Femtosecond scale diagnostics

William S. Graves

MIT-Bates Laboratory

Presented at ANL

September, 2003

Experiments

MIT

•Sub-fs laser synchronization

BNL

•Measurement of UV laser time profiles

•Streak camera time resolution

•Slice emittance measurements of electron beam

Cooperation on Frequency Metrology and Timing Distribution

Both at MIT and JILA-NIST: MURI-Projects funded by ONR

Frequency Metrology
and
Femtosecond Technology for Optical Clocks

MIT:
E. P. Ippen (PI)
Y. Fink
F. Kaertner
D. Kleppner
L. Kolodziejski
J. Shapiro
F. Wong

JILA-NIST:
J. Ye (PI)
S. Diddams
L. Holberg
…..

J. Ye, JOSA B 20, 1459 – 1469 (2003)

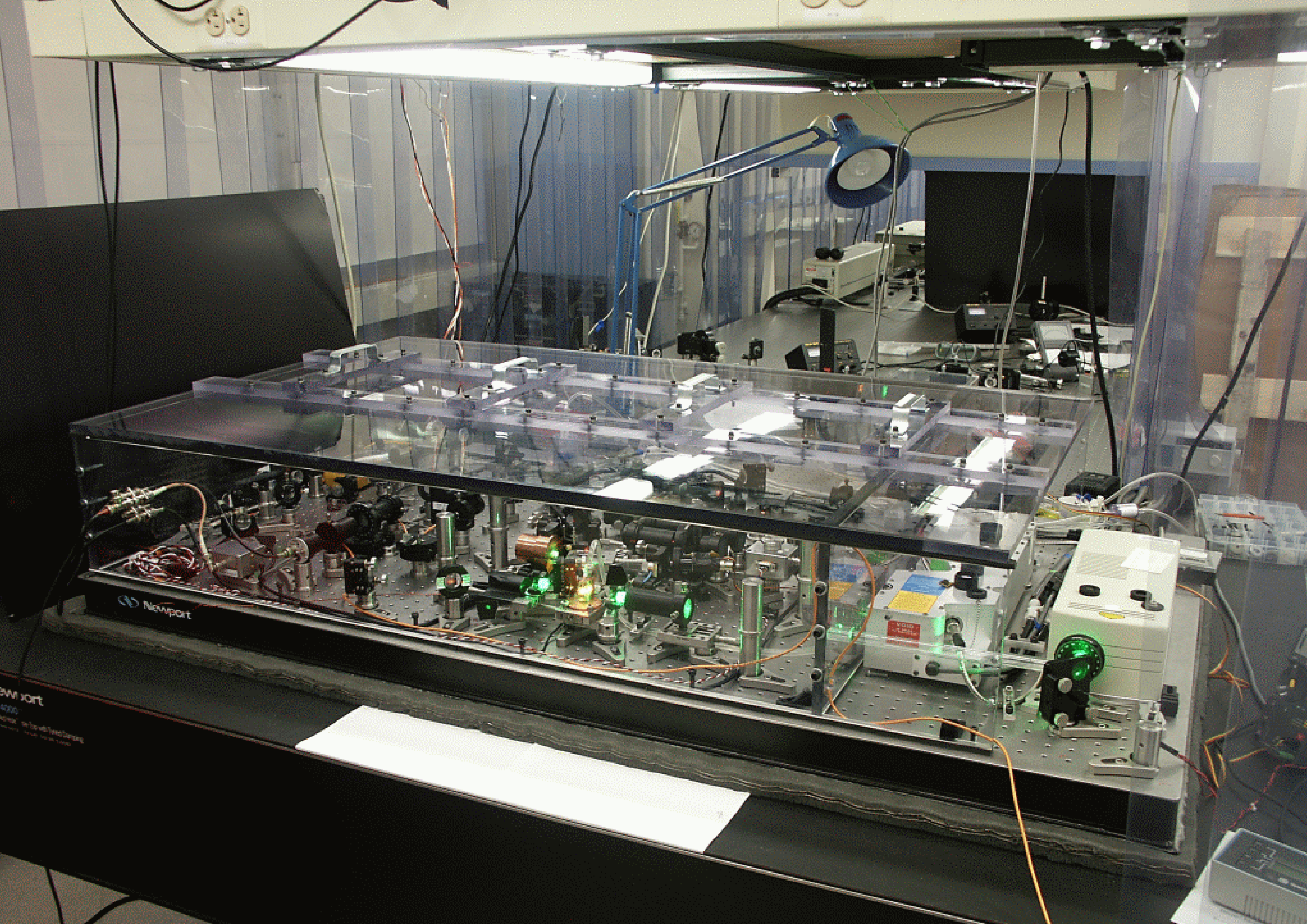
Laser and RF timing

Program at MIT aims to demonstrate

•10 fs timing synchronization of multiple lasers separated by ~1 km.

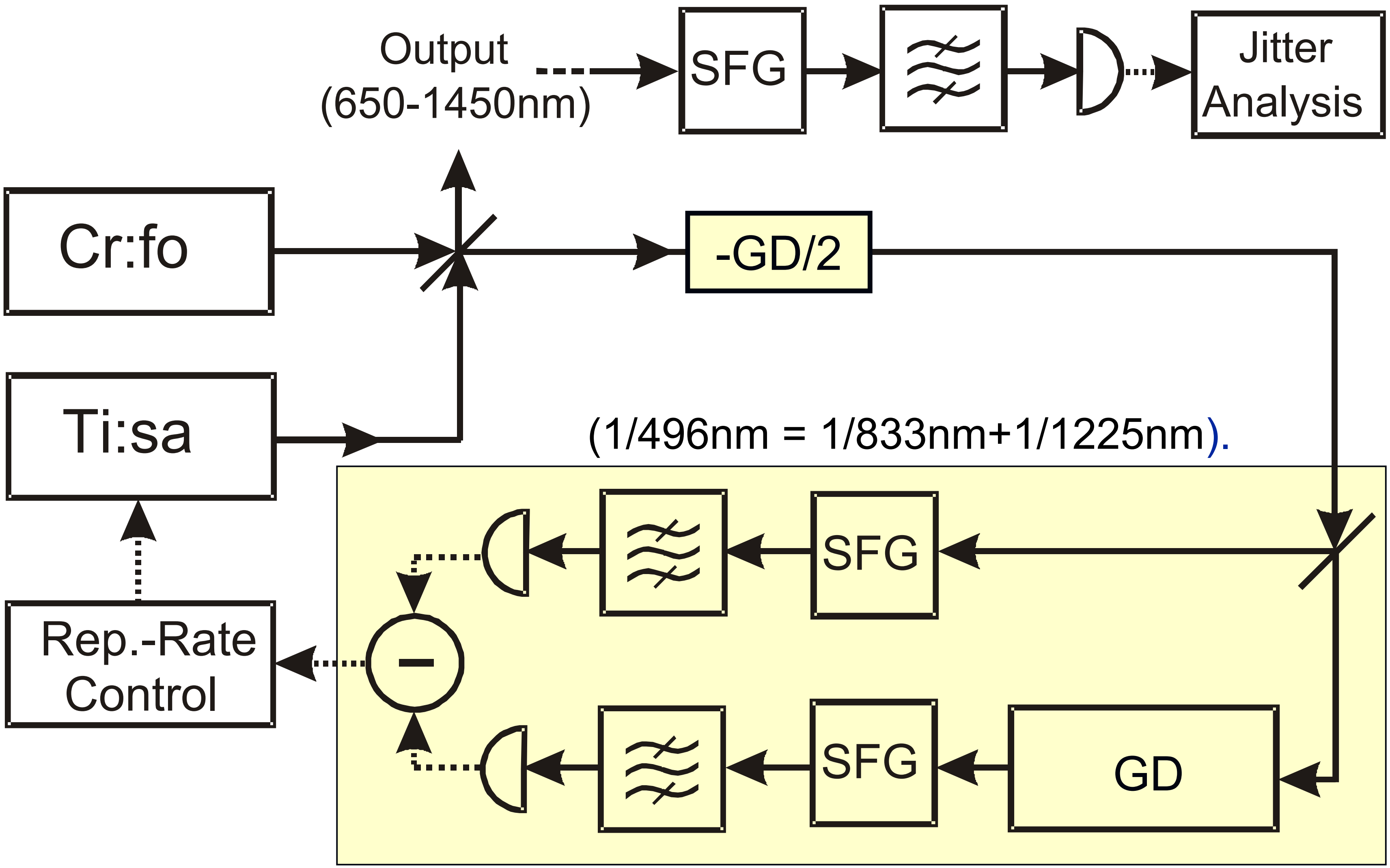
•Measurement and control of laser timing relative to RF oscillator at 10 fs level, in lab and in accelerator environment.

•Control ultrashort pulse carrier envelope phase to fraction of an optical cycle. Necessary for generation of FEL seed pulse in 10 – 30 nm range.



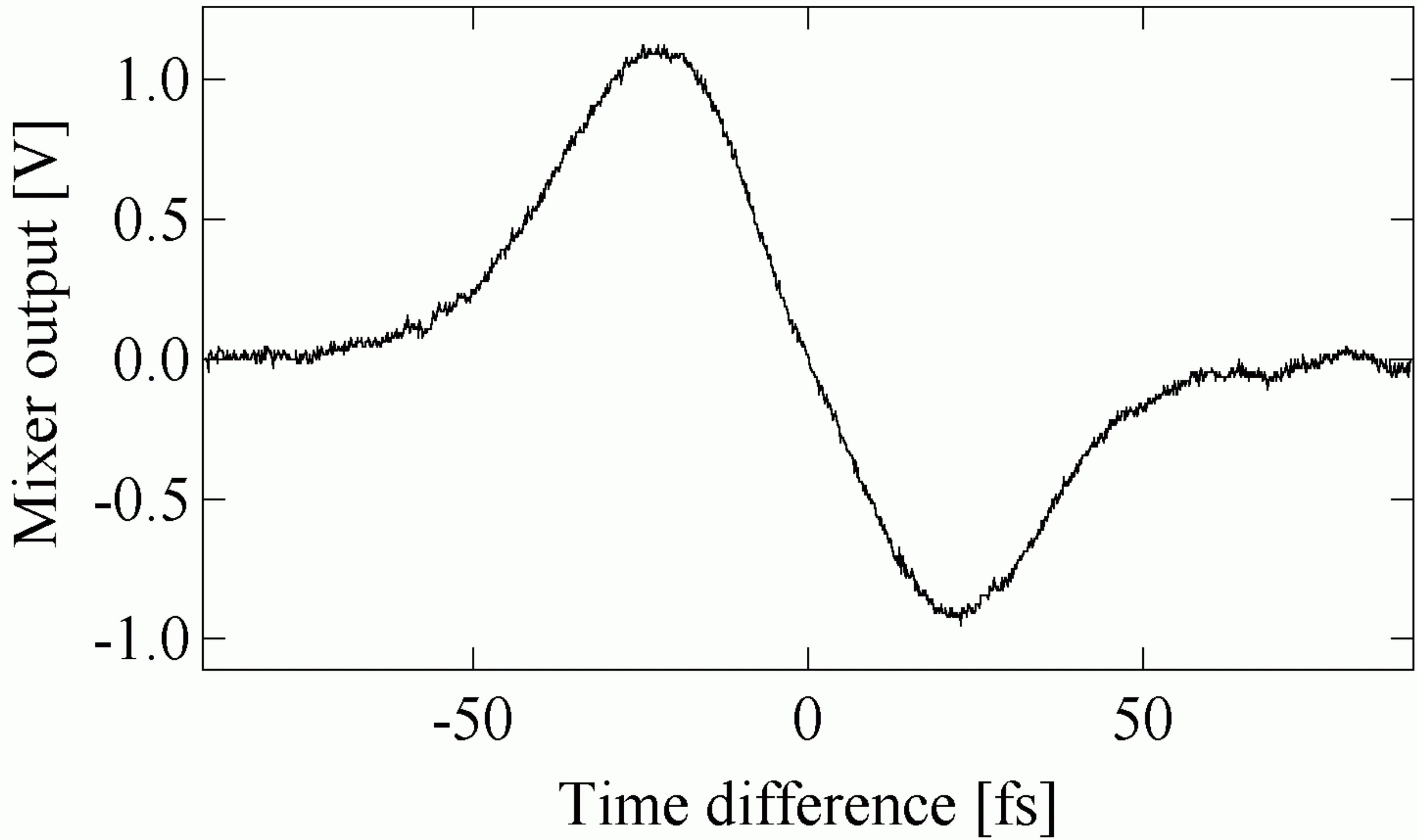
Courtesy of F. Kaertner, MIT EECS

Measuring the residual timing jitter



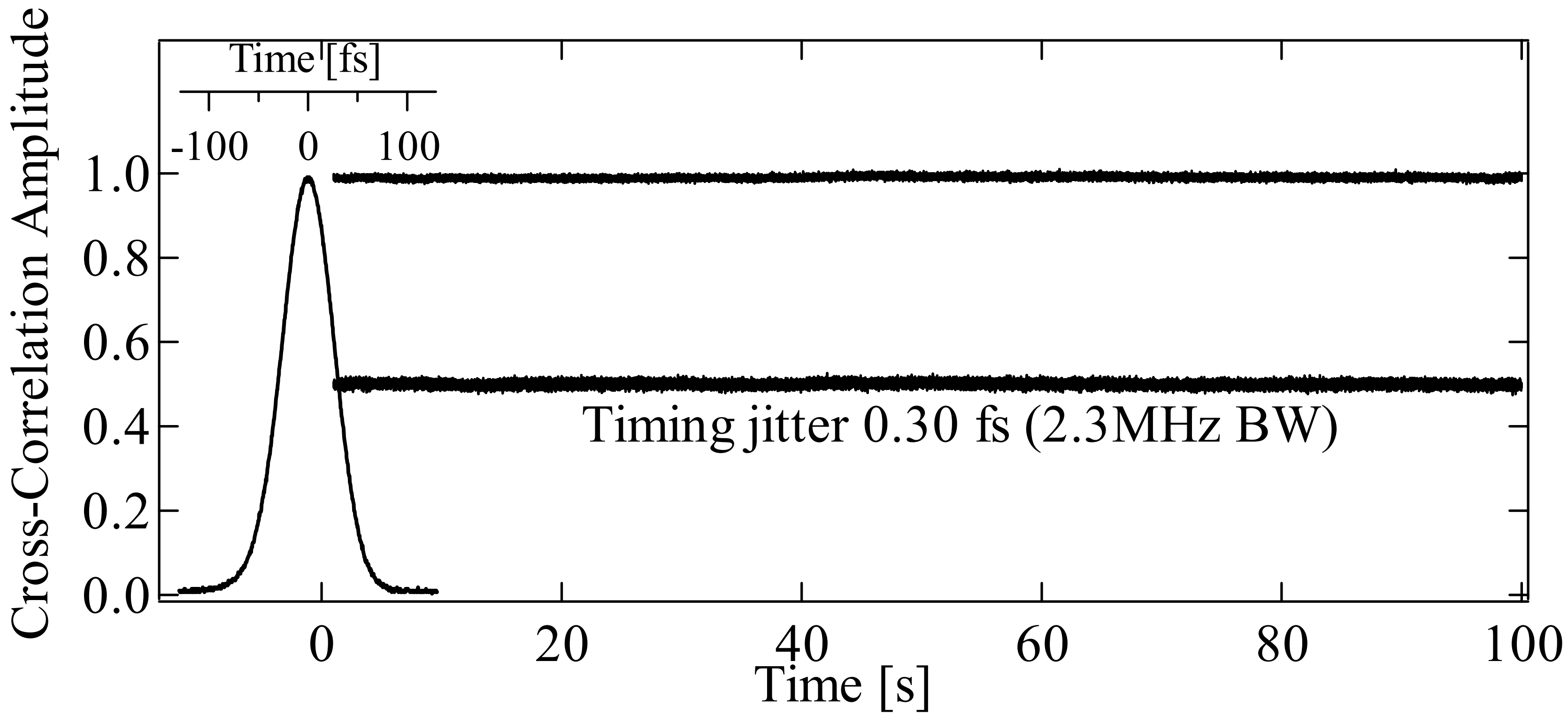
Courtesy of F. Kaertner, MIT EECS

Balanced Cross-Correlator



Courtesy of F. Kaertner, MIT EECS

Experimental result: Residual timing-jitter

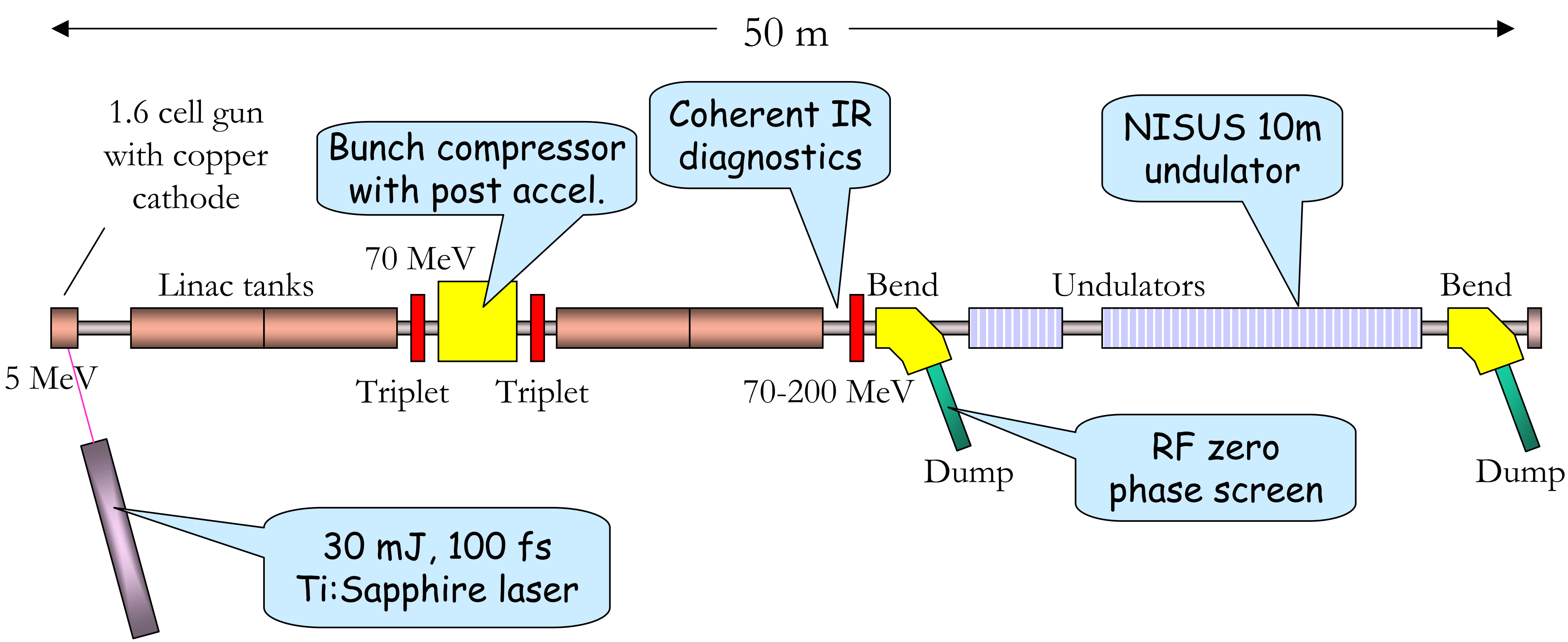


The residual out-of-loop timing-jitter measured from 10mHz to 2.3 MHz is 0.3 fs (a tenth of an optical cycle)

Long Term Drift Free

Courtesy of F. Kaertner, MIT EECS

DUVFEL Facility at BNL



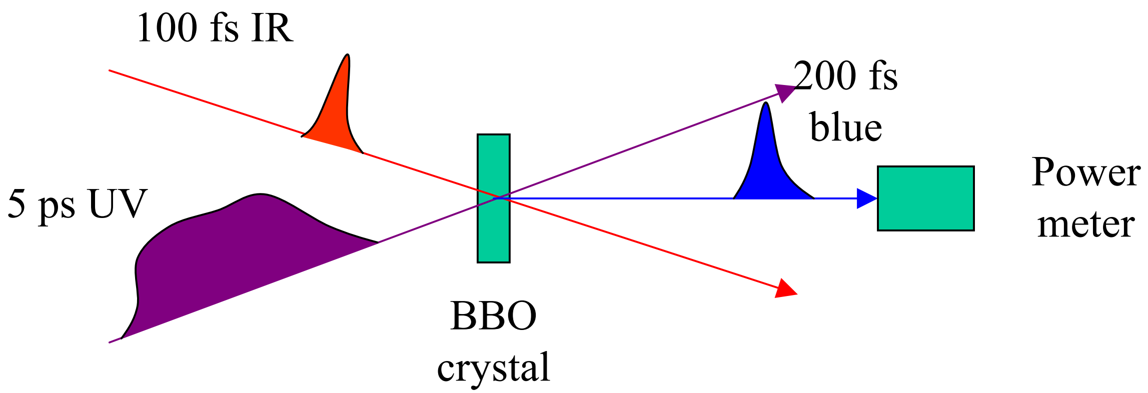
Photoinjector: 1.6 cell BNL/SLAC/UCLA with copper cathode

4 SLAC s-band 3 m linac sections

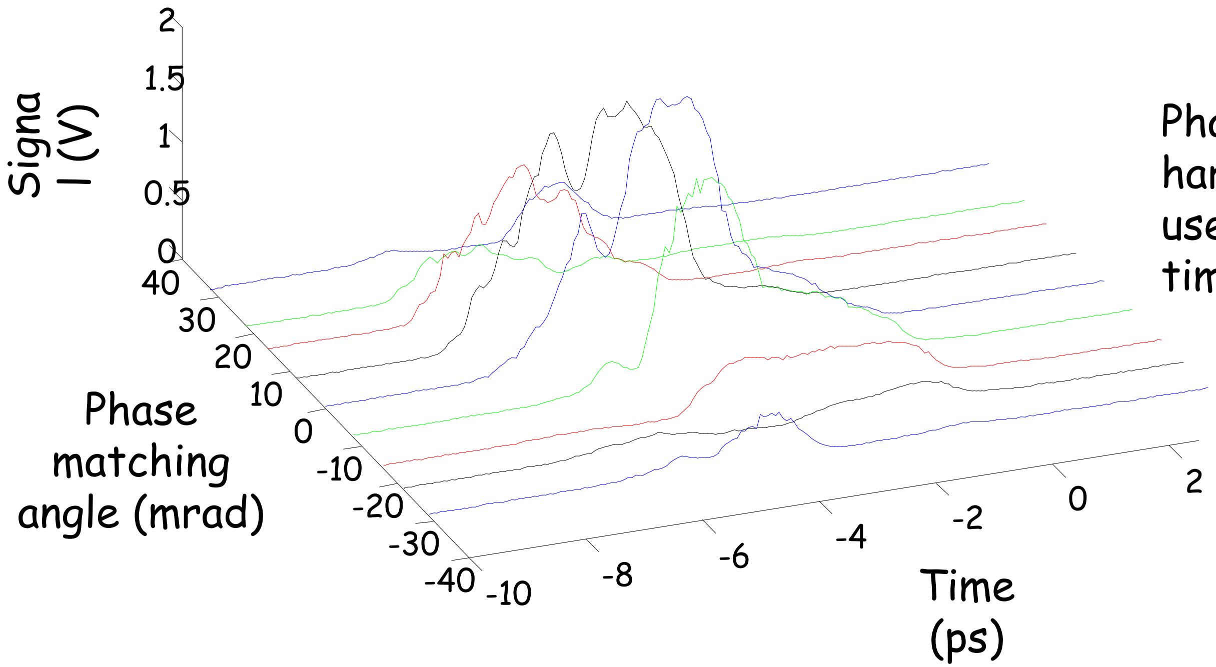
Bunch compressor between L2 and L3

Approximately 60 CCD cameras on YAG screens.

Time profile of UV laser pulse



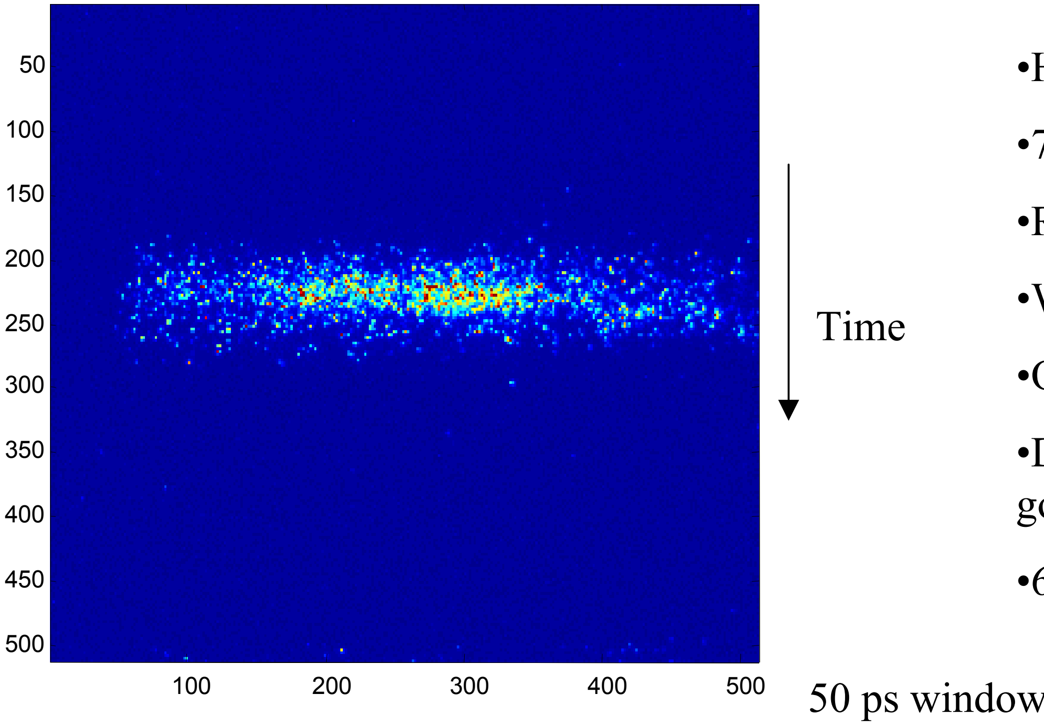
Cross-correlaton difference frequency generation – experiment by B. Sheehy and H. Loos



Phase matching angle of harmonic generation crystals used to produce UV affects time and spatial modulations.

Note: "Sub-ps" streak camera is inadequate for this measurement

Streak Camera



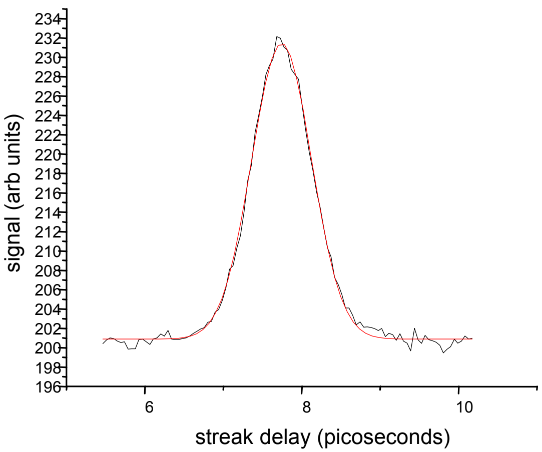
Streak image

- Hammamatsu FESCA 500
- 765 fs FWHM measured resolution
- Reflective input optics (200-1600 nm)
- Wide response cathode (200-900 nm)
- Optical trigger (<500 fs jitter)
- Designed for synchroscan use. Also good single-shot resolution.
- 6 time ranges: 50 ps - 6 ns

Very helpful for commissioning activies and for timing several optical signals.

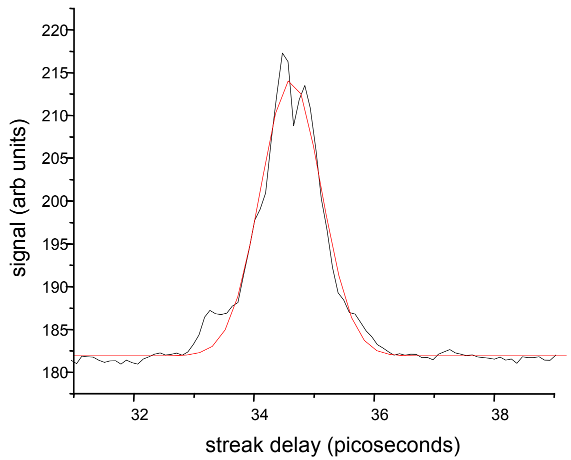
Limited time resolution below 1 ps.

Streak camera time profiles of laser pulses



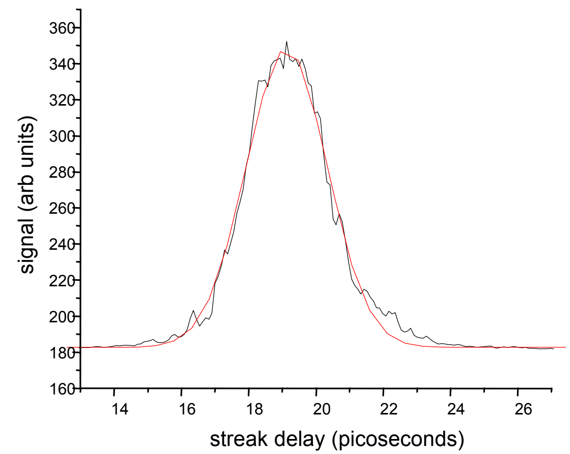
Oscillator 796 nm

FWHM 765 fs



Amplified IR 796 nm

FWHM 1.01 ps single shot

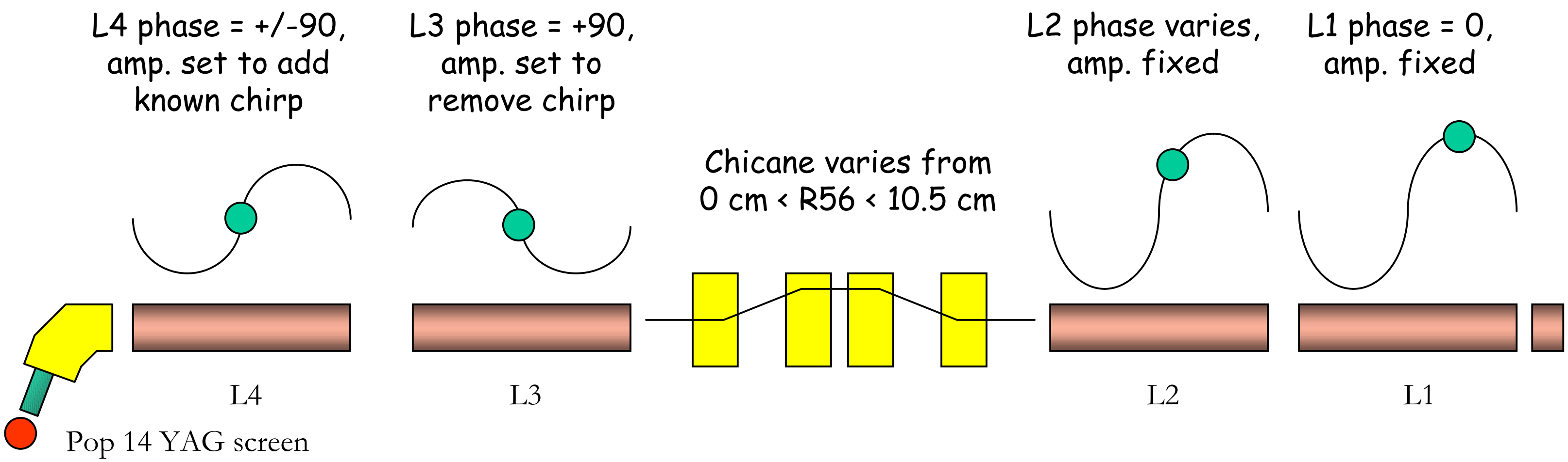


UV 266 nm

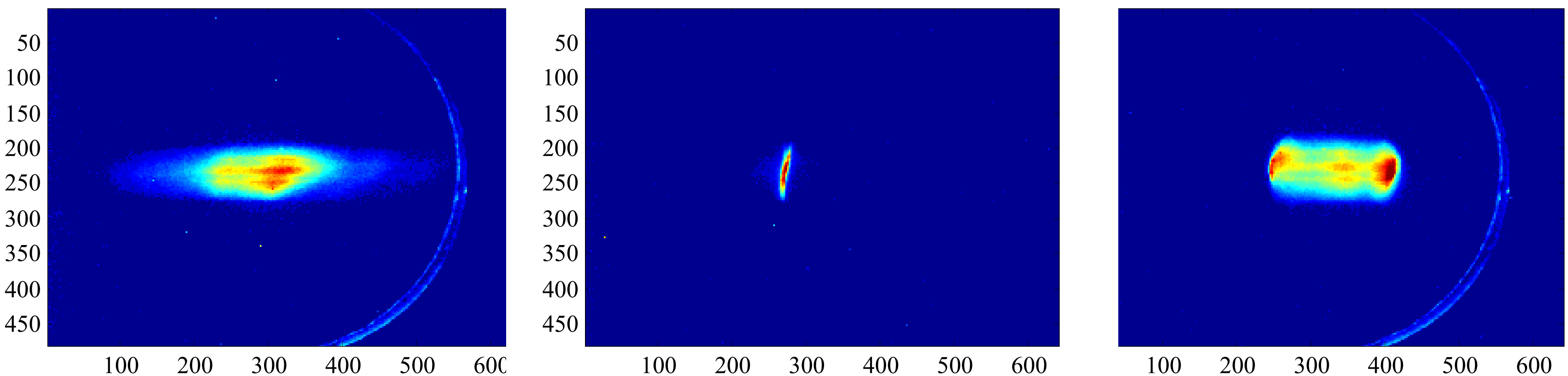
FWHM 2.40 ps singleshot

Time resolution depends on photon energy: energetic UV photons create photoelectrons with energy spread that degrades time resolution

RF zero-phase time profile



YAG images at pop 14

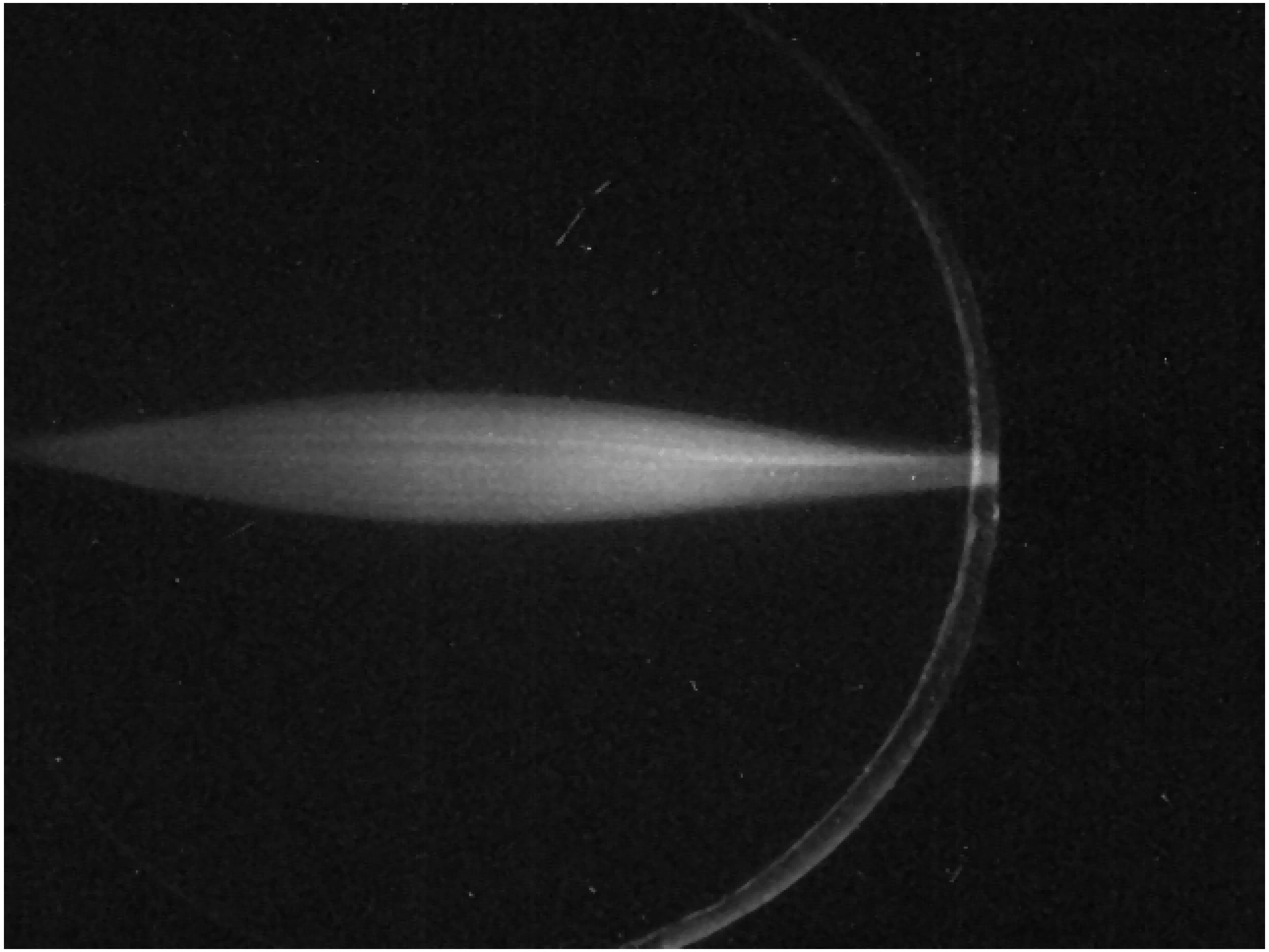


L4 phase = -90 degrees

L3 corrects residual chirp, L4 is off

L4 phase = +90 degrees

Quad scan during RF zero phase



Movie of slice emittance measurement.

Left side

Beam size squared vs quadrupole strength.

Each plot is a different time slice of beam.

Right side

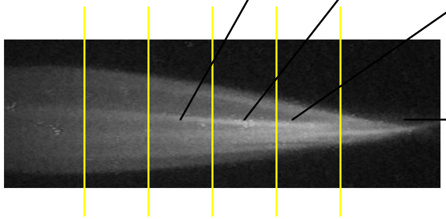
Circle is matched, normalized phase space area at upstream location.

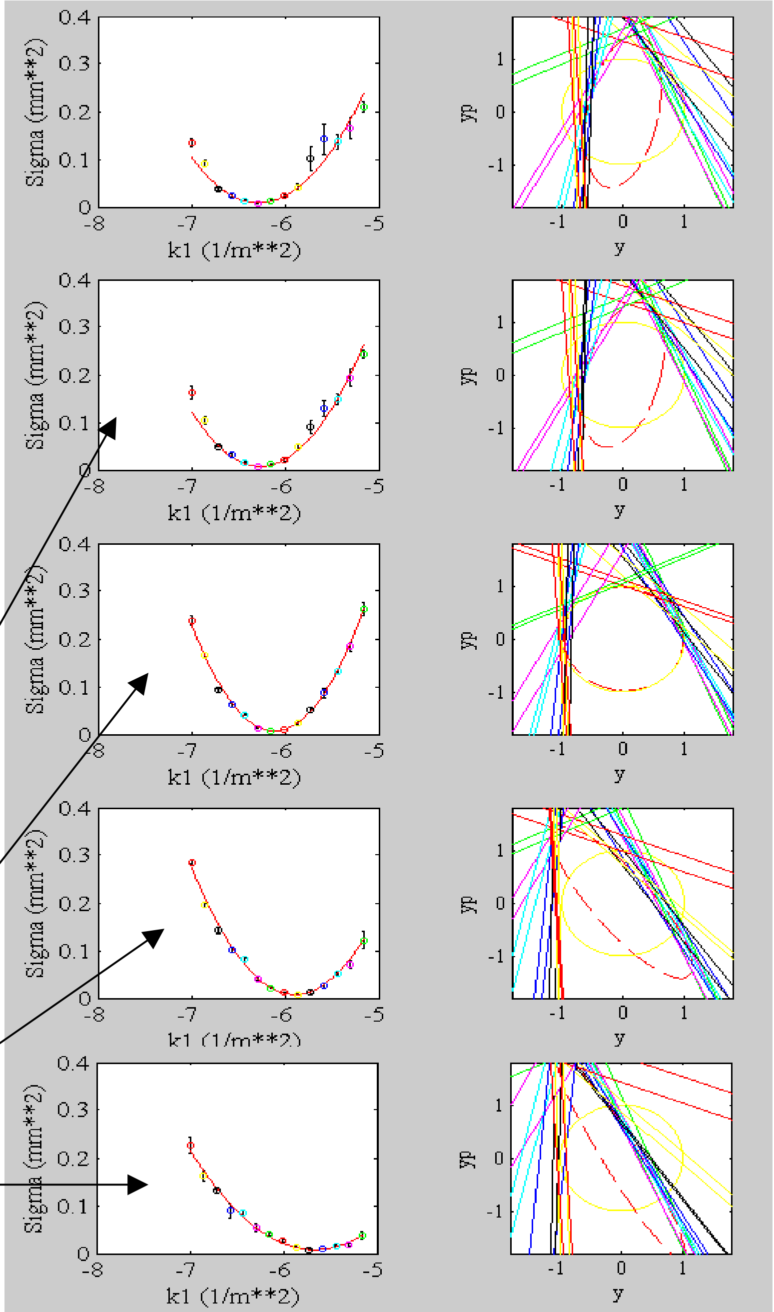
Ellipse is phase space area of slice at same location.

Straight lines are error bars of data points projected to same location.

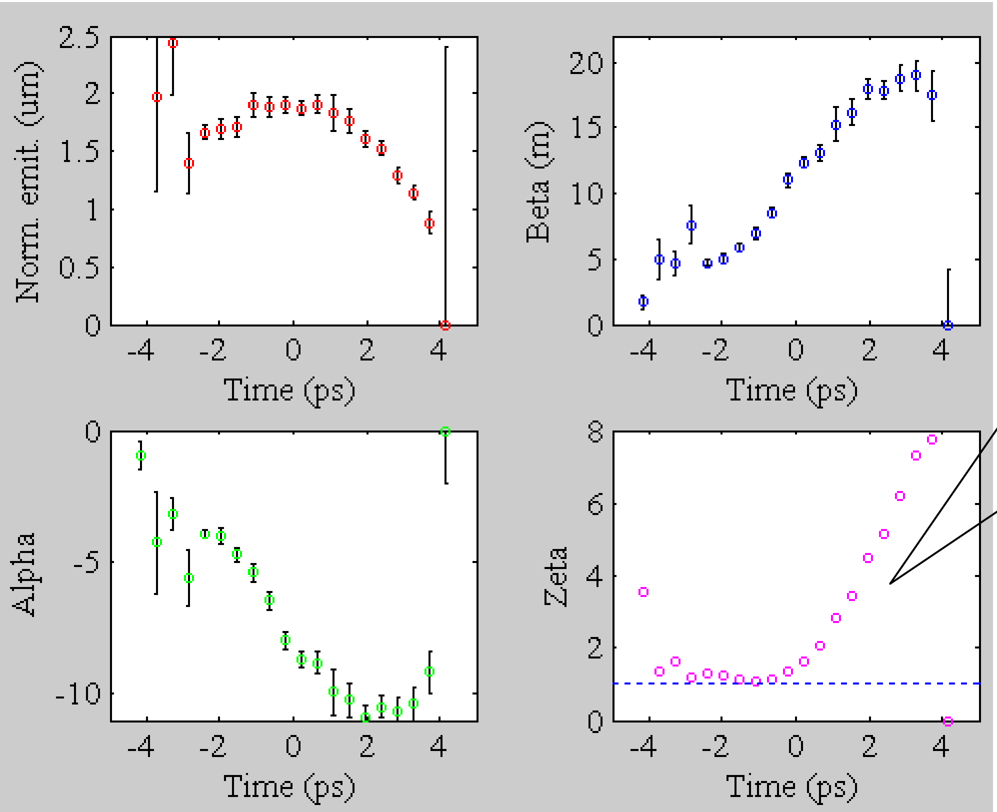
Recent experiment at DUVFEL by BNL/SLAC/DESY

Software is used to time-slice beam resolving transverse dynamics on timescale of 10's of femtoseconds.





Slice emittance and Twiss parameters



ζ is parameter that characterizes mismatch between target and each slice.

$\zeta = ½ (\beta_0 \gamma - 2 \alpha_0 \alpha + \beta \gamma_0)$

α_0, β_0, γ_0 are target Twiss param.

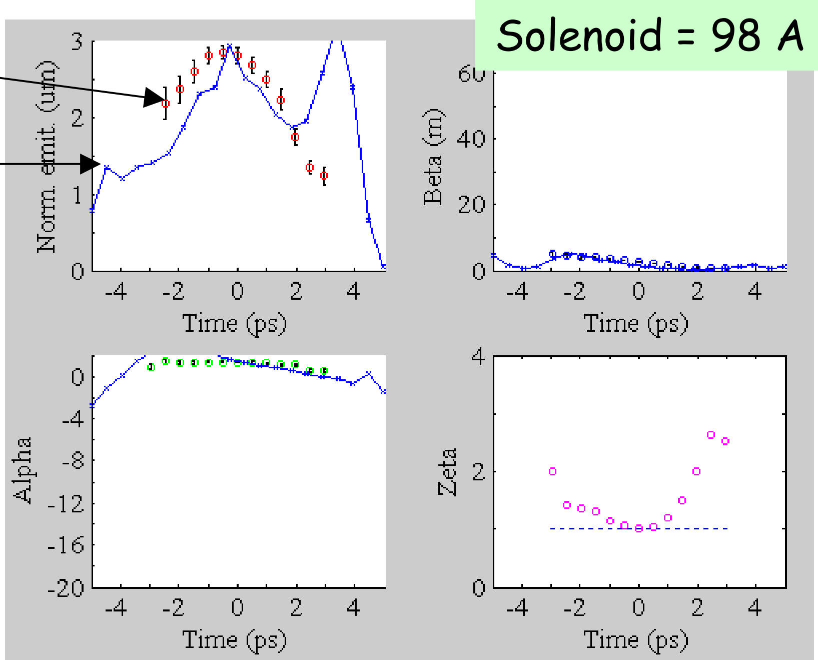
α, β, γ are slice Twiss param.

Beam Parameters: 200 pC, 75 MeV, 400 fs slice width

Note strongly divergent beam due to solenoid overfocusing at tail, where current is low.

Space charge forces near cathode caused very different betatron phase advances for different parts of beam.

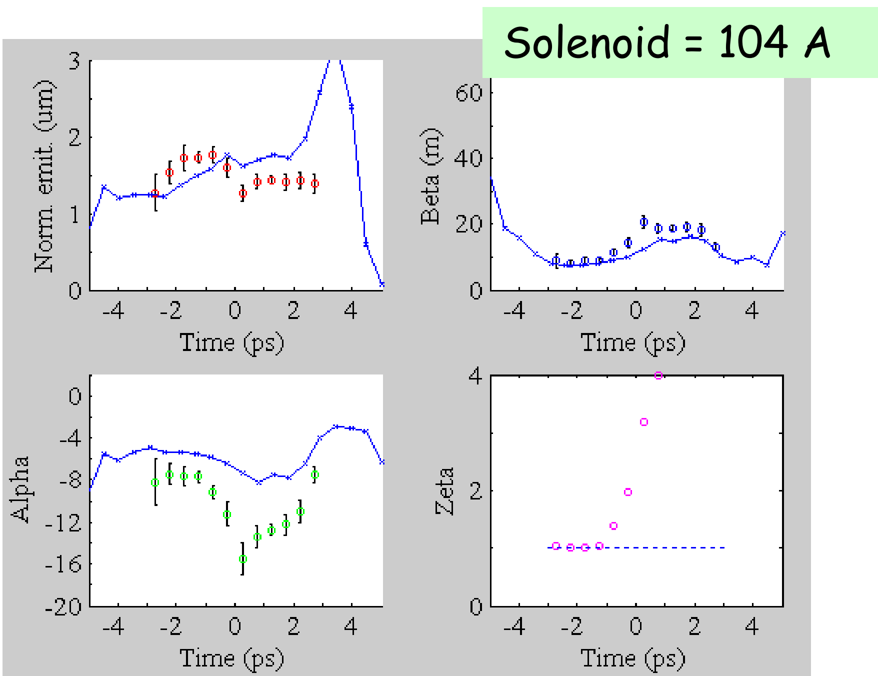
Slice emittance vs solenoid strength. Charge = 200 pC.

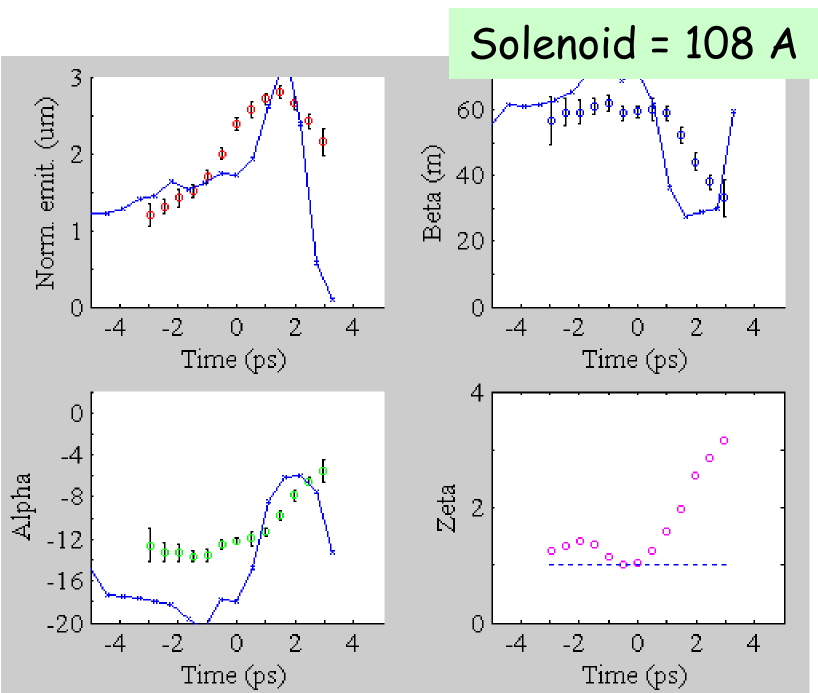


Projected Values

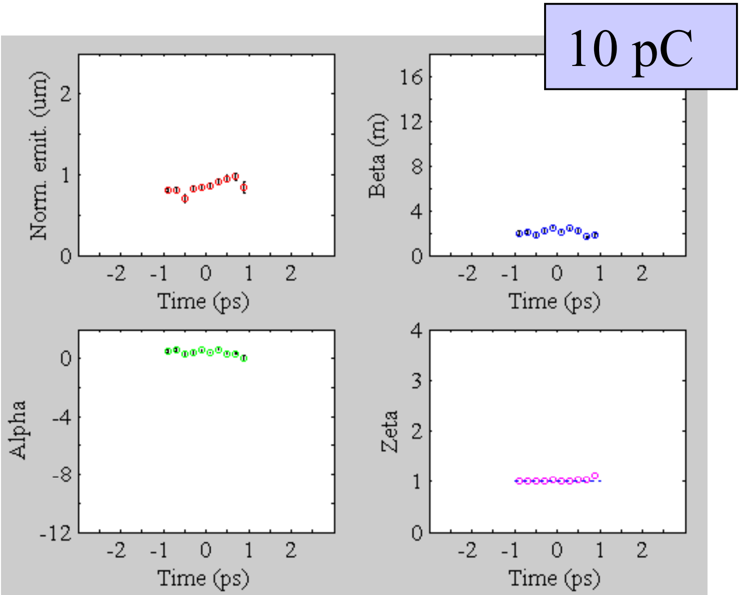
(parmela in parentheses)

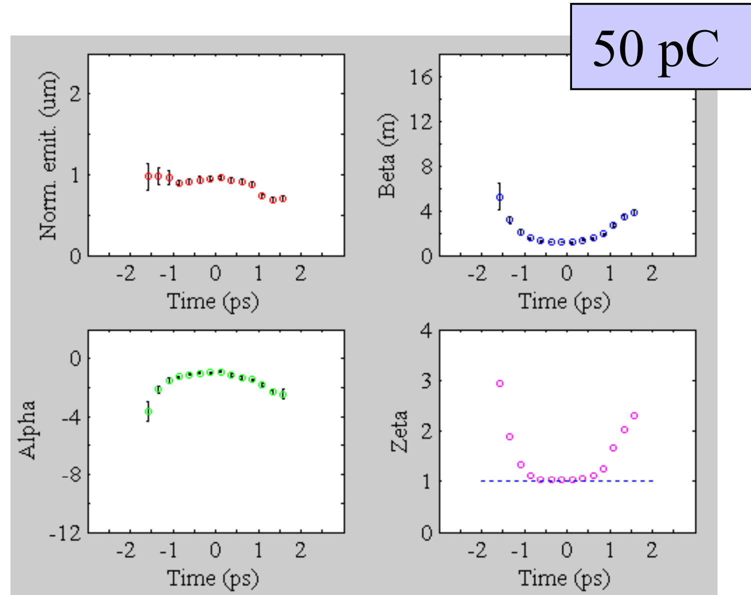
Solenoid	98 A	104 A	108 A
Eyn	3.7 um (3.2)	2.1 um (2.8)	2.7 um (2.7)
Alpha	0.4 (1.0)	-6.9 (-3.6)	-9.0 (-9.6)
Beta	1.3 m (1.3)	9.8 m (6.8)	45 m (36)



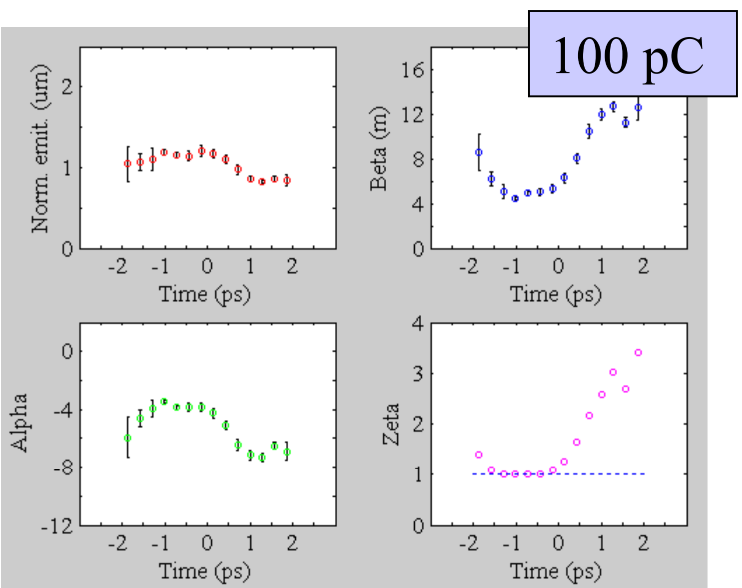


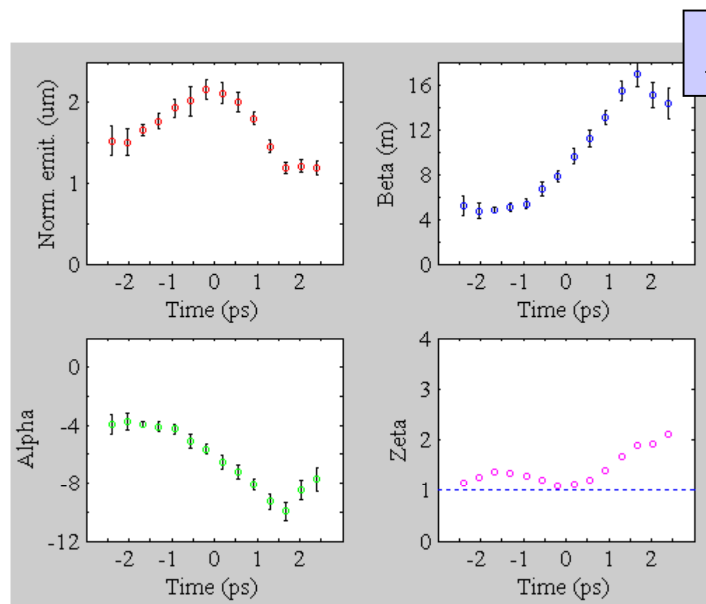
Slice parameters vs charge





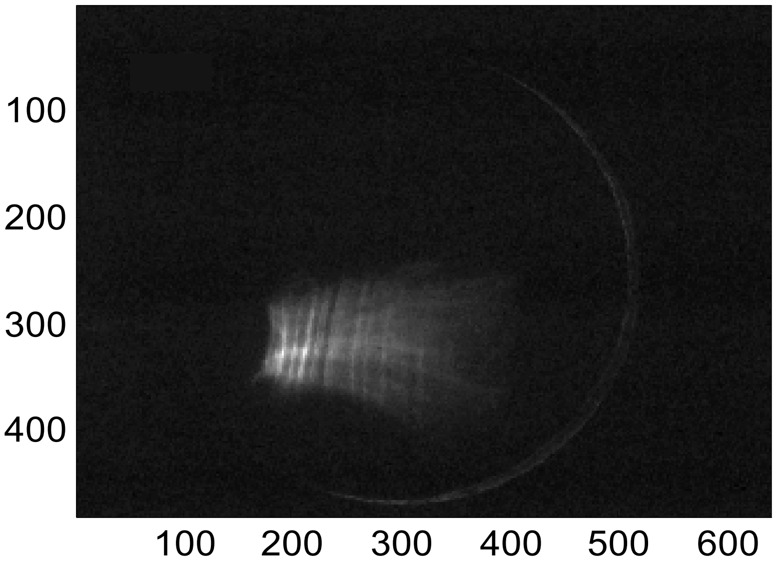
Low charge cases show low slice emittance and little phase space twist.

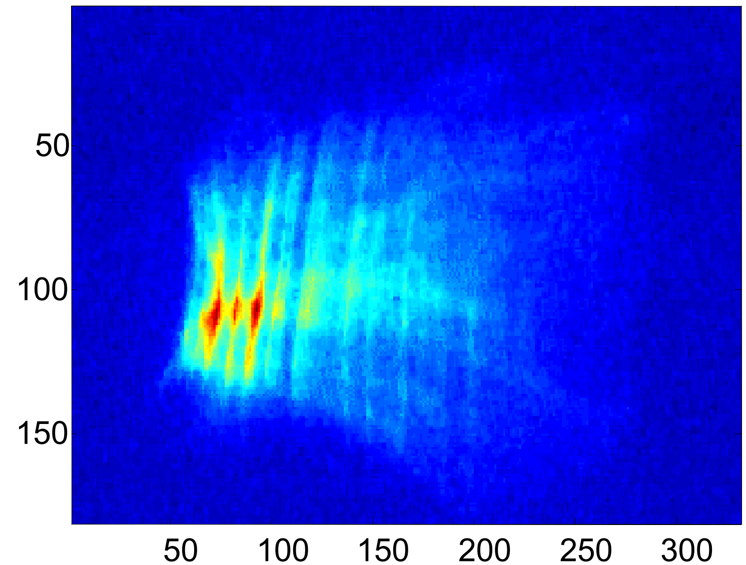




High charge cases demonstrate both slice emittance growth and phase space distortion.

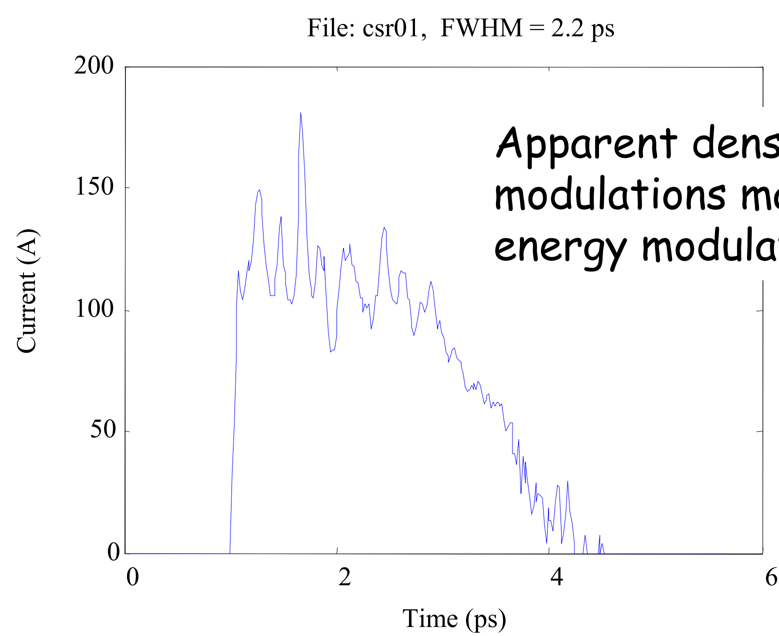
Longitudinal structure





Analysis of RF zero phasing data can be complicated by modulations in energy plane.

See contribution from C. Limborg for detailed description.



Apparent density modulations may be energy modulations

Concluding Remarks

•Femtosecond timing is possible between multiple lasers, perhaps between lasers and RF devices using optical methods.

•Experience seems to indicate that most differences between experiment and simulation are due to lack of knowledge of the actual experimental conditions.

•Slice emittance is substantially larger than thermal or intrinsic emittance at high charge (for imperfect laser shapes).

•Electron beam quality depends strongly on laser properties at cathode. Characterization of UV laser properties is important.