Experimental Characterization of Transverse Phase Space of a 60-MeV Electron Beam through a Compressor Chicane

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Brief description on the bunch compressor study

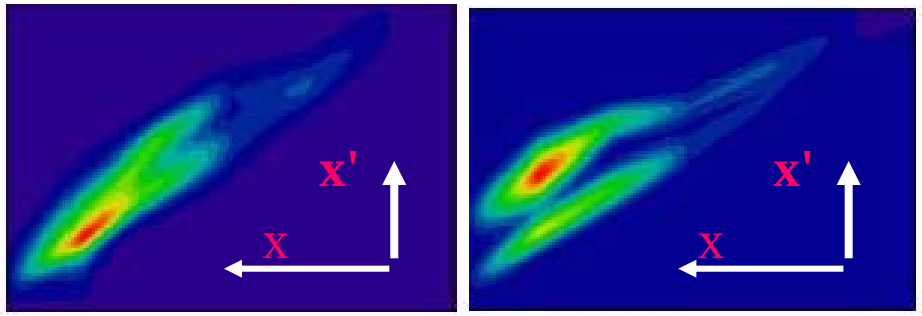
- Three typical kinds of compressors:
  - Chicane: simple, emittance growth; FEL
  - Wiggler: nonlinear dispersion min.; ILC
  - FODO arc: tolerance tight; SLC and ERL
- Pros: compress bunch down to fs level
- Cons: space charge and CSR effects created distortion of energy spectrum and transverse phase spaces.
- This talk focuses on the transverse part

Transverse emittance measurements

- Emittance measurements for a compressed beam were already taken in many labs.
- But, emittance is based on a prior assumption on the beam's phase-space distribution; it may not represent all information about the beam if the phase space is seriously distorted.
- Need to reconstruct the real phase-space of a compressed beam using phase-space tomography techniques.

Neptune data @ 12-MeV

- Neptune/UCLA applied a tomography using multi-slit system to reconstruct transverse phase spaces of a 12-MeV compressed electron beam.
- First observed transverse phase space bifurcation of a compressed beam at the low energy; detail analyses show the space charge plays dominant role.

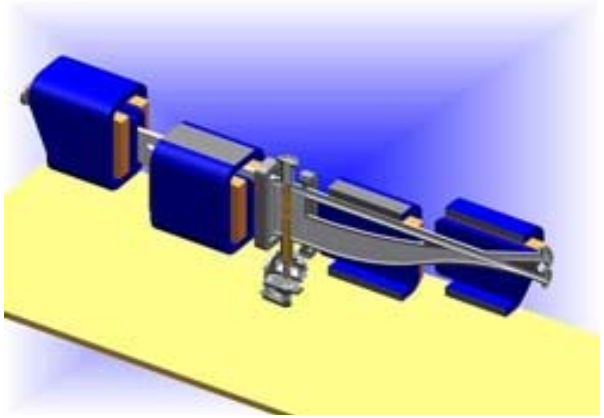


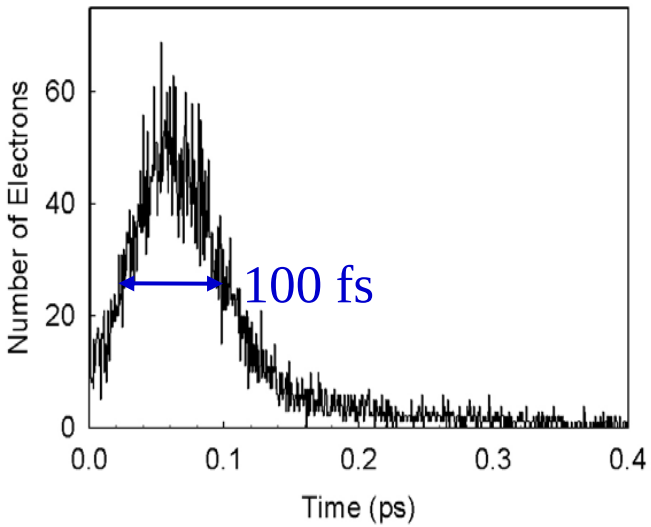
S. Anderson, et al., PRL, 2003

- We measured phase-space of a 60-MeV compressed electron beam since most compressors run at higher energy to overcome the space charge effects.

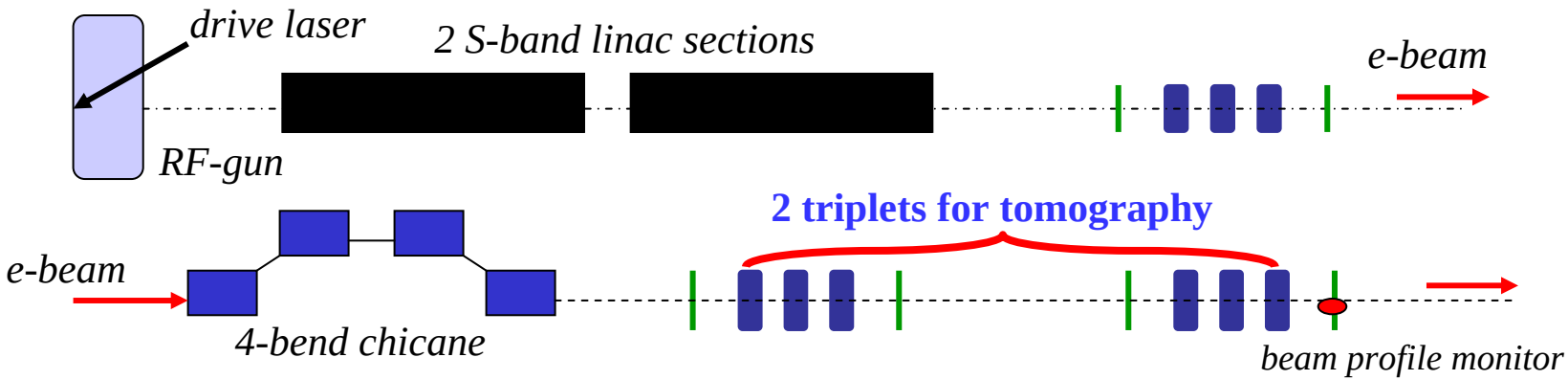
UCLA/ATF chicane

- ATF delivers low-emittance e-beam; 4-bend chicane with 20°/bend was built by UCLA.
- CSR simulations with 'elegant' code:
  - R56=-9.3 cm for 20° bending
  - initial σz 1.0 ps rms, and can be compressed down to σz 110 fs with correlated δE 0.32% rms.
  - ε_y increased by a factor of ~5
- Quad-scan based tomography is used to reconstruct transverse phase-spaces to characterize space charge and CSR effects at 60 MeV level.





Tomography for a compressed beam

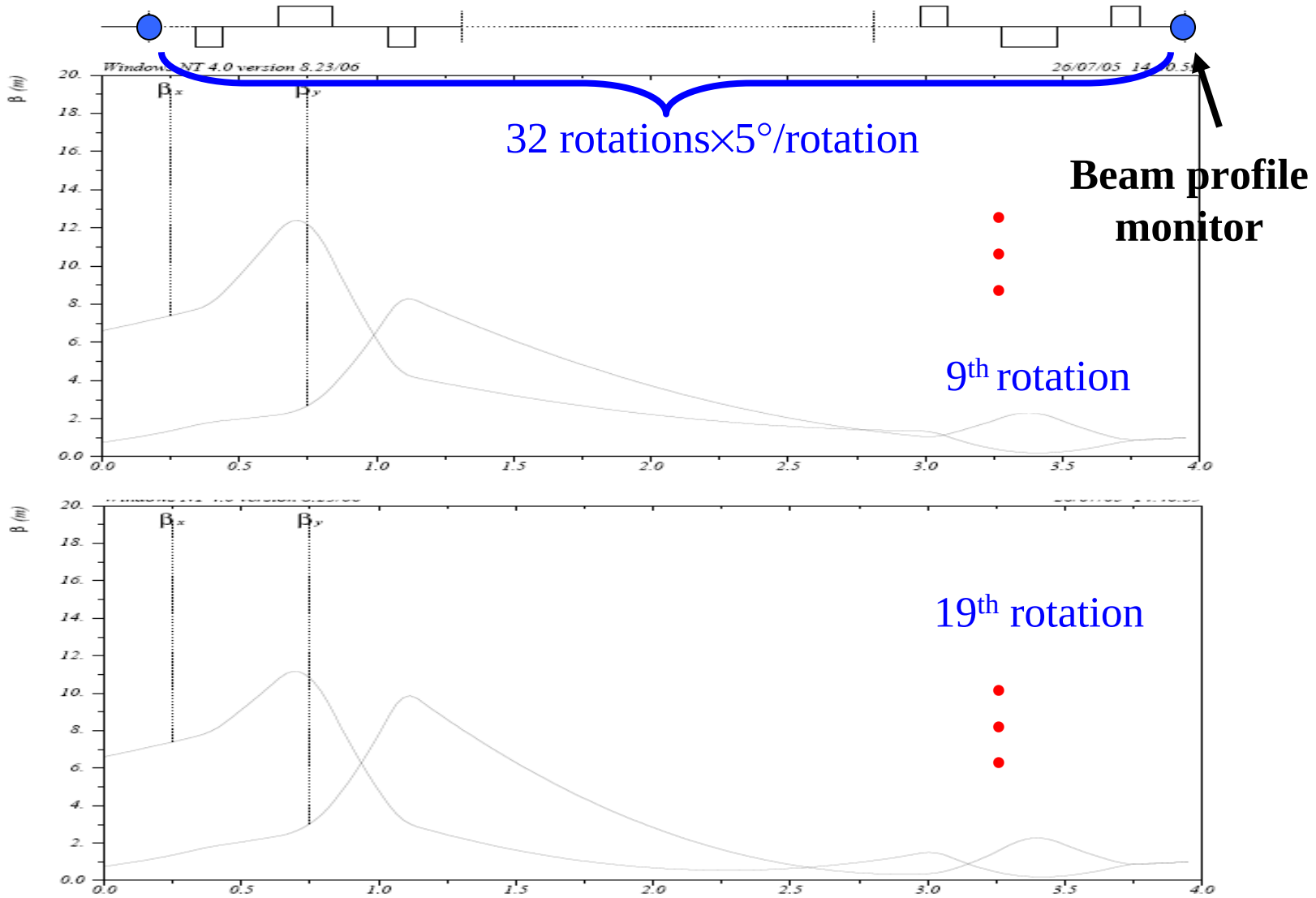


- Measure Twiss by measuring beam sizes at different beam profile monitors for different degree of bunch compression.
- Match multi-set of beam optics for different phase rotations based on the initial measured Twiss.
- Apply the optics and record beam sizes at the monitor.
- Reconstruct the phase space of a beam:

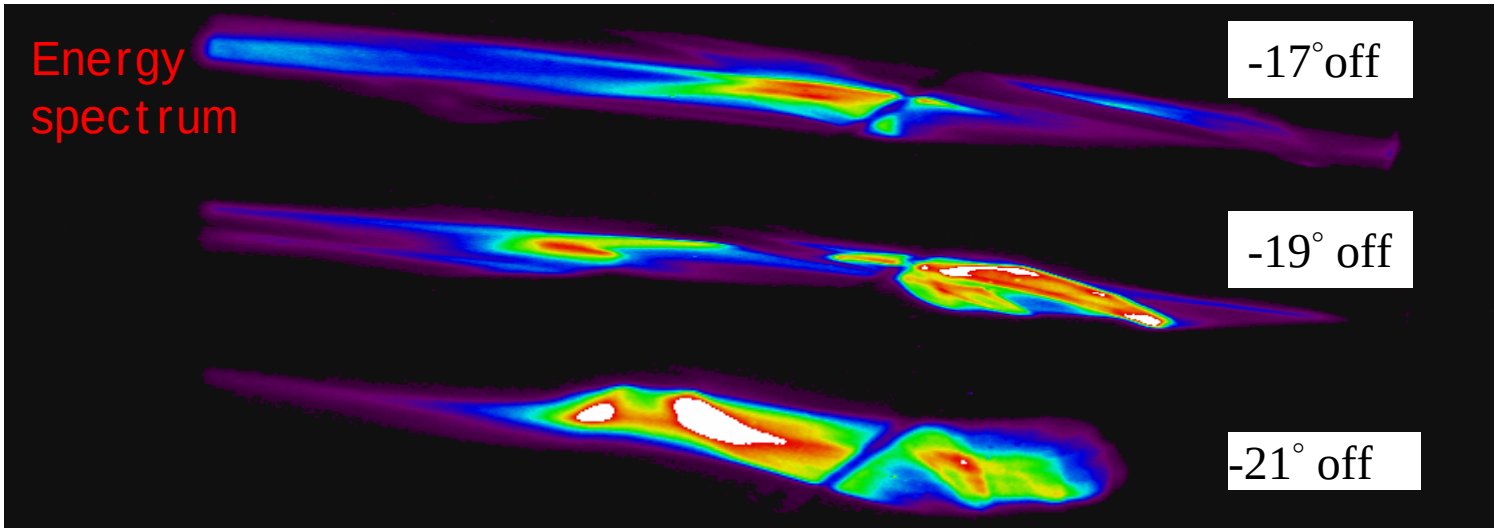
$$\mu(x,x') = \int_0^{\pi} \lambda_\phi^{\,*}(\xi)\, d\phi \,|_{\xi = \cos\phi + x'\sin\phi}$$

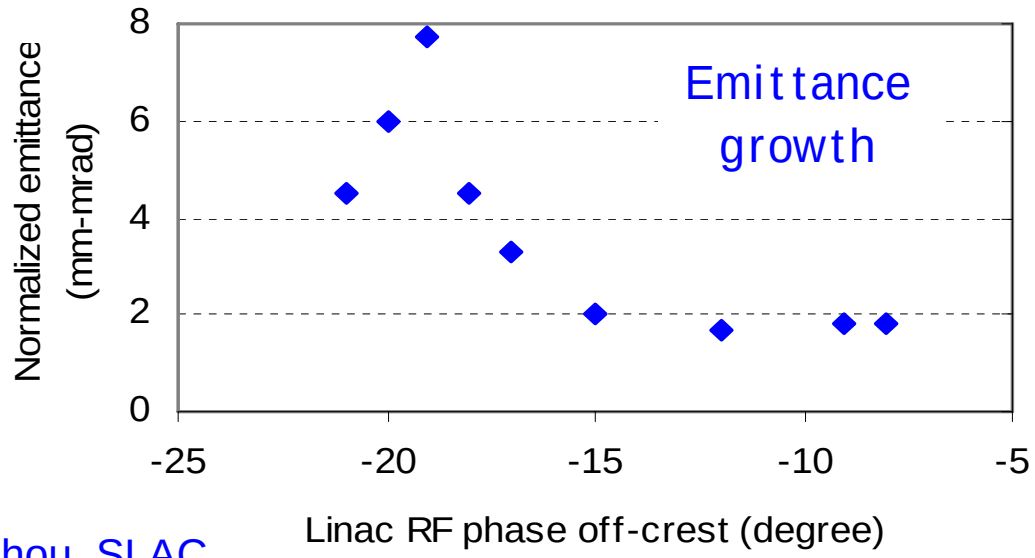
filtered projection: $\lambda_\phi^{\,*}(ms) = \frac{1}{4s}\lambda_\phi(ms) - \frac{1}{\pi^2 s}\sum_{\substack{n \\ m-n(odd)}} \frac{\lambda_\phi(ns)}{(m-n)^2}$

Transverse tomography optics



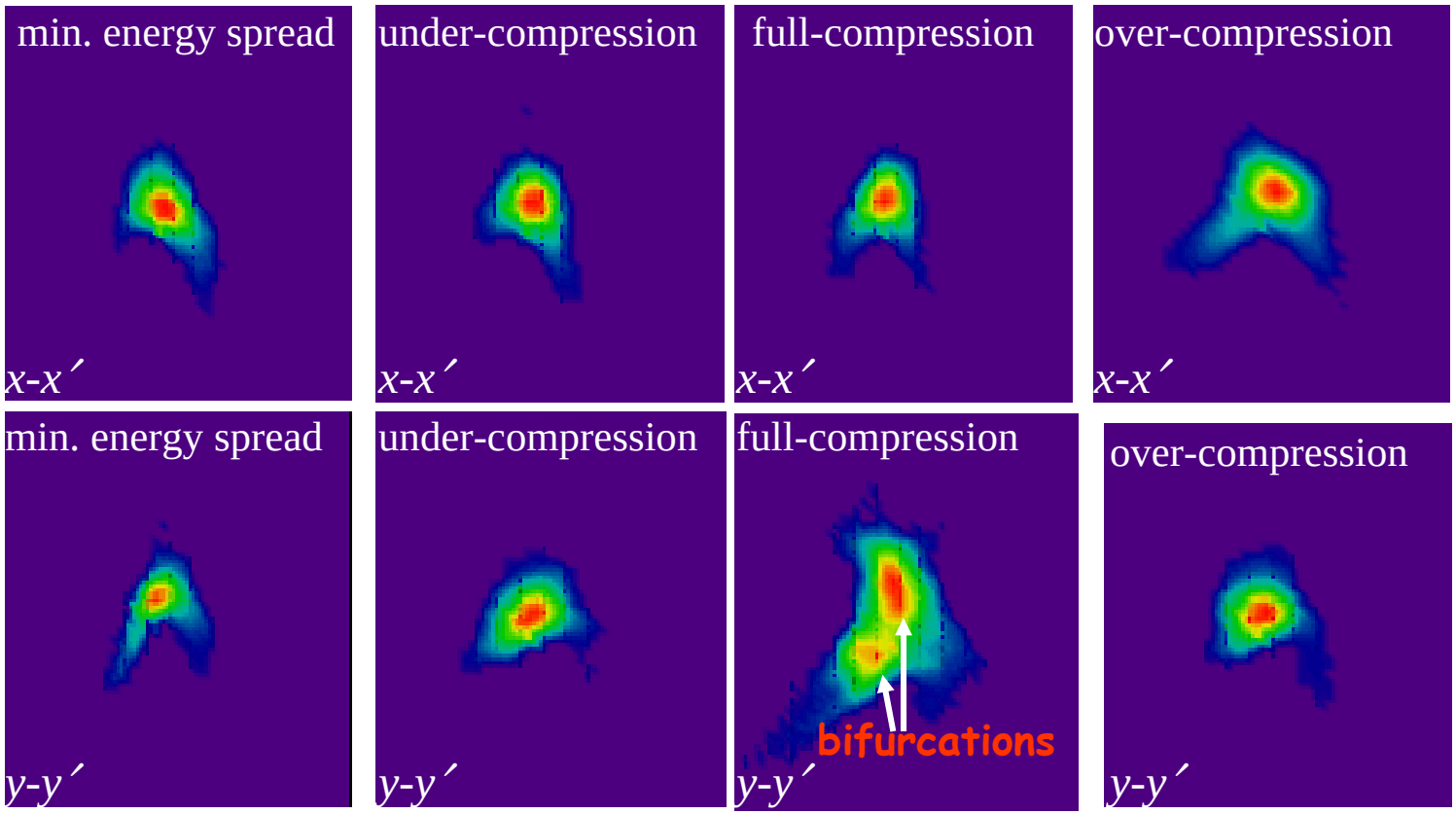
Full compression indications





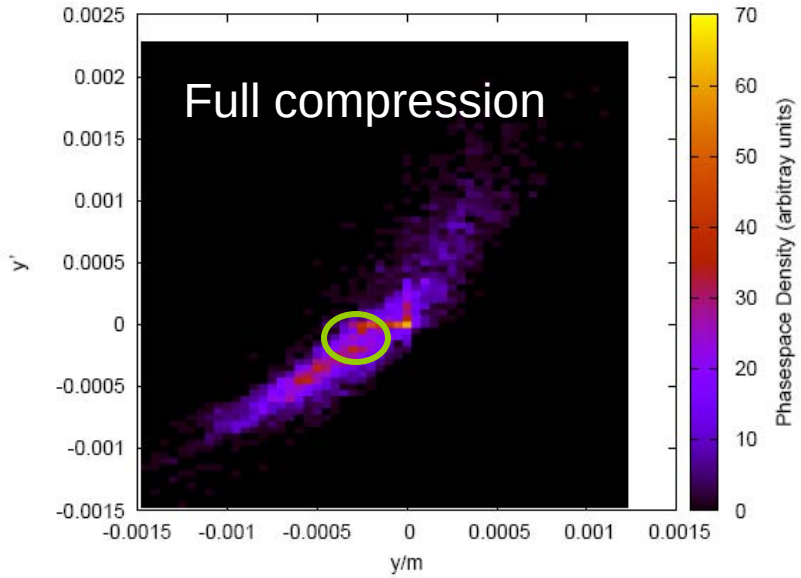
- Min. energy spread is at -*8°* off-crest.
- Dispersion in horiz. plane
- Bunch charge is 200 pC
- Agree with ‘elegant’ simulation

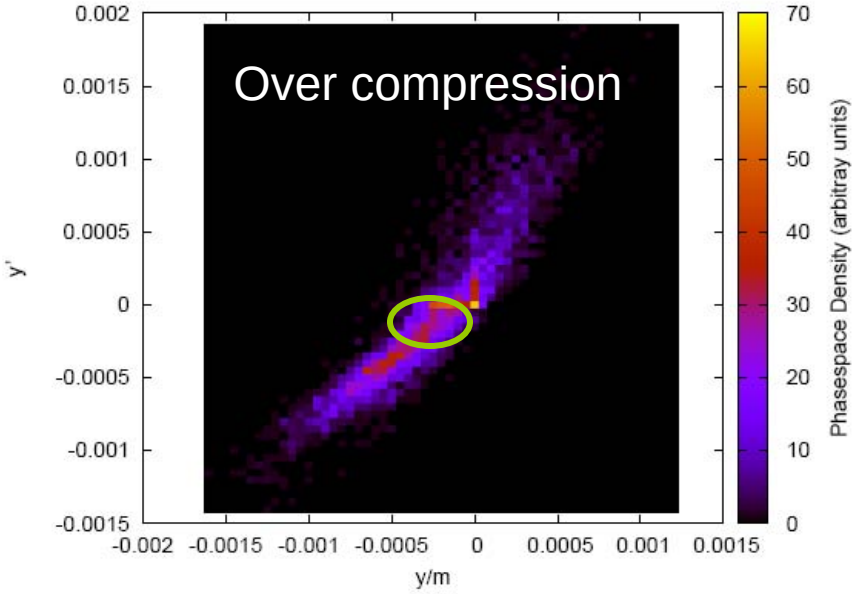
Reconstructed phase spaces of compressed beam @ 60-MeV



Trafic4 simulation

- It includes space charge and CSR effects to simulate compressor chicane. The bunch is represented as a set of macroparticles, each of which has a longitudinal and transverse size. Their EM fields are calculated from the 1st principle by solving Maxwell's equations.
- Initial conditions such as Twiss, energy, etc., are taken from the real experiment.





Interpretations

- The Trafic4 simulations qualitatively agree well with experimental observations: two humps are distinctly separated with full compression while they are less distinctly separated at over-compression.
- Trafic4 simulations (w/ both CSR and space charge) together with ‘elegant’ simulations (w/ only CSR) indicated the space charge play dominant role.
- Additional phenomena: the bifurcation disappears when enlarging beam spot size in the chicane.
- In comparison to Neptune data, the longitudinal space charge field in our experiment is reduced by a factor of 25, and thus the force to drive the bifurcation should be drastically mitigated at the higher energy.

Summary

- Transverse phase-spaces of a 60 MeV compressed beam are reconstructed: the phase space of a 60-MeV fully compressed beam is bifurcated, but notably less than previously observation at 12 MeV.
- Simulations indicate that the space charge driving the bifurcation is significantly mitigated at 60 MeV.
- The results may help to suitably select the energy of first stage of bunch compression at advanced machines.

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