APD

Accelerator Physics and synchrotron Design

Scenarios for upgrading the LHC injectors

- Context & Physics guidelines
- The LHC injection chain & its limitations
- Needs of SLHC
- Proposed improvements
- Consequences and plans

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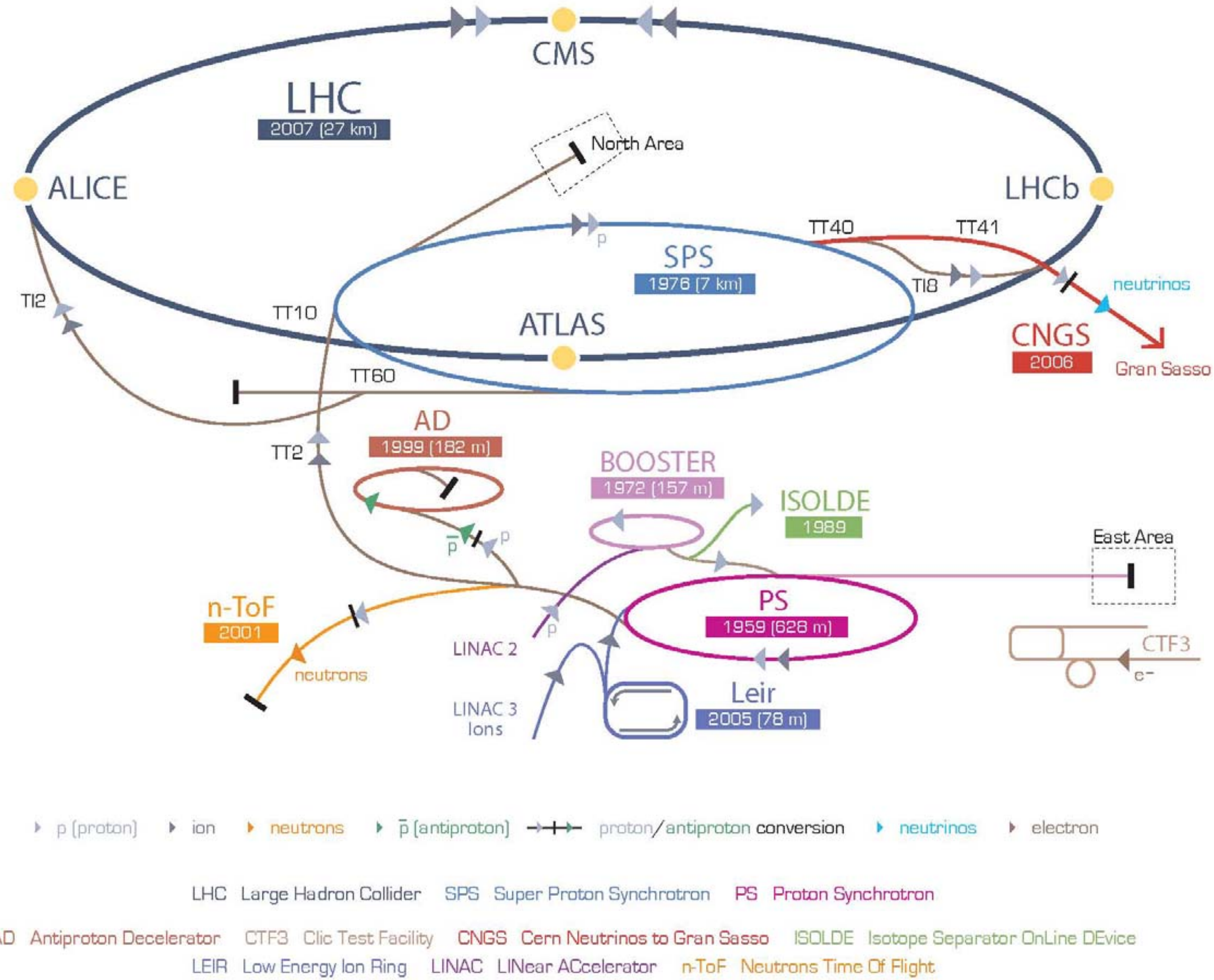
CERN accelerator complex



Physics guidelines (POFPA)

1. LHC
   - "Maximize the integrated luminosity"
     - ⇒ Minimize turn-around time by improving reliability / minimizing duration of stops
     - ⇒ Remove bottle-necks towards ultimate luminosity
     - ⇒ Refine / select scenario for SLHC (start in ~ 2015); progressive implementation
   - "Study the possibility of a higher energy LHC"
2. Neutrino physics
   - Until the physics case is clear (~ 2010-2012)
     - ⇒ Pursue development for {β-beam + super-beam} and ν factory
     - ⇒ Depending on physics and outcome of technical developments, elaborate a proposal for a ν facility at CERN
   - After ~2010
     - ⇒ Prepare for a ν facility at CERN
3. Other physics [physics with kaons, muons, heavy-ions (fixed-target), antiprotons and nuclear physics]
   - Complement the accelerators resulting from the needs of priorities 1 & 2
   - Adapt experiments to the capabilities of the accelerators

The LHC injection chain

LHC beam characteristics at extraction from the SPS

Kinetic energy	[GeV]	450	
Number of SPS batches to fill LHC		2 × 12	1 SPS batch = 3 or 4 PS batches
SPS repetition time	[s]	21.6	
Number of bunches in SPS		3 or 4 × 72	
Bunch spacing in a PS batch	[ns]	25	
Time interval between PS batches	[ns]	225	SPS injection kicker rise-time: 220 ns
N_b (intensity per bunch) nominal ultimate	[ppb]	1.15×10^{11} 1.70×10^{11}	**Assuming no loss between SPS and LHC**
ε_n (transverse emittance, rms, normalized)	[μm]	3.5	
ε_L (longitudinal emittance, total)	[eVs]	0.6	
4σ (bunch length, total)	[ns]	1.7	Limited by LHC 400 MHz buckets

Reaching the required transverse beam density in the LHC injectors' chain

Main limitations before "PS for LHC" upgrade (1994)

Excessive incoherent space charge tune spreads ΔQ_{SC} at injection in the PSB (50 MeV) and PS (1GeV) because of the high required beam brightness N/ε^*.

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

with N_b : number of protons/bunch

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

R : mean radius of the accelerator

$\beta\gamma$: classical relativistic parameters

⇒ "PS for LHC" project designed to enable production of ultimate beam, by fighting the space charge limit:

- at PSB injection, filling the PS with two PSB batches to halve N/ε^* and therefore the tune spread in the PS Booster.

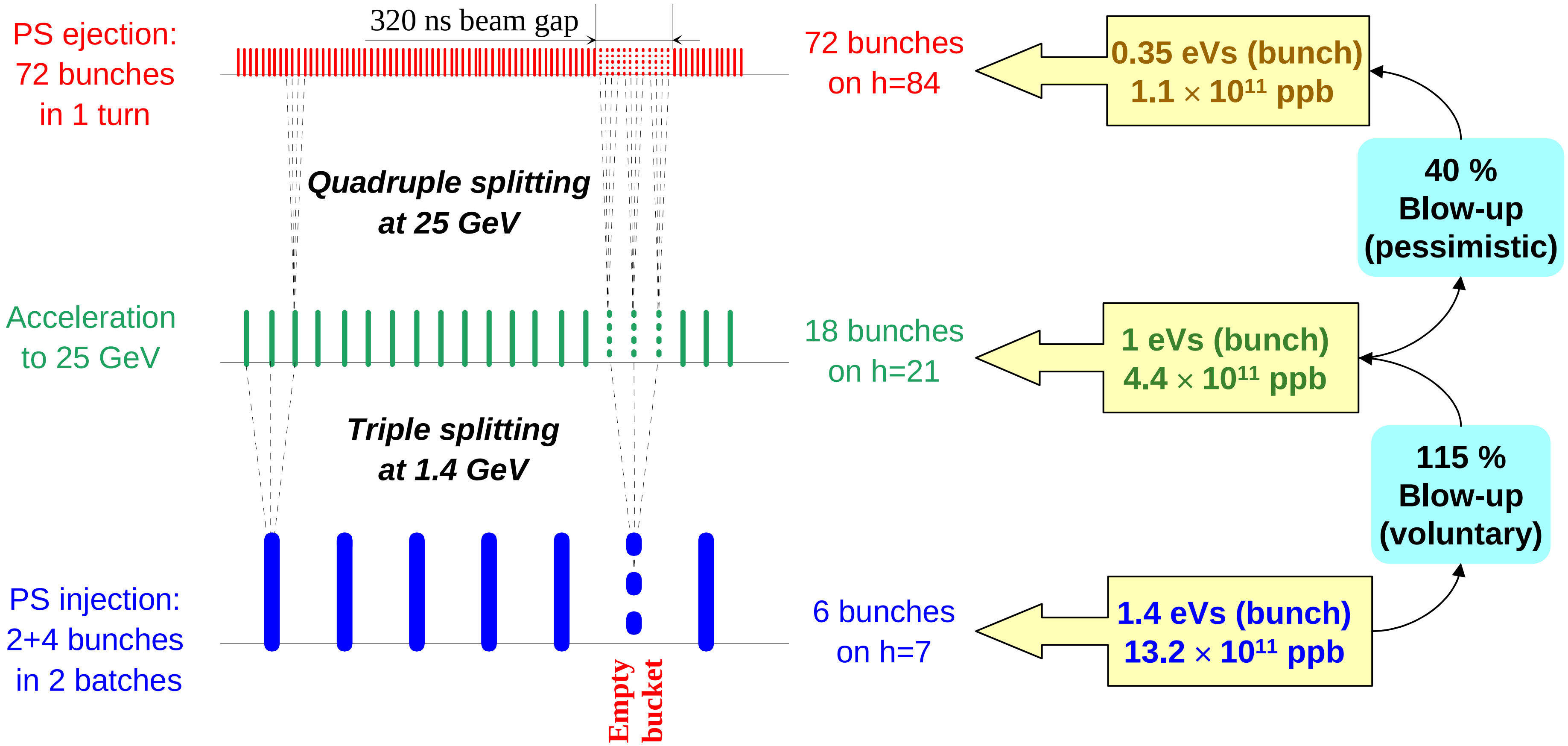
  ⇒ ΔQ from 0.7 to 0.35 for nominal beam and to 0.55 for ultimate beam.

- at PS injection, increasing the PSB - PS transfer energy from 1 GeV to 1.4 GeV.

  ⇒ ΔQ from 0.3 to 0.2 for nominal beam and to 0.32 for ultimate beam.

Reaching the required longitudinal beam density in the LHC injectors' chain

Main limitations before 2000 – Solved with "Beam gymnastics" in the PS



Today's performance of the LHC injection chain

	Maximum energy	Number of pulses for the next machine	Repetition period for LHC	Intensity/bunch within required emittances (at ejection)	Limitations*
Linac2	50 MeV	1	1.2 s		▪ Too low energy
PSB	1.4 GeV	2	1.2 s	~ ultimate beam	▪ Too low injection energy (space charge)
PS	25 GeV	3-4	3.6 s	$1.5\ 10^{11}$ p/b (~ 90 % of ultimate beam)	▪ Transition / Impedance ? ▪ Poor longitudinal match with SPS ▪ Reliability (age)
SPS	450 GeV	12	21.6 s	$1.15\ 10^{11}$ p/b (nominal beam)	▪ Too low injection energy ▪ e-cloud ▪ Impedance
LHC				???	▪ Too low injection energy (DA, Snap-back) ? ▪ e-cloud ?

Unexpected beam loss: > 10 %

* More in G. Arduini's talk on Friday morning

Needs of SLHC

Beam parameters [tentative…]	Bunch spacing [ns]	Protons per bunch* [10^{11}]	Transverse emittance in LHC [mm.mrad]	Intensity factor at PS injection*
Nominal	25	1.15 (1.4)	3.75	0.68 (0.81)
Ultimate	25	1.7 (2.1)	3.75	1 (1.2)
Ultimate & 12.5 ns spacing	12.5	1.7 (2.1)	3.75	2 (2.4)
2 x ultimate & 25 ns spacing	25	3.4 (4.1)	3.75 (blown-up to 7.5 in LHC)	2 (2.4) if SPS unchanged
3 x ultimate & 50 ns spacing	50	4.9 (5.9)	3.75	1.44 (1.73)
3.5 x ultimate & 75 ns spacing	75	6 (7.2)	3.75	1.17 (1.41)

Proposed final goal (→ 2 x ultimate & 25 ns spacing)

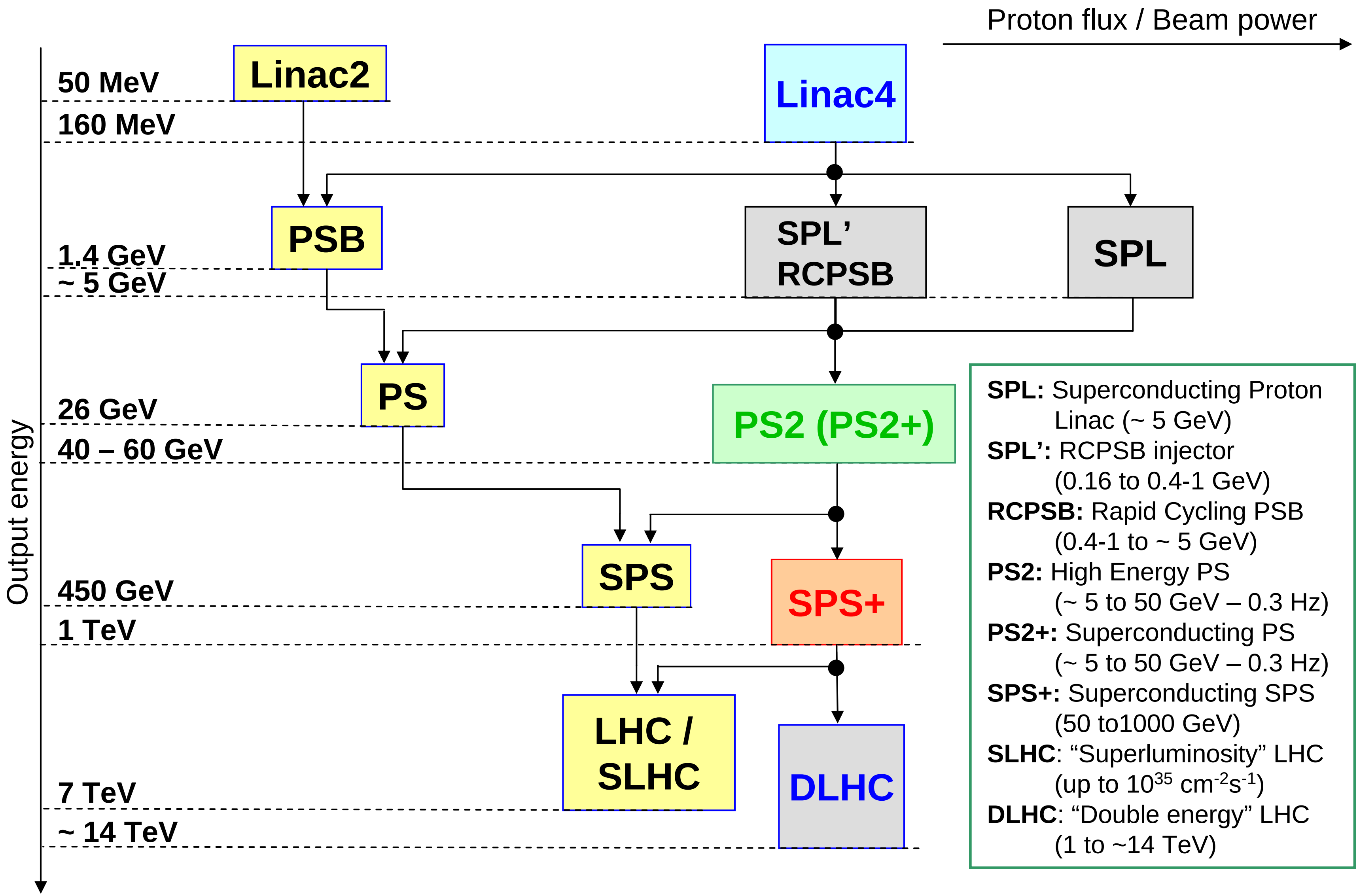
*** Case of 100 % (80 %) transmission PS → LHC**

Main line of action

Guidelines: economy / reliability / timing / flexibility

Stage		Main effect	Additional benefits
1	**Linac4** **[160 MeV, H$^-$]**	▪ PSB beam brightness x2 => ultimate beam in PS in a single pulse	▪ Easier operation, flexibility ▪ New accelerator ▪ Possibility of > ultimate beam from the PS
2	**New PS** **[~50 GeV, PS2]**	▪ Higher injection energy in the SPS => better SPS performance ▪ New accelerator + less demand on the PS => higher reliability	▪ Shorter injection flat porch in SPS and LHC ▪ Potential injector for a new (higher energy) SPS
2'	**New injector for PS2**	▪ Reach full potential of PS2 (brightness & intensity) ▪ No PS any more => higher reliability	▪ Easier operation (minimum RF gymnastics in PS2 + shorter injection flat porch in SPS and LHC) ▪ New accelerator ▪ Flexibility
3	**New SPS** **[>500 GeV]**	▪ Reach full potential of LHC ▪ New accelerator => higher reliability	▪ Easier operation ▪ Potential injector for a DLHC

Scenarios for improving the CERN accelerator complex (1/3):
- Proposed combinations



SPL: Superconducting Proton Linac (~ 5 GeV)
SPL': RCPSB injector (0.16 to 0.4-1 GeV)
RCPSB: Rapid Cycling PSB (0.4-1 to ~ 5 GeV)
PS2: High Energy PS (~ 5 to 50 GeV – 0.3 Hz)
PS2+: Superconducting PS (~ 5 to 50 GeV – 0.3 Hz)
SPS+: Superconducting SPS (50 to1000 GeV)
SLHC: "Superluminosity" LHC (up to 10^{35} $cm^{-2}s^{-1}$)
DLHC: "Double energy" LHC (1 to ~14 TeV)

Scenarios for improving the CERN accelerator complex (2/3):
- Stages of implementation & benefits

	STAGE	1	2	3	4
	DESCRIPTION (*new accelerator*)	*Linac4* PSB PS SPS	*Linac4* PSB *PS2 or PS2+* (& PS) SPS	*Linac4* *SPL* *PS2 or PS2+* SPS	*Linac4* *SPL* *PS2 or PS2+* *SPS+*
INTEREST FOR	Performance of LHC injectors (SLHC)	+ Ultimate beam from PS	++ Ultimate beam from SPS	++ Maximum SPS performance	+++ Highest performance LHC injector
	Higher energy LHC	-	-	-	+++
	β beam	-	-	++ (γ ~100)	++ (γ ~200) [2]
	ν Factory	-	-	+++ (~ 5 GeV prod. beam[1])	+++ (~ 5 GeV prod. beam[1])
	k, μ	-	~ 150 kW beam at ~50 GeV	~ 200 kW beam at ~50 GeV	~ 200 kW beam at ~50 GeV
	EURISOL	-	-	+++ (5 MW at a few GeV[1])	+++ (5 MW at a few GeV[1])

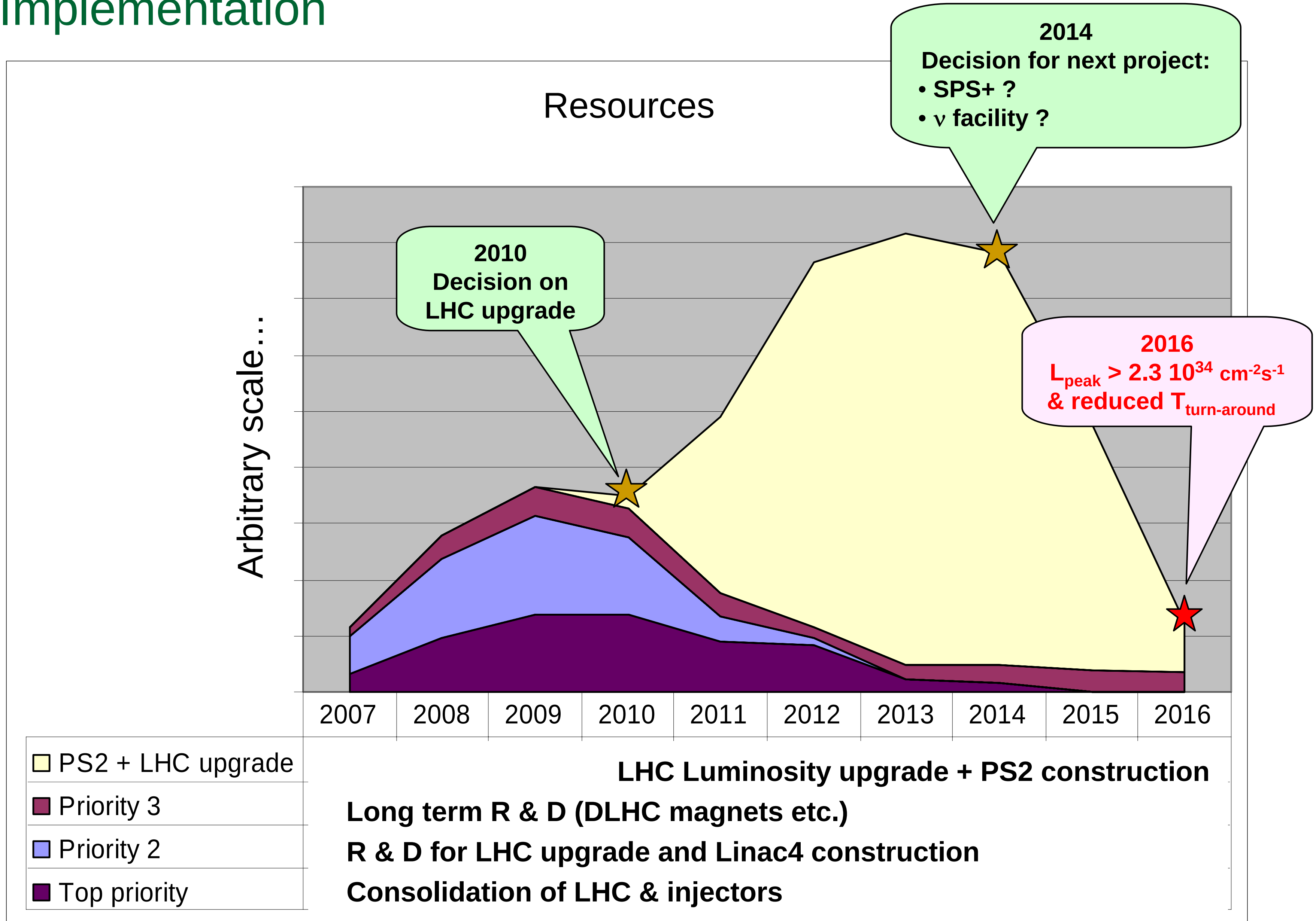
[1] Full beam power alternatively for ν factory or an ISOL RIB facility if the SPL is built for 5 MW; simultaneously if the SPL is built for 10 MW.

[2] Reduced synergy between super-beam and β beam because of the different ν energies.

Scenarios for improving the proton accelerator complex (3/3):
- Expected performance improvement

STAGE	1	2	3	4
DESCRIPTION (*new accelerator*)	*Linac4* PSB PS SPS	*Linac4* PSB (& PS) *PS2 or PS2+* SPS	*Linac4* *SPL* *PS2 or PS2+* SPS	*Linac4* *SPL* *PS2 or PS2+* *SPS+*
Characteristics of beam entering PS/PS2	- Ultimate LHC beam in 1 PSB pulse instead of 2	- As in stage 1	- 2x ultimate LHC beam in 1 injection	- As in stage 3
Characteristics of beam entering SPS/SPS+	- 72 ultimate LHC bunches every 2.4s (instead of 3.6s) - Higher reliability (no long flat porch at PS injection) - Reduced injection flat porch (7.2s instead of 10.8s) - Possibility to study SPS limitation with brightness beyond ultimate	- Energy x2 (~50GeV) => improved SPS behaviour (farther from transition, reduced space-charge etc.) - Reduced injection flat porch (3.6s instead of 10.8s) - Higher reliability (limited use of PS)	- Energy x2 (~50GeV) - Reduced injection flat porch (2.4s instead of 10.8s) - Highest reliability (no PS) - Capability to push the SPS to its maximum potential	- As in stage 3
Characteristics of beam entering LHC	- Capable of beam luminosity above nominal ($\geq 10^{34}$ $cm^{-2}s^{-1}$) - Higher reliability - Reduced filling time	- Capable of beam luminosity at/beyond ultimate ($\geq 2.5\ 10^{34}$ $cm^{-2}s^{-1}$) - Higher reliability - Reduced filling time	- Beam characteristics for LHC luminosity upgrade ($\gg 2.5\ 10^{34}$ $cm^{-2}s^{-1}$) - Highest reliability - Minimum filling time	- As in stage 3 + - Energy x2 (~1 TeV) - Capability to push the LHC to its maximum potential - Adequate for DLHC

Implementation



Summary

- Preliminary draft scenarios have been sketched for the evolution of the CERN proton accelerator complex, according to the physics priorities. They have been used to estimate the required resources.

- Extensive studies have to take place to optimize/refine the present proposals, using the experience gained with running-in the LHC and the whole injector complex. Many MDs are needed for a better understanding.

- A detailed project proposal has to be ready in ~2010. The LHC physics results at that date will guide the choices, possibly modulated by the needs of other physics communities.

- Decision in favour of a neutrino and/or a second generation ISOL facility at CERN could take place in 2012-2014.

Conclusion

- The recent statement of the Strategy Group, endorsed by the CERN Council, confirms the physics ambitions.
- The Medium & Long term plans submitted this week by the CERN direction are matched to these needs. The Council decisions at the end of 2006 will be decisive…
- If these decisions are positive, a vigorous effort will be necessary to prepare the accelerator complex for this future. Accelerator physics as well as all accelerator technologies are concerned (RF, collimators, detectors, magnets,…).

We'll need You !

REFERENCES

Quotes from the Statement of the CERN Council Strategy Group

Scientific activities

3. The LHC will be the energy frontier machine for the foreseeable future, maintaining European leadership in the field; *the highest priority is to fully exploit the physics potential of the LHC, resources for completion of the initial programme have to be secured such that machine and experiments can operate optimally at their design performance.* A subsequent major luminosity upgrade (SLHC), motivated by physics results and operation experience, will be enabled by focussed R&D; *to this end, R&D for machine and detectors has to be vigorously pursued now and centrally organized towards a luminosity upgrade by around 2015.*

4. In order to be in the position to push the energy and luminosity frontier even further it is vital to strengthen the advanced accelerator R&D programme; *a coordinated programme should be intensified, to develop the CLIC technology and high performance magnets for future accelerators, and to play a significant role in the study and development of a high-intensity neutrino facility.*

5. It is fundamental to complement the results of the LHC with measurements at a linear collider. In the energy range of 0.5 to 1 TeV, the ILC, based on superconducting technology, will provide a unique scientific opportunity at the precision frontier; *there should be a strong well-coordinated European activity, including CERN, through the Global Design Effort, for its design and technical preparation towards the construction decision, to be ready for a new assessment by Council around 2010.*

6. Studies of the scientific case for future neutrino facilities and the R&D into associated technologies are required to be in a position to define the optimal neutrino programme based on the information available in around 2012; *Council will play an active role in promoting a coordinated European participation in a global neutrino programme.*