PAF Preliminary Analysis
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- Physics guidelines
- Maximizing $\int Ldt$ in LHC
  - reduction of turn-around time
  - improvement of injectors
  - LHC luminosity upgrade
- Scenarios for the proton accelerator complex
- Conclusions

Physics guidelines (POFPA)

1. LHC
   - "Maximize integrated luminosity"
     - ⇒ Minimize turn-around time by improving reliability / minimizing duration of stops **(L1)**
     - ⇒ Remove bottle-necks towards ultimate luminosity **(L2)**
     - ⇒ Refine / select scenario for SLHC (start in ~ 2015); progressive implementation **(SL)**
   - "Be ready to prepare for DLHC" **(DL)**

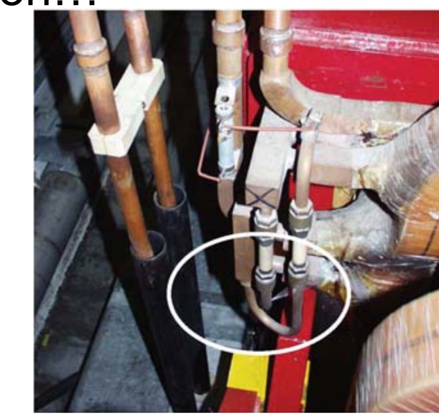
2. Neutrino physics
   - Until the physics case is clear (~ 2010)
     - ⇒ Pursue development for {β-beam + super-beam} **(βB)** and ν factory **(νF)**
     - ⇒ Depending on physics and outcome of technical developments, elaborate a proposal for a ν facility at CERN
   - After ~2010
     - ⇒ Implement a ν facility at CERN

3. Other physics [physics with kaons **(k)**, muons **(μ)**, heavy-ions (fixed-target), antiprotons and nuclear physics **(NP)**]
   - Complement the accelerators resulting from the needs of priorities 1 & 2
   - Adapt experiments to the capabilities of the accelerators

Maximizing integrated luminosity (1/3)

- Minimize turn-around time by improving reliability / minimizing duration of physics interruptions **(L1)**

- Consolidation. Example of acute needs: magnets:
  - PS: "…degradation is the worst but taken care of…" [1]
    - 24 dipoles refurbished in 2005 (1rst part of "phase 1")
    - rate for continuation: 8 additional dipoles / year (end of "phase 2" in 2015)
  - SPS: "…seems to be a victim of accelerated degradation…" [1]
    - 7 leaks detected in 2004…
    - Repair => ~1 day lost for physics/magnet
    - More measurements and proposal for extensive consolidation by the end of 2006



- Decrease of LHC filling time
  - Single batch injection in the PS using Linac4
  - 0.9 s cycling rate of the PSB and shorter acceleration cycle in the SPS
- Operational simplifications. E.g.:
  - Single batch filling of the PS using Linac4 as PSB injector
  - Higher injection energy in the LHC using SPS+

Reference 1: K.H. Mess – 15/08/2005

Maximizing integrated luminosity (2/3)

– Improvement of the injectors **(L2)**

- Increase injection energy in the PSB (→ **Linac4**)
  - Incoherent space charge tune spread at 50 MeV limits PSB performance. Even with 2 PSB batches, the ultimate beam for LHC cannot be obtained at the PS exit.
  - With Linac4 injecting at 160 MeV, a factor of 2 is gained.

$$\Delta Q_{SC} \propto \frac{N_b}{\varepsilon_{X,Y}} \cdot \frac{1}{B_b \beta \gamma^2}$$

with N_b : number of protons/bunch

$\varepsilon_{X,Y}$: normalized transverse emittances

B_b : bunching factor (average/peak line density)

$\beta\gamma$: classical relativistic parameters

- Reduce the impedance of the SPS
  - Higher threshold for transverse and longitudinal instabilities

- (L3) Increase injection energy in the SPS (→ **PS+ / PS2**)
  - Reduced space charge tune spread
  - Higher threshold of Transverse Mode Coupling Instability
  - Higher threshold of coupled bunch transverse instabilities in H-plane due to e-cloud
  - Smaller beam size => reduced loss at high intensity
  - Shorter acceleration time (- 10 %)

Maximizing integrated luminosity (3/3)

- Refine / select / progressively implement scenario for SLHC **(SL)**.

- Phase 0: without hardware changes in the LHC
  - Improve injectors (⇒ actions L1 and L2) to increase brightness N_b/ε up to ultimate
  - collide beams only in IP1 and IP5 with alternating H-V crossing:

    $\rightarrow L_0 = 2.3 \times 10^{34}$ cm^{-2} s^{-1} & $\int Ldt \sim 1.5 \times$ nominal (= 100 fb^{-1} / year)
  - increase the dipole field from 8.33 to 9 T: ↑ E_{max} = 7.54 TeV
- Phase 1: with major hardware changes in the LHC (IR, RF, collimation, dump, …)
  - modify the insertion quadrupoles and/or layout: ↓ β^* = 0.25 m
  - increase crossing angle θ_c by $\sqrt{2}$: ↑ θ_c = 445 μrad
  - halve bunch length with new high harmonic RF system in the LHC:

    $\rightarrow L_0 = 4.6 \times 10^{34}$ cm^{-2}s^{-1} & $\int Ldt \sim 3 \times$ nominal (= 200 fb^{-1} / year)
  - double the number of bunches [⇒ new RF systems in the injectors (including SPS if 12.5 ns bunch spacing)] & increase θ_c:

    $\rightarrow L_0 = 9.2 \times 10^{34}$ cm^{-2}s^{-1} & $\int Ldt \sim 6 \times$ nominal (= 400 fb^{-1} / year)
- Phase 2: with a new 1 TeV injector (SPS+)

  → doubling of intensity per bunch at constant brightness

  → ultimate reduction of turnaround time (factor up to 2) by simplification of LHC injection setting-up

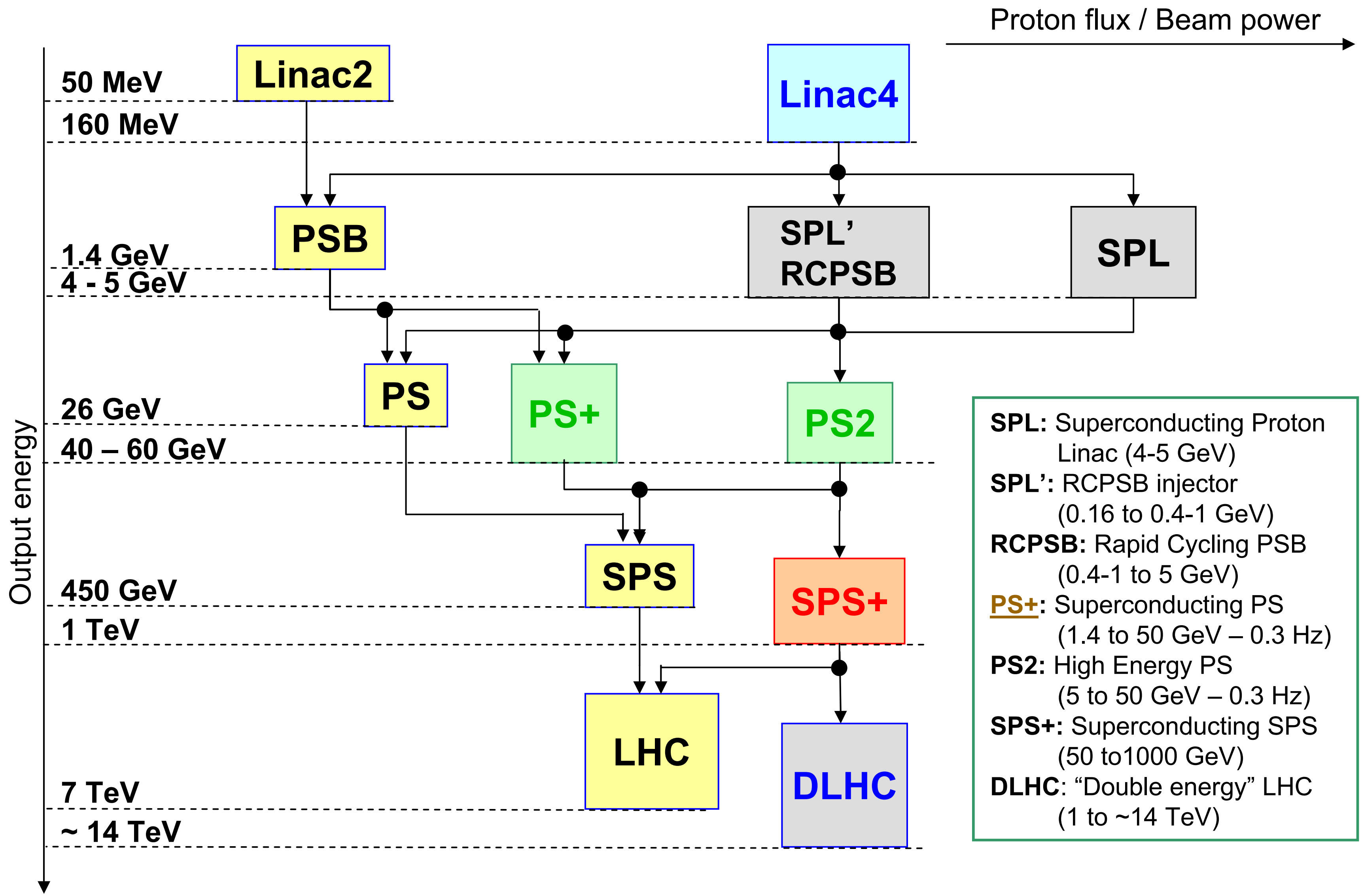
  → factor of up to 1.4 in $\int Ldt$

  $\rightarrow L_0 = 10^{35}$ cm^{-2}s^{-1} & $\int Ldt \sim 10 \times$ nominal (= 600 fb^{-1} / year)

  → preparatory step towards DLHC

Scenarios for the proton accelerator complex (1/2):

- Proposed combinations



SPL: Superconducting Proton Linac (4-5 GeV)
SPL': RCPSB injector (0.16 to 0.4-1 GeV)
RCPSB: Rapid Cycling PSB (0.4-1 to 5 GeV)
PS+: Superconducting PS (1.4 to 50 GeV – 0.3 Hz)
PS2: High Energy PS (5 to 50 GeV – 0.3 Hz)
SPS+: Superconducting SPS (50 to1000 GeV)
DLHC: "Double energy" LHC (1 to ~14 TeV)

Scenarios for the proton accelerator complex (2/2):

- Stages of implementation

	1	2	3	4
	Linac4 PSB PS SPS	*Linac4* PSB *PS+ or* (PS & *PS2*) SPS	*Linac4* *SPL* *PS+ or PS2* SPS	*Linac4* *SPL* *PS+ or PS2* *SPS+*
L1, L2	Ultimate beam from PS	Ultimate beam from SPS	PSB & PS replaced Ultimate beam from SPS	PSB, PS & SPS replaced
SLHC	+	++	++	+++
DLHC	+	++	++	+++
β beam	-	-	++ (γ ~100)	++ (γ ~200)
ν Factory	-	-	+++ (~5 GeV prod. beam)	+++ (~5 GeV prod. beam)
k, μ	-	~200 kW beam at 50 GeV	~200 kW beam at 50 GeV	~200 kW beam at 50 GeV
Nuclear Physics	-	-	+++	+++

Preliminary recommendations (1/3)

- **Extensive consolidation**
  - of the injectors:
    - PS magnets (phases 1 & 2) + SPS magnets (procedure to be defined by end 2006)
    - other items (to be analysed later)
  - of the LHC
    - implement all “delayed” equipments
    - bring-up to the nominal (if possible ultimate) performance level

- **Intensive machine studies (all machines)**

- **Short & Medium term improvements of the injectors:**
  - Reduction of SPS impedance (kickers + ?)
  - Reduction of the SPS & LHC filling time (900 ms cycling period for the PSB, reduced acceleration time in the SPS…)
  - Reduction of the irradiation of the PS (new multi-turn ejection)

- **Construction of Linac4**
  - Design report in autumn 2006

Preliminary recommendations (2/3)

Prepare for submission of project proposals in ~ 2010 and for subsequent construction of:

- upgrades for SLHC
- new injectors
- ν facility

⇒ Vigorous efforts on:

- accelerator design [SLHC, proton RCS, ν factory (ISS), β-beam, …]
- design of accelerator components (high power RF, normal conducting magnets, …)
- radio-protection / environmental impact studies

⇒ Aggressive R & D on:

- high field magnets (LHC IR, DLHC dipoles ?)
- fast cycling superconducting magnets
- superconducting RF
- high power targets

Preliminary recommendations (3/3)

Additional internal resources (manpower and material) inside CERN are mandatory for any of the goals envisaged!

It is worth commenting that:

- The EU-supported programmes (mostly CARE and EURISOL) are already contributing. Extending and strengthening them would be very beneficial.
- The LARP programme in the USA will provide important contributions. Its extension and strengthening would be highly welcome.

But more is clearly needed, both in terms of organization and resources. Suggestions:

- **Setting-up of an internal team in charge of preparing a design report for the LHC upgrade**
- **Active CERN participation in the BENE-supported study for a ν facility (ISS).**

  + Decision as soon as possible for the type of ν facility to be built and setting-up of an internal team in charge of preparing a design report
- **Request for additional EU-supported programmes in collaboration with other European laboratories / universities (e.g.: Design Study for a Neutrino Factory).**
- **Additional contributions…**

The ambitions of the future CERN proton and ν programmes will be determined by the level of support from inside and outside the organization.

ANNEX

R & D on fast cycling superconducting magnets

- 2 types of dipoles

	Peak field	Ramp-rate	Cycle	Aperture	Length	Salient aspects
PS+	3.5 T	4 T/s	3.6 s	Φ 150 mm	4 m	High ramp-rate, large aperture
SPS+	4.5 T	1.5 T/s	12 s	Φ 80 mm	6 m	Moderate ramp-rate, higher field

- 2 types of superconducting wires / cables

	Filament Φ	Matrix	Cable Ra	Cable Rc	Status of wire
PS+	~ 1 μm	Cu-Mn or Cu-Ni	>0.8 mΩ	>40 mΩ	Feasible, but need R&D and industrialization
SPS+	< 3 μm	Cu-Mn or Cu-Ni	>0.3 mΩ	>10 mΩ	

⇓

- industrialize 3 μm filaments in resistive matrix : moderate R&D, billets, measurements
- develop 1 μm filaments in resistive matrix : massive R&D, billets, filaments
- optimize wire coating techniques to achieve the required electrical and thermal properties
- study stability of cables as a function of adjacent and cross inter-strand resistance
- establish, and validate with experimental results, loss computations models
- build instrumented model magnets to provide feedback to wires/cables

Importance of reducing the "turn around time"

- Machine parameters and initial luminosity L_0, determine the luminosity life-time τ_L
- For a given $T_{turnaround}/\tau_L$ there is an optimum T_{run} maximizing $\int L dt$
- It is always worthwhile to reduce $T_{turnaround}$, and even more so when L_0 is increased because τ_L is decreased

$$T_{\text{run}}\ (\text{optimum}) \Rightarrow \begin{cases} 1+\dfrac{T_{\text{run}}+T_{\text{turnaround}}}{\tau_{\text{L}}} = e^{\frac{T_{\text{run}}}{\tau_{\text{L}}}} \\ Average(L) = L_0 \times \dfrac{\tau_L}{T_{\text{run}}+T_{\text{turnaround}}+\tau_{\text{L}}} \end{cases}$$

Examples with τ_{gas} = 85 h and τ^x_{IBS} = 106 h (nom) ⇒ 40 h (high-L)

L_0 [cm^{-2}s^{-1}]	τ_L [h]	$T_{turnaround}$ [h]	T_{run} [h]	$\int_{200\ days} L\ dt$ [fb^{-1}]	gain
10^{34}	15	10	14.6	66	x1.0
10^{34}	15	5	10.8	85	x1.3
10^{35}	6.1	10	8.5	434	x6.6
10^{35}	6.1	5	6.5	608	x9.2