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Vacuum acceptance tests for particle accelerator equipment

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LABORATORY

Vacuum for Particle Accelerators
Glumslöv, Sweden, 6 - 16 June, 2017

Outline

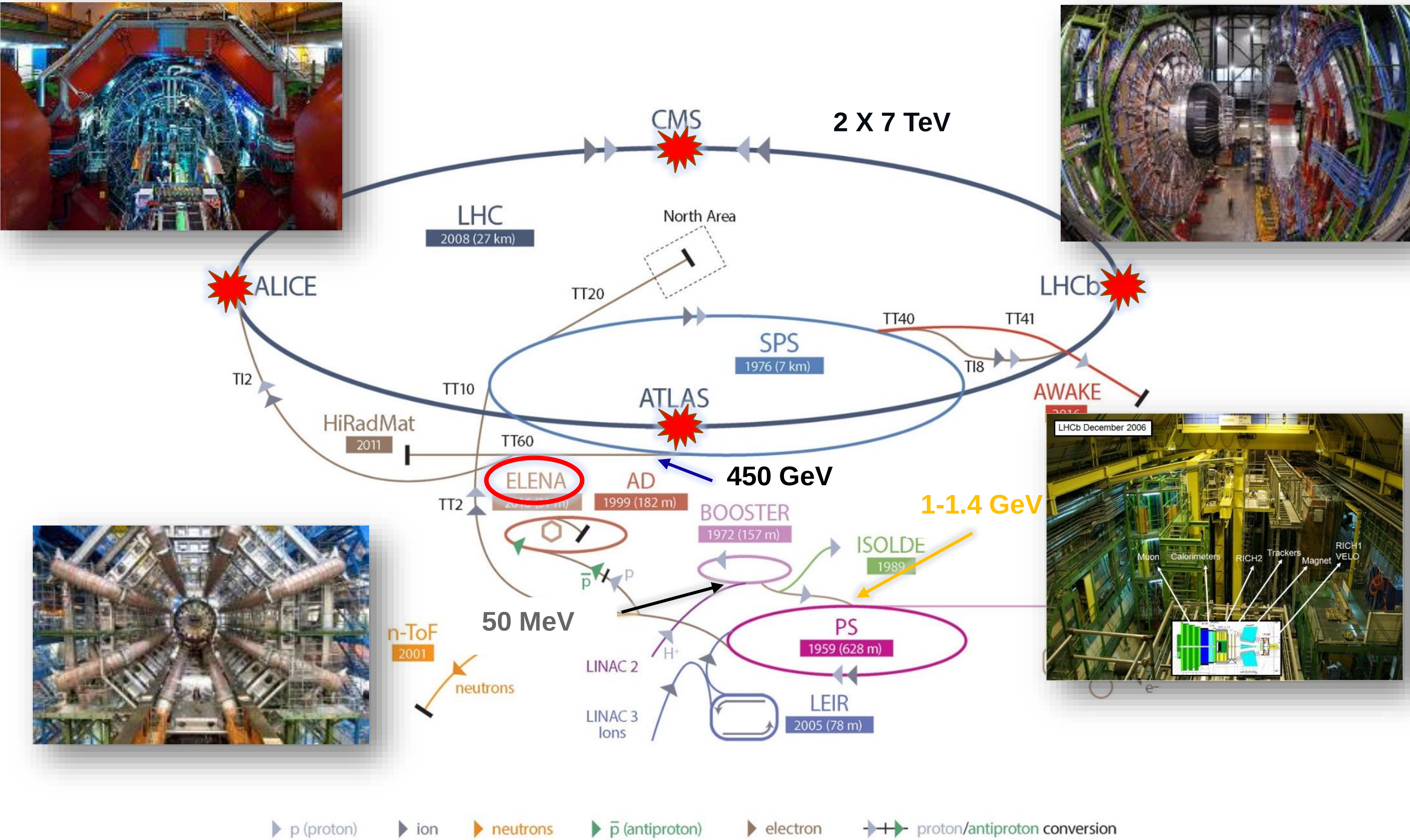
1. **The CERN accelerator complex**
2. **Vacuum requirements evolution: An historical example**
3. **Acceptance thresholds**
4. **Acceptance tests procedures:**
   - **Unbaked system**
     - **Example of polymeric component**
     - **Partially baked equipment**
   - **Baked system**
     - **Low outgassing but not conform RGA**
   - **Non Evaporable Getter (NEG) coating qualification**
5. **Conclusions & Advices**
6. **Additional slides: Some special needs and examples:**
   - **Beam induced effects: ESD & PSD cases**
   - **New sintered materials**
   - **Glues vs. NEG**

Why Vacuum Acceptance Tests?

1. One of the main mandates of the CERN Vacuum Surfaces Coatings group is to provide the beam operation with a required vacuum level on all the accelerator complex.

2. To achieve that mandate, acceptance tests are needed to assess the compatibility of all pieces of equipment to be installed in the beam vacuum system of the accelerator complex:
   - Leak tightness.
   - Detection of contamination.
   - Measurement of outgassing rate and its time variation.
   - Measurement of virtual leaks (in leakage).

CERN accelerators chain



LINAC 2

LINAC 2: 39 Years old

LINAC 2 started up in 1978 when it replaced LINAC 1. It was originally built to allow higher intensity beams for the accelerators that follow it in CERN's accelerator complex. LINAC 2 will be replaced by LINAC 4 in 2020.

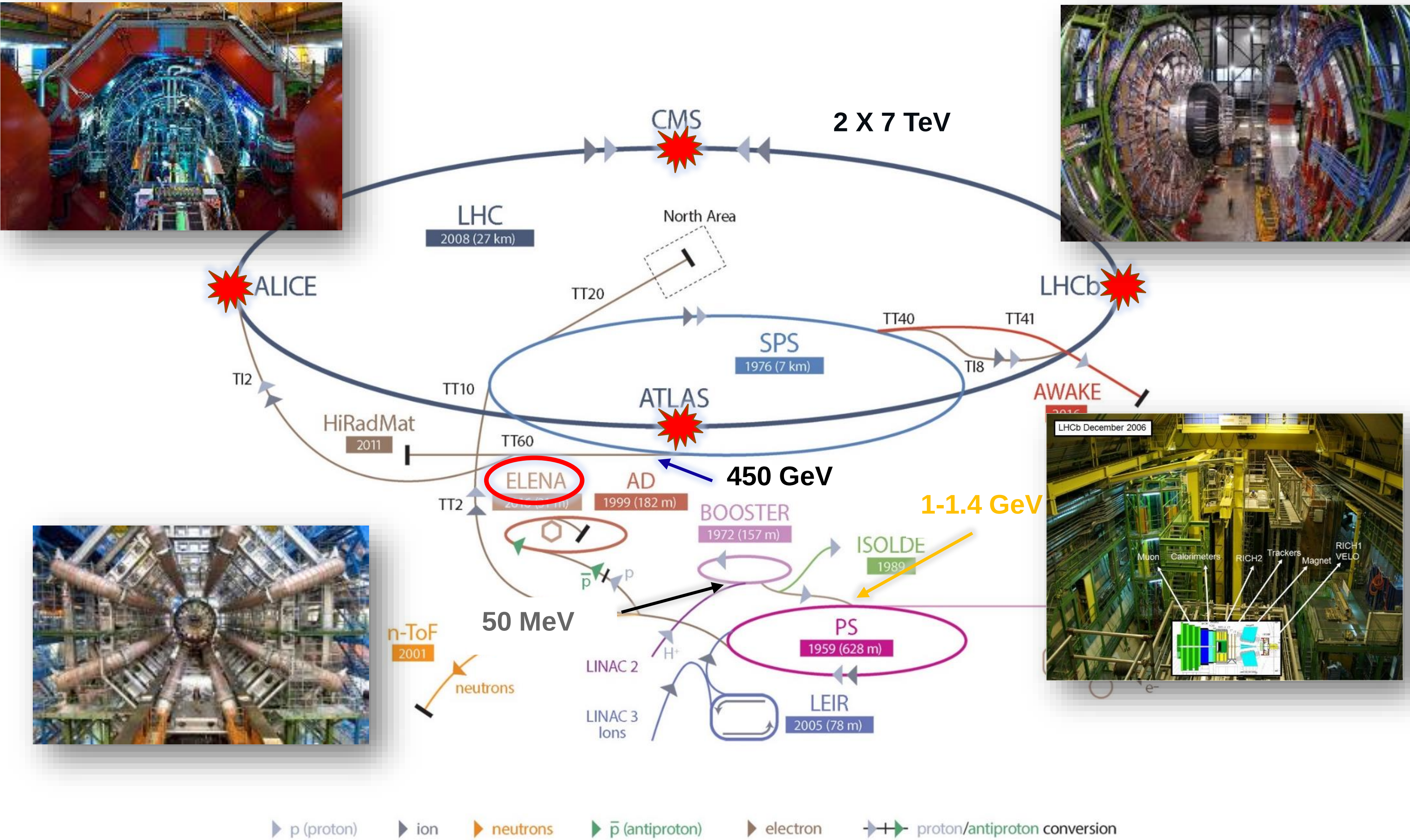
Unbaked system

$P_{Limit} < 2x10^{-6}$ mbar*

ENERGY: Linac 50 MeV

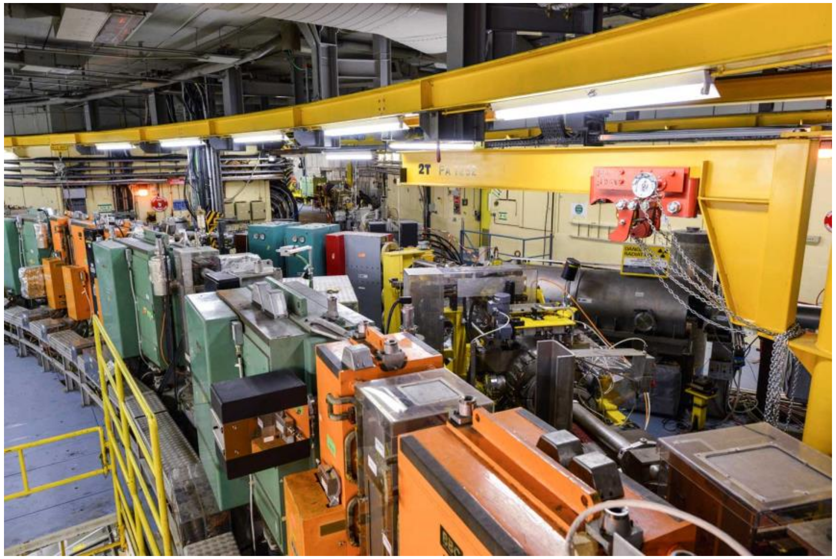
* After 24 h pump down

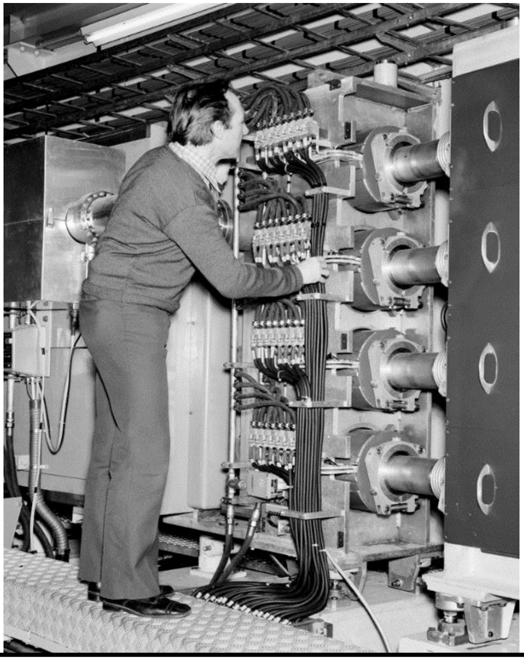
CERN accelerators chain



PS Booster

The Proton Synchrotron Booster is made up of four superimposed synchrotron rings that receive beams of protons from the linear accelerator Linac 2 at 50 MeV and accelerate them to 1.4 GeV for injection into the Proton Synchrotron (PS).





PS Booster: 45 Years old

Unbaked system

$P_{Limit} < 5x10^{-8}$ mbar* for ions run

* After 24 h pump down

Proton Synchrotron

ENERGY:

PS 25 GeV

The PS first accelerated protons on 24 November 1959, becoming for a brief period the world's highest energy particle accelerator

The Proton Synchrotron (PS) is a key component of CERN's accelerator complex, where it usually accelerates either proton delivered by the Proton Synchrotron Booster or heavy ions from the Low Energy Ion Ring (LEIR).

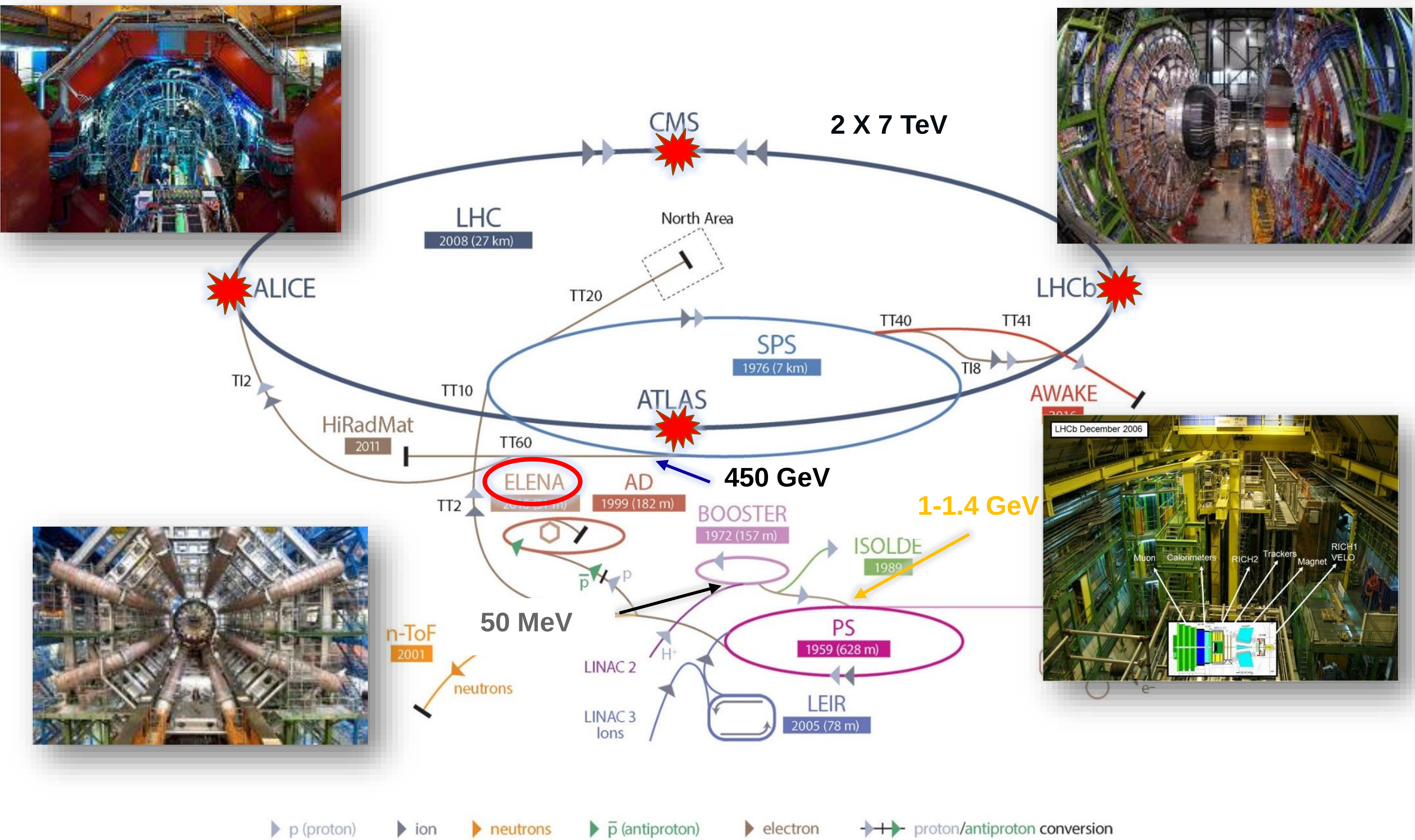
With a circumference of 628 metres, the PS has 277 conventional (room-temperature) electromagnets, including 100 dipoles to bend the beams round the ring. The accelerator operates at up to 25 GeV.

Unbaked system

$P_{Limit} < 2x10^{-8}$ mbar* for ions run

* After 24 h pump down

CERN accelerators chain



Super Proton Synchrotron

Unbaked system
$P_{Limit} < 1x10^{-7}$ mbar*

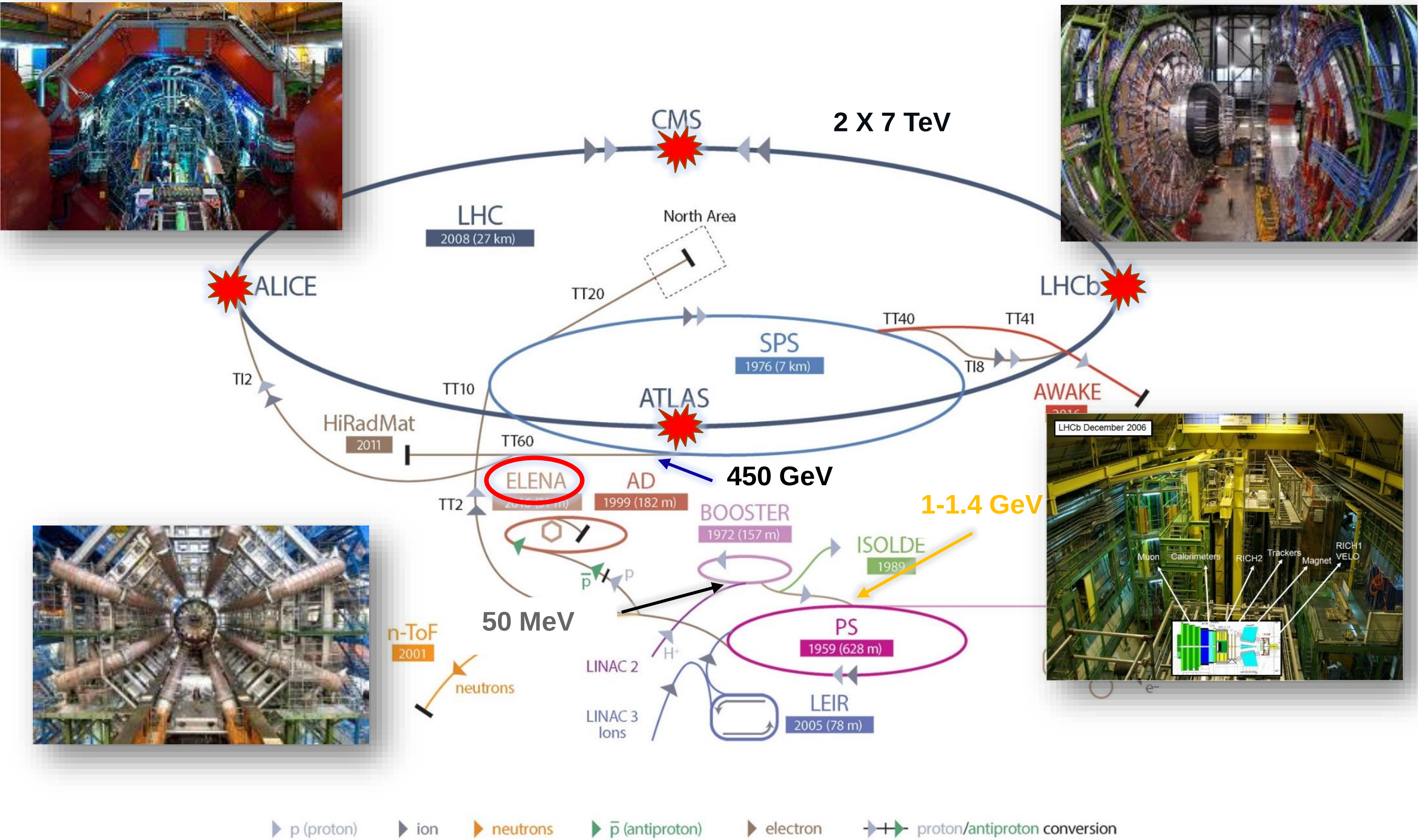
ENERGY: SPS 450 GeV

Seven kilometres in circumference, the Super Proton Synchrotron (SPS) was the first of CERN's giant underground rings. It was also the first accelerator to cross the Franco–Swiss border.
Eleven of CERN's member states approved the construction of the SPS in February 1971, and it was switched on for the first time on 17 June 1976, two years ahead of schedule.

The SPS operates at up to 450 GeV. It has 1317 conventional (room-temperature) electromagnets, including 744 dipoles to bend the beams round the ring

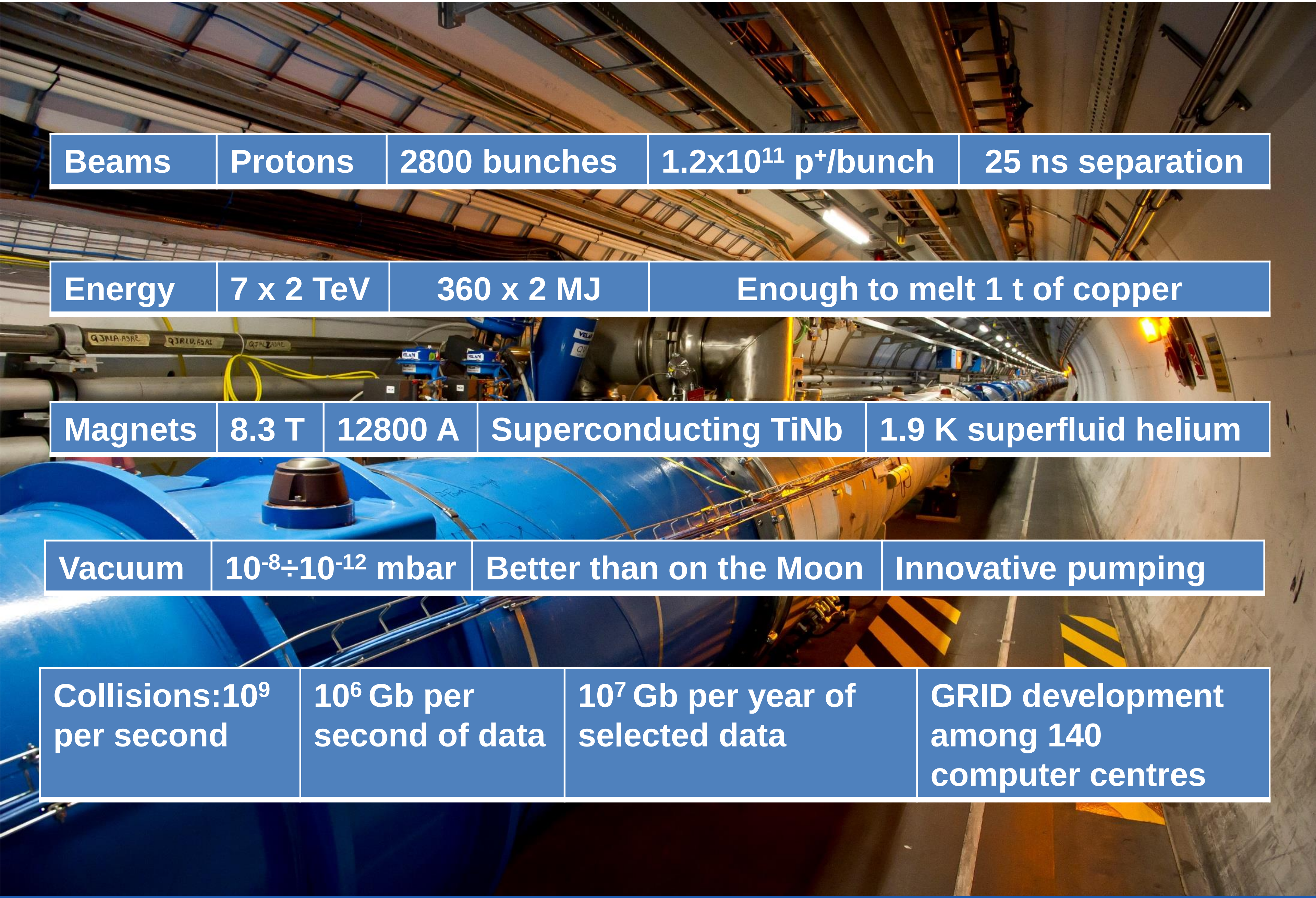
* After 24 h pump down

CERN accelerators chain



The Large Hadron Collider: LHC

At 10.28am on 10 September 2008, a beam of protons is successfully steered around the 27-kilometre Large Hadron Collider (LHC) for the first time. The machine is ready to embark on a new era of discovery at the high-energy frontier.
LHC experiments address questions such as what gives matter its mass, what the invisible 96% of the universe is made of, why nature prefers matter to antimatter and how matter evolved from the first instants of the universe's existence.



Beams	**Protons**	**2800 bunches**	**1.2×10^{11} p^+/bunch**	**25 ns separation**

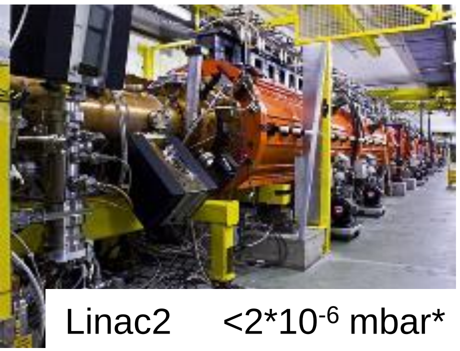
Energy	**7 x 2 TeV**	**360 x 2 MJ**	**Enough to melt 1 t of copper**

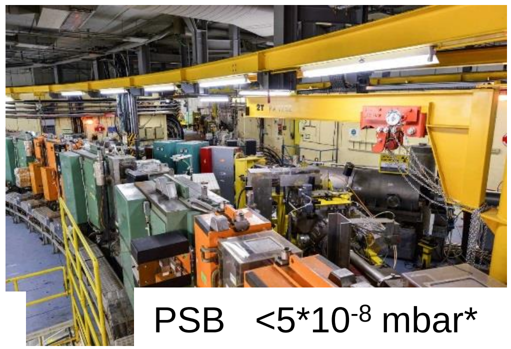
Magnets	**8.3 T**	**12800 A**	**Superconducting TiNb**	**1.9 K superfluid helium**

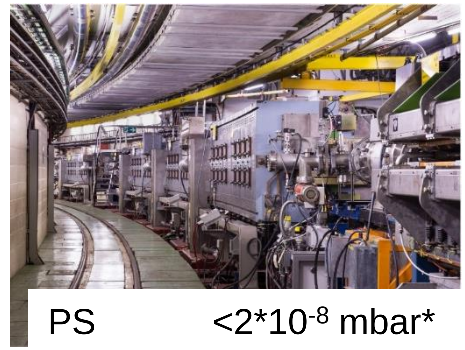
Vacuum	**10^{-8}÷10^{-12} mbar**	**Better than on the Moon**	**Innovative pumping**

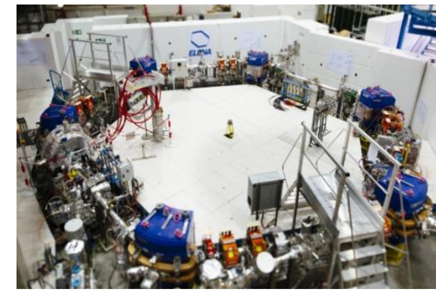
Collisions:10^9 per second	**10^6 Gb per second of data**	**10^7 Gb per year of selected data**	**GRID development among 140 computer centres**

CERN accelerators chain: vacuum systems and requirements

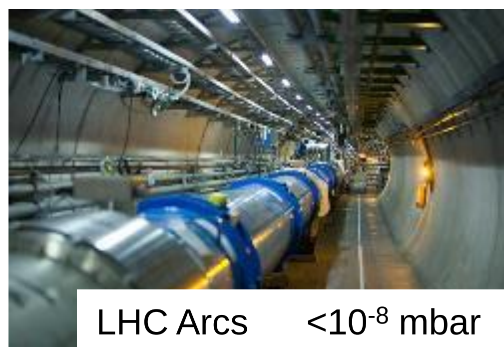

Linac2 $<2*10^{-6}$ mbar*

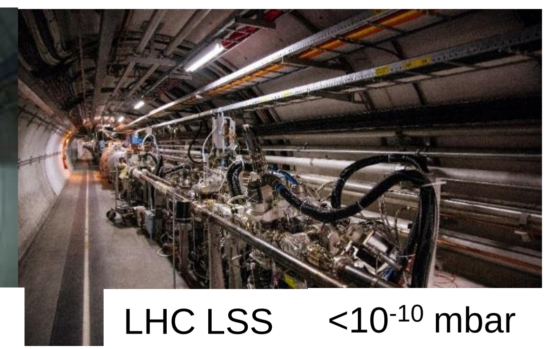

PSB $<5*10^{-8}$ mbar*


PS $<2*10^{-8}$ mbar*


ELENA ring $<4*10^{-12}$ mbar

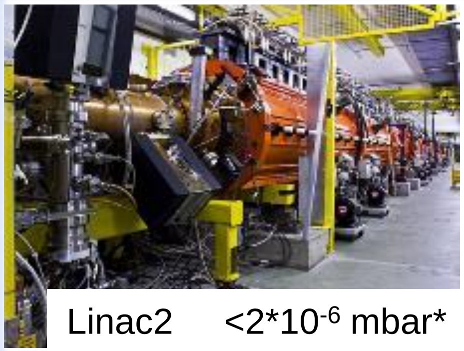

SPS LSS $<10^{-7}$ mbar*


LHC Arcs $<10^{-8}$ mbar

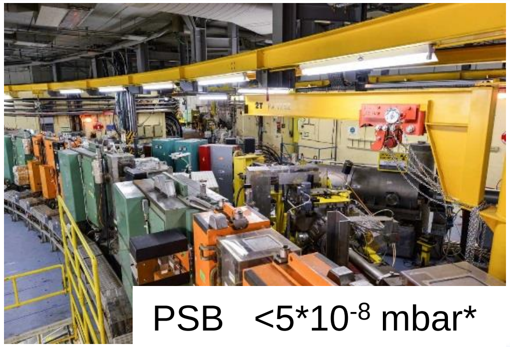

LHC LSS $<10^{-10}$ mbar

* After 24 h pump down

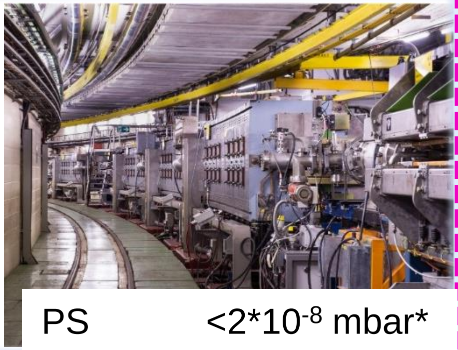
CERN accelerators chain: vacuum systems and requirements



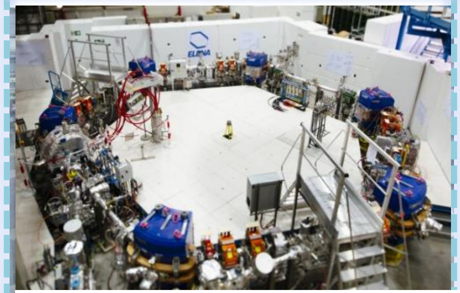
Linac2 <2*10^{-6} mbar*



PSB <5*10^{-8} mbar*

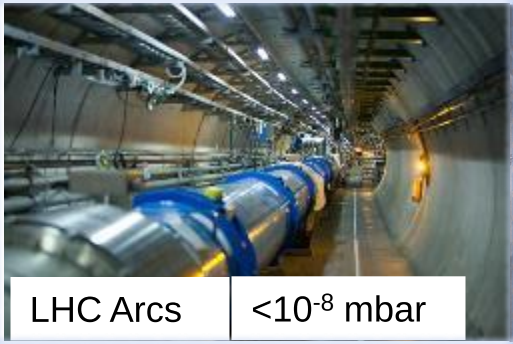


PS <2*10^{-8} mbar*

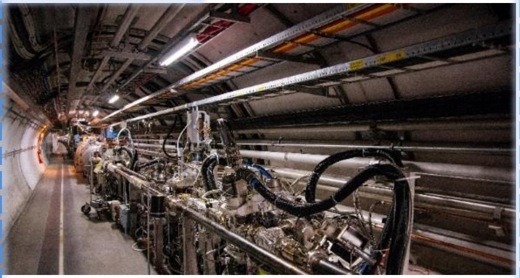


ELENA ring<4*10^{-12} mbar

SPS LSS <10^{-7} mbar*



LHC Arcs <10^{-8} mbar



LHC straight sections <10^{-10} mbar

UNBAKED SYSTEMS (SEPTA..):
- TMP, ION PUMPS;
- SUBLIMATORS;

CRYO SYSTEMS:
- CRYOPUMPING;

BAKED SYSTEMS:
- ION PUMPS;
- Non Evaporable Getter (TiZrV) coating

CERN's vacuum beamlines

Machine	Type	Year	Energy	Bakeout	Pressure (Pa)	Length	Particles
Linac, Booster, ISOLDE, PS, n-TOF and AD Complex						**2.6 km !**	
LINAC 2	linac	1978	50 MeV	Ion pumps	10^{-7}	40 m	p
ISOLDE	electrostatic	1992	60 keV	-	10^{-4}	150 m	ions: 700 isotopes and 70 (92) elements
REX-ISOLDE	linac	2001	3 Mev/u	partly	10^{-5} - 10^{-10}	20 m	
LINAC 3	linac	1994	4.2 MeV/u	Ion pumps	10^{-7}	30 m	ions
LEIR	accumulator	1982/2005	72 MeV/u	complete	10^{-10}	78 m	pbar, ions
PSB	synchrotron	1972	1-1.4 GeV	Ion pumps	10^{-7}	157 m	P, ions
PS	synchrotron	1959	28 GeV	Ion pumps	10^{-7}	628 m	P, ions
AD	decelerator	?	100 MeV	complete	10^{-8}	188 m	pbar
CTF3 complex	linac/ring	2004-09		partly	10^{-8}	300 m	e
PS to SPS TL	Transfer line	1976	26 GeV	-	10^{-6}	~1.3 km	P, ions
SPS Complex						**15.7 km !**	
SPS	synchrotron	1976	450 GeV	Extractions	10^{-7}	7 km	p, ions
SPS North Area	Transfer line	1976		-	10^{-6} - 10^{-7}	~1.2 km	
SPS West Area	Transfer line	1976				~ 1.4 km	
SPS to LHC TI2/8 Line	Transfer line	2004/2006				2 x 2.7 km	
CNGS Proton Line	Transfer line	2005				~730 m	
LHC Accelerator						***~109 km !***	
LHC Arcs (Beam x2, Magnets & QRL insul.)	collider	2007	2 × 7 TeV	-	< 10^{-8}	2 x (2 x 25 km)	p, ions
LSS RT separated beams				complete		2 × 3.2 km	
LSS RT recombination						~ 570 m	
Experimental areas						~ 180 m	
Beam Dump Lines TD62/68	Transfer line	2006	7 TeV	-	10^{-6}	2 × 720 m	
				High Vacuum		~20 km	**~128 km !**
				UHV w/wo NEG		~ 57.5 km	
				Insulation vacuum		~ 50 km	

Vacuum requirements: A little bit of history The Proton Synchrotron case

The CERN Proton Synchrotron project (henceforth referred to as the CPS) was started in 1954, and it has now -- 1958 -- reached a sufficient stage of development for a general report to summarize the progress achieved in the design of the various components of the machine. Although a number of details still remain to be worked out, the chief parameters for the machine are finally fixed, construction is under way and assembly of the components is due to begin shortly. This seems a suitable time for a general review of the work done and of the difficulties encountered.

THE CERN PROTON SYNCHROTRON

(1st Part)

CERN 59-29

by

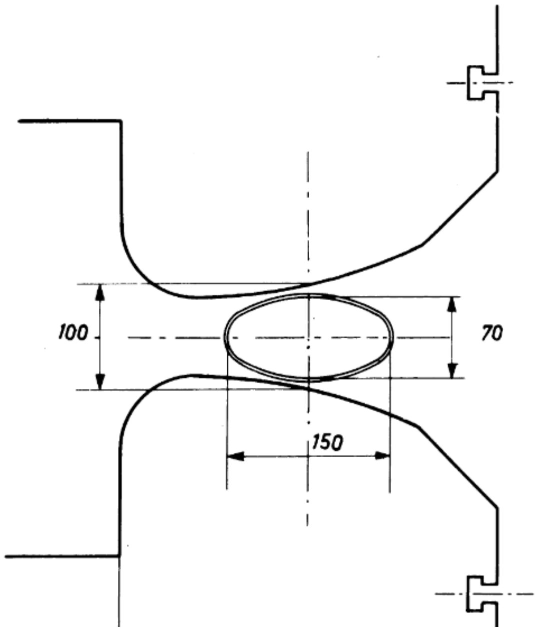
Proton Synchrotron Division
21st August 1959

E. Regenstreif

Vacuum requirements: A little bit of history
The Proton Synchrotron case

15. Gas scattering.

Owing to scattering by residual gas molecules, the cross-section of the beam increases during the time interval between injection and the moment when the energy of the particles becomes about double the energy at injection. The damping of the betatron oscillations due to the rise of the magnetic field subsequently leads to a gradual diminution of the scattering effect. In accordance with theoretical forecasts, for a vacuum of 10^{-5} mm Hg and an energy of 50 MeV at injection in the CPS, scattering by gas adds only a few millimetres to the beam diameter, and should cause negligible loss of beam.



CERN 59-29

Proton Synchrotron Division
21st August 1959

Vacuum requirements: A little bit of history
The Proton Synchrotron case

3. Système à vide

E. Fischer

Les anneaux de stockage d'électrons et de protons exigent une pression de gaz résiduel beaucoup plus basse que les accélérateurs classiques. Alors que, par exemple, le PS du CERN fonctionne de manière satisfaisante avec une pression d'environ 10^{-6} torr, pour les ISR, la pression moyenne autour des anneaux doit être mille fois plus basse, c'est-à-dire de 10^{-9} torr. Cette pression est même encore trop forte pour les régions d'interactions où elle doit être inférieure à 10^{-10} torr et si possible d'environ 10^{-11} torr.

Courrier CERN Volume 6, N° 7, Juillet 1966

Vacuum requirements: A little bit of history The Proton Synchrotron case

1. THE VACUUM SITUATION PRIOR TO 1990

The PS was designed and build in the mid 50ties and entered service in 1959. Vacuum was realised with some 100 pumping groups each one composed of a rotary pump and an oil diffusion pump. Most of the seals were made of elastomer materials. The pressures reached at that time were in the 10^{-4} Pa region. Besides the high pressure the bad influence on the beam of the heavy hydrocarbon molecules was detected and in the late 60ties the change to Ion Getter Pumps was made. This left of course much of the vacuum containment wall contaminated. It was only after the mid 80ties that all 100 magnets received new vacuum chambers made out of vacuum fired 316L+N stainless steel. Almost all seals used were by then made in metal; lead, aluminium or copper. Most of the big equipment tanks like for septa, or kickers were equipped with rectangular covers with vacuum seals made up out of a diamond shaped aluminium extrusion bend and welded in the

- Elastomers seals: not more adequate
- **Contamination problems**: Heavy hydrocarbons bad influence on the beam

THE VACUUM UPGRADE OF THE CERN PS AND PS BOOSTER

M. van Rooij, J.-P. Bertuzzi, M. Brouet, A. Burlet, C. Burnside, R. Gavaggio, L. Petty, A. Poncet, CERN

Vacuum requirements: A little bit of history The Proton Synchrotron case

In order to reach the required vacuum improvement, besides a general cleaning action, adding sublimation pumps and cryo pumps to the existing ion pumps was considered. There exists a CERN design of a Ti sublimation cartridge depositing Ti on the inside of a ø 200 mm pump body along a length of some 150 mm. Connected with a proper conductance that gives a pumping speed around 600 l/s for air mixture at the beam tube. That would so roughly quadruple the pumping speed there. For the PS that would not be entirely sufficient, for the PSB a factor of more than 2 would still be missing.

The choice of cryo pumping to improve pressure in high outgassing areas was not retained, but improving the vacuum quality of the beam tubes and specially of the necessary equipment in tanks was considered to be a more economic approach, certainly point of view of later exploitation cost.

SOLUTION

- **Vacuum chemical cleaning**
- **Decrease the outgassing rate more than increase pumping speed**

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Intermediate Summary

From PS Experience:

1. Beam losses and beam lifetime drive the vacuum level but maximum pressure in N_2 equivalent is used as acceptance criteria.
2. Work mainly on the total outgassing more than increase the pumping speed.
3. Cleanliness important factor: consequently gas composition start to have an important role

Pressure requirements different as a function of each machine:

- Difficult to define general criteria.
- Impossible to have a detailed simulation of each machine.

So….how to define the acceptance criteria?

How to define the acceptance criteria?

1. ADMISSIBLE OUTGASSING RATE

a) **DRIVEN BY Beam-gas scattering**: Beam losses and beam lifetime
   - Estimation of average pumping speed to define a total admissible outgassing rate;
   - Determine admissible molecules density;

b) **DRIVEN BY Beam downtime**: Allowed time to restart the machine in case of components exchange.

c) **DRIVEN BY Equipment requirement**: Maximum allowed pressure/molecules density to run devices like kickers or RF cavities.

2. NO CONTAMINATION

- Anomalous presence of **hydrocarbons**, most probably due to error in design and/or lack of appropriate cleaning (error in cleaning procedure or post-cleaning pollution); inappropriate choice of materials (polymers, glues, lubricants …);
- Higher than expected **CO and CO_2 outgassing** indicating the presence of carbonised elements;
- Any chemical element or compound usually not present in the residual gas phase, for example, **F and Cl** (issue with etching and cleaning), **K and Na** (manipulation), **P and S** (issue with electrolytic treatments).

Some examples: Baked system

LHC

Area	Equivalent Hydrogen gas density	Effective pumping speed (indicative)
Arcs	≤10 $^{+15}$ H_2 m^{-3}	≥100 l.s^{-1}
Experiments	≤10 $^{+13}$ H_2 m^{-3}	

GAS	Nuclear scattering cross section(cm^2)	Gas density (m^{-3}) for a 100 hour lifetime
H_2	9.5 10^{-26}	9.8 10^{14}
He	1.26 10^{-25}	7.4 10^{14}
CH_4	5.66 10^{-25}	1.6 10^{14}
H_2O	5.65 10^{-25}	1.6 10^{14}
CO	8.54 10^{-25}	1.1 10^{14}
CO_2	1.32 10^{-24}	7 10^{13}

LHC ACCEPTANCE THRESHOLDS
Ensure 100 h of circulating beams before intensity degradation due to residual gas interactions occurs and minimise the background for the experiments.

LHC Design Report
CERN-2004-003
4 June 2004

ELENA

Area	Pressure requirements	Effective pumping speed (indicative)
Ring	≤4 x10^{-12} mbar	Depend upon position (NEG sticking probability)
Transfer lines	≤10^{-10} mbar	

ELENA ACCEPTANCE THRESHOLDS
Ensures the limitation of momentum and emittance blow up induced by the interaction of 100 keV antiprotons with a beam population of 10^7. No specification on gas composition

Extra Low ENergy Antiproton (ELENA) ring and its Transfer Lines

Design Report CERN–2014–002 3 April 2014

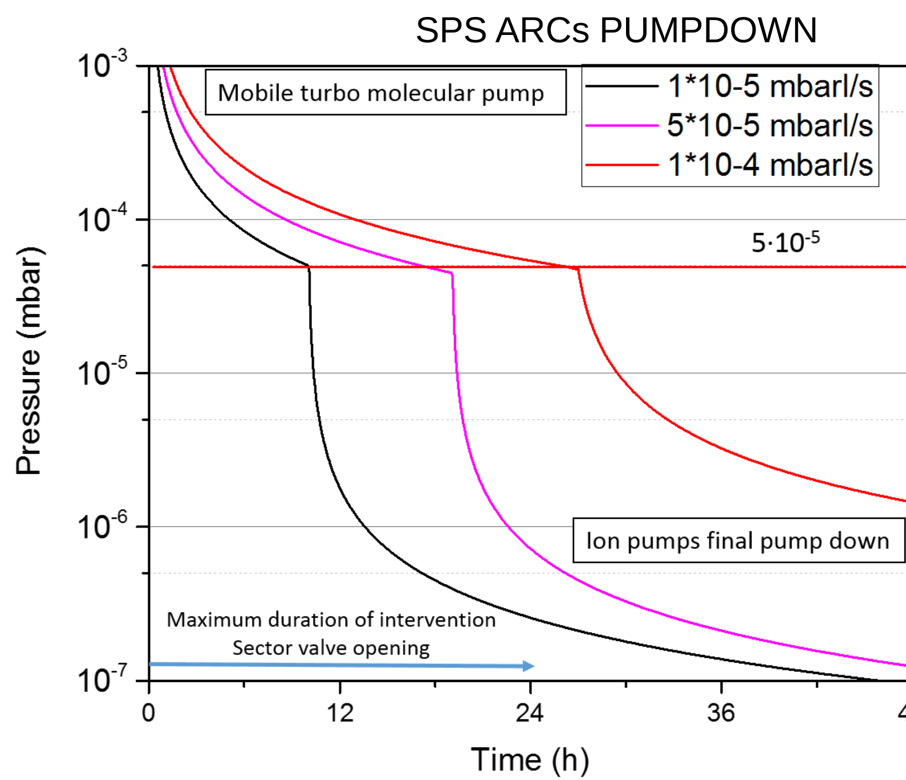
Dynamic effects included!

In both examples, the pressure requirements are driven by **beam** requirements.

Courtesy: C.Pasquino – OLAV - V

Some examples: Unbaked system

Accelerator	Area	Operational pressure requirement (24h pumping) [mbar]	Average effective pumping speed (indicative) [l s^{-1}]	Outgassing rate limit at 24 h [mbar.l.s^{-1}]
PS complex	LINACS AND TRANSFER LINES CLOSE TO PSB AND PS	≤2.10^{-6}	100	5·10^{-5} (*)
	PSB AND TRANSFER LINES CLOSE TO THE PS RING	≤5.10^{-8}	100	5.10^{-6} (*)
	PS ring	≤2.10^{-8}	70	1.5.10^{-6} (*)
SPS	Arcs	≤10^{-6}	10	10^{-5}
	LSS (kickers, septa, RF cavities)	≤10^{-7}	100	10^{-5} (*)
	TI2&TI8: From SPS to TED	≤10^{-5}	1-2	2.10^{-5}
	TI2&TI8: From TED to LHC	≤5.10^{-7}	5	2.5.10^{-6}



ACCEPTANCE THRESHOLDS

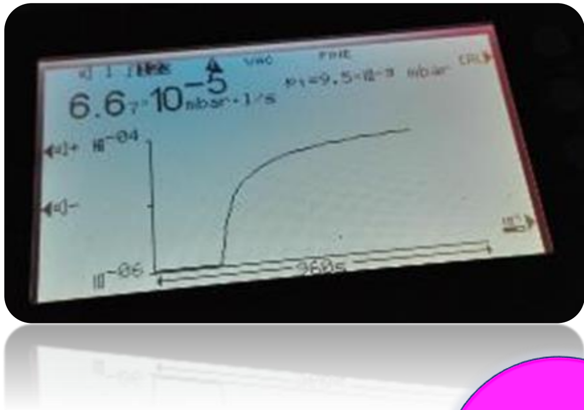
LHC injectors:

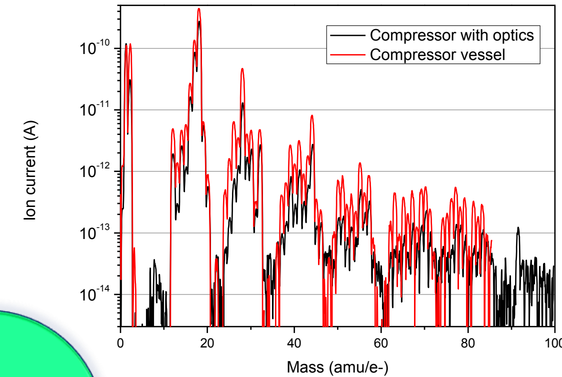
- **Ensure beam operation after 24h pump down;**
- **Ensure proper functioning of High Voltage and RF devices;**
- **Ensure ion operation at low energy (e.g. LEIR, PS);**

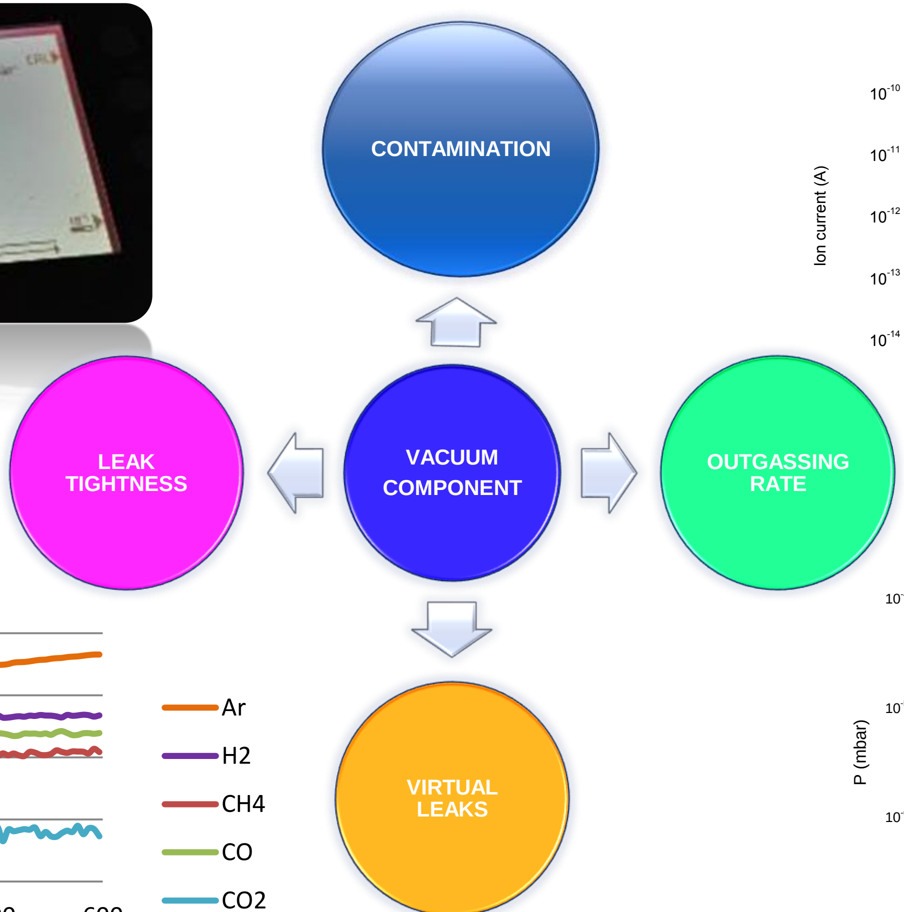
In this case, the acceptance thresholds are **beam downtime** and **equipment driven**.

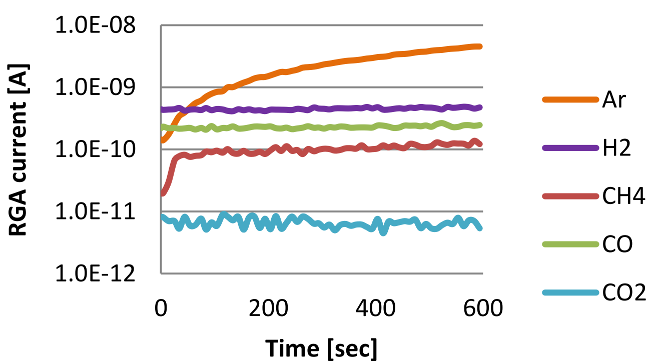
Courtesy: C.Pasquino – OLAV - V

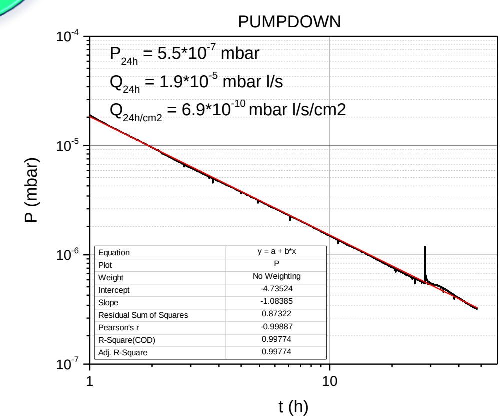
Acceptance Criteria





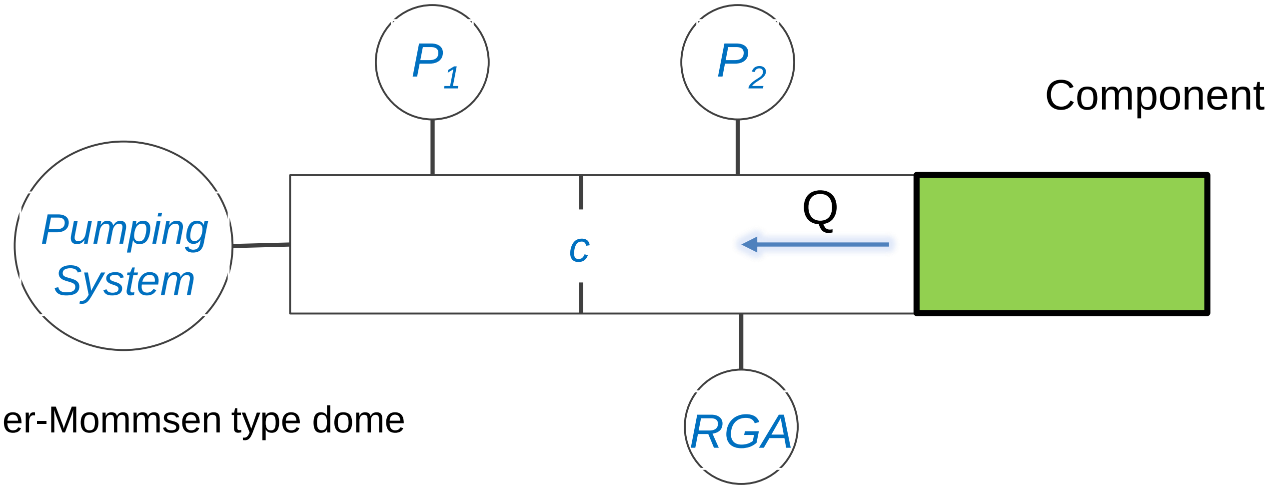






Courtesy: C. Pasquino – OLAV -V

Outgassing rate measurements



Fisher-Mommsen type dome

- Outgassing rate:

$$Q = \frac{\Delta P_2 - \Delta P_1}{C}$$

- Pumping system:
  I. Unbaked system:
  II. Baked System

Turbo molecular pumps
Chemical pumps

Unbaked: Vacuum validation steps

Measurement and verification of vacuum performance

- Functionality
- Leak tightness (First: high background)
- Outgassing rate after 24h of pump down
- Residual Gas Analysis
- Leak tightness (Final)

Unbaked: Acceptance Thresholds Overview

- He leak rate:
  - $Q_{AIR} < 10^{-10}$ mbar·l/s
- Outgassing rate after 24h of pump down:
  - Q_{Out} < Depends on the machine
- Gas composition: **H_2O** is the dominant peak

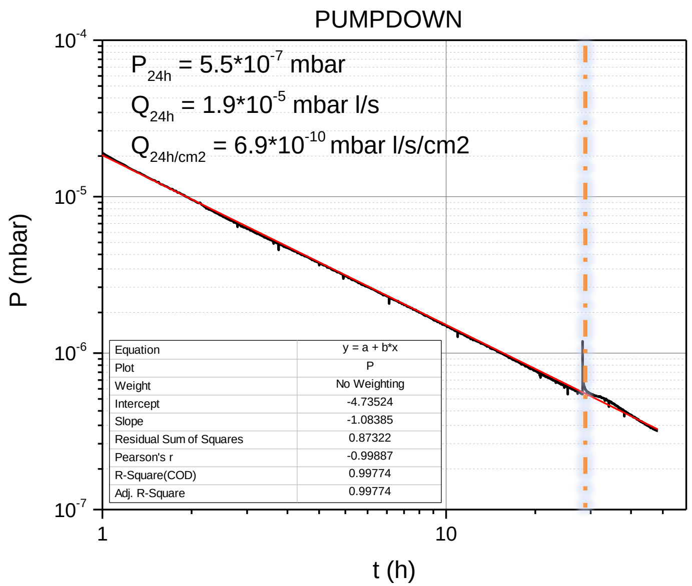
Atomic mass units from 18 to 44

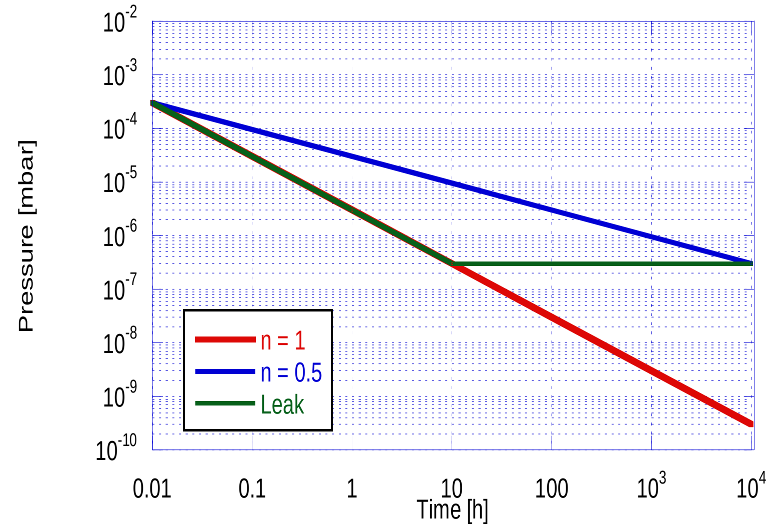
All the masses between **18 et 44** are at least **100 lower of the intensity of peak 18** (2 order of magnitude lower) except for masses 28 et 44

Atomic mass units from 44 to 100 (Indication of organic contamination)

All the masses from **44 to 100** are at least **1000 lower of the intensity of peak 18** (3 order of magnitude lower) except for mass 44

Acceptance tests for unbaked components





Pump down curve: outgassing rate value at 24h in N_2 equivalent to be compared with the acceptance criteria for each specific accelerator and transfer line.

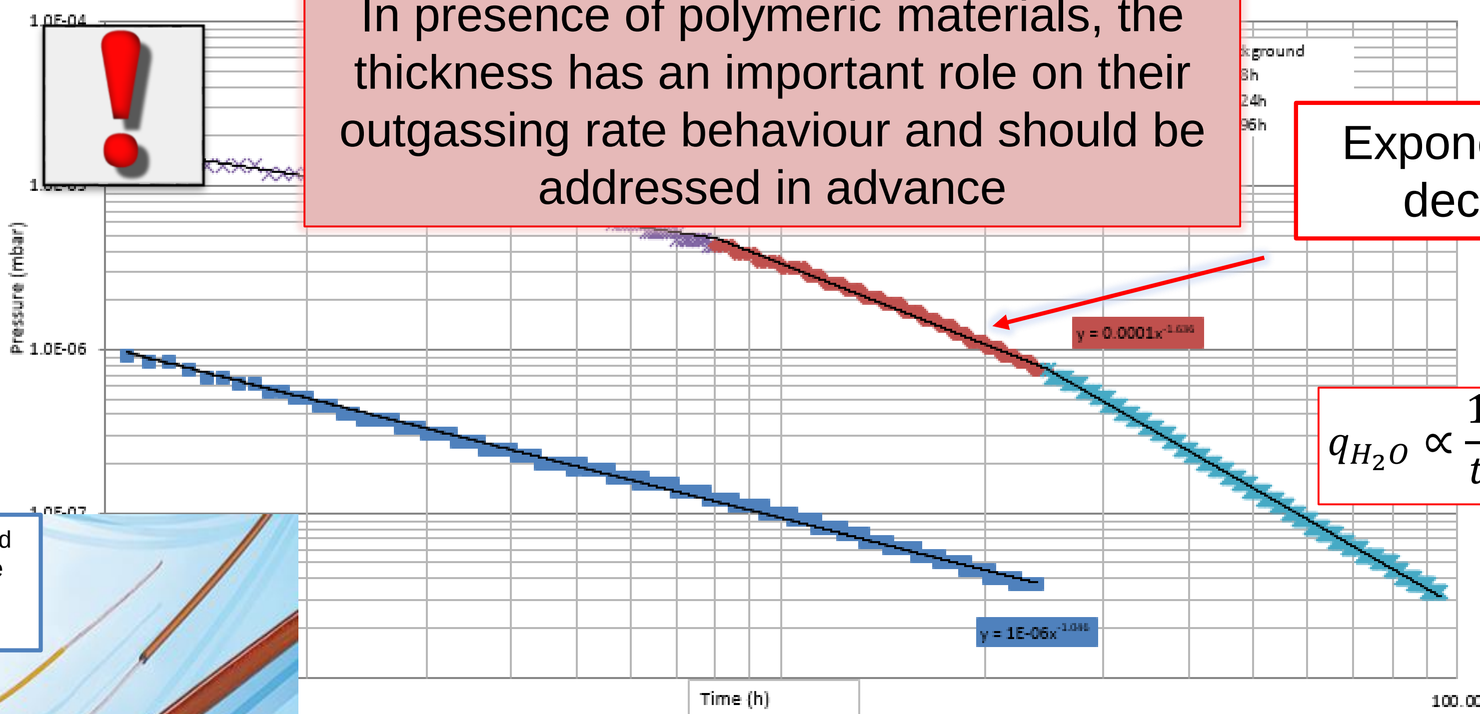
KEY FACTORS:

- The chosen materials (polymers, synthered materials, high vapour pressures materials);
- The thermal treatments (pre-baked in air or under vacuum (cladded cables));
- The mechanical design: trapped volumes, leak tightness.

Courtesy: C. Pasquino – OLAV -V

Is it 24h of pump down enough?

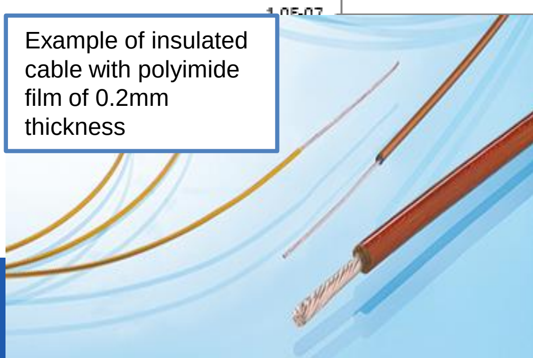
- 24h represent a good compromise that allows performing test within 1 week of time: installation, first leak detection, air venting overnight and final test. However…………..



In presence of polymeric materials, the thickness has an important role on their outgassing rate behaviour and should be addressed in advance

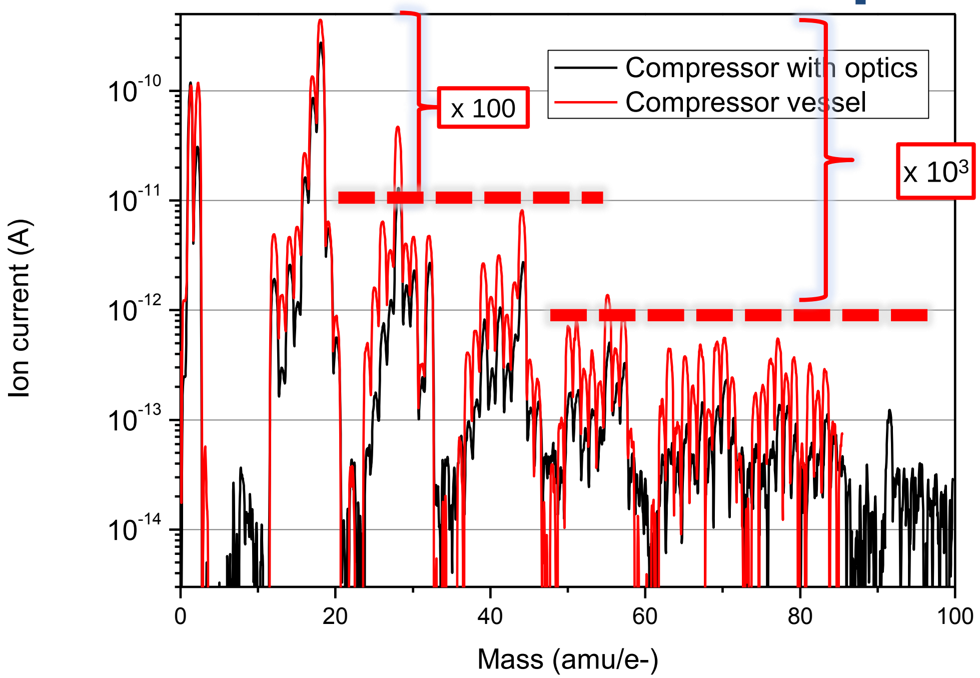
Exponential decay

$$q_{H_2O} \propto \frac{1}{t}$$



Example of insulated cable with polyimide film of 0.2mm thickness

Acceptance tests for unbaked components



Residual Gas Analysis: after few hours of filament conditioning, the amplitude of the peaks is compared to the water content in the system. The component is considered accepted if the ratio between the water peak and the peaks up to mass 44 is higher than 100 and if the same ratio is higher then 1000 for peaks above mass 44.

KEY FACTOR

Detect the presence of hydrocarbons, CO, CO_2, P, S, F, Cl or any unusual peak.

POSSIBLE SOURCES?

- NONCONFORMITY IN THE DESIGN (lubricants under vacuum, glues…);
- NONCONFORMITY IN THE CLEANING PROCEDURES;
- NON-CONFORMITIES IN THE HANDLING PROCEDURES;

- He leak rate:
  - $Q_{AIR} < 10^{-10}$ mbar·l/s

Courtesy: C. Pasquino – OLAV - V

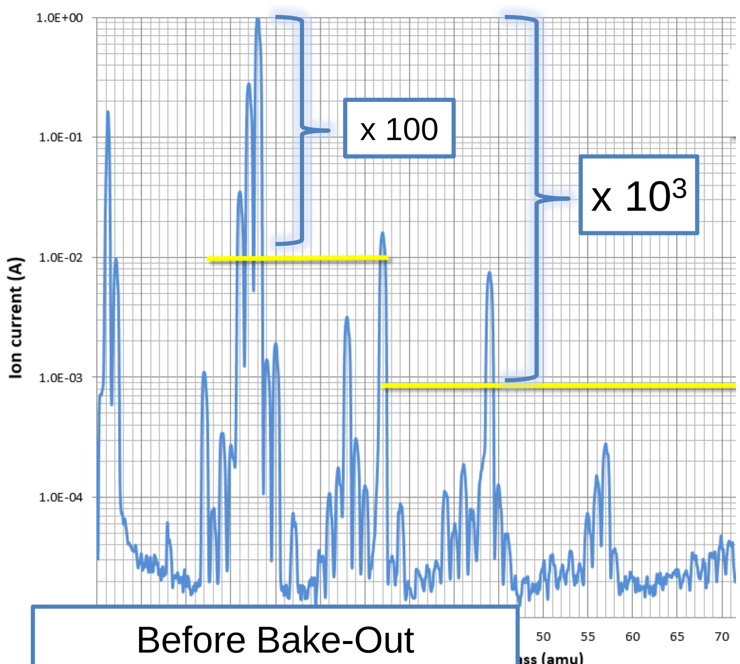
Acceptance Thresholds

Equipment subjected to partial bake-out

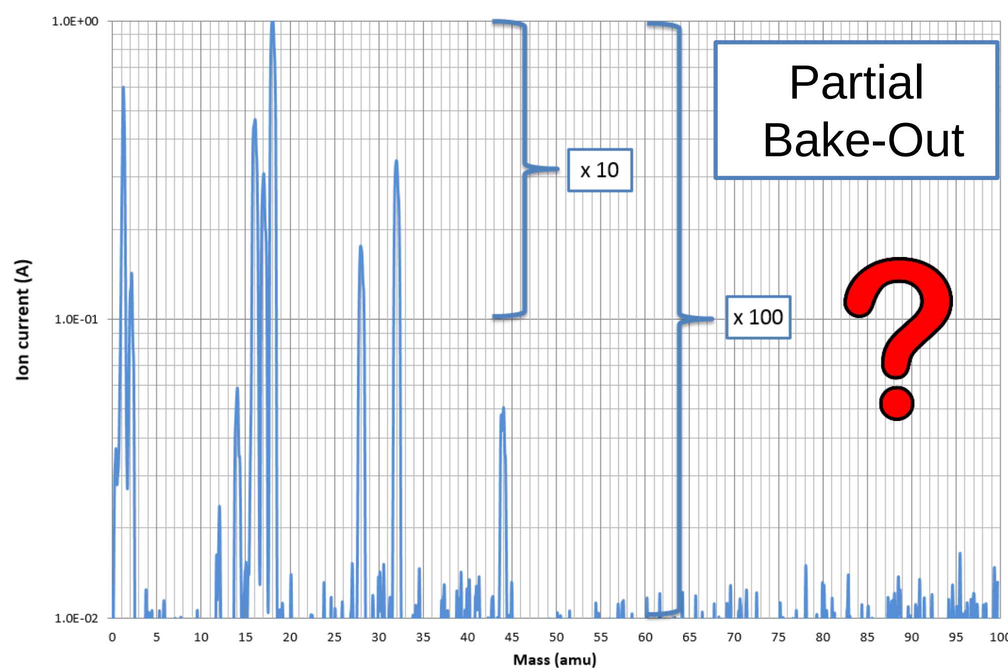
After bake ... a

In general, before bake-out, the total outgassing rate is dominated by H_2O: porous materials, polymers, etc.…
Need to have an in-situ bake out before installation…..**however**

How consider the RGA Scan: Normalized? baked or unbaked?

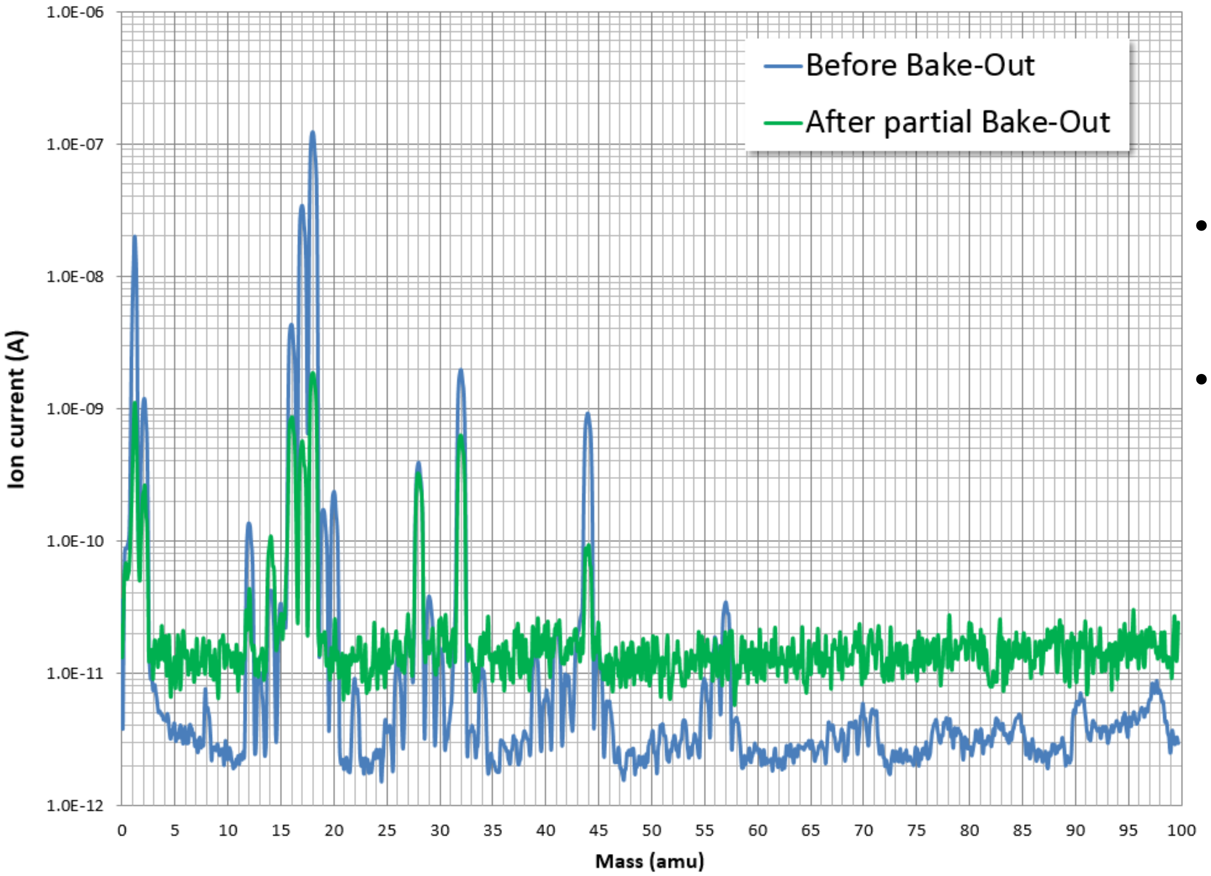


Before Bake-Out
Q_{TOT} >>>10^{-7} mbarl/s



Acceptance Thresholds

Equipment subjected to partial bake-out



RGA Guideline

- H_2O intensity should decrease of ≈2 orders of magnitudes:
- No more traces of contamination: hydrocarbons, carbonised elements and any chemical elements not present in a gas phase.

Baked: Vacuum validation steps

Measurement and verification of vacuum performance

Before bake out cycle:

- Functionality
- Leak tightness

After bake out cycle:

- Outgassing rate
- Residual Gas Analysis
- Leak tightness
- Functionality

Baked: Acceptance Thresholds Overview

LHC Case

- He leak rate:
  - $Q_{AIR} < 10^{-10}$ mbar·l/s
- Internal leak rate:
  - $Q_{AIR} < 5 \cdot 10^{-9}$ mbar·l/s
- Outgassing rate:
  - $Q_{Out} < 1 \cdot 10^{-7}$ mbar·l/s
- Gas composition: H_2 is the dominant peak

Atomic mass units from 18 to 44
(Possible impact on NEG performance)

Different acceptance thresholds are selected as a function of the gas.

Atomic mass units from 44 to 100
(Indication of organic contamination)

Acceptance criterion: RGA signals for all masses higher than 44 are at least 10000 times lower than the signal of peak H_2 (mass 2).

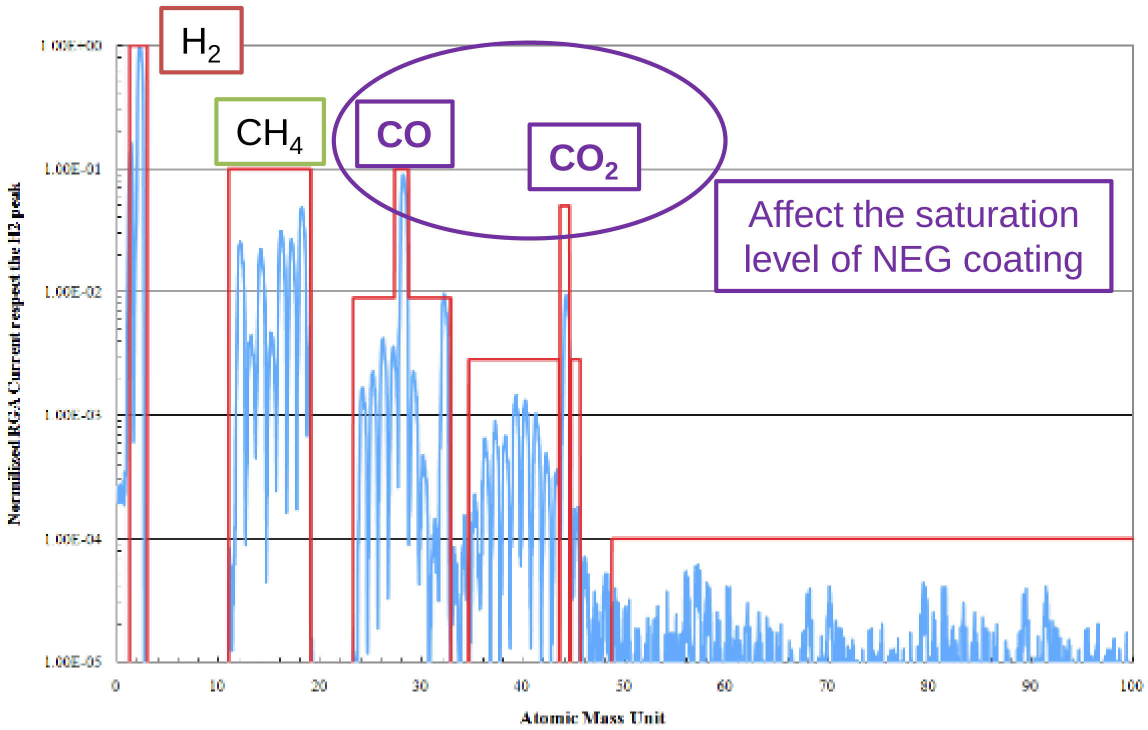
Baked: Acceptance Thresholds Overview

LHC Case

Maximum total outgassing **≤$1\cdot10^{-7}$ mbar·l/s**

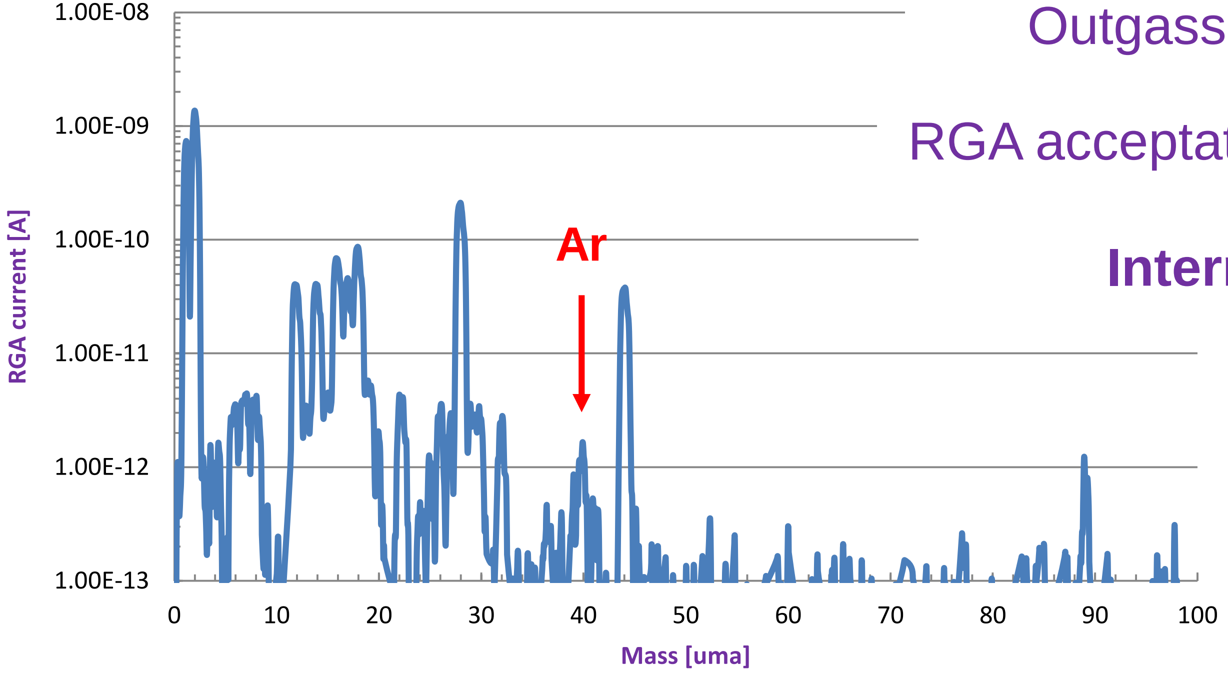
+

RGA Scan normalized to H_2



Baked: Acceptance Thresholds Overview

LHC Case



Externally leak tight ✔

Outgassing rate ✔

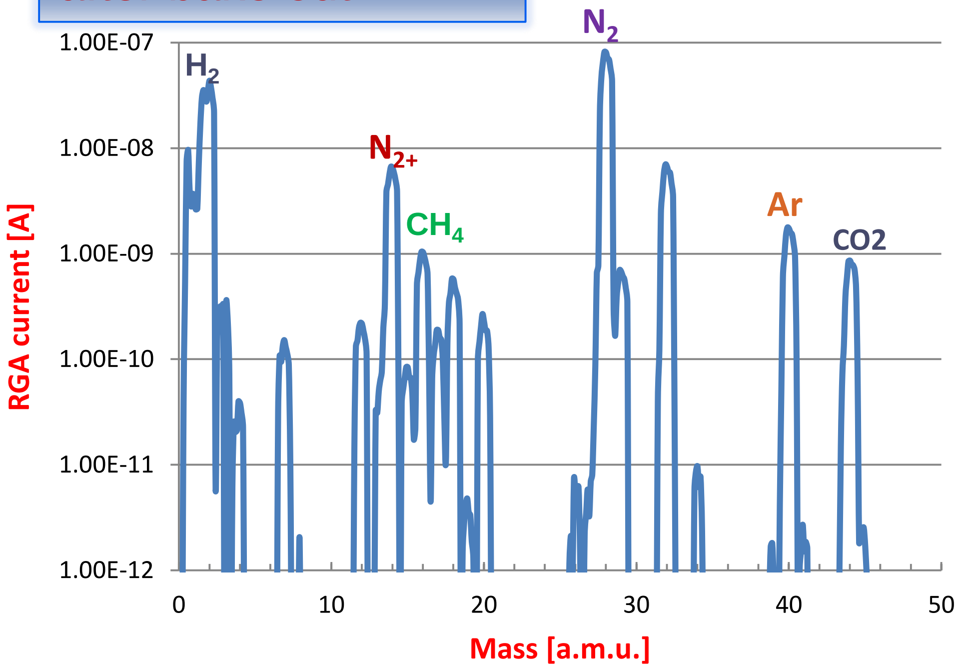
RGA acceptation limit ✔

Internal leak ?

Baked: Acceptance Thresholds Overview

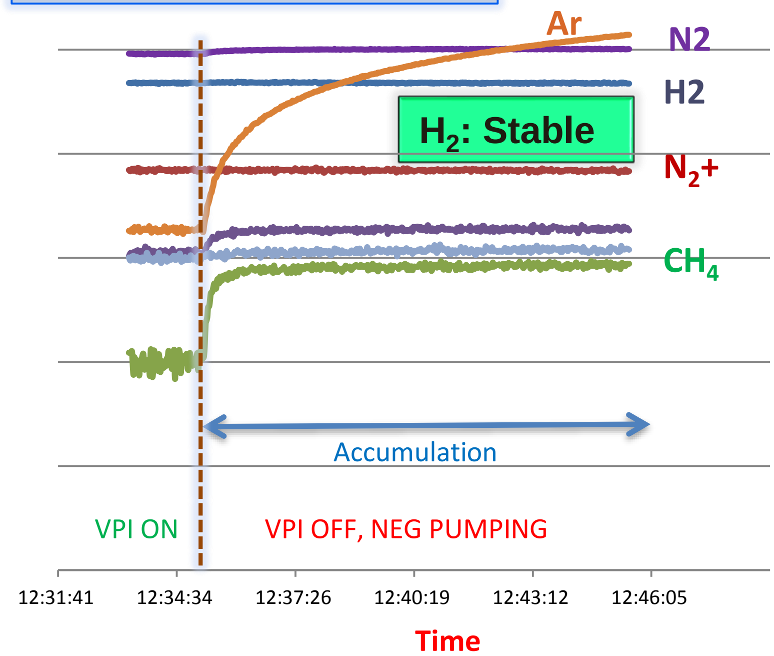
LHC Case

Air leak RGA spectra after bake out



Leak flow estimation

Ar increase



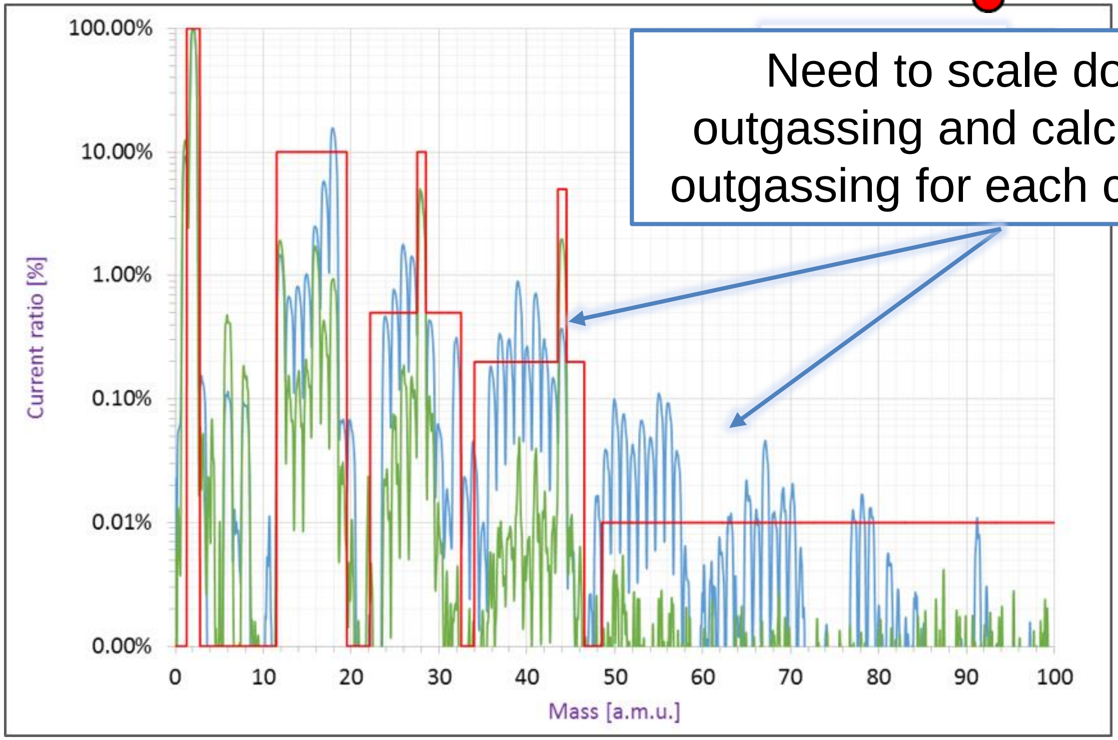
$Q_{[air\_eq.]} < 5 \cdot 10^{-9}$ mbar·l/s correspond to ≈ 1 m saturated NEG (80mm ϕ) every 150 days

Acceptance thresholds:
Low outgassing but not conform RGA

Maximum total outgassing **<< 1·10^{-7} mbar·l/s**

+

RGA Scan normalized to H_2



Need to scale down total outgassing and calculate partial outgassing for each contaminants

NEG coatings in particle accelerator

NEG coatings provide very large pumping speeds:

for H_2 0.3 ~ 1 l/s/cm^2

for CO 5 ~ 10 l/s/cm^2

Surface capacity of ~5 10^{14} molecules/cm^2.

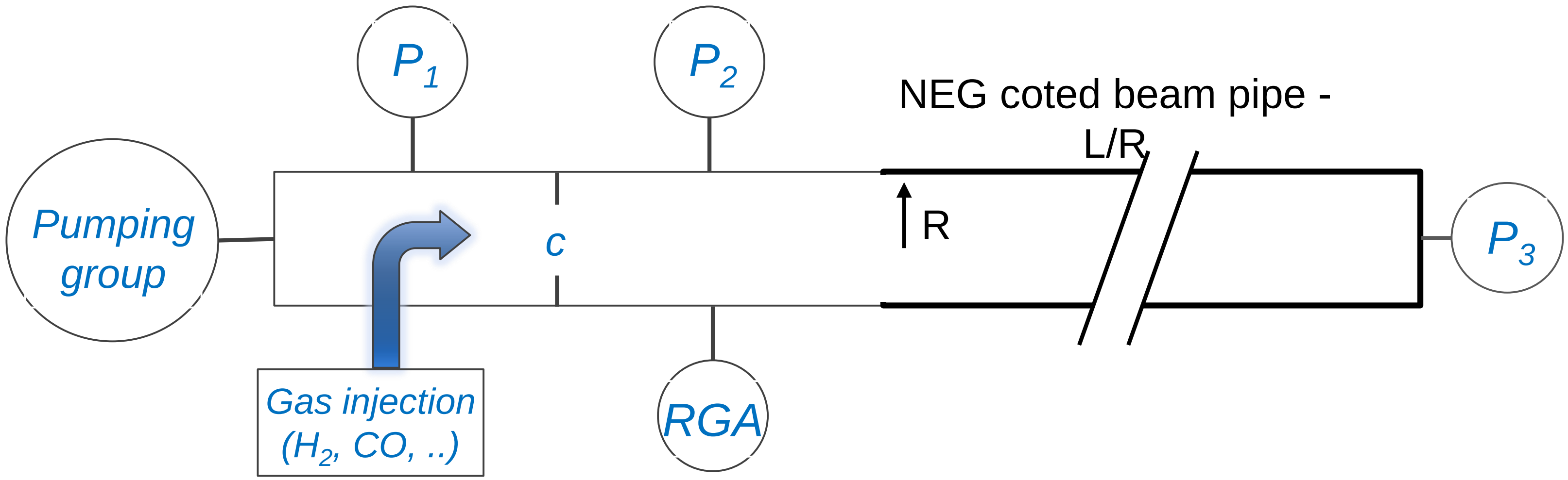
EXAMPLE: chamber of 1 meter, ϕ=80 mm (LHC):
S_{H_2}~750 l/s; S_{CO}~10000 l/s;
Capacity for CO ~1.25x10^{18} molecules:

Leak rate [mbar.l/s]	*Time to saturate*
10^{-5}	*~1 hours*
10^{-7}	*~4.5 days*
10^{-9}	*~1.3 years*
10^{-11}	*~125 years*

Zero order approach: considers homogeneous saturation.

Courtesy: P.Costa Pinto & G.Bregliozzi EVC13

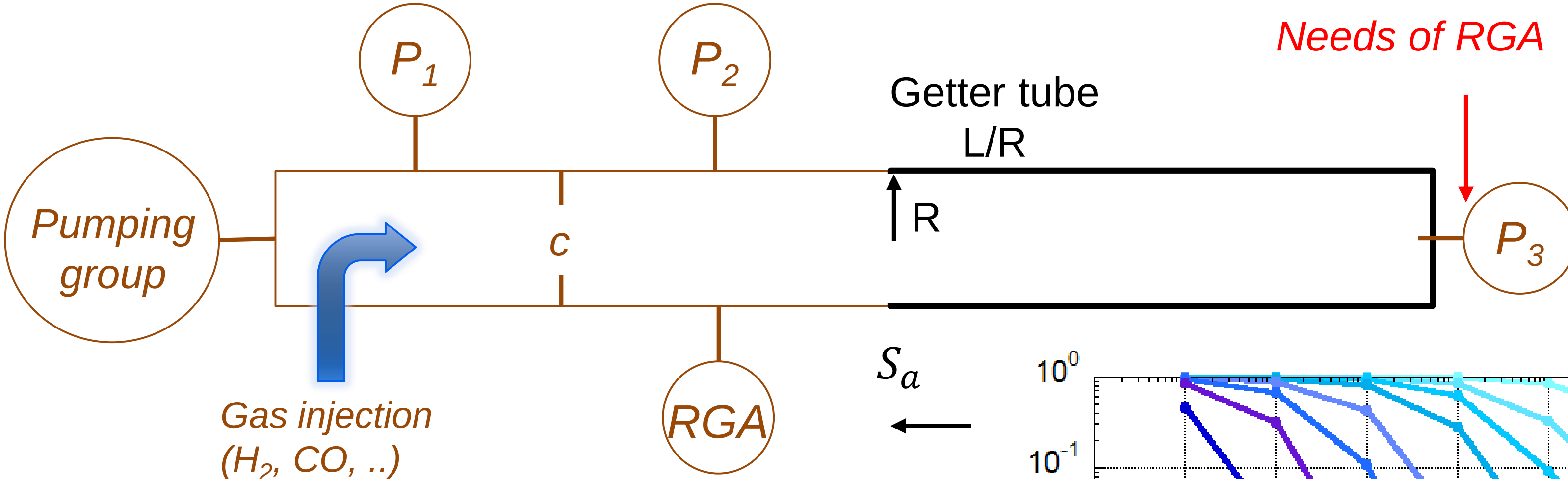
Evaluation of NEG performance



- Transmission: $$Tr = \frac{\Delta P_3}{\Delta P_2}$$
- Pumping speed: $$S = \frac{Q}{\Delta P_{BEGIN}} \quad [l/s]$$
- Capture probability: $$CP = \frac{S}{C_{AP}}$$

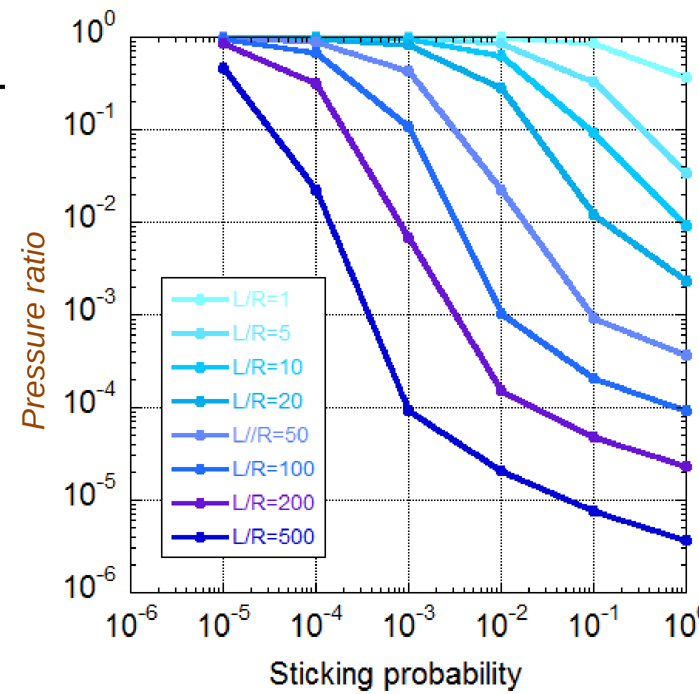
Practical use of NEG coatings

Measure the pumping speed of a thin film: transmission method



$$\text{Pressure ratio} = \frac{\Delta P_3}{\Delta P_2}$$

Monte Carlo simulation



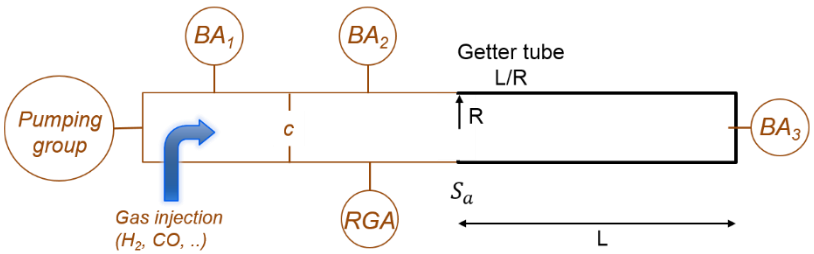
If pressure ratio too low:
very high P_2 is necessary to get a signal in P_3

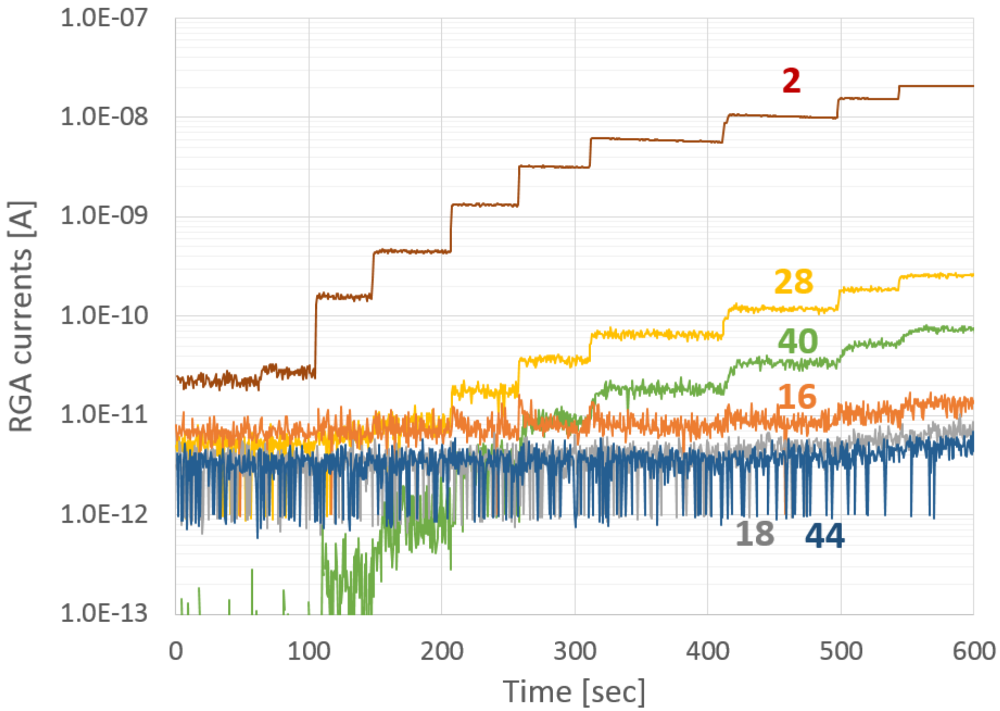
If using CO => fast saturation at the entrance

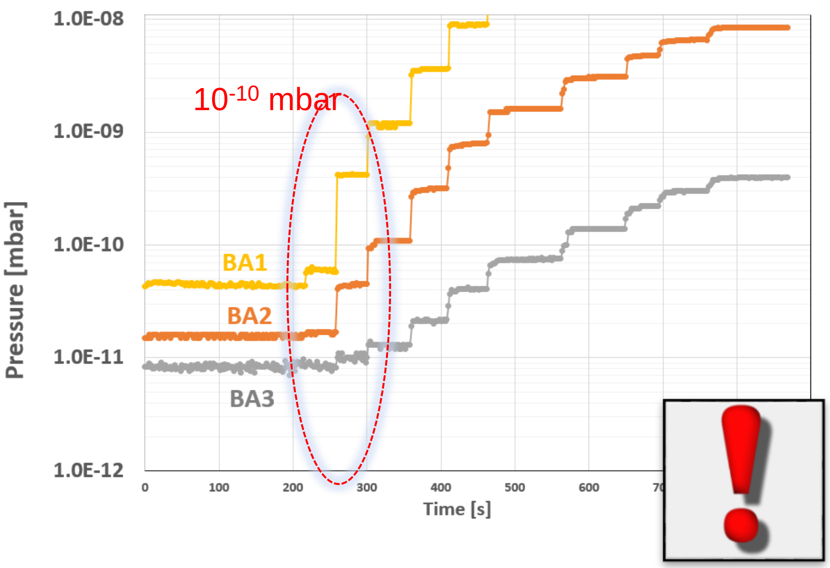
If using H_2 => dissociation of H_2 in hot filament => methane

Courtesy: P.Costa Pinto & G.Bregliozzi EVC13

NEG Transmission limitation: H_2 Injection







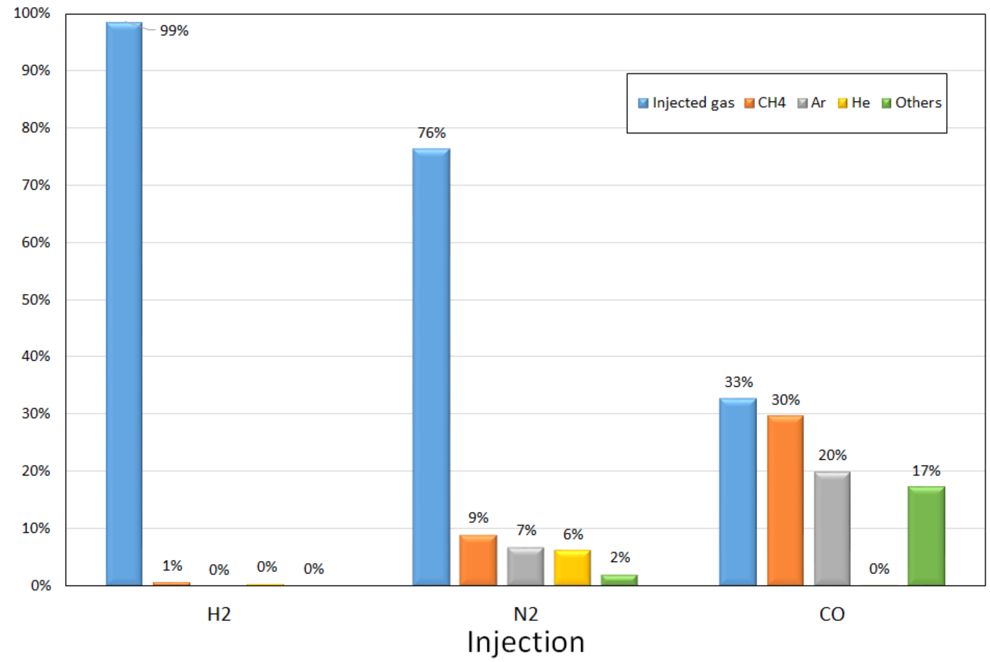
In case of long coated beam pipe need to carefully consider the cleanliness of the injection line and presence of hot filaments or selective pumping in the system.

Transmission method limitations

NEG Coated copper beam pipe - Length of 1 m – ϕ 80 mm

- H_2 injection: 99% of the total pressure is due to hydrogen, allowing to always use the ΔP_{TOTAL} transmission to evaluate the sticking factor

- N_2 injection: 26% of the total pressure is due to methane and noble gases, so the $\Delta P_{PARTIAL}$ transmission has to be used.

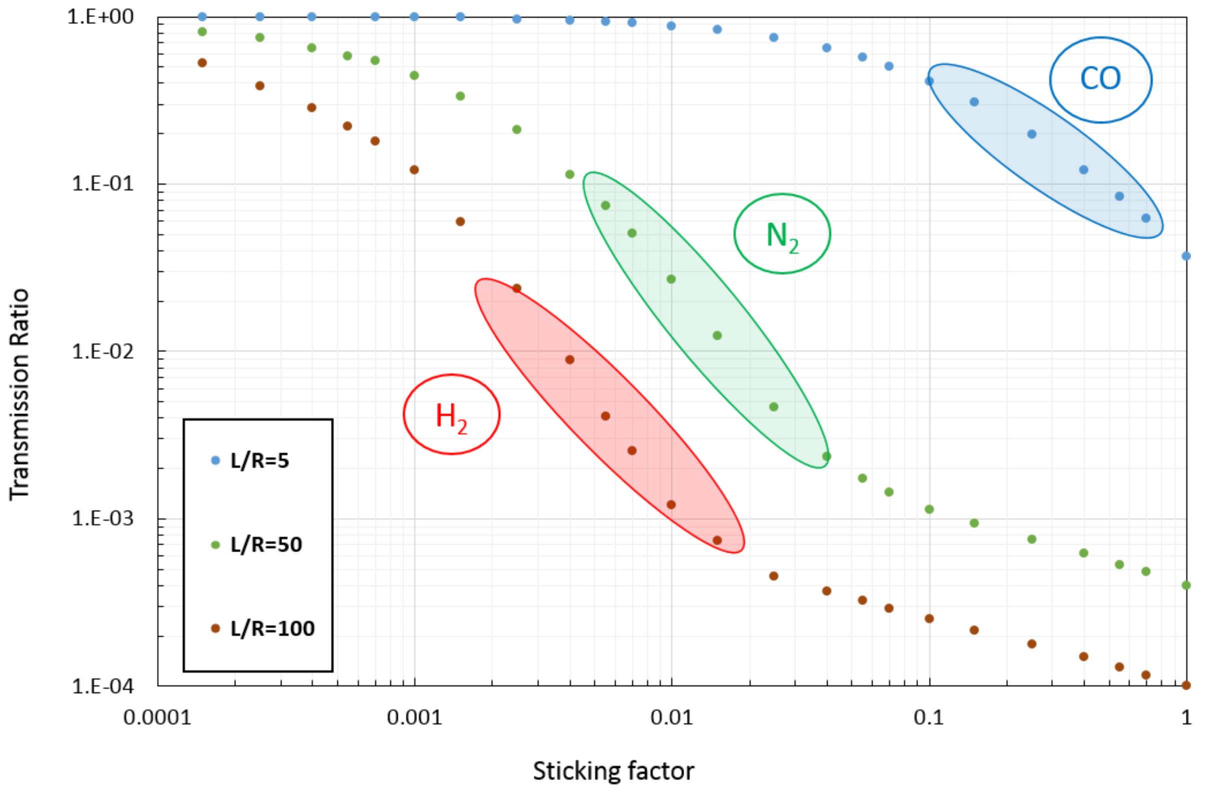


- CO injection: 66% of the pressure reading is due to gases others than CO. Only using $\Delta P_{PARTIAL}$ transmission it is possible to obtain representative results.

Transmission method optimization

- The sticking factor strongly depends on the ratio L/R between the length and the radius of the chamber
- To have representative sticking factor values the transmission has to be in the range where the curve is steepest
- Different gases have different sticking factors

	Sticking factor
H_2	$7.0 \cdot 10^{-3}$ - $7.0 \cdot 10^{-4}$
N_2	$5.0 \cdot 10^{-2}$ - $1.2 \cdot 10^{-3}$
CO	$7.0 \cdot 10^{-1}$ - $1.2 \cdot 10^{-2}$



Conclusion & Advices

- Need to clearly analyze and define which is your driving parameter and then set the acceptance criteria;
- Once defined stick to the acceptance limits and try to be always coherent;
- Define gas density more than general pressure;
- Try to find a compromise: Do not be too stringent
- Be flexible on the total outgassing but do not accept any form of contaminations;
- Participate as much as possible to the design phase to eliminates problems and non conformities at the source.

You'll be able to predict much better your vacuum system, anticipate problems and malfunctioning and have fastest and simpler intervention in the accelerators.

…….thank you very much for your attention

The CERN Accelerator School

MAX IV LABORATORY

Vacuum for Particle Accelerators
Glumslöv, Sweden, 6 - 16 June, 2017

Additional Slides:

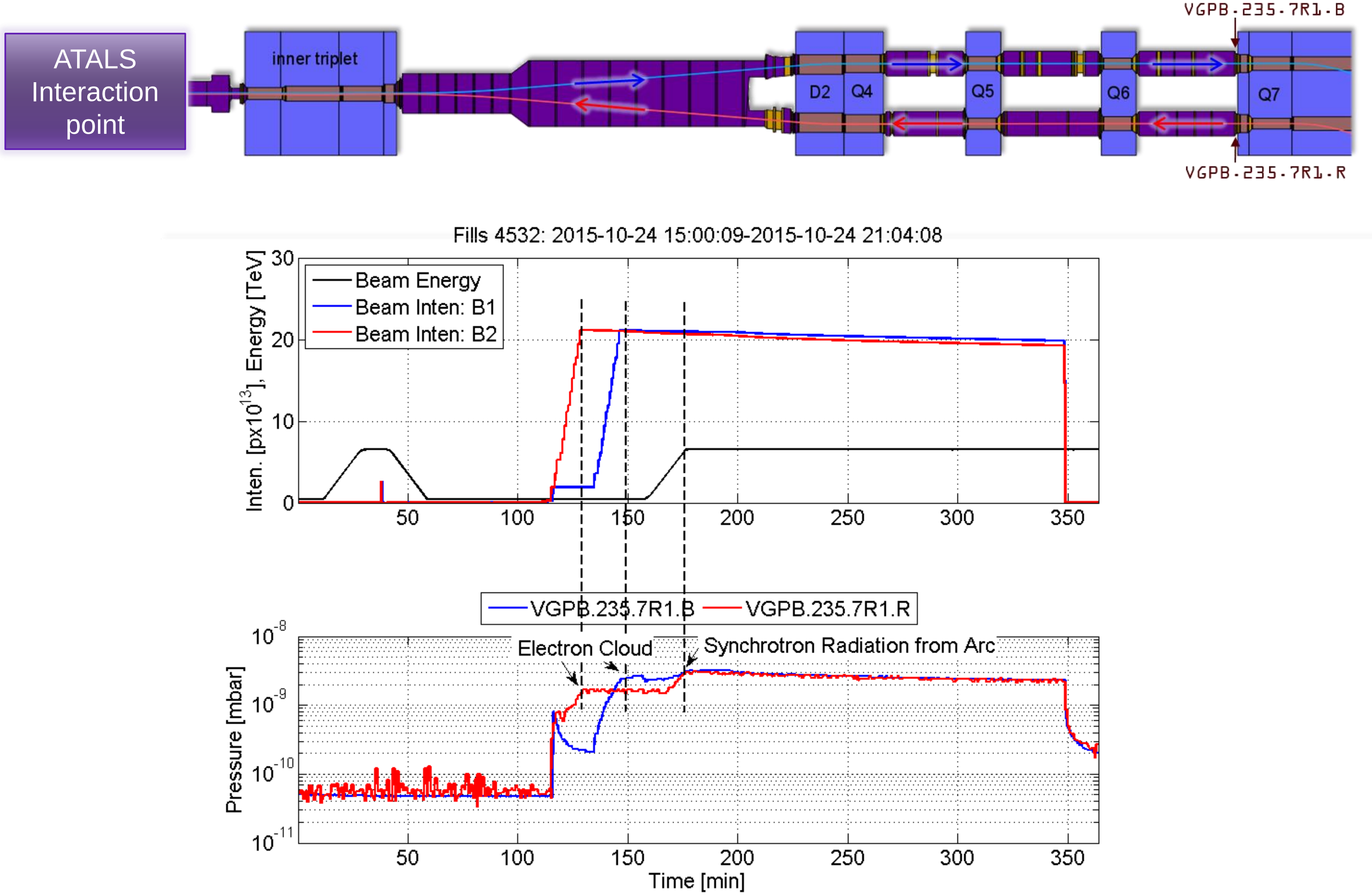
Some special needs and examples

What about beam induced pressure increase?

How to deal with it?

An example in case of electron and photon flux

Beam induced pressure increase

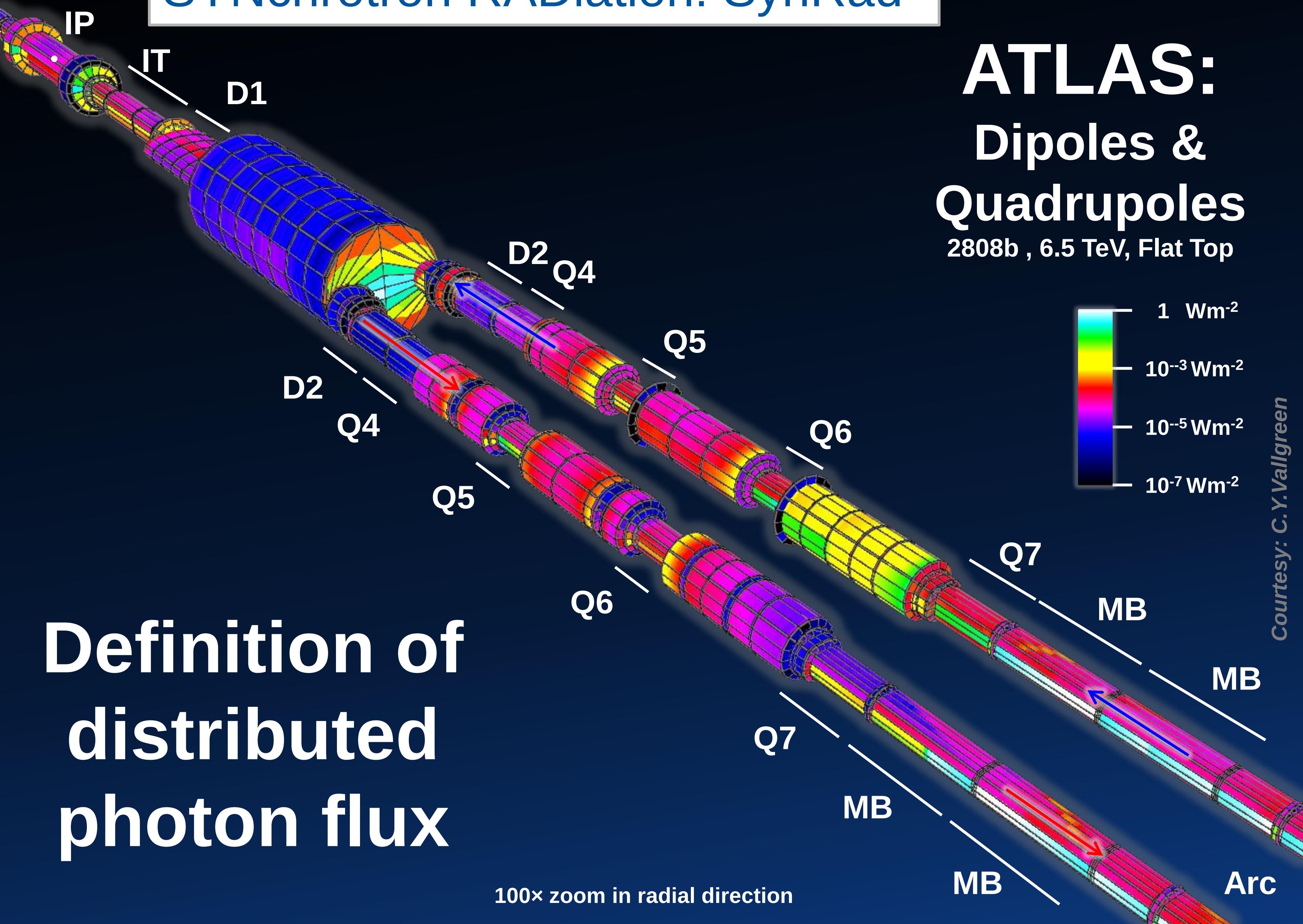


Courtesy: C.Y.Vallgreen

SYNchrotron RADiation: SynRad

ATLAS:
Dipoles & Quadrupoles

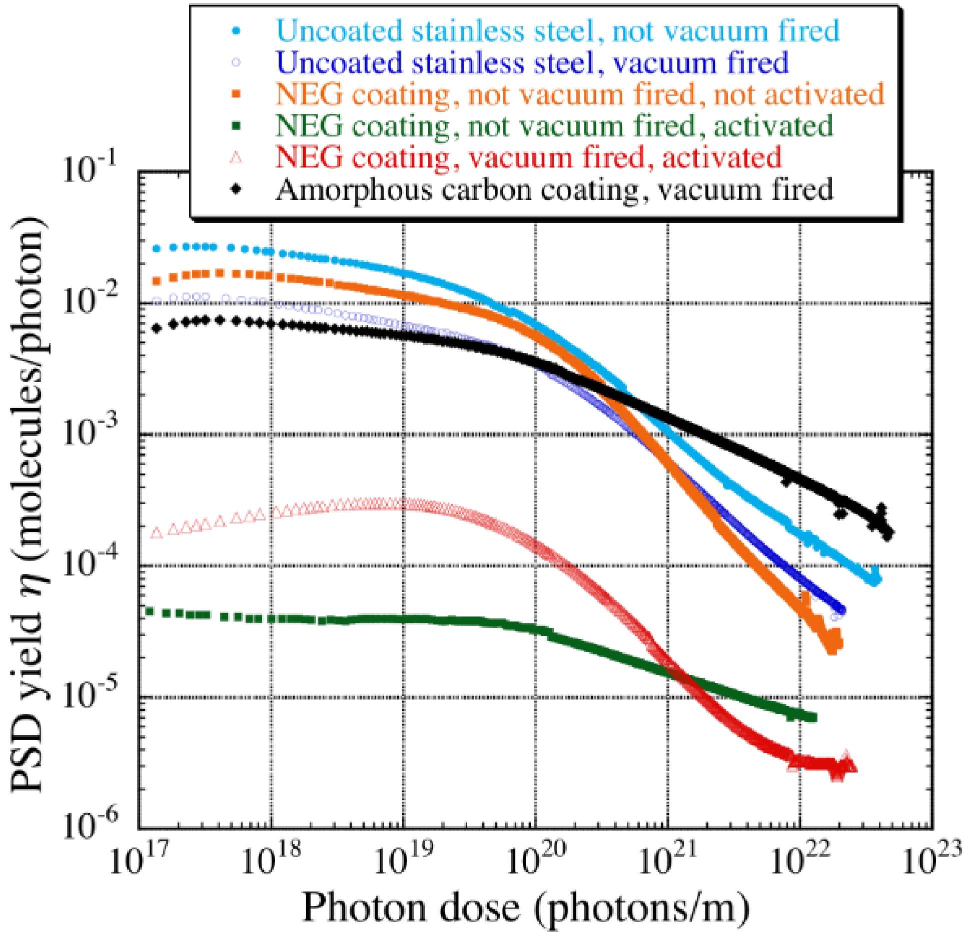
2808b , 6.5 TeV, Flat Top



Definition of distributed photon flux

Material characterization: η_{ph}

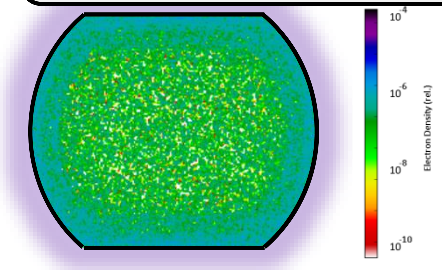
Sample	Treatment and coating
1	Reference stainless steel sample basic treatment only
2	Stainless steel sample vacuum fired
3	TiZrV NEG coating not activated
4	TiZrV NEG coating, activated prior to the experiment
5	TiZrV NEG coating vacuum fired, activated
6	Amorphous carbon coating vacuum fired



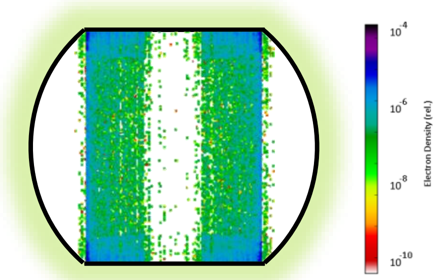
Courtesy: M.Ady et Al. IPAC15

Definition of the SEY Threshold & Electron Flux

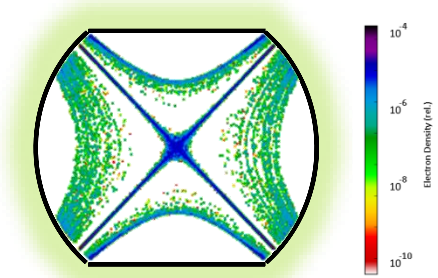
Electron flux distribution
Allow to determine the impact of the electron flux on the beam pipe surface



Without Field:
- High SEY treshold

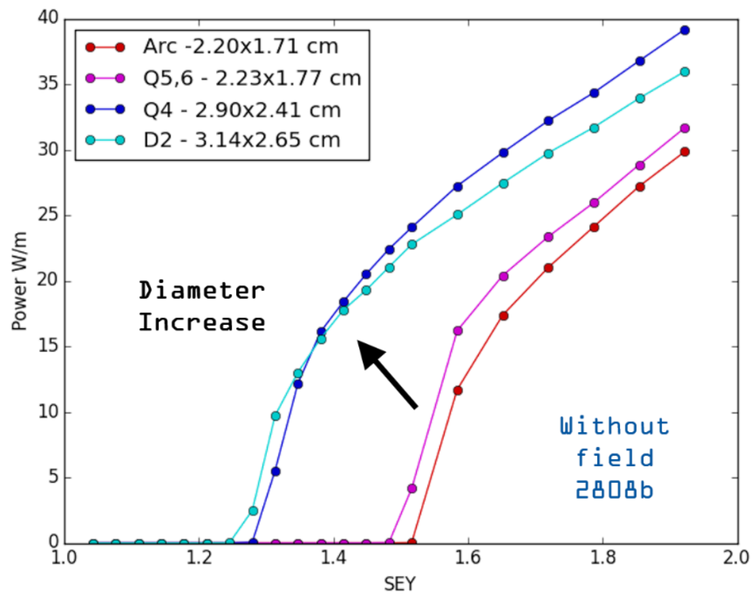


Dipole Field:
- Concentrated electron flux



Quadrupole Field:
- Trapping effect, area dependent on magnetic field

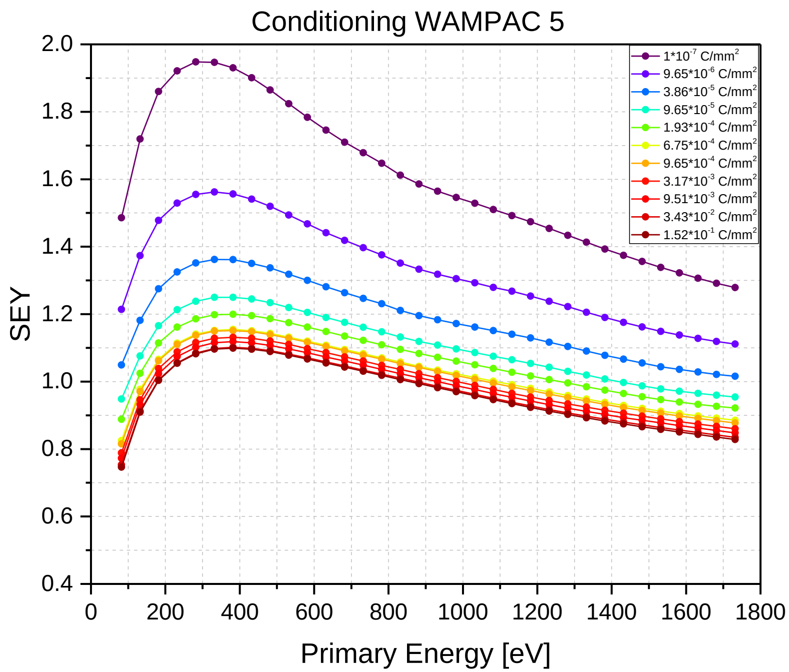
Example of LHC Beam Screen

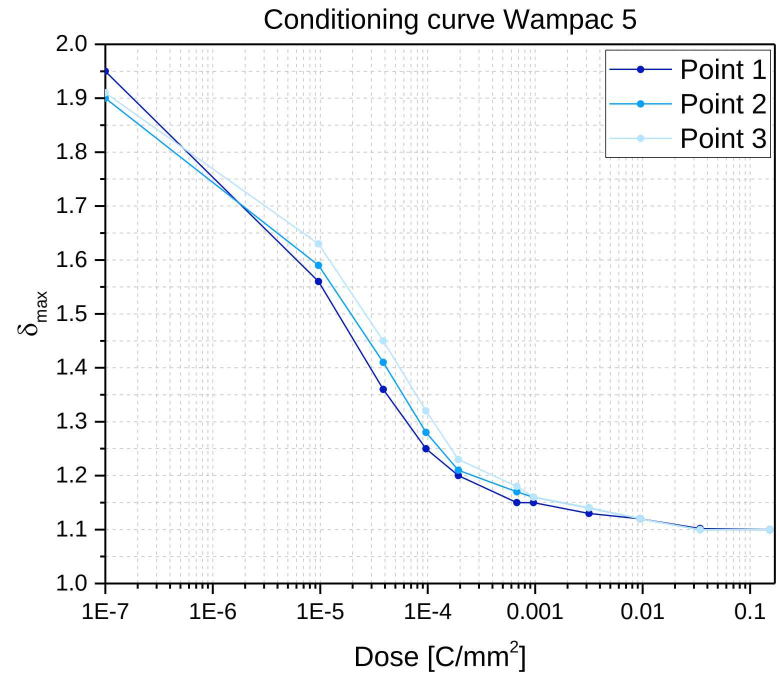


SEY Threshold
Allow the definition of the minimum acceptable SEY for each materials

Courtesy: C.Y.Vallgreen

Material characterization





SEY vs Primary energy:

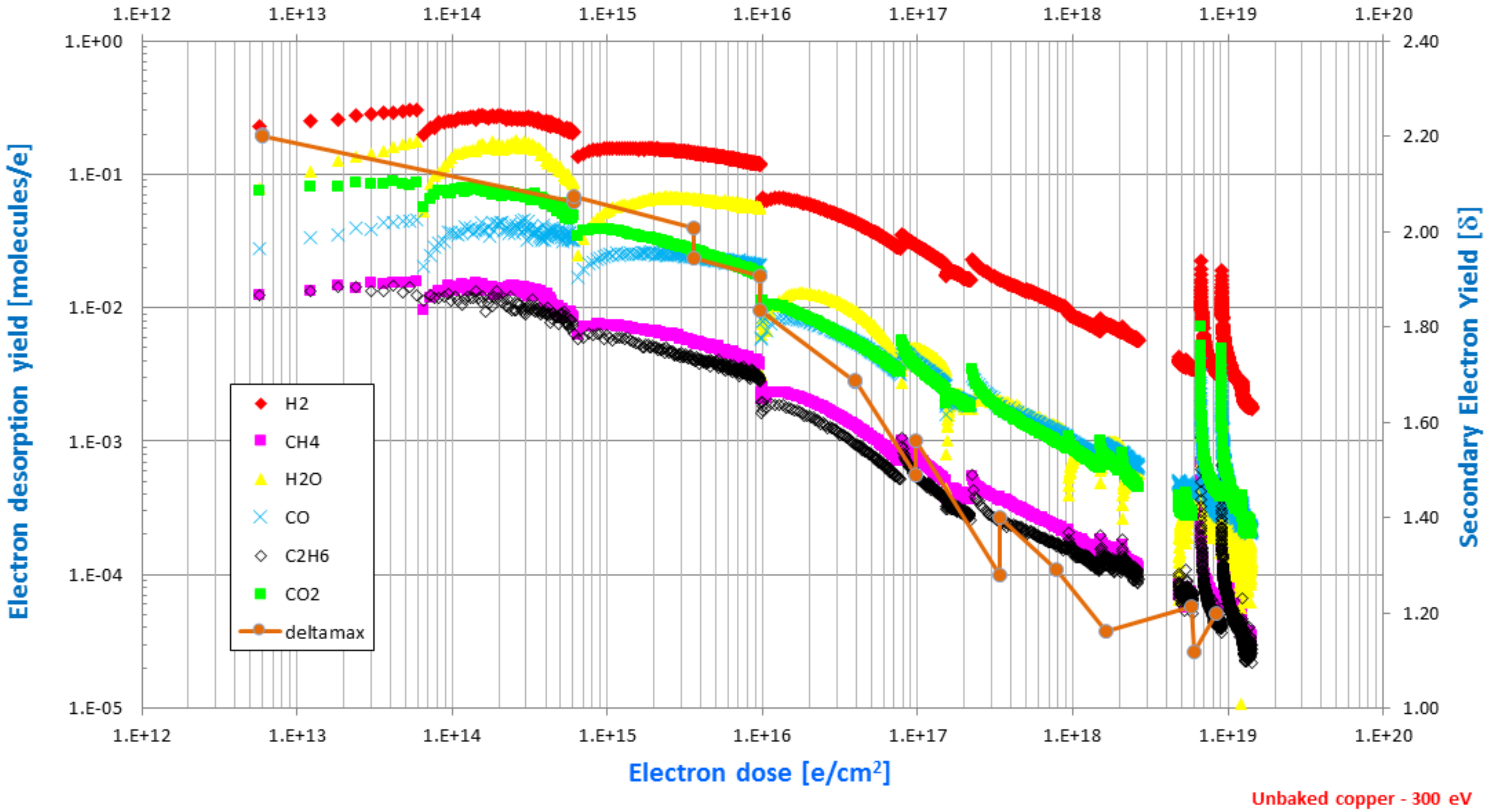
- The SEY scan allow determining the secondary electron evolution function of primary energy;
- Accumulating electron dose bombardment it reduces the SEY and allow to create the ‘conditioning’ curve;

Conditioning Curve:

- Allow determining and the SEY evolution and study its impact function of the simulated SEY threshold and electron flux.

Courtesy: R.Salemme & M.Taborelli

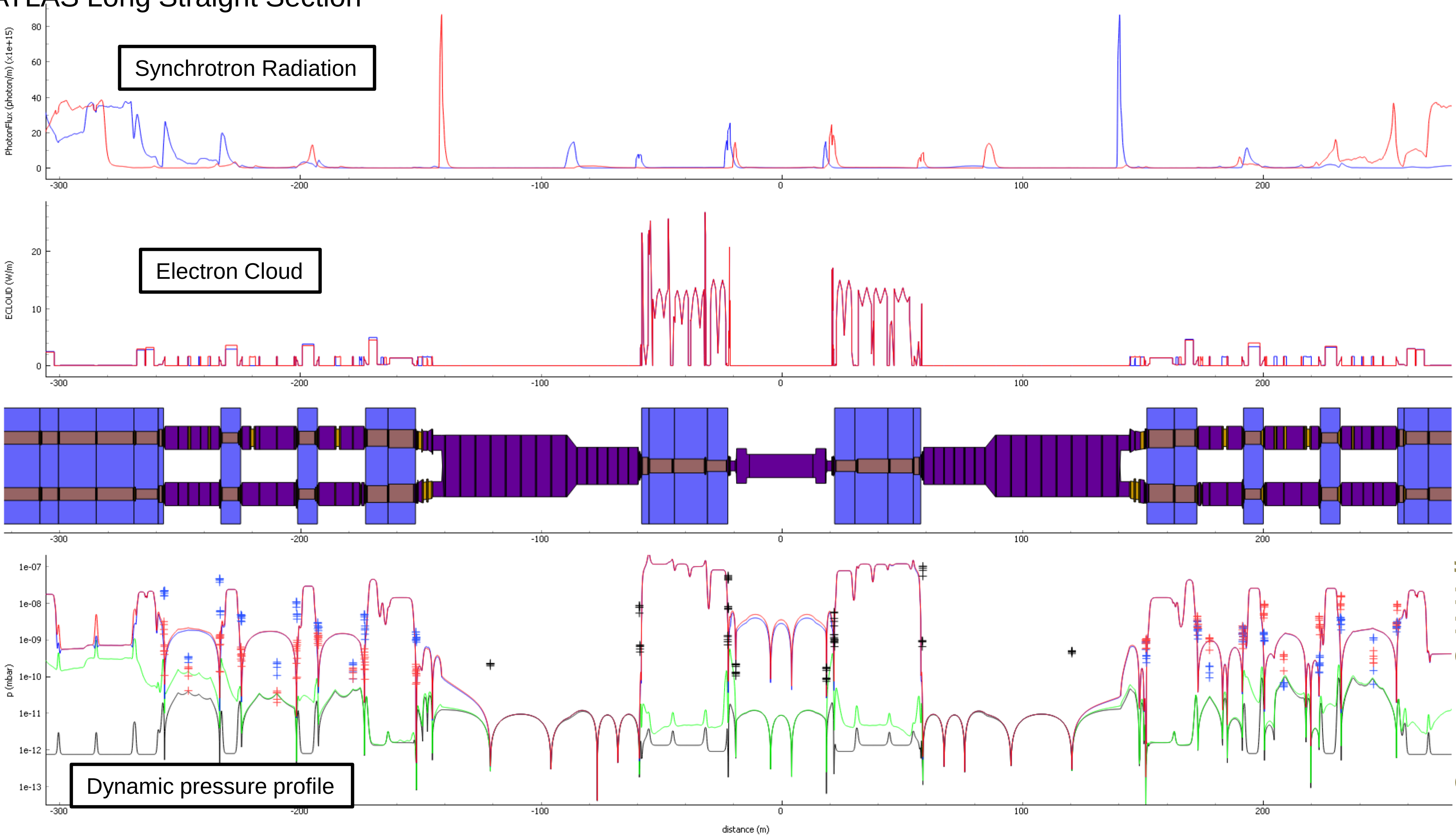
Material characterization: η_{el}



Courtesy: V.Baglin

Synchrotron Radiation & Electron Cloud
Dynamic Pressure Profile: VAcuum Stability COde (VASCO)

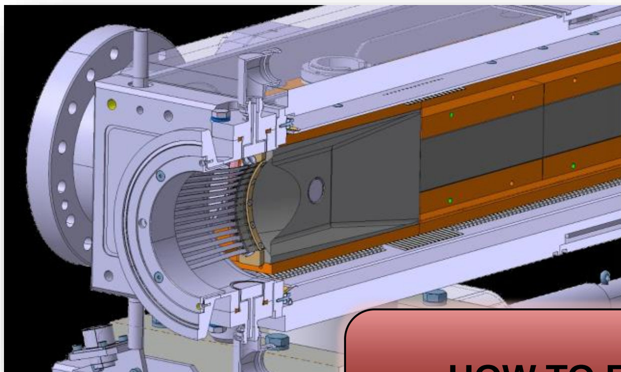
ATLAS Long Straight Section

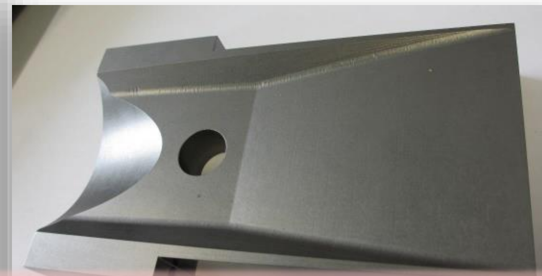


Courtesy: C. Y. Vallgreen

New Sintered Materials

new materials characterisation, MoGr





Collimator upgrade for LHC → reduction of the transverse impedance contribution of the collimator jaws → new proposed material MoGr.

HOW TO FIND THE CORRECT RECIPE TO MINIMISE THE OUTGASSING RATE?

Two grades have b far, with same initial composition but different atmospheres during the production process.

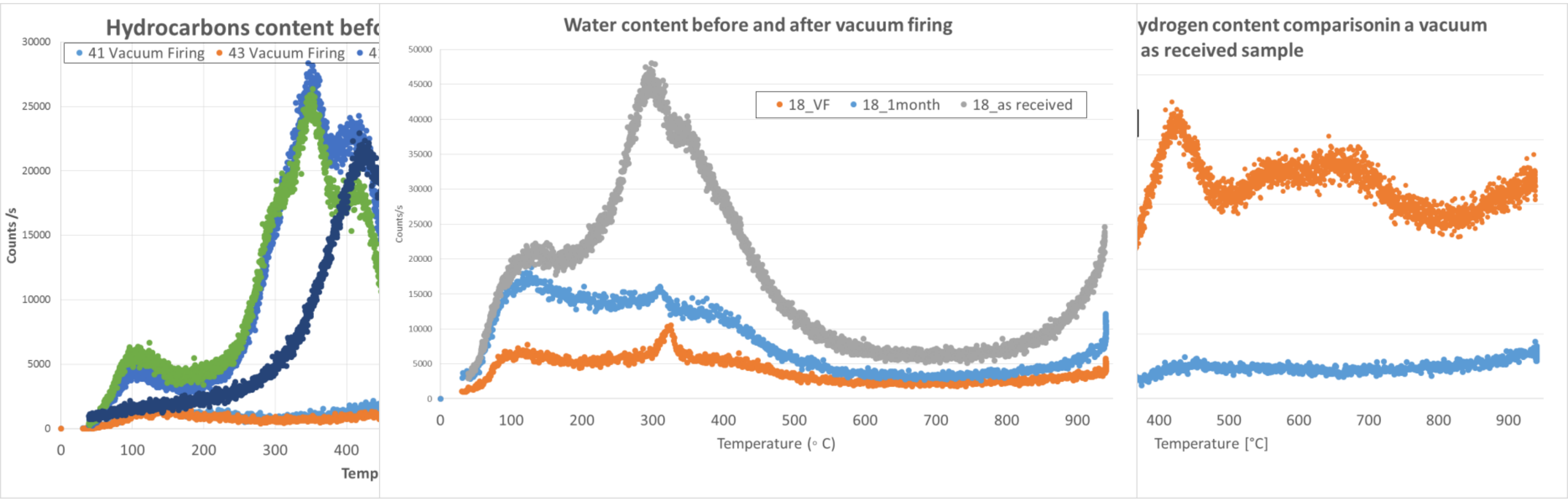
*

%vol Mo=4.5
%vol Graphite=95.3
%vol Ti=0.2

		MG6403He *
	Atmosphere: air	P= 300Mpa T=250°C Atmosphere: vacuum
Sintering	T=2300°C Duration= 2400s Atmosphere: vacuum Venting gas: air	T=2300°C Duration= 2400s Atmosphere: vacuum Venting gas: Ar
Post sintering	T=2400°C Duration= 3000s Atmosphere: vacuum Venting gas: air	T=2400°C Duration= 3000s Atmosphere: vacuum Venting gas: Ar

New Sintered Materials

Thermal Desorption Spectroscopy of MoGr



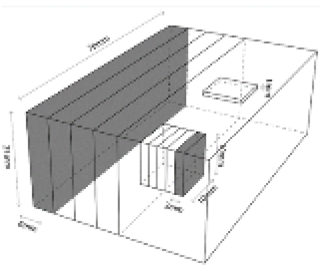
TDS (Thermal desorption spectroscopy) is used to study gases evolution from the material under different conditions (before and after vacuum firing, air time exposure..).

New Sintered Materials

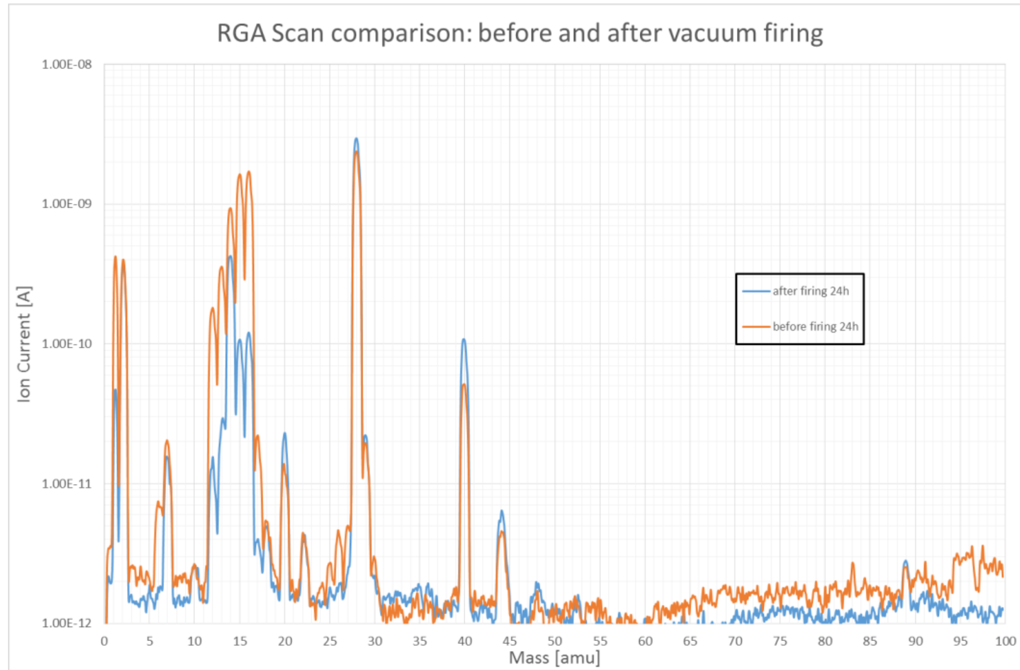
new materials characterisation, MoGr

Thickness 6mm

Thickness 25mm



- Different thickness
- Different orientation
- Different machining
- Different production plate

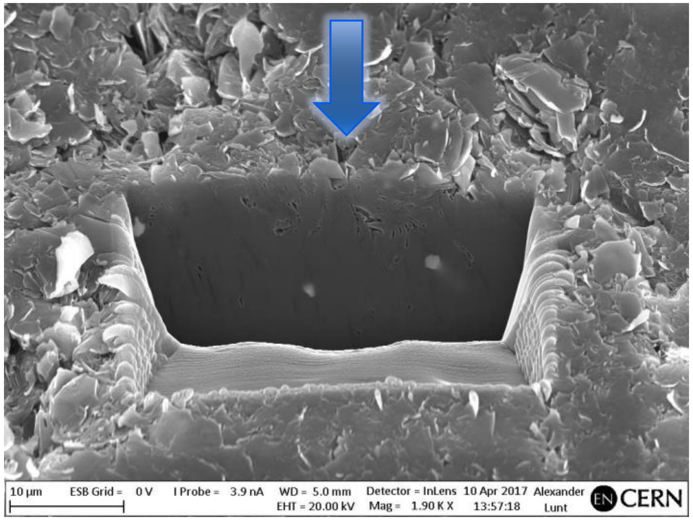


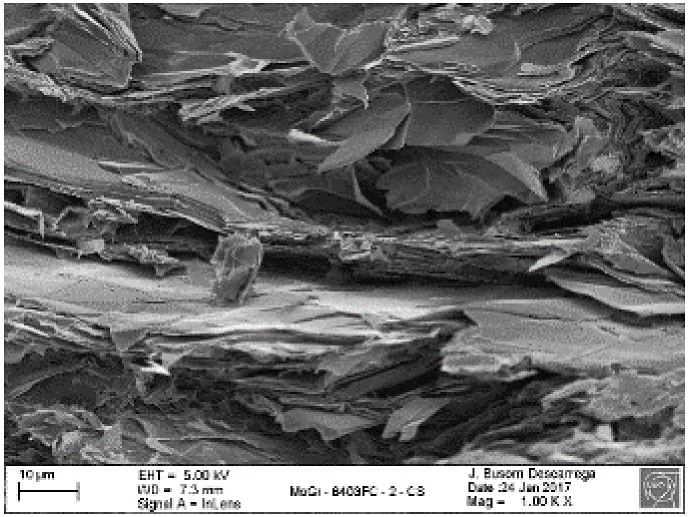
Effect of the vacuum firing (2h @ 950 ℃) on the outgassing.

New Sintered Materials

new materials characterisation, MoGr

Ion beam





Focus Ion Beam and SEM analysis to evaluate the presence of voids, pores and surface damages induced by machining.

Glue or “strange materials” v.s. NEG

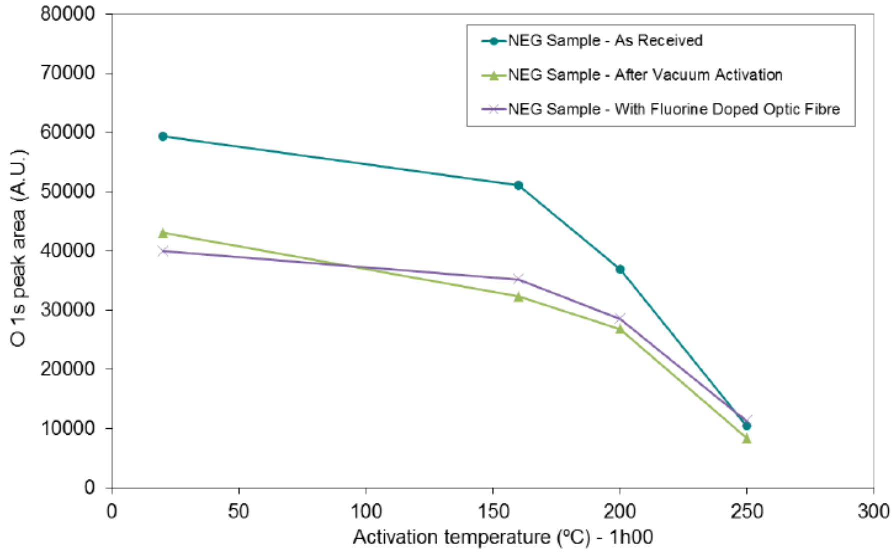
- Few tests done to validate the use of small not conventional components with NEG: Finally validated by XPS*

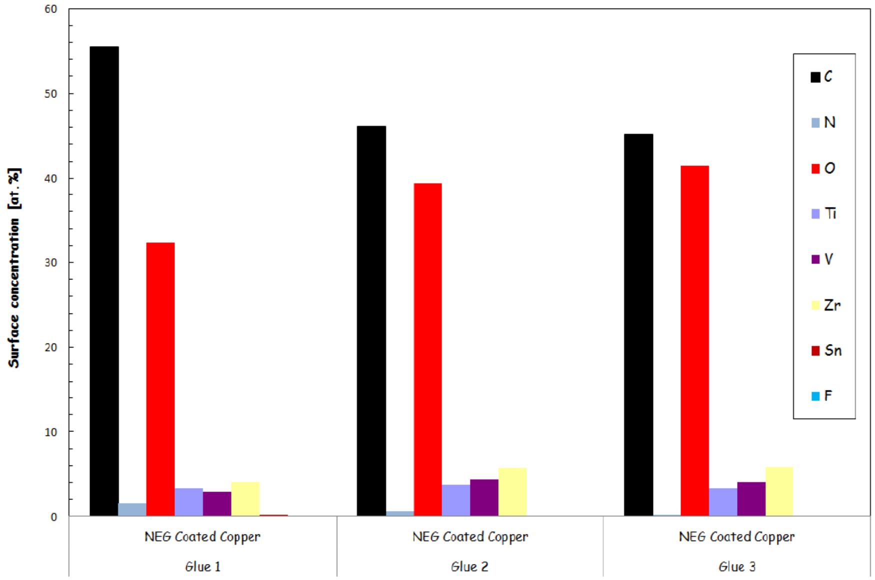
Chamber 2
NEG coated sample

	Chamber 1	Chamber 2
Step 1 – Temp for 24h	**250ºC**	**120ºC**
Step 2 - Temp for 24h	**150ºC**	**180-250ºC**

*X-ray photoelectron spectroscopy

XPS on NEG coated sample





NEG sample with fluorine doped optic fibre

NEG sample with 3 different glues

Courtesy: M. Taborelli