Laslett tune shifts for HL-LHC

S. ANTIPOV

HSC SECTION MEETING 17.02.20

MANY THANKS

S. ARSENYEV, G. IADAROLA

Laslett tune shift

L. Vos, *EPAC 2000*

Preceding bunches create a force that shifts the tune

Approximations:

- Uniform bunch train of length τ
- Resistive wall impedance $Z \sim (j/\omega)^{1/2}$

$$\Delta Q_{full} = \frac{1}{4\pi Q}\frac{R}{E/e}Z_{\perp}I_b$$

$$q(t) = \sum_{\omega=-\infty}^{\infty} e^{j\omega t}\,\frac{\sin(\omega\tau/2)}{\omega/2}\sqrt{\frac{j}{\omega}}$$

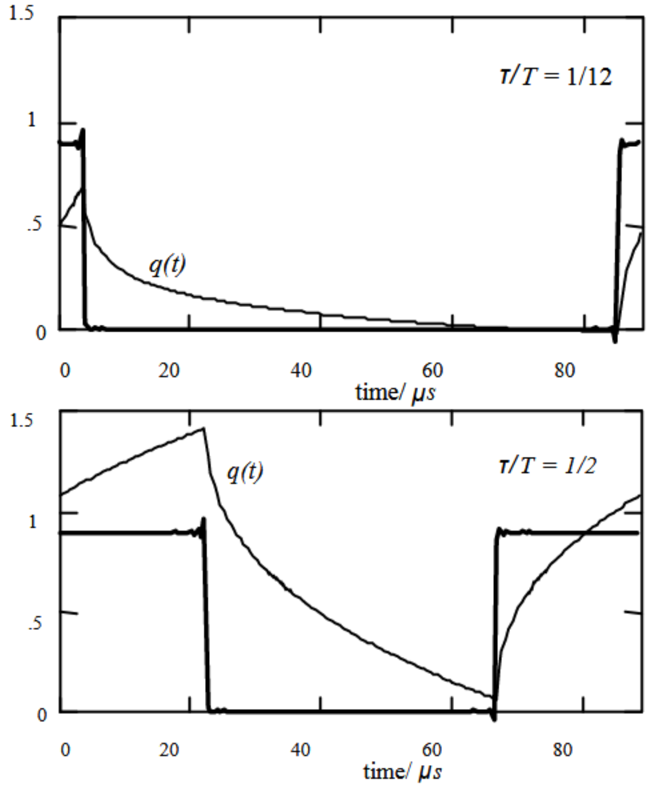


Figure 1 : Tune evolution across a bunch train, *top:* train (heavy line) occupies τ/T=1/12 of circumference, *bottom* : train occupies τ/T=1/2 of circumference

Laslett tune shift

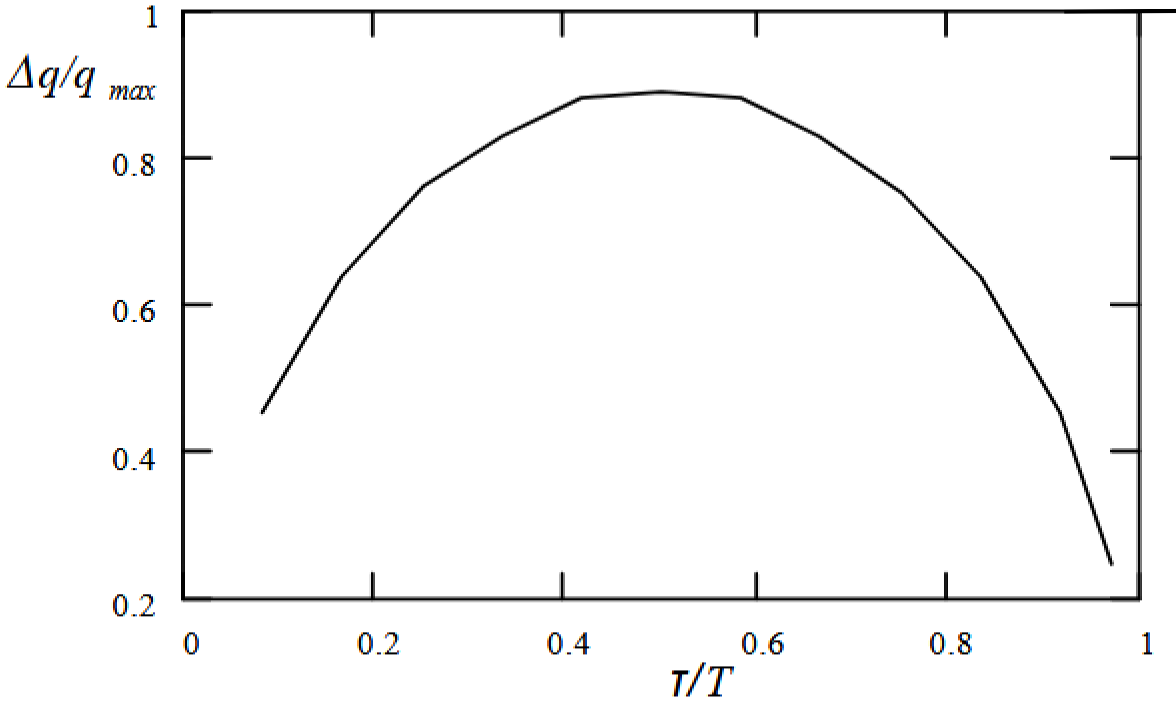


Figure 2 : Tune spread in bunch train versus fraction of machine circumference τ/T occupied by the beam.

$$\Delta Q_{full} = \frac{1}{4\pi Q}\frac{R}{E/e}Z_{\perp}I_b$$

Maximum tune shift along the train due to impedance

Machine	**LHC - 2017**	**LHC - 2017**	**HL-LHC**	**HL-LHC**	**HE-LHC**	**HE-LHC**
Cycle state	Injection	Flat-top	Injection	Flat-top	Injection	Flat-top
Energy, GeV	450	6500	450	7000	1300	13500
Intensity, ppb	1.05×10^{11}	1.05×10^{11}	2.3×10^{11}	2.3×10^{11}	2.2×10^{11}	2.2×10^{11}
Current full, A	0.67	0.67	1.47	1.47	1.4	1.4
Imp, MΩ/m	100	900	100	800	250	2000
Tune shift full	**8.8×10^{-4}**	**5.5×10^{-4}**	**1.9×10^{-3}**	**1.0×10^{-3}**	**1.6×10^{-3}**	**1.2×10^{-3}**

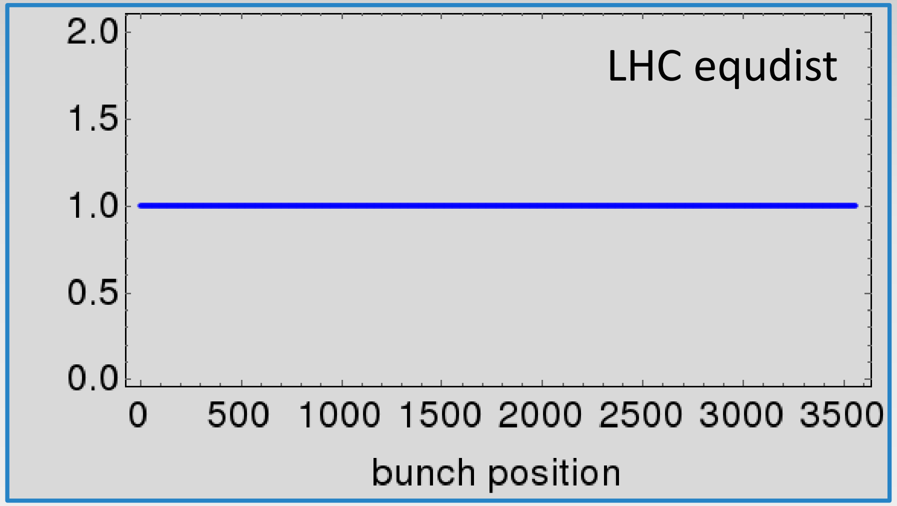
Estimates agree with tune shifts of the most unstable mode in NHT

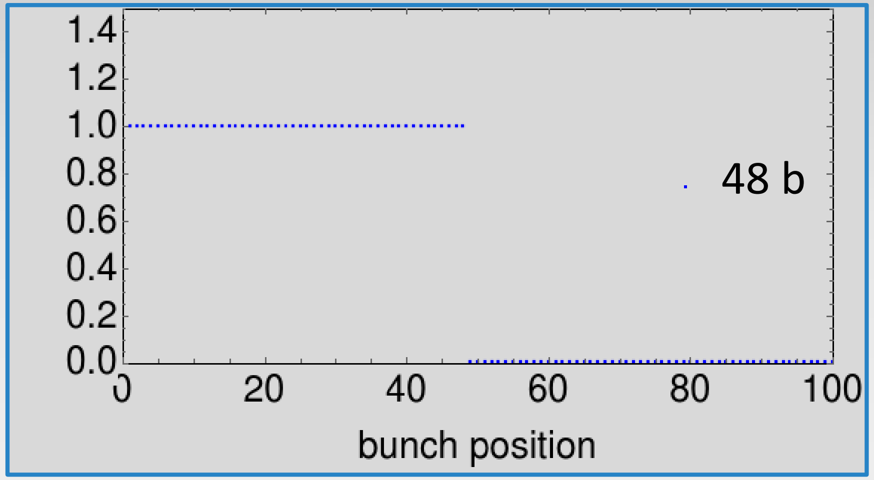
Machine	**LHC - 2017**	**LHC - 2017**	**HL-LHC**	**HL-LHC**
Cycle state	Injection	Flat-top	Injection	Flat-top
Energy, GeV	450	6500	450	7000
Intensity, ppb	$1.05\text{x}10^{11}$	$1.05\text{x}10^{11}$	$2.3\text{x}10^{11}$	$2.3\text{x}10^{11}$
Current full, A	0.67	0.67	1.47	1.47
Imp, MΩ/m	100	900	100	800
Tune shift full	$8.8\text{x}10^{-4}$	$5.5\text{x}10^{-4}$	$1.9\text{x}10^{-3}$	$1.0\text{x}10^{-3}$
NHT Estimate		**$6.2\text{x}10^{-4}$**		**$1.0\text{x}10^{-3}$**
R3 Beam, NHT		$4.6\text{x}10^{-4}$		$7.3\text{x}10^{-4}$
8b4e, NHT		$4.2\text{x}10^{-4}$		$6.7\text{x}10^{-4}$

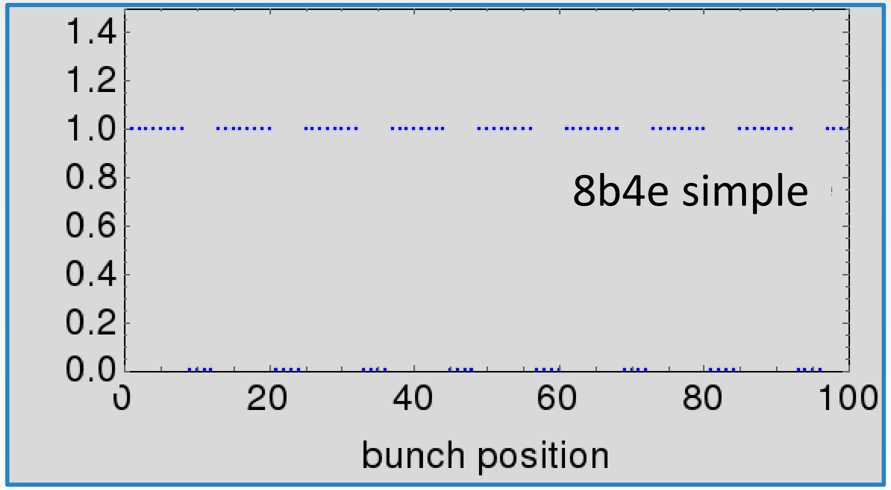
Original estimates of L. Vos

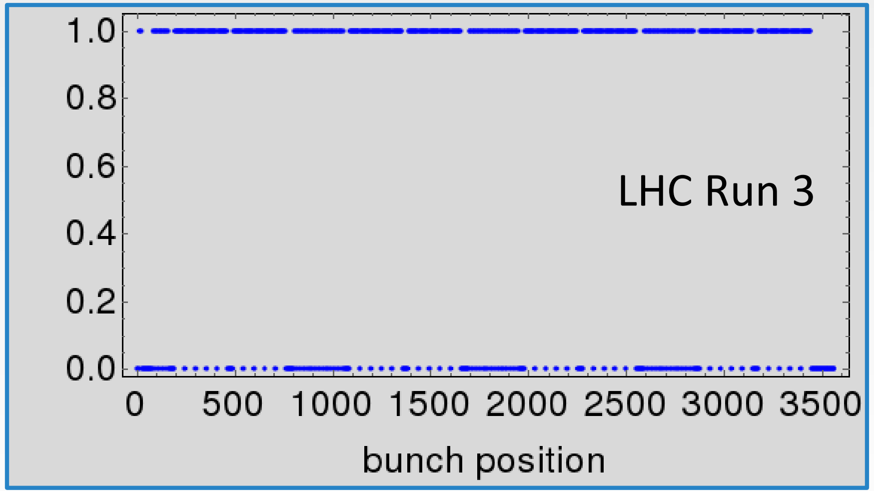
Machine	LHC – L. Vos	LHC – L. Vos
Cycle state	Injection	Flat-top
Energy, GeV	450	7000
Intensity, ppb	$1.05\text{x}10^{11}$	$1.05\text{x}10^{11}$
Current full, A	0.67	0.67
Imp, MΩ/m	52	116
Tune shift full	**$4.6\text{x}10^{-4}$**	**$6.7\text{x}10^{-5}$**

Filling patterns









Tune variation along the bunch: NHT