Report on 2010 MD results and implications for the PSB upgrade

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2010 MDs
(relevant for the PSB Upgrade studies)

• In 2010 several **LHC beam high intensity MDs** took place in order to check intensity limitations for LHC-type beams along the injector chain
  - Single bunch LHC-type beams
  - Multi-bunch LHC-type beams
    - Single batch transfer to the PS (50, 75, 150ns bunch spacing)
    - Double batch transfer to the PS (25ns bunch spacing)
  - Neither single bunch nor multi-bunch LHC-type beams with single batch transfer need the (longer than) 1.2s flat bottom in the PS, during which a strong space charge could play a detrimental role in terms of beam quality
Single bunch LHC-type beams (PSB)

- The LHCINDIV beam, originally limited in intensity between $2 \times 10^{10}$ and $1.3 \times 10^{11}$ p, was produced in the PSB up to $3.5 \times 10^{11}$ keeping the longitudinal properties unchanged and within transverse emittances of $<1.5 \mu$m.
- The transverse emittances can be easily blown up to values around the nominal $\varepsilon_{x,y} = 3.5 \mu$m by missteered injection into the PS.
- This variant of the LHCINDIV is presently an archived MD beam that can be loaded on request on any of the PSB MD users (e.g. MD3, MDPSB).
Single bunch LHC-type beams (PS)

- The high intensity LHCINDIV was sent to the PS, where it could be accelerated and rotated at flat top
- The resulting beam had the nominal longitudinal specs to be injected into the SPS (bl=4ns at extraction)
- Transversely no significant emittance blow up was observed along the cycle
Single bunch LHC-type beams (SPS)

- The high intensity LHCINDIV was injected into the SPS for the first time in W27, and was later on injected on several more parallel MD sessions for the SPS Upgrade studies.
- Because of the very high peak signal the MOPOS PUs had to be disconnected prior to the MD.
- The beam was taken on an LHCFAST cycle. So far it has been studied at flat bottom, but was never accelerated.
- Measurements:
  - A longitudinal high order instability is observed to develop above a threshold of about $1.9 \times 10^{11}$ p.
  - A transverse instability (TMCI) at injection causes a sharp loss if we inject with 0 chromaticity and currents above $1.7 \times 10^{11}$. Vertical chromaticity of 0.3 permits stable injection of bunches up to $\sim 3 \times 10^{11}$ (with losses on the flat bottom).
Single bunch LHC-type beams

General remarks

- The high intensity \textit{LHCINDIV} is still a low intensity beam at the PSB and its production was not expected to cause major problems.
- Space charge tune spread at the PS injection with $N=3.5\times10^{11}$ and $\varepsilon_{x,y}=1.5\mu m$ is

$$\Delta Q_{y}^{\text{LHCINDIV}}@\text{PSinj} = -0.2$$

and therefore this beam is comparable in brilliance to other beams.
- The main interest for this beam lies in the SPS to study \textit{single bunch intensity limits for LHC beams} (wide range tune shift measurements, instability thresholds in both the longitudinal and the transverse plane, impedance localization studies, etc.)
- It may be interesting \textit{for the LHC}, too, if they will decide to try increasing the luminosity by increasing the charge per bunch (to be seen after the tests with the 150ns bunch trains....)
Multi-bunch LHC-type beams
The 150 and 75ns beams

- The **150ns beam** was produced for the first time this year under request of the LHC physics coordinator. Over a few MD sessions:
  - Successfully produced within longitudinal specs (and lower transverse emittances) at the PSB and transferred in single batch to the PS
  - The PS could first accelerate 2/3 of the nominal intensity without problems. Nominal intensity was unstable (longitudinal quadrupole instability on the ramp) with low longitudinal emittance, stabilized by nominal longitudinal emittance
  - The SPS could successfully take and accelerate both the the unstable and the stable nominal beam coming from the PS.
  - **First injection tests into the LHC** took place Friday last week, and they will be continued after the technical stop

- The **75ns beam** was checked only at the beginning of the 2010 run. We might have to resume MDs on this type of beam soon (it’s next on the LHC wish list if the 150ns is not satisfactory). However, LHC75 and LHC150 are presently on the same PSB and PS users (planned to sacrifice the never used LHCPILOT user in both)
Multi-bunch LHC-type beams
The 150 and 75ns beams

• The 150ns beam has a relatively small space charge tune spread at injection into the PS

$$\Delta Q_y^{LHC150}@PSinj = -0.16$$
Multi-bunch LHC-type beams
The 50ns beam

- The **50ns** is available within specs in single batch transfer to the PS
- This year its intensity has been pushed from the nominal 1.6e12 per ring to the “ultimate” **2.4e12** per ring within transverse emittances of ~3.5μm.
- The ultimate was taken and accelerated in the PS, resulting in a train of bunches with **1.9e11** ppb at the PS exit
Multi-bunch LHC-type beams
The 50ns beam

• This gives the limit of what can be produced in terms of LHC50 beam “within specs” with the present injectors
• It is very useful for SPS studies (electron cloud, high single bunch intensity in multi-bunch mode), first session scheduled for this Friday
• Not too challenging for space charge at the PS injection

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\Delta Q_y^{LHC50}@PSinj = -0.18 \\
\Delta Q_y^{LHC50ult}@PSinj = -0.21
\]
Multi-bunch LHC-type beams

The 25ns beam

- This is presently the only beam still transferred in double batch to the PS (with 4+2 rings from the PSB, each one with one bunch 1.6e12 p)
- A sort of ultimate version (~2.5e12 p) has been produced at the PSB within longitudinal specs and relaxed transverse emittances $\varepsilon_{x,y} \approx 4 \mu m$
- While this “ultimate” beam is very useful in the PS and SPS to study longitudinal instabilities and intensity effects expected to be not too much dependent on the transverse emittances (e.g. e-cloud, TMCI), the space charge limit at the PS injection has not been pushed much further....
- Went well through the PS, up to 3 batches were injected into the SPS (but even one batch alone exhibits significant losses –needs optimization)

$$\Delta Q_{y}^{LHC25} @PSinj = -0.208$$
$$\Delta Q_{y}^{LHC25ult} @PSinj = -0.213$$
Beams with strong space charge effect at the PS injection

- From normal operation, the TOF beam is the one that is injected into the PS with the largest tune spread (N=800e10 p). It has, however, a 1bp cycle in the PS and sits on a very short flat bottom before being accelerated.
- From 2010 MDs, on June 24th there was a joint PSB/PS MD on the LHC25 single-batch intensity limit at PS injection:
  - The beam was produced in the PSB from the LHC50. The ~1.6e12 p accelerated on h=1 are re-bucketed in one of the two available buckets of h=2, instead of being equally split between the two. This gave more than 1.6E12 p crammed longitudinally in 135ns and 0.9 eVs, and transversely in $\varepsilon_{x,y} \approx 2.5 \mu m$.
  - This beam was injected into the PS on a 3bp cycle and a transverse emittance increase of only 10% was observed at the end of the flat bottom, with no discernible blow up in the longitudinal plane.

$$\Delta Q_{y}^{\text{TOF}}_{@PSinj} = -0.31$$

$$\Delta Q_{y}^{\text{MDLHC25}}_{@PSinj} = -0.338$$
PSB extraction energy upgrade

• Beams with **double the present intensities and within their unchanged transverse/longitudinal specs** are expected to be available at the PSB exit after connection to Linac4

• The main purpose of the extraction energy upgrade would then be to allow injection into the PS of LHC25 beams (double batch) with twice the present intensity keeping the same tune spread at injection.

• Relevant for our working group, there are a few things we have learnt so far with this year’s MDs:
  
  – **Space charge at the PS injection** has not been really pushed too far with most of the MDs, with the exception of the MD on the LHC25 single-batch intensity limit at PS injection. There it was observed that a tune spread of ≈-0.33 does not cause excessive emittance growth on the 1.2s flat bottom. But what would happen for tune spreads of -0.44 and lower? We could perhaps push the tune spread at PS injection further to about -0.37 by re-bucketing on h=2 the ultimate LHC50 in the PSB….  

  – **High intensity MDs with the LHC25 beam** in the PS have shown that for intensities up to ultimate (and even slightly higher) longitudinal coupled bunch instabilities, TMCI at transition, transverse instabilities at flat bottom or flat top have not been a limiting factor.