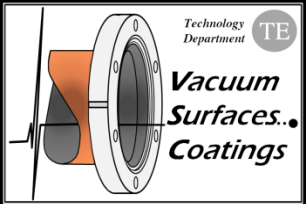


# **Vacuum and Cryogenics observations for different bunch spacing**

**J.M. Jimenez**

**On behalf of CRG and VSC Groups**

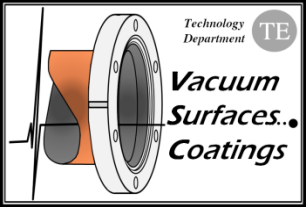
**with the contributions of G. Arduini, V. Baglin, G. Bregliozzi,  
P. Chiggiato, S. Claudet, G. Lanza, L. Taviani and BE-OP EICs**



# Main Topics



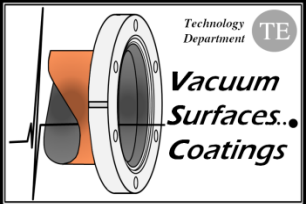
- **Introduction**
- **Review of Results: 150 / 75 / 50 ns bunch spacing**
- **Operation in 2011**
- **Conclusions**



# Electron cloud: Parameters & Limitations

- **The electron cloud build-up:**

- Is a threshold phenomenon
  - ↙ bunch population
  - ↘ number of bunches in the train
    - └──→ Linear build-up
- Depends highly on the Secondary Electron Yield (SEY)  $\delta$ 
  - Is enhanced by the low energy electrons surviving the gaps between bunch trains (reflectivity of low-energy electrons)
- Is attenuated by the spacing between bunches and bunch trains
- Is affected by many other parameters like:
  - Size of the beam vacuum pipe
  - Magnetic field
  - Temperature of the beam pipe walls

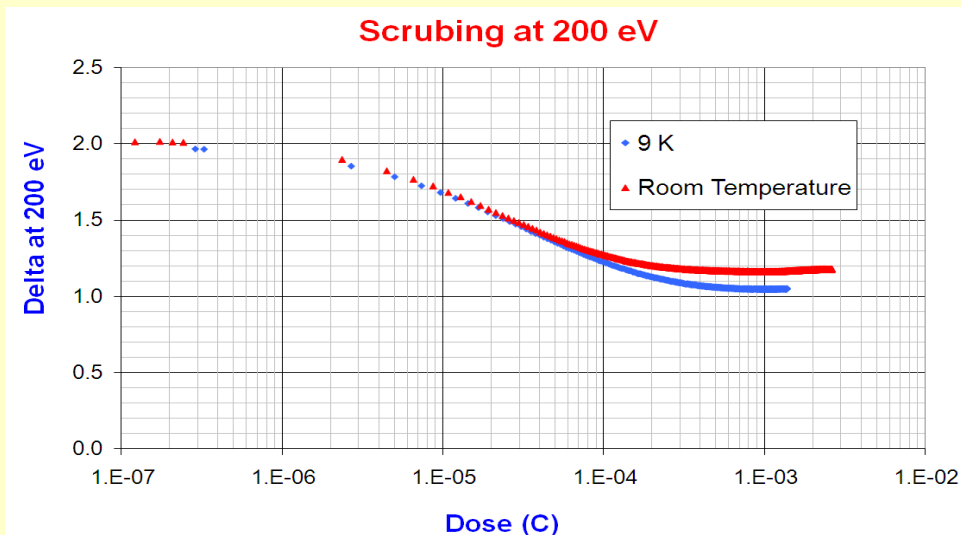


# Electron cloud: induced limitations

- **Vacuum pressure rise**
  - Electron stimulated desorption (ESD) / Multipacting length vs pumping speed
- **Cryogenic cooling capacity**
  - Electron flux to the wall (heat deposition) / Limitation by the available cooling capacity (capillaries / cryoplants)
- **Beam instability**
  - Electron density / Limiting factor for the scrubbing run (emittance blow-up and losses)
- **Beam-gas scattering induced radiation to cables and electronics**
  - Dynamic vacuum in the beampipe (total/partial pressures of gas species)
    - Radiation to cables and electronics / Single events / Quench limit
- **Background to Detectors**
  - Beam-gas scattering / Dynamic pressure in the beampipe / Length of the pressure bumps

# Electron cloud: Pressure rise @ cold parts

- Unbaked by design
- Beam sees a Copper envelope
- Beam screen's pumping hole provide the required pumping speed
- Recycling desorption yields much worse than Primary desorption yields
  - $\eta'_{\text{monolayer}} \gg \eta$
  - Beam screen's surface coverage should stay below a monolayer
    - Cool down CB first
- Scrubbing at cryogenic temperature confirmed in the Lab



$$P_{\text{cryo}} = \frac{\eta_{\text{Electrons}} \dot{\Gamma}_{\text{Electrons}}}{c}$$

**Scrubbing: Surfaces at cryogenic temperatures behaves similarly to surfaces at RT !**

## Electron cloud: Pressure rise @ RT parts

- **Cold-Warm transitions (CWT)**

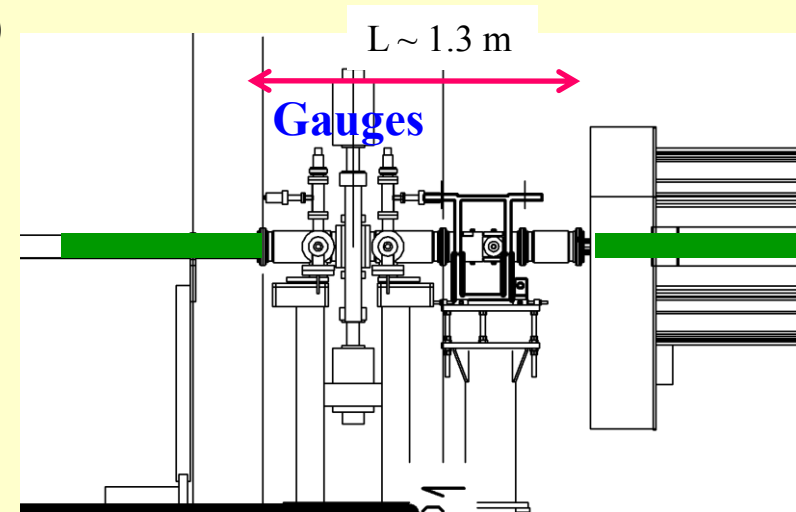
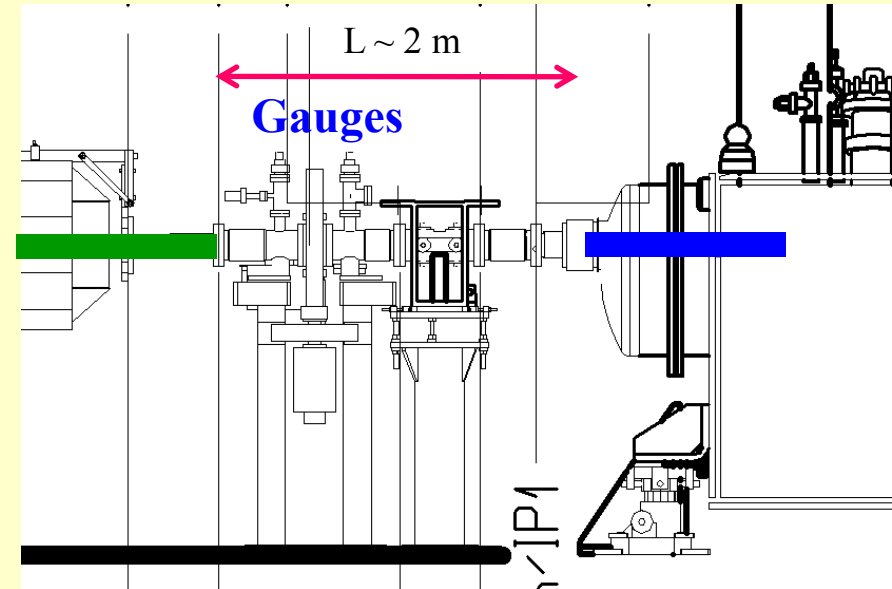
- Unbaked by design (SEY ~2.3)
- LHC's Longest area at D1
- $S_{eff} \sim 0.5 S_{max}$

$$P_{D1} \approx \frac{\eta_{Electrons} \dot{\Gamma}_{Electrons}}{c_{eff} + S_{eff}}$$

- **Warm/warm transition areas**

- Baked but uncoated by design (SEY ~1.6-1.9)
- LHC's largest pressure in LSS3 (VGPB.2.5L3.B) Elliptical transition (52/30)
- $S_{eff} \sim 0.5 S_{max}$

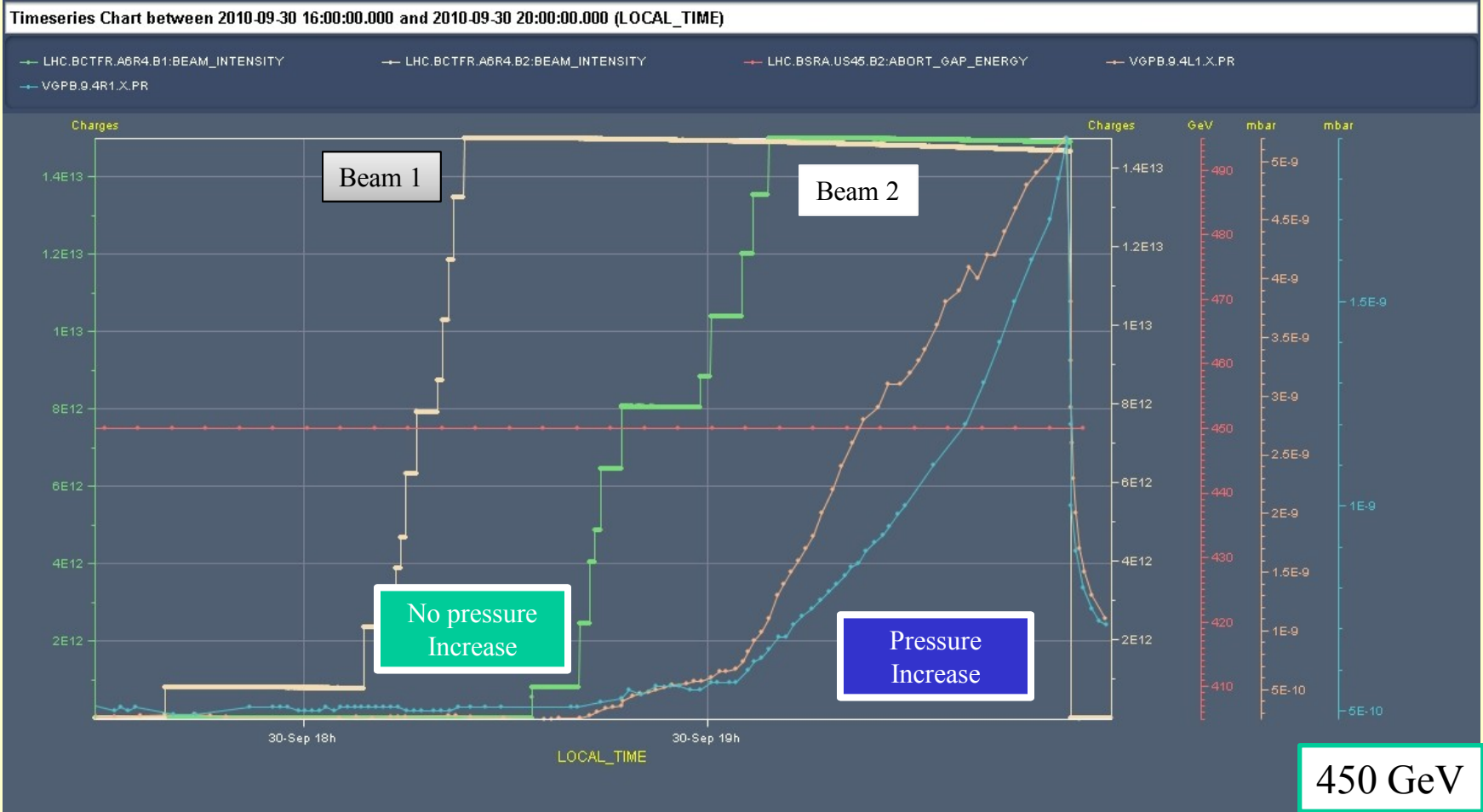
$$P \approx \frac{\eta_{Electrons} \dot{\Gamma}_{Electrons}}{S_{left,eff} + S_{right,eff}}$$



 Cold  
 NEG

# Review of Results

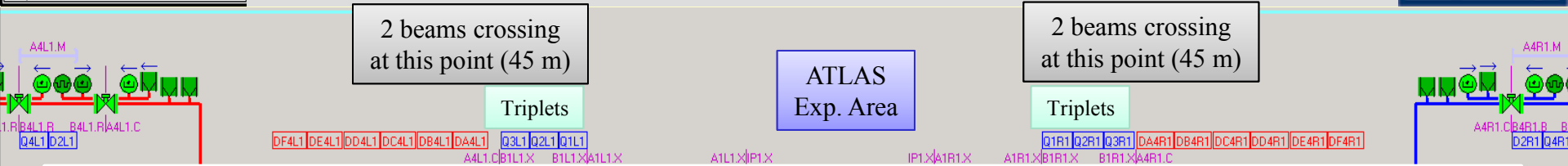
## 150 ns Bunch Spacing



Electron cloud only visible in recombination areas WITH 2 beams circulating  
 NOTHING visible in the arcs (Cryogenic systems)

# Review of Results

## 150 ns Bunch Spacing

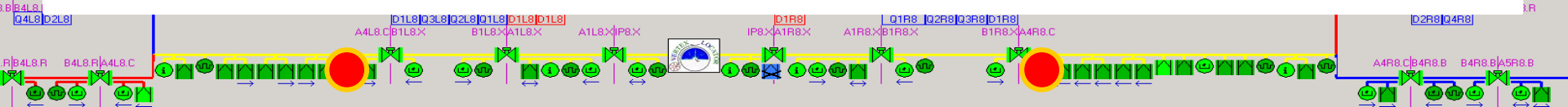


### Summary with 150 ns at 3.5 TeV:

#### ❖ In the LSS

- Pressure rises in the pipes **with 1 circulating beam** explained by Synchrotron Radiation (SR), E and I dependent.
- Pressure rises in the pipes **with 2 circulating beams** cumulate different effects:
  - SR induced by D1 or D2 bending magnets.
  - Electron stimulated desorption (E-cloud): bigger effects observed in the Cold/Warm transition of the Inner triplets on Q3/DFBX side for ATLAS, ALICE and LHCb.
  - No pressure increase in CMS due to leak magnetic field from the solenoid variable from 10 up to 150 Gauss.

#### ❖ In the arcs: Nothing observed (Cryogenics resolution: 5 mW/m)

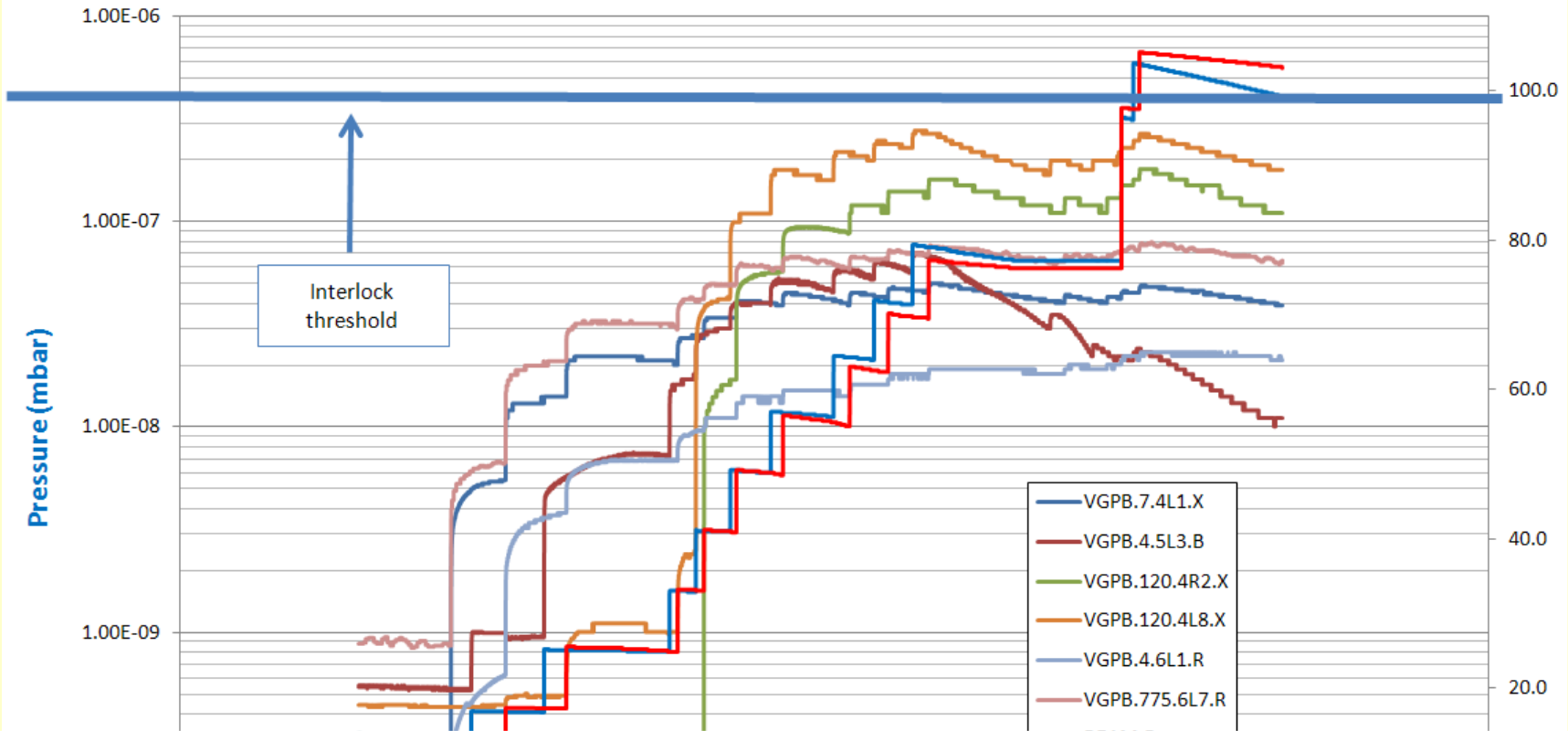




# Review of Results

## 75 ns Bunch Spacing

75 ns spacing - Injecting 24+24 b up to 680 b - 18 Nov 2010

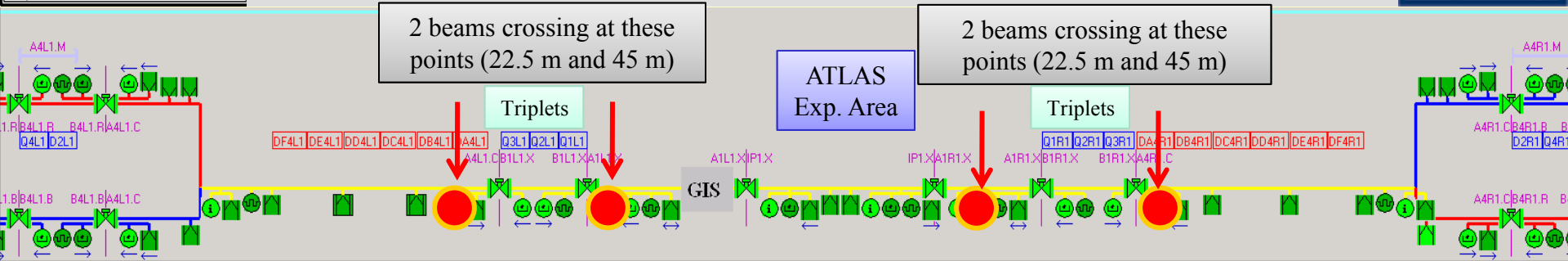


Diversity in pressure rise resulting from:

- 1 or 2 circulating beams in the beampipe, electron cloud higher with 2 beams
- Synchrotron radiation (SR) close to arcs or D1, D2, D3, D4
- Multipacting length vs pumping speed configurations

# Review of Results

## 75 ns Bunch Spacing

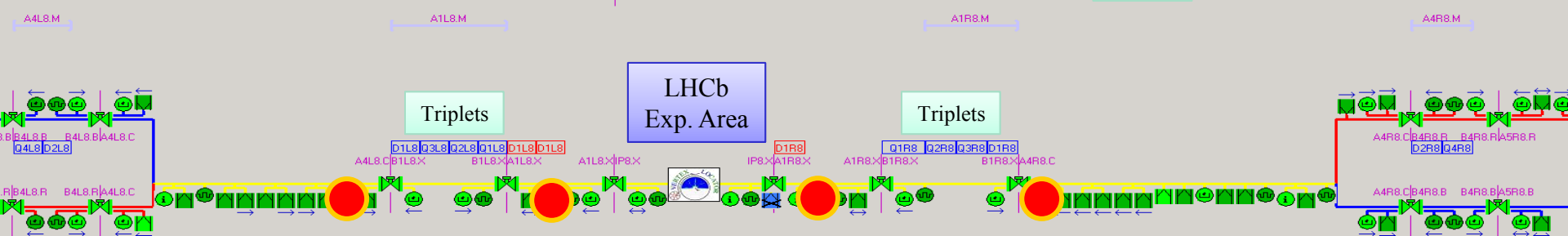


### Summary with 75 ns at 450 GeV:

#### ❖ In the LSS

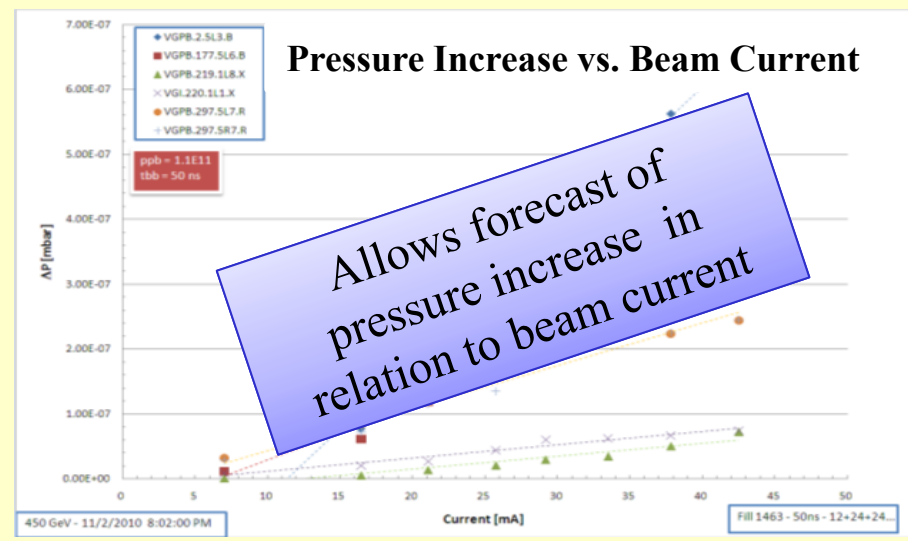
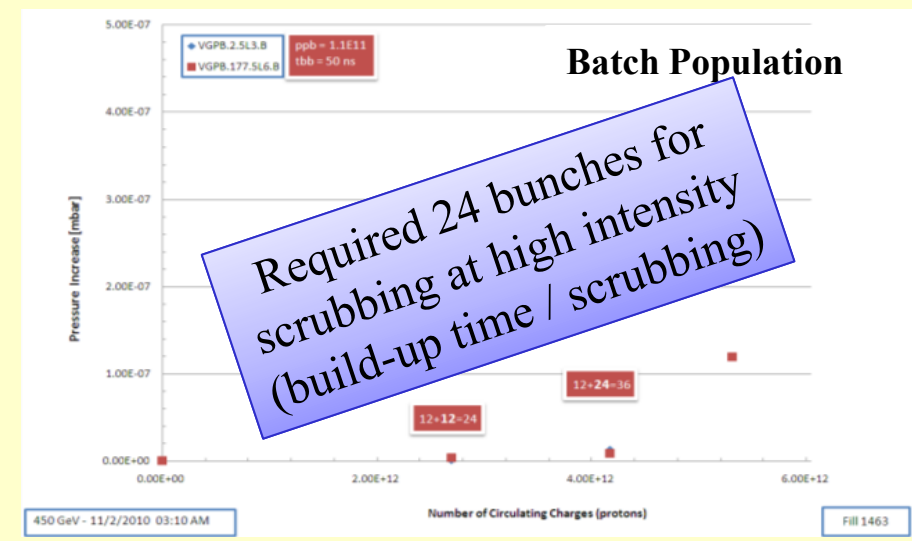
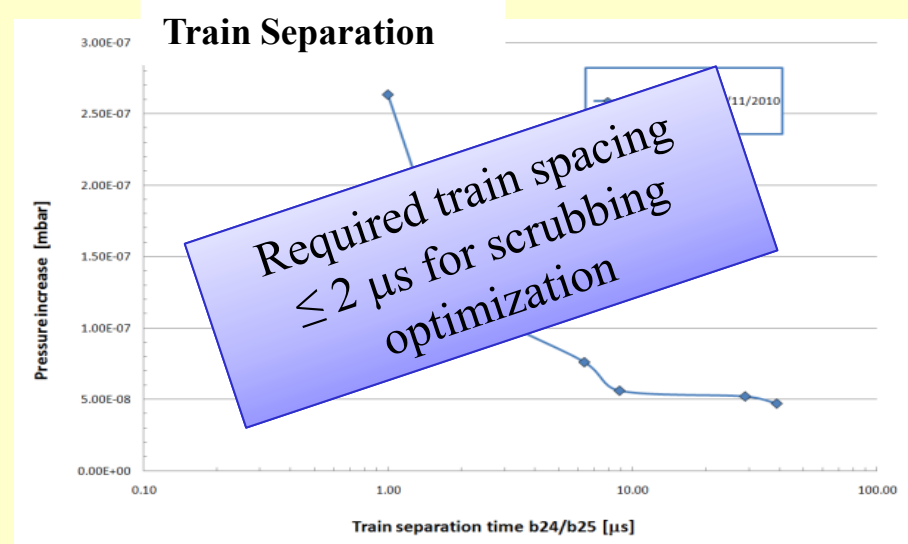
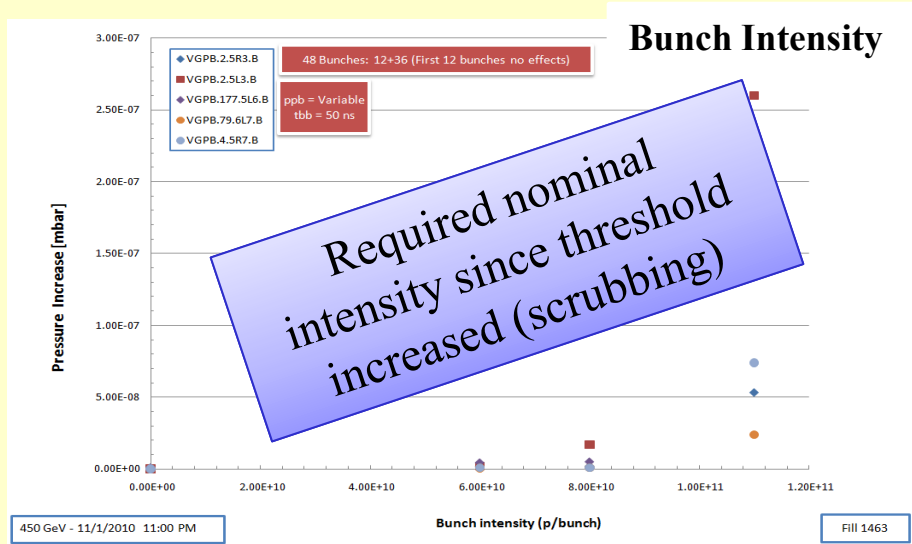
- Pressure rises in the pipes **with 1 circulating beam** explained by SR and electron cloud;  $\Delta P$  results from the multipacting length vs pumping speed configurations.
- Pressure rises in the pipes **with 2 circulating beams** is enhanced in particular in the Cold/Warm transition of the Inner triplets on Q3/DFBX side for ATLAS, ALICE and LHCb.

#### ❖ In the arcs: Nothing observed (Cryogenics resolution: 5 mW/m)



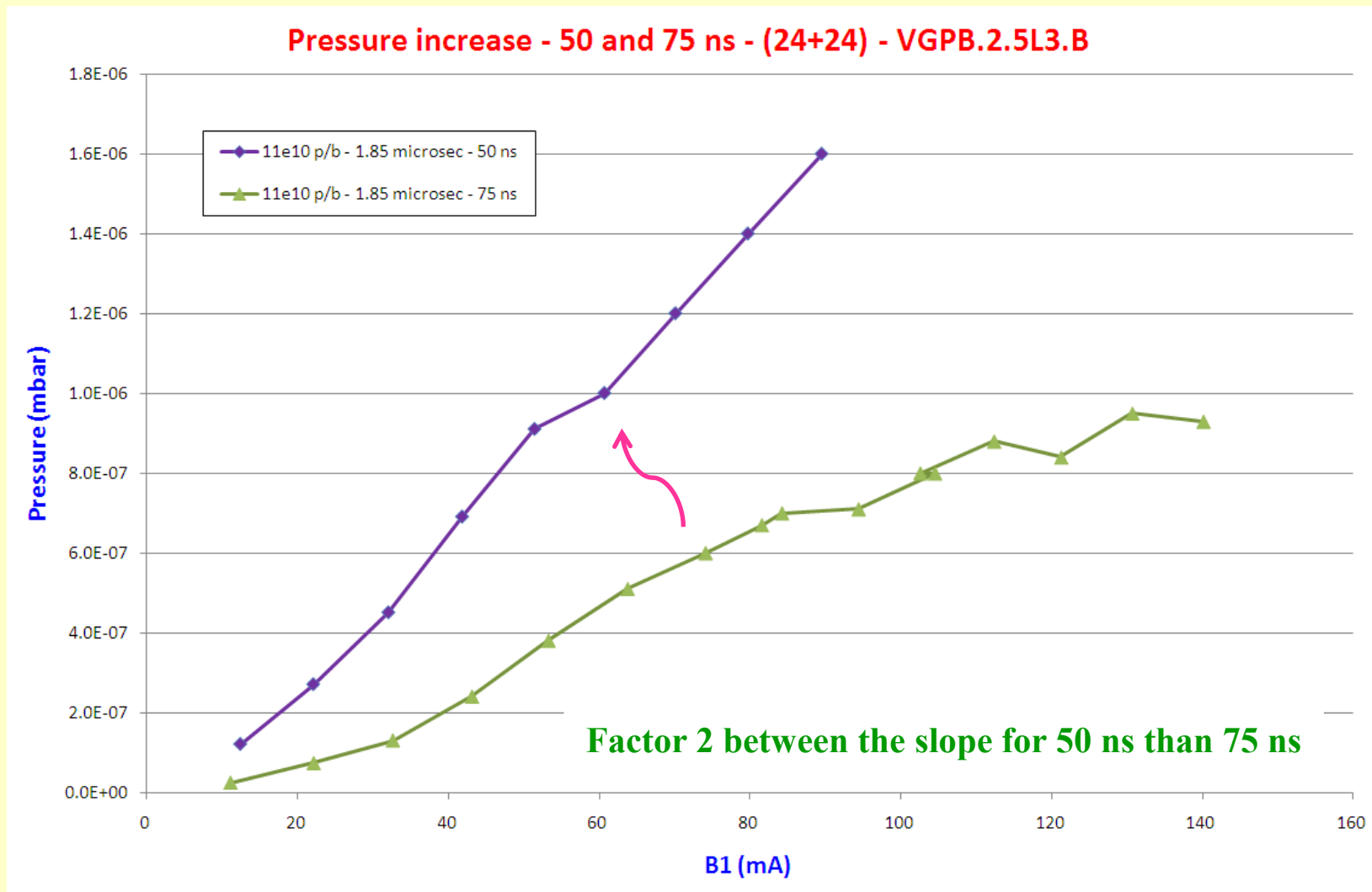
# Review of Results

## 50 ns Bunch Spacing



# Review of Results

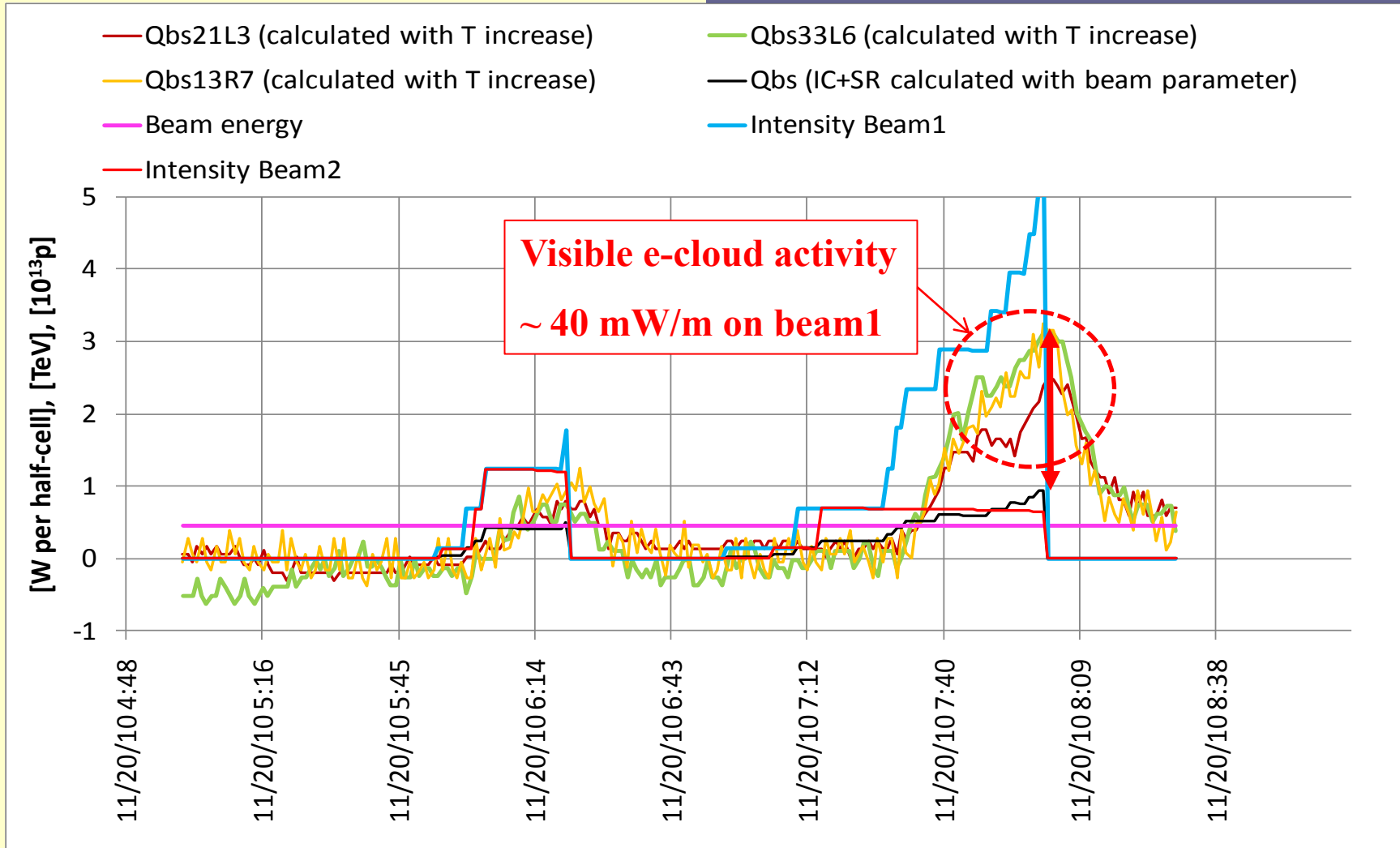
## 75 vs 50 ns Bunch Spacing



# Review of Results

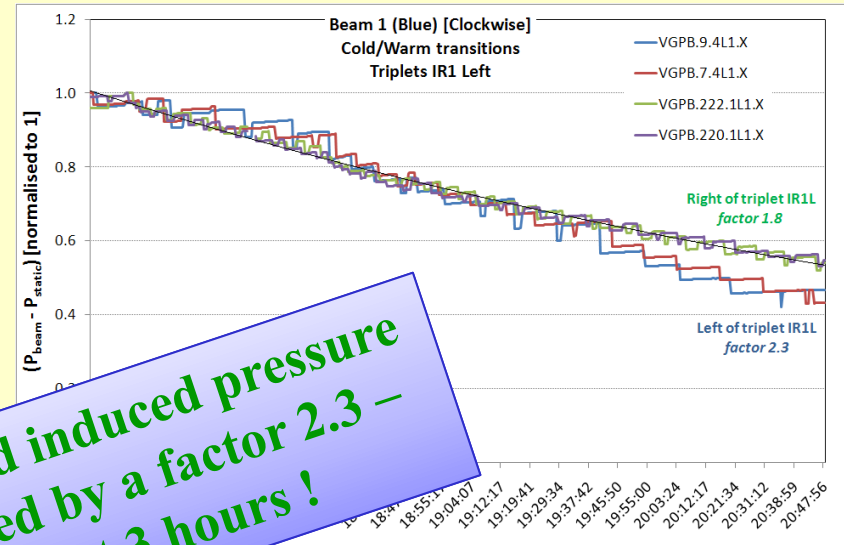
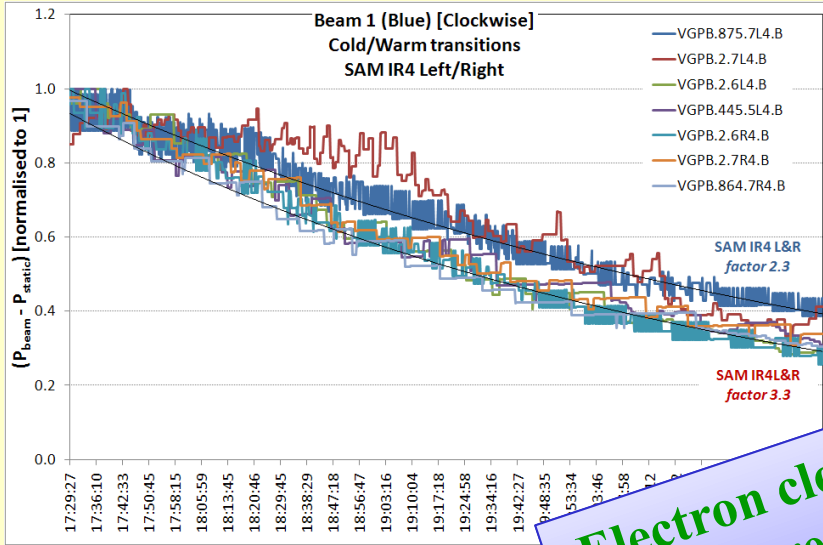
## 50 ns Bunch Spacing

50 ns, up to 444 b (Beam1), 450 GeV

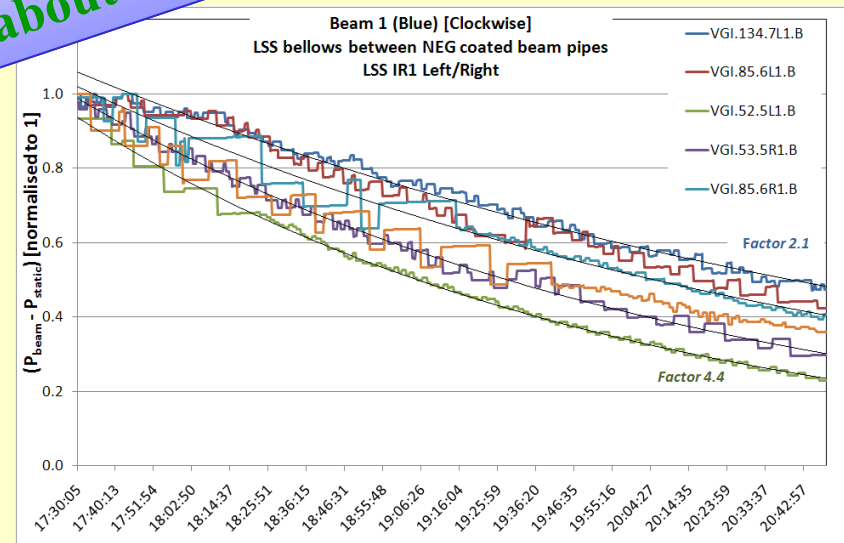
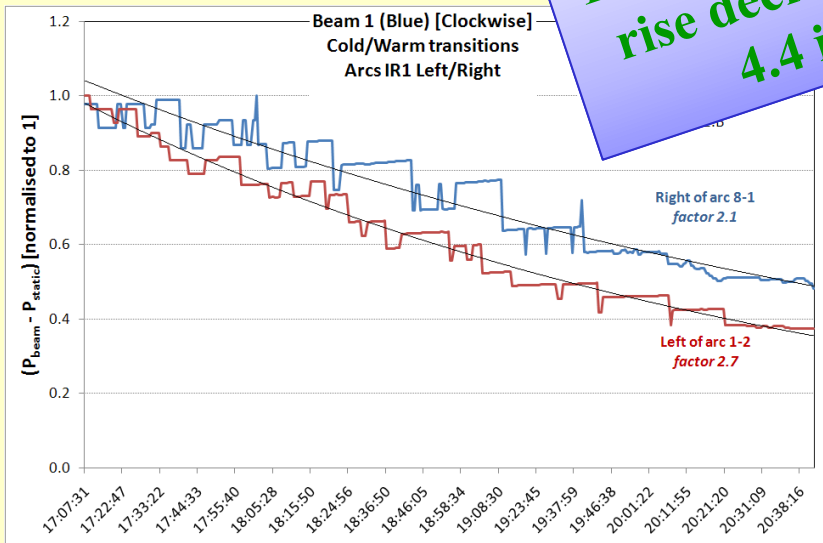


# Review of Results

## Cleaning + Scrubbing (1/2)

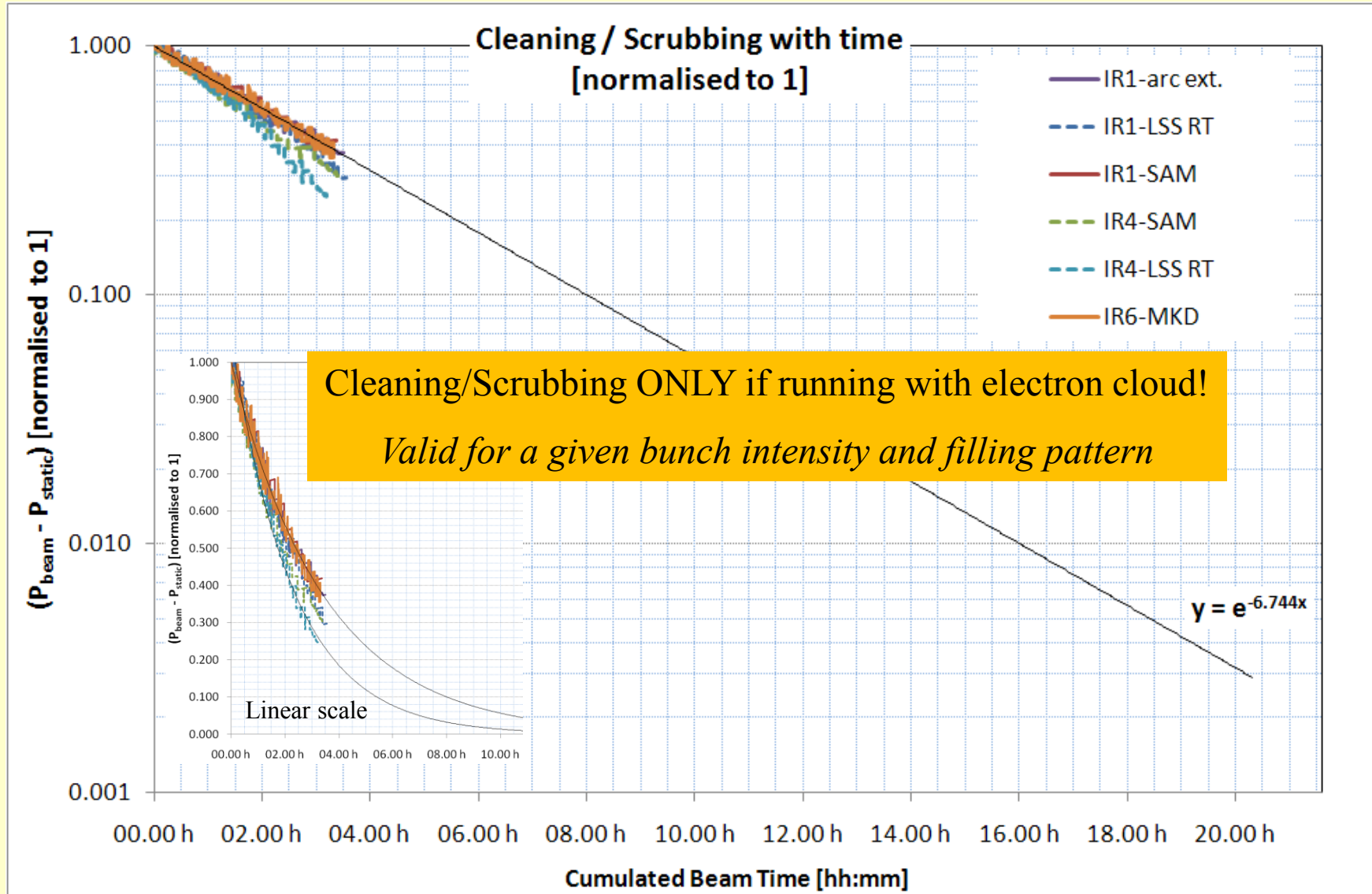


**Electron cloud induced pressure rise decreased by a factor 2.3 – 4.4 in about 3 hours !**



# Review of Results

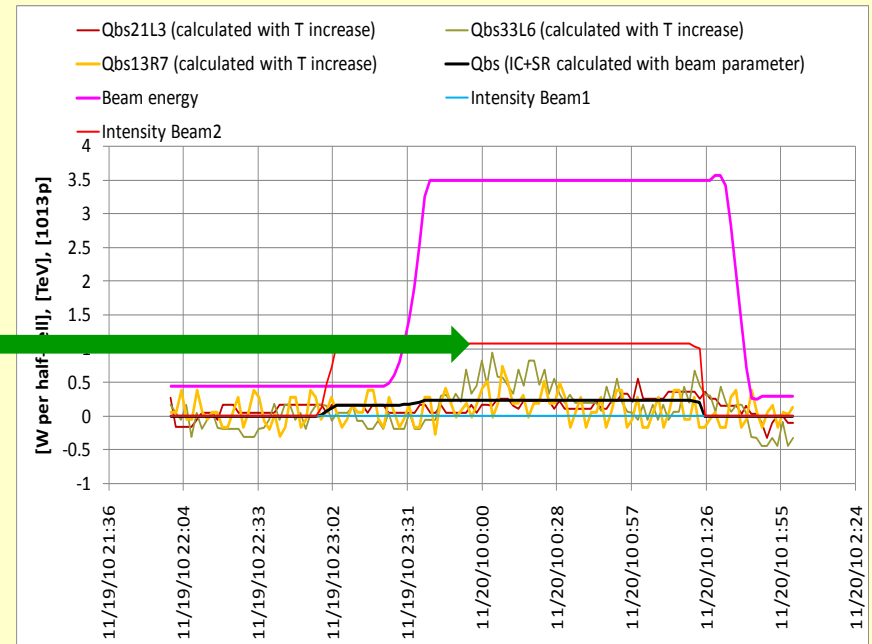
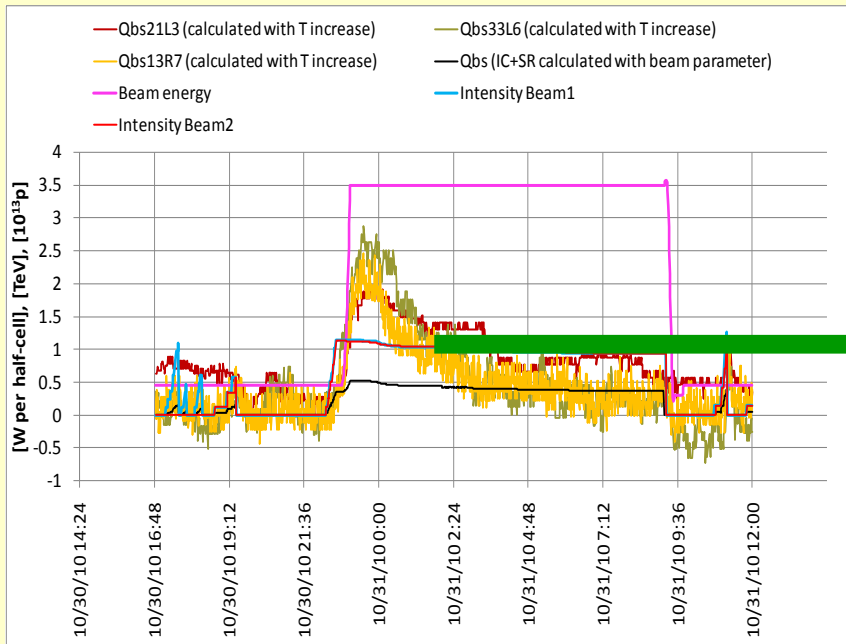
## Cleaning + Scrubbing (2/2)





Before scrubbing (30/10)  
Heat load  $\sim 20$  mW/m/beam

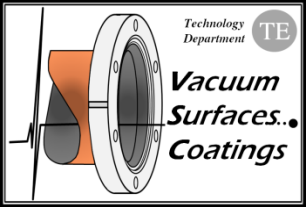
After scrubbing (19/11)  
Heat load  $< 10$  mW/m/beam (Only B2)



Same filling pattern 50ns\_109b\_91\_12\_90\_12bpi10inj and bunch population ( $\sim 10^{11}$  p).

**Scrubbing at 450 GeV effective also for 3.5 TeV in the arcs.**





# Expected decrease $\eta$ and $\delta$ (calculations) (1/2)

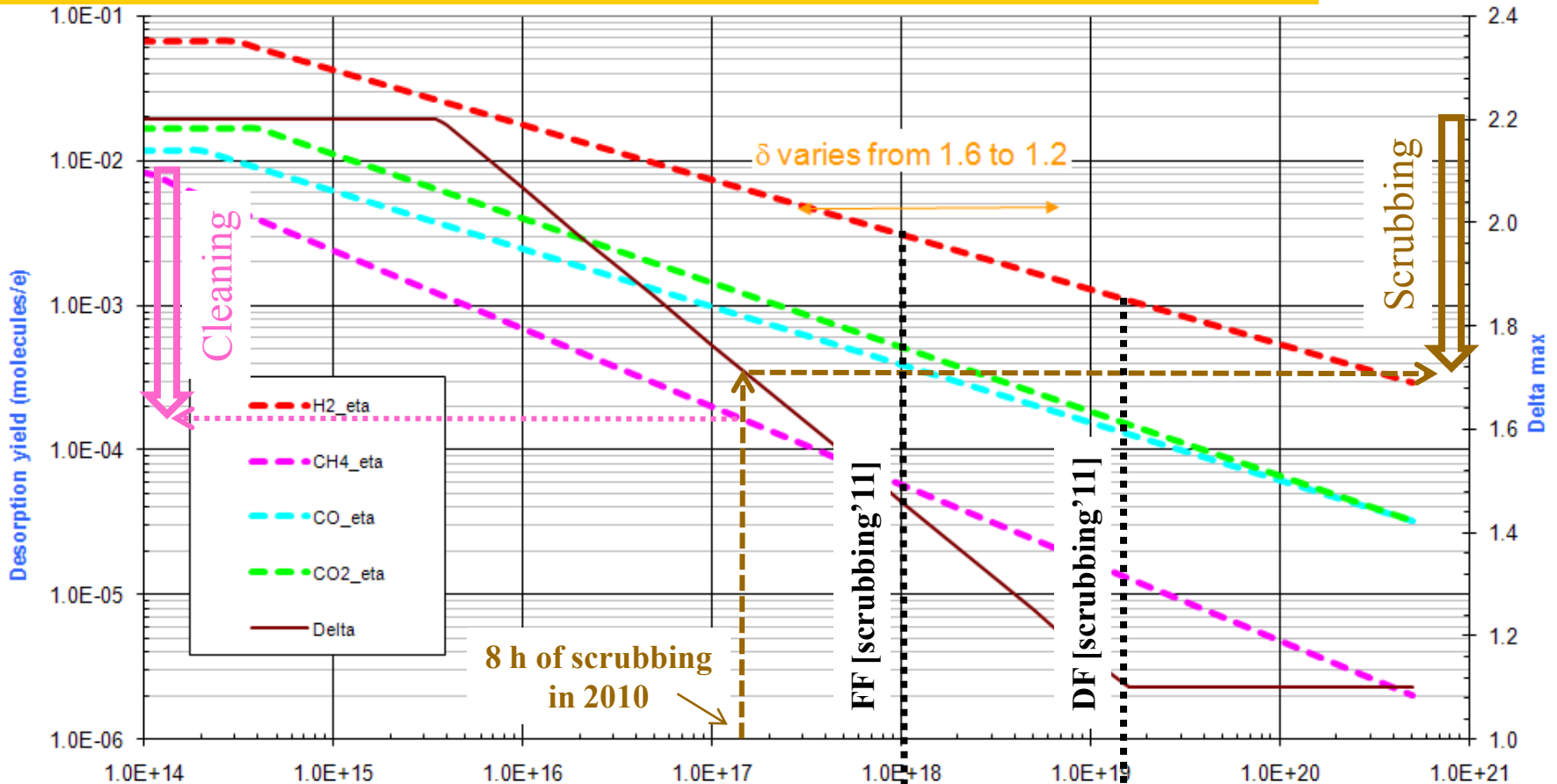
- **Dose [in  $e^-/\text{cm}^2$ ] depends on magnetic field conditions**
    - Field free: homogeneous bombardment of the beampipe surface
    - Dipole field: electrons are confined in two vertical strips
- ☞ 15 times more dose expected in LHC arcs compared to LSS

## Recall:

- **Vacuum Cleaning**
    - Is a dose effect characterized the reduction of the desorption yields ( $\eta$ )  
 $\eta$  = Number of gas molecules desorbed from the surface/bulk by a primary electron, photon, ion.
  - **Beam Scrubbing**
    - Is a dose effect characterized the reduction of the secondary electron yield ( $\delta$ )  
 $\delta$  = Number of secondary electrons generated by a primary electron.
- ☞ **Pressure decrease results from the combined effect of vacuum cleaning and beam scrubbing**

## Expected decrease $\eta$ and $\delta$ (calculations) (2/2)

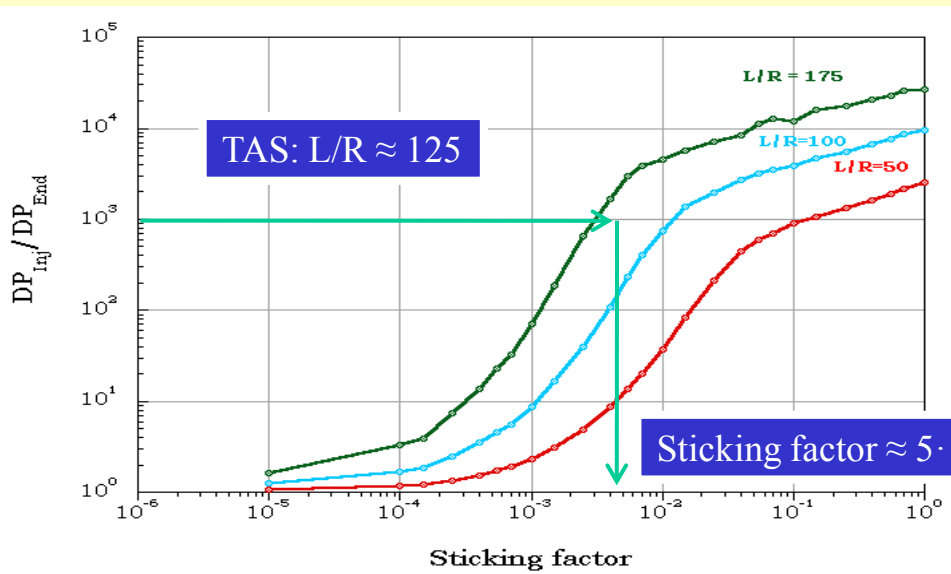
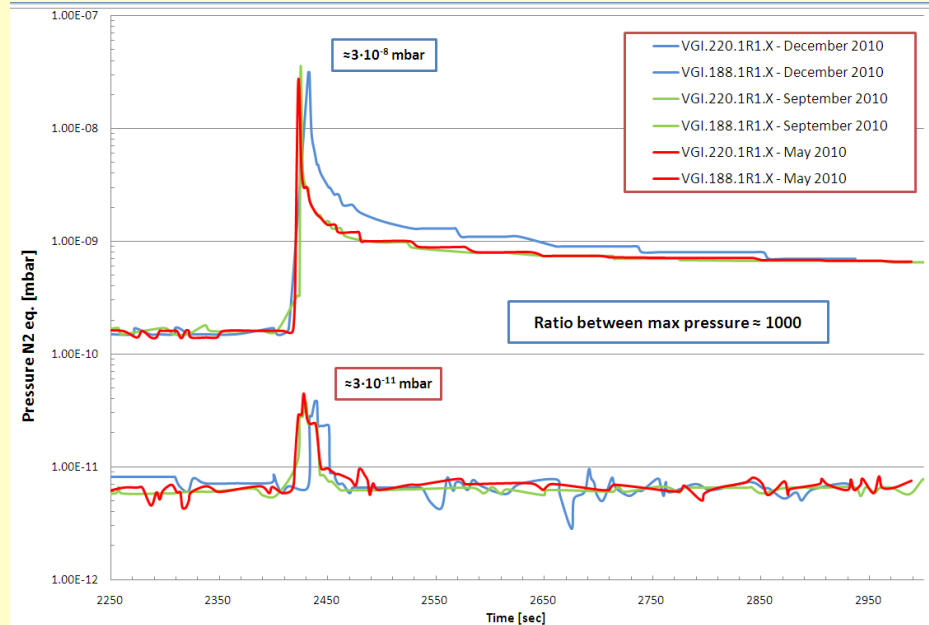
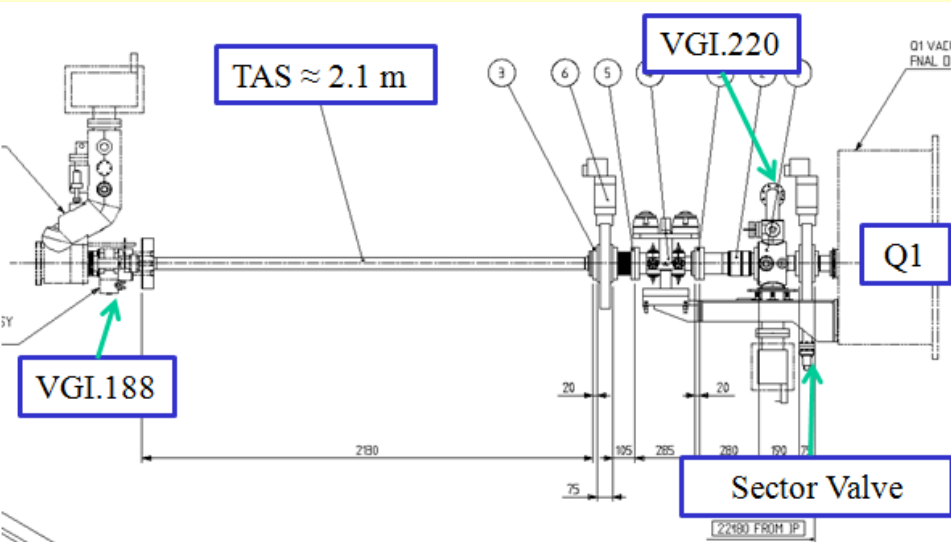
Assumptions: 1 mA/m of  $e^-$  flux bombarding the beampipe (or  $1.6 \cdot 10^{16} e^-/s.m$ )  
 FF:  $5.1 \cdot 10^{12} e^-/s.cm^2$   
 DF:  $8.0 \cdot 10^{13} e^-/s.cm^2$   
 ~8 h of scrubbing in 2010



Field free:	200 s	33 min	5 h	54 h	1 w	23 d
Dipole field:	13 s	125 s	21 min	3 h		35 h

# Operation in 2011

## Impact on NEG coatings

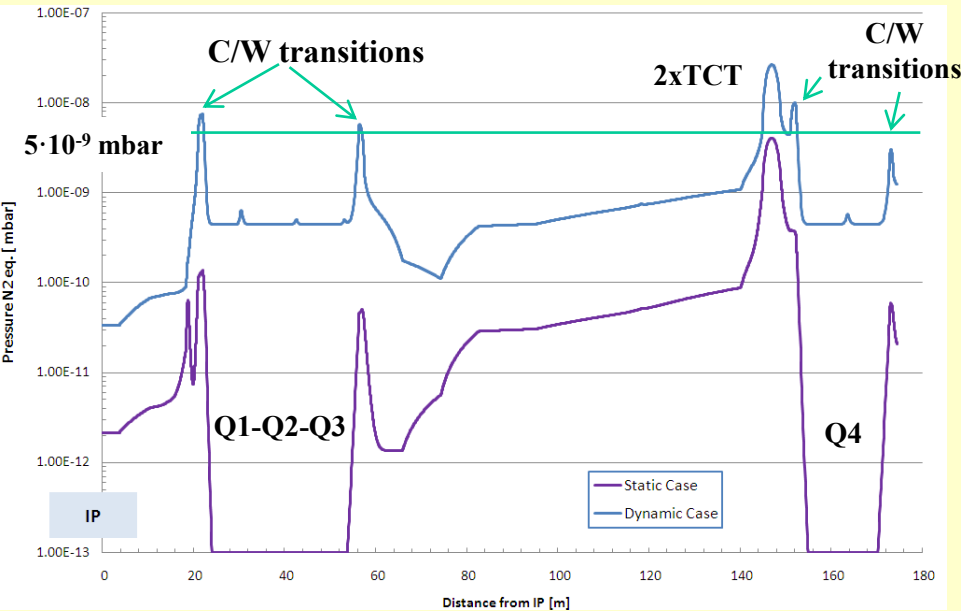


Fully activated NEG coating:

$$5 \cdot 10^{-3} < \text{Sticking factor} < 5 \cdot 10^{-2}$$

**No deterioration is observed**

### Situation before the Winter Stop



Huge electron cloud activity in C/W and RT non-NEG coated parts

RT: electron flux of  $1.10^{16}$  [e/m.s]  
 Cold: electron flux of  $1.10^{14}$  [e/m.s]

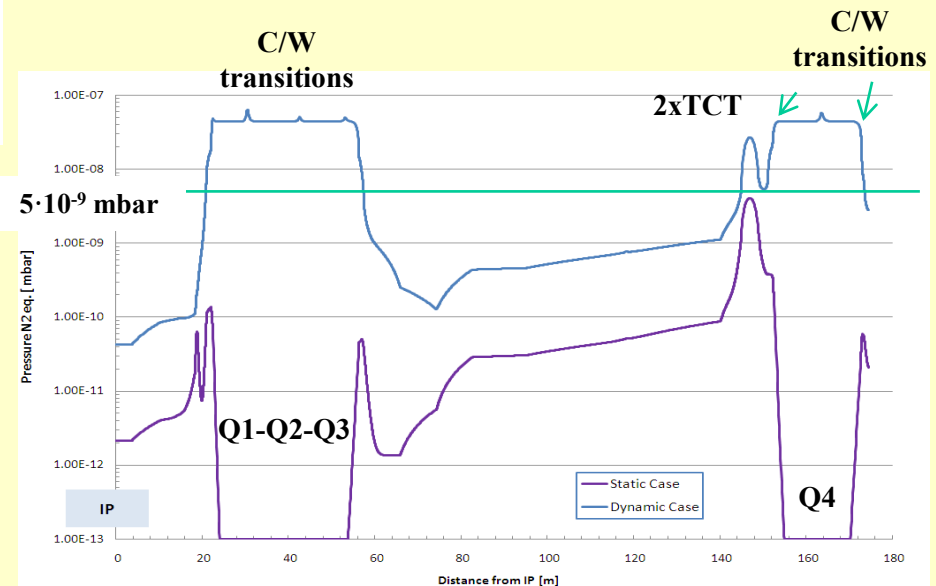
**About 9% of the LSS at pressure higher than  $5 \cdot 10^{-9}$  mbar**

### Situation during the scrubbing run (2011)

Huge electron cloud activity in Cold, C/W and RT non-NEG coated parts

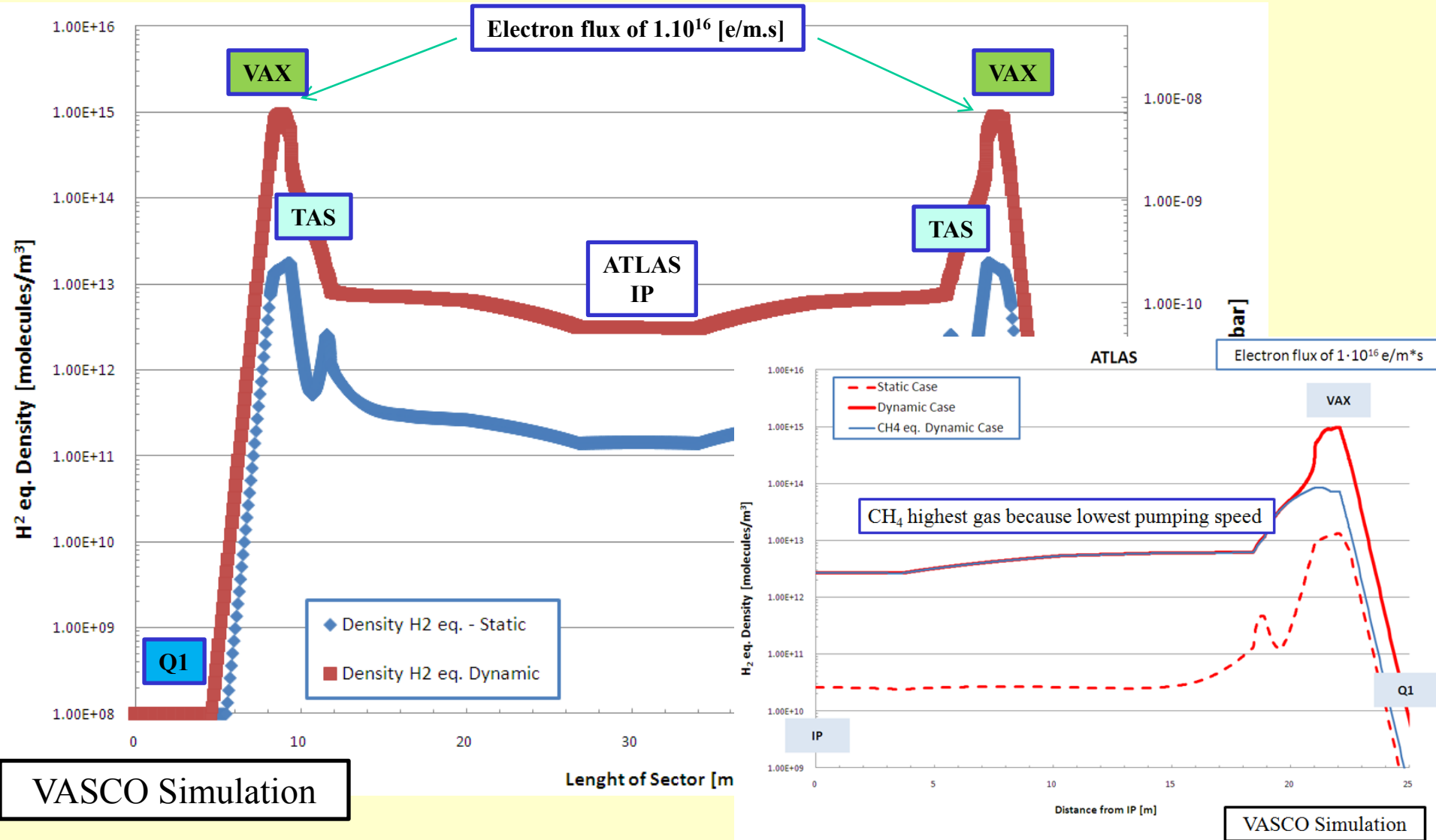
RT & Cold: electron flux of  $1.10^{16}$  [e/m.s]

**About 25% of the LSS at pressure higher than  $5 \cdot 10^{-9}$  mbar**



# Operation in 2011

## Background to be expected (2/2)



VASCO Simulation

VASCO Simulation

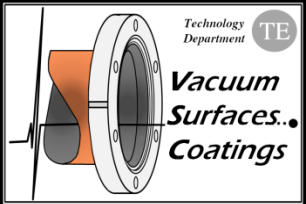
- **Confirmation that vacuum cleaning and beam scrubbing work at Cold and RT in the LHC**
  - Vacuum cleaning: more than a factor of 10 observed after the 2 scrubbing periods
  - Beam scrubbing: factor 2 observed during the 2<sup>nd</sup> scrubbing period
- **Range of pressure rise in LSS results from local configurations: multipacting length vs pumping speed**
  - Electron cloud build-up is not worse in given areas except in recombination zones
- **Pressure rise are expected to be 2 times higher at 50 ns vs 75 ns**
- **Expectations from the Scrubbing week**
  - At least 3 orders of magnitude of vacuum cleaning are expected in RT after a week
  - 1 week of scrubbing should be enough to run with 50 ns beams
  - ☞ **IF WE CAN KEEP THE BEAM STABLE WITH 1 mA/m OF ELECTRON CLOUD BUILD-UP IN THE BEAMPIPES**

- **Solenoids**

- LSS1 and LSS5 entirely equipped during this Winter Stop
- Recombination zones equipped in IR2 and IR8
  - Work will be finished during the coming Technical Stops
- 20 km of cables ordered to wind the solenoids...!

- **Re-cooling sequence of SAM in case of failure of the cryogenics**

- Beam Screen shall be kept at a higher temperature than Cold Bore including after a stoppage of a cryoplant
  - Takes longer BUT is absolutely required to avoid gas condensation on Beam Screens!

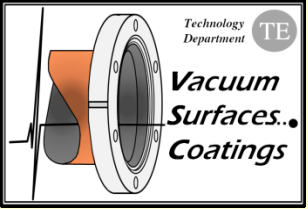


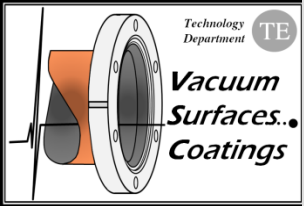
# Acknowledgements



**Many thanks to TE, BE, EN, PH and FP  
Colleagues for their help, contributions,  
helpful discussions and support.**





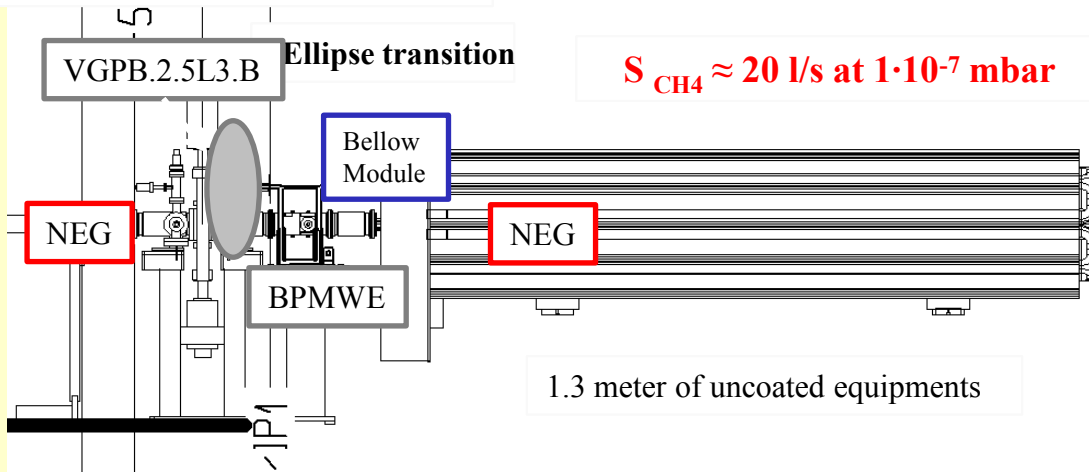


# Reserve



# Review of Results 50 ns Bunch Spacing

## Case of VGPB.2.5L3.B

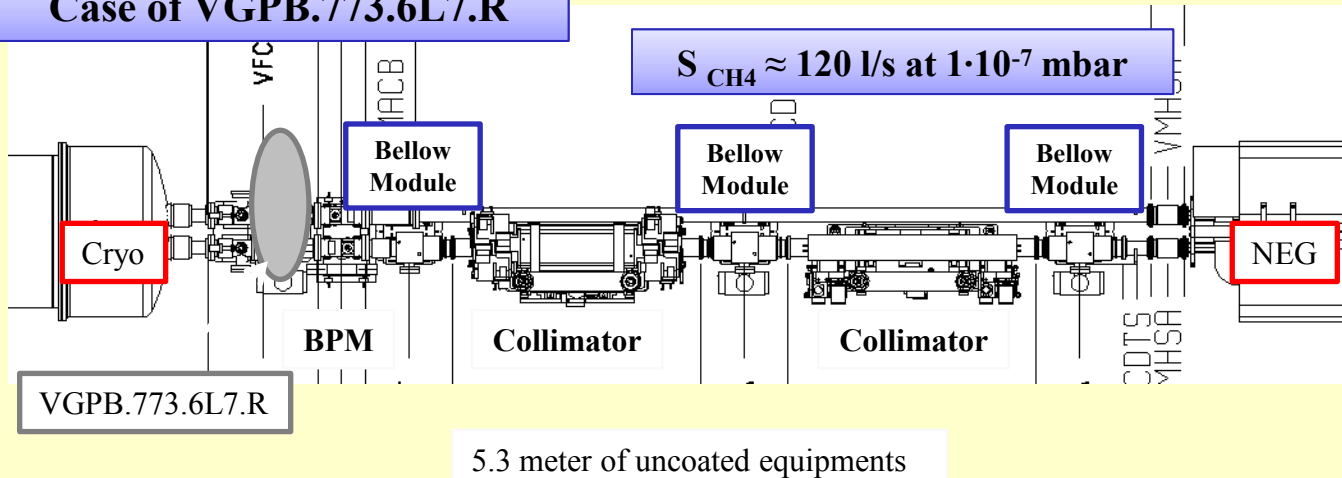


$$P \approx \frac{\eta_{Electrons} \cdot \dot{\Gamma}_{Electrons}}{S}$$

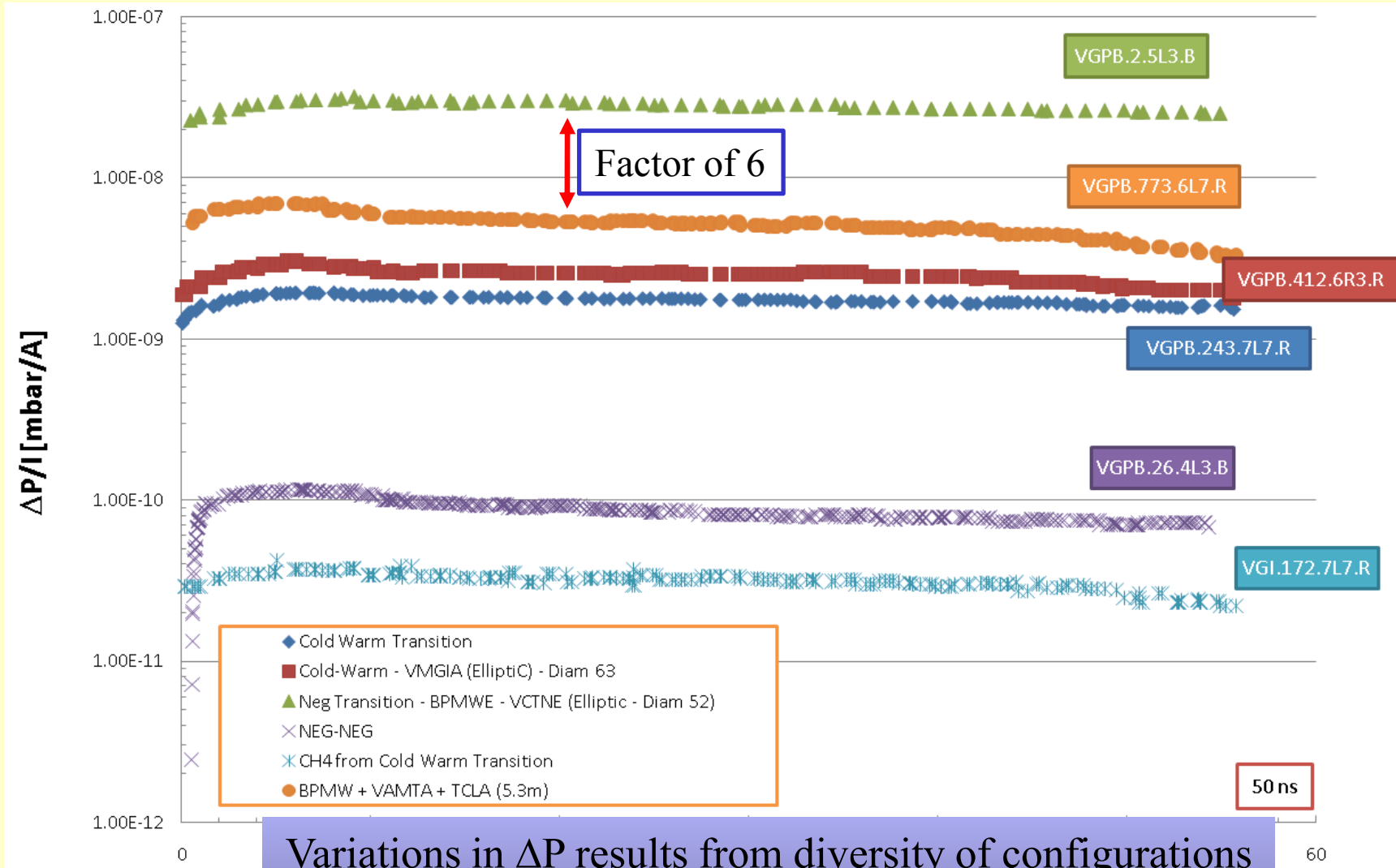
If we consider the  $\Delta P$  dominated by  $CH_4$

$$S_{CH_4 LSS7} / S_{CH_4 LSS3} \approx 6$$

## Case of VGPB.773.6L7.R



# Review of Results 50 ns Bunch Spacing



Variations in  $\Delta P$  results from diversity of configurations  
 NOT  
 on a higher local electron cloud build-up

- **Vacuum Cleaning**

- Characterize the reduction of the desorption yields ( $\eta$ ) of a surface resulting from the bombardment of the surface by electrons, photons, ions.

☞  $\eta$  = Number of gas molecules desorbed from the surface/bulk by a primary electron, photon, ion.

- **Beam Scrubbing**

- Characterize the reduction of the secondary electron yield ( $\delta$ ) of a surface resulting from the bombardment of the surface by electrons, photons, ions.

☞  $\delta$  = Number of secondary electrons generated by a primary electron, photon, ion.

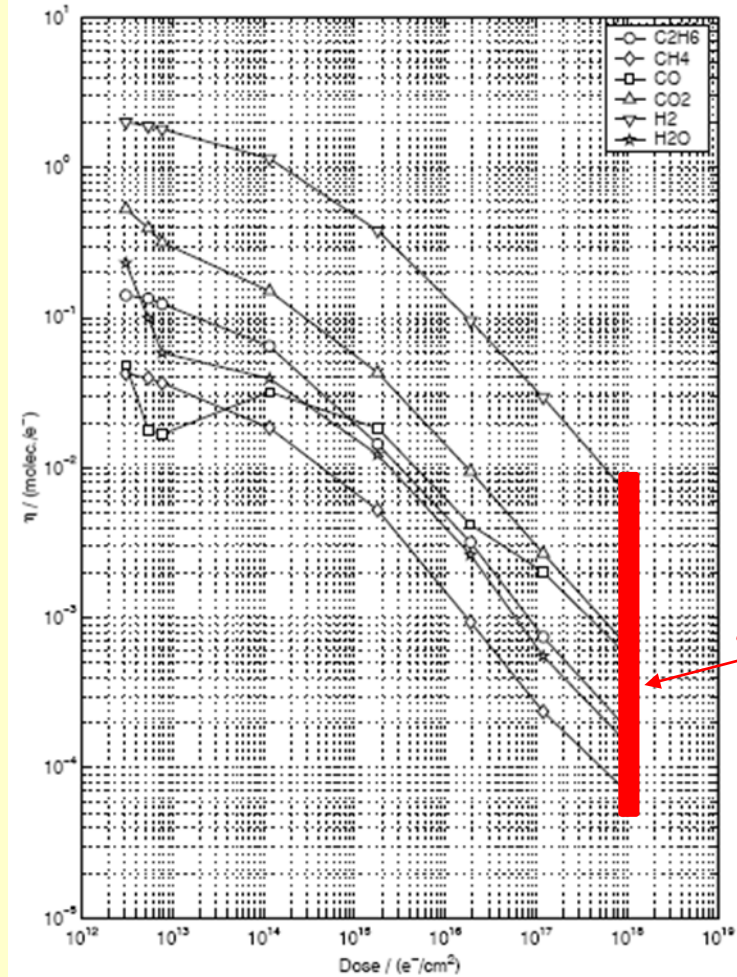
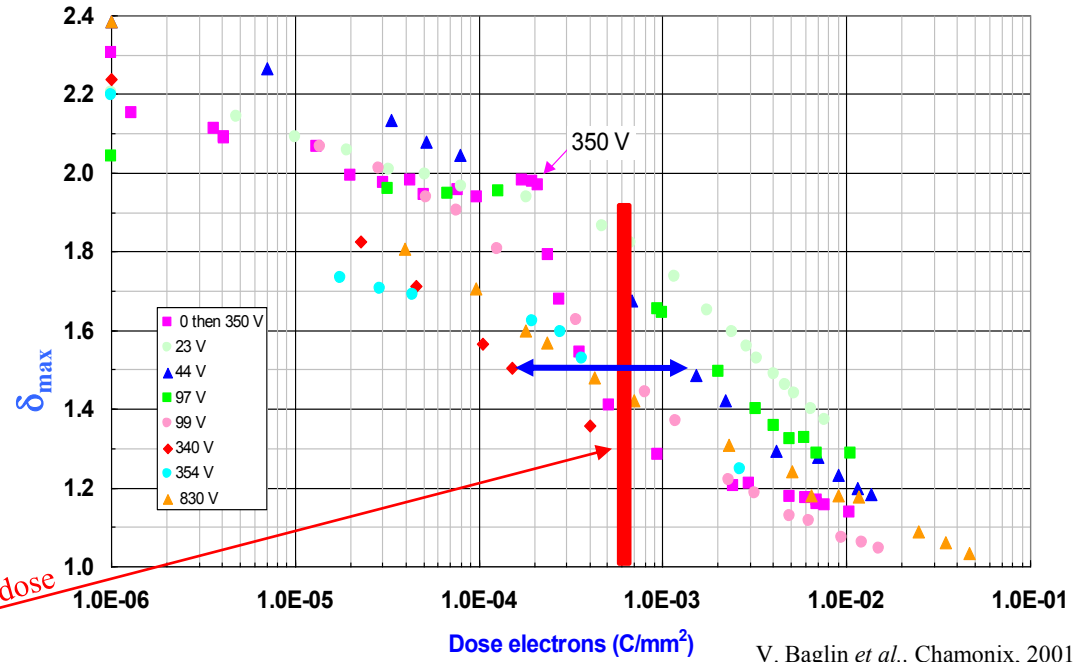


Figure 3: Effect of the electron dose on the electron induced desorption yield of an unbaked copper sample. The electron energy during bombardment and measurement was 300 eV.

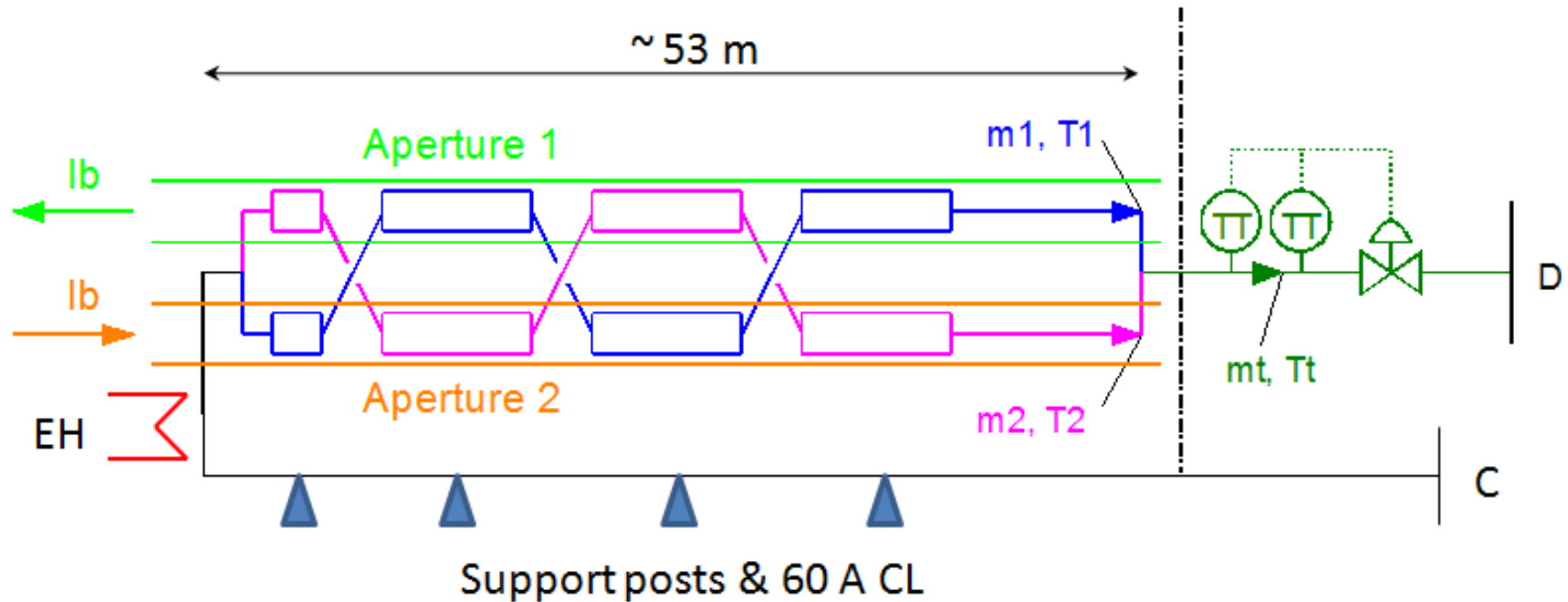
G. Vorlaufer *et al.*, CERN VTN, 2000



V. Baglin *et al.*, Chamonix, 2001

- Log scale for  $\eta$  versus linear scale for  $\delta$  (scrubbing)
- 6 orders of magnitude on  $\eta$  while  $\delta$  goes down to 1.4
- $\eta$  impacts the pressure rise as  $\delta$  affects the electron cloud density
- Electrons with energies between 5 and 50 eV decrease  $\eta$  BUT their efficiency on the reduction of  $\delta$  is significantly lower

# Basic cooling scheme of beam screens



- Calibration of 3 loops (21L3, 33L6 & 13R7):
  - Unknowns: Flow coefficient of the valves  
Static heat inleaks
  - Application of different electrical heating EH to solve the system

# Calibration results

Loop	Static heat inleaks [W]	Kv CV94x [m3/h]
21L3	11	0.0214
33L6	21.9	0.0203
13R7	19.9	0.0195

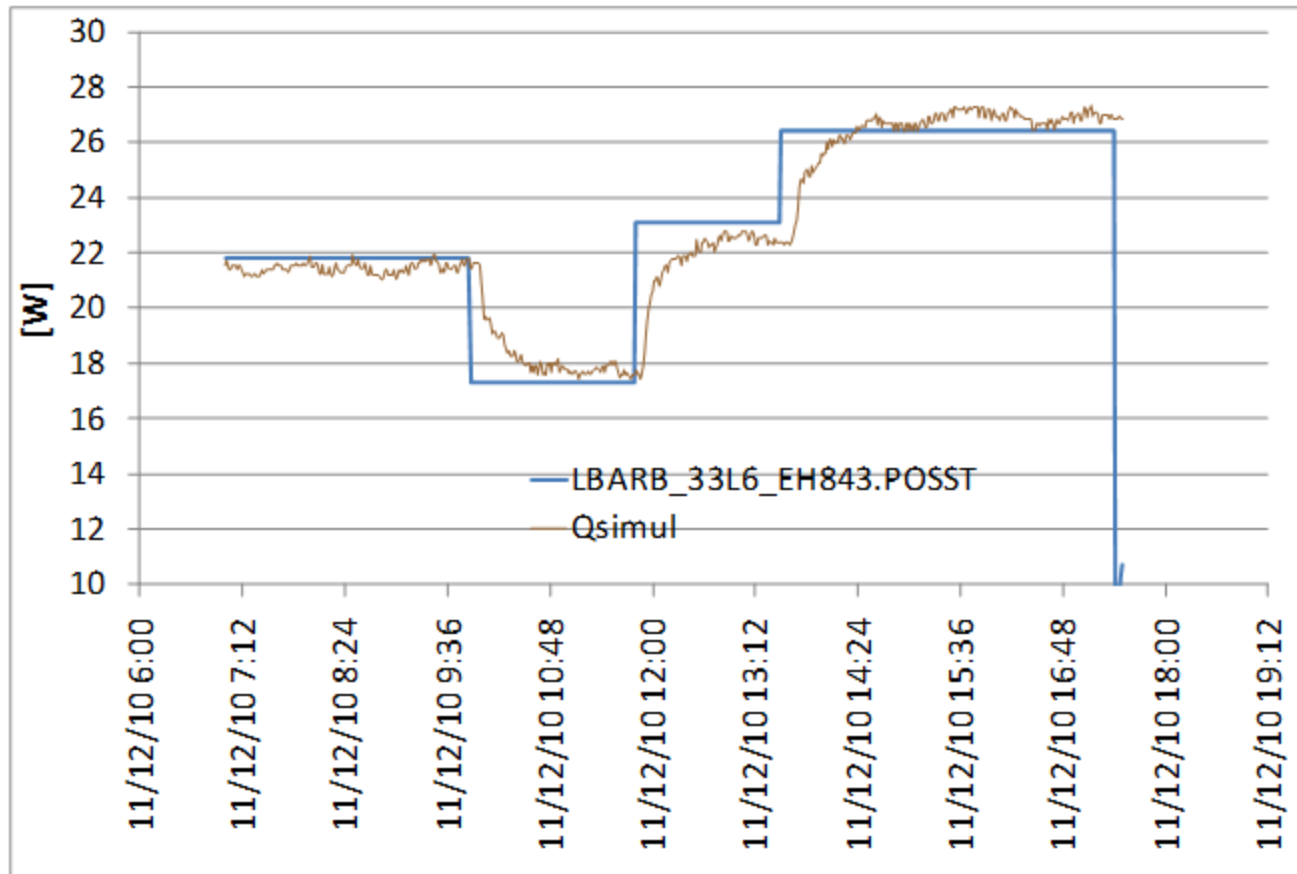
Factor 2 on the heat inleaks still to be understood!

Fit of the electrical heating after calibration:

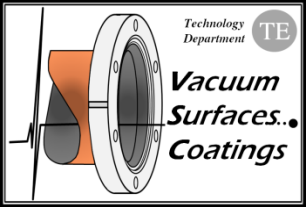
Accuracy:  
+/- 0.5 W/half-cell and  
for both beams

+/- 4.7 mW/m of beam  
screen

Response time: 45 min







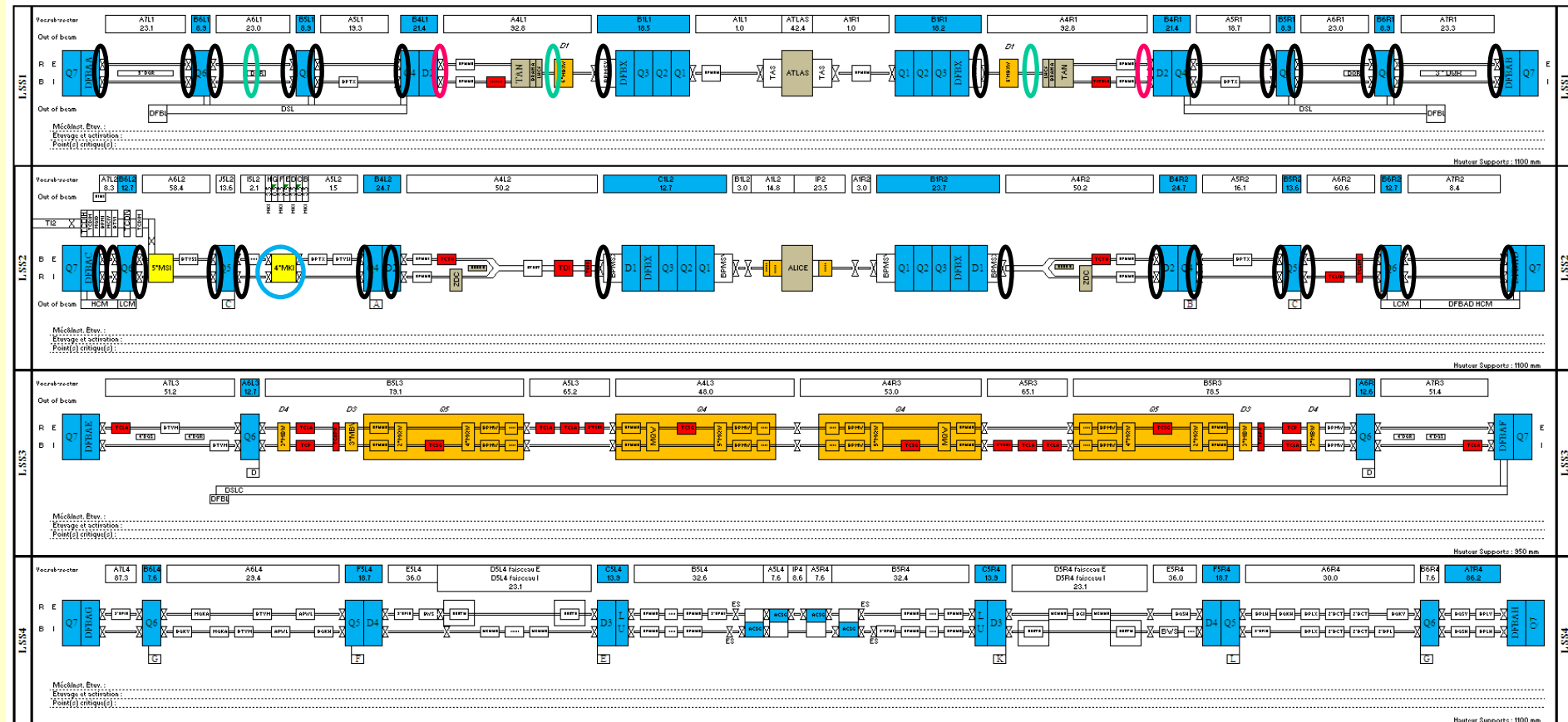
# LHC solenoids(1)



- No solenoids between Q1L-Q1R : radiation issue, experimental beampipe
- LSS1 : Independent supply L/R and quad/dipole + 4 NEG pilot sectors
- LSS2 : Independent supply L/R + MKI

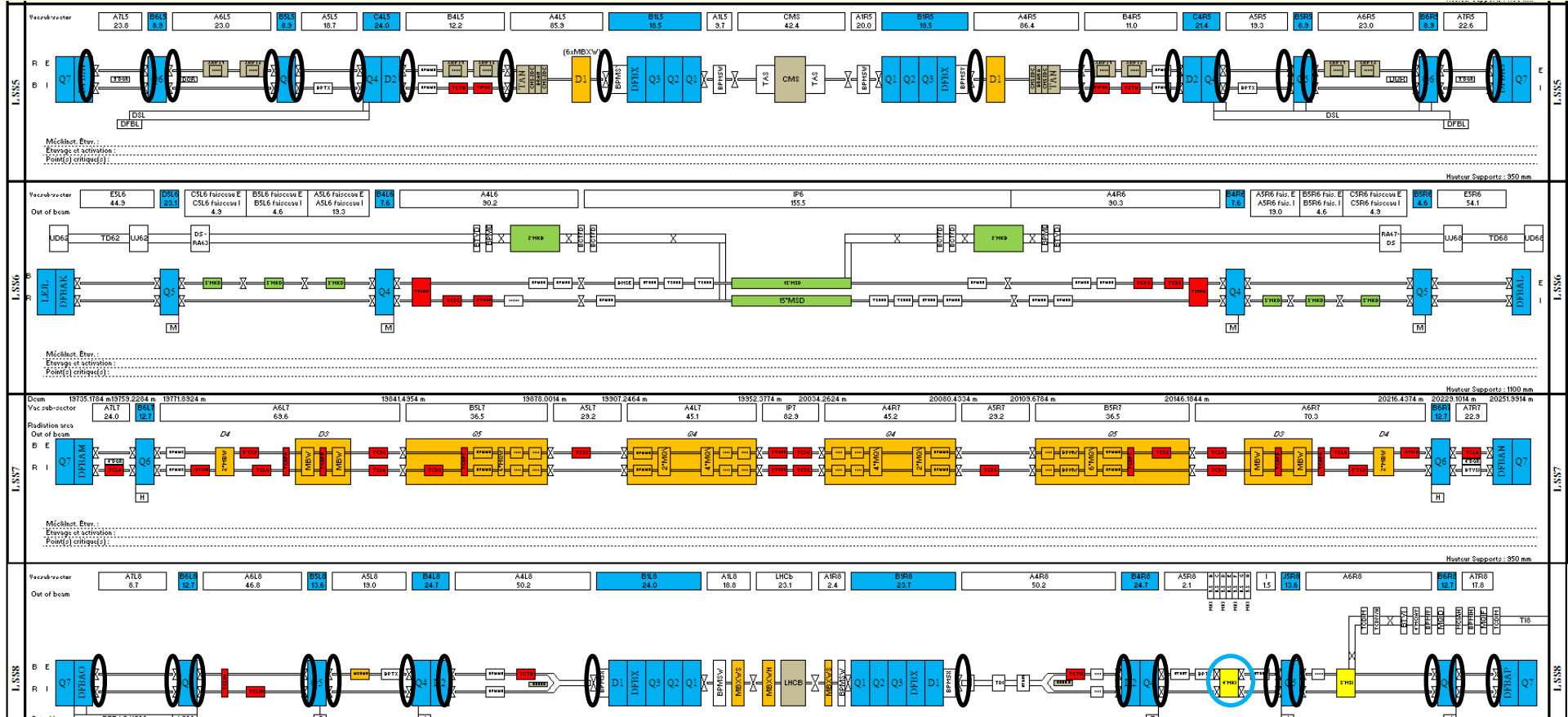
LSS Schematic View - Installation 2008

TS-ACC-PL-2008



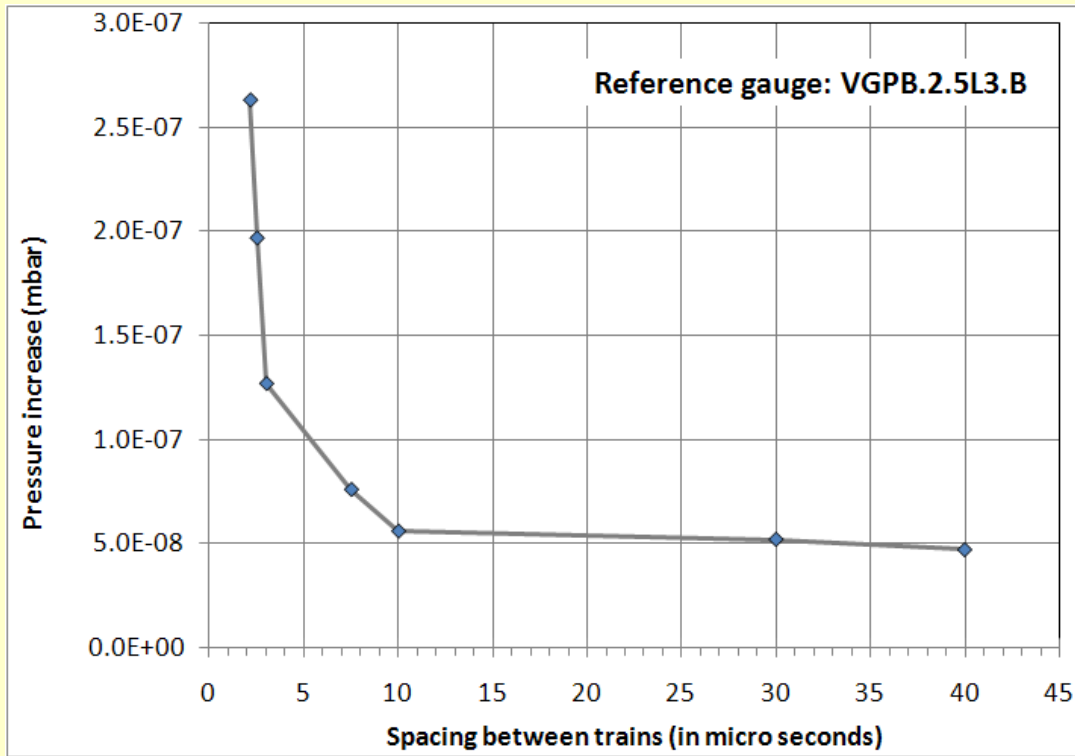
# LHC solenoids(2)

- LSS5 : Independent supply L/R
- LSS8 : Independent supply L/R + MKI



# Electron Cloud Build-up (SPS) [cont.]

## Surviving low-energy electrons and seed electrons



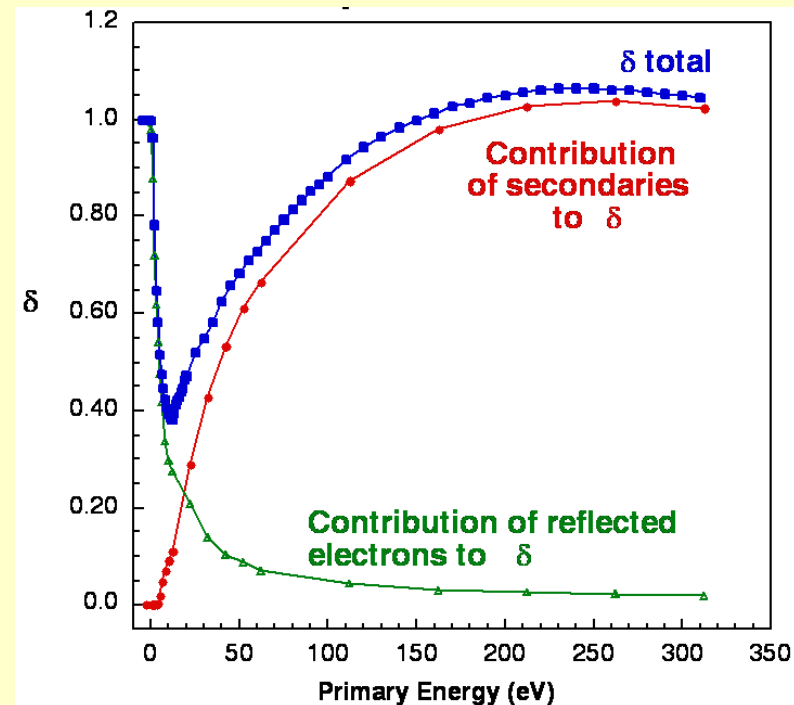
Measurement made with 2 trains of 24 bunches with a 50 ns bunch spacing @ 450 GeV

Crosstalk between bunch train's build-ups start at 10  $\mu$ s, increasing very quickly below 3  $\mu$ s bunch train spacing

Seed photo-electrons to be considered above 2 TeV

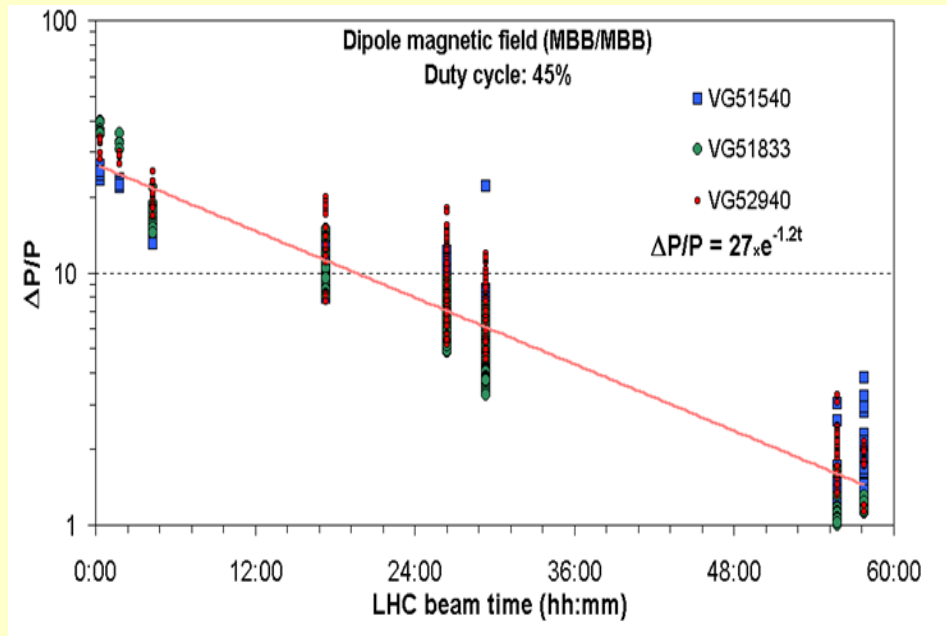
Secondary Electron Yield (SEY) measurement of a scrubbed copper sample

Low-energy electrons are reflected by the surface



# Vacuum Cleaning / Beam Scrubbing

## Guidelines from SPS Measurements



Measurements of the Pressure decrease in the SPS (25 ns bunch spacing) as a function of the cumulated LHC-type beam time

Dipole field conditions showed a decrease by 15 in 58 hours

Measurements of the Pressure decrease in the SPS (25 ns bunch spacing) as a function of the cumulated LHC-type beam time

Field free conditions showed a decrease by 50 in 58 hours

