Status of the LHC Proton Beam in the CERN SPS

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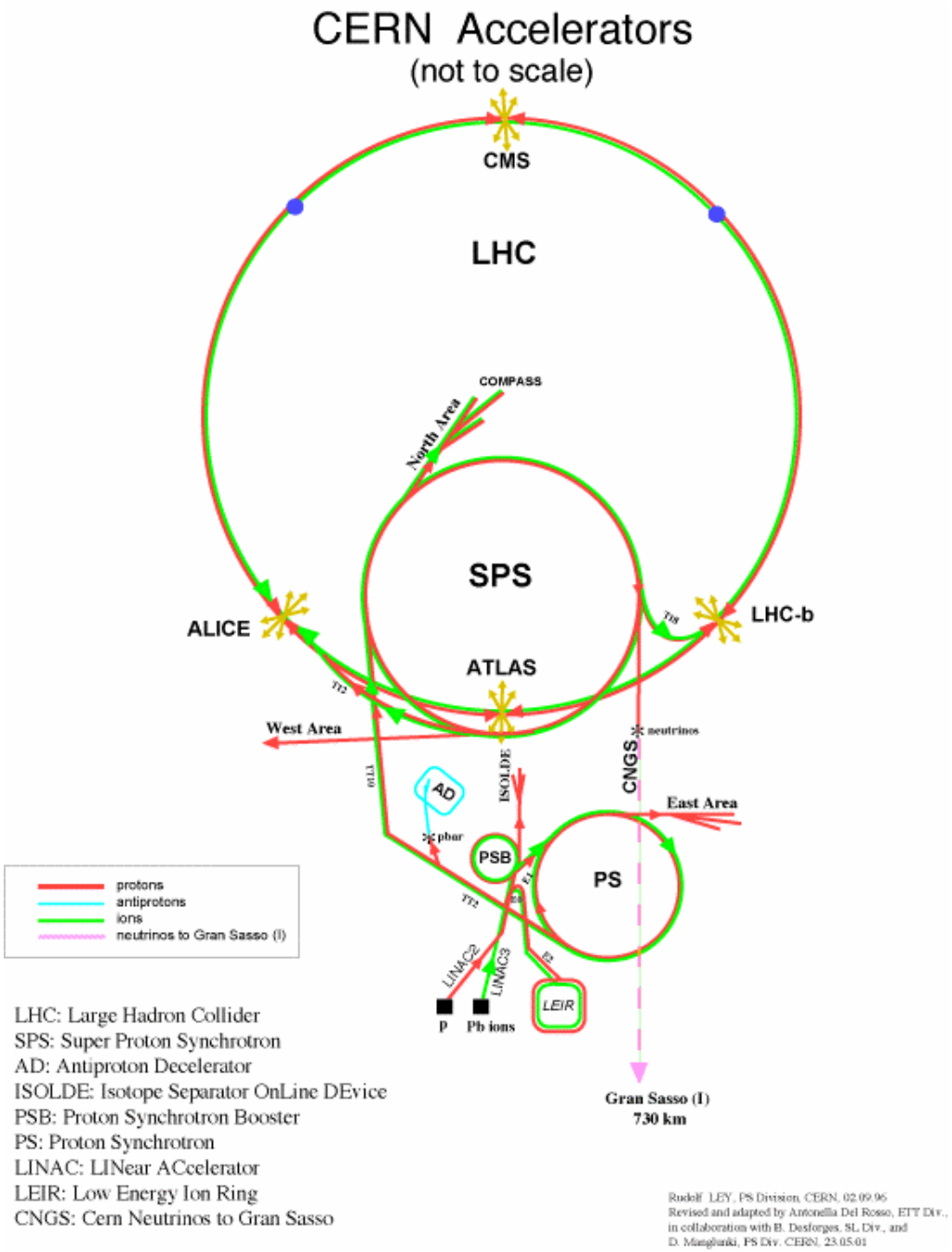
CERN – SL Division

Overview

- The LHC beam in the SPS
- The Challenges
- Present limitations and perspectives


CERN Accelerators
(not to scale)
CMS
LHC
COMPASS
North Area
SPS
ALICE
LHC-b
ATLAS
West Area
CNGS
neutrinos
East Area
AD
ISOLDE
PSB
PS
LINAC2
LINAC3
LEIR
p
Pb ions
Gran Sasso (I)
730 km
protons
antiprotons
ions
neutrinos to Gran Sasso (I)
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

The LHC beam in the SPS

Momentum [GeV/c]	26	450
Revolution period [μs]	23.07	23.05
Tunes (H/V)	26.19/26.24	
Gamma transition	22.81	
Max. n. of batches	4	
n. bunches/batch	72	
Nominal I_{bunch} [10^{11} p]	1.1	
Peak current [A]	1.4	1.4
Bunch spacing [ns]	24.97	24.95
Full bunch length [ns]	4	1.74
Batch spacing [ns]	224.7	224.6
r.m.s. $\varepsilon^*_{H,V}$ [μm]	3	3.5
ε^*_L [eV s]	0.35	0.5 - 1

The LHC beam in the SPS

- Unprecedented I_{peak} (twice Fixed Target record) – Less than $\frac{1}{2}$ SPS is filled
- High I_{bunch} - similar to ppbar - BUT in smaller longitudinal and transverse emittance and with 6 bunches
- Tight transverse/longitudinal emittance budget

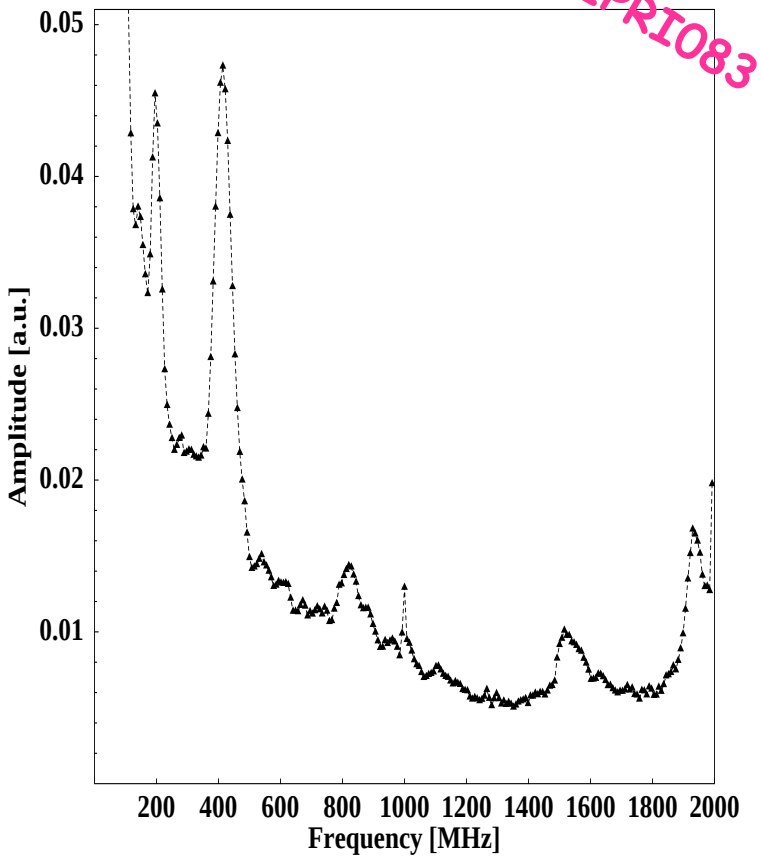
The Longitudinal Challenge

- Constraints in longitudinal emittance (< 1 eVs) and in phase error (less than ± 0.2 ns) at extraction to minimise capture losses (< 1%) in the LHC
- …can be relaxed if 200MHz cavities in LHC (decision pending)
- Main sources of concern:
  - μ-wave instability
  - Coupled bunch instability
  - Beam loading

μ-wave instability

- Threshold for the LHC-type bunch (measured 1999): 0.6 x 10^{11} p
- Sources of impedance identified in the pumping ports (~1000)
- Shielded in the long SD 2000-2001 (WEPRI082)

WEPRI083

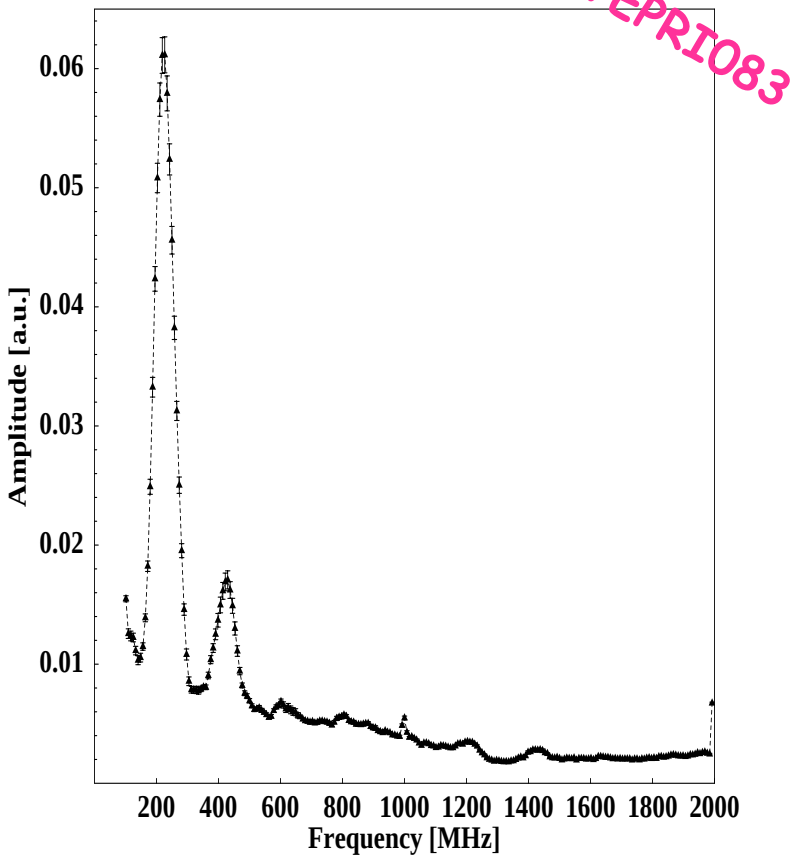


μ-wave instability

WEPRI083

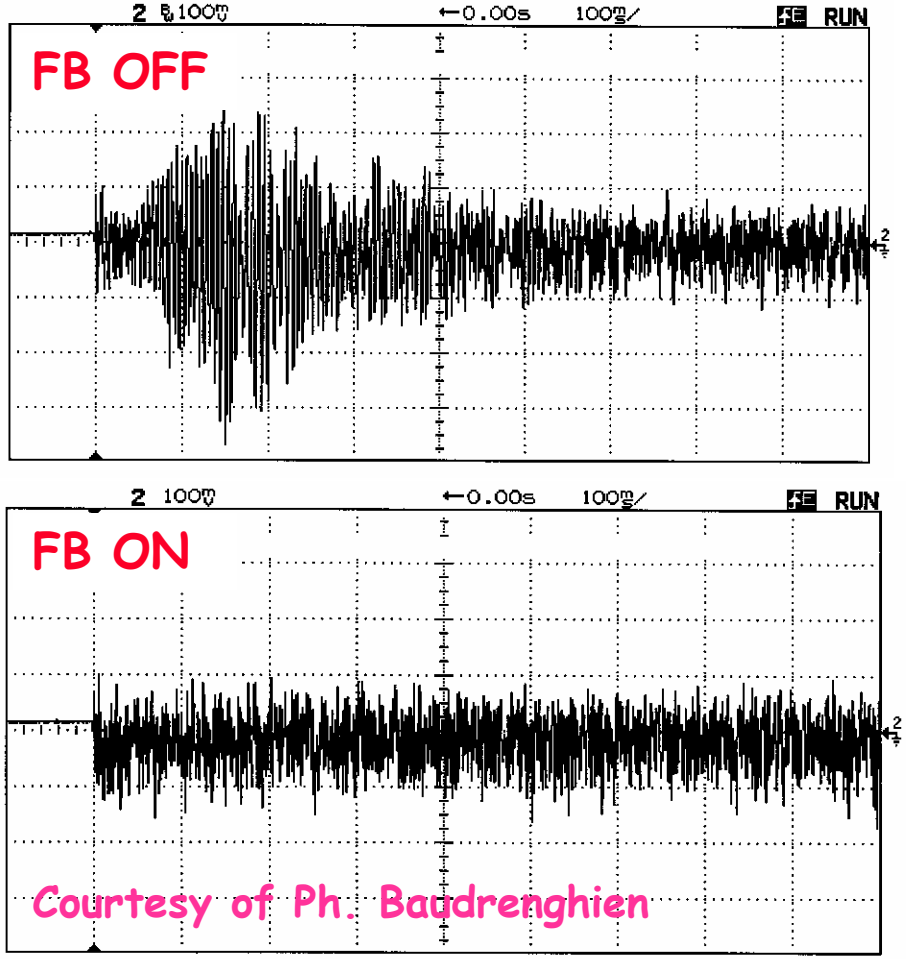
After:

- No sign of high frequency signals up to nominal bunch intensity
- Decrease in bunch lengthening with intensity by a factor 7



Coupled-bunch instabilities

- Low order modes due to the impedance of the main RF system around the fundamental (200 MHz)
- Bunch to bunch feedback (using main RF system). Successful operation at injection energy.
- At higher energy Landau damping by using 800 MHz in bunch shortening mode.



Beam Loading

- Also due to impedance of the TWC200 MHz around the fundamental
- If no compensation: 6 MV induced voltage within 800 ns (filling time) – comparable to max. RF voltage available.
- Cure: feed-forward and one-turn delay feedback working in parallel on each of the 4 TWC200 MHz

The Longitudinal Challenge

With all that:

- Longitudinal emittance < 1 eV s
- Bunch-to-bunch phase error: ± 60 ps

At 450 GeV/c

For half the nominal intensity

The Transverse Challenge

- Less than 20 % blow-up allowed from injection to high energy!!
- Expected sources of emittance blow-up were:
  - Betatron and dispersion mismatch
  - Injection errors
  - Resistive wall instability

The Transverse Challenge

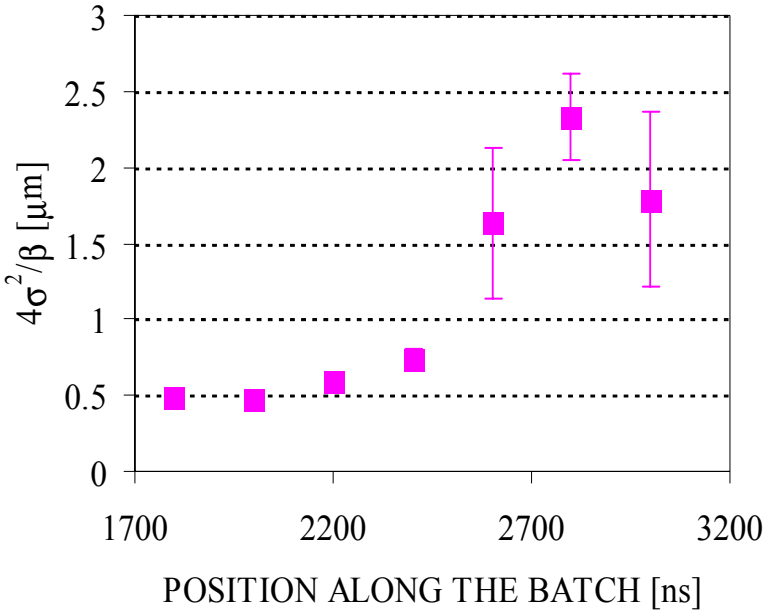
- **Solutions put in place:**
  - Detailed measurements of the extraction conditions and of injection line optics + rematching (blow-up reduced from 100 to 10 %)
  - Upgrade of the Injection kicker: reduction of the ripple in the pulse flat-top from ± 1 %, to ± 0.5 %, reduction of the pulse rise time to < 220 ns (achieved ~300 ns)
  - Upgrade of the transverse feedback: bandwidth from 6 MHz to 20 MHz, to damp all possible coupled-bunch modes. Not all the kick strength was available in 2001.

Cloudy Skys

- Beam Induced Multipacting observed for $I_{bunch} > 0.3 \times 10^{11}$.
- Pressure rises up to the vacuum intlk. level
- Fast Single (high-order head-tail - ~600 MHz) and Coupled bunch (a few MHz) instabilities
- Blow-up > factor 4
- Losses after few ms from injection
- Perturbation of the signal of the TFB pick-ups

Vertical plane

Beam size along the batch

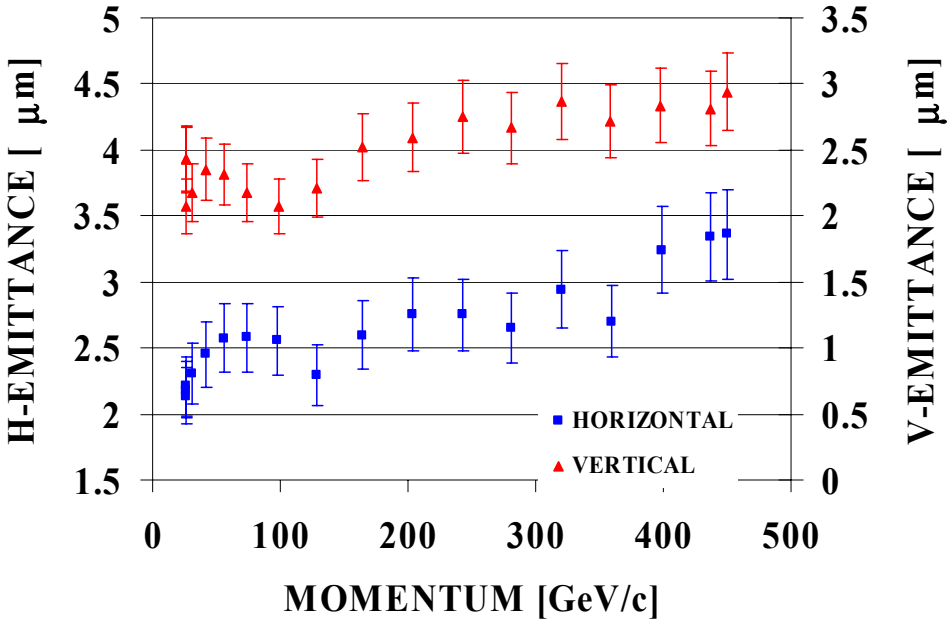


Cures for ECI

- 120 MHz electronics for the TFB pick-ups: insensitive to baseline distortion due to electron cloud
- Fine-tuning of the transverse feedback (H-plane)
- High Chromaticity ξ=+0.5(H)/+1.5(V)
- New working point (Q_H=26.19/Q_V=26.24) more favorable against resistive wall as compared to (Q_H=26.62/Q_V=26.58)

The Transverse Challenge

- One batch with half nominal I_{bunch} accelerated to 450 GeV/c with $\varepsilon^*_{H,V}$<3.5 μm.
- Still blow-up (~ 50 %)
- Reduced dynamic aperture due to high ξ



Present limitations and perspective

- Nominal emittances could be obtained at 450 GeV for 1 batch and half the nominal I_{bunch}
- Vacuum pressure increase prevented stable operation with more than 1 batch at half nominal I_{bunch} or with 1 batch at higher I_{bunch}
- 2 viable solutions to increase the threshold for BIM:
  - Increase bunch spacing (e.g. 75 ns)
  - Reduce the SEY by 'beam scrubbing'

Breaking news…

- In May 2002 after 10 days of continuous operation with the LHC beam, up to 3 batches with $I_{bunch} > 1.3 \times 10^{11}$ p could be injected with acceptable vacuum activity.
- Transverse and longitudinal parameters could be kept below the nominal ones in a long injection pleateau also thanks to the reliable operation of the transverse feedback at nominal strength.