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

C.R. Prior for

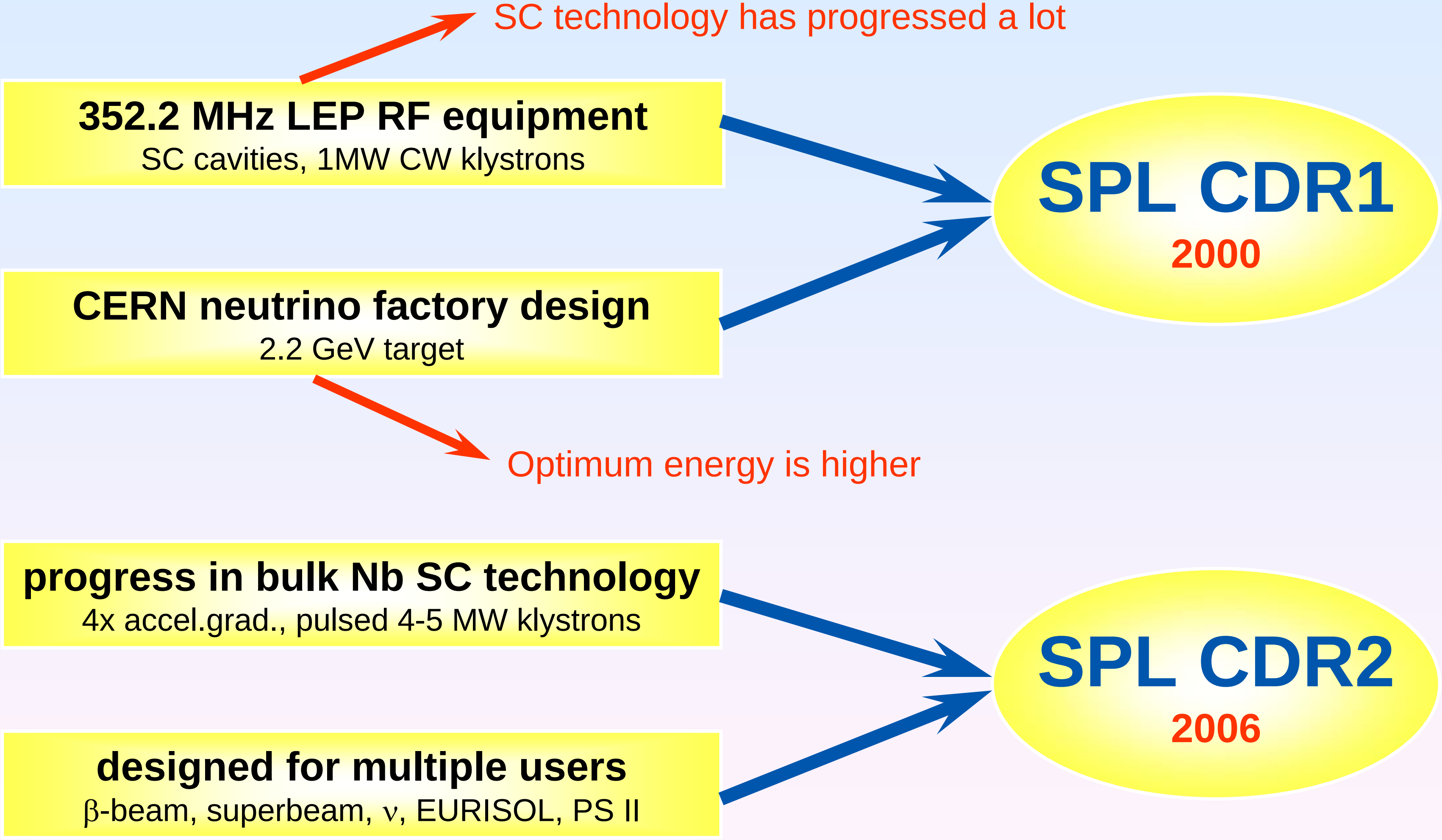
R. Garoby, F. Gerigk and the SPL study group

ISS meeting, 23-25.1.06

Outline

1. Re-design of the SPL
2. Applications
3. Staged construction
4. SPL beam characteristics
5. Scenarios for accumulation and compression
6. Conclusions & outlook

1. Re-design of the SPL (2005/6)



SC technology has progressed a lot

352.2 MHz LEP RF equipment
SC cavities, 1MW CW klystrons

CERN neutrino factory design
2.2 GeV target

Optimum energy is higher

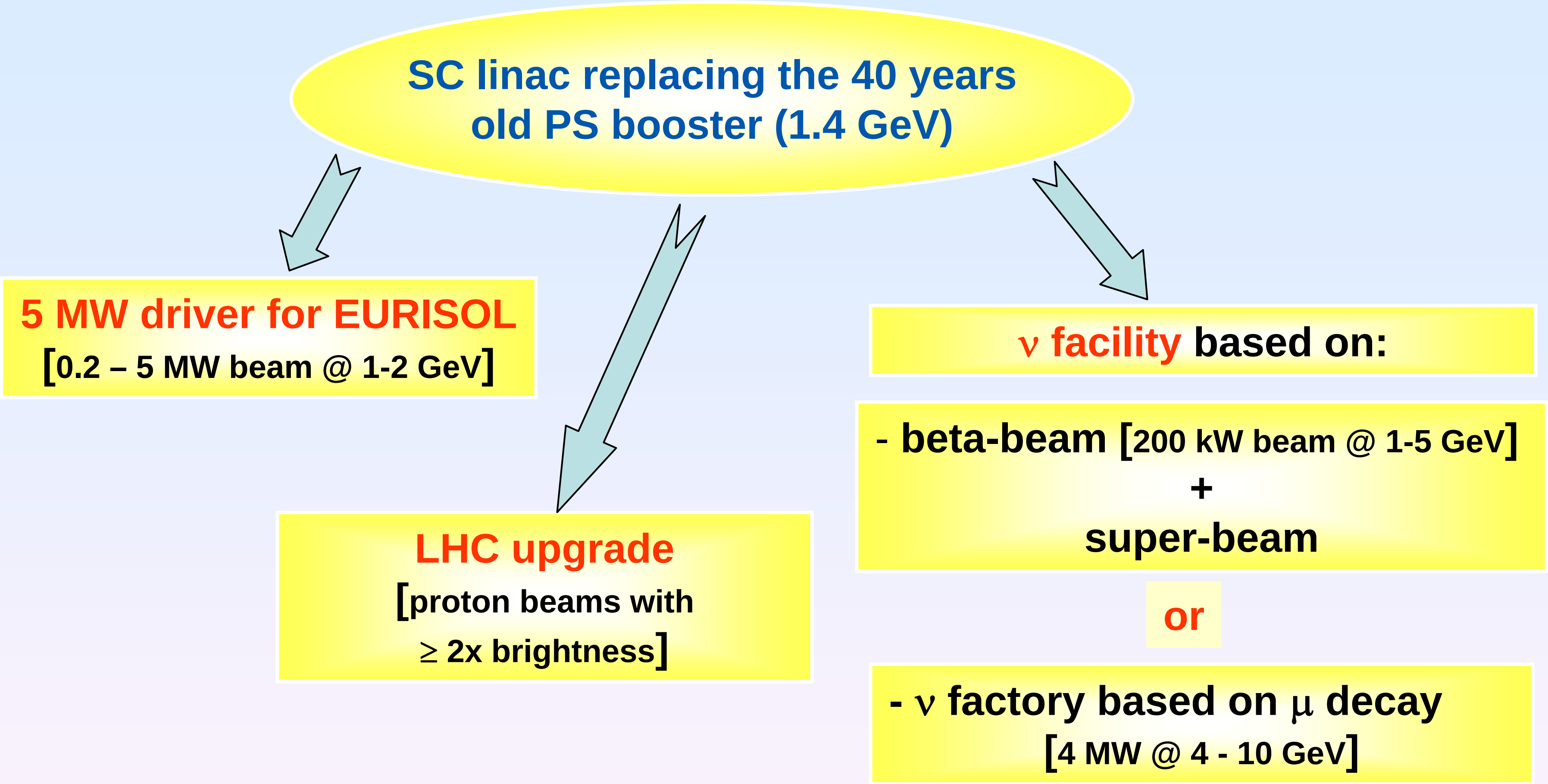
SPL CDR1
2000

progress in bulk Nb SC technology
4x accel.grad., pulsed 4-5 MW klystrons

designed for multiple users
β-beam, superbeam, ν, EURISOL, PS II

SPL CDR2
2006

2. Applications



SC linac replacing the 40 years old PS booster (1.4 GeV)

5 MW driver for EURISOL
[0.2 – 5 MW beam @ 1-2 GeV]

LHC upgrade
[proton beams with ≥ 2x brightness]

ν facility based on:

- beta-beam [200 kW beam @ 1-5 GeV]
+
super-beam

or

- ν factory based on μ decay
[4 MW @ 4 - 10 GeV]

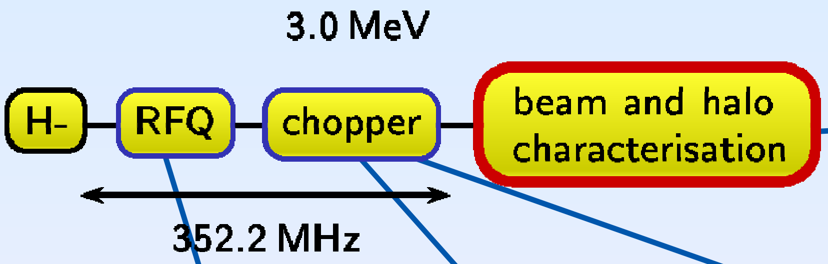
⇒ Major upgrade of the proton injector complex at CERN [performance: ≥ 2x higher brightness + reliability] for the benefit of all users (LHC, fixed target etc.)

⇒ Cost-effective time sharing between nuclear [ISOL] and ν applications

⇒ Potential for future increases in energy and/or power

3. Staged construction (1/5)

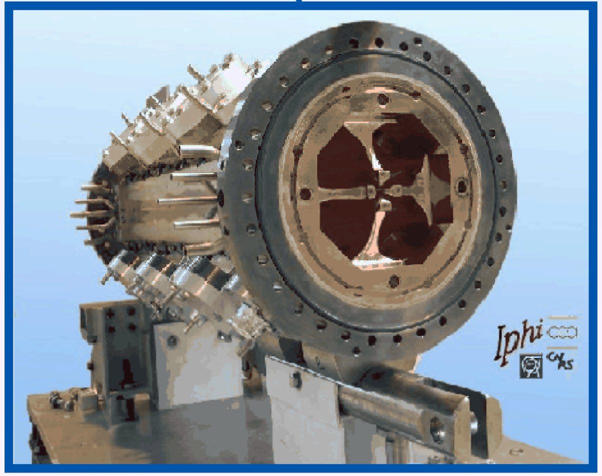
3 MeV test stand (beam in 2008)


3.0 MeV

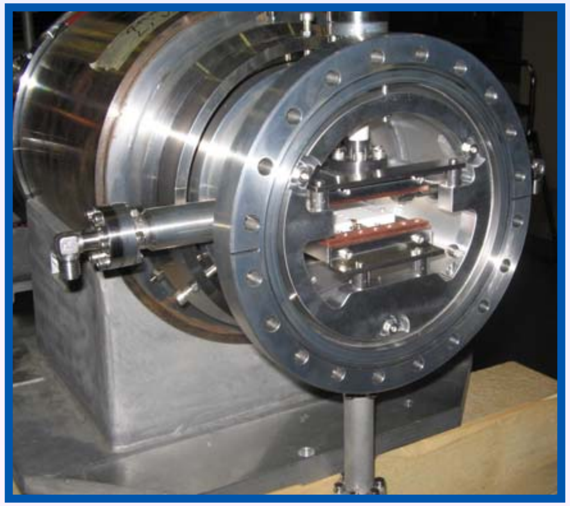
H- — RFQ — chopper — beam and halo characterisation

352.2 MHz

halo monitor



IPHI RFQ (CEA)



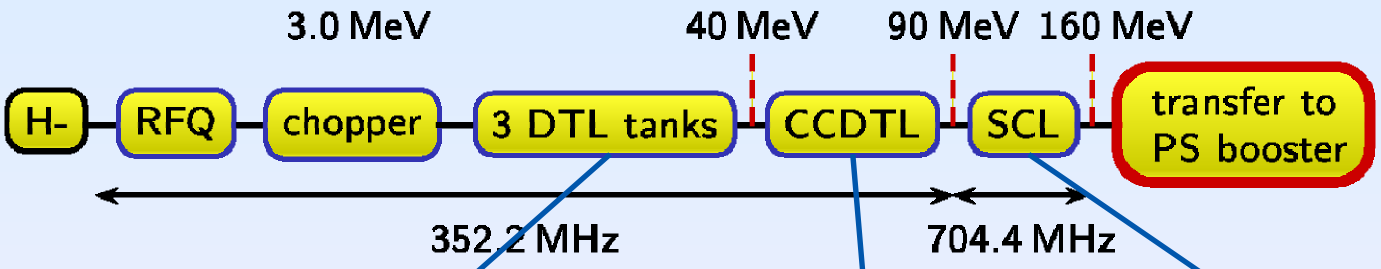
chopper in quadrupole

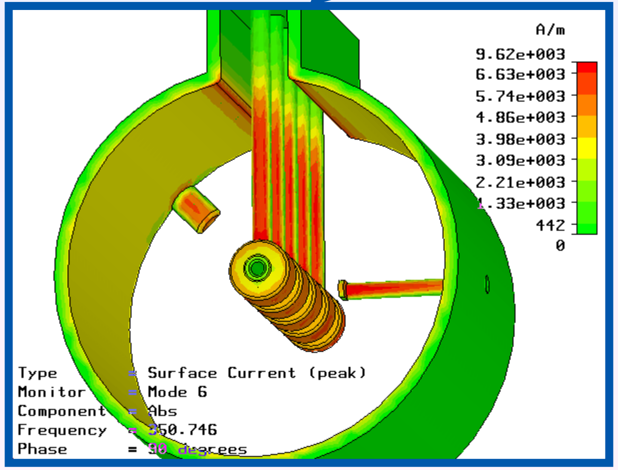
buncher cavity

3. Staged construction (2/5)

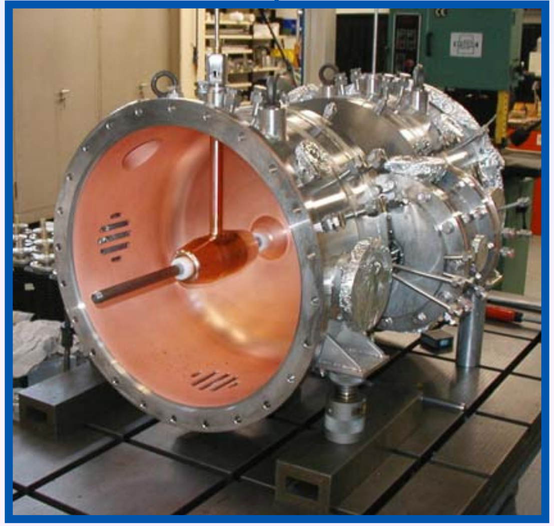
Linac4 (beam in 2010)

low duty cycle: 0.08%

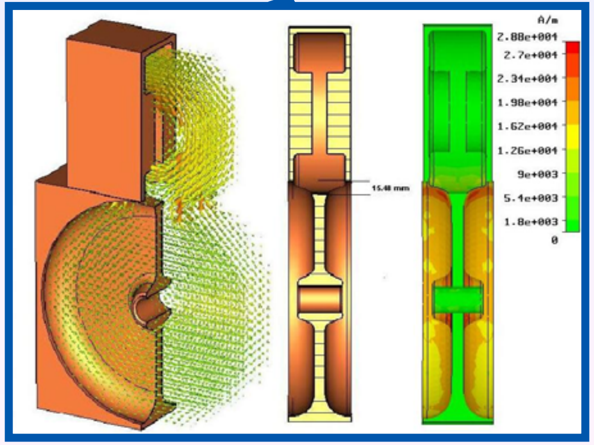




ITEP Moscow & VNIIEF Sarov & IN2P3



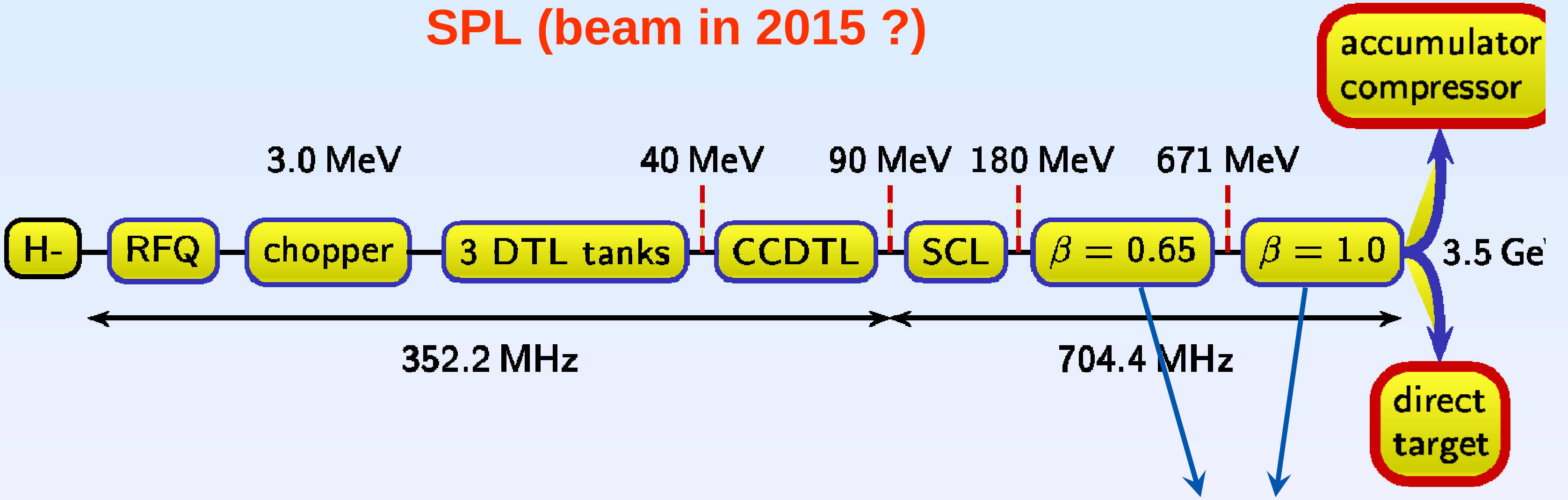
BINP Novosibirsk & VNIITEF Snezinsk



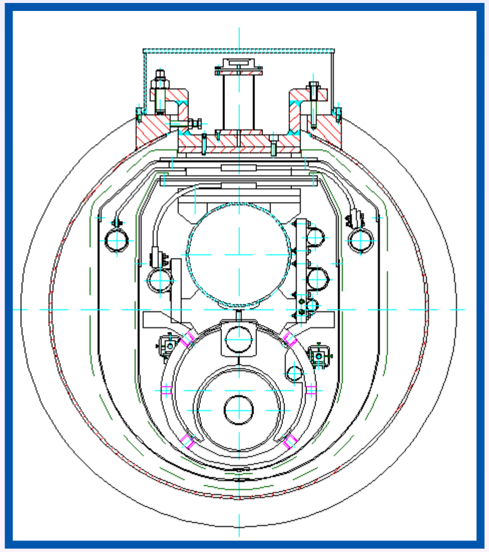
IN2P3, BINP, CEA, VNIITEF

3. Staged construction (3/5)

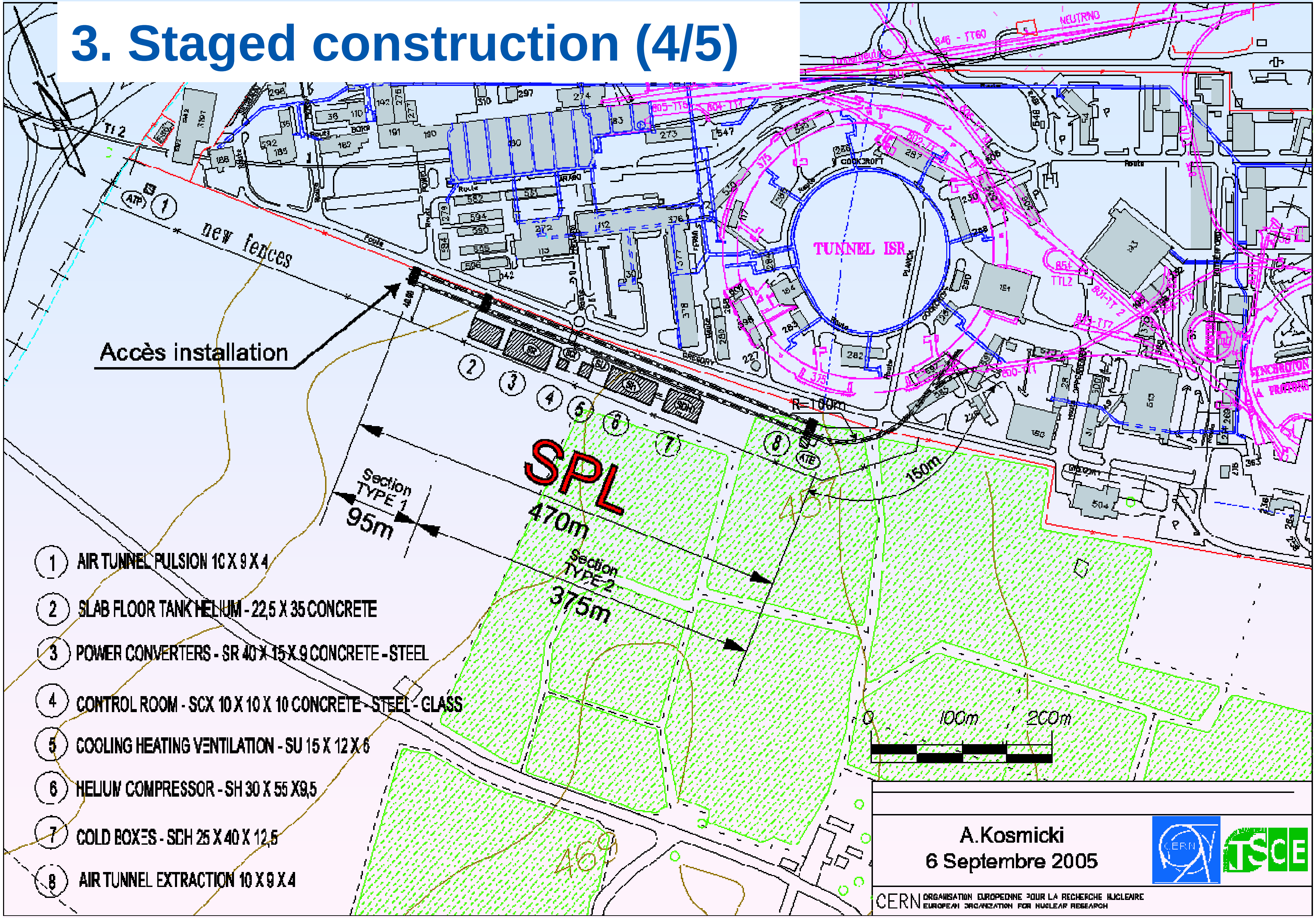
SPL (beam in 2015 ?)



- 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).



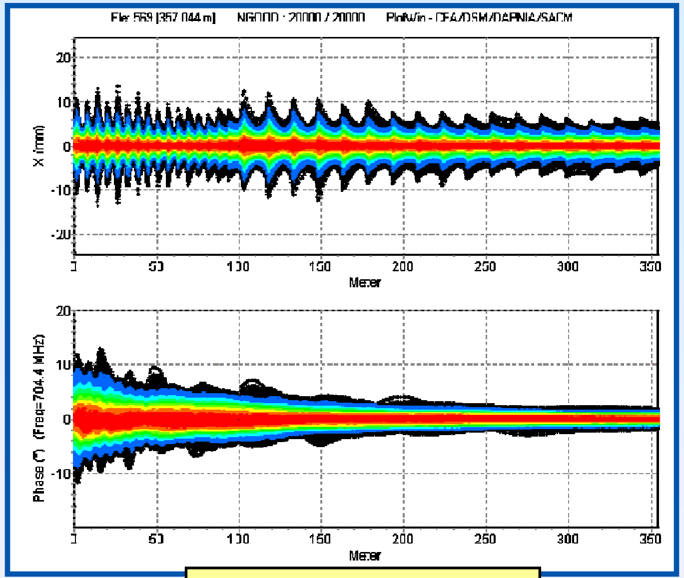
3. Staged construction (4/5)



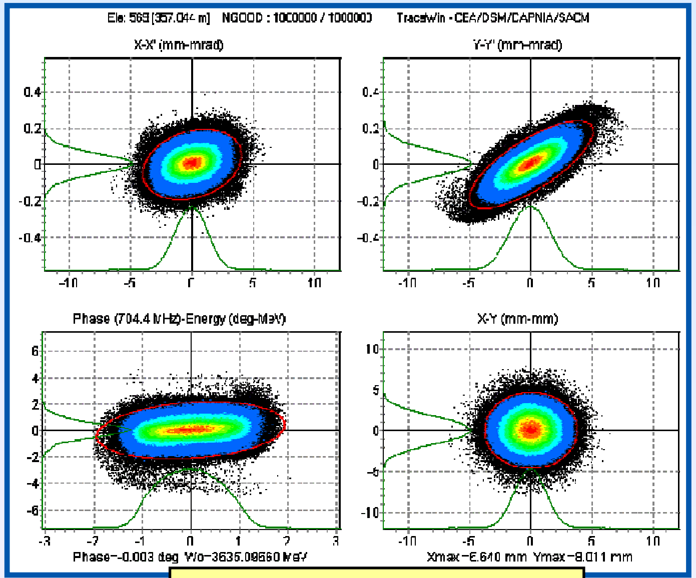
1. AIR TUNNEL PULSION 10 X 9 X 4
2. SLAB FLOOR TANK HELIUM - 22,5 X 35 CONCRETE
3. POWER CONVERTERS - SR 40 X 15 X 9 CONCRETE - STEEL
4. CONTROL ROOM - SCX 10 X 10 X 10 CONCRETE - STEEL - GLASS
5. COOLING HEATING VENTILATION - SU 15 X 12 X 6
6. HELIUM COMPRESSOR - SH 30 X 55 X9,5
7. COLD BOXES - SDH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

3. Staged construction (5/5)

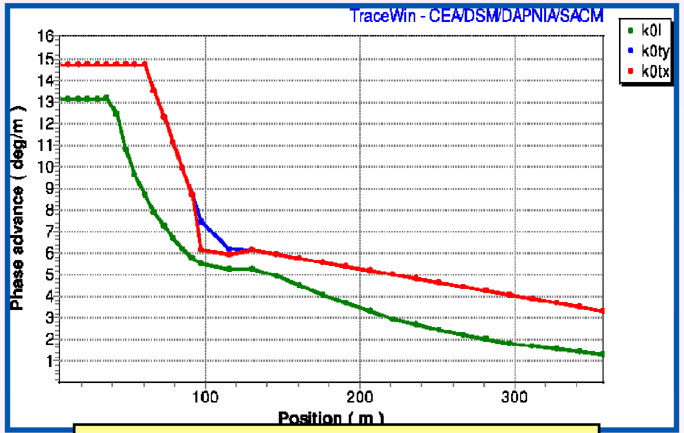
Beam dynamics (CEA Saclay)



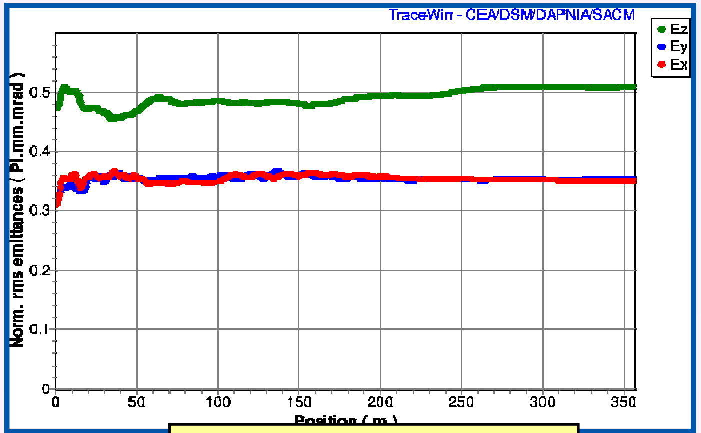
beam envelopes



output phase space



phase advance per metre



emittance evolution

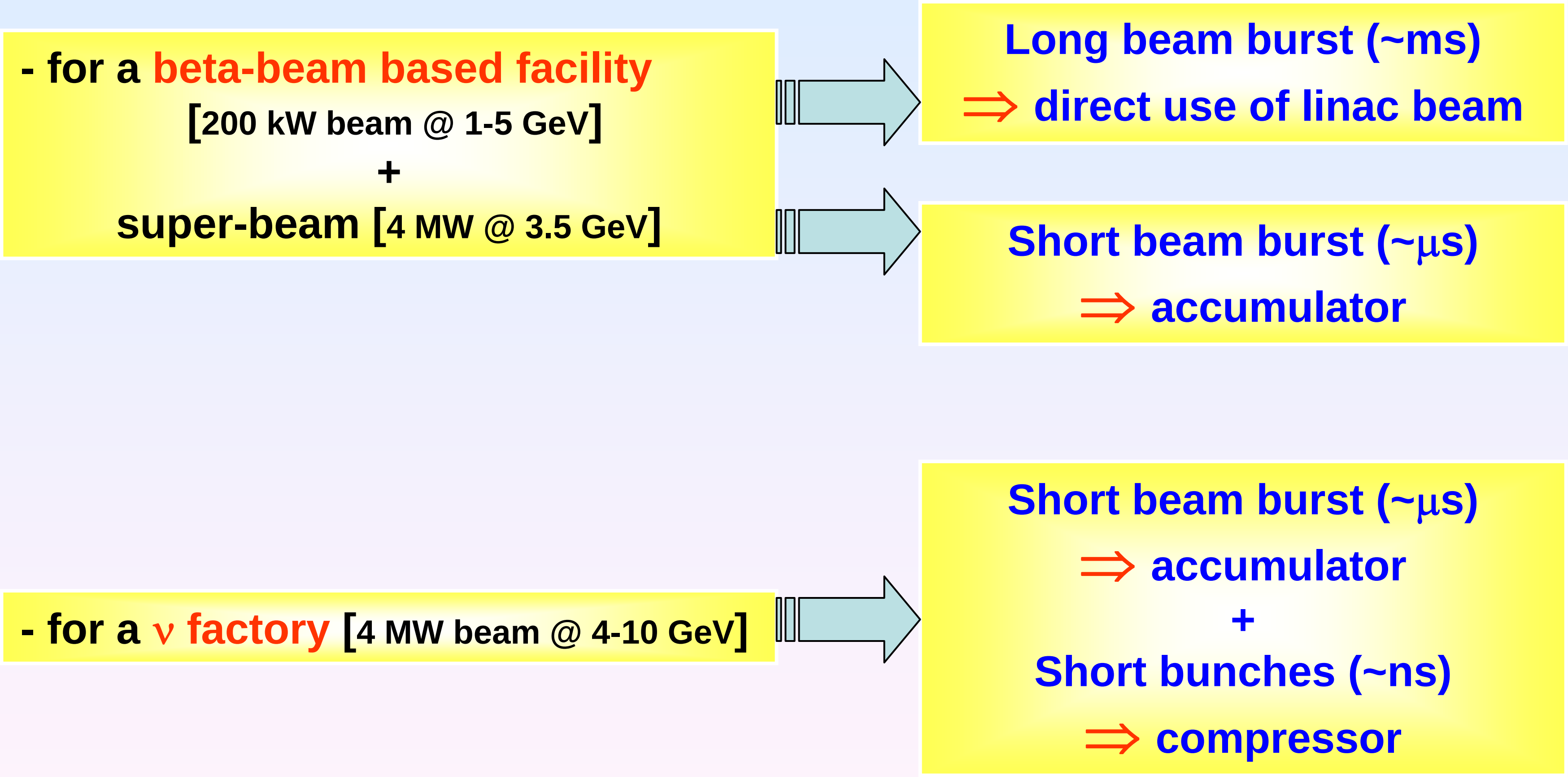
4. SPL beam characteristics

	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

5. 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.

5. 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	**1-2 ns rms**
Distance between bunches	**≥ 100 ns**
Burst length	**1-3 μs**
Repetition rate	**≤ 50 Hz**

*** As estimated today**

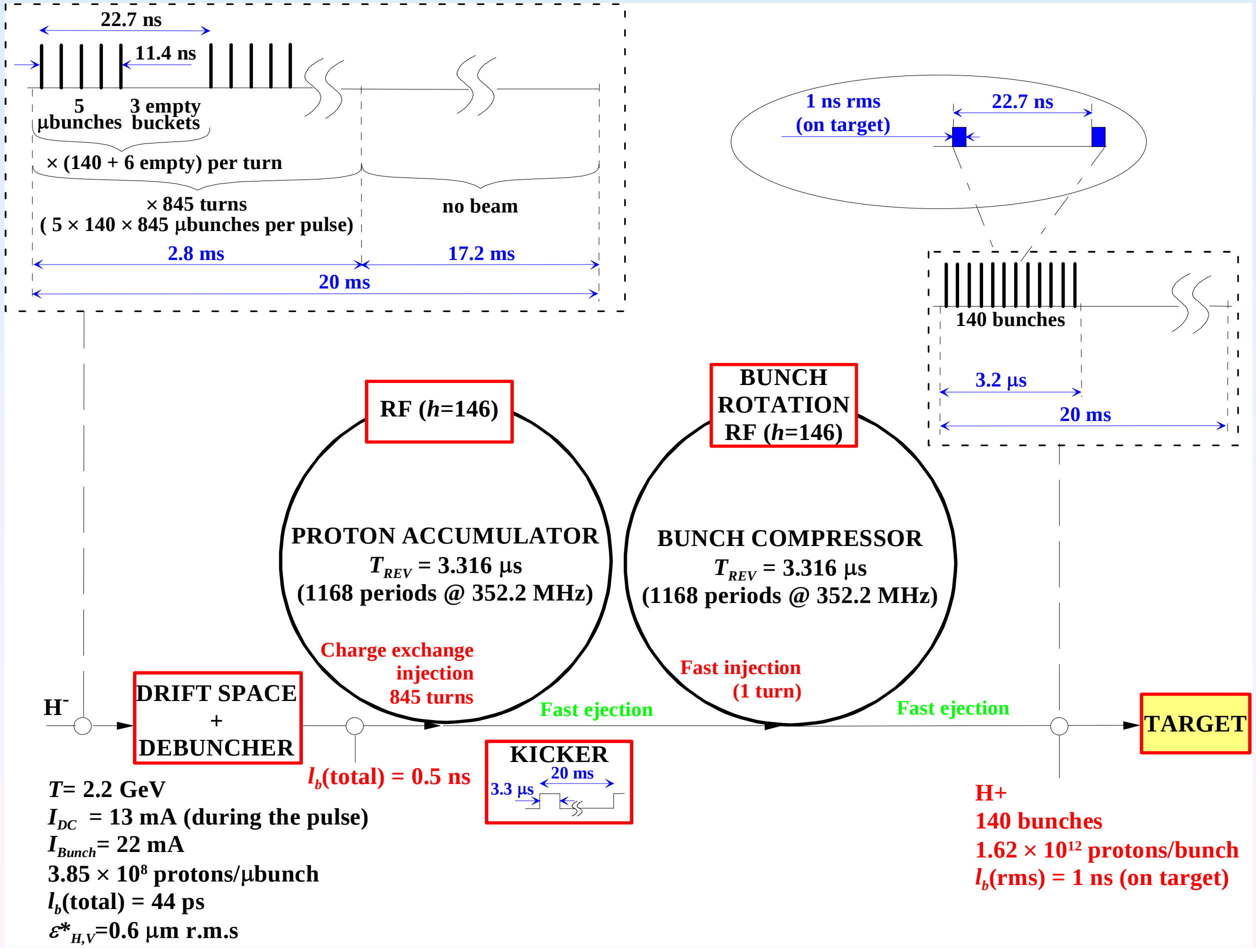
5. Scenarios for accumulation & compression (3/7)

Consequences for a linac-based driver

Kinetic energy (T)	**Cost increases with T** **⇒ Minimize T (< 4 – 8 ? GeV)**
Repetition rate (f_{rep})	**Constraints to a minimum number of protons/pulse N_p**
Bunch length (l_b)	**Energy acceptance + longitudinal space charge restrict to low longitudinal emittance** **⇒ 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** **⇒ minimize d_b to minimize ΔQ & cost**
Burst length	**Constraints the highest value of C**

5. 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

5. Scenarios for accumulation & compression (5/7)

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

Aggressive 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 Δp/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**

Study is going on to check feasibility…

5. 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…

5. Scenarios for accumulation & compression (7/7)

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

If the first set of parameters is unfeasible: pulse twice the accumulator/compressor

If the first set of parameters is feasible: pulse twice the accumulator/compressor and divide f_{rep} by 2

Kinetic energy (T)	**3.5 GeV**	**3.5 GeV**
Repetition rate (f_{rep})	**50 Hz ⇒ $N_p = 2 \times 0.72\ 10^{14}$ p/p**	**25 Hz ⇒ $N_p = 2 \times 1.43\ 10^{14}$ p/p**
Time interval between pulses	**0.285 ms**	**0.570 ms**
Bunch length (l_b)	**$N_b = 17$** **[$4.21\ 10^{12}$ p/b]**	**$N_b = 17$** **[$8.41\ 10^{12}$ p/b]**
Distance between bunches (d_b)	**$d_b = 90.86$ ns** **C = 1.635 μs**	**$d_b = 90.86$ ns** **C = 1.635 μs**

6. 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 has an unmatchable flexibility to adapt to the requirements of the following part of the facility.