Estimates of residual gas pressure in the LHC

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Workshop on Experimental Conditions and Beam Induced Detector Backgrounds

03-04 April 2008

Outline

- Vacuum calculations for LHC runs
  - *Input parameters*
- Machine layout
- Results for “static pressure” in the experimental LSS and comparison with measured values
- Comparison between filling factors
- Arcs
- Effect of collimators
- Ion operations
- Discussion
- Questions

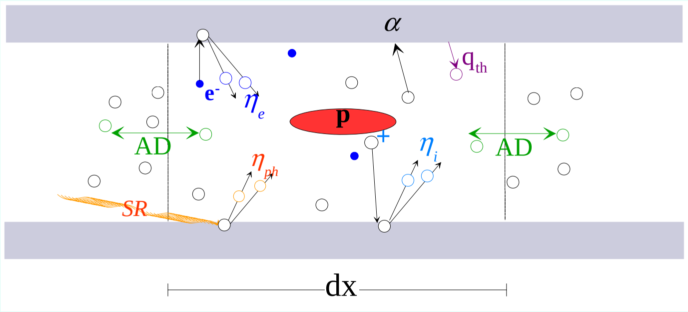
Vacuum calculations for LHC runs

Dynamic effects in LHC

- Beam induced phenomena : ion, electron and photon induced molecular desorption.
- Ion induced desorption instability
- Electron cloud build up

Simulations code

- Cylindrical geometry
- Time invariant parameters
- Multi-gas model
- Finite elements



Input parameters depend on:

- Incident energy
- State of the surface (baked-unbaked)
- Dose

The sources of gas depend on the surface properties and on the operating scenarios.

Estimates are only a snapshot of specific conditions

Photon Induced gas Desorption

[Gröbner et al. Vacuum, Vol 37, 8-9, 1987]

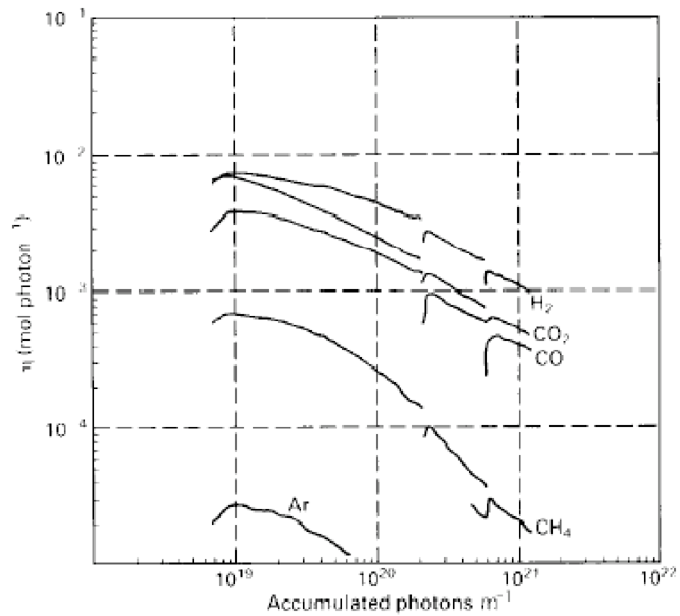


Figure 1. The molecular desorption yield η (molecules per incident photon) as a function of the accumulated photons per m for a LEP sample vacuum chamber exposed to synchrotron light at DCI (Orsay).

Evolution with dose

[Gómez-Goñi et al., JVST 12(4), 1994]

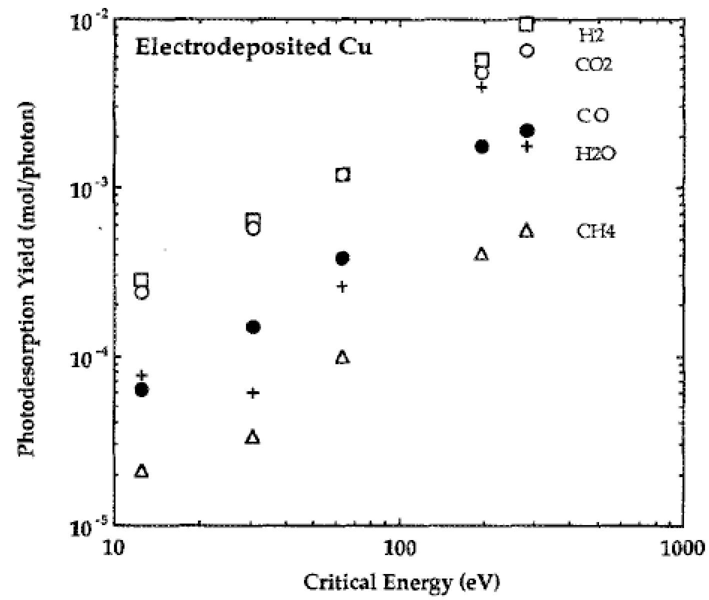
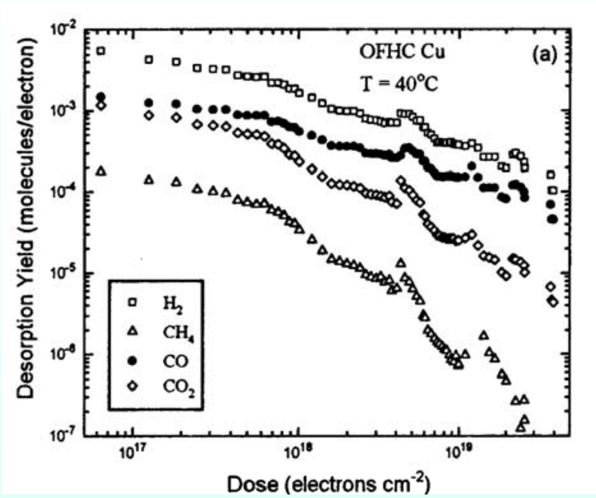


FIG. 5. Photon-induced gas desorption yields from unbaked electrodeposited copper at different critical energies.

Energy dependence

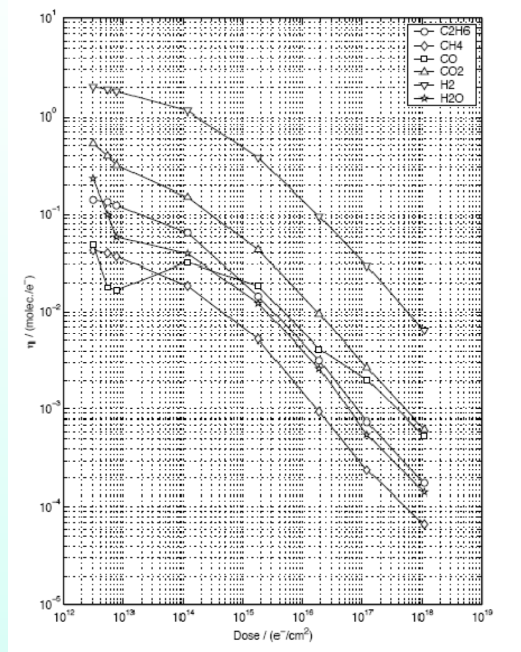
Electron Induced Gas Desorption

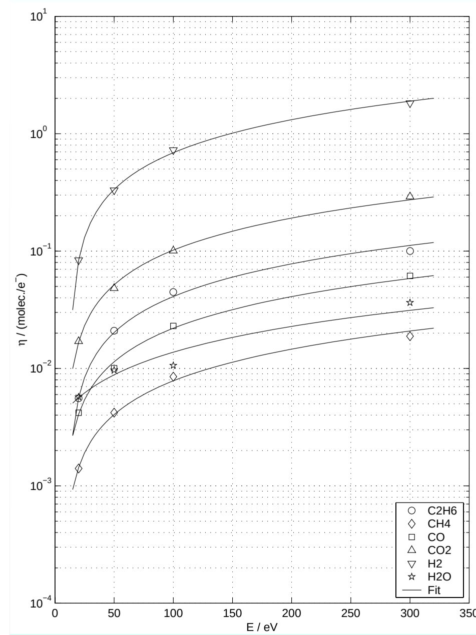
J. Gómez-Goñi et al., JVST A 15(6), 1997
Copper baked at 150ºC



Evolution with dose

G. Vorlaufer et al., Vac. Techn. Note. 00-32
Copper Unbaked



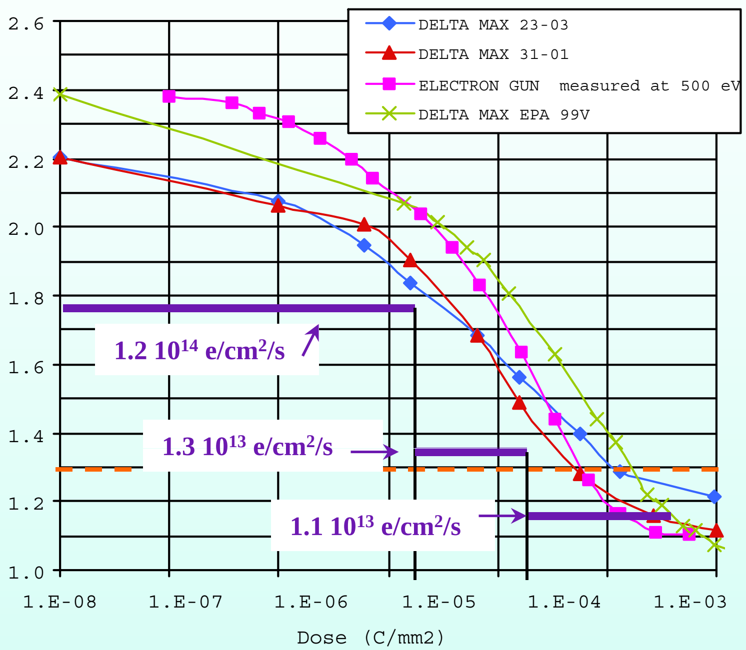


Evolution with dose

Energy dependence

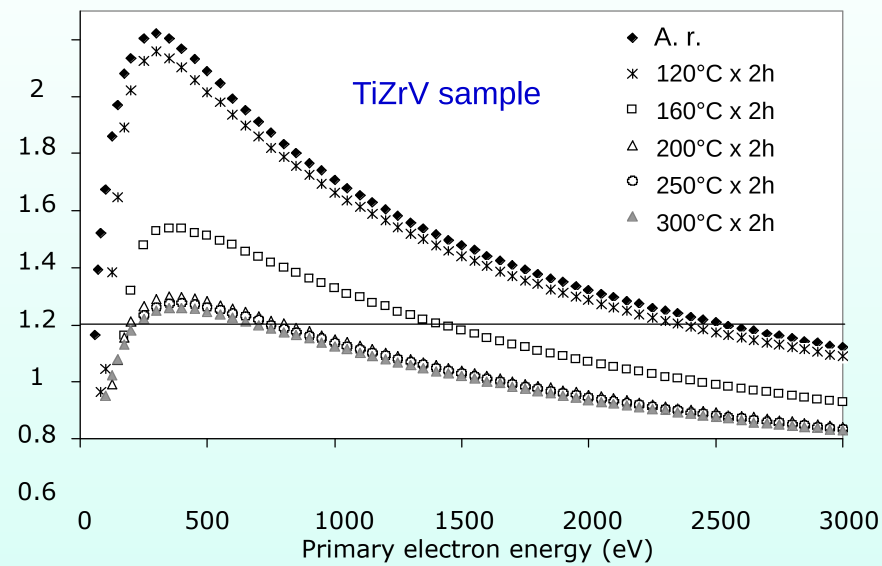
Secondary electron emission

N. Hilleret et al., LHC Proj. Rep. 472, 2001
For "as received" Copper and
electron energy of 99eV and 500eV



Evolution with dose

C. Scheuerlein et al., JVST A 18(3), May/Jun 2000.

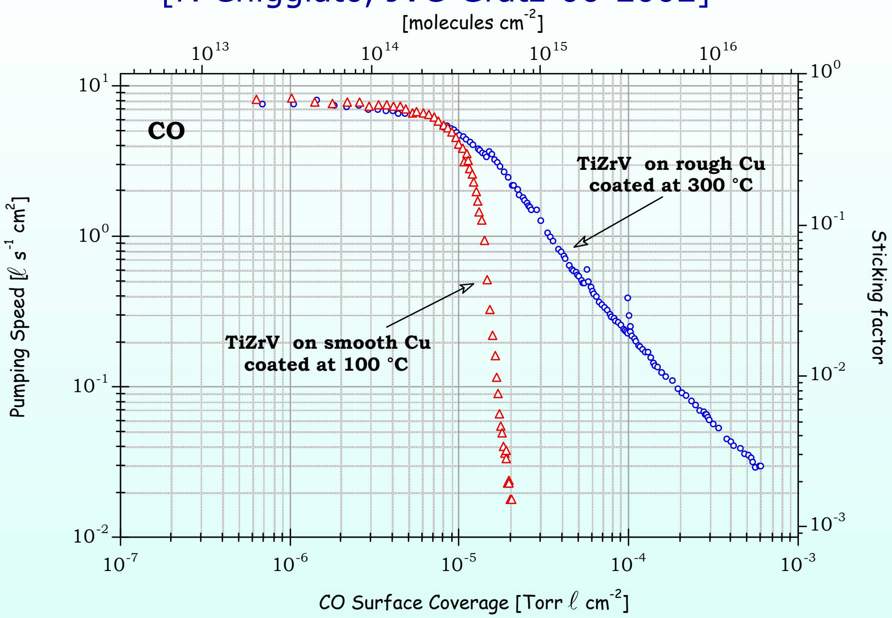


Energy dependence at different activation temperature

At few 10^{-10} p/b no e-cloud expected

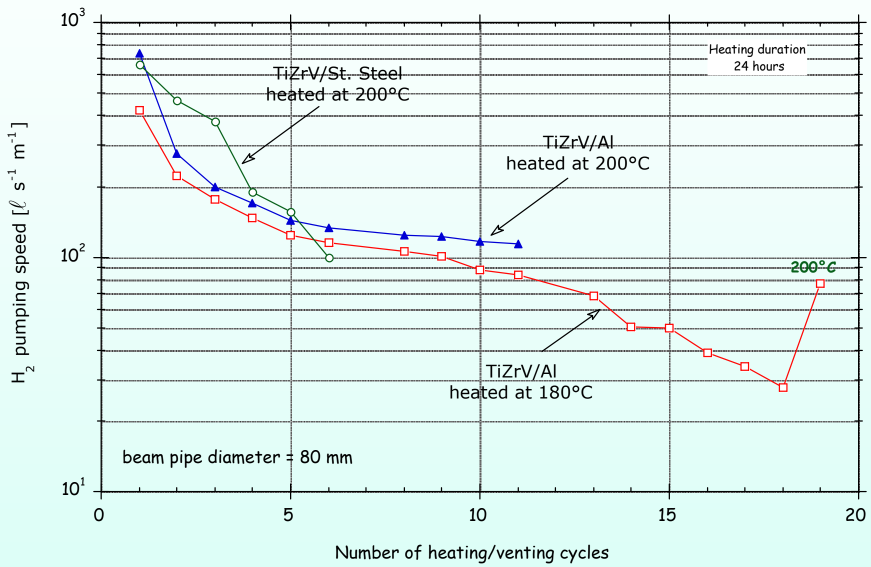
NEG properties

[P. Chiggiato, JVC-Gratz-06-2002]



Pumping speed

[P. Chiggiato, JVC-Gratz-06-2002]

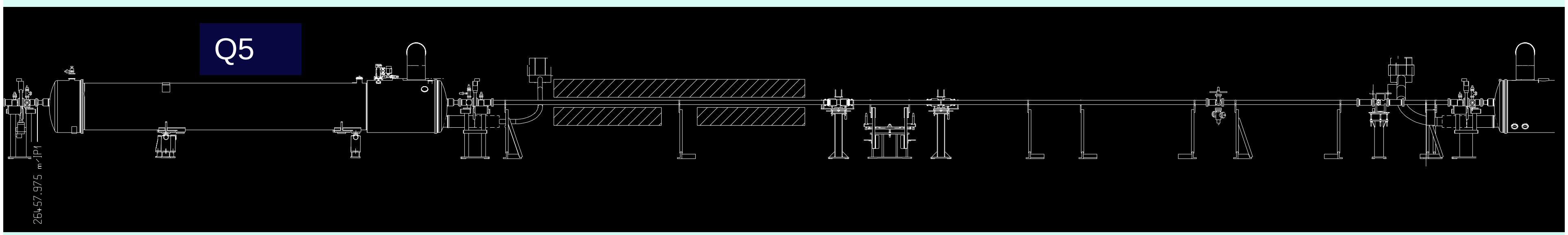


Aging

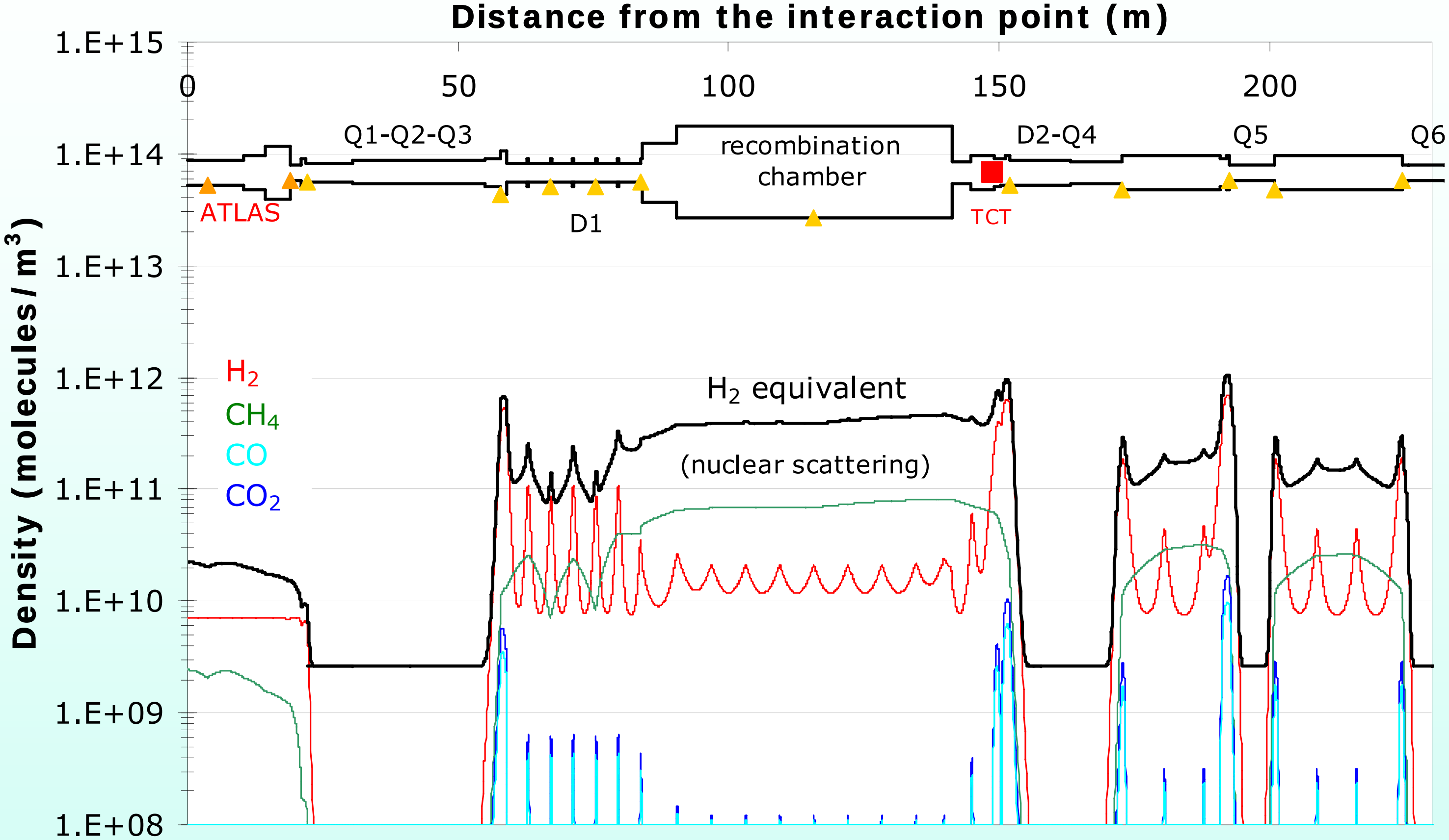
Machine layout

- Cold magnets provided with beam screen actively cooled between 5 and 20K :

  - Avoids ion induced pressure instability and guarantees a low background pressure.
  - In the CB at 4.5K, H2 will be cryosorbed on dedicated materials placed on the rear of the BS.
- LSS room temperature sections are copper chambers coated with ~1 to 2 μm of TiZrV sputter NEG
  - NEG coating is employed to prevent electron multipacting, given the low secondary electron yield after activation at a temperature between 160 and 200ºC for 2 hours, and to ensure low desorption and the gas pumping necessary for ion induced desorption stability and low background pressure
  - **All room temperature sections are being baked-activated**

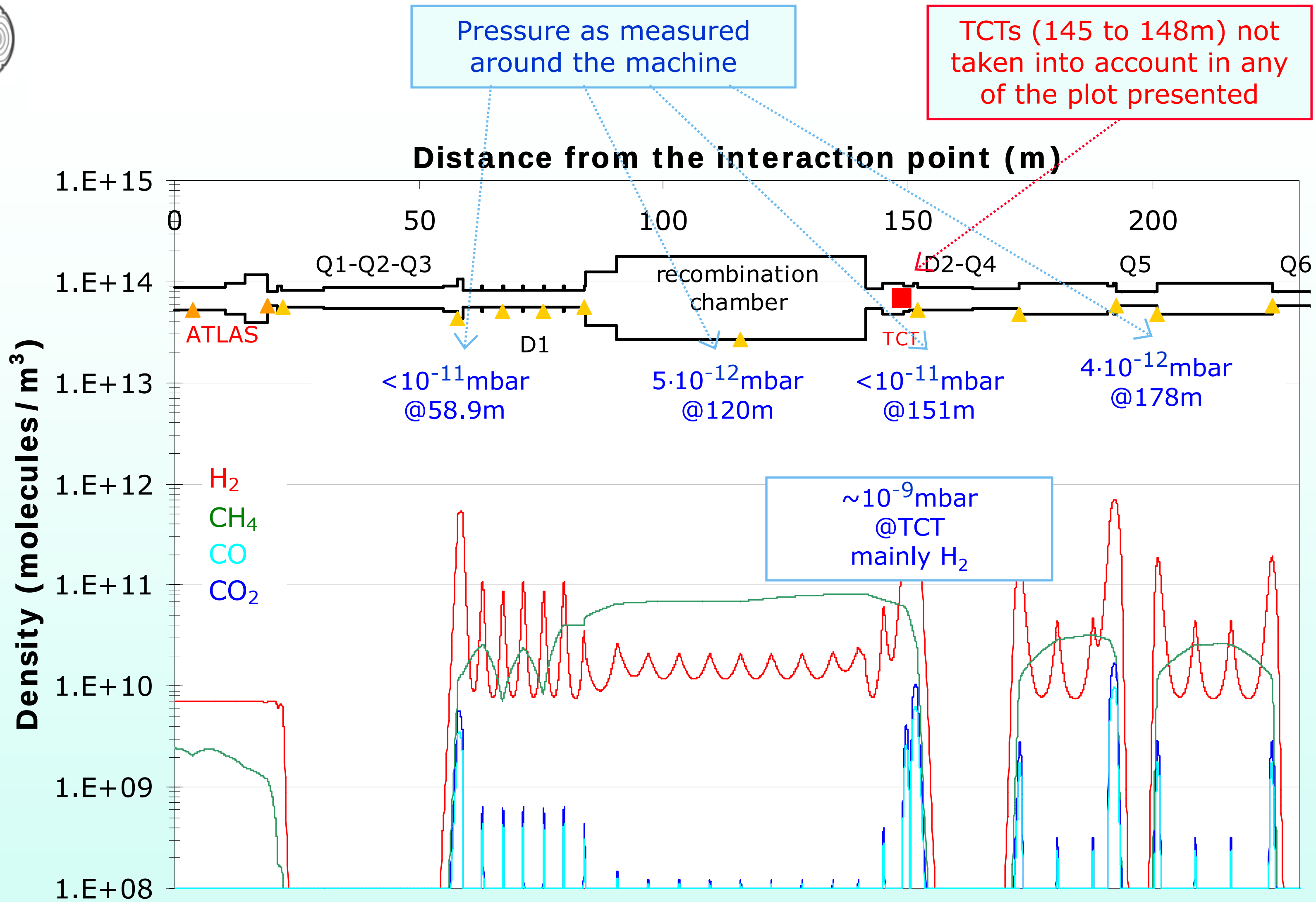


LSS 1/5
static pressure (w/o dynamic effects)



$$n_{H_2 equiv.} = n_{H_2} + \frac{\sigma_{CH_4}}{\sigma_{H_2}} n_{CH_4} + \frac{\sigma_{CO}}{\sigma_{H_2}} n_{CO} + \frac{\sigma_{CO_2}}{\sigma_{H_2}} n_{CO_2}$$

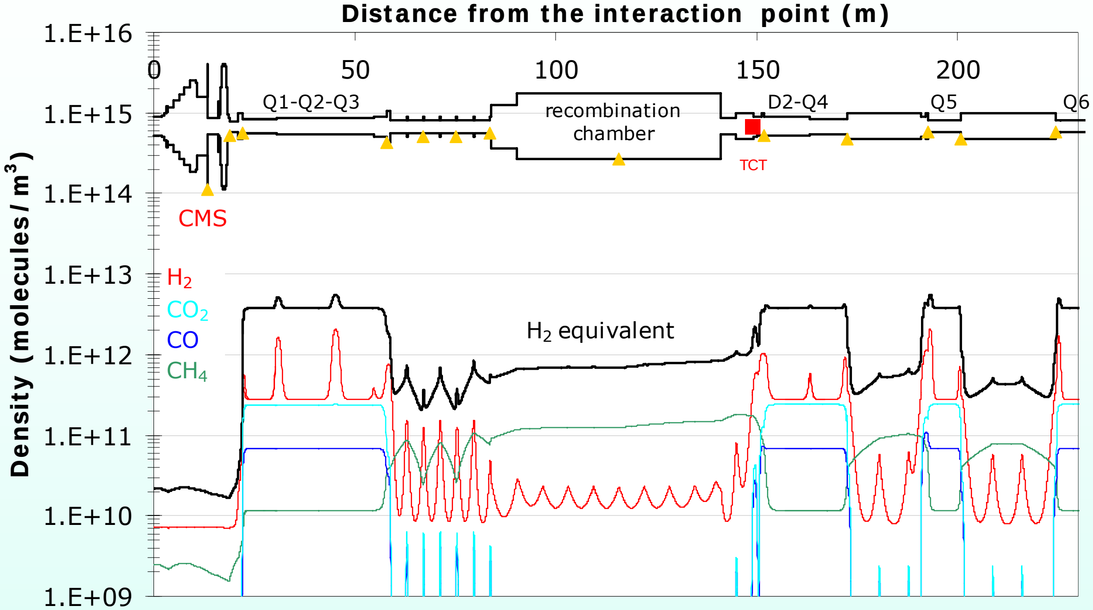
Nuclear scattering cross section: $\sigma_{CH4}/\sigma_{H2}=5.4$; $\sigma_{CO}/\sigma_{H2}=7.8$; $\sigma_{CO2}/\sigma_{H2}=12$



$1\cdot10^{11}$ molec/ m³ = $2.7\cdot10^{-14}$ mbar at 2K

$1\cdot10^{11}$ molec/ m³ = $4\cdot10^{-12}$ mbar at 293K

LSS 1 at machine startup



A. Rossi, LHC Project Report 783

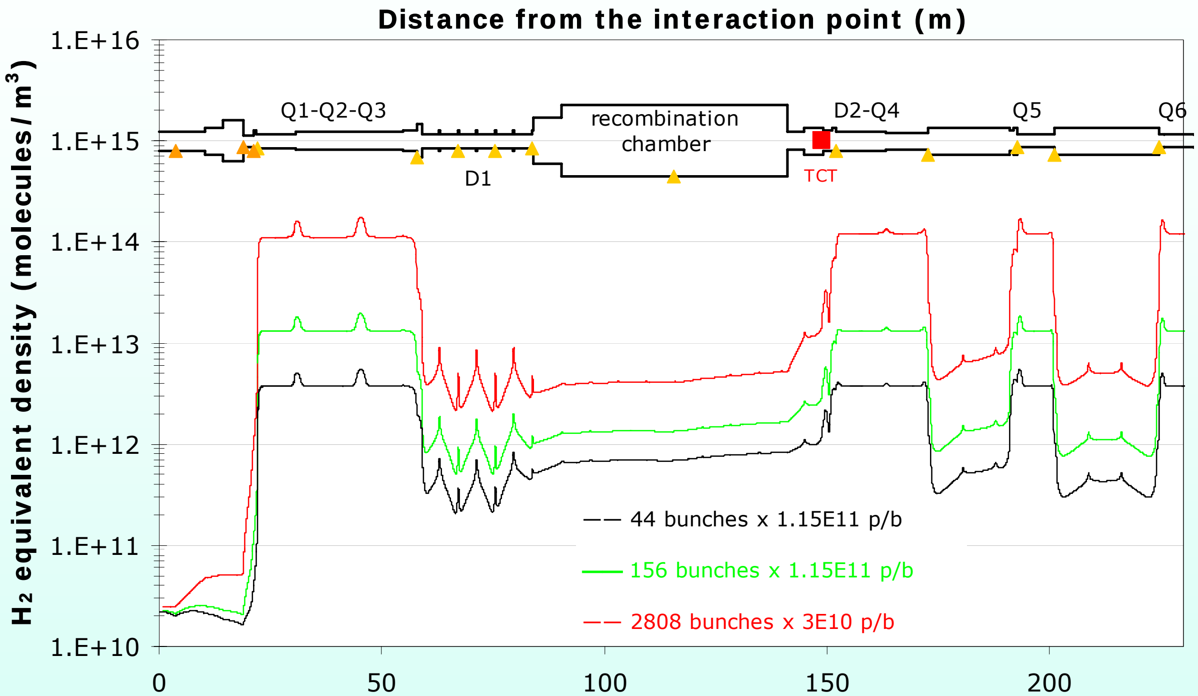
Scenario in 2004:
44 bunches x $1.15 \cdot 10^{11}$ p/b
7TeV

- Present scenario (MARIC)
  - 2008: 43 bunches – few 10^{10} p/b – 5TeV ➤➤➤ photon flux reduced by ~50
    ➤➤➤ *expected pressure profile ⁄ static*
  - 2008/9: 43 bunches – few 10^{10} p/b - 7TeV
  - 2009: higher number of bunches

LSS 1

— *44 x 1.15·10¹¹ p/b* — *156 x 1.15·10¹¹ p/b* — *2808 x 3·10¹⁰ p/b*

A. Rossi, LHC Project Report 783



- Calculation parameters
  - NEG with 1/10 of maximum pumping speed (to be conservative)
  - Desorption yields as for surfaces never exposed to photons-electrons

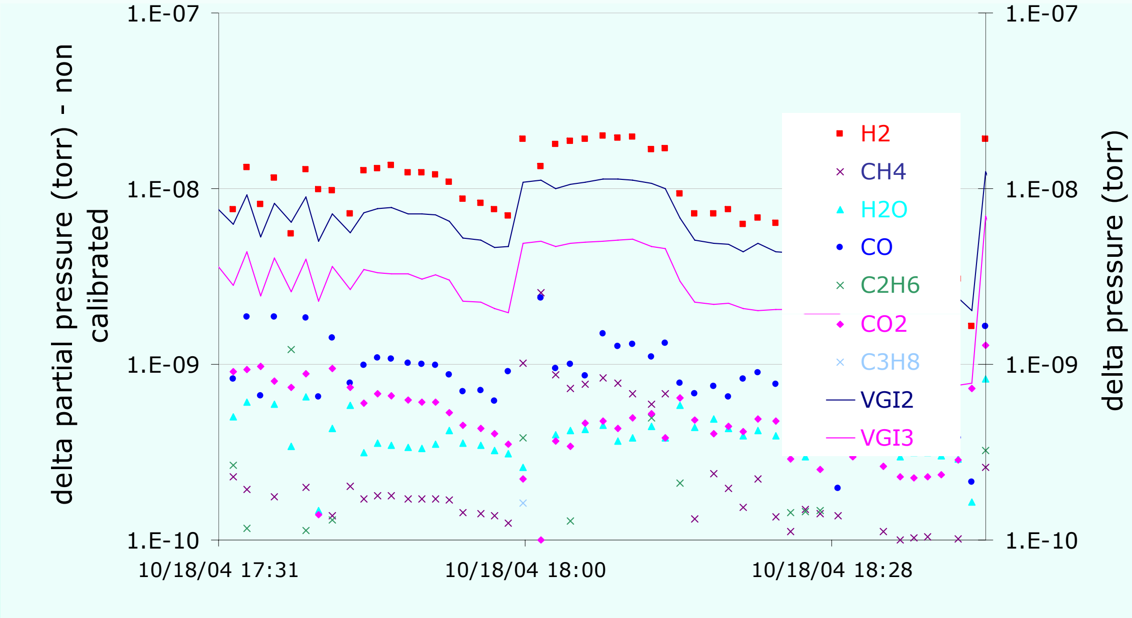
Is this the upper limit?

- Pressure estimates have a factor ~ 2 uncertainties and depends on assumptions made for calculations
- Photon flux is an upper limit
- The desorption yields considered on Cu and uncoated parts corresponds to what is expected at the beginning period
  - The yields decrease with dose (ph and e- bombardment) : conditioning
- Cryo-pumping is neglected (i.e. beam screen pumps only via pumping holes)

The given estimate is the upper limit

Effect of collimators

- Collimator outgassing fully characterised: main gas H_2
- Experience to be made during operation: outgassing depends on jaw temperature



A. Rossi - unpublished

Measurements in SPS

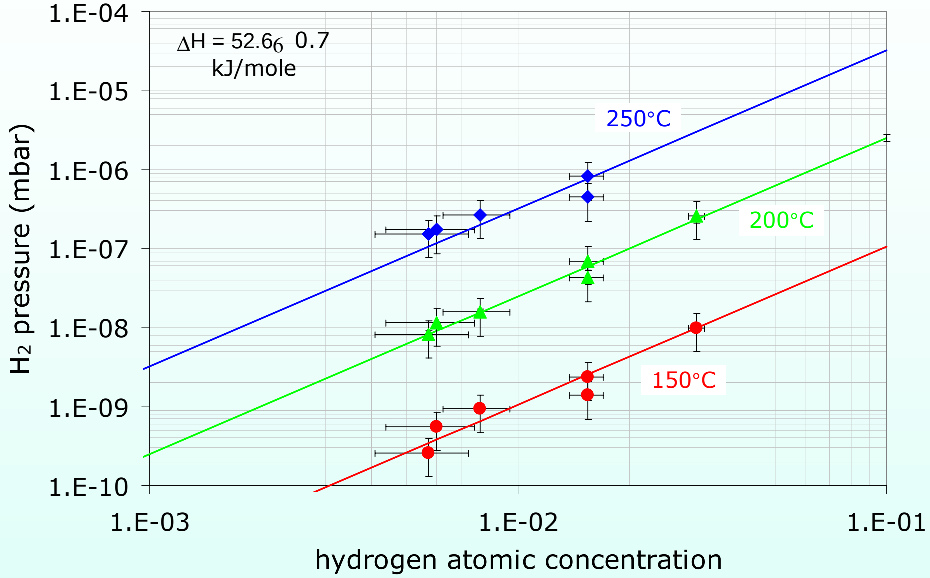
Insertion of Graphite collimator jaw ~1mm into beam

$\Delta p \sim 5 \cdot 10^{-9}$ mbar

H_2 main gas – unbaked system

Effect of collimators: heating of vacuum chamber due to energy deposition from particle losses

$$c_H = s\sqrt{P_{H_2}}\exp(-\Delta H/RT)$$



A. Rossi - EPAC, Edinburgh UK, June 2006

- Temperature rise estimated to 150°C (R. Assmann) in momentum and betatron cleaning insertions, at nominal intensity
- The pressure will recover when back to room temperature
- Standard section - atomic concentration of <$1\cdot10^{-3}$ H_2 pressure at 150°C ≤ 10^{-10} mbar

- MBW worst case scenario - atomic concentration of $2\cdot10^{-2}$
  - System not pumped from extremities
  - In proximity of graphite collimators, after 9 month operations

  H_2 pressure at 150°C ~ $5\cdot10^{-9}$ mbar < 100h beam lifetime

COLD ARCS (with proton beam)

Assumptions

- Beam screen pumping only via holes (as in LSS)
- Photon critical energy about 3 x in LSS
- Photon (and photoelectrons) flux about 10 x in LSS
- Photon and photo-electron gas desorption about the same

Results

- Pressure expected in the arcs ≤ 20 x in the cold sections of the LSS

Residual gas pressure for ions operations

A. Rossi, presented at I-LHC meeting on December 9, 2004

- Gas sources: only ions from beam losses
  - Residual gas ionisation neglected + ion estimated energy ~ 2eV (no gas desorption expected);
  - Synchrotron radiation desorption neglected at critical energy ~ 2.8eV
  - No photoelectron or electron multipacting expected (low current and long bunch spacing)
  - Desorption yield for ions ~ 10^5 molecules/ion [E. Mahner, lhc-project-report-798] for each gas species considered (H_2, CH_4, CO and CO_2)
- Beam screen holes pumping only = neglect cryopumping (worst case scenario)
- Ion losses $2 \cdot 10^6$ ions/turn ➢➢➢ density for 100h beam lifetime

  real lifetime < 2s
- Estimated localised losses for quench limit
  - 200x100 beam lifetime if lost over a sec.
  - 2h if lost in 1 turn, but pressure recovery <1s

Vacuum not expected to be limiting factor to beam lifetime

Discussion

- Calculations of residual gas pressure strongly depend on surface properties and on the operating configuration, and give only a snapshot in time.
- Estimates made so far are for stable beam and do not include collimators.
  - Their effect is well understood on the static pressure.
  - Long term and beam effects will be studied.
- In the cold arc:
  - The gas density for 100h lifetime (10^{15} H_2 equiv./m^3) gives an upper limit and is the value to be used for experiment b.g. estimates.
  - The gas composition is expected to be similar to what calculated in the LSS.

Discussion

- Machine layout will evolve:
  - Part of 2nd phase collimators under design (2010)
  - Inner triplets with larger aperture (2012/2013)
- The pressure during stable beam may also depend on a transient during the beam cycle that causes particle losses, beam displacement, collimator setting, …

In order to estimate the gas density profile it is necessary to study case by case.

Questions - Answers

- Is the lifetime a useful information to renormalise the pressure estimate:
  - The vacuum group will be working close to the operation to learn how to use this information
- What happens if we have a He leak in the arcs:
  - It is expected to have a magnet quench before any effect of pressure can be seen.
  - BLM will give us some information. We have to learn if beam lifetime can give us an early warning
- What could go wrong:
  - Fast temperature gradients could open leaks (in LEP, with beam at 80GeV due to synchrotron radiation hitting transitions)
  - Damage caused by loss of beam
  - ……
- Can HOM in the experiments cause temperature rise?
  - No, according to estimates (L. Vos) made at time of design: Cu coating, conical transition, RF contact, RF screen for pumps
  - Matter under investigation