The VISA Program:
Recent Results and Measurements

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Collaboration

• UCLA PBPL

• BNL ATF
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• INFN LNF
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Outline

• History and Motivation
• Experiment Description
• 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**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undulator type</td>
<td>Planar (NdFeB)</td>
</tr>
<tr>
<td>Number of periods ($N_u$)</td>
<td>220</td>
</tr>
<tr>
<td>Peak field ($B_{pk}$)</td>
<td>.75 T</td>
</tr>
<tr>
<td>Undulator Period ($\lambda_u$)</td>
<td>1.8 cm</td>
</tr>
<tr>
<td>Gap (g)</td>
<td>6 mm</td>
</tr>
<tr>
<td>Undulator Parameter (K)</td>
<td>1.26</td>
</tr>
</tbody>
</table>
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 IB Summary

- High gain FEL
  - Chirped beam amplification
  - SASE energy ~2 \( \mu \)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 ~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

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

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

e-beam profile in F-line with sextupoles on
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

Dove prism flips image about one axis

$\begin{align*}
  x &\rightarrow -x \\
  y &\rightarrow y
\end{align*}$

Hollow Modes

Spiral Modes

$l=1$

$l=2$

$l=0,1$

$l=1,2$

courtesy E. Hemsing
Coherence (Pepper-pot)

$LG^2_0 + LG^3_0$

$LG^1_0$

Gaussian

Peak

Null

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

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

Current profile
(>300A)
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