



UPGRADE PLANS FOR THE LHC INJECTOR COMPLEX*

* Protons only



UPGRADE PLANS FOR THE LHC INJECTOR COMPLEX



- **Setting the scene**
- The LIU project
- Action plan
- Beam characteristics
- Planning





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

$$L_{LHC} = \frac{\gamma}{4\pi} \underbrace{\frac{1}{\beta^*} f_{rev} F}_{\text{Collider related}} \cdot \underbrace{(n_b N_b)}_{\text{Total current}} \cdot \underbrace{\left(\frac{N_b}{\epsilon_n} \right)}_{\text{Brightness}}$$

Injectors' related

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

n_b : number of colliding bunches in each LHC ring ($\sim$ 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

Operational production scheme		25 ns ~nominal	50 ns (CBI-limit)
PS injection (12 or 6 LHC bunches / PS bunch)	Bunch intensity, $\times 10^{11}$ p/b	16	12
	Emittance, $\beta\gamma\epsilon$	2.4 μm	1.8 μm
	Vert. tune spread, ΔQ_y	-0.26	-0.25
PS ejection (1 LHC bunch / PS bunch)	Bunch intensity, $\times 10^{11}$ p/b	1.27	1.90
	Emittance, $\beta\gamma\epsilon$	2.5 μm	1.9 μm
	Bunches per batch	72	36
Brightness limit PSB		X	X
Space charge limit PS		X	X
Coupled-bunch limit PS			X
SPS ejection: nominal (achieved)	Bunch intensity, $\times 10^{11}$ p/b	1.15 (1.15)	1.7 (1.6)
	Emittance, $\beta\gamma\epsilon$	3.5 (3) μm	3.5 (2) μm
Beam quality factor $n_b N_b^2 / \epsilon_n$ wrt nominal		1.2	1.7



Potential for nominal luminosity in LHC...



Requirements from HL-LHC (> 2020)



Target: 250-300 fb⁻¹ per year

Poster MOPPC05

Parameter	nominal	minimum β^*	
		25ns	50ns
N	1.15E+11	2.2E+11	3.5E+11
n_b	2808	2808	1404
beam current [A]	0.58	1.12	0.89
x-ing angle [μ rad]	300	480	550
beam separation [σ]	10	10	10
β^* [m]	0.55	0.15	0.15
ε_n [μ m]	3.75	2.5	3.0
ε_L [eVs]	2.51	2.5	2.5
energy spread	1.20E-04	1.20E-04	1.20E-04
bunch length [m]	7.50E-02	7.50E-02	7.50E-02
IBS horizontal [h]	80 -> 106	20.0	20.7
IBS longitudinal [h]	61 -> 60	15.8	13.2
Piwinski parameter	0.68	2.54	2.66
geom. reduction	0.83	0.37	0.35
beam-beam / IP	3.10E-03	3.9E-03	5.0E-03
Peak Luminosity	1 10 ³⁴	9.0 10³⁴	9.0 10³⁴
Events / crossing	19	171	340
Beam quality factor $n_b N_b^2 / \varepsilon_n$ wrt nominal		5.1	5.6

at LHC collision





UPGRADE PLANS FOR THE LHC INJECTOR COMPLEX



- Setting the scene
- **The LIU project**
- Action plan
- Beam characteristics
- Planning





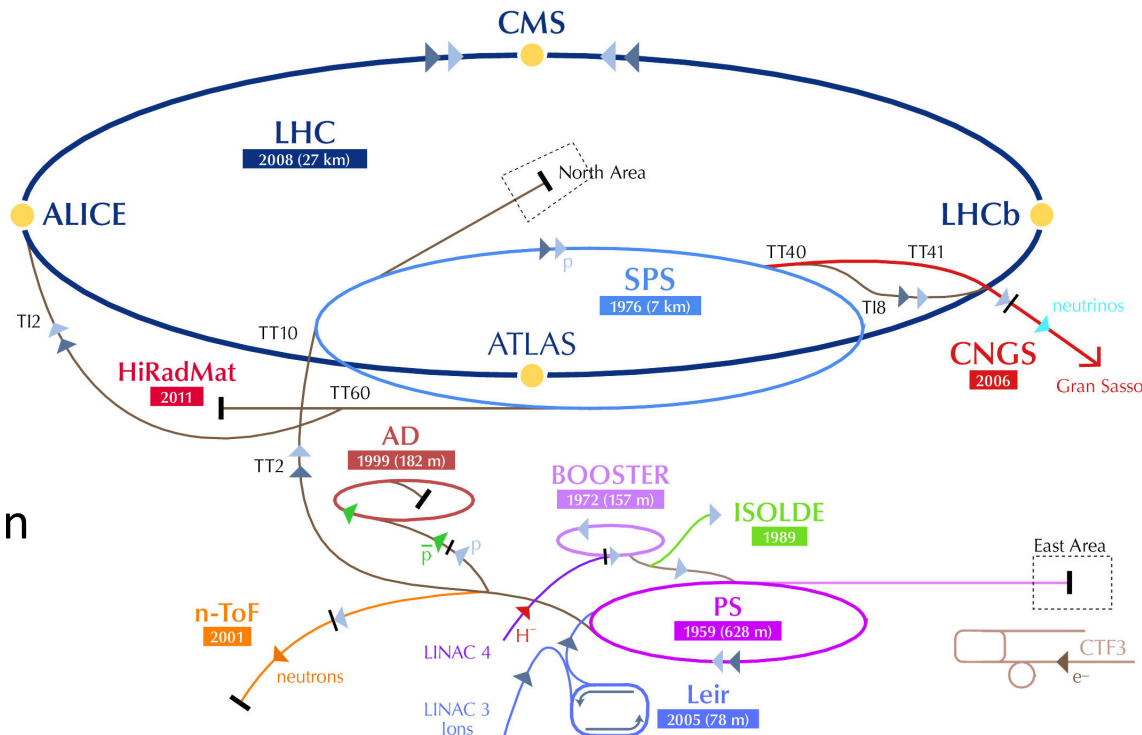
Mandate (December 2010)

“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.”

Implementation

The LIU Project will:

- Analyze the status of the injectors and the HL-LHC requirements,
- Propose an upgrade path for the injectors, exploiting the work done by the Task Forces on the „PSB energy upgrade“ and „SPS upgrade“ and by the Working Group on the SPS upgrade,
- Organize the upgrades (WBS with resources and planning) and take care of their implementation,
- Take care of hardware and beam commissioning.





The Actors...



R. Garoby (Project leader) , M. Meddahi (Deputy), L. Ponce (Project Safety Officer)

- [Linac4 Project \[http://linac4-project.web.cern.ch/linac4-project/\]](http://linac4-project.web.cern.ch/linac4-project/)
M. Vretenar, A. Lombardi (Deputy)
- [LIU-PSB coordination \[https://espace.cern.ch/liu-project/liu-psb/\]](https://espace.cern.ch/liu-project/liu-psb/)
K. Hanke, B. Mikulec (Deputy), V. Raginel (Scientific secretary)
- [LIU- PS coordination \[https://espace.cern.ch/liu-project/liu-ps/\]](https://espace.cern.ch/liu-project/liu-ps/)
S. Gilardoni, H. Damerau (Deputy), C. Yin Vallgren (Scientific secretary)
- [LIU-SPS coordination \[https://espace.cern.ch/liu-project/liu-sps/default.aspx\]](https://espace.cern.ch/liu-project/liu-sps/default.aspx)
B. Goddard, E. Shaposhnikova (Deputy), G. Rumulo (Scientific secretary)
- [LIU- Ion chain coordination](#)
D. Manglunki

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>





UPGRADE PLANS FOR THE LHC INJECTOR COMPLEX



- Setting the scene
- The LIU project
- **Action plan**
- Beam characteristics
- Planning





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 ~2030!) (tightly linked with consolidation)

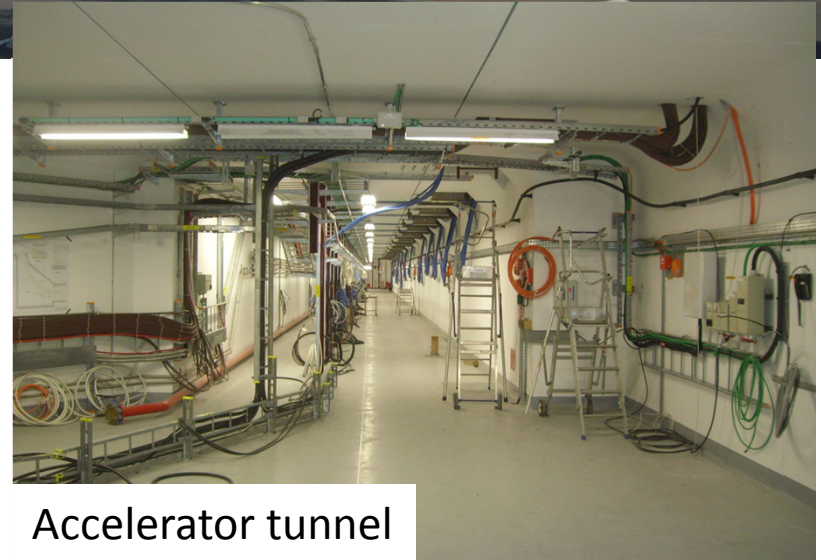
- ⇒ Upgrade/replace ageing equipment (power supplies, magnets, RF...)
- ⇒ Improve radioprotection measures (shielding, ventilation...)



Surface building



Equipment hall



Accelerator tunnel



Linac4 beam parameters



Ion species	H ⁻
Output Energy	160 MeV
Bunch Frequency	352.2 MHz
Max. Rep. Frequency	2 Hz
Max. Beam Pulse Length	0.4 ms
Max. Beam Duty Cycle	0.08 %
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
Transverse emittance	0.4 π mm mrad

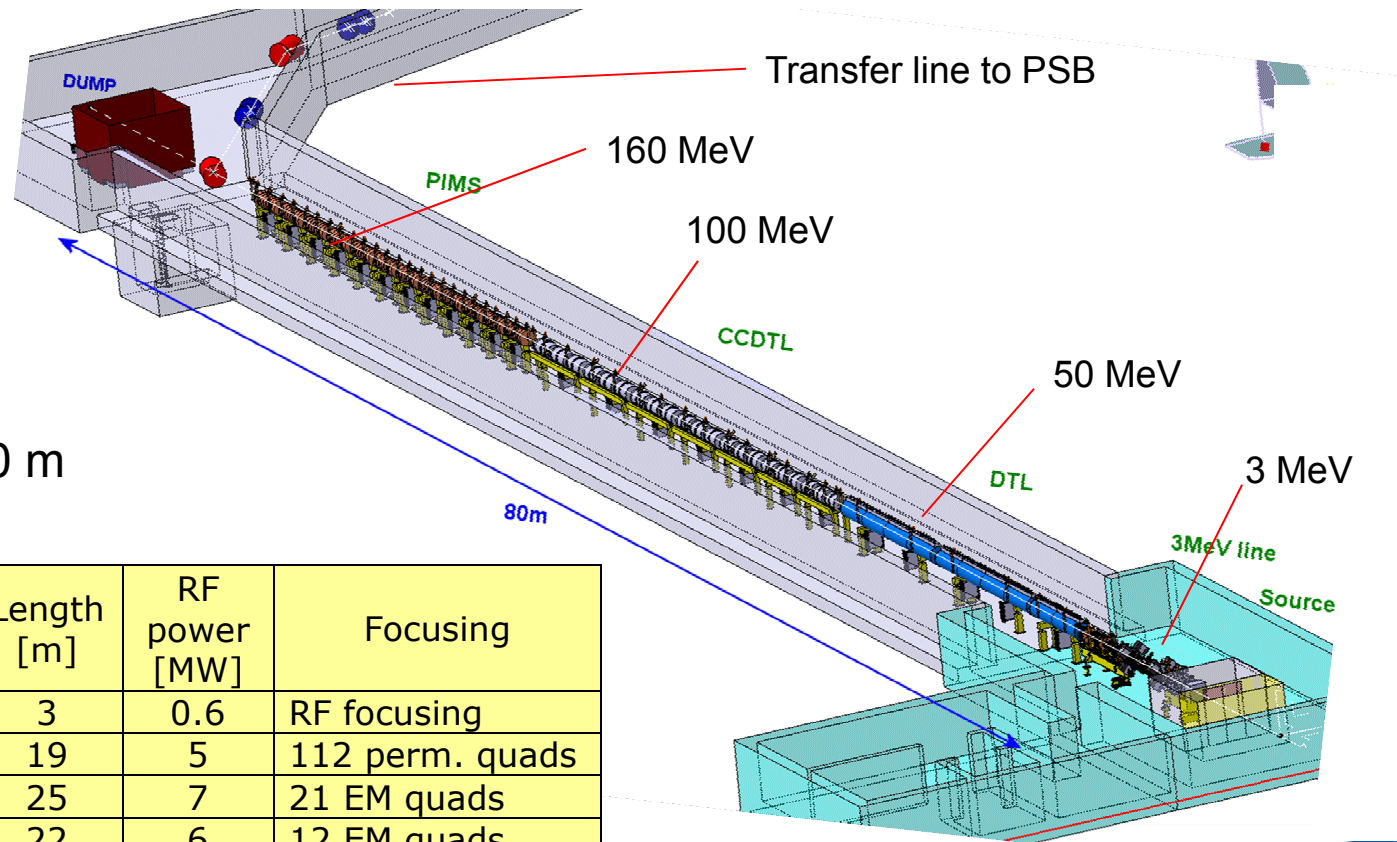
Max. repetition frequency for accelerating structures 50 Hz





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

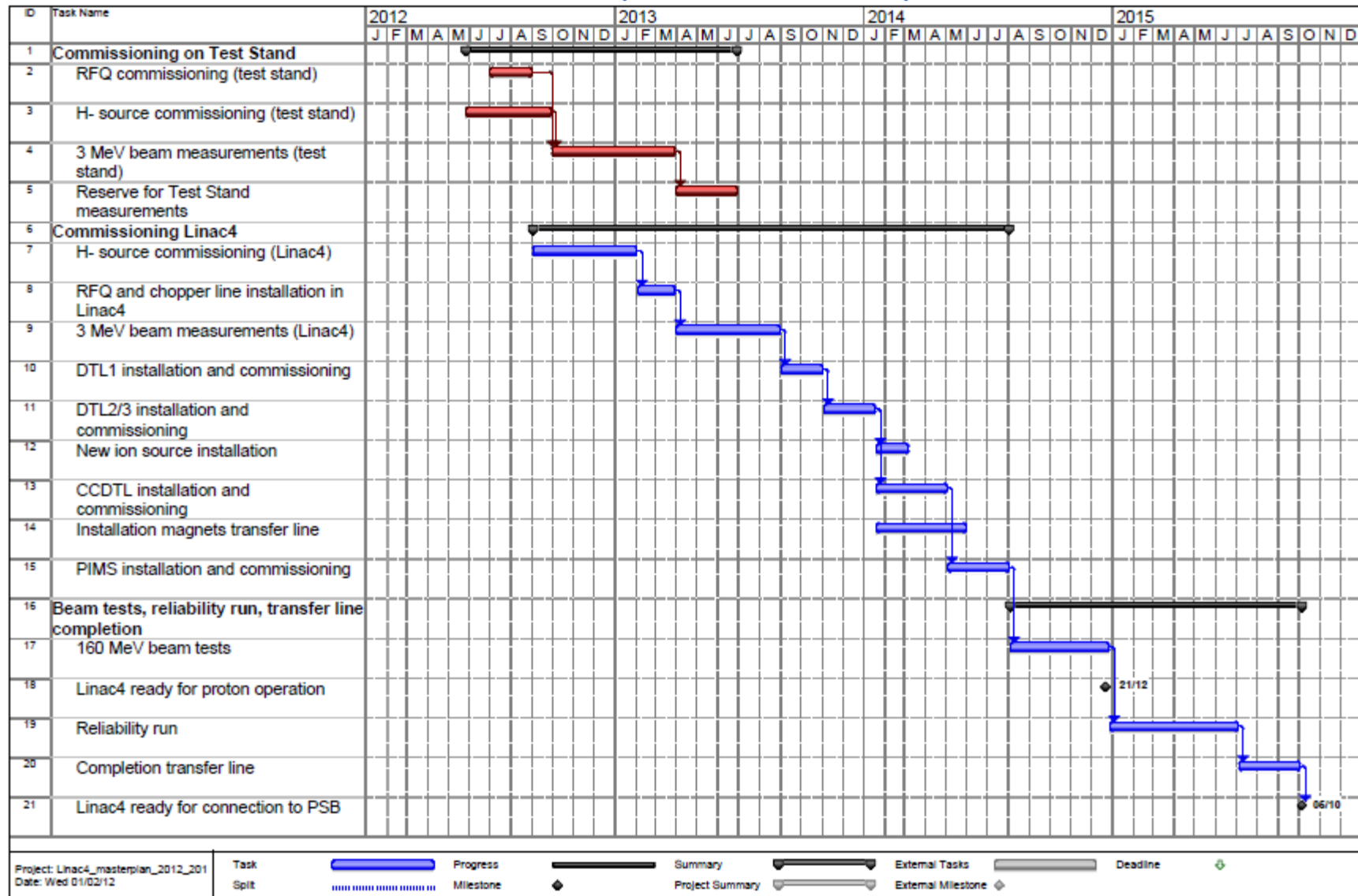
	Energy [MeV]	Length [m]	RF power [MW]	Focusing
RFQ	0.045 – 3	3	0.6	RF focusing
DTL	3 – 50	19	5	112 perm. quads
CCDTL	50 – 102	25	7	21 EM quads
PIMS	102 – 160	22	6	12 EM quads



Linac4 planning



Shutdown of LHC injectors
(part of LS1)



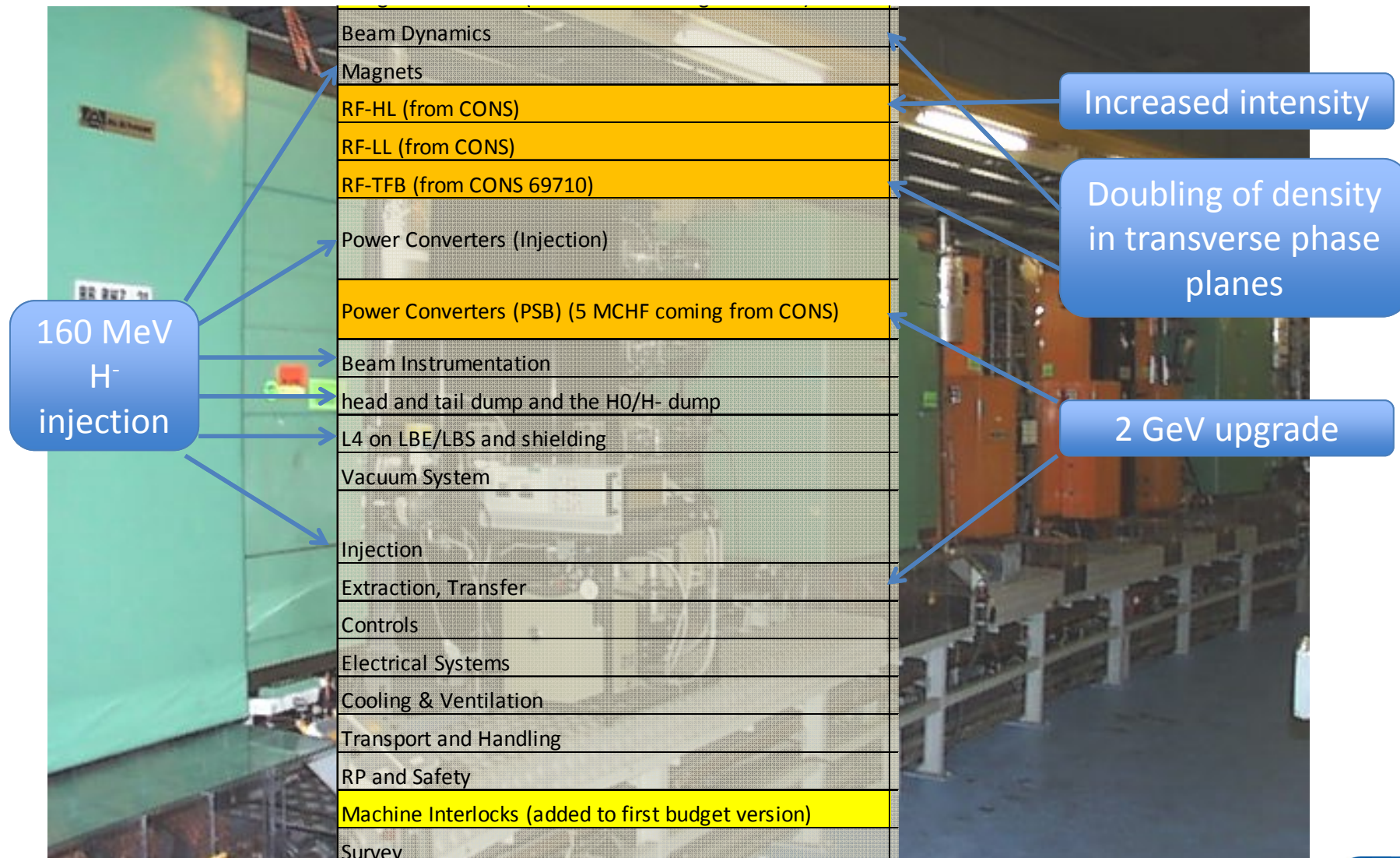


All details are available at: <https://espace.cern.ch/liu-project/liu-psb/default.aspx>





PSB upgrade



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

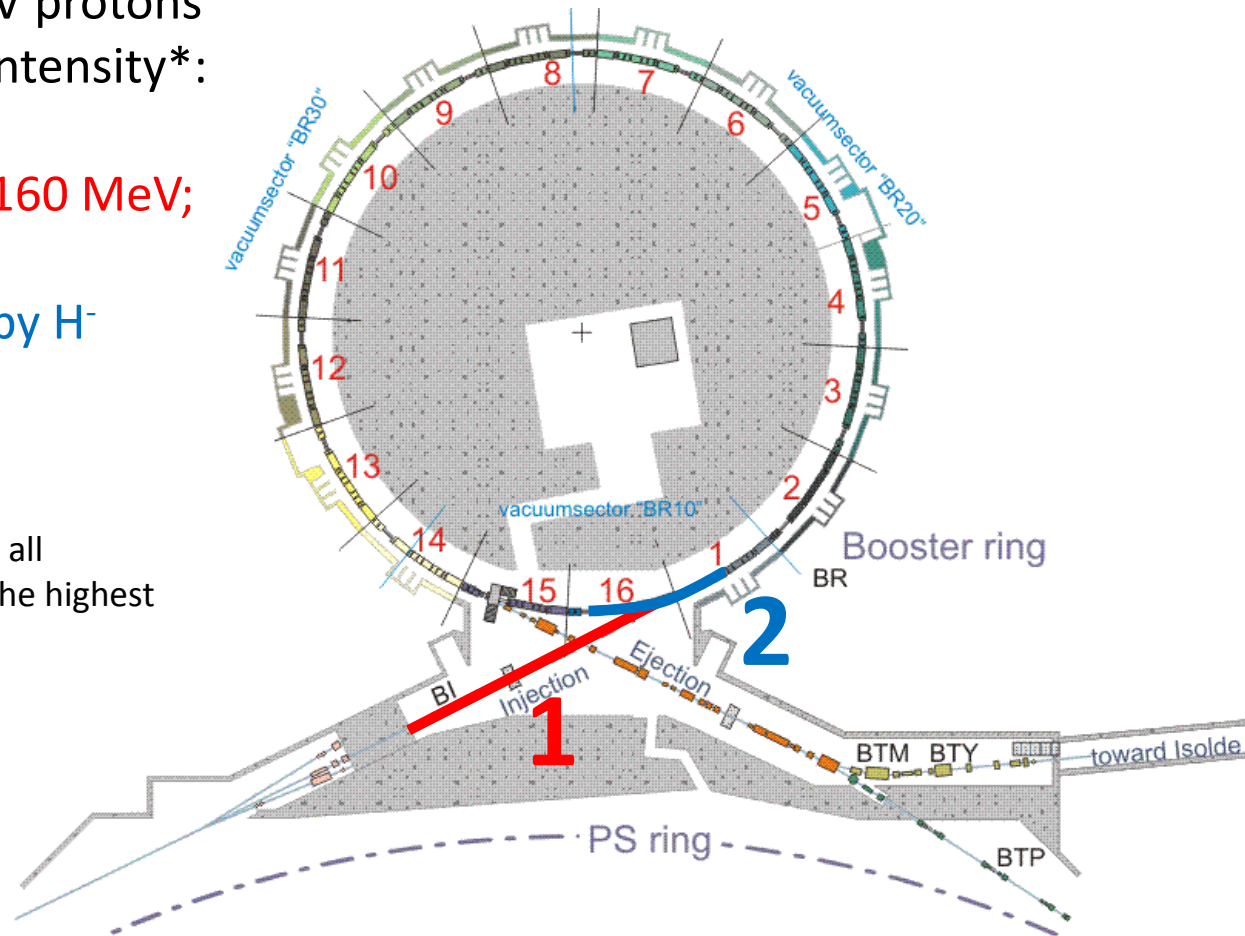


Scope of the injection upgrade

Injection upgrade from 50 MeV protons to 160 MeV H^- and increased intensity*:

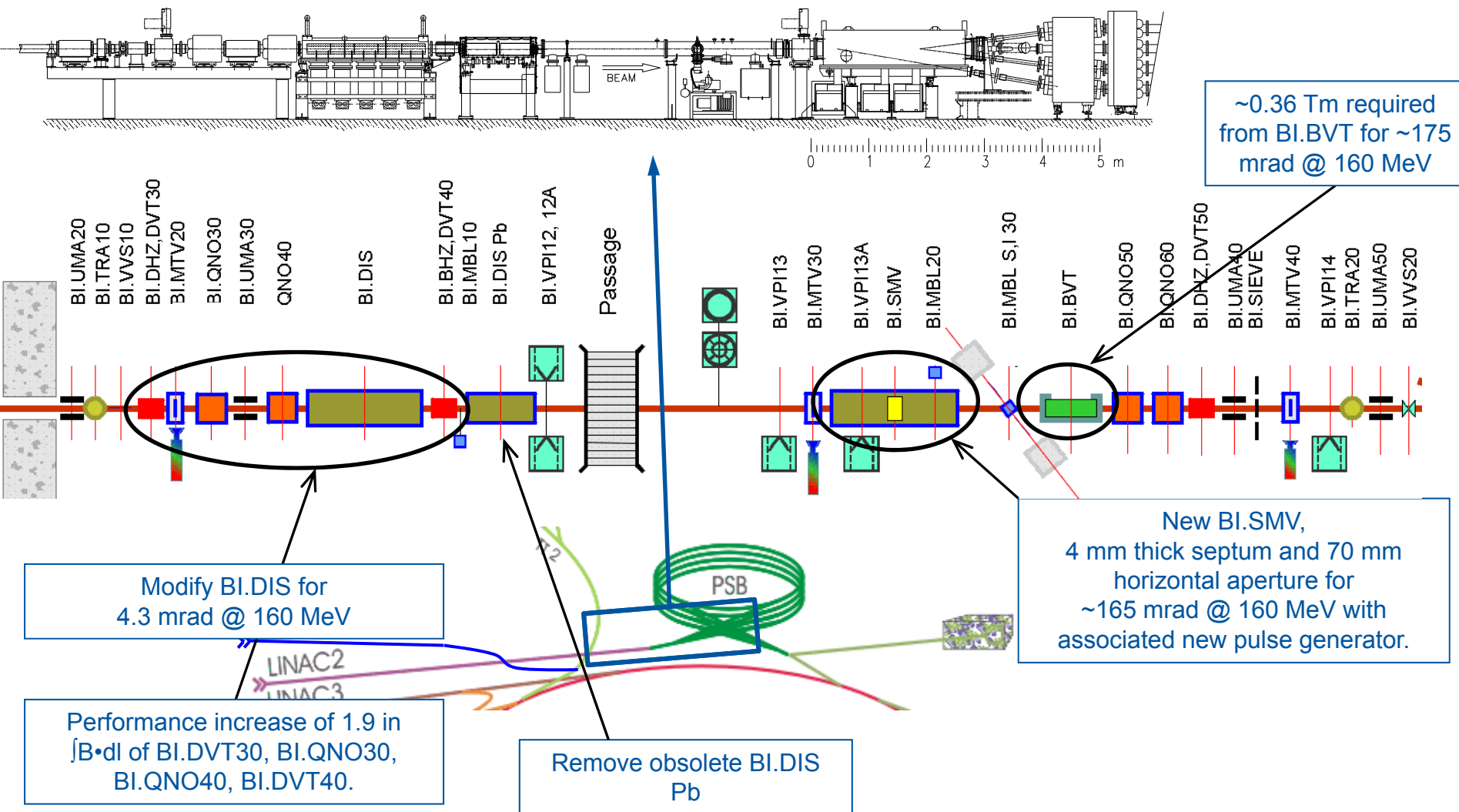
1. re-build injection line for 160 MeV;
2. replace injection septum by H^- injection system.

* although LIU aims at LHC-type beams, all equipment must be compatible with the highest intensities that can be expected.



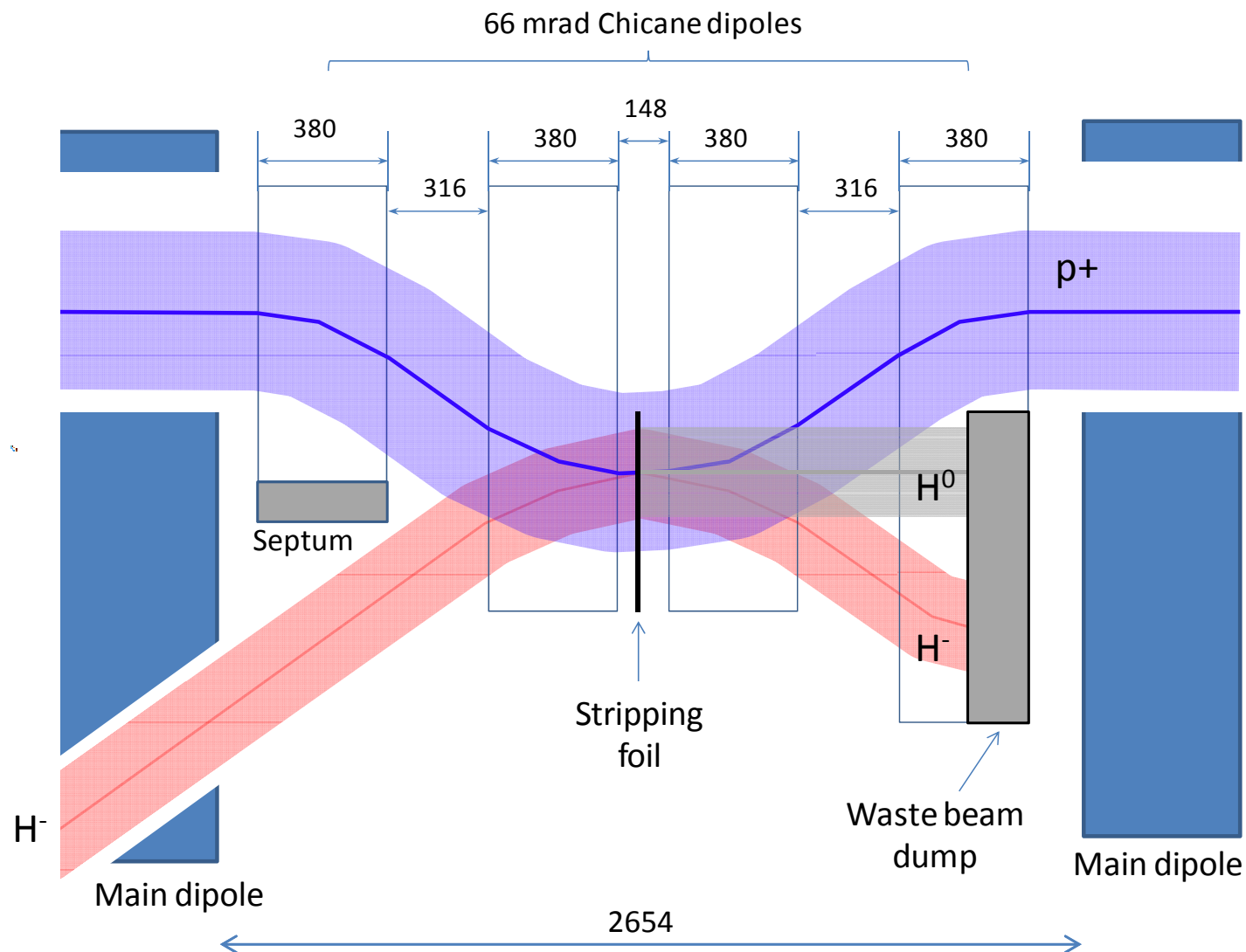


Injection line for 160 MeV



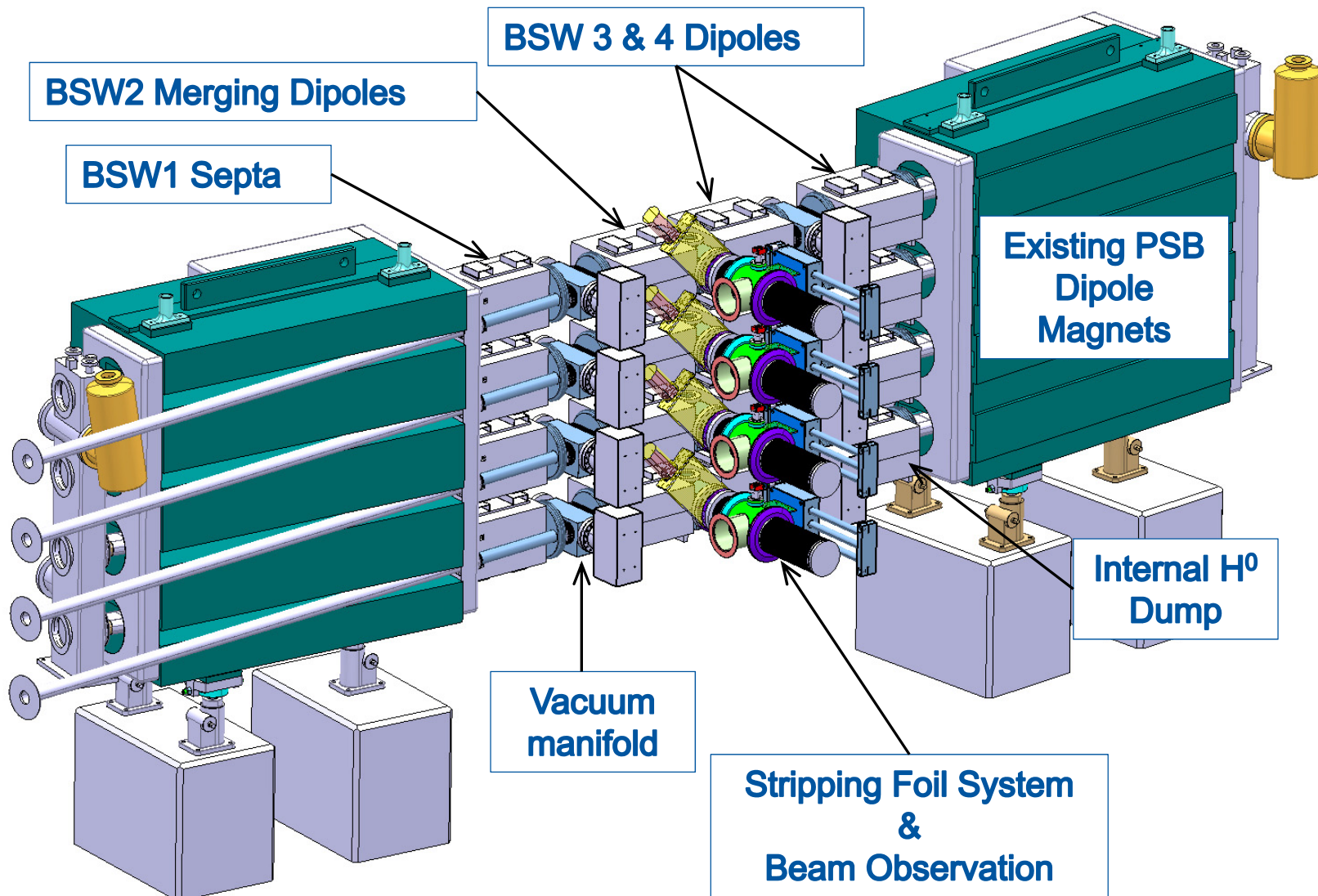


PSB H⁻ injection chicane concept





PSB H⁻ injection chicane design



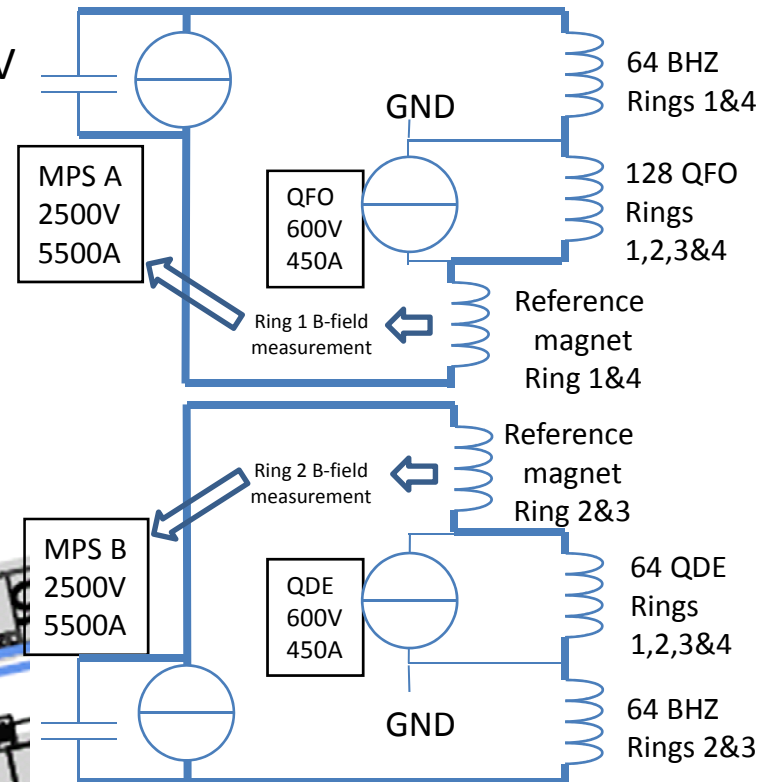
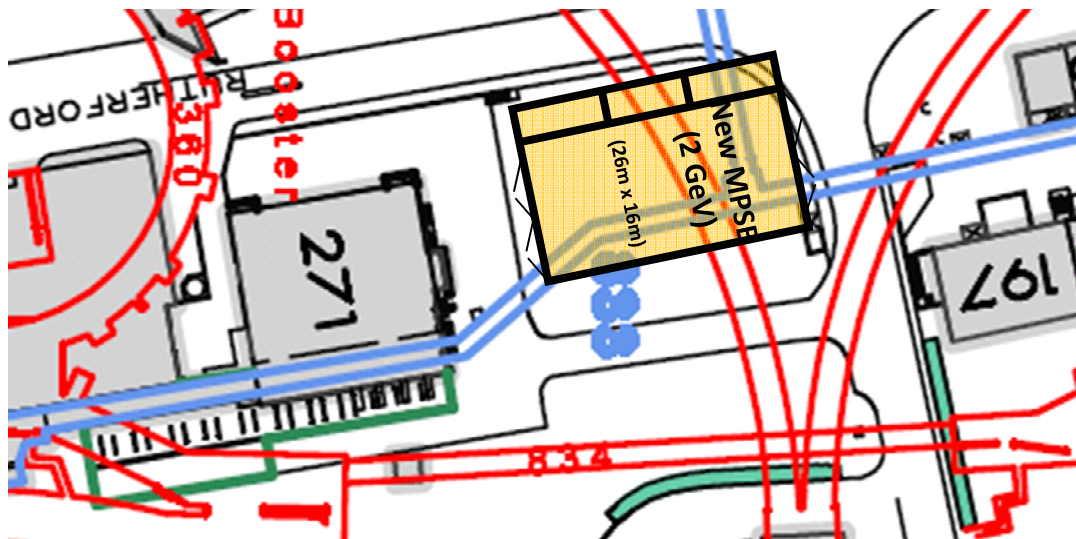


- **Main Power Supply**

- present converter cannot operate higher than 1.4 GeV
- POPS-type converter proposed (capacitor bank)
- divide machine in 2 circuits (inner and outer rings)
- will make R 1+4 trim power supply obsolete
- new building needed

- **Other Power Supplies**

- number of smaller converters to be changed



S. Pittet



PSB magnets, dumps, and beam transfer equipment

- **Magnets**

- main dipoles can operate at 2 GeV with some modifications (cooling, retaining plates)
- number of other magnets to be changed

- **Beam Intercepting Devices**

- new dump and beam stopper being designed
- removal of the old and installation of the new dump being studied for LS1

- **Extraction & Transfer**

- number of septa/kickers cannot operate at 2 GeV, notably extraction kickers (BE.KFA) and recombination septa (BT.SMV)

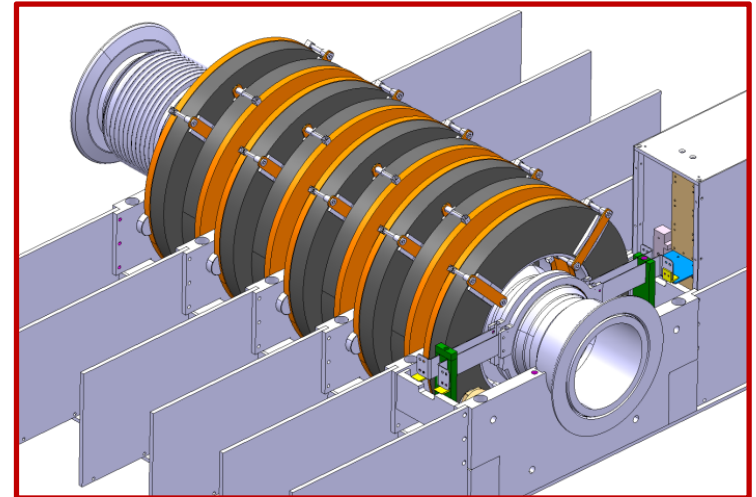


Booster main magnet undergoing tests for operation at 2 GeV

A. Newborough, M. Buzio



- Replacement of 2 RF systems per ring with Finemet® cavities-based system:
 - Development of a prototype system (collaboration with KEK-RF)
 - Prototype installed in the PSB during the winter stop 2011-2012
- Extensive renovation of the LL RF



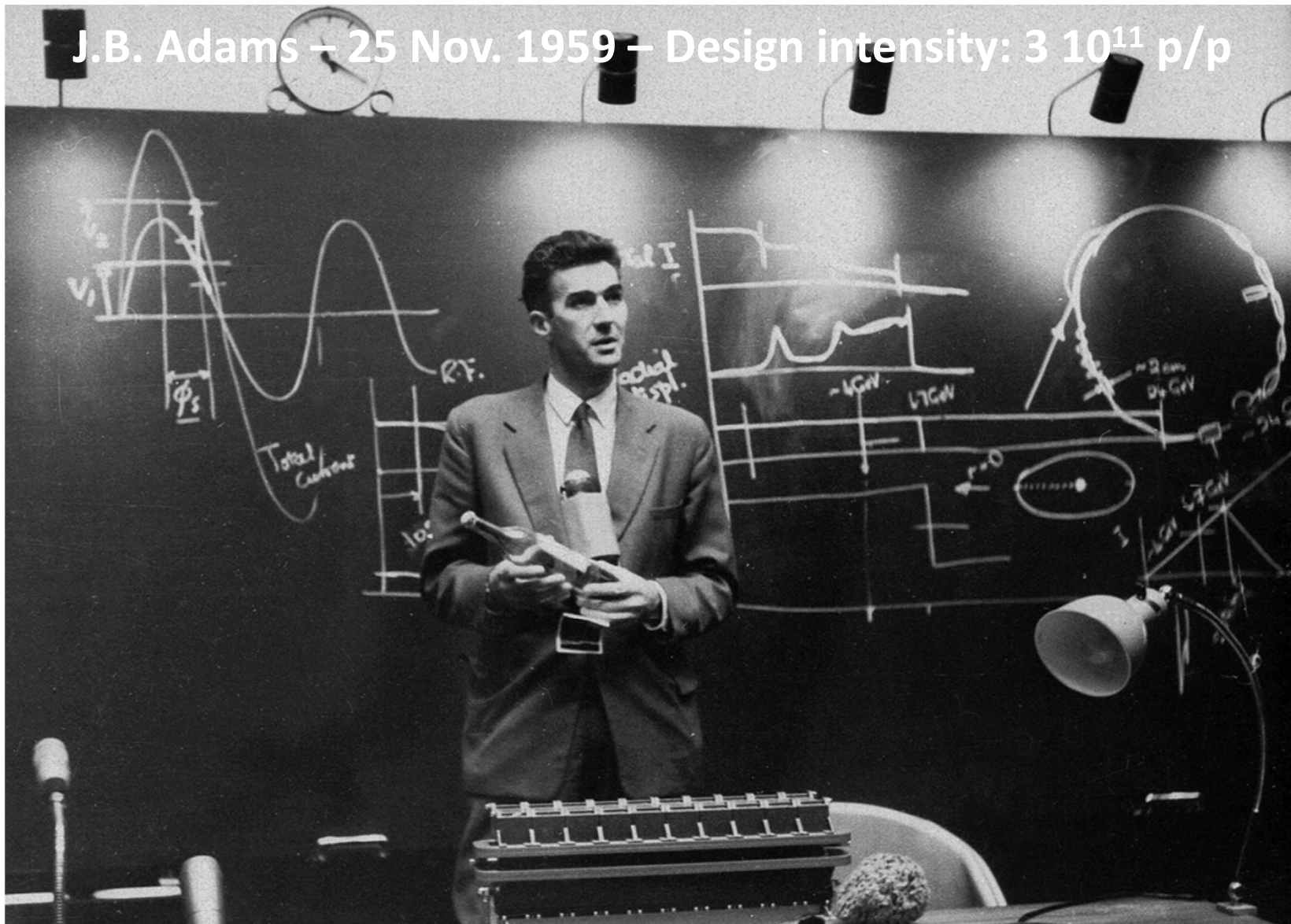
Prototype Finemet® cavity
Installed in the PSB

Poster THPPP011





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





J.B. Adams – 25 Nov. 1959 – Design intensity: $3 \cdot 10^{11}$ 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



J.B. Adams – 25 Nov. 1959 – Design intensity: $3 \cdot 10^{11}$ 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

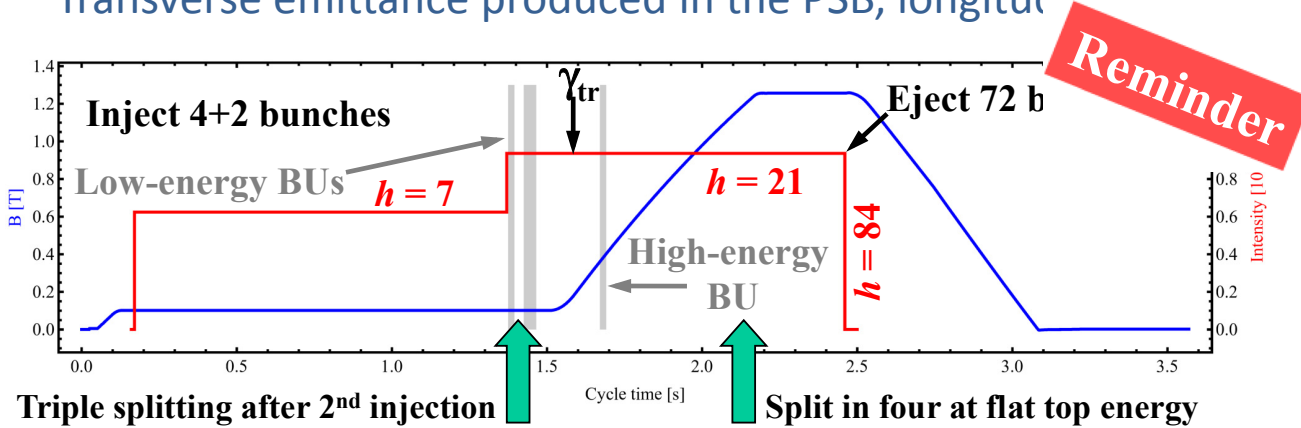
Radioprotection



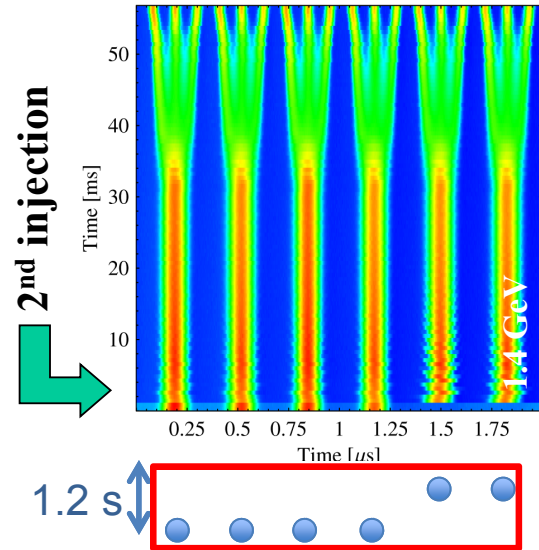
Generation of the beam time structure for LHC in the PS

Baseline: Double batch injection from PSB (4+2 bunches, 6 bunches for PS at h=7)

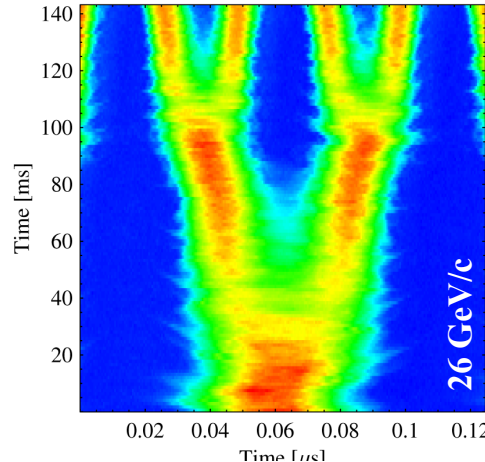
Transverse emittance produced in the PSB, longitudinal in the DC



Triple splitting after 2nd injection



Split in four at flat top energy

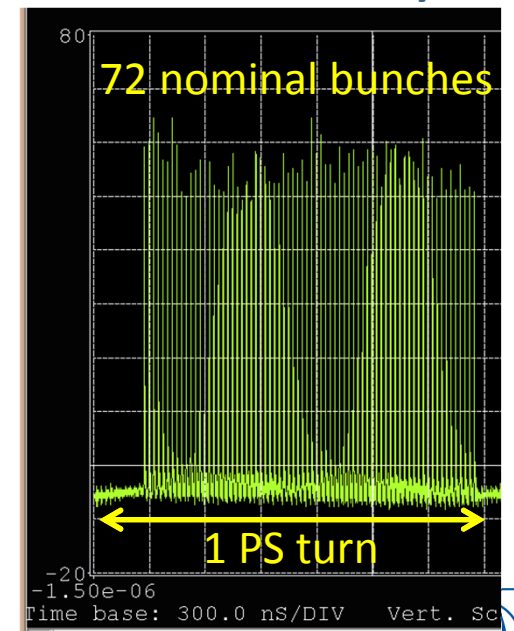


Each bunch from the PSB is divided by 12 → 6 x 3 x 2 x 2

RF gymnastics in the PS:

- Triple splitting
- Acceleration
- Double splitting
- Double splitting
- Bunch rotation

With 5 different RF systems



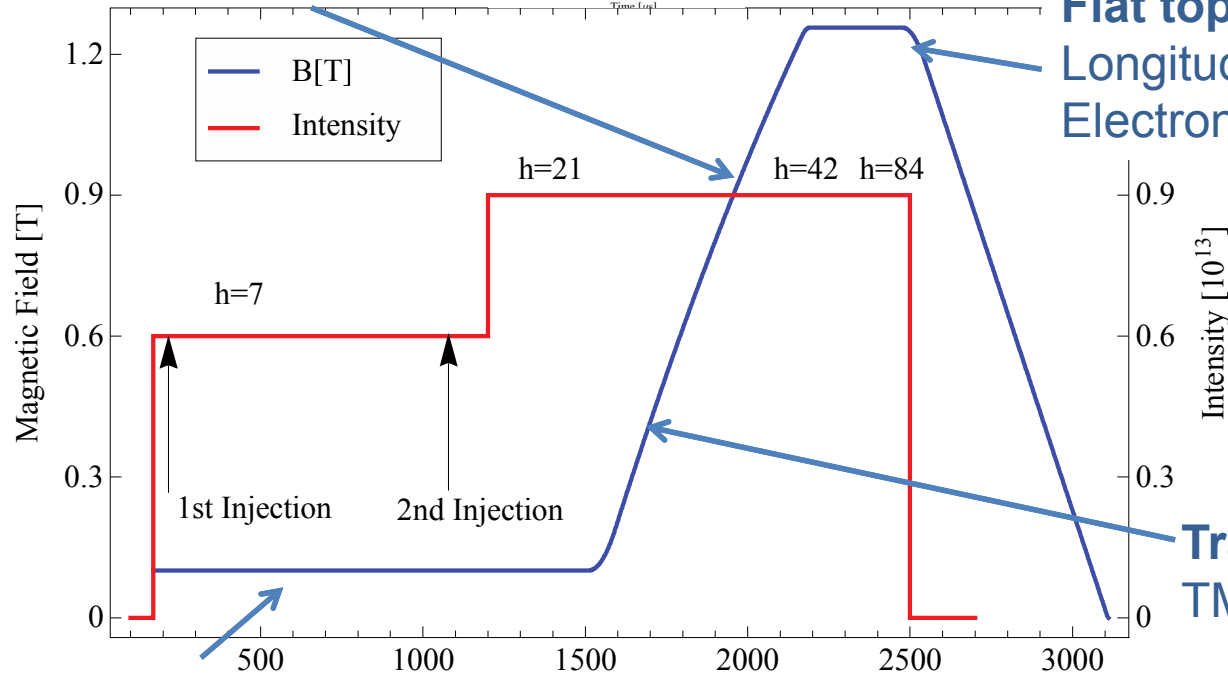
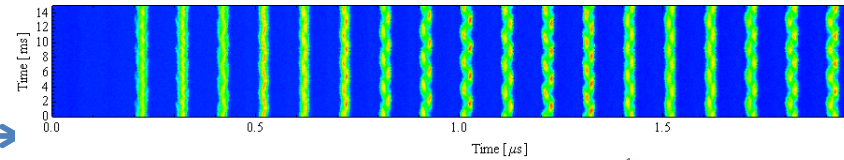
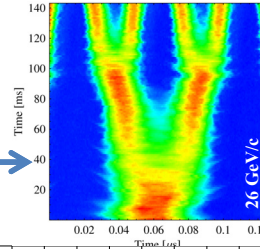


Known limitations of the PS

Acceleration/Bunch splittings

Longitudinal beam stability

Transient beam loading



Flat top:

Longitudinal beam stability
Electron cloud

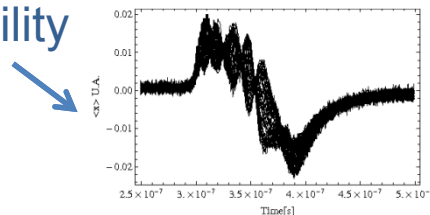
Talk THYB03

Transition crossing:
TMCI

Injection Transverse flat bottom:

Transverse emittance blow-up due to space charge if beam density too high

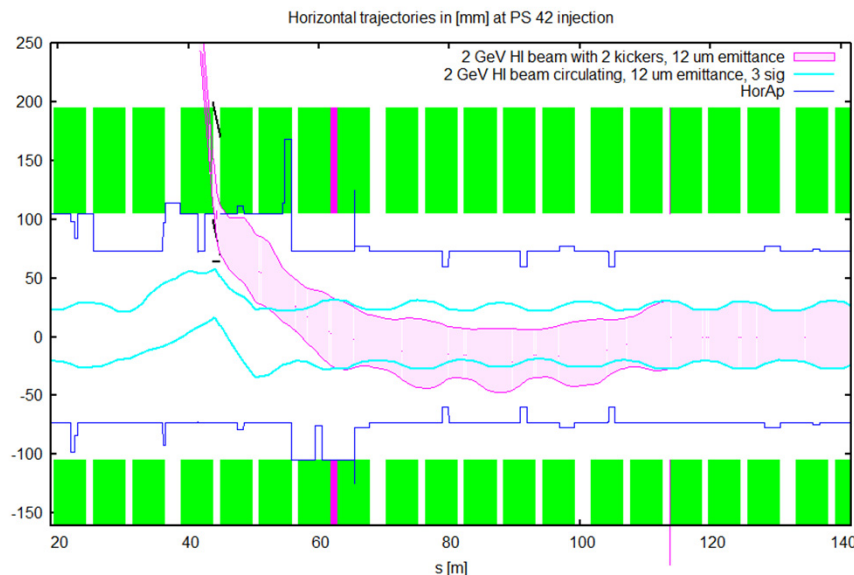
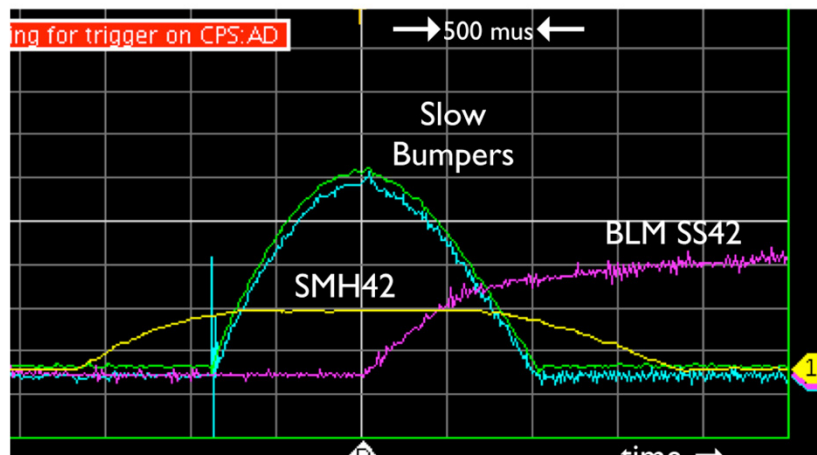
Headtail instability





PS injection at 2 GeV

- LHC beam injected using new septum and existing kicker + new kicker to improve operational margin
- High Intensity beams injected using new septum, existing+new kicker
- 5 bumper forming slow bump: rapidity of the slow bump will be increased to reduce losses during the bump collapsing
- **Injection optics different for LHC and non-LHC beams:**
 - LHC: optimize space-charge → Study ongoing
 - non-LHC: optimize losses → First solution found



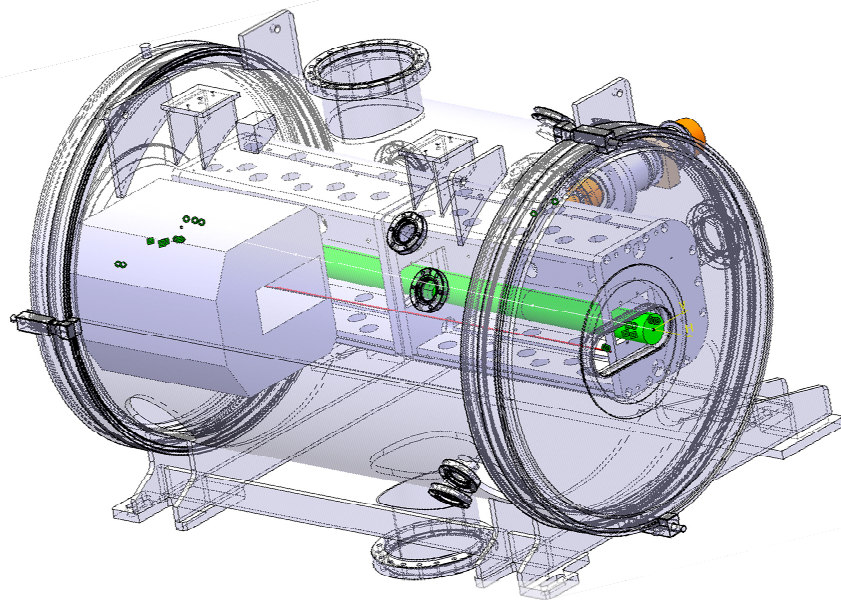


PS Injection septum 42

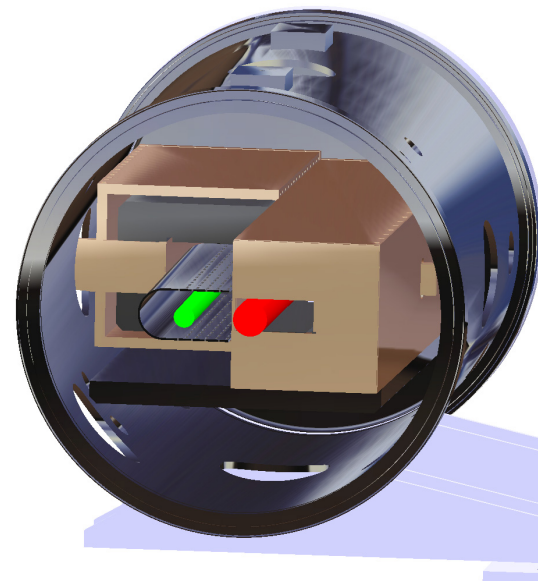
R&D required:

- Less experience at CERN with eddy current devices, but possibly more robust (R&D required).
- Bumper included in vacuum vessel: issue of field tracking wrt other bumpers.

	1.4 GeV	2 GeV
B_{gap} (T)	0.7	0.7
I_{nominal} (kA)	33.5	33.6
Physical length (mm)	620	790



«Direct drive» device

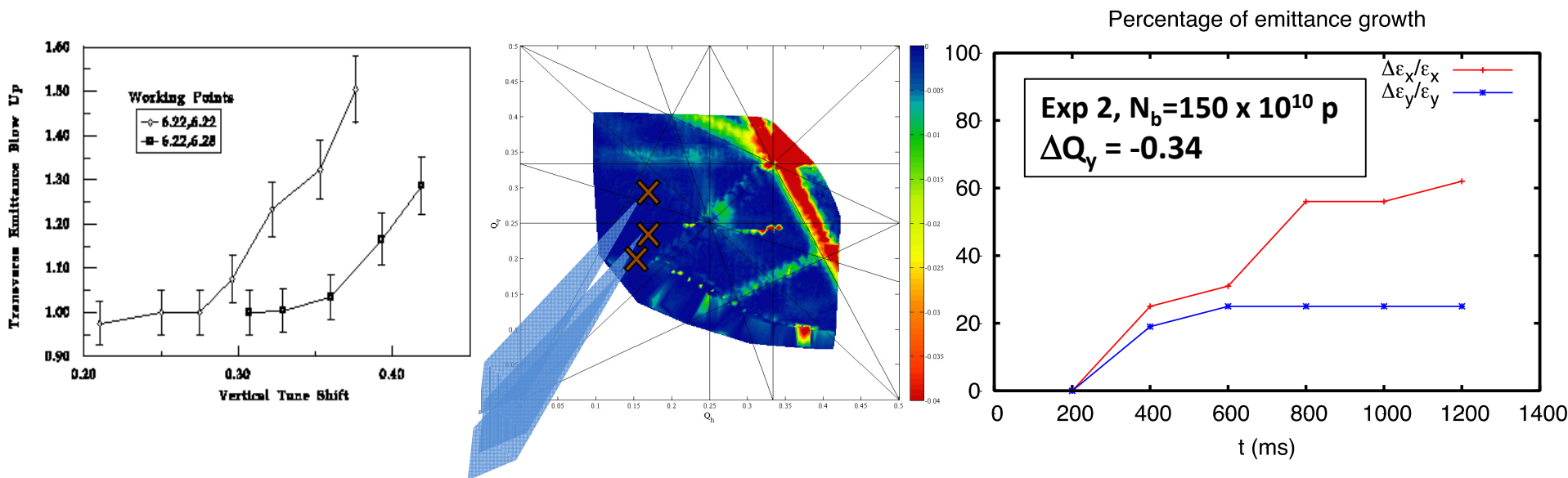


«Eddy current» device



Past measurements have shown that:

- $\Delta Q \sim -0.3$ could be accepted, *if correct working point is chosen* (left, Capii -1997)
- There are dangerous resonances (center – 2011)
- Blow-up of transverse emittance takes time, depending on ΔQ (right, 2010)



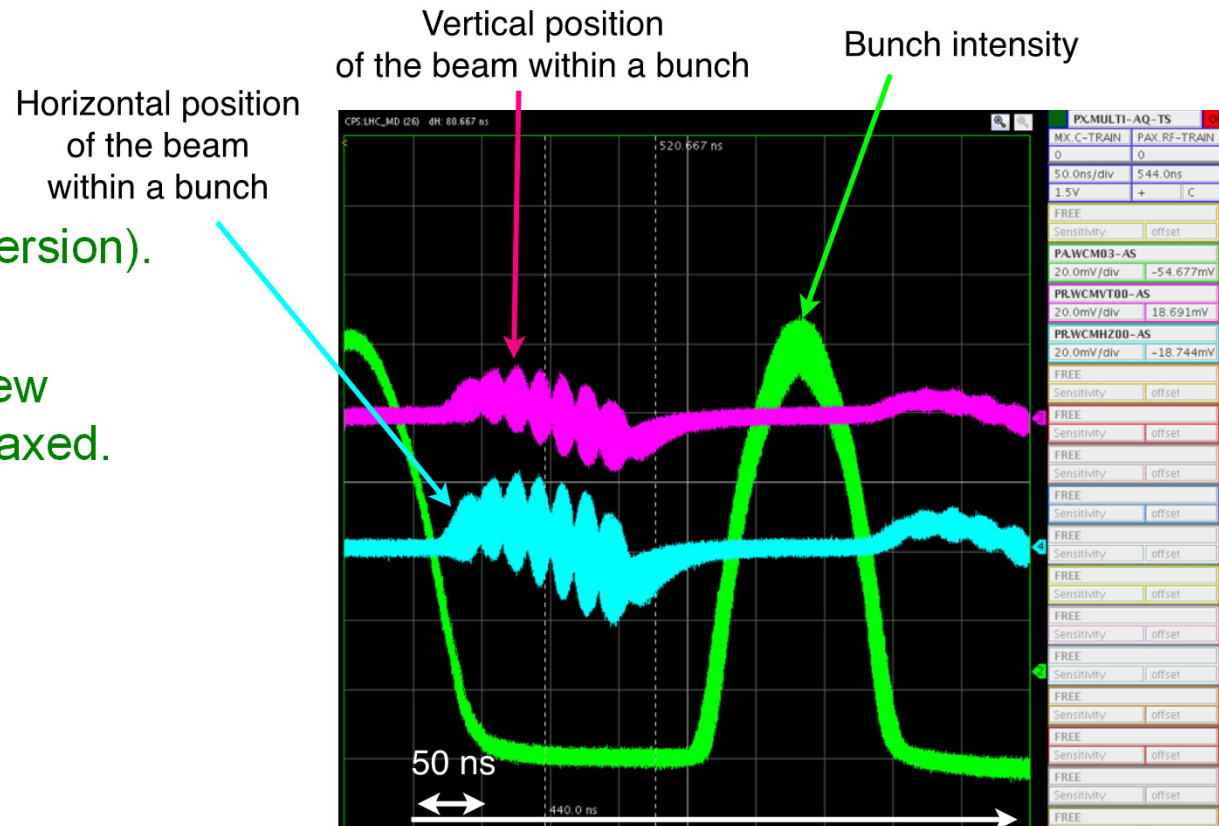
Outstanding questions for MDs and simulations (PTC-Orbit):

- With large ΔQ , a large part of the beam is below the integer resonance: Are we correctly estimating/overestimating ΔQ ?
- Growth rate of transverse emittance (duration, ΔQ , initial emittance ...)
- Can we compensate resonances to increase maximum ΔQ ?

Talk THYB03

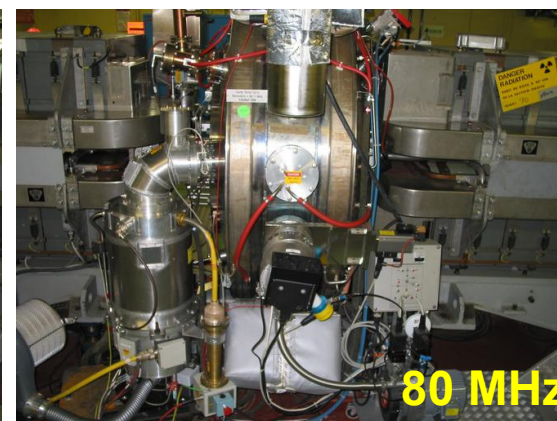
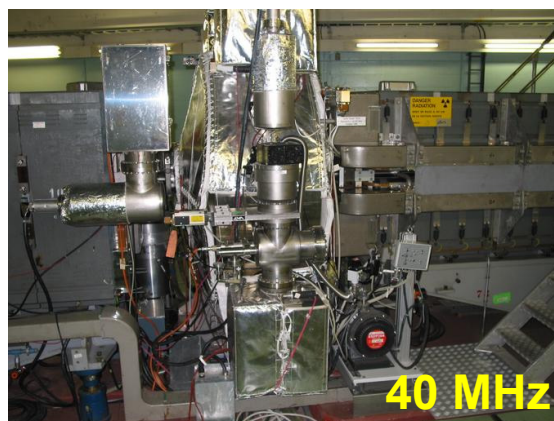
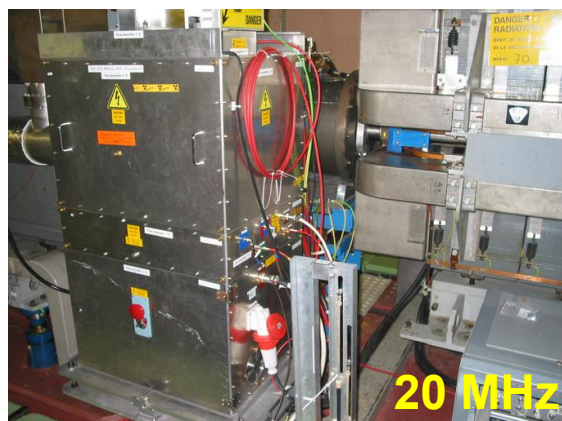
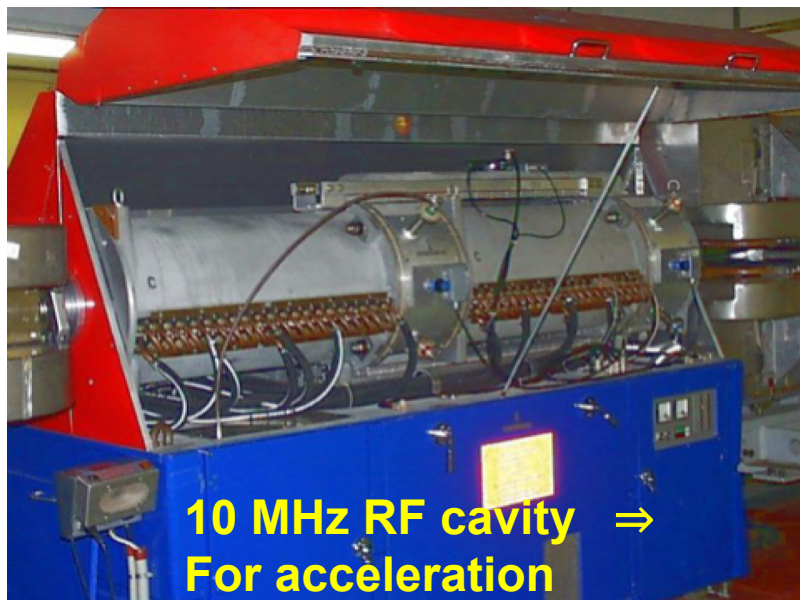
Headtail instability observed on injection flat bottom:

- Today cured by introducing linear coupling. In the future trying to lower headtail mode by controlling chromaticity and use a transverse damper.
 - Commissioning of transverse damper delayed to 2012 (intermediate hardware version).
 - If positive, demand on skew quadrupoles could be relaxed.
-
- Vertical position of the beam within a bunch
- Bunch intensity
- Horizontal position of the beam within a bunch





Five different RF systems are involved in the beam gymnastics for LHC



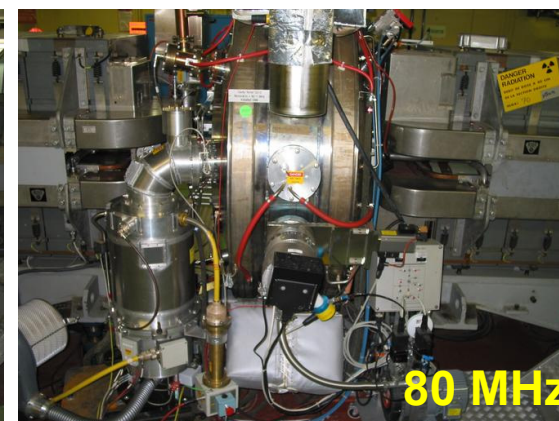
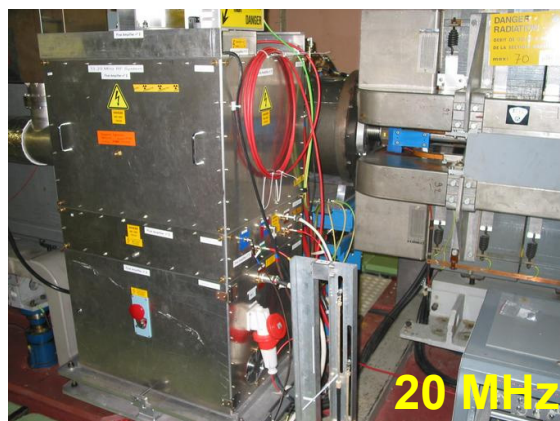


Five different RF systems are involved in the beam gymnastics for LHC

Planned improvements for reducing transient beam loading and increasing the threshold of Coupled Bunch Instabilities (CBI):

Poster WEPPR061

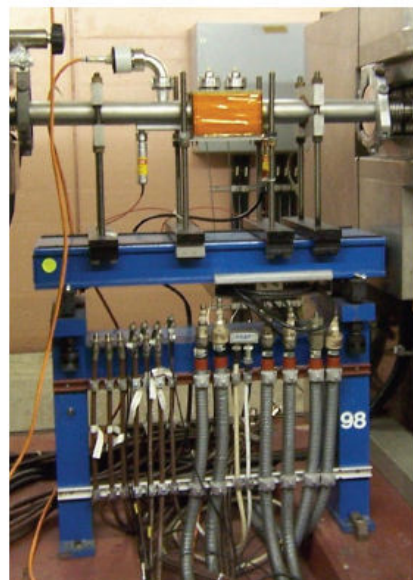
- Increased open loop gain of fast RF feedbacks
- Installation of 1-turn delay feedback on all non-equipped systems
- Installation of a wide band feedback system against coupled bunch instabilities using a dedicated Finemet® cavity.



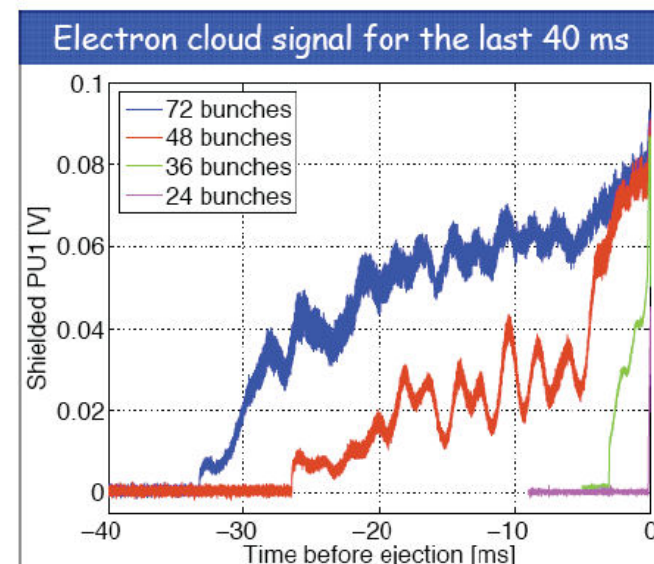
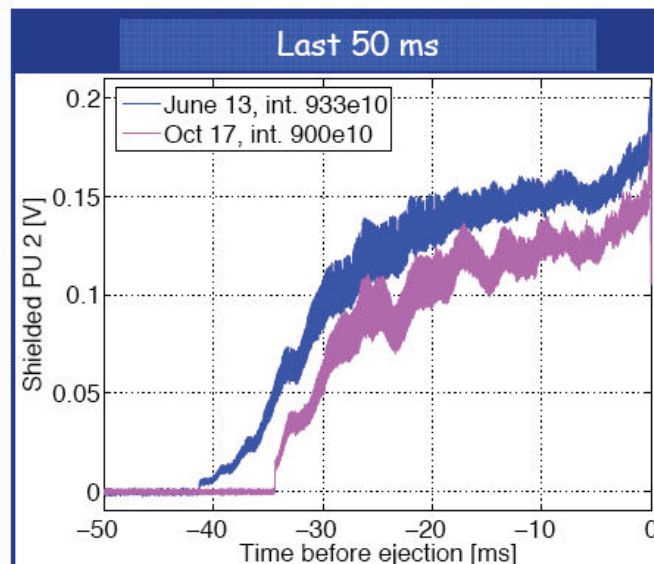


Electron clouds deserve attention:

- Observed in the PS since a decade without obvious detrimental effect to the present type of beam but applying constraints on the RF gymnastics before ejection.
- However, horizontal transverse instabilities have already been seen in 2001, 2004 and 2006...
- What will the situation be like with the HL-LHC types of beams?



(F. Caspers, T. Kroyer, E. Mahner)

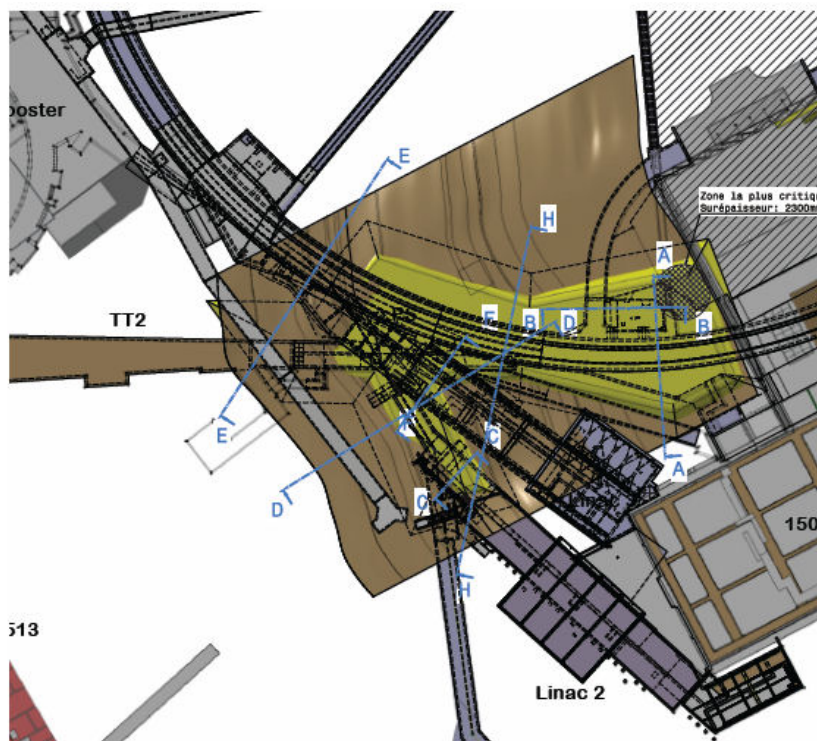


⇒ specific action may be required (aC coating of vacuum chamber of wide band transverse feedback)

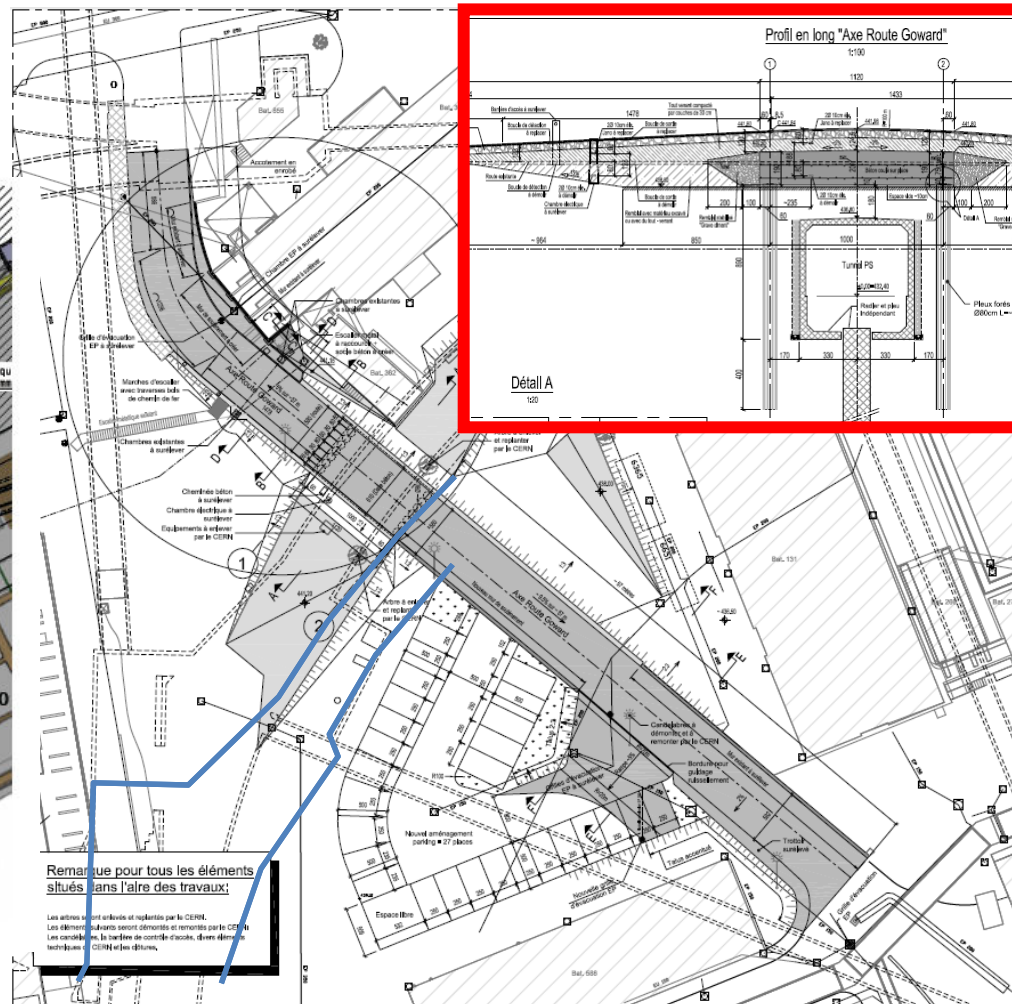


Work planned during LS1 (2013)

Above ejection region (Septum 16)



Above injection region (Road Goward)



Remarque pour tous les éléments situés dans l'aire des travaux:

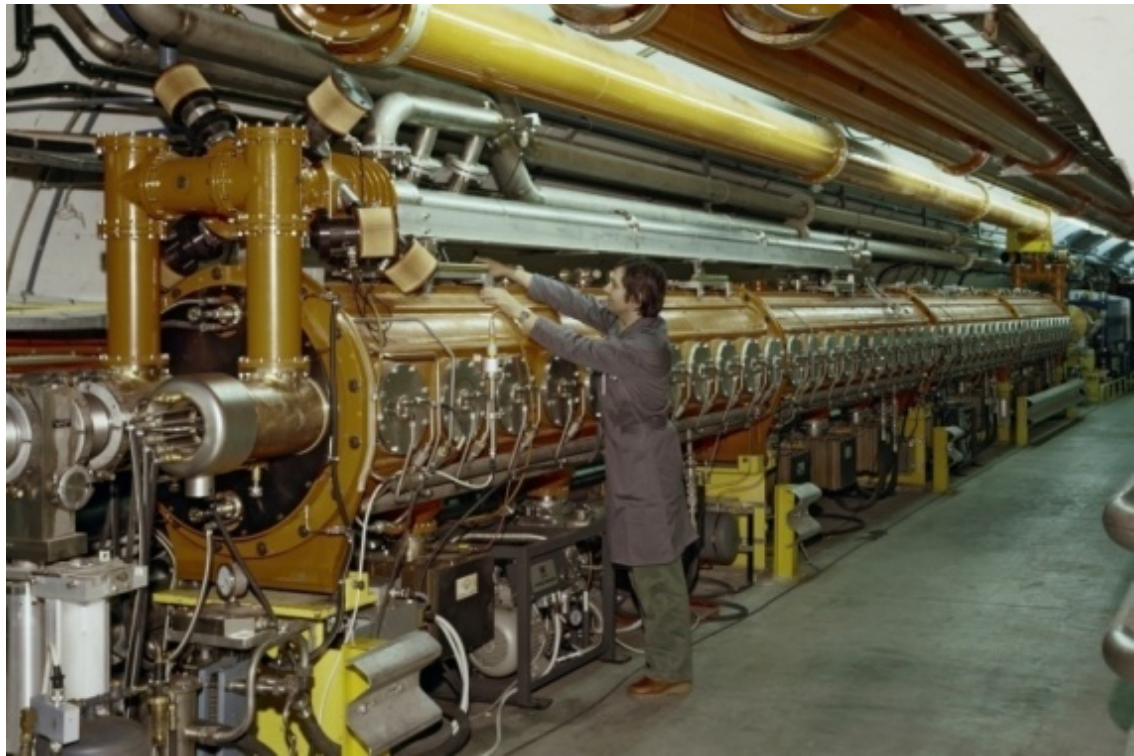
Les éléments seront retirés et remplacés par le CERN. Les éléments suivants seront démontés et remplacés par le CERN. Les conditions, la portée de contrôle d'accès, divers éléments techniques CERN et les autres.



200 MHz Travelling Wave Accelerating Structures

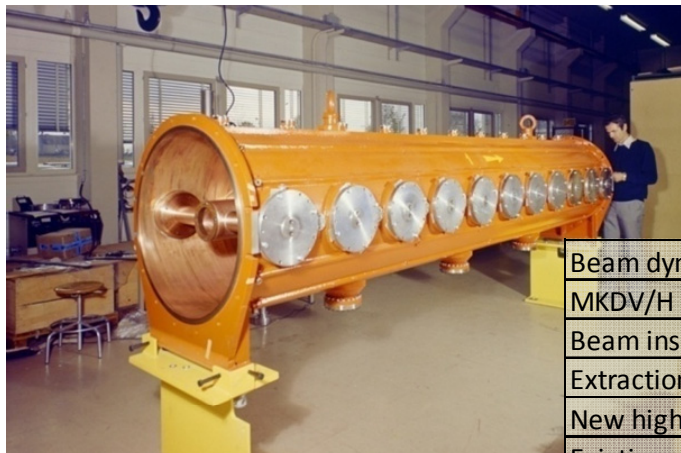


One four sections cavity
(four power couplers and two terminating power loads)





200 MHz Travelling Wave Accelerating Structures



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

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)

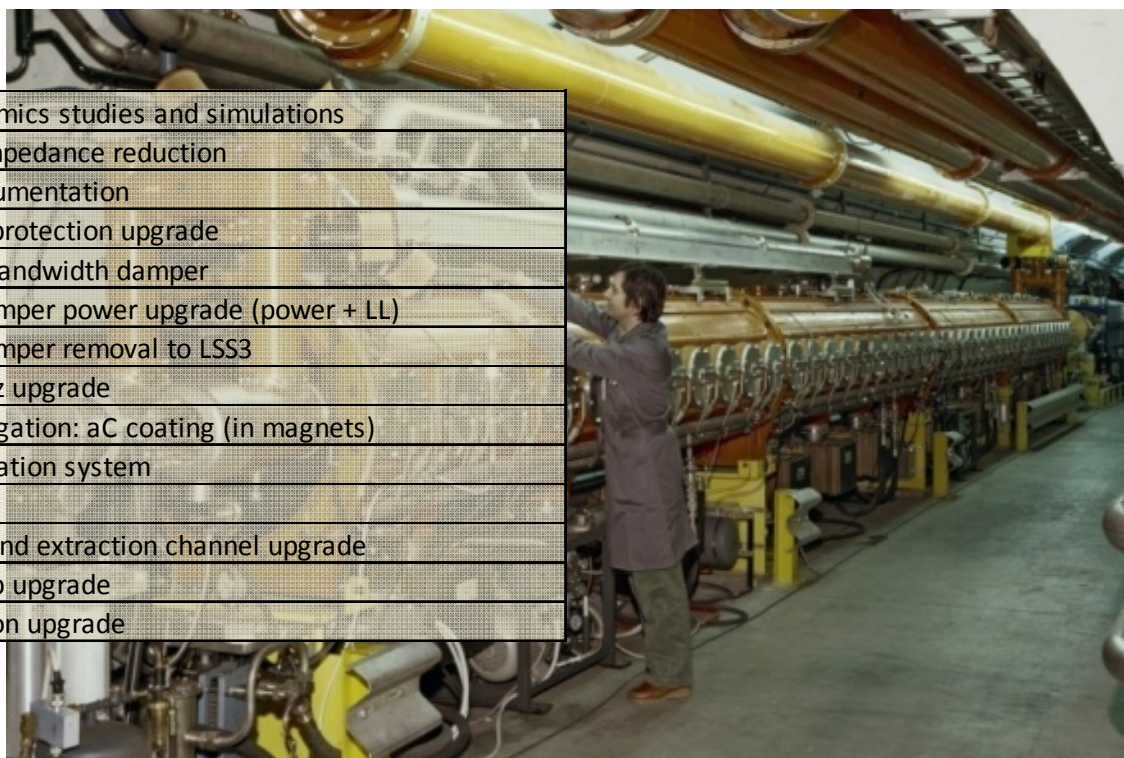
New collimation system

STI

New MKE and extraction channel upgrade

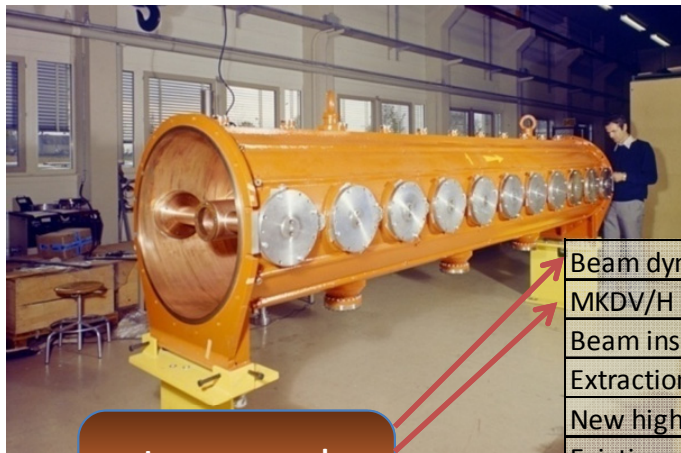
Beam dump upgrade

TL protection upgrade

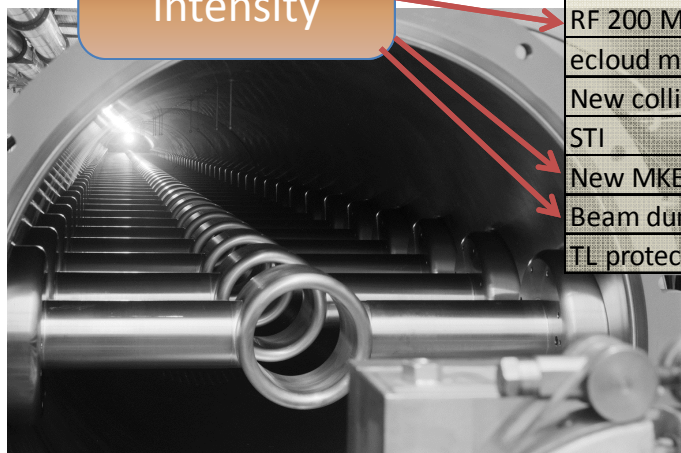




200 MHz Travelling Wave Accelerating Structures



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

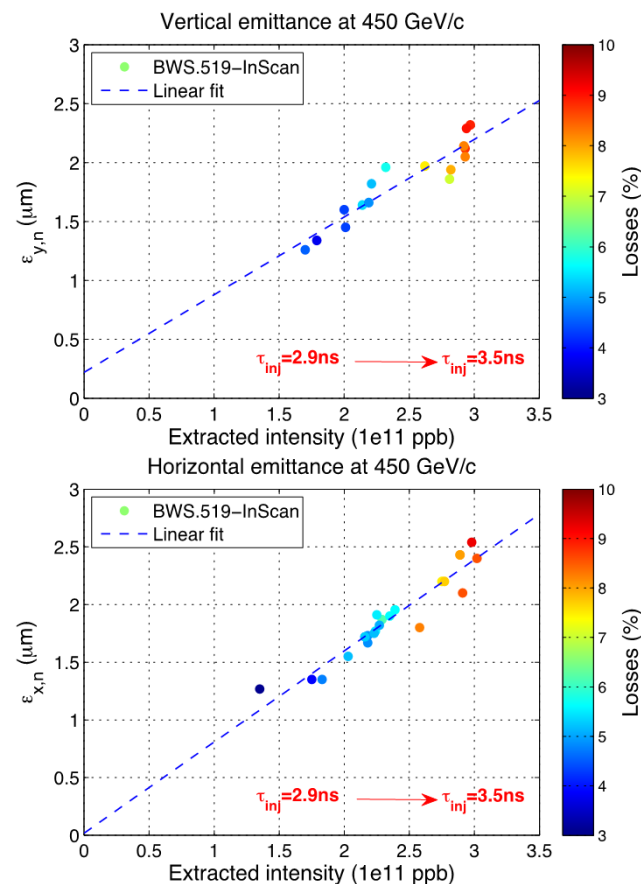
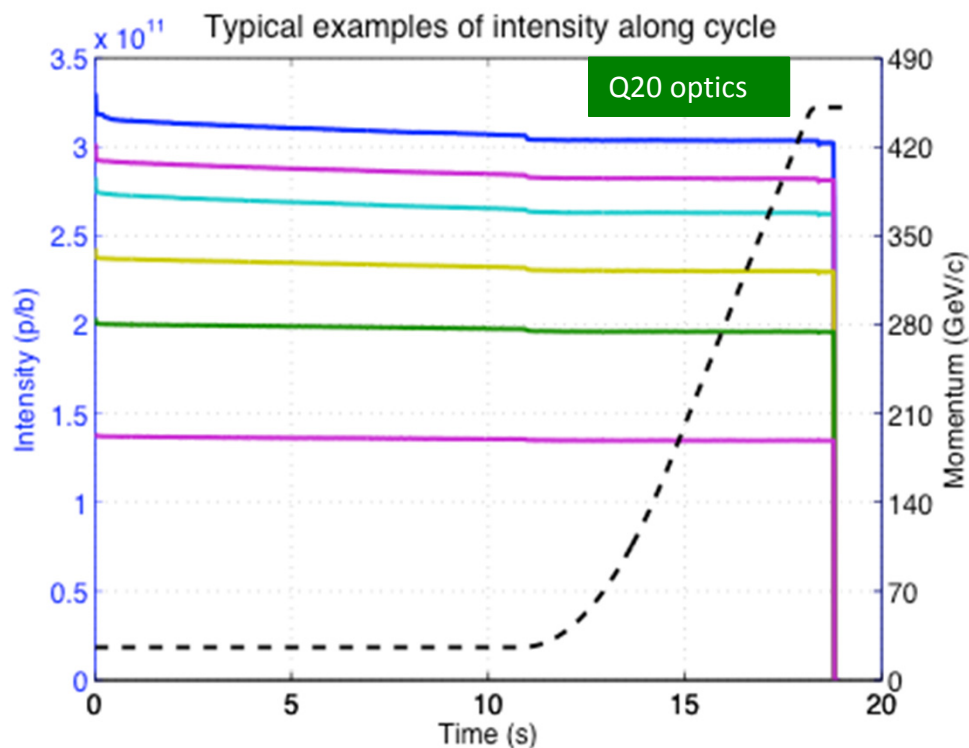


- **Single bunch**
 - TMCI (transverse mode coupling instability)
 - loss of Landau damping
 - space charge
 - longitudinal instability
- High (twice ultimate) intensities, nominal and small transverse emittances, $\gamma_t=22.8$ (Q26) and $\gamma_t=18$ (Q20) optics
- **Multi-bunch**
 - e-cloud
 - beam loss (many reasons)
 - longitudinal coupled bunch instabilities
 - beam loading in the 200 MHz and 800 MHz RF systems
 - heating and outgassing of machine elements, septum (ZS) sparking
- Nominal 25, 50, 75, (150) ns spaced LHC beam,
Ultimate (injected) 25&50 ns spaced beam



Q20: single bunch results

- Instability threshold for TMCI with low chromaticity in **nominal optics: $1.6 \cdot 10^{11}$ p/b**
 - Threshold intensity scales like $N_{th} \sim \eta/\beta_y$ (higher η means lower γ_t)
 - **SPS Q20 optics** with lower transition energy increases the single bunch instability threshold **above $3.5 \cdot 10^{11}$ p/b with low chromaticity**
- => Demonstrated with successful acceleration of single bunches with intensities up to **$3.3 \cdot 10^{11}$ p/b with low chromaticity and small transverse emittances**

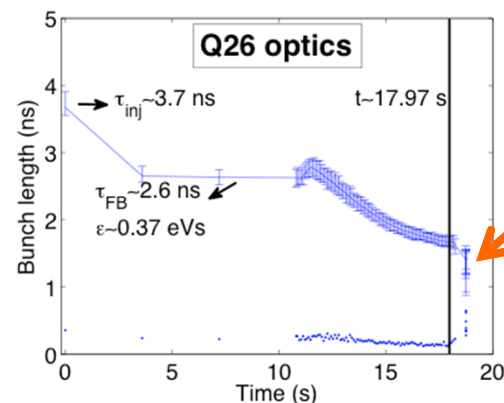
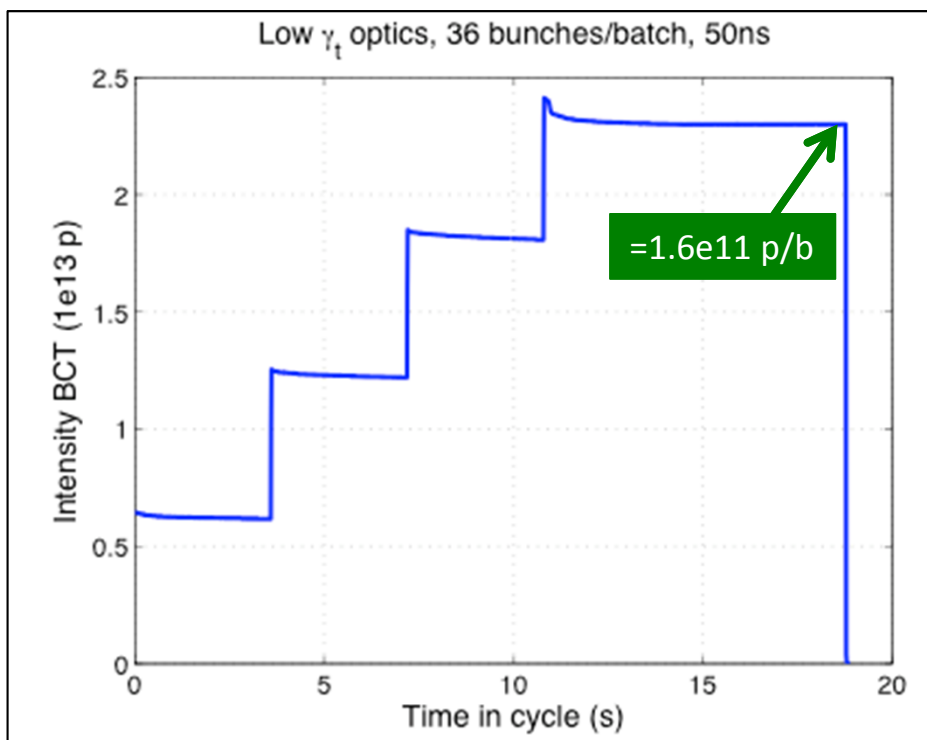




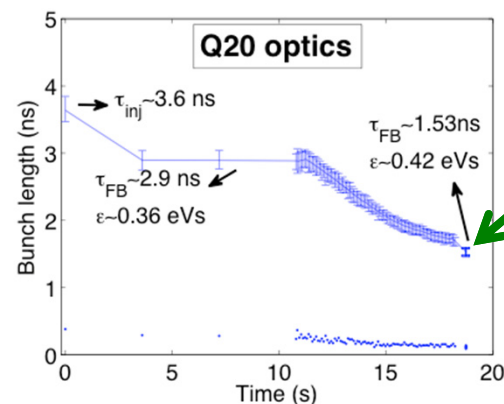
Q20: results with 50ns LHC bunch trains

- Successful acceleration of 4 batches with intensities up to $1.6 \cdot 10^{11}$ p/b on flat top
- Higher slip factor η with Q20 => more stability also in longitudinal phase plane

=> Demonstrated by **no need for longitudinal emittance blow-up to preserve stability in Q20 cycle** [while longitudinal controlled blow-up is required for beam stability with nominal optics (threshold decreases with energy $\rightarrow$ instability in high energy part of cycle)].



Bunches become unstable for high energy $\rightarrow$ increased spread in bunch length



Bunches remain stable up to flat top – bunch length compatible with LHC bucket length



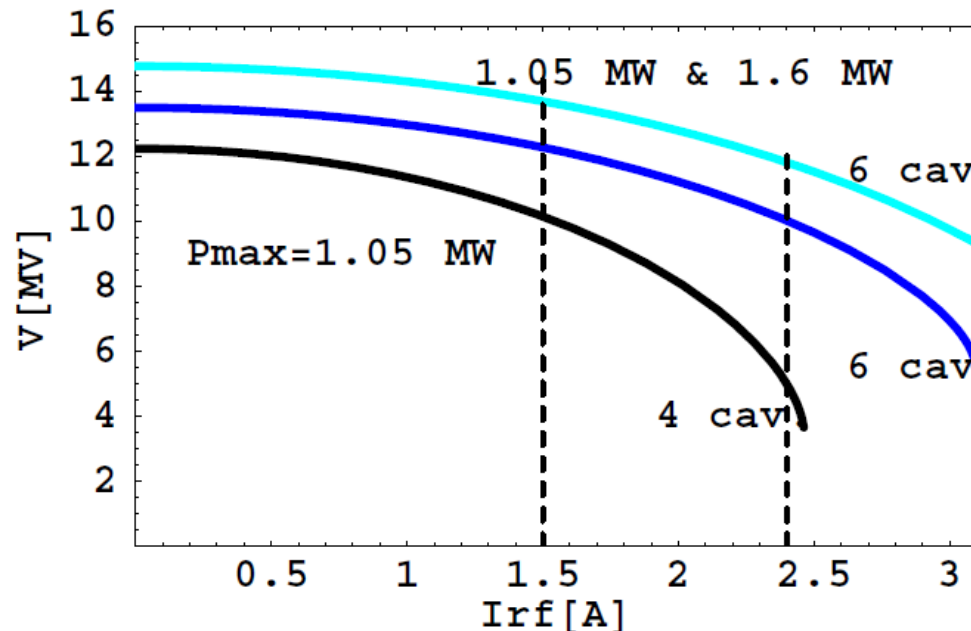
SPS 200 MHz: x2 power, 4→6 (shorter) cavities, -20% impedance

- Upgrade of existing power plants in pulsed mode (0.75→1.05 MW)
- Addition of 2 additional 1.7 MW amplifiers (2 x 1.4 MW for the cavities)
- Will allow getting 10 MV at extraction for 3 A RF current (now 1.5 A)

After upgrade: same voltage available as now (if pulsed) for

$2.3 \cdot 10^{11}$ p/b (25 ns) and $4.6 \cdot 10^{11}$ p/b (50 ns):

- With larger emittance more V_{RF} needed for same bunch length
- Will anyway have 10% longer bunches for 2x nominal I, with 10 MV

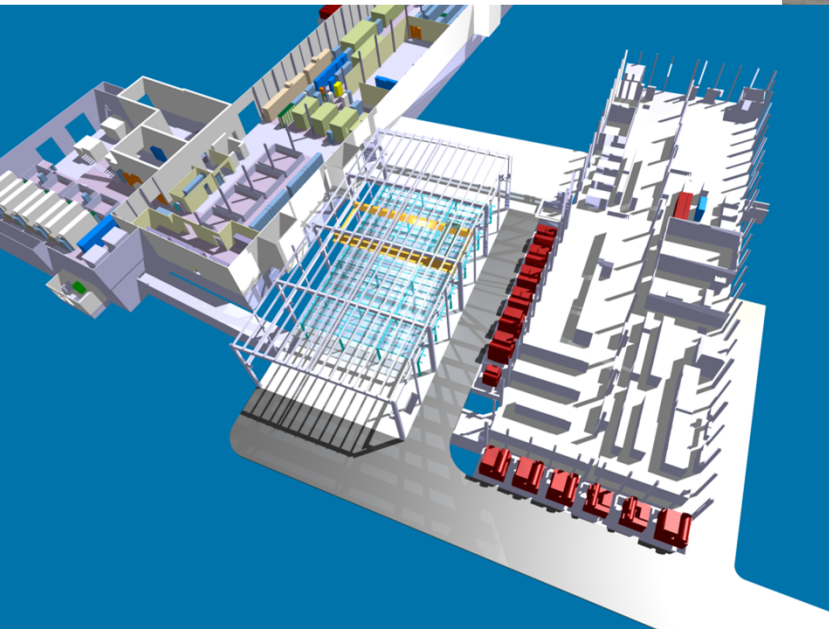




RF 200 MHz reorganisation

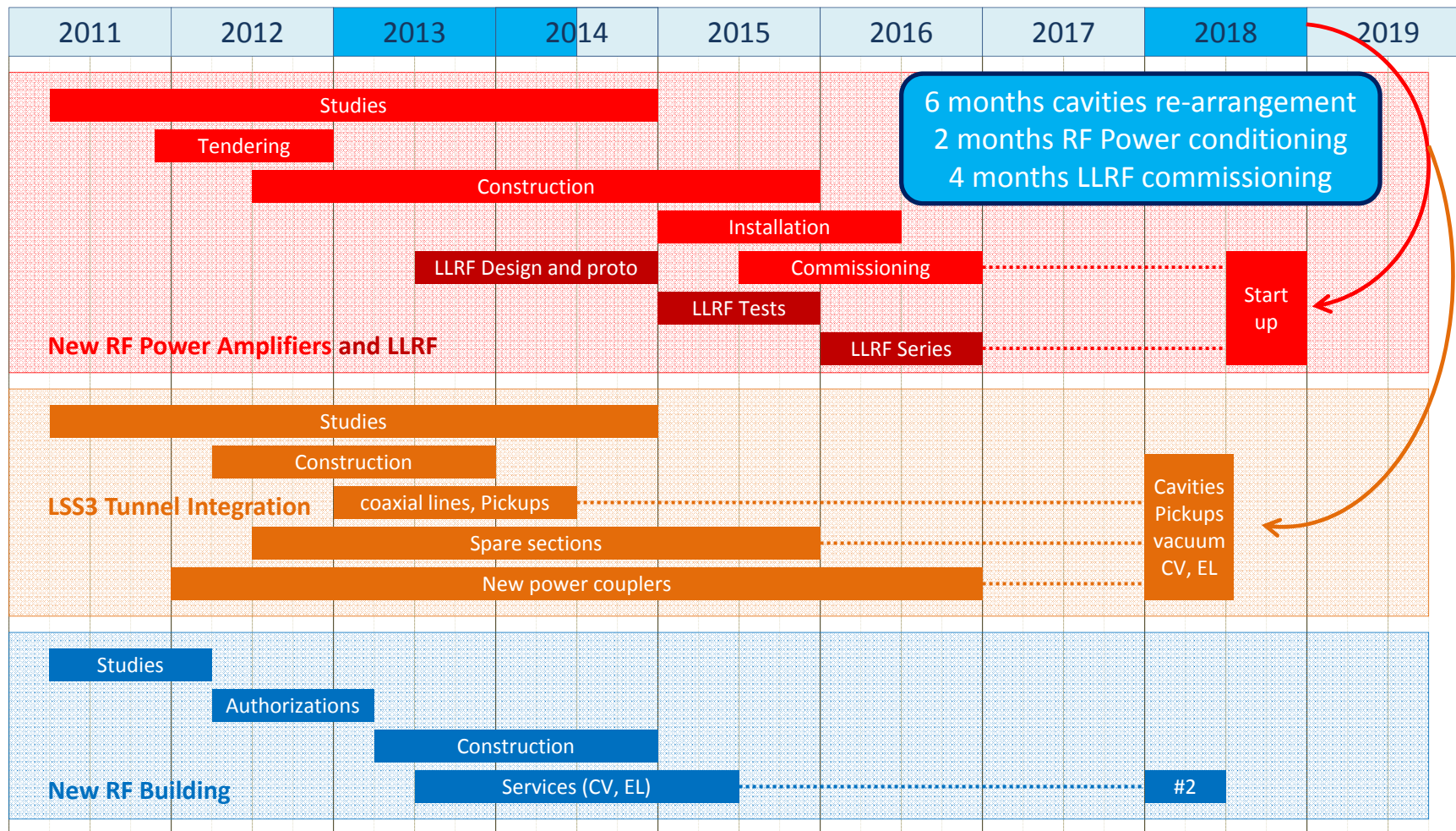
Increase power to 6 MW into 6 shorter cavities (from present 4) to reach 10 MV at ultimate intensity

- Needed for longitudinal stability (increase emittance from 0.6 eVs)
- Reduces impedance by 20%
- Big job: new BC3 building, new LSS3 layout, 26.5 MCHF over 7 years





Schedule

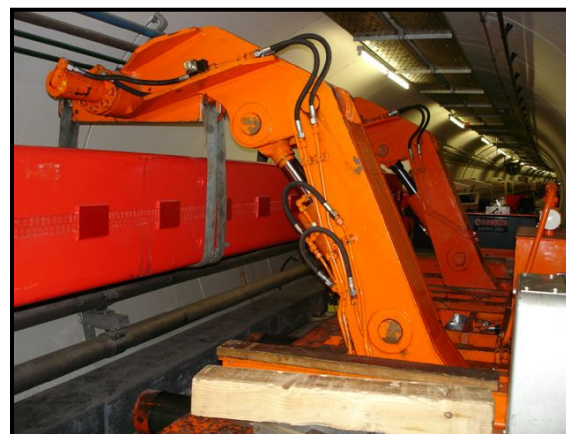
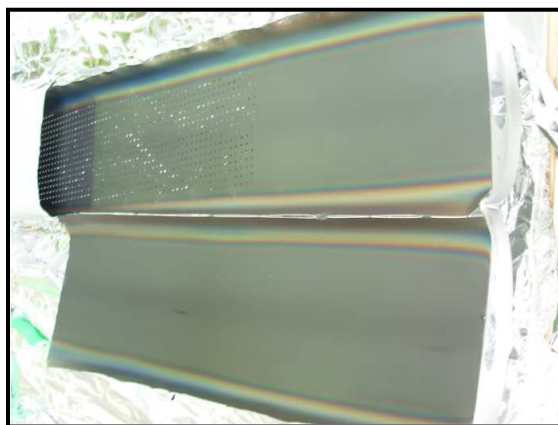
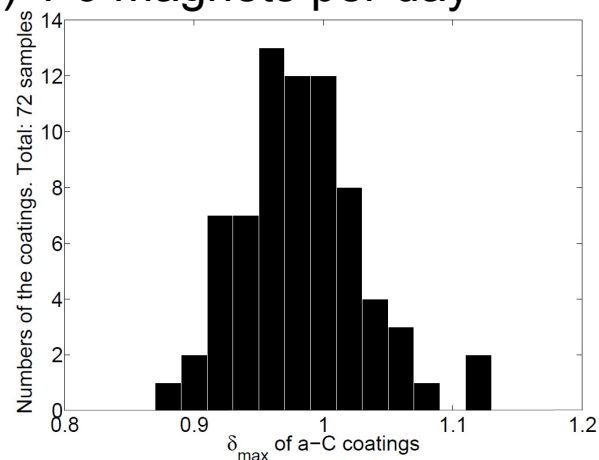
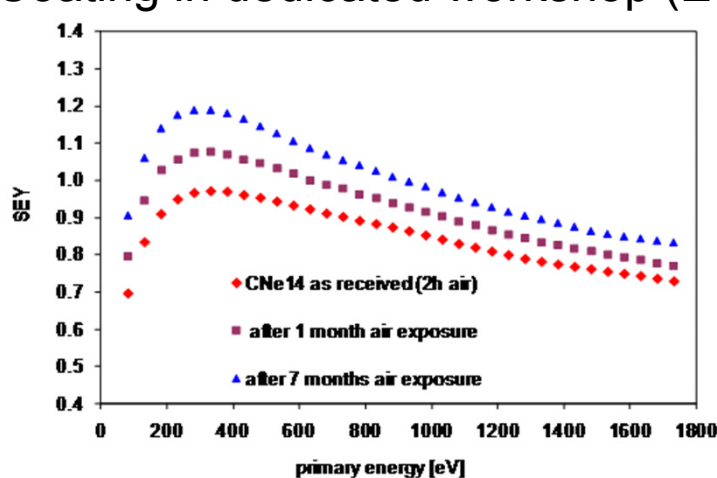




HC sputtering to deposit amorphous carbon (aC) layer

- Large reduction of SEY below ecloud threshold
- Coating in dedicated workshop (ECX5) 4-6 magnets per day

Poster MOPPC009





Ecloud mitigation with wide band feedback (1/2)



SPS Ecloud/TMCI Instability R&D Effort

- Motivation - control Ecloud and TMCI effects in SPS and LHC via GHz bandwidth feedback
- Ongoing project SLAC/LBL/CERN via US LARP
- Proton Machines, Ecloud driven instability - impacts SPS as high-current LHC injector
 - Photoelectrons from synchrotron radiation - attracted to positive beam
 - Single bunch effect - head-tail (two stream) instability
- TMCI - Instability from degenerate transverse mode coupling - may impact high current SPS role as LHC injector
- Multi-lab effort - coordination on
 - Non-linear Simulation codes (LBL - CERN - SLAC)
 - Dynamics models/feedback models (SLAC - LBL-CERN-Stanford STAR lab)
 - Machine measurements- SPS MD (CERN - SLAC - LBL)
 - Hardware technology development (SLAC)

Posters

MOEPPB015

WEPPP074

WEPPP076

WEPPP079

WEPPP080

WEPPR090





Ecloud mitigation with wide band feedback (2/2)



Boundary conditions:

LS1: 2012
LS2: 2017+

Phase 1: The demonstrator → end 2012

minimum goal: damp head tail motion of single bunch

existing equipment (amplifiers, BPWs as kicker and PU)
electronics (LARP), close FB loop

all design specifications for phase 2: end of 2012

Phase 2: New pick-up, new kicker, consolidated electronics,
higher power amplifiers,
preparation of LSS3 in LS1 for installation of equipment
at the end of LS1 or later in a short winter shutdown post-LS1
feedback on multi-bunch beam in presence of e-cloud
decide on final implementation and LSS3 vs. LSS5 before LS2

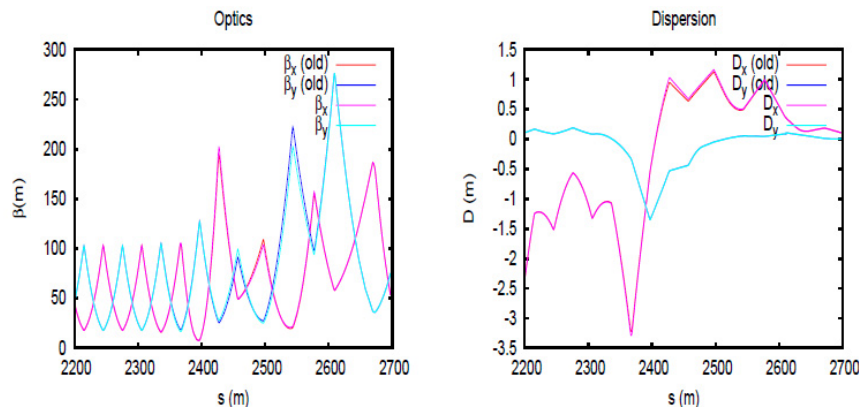




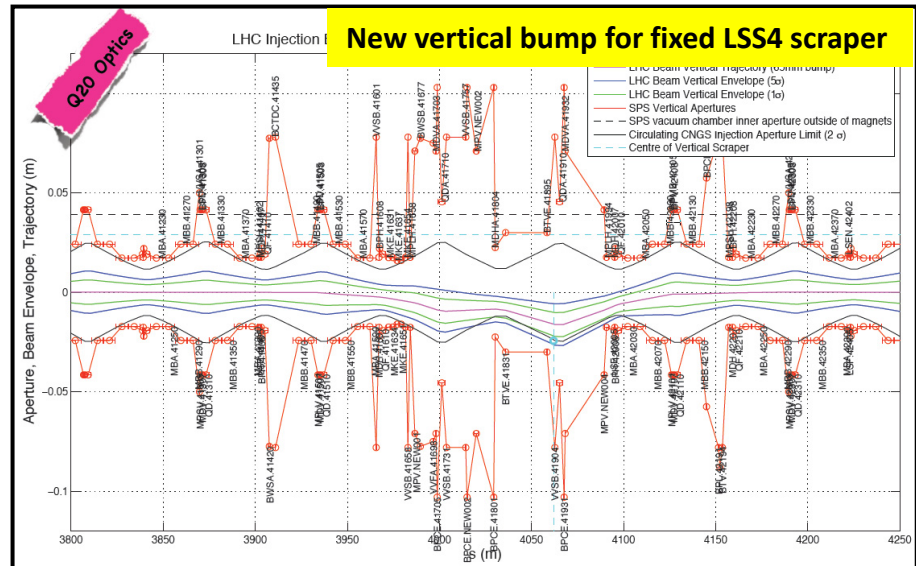
Other ongoing studies

- **Scrapper with magnetic bump**
 - ✓ LSS4, using extraction bumpers
- **New TI2/TI8 TCDI designs**
 - ✓ New locations for LHC injection
 - ✓ Updated collimator design
- **Open core MKE**
 - ✓ Beam in kicker for 100 ms at flat top

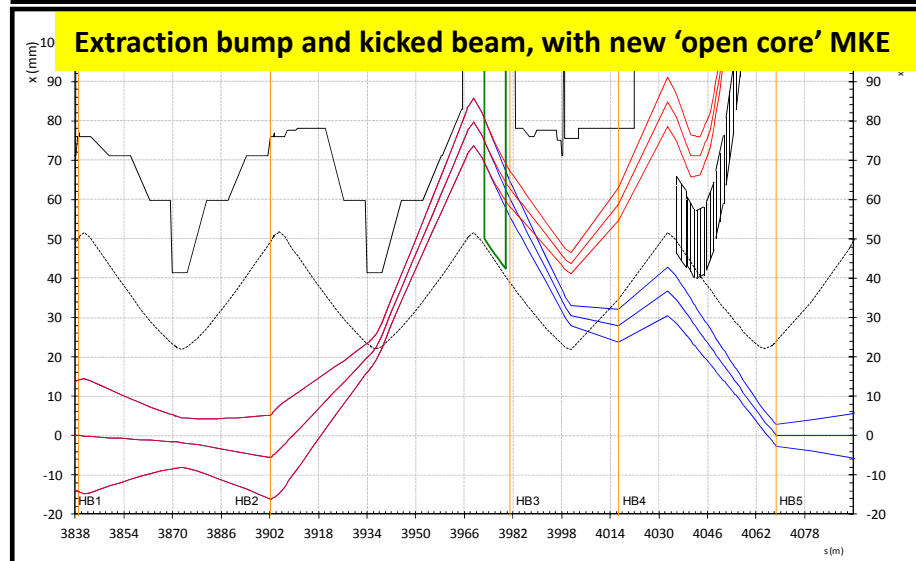
TI 8 optics rematched for new TCDI locations



New vertical bump for fixed LSS4 scrapper



Extraction bump and kicked beam, with new 'open core' MKE





UPGRADE PLANS FOR THE LHC INJECTOR COMPLEX



- Setting the scene
- The LIU project
- Action plan
- **Beam characteristics**
- Planning





- LIU beam characteristics are given at injection in LHC

- Estimated beam degradation in the accelerators (based on observations in 2010 and 2011):
 - ✓ PS: 5 % beam loss, 5 % transverse blow-up
 - ✓ SPS: 10 % beam loss, 10 % transverse blow-up
 - ✓ LHC: 0 % beam loss, 10 % transverse blow-up

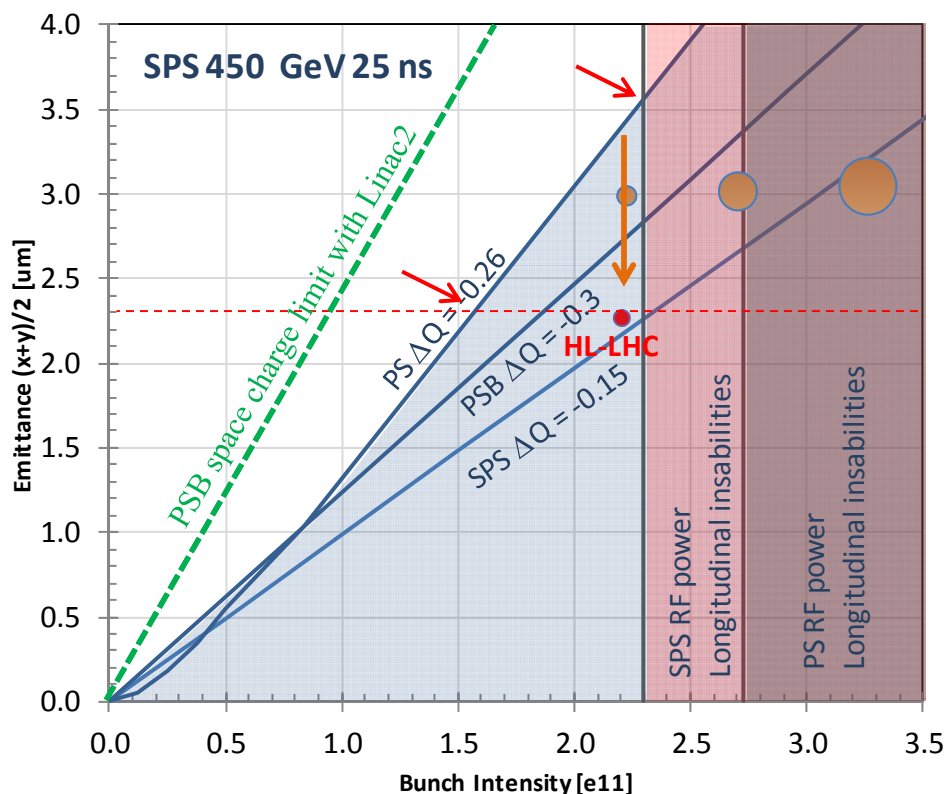
- Multiple RF gymnastics $\Rightarrow$ imperfections:
 - ✓ ± 10 % fluctuation of bunch characteristics within a given PS bunch train.
 - ✓ Unavoidable presence of ghost/satellite bunches.



Potential beam characteristics after LS2 with 25 ns

Performance after LIU: $2.3 \cdot 10^{11}$ p/b in 3.6 mm.mrad at SPS extraction
to be compared with

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



Batch compression
might also bridge
the gap (but with
10% less bunches)...

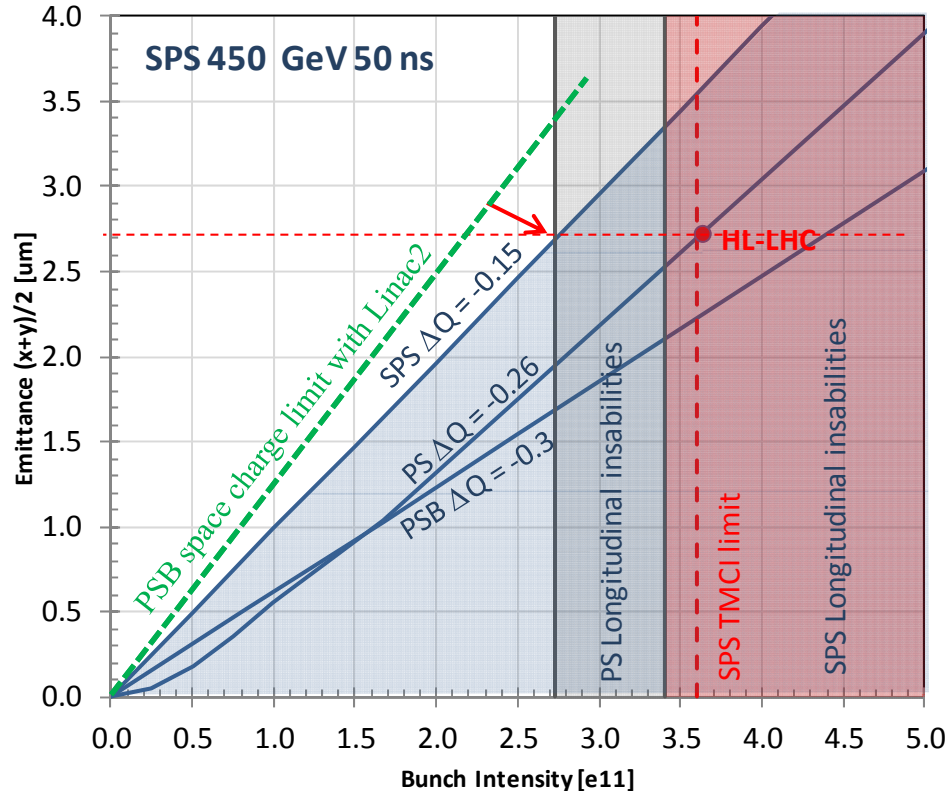
⇒ **Limited by space charge in the PS**



Potential beam characteristics after LS2 with 50 ns

Performance after LIU: $2.7 \cdot 10^{11}$ p/b in 2.7 mm.mrad at SPS extraction
to be compared with

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



$\Rightarrow$ Limited by longitudinal instabilities in the PS and SPS,
and by brightness in SPS

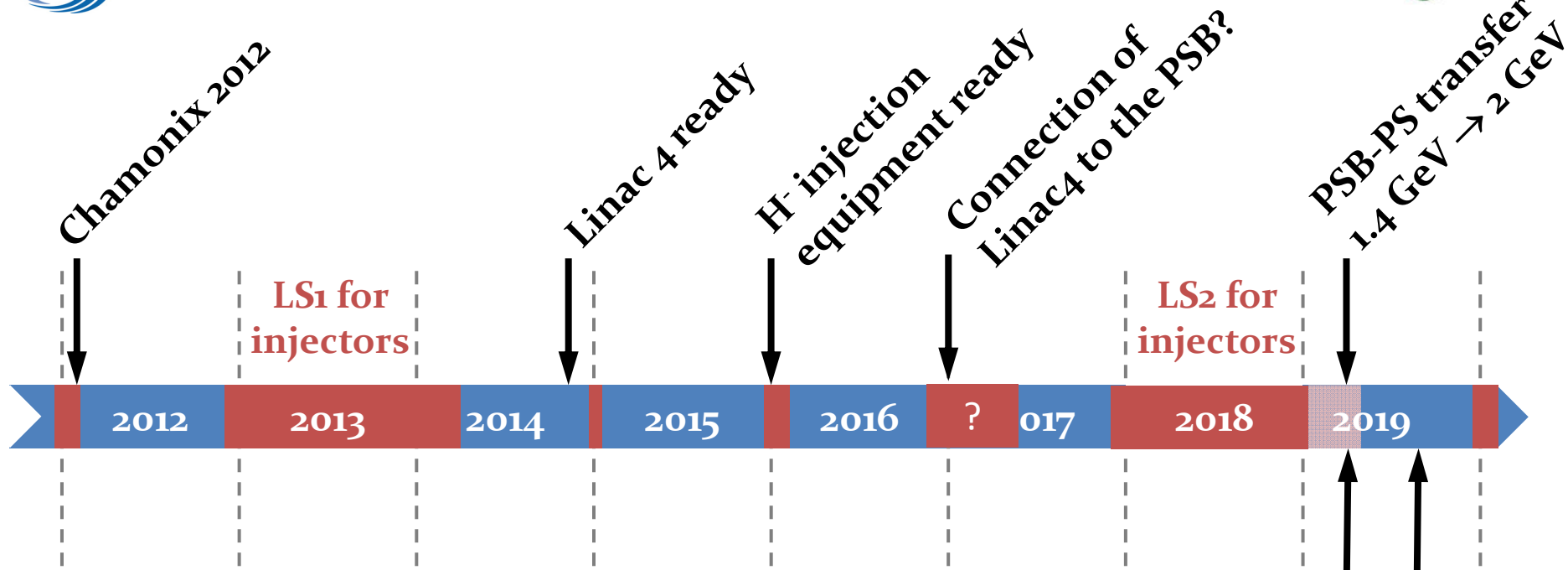


UPGRADE PLANS FOR THE LHC INJECTOR COMPLEX



- Setting the scene
- The LIU project
- Action plan
- Beam characteristics
- **Planning**





Length of LS2: minimum 12months

(assuming that H⁻ injection from Linac4 in the PSB has been commissioned before)

- Required by SPS 200 MHz
- 18 months if new 850 kW cooling not ready in 2016

2019 commissioning: several months

SPS aC coating, 200 MHz
power upgrade completed
Injectors commissioned

THANK U

FOR YOUR ATTENTION!