Chicane Compressor at the BNL ATF

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ATF compressor development

- Background — chicane compressor basics
- BNL context
- Advanced high brightness beam physicsissues
- UCLA experience with compressors/magnet design
- Beam optics and compressor performance
- Basic design and implementation
- Engineering issues discussed by R. Aguttson

Why compression (in general)?

- High brightness for FEL radiation production

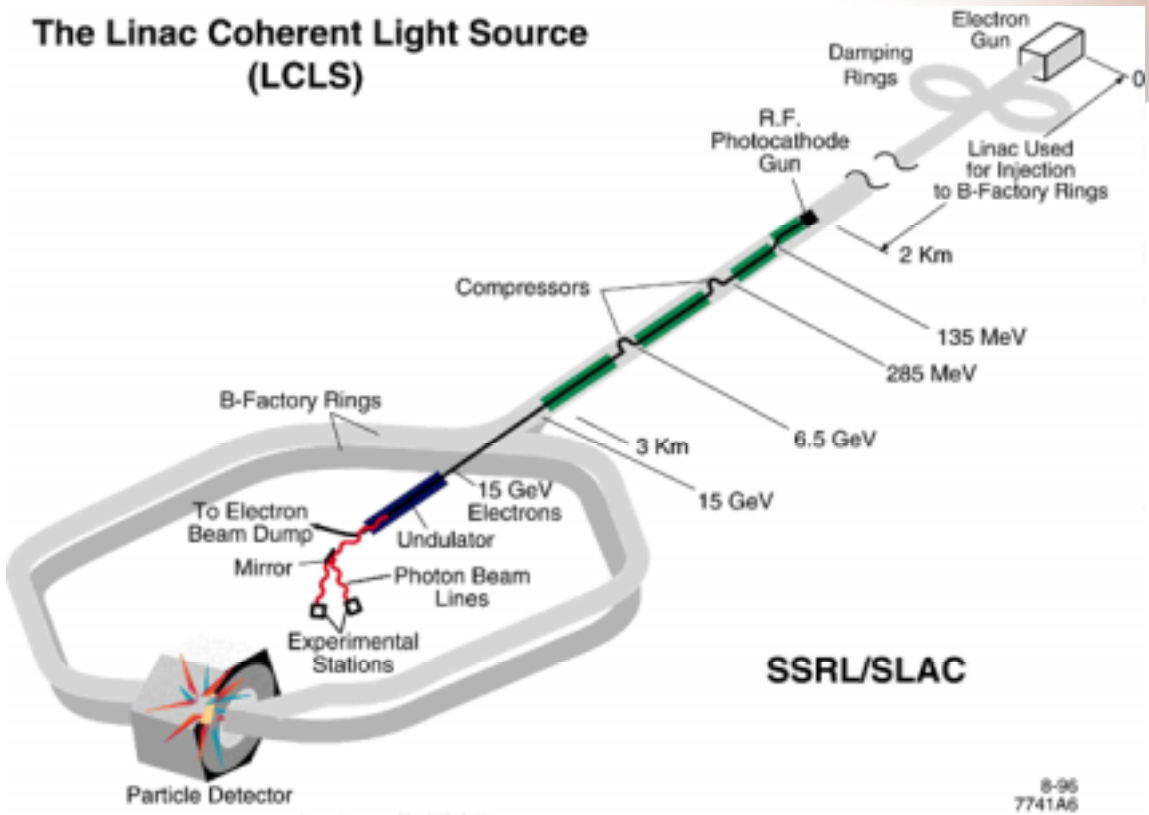
$$B = 2I / \varepsilon_n^2$$

- High peak current for wake (e.g. plasma) work

$$E_z \propto Q / \sigma_z^2$$

- Physics of compressions (space charge, CSR)
- Critical input for LCLS and NLC design…
- UCLA work at ATF partially funded by ONR for these reasons

Motivation: An X-Ray FEL

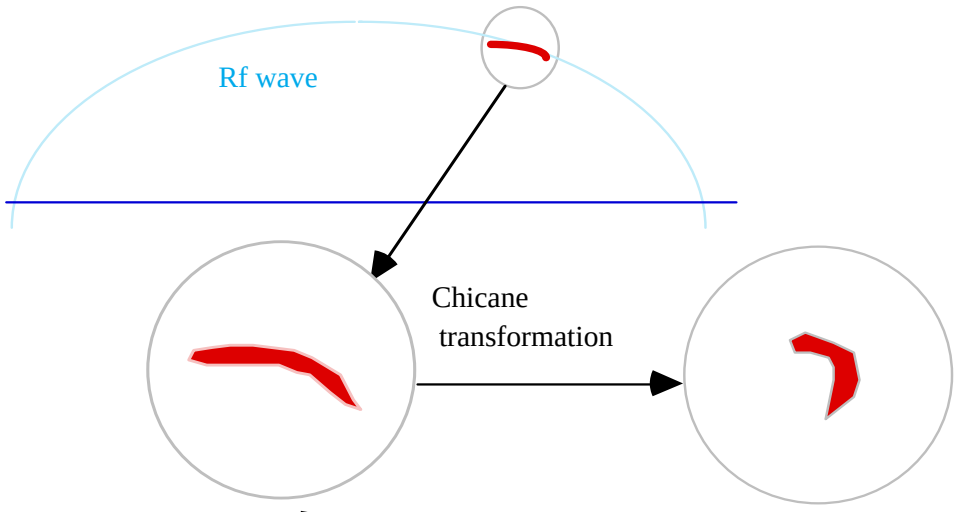


Note existence of at least two compressors!

Why compression (at ATF)?

- Fundamental work on emittance growth
- Observation of CSR
- Ultra-high current beams
- Super-VISA!
- Plasma wake-fields?

Compression physics I: schematic



- Run off-crest in linac to produce momentum -phase correlation
- Introduce path length dependence on momentum error (TRANSPORT R_{56})
- Lots of collective effects to make things complicated

Analytical model (non-interacting particles)

Twiss parameters at end of linac $E(\phi) \cong E_m \cos(\phi)$

$$\varepsilon_\phi \equiv \sqrt{\left\langle \phi^2 \right\rangle \left\langle \left(\tfrac{\Delta p}{p}\right)^2 \right\rangle - \left\langle \phi \tfrac{\Delta p}{p} \right\rangle^2} \cong \tfrac{1}{2}\sigma_\phi^3 \cos(\phi_0)$$

$$\beta_\phi \equiv \frac{\left\langle \phi^2 \right\rangle}{\varepsilon_\phi} \cong \frac{2\cos(\phi_0)}{\sigma_\phi}$$

$$\alpha_\phi \equiv -\frac{\left\langle \phi \tfrac{\Delta p}{p} \right\rangle}{\varepsilon_\phi} \cong \frac{1}{\sigma_\phi}\tan(\phi_0)$$

$$\gamma_\phi \equiv \frac{\left\langle \left(\tfrac{\Delta p}{p}\right)^2 \right\rangle}{\varepsilon_\phi} = \frac{1+\alpha_\phi^2}{\beta_\phi}$$

Note: emittance is very strong function of initial bunch length due to rf nonlinearity

Optimum compression

- Maximum compression ratio

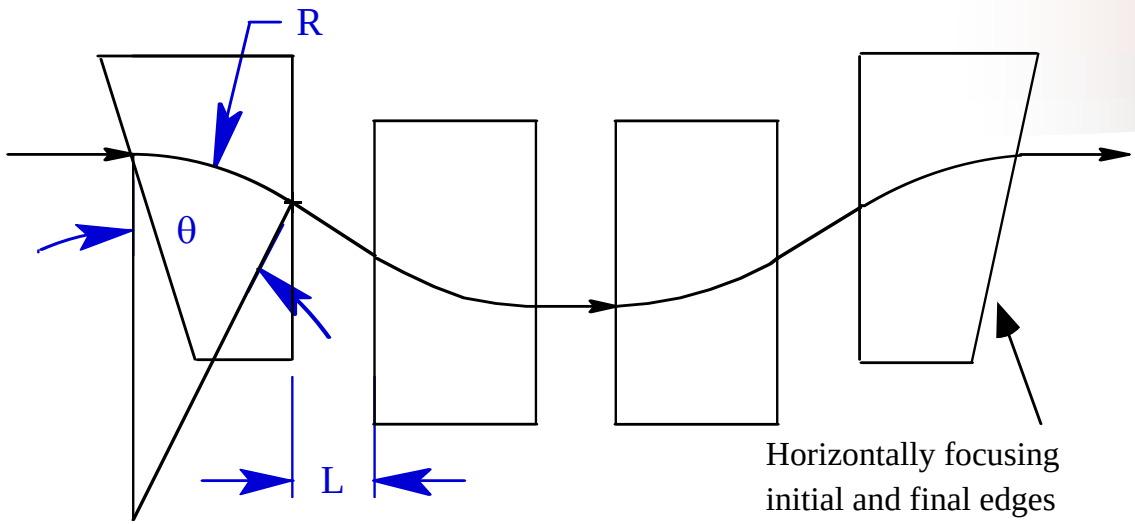
$$r_c = \sqrt{\alpha_\phi^2 + 1}$$

is obtained when the "longitudinal drift"

$$R_{56} \equiv \frac{\partial \phi}{\partial \left(\Delta p / p \right)} = \frac{\alpha_\phi \beta_\phi}{r_c^2} = \frac{\beta_\phi}{\alpha_\phi - \alpha_\phi^{-1}}$$

For initially short, correlated beam one needs less R_{56}

The chicane



- **Dispersionless to all orders**
- **Storage**
- **Tunable**

$$R_{56} \cong 2R[\theta - \sin(\theta)] + L\left(\frac{\theta \sin(\theta)}{\cos^3(\theta)}\right)$$

The caveats/the physics

- Wakes and longitudinal space charge cause “chirp” to be lessened.
- Space charge SC (*velocity fields*) cause dispersion errors.
- Coherent synchrotron radiation CSR (acceleration fields) wake causes energy changes (effective dispersion error). SC force and large angular motion also causes this.
- “Natural” vertical focusing exacerbates problems.

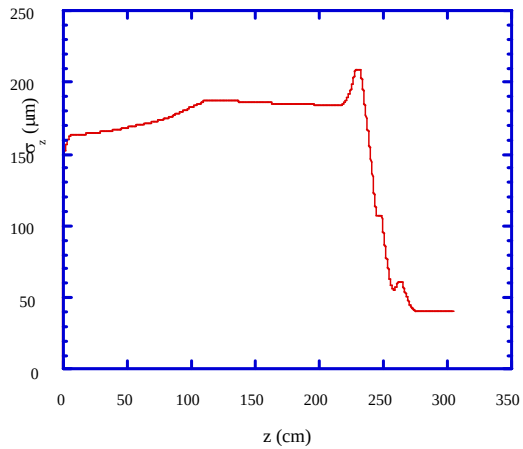
UCLA experience with compressors

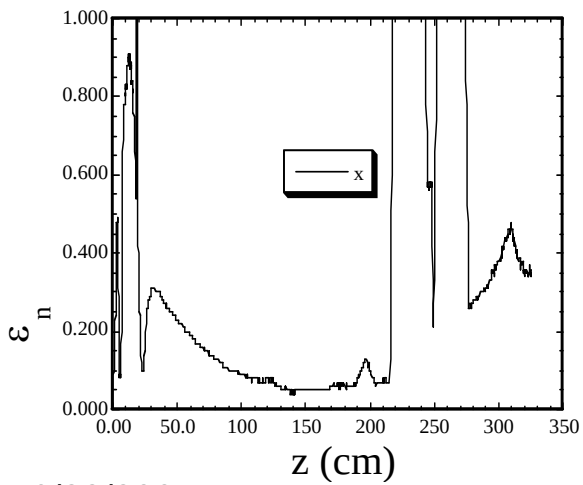
- Original design by Rosenzweig-Colby for TTF/FTF. Analytical model, TRACE3D and PARMELA tools, scaling developed.
- Scaled design to S-band for Neptune
- Neptune constructed under commissioning
- New magnets designed with 3D code AMPERES
- Negative R_{56} design.

Neptune chicane compressor

- 4-bend chicane, achromatic to all orders
- Horizontal focusing initial and final edges
- Run in chicane and spectrometer mode
- First generation built, installed and tested; second generation designed and under construction

Neptune compressor performance





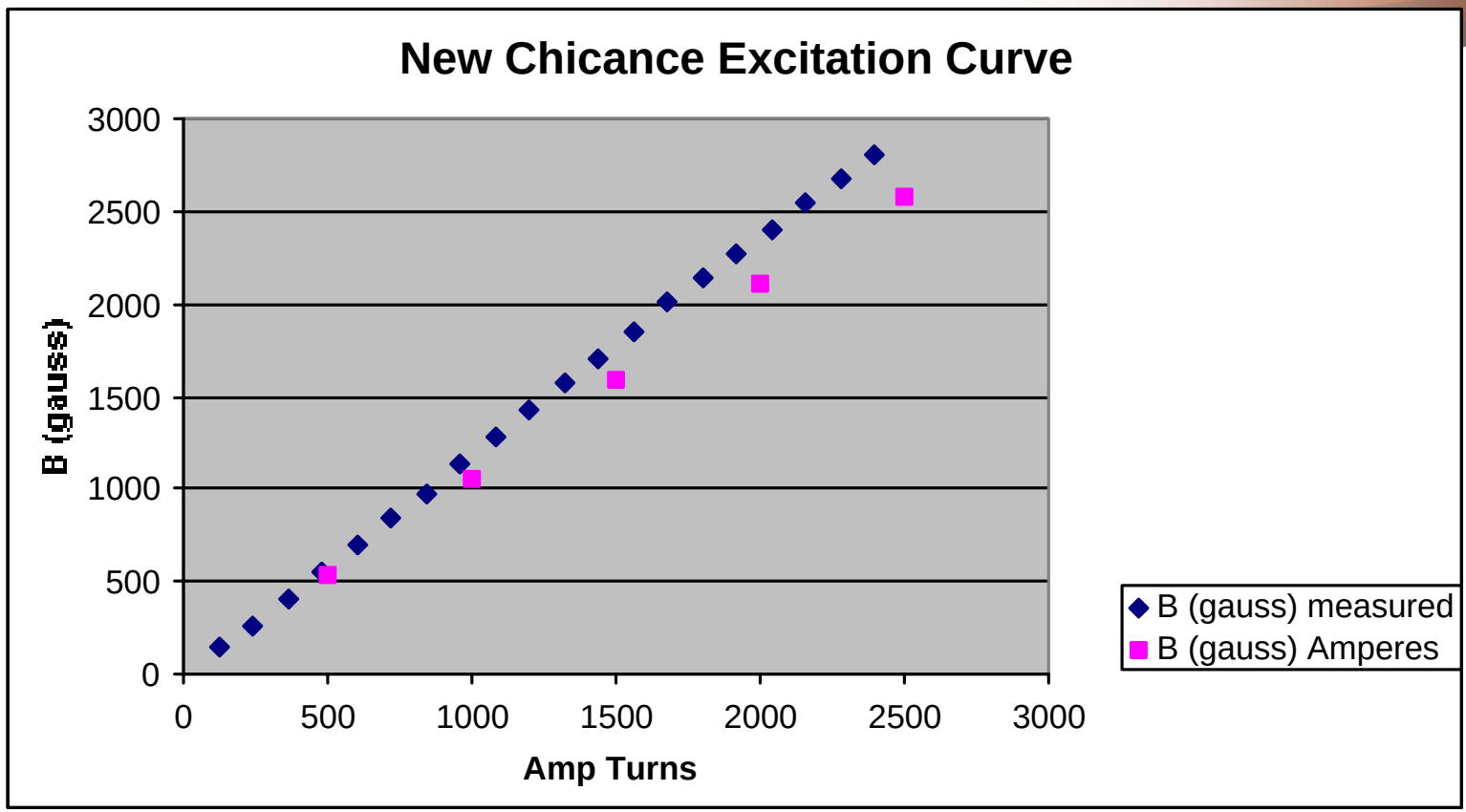
- Low charge case for PBWA experiment
- Compression by typical factor of >4
- Velocity fields dominant
- Emittance growth calculated by point-to-point space-charge in PARMELA

Second generation Neptune chicane

QuickTime™ and a
GIF decompressor
are needed to see this picture.

- Unexpected saturation from 2D models
- More iron, curving of return yokes
- Reconfiguration of coils,
- AMPERES design and benchmark

Saturation study for new dipoles

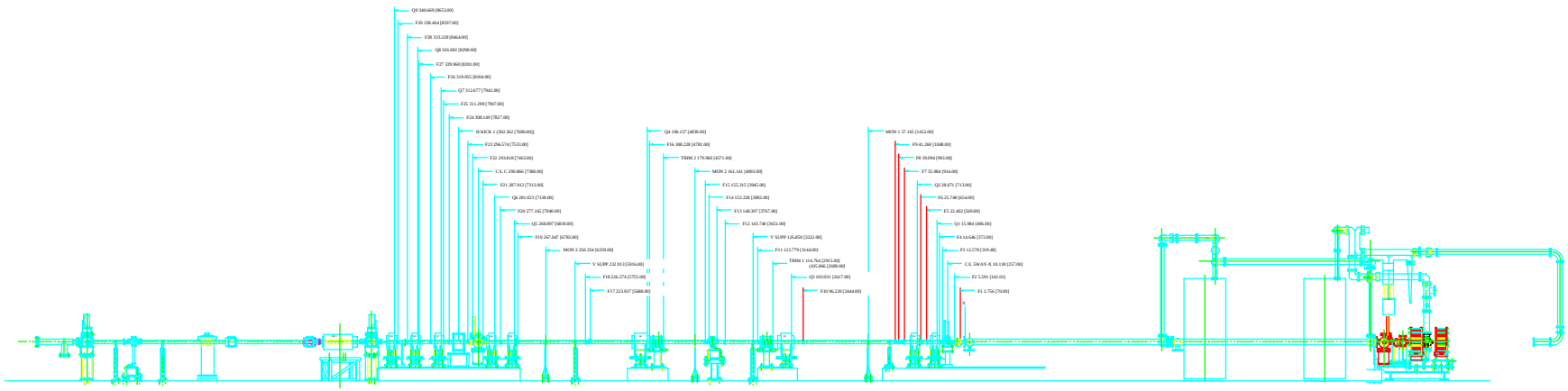


ATF compressor design

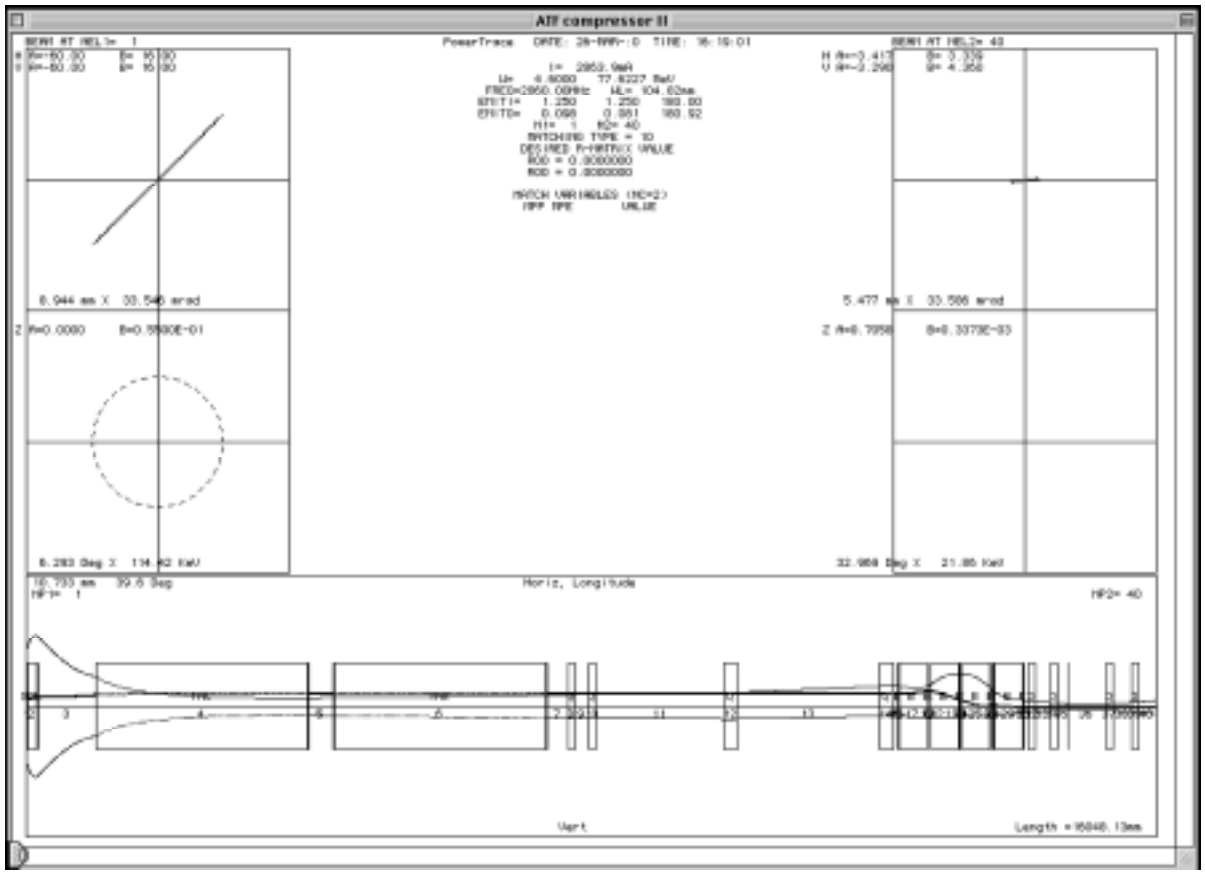
- Lower R56 due to initially short bunches
- H-focusing initial/final edges
- Limited field strength(~2 kG) to mitigate magnet engineering
- 2 cm gap to obtain aperture
- Optics simulated with TRACE3D — space charge fields not ignorable

Radius of curvature	1.2 m
B-field	2.1 kG
Magnet gap	2 cm
Nominal bend angle	20 degrees
Outer edge angles	20 degrees
Total length	1.7 m

Optics consistent with tunnel layout

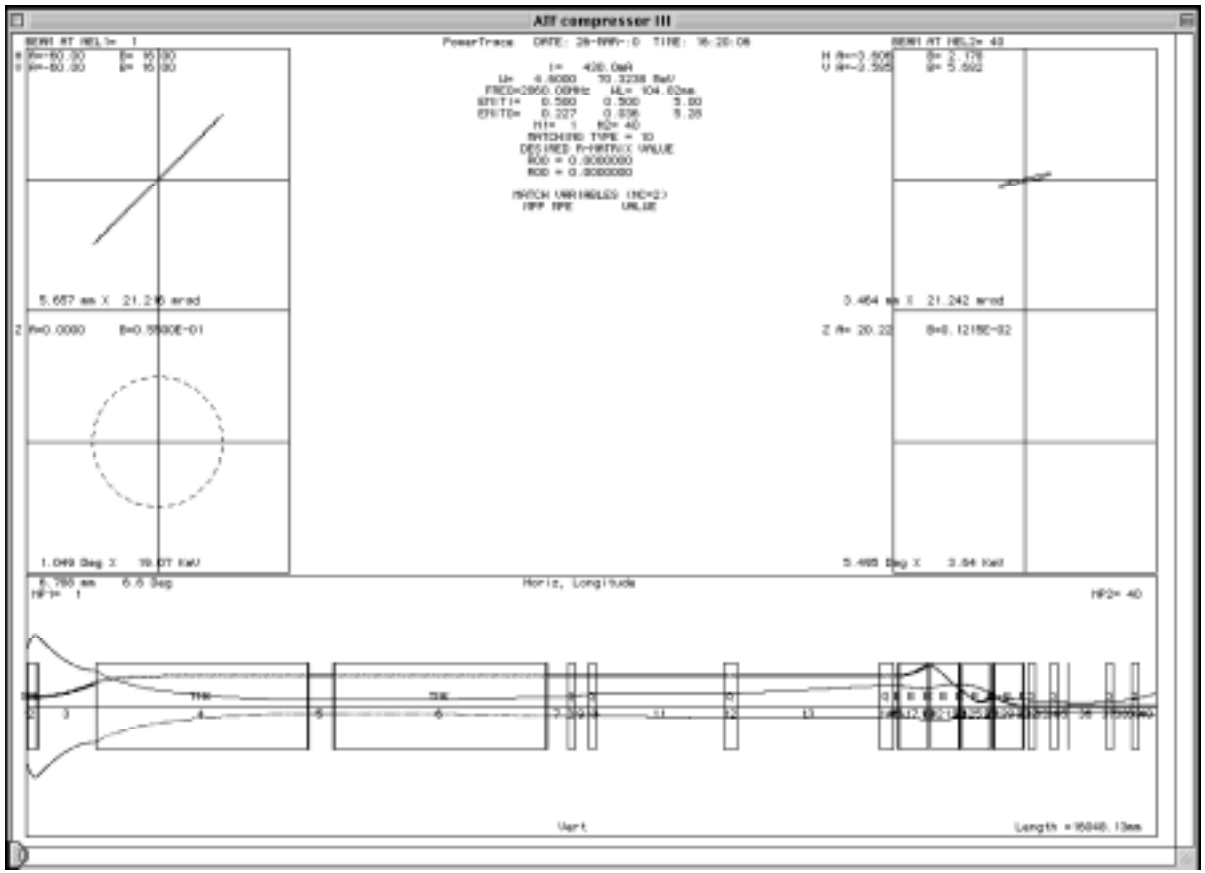


High charge case



Q	1.0 nC
Initial bunch length (FWHM)	1.0 mm (3.3 psec)
Comp. bunch length (FWHM)	72 μm (0.29 psec)

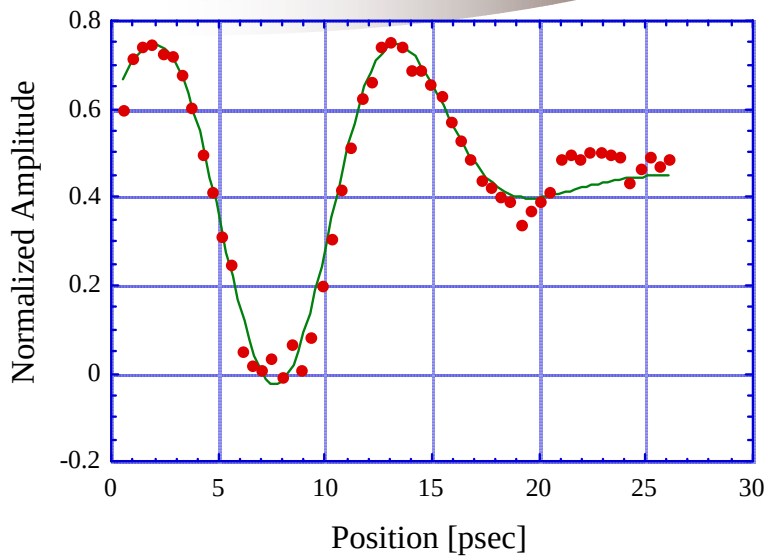
Low charge case



Q	0.15 nC
Initial bunch length (FWHM)	0.5 mm (1.65 psec)
Comp. bunch length (FWHM)	23 μm! (75 fsec)

Compressor physics

- Emittance growth due to acceleration fields expected to be similar to SC fields. First definitive test of models?
- Measure coherent synchrotron radiation from chicane using interferometer, compare with emit. growth for consistency.
- Will begin comput. estimates of VISA performance using compressed beam
- <u>Need to specify needed beam diagnostic systems at this meeting</u>



CTR autocorrelation using polarization Michelson interferometer (w/U. Happek)

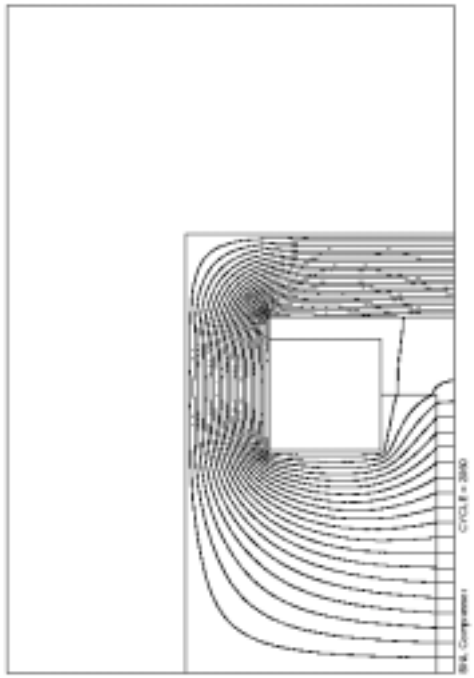
Super-VISA?

QuickTime™ and a
GIF decompressor
are needed to see this picture.

Must understand momentum acceptance of BL3 and matching optics system

Dipole design

- First pass with POISSON
- Detailed AMPERES work (Ron Aguttson)
- Engineering design, fabrication, status, discussed by Ron.
- Vacuum vessel preliminary study



Points to discuss

- Plans for supports, alignment, installation
- Vacuum vessel and aperatures
- Optimum integration of compressor into the ATF post-linac region
- Instrumentation requirements and availability
- Schedule
- Future experimental plans