Observation of Ultra-Wide Bandwidth SASE FEL

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Collaboration

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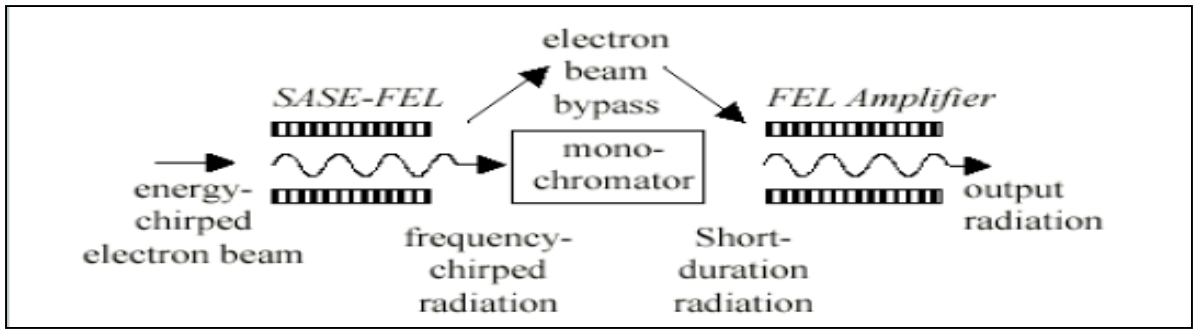
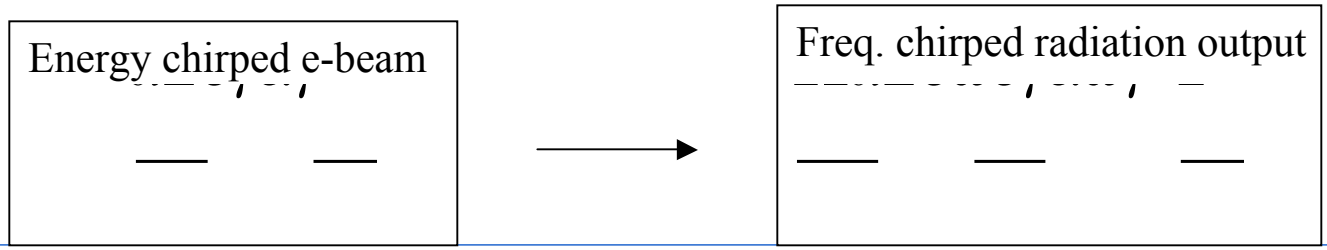
Outline

- Experiment Description
- VISA I Summary
- VISA IB Experiment
  - Results
  - Analysis (Start-to-end)
  - Double Differential Spectrometer
- VISA II
- Seeded Amplifier Experiment
- Conclusions

Motivation

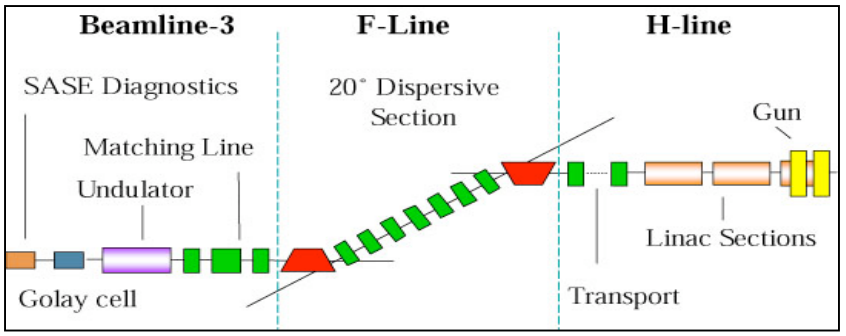


- Proposed Scheme for ultra short pulses
  - Energy chirped e-beam ➔FEL➔ freq. chirped radiation
- Explore Limits of SASE FEL with energy chirped e-beam
- Develop advanced beam manipulation techniques & measurements



Experiment Layout

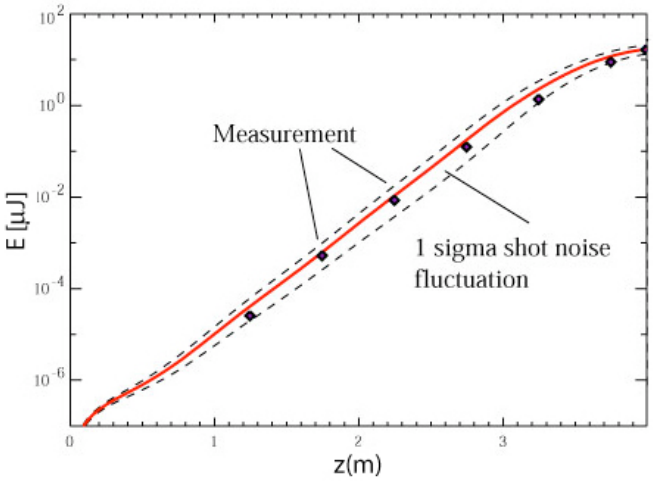
- Accelerator Test Facility (ATF) at BNL
  - Host for VISA I & II
  - 70 MeV beam
  - 28 m beam transport
    - 20 deg bend (F-line)
- Undulator
  - 4 x 1m sections
  - FODO lattice superimposed (25 cm period) –strong focusing
  - External steering coils (8)
  - Intra-undulator diagnostics
    - 50 cm apart
    - double-sided silicon
    - SASE FEL
    - e-beam (OTR)



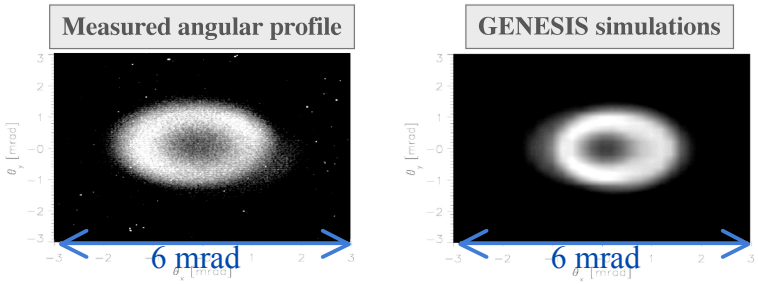
VISA Undulator Parameters	
Undulator type	Planar (NdFeB)
Number of periods (N_u)	220
Peak field (B_{pk})	.75 T
Undulator Period (λ_u)	1.8 cm
Gap (g)	6 mm
Undulator Parameter (K)	1.26

VISA I Summary

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



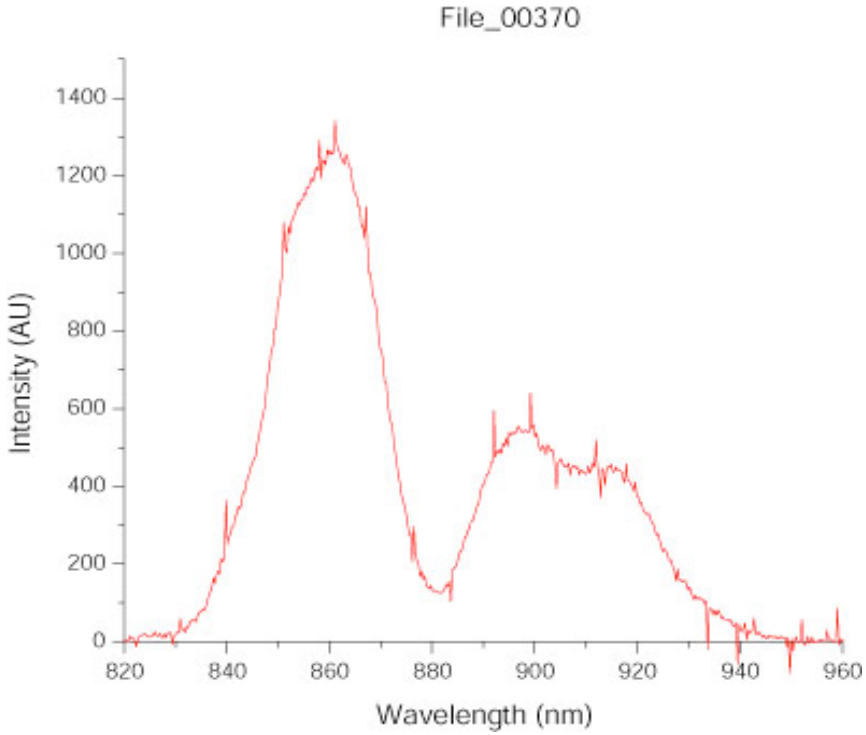
VISA I Gain Curve



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

VISA IB: Experiment

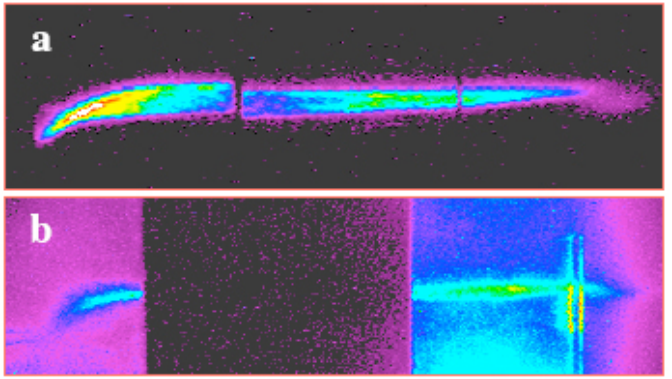
- High gain FEL
  - Chirped beam amplification
  - SASE energy ~2 μJ
  - close to saturation
- Up to 15% bandwidth observed
- Very reproducible and unusually stable
  - insensitive to RF drifts and phase jitter
- Characteristic double-spike structure



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

VISA IB: Experiment

- High energy slits (HES)
  - adjustable collimator
  - Controls beam size in F-line
- FEL stability
  - same fraction of beam propagates through HES, regardless of centroid jitter
- Compression
  - monitored by Golay cell
    - measures CTR
    - CTR peaked when p_0 set to optimize compression
  - Current ~ 300A
  - Compression stronger
    - higher degree of chirp



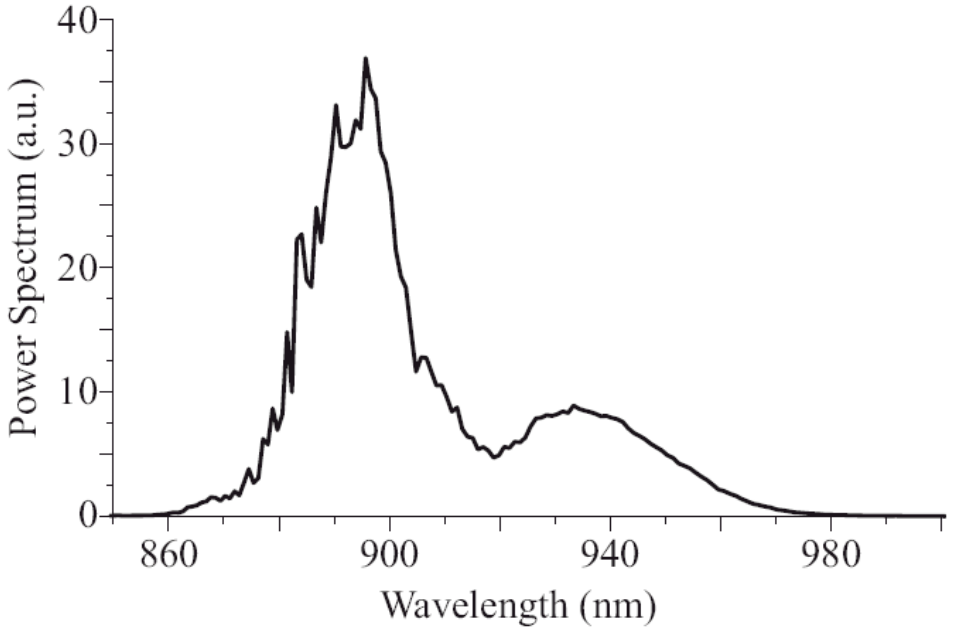
e-beam at HES

a) fully closed slits (500 pC, 2.8% chirp)

b) fully open slits (60 % Transmission, 330pC)

VISA IB: Analysis

- Start-to-End
  - Experimental Spectrum features reproduced
  - Angles Important
    - Off-axis Doppler Shift

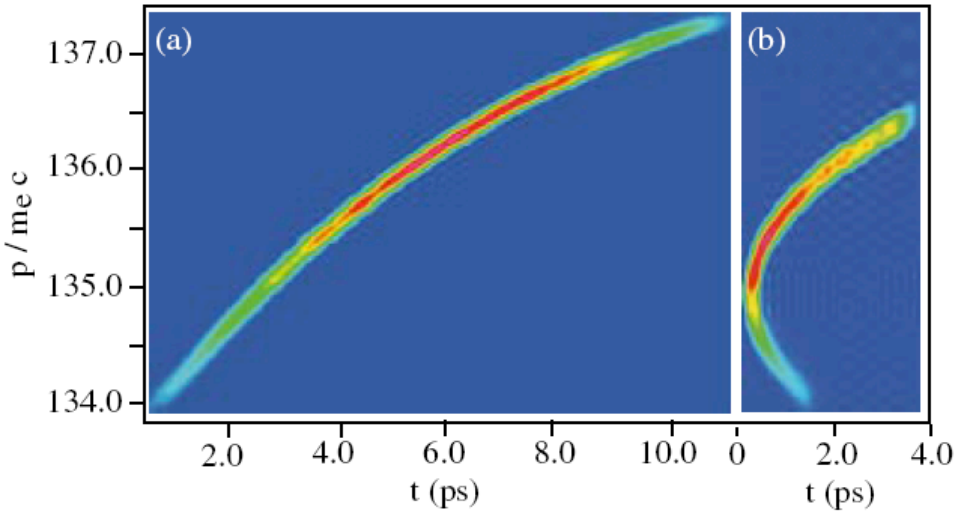


FEL output Spectrum reproduced by Genesis (~11% bandwidth)

VISA IB: Analysis

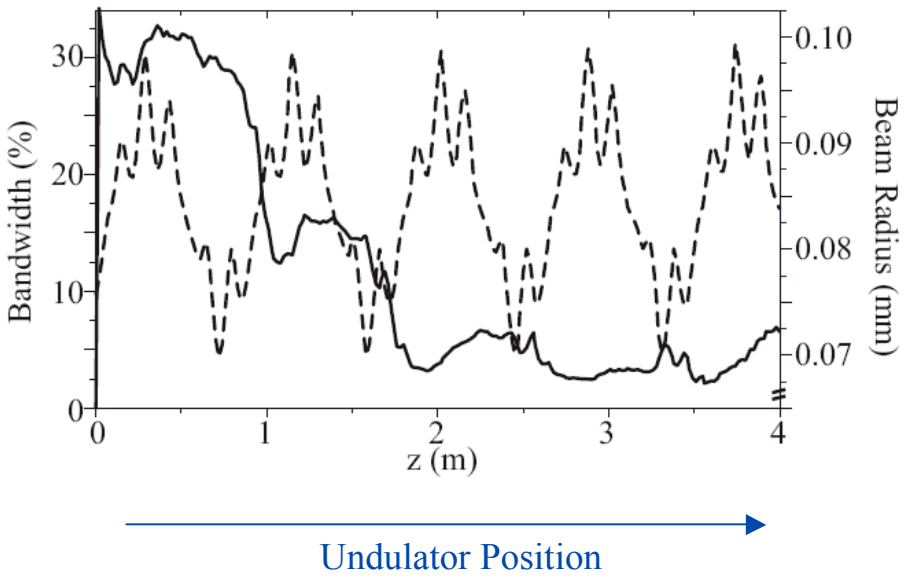
- Linear chirp applied at linac
- Compression in dogleg
  - Portion of beam is always in “correct” comp. regime
  - Collimation ~40% (300 pC)
  - Benchmarked to data taken in F-line
- Leads to off-axis injection of compressed core

- High Current
  - I ~ 300 A
  - Better than VISA I

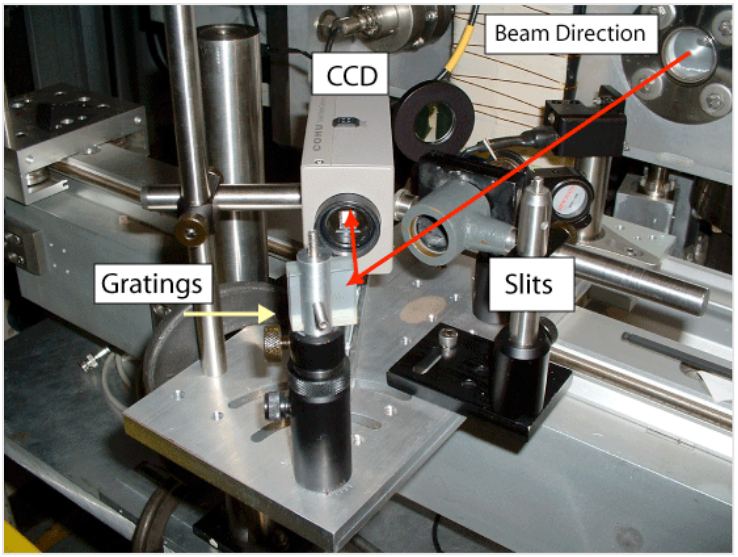


VISA IB: Analysis

- Start-to-End
  - Beam radius
  - Bandwidth Evolution
    - Oscillates with double the freq. as betatron motion
    - Mismatch due to dispersion
    - Off-axis gain when beam is small
    - Final growth in BW near saturation

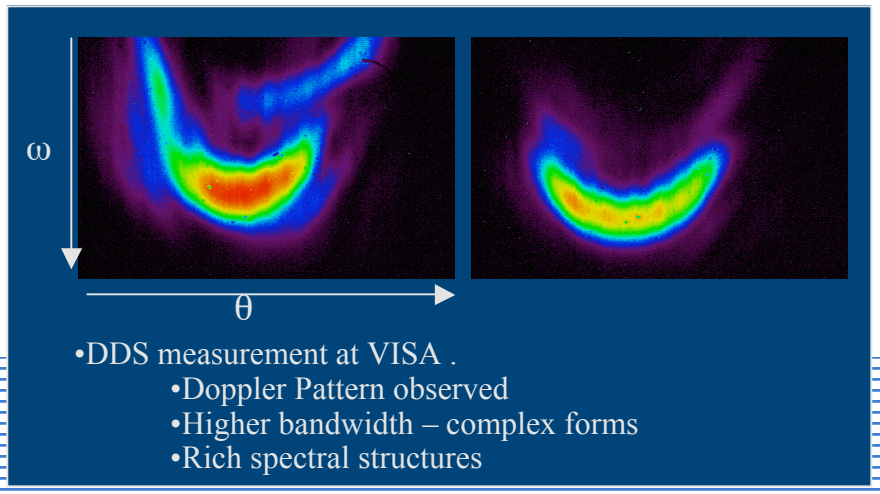


Double Differential Spectrum

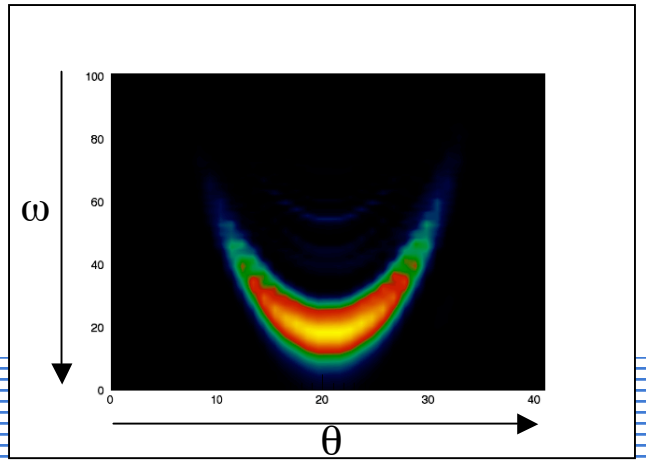


Double differential spectrum: Experimental Setup

- Double Differential Spectrum (DDS)
  - Unfolds correlation between angle (slits) and frequency (gratings)
  - Preliminary setup
    - improvements coming
    - calibration lamp
    - graduated slits

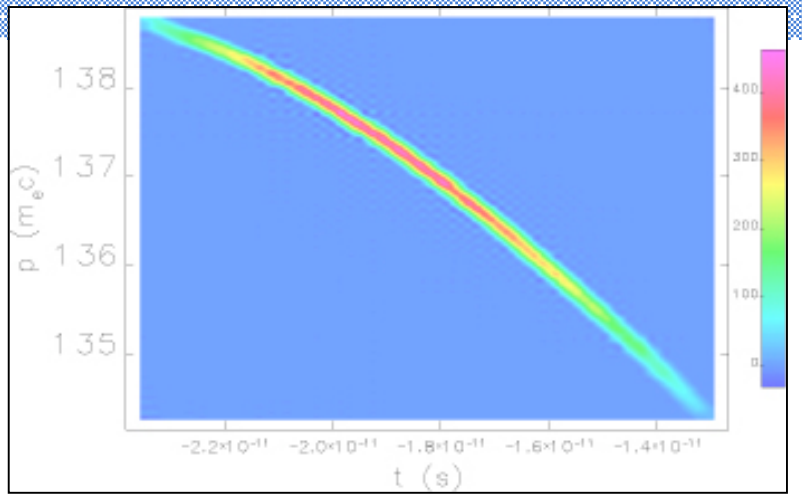


Genesis Simulation of DDS for VISA IB running conditions

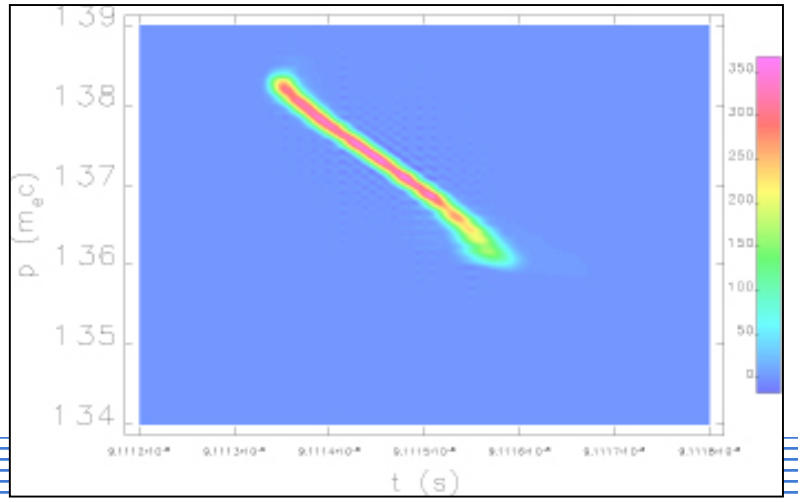


VISA II

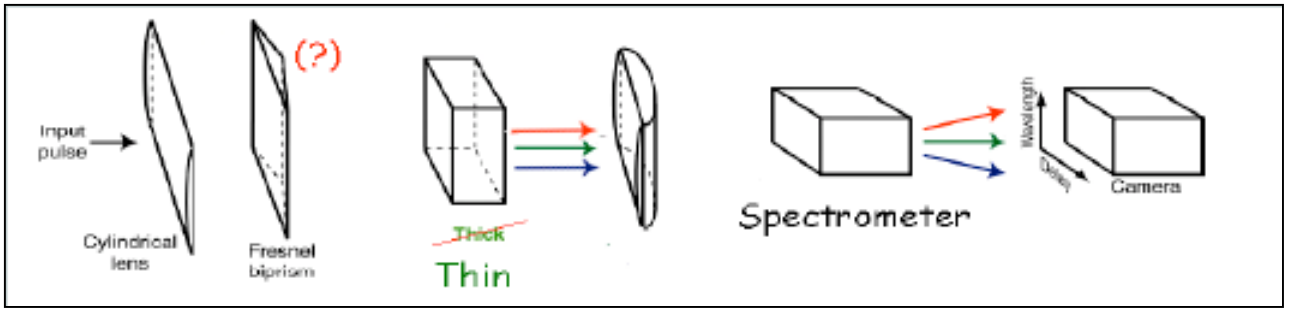
- Energy chirp SASE FEL operation
  - linearize transport
    - Sextupole correction in F-line
- Running Conditions
  - Back of crest acceleration
  - Negative R_{56} compression
  - 70% Transmission
- Start-to-end Simulations
  - High Current
  - Low Emittance
  - High gain FEL
    - Frequency chirped radiation
- Modified FROG



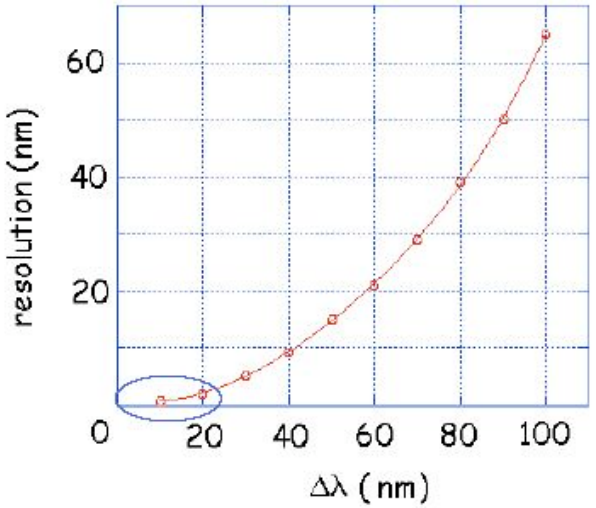
Longitudinal Phase Space for VISA II Case post linac (above) and pre-undulator (below).



Modified FROG



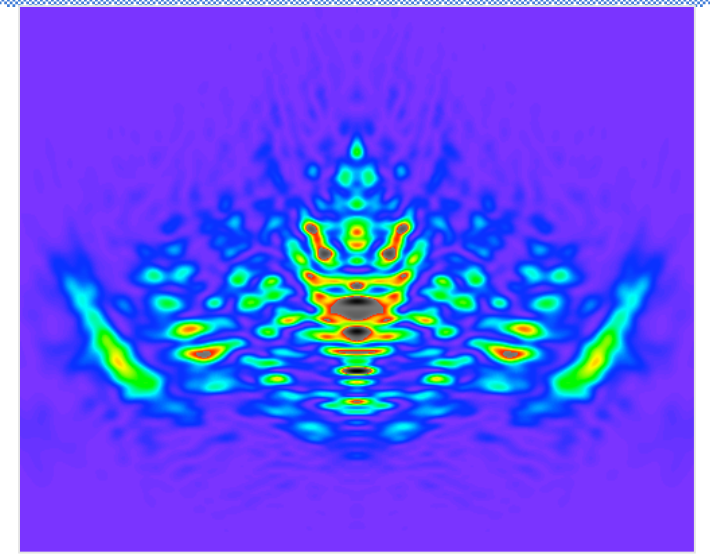
- Grenouille
  - single shot, auto aligning, SHG FROG
  - yields full pulse phase & intensity
- Resolution
  - System is too constrained by doubling crystal
    - Replace thick crystal with thin crystal and spectrometer
- Cutting edge measurement
  - Interrogation on fs scale



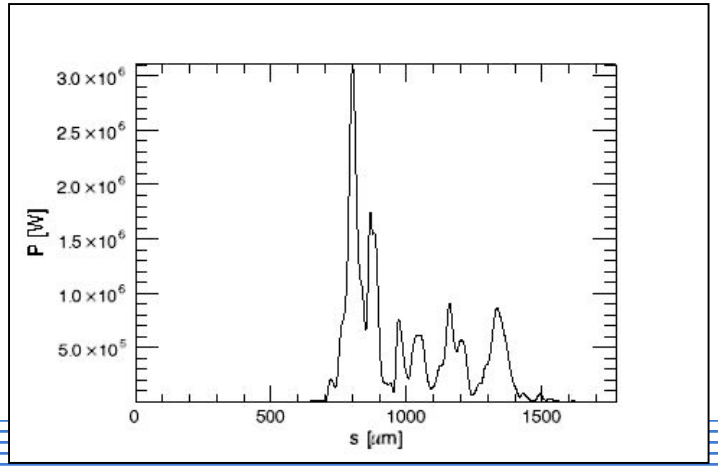
S.Cialdi, "Temporal Characterization of FEL pulse by Grenouille" , PBPL Seminar Series, Lecture 11

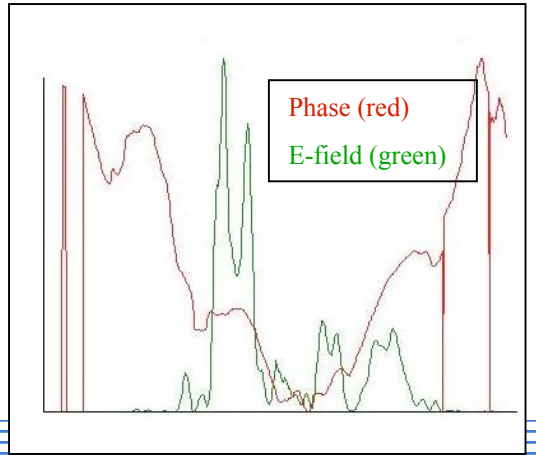
FROG Simulations

- FROG output for VISA II (Genesis)
  - Spectrogram
  - visualize chirp
  - pulse profile is reproduced
  - Power ~ $|E|^2$



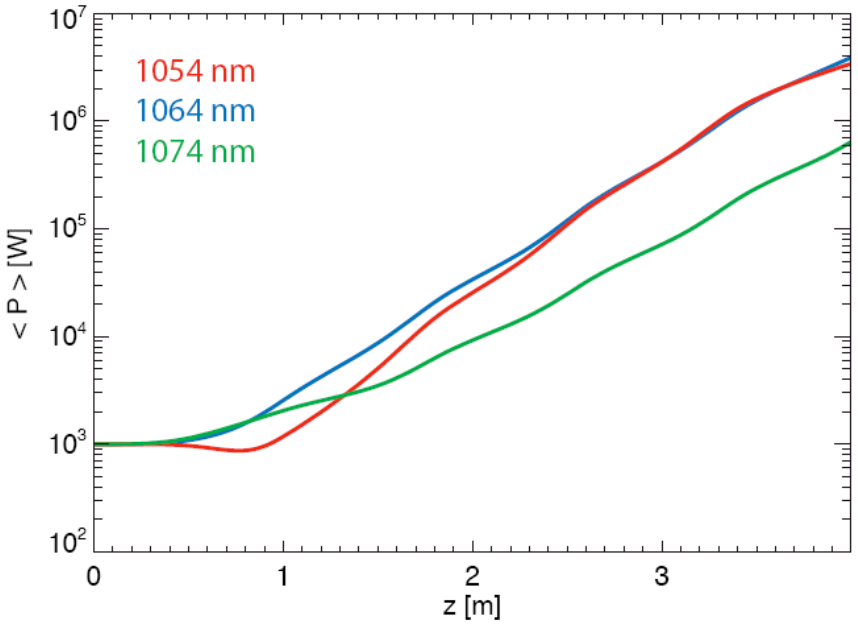
Temporal profile of VISA II pulse: Genesis output (left) FemtoSoft FROG reconstruction (right).





Seeded Amplifier

- Motivation
  - Control and manage high power FEL beam in far-field
  - Establish transverse coherence with seeded pulse (low bandwidth, high brightness)
- Far field studies
  - Increase angle, decrease intensity
  - Need short gain length to obtain short Rayleigh length
  - e.g. deliver high power without damaging optics
- Experiment
  - VISA undulator with 61 MeV beam
  - Seed with 1064 nm YAG
- Alignment Issues
  - Delay line
- Study detuning effects with start-to-end simulations



Conclusions

- VISA yields rich data sets
  - VISA I, VISA IB
    - Observed ultra wide bandwidth
    - High gain chirped beam FEL
    - Further studies on hollow modes
  - Confidence in Start-to-end suite
- Develop new diagnostics
- Seeded amplifier runs & data forthcoming