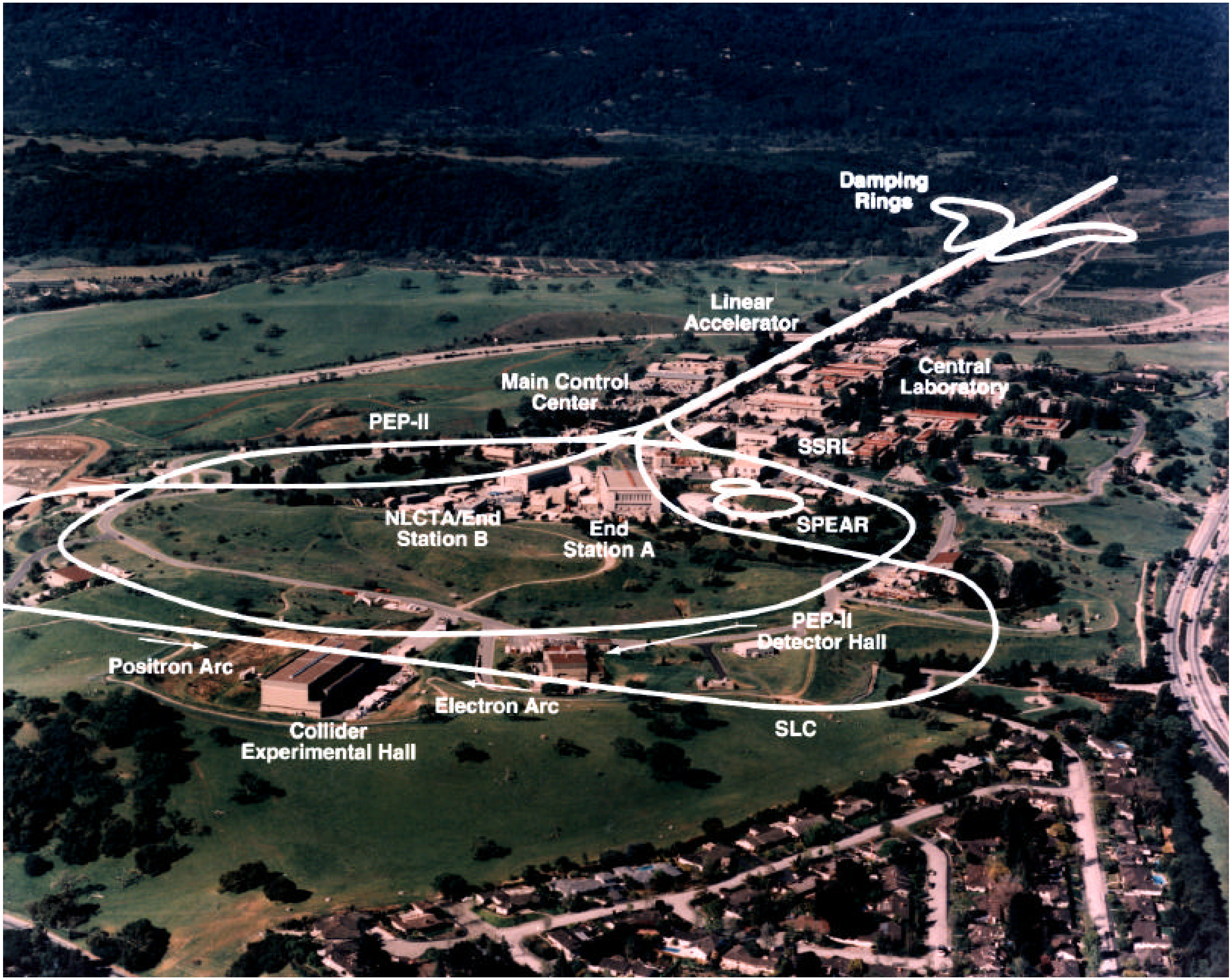
Radiation Damage in Diamond

Experimental data from SLAC

Patrick Krejcik, SLAC

Limitations due to radiation damage

- Total dose
  - Data accrued from coherent bremsstrahlung experiments at SLAC dating back to 1970
- Single pulse damage
  - Test samples at the Final Focus Test Beam IP at SLAC


Damping Rings
Linear Accelerator
Central Laboratory
Main Control Center
PEP-II
SSRL
NLCTA/End Station B
End Station A
SPEAR
PEP-II Detector Hall
Positron Arc
Electron Arc
Collider Experimental Hall
SLC

Single pulse damage

- Extreme charge density at the IP of a γ- γ collider
  - Dielectric breakdown at peak field from electron bunch
  - Energy deposition and heating

FFTB Parameters

- **Present mode of operation**
  - **30 GeV** electrons or positrons (50 GeV)
  - **$2*10^{10}$** particles per bunch ($4*10^{10}$)
  - **10 Hz** repetition rate (120 Hz)
  - **3-4** m**m** transverse beam sigma (σ_y~0.7 μm)

Extreme fields

$N_e \sim 2*10^{10}$

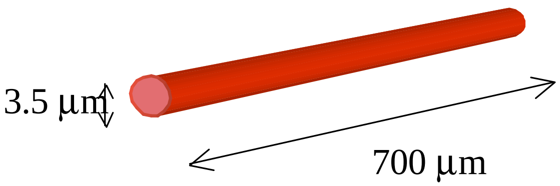
Max electric field

$\sim 2.3*10^{10}$ Volts/meter

Peak current is

1370 Amp

B~80 Tesla



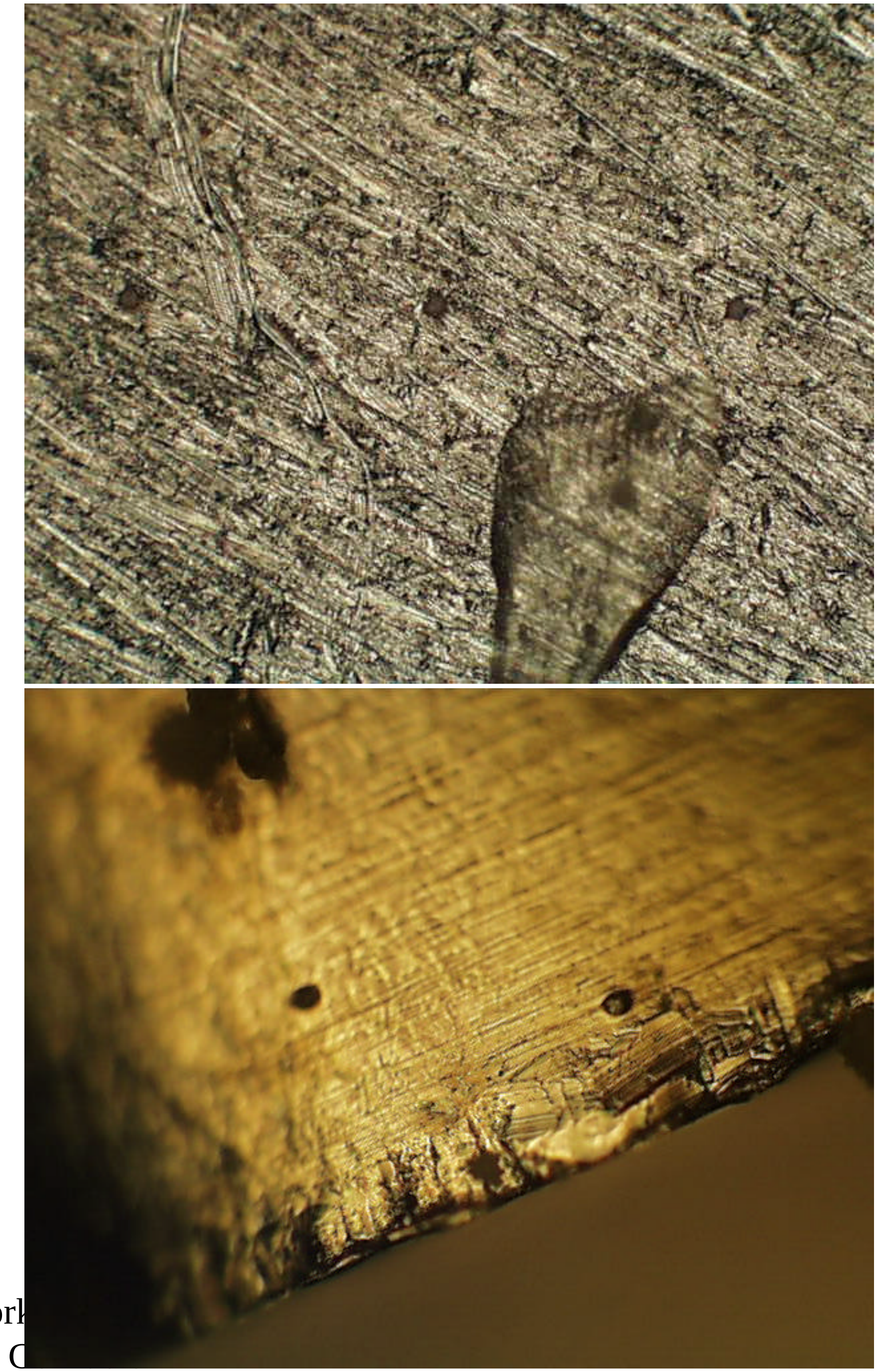
Recent experiments at FFTB

- “coupon” tests to determine damage threshold in metals for collimators, vacuum chambers etc. for the NLC
  - Found threshold< $1*10^{10}$ particles per pulse

  Above which thermal damage is observed, leading to holes in the sample.
- Does diamond survive a single pulse?

First diamond test October, 2000

- 2 mm square x 0.25 mm thick diamond crystals supplied by APS, Argonne (W-K. Lee, E. Gluskin)
- Damage only observed in Al sample holder, none seen in diamond.

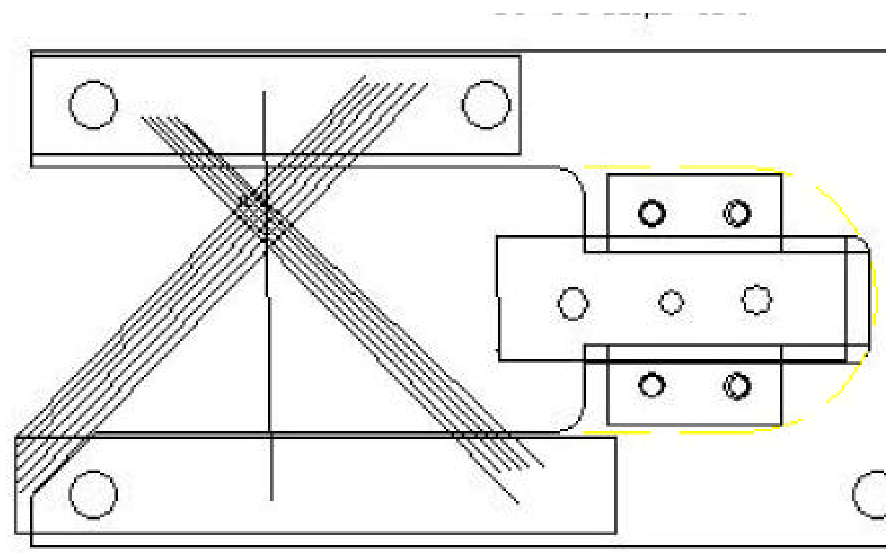


Second diamond test March, 2001.

- Better quality diamond crystal
- Characterize the diamond before and after radiation by x-ray topographic imaging.
  - Measure rocking angle before and after
- Sample is mounted in the beamline awaiting allocation of beamtime (2 shifts)
  - Will be using positrons

Experimental details

- With very small beam spot sizes, difficulty is in locating the area irradiated
- Sample is mounted on a wire scanner. Beam position located on 4 μm wires.
- Irradiate a 25 x 25 grid of points



Total dose limitations

Diamonds used for "The SLAC Coherent Bremsstrahlung Facility", R. Schwitters, SLAC-TN-70-32, 1970.

Beam

- 16 Gev electrons
- Few 10^{11} electrons per pulse
- Up to 60 Hz rep. Rate
- 25 kW beam power
- Spot size ~7 mm

Diamond crystal

• selected out of ~3000 natural 5-6 carat diamonds

• 7 mm square slabs 0.5 to 1 mm thick

•Major face is 100 plane, edge parallel to 011 axes

Total dose limits

- **Severe radiation damage after $2*10^{19}$ electrons**
  - **$5*10^{19}$ electrons per cm^2**
- Observed as degradation in coherent to incoherent bremsstrahlung ratio
  - Accompanied by discoloration of crystal
  - Color centers that are single vacancies and interstices could be annealed with UV
  - Annealing can be applied once or twice, but eventually multiple defects accumulate that are immobile and cannot be annealed.
- dE/dX losses for a 25 kW beam amount to ~1/2 watt
  - Result in some misalignment of crystal mount
  - Radiation length in diamond ~22 cm

Dose at the NLC IP

$\sigma_{x,y}$ = 332 x 4.5 nm ***WORST Case at the IP!***

$N_e = 0.82*10^{10}$

Bunch train 90 bunches 1.4 ns spacing repeated 120 Hz

Dose from a single bunch = $5*10^{20}$ electrons cm^{-2}

Diamond will last only one bunch passage !!

Move diamond over 4.5 nm in 1.4 ns

- Peak velocity = 3.2 ms^{-1}
- Average target velocity = 50 μm s^{-1}

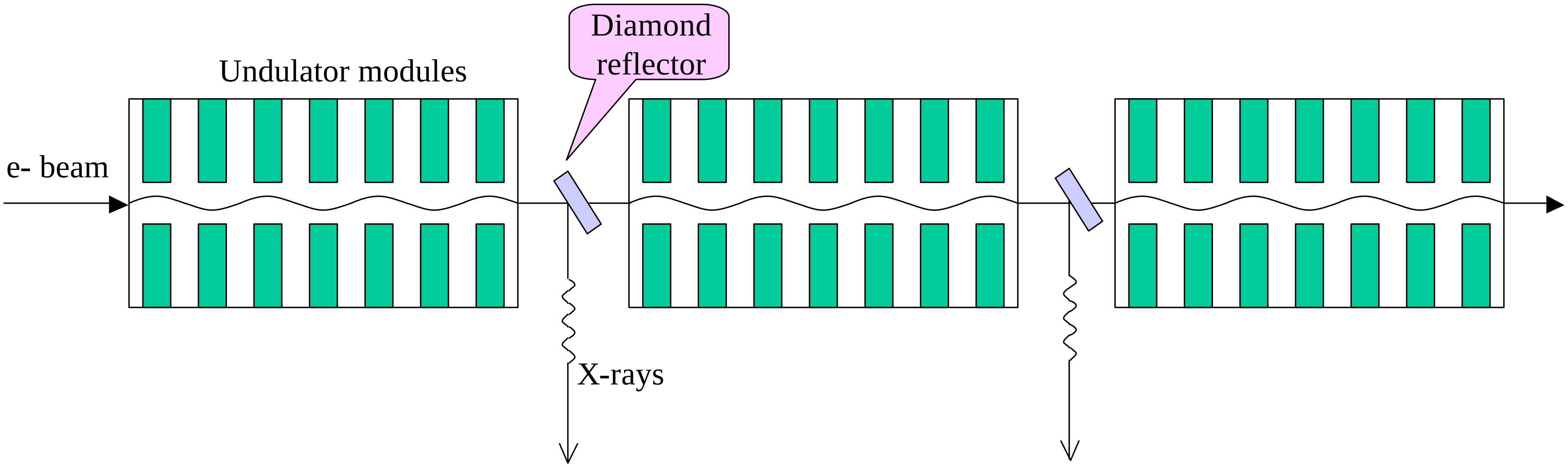
Other diamond experiments at SLAC

- Channeling experiments circa 1980,
  - I.I. Miroschichenko, R. Avakian et al
- Coherent photon production, starting again ~2003
  - R. Arnold, P. Bosted et al
- Diamond crystals will be used for x-ray beam diagnostics at the SLAC Linac Coherent Light Source …

T450 – Damage Tests in Diamond for LCLS

Rick Iverson, Patrick Krejcik, Doug McCormick, ***SLAC***

Efim Gluskin, Wah-Keat Lee, ***Argonne National Lab***.



- LCLS needs X-ray diagnostics along the undulator
- Single crystal diamond Bragg reflector needs to survive single pulse radiation damage from intense electron beam