Photoemission-based evaluation of cathode illuminating laser pulse length

- Emission measurements with MBI and ELLA
- Poisson solver-based steady state current limit
- Emission model characterzaition and application
- Simulations of electron bunch length
- Summary

Ye Chen, DESY Zeuthen, 23.03.2017

[1] Child, C. D., Physical Review. Series I. 32 (5): 492–511 (1911)

[2] D. Filippetto, et al., PRST-AB 17, 024201 (2014)

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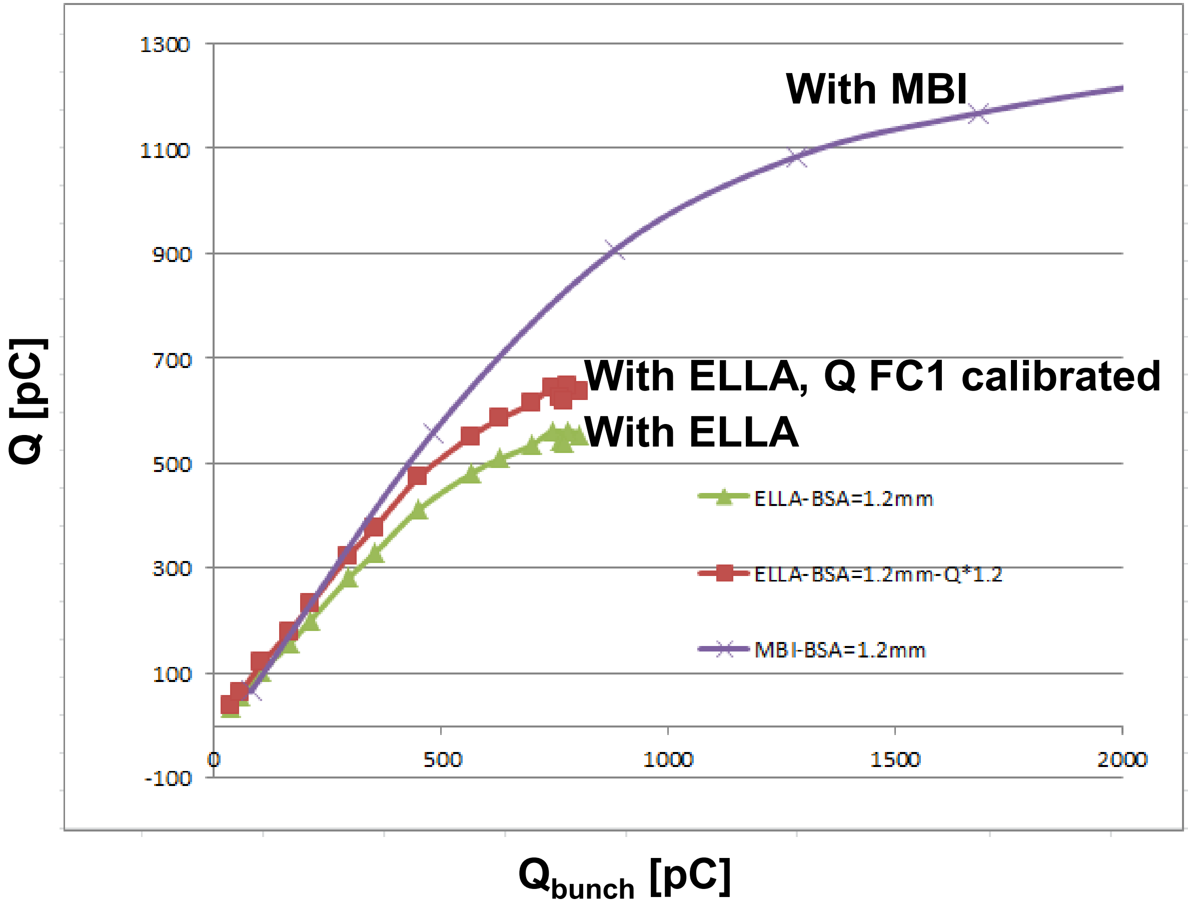
DESY

Emission measurements with MBI and ELLA

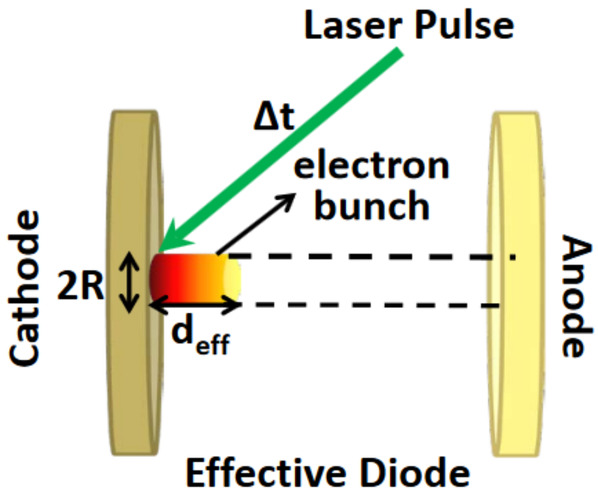


- BSA=1.2mm for both MBI and ELLA
- Charge of ELLA measured with LOW.FC1, calibration factor given as 1.2 w.r.t. LOW.ICT1
- ~same emission fields

Charge extraction with ELLA saturated much earlier than MBI

-> shorter pulse length of ELLA?

Poisson solver-based steady state current limit



Steady state current limit described by Poisson equation

$$\Delta\phi = -\frac{1}{\varepsilon_0} j_z \sqrt{\frac{m}{2e(\phi + E_o z)}}$$

$$\frac{\partial\phi}{\partial z}\Big|_{z=0, r\le R} = -E_0 \quad \phi(r,0) = 0$$

Child-Langmuir Law[1]

$$J_{sat} = \frac{4\varepsilon_0}{9}\sqrt{\frac{2e}{m}}\frac{V^{3/2}}{d^2}$$

Enhanced Child-Langmuir Law with finite transverse dimensions [2]

Valid for temporally flattop shaped bunch in cigar beam ratio regime with Cc ≈ 1, meaning effective diode length close to beam radius

$$I_{sat} = \frac{Q_{sat}}{\Delta t} = C_c\, I_0 \frac{\sqrt{2}}{9}\left(\frac{eE_0R}{mc^2}\right)^{1.5}$$

Δt -> laser pulse length

Q_{sat} -> space-charge limited bunch charge (onset)

R -> radius of emission area

E_0 -> accelerating field gradient

I_0 -> constant, 17kA

Δt -> Pulse length should be much shorter than RF period

Poisson solver-based steady state current limit

- **Re-formulize D. Filippetto's effective diode emission model[1] based on C-L law[2] for Gaussian bunches:**

$$\Delta t = \frac{9}{\sqrt{2 I_0}} \left(\frac{mc^2}{eE_0}\right)^{1.5} \frac{\sqrt{d_{eff}} Q_{sat}}{R^2}$$

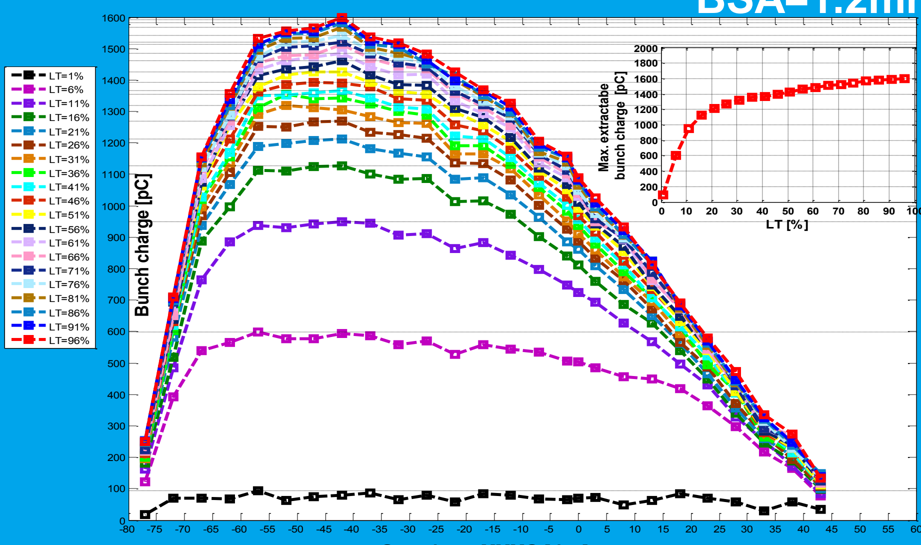
d_{eff} -> effective length of emission diode

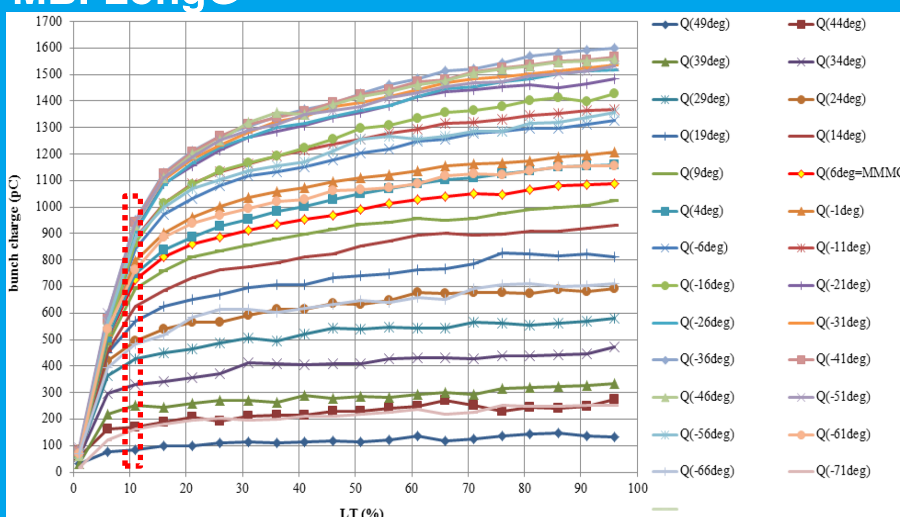
C_c -> based on first simulations for guassian bunches C_c is no longer a constant, here taken as $\sqrt{R/d_{eff}}$ from the original C-L law

→To be discussed in a separate talk

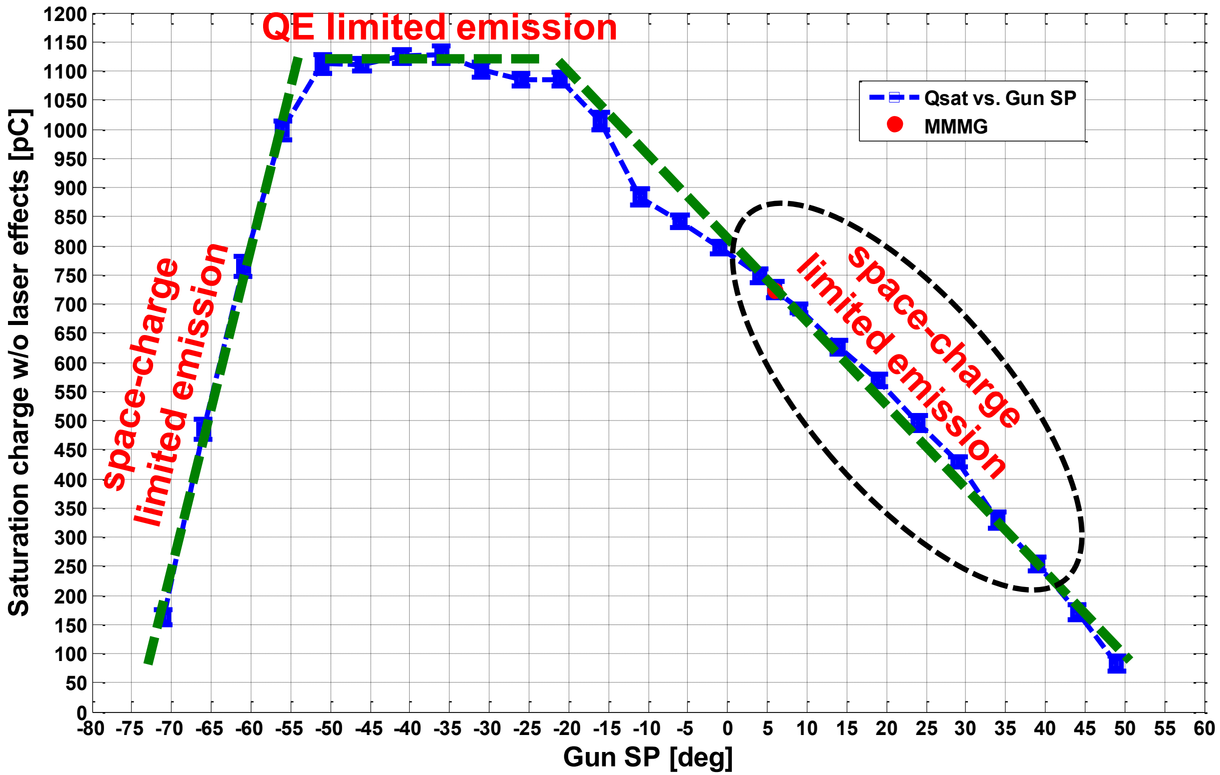
- **Model characterization based on measurements in a simplified case**
  - Fix R and Δt
  - Use Q_{sat} and E_0 to Fit d_{eff}

BSA=1.2mm, MBI LongG





Emission model characterization
BSA=1.2mm, MBI LongG



- Saturated bunch charges w/o beam halo at different gun phases defining onsets of space-charge limitation

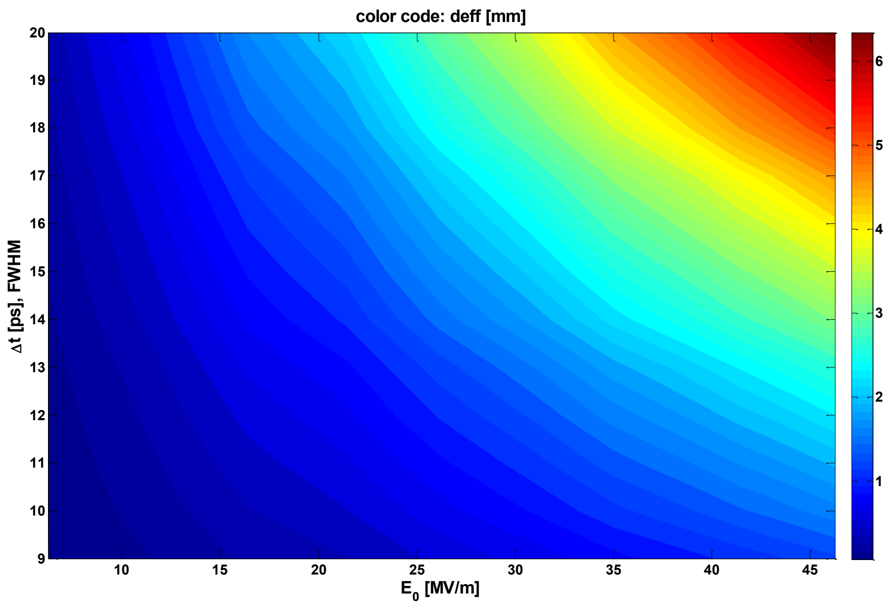
- Egun≈ 59.5MV/m to reproduce MMMG

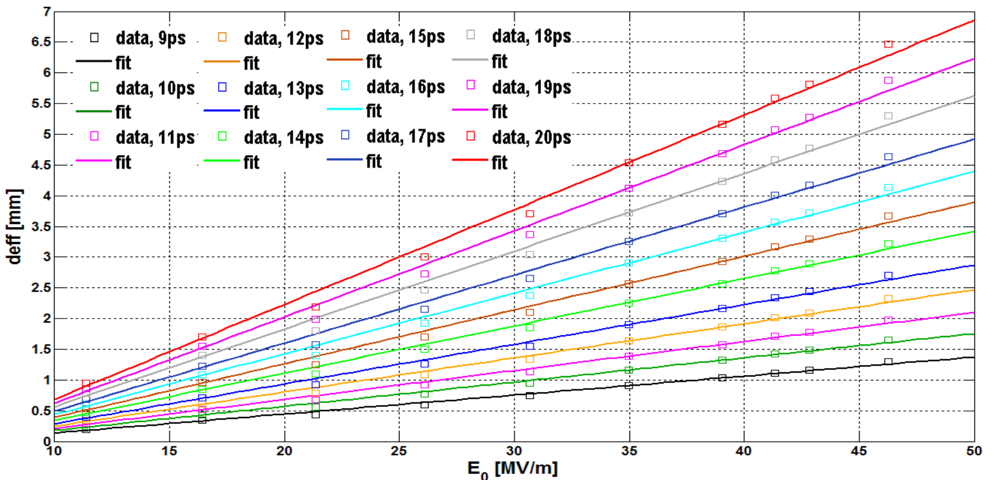
R [mm]	E_0 [MV/m]	Q_{sat} [pC]
0.6 (BSA = 1.2mm)	46.2520	796.8
	42.8152	748.4
	41.3476	724.6
	39.0525	692.2
	34.9925	626.3
	30.6663	568.3
	26.1067	495.5
	21.3484	429.2
	16.4276	328.8
	11.3818	253.6

Emission model characterization
BSA=1.2mm, MBI LongG

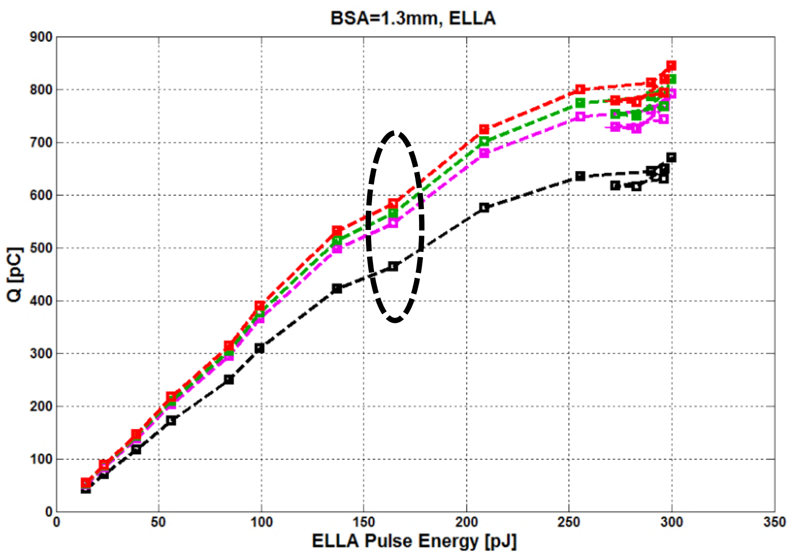
- Scan MBI laser pulse length
- At each Δt, dependence of effective diode length on emission field characterized based on measurement data
- Fix R and Δt, fit d_{eff} versus E_0 using measurement data from charge phase scans

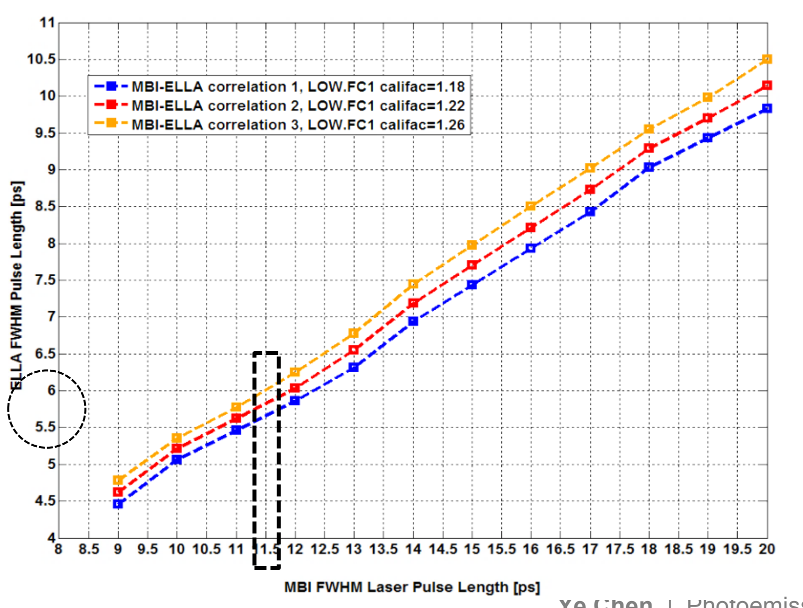
Δt_fwhm [ps]	d_{eff} [mm] vs. E_0[MV/m]
≤8	No cigar bunch solution
9	d_{eff} [mm]=0.03089E_0[MV/m]-0.1722
10	d_{eff} [mm]=0.03949E_0[MV/m]-0.2190
11	d_{eff} [mm]=0.04719E_0[MV/m]-0.2619
12	d_{eff} [mm]=0.05556E_0[MV/m]-0.3079
13	d_{eff} [mm]=0.06460E_0[MV/m]-0.3581
14	d_{eff} [mm]=0.07692E_0[MV/m]-0.4270
⋮ ⋮	⋮ ⋮
20	d_{eff} [mm]=0.15430E_0[MV/m]-0.8558





MBI-ELLA pulse length correlation





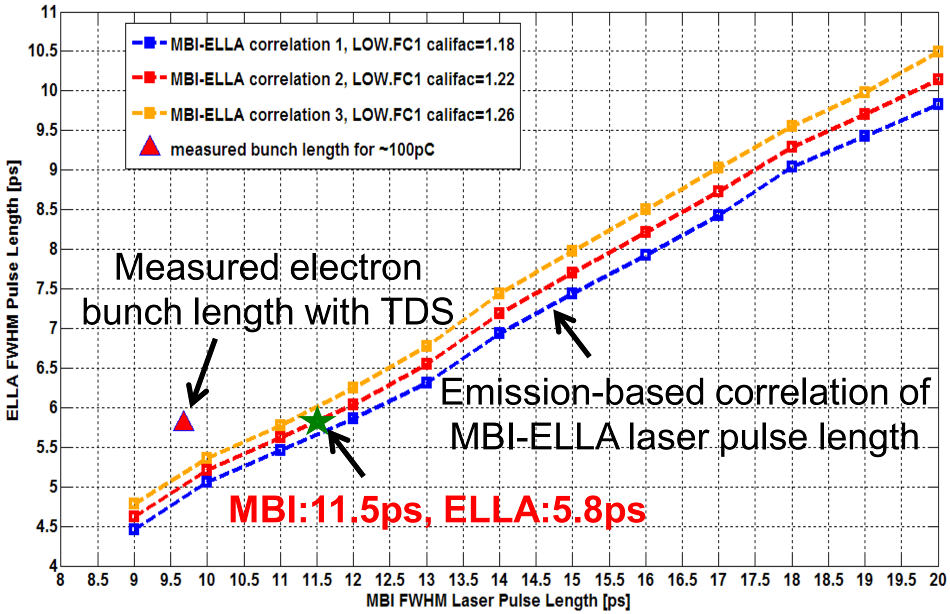
- ELLA bunch charge measured with LOW.FC1, scaling factor w.r.t. LOW.ICT1 given as 1.18, 1.22 and 1.26 for tests
- ELLA pulse length calculated and correlated with MBI laser pulse length scan

		1.18*Qsat	1.22*Qsat	1.26*Qsat
MBI Δt_fwhm [ps]	d_{eff} [mm]	ELLA Δt_fwhm [ps]	ELLA Δt_fwhm [ps]	ELLA Δt_fwhm [ps]
9	1.5686	4.4621	4.6217	4.7816
10	2.0065	5.0635	5.2081	5.3526
11	2.3975	5.4605	5.6185	5.7764
12	2.8232	5.8574	6.0360	6.2503
13	3.2825	6.3166	6.5476	6.7787
14	3.9079	6.9376	7.1897	7.4419
15	4.4465	7.4336	7.7025	7.9715
16	5.0194	7.9292	8.2149	8.5007
17	5.6245	8.4228	8.7253	9.0222
18	6.4372	9.0366	9.2955	9.5543
19	7.1234	9.4333	9.7056	9.9780
20	7.8399	9.8277	10.1417	10.4988

TDS electron bunch length measurements and comparisons

➢ TDS electron bunch length measurements using MBI and ELLA at different bunch charges

Bunch length measurements	
MBI	ELLA
105pC: 9.68ps	100pC: 5.8 ps ± 0.25
233pC: 12.7ps	250pC: 8.7ps ± 0.30
500pC: 16.2ps	500pC: 14.3ps ±0.33



logbook:

❑ Lowest measurable charge was ~100 pC during these measurements

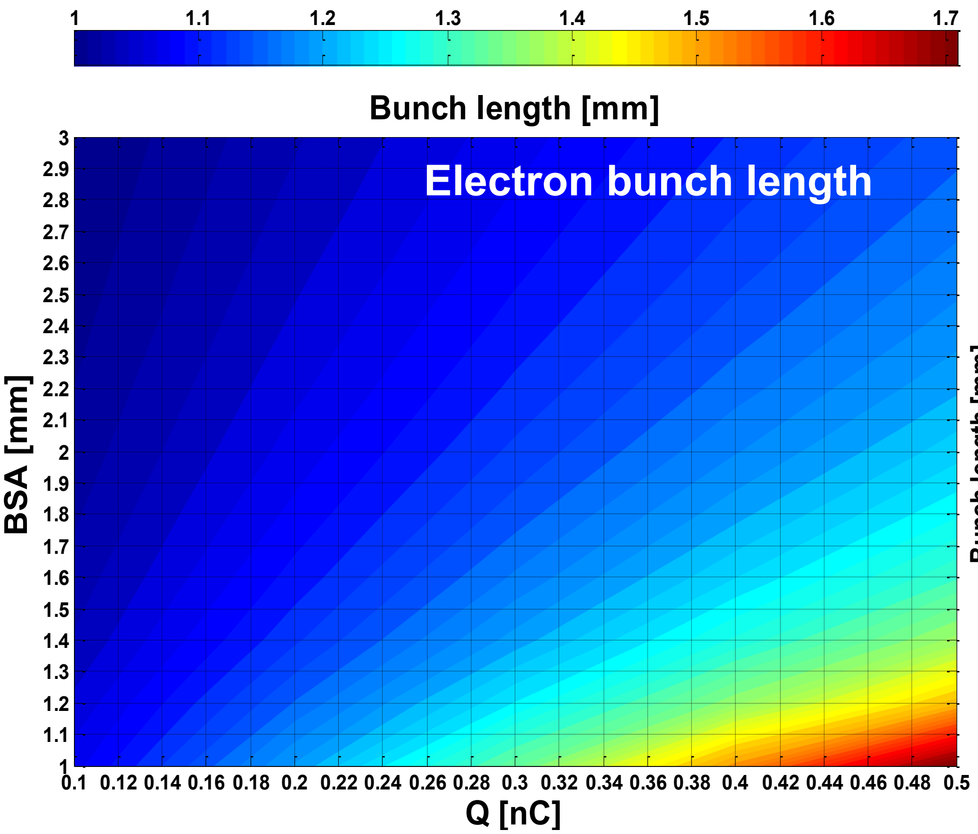
❑ ELLA bunch charges were measured using LOW.FC1, calibration factor w.r.t. LOW.ICT1 was estimated as 1.18, 1.22 and 1.26, respectively

Some numbers:

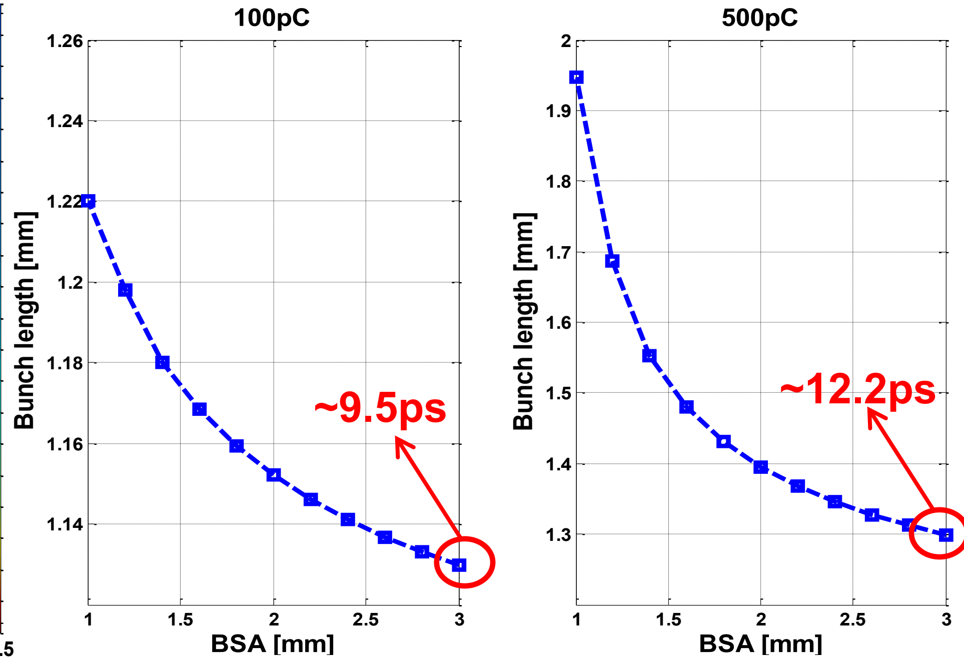
❑ **100pC measurements with TDS close to emission-based pulse length calculation, example:**
Measure(e-bunch) -> MBI: 9.68ps; ELLA:5.8ps
Emission model(laser) -> MBI: 9.68ps; ELLA:5.3ps

How exactly electron bunch length correlates with laser pulse length for different BSAs, laser pulse length, bunch charges, etc.?

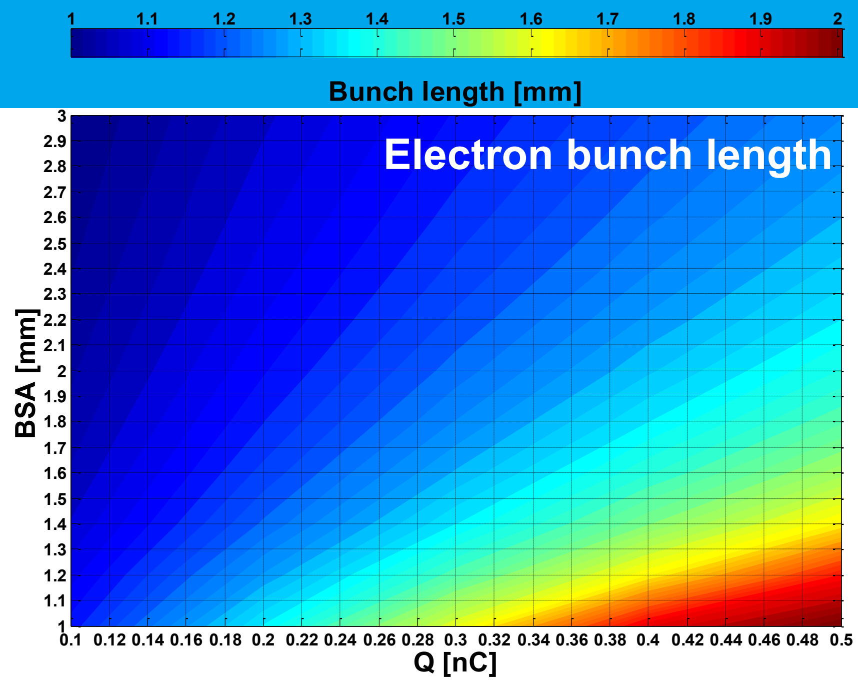
Simulations of electron bunch length

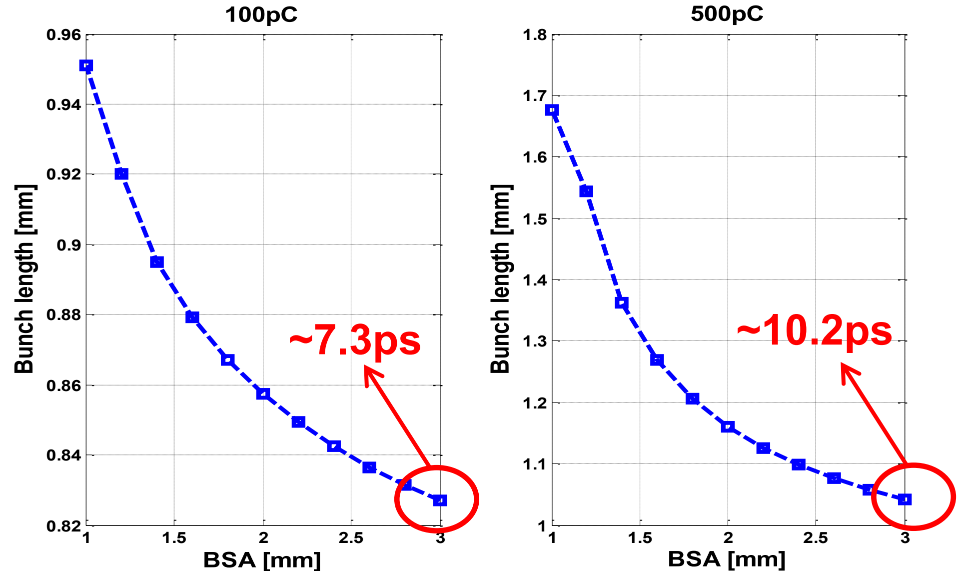


Cathode laser: 10ps FWHM Gaussian

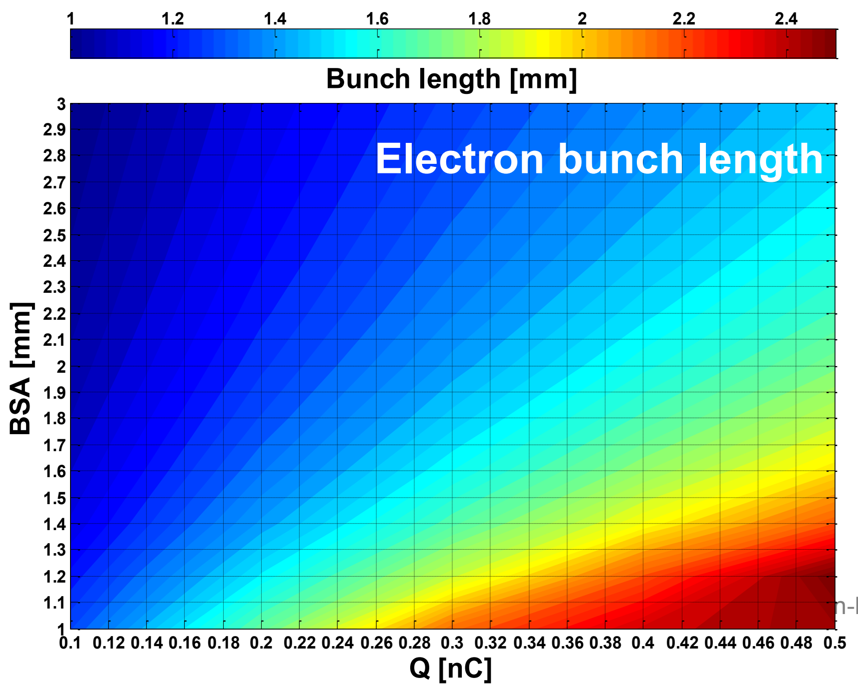


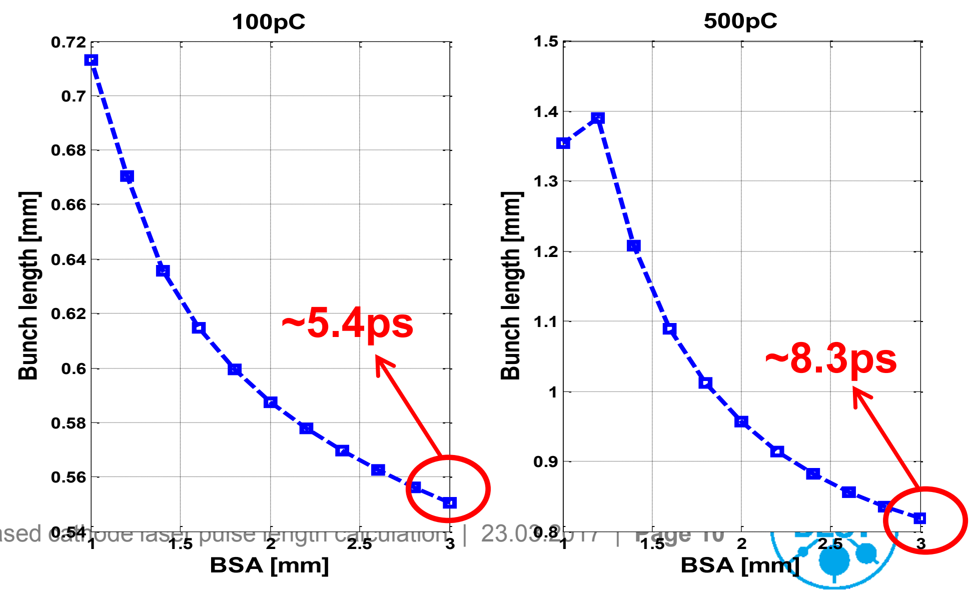
Cathode laser: 7ps FWHM Gaussian





Cathode laser: 4ps FWHM Gaussian





Summary

- Shorter pulse length of ELLA than MBI, ~same in experiments
- MBI-ELLA pulse length correlation gives ~5.8ps for ELLA when MBI is 11.5ps
- Simulations of electron bunch length done for different BSAs, laser pulse lengths and bunch charges
  - ~10ps FWHM laser pulse length ≈ e-bunch length measured with 100pC and BSA=3mm
  - For MBI, 100pC and BSA=3.0mm sufficient for measuring laser pulse length; For ELLA, this condition probably not sufficient
- Characterization of enhanced C-L emission model needs detailed emission measurements and further simulations