Summary of HIP analysis on performance of the CERN Accelerator Complex

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Introduction

- Aims of the analysis done by HIP
  - Estimate availability of proton beams for 2006 – 2010.
  - Comparison to the anticipated physics programme.
  - Detection of eventual shortfalls in beam availability.
  - Search for upgrade and improvement possibilities.
  - Study was made in 2003, documented in detail in "Report of the High Intensity Proton Working Group", CERN-AB-2004-022 OP/RF
  - Members: M. Benedikt, K. Cornelis, R. Garoby (study leader), E. Metral, F. Ruggiero, M. Vretenar.

Strategy for the Analysis

- Provide a transparent analysis based on a well defined model for operation (running time, supercycles, etc.)
  - Estimate the yearly time available for all physics operation.
  - Calculate the time required to fulfil each physics user request (based on present performance in routine operation, e.g. intensity…).
  - Assign time slots to different physics users, respecting eventual supercycle constraints.

- Distribution of beam time used for the analysis
  - Fulfil LHC beam request → fixes time for SPS physics (CNGS + FT).
  - Fulfil CNGS request → fixes time for SPS FT
    → fixes remaining time on PS and Booster.
  - Fulfil PS EAST and nTOF requests → fixes Booster time for ISOLDE.

- NOTE: The distribution used for the analysis is by no means a definition of priorities for future operation!

Assumed Machine Schedules

- Total running time 6000 h (PS) and 5500 h (SPS).
- Reduced by start-up, setting-up time and dedicated MDs.
- Correction for machine availability; experience: 90% (PS), 80% (SPS).
- Gives effective time for physics operation.

		2006		2007 - 2010			
		PSB/PS complex	SPS complex	PSB/PS complex	SPS complex		LHC
					2007*	2008-10	
Total running time with beam	[h]	6000	5500	6000	5500	5500	5000
Setup and dedicated MD	[h]	1500	1500	600	1000	800	-
Physics operation	[h]	4500	4000	5400	4500	4700	-
Effective physics hours	[h]	4050	3200	4860	3600	3760	-

- 2006: more time needed for start-up after long shut-down.
- 2007: LHC operation assumed to start in April, 5000 h / year.
- 2007* : Ions for LHC commissioning in SPS requires ~200 h operation time.

SPS Operation Modes (i)

From start of LHC in 2007 there will be 3 SPS operation modes:

- LHC filling mode (single SPS user):
  - For preparation of filling and during filling.
  - The SPS supercycle will contain only the full LHC cycle to guarantee a fully identical machine situation from cycle to cycle.
  - No other SPS physics in parallel.

- LHC set-up mode (multiple SPS users):
  - For verification of injection lines, problem investigations, etc.
  - The SPS supercycle will contain only the short LHC pilot cycle and either CNGS or FT cycles so that every 20s s pilot is available.

- CNGS – FT mode (multiple SPS users):
  - Whenever there is no LHC request (e.g. during physics, access).
  - The SPS supercycle will contain CNGS, FT and MD cycles.

SPS Operation Modes (ii)

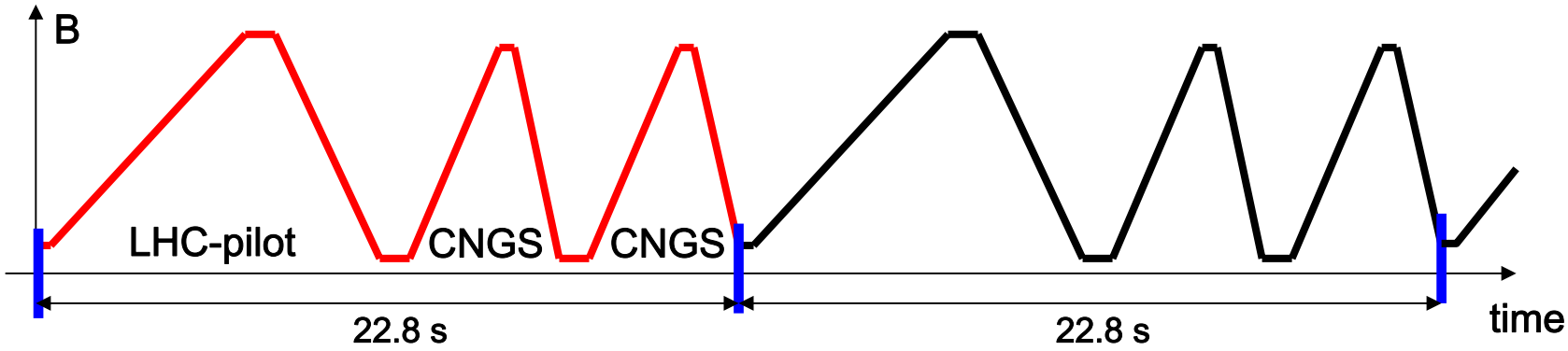
- Estimated distribution of SPS operation modes from LEP experience:
  - 2007: 50% of overall SPS time with 15% filling and 35% set-up mode.
  - LHC request should fall ~linearly to 15% of overall SPS time by 2010.
  - Once the LHC starts with ions, no difference is expected for the distribution of operation modes.

SPS operation mode		**2006**	**2007**	**2010**
Physics operation	[h]	4000	4500	4700
LHC filling mode	[%]	0	15	5
LHC setup mode	[%]	0	35	10
CNGS – FT mode	[%]	100	50	85

  - The switching time between different operation modes (supercycles) should be below 10 min, work in progress.

SPS Supercycle Composition (i)

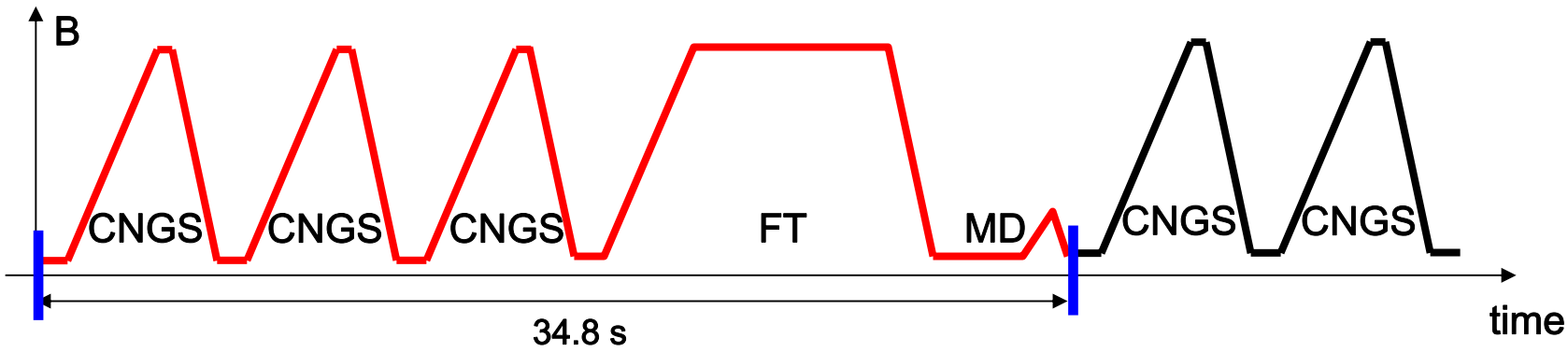
- LHC filling mode:
  - Full LHC cycle (4 batch injection plateau). No other cycles. 21.6 s
- LHC set-up mode:
  - Single batch LHC (1 injection) and 2 CNGS. 10.8 s + 2 x 6 s = 22.8 s.



  - LHC requirement for pilot bunch every 20 – 25 s fulfilled.
  - Replacing the two CNGS by a single FT cycle (12 s) is not possible due to SPS main magnet rms power limitation. An additional “low power” MD cycle would be needed.

SPS Supercycle Composition (ii)

- CNGS – FT mode:
  - 3 CNGS, 1 FT, 1 MD cycle. 3 x 6 s + 12 s + 4.8 s = 34.8 s.



  - This SC was used for the study but again other combinations are possible.
  - Various combinations from only CNGS + MD to only FT + MD are feasible from machine operation point of view.
  - For continuous running with CNGS there will be radiation protection problems in the PS complex (CT transfer extraction) – study ongoing.

PS and PSB Supercycles

- PS and PSB SC can be modified on a cycle to cycle basis, in general more flexibility than for the SPS.
- Highest priority are all beams requested by SPS.
- Remaining slots on PS will be distributed:
  - East Area with parasitic nTOF.
  - nTOF (dedicated operation).
  - MD (PS).
  - AD operation is transparent, single cycle every ~2 min.
- Remaining slots on PSB:
  - ISOLDE.
  - MD (PSB)

CNGS Performance

- Requested performance:
  - 4.5E19 protons on target per year.
- Standard operation conditions:
  - 4.4E13 protons on target / SPS CNGS cycle (90% record intensity).
  - 1E6 SPS cycles to fulfil request. (90 days of continuous running, machine availability included.)

Year	SPS physics operation [hours]	SPS in CNGS-FT or LHC setup mode [%]	Available [pot per year]	Requested [pot per year]
2006	4000	100	4.4×10^{19}	4.5×10^{19}
2007	4500	85	4.2×10^{19}	4.5×10^{19}
2010	4700	95	4.9×10^{19}	4.5×10^{19}

CNGS Operation - Beam Losses

- Based on high intensity SPS FT operation 97/98 (similar to CNGS).

Machine / process	Intensity/cycle	Transmission	Loss/year
CNGS target SPS 400 GeV to target (fast extraction)	4.40×10^{13}	~100%	**negligible**
400 GeV SPS TT10 to SPS 400 GeV (two injections)	4.40×10^{13}	92%	$\mathbf{4.2 \times 10^{18}}$
TT2/TT10 (two batches) Continuous transfer PS - TT2 (two batch)	4.78×10^{13}	90%	$\mathbf{6.8 \times 10^{18}}$
PS 13 GeV (two batches) PSB 1.4 GeV to PS 13 GeV (two batch)	5.31×10^{13}	92%	$\mathbf{5.9 \times 10^{18}}$
PSB 1.4 GeV (two batch)	5.78×10^{13}		

- For 4.5E19 pot, 1.7E19 lost in the accelerators (~factor 2 more than '98).
- PS CT is most critical process, 40% of all losses (studies for replacement).
  - More maintenance, longer cooling down, increased dose to personnel.
  - Continuous CNGS operation with nominal intensity will exceed dose rate limits in several surface buildings close to PS tunnel.

SPS Fixed Target Performance

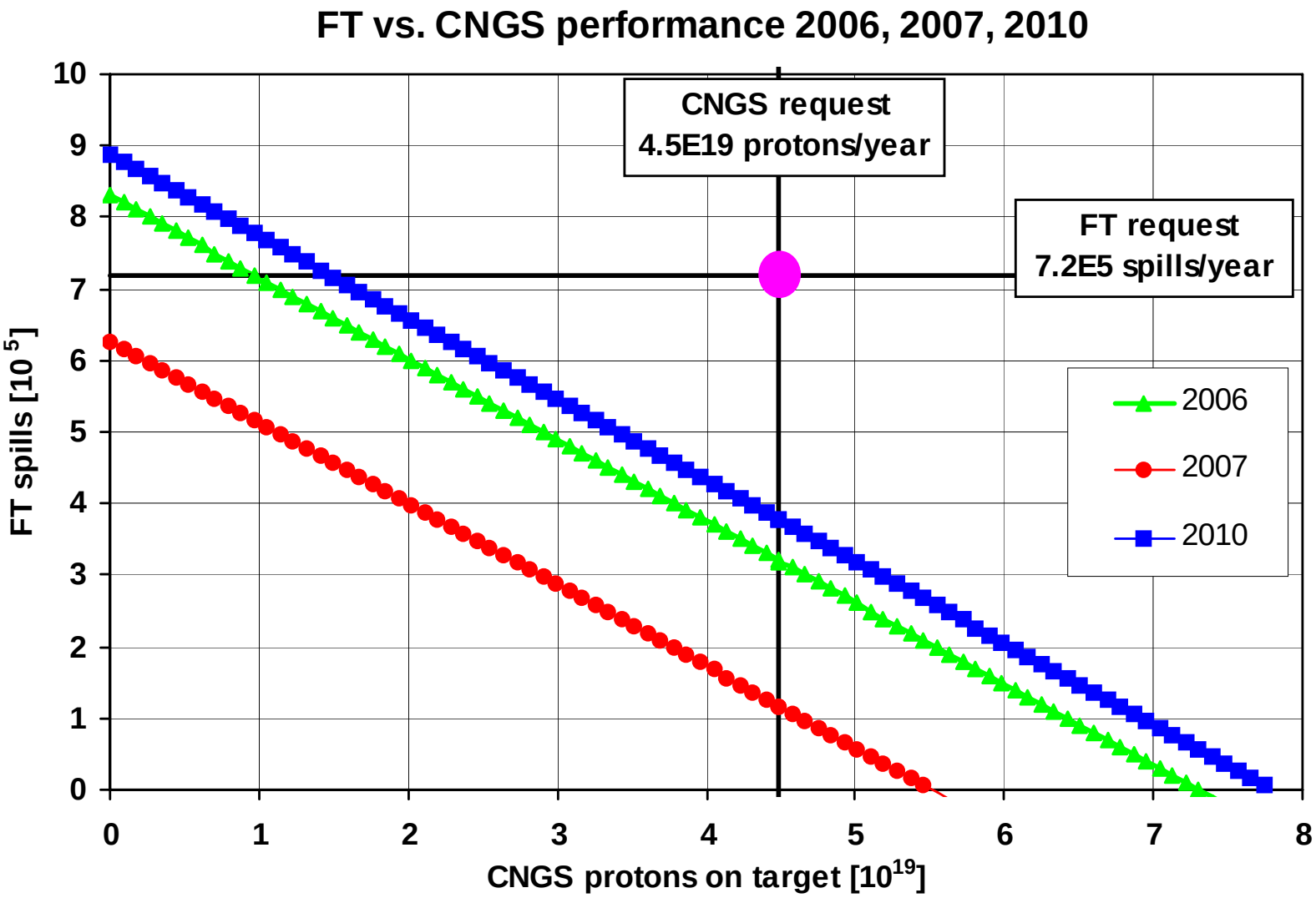
- Requested performance:
  - 7.2E5 spills per year (COMPASS proposal 1996).
- Standard operation conditions:
  - Spill of 4.8s per SPS FT cycle, considered a routine operation.

Year	SPS physics operation [hours]	SPS in CNGS – FT mode [%]	Spills for FT physics	FT physics request
2006	4000	100	3.3×10^5	7.2×10^5
2007	4500	50	1.8×10^5	7.2×10^5
2010	4700	85	3.3×10^5	7.2×10^5

  - Available spills are significantly below request.

- FT is competing with CNGS for SPS operation time, performance depends linearly on assigned operation periods.
- Any additional SPS programme e.g. non LHC ion physics is also competing.

CNGS vs. FT Performance



PS East Area and nTOF Performance

- Assumed requests:
  - 1.3E6 spills (2006), 2.3E6 spills (from 2007) for East Area (DIRAC proposal).
  - 1.5E19 protons on target for nTOF.
- Standard operation conditions:
  - Spill of ~450 ms per East Area cycle, routine operation.
  - 4E12 pot for parasitic nTOF and 7E12 pot for dedicated operation.

Year	PS physics operation [hours]	Spills to East Area	East Area request	Protons for nTOF	nTOF request
2006	4500	1.3×10^{6}	1.3×10^{6}	1.4×10^{19}	1.5×10^{19}
2007	5400	2.3×10^{6}	2.3×10^{6}	1.6×10^{19}	1.5×10^{19}
2010	5400	2.3×10^{6}	2.3×10^{6}	1.6×10^{19}	1.5×10^{19}

- PS user requests can be fulfilled (AD included).
  - No cycles assigned to East Area test beams.

ISOLDE Performance

- Assumed request:
  - 50% of yearly PSB cycles (1350 cycles/hour on average).
- Standard operation conditions:
  - Up to 3.3E13 pot per cycle, routine operation.

Year	PSB physics operation [hours]	PSB cycles to ISOLDE [%]	[cycles/h]	PSB cycles requested [%]	[cycles/h]
2006	4500	48 %	1296	50%	1350
2007	5400	43 %	1160	50%	1350
2010	5400	45 %	1220	50%	1350

- Isolde performance estimated to be around 10% below request.
  - Increase of East Area spills or CNGS operation in double batch mode will have direct impact on ISOLDE performance.

Conclusions

- All present requests for physics on PS can be fulfilled.
- ISOLDE performance is around 10% below request.
- Significant shortfall on SPS for CNGS and FT physics together.
  Any additional SPS programme will be competing for operation time.
- The only immediate “fix” would be to increase the yearly physics operation time (potential gain for all users).

Outlook

- A possible scenario for improvement:
  - Significant increase of intensity per SPS CNGS cycle.
  - Redistribution of the “gained” SPS operation time.

  - Machine operation issues (how to do this).
  - Radiation protection issues (PS Continuous Transfer Extraction).
  - Requires 2 batch injection from PSB to PS (i.e. twice as many PSB cycles).
  - Will decrease significantly ISOLDE performance.

- 3 studies have been launched in this context:
  - “Increase of intensity per pulse for CNGS operation” (PS&SPS high intensity).
  - “Multi-turn island extraction from the PS” to replace C.T. and reduce losses.
  - “Increase of the PSB repetition rate” to have more PSB cycles available.