5 TeV Stage A parameter list

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- **Recap of previous presentation**
- **Longitudinal beam parameters**
- **IBS**
- **Luminosity**
- **Overall target parameters**

Acknowledgements: G. Arduini, H. Burkhardt, E. Shaposhnikova, W. Herr, J. Jowett, E. Métral, F. Zimmermann

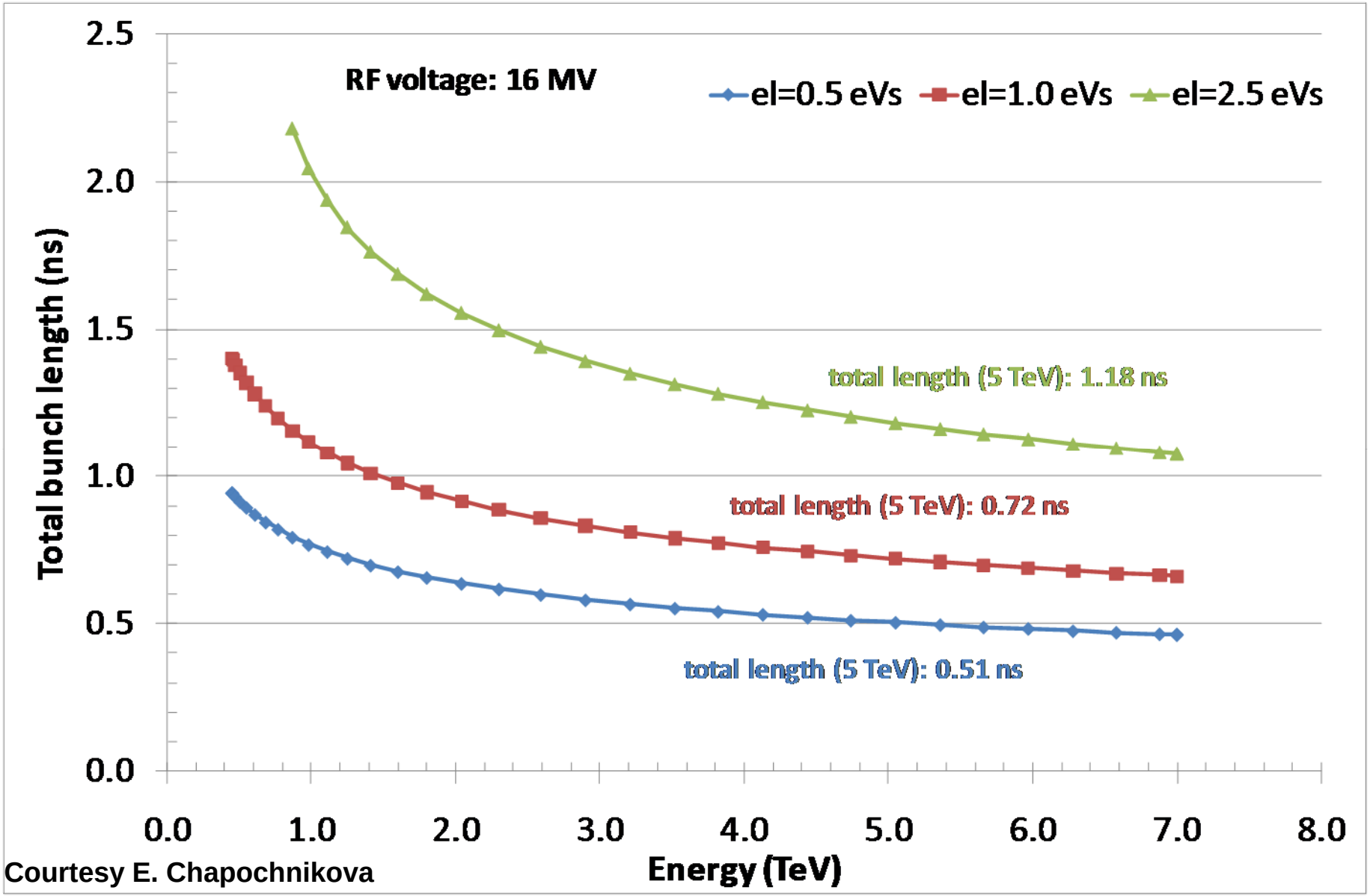
Recap of previous presentation

- Transverse parameters seems correct (i.e. aperture ok).
- Proposal to re-define target for beta* in IP1/5/8 as 3 m to keep the same aperture margin as for the planned 7 TeV run.
- In the parameter tables (see later) the value of 6 m is assumed (missing collimators due to hardware contamination) for IP8.
- Longitudinal beam parameters to be reviewed (longitudinal emittance blow-up will not be possible from Day 1)

Longitudinal parameters - I

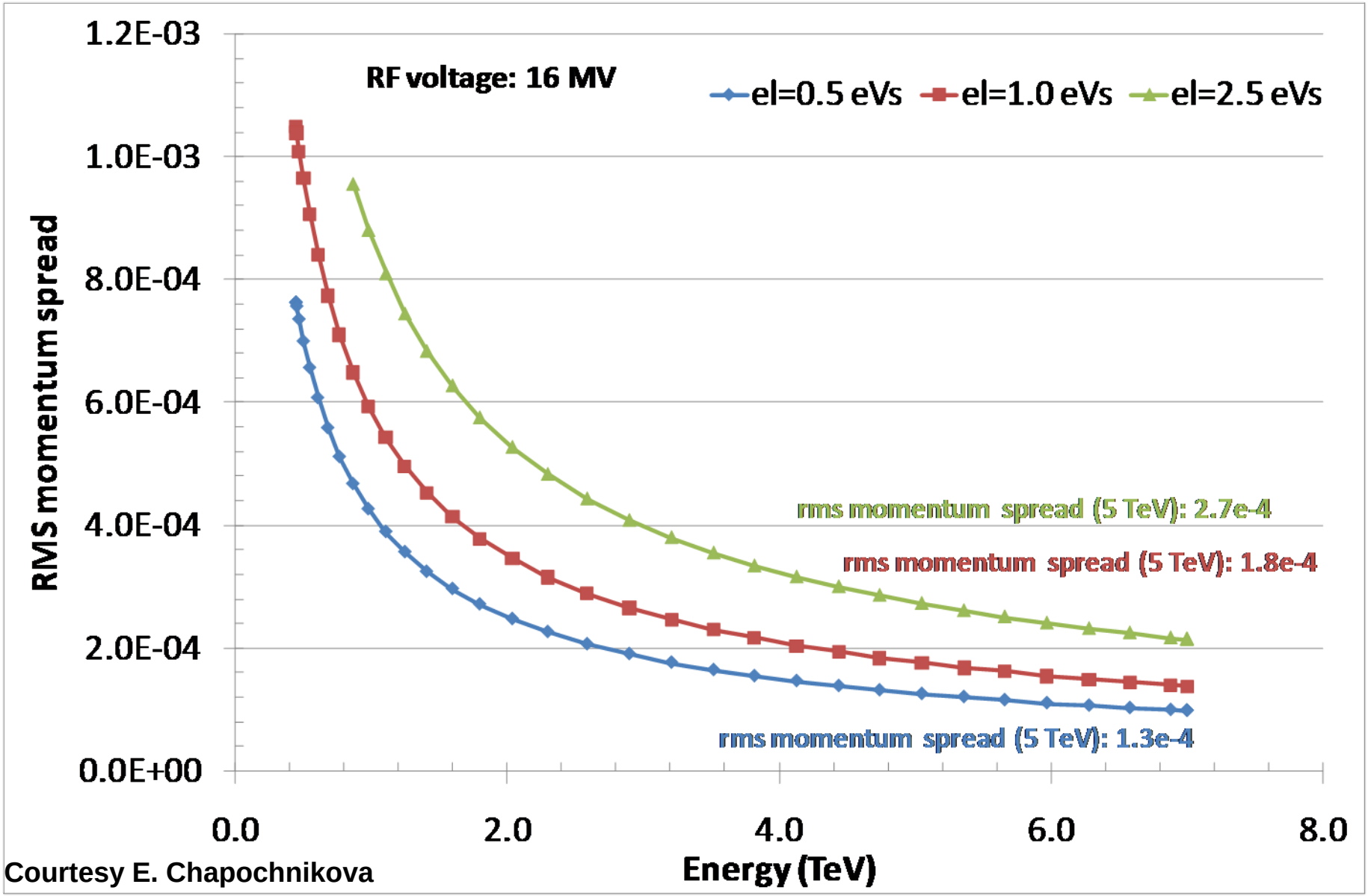
- Three sets of parameters:
  - EI=0.5 eVs (natural value at SPS extraction for low intensities)
  - EI=1.0 eVs (possible with blow-up at SPS and mismatch at LHC injection)
  - EI=2.5 eVs (nominal case, for comparison)

Longitudinal parameters - II



Courtesy E. Chapochnikova

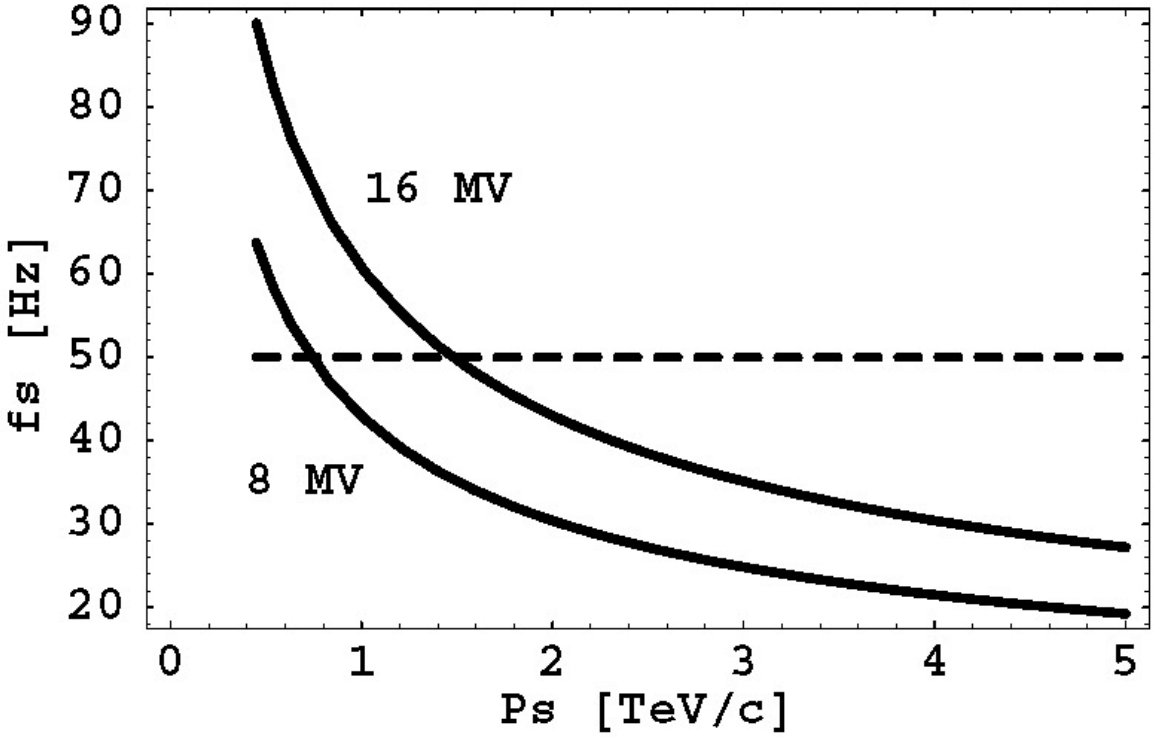
Longitudinal parameters - III



Courtesy E. Chapochnikova

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 ps=5 TeV/c.

Longitudinal parameters - V

- Comments:
  - The general problem is the loss of Landau damping leading to longitudinal instability.
    - 0.5 eVs: the intensity threshold is 2.2E10 p/b.
    - 1 eVs: the intensity threshold is 1.3E11 p/b.
    - 2.5 eVs: the intensity threshold is 1.5E12 p/b.

    Courtesy E. Métral
  - 1 eVs is the target for the 2008 run at 5 TeV:
    - Shorter bunch length-> smaller luminous region
    - Smaller momentum spread -> improve the mechanical aperture
    - Any potential issue for machine protection?

Longitudinal parameters - VI

- Comments:
  - The intensity threshold depends on the bunch length.

$$I_b \le \left(1+\frac{5}{3}\tan^2\phi_{s0}\right)\frac{3\pi^2}{32}\times\frac{h^3\hat{V}_{RF}\left|\cos\phi_{s0}\right|B_0^5}{\left|\frac{Z_l(p)}{p}\right|_{11}^{eff}}\times F_{PWD}$$

E. Métral, CERN-AB-2004-002

  - For the intensity of 9×10^{10} the total bunch length should > 0.67 ns.
  - At 7 TeV the total bunch length corresponding to 1 eVs is just 0.67 ns!
  - Only safety margin is in the longitudinal broad band impedance value used for these computations: 0.1 Ω (in the LHC DR it was assumed 0.07-0.08 Ω).

Synchrotron radiation for 2008 proton beams

- Same quantities as LHC Design Report Vol. I, Table 2.2

E	Energy
N_b	Particles per bunch
U_0	energy loss per turn
P_p	power radiated per proton
P_{arc}	power radiated/m in arc
P_{ring}	power radiated per ring
E_c	critical energy of photons
$\tau_{x,y}$	transverse radiation damping time
τ_s	longitudinal radiation damping time

E/TeV	N_b	U_0/eV	P_p/W	P_{arc}/(W m^{-1})	P_{ring}/W	E_c/eV	$\tau_{x,y}$/h	τ_s/h
5.	$4.\times10^{10}$	1746.98	4.79644×10^{-12}	0.000309461	5.41383	16.0873	70.6971	35.3486
5.	$9.\times10^{10}$	1746.98	4.79644×10^{-12}	0.000696287	12.1811	16.0873	70.6971	35.3486
7.	$4.\times10^{10}$	6711.18	1.8426×10^{-11}	0.00118882	20.7978	44.1435	25.7643	12.8821
7.	$9.\times10^{10}$	6711.18	1.8426×10^{-11}	0.00267486	46.795	44.1435	25.7643	12.8821

Courtesy J.M. Jowett

IBS at 5 TeV

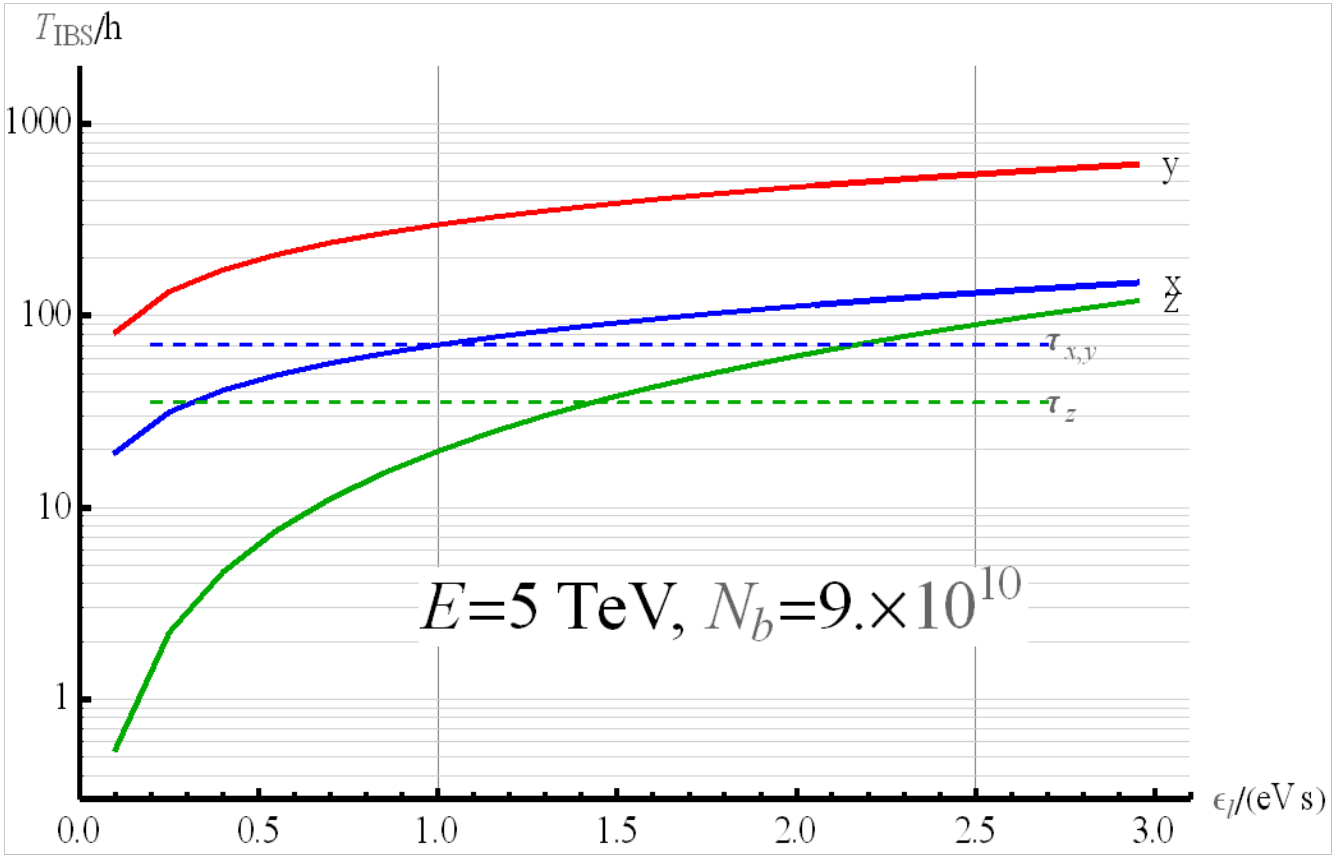
Emittance growth rates plotted vs. longitudinal emittance.

Nominal transverse normalised emittances assumed.

Vertical lines show nominal longitudinal emittance values at injection and at collision (after blow-up by RF noise).

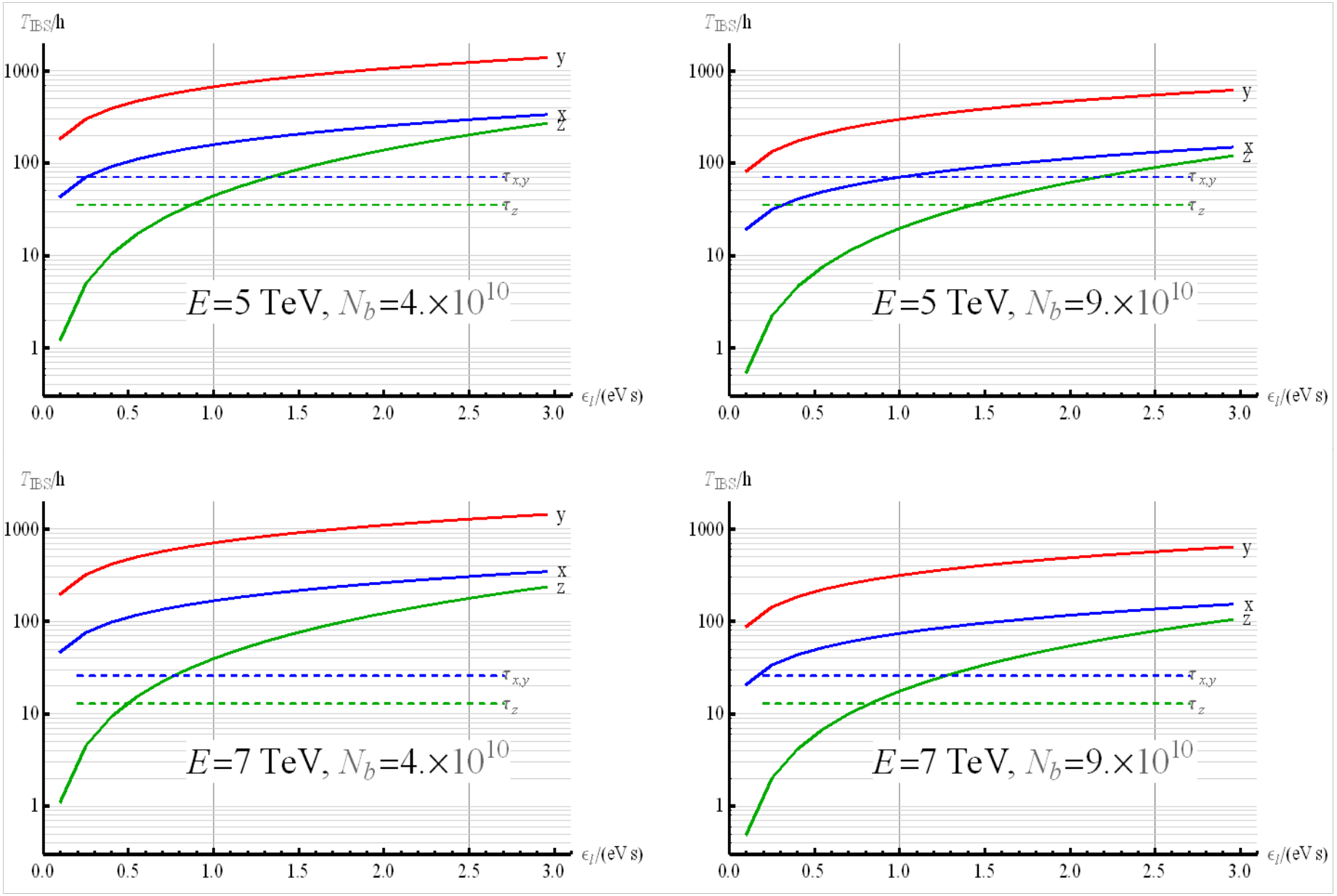
Horizontal dashed lines show the radiation damping times (for the emittances) for comparison.

In reality, transverse IBS growth will be shared equally between *x* and *y* planes because of betatron coupling (so could be almost factor 2 longer).



Courtesy J.M. Jowett

IBS Summary for 2008 proton beams



Courtesy J.M. Jowett

IBS and Radiation Damping Summary

				$\varepsilon_l = 1.0$ eVs		$\varepsilon_l = 2.5$ eVs	
E / TeV	N_b	$\tau_{x,y}$ / h	τ_z / h	$T_{\mathrm{IBS}x,y}$ / h	T_{IBSz} / h	$T_{\mathrm{IBS}x,y}$ / h	T_{IBSz} / h
5	4×10^{10}	71	35	>158	44	>296	202
5	9×10^{10}	71	35	>70	20	>131	90
7	4×10^{10}	26	13	>167	40	>306	178
7	9×10^{10}	26	13	>74	18	>136	79

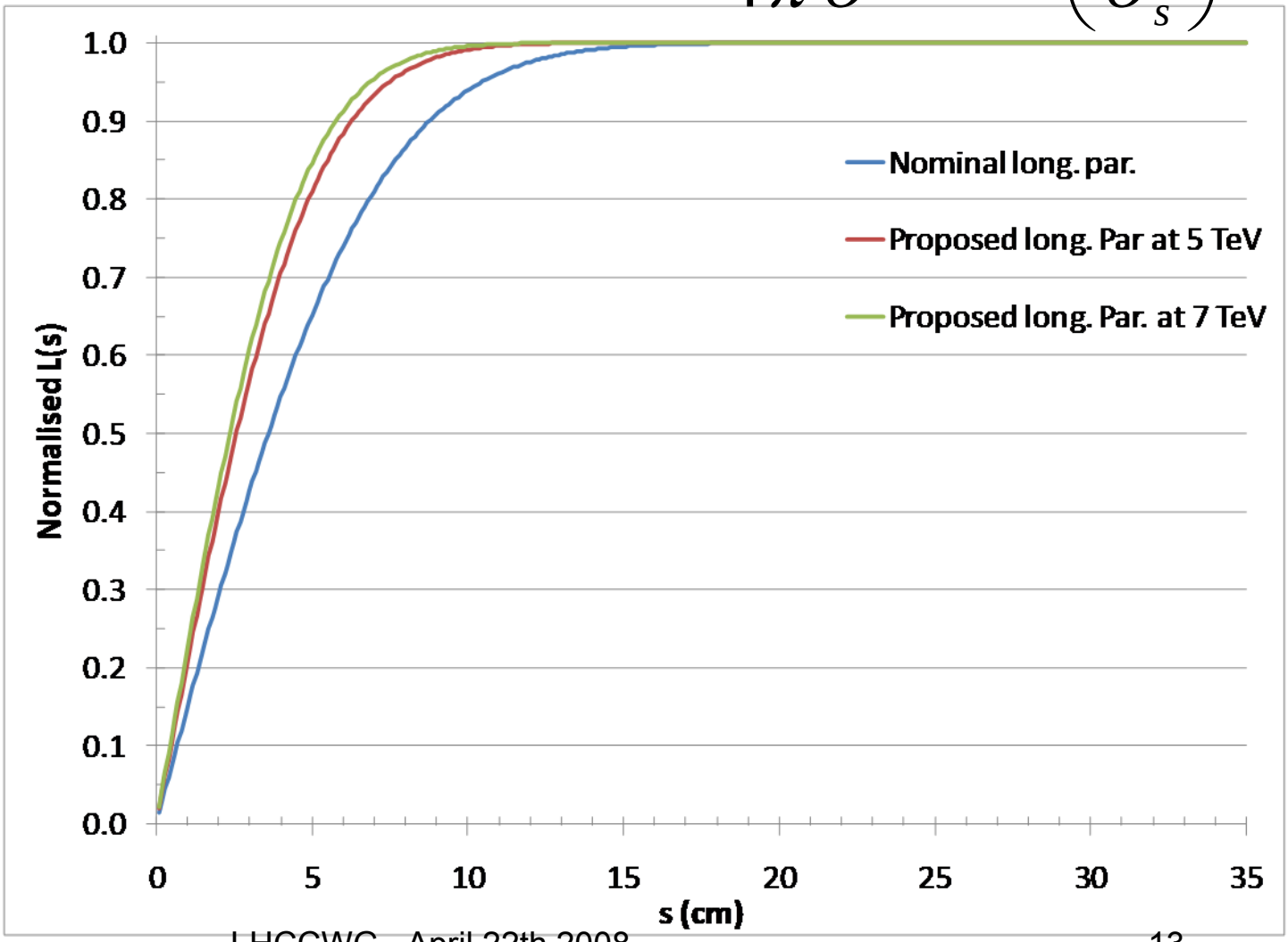
- For the same intensity, IBS growth rates at 5 and 7 TeV are very similar because the transverse normalised emittance is the same (real geometric emittances are larger at 5 TeV).
  - Also simply proportional to intensity.
- Transverse synchrotron radiation damping is stronger than IBS growth in all practical cases.
- For these intensities, operation without the blowup of the longitudinal emittance by RF noise in the ramp looks acceptable.
  - With higher bunch intensity, longitudinal IBS may do the job of RF noise at 5 TeV.

Courtesy J.M. Jowett

Luminosity

- Luminous region:
  - Nominal case:

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



Overall target parameters

- Tables for collision schedules collected:

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**

75 ns	E
IP1	**936**
IP2	**912**
IP5	**936**
IP8	**874**

50 ns	A	B	C	D	E
IP1	1404	1404	1404	1404	**1333**
IP2	1368	684	0	72	**2**
IP5	1404	1404	1404	1404	**1333**
IP8	0	655	1311	1242	**1173**

25 ns	E
IP1	**2808**
IP2	**2736**
IP5	**2808**
IP8	**2622**

Courtesy W. Herr.
Note in preparation W. Herr, M. Ferro-Luzzi, T. Pieloni

Overall target parameters: Phase A - I

Parameter	Unit	Injection	Collision	Collision
Total crossing angle IP1 & IP5	murad	0.00	0.00	0.00
Total effective crossing angle IP2	murad	2177.78	196.00	140.00
Total effective crossing angle IP8	murad	4200.00	378.00	270.00
Spectrometer crossing angle IP2	murad	2177.78	196.00	140.00
Spectrometer crossing angle IP8	murad	4200.00	378.00	270.00
Total external crossing angle IP2	murad	0.00	0.00	0.00
Total external crossing angle IP8	murad	0.00	0.00	0.00
Separation IP1 & IP5	mm	5.00	5.92	5.00
Transverse IP shift (crossing plane)	mm	0.00	0.00	0.00
Separation IP2	mm	4.00	4.73	4.00
Transverse IP shift (crossing plane)	mm	0.00	0.00	0.00
Separation IP8	mm	4.00	4.73	4.00
Transverse IP shift (crossing plane)	mm	0.00	0.00	0.00
Beta * IP1 & IP5	m	11.00	3.00	2.00
Beta * IP2	m	10.00	10.00	10.00
Beta * IP8	m	10.00	6.00	2.00
Crossing/Separation plane IP1		NA/V	NA/V	NA/V
Crossing/Separation plane IP2		V/H	V/H	V/H
Crossing/Separation plane IP5		NA/H	NA/H	NA/H
Crossing/Separation plane IP8		H/V	H/V	H/V
Energy	TeV	0.45	5.00	7.00
Number of bunches		43	43	43
Bunch intensity		4.00E+10	4.00E+10	4.00E+10
Longitudinal emittance	eV.s	1.00	1.00	2.50
Normalised transverse emittance	mum.rad	3.50	3.75	3.75

Overall target parameters: Phase A - II

Derived parameters	Unit			
Protons per beam		1.72E+12	1.72E+12	1.72E+12
Current per beam	mA	3.09	3.09	3.09
Stored energy per beam	MJ	0.12	1.38	1.93
Relativistic Gamma		479.60	5328.90	7460.46
RMS bunch length	cm	10.49	5.40	4.96
Beam size IP1 & IP5	mm	0.283	0.046	0.032
Beam size IP2	mm	0.270	0.084	0.071
Beam size IP8	mm	0.270	0.065	0.032
Geometric factor IP1 & IP5			1.000	1.000
Geometric factor IP2			0.998	0.999
Geometric factor IP8			0.988	0.978
Number of bunches crossing in IP1 & IP5			43	43
Number of bunches crossing in IP2			4	4
Number of bunches crossing in IP8			19	19
Luminosity in IP1 & IP5	cm-2 s-1		2.92E+30	6.12E+30
Luminosity in IP2	cm-2 s-1		8.12E+28	1.14E+29
Luminosity in IP8	cm-2 s-1		6.36E+29	2.65E+30
Events per crossing IP1 & IP5 (60 mbarn)			0.36	0.76
Events per crossing IP2 (60 mbarn)			0.11	0.15
Events per crossing IP8 (60 mbarn)			0.18	0.74

Alternative collision schedules	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**

IBS			
Longitudinal emittance growth time	h	44	40
Transverse emittance growth time	h	158	167

Synchrotron radiation			
Power radiated per proton	W	4.80E-12	1.84E-11
Power radiated/m in arc	W/m	3.09E-04	1.19E-03
Power radiated per ring	W	5.41	20.80
Critical energy of photons	eV	16.09	44.14
Longitudinal emittance damping time	h	35.35	12.88
Transverse emittance damping time	h	70.70	25.76

Tables in similar format have been re-generated for the other commissioning phases.