Estimated beam characteristics from the upgraded injectors

R. Garoby for the LIU Project Team

- **Planned actions**
- Status of investigations
- Estimated beam characteristics
- Planning
- Summary

Principles of action

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…)**

⇒ **Procure spares**

⇒ **Improve radioprotection measures (shielding, ventilation…)**

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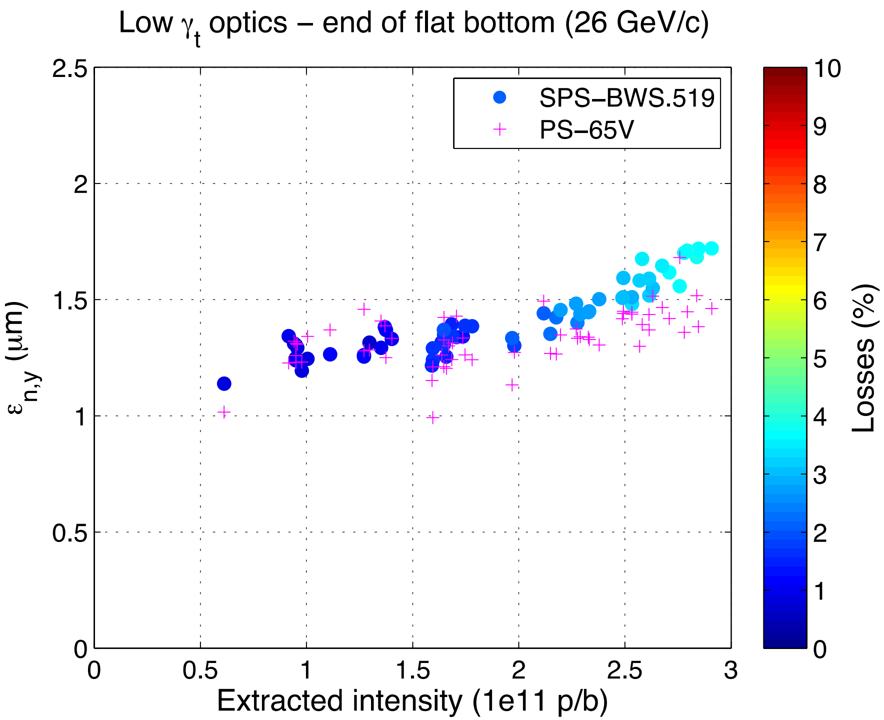
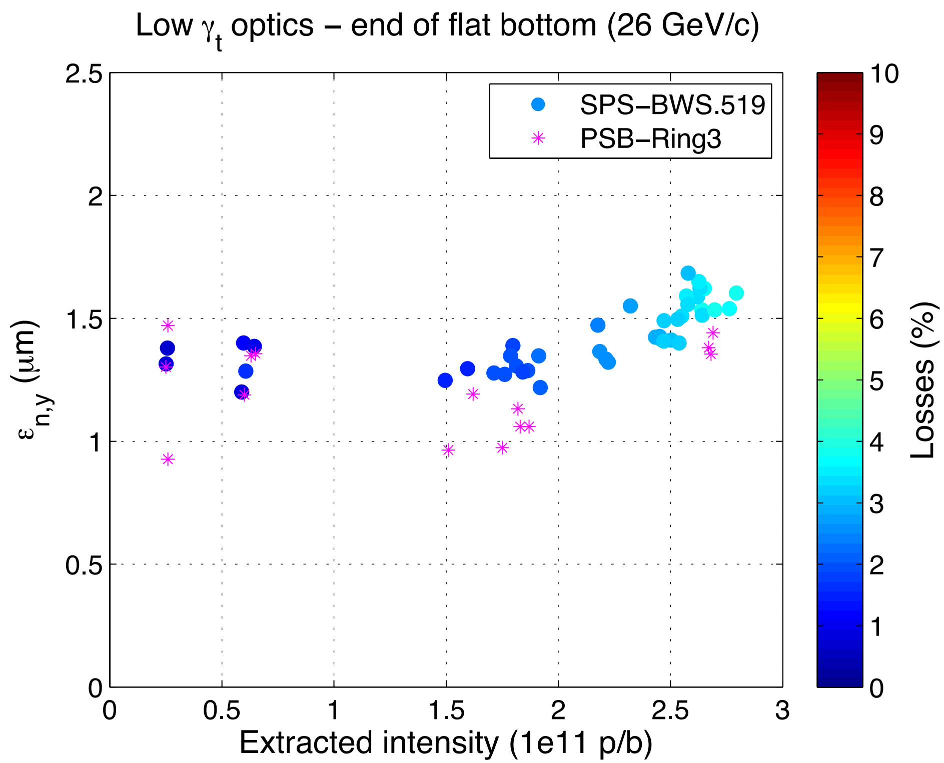
Present focus: debugging of transverse emittance measurement – Emittance evolution from PSB to SPS

A. Guerrero
§ H. Bartosik



Emittance preservation (?) between PS @ 26 GeV and SPS flat bottom



Emittance preservation (?) between PSB and SPS flat bottom

Puzzle: SPS performance in 2011 wrt 2010?

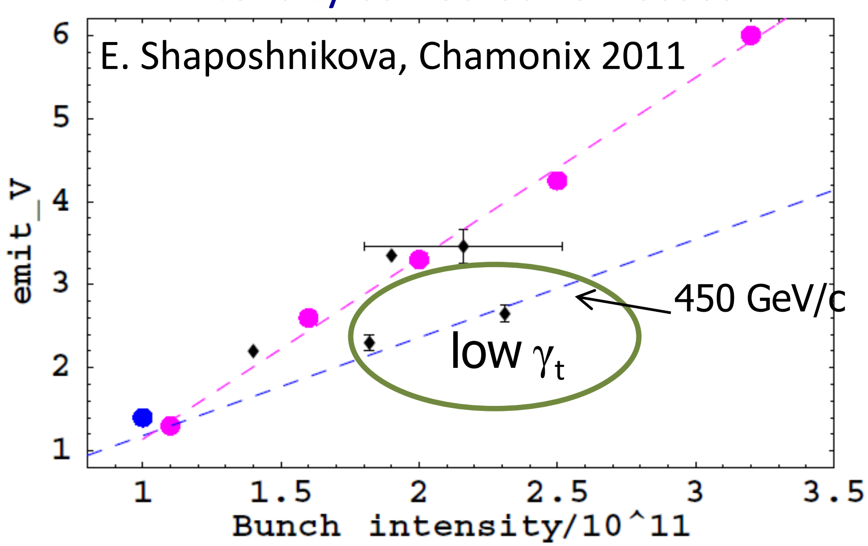
H. Bartosik

No dedicated measurements of emittance as function of intensity in 2010
- In 2010, emittance blow-up in PS was necessary in order to reduce blow-up in the SPS nominal optics
- In low γ_t optics, no blow-up in PS was necessary

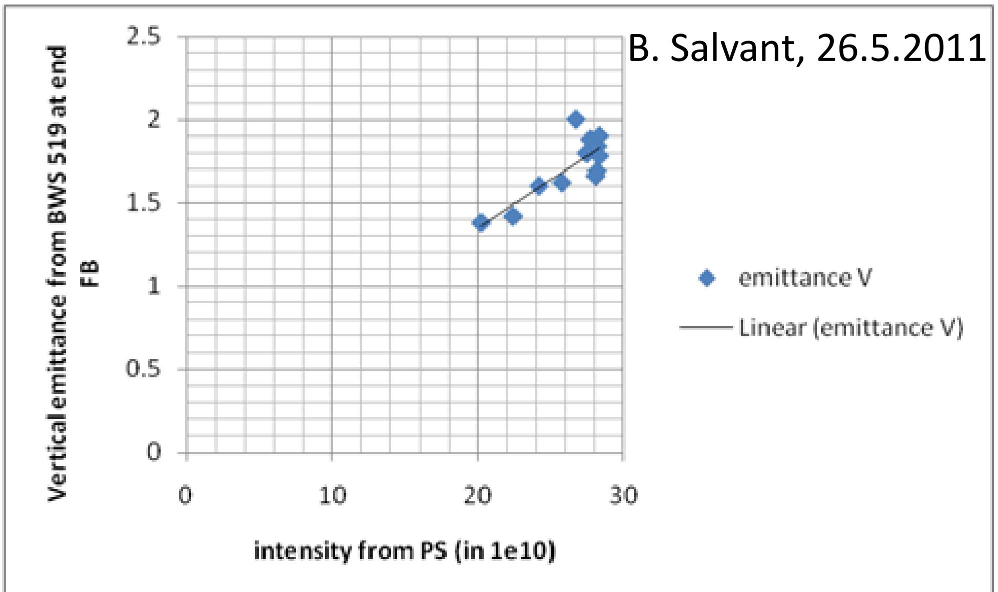
Dedicated measurements in 2011
- 2010 results for low γ_t optics confirmed (or outreached)
- No additional blow-up in PS needed for nominal optics – in general beam is more stable
- First measurement of emittance for high intensity in nominal optics shows promising results

What is different in 2011? Why is beam is so much more stable?

Emittances measured 2010, intensity corrected for losses



Nominal SPS optics, end of flat bottom (26 GeV/c)



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Caveat…

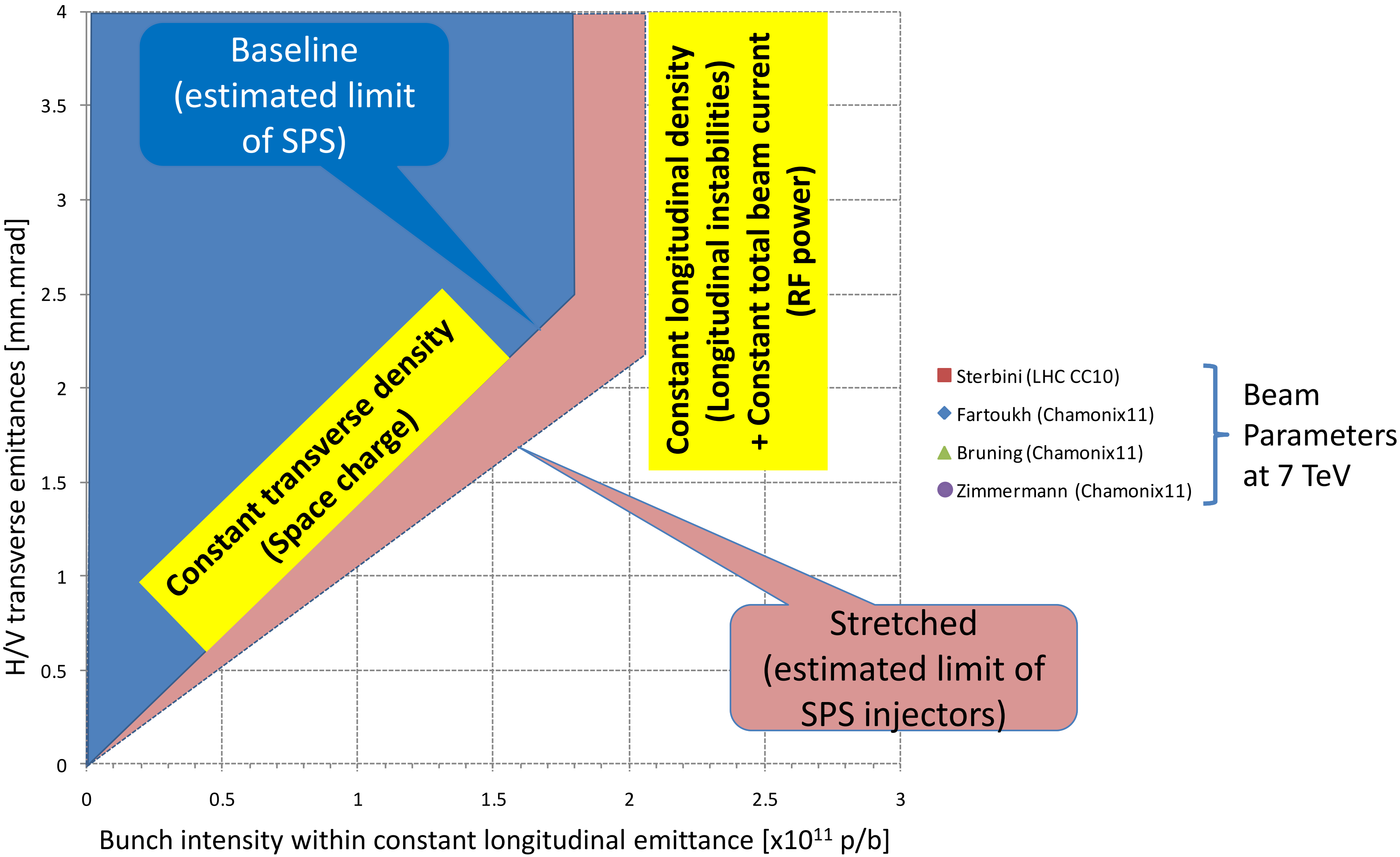
- Beam parameters are given at injection in LHC: beam loss and blow-up inside the LHC are not accounted for.

- 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…)

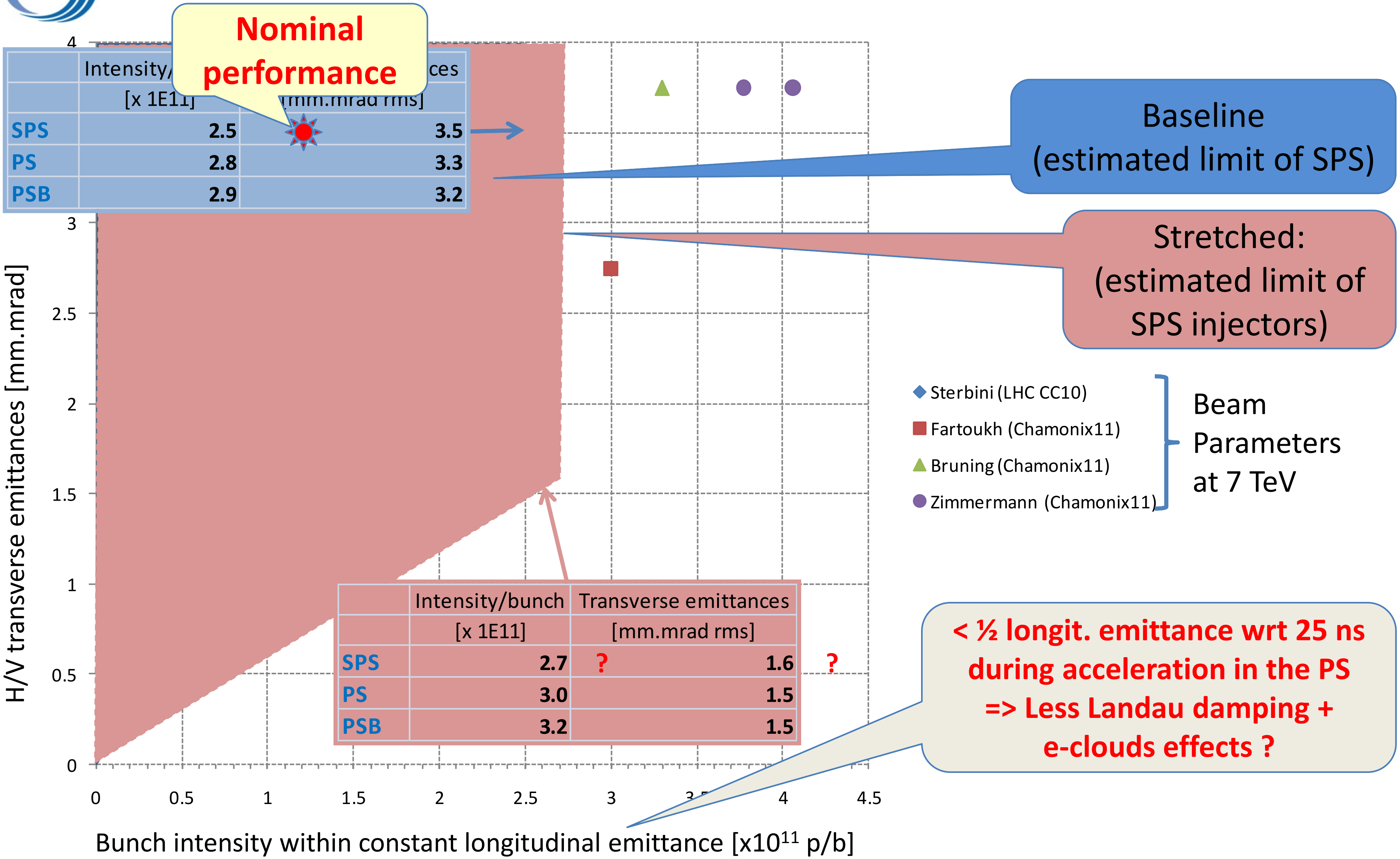
- Estimated beam degradation in the accelerator chain (based on observations in 2010):
  - ✓ PS: 5 % beam loss, 5 % transverse blow-up
  - ✓ SPS: 10 % beam loss, 5 % transverse blow-up.

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

Beam parameters: Comments



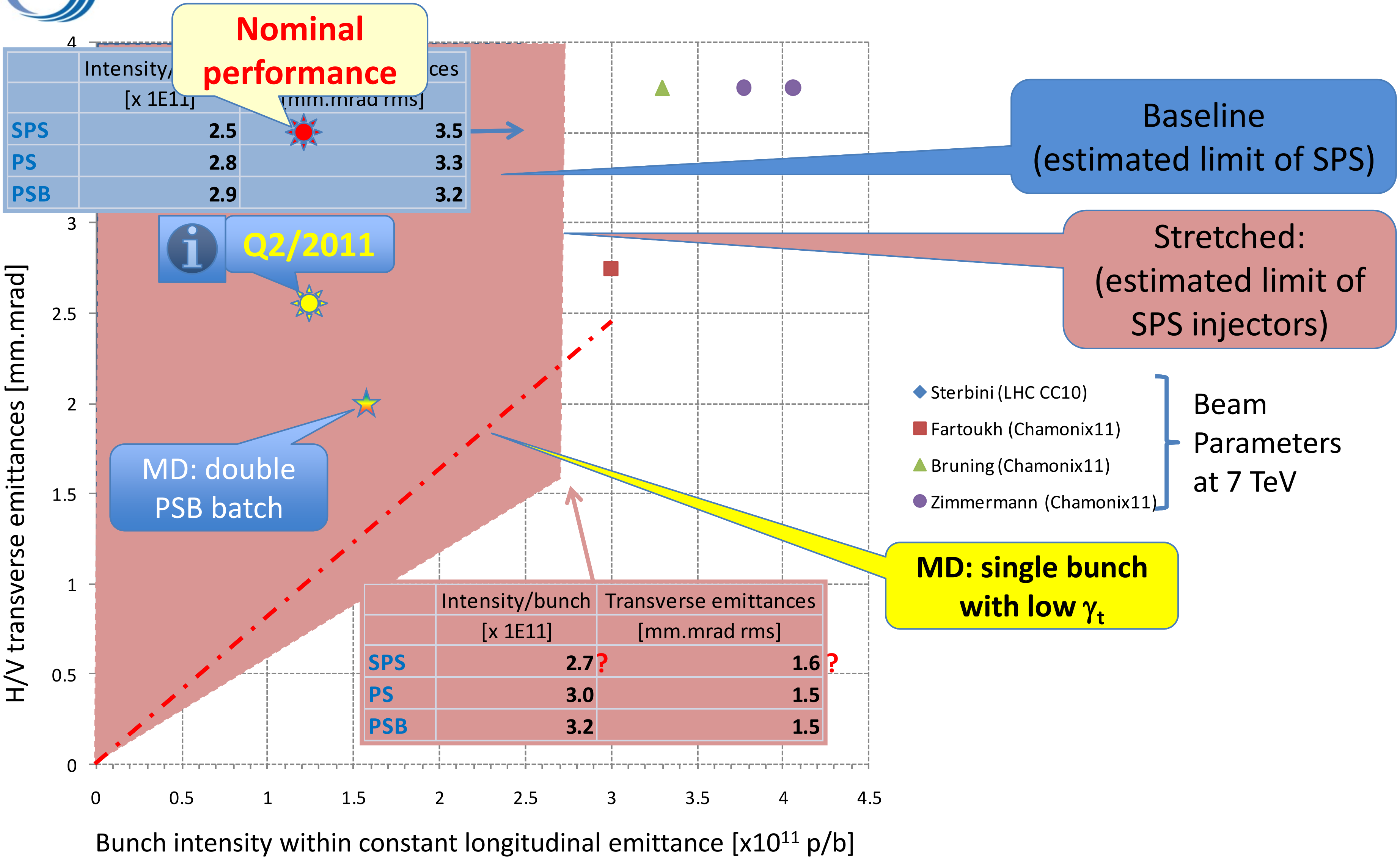
Beam parameters at LHC injection [50 ns]



	Intensity/bunch [x 1E11]	Transverse emittances [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

Beam parameters at LHC injection [50 ns]

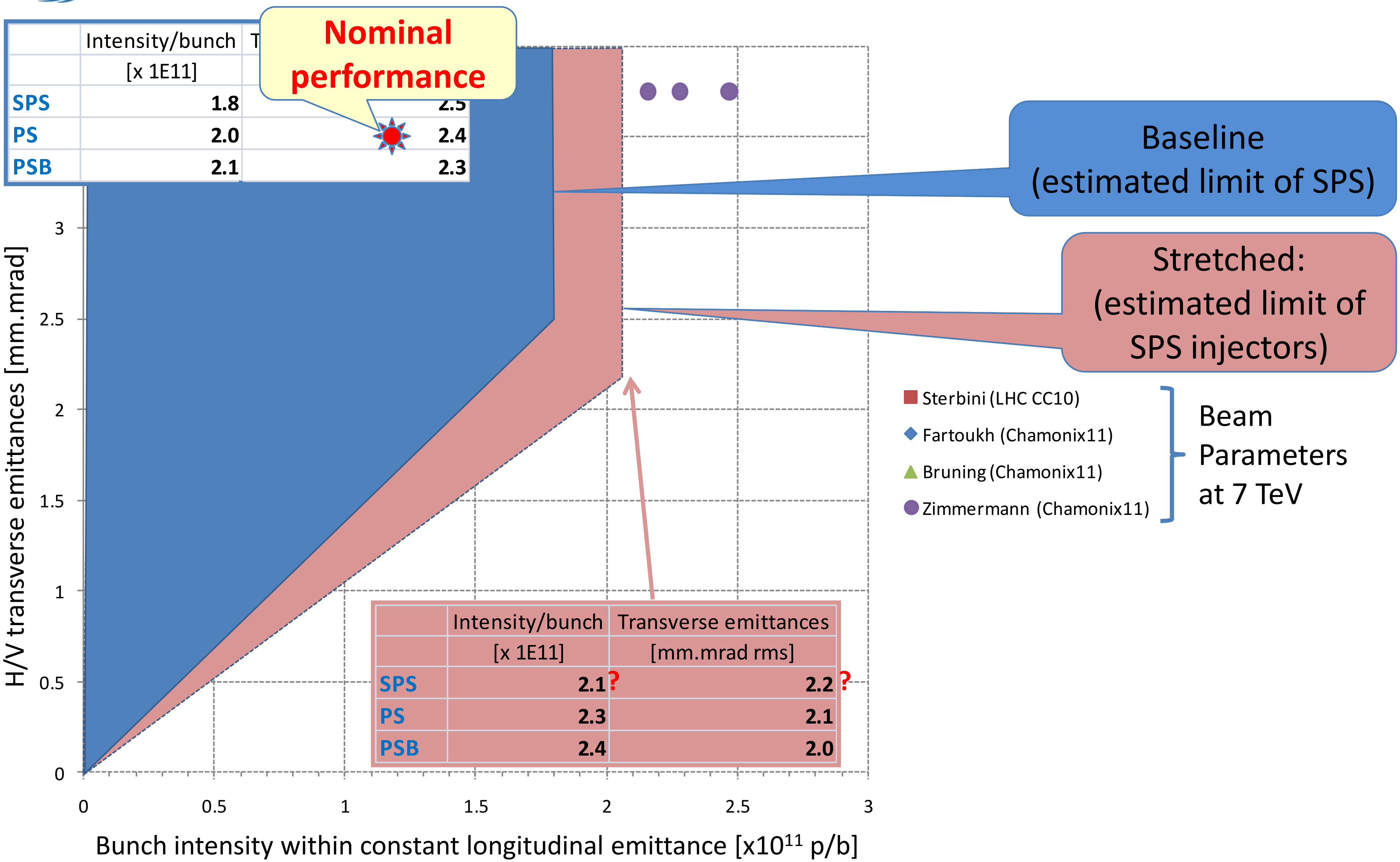


	Intensity/	ces
	[x 1E11]	[mm.mrad rms]
SPS	**2.5**	**3.5**
PS	**2.8**	**3.3**
PSB	**2.9**	**3.2**

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

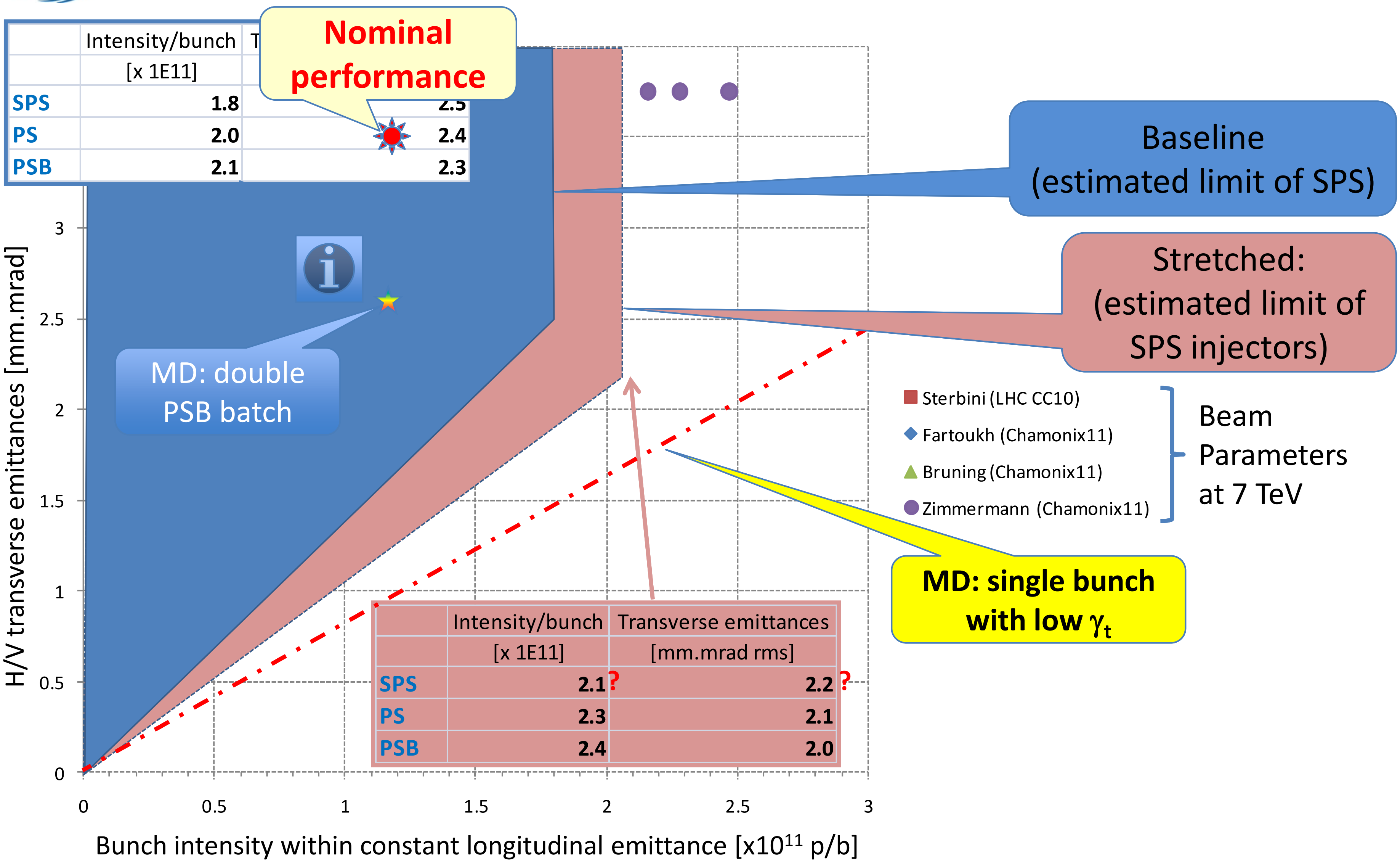
Beam parameters at LHC injection [25 ns]

	Intensity/bunch [x 1E11]	T
SPS	1.8	2.5
PS	2.0	2.4
PSB	2.1	2.3



	Intensity/bunch [x 1E11]	Transverse emittances [mm.mrad rms]
SPS	2.1 ?	2.2 ?
PS	2.3	2.1
PSB	2.4	2.0

Beam parameters at LHC injection [25 ns]



	Intensity/bunch [x 1E11]	T
SPS	1.8	2.5
PS	2.0	2.4
PSB	2.1	2.3

	Intensity/bunch [x 1E11]	Transverse emittances [mm.mrad rms]
SPS	2.1?	2.2?
PS	2.3	2.1
PSB	2.4	2.0

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Overall LIU Planning

	Linac4	PS injector, PS and SPS	Beam characteristics at LHC injection
2011 - 2012	Continuation of construction…	• Beam studies § simulations • Investigation of RCS option • Hardware prototyping • Design § construction of some equipment • TDR	25 ns, 1.2 10^{11}p/b, **~2.5 mm.mrad** 50 ns, 1.7 10^{11}p/b, **~2.2 mm.mrad** 75 ns, 1.2 10^{11} p/b, $\leq$ 2 mm.mrad
2013 – 2014 (Long Shutdown 1)	• Linac4 beam commissioning • Connection to PSB ?	• PSB modification (H^- injection) ? • PSB beam commissioning ? • Modifications and installation of prototypes in PS and SPS	
2015 - 2017	• Progressive increase of Linac4 beam current	• If Linac4 connected: progressive increase of PSB brightness • Some improvement of PS beam (Injection still at 1.4 GeV) • Equipment design § construction for PS injector, PS and SPS • Beam studies	• Limited gain at LHC injection (pending PSB (or RCS), PS and SPS hardware upgrades)
2018 (Long Shutdown 2)		• Extensive installations in PS injector, PS and SPS • Beam commissioning	
2019 –2021			After ~1 year of operation: beam characteristics for HL-LHC…

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Summary

- MDs during 2011-2012 are essential to refine the knowledge and understanding of the injectors and to check the potential of upgrades.
- Preliminary requirement/First goal: getting confidence in beam instrumentation => Extensive debugging: progressing well, but time – consuming...
- Recent observations in 2011 tend to demonstrate that the accelerators perform better than in the previous years. Not fully understood.
- Need to interact with HL-LHC for selecting reachable beam parameters. Main purpose of the present meeting!
- Irrelevant to the decision to connect Linac4 to the PSB during LS1 and to the choice between PSB/RCS, the beam characteristics specified for LIU will be met some time after the end of LS2 (~2020).

THANK YOU
FOR YOUR ATTENTION!

Reference

Why is today's beam better than nominal?

Simple! No more blow-up along the accelerators cascade…

- PSB:
  - Improved (achromatic) optics in the Linac2 to PSB transfer line since 2005 [http://khanke.home.cern.ch/khanke/papers/2006/ab_note_2006_001.pdf]
- PS:
  - Injection trajectories
  - Working point along the whole cycle
  - Transition
- PS to SPS:
  - Transverse matching with better optics in TT2-TT10

WARNING: NO MARGIN LEFT!

Spare slides

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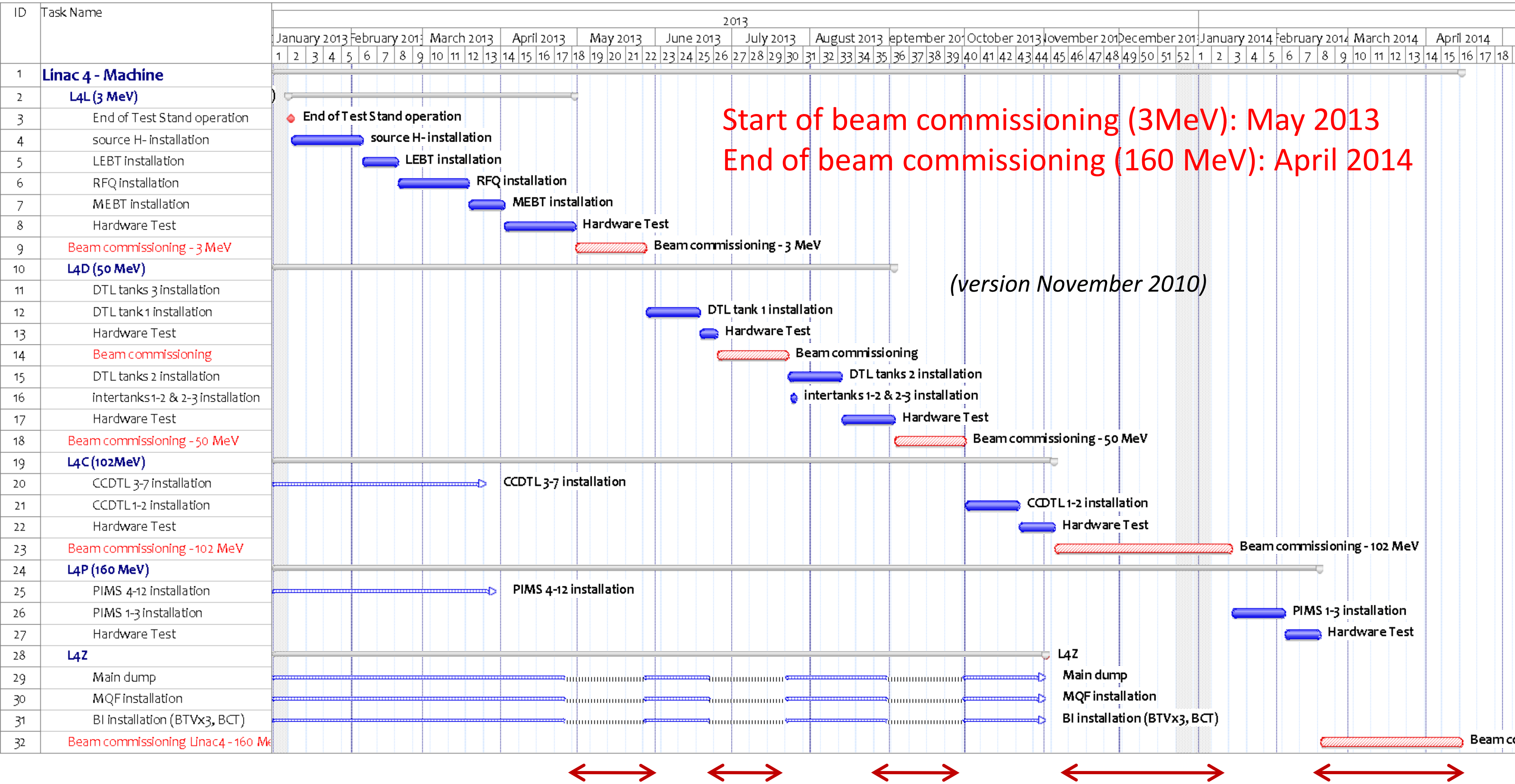
Linac4: Commissioning schedule

M. Vretenar



5 commissioning stages: 3 MeV 10 MeV 50 MeV 100 MeV 160 MeV

In 2013/14 (15 months), 6.5 months of beam commissioning, 3 months of HW tests, 5.5 months of installation

PS injector - option 1: PSB Upgrade

K. Hanke

		BC	Group	WBS	2011	2012	2013 (LS1)	2014 (LS1)	2015	2016	2017 (LS2)	2018 (LS2)	Total kCHF
PSB	Management (M resources)	67020	BE-OP	LIU-PSB 1	40	80	80	80	80	80	80	40	**560**
	Beam Dynamics	61020	BE-ABP	LIU-PSB 2		10	10	10	10	10	0		**50**
	Magnets	99281	TE-MSC	LIU-PSB 3		165	65	65	660	1080	90		**2125**
	Magnetic Measurements			LIU-PSB 3	20	40	60	60	60	60	60		**360**
	RF	69020	BE-RF	LIU-PSB 4									**0**
	Beam Intercepting Devices		EN-STI	LIU-PSB 7	25	45	50	50	25	25	25		**245**
	Power Converters (PSB)	99237	TE-EPC	LIU-PSB 5.2		745	450	5590	6370	1660	1190		**16005**
	Power Converters (Injection)	Existing*	TE-EPC	LIU-PSB 5.1	330	1045	105			45	45		**1570**
	Vacuum System	99271	TE-VSC	LIU-PSB 8		390	290						**680**
	Beam Instrumentation	64020	BE-BI	LIU-PSB 6	20	368	710	157					**1255**
	Commissioning		BE-OP	LIU-PSB 21							75	75	**150**
	Injection	Existing*	TE-ABT	LIU-PSB 9	1000	1000	1500	2125	1500	1000	155		**8280**
	Extraction, Transfer	99236	TE-ABT	LIU-PSB 10			360	1000	750	450			**2560**
	Controls	66020	BE-CO	LIU-PSB 11							500		**500**
	Electrical Systems		EN-EL	LIU-PSB 12		1100	500				100		**1700**
	Cooling & Ventilation		EN-CV	LIU-PSB 13						100	900		**1000**
	RP and Safety		DGS-RP	LIU-PSB 16									**0**
	Transport and Handling		EN-HE	LIU-PSB 14			25	25		30	200		**280**
	Survey	61021	BE-ABP	LIU-PSB 20	5		25	5	5		10		**50**
	PSB Total				1440	4988	4230	9167	9460	4540	3430	115	**37370**

+ Consolidation (Dipoles Power Supply, RF, Cooling § Ventilation) >20 MCHF

PS injector - option 2: RCS

Tentative RCS parameters

=> Same beam characteristics than PSB @ 2GeV
=> Shorter PS § SPS injection flat bottoms

Energy range	160 MeV to 2 GeV
Circumference	(200x 4/21) π m ≈ 119.68 [illegible]
Repetition rate	~10 Hz
RF voltage	60 k[illegible]
Harmonics	[illegible]
Frequency range	[illegible]ection)
Beam param[illegible] (for [illegible]	[illegible]ycle (3.25 10^{12} p/p) [illegible] μm [illegible]2×0.27 eVs (determined by [illegible] for most cases)
[illegible]	[illegible]d symmetry 21 cells, 5 cells/arc, 2 cells/straight section
[illegible]	$3.5 < Q_{H,V} < 4.5$
L[illegible] section (4x)	2 x 2.35 m
Rel[illegible]stic gamma at transition	~4
Maximum magnetic field	< 1.3 T

Benefits:

- Competitive cost wrt PSB consolidation and upgrade (? Study in progress…
- Reliability (new hardware / modern design)
- Commissioning decoupled from physics operation

K. Hanke

PS Upgrades

		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

+ Consolidation (Cooling § Ventilation, cables replacement…) ~43 MCHF

SPS Upgrades

		BC	Group	WBS	2011	2012	2013	2014	2015	2016	2017	2018	Total kCHF
							LS1				LS2		
SPS	Management (M resources)	99241	TE-ABT	LIU-SPS 1	40	80	80	80	80	80	80	40	560
	Beam dynamics studies and	69042	BE-RF	LIU-SPS 2	10	10	10	10	10	10	10	10	80
	MKDV/H impedance reduction	99242	TE-ABT	LIU-SPS 9.2		50	100						150
	Beam instrumentation	64040	BE-BI	LIU-SPS 6	200	600	500	500	300				2100
	Extraction protection upgrade	99243	TE-ABT	LIU-SPS 9.1		100	200	350	300	150			1100
	New high bandwidth damper	69040	BE-RF	LIU-SPS 4.3	150	150	600	600	300				1800
	Existing damper power upgrade					100	450	300	150				1000
	Existing damper removal to					200	300						500
	RF 200 MHz upgrade	69041	BE-RF	LIU-SPS 4.2	850	1400	2400	9850	7450	3650	600	300	26500
	ecloud mitigation: aC coating	99273	TE-VSC	LIU-SPS 8.2	145	350	550	505	620	1050	1800	600	5620
	New collimation system	99244	TE-ABT	LIU-SPS 7		100	200	800	2700	2700	1500	1200	9200
	New MKE and extraction channel upgrade	99245	TE-ABT	LIU-SPS 9.4		200	300	600	1800	1700	1200	600	6400
	Beam dump upgrade	99246	TE-ABT	LIU-SPS 9.5		150	250	800	2500	2100	1300	1000	8100
	TL protection upgrade	99247	TE-ABT	LIU-SPS 9.3		100	200	1500	1500	1500	1000	200	6000
	SPS Total				1395	3590	6140	15895	17710	12940	7490	3950	69110

+ Consolidation ~ ? MCHF

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PS injector: RCS feasibility study

Beam characteristics:

- for all PS users: equivalent to PSB at 2 GeV
- for ISOLDE: ~ 7 10^{13} p/s @ 2 GeV (today: ~ 10^{13} p/s @ 1.4 GeV)

Feasibility report with cost estimate: end of July

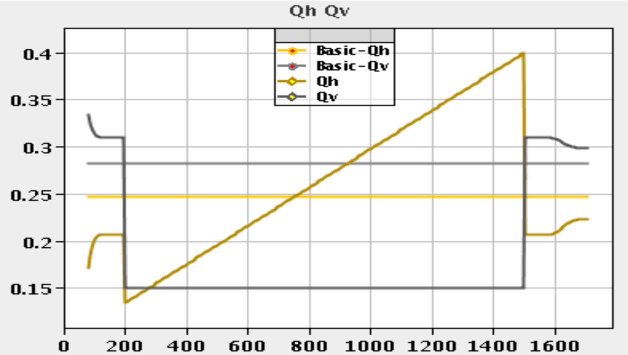
Principle of Working Point Scans

E. Benedetto

GOAL: Identify dangerous resonance lines in tune diagram

Loss measurement for different WPs:

- Low intensity beam (not SC-dominated) → 130 x 10^{10} protons
- Large emittance (to fill the chamber & provoke immediate losses)
- Long flat bottom @ 1.4 GeV
- Tune program:
  - Scan between (0.1 - 0.4)
  - Vertical tune constant
  - Sweep of the horizontal tune



Slope in the intensity signal indicates importance of the crossed resonance line

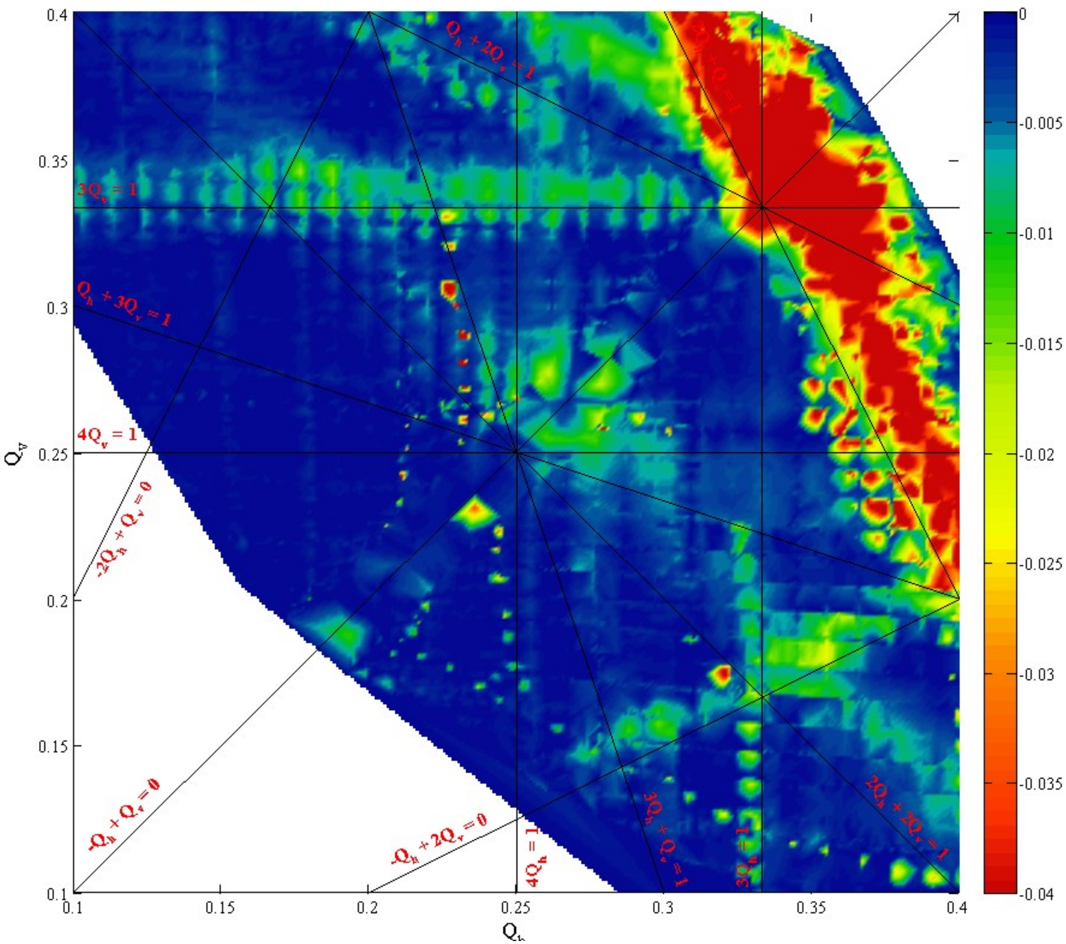
PS Transverse: Tune Scans

2 GeV

E. Benedetto

⇒ w/o PFW : no surprises

⇒ with PFW ongoing

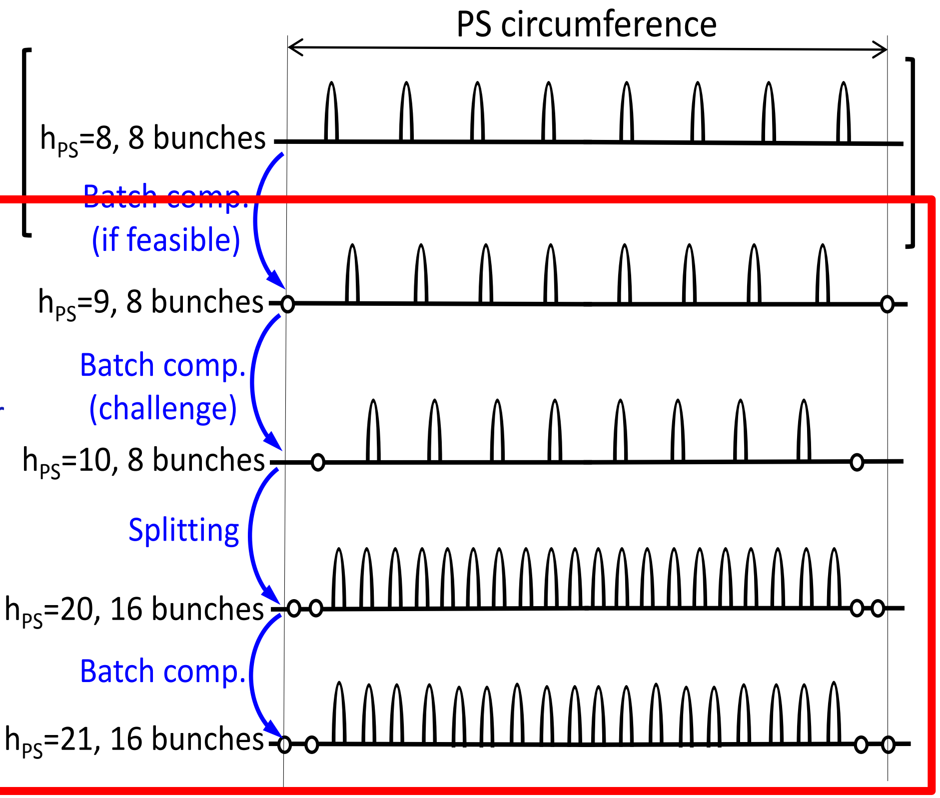


PS Longitudinal: Batch Compression (1/2)

Batch Compression Schemes in the PS

Compression to h_{PS} = 10 and generation of 64 bunches

- Injection and first acceleration with h_{PS}=8 or h_{PS}=9
- Potential brightness increase: 12/8 = 1.50*
  - Corresponds to PSB upgrade: 1.4 GeV to 1.77 GeV
  - Brightness per bunch for 25 ns trains out of PSB
    - ε*=2.5 μm and 2.23 10^{11} or
    - ε*=1.90 μm and 1.7 10^{11}
- Estimate of longitudinal parameters at injection for 25 ns trains
  - Every bunch split into 8 LHC bunches with 0.35 eVs
  - 1.6 eVs per injected bunch allows a factor 1.75 blow-up



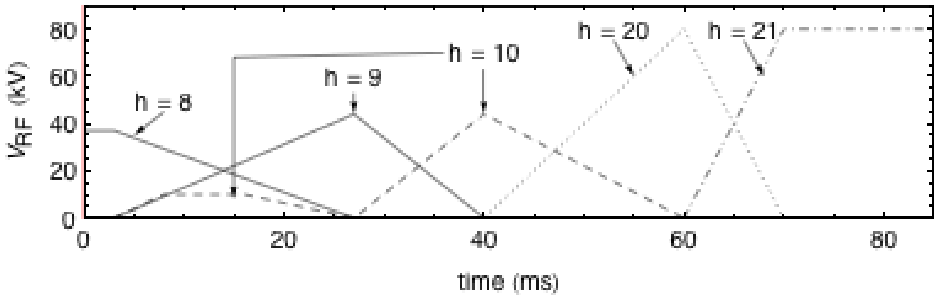
RF gymnastics at an appropriate intermediate energy (hypothesis 2.5 GeV)
(Injection and first acceleration with h_{PS}=8 or h_{PS}=9)

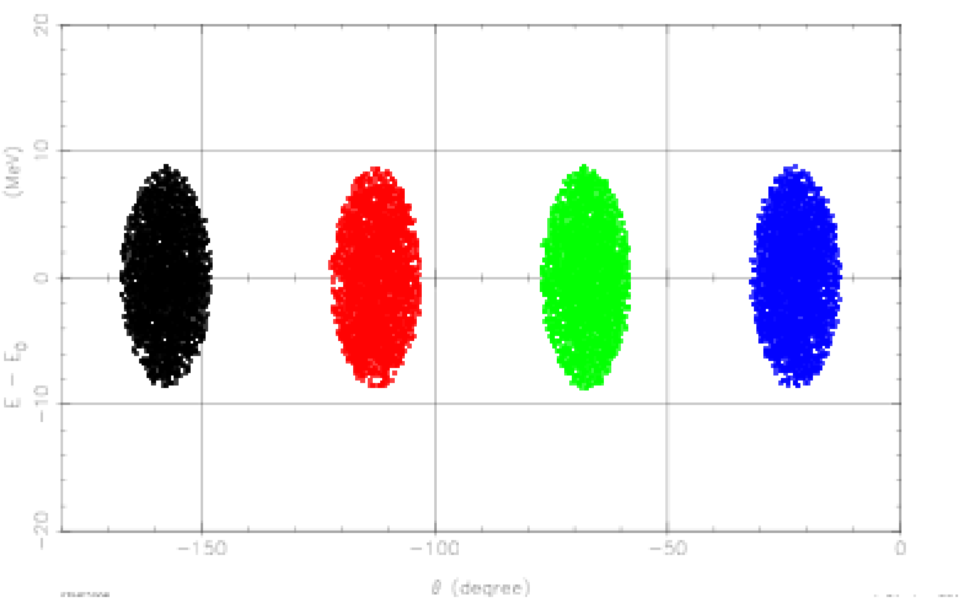
*) With h_{PS}=8 at injection, compared to present situation with Linac2 and double batch PSB to PS transfer

MD tests – H. Damerau, S. Hancock – May 2011

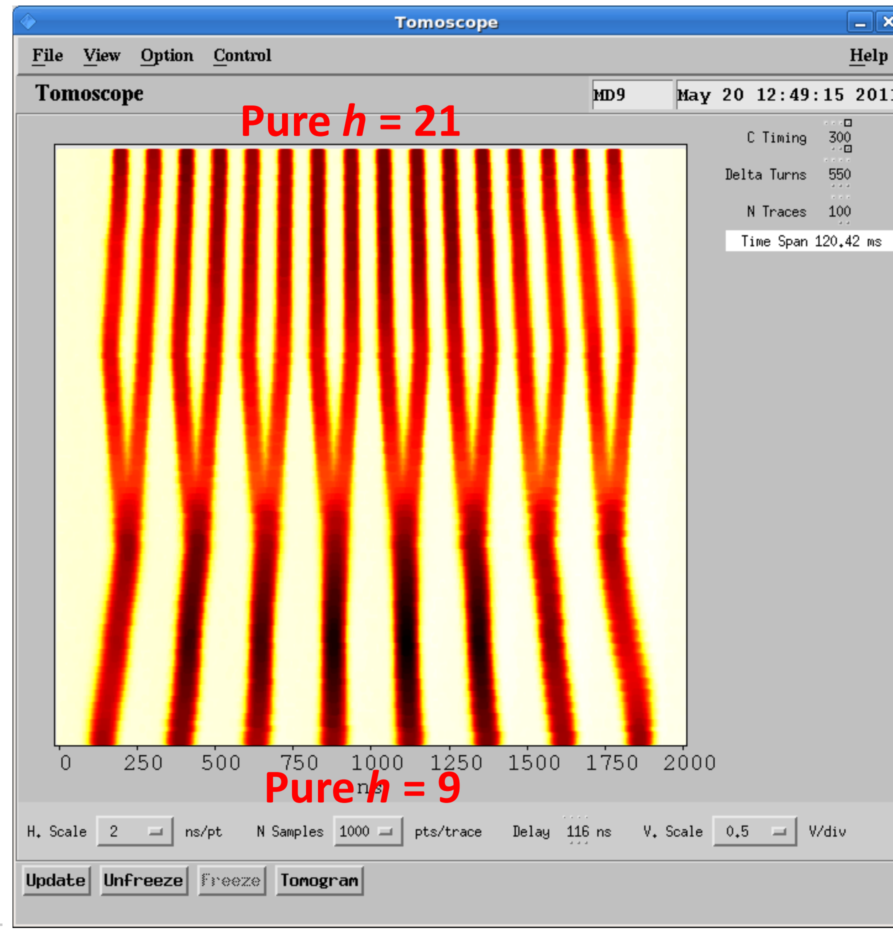
PS Longitudinal: Batch Compression (2/2)

Simulation (C. Carli)





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

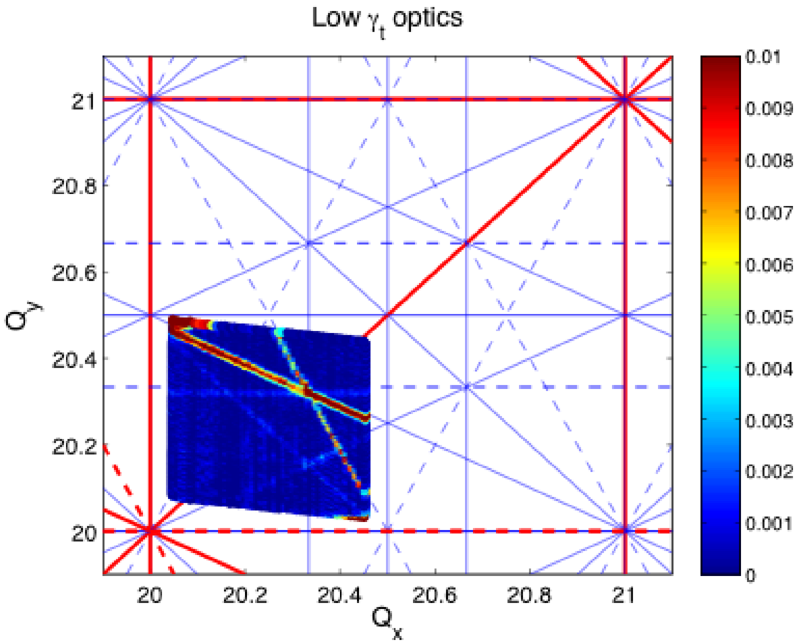


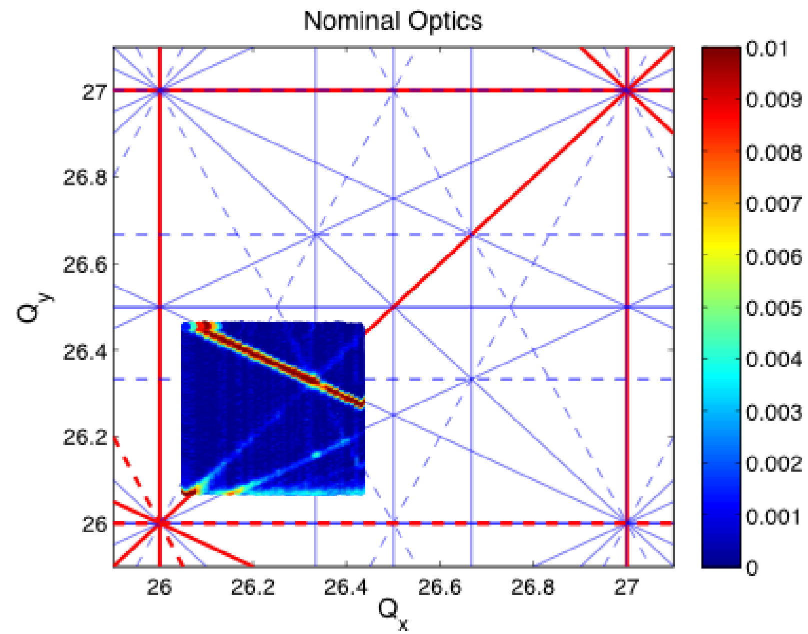
- RF gymnastics OK up to intermediate energy
- Significant effort required to reach 26 GeV and make beam available for the SPS (RF preparation § beam adjustment) **=> Need for precise measurement of transverse emittances before continuing**

SPS Transverse: Tune Scans

H. Bartosik

- Identified resonances in the low γ_t optics
  - normal sextupole resonance Qx+2Qy is the strongest
  - skew sextupole resonance 2Qx+Qy quite strong !!??
  - normal sextupole Qx-2Qy, skew sextupole resonance at 3Qy and 2Qx+2Qy fourth order resonances visible
- Identified resonances in the nominal optics
  - normal sextupole resonance Qx+2Qy is the strongest
  - Coupling resonance (diagonal, either Qx-Qy or some higher order of this), Qx-2Qy normal sextupole
  - skew sextupole resonance 2Qx+Qy weak compared to Q20 case
  - It seems that the stop-band width of the vertical integer is stronger than in Q20 optics



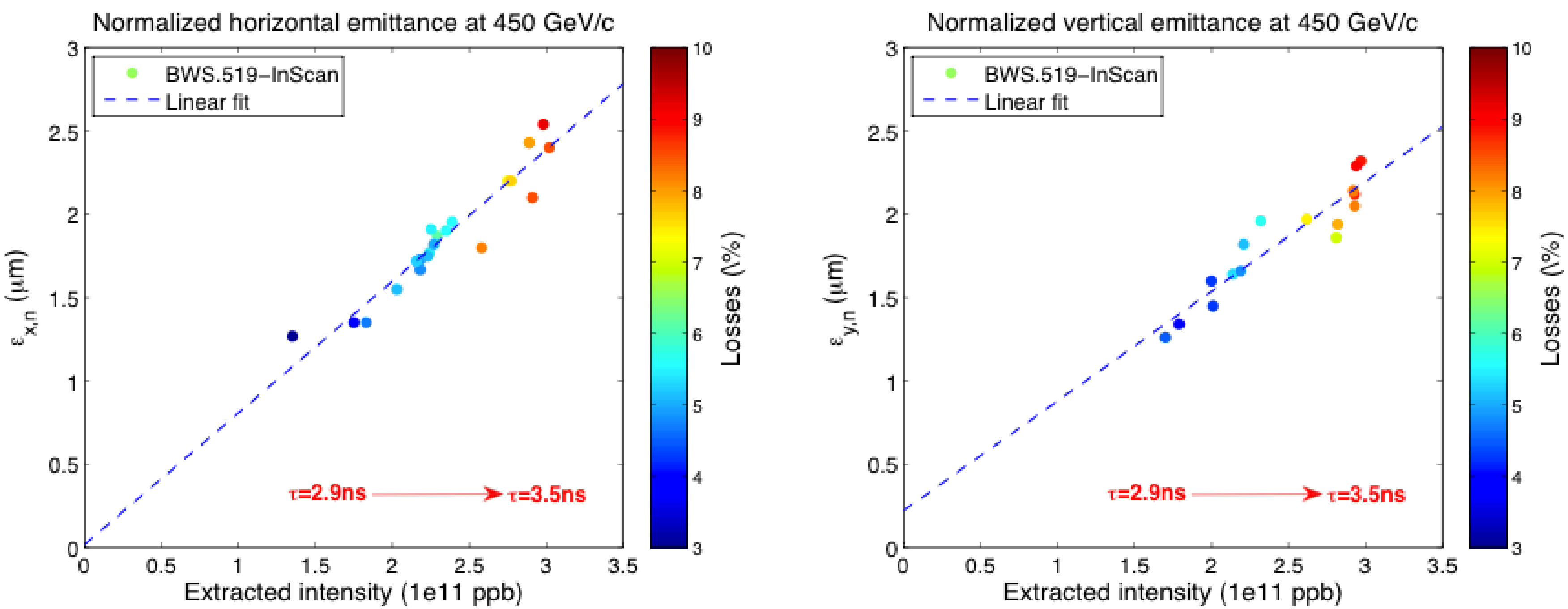


SPS Transverse: Single Bunch Emittances

H. Bartosik

Measurement of single bunch emittances
- In scan with “reference” wire scanner BWS.519 at flat top
- Long cycle (~10s injection plateau, ~10s acceleration)
- Losses along the cycle extracted from DC-BCT measurement

PS bunch length increasing with intensity
- T=2.9ns @ 1.5e11 p/b, T=3.5ns @ 3e11 p/b
- Emittances in PSB: ~ 1µm < 1.5e11p / ~ 1.1µm @ 2e11p / ~ 1.3µm @ 3e11p (Well adjusted beam in the PSB!)

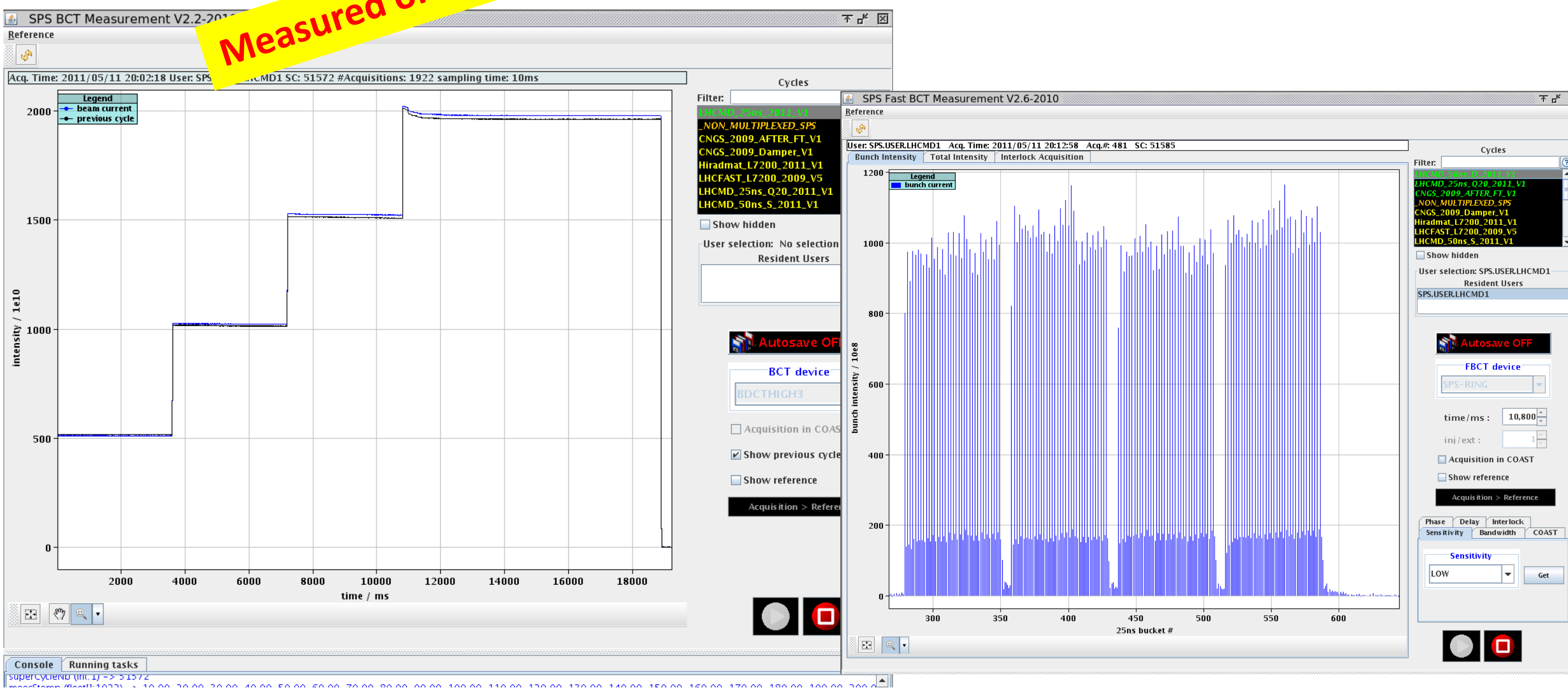


SPS: 50ns bunch train – Double PSB batch

Intensity 1.65 10^{11} p/b

- Up to 4 batches injected
- **Very low losses** along the c… …ducible 3%)
- Eh=2.0 μm and E… …flat top (sum 3.9)

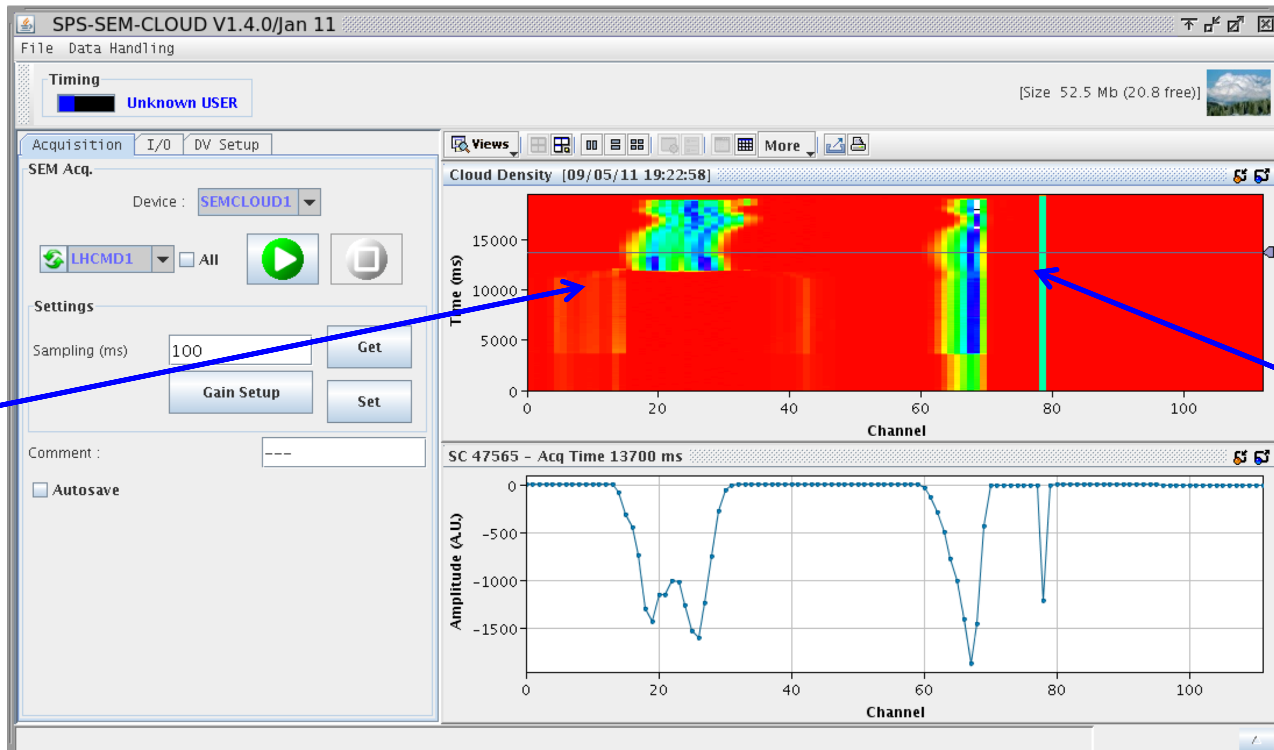
Measured on 1st batch – to be confirmed



SPS: e-cloud with 25 ns bunch train

M. Taborelli

- Electron cloud measured at all the liners
  - Signal already visible with 1 batch on both stainless steel liners
  - No signal visible on the a-C coating liner
  - Half signal clearly visible on the half coated chamber
  - Effect of the clearing electrode checked scanning points on a grid of voltage vs. magnetic field values

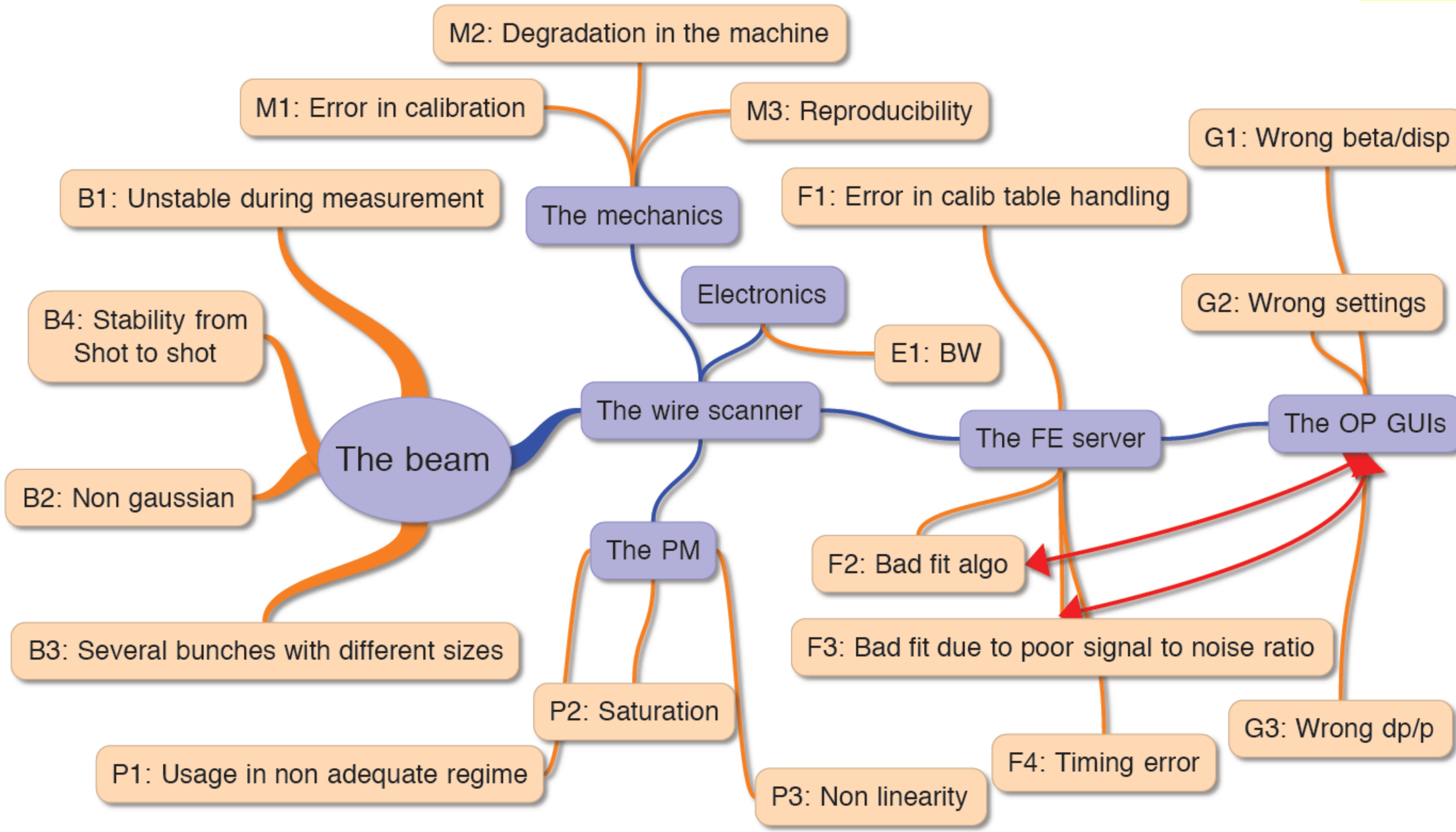


Clearing electrode: it was switched off in the middle of cycle

Half-coated liner, only stripe on StSt visible

Present focus: debugging of transverse emittance measurement – Error source inventory

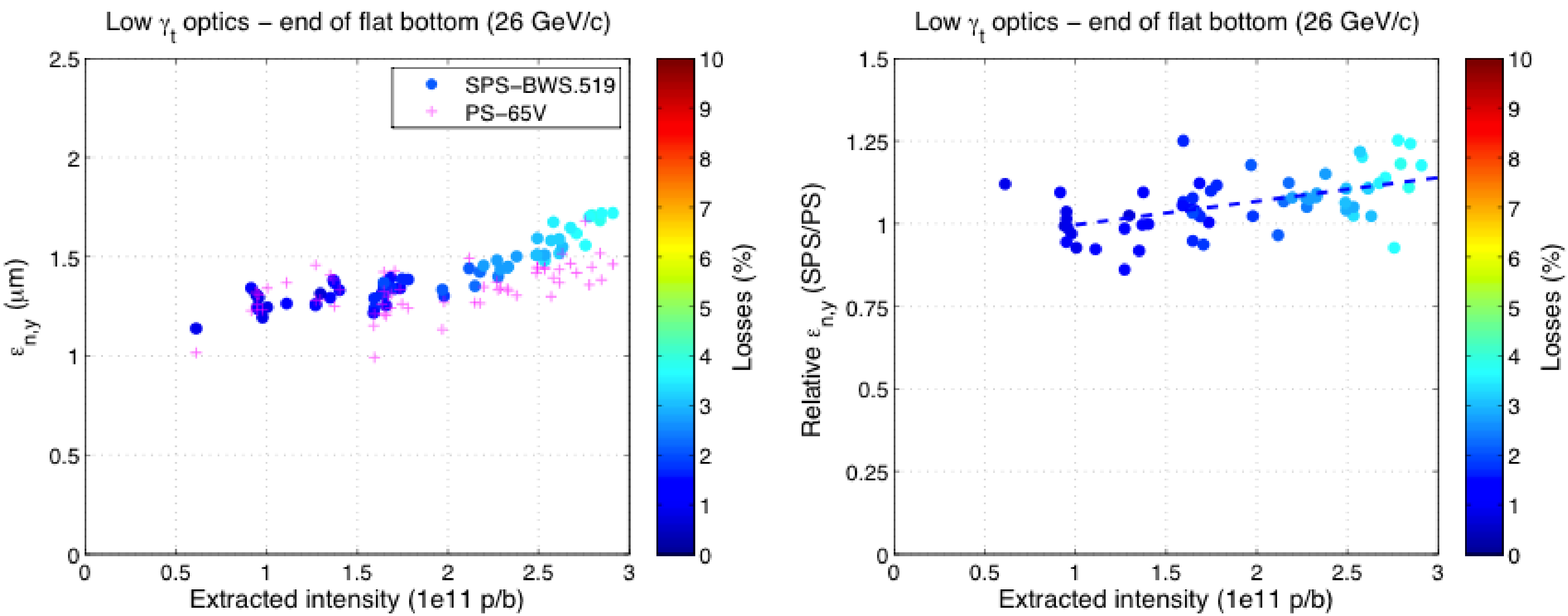
J.J. Gras



Emittance blow-up in SPS with low γ_t

H. Bartosik

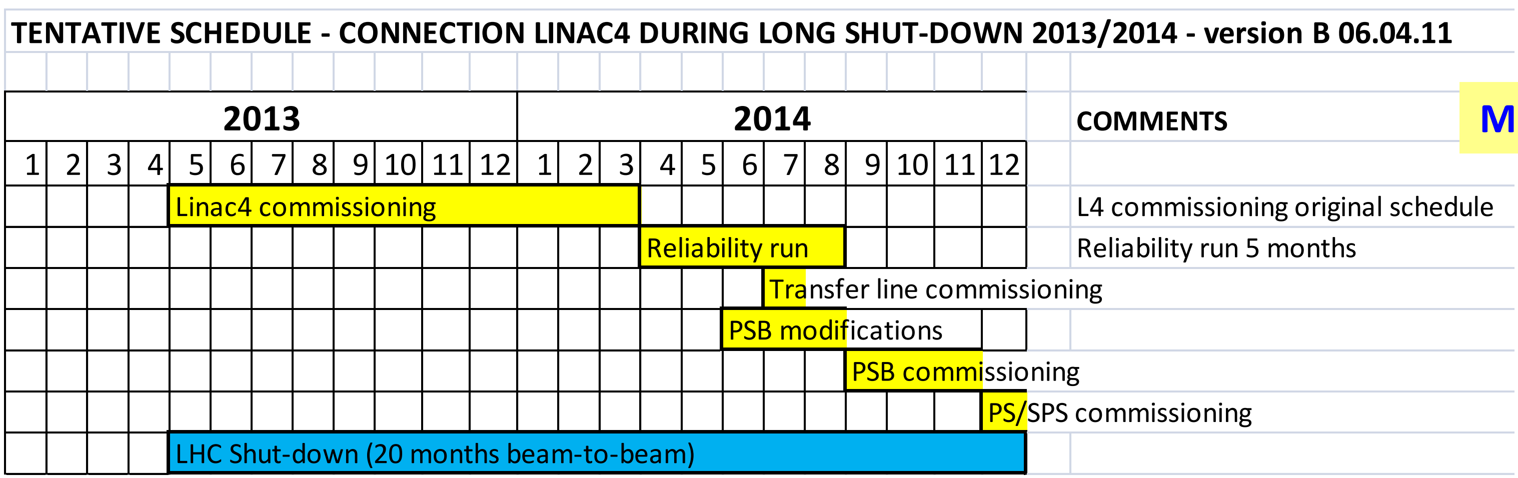
- MD4 beam in PSB with 1.1 turns injected (slightly smaller transverse emittances)
- Simultaneous measurements of vertical emittance in PS and SPS
  - ✓ At extraction (just before bunch rotation) in PS using PS-65.V
  - ✓ At end of flat bottom using SPS-BWS.519
  - ✓ Here RF-voltage of 5.75 MV in SPS
- If calibration of wire scanners between machine is believed → emittance blow-up for intensities above 1.5e11 p/b with peak values of 25% at 3e11 p/b



- Planned actions
- Status of investigations
- Estimated beam characteristics
- **Planning**
- Summary

Linac4 connection to the PSB

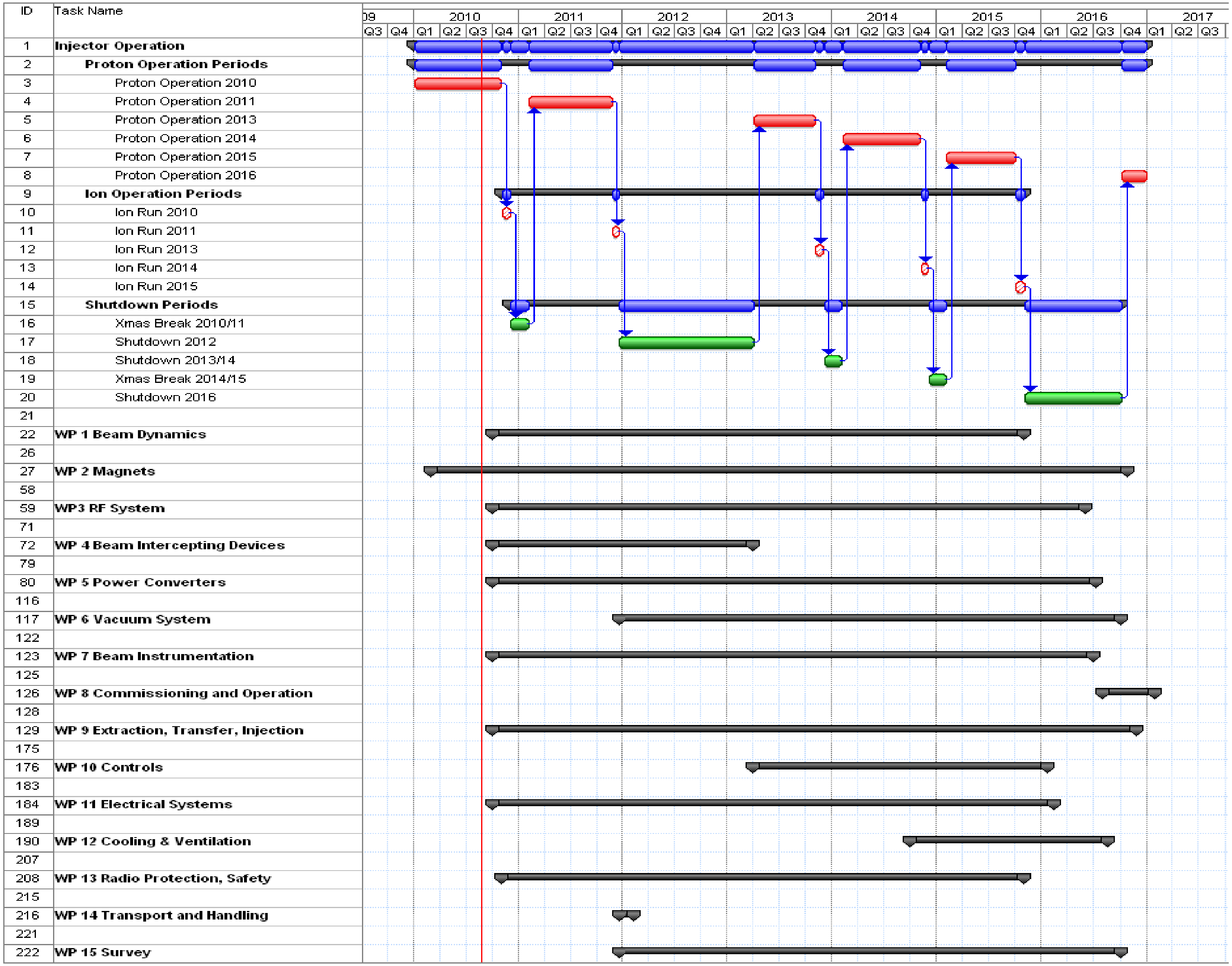
- High interest of connecting Linac4 to the PSB during LS1:
  - ✓ **Staged upgrade spread between LS1 and LS2 (shorter LS2 ?)**
  - ✓ **Timely termination of the Linac4 project**
- Reasonable scenario (with 20 months LHC shutdown) if LHC stops in May 2013
  - ⇒ **Possibility to run the injectors until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



M. Vretenar

- 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…

PSB Upgrades



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

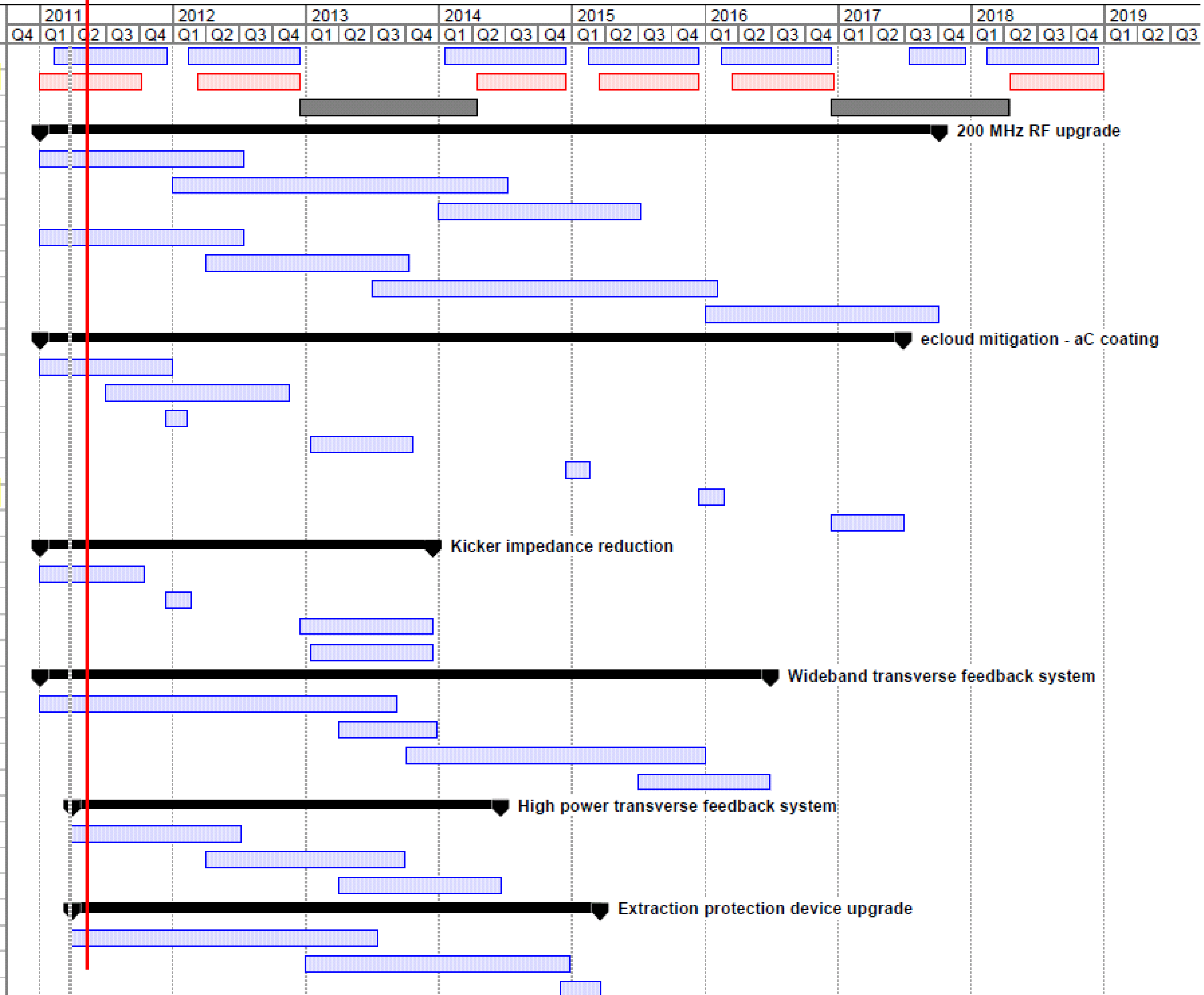
S. Gilardoni

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	???

SPS Upgrades (1/2)

B. Goddard

ID	Task Name
1	**SPS operation**
9	
16	**LHC LS**
19	**200 MHz RF upgrade**
20	
21	Main building construction
22	Services
23	Aplifier studies, prototypes, specs
24	Purchase
25	
26	Installation, commissioning
27	**ecloud mitigation - aC coating**
28	studies and specifications
29	Facility preparation
30	Coating 2 half-cells
31	Coating 1 sextant
32	Coating 0.5 sextant
33	
34	Coating 4 sextants
35	**Kicker impedance reduction**
36	Kicker preparation (2xMKE)
37	Kicker installation, bakeout & tests
38	
39	MKDV/H transitions
40	**Wideband transverse feedback system**
41	Prototype
42	Specifications
43	
44	Installation and commissioning
45	**High power transverse feedback system**
46	Specifications
47	
48	Installation and commissioning
49	**Extraction protection device upgrade**
50	Design, feasibility studies and HiRadMat tests
51	Detailed design and fabrication
52	Installation and commissioning



SPS Upgrades (2/2)

B. Goddard

ID	
54	**Beam instrumentation**
55	Wirescanners
56	Headtail
57	BGI
58	BCTs
59	Tune
60	
61	BLMs
62	**Scraper/collimation upgrade study**
63	Design and feasibility studies
64	Technical design studies
65	**New scraper/collimation system**
66	Tendering and procurement
67	
68	Installation and commissioning
69	**Beam dump system design study**
70	Design and feasibility studies
71	Technical design studies
72	Prototype fabrication and tests
73	**New beam dump system construction**
74	Tendering and procurement
75	
76	Installation and commissioning
77	**Transfer line protection design study**
78	Design and feasibility studies
79	Technical design studies
80	**Transfer line protection upgrade**
81	Tendering and procurement
82	
83	Installation and commissioning
84	**New MKE design study**
85	Impedance and feasibility studies
86	Technical design studies
87	Prototype fabrication and tests
88	**New MKE construction**
89	Tendering and procurement
90	Construction
91	Installation and commissioning