Advanced beam dynamics experiments at SPARC

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on be half the SPARC group

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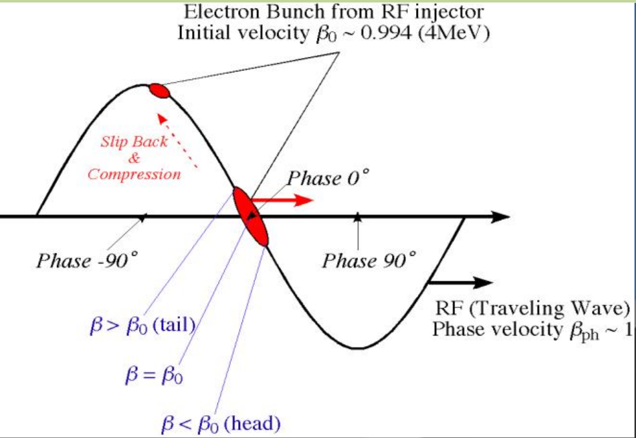
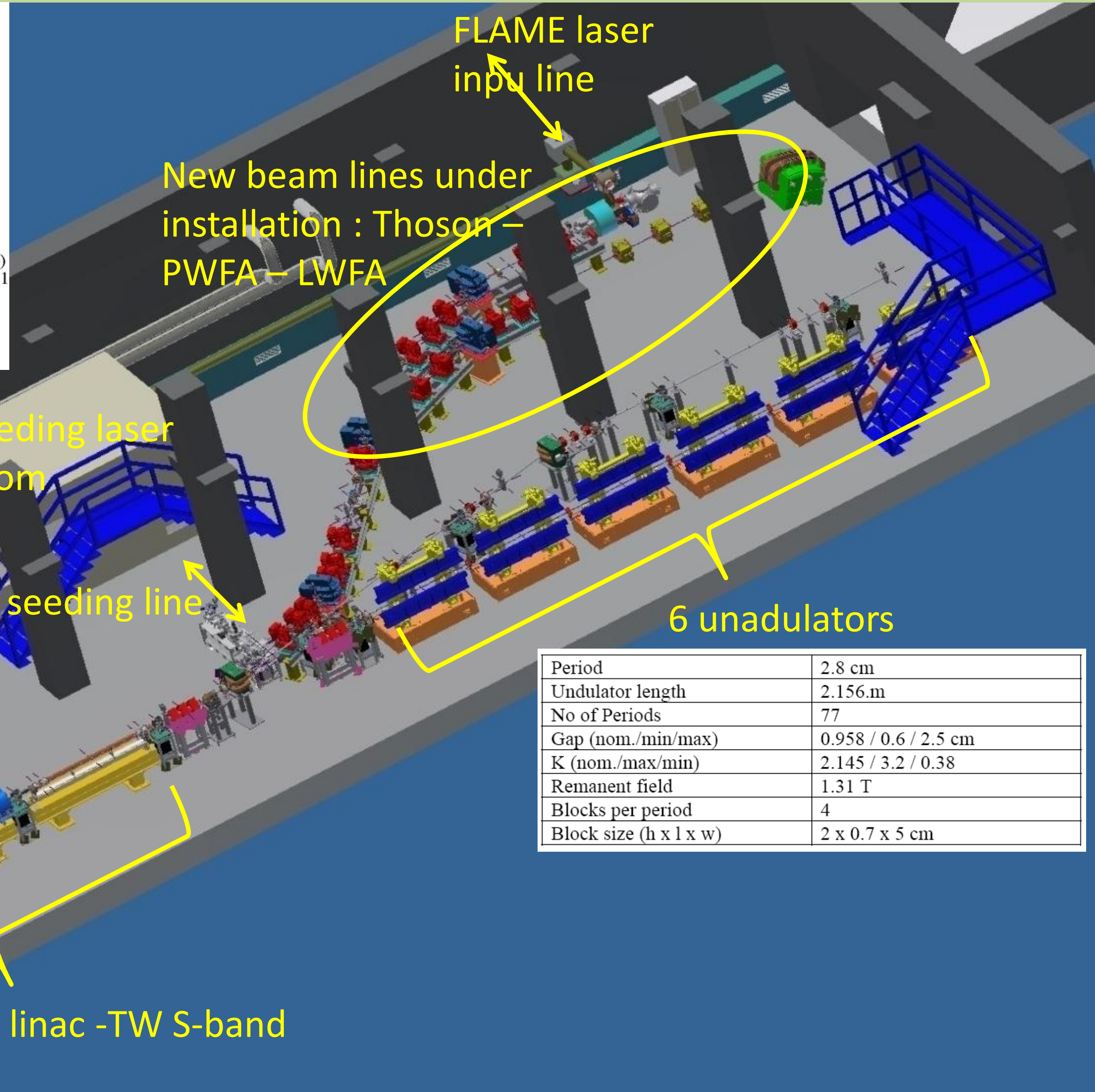
SPARC layout





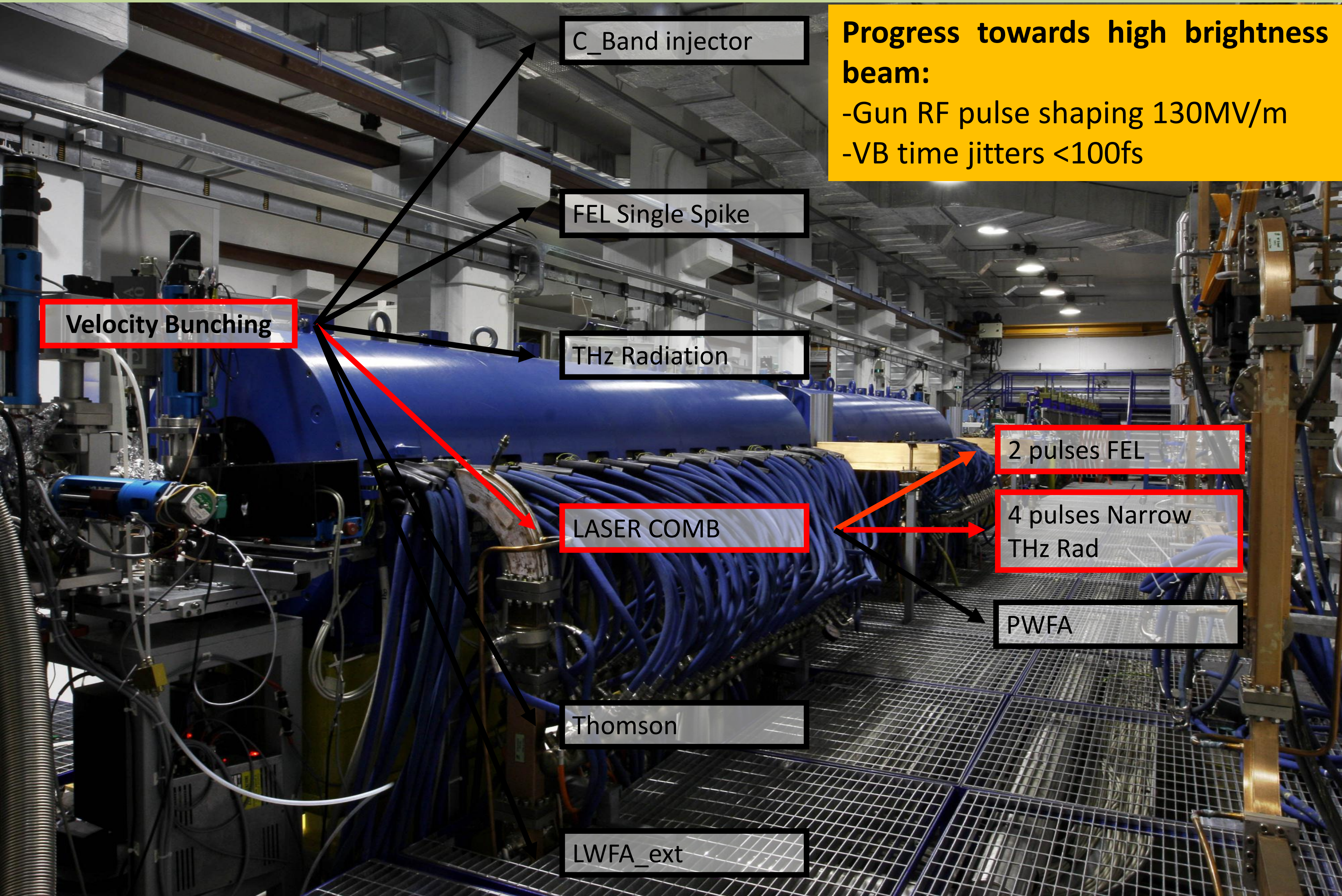
Period	2.8 cm
Undulator length	2.156.m
No of Periods	77
Gap (nom./min/max)	0.958 / 0.6 / 2.5 cm
K (nom./max/min)	2.145 / 3.2 / 0.38
Remanent field	1.31 T
Blocks per period	4
Block size (h x l x w)	2 x 0.7 x 5 cm

SPARC Velocity Bunching applications

Progress towards high brightness beam:

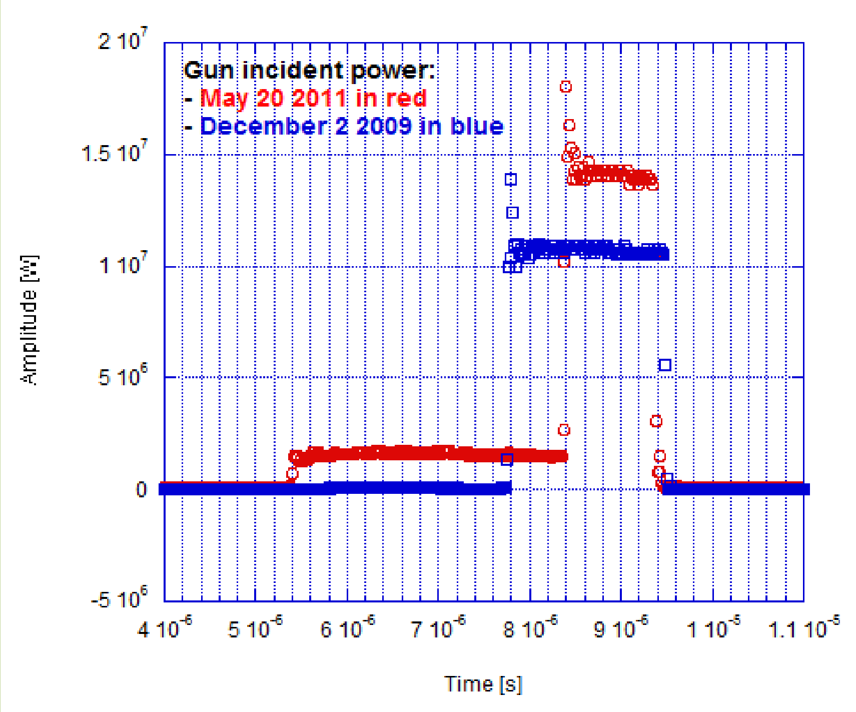
-Gun RF pulse shaping 130MV/m

-VB time jitters <100fs



New RF pulse shaping for Gun feeding

Goals:
- Increase the gun accelerating gradient
- Maintain the residual phase noise, respect to the main oscillator, below 100fs
- Have a breakdown rate as low as possible



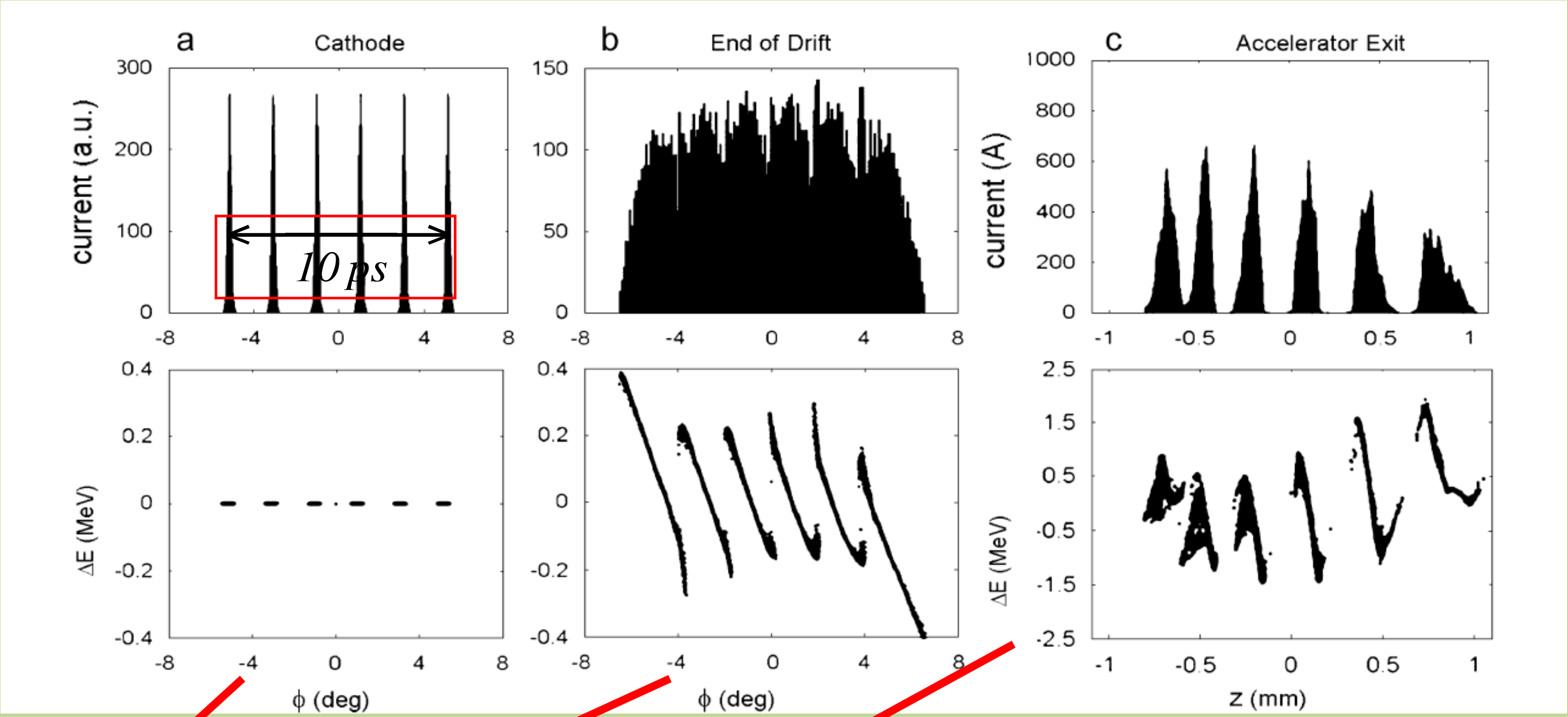
Solution:
- In the first 3us the RF level is kept as low as possible to make the PLL (Phase Locked Loop) working
- The RF is brought to the maximum level in the last 0.8 us

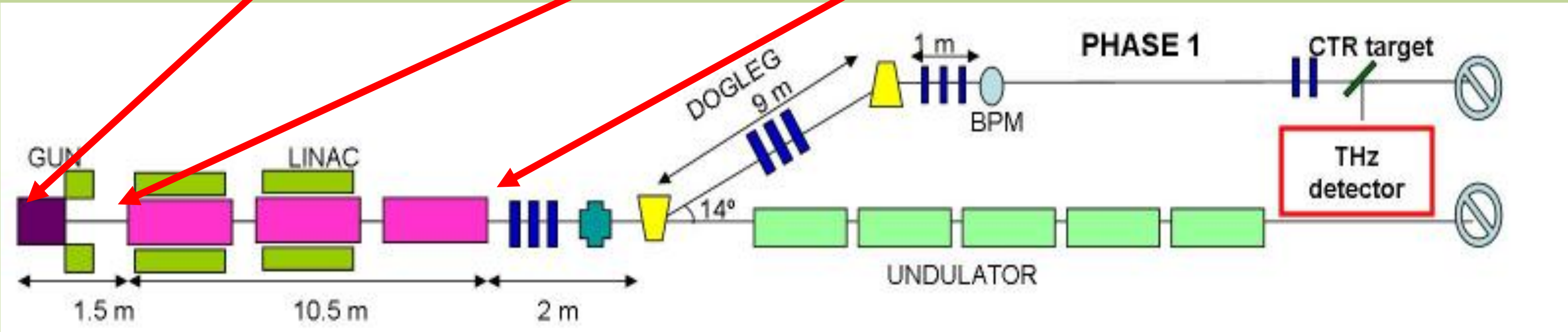
Before (11 MW - 112 MV/m – 4.7 MeV)

Now (14 MW - 130MV/m – 6.2 MeV)

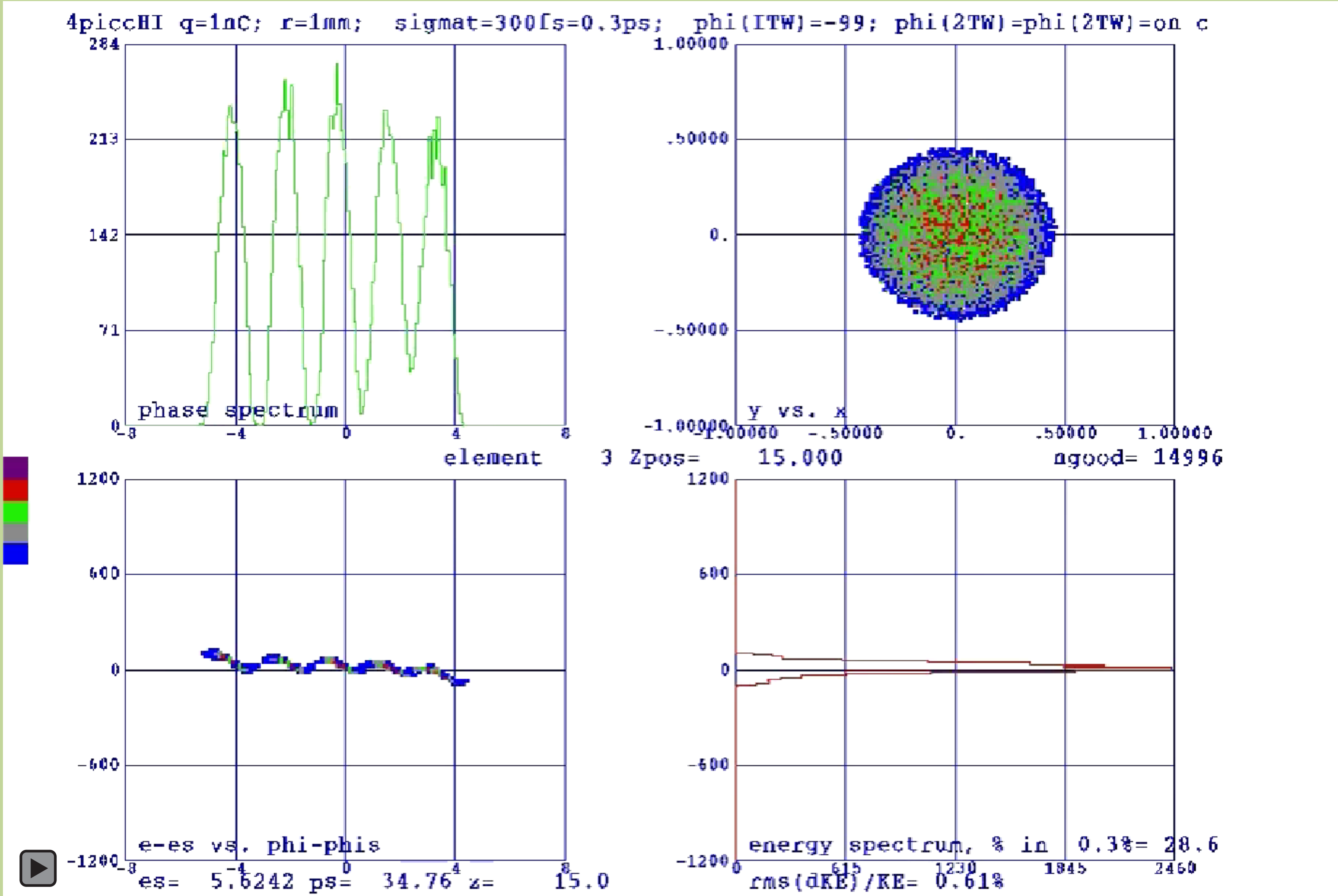
M. Bellaveglia, M. Ferrario, A. Gallo, RF pulse shaping optimization to drive low emittance RF photoinjector, to be published

Laser Comb: beam echo generation of a train bunches



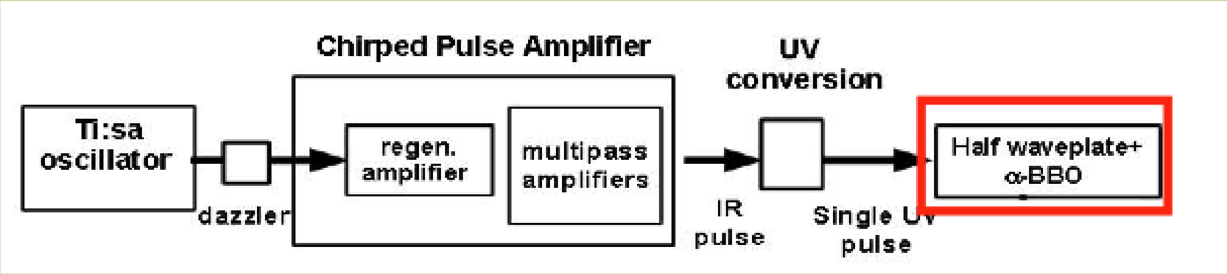


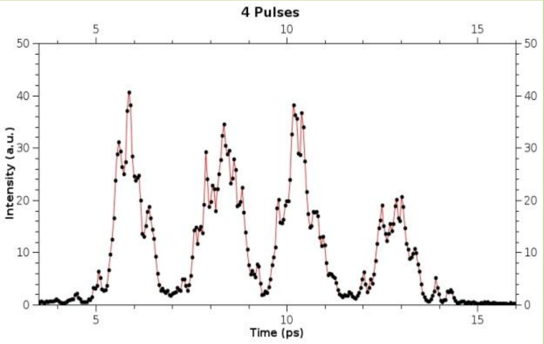
- P.O.Shea et al., Proc. of 2001 IEEE PAC, Chicago, USA (2001) p.704.
- M. Ferrario. M. Boscolo et al., Int. J. of Mod. Phys. B, 2006 (Taipei 05 Workshop)



Click to play movie

A train of laser pulses at the cathode by birefringent crystal





$$\Delta\tau = (1/v_{go} - 1/v_{ge})L_1$$

The technique used for this purpose relies on a birefringent crystal, where the input pulse is decomposed in two orthogonally polarized pulses (ordinary, extraordinary) with a time separation proportional to the crystal length.

Different crystal thickness are available (10.353 mm in this case).

Putting more crystals, one can generate bunch trains (e.g. 4 bunches).

The intensity along the pulse train can be modulated (e.g. PWFA)

Experimental results

Systematic analysis by simulations

Free parameters:

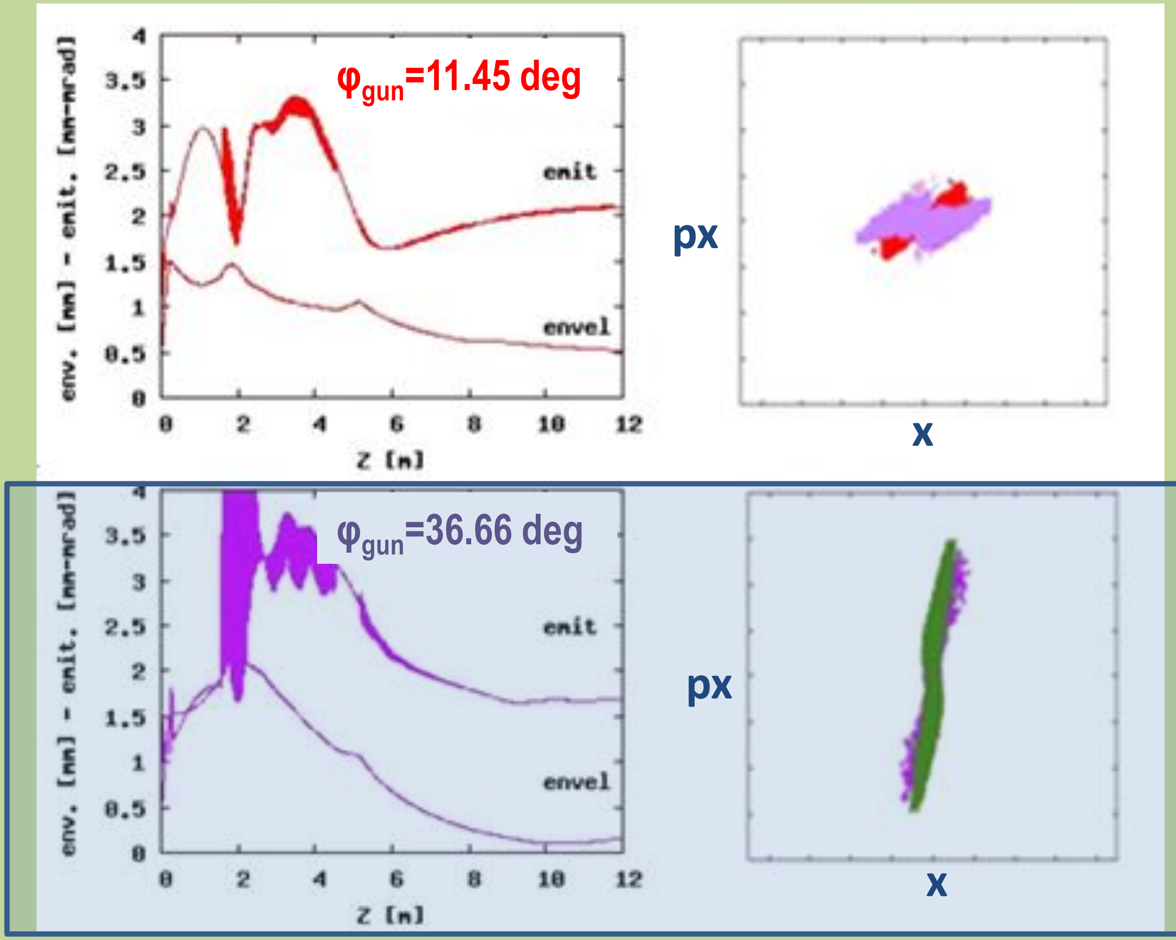
Gun ijection phase
VB ijection phase
Bz field Gun Solenoid
Bz field Tw_{cavity} N. 1

Initial parameters:

$T_{separation}$ at chathode = 4.27 ps
Q = 80 pC + 80 pC
$\sigma_x = \sigma_y = 400\ \mu m$
Tw_{cavity} II–III on crest

Final Condition:

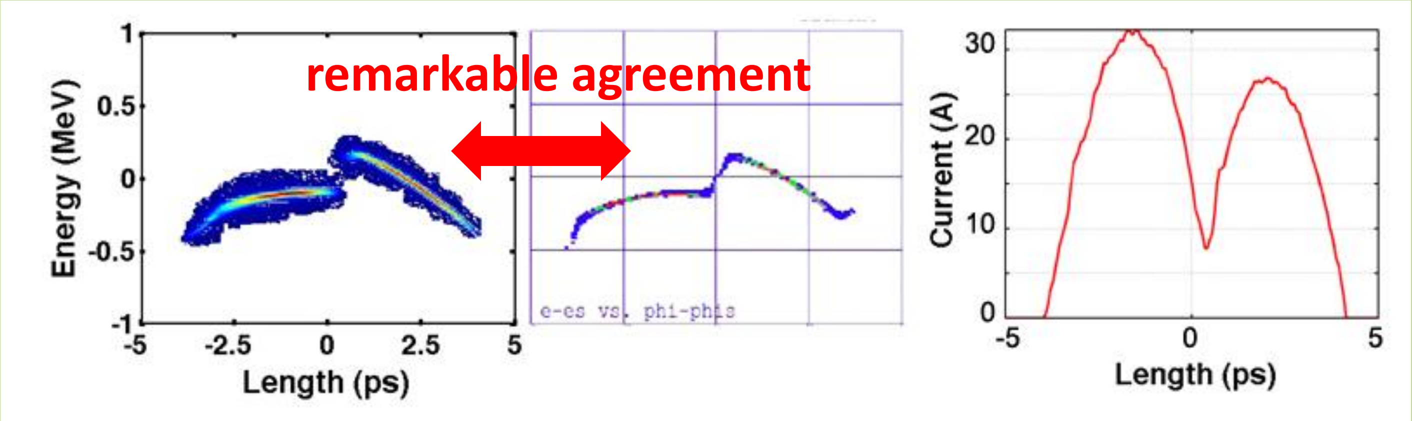
$T_{separation} \approx 1$ ps
current I = current II
Minimum total rms ε



The minimum total projected emittance (measurable) corresponds to a similar behaviour of both sub-bunches (emittance and current)

Two bunches train caracterization Q_t=166 pC (92+78)

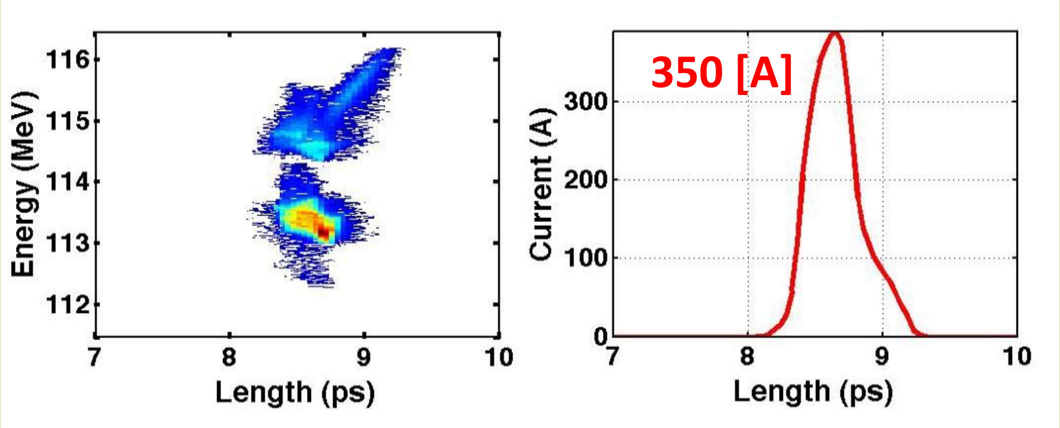
on crest



$T_{sep.}$ = 4.27 ps
$\sigma_{t\text{-pulses}} \approx$150fs
$\sigma_x = \sigma_y$ = 400 µm

$\varepsilon_{x,y}$(100%) = **0.8,1.1** mm-mrad, E_{spread} for each pulse < 0.1 % (170 MeV)
$\varepsilon_{x,y}$ (90%) = **0.5,0.5** mm-mrad, σt1 ≈ σt2 ≈ 1ps

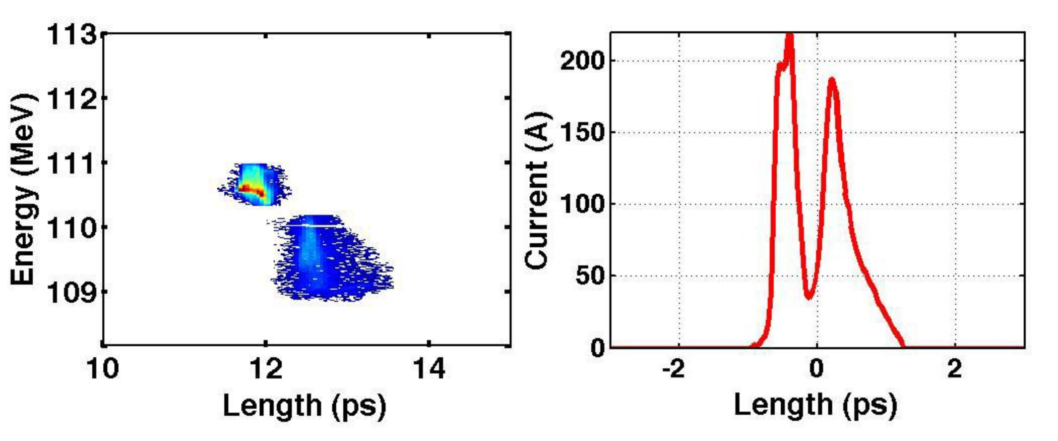
maximum compression VB phase -90.4



σt=140 fs
$\varepsilon_{x,y}$(100%) = 4.5,3.3 mm-rad
$\varepsilon_{x,y}$ (90%) = 3.6,2.6 mm-rad
E_{spread} 0.4% and 0.25% (110 MeV)
Energy separation ≈ 1.5 MeV

Two bunches train caracterization

Over-compression VB phase -95.6



σt I =140 fs, σt II =270 fs

$T_{separation}$≈0.8 ps

$\varepsilon_{x,y}$(100%) = 6.2,4.4 mm-rad

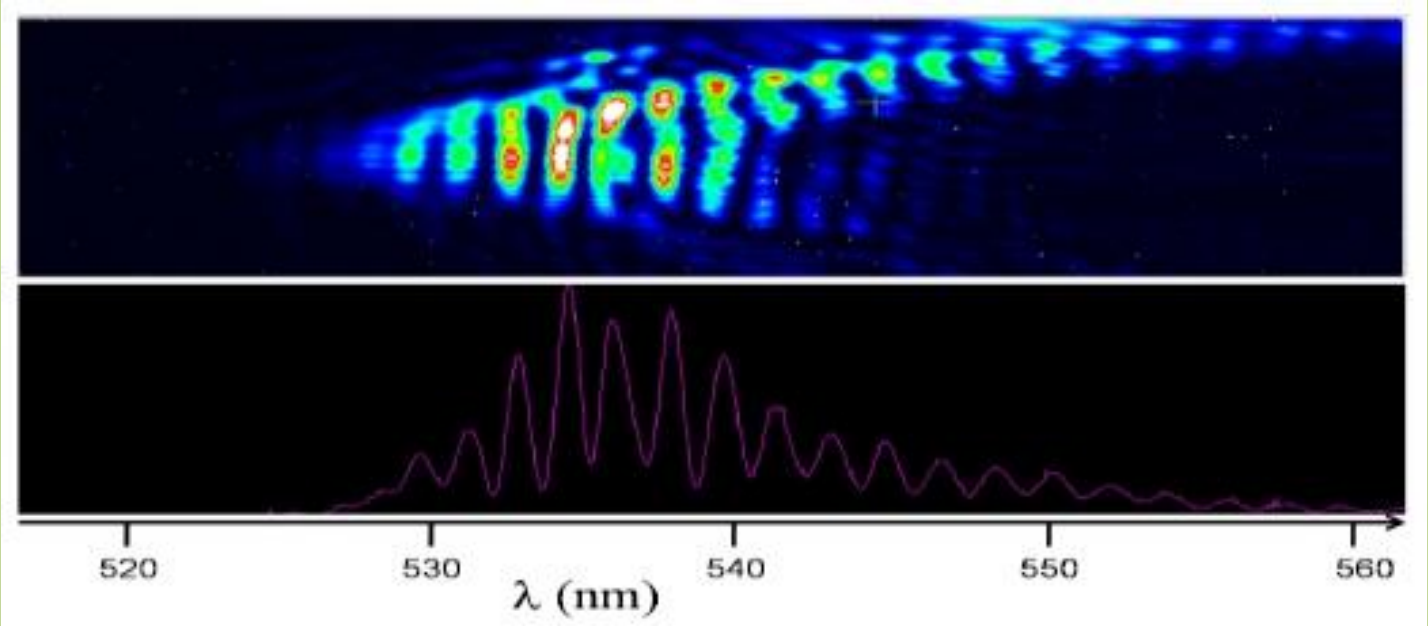
$\varepsilon_{x,y}$ (90%) = 5.8,4.0 mm-rad

E_{spread} 0.16% and 0.4%

Energy separation ≈ 1.2 MeV

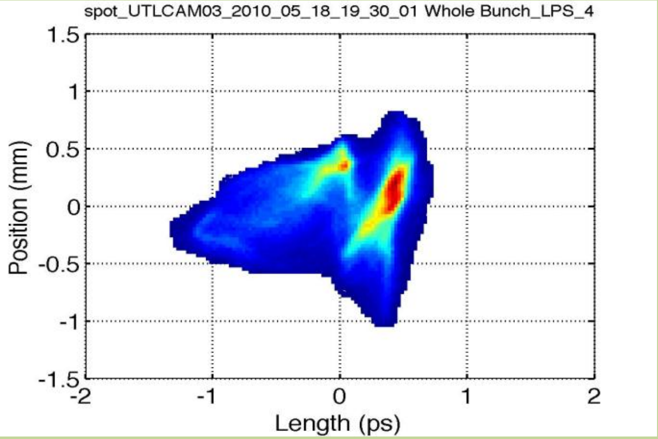
	MEASUREMENTS	SIMULATIONS
Total length (ps)	0.3998 (σ/√10=0.0098)	0.3995
Time Separation (ps)	0.789 (σ/√10=0.061)	0.7743
Energy Separation(MeV)	1.192 (σ/√10=0.056)	1.4
Bunch 1 length (ps)	<0.21 (res.)	0.0963
Bunch2 length (ps)	0.172 (σ/√10=0.022)	0.1108

FEL Comb at SPARC (two bunches train)



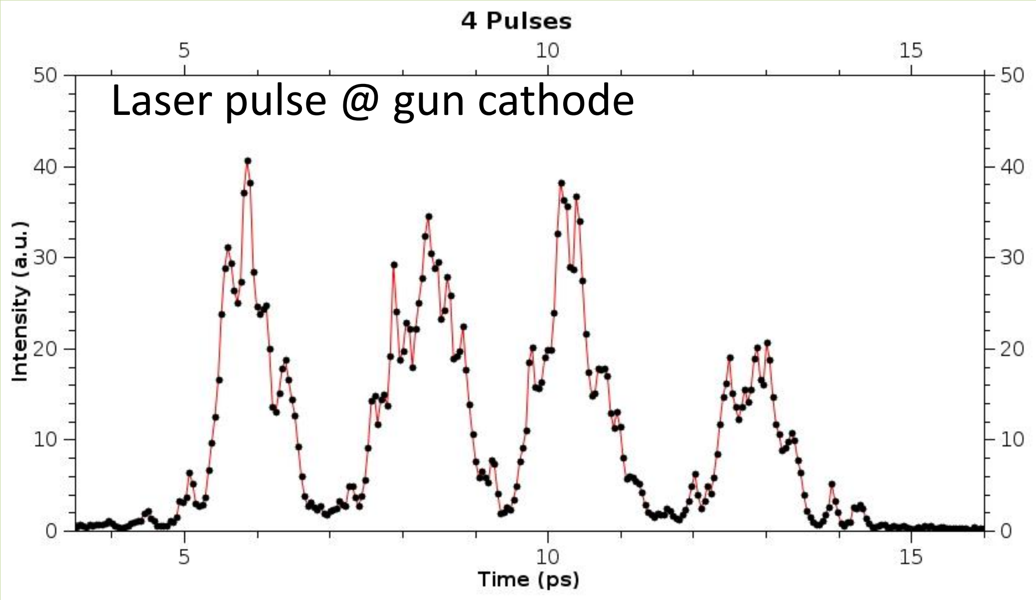
$$dt = \frac{\lambda^2}{\Delta\lambda}$$

From the spectrum dt ≈ 0.615 ps; comparable with data

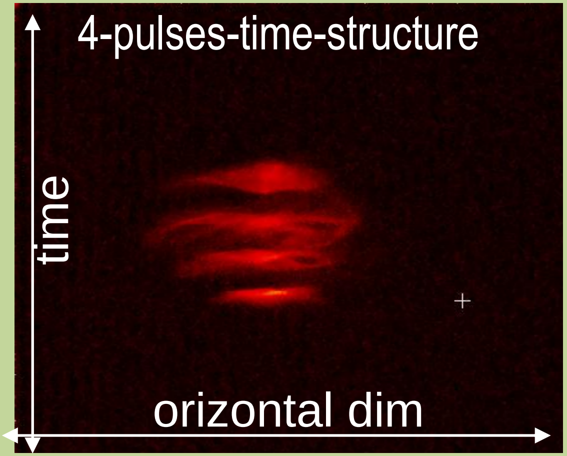


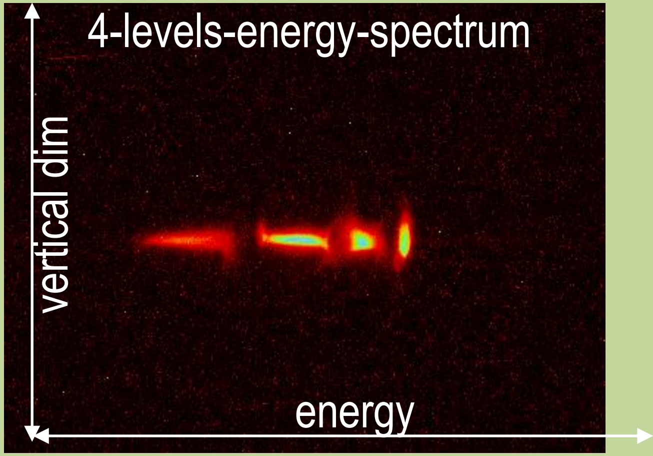
<dt> = 0.8 ps

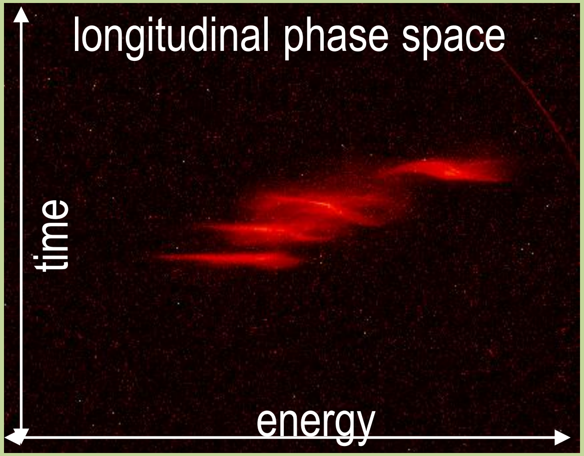
Four pulses COMB structure (200 pC)

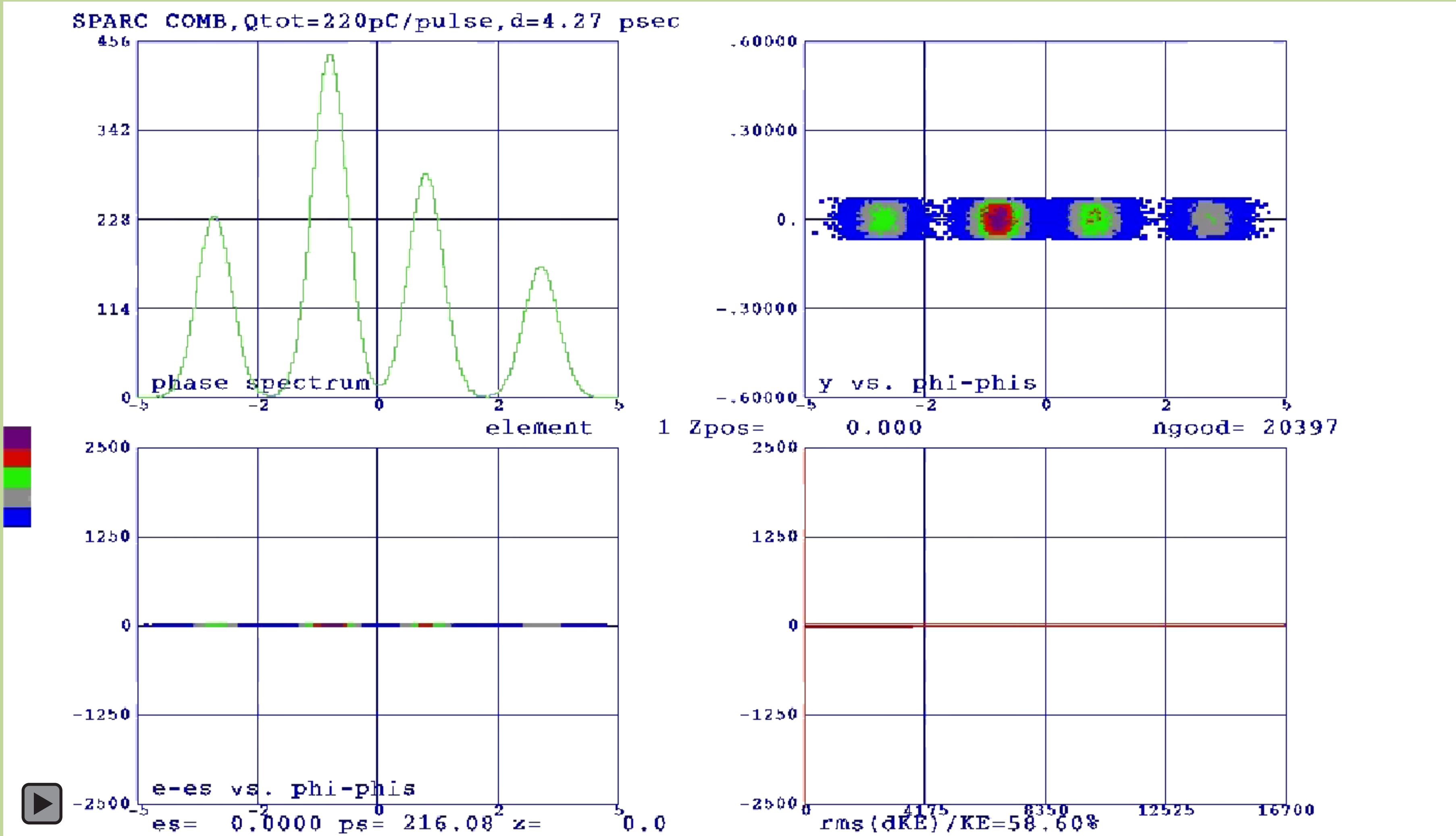


whole train length ≈ 9 ps
σ_t(per spike) ≈ 200 fs









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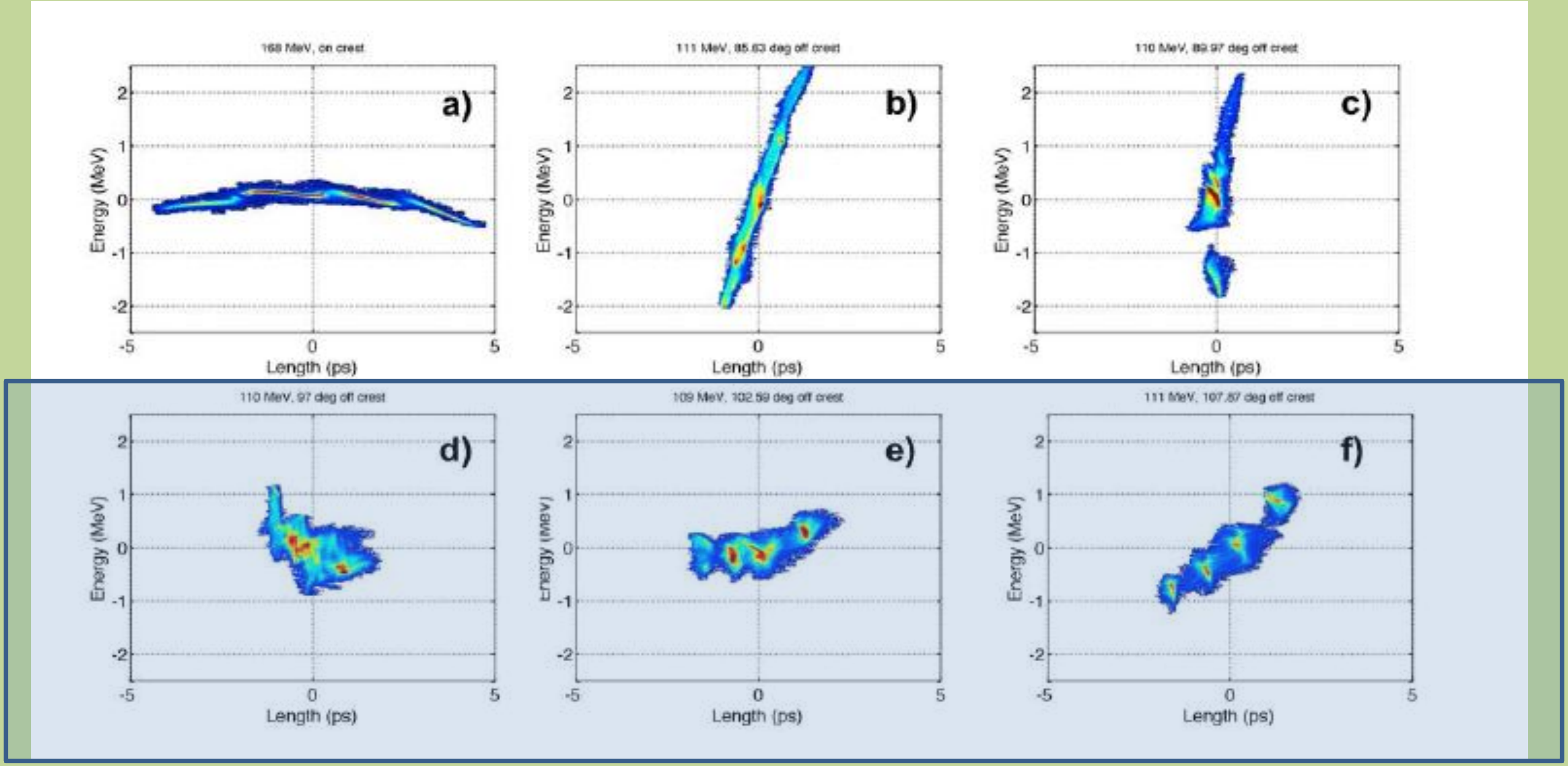
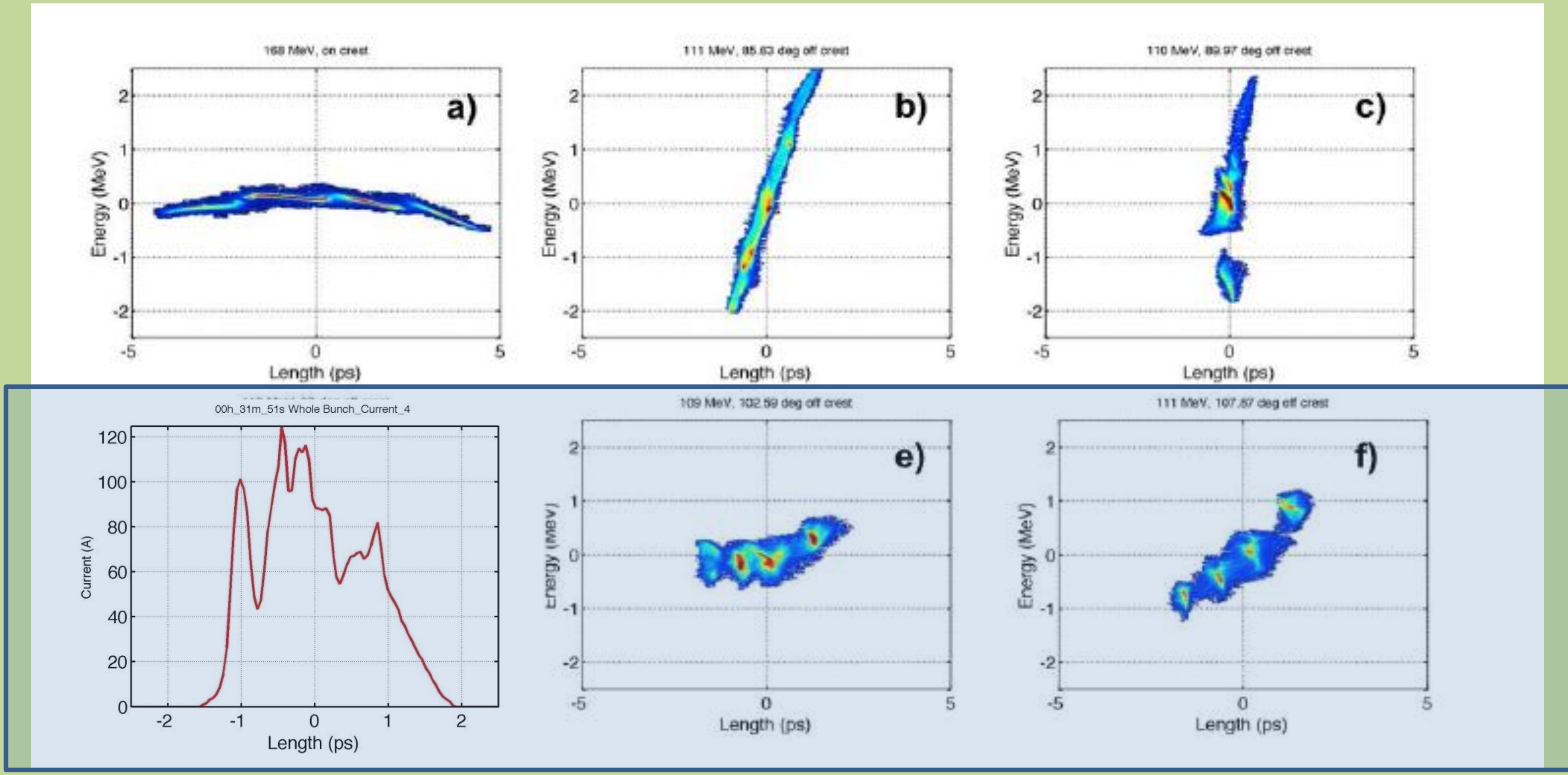
4 comb pulses and long. phase space rotation



Over-compression region: The sub-bunches are well separated; their distance can be controlled by VB phase injection

4 comb pulses and long. phase space rotation



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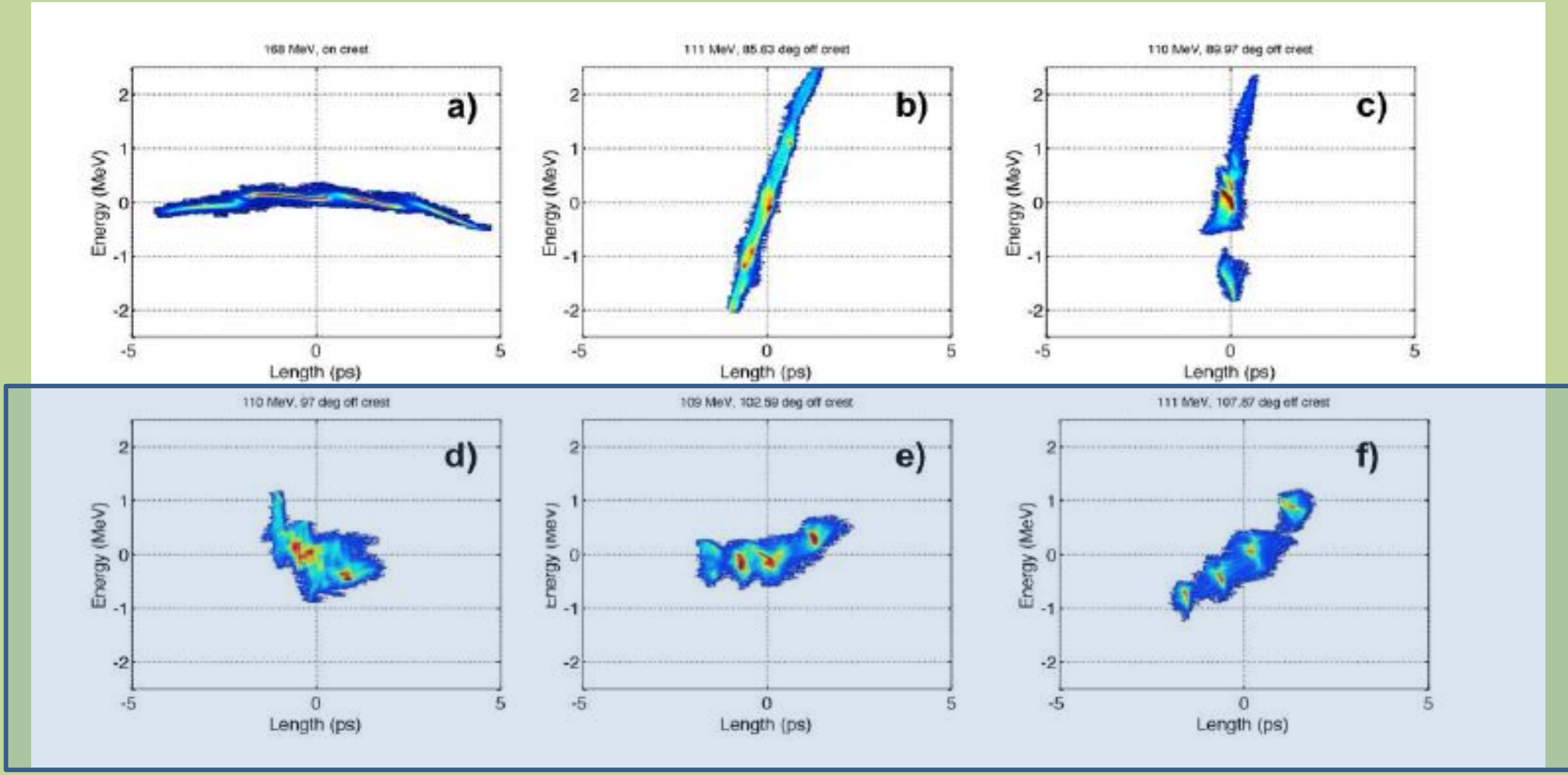

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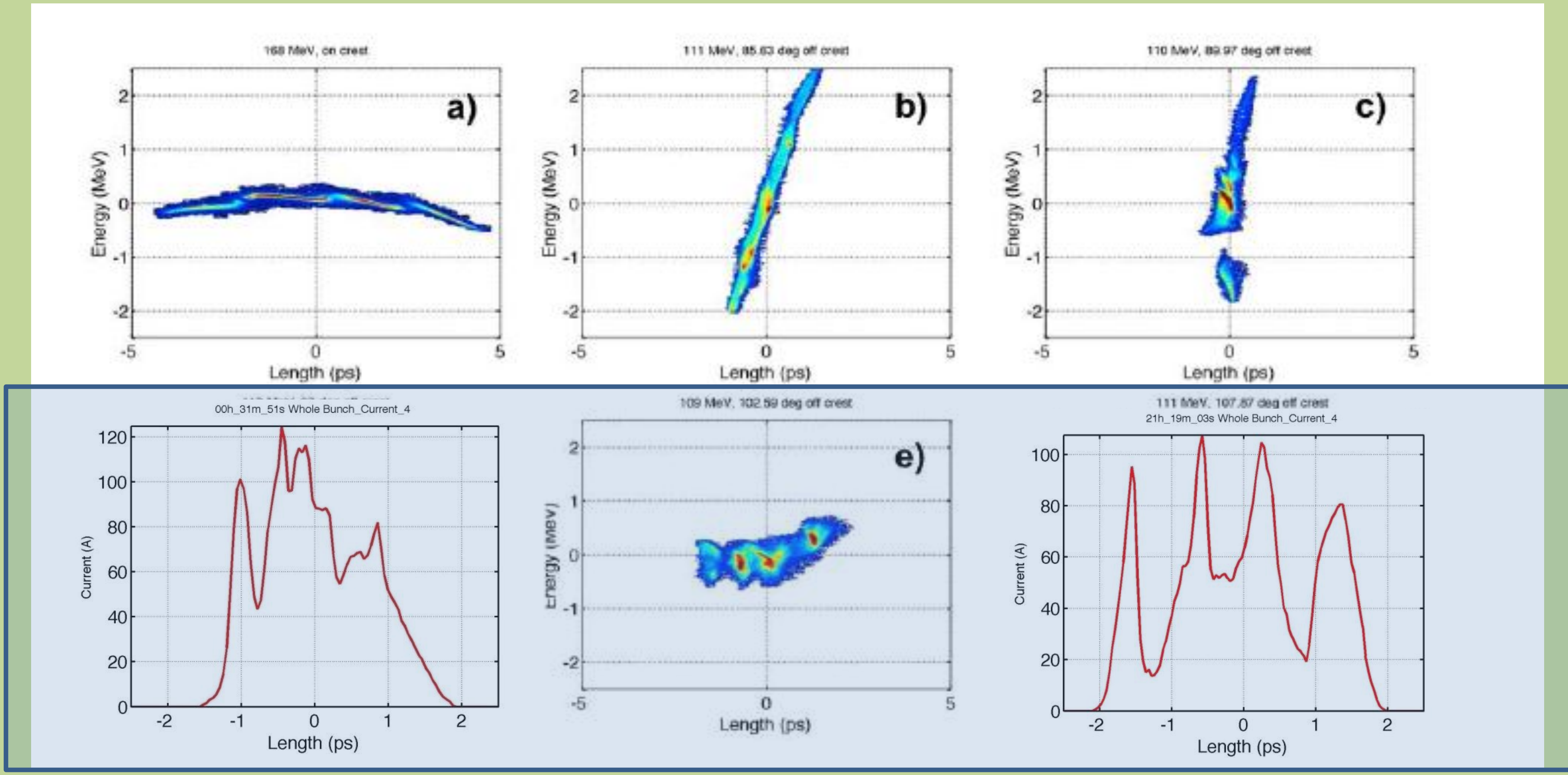

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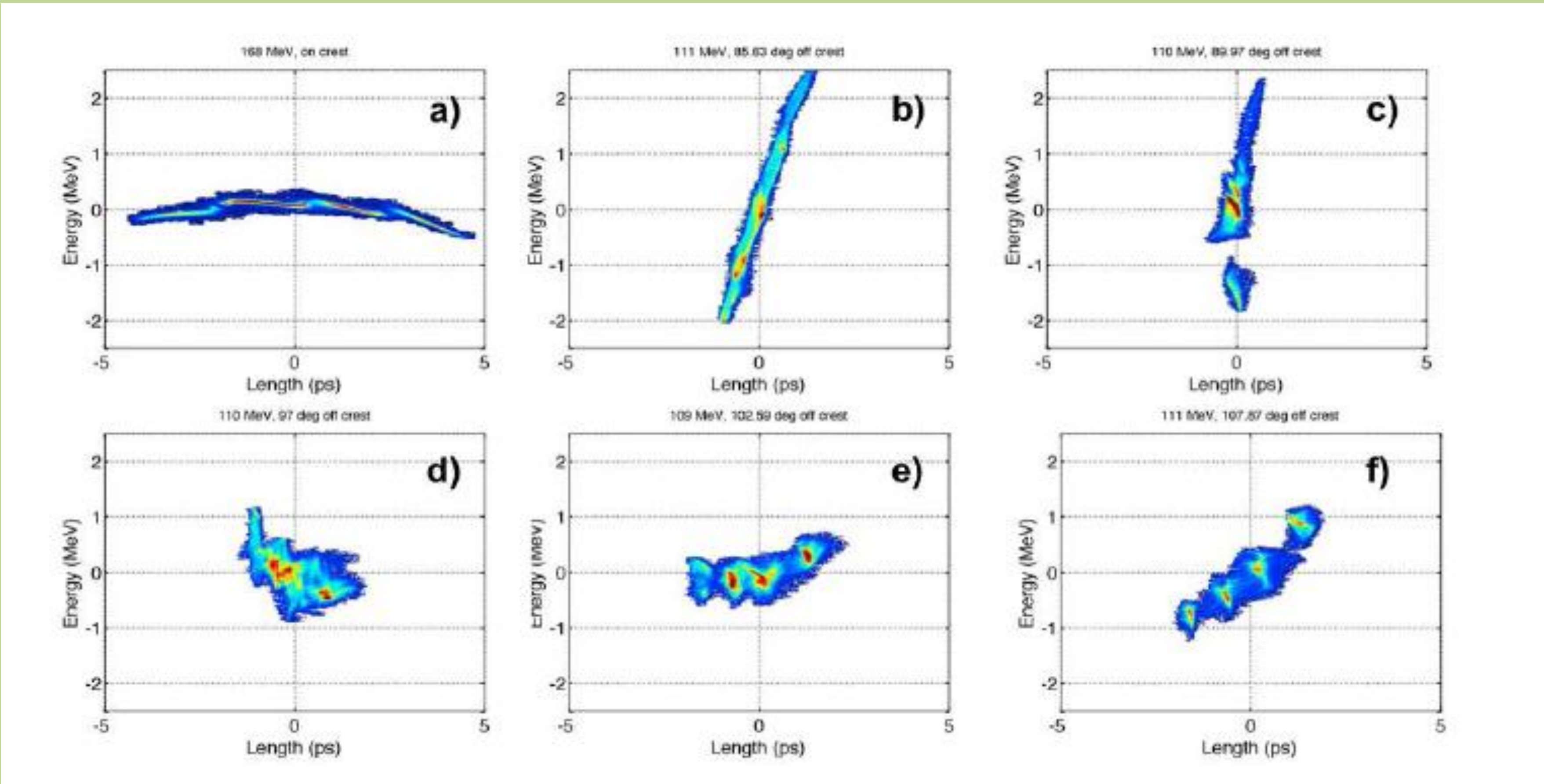

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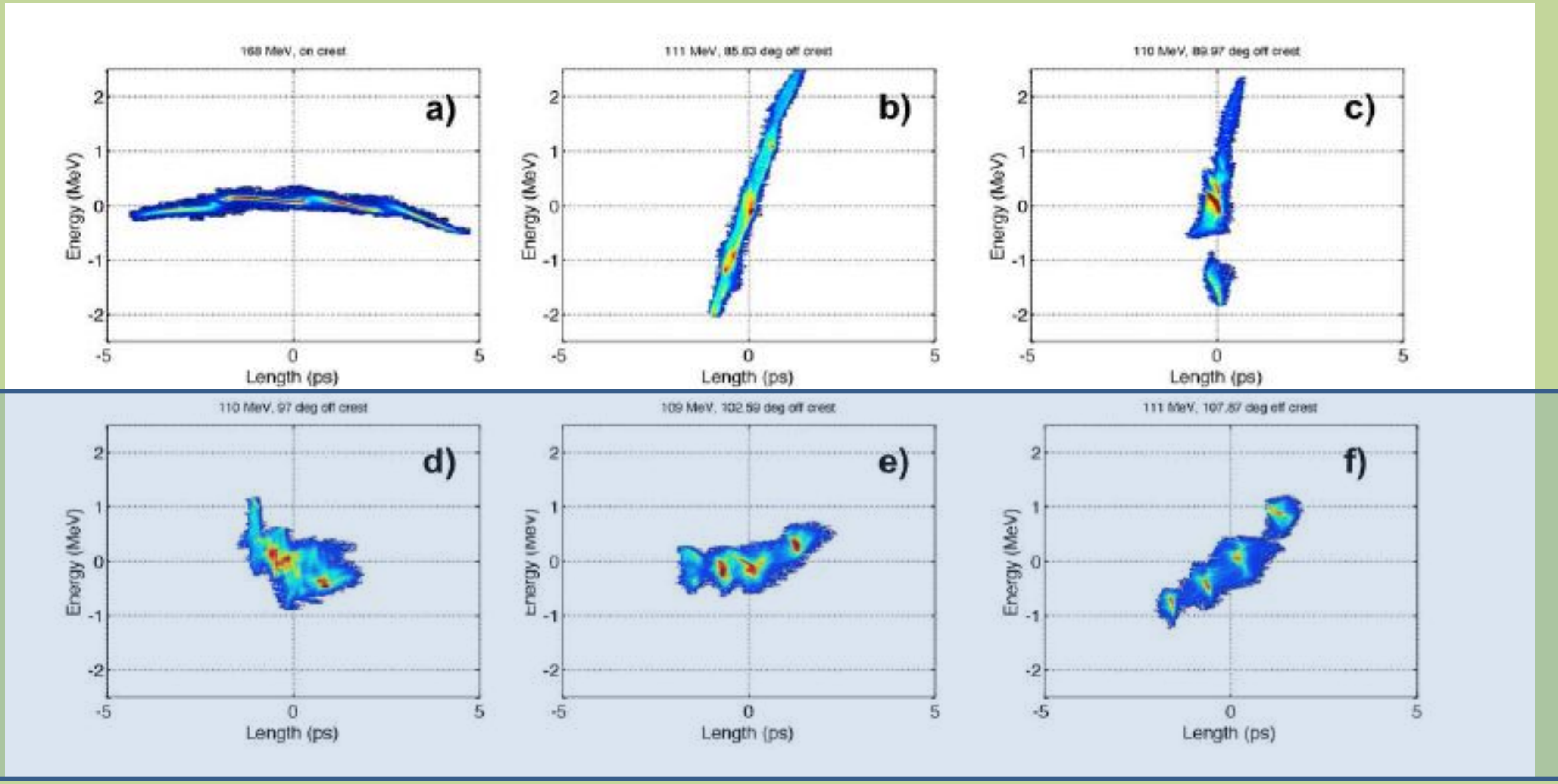

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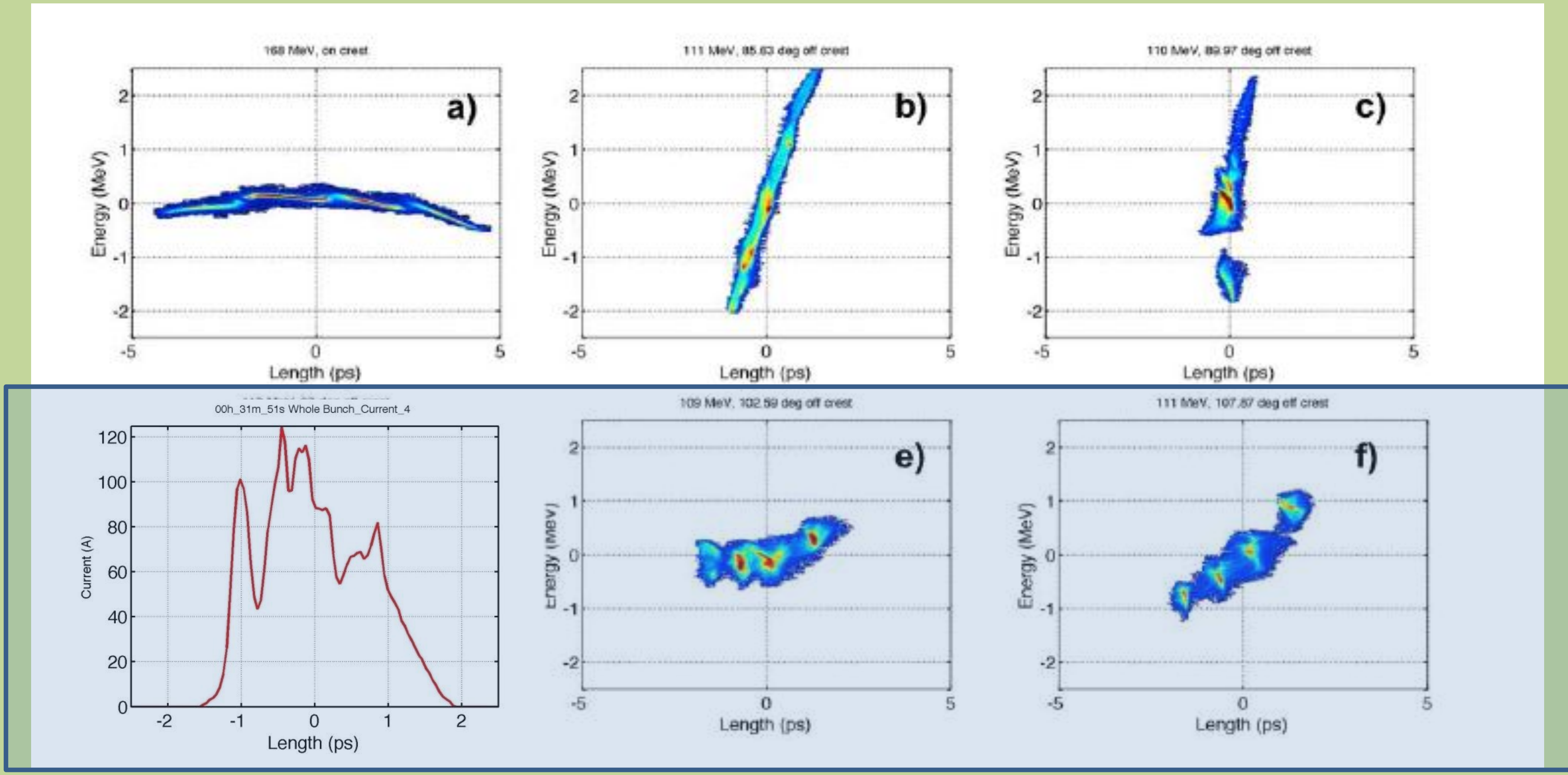

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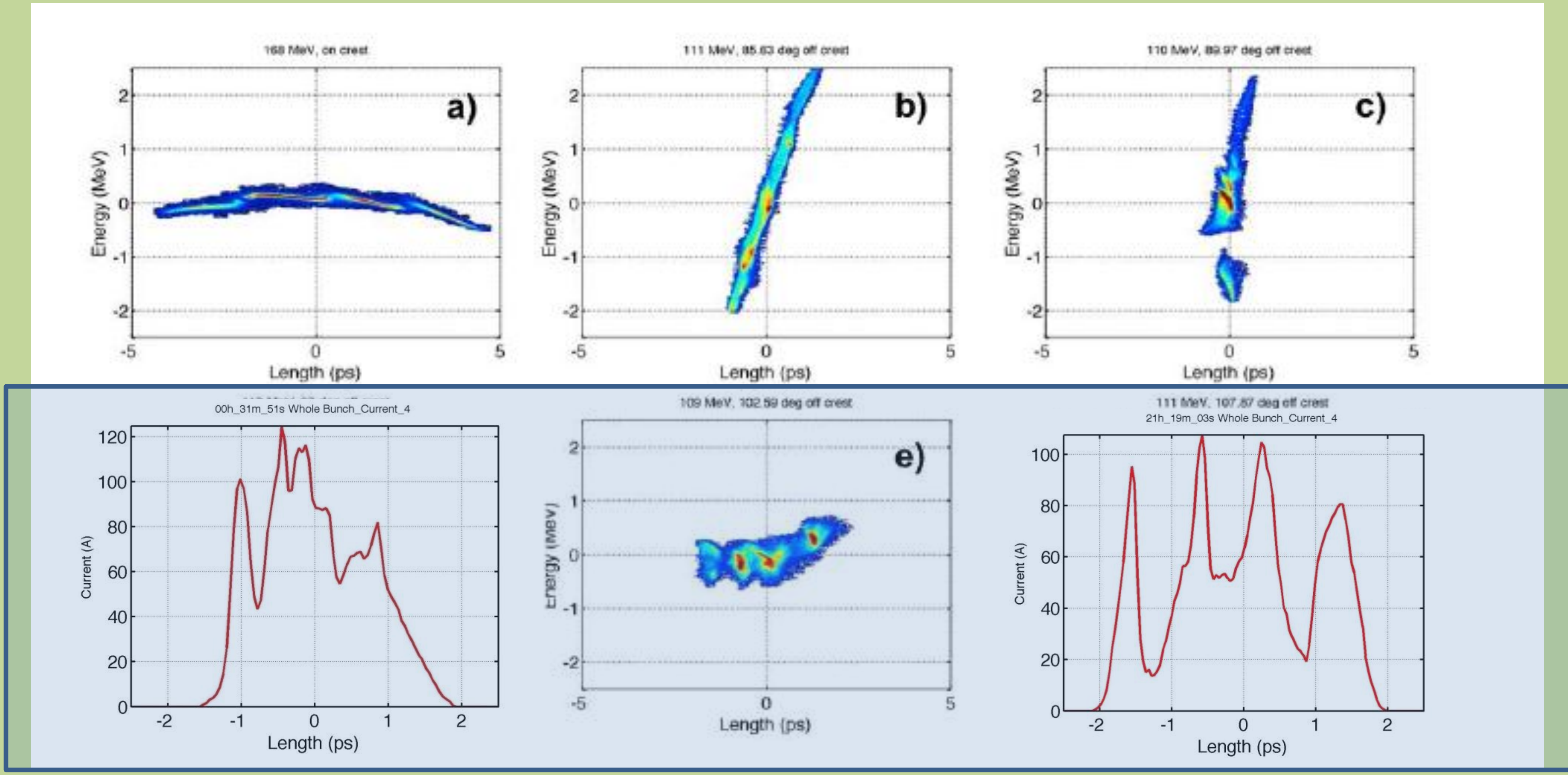

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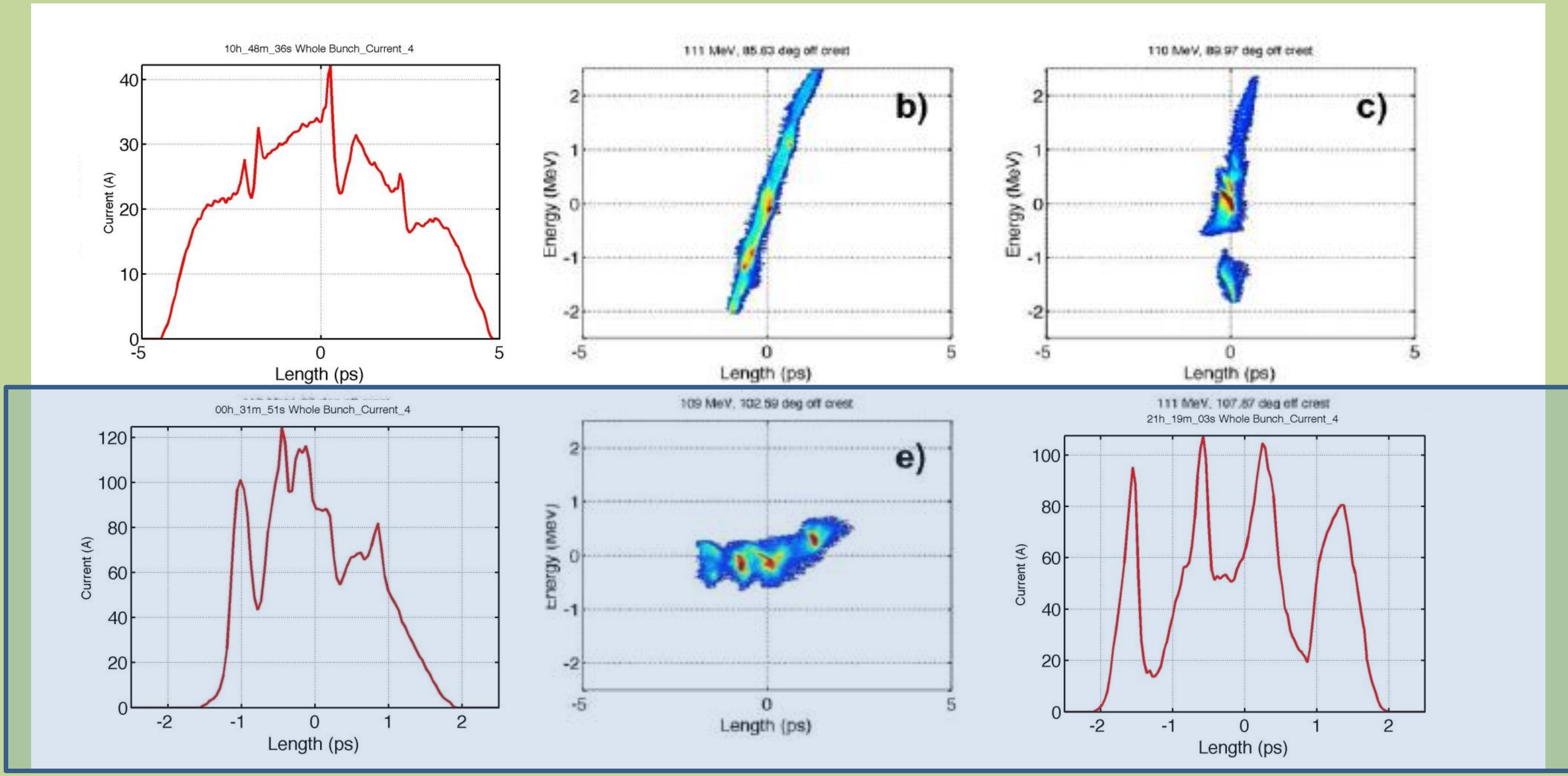

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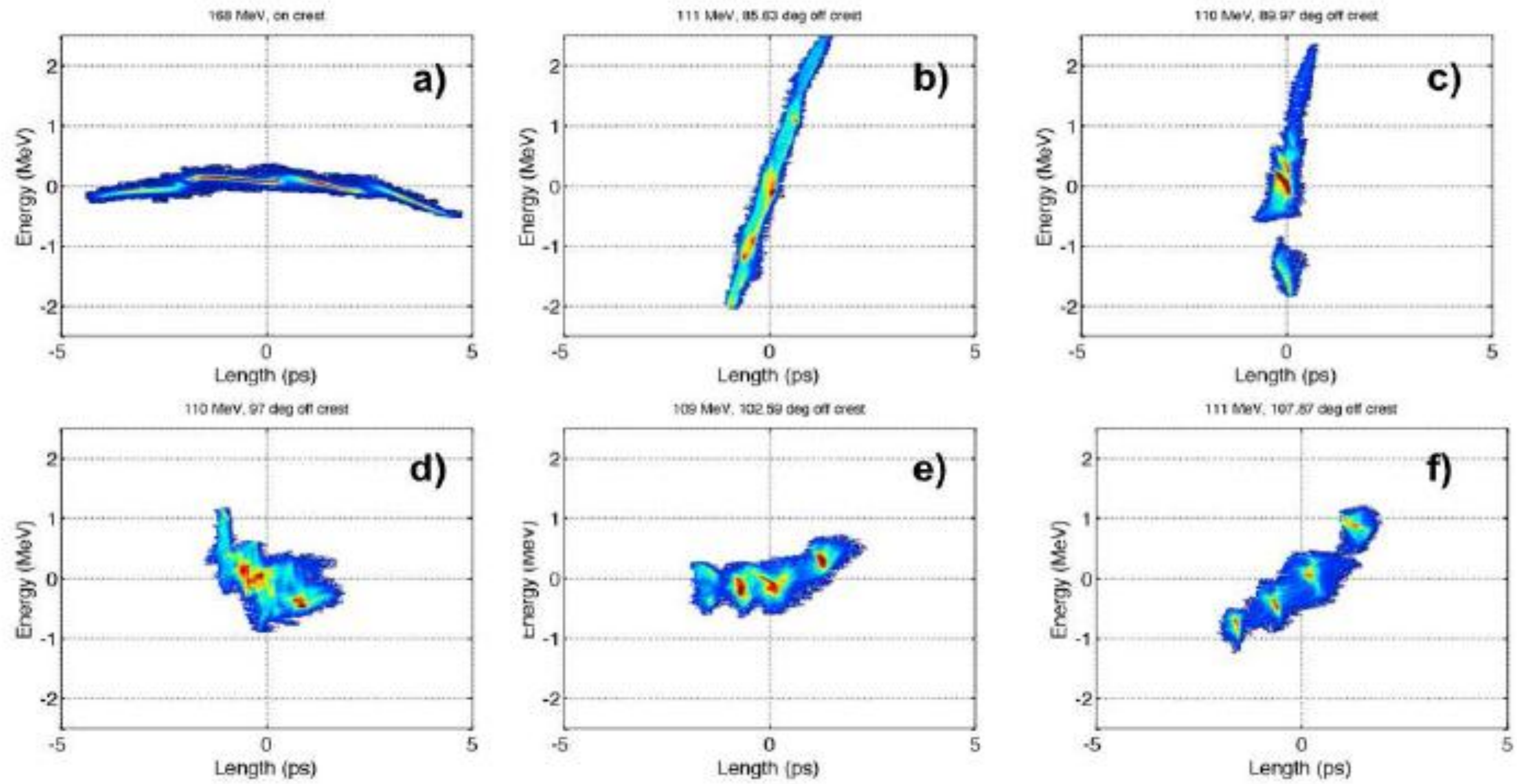

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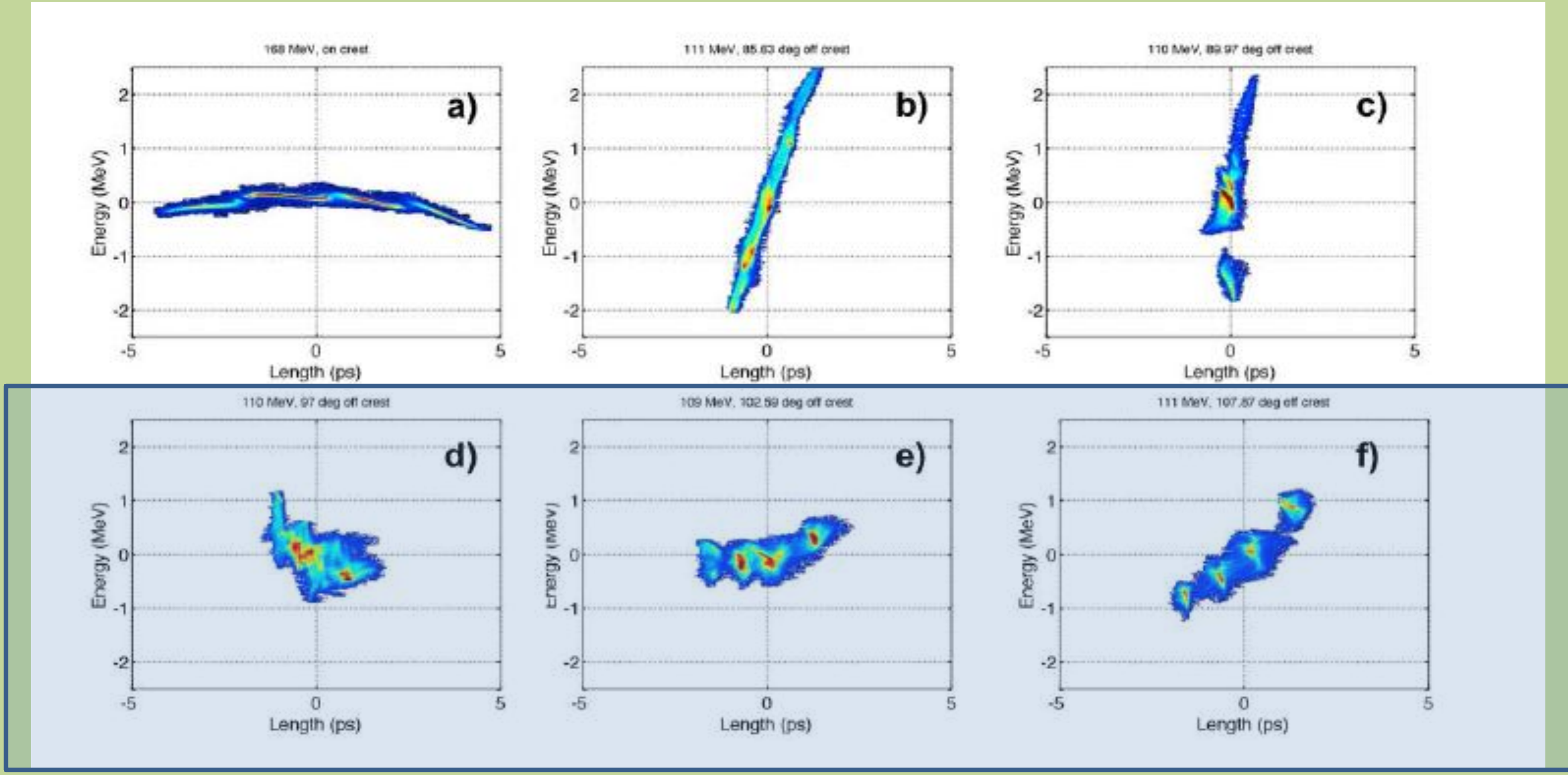

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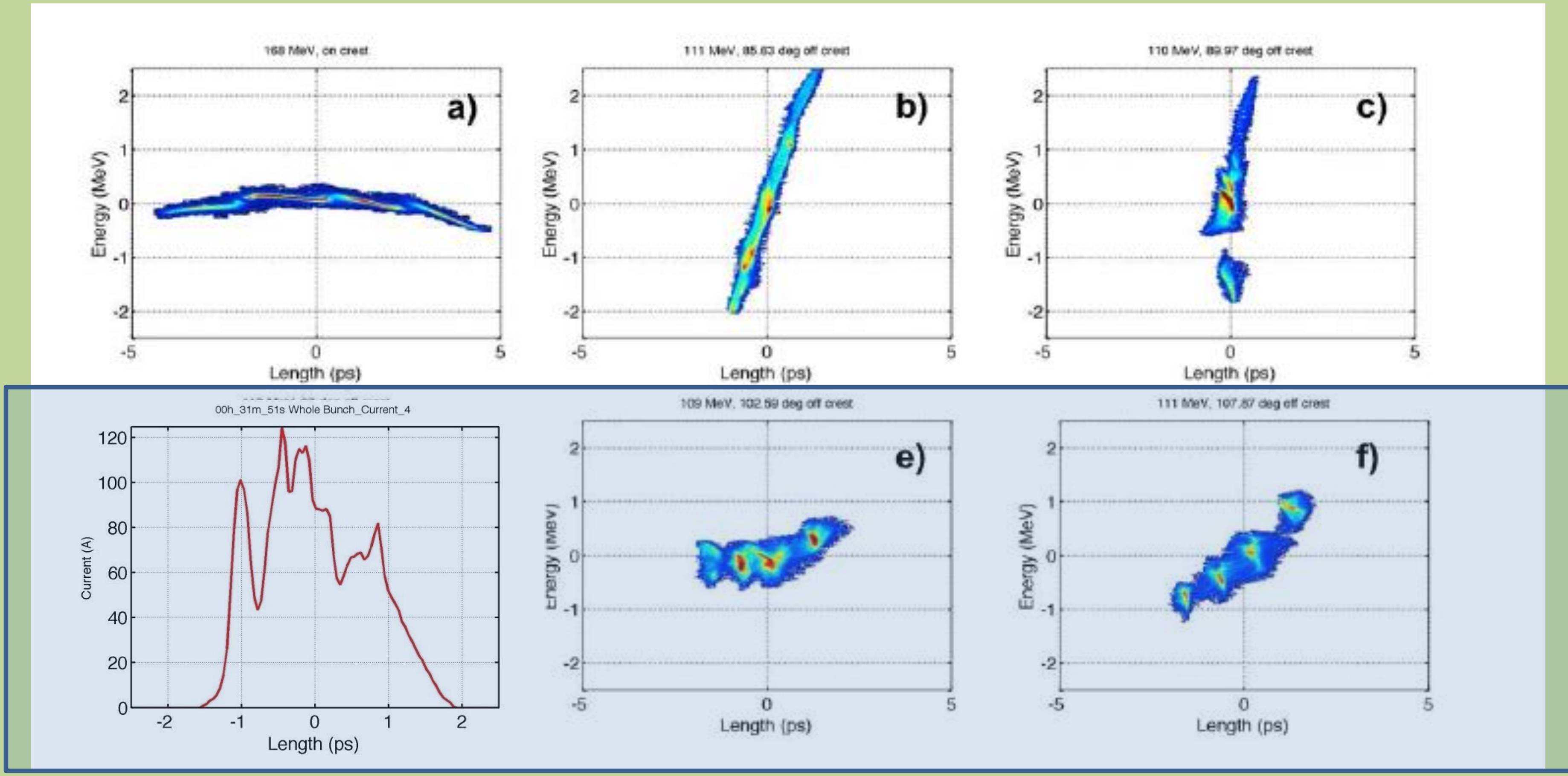

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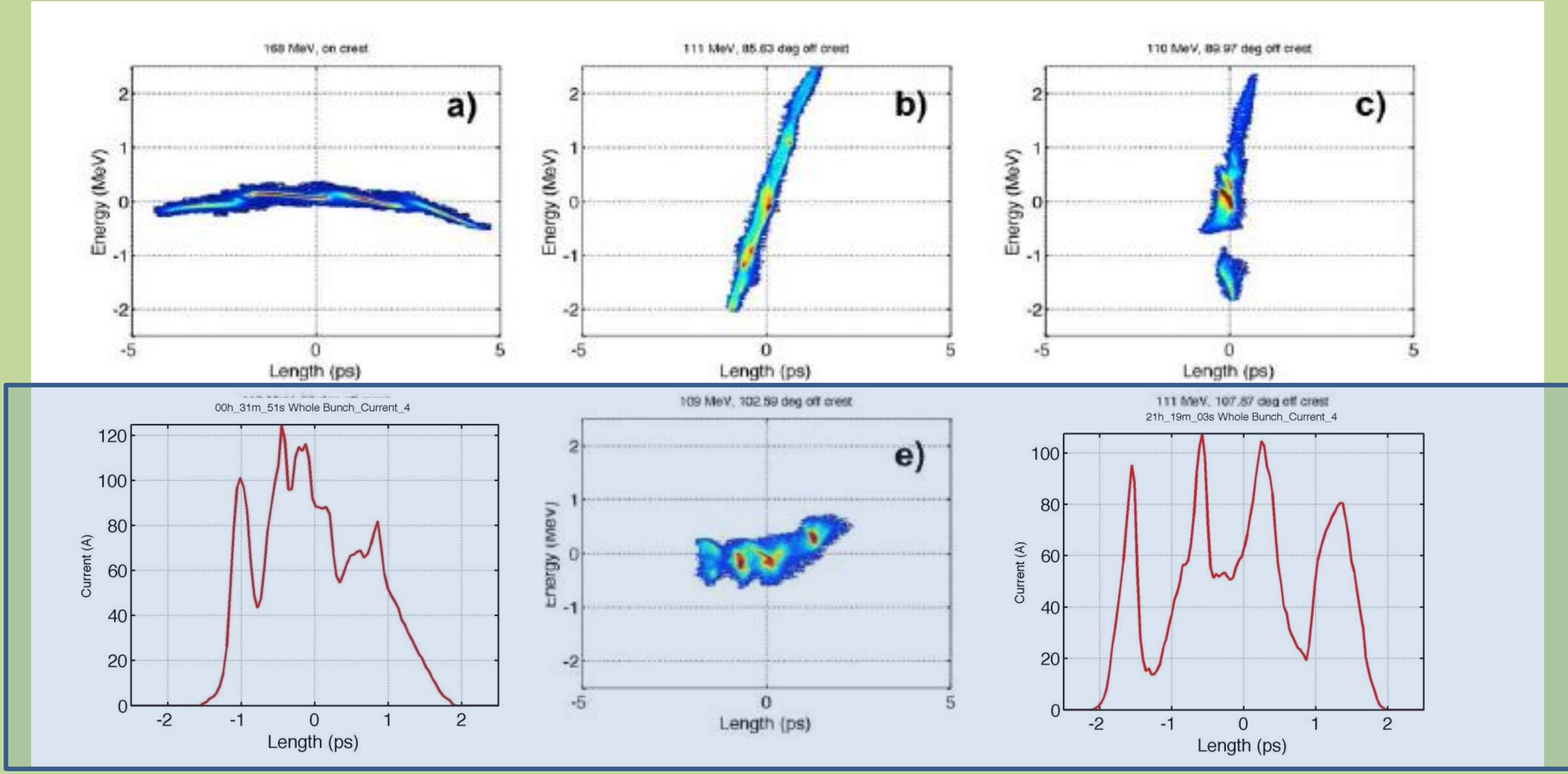

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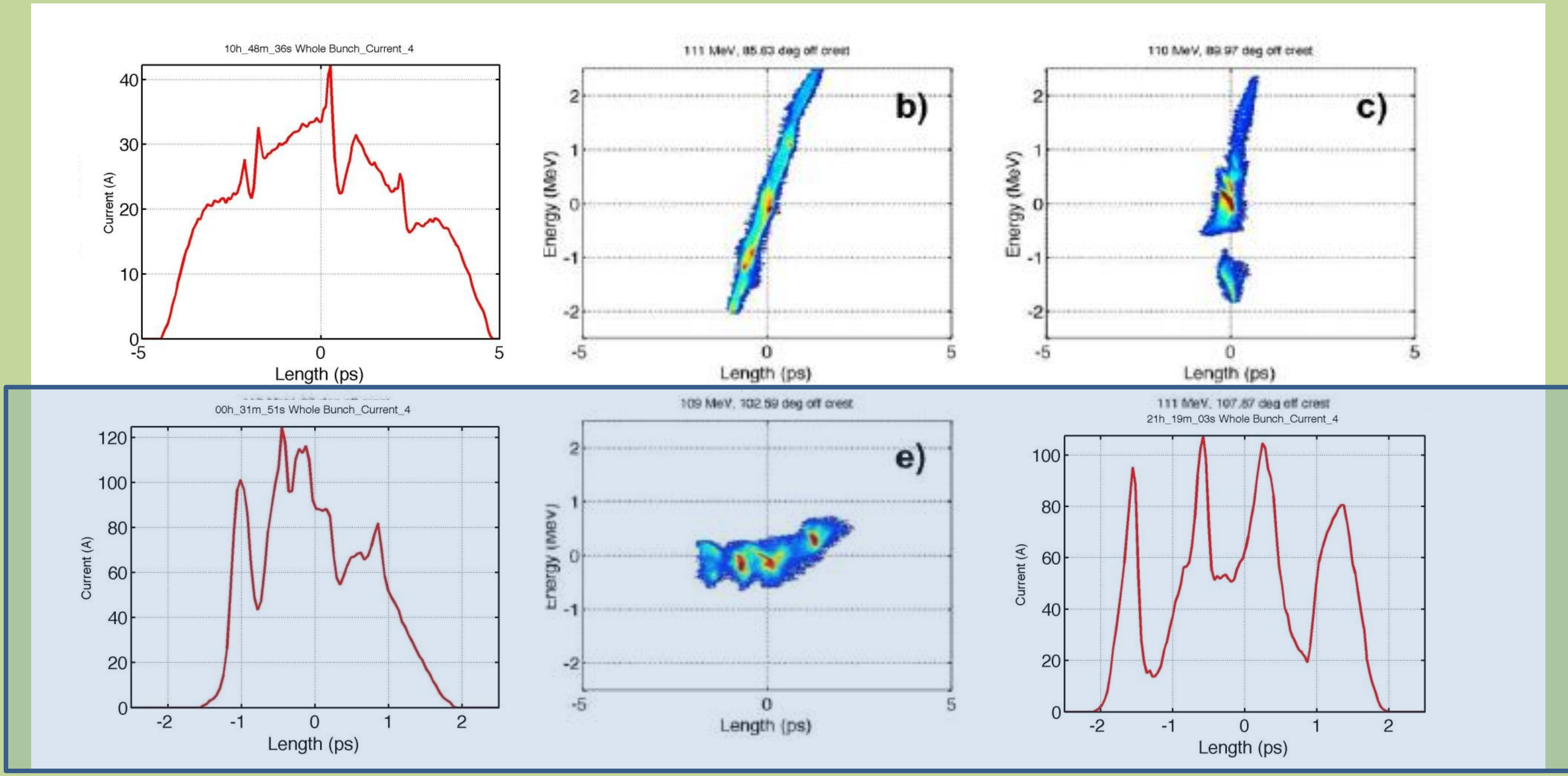

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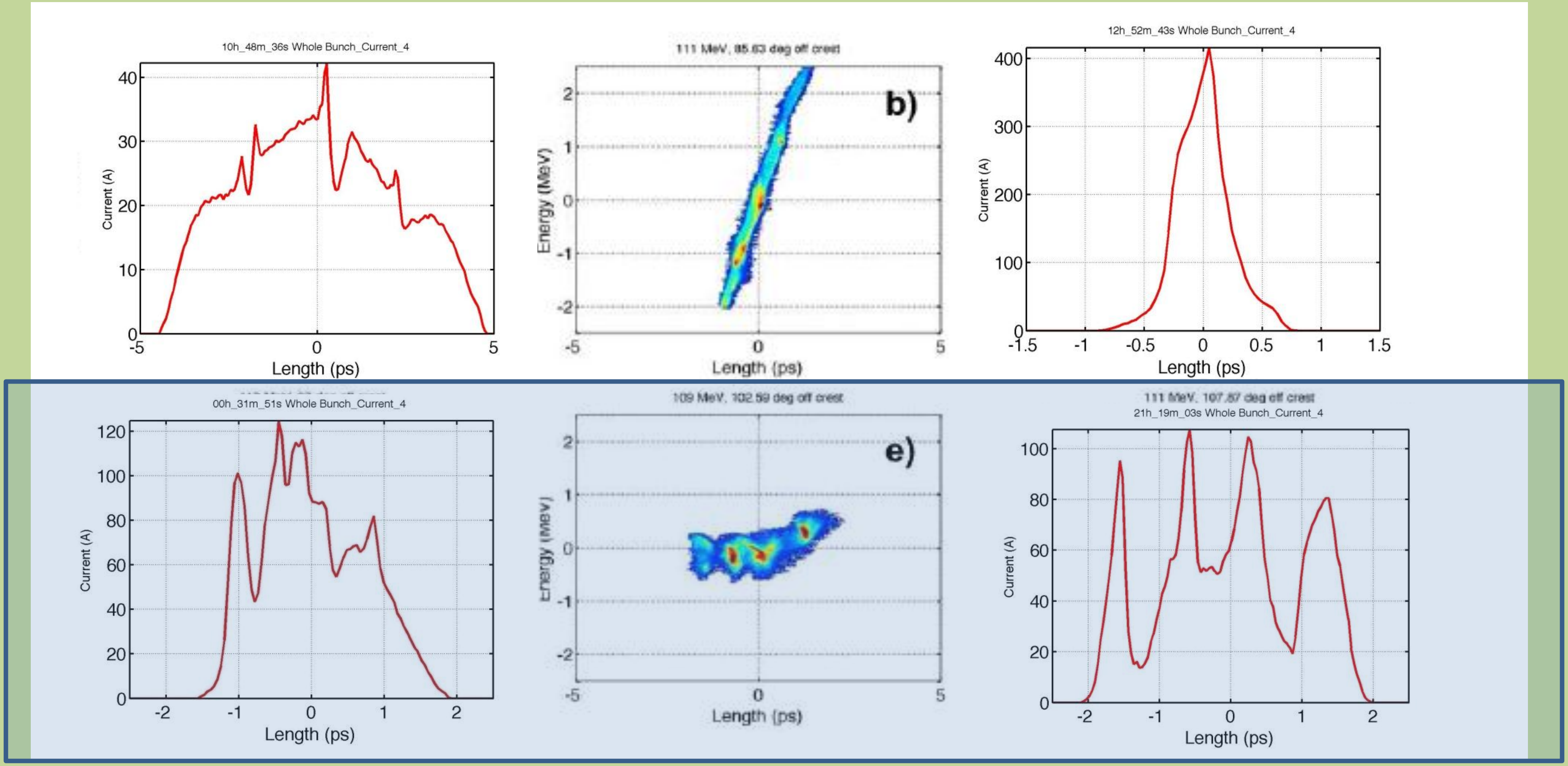

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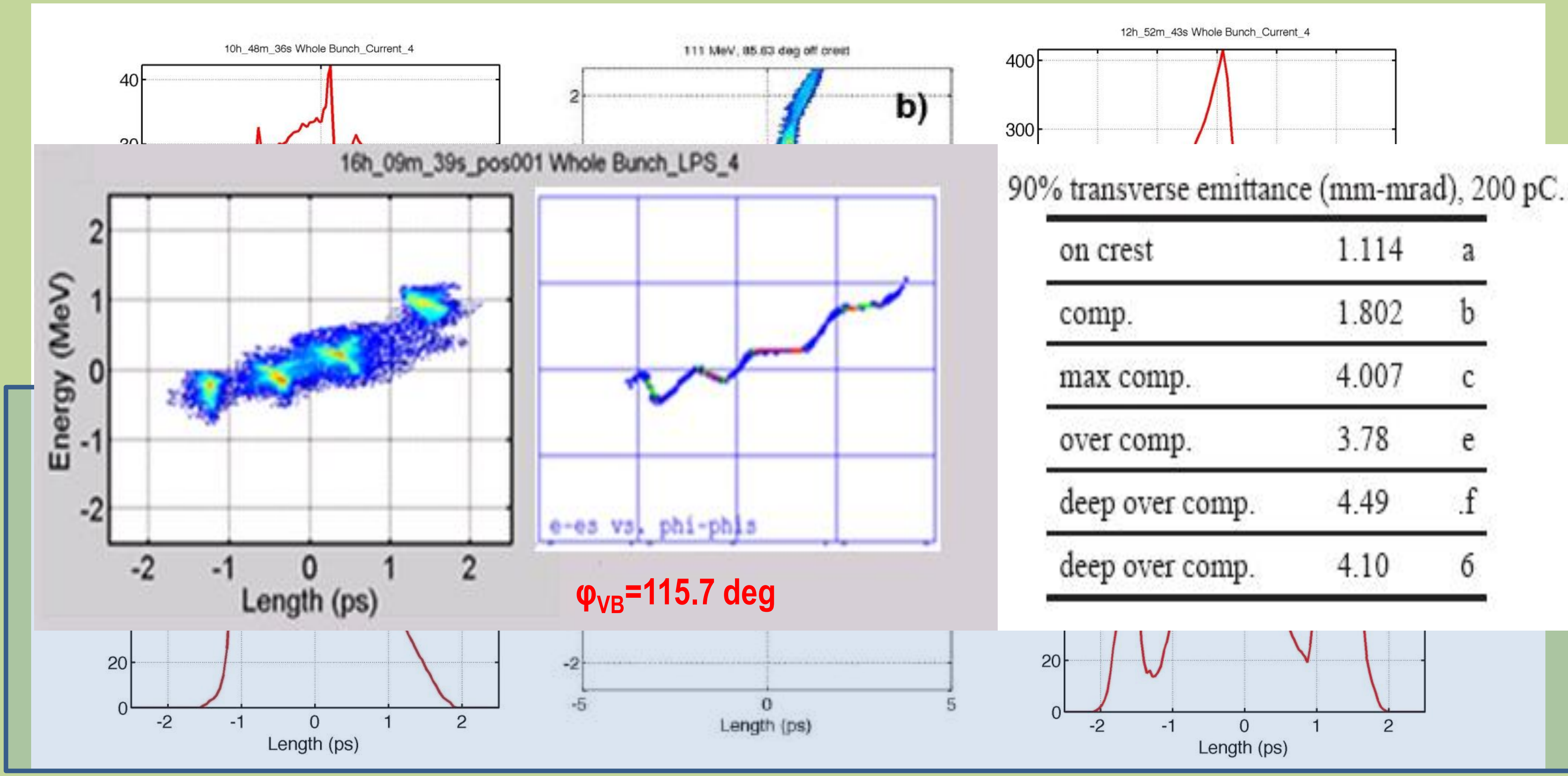
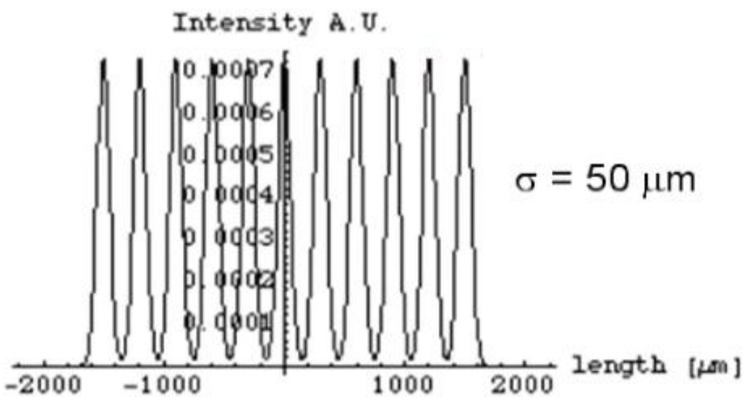


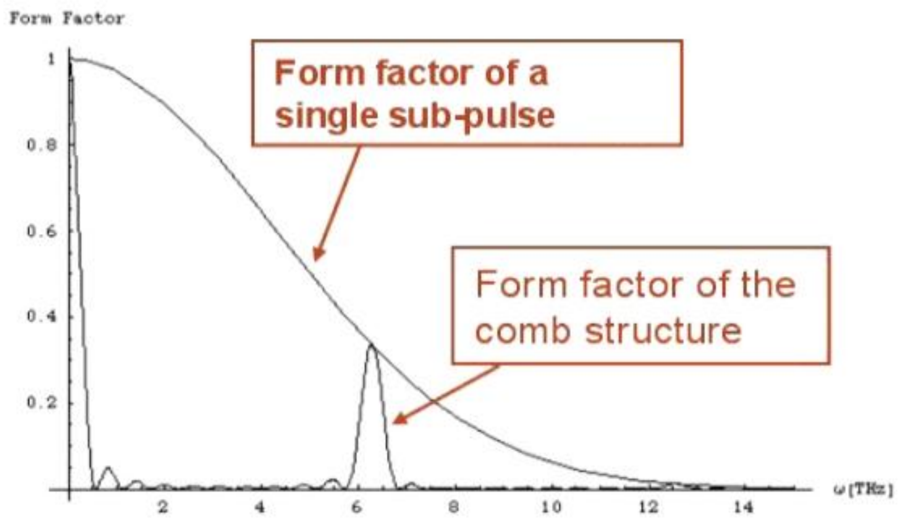
90% transverse emittance (mm-mrad), 200 pC.

on crest	1.114	a
comp.	1.802	b
max comp.	4.007	c
over comp.	3.78	e
deep over comp.	4.49	f
deep over comp.	4.10	6

Over-compression region: **The sub-bunches are well separated; their distance can be controlled by VB phase injection**

The SPARC THz source – narrow band





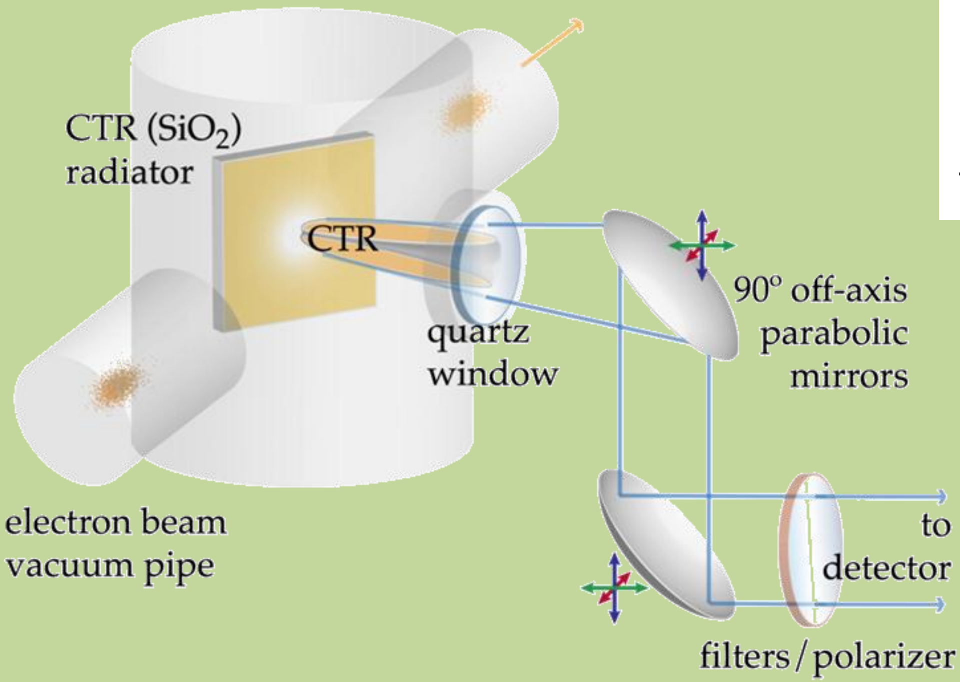
THz radiation can be easily produced by means of CTR

It is difficult to put high charge in sub-ps bunches

A laser comb structure in the longitudinal laser profile can solve this problem

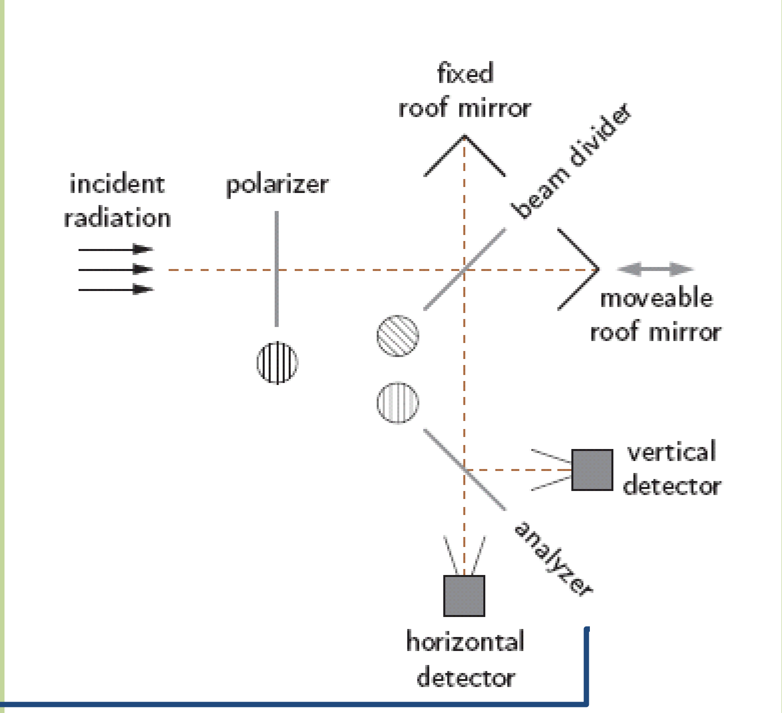
The SPARC THz source

Silicon Aluminated screen (40 nm coating)



Martin-Puplet interferometer

- Operating spectral range: 100 GHz-5 THz
- It allows to reconstruct the beam profile
- First test with pyroelectric detector; foreseen Golay cell or bolometers



CTR spectrum ← by Fourier trasforming ← Interferogram

The SPARC THz source

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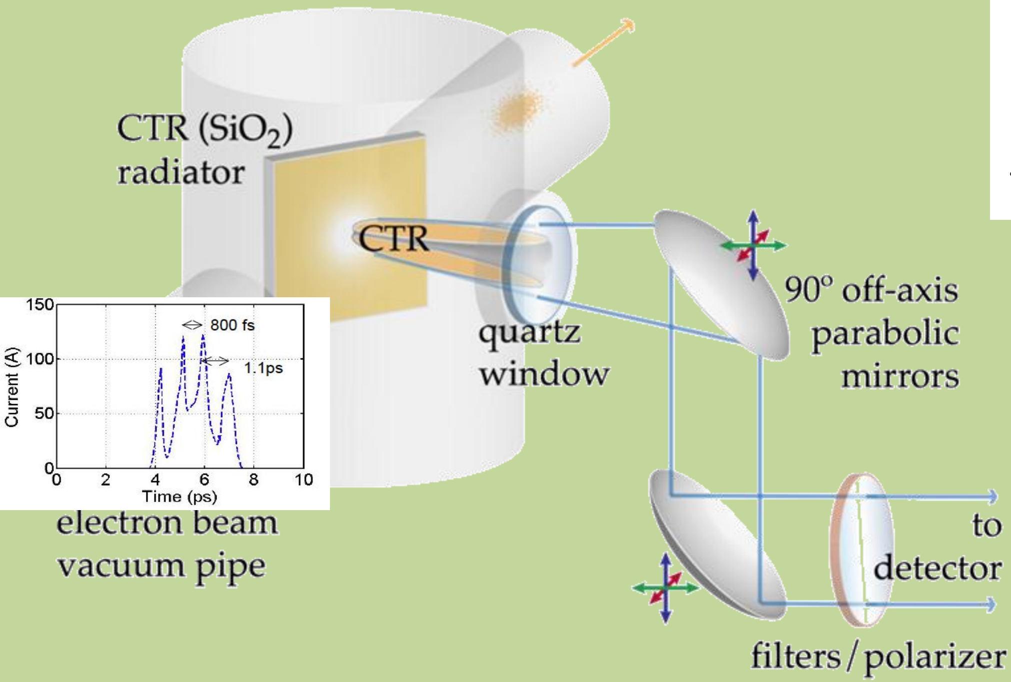

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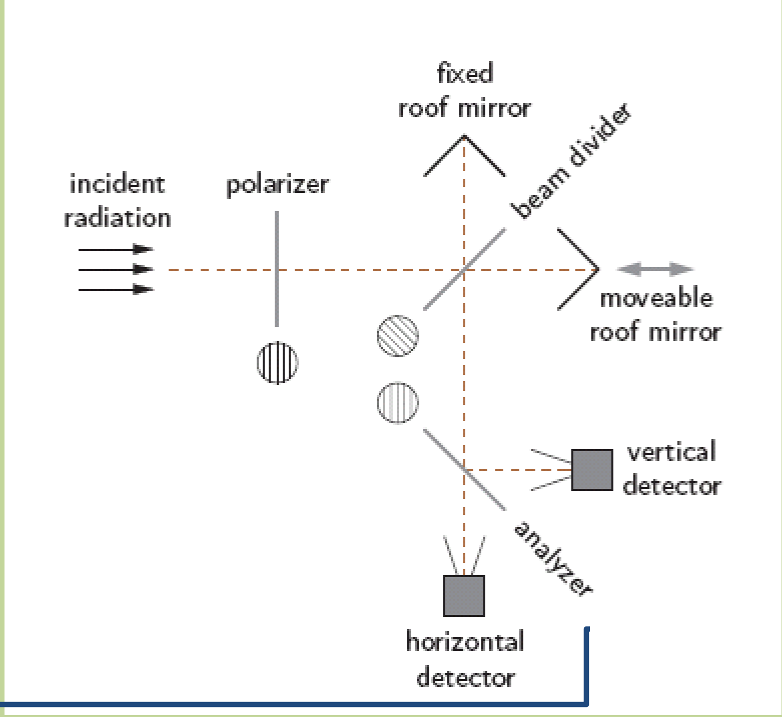
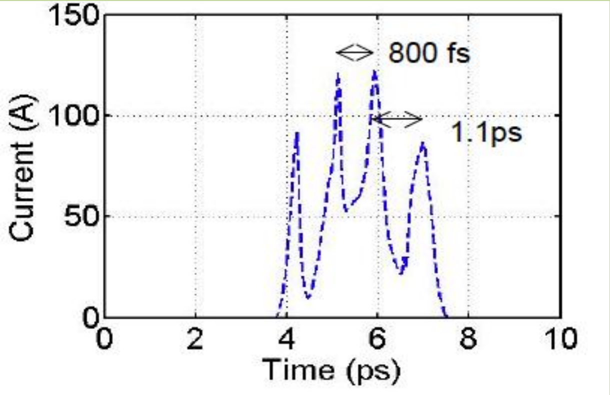


Interferogram → by Fourier trasforming → CTR spectrum

Narrow THz radiation measured

Interferogram for bunches train show 2N-1 peaks (inter-distance = sub-bunches distance)

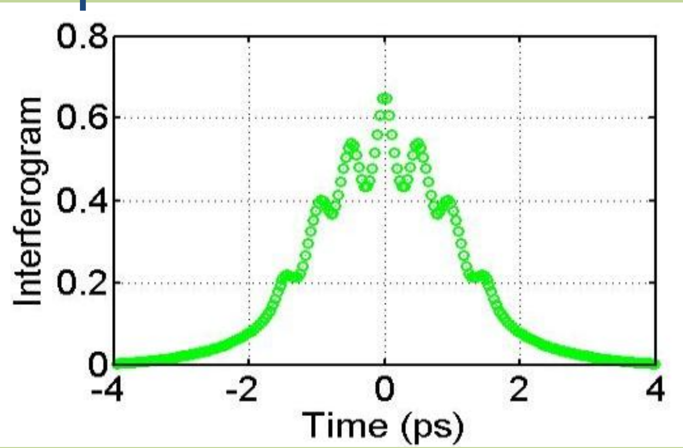
→ Radiation spectrum is strongly suppressed outside the comb rep. ferquency

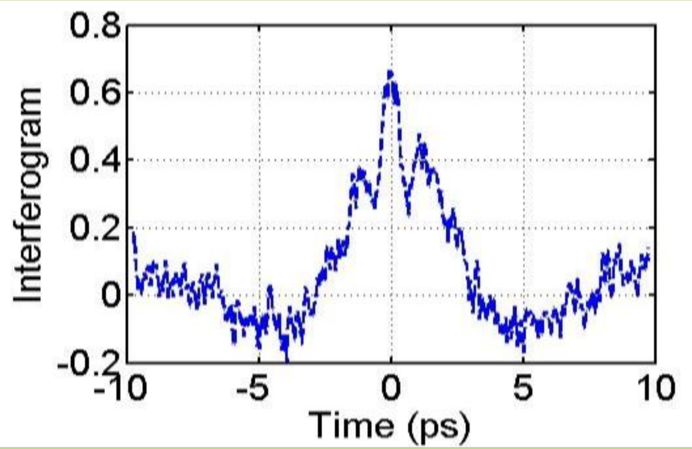


Expected

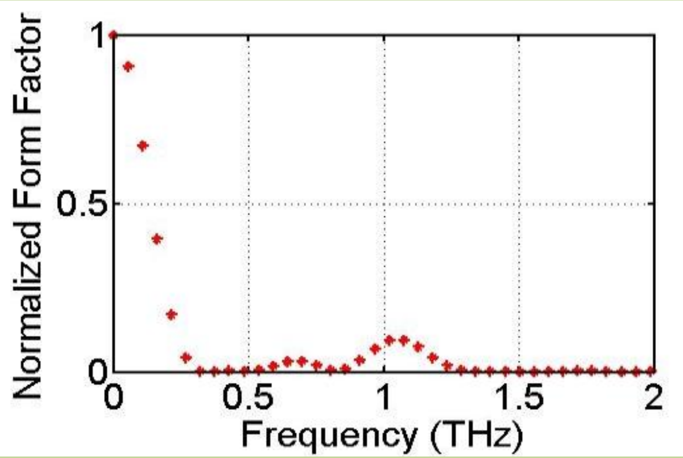
Measured

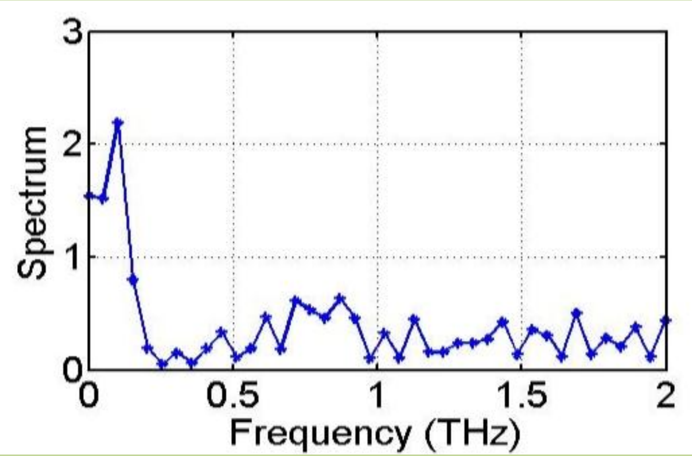
Interferogram





Spectrum





Conclusion

- The SPARC linac has improved the machine stability and the gun gradient

- We have demonstrated, from experimental point of view, that one can control pulse spacing, length, current and energy separation by properly setting the accelerator.

- A very good agreement with simulations


Thanks for your attention