LINAC4 and the Upgrade of the LHC Injector Complex

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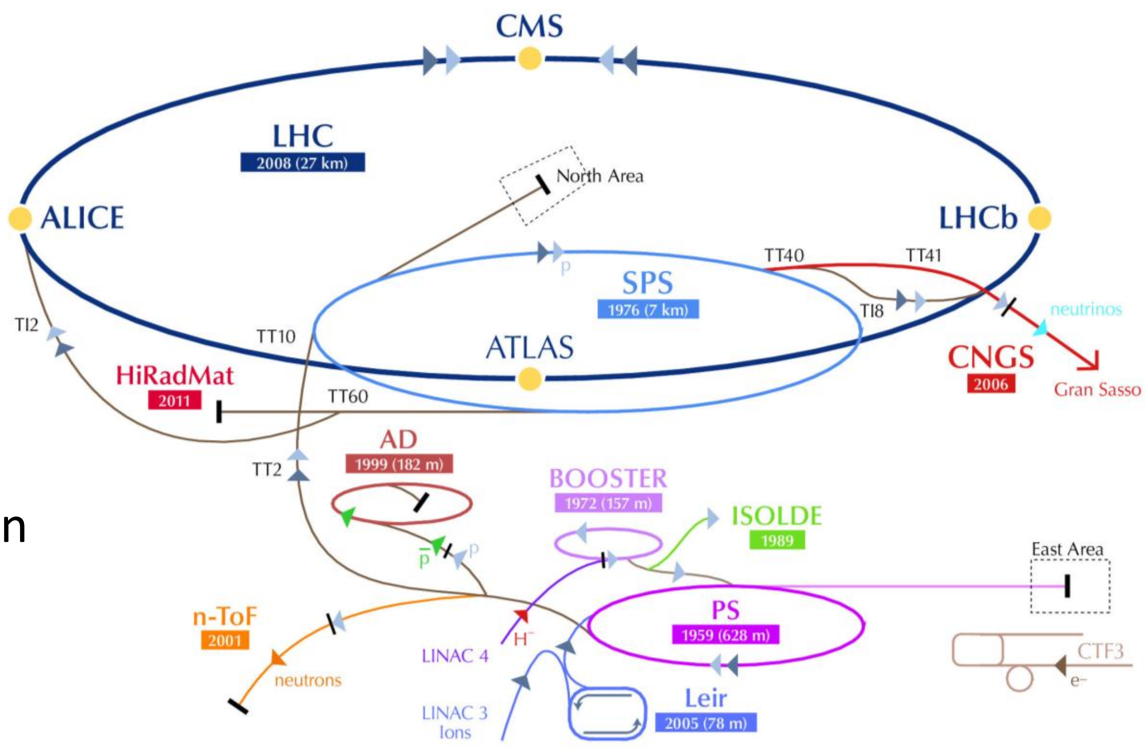
UPGRADE PLANS FOR THE LHC INJECTOR COMPLEX

- **The LIU project**
- Action plan
- Planning

LIU Project Definition

Mandate *(December 2010)*

"The LHC Injectors Upgrade should plan for delivering reliably to the LHC the beams required for reaching the goals of the HL-LHC. This includes LINAC4, the PS booster, the PS, the SPS, as well as the heavy ion chain."



Web site: https://espace.cern.ch/liu-project/default.aspx
Meetings/workshops etc.: http://indico.cern.ch/categoryDisplay.py?categId=3208
EDMS: https://edms.cern.ch/nav/P:LIU-000363:V0/P:LIU-000363:V0

Importance of the Injectors…

- Luminosity in LHC depends directly upon the characteristics of the injected beam:

$$L_{LHC} = \frac{\gamma}{4\pi}\frac{1}{\beta^*} f_{rev} F \cdot (n_b N_b)\left(\frac{N_b}{\varepsilon_n}\right)$$

Total current Brightness

Collider related Injectors' related

- More precisely , the critical parameters for the injectors are:

  n_b : number of colliding bunches in each LHC ring (~ prop. to 1/distance between bunches)

  N_b : number of protons per bunch

  ε_n : normalised transverse emittance (assuming round beams)

- Beam transverse brightness (N_b/ε_n) is an especially important quantity which governs space charge effects at low energy in the injectors

Goals § Means

To increase performance

Brightness ↗

- ⇒ **Increase injection energy in the PSB from 50 to 160 MeV, Linac4 (160 MeV H^-) to replace Linac2 (50 MeV H^+)**
- ⇒ **Increase injection energy in the PS from 1.4 to 2 GeV, increasing the field in the PSB magnets, replacing power supply and changing transfer equipment**
- ⇒ **Upgrade the PSB , PS and SPS to make them capable to accelerate and manipulate a higher brightness beam (feedbacks, cures against electron clouds, hardware modifications to reduce impedance…)**

To increase reliability and lifetime (until ~2035!)
(tightly linked with consolidation)

- ⇒ **Upgrade/replace ageing equipment (power supplies, magnets, RF…)**
- ⇒ **Improve radioprotection measures (shielding, ventilation…)**

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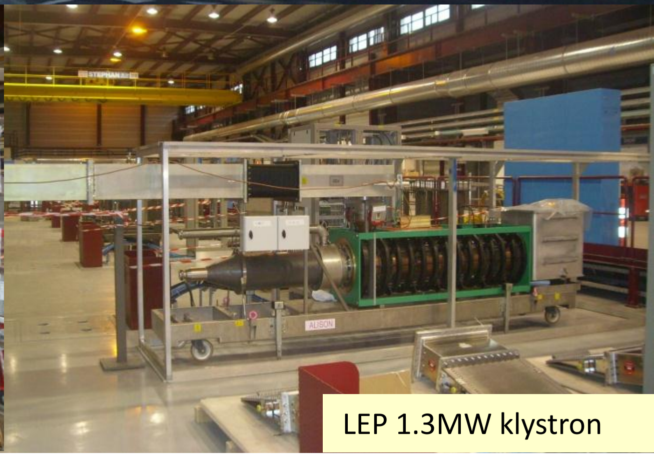
Linac4

Surface building

Equipment hall

New 2.8MW klystron

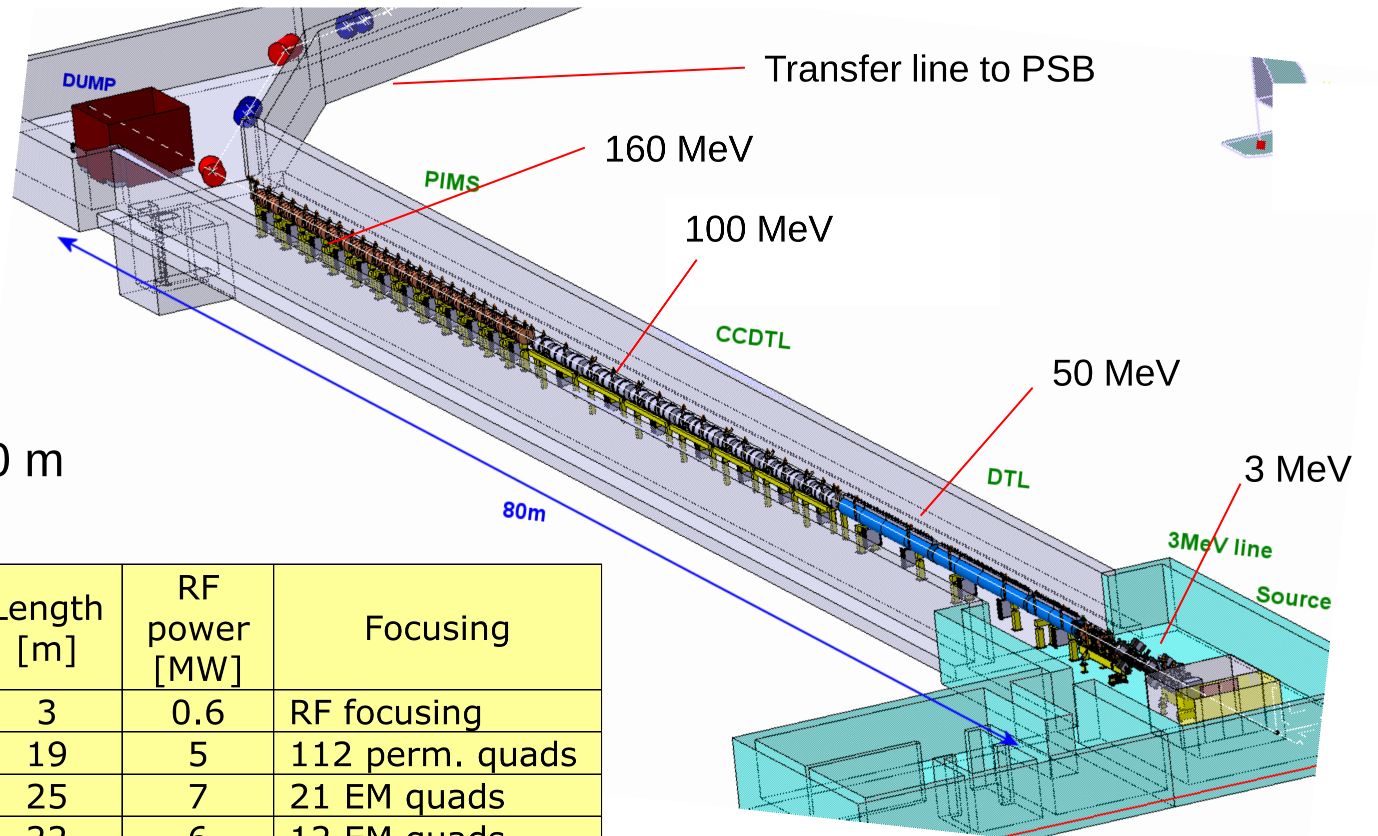


LEP 1.3MW klystron

Linac4 architecture

Linac4 is a normal-conducting H⁻ linear accelerator with an energy of 160 MeV, made of:

1. **Pre-injector (source, magnetic LEBT, 3 MeV RFQ, chopper line)**
2. **Three types of accelerating structures, all at 352 MHz.**
3. **A 70 m transfer line towards the PS Booster (plus a dump line at linac end).**



Linac length ~ 80 m

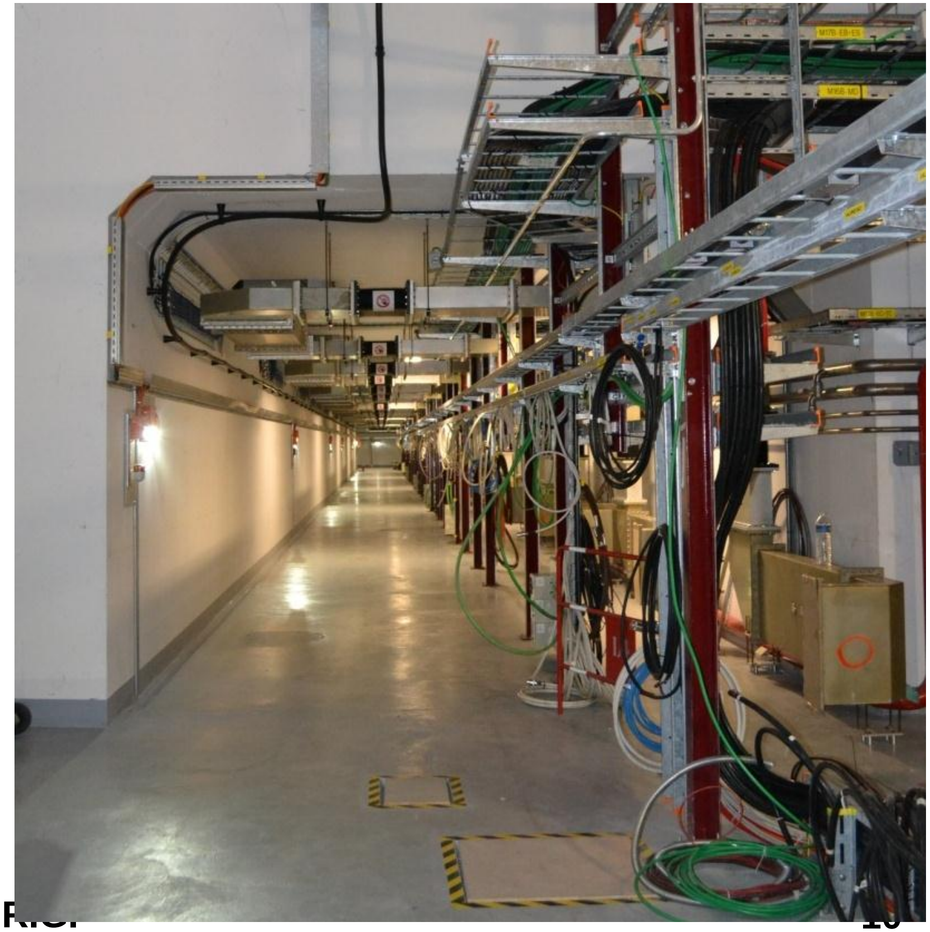
	Energy [MeV]	Length [m]	RF power [MW]	Focusing
RFQ	0.045 – 3	3	0.6	RF focusing
DTL	3 – 50	19	5	112 perm. quads
CCDTL	50 – 102	25	7	21 EM quads
PIMS	102 – 160	22	6	12 EM quads

Linac4: Achievements in 2012

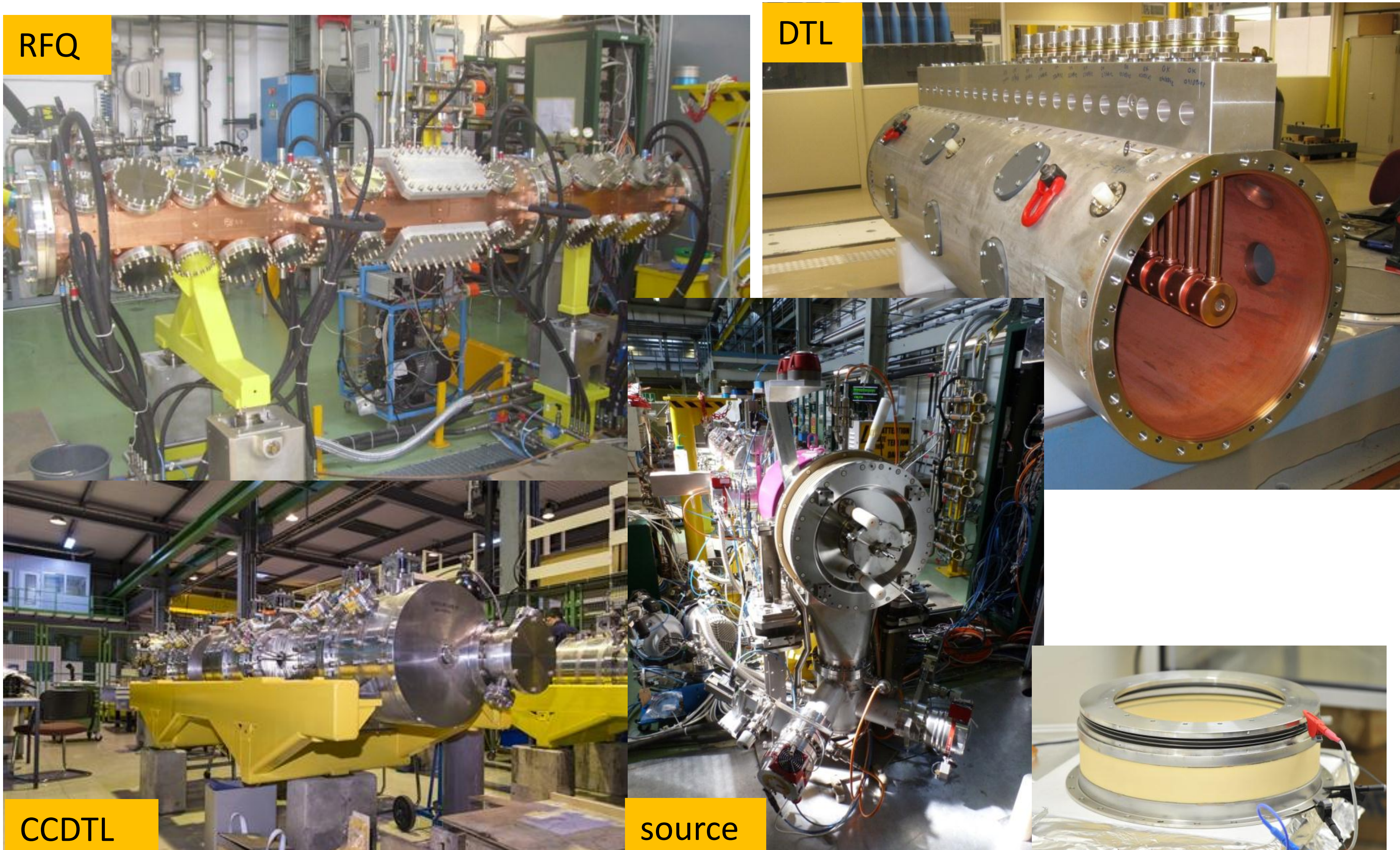
- RFQ completed and installed in the 3 MeV test stand – RF coupler fabrication started, RF high-power tests January 2013.
- New H^- source being tested. Plasma production optimized, problems with HV extraction (bad ceramics insulator received from industry, being cleaned/repaired – reassembly in progress)
- Prototypes 2.8 MW klystron successfully tested, first unit delivered to CERN by CPI, Thales unit to be delivered before end of year.
- 1st DTL tank section (half Tank1) completed, alignment checked. Components for other tanks in production.
- 1st batch of 2 CCDTL modules from BINP Novosibirsk received: remaining 5 to be delivered beginning 2013.
- Production of PIMS modules started in Poland.
- Final large orders (magnets) placed, production so far on schedule.

Linac4: Tunnel

- Waveguide network completely installed
- Cabling and piping completed
- Ion source Faraday cage and support installed

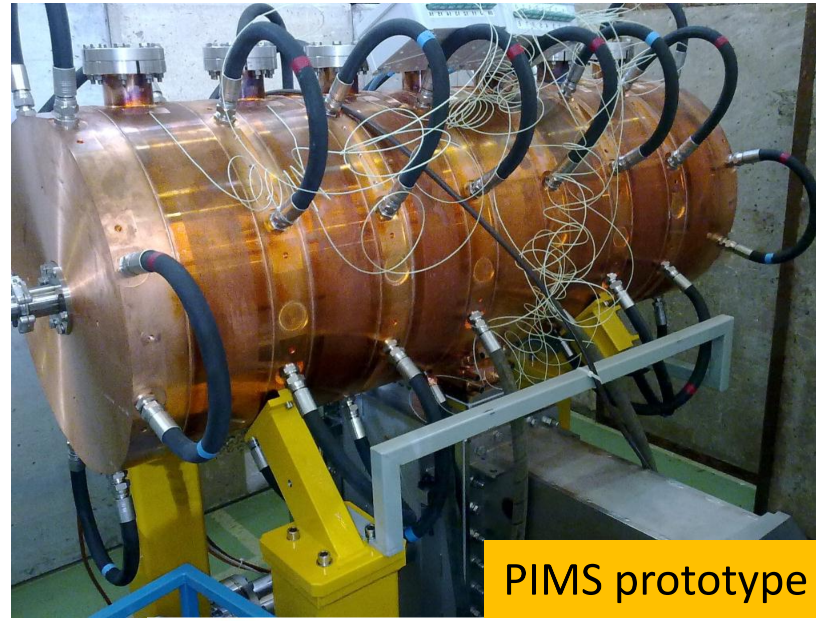


Linac4 hardware construction (1)

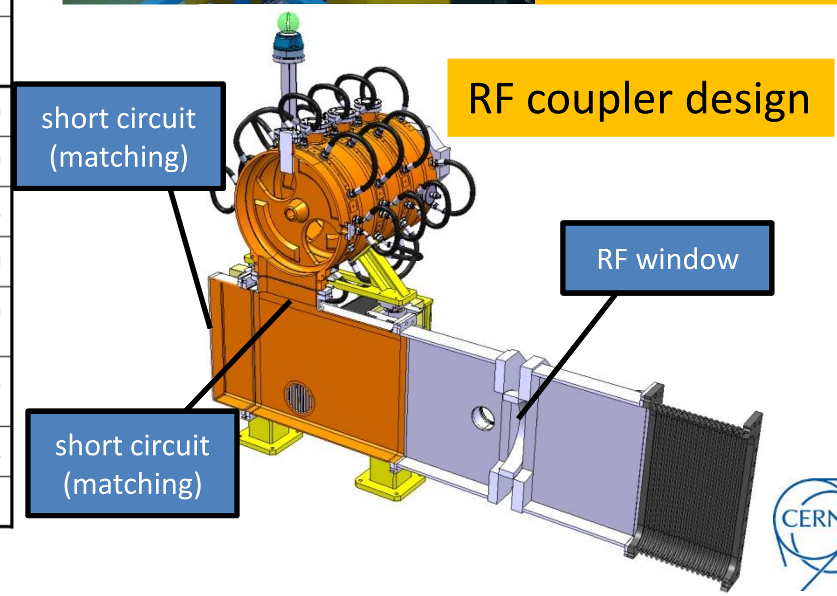


Linac4 hardware construction (2): PIMS…

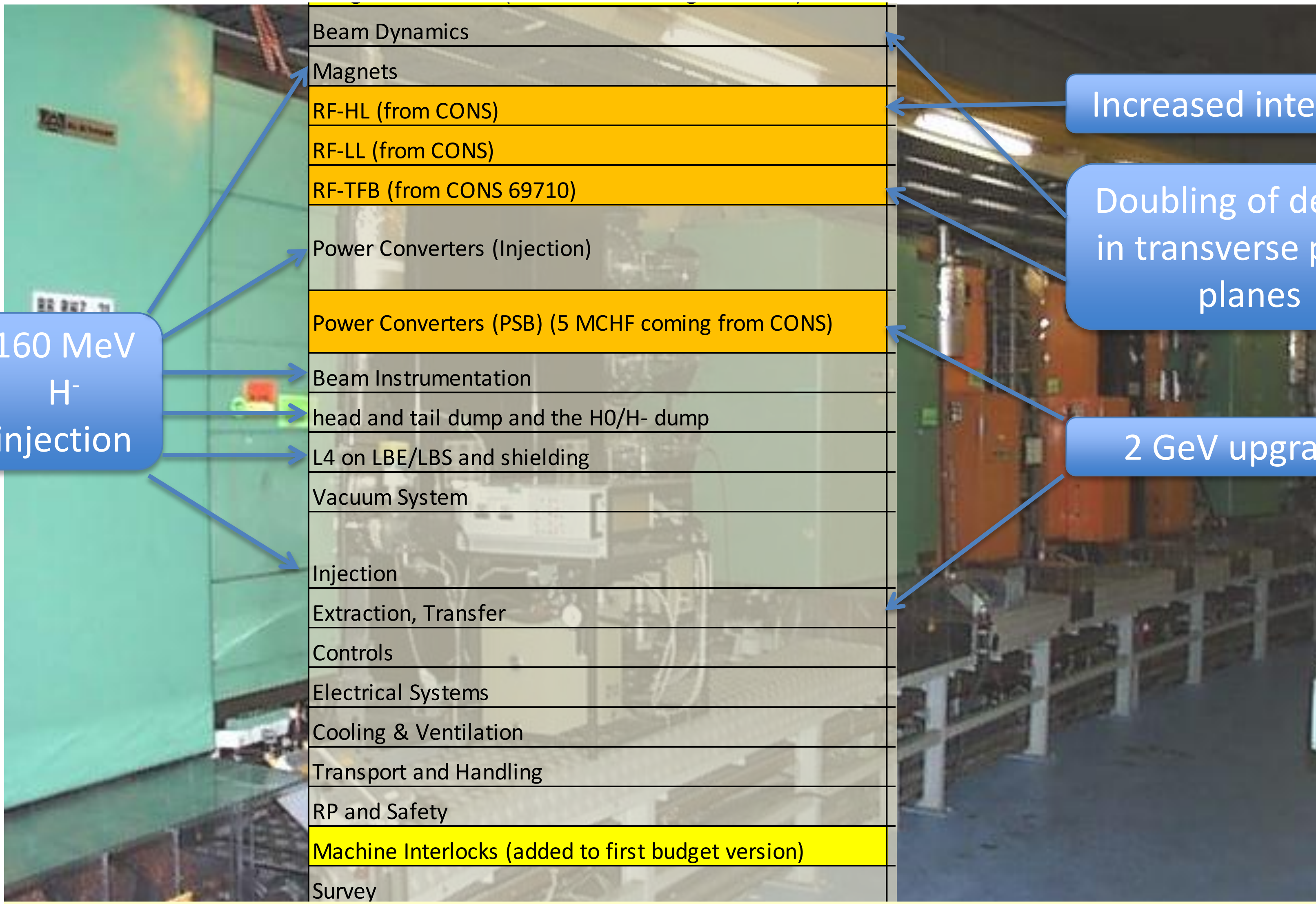
- cavity #1, length 1.4 m, weight ~700 kg
- ZT^2: 26.5 MΩ/m (95% of HFSS calculation)
- cell to cell coupling k: 5.6% to 4.8%
- $E_{S,max}$ = 1.8 Kilpatrick (33.2 MV/m @ 352MHz)



day 2010	T_{RF} [h]	com.	P_{peak}	T_{pulse} [μs]	vacuum [mbar]	X-ray $_{axis}$ [mSv/h]	X-ray$_{ext}$ [μSv/h]
2.11.	2	setup	1 kW	800	$5 \cdot 10^{-6}$	0	0
3.11.	6	multipactor	1 .. 10 kW	25	$8 \cdot 10^{-6}$	0	0
4.11.	6		700 kW	180	$8 \cdot 10^{-6}$	12	14
5.11.	2	modulator	700 kW	300	$4 \cdot 10^{-6}$	15	20
8.11.	4	roof, temp. sens.	700 kW	500	$1 \cdot 10^{-6}$	17	30
9.11.	5	trigger, temp.	~ 500 kW	800	$8 \cdot 10^{-7}$	17	36
10.11.	3		700 kW	800	$1 \cdot 10^{-6}$	25	44
sum	28	cavity conditioned to P_{peak}= 700 kW, f_{rep}=2 Hz, T_{pulse}=800 μs					



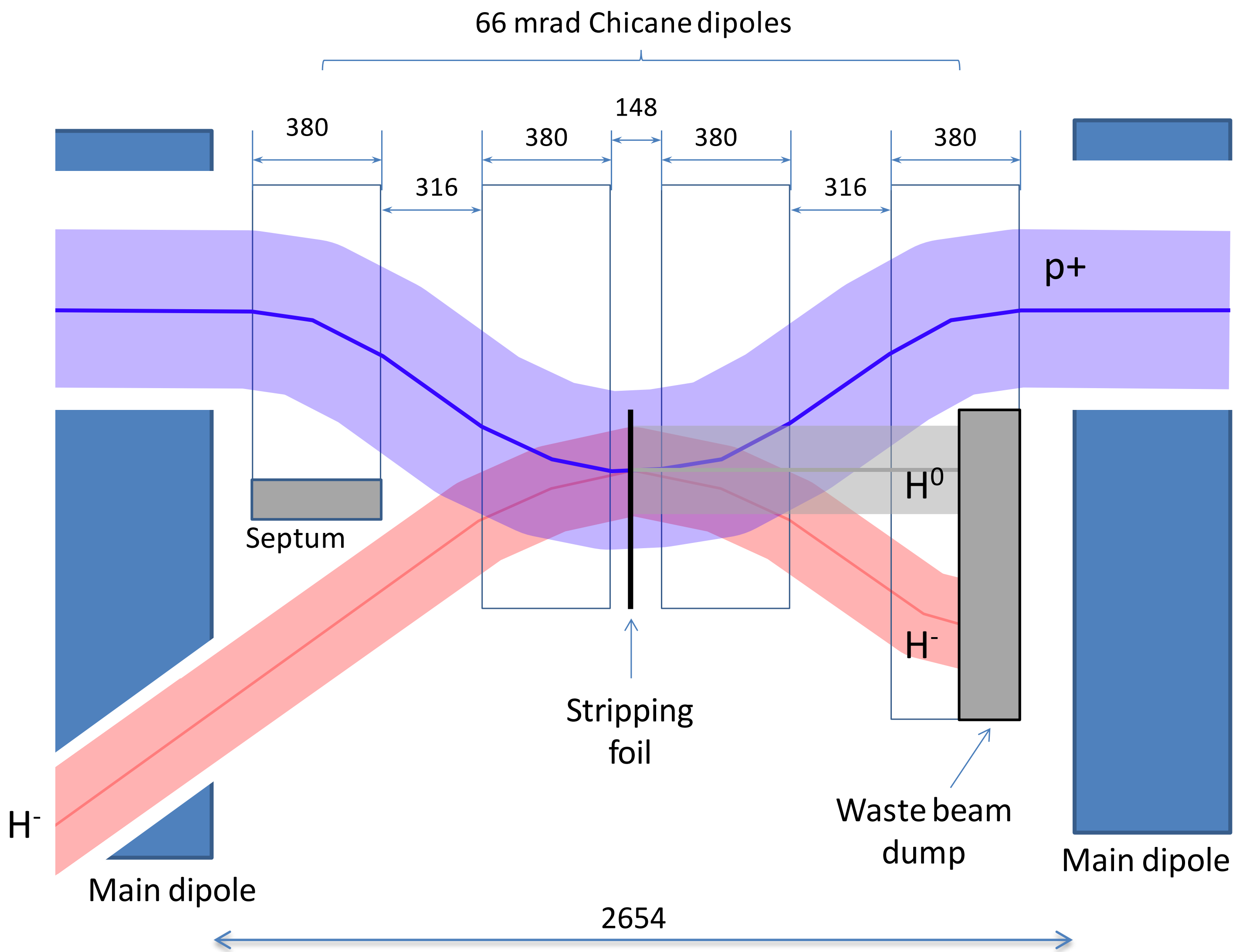
PSB upgrade



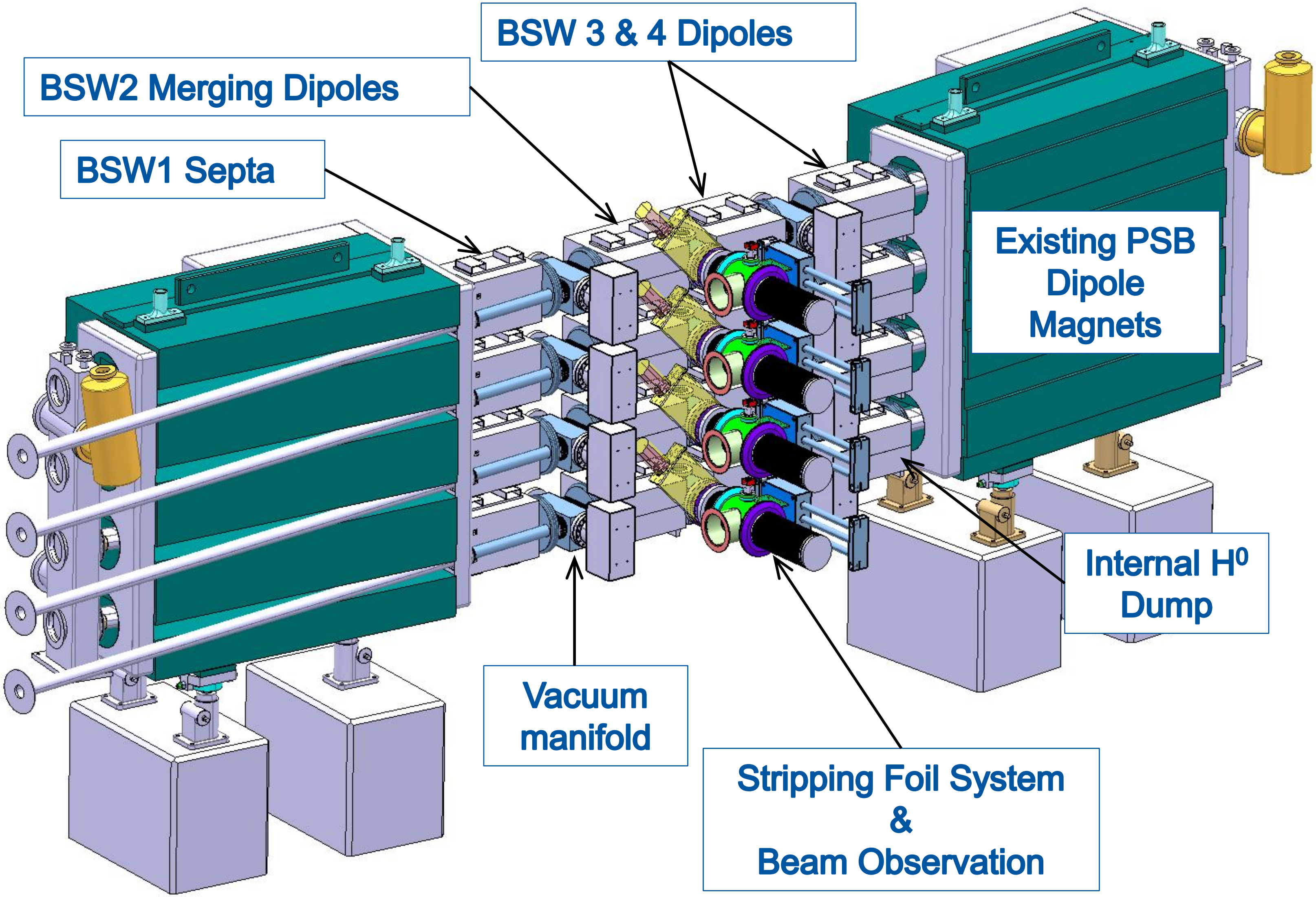
Beam Dynamics
Magnets
RF-HL (from CONS)
RF-LL (from CONS)
RF-TFB (from CONS 69710)
Power Converters (Injection)
Power Converters (PSB) (5 MCHF coming from CONS)
Beam Instrumentation
head and tail dump and the H0/H- dump
L4 on LBE/LBS and shielding
Vacuum System
Injection
Extraction, Transfer
Controls
Electrical Systems
Cooling & Ventilation
Transport and Handling
RP and Safety
Machine Interlocks (added to first budget version)
Survey

All details are available at: https://espace.cern.ch/liu-project/liu-psb/default.aspx

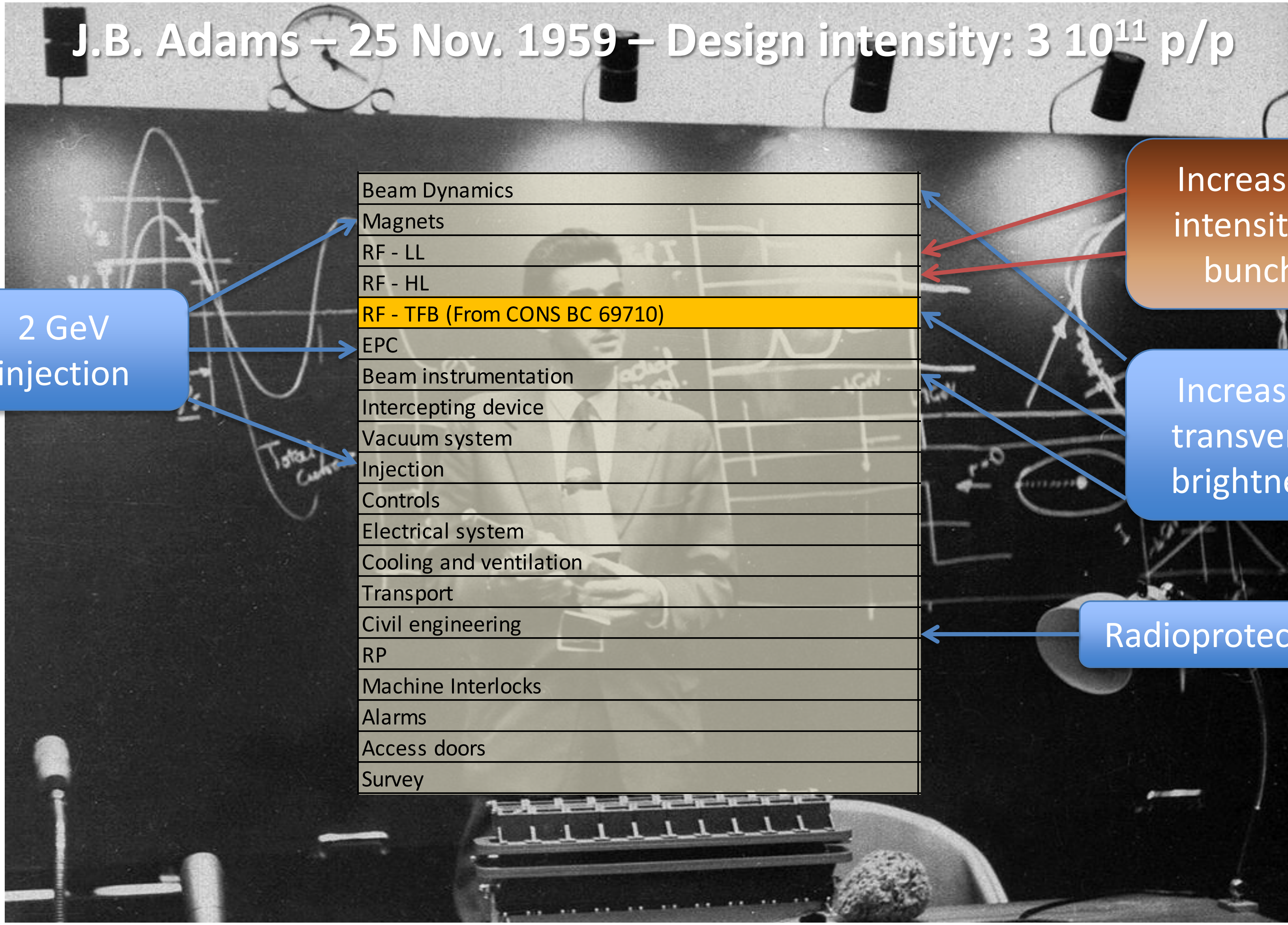
PSB H^- injection chicane concept



PSB H$^-$ injection chicane design



PS upgrade



J.B. Adams – 25 Nov. 1959 – Design intensity: 3 10^{11} p/p

Beam Dynamics
Magnets
RF - LL
RF - HL
RF - TFB (From CONS BC 69710)
EPC
Beam instrumentation
Intercepting device
Vacuum system
Injection
Controls
Electrical system
Cooling and ventilation
Transport
Civil engineering
RP
Machine Interlocks
Alarms
Access doors
Survey

2 GeV injection

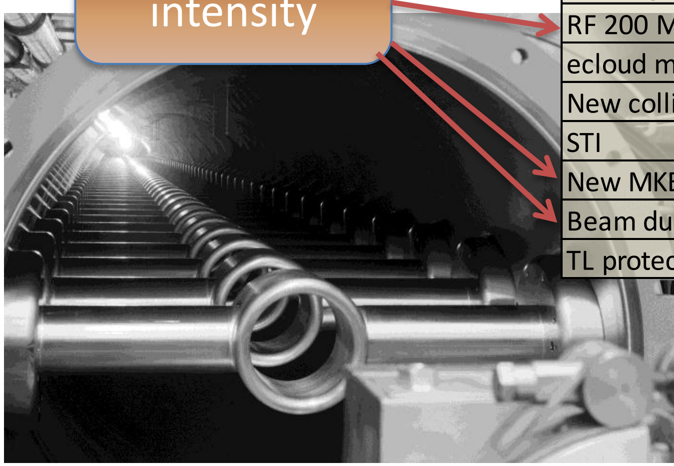
Increased intensity / bunch

Increased transverse brightness

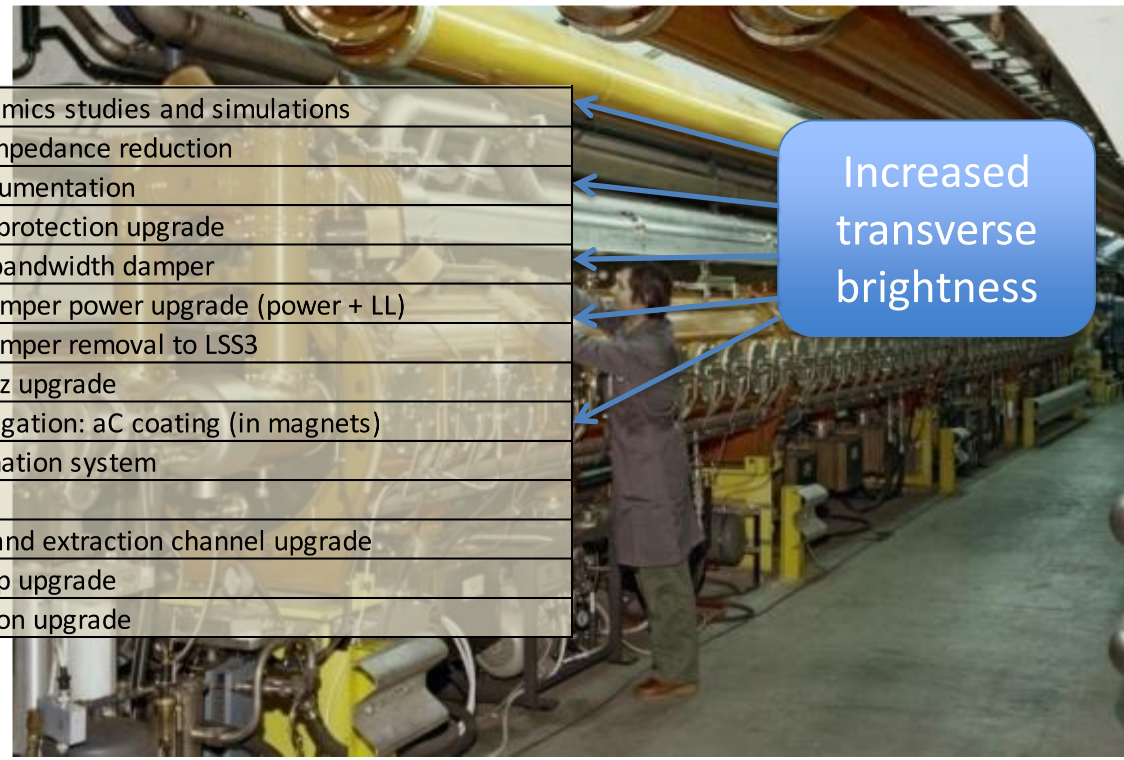
Radioprotection

SPS upgrade

200 MHz Travelling Wave Accelerating Structures



One four sections cavity
(four power couplers and two terminating power loads)



Increased intensity

Increased transverse brightness

Beam dynamics studies and simulations
MKDV/H impedance reduction
Beam instrumentation
Extraction protection upgrade
New high bandwidth damper
Existing damper power upgrade (power + LL)
Existing damper removal to LSS3
RF 200 MHz upgrade
ecloud mitigation: aC coating (in magnets)
New collimation system
STI
New MKE and extraction channel upgrade
Beam dump upgrade
TL protection upgrade

- The LIU project
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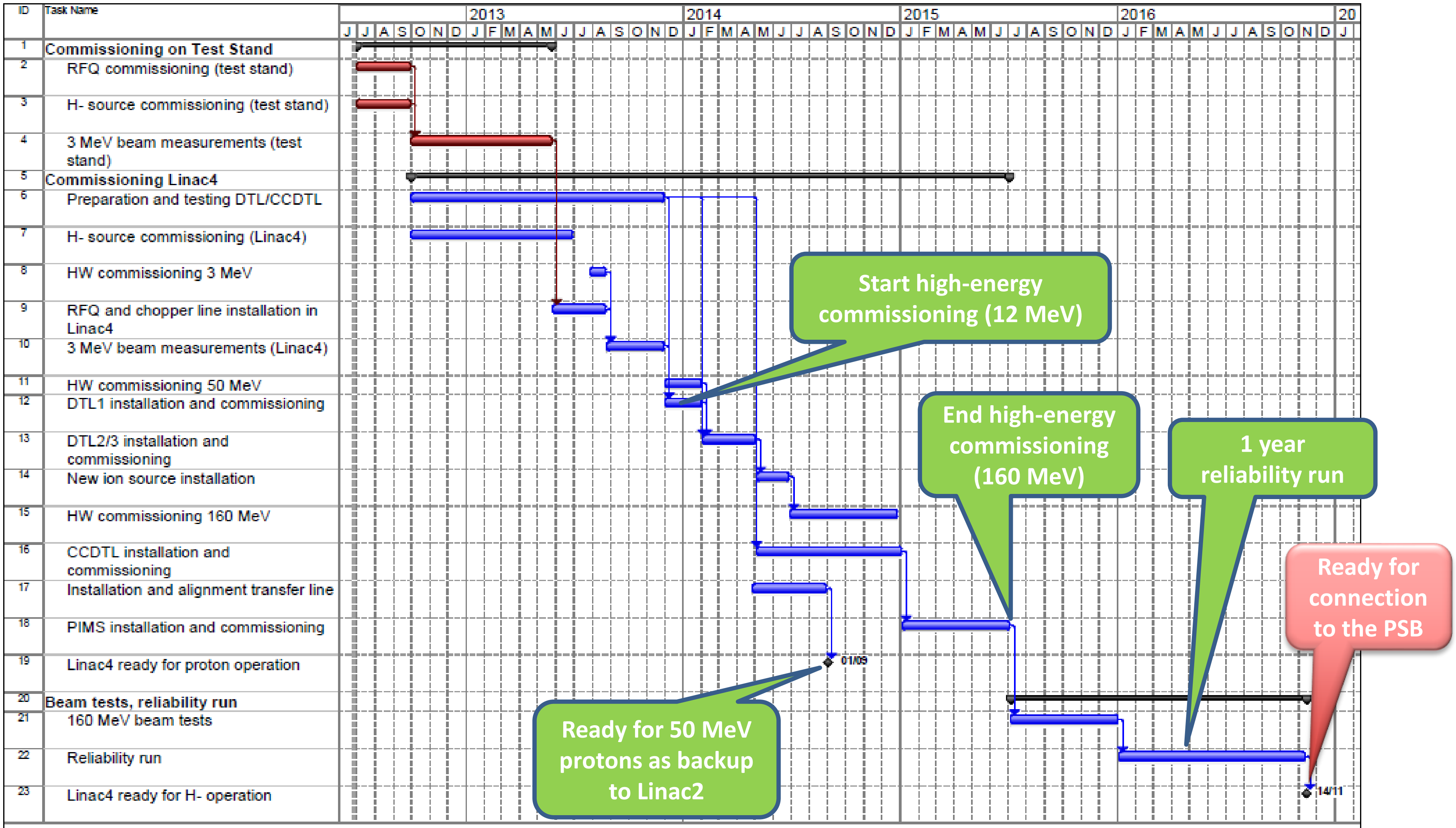
- **Planning**

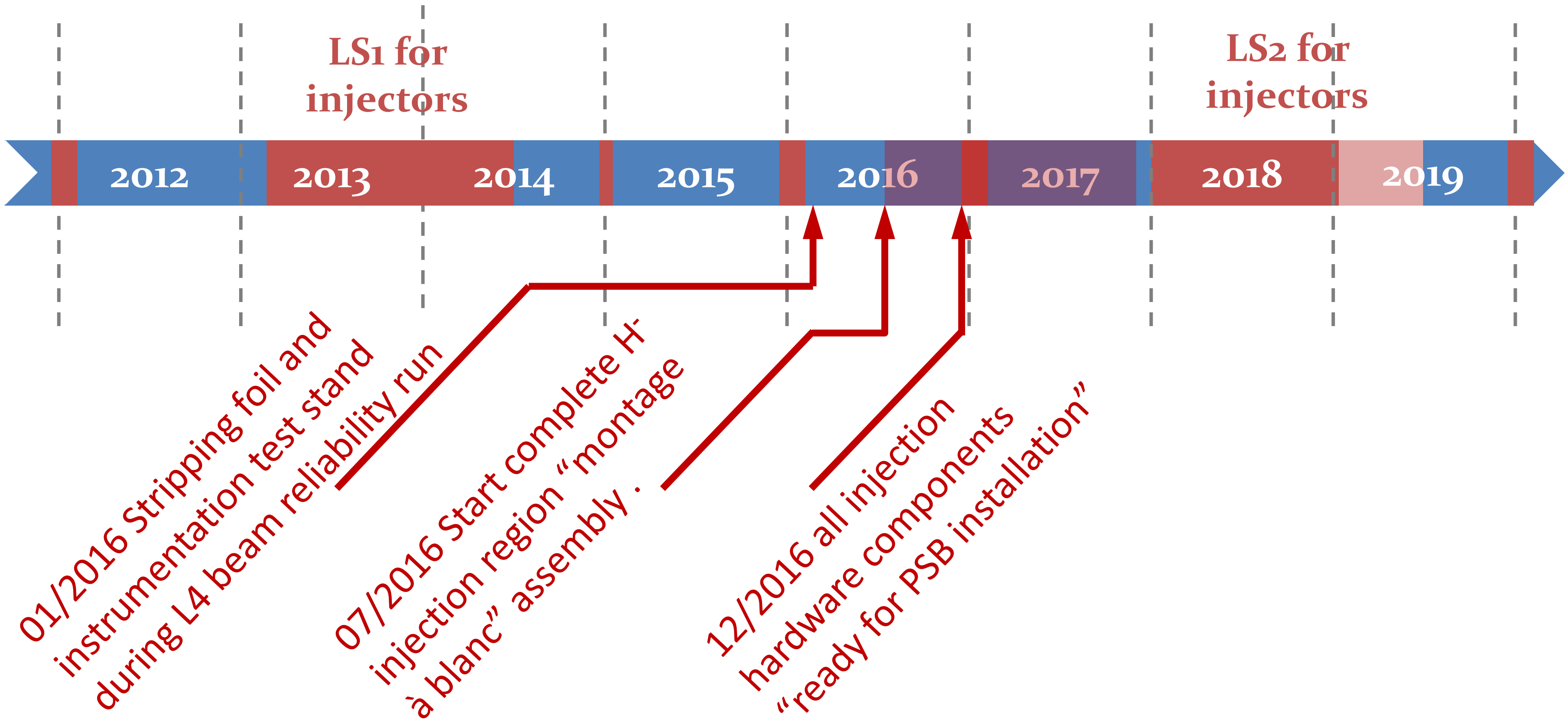
Linac4 Masterplan

2012/16 Masterplan (as of June 2012)



Reliability run during 2016, **Connection of Linac4 to the PS Booster any time after 2016…**

Linac4 to PSB Connection



- The planning of LHC shutdowns is being revisited.
- One important goal is to implement and commission H- injection in the PSB before proceeding with the other upgrades.

=> Linac4 must be fully ready by the end of 2016!

THANK U
FOR YOUR ATTENTION!

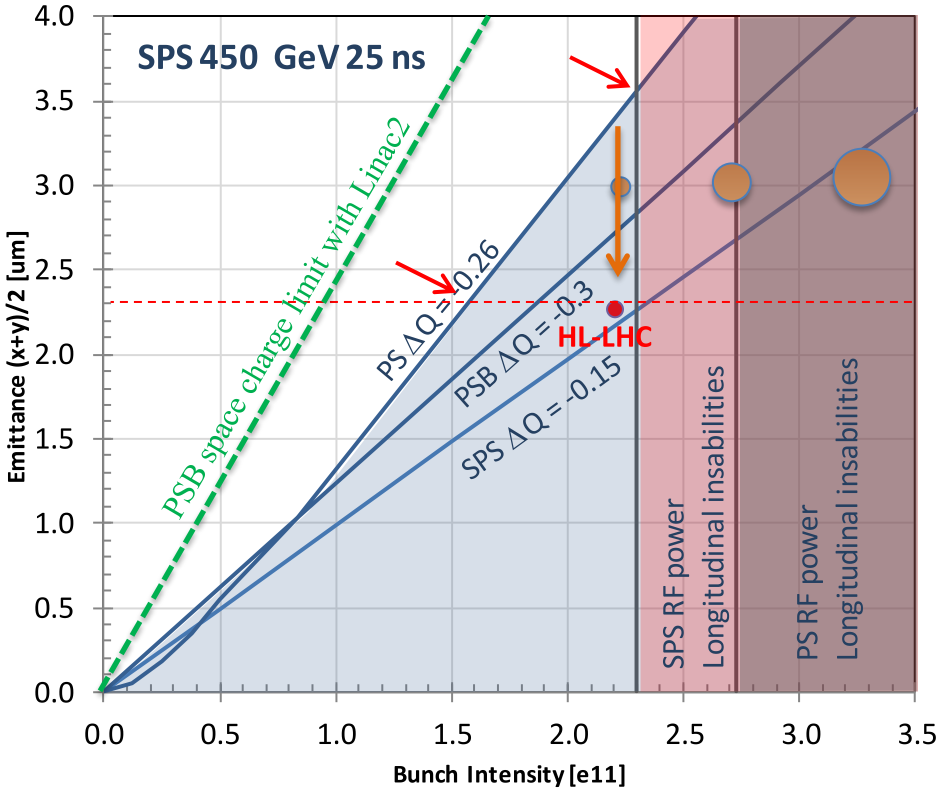
SPARE SLIDES

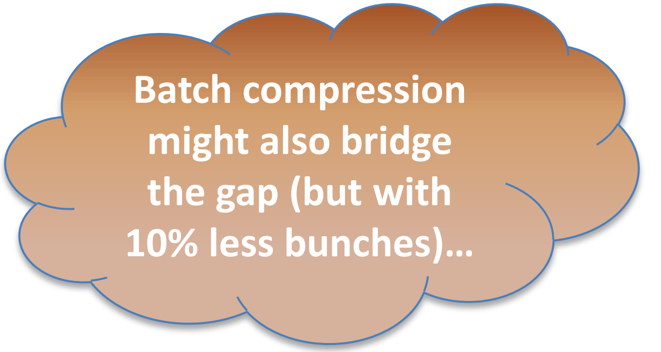
Potential beam characteristics after LS2 with 25 ns

Performance after LIU: **2.3 10^{11} p/b in 3.6 mm.mrad** at SPS extraction

to be compared with

HL-LHC objective (450 GeV): **2.2 10^{11} p/b in 2.3 mm.mrad**





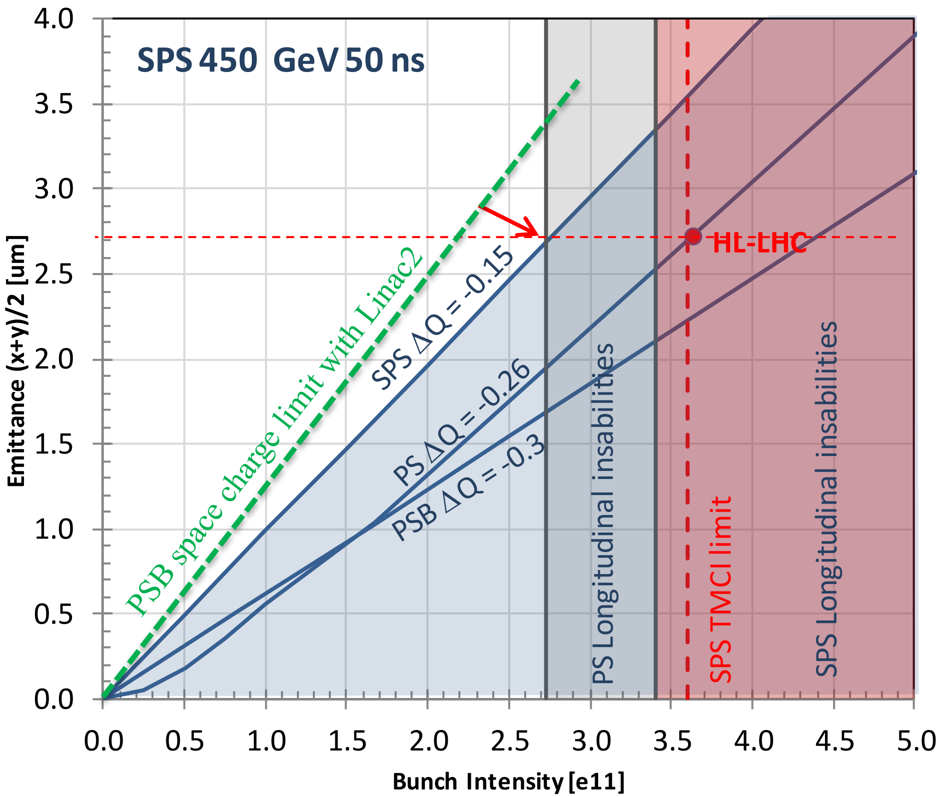
⇒ Limited by <u>space charge in the PS</u>

Potential beam characteristics after LS2 with 50 ns

Performance after LIU: **2.7 10^{11} p/b in 2.7 mm.mrad** at SPS extraction

to be compared with

HL-LHC objective (450 GeV): **3.5 10^{11} p/b in 2.7 mm.mrad**



⇒ Limited by <u>longitudinal instabilities in the PS and SPS</u>, and by <u>brightness in SPS</u>