beam lifetime
  - Increases radiation hazard
- In Beamlines
  - Hydrocarbon(carbon) contamination of x-ray optics (mirrors, gratings, crystals)
  - Some sample environments require UHV
  - Gas phase absorption and scattering

Why do synchrotrons need vacuum?

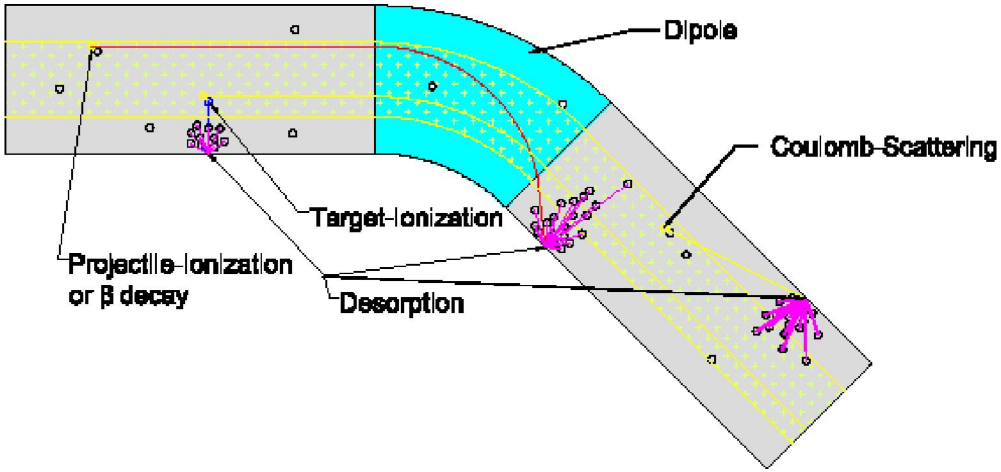
- Residual gas
  - Hydrogen usually predominant fortunately low Z, non - contaminating but can be a problem for some sample environments and cryogenic systems
  - Water and hydrocarbons need to be controlled – materials, cleaning, bakeout

- Particle-gas interaction depends on number density and nature of gas molecules (and particles)
  - Effects scale as Z^2 – minimise high Z gases

    (ΣZ^2 H_2=2, CO=100, Ar =324)

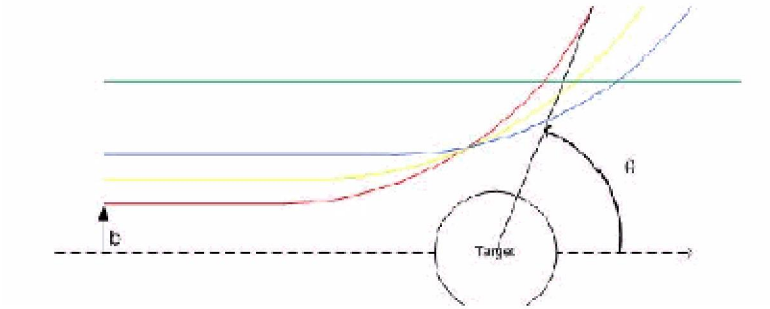
scattering

- Two types of scattering:
  - Elastic
    - Coulomb scattering
  - Inelastic
    - Any scattering that is not elastic
    - Electromagnetic
      - Bremsstrahlung
      - Ionisation
      - Electron capture/loss
    - Nuclear
      - Nuclear Reactions
      - Particle break up
      - Particle creation



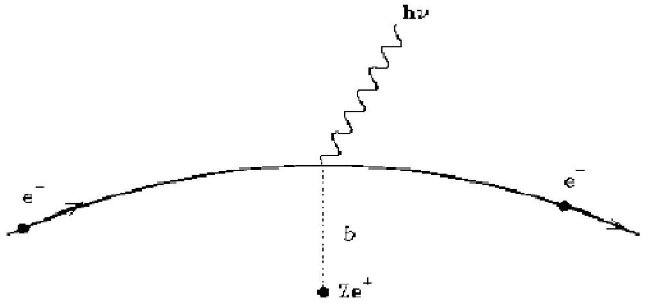
Elastic and inelastic Scattering

- Coulomb scattering



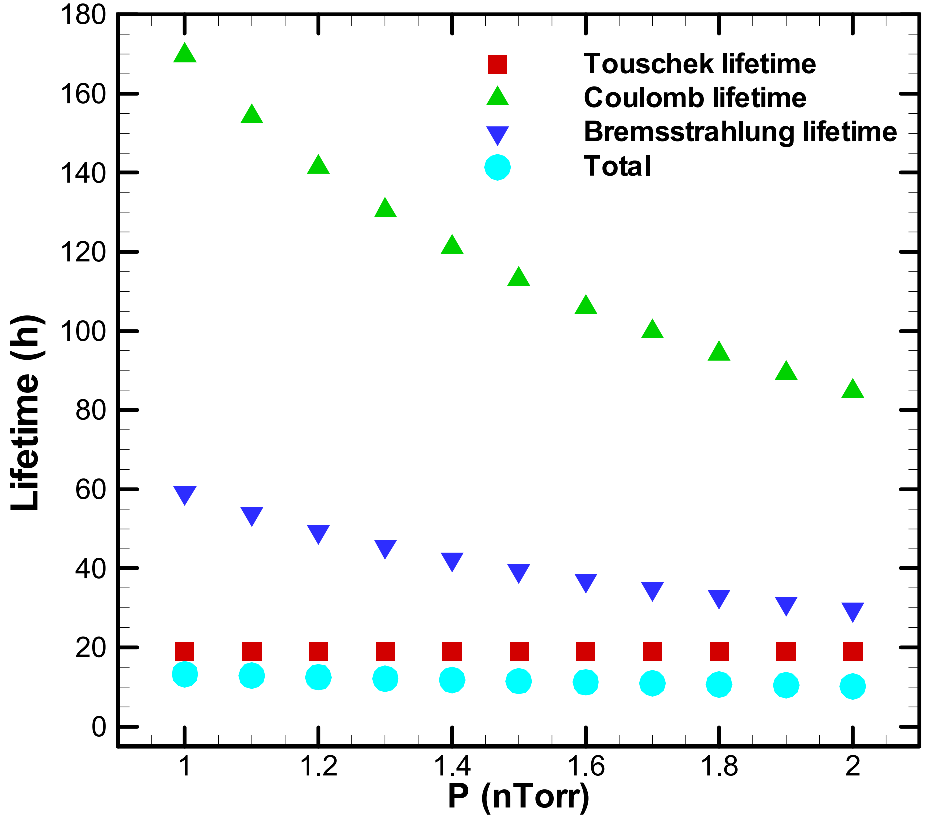
$$\frac{1}{\tau_{el}} = \frac{4\pi r_0^2 c}{\gamma^2} \frac{\langle \beta_y \rangle}{A_y} \frac{P}{k_B T} \sum_i^N Z_i (Z_i + 1) N_i r_{pi}$$

- Bremsstrahlung



$$\frac{1}{\tau_{br}} = \frac{4 r_0^2 c}{137} \frac{4}{3} \left(\ln \frac{1}{\delta_{RF}} - \frac{5}{8} \right) \frac{P}{k_B T} \sum_i^N \ln\left(\frac{183}{\sqrt[3]{Z_i}} \right) Z_i \left(Z_i + \frac{\ln(1440 Z_i^{-2/3})}{\ln(183 Z_i^{-1/3})} \right) N_i r_{pi}$$

Lifetime (ILSF I)



$$\frac{1}{\tau}=\frac{1}{\tau_q}+\frac{1}{\tau_T}+\frac{1}{\tau_{Co}}+\frac{1}{\tau_{br}}$$

To achieve beam lifetimes in the range of 10 hours a residual gas pressure in the level of 1 nTorr is required.

Beam Stability

- Mechanical stability: as stable as possible

  vibration or thermal expansion of vacuum chambers

  → movement of Magnets or BPMs

  → Beam Orbit Change

- Beam duct cross section: as smooth as possible

  abrupt change of cross section → wake field

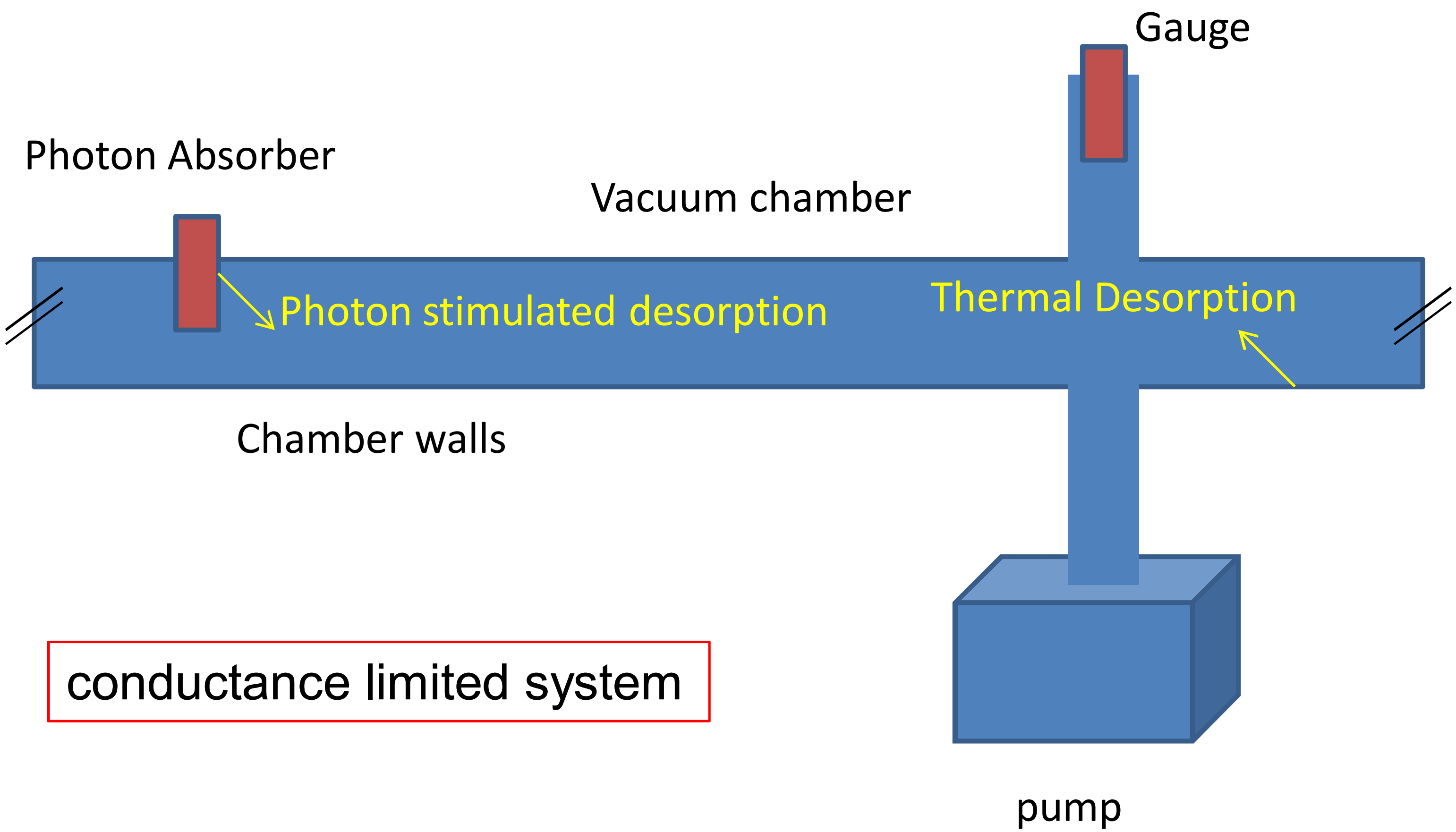
  → Induce Beam Instability (and the lost energy could also heat up vacuum components)

- Chamber material and thickness: Frequency Response

  AC or pulse magnetic field → Eddy current

  → Shielding or Changing the Original Magnetic Field and Heating the vacuum Chamber

Vacuum system of synchrotron



conductance limited system

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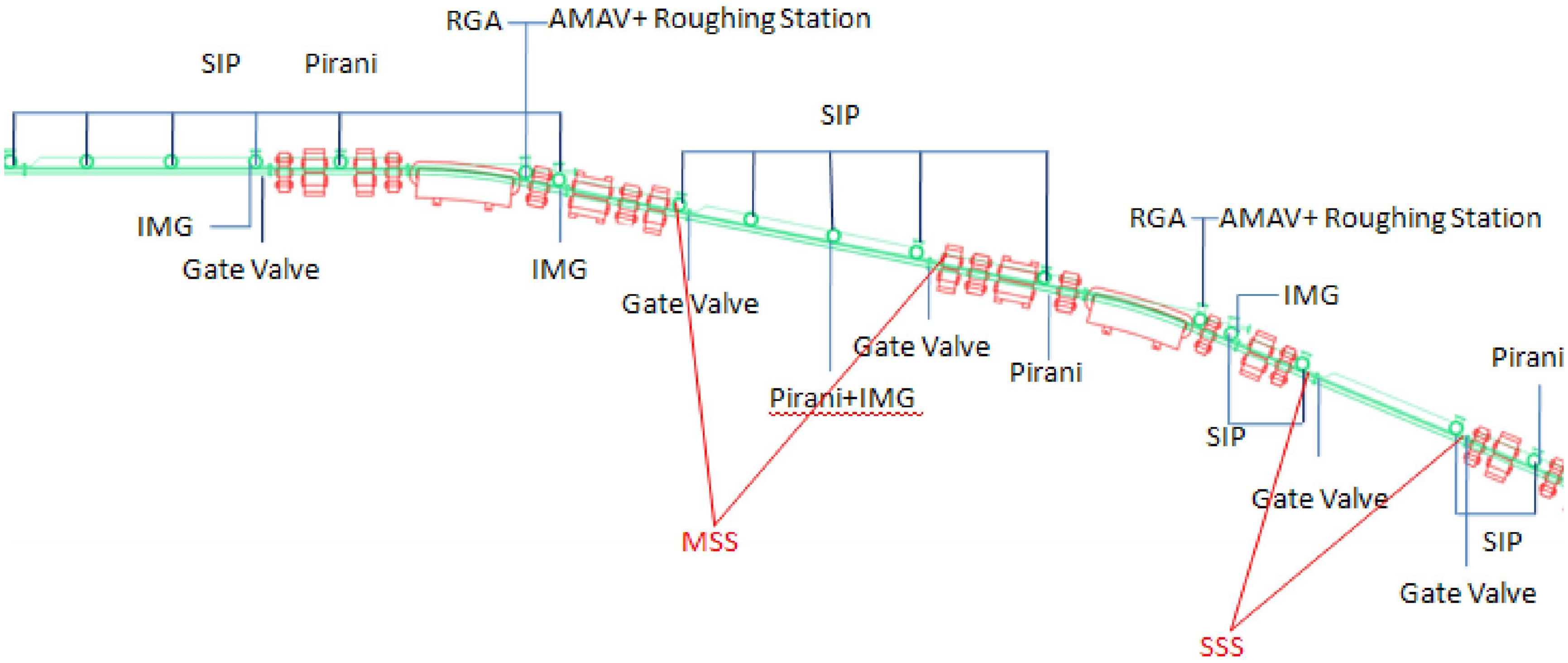
ILSF Vacuum System



4 fold symmetry

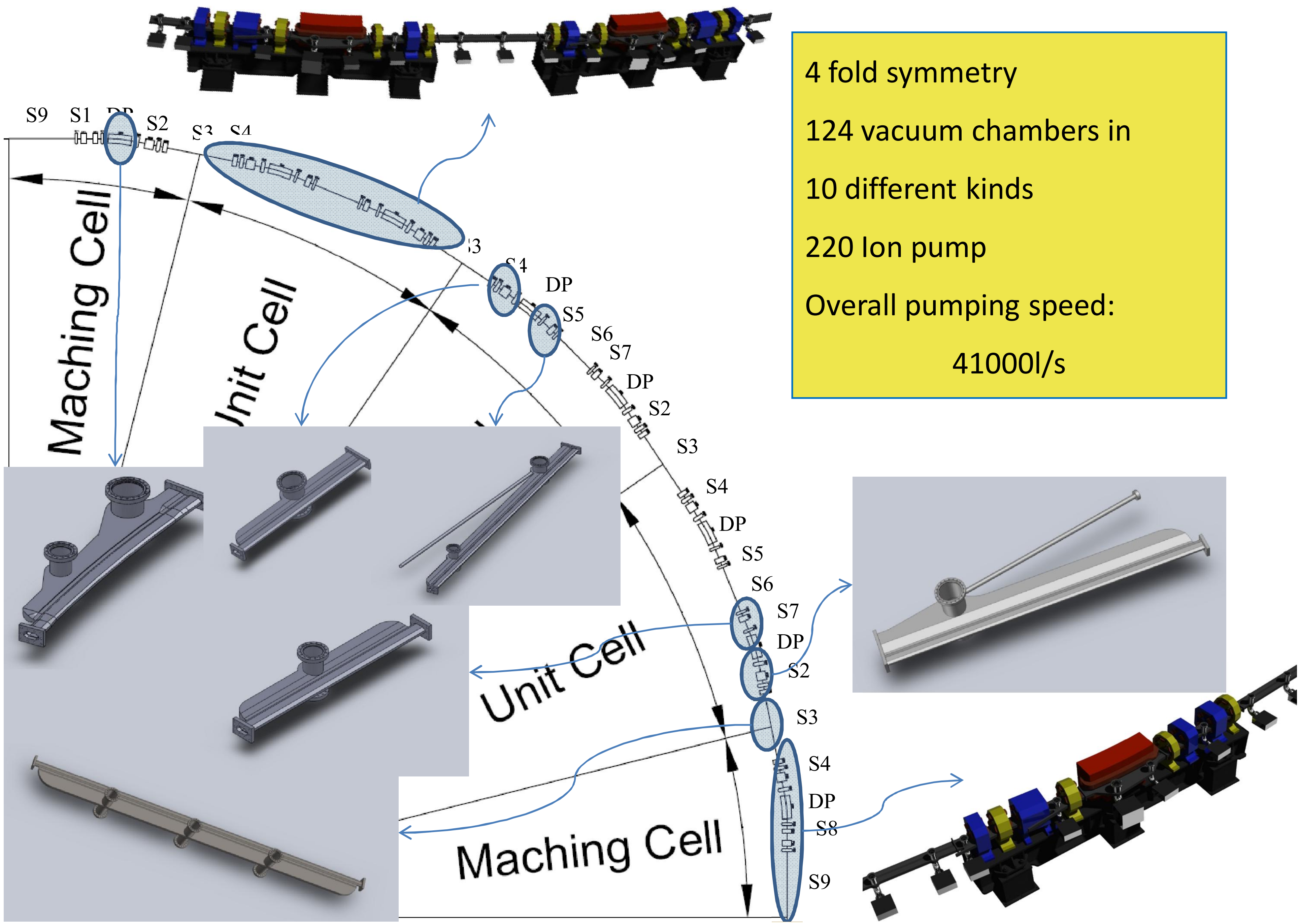
124 vacuum chambers in

10 different kinds

220 Ion pump

Overall pumping speed:

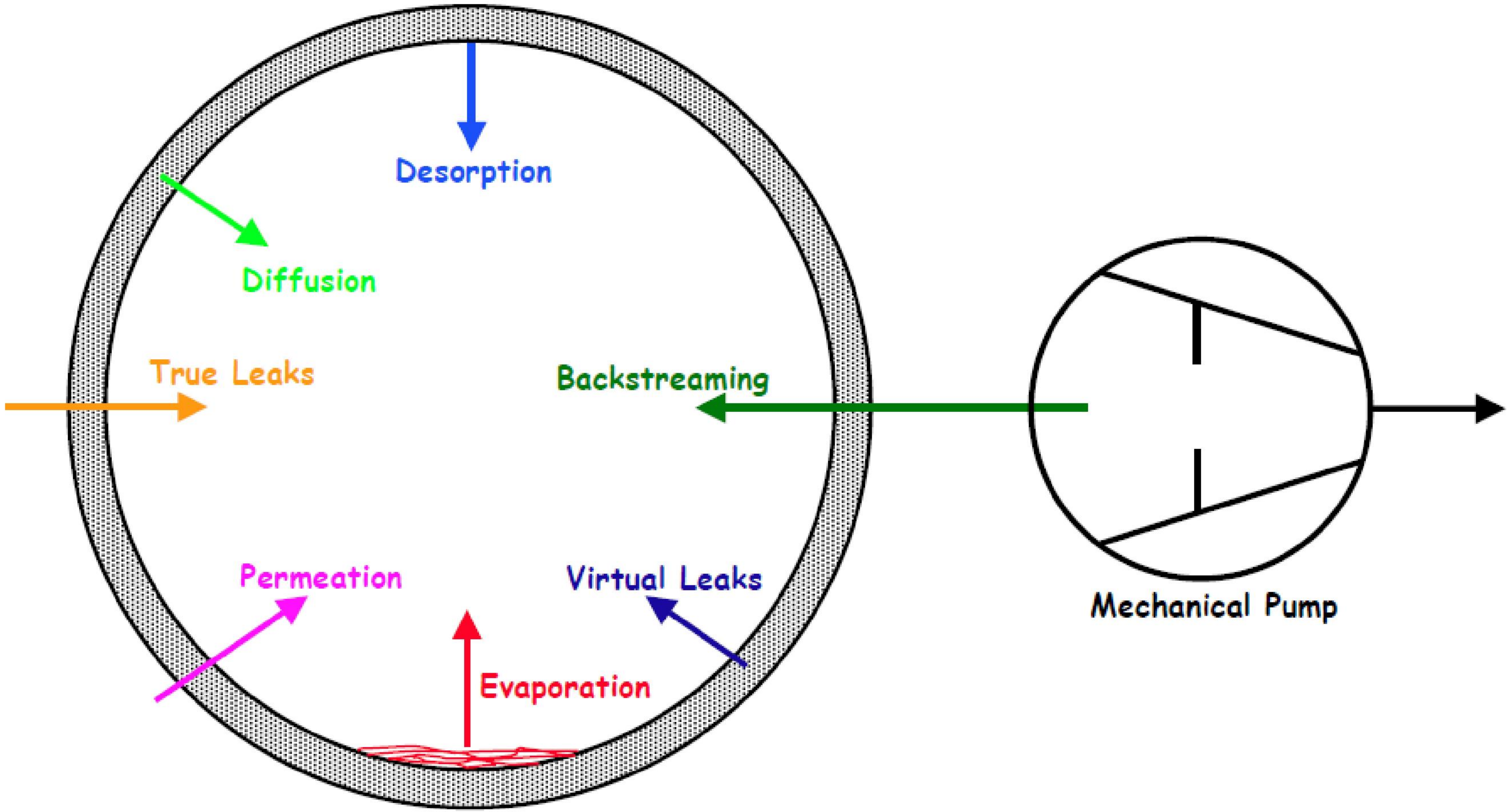
41000l/s



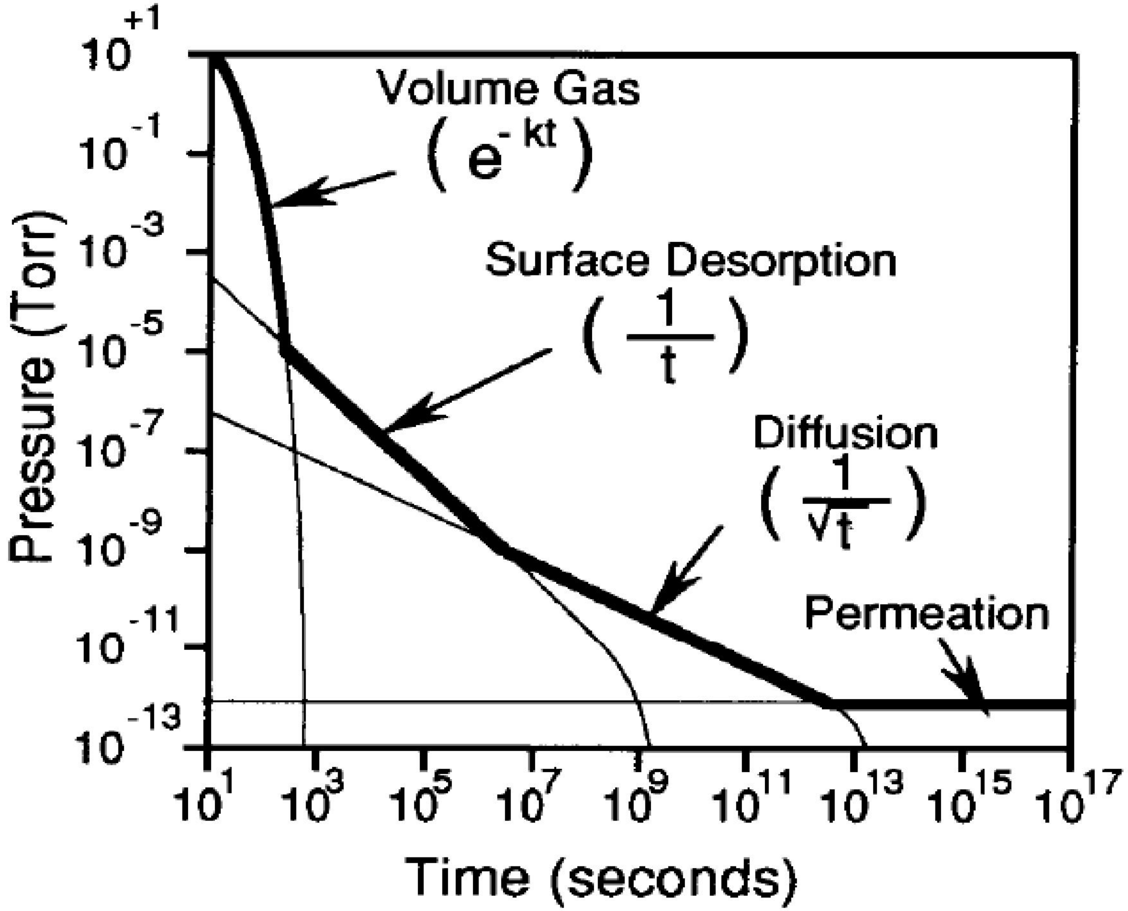
Some challenges

- High radiation environment
  - Materials – stainless steel, copper, ceramic
  - Electronics – avoid near beam channel
  - Personnel access - remote control and monitoring
- High heat loads and power densities – up to 30kW some insertion devices
- Photon stimulated desorption – pressure can rise by orders of magnitude with beam
- Locally high magnetic fields
- Long narrow beam channels with little space for vacuum pumps: conductance limited, many pumps
- High reliability
  - 12/4 operation, 2 shutdowns a year
  - Quality control at every stage is vital
- In - situ bakeout is not possible in many sections
- More than 2km of UHV beam pipe at Low Field option

Sources of Gas in a Vacuum System



Evacuation of vacuum svstem



$$P = P_o e^{-St/V} + \frac{Q_o}{S} + \frac{Q_D}{S} + \frac{Q_k}{S}$$

Rate limiting steps during the pumping of a vacuum chamber

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Sources of Gas in a Vacuum System : Thermal Desorption

- It will define the base pressure of the system

$$q = \eta_t F$$

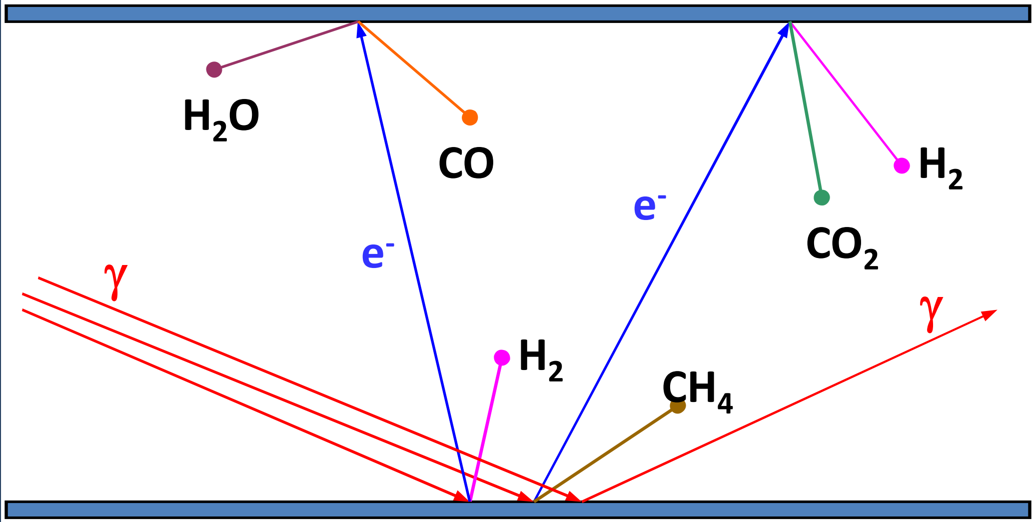
- *F* Vacuum chamber surface area
- η_t Specific desorption rate that depending on:
- Choice of material
- Cleaning procedure
- History of material
- Temperature
- Pumping time

(For clean stainless steel chambers η_t=10^{-11} - 10^{-12} mbar.L/sec.cm^2)

Sources of Gas in a Vacuum System: PSD

Photon stimulated desorption (PSD) is one of the most important sources of gas ***in the presence of SR***.

Gas molecules may be desorbed from a surface when and where *photoelectrons* leave and arrive at a surface



PSD depends on:

- Choice of material
- Cleaning procedure
- History of material
- Pumping time
- Temperature

- Energy of photons
- Photon flux
- Integral photon dose
- Temperature

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Photon Stimulated Desorption (PSD)

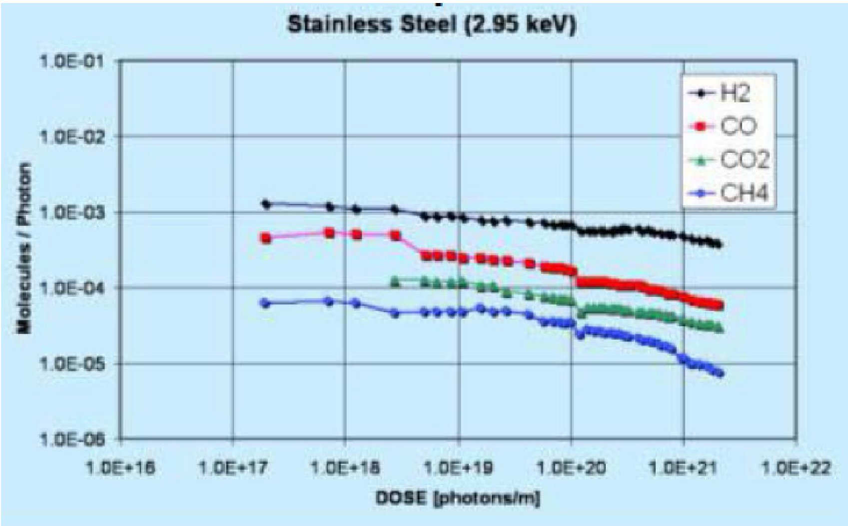
$$Q = \eta_\gamma D$$

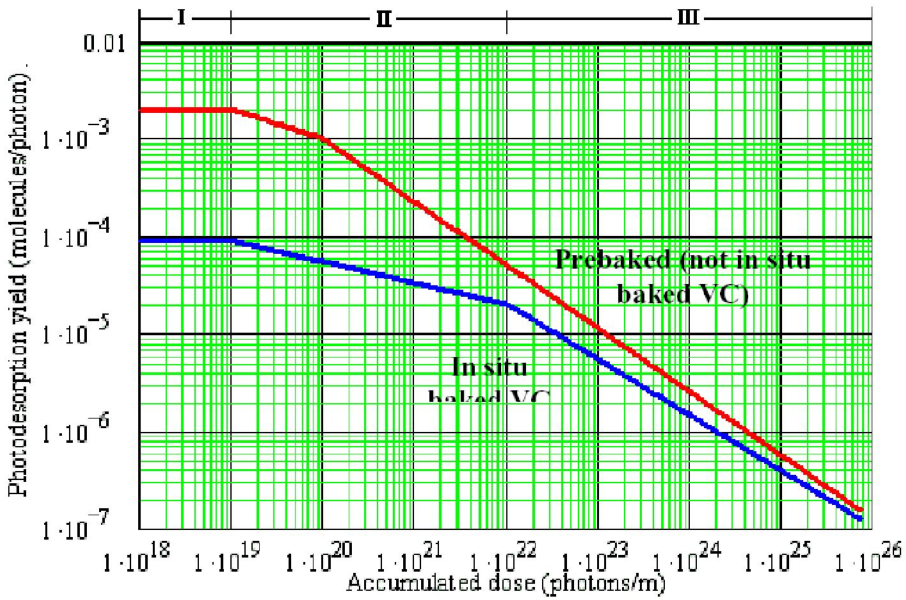
$$\eta = \eta_0 \left(\frac{D_0}{D} \right)^\alpha , \quad 0.65 < \alpha < 1$$

η Photodesorption yields, (molecules/photon)

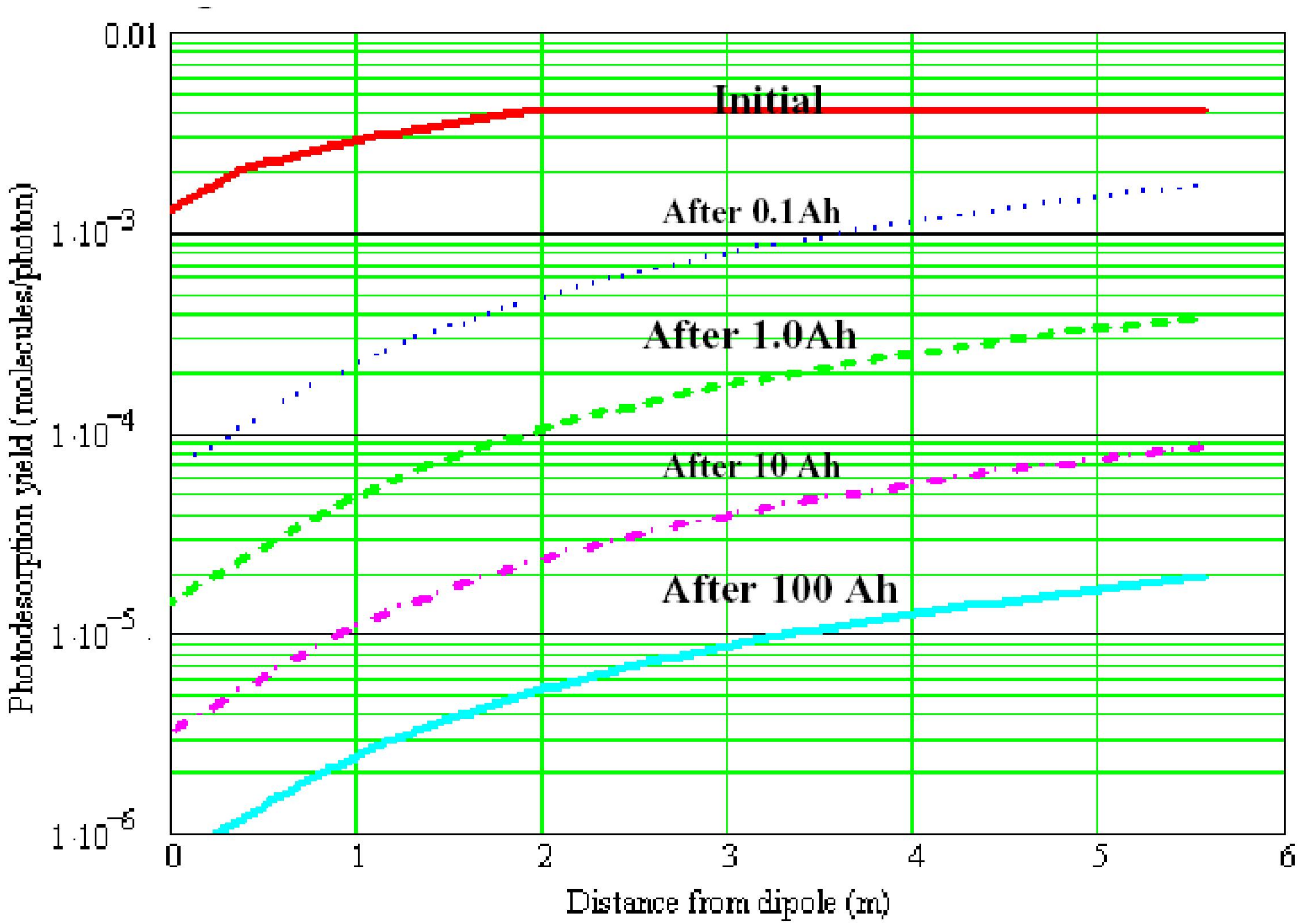
Pre-baked: Pre-baked at 200°C for 24 h (but not baked in-situ).

In-situ baked: Baked insitu at 200°C for 48 h.



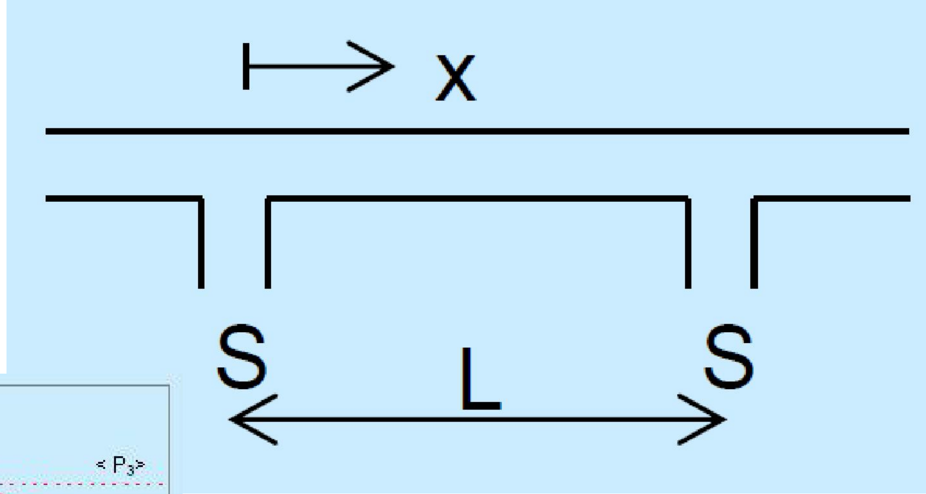


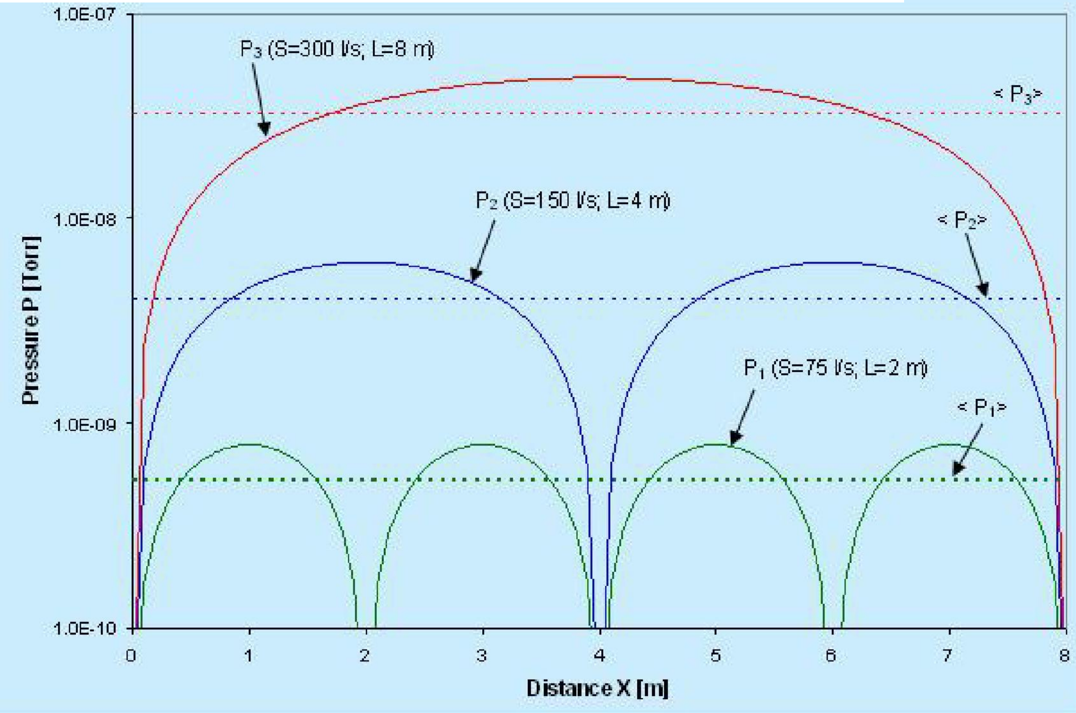
Photon Stimulated Desorption (PSD)



Linear Vacuum System

A=1650 cm²/m
q=5E-12 Torr l/s/cm2
W=11 m l/s





Pressure distribution

$$P(x) = Aq\left(\frac{Lx - x^2}{2w} + \frac{L}{S}\right)$$

Average pressure

$$< P >= Aq\left(\frac{L^2}{12w} + \frac{L}{S}\right)$$

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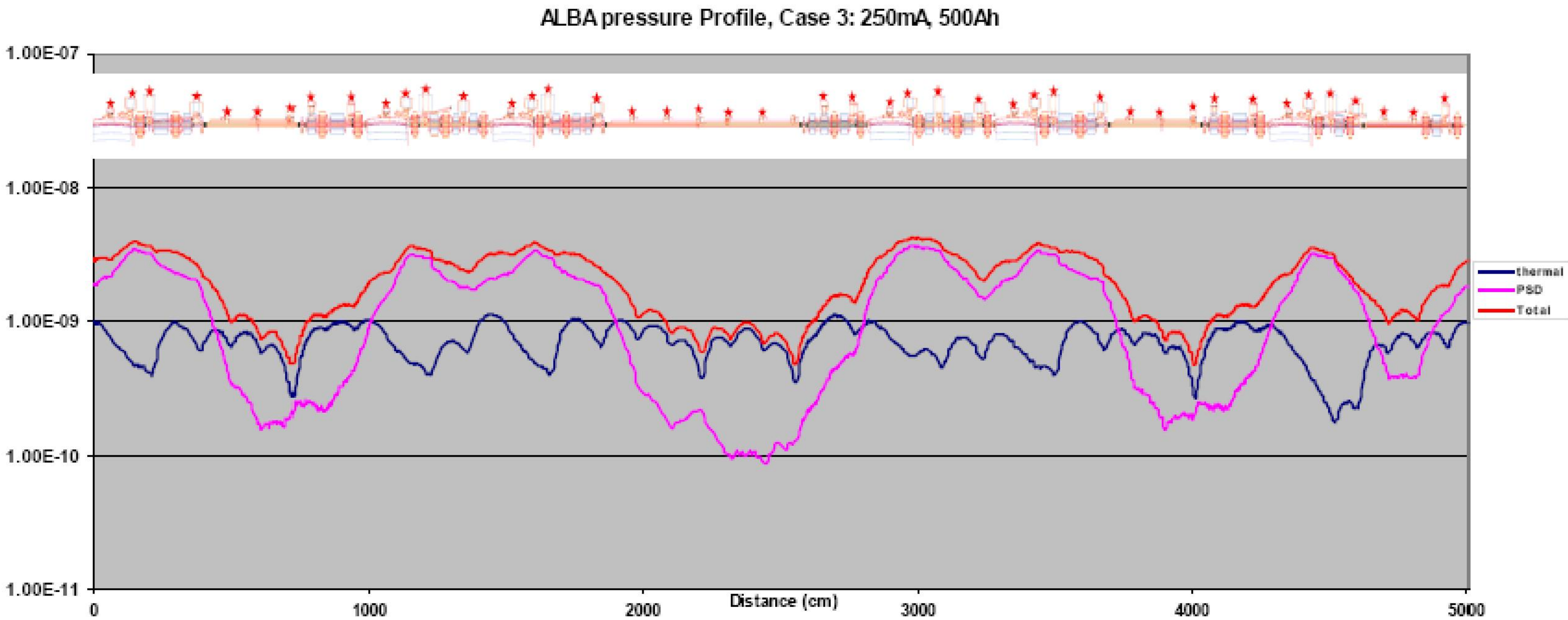
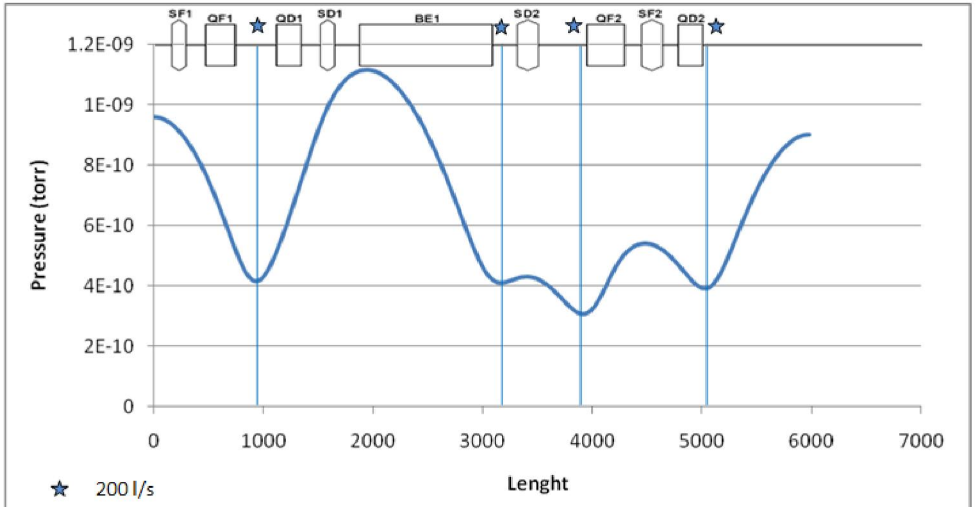
Models commonly used in the molecular gas flow regime

- Analytical 1D diffusion model (Knudsen-Clausing)
  - analytic method (Diamond)
  - Transfer matrix (SLAC)
  - finite difference (VACALC)
- Continuity principle of gas flow (CpoGF)
- Three-dimension (3D) Test Particle Monte-Carlo (TPMC)
  - The most accurate vacuum system modeling
  - MOLFLOW (R. Kersevan)
  - time consuming:
    - building the TPMC model
    - Modifying
    - calculations

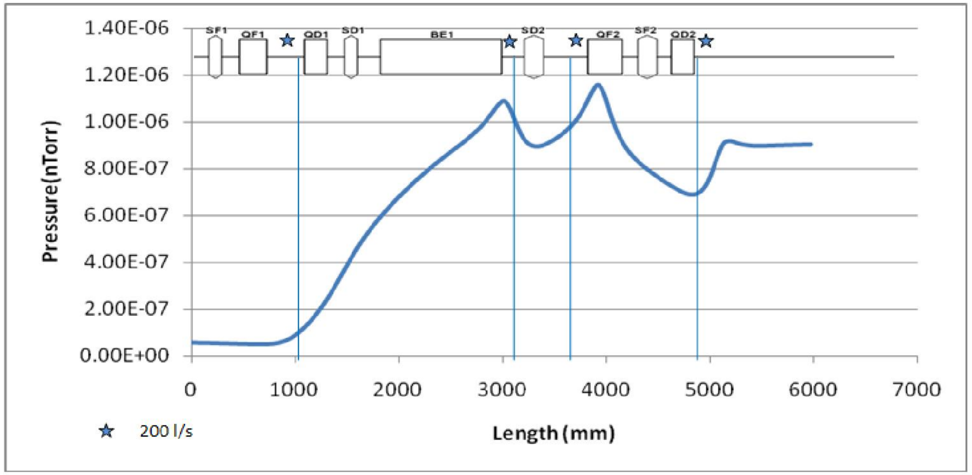
Pressure profile calculation



Pressure profile calculation

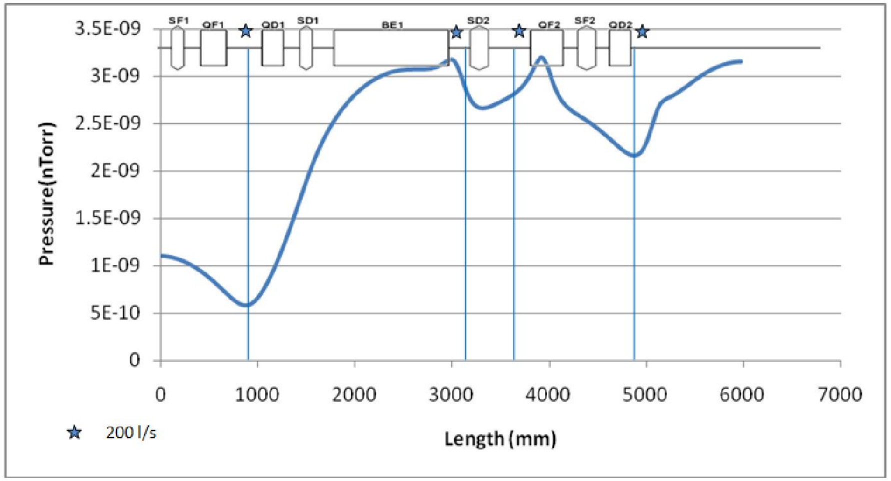


Base pressure of 6m of storage ring.

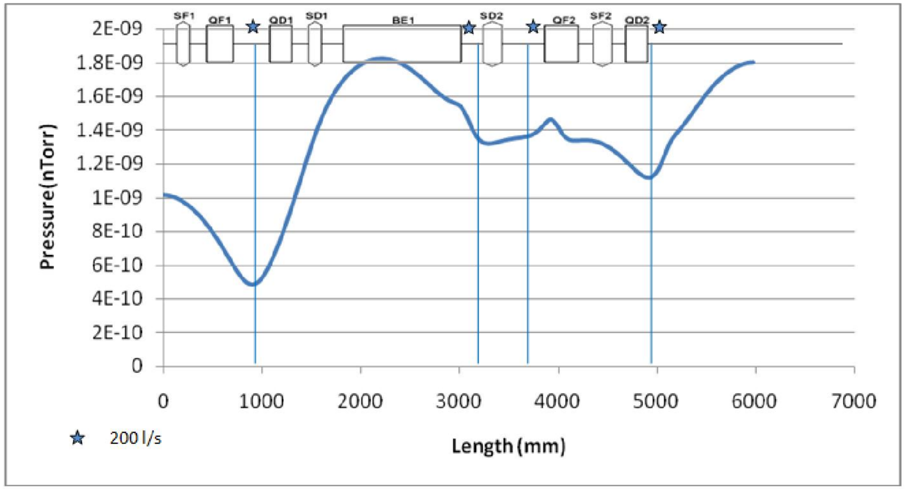


Pressure profile of 6 m of storage ring, first injection

Pressure profile calculation

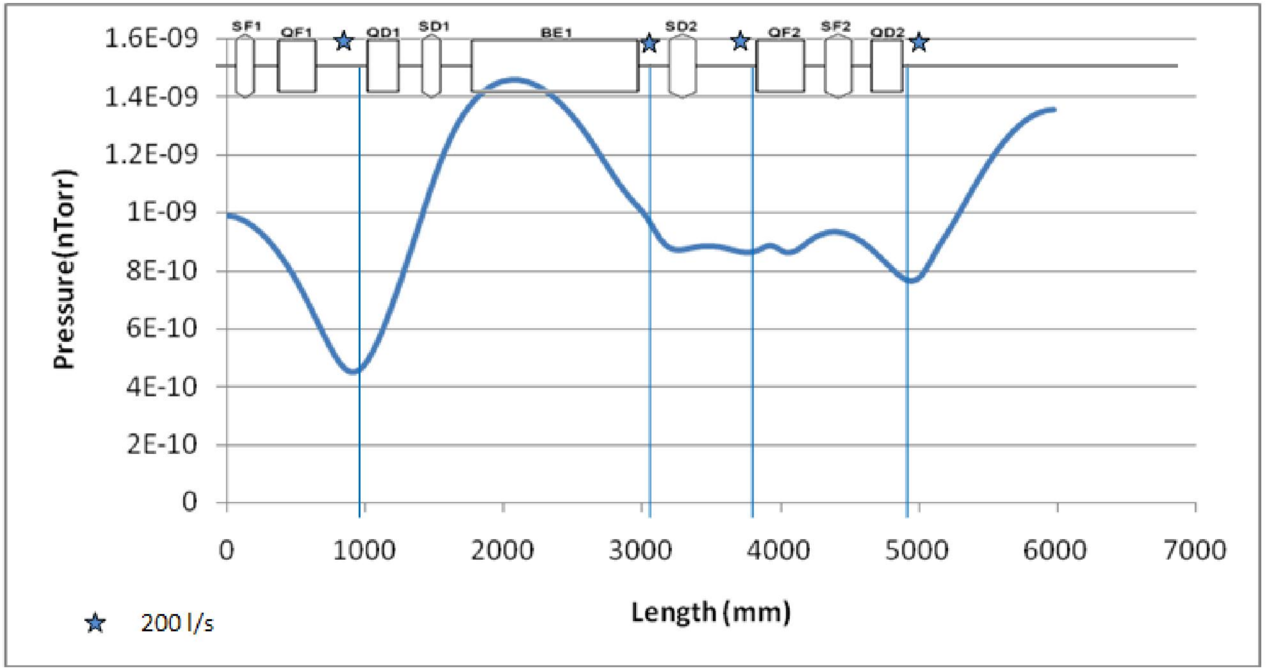


Pressure profile of 6 m of storage ring, (100mA, 100Ah).



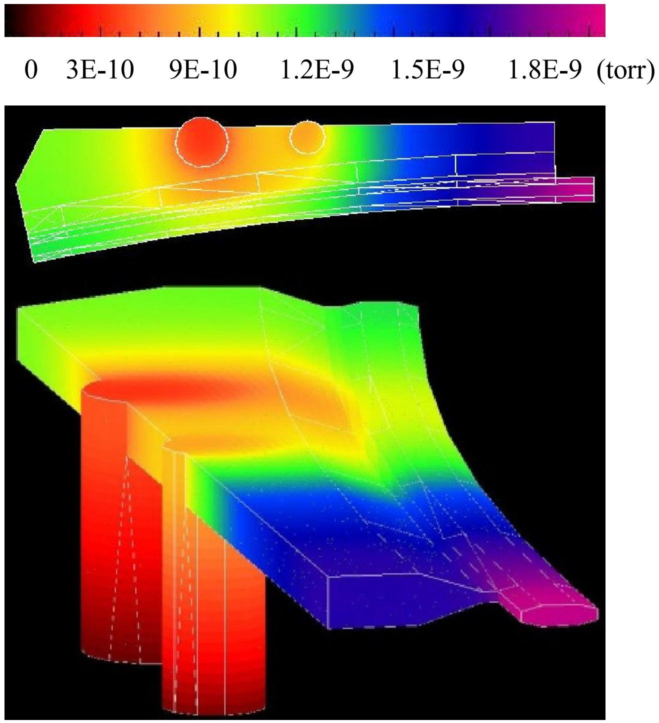
Pressure profile of 6 m of storage ring, (250mA, 500Ah).

Pressure profile calculation

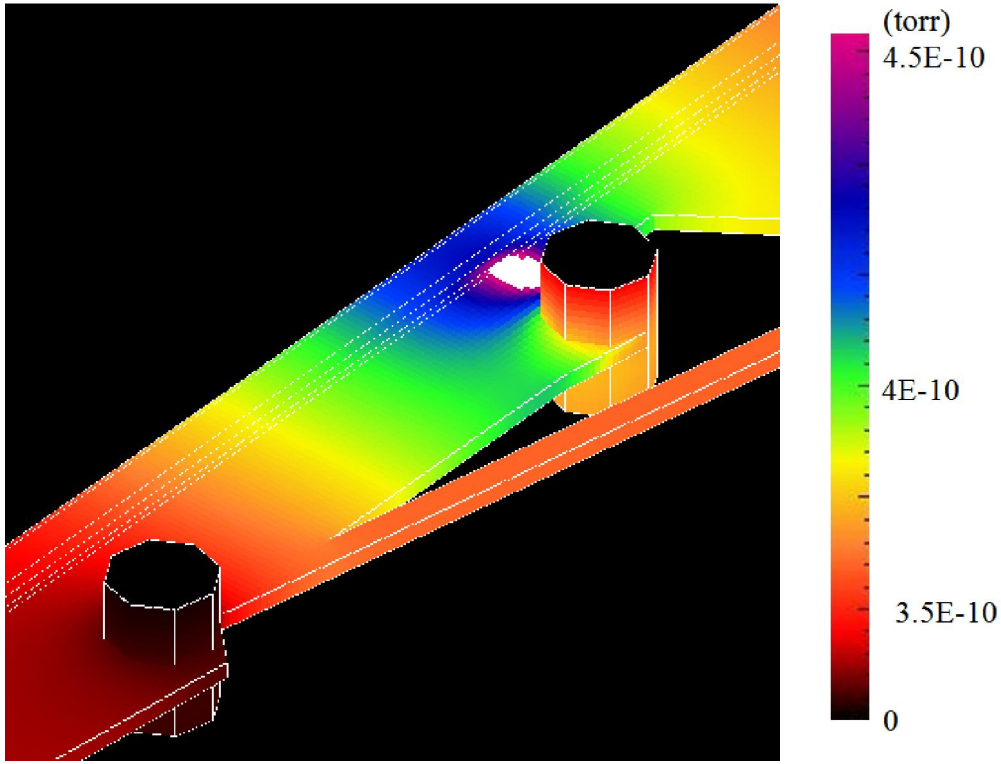


Final Pressure profile of 6 m of storage ring, (400mA, 1000Ah).

Pressure textures



pressure texture of dipole vacuum chamber



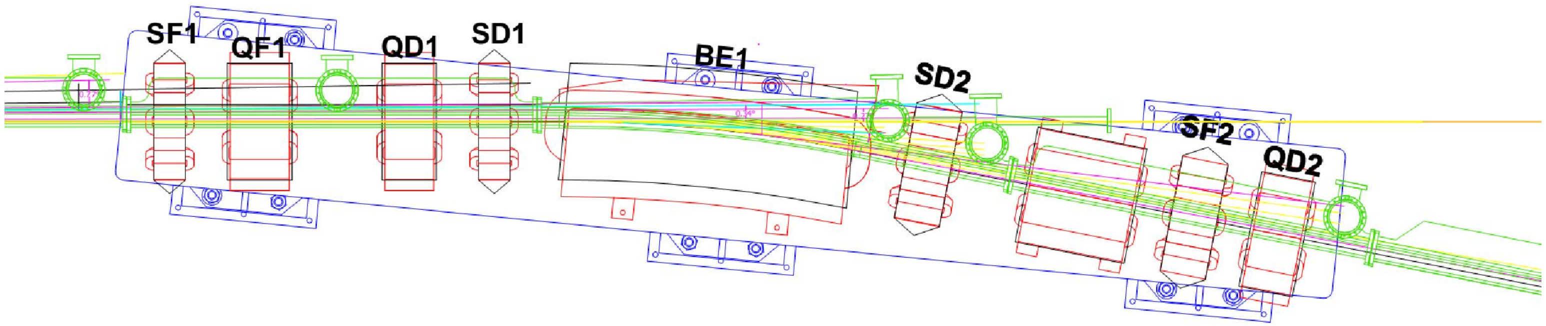
Pressure texture induced by ABS12

Ray tracing for SR of the bending magnets on the horizontal plane

the clearance between vacuum chamber and rays stay at least 5 mm

we use :

- two in house computer codes
- a detailed drawing



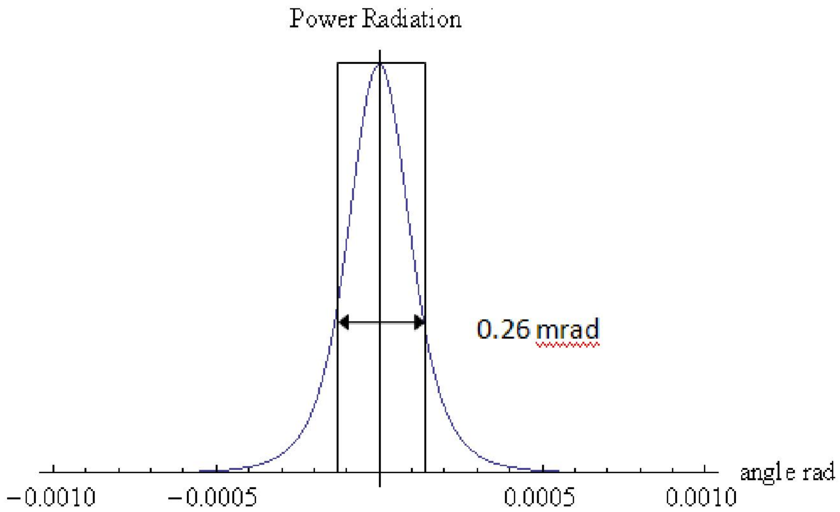
Ray tracing for SR of the bending magnets on the vertical plane

$$P_\gamma = \tfrac{2}{3} r_c mc^2 \frac{c\,\beta^4\gamma^4}{\rho^2},$$

$$P_\gamma(\mathrm{MW}) = C_\gamma \frac{E^4(\mathrm{GeV})}{\rho(\mathrm{m})} I(\mathrm{A})\,.$$

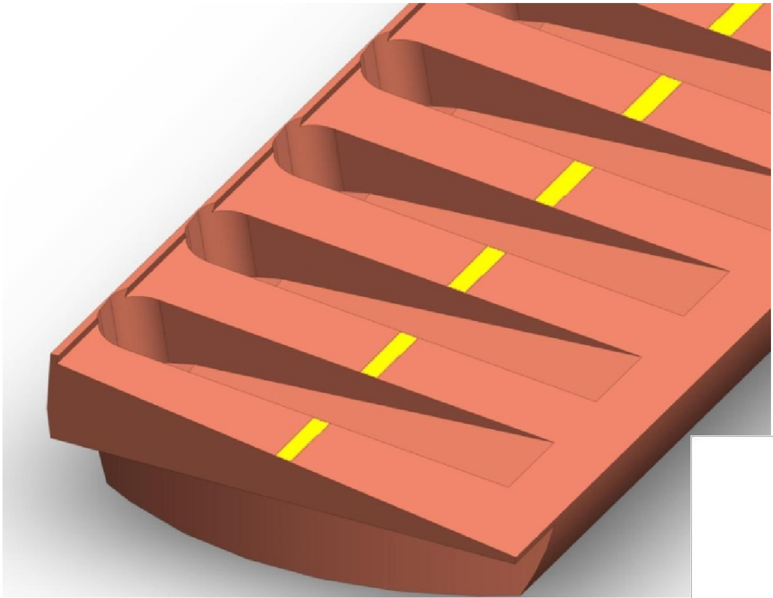
$$C_\gamma = \frac{4\pi}{3}\frac{r_c}{(mc^2)^3} = 8.8575 \times 10^{-5}\ \mathrm{m/GeV^3}\,.$$

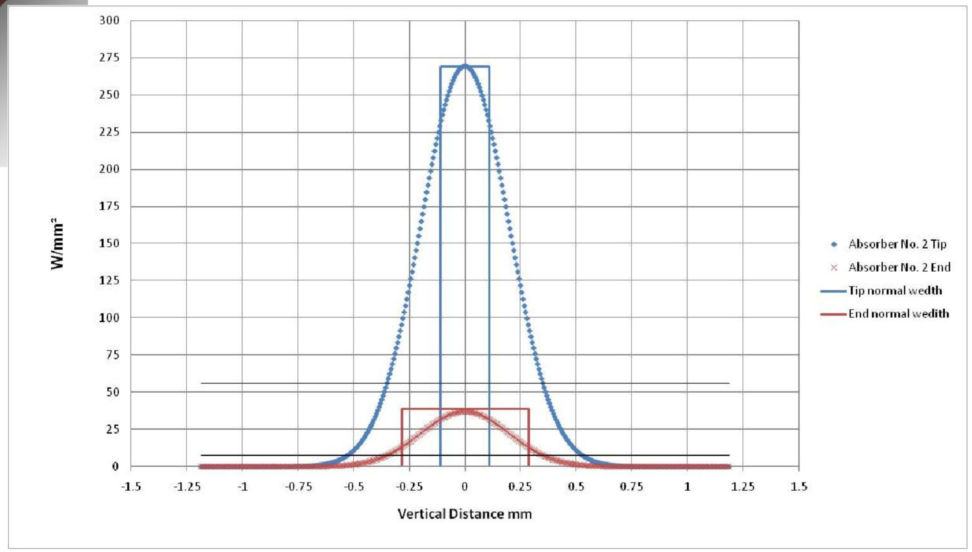
$$\frac{\mathrm{d}P_\gamma}{\mathrm{d}\Omega} = \frac{21}{32}\frac{P_\gamma}{2\pi}\frac{\gamma}{(1+\gamma^2\theta^2)^{5/2}}\left(1+\frac{5}{7}\frac{\gamma^2\theta^2}{1+\gamma^2\theta^2}\right)\,.$$



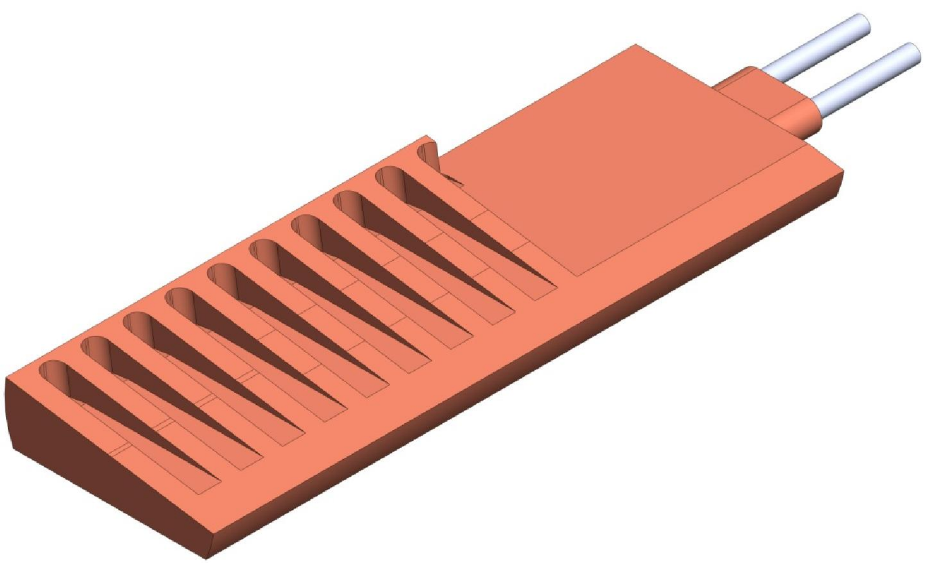
total opening angle in our case is 0.26 mrad

Widths of collision cross section

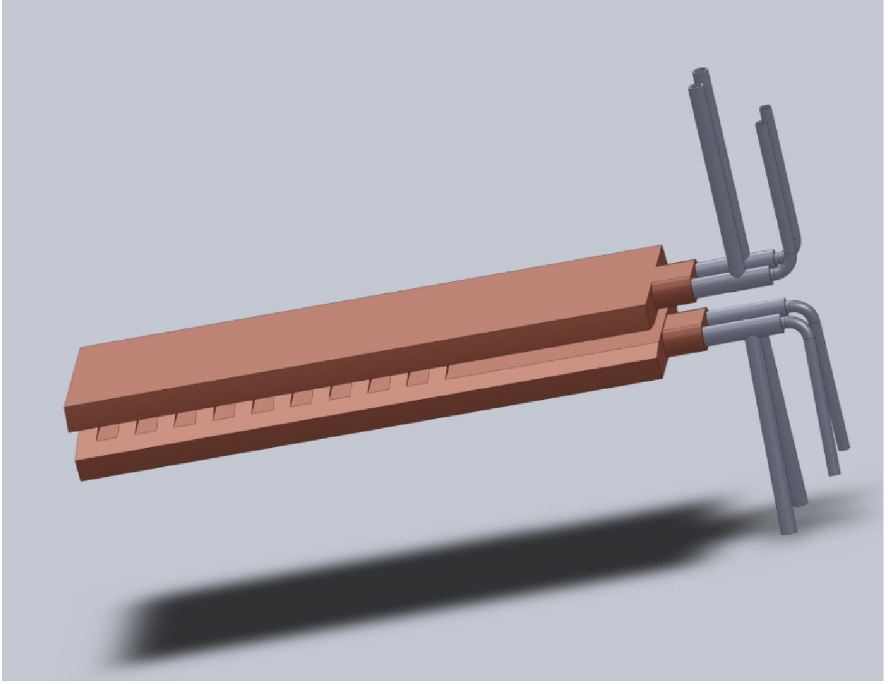




Absorbers

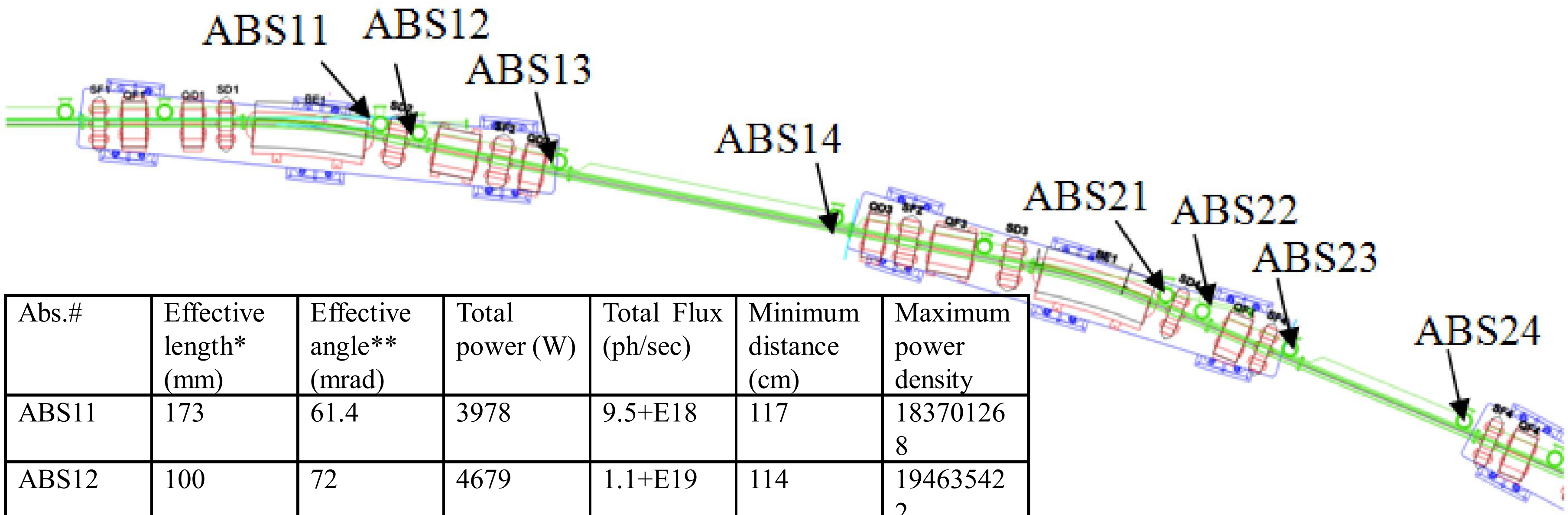


3D model of lower jaw of ABS11



3D model of ABS11

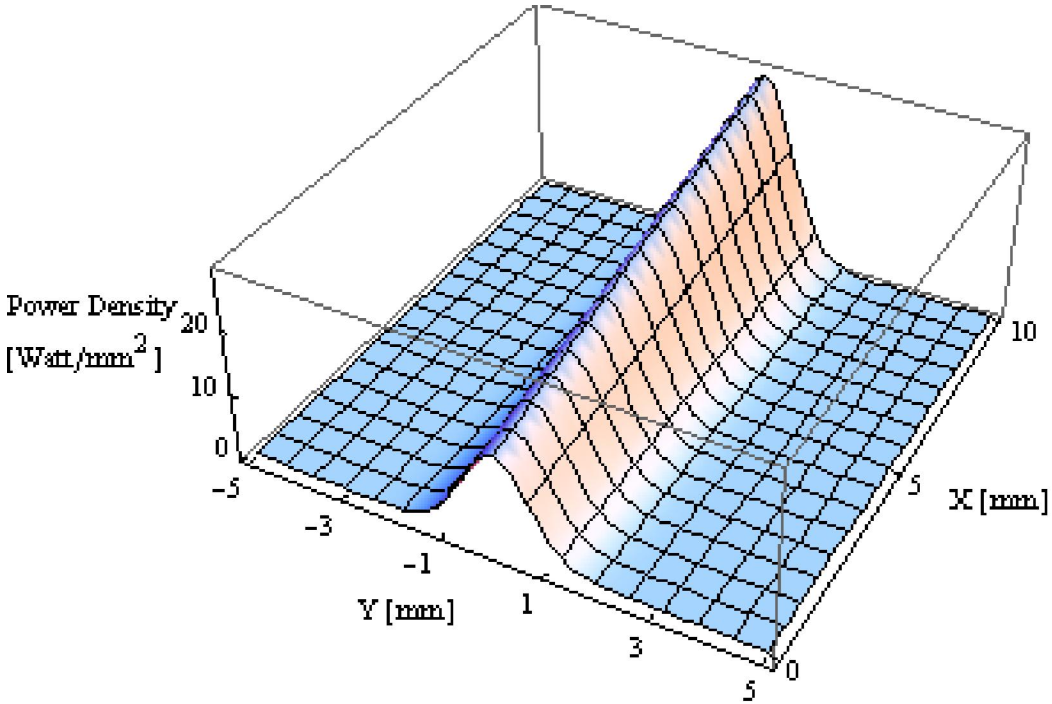
Absorbers



Abs.#	Effective length* (mm)	Effective angle** (mrad)	Total power (W)	Total Flux (ph/sec)	Minimum distance (cm)	Maximum power density
ABS11	173	61.4	3978	9.5+E18	117	183701268
ABS12	100	72	4679	1.1+E19	114	194635422
ABS13	117	43	2796	6.7+E18	256	38584724
ABS14	96	16.2	1050	2.5+E18	588	7327407

* Length of absorber exposed to synchrotron radiation
** Angle of radiation fan incident absorber

Absorbers



Real power density on ABS12

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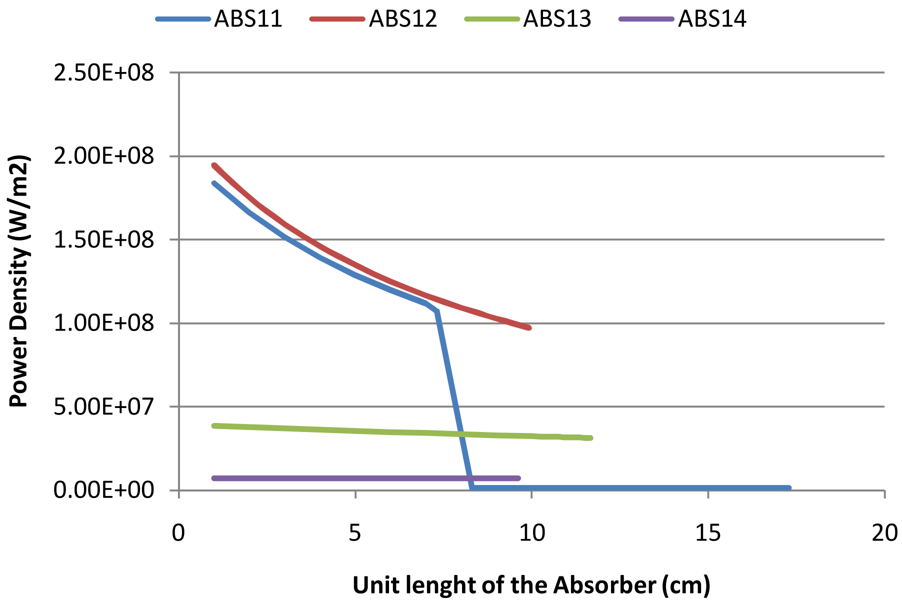
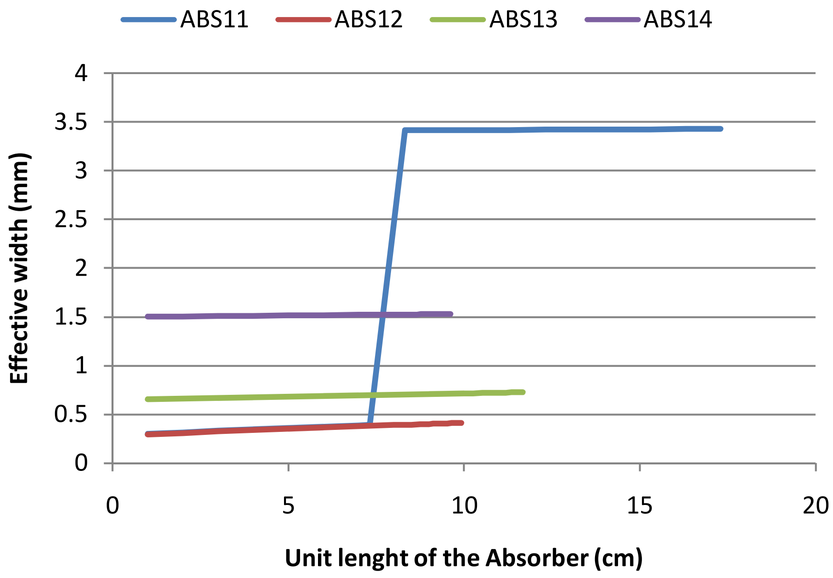
Absorbers

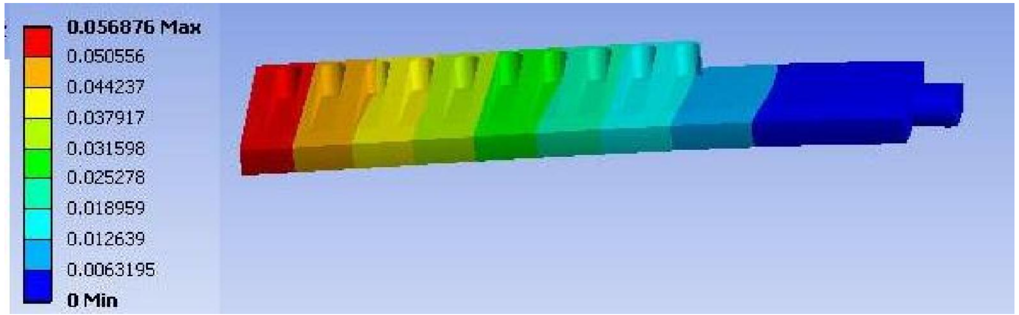


power density along absorbers of the first block

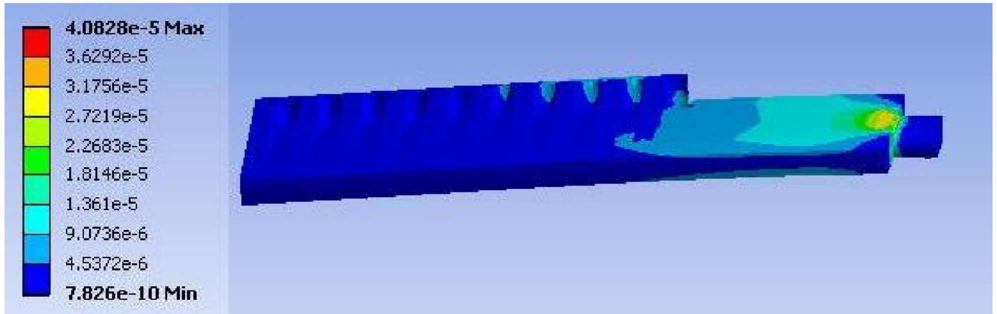


effective width along absorbers of first block

Absorbers (Analysis)

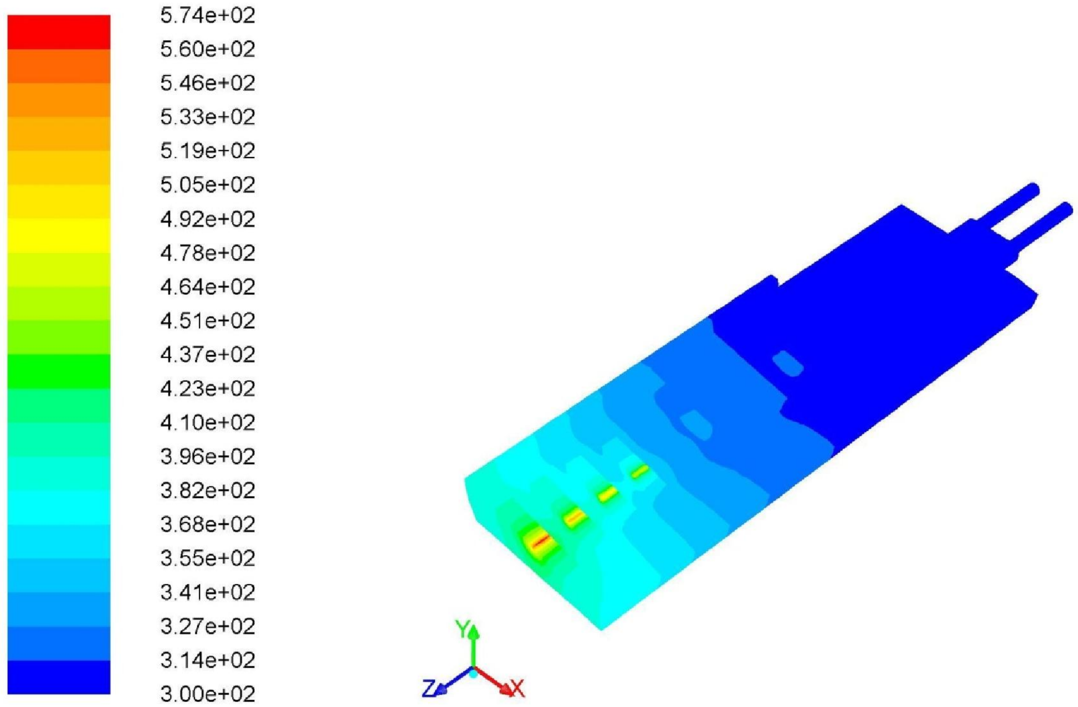


FEA result for crotch absorber kind ABS11, deformation of lower jaw due to gravity

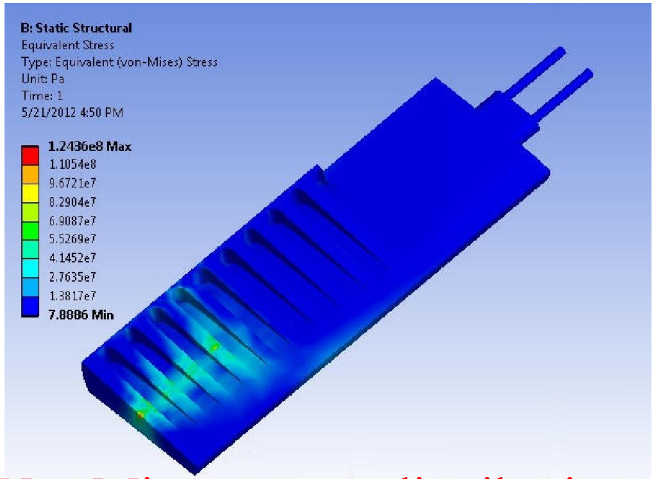


FEA result for crotch absorber kind ABS11, stress in lower jaw due to gravity

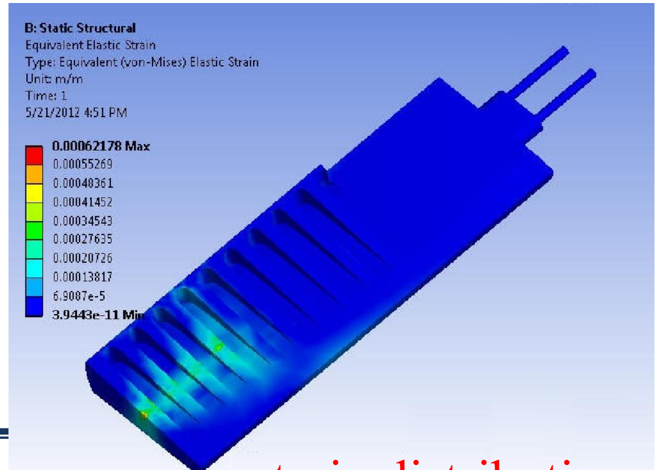
FEA result for crotch absorber kind ABS11 in lower jaw



Thermal distribution

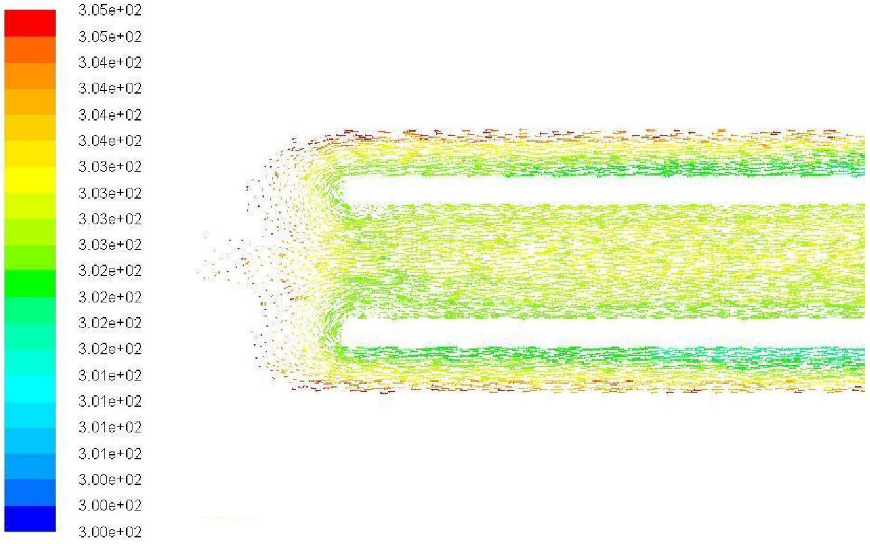


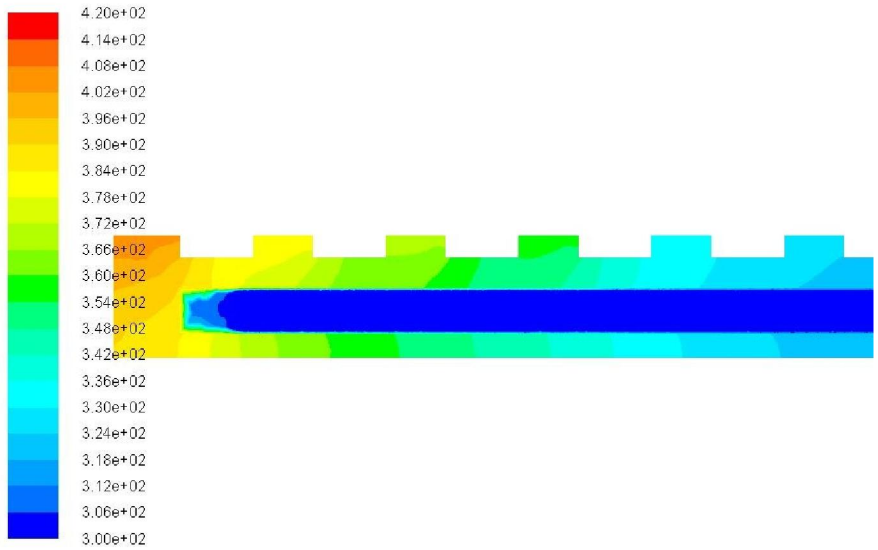
Von Misses stress distribution



strain distribution

FEA result for crotch absorber kind ABS11 in lower jaw

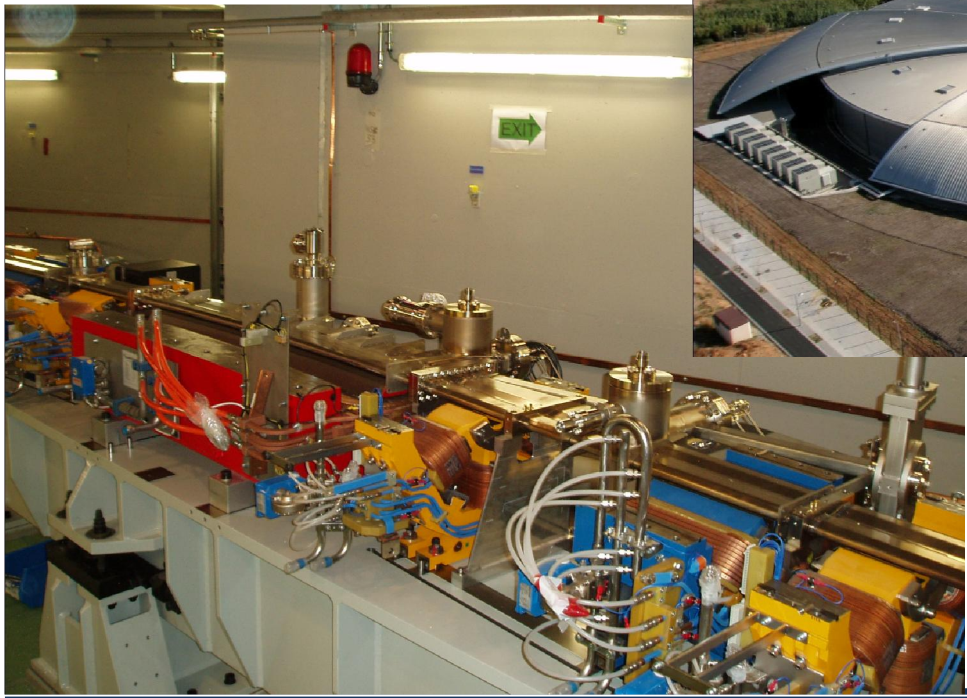




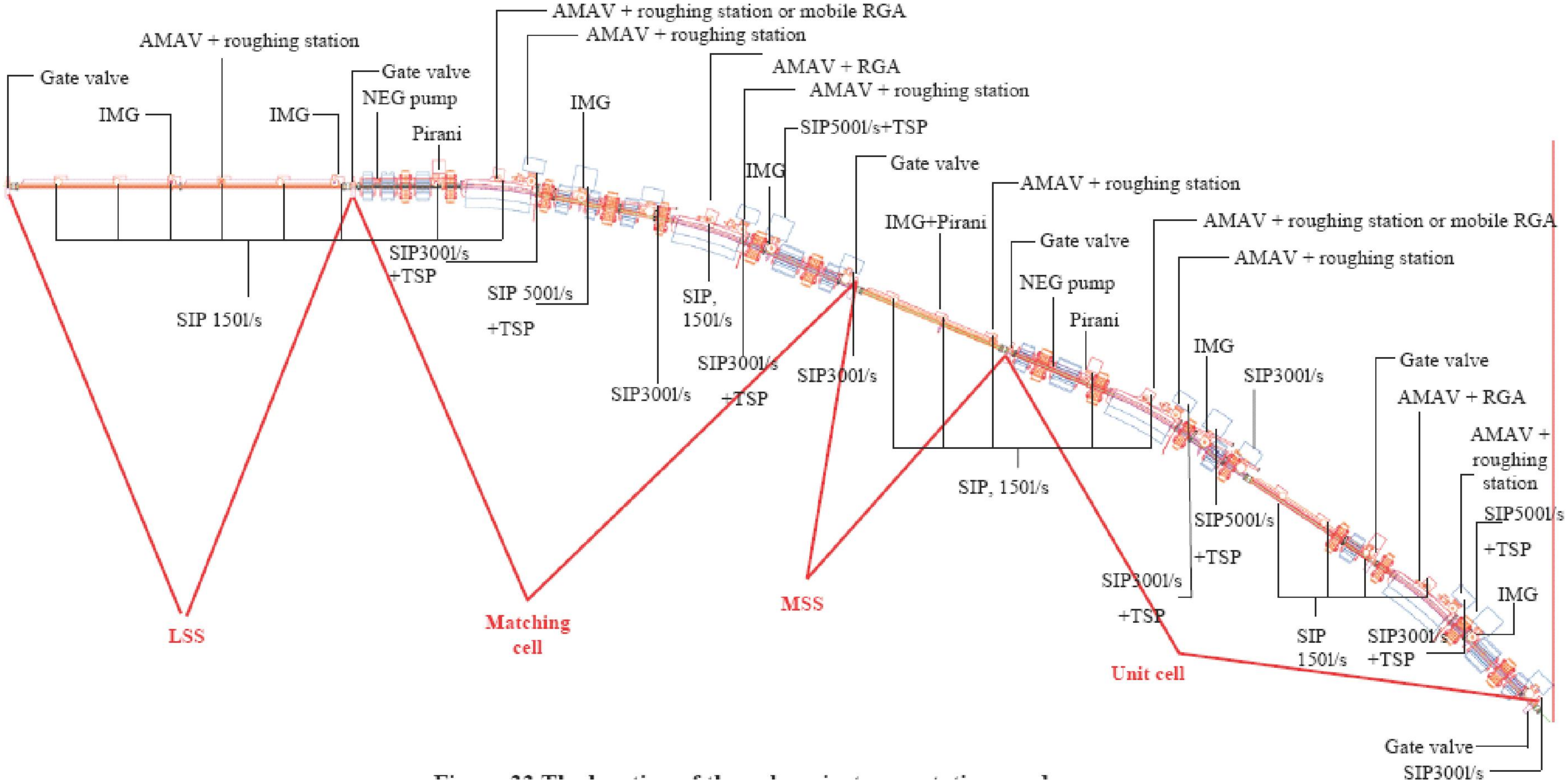
Water flow in pipe of absorber ABS11

Temperature distribution in ABS11

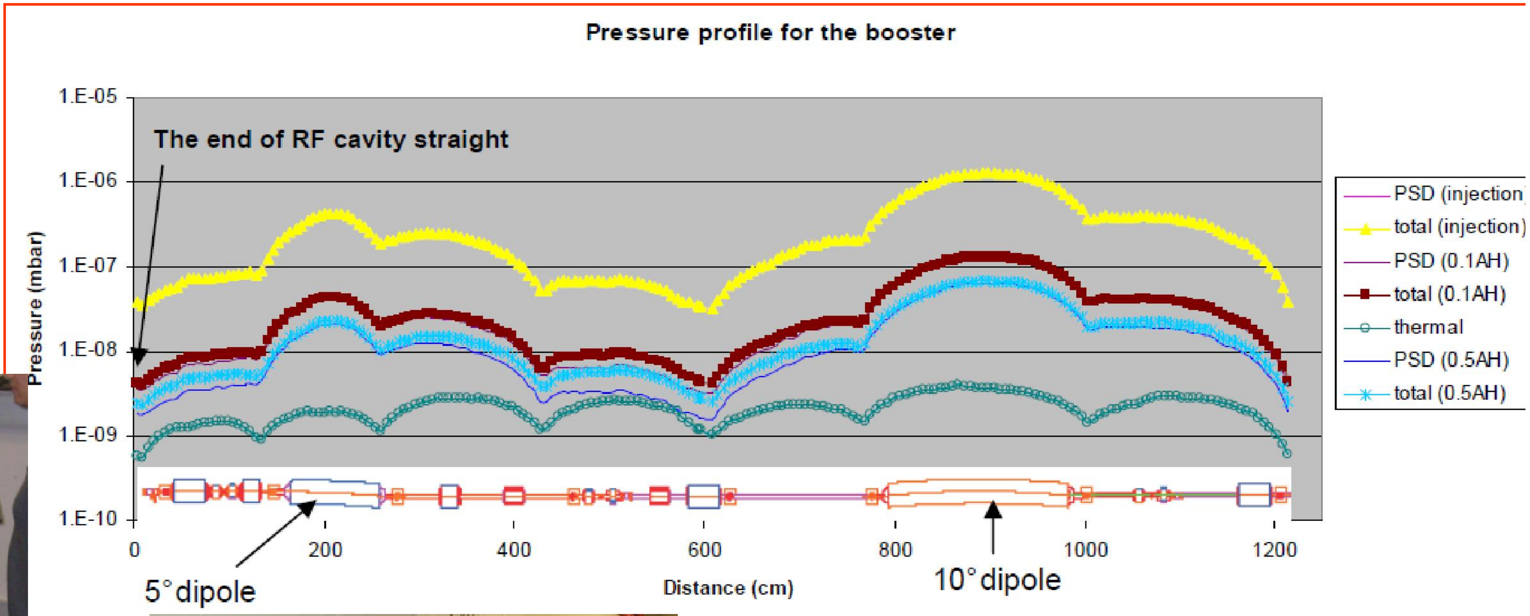
The vacuum system of the Spanish Light source ALBA



ALBA Vacuum system



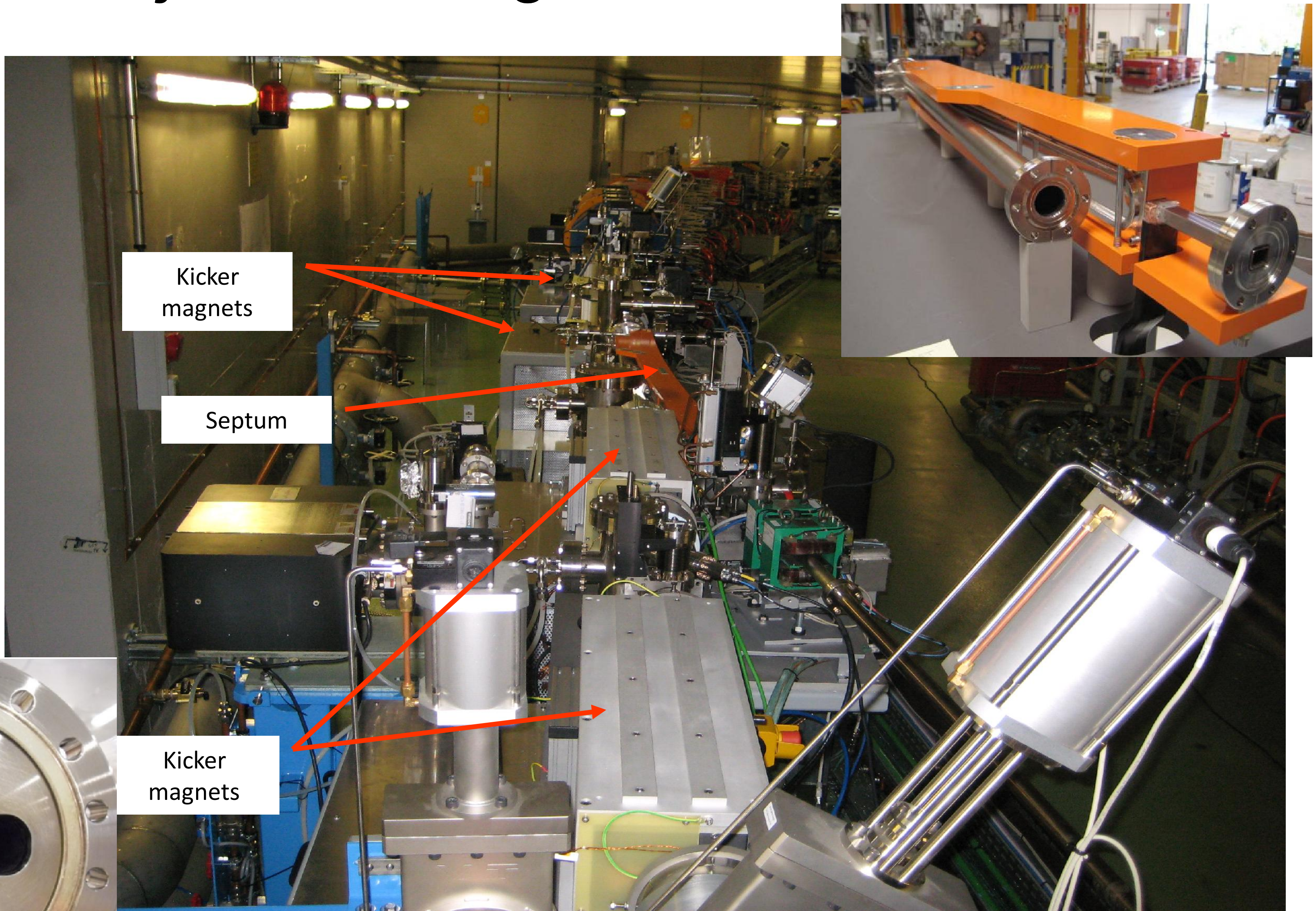
Booster



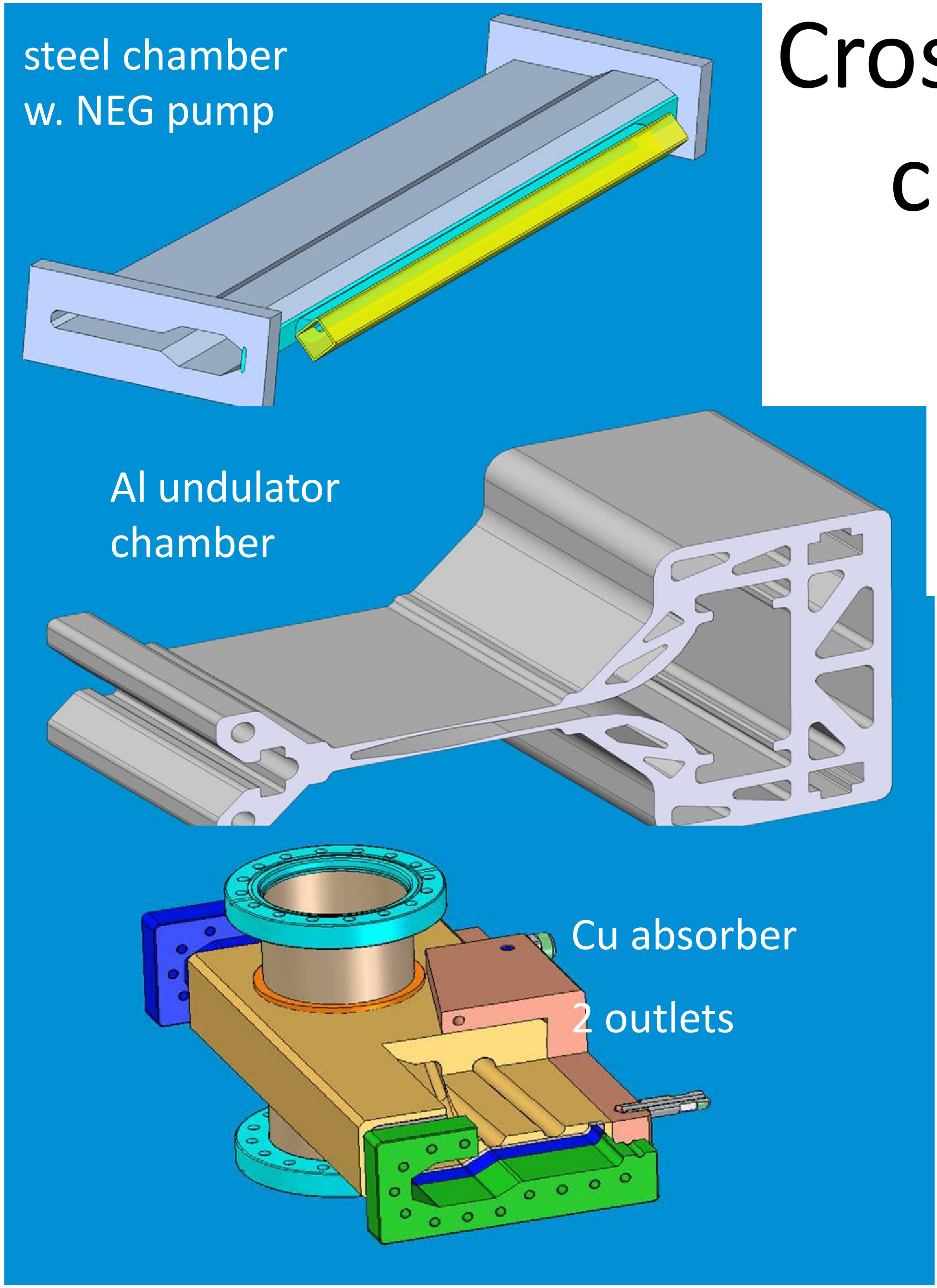
Pressure profile for the booster
The end of RF cavity straight
Pressure (mbar)
1.E-05
1.E-06
1.E-07
1.E-08
1.E-09
1.E-10
0
200
400
600
800
1000
1200
Distance (cm)
5° dipole
10° dipole
PSD (injection)
total (injection)
PSD (0.1AH)
total (0.1AH)
thermal
PSD (0.5AH)
total (0.5AH)

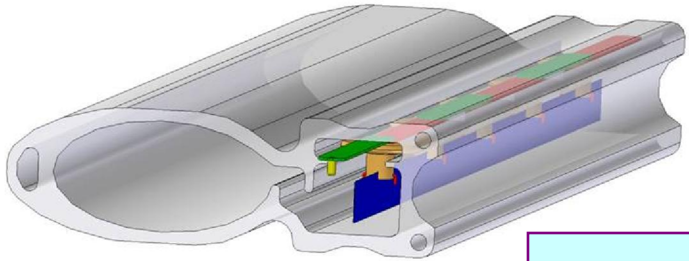
Q03

Injection straight installation



Cross Sections of vacuum chambers: PETRA III

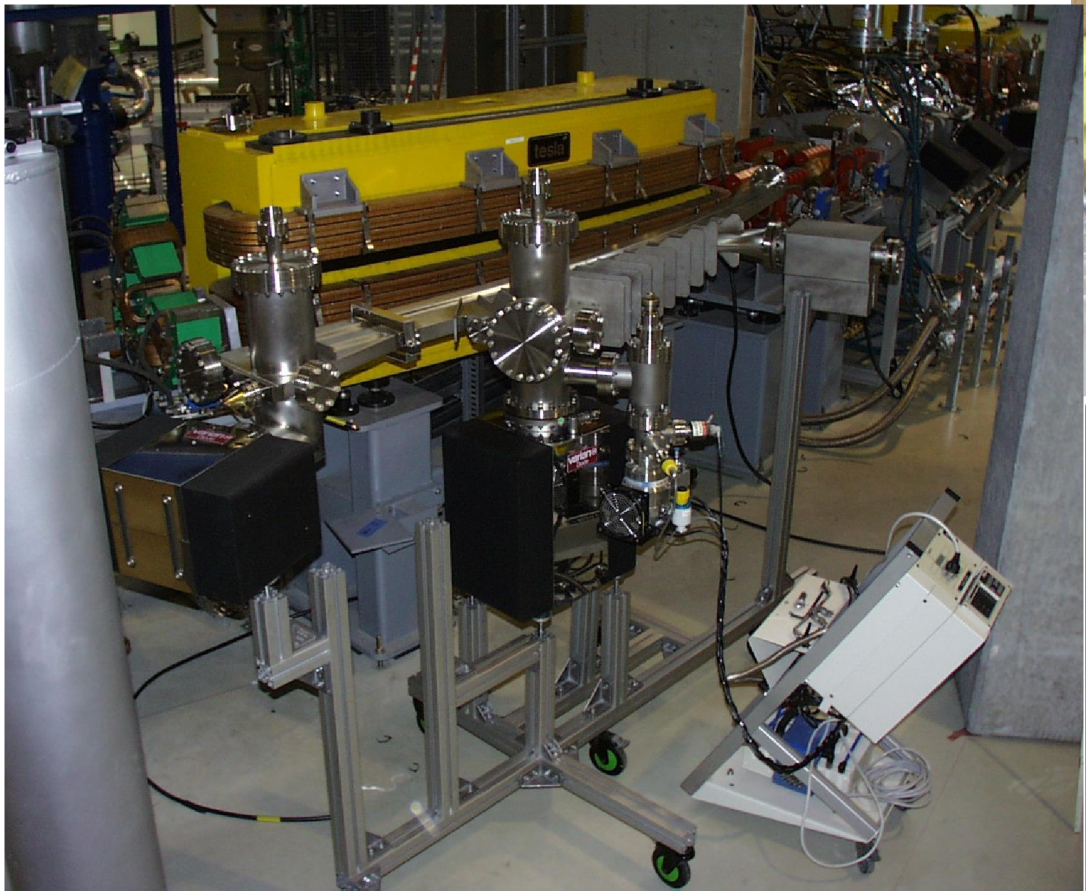




pumped via

NEG strip

ANKA vacuum system



ASP Vacuum System

Thank for your attention