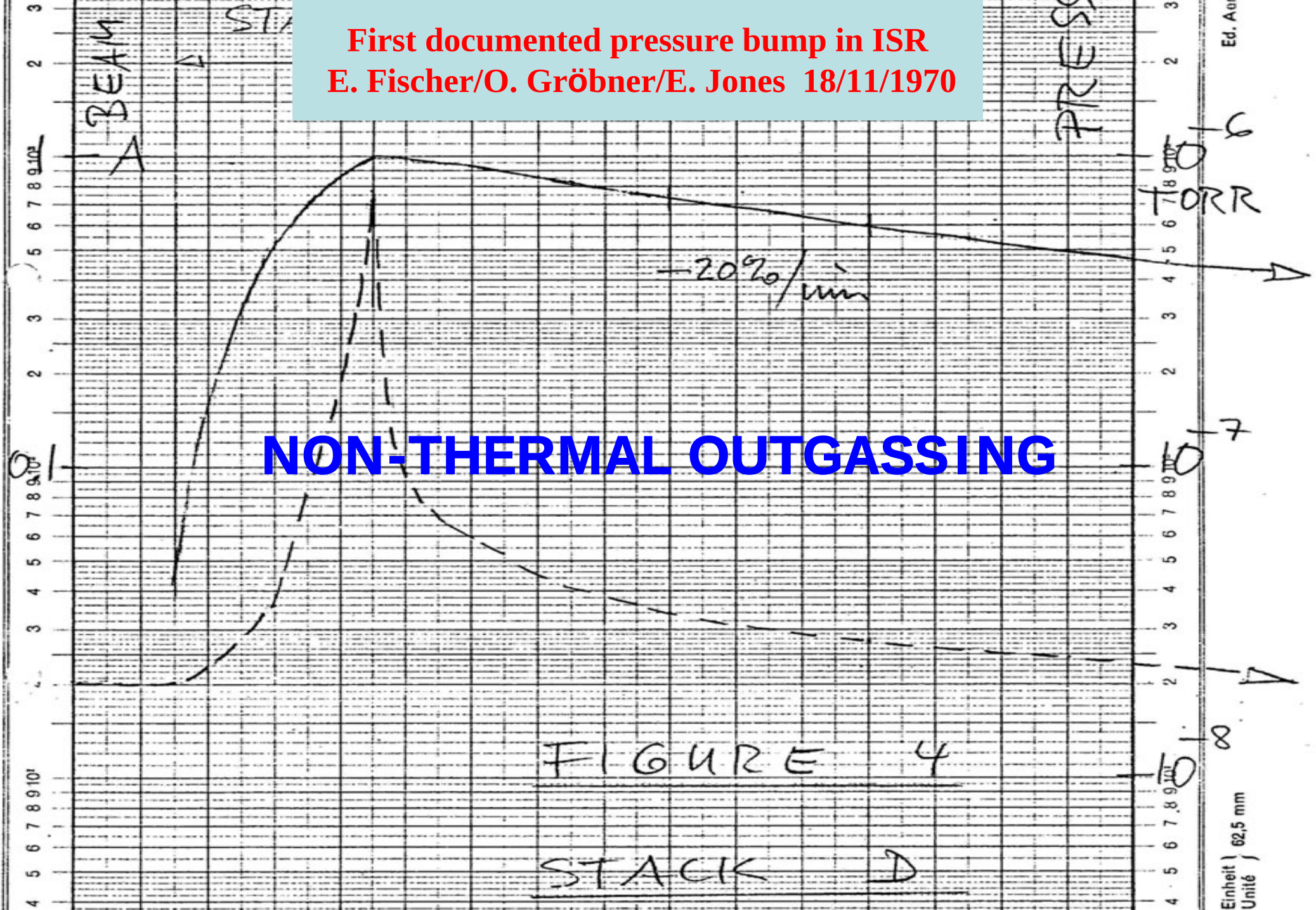

First documented pressure bump in ISR
E. Fischer/O. Gröbner/E. Jones 18/11/1970
BEAM
A
PRESSURE
TORR
-20%/mm
NON-THERMAL OUTGASSING
FIGURE 4
STACK D

NON-THERMAL OUTGASSING

- **AIM OF THE TALK**
  - **–ATTEMPT TO SUMMARIZE THE ACTUAL KNOWLEDGE USEFUL TO DESIGN AND OPERATE ACCELERATORS**
- **OUTLOOK OF THE TALK**
  - **–ION INDUCED DESORPTION**
  - **–ELECTRON INDUCED DESORPTION**
  - **–PHOTON INDUCED DESORPTION**
  - **–THE CASE OF COLD SYSTEMS**
- **CONCLUSIONS**
- **THANKS**
  - **–To my colleagues for their help and patience. Have specially suffered: V. Baglin, D. Brandt, E. Mahner, P.Strubin**

NON-THERMAL OUTGASSING

- **HISTORY**
  - **–BIBLIOGRAPHY:**
    - *P.A. REDHEAD* VACUUM *48, 585-596 (1997)*
    - *D. MENZEL NIM B101, 1-10 (1995)*
    - *T.E. MADEY SURFACE SCIENCE 299/300, 824-836 (1994)*

NON-THERMAL OUTGASSING

- **HISTORY**

  –THE START:

A new Method of Positive Ray Analysis

A. J. Dempster

Ryerson Physical Laboratory, Chicago

Phys. Rev. 11, 316-325 (1918)

RYERSON PHYSICAL LABORATORY,
CHICAGO,
October 20, 1917.

A NEW METHOD OF POSITIVE RAY ANALYSIS.

BY A. J. DEMPSTER.

THE analysis of positive rays is based on the determination of the ratio of the charge to the mass of various constituents. The corre-

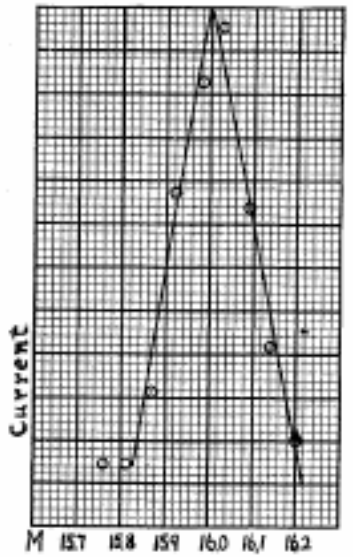
VOL. XI.] No. 4. *POSITIVE RAY ANALYSIS.* 323

POSITIVE IONS FROM ELECTRON BOMBARDMENT.

It was thought that the bombardment of salts by electrons might break up the chemical compounds and give rise to many positive ions. Although the aluminium phosphate was chemically pure, the rays obtained under the bombardment of 128 volt electrons were very complex; the following ions were observed besides a couple of unresolved groups; H_1, H_2, Li (weak), O_1 (strong), Na (strong), O_3 (?) (weak), $M = 62$ (weak, possibly Na_2O), $M = 67$ (strong, possibly $H_3PO_2 = 66$), $M = 76$ (strong), $M = 86$ (weak, possibly Rb = 85.5), $M = 112$ (strong, possibly $P_2O_3 = 110$).

The experiments indicated the convenience of the method of obtaining positive rays and opened up an interesting field for investigation.

The experiments were however first directed

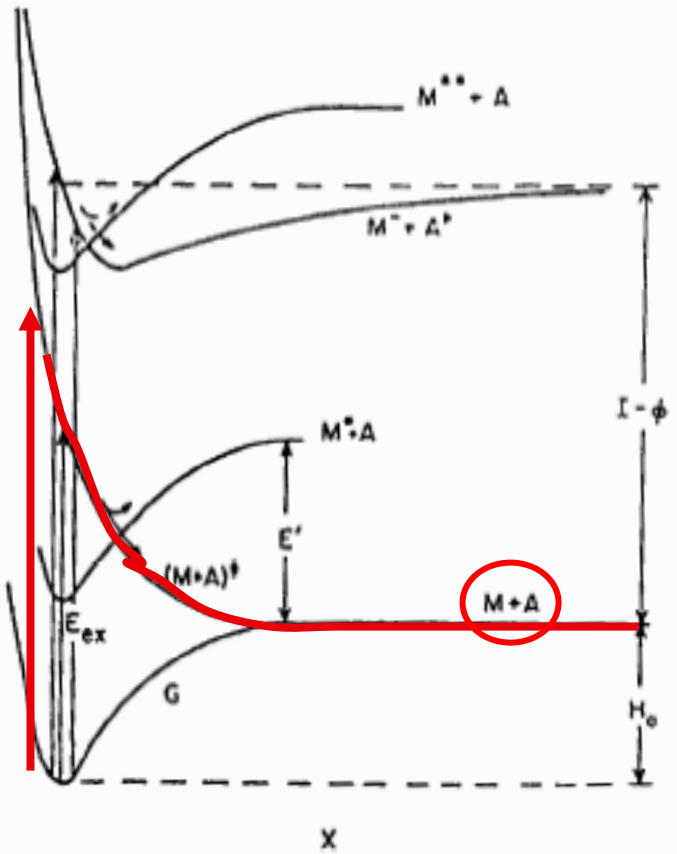


NON-THERMAL OUTGASSING

- **HISTORY**
  - **–THE TUBE INDUSTRY (1930)**
    - *EMPIRICAL STUDIES TO EXTEND CATHODES LIFETIME ("poisoning")*
    - *ESD THRESHOLD ALREADY ANTICIPATED: "10V EFFECTS"*
  - **–STUDIES 0N VACUUM GAUGE LIMITATIONS (1960) P. REDHEAD**
  - **–THE LARGE DEVICES (1960)(cf. F. DYLLA'S TALK)**
    - *e^+e^- STORAGE RINGS*
      Fischer and Mack, Bernardini and Malter (JVSTA 1965), Garwin (1968)
    - *FUSION DEVICES (McCracken (1967) (ESD and ISD)*
    - *PROTON STORAGE RINGS ISR (1970) ISD*

NON-THERMAL OUTGASSING

- **HISTORY**
  - **–THE MODELS FOR ESD**
    - ***THE "MGR" MODEL (1964)***
      - –TWO INDEPENDENT TEAMS: P. REDHEAD B. GOMER AND D. MENZEL
      - –EXCITATION TO AN A
    - ***THE KNOTEK-FEIBELMA***
      - –AUGER EFECT
  - **–ACTUAL EVOLUTIO**
    - ***SURFACE PHYSICS ISSU***
    - ***MAINLY MODELS FOR E***



NON-THERMAL OUTGASSING

- **APPLICATION FOR ESD:**
  - **–SURFACE CHARACTERISATION**
    - *K.J. Middleman, J.D. Herbert, R.J. Reid Vacuum in Press (2006)*
  - **–BIOLOGY**
    - ***ANALYTICAL TOOL (COUPLING ESD+SEM F. DYLLA)***

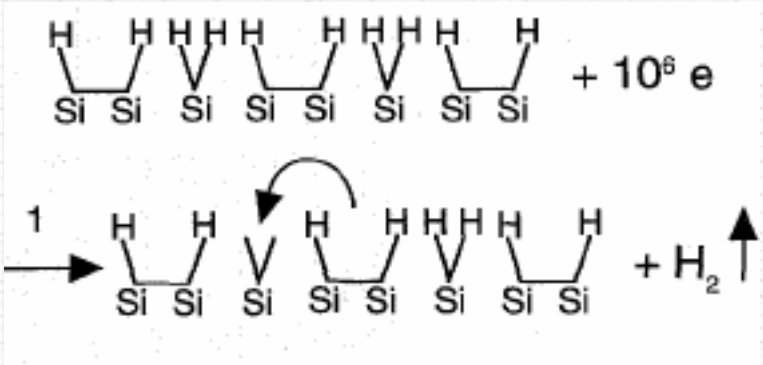
      H. F. Dylla and J. H. Abrams, Scanning Electron Microscopy, 1219 (1984).
    - ***STUDIES OF DAMAGE INDUCED TO DNA BY LOW ENERGY e^-***

      H. Abdoul-Carime, P. Cloutier, and L. Sanche, Radiation Research 155, 625 (2001).

NON-THERMAL OUTGASSING

- **APPLICATION FOR ESD:**
  - **–STM LITHOGRAPHY (nm range) Si/H**

T. C. Shen and P. Avouris, Surface Science 390, 35 (1997)



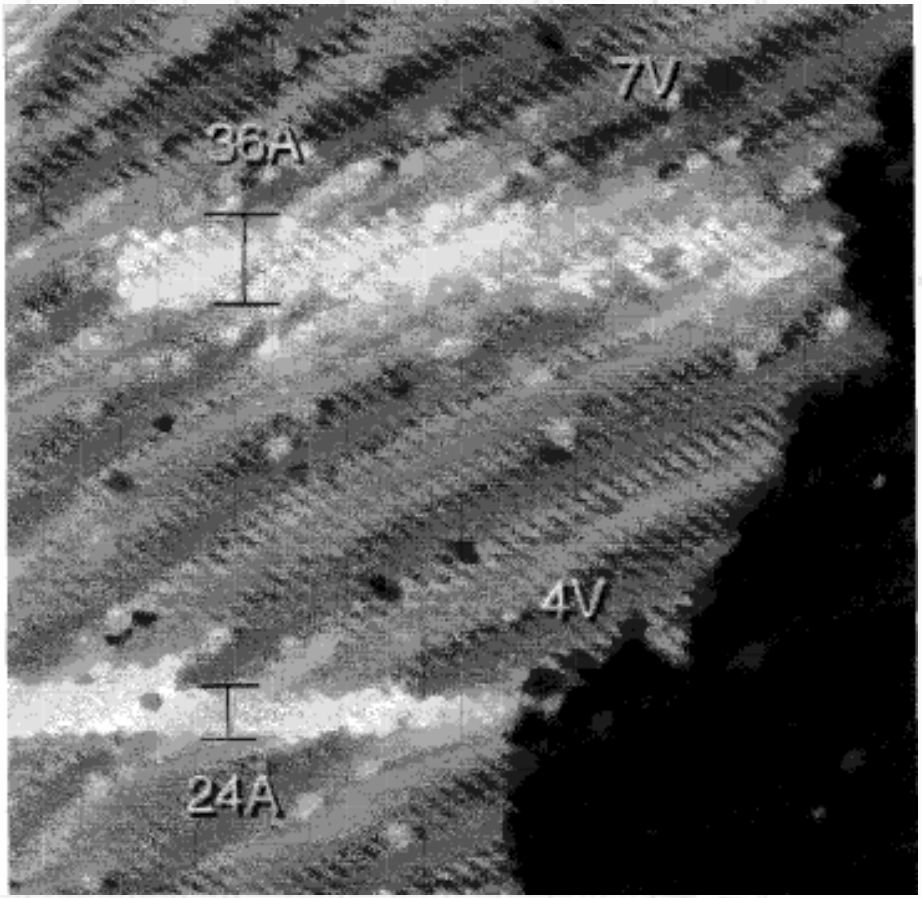
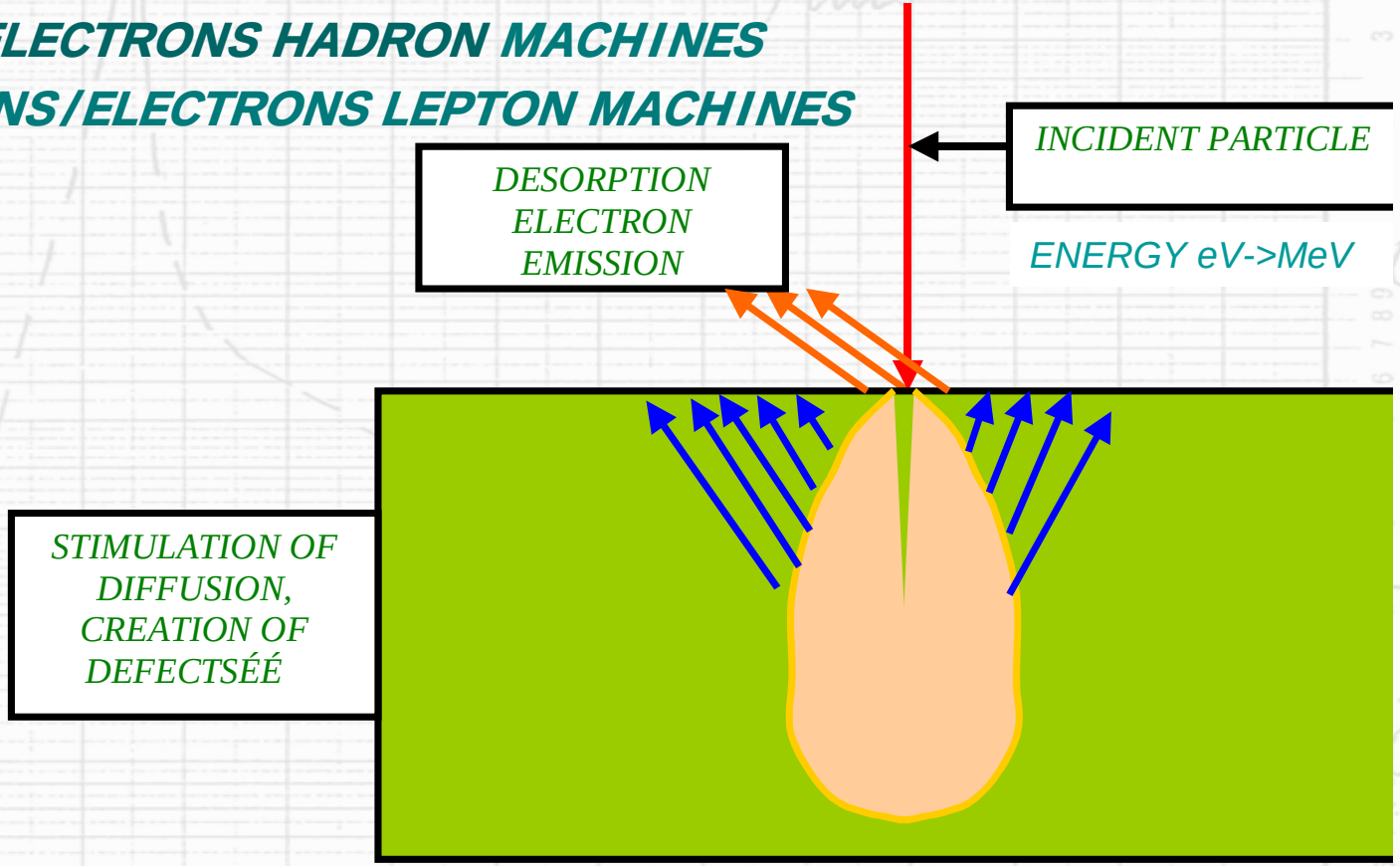


Fig. 8. A comparison of the desorption area written by the same tip. The top line is written with e-irradiation of 7 V, 0.1 nA and line dose 1×10^{-4} C cm^{-1}. The bottom line is written with 4 V, 4 nA and 4×10^{-3} C cm^{-1}.

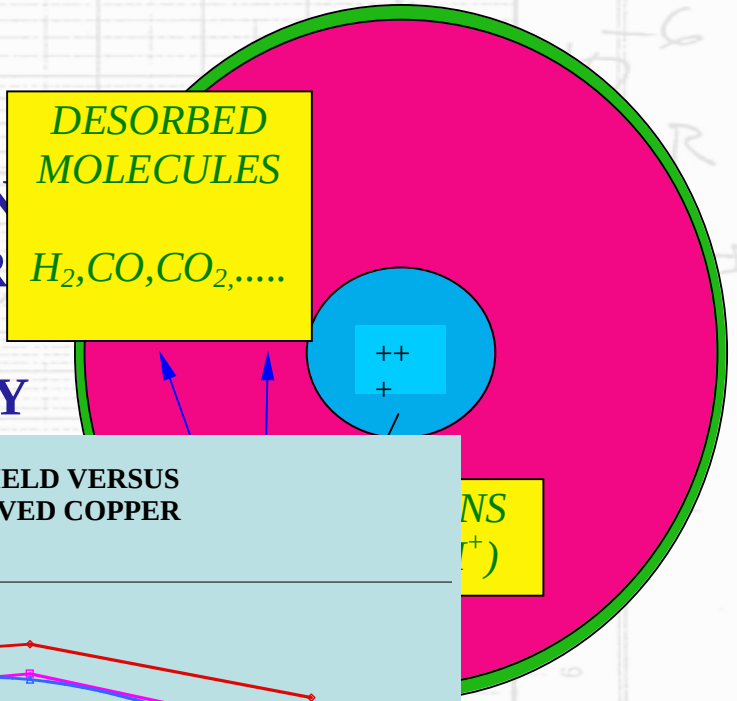
NON-THERMAL OUTGASSING

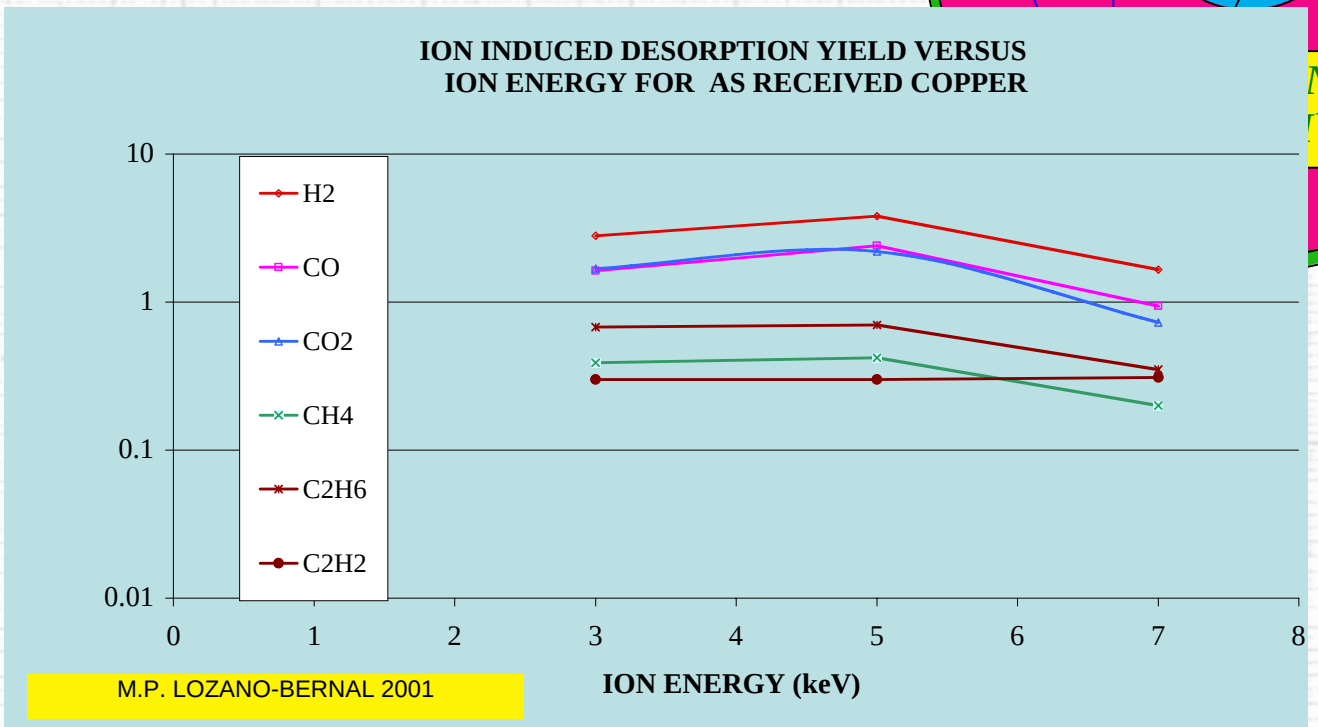
- **BEAM DEPENDENT PRESSURE VARIATION**
- **STIMULATED DESORPTION**
  - **–INDUCED BY ENERGETIC PARTICLE BOMBARDMENT**
    - ***IONS/ELECTRONS HADRON MACHINES***
    - ***PHOTONS/ELECTRONS LEPTON MACHINES***



NON-THERMAL OUTGASSING

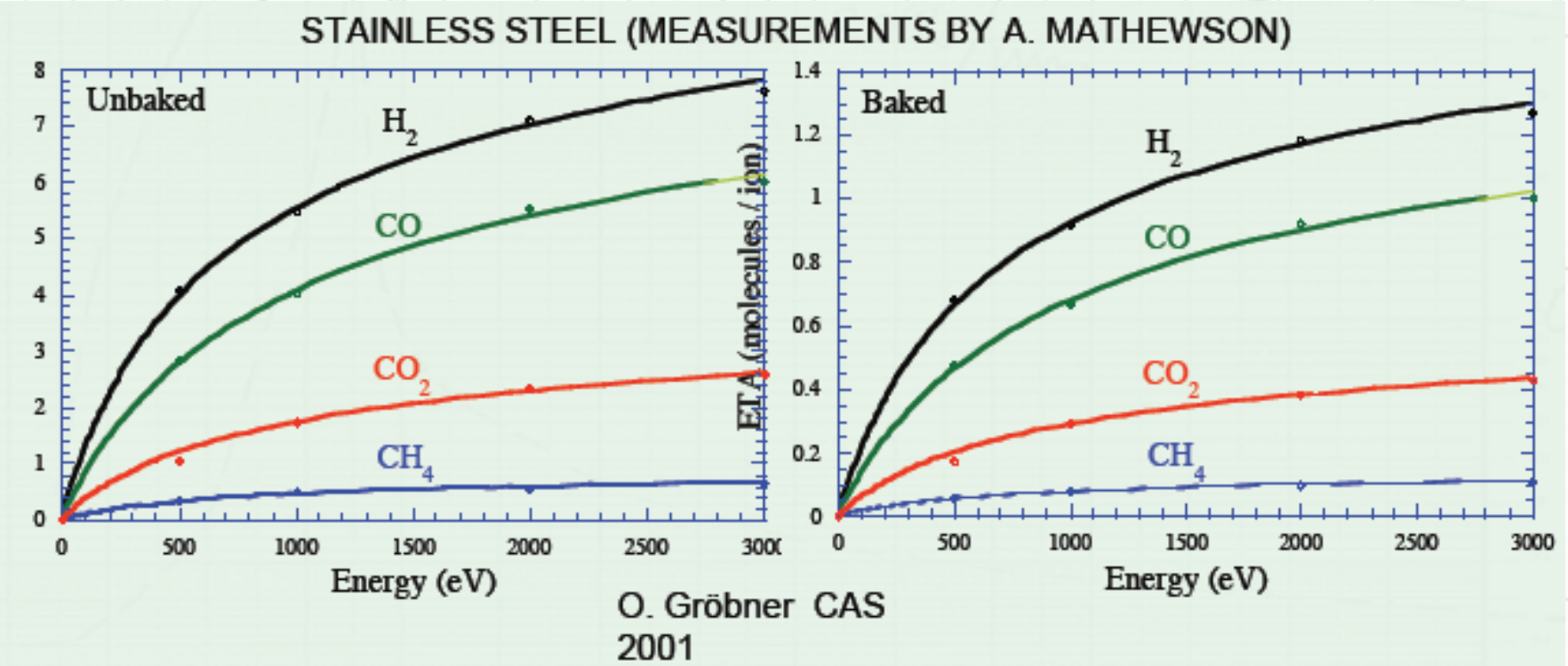
- **ION INDUCED DESORPTION**
  - –PROTON MACHINES
  - –DEPENDS MORE ON TREATMENTS THAN
  - –TYPICAL DESORPTION YIELDS (COPPER
    0.1->2 AFTER BAKING (300ºC)
  - –VARY WITH ION MASS/NATURE, ENERGY





NON-THERMAL OUTGASSING

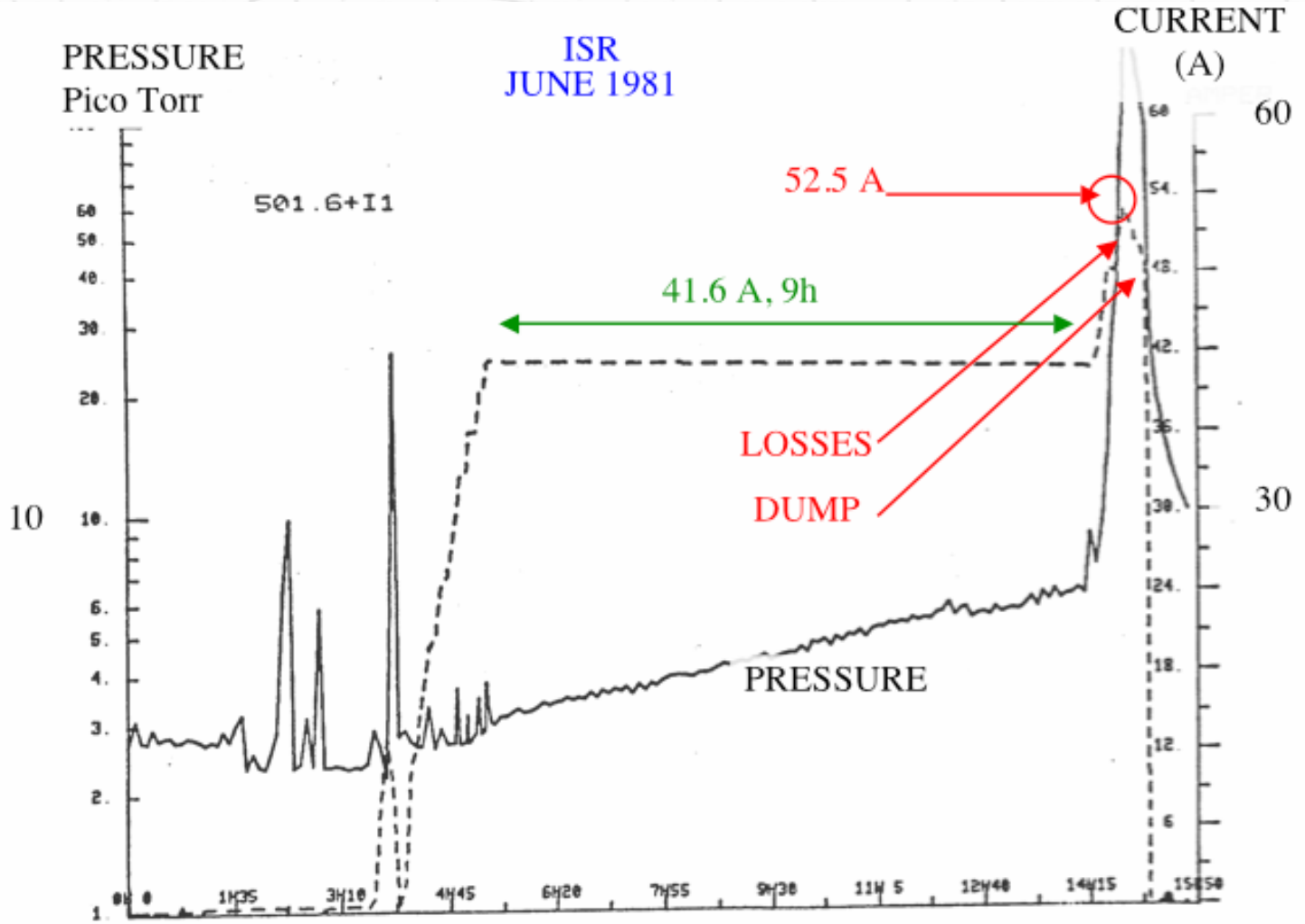
- **ION INDUCED DESORPTION**
  - **YIELDS FOR STAINLESS STEEL**



- **In accelerator: correction for net yield** $\eta_{mach} = \eta_{lab} - 1$

NON-THERMAL OUTGASSING

- **Proton machines: The ion induced instability**
- **Dyna**



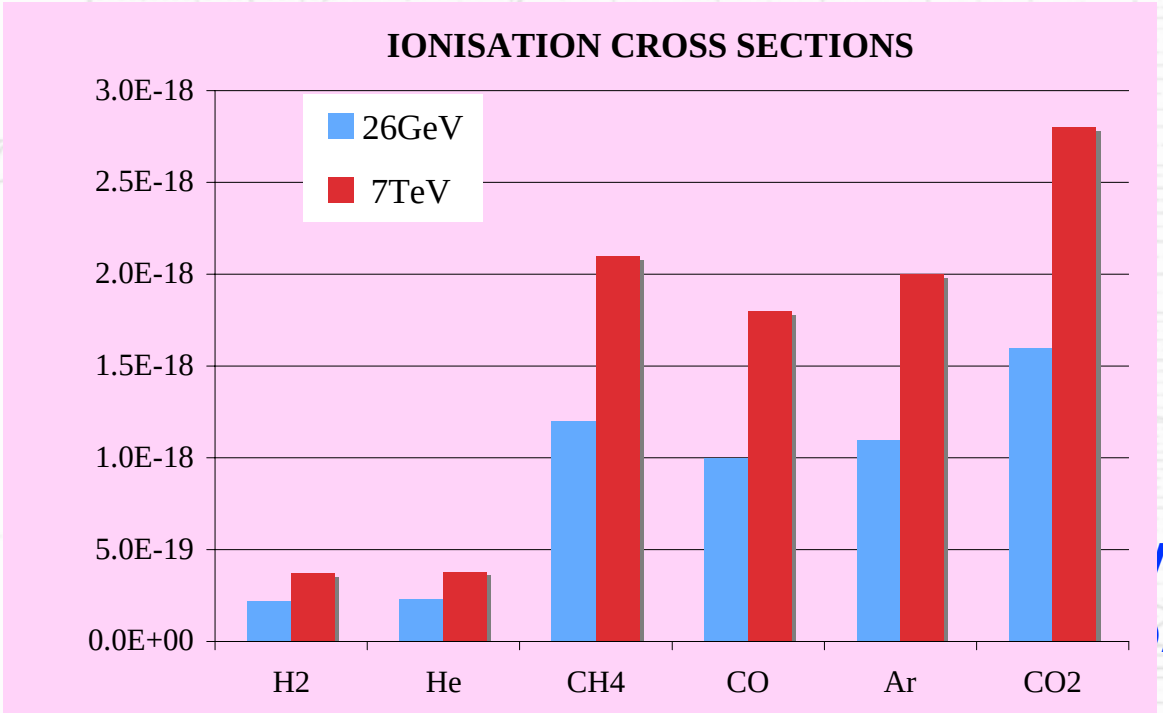
$I_c \quad P \to \infty$

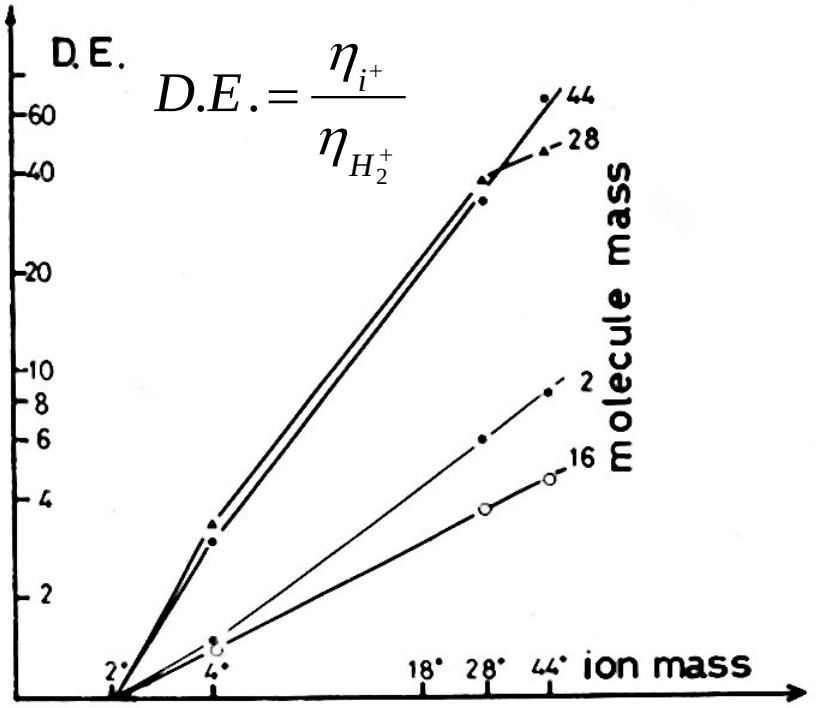
NON-THERMAL OUTGASSING

- **THE ION INDUCED INSTABILITY**

- **EFFECT OF THE ION MASS**

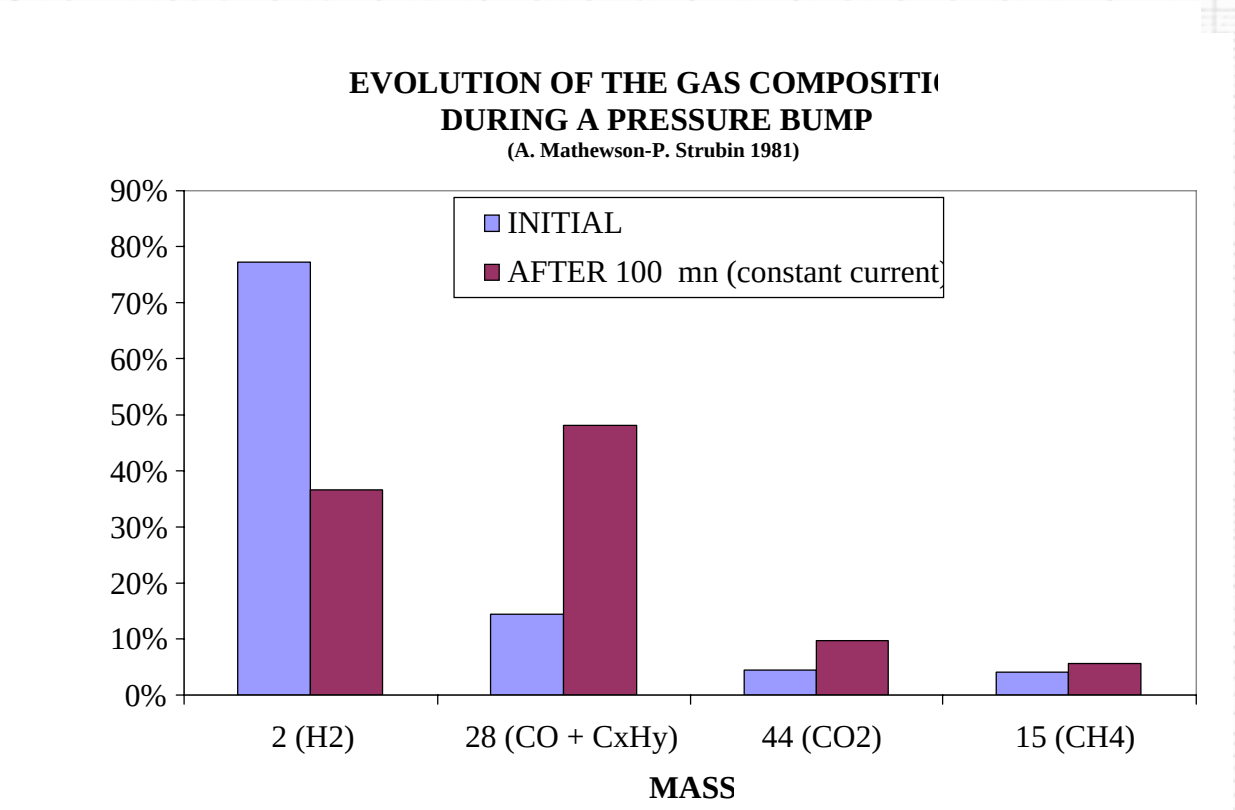
$$P(I) = \frac{P_0}{1 - I * \frac{\sigma}{e} * \frac{\eta}{S}} \Rightarrow \quad I \to \frac{e * S}{\sigma * \eta} = I_c \quad P \to \infty$$





NON-THERMAL OUTGASSING

- **THE ION INDUCED INSTABILITY**
- **EFFECT OF THE ION MASS**
  - **–=>Long term drifts**
  - **–=>Change in gas composition : more heavy gases**



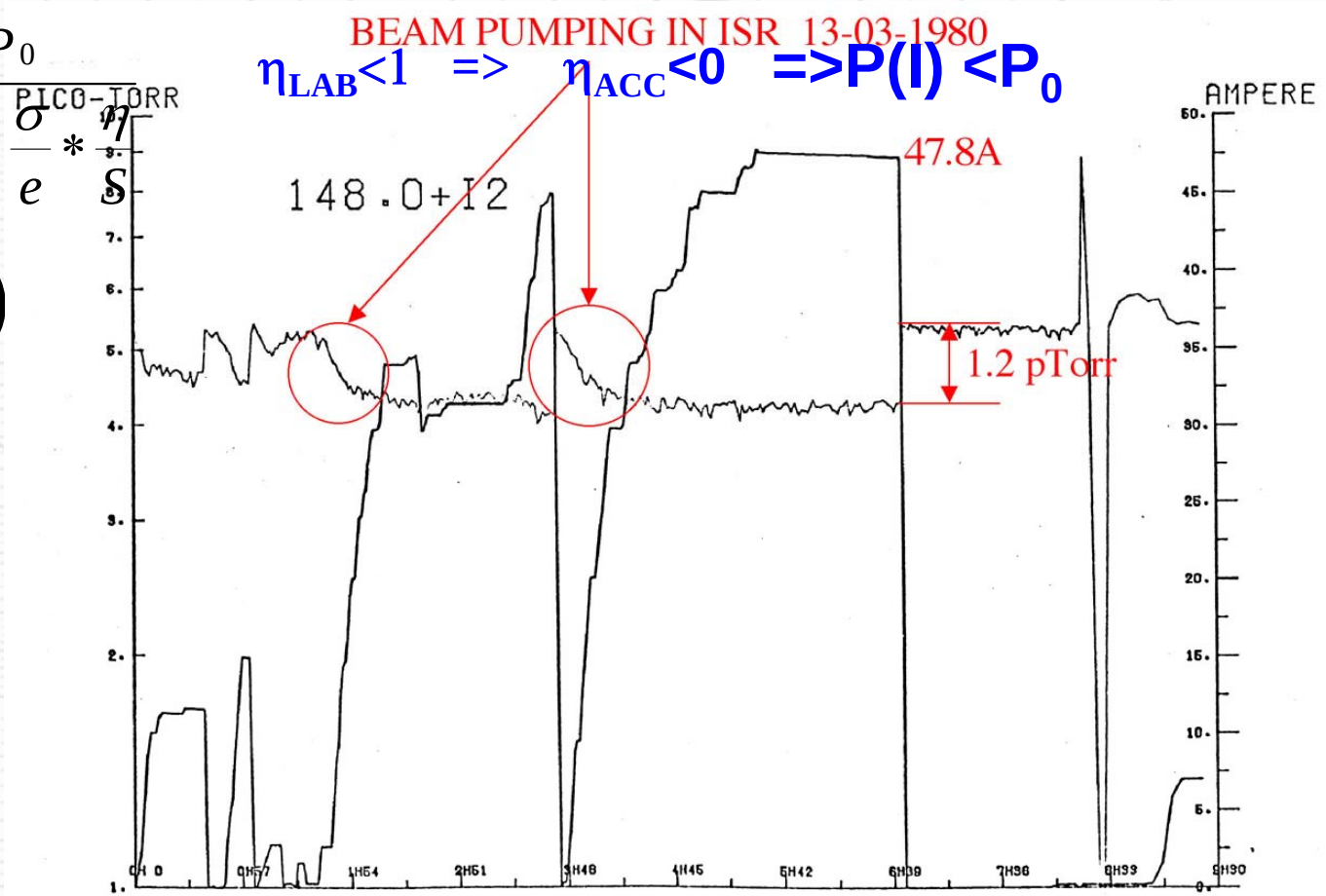
NON-THERMAL OUTGASSING

- **OTHER TYPES OF PRESSURE VARIATION**
  - **–BEAM PUMPING :** IF

$$P(I) = \frac{P_0}{1 - I * \frac{\sigma}{e} * \frac{\eta}{S}} \quad \text{PICO-TORR}$$

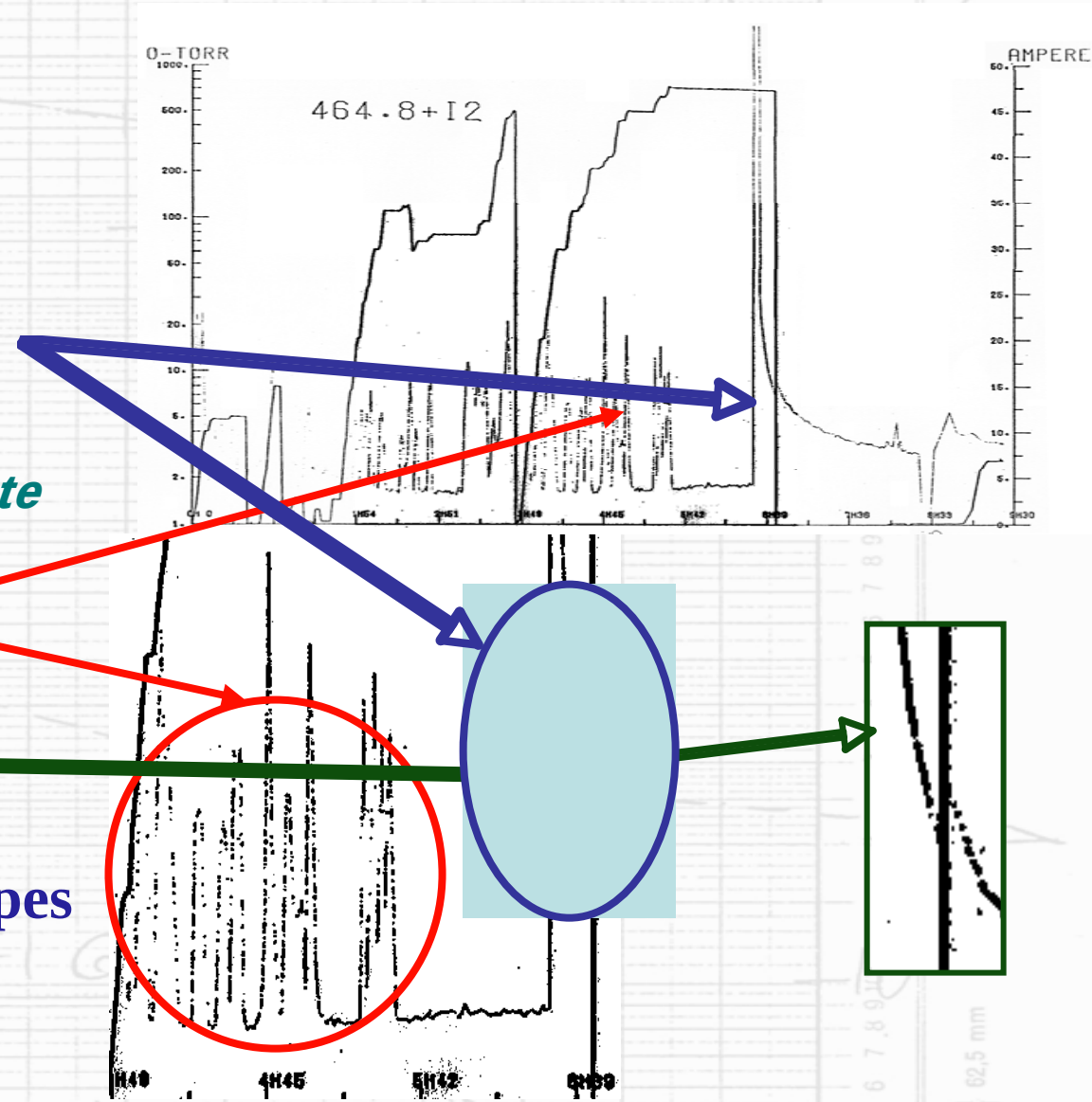
$$S_{beam} = \frac{\sigma\kappa}{e} I \quad \left(m^2 s^{-1}\right)$$

σ : Ionisation C.S. (m^2)
κ: Trapping probability
I: Beam intensity (A)
E: Electron charge (C)



NON-THERMAL OUTGASSING

- **OTHER TYPES OF PRESSURE VARIATION**
  - –Beam losses
    - *Sudden increase, pressure decay with time constant*
  - –Radiation burst
    - *Sudden increase, immediate recovery (ionisation in the gauge collector cable)*
  - –This case:
    - *Beam pumping*
  - –Simultaneity of several types

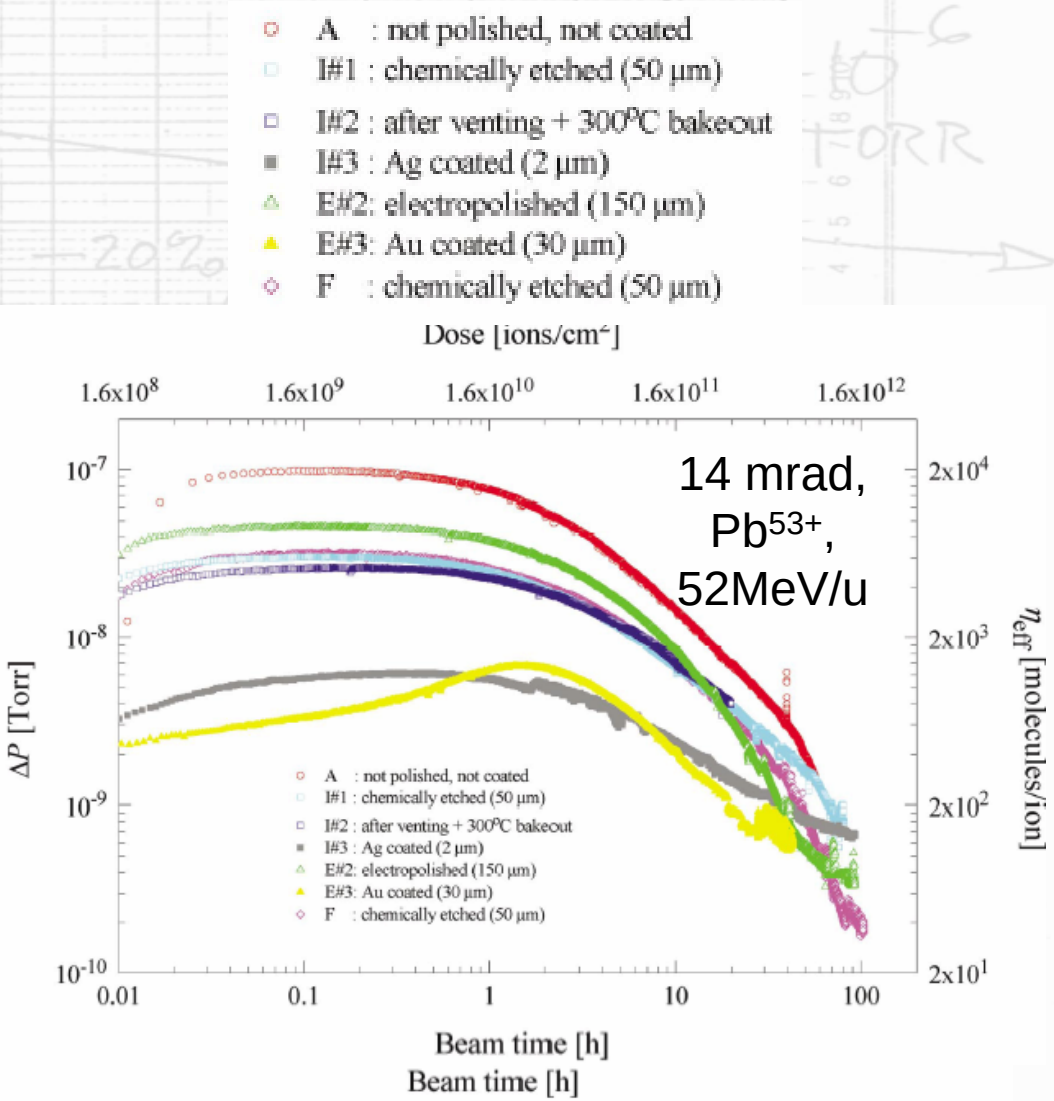


NON-THERMAL OUTGASSING

- **SWIFT HEAVY IONS**
  - **–DESORPTION AND BEAM CLEANING**
    - ***HIGH YIELDS >10^4 measured at CERN***

E. Mahner, D. Küchler, M. Malabaila, and M. Taborelli, PRST AB **8**, 053201 (2005).

- ***DESPITE HIGH PENETRATION (30μ) SENSITIVE TO SURFACE (2 μ Ag)***
- ***ELECTRONIC STOPPING PREDOMINANT***



NON-THERMAL OUTGASSING

- **SWIFT HEAVY IONS**
  - –SIMILAR YIELDS FOUND IN GSI :Pb^{27+},Cr^{7+},C^{2+} 1.4 MeV/u

    AND BNL

P. Thieberger et al. PRST AB 7 093201 2004

  - cf SPUTTERING YIELDS OF INSULATORS
    - *LiF >10^4 Au^{29+}, 230MeV, 20° incidence*

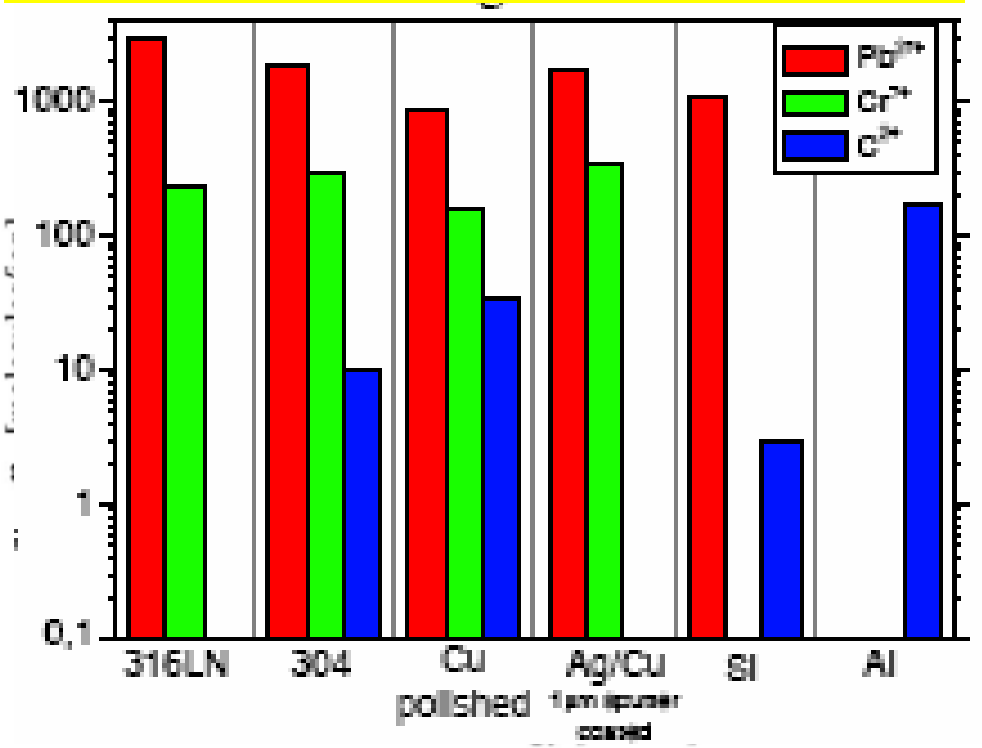
M. Toulemonde et al. NIM B212 346 2003

  - -H_2 DESORPTION FROM C: 7x10^6 700 MeV I^+

R. Behrisch et al. NIM B118,262 1996

H. Reich-Sprenger et al. pp1657-1659 EPAC 2004

E. Mahner and al. PRST AB **7**, 103202 (2004).



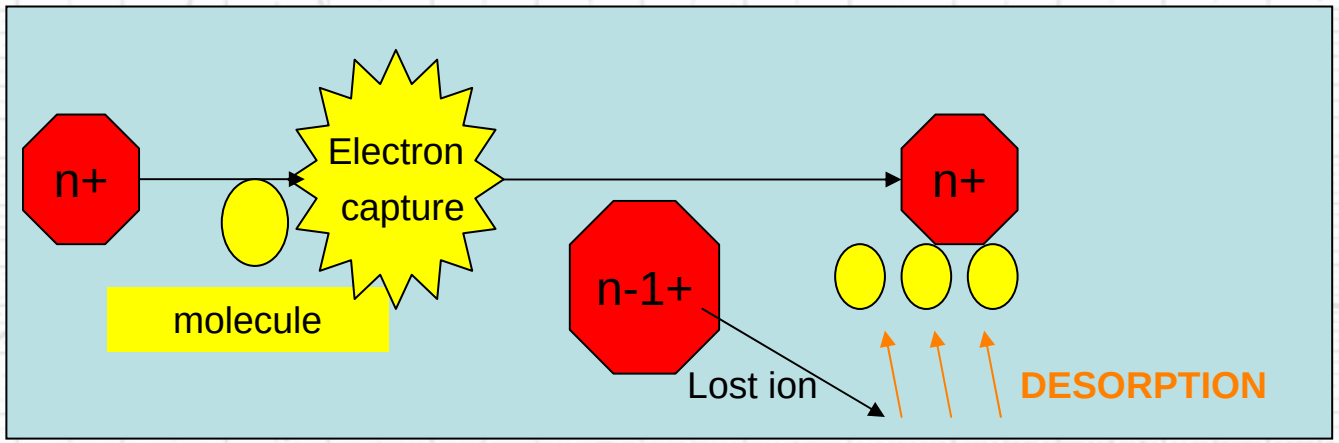
NON-THERMAL OUTGASSING

- **INFLUENCE ON OPERATION**

E. Mustafin et al.,
NIM A: 510, 199 (2003).

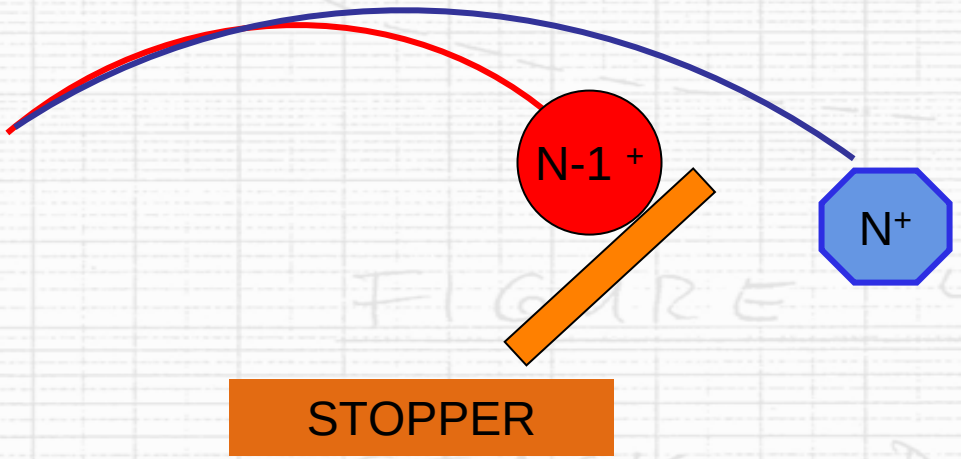
- ***AT MODERATE ENERGY (MeV/U) HIGHLY CHARGED IONS VERY SENSITIVE TO CHARGE EXCHANGE***

- ***=>BEAM LOSS=>DESORPTION=> CHARGE EXCHANGE***



NON-THERMAL OUTGASSING

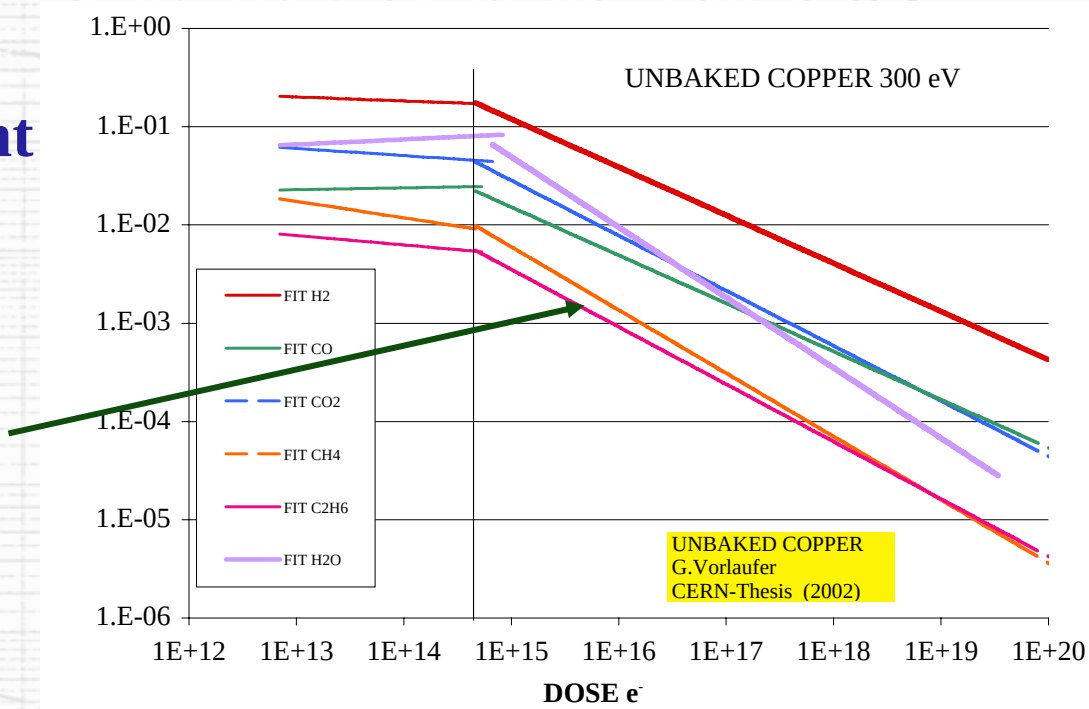
- **REMEDIES**
  - *WHEN CRITICAL PLACES FOR BEAM LOSSES KNOWN*
  - *INSTALL STOPPERS*
  - *PERPENDICULAR INCIDENCE*
  - *ADEQUATE COATING*
  - *LOCAL PUMPING*



NON-THERMAL OUTGASSING

ELECTRON INDUCED DESORPTION

- Important where/when resonant multiplication of electrons e$^-$cloud, RF devices (couplers)
- Many similarities with PSD
- Decrease with e$^-$ dose $\eta=\eta_0 D^{-n}$
- Beam cleaning

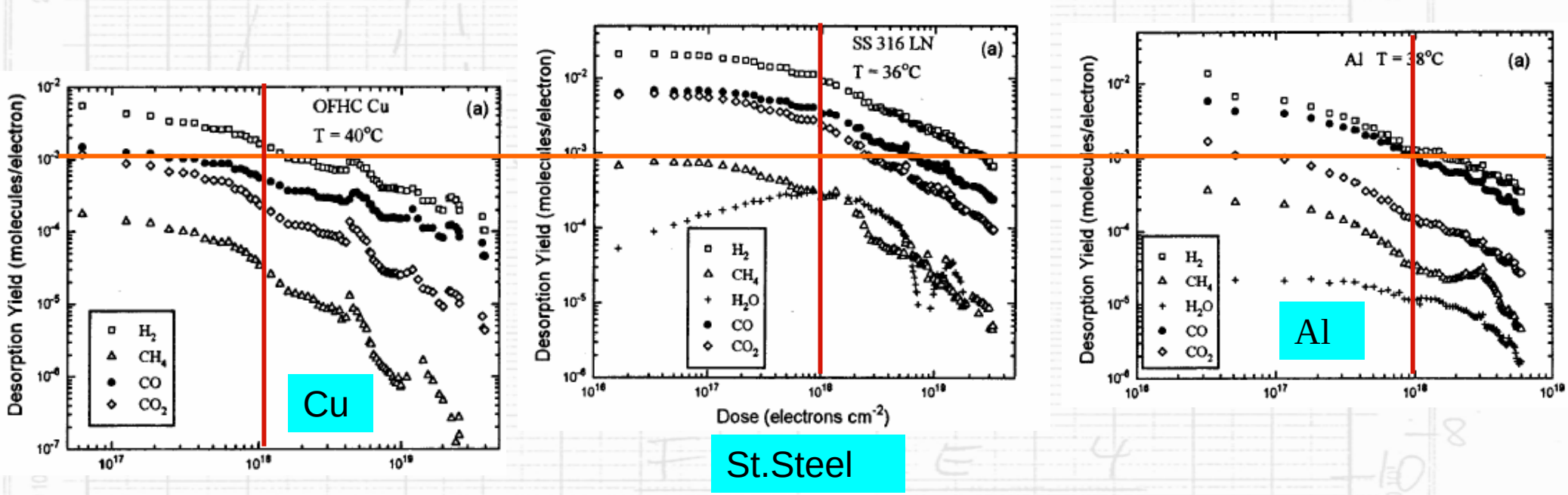


GAS	H_2	CH_4	CO	C_2H_6	CO_2
$\eta(>10^{15})$	-0.489	-0.643	-0.489	-0.584	-0.561
$\eta_0(>10^{15})$	2.68×10^{6}	2.67×10^{7}	3.36×10^{5}	2.02×10^{6}	7.36×10^{6}

NON-THERMAL OUTGASSING

- **ELECTRON INDUCED DESORPTION**
  - **–INFLUENCE OF THE MATERIAL (Baked 150ºC+300ºC 2h)**

•J. Gómez-Goñi and A. G. MathewsonJ. Vac. Sci. Technol. A 15, 3093 (1997)

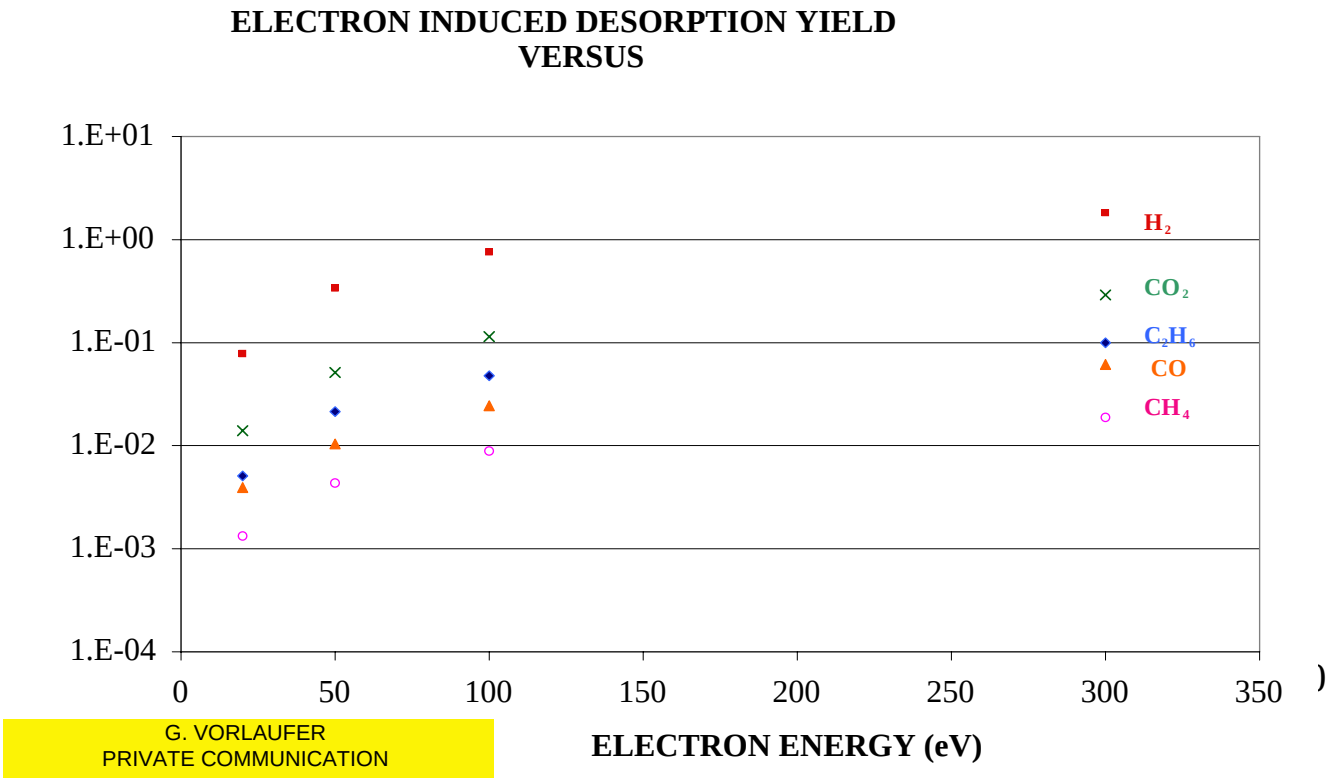


NON-THERMAL OUTGASSING

ELECTRON INDUCED DESORPTION

- Variation of ESD with electron energy
- Threshold close to 10 eV

$$\eta(E) = \eta_{300} \times \left(\frac{E - E_c}{300 - E_c} \right)^{0.85}$$



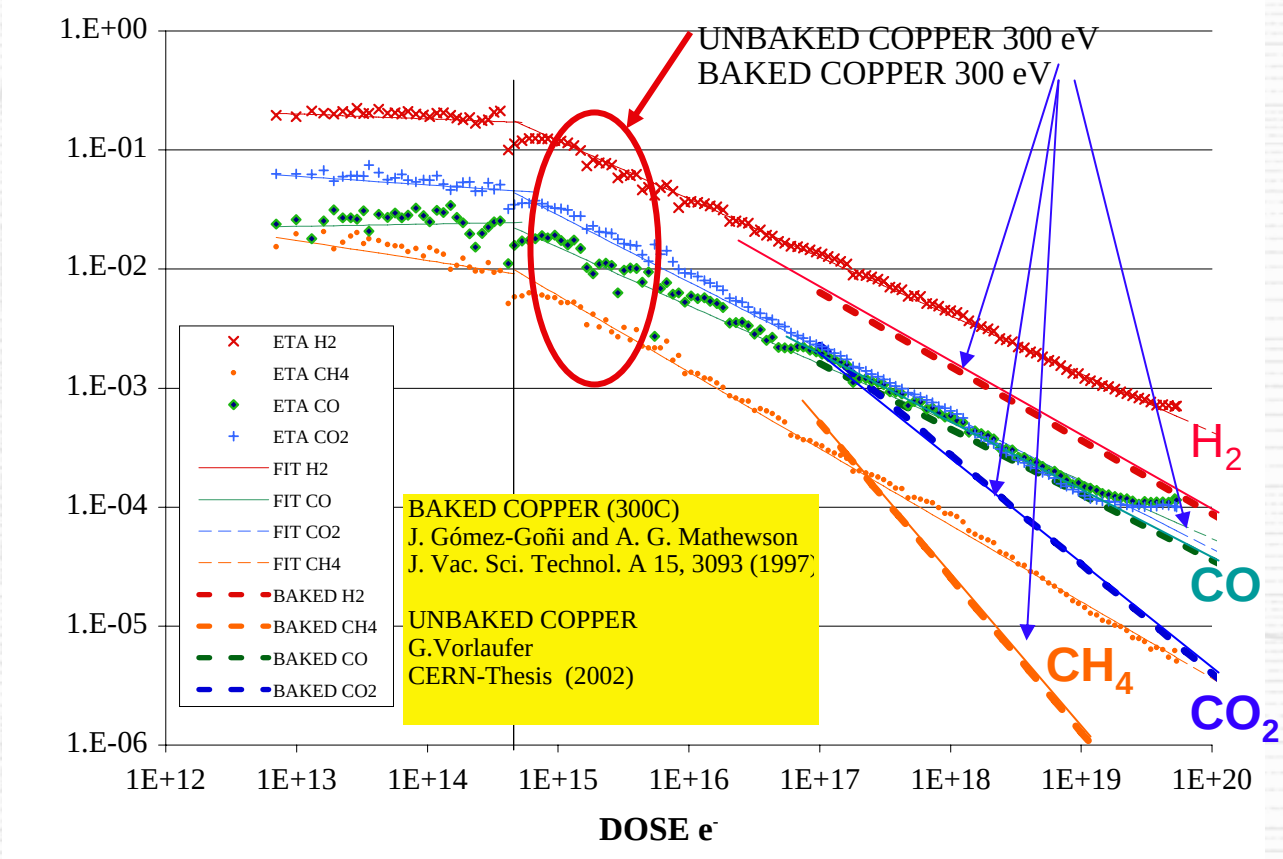
G. VORLAUFER
PRIVATE COMMUNICATION

Table 1: Fit parameters

	η_0 / (molec./e$^-$)	E_C / eV
C_2H_6	1.1×10^{-1}	11.4
CH_4	2.1×10^{-2}	7.5
CO	5.8×10^{-2}	7.2
CO_2	2.7×10^{-1}	9.1
H_2	1.9×10^{0}	12.7

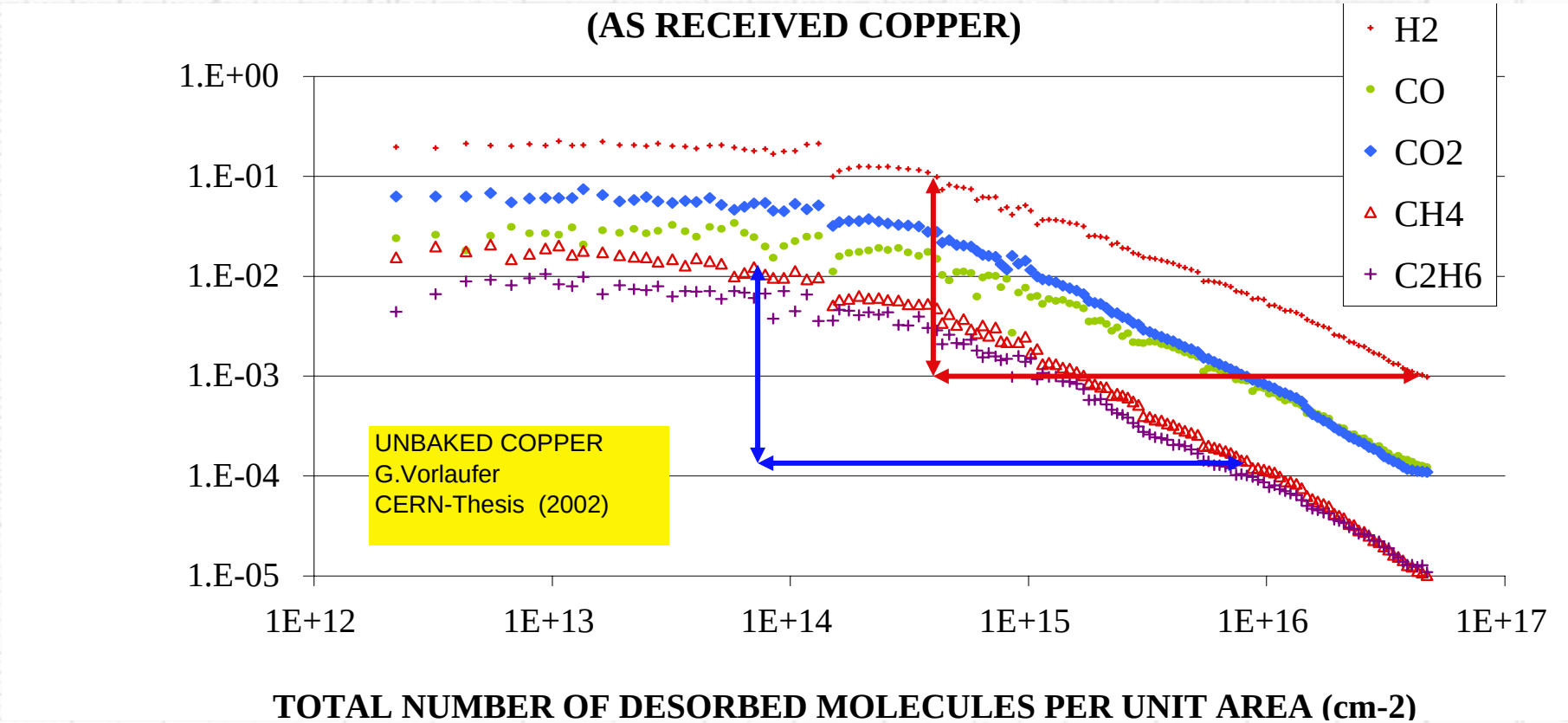
NON-THERMAL OUTGASSING

- **ELECTRON INDUCED DESORPTION**
  - **–INFLUENCE OF BAKE-OUT**



NON-THERMAL OUTGASSING

- **ELECTRON INDUCED DESORPTION**
  - **–TOTAL NUMBER OF RELEASED MOLECULES**
    - ***X 100 Monolayers desorbed <=> η/100***



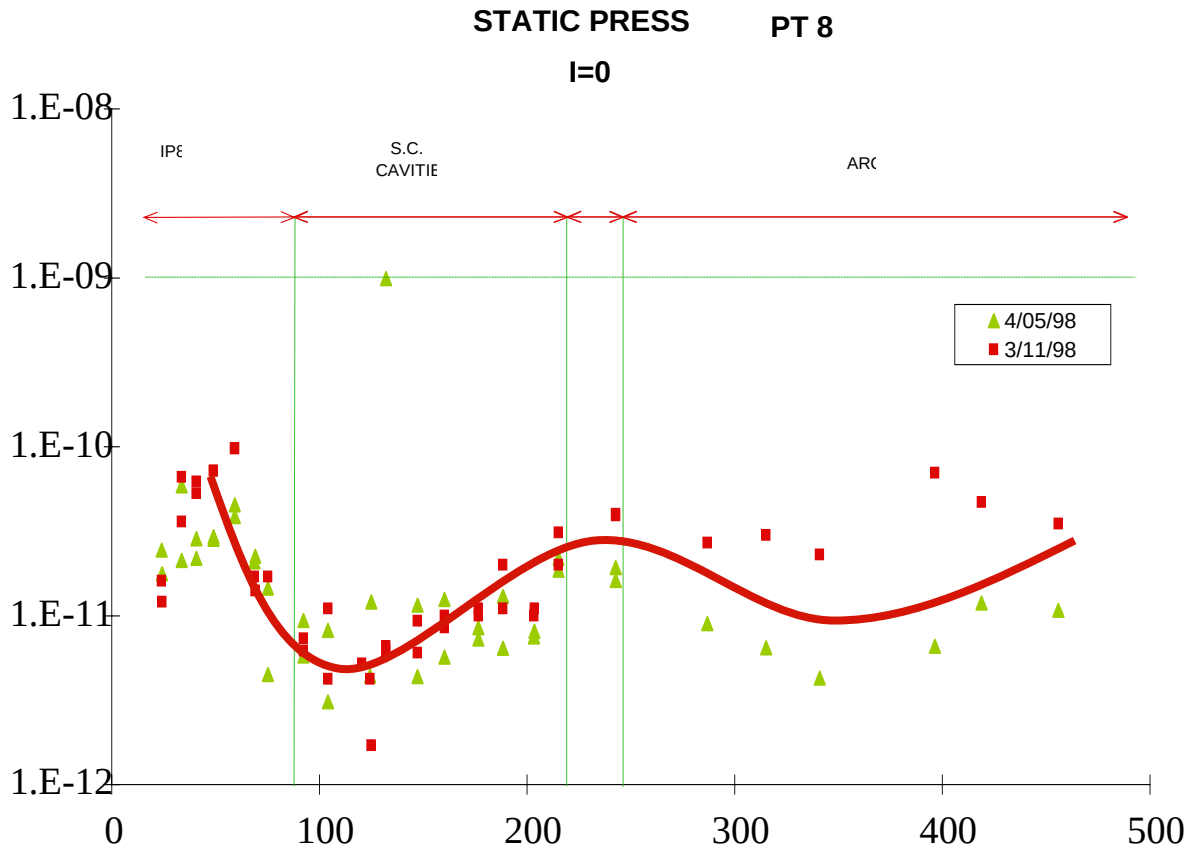
NON-THERMAL OUTGASSING

- **PHOTON STIMULATED DESORPTION**

  –LEPTON MACHINES DESORPTION:

  PHOTONS =>PHOTOELECTRONS

  STATIC =>DYNAMIC PRESSURE



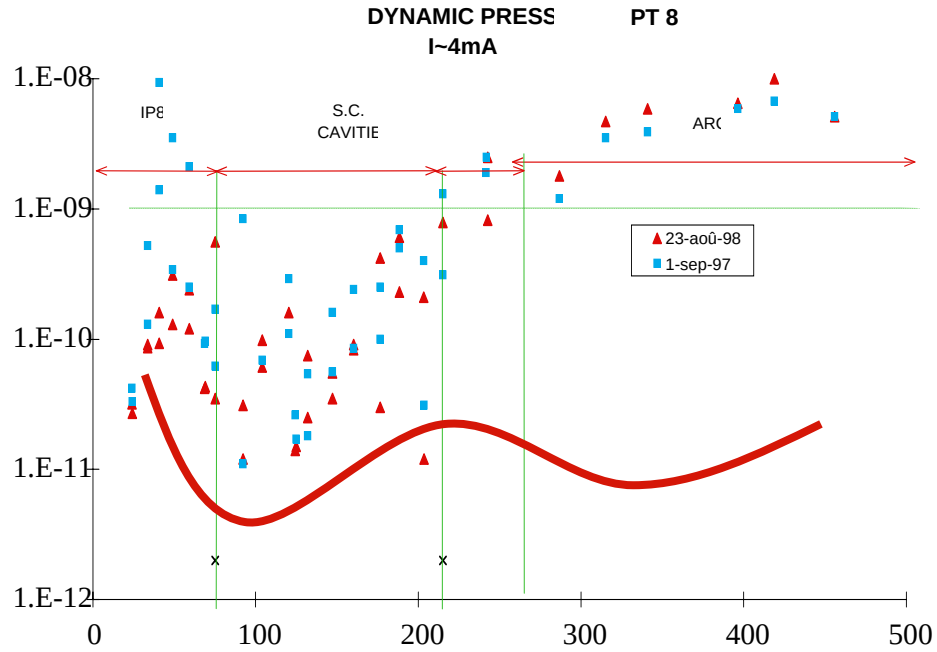
NON-THERMAL OUTGASSING

- **PHOTON STIMULATED DESORPTION**

$$ph/m: \frac{dN}{ds} = 1.28 \times 10^{17} \times I \times \frac{E}{R}$$

DYNAMIC PRESSURE

$$\frac{\Delta P}{I} = K \times \frac{E}{R} \times \frac{\eta}{S}$$



NON-THERMAL OUTGASSING

- **PHOTON STIMULATED DESORPTION**
  - **Synchrotron light**

$$P(W) = 88.6 \times E^4 \times \frac{I}{R} \qquad E(GeV), I(mA), R(m)$$

$$\varepsilon_c(eV) = 2.2 \times 10^3 \times \frac{E^3}{R}$$

NON-THERMAL OUTGASSING

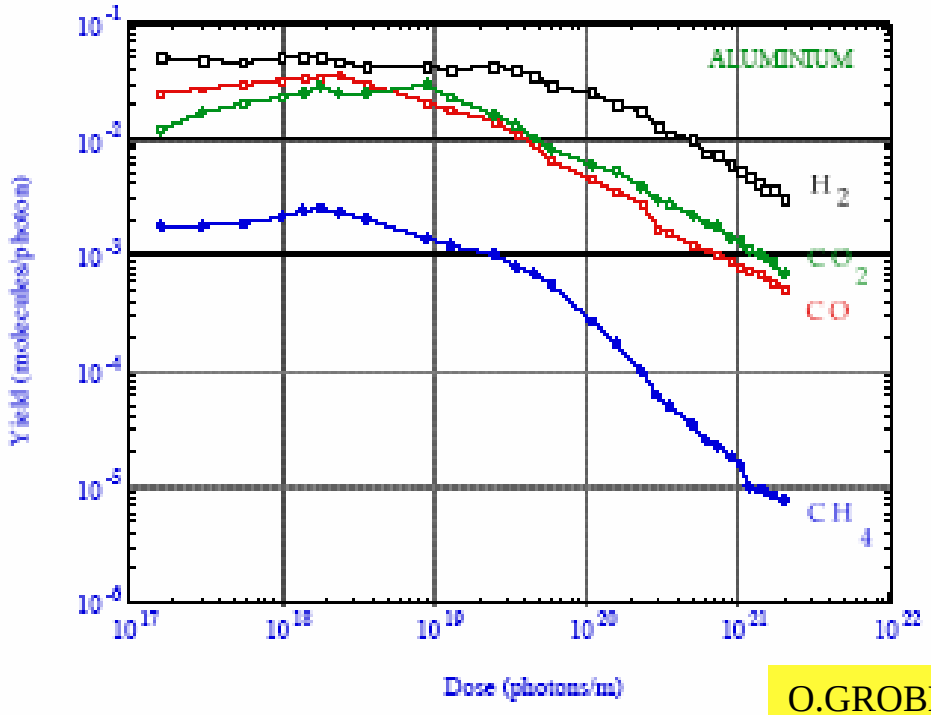
PHOTON STIMULATED DESORPTION

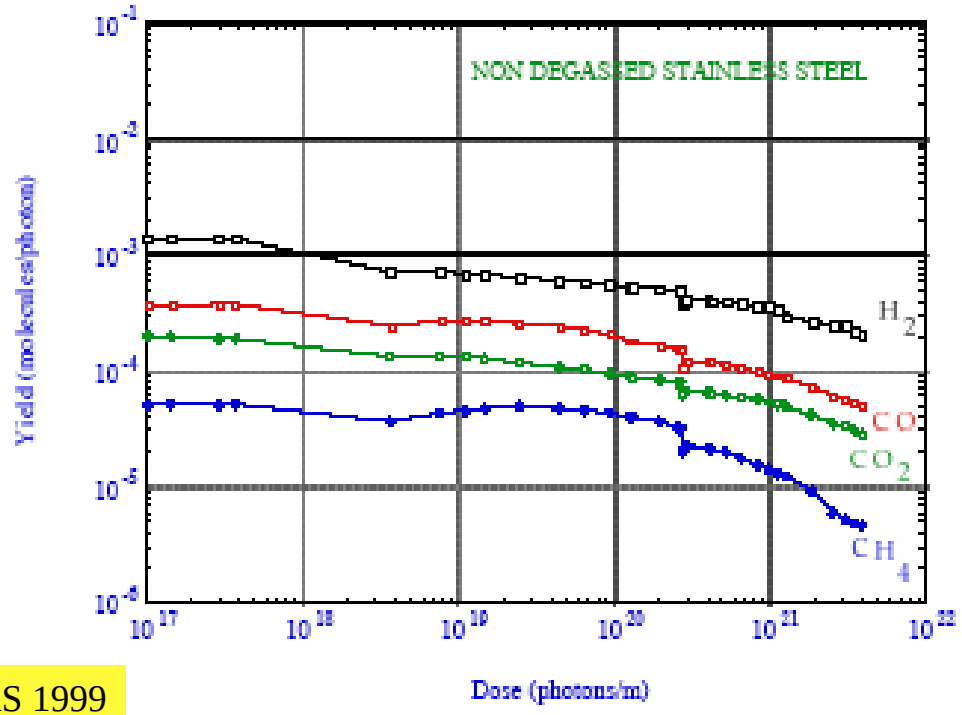
Synchrotron light

MACHINE	ENERGY (GeV)	CRITICAL ENERGY (keV)	POWER W/m	PHOTONS/m/s
KEK-LER	3.5	5.9	2.15×10^{4}	7.2×10^{19}
PEP II-LER	3.1	4.8	1.5×10^{4}	6.2×10^{19}
LEP	100	711	9×10^{2}	2.5×10^{16}
ESRF	5	2.2	56	5.3×10^{17}
LHC (protons)	7000	0.044	0.22	1×10^{17}

NON-THERMAL OUTGASSING

- **PHOTON STIMULATED DESORPTION**
  - **–MATERIAL DEPENDENCE**





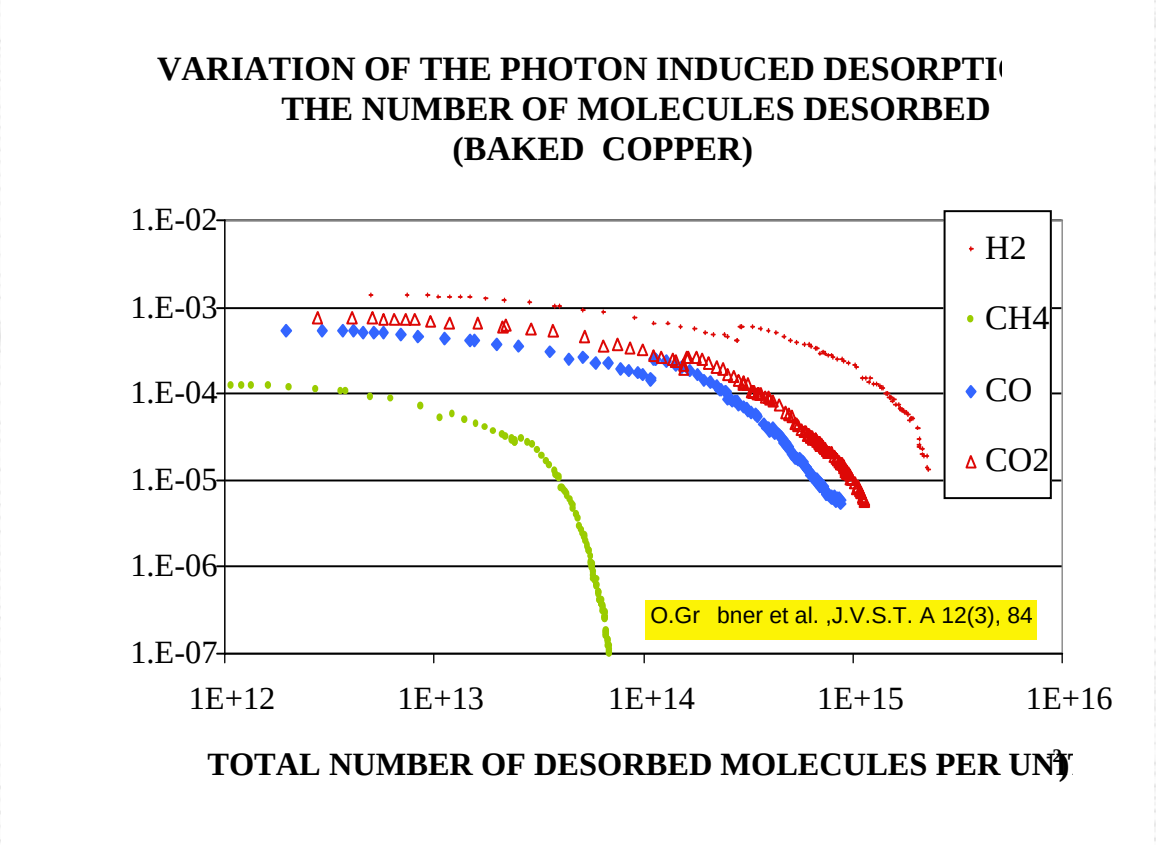
O.GROBNER CAS 1999

Fig. 3 Molecular desorption yields for aluminium alloy.

Fig. 4 Molecular desorption yields for stainless steel.

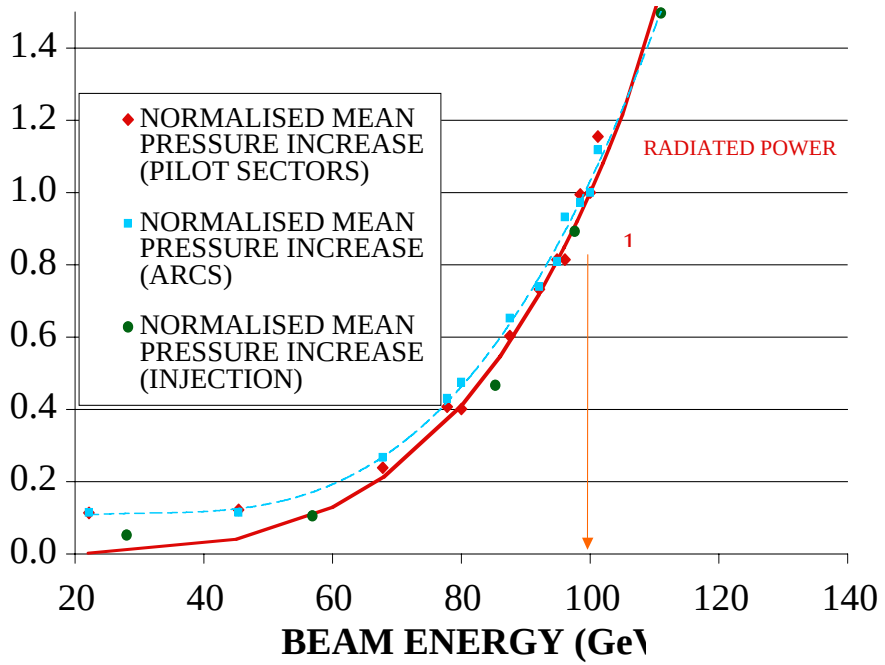
NON-THERMAL OUTGASSING

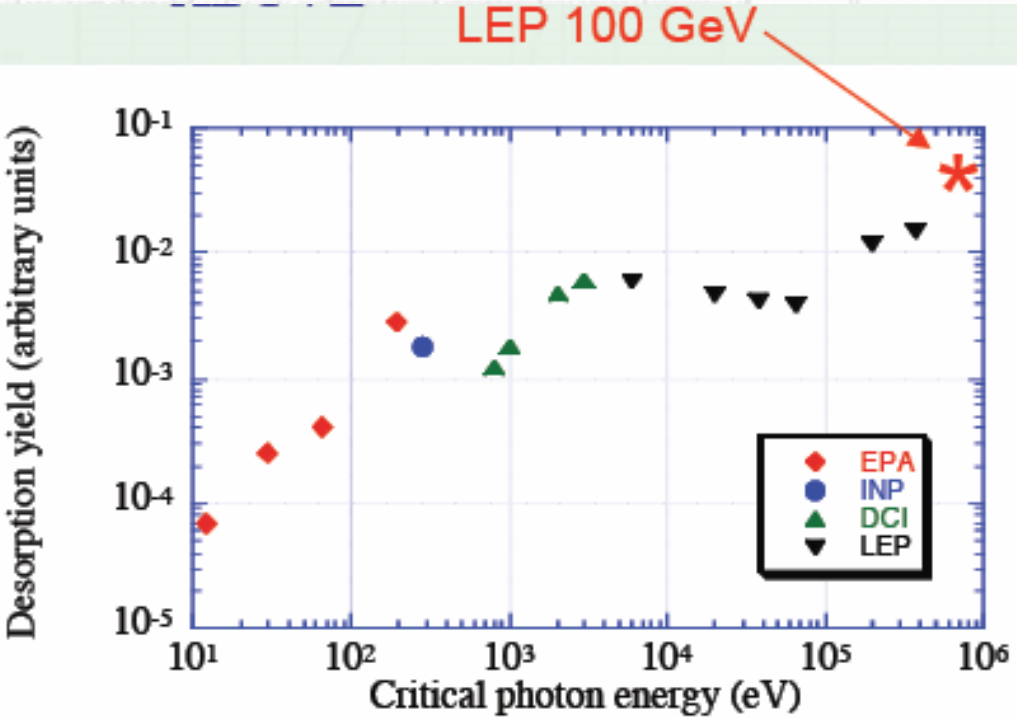
- **PHOTON INDUCED DESORPTION**
  - **–MATERIAL DEPENDENCE**
  - **–3.75 keV photons / Cu (unbaked)**



NON-THERMAL OUTGASSING

- **PHOTON INDUCED DESORPTION**
  - –ENERGY DEPENDANCE (CRITICAL ENERGY)
  - –CONSTANT IN THE keV/100 keV RANGE SCALES WITH POWER ABOVE

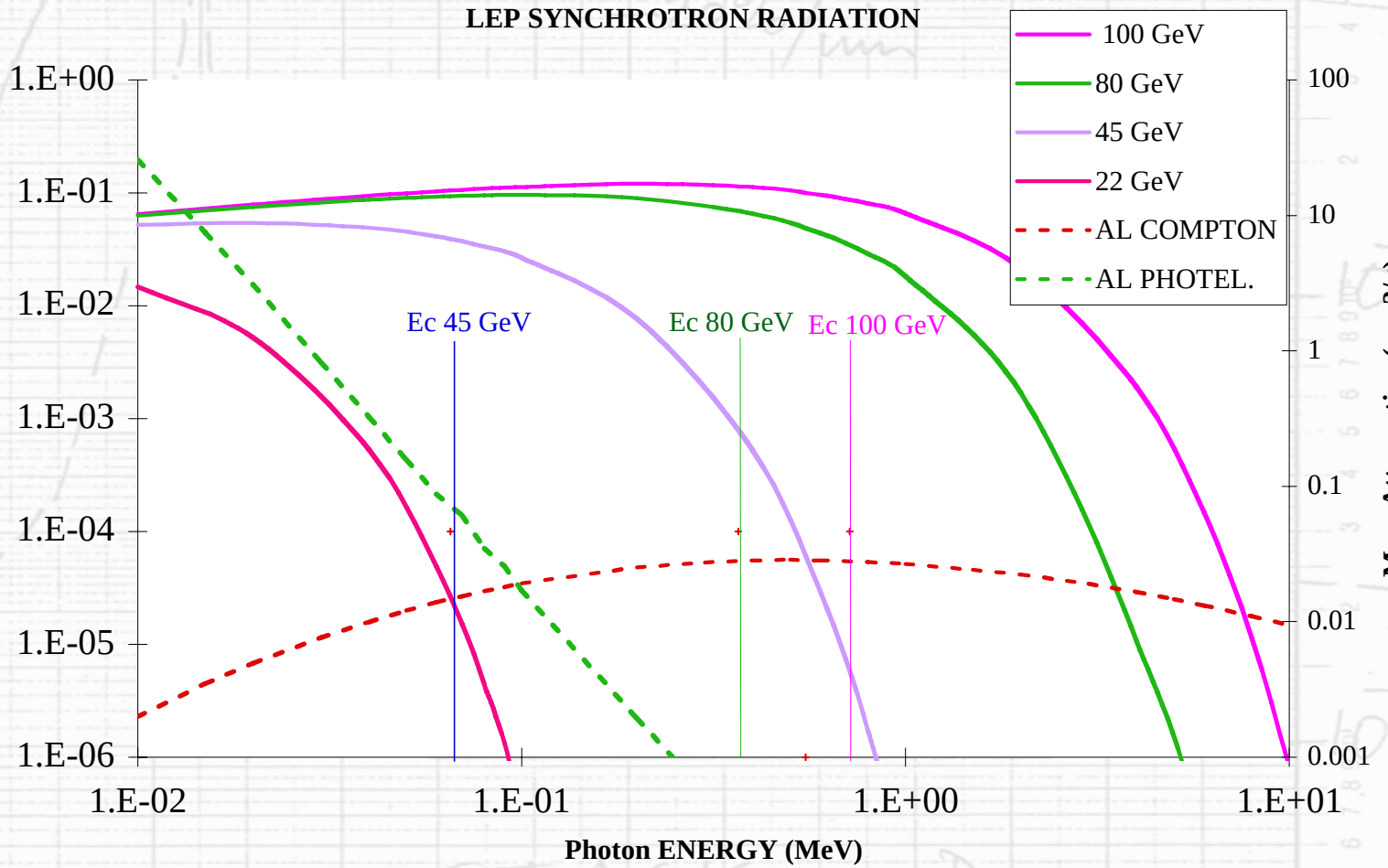




Gröbner, O. *Dynamic outgassing*. in *CERN Accelerator Scool*. 1999. Snekersten (DK): CERN Geneva.

NON-THERMAL OUTGASSING

- **PHOTON INDUCED DESORPTION**
  - **–Energy dependence (Compton)**



NON-THERMAL OUTGASSING

- **ANGULAR DEPENDENCE**
  - ***SATURATION AT GLANCING ANGLE (FLATNESS/SMOOTHNESS OF TECHNOLOGICAL SURFACES)***

O Gröbner et al. Vacuum 33,7,397-406 (1983)

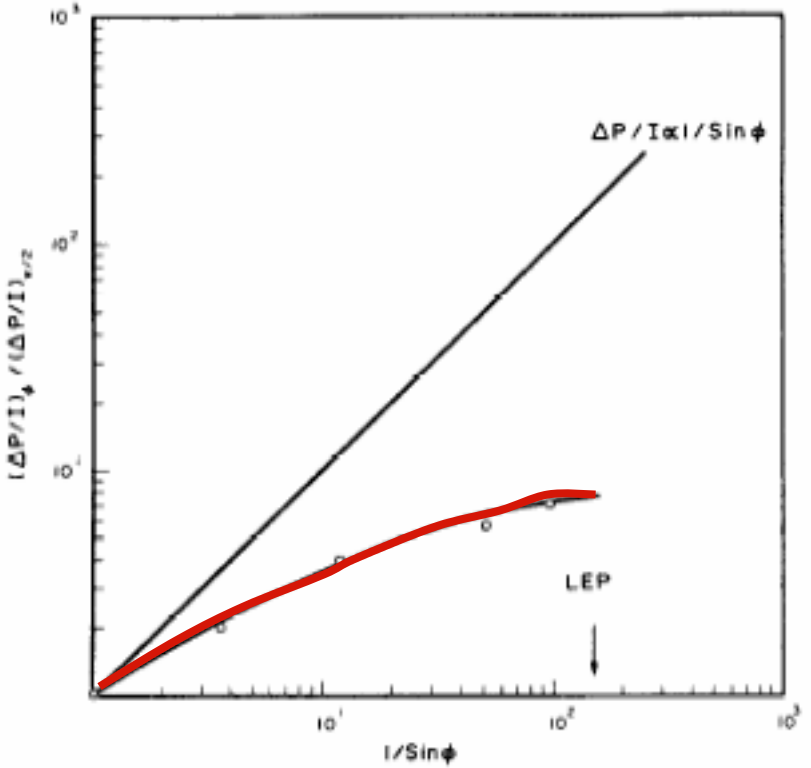


Figure 11. The dependence of the total specific pressure rise on the glancing angle of incidence at a beam energy of 1.72 GeV.

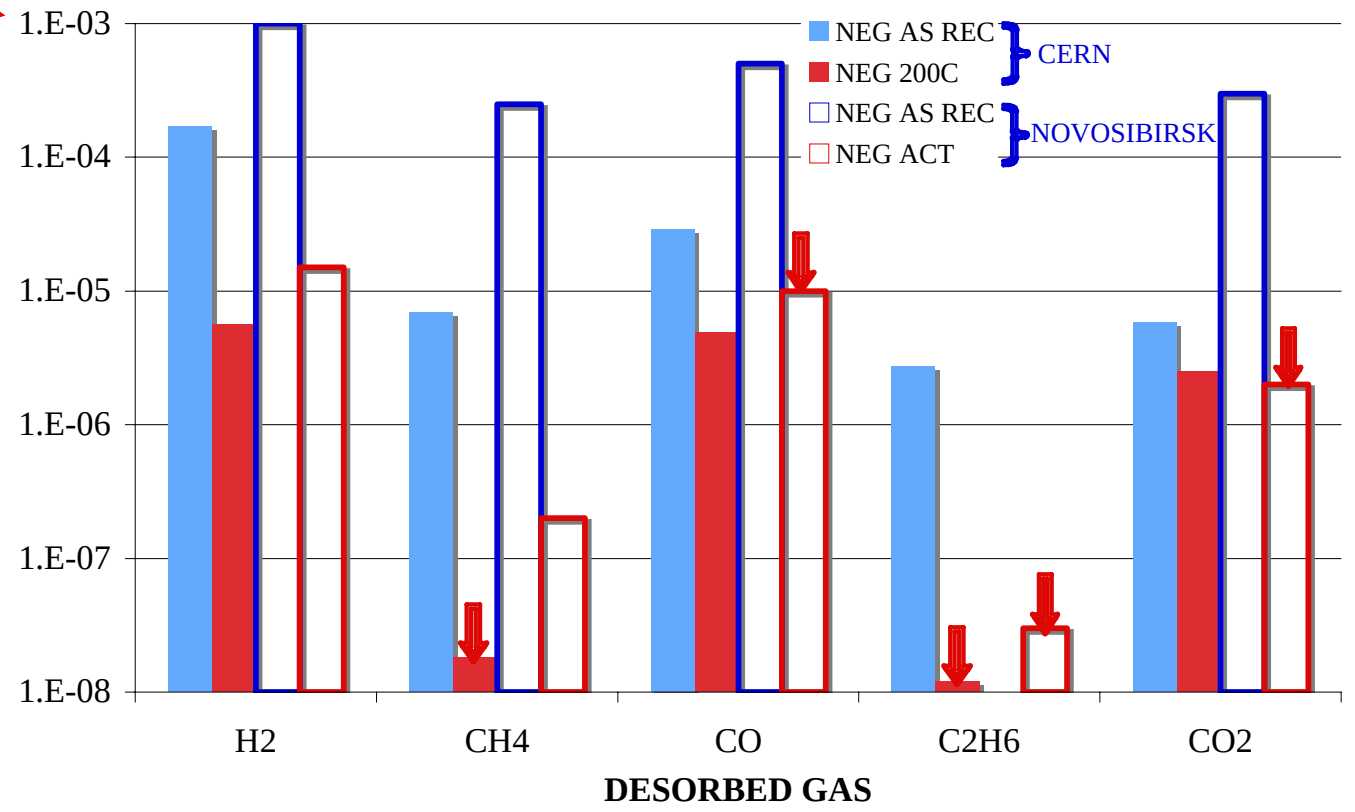
NON-THERMAL OUTGASSING

- **PHOTON INDUCED DESORPTION**
  - **–THE CASE OF NEG**

V. BAGLIN et al. CERN IVC 15 San Francisco (2001)
V. ANASHIN et al. Vacuum 75 155-159 (2004)

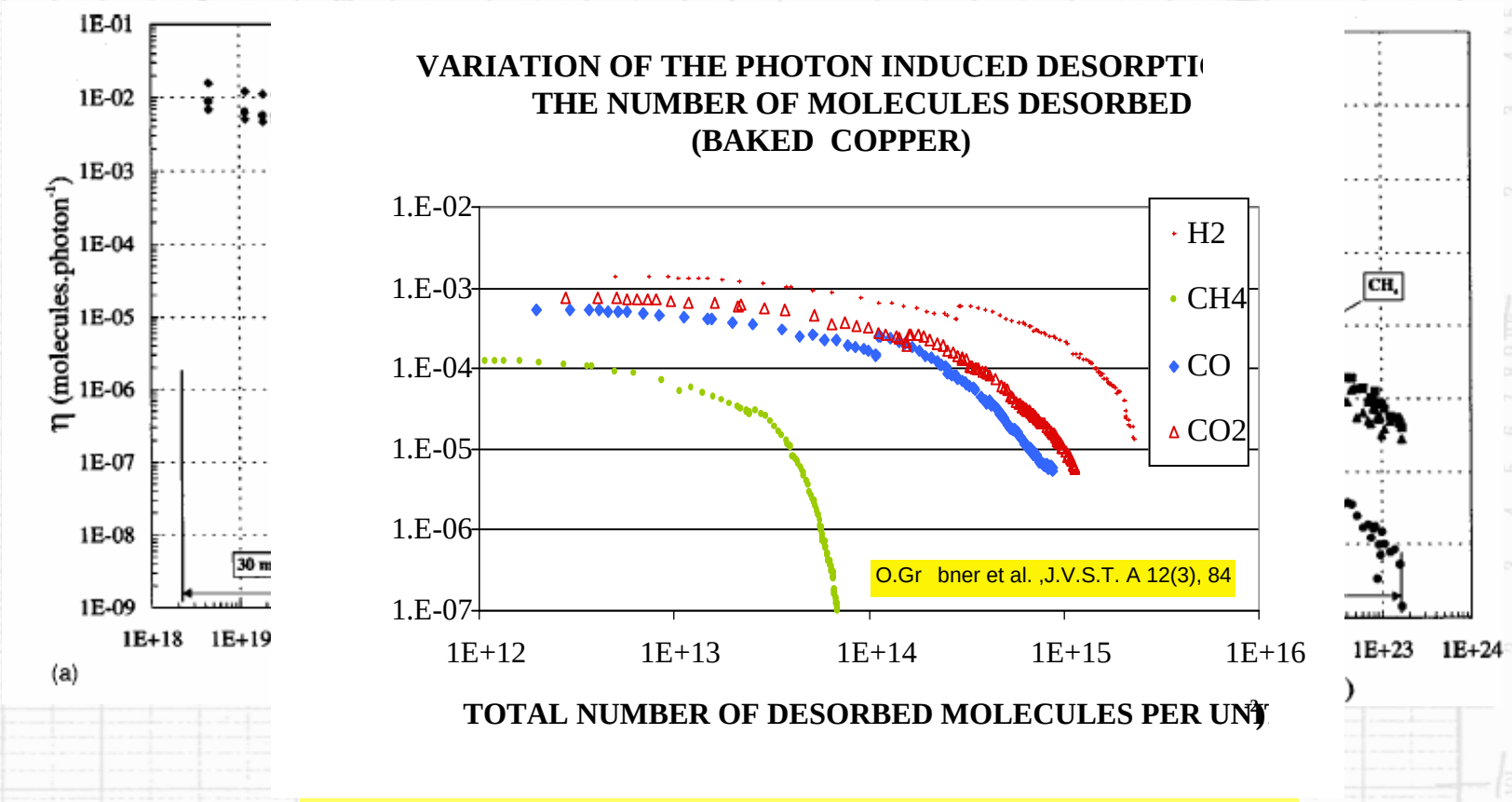
BAKED Cu
(H_2,CO)

INCIDENCE: CERN 90°
NOVOSIBIRSK 10 mrad



NON-THERMAL OUTGASSING

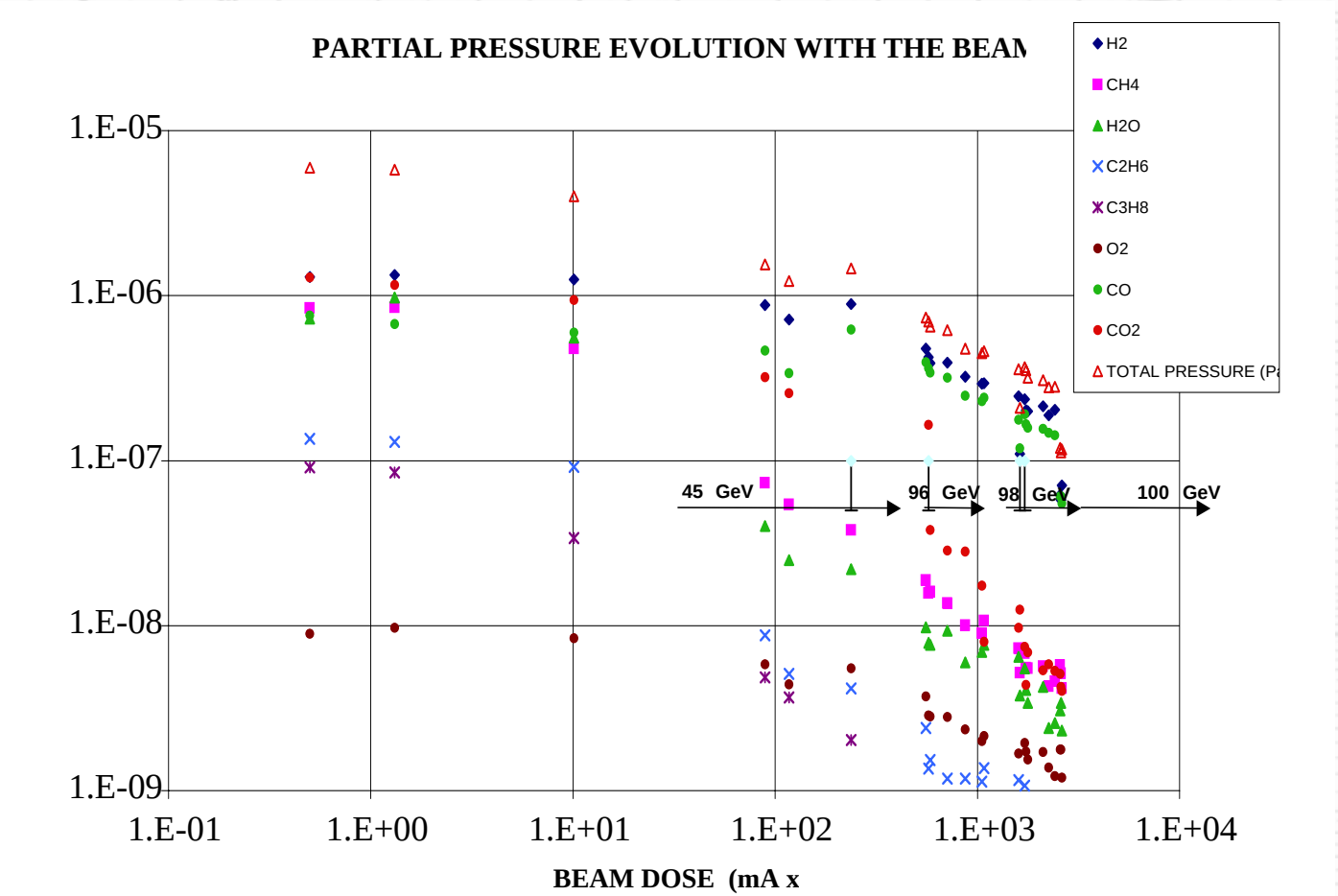
- **PHOTON INDUCED DESORPTION**
  - **–BEAM CLEANING**



C. Herbeaux et al. JVSTA 17(2) 635-643 (1999)

NON-THERMAL OUTGASSING

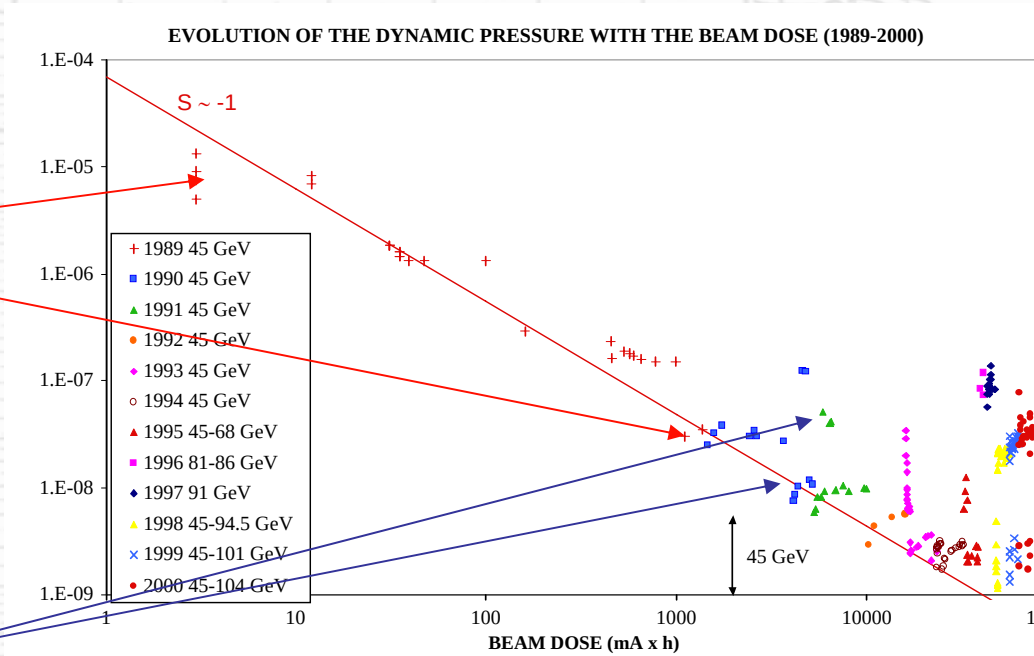
- **PHOTON INDUCED DESORPTION**
  - **–BEAM CLEANING :GAS COMPOSITION VARIATION**



NON-THERMAL OUTGASSING

- **BEAM CLEANING**
  - –Important effect in lepton machines (synch radiation)
    - *Gas load reduced by ~ 300 during 1st year in LEP (1 A.h)*
  - –Consequences for design
    - *Pumping speed tailored to reduced desorption:*

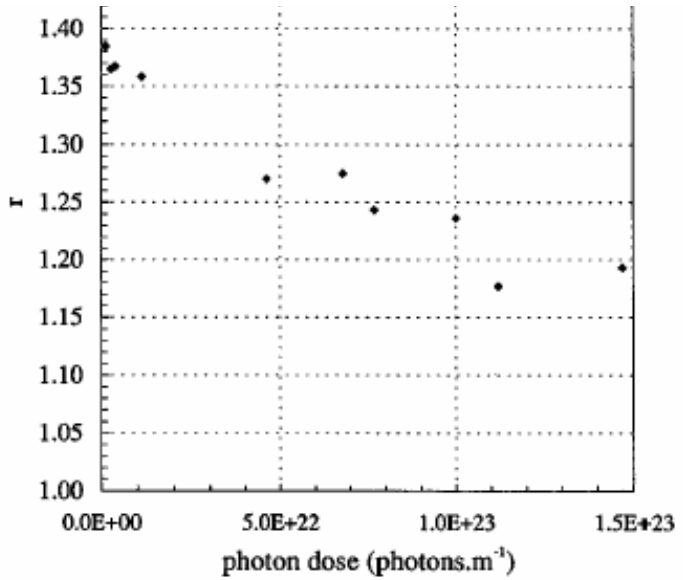
      –=>Pump budget / Cleaning time
    - *Cleaning partly lost in absence of operation (quick recovery)*
  - –Also valid for photoelectron/electron emission (δ decrease 2->1.3)



NON-THERMAL OUTGASSING

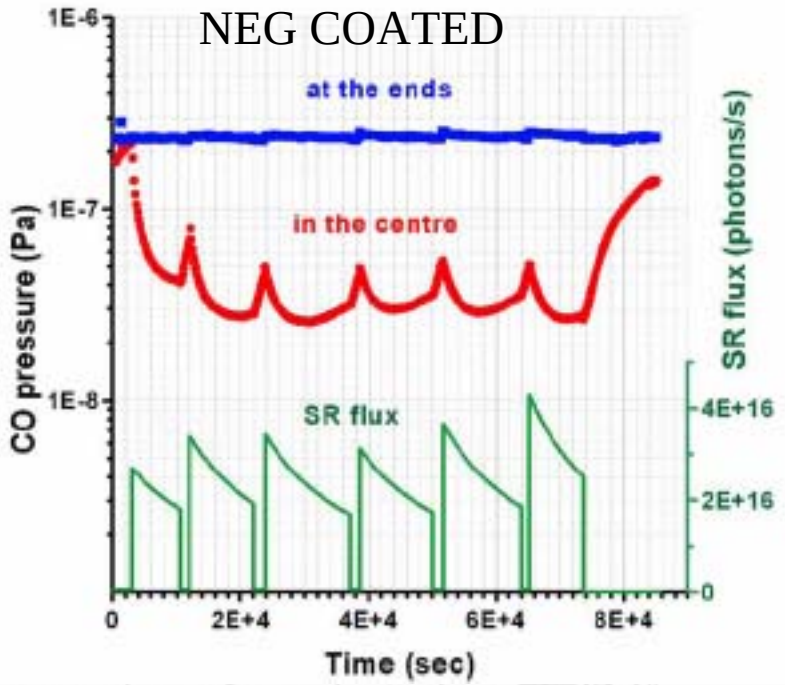
- **PHOTON INDUCED DESORPTION**
  - **–PUMPING**
    - ***on st. steel: limited capacity: 10^{-4} monolayer***
    - ***on getter: limited to CO (?) re-saturate quickly in absence of synch. rad.***

CO: 300 l/s/m 10^{23} phot/m
ST.STEEL



C. Herbeaux et al. JVSTA 17(2) 635-643 (1999)

NEG COATED



V. Anashin et al. Vacuum 75 155-159 (2004)

NON-THERMAL OUTGASSING

- **COMPARISON ION/PHOTON DESORPTION**
  - **–IMPLICATIONS FOR ACCELERATORS**

•ION

$$P(I)=\frac{P_0}{1-I*\frac{\sigma}{e}*\frac{\eta}{S}} \Rightarrow \quad I \rightarrow \frac{e*S}{\sigma*\eta} \quad P \rightarrow \infty$$

•PHOTON

$$\frac{\Delta P}{I} = K*\frac{1}{\rho}*\frac{E*\eta}{S}$$

– **Runaway process if I_c exceeded**

– ***=>FAST PRESSURE INCREASE WHEN I_C APPROACHED***

- ***REFUELING OF THE SURFACE***
- ***=>NO BEAM CLEANING***

–**Elaborated surface treatments**

- ***=>ION BOMBARDMENT CLEANING***
- ***=> BAKE OUT MANDATORY IN STORAGE RINGS***

–**Baked machine=> longer repair time**

–**Pressure increases linearly with current => stability**

- ***=>BEAM CLEANING***

-Simpler preparation procedure

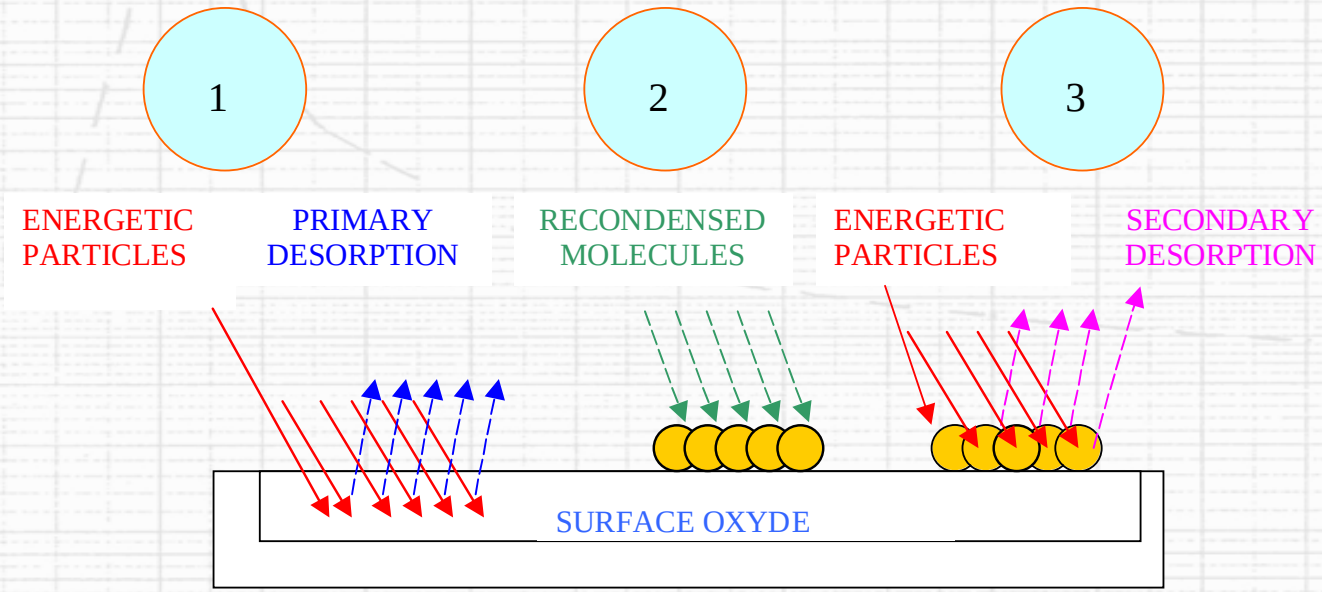
⇒ ***(BAKE-OUT OPTIONAL)***

-Shorter interventions

-Heavy power load on surfaces (synchrotron radiation)

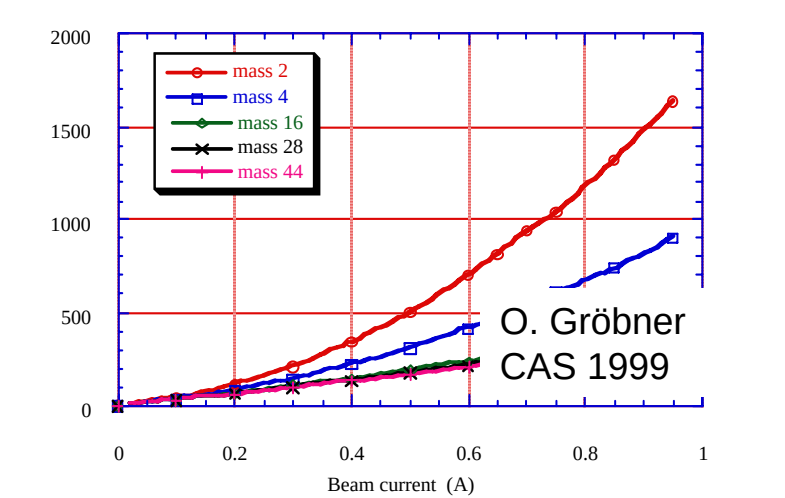
NON-THERMAL OUTGASSING

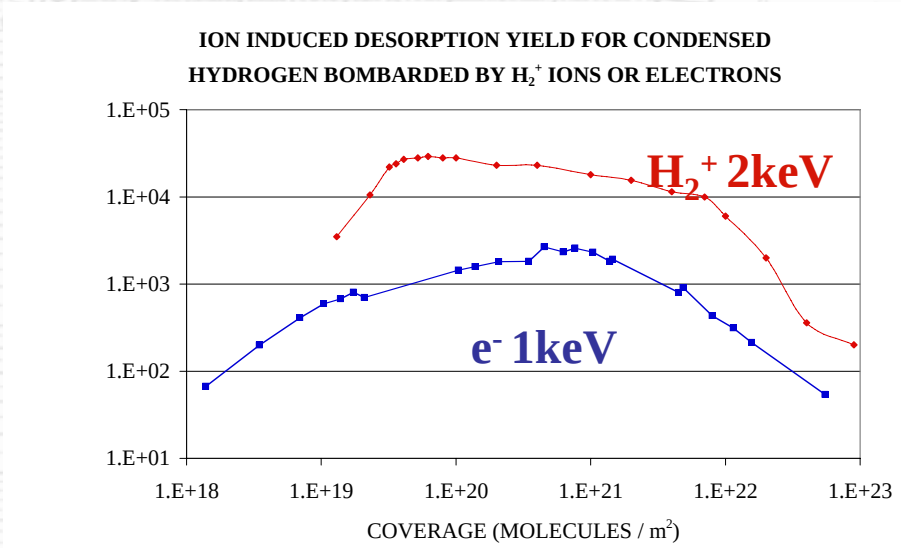
- **COLD SYSTEMS (cf. V. Baglin)**
  - **–DIFFERENCE WITH WARM SYSTEMS**
    - ***SMALL HEAT LOADS DANGEROUS (HIGH PRESSURE => QUENCH SC MAGNETS)***
    - ***POSSIBILITY OF THICK CONDENSED LAYER (VAPOUR PRESSURE, DESORPTION) ENERGETIC PARTICLES: PHOTONS, ELECTRONS, IONS***
    - ***TWO SOURCES OF DESORPTION:***
      - –CHEMISORBED GAS (AS FOR WARM SYSTEMS)
      - –PHYSISORBED GAS (INITIALLY NOT PRESENT)



NON-THERMAL OUTGASSING

- **THE GAS SOURCES**
  - **–LHC CIRCULATING CURRENT .56 A: SPACE CHARGE**
    - ***=> ION INDUCED DESORPTION***





  - **–SYNCHROTRON RADIATION : 10^{17}PHOTONS/s/m,**
    Ec =45 eV, 0.2 W/m
    - ***=> PHOTON INDUCED DESORPTION***
  - **ELECTRON MULTIPLICATION BY PARTICLE BUNCHES (cf :O. Gröbner talk)**
    - ***=>ELECTRON INDUCED DESORPTION***

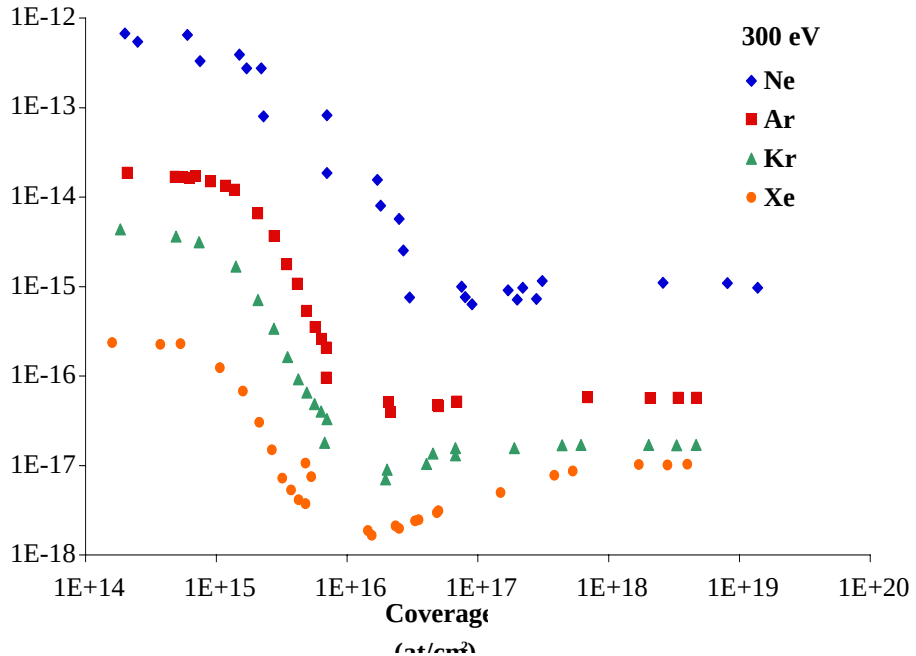
NON-THERMAL OUTGASSING

- **ESD OF CONDENSED GASES**
  - *LARGE YIELDS VARYING WITH COVERAGE*
  - *PEAK AT LOW COVERAGE*

$$\sigma = \frac{\eta}{\theta}$$

  - *FLAT MAXIMUM ABOVE 300 eV*
  - *DEPENDS ON THE SUBLIMATION ENERGY*

H. Tratnik et al. Vacuum in press (2006)



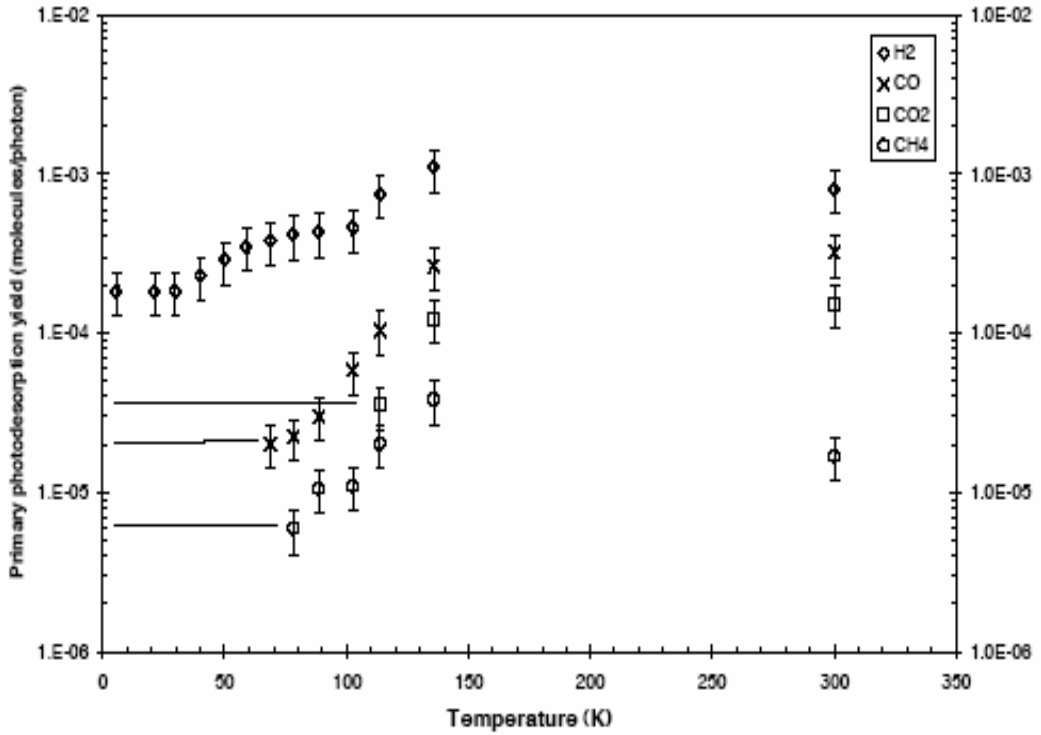
–Large amount of data for higher e^- energy and higher coverages in:

J. Schou Risø-R-591 (EN) Risø National Laboratory, Roskilde, Denmark

NON-THERMAL OUTGASSING

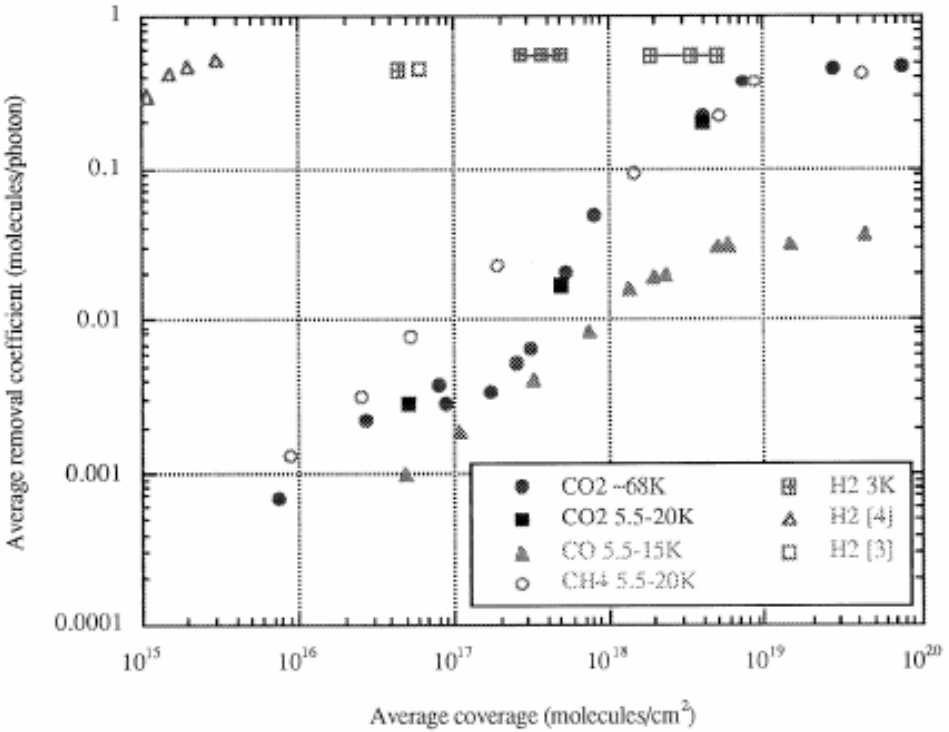
- **PSD OF CONDENSED GASES**

V. Baglin et al. Vacuum 67 421-428 (2002)



PRIMARY DESORPTION

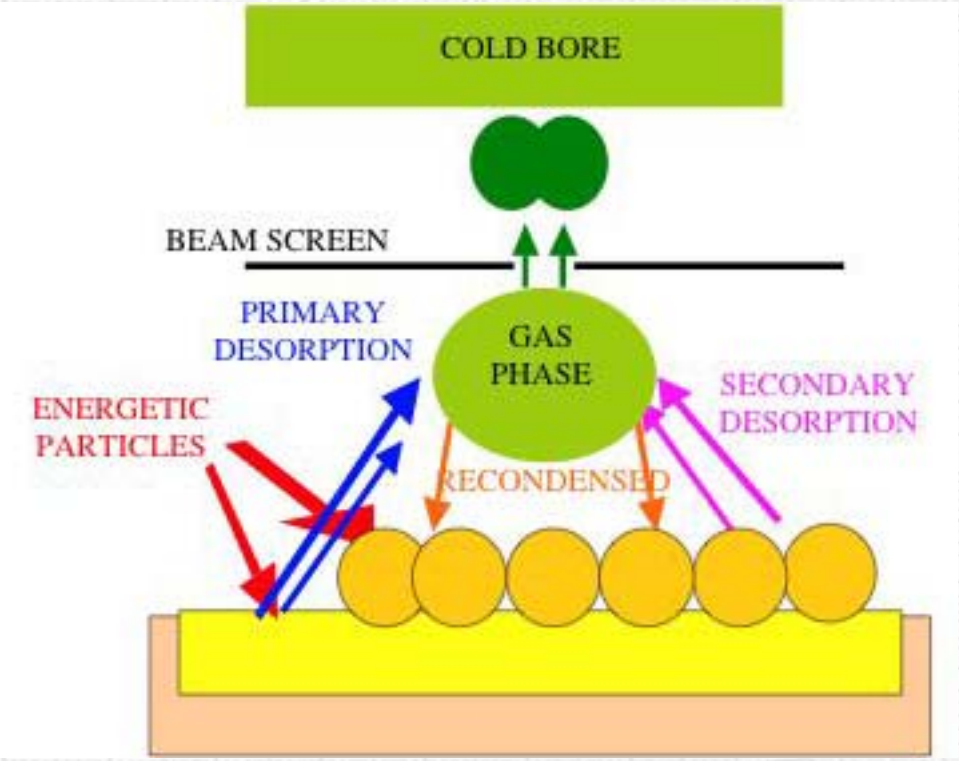
V. Anashin et al. Vacuum 53 269-272 (1999)

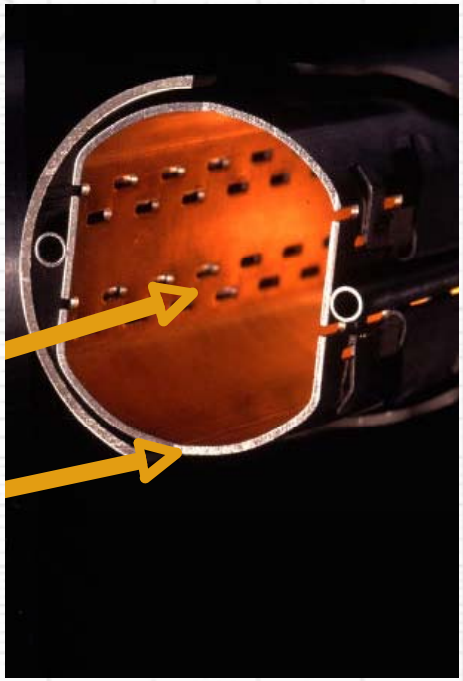


PHYSISORBED GAS DESORPTION (recycling)

NON-THERMAL OUTGASSING

- **COLD SYSTEMS**
  - **–PRIMARY DESORPTION => COVERAGE INCREASE=> SECONDARY DESORPTION=> PRESSURE=> GAS FLOW TO COLD BORE**

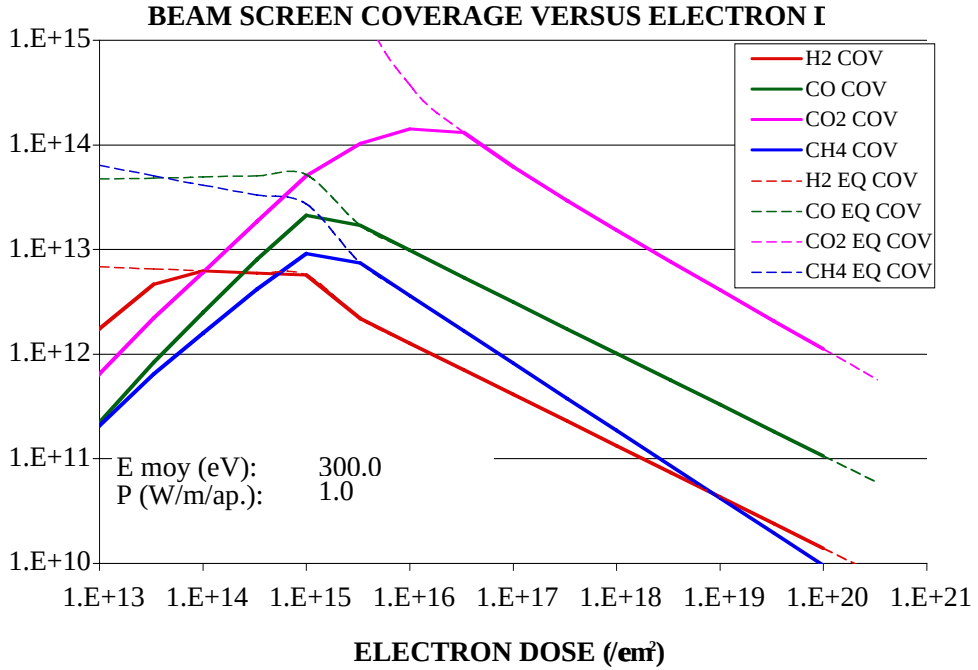


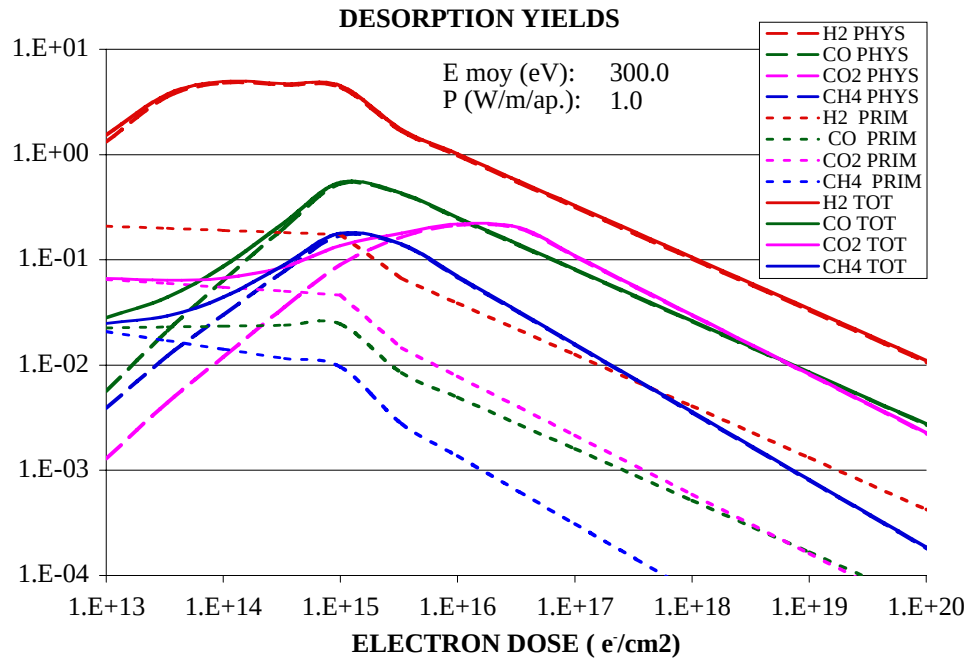


  - **–EQUILIBRIUM : PRIMARY DESORPTION ~ FLOW TO COLD BORE**

NON-THERMAL OUTGASSING

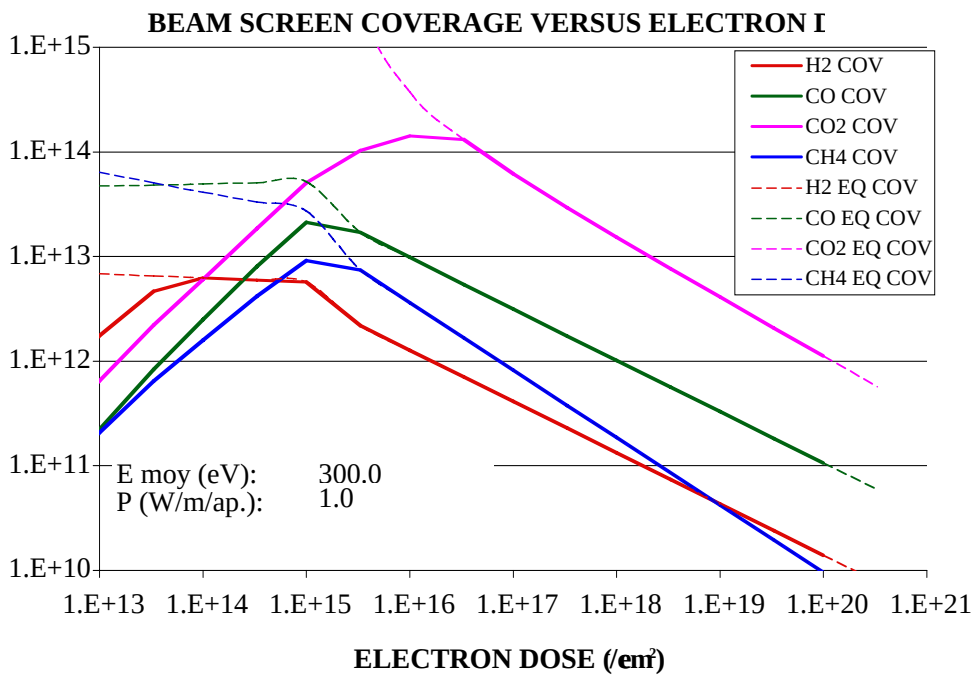
- **COLD SYSTEMS**
  - **–EVOLUTION DURING OPERATION**

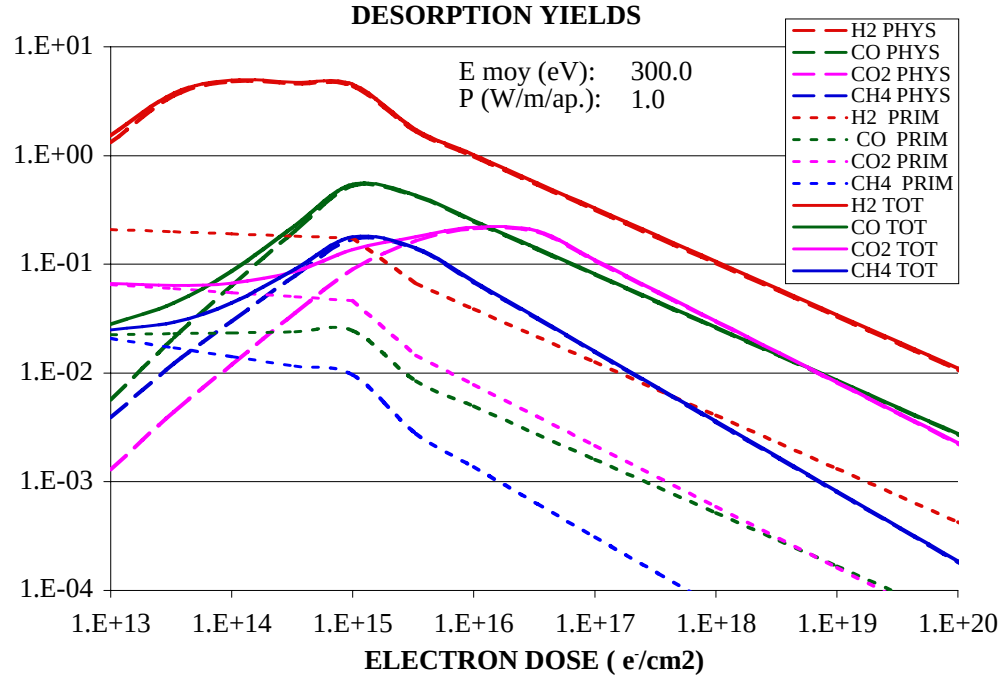




NON-THERMAL OUTGASSING

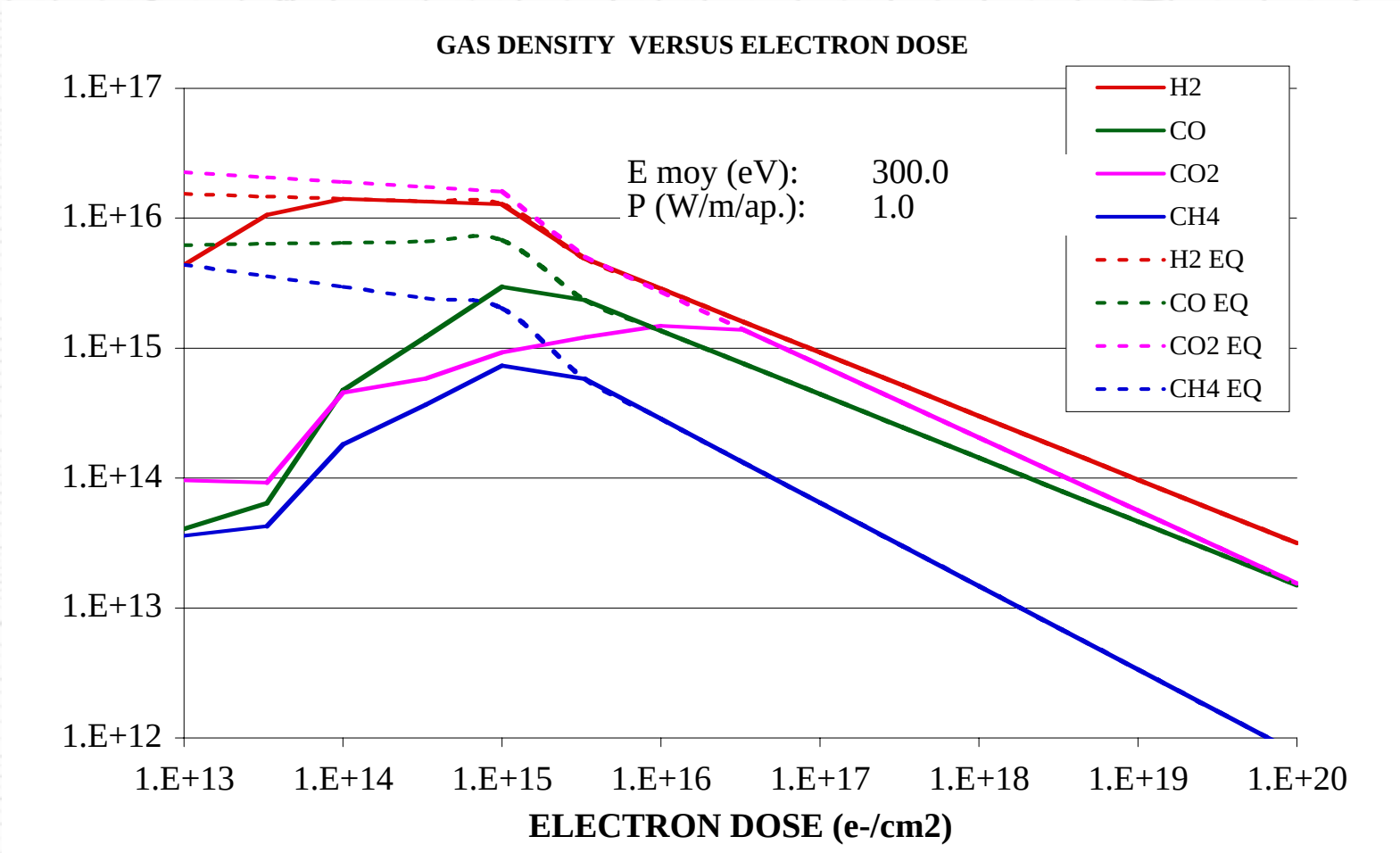
- **COLD SYSTEMS**
  - **–EVOLUTION DURING OPERATION**





NON-THERMAL OUTGASSING

- **COLD SYSTEMS**
  - **–EVOLUTION DURING OPERATION**



NON-THERMAL OUTGASSING

- **CONCLUSIONS**
  - **–NON THERMAL OUTGASSING IS THE PREDOMINANT GAS LOAD DURING OPERATION OF ACCELERATOR**
  - **–PRODUCED BY THE IMPACT OF PHOTONS, ELECTRONS AND IONS GENERATED/ACCELERATED BY THE BEAM**
  - **–THE DESORPTION COEFFICIENT η IS SURFACE (MORE THAN MATERIAL) DEPENDANT**
  - **–STRONGLY INFLUENCED BY SURFACE TREATMENTS**
  - **–OXIDE LAYER IS SUSPECT OF PLAYING A DETERMINANT DETRIMENTAL ROLE**
  - **–EQUIVALENT OF ~n* 10 MONOLAYERS TO BE REMOVED TO REDUCE η BY A FACTOR 100 (PSD)**

NON-THERMAL OUTGASSING

- **CONCLUSIONS**

–DETERMINES THE PREPARATION PROCEDURES TO ACHIEVE NOMINAL CONDITIONS

–MAKE THE VACUUM SYSTEM OF ACCELERATORS ALIVE

…….AND THE LIFE OF THE DESIGNER / OPERATOR

THANKS FOR YOUR ATTENTION

EXCITING !!!

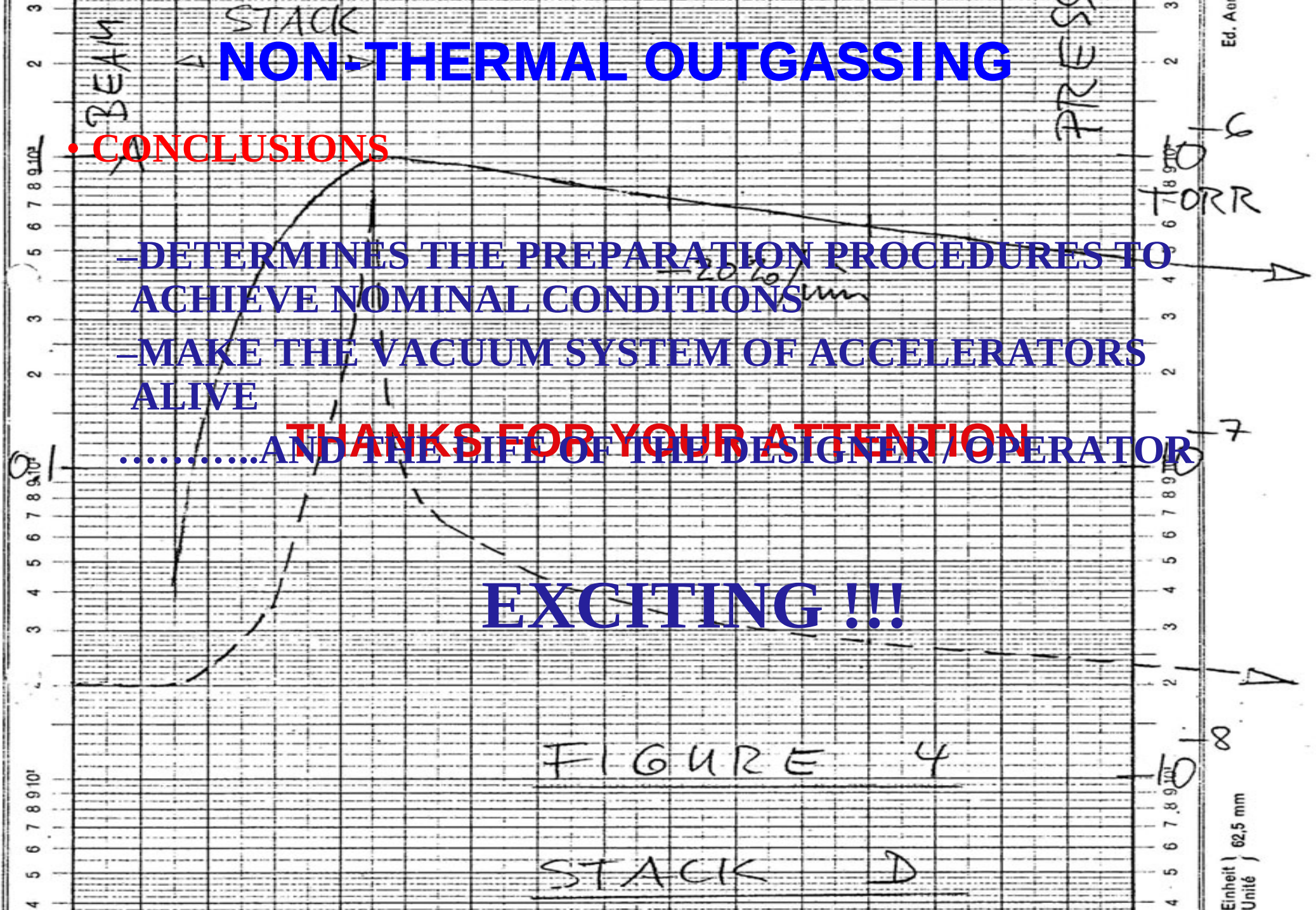


FIGURE 4