CERN

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Summary of Session 7:
Future Upgrade Scenarios for the Injector Complex

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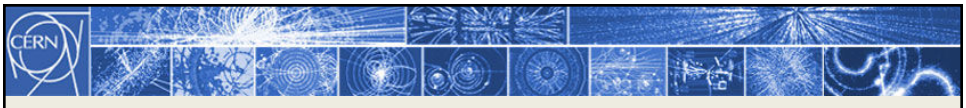


Session Presentations:

What will PS2 + SPL provide for LHC? — **Michael Benedikt**

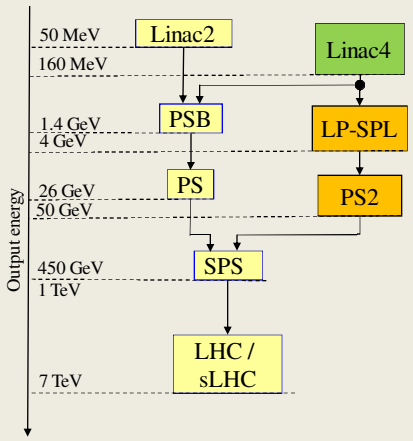
Keeping the present injector complex running with high reliability for 10-20 more years — **Simon Baird**

Possible improvements to the existing pre-injector complex in the framework of continued consolidation — **Massimo Giovannozzi**

Upgrade possibilities in the SPS — **Elena Shaposhnikova**

Other scenarios for a partial upgrade of the injector complex — **Christian Carli**

Rationale



Review the present ideas for the upgrade of the injector complex

Based on the real needs of the LHC for the medium and long term.

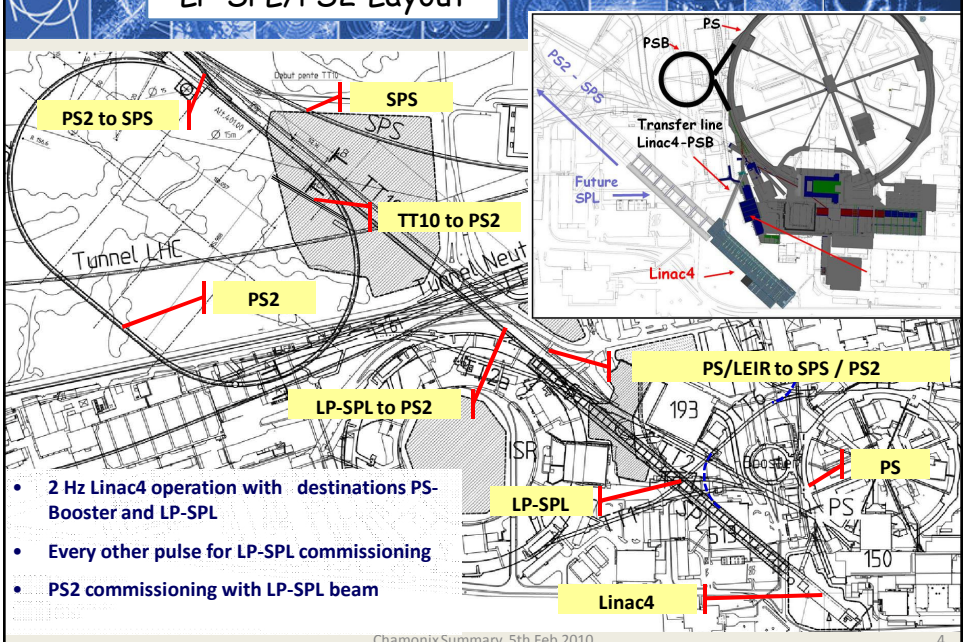
Taking into account the 'new' information on the schedule for the LHC.

Based on the optimum way to produce the beam required by the LHC to maximize the integrated luminosity delivered to the experiments.

Reliability and performance.

The session was dedicated to the LHC and its needs.

LP-SPL/PS2 Layout



- **2 Hz Linac4 operation with destinations PS-Booster and LP-SPL**
- **Every other pulse for LP-SPL commissioning**
- **PS2 commissioning with LP-SPL beam**

LP-SPL/PS2

Aim at doubling the beam brightness (with margin) available to the LHC

- **Provide up to 4x10^{+11} protons per bunch in 25ns at a transverse emittance of 3µm**
- **OR Low emittance beam -> 1.7x10^{+11} ppb at 1.5µm.**

Input on what LHC actually wants, or can swallow, session 9

Ease the possible intensity limitations in the present complex by increasing the SPS injection energy from 26 to 50 GeV

$$\Delta Q_{SC} \propto \frac{N_b}{\varepsilon_{X,Y}} \cdot \frac{R}{\beta\gamma^2}$$

with N_b : number of protons/bunch

$\varepsilon_{X,Y}$: norm. transverse emittances

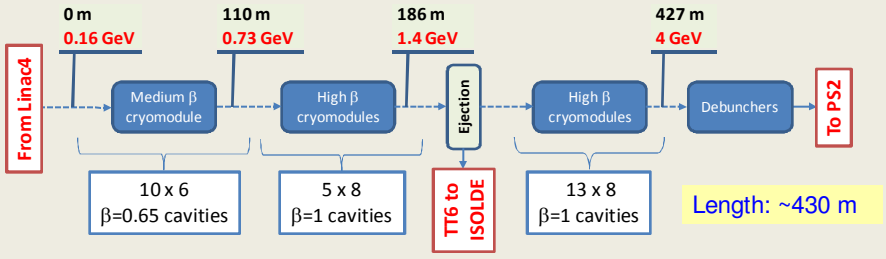
R : mean radius of the accelerator

Increase the reliability of the complex by replacing the present ageing machines

Simplify the production of the LHC beams by direct production of the 25ns bunch structure -> faster filling of the LHC

Marginal

LP-SPL – block diagram & beam parameters



LP-SPL beam characteristics

Kinetic energy (GeV)	4
Beam power at 4 GeV (MW)	0.12
Rep. period (s)	0.6
Protons/pulse (x 10^{14})	1.1
Average pulse current (mA)	20
Pulse duration (ms)	0.9

PS2 main parameters

Parameter	unit	PS2	PS
Injection energy kinetic	GeV	4.0	1.4
Extraction energy kinetic	GeV	20 - 50	13 - 25
Circumference	m	1346	628
Max. bunch intensity LHC (25ns)	ppb	4.0×10^{11}	1.7×10^{11}
Max. pulse intensity LHC (25ns)	ppp	6.7×10^{13}	1.2×10^{13}
Max. pulse intensity FT	ppp	1.0×10^{14}	3.3×10^{13}
Linear ramp rate	T/s	1.5	2.2
Repetition time (50 GeV)	s	~ 2.4	1.2/2.4
Max. stored energy	kJ	800	70
Max. effective beam power	kW	350	60

In comparison with PS: line density x 2, circumference x 2, energy x 2

LP-SPL/PS2 Costs

LP-SPL
Materials Cost : 480 MCHF + ~900MY (140 MCHF)

PS2
Materials Cost : 410 MCHF + ~700MY (110MCHF)

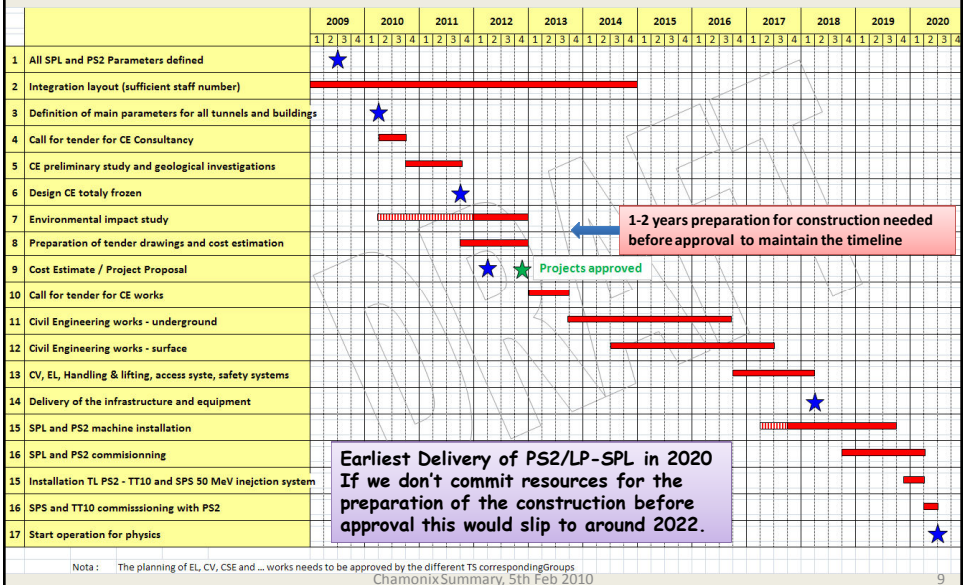
In addition Upgrades of the SPS needed to benefit from the new chain (65MCHF +?MY)

Total Cost ~1.25BCHF

New injector chain can be built and commissioned without disturbing operation of the complex

- Final connection to the SPS can be done within a 'normal' shutdown.
- Production of Ions for LHC using LEIR adds complexity but solutions (on paper) exist.

PS2/LP-SPL Draft timeline



The Existing Complex

If we construct LP-SPL/PS2, they cannot be ready until 2020-2022.

Allowing for a reasonable overlap in case of delays means the present complex must run until at least 2025 (15 years)

- **Providing the high performance beams required by LHC during its operational development**
- **With very high reliability in order to ensure maximum integrated Luminosity.**

If we do not construct LP-SPL/PS2

The existing complex must run for 20-25 years with high reliability providing the beams needed by the LHC throughout its operational cycle

In either case the existing complex must be consolidated for high reliability and upgraded for high performance

By the way there is not that much of the PS that is actually 50 years old!

Consolidation of the Existing machines

Review of major systems in the chain Linac4,PSB,PS and SPS

What will now be needed

- **Separation of consolidation concerning the machines from the experimental areas**
- **Put together with the present consolidation programmes**
- **Re-do the comprehensive risk analysis to define priorities and timescales**

- **Put together with the upgrade plans for the complex (see later) since in many cases upgrades will replace/reduce consolidation needs**

Session in the Injectors and Experimental Facilities (IEFC) Workshop next week

Rough figures 300MCHF over 20 years = 15MCHF/year
(covers much more than the LHC injector chain)
… Plus the manpower to spent that kind of money …

Upgrade possibilities for the PSB/PS

Present intensity limitation at injection will be removed by the increased injection energy from Linac4

- **Will reach the equivalent of $3x10^{+11}$ ppb for a 25ns PS Bunch Train (6 bunches of $3.6x10^{+12}$ to be split in the PS to 72 bunches of $3x10^{+11}$)**

The next fundamental limit comes from the space charge tune shift at injection into the PS.

- **Present limit at 1.4GeV injection energy is the 'Ultimate' intensity $1.7x10^{+11}$ ppb**

The possibility exists to increase the energy of the PSB to 2 GeV

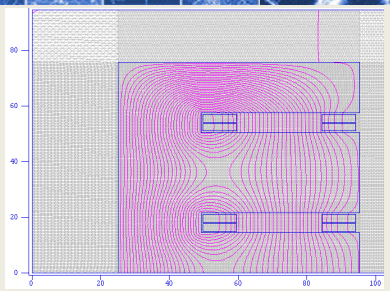
- **This would raise the limit in the PS to around $2.7x10^{+11}$ ppb**

Impact on other systems in the PS would need study but this looks a very promising way of significantly increasing the performance of the present LHC pre-injectors

PSB Energy Increase

The PSB Main magnets seem to be perfectly capable of reaching the higher field

- New power supplies
- New/Upgraded RF
- Septa and Kickers
- Transfer line magnets and power supplies
- PS injection equipment
- …etc..



…An Urgent study to be launched with the aim of demonstrating the feasibility and providing cost and time estimates for a 2GeV PSB upgrade project

	Present	+30%
FIELD STRENGTH (T)	0.86	1.12
PEAK CURRENT (A)		
Inner Rings	4032	5255
Outer Rings	4065	5515
POWER COMSUMPTION (kW)	49	83
Q (@ ΔT= 28 K) (l/min)	26	44
ΔT (@ Q = 26 l/min) (K)	28	47

Impact on the PS

Increasing the LHC bunch intensity in the PS to ~2.7x10^{+11} will bring a raft of new issues to the machine

- Electron cloud instabilities at extraction
- Longitudinal coupled bunch instabilities

However these already manifest themselves at the present intensities and are not 'hard' limits as potential solutions exist and must be studied and implemented.

The increased intensities available from the PSB could bring issues with the shielding of the PS tunnel

- This should not be an issue for the 'clean' LHC beam
- But might limit the use of the possibilities for higher intensities for other users

To be studied in detail

SPS

The SPS represents the most significant intensity limitation for the present injector complex

- Presently can reliably produce intensities just above 'nominal' ($1.2 \times 10^{+11}$ ppb)

These limitations would be eased – but not fully solved by the increased injection energy from LP-SPL/PS2

In either case the SPS needs a serious upgrade!!

Limitations in 3 main areas (and solutions under study)

- **Electron Cloud instabilities (Multi-bunch)**
  (coating of vacuum chambers, wideband feedback)
- **Transverse Mode Coupling Instabilities (Single Bunch)**
  (impedance reduction, replace/shield elements)
- **RF Power Limitation**
  (New layout of 200MHz RF System with more shorter cavities)

SPS Continued

Do we know what further limitations there might be in the SPS?

The ultimate bunch intensity in single bunches was achieved during p-pbar operation. Since then the impedance of the vacuum system had been reduced – but more kickers added …

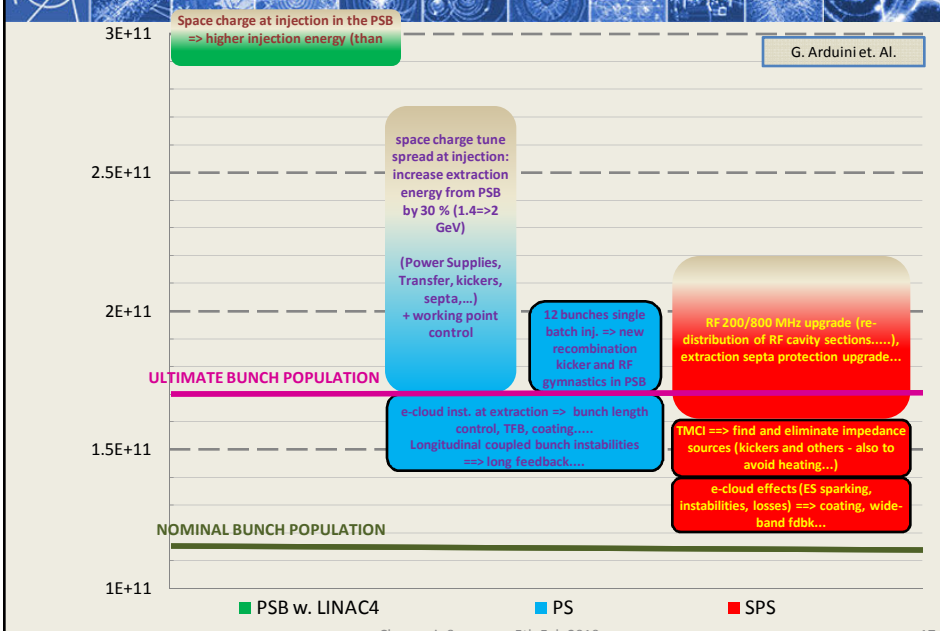
The space charge tune shift at injection should not be a limitation since larger values than that needed for ultimate have been achieved (albeit at lower energies)

The present limitations are both multi-bunch and single-bunch phenomena and have to be removed before anything else.
We also know that many limitations scale with energy and 50GeV injection would probably help…

We need to remove the present limitations in the SPS and upgrade the PSB/PS in order to be able to deliver LHC beams above ultimate intensities to the SPS.

Machine studies before, during and after the upgrades will be needed to follow the evolution of the various limits.

Summary of Intensity Limitations in the present Injector Complex



Other Possibilities for a Partial Upgrade of the Injector Complex

Other possibilities have been investigated briefly but they all concentrate on replacing the present PSB with an alternative machine:

Possibilities include: **Low-energy SPL, FFAG, Super-PSB and RCS**

Assumptions based on reproducing the intensities promised by LP-SPL/PS2 involve machines with an injection energy in the range 500-1000 MeV and extraction to the PS at around 2.5GeV.

Some interesting ideas and possibilities …

However, Interest in these options has waned since the possibility of an energy upgrade of the PSB became apparent.

Conclusions I

The session looked at the possible upgrade of the complex with LP-SPL/PS2 and the present limitations and upgrade possibilities for the existing complex.

The outcome here must be put into the context of what the LHC actually wants (sessions 8 and 9)

Some things are already very clear:

- **The present injector complex must run with high performance and high reliability for 15-25 years more.**

  Consolidation Plan/Risk Analysis to be done

- **The present bottleneck in the complex is the SPS and this would remain even with SPL/PS2**

  Urgently Launch a Task Force to complete studies and propose upgrade projects.

- **A possible upgrade path in the existing complex by increasing the energy of the PS Booster to 2GeV has been identified**

  Launch a Study/Project to Upgrade the PSB Energy to 2 GeV

Conclusions II

The consolidation and upgrade path outlined for the present injector complex seems to present an attractive alternative to the construction of SPL/PS2

- **It offers a bunch intensity which may be sufficient to satisfy the needs of the LHC (see later)**
- **Most of it has to be done in any case! Even if SPL/PS2 were to go ahead!**
- **It's a bit cheaper.**
- **Resourcing the outlined consolidation programme as well as the construction of SPL/PS2 would be problematic.**
- **The new limits of the complex (especially SPS) after these upgrades will have to be explored … There is reasonable hope that bunch intensities in excess of the present 'ultimate' beam can be produced.**