

# The Research Program at the Brookhaven National Laboratory Accelerator-Test-Facility (ATF)



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Brookhaven National Laboratory

<http://www.bnl.gov/atf/>

# What is the concept of the ATF?

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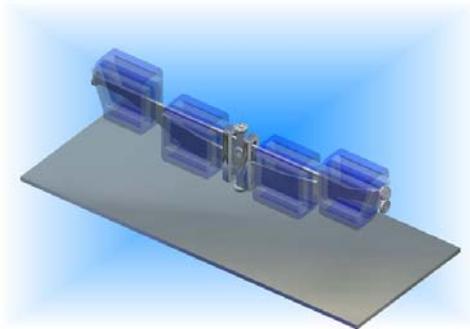
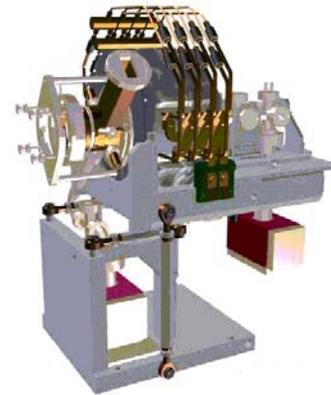
- The ATF is a proposal-driven, advisory committee reviewed User's Facility for long-term R&D in Accelerator and Beam Physics.
- The ATF serves the whole community: National Labs, universities, industry and international collaborations.
- The ATF provides all with a place to carry out such R&D without having to invest in basics, excellent equipment, trained staff, full hand-holding support of users.
- ATF contributes to graduate education in Beam Physics.
- Joint support of HEP and BES.
- A resource for accelerator science for over 12 years
- The value of this approach has been recognized, leading to proposals for similar facilities:
  - ORION An Advanced Accelerator Research Facility at SLAC.
  - NICADD, Northern Illinois Center for Accelerator & Detector Development.

# Photoinjector R&D

The ATF runs a complete R&D program in photocathode RF gun systems:

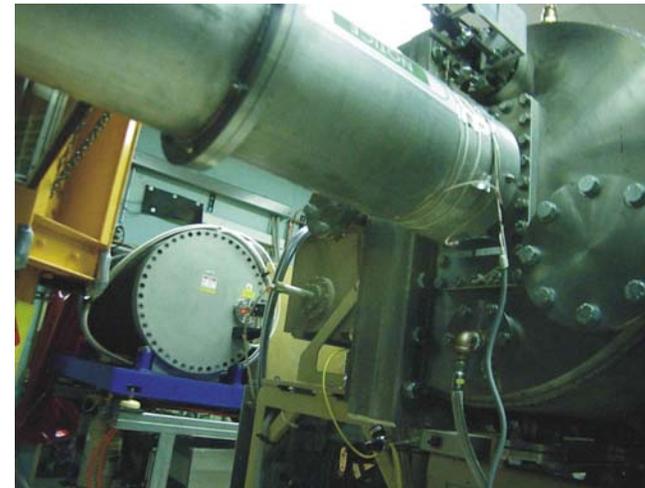
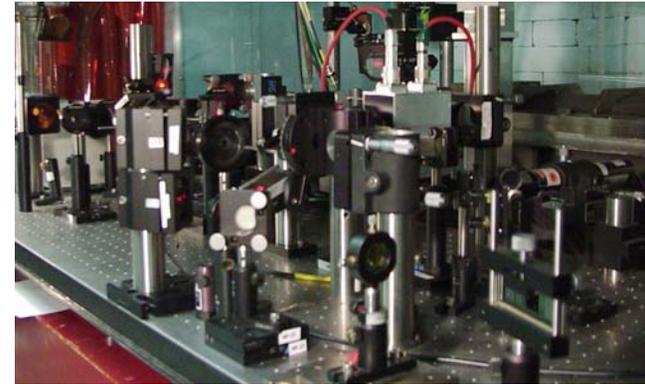
- High-duty RF gun (50 Hz) design and built by ATF is in operation at SDL, ANL and Japan. Closest to the LCLS 120 Hz design. ⇒
- A photocathode RF injection system including emittance compensation magnet, RF gun and beam diagnostics system. ⇒
- Drive laser system R&D on shaping, stability and reliability.
- Demonstrated technique of high QE Mg cathode with lifetime on the order of month, QE of  $2 \times 10^{-3}$ .
- Superconducting photoinjector ⇒
- Bunch compressor

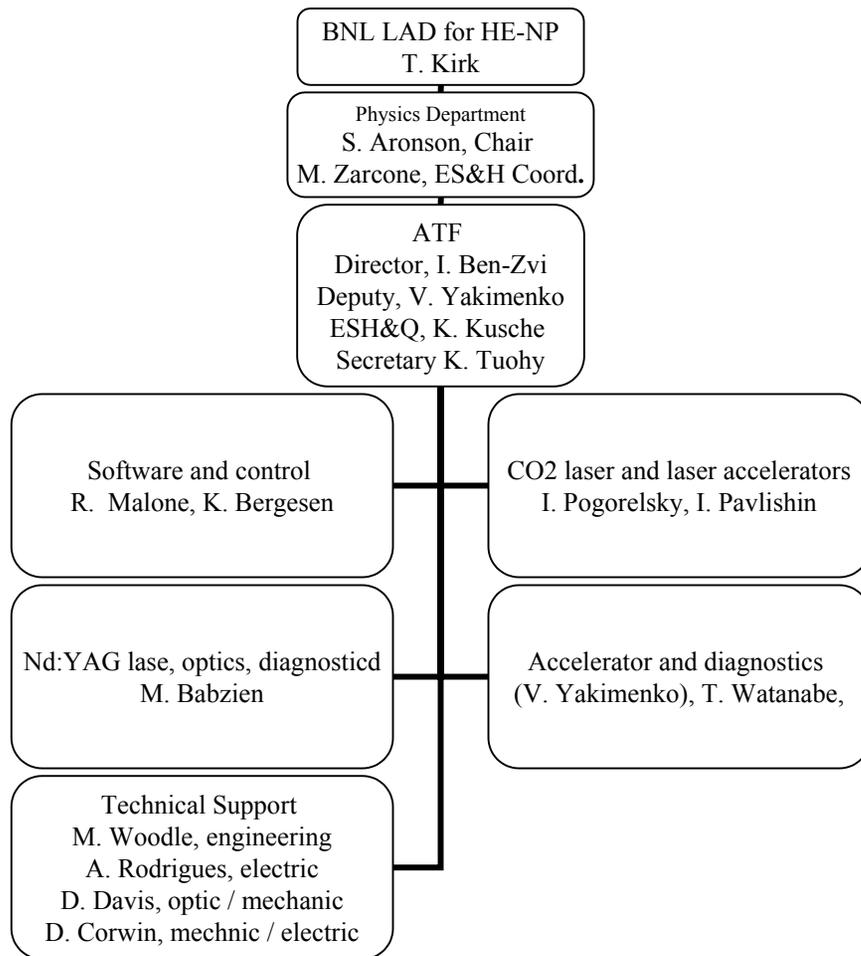
Best brightness.  
Widespread use.



# ATF's picosecond, terawatt CO<sub>2</sub> Laser System

One of a kind high-power, short pulse laser, at a wavelength 10 times longer than the norm. This makes the pondermotive potential 100 times larger and facilitates optical synchronization. The laser is synchronized to the electron beam, enabling a large variety of experiments.



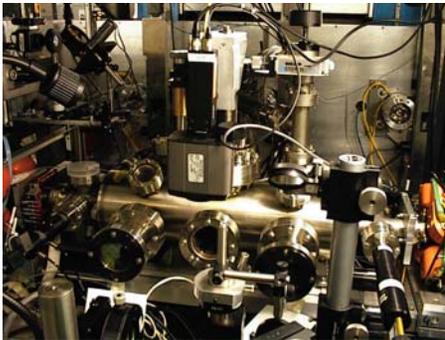


# ATF Experiment Hall

Experiment hall



Compton ps source



3 beam lines, one beam line directly past linac.  
Spacious control area, set-up area, optical  
diagnostics area, offices and more.

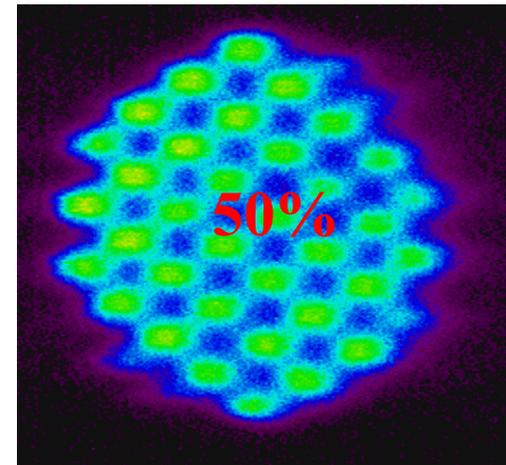
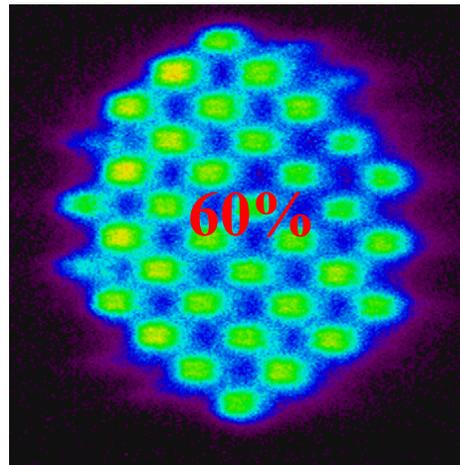
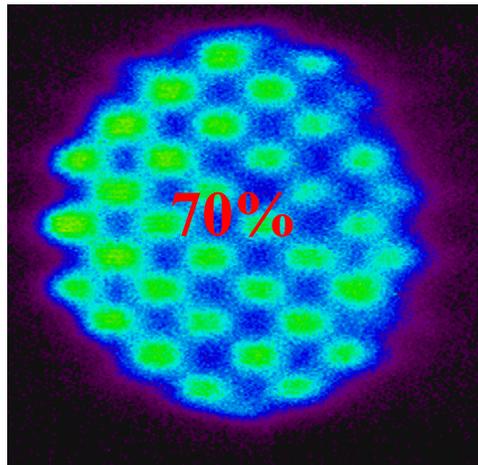
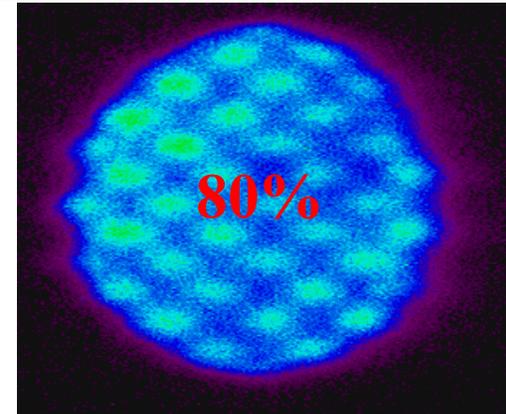
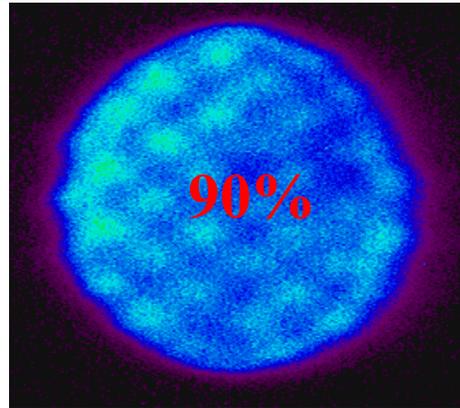
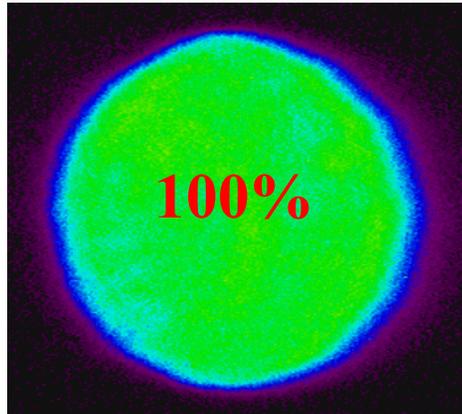
# 14 currently active experiments: 14 experiments completed

- Nonlinear-Compton Scattering
- Photocathode R&D
- Beam Position Monitors for Linear Colliders
- Stimulated Dielectric Wakefield Accelerator
- Compton Scattering of ps Electron and CO<sub>2</sub> Beams
- Ultra-fast Optical Detection of Charged particles
- Laser Driven Cyclotron Autoresonance Accelerator (LACARA)
- A SASE-Free Electron Laser Experiment, (VISA)
- Electron Beam Compression Based Physics at the ATF
- Structure-based Laser Driven Acceleration in a Vacuum
- Optical Diffraction-Transition Radiation Interferometry Diagnostics
- Particle Acceleration by Stimulated Emission of Radiation
- Multi-bunch Plasma Wakefield Acceleration at ATF.
- Laser Wakefield Acceleration Driven by a CO<sub>2</sub> Laser

Steady state

# Emittance as a function of charge uniformity

F. Zhou, et al., PR ST-AB, 5 094203, (2002).

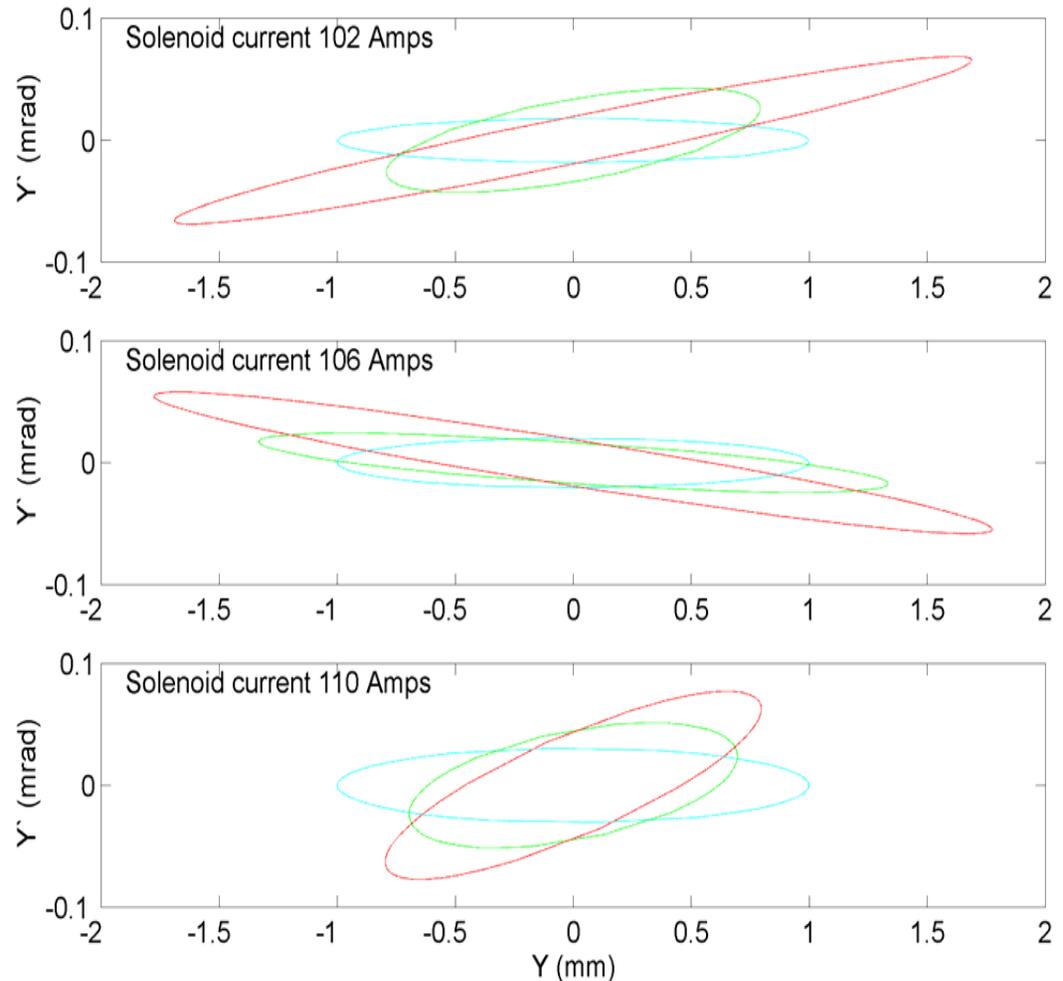
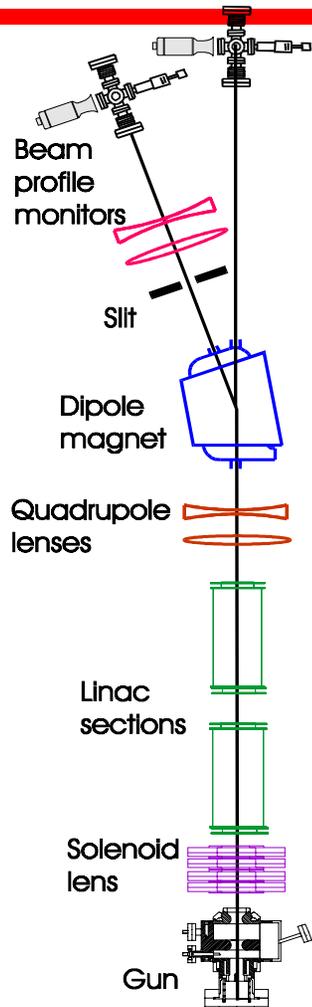


# Results of Experiment

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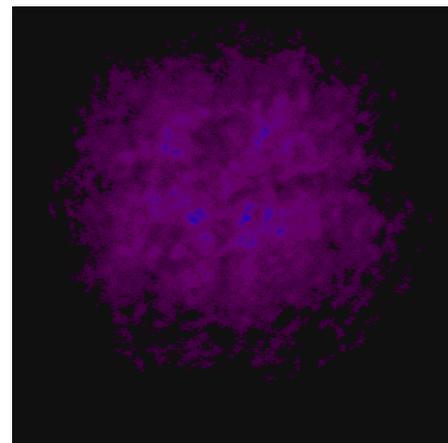
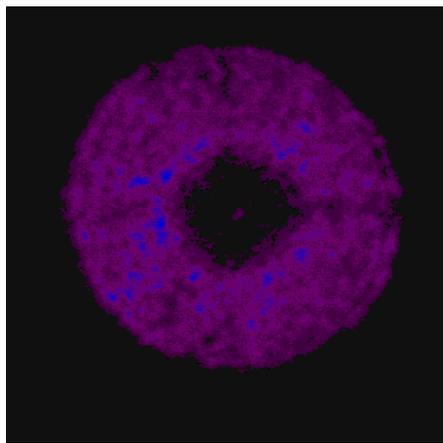
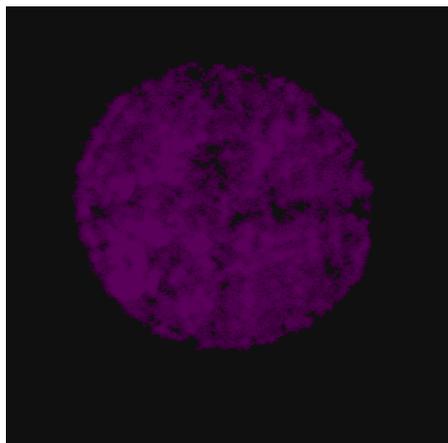
# Picosecond 'Slice' emittance

X. Qiu, et al., PRL 76, 3723 (1996)

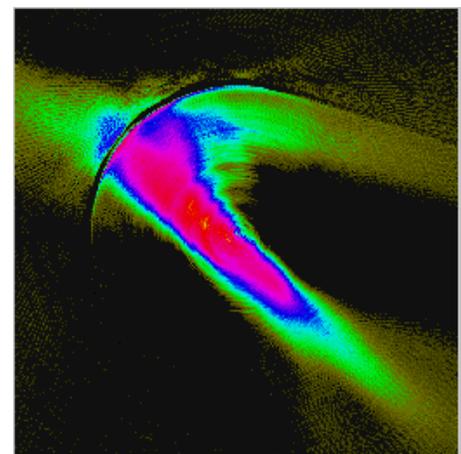
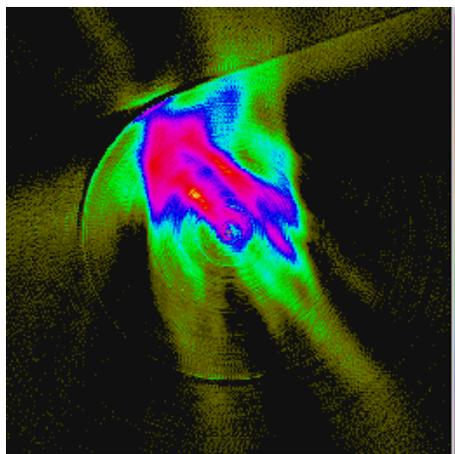
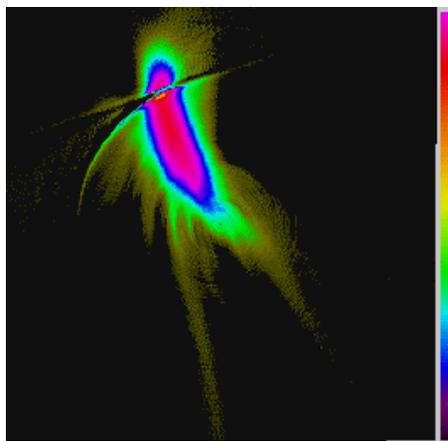


# Tomographic Studies of the phase space of an electron beam

Laser Profiles On Cathode:

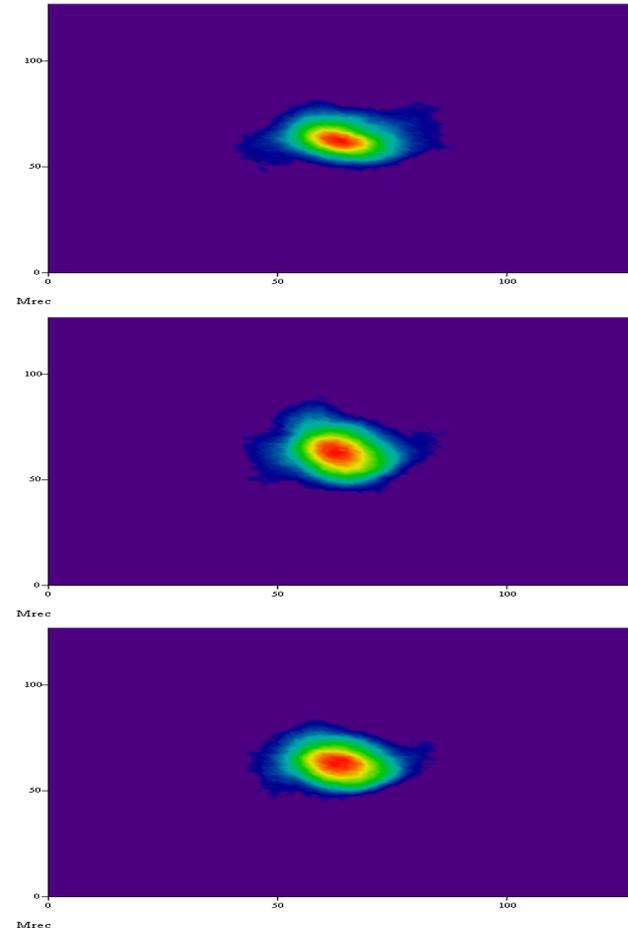


Phase-Space Density Map:



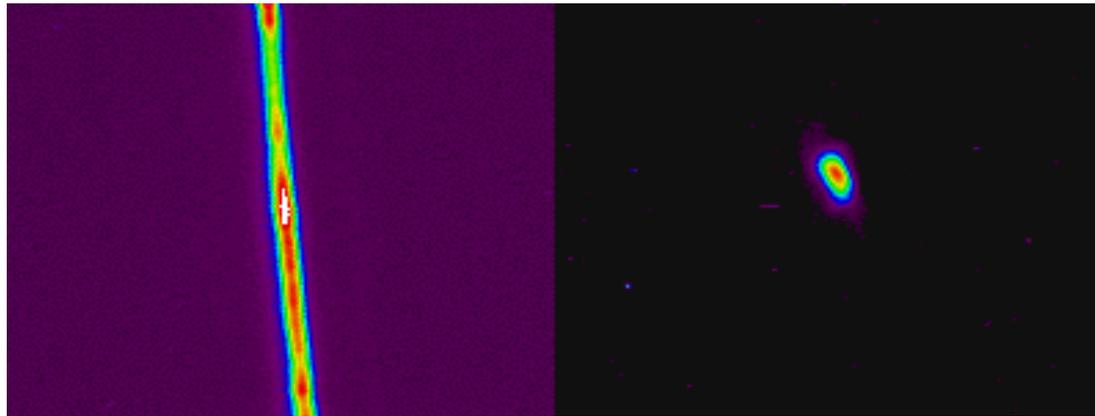
# Slice Emittance + Tomography!

- Measure electron density in phase space of a photoinjector.
- Slice emittance – a peek into the heart of emittance compensation.
- Phase-space tomography – what emittance really means.
- On right: Measured Transverse phase space of three different 1.5 ps slices of a 5 ps bunch.

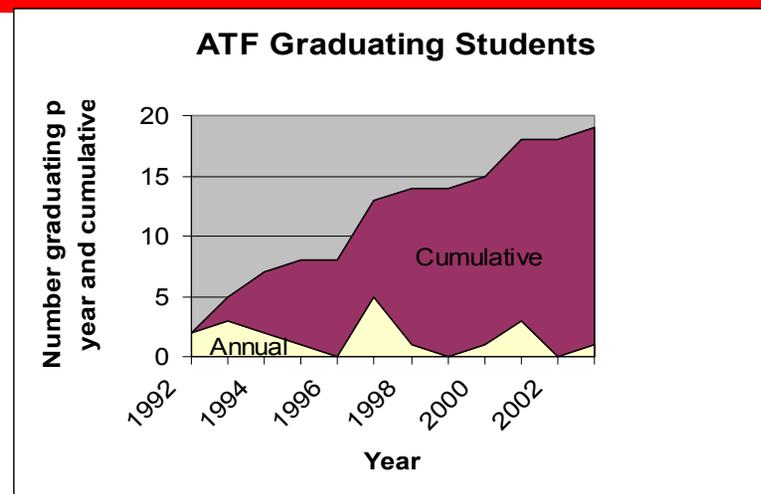
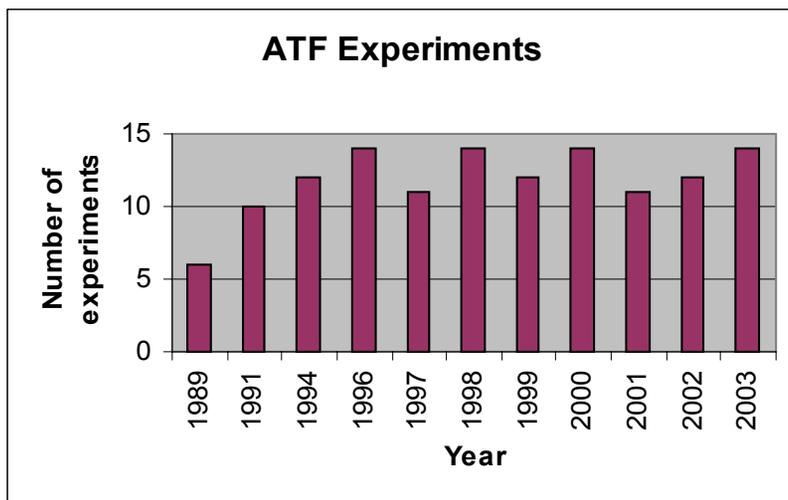


# Small emittance and beams

- We measured an emittance of 0.8 microns at a charge of 0.5 nC (record)
- Made small beams (below, right) 10 microns rms spot size (see 30 micron diameter wire on left)



# Some ATF Statistics



Run time: ~ 1000 hour / year

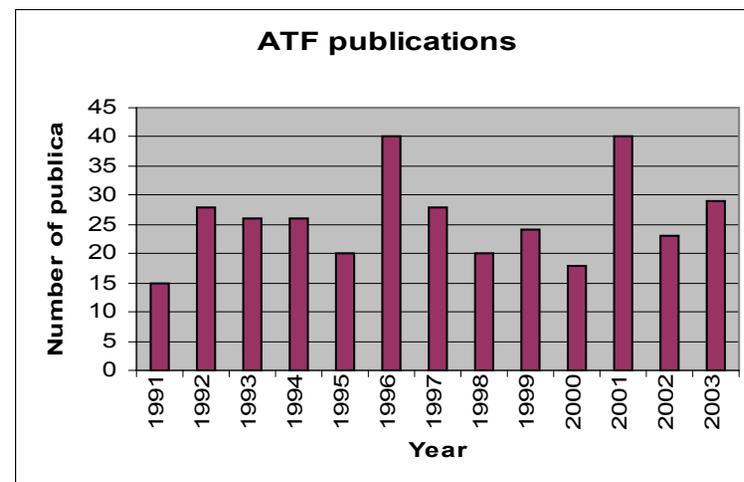
Current Graduate students: 8

M.Sc./Ph.D. students: 4/15

Current experiments: 14

Staff members: 11

Phys Rev X: > 3 / year



# Getting spectacular results...

The best measures of the performance of the ATF are the results that users get from their experiments.

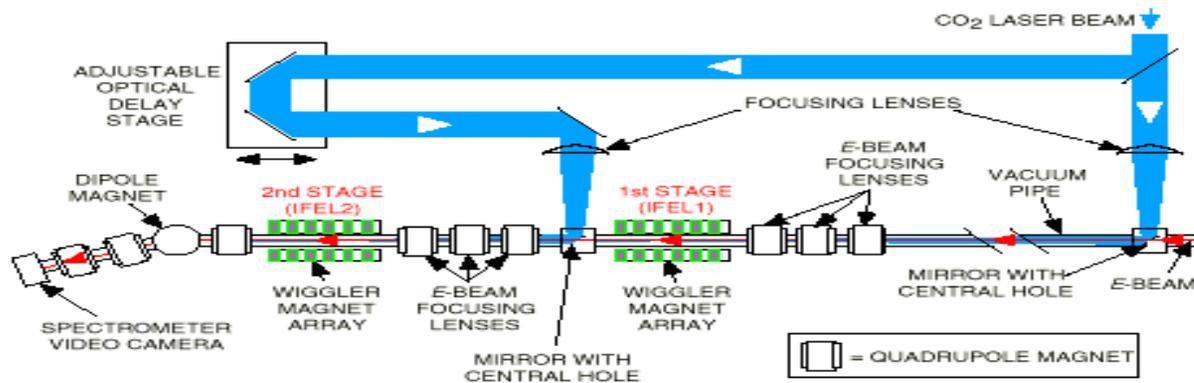
Some examples follow.



# Staged Electron Laser Accelerator (STELLA)

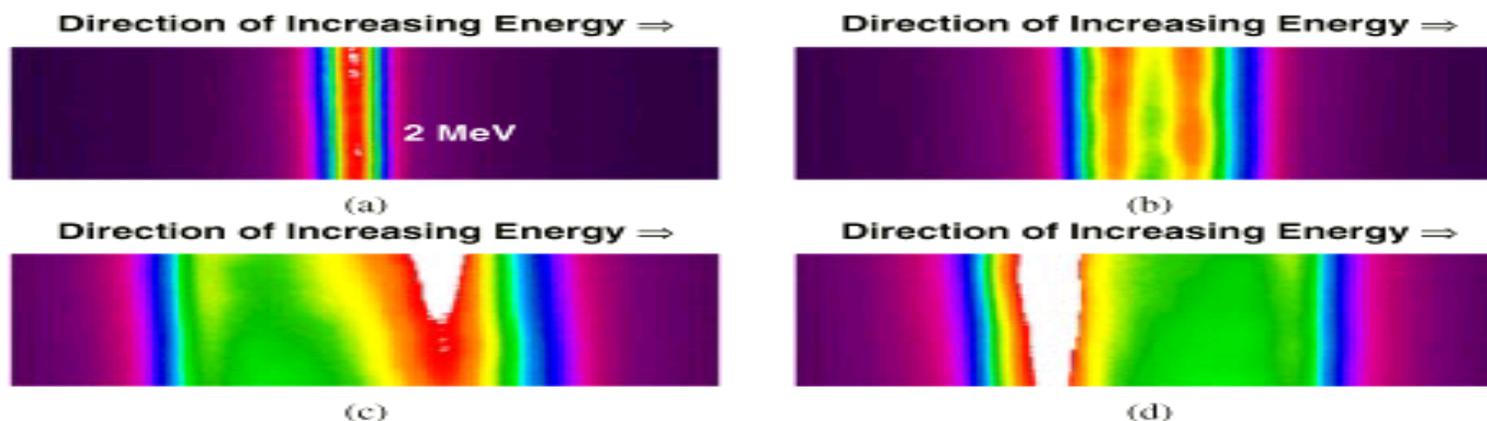
W. D. Kimura, et. al., PRL 86 no. 18, 4041 (2001)

- Demonstrated staged laser acceleration
- Demonstrated 3 fs FWHM bunching



# Results from STELLA Experiment

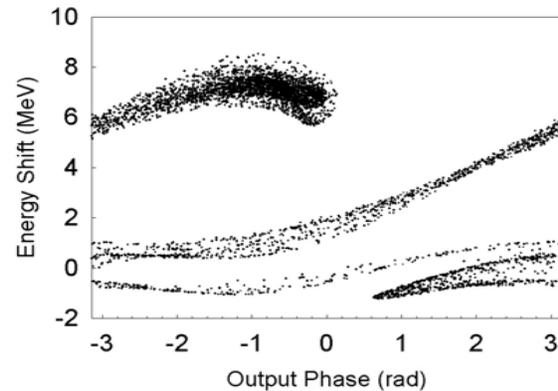
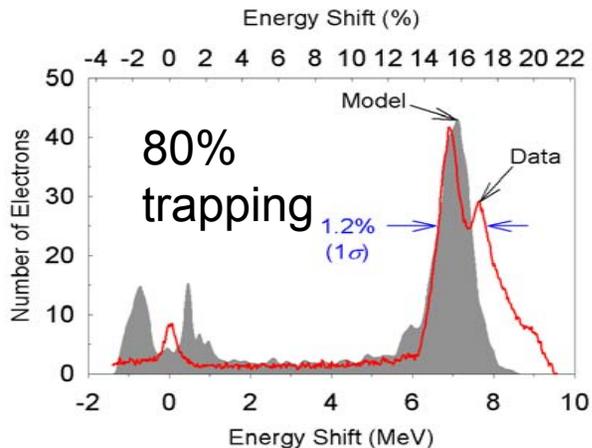
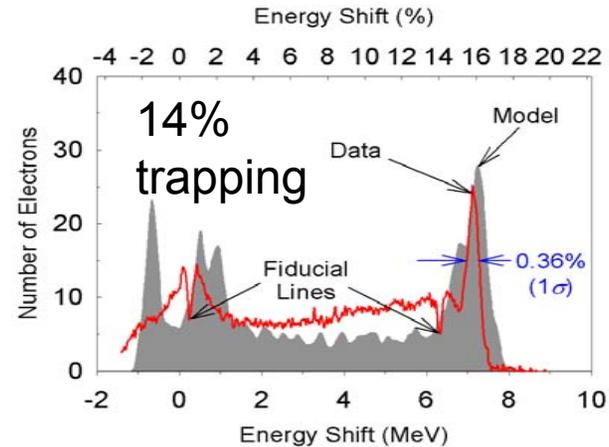
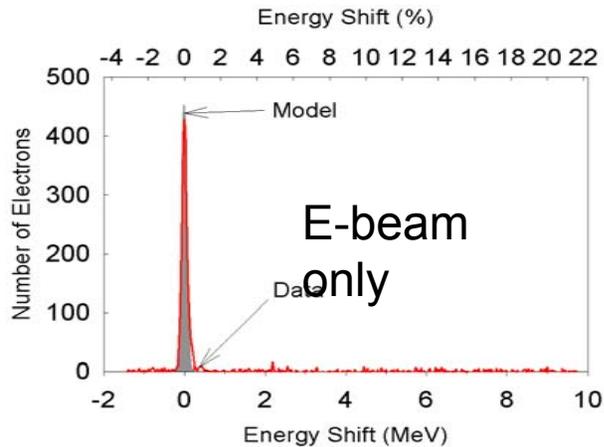
- Stable, reproducible phase control on an optical scale



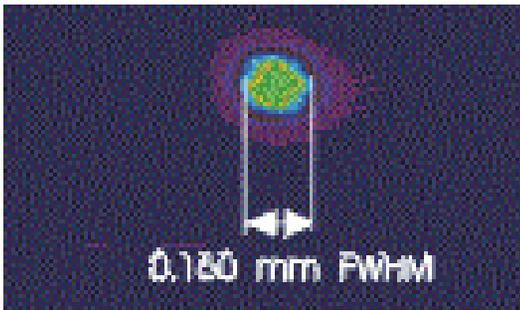
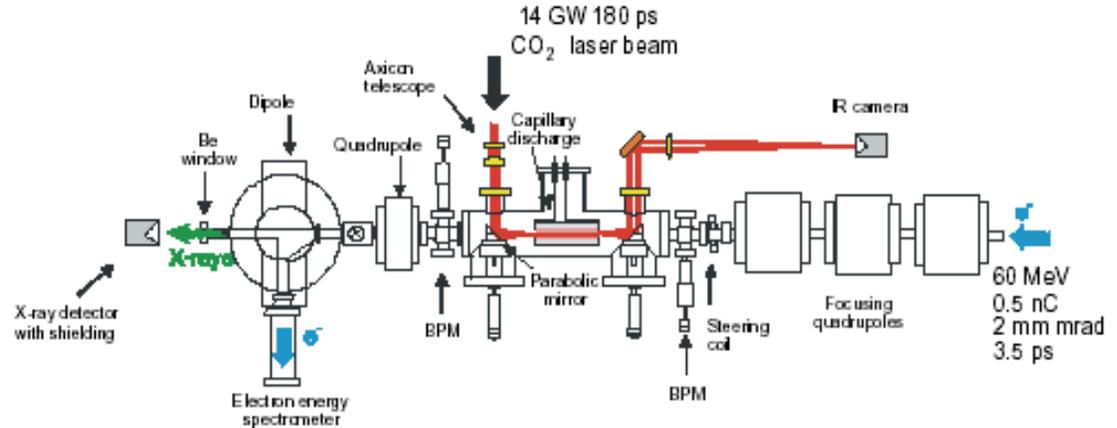
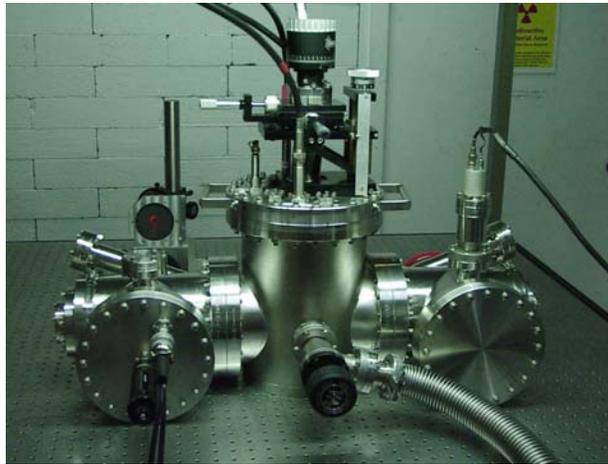
Raw video images from electron energy spectrometer for the conditions given in Table 1. (a) Laser off to both IFELs. Signal strength increases from violet, blue, green, yellow, to red. White is saturation. (b) Sinusoidal energy modulation from first IFEL only. (c) Lasers on to both IFELs. Phase delay set for maximum acceleration. (d) Same conditions as (c) with phase delay set  $180^\circ$  from (c).



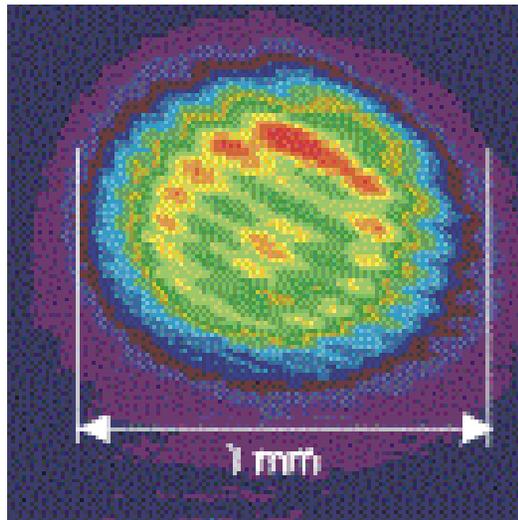
# Examples of Experimental Results



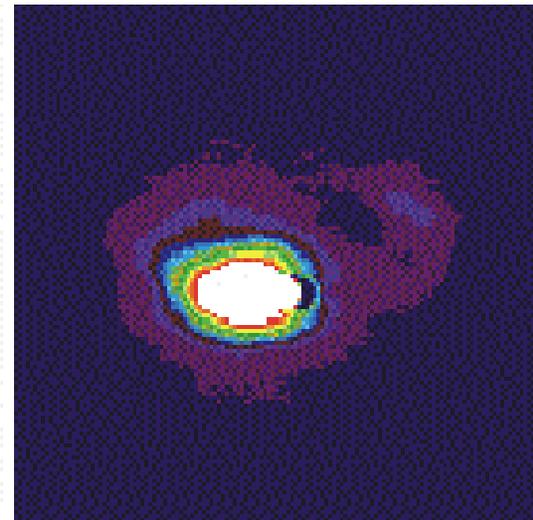
# Capillary Plasma Channeling of CO<sub>2</sub> laser



At focal point

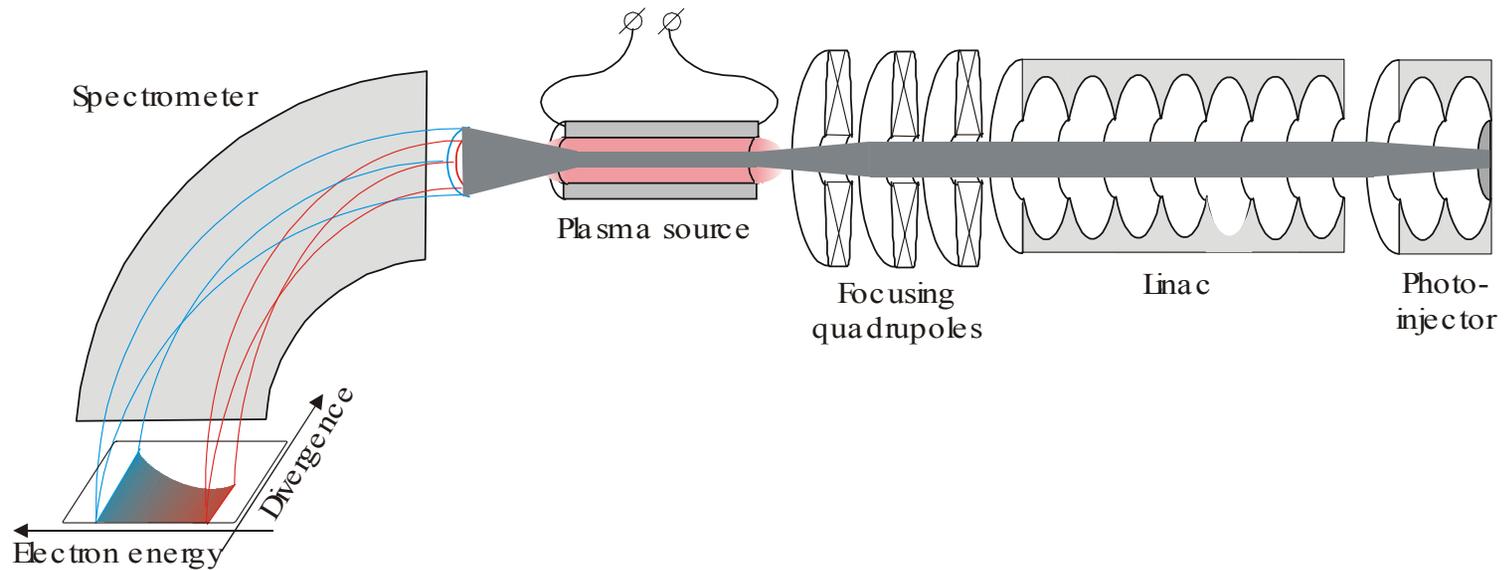


18 mm Downstream



At 18 mm, plasma on

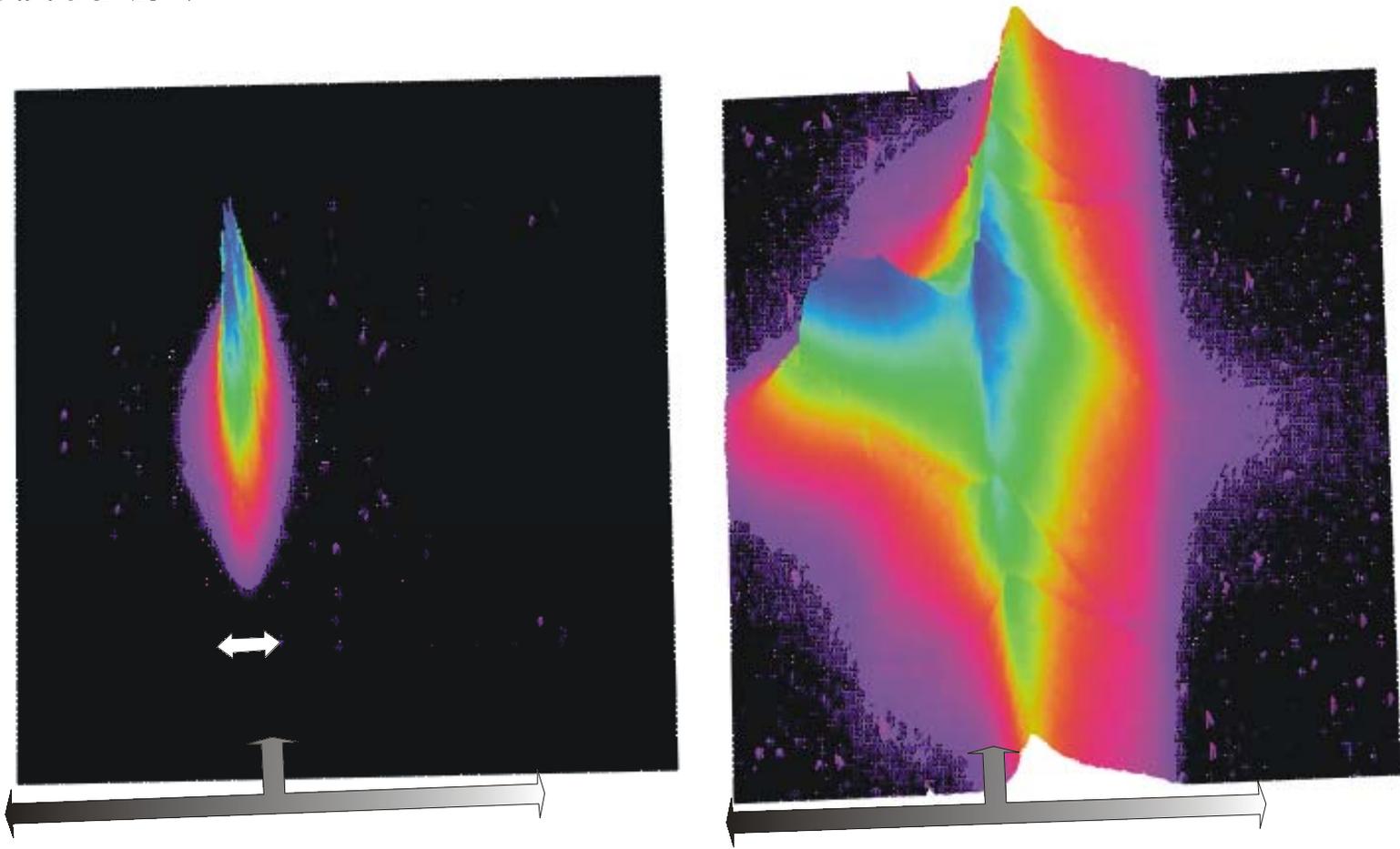
# Plasma Wakefield Schematic



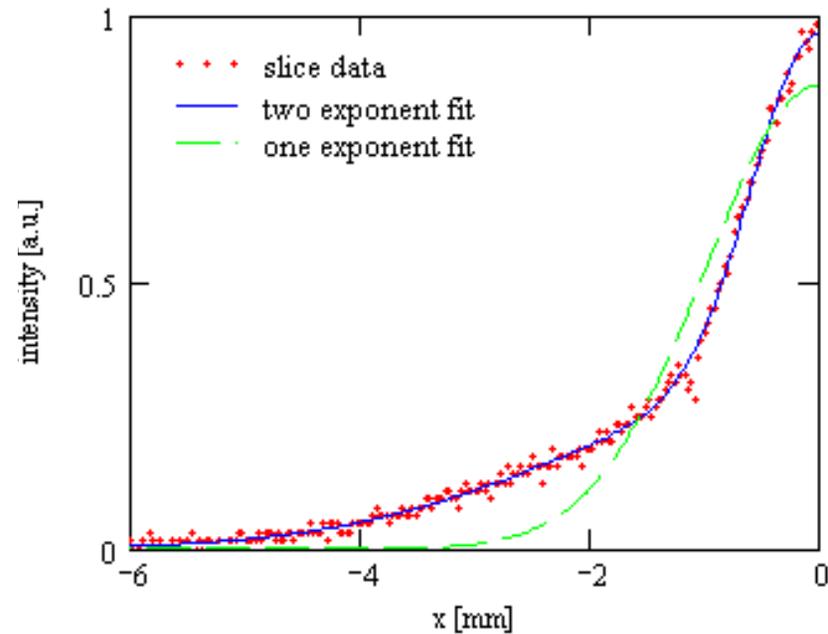
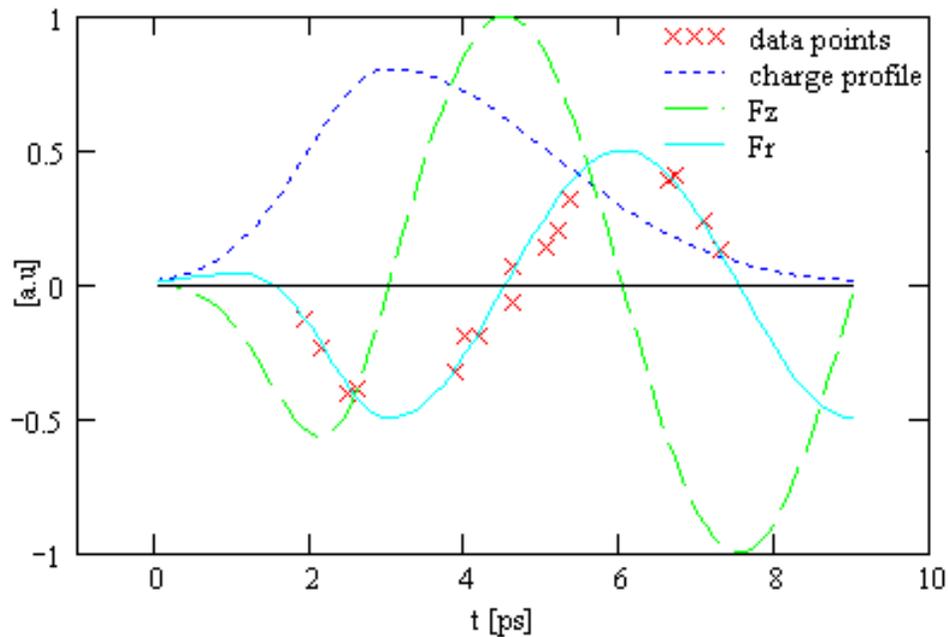
**Goal of the experiment:** 45 MeV, 1 nC electron beam excites plasma waves. As a result we observe acceleration and focusing.

# V. Yakimenko, et. al, Observation of Cohesive Acceleration and Focusing of Relativistic Electrons in Overdense Plasma,

Phys. Rev. Lett. **91**, 014802 (2003)



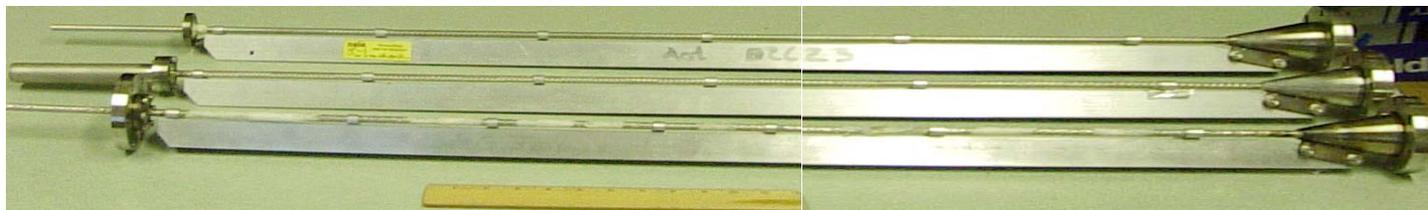
# Focusing as function of phase



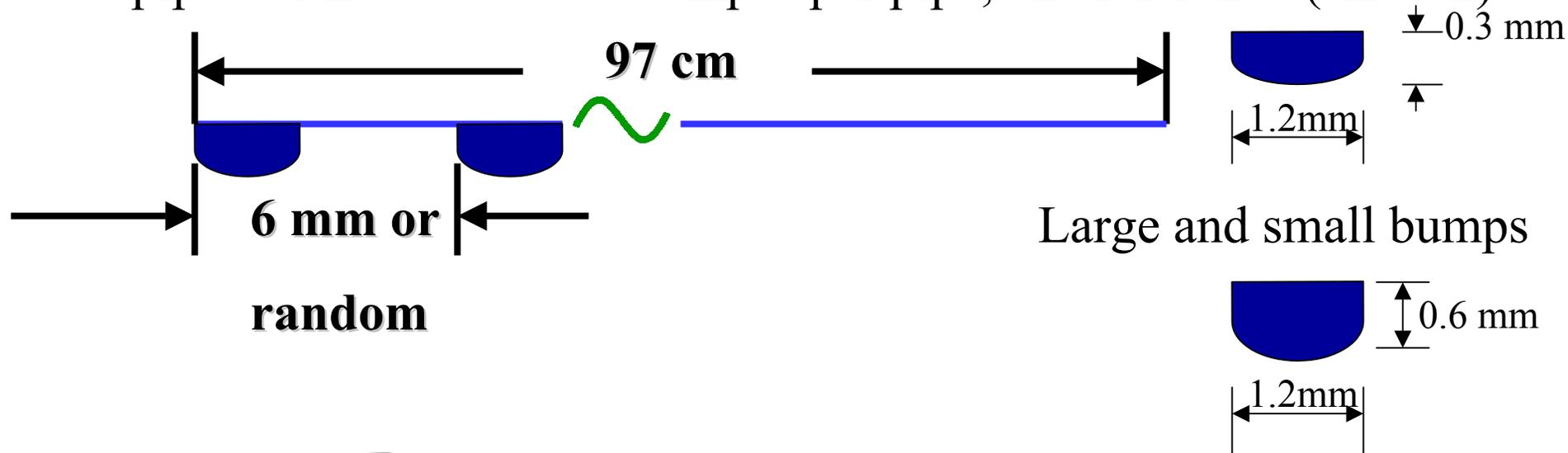
# Surface roughness wake field

F. Zhou, et al., PRL , 89 No. 17, 174801-1, (2002)

**Important subject for linear collider dynamics.**



3 pipes with about 3000 “bumps” per pipe, one reference (smooth)



# One of the Measurements (Energy loss vs. bunch-length)

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# Optical Stochastic Cooling (LDRD) in collaboration with LBNL

Repeat  $n_d$   
times for  
 $1/e$   
reduction  
of  
emittance

- 'Read' particle by spontaneous emission wiggler.
- Amplify signal with laser
- Apply correction 'kick' to the particle in IFEL wiggler
- 'Mix' particles (to de-phase spurious part.)

■ **Non power-limited:**  $n_d \approx 2eN_s$   $N_s = \frac{\lambda}{3\Gamma} \frac{N_i}{\sigma_l}$

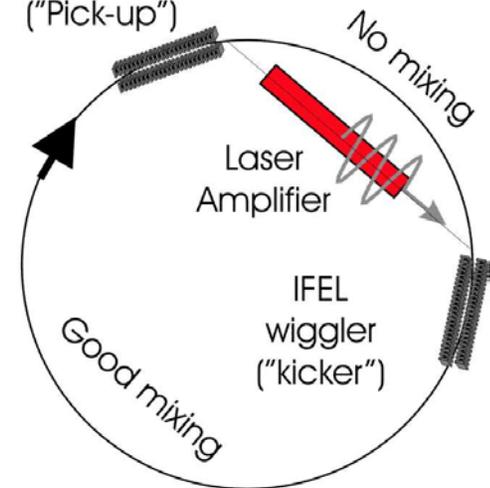
11 seconds, MW laser

■ **Power-limited:**  $\frac{1}{n_{x,\epsilon}^2} = \frac{16}{e} \frac{P}{I} \frac{\Delta E}{\Delta E} \frac{\delta E}{\Delta E} N_u \Gamma f_{x,\epsilon}$

1 hour, 16 watts

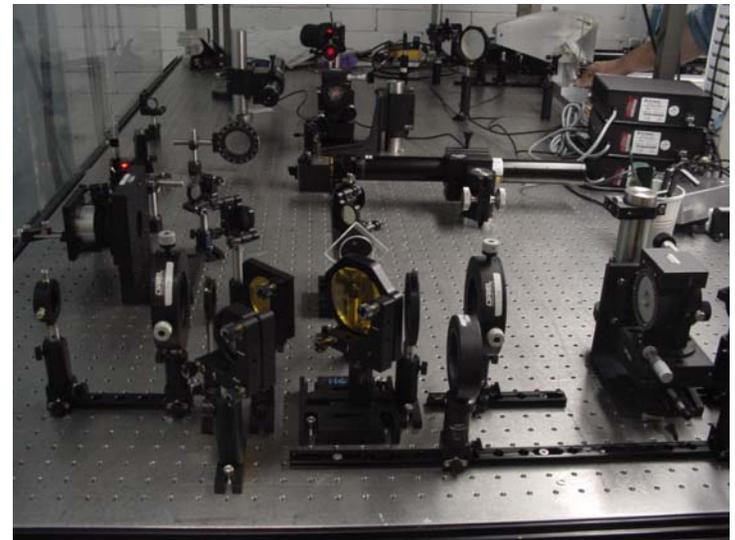
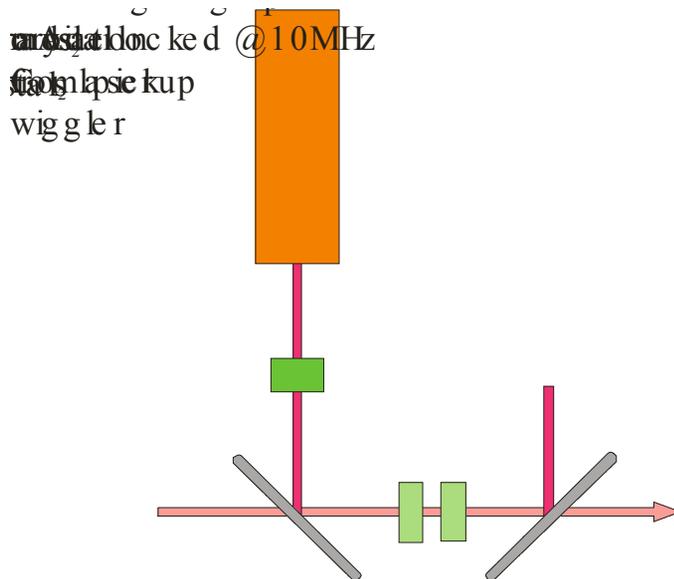
$$\delta E = 4.12q^2k \frac{K^2}{2+K^2} \left[ J_0\left(\frac{1}{2} \frac{K^2}{2+K^2}\right) - J_1\left(\frac{1}{2} \frac{K^2}{2+K^2}\right) \right]^2,$$

Spontaneous  
emission  
("Pick-up")



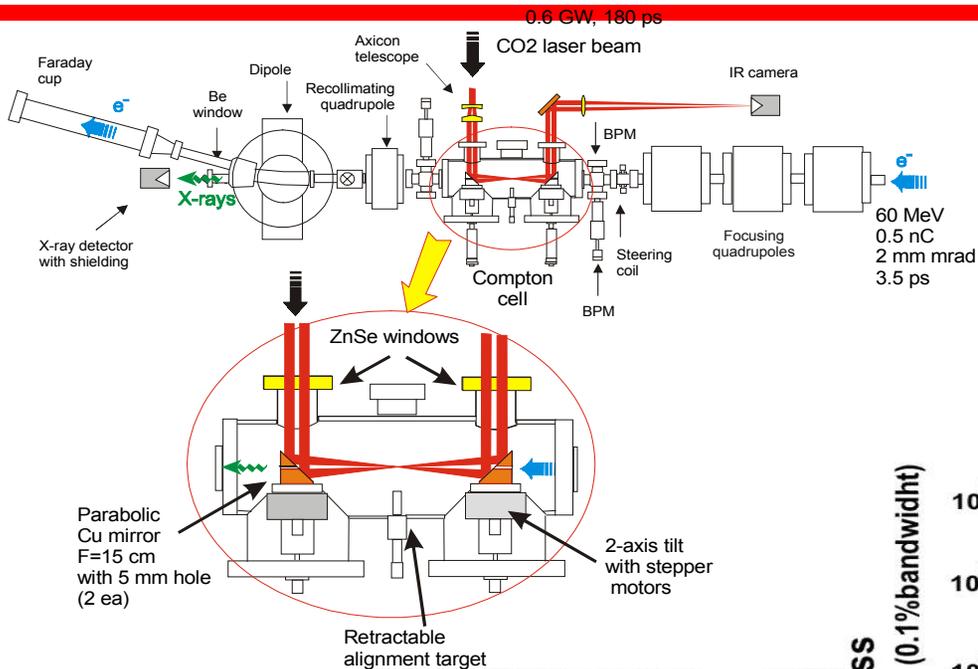
# OPA for the OSC Amplifier

M. Babzien, I. Ben-Zvi, I. Pavlishin, I. V. Pogorelsky, V. E. Yakimenko, A. A. Zholents, and M. S. Zolotorev, “Optical stochastic cooling for RHIC using optical parametric amplification”, Phys. Rev. ST Accel. Beams volume 7, issue 1, 012801 (2004)

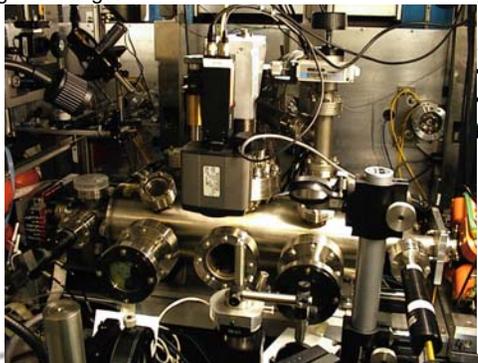
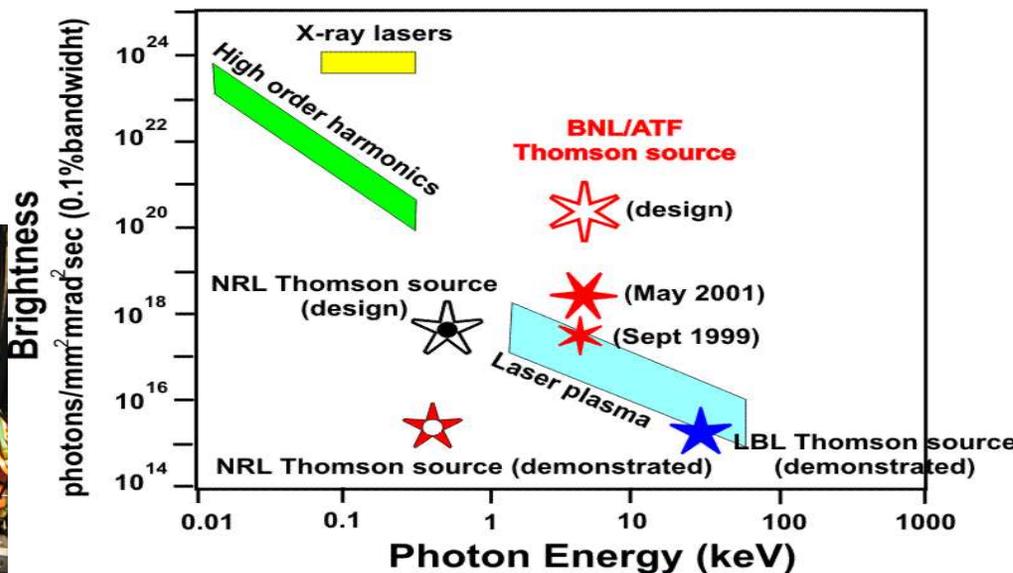


# Compton Scattering AE22

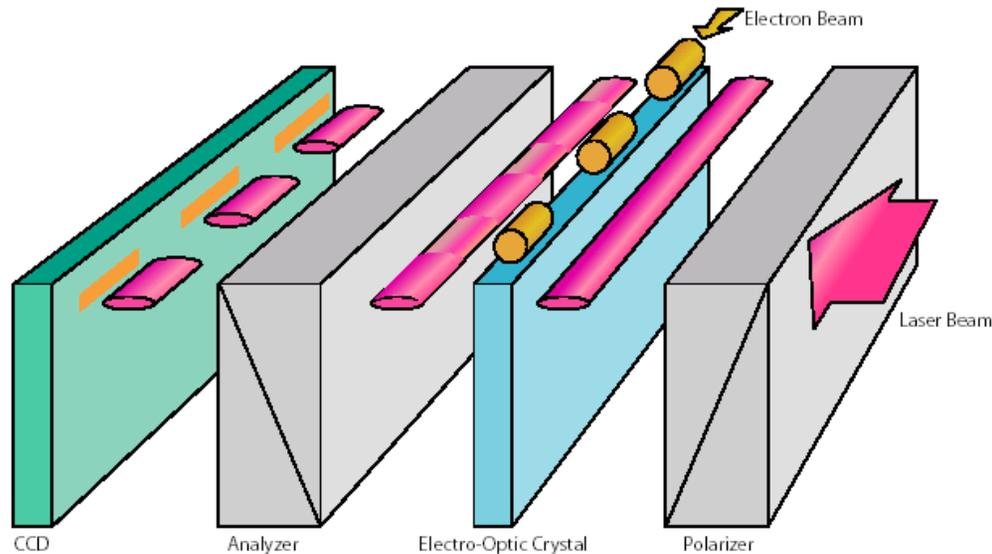
I.V. Pogorelsky, et al., PR ST-AB, 3, 090702, (2000)



Source of high peak flux  
picosecond x-rays,  
R&D towards a source of  
Polarized positrons for  
Linear colliders.



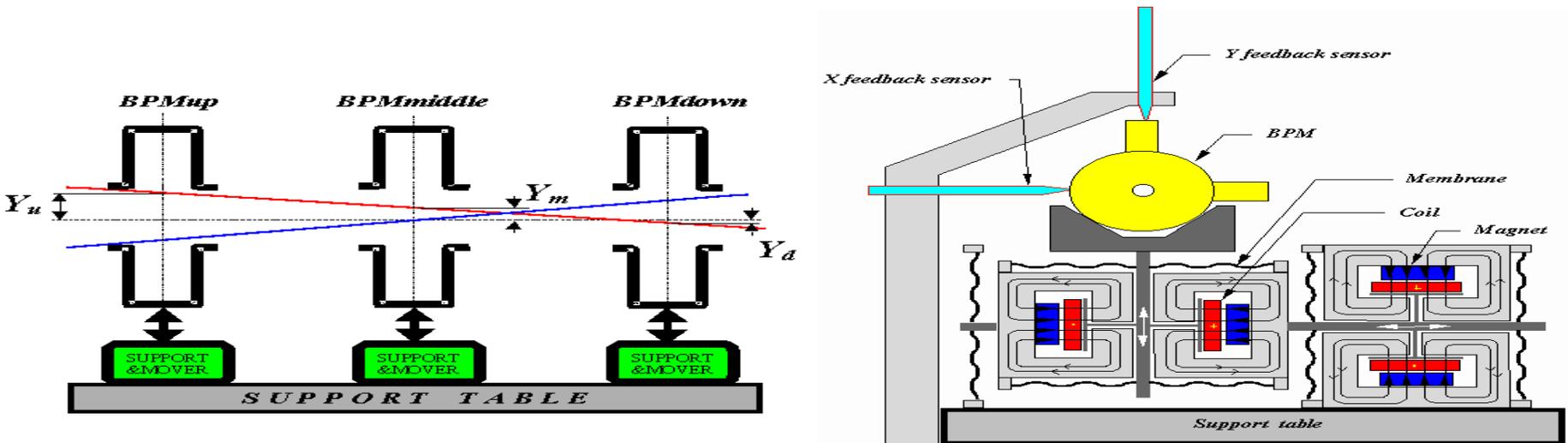
# Ultra-fast Optical Detection of Relativistic particles, AE23



- The "EO flash photo technique"
- The beam's temporal charge distribution is transformed into a spatial distribution.
- Very Promising New Detector with many Applications

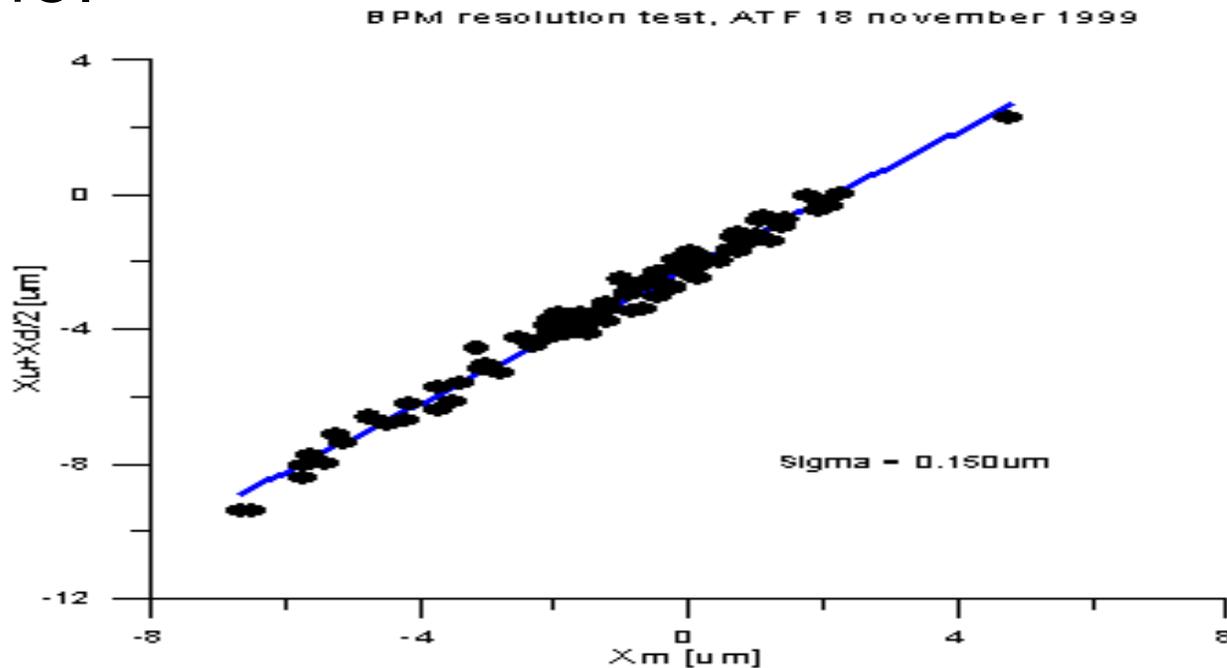
# Nanometer scale, non-intercepting Beam Position Monitors for Linear Colliders, AE16

- 3 cavities for complete redundancy
- Precision movers, 0.3  $\mu\text{m}$  resolution
- Sophisticated detection electronics



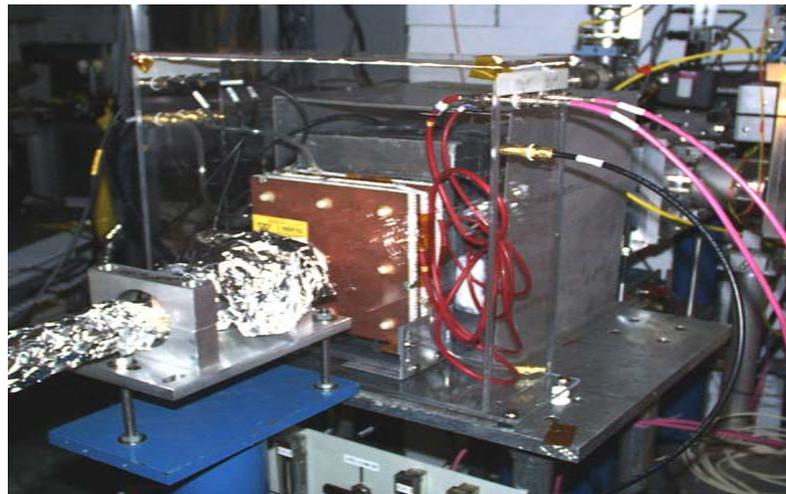
# Experimental results

- Potential resolution  $< 0.1 \mu\text{m}$
- Measured resolution  $0.16 \mu\text{m}$  for single pulses of  $0.5 \text{ nC}$ .



# Fermilab's MINOS Beam Monitoring Detectors, AE28

- The goal of the experiment was to learn how ionization in gases saturates at high charged particle intensities.
- Experiment completed successfully



# Path for higher energies wide open:

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# Summary

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- The ATF is a steady, productive users' facility that has been doing science, graduating students and providing service to the HEP community for the past 13 years.
- A comprehensive users program, hand-holding by ATF staff.
- The ATF is continuously evolving. It has the highest-brightness electron beams anywhere, powerful lasers and complete infrastructure.
- The ATF users are preparing or carrying out every single laser acceleration mechanism that was ever imagined.
- The ATF is under-utilized and could serve more users.
- The ATF can be upgraded cost effectively up to 1 GeV.