

# Observations of the Electron Cloud effects at the CERN SPS

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**Acknowledgements: T. Bohl, K. Cornelis, G. Ferioli, O. Gröbner, W. Höfle, H. Jakob, L. Jensen, J.M. Jimenez, T. Linnecar, R. Louwarse, J.F. Malo, G. Moulard, M. Pivi, F. Ruggiero, J. Tuckmantel, K. Weiss, F. Zimmermann**

# Observations of the Electron Cloud effects at the CERN SPS

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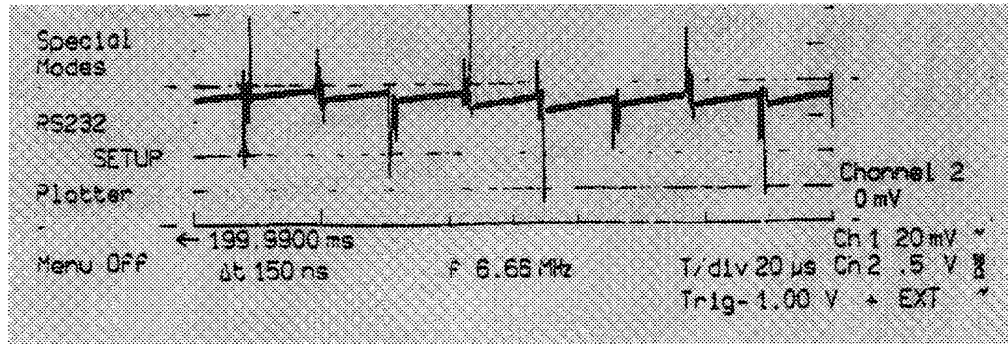
- Effects on pick-up signals
- Effects on vacuum
- Beam observations
- Summary

# The LHC beam in the SPS

- Injection energy: 26 GeV
- N. bunches: 81
- Bunch spacing: 25 ns
- Bunch length: 4 ns
- $I_{\text{bunch}}: 1.1 \times 10^{11} \text{ p}; I_{\text{batch}} \sim 9 \times 10^{12} \text{ p}$
- $\epsilon_{H,V}^* (\text{rms}) = 3 \mu\text{m}$
- $\epsilon_L^* (2\sigma) = 0.35 \text{ eV}\cdot\text{s}$

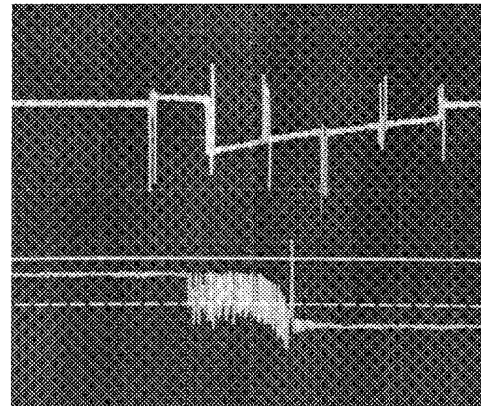
Electron cloud effect on pick-up signals

First observations



01.09.98  
2-3  $10^{12}$  protons/batch  
LHC beam  
25 ns bunch spacing

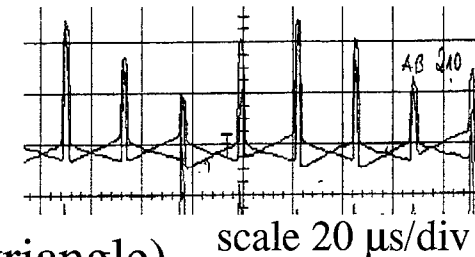
Observation:  
Baseline drifts on  
pick-up signals  
during the passage  
of an LHC batch  
What is going on?



14.06.99  
2-3  $10^{12}$  protons/batch  
LHC beam  
25 ns bunch spacing  
Top trace: 20 μs/div  
Bottom trace: 1 μs/div

## Estimation of number of electrons captured during single batch passage

Example: horizontal pick-up 2.10 on 22.07.99



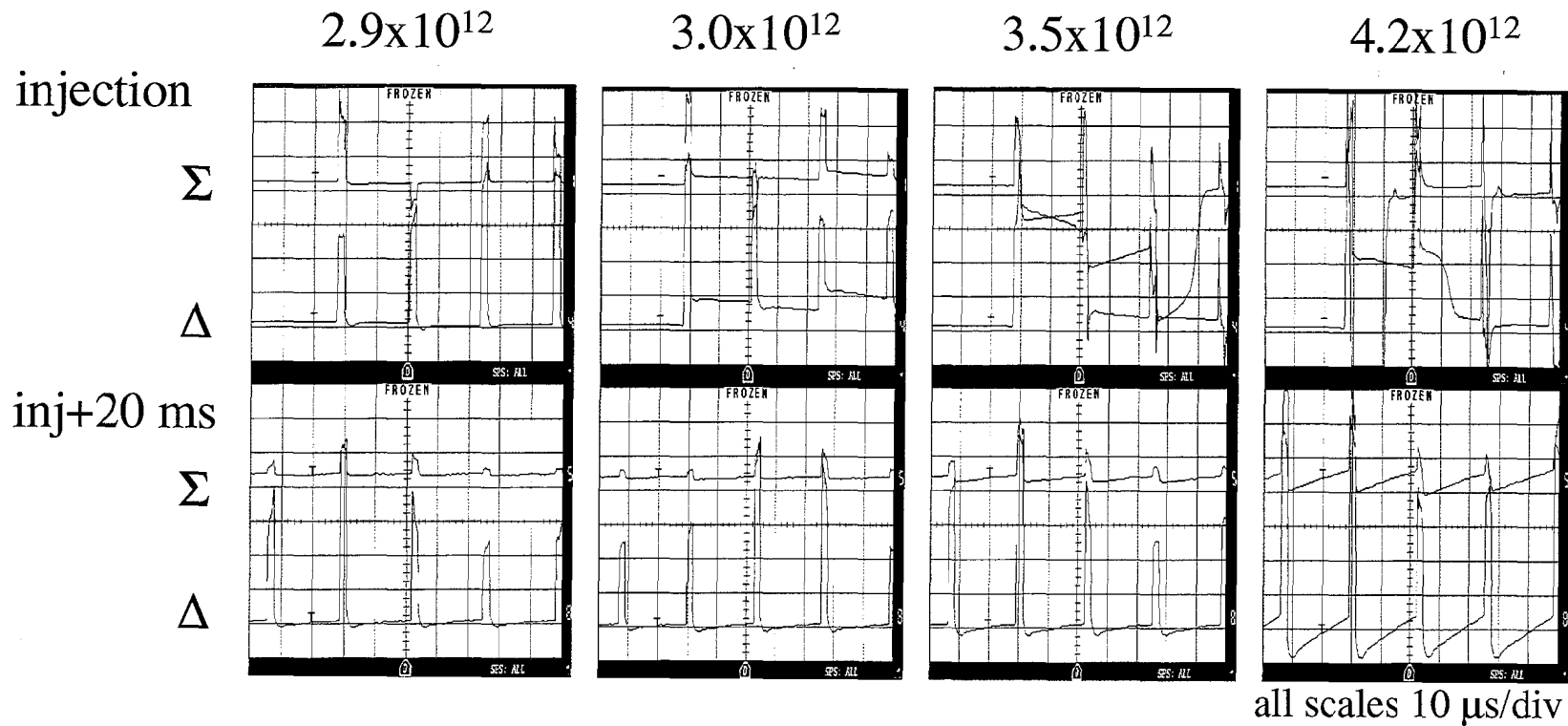
pick-up dimensions:	125x150 mm (triangle)
pick-up area (one triangle!):	$9.4 \times 10^{-3} \text{ m}^2$
beam intensity:	$4 \times 10^{12}$ protons in one LHC batch
observation time in cycle:	3 ms after inj, beam stable & centered
electron cloud effect starts:	after approximately 30 bunches
total charges collected / batch:	$4 - 6 \times 10^8$
charges per bunch and $\text{m}^2$ wall:	about $10^9$

## Correlation with machine state and beam parameters

- the effect is very violent at injection,  
and also when the beam is transversely oscillating (e.g. kicked)
- it is very regular (turn by turn) when the beam is not oscillating
- no correlation with beam losses at the pick-ups were observed
- no correlation with the orbit was seen
- there was no correlation with the presence of lepton beams  
on the SPS lepton cycle within the super-cycle
- the threshold intensity decreased during the summer 1999
- the threshold intensity increased (went back to the original state  
of the beginning of the 1999 run) during the ion run (autumn 99)

### Threshold intensity

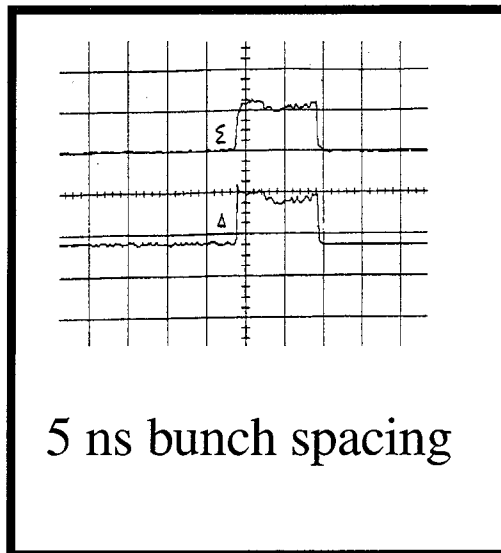
Example pick-up 2.14 (horizontal) 09.10.99



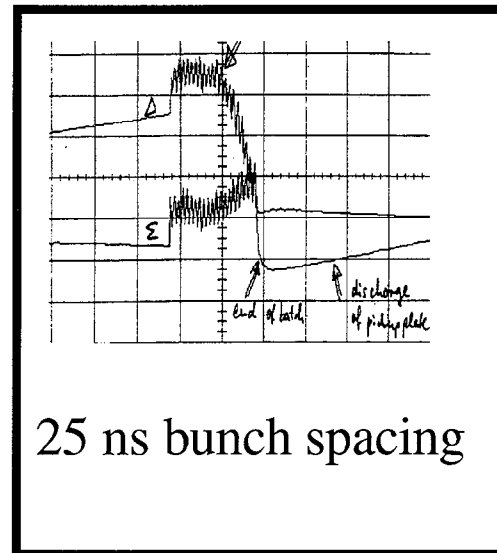
## Different bunch spacings

at the same average beam current/batch

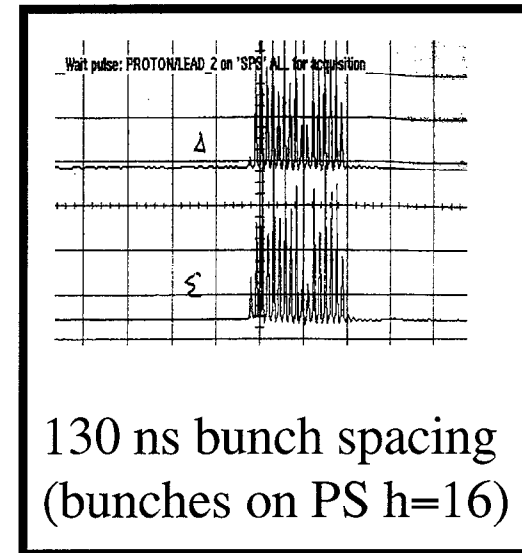
clean signals for  
5 ns bunch spacing  
( $10^{10}$  protons per bunch)



Electron cloud effect  
for 25 ns bunch spacing  
( $5 \times 10^{10}$  protons per bunch)



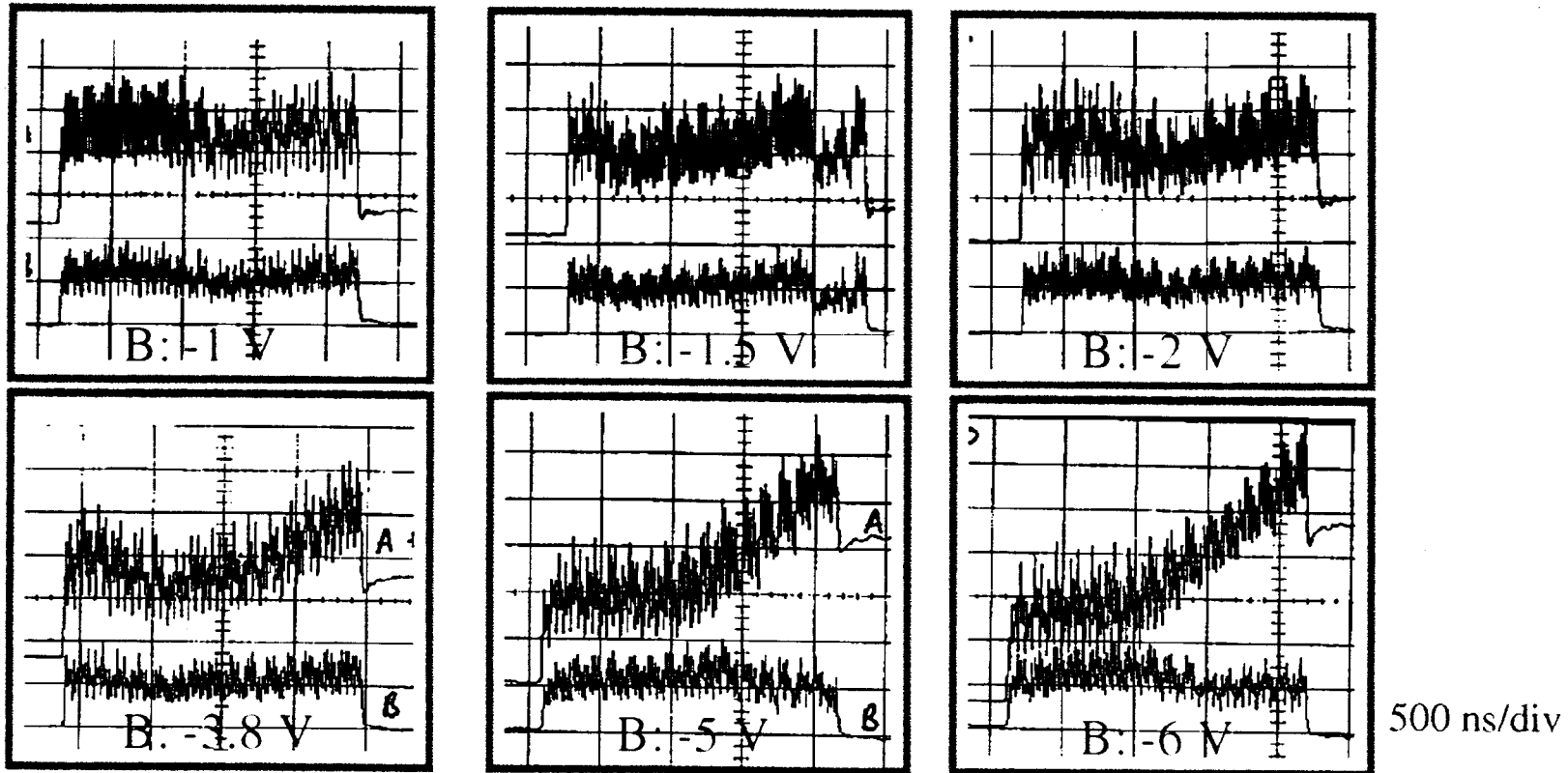
no effect for  
130 ns bunch spacing  
( $25 \times 10^{10}$  protons per  
bunch - long bunch)





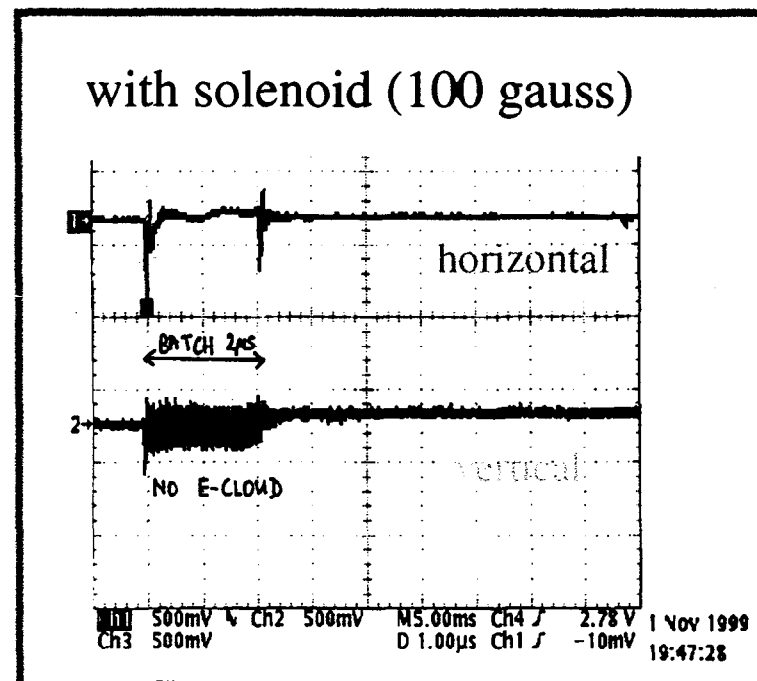
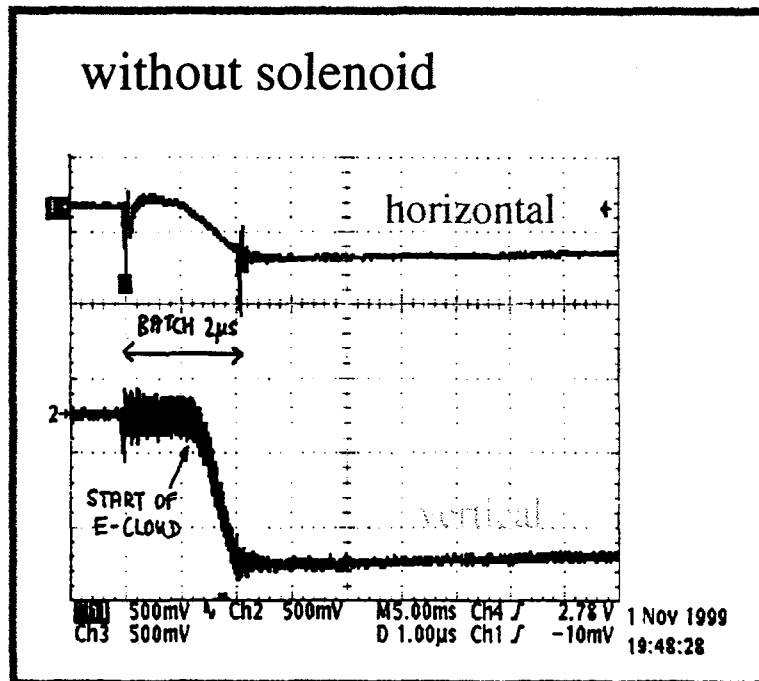
### Influence of electrode bias

top trace: signal on A electrode with +1 V of bias to ground  
bottom trace: signal on B electrode with varying bias to ground



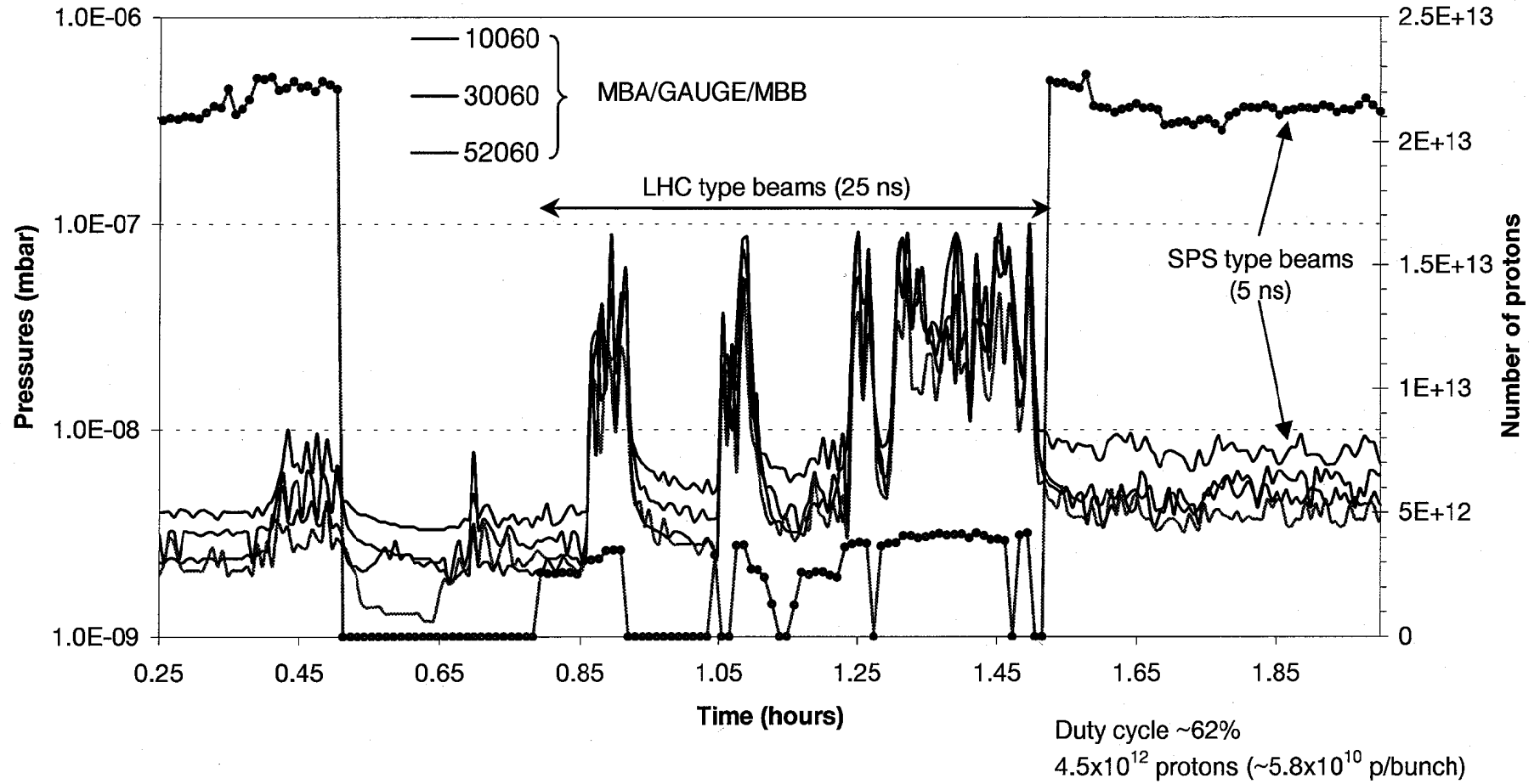
## Magnetic solenoid field - a solution?

The resonant build-up of the electron generation can be disrupted by applying a magnetic solenoid field



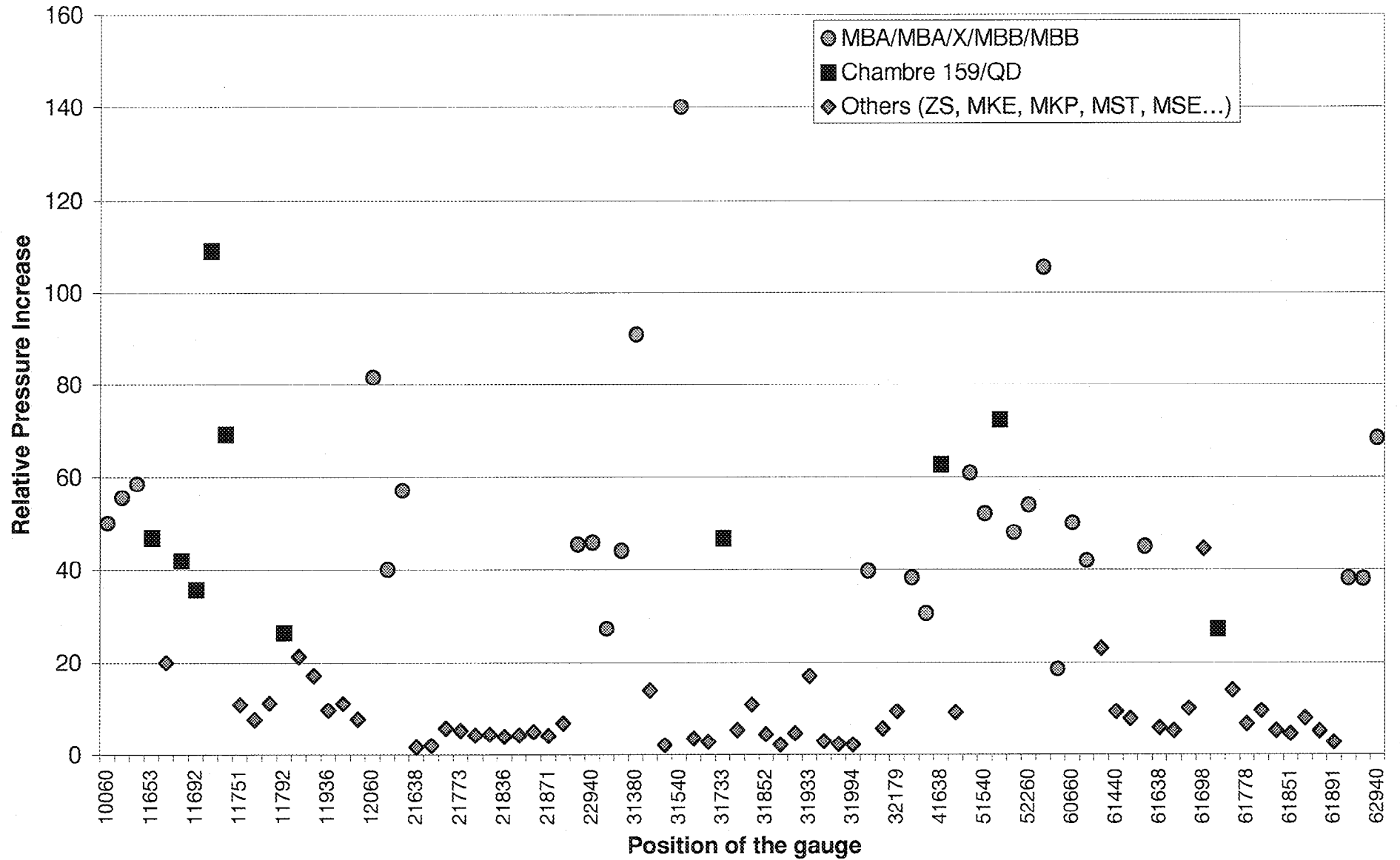
scales 1 µs/div

**- LHC type Beams -**  
**Pressure Increase versus time (26/08/99)**



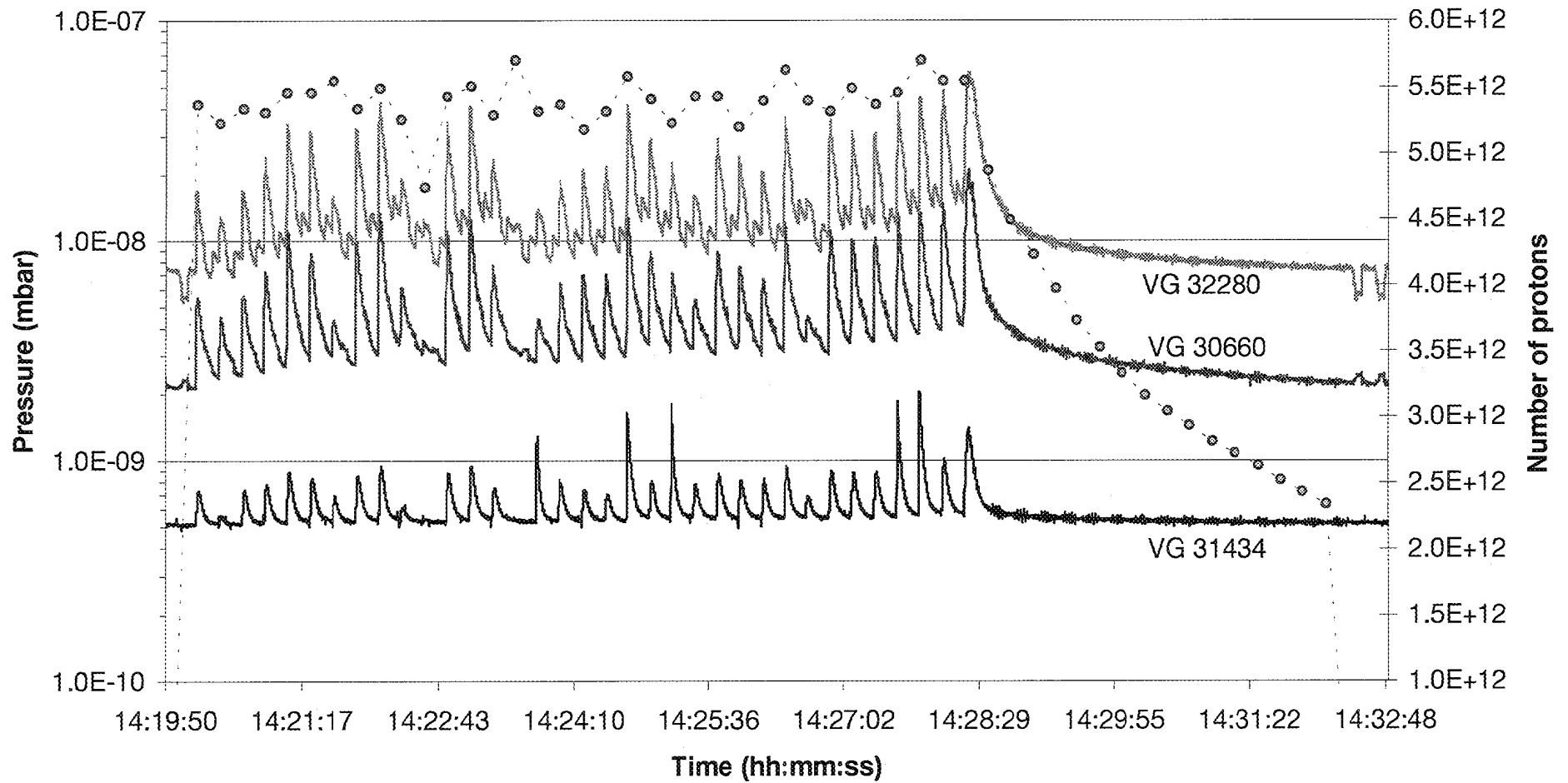
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## Relative Pressure Increase versus Position and Vacuum Shape

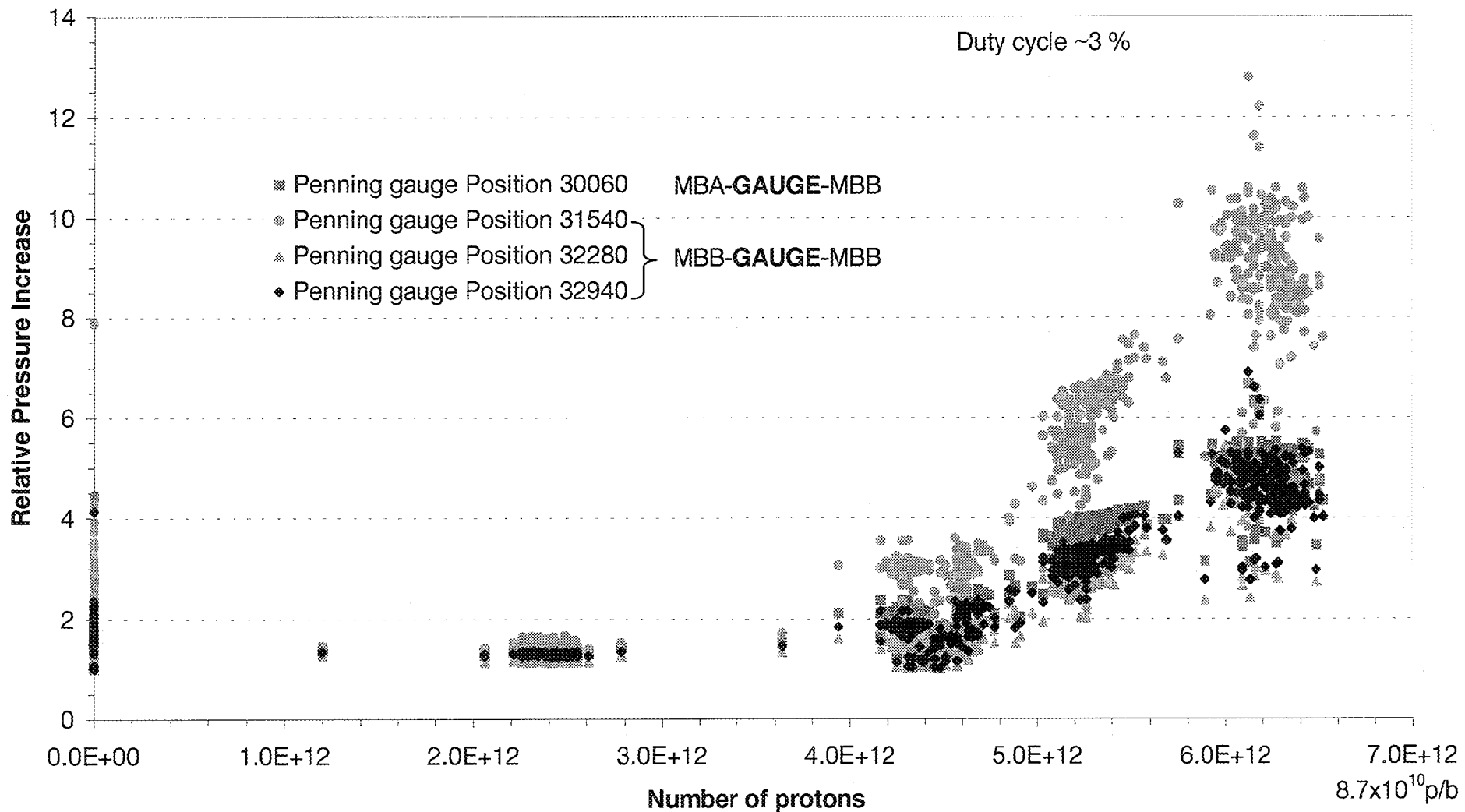


- LHC type Beams -  
Pressure Increase versus time (06/10/99)

Duty cycle ~ 4 %



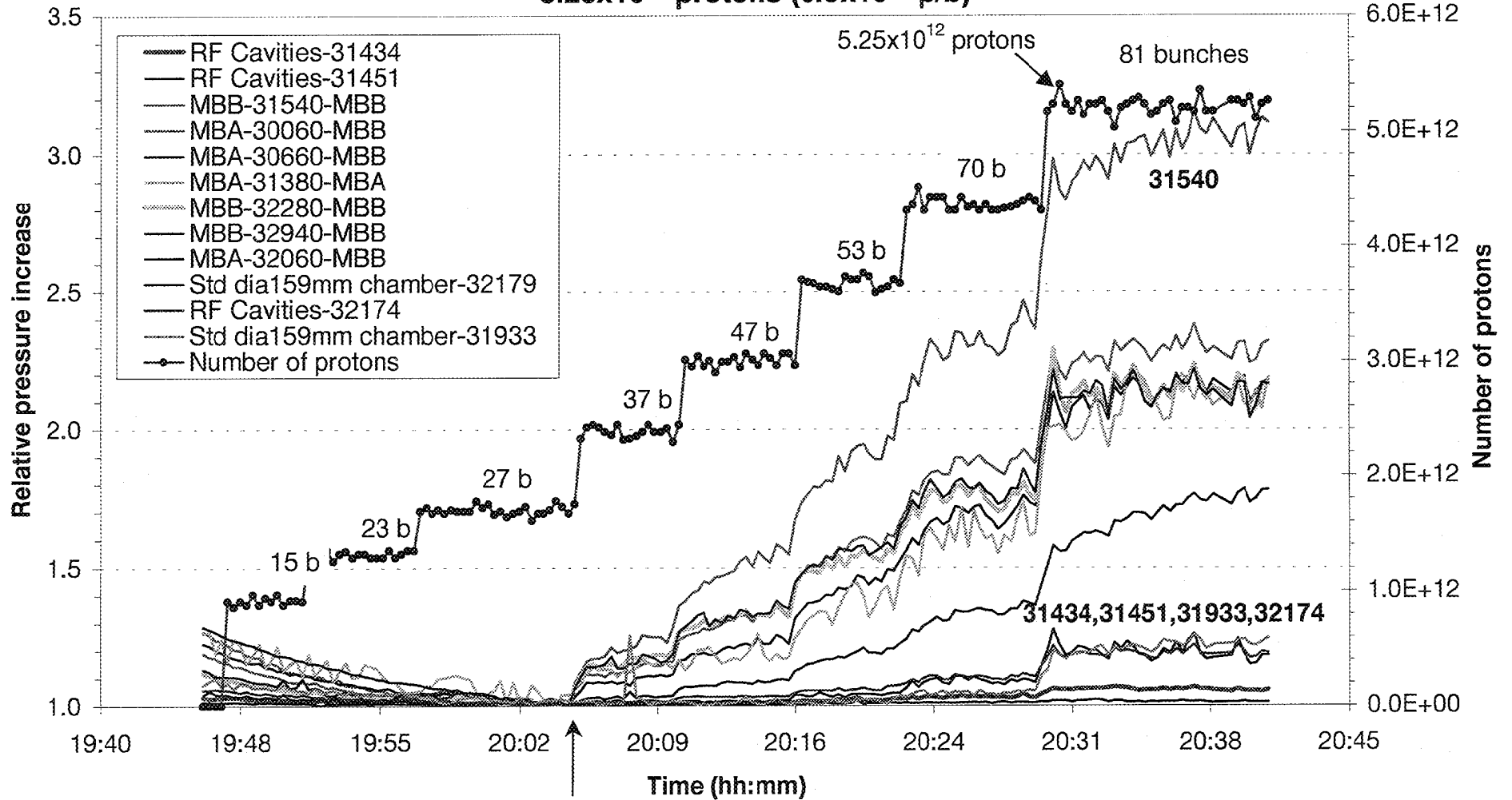
**- LHC Type Beams -**  
**Relative Pressure Increase versus Total Number of Protons**



# Pressure increase versus Batch Length

Duty cycle ~ 3 %

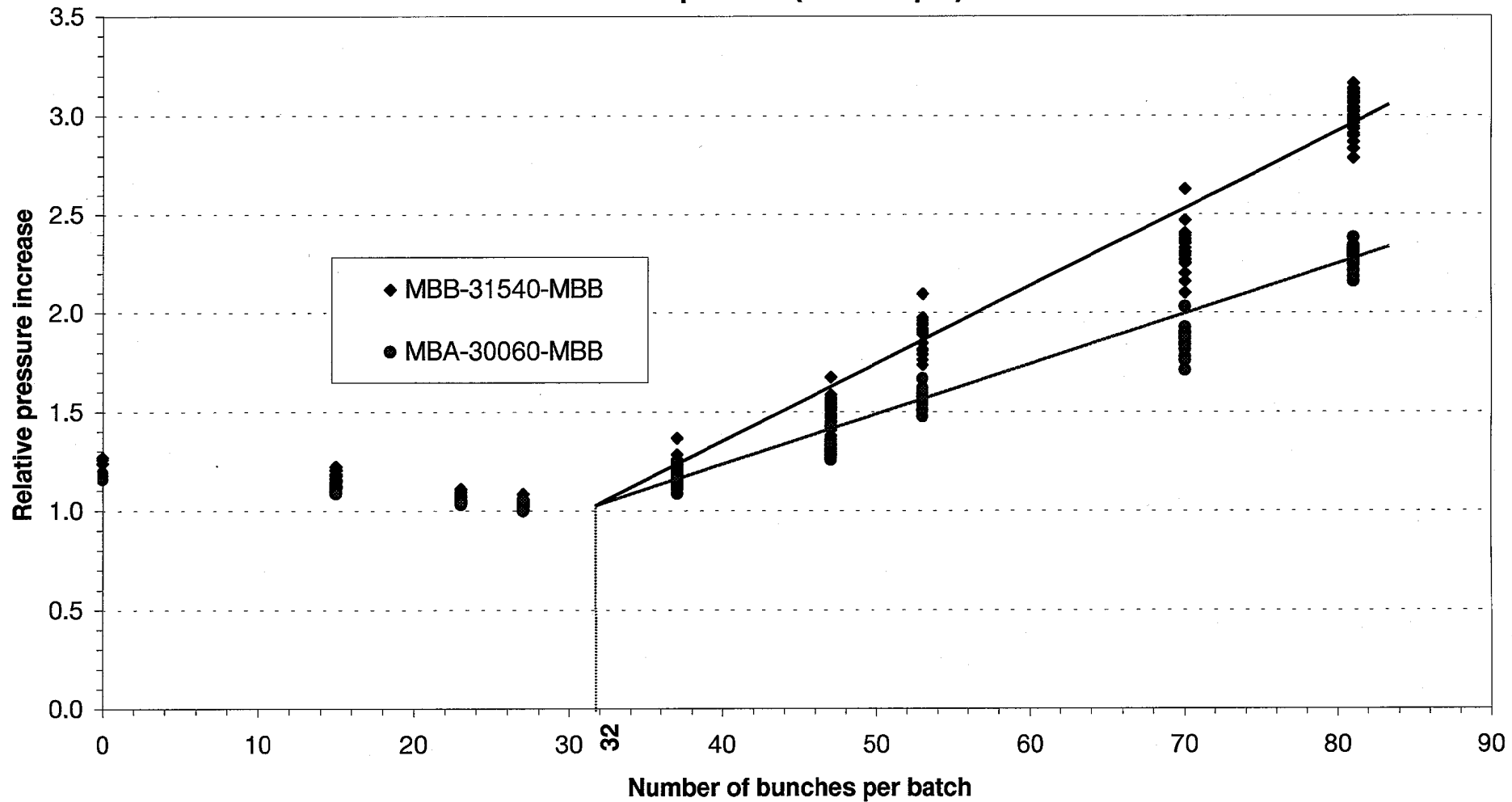
$5.25 \times 10^{12}$  protons ( $6.5 \times 10^{10}$  p/b)



# Pressure increase versus Batch Length

Duty cycle ~ 3 %

$5.25 \times 10^{12}$  protons ( $6.5 \times 10^{10}$  p/b)

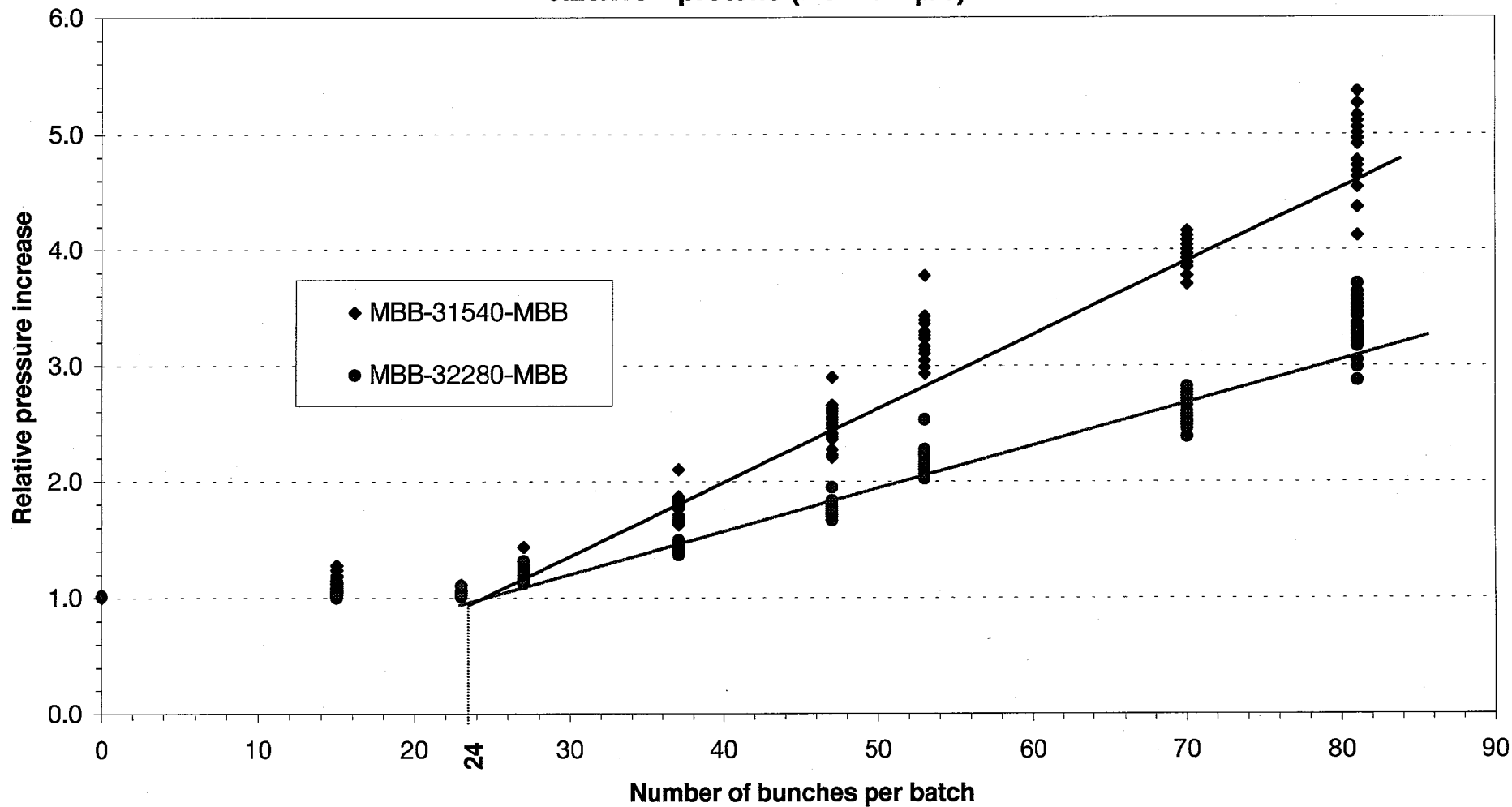




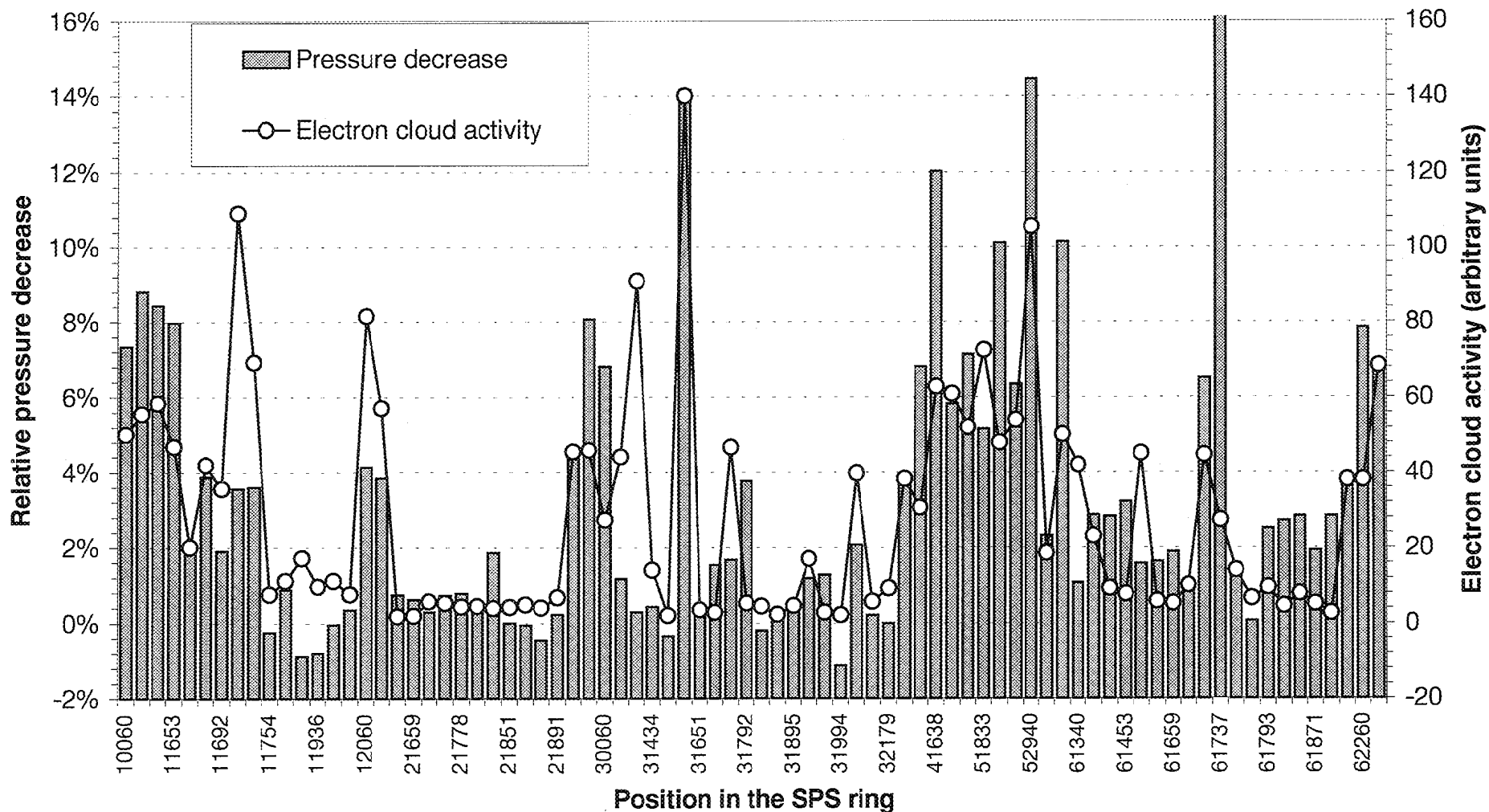
# Pressure increase versus Batch Length

Duty cycle ~ 3 %

$6.25 \times 10^{12}$  protons ( $7.5 \times 10^{10}$  p/b)



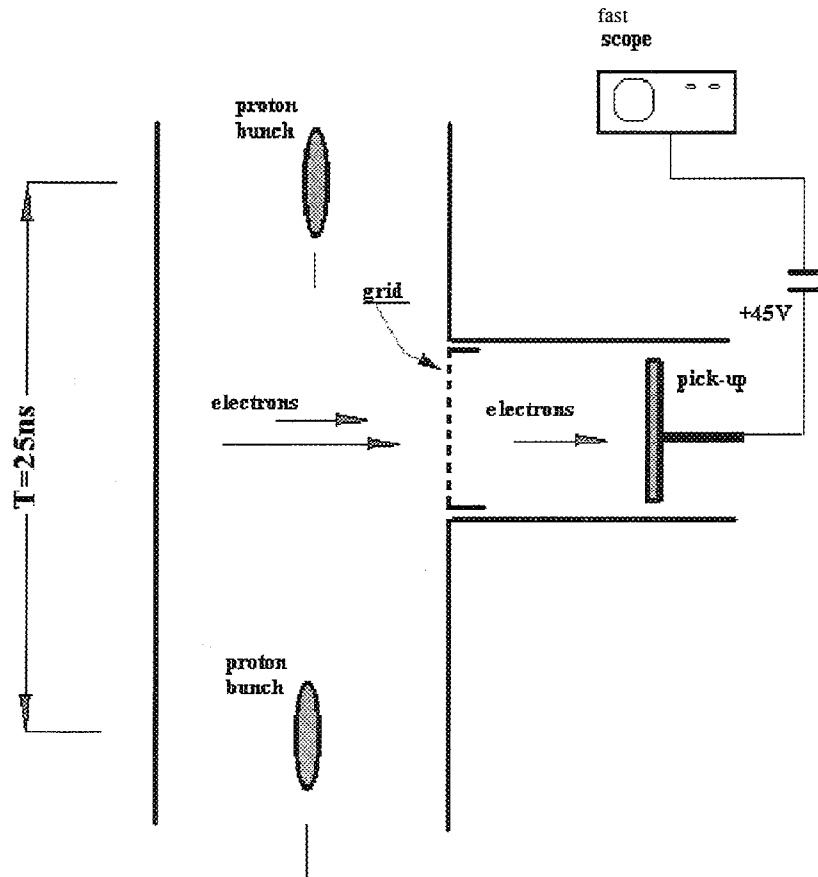
## Cleaning effect after 14 h @ $4.5 \times 10^{12}$ protons



# - LHC TYPE BEAMS -

## Pick-up Set-up

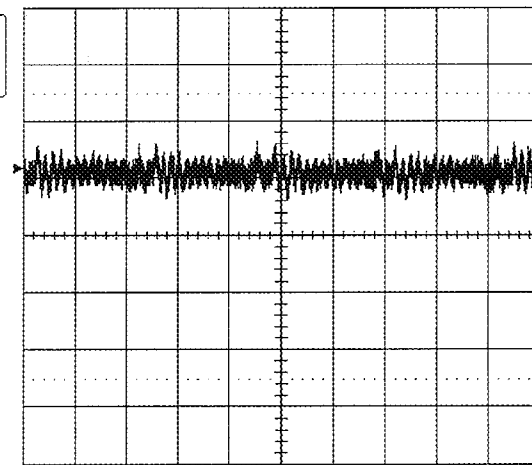
### Experimental set-up



20-Nov-99  
16:05:49

10  $\mu s$   
2.00 mV

10  $\mu s$   
1 2 mV 500  
2 50 mV 500  
3 50 mV 500  
4 1 V 500



TRIGGER SETUP

EDGE SMART

trigger on  
1 2 3 4 Ext  
Ext5 Line

coupling 1  
AC LFREJ  
HFREJ HF

slope 1  
Neg  
Window

holdoff  
Time Evts

500 MS/s

1 DC 0.36 mV

STOPPED

Horizontal scale : 10  $\mu s$ /div  
Vertical scale : 2 mV/div  
Proton intensity  $2.9 \cdot 10^{12}$  ( $3.6 \cdot 10^{10}$  p/b)

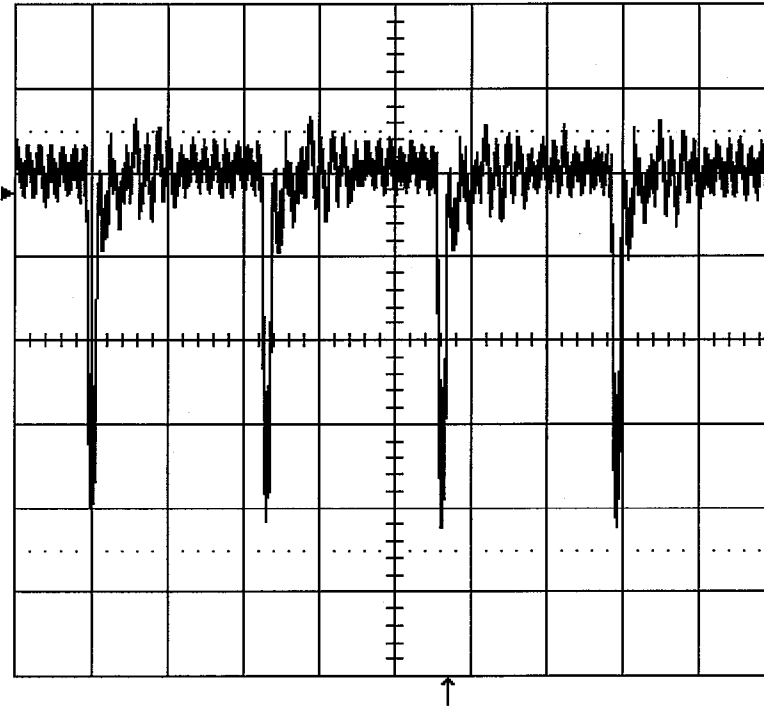
Bunch-to-bunch period  $25ns$ , 81 bunches per batch, SPS revolution time  $23\mu s$

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# - LHC Type Beams - Pick-up signal

20-Nov-99  
12:26:33

10  $\mu$ s  
2.00mV



10  $\mu$ s  
**1** 2 mV 50 $\Omega$   
**2** 50 mV 50 $\Omega$   
**3** 50 mV 50 $\Omega$   
**4** 1 V 50 $\Omega$



1 DC -0.48mV

HARDCOPY

output to  
 Int. Printer  
 Flow  
 GPIB  
 RS232  
 Centronics

page Feed  
 OFF On

protocol  
 HP 7470  
 HP 7550  
 TIFF b/w  
 TIFF color  
 BMP color

500 MS/s

STOPPED

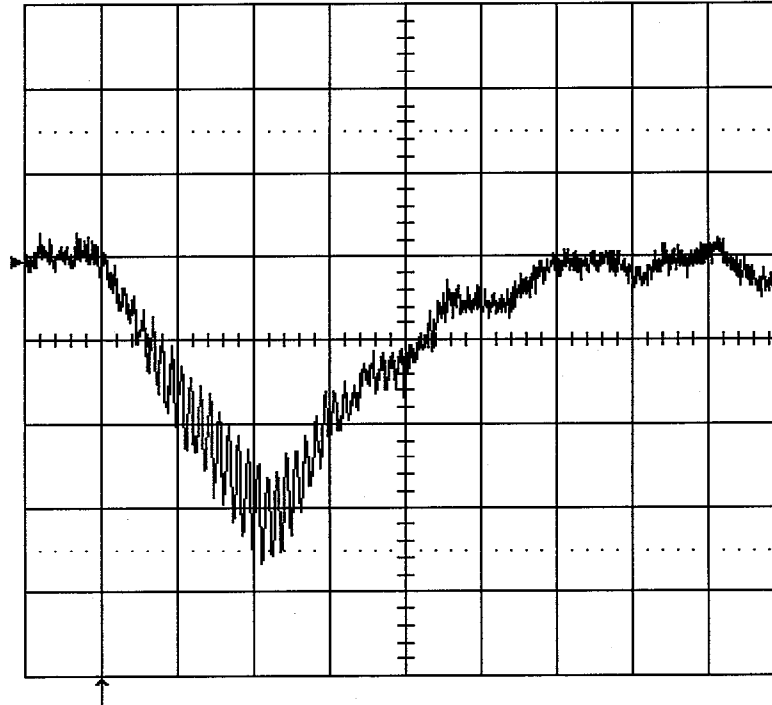
Horizontal scale : 10 $\mu$ s/div, Vertical scale : 2mV/div, Proton intensity  $6.0 \cdot 10^{12}$  ( $7.5 \cdot 10^{10}$  p/b), Revolution time 23 $\mu$ s

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## - LHC Type Beams - Pick-up signal

20-Nov-99  
13:32:49

**1**  
.2  $\mu$ s  
2.00mV



TIMEBASE  
T/div .2  $\mu$ s  
4000  
samples at  
2 GS/s  
(500 ps/pt)  
For 2.0  $\mu$ s  
Sampling  
**Single Shot**  
RIS

Channel Use  
**4** 2 Automatic

Sequence  
**OFF** On

Record up to  
25k  
samples

.2  $\mu$ s  
**1** 2 mV 50 $\Omega$   
**2** 50 mV 50 $\Omega$   
**3** 50 mV 50 $\Omega$   
**4** 1 V 50 $\Omega$

**1** DC -0.12mV

2 GS/s  
 STOPPED

Horizontal scale : 200 ns/div, Vertical scale : 2mV/div, Proton intensity  $6.0 \cdot 10^{12}$ , Revolution time  $23\mu$ s  
The increasing of the multipacting signal is repeated every passage of the proton bunches

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# Preliminary observations

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- Need strong octupoles (radial plane) to get decent inj. efficiency for  $I_{\text{batch}} > 4 \times 10^{12}$  p even with dampers ON
- Important emittance blow-up observed during the LHC cycle
- Symptoms of beam induced electron-cloud from damper pick-up behaviour and vacuum measurements

# Profile measurements

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## ■ Profile measurements along the batch

- | TSTLHC beam @ 26 GeV
- | 1 H + 1 V damper ON
- | Low positive chromaticity ( $<0.02$ )
- | Strong negative radial octupole component

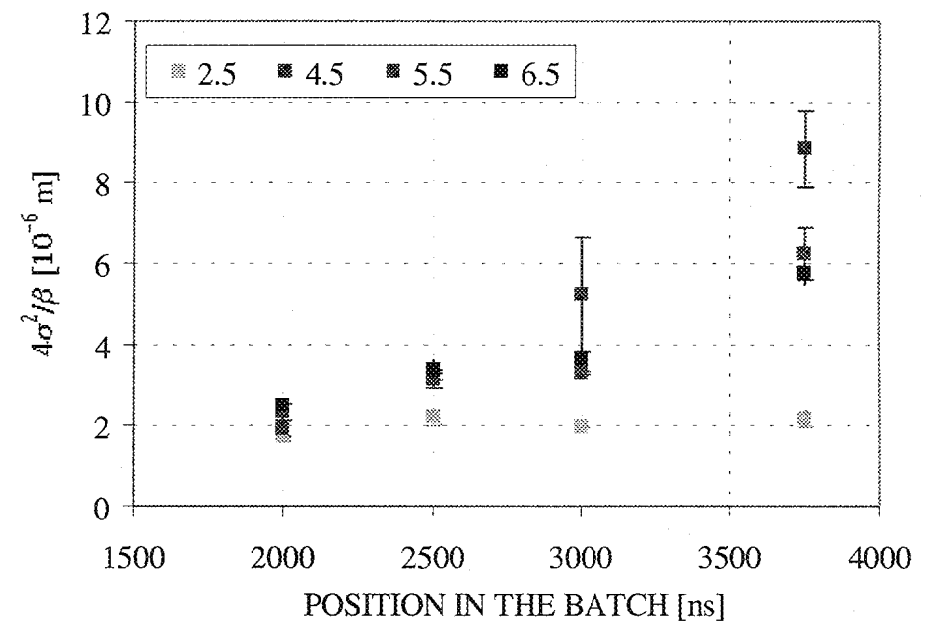
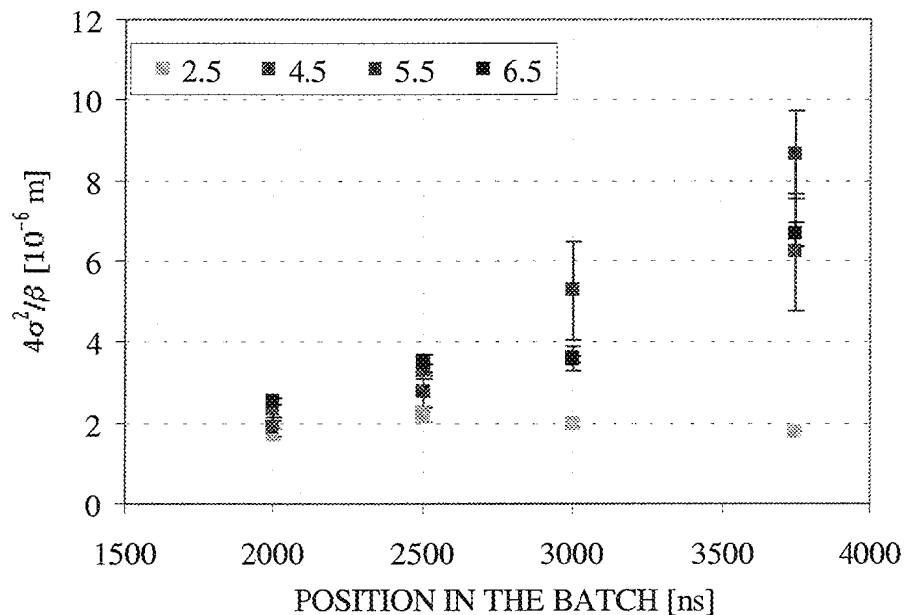
## ■ Device:

- | rotational wire scanner (dispersive region) with gated (350 ns) reading of the photomultiplier. Expected time constant of the electronics: few hundreds ns.

# Profile measurements (hor.)

■ few ms after inj.

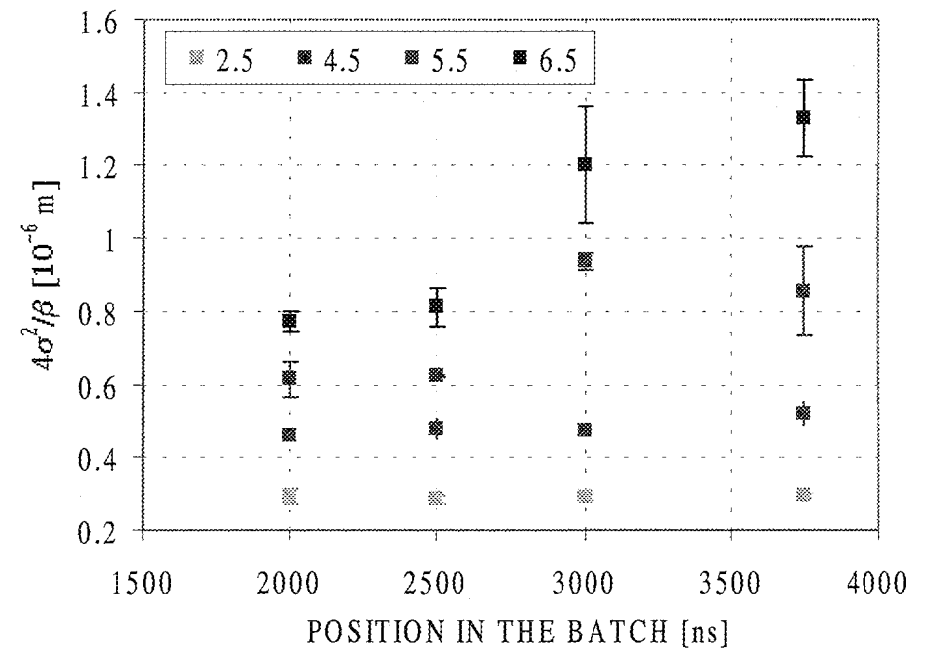
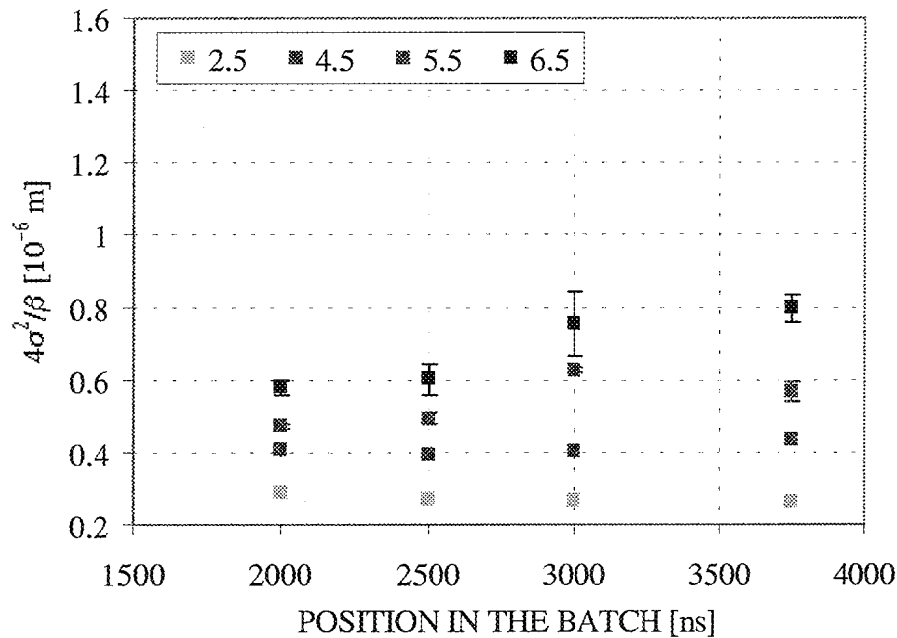
■ 600 ms after inj





# Profile measurements (ver.)

■ A few ms after inj.    ■ 600 ms after inj.



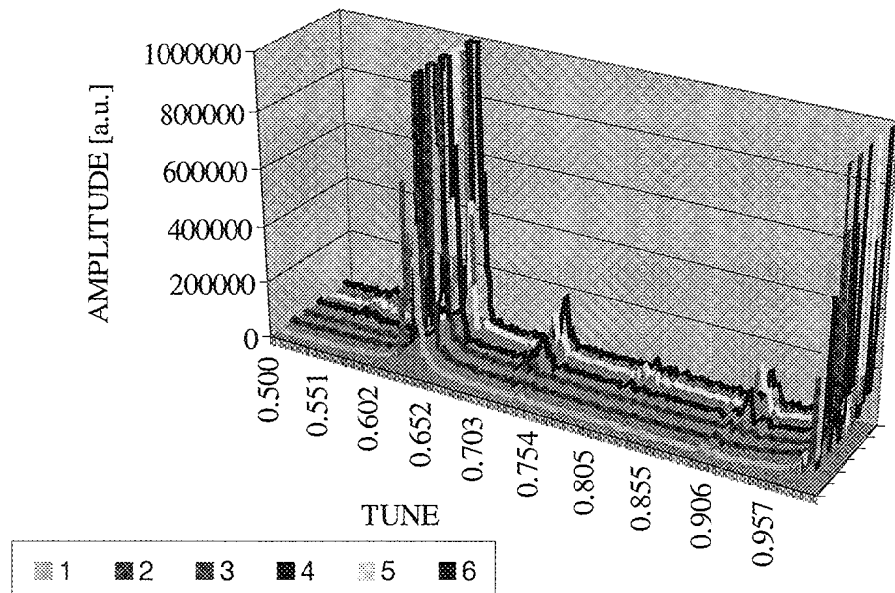
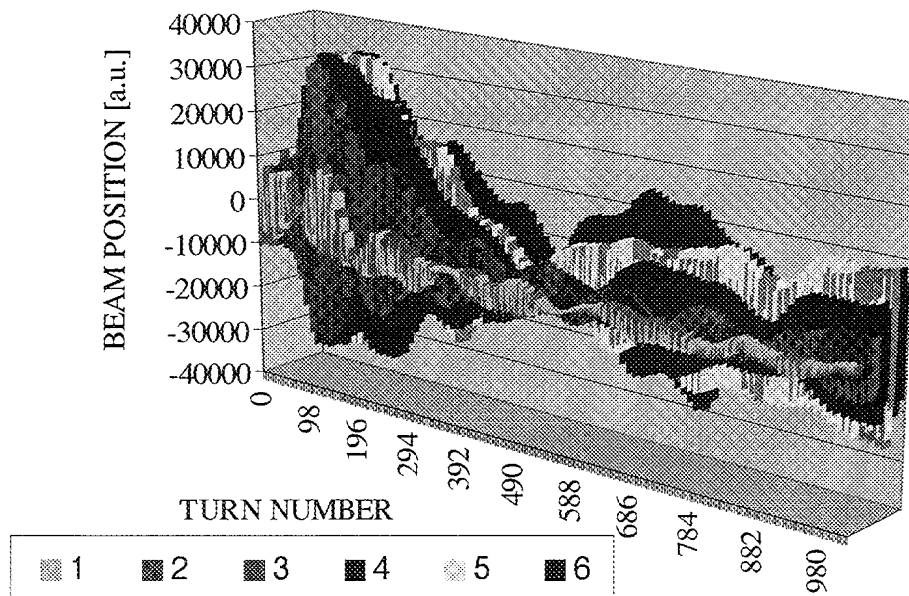
# Beam oscillation measurements

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- **Measurements along the batch:**
  - **Electrostatic pick-ups with FET amplifier (0 - 2 MHz): baseline distortion for a few tens of ms from injection**
  - **Couplers with a 200 MHz receiver and a 2 MHz bandwidth: no signal distortion. Batch subdivided in 6 consecutive slices of 400 ns (first and last at the edge)**

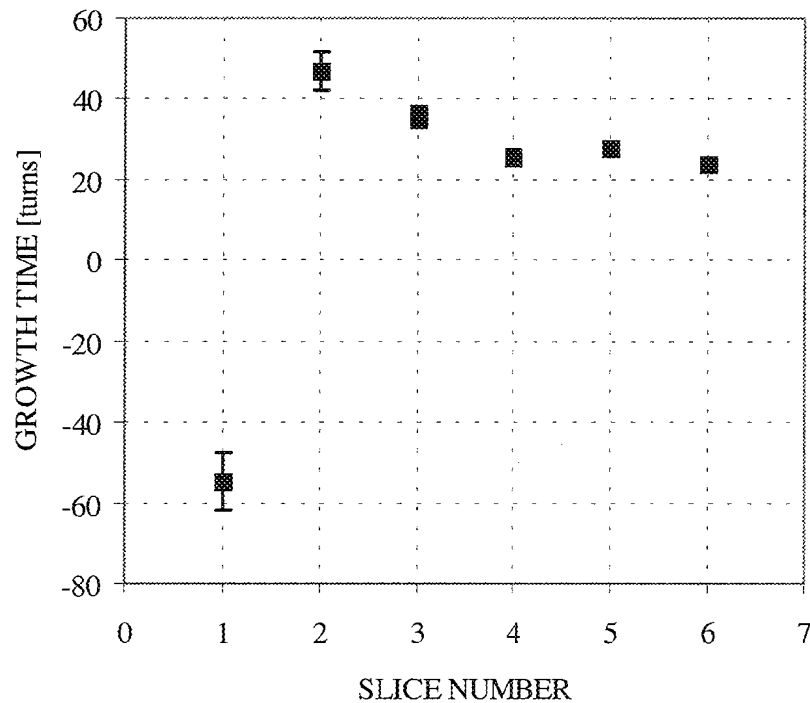
# Beam oscillation measurements (Horizontal) - Injection

- I TSTLHC beam @ 26 GeV,  $I_{\text{batch}} \sim 4 \times 10^{12}$  p
- I No Landau damping, 2 H + 1 V damper
- I Low positive chromaticity ( $< 0.02$ )

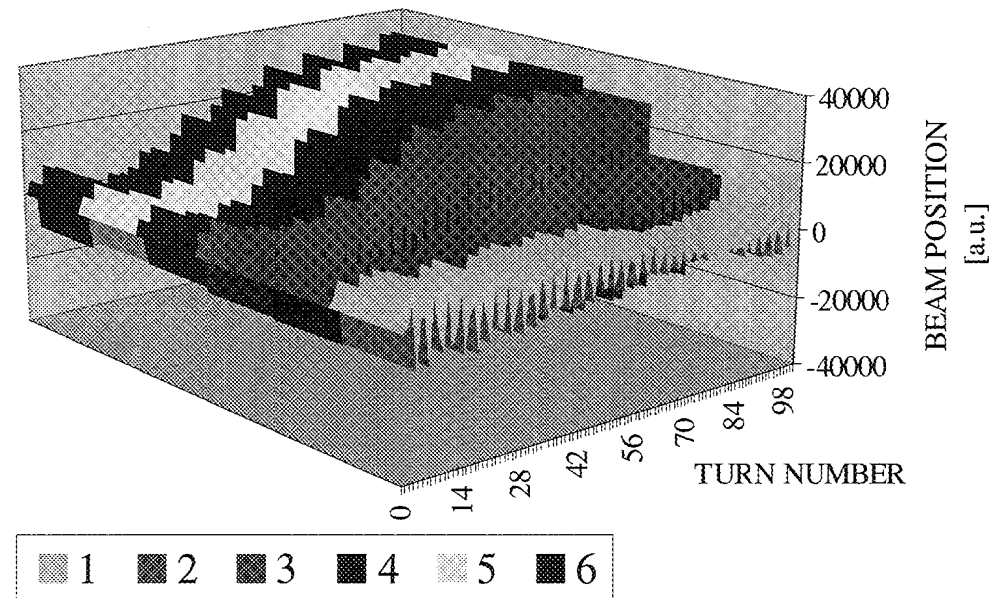


# Beam oscillation measurements (Horizontal) - Injection

I Fit with exp. growing (damped) Sin ( $q=0.637$ )

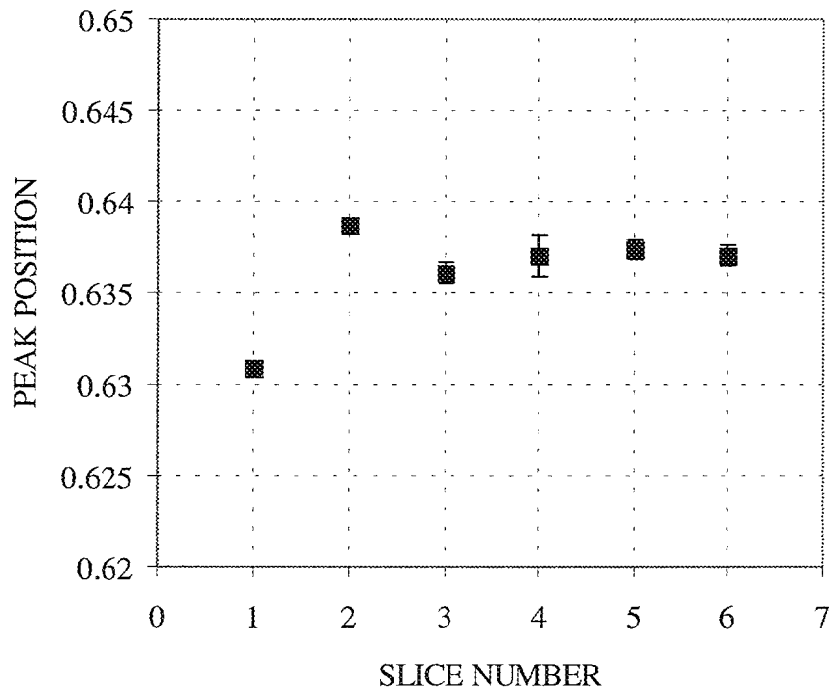


I Amplitude saturation and growth rate saturation

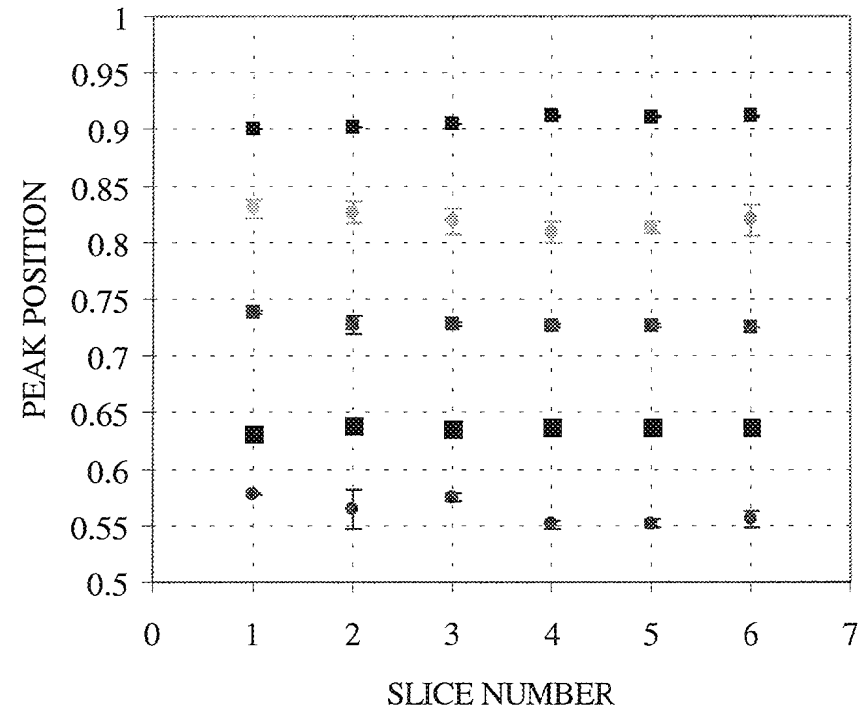


# Beam oscillation measurements (Horizontal) - Injection

I  $q_H$  increasing from head to the tail

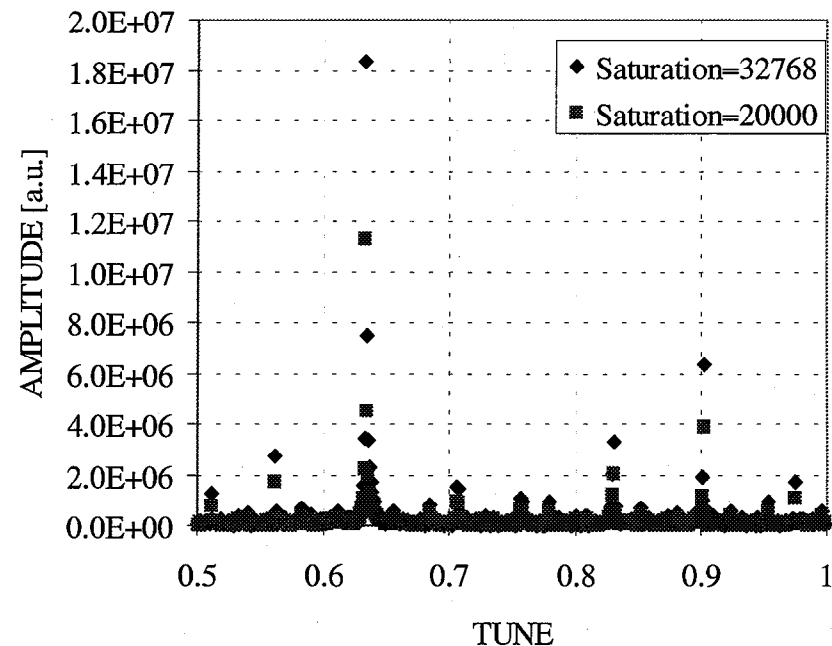


I Equidistant peaks



# Beam oscillation measurements (Horizontal) - Injection

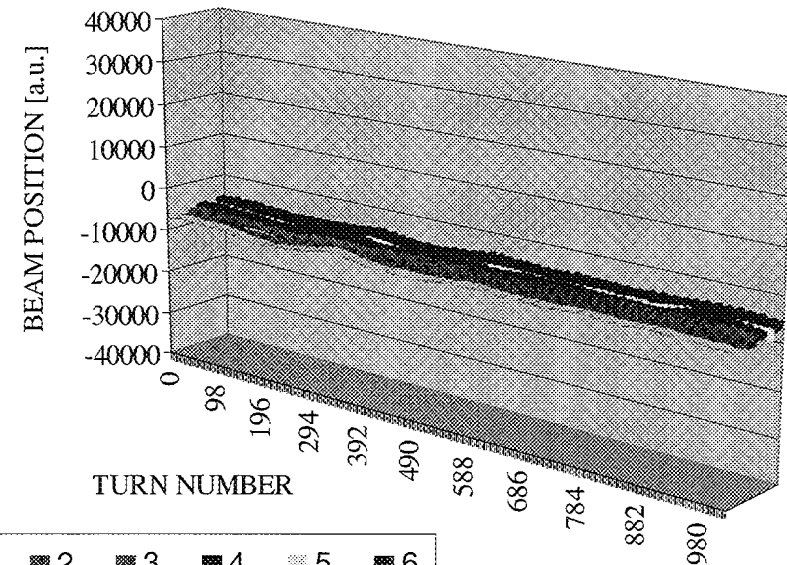
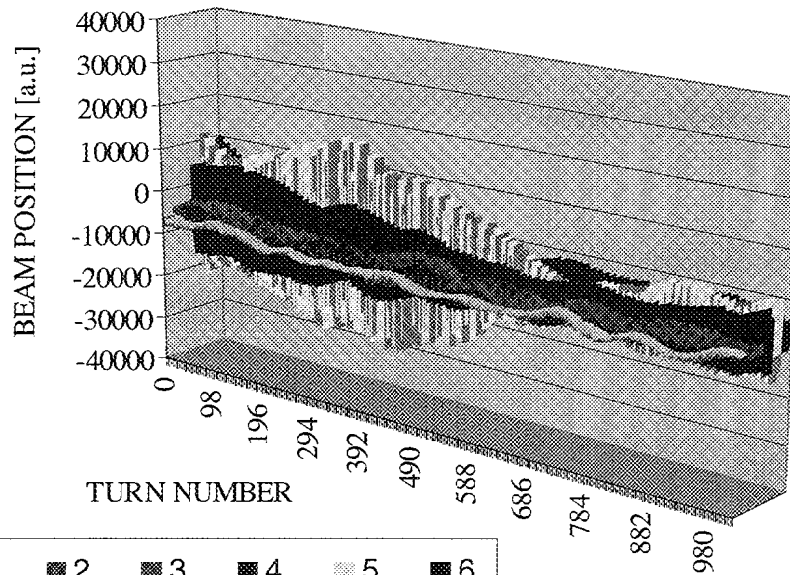
- I The observed structure is typical of a saturation of the growth of an oscillation at  $q=q_H$
- I The case of a saturating exponentially growing Sin function ( $q=0.637$ ) is shown



# Beam oscillation measurements (Horizontal)

- I Inj. + 30 ms
- I Oscillation creeping from the tail to the head

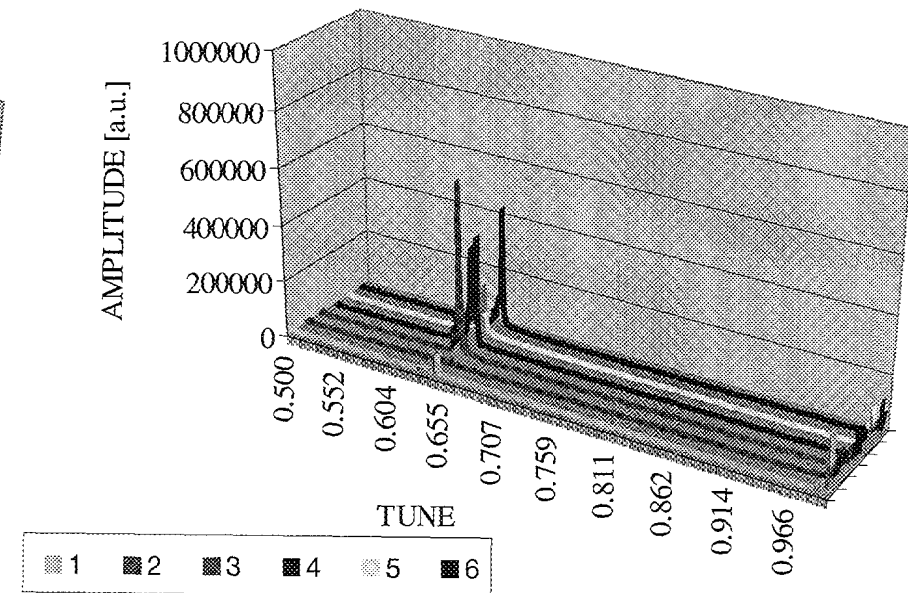
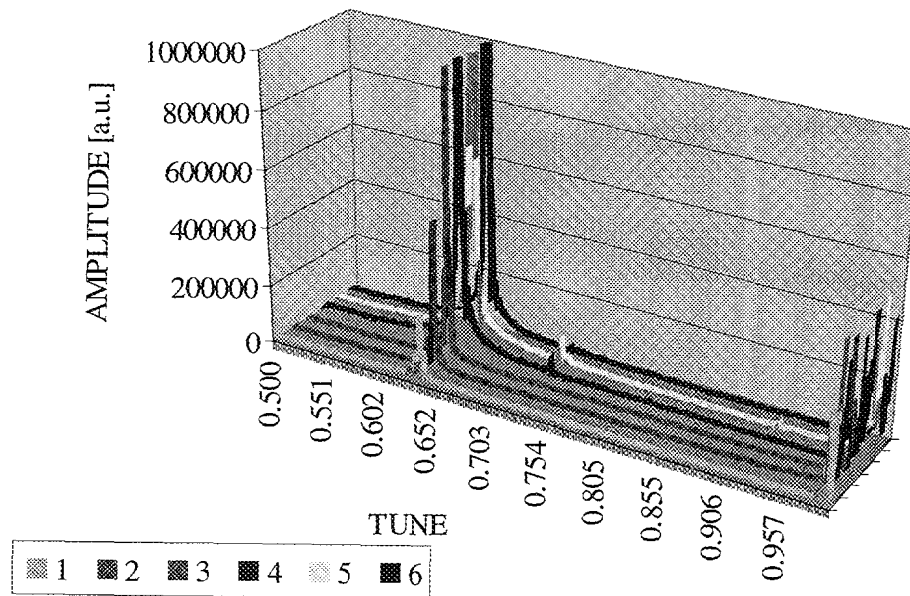
- I Inj. + 500 ms
- I Strong attenuation of the phenomenon



# Beam oscillation measurements (Horizontal)

■ Inj. + 30 ms

■ Inj. + 500 ms



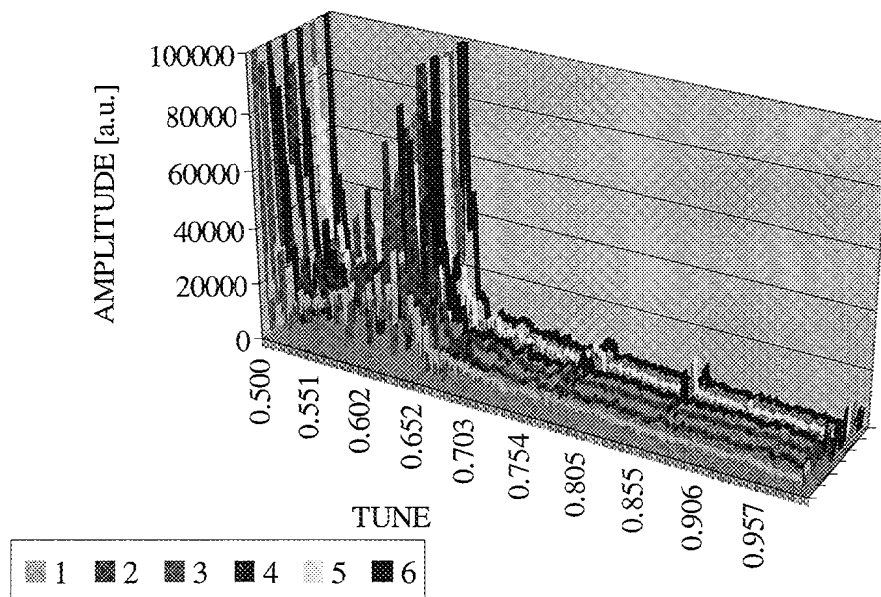
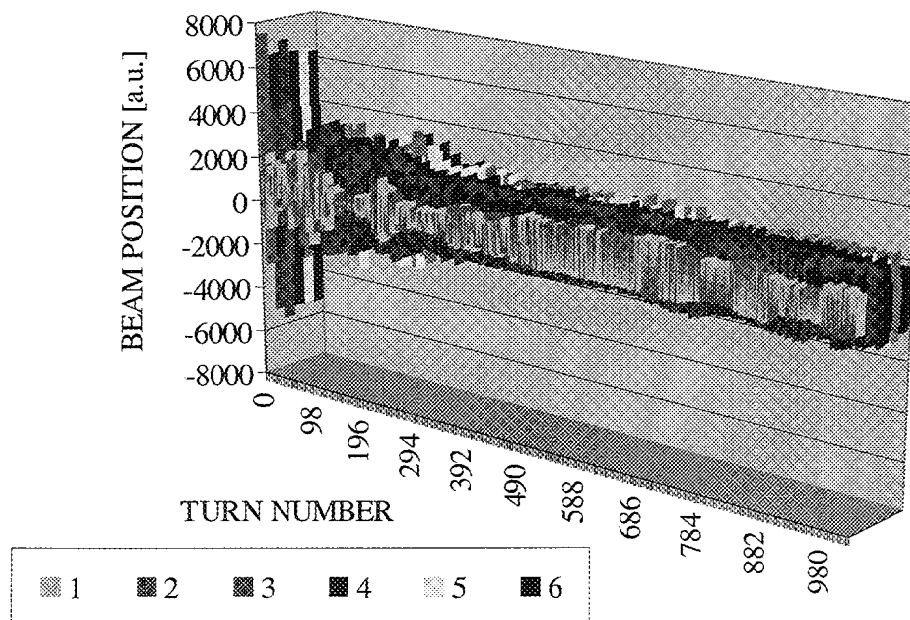
17/02/2000

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# Beam oscillation measurements (Vertical) - injection

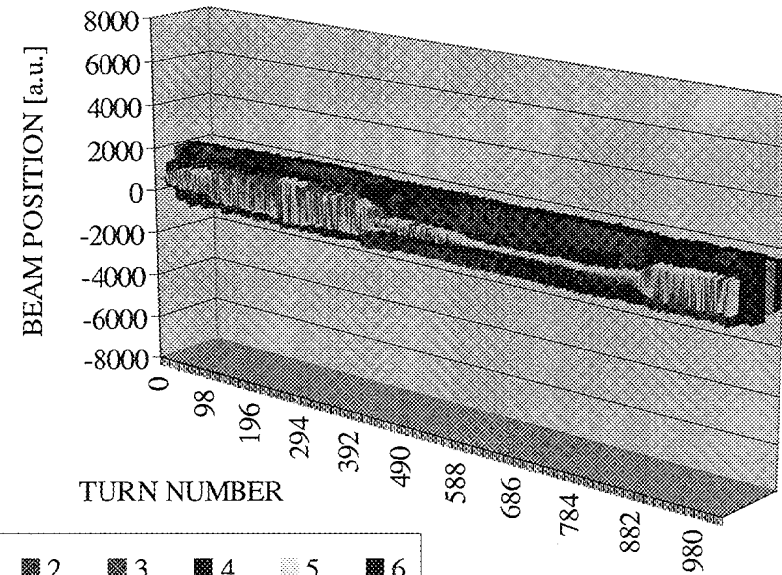
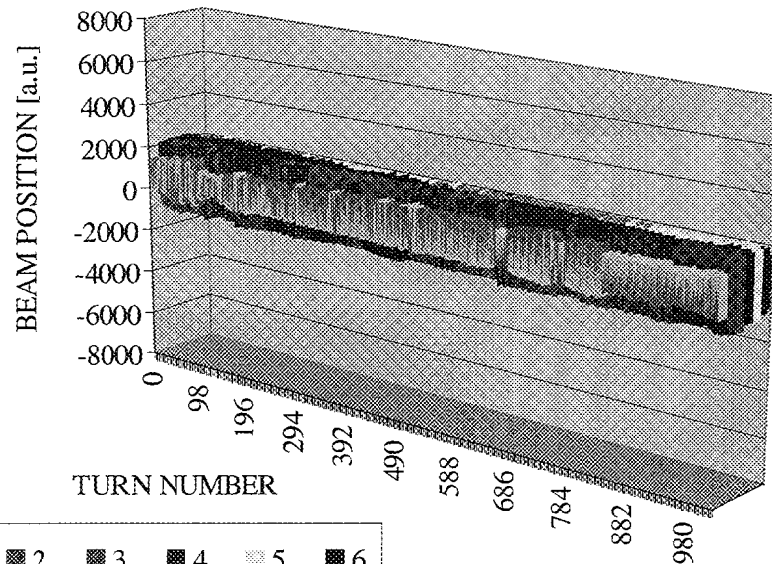
- I Strong half-integer component due to transverse feedback over-damping



# Beam oscillation measurements (Vertical)

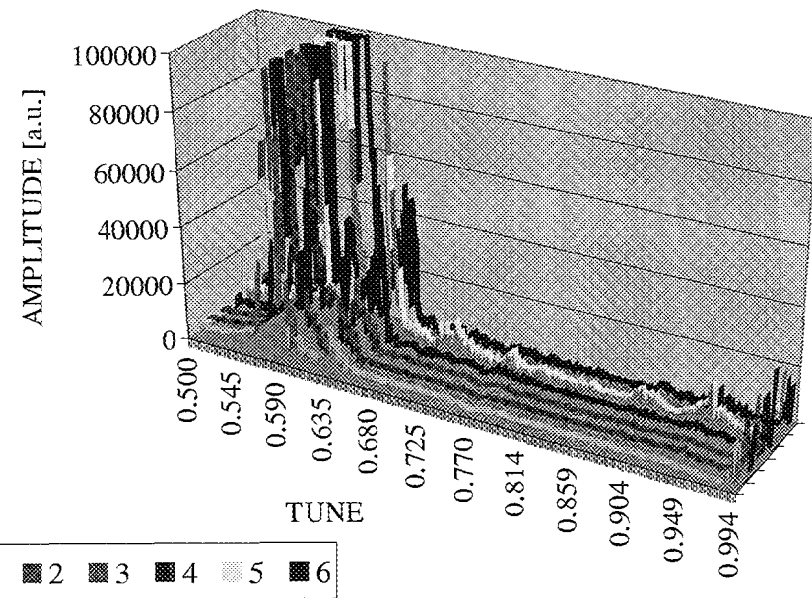
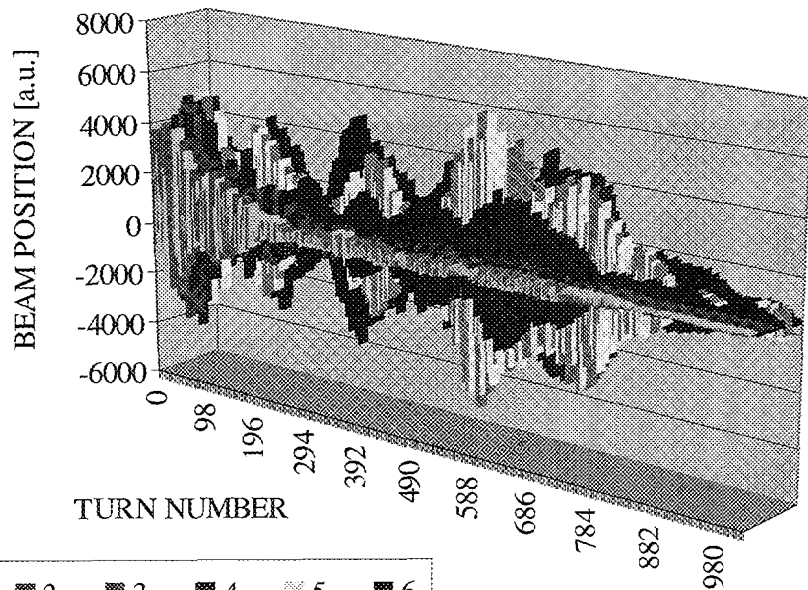
■ Inj. + 30 ms

■ Inj. + 500 ms



# Beam oscillation measurements (Vertical) - injection

- I Vertical damper off
- I  $I_{\text{batch}} = 6 \times 10^{12}$  p, injected  $5\text{-}5.5 \times 10^{12}$  p
- I Strong negative radial octupolar component



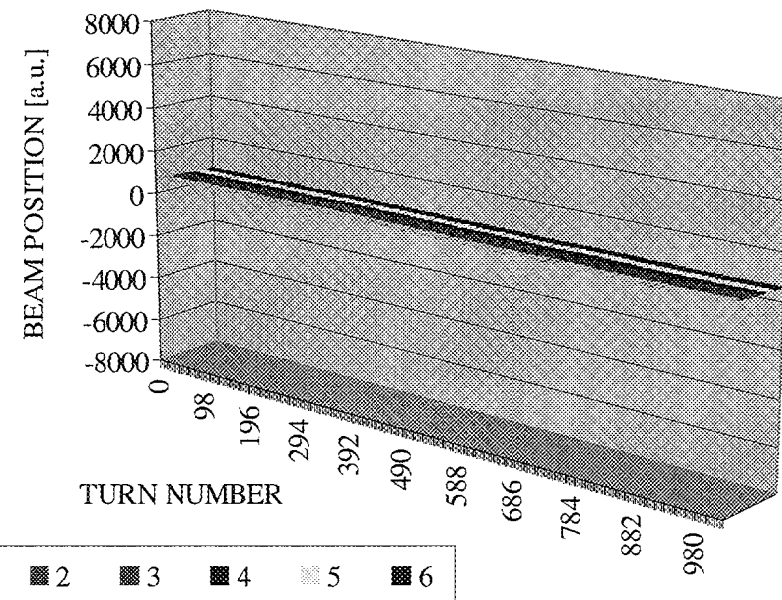
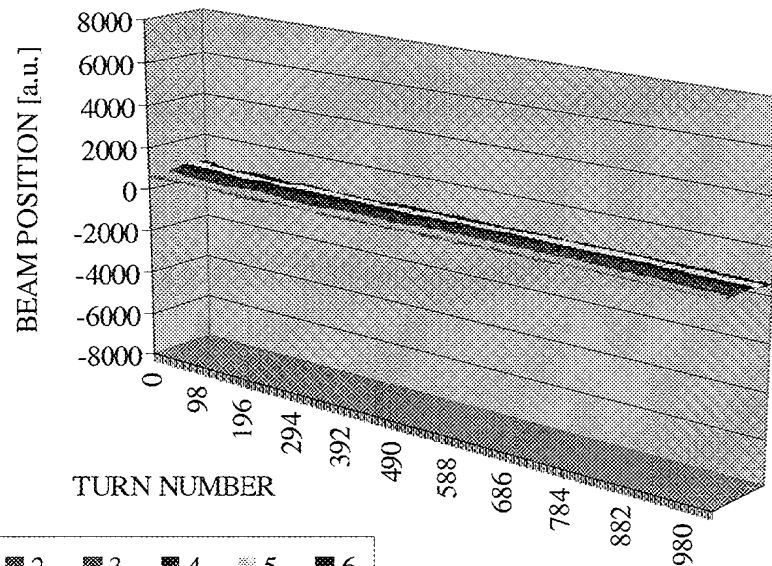
# Beam oscillation measurements (Vertical) - V damper OFF

I  $I_{\text{batch}} = 6 \times 10^{12}$  p, injected  $5-5.5 \times 10^{12}$  p

I Strong negative radial octupolar component

I Inj. + 30 ms

Inj. + 500 ms

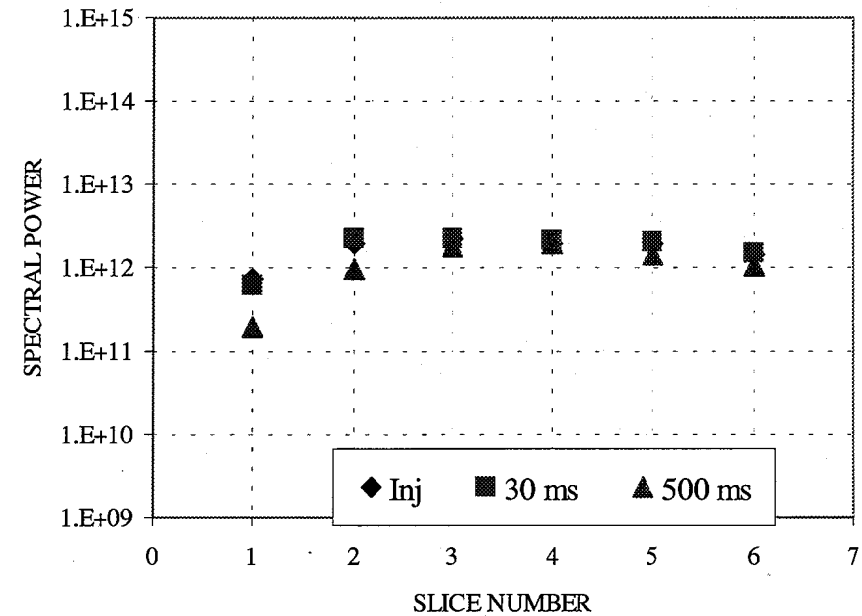
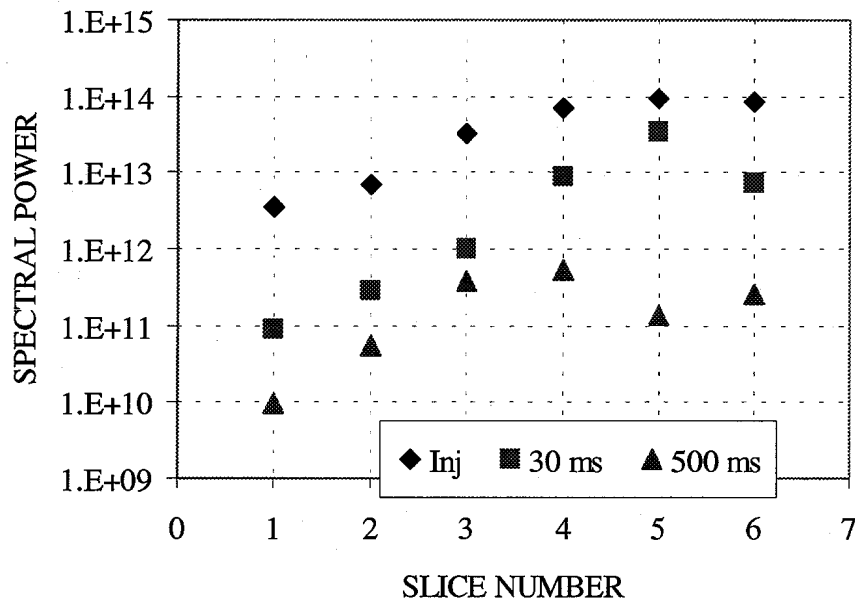


# Beam oscillation measurements

I Spectral power between 0.5 and 0.95

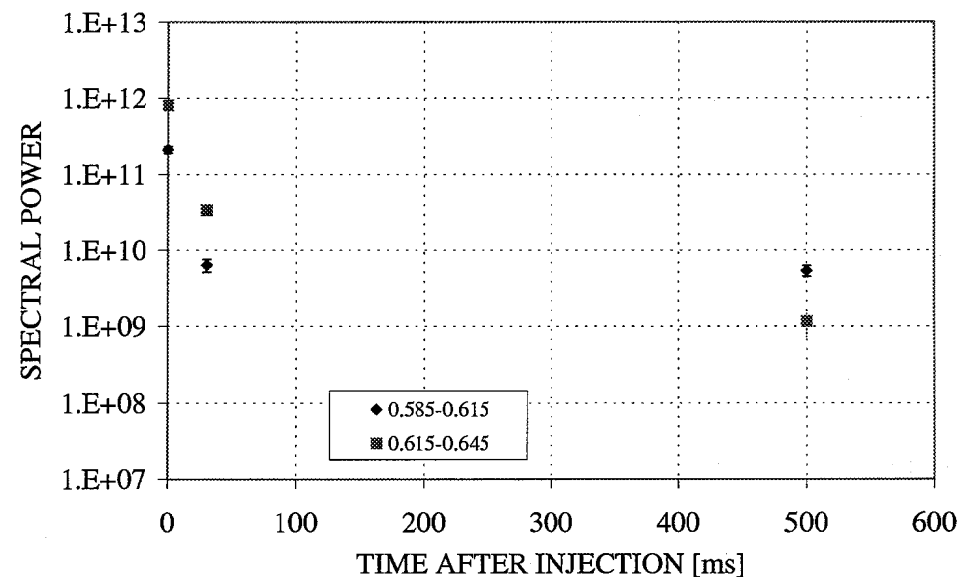
I H-plane

V-plane



# Beam oscillation measurements

- Horizontal transfer dominates at injection and then is overwhelmed by oscillation @  $q_v$



# Other observations

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- Losses in the last 1/3 of the batch for intensities  $I_{\text{batch}} > 4.5 \times 10^{12}$  p
- Vertical oscillations in the range 400-800 MHz (from vertical wideband PU) from injection and slowly disappearing

# Summary

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- | In the presence of LHC beams in the SPS for  $I_{\text{batch}} > 3-4 \times 10^{12}$  p (i.e.  $I_{\text{bunch}} > 4-5 \times 10^{11}$  p - half of the nominal) several effects point to the generation of beam induced electron cloud:
  - | electrostatic pick-up signal distortion
  - | vacuum deterioration
- | In the same conditions beam blow-up and instabilities of the tail of the batch are observed



# Summary (ES pick-ups)

- | Signal distortion is observed only for the 25 ns spacing for similar  $I_{\text{batch}}$  (this seems to rule out ions)
- | Small bias voltages seem to “steer” the flow of electrons
- | Solenoidal fields (100 Gs) suppress the phenomenon (up to  $I_{\text{batch}} = 5 \times 10^{12}$  p)

# Summary (Vacuum)

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- Threshold batch intensity
- Threshold in number of bunches  
(decreasing with bunch intensity)
- No clear evidence of 'beam scrubbing'  
observed

# Summary (effects on beam)

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- | Strong instability in the H-plane @ inj.
- | Mainly affecting the tail of the batch (20-25 turns growth rate) and saturating in the second half of the batch
- | Oscillation amplitude saturating after ~100 turns
- | Creeping to the head of the batch
- | Transfer to the vertical plane observed (though coupling is low -  $< 0.005$ )

# Summary (effects on beam)

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- | Activity in the vertical plane (mainly in the tail) dominated by H-transfer at injection and emerging after a few tens of ms. Feedback over-damping?
- | These observations are compatible with the profile measurements:
  - | horizontal blow-up (mainly tail) at injection
  - | vertical blow-up (mainly tail) continuously through the inj. plateau

# Summary (effects on beam)

---

- **Is it electron cloud related?**
  - Same threshold as for beam induced electron cloud
  - Stronger in the horizontal plane
  - Increase of the growth rate along the batch and saturation in the second half of the batch
  - More worrying: high frequency instability (bunch distortions)