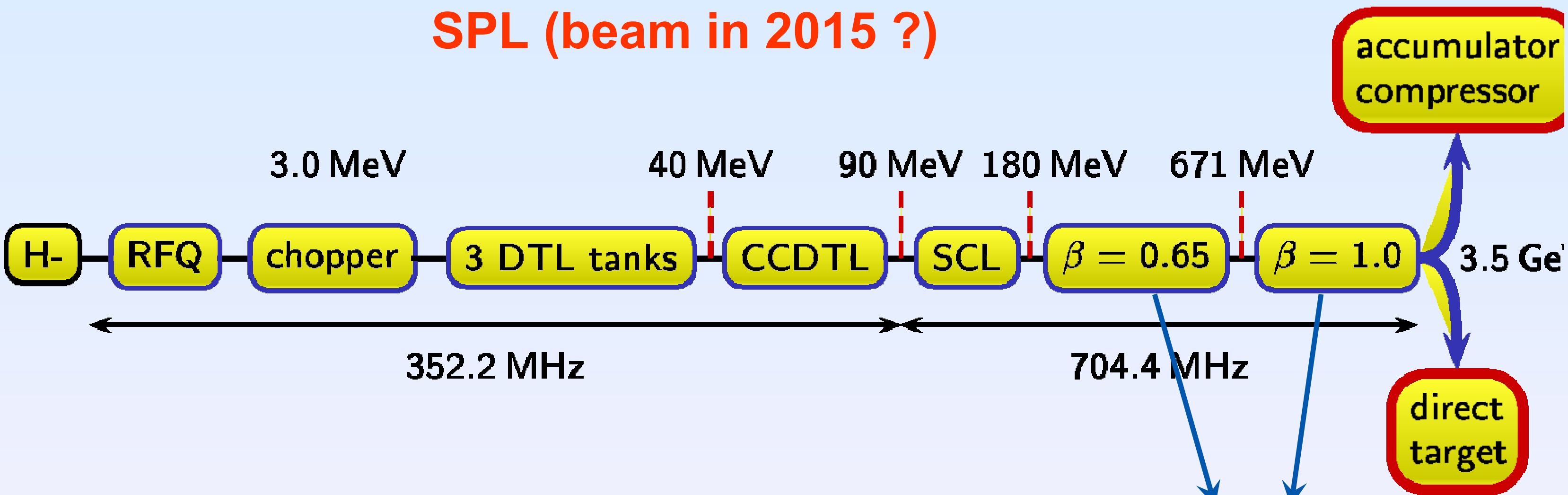
SPL-based Proton Driver for ν Facilities at CERN: Updated Description

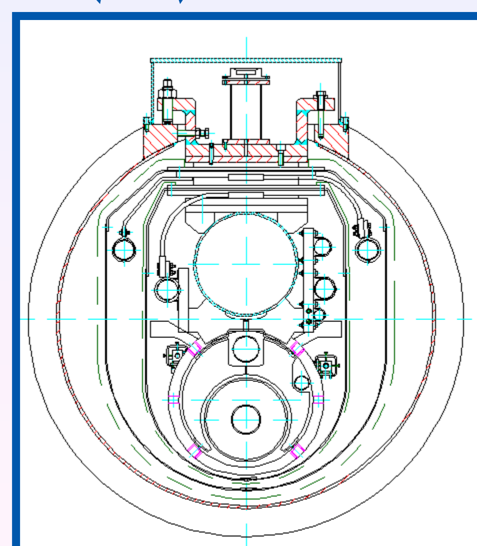
R. Garoby, F. Gerigk and the SPL study group

ISS meeting, 25-28.4.06

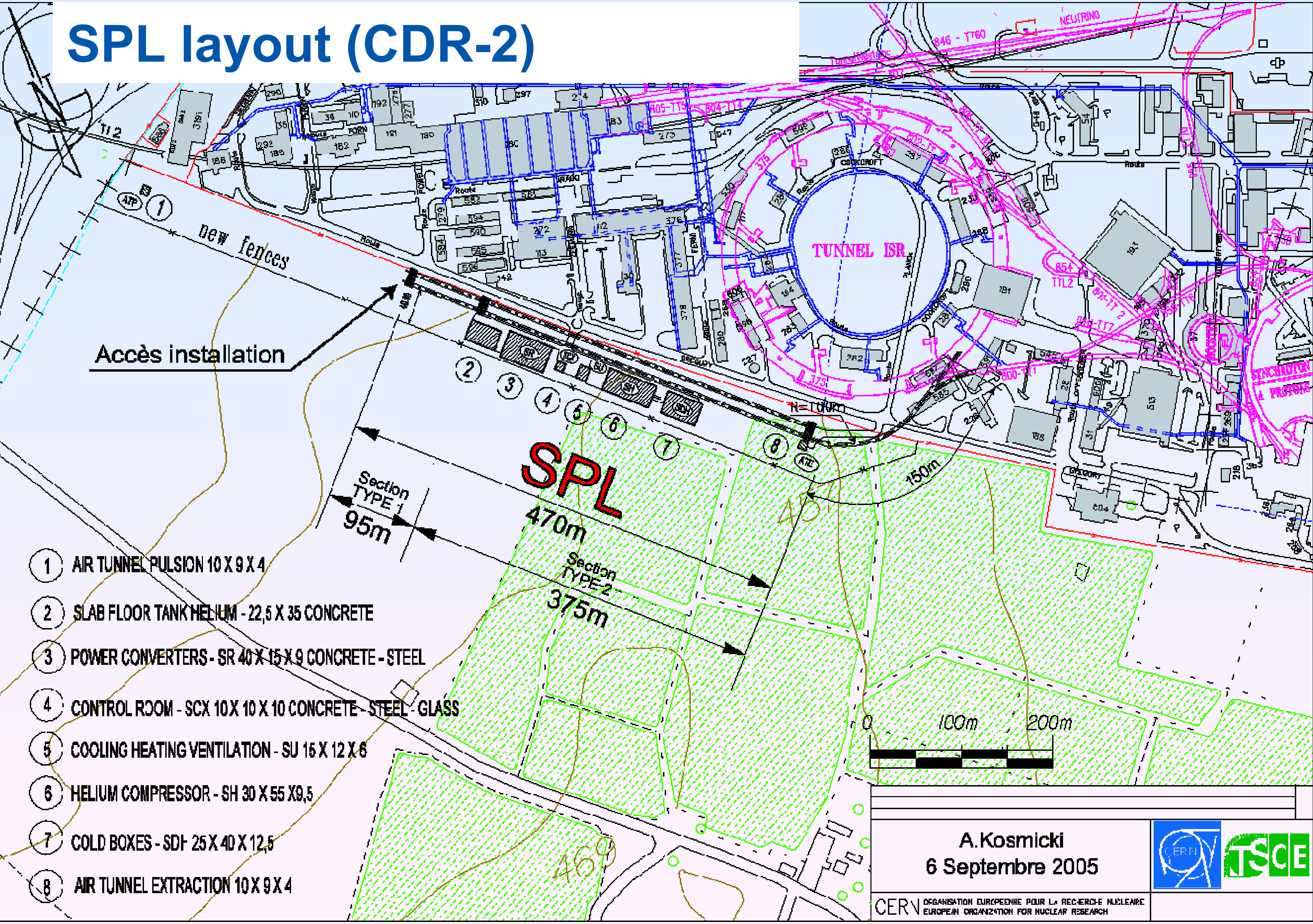
SPL block diagram (CRD-2)



- relocation of Linac4, adding 366 m of SC RF,
- PS booster becomes obsolete,
- cavity power < 1 MW,
- TESLA/ILC type cryostats (INFN Milano) with 5-cell SC Nb cavities (CEA/INFN) and cold quadrupoles,
- layout and beam dynamics (CEA Saclay).



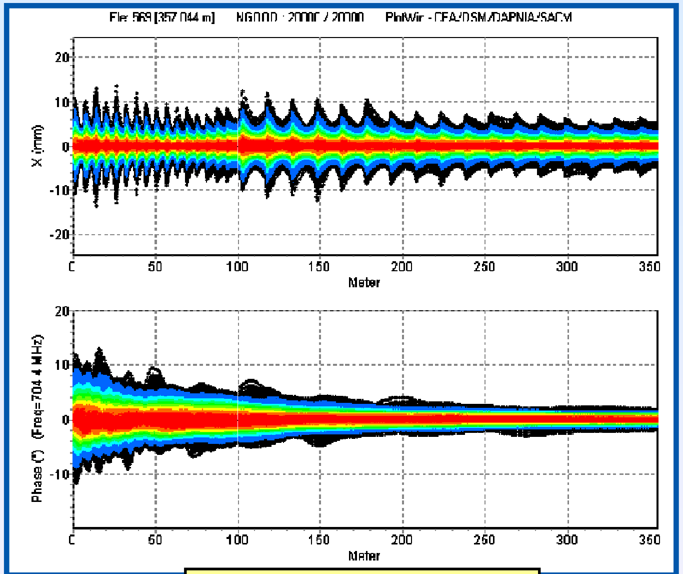
SPL layout (CDR-2)



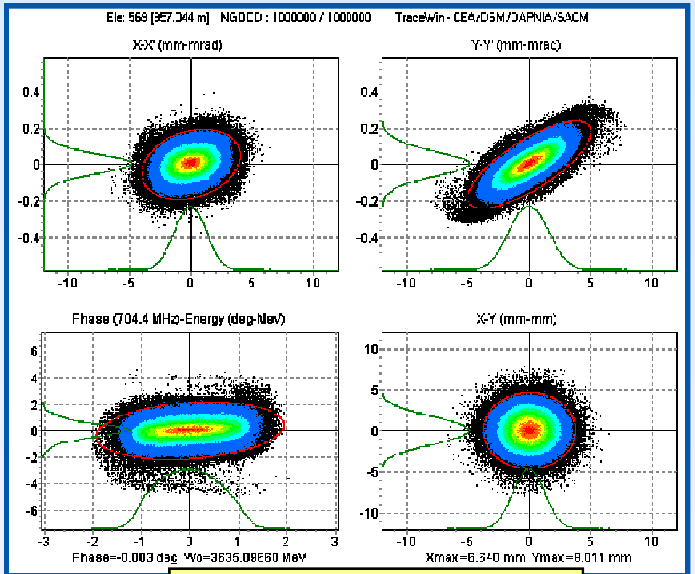
1. AIR TUNNEL PULSION 10 X 9 X 4
2. SLAB FLOOR TANK HELIUM - 22,5 X 35 CONCRETE
3. POWER CONVERTERS - SR 40 X 15 X 9 CONCRETE - STEEL
4. CONTROL ROOM - SCX 10 X 10 X 10 CONCRETE - STEEL - GLASS
5. COOLING HEATING VENTILATION - SU 15 X 12 X 6
6. HELIUM COMPRESSOR - SH 30 X 55 X9,5
7. COLD BOXES - SDH 25 X 40 X 12,5
8. AIR TUNNEL EXTRACTION 10 X 9 X 4

SPL beam dynamics (CDR-2)

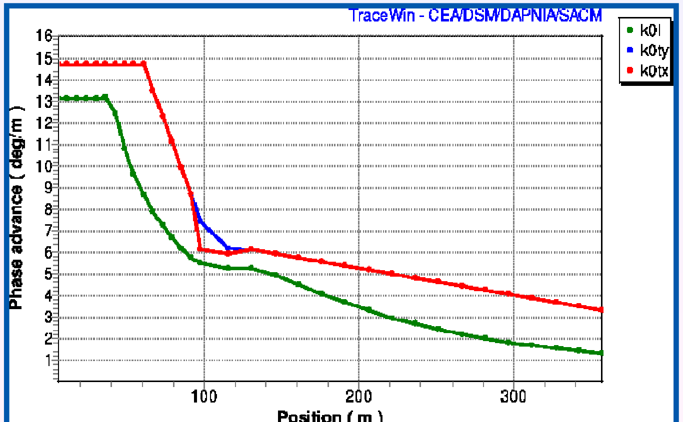
Beam dynamics (CEA Saclay)



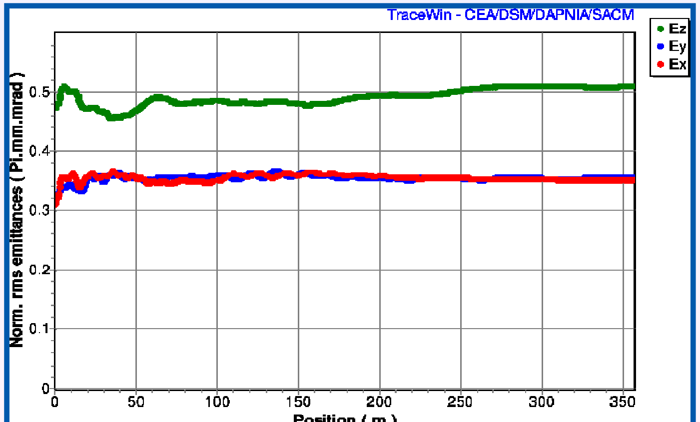
beam envelopes



output phase space



phase advance per metre



emittance evolution

SPL beam characteristics

	CDR1 [2000]	CDR2 [2006]	
energy	2.2	**3.5** ⇧	GeV
average beam power	4	**4**	MW
length	690	**450** ⇩	m
average RF power	24	**17.4** ⇩	MW
average cryogenics power	9.6	**6.7** ⇩	MW
repetition rate	50	**50**	Hz
beam pulse length	2.8	**0.57** ⇩	ms
average pulse current*	13	**40** ⇧	mA
peak current*	20.8	**64** ⇧	mA
beam duty cycle	14	**2.9** ⇩	%
peak RF power	32	**163** ⇩	MW
no. of 352.2 MHz klystrons (1 MW)	44	**14** ⇧	
no. of 704.4 MHz klystrons (5 MW)	-	**44**	
no. of tetrodes	79	**3**	
cryo temperature	4.5	**2** ⇩	K

* after chopping

Scenarios for accumulation & compression (1/7)

For ν physics, the time structure of the linac beam has to be changed:

- for a beta-beam based facility
[200 kW beam @ 1-5 GeV]
+
super-beam [4 MW @ 3.5 GeV]

Long beam burst (~ms)
⇒ direct use of linac beam

Short beam burst (~μs)
⇒ accumulator

- for a ν factory [4 MW beam @ 4-10 GeV]

Short beam burst (~μs)
⇒ accumulator
+
Short bunches (~ns)
⇒ compressor

The requirements of a ν factory are the most demanding.

Scenarios for accumulation & compression (2/7)

Parameters required by a ν factory*

Beam power (P)	**~ 4 MW**
Kinetic energy (T)	**4 – 10 GeV**
Bunch length	**1-3 ns rms**
Distance between bunches ???	**$\geq$ 100 ns**
Burst length	**1-3 μs**
Repetition rate	**$\leq$ 50 Hz**

*** Partial understanding…**

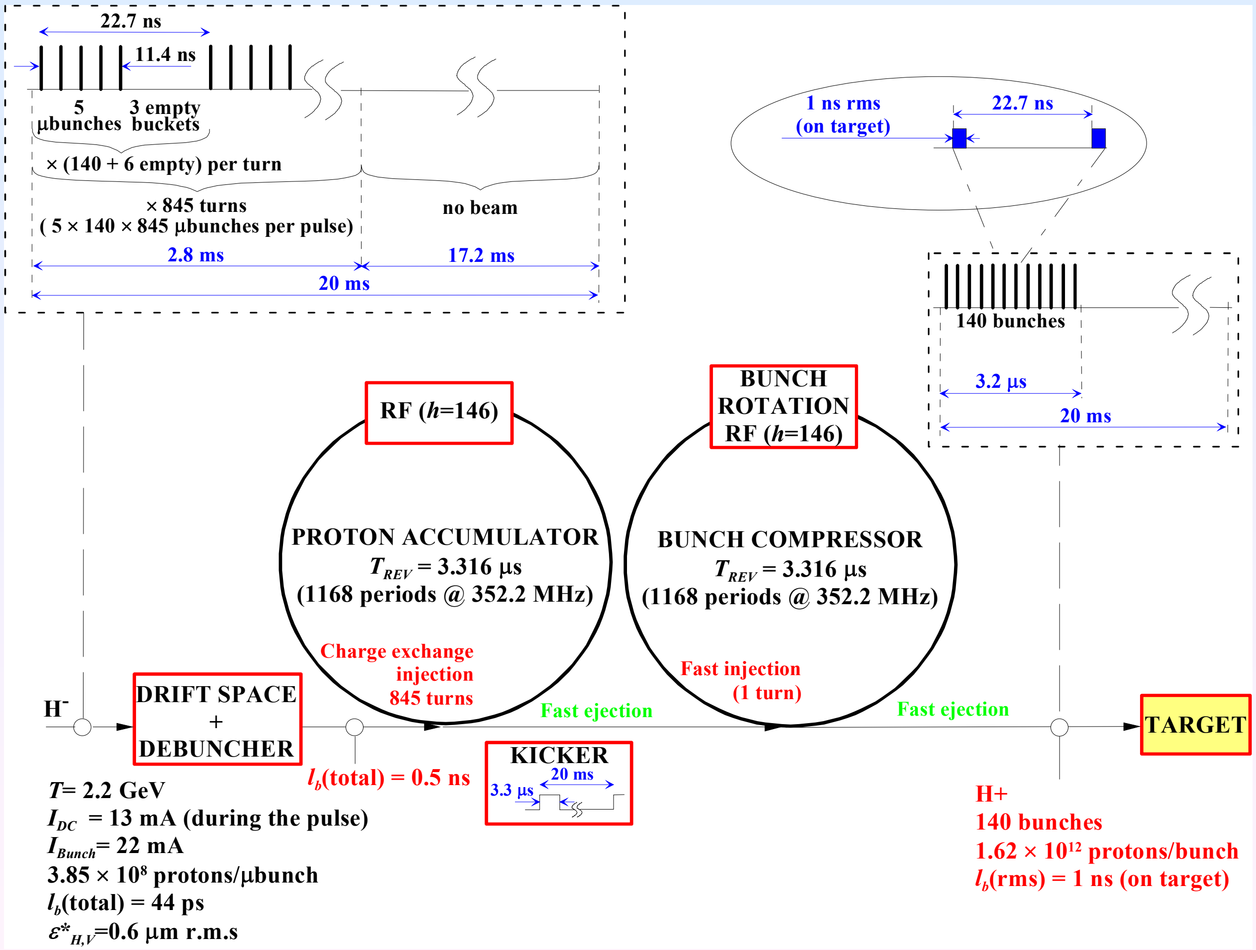
Scenarios for accumulation & compression (3/7)

Consequences for a linac-based driver

Kinetic energy (T)	**Cost increases with T** **$\Rightarrow$ Minimize T (< 4 – 8 ? GeV)**
Repetition rate (f_{rep})	**Constant beam power imposes the number of protons/pulse N_p**
Bunch length (l_b)	**Energy acceptance + longitudinal space charge restrict to low longitudinal emittance** **$\Rightarrow$ minimum number of bunches (N_b)**
Distance between bunches (d_b)	**Accumulator circumference C is proportional to $N_b \times d_b$** **& Laslett tune shift ΔQ is proportional to C** **$\Rightarrow$ minimize d_b to minimize ΔQ & cost**
Burst length	**Constraints the highest value of C**

Scenarios for accumulation & compression (4/7)

With SPL CDR1 (2000): severe constraint due to the low beam energy



T	2.2 Gev
f_{rep}	50 Hz
N_p	$2.27\ 10^{14}$
l_b	1 ns
N_b	140
d_b	22.7 ns
C	3.316 µs

Scenarios for accumulation & compression (5/7)

With SPL CDR2 (2006): higher beam energy => less constraints

First approach…

Kinetic energy (T)	**3.5 GeV**
Repetition rate (f_{rep})	**50 Hz $\Rightarrow$ N_p= 1.43 10^{14} p/p**
Bunch length (l_b)	**For the same $\Delta p/p$ acceptance + because of lower N_p + relaxing on l_b (2 ns instead of 1 ns)** **$\Rightarrow$ N_b (goal) = 17** **[8.41 10^{12} p/b]**
Distance between bunches (d_b)	**d_b (goal) = 90.86 ns** **C (goal) = 1.635 μs**

Feasibility in the accumulator/compressor has been pre-checked

Scenarios for accumulation & compression (6/7)

With a linac-based driver there is the possibility to do multiple accumulations with a single linac beam pulse, and therefore generate multiple bursts of beam onto the target.

This is of interest if:
- all parameters are constant in the μ channel during the whole duration of the proton beam on the target (transverse focusing, gradient in the RF cavities…). It is not unreasonable to hope for ~ 1 ms.
- the μ storage ring is long enough to contain all the successive bursts.

The main disadvantage is that the kickers must provide multiple kicks within ~ 1 ms.

This makes it possible to tailor the intensity per burst / the distance between bunches / the main cycling rate of whole facility…

Scenarios for accumulation & compression (7/7)

With SPL CDR2 (2006): other approach using multi-pulsing

Fill & eject 6 times single bunches from an accumulator/compressor of 272 ns revolution period

Fill & eject 12 times single bunches from an accumulator/compressor of 272 ns revolution period

Kinetic energy (T)	**> 3.5 GeV**	**3.5 GeV**
Repetition rate (f_{rep})	**6 bunches at 50 Hz**	**12 bunches at 25 Hz**
Number of protons/bunch	**$2.4\ 10^{13}$ p/p**	**$2.4\ 10^{13}$ p/p**
Time interval between bunches	**95 μs**	**95 μs**
Total burst duration	**475 μs**	**1.045 ms**
Bunch length (l_b)	**~ 3 ns ?**	**~ 3 ns ?**

Many open questions to be studied …

Conclusions & outlook

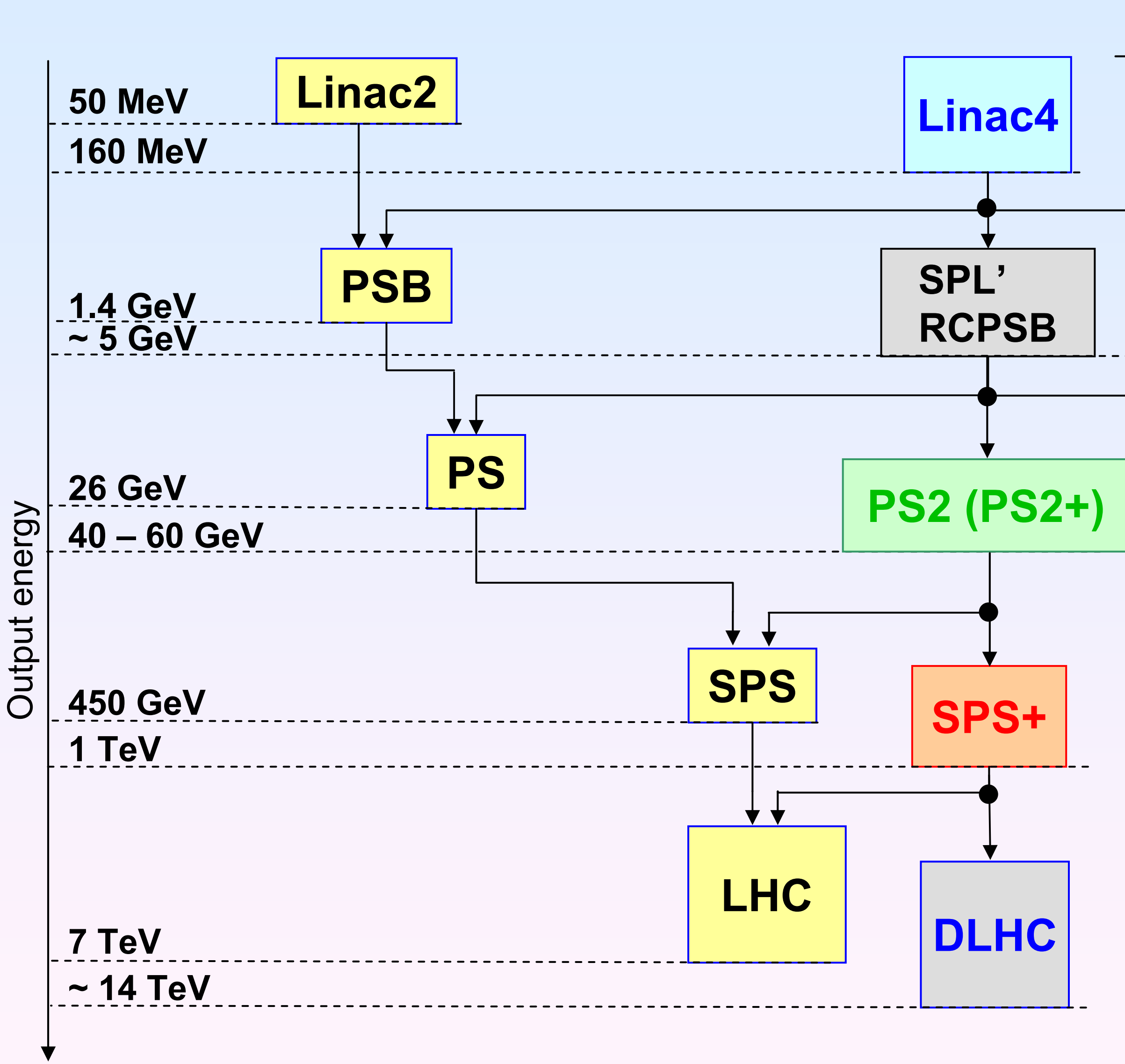
The new SPL design (CDR2 – 2006) is largely improved:

- energy (3.5 GeV) is a compromise that can potentially satisfy EURISOL, neutrino applications, and LHC upgrade scenarios,
- design is more optimum (length reduced by 35% while the energy is increased by 60%, higher instantaneous current reducing the number of turns for accumulation in the ring…)
- upgrades are possible in terms of energy and/or power.

This typically illustrates the potential of a linac-based proton driver for a ν factory, which can be the basis of a high energy accelerator complex [→] and has a remarkable flexibility to adapt to the requirements of the following part of the facility.

ANNEX

Evolution of the CERN accelerator complex



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)
DLHC: "Double energy" LHC (1 to ~14 TeV)

Scenarios for the proton accelerator complex

- Stages of implementation

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+*
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)
ν Factory	-	-	+++ (~5 GeV prod. beam)	+++ (~5 GeV prod. beam)
k, μ	-	~150 kW beam at 50 GeV	~200 kW beam at 50 GeV	~200 kW beam at 50 GeV
EURISOL	-	-	+++	+++

Exotic scenarios for accumulation & compression

With SPL CDR2 (2006): other approach using multi-pulsing

Fill & eject 6 times multiple bunches from an accumulator/compressor of 272 ns revolution period

Fill & eject 12 times multiple bunches from an accumulator/compressor of 272 ns revoluton period

Kinetic energy (T)	**> 3.5 GeV**	**3.5 GeV**
Repetition rate (f_{rep})	**6 batches of 3 bunches at 50 Hz**	**12 batches of 3 bunches at 25 Hz**
Number of protons/bunch	**2.4 10^{13} p/p**	**2.4 10^{13} p/p**
Time interval between bunches	**95 μs**	**95 μs**
Total burst duration	**475 μs**	**1.045 ms**
Bunch length (l_b)	**~ 2 ns ?**	**~ 2 ns**

<u>Main issue</u>: the distance between bunches imposes a quantum Δf in the μ capture & bunch rotation channel. How much is acceptable ? 10 MHz ?