Hardware needs specific to the 12.5 ns option

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Acknowledgments: R. Garoby, W. Hofle, T. Linnecar,
J. Tuckmantel, F. Zimmermann

LHC upgrade options

Parameter at 7 TeV	nominal intensity	ultimate intensity	shorter bunch	longer bunch
bunch intensity [10^{11}]	1.15	1.7	1.7	6.0
bunch spacing [ns]	25	25	12.5	75
bunch length $4\sigma_t$ [ns]	1.0	1.0	0.5	2.0
long. bunch profile	Gaus.	Gaus.	Gaus.	flat
e-cloud heat load [W/m]	1.1	1.0	13.3	0.3
events per crossing	19	44	88	510
luminosity increase	1.0	2.0	6.0	4.8

F. Ruggiero, W. Scandale, F. Zimmermann, 2006

Plus intermediate options after LUMI'06 (*F. Zimmermann et al.*)

Closer bunches (1/4)

Bunch spacing: 10/15 ns or 12.5 ns?

Report of the Working Group POFPA, CERN, June 2006:

- **"The LHC experiments have expressed clear preferences for going to a spacing of 12.5 ns that could allow most of the front-end electronics to continue running at 40 MHz. A spacing of 10 or 15 ns - which would avoid changes to the timing of the SPS - would be likely to require much more complex modifications..."**

- **"The planning of the R&D and of the upgrade depends crucially on the bunch crossing frequency, it is important that issues are clarified experimentally during the first LHC runs, if possible before the end of 2008."**

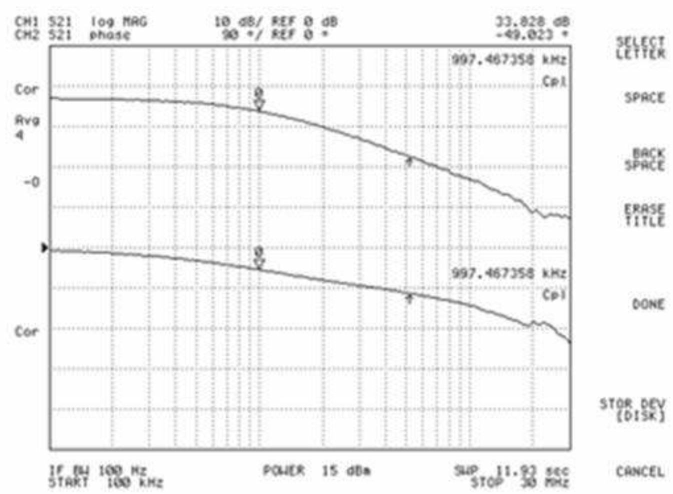
- **The core cost (of SLHC upgrade) estimated both by ATLAS and CMS $\sim$ 200 MCHF/experiment. An additional 25(x2) MCHF are needed if a bunch spacing of 10 or 15 ns is chosen.**

Closer bunches (2/4)

Issues common for closer bunches (with any bunch spacing)

• **Transverse damper/feedback in the SPS and LHC (*W. Hofle*):**
- LHC: 4 kickers/plane/beam=16 total, 20 MHz bandwidth, cost 10 MCHF
→ additional system (10 - 40) MHz for 12.5 ns spacing. Space in the ring reserved for 50% upgrade (current or bandwidth)
- SPS: 2 kickers/plane, 20 MHz bandwidth
• **Beam control system: 40 MHz sampling in the LHC, 80 MHz in the SPS, but analog electronics for 40 MHz**

LHC kicker amplifier



30 MHz ↑

Issues due to increased total current:

• **collimators, RF power, beam dump, element heating, beam control...**

Closer bunches (3/4)

Actual situation: LHC beam with 25 ns bunch spacing

PS: 10 MHz $\rightarrow$ 20 MHz $\rightarrow$ bunch rotation in (40+80) MHz

SPS: 200 MHz (+ 800 MHz for beam stabilisation)

LHC: 400 MHz (+ 200 MHz capture system - staged)

(I) 10 or 15 ns bunch spacing

$\oplus$ SPS: no changes

$\oplus$ LHC: no changes

$\ominus$ PS: a new RF system (the 6th?)

- 10 ns - (95.4-100 MHz)
- 15 ns - (63.5-66.7 MHz)

Closer bunches (4/4)

(II) 12.5 ns bunch spacing

⊕ **Smaller changes in LHC detectors**

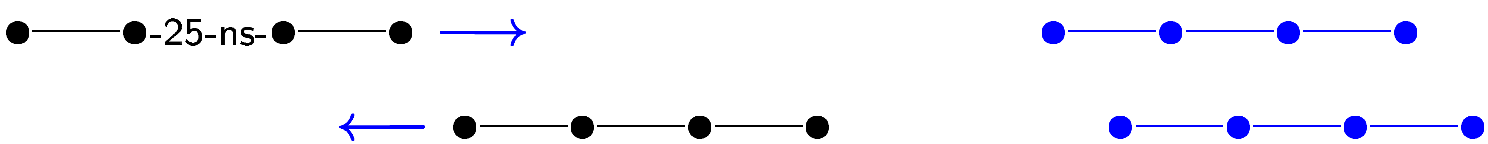
⊕ **PS: only one more bunch splitting...**

⊖ **LHC: a new capture RF system**

⊖ **SPS: no RF system for acceleration**

- RF manipulations on the SPS flat top (momentum slip stacking) → longitudinal emittance blow-up, increased capture losses in the LHC, not robust for high intensity operation

$t = 0$ $\qquad\qquad$ $t \simeq$ **700 ms, extraction**



⇒ new RF system(s) for SPS/LHC

New RF systems (1/6)

(1) 160 MHz in the SPS

$\oplus$ less$^{(*)}$ capture loss in the SPS

$\ominus$ more$^{(**)}$ capture loss in LHC $\rightarrow$ capture system in LHC at 160 MHz (too large - not enough space!) or 240 MHz

$\oplus$ 800 MHz can still be used for FT beam (all buckets full)

(2) 240 MHz in the SPS

$\oplus$ less$^{(**)}$ capture loss in LHC $\rightarrow$ no need for a capture system

$\ominus$ more$^{(*)}$ capture loss in the SPS

$\ominus$ 800 MHz cannot be used for FT beam

(*) in comparison with the nominal PS-SPS transfer

(**) in comparison with the nominal SPS-LHC transfer

New RF systems (2/6)

(3) 400 MHz in the SPS

- ⊕ can be SC - minimise power and impedance
- ⊕ the same as in LHC (?) - easy maintenance
- ⊕ no need for capture system in the LHC: 1 for each ring
- ⊕ 800 MHz in the SPS can be used for all beams if needed
- ⊖ needs a 160 MHz capture system in the SPS

New RF systems (3/6)

Beam stability in the SPS

- Coupled bunch instabilities: $R_{sh}^{th} \propto (\varepsilon f_{rf})^2/\tau$
- Loss of Landau damping (single bunch): $\mathrm{Im}Z^{th}/n \propto (\varepsilon f_{rf})^2\tau$

$\Rightarrow$ Beam stability is higher with a 400 MHz RF system (factor 4) and lower ($\sim$ factor 2) with a 160 MHz RF system (for the same ε) compared to the actual situation (200 MHz)

$\Rightarrow$ Controlled emittance blow-up for 160 MHz option

- flat bottom (26 or 50 GeV/c): $\varepsilon = 1.0$ eVs
- flat top: $\varepsilon = 1.45$ eVs @ 450 GeV
  $\rightarrow$ capture RF system in the LHC (240 MHz?)

New RF systems (4/6)

Accelerating voltage for different RF systems and longitudinal emittances (present 7.5 s ramp)

	V [MV] for ε [eVs]		
f_{rf}	1.0	0.5	0.4
160 MHz	6.3	3.5	
200 MHz	10.6	4.2	
400 MHz	71.0	19.3	13.0

$\Rightarrow$ **The 400 MHz RF system needs much more voltage**

New RF systems (5/6)

160 $\longrightarrow$ 400 MHz transfer

(I) On the flat bottom in the SPS:

ε eVs	V [MV] @160 MHz at P_s [GeV/c]			
	26	40	50	100
0.35	2.5	3.6	3.3	1.9
0.5	5.2	7.3	6.7	4.0

⊖ More volts for transfer at 40 and 50 GeV/c compared to 26 and 100 GeV/c. Plus 13 MV @ 400 MHz for acceleration

(II) At 450 GeV in the SPS for 1.5 eVs:

16 MV @ 160 MHz and 8 MV @ 400 MHz required (adiabatic)

(III) At 450 GeV in LHC for 1.75 eVs:

7 MV @ 160 MHz per ring (x2). Also 10 MV @ 160 MHz in SPS.

$\Rightarrow$ Transfer to 400 MHz on the SPS flat bottom or rise

New RF systems (6/6)

Possible combinations

	RF system at f_{rf} [MHz]				
ring	SPS (1 ring)			LHC (2 rings)	
	capture	accel.	flat top	capture	accel.
actual	200	200	200	- (200)	400
1a	160	160	160	160	400
1b	160	160	160	-	400
1c	160	160	160	240	400
1d	160	160	400	-	400
2a	80/160	240	240	-	400
2b	240	240	240	-	400
2c	80/160	240	240	240	400
3a	160	400	400	-	400

$\Rightarrow$ **Two different RF systems to replace one?**

Summary (1/2)

⇒ **Two main options for the SPS:**

(I) SPS: 80/160 MHz plus 240 MHz, LHC: 240 MHz

(II) SPS: 160 MHz plus 400 MHz

Research and development

- **Superconducting 240 MHz**
- **Wide range tuning systems for low energies and heavy ion acceleration**
- **High power couplers, high power sources and HOM couplers**

Resources

Cost and manpower estimates: "LHC upgrade Scenarios - preliminary estimations of the RF systems", *T. Linnecar et al., 2006*

LHC: RF (I) - 24.2 MCHF + 70 FTE, Tr. damper - 10 MCH + 19.5 FTE

SPS: RF (I) - 34.8 MCHF + 71 FTE, Tr. damper - 5.2 MCHF + 14 FTE

Summary (2/2)

- **Significant resources needed to bring LHC bunches closer and in particular at 12.5 ns**
- **There is no perfect solution for 12.5 ns bunch spacing to replace the actual situation:**

  - at least two new RF systems are required in the SPS

  - operation of 800 MHz RF system, essential for high intensity beams (CNGS), is not possible for 240 MHz option
- **Closer bunches will require upgrade of many other systems: transverse damping/feedback systems in the SPS and LHC, beam control and beam instrumentation to cover increased (40 MHz) bandwidth**
- **Increased total current leads to problems with heating and power**
- **Nevertheless if needed this possibility (resources) can be used for upgrade of 30 years old RF system in the SPS...**