Plasmas, Dielectrics and the Ultrafast: First Science and Operational Experience at FACET

LINAC12, Tel-Aviv, Israel

Christine Clarke 13th September 2012

U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

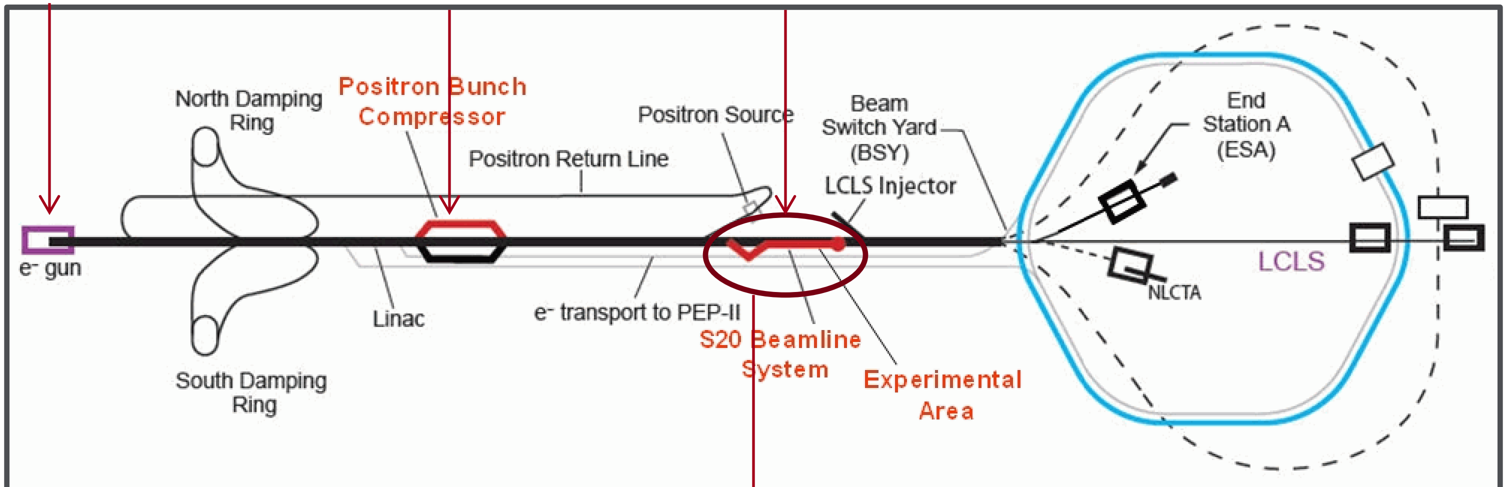
Introduction to FACET

Facility for Advanced Accelerator Experimental Tests

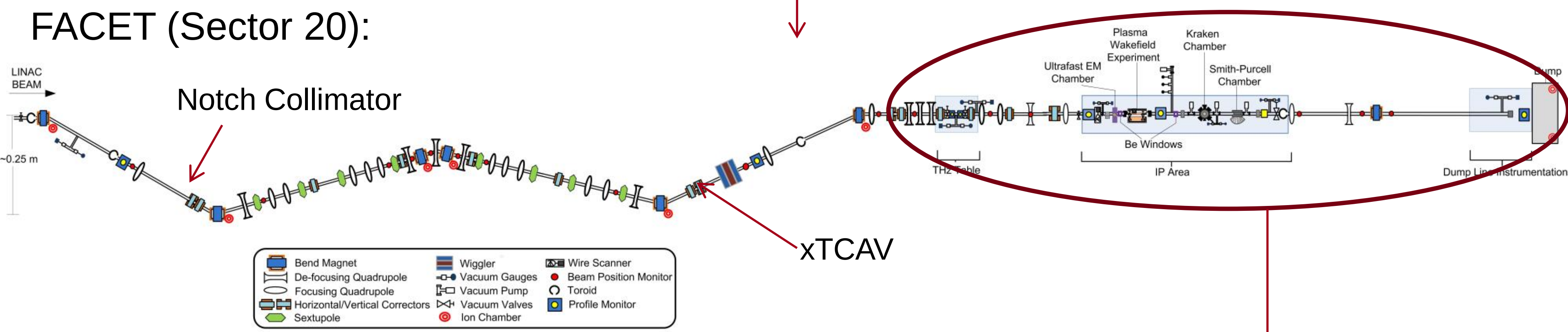
- FACET uses 2/3 SLAC linac to deliver electrons to the experimental area in Sector 20
- Mission Need Statement for an Advanced Plasma Accelerator Facility (CD-0) in 2008
- User Facility in 2012
- First User Run was April-July 2012

FACET Beamline

Linac: Sector 0 Sector 10 Sector 20

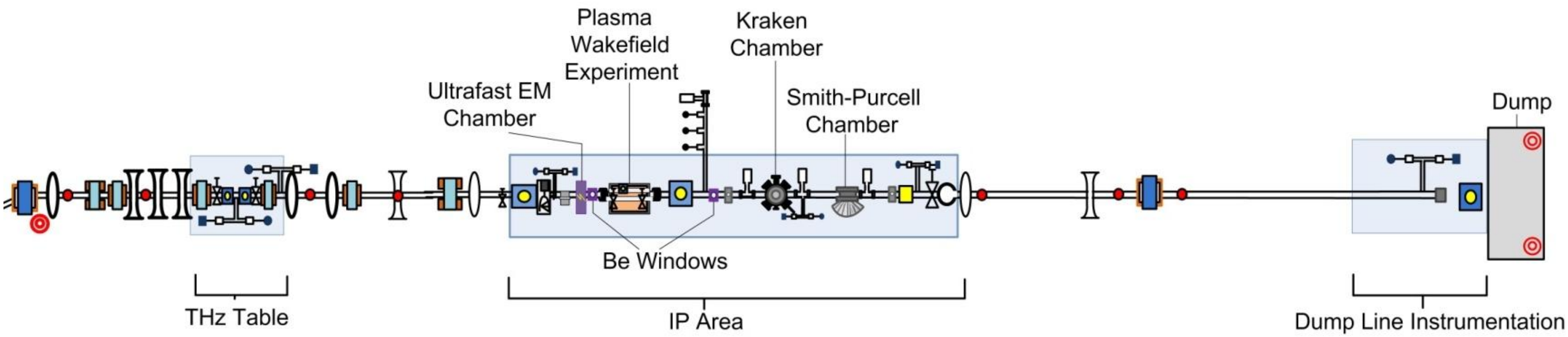


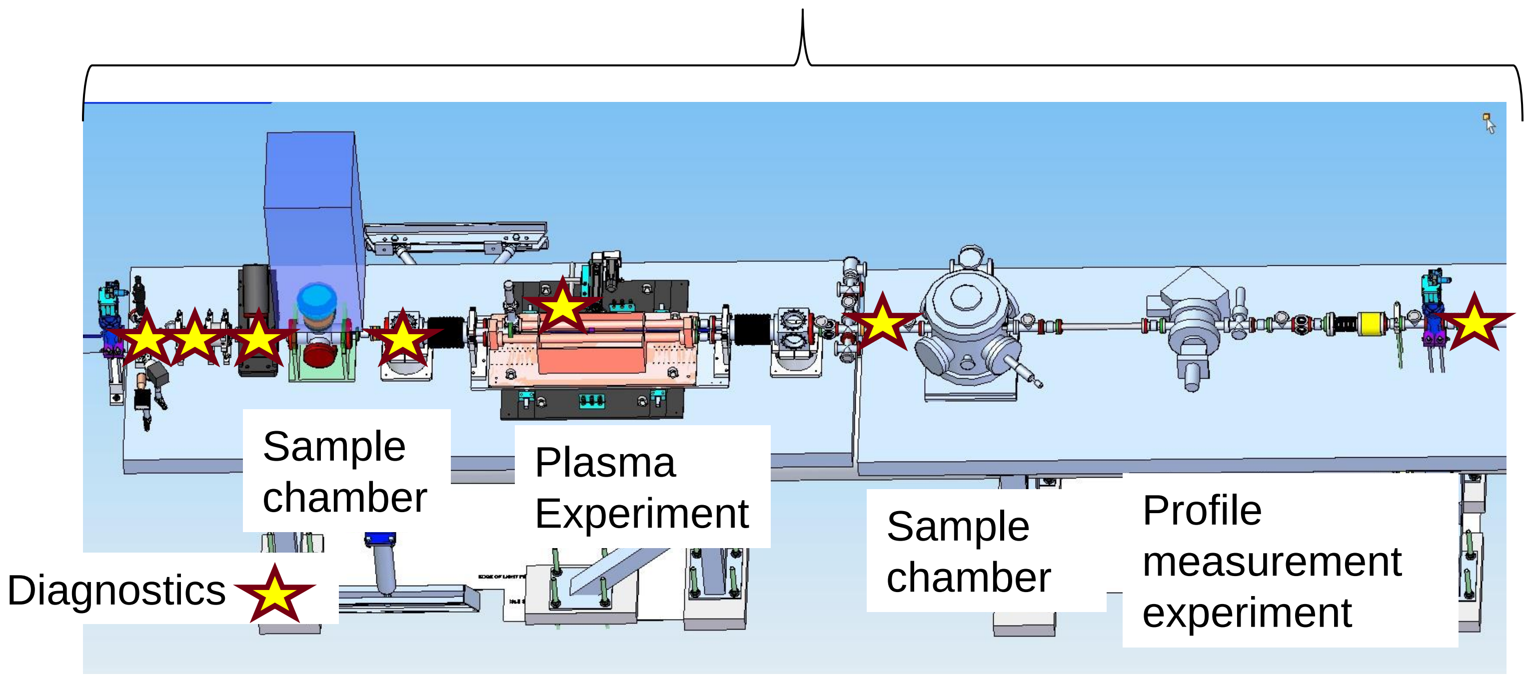
FACET (Sector 20):



Experimental Area (next slide)

FACET's Experimental Area

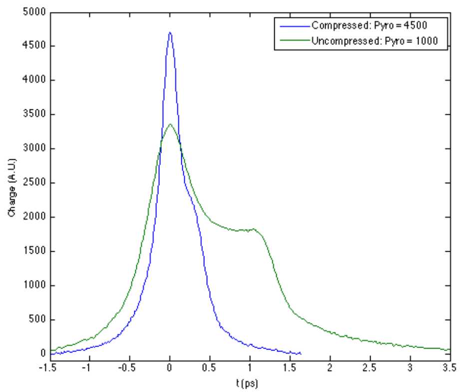


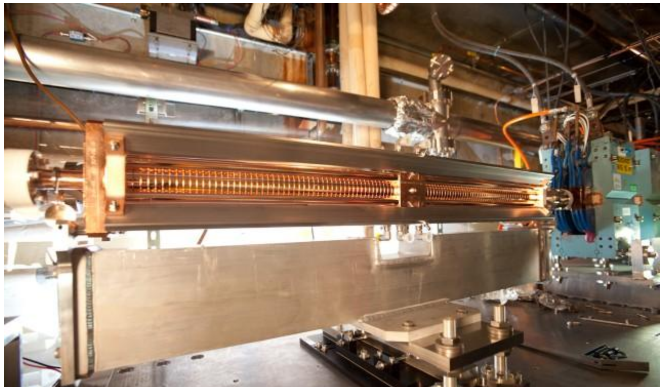


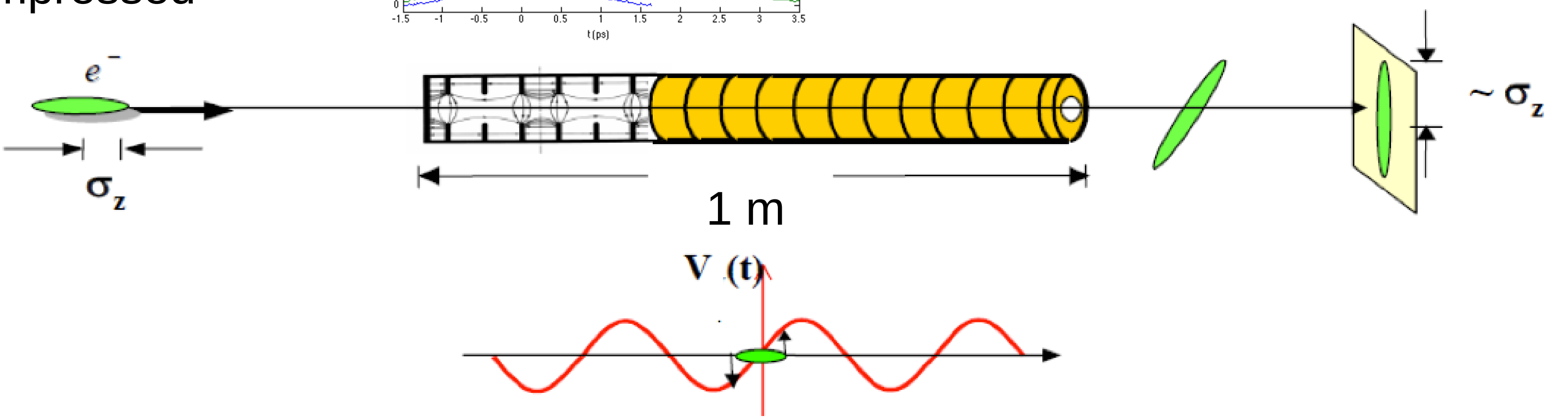
Bunch Length Measurements

- The time profile of the bunch is important to know at FACET
- Pulse by pulse relative indication of bunch length through CTR
- Direct imaging of longitudinal profile by xTCAV (invasive)
- Experimental diagnostics – bunch profile reconstructions through Smith-Purcell and CTR

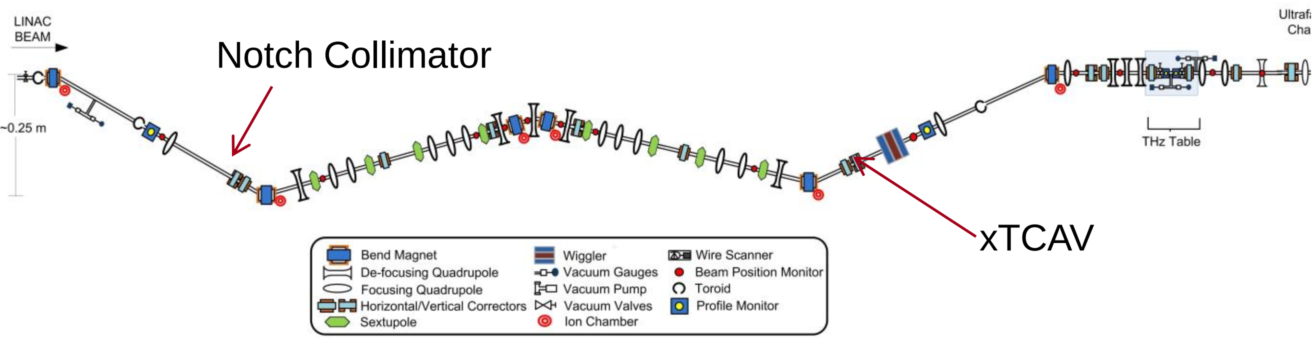
FACET longitudinal bunch profile:
Blue curve- fully compressed
Green curve - uncompressed



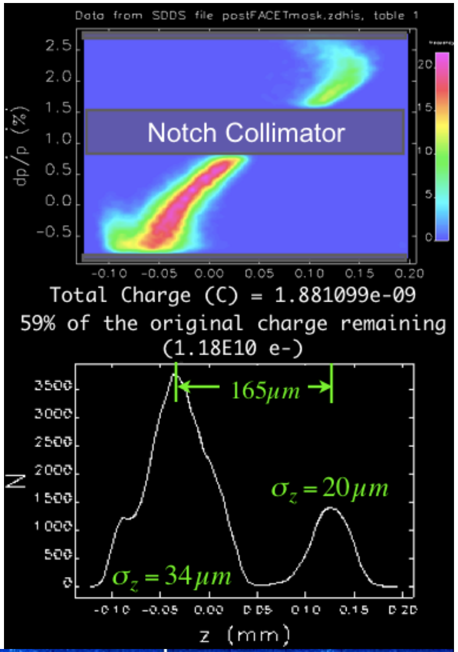


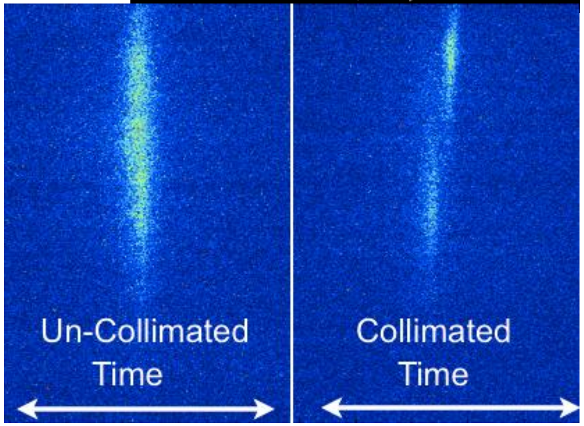


Two-bunch production



- In 2012, started commissioning Notch Collimator for creating two bunches
- Tantalum blade inserted into first leg of W chicane
- x ∝ ΔE/E
- This provides drive and witness bunches for wakefield acceleration experiments





Profile screen image with xTCAV on

The FACET Beam

- FACET's electron beam was commissioned during two periods- 12 weeks in 2011 and 5 weeks in 2012
- Downtime period allowed
  - Installation of new diagnostics
  - Alignment of sections of linac
  - Simulation work and development of new software
- Accelerator hardware uptime rose from ~75% to ~90% by User Run
- Between 2011 and 2012, there was considerable improvement in tuning on beam size (best sizes were 30μm in 2011, 20μm in 2012)
- Machine Development studies were scheduled throughout User Run

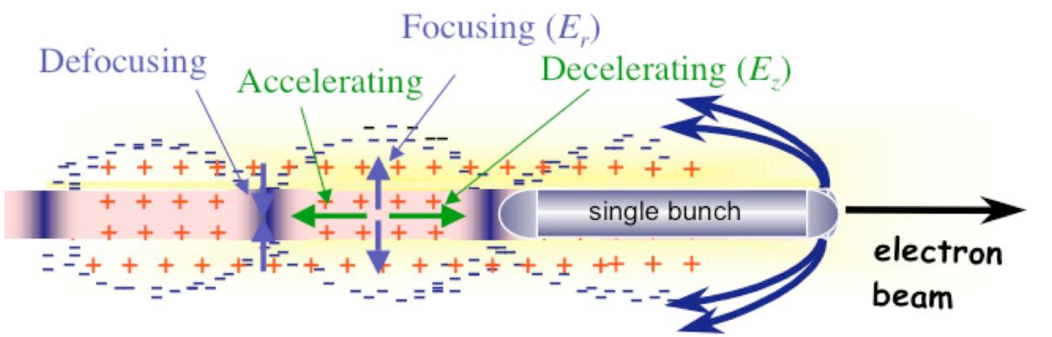
Parameter	Typical Value 2012	Best Value 2012
Energy (GeV)	20.35	
Charge per pulse	2.7 nC (1.7e10 e-)	3.0 nC (2.0e10 e-)
Bunch length σ_z (μm)	20-25	20
Beam size σ_x x σ_y (μm)	35 x 35	20 x 23
Particle	Electrons	

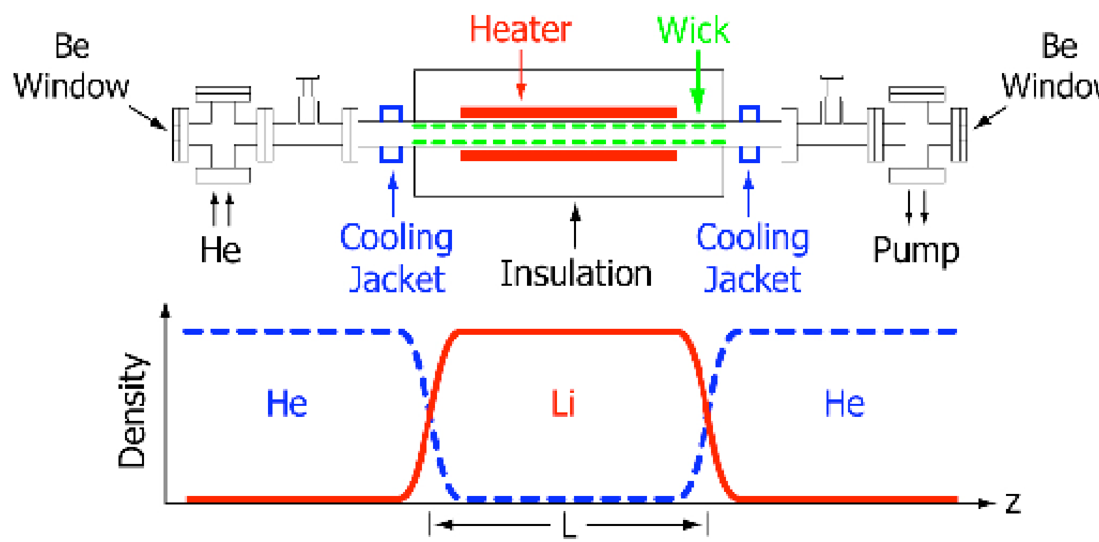
Operational Challenges

- Experiments need:
  - To change location of beam waist
  - To change bunch length
  - To change charge
  - To access FACET tunnel
- Solutions to meet needs:
  - Plan experiments well
  - Scheduled access day each week
  - Continuous study of the machine
  - Operating Procedures
  - Hands-on operators, constant attention and documentation
- Breakage of OTR foils - few diagnostics in experimental area
- ~kRad/week doses in experimental area – dead cameras, restrictions on access

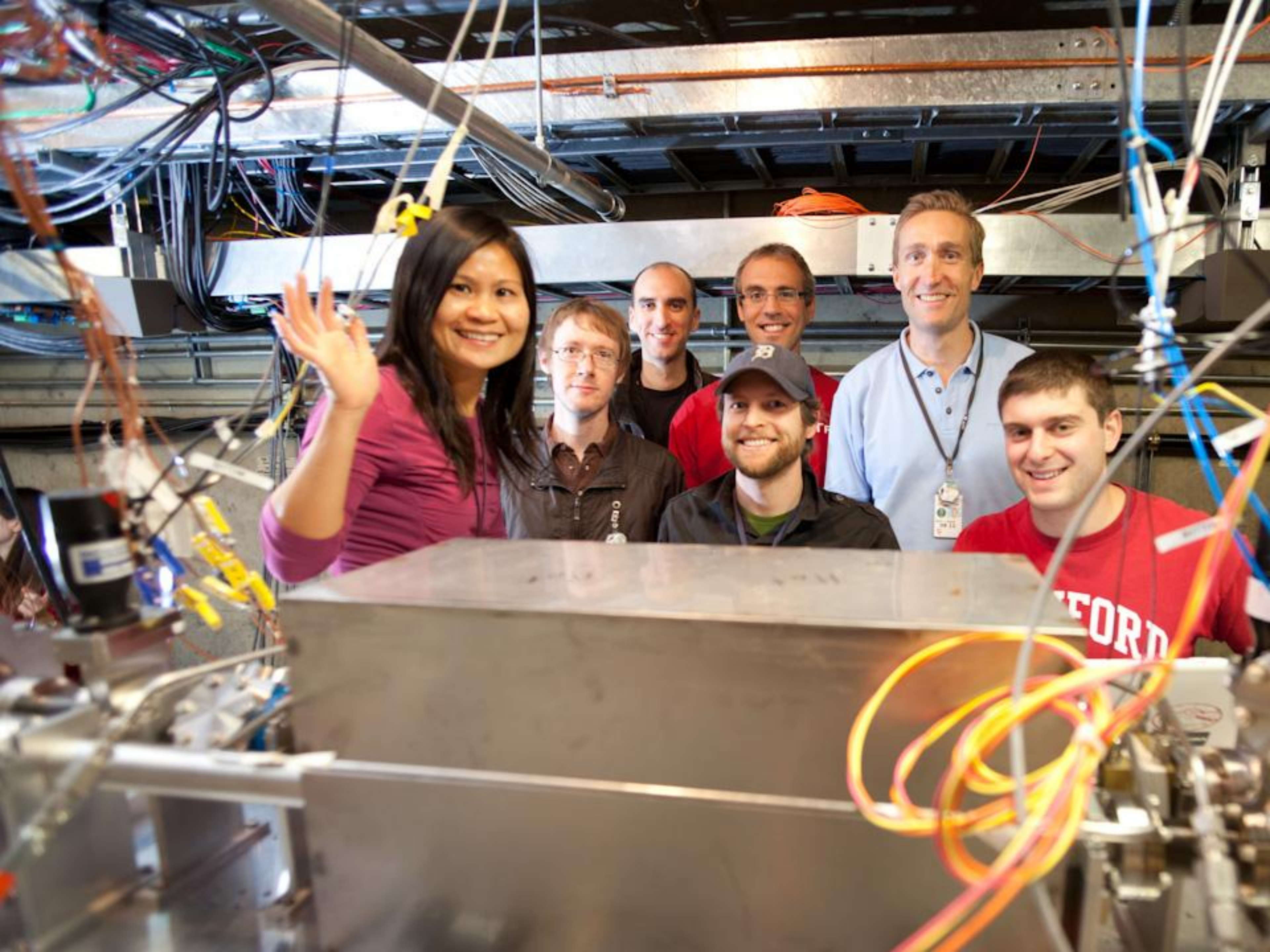
E-200 Multi-GeV Plasma Wakefield Acceleration - Apparatus

- SLAC, UCLA, MPI
- FACET's high power electron beam ionises alkali vapour and interacts with the plasma
- Wakefields accelerate part of the bunch
- Multiple plasma cells could access the energy frontier –
  - FACET studies the single plasma cell
  - multiple stages planned for FACETII
- Unique SLAC Facilities:
  - High Beam Energy, Short Bunch Length, High Peak Current, Power Density





10^{14}-10^{17} e^-/cm^3 Li or Rb plasma, L= 20-30 cm

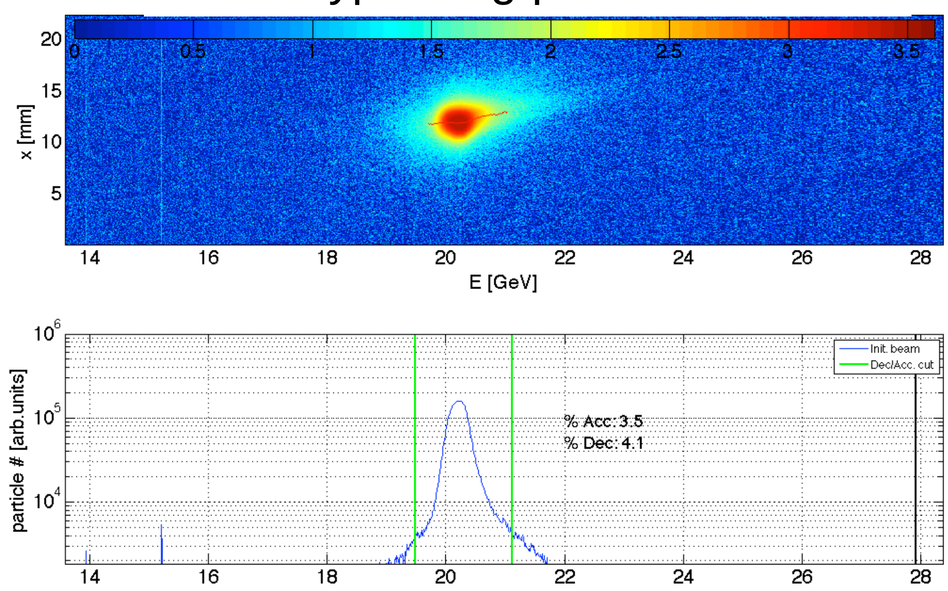


E-200 Multi-GeV Plasma Wakefield Acceleration - Results

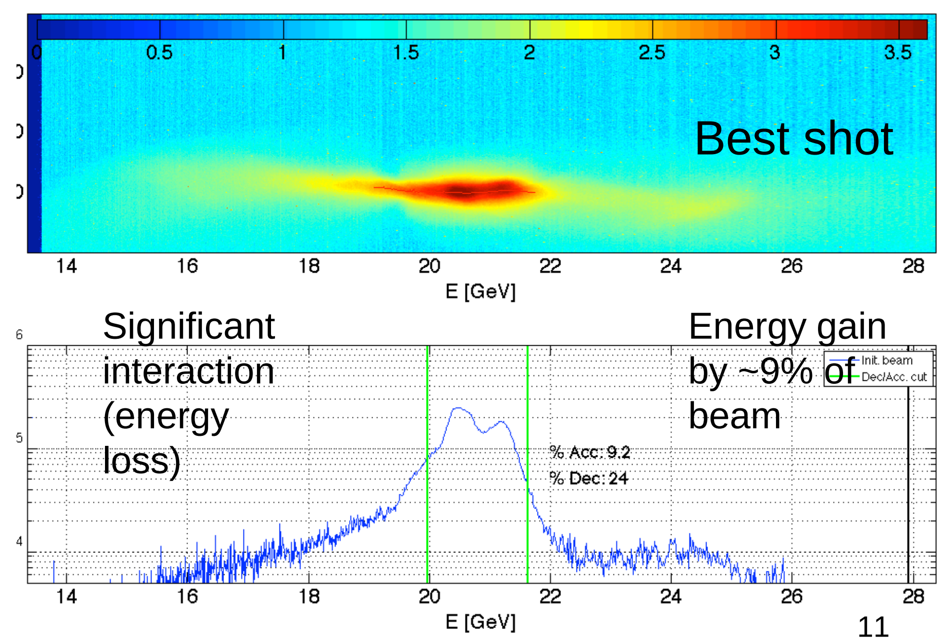
SLAC

- A Cherenkov light based spectrometer on the dump table is used to measure the energy loss and gain of particles in the beam
- Lithium – often small interaction, occasionally significant acceleration observed
- Rubidium - consistently lots of interaction and good acceleration

Beam bypassing plasma

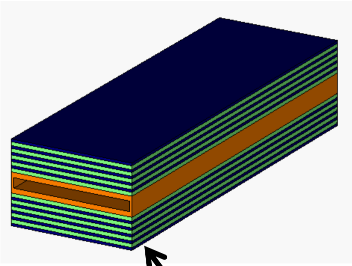


Beam going through lithium plasma

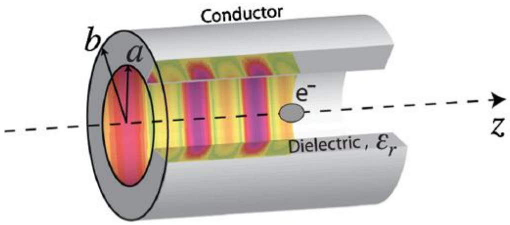


Mark Hogan for E-200 collaboration

E-201 Wakefield Acceleration in Dielectric Structures



Slab-symmetric Structures



Axi-symmetric Tubes

- UCLA, Euclid Techlabs, Tech-X, Radiabeam Technologies, NRL, SLAC, MPI, Argonne

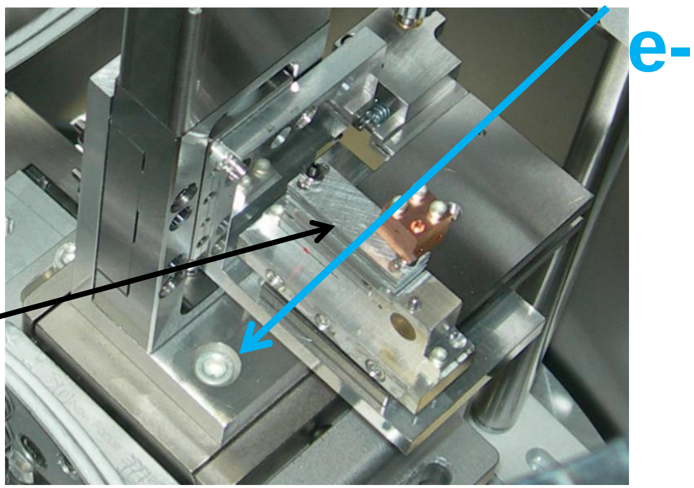
FACET provides unique high-field regime to test limits of dielectric wakefield structures

- >1GV/m acceleration anticipated

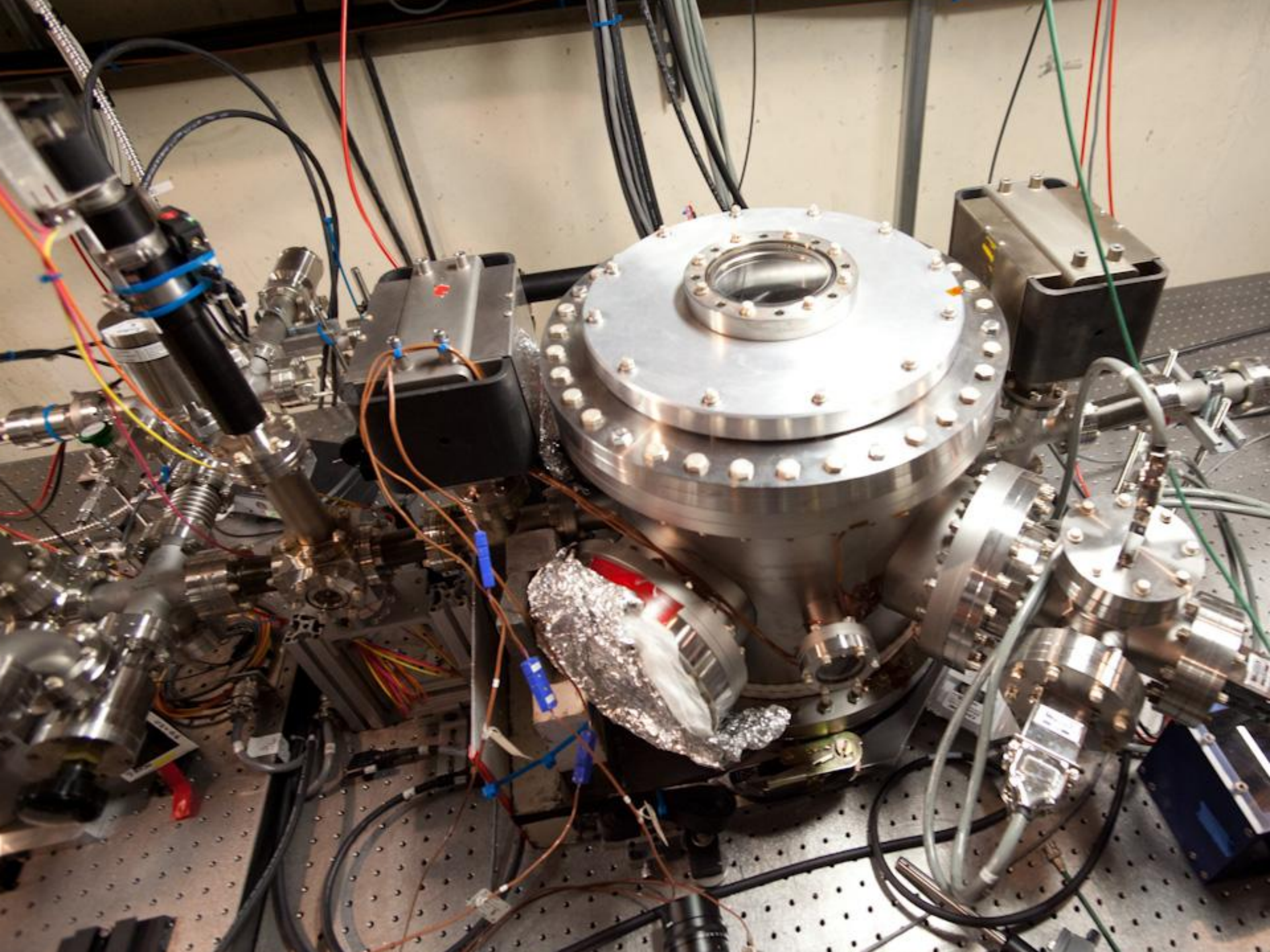
Coherent Cherenkov Radiation (CCR) spectrum gives information about the excited modes

- Narrowband THz frequency light source

Sample holder on stages for alignment

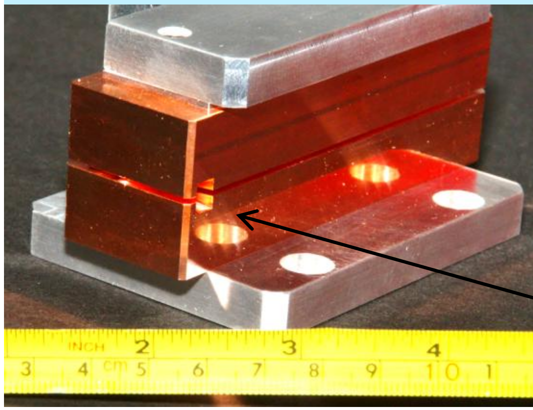


The FACET beam is sent through prototype structures of varying dimensions and materials



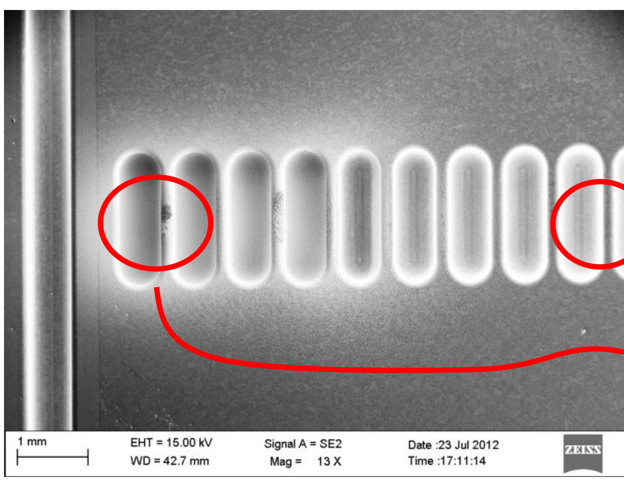
E-204 RF Breakdown Test of Metal Accelerating Structure

Accelerating structure made by Makino. Beam gap is 0.9 mm.

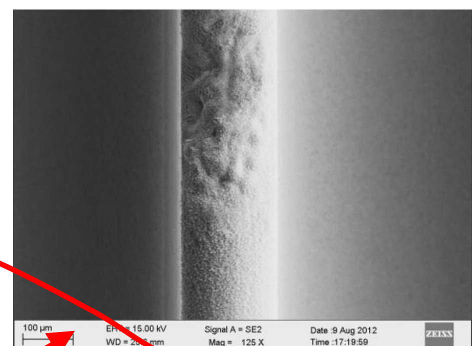


Output horn

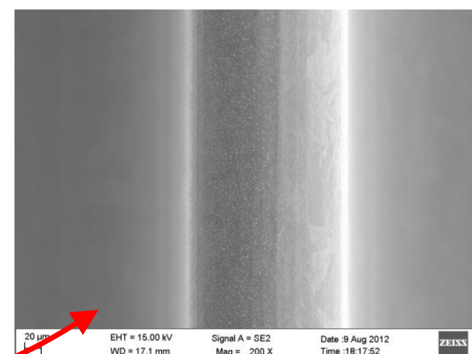
- SLAC
- Wakefield acceleration with metallic structures
- First study: breakdown properties of structures at high surface fields
- Ultra-short FACET bunch excites THz frequency, multi-GV/m surface fields
- RF power extracted through output horn to a detector



Autopsy of output part of the structure



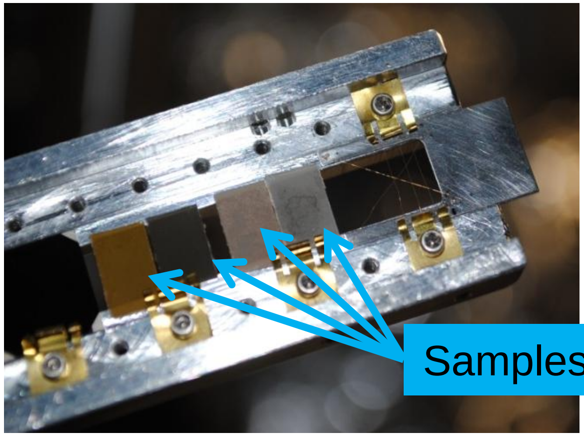
1st iris – breakdown damage, peak surface fields <1.3 GV/m



9th iris – no breakdown damage, peak surface fields > 0.64 GV/m, pulse length ~3ns

Valery Dolgashev, Sami Tantawi, SLAC

E-202 Study of Ultrafast Processes in Magnetic Solids following Excitations with Electron Beams



- SLAC, IBM, Univ. Regensburg, Bogolyubov Institute

A novel process –ballistic /precessional switching

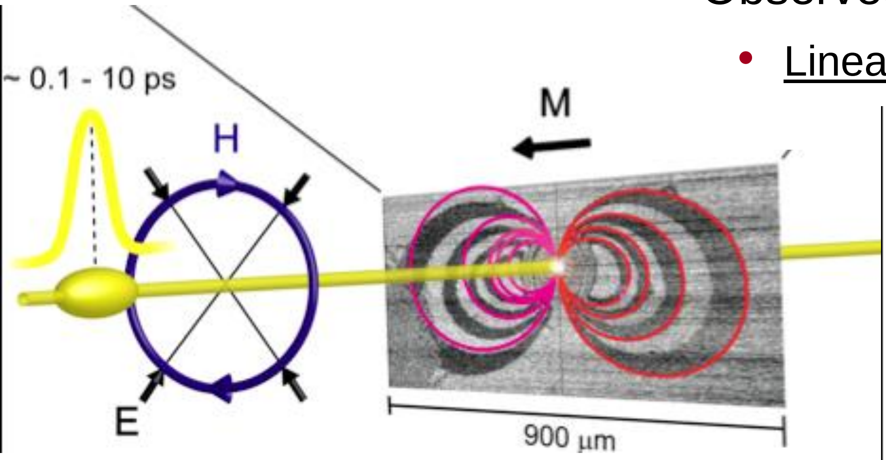
- Fastest and most efficient method of switching

What is the microscopic origin for observed phenomena?

- Exposed magnetic samples to the electron beam
- Began study of ferroelectric films and resistive memories
- Exposed materials used in spintronics applications
- Signs of polarisation switching in PZT

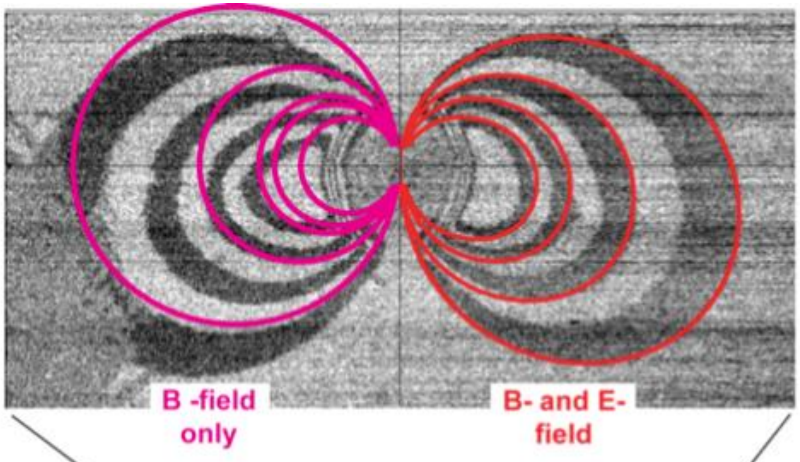
Observed electrical field induced magnetic anisotropy

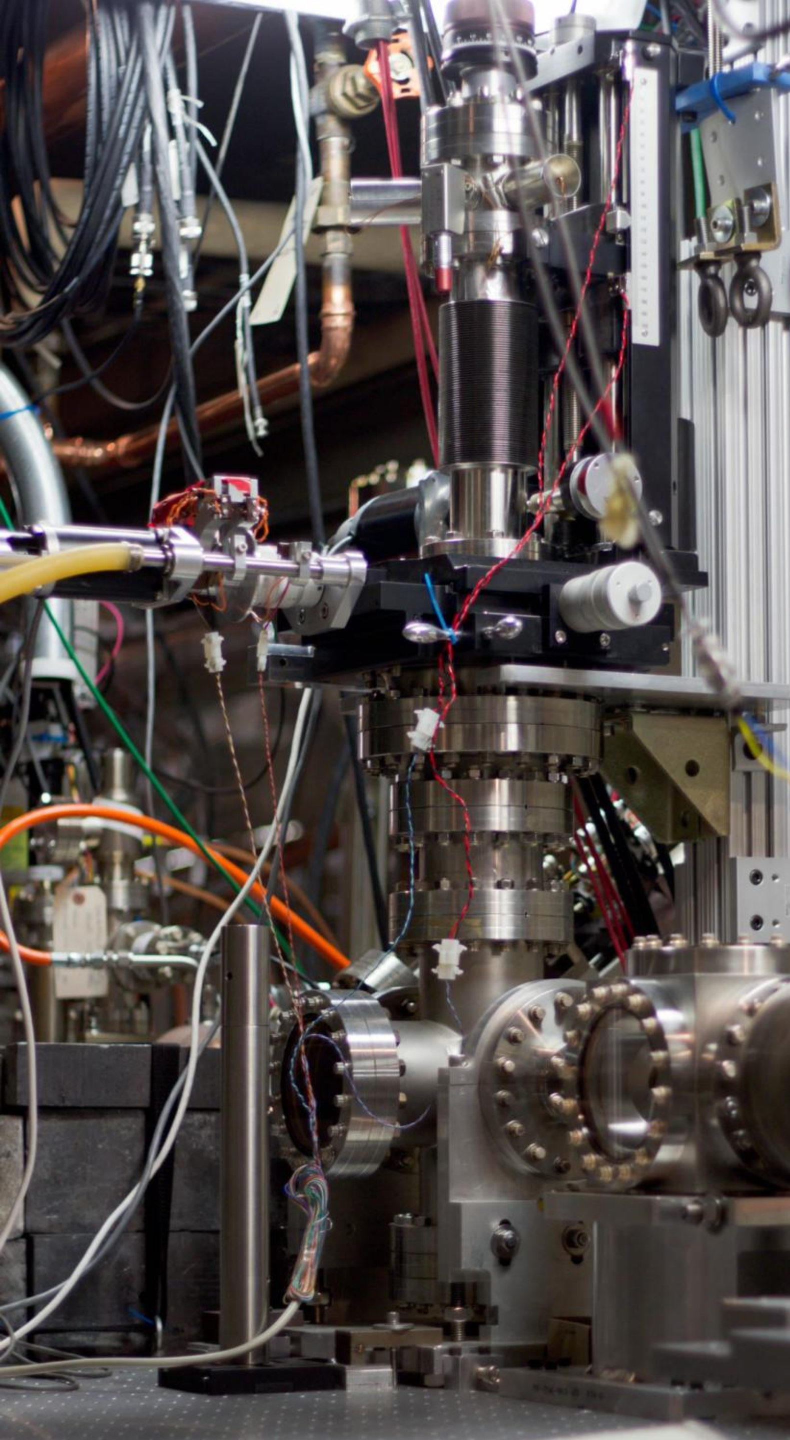
- Linear with E

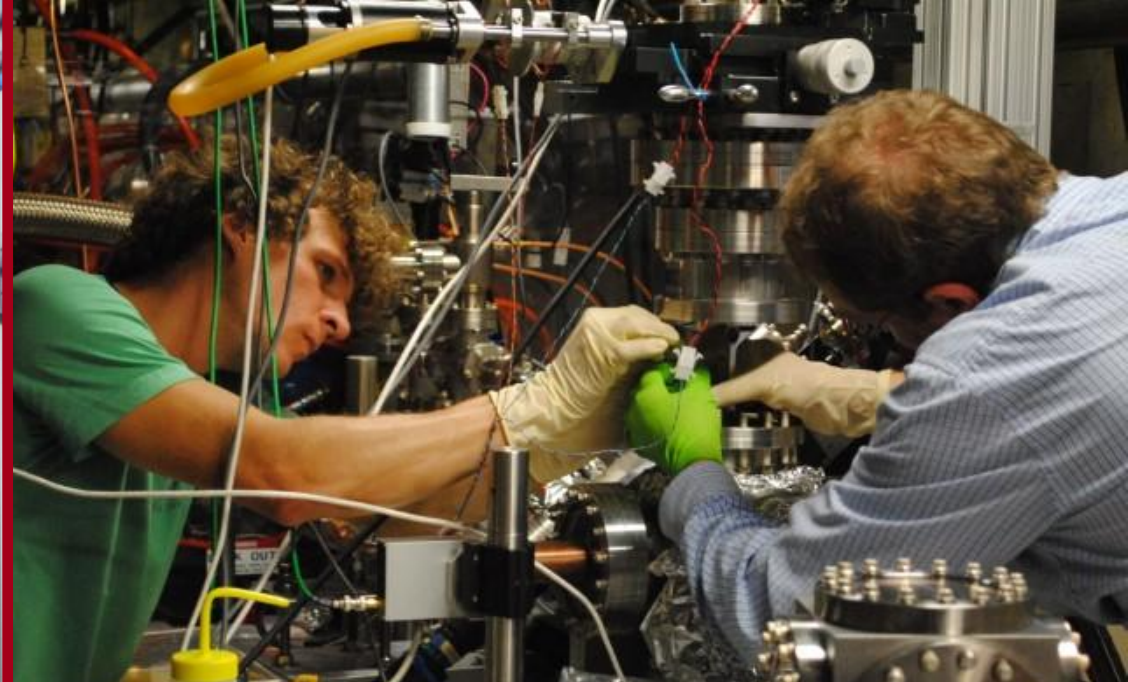


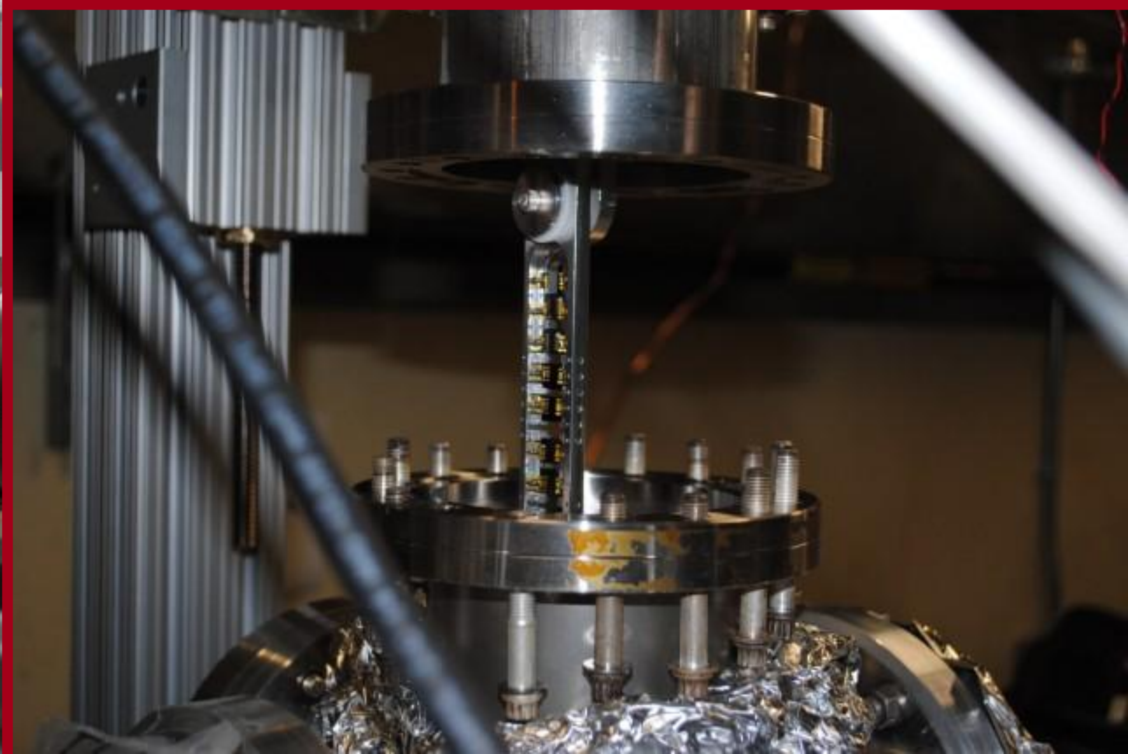
I. Tudosa, SLAC

60 ML Fe / W(110) epitaxially grown:









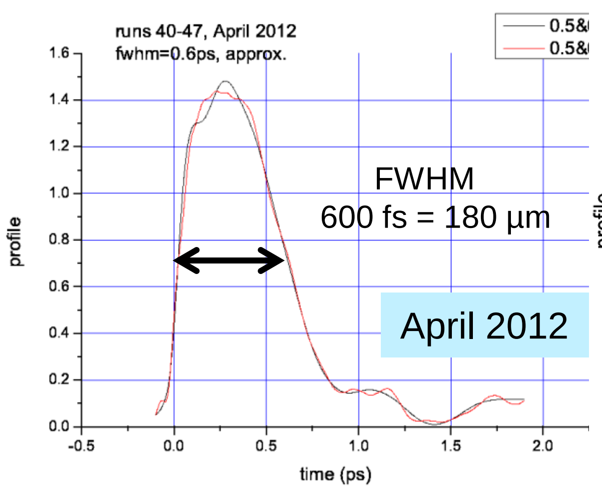
E-203 Determination of the time profile by means of coherent Smith-Purcell radiation

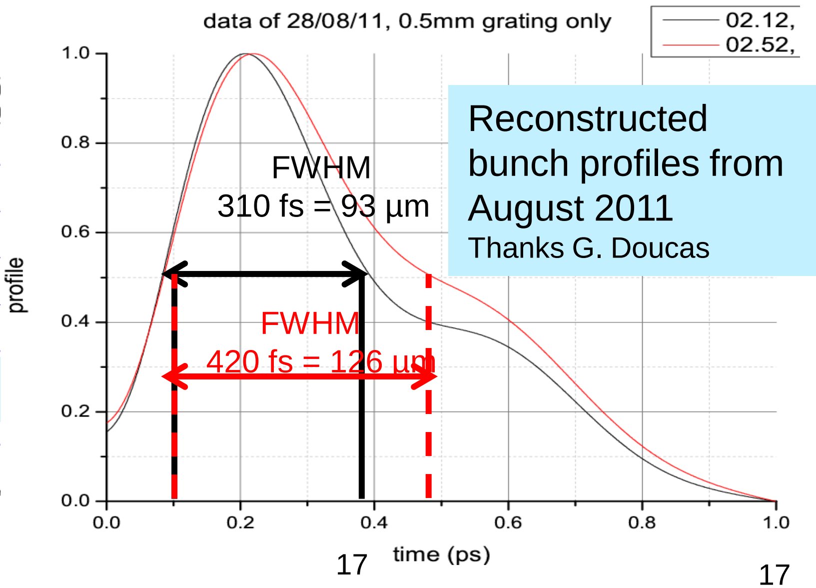
- Univ. Oxford, LAL Orsay, Univ. Valencia, ENS Lyon, Los Alamos, SLAC
- Comparatively cheap, compact, non-destructive bunch length diagnostic
- FACET provides ultra-short bunch length regime

Data from August commissioning and April this year

- Main uncertainties from the inaccurate knowledge of the beam-grating distance
- Not yet one-shot, data were averaged over time and beam conditions may have changed

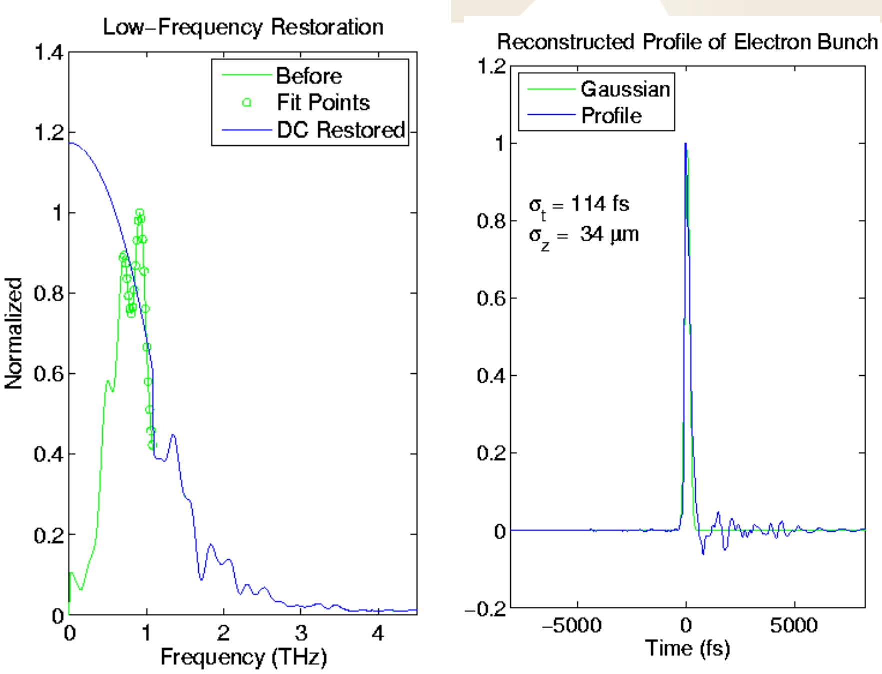
Can directly compare measurements to transverse deflecting cavity and E-206





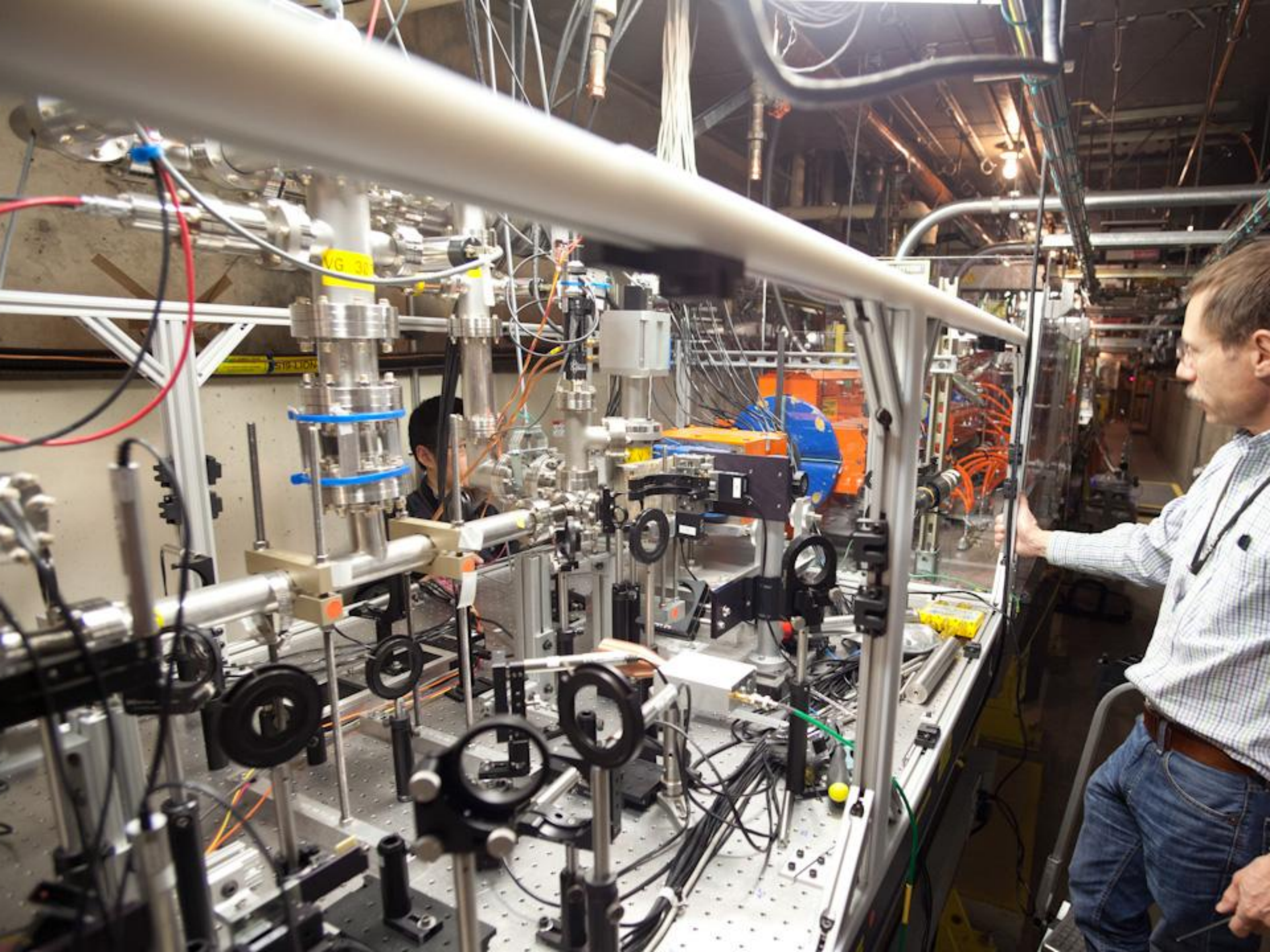
E-206/T-500 THz Studies of FACET Source

- THz frequency electromagnetic radiation is produced at 1μm titanium foil inserted into beamline upstream of IP Area
- <u>Goal: characterize THz pulses, determine peak fields</u>
- Measure temporal profile and spectrum – affected by source size
- Determine peak electric and magnetic fields.
- Can also reconstruct electron bunch length
  - There is interest from SLAC's PULSE and SIMES to use extracted THz for materials studies



Property	Preliminary Result
For incident e- bunch…	3nC, 300μmx30μm
Energy per pulse	0.46 mJ
Focus size σ_r	1 mm
Electric field strength at focus	~0.057 V/Å

Thanks A. Fisher and Z. Wu



Future at FACET

- New features to the facility are coming:
  - E-200 PWFA is installing a 10TW Laser to pre-ionise plasma
  - Positrons will be commissioned in 2013 for delivery to experiments in 2014
  - Designs for a THz transport line are in place to take THz up to the laser room

- FACET's second User run is in spring 2013
  - New experiments are coming
    - Self-modulation of long lepton bunches
    - Trojan Horse PWFA
    - Wakefield measurements in CLIC accelerating structure
  - Existing experiments will continue
    - Plasma Wakefield Acceleration with two bunches and pre-ionised plasma
    - Dielectric Wakefield Acceleration
    - Ultrafast Magnetic Switching
    - Smith-Purcell bunch profile diagnostic
    - THz-based Experiments
  - Next proposal review is in October 2012

- FACET continues to run 4-5 months/year until 2016

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Thank you for your attention – for more, go to http://facet.slac.stanford.edu