CERN SPS Emittance Measurements

F. Roncarolo, CERN AB/BDI
University of Lausanne

Acknowledgments:

B.Dehning, R.Jung, J.Koopman, G.Ferioli, C.Fischer
J.J.Gras, A.Guerrero
G.Arduini
F.Caspers

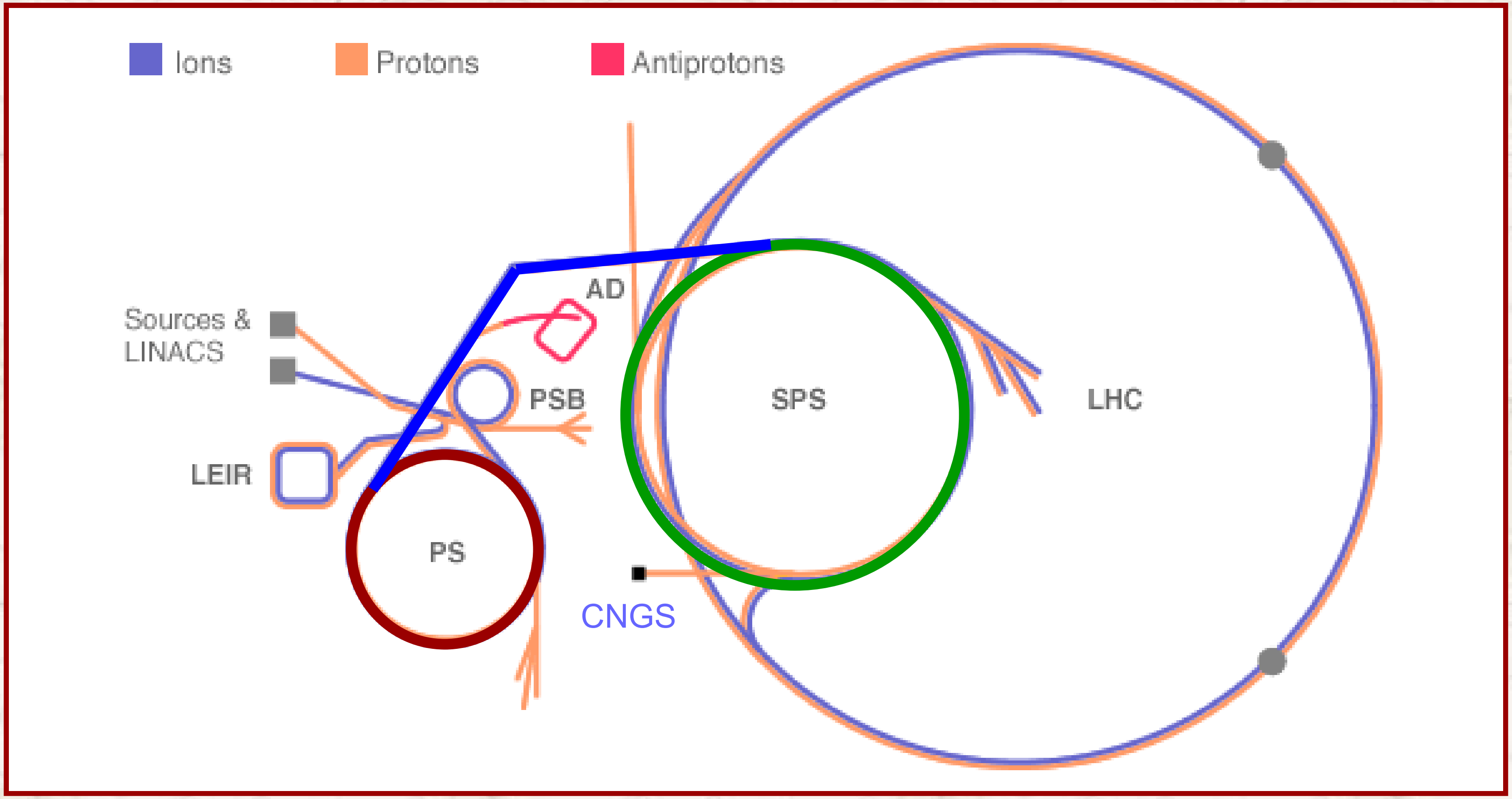
Contents

- The proton acceleration from the LINAC to the LHC
- Introduction to emittance measurements
  - The quantities to be measured
  - Some of the SPS-LHC beam design parameters

- Overview of the CERN SPS emittance monitors
  - Flying Wires
  - Ionization Profile Monitor
  - Luminescence Monitor
  - Synchrotron Light Monitor

- Data Analysis and Results
  - The off-line analysis with ROOT
  - The fitting strategies
  - Some results
- Conclusions

Proton Acceleration Chain



SPS-LHC Design Parameters

LHC Beam in the SPS

Proton Momentum	26 → 450 GeV/c
Protons/Bunch	$1.1*10^{11}$
Bunches/Batch	72
N Batches	3 or 4
Bunch Length Bunch Spacing	4 → 1.5 ns (@ 4 σ) 25 ns
H (V) Emittance From PS (26 GeV) H (V) Emittance To LHC (450 GeV)	3 µm 3.5 µm

Some LHC numbers

- Particle Momentum @ collision: 7TeV
- 12 SPS Pulses with the scheme:
  - (334 334 334 333) → 39 PS Pulses = 2808 bunches

Transverse Emittance

- The transverse emittance is measured in the SPS during machine development periods dedicated to the LHC beam

Profile Monitors

$$\sigma^2_{meas} = \sigma^2_{emit} + \sigma^2_{disp} = \beta\varepsilon + \left(D \frac{dp}{p} \right)^2$$

$$\varepsilon_{x,y}^{n} = \frac{(\beta\gamma)_{beam}}{(\beta_{x,y})_{lattice}} \cdot \left[\sigma_{x,y}^{2} - \left(D_{x,y} \frac{dp}{p} \right)^2 \right]$$

- The normalized emittance is specified in [μm]
- Betatron Function: we performed measurements in 2002, exciting 6 Quad (ΔK), measuring the tune (ΔQ) and getting the Beta according to

$$\frac{4\pi \cdot \Delta Q}{\Delta k \cdot L_Q}$$

(the data analysis has to be completed)

- Dispersion Function: is computed from lattice design (MAD)
- Momentum Spread: is derived from RF voltages and when possible is also derived from the profile monitors

Monitors Overview

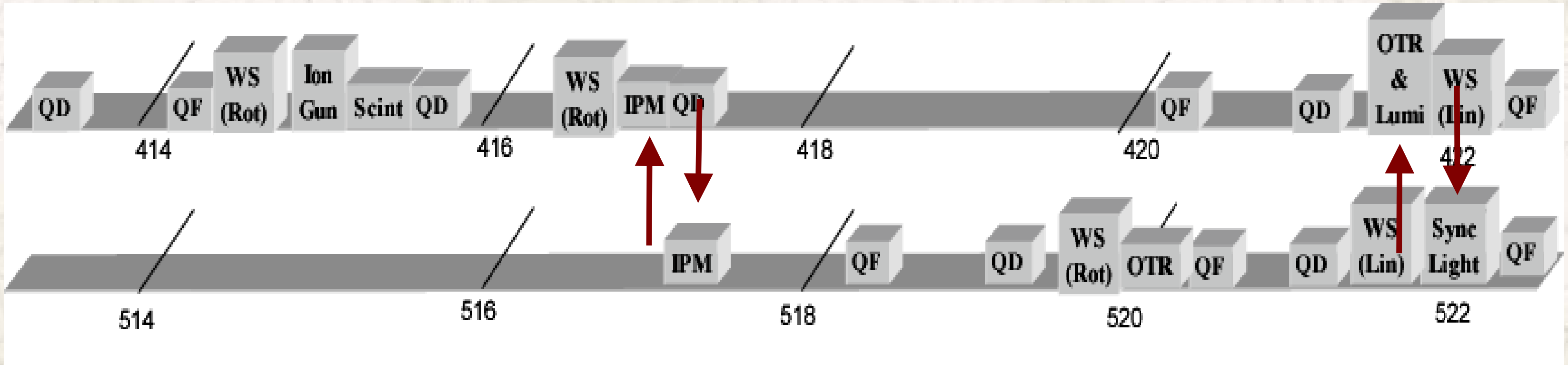
- **Gas Monitors:**

  IPM in the H Plane

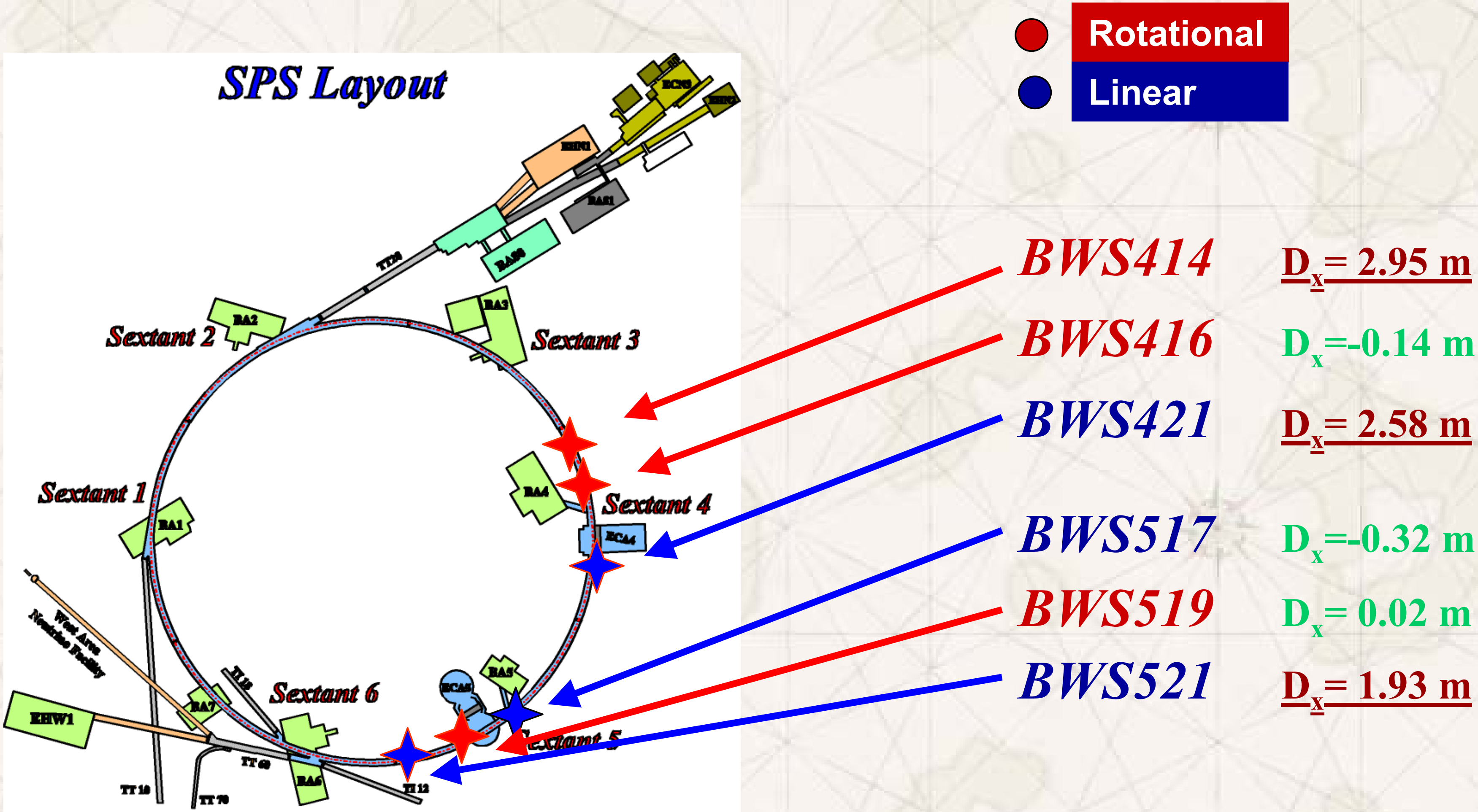
  IPM in the V Plane + Luminescence in the H Plane

  Luminescence in the H & V Planes

- **Synchrotron Light Monitor**



SPS Flying Wires Location



- Each tank is equipped with H&V FW

Flying Wire Pictures

Rotational Tank

Rotational Fork

Rotational Fork

Linear Motor

Linear Wire

Ionization Profile Monitor in LSS4

- Installed in 1997 (from Desy)
- Modified in 2000 (electron collection)

Characteristics

- It provides horizontal profiles
- The phosphor decay time is 300 ns
- It collects electrons, by means of two high voltage plates and a dipole magnetic field ranging from 0.018 to 0.036 T (B^{maz} = 0.06 T)
- During operation the image is acquired with a CCD camera

Performances

- The maximum refresh rate is 1 profile each 40ms
  (the limit is imposed by the camera which is always recording images in the two planes and taking 20ms for each image)
- The acquisition window size is adjustable, the maximum number of profiles per acquisition depends on the window dimensions

- There is also a second acquisition mode tested:
  - A multi anode PMT with 32 channels equipped with a 40MHz electronics
  - It was used to do turn-to-turn measurements with acceptable results despite the short integration time (1 turn=23us to be compared to the 20ms integration time of the camera)

Ionization Profile Monitor in LSS5

- A second IPM monitor has been installed in 2002 LAYOUT

Characteristics

- It provides vertical profiles
- The phosphor decay time is < 1 ns
- It is also equipped with a dipole magnet, 4 times stronger than the one of the IPM in LSS4)
- The design includes 2 MCP plates

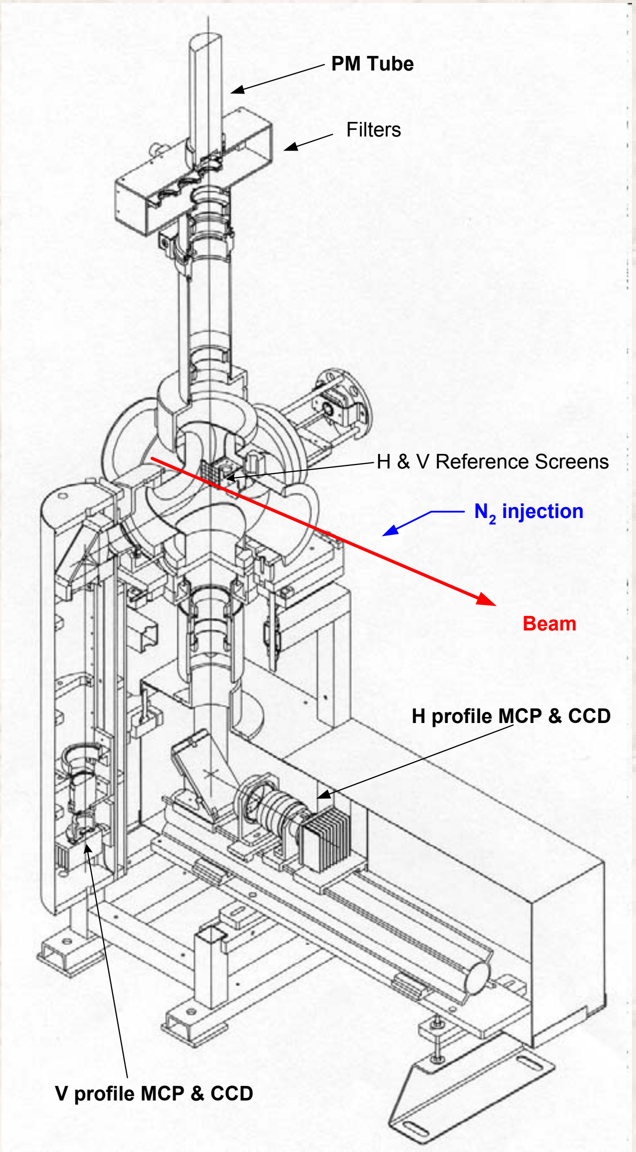
2002 Operation

- Only one MCP was available (the second was not provided by firm)
- Frequent HV perturbations appeared with the LHC beam
  - HV trips
- The gain was unstable (electron cloud?)
- Several tests have been performed, few profiles were recorded

2003 Planning

- The installation of the second MCP will enhance the signal amplification
- The HV electrodes have been NEG coated in order to reduce SEY

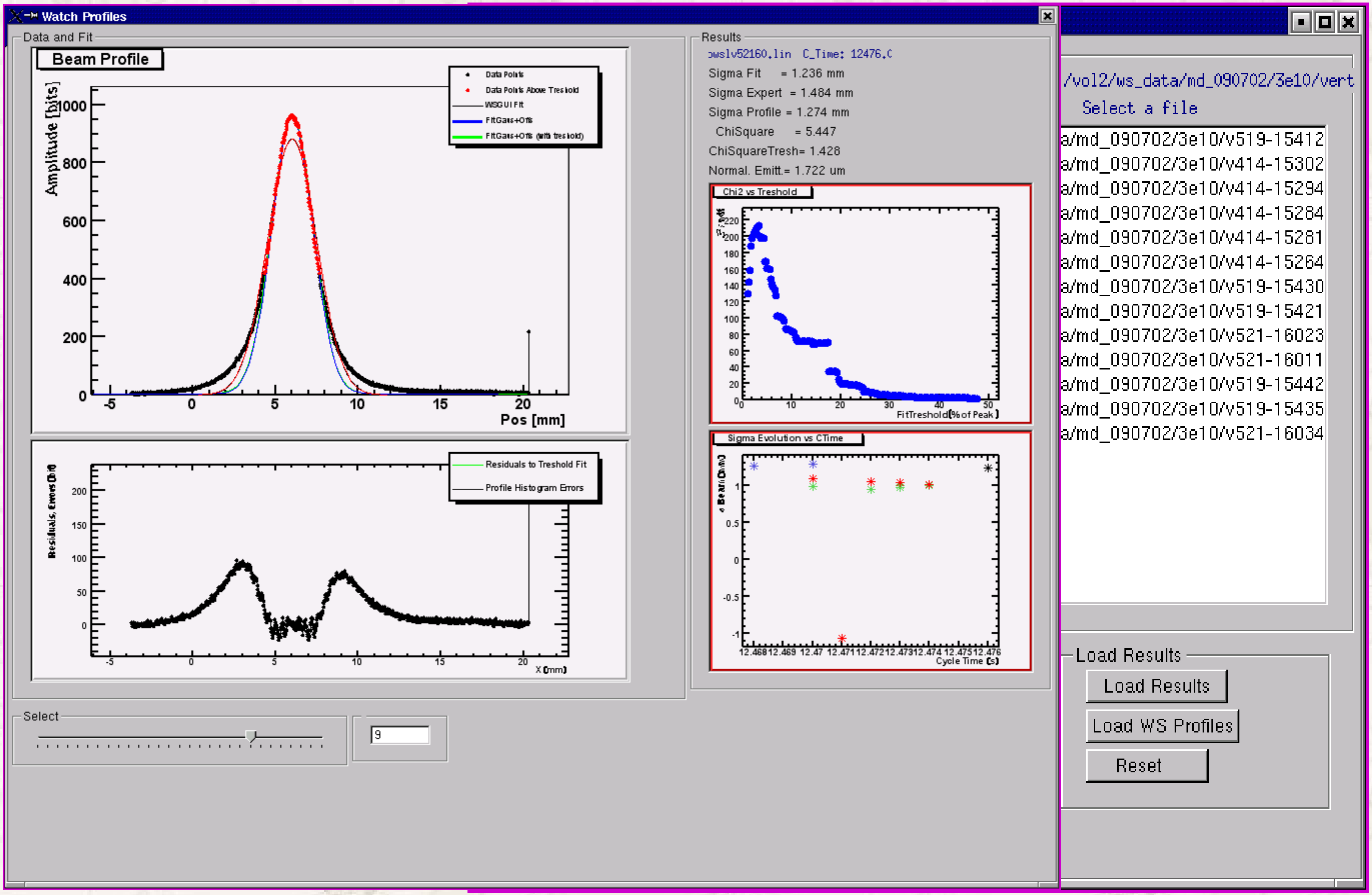
Luminescence Monitor



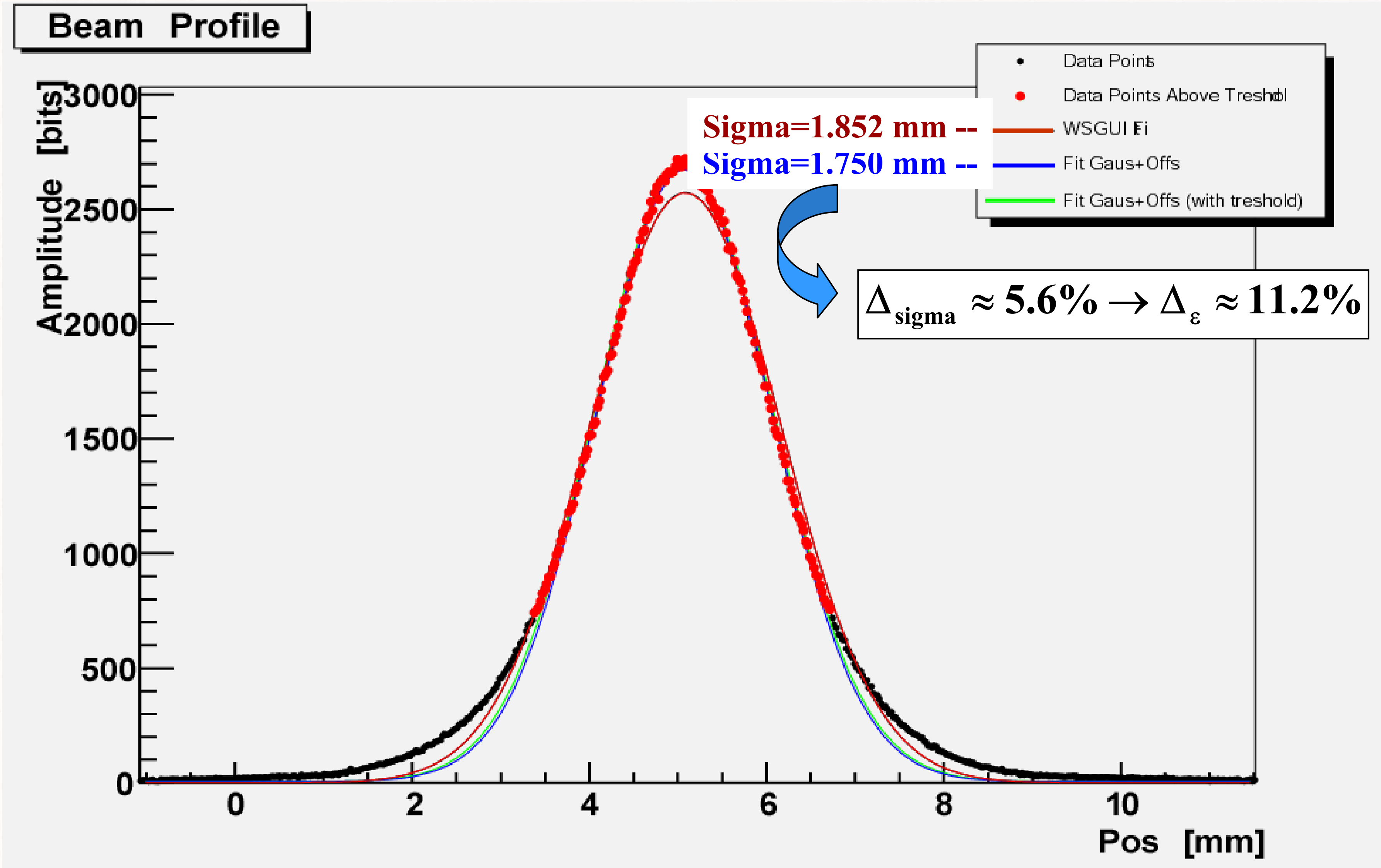
- It works with N_2 injection
- 1 light channel is going to a PM for gas-luminescence studies (decay time etc.)
- 2 channels are used for profile measurements:
  - The H channel is in air: it showed high background with LHC beam, due to beam losses
  - The V channel is in vacuum
- The MCP has a pre-programmed variable gain over cycle

  (it showed some problems to log on timing events)

Data Analysis



The Fitting Strategies

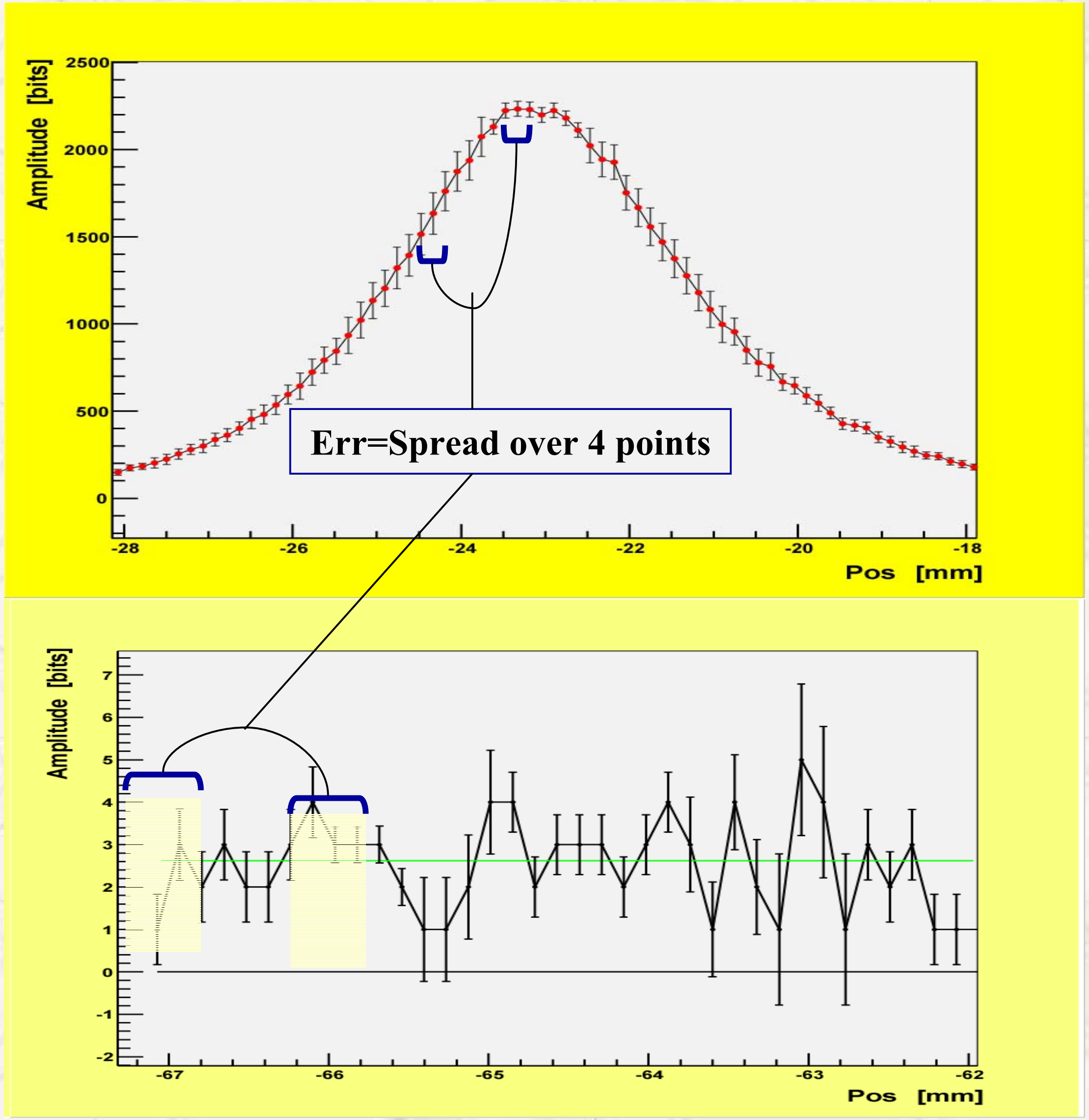


$$\Delta_{sigma} \approx 5.6\% \rightarrow \Delta_{\varepsilon} \approx 11.2\%$$

Assignment of Error Bars (I)

- The assignment of the uncertainty of each profile point is implemented in the ROOT based Graphical User Interface
- The error bars are computed from the spread of N consecutive point (default N = 4)
- The estimation is good outside the tails and on the peak (each of the 4 points is supposed to measure the same quantity)
- The uncertainty results over-estimated in the regions with slope

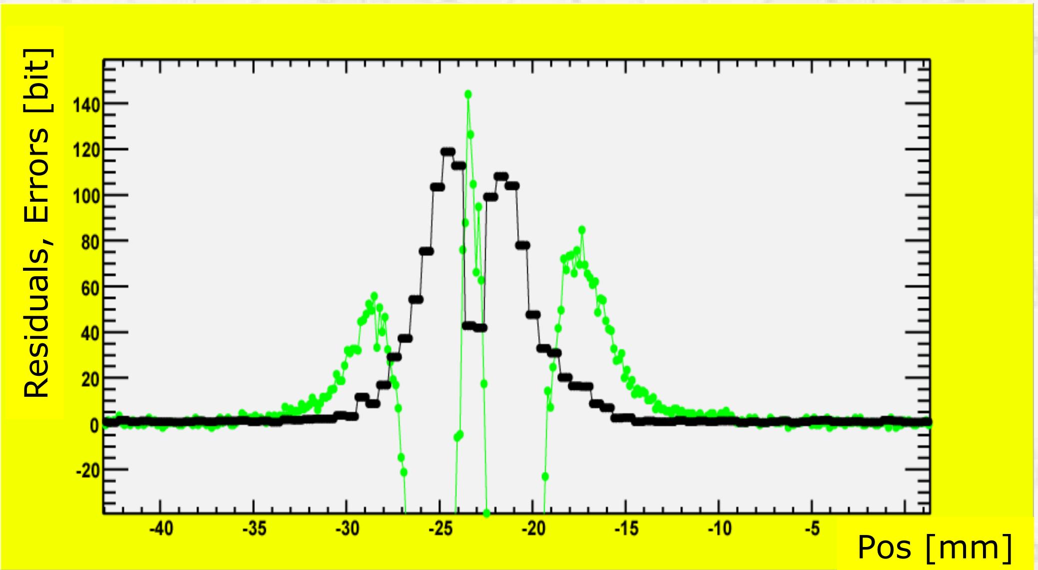
Assignment of Error Bars (II)



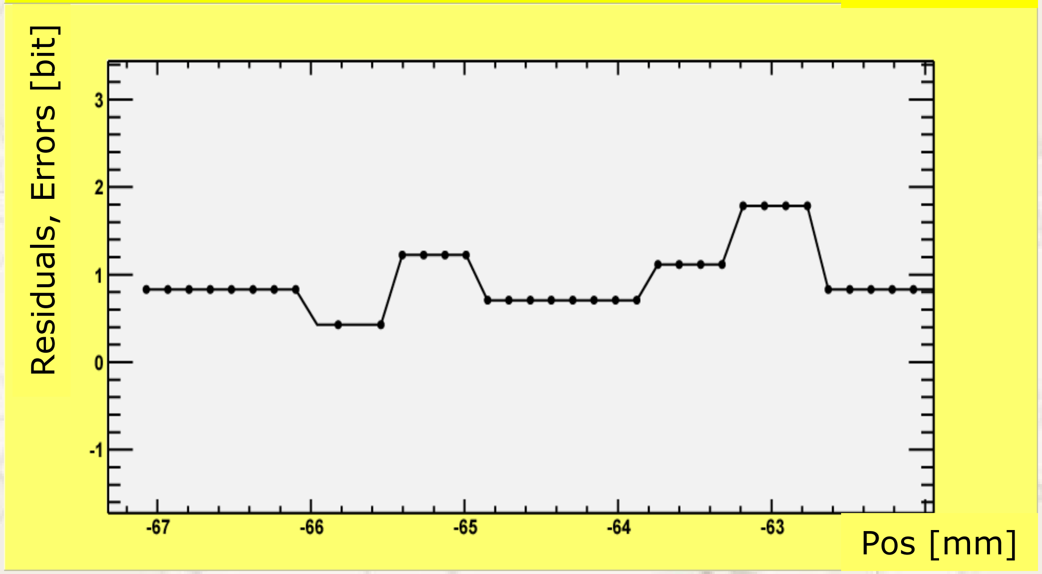
- **Zoom on the beam-core region**
- **Zoom on the beam-tail region**

Assignment of Error Bars (III)

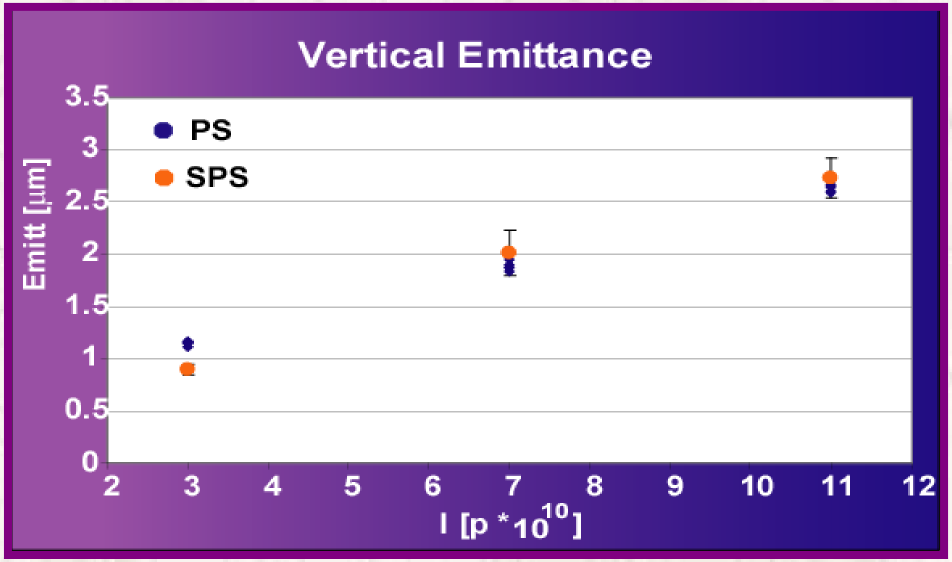
- Error distribution as function of position
- Green Line: residuals to fit



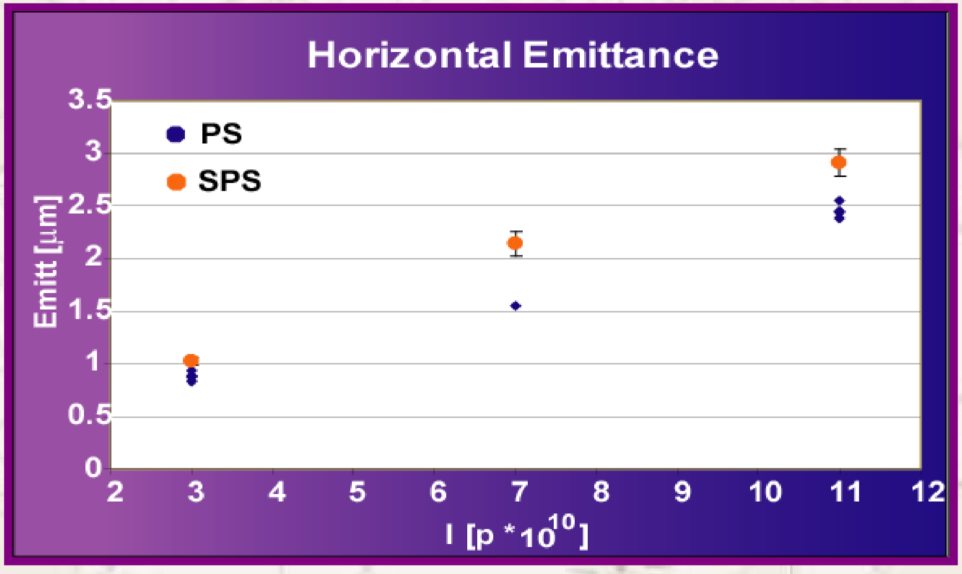
- Zoom on the beam-tail region



Example of PS-SPS comparison



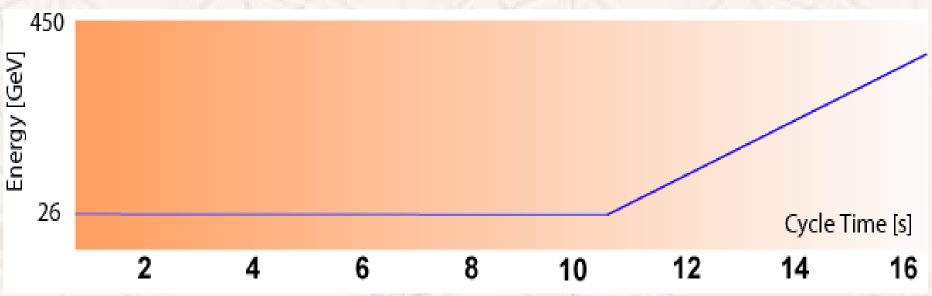
- PS-SPS Studies done on 09-07-2002
- The beam has been injected with 3 different proton intensities
- The SPS measurements were performed using 5 different FW



- For each beam intensity the dots are the average over all the scans and the error bars their spread
- It is not clear yet whether the differences come from:
  - instrument systematic
  - beam mismatching
- The Vertical Emittance at low intensity is likely wrong

IPM Results (I)

Emitt vs Time, Different MCP gains

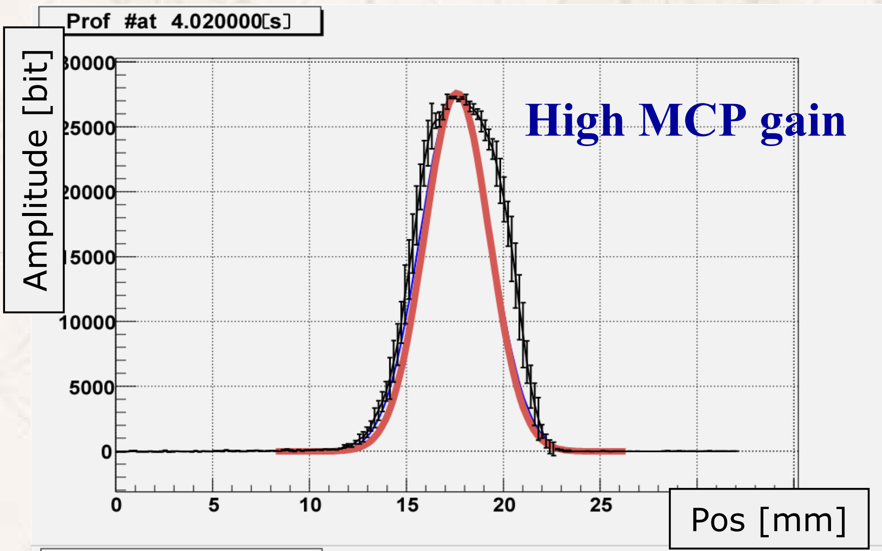


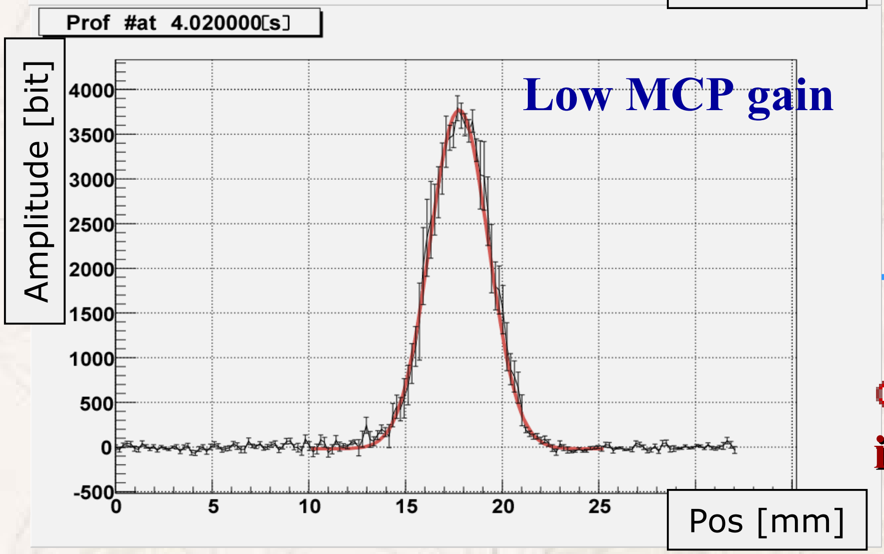
Results Example:

- These are two set of measurements with an LHC Beam of
  - 3 Batches
  - 72 bunches/batch
  - $1.1*10^{11}$ p/bunch

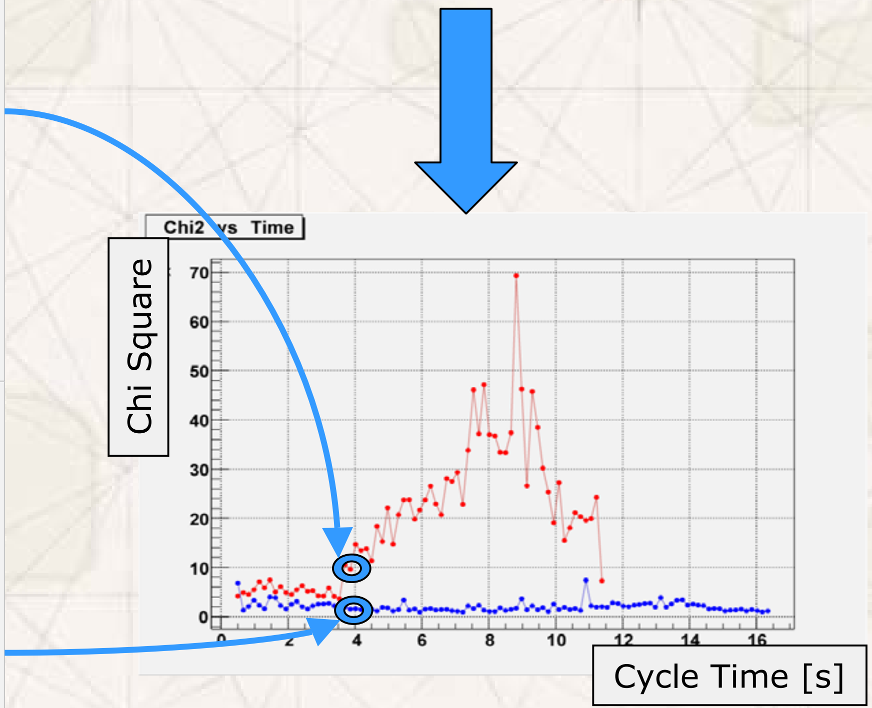
- Different MCP gains give different results
- IPM is likely saturating @ 12 s where the energy ramp has just begun

IPM Results (II)



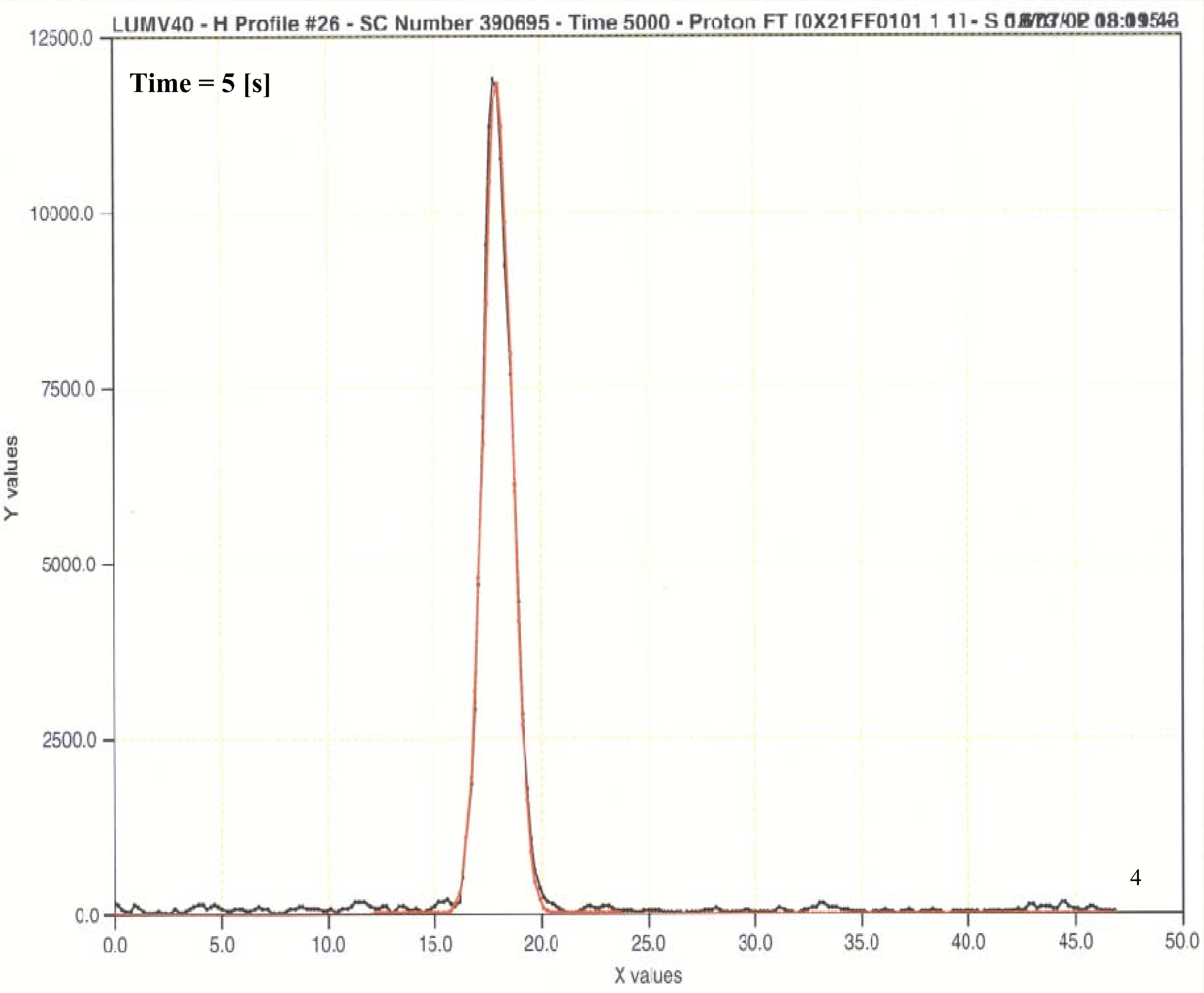


Errors = spread of 4 consecutive points (is important for the χ^2 computation)

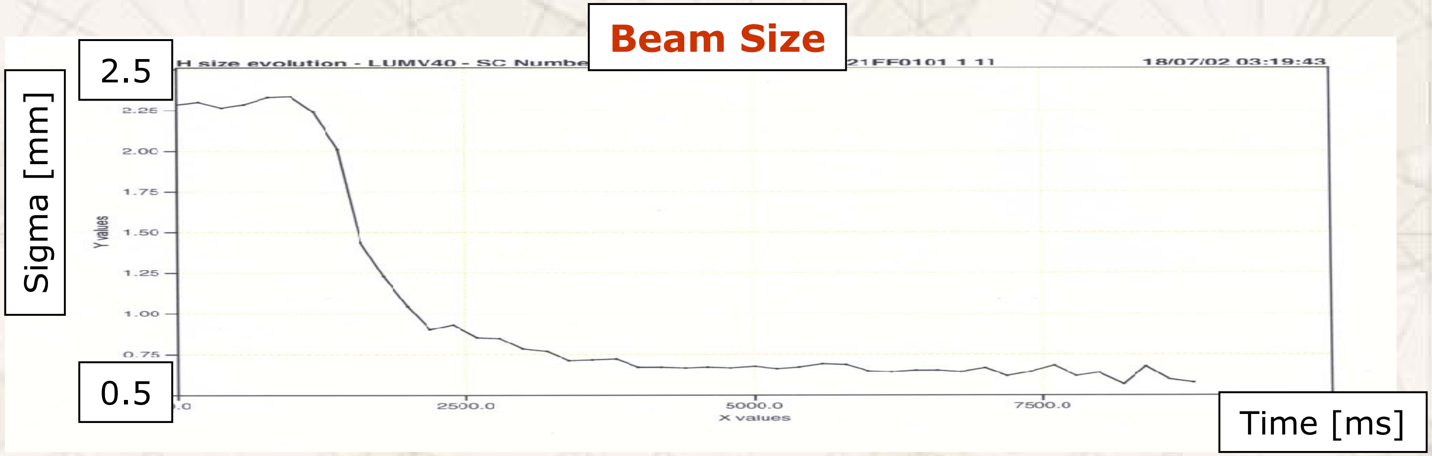


- **When Applying an high MCP gain there are indications of saturation**

Profiles from the Luminescence Monitor



Parameters From Luminescence



- These measurements were done on the SPS fix target beam
- The integral signal indicates the efficiency of the MCP pre-programmed gain

Wire Breaking (I)

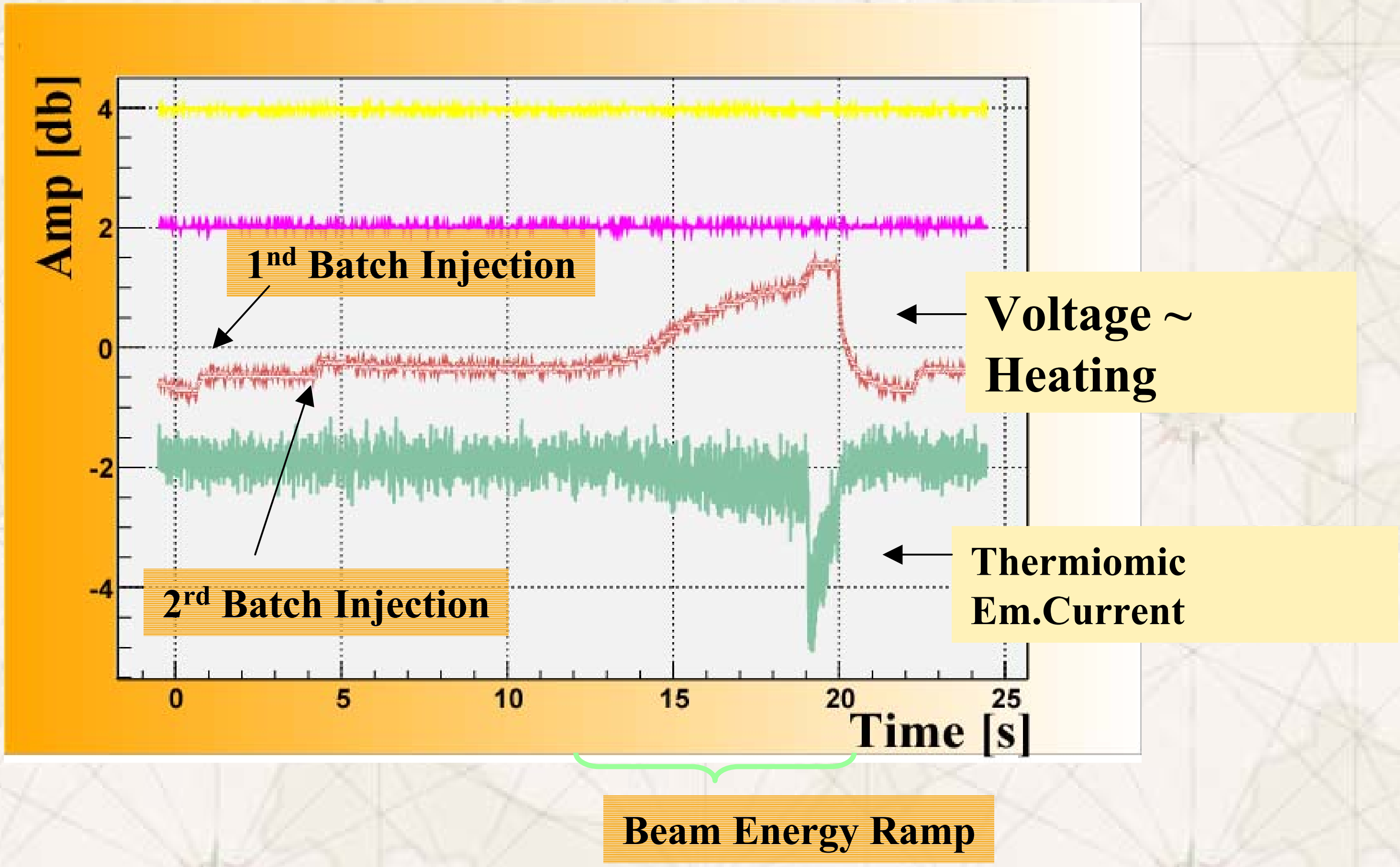
- **All rotational WS wires broke during two periods of measurements (Sept 26th , Oct 20th)**
- **The LHC beam had the following characteristics:**

From 1 to 4	Batches
From 12 to 72	Bunches/Batch
From $3 \cdot 10^{10}$ to $1.1 \cdot 10^{11}$	p/bunch
From 4 to 1.5 ns (4 sigmas)	bunch length
25 ns	bunch spacing

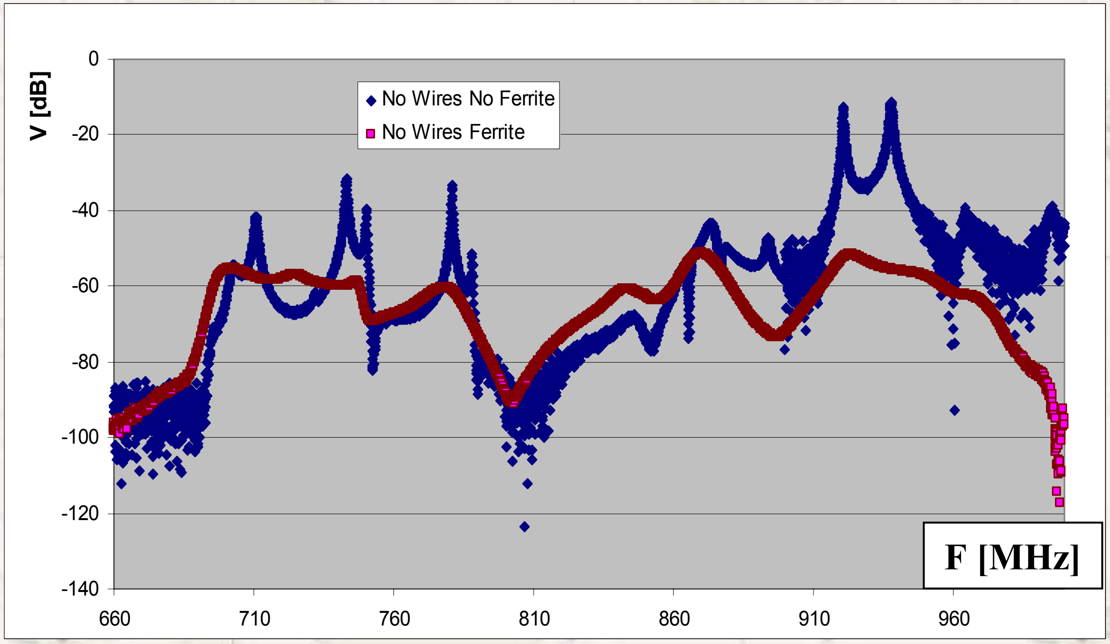
- **The injection of 2 Batches at full intensity was enough to break the wires in the parking position**
- **The bunch length was pushed to the nominal value for the first time**
- **The bunch length and the spacing give the characteristic beam spectrum**

Wire breaking (II)

- **These measurements are done on a rotational wire in the parking position**



RF Coupling Studies

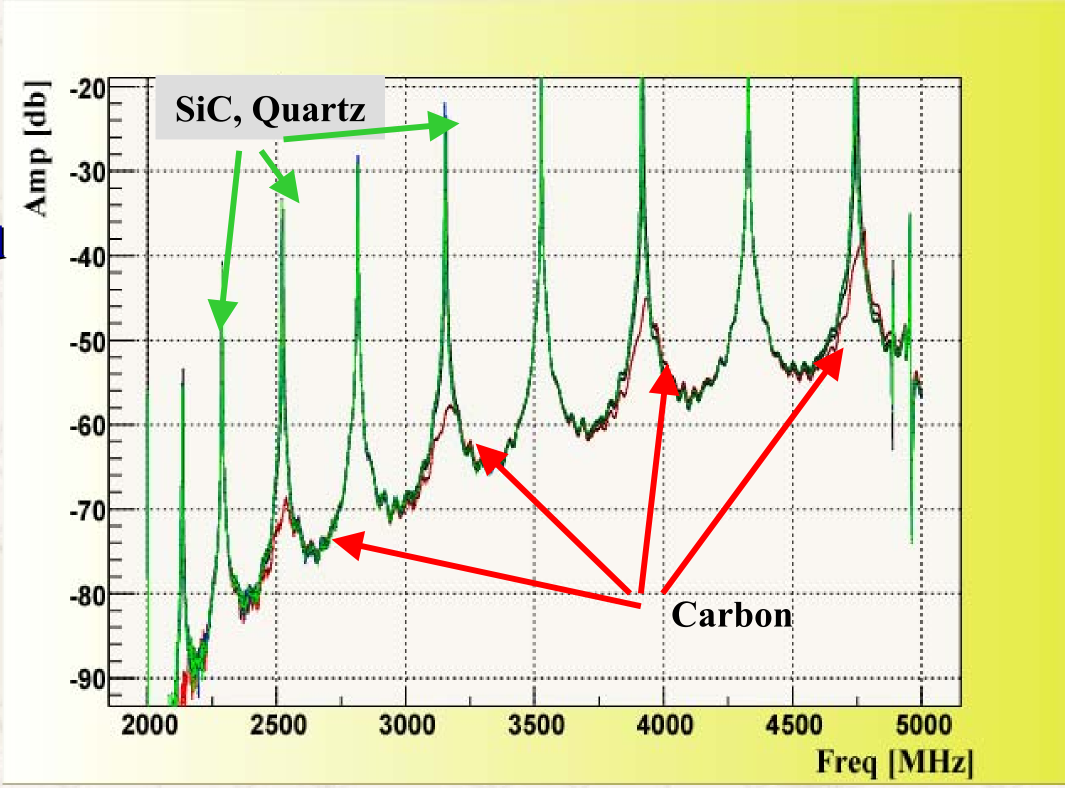


- **Plot from laboratory measurements dedicated to simulate the RF mode coupling between the beam and the wire**
- **The insertion of ferrite tiles insures mode dumping**

Ferrite:
- Lower Q – Lower RF power
- Absorption

Wire Material Studies

- Classical cavity modes technique
- TE01N rectangular resonator (from F.Caspers)
- Wire of different materials inserted
  - Carbon
  - Silicon Carbide (SiC)
  - Quartz
- C has been used in SPS WS until now
- SiC and Quartz fibers used in LEP
- SiC used as RF absorber (i.e. CLIC, fiber composition different from LEP one)



- **Results:**
- C proves to be an excellent absorber
- SiC & Quartz not
- SiC & Quartz drawbacks:
- High resistivity

Possible problems due to static charges
Wire integrity check & S.E. detection not available

Conclusions and Planning (IPM)

- The 2002 SPS confirmed that the IPM monitors are suitable for continuous emittance measurements in almost all the LHC beam conditions

- They need a more systematic calibration and the problems with unstable gain have to be understood

- A second MCP will be installed in the new IPM, providing an enhanced signal
- The automatic setting of the instrument gain, over the energy ramp, will control saturation problems

- One IPM has been also coated in order to reduce the secondary emission yield of the electrodes material and thus face the possible formation of the e-cloud
- In this monitor we will also try gas injection to further improve the signal and go for bunch-to-bunch measurements

Conclusions and Planning (FW)

- The Flying Wires proved to be the only available instrument for an absolute calibration of the whole emittance monitoring system
- They are constantly used by beam instrumentation experts and by the machine operators during the LHC beam setup and tuning in the SPS

- All the rotational wires broke in the second part of the 2002 run

- The 2003 hardware modifications
  - Ferrite tiles to dump the RF modes
  - Installation of SiC wires on test instruments

should protect the wires from the RF heating

Conclusions and Planning (Data Analysis)

- The presented off-line analysis is investigating the beam-related and the instrument-related emittances uncertainty
- Preliminary results demand attention on the fitting strategies and error assignment

- A detailed error propagation analysis for each monitor type could help in understanding and correcting systematic errors
- The 2003 SPS run will be dedicated to repeated measurements under different beam conditions
- The aim is to organize the measurements in order to synchronize the emittance monitoring with all the available instruments, including the Luminescence and Synchrotron Light monitors

References

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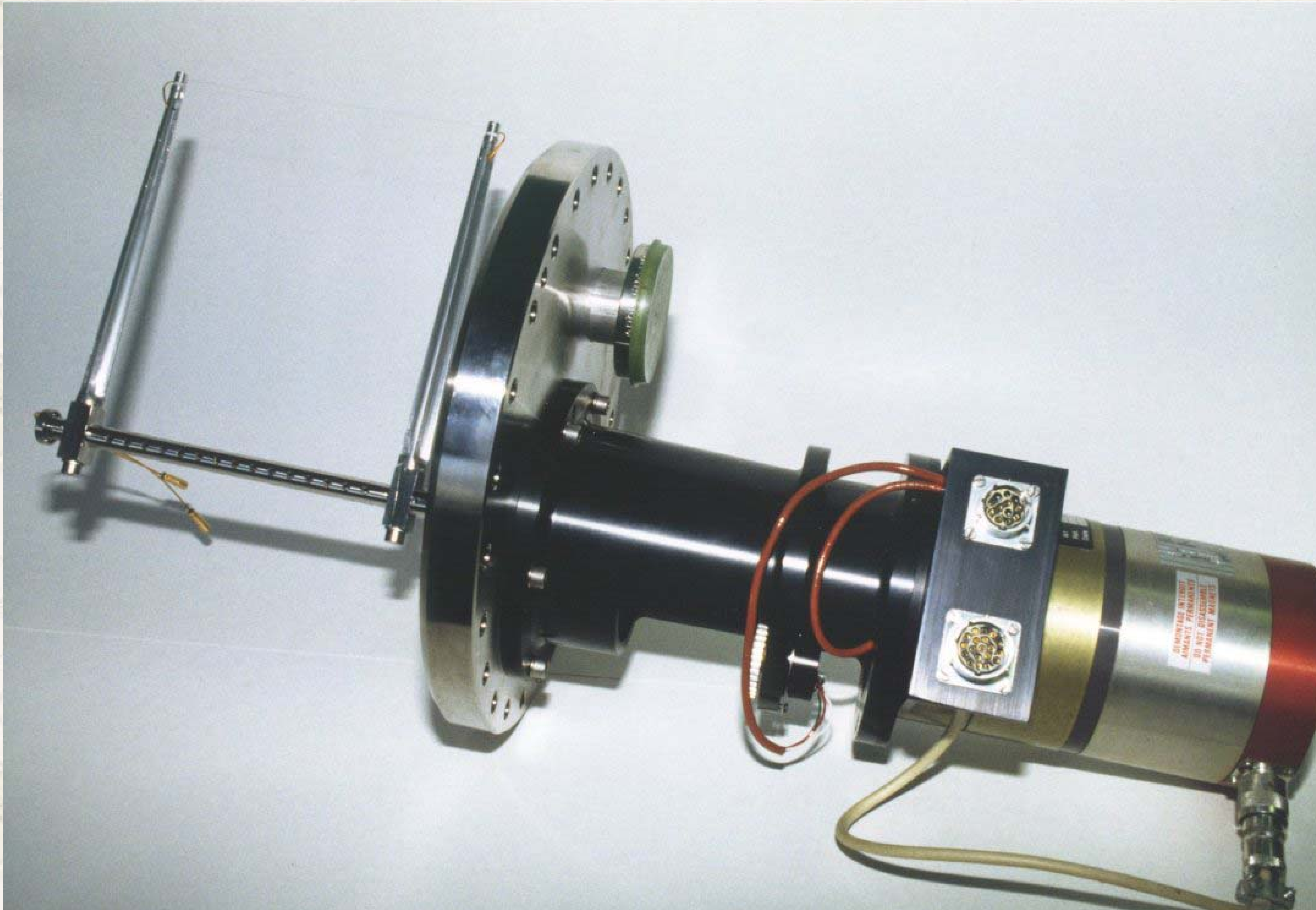
- **C.Fischer and J.Koopman,** *"Measurements made in the SPS with a rest gas profile monitor by collecting electrons"* **, CERN-SL-2000-053-BI (2000)**
- **G.Burtin et al.** *"The luminescence profile monitor of the CERN SPS"*, **CERN-SL-2000-031-BI (2000)**
- **F.Roncarolo et al.** *"Cavity mode related wire breaking of the SPS wire scanners and loss measurements of wire materials"*, **Proceedings of PAC2003**

- **Measurement of the Beam Transverse Distribution in the LHC Rings @**
  http://edms.cern.ch/document/328147

- **LHC Ring Instrumentation @**
  http://sl-div-bi.web.cern.ch/sl-div-bi/LHC/ParamAndLayouts/Doc/FuncSpec.htm
- **LHC beam parameters @**
  http://slap.web.cern.ch/slap/parameters_side.html

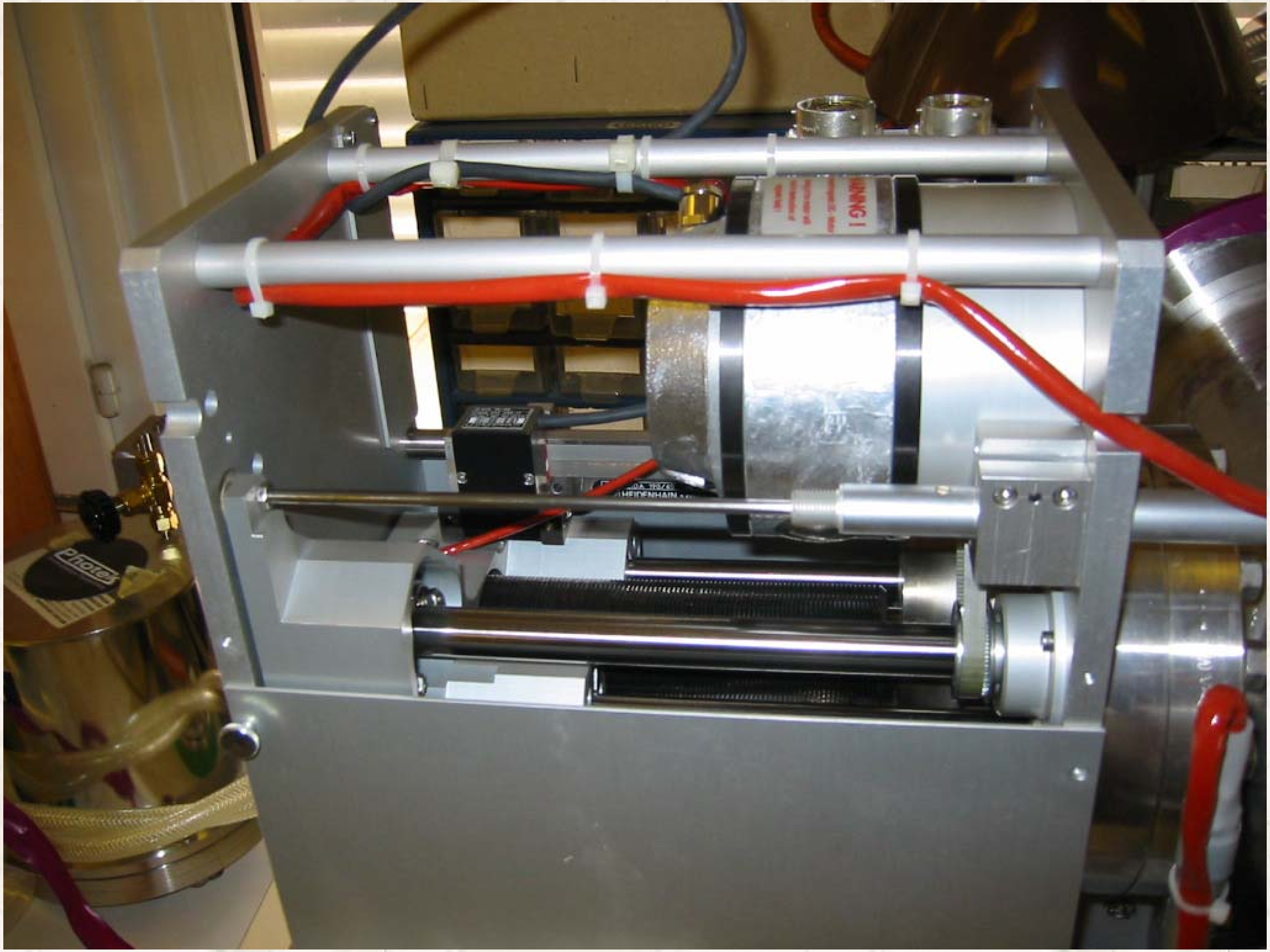
Rotational FW Tank

Rotational FW Fork (1)



Rotational FW Fork (2)

Linear FW Motor

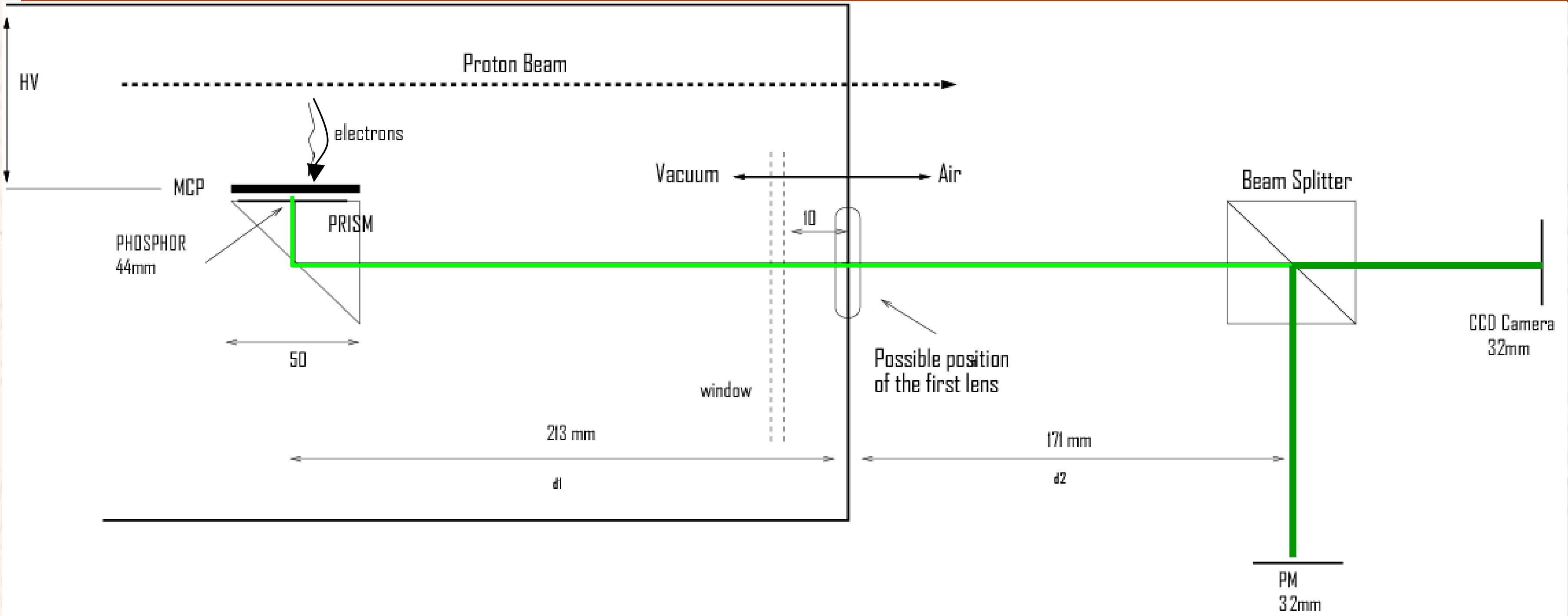


Linear FW Wire

IPM Installed in SPS LSS4

IPM installed in LSS5

IPM Layout



- The whole tank is in between the dipole magnet poles
- Two light channels
  - IPM
  - Luminescense (not drawn)
- IPM light is split to
  - CCD Camera
  - Photo Tube

IPM inside