Beam parameters and machine performance to be reached in 2010

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Introduction - I

- The objective is:
  - Derive detailed beam parameters' tables taking into account:
    - Experiment desiderata (see Massimiliano's talk)
    - Machine protection constraints (aperture, collimation settings, maximum intensity…)
    - Beam dynamics considerations (performance reach, crossing angle, collision schedules…)
    - Evolution of beam parameters (see Mike's talk)
  - All three topics covered by many talks at LMC in 2009 (Ralph, Massimiliano , Werner, Mike).

See Werner's talk

Introduction - II

- Experiment desiderata (very, very short summary):
  – ATLAS and CMS, as well as LHCb, require the highest possible integrated luminosity. Pile up will not be a problem.
  – Alice needs to squeeze the optics.
- Machine protection constraints:
  – Intermediate collimator settings. This implies that n1> 10.5
  – Maximum intensity: 5×10^{13}p

Introduction - III

- Beam dynamics considerations:
  - Minimum beta* without crossing angle: 2 m
  - Minimum beta* with crossing angle: 2.5 m
  - Crossing angle is mandatory to widen the performance reach
  - Trains (based on 50 ns spacing) are the solution (new bunches do not add new beam physics issues)
- Evolution of beam parameters:
  - Go to a given intensity/bunch and then add more trains

Proposed parameters evolution - I

Step	E [TeV]	Fill scheme	N	β* [m] IP1 / 2 / 5 / 8	Run time (indicative)
1	0.45	2x2	$5x10^{10}$	11 / 10 / 11 / 10	Weeks
2	3.5	2x2	$2 - 5x10^{10}$	11 / 10 / 11 / 10	
3	3.5	2x2*	$2 - 5x10^{10}$	2 / 10 / 2 / 2	
4	3.5	43x43	$5x10^{10}$	2 / 10 / 2 / 2	Weeks/Months
5	3.5	156x156	$5x10^{10}$	2 / 10 / 2 / 2	
6	3.5	156x156	$9x10^{10}$	2 / 10 / 2 / 2	Months
7	3.5	50 ns - 144**	$7x10^{10}$	2.5 / 3 / 2.5 / 3	
8	3.5	50 ns - 288	$7x10^{10}$	2.5 / 3 / 2.5 / 3	
9	3.5	50 ns - 720	$7x10^{10}$	2.5 / 3 / 2.5 / 3	Months

* Turn on crossing angle at IP1.

**Turn on crossing angle at all IPs.

Proposed parameters evolution - II

Step	Phase	N	N_b^{max}	N_{tot}/N_{tot}^{nom} [%]	E_{beam} [MJ]	L [$cm^{-2}s^{-1}$]
2/3	Beam commissioning – respecting safe beam limit	$2x10^{10}$	2	0.01	0.02	$3.6x10^{28}$
3	Pilot physics – squeeze to target values	$3x10^{10}$	43	0.4	0.7	$1.7x10^{30}$
4		$5x10^{10}$	43	0.7	1.2	$4.8x10^{30}$
5		$5x10^{10}$	156	2.4	4.4	$1.7x10^{31}$
5/6		$7x10^{10}$	156	3.3	6.1	$3.4x10^{31}$
7	Bring on crossing angle – truncated 50 ns.	$7x10^{10}$	144	3.1	5.7	$2.5x10^{31}$
8		$5x10^{10}$	288	4.4	8.1	$2.6x10^{31}$
8/9		$7x10^{10}$	432	9.3	17	$7.5x10^{31}$
9		$7x10^{10}$	796	17.1	31.2	$1.4x10^{32}$

See also Mike's talk

Proposed collision schedules

- Tables for collision schedules collected for the configuration without crossing angle:

43	A	B	C	D	E
IP1	43	39	43	43	**43**
IP2	42	38	34	21	**4**
IP5	43	39	43	43	**43**
IP8	0	4	4	11	**19**

156	A	B	C
IP1	156	156	**156**
IP2	152	76	**16**
IP5	156	156	**156**
IP8	0	36	**68**

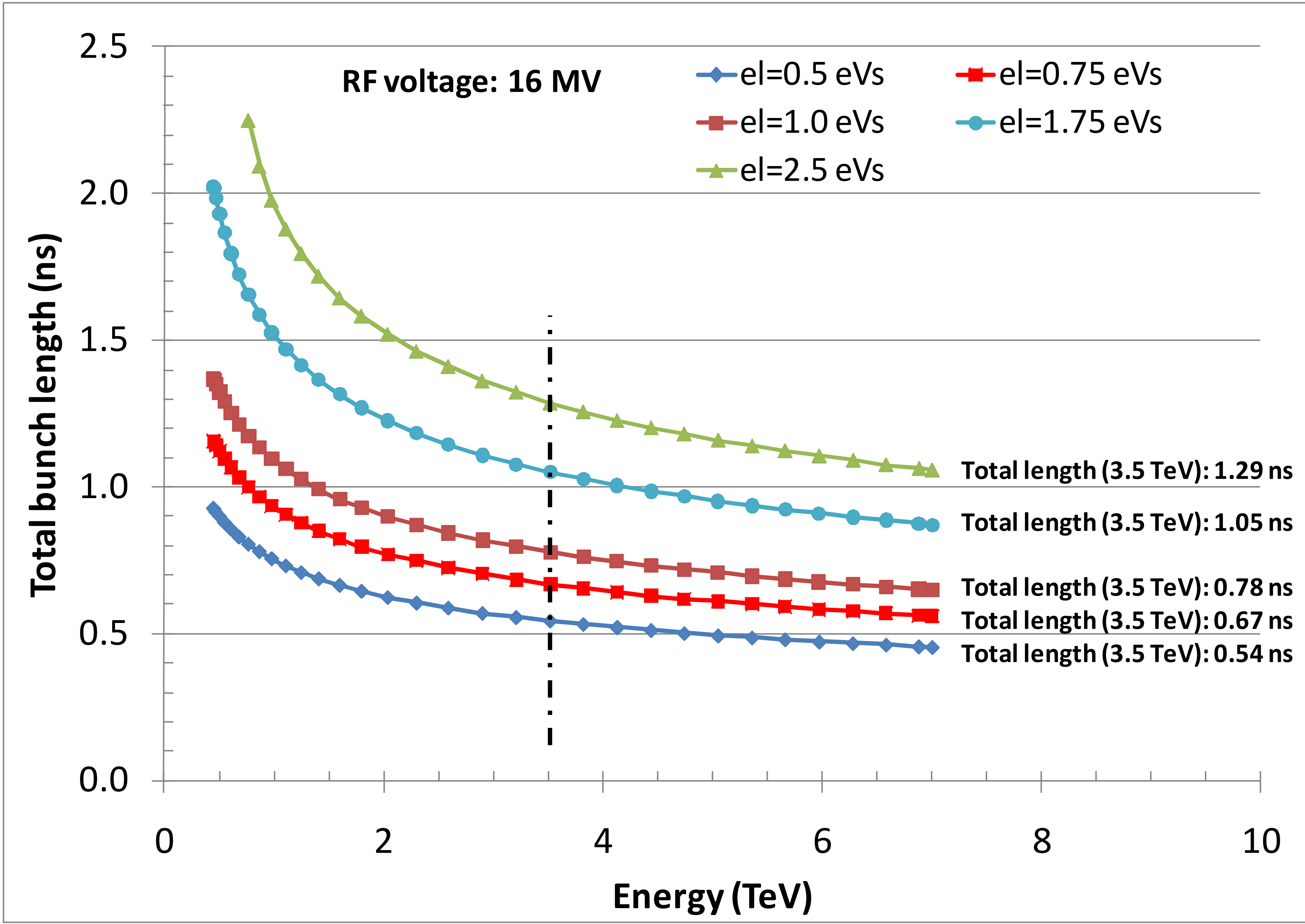
- The flexibility is very important! It enables changing the luminosity in IR2 without varying the optics (un-squeeze) or the crossing scheme (colliding partially separated bunches).

Longitudinal parameters - I

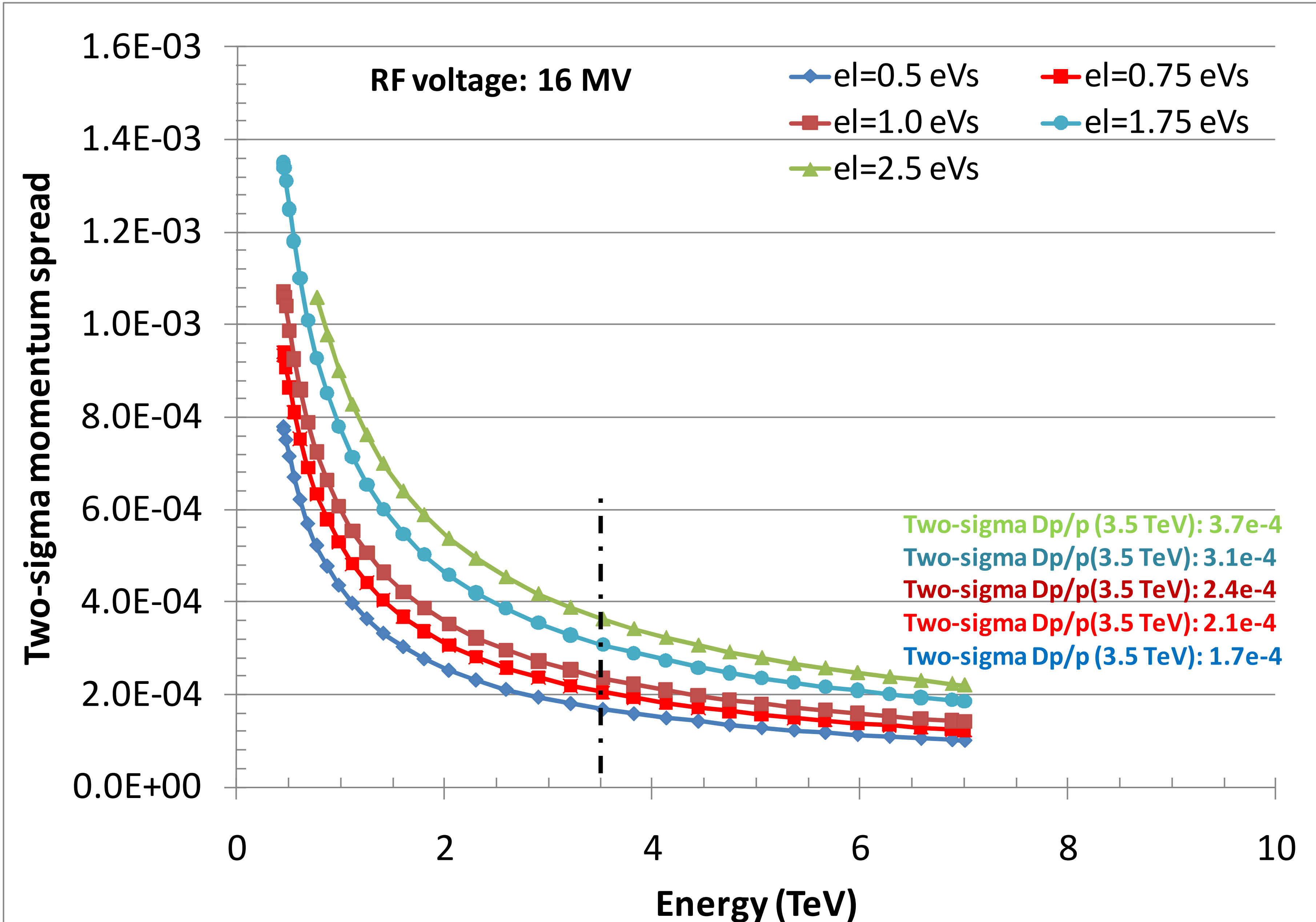
Different options to increase the longitudinal emittance are available. Typical values are:

- 0.5 eVs corresponds to the natural longitudinal emittance delivered by the SPS.
- 0.75 eVs corresponds to the emittance after applying longitudinal blow-up in the SPS (required for stability of nominal intensity beam in the SPS) and filamentation at LHC injection.
- 1.00 eVs corresponds to the combination of maximum blow-up in the SPS (not tried yet) and filamentation at LHC injection.
- 1.75 eVs corresponds to the emittance value required to have the same beam stability at 3.5 TeV as at 450 GeV, achievable only with controlled blow-up in the LHC.
- 2.5 eVs is the nominal value at 7 TeV.

Longitudinal parameters - II



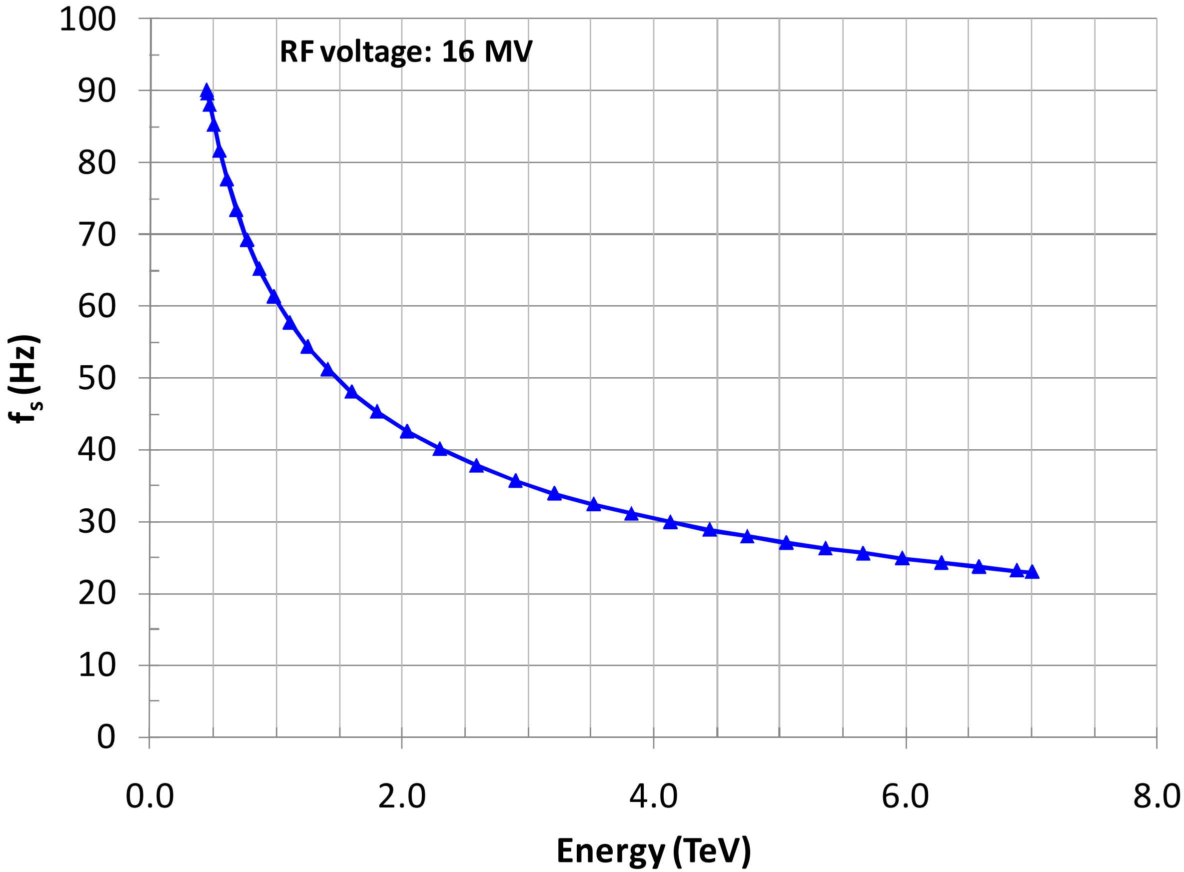
Longitudinal parameters - III



Longitudinal parameters - IV

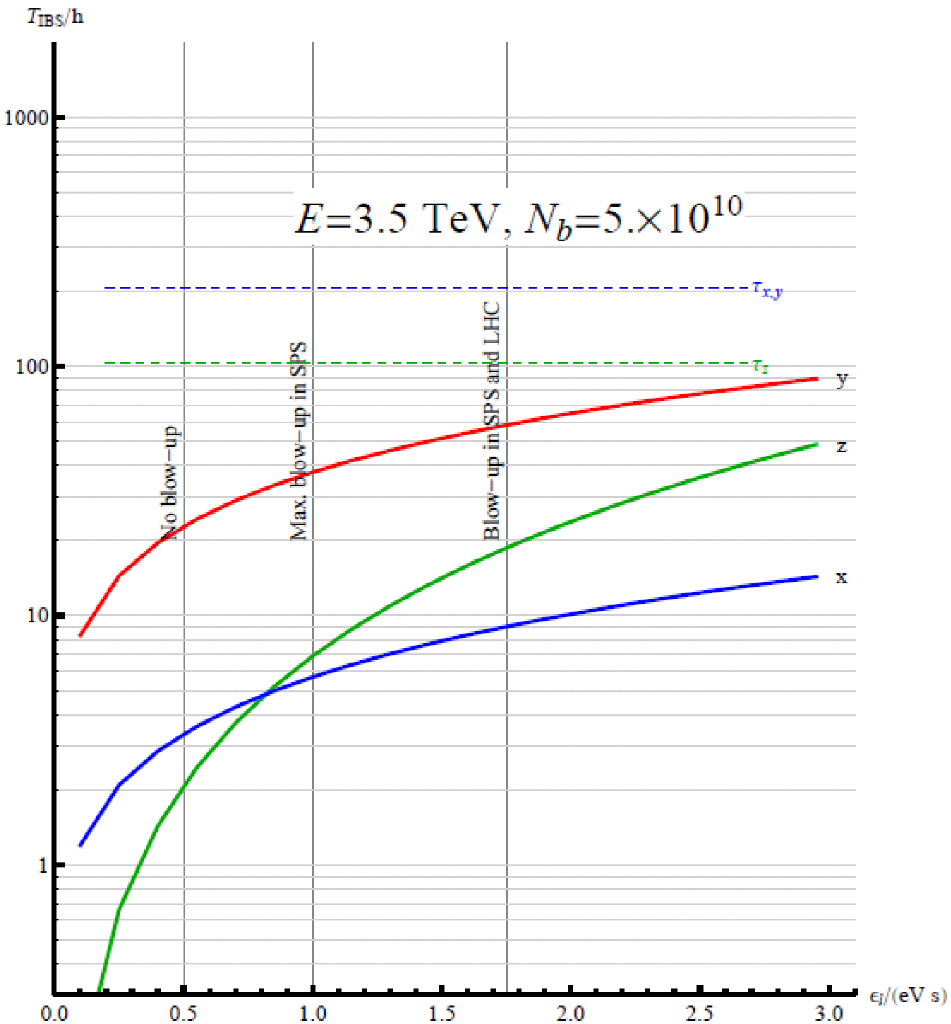
- Do we have to worry about 50 Hz crossing of synchrotron frequency?

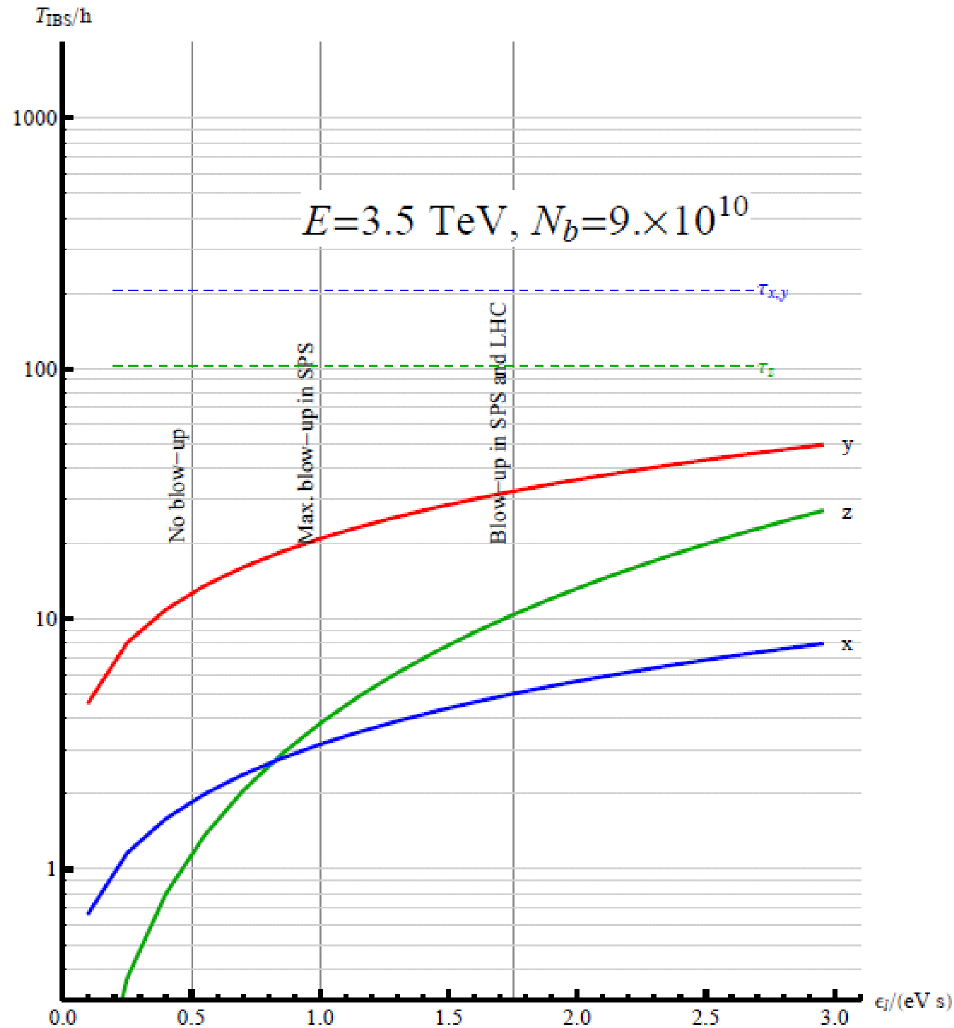
- In the case of the special parameters for the initial run no harmful effects are to be expected.



- In particular, fs will cross 50 Hz far away from 3.5 TeV/c.

IBS Summary at 3.5 TeV/c proton beams





Comments on longitudinal parameters and IBS

- The value of emittance which ensures that the beam will be stable up to the intensities considered is not known.
- The value of 1 eVs would not require any special effort to blow it up in the LHC. The blow-up of the longitudinal emittance by IBS will also help to stabilise the transverse emittance. However the initial transverse IBS growth rates are rather fast and might require some additional blow-up of the longitudinal emittance in the LHC.
- The growth rates are simply proportional to bunch intensity. The values plotted are calculated in the absence of betatron coupling with the small vertical growth being due to the crossing-angle bumps.
- In reality, the coupling will tend to share the growth between horizontal and vertical planes, potentially lengthening the horizontal growth time by a factor ~1.8–2. This curve can be regarded as a worst case. The general problem is the loss of Landau damping leading to longitudinal instability.

IBS and Radiation Damping Summary

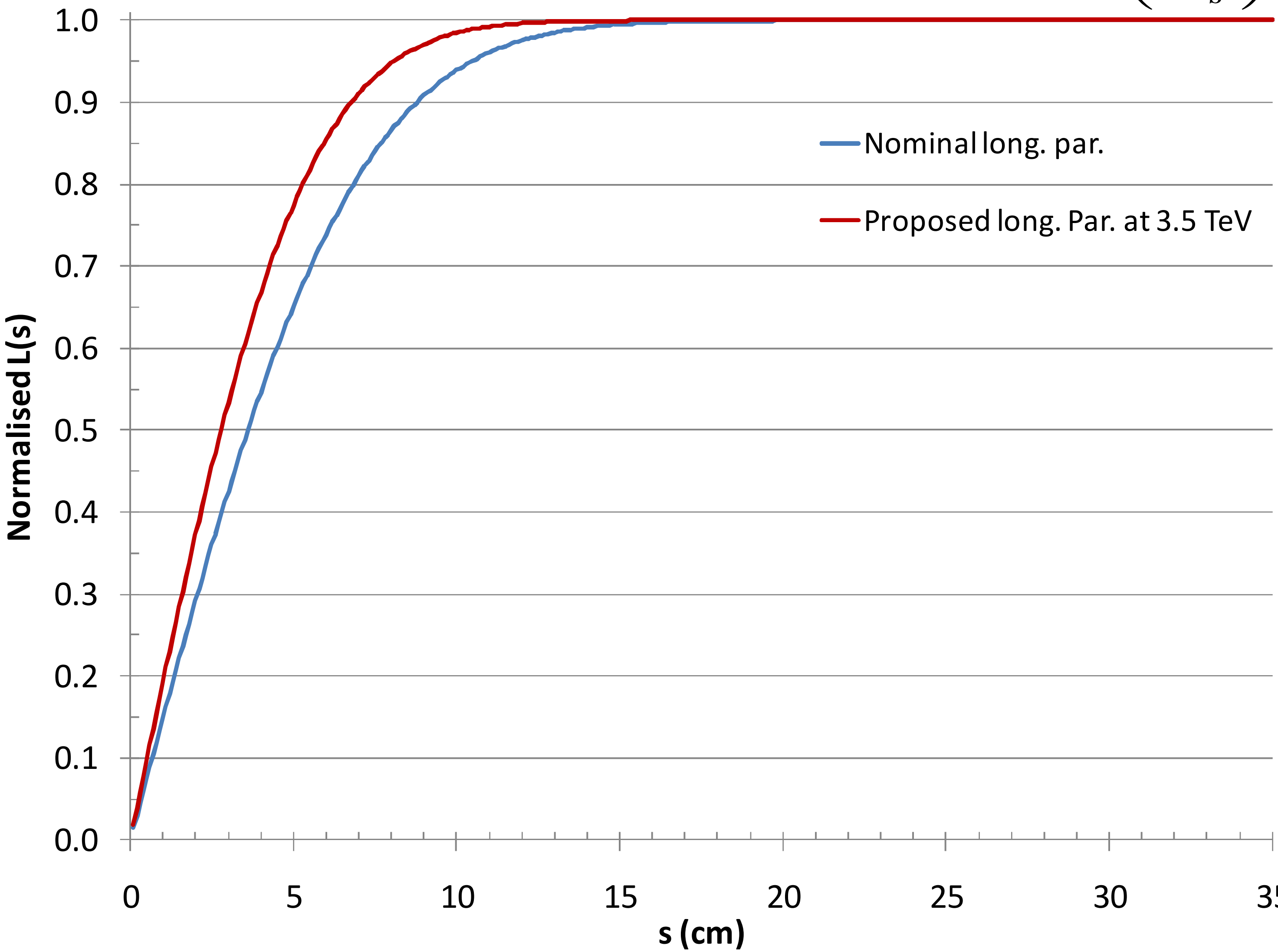
IBS effects		$N_b=5\times10^{10}$	$N_b=9\times10^{10}$
Longitudinal emittance growth time	h	9	4
Transverse emittance growth time	h	8	3
Synchrotron radiation effects			
Power radiated per proton	W	1.15×10^{-12}	1.15×10^{-12}
Power radiated/m in arc	W/m	9.29×10^{-5}	6.07×10^{-4}
Power radiated per ring	W	1.62	10.61
Critical energy of photons	eV	5.52	5.52
Longitudinal emittance damping time	h	103	103
Transverse emittance damping time	h	206	206

- Transverse synchrotron radiation damping is much weaker than IBS growth in all practical cases.

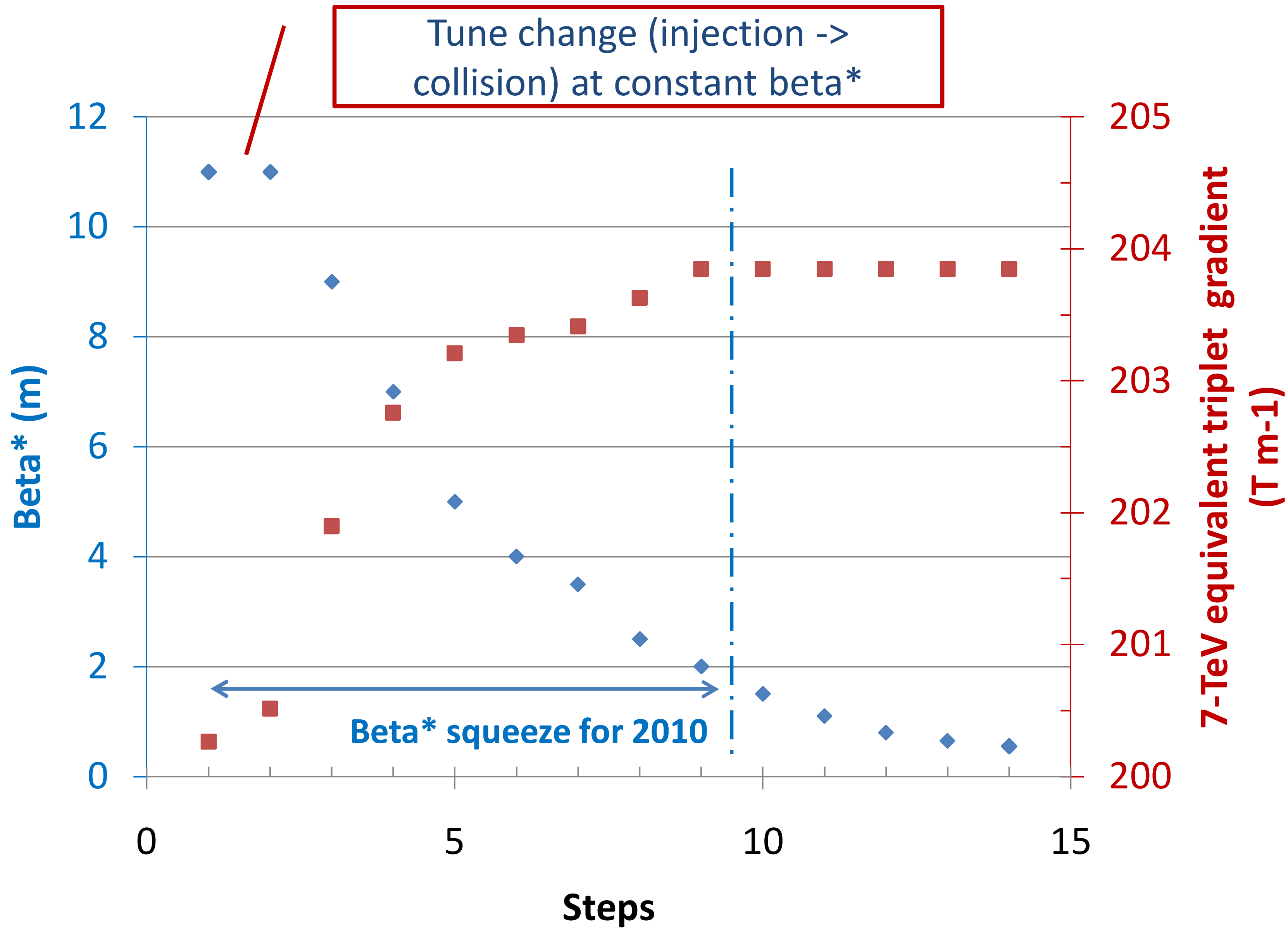
Luminosity

- Luminous region:

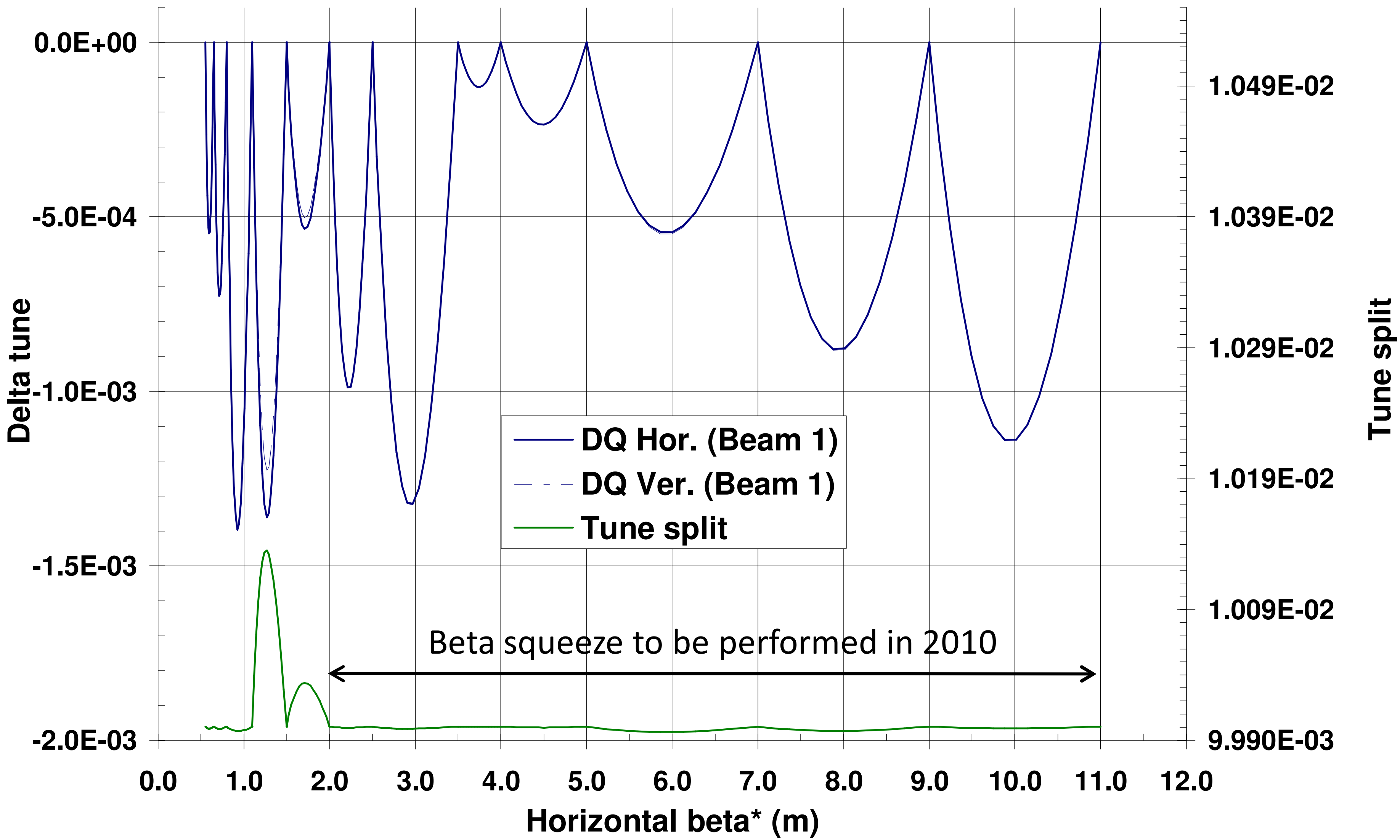
$$L(s) = \frac{N_p^2 \, f \, N_b}{4\pi\sigma^2} Erf\left(\frac{s}{\sigma_s}\right)$$



Optics configuration for 3.5 TeV in IR1/5

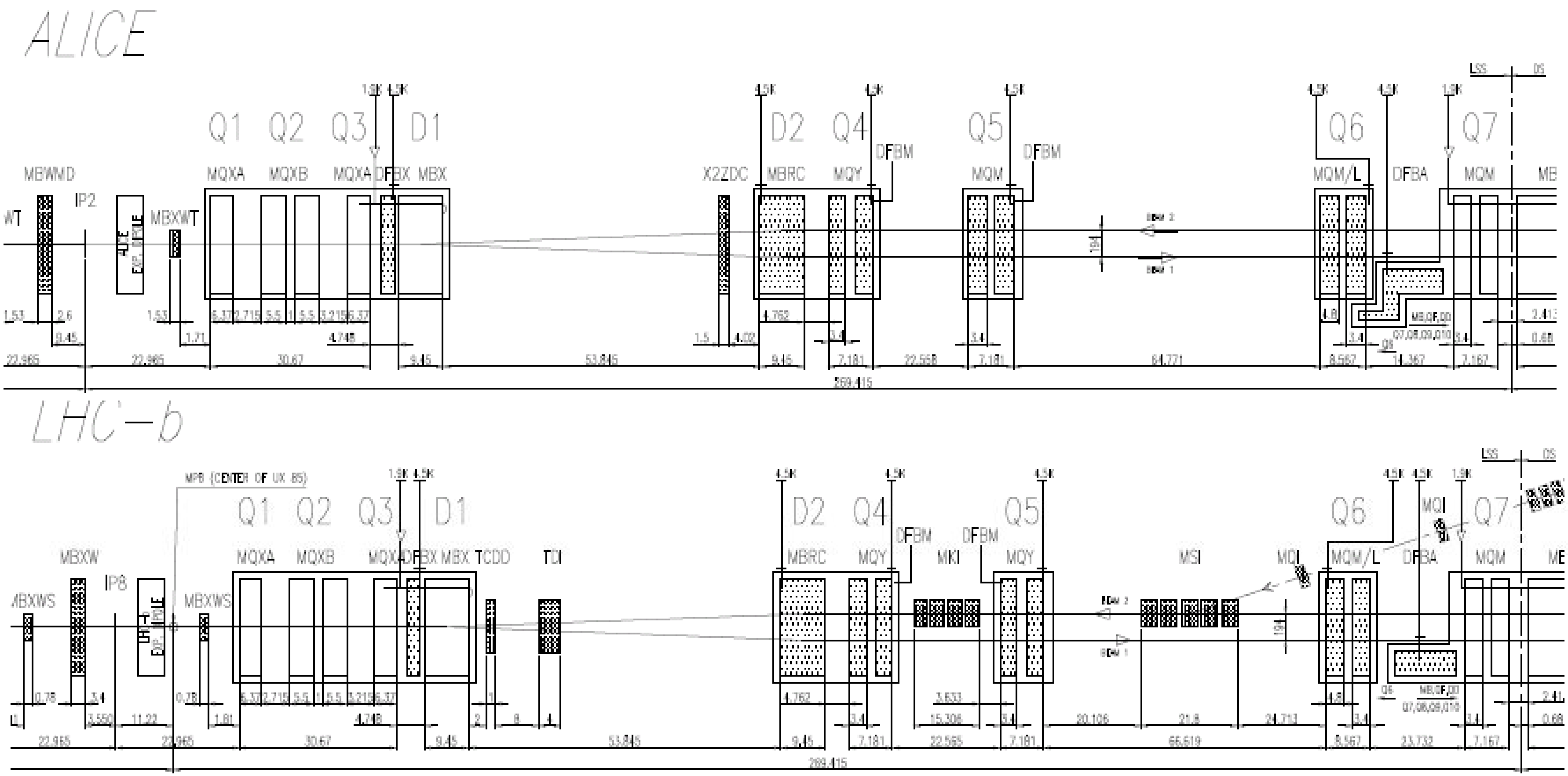


Performance analysis of 3.5 TeV squeeze



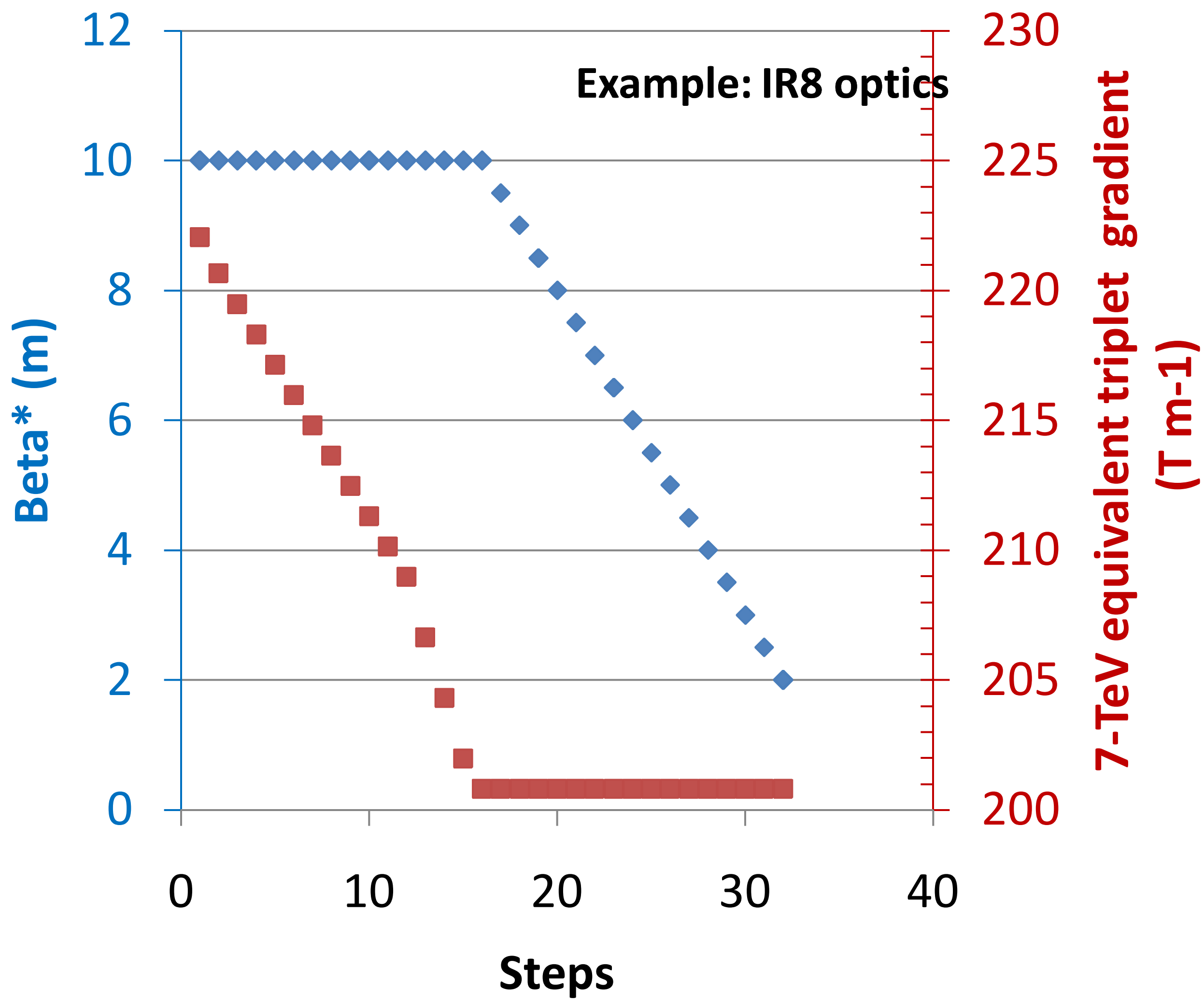
Special situation of triplets in IR2/8 - I

- Injection process imposes a number of constraints on phase advance (kicker/septum, kicker/TDI).
- Solution presented in LHC PR Notes 188 (IR2) and 193 (IR8) by O. Brüning.
- The gradient for injection optics is 222 T/m.



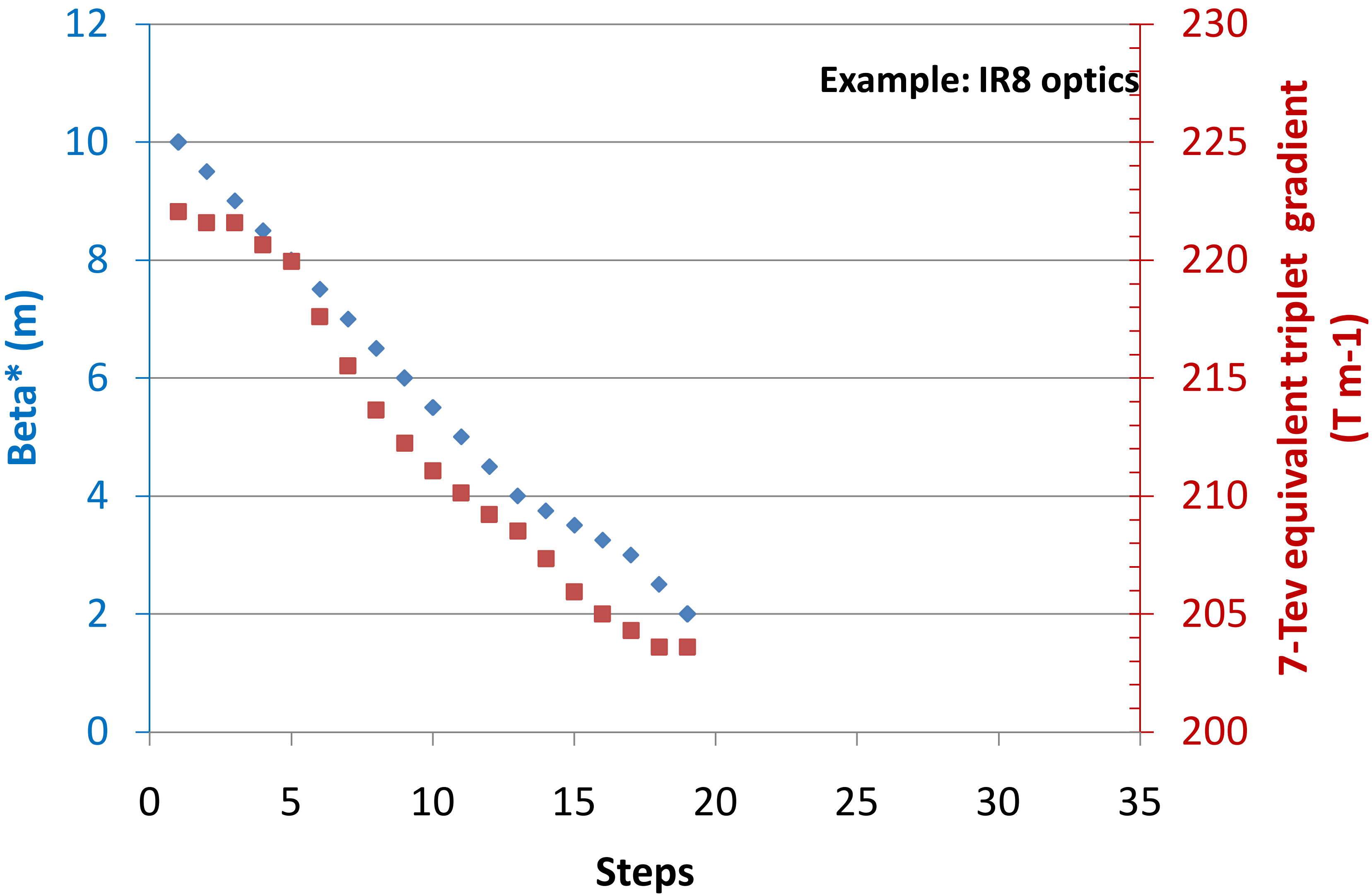
Pre-squeeze for nominal configuration

- Triplets acceptance tests were performed up to 230 T/m. However it was decided to limit the magnets to 215 T/m. Hence:
  - Optics is kept constant from injection to about 6 TeV.
  - Then the pre-squeeze is performed, with the triplets decreasing strength at constant beta*.
  - At top energy beta* is reduced at constant triplet strength.



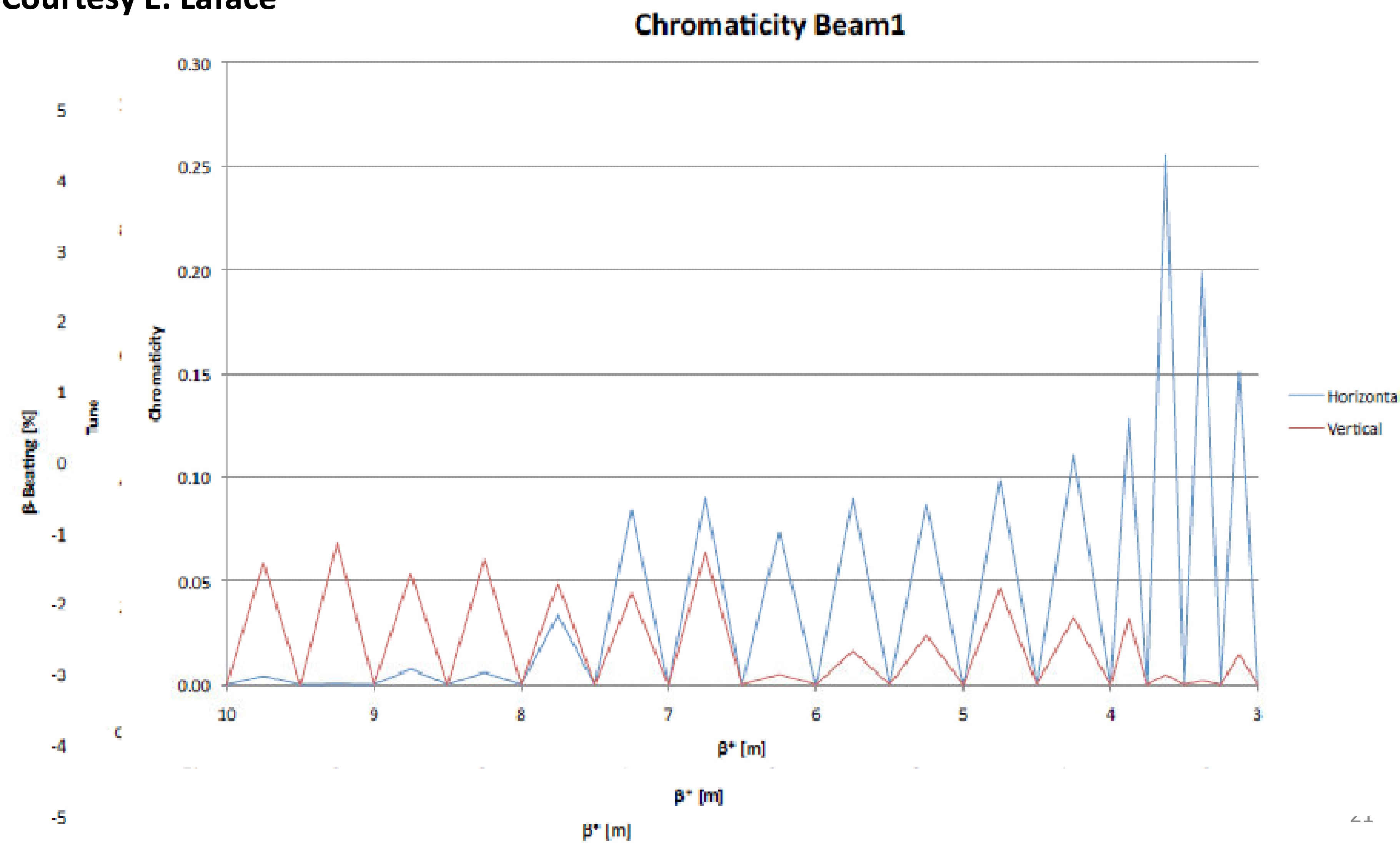
Pre-squeeze for 3.5 TeV

- No pre-squeeze is foreseen at 3.5 TeV separate from the actual squeeze.



Performance analysis of 3.5 TeV squeeze

Courtesy E. Laface



Some comments on spectrometers

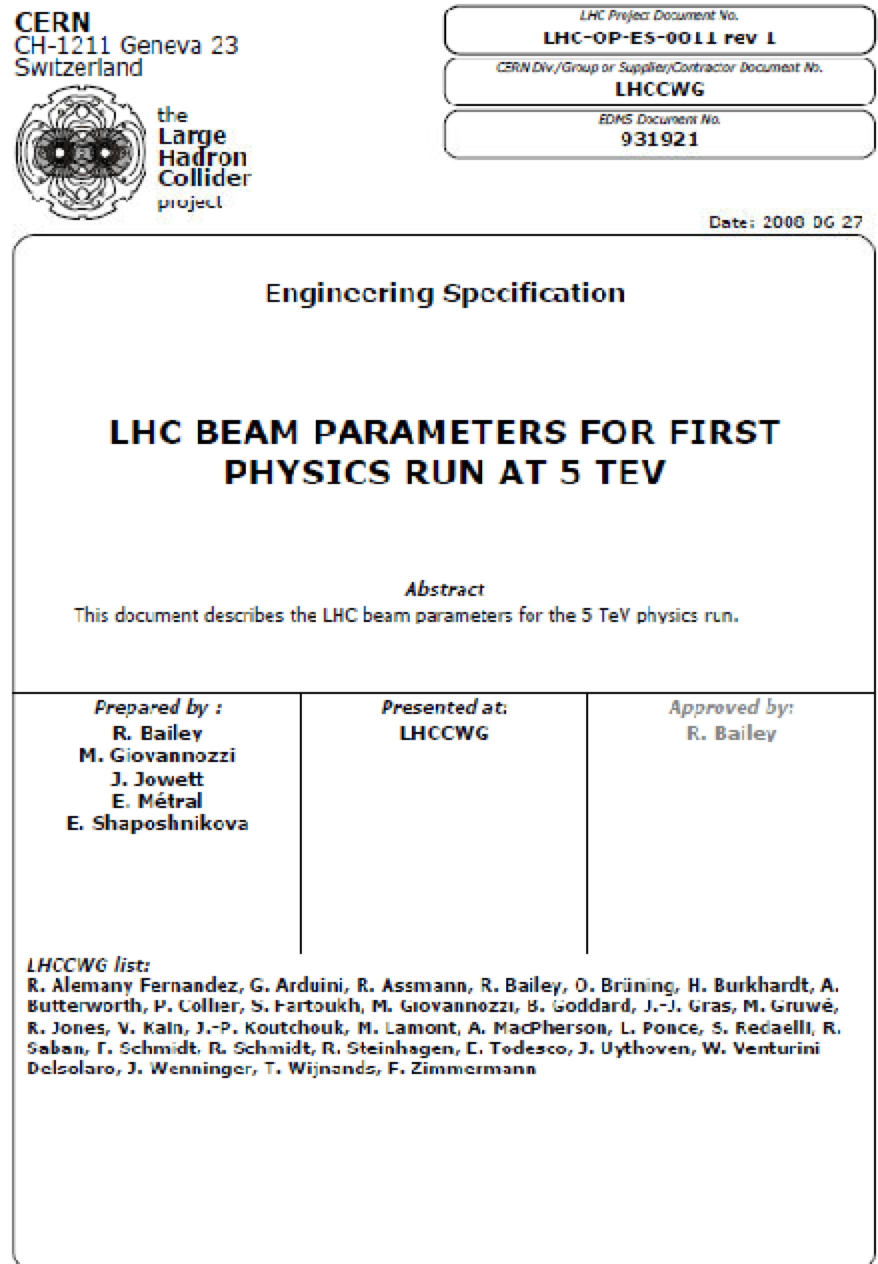
- LHCb
  - The preferred option would be to leave the spectrometer at nominal field from injection to top energy.
  - This is not possible for one of the two polarities.
  - For the "bad" polarity the spectrometer will have to be ramped.
- ALICE
  - The spectrometer is supposed to remain at nominal field from injection to top energy.
  - Change of polarity is not a problem.
- A side remark: could the ALICE spectrometer and/or its compensators be the source of the perturbation generating the "hump"? EPC experts are verifying the performance of the power converters.

Some general comments on optics

- Settings are generated starting from MAD-X strengths (see Stefano's talk).
- The decision was taken to separate optics from bumps (separation and crossing).
- Some improvements are under study for the various bumps:
  - IR2/8: the bumps are closed between Q5 (L/R). This decouples the injection conditions from the bump settings.
  - All IRs: the MCBX strength is being reviewed in order to take into account the limitations observed during Hardware Commissioning (350 A instead of 550 A).

The case of higher energies - I

- A set of 5 TeV beam parameters was already worked out in 2008.
- Main assumptions:
  - Only "pilot physics" (i.e., up to 156 bunches and no crossing angle) would have been performed at 5 TeV (the rest at 7 TeV).
  - The missing TCTVs in IR8 imposed a limitation on beta* to 6 m (minimum).
  - A rather large safety margin on aperture was considered (n1 about 14 was assumed).
  - Luminosity could reach 5×10^{31} cm^{-2} s^{-1} (IP1/5).



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Engineering Specification

LHC BEAM PARAMETERS FOR FIRST PHYSICS RUN AT 5 TEV

Abstract
This document describes the LHC beam parameters for the 5 TeV physics run.

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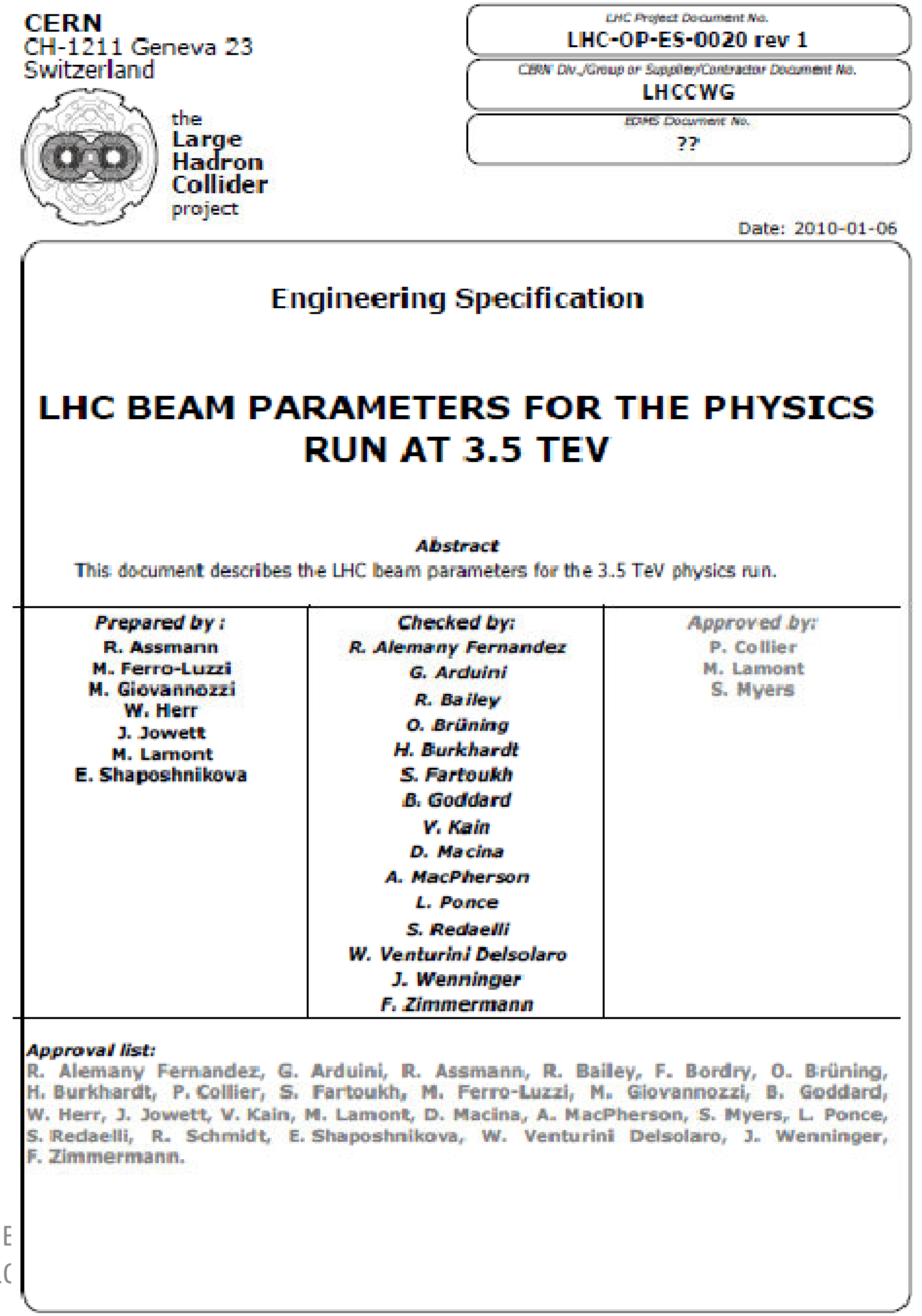
The case of higher energies - II

- Performance estimates might be revised taking into account:
  - Target n1 for intermediate setting: about 11.5
  - Maximum intensity: about 2×10^{13}
  - Add crossing angle scenarios
  - Assume similar parameter evolution strategy as for 3.5 TeV case
  - NB: the situation with IBS will be much better than at 3.5 TeV.

Summary

- Taking into account:
  - Experiments desiderata
  - MP constraints
  - Performance considerations
  - Beam dynamics considerations
- Detailed beam parameters tables for 3.5 TeV have been compiled and will be published in a note to be circulated soon for approval.



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Engineering Specification

LHC BEAM PARAMETERS FOR THE PHYSICS RUN AT 3.5 TEV

Abstract
This document describes the LHC beam parameters for the 3.5 TeV physics run.

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