The VISA Program:
Recent Results and Measurements

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ATF Users Meeting

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Collaboration

- UCLA PBPL
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- BNL ATF
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- INFN LNF
  - M. Ferrario, L. Palumbo, C. Vicario

Outline

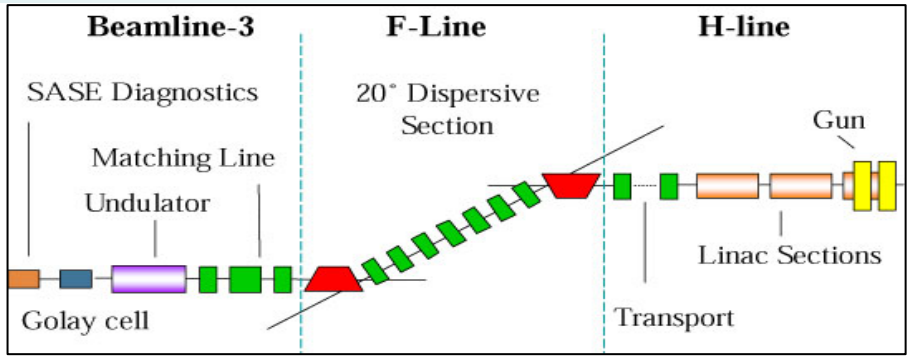
- History and Motivation
- Experiment Desciption
- VISA I Summary
- VISA IB Summary
- VISA II
- Current Program
  - Seeding Experiments
  - Orbital Angular Momentum
  - High Current Operation
  - Other Measurements
- Progress Report and Timeline

History

- VISA program has 10 year history with ATF
  - 1998: Proposed as precursor to LCLS
  - 2001: First lasing and saturation (840nm)
  - 2002: Harmonics, micro-bunching
  - 2004: Observation of ultra-wide bandwidth FEL
  - 2005: DDS (Double-differential spectrometer)
  - 2007: First lasing at 1micron
  - 2007: Seeding Studies
- Scientific results / publications
  - Journals - PRL, PRE, NIMA, etc.
  - Numerous Conf. Proc. (PAC, FEL, etc.)
  - Tech. Notes
  - 2 PhD dissertations (at least 2 more coming)
- Funding
  - ONR, NSF, DoE BES, DoE HEP

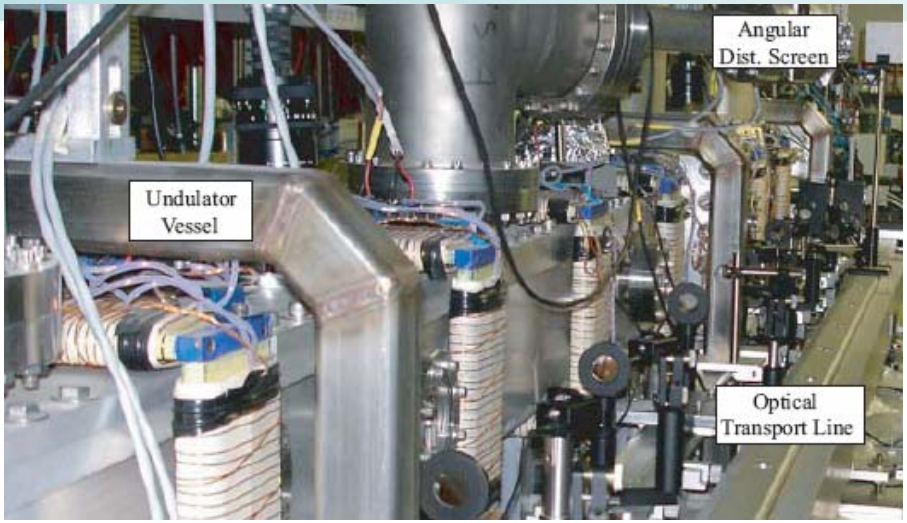
Experiment Layout

- Accelerator Test Facility (ATF)
  - Host for VISA program
  - up to 72 MeV beam
  - 28 m beam transport
    - 20 deg bend (F-line)
  - ATF provides maintenance and support
- Undulator
  - 4 x 1m sections
  - FODO lattice superimposed (25 cm period) –strong focusing
  - External steering coils (8)
  - Intra-undulator diagnostics
    - 50 cm apart
    - double-sided silicon
    - SASE FEL & e-beam (OTR)



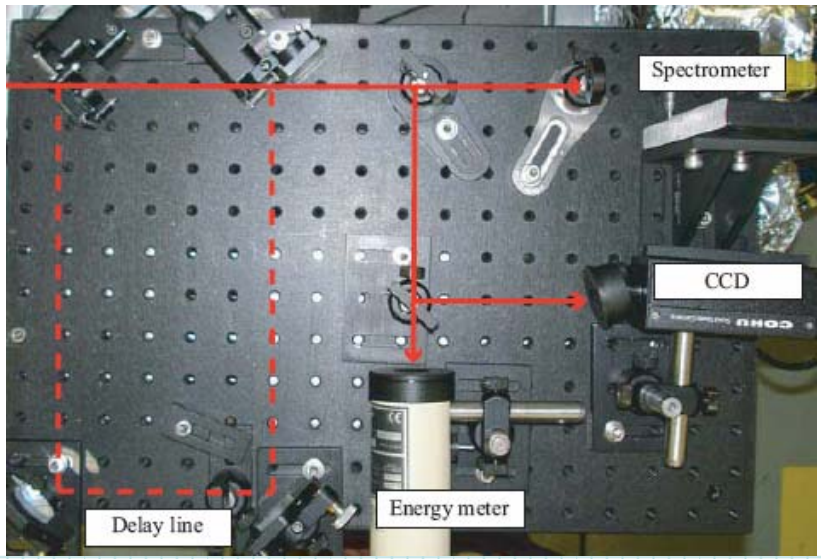
VISA Undulator Parameters	
Undulator type	Planar (NdFeB)
Number of periods (N_u)	220
Peak field (B_{pk})	.75 T
Undulator Period (λ_u)	1.8 cm
Gap (g)	6 mm
Undulator Parameter (K)	1.26

Hardware and Diagnostics



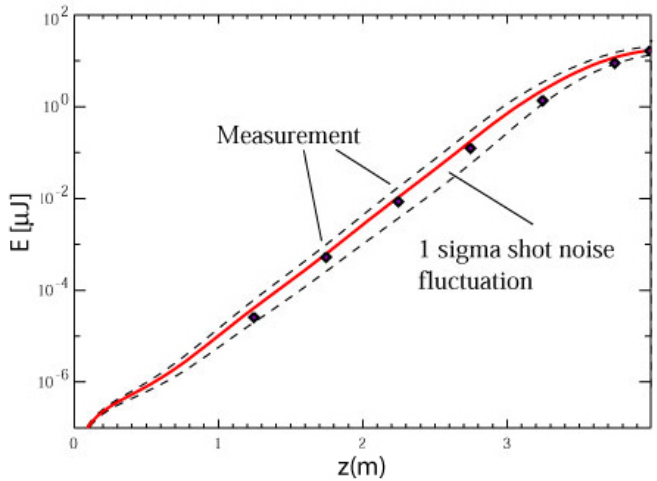
Optical Transport Line
- Array of lenses, mirrors
- transport radiation from each port

Simultaneous Diagnostic Station
- Beam splitter, delay line
- Shot-to-shot diagnostic
  - charge, spectrum, profile, energy
- modular
  - add new diagnostics (FROG)
  - advanced diagnostics (DDS)

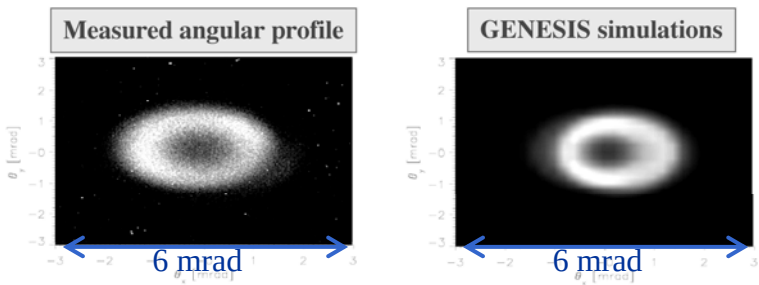


VISA I Summary

- Results
  - Gain ~ 10^8 due to nonlinear compression in dog-leg (F-line)
  - Shortest gain length recorded in NIR (18 cm @ 840nm)
  - Higher order angular spectra
  - CTR & Higher Harmonic Gain
- Start to End Simulation Suite
  - Parmela
  - Elegant
  - Genesis
- Codes Benchmarked to measurements
  - Post linac, post-dogleg, FEL



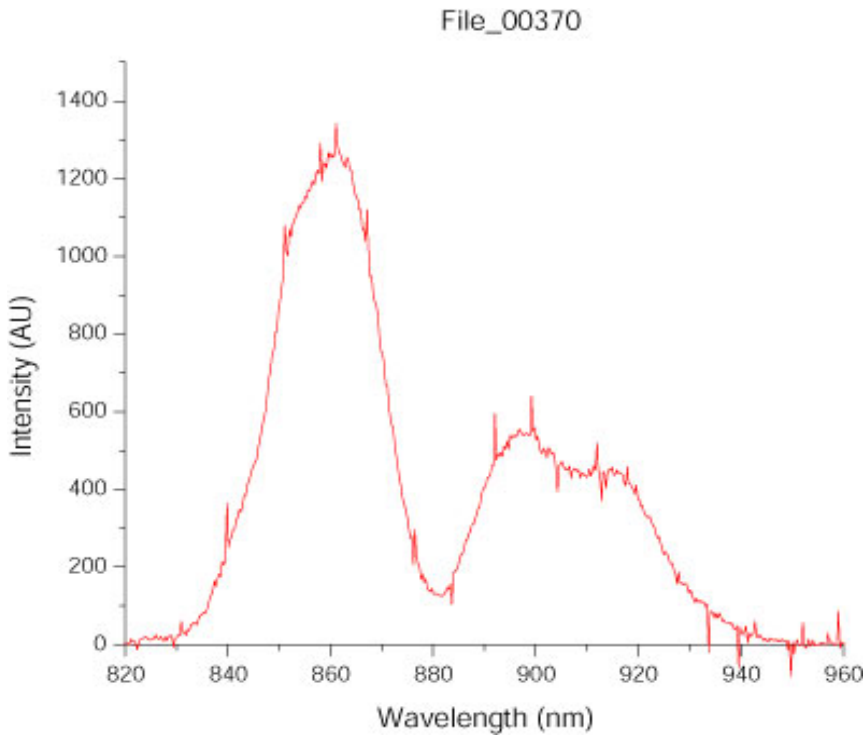
VISA I Gain Curve



Far-field radiation pattern (angular spectrum): measured (left), simulation (right)

VISA IB Summary

- High gain FEL
  - Chirped beam amplification
  - SASE energy ~2 μJ
  - close to saturation
- Up to 15% bandwidth observed
- Very reproducible and unusually stable
  - insensitive to RF drifts and phase jitter
- Characteristic double-spike structure

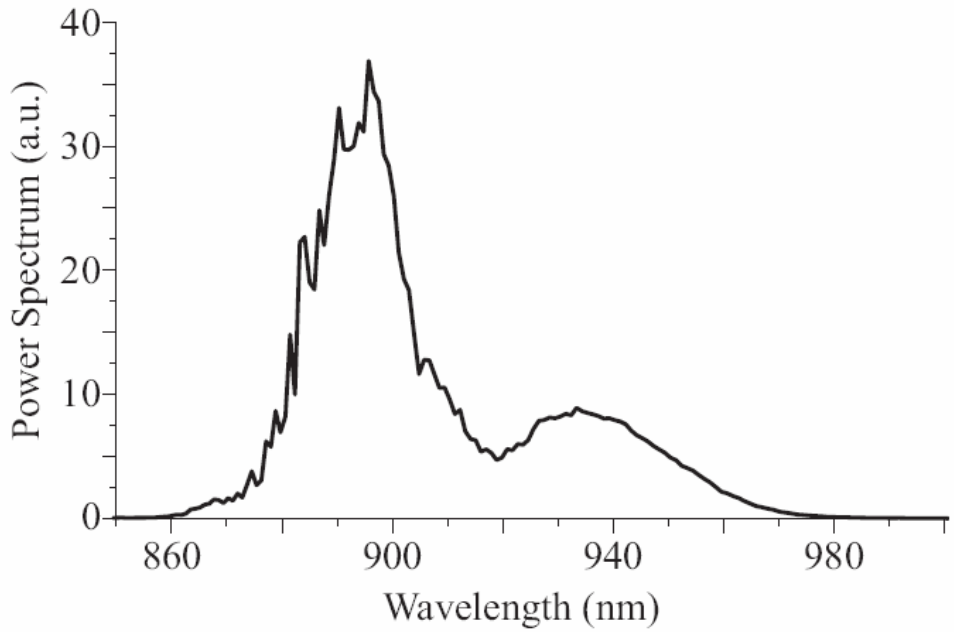


Wavelength Spectrum of FEL at VISA measured with Ocean Optics USB2000 Spectrometer.

VISA IB Analysis

- Start-to-End
  - Experimental Spectrum features reproduced
  - Numerical Studies on no energy spread case yield similar results
  - Angles Important
    - Off-axis Doppler Shift

$$\lambda_r = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{1}{2}K^2 + (\gamma\theta)^2\right)$$

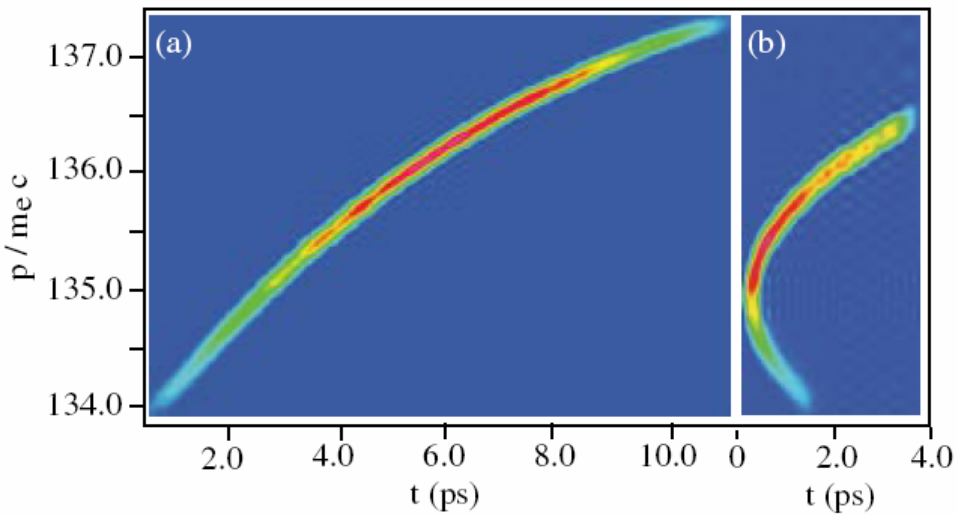


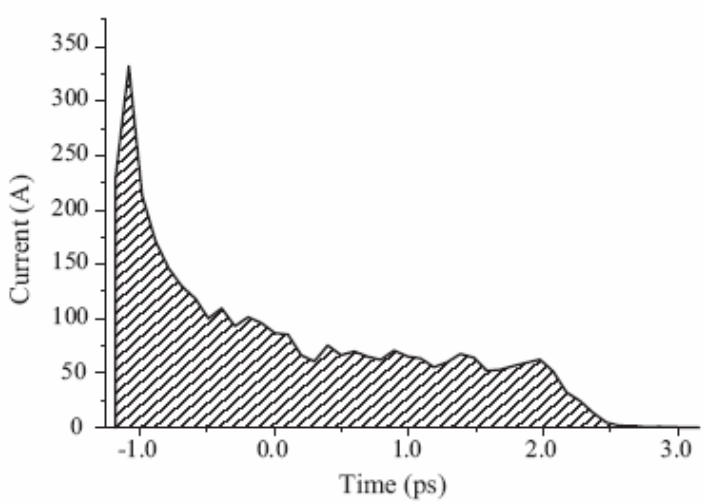
FEL output Power Spectrum reproduced by Genesis (~12% bandwidth)

VISA IB Analysis (STE)

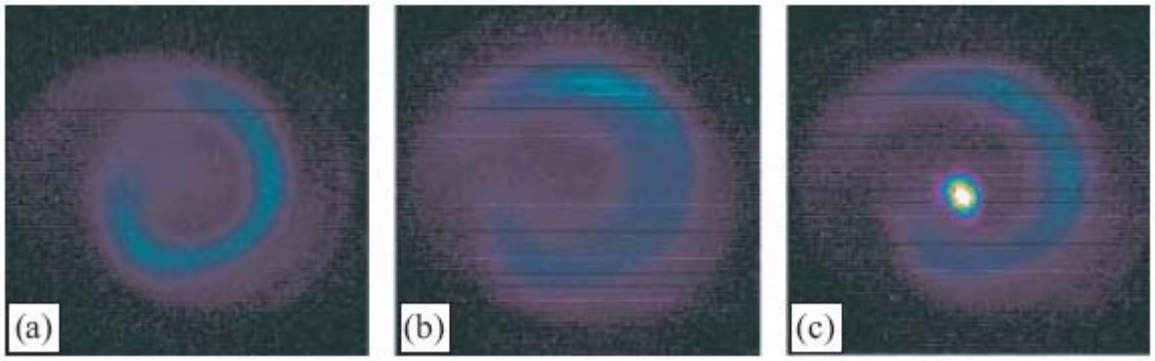
- Linear chirp applied at linac
- Compression in dogleg
  - Portion of beam is always in “correct” comp. regime
  - Collimation ~40% (~300 pC)
  - Benchmarked to data taken in F-line
- Leads to off-axis injection of compressed core

- High Current
  - peak > 300 A
  - Better than VISA I





Angular Dist.

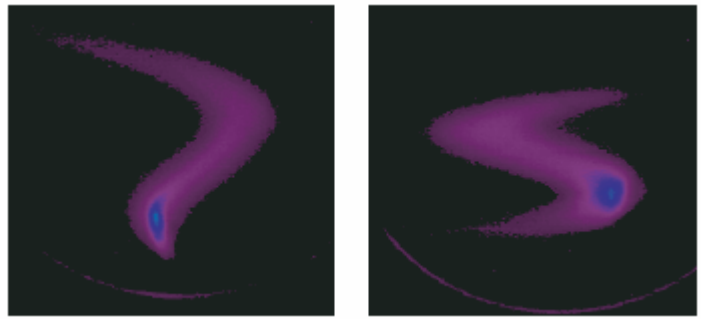


- Far-field Angular Distribution Pattern
  - Screen placed ~3m (10 Z_R) away
  - Hollow modes similar to VISA I
    - more pronounced in angle
    - Helical patterns observed
  - Investigate with mode converter (later)

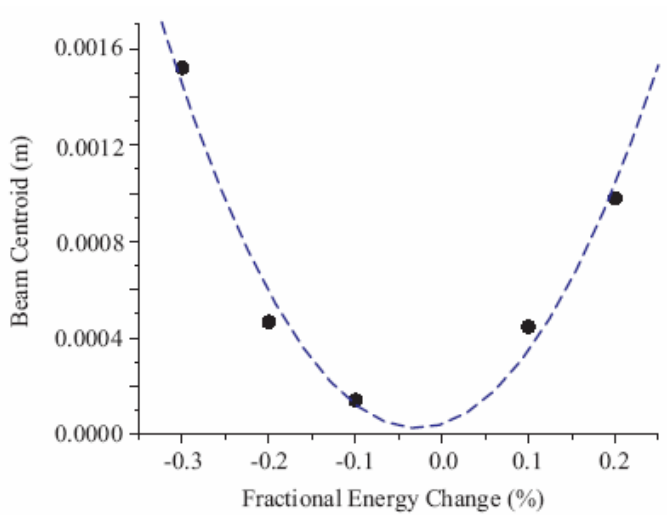
VISA II: Sextupoles

- Hardware Status
  - Sextupoles installed
  - Tested and operational
- Sextupole operation
  - T_{166} measurement
  - correlate to T_{566} from simulations

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



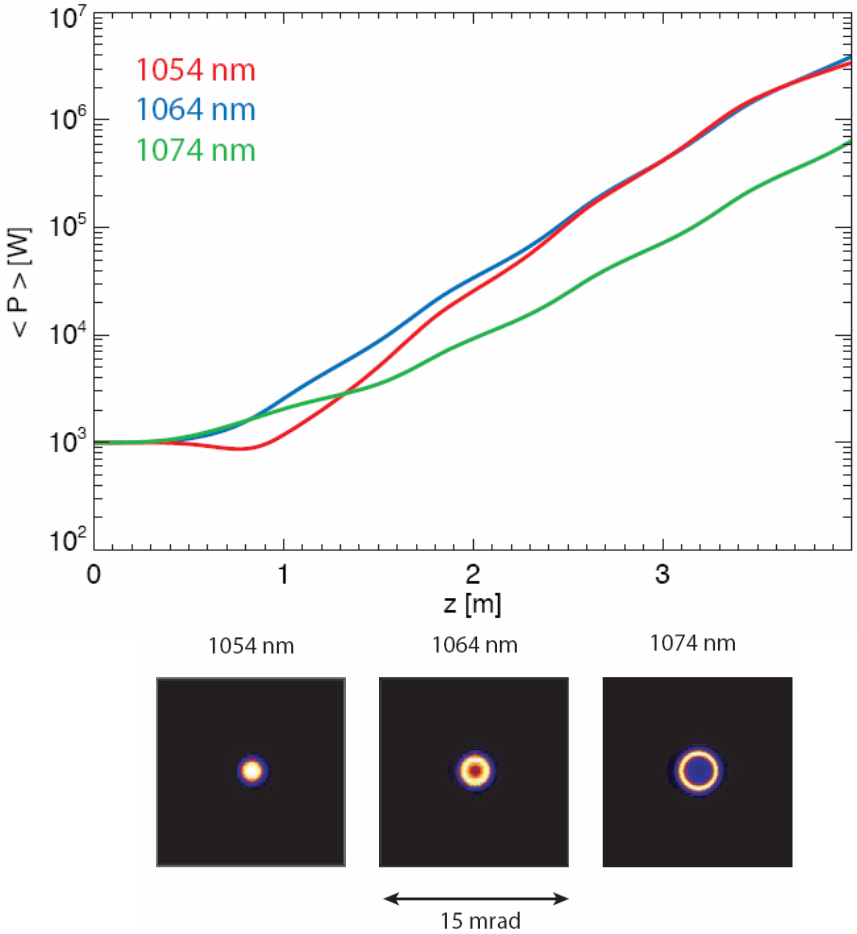
e-beam profile in F-line with sextupoles on



T_{166} measurement: T_{166}=1.94 m, R_{16}=0.01m

Seeded Amplifier

- Motivation
  - Control and manage high power FEL beam in far-field
  - Establish transverse & longitudinal coherence with seeded pulse (low bandwidth, high brightness)
- Far field studies
  - Increase angle, decrease intensity
  - e.g. deliver high power without damaging optics
- Experiment
  - VISA undulator with 61 MeV beam
  - Seed with 1064 nm YAG
- Study detuning effects with start-to-end simulations
- Study coherence with double-slit, pepper-pots



SA Status

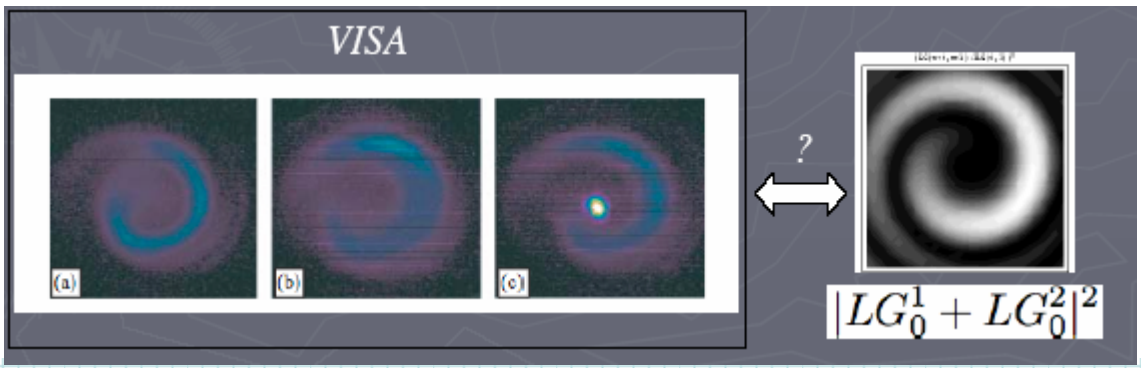
- Transverse Alignment
  - aligned on profile monitors
  - waist positioned ~40cm downstream of undulator entrance
    - maximize the interaction with e-beam and seed when the seed is most intense (combat diffractive effects)
- Longitudinal alignment (timing)
    - sensitive photodiode (100-200ps resolution)
    - using YAG with SASE signal (or striplines)
    - scan in 10ps steps with delay line “trombone”
  - upgrade diagnostics for 1 micron
    - CCD, spectrometer
- Observed SASE at 1030-1064nm
  - high gain (~20nJ)

Ongoing Projects

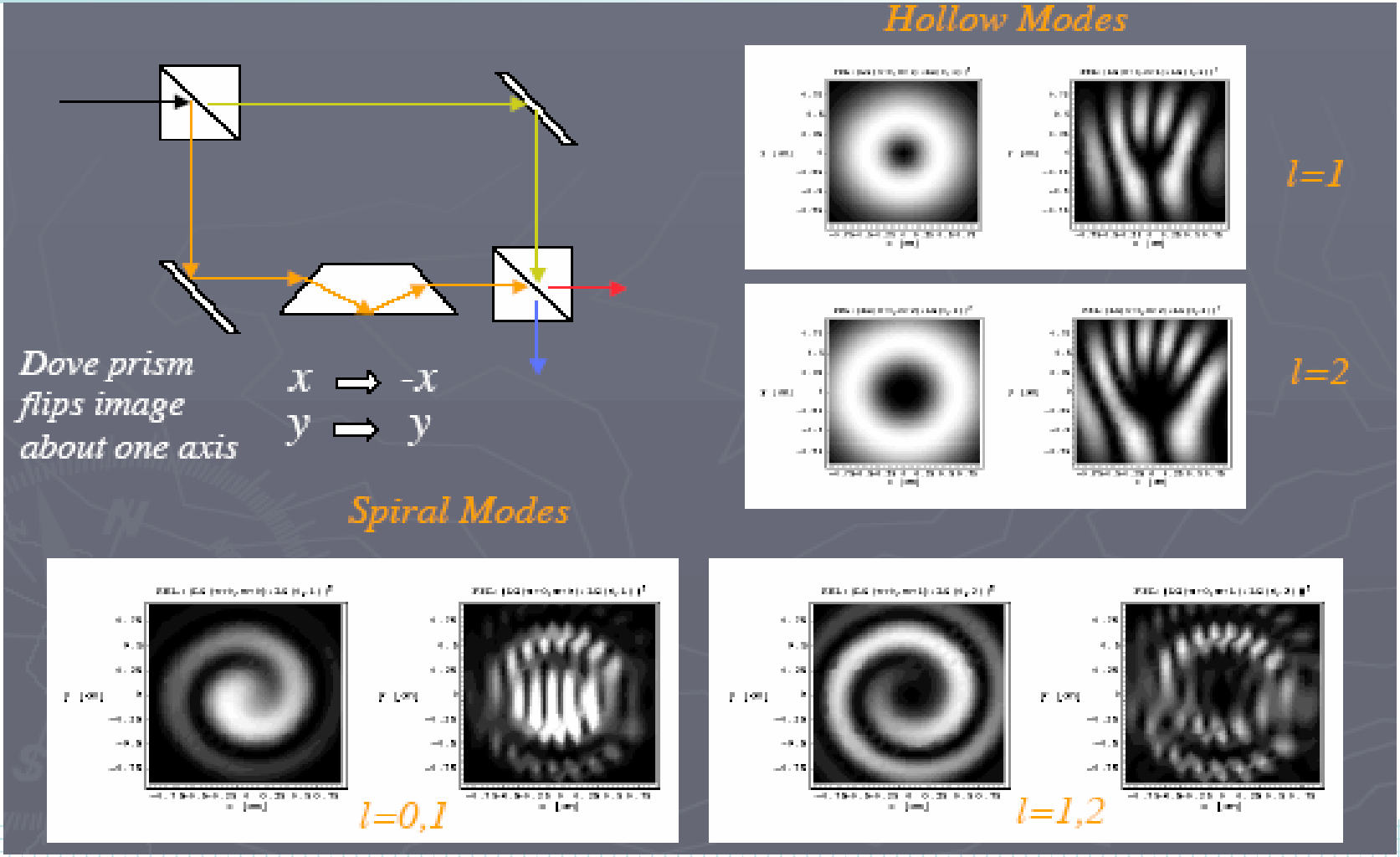
- VISA Collaboration has more ideas and measurements
  - Orbital Angular Momentum measurement
    - further investigate hollow modes and spiral features of FEL
  - High Current FEL
    - SASE with dedicated beam compressor
    - Energy spread mitigated by x-band cavity (silencer)
  - Transition Undulator Radiation
    - radiation due to the change in long. velocity of e-beam at entrance and exit of undulator
    - radial polarization
    - need polarizer, rotatable mount, and dipole (or steerer) to kick beam before exit port

OAM Measurements

- Research goal
  - Characterize and determine the origin of exotic structures in distribution of VISA
  - OAM describes the helicity of the phase evolution
    - “helical” light described as a combination of LG modes
  - Experiments
    - Off-axis interferometer
    - Coherence measurement (pepper-pot)

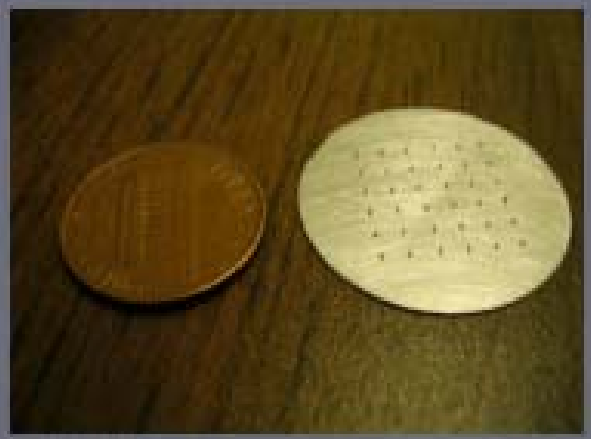


Off-Axis Interferometry



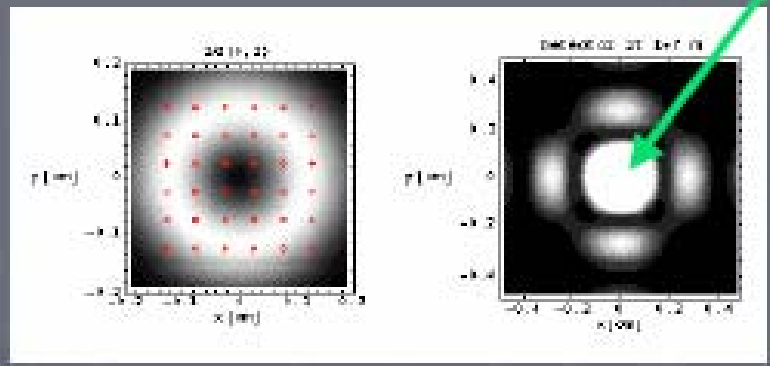
courtesy E. Hemsing

Coherence (Pepper-pot)



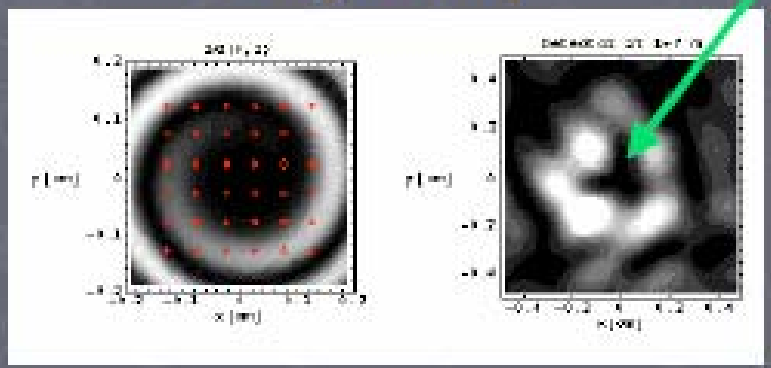
Gaussian

Peak



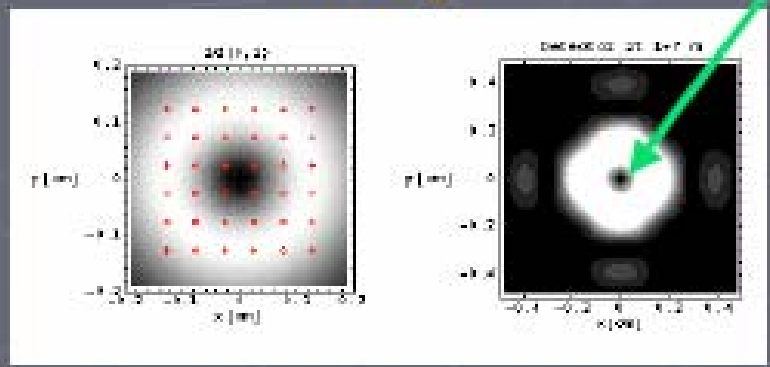
$LG^2_0 + LG^3_0$

Null



LG^1_0

Null

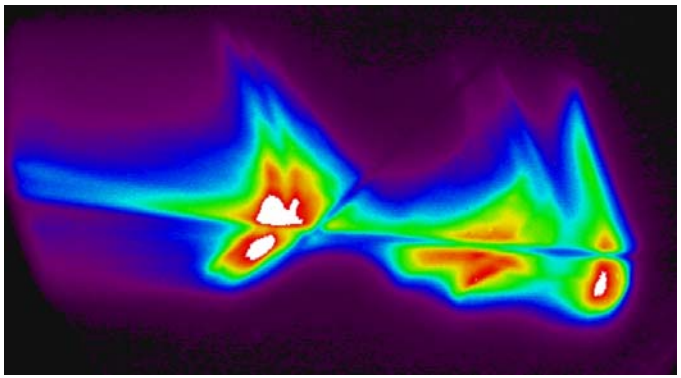


courtesy E. Hemsing

High Current VISA

- Chicane bunch compressor
  - increase current to kA level
    - shorten gain length
    - deep saturation studies
  - bifurcation
    - phase-space shredding
  - add x-band linac
    - “silence” energy spread
    - continue STE

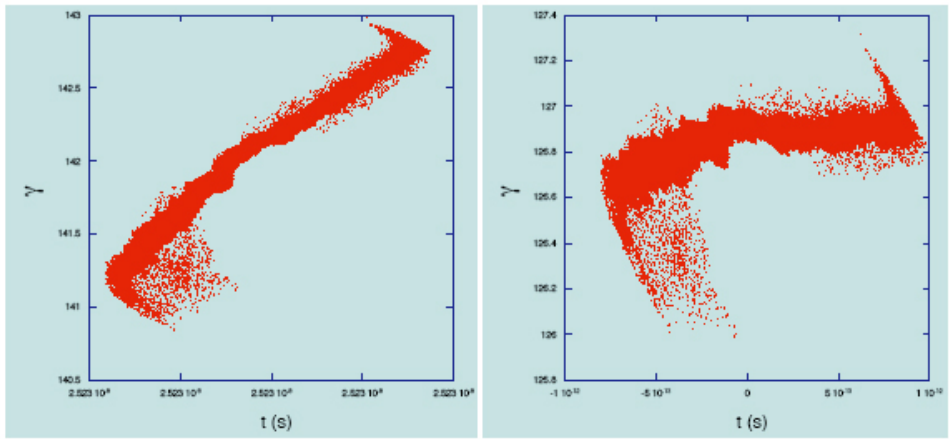
ATF bunch compressor CAD drawing.



Beam bifurcation of compressed beam

ATF bunch compressor installed in tunnel.

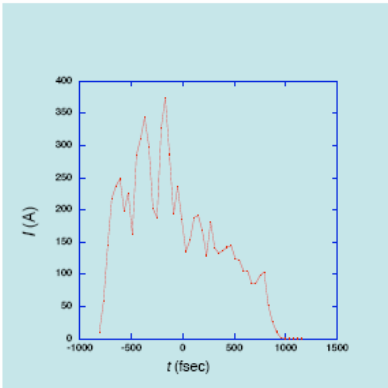
Silencer STE



after X-band linac (15MV/m)

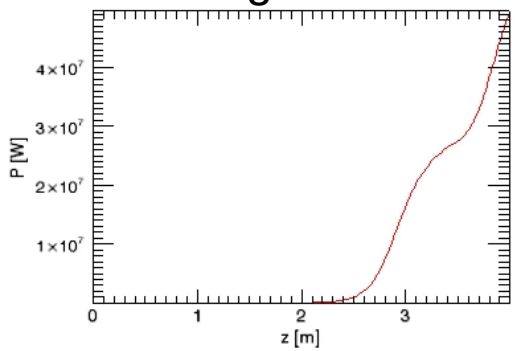
Longitudinal Phase space

(before and after x-band linac)



Current profile
(>300A)

Power gain curve



Near-term goals

- Measurements
  - Seeded Amplifier
    - Data by PAC (or FEL), PhD Thesis by M. Dunning
  - OAM
    - Mode-converter, phase front detector
    - Start-to-end studies, analytical studies
    - Data by end of year (or next), PhD Thesis by E. Hemsing
  - CTUR
    - Polarizer after undulator
- Hardware Upgrades
  - F-line enhancements
    - alignment laser (straighten if necessary)
  - Sensitive photodiode
    - higher resolution for seeding scans
  - x-band “silencer”

Conclusions

- The VISA program yields rich data sets
  - VISA I, VISA IB, VISA II, SA, OAM
    - Non-linear Compression
    - Observed anomalous ultra wide bandwidth
    - High gain chirped beam FEL
    - Studies on seeding and angular distribution meas.
    - Studies on hollow modes
  - Confidence in Start-to-end suite
  - Develop new diagnostics
- Only ultra short gain length SASE FEL in operation
  - great test facility for x-ray FEL projects that must use SASE
  - many surprises arise in any experiment
    - minimize the “surprises” one may encounter in large scale expt.
- More runs & data forthcoming
  - SA, OAM, Silencer, also Compressor Studies and RF undulator