Plans for the PS upgrade

S. Gilardoni (BE/ABP)

for the PS-LIU working group

The role of the PS in the LHC injector chain

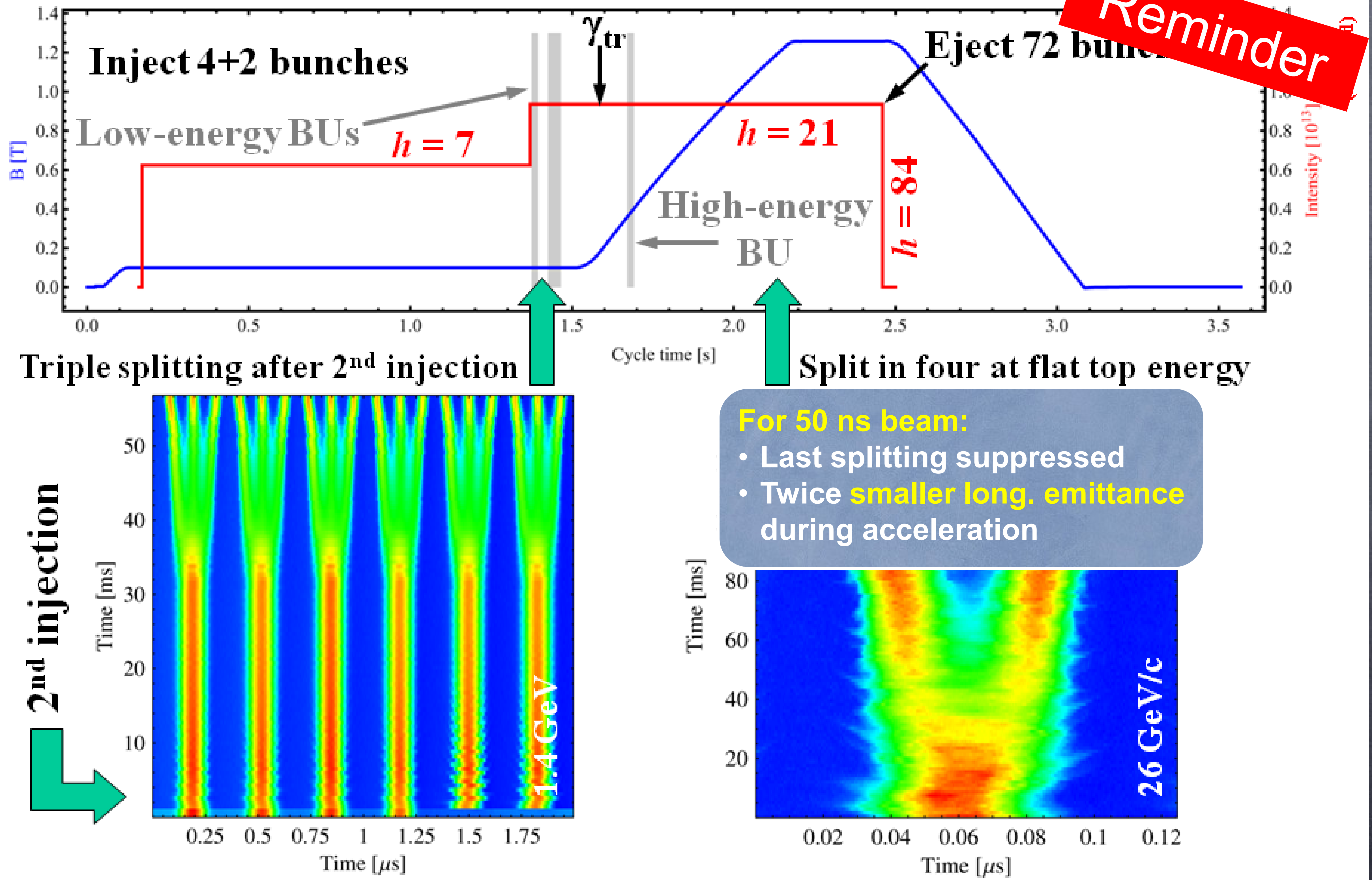
- **Conserve the transverse emittances produced in the PSB:**
  - Causes of blow-up:
    - Laslett tune shift due to space charge: < |0.3|
      → **Blow-up of first batch waiting for the second batch injection**
      → **Can be beaten by increasing the injection energy → 2 GeV**
      (Chamonix 2010 proposal from M. Giovannozzi,
      reason of the previous PSB extraction energy upgrade from 1 to 1.4 GeV)
  - Injection mis-steering/oscillations → **good transverse damper needed**
  - Other effects: head-tail instability at injection energy, TMCI at transition crossing, el[illegible]tion.

Upgrade: High luminosity in LHC

- **Defin[illegible]tructure of the beam**
  - 25-50-75-150 ns bunch spacings are defined by RF gymnastics in the PS.
  - Longitudinal beam quality can be spoiled mainly by coupled-bunch instabilities (ε_l) and transient beam loading (bunch-to-bunch equalization).

Production of nominal LHC beam with 25 ns spacing

Reminder



For 50 ns beam:

- Last splitting suppressed
- Twice smaller long. emittance during acceleration

→ Each bunch from the Booster divided by 12 → 6 × 3 × 2 × 2 = 72

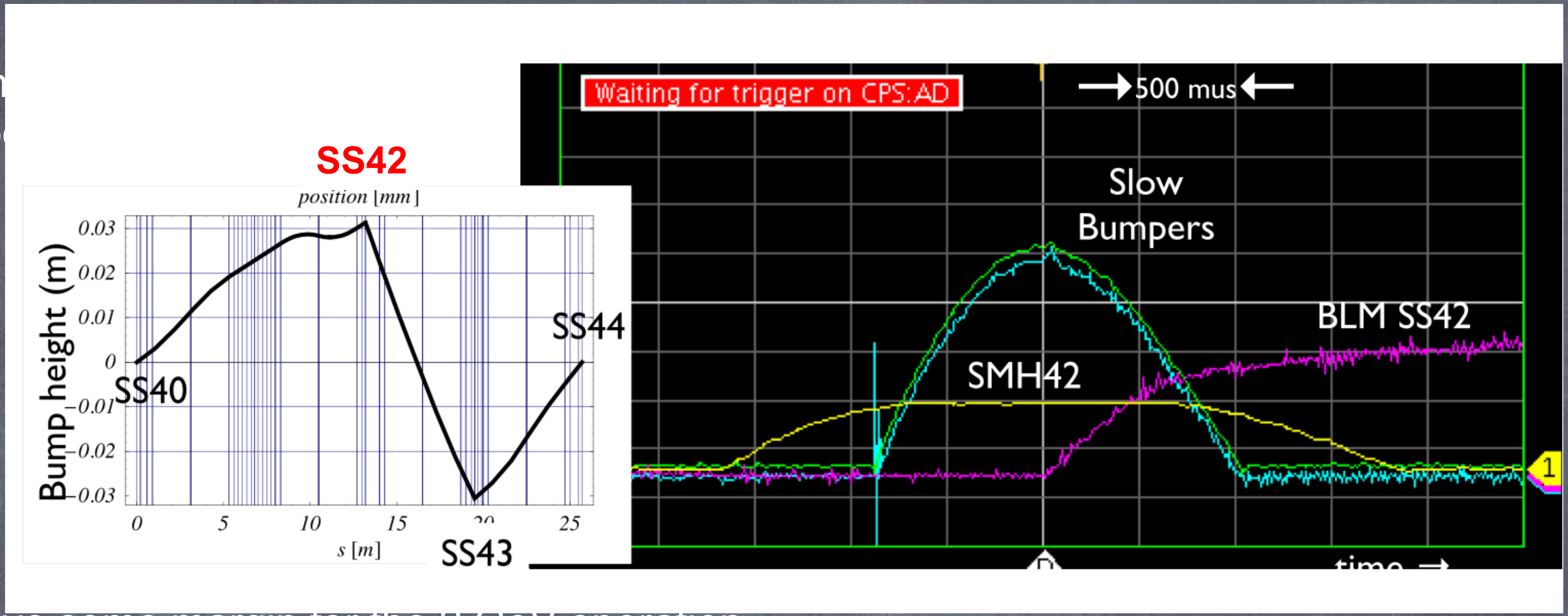
Baseline for PS-LIU: 2 GeV injection from PSB

Achievable intensity with Linac4 (at PS ejection. max, 72 bunches for the 25 ns, 36 for 50 ns) using the hypothesis $\varepsilon_{(x,y)} \propto$ ppb and injection at 2 GeV

Bunch spacing	Intensity/bunch at extraction [10^{11}]	RMS $\varepsilon_{l/v}$ [mm · mrad]	Remark
25 ns	2.0	2.4	Baseline
	2.3	2.1	Stretched
50 ns	2.8	3.3	Baseline
	3.0	1.54	Stretched

2 GeV Injection from PSB

Current injection con
- 4 independent dip
- Magnetic septum.
- Kicker.

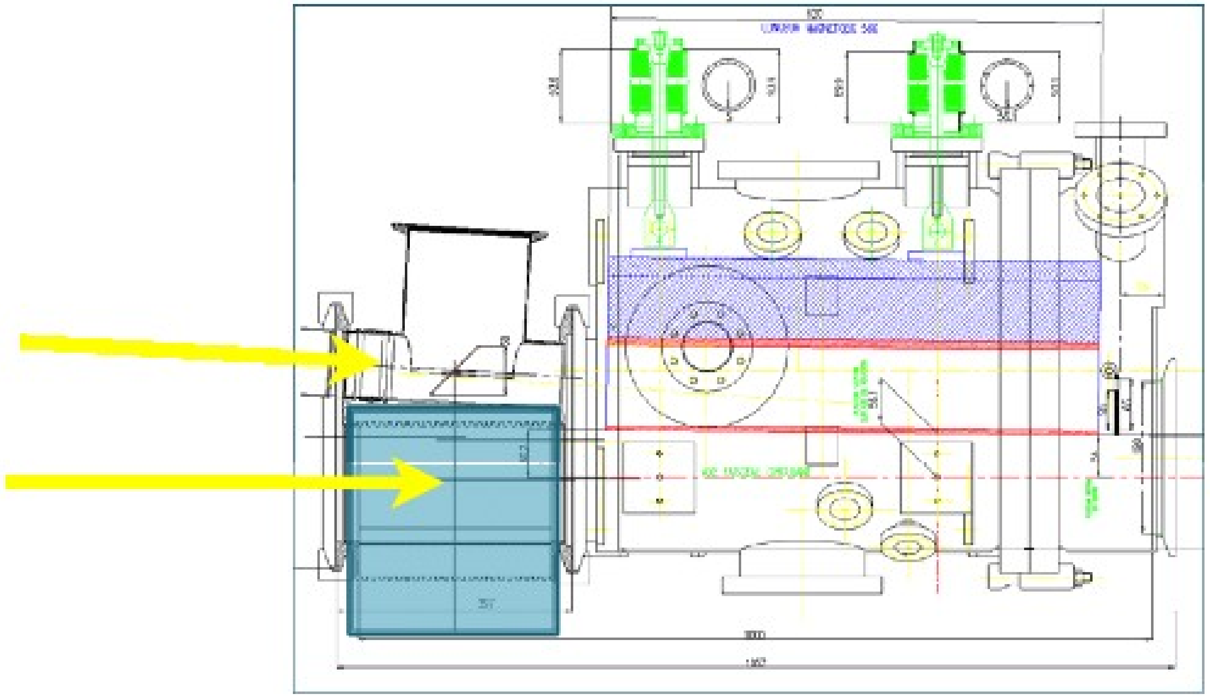


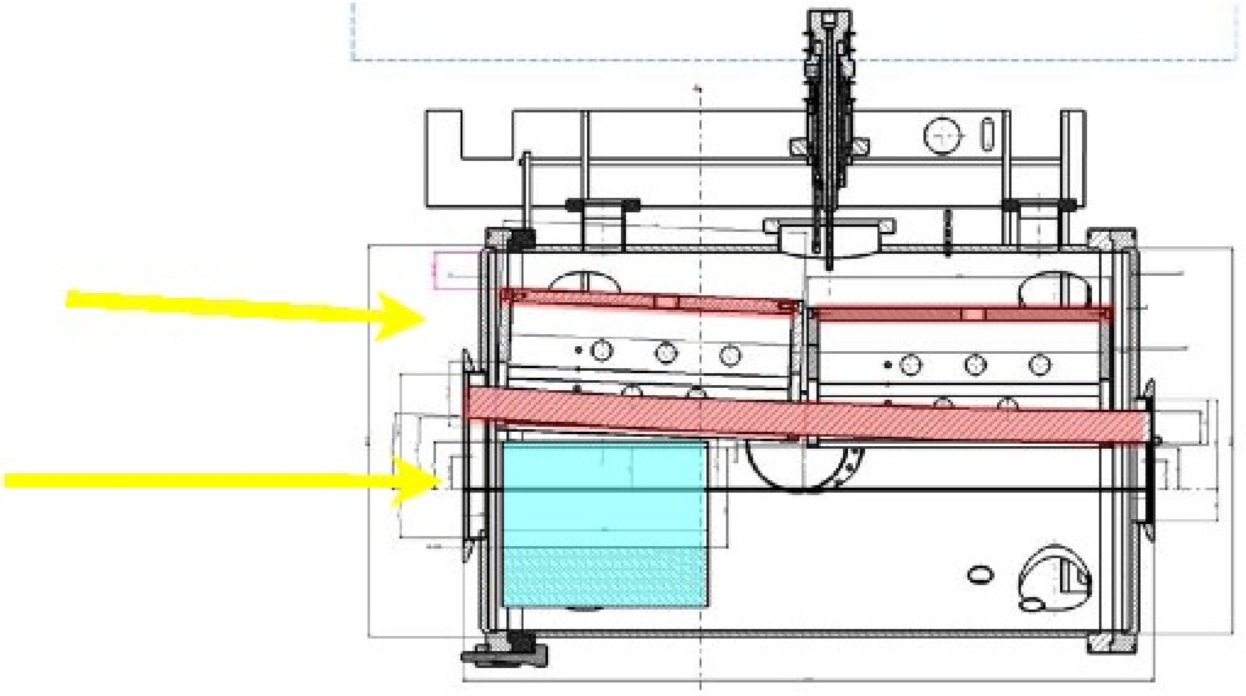
Bumper magnets have some margin for the 2 GeV operation.
- New design to avoid captive vacuum chamber.
- One bumper will be installed in the septum vacuum tank and it will have a septum-like design.

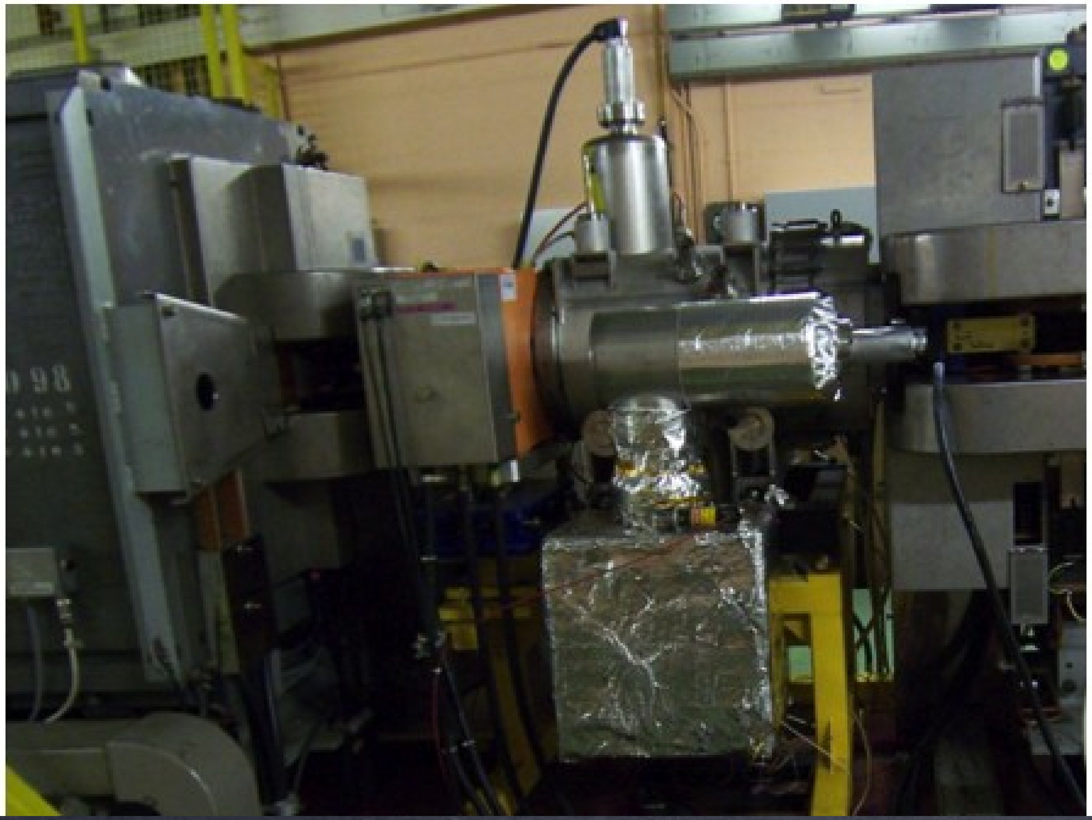
Septum should be exchanged, too short and no margin.
- Change of the injection point considered too difficult.
- Consolidation of power converter already foreseen.
- New design with septum-like bumper in septum vacuum under study.

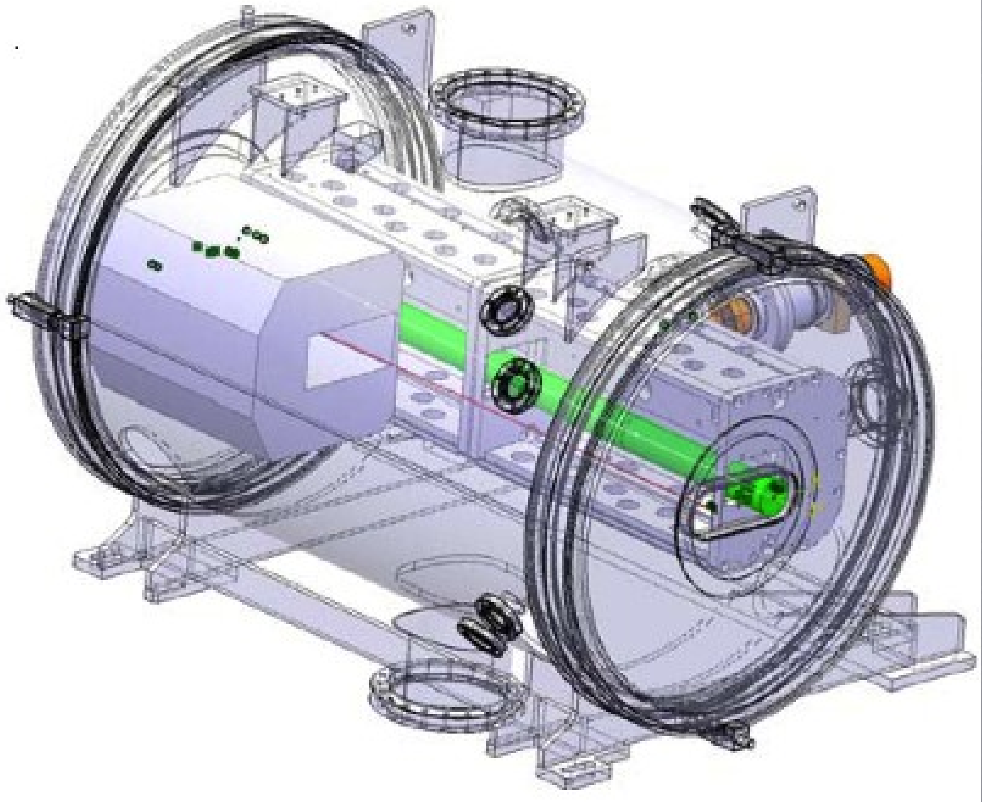
Kicker should be operated at 2 GeV in short-circuited mode to avoid changing the power converter.
- Kicker was not modified during the 1 to 1.4 GeV upgrade.
- First test showed ~10% emittance blow up due to ripple on kicker flat top: could be cured by transverse damper.
- Possible to inject only the LHC-type beams at 2 GeV with the existing kicker (little margin left however).
- Supplementary kicker needed in SS53 to relax operation of existing kicker and inject non-LHC beams.

New septum design





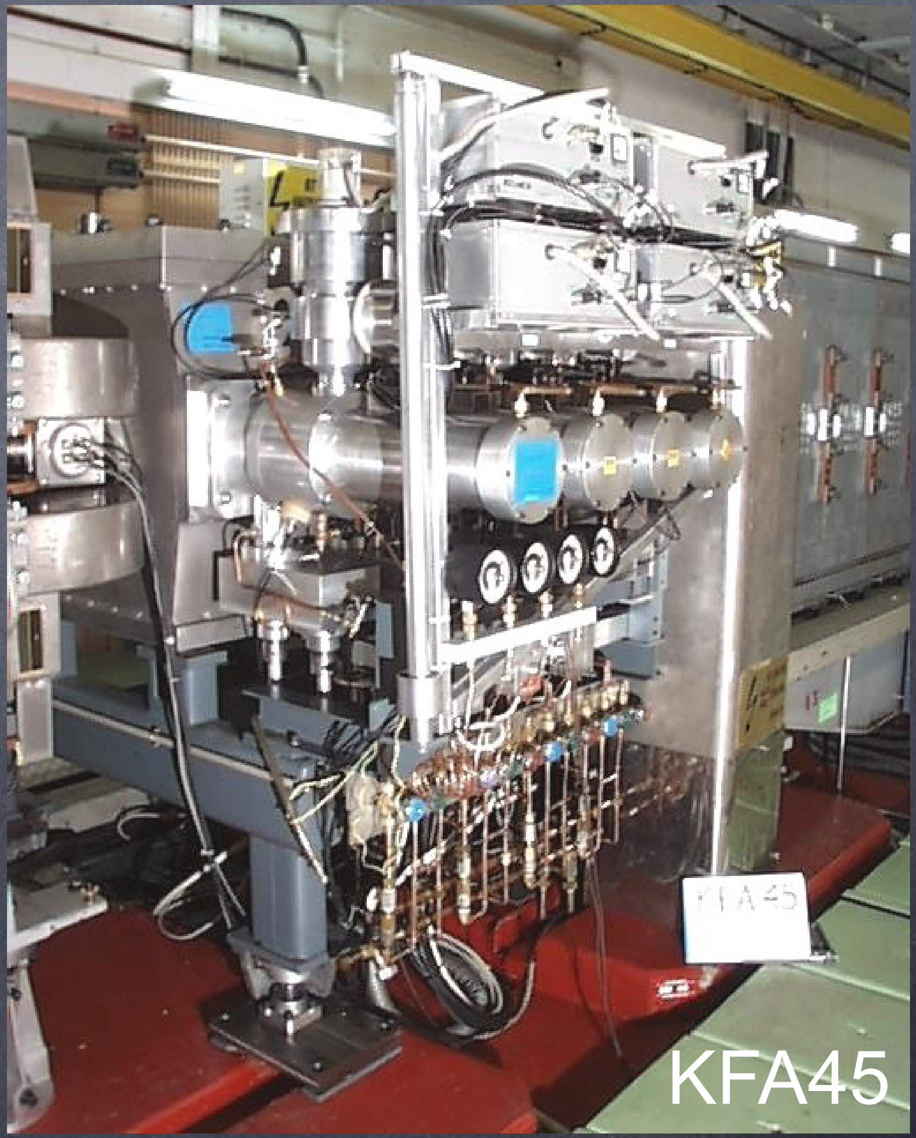




Injection equipment/power converters planning

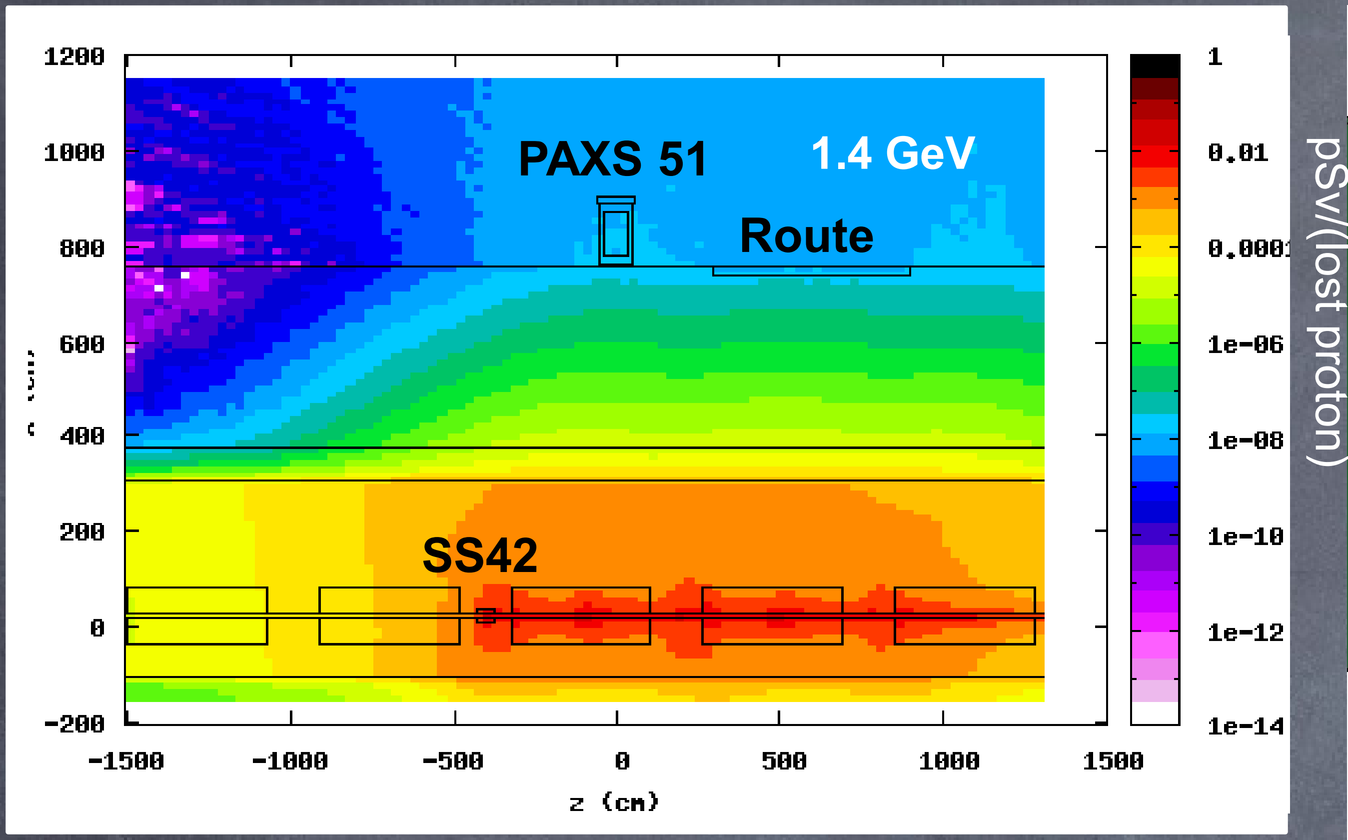
- *BT related elements:*
  - Start on BT-PS injection equipment development as from 2012.
  - No equipment ready for installation during LS1.
  - All kicker, septum, bumper modifications to be carried out during LS2.

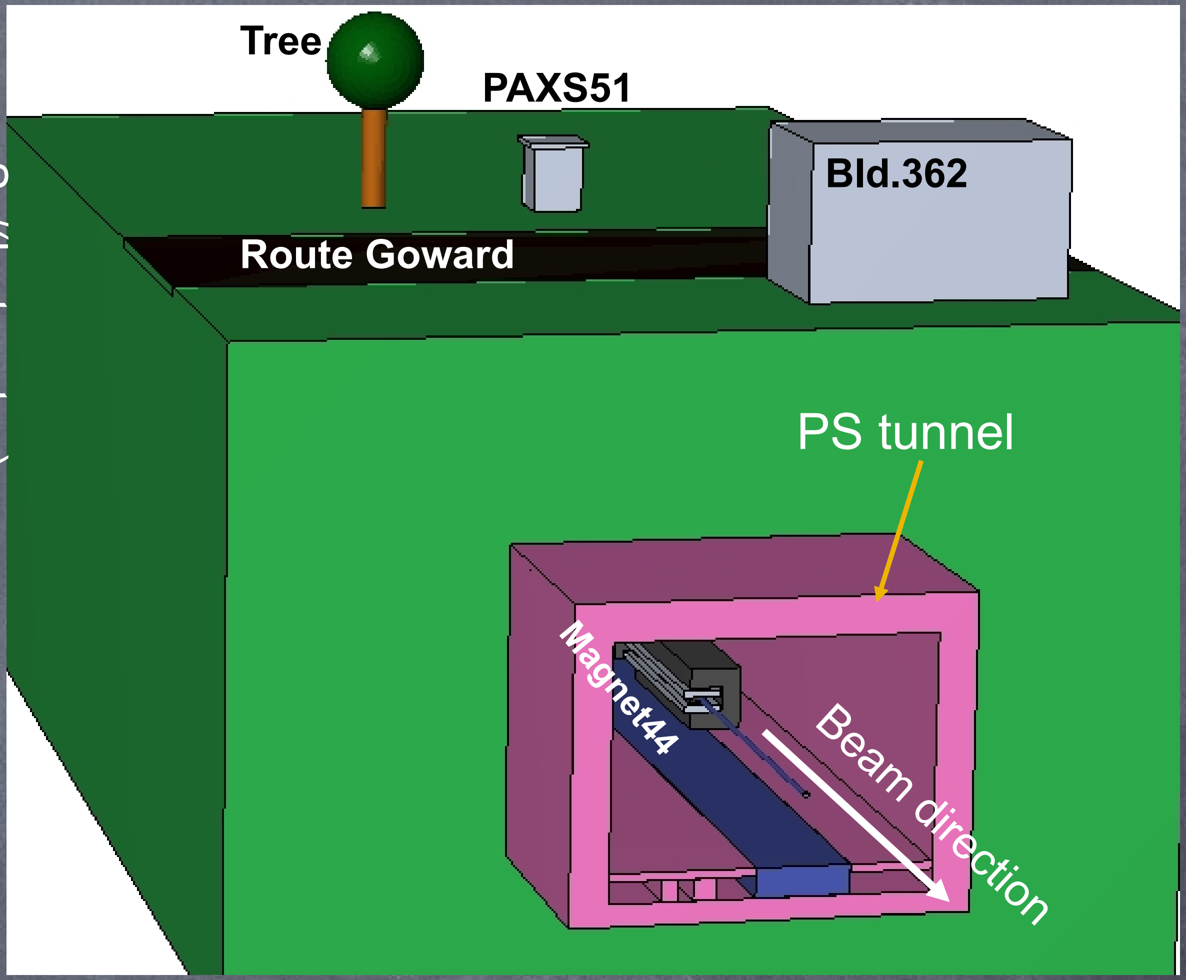
- *PS Injection Power converters:*
  - New converter needed for injection septum 42
  - Falling edge matching between BSM42 (28kA) and BSM 40,42 & 43 (1kA) challenging.



→ Final design cannot be expected for LS1.

Losses at injection





FLUKA simulations showed that the activation of material and on Route Goward would increase **when going to 2 GeV <u>assuming the same losses as at 1.4 GeV</u>.**

- Losses should be reduced thanks to the reduced physical emittances.
- Losses happen during the decrease of the injection bump → implement a faster bump.
- **LHC beam-type losses at injection are small even today.**

-Issue if fixed target beams are going to be injected at 2 GeV (current baseline for LIU).

Implement new shielding on top of route Goward during the LS1
(needed in any case for today high-intensity beams)

Flat bottom blow-up/instabilities

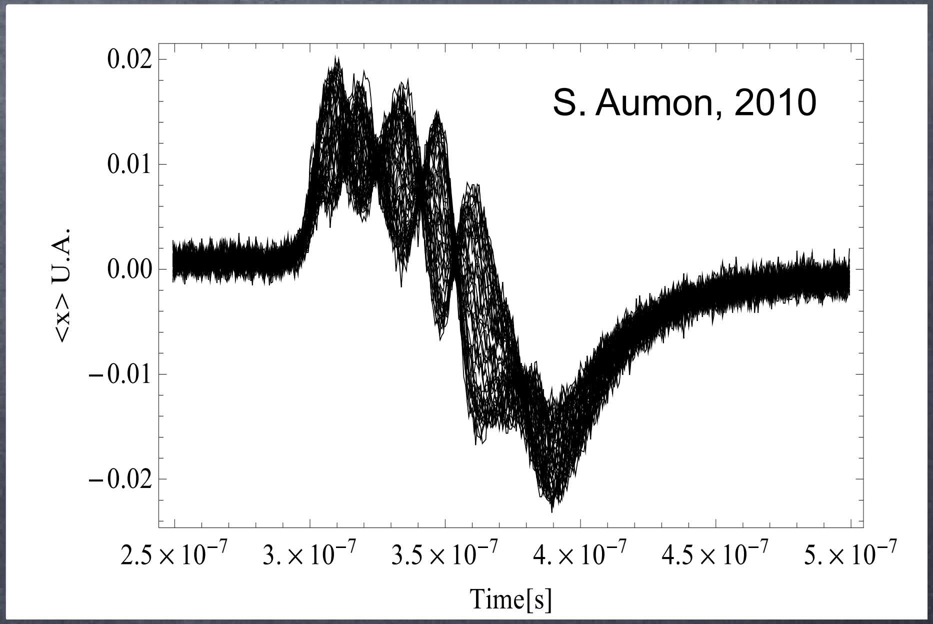
- Transverse **blow-up due to space charge needs** further studies. Not completely clear yet the mechanism which blow-up the emittance for a large Laslett nor the growth rate. Also the limit on the tune shift of **|0.3| merits to be revised**.

- If emittance **blow up grow rate of the order of 1 s**, PSB second injection after 900 ms?

- Growth rate of **head-tail instabilities at the flat bottom scales like N/γ** → issue for the first batch waiting for the second → 50% faster instabilities if twice the intensity at 2 GeV

Observed during 2010 tests with large Laslett tune shift beams:

- **No significant emittance transverse blow-up was observed.**



PS transverse FB requirements for 2 GeV injection

- Apart from calculations, test in the PS machine proved that the 3 kW per kicker plate TFB setup is just adapted to the most demanding constraint in terms of injection damping time at 1.4 GeV (3 mm in 50 μs for the LHC pilot beam)

- To obtain the same damping rate at 2 GeV required power to be multiplied by 1.7
- 3 kW amplifier for 1.4 GeV → 5.1 kW amplifiers at 2 GeV
- Adding a second transverse kicker (at additional cost) would be ideal

- The present bandwidth is 23 MHz.
- It is likely that 50 MHz can be reached with a new design (if required)
  → Could this be enough for the bunch structure (40/80 MHz) before extraction and its related electron cloud effect?

- **Commissioning of the existing TFB should take place during the 2011 run**

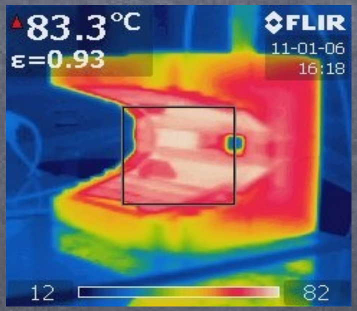
Magnet status

- In view of the PS upgrade a preliminary study has demonstrated that amongst the 7 different magnet types concerned by the upgrade (90 magnets, 100 windings), 3 magnet types are to be replaced.

- The Injection Bumpers:
  - 3 magnets + 1 spare + 1 spare coil set
  - Replacement by a non-captive vacuum chamber

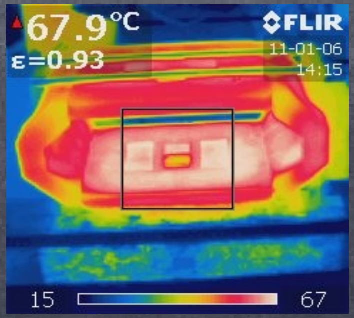
Injection bumper type 209

- The low energy quadrupole skew normal including DVT and QSK function
  - 25 magnets + 2 spares
  - Operating temperature 83.3 °C above limit (65 °C max)



Thermal inspection magnet 403

- The Low Energy quadrupole skew enlarged
  - 21 magnets + 2 spares
  - Operating temperature 67.9 °C above limit (65 °C max) and poor power terminal connection with high electrical resistance



Thermal inspection magnet 404

→ **MDs at 2 GeV injection energy will confirm the situation for all magnet types.**

Power converters

Low energy quadrupoles and dipole correctors:

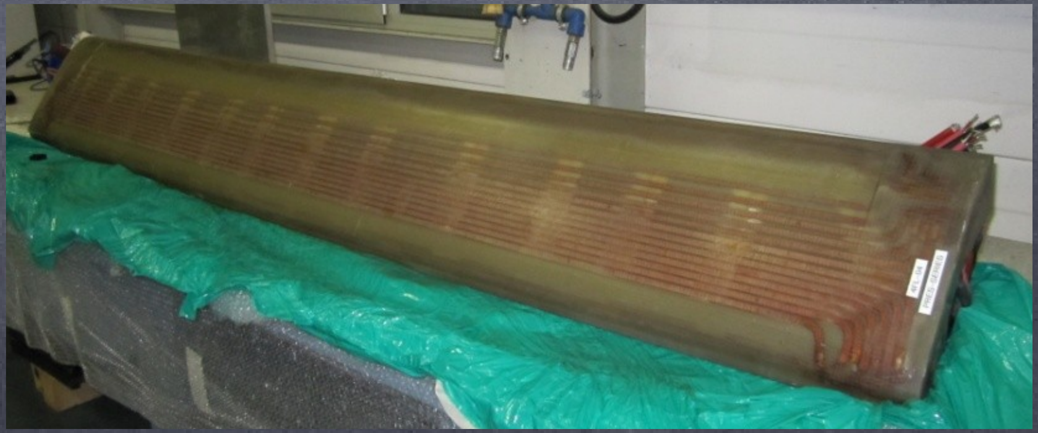
- Most of the converters were installed during the 1969-1975 period.
- Consolidation was foreseen for 2015.
- New converters will be installed in 2014 with enough margin to cover the 2 GeV upgrade requirements.
- Dipole corrector needs/specifications to be confirmed by MDs.

Before accelerating: MU consolidation status

- **Preventive maintenance and monitoring of Main Magnets:**
  - Anticipate degradation of the magnets in order to repair / replace the failed components and avoid down time
  - Extensive yearly monitoring activities
  - Everything OK → No main magnet renovation foreseen
  - Bus-bar measurements in the PS during next shut down in order to evaluate their status. Decide if all the bus-bars must be replaced.

- **The Pole Face Windings**
  - Procurement of 30 sets of spare PFW was launched in 2010 for long term operation of the PS
  - Status of production: Five pre-serie are being made with on-going development of the process (conductor positioning, curing cycle, hardware de-bugging, etc.). The production is planned to start in May 2011 and finish in May 2012.
  - A diagnostic campaign for detection of the weak PFW will be performed during the next shut down.

Coil winding of the Narrow and Wide circuits



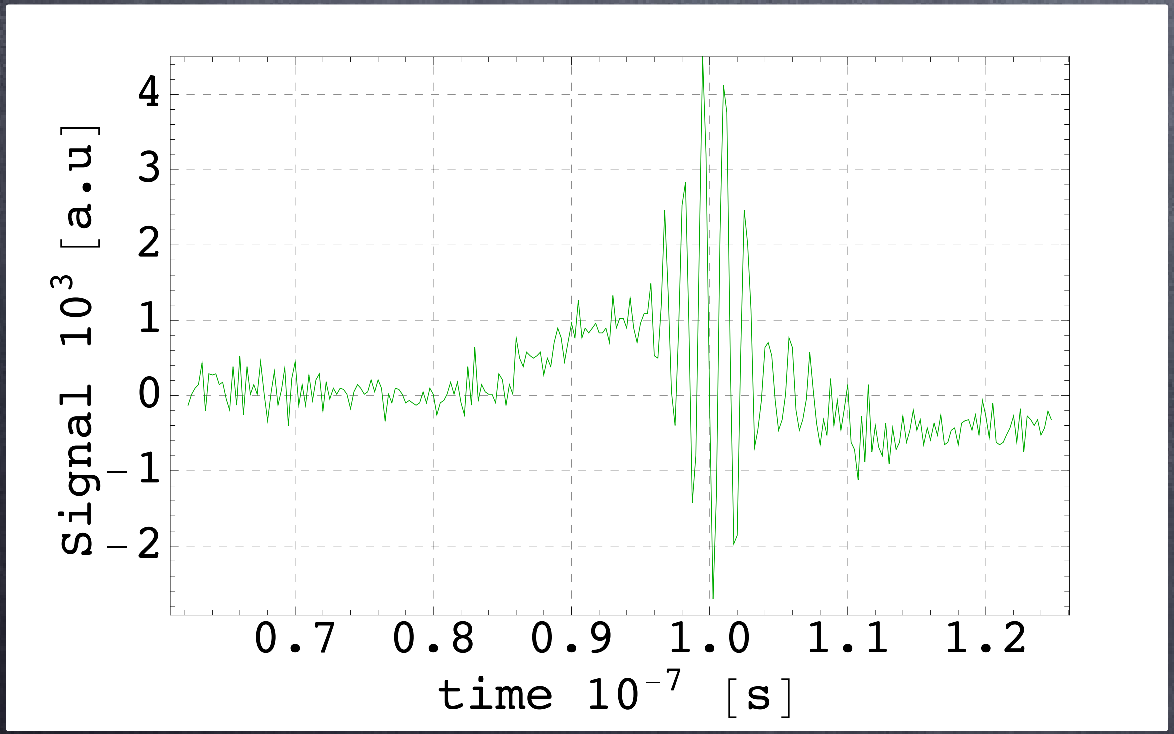
Pre-serie #4 during inspection

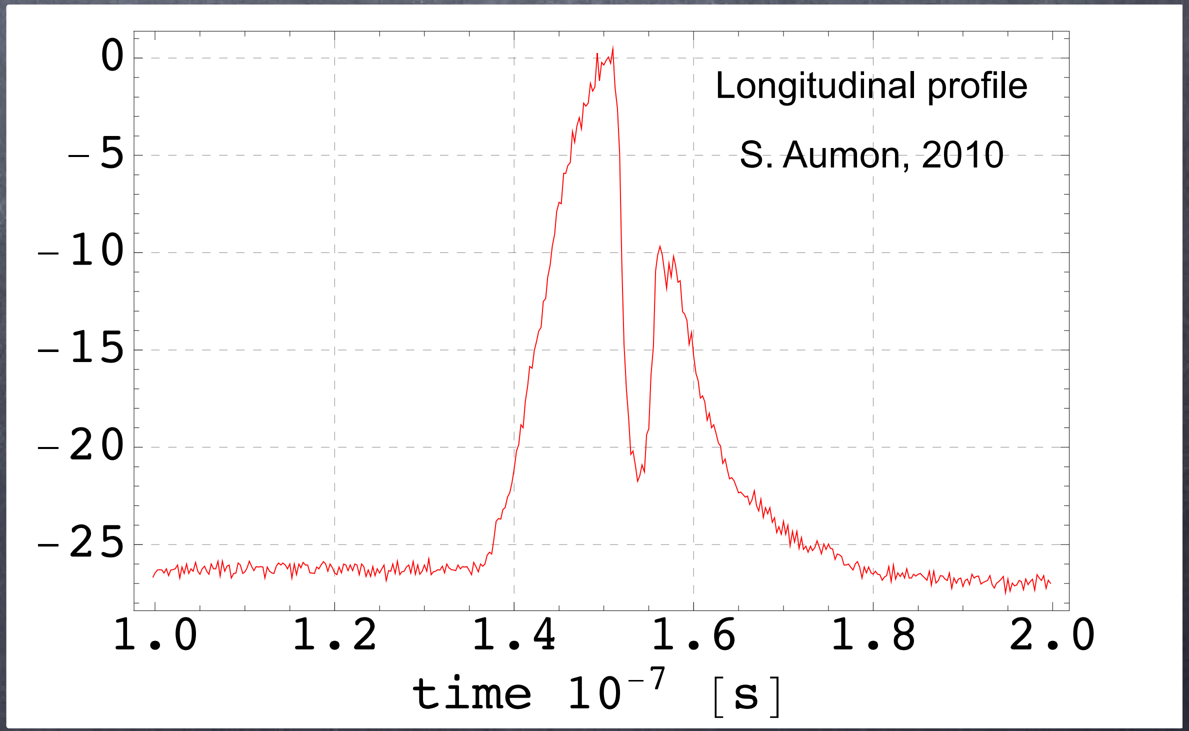
Transition

- **Longitudinally no problem up to $2 \cdot 10^{11}$ ppb** (at PS ej., demonstrated in 2010) during ultimate LHC25 tests (good for crossing transition with up to $4 \cdot 10^{11}$ ppb at ej. with LHC50).
- Peak current only allows an estimation, no direct scaling.
- Peak current of ultimate beams below present limitations (with e.g. TOF or AD beams).

Beam	Int. [10^{11} ppb] at ejection	Intensity [10^{11} ppb]	Long. emittance ε_l [eVs]	Pk. current at γ_{tr} [A]
LHC25, nominal	1.3	5.2	0.65	8.4
LHC25, ultimate	2.1	8.4	0.65	14
LHC50, nominal	1.3	2.6	0.65	4.2
LHC50, beyond ult.	3.0	6.0	0.65	9.7
SFTPRO/CNGS		17	1.4	15
AD		40	2.3	23
TOF		89	2.6	40

- **TMCI instability** observed on the TOF beam with a threshold **beyond the more-than-ultimate LHC beam**, stable for ~$2 \cdot 10^{12}$ ppb (2010 results). Further studies in 2011.
- **Might cause ε(x,y) blow-up.** Transverse emittance blow-up observed during 2010 with ultimate.





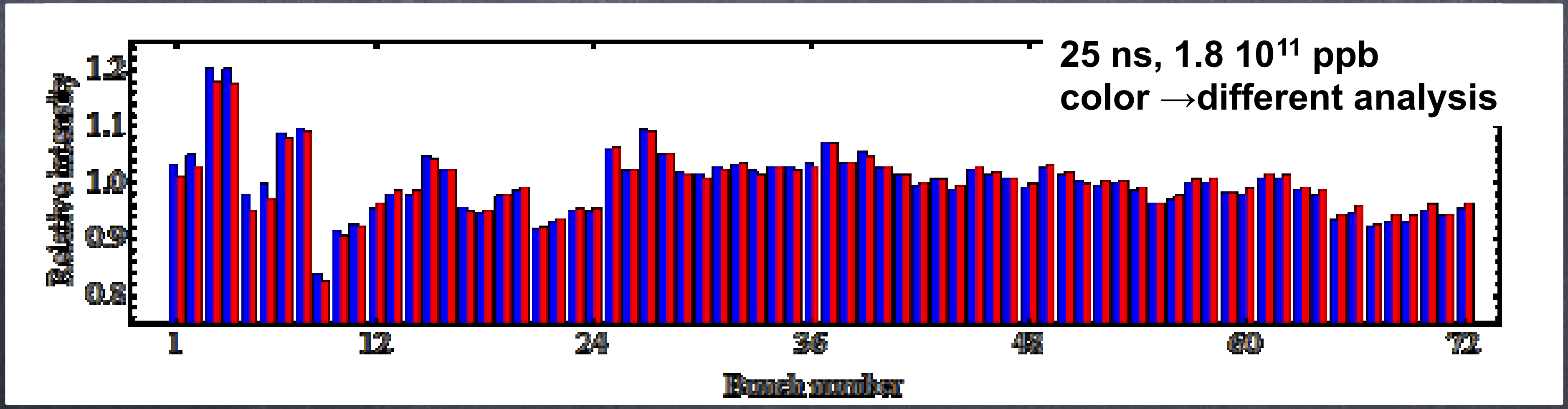
Sources of longitudinal beam parameter degradation

Coupled-bunch instabilities observed during acceleration and at flat top, uncontrolled longitudinal emittance blow-up:

- **Very similar for the same average longitudinal density (25 ns or 50 ns) ~ N/ε_l (empiric scaling).**
- **10 MHz cavities main impedance source.**

Transient beam loading causes relative intensity errors of up to 20% (± 10%) per splitting:

- **Pattern well understood from RF manipulations.**
- **Distributed problem since all the RF systems are used for splitting, i.e. contributed to the final spread.**
- **Bunch length and longitudinal emittance also affected.**



RF upgrades within PS-LIU

- **2011/2012: Study phase for RF**

→ MD studies and measurements on equipment

→ Check feasibility and benefits of upgrade ideas

→ Prioritize

Decisions after study phase

- **Low-level RF:**

→ Equip high frequency cavities with 1-turn delay feedbacks, reducing transient beam-loading?

→ Improve coupled-bunch feedback for better longitudinal stability (started before PS-LIU)

→ **Man-power intensive**

- **High-power RF:**

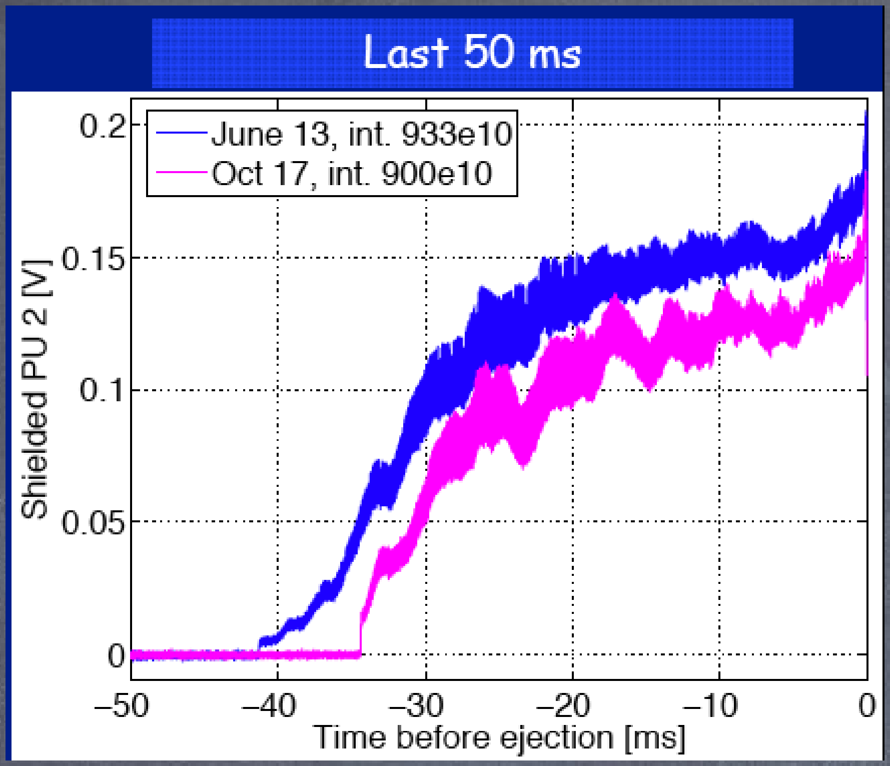
→ Improved feedback amplifiers closer to cavities?

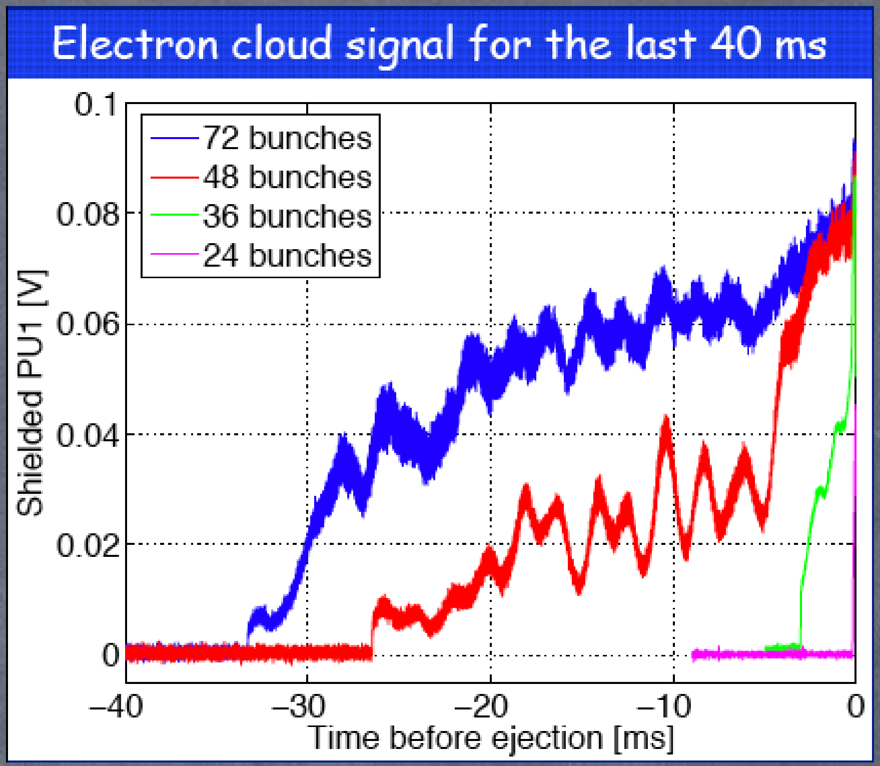
→ Possibility of more RF voltage and power per cavity?

→ **Expensive equipment with significant man-power involved**

Flat top (transverse)

Electron Cloud: electron cloud signal is observed after the second double splitting, with little conditioning effect over 1 year run





Electron cloud was observed but not clear yet if any deleterious effect on the beam. Might become more critical with higher brillance. New studies in 2011 since direct impact on the time available for the last RF manipulation.

Transverse instabilities at flat top observed in 2001, 2004 and again 2006.
Probably related to electron cloud (why mainly horizontal and why not cured by chromaticity).

- Coupled bunch or single bunch effect?
- Threshold of $4.5 \cdot 10^{10}$ ppb for a bunch length of 10 ns.

If solution like coating will be needed → MU removal → staging the intervention or LS2

MDs during 2011

Energy

- Injection/matching studies (dedicated MD required).
- Acceleration on $h = 7$ to study machine and hardware performances at 2 GeV with LHC-type beam.
- Study of HW limitations of the low energy correctors/quadrupoles at 2 GeV.
- Study of injection working point using the PFW (tune and chromaticity control).
- Check of RF manipulations at 2 GeV.
- Emittance evolution on 2 GeV long flat bottom (headtail instabilities, space charge).
- Double injection separated by less than 1.2 s.
- Emittance grow-up after transition crossing (also TMCI related studies).
- Longitudinal instability during acceleration and on the flat-top.
- Electron cloud studies during phase rotation before extraction.
- Study of bunch length/longitudinal emittance optimum/margin for transfer to SPS.

Alternative schemes: batch compression

- **Batch compression in the PS to increase brightness after acceleration to a suitable energy**

  Abandon factor 7 in PS harmonics to
  (i) use all four PSB rings (with singe batch transfer) and (ii) use batch compression to increase brightness

- Fill as much as possible of the PS circumference at injection

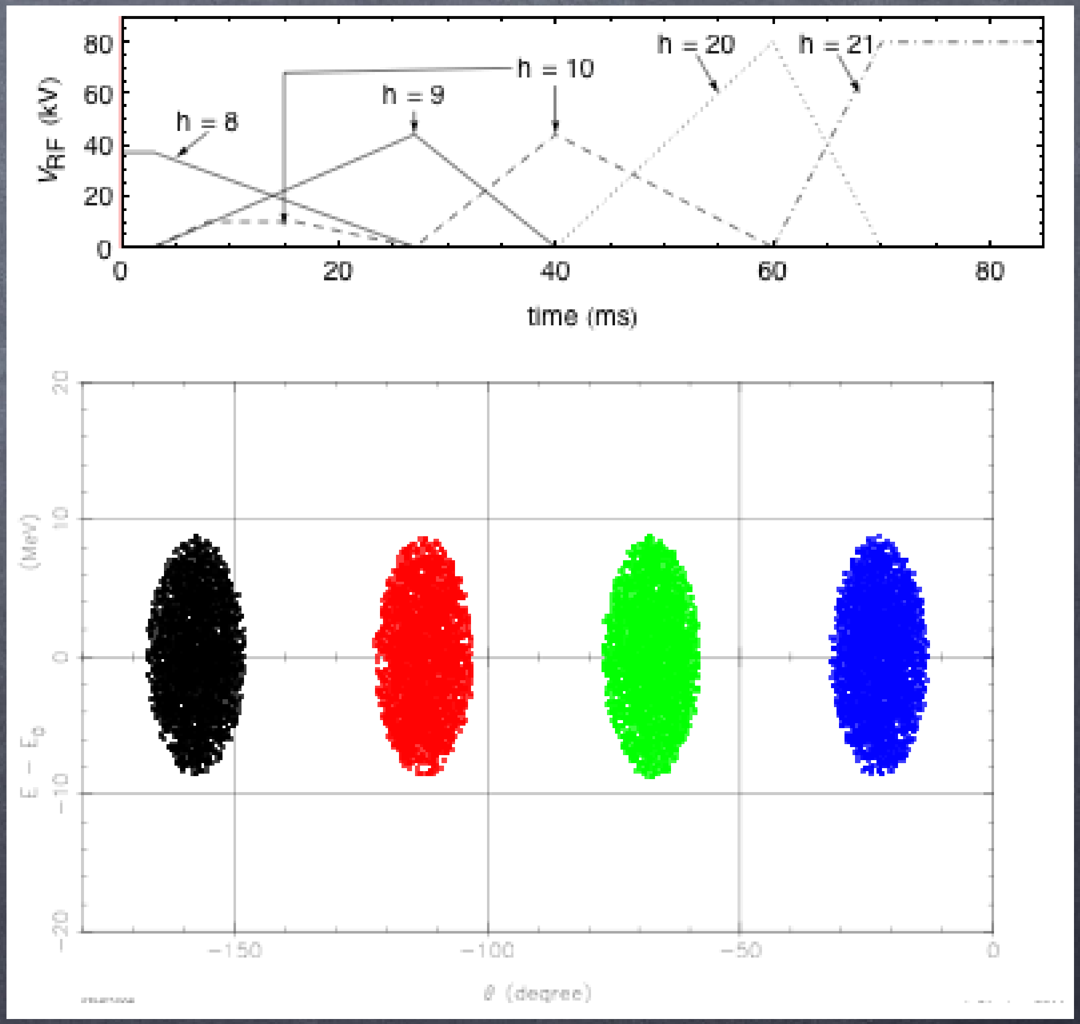
- Batch compression after first acceleration to an appropriate energy

- Shorter batches at PS extraction (64 bunches)
  → Higher intensity per bunch and brightness

- Difficult operation due to many RF harmonics changes

- MDs and studies in 2011

- Could be use to produce beams for tests in he SPS



See C. Carli, Chamonix 2011

Preliminary PS-LIU budget estimate

WU	Est. cost (kCHF)	Comments
Management	560	
Beam dynamics	70	
Magnets	1000	only for 2 GeV upgrade
RF	13175	
Power converters	2360	
BI		To be analysed (see J.J. Gras presentation)
Intercep. device	100	
Vac. systems	4000	If coating for e-cloud required
Injection	2685	Including second kicker
Controls	25	Partial estimate
Electrical systems		To be analysed
Cool. and Ventil.		To be analysed (see M. Nonis presentation)
Transport	880	If coating for e-cloud required
Civil Engineering	730	Includes R. Goward shielding
RP	450	
Interlock systems		To be analysed
Survey	90	
Operation	140	
Total	**26265**	

PS-upgrade project started in January 2011

Very First budget estimate:

a) not all the items could be analyzed with the same accuracy

b) some items could not be analyzed yet

c) some items are underestimated due to our current ignorance on the future systems/choices: a number of technical solutions are not yet decided

e) the design of many equipment has to be made

Clearly the errors bars are large!

+ Consolidation items not approved (S. Baird's list, order of 16 MCHF)

Conclusions

- PS-LIU started end of last year

  → Not the same depth of study as for PSB/SPS yet

- PS-LIU presently in study phase:
  - Parameter space in terms of Laslett tune shift, long. limitations, hardware limitations to be fully exploited and verified → Lots of MDs!
  - Decision on upgrade of many elements only at end of 2012

- First cost estimates of all elements to upgraded or exchanged
  - 26.3 MCHF for upgrade related activities → Still large error bar

spare

Beam instrumentation

- **If the upgrades aim to smaller emittance to get larger brillance, the injectors should be able to precisely measure them.**

In PS, ongoing revision of emittance measurement devices:

- BWS: the precision on the small emittance beams was not good enough.
- BWS: cannot measure emittance bunch-by-bunch.

- Matching with PSB should be optimised as much as possible to preserve emittance.
  Current system had to be revised for the 2 GeV case.
  May be install a turn-by-turn measurement. With new SMH42, should revise the profile detectors in the injection region.

- TT2 OTR screens should be revised for higher-brilliance beams.

- **Need to improve intensity measurement to better evaluate losses between machines.**

- **Need to measure the extraction trajectory or beam radial position before extraction.**

- **New dedicated PU could be installed to measure on large h, beyond the h=21 limit of today**

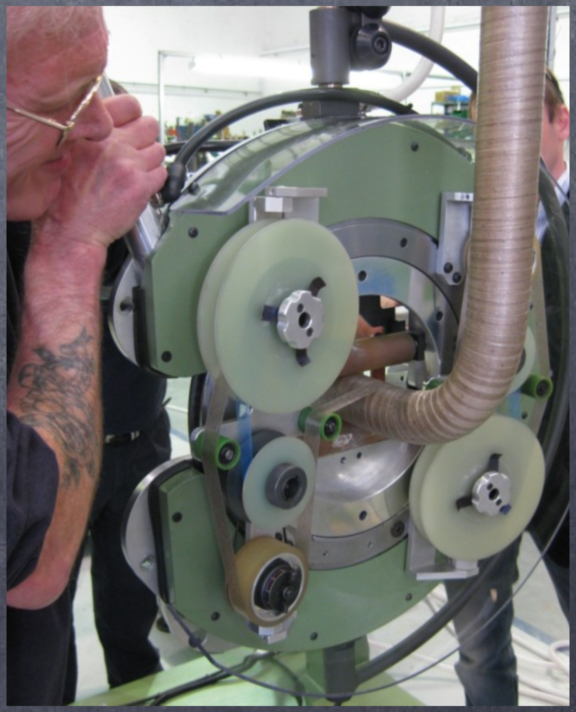
Revision of the systems might lead to an important upgrade of some of them (see talk of J. J. Gras on Tuesday)

Bus bars (main magnet interconnects)

- Actual Status of the main bus bars:
  - **The design of new PS bus bars started in 2010 is driven by studies and extensive testing (more than 55 samples).**
  - **Cylindrical aluminium conductor with pre-impregnated resin rich tape with Mica flakes as dielectric insulation not sensitive to the ionizing radiations.**
  - **Manufacturing of 8 spare bus bar sets (one of each type) to cover the full machine.**
  - **Measurements in the PS during next shut down in order to evaluate their status. Decide if all the bus Bars must be replaced.**

Initial longitudinal samples

Holding frames for Bus Bar handling during taping



Wrapping head during testing

Planning for 2011-2014

Foreseeable studies and upgrades:

Item	Cost [kCHF]	Remark
Longitudinal instability studies	60	Improve measurement set-up
1-Turn feedback 40 MHz	80	Beam stability during acceleration
1-Turn feedback 80 MHz	80	Beam stability during acceleration
1-Turn feedback 20 MHz	80	Not clear if needed
Phase control loops 10/20 MHz	25	Study benefits first
Study benefit of improved direct FBs	50	Required for later decisions
Modifications and tests, FB amplifiers	50	Further needs depend on study

Low-level

High-power

→ RF upgrades within PS-LIU aim at improving longitudinal beam stability and reduction of transient beam loading

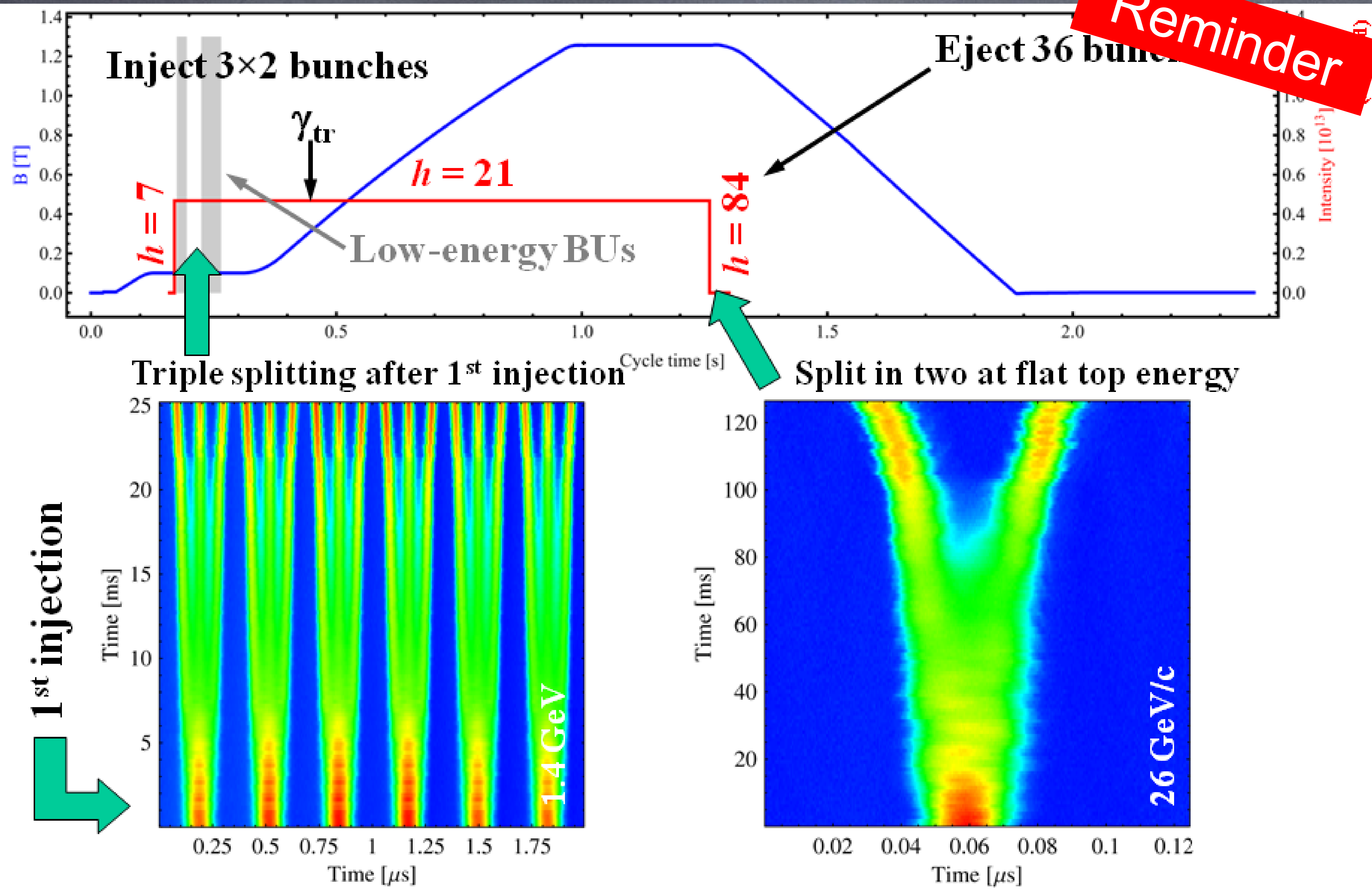
→ Essentially independent from 1.4 GeV or 2 GeV injection energy

Summary of RF-HW interventions

Priority	Item	When	Remarks
[1]	**New coupled-bunch FB**	**2012**	**ongoing, budgeted**
2	Dedicated kicker cavity	2015-2020	on consolidation list
10 MHz			
[1]	**1-turn delay FB**	**2011**	**budgeted, prototype tests in 2011**
1	**Renovate FB amplifiers**	**2011-2015 (?)**	**study until end 2011**
1	**Slow phase loops around each cavity**	**2013-2014**	
2	New power amplifier (1 tube/gap)	2014-2018 (?)	study until end 2012
20 MHz			
1	**1-turn delay FB**	**2012**	**study until mid 2011**
2	Slow phase loops around each cavity	2012	
40 MHz			
[1]	**Automatic tuning system**	**2011**	
1	**1-turn delay FB**	**2012**	**study until mid 2011**
2	New feedback amplifier in grooves	2014	study until end 2012, priority to be redefined after first study 2011
2	Slow phase loops around each cavity	2012	
3	Study more voltage per cavity	2013	shut-down time with infrastructure (water, etc.) needed
3	New power supplies	2014-	can be specified after voltage tests
80 MHz			
1	**1-turn delay FB**	**2012**	**study until mid 2011**
1	**Automatic tuning system - PLC, prot./ions switching**	**2011-2012**	
2	Slow phase loops around each cavity	2012	
2	New feedback amplifier in grooves	2014	study until end 2012, priority to be redefined after first study 2011
2	Fast ferrite tuner	2016	feasibility study by end 2011
3	Study more voltage per cavity	2013	shut-down time with infrastructure (water, etc.) needed
3	New power supplies	2014-	can be specified after voltage tests
3	Extra 80 MHz cavity		

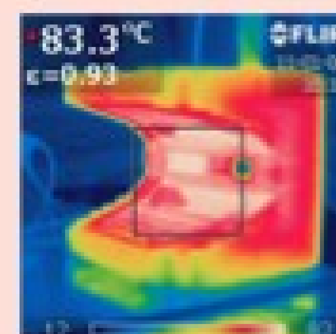
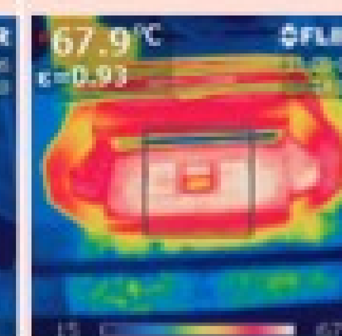
- The years of completion are crudely estimated as well, some of the items may only be fully implemented beyond 2017
- Items with priorities in brackets indicate activities already ongoing before the LIU framework started- The priorities may change according to the outcome of the studies proposed

Single-batch LHC beam with 50 ns spacing



→ Each bunch from the Booster divided by 6 → 6 × 3 × 2 = 36

Performances of magnets/PO used at low energy

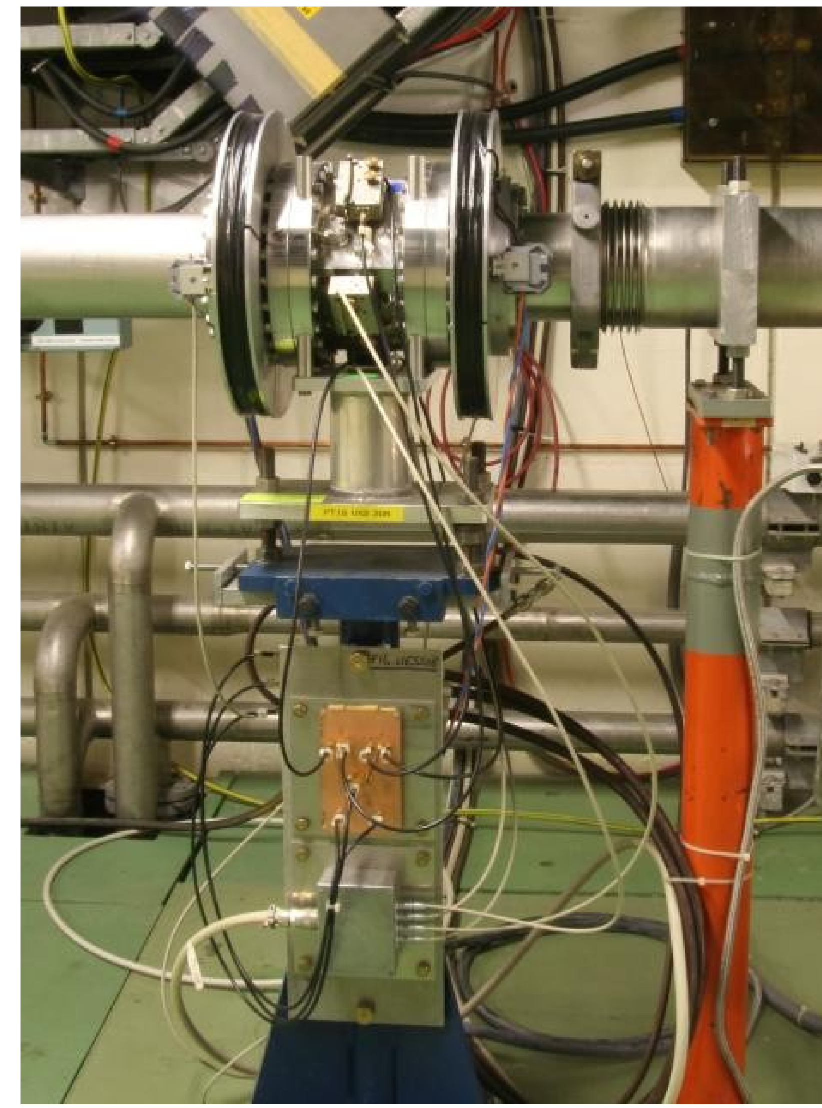
	DHZ	DVT	QFN – QDN	QFN - QDN	QSK + DVT	QSK
Use	H dipole correctors	V dipole correctors	Lattice quadrupoles (1)	Lattice quadrupoles (2)	Combined function skew quadrupole	Skew quadrupoles
Number of magnets	100	5	20	20	25	20
View						
Power converters		To be consolidated	To be consolidated	To be consolidated	To be consolidated	To be consolidated
For 2 GeV	Ok (MD to confirm)	Ok (MD to confirm)	OK (MD to confirm)	OK (MD to confirm)		

Magnets have been tested in 2010 with maximum RMS which seems to be compatible with operation at 2 GeV except Skew quadrupoles used to damp the HEADTAIL instability

Power converters should be renovated in any case, new specifications for more flexible operation at 2 GeV will be provided

TT2 wide band pickups

- F16.UES208 and F16.UES228
  - Bandwidth: 5 kHz – 400 MHz
- Presently OASIS limits observation bandwidth to maximum 250 MHz
- Need for faster oscilloscopes integrated in OASIS
- Could be available for 2012 run



Post Mortem logging of PS last turn

- In Chamonix 2011 enhanced injector post mortem analysis capabilities were requested
- Procure two additional fast oscilloscopes:
  - Systematic logging of the last turn of all beam going to the LHC
  - 2nd channel for bunch shape measurement in order to avoid user limitations in view of many LIU related and other machine studies in parallel to normal operation
- Could be available for 2012 run