sLHC

LHC Luminosity upgrade
- The Injectors -

… extensively using material from

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1. Present injector complex

Described in detail during Academic training lectures in:
- June 2003 (K. Schindl)
- March 2005 (M. Benedikt, P. Collier, K. Schindl)

Design published in “LHC Design Report: Vol. III” (CERN-2004-003)

Design procedure

1. Nominal (& ultimate) LHC requirements

N_b, $\varepsilon_{X,Y}$ and k_b (in fact distance between bunches) are imposed

($N_b/\varepsilon_{X,Y}$ is called the "beam brightness")

$$L \propto \frac{N_b}{\varepsilon_{X,Y}} \cdot N_b \cdot k_b$$

with N_b : number of protons/bunch

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

k_b : number of bunches per ring

2. Consequence on the injectors

Liouville's theorem ⇒ Brightness is (at best) conserved in a cascade of proton accelerators.

⇒ the LHC imposed brightness must be present from the lowest energy.

⇒ constraint on incoherent space charge tune spread ΔQ_{SC} at injection in the PSB and PS

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

with N_b : number of protons/bunch

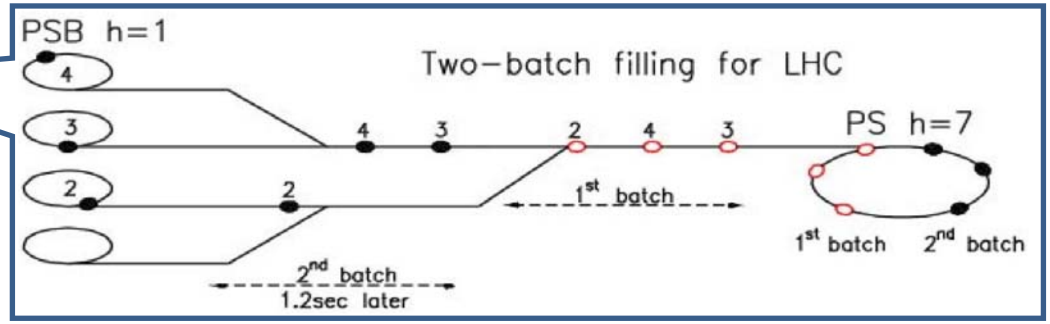
$\varepsilon_{X,Y}$: normalized transverse emittances

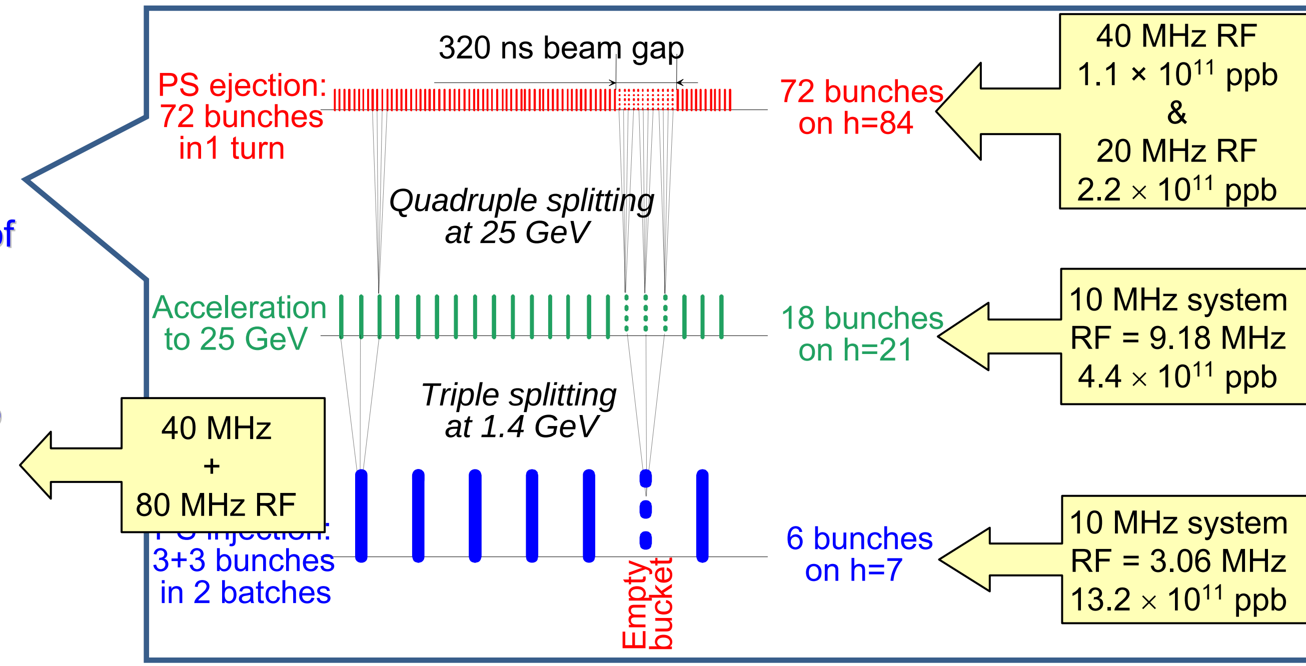
R : mean radius of the accelerator

$\beta\gamma$: classical relativistic parameters

Description (case of proton bunches spaced by 25 ns)

1. Division by 2 of the intensity in the PSB (one bunch per ring and double batch filling of the PS)
2. Increase of the injection energy in the PS (from 1 to 1.4 GeV)
3. Quasi-adiabatically splitting of each bunch 12 times in the PS to generate a train of bunches spaced by 25 ns
4. Compression of bunches to ~4ns length for bunch to bucket transfer to the SPS
5. Stacking of 3-4 PS batches in the SPS and acceleration to 450 GeV





Comments

1. **It works!**
   - Nominal beam characteristics (N_b=1.15 10^{11} p/b, $\varepsilon_{X,Y}$ =3.5 mm.mrad) are obtained in the SPS at 450 GeV
   - Nominal beam is available from Day-1 for the LHC
   - Cost was minimized (construction of a limited number of equipment for beam transfer between PS and PS, and of new RF systems in the PSB and PS)

2. **However:**
   - Beam loss is higher than foreseen: ultimate beam characteristics (N_b=1.7 10^{11} p/b, $\varepsilon_{X,Y}$ =3.5 mm.mrad) cannot be obtained
   - Operation is complicated and involves the control of many RF systems: risk of drift and of long duration of repair/re-adjustment
   - Reliability is uncertain: many equipments are old (e.g. PS magnets) and used at the limit of their capability

2. Future injectors

Requirements of the LHC upgrade

1. Beam brightness

Goal for meeting the needs of all scenarios under consideration:
N_b=3.4 10^{11} p/b, $\varepsilon_{X,Y}$ =3.75 mm.mrad at 7 TeV with 25 ns time interval between bunches

⇒ **Beam at LHC injection shall have up to twice the ultimate brightness**

2. Turn-around time

(time between two data-takings in the experiments)
To be minimized => high availability of the injectors + high reproducibility of beam characteristics

⇒ **Simple operating mode**
⇒ **Margin in beam performance**
⇒ **Margin in equipment ratings**
⇒ **Advantage of shorter LHC filling time**

3. Reliability

Large MTBF + Small MTTR…

⇒ **New, state-of-the-art and well-documented equipment**

4. Flexibility

(Capability to adapt to different scenarios in LHC)

Design procedure

Single batch injection in the PS

⇒ Better performance

⇒ Simpler operation

New chopper equipped H^- Linac

Higher beam brightness

⇓

Start by improving the lowest energ... accelerators

New SPS injector complex & SPS upgrade

⇒ Simplest operation (no gymnastics)

⇒ Maximum performance

⇒ Margin in equipment ratings

⇒ Shorter LHC filling time

⇒ Higher reliability

Stage 1: reach ultimate bri... the 1st bottleneck... PSB)

⇒ increase from 50 M... space charge limitations... PSB and in the PS with a new linac (Lina...

...d time ...ability

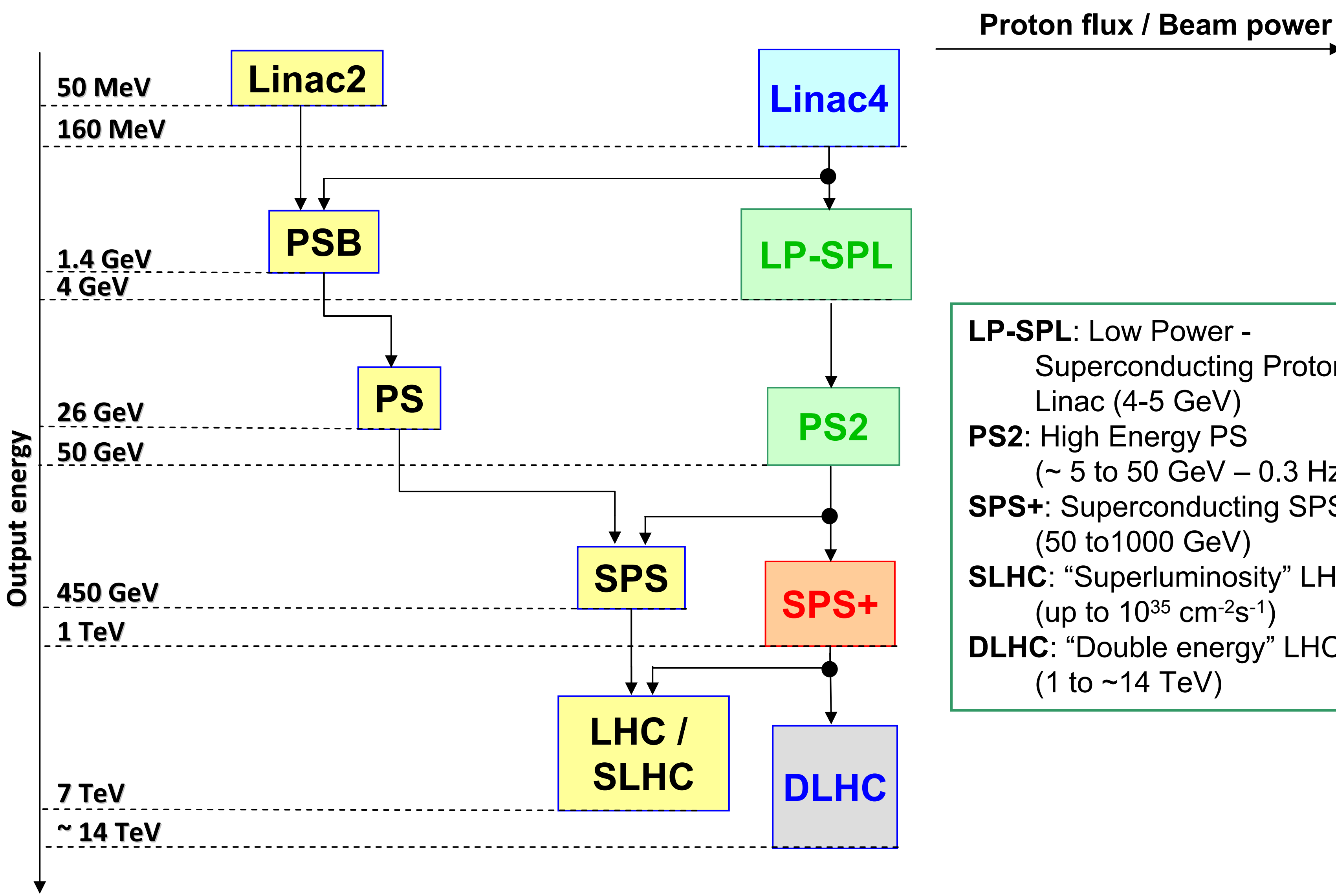
Stage 2: deliver the brightness for sLHC by removing the bottlenecks at PSB and P... injection

⇒ Build a new "PS" and its injector + upgrade the SPS (in particular with an injection energy far above transition)

⊕⊕⊕

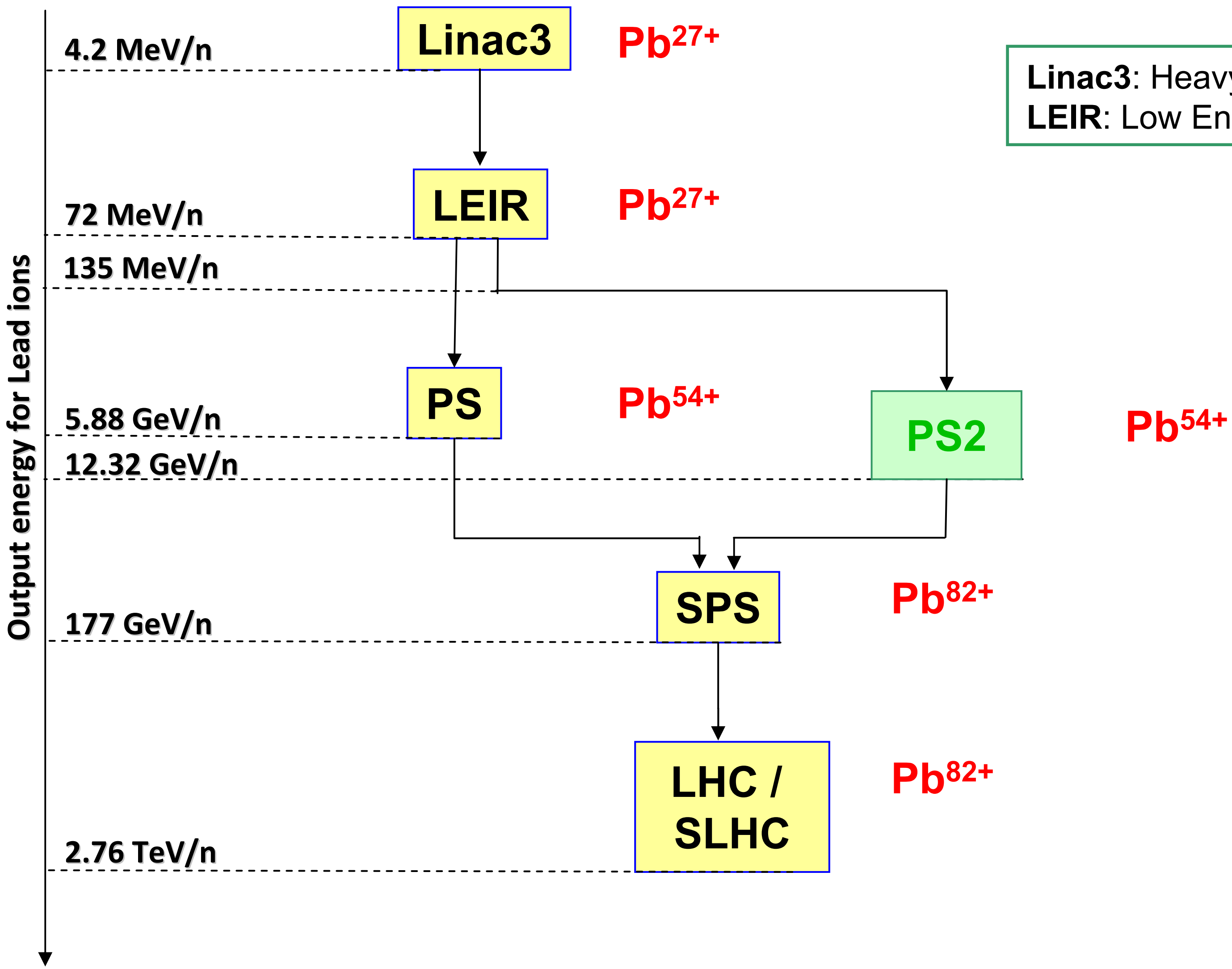
for Turn-around time and reliability

Baseline solution for future proton accelerators



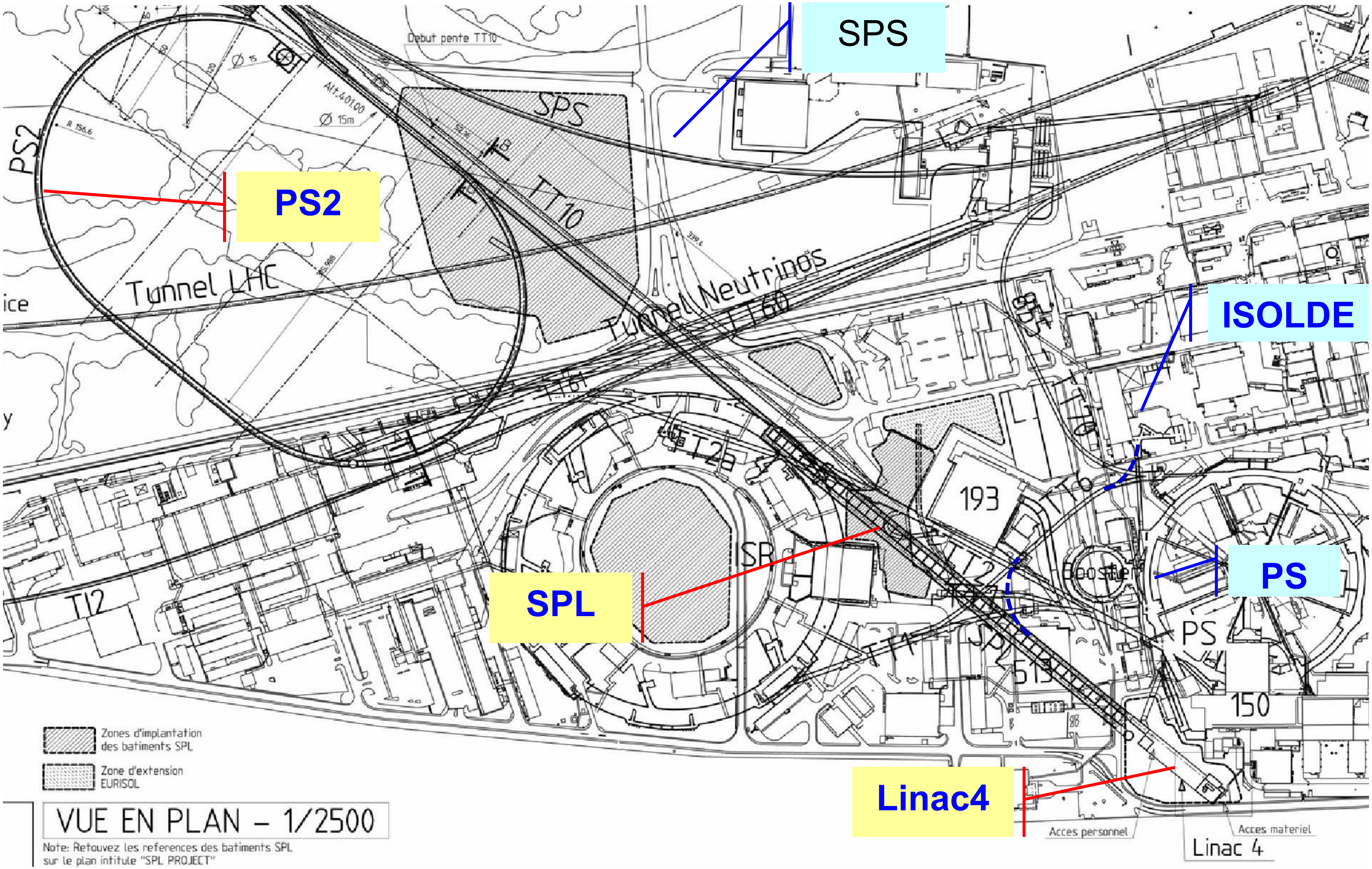
LP-SPL: Low Power - Superconducting Proton Linac (4-5 GeV)
PS2: High Energy PS (~ 5 to 50 GeV – 0.3 Hz)
SPS+: Superconducting SPS (50 to1000 GeV)
SLHC: “Superluminosity” LHC (up to 10^{35} cm^{-2}s^{-1})
DLHC: “Double energy” LHC (1 to ~14 TeV)

Baseline solution for future heavy ion accelerators

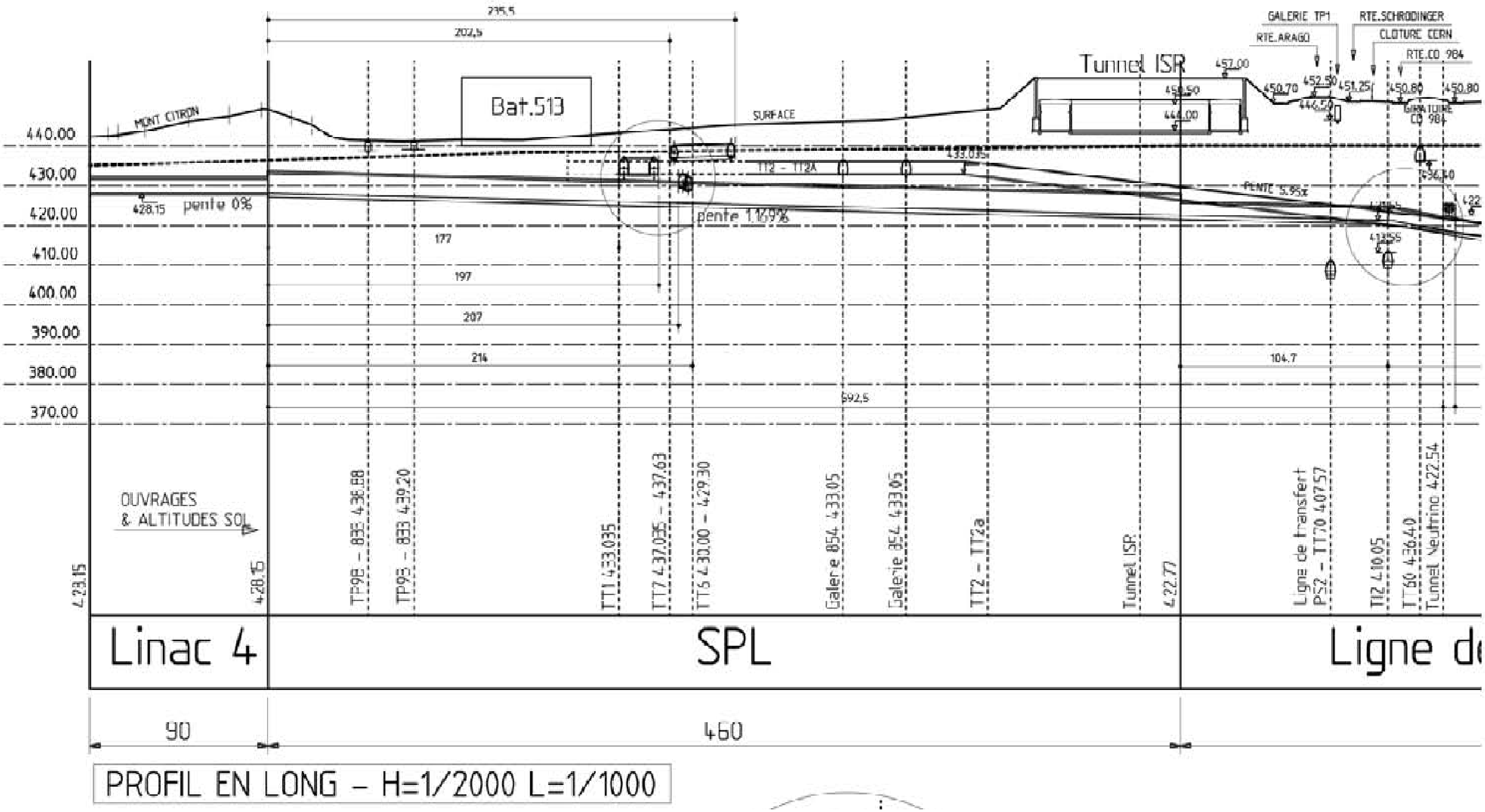


Linac3: Heavy Ion Linac
LEIR: Low Energy Ion Ring

Site layout - Top view



Site layout - Vertical cut



3. Implementation stages

Stage 1: Linac4 - Main characteristics

Ion species	H^-	
Output Energy	160	MeV
Bunch Frequency	352.2	MHz
Max. Rep. Rate	2	Hz
Max. Beam Pulse Length	1.2	ms
Max. Beam Duty Cycle	0.24	%
Chopper Beam-on Factor	65	%
Chopping scheme: 222 transmitted /133 empty buckets		
Source current	80	mA
RFQ output current	70	mA
Linac pulse current	40	mA
N. particles per pulse	1.0	$\times 10^{14}$
Transverse emittance	0.4	π mm mrad

Max. rep. rate for accelerating structures: 50 Hz

H^- ⇒ charge exchange injection and painting in PSB

Higher injection energy on PSB (160/50 MeV, factor 2 in $\beta\gamma^2$) → same tune shift with twice the intensity.

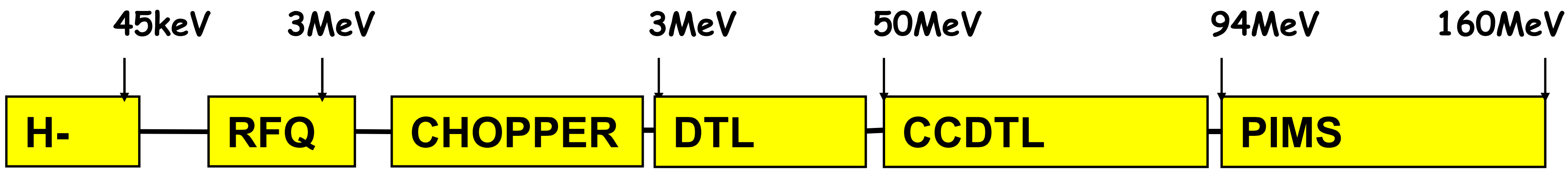
Re-use of LEP RF components: klystrons, waveguides, circulators.

Chopping at low energy to reduce beam loss at PSB.

- Structures and klystrons dimensioned for 50 Hz
- Power supplies and electronics dimensioned for 2 Hz, 1.2 ms pulse.

Stage 1: Linac4 - Block diagram

Linac4: 80 m, 18 klystrons



H-	RFQ	CHOPPER	DTL	CCDTL	PIMS
RF volume source (DESY) 45 kV Extrac.	Radio Frequency Quadrupole 3 m 1 Klystron 550 kW	Chopper & Bunchers 3.6 m 11 EMquad 3 cavities	Drift Tube Linac 18.7 m 3 tanks 3 klystrons 4.7 MW 111 PMQs	Cell-Coupled Drift Tube Linac 25 m 21 tanks 7 klystrons 7 MW 21 EMQuads	Pi-Mode Structure 22 m 12 tanks 8 klystrons ~12 MW 12 EMQuads

Ion current:
40 mA (avg.),
65 mA (peak)

RF accelerating structures: 4 types (RFQ, DTL, CCDTL, PIMS)
Frequency: 352.2 MHz
Duty cycle: 0.1% phase 1 (Linac4), 3-4% phase 2 (SPL), (design: 10%)

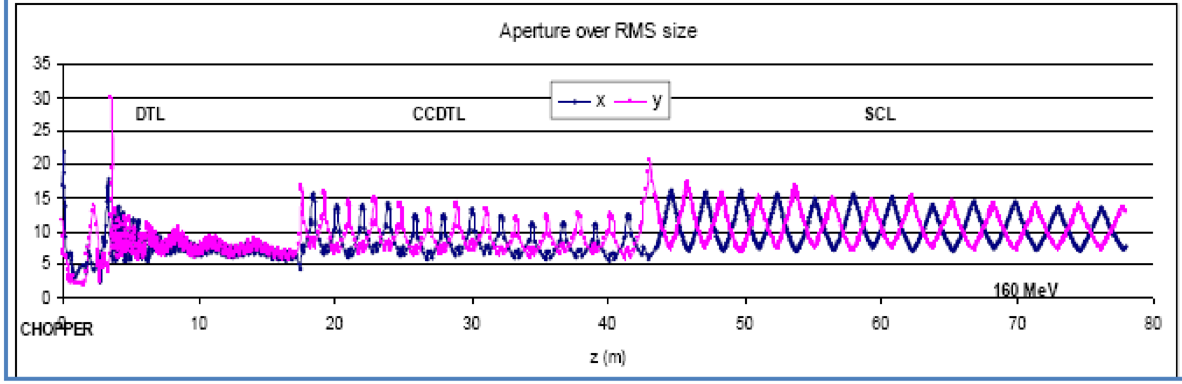
Stage 1: Linac4 - Beam dynamics

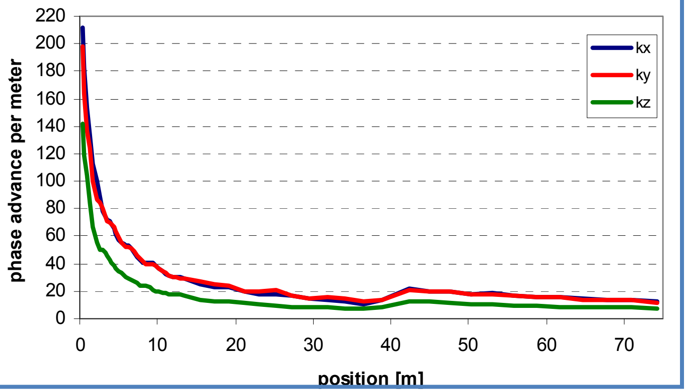
The Linac4 design (machine architecture, beam optics) allows for high beam power operation → it incorporates modern linac technologies developed for high-power projects (SNS, JPARC, ESS,…) – and has contributed to the development of some of these technologies ! – providing an operational margin for PSB and LP-SPL.

1. Beam optics design to minimize beam loss.
2. Chopping at low energy to reduce longitudinal capture losses in the synchrotron.
3. Charge exchange injection.
4. Remaining losses concentrated on defined spots (collimation)

Measures used for keeping beam loss < 1W/m (for hands-on maintenance) at high beam power:

1. Smooth phase advance transitions.
2. Operating point far from resonances.
3. Longitudinal to transverse phase advance ratio 0.5-08 (no emittance exchange).
4. Smooth variation of transverse and longitudinal phase advance.
5. Large apertures (> 7 rms beam size)





Stage 1: Linac4 - Ion source (DESY design)

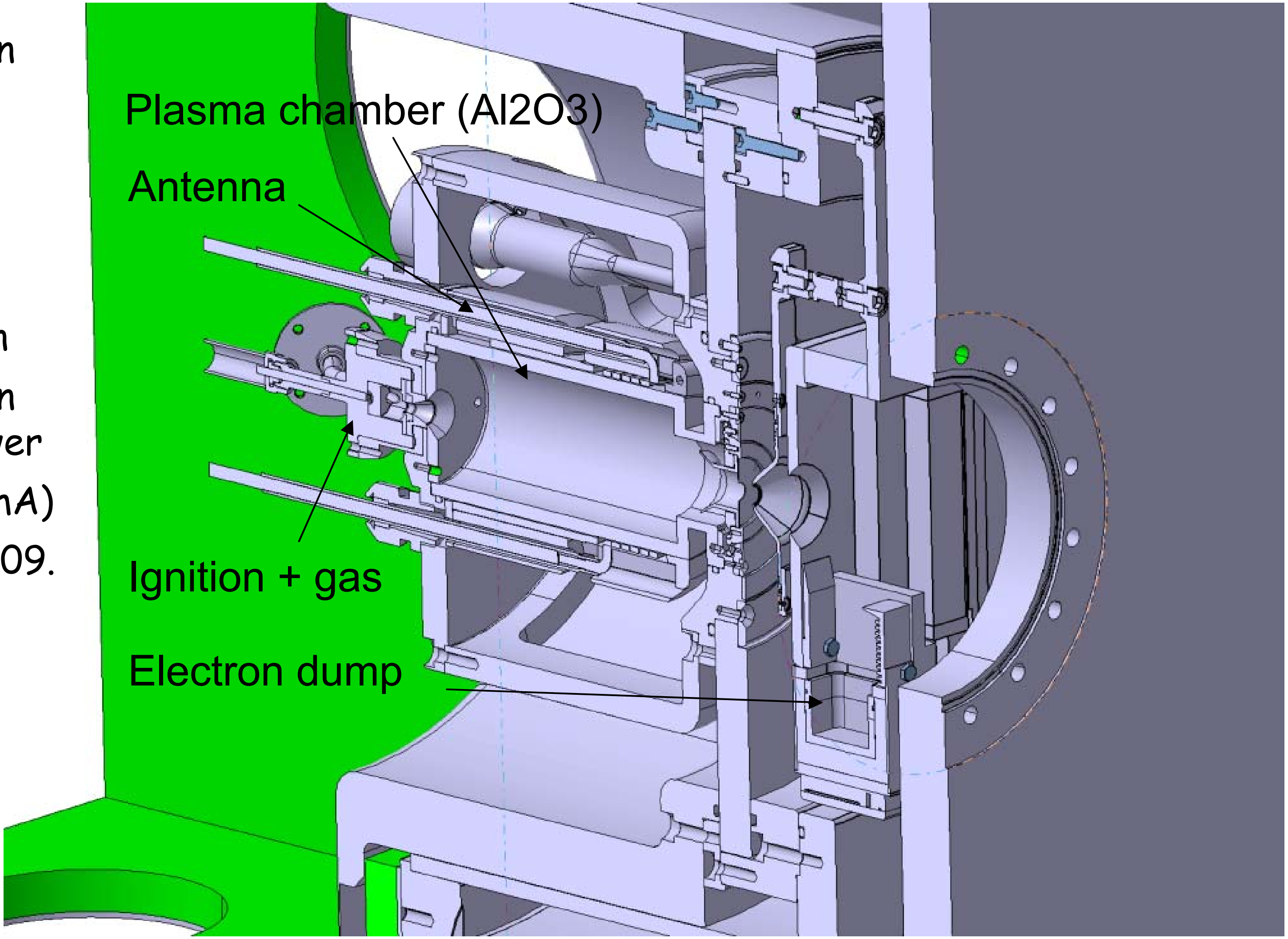
Improved version of the DESY RF volume source (antenna outside vacuum→ higher reliability).

45 kV extraction

2 MHz excitation at increased power

(100 kW for 80mA)

First tests in 2009.

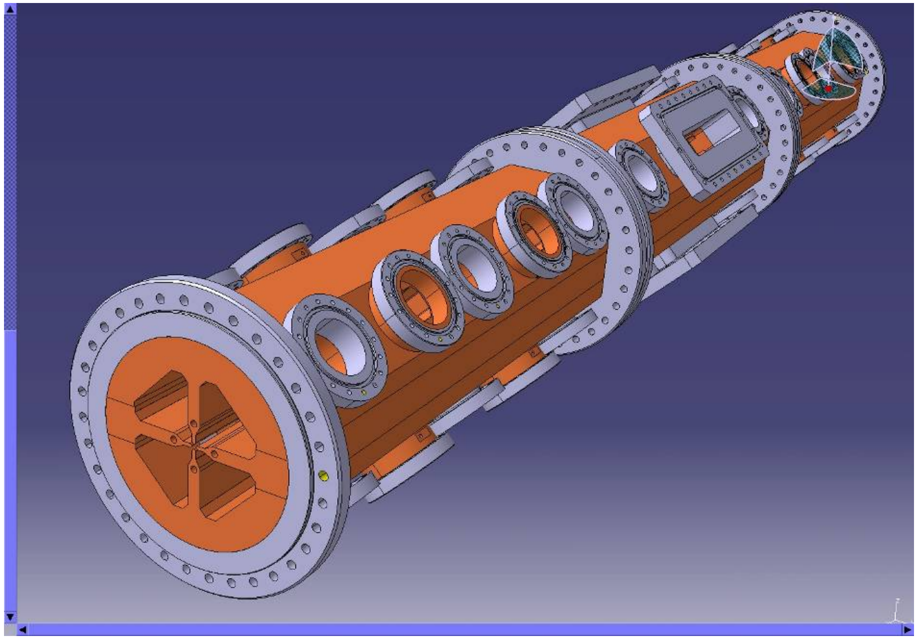


Stage 1: Linac4 - RFQ

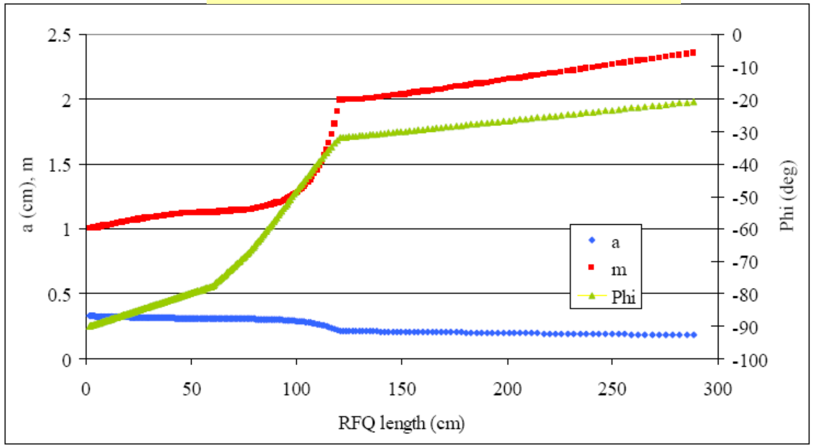
352 MHz RFQ, 3 MeV energy

Decision (summer 07) to build a taylor-designed CERN RFQ optimised for Linac4, using the experience gained in IPHI and TRASCO:

- 45 kV injection, 3 m length
- beam dynamics and RF design jointly by CEA & CERN
- based on the IPHI (CEA) & TRASCO (INFN) general mechanical design
- detailed design, construction and brazing by CERN (EN/MME); availability by end of 2010

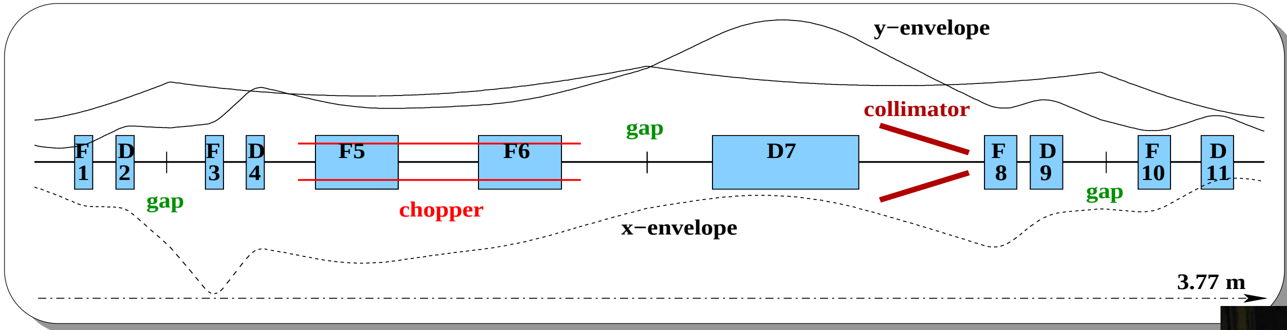


Main RFQ characteristics



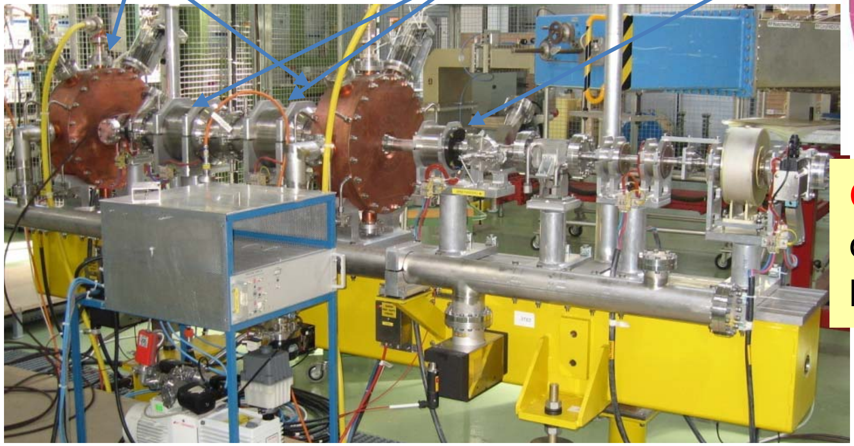
Stage 1: Linac4 - 3 MeV chopper line

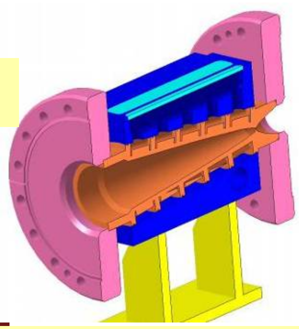
Chopper = fast electrostatic deflector, removing the fraction of the linac beam pulse which would not be captured in the PSB bucket, in order to reduce beam losses.



Compact line design 3.7 m
Dynamic range 20 – 60 mA
Small ε growth 4% long., 8% trans.
Tolerant to alignment errors

RF bunchers | Choppers inside quads | Dump

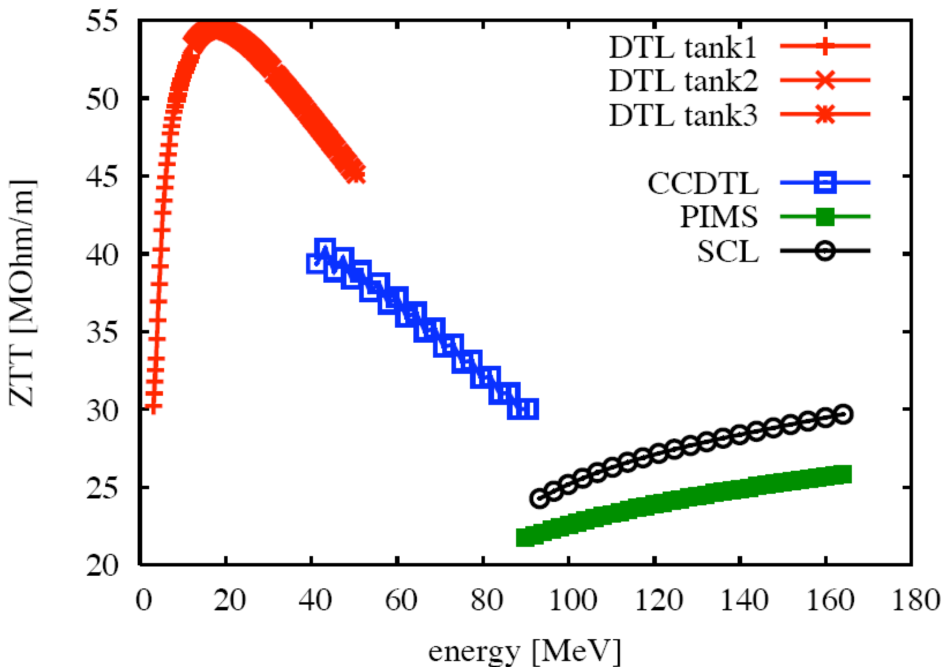




Conical dump: dumping of chopped beam and collimation

Chopper structure: double meander strip line, 400mm length, metallized ceramic plate. 2 ns rise/fall time for bunch selectivity (352 MHz beam structure), ±500V between deflecting plates, provided by a special pulse generator (FID technology).

Stage 1: Linac4 - Design of accelerating structures



	E_0 (MV/m)	Max. field (Kilpatrik)	E_0 (MV/m, cost optimum for 10 yrs. op.)
DTL	3.2	1.6	4.3
CCDTL	2.8-3.9	1.7	3.1
PIMS	4.0	1.8	2.7

1. Distributed focusing by PMQs (Permanent Magnet Quadrupoles) at low energy, where space is tight. Use of conventional EMQs above 50 MeV, for flexibility-reliability.
2. 352.2 MHz RF frequency.
3. Maximum RF efficiency (shunt impedance ZT^2) $\rightarrow$ 3 different RF structures (two 0-mode, one π-mode).
4. High accelerating gradients because of space constraints, but still in a safe range (<1.8 Kilpatrick peak surface field).
5. Safety margins: 25% on klystron max. power, 20% on theoretical Q-value.

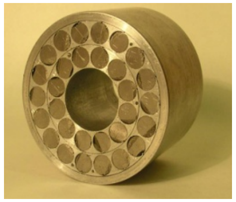
Stage 1: Linac4 - Alvarez DTL (“Drift Tube Linac”)

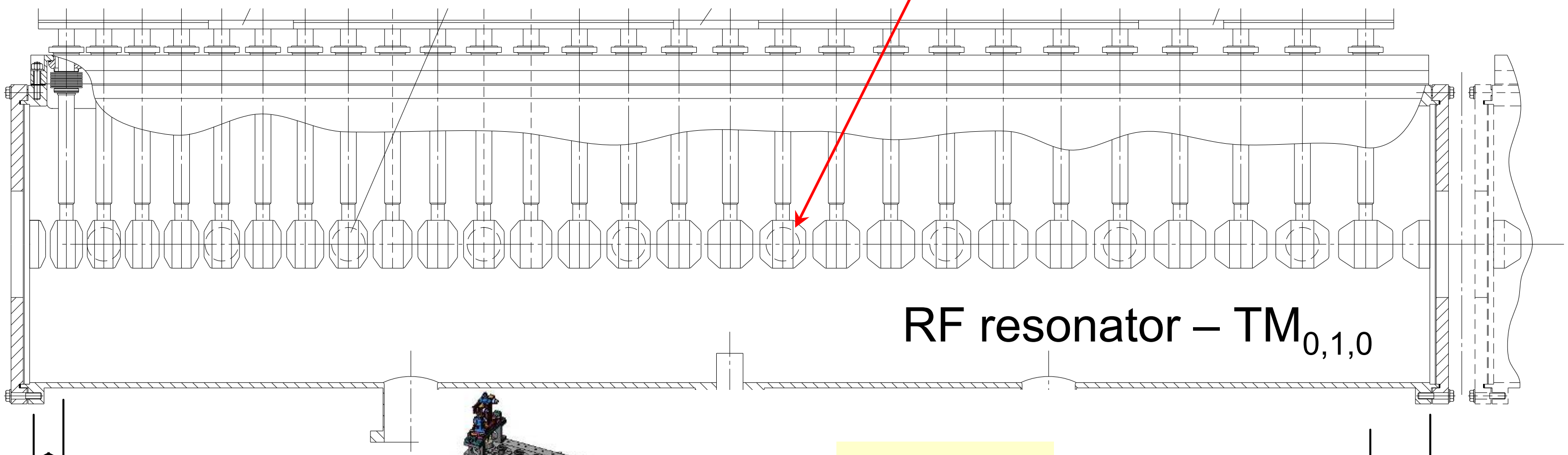
Typical geometry

f=352 MHz $\rightarrow$ λ=85 cm
W=3…10 MeV $\rightarrow$ β= 0.08…0.145
for E_0=3.3 MV/m, 28 cells
Cell length: $\beta\lambda$ = 6.8cm … 12.3cm

3 tanks (36-42-30 cells). Overall length 18.7 m.

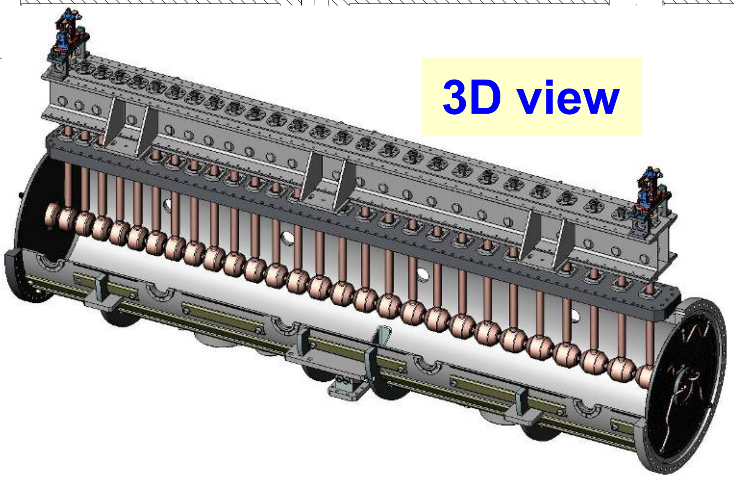
PMQ equipped Drift Tube





Cell#1
6.8cm

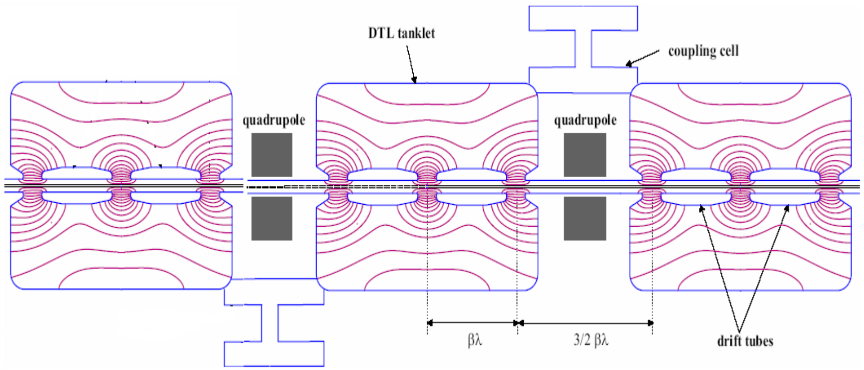
3D view

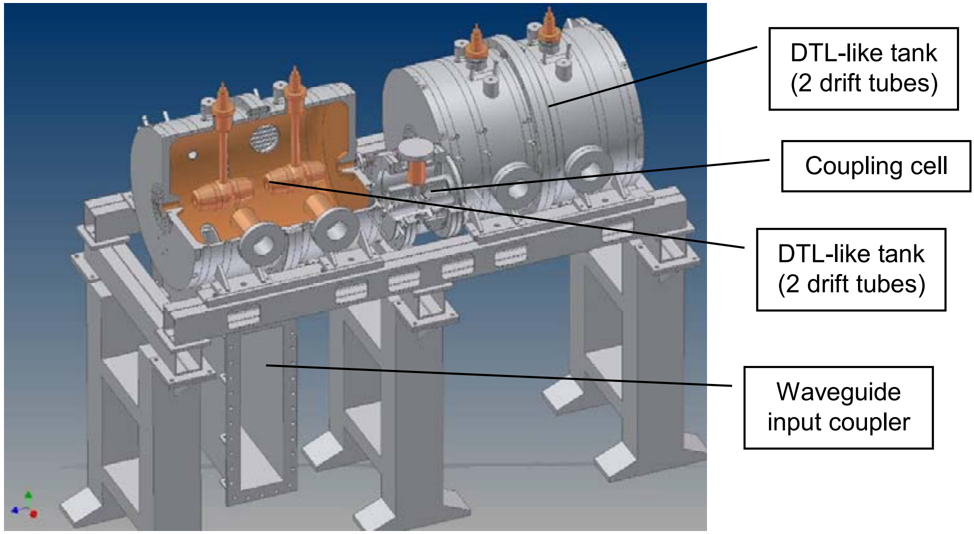


Cell#28
12.3cm

Stage 1: Linac4 - CCDTL ("Cell Coupled DTL")

21 short (~1m) 2-drift tube tanks with quadrupoles in between, coupled in 3-tanks modules by coupling cells





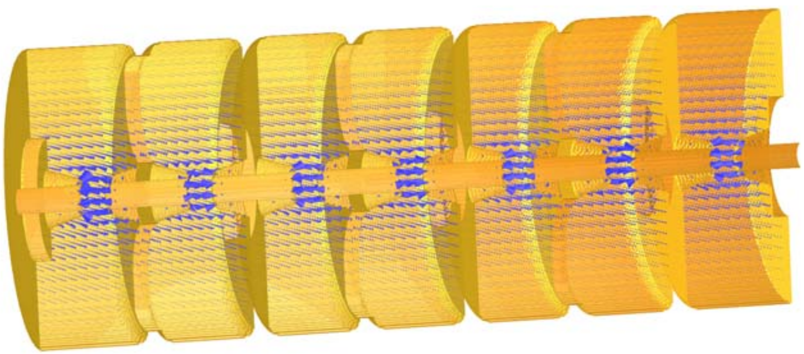
CERN development since 2000.

Useful above ~40 MeV where the length of the focusing period allows to bring quadrupoles out of the drift tubes.

Advantages wrt to DTL: easy use of EMQs (possible adjustment for different currents), relaxed tolerances on machining and alignment, simpler and more economic construction.

Stage 1: Linac4 - PIMS ("PI Mode Structure")

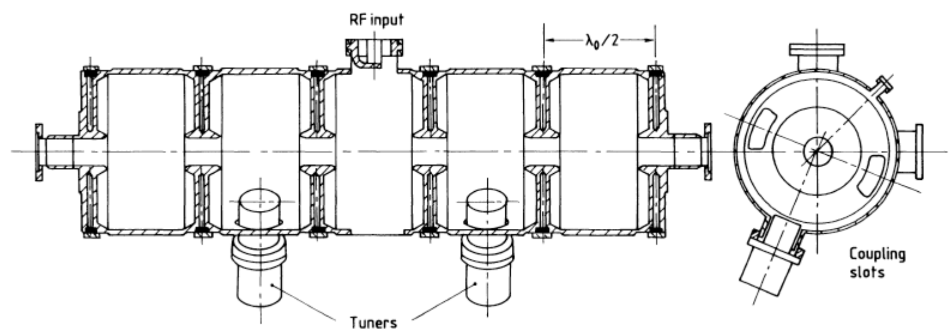
12 tanks (~1m) made of 7 cells operating in Pi-mode, coupled via slots. Overall length 22 m.



Similar to LEP copper cavities.

Pi-mode required for efficient acceleration above 100 MeV.

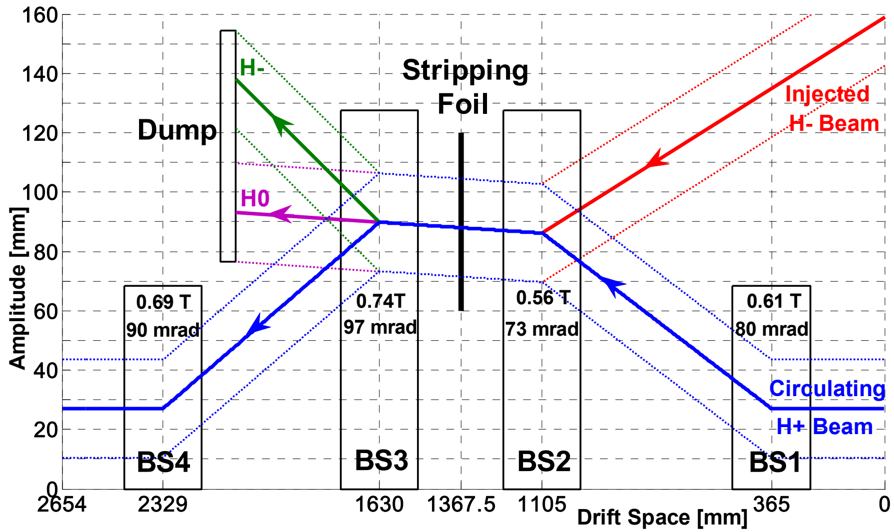
Compact size at 352 MHz (no need for 704 MHz).



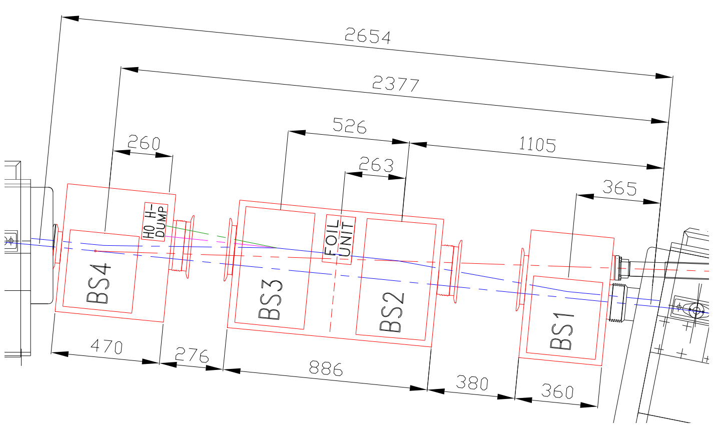
Stage 1: PSB - Charge exchange injection

The injected H^- beam crosses a stripper foil (carbon, 1-2 μm thick) together with the circulating proton beam. After the foil, ~ 98 % of the ions are stripped to protons.

Allows to avoid the septum losses of the present proton injection scheme (estimated to 20 – 30%). The losses inherent to the charge exchange injection (unstripped ions) are concentrated on dedicated dumps.



H⁻ charge-exchange injection system



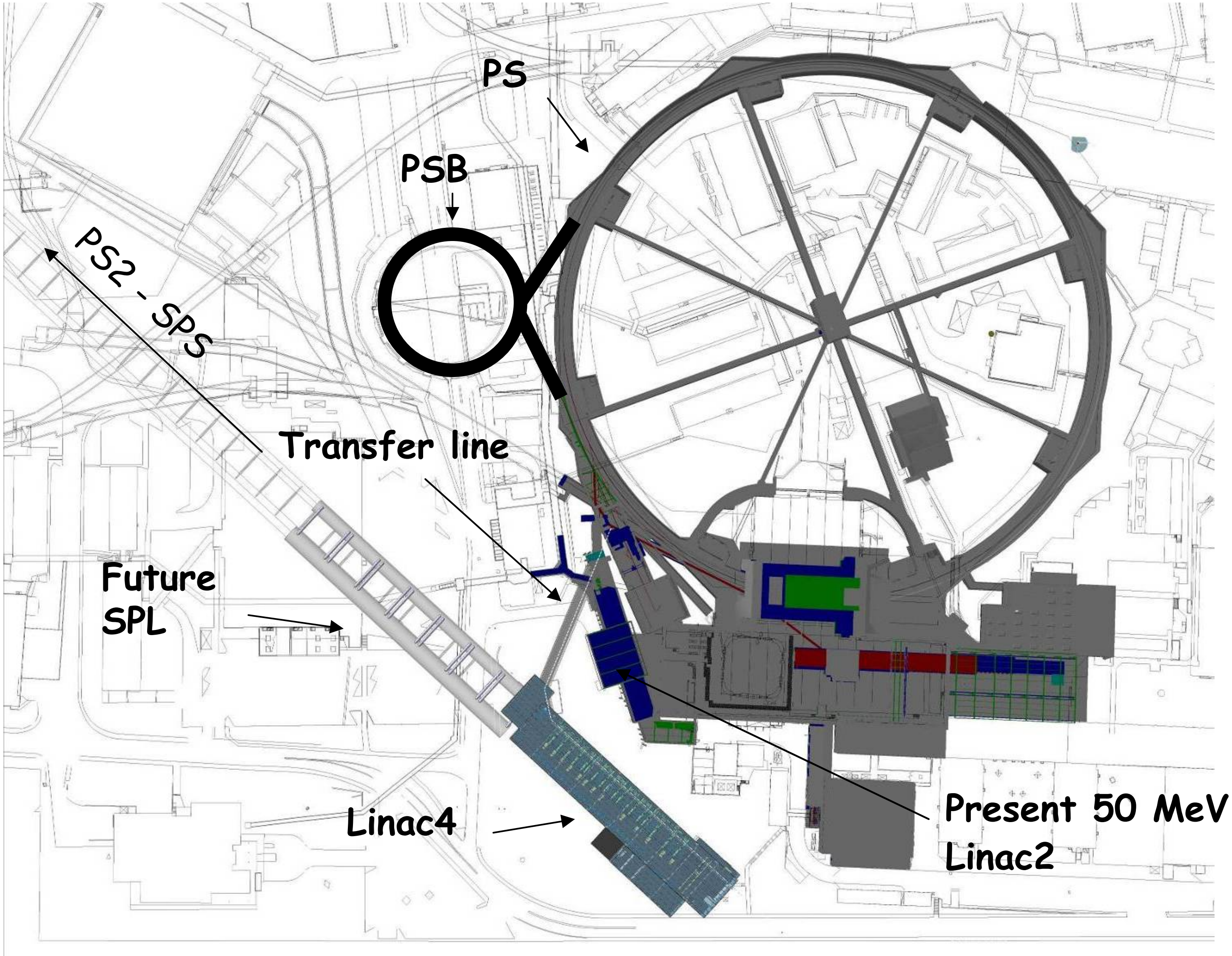
Stage 1: Linac4 - Site layout

Main requirements:

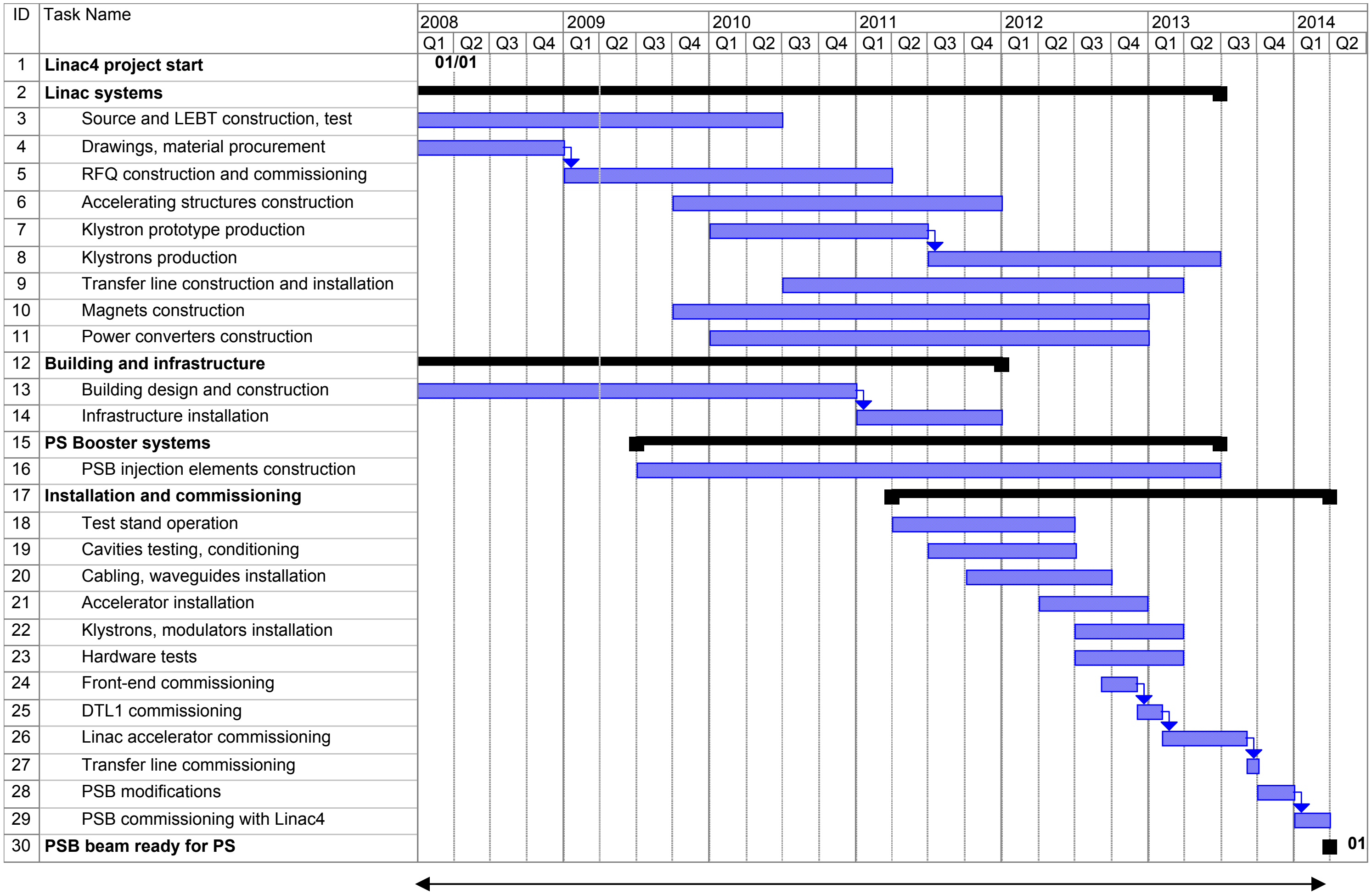
• Length ~100m
• Connection with the PSB
• Possible extension to the future SPL

Preferred location ("Mount Citron"):

- Correct size (~100m x 30m).
- Easy connection to existing Linac2-PSB line.
- Orientation towards SPL – PS2.
- Natural shielding: underground, but at PSB level.



Stage 1 - Planning



project duration: 6 years

MILESTONES:

✓Building delivery: December 2010

✓ Infrastructure installation: 2011

✓ Machine and equipment installation: 2012

✓Linac commissioning: 2013

✓ PSB modifications: shut-down 2013/14.

✓Beam from PSB: April 2014.

Stage 2: PS2 - Main characteristics

PS2 main characteristics compared to the present PS

	PS	PS2
Injection energy kinetic (GeV)	1.4	4.0
Extraction energy kinetic (GeV)	13/25	~ 50
Circumference (m)	628	1346
Generation of the beam time structure for LHC and SPS-FT	Multiple gyms.	No gym.
Maximum intensity for LHC (p/b) [25ns & nominal emittances]	$\sim 1.7 \times 10^{11}$	4.0×10^{11}
Maximum intensity for LHC (p/p) [25ns & nominal emittances]	$\sim 1.2 \times 10^{13}$	6.7×10^{13}
Maximum intensity for fixed target physics (p/p)	3.3×10^{13}	10^{14}
Maximum energy per beam pulse (kJ)	70	800
Max ramp rate (T/s)	2.2	1.5
Cycle time at 50 GeV (s)	1.2/2.4	2.4

Required by space charge tune spread at the specified beam brightness

Specified for injection far above transition in the SPS

- ~ 2 x PS circumference specified for single pulse filling of SPS in FT mode + reduction of LHC filling time.
- Size ratio SPS/PS2 set at 77/15 for easy synchronisation with all foreseen distances between bunches

Required for simple and reliable operation

Specified for sLHC

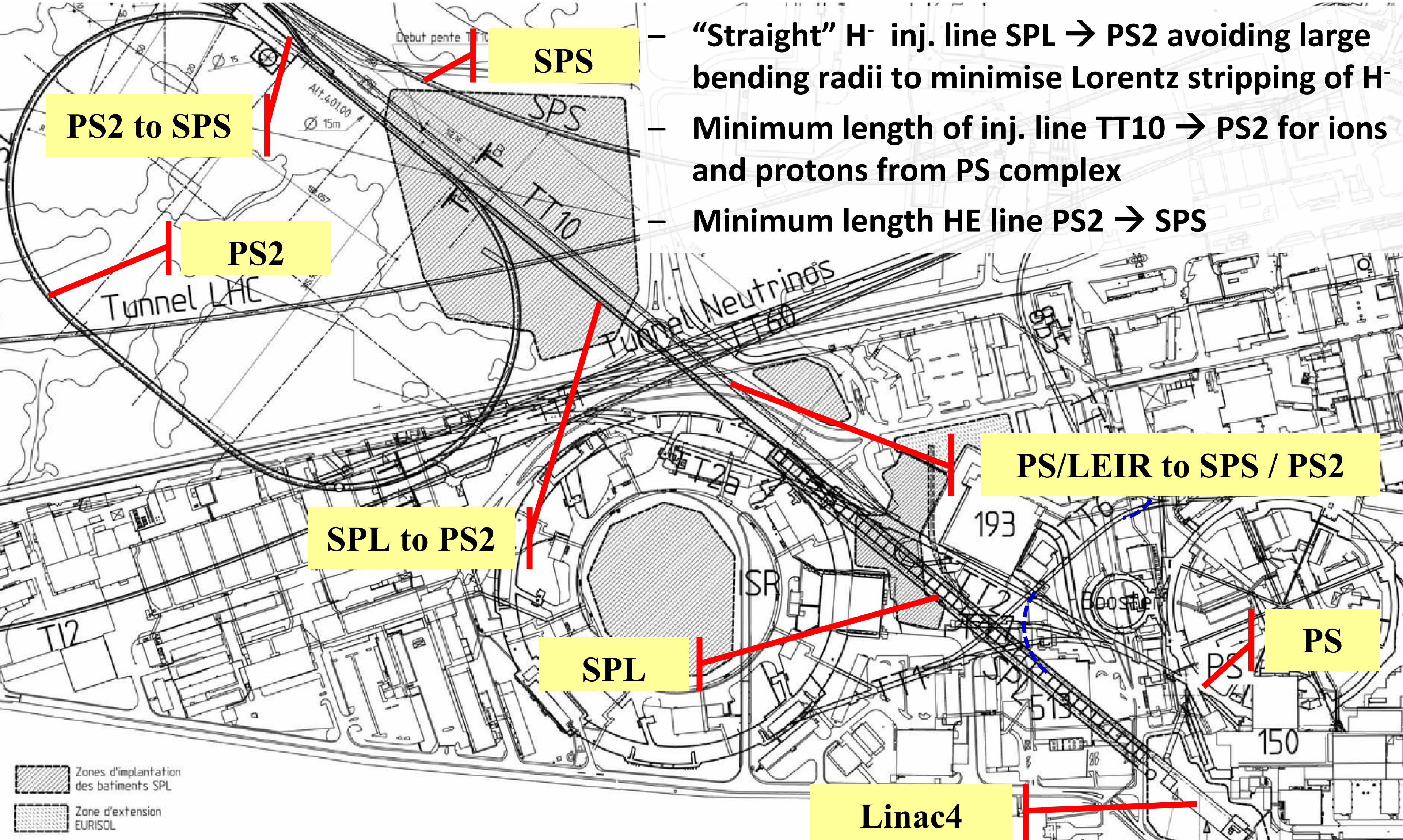
Stage 2: PS2 - Integration and shape (1/2)

- **Integration**
  - **Main requirements**
    - H^- Injection from LP-SPL
    - Injection of ions from LEIR via TT10 transfer line
    - Injection of protons from PS complex viaTT10 for commissioning (low rigidity)
    - Extraction towards the SPS via TT10
  - **Region at end of TT10 transfer line from PS to SPS was identified as optimum location for PS2**

- **Ring shape**
  - Geometrical optimisation leads to a racetrack shape of the machine
  - Two compact arcs and two long zero-dispersion straight sections
  - One long straight section for all injection and extraction systems
  - Second long straight section dedicated for RF and collimation

Stage 2: PS2 - Integration and shape (2/2)

– "Straight" H^- inj. line SPL → PS2 avoiding large bending radii to minimise Lorentz stripping of H^-
– Minimum length of inj. line TT10 → PS2 for ions and protons from PS complex
– Minimum length HE line PS2 → SPS



Stage 2: PS2 - Lattice design (1/2)

- **Imaginary γ_{tr}** (Higher energy particles follow an orbit with a shorter circumference)
  - No transition crossing
    - No beam losses at transition
    - Simplification for operation by avoiding transition jump scheme
  - More complicated lattice design and more magnet types/families than in e.g. regular FODO lattices
- **Structure**
  - Injection/extraction requirements limit tuning flexibility of long straight sections
  - Arcs have to provide not only imaginary gamma transition but also tuning flexibility
    - Regular arc modules
    - Dispersion suppressor modules to match to straight sections
    - Long straight sections with zero-dispersion
- **Collaborations with LARP, US labs**

Stage 2: PS2 - Lattice design (2/2)

Transition gamma: 37i

Tunes: 13.25 / 8.25 (h/v)

Beta max: 59 m (h and v)

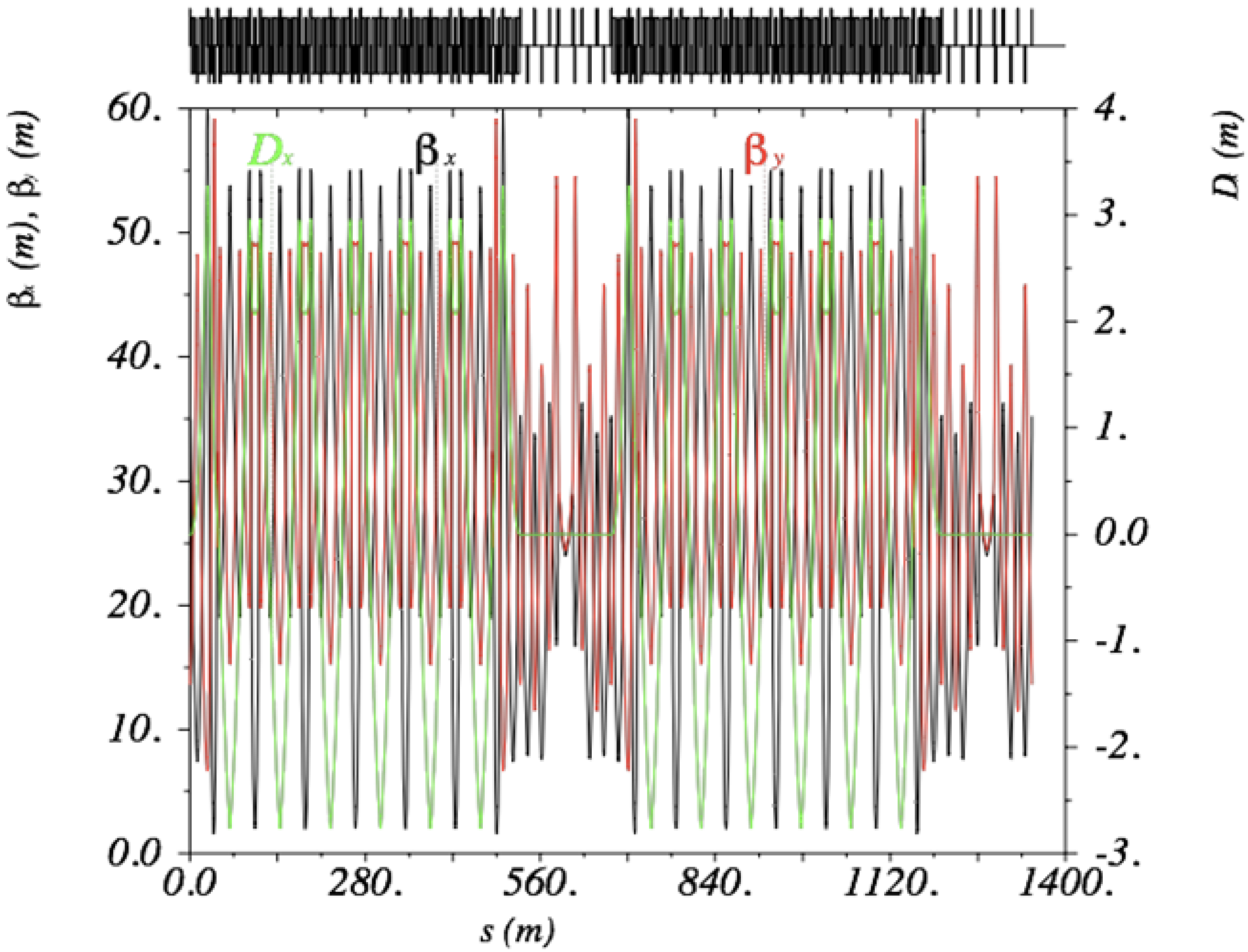
Dispersion min.: -2.8 m
Dispersion max.: 3.3 m

Relative chromaticities -1.65 / -1.59 (h/v)

Circumference: 1346.4m

166 dipoles, 3.78m long (1.7T field)

132 quadrupoles in 4+6+7 = 17 families of 5+1 types (lengths and apertures), with max. strength of $0.1m^{-2}$
Not yet optimized



Stage 2: Proton injector of PS2 (1/2)

Main requirements of PS2 on its proton injector

Requirement	Parameter	Value
2.2 x ultimate brightness with nominal emittances	Injection energy	4 GeV
	Nb. of protons / cycle for LHC (180 bunches)	6.7×10^{13}
Single pulse filling of SPS for fixed target physics	Nb. of protons / cycle for SPS fixed target	1.1×10^{14}
Provide all beam time structures for LHC	Bunch spacing	25/50/75 ns
	Number of bunches / missing bunches	1 - 168
Flexible control of emittance and intensity per bunch	$\varepsilon_{X,Y} / \varepsilon_L / N_b$	

Stage 2: Proton injector of PS2 (2/2)

Comparison between LP-SPL and RCS:

- RCS (10 Hz) filling PS2 in 14 pulses (1.3 s) + multiple gymnastics in PS2
- LP-SPL (2Hz) filling PS2 in 0.6 ms + no gymnastics in PS2

	Filling time PS2	Time structure for LHC	Relative proton rate	Fixed target physics	Heavy Ions	Upgrade potential	Relative Cost[1]
LP-SPL	0.6ms	inherent	2.5	ideal	OK	high	1.28
RCS	1.3s	different	1	OK	ideal	low	1
Advantage	**SPL**	**SPL**	**SPL**	**SPL**	**RCS**	**SPL**	**RCS**

[1] The relative cost considers only the items that differ between both options

⇓

The LP-SPL is the best solution for the LHC and it offers a large upgrade potential for the future needs of physics.

Ref.: Comparison of Options for the Injectors of PS2, CERN-AB-2007-014 (PAF), http://cdsweb.cern.ch/record/1029954/files/ab-2007-014.pdf

Stage 2: LP-SPL - Main characteristics

Ion species	H^-	
Output Energy	4	GeV
Bunch Frequency	352.2	MHz
Max. Rep. Rate	2	Hz
Max. Beam Pulse Length	0.9	ms
Max. Beam Duty Cycle	0.2	%
Nominal chopping factor (Flexible chopping scheme)	65	%
Source current	40	mA
Linac pulse current	20	mA
Number of ions per pulse	1.1	$\times 10^{14}$
Transverse emittance	0.4	π mm mrad
Max. rep. rate for accelerating structures and klystrons:	50	Hz

Required for flexibility and low loss in PS2

Required by space charge tune spread at the specified beam brightness

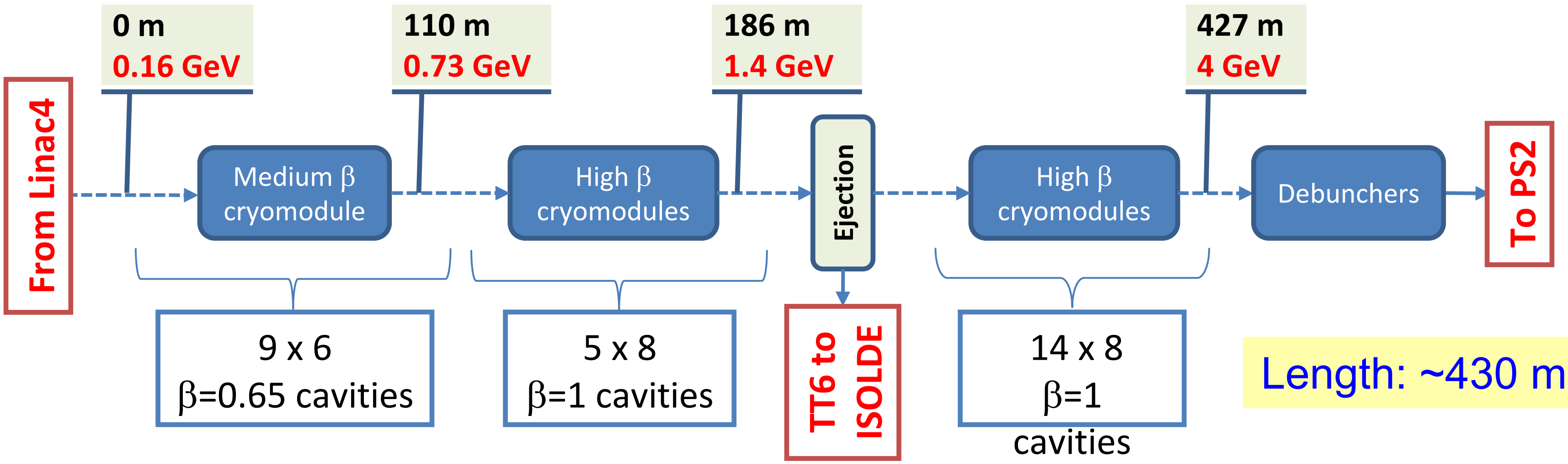
Re-use of LEP RF components in Front-end (Linac4)

Required for flexibility and low loss in PS2 (linac4 chopper with new driver)

- Structures and klystrons dimensioned for 50 Hz
- Power supplies and electronics dimensioned for 2 Hz, 2 ms pulse.

Stage 2: LP-SPL - Block diagram

SC-linac (160 MeV → 4 GeV) with ejection at intermediate energy

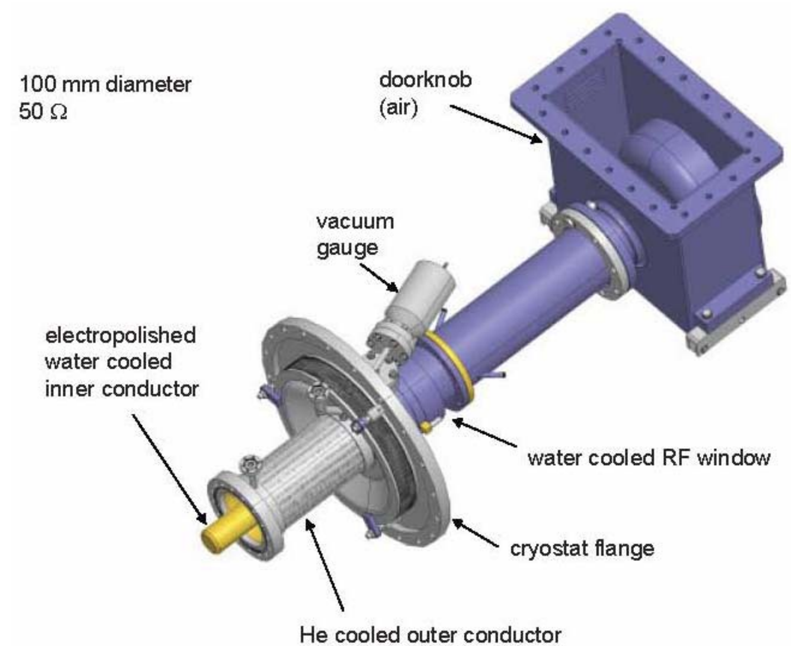


Length: ~430 m

Stage 2: LP-SPL - Technology (1/3)

Elliptical 5 cell bulk Niobium cavities
(e.g.: β=0.47)

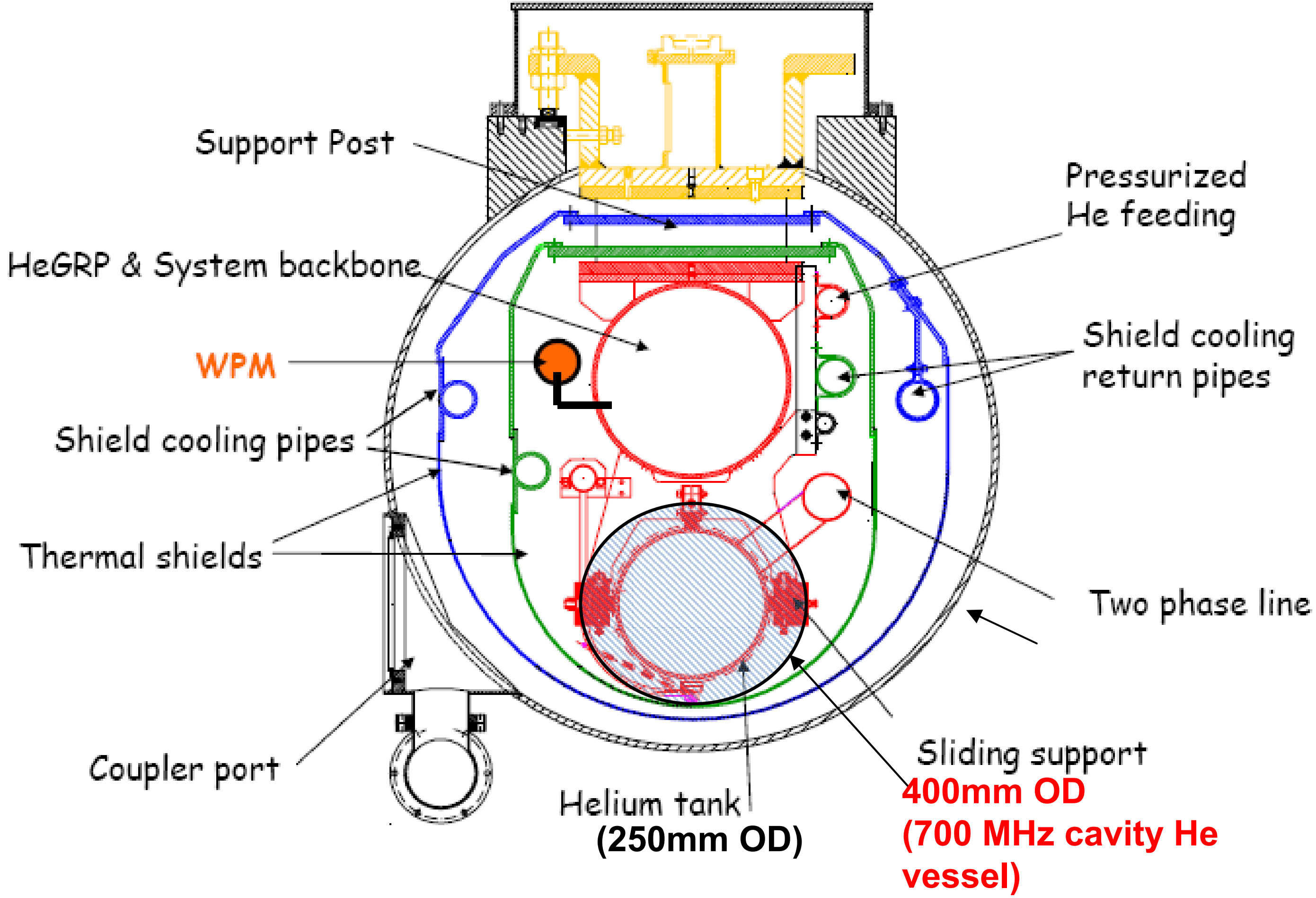
Auxiliary equipment
(e.g.: 1 MW RF coupler)



from G. Devanz – HIPPI meeting Nov. 2007)

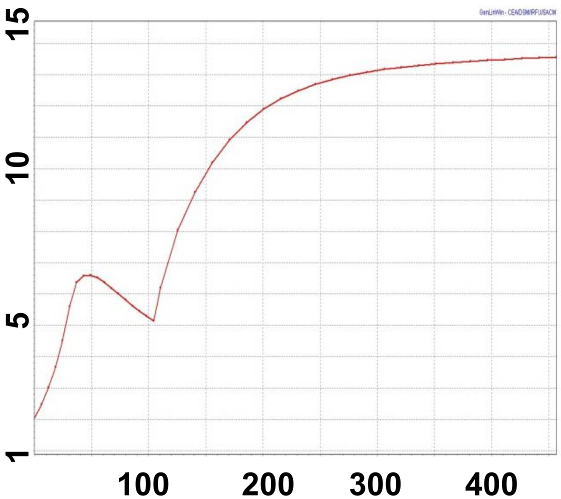
Stage 2: LP-SPL - Technology (2/3)

"Typical" cryomodule (TTF III)



Stage 2: LP-SPL - Technology (3/3)

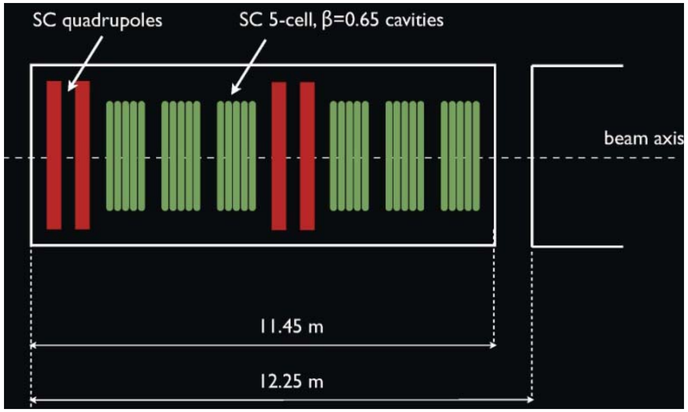
Energy gain (MeV/m)



Position (m)

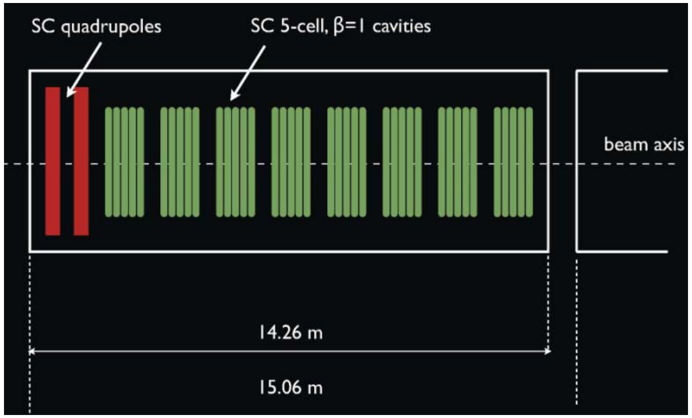
Medium β cryomodule

Energy range: 160 MeV – 732 MeV
5 cell cavities
Geometrical β: 0.65
Maximum energy gain: 19.4 MeV/m
54 cavities (9 cryomodules)
Length of medium β section: ~110.35 m



High β cryomodule

Energy range: 732 MeV – 4 GeV
5 cell cavities
Geometrical β: 1
Maximum energy gain: 25 MeV/m
152 cavities (19 cryomodules)
Length of medium β section: ~286.2 m



Stage 2: SPS - Present achievements wrt needs

Parameters	PS2 offer per cycle at 50 GeV			SPS record at 450 GeV		LHC request at 450 GeV	
	25 ns	50 ns	FT	25 ns	FT	25 ns	50 ns
bunch intensity $/10^{11}$	4.4	**5.5**	1.6	**1.2**	0.13	1.7	**5.0**
number of bunches	168	84	840	288	4200	336	168
total intensity $/10^{13}$	7.4	4.6	**12.0**	3.5	**5.3**	5.7	8.4
long. emittance [eVs]	0.6	0.7	0.4	0.6	0.8	<1.0	<1.0
norm. H/V emitt. [μm]	3.5	3.5	15/8	**3.6**	8/5	3.5	3.5

→ **SPS upgrade is necessary**

Stage 2: SPS - Known limitations

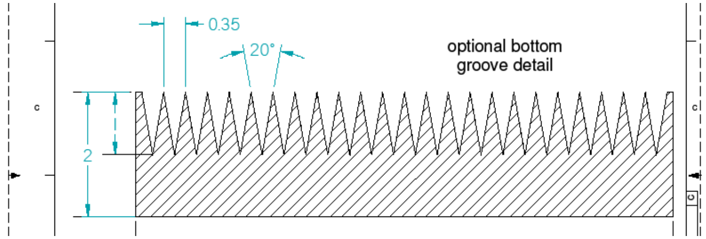
- **Single bunch effects:**
  - space charge
  - TMCI (transverse mode coupling instability)
- **Multi-bunch effects:**
  - e-cloud
  - coupled bunch instabilities at injection and high energy
  - beam loss (7-10% for 25 ns bunch spacing and 5% for 50 ns bunch spacing and nominal bunch intensity)
  - beam loading in the 200 MHz and 800 MHz RF systems
  - heating of machine elements (MKE, MKDV kickers, …)
  - vacuum (beam dump and MKDV outgassing), septum sparking

Stage 2: SPS upgrade - Benefits of 50 GeV injection

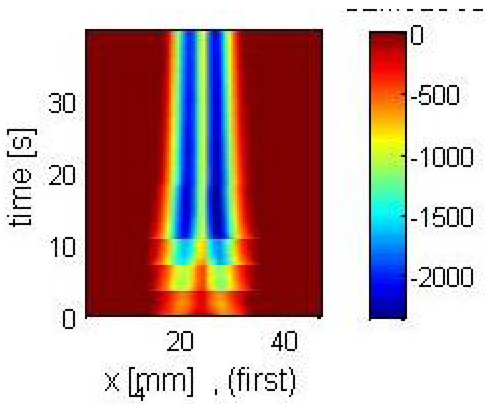
- Sufficient improvement for space charge tune spread up to bunch intensity of 5.5 $x10^{11}$
- Increase in TMC instability threshold by a factor 2.5
- Shorter injection plateau (2.4 s instead of 10.8 s) and acceleration time (10%) – shorter LHC filling time (and turnaround time)
- No transition crossing for all proton beams and probably light ions
- Easier acceleration of heavy ions (lead):
  - smaller tune spread and IBS growth rate,
  - smaller frequency sweep - no need for fixed frequency acceleration
- Smaller physical transverse emittance – less injection losses

Stage 2: SPS upgrade - e cloud mitigation

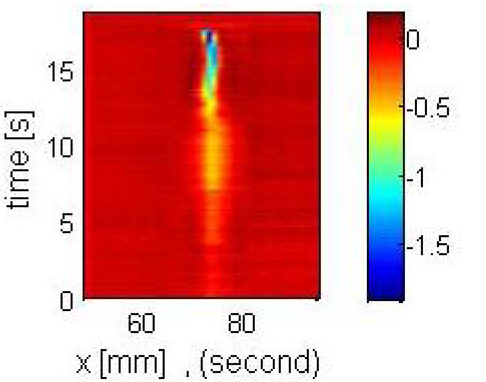
- surface treatment: in-situ, no aperture reduction, no re-activation (S. Calatroni, P. Chiggiato, M. Taborelli, C. Yin Vallgren…)
  - carbon based composites, SEY<1 obtained, - ageing problem (with venting)
  - rough surfaces – 2 layers
  - electromagnetic roughness (F. Caspers)
- clearing electrodes (F. Caspers et al.)
- active damping system in V-plane (W. Hofle + LARP)
- grooves - 35% reduction was measured in lab (for Al) (M. Pivi – SLAC, M. Taborelli)



Stainless steel

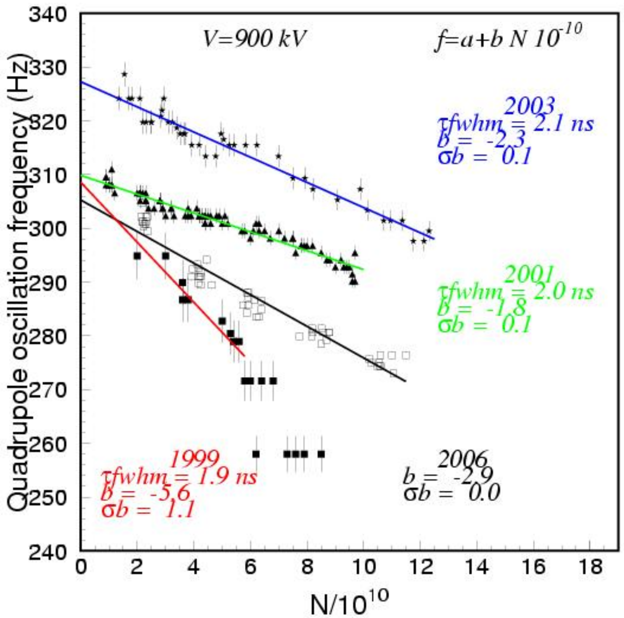


a-Carbon C-8



M. Taborelli

Stage 2: SPS upgrade - Impedance



Quadrupole oscillation frequency as a function of bunch intensity

$\text{Im } Z_{eff} \sim \text{slope}$

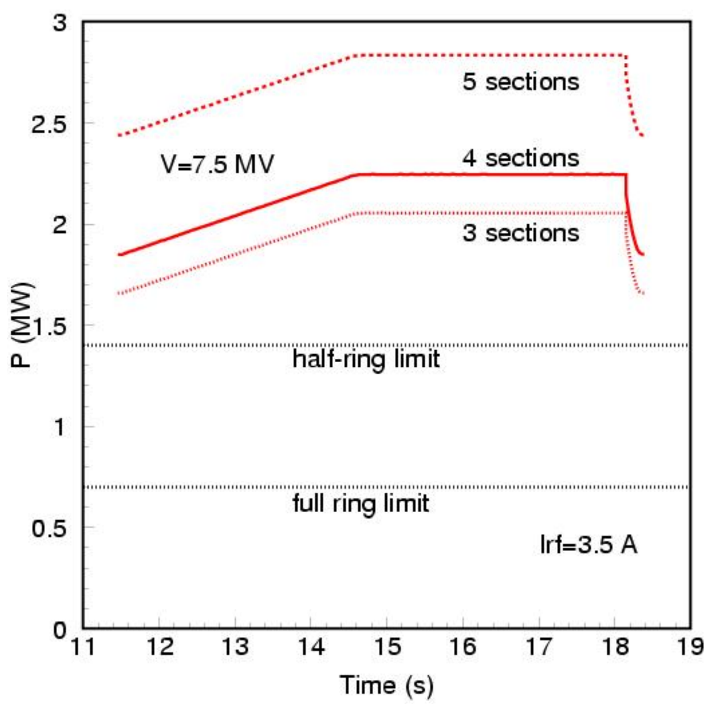
Similar measurements in V-plane (H. Burkhardt et al.)

- 1999-2001: SPS impedance reduction in preparation for nominal LHC beam → no microwave instability
- 2003-2006: impedance increase, mainly due to re-installation of 8 MKE (extraction kickers for LHC)
- Only 50% of SPS transverse impedance budget is known

  → search for the rest
- Shielding of the known impedance sources (MKE, MKDV...)
- Active damping of the 800 MHz impedance (FB and FF)

Stage 2: SPS upgrade - RF systems

200 MHz RF power (max LHC upgrade intensity)



- Coupled-bunch (long.) instability threshold ~1/5 nominal intensity
- Larger emittance needed for higher intensities (ε~√N)

- The 200 MHz RF system limits:
  - Voltage 7.5 MV
  - Power 0.7 MW for full ring
- (3.3-4.5) MW/cavity (200 MHz) for max PS2 intensity

→ The 200 MHz and 800 MHz power plant should be increased

→ R&D for re-design of couplers and coaxial lines

→ Cavity length (200 MHz) could be optimised (5 → 3 sections)

Stage 2 - Planning

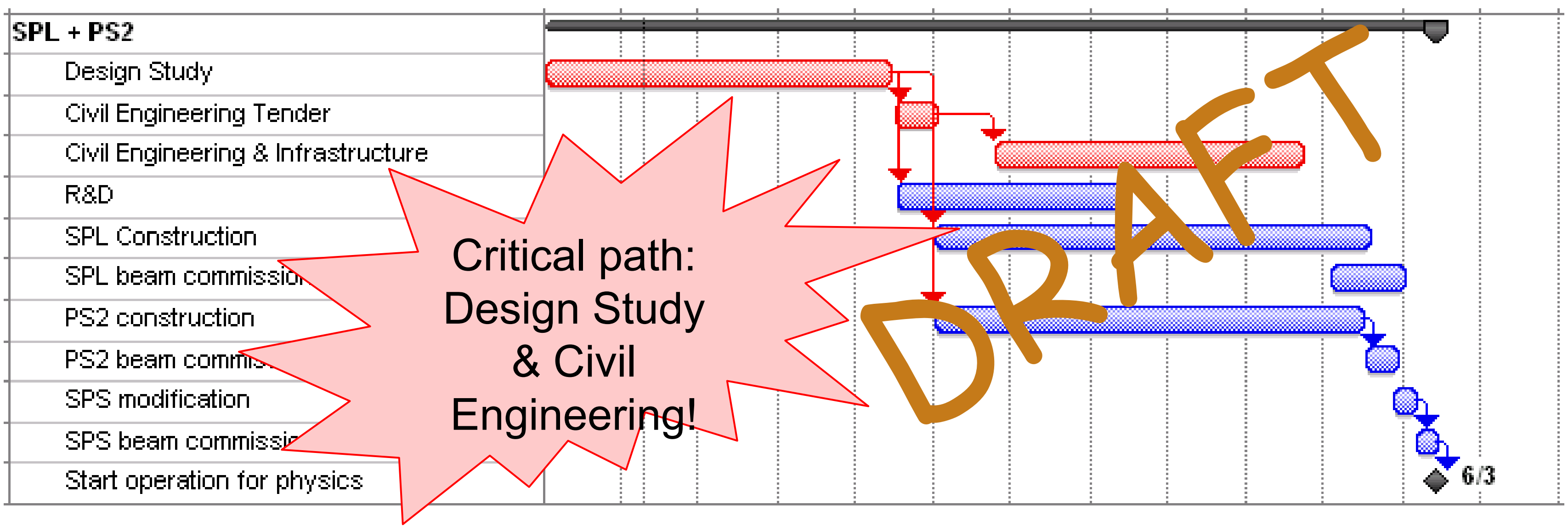
2008 – mid-2012:

• Study phase, preparing for a start of construction of the new sLHC injectors at the beginning of 2013.

Additional comments:

• Construction and beam commissioning of LP-SPL and PS2 will not interfere with the regular operation of Linac4 + PSB for physics.

• Coating of SPS vacuum chamber to reduce SEY should start immediately to benefit quickly to LHC.



First milestones

➢ Project proposal with detailed CDR and cost estimates: mid - 2012

➢ Project start: January 2013

4. Final word

Summary

- A new injector complex has been defined which will allow to maximize the physics reach of the LHC
- Some resources have been allocated for the study phase / work has started
- Specifications are challenging, but within reach
- Meeting the 2012 and the 2020 deadlines will be difficult…

Additional comments

- Large potential for new experiments during and after the LHC [the new accelerators will be used <10 years by the LHC and 10-20 years for other purposes…]
- Excellent opportunity for working in synergy/collaborating with other projects (ESS, Project-X, SNS PRP,…)
- ??? Need for a clear strategy with adequate priority:
  - Resources must be matched to the size of the project: not yet the case (2 years delay after 1 year…)
  - Unambiguous support by the management is mandatory to meet the aggressive planning

THANK YOU
FOR YOUR ATTENTION!

Spare slides

Selection of LP-SPL parameters

Parameters: RF frequency [1/3]

Frequency	704 MHz	1408 MHz
Length (5 GeV)	472 m	+12%
$N_{cavities}$	246	+15%
$N_{\beta\text{-families}}$	2	3
ε-growth (x/y/z)	5.6/8.2/6.8	6.3/7.8/12.1
Longitudinal beam loss	none in simulations	lossy runs for realistic RF gradient/phase variations
BBU (HOM)	$I_{BBU,704}$	1/(8..128)
Trapped modes	normal risk	2..4 higher risk
RF power density limit (RF distribution)	ok	problematic
Klystrons	comfortable: MBK	difficult
Overall power consumption (RF+cryo, nom. SPL)	28 MW	up to -30%
Power converter	more bulky	saves tunnel space
Synergy with ESS	yes	no

Parameters: Cooling temperature [2/3]

@ 704 MHz	T [K]	Eq. capacity @ 4.5 K [kW]	Electrical power [MW]
HP-SPL, 2% beam d.c. (4% cryo d.c.)	2	19.4	4.48
HP-SPL, 2% beam d.c. (4% cryo d.c.)	4.5	104	26.0
LP-SPL, 0.24% beam d.c. (0.32% cryo d.c.)	2	6.1	1.5
LP-SPL, 0.24% beam d.c. (0.32% cryo d.c.)	4.5	11	2.75

+ not clear that 25 MV/m can be achieved at 4.5 K!

Parameters: Summary [3/3]

Frequency/temperature:

704 MHz and 2 K are confirmed,

Cavity gradient:

- 25 MV/m "on average" (= with a high yield) is very challenging and may be costly (in terms of reprocessing),
- 20 MV/m seems more achievable but will have an impact on linac length (or energy).

⇓

High-power RF cavity tests of fully equipped cryo-modules are mandatory for realistic SPL layout estimates!!

Ref.: Assessment of the basic Parameters of the CERN SPL, CERN-AB-2008-067-BI-RF, http://cdsweb.cern.ch/record/1136901/files/CERN-AB-2008-067.pdf

Beam for ISOLDE

LP-SPL beam characteristics for ISOLDE

	Beam energy (GeV)	Max. pulse duration (ms)	Max. current during pulse (mA)	Repetition period (s)	Max. protons /pulse ($x10^{13}$)	Max. beam power (kW)
PS2	4	0.9	20	0.6	11	120
ISOLDE — Basic performance	1.4	0.9	20	~ 0.6 (3 out of 4 pulses)	11	31
ISOLDE — Need phase modulation	1	0.35	28	~ 0.3 (7 out of 8 pulses)	6.1	29
ISOLDE — Needs higher power klystron modulators	1	0.35	28	~ 0.1 (23 out of 24 pulses)	6.1	94

Basic performanc e

Need phase modulation

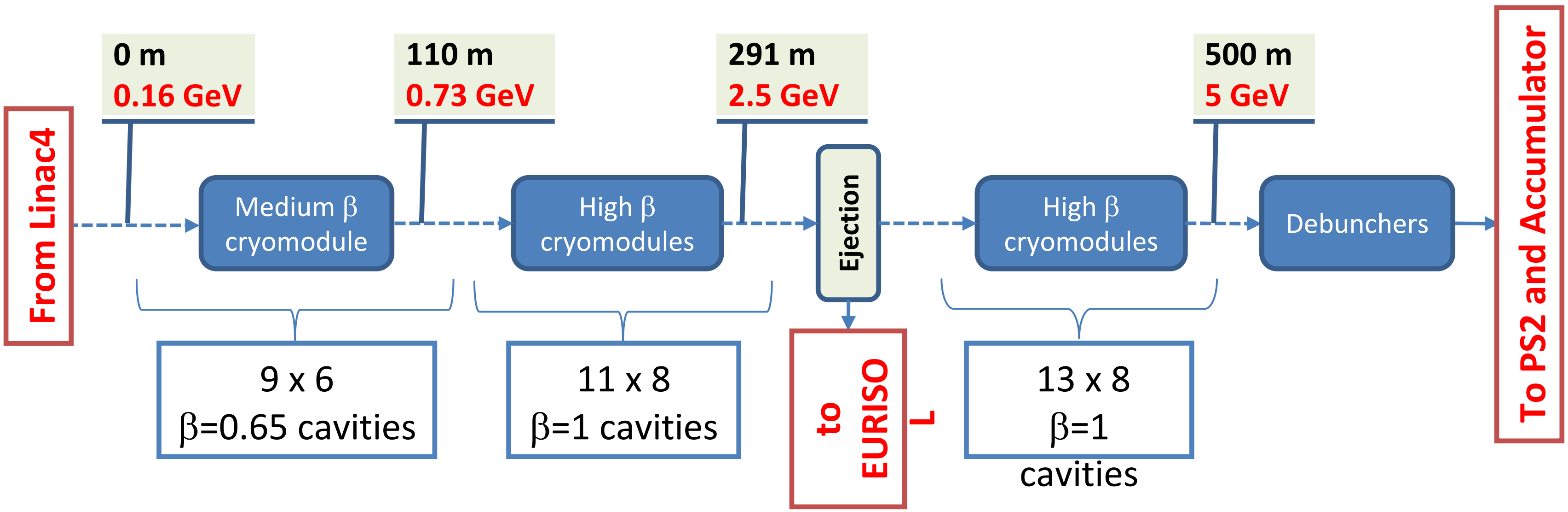
Needs higher power klystron modulators

Possible options

High Power proton beams (HP-SPL) [1/2]

• Replacement of klystron power supplies, upgraded infrastructure (cooling & electricity, etc.)
• Addition of 5 high β cryomodules to accelerate up to 5 GeV (π production for ν Factory))

SC-linac (160 MeV → 5 GeV) with ejection at intermediate energy



Length: ~500 m

High Power proton beams (HP-SPL) [2/2]

Beam characteristics of the main options

	Option 1	Option 2
Energy (GeV)	2.5 or 5	2.5 and 5
Beam power (MW)	2.25 MW (2.5 GeV) or 4.5 MW (5 GeV)	4 MW (2.5 GeV) and 4 MW (5 GeV)
Rep. frequency (Hz)	50	50
Protons/pulse (x 10^{14})	1.1	2 (2.5 GeV) + 1 (5 GeV)
Av. Pulse current (mA)	20	40
Pulse duration (ms)	0.9	0.8 (2.5 GeV) + 0.4 (5 GeV)

Faster rep. rate $\Rightarrow$ new power supplies, more cooling etc.

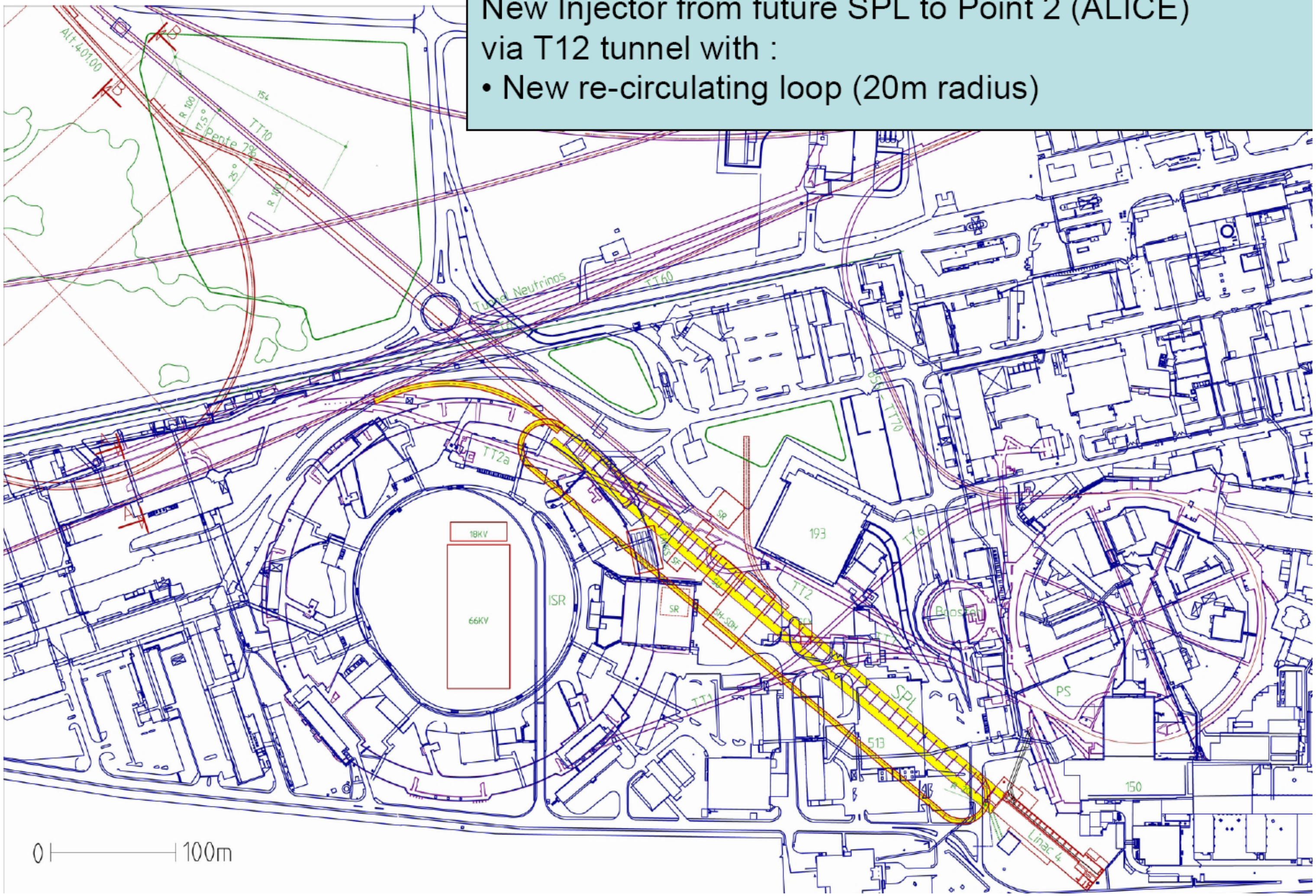
2 $\times$ beam current $\Rightarrow$ 2 $\times$ nb. of klystrons etc .

e+/e- acceleration

LHeC: 20 GeV e+/e- from the SPL (5-pass acceleration in the β=1 section) as a pre-injector for a lepton ring in the LHC tunnel (Ring/Ring option)

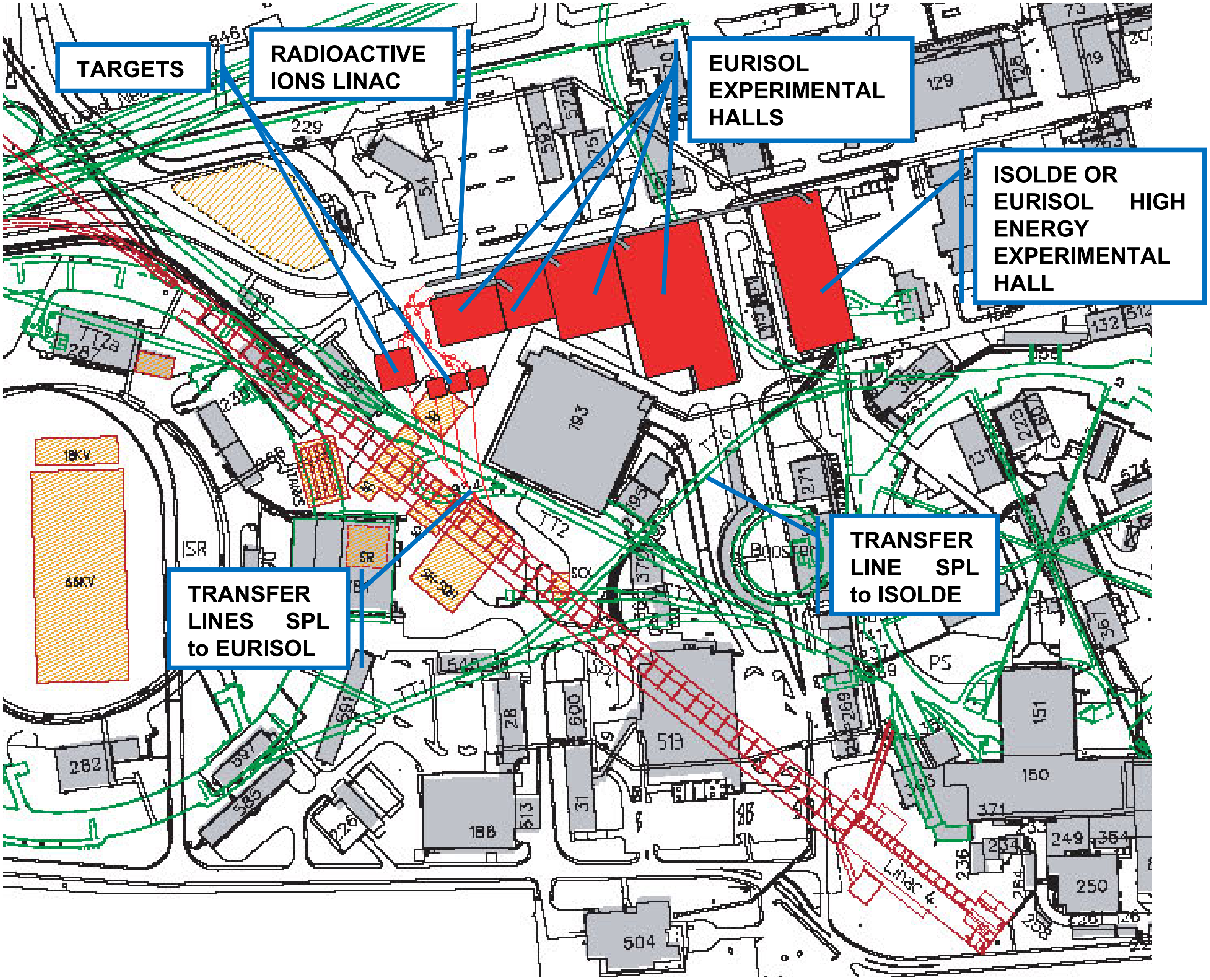
New Injector from future SPL to Point 2 (ALICE) via T12 tunnel with :

- New re-circulating loop (20m radius)



High power proton applications

ISOLDE & EURISOL



Neutrino Factory