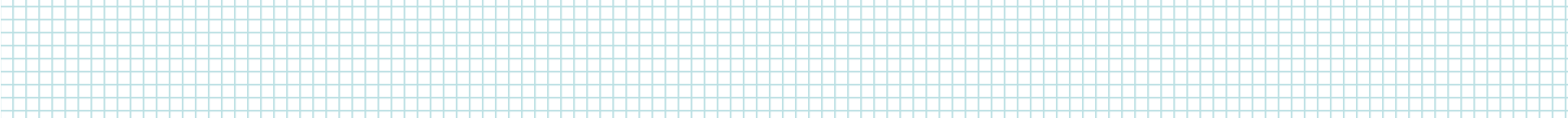




The VISA Program: Recent Results and Measurements

Gerard Andonian, UCLA
FEL Frontiers 2007
Elba, Italy
Sept 9-13, 2007



Collaboration

- UCLA PBPL
 - G. Andonian, M. Dunning, P. Frigola, E. Hemsing, A. Murokh, C. Pellegrini, S. Reiche, J.B. Rosenzweig
- BNL ATF
 - M. Babzien, I. Ben-Zvi, K. Kusche, R. Malone, V. Yakimenko
- INFN LNF
 - M. Ferrario, L. Palumbo, C. Vicario

Outline

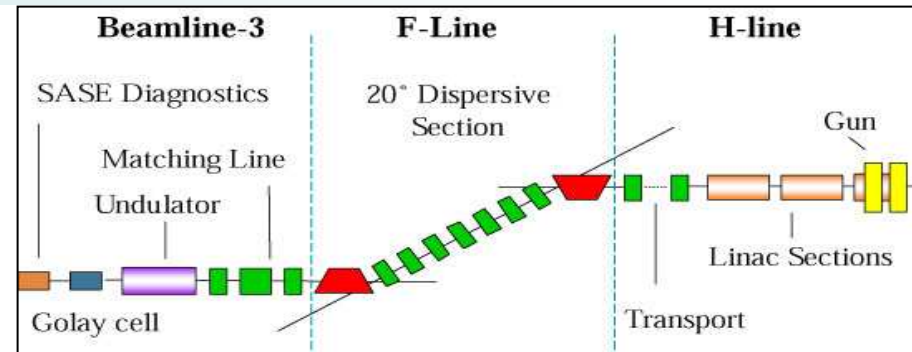
- Experiment Description
- Summary of Prior Results
- Current Program
 - Seeding Experiments
 - Orbital Angular Momentum
 - E. Hemsing Talk on Tuesday
 - High Current Operation
 - Other Measurements
- Conclusions

History

- VISA program has 10 year history
 - 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

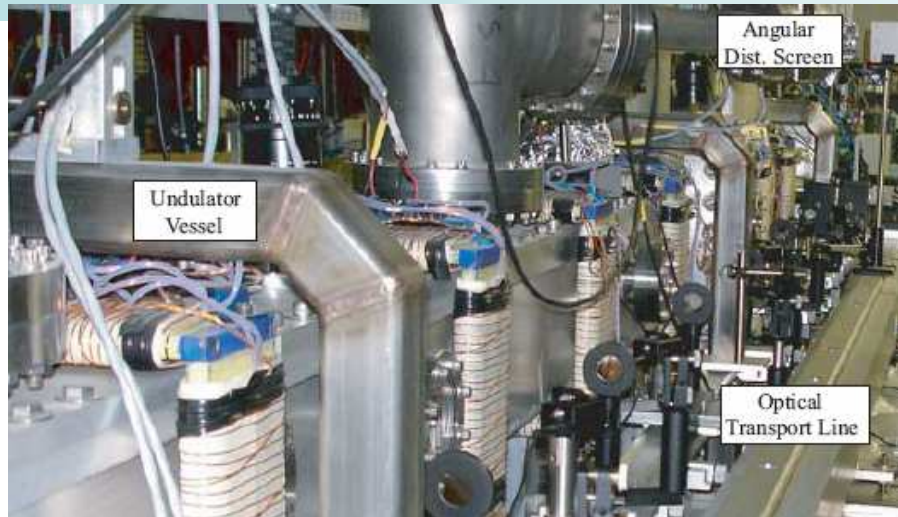
Experiment Layout

- 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



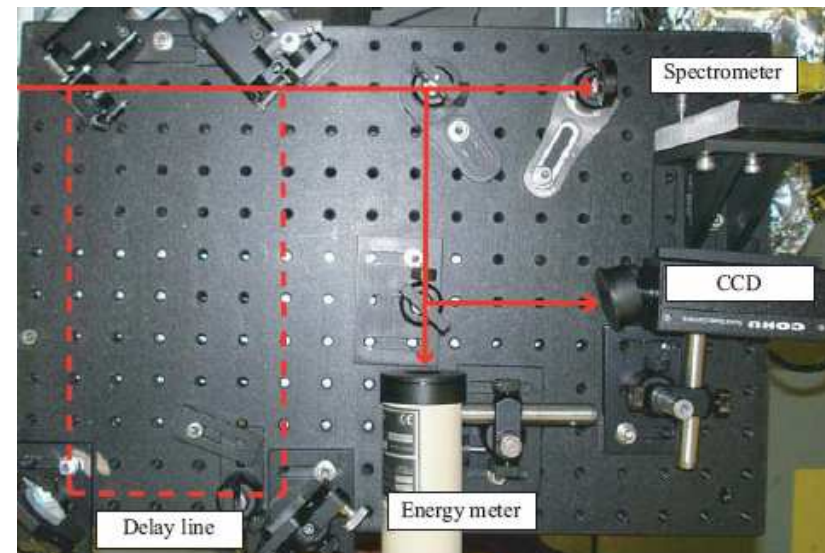
Optical Transport Line

- Array of lenses, mirrors
- transport radiation from each port



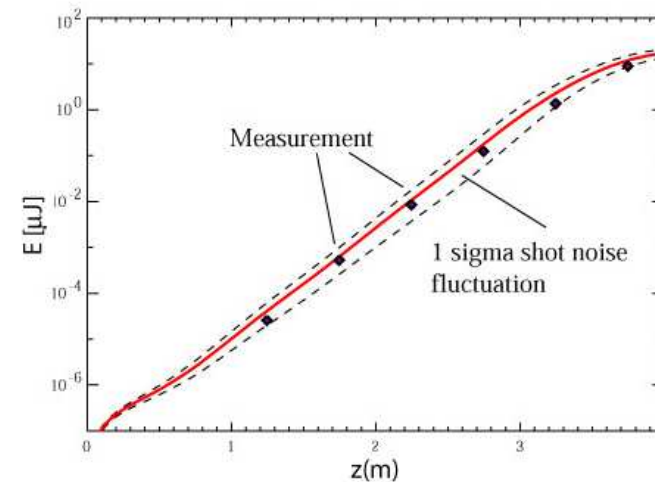
Simultaneous Diagnostic Station

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

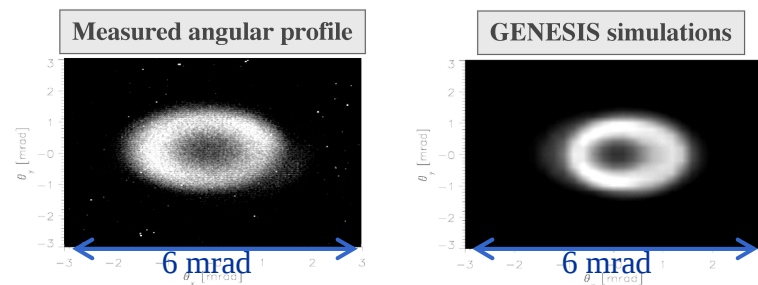


VISA I Summary

- Results
 - Gain $\sim 10^8$ 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



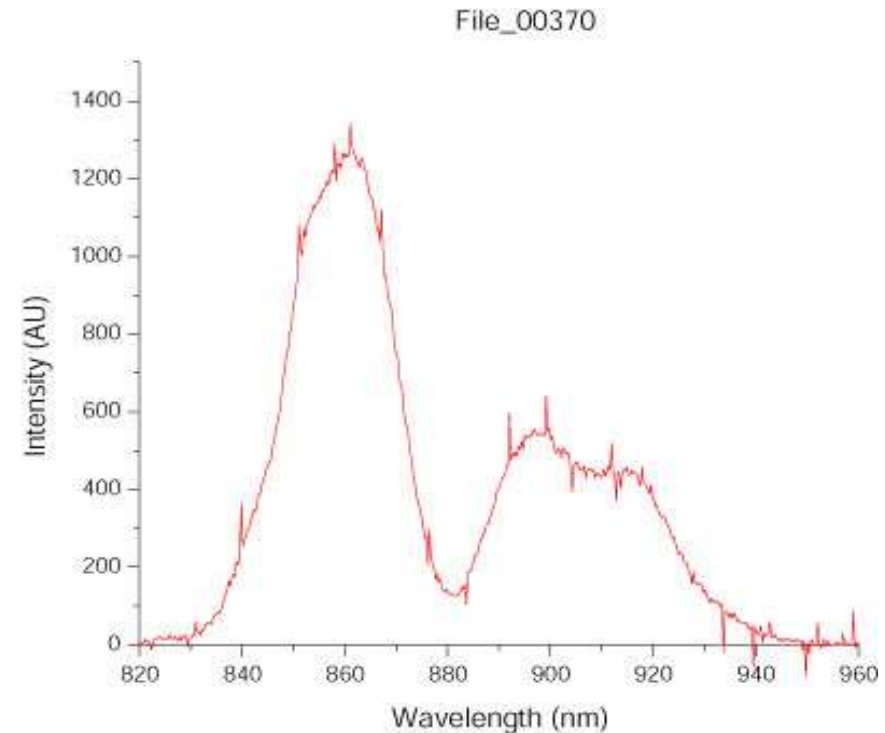
VISA I Gain Curve



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

VISA IB Summary

- High gain FEL
 - Chirped beam amplification
 - SASE energy $\sim 2 \mu\text{J}$
 - close to saturation
- Up to 15% bandwidth observed
- Very reproducible and unusually stable
 - insensitive to RF drifts and phase jitter
- Characteristic double-spike structure

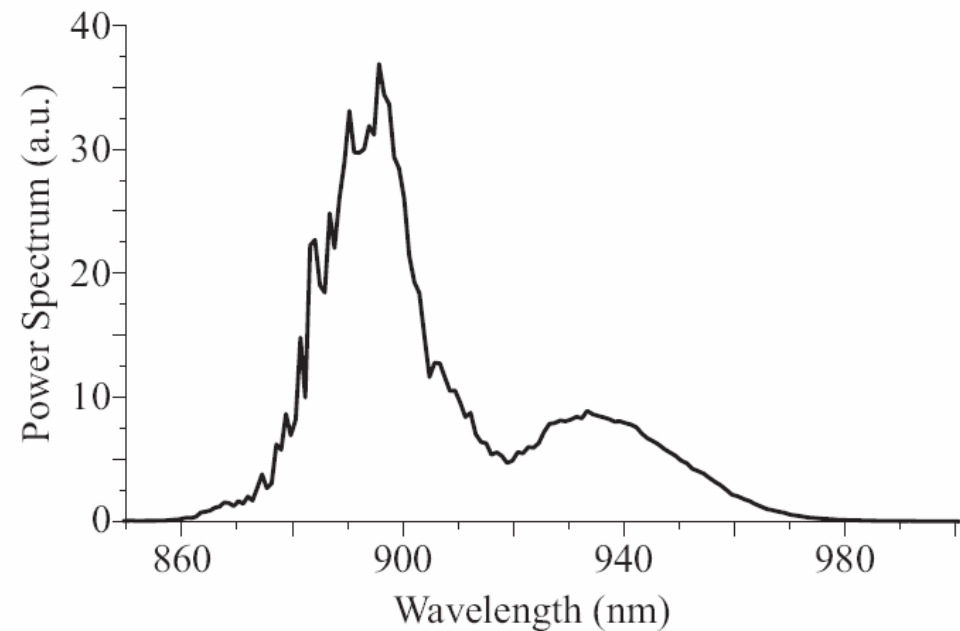


Wavelength Spectrum of FEL at VISA
measured with Ocean Optics USB2000
Spectrometer.

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

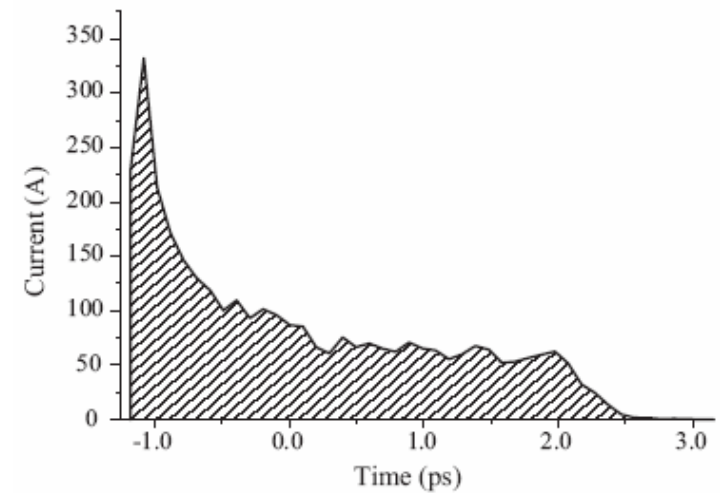
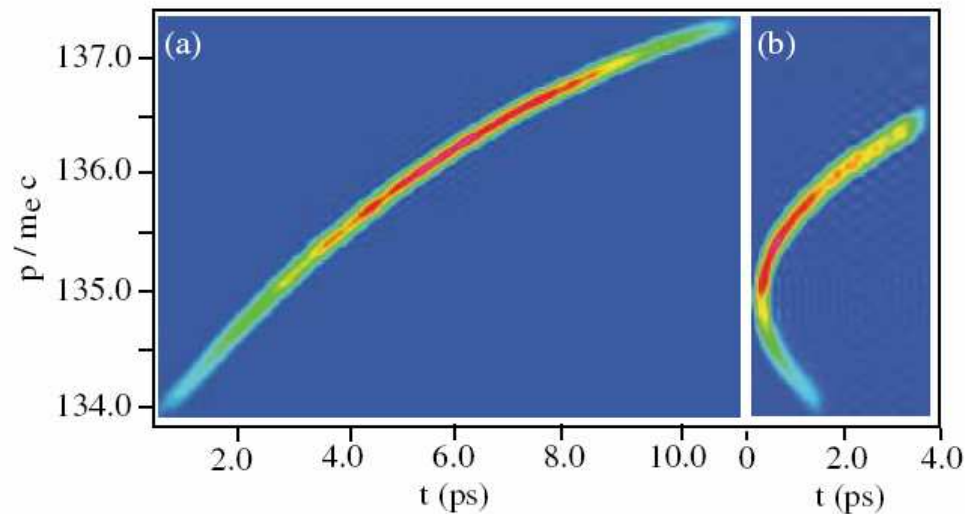
$$\lambda_r = \frac{\lambda_u}{2\gamma^2} \left(1 + \frac{1}{2}K^2 + (\gamma\theta)^2 \right)$$



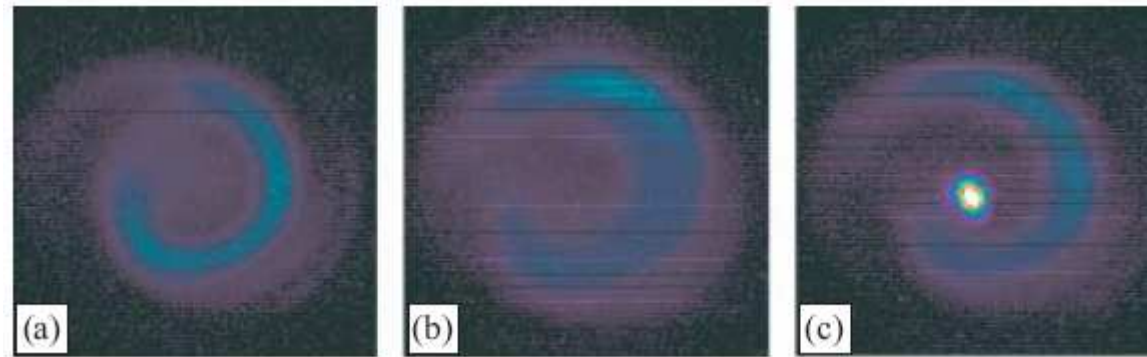
FEL output Power Spectrum reproduced by
Genesis (~12% bandwidth)

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.

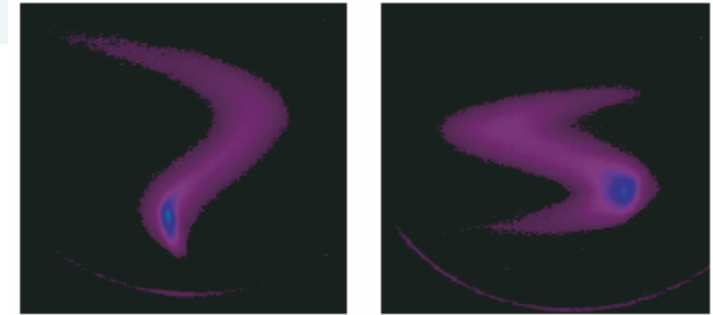


- Far-field Angular Distribution Pattern
 - Screen placed $\sim 3\text{m}$ ($10 Z_R$) away
 - Hollow modes similar to VISA I
 - more pronounced in angle
 - Helical patterns observed
 - Investigate with mode converter (later)

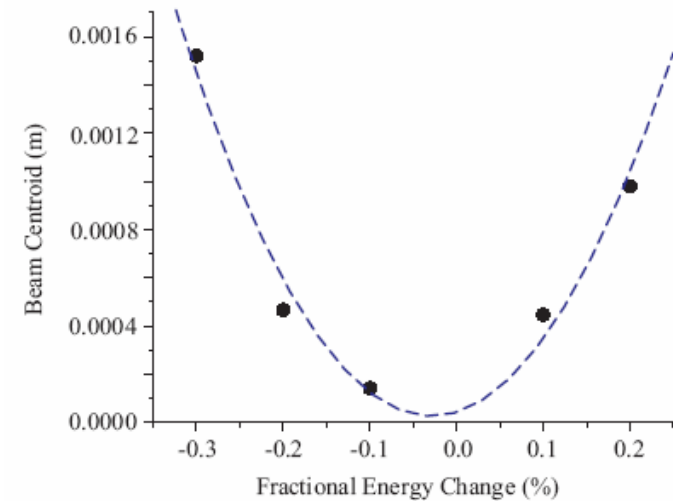
VISA II: Sextupoles

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

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



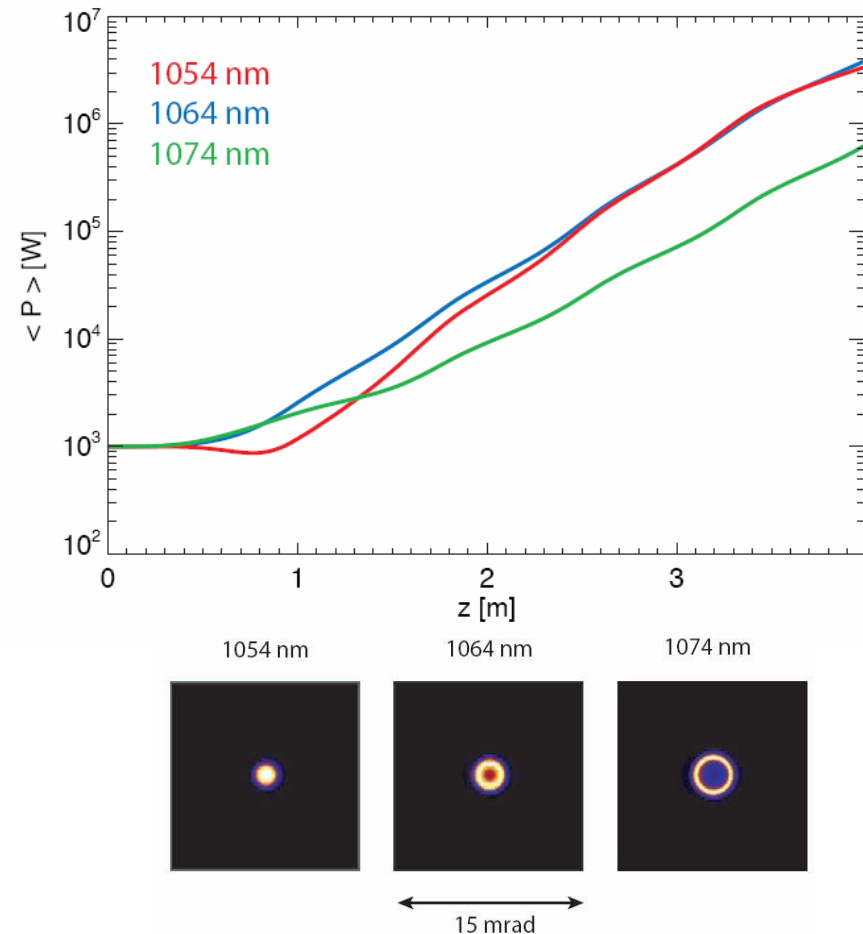
e-beam profile in F-line with sextupoles on



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

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

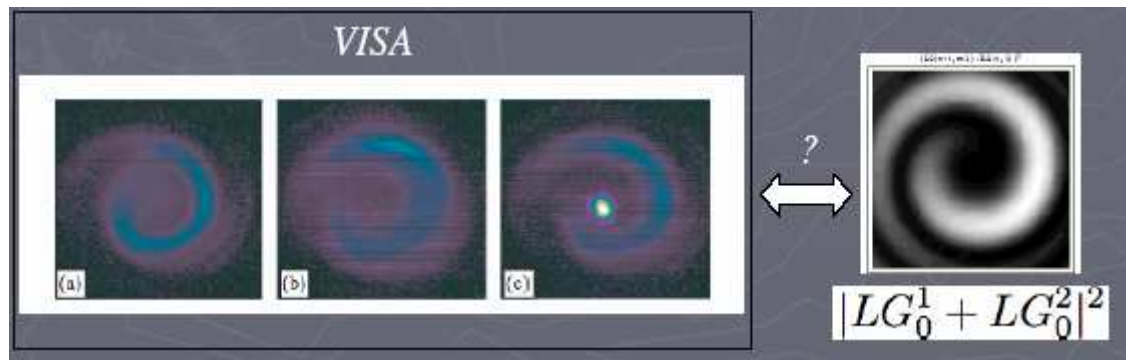
- Transverse Alignment
 - aligned on profile monitors
 - waist positioned ~40cm downstream of undulator entrance
 - maximize the interaction with e-beam and seed when the seed is most intense (combat diffractive effects)
- Longitudinal alignment (timing)
 - sensitive photodiode (~100ps resolution)
 - 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 (~270nJ)

Ongoing Projects

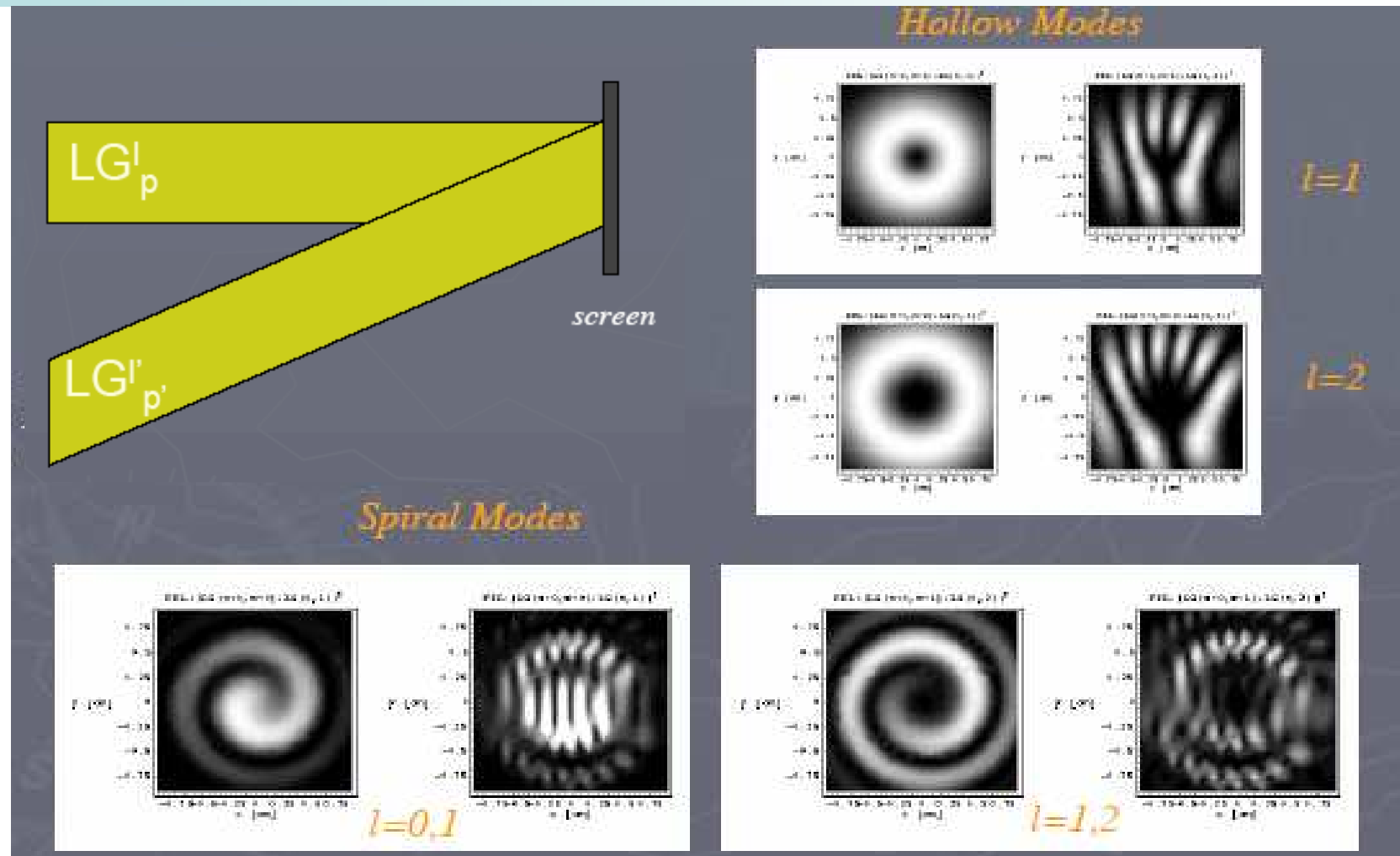
- VISA Collaboration has more ideas and measurements
 - Orbital Angular Momentum measurement
 - further investigate hollow modes and spiral features of FEL
 - High Current FEL
 - SASE with dedicated beam compressor
 - Energy spread mitigated by x-band cavity (silencer)
 - Transition Undulator Radiation
 - 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
 - Erik Hemsing talk (Tuesday)
 - Experiments
 - Off-axis interferometer
 - Coherence measurement (pepper-pot)

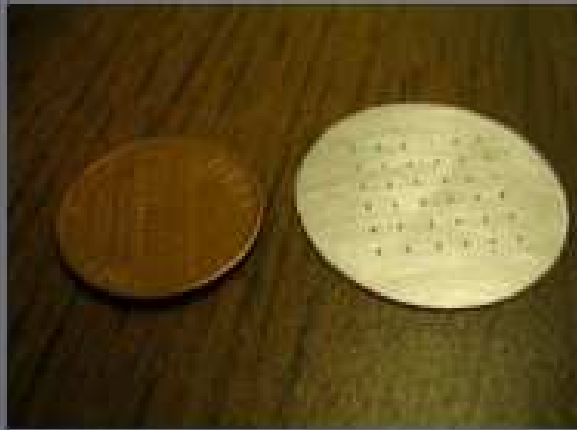


Off-Axis Interferometry



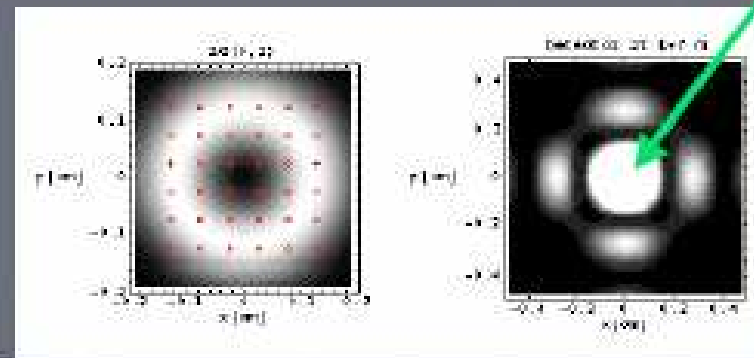
courtesy E. Hemsing

Coherence (Pepper-pot)



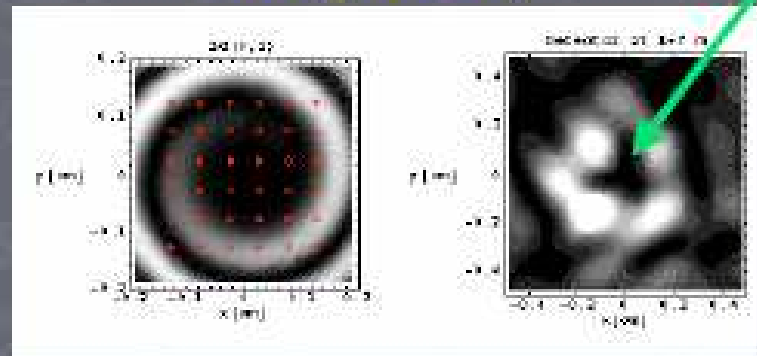
Gaussian

Peak



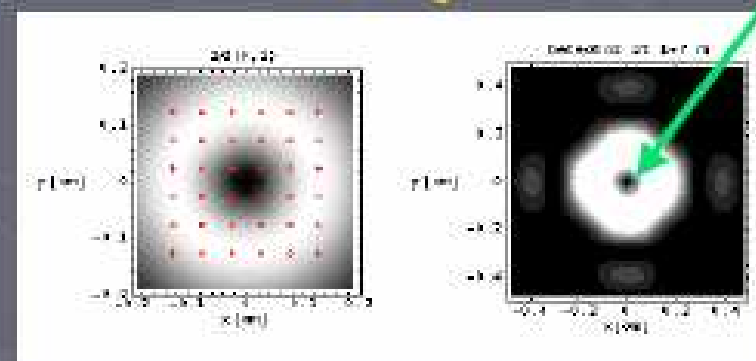
$LG^2_0 + LG^3_0$

Null



LG^1_0

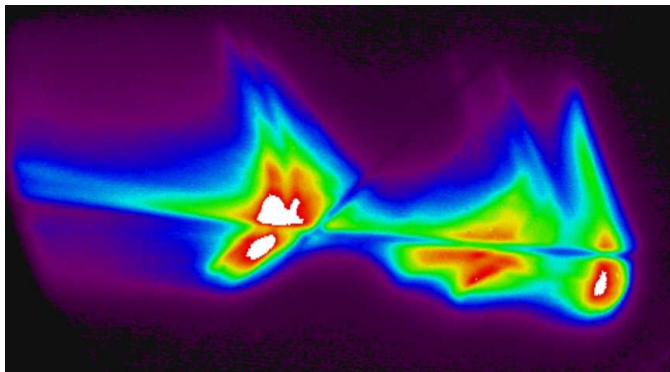
Null



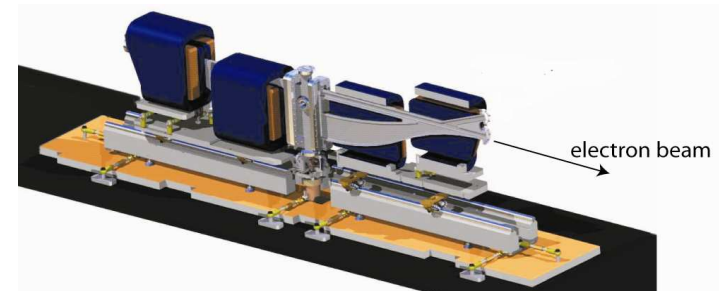
courtesy E. Hemsing

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



Beam bifurcation of compressed beam

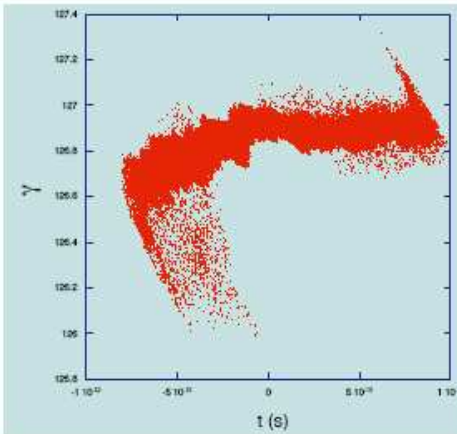
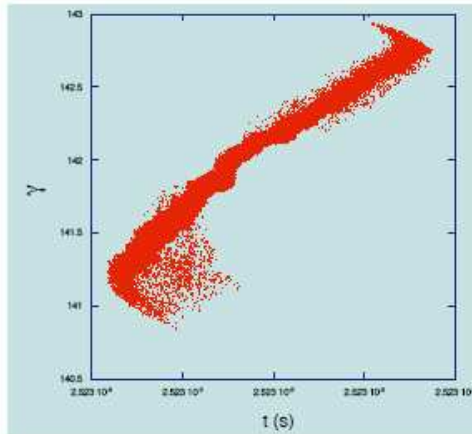


ATF bunch compressor CAD drawing.



ATF bunch compressor installed in tunnel.

Silencer STE

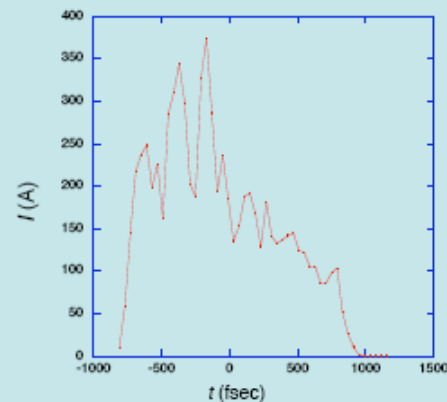


after X-band linac (15MV/m)

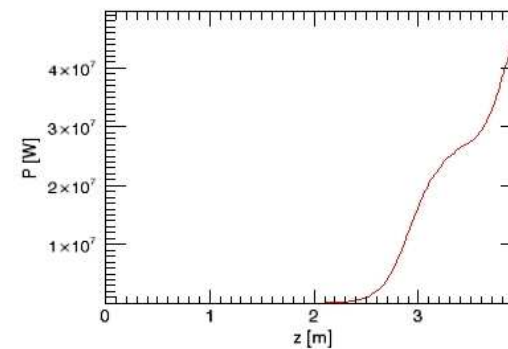
Longitudinal Phase space
(before and after x-band linac)

Partial Compression, energy spread
compensation

Current profile (>300A)



Power gain curve



Near-term goals

- Measurements
 - Seeded Amplifier
 - PhD Thesis by M. Dunning
 - OAM
 - Mode-converter, phase front detector
 - Start-to-end studies, analytical studies
 - PhD Thesis by E. Hemsing
 - CTUR
 - Polarizer after undulator
- Hardware Upgrades
 - F-line enhancements
 - 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
 - new tools and additions
 - Develop new diagnostics
- One of the only ultra short gain length SASE FELs in operation
 - great test facility for x-ray FEL projects that must use SASE
 - many surprises arise in any experiment
 - explore implications for larger scale experiments (not seen in STE)
- More runs & data forthcoming
 - SA, OAM, Silencer, also Compressor Studies and RF undulator
 - VISA always looking for novel measurements