LHC BEAMS PRODUCTION

LOSSES AND IMPACT ON NON-LHC PHYSICS

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With thanks to the OP-teams and Machine supervisor teams

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Content

- The LHC beams produced
- LINAC2 & PSB
- The PS
- The SPS
- Super Cycles and Non-LHC physics
- Conclusions

The LHC Beams Menu

- There are at least 10 flavours of LHC beams that have been produced in the injectors, not all beams are readily available.

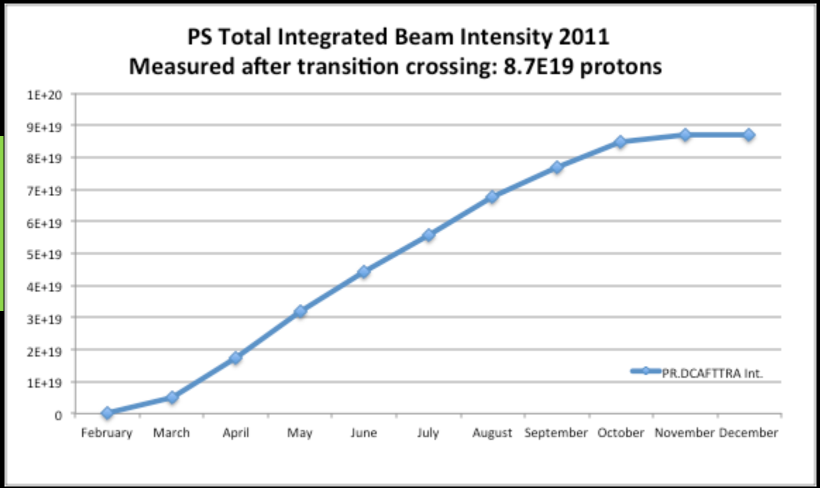
Overview of LHC beams

	PSB extraction				PS extraction			SPS extraction			
	Ip / ring [x10¹¹]	ε_h and ε_v [mm · mrad] 1σ, norm.	nb batches	nb bunches	Ip / bunch [x10¹¹]	ε_h and ε_v [mm · mrad] 1σ, norm.	nb bunches	Ip / bunch [x10¹¹]	ε_h and ε_v [mm · mrad] 1σ, norm.	ε_{longit} [eVs]	nb bunches
LHCPROBE	0.05 - 0.2	≤ 1	1	1	0.05 - 0.2	≤ 1	1	0.05 - 0.2	≤ 1	≤ 0.3	1
LHCPILOT	0.05	≤ 2.5	1	1	0.05	≤ 3	1	0.05	≤ 3.5	≤ 0.8	1
LHCINDIV	1.2	≤ 2.5	1	1 to 4	1.2	≤ 3	1 to 4	1.2	≤ 3.5	≤ 0.8	1, 4 or 16
LHCINDIV (HI)	2.5	-	1	1 to 4	2.5	-	1 to 4	2.5	-	≤ 0.8	1, 4 or 16
LHC150	5	< 1.5	1	6	1.2	< 2	12	1.1	< 2.5 (1.6)	≤ 0.8	1 - 4 x 12
LHC100	Is being reviewed										
LHC75 (SB)	11	1.5	1	6	1.3	1.8	24	1.2	2	≤ 0.8	1 - 4 x 24
LHC50 (SB)	24	3.5	1	3 x 2	1.75	3.5	36	1.45	3.5	≤ 0.8	1 - 4 x 36
LHC50 (DB)	10	1.4	2	4 + 2	1.6	1.6	36	**1.5**	**1.9**	≤ 0.8	1 - 4 x 36
LHC25 (DB)	16	2.5	2	4 + 2	1.3	2.5	72	1.1 5	3.5	0.7	1 - 4 x 72

- The ones used are:
  - LHCPROBE
  - LHCINDIV (normal and high intensity)
  - LHC50 (DB) with 12 and 36 bunches
  - LHC100 for p-pb collisions (low int.)
  - LHC25 (mainly for scrubbing and MD's)
- Considered no longer necessary:
  - LHCPILOT
  - LHC50 (SB)
  - LHC75
  - LHC150

How much protons were produced

- LHC beams represent less than 1% of the total intensity produced by the PS.



8.7×10^{19} of which $\sim 7.5 \times 10^{17}$ for LHC beams to SPS

- To put this in perspective 7.5×10^{17} is less than 1 year of integrated PS extraction losses on the present CNGS beam.
- Due to their low emittances the LHC beams generate little uncontrolled losses in the whole accelerator chain.
- The majority of the losses are voluntary to tailor the beam to the required characteristics.

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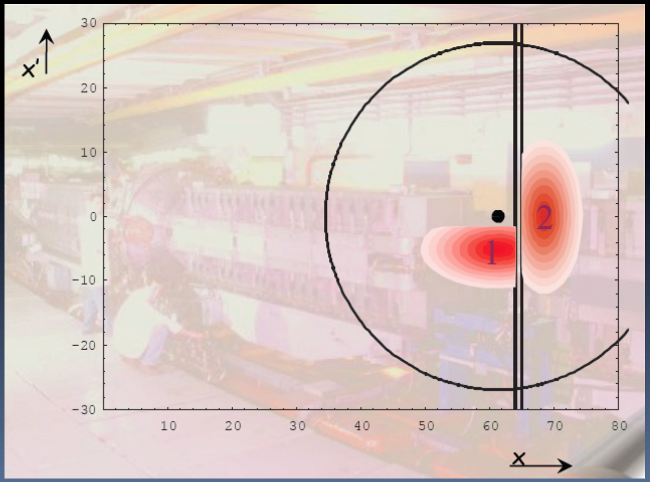
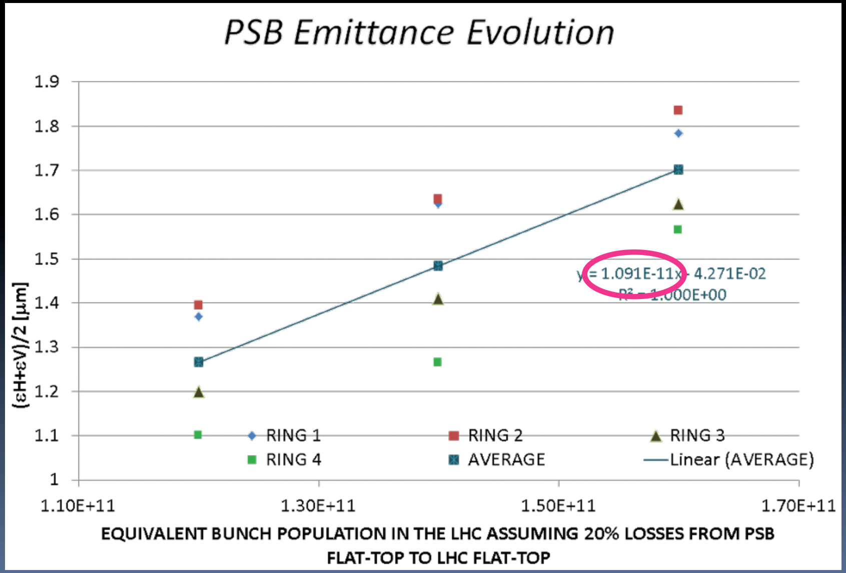
LINAC2 and PS Booster Injection

- LINAC2 will work around 165 mA.
  - Tests to run at 175 mA showed too little gain in brightness.
- The PS Booster uses at present a multi turn injection.
  - Intrinsically lossy (50 MeV).
  - $\varepsilon_h + \varepsilon_h = f$ (intensity).





Courtesy of PSB team

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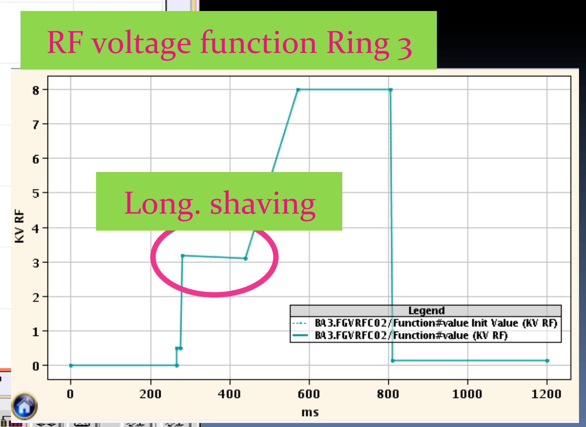
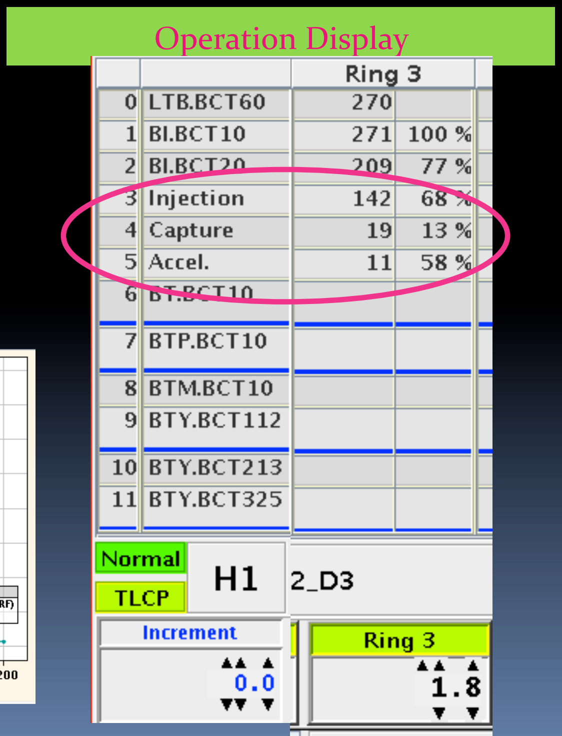
PSB LHCINDIV Beam

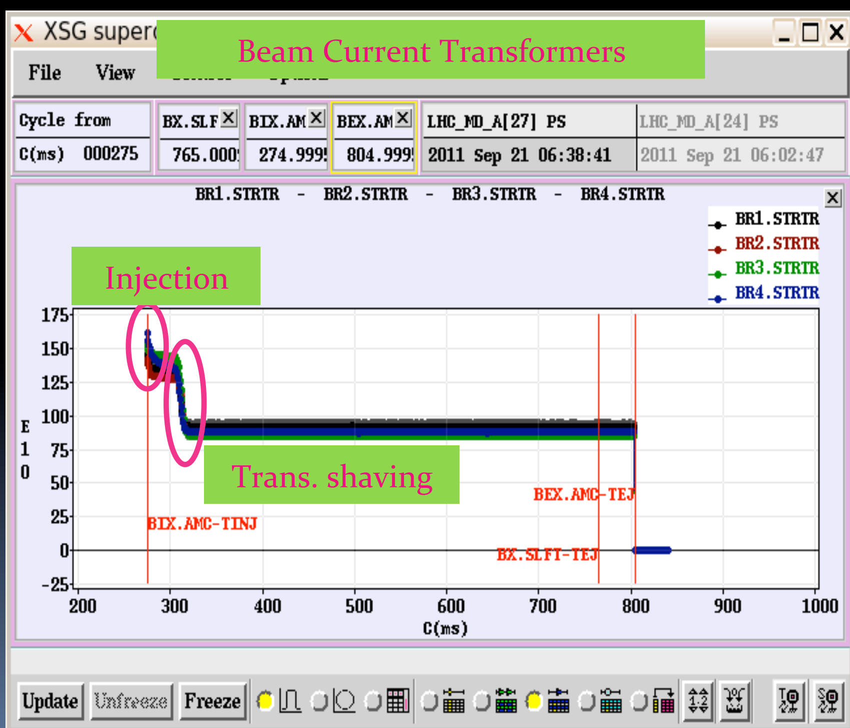
- Injection: ~1.2x10^{12} protons.
- Intentionally badly captured (reduced long. Acceptance).
- Additional longitudinal shaving, reduces intensity from ~2x10^{11} to ~0.2-1.2x10^{10} protons:
  - Starts at ~350 ms after start of cycle.
  - Duration: ~70 ms (depending on final intensity requirement).

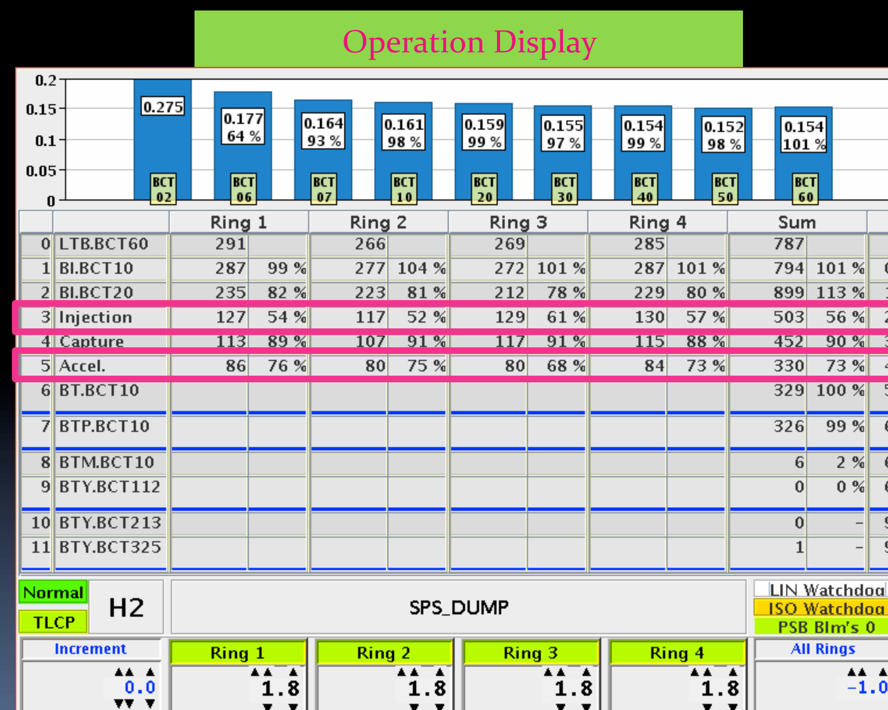




PSB LHC 50 ns beam

- Injection: ~1.5×10^{12} protons.
- Transverse shaving reduces intensity to 8.5×10^{11} protons:
  - starts at 305 ms after start of cycle.
  - Duration: ~10 ms.





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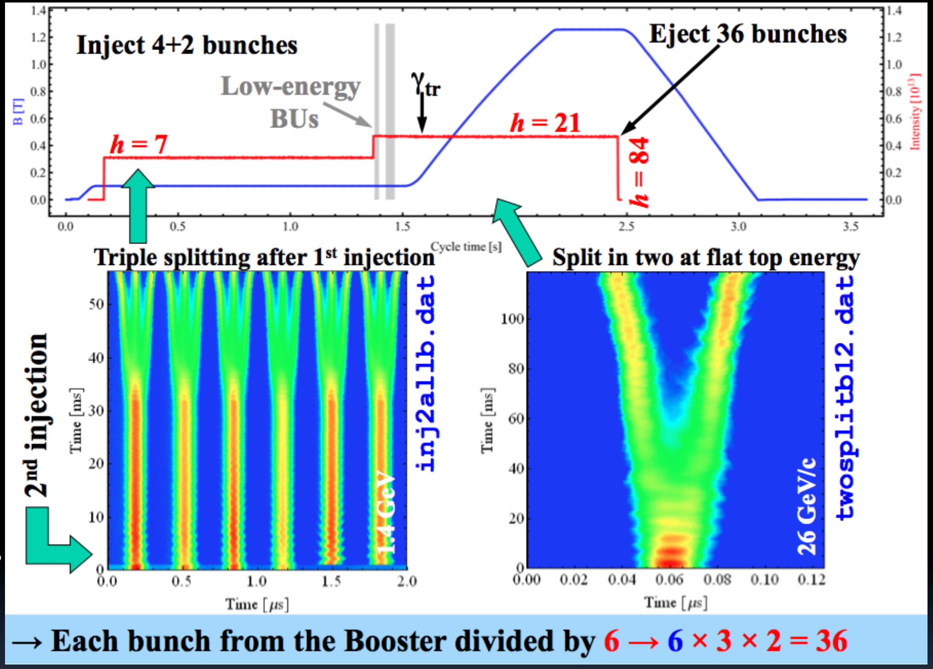
LHC 50 ns Double Batch Production

- Double batch injection from PSB.
- Single Bunch per PSB ring:
  - 1st batch → 4 bunches.
  - 2nd batch → 2 bunches.
- Triple splitting in PS.
- Acceleration.
- Double splitting in PS.
- Bunch rotation in PS.
- $\varepsilon_{Long\ final} = \varepsilon_{Long\ init}$ x 2.33/6.
- $\varepsilon_{h/v} < \varepsilon_{nom}$ and well preserved.



Courtesy of H. Damerau

- Potential issues:
  - Space charge at injection.
  - CBI after γ-jump → ε_{Long}, τ_{bunch}, bunch-to-bunch intensity variations (feedback available).
  - Satellites in kicker gap.

Loss Sources of the LHC 50 ns beam

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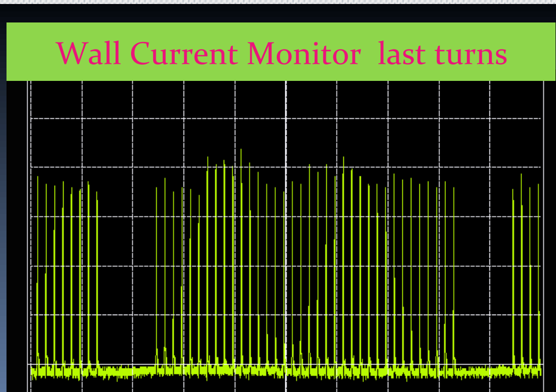
- Slow losses more or less constant along the cycle.
- No noticeable additional losses during RF manipulations.



	Label	Value		
0	PSB acc	325.06		
1	Injection	312.57	96 %	0
2	Bef Trans	472.48	151 %	1
3	Aft Trans	472.48	151 %	1
4	Ejection	470.06	150 %	1
5	Aft Ej	-0.14	-0 %	4
6	BCT 203	472.14	100 %	4
7	BCT 212	489.49	104 %	4
8	BCT 372	469.08	100 %	4
9	BCT 379 (SPS)	461.49	98 %	4
10	BCT 38			4

Very good transmission efficiency

Improved Operability

- The 50 ns double batch beam only became really operational in 2011.
- Two dedicated users for 12 and 36 bunch version were introduced:
  - More cycles/beams to maintain (identical).
  - Improved stability/reproducibility.
  - Reduced switching time.
- Continuous improvement on the RF beam control system improved stability.
- The Operations teams became more and more autonomous in adjustments and optimization.

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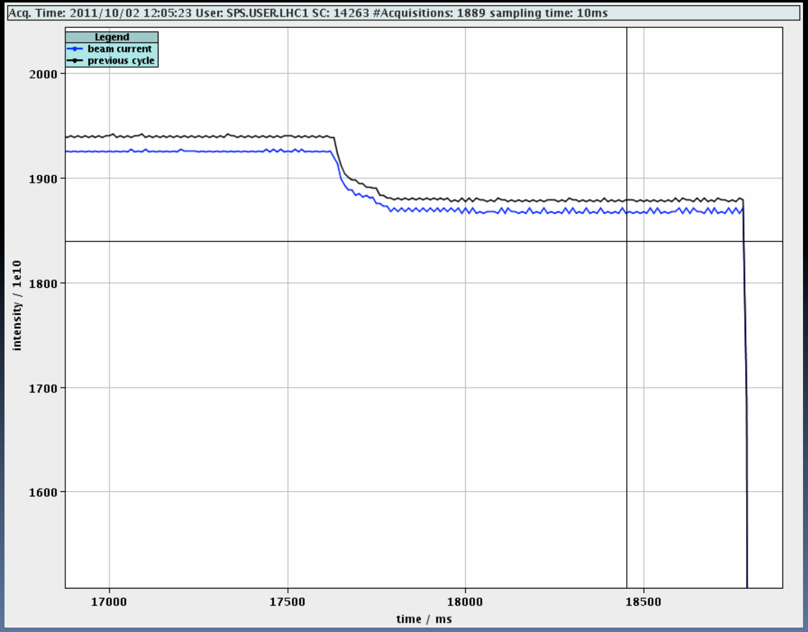
LHC Beams and Losses in the SPS

- During setting up and LHC filling preparation the beam is systematically dumped at 450 GeV on the TIDV.
- A few % of the beam is systematically scraped away.
- During 2011 run, new scrapers were used in LSS1 instead of the old ones in LSS5.

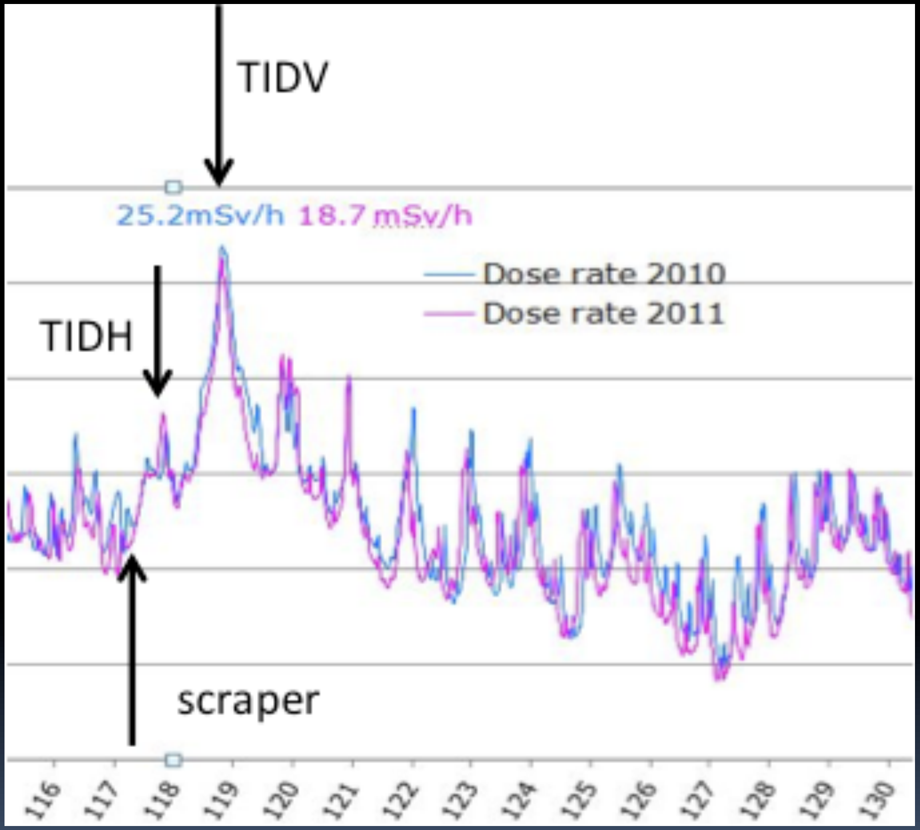


LHC Beams in SPS compared to FT and CNGS

	Total accelerated	dumped	scraped	Total cycle losses
FT	5.85×10^{18}	4×10^{17}	0	9×10^{17}
CNGS	4.82×10^{19}	6×10^{17}	0	2.5×10^{18}
LHC cycles	7.3×10^{17}	5.8×10^{17}	1×10^{16}	5×10^{15}

- Although much less protons are accelerated on LHC type cycles, the amount of protons on the beam dump is comparable to CNGS.
- With the scrapers in LSS1, the lost beam is mainly intercepted by TIDH and TIDV.

Impact of Scraper on the Radiation in LSS1



Comparison between 2010 (no scraper) and 2011 (scraper) surveys shows little impact from the scraper losses on LSS1 radiation levels.

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Impact of LHC Filling on SPS Physics 1/2

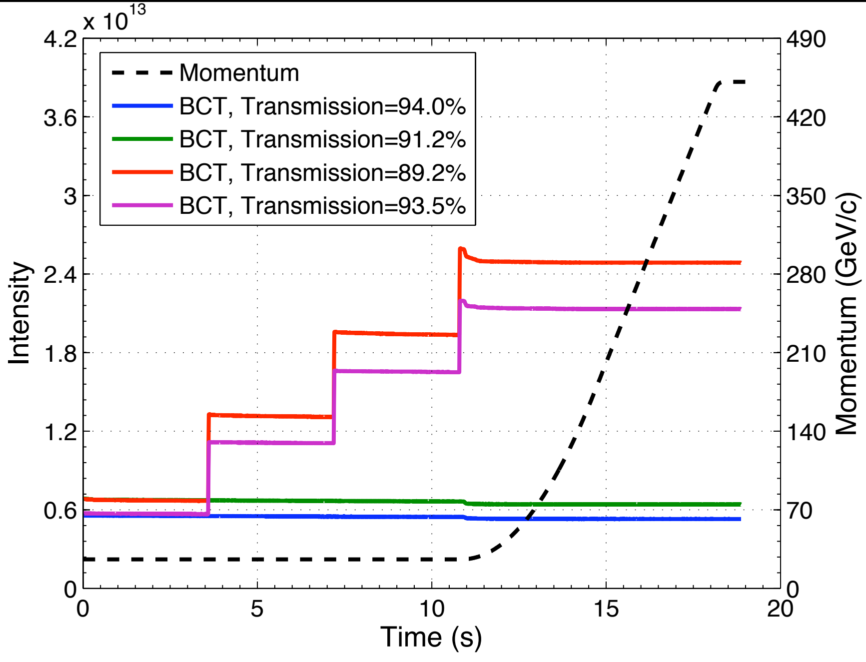
- In 2011, the FT cycle was kept during the LHC filling, but the CNGS duty cycle was reduced from 65% to 15%.
- With the very intense 50 ns beam at the end of 2011, the ZS suffered from sparking and the voltage had to be reduced so that slow extraction was off during LHC filling.
- If ZS sparking problem persists with high intensities, we can consider removing the FT cycle out of the filling super cycle in 2012.

Impact of LHC Filling on SPS Physics 2/2

- Removing the FT cycle from the SC has some undesired operational consequences :
  - The NA users will clearly have less beam.
  - During the LHC filling, the NA timing events will have to continue.
  - For the super cycle with FT, they want the NA timing events only during FT cycle.
  - Interlocks will have to be disabled during LHC filling and re-enabled for FT physics.
  - Fooling around with timing events and interlocks will increase the risk of mistakes and damage. Work on sequencer tasks to reduce those risks is ongoing.
  - The FT cycle is not very demanding for PS and PSB (only two short cycles in 15.6 seconds). Taking it out will have certainly an effect on PS and PSB users.

Transmission in the SPS with Q20

- Higher transmission (less losses) with Q20 low gamma transition optics compared to nominal optics due to:
  - Higher stability → low chromaticity sufficient.
  - Smaller sextupole gradients for chromaticity correction due to higher dispersion.
- Injection to the LHC (at least in MD) to be tried this year.



Q20 – low γ_t optics
50 ns LHC beam

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Parallel Versus Dedicated Filling

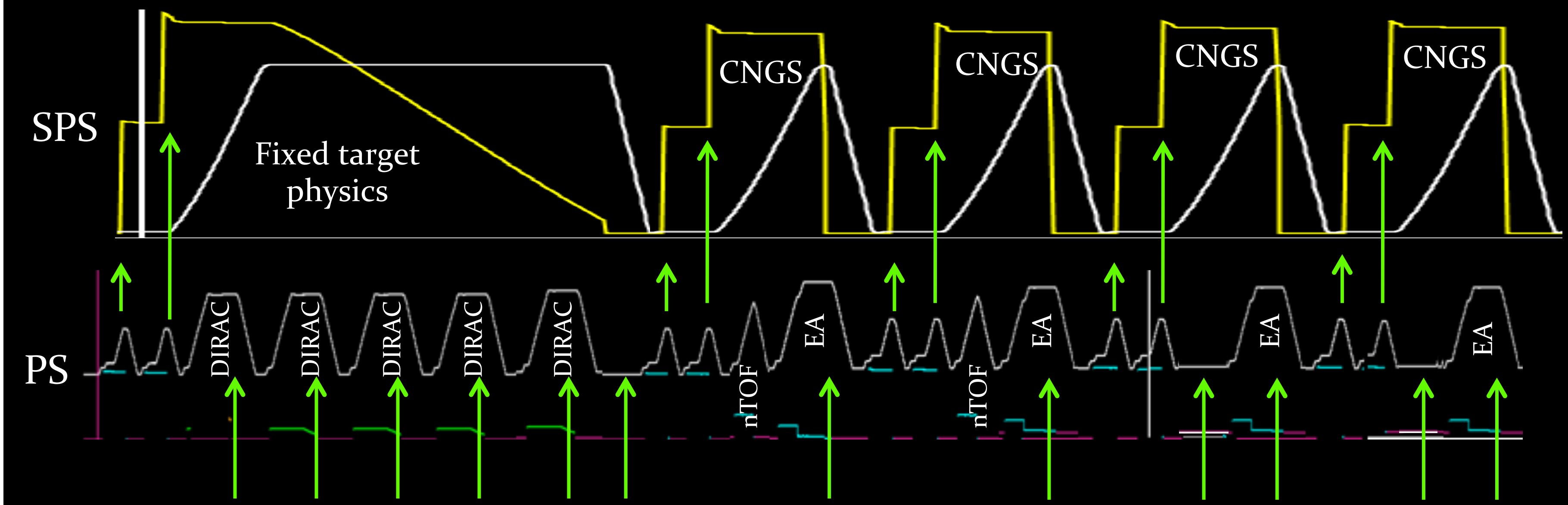
- Assumption: 2 hours filling per 24 hours.
- During parallel filling (~ 8.5% of the time):
  - NA physics can continue, provided ZS does not spark.
  - CNGS reduced from ~65% to ~15% duty cycle.
  - ISOLDE reduced from ~37% to ~34% duty cycle.
  - TOF and EAST no notable change.
  - AD not affected.
- During dedicated filling (problematic for SPS ZS too):
  - No NA physics, no CNGS.
  - ISOLDE from ~37% to ~39%.
  - TOF reduced from ~8% to ~6%.
  - EAST reduced from ~30% to ~10%.
  - AD not affected.
- Relatively little impact for majority of the PS/PSB users, but….

Impact of High Intensity LHC Beams on NA

- For intensities > 1.4x10^{11} ppb the SPS ZS voltage will have to be reduced → no NA physics possible:
  - During parallel and dedicated filling.
  - Also during the parallel MD's with high intensity LHC beams.
  - No NA cycle results in a major reduction for EAST in PS, but more or less neutral for ISOLDE.
- LHC filling represents ~ 8.5% of the time.
- Parallel MD's:
  - Only during day time (~ 40% of the time).
  - Assume ¼ of all parallel MD's to use high intensity LHC beams (~ 10% of the time).
- This means a reduction of ~ 20% in the NA beam time.

LHC BEAMS PRODUCTION

A Super Cycle Example



- Removing the Fixed target cycle has knock-on effects in the PS and possibly in the PS booster.
  - EAST (DIRAC) will suffer.
  - Reshuffling will distribute the burden.

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Conclusions & Questions

- The number of protons produced for LHC is less than 1% of the total amount of protons produced.
- The LHC beam sizes are small:
  - Therefore they produce few losses.
  - The majority of the losses are made "on purpose" to obtain the correct beam characteristics.
  - Many of them are at low energy, apart from SPS scraping and beam dumping.
  - Other beam loss sources on LHC beams are actually due to equipment failures (see G. Metral talk earlier).
- LHC beam with 1.4×10^{11} ppb means no NA.
  - This results in approximately 20% less FT physics time.
- Are there mitigation measures for ZS sparking ?