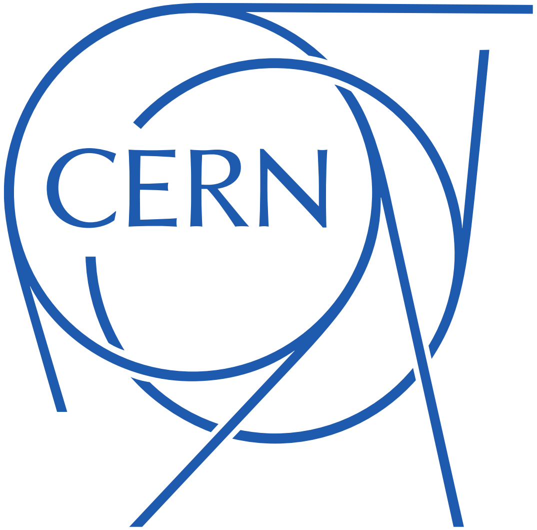

CERN

Vacuum Systems
Slot 6

V. Baglin

CERN TE-VSC, Geneva

Joint Universities Accelerator School

https://indico.cern.ch/event/1470062/timetable/?view=standard#day-2025-02-17

Outline

1. Photon induced molecular desorption
2. Vacuum instability and ion stimulated desorption
3. Particle losses and heavy ions stimulated desorption

1. Photon induced molecular desorption

Photodesorption

- The interaction of photons (light) with matters produce the **desorption of neutral gases** inside the vacuum system

- The photon stimulated desorption (PSD) of physisorbed (meV) or chemisorbed (eV) molecules can be direct or non-direct

- The identified transmitters are photoelectrons, secondary electrons and phonons

- The photon stimulated molecular desorption is a function of the nature of the material, its temperature, its surface state, and of the photon energy and the angle of irradiation.

- No model exists, therefore ***in-situ* qualification** of the material is required for the design of a future machine.

Photodesorption: present understanding

- The photodesorption process is linked to the production of photoelectrons and secondary electrons
- Photoelectrons contribute to the gas load by ESD

- The oxide and carbon layers are believed to be the source of gas
- The diffusion of atoms into the solid and their recombination at the surface plays a role

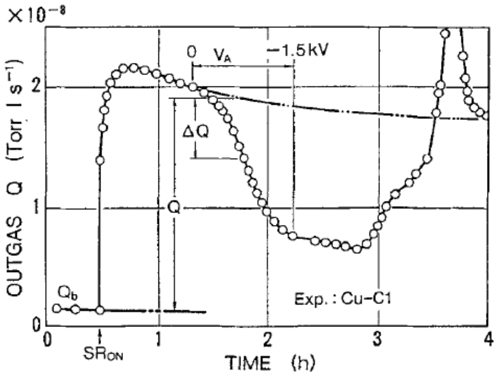


Fig. 5. Changes of outgas due to the bias voltage V_A.

T. Kobari *et al* Proc .of Vacuum Design of Synch Light Sources Conference, Argonne, 1990

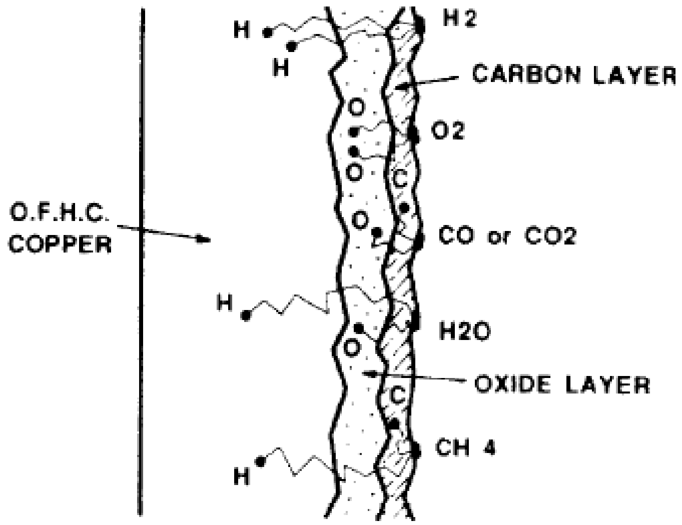
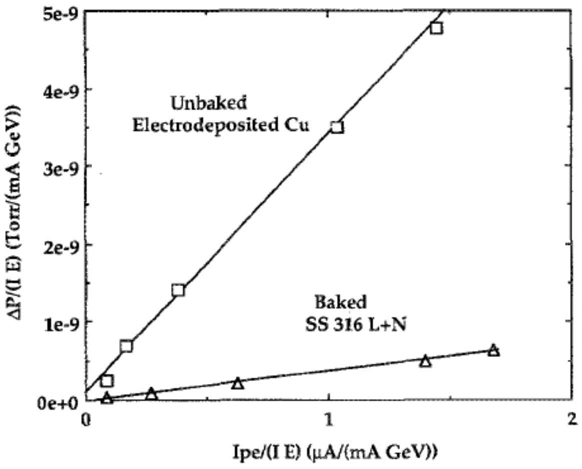


Fig. 6. Tentative Microscopic Model for PSD from OFHC Copper.

O. Gröbner *et. al.* EPAC 1992



J. Gómez-Goñi *et al.* JVSTA 12(4) Jul/Aug 1994, 1714

Dynamic pressure due to PSD

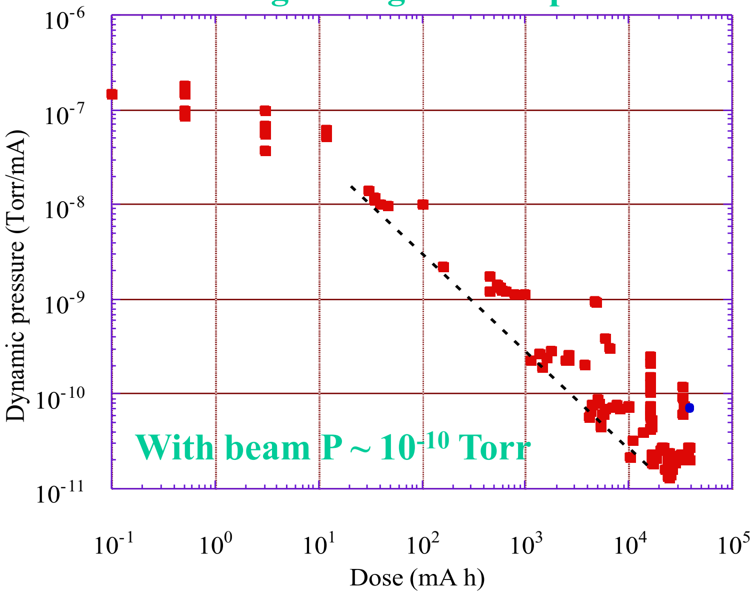
- The dynamic pressure decreases by several orders of magnitude with photon dose: “photon conditioning”
- The photon desorption yield is characterised by η_{photon}

$$\boxed{P = \frac{Q + \eta_{Photons}\,\dot{\Gamma}_{Photons}}{S}}$$

Dynamic pressure:

$$P = \frac{\eta_{Photons}\,\dot{\Gamma}_{Photons}}{S}$$

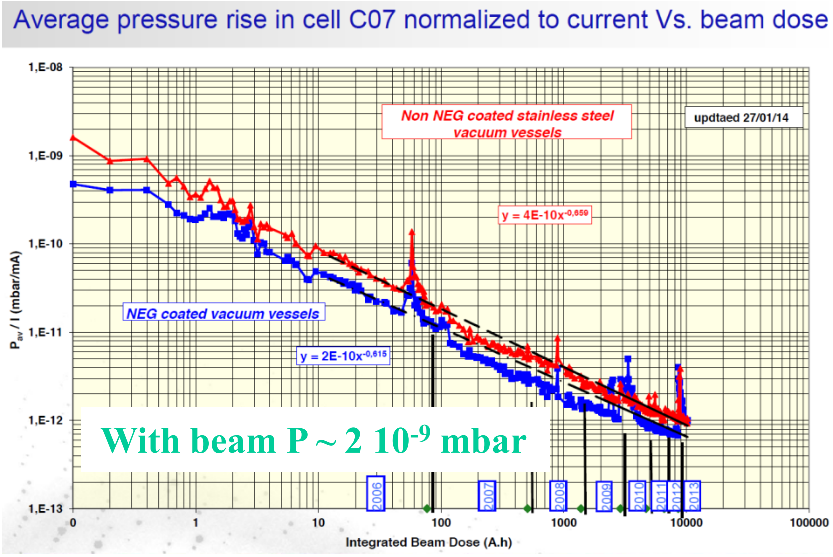
Beam cleaning during the first period of LEP



With beam $P \sim 10^{-10}$ Torr

O. Gröbner. Vacuum 43 (1992) 27-30

SOLEIL



Average pressure rise in cell C07 normalized to current Vs. beam dose

With beam $P \sim 2\ 10^{-9}$ mbar

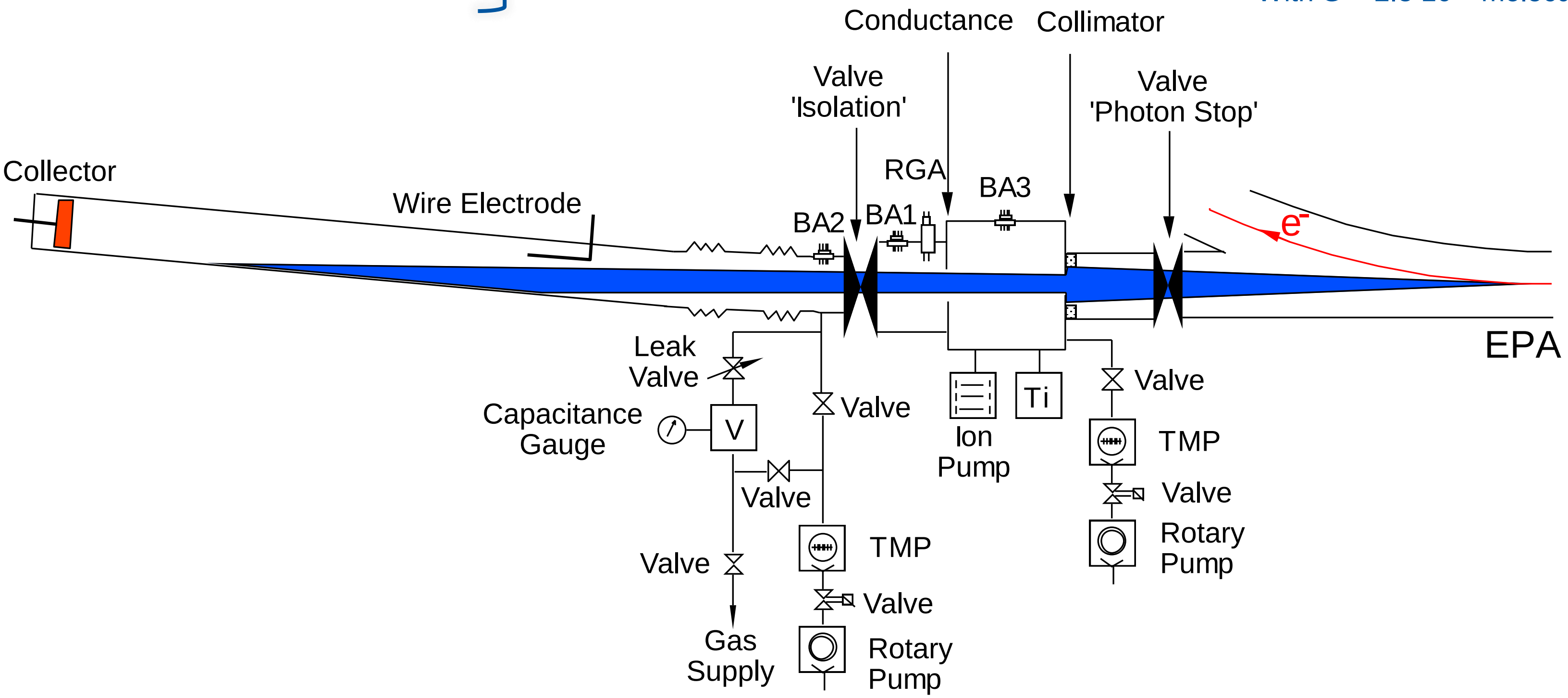
C. Herbeaux, Journée thématiques RTVide, décembre 2014

Photo-desorption yield measurement

- SR light is extracted from a dipole magnet to irradiate the test chamber at ~ 11 mrad
- SR fan is vertically collimated therefore photon flux < 4 eV are attenuated
- The gas load is measured by the throughput method via a conductance (72.5 ℓ/s for N_2)
- A wire and a collector are biased for current measurement to estimate the photon reflectivity and photoelectron yield

$$\left.\begin{aligned} Q_0 &= C\,(P_2 - P_1) \\ Q &= \eta\dot{\Gamma} + Q_0 = C\,(P_2' - P_1') \end{aligned}\right\} \quad \eta = \frac{G}{\dot{\Gamma}}\,C\,(\Delta P_2 - \Delta P_1) \approx \frac{G}{\dot{\Gamma}}\,C\Delta P_2$$

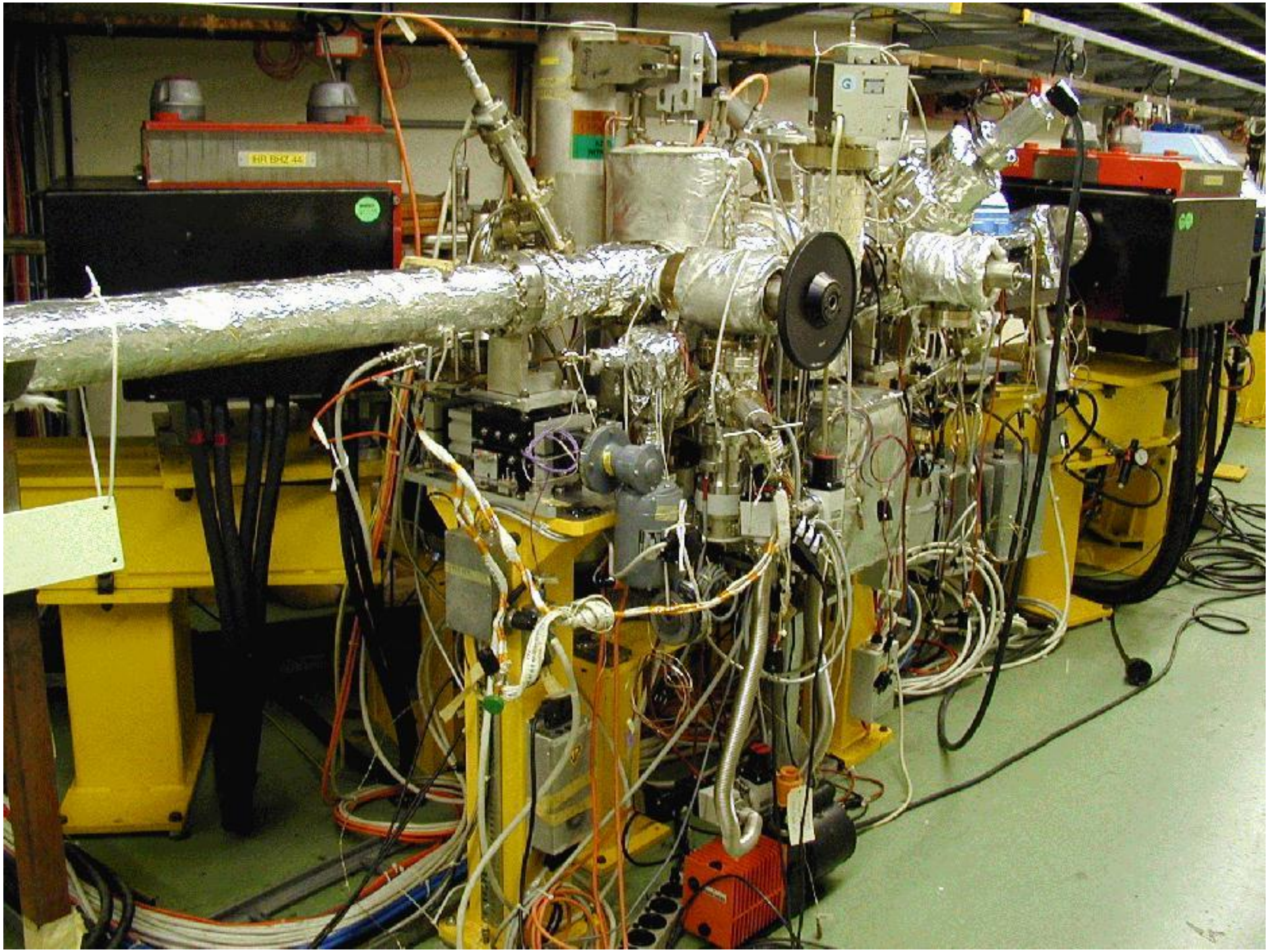
With G = 2.5 10^{19} molecules/mbar.ℓ at RT



J. Gómez-Goni et al. J. Vac. Sci. Technol. A 12(4), Jul/Aug 1994, 1714

V. Baglin *et al.* EPAC 1998, Stockholm, Sweden.

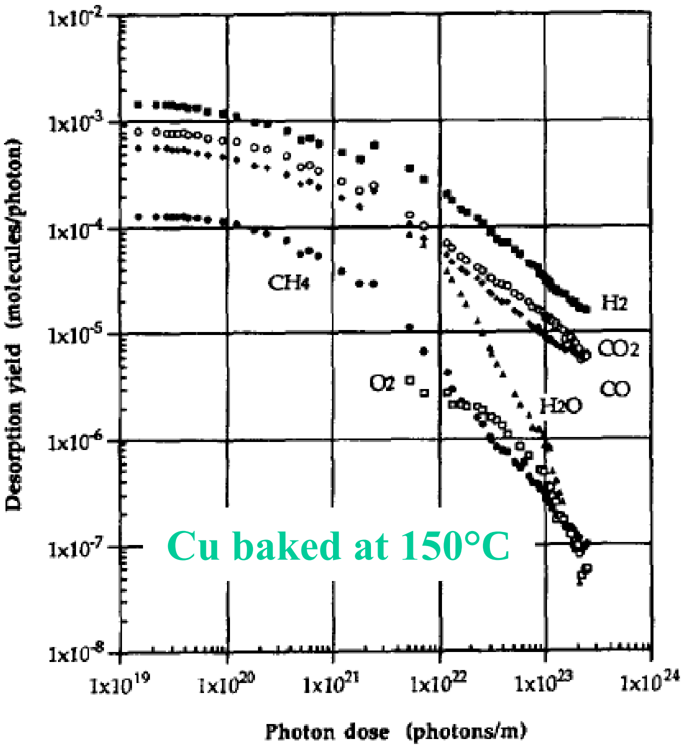
CERN EPA Synchrotron Light Facility 42 - 1999



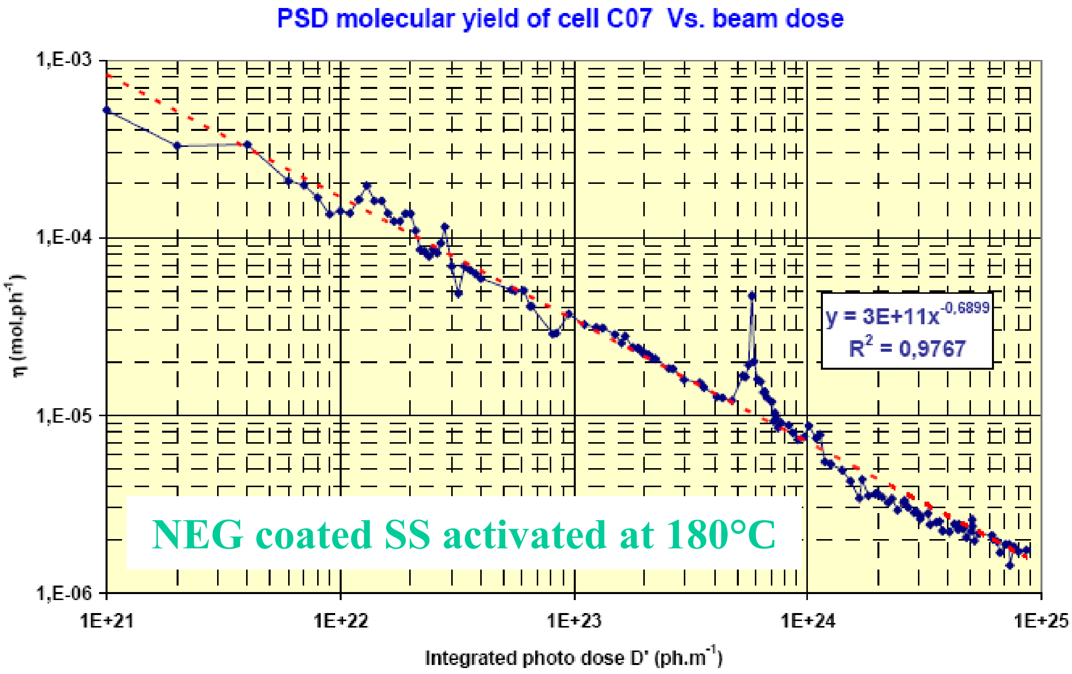
The LEP Pre-Injector as a multipurpose facility, J-P. Potier, L. Rinolfi, EPAC 1998, Stockholm, Sweden, 1998

Conditioning under photon irradiation

- Typical desorption yield range: from 10^{-3} molecule/photon to 10^{-6} when conditioned



O. Gröbner *et al.*
J.Vac.Sci. 12(3), May/Jun 1994, 846-853



C. Herbeaux *et. al.* EPAC 2008, Genoa, Italy

$$\eta_{Photons} = \eta_0 \left(\frac{D}{D_0} \right)^{-a}$$

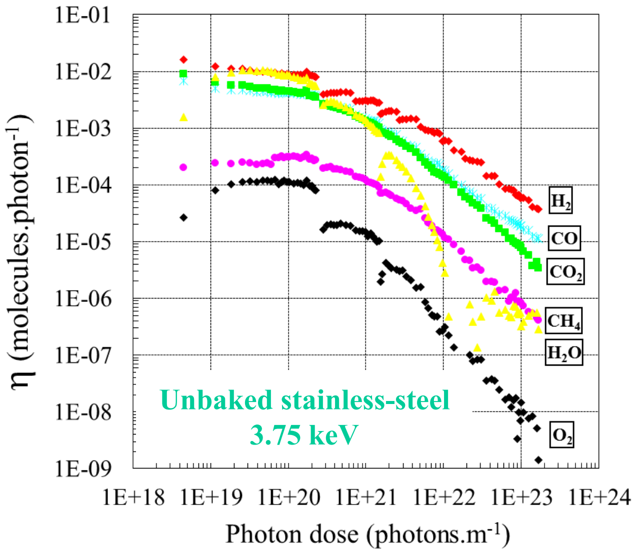
- The hydrogen desorption is characterised by a diffusion process: a = 0,5

M. Andritschky *et al.*, Vacuum 38 (8-10), 933, (1988)

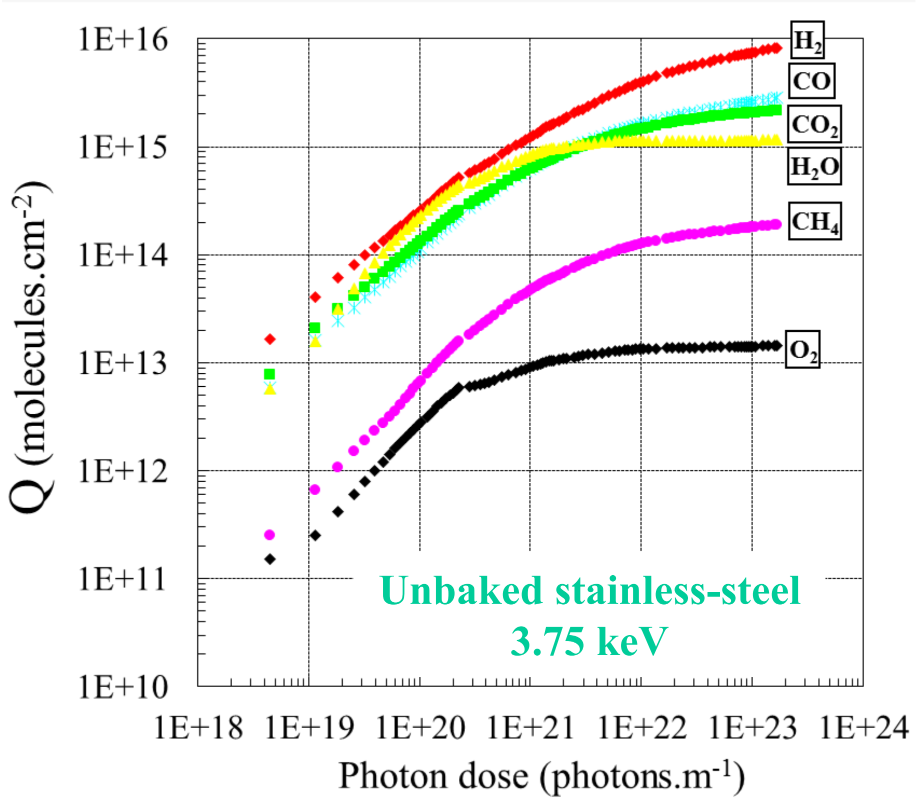
a ~ 0,9-1,3

Gas load

- The total desorbed quantity amounts to 15 monolayers for an unbaked system



$$Q = \int \eta d\Gamma$$



Gas	H_2	CH_4	H_2O	CO	CO_2	Total
molecules/ cm^2 x 10^{15}	8.1	0.2	1.1	2.8	2.2	**14.4**

C. Herbeaux *et al.* JVSTA 17(2) Mar/Apr 1999, 635

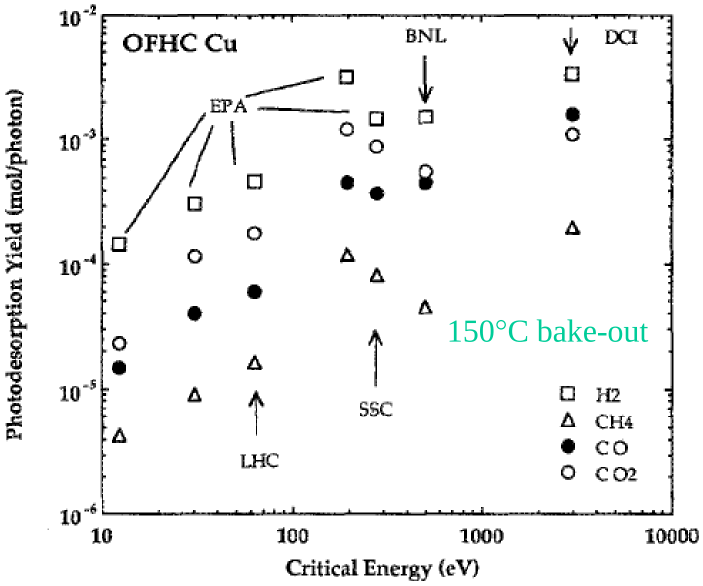
Evolution with critical energy

- At low energy, the photoelectric effect dominates: linear trend until ~ 5 keV

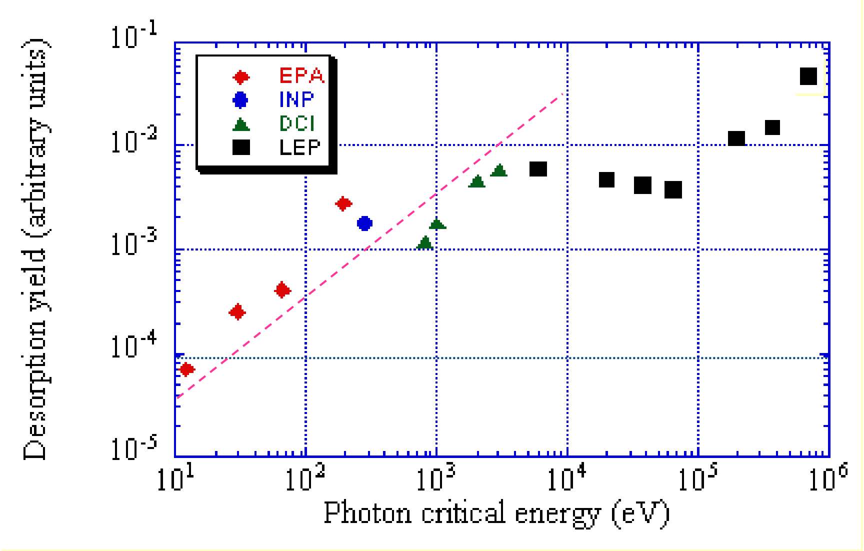
- Above a few 100 keV, Compton diffusion dominates and produce a cascade of energetic recoil electrons with a diffusion of secondary photons

$\eta(H_2) \sim E_c^{0.74}$, $\eta(CH_4) \sim E_c^{0.94}$

$\eta(CO) \sim E_c^{1.01}$, $\eta(CO_2) \sim E_c^{1.12}$



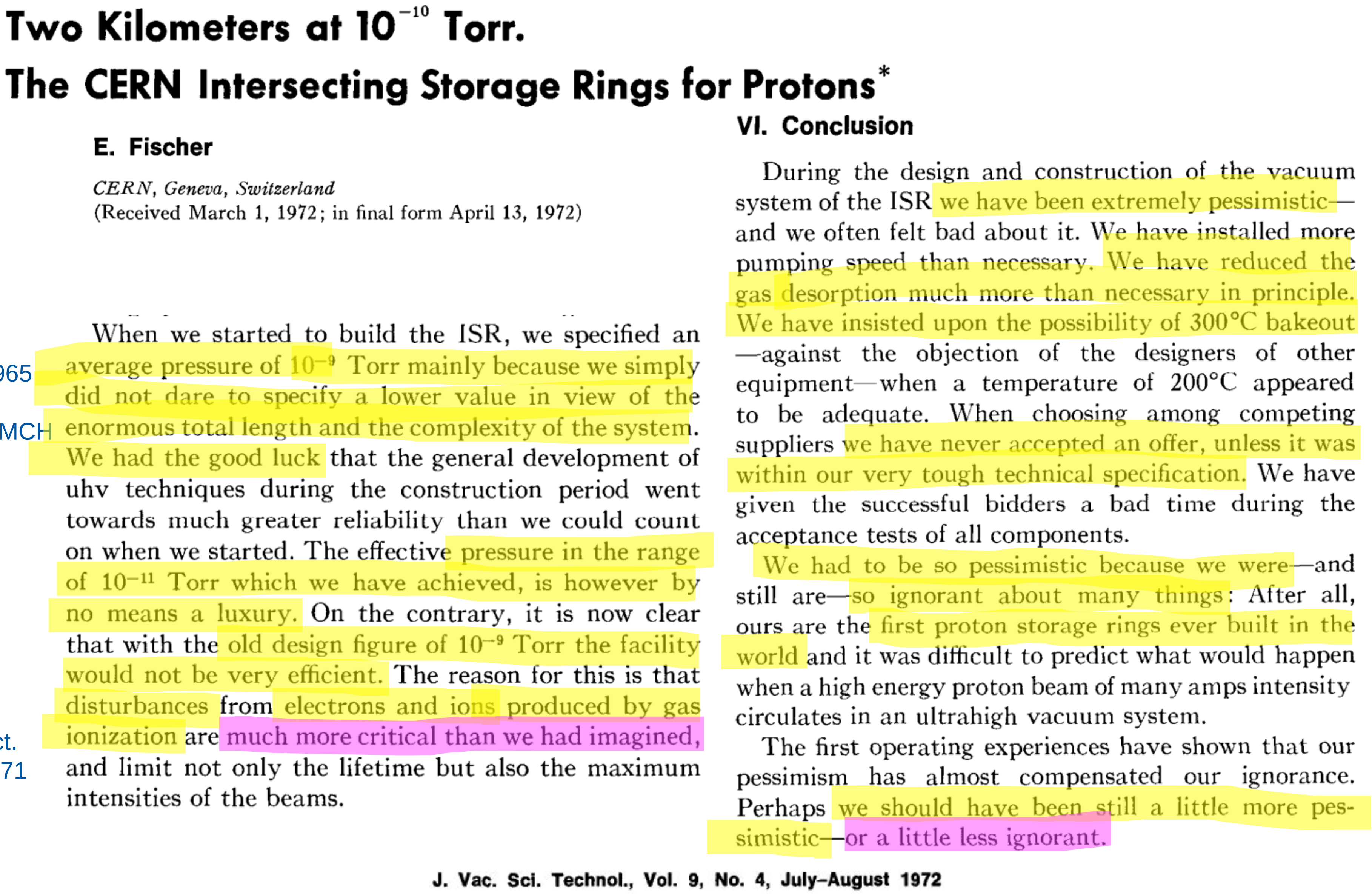
J. Gómez-Goñi *et al.* JVSTA 12(4) Jul/Aug 1994, 1714



O. Gröbner. CAS 99-15

2. Vacuum instability and ion stimulated desorption

A lesson from history



Two Kilometers at 10^{-10} Torr.

The CERN Intersecting Storage Rings for Protons*

E. Fischer

CERN, Geneva, Switzerland

(Received March 1, 1972; in final form April 13, 1972)

When we started to build the ISR, we specified an average pressure of 10^{-9} Torr mainly because we simply did not dare to specify a lower value in view of the enormous total length and the complexity of the system. We had the good luck that the general development of uhv techniques during the construction period went towards much greater reliability than we could count on when we started. The effective pressure in the range of 10^{-11} Torr which we have achieved, is however by no means a luxury. On the contrary, it is now clear that with the old design figure of 10^{-9} Torr the facility would not be very efficient. The reason for this is that disturbances from electrons and ions produced by gas ionization are much more critical than we had imagined, and limit not only the lifetime but also the maximum intensities of the beams.

1965

7 MCH

Oct. 1971

VI. Conclusion

During the design and construction of the vacuum system of the ISR we have been extremely pessimistic—and we often felt bad about it. We have installed more pumping speed than necessary. We have reduced the gas desorption much more than necessary in principle. We have insisted upon the possibility of 300°C bakeout—against the objection of the designers of other equipment—when a temperature of 200°C appeared to be adequate. When choosing among competing suppliers we have never accepted an offer, unless it was within our very tough technical specification. We have given the successful bidders a bad time during the acceptance tests of all components.

We had to be so pessimistic because we were—and still are—so ignorant about many things: After all, ours are the first proton storage rings ever built in the world and it was difficult to predict what would happen when a high energy proton beam of many amps intensity circulates in an ultrahigh vacuum system.

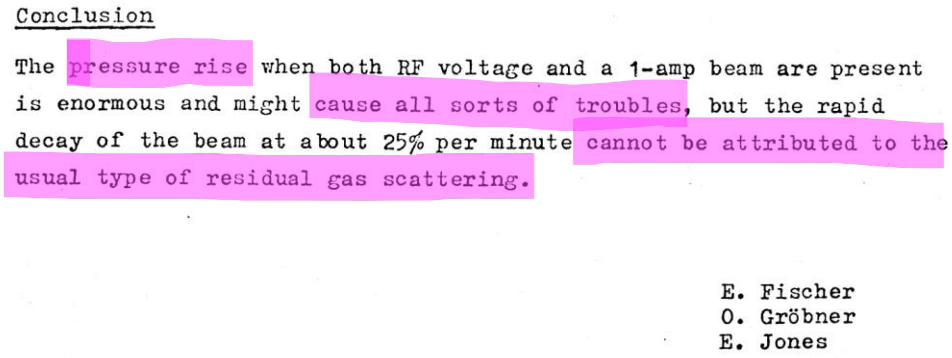
The first operating experiences have shown that our pessimism has almost compensated our ignorance. Perhaps we should have been still a little more pessimistic—or a little less ignorant.

J. Vac. Sci. Technol., Vol. 9, No. 4, July–August 1972

Vacuum Instability : the Effect

- In circular machine with large proton current :
  Intersecting Storage Rings (routine 40 A, record 57 A), LHC (0.6 A)

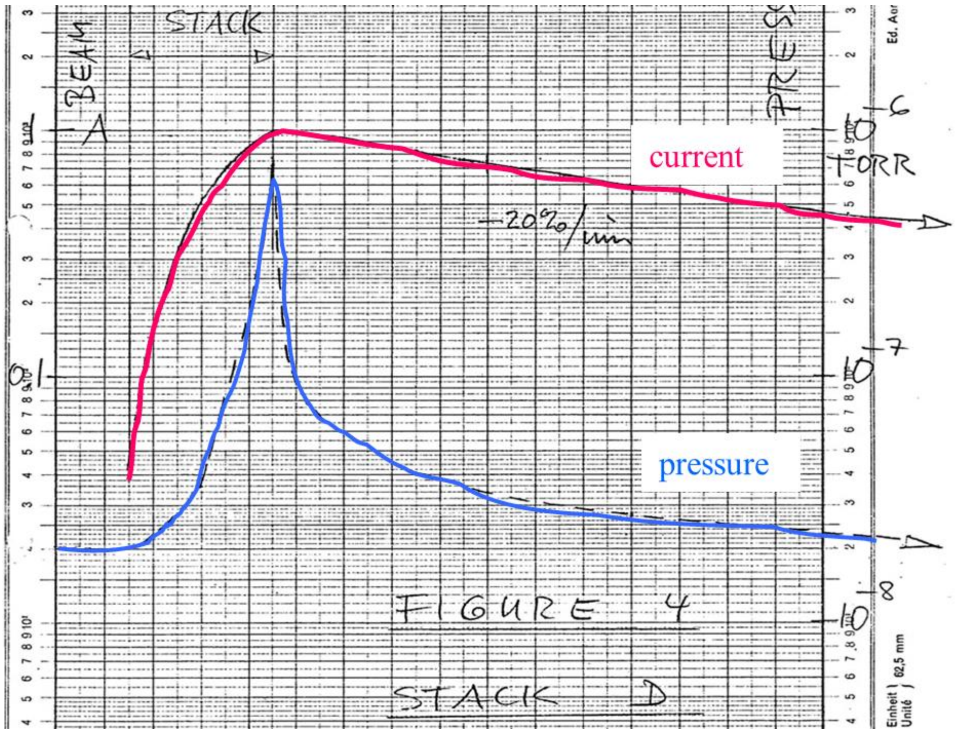
- Beam current stacking to 1 A
- Pressure increases to 10^{-6} Torr (x 50 in a minute)
- Beam losses



Conclusion

The pressure rise when both RF voltage and a 1-amp beam are present is enormous and might cause all sorts of troubles, but the rapid decay of the beam at about 25% per minute cannot be attributed to the usual type of residual gas scattering.

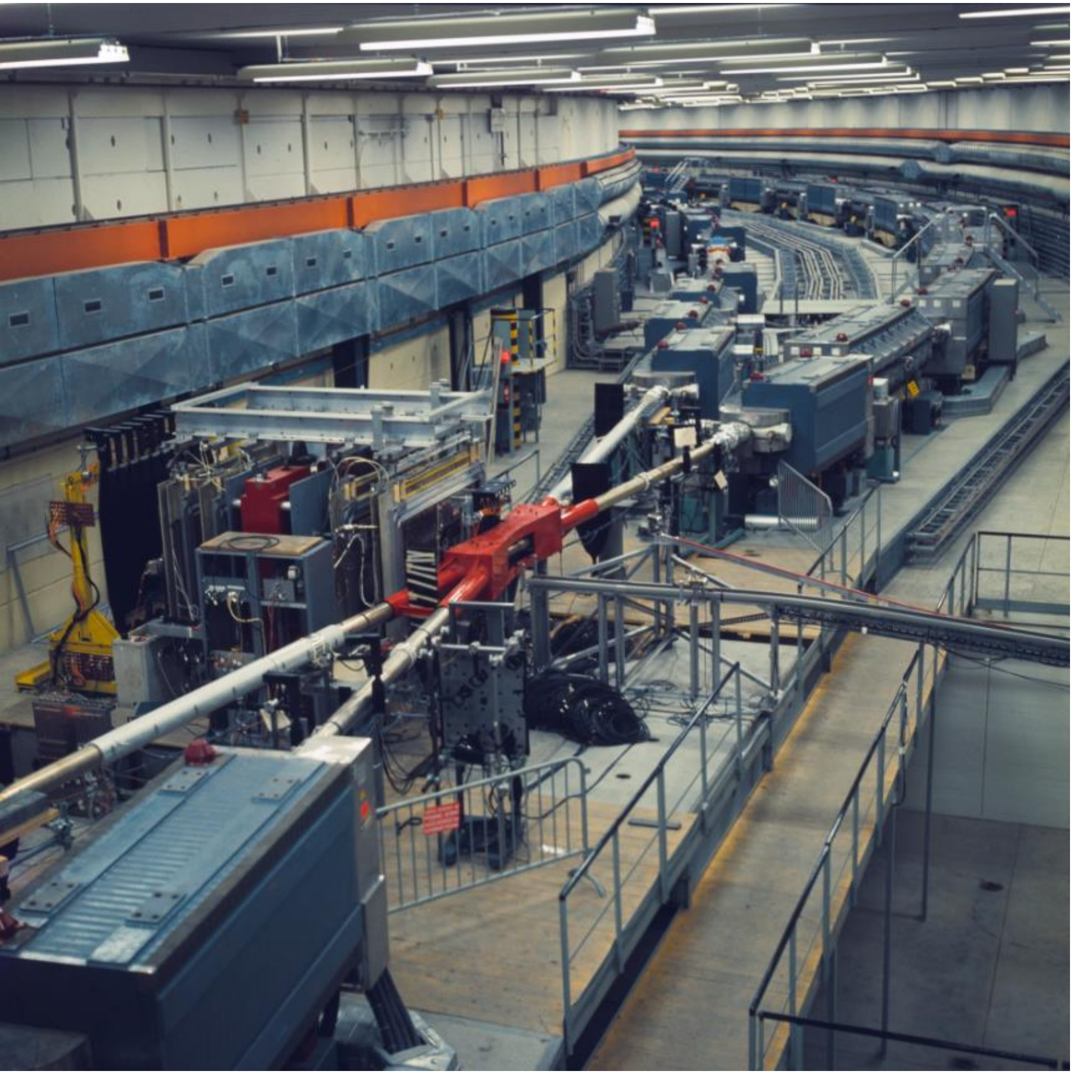
E. Fischer
O. Gröbner
E. Jones



First documented pressure bump in the ISR

E. Fischer/O. Gröbner/E. Jones RUN8: 18/11/1970

Intersecting Storage Rings



August 1971

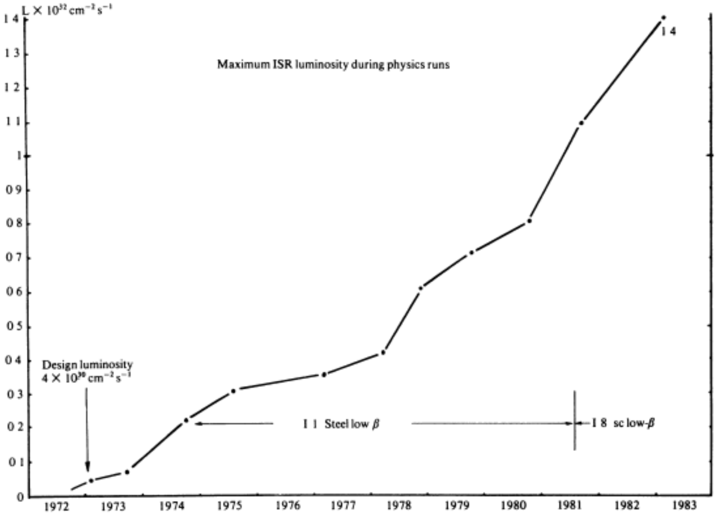


Fig 9 ISR luminosity during physics runs: September 1971 -- First ISR experiment to be completed, R101; maximum luminosity = 1 3 x 10^{29} cm^{-2} s^{-1}, December 1982 -- Highest luminosity achieved for physics (R807) = 1 4 x 10^{32} cm^{-2} s^{-1}

L: 4 10^{30} to 1.4 10^{33} Hz/cm^2

62 GeV in center of mass

30-40 A (until 57 A)

50-60 h fills (10 h turn over)

The mechanism of vacuum instability

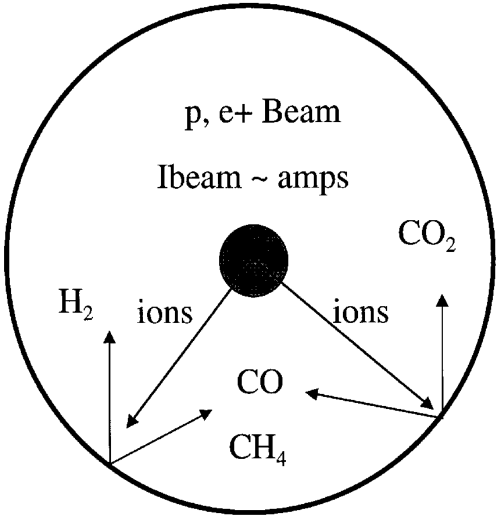
- Origin are ions produced by beam gas ionisation
- Reduction of the effective pumping speed, Seff

$$\boxed{V\frac{dP}{dt} = Q_0 + \eta_{ion}\sigma\frac{I}{e}P + C\frac{d^2P}{dx^2}}$$

- Quasi stationary long tube (C=0)

$$Q_0 + \eta_{ion}\sigma\frac{I}{e}P = P\,S_{eff}$$

$$\boxed{P = \frac{Q_0}{S_{eff}\left(1 - \frac{\eta_{ion}}{S_{eff}}\sigma\frac{I}{e}\right)}}$$

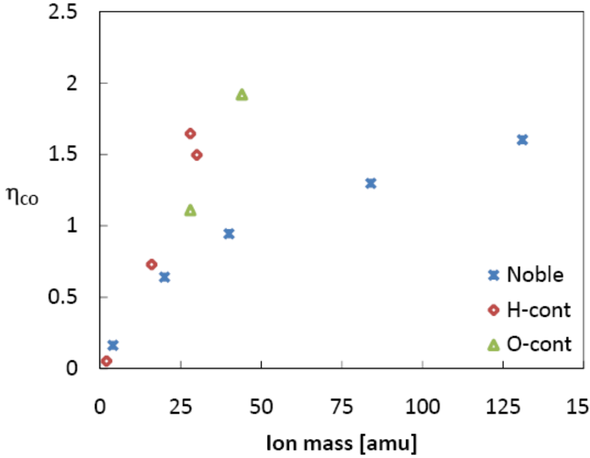


- When the beam current approach the **critical current**, the pressure increases to infinity

$$\boxed{(\eta_{ion}I)_{crit} = \frac{e\,S_{eff}}{\sigma}}$$

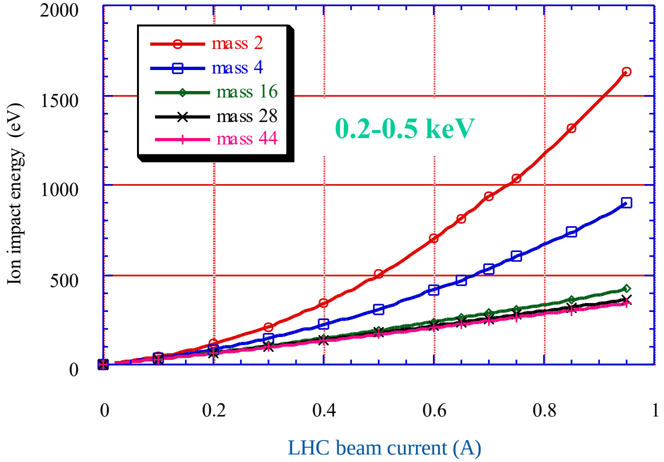
Ion desorption yield

- Varies with the material, the ion energy and ion species
- Several units of molecules can be desorbed by ions ➔ Sputtering

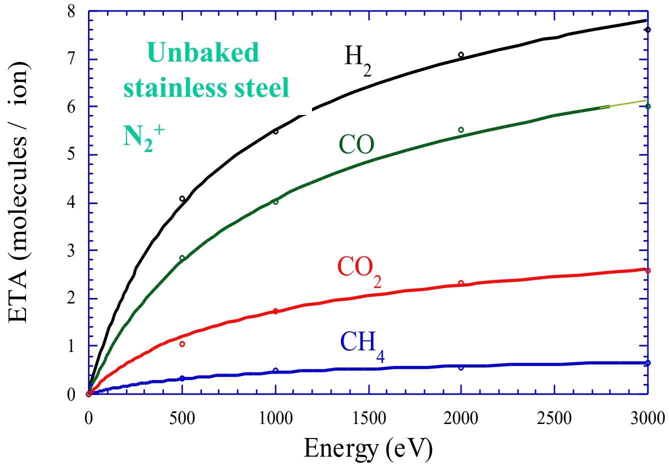


He^+, Ne^+, Ar^+, Kr^+, Xe^+
H_2^+, CH_4^+,$C_2H_4^+$, $C_2H_6^+$
CO^+,N_2^+,CO_2^+

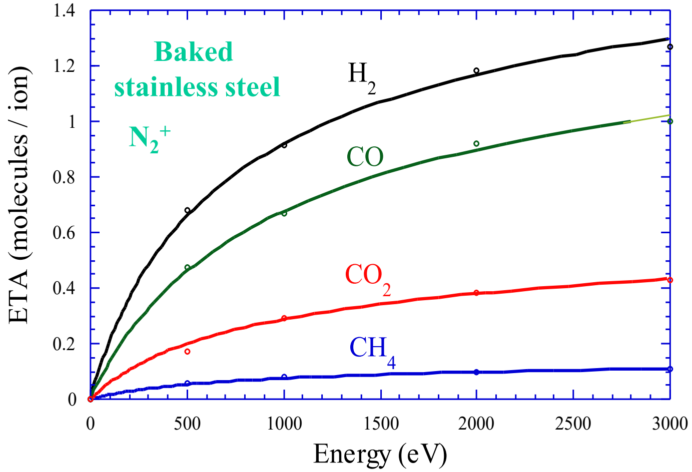
G. Hulla, PhD Thesis, Vienna Tech. U, 2009



O. Gröbner, CERN 99-05



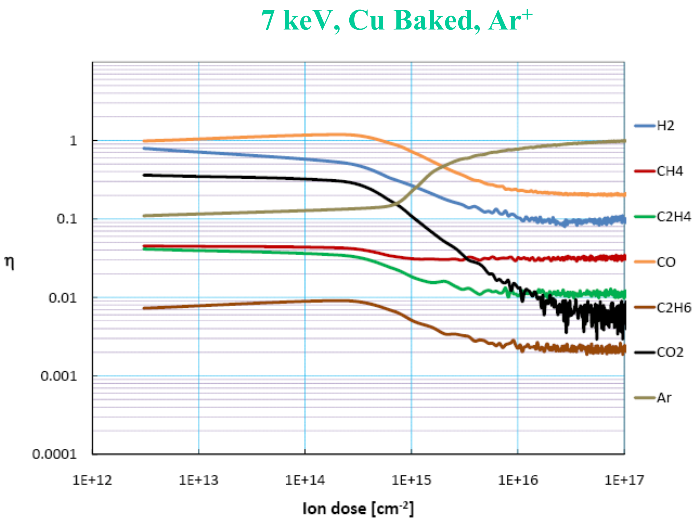
A.G. Mathewson, CERN ISR-VA/76-5



A.G. Mathewson, CERN ISR-VA/76-5

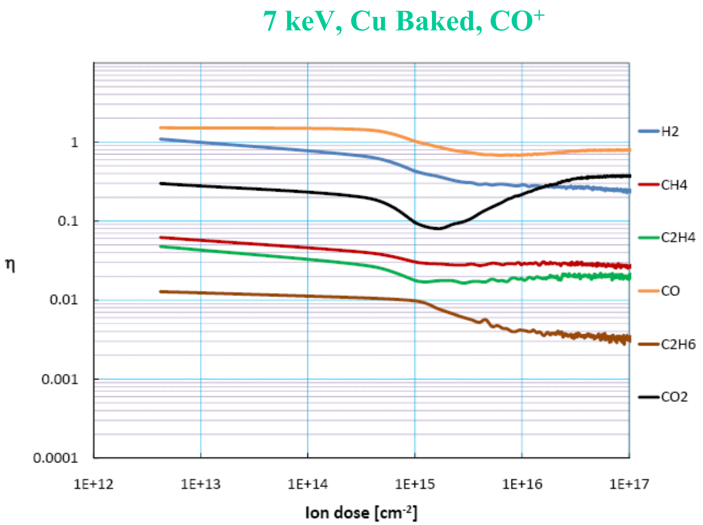
Conditioning and implantation

- A conditioning is observed but at high dose, some ions can be implanted !



7 keV, Cu Baked, Ar^+

G. Hulla, PhD Thesis, Vienna Tech. U, 2009



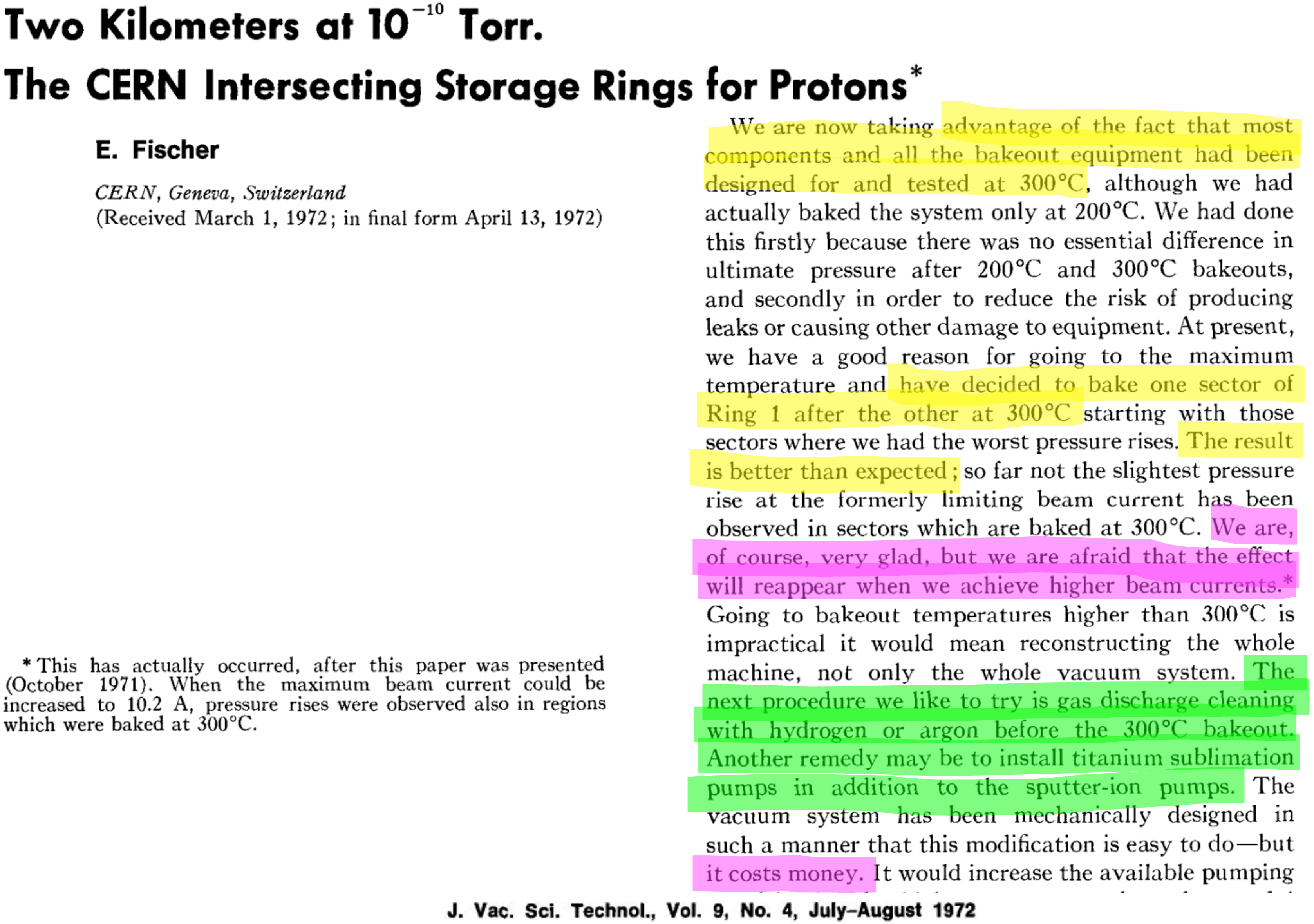
7 keV, Cu Baked, CO^+

G. Hulla, PhD Thesis, Vienna Tech. U, 2009

- In the LHC : the maximum flux is about 3 10^8 ions/(cm^2.s) *i.e.* a dose of 3 10^{15} ions/(cm^2.year)

- **In the LHC, there is no “beam” conditioning under ion bombardment**

A lesson from history - Epilogue



Two Kilometers at 10^{-10} Torr.

The CERN Intersecting Storage Rings for Protons*

E. Fischer

CERN, Geneva, Switzerland

(Received March 1, 1972; in final form April 13, 1972)

We are now taking advantage of the fact that most components and all the bakeout equipment had been designed for and tested at 300°C, although we had actually baked the system only at 200°C. We had done this firstly because there was no essential difference in ultimate pressure after 200°C and 300°C bakeouts, and secondly in order to reduce the risk of producing leaks or causing other damage to equipment. At present, we have a good reason for going to the maximum temperature and have decided to bake one sector of Ring 1 after the other at 300°C starting with those sectors where we had the worst pressure rises. The result is better than expected; so far not the slightest pressure rise at the formerly limiting beam current has been observed in sectors which are baked at 300°C. We are, of course, very glad, but we are afraid that the effect will reappear when we achieve higher beam currents.* Going to bakeout temperatures higher than 300°C is impractical it would mean reconstructing the whole machine, not only the whole vacuum system. The next procedure we like to try is gas discharge cleaning with hydrogen or argon before the 300°C bakeout. Another remedy may be to install titanium sublimation pumps in addition to the sputter-ion pumps. The vacuum system has been mechanically designed in such a manner that this modification is easy to do—but it costs money. It would increase the available pumping

---

* This has actually occurred, after this paper was presented (October 1971). When the maximum beam current could be increased to 10.2 A, pressure rises were observed also in regions which were baked at 300°C.

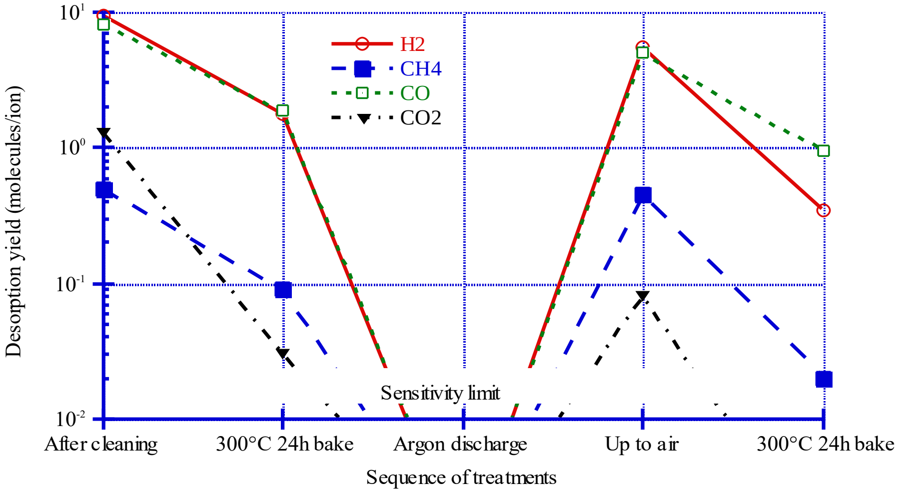
J. Vac. Sci. Technol., Vol. 9, No. 4, July–August 1972

ISR Remedy

- Beam cleaning being negligible:
  - Increase number of pumps
  - Reduce outgassing using 300°C bakeout
  - Perform ex-situ Ar/O_2 glow discharge cleaning with in-situ bakeout

$$(\eta_{ion} I)_{crit} = \frac{e S_{eff}}{\sigma}$$

➔ ηI_{Crit} increased to ~ 60 A and the machine could reached 57 A and 2×10^{-12} Torr!



A.G. Mathewson, CERN ISR-VA/76-5

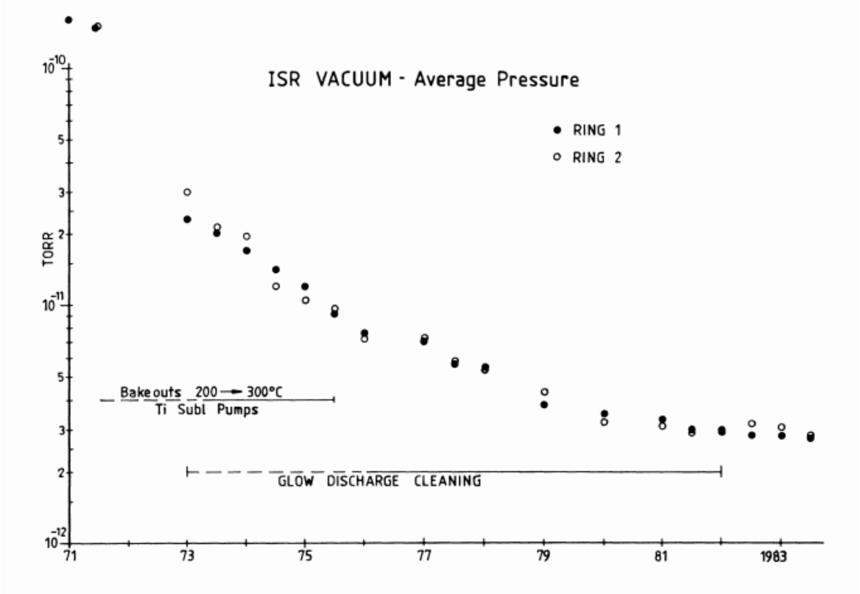


Fig 5 The average pressure of the ISR vacuum for the years 1971-83

M. Jacob and K. Johnsen, CERN 84-13, 1984

Vacuum Instability in J-Parc?

- J-Parc Rapid Cycling Synchrotron (RCS), Main Ring (MR) injector

- RF shielded (Cu stripes with capacitors) ceramic chambers in dipoles and quadrupoles and Ti chambers for straights

- Probable signature of Ion Stimulated Molecular Desorption

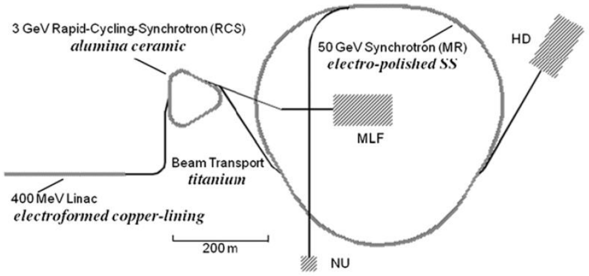


Fig. 1. Layout of the J-PARC and materials to be used for fabricating the cavity and the beam chambers. NU: neutrino to Super Kamiokande, HD: hadron experimental hall, and MLF: material and life science facility.

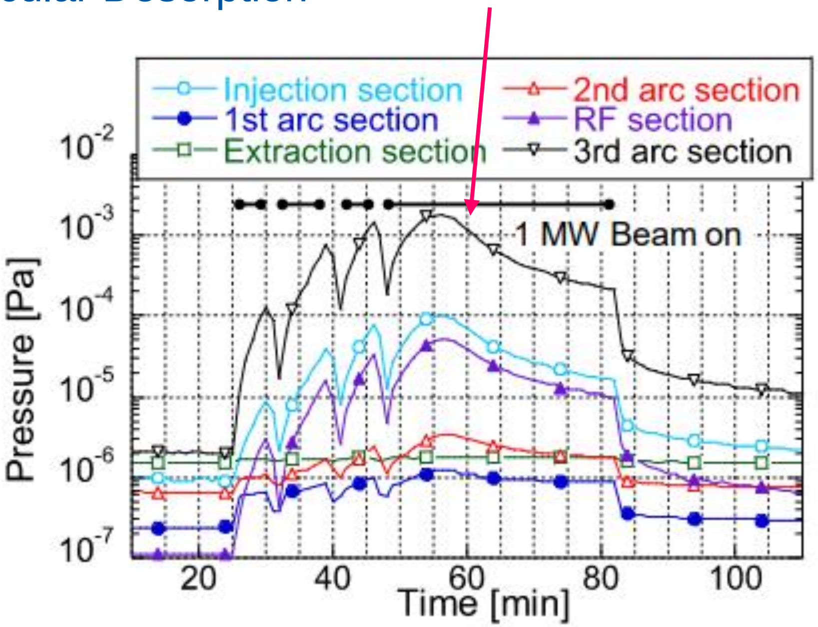


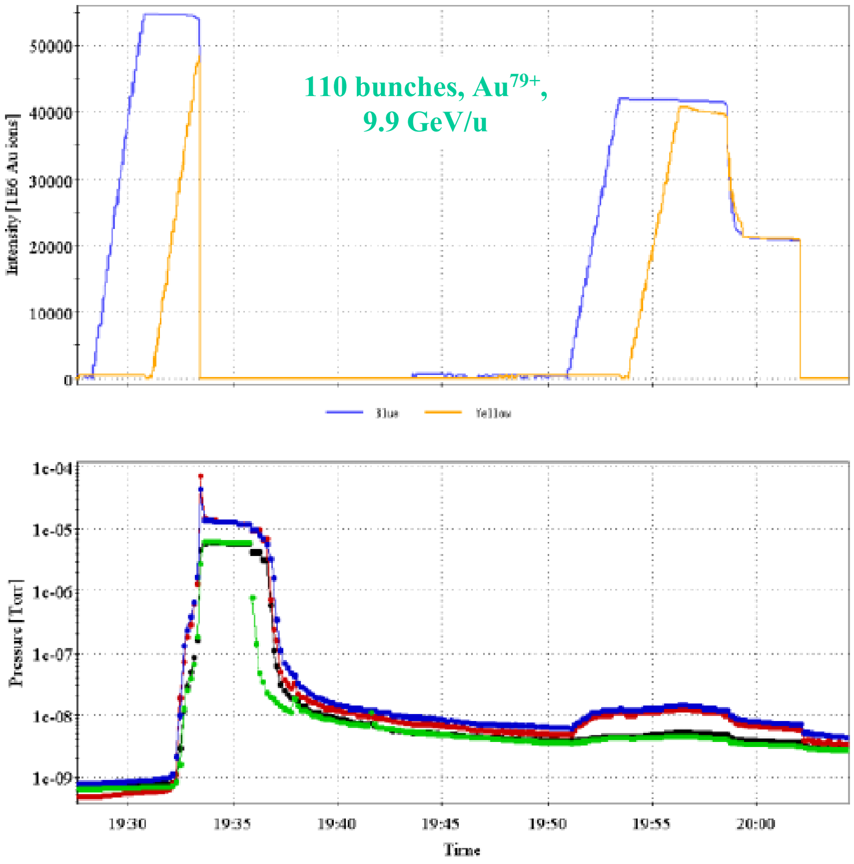
Fig. 3. Dynamic pressure in the beam line during the first beam operation trial with 1 MW beam power in July 2018.

J. Kamiya et al., JPS Conf. Proc. , 011023 (2021)

3. Particle losses
and
heavy ion stimulated desorption

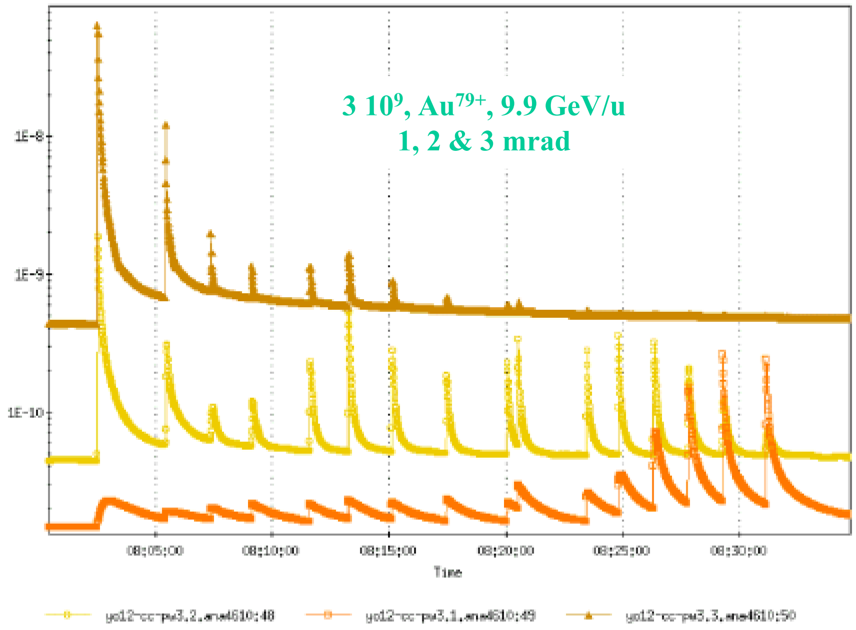
RHIC

- Loss of ions from a beam leads to large pressure increases: 10^{-8} …10^{-5} mbar!



110 bunches, Au^{79+}, 9.9 GeV/u

W. Fischer *et. al.* EPAC 2002, Paris, France



3 10^9, Au^{79+}, 9.9 GeV/u
1, 2 & 3 mrad

W. Fischer *et. al.* EPAC 2006, Edinburgh, Scotland

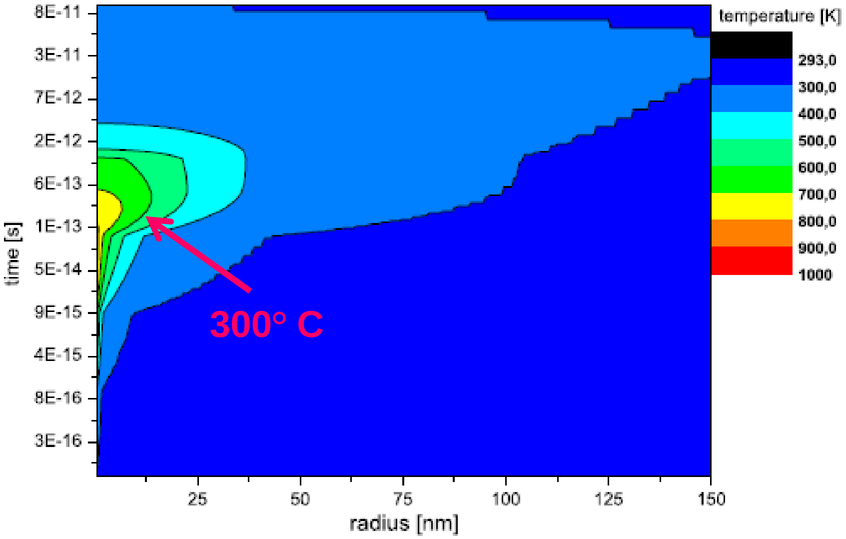
Mecanism

- Surface effect (except diffusion H_2) due to a thermal activation
- « Inelastic thermal spike model » : a temperature map coupled to the thermal desorption model

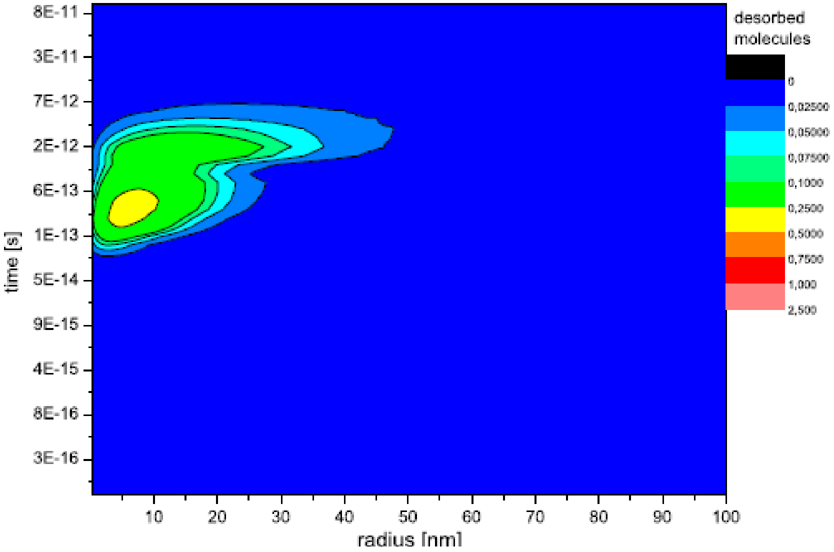
$$\eta = \int_0^{t_{max}} \int_0^{r_{max}} \nu_0(T(r,t)) \cdot \tilde{n}(r,t) \cdot \exp\left(-\frac{E_{des}}{k_B \cdot T(r,t)}\right) \cdot 2\pi \cdot r dr dt,$$

M. Bender *et al.* , NIM B 267 (2007) 885-890

Xe^{29+}, 1.4 MeV/u, Perpendicular



Temperature of atomic Cu subsystem after Xe impact



Desorbed particles per Xe per dt

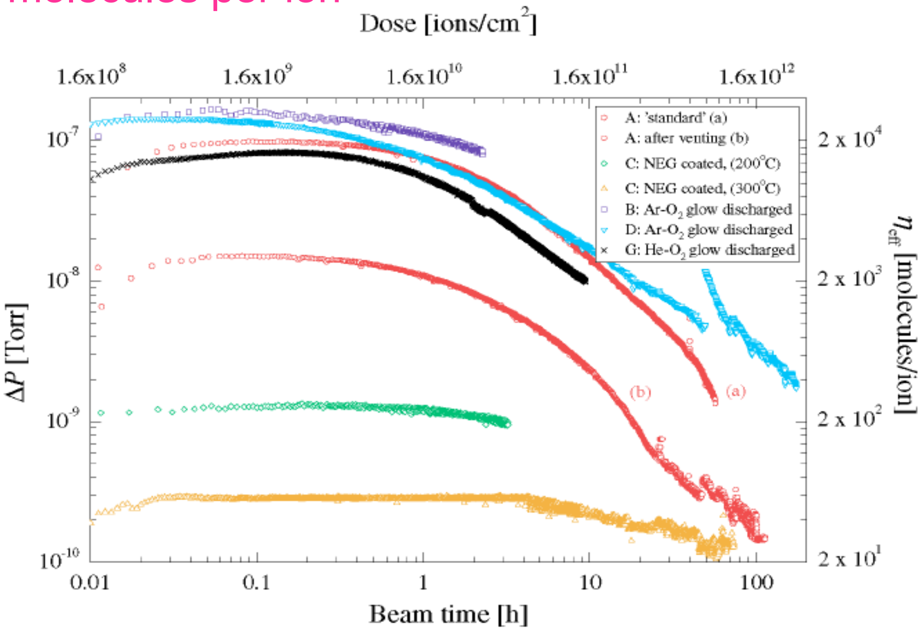
$$\eta_{calculated} = 185$$

High energy ions

- Desorption yields range from 20 – 20 000 molecules per ion

Pb^{53+}, 4. 2 MeV/u, 14 mrad

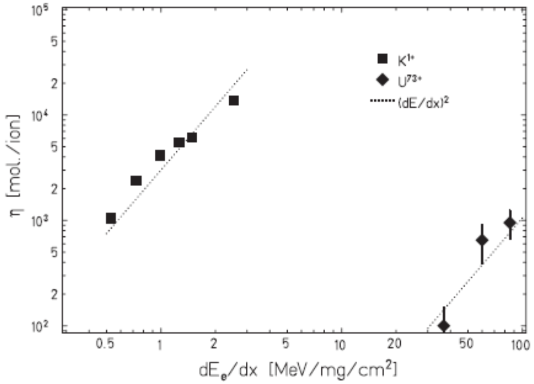
E. Mahner *et al.* ,
Phys. Rev. ST Accel. Beams 6, 013201 (2003)



- The desorption is determined by the energy given to the electrons (electronic stopping force)

$$\eta_{ion} \propto \left(\frac{dE_e}{dx}\right)^2$$

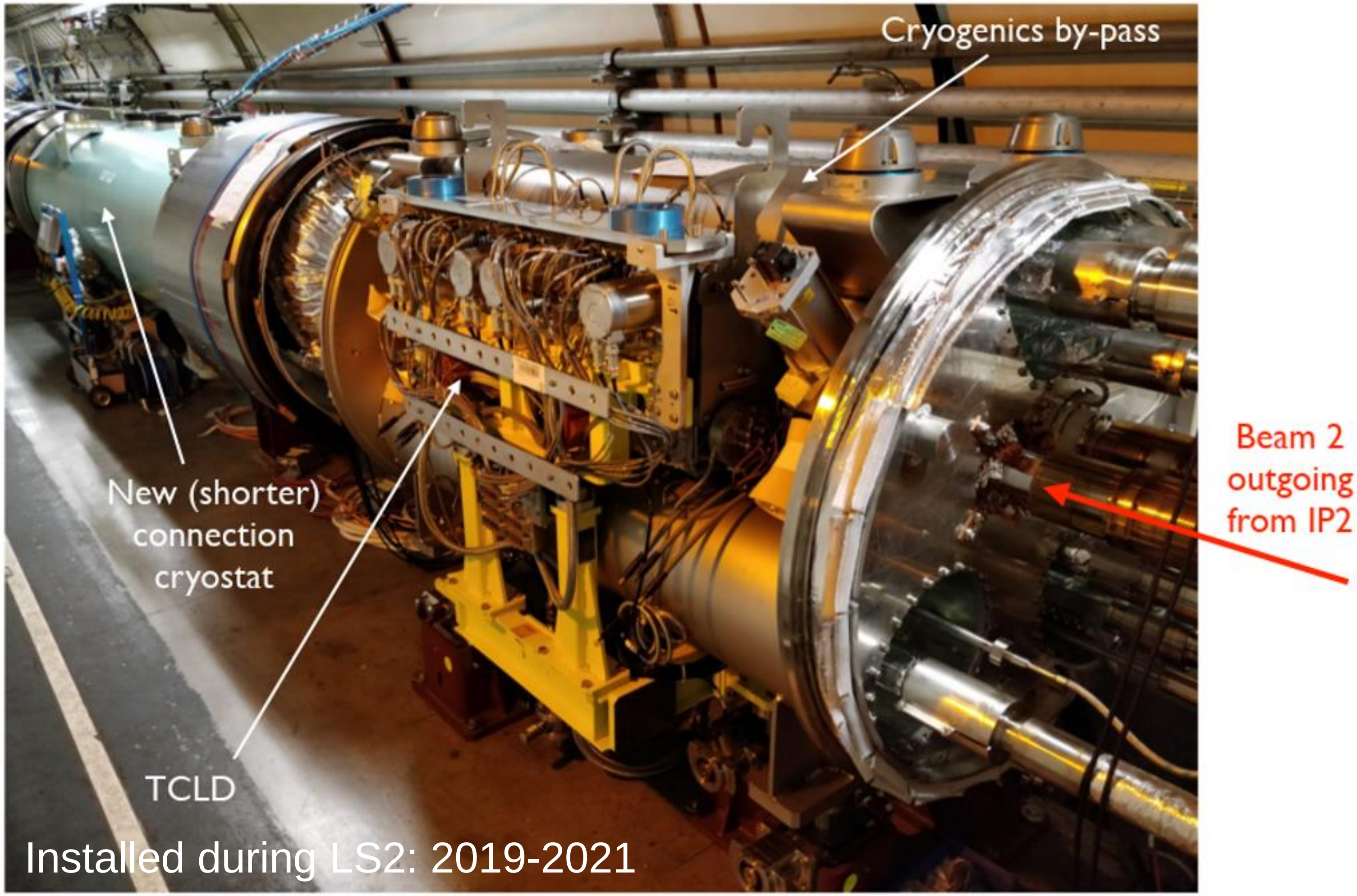
L. Prost *et al.* , PRL 98, 064801 (2007)



- The desorption induced by the electrons is the responsible mechanism

HL-LHC ions collimator

- Located in the LHC arcs around IP2 to intercept lead beams with modified charge produced at the interaction point: Pb81$^+$ instead of PB82$^+$
- W jaws



Installed during LS2: 2019-2021

Courtesy S. Redaelli, F. Savary

Slot 7 summary

- In accelerators, the circulating beam can contribute to stimulate molecular desorption

- Those phenomenon can lead to much larger gas load than the thermal outgassing rate
  ➔ *« Dynamic pressure »*

- Photon stimulated desorption originates from SR

- Ion stimulated desorption originates from beam gas ionisation and can lead to vacuum instability

- Particle losses may trigger beam dumps / other unwanted phenomena

Thank you for your attention !!!

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