High Luminosity LHC with Large Piwinski Angle Scheme: A Recent Look

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  - H. Damerau, S. Hancock, E. Mahner, S. Gilardoni, F. Casper
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Motivation and Recent Progress

- Recent studies showed that
  - LHC beam-beam tune shift is > 0.015/IP (W. Herr et. al.)
  - Acceptable pileup events/crossing <200 (ATLAS and CMS)

  Therefore a leveled peak luminosity goal of about **5×10^{34}cm^{-2}sec^{-1}** has been defined [F. Zimmermann, EuCARD-CON-2010-041 (2010)].

  These changes prompted us to revisit the parameter list for the LPA scheme. ←Table on the next slide

$$\Phi_P = \frac{\theta_c \sigma_z}{2\sigma_{transv}}$$

- Here we address
  - Recent progress in LHC Injectors: PS, SPS ← which are directly beneficial to the LPA scheme for the HiLumi LHC
  - Mitigation of e-cloud issues in the LHC
    - Effect of bunch profile on e-cloud ← A dedicated expt. in PS
    - e-cloud simulations specific to LHC - LPA scheme
  - What have we learnt from these studies?

New Parameter List for LPA scheme

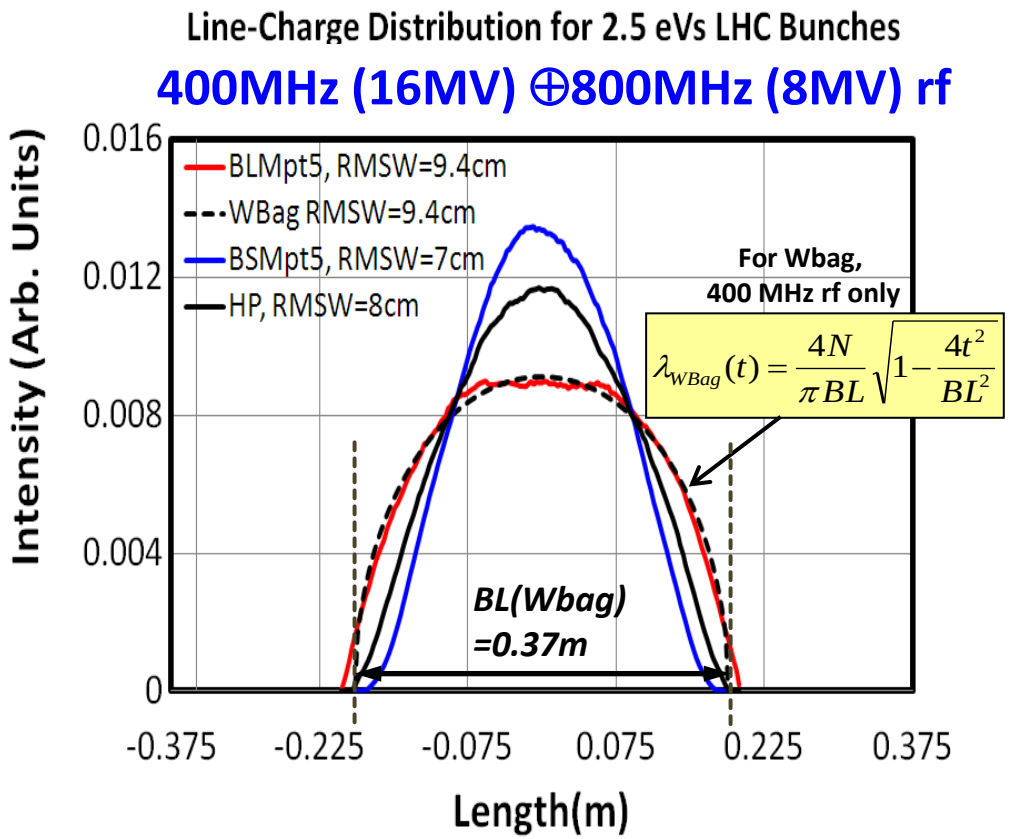
LHC at 7 TeV: "BLMpt5" and "BSMpt5" represent the rf voltage ratio of 0.5 with 180 deg phase apart for 1st and 2nd harmonic rf cavities. (IPAC2011)

Parameters		Nominal	Ultimate	LPA (200MHz +400MHz RF) BLMpt5 (A)	LPA (200MHz +400MHz RF) BSMpt5 (B)	LPA (400MHz +800MHz RF) BLMpt5 (C)	LPA (400MHz +800MHz RF) BSMpt5 (D)	Water Bag § (400MHz)
# of Bunches		2808	2808	1404	1404	1404	1404	2808/1404
ppb	$x10^{11}$	1.15	1.7	3.9	3.3	3.4	3.4	2.0/ 3.4
Beam Current	[A]	0.58	0.86	1	0.84	0.86	0.86	1/ 0.85
(e_T)Normalized	μm	3.75	3.75	3.0-3.75	3.0-3.75	3.0-3.75	3.0	3.75
σz (2.5 eVs @7TeV) BL(90%)	cm cm	7.55 -	7.55 -	16 (52)	11 (36)	9.4 (30)	7 (23)	9.4 (30)
Bunch Spacing	nsec	25	25	50	50	50	50	25/ 50
β* at IP1 and IP5	m	0.55	0.5	0.25	0.25	0.34	0.25	0.25/ 0.34
θc	μRadian	285	315	380	380	380	285	290/ 380
Piwinski Angle	Radian	0.64	0.75	3.03-2.71	2.08-1.86	1.5-1.4	1.0	1.2/ 1.4
ΔQbb (IP1+IP5)		0.006	0.009	0.01-0.009	0.012-0.01	0.015-0.013	0.02	0.008/ 0.013
Peak Luminosity	$10^{34}cm^{-2}s^{-1}$	1	2.3	6-5.3	5.9-5.1	5.8-5.0	10	5/ 5
<L> w/o leveling (10 hr TA)	$10^{34}cm^{-2}s^{-1}$	0.46 -	0.91 -	1.68-1.6 -	1.5-1.4 -	1.5-1.4 -	L_{level}=5	1.5/1.54 -
Event Pileup with $\sigma_{inelastic}$=60 mb★	Pileup	19	44	201-227	224-196	221-190	192	96/190

§ Detailed calculation yet to come; currently we assume similar to "Ultimate" for 25 nsec and case "(C)" for 50 nsec.
★ATLAS-CONF-2011-002

Mikhail Zobov from INFN, Frascati

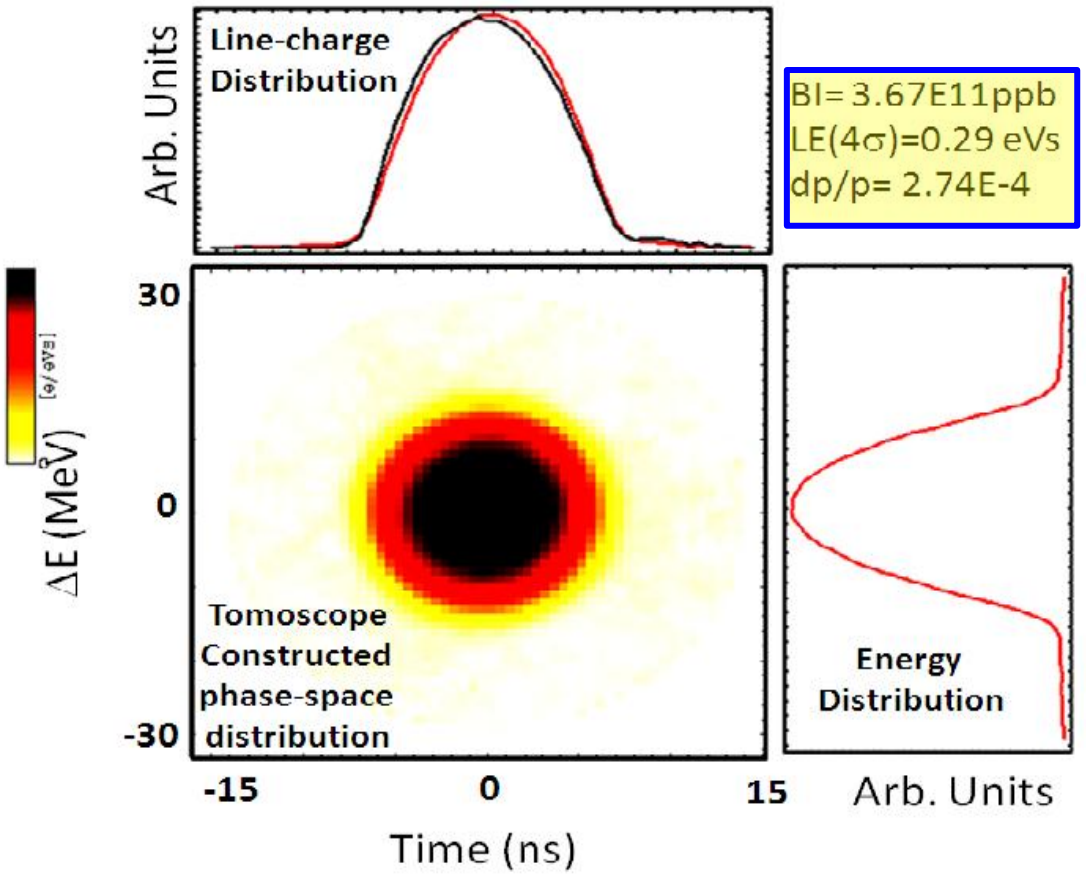
Longitudinal Profiles for the LHC Bunches @7TeV



BSM➔ Bunch Shortening Mode
BLM➔ Bunch Lengthening Mode
HP➔ Hoffman-Pedersen dist.
WBag➔ Water Bag dist.

All bunch profiles are simulated using ESME including broadband Z||/n effect.

PS towards high brightness beam



H. Damerau and S. Hancock

- Significant progress has been made in the PS to produce single stable bunches of
  - Intensity >3.6E11ppb
  - LE(4σ) <0.3eVs
  - dp/p ≈2.7E-4 and
  - εT ~3 μm
- High intensity bunches have been injected in to SPS and to LHC.
- HD, AB and CB are proposing an experiment in the PS to produce "**QUASI Water Bag**" distribution and study its stability.
- **Challenges:** How to produce multiple bunches of this quality and address beam instability in the PS.

  ← Currently this is one of the ongoing activities in the PS as a part of the PS upgrade

Progress in SPS

- During 2010-2011 a lot of effort has gone into
  - Inject to SPS, accelerate and extract high intensity single bunch to the LHC
    - Using nominal Q23 (γ_T=23) lattice ← E.Shaposhnikova, et.al.

      (bunch int. limit:1.7E11ppb(Q'=0), 2.2Eppb(Q'=0.07) **Benoit Salvant**)
    - With Q20 (γ_T=18) lattice ← H. Bartosik, et. al.

      (bunch int. limit:2.8E11ppb(Q'=0), 3.8Eppb(Q'=0.07) **Benoit Salvant**)

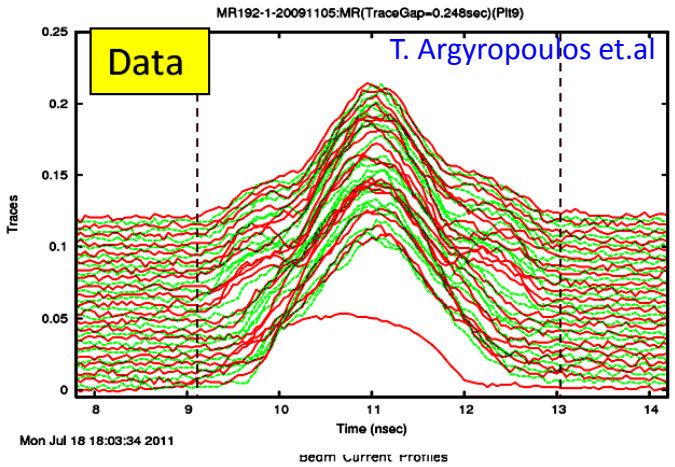
      This lattice seems to have many advantages over Q23 from the point of view of intensity threshold for beam instability.

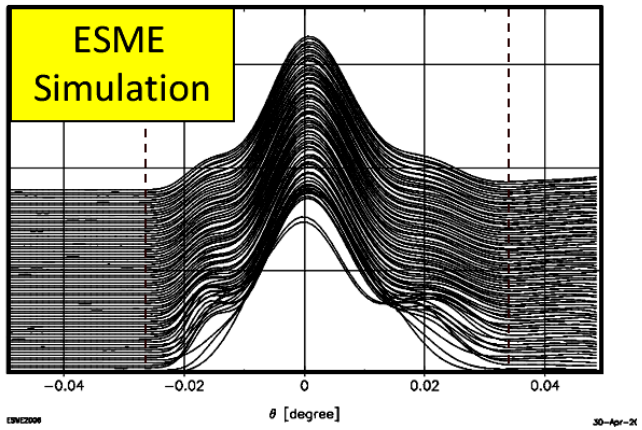
      Comment: Q20 Beam is not yet fully commissioned for LHC.
  - Beam dynamics simulations of single bunch instability in double harmonic rf bucket ←200MHz⊕800MHz in SPS

Example of Single Bunch Instability in Double harmonic rf in the SPS

(Measurement and Simulations)

Measured and predicted mountain range of the bunch in the SPS with1.1E11ppb.





- Similar studies have been made on a number of data set taken at different beam conditions and behavior is explained quite well.
- We were also able able to predict the longitudinal dynamics of single bunch in the presence of existing RF Feed Forward turned on.
- Extension of such simulations show that the current RFFF should be good enough for single bunch up to **~4E11ppb (**with a only a few% beam loss).
- **Challenges:** A lot of effort is being made on high intensity multi-bunch
  - **injection,**
  - **acceleration,**
  - **mitigation of e-cloud/impedance related beam instabilities.**

High Intensity Bunches in the LHC (25/Oct/2011)

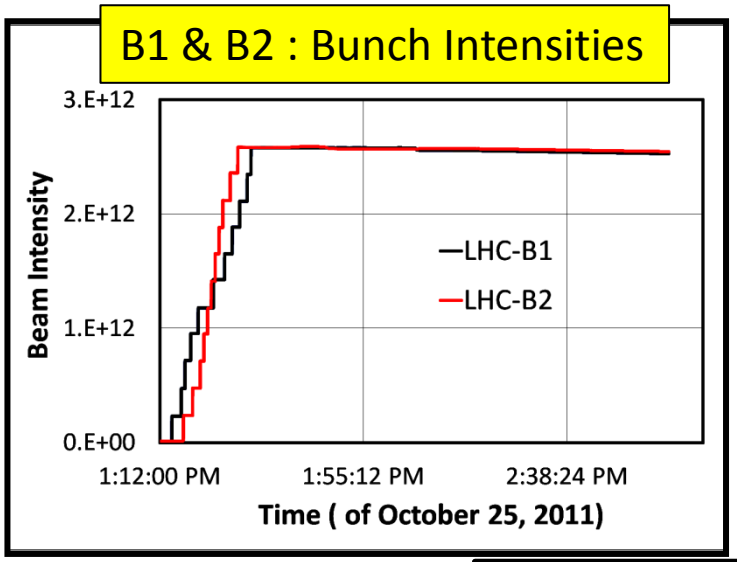
High-Pileup Test of LHC (Oct. 25): Eleven "High Intensity" bunches were injected into the LHC using Q23 lattice in the SPS and accelerated to collision at 3.5 TeV.

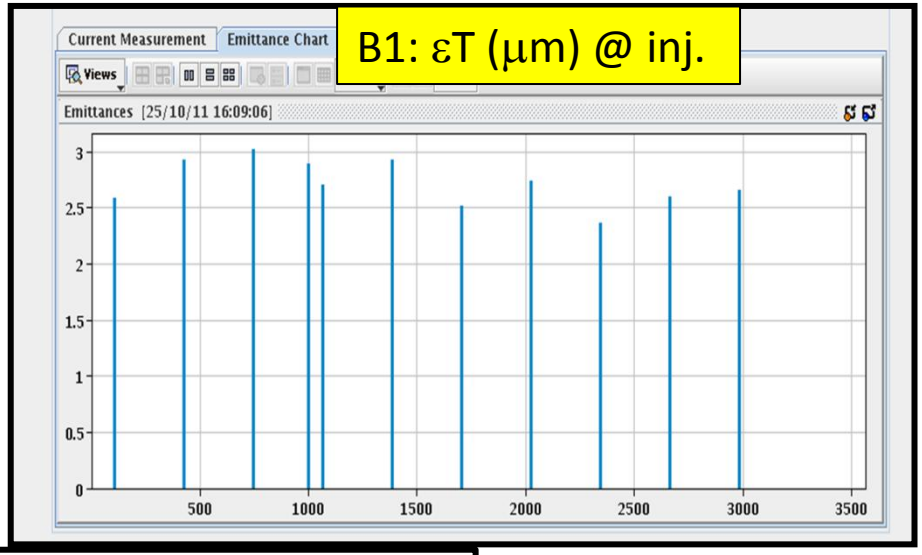
Bunch Intensity~ **2.4E11ppb**

ε_T(450GeV) ~**2μm** (B1) &~**3 μm** (B2)

ε_T(3.5 TeV/collision) ~**3μm** (B1) &~**3.6μm** (B2)

} **Using WS**



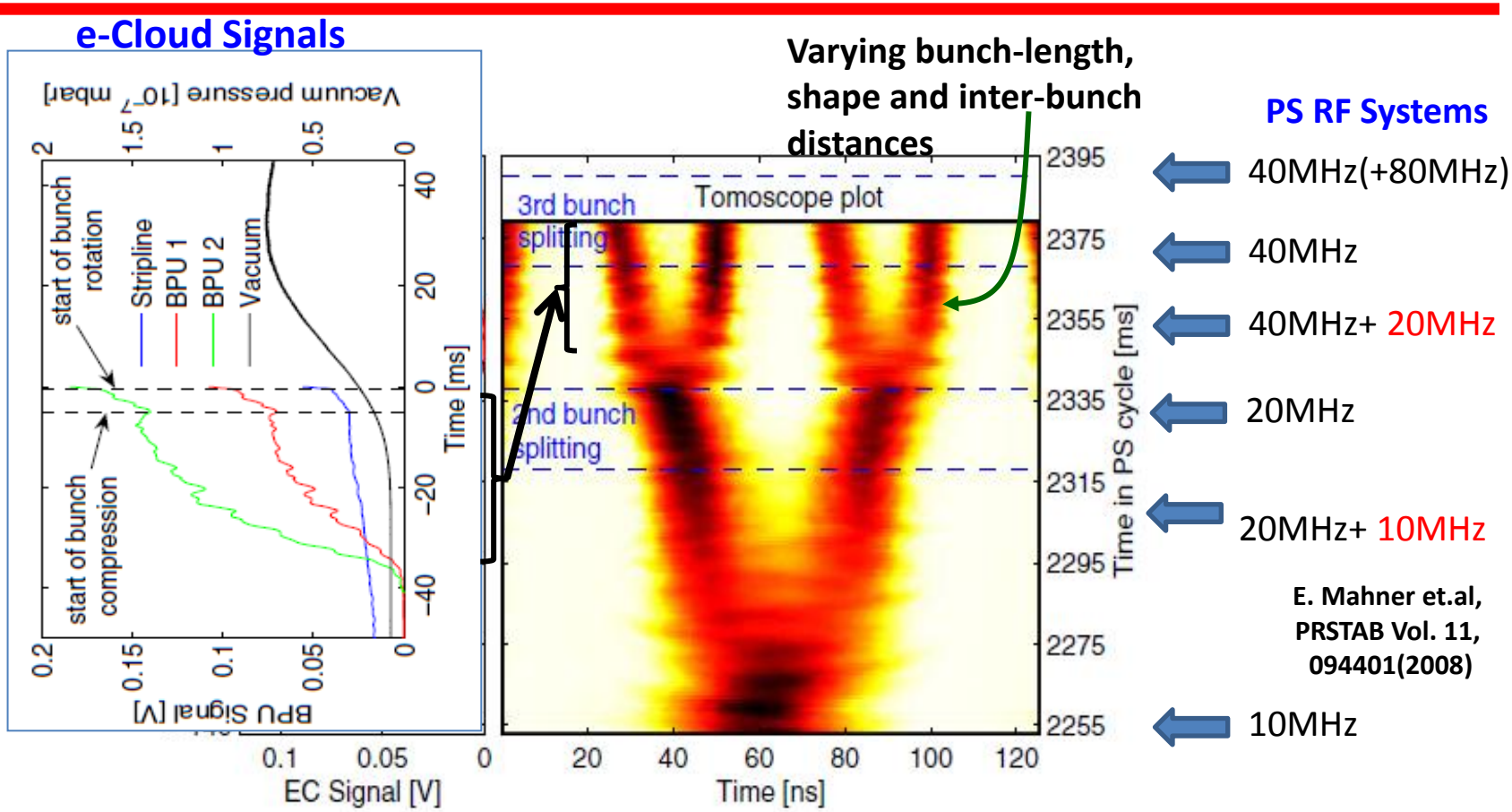


Georges, Giulia, Michaela, Werner, Xavier

e-Cloud in the LHC

- e-cloud is one of the major issues to increase the intensity per bunch and number of bunches for the HiLumi LHC .
- To mitigate e-cloud related issues
  - Dedicated beam scrubbing campaign is undertaken at the LHC during 2010-11. Significant progress has been made.
  - Detailed e-cloud simulation/dedicated experimental effort are also going on to understand & find ways to mitigate e-cloud and extrapolate the findings to HiLumi LHC. Here an account of recent effort on
    - Experiment/simulation in the PS to study **e-cloud effect on bunch profiles**
    - e-cloud effect at the LHC on bunch spacing and bunch population using realistic bunch profiles ⇦ **Also, confirm the earlier findings of Frank Zimmermann et. al.**

2007 Observation of e-cloud in the PS



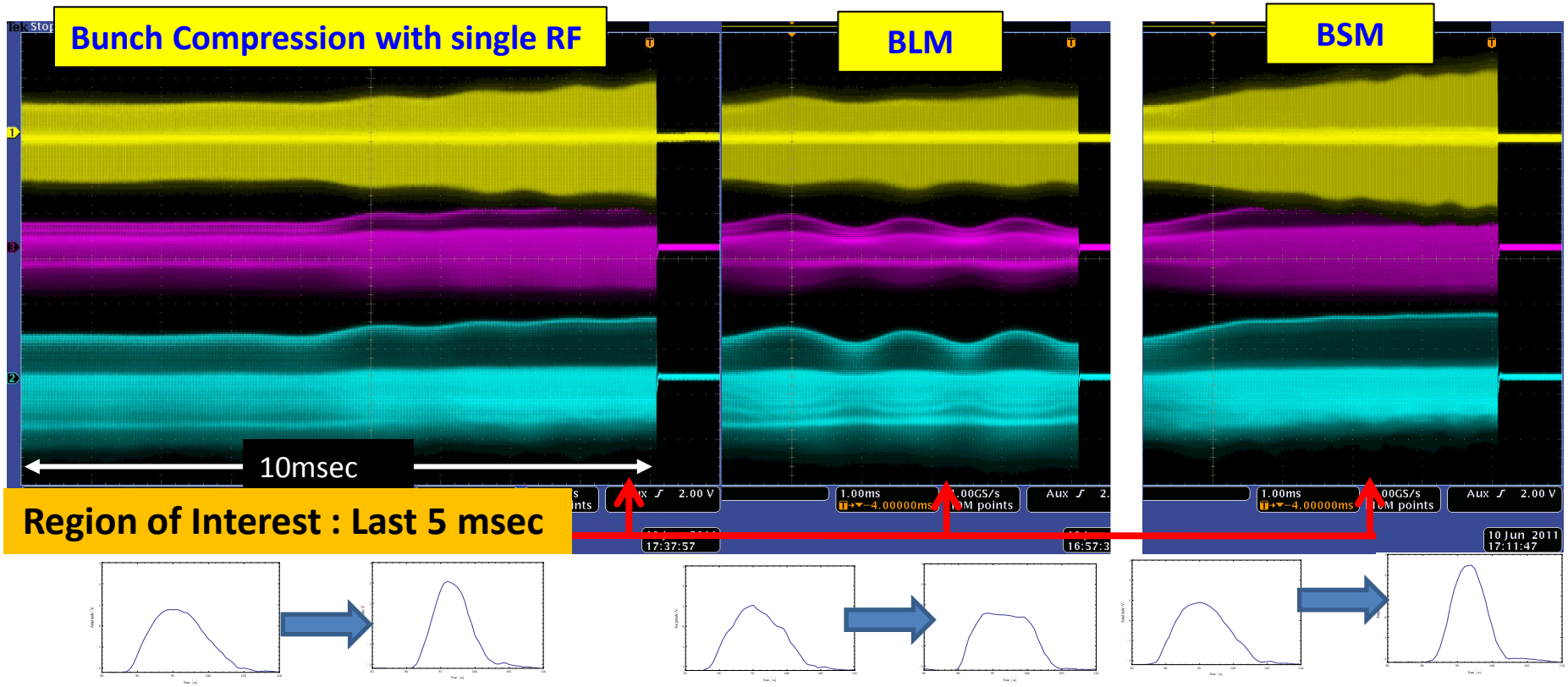
E. Mahner et.al, PRSTAB Vol. 11, 094401(2008)

e-cloud is observed in the PS during quadrupole splitting on the LHC25

Dependence of bunch profiles on e-cloud in PS (10/6/2011)

V(80MHz): **0 to 50 kV**, V(40MHz): 40kV to 100 kV

Int.= 1.36E11ppb



BLM shows lesser e-cloud development

Example of PS ECLOUD Simulations

σ_{ion}=2 MBarn, SEY=1.5, R=0.5, BF=0G, sz=60-105cm, Gaussian bunch

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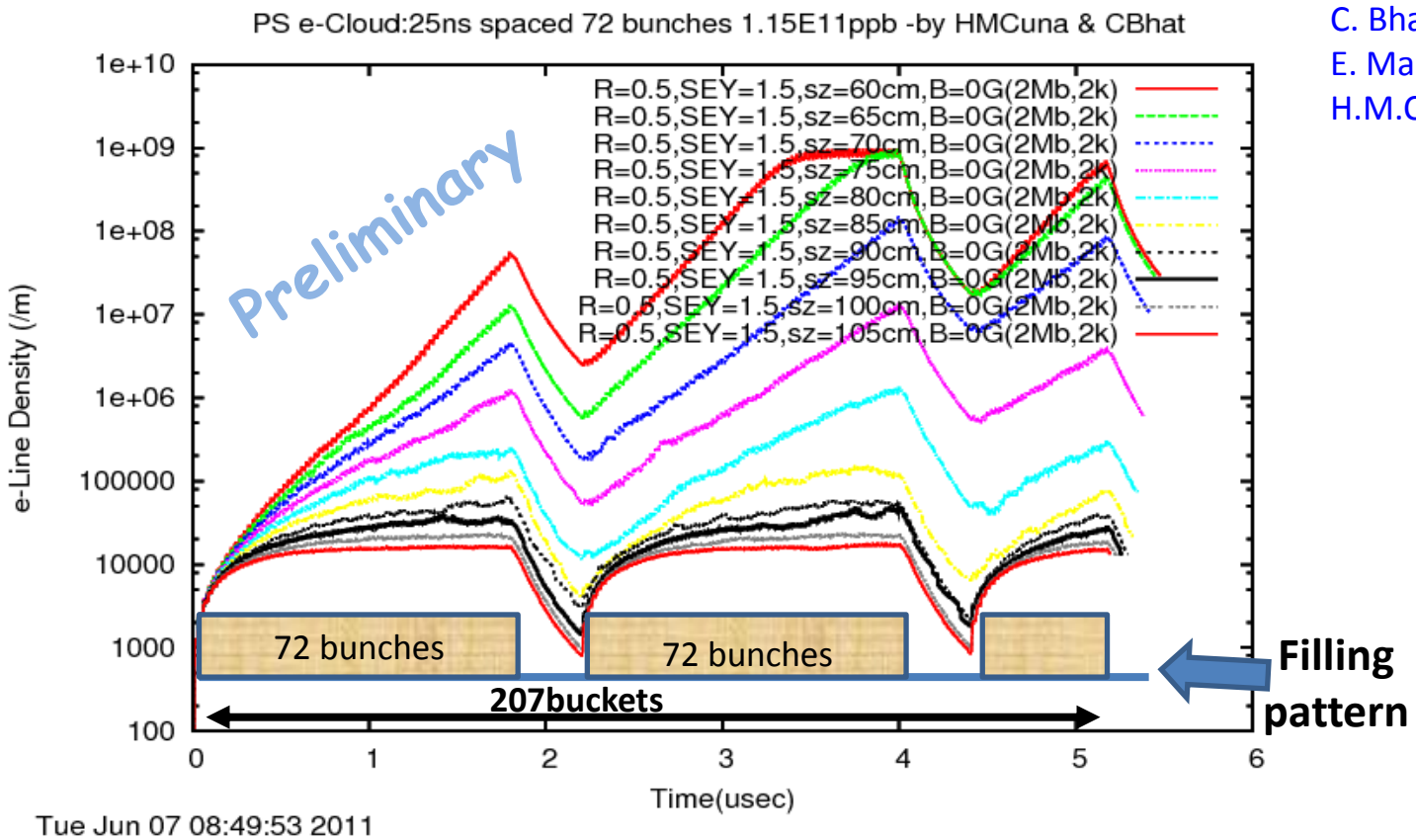
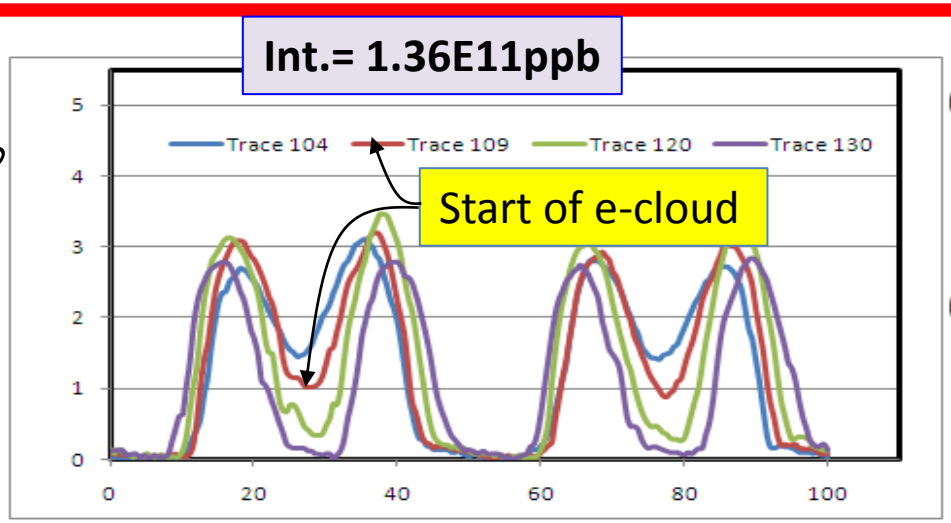


Longer bunches implies smaller e-cloud effect

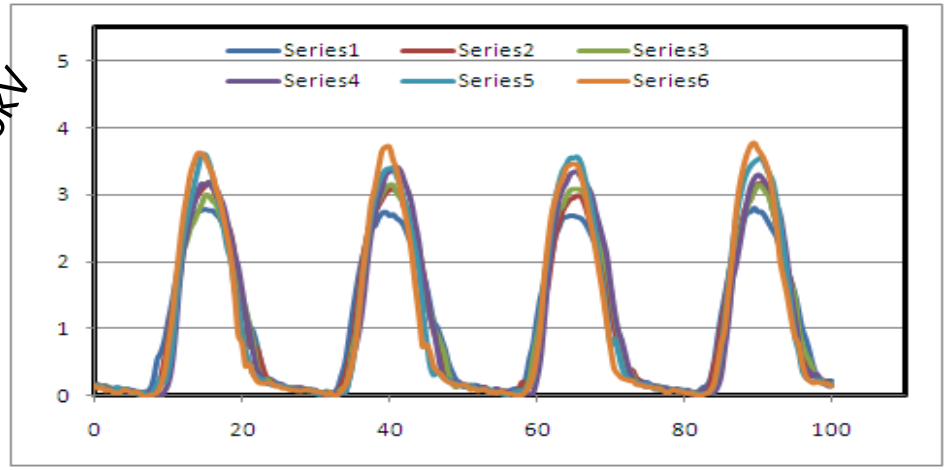
PS e-cloud Data Analysis

(Non-Standard Bunch profiles on LHC25)

Bunch Profiles during the splitting



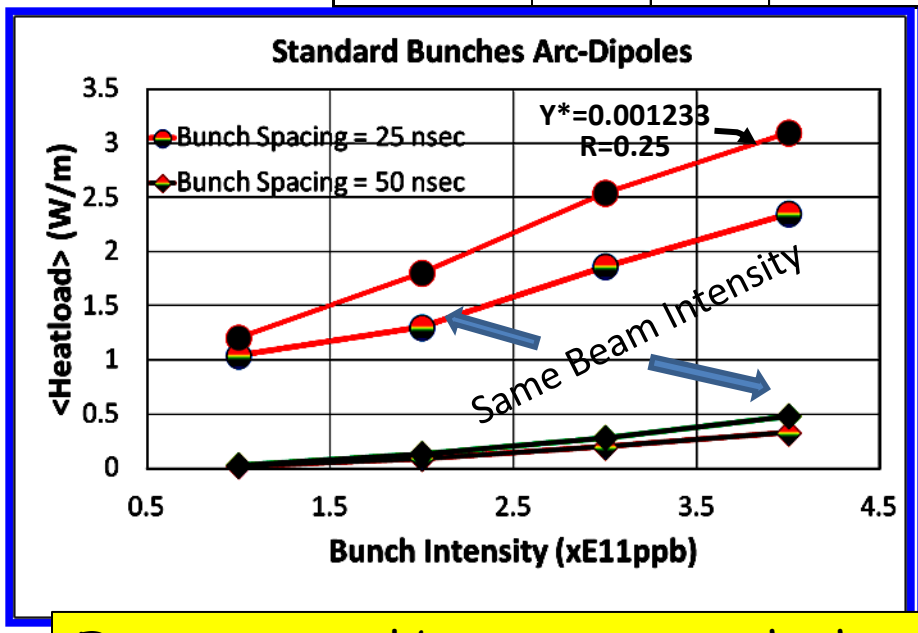
Bunch Profiles for V2/V1= 0 V1=40kV to 100kV

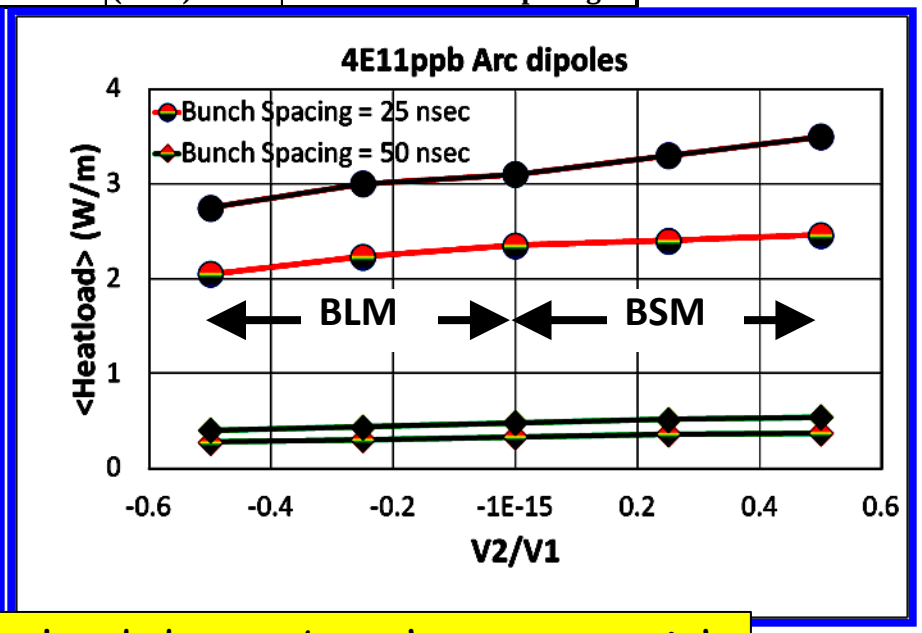


- Arbitrary bunch profile is implemented in the ECLOUD.
- Detailed Data analysis and ECLOUD simulations for the PS are in progress.

e-cloud Dependence of Bunch Profile and Filling Pattern in the LHC

Ep=	7 TeV		Reflectivity R=	0.2			
SEY(dMax)=	1.5		Beam LE	2.5	eVs		
Y*	0.00087	e/p/m	sx=sy=	300	mm		
Idistr=	7		B-Field (@7 TeV)	8.39	Tesla		
Photon q_{cutoff}=	0.041	radian	# of Bunches	81			
Emax=	230	eV	Filling Pattern	(36+4)x4	for 50 nsec bunch spacing		
				(72+9)x2 or 4	for 25 nsec bunch spacing		





For same total beam current, the heat load due to bunch pattern with 25 nsec bunch spacing is ≈3 times that with 50 nsec bunch spacing

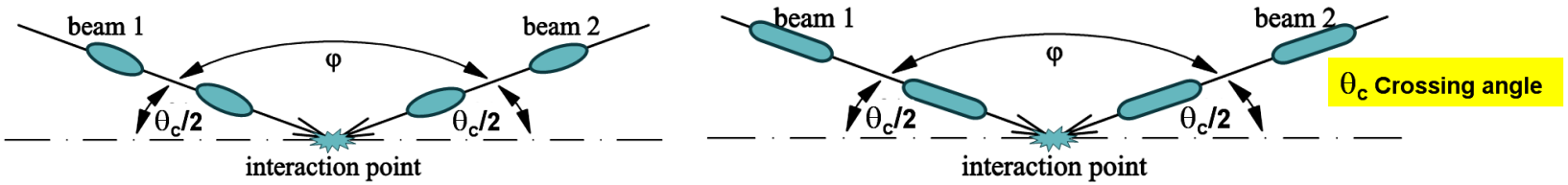
Summary

- Significant progress are being made in the injectors which are critical to the HiLumi LHC using LPA scheme.
- The LPA parameter list is revised taking into account
  - the recent findings in the LHC in our analysis
  - realistic distribution/bunch profiles
  - Mitigating the e-cloud effect in the LHC

  We find that with ~3.4E11ppb, 50 nsec bunch spacing and proper bunch shaping one can achieve HiLumi goal of **$5\times10^{34}cm^{-2}sec^{-1}$** .
- Studies Underway:
  - Producing trains of high intensity bunches and controlling beam instability
  - Bunch Shaping ← Need 2nd harmonic rf cavity
  - e-cloud dependence on bunch profile and filling pattern

Backup Slides

LPA Scheme in a nutshell



- One can increase the LHC luminosity by $\sqrt{2}$ (!!) for the same number of particles and the same total beam-beam tune shift, **by simply flattening** the bunches (F. Ruggiero and Frank Zimmermann).
  ← Increasing the Piwinski angle $\phi = \theta_c \sigma_z / (2\sigma^*_x)$
- Merits: No elements in the detectors, Lower Chromaticity, reduced e-cloud issues, Less demands on the IR quadrupoles
- Challenges: Flat bunch production and Acceleration, High bunch charges

Experiment in SPS

- Beam Intensity at Injection ~1.1E11ppb
- LE(4σ) (PS) = 0.21 eVs ← This is needed to match the profile in the SPS
- PS to SPS beam transfer
  - PS Bunch is prepared in 40MHz,
  - Compressed and Fast bunch rotation in 40 MHz and 80MHz in 5msec
  - Transferred to SPS bucket of 200MHz+800MHz with different voltage ratios and initial phases (not matched, emittance growth is inevitable)
  - Beam is held in the SPS at 26GeV Flat-bottom for 10 sec, data is collected.
- In the SPS all Feedback loops were turned off
- The Impedance table for the SPS cavities

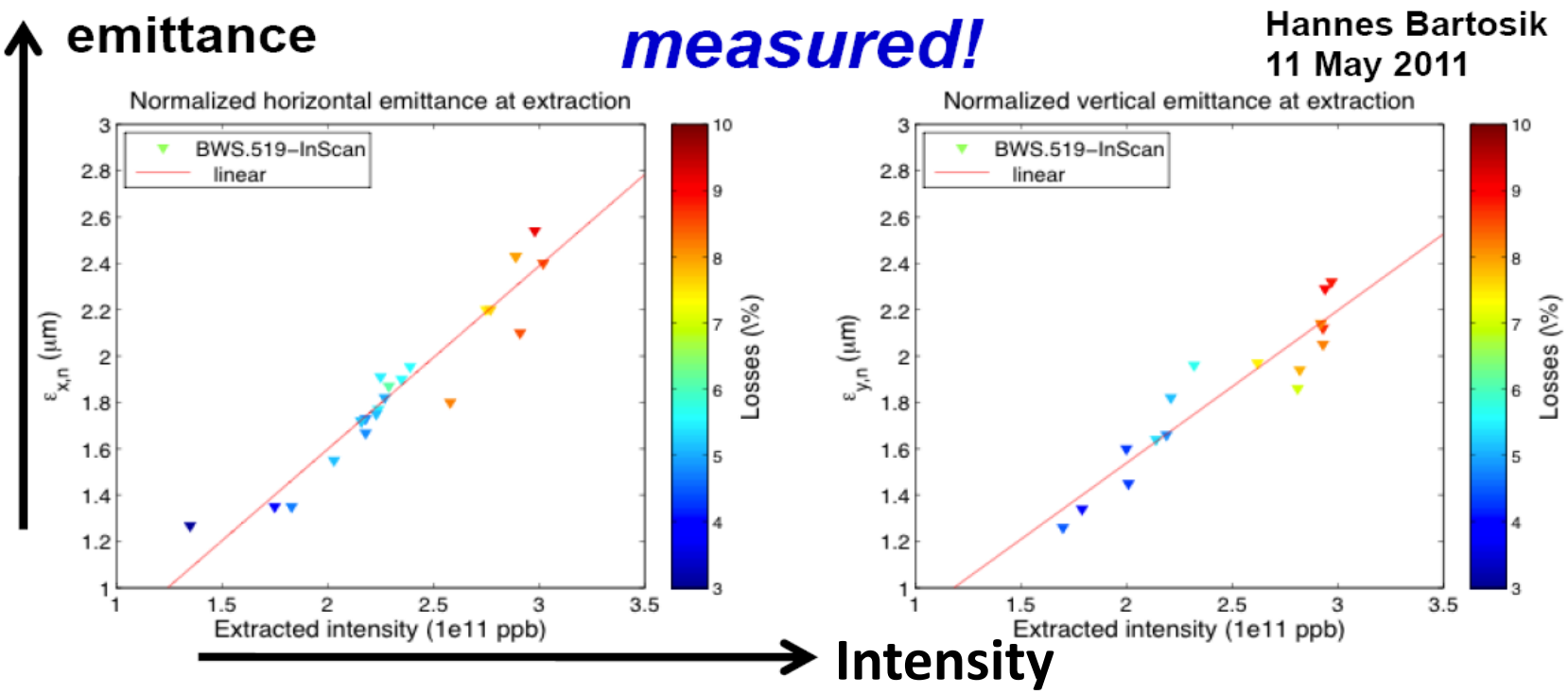
f(MHz)	Source	# of Cavities	Total R (kΩ)	Q
200.2	TW200-F	2	2860	150
"	TW200-F	2	1840	120
629	TW200-H	2	216	500
"	TW200-H	2	172	500
800.9	TW800-F	2	1940	150
800	Kicker (acting like resonator)		60	1

Ref. T. Linnecar and E. Shaposhnikova, SL-Note-96-49-RF(1996);

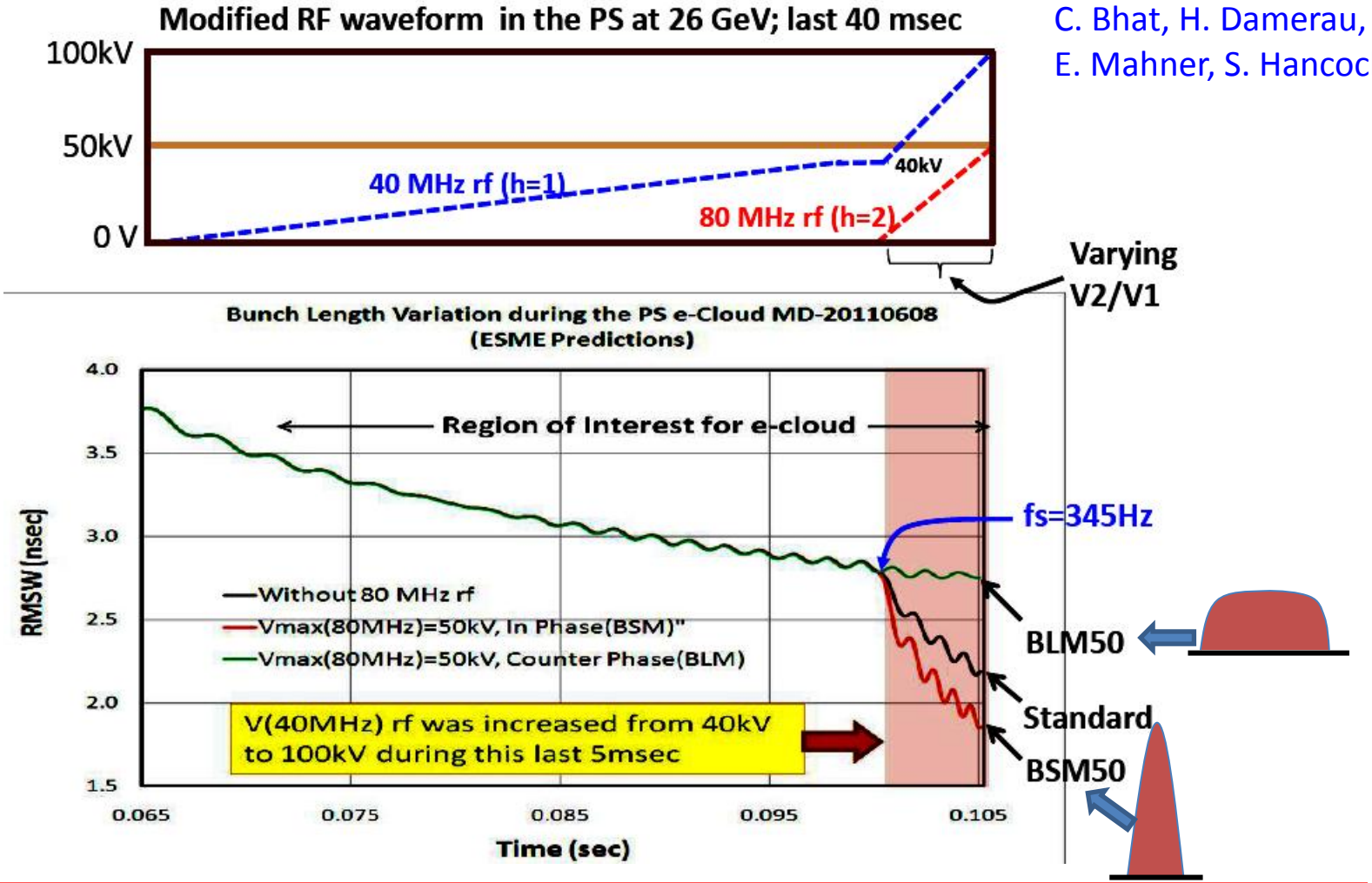
- Standard γT=23.2 and reduced γT=18

Progress in SPS/MDs

(Measurements with Q20 lattice)



During the Oct, 25 LHC MD of High-Pileup Measurements, eleven “High Intensity” bunches ~2.5E11ppb, were injected and accelerated to 3.5 TeV using Q23 lattice in the SPS.

Recent PS Experiment to study e-cloud effect on Bunch Profile

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