FT/CNGS beam in the SPS now and with PS2

SPSU Meeting, July 5, 2007

Based on Report CERN-AB-2007-013-PAF,
"Analysis of the maximum potential proton flux to CNGS",
M. Meddahi and E. Shaposhnikova

Acknowledgments:
PAF Working Group, T. Linnecar

Maximum proton flux to CNGS

Flux: $n_{cycle} \times$ availability $\times N_{tot}$

- **Total beam intensity per SPS cycle N_{tot} - ?**
- **Beam availability $\sim$ 80%**
- **Number of cycles n_{cycle}**

$$n_{cycle} = n_{days} \times 24 \times 3600 \times S/T_{cycle}$$

- **Number of days of operation $n_{days} = 200$**
- **$T_{cycle} = 6$ s, 7.2 s and 4.8 s**
- **Beam sharing S (different SPS users)**

For $S = 0.5$ and $T_{cycle} = 6$ s $\rightarrow n_{cycle} = 1.44 \times 10^6$ and for 80% availability, $N_{tot} = 4.8 \times 10^{13} \rightarrow$ flux $= 5.5 \times 10^{19}$ (nominal CNGS - 4.5×10^{19} pot/year for 5 years)

Number of cycles for CNGS

Beam sharing

(updated analysis of HIPWG, 2004)

1. **CNGS-FT mode - 85% (80%) of the SPS beam time:**
   1FT (16.8 s) + 3 CNGS (18 s) + MD (4.8 s) $\rightarrow S_1 = 0.45$
2. **LHC set-up mode - 10% of the SPS beam time:**
   pilot (7.2 s) + 2 CNGS (12 s) $\rightarrow S_2 = 0.625$
3. **LHC filling mode - 5% (10%)** $\rightarrow S_3 = 0$

- **SPS users: CNGS, LHC, FT and MD**

$$S = 0.85 \cdot 0.45 + 0.1 \cdot 0.625 = 0.445(0.425) \rightarrow S = 0.45$$

- **SPS users: CNGS and LHC**

$$S = 0.85 + 0.1 \cdot 0.625 = 0.9125(0.8625) \rightarrow S = 0.85$$

CNGS cycle length

Present situation:

- **PS: 1.2 s basic period,**

  - 1.2 s CNGS cycle @14 GeV/c: - below the SPS γ_t

  - 3.6 s LHC cycle @26 GeV/c: - above the SPS γ_t

- **SPS: 14 GeV/c $\rightarrow$ 400 GeV/c, 1.2 s flat bottom,**

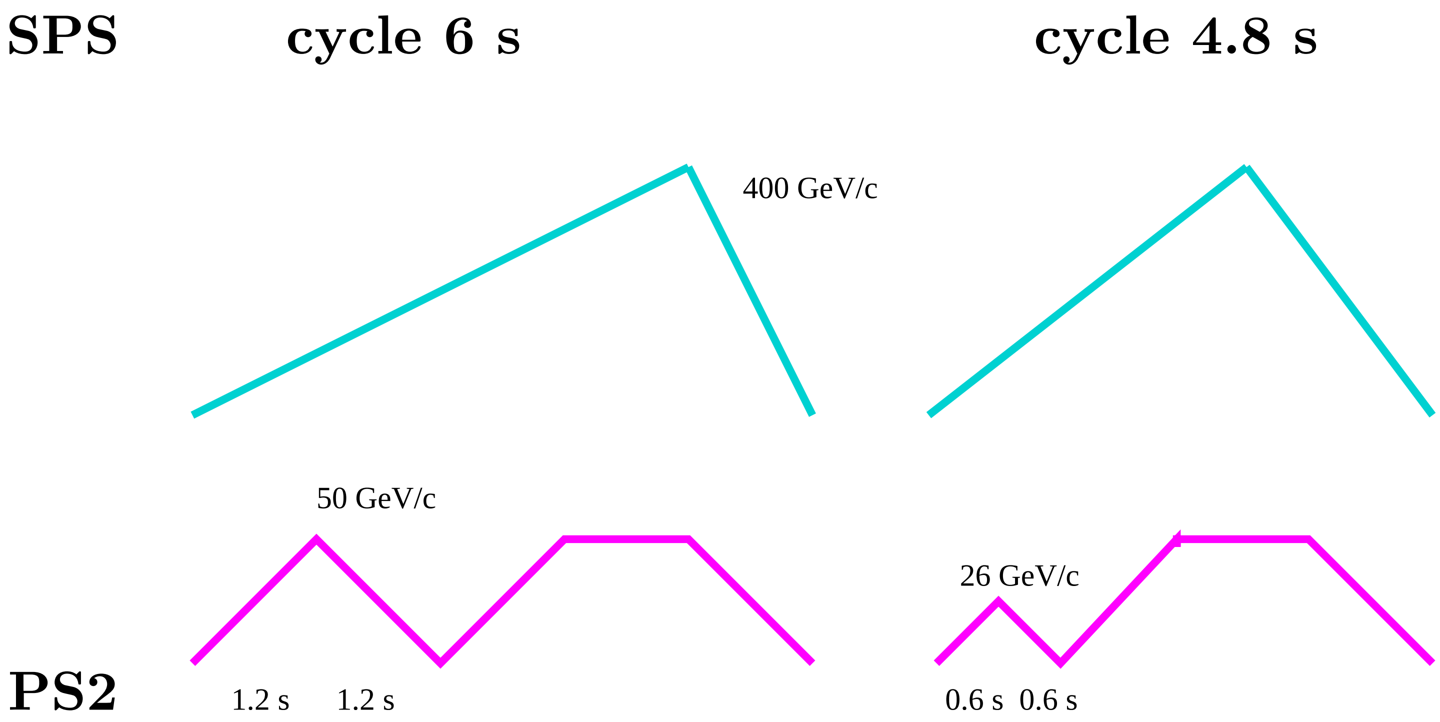
  $t_{acc} = 3$ s and $T_{cycle} = 6$ s

With PS2: no 1.2 s flat bottom in the SPS $\rightarrow$ 6 - 1.2 = 4.8 s?
but FT users in the PS2 (slow extraction $\sim$ 1.2 s - PS2 WG)

Different possible supercycles in the PS2:

- **(50 & 50) GeV/c: (1.2+1.2) s + (1.2+1.2+1.2) s = 6 s**
- **(26 & 50) GeV/c: (0.6+0.6) s + (1.2+1.2+1.2) s = 4.8 s**
- **(50 & 26) GeV/c: (1.2+1.2) s + (0.6+1.2+0.6) s = 4.8 s**

CNGS cycle length



Maximum intensity in the SPS

$$N_{tot} = ?$$

- **nominal CNGS:** $N_{tot} = 4.8 \times 10^{13}$ **(record 1997)**
- **new record** (*G. Arduini et al., 2004*)**:**

  - 5.7×10^{13} **above transition (early dump due to losses)**

  - 5.3×10^{13} **at 400 GeV/c**
- $N_{tot} = 7 \times 10^{13}$ **- maximum from PS with a double batch injection** $\rightarrow T_{cycle} = 7.2$ **s - ultimate CNGS**
- $N_{tot} = 1 \times 10^{14}$ **- maximum from PS2 (PS2 WG)**
- **CNGS target:** $N < 3.5 \times 10^{13}$ **per extraction**

Different SPS filling schemes (1/4)

- **PS:**

  SPS = 11 x PS: 2 x 10.5 μs $\rightarrow$ 21/23 = 0.913 SPS filled

- **PS2 (with 5-turn extraction, kicker gap of 1.1 μs and intensity limitation for CNGS target)**

  SPS = 5.5 x PS2: 5 x 3.1 μs $\rightarrow$ 15.5/23 = 0.67 SPS filled

  SPS = 5.0 x PS2: 5 x 3.5 μs $\rightarrow$ 17.5/23 = 0.76 SPS filled

  SPS = 5.13 x PS2: 5 x 3.38 μs $\rightarrow$ 16.9/23 = 0.735 SPS filled

  (5.133=77/15, *R. Garoby, AB-Note-2007-020 BI***)**

Different SPS filling schemes (2/4)

Additional considerations after discussion at APC on 8.06.2007:

- **The PS2 extraction kicker rise time is only 150 ns**

(*M. Barnes et al, AB-Note-2007-001*)

- **With the CNGS target which can stand whole intensity**

(1) For SPS = (5.25=21/4) x PS2 $\rightarrow$ 21.15/23 = 0.92 SPS filled
(23/5.25 - 0.15 = 4.23, 5 x 4.23=21.15) $\rightarrow$ t_{gap} = 1.25 μs

(2) For SPS = 5.13 x PS2 (present option)

- **21.67/23 = 0.94 SPS filled $\rightarrow$ t_{gap} = 0.73 μs**
- **19.8/23 = 0.86 SPS filled with 0.5 μs gap in PS2**
  $\rightarrow$ t_{gap} = 1.1 μs
- **e-cloud with smaller gaps and lower bunch intensity?**

Different SPS filling schemes (3/4)

Consequences for the FT beam

Present situation:

- **total intensity $\sim 3.2 \times 10^{13}$, flat top: 4.8 s**
- **two beam gaps of 1 μs**

  - after RF gymnastics (jump to unstable phase) filled from both sides during $\sim$ 0.3 s

  - still 1 s of the spill is practically lost due to the residual beam structure at the revolution (43 kHz) and RF (200 MHz) frequencies

  - recent proposal (G. Arduini et al): 9.6 s long flat top with twice more intensity for COMPASS and 60% more for the North Area

In future beam gap t_{gap} with PS2 =

- **SPS/5.5 $\longrightarrow 23 \times (1 - 5/5.5) = 2.1\ \mu s,\ t_{gap} = 2.25\ \mu s$**
- **SPS/5.13 $\longrightarrow 23 \times (1 - 5/5.13) = 0.6\ \mu s,\ t_{gap} = 0.73\ \mu s$**
- **SPS/5.25 $\longrightarrow 23 \times (1 - 5/5.25) = 1.1\ \mu s,\ t_{gap} = 1.25\ \mu s$**

Different SPS filling schemes (4/4)

- **PS:** 5 ns bunch spacing in the SPS (4210 bunches)
- **PS2:** 25 ns bunch spacing in the SPS (620-700 bunches)

N_{tot}	$N_b/10^{10}$ for SPS size =			
$[10^{13}]$	11xPS	5.5xPS2	5xPS2	5.14xPS2
4.8	1.14	7.74	6.86	7.1
7.0	1.66	11.3	10.0	10.3
10.0	2.38	16.1	14.3	14.8

⇒ Single bunch intensity is below the ultimate LHC

Main intensity limitations

- **e-cloud**
- **Equipment heating (MKE, HOM couplers, beam instrumentation...)**
- **Beam losses**
- **Transverse damper**
- **RF voltage and power, beam control**
- **...**

Main RF limitations

- **Beam stability and sufficient bucket area for controlled emittance blow-up: scaling from the LHC beam, $\varepsilon_L \propto \sqrt{N}$**
- **Maximum available voltage in the 200 MHz RF system: 7.5 (8) MV**
- **Maximum available RF power in one 200 MHz TW cavity in the pulsed mode**

  - 700 kW for full SPS ring

  - 1.4 MW for 1/2 ring - not tested experimentally

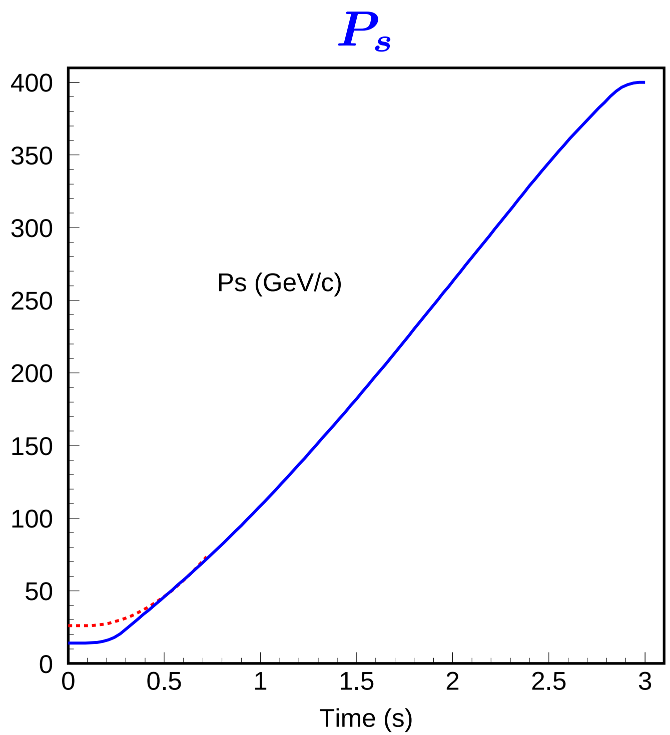
  $\sim$ 1 MW (for full ring) - with serious upgrade

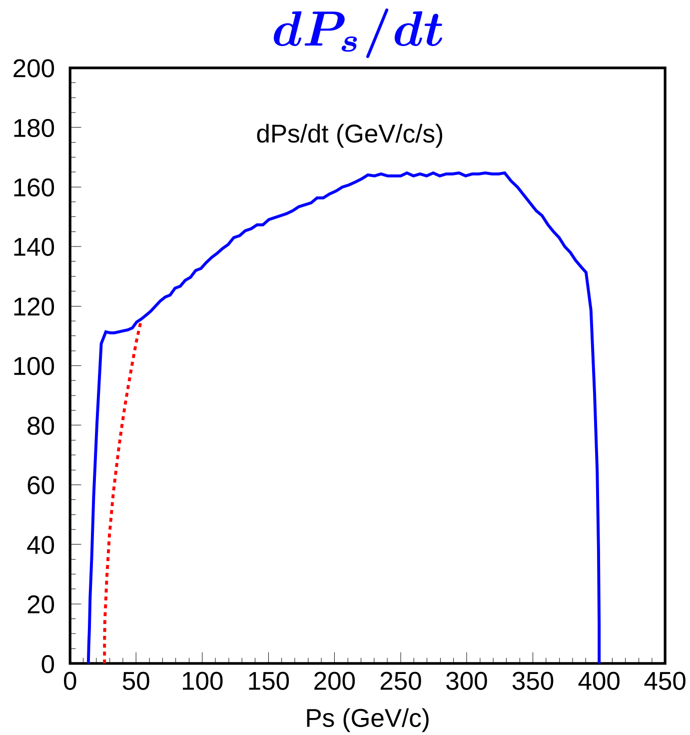
RF current used for RF power estimations

N	I_{rf} [A] for SPS =			
[10^{13}]	11xPS	5.5xPS2	5xPS2	5.13xPS2
4.8	0.73	1.0	0.88	0.91
7.0	1.06	1.45	1.28	1.32
10.0	1.52	2.07	1.83	1.89

Nominal cycle (1/2)

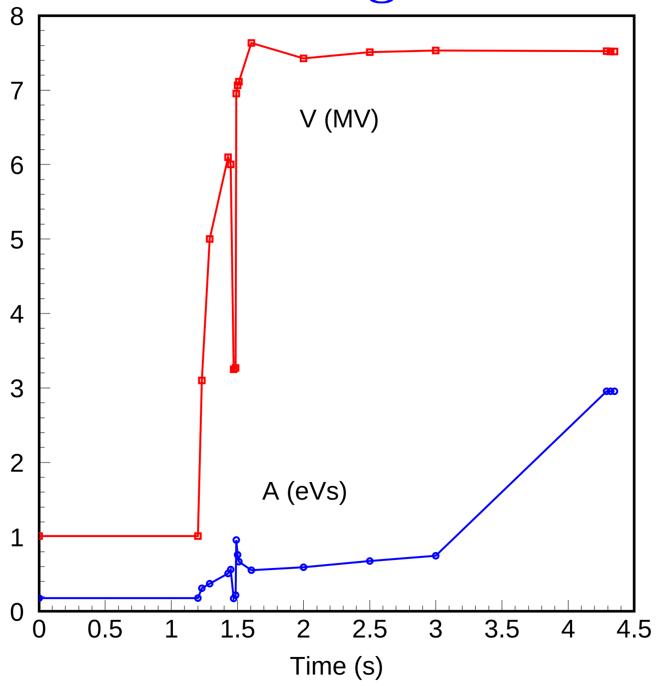
Synchronous momentum



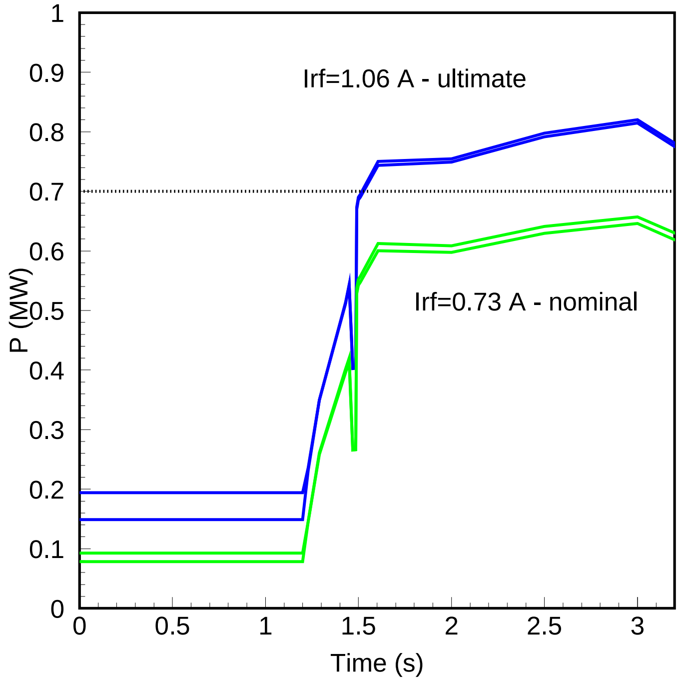


Nominal cycle (2/2)

Voltage

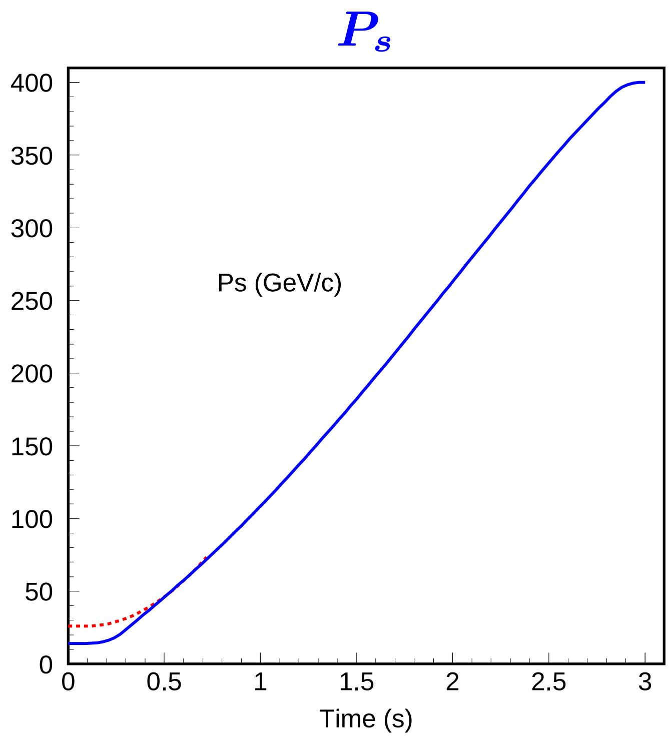


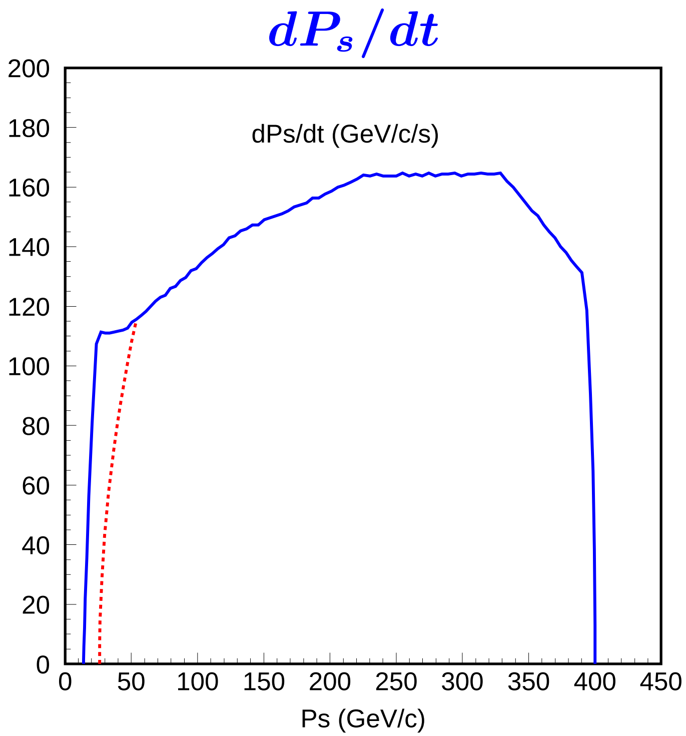
Power



Short cycle from 26 GeV/c (1/5)

Synchronous momentum

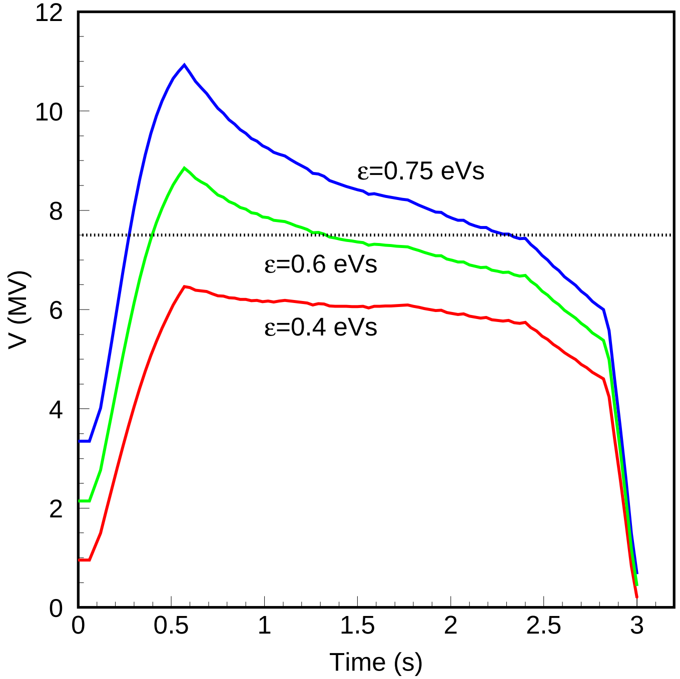




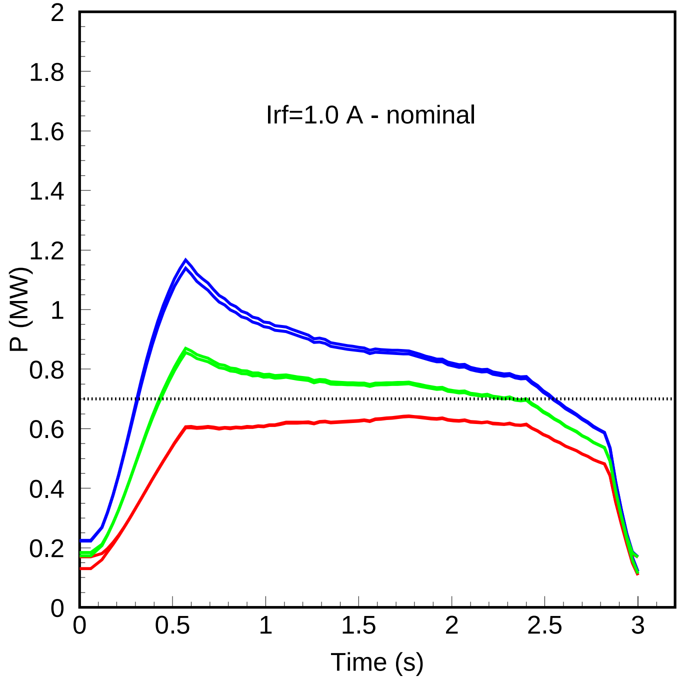
Short cycle from 26 GeV/c (2/5)

SPS = 5.5 PS2

Voltage



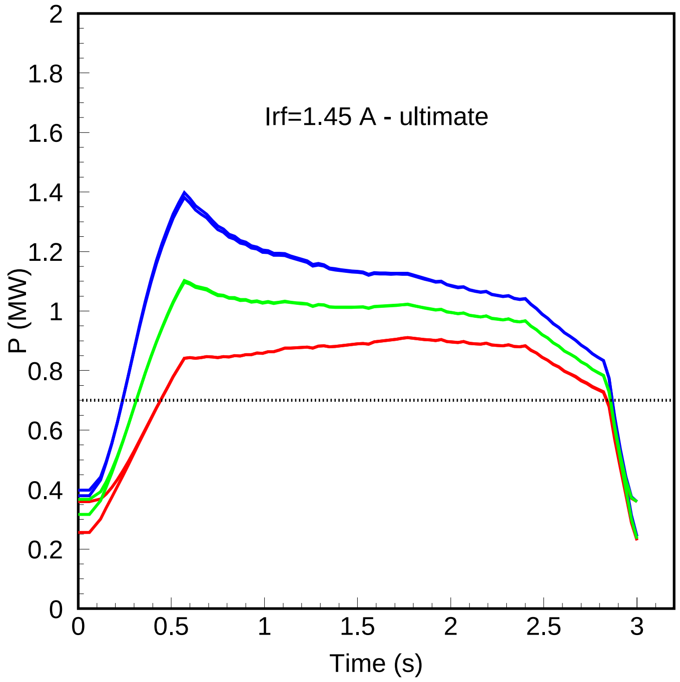
Power



Short cycle from 26 GeV/c (3/5)

SPS = 5.5 PS2

Power



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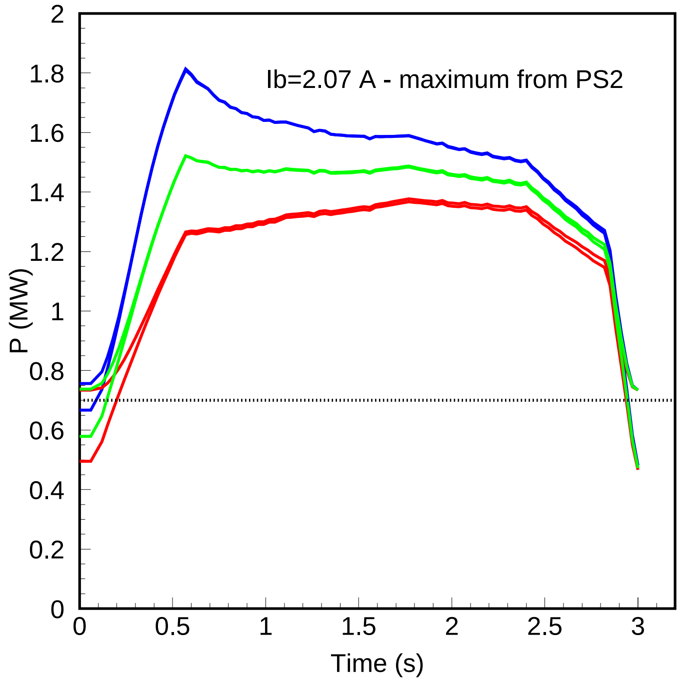
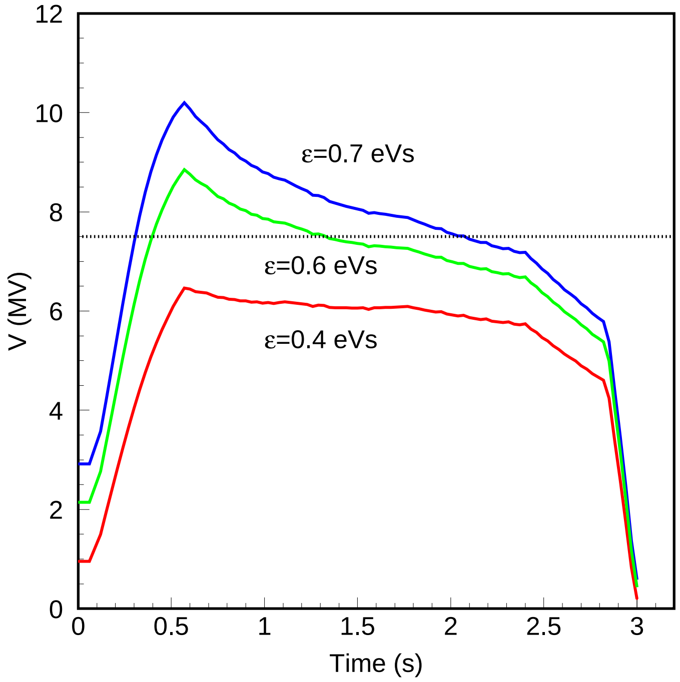


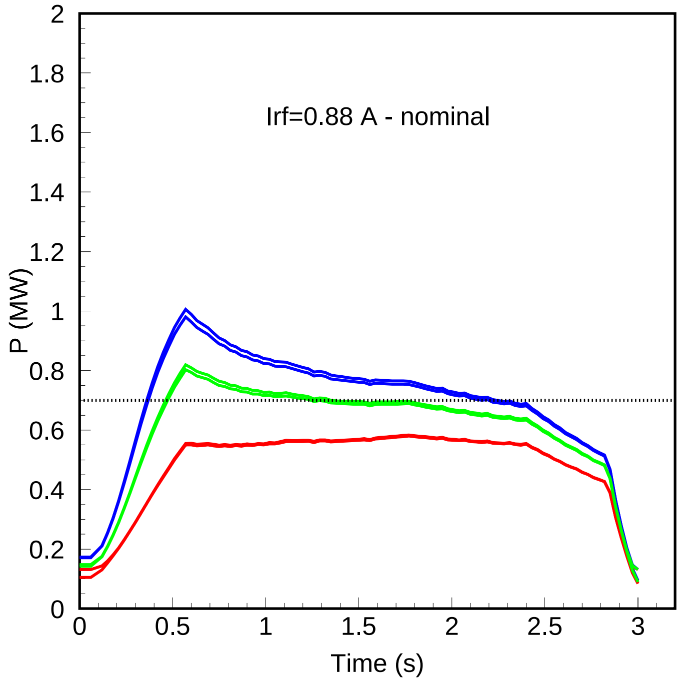
Short cycle from 26 GeV/c (4/5)

SPS = 5.0 PS2

Voltage



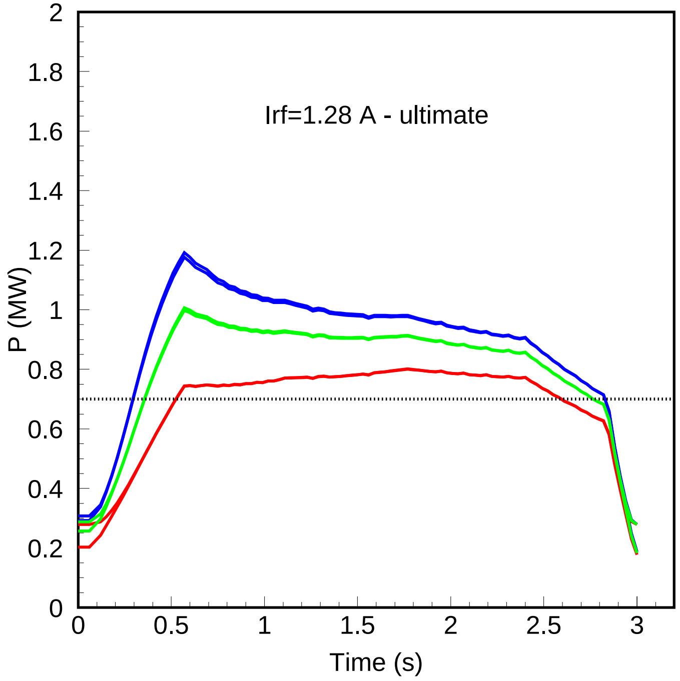
Power



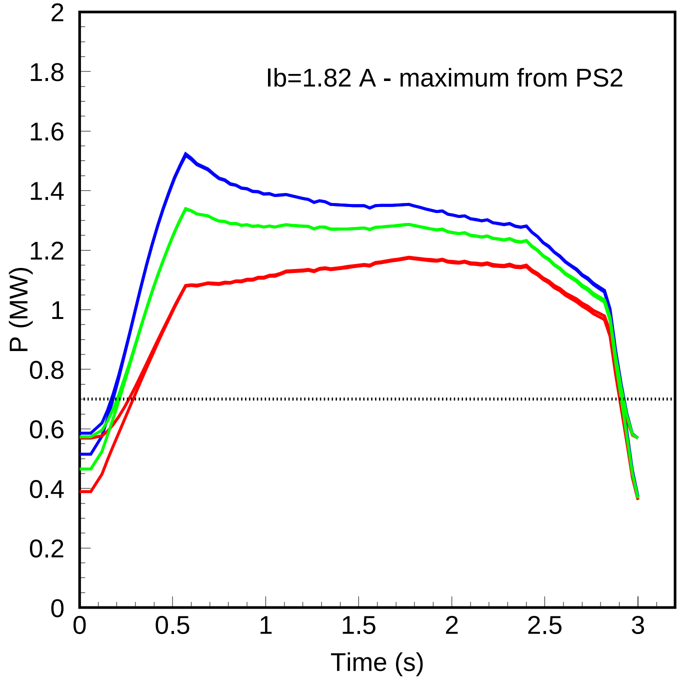
Short cycle from 26 GeV/c (5/5)

SPS = 5.0 PS2

Power



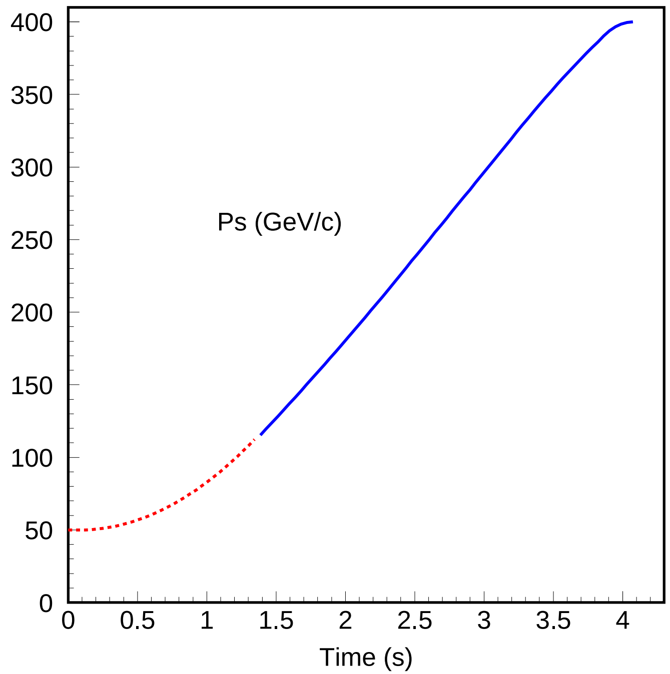
Power



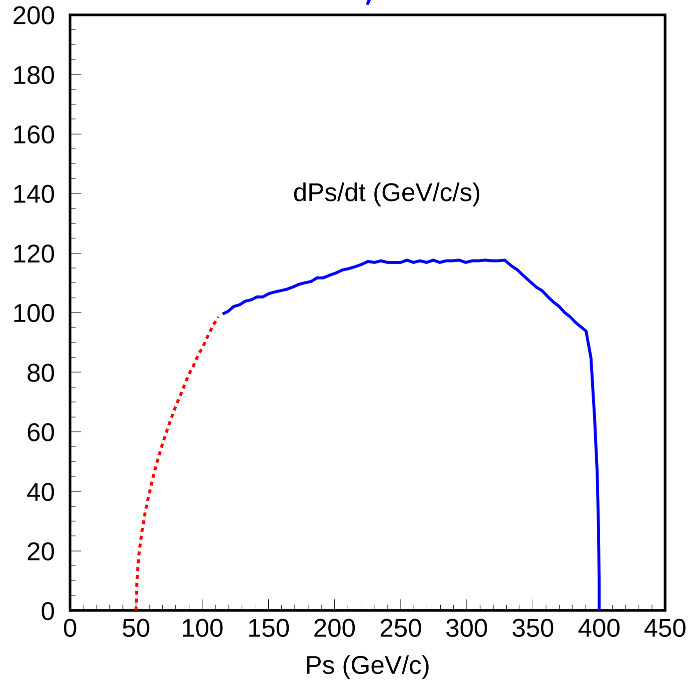
Long cycle from 50 GeV/c (1/3)

Synchronous momentum

P_s



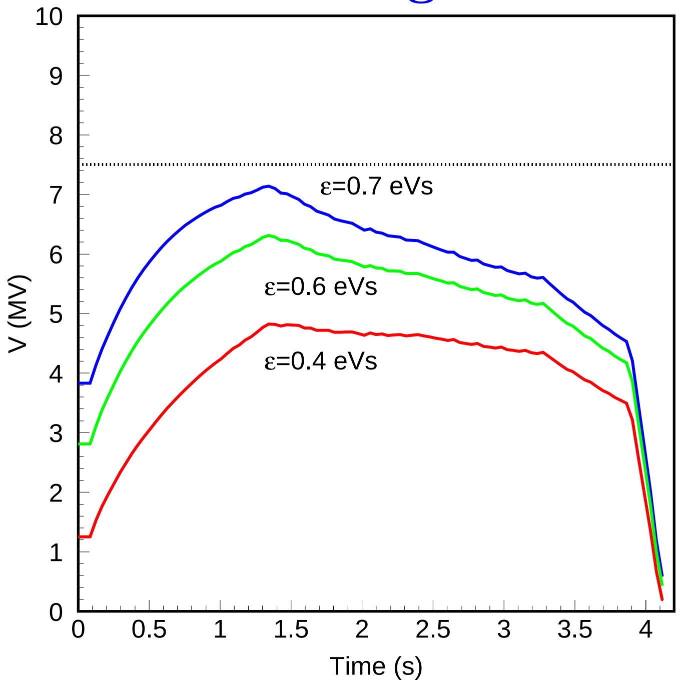
dP_s/dt



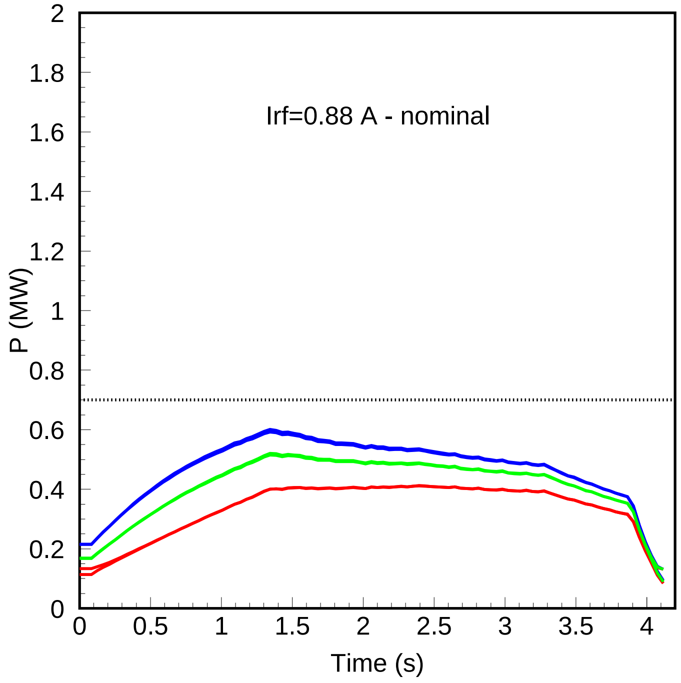
Long cycle from 50 GeV/c (2/3)

SPS = 5.0 PS2

Voltage

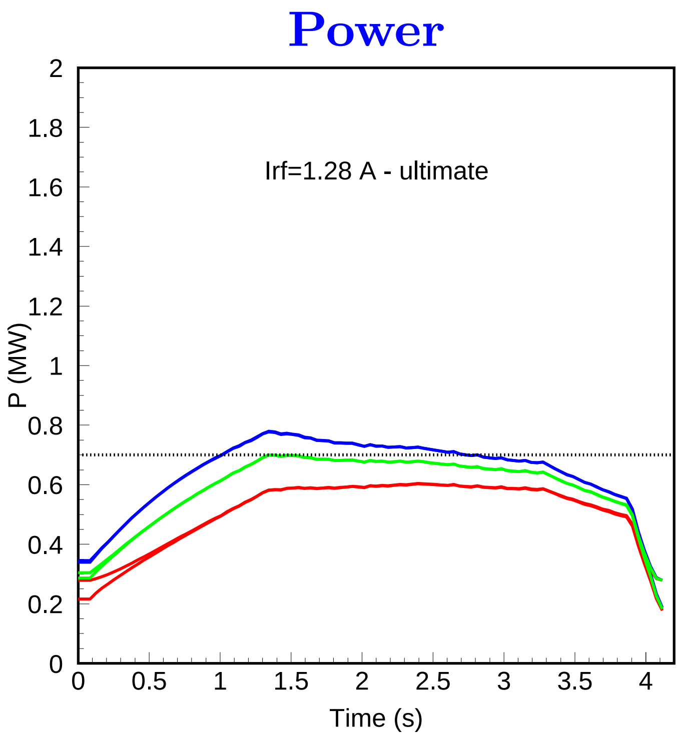


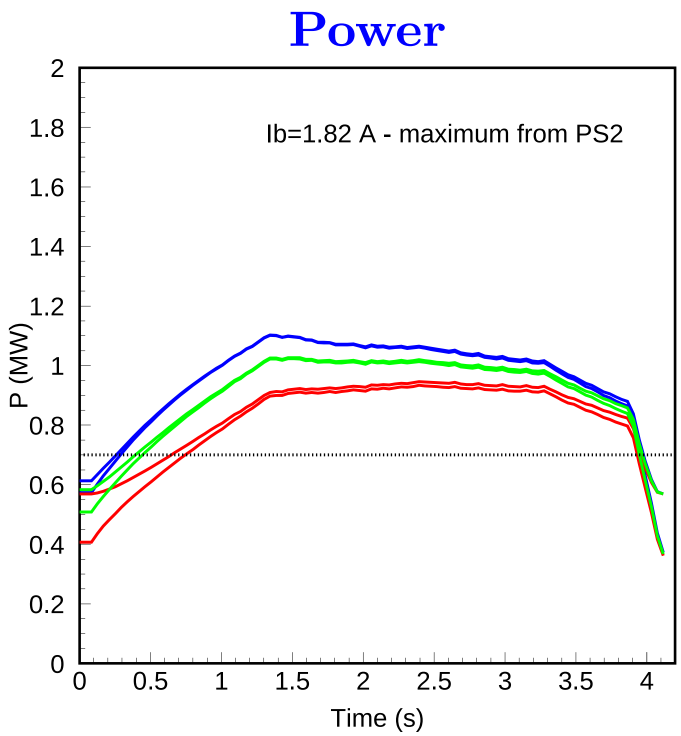
Power



Long cycle from 50 GeV/c (3/3)

SPS = 5.0 PS2





Summary for RF limitations

RF voltage [MV] for different t_{acc}

	SPS= 11 PS	SPS = 5.5 PS2	SPS ≃ 5 PS2	
	3.0 s	3.0 s	3.0 s	4.2 s
≥ 250 GeV/c	7.5	8.0	7.5	6.0
maximum	7.6	11.0	10.5	7.0

RF power per cavity [MW] for different t_{acc}

N	SPS= 11 PS	SPS = 5.5 PS2	SPS ≃ 5 PS2	
$[10^{13}]$	3.0 s	3.0 s	3.0 s	4.2 s
4.8	0.65	0.9	0.75	0.5
7.0	0.85	1.15	1.0	0.7
10.0		1.6	1.4	1.1

To provide the same number of pot/year with 6 s cycle ($t_{acc} = 4.2$) s the SPS should run at 25% higher intensity than with 4.8 s cycle

Beam losses (1/2)

- **Beam loss is at the moment the most critical issue for CNGS beam due to**

  - induced radiation (even for nominal intensity)

  - eventual lack of protons (ultimate intensity)

- **To provide nominal CNGS beam intensity $\sim$ 3 times more particles needed from Linac.**

- **Radiological impact increases with number of particle lost and their energy**

  $\Rightarrow$ losses in the PS and especially in the SPS are more critical $\Rightarrow$ to keep absolute losses constant, relative losses should decrease with intensity

  $\ominus$ But... relative losses are increasing with intensity (collective effects, beam size ...)

Beam losses (2/2)

Relative beam loss as a function of the SPS intensity

Beam		FT	CNGS		
		2004	nomin.	record	ultimate
Intensity at SPS extraction	$[10^{13}]$	2.6	4.4	5.3	7.0
Relative loss	[%]	16	24	38	< 20

Maximum proton flux to the CNGS

Pot per year [10^{19}] for 200 days of operation with 80% machine availability for beam sharing of 0.45/0.85

cycle length		6 s	7.2 s	4.8 s	6 s
acceleration time		3 s	3 s	3 s	4.2 s
injection momentum GeV/c		14	14	26	50
situation	N_{tot} 10^{13}				
PS + improvements in the SPS	4.8	5.0/9.4			
	5.7	5.9/11.1			
PS + improvements + SPS RF upgrade	7.0		6/11.4		
PS2	7.0				7.2/13.7
PS2 + RF upgrade	7.0			9.0/17.1	
PS2 + RF upgrade + new CNGS equipment	10.0				10.3/19.6
PS2 + new SPS RF + new CNGS equipment	10.0			12.9/24.5	

Summary

- Future CNGS/FT beam will be injected above transition
- Beam structure will be similar to the LHC beam with maximum bunch intensity below ultimate LHC
- There is an increase in local density with a new filling scheme for the CNGS beam (for the same total intensity)
- For the FT beam (slow extraction) optimum PS2 size is SPS/5.13
- For the CNGS beam (fast extraction) optimum PS2 size is

  - SPS/5.13 with persent limitations to intensity on target and SPS kicker rise time as well as with new requirements (whole intensity on target and short kicker rise time)

  - SPS/5.25 only if target limitation can be changed but kicker rise time not
- Any other ideas?..