Dependence of e-Cloud on the Longitudinal Bunch Profile

Studies in the PS & Extension to the HL-LHC

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Motivation

- Even with the nominal LHC beam parameters the e-cloud related issues are currently prohibiting us to go to 25 ns bunch spacing. During the HL-LHC era the bunch brightness will be ≈ 4 x the LHC nominal value.
  - Mitigation of the e-cloud effect in the LHC is highly critical. Some early simulation studies on LHC indicated that the longitudinal profiles of the bunches may have effect on growth of e-cloud and bunch lengthening may be a possible mitigation technique. In this regard we have carried out
    - An experiment in the PS and Bench-marking with e-cloud simulations using ECLOUD and PyECloud
    - Results are extended to the e-cloud scenarios for the HL-LHC

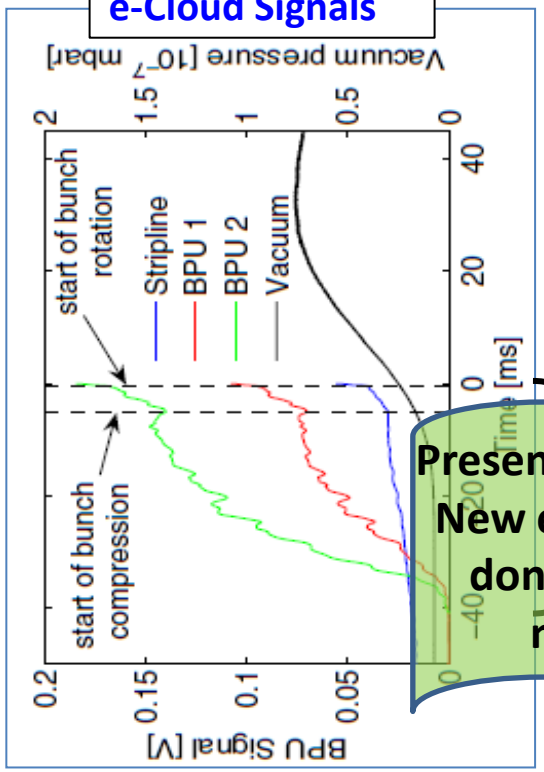
  Here we present our findings

e-cloud studies in the PS

(Past and Present)

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

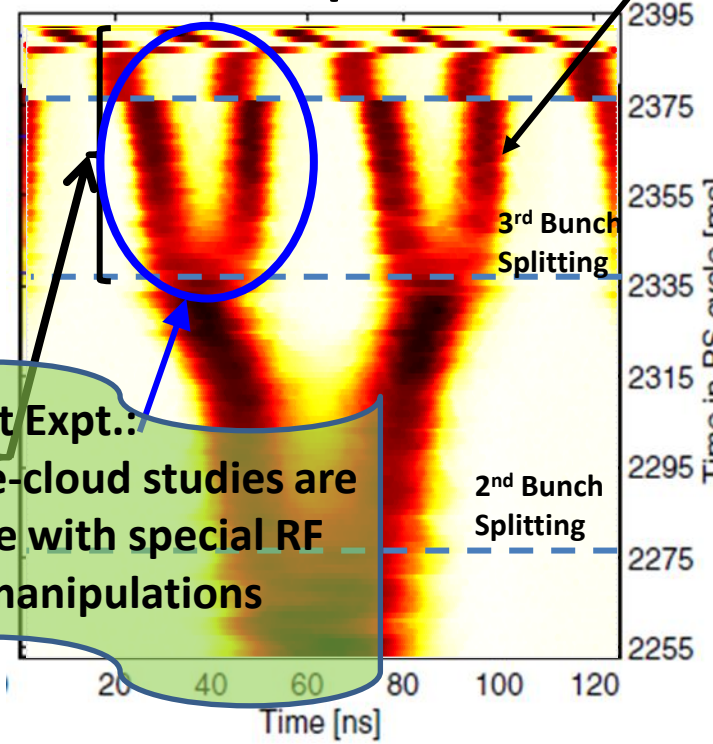
e-Cloud Signals



LHC25@26GeV

Tomoscope Data

Varying bunch-length, shape and inter-bunch distances



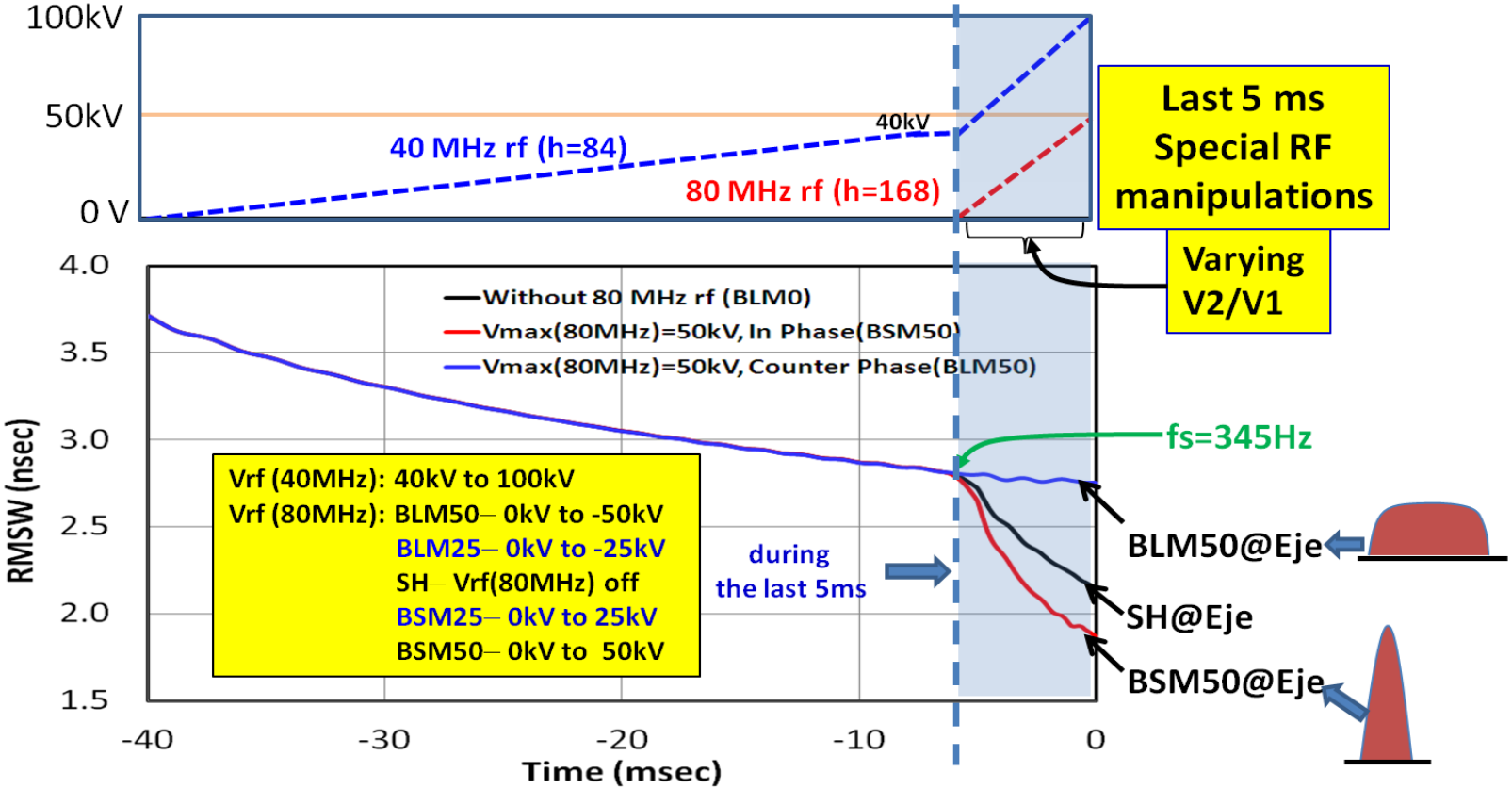
PS RF Systems

- 40MHz(+80MHz)
- 40MHz(h=84)
- 40MHz+ 20MHz
- 20MHz (h=42)
- 20MHz+ 10MHz
- 10MHz(h=21)

Present Expt.: New e-cloud studies are done with special RF manipulations

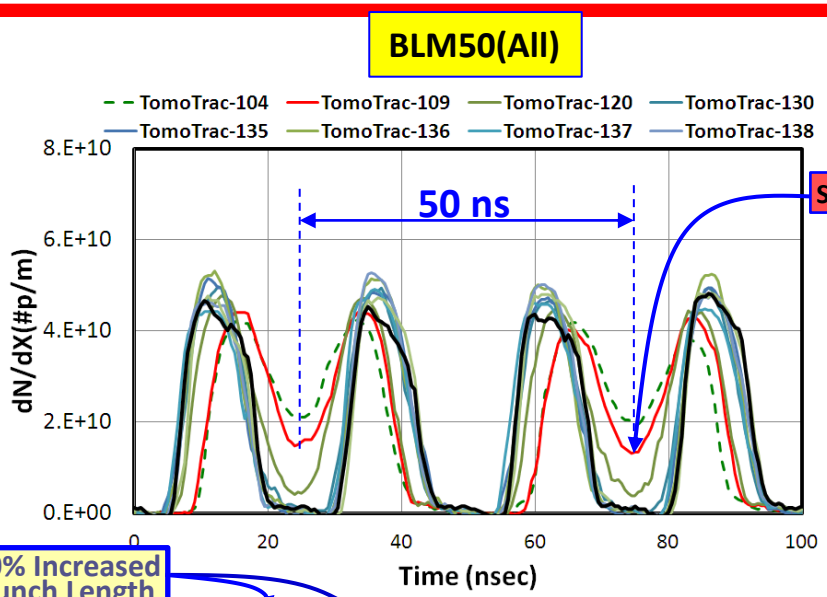
e-cloud is observed in the PS during quadrupole splitting

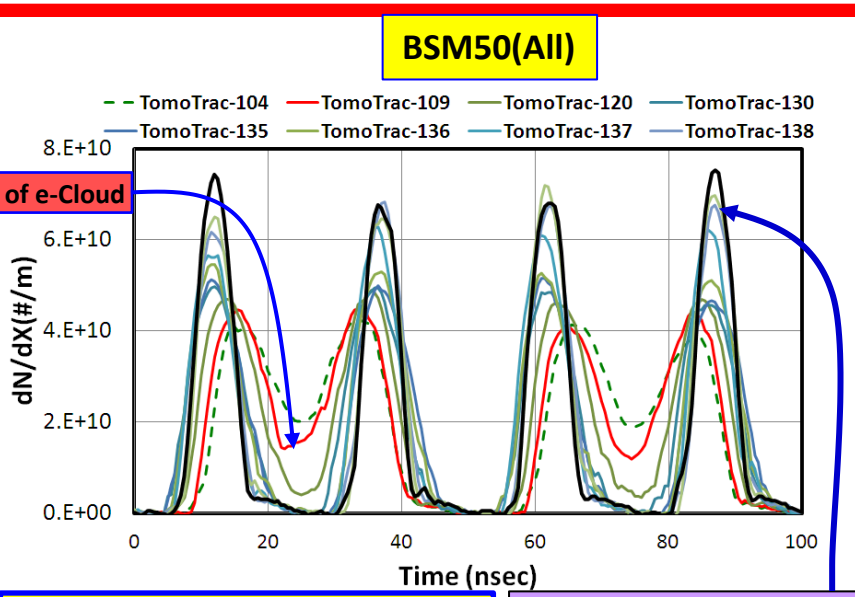
Bunch Shaping in the PS
for e-cloud Measurements



- With the combination of LHC25 type and special RF manipulations we studied the e-cloud phenomenon in the PS under varieties of conditions of Bunch Lengthening Mode(**BLM**), Bunch Shortening Mode (**BSM**),Single Harmonic (**SH**) and with more complex bunch profiles

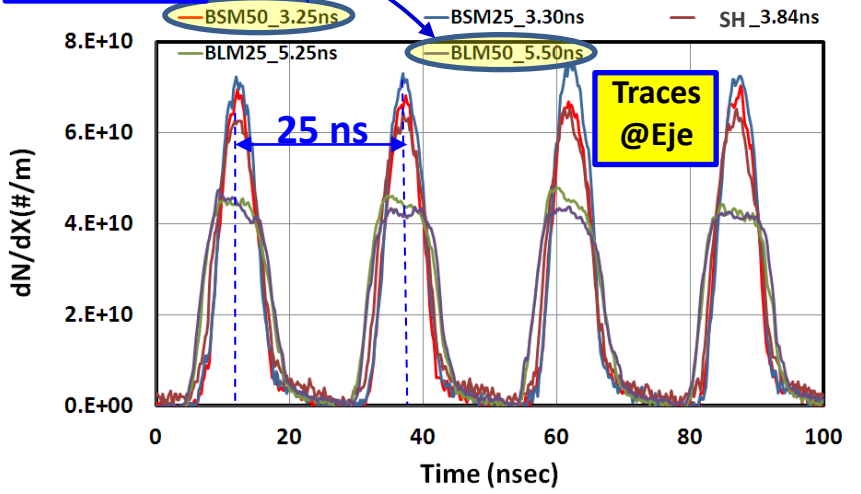
Measured PS –Bunch Profiles
During e-Cloud Formation

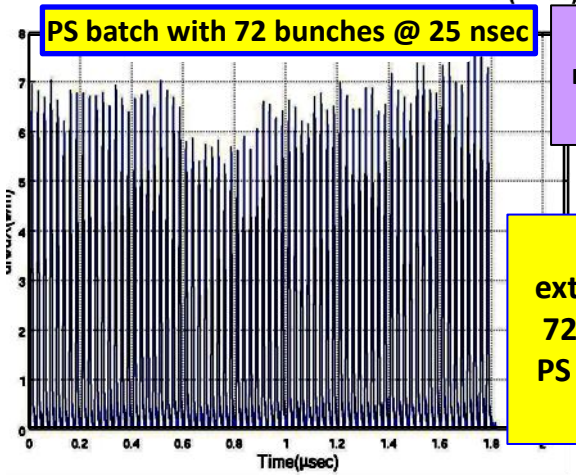




Start of e-Cloud

70% Increased Bunch Length



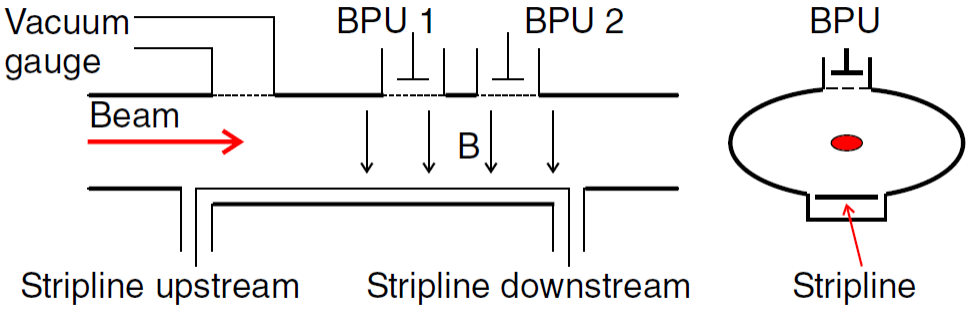


In normal operation the rmsw<0.8 ns as compared to current rmsw≈3.25ns at Eje

These bunch profiles extrapolated/repeated to get 72 bunches/batch and seven PS cycles are employed in the e-cloud simulations

PS e-Cloud Measurements:
e-cloud Monitor

Straight Section 98



The system is capable of applying magnetic field (0-100 Gauss) to study e-cloud suppression

Electron line Density

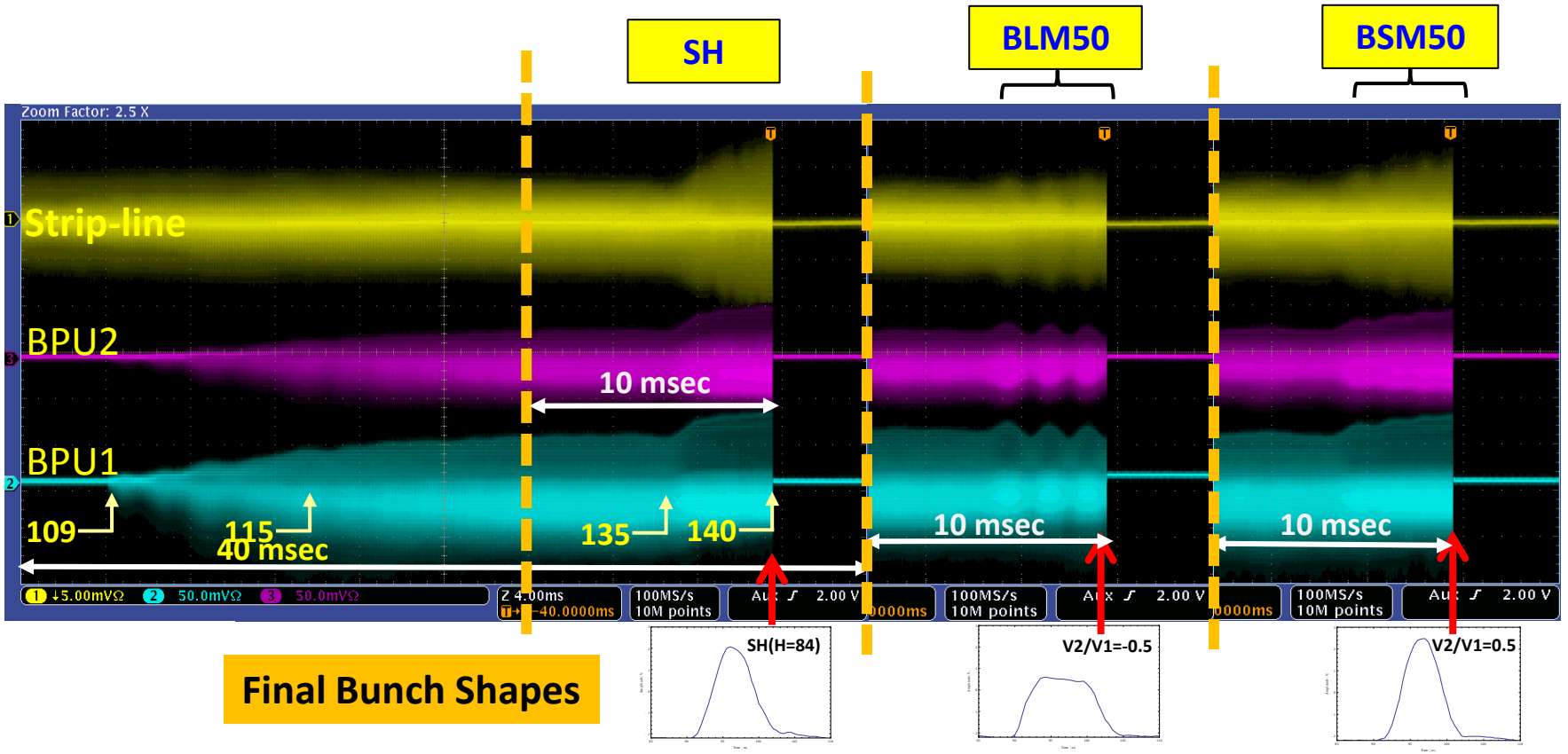
$$\lambda = 2.3\times10^{8}\,\frac{U_{pu}}{mV}\,(e^{-}/meter)$$

PRSTAB Vol. 11, 094401(2008)

(Error in this conversion is not well known)

e-Cloud Data

Int. ≈ 1.35E11ppb, $\varepsilon_T \approx 2.1\mu m$

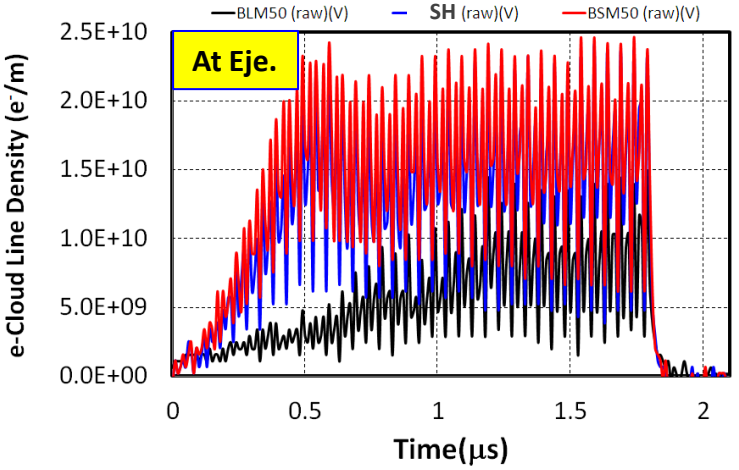


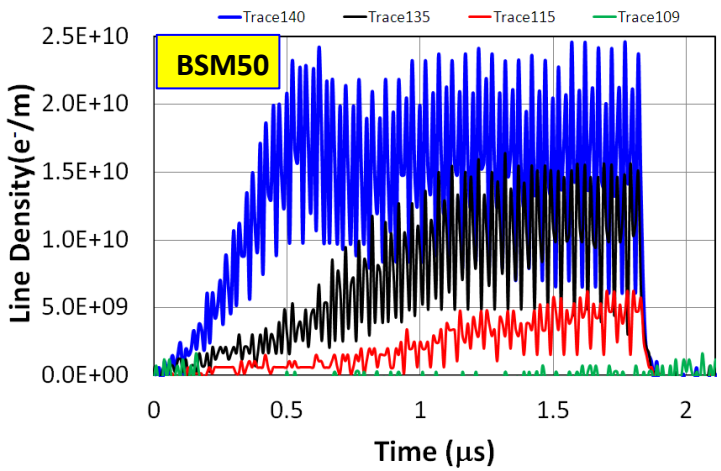
Final Bunch Shapes

- Button Pickup 1 and 2: Clearly show start & growth of e-cloud at about beginning of the final bunch splitting (~ -35 ms before ejection)
- Strip-line Detectors: As expected, their responses are only to the proton bunches.

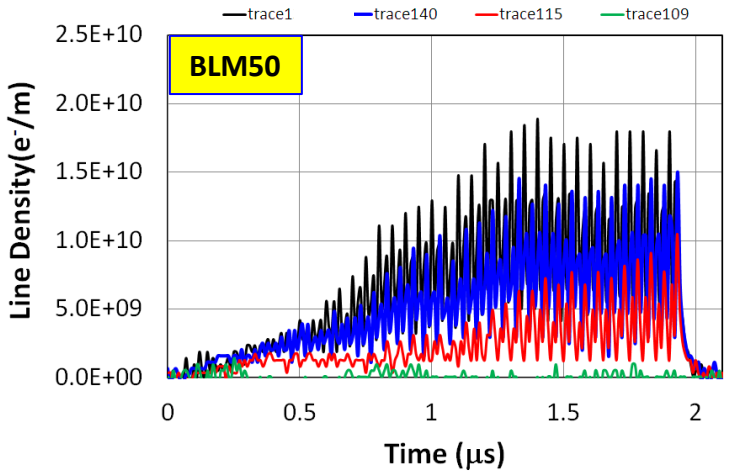
e-Cloud Data (Cont.)

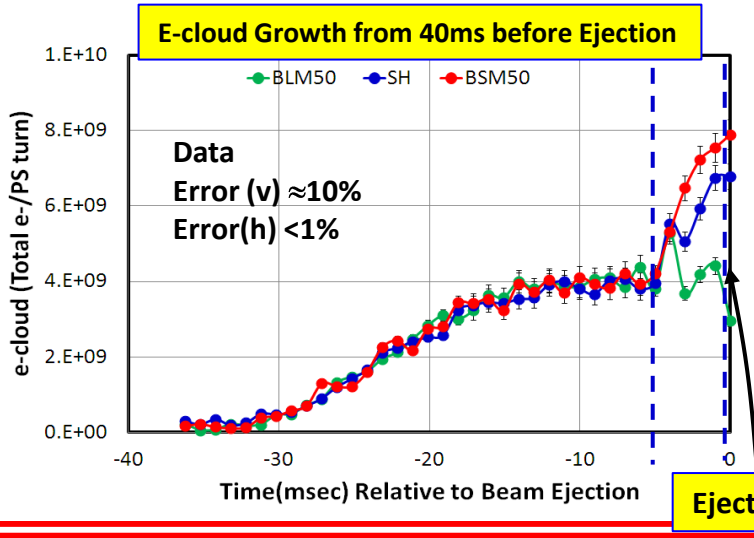
Int. ≈ 1.35E11ppb, $\varepsilon_T \approx 2.1\mu m$





Now our goal is to determine the e-cloud parameters in the PS by comparing the data with simulations carried out using known quantities and the measured longitudinal profiles.





Case	# of e (R.U)
BLM50	1
SH	2.3
BSM50	2.7

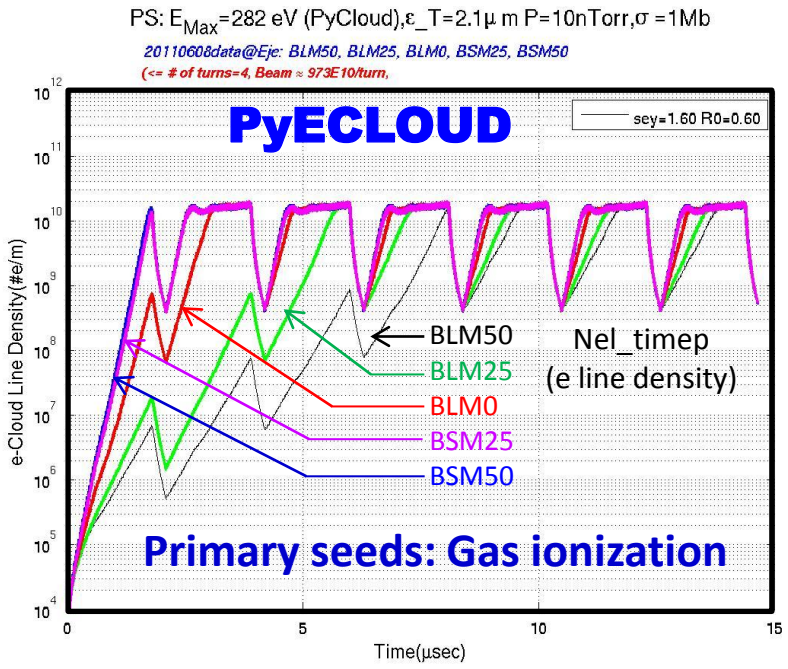
PS Data shows that by increasing the bunch length one can reduce the e-cloud effect considerably

PS e-Cloud Simulations

ECLOUD (FZ & GR) and PyECLOUD(GI)

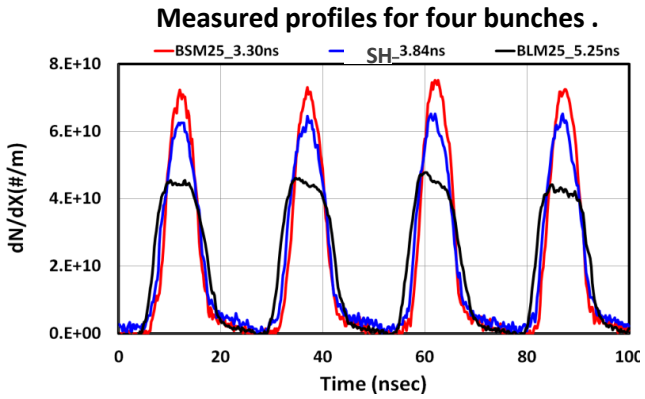
- Simulations were performed using
  - The measured bunch profiles
    - Starting from ~5 ms before the start of the e-cloud formation (at tomoscope trace=104) upto the beam extraction point (Trace140)
    - .Up to seven PS turns
    - With and without the bunch-to-bunch intensity variation.

Parameters	Values
Proton Momentum	26 GeV
Number of Bunches/turn	72
Bunch Intensity	1.35E11ppb
Bunch spacing	Varying (25-50nsec)
Bunch Length	Varying
Bunch Shape	From data
Kicker Gap	0.3 μs
Beam Pipe: H and V Aperture (half)	7.3cm(H), 3.5cm(V)
Material pf the Beam Pipe	Stainless Steel 316 LN
Beam Transvers Emit. $\varepsilon_x=\varepsilon_y$	2.1 μm
Lattice Function at the Detector	
βx and βy=	22.14 m, 12.06 m
Ionization Crossection	1 Mbarn
Gas Pressure	10 nTorr
Maximum SEY yield δ_{Max}	1.3-1.7
Reflectivity R	0.3-0.7
Electron Energy at δ_{Max}	230-332 eV

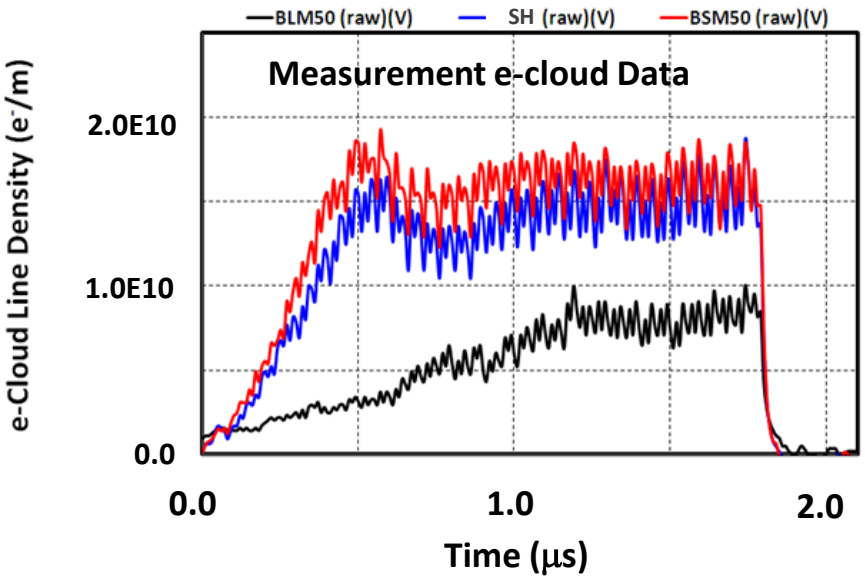


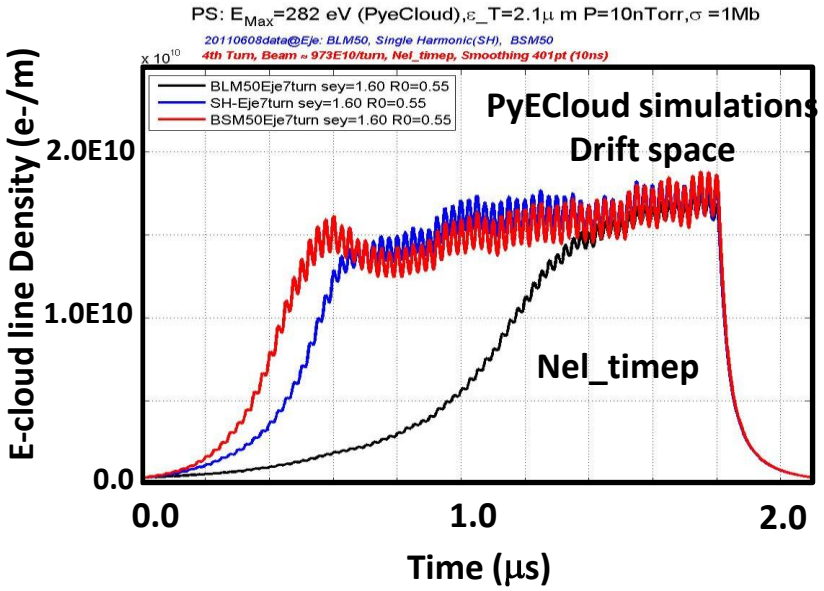
e-Cloud: Comparison between Data and Simulations: @ Ejection

(Preliminary Results)



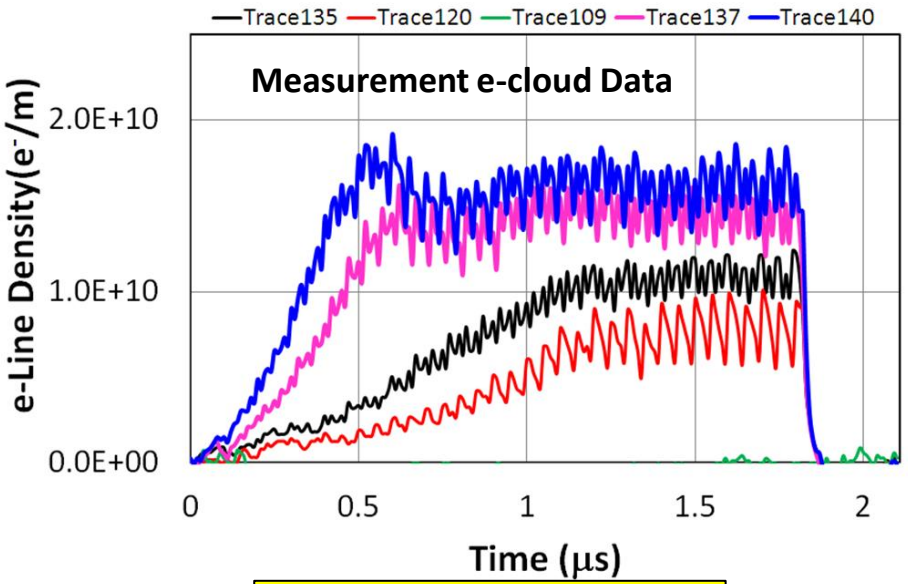
- PyECloud calculates
  - e-cloud line density **(Nel_timep)**
  - # of electrons hitting the chamber **(Nel_imp_time)**
- Tried to compare the absolute values of the measured e-cloud line-density with the predictions.

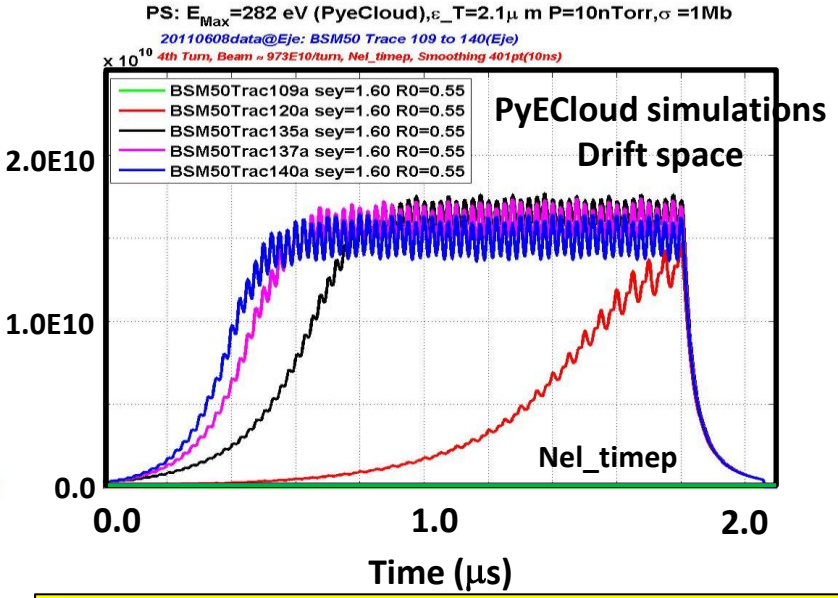




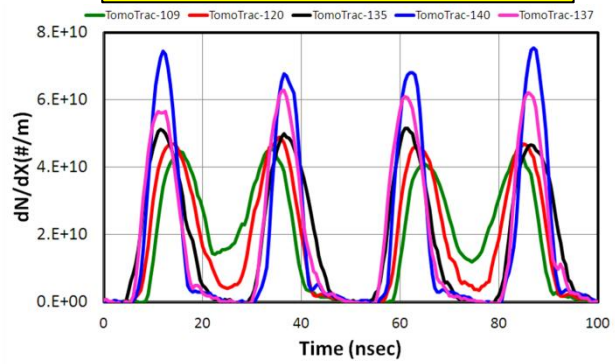
e-Cloud: Comparison between Data and Simulations: BSM50-All

(Preliminary Results)





Measured profiles for four bunches used in the simulations



Conclusions:

1) **In the PS, we certainly see a clear bunch length dependence of the e-cloud growth**
2) **By comparing the measured data with the PyECloud predictions we set SEY=1.55-1.6 and R=0.55-0.6**

HL-LHC Parameter List

LARP CM 18 – FERMILAB: Lucio Rossi – CERN (HL-LHC Project Coordinator)

HL-LHC Performance Estimates

Putting it all together:

Parameter	nominal	minimum β* 25ns	minimum β* 50ns
N	1.15E+11	**2.2E+11**	**3.5E+11**
n_b	2808	2808	1404
beam current [A]	0.58	**1.12**	**0.89**
x-ing angle [μrad]	300	480	550
beam separation [σ]	10	10	10
β* [m]	0.55	**0.15**	**0.15**
ε_n [μm]	3.75	2.5	3.0
ε_L [eVs]	2.51	2.5	2.5
energy spread	1.20E-04	1.20E-04	1.20E-04
bunch length [m]	7.50E-02	7.50E-02	7.50E-02
IBS horizontal [h]	80 -> 106	**20.0**	**20.7**
IBS longitudinal [h]	61 -> 60	**15.8**	**13.2**
Piwinski parameter	0.68	**2.54**	**2.66**
geom. reduction	0.83	**0.37**	**0.35**
beam-beam / IP	3.10E-03	**3.9E-03**	**5.0E-03**
Peak Luminosity	1 10^{34}	**9.0 10^{34}**	**9.0 10^{34}**
Beam Brightness (R.U.)	**1**	**2.9**	**3.8**
Events / crossing	19	**171**	**340**

6.2 10^{14} and 4.9 10^{14} p/beam

→ sufficient room for leveling (with Crab Cavities)

Virtual luminosity (25ns) of L = 9 / 0.37 10^{34} cm^{-2} s^{-1}

= 25 10^{34} cm^{-2} s^{-1} ('k' = 5)

Virtual luminosity (50ns) of L = 9 / 0.35 10^{34} cm^{-2} s^{-1}

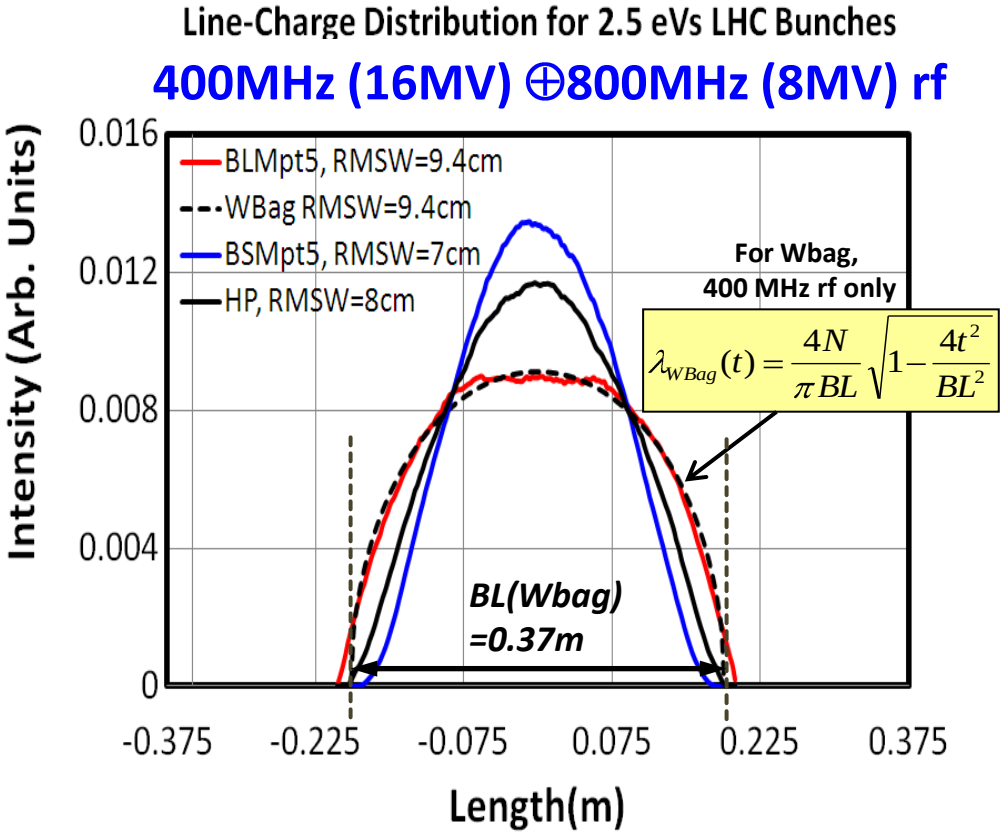
= 25 10^{34} cm^{-2} s^{-1} ('k' = 10)

(Leveled to 5 10^{34} cm^{-2} s^{-1} and 2.5 10^{34} cm^{-2} s^{-1})

95 **95**

2nd LIU-HL-LHC Brainstorming meeting 30 March 2012 Oliver Brüning BE-ABP 1

Longitudinal Bunch Profiles for the HL-LHC cases @7TeV



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

- Each bunch profile is repeated to produce a LHC batch of
  - 278 bunches for 25 nsec case &
  - 144 bunches for 50 nsec case

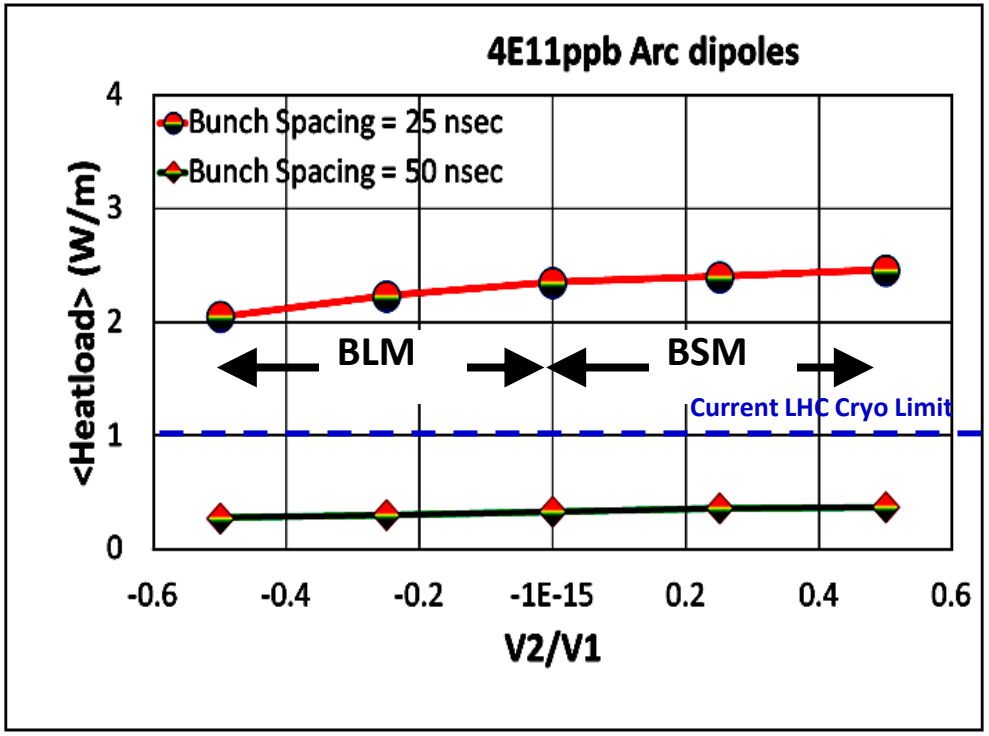
  As an input to the ECLOUD simulations.

e-cloud Dependence on Bunch Profile for HL-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		

ECLOUD Simulations

Primary seeds: Photoelectrons



- The effect of bunch shape on the e-cloud is less than 20%.
  - This implies that the fore seen 800 MHz Landau Cavity to make high intensity beam bunches more stable would have little effect on the e-cloud growth during HL-LHC era.

Summary

- Mitigation of the e-cloud effects for the LHC/HL-LHC scenario is essential.
- We have carried out a detailed investigation of the e-cloud dependence on the bunch profile.
  - An experiment in PS was carried out for varieties of bunch profiles. we see significant dependence of e-cloud on the bunch profile.
  - Our simulations explain the data reasonably well.
  - Extension of these studies to the HL-LHC parameters via simulations were done. The study indicates that the e-cloud dependence on the bunch profile is very small (<20%). Bunch lengthening with the 400MHz+800MHz rf may not help with mitigation of e-cloud in HL-LHC.
  - However, the weak dependence of e-cloud on bunch profile is **a good news for the foreseen use of Landau cavity** to stabilize high intensity beam in the HL-LHC.
- The observed differences in the e-cloud dependence on the bunch-profile may be due to the difference in the **bunch lengths** & **mechanisms of e-cloud formation** in the PS and the LHC .

Acknowledgements

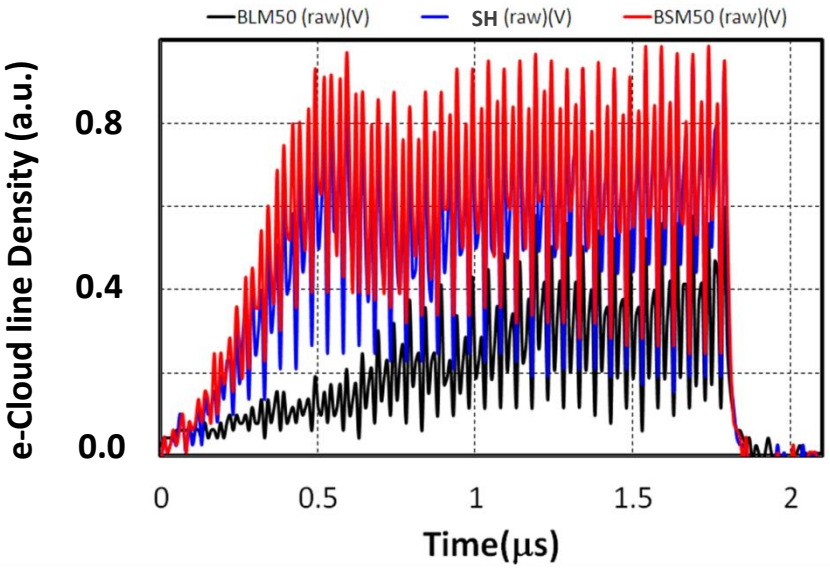
- O. Brüning, E. Shaposhnikova, G. Arduini, G. Rumolo, S. Gilardoni, R. Garoby, E. Metral
- BE/LHC/SPS/RF Groups
  - H. M. Cuna, J.E. Miller, T. Bohl, H. Bartosik, B. Salvant, M. Taborelli, J. Tuckmantel, P. Baudrenghien, Urs Wehrle, G. Papotti
- Fermilab
  - A. Burov, F.-J. Ostiguy, T. Sen and J. MacLachlan

The work is supported by Fermi Research Alliance and US LHC Accelerator Research Program(LARP) and by EuCARD-AccNet

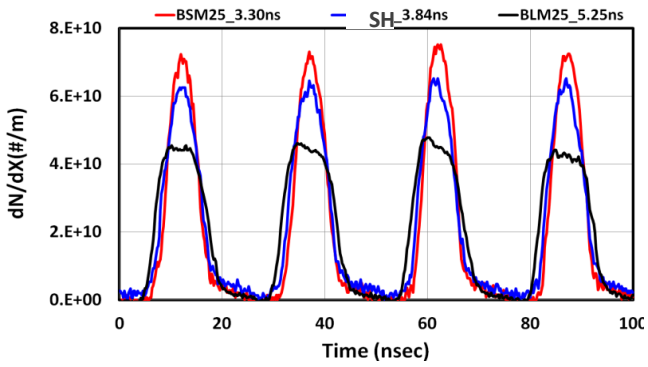
Backup Slides

e-Cloud: Comparison between Data and Simulations: @ Ejection

Measurement e-cloud Data

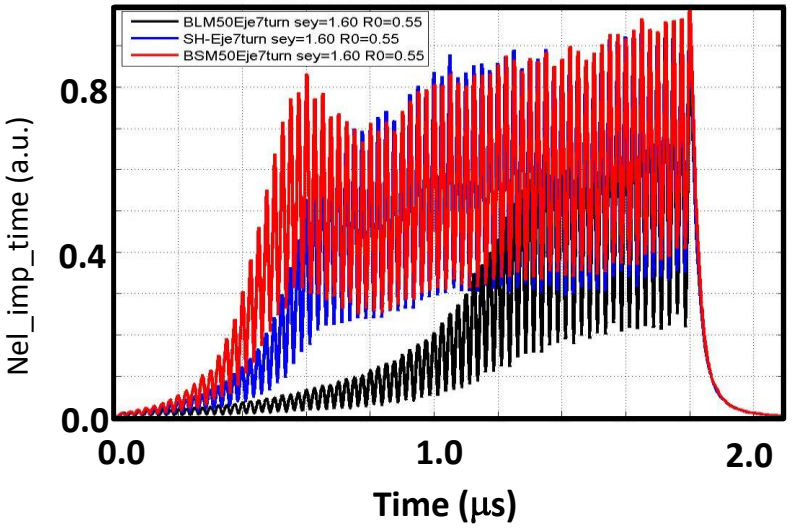


Measured profiles for four bunches .



- PyECloud calculates
  - # of electrons hitting the chamber ← Nel_imp_time
  - e-cloud line density ←Nel_timep

PyECloud simulations employing all 72 bunches in PS.



e-cloud Dependence on Bunch Profile for HL-LHC

ECLOUD Simulations

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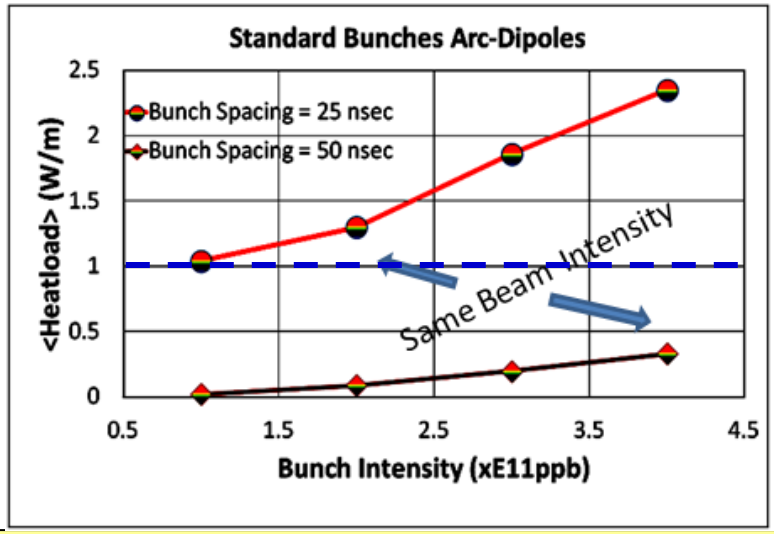

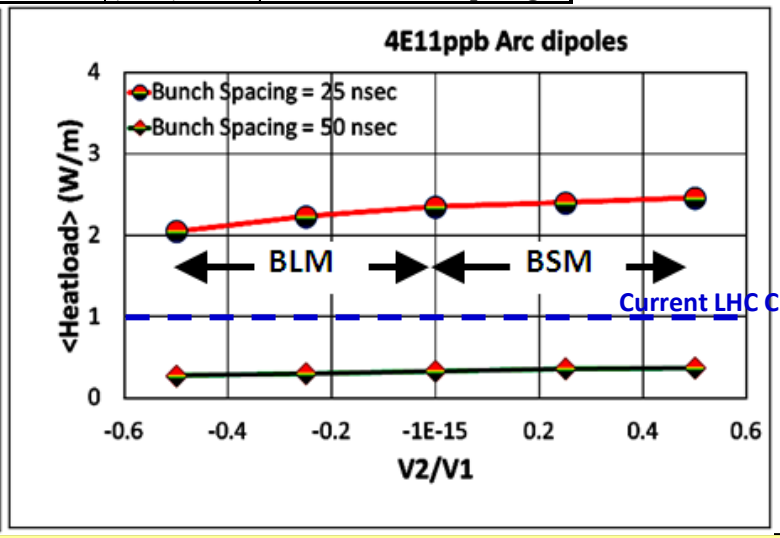

- The effect of bunch shape on the e-cloud is less than 20%.
  - This implies that the fore seen 800 MHz Landau Cavity to make high intensity beam bunches more stable would have little effect on the e-cloud growth during HL-LHC era.
- For the same total beam current, the heat load due to bunch pattern with 25nsec spacing is ≈3 times that with the 50 nsec bunch spacing.