FACET: A Facility for Advanced Accelerator Research at SLAC

U. Wienands, SLAC

presently at CERN on a LARP-sponsored Long Term Visit

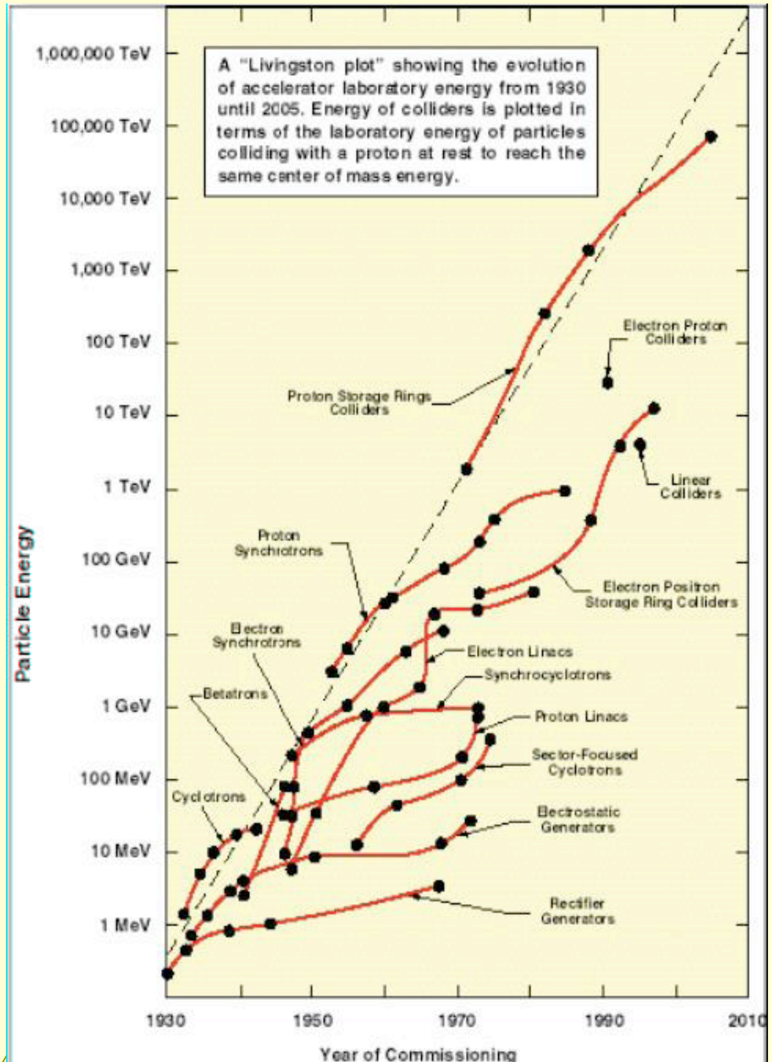
Division Head for FACET Linac

I am indebted to Mark Hogan for providing material on plasma acceleration

Outline

- Motivation
- The FACET Project
- The Experimental Program
- Conclusion

Accelerator Evolution



The Evolution of Particle Accelerators & Colliders
by W. K. H. Panofsky

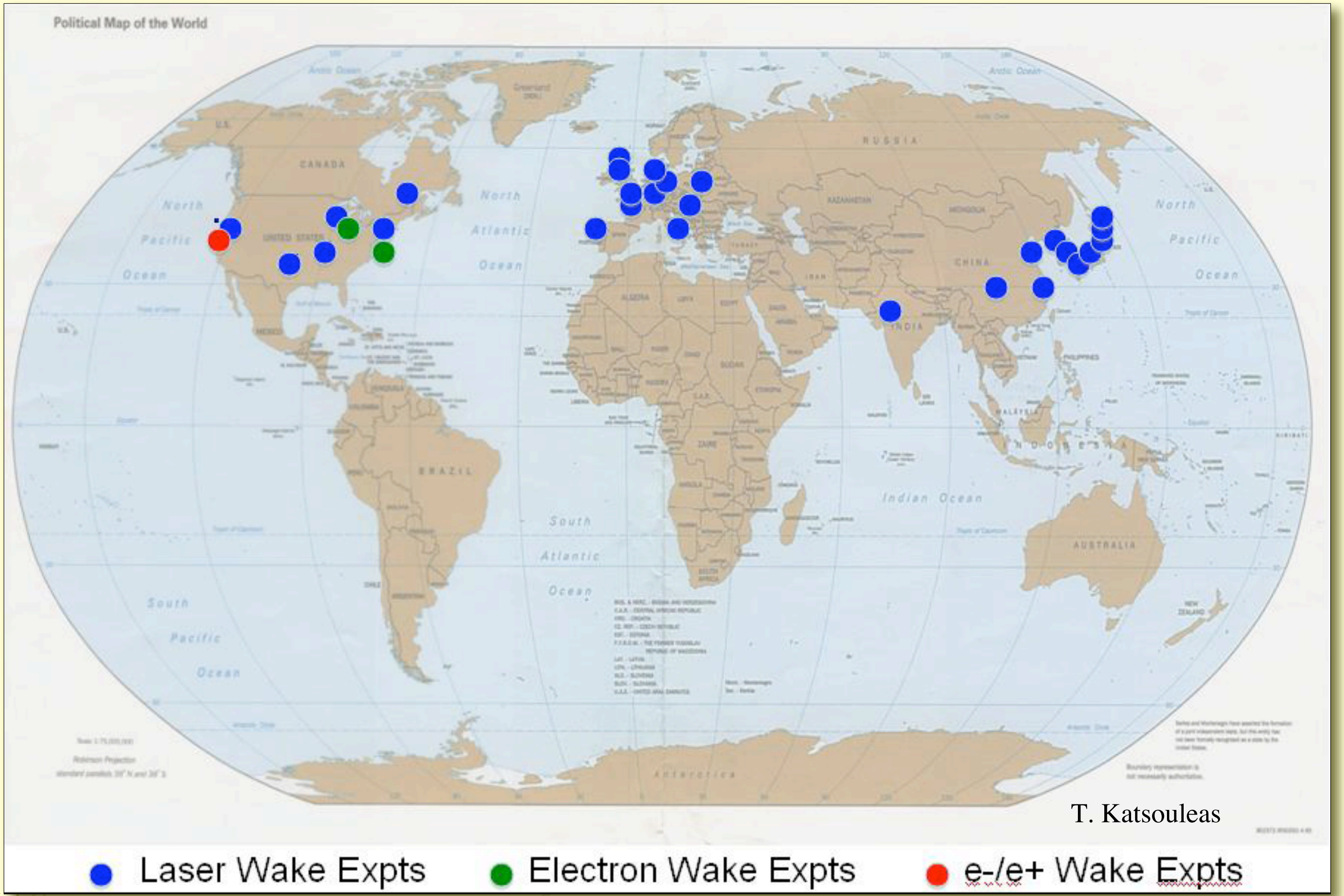
2-017

- Primary tools to advance HEP
- Reaching limits of support
  - size, costs, time scales
  - Internationalization can buy time, but only a little
- Advance can come from fundamental research into new accelerating mechanisms
  - Different materials
  - Higher frequencies
  - …

High Gradient Acceleration

- The fundamental parameter is the accelerating gradient
  - reduce size, thus costs, of new facilities
  - may help in increasing beam brightness as well
- Candidate technologies for high gradients:
  - **O(100) MV/m** – High-frequency metallic structures (=> CLIC)
  - **O(1) GV/m** – Dielectric structures (beam or laser driven)
  - **O(10) GV/m** – Plasma wakefields
- FACET aims at plasma and dielectric acceleration

World-wide interest in Plasma-Wakefield Acceleration

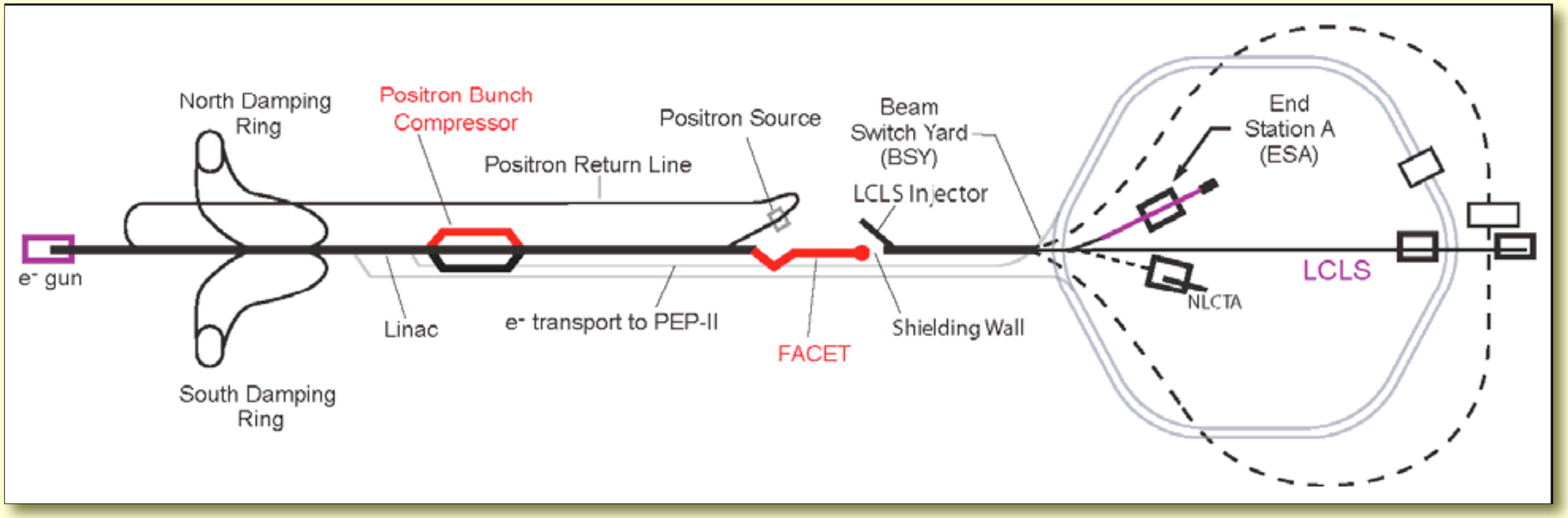


Overall Thrust of FACET

- The primary goal of FACET is proof in principle that plasma acceleration can accelerate a bunch
  - characterize the mechanism under beam loading
  - estimate beam parameters (witness)
  - estimate the efficiency and gradient reachable in practice
  - demonstrate acceleration of a positron bunch
- Beyond that, FACET will provide a facility to explore other accelerator physics issues
  - Wakefield measurements (ILC, CLIC)
  - Matter in extreme fields
  - new radiation sources using crystals

The FACET Facility

- Driven by first 2/3rd of the SLAC 2-mile linac
  - new exp. area in Sec. 19-20.
  - new compressor chicane in Sec. 10 for e^+
  - new compressor chicanes in Sec. 19.
  - e^- and slightly later also e^+



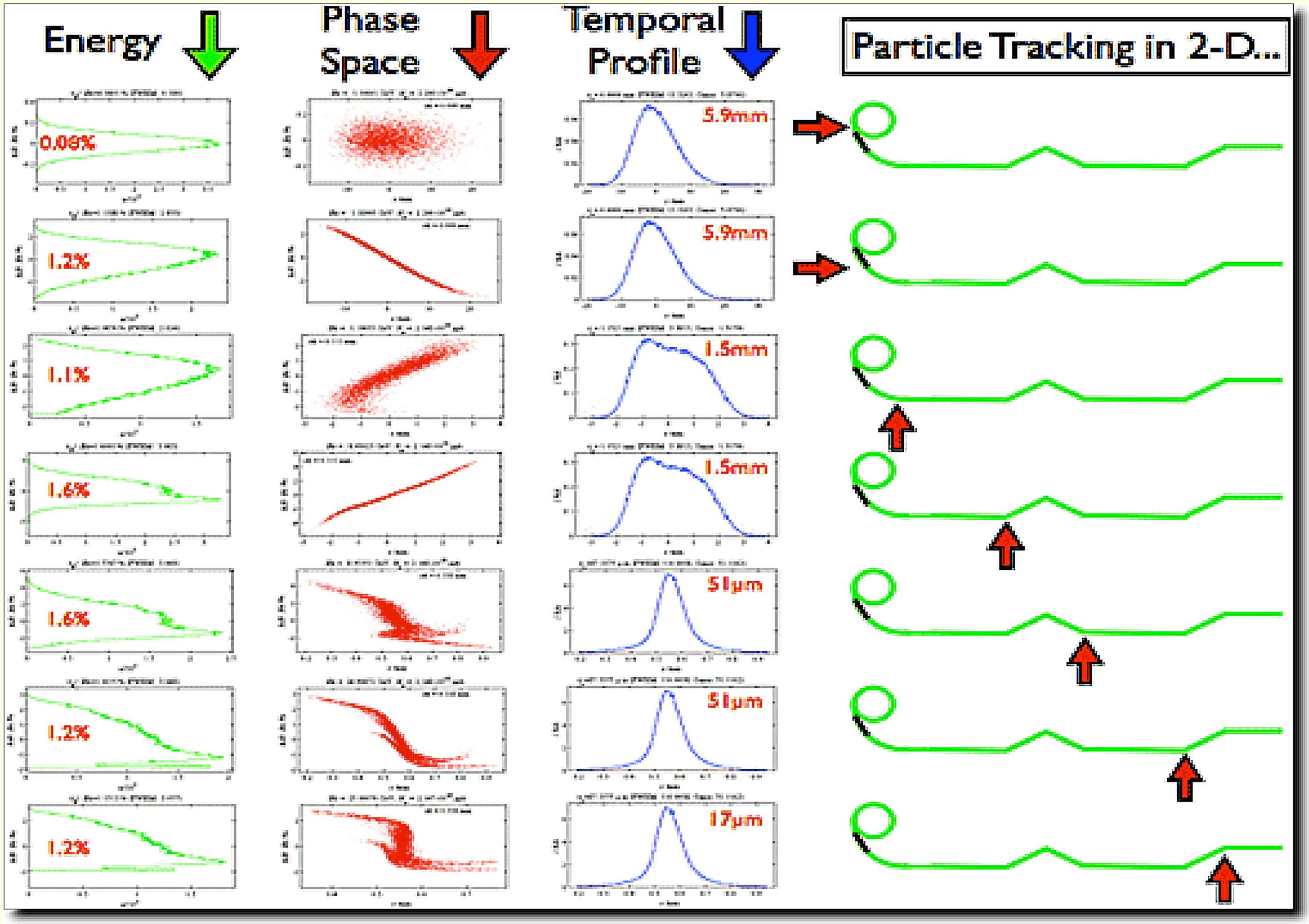
The FACET Facility

- Beam Parameters:

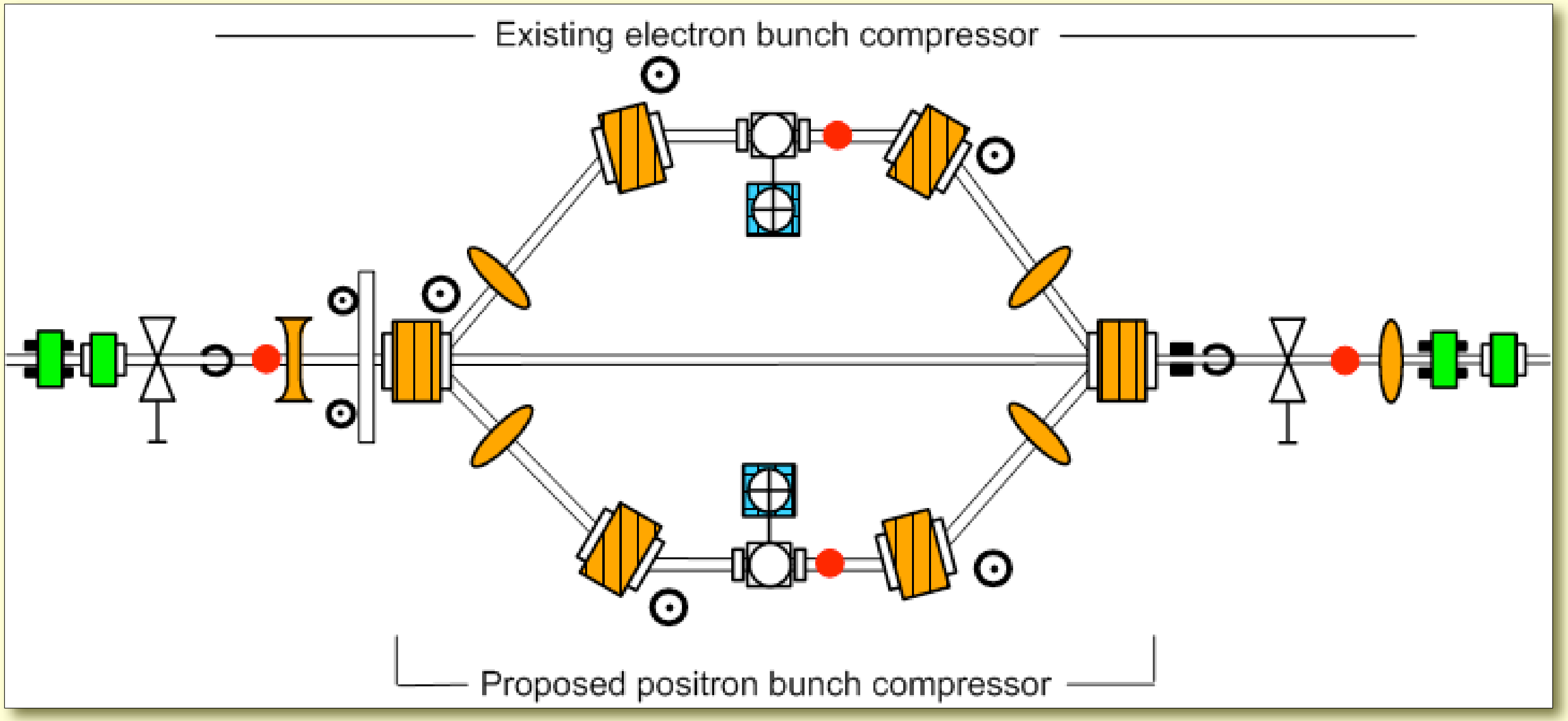
Energy	23 GeV
Charge	3 nC
Sigma z	14 μm
Sigma r	10 μm
Peak Current	22 kAmps
Species	e^- & e^+

  - many of these can be tuned to match requirements
  - 30 Hz repetition rate

Staged Bunch Compression

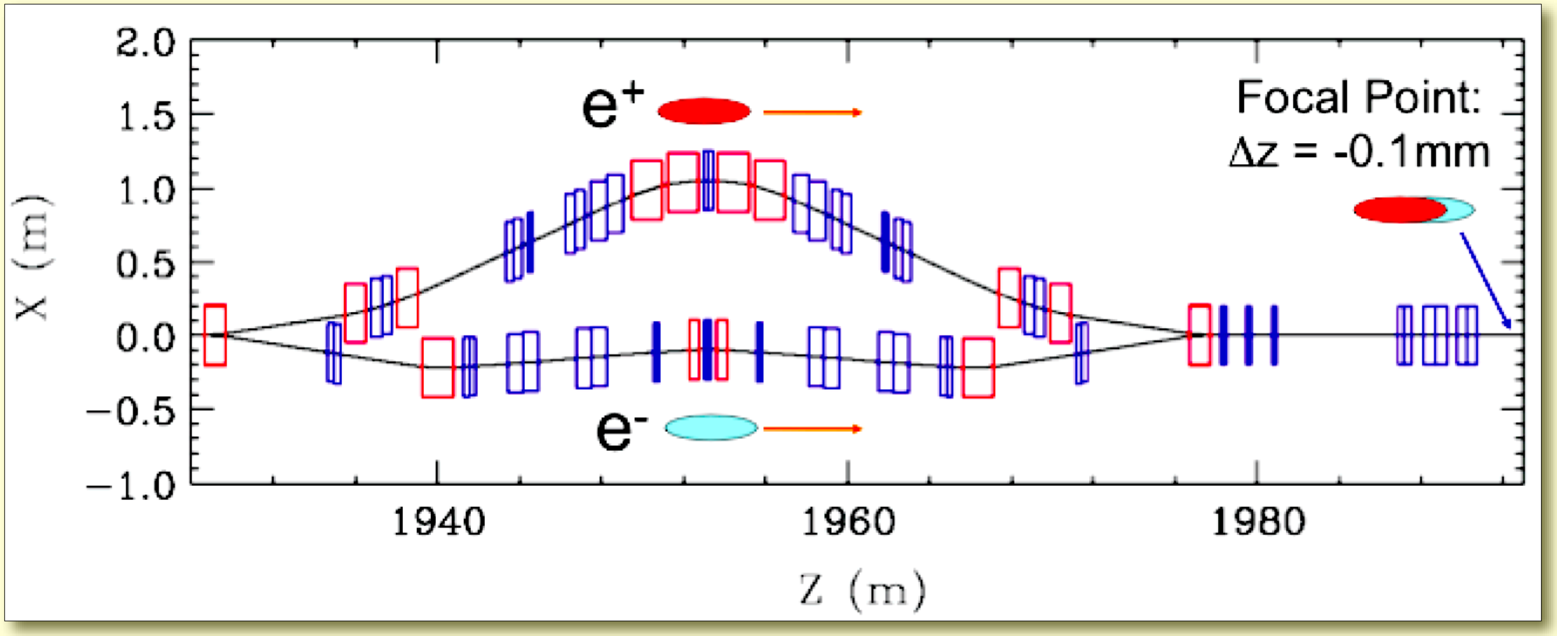


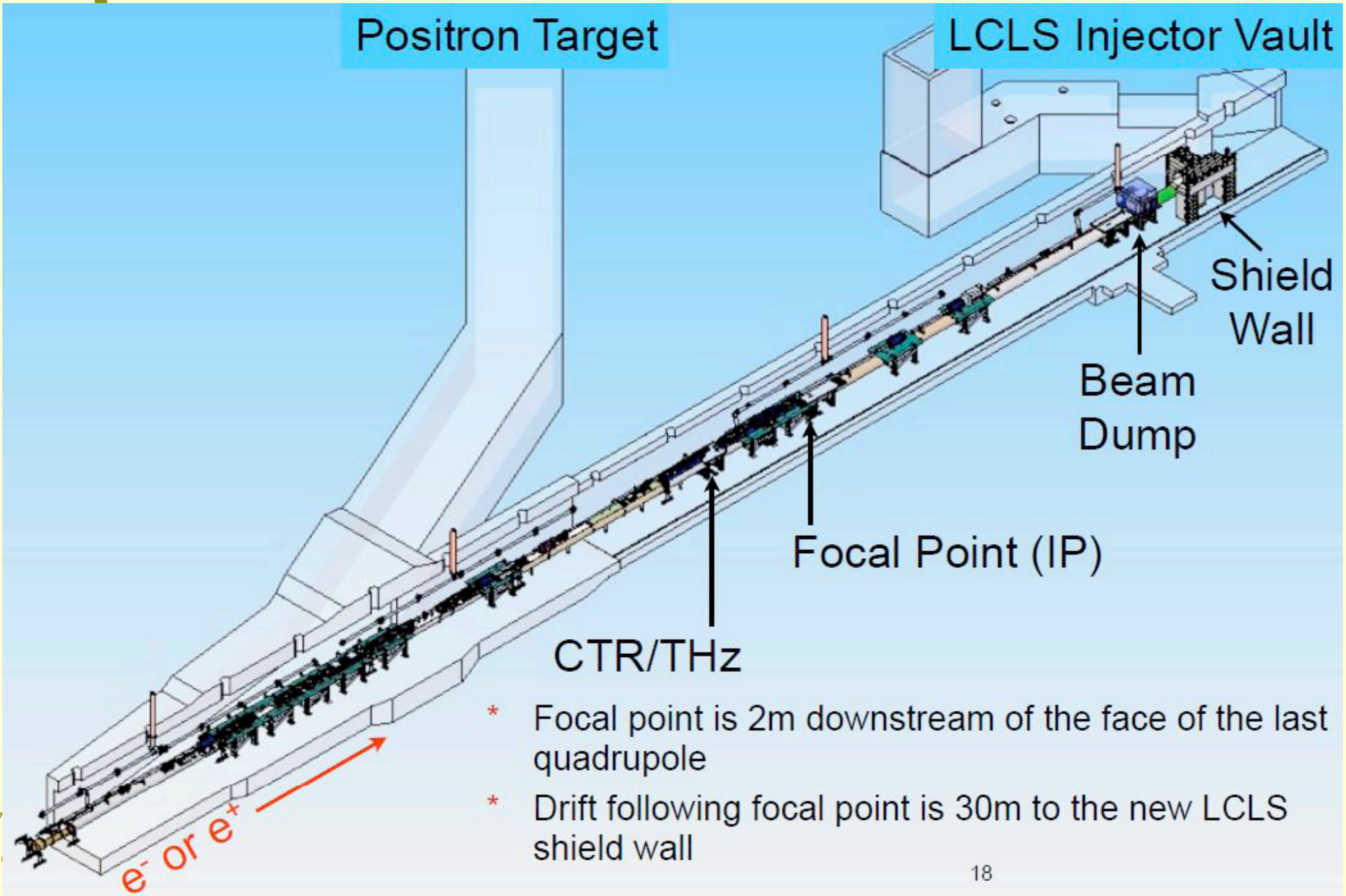
S10 Compressor Chicane



“Sailboat” Chicane (S20)

- 3rd-stage bunch compression
- precision timing e^+ and e^- bunches wrt. each other
  - allow e^+ bunch to sample wake from e^- bunch

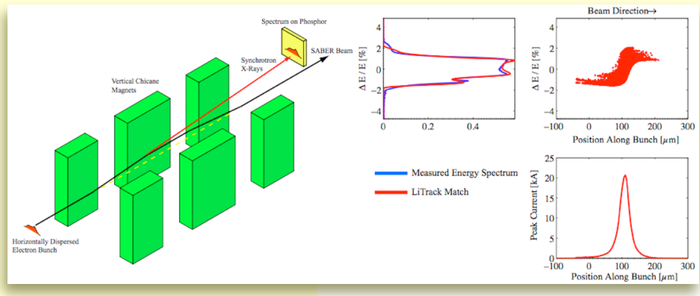


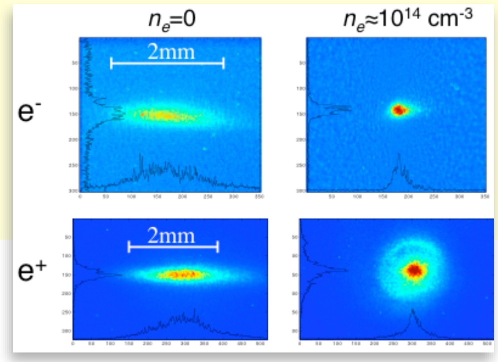


- Focal point is 2m downstream of the face of the last quadrupole
- Drift following focal point is 30m to the new LCLS shield wall

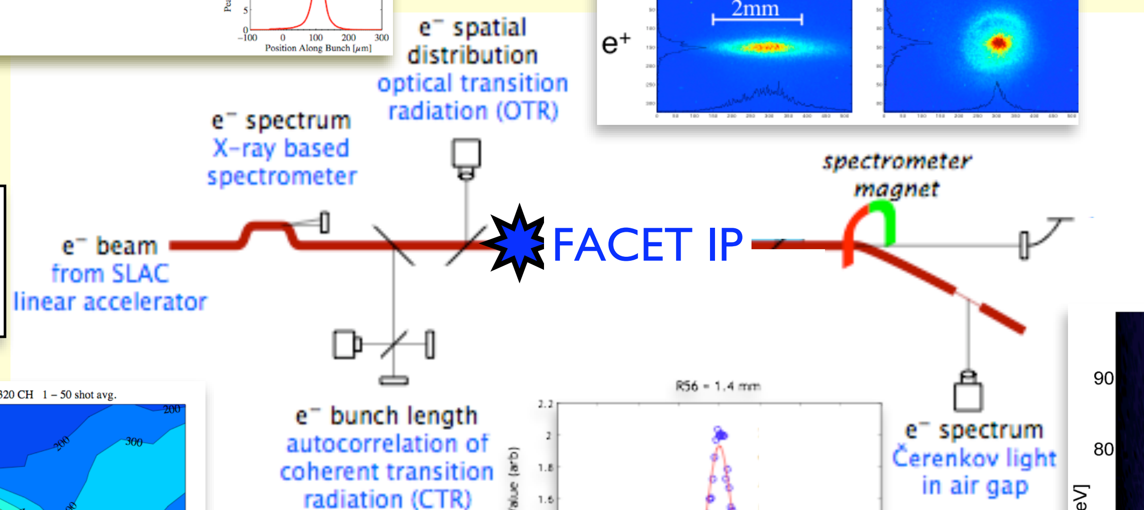
Linac Removed from FACET Expt. Area

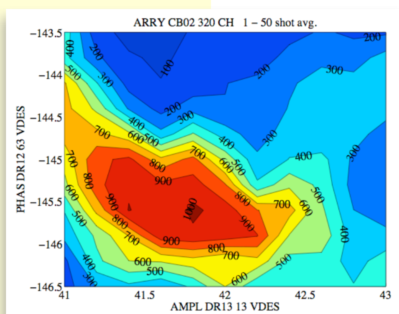
Some of the Beam Diagnostics

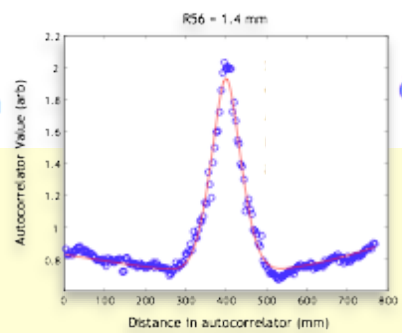


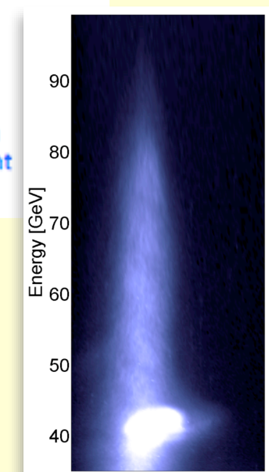


SLAC linac:
BPM's, Toroids,
Feedbacks,
GADCs, triggers





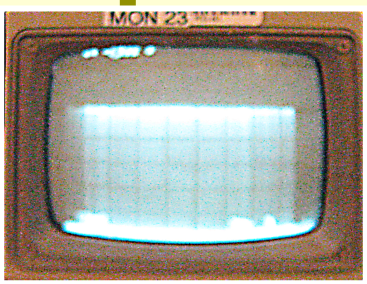


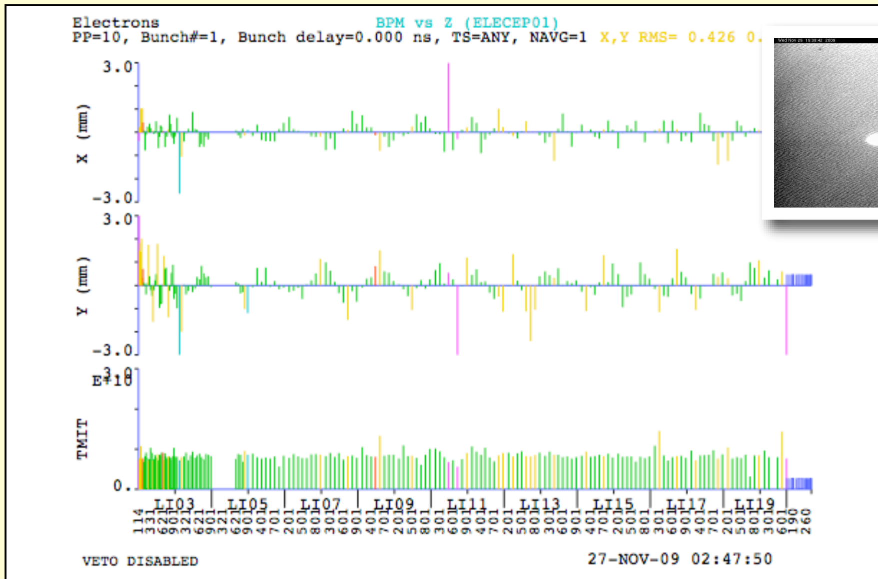


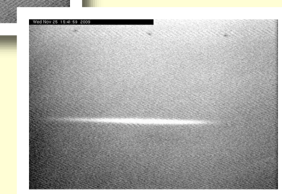
FACET Status

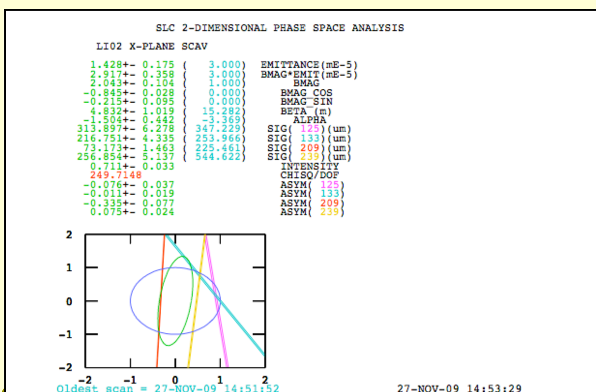
- Construction expected to finish in Spring 2011
  - accelerator and beam commissioning soon after.
- Experimental program to begin Summer 2011
- First Users Workshop @ SLAC March 18-19, 2010
  - http://www-conf.slac.stanford.edu/facetusers/spring2010/
  - 40 people, 9 institutions
    - Argonne, Brookhaven, Euclid Techlabs, Fermilab, SLAC, Stanford, UCLA, USC, UT Austin
  - 4 Working groups considered ideas for first experiments:
    - Plasma Wakefield Acceleration
    - Dielectric Wakefield Acceleration
    - Materials in Extreme Conditions
    - Crystals & Novel Sources of Radiation
- Beamtime allocated in a proposal driven process

Checking out the Linac…



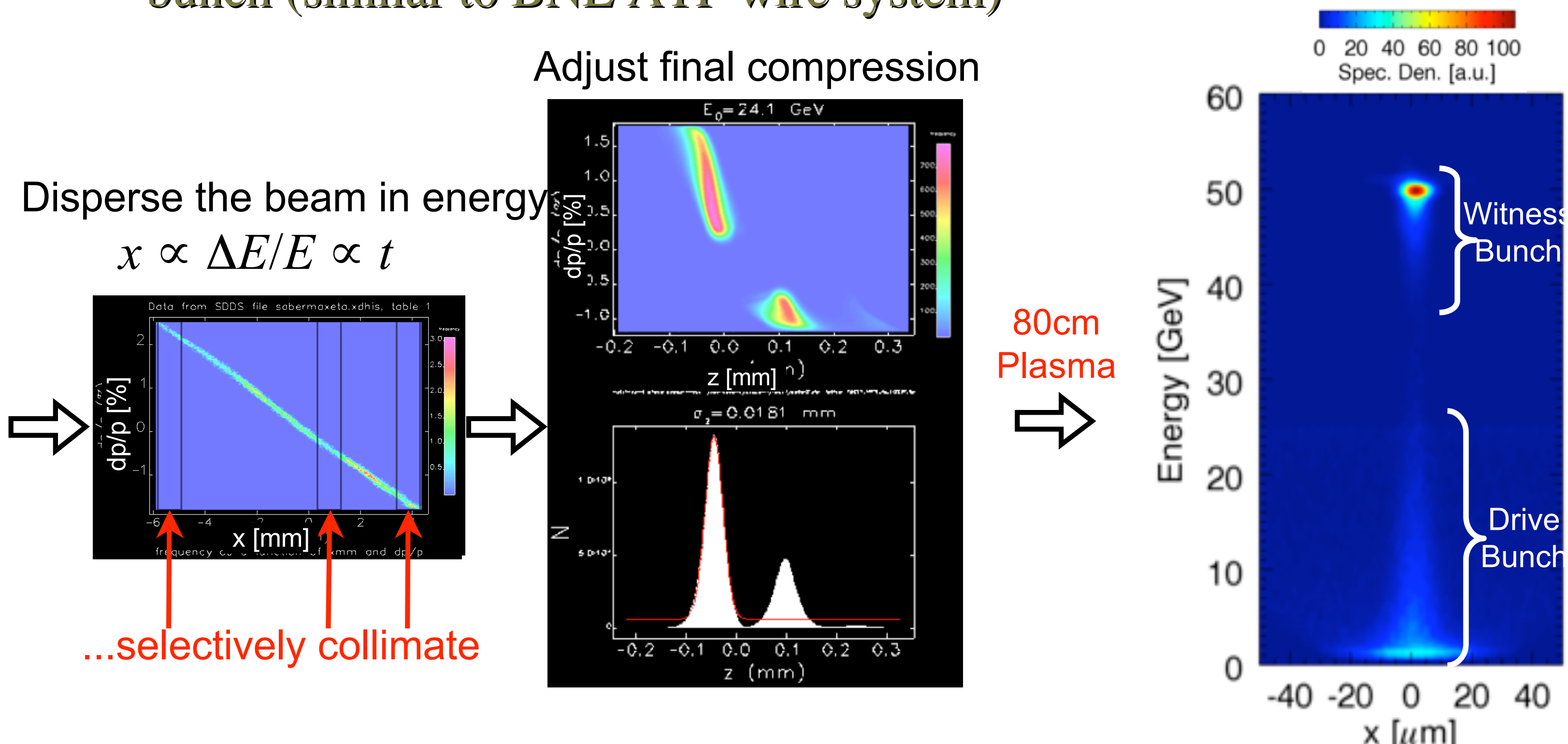






PWFA: Particle to Beam Acceleration

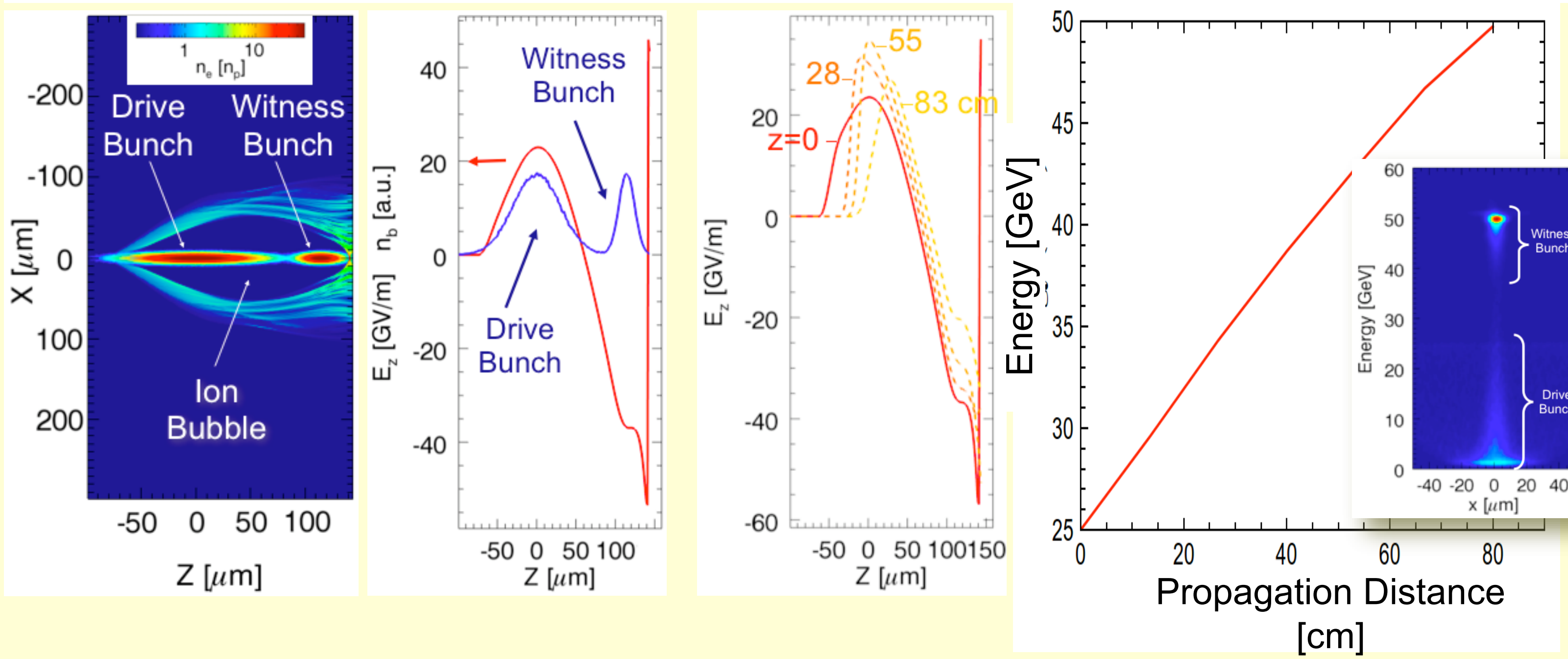
- Collimation system to craft drive/witness bunch from single bunch (similar to BNL ATF wire system)



- Vary charge ratio, bunch lengths, spacing by changing collimators and linac phase, R56
- Study wake loading in the non-linear regime for the first time

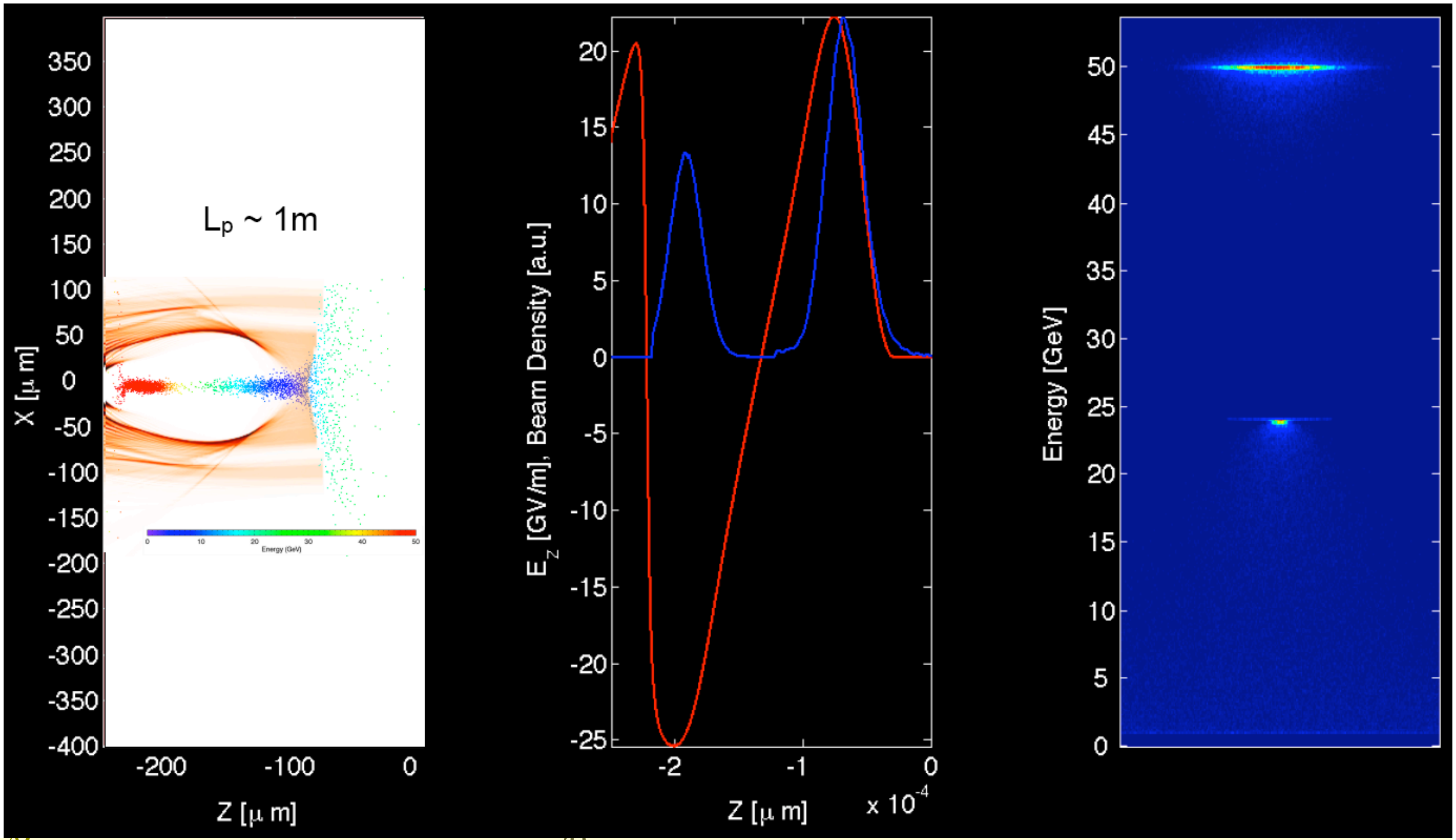
Beam Loading & Wake Evolution

QuickPIC simulation, D: σ_z=30μm, N=3x10^{10}e$^-$, W: σ_z=10μm, N=1x10^{10}e$^-$, σ_{r0}=3μm, Δz=115μm, n_e=10^{17}cm^{-3}



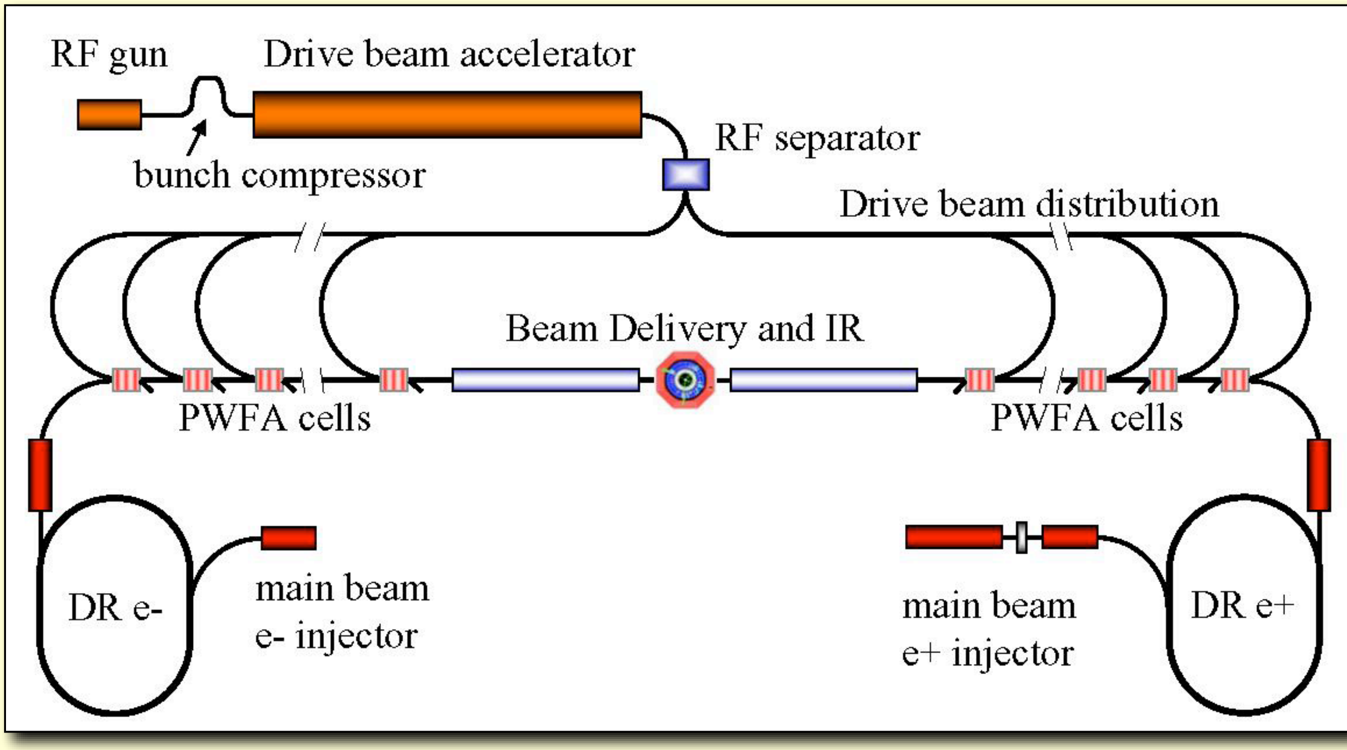
- Beam loading at 37GeV/m (z = 0)
- After 80 cm plasma, gain 25 GeV with 3% $\delta E/E$
- Wake evolution due to bunch head erosion, but no dephasing
- Wake evolution "bends" energy gain but preserves low ΔE/E
- Drive to witness Energy transfer efficiency ~ 30%

* Double Energy of a 25GeV Beam in ~1m
* Drive beam to witness beam efficiency of ~30% with small dE/E



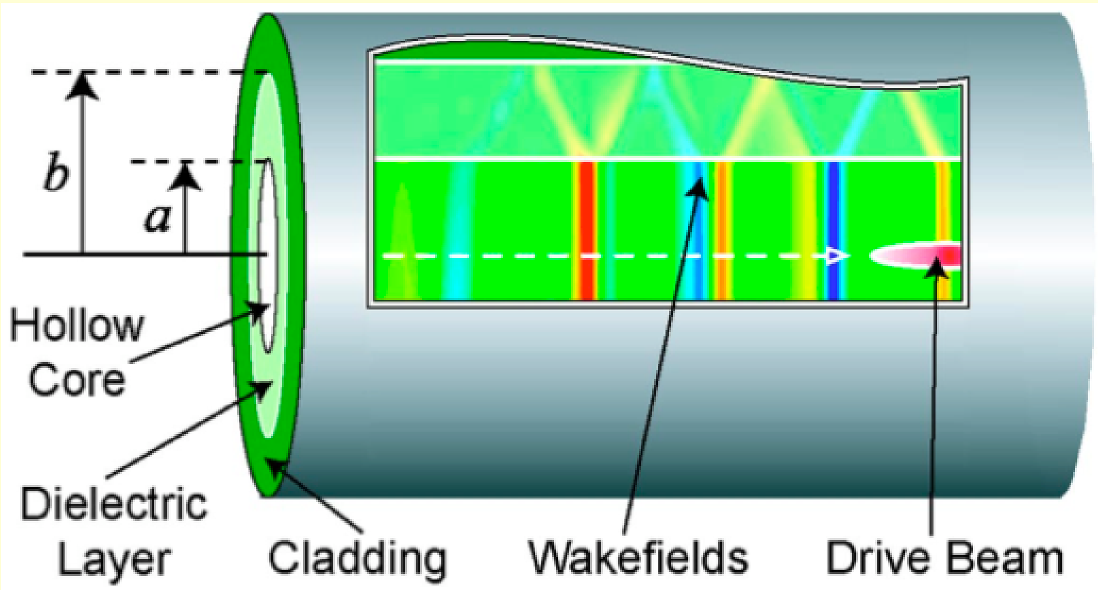
PWFA Collider

- Concept for a beam-driven PWFA collider (1TeV)
  – R&D: e^+, emittance, efficiency



FACET Beam is Well Suited for Studying DWA

A "drive" beam excites wake-fields in the tube, while a subsequent witness beam (not shown) would be accelerated by the Ez component of the reflected wakefields (bands of color).



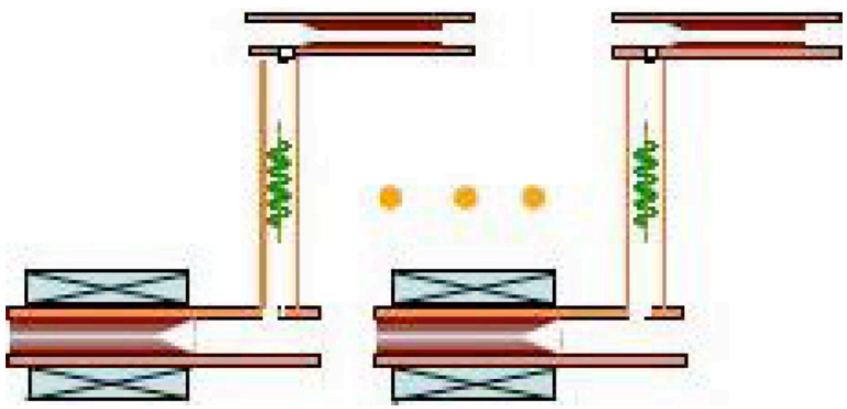
$$eE_{z,\mathrm{dec}} = eE_{r,\mathrm{surf}} \frac{\sqrt{\varepsilon - 1}}{\varepsilon}$$

$$\cong -\frac{4N_b r_e m_e c^2}{a[\sqrt{\frac{8\pi}{\varepsilon-1}}\varepsilon\sigma_z + a]}$$

For large wakes want high charge, short bunches and narrow tubes,
e.g. 2E10 e-, σ_z=20μm, Si with 200μm ID get 85GV/m surface fields!

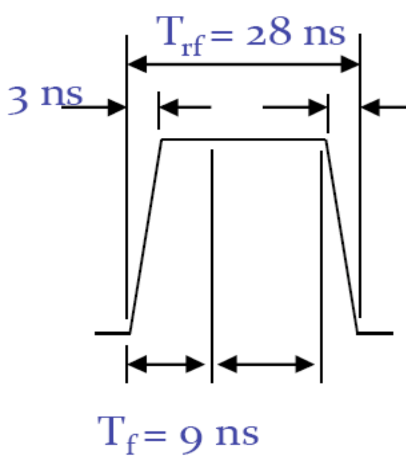
3GeV module (15m)

(38 DWPE & 38 DLA→ fill factor=76%)



1.33 GW output/Dielectric PETS;
5% rf transportation loss;
E_{load} = 267 MV/m (I_b=6.5A);

Drive beam becomes 80MeV, main beam gain 3GeV



Competitive rf-beam efficiency for the short pulse TBA

$$\eta_{bRF} = \frac{I_{beam} E_{load} L_s}{P_{rf}} \times \frac{T_{beam}}{T_{rf}} = 26\%$$

T_{beam}= 16 ns = 416 rf cycles (26 GHz)
(Q_{total}= 208 nC per pulse)
1 bunch / 2 rf periods, 0.5nC / bunch

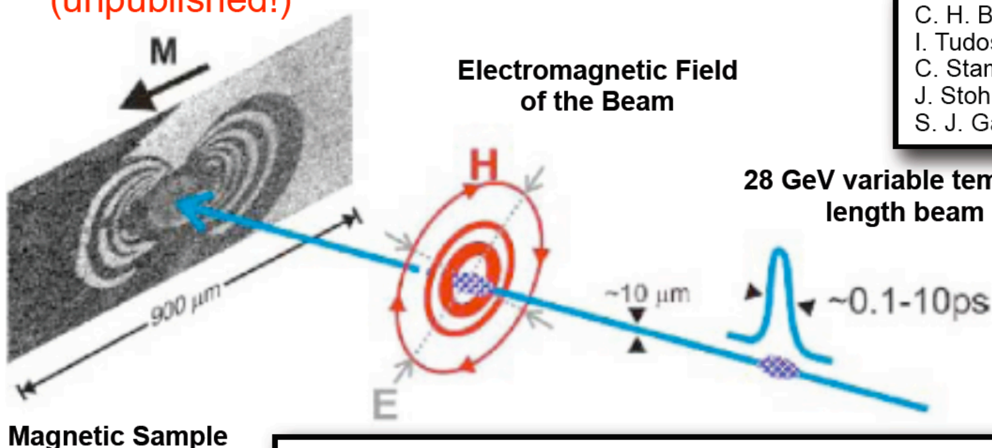
	AWA Short Pulse (1.5TeV,e+)
Average drive beam current	80 mA 1 GeV
Average drive beam power	68.8 MW
Average rf power to main linac	60MW
Average main beam current	10.4 uA 1.5 TeV
Average main beam power	15.6 MW

Other Proposed Research

- Ultrafast processes in magnetic solids.
- Wakefield measurements of CLIC structures
- Optical diffraction radiation tests
- Time profile of 50 fs bunches
- Test of advanced Feedback Algorithms.

* The future of magnetic recording lies in smaller bits and faster switching
* FFTB experiments demonstrated:
  – Ultrafast precessional switching
  – Increased damping at high magnetic fields from spin wave instabilities
  – Generation of a NEW type of magneto-electronic anisotropy (PRL in press)
  – Modification of electronic structure and non-linear conduction at high fields (unpublished!)

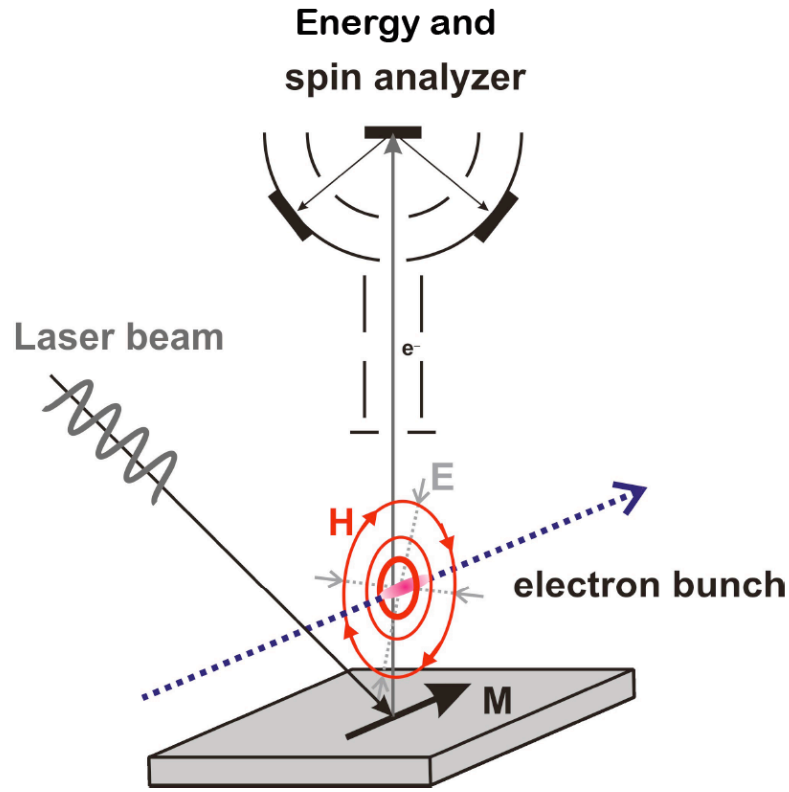
C. H. Back et. al. Science 285, 864 (1999)
I. Tudosa et. al. Nature 428, 831 (2004)
C. Stamm et. al. Phys. Rev. Lett. 94, 197603 (2005)
J. Stohr et al., Appl.Phys. Lett. 94, 072504 (2009)
S. J. Gamble et al, Phys. Rev. Lett, in press



FACET offers important opportunities in material science, condensed matter physics and chemistry

Pump-Probe experiments:

* Several versions of this experiment are foreseen, but idea illustrated here:
* Interest from Photon Science Colleagues



FACET design provides the beams and infrastructure necessary to continue and expand this line of research

Hogan, FACET CD1 Review July 30-31, 2009, Page 25

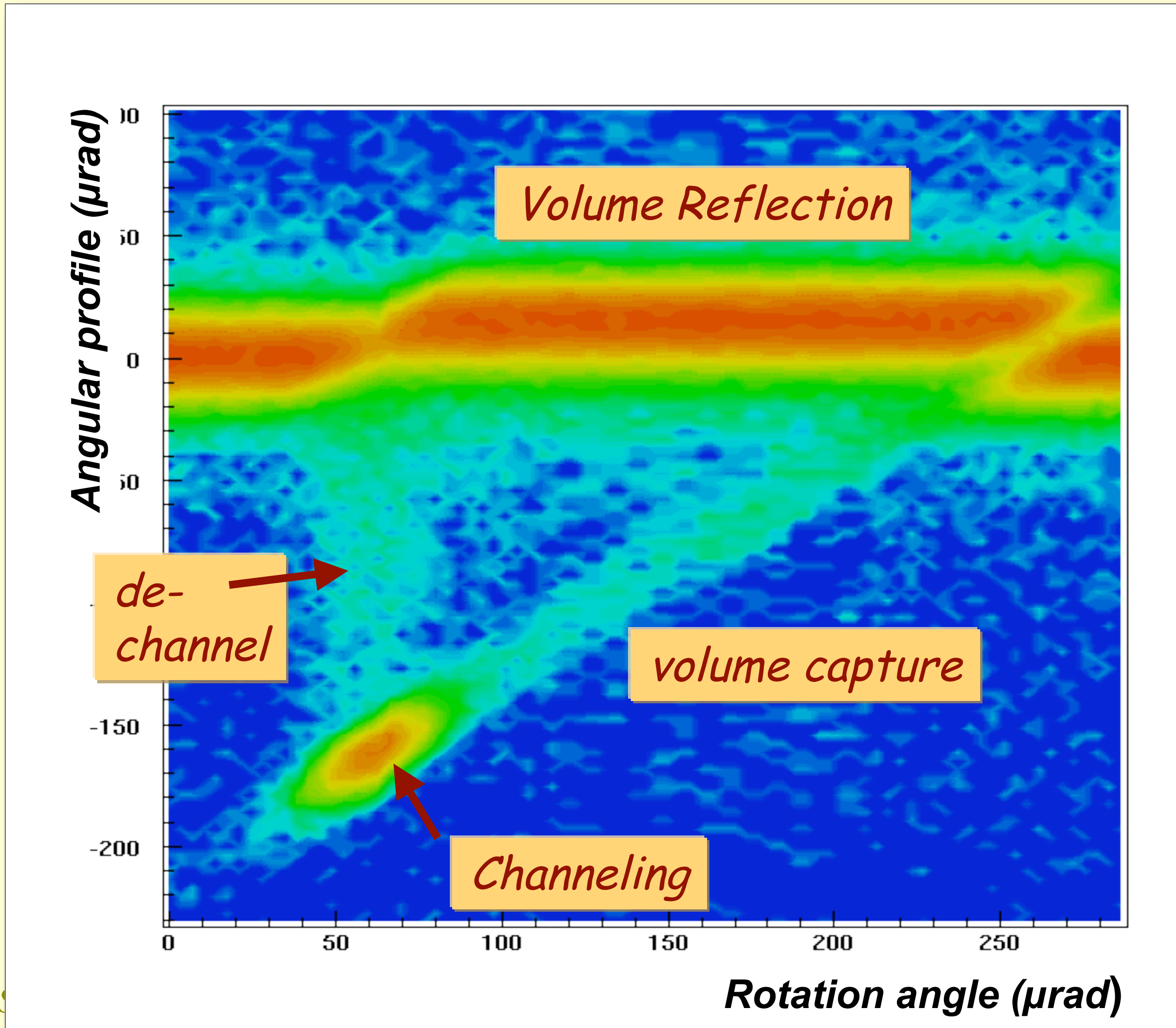
Other Research Considered

- Crystal Accelerator:
  - idea has been around for a while, inverse FEL process
  - at FACET could be done with high-energy photons
- Crystal collimation and X-ray generation
  - use the strong bending in channeling to make Xrays
  - tried at other facilities (mostly e^-: not efficient)
  - at FACET can use e^+ & get to non-negligible intensities
- Bragg diagnostics.
- Beam collimation studies
- High-gradient structure tests.

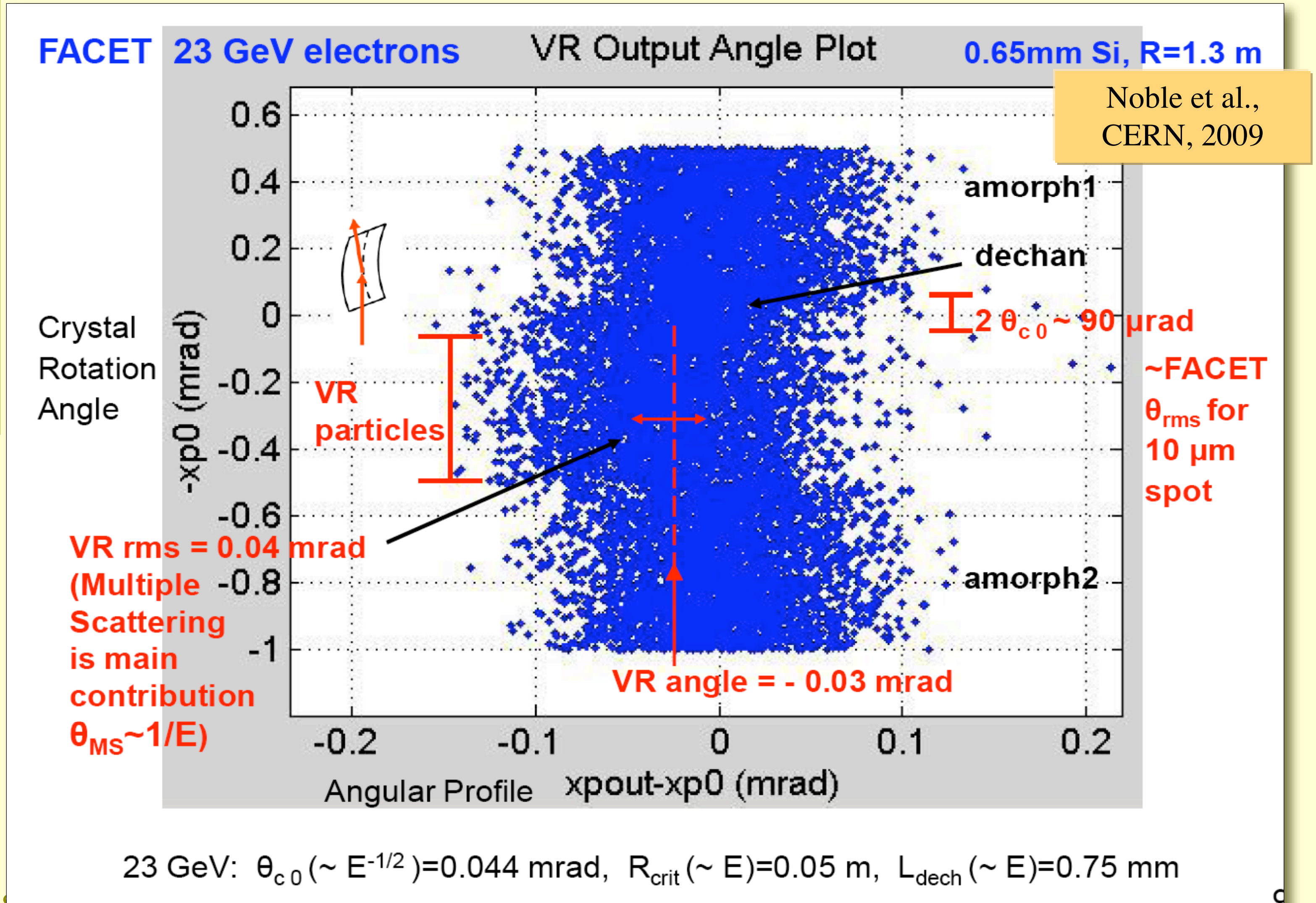
Crystal Channeling @ FACET

- Study of volume reflection of e^+ and e^-
  - test continuum model of VR for light particles
  - study effect of multiple scattering on vr
  - possible application for halo cleaning in lin. colliders
- Physics of volume-reflection radiation by e^+ & e^-
  - test radiation models for channeled light particles in region of undulator parameter $K = E/m^* \Theta \approx 1$.
  - possible applicatin as new photon source

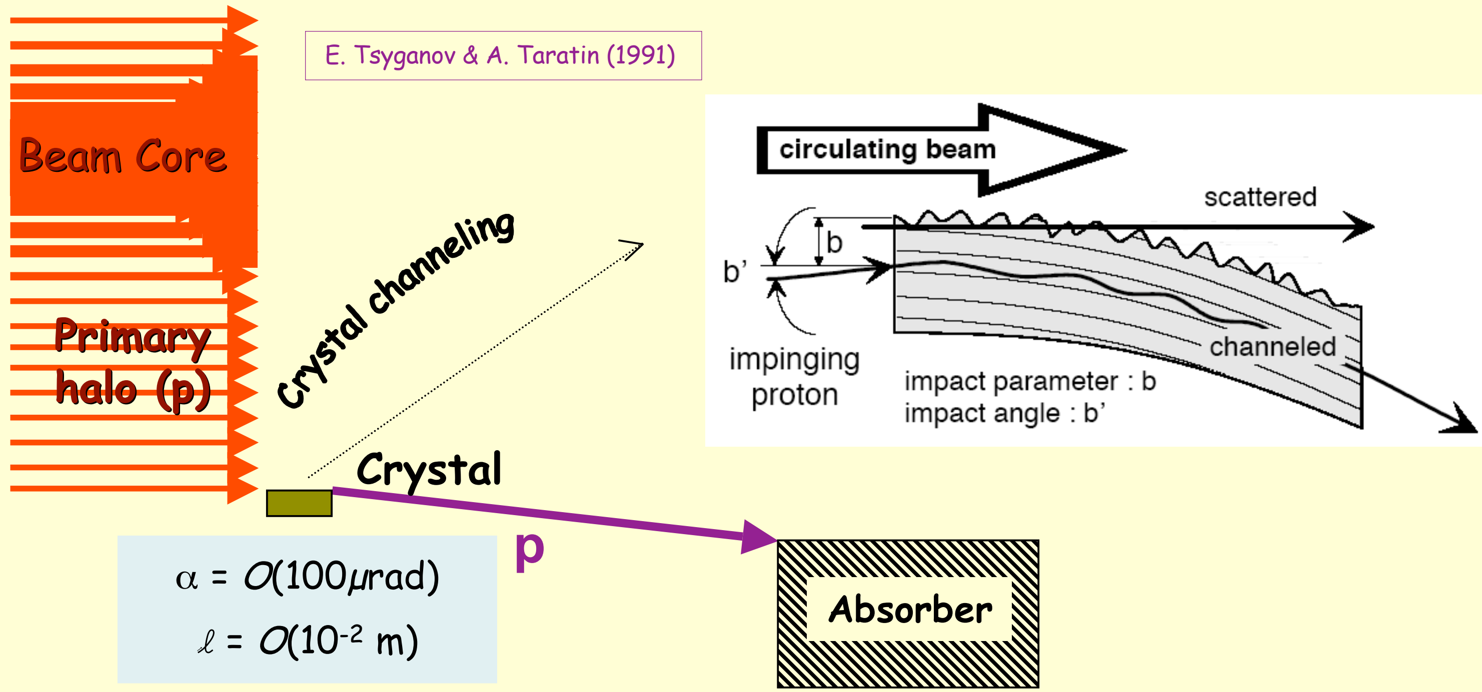
9 mm Si Crystal, 400 GeV *p*



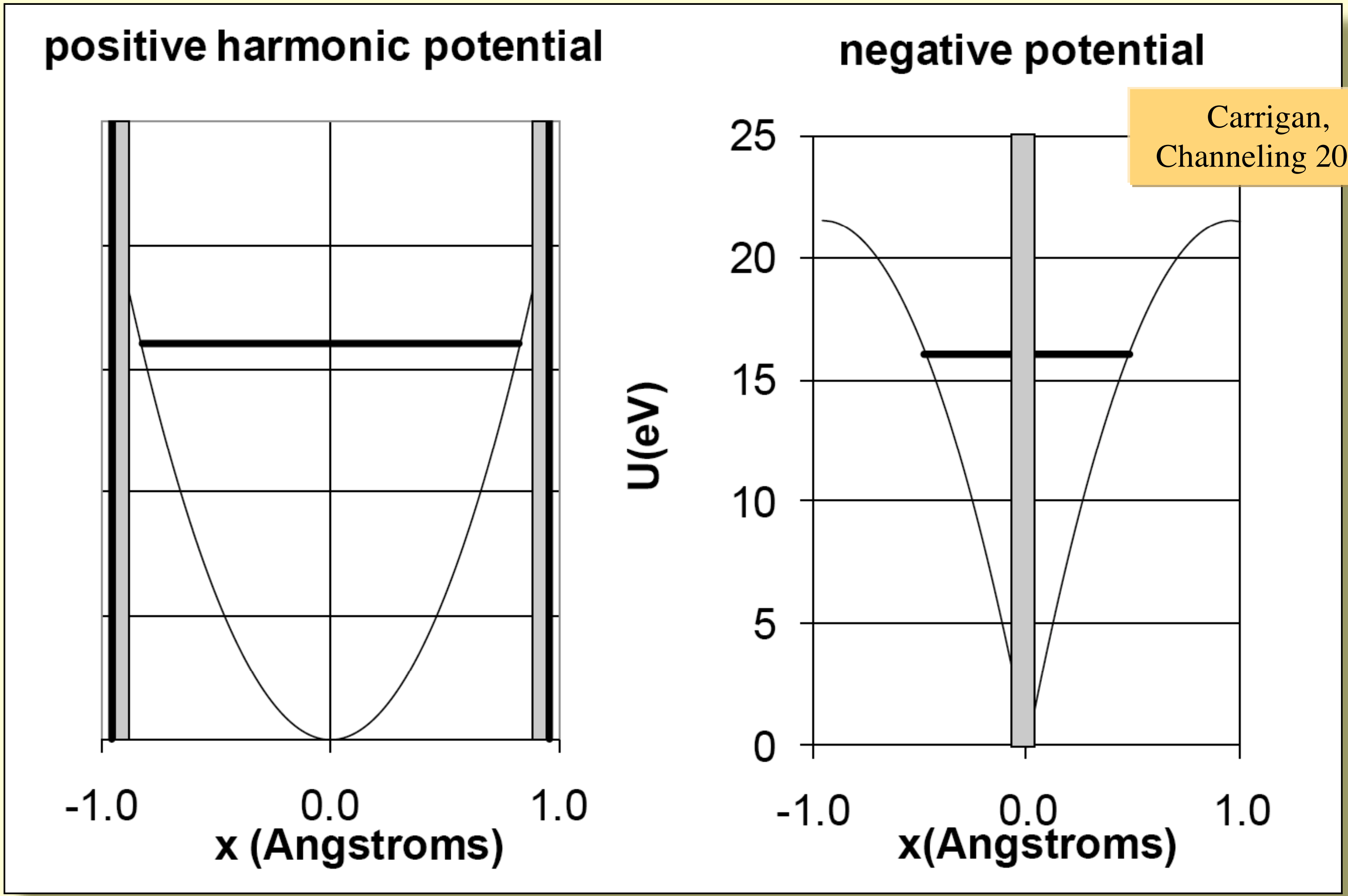
VR Simulation for FACET



Crystal Collimation



- Coherent deviation of the primary halo
- Very small probability of inelastic interaction in the crystal
- Larger collimation efficiency
- Less impedance
- Reduced tertiary halo

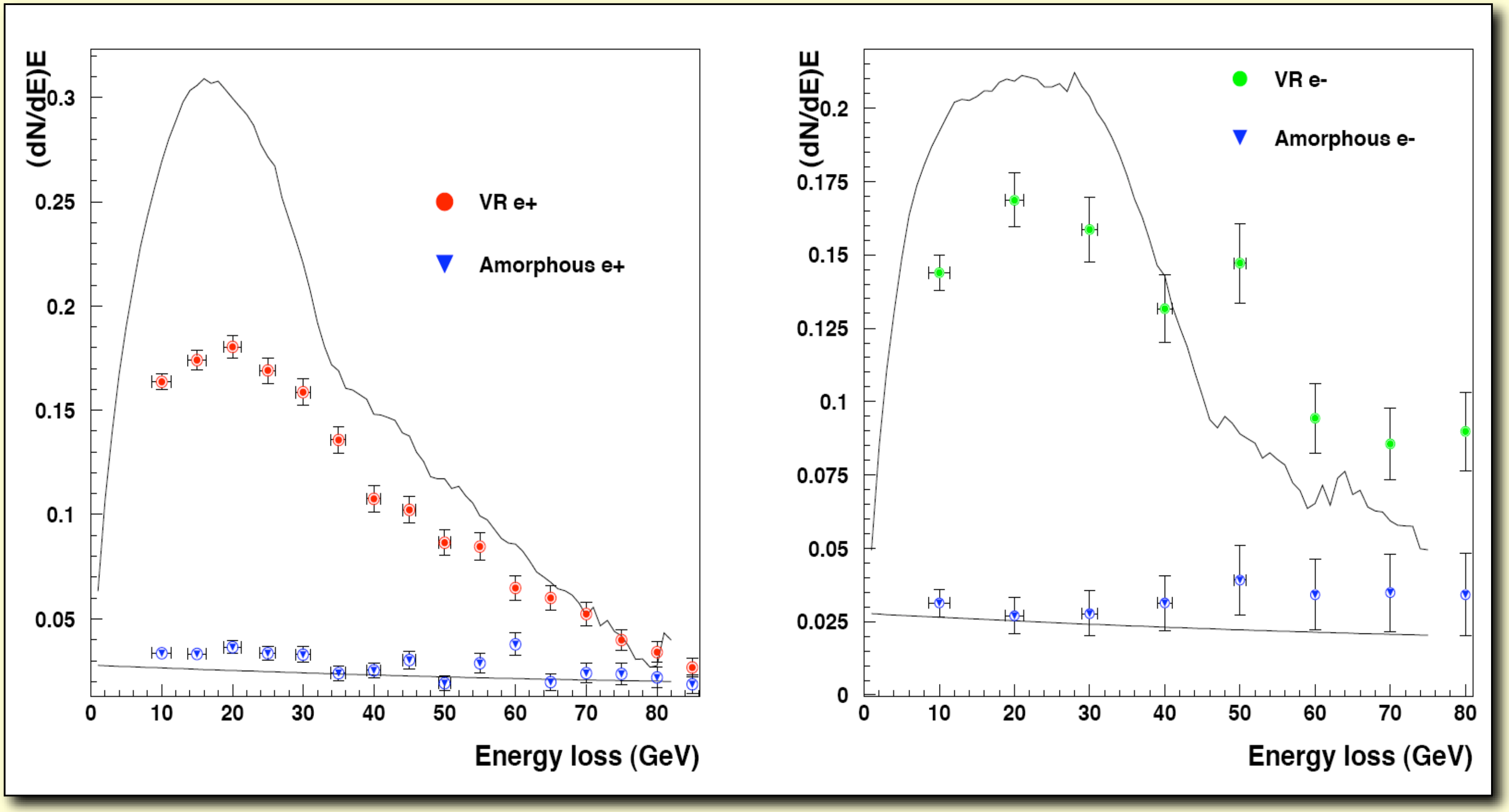


Carrigan, Channeling 2008

X-ray Generation

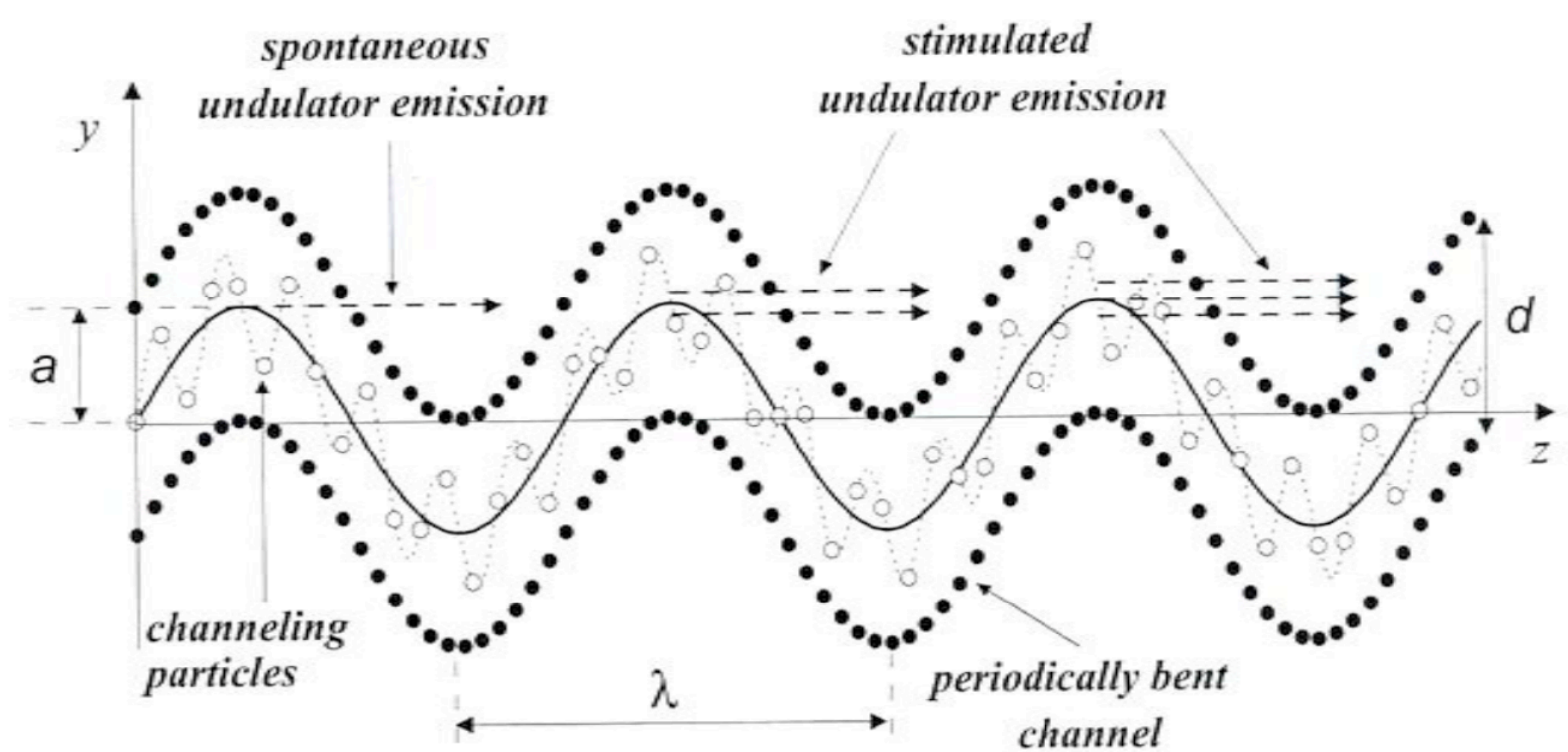
Bolognini, Thesis

180 GeV e^- and e^+



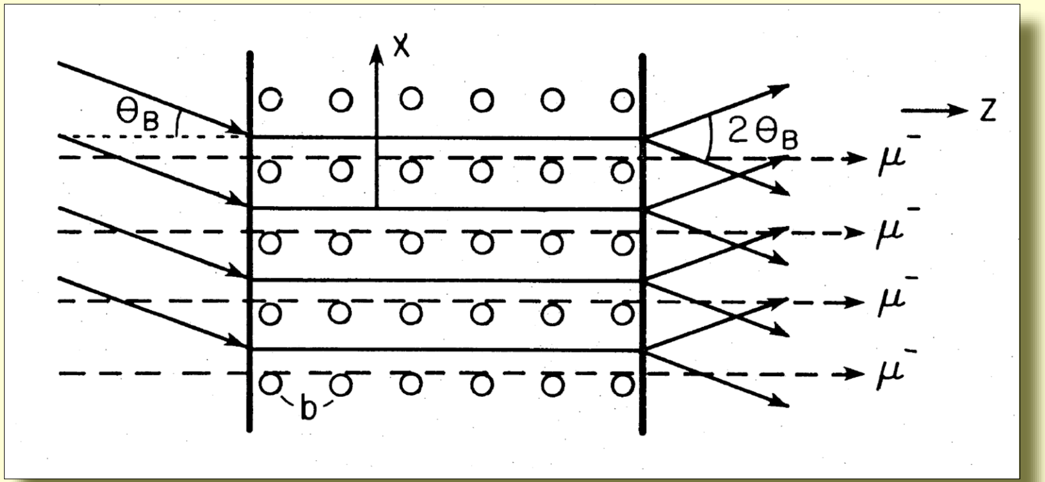
Undulator Radiation possible?

A. Solov'yov, A. Korol, W. Greiner *et al.*



Crystal Accelerator

- Idea: intense Xrays (40 keV, 10^9 W) shone on crystal at Bragg angle setup accelerating field
  - channeled μ^+ see accelerating field of GV/m
  - (Tajima & Cavenago 1987)



Summary of non-WFA expts.

- At FACET, we can
  - Study collimation schemes for a linear collider
    - e+ and in particular e– as well
    - crystals may offer important advantages
    - extension of proton expts. at FNAL and CERN (UA9)
  - behaviour of crystals at high intensities
  - Study the generation of X-rays by the extreme fields
    - equivalent to kTesla of magnetic fields
    - use e+: stronger effects than with e–
    - Possible to get coherent light?
      - with sizeable intensities??

Summary

- FACET will be a unique facility to advance the high-gradient acceleration research with plasmas and dielectrica
- Beyond this, FACET will allow a number of advanced experiments in solid-state physics and the study of particle interaction with matter.
- An open, proposal-driven process of experiment approval will allow equitable access to the facility to fore-front experiments

Apply Now!