PS Upgrade plans, issues and status

S. Gilardoni BE-ABP

LHC50ns Production Scheme & Issues

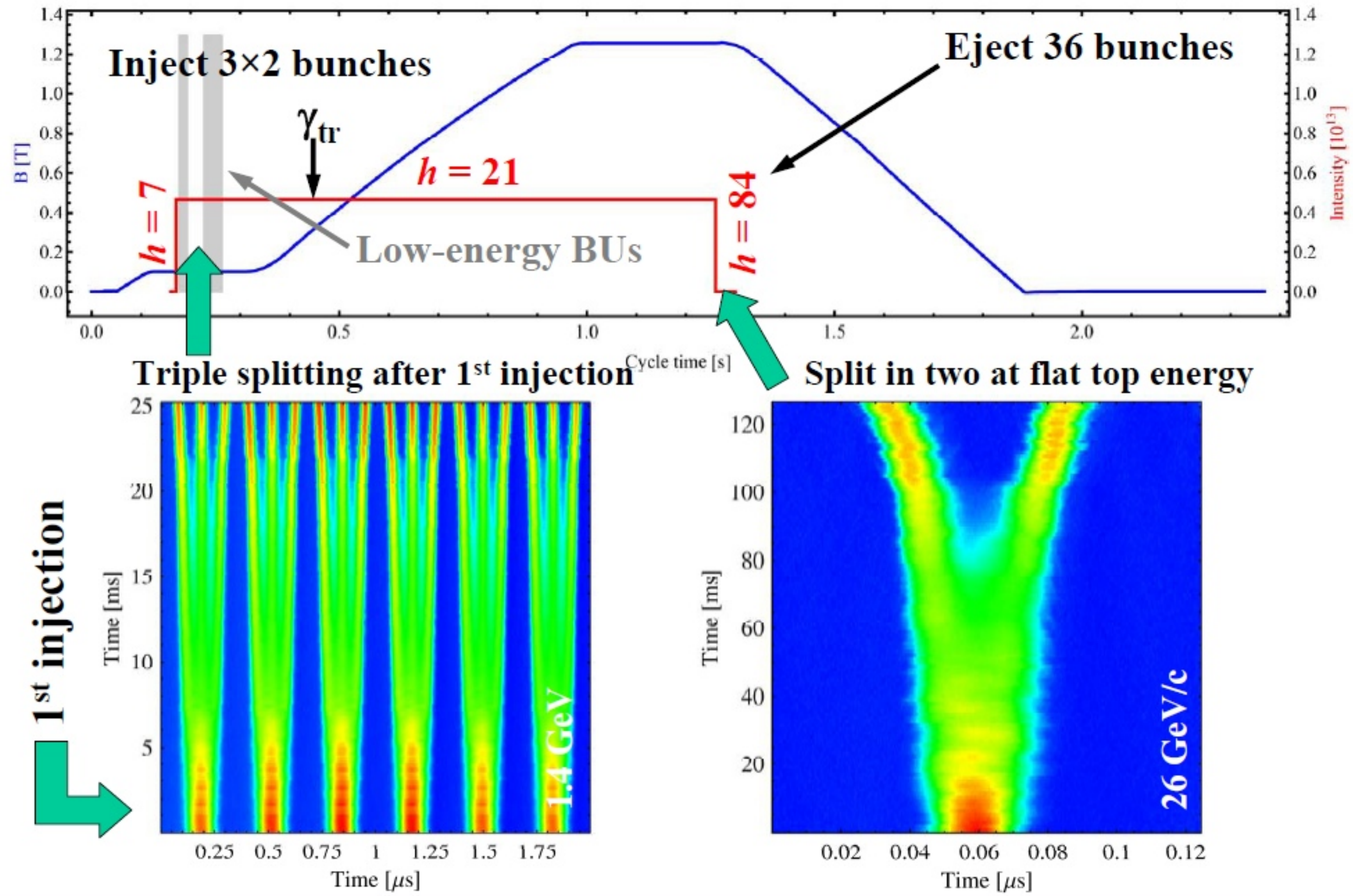
Single batch injection from PSB (3 x 2 bunches, 6 bunches for PS at h=7)
Transverse emittance produced in the PSB, longitudinal in the PS

RF gymnastics in PSB:
- ➡ RF capture
- ➡ Splitting
- ➡ Bunch distance adjustment

RF gymnastics in PS:
- ➡ Triple splitting
- ➡ Acceleration
- ➡ Double splitting
- ➡ Re-bucketing
- ➡ Bunch rotation

SPS acceleration

- ➡ 3 RF systems in PSB
- ➡ 5 RF systems in PS
- ➡ 2 RF systems in SPS



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

One splitting less compared to 25ns beam requires acceleration and splitting of long. small and dense bunches

Beam quality (assuming perfect SPS)

Nominal conditions @ PS extraction: → +/- 10% intensity spread along the batch

→ average bunch length about 4 ns within 0.35 eVs, 1.3E11 ppb within 3 μmrad (1 σ norm)

→ first bunch always different as first third of batch since affected by transient beam loading

→ satellite bunches ~1% (cannot measure less in the PS), observed to be less than 1% in LHC

Sources of spread

Due to slow drift or wrong adjustment (solvable)	Due to beam intensity (difficult to avoid)
Relative phase settings between RF harmonics	Shot-to-shot variations in PSB, also ring-to-ring
Badly adjusted beam transfer PS-SPS	Transient beam loading → rel. RF phase diff. along batch
Big intensity differences of PSB rings or number of rings	Coupled-bunch instabilities

LIU project goals... a reminder

Goal: increase performance of the LHC

Brightness:

- Increase injection energy in the PSB from 50 to 160 MeV, Linac4 (160 MeV H-)
- Increase injection energy in the PS from 1.4 to 2 GeV
- 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…)

Increase reliability and lifetime (until ~2030!): tightly linked with consolidation

- Upgrade/replace ageing equipment (power supplies, magnets, RF…)
- Procure spares
- Improve radio-protection measures (shielding, ventilation…)

PS - LIU Budget as included in the 2011 MTP

		BC	Group	WBS	2011	2012	2013	2014	2015	2016	2017	2018	Total kCHF
							LS1				LS2		
PS	Management (M resources)	61030	BE-ABP	LIU-PS 1	40	80	80	80	80	80	80	40	560
	Beam Dynamics	61031	BE-ABP	LIU-PS 2		10	10	10	10	10	10	10	70
	Magnets	99282	TE-MSC	LIU-PS 3			670	330					1000
	RF	69030	BE-RF	LIU-PS 4	110	305	1230	1330	3500	3500	3200		13175
	EPC	99263	TE-EPC	LIU-PS 5	70	140	1110	580	70	210	180		2360
	Beam instrumentation	64030	BE-BI	LIU-PS 6									0
	Intercepting device		EN-STI	LIU-PS 7		100							100
	Vacuum system	99272	TE-VSC	LIU-PS 8	25	125					3850		4000
	Injection	99253	TE-ABT	LIU-PS 9		135	300	820	780	560	90		2685
	Controls		BE-CO	LIU-PS 11			25						25
	Electrical system		EN-EL	LIU-PS 12									0
	Cooling and ventilation		EN-CV	LIU-PS 13									0
	Transport		EN-HE	LIU-PS 14							880		880
	Civil engineering	76800	GS-SE	LIU-PS 15	30		700						730
	RP	57393	DGS-RP	LIU-PS 16		225	225						450
	Machine Interlocks		TE-MPE	LIU-PS 17									0
	Alarms			LIU-PS 18									0
	Access doors			LIU-PS 19									0
	Survey		BE-ABP	LIU-PS 20							90		90
	OP	67030	BE-OP	LIU-PS 21	140								140
	PS Total				415	1120	4350	3150	4440	4360	8380	50	26265

Plus consolidation work that should be of the order of about 43 MCHF

PS Upgrades

Injection, magnets,power converters

System	Elements
Injection elements	Injection septum Injection bumpers Eventual extra kicker
Low energy correctors	100 horizontal correctors 30 vertical correctors
Low energy skew quadrupoles	45 magnets
Low energy quadrupoles	40 magnets
Transverse damper	Power part of existing system
e-cloud attenuation system	Chamber coating or electrode Installation
Instrumentation	BWS, BCT, Orbit system, profile monitors.
Improved shielding on top of route Goward and on top of SMH16	Shielding elements

RF

Priority	Item	When
[1]	New coupled-bunch FB	2012
2	Dedicated kicker cavity	2015-2020
10 MHz		
[1]	1-turn delay FB	2011
1	Renovate FB amplifiers	2011-2015 (?)
1	Slow phase loops around each cavity	2013-2014
2	New power amplifier (1 tube/gap)	2014-2018 (?)
20 MHz		
1	1-turn delay FB	2012
2	Slow phase loops around each cavity	2012
40 MHz		
[1]	Automatic tuning system	2011
1	1-turn delay FB	2012
2	New feedback amplifier in grooves	2014
2	Slow phase loops around each cavity	2012
3	Study more voltage per cavity	2013
3	New power supplies	2014-
80 MHz		
1	1-turn delay FB	2012
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
2	Fast ferrite tuner	2016
3	Study more voltage per cavity	2013
3	New power supplies	2014-
3	Extra 80 MHz cavity	???

Caveat for beam characteristics prediction…

- Beam parameters are given at injection in LHC: beam loss and blow-up inside the LHC are not accounted for.

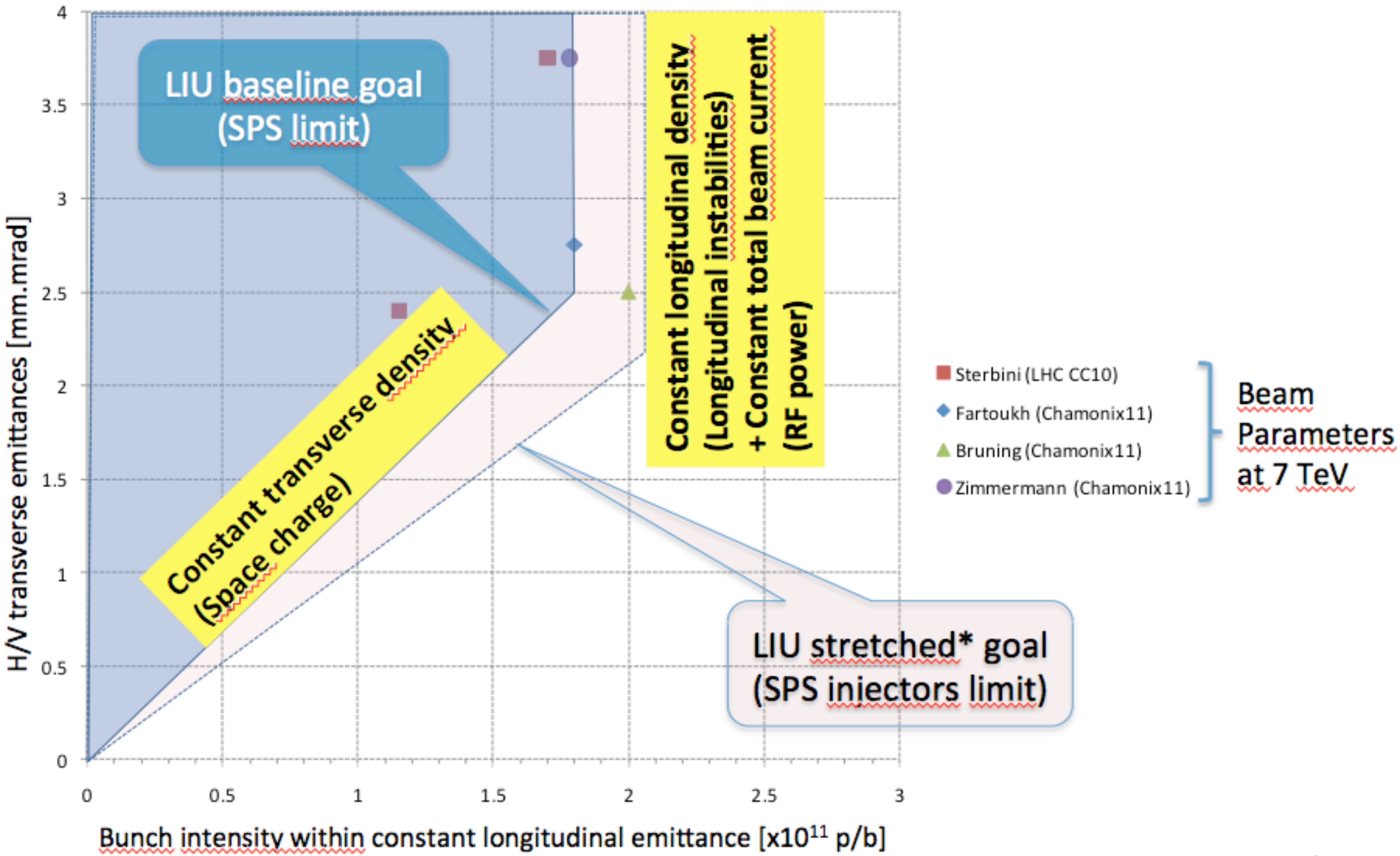
- All necessary improvements are implemented in the injectors (Linac4, PSB to PS transfer at 2 GeV, coupled bunch instabilities suppressed, e-cloud suppressed, hardware upgraded…)

- Estimated beam degradation in the accelerator chain (based on observations in 2010):
  - ✓ PS: 5 % beam loss, 5 % transverse blow-up
  - ✓ SPS: 10 % beam loss, 5 % transverse blow-up.

- RF gymnastics being kept, imperfections are unchanged:
  - ✓ +-10 % fluctuation of all bunch parameters within a given PS bunch train.
  - ✓ Traces of ghost/satellite bunches.

R. Garoby

Beam parameters: Comments



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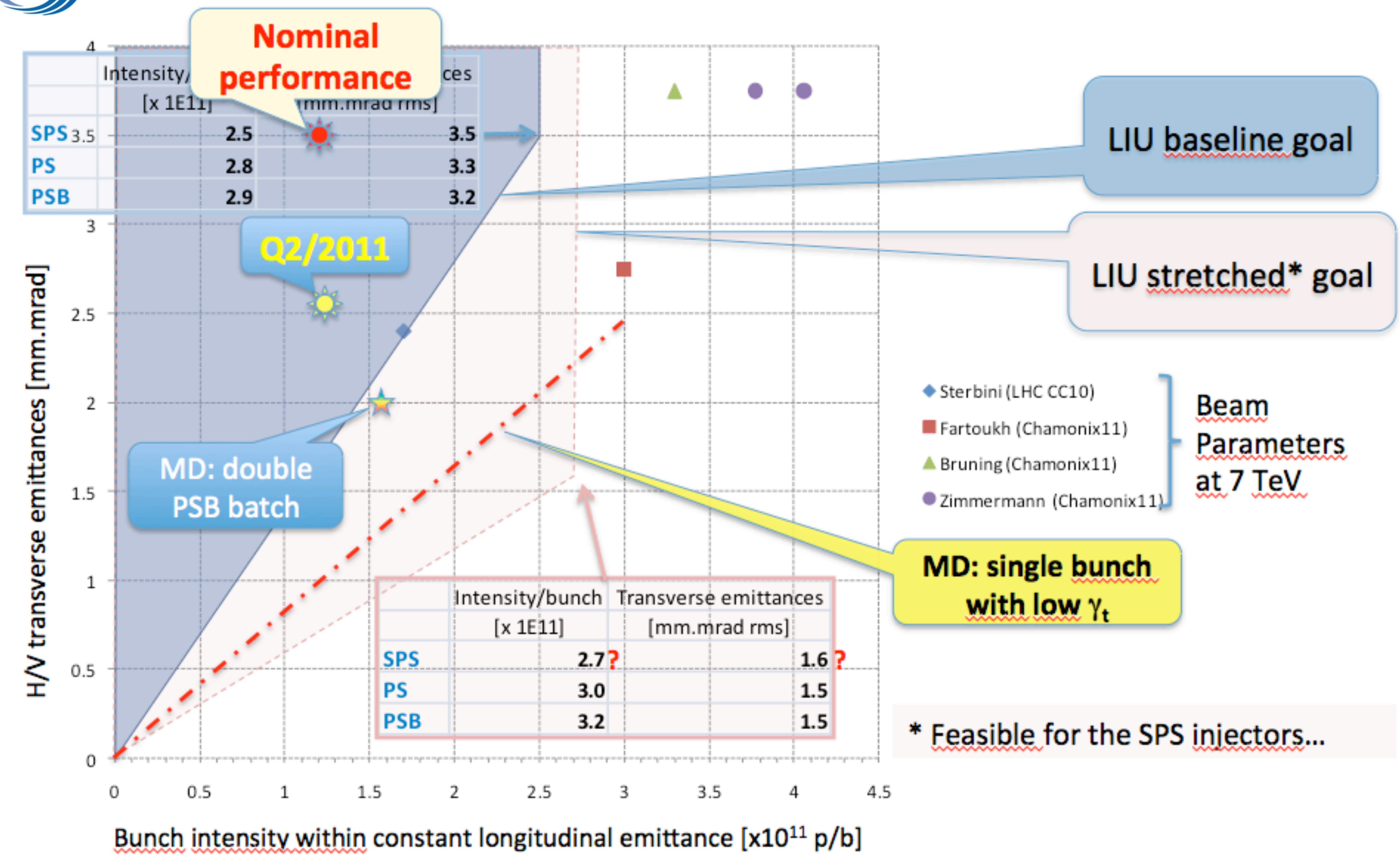
Beam parameters at LHC injection [50 ns]



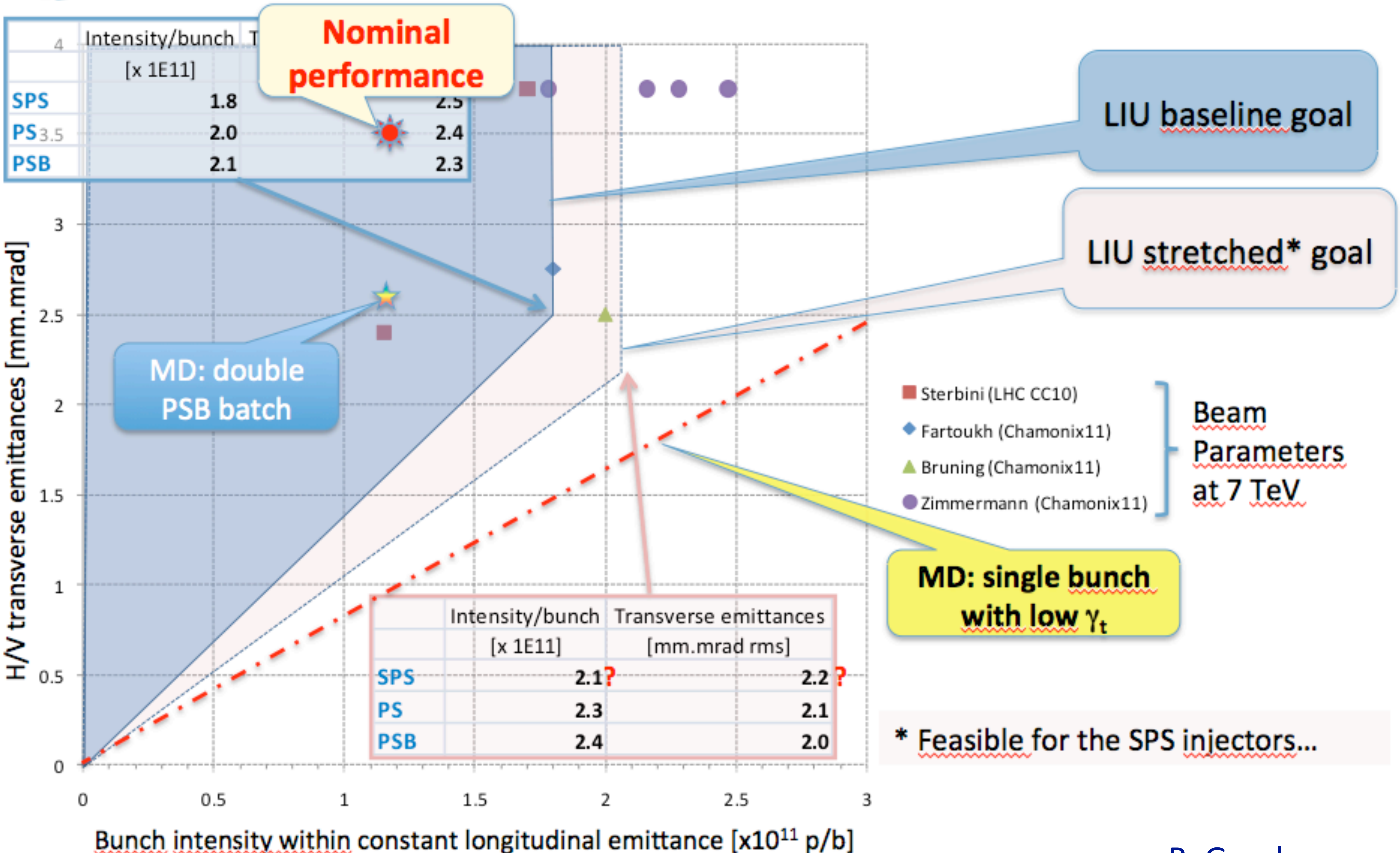
	Intensity/... [x 1E11]	...ces ...mm.mrad rms]
SPS	2.5	3.5
PS	2.8	3.3
PSB	2.9	3.2

	Intensity/bunch [x 1E11]	Transverse emittances [mm.mrad rms]
SPS	2.7?	1.6?
PS	3.0	1.5
PSB	3.2	1.5

* Feasible for the SPS injectors…

R. Garoby

Beam parameters at LHC injection [25 ns]



* Feasible for the SPS injectors…

R. Garoby

PS injector: PSB or RCS

Available options:

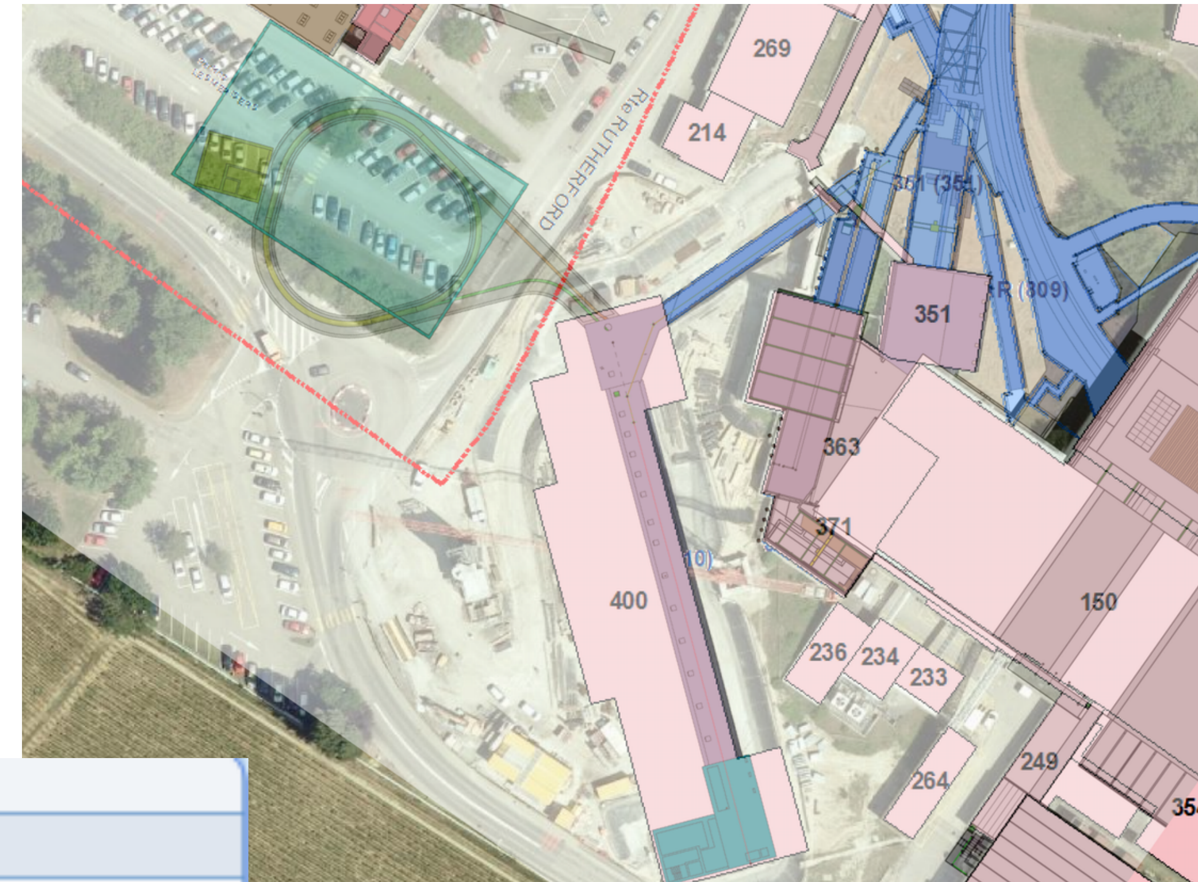
(a) Increase PSB extraction energy to 2 GeV

(b) Build new RCS at 10 Hz **(report for end of June, news in September)**

Impact on PS injection design:

- Option (a)
  - same geometry of the injection as today
  - BT-BTP ppm (new magnets, new power converters)
  - new septum
  - extra kicker to inject high intensity beam
- Option (b)
  - same injection point as today
  - new septum **(new technology, never built for such high energy and large aperture)**

RCS at 10 Hz



RCS pulsing at 10 Hz

- beams with same characteristics as from PSB at 2 GeV

Energy range	160 MeV to 2 GeV
Circumference	(200x 4/21) π m ≈ 119.68 m
Repetition rate	~10 Hz
RF voltage	60 kV
Harmonics	h = 1 + 2 (in option: 4)
Frequency range	1.3 MHz (h=1 at injection) to 9.5 MHz (h=4 at ejection)
Beam parameters for LHC (for lower emittances scale down intensity accordingly)	Intensity: up to 12×2.7 10^{11} protons/cycle (3.25 10^{12} p/p) Transv. emittance: ε^*_{rms} ≈ 2.5 μm Long. emittance: ε_l < 12×0.27 eVs (determined by acceptance for most cases)
Lattice	3-fold symmetry 21 cells, 5 cells/arc, 2 cells/straight section
Tunes	$3.5 < Q_{H,V} < 4.5$
Length of straight section (4x)	2 x 2.35 m
Relativistic gamma at transition	~4
Maximum magnetic field	< 1.3 T

Injection scheme

Injection to be re-designed (common to PSB or RCS)

- No margin left for the existing septum
- Kicker strength not enough to inject non-LHC-type beams at 2 GeV, second kicker in SS53

Injection point

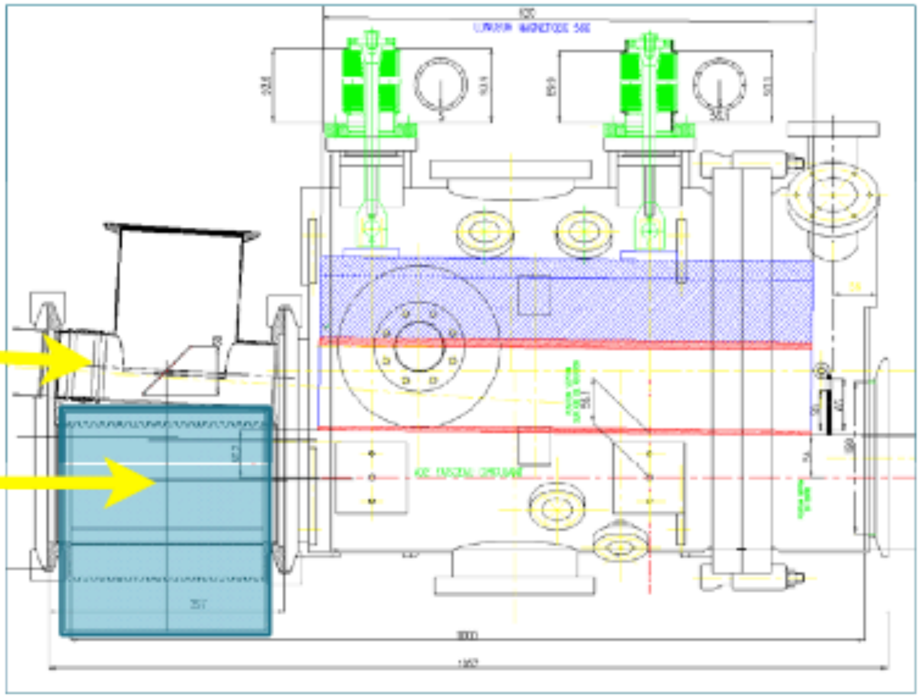
- not changed wrt to today to minimise intervention and reshuffling of the elements in the tunnel
- Route Goward shielding must be increased

Injection design done to minimize continuous losses

- Assumption on the injection: physical emittance the same as today.

PSB injection: new septum design

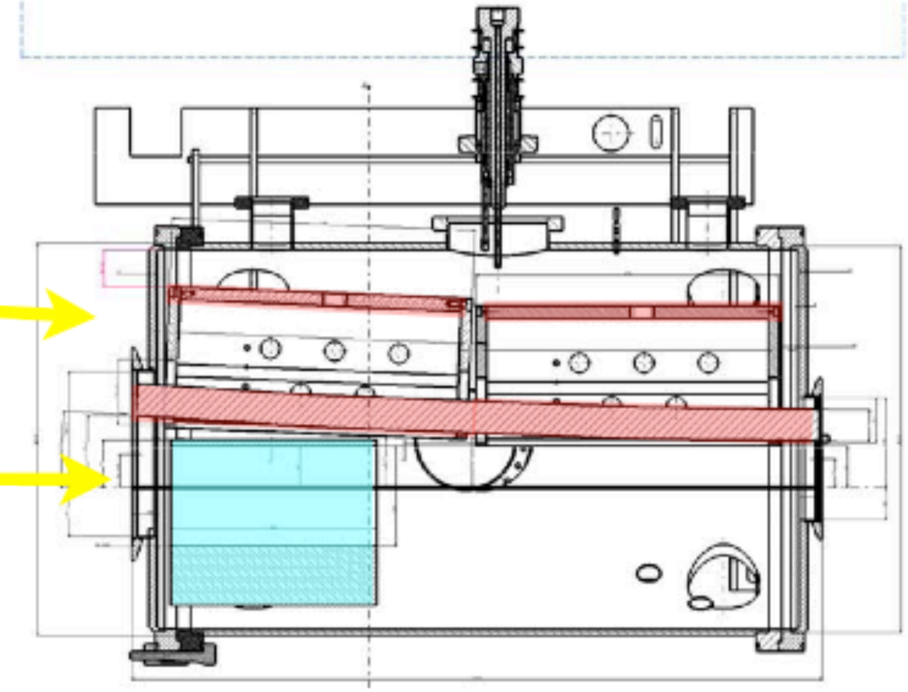
Old



BTP

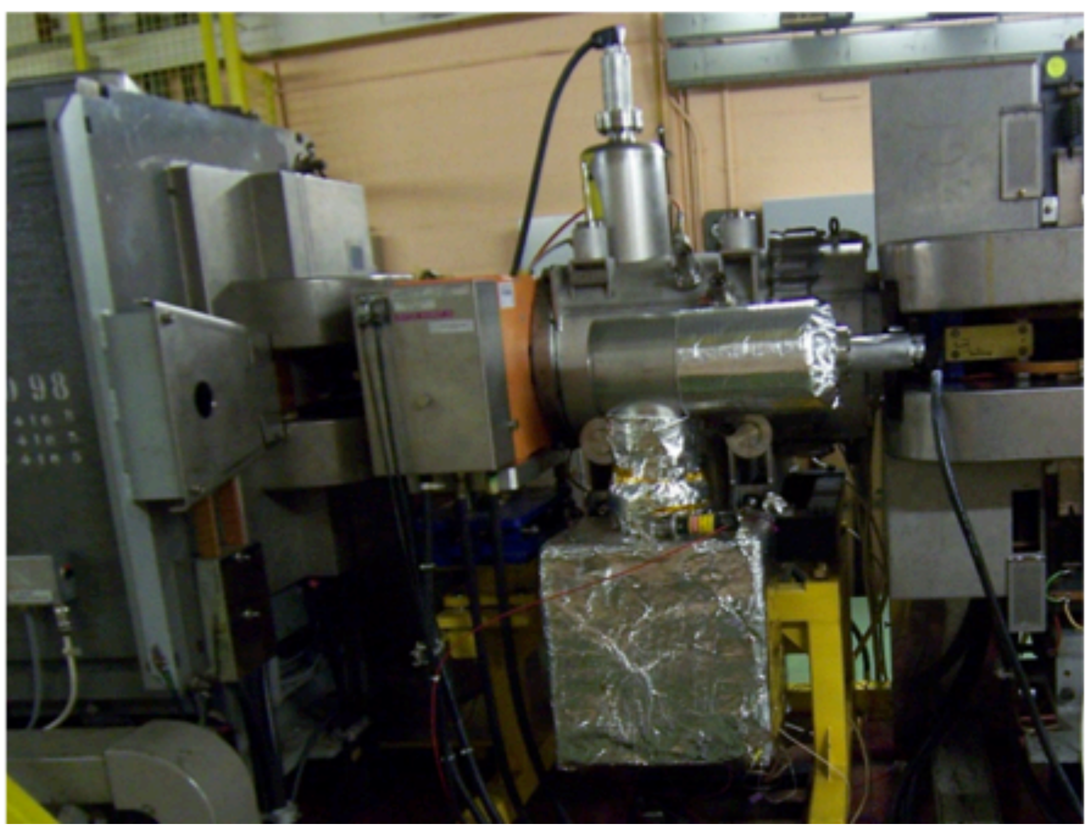
Ring

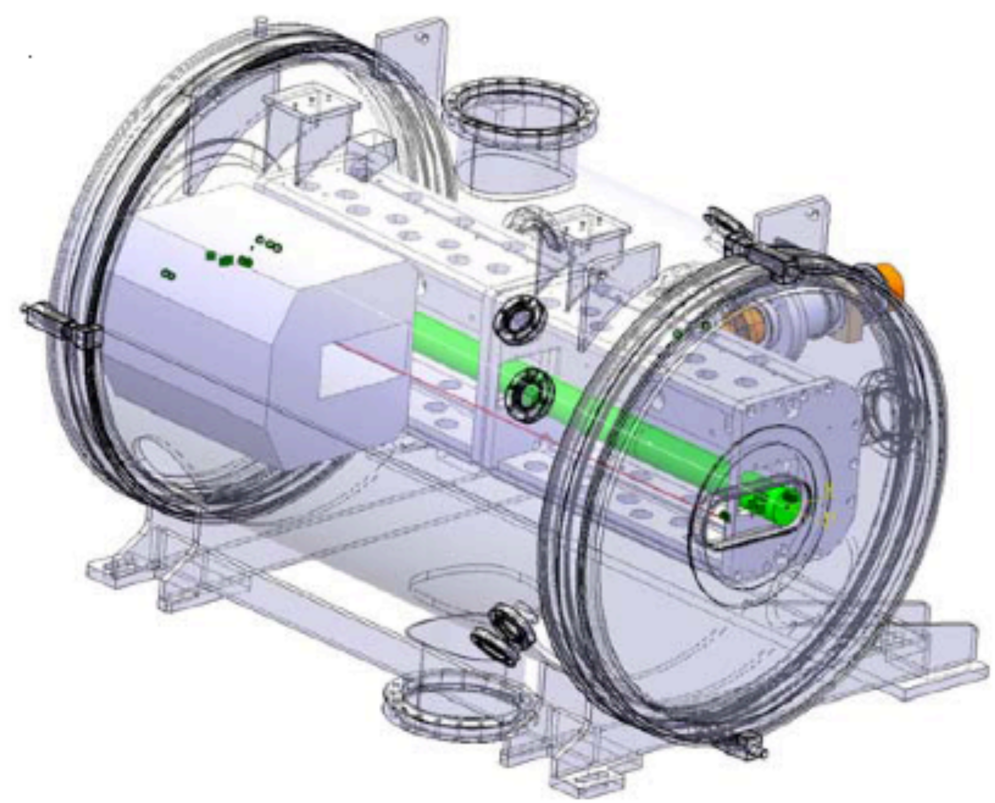
New



BTP

Ring

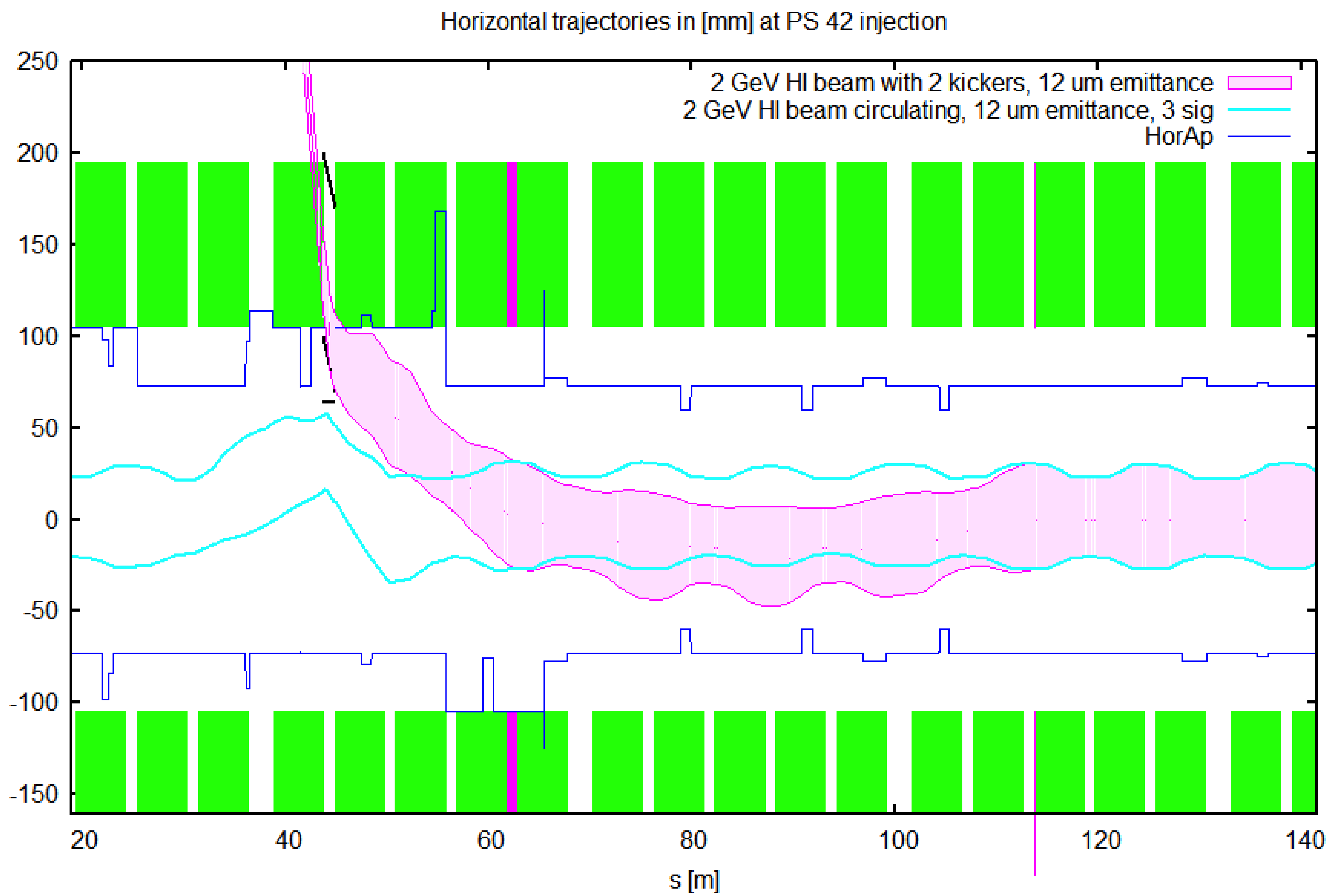


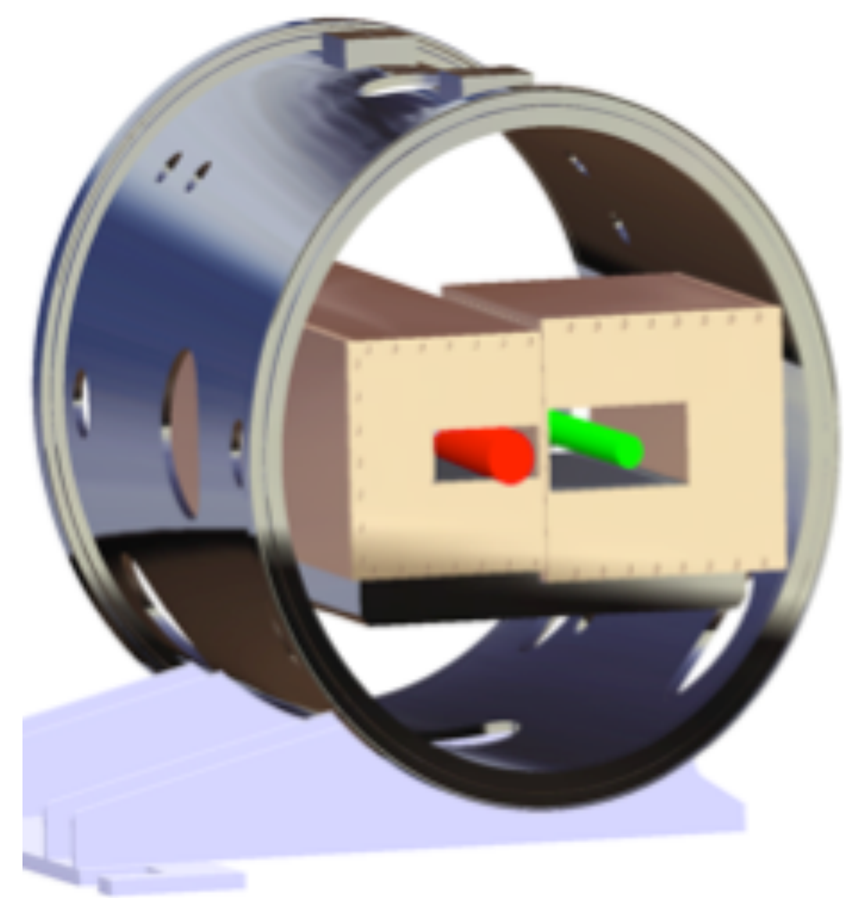


RCS injection

Vertical septum aperture on the injection line side limited to 48 mm

Re-use existing kicker and the new one proposed for the PSB injection

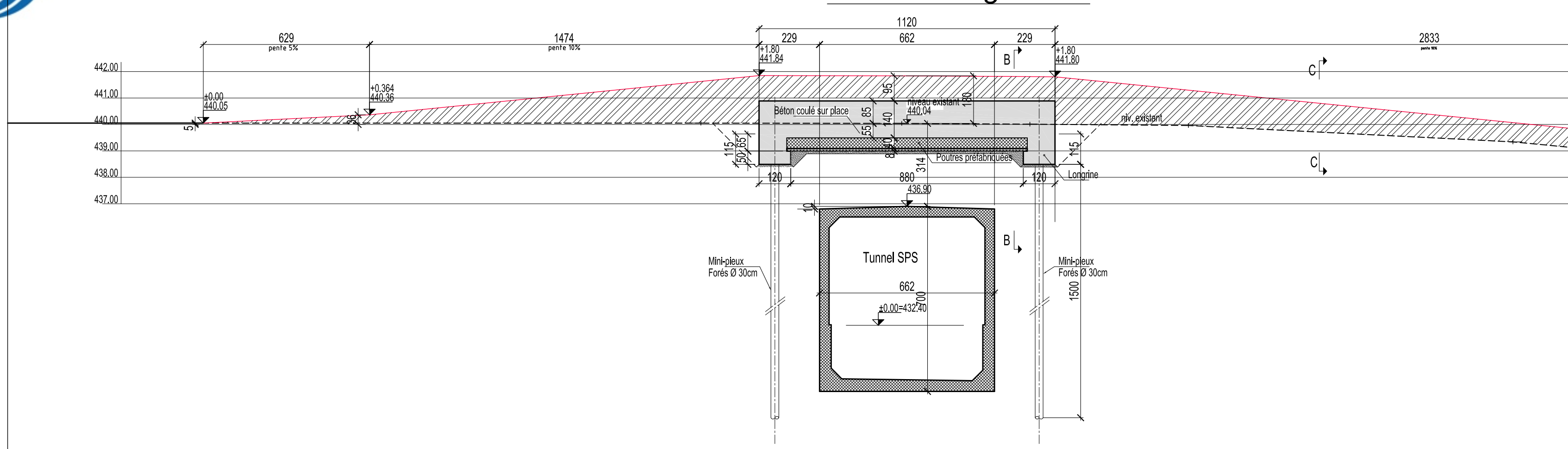




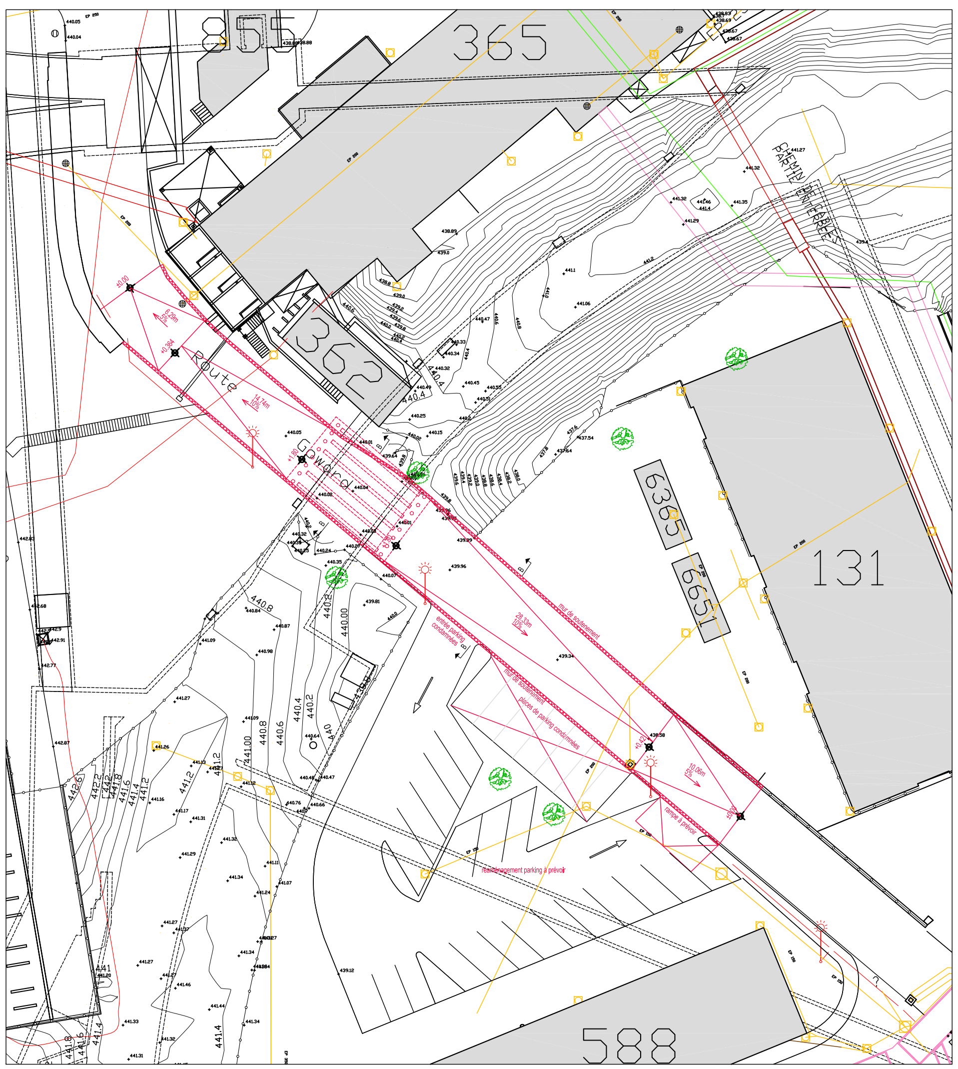
W. Bartmann

Route Goward shielding

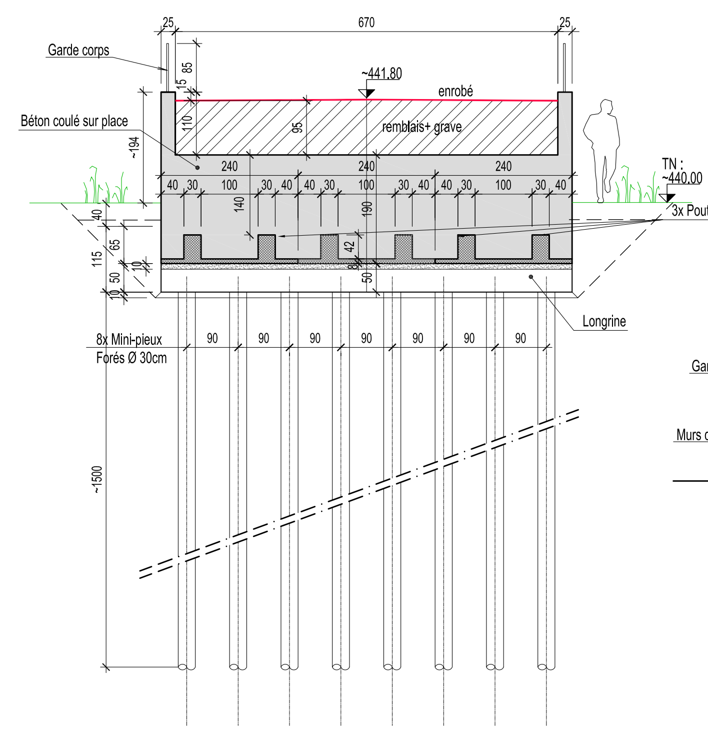
Profil en long 1:100



Vue en plan 1:250



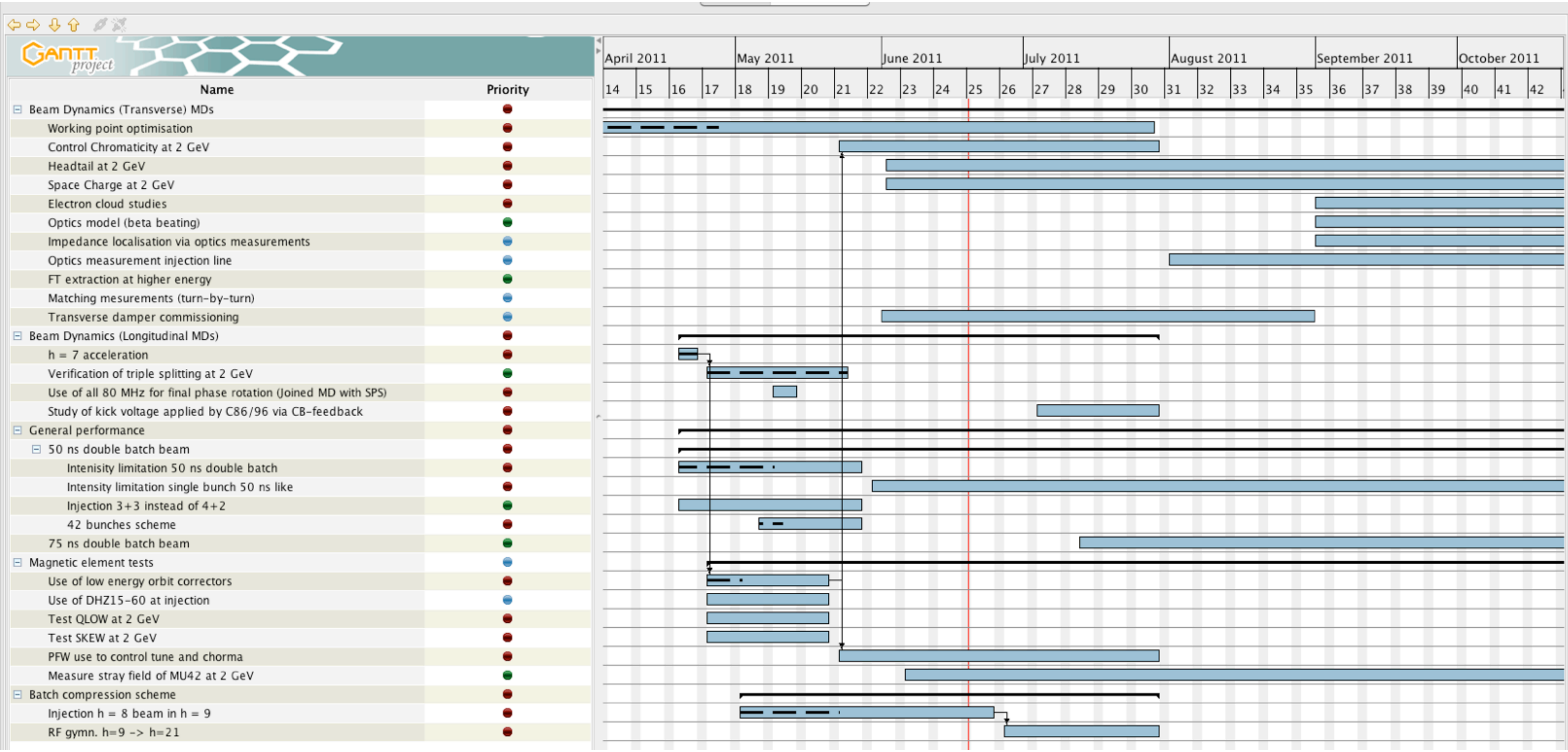
Coupe B-B 1:50



Shielding: 1.8 m of concrete on top of the injection plus earth on the sides

ROUTE GOWARD
PROJET DE RENFORCEMENT SUR TUNNEL SPS
NON VALABLE POUR EXECUTION
NOT VALID FOR EXECUTION
----.CE-1.14600001

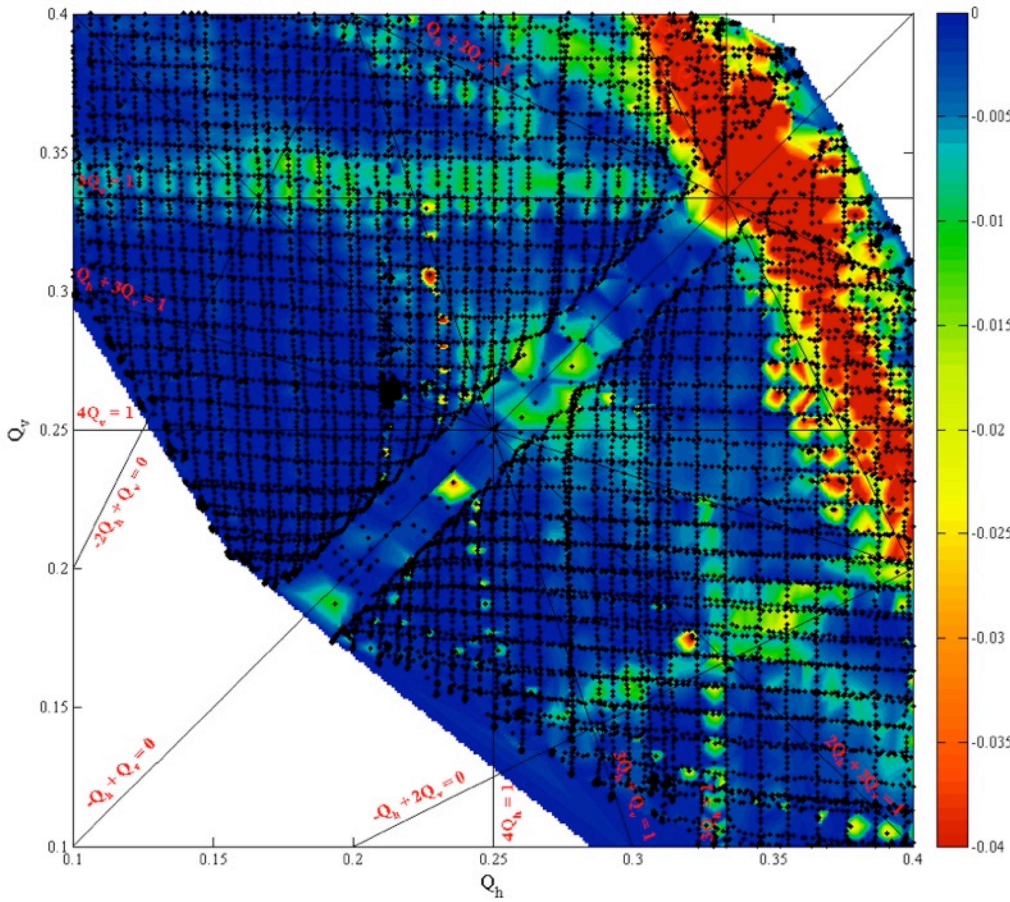
MD initial planning



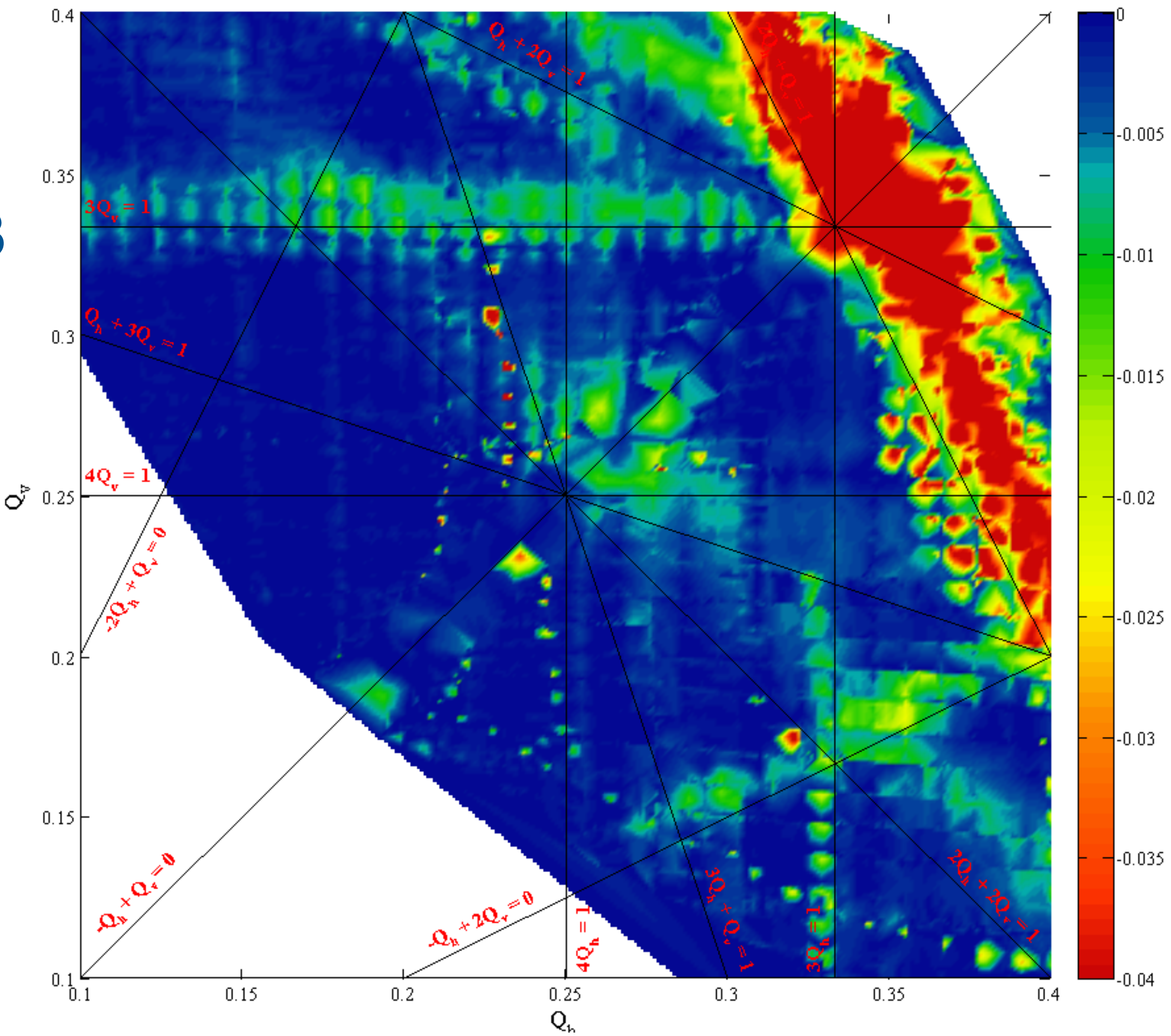
MD resonance studies on injection flat bottom

Measurement to determine the best injection working point and dangerous resonances.

Today WP (LHC50): Qx=0.21 Qy=0.23



Measurements @ 2 GeV



From E. Benedetto

Next steps for resonance studies

Measurement to be finalized without PFW/F8L

- measurements done with and w/o Landau octupoles
- measurements with octupoles useful for Headtail cure

Measurement with PFW/F8L

- needed to access the lower left angle of the tune diagram
- high order multipoles would excite high order resonances
- three-current working point preferred to minimize the octupolar component (no matrix for that)

Simulations

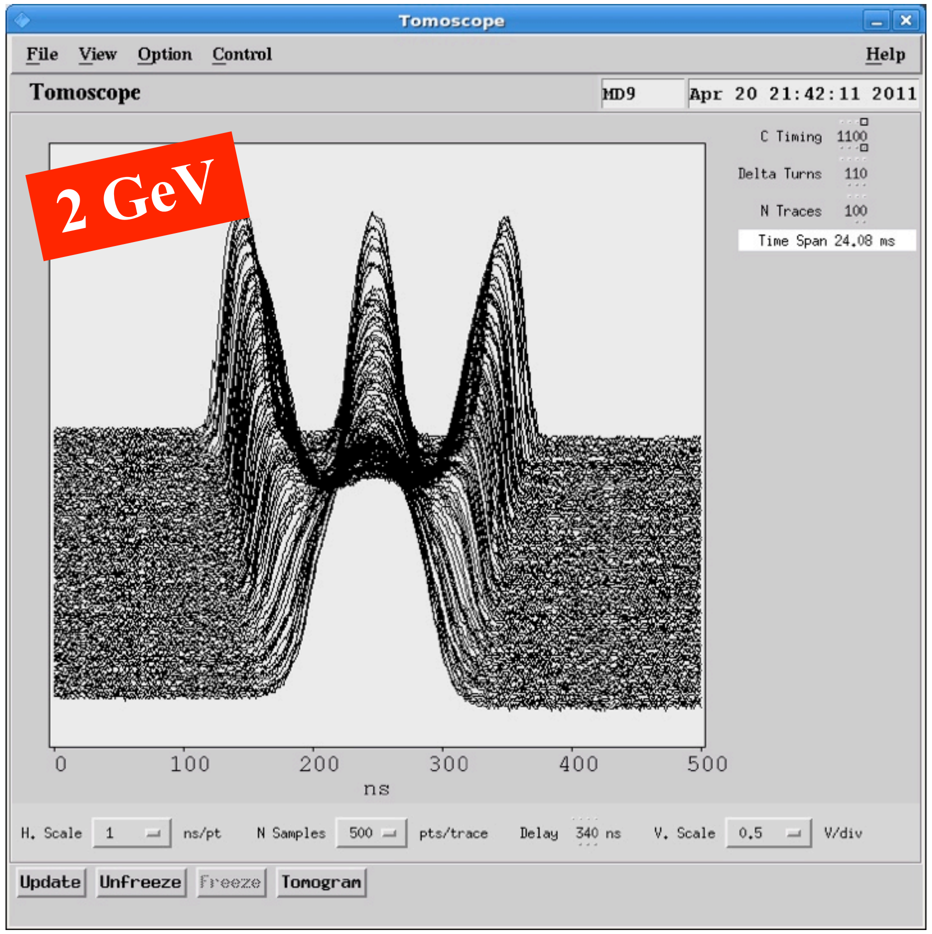
- PTC-ORBIT implemented for the PS
- No results yet on space-charge but only for single-particle optics

Acceleration to 2 GeV on h = 7 + triple split

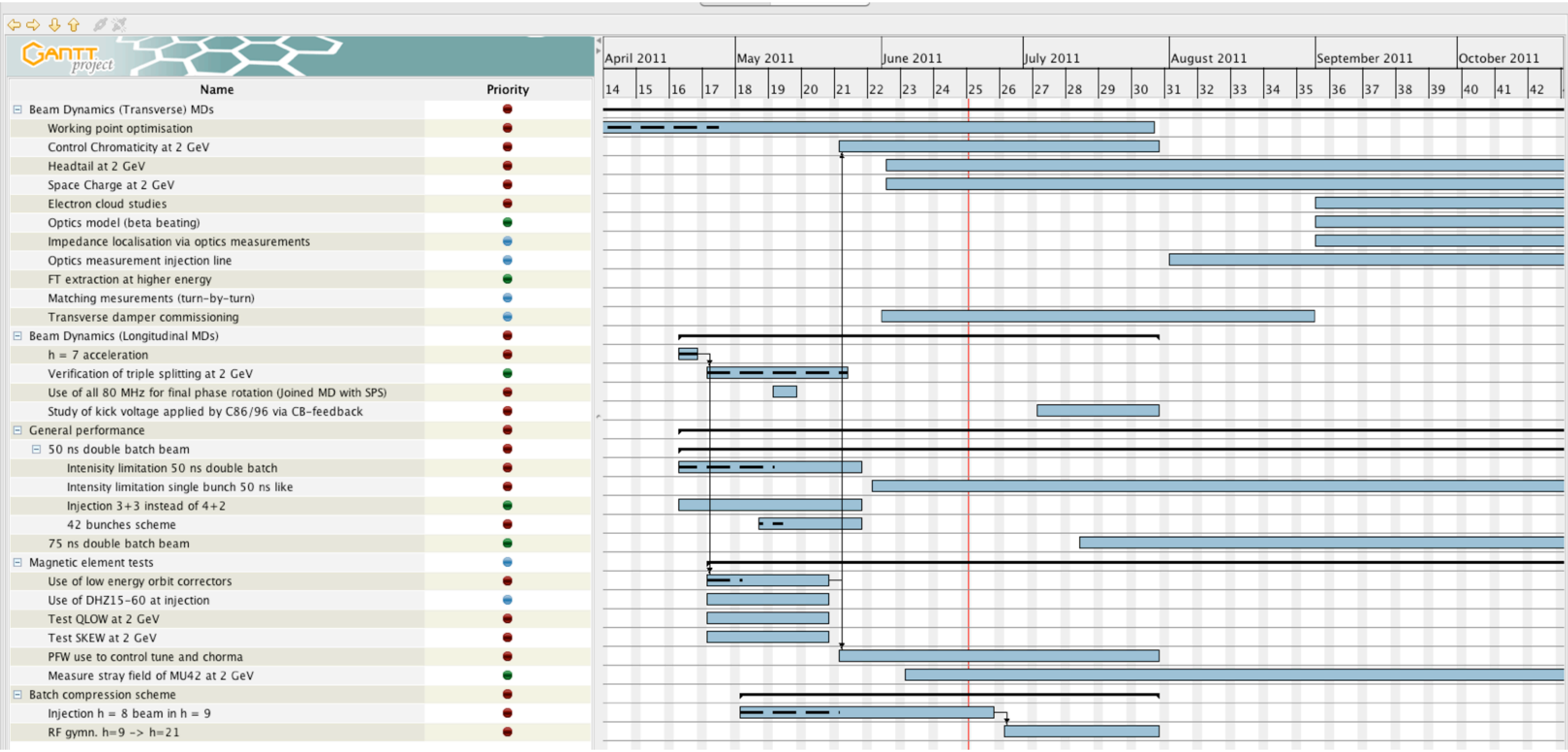
Injection at 1.4 GeV identical to LHC25ns (but only one bunch)
Acceleration to 2 GeV with phase and radial loop, but without stable phase programme → OK

First test of triple splitting at 2 GeV using copy of voltage programmes for 1.4 GeV successful

- Straight-forward to establish triple splitting (forward and return phase adjustments, all PPM)
- No problem with adiabaticity, even though $fs_{,1.4GeV}/fs_{,2GeV} = 1.5$



Other MDs...


GANTT project
Name
Priority
April 2011
May 2011
June 2011
July 2011
August 2011
September 2011
October 2011
14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42
Beam Dynamics (Transverse) MDs
Working point optimisation
Control Chromaticity at 2 GeV
Headtail at 2 GeV
Space Charge at 2 GeV
Electron cloud studies
Optics model (beta beating)
Impedance localisation via optics measurements
Optics measurement injection line
FT extraction at higher energy
Matching mesurements (turn-by-turn)
Transverse damper commissioning
Beam Dynamics (Longitudinal MDs)
h = 7 acceleration
Verification of triple splitting at 2 GeV
Use of all 80 MHz for final phase rotation (Joined MD with SPS)
Study of kick voltage applied by C86/96 via CB-feedback
General performance
50 ns double batch beam
Intenisity limitation 50 ns double batch
Intensity limitation single bunch 50 ns like
Injection 3+3 instead of 4+2
42 bunches scheme
75 ns double batch beam
Magnetic element tests
Use of low energy orbit correctors
Use of DHZ15-60 at injection
Test QLOW at 2 GeV
Test SKEW at 2 GeV
PFW use to control tune and chorma
Measure stray field of MU42 at 2 GeV
Batch compression scheme
Injection h = 8 beam in h = 9
RF gymn. h=9 -> h=21

TFB

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 us for the LHC pilot beam)

Existing system commissioning should take place in 2011 run (currently not operational).

Commissioning delayed to September

To obtain the same damping rate at 2 GeV the required power need to be multiplied by 1.7

3 kW amplifier for 1.4 GeV → 5.1 kW amplifiers at 2 GeV

There is possibility that adding another kicker would be best suited… with increased costs

The present bandwidth is 23 MHz.

It is likely that 50 MHz can be reached with a new design (if required)
→ is this enough with the extraction bunching at 40 and 80 MHz and its related electron cloud effect???

Transition crossing

- Longitudinal plane: no limitations at transition crossing expected for (beyond) ultimate beams. Peak current only allows an estimation, no direct scaling.
- No problem up to 2 10^{11} ppb (at PS ej.) during ultimate LHC25 tests (good for crossing transition with up to 4 · 10^{11} ppb at ej. with LHC50).
- Peak current of ultimate beams below present limitations (with e.g. TOF or AD beams).

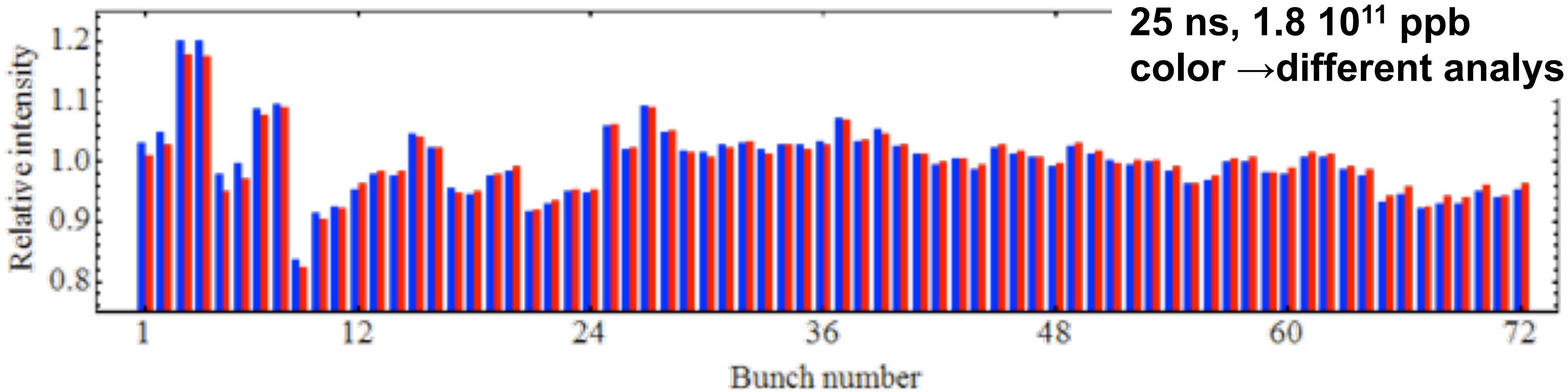
Beam	Int. [10^{11} ppb] at ejection	Intensity [10^{11} ppb]	Long. emittance ε_l [eVs]	Pk. current at γ_{tr} [A]
LHC25, nominal	1.3	5.2	0.65	8.4
LHC25, ultimate	2.1	8.4	0.65	14
LHC50, nominal	1.3	2.6	0.65	4.2
LHC50, beyond ult.	3.0	6.0	0.65	9.7
SFTPRO/CNGS		17	1.4	15
AD		40	2.3	23
TOF		89	2.6	40

- The TMCI instability observed on the TOF beam, and causing vertical losses, has a threshold beyond the more-than-ultimate LHC beam, stable for ~2 x 10^{12} ppb (2010 results). Further studies will be done. Might cause ε(x,y) blow-up. Transverse emittance blow-up observed during 2010 tests with ultimate beam.

Sources of longitudinal beam parameter degradation

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 with consequences for the SPS.



25 ns, 1.8 10^{11} ppb
color →different analysis

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

Mode spectrum very similar for the same average longitudinal density (25 ns or 50 ns) ~ N/εl .

Very different mode spectra during acceleration and on the flat-top depending on bunch spacing (25 ns or 50 ns).
→ Impedance change of 10 MHz cavities due to gap relay closing.

RF Upgrades within PS-LIU

2011/2012: Study phase for RF

- MD studies and measurements on equipment
- Check feasibility and benefits of upgrade ideas
- Prioritise

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

Planning for 2011-2014

Foreseeable studies and upgrades:

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

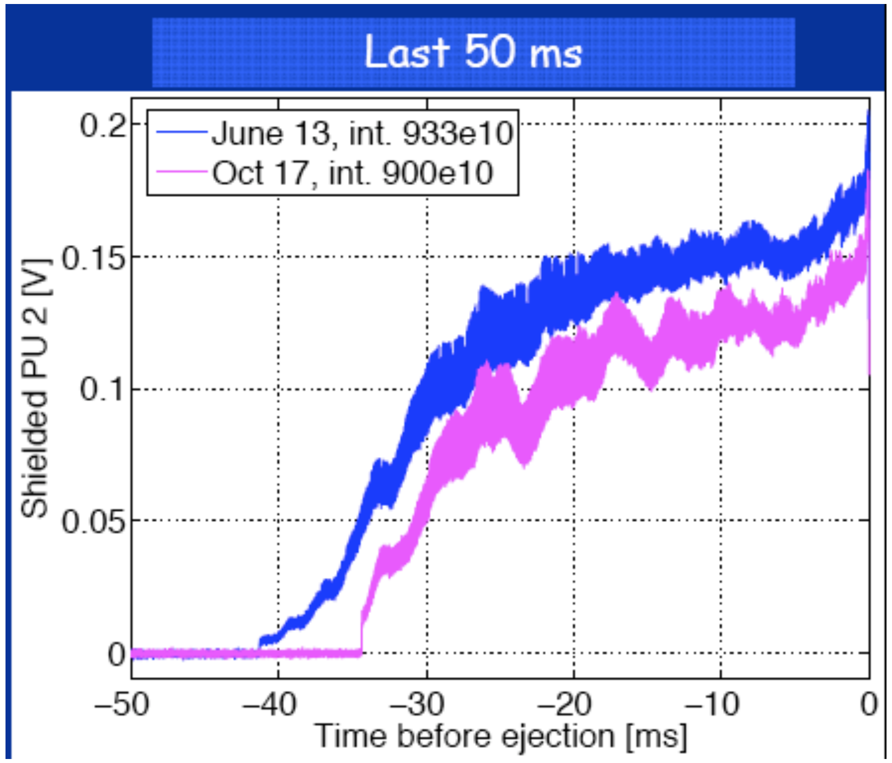
→ RF upgrades within PS-LIU aim at improving longitudinal beam stability and reduction of transient beam loading

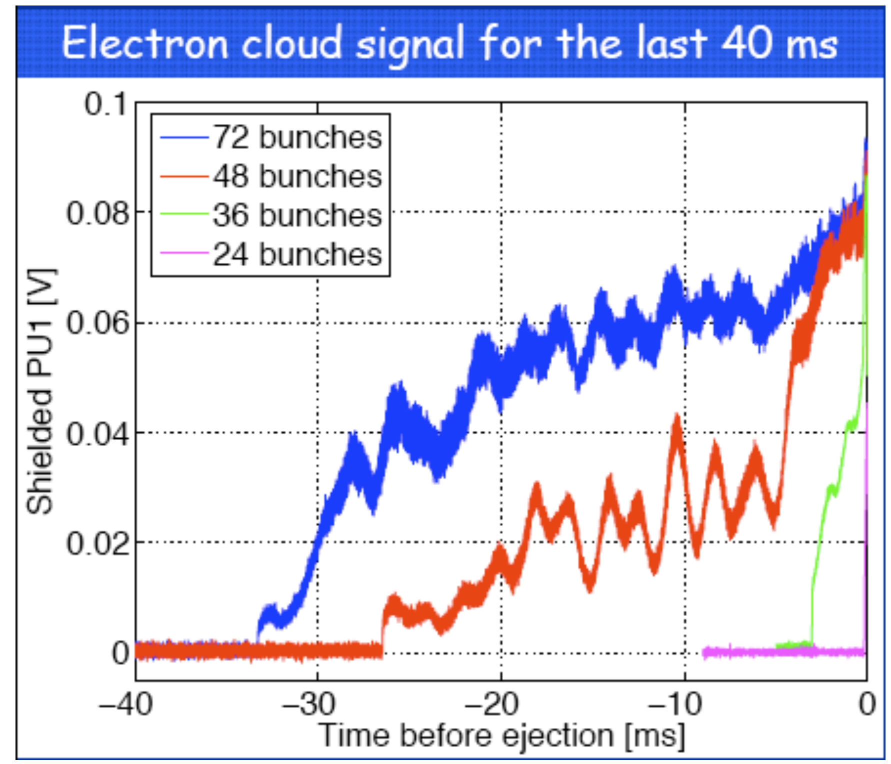
→ Essentially independent from 1.4 GeV or 2 GeV injection energy

Flat top (transverse)

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

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





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. Starting in september

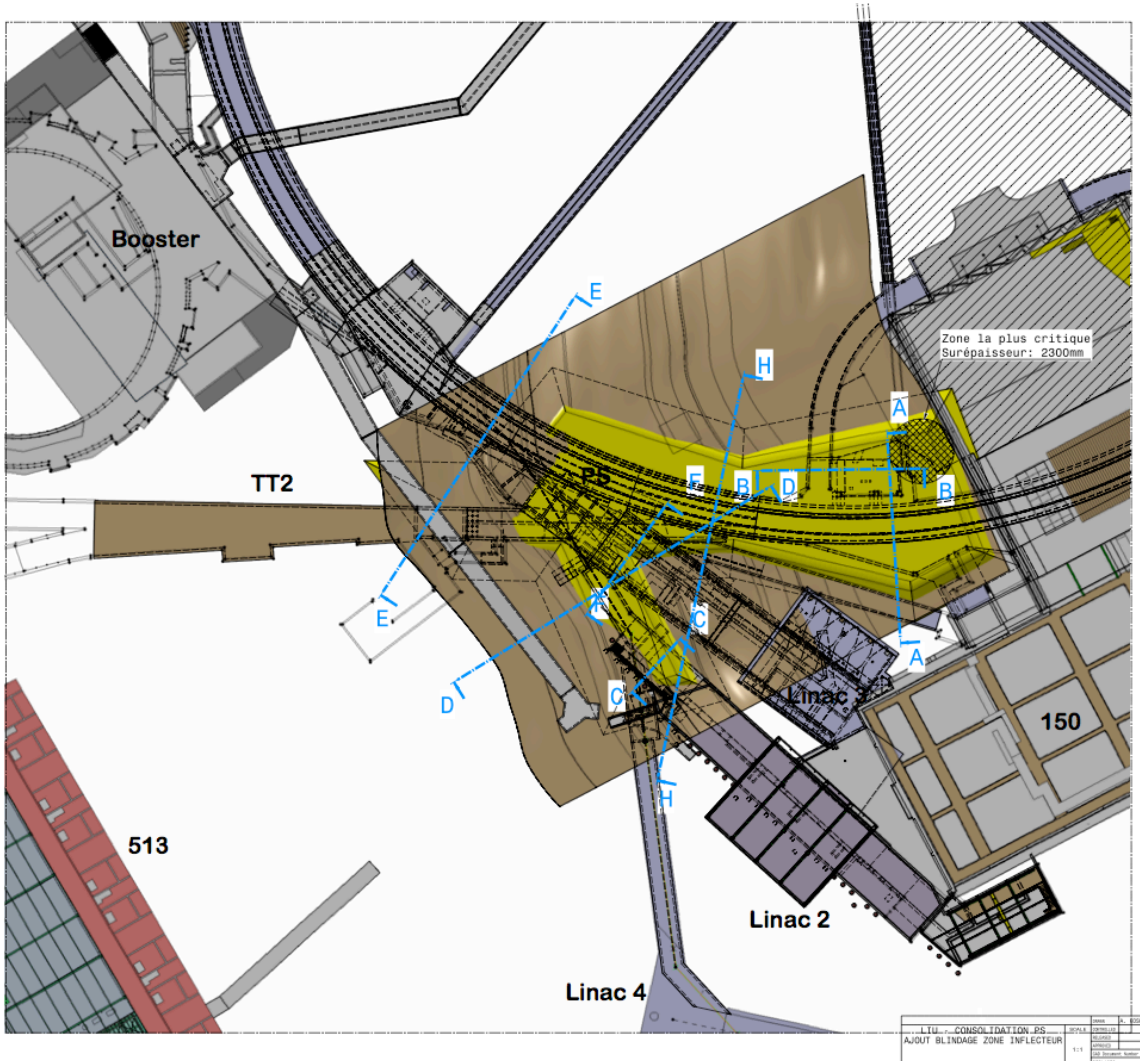
- Transverse instabilities at flat top observed in 2001, 2004 and again 2006.
- Probably related to electron cloud (why mainly horizontal and why not cured by chromaticity).
- Coupled bunch or single bunch effect?
- Threshold of 4.5 x 10^{10} ppb for a bunch length of 10 ns.

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

Septum 16 shielding

Shielding on top of SMH16 found too thin for the high intensity operation (MTE or not

- Proposal to increase the thickness (yellow part)

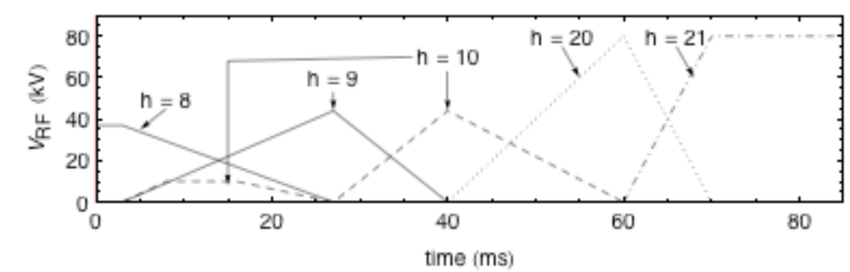


Alternative schemes: batch compression

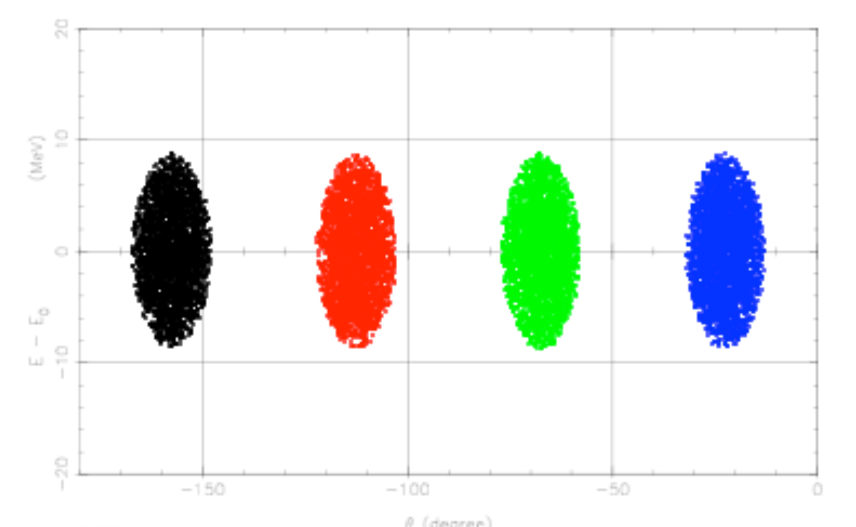
Batch compression in the PS to increase brightness after acceleration to a suitable energy

Abandon factor 7 in PS harmonics to:
(i) use all four PSB rings (with single batch transfer)
(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



Reduced number of bunches per PS cycle
→ Higher intensity per bunch and, thus, brightness



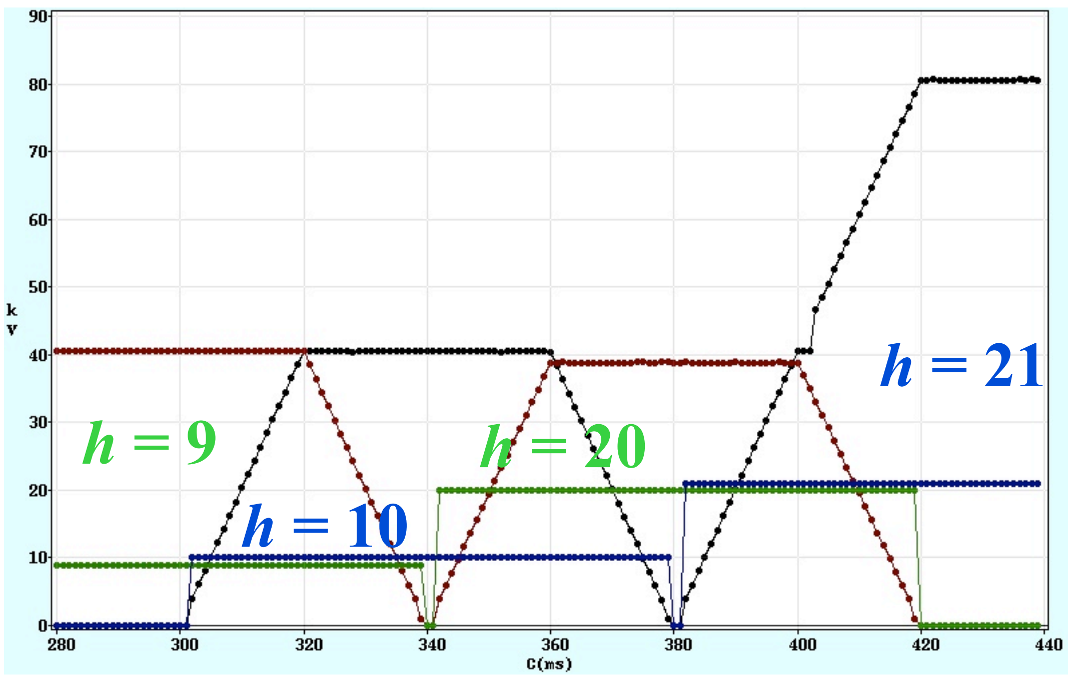
- Difficult operation due to many RF harmonics changes
- MDs and studies in 2011 (see next slide)
- Could be use to produce beams for tests in the SPS

See C. Carli, Chamonix 2011

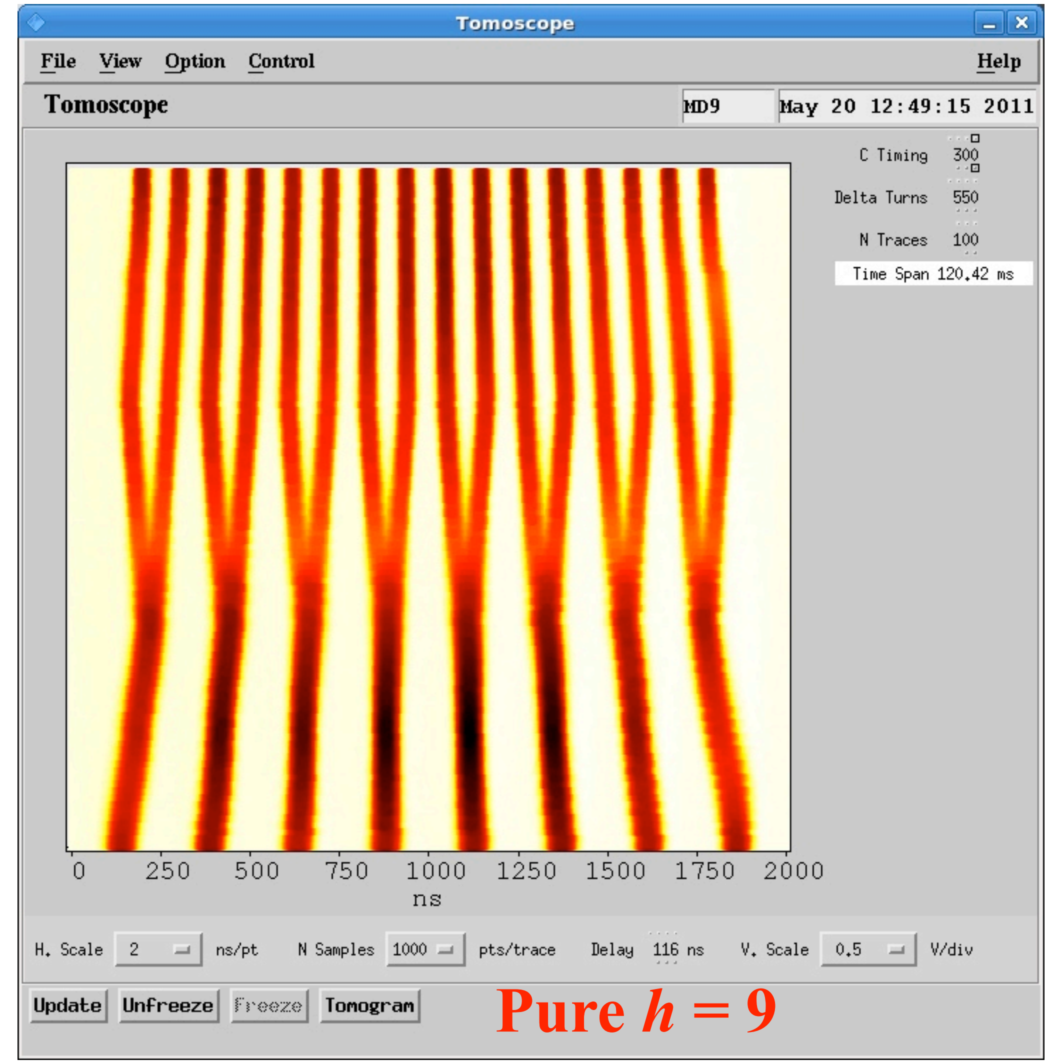
25/50 ns bunch spacing without triple splitting

$h2+1_{PSB} \rightarrow h9_{PS}$ and $h = 9 \rightarrow 10 \rightarrow 20 \rightarrow 21$

Voltage programs:



Pure $h = 21$



Pure $h = 9$

✓ Proof-of-principle OK

- 2 GeV: ε_l = 1.2 eVs max. (0.8 @ 1.4 GeV)

→ But, several technical issues + developments to make it operational:

- Need injection bucket selector for h = 9 (+ 2nd inj.?) → new development
- Switching to h = 9 local oscillators must be correctly implemented
- Need to switch to h = 21 phase loop using real cavity return before acc. → modifications to LHC beam control for more phase loop harmonics
- Cavity return sum h = 20?

Works foreseen for LS1: magnets (tunnel work)

- Low energy magnet replacement:
  - Orbit correctors
  - Trim quadrupoles
  - Skew quadrupoles
- Definitive list of magnets to be replaced: pending results of MDs
- Magnet exchanges not in conflict with LHC interventions in terms of resources
- Possible exchange of main bus-bars in conflict with the interventions
- Work could be postponed during LS2

Works foreseen for LS1: civil

R.te Goward: increase of the shielding should be done during the LS1 to avoid interference with the LS2 upgrade work: route is the only access to the center of the ring.

Shielding on top of SMH16: study should be started this year, not clear if can be done during LS1

Comment on PS-upgrade

Not many activities in the tunnel foreseen during LS1 because:

- ➡Upgrade studies recently started: studies still to be done to decide equipment/solution to be applied (eg. LL/HL RF)
- ➡the technical design of many components remains to be made, even if choice already done (eg. Injection elements will be ready only for LS2)

Many activities are outside the tunnel, like:

- ➡renovation/consolidation of power converters

Most of activities concentrated during LS2.

Conclusions

- Beam parameters for the LIU defined as exclusion plots based on current operation and educated-guess extrapolations
- Short for the 25 ns, to be discussed end of this week with HL-LHC
- MDs ongoing
  - difficult due to sometimes lack of beam time, instrumentations (improved!)
  - limited resources: new comers, operators, + Elena (synergy of some studies with Beta-Beam)
- Simulation studies
  - Space charge: first tests with PTC-ORBIT seems to be encouraging, technically the code works, physics results to be discussed
- In general, project suffering due to lack of resources:
  - within the group in particular for the collective effect studies. Solution under investigation (outsourcing ....)
  - for the MDs, relying on the operators, Elena, Gersende, Sandra (none of them in principle should work on PS-LIU)
  - for the BI specifications
  - looking for help to follow-up the organization-managing of the project

Spares...

Linac4 connection to the PSB

- High interest of connecting Linac4 to the PSB during LS1:
  - ✓ **Staged upgrade spread between LS1 and LS2 (shorter LS2 ?)**
  - ✓ **Timely termination of the Linac4 project**
- Reasonable scenario (with 20 months LHC shutdown) if LHC stops in May 2013
  - ⇒ **Possibility to run the injectors until the end of 2013**
  - ⇒ **No beam for physics before early 2015**

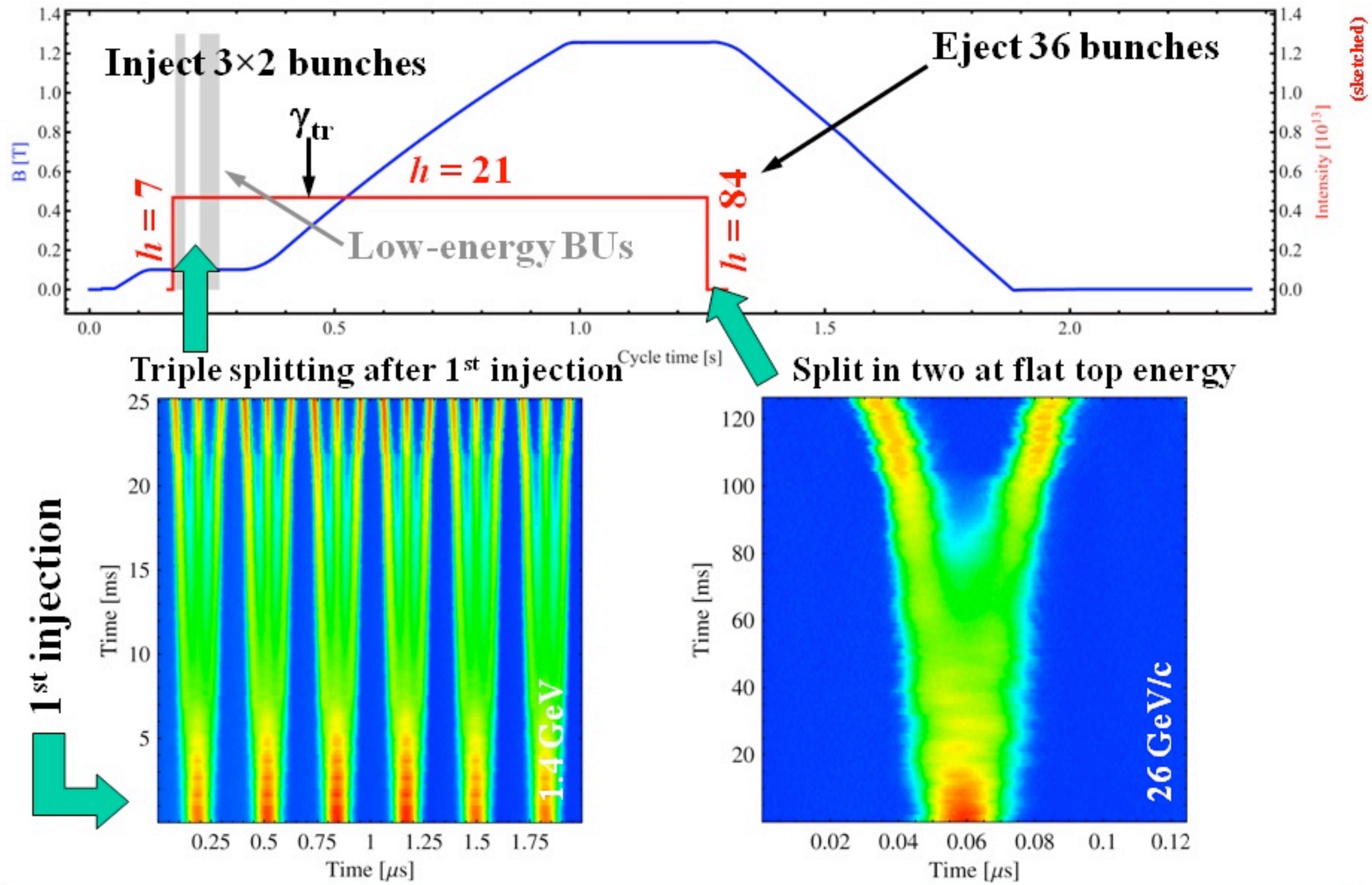
TENTATIVE SCHEDULE - CONNECTION LINAC4 DURING LONG SHUT-DOWN 2013/2014 - version B 06.04.11

M. Vretenar

2013												2014												COMMENTS
1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	
				Linac4 commissioning																				L4 commissioning original schedule
															Reliability run									Reliability run 5 months
																		Transfer line commissioning						
																	PSB modifications							
																				PSB commissioning				
																							PS/SPS commissioning	
				LHC Shut-down (20 months beam-to-beam)																				

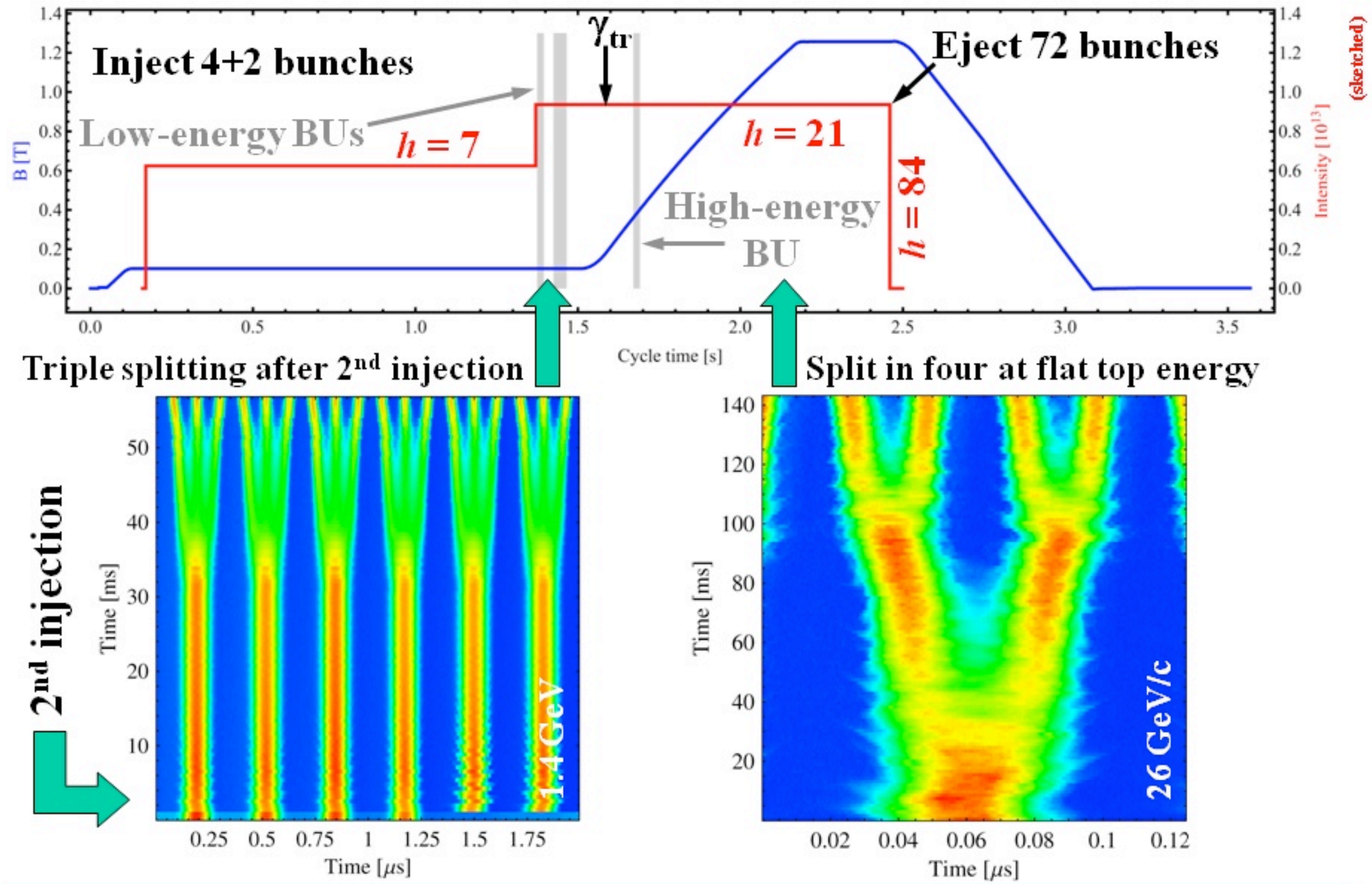
- Scenario based on LHC stop at end 2012 is more risky / not recommended: when physics resumes after 20 months interruption, users will expect similar performance § reliability than before the shutdown…

Single-batch LHC beam with 50 ns spacing



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

LHC beam with 25 ns spacing, double-batch

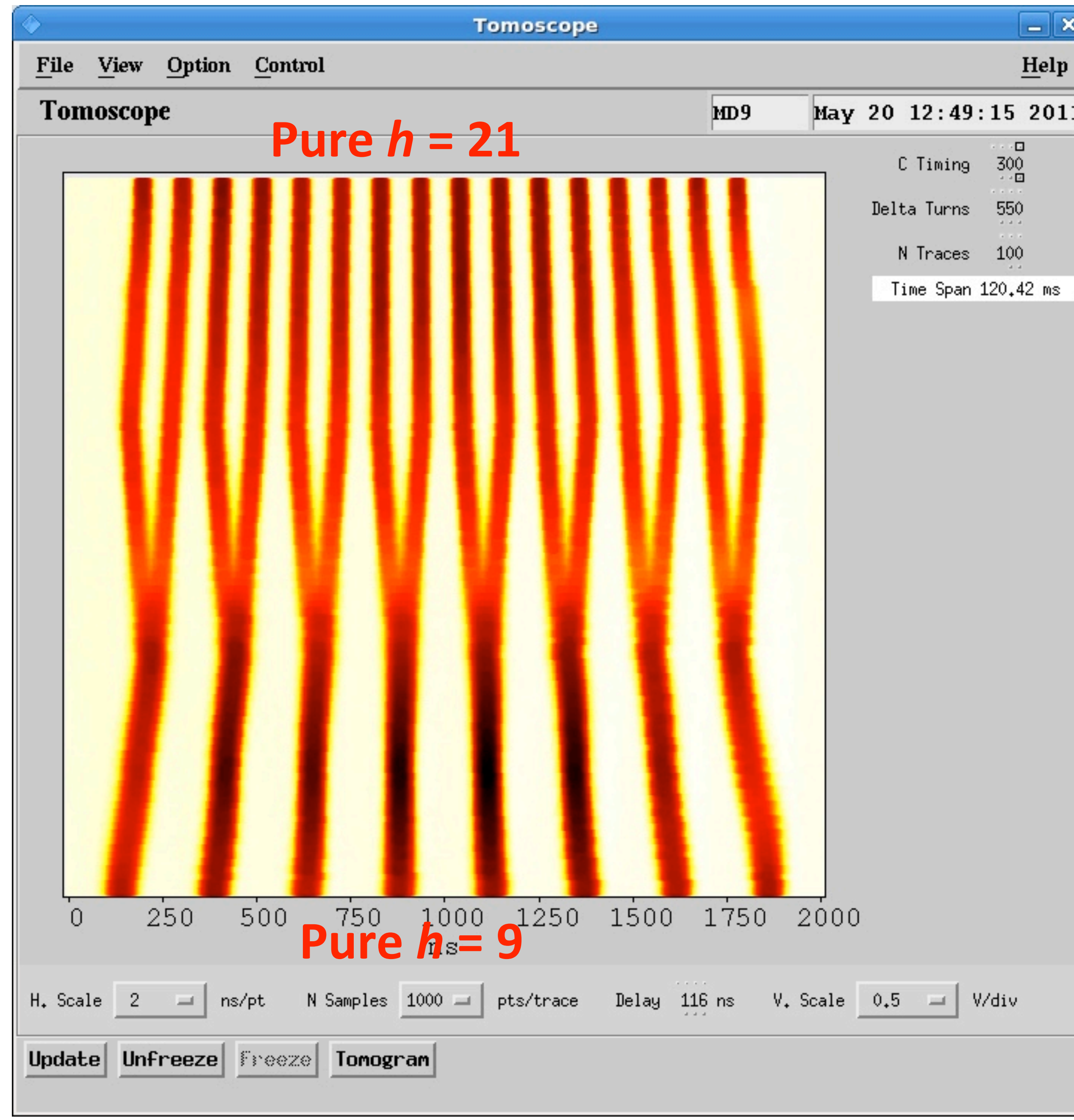


→ Each bunch from the Booster divided by 12 → 6 × 3 × 2 × 2 = 72

PS longitudinal: batch compression (2/2)

Simulation (C. Carli)

MD result at 2 GeV (H. Damerau, S. Hancock)



- RF gymnastics OK up to intermediate energy
- Significant effort required to reach 26 GeV and make beam available for the SPS (RF preparation § beam adjustment) **=> Need for precise measurement of transverse emittances before continuing**