New Opportunities
in the Physics Landscape at CERN
New Proton Drivers at CERN

SPS

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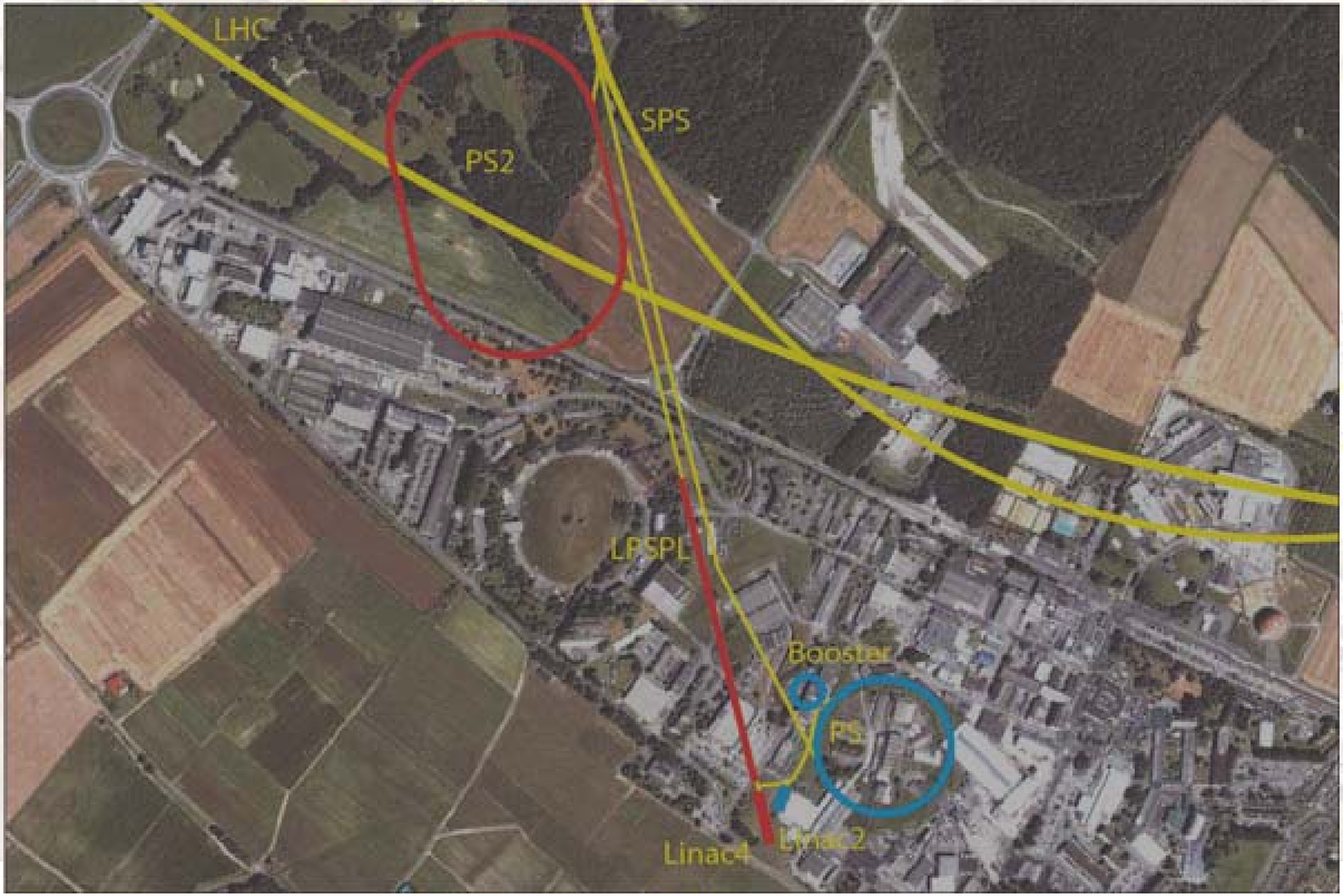
for SPSU (SPS Upgrade) Study Group

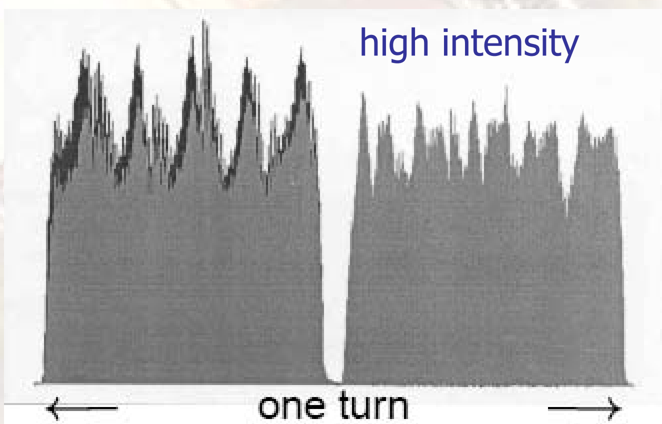
SPS injectors: present and future



UNOSAT

SPS now

- Commissioned in 1976, accelerated p, pbar, e-, e+, light and heavy ions
- FT/CNGS beam from PS:
  - **practically debunched beam**
  - **5-turn extraction**
  - **no bunch-to-bucket transfer**
  - **injection below transition**



Nominal parameters of two main types of proton beam in the SPS

		CNGS	LHC
injection P_s	GeV/c	14	26
extraction P_s	GeV/c	400	450
transition		yes	no
bunch spacing	ns	5	25
filling pattern		10/11	(3-4)/11
N of batches		2	3-4
bunches/batch		2100	72
intensity/bunch	10^{10}	1.05	11.5
total intensity	10^{13}	4.4	3.3
cycle length	s	6.0	21.6
trans. emit.	μm	12	3.5

→ Present LHC and FT/CNGS beams are very different

SPS in future (> 2018)

Parameters	PS2 offer per cycle at 50 GeV			SPS record at 450 GeV		LHC request at 450 GeV	
	LHC I	LHC II	FT	LHC	CNGS	I	II
bunch spacing [ns]	25	50	25	25	5	25	50
bunch intensity $/10^{11}$	4.0	**5.5**	1.2	**1.2**	0.13	>1.9	5.0
number of bunches	168	84	840	288	4200	336	168
total intensity $/10^{13}$	6.7	4.6	**10.0**	3.5	**5.3**	>6.4	8.4
long. emittance [eVs]	0.4	0.4	0.4	0.6	0.8	<1.0	<1.0
norm. H/V emitt. [μm]	3.0	3.0	9/6	3.6	8/5	3.5	3.5

M. Benedikt et al., PS2 WG

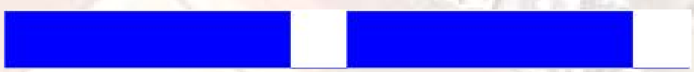
F. Zimmermann et al.

→ **SPS upgrade is necessary**

FT beam in SPS with PS2

- Total maximum intensity: 2 x higher → 10^{14} (minus losses)
- Maximum injection energy: 13 GeV→ 25 GeV or 50 GeV
- Pulse length at injection: 2 x longer → no flat bottom
- Beam macro and micro structure in SPS: 5 times less bunches, more gaps

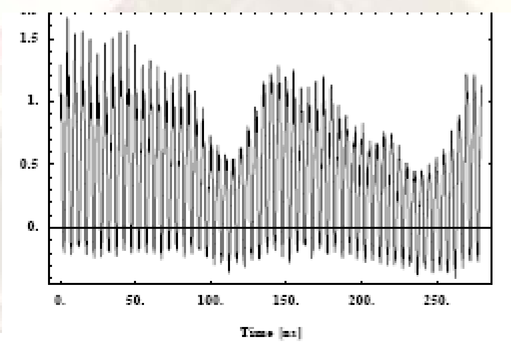
with PS



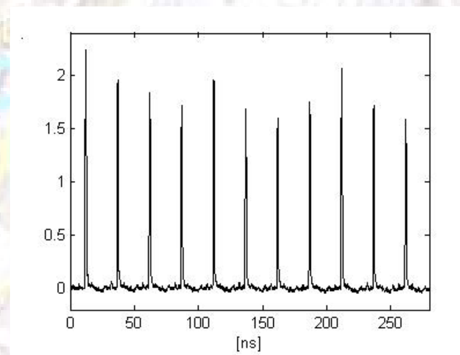
←one PS cycle→ ←one PS cycle→

with PS2

←one PS2 cycle (5-turn extract.) →



5 ns → 25 ns
bunch spacing



Slow-extracted beam: time scales

- Now:
  - 43.4 kHz, 2 x 43 kHz and 200 MHz structure
  - RF gymnastics at 400 GeV during 2.5 ms, extraction 30 ms after
    - time to close 5 ns bunch spacing ≈2.5 ms
    - min time to close max 1.05 μs gap ≈230 ms (8 MV + unstable phase)
  - first (100 -1000) ms of spill are not used (depending on experiment)

- With PS2:
  - 43.4 kHz, 5 x 43 kHz and 40 MHz structure
  - larger beam gaps and bunch spacing → longer debunching time
    - time to close 25 ns bunch spacing ≈11 ms
    - min time to close max 1.7 μs gap ≈370 ms (8 MV + unstable phase)
    - spill can be improved by RF manipulations (200 or 800 MHz recapture)
  - up to 15 x higher bunch intensity for FT beam
  - higher duty cycle (see talk by I. Efthymiopoulos)

Potential proton flux per year

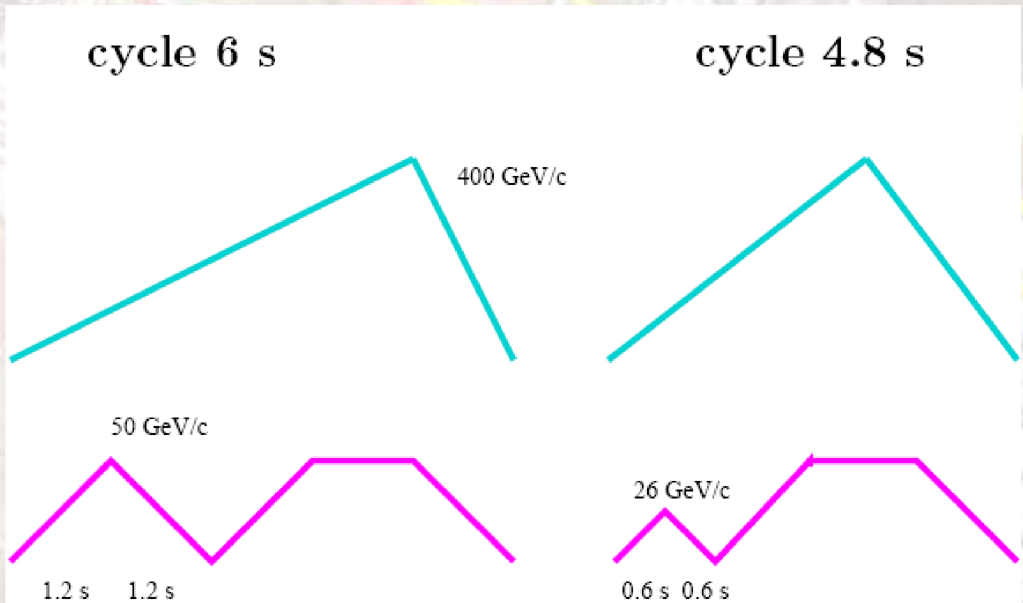
flux = intensity x availability x $\mathbf{n_{cycle}}$

- Maximum intensity 10^{14} (minus losses)
- Average **availability** now $\approx$ 80% $\rightarrow$ should be better in future
- $\mathbf{n_{cycle}} = n_{day} \times 24 \times 3600 \times$ sharing/ T^{SPS}_{cycle}
  - typically $n_{day} \approx 200$
  - sharing $\approx$ 0.85 if only user apart from LHC (maybe $\approx$ 0.5 more realistic)
  - $T^{SPS}_{cycle} = k \times T^{PS}_{cycle}$, now T^{SPS}_{cycle} = 6 s (with 1.2 s flat bottom)
  - in future minimum cycle length could be 6 s – 1.2 s = 4.8 s with 3 s acceleration time but at much higher intensities (acceleration of nominal LHC beam in SPS to 450 GeV takes 7.5 s!) $\rightarrow$ 6 s cycle?

SPS cycle length

SPS

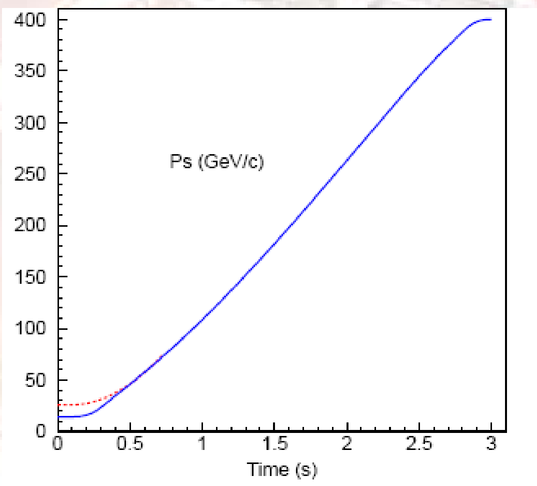
PS2
(examples)



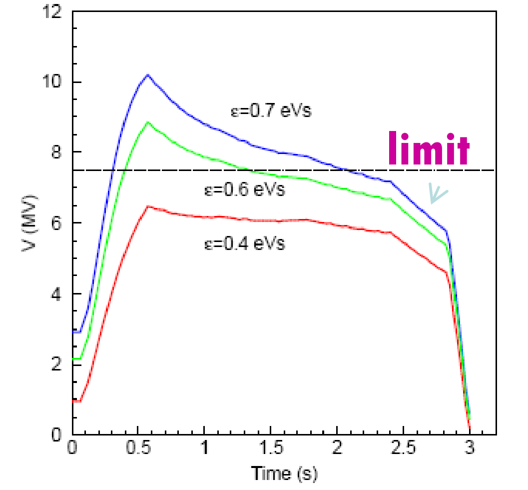
→ Depending on PS2 physics program beam could also be injected at 26 GeV

Short SPS cycle - 4.8 s
(26 – 400) GeV/c

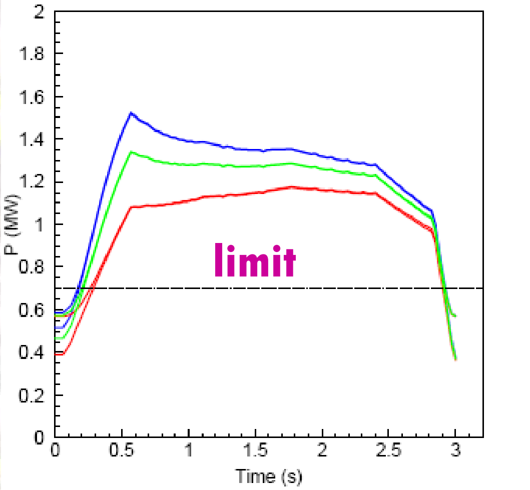
Beam momentum



RF voltage 200 MHz



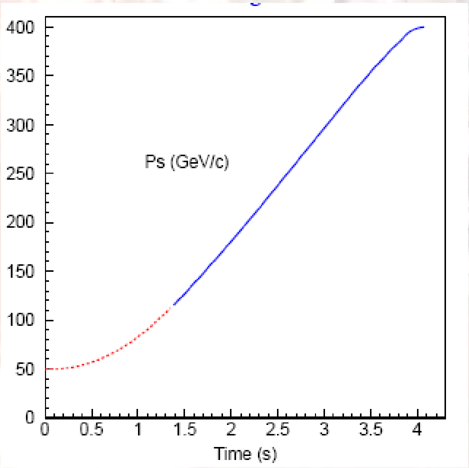
RF power 200 MHz



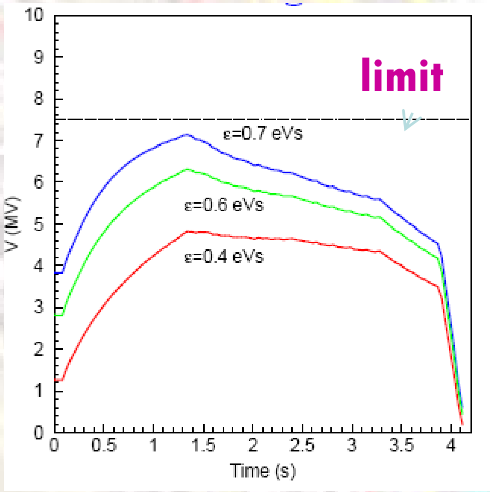
→ 50 % more RF voltage (cavities) - additional RF system
→ Twice more RF power at 200 MHz - upgrade after R&D

Long SPS cycle - 6 s
(50 – 400) GeV/c

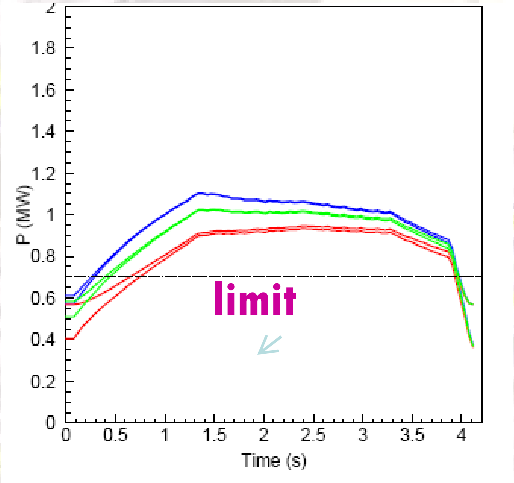
Beam momentum



RF voltage 200 MHz



RF power 200 MHz



→ 50 % more RF power for 200 MHz power plant

Known intensity limitations and possible actions (under study in SPSU)

- transition crossing → injection above transition (25 GeV or 50 GeV)
- e-cloud effect → beam pipe coating
- instabilities → impedance search and reduction, active (feedbacks) and passive (increased nonlinearity) damping
- beam loss → collimation system, e-cloud elimination, radioprotection
- beam loading in the 200 MHz and 800 MHz RF systems → power upgrade, reduction of number of sections per cavity
- heating of machine elements (MKE, MKDV kickers, …) → impedance reduction, new design
- vacuum (beam dump and MKDV outgassing), septum sparking,…
- hardware modifications (injection kickers, beam dump, RF systems, transverse damper, beam diagnostics)

Protons on target per year @400 GeV

For 200 days of operation, 80% beam availability and 0.85 beam sharing

SPS cycle length	6.0 s	4.8 s	6.0 s
SPS acceleration time	3.0 s	3.0 s	4.2 s
Injection energy / SPS intensity/pulse	13 GeV	25/50 GeV	25/50 GeV
4.4×10^{13} – “nominal” CNGS	0.86×10^{20}		
5.7×10^{13} – “record” SPS	1.11×10^{20}		
with new injectors 9×10^{13} – maximum PS2 (-10%)		2.2×10^{20}	1.8×10^{20}

M. Meddahi, E. S., CERN-AB-2007-013

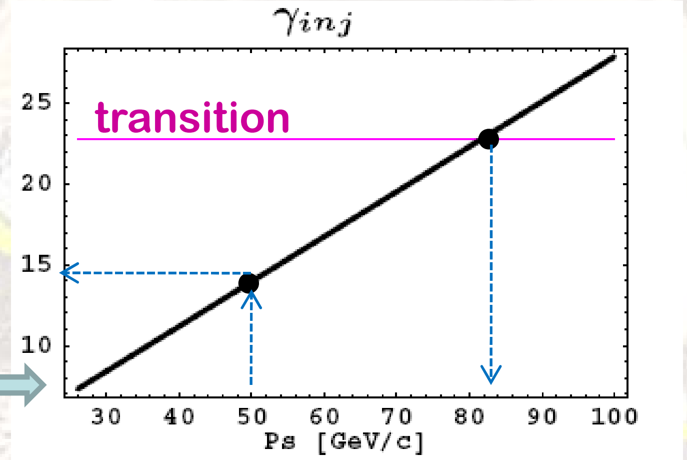
Dreaming…

- Inject 5 times 10^{14} from PS2 at 26 GeV/c $\rightarrow$ 1.2 s x 4 flat bottom
- Cycle length 4.8 s + 4.8 s = 9.6 s, twice longer
- Factor 2.5 increase in POT per year
- But very high intensity in the SPS…

Ions in the SPS with PS2

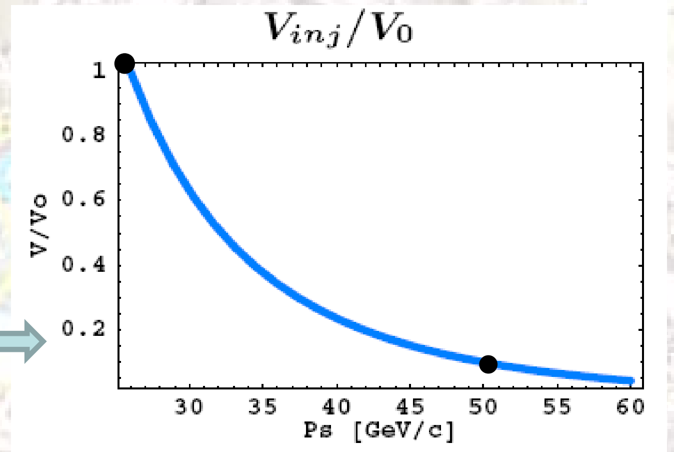
• From now on the injected FT ions in the SPS will be similar to the LHC ions + debunching at a higher (intermediate) energy needed for an acceptable spill

•Injection into SPS above transition only for $P_s > 82$ GeV/c (proton equivalent for Pb^{54+}_{208} in PS2)



•With PS2:

- •smaller RF frequency sweep → no fixed frequency acceleration (used now)
- •smaller space charge tune spread
- •shorter injection plateau
- •smaller matched RF voltage at injection



Summary

- The upgraded CERN accelerators will produce high intensity beam with high reliability both for the LHC and SPS physics programs
- All machines in the LHC chain will be replaced except the SPS, which will profit from a higher injection energy
- The SPS upgrade is a key element for the SPS physics program and LHC to benefit fully from the new upstream machines
- Improvements to SPS performance can be implemented on a different time scale (before 2018)

Acknowledgments

SPS Upgrade Study Group: http://paf-spsu.web.cern.ch/paf-spsu/

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