UCLA Neptune Ramped Bunch Experiment

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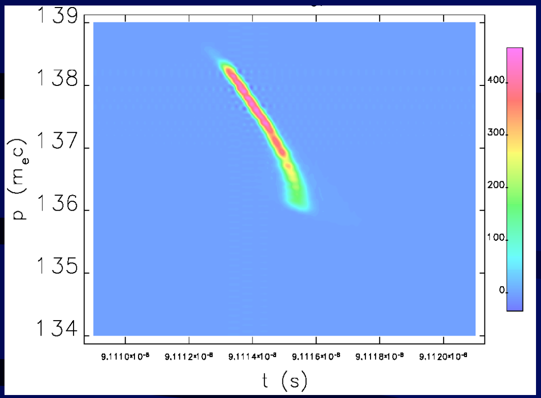
Outline

- 1. Background & Motivation
- 2. Neptune Dogleg Compressor
- 3. Recent Results
- 4. Future Experiments
- 5. Conclusions

Background

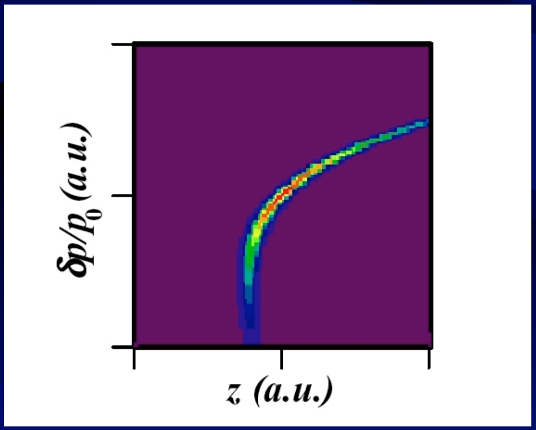
Bunch Shaping and Compression

Compression: ps to sub-ps => large beam current
Bunch shaping: asymmetric current profile



- **Ultrafast Radiation Sources:**
  SASE-FEL
  - compression: high current - improved gain
  - shaping: chirped beam - time-frequency chirped radiation (VISA II)
  Thomson Scattering

ELEGANT simulation of chirped beam profile from ATF-VISA II



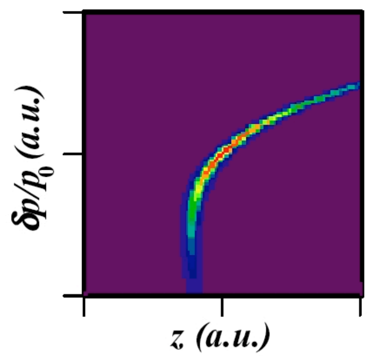
- **Plasma Wake-Field Accelerator (PWFA)**
  - compression: high current - large wakefields
  - shaping: ramped beam - improved transformer ratio

Neptune: beam optics studies ; ORION: future PWFA work

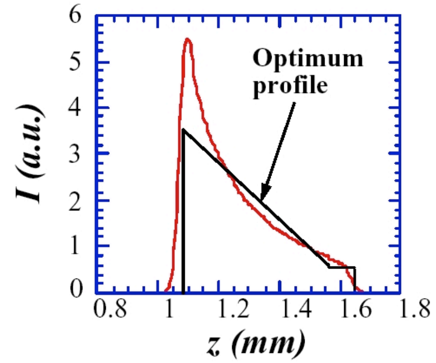
Profile from plasma drive beam study for ORION

Background

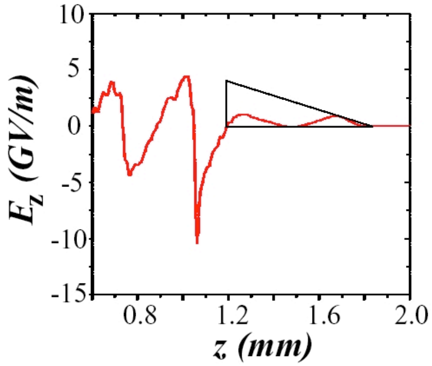
Ideal PWFA Drive Beam



Phase space



Current profile



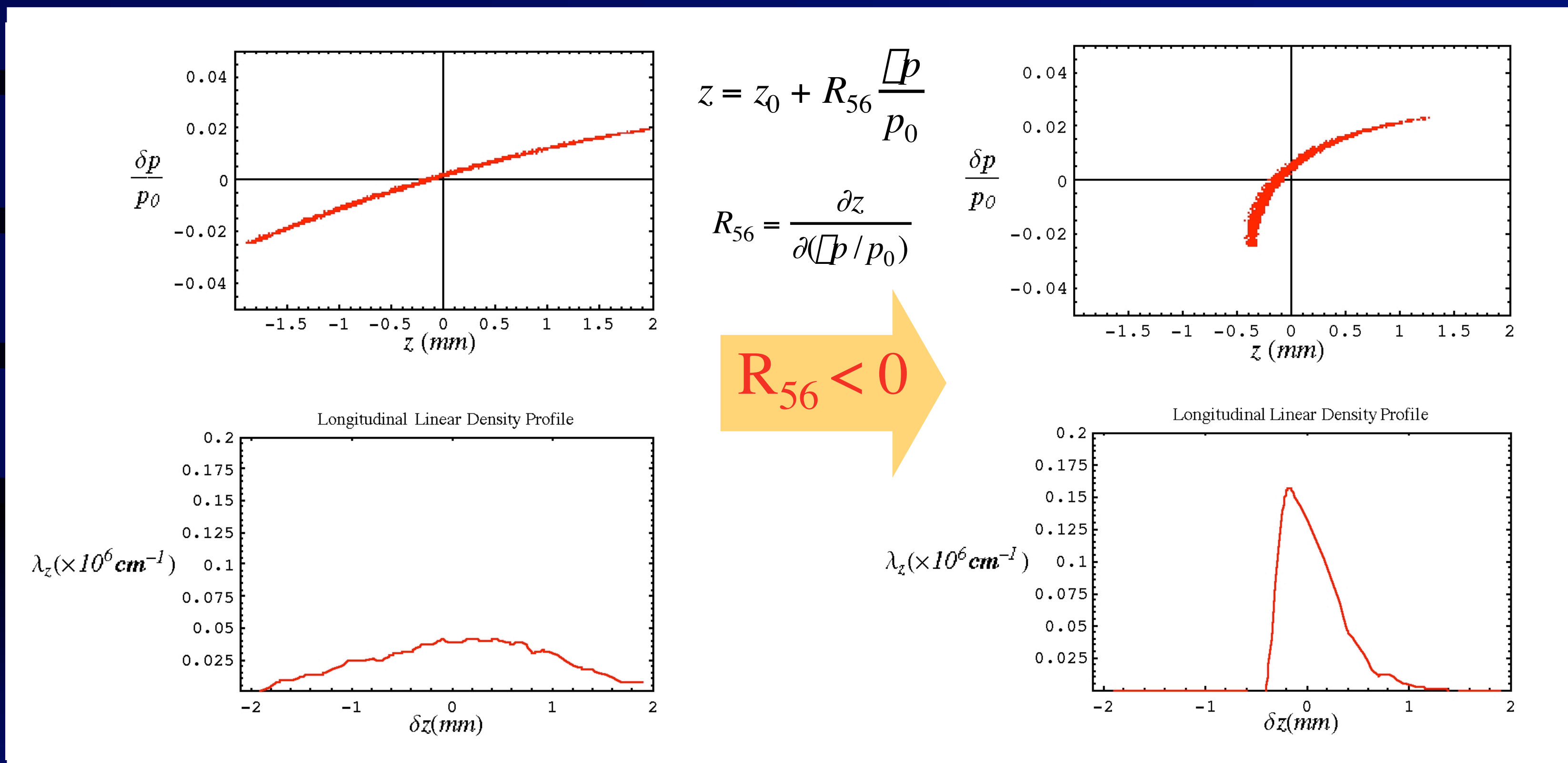
Wakes in 1E16/cm^3 plasma from PIC simulation

- Negative R_{56} provides longitudinal beam compression.
- Compressed beam = stronger plasma wake-fields.
- Ramped beam gives improved transformer ratio (i.e.R >2).
- R = peak accelerating field / peak decelerating field.
- For ramped bunch, R = k_pL

Background

Negative R56 Compression to Get Ramped Beam

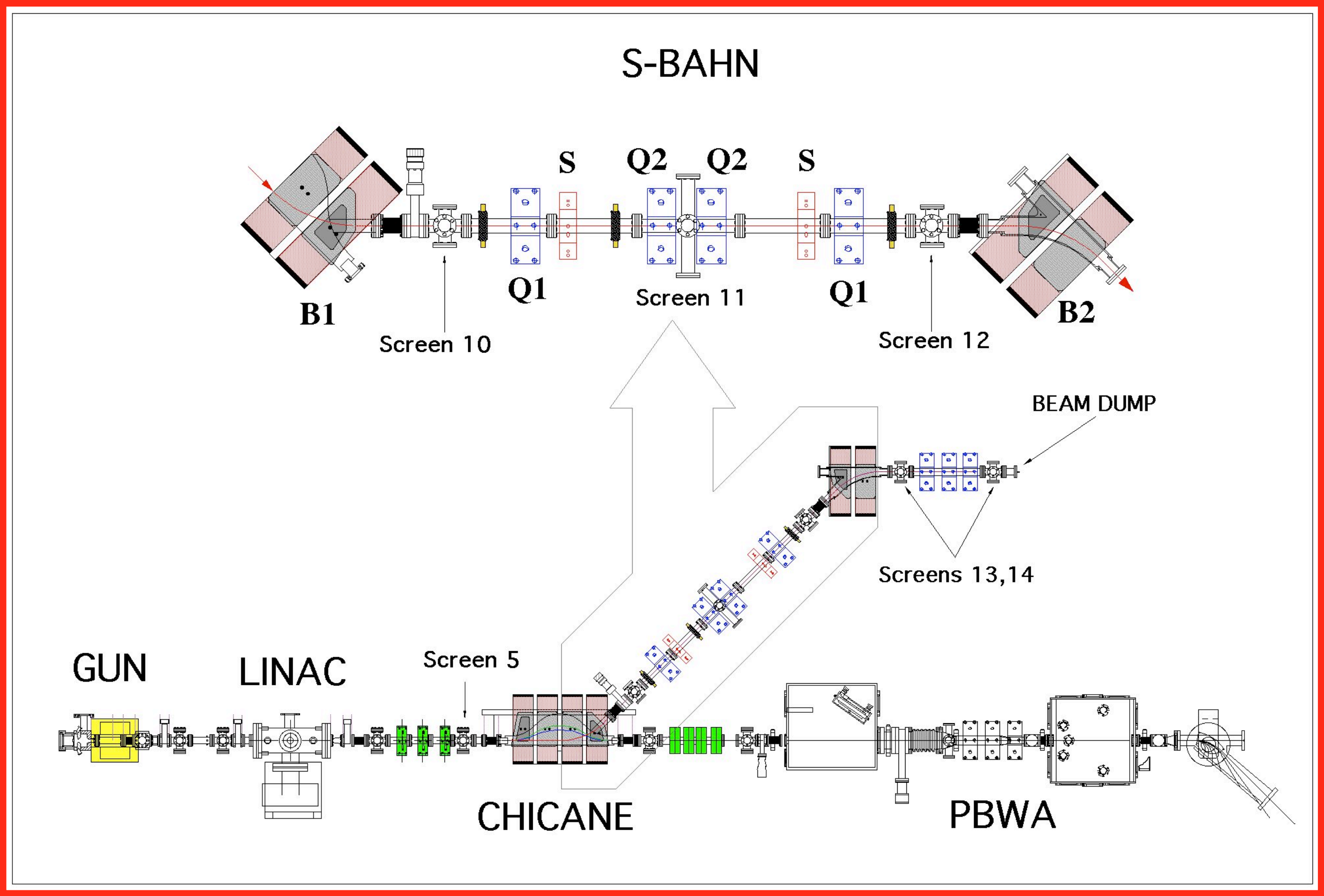
- Only works if the z phase space transformation is *linear*.
- Nonlinearities must be eliminated by use of correcting elements.
- Requires a momentum-chirped (back of crest) initial beam.



Initial beam **Final beam**

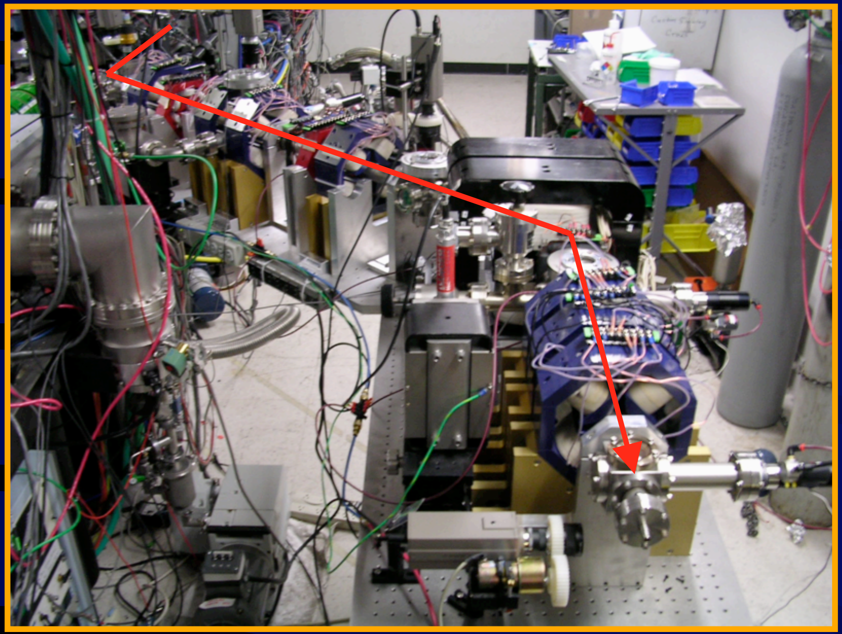
Neptune Dogleg Compressor

S-Bahn Compressor



Neptune Dogleg Compressor

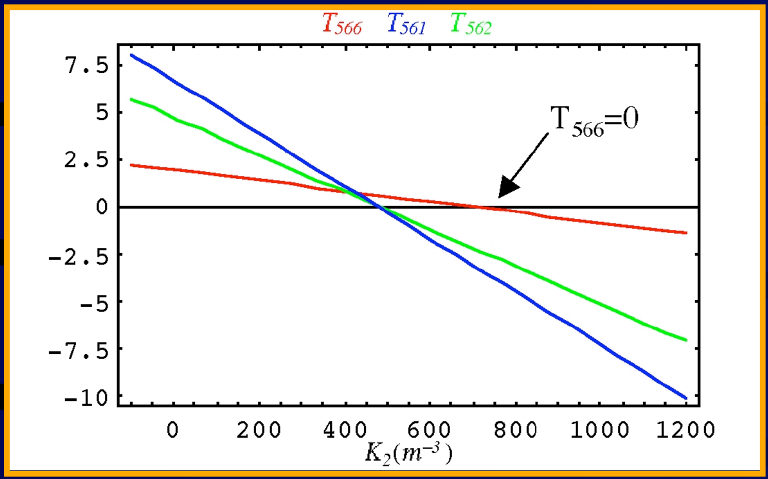
S-Bahn Compressor



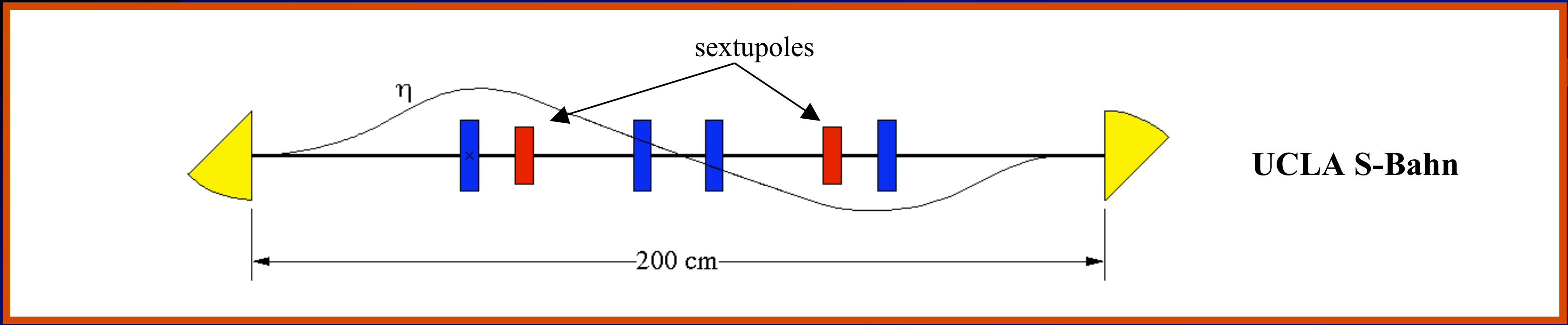
- S-Bahn is a “dogleg” or dispersionless translating section.
- Half-chicane with focusing elements between the bends.
- Can be operated in a nondispersive mode with symmetric beta function and 2π betatron advance.
- Like a chicane, may be used as a bunch-length compressor.
- Nominal first order temporal dispersion (R_{56}=-5cm) is suitable for beam-shaping.

Neptune Dogleg Compressor

Sextupole Design

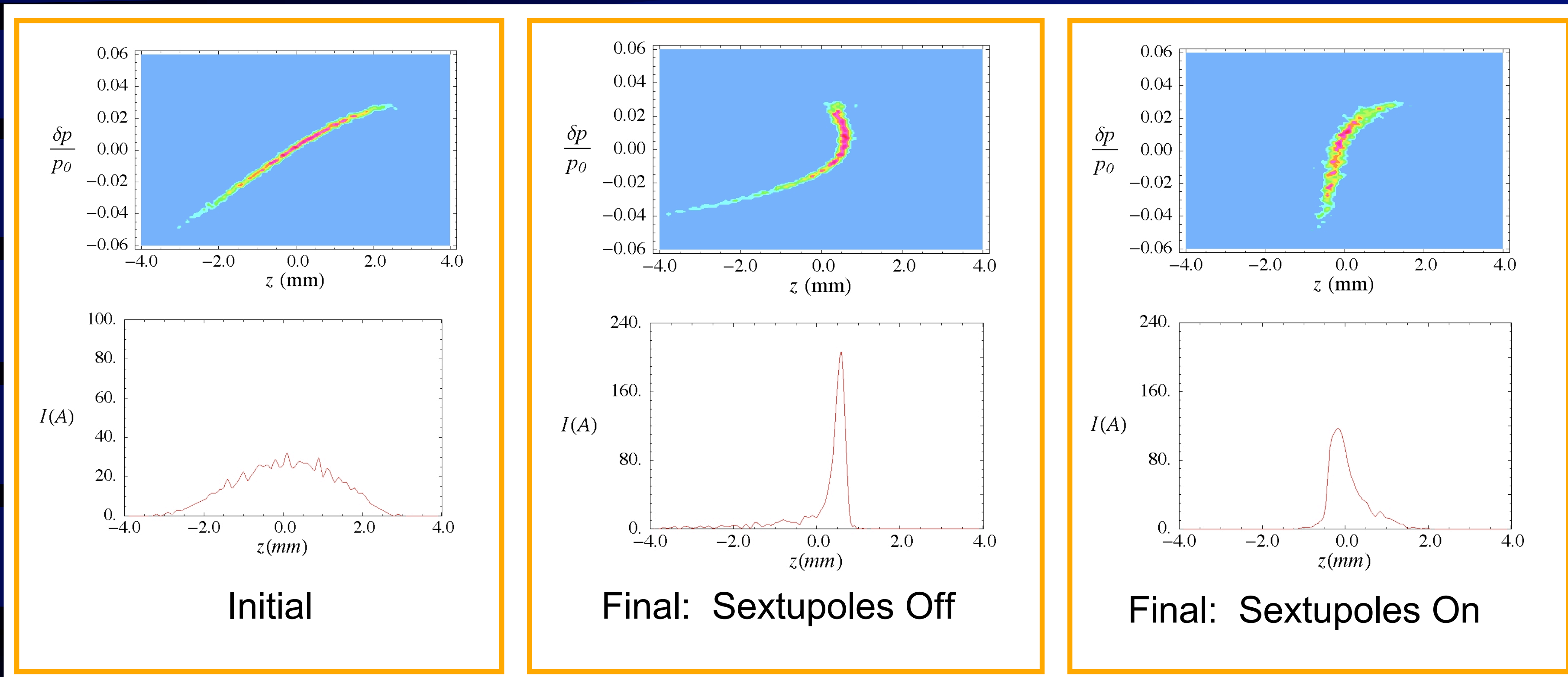


- Elegant matrix analysis.
- Sextupoles included to 2nd order.
- T_{566} vanishes at sufficient sextupole field strength K_2.
- Other nonlinearities (T_{561}, T_{562}) are also reduced by about 50%.



Neptune Dogleg Compressor

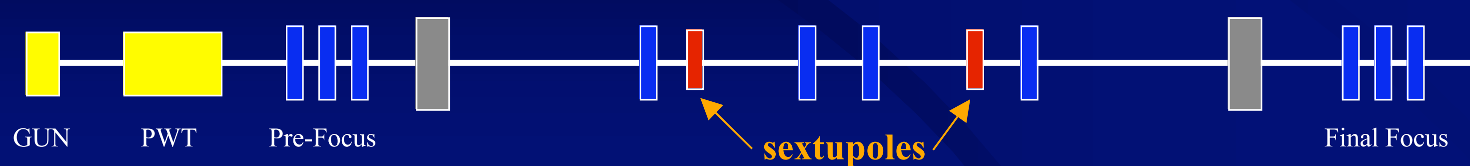
PARMELA Simulation Results: 1000 particles, 300pC



Initial | Final: Sextupoles Off | Final: Sextupoles On

$\varepsilon_{x,N\,(\text{initial})}$ = 4.9 μm

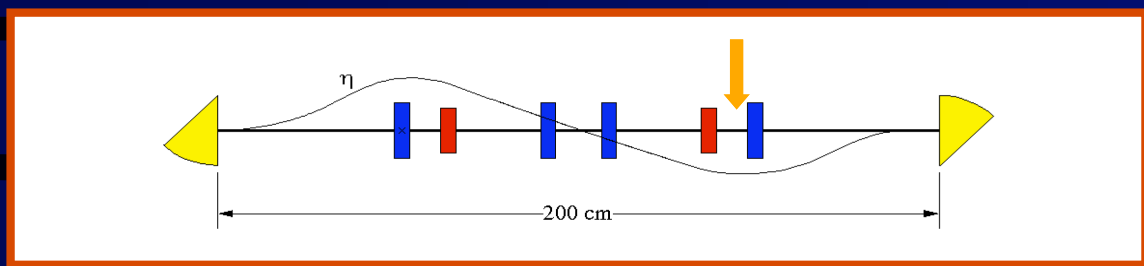
$\Delta\varepsilon_{x,N}$ = 9.9 μm (space-charge) + ~~12.7~~ 1.6 μm (nonlinear) = ~~22.6~~ 11.5 μm (total)



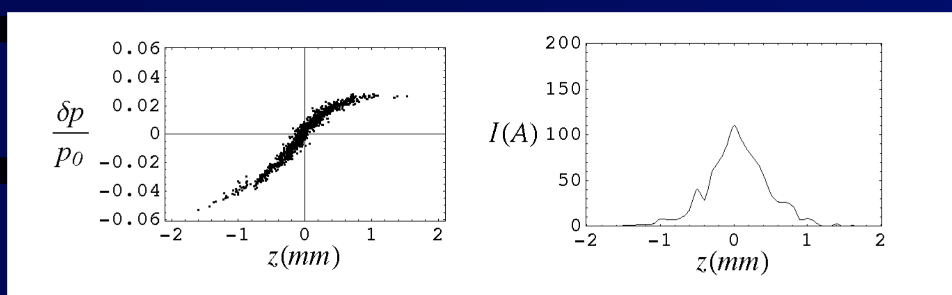
Neptune Dogleg Compressor

ELEGANT: Simulated Witness Beam

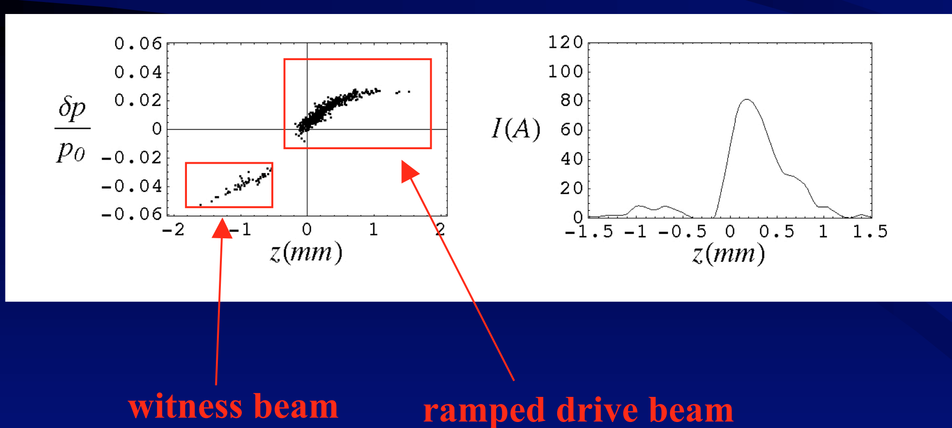
For PWFA application, drive beam needs a witness beam to accelerate.



Region of high dispersion in x
Strong correlation b/w x and z
Insert mask in x to **sever** beam in z



No mask inserted
Undercorrected with sextupoles to elongate profile



With 1cm mask inserted at above location

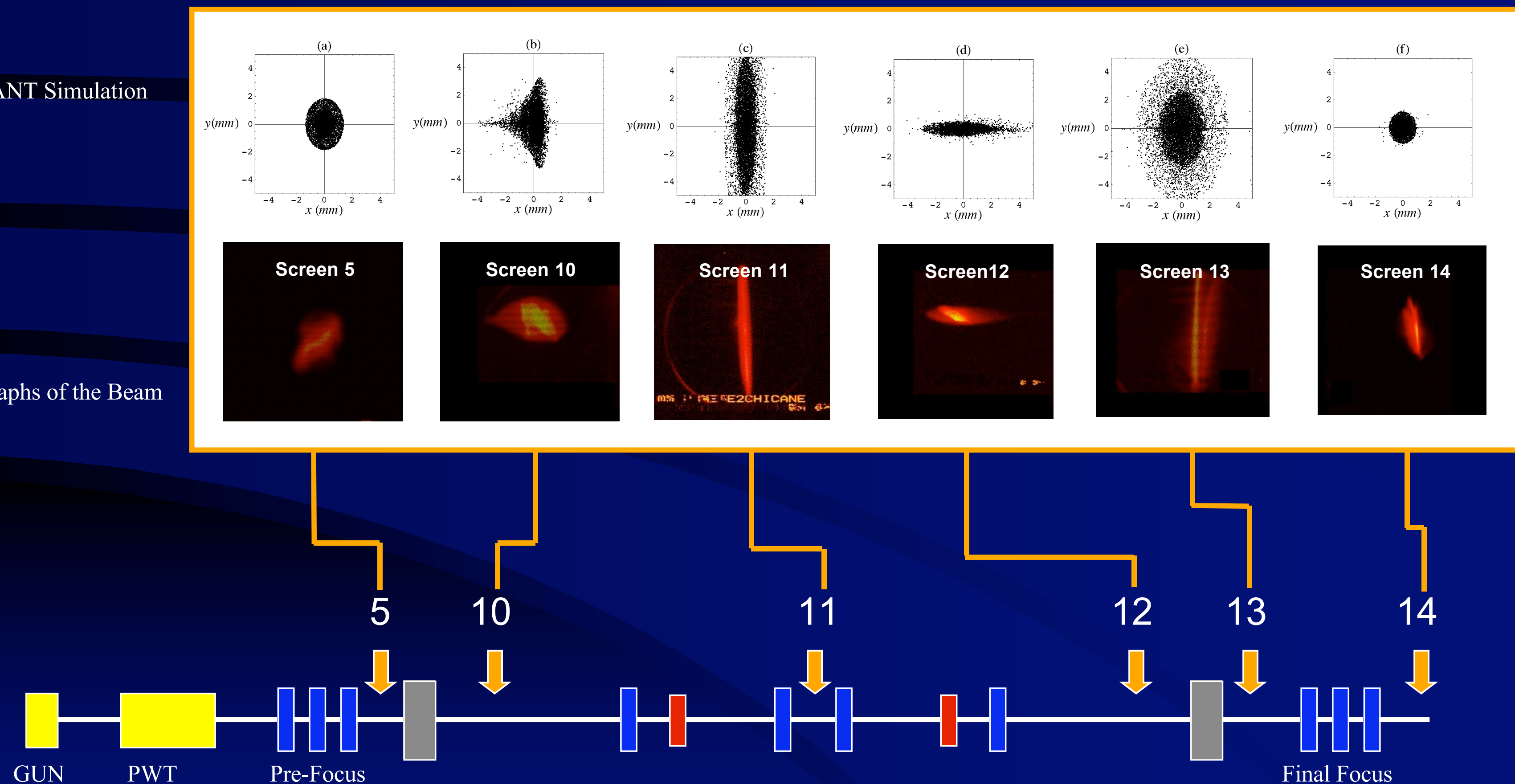
Recent Results

Transverse Measurements: Beam Size

Measured beam size and simulation agree within 20%.

ELEGANT Simulation Results

Photographs of the Beam



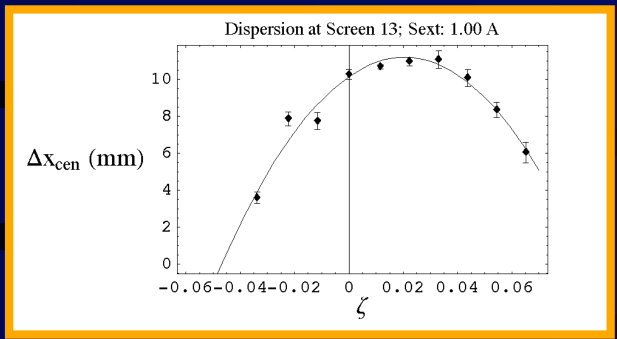
Recent Results

Transverse Measurements: Nonlinear Dispersion T_{166}

Nonlinear Horizontal Dispersion

- Can be manipulated with the sextupoles.
- T166 is correlated with T566.
- Nonlinear emittance growth is dominated by T166.

Example data with quadratic fit.



Changing the fields of all magnetic elements by a fractional amount δ produces a centroid offset Δx_{cen}.

$$\Delta x_{cen} = - R_{16}\,\delta + T_{166}\,\delta^2$$

Fitting centroid data to a *quadratic* in δ gives dispersion terms to 2nd order.

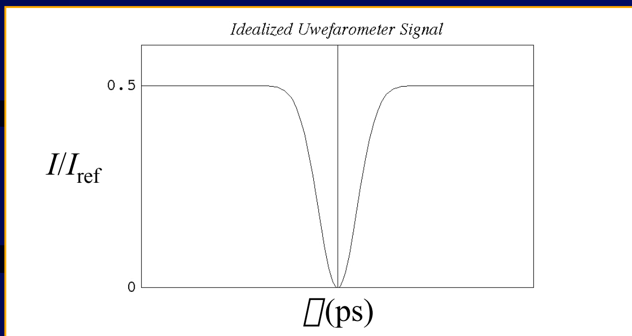
K_2 (m^{-2})	a	$T_{166,exp}$ (m)	$T_{166,sim}$ (m)
0	0	2.56±0.59	2.54
537	-2.13	0.22±0.77	0.26
995	-1.55	-1.27±0.93	-1.69

Experiment vs. ELEGANT simulation.

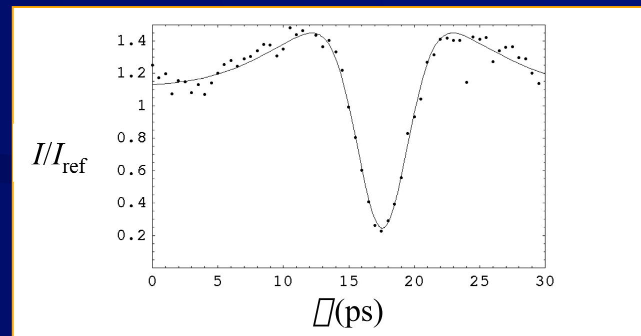
Recent Results

Longitudinal Measurements

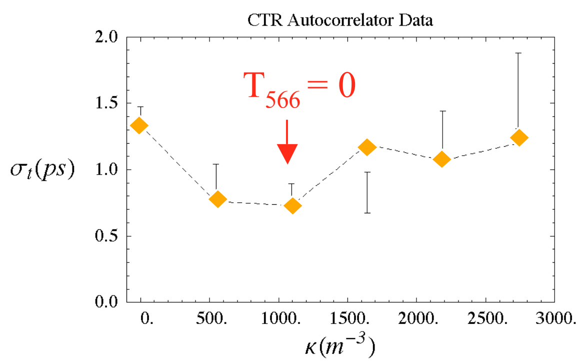
- Martin-Puplett CTR Interferometer
- Bunch length measurement by autocorrelation.
- Sub-picosecond resolution obtainable.



Ideal

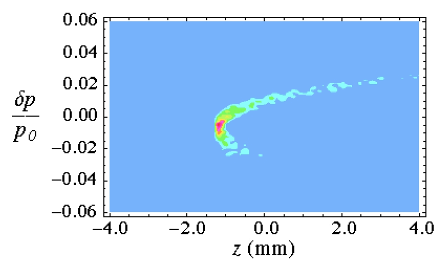


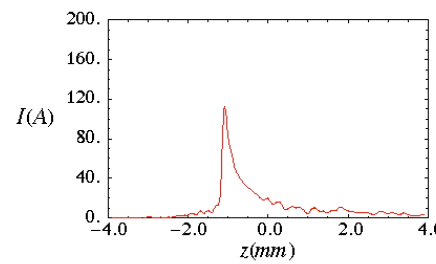
Actual Data



Comparison of Data with Simulation

Sextupole Field: 2735 m^{-3}





ELEGANT Simulation

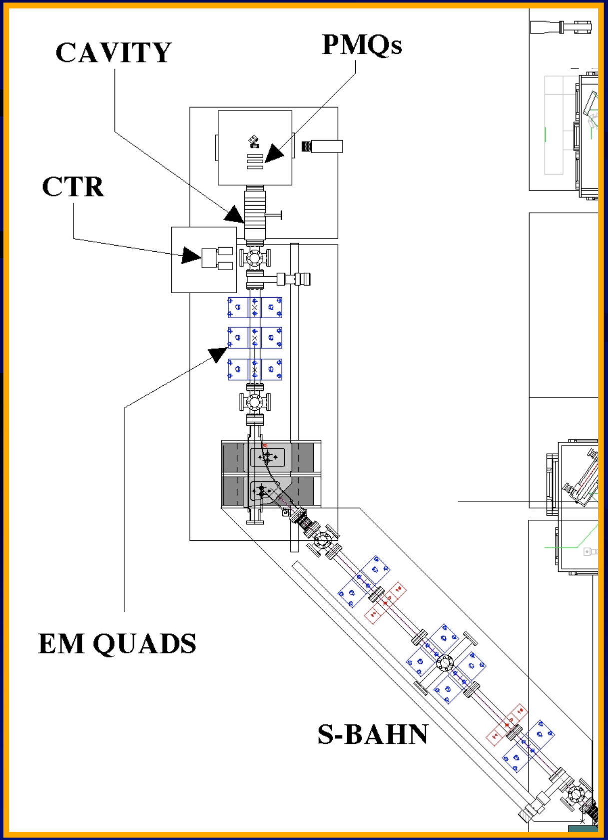
Future Experiments

Overview

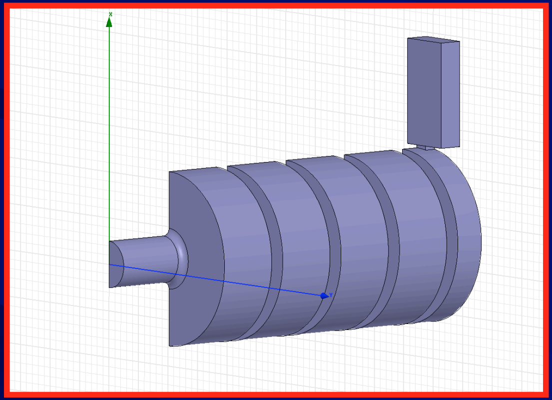
To develop this scheme for use as a PWFA drive beam, we need:

- **Asymmetric bunch, with a ramped profile**
- **Large beam density (600 pC, 70µm spot size)**

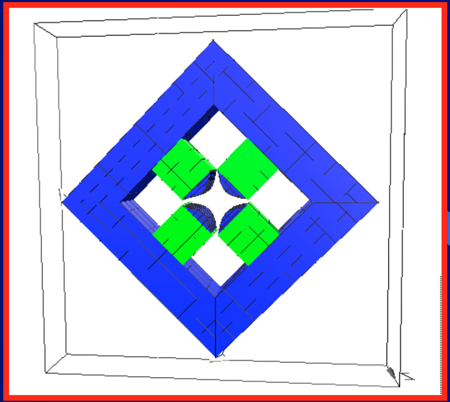
For which we require appropriate hardware and diagnostics:



Deflecting Cavity
z profile measurement



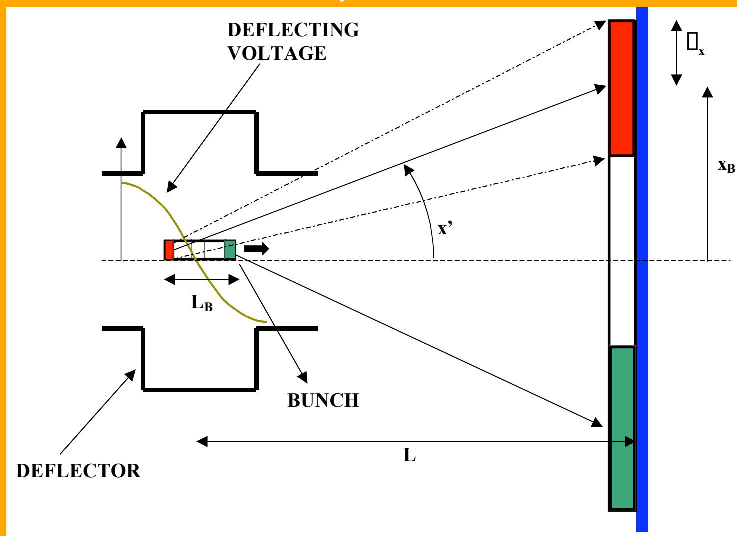
PMQ Final Focus
$n_b > 10^{13}\ cm^{-3}$



Future Experiments

Deflecting Mode Cavity

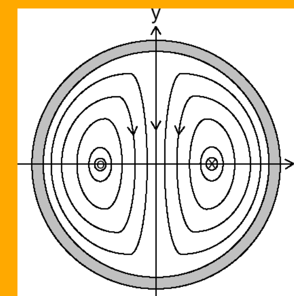
Courtesy of D. Alesini



Lowest dipole mode is TM_{110}
Zero electric field on-axis (in pillbox approx.)
Deflection is purely magnetic
Polarization selection requires asymmetry

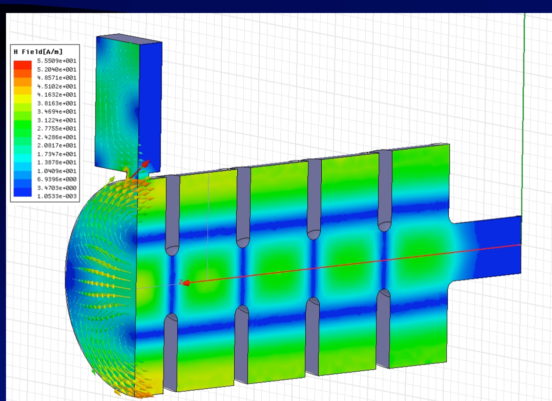
$$x' = \frac{\pi f_{RF} L_B \sqrt{2 P_{RF} R_{\perp}}}{cE/e}$$

$$x_B = \frac{\pi f_{RF} L L_B \sqrt{2 P_{RF} R_{\perp}}}{cE/e}$$



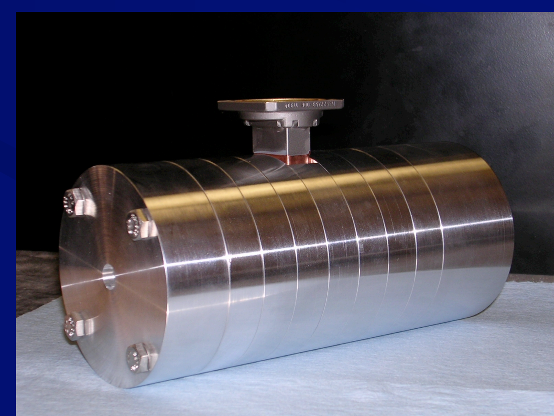
J.D. Fuerst, et. al., DESY Report CDR98, 1998

Half-cavity (4.5 cells) from HFSS.



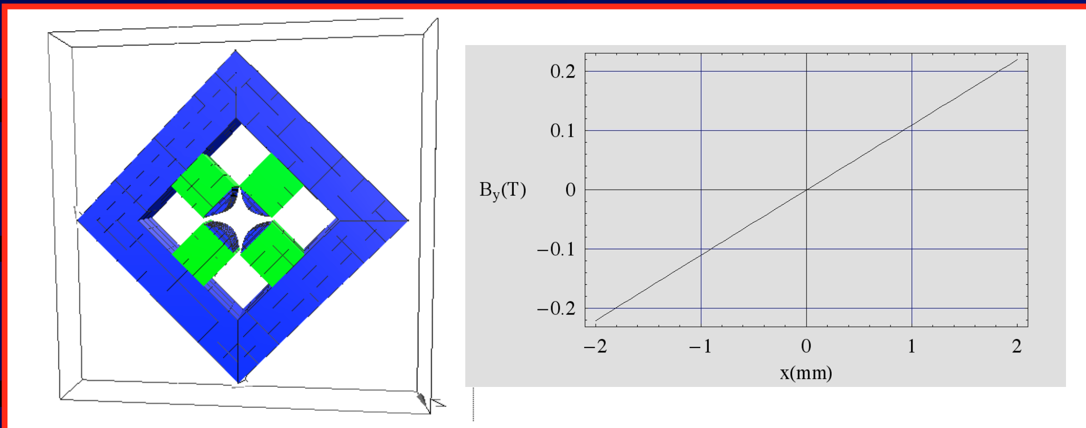
- X-Band, 9-cell design.
- Collaboration with INFL Frascatti.
- Will be built at UCLA;
- Diffusion bonded at SLAC.
- Powered by 50 kW X-Band klystron
- Frequency: 9.3296 GHz

Photo of cold-test prototype.



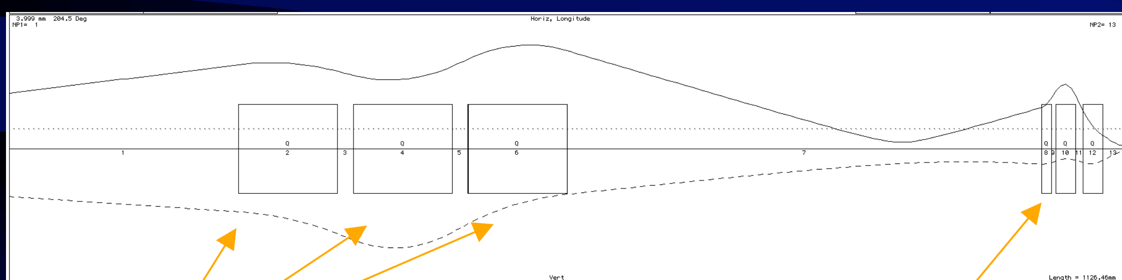
Future Experiments

PMQ Final Focus



- Hybrid Permanent Magnet and Iron
- Green cubes are Alnico; M=1.175 T
- Field gradient:
  B'=110 T/m; B''=-0.002 T/m^2
- Bore diameter: 8mm
- Benefits: cheaper, better field profile
- Downsides: small bore; in-vacuum

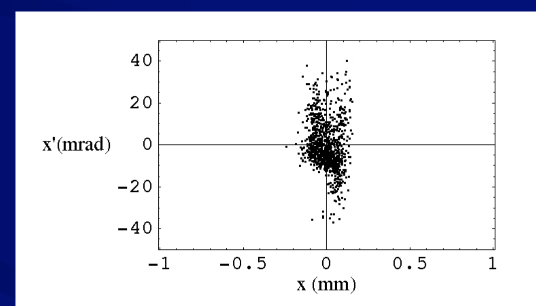
← S-Bahn



PowerTrace Simulation

standard iron quads

PMQs



ELEGANT Simulation

$\square_{x,f} = 67\mu m$; $\square_{y,f} = 75\ \mu m$

Conclusions

Dogleg Compression and Beam Shaping:

1. Application to PWFA Drive Beam Studies
2. Neptune and ORION
3. Use of sextupoles for T_{566} correction: linearize compression

Initial experimental results show:

1. Horizontal dispersion measurement: successful use of sextupoles
2. CTR interferometry: sub-ps beam (RMS) and longitudinal manipulation

Long-term experiments:

1. PMQ Final Focus: generate σ_r<70µm compressed beam (n_b>10^{13} cm^{-3});
2. Deflecting Cavity: longitudinal profile measurement