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Longitudinal Dynamics in the ALICE Injection Line

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Alice
Accelerators and Lasers In Combined Experiments

ERL 2011 Workshop
KEK, Tsukuba, Japan
20 October 2011

ASTeC

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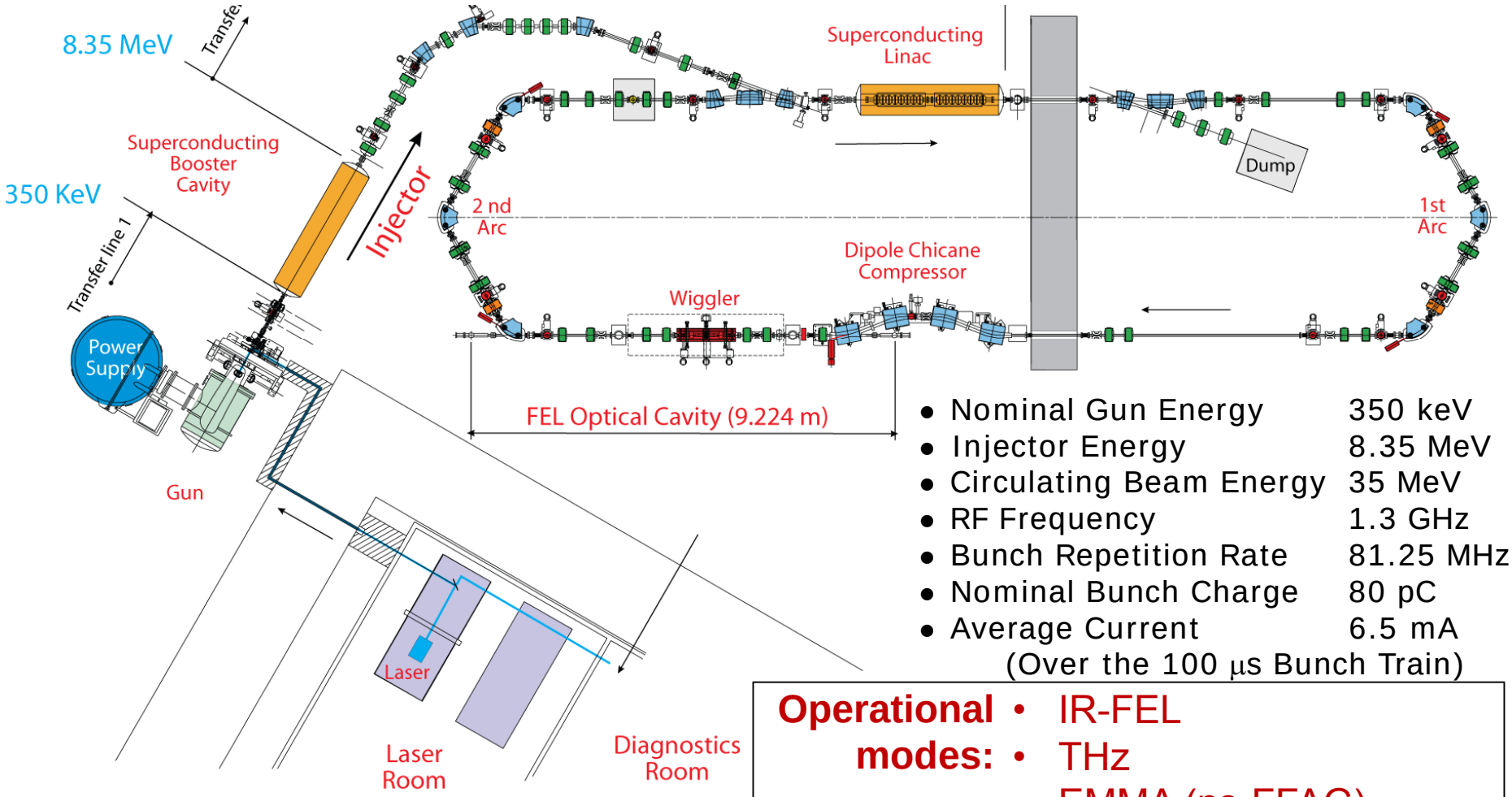
ALICE Overview



- Nominal Gun Energy 350 keV
- Injector Energy 8.35 MeV
- Circulating Beam Energy 35 MeV
- RF Frequency 1.3 GHz
- Bunch Repetition Rate 81.25 MHz
- Nominal Bunch Charge 80 pC
- Average Current 6.5 mA
  (Over the 100 μs Bunch Train)

Operational modes:

- IR-FEL
- THz
- EMMA (ns-FFAG)
- Compton back-scattering
- Many more…

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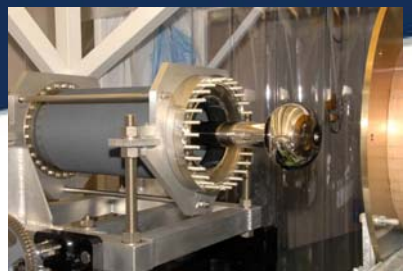
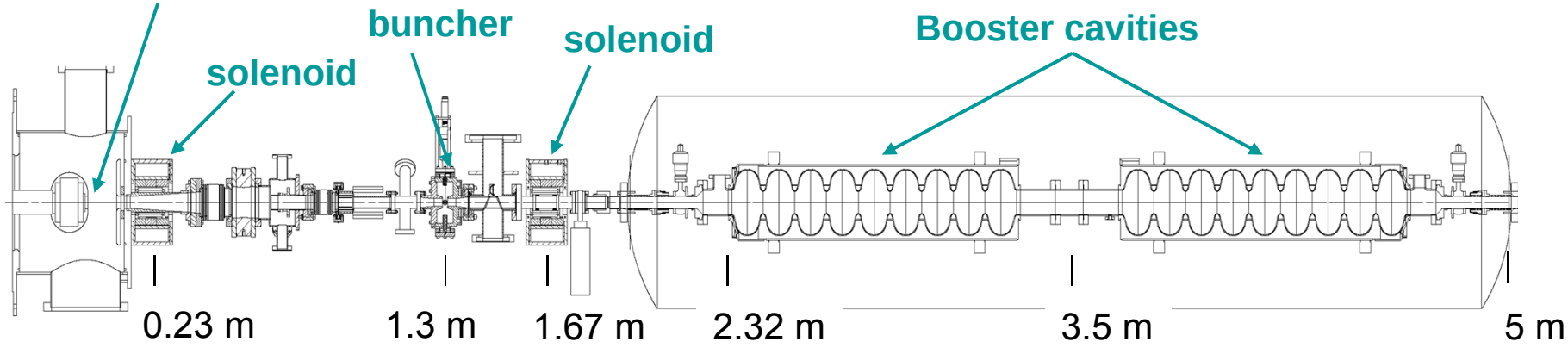
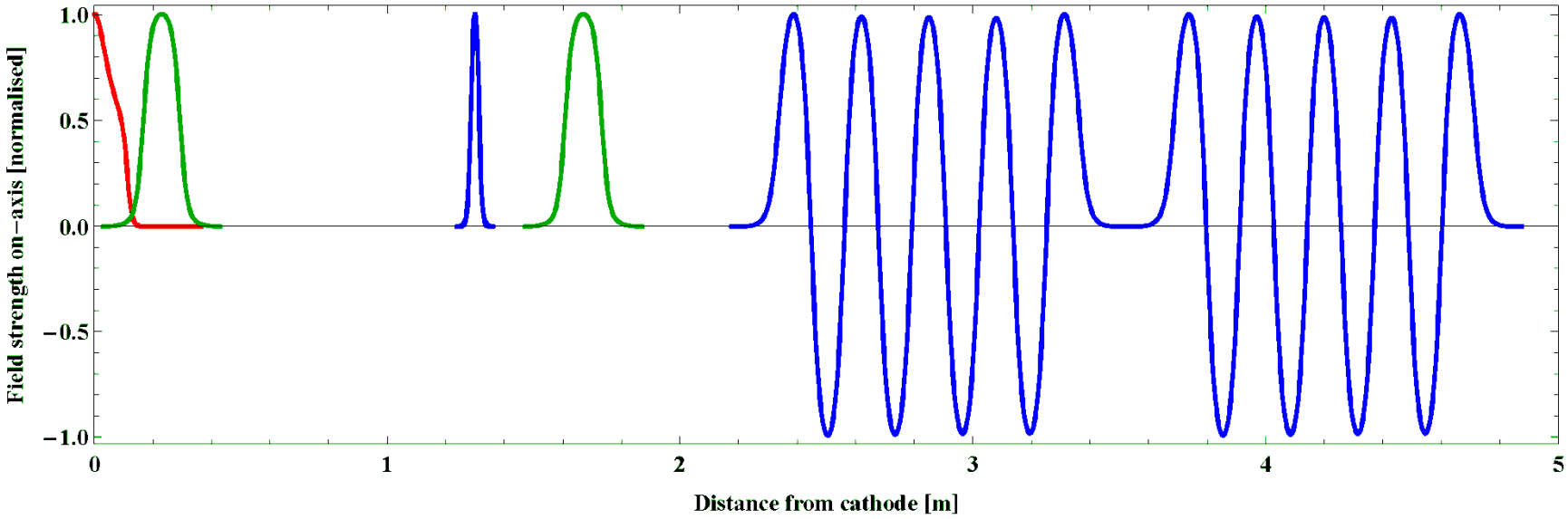
Injector Layout



DC electron gun
JLab FEL
GaAs photocathodes





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ALICE Injection Line

- ~10m between booster and linac
- Layout restricted by building
- Only 1 screen after 3 dipoles and 6 quads...

Operational parameters

Parameter	Design	Operating	Units
Bunch charge	80	20 - 80	pC
Gun energy	350	230	kV
Booster energy	8.35	6.5	MeV
Linac energy	35	27.5	MeV
Repetition rate	81.25	16.25 - 81.25	MHz

- Gun voltage limited by ceramic – replacing in winter shutdown.
- Linac energy and bunch repetition rate is limited by beam loading, replacing cryomodule with new DICC module in winter shutdown

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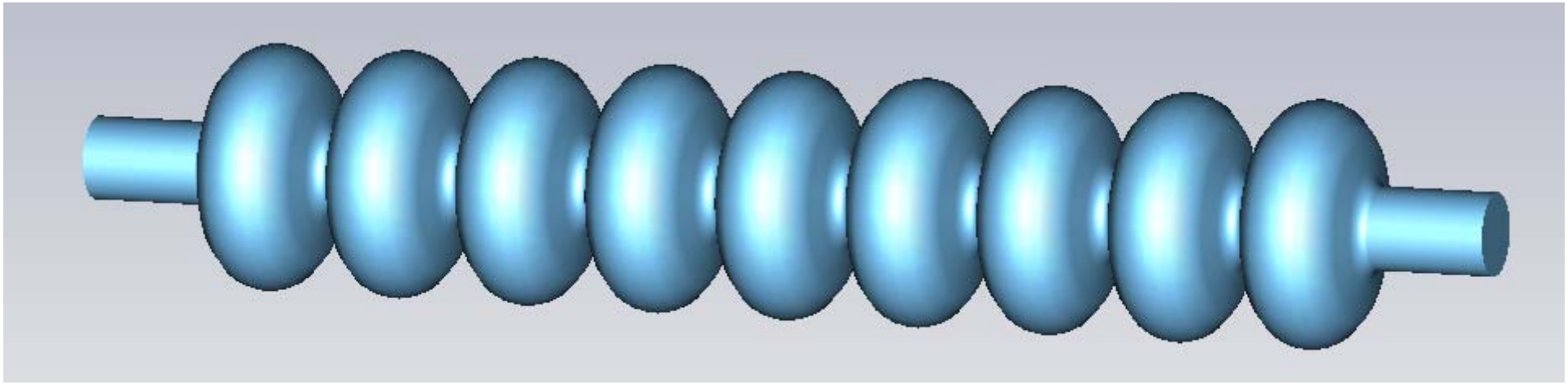
Booster issues



- Booster cryomodule consists of two 9-cell TESLA type cavities
- Each ~ 1 m long and designed for electrons with β=1
- We inject at 230 keV and accelerate to 4 MeV in first cavity
- Therefore phase beam sees in each cell is completely different
- Beginning of BC1 completely dominates dynamics

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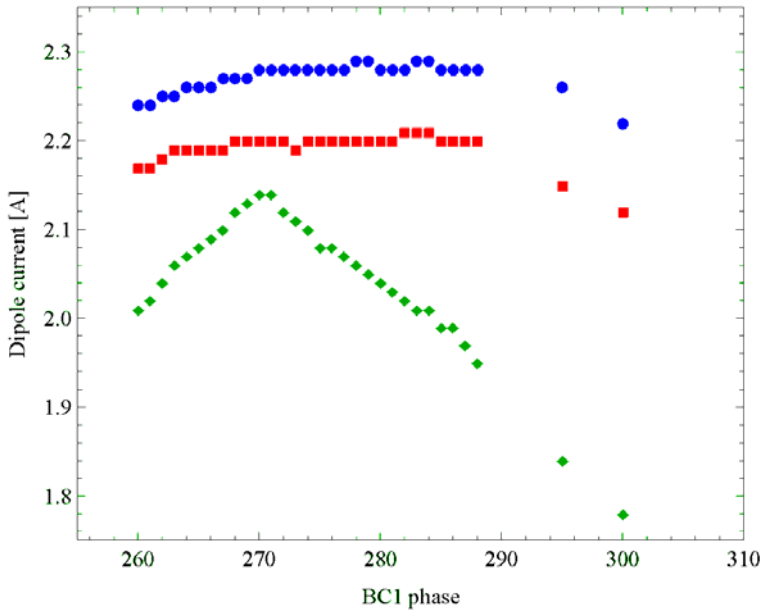
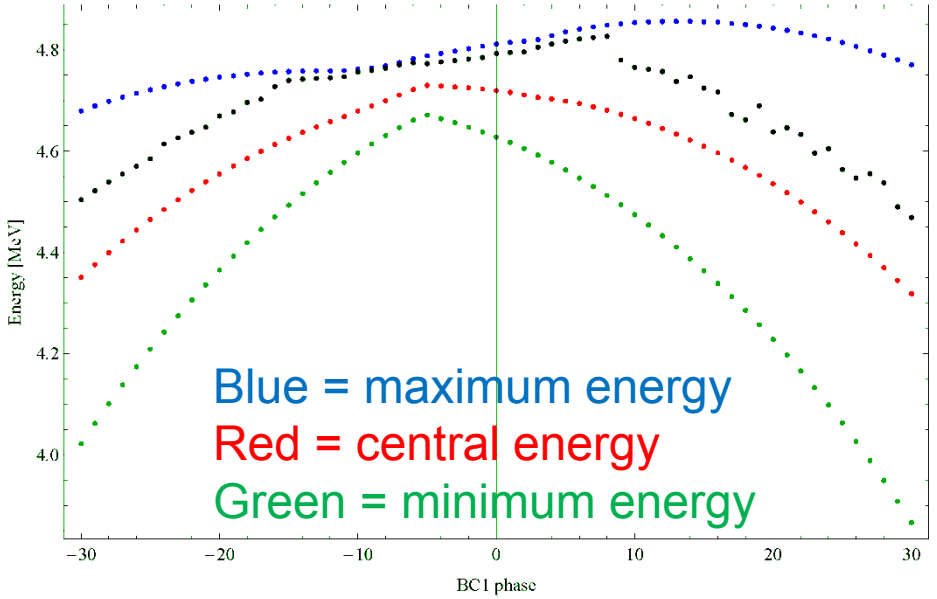
BC1 cresting issues

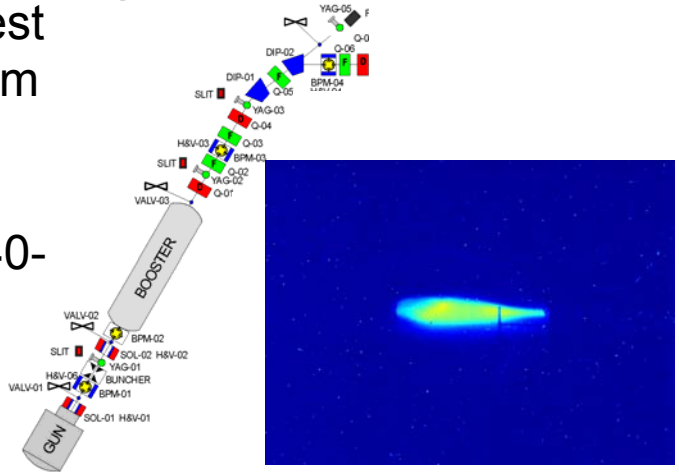
Experimental data

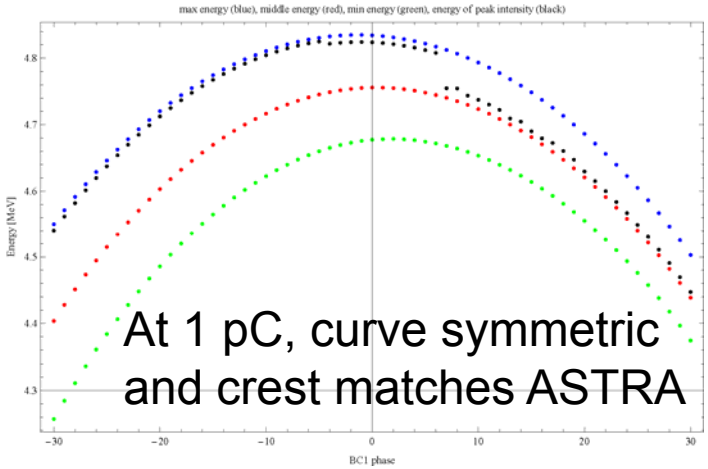


ASTRA simulation



- Measure BC1 crest by observing beam after first dipole
- At operational bunch charges (40-80pC), beam can be very large on screen





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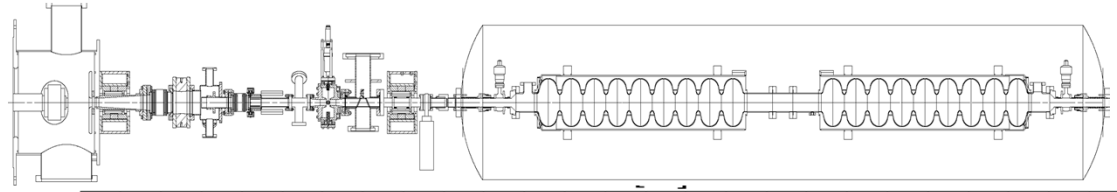
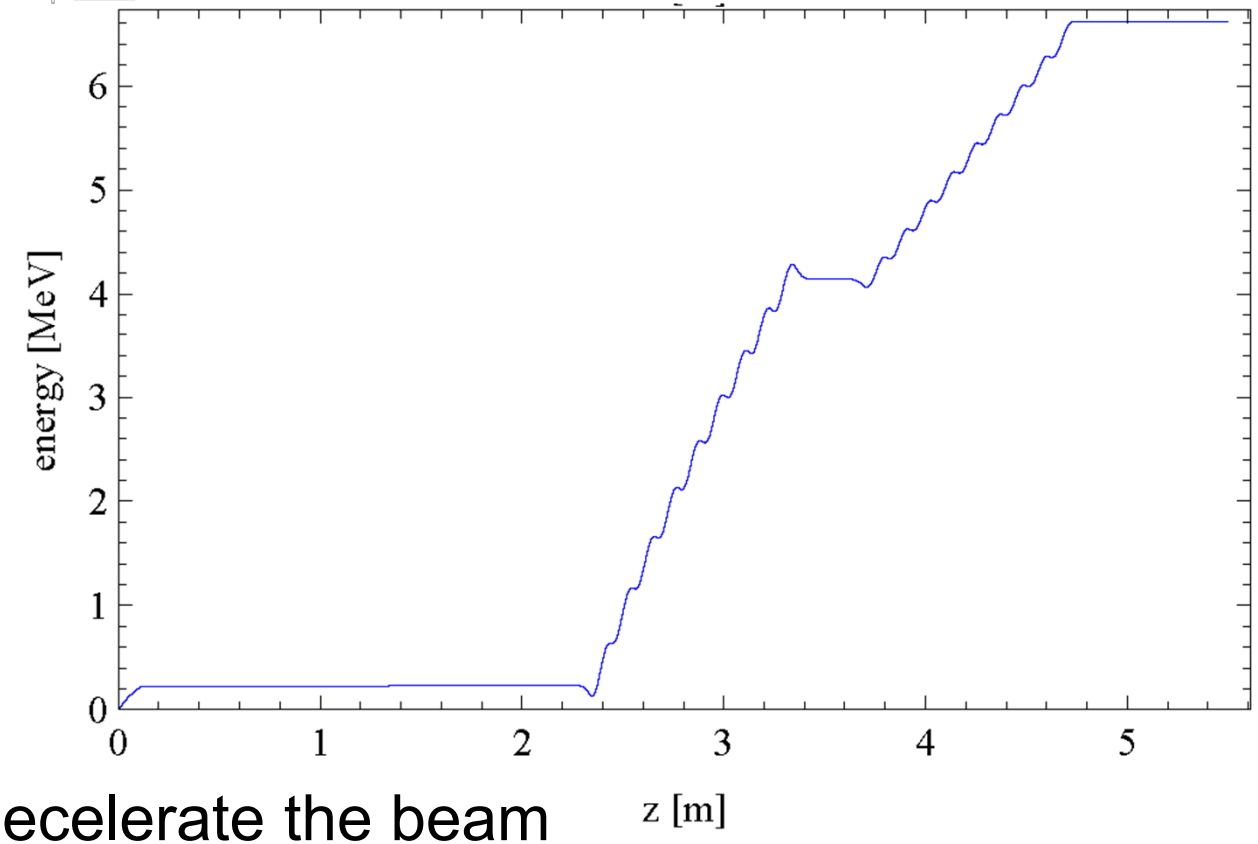
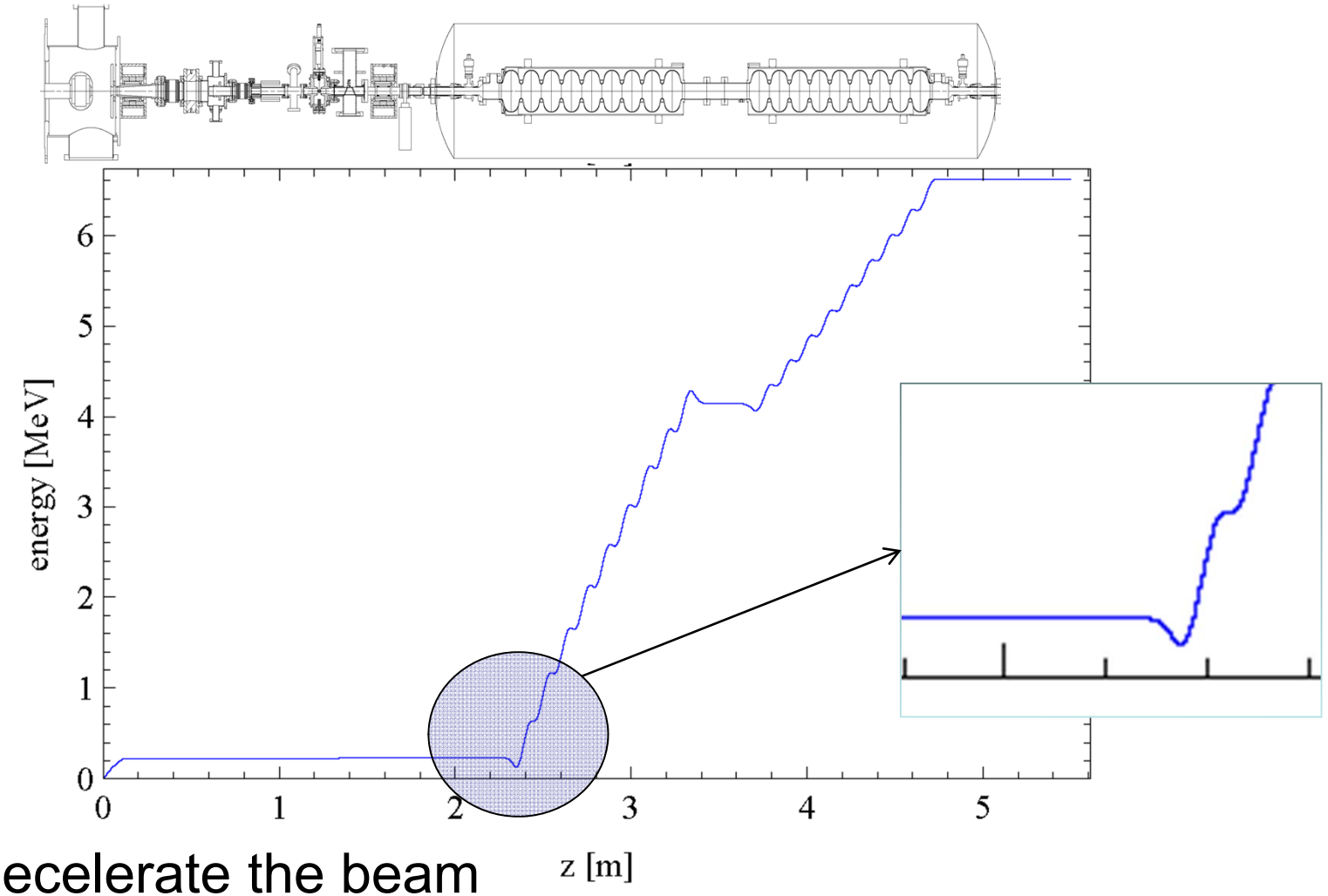
Energy





Almost decelerate the beam completely at start of BC1

Energy



Almost decelerate the beam completely at start of BC1

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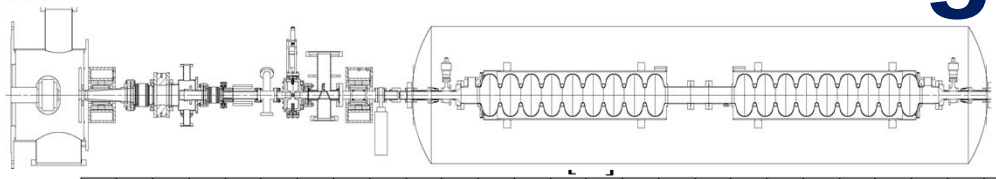
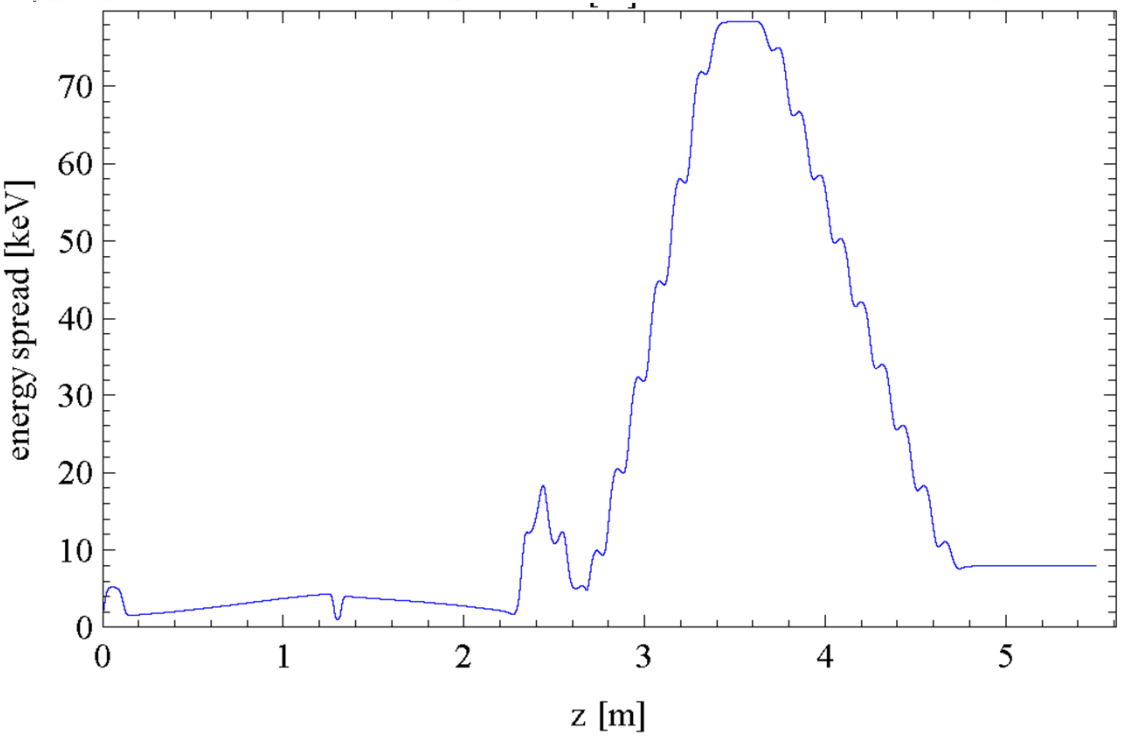
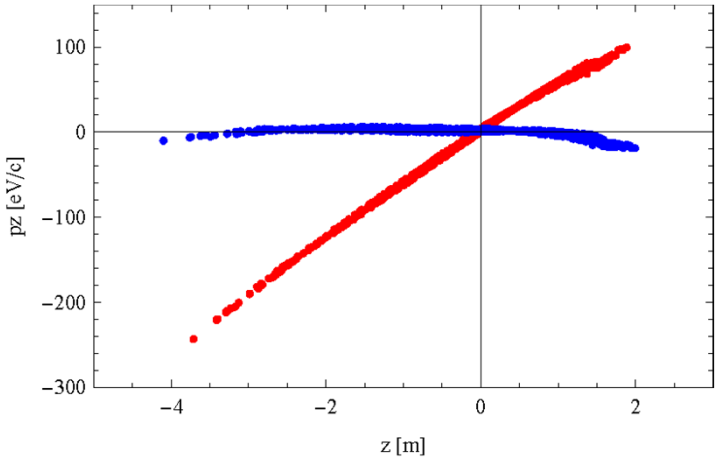
Energy spread







Red = after BC1
Blue = after BC2

BC2 phase used to compensate energy spread from first cavity by rotating the chirp in longitudinal phase space

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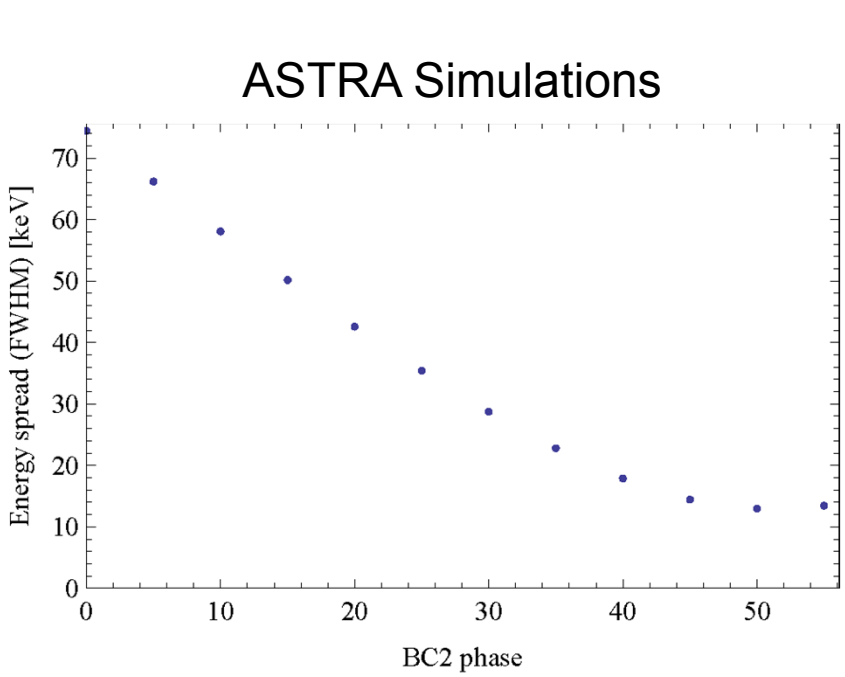
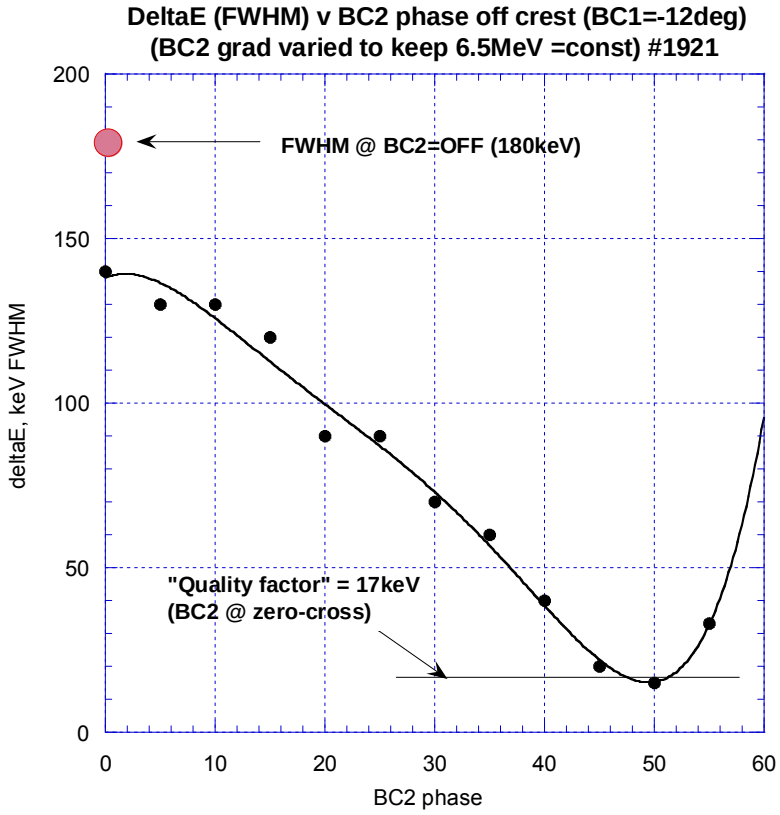
Energy spread measurements





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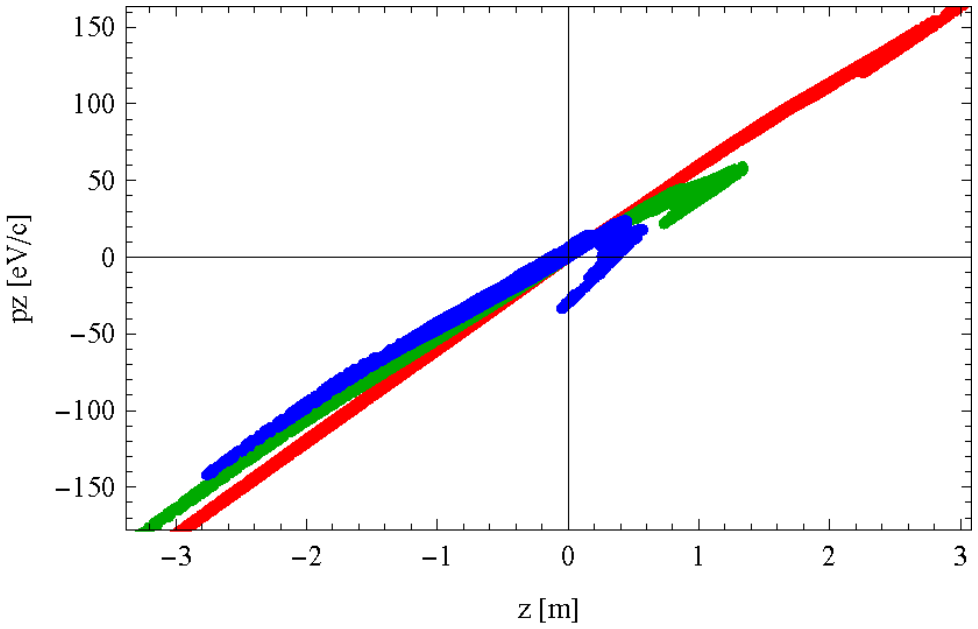
Longitudinal phase space



BC1 Phase:

Red = -20°
Green = -10°
Blue = -5°

“Hooks” and other features can easily develop

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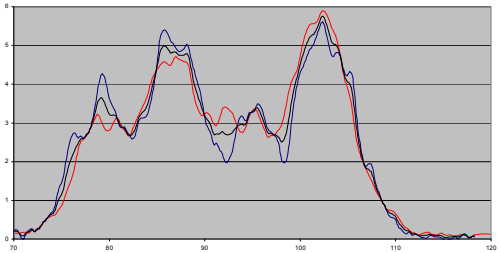
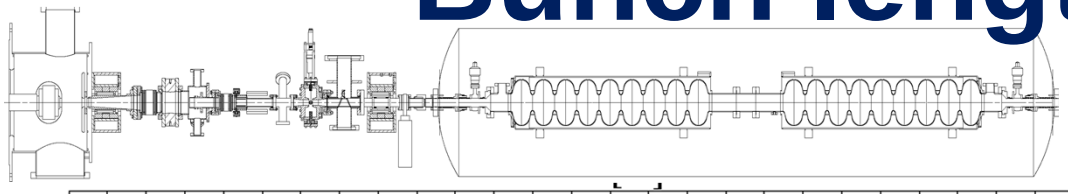
Bunch length

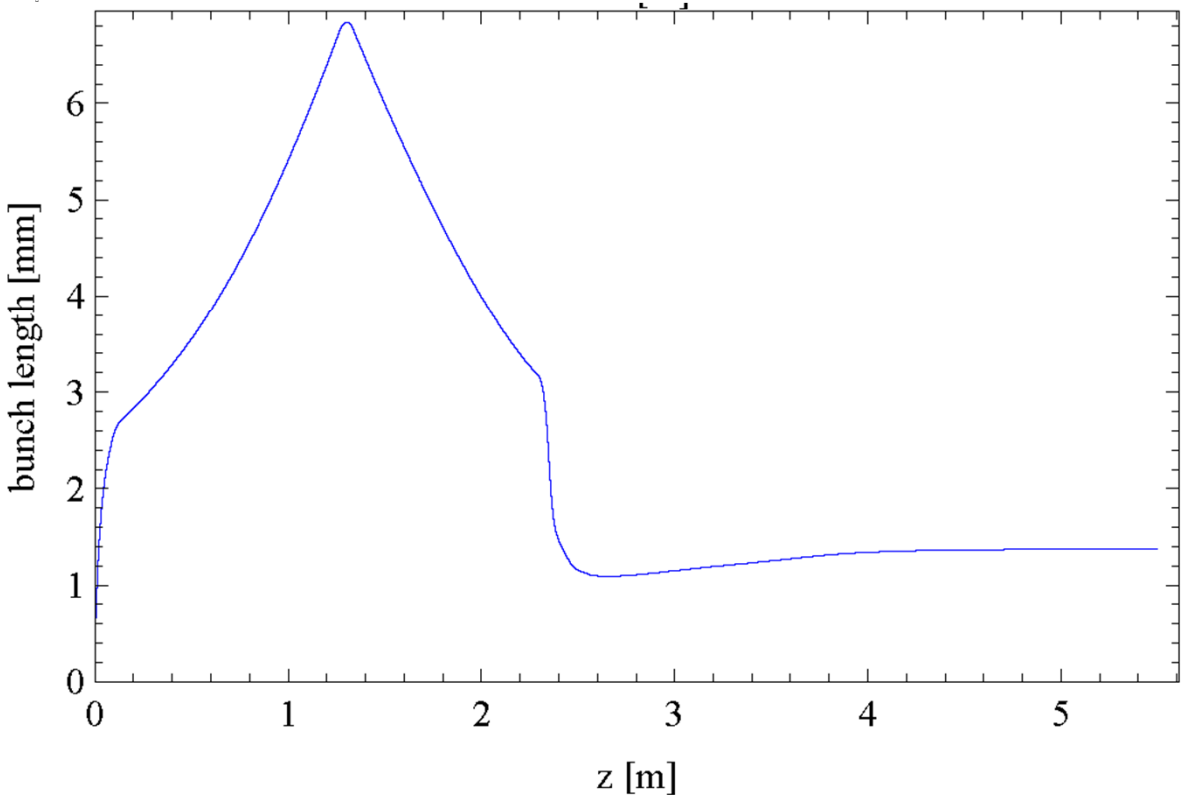
~27 ps laser pulse formed by stacking 7ps Gaussian pulses

Doesn't provide ideal flat-top



Laser temporal profile in 2008





- Bunch length expands after gun due to space charge.
- Buncher cavity only reduces bunch length down to same level as initial
- Further compression occurs in BC1

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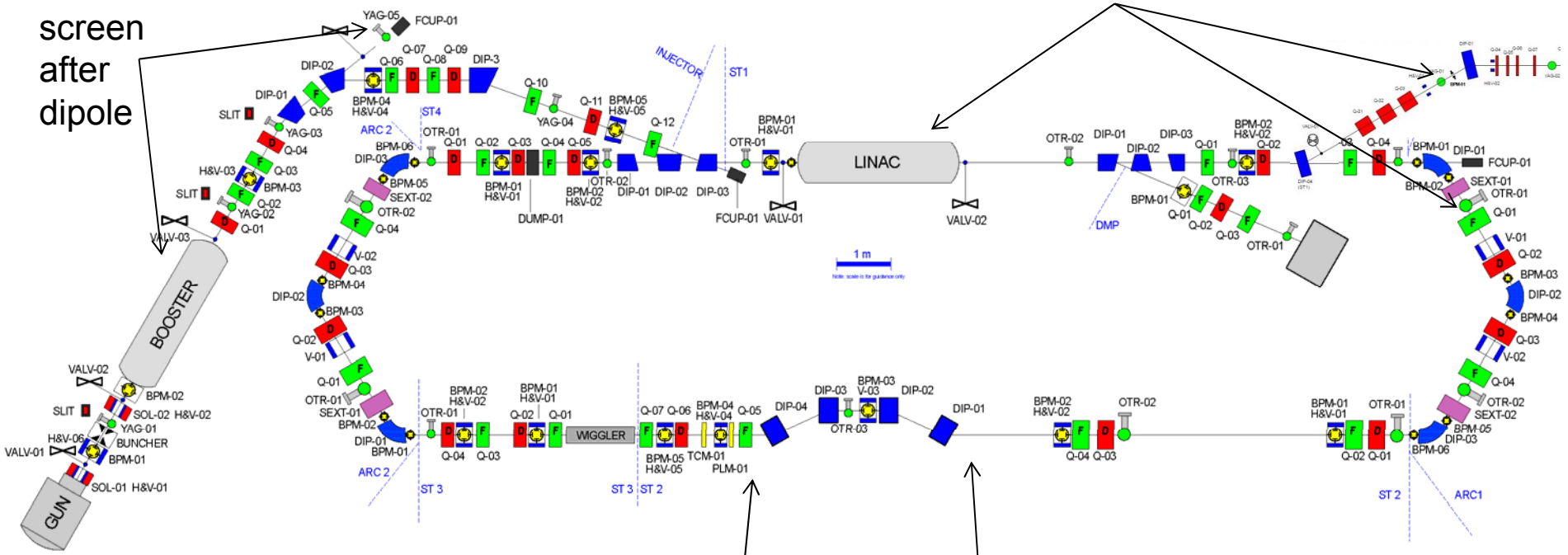
Bunch length measurements

Use BC2 and screen after dipole

Use LC2 and screens after dipoles



Electro-optic

Streak camera

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Zero-crossing method:

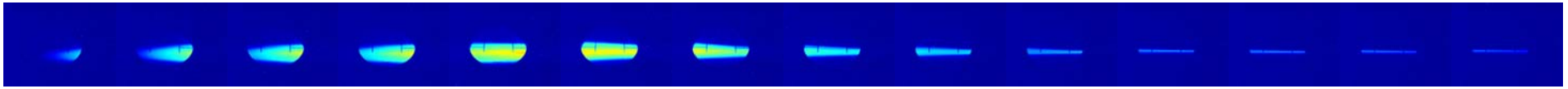
- Use second cavity in cryomodule at zero-cross phase to give energy chirp
- View energy spread as transverse spread after dipole
- Take images at both zero-crosses

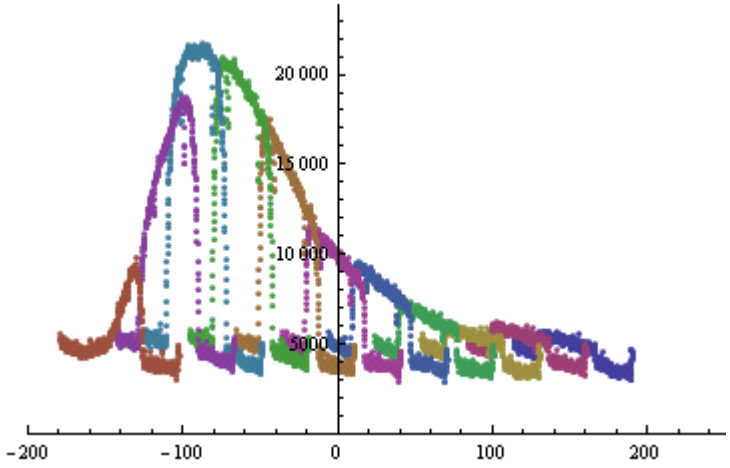
$$\sigma_z(@\,\text{entrance to zero crossing cavity}) = \frac{\sigma_x^+(\text{screen}) + \sigma_x^-(\text{screen})}{2C_2}$$

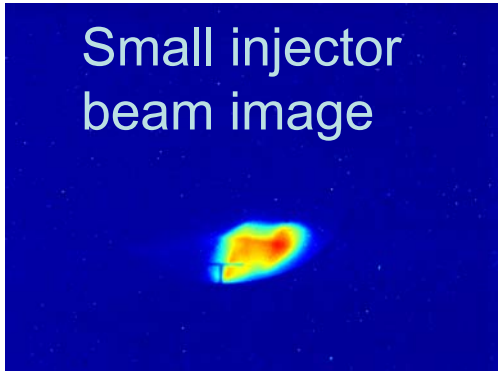
$$\text{where } C_2 = \frac{2\pi D}{\lambda}\frac{E_2}{E_1} \qquad \text{or} = \frac{\sigma_x^+(\text{screen}) - \sigma_x^-(\text{screen})}{2C_2}$$

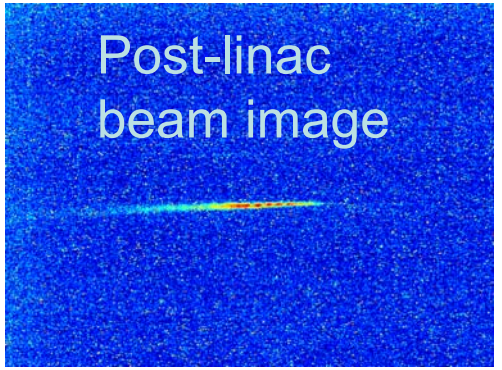
Problems:

- Minimising beta for each image
- Jitter
- Non-Gaussian beams
- Background noise (post-linac only)
- Reconstructing transverse beam profile from numerous screen images stitched together









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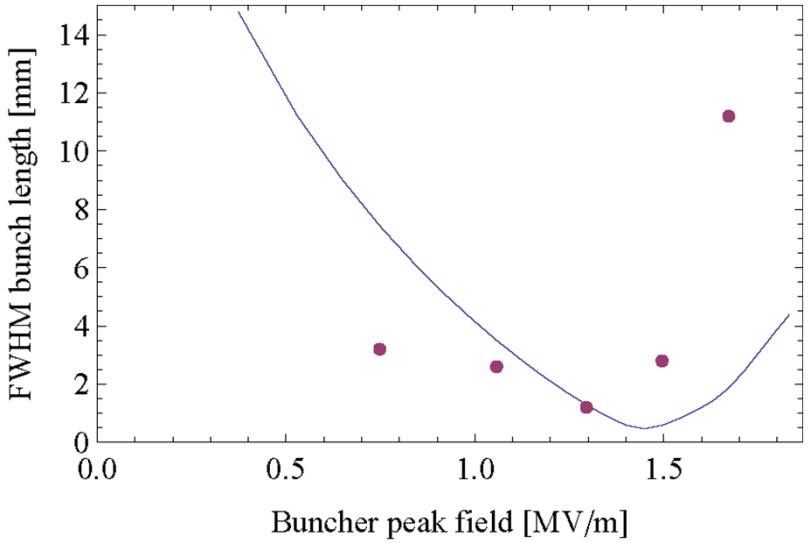
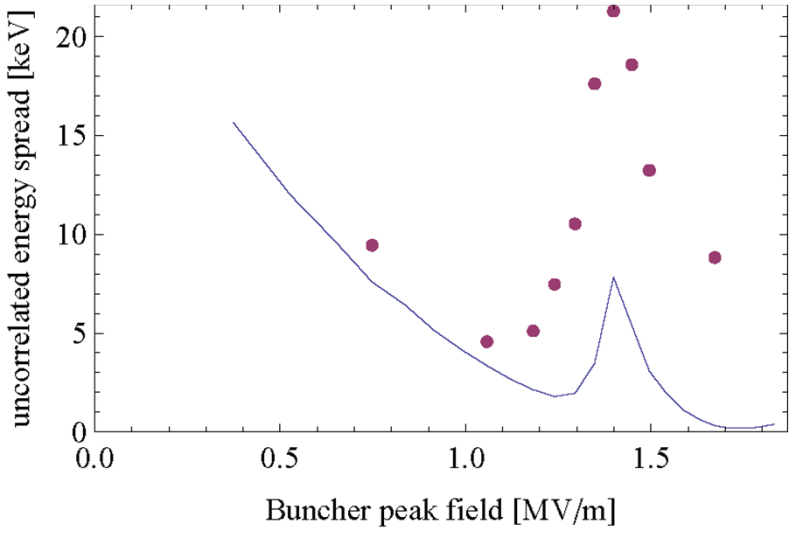
Buncher power scans



Lines = simulation
Dots = measurements

BC1 set to -10
Bunch charge 40pC



Uncorrelated energy spread found by operating BC2 at zero-cross to minimise energy spread by compensating for the chirp.

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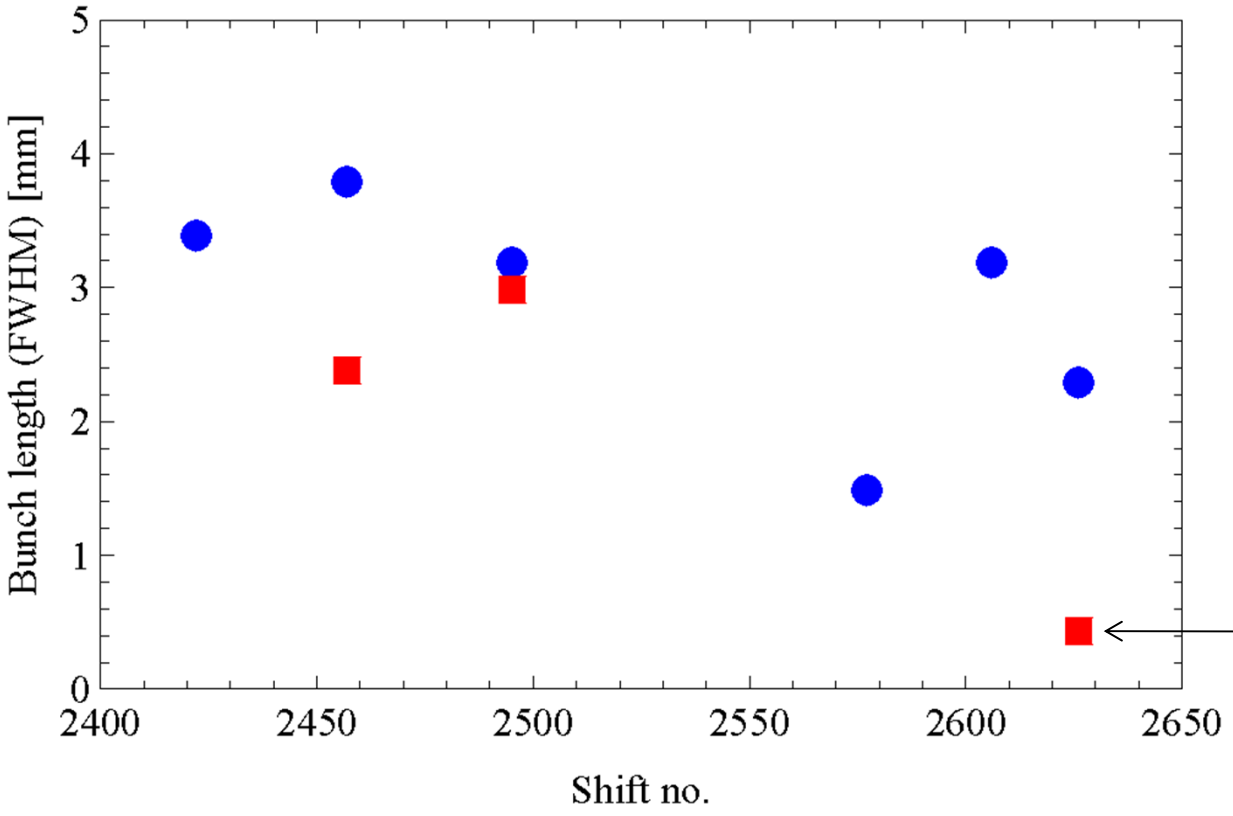
Measurement repeatability:



Blue = booster
Red = linac

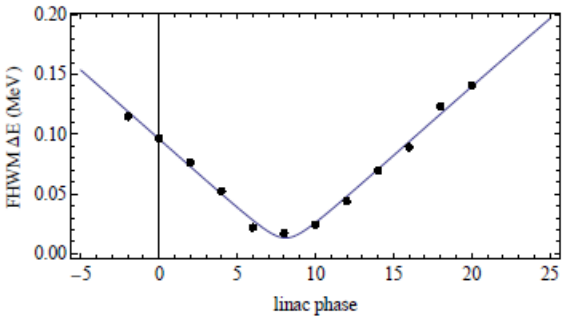
Same machine setup used for these measurements:

Buncher power 0.53kW
BC1 phase -20° with
4 MeV energy on-crest

Energy spread method:

$$\Delta E = \sqrt{\Delta E_0^2 + h^2 \Delta z^2}$$

chirp $h = E_L \frac{2\pi}{\lambda} \sin(\phi - \phi_0)$



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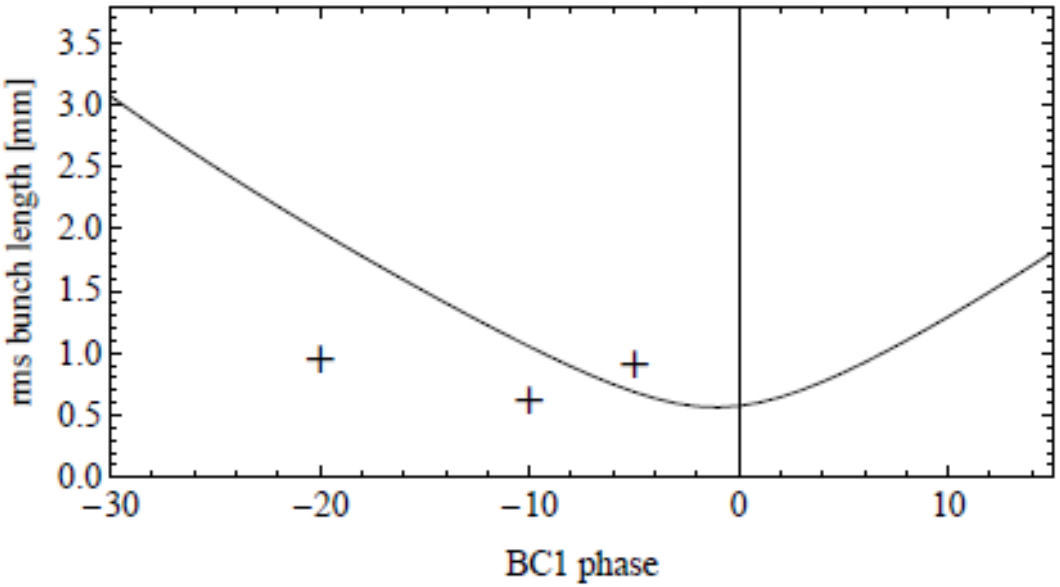
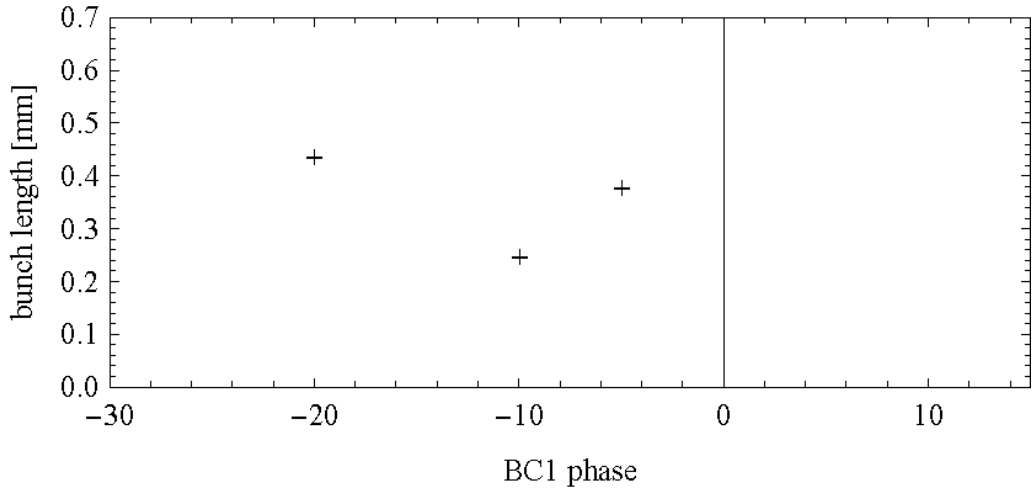
BC1 phase vs bunch length

Booster



Linac



Lines = simulation
Crosses = measurements

Buncher power = 0.53kW
Bunch charge 60pC

Bunch length consistently shorter at linac than booster

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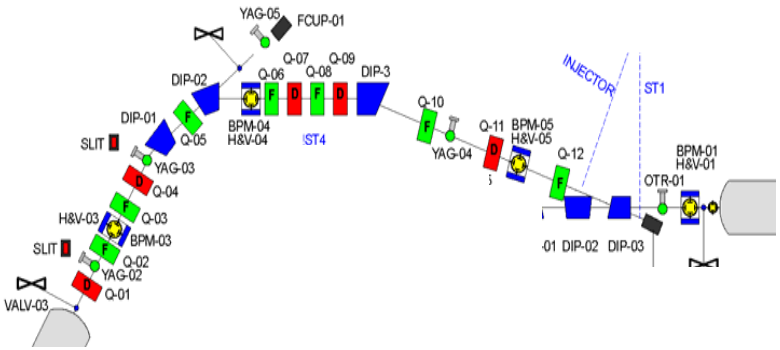
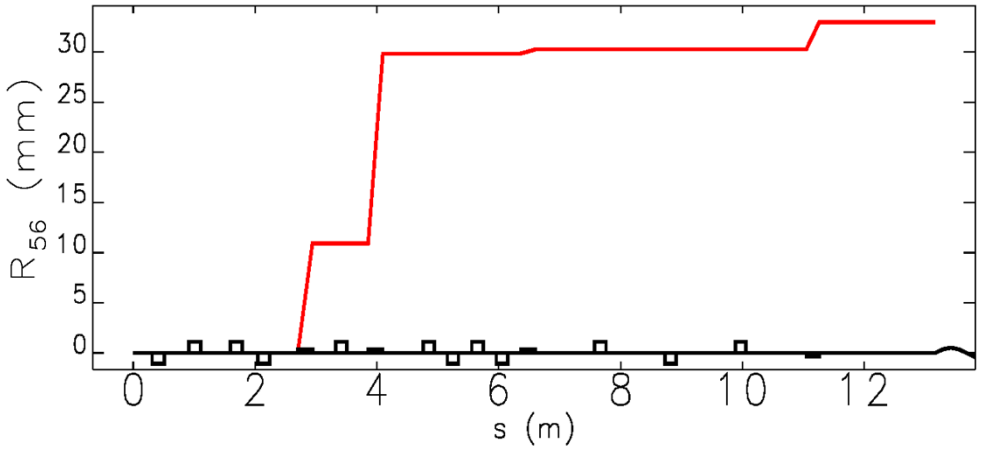
Compression in booster to linac transport line





- Total R56 of injection line ~30mm
- Very small compared to 28cm in chicane
- However, it is of the right sign to compress bunch if chirp not fully compensated by BC2

ELEGANT simulations can show compression but don't take into account all effects, space charge still important at 6 MeV

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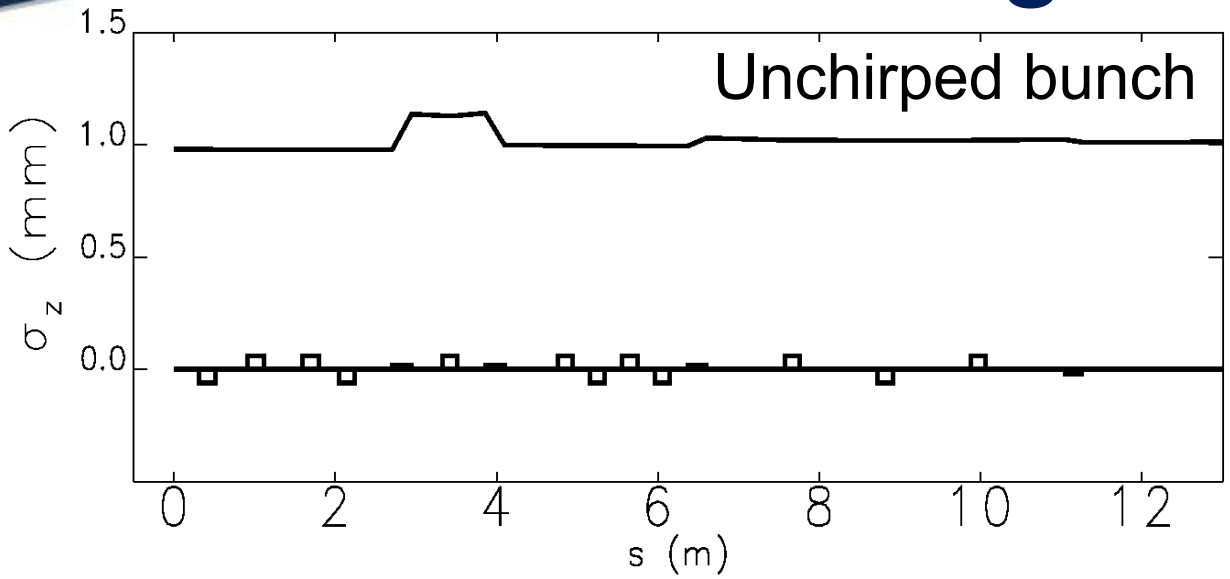
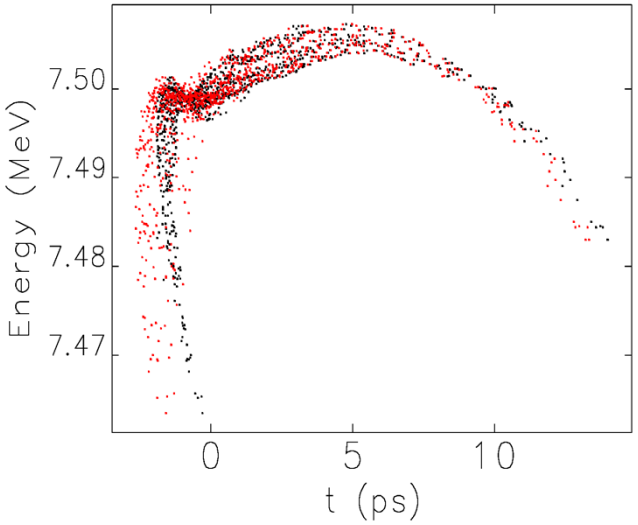
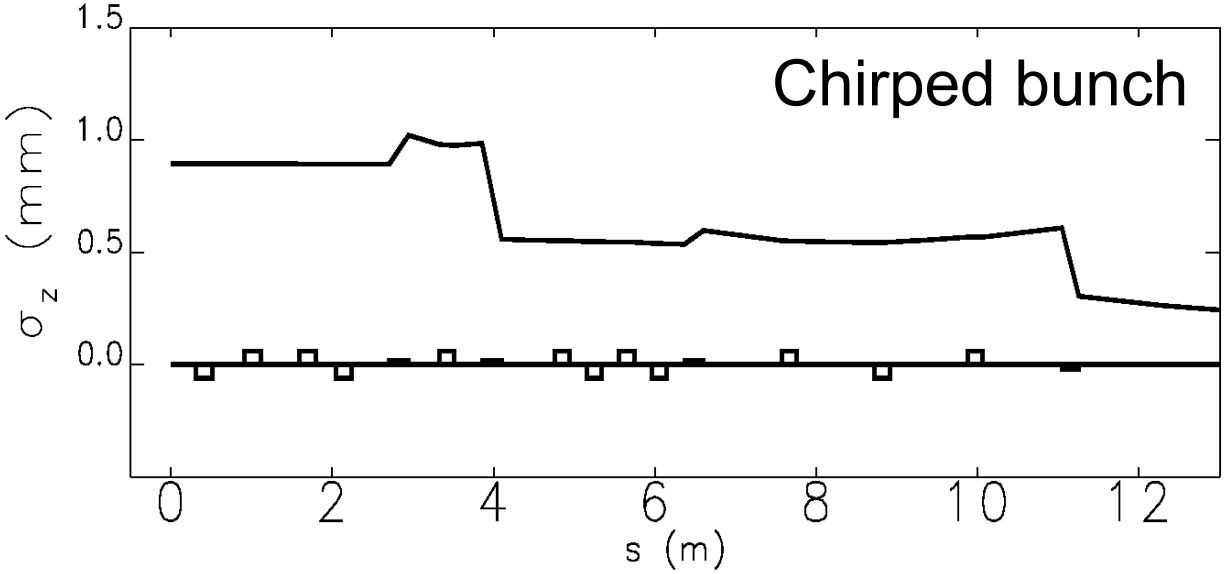
Elegant simulations

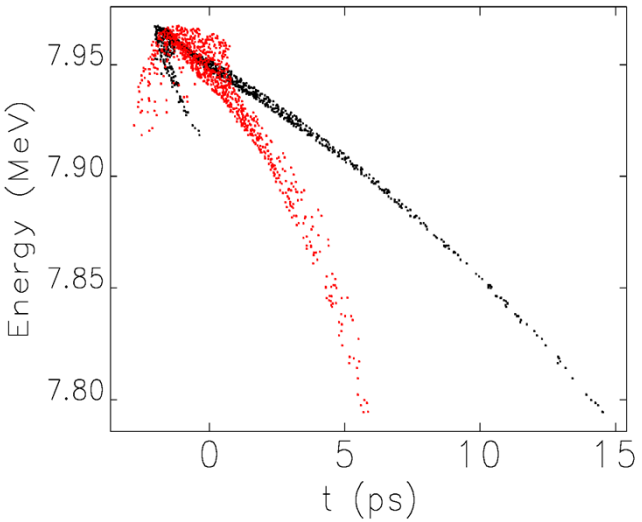




Black = After booster

Red = Before linac





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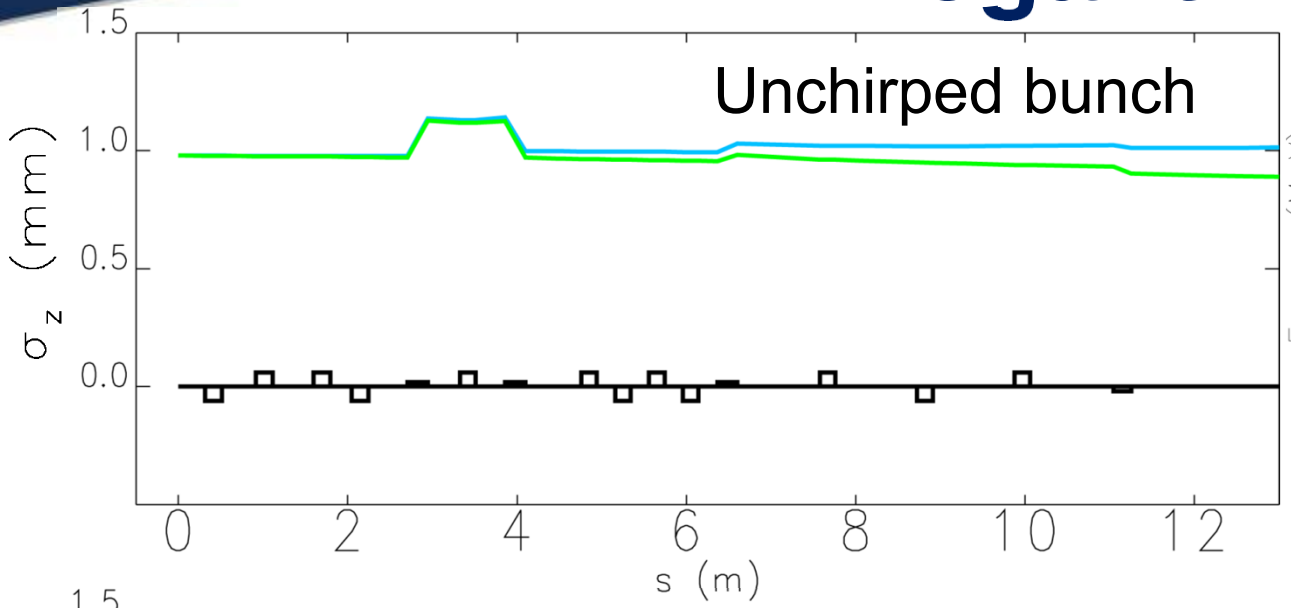
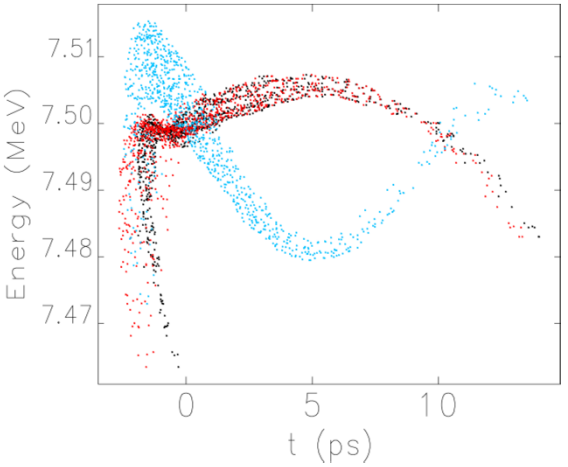
Elegant with LSC on

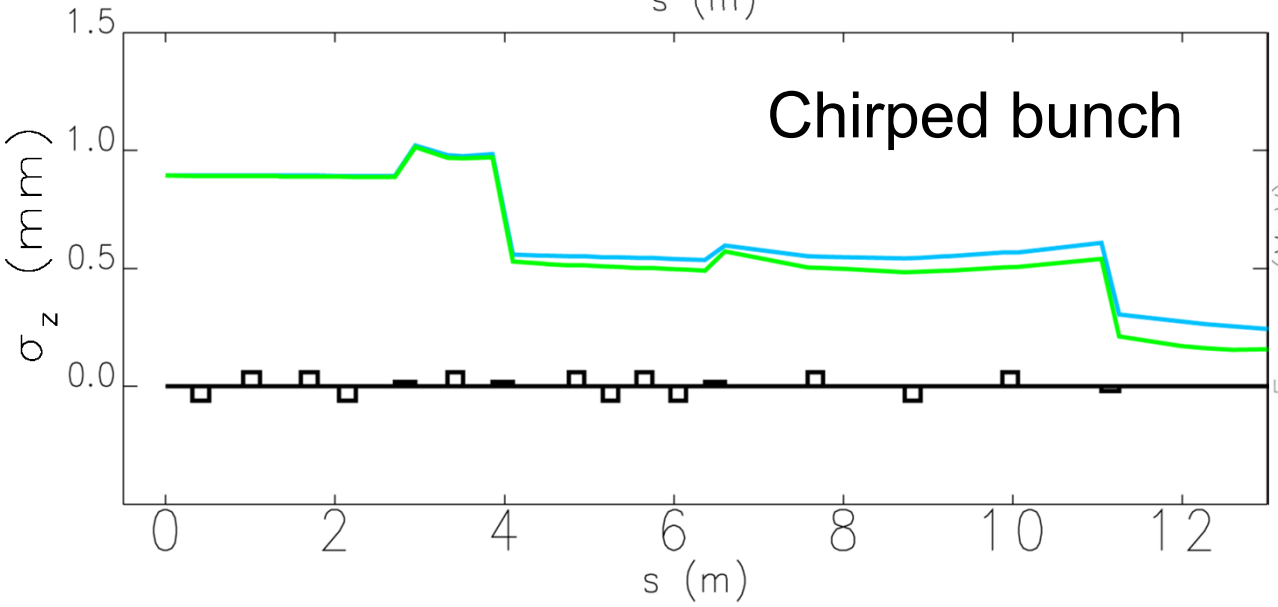


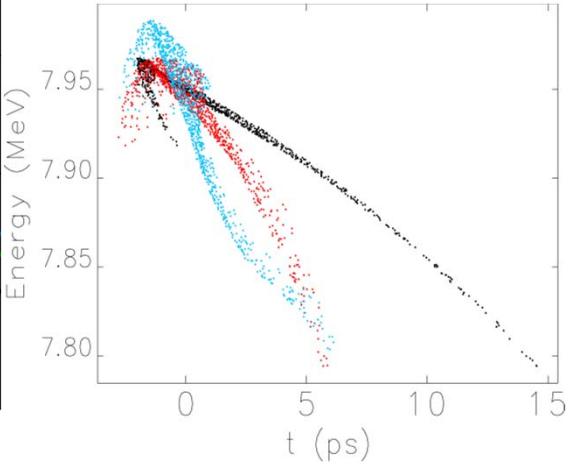


Black = After booster

Red = Linac, no LSC

Blue = Linac, with LSC





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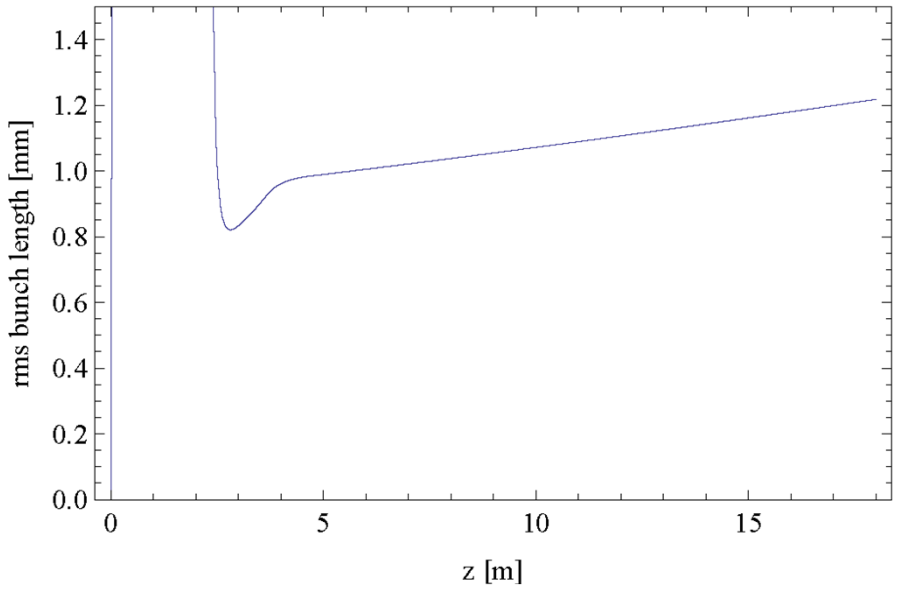
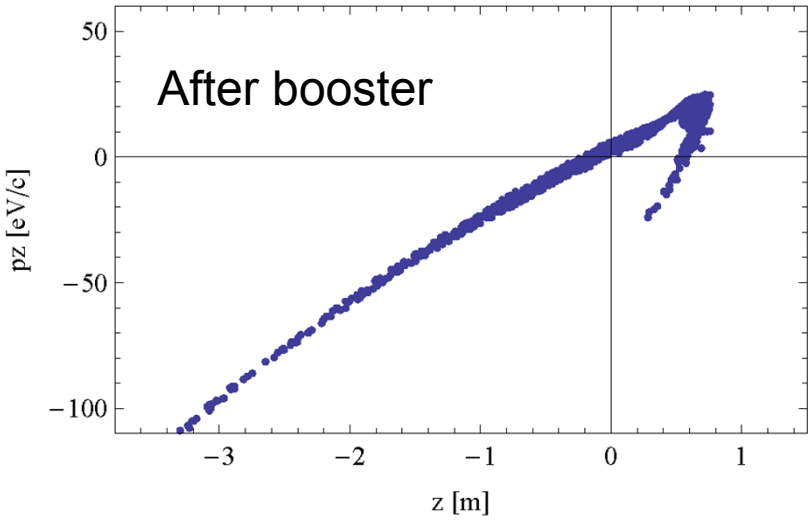
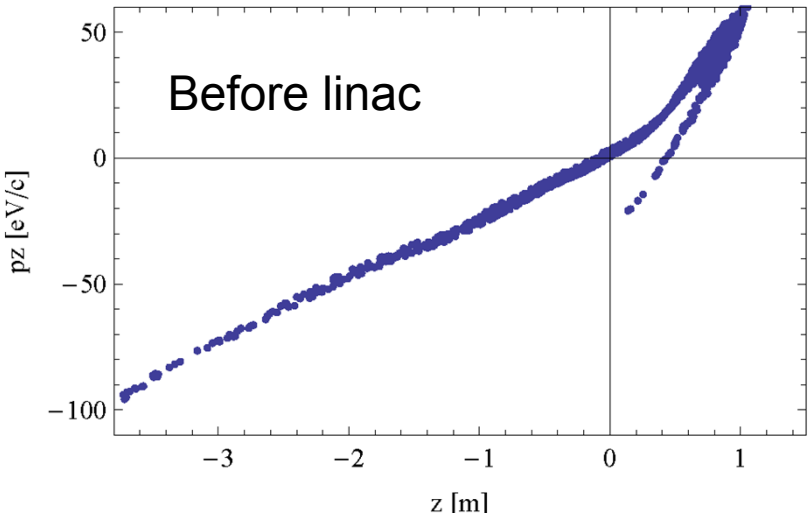
Velocity de-bunching between booster and main linac







ASTRA simulation (for long drift, doesn't include dipoles)

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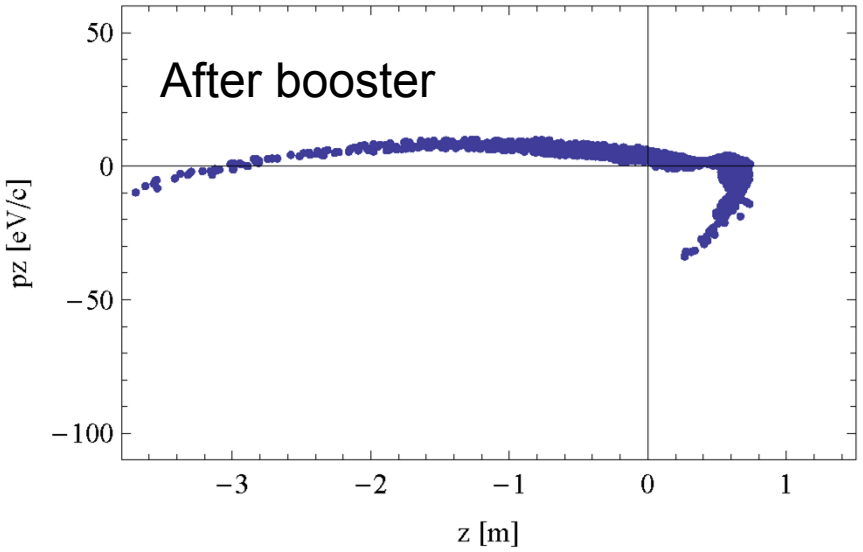
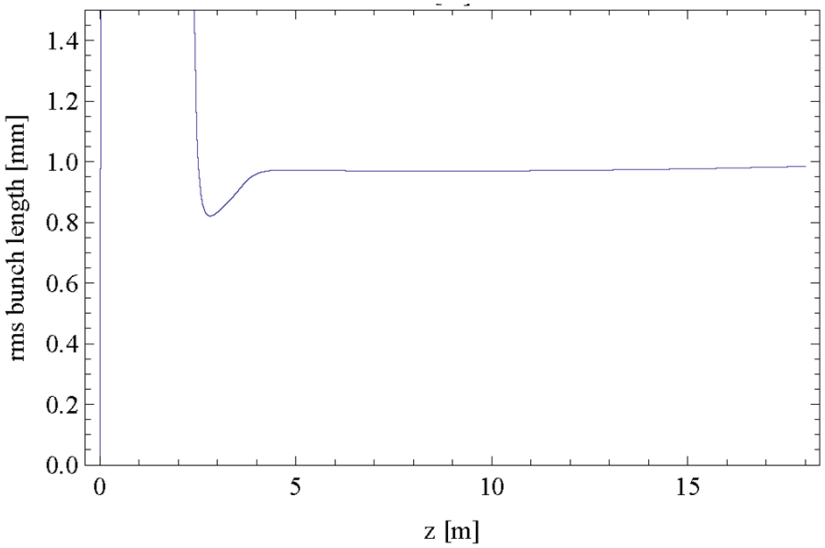
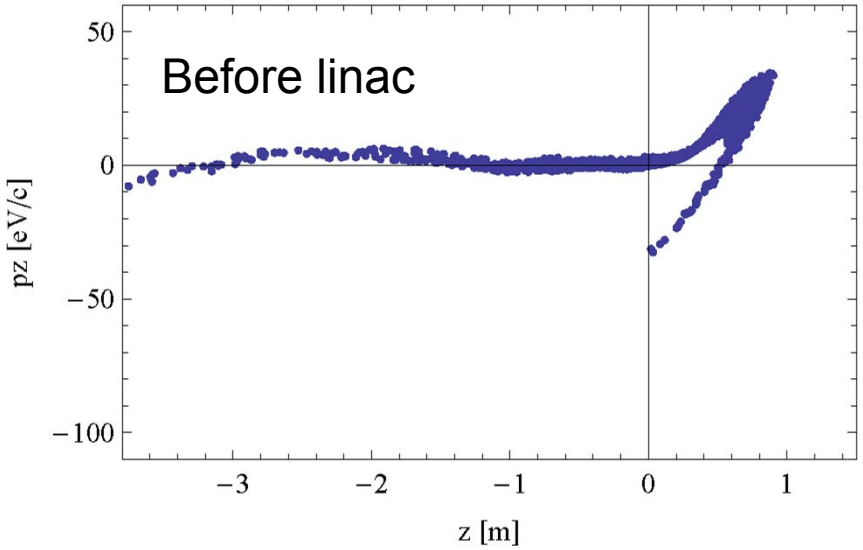
Even with fully rotated bunch, can have adverse effects if phase-space has “hook”







ASTRA simulation (for long drift, doesn’t include dipoles)

Summary:

- Injector dynamics complicated by reduced gun energy and long multi-cell booster cavity
- Can achieve bunch length and energy spread needed for FEL operations
- Bunch length measurements show < 2mm (6ps) rms bunch length in injector
- Measurements indicate reduction bunch length between booster and linac
- Simulations/measurements still not fully understood – more investigations under way
- Have to be careful with “features” in the longitudinal phase space

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Thanks to all the ALICE team!