Electron Cloud Studies made at CERN in the SPS

J.M. Jimenez

On behalf of the Electron Cloud Study Team, a Collaboration between AT and AB Departments

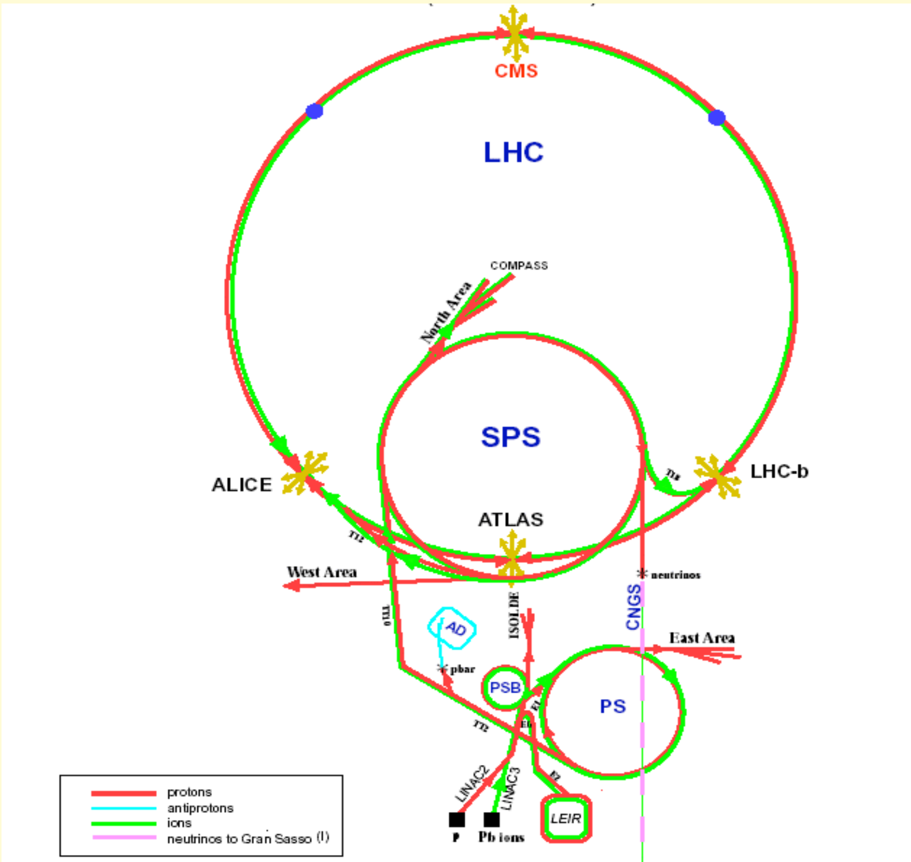
Globe of Innovation

Accelerator Technology Department

Main Topics

- **Introduction**
  - LHC Injectors
  - SPS Running with LHC-type beams
  - Electron Cloud Signatures
- **Main Results in the SPS**
  - Electron Cloud Build up
  - Vacuum Cleaning and Beam Conditioning
  - Role played by the Physisorbed Gasses
- **Scrubbing Runs Scenarios**
- **Conclusions**

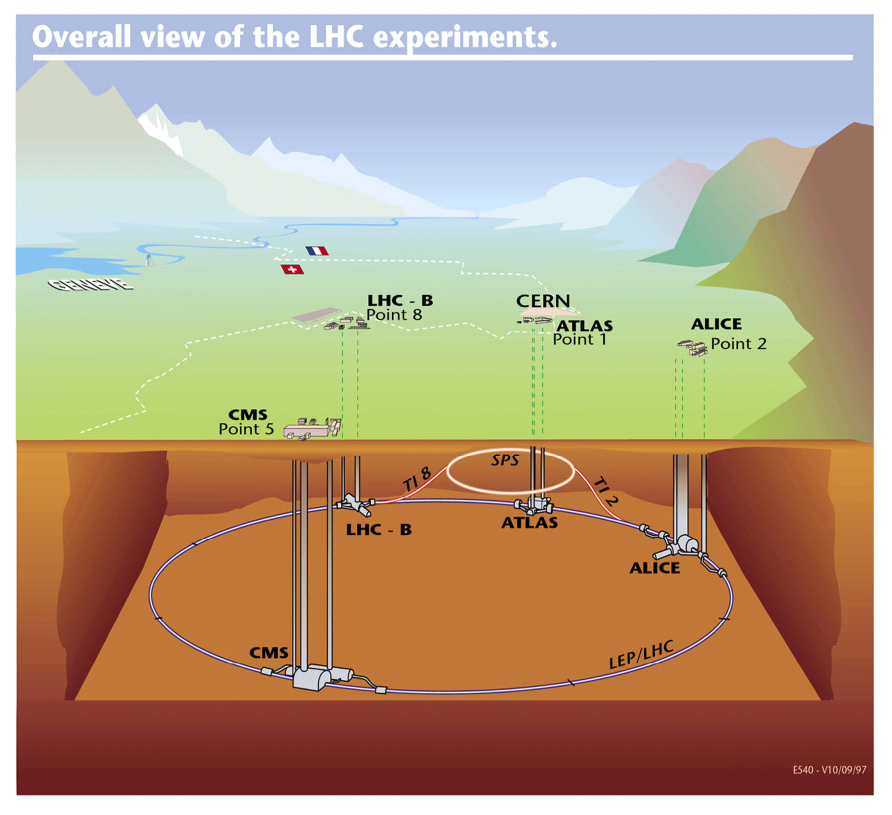
Introduction
CERN Facilities – LHC Injectors (1)

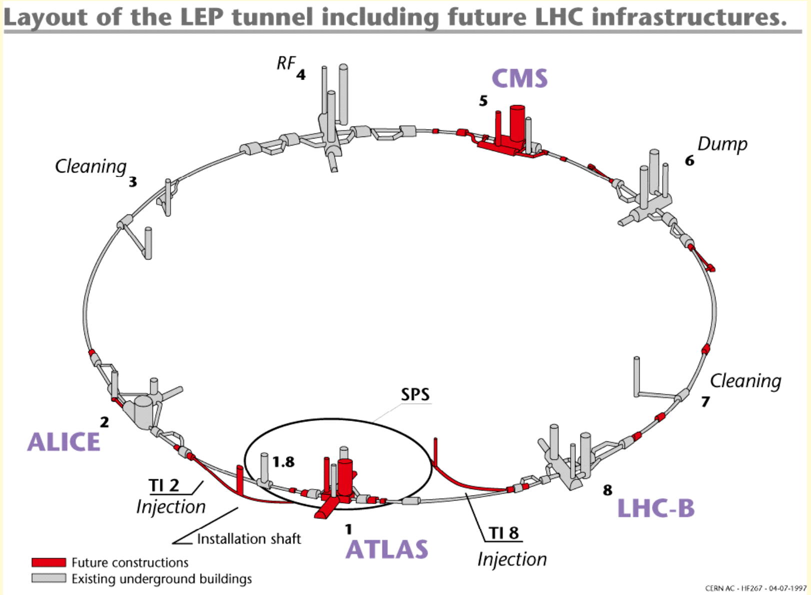


LHC: Large Hadron Collider
SPS: Super Proton Synchrotron
AD: Antiproton Decelerator
ISOLDE: Isotope Separator OnLine DEvice
PSB: Proton Synchrotron Booster
PS: Proton Synchrotron
LINAC: LINear ACcelerator
LEIR: Low Energy Ion Ring
CNGS: Cern Neutrinos to Gran Sasso

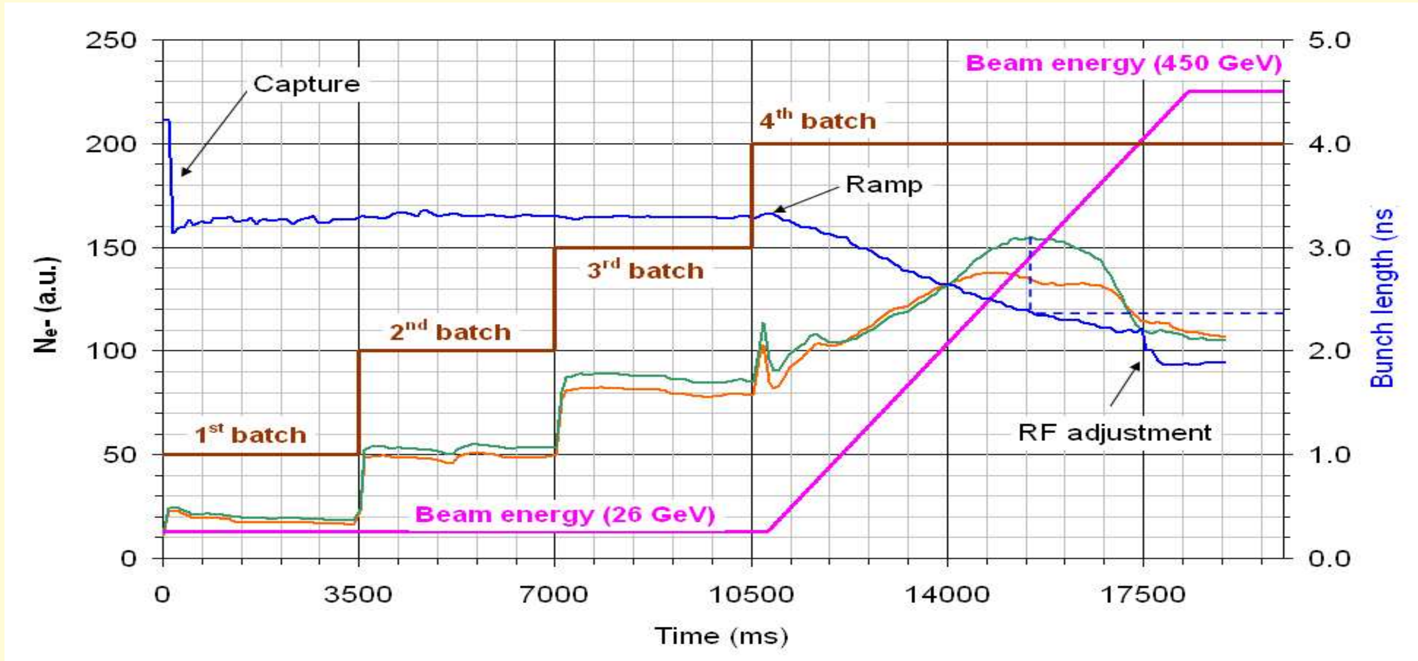
Rudolf LEY, PS Division, CERN, 02.09.96
Revised and adapted by Antonella Del Rosso, ETT Div.,
in collaboration with B. Desforges, SL Div., and
D. Manglunki, PS Div. CERN, 23.05.01

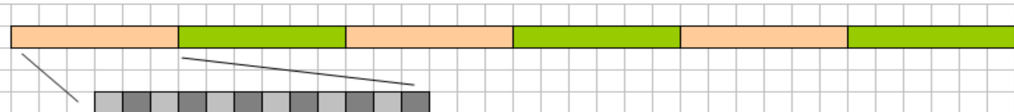
Introduction
CERN Facilities – LHC Injectors (2)





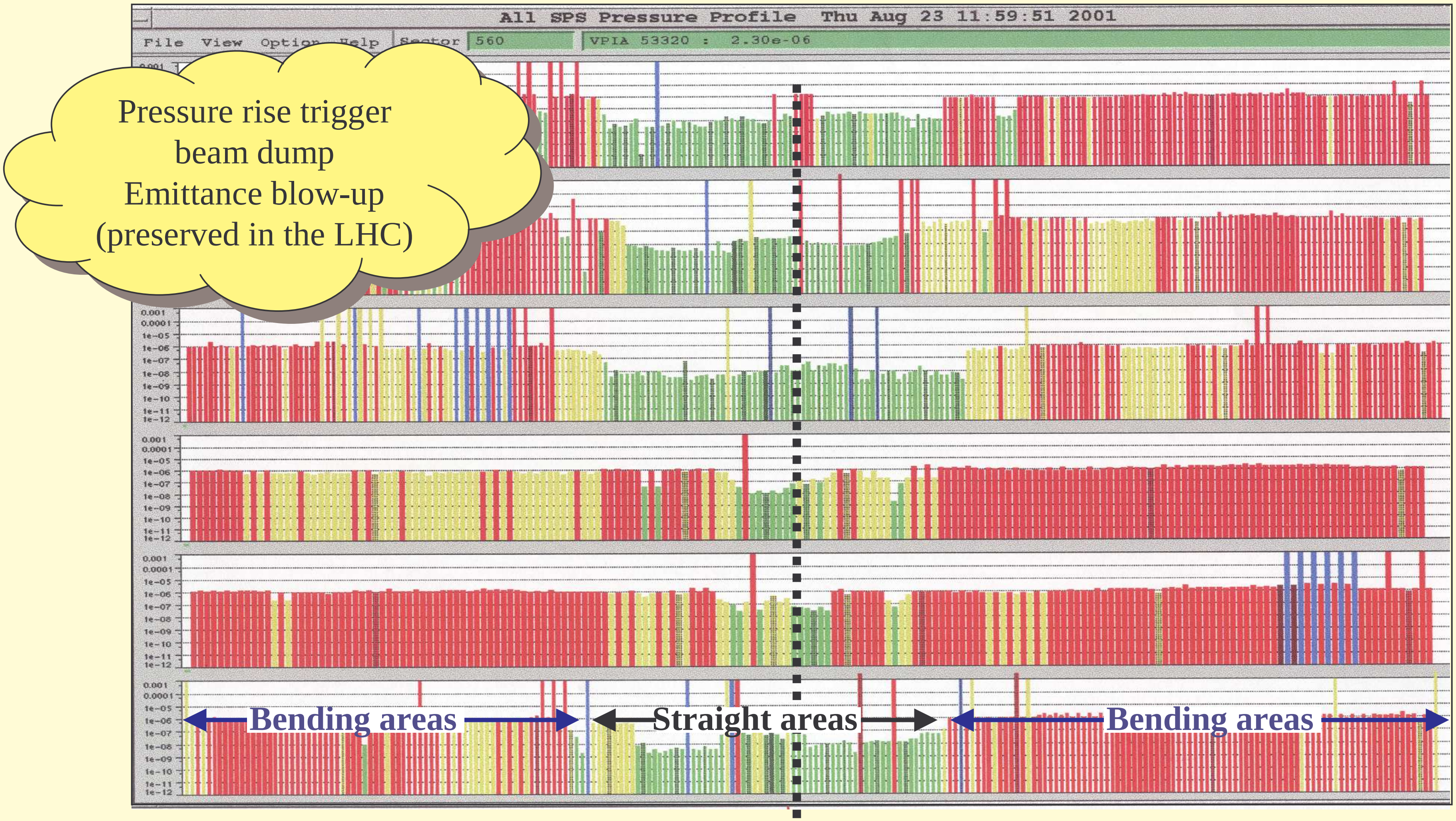
Introduction
SPS Running with LHC-type beams





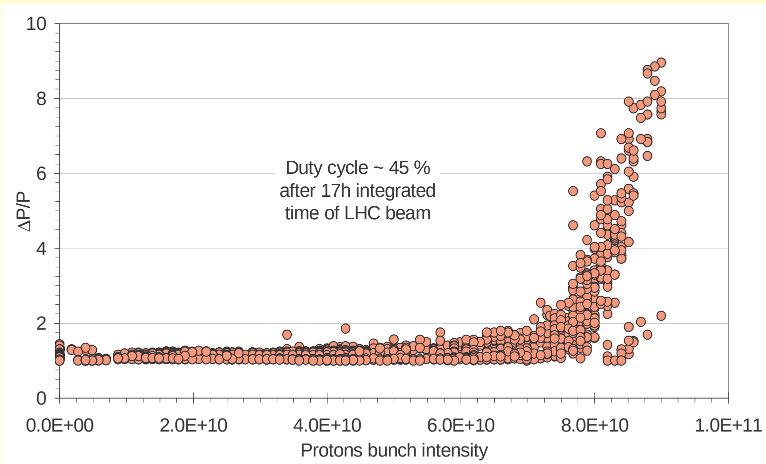
3 or 4 batches injected in the SPS		0	Injection of 1st batch at 26 GeV
Batch injection every 3.5 s		3500	Injection of 2nd batch
225 ns batch spacing		7000	Injection of 3rd batch
72 bunches per batch		10500	Injection of 4th batch
25 ns bunch spacing		10800	Staring ramp to 450 GeV
10^{11} protons per bunch		18300	Flat top at 450 GeV during ~ 2 s
4ns bunch length at injection			

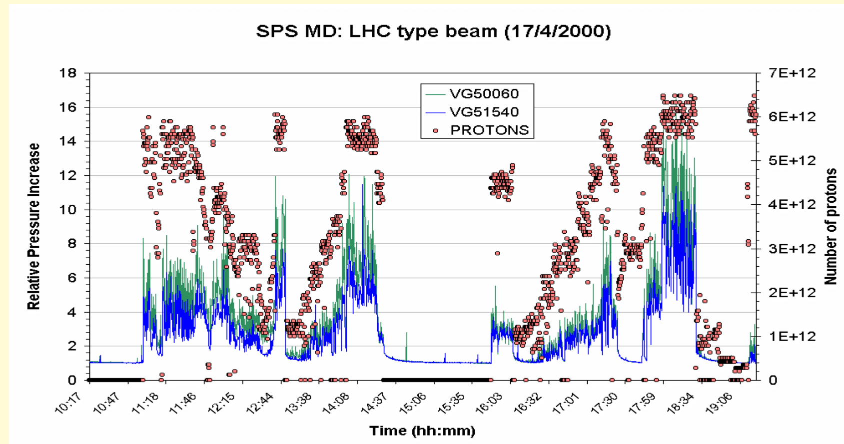
Introduction
Electron Cloud Signature in the SPS



Red = P >10^{-4} Pa, Green = P < 10^{-4} Pa

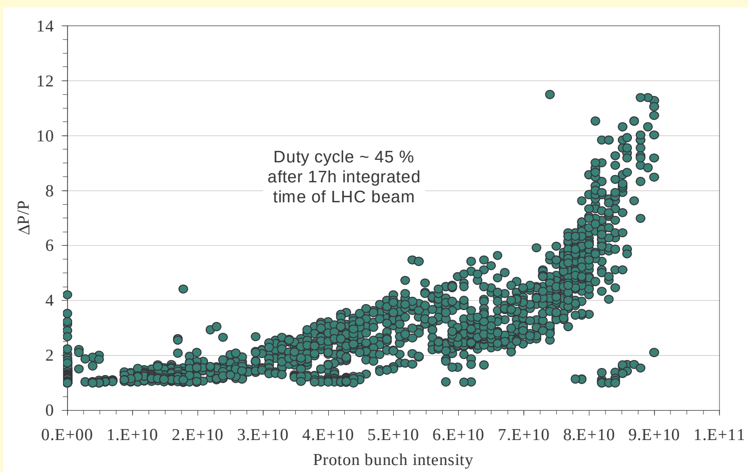
Introduction
Pressure readings give indications…

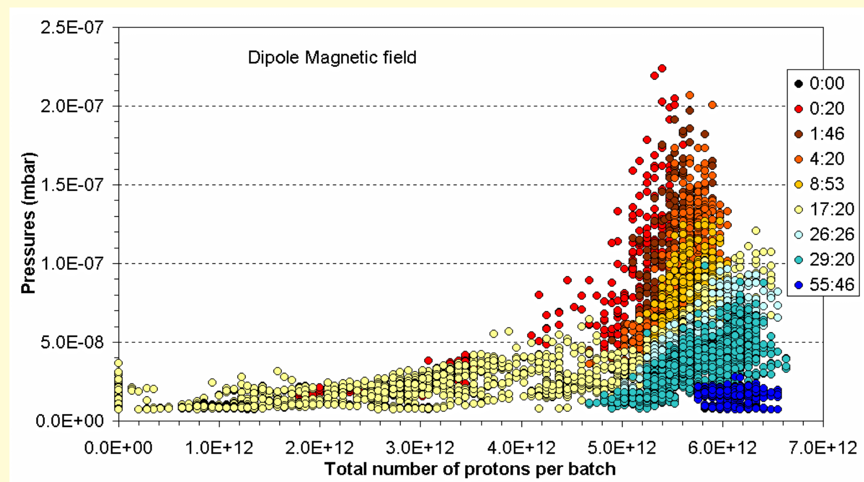




Beam conditioning and bunch dependence observed but results not easily understandable

Different behavior between DF and FF





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  - Vacuum Cleaning and Beam Conditioning
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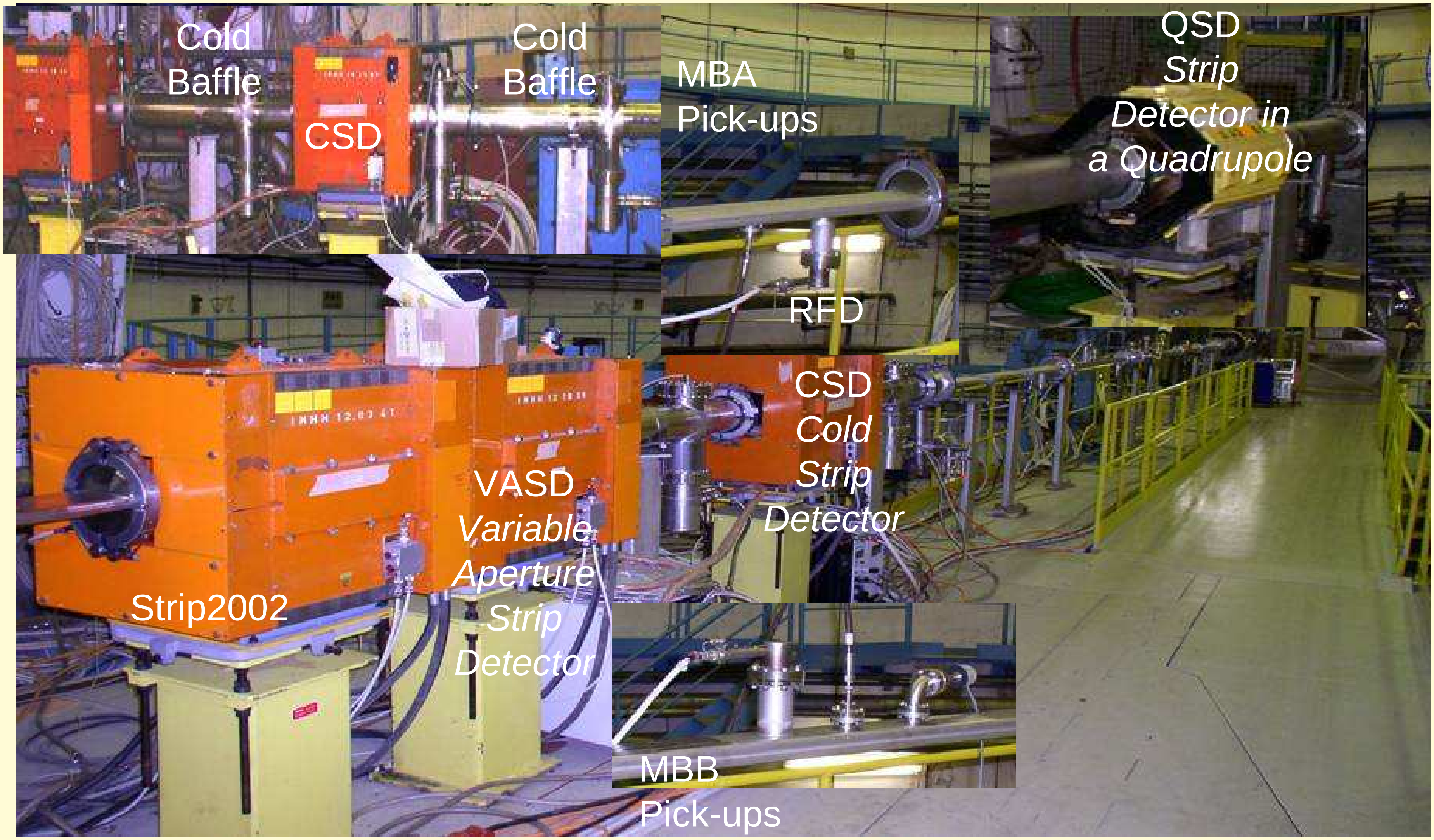
Main Experimental Set-ups
SPS Electron Cloud Test Bench



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Main Results in the SPS (1)
Electron Cloud Build-up

…is a threshold phenomenon:

- $3\ 10^{10}$ p/bunch in Dipole Field regions
- $5\ 10^{10}$ p/bunch in Field Free regions

…Intensity varies linearly with the bunch intensity

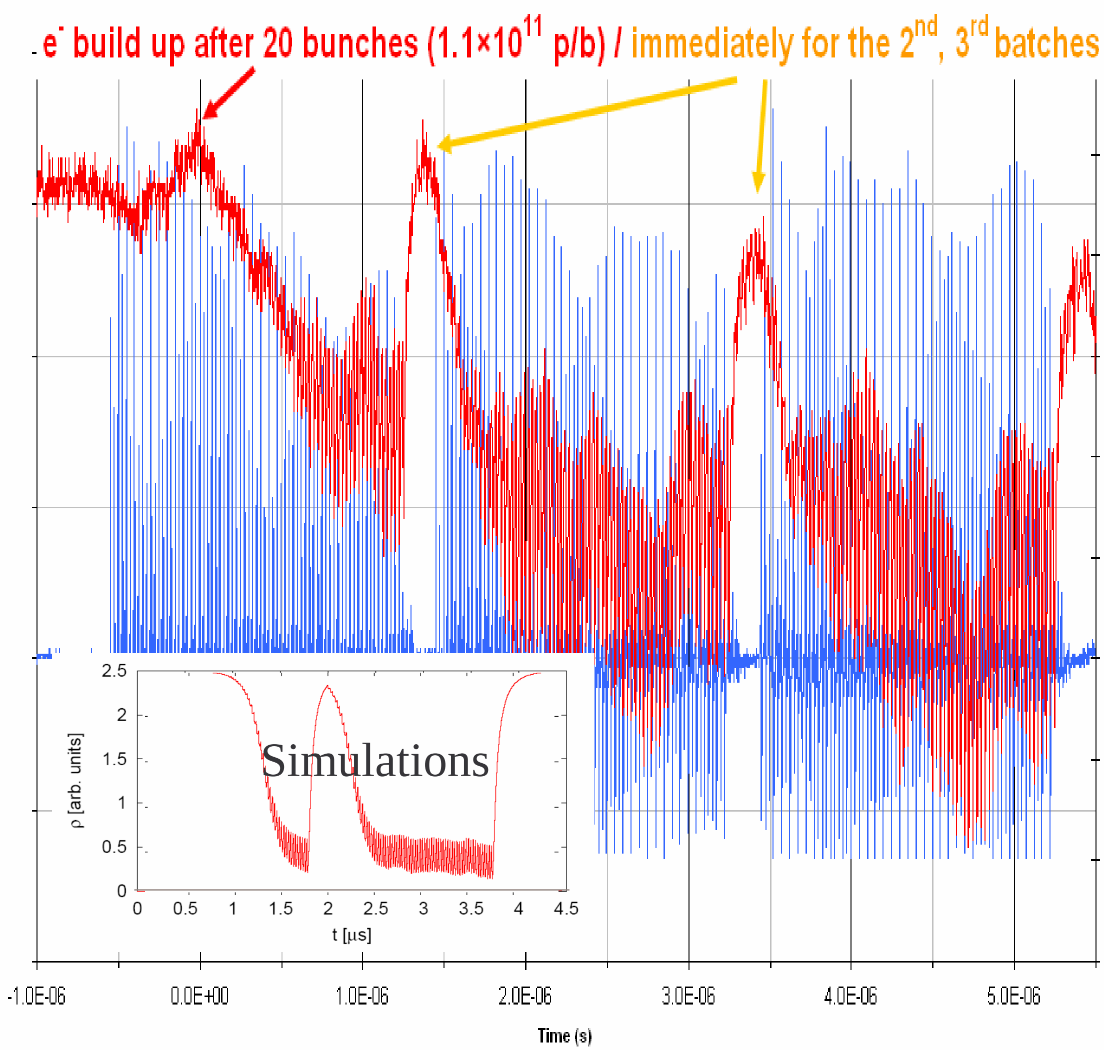
- Non-homogeneous spatial distributions in dipole and quadrupole fields

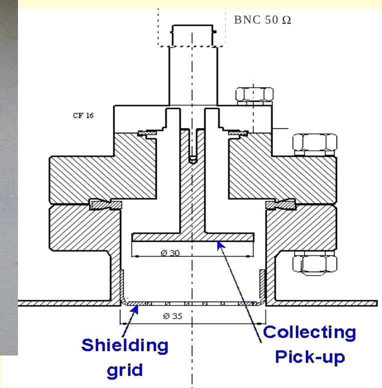
…Intensity varies linearly with the filling pattern

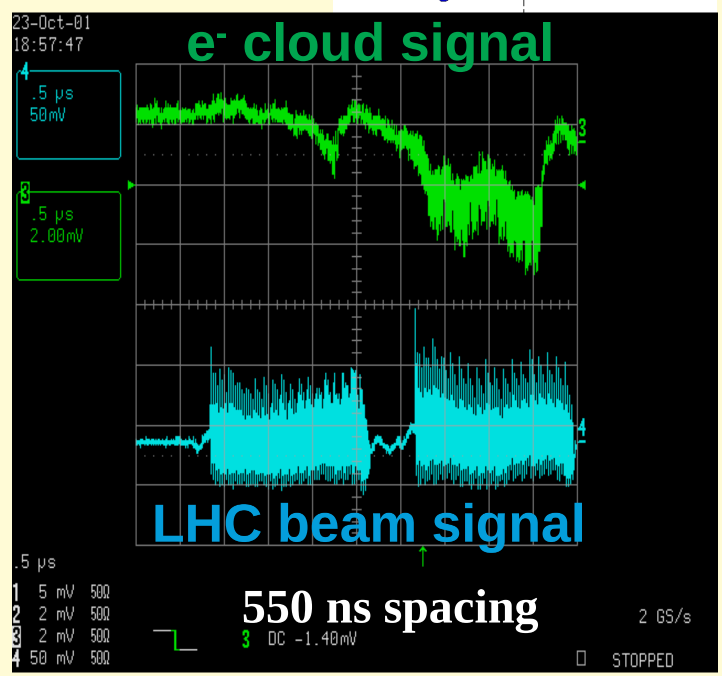
- No extinction during the 225 ns batch spacing ð evidence of surviving electrons

- **NEG coatings will decrease the electron cloud activity by their intrinsic low SEY: 1.1 after activation and 1.3 if saturated by water**
  - Baseline for the LSS RT parts

Main Results in the SPS (2)
Electron Cloud Build-up

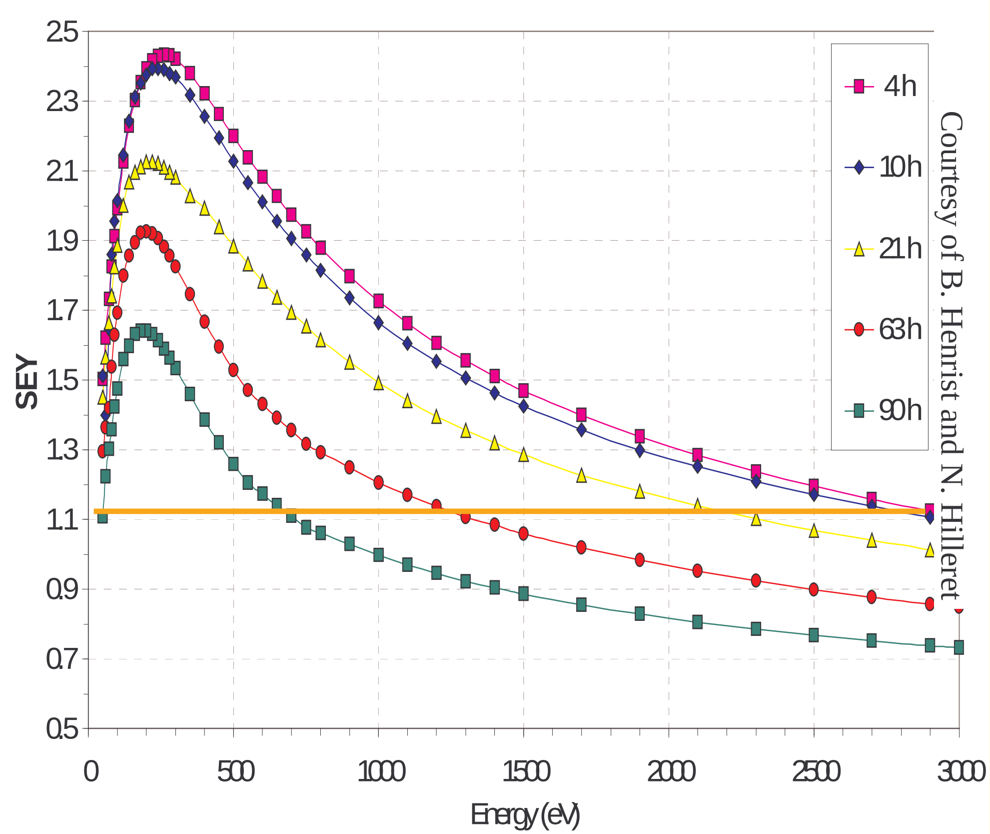




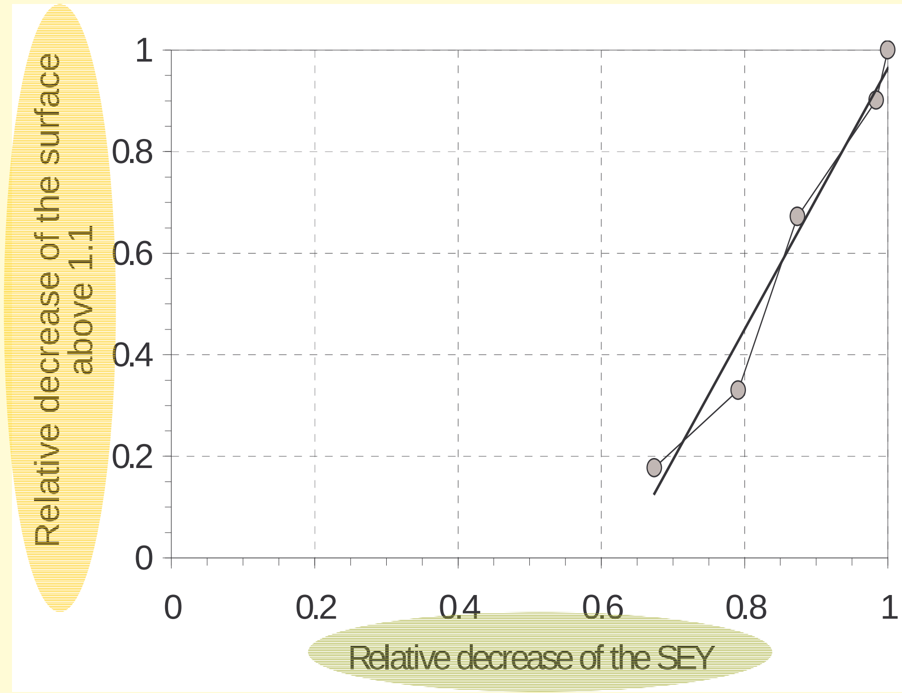


Main Results in the SPS (3)
SEY Decrease measured in situ in the SPS

Evolution of the SEY=f(*E*) with the conditioning



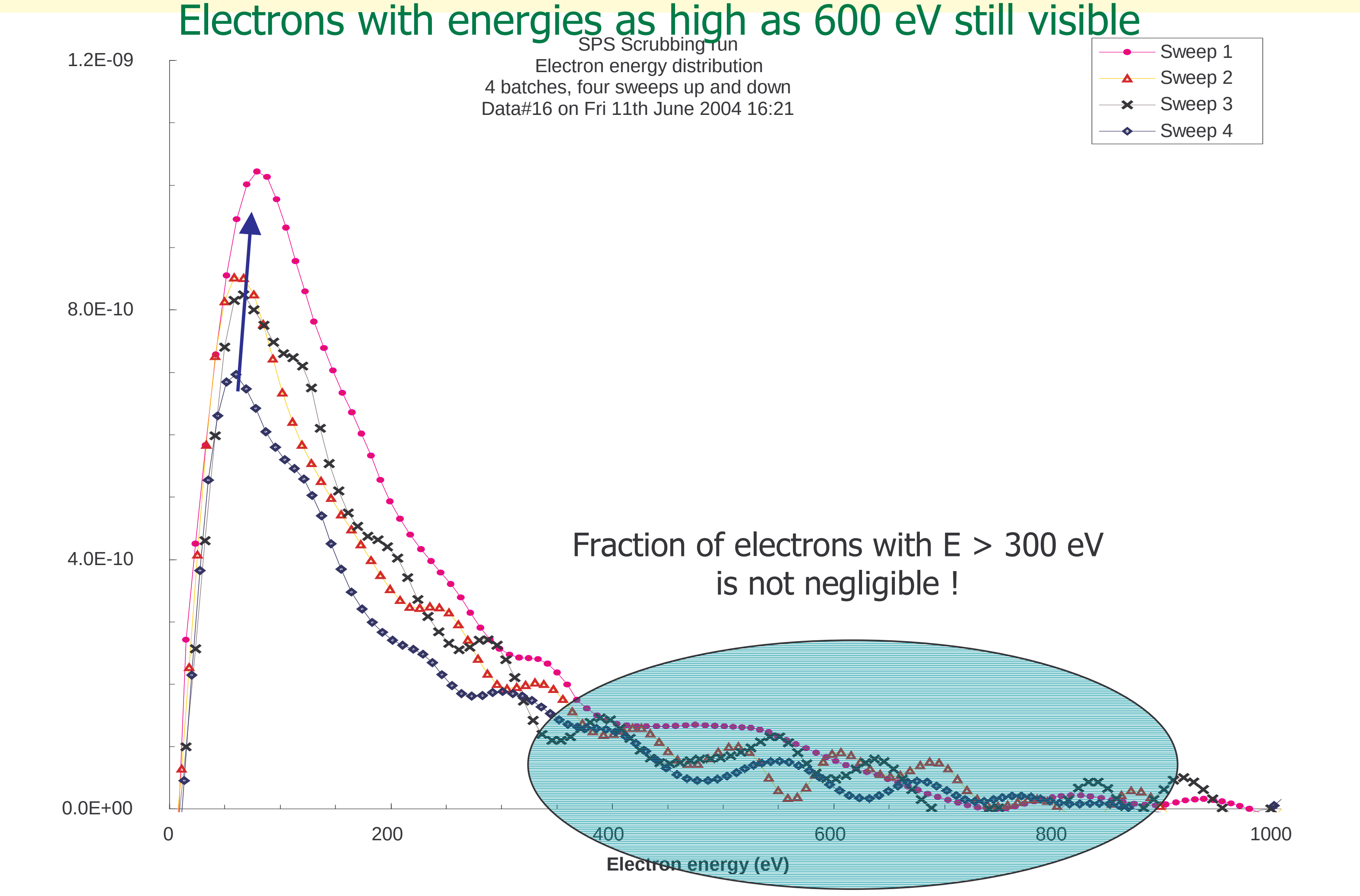
Total number of electrons contributing to the build up



Number of secondary electrons generated by a primary electron

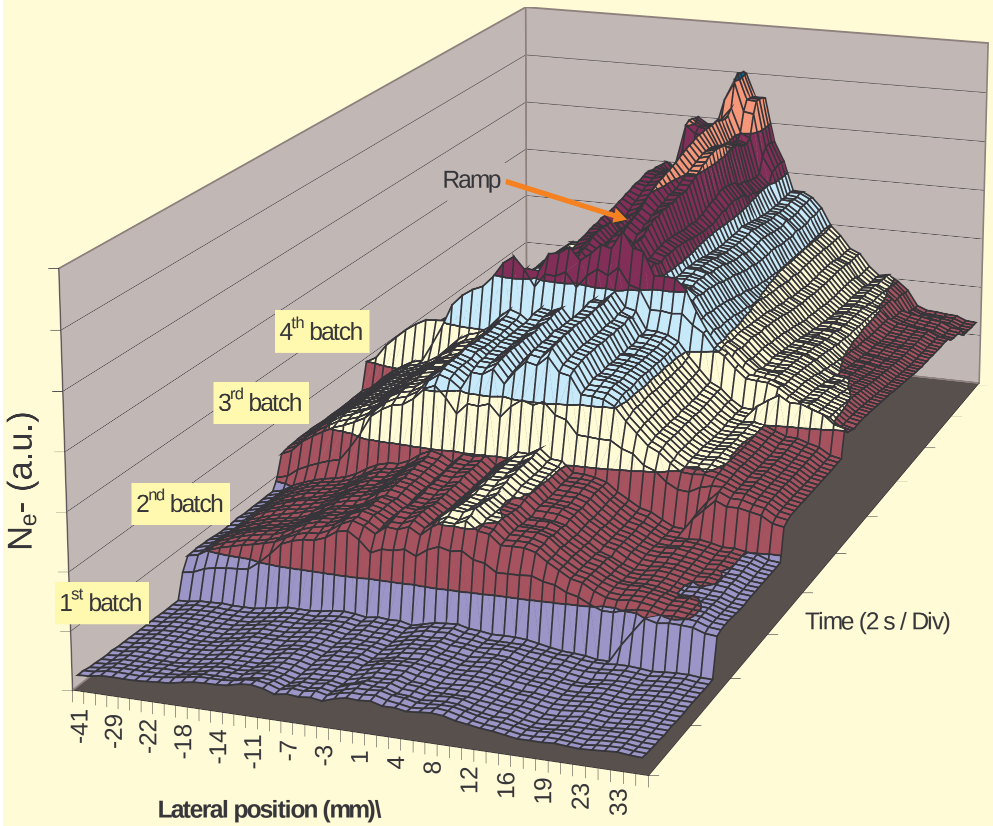
Main Results in the SPS (4)
Typical Signal from the RFD Detector

Maximum of energy distribution around 100 eV
Electrons with energies as high as 600 eV still visible

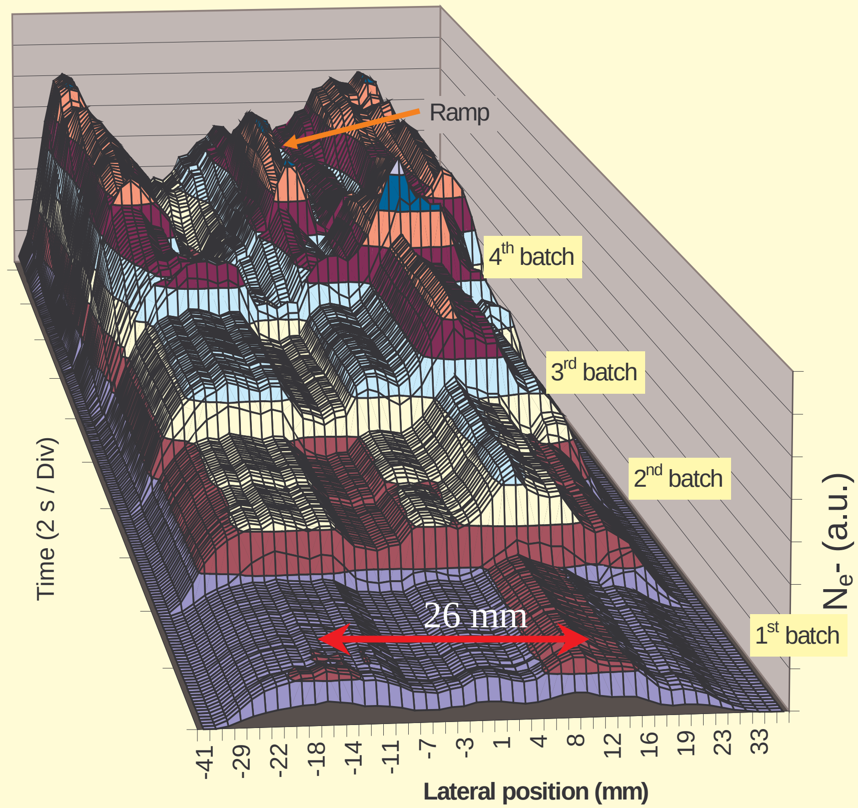


Main Results in the SPS (5)
Spatial distribution of e^- in Dipole and Field free regions

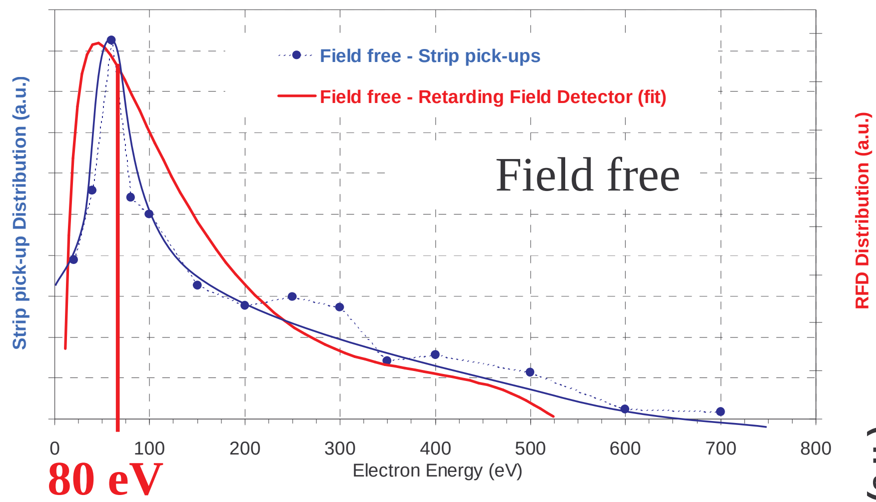
In field free conditions

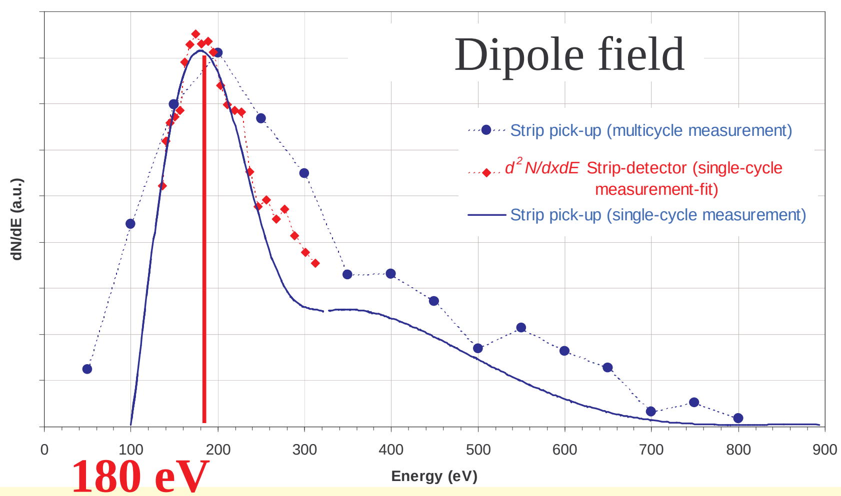


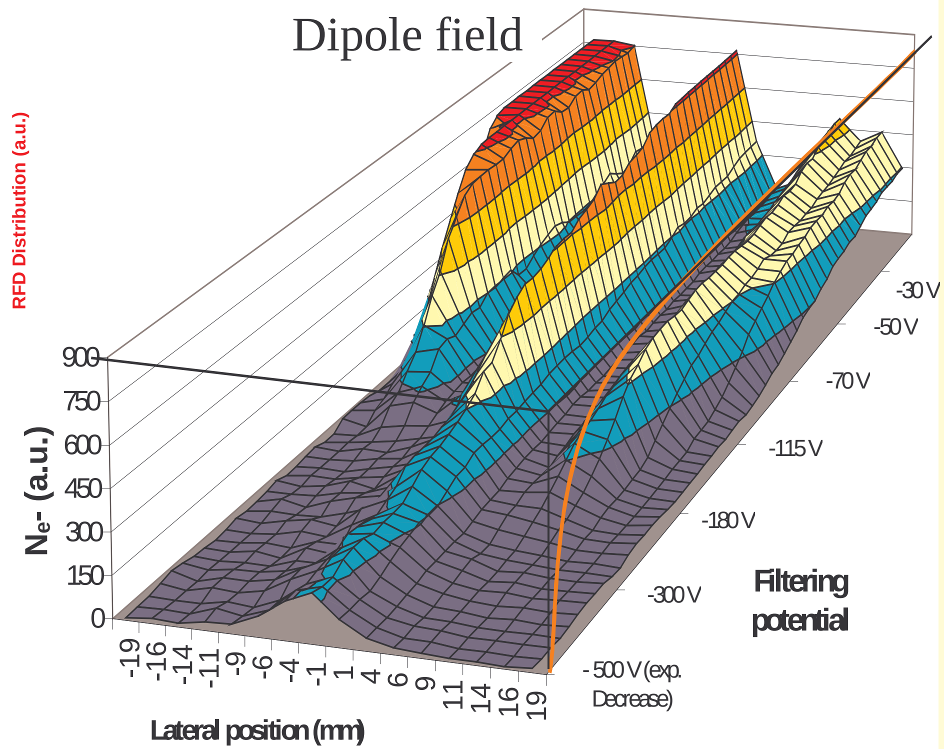
In dipole field conditions



Main Results in the SPS (6)
Spatial and Energy Distributions in Dipoles







Heat load efficiency = HLE

$e^-_{HLE}(DF) = 1.7 \times e^-_{HLE}(FF)$

E_e->180 eV located in the centre

ð faster beam conditioning observed

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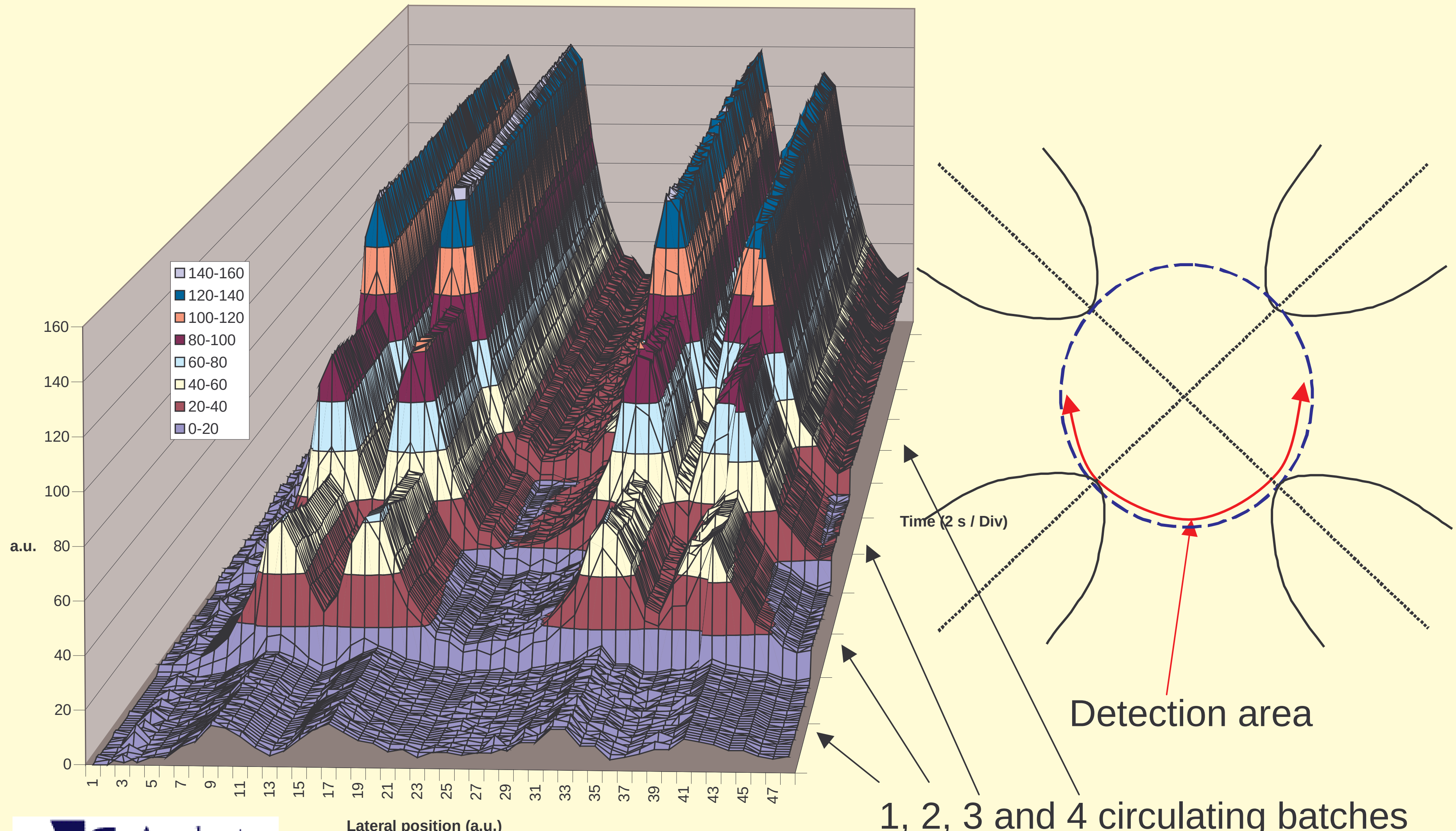
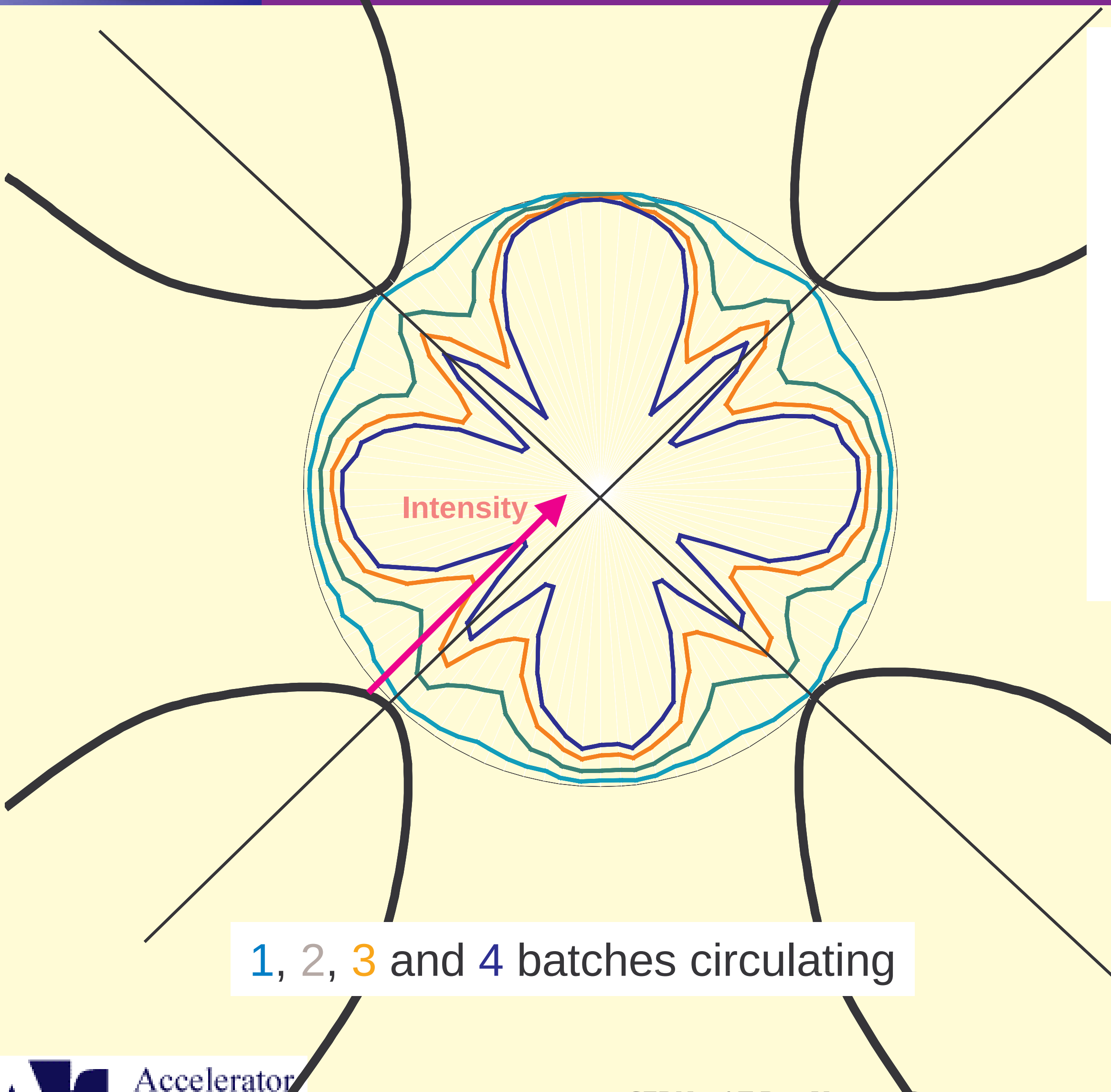
Main Results in the SPS (7)
Spatial Distribution in Quadrupoles

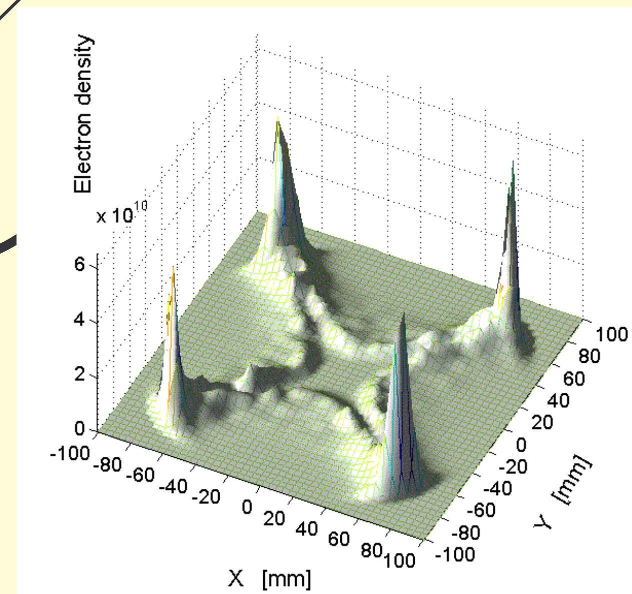


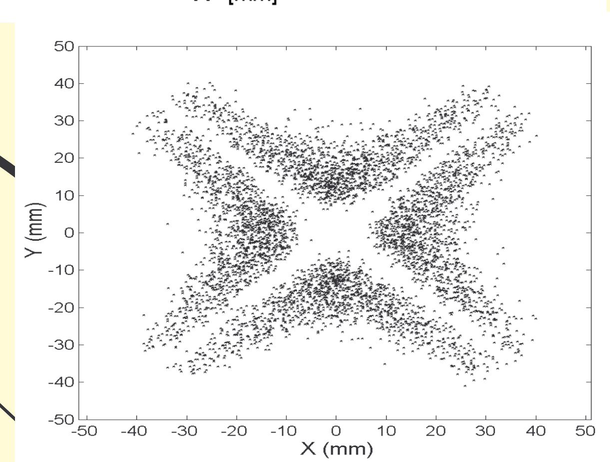
Main Results in the SPS (8)

Spatial Distribution in Quadrupoles

Results compared to Simulations

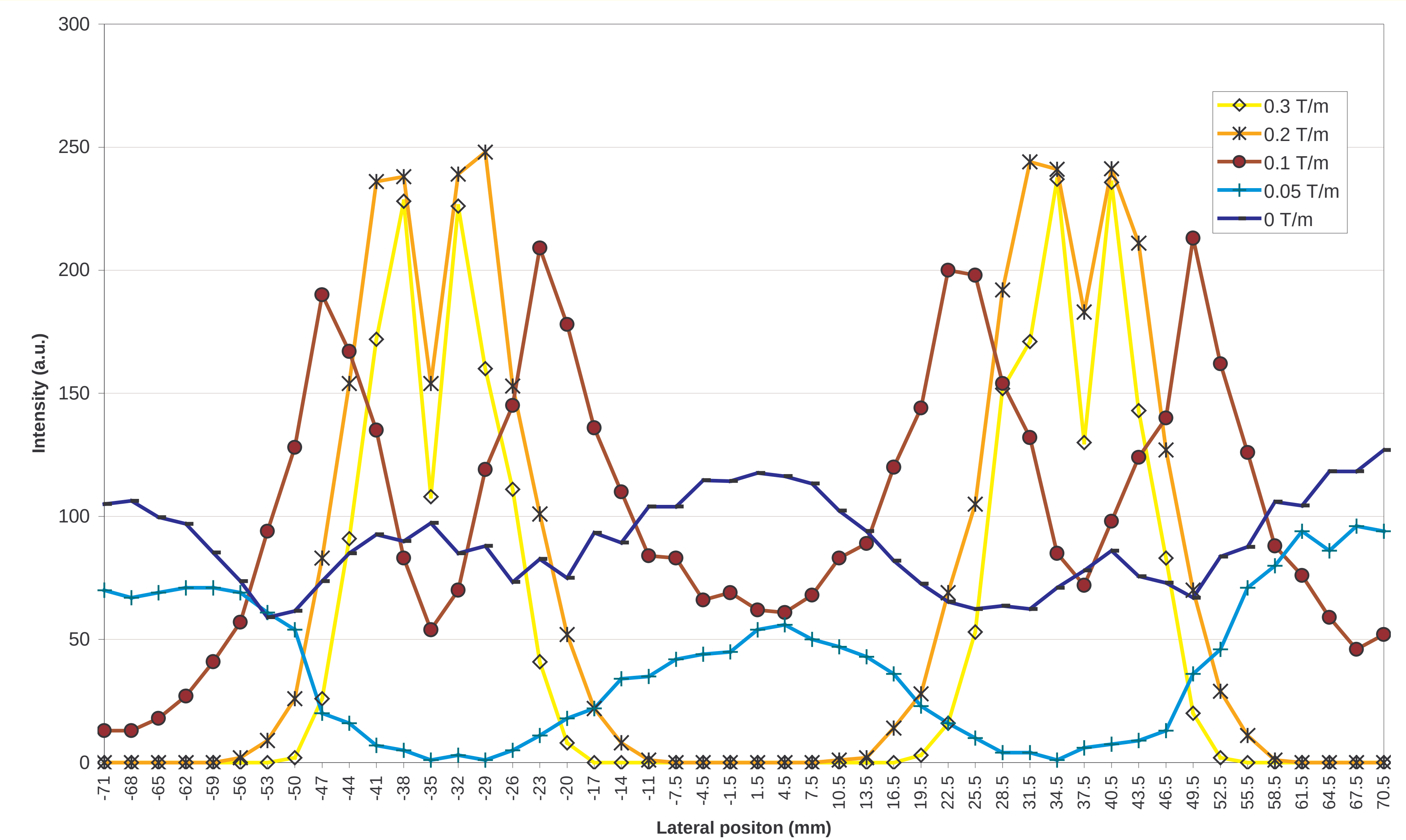




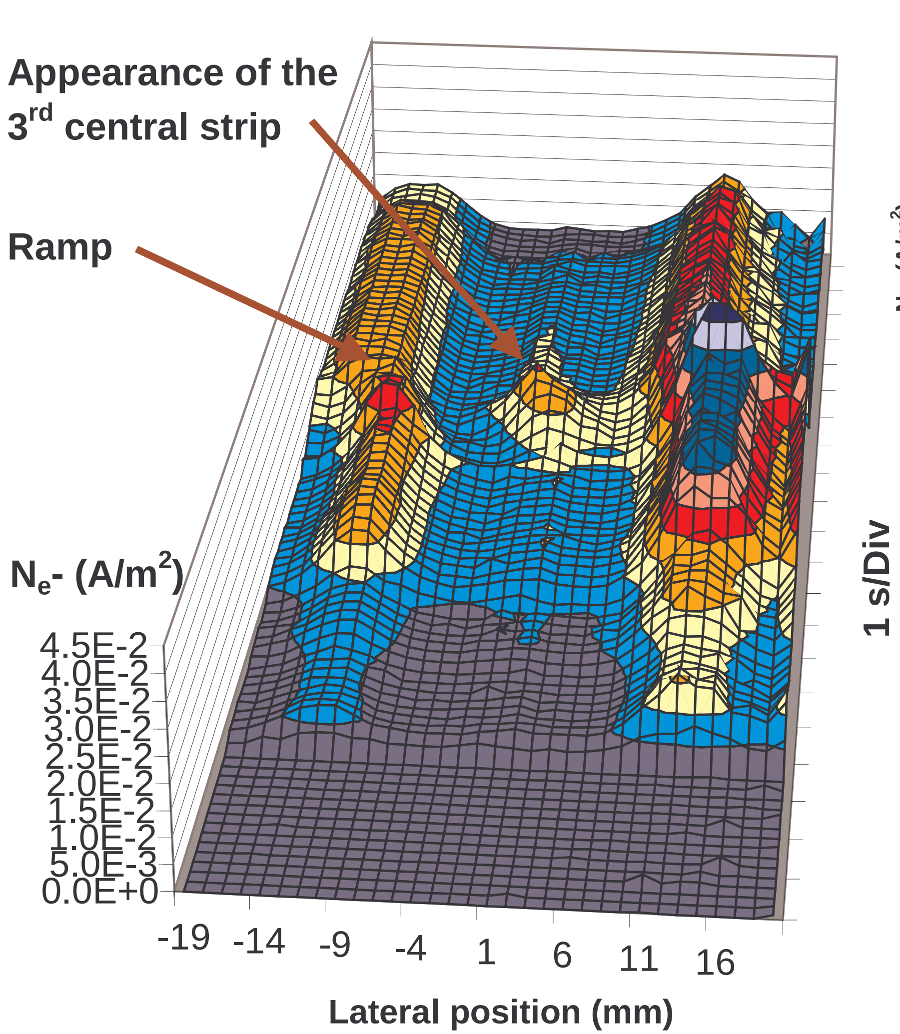


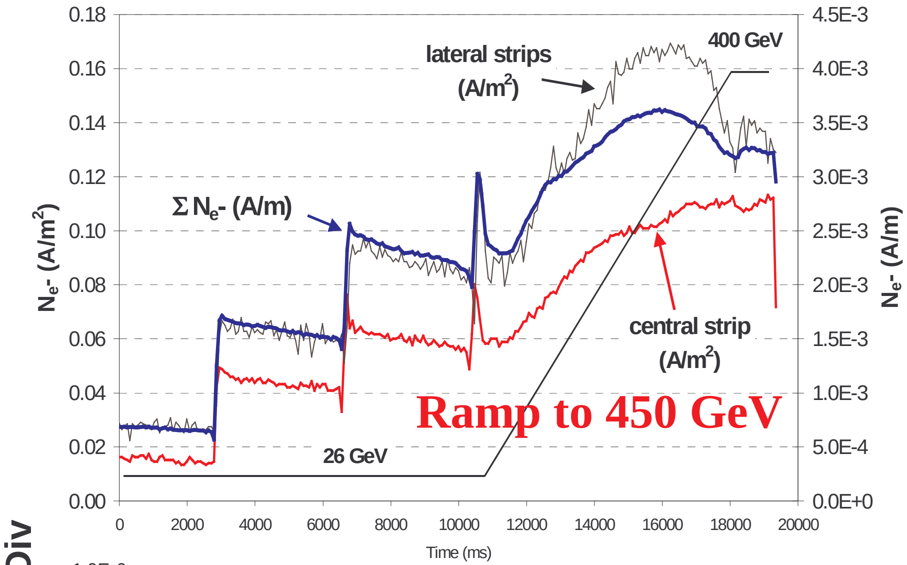
3D simulations made by L. Wang,
13th ICFA Mini-Workshop, BNL 12/2003

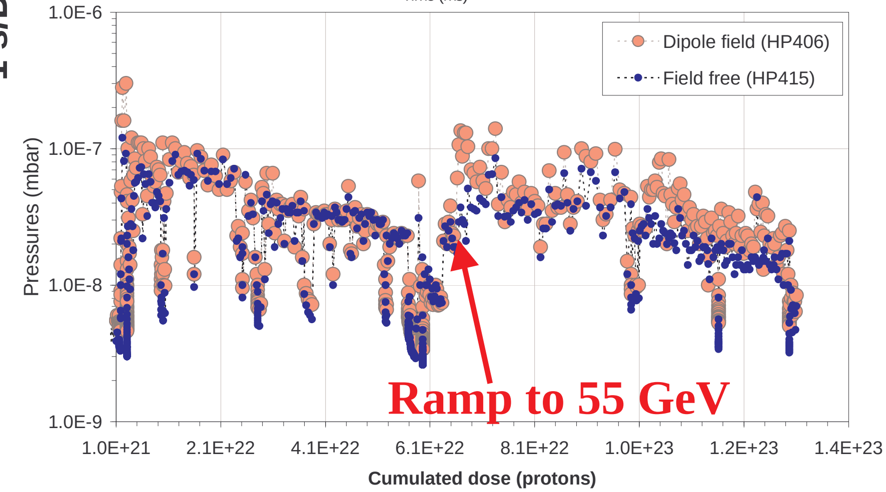
Main Results in the SPS (9)
Spatial Distribution in Quadrupoles
Effect of the Field Strength



Main Results in the SPS (10)
Energy Ramp / Orbit Displacement



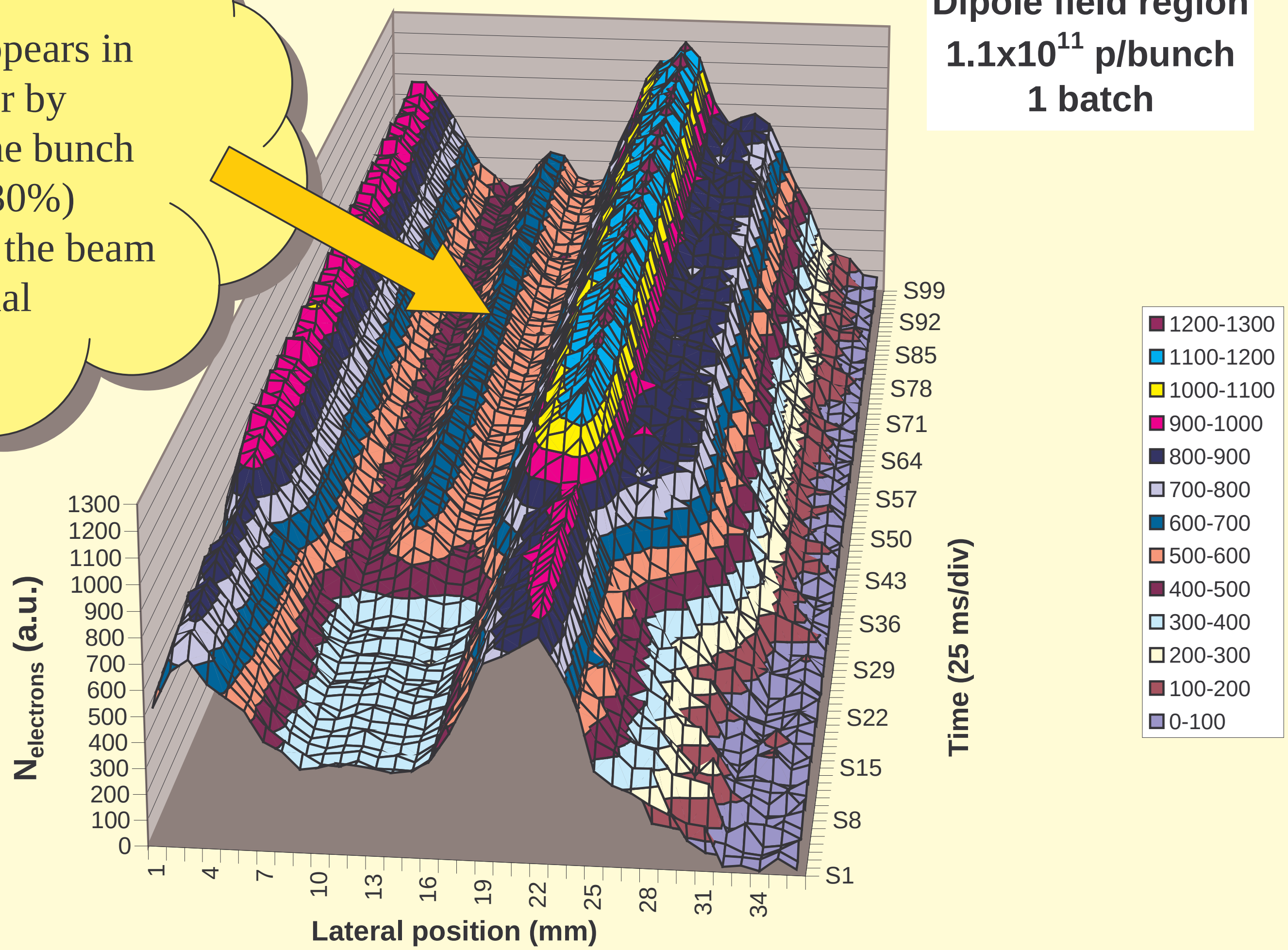




Main Results in the SPS (11)
Bunch Shortening enhances ECloud

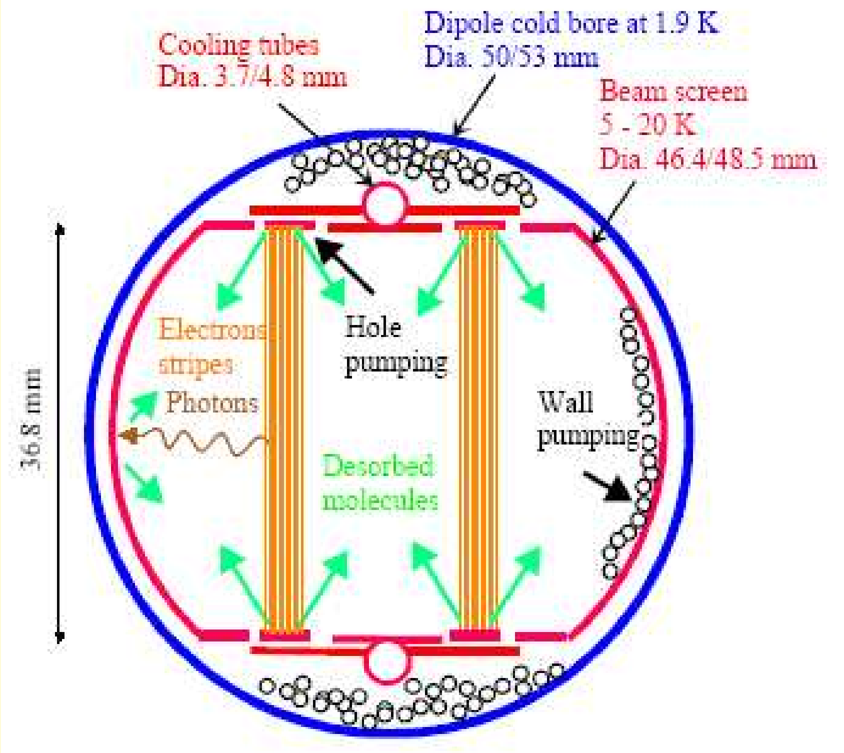
A 3rd strip appears in the center by decreasing the bunch length (-30%)
F increase of the beam potential

Dipole field region
$1.1x10^{11}$ p/bunch
1 batch



Main Results in the SPS (12)
Role played by the Physisorbed Gasses

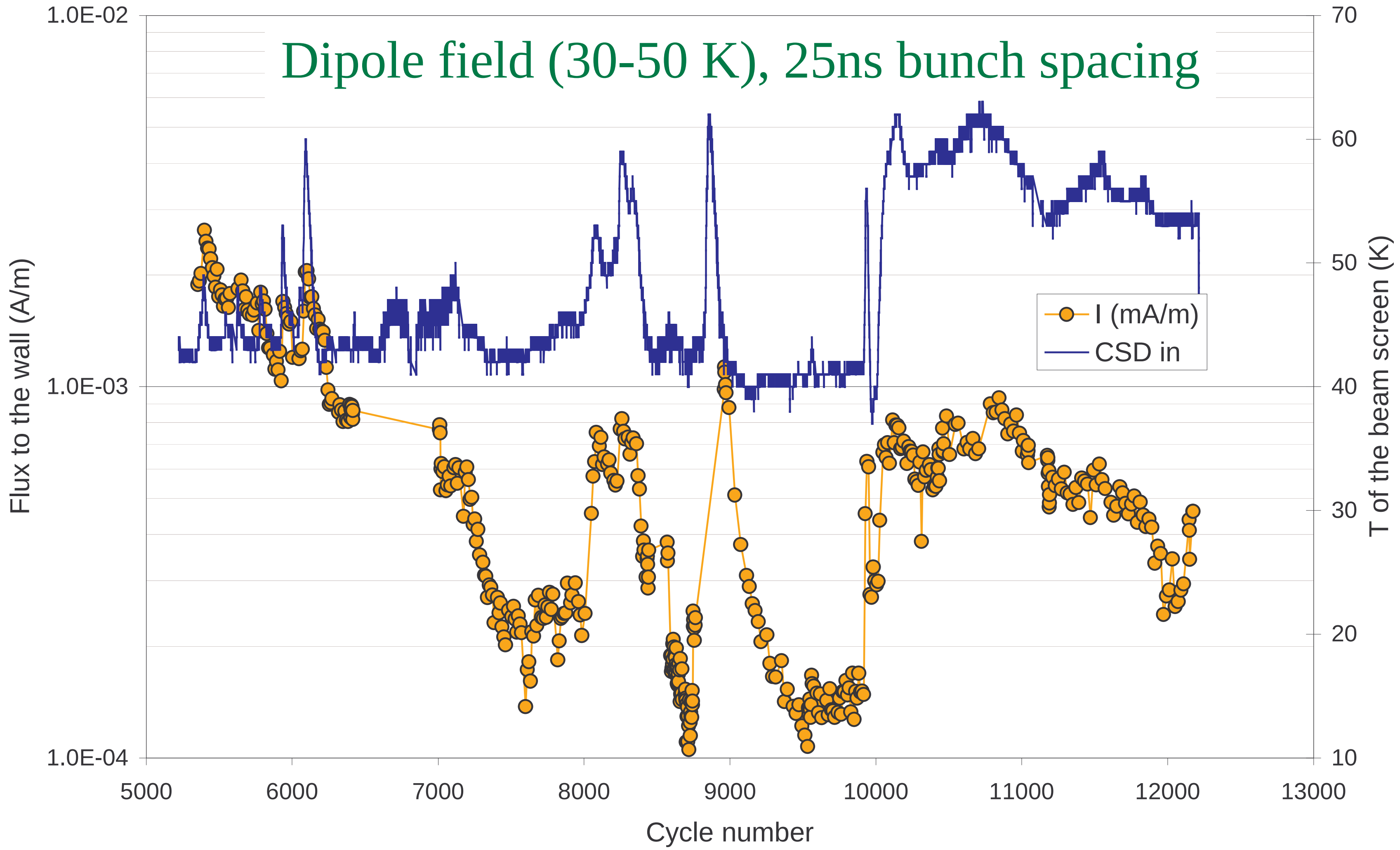
- **Physisorbed water identified as a potential problem:**
  - Conditioning has been observed in the SPS if the cold detector is protected against water back streaming from the unbaked parts
  - In the LHC, low water coverage is expected:
    - Pumping down to 10^{-6} torr of the cold parts prior to the cooling
    - Controlled cool down sequence where the cold bore is cooled while the beam screen is kept as warm as possible
- **Results obtained with the CSD in the SPS can not be extrapolated to the LHC since the SPS detector do not have the Beam screen/Cold bore arrangement:**
  - The molecules desorbed by the electrons will stay in the beam pipe as they will migrate to the cold bore in the LHC case
  - Thick coverage (>5 monolayer) are not expected in the LHC due to the continuous bombardment by the electrons and to the pumping speed through the beam screen pumping slots.



Courtesy of V. Baglin (CERN)

⇒ LHC cold surfaces should behave like bare copper surfaces

Main Results in the SPS (13)
Conditioning of Cold Surfaces



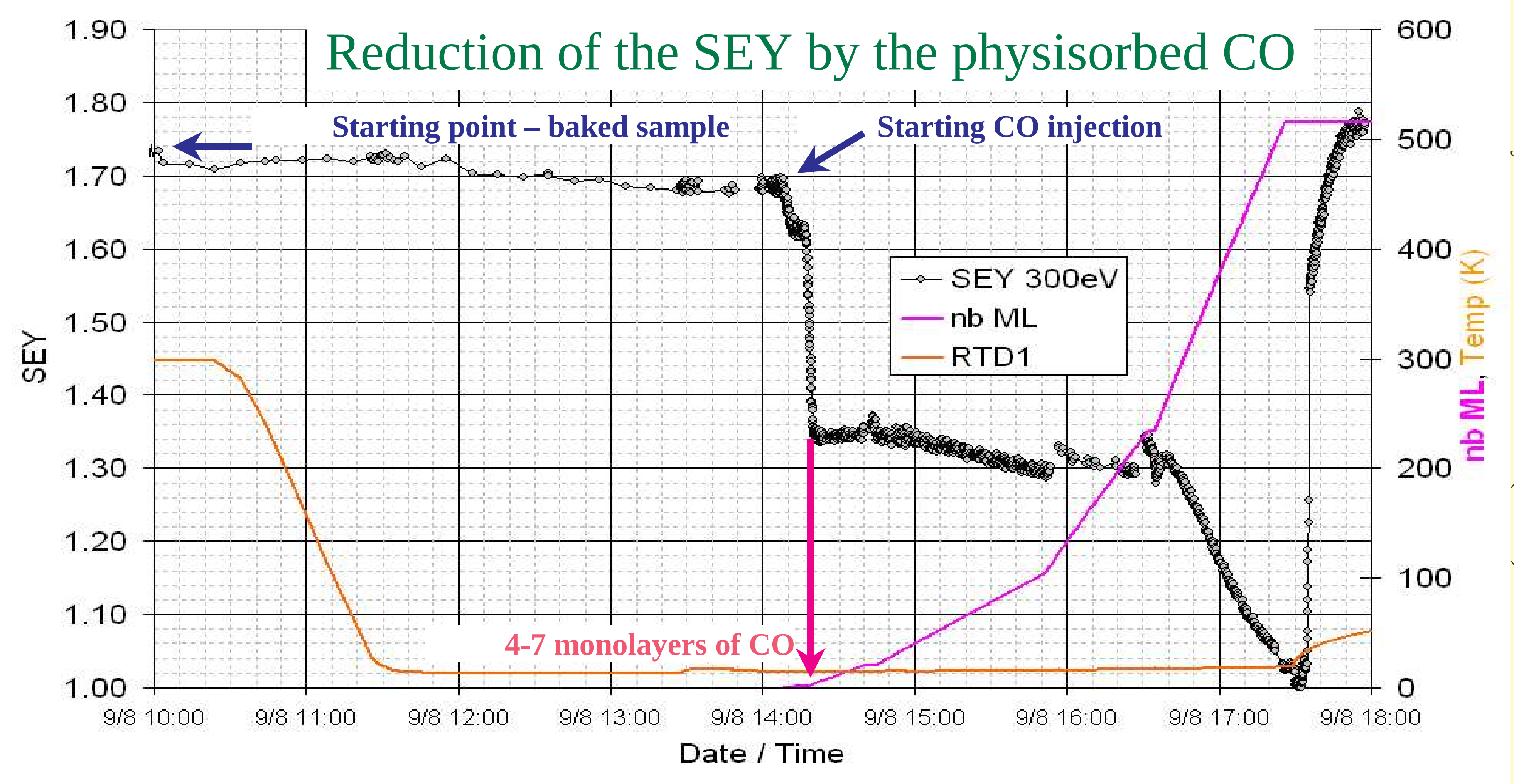
Main Results in the SPS (14) Vacuum Cleaning and Beam Conditioning

- **Vacuum Cleaning observed in the SPS during the 25 ns / 75 ns Periods**
  - ð Factor 10 during the 75 ns period, 100 during the 25 ns period for both FF and DF
- **Beam Conditioning on the cold surfaces has been observed in the SPS, probably a different physical process than at RT**
  - Beam Conditioning @ 75 ns
    - Dipole field at Cold ð Factor 100 after 7 hours
  - Beam Conditioning @ 25 ns
    - Dipole field at Cold ð Factor 10 after 1½ day
    - Quadrupole field at RT ð Factor 2.5 after 2 days
  - Gasses physisorbed on the cryogenic surfaces will play a predominant role (see next slide)
- **Effect of a Cycling in Temperature**

  As expected from Lab measurements, a water condensation will reset the beam conditioning. A temperature cycling did not helped to recover the initial value.

  ð Electron cloud intensity back to the initial value before the conditioning

Main Results in the SPS (15)
Role played by the Physisorbed Gasses



Courtesy of B. Henrist and N. Hilleret (CERN)

CO_2 and H_2O could have a detrimental effect as the others like H_2 and CO will decrease the SEY

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- **Scrubbing Runs Scenarios**
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Scrubbing Runs Scenarios (1)
Maximizing the Efficiency…

- **Beam related issues**
  - To maximize the scrubbing efficiency, the beam emittance, beam losses and beam instabilities has to remain under control

  F Not an issue in the SPS since a new beam is injected every 21 s
- **Bunch Spacing, Filling Pattern and Beam energy**
  - Bunch Spacing
    - No limitation expected with the 75 ns bunch spacing up to nominal
    - No limitation expected with the 25 ns bunch spacing if < 3 10^{10} p/bunch
    - > 3 10^{10} p/bunch F will depend on the induced heat load provided that beam instabilities and emittance growths are kept under control

      ~8 10^{10} p/bunch is the expected limit prior to the beam conditioning
  - Filling pattern
    - A modification of the filling pattern by increasing the gaps (RHIC case) between the batches shall be preferred to the reduction of the bunch intensity:
      - Displacement of the lateral strips in a dipole field with the bunch intensity
      - Decreases the average energy of the electrons from the cloud ð reduction of the conditioning efficiency

Scrubbing Runs Scenarios (2)
Maximizing the Efficiency…

- Scrubbing runs at injection energy
  - Will increase the cooling budget available for the electron cloud-induced heat load,
  - Will only work if not limited by other effects like beam instabilities or emittance growths,
  - Will require a short scrubbing run period @ top energy in case of a small orbit displacement during the ramp in energy

- **De-conditioning effect**
  - Has been observed both in the Lab and in accelerators (EPA and SPS) when the surface is no longer bombarded
  - F Subsequent conditioning is 10 times faster
  - Is expected as a consequences of a partial warming up of the cold parts during the shutdown ð physisorbed gasses will go back to the gas phase and be recondensed during the following cooling down
  - F Part of the molecules in the gas phase will be pumped by the mobile pumping stations

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Conclusions (1)
SPS as the LHC Injector

- **SPS shall be available for LHC injection but also for the CNGS**
  - After shutdowns, 5 days of beam conditioning are required
    - No signal in the field-free regions (long straight sections)
    - In the arcs (dipole field), electron cloud still “visible”
    - Strong vacuum cleaning (factor 100 in 4 days)
  - Beam conditioning limited to the parameters used during the scrubbing
    ð will not be effective if running conditions become more favourable
- **SPS Electron Cloud Test Bench will be kept for electron cloud build up and induced instabilities studies and benchmarking of the simulations**
- **Electron Cloud Build up**
  - Comparison 25 / 75 ns and 225 ns Batch Spacing
    - In Dipoles: Factor 10 less @ 75 ns compared to 25 ns
      In Quadrupoles: Factor 2 less @ 75 ns compared to 25 ns
  - Batch Spacing
    ð Spacing > 1000 ns are useless if balanced with luminosity reduction
    ð Potential gain if 25ns / 75ns bunch spacing is adopted
  - Measurement of Spatial and Energy Distribution consolidated

Conclusions (1)
LHC Issues

- **There is conditioning on the cold surfaces, probably a different physical process than at room temperature**
  - Water identified as the "culprit" in SPS ð No reason to have condensed water in the LHC arcs
  - Physisorption of CO on beam screen will help conditioning
    - But not yet clear where it will start after a warm-up !
- **No limitation if running with 75 ns bunch spacing**
- **Beam Conditioning @ 75 ns**
  - Dipole field at Cold ð Factor 100 after 7 hours
- **Beam Conditioning @ 25 ns**
  - Dipole field at Cold ð Factor 10 after 1½ day
  - Quadrupole field at RT ð Factor 2.5 after 2 days
- **Vacuum Scrubbing in the SPS during the 25 ns / 75 ns Periods**

  ð Factor 10 during the 75 ns period, 100 during the 25 ns period for both FF and DF
- **Effect of a Cycling in Temperature**

  A cycling in temperature aimed to condensate water on the CSD. As expected from Lab measurements, it reset the beam conditioning

  ð Electron cloud intensity back to the initial value before the conditioning

Acknowledgements

- **Many thanks to G. Arduini, V. Baglin, P. Collier, O. Gröbner, G. Ferioli, J. Hansen, B. Henrist, N. Hilleret, L. Jensen, D. Schulte, P. Strubin, A. Rossi, F. Ruggiero, J. Wenninger and F. Zimmermann for their help**
- **To the operation crew of both PS and SPS**
- **To the AT/VAC-SL Section collaborators for the installation of the detectors**
- **To the TS Department collaborators for the design and manufacturing of the detectors**