Fiber Mesh Diagnostic for Transverse Profile Measurements

RadiaBeam Technologies
October 2010
ATF User's Meeting
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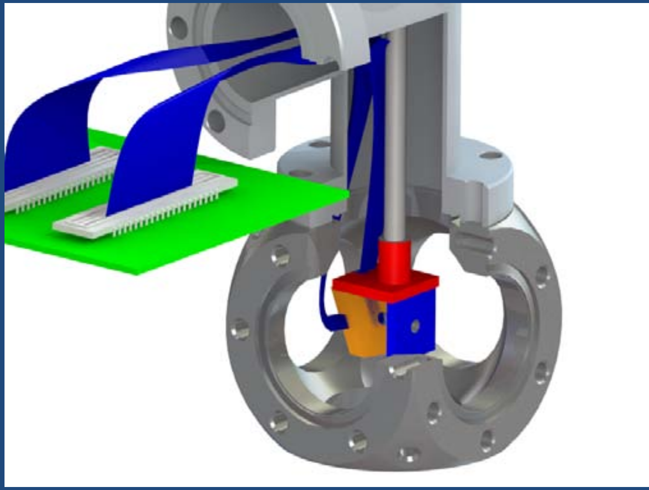
Funded by DOE SBIR 2010 Phase II

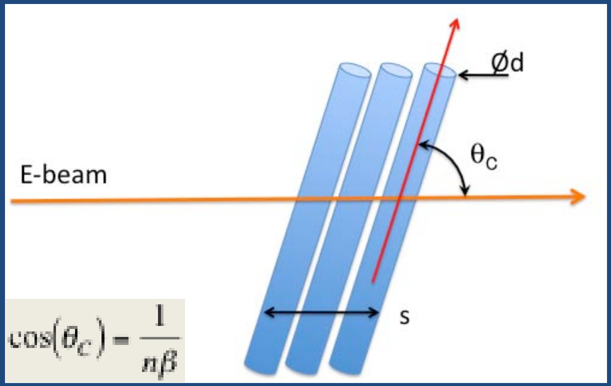
Motivation

- Advanced accelerators and light sources require better resolution on beam transverse profile
  - Current techniques require scintillating materials or OTR
  - Resolution limited to ~40µm,
    - Need imaging optics
    - Blooming, limited depth-of-focus, etc.
  - COTR can contaminate data for compressed bunches
- Exploit advances in fiber industry, nano-fabrication techniques
- Fibers mesh laid across beam path
  - Cerenkov radiation is collected/analyzed
- Fiber-mesh diagnostic (FMD)
  - adequate photon yield
  - minimal real-estate
  - FOV is arbitrarily large
  - Sub-10µm resolution
    - With appropriate fiber choice



Angular Acceptance and yield

- Typical fibers n~1.5
  - θ_c~47^o
  - Angular acceptance peaked at θ_c
  - Rotation of fibers can increase/decrease acceptance
- Photon yield
  - N_{ph}~10^5



$$\cos(\theta_C) = \frac{1}{n\beta}$$

$$\frac{dE}{dz d\omega} \approx \frac{e^2\omega}{4\pi\varepsilon_0 c^2}\sin^2(\theta_C)$$

Cerenkov radiation from single e^-

$$N_0 \approx 2\pi\alpha\left[\frac{d\sqrt{2}\sin(\theta_C)}{\lambda}\right]\left(\frac{\Delta\omega}{\omega}\right)$$

Avg Photon flux per e^-

$$N_{ph} \approx \frac{2\alpha}{\sqrt{\pi}} N_e \left[\frac{d^2}{\lambda\sigma_x}\right]\left(\frac{\Delta\omega}{\omega}\right) NA$$

Total Photon yield

Fujikura SM85-7/125-R Fiber Properties	
Central Wavelength	850 nm
Bandwidth	10%
Mode Fiber Diameter (MFD)	6.8μm
Numerical Aperture (NA)	0.13

E-beam properties & Cerenkov yield	ATF
Charge	300 pC
Energy	50 MeV
Cerenkov angle	46.7
RMS spot size	50 μm
Peak photon yield per fiber	2.2×10^5

Radiation dose on fiber

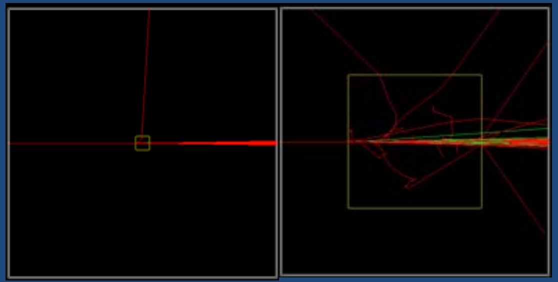
- Background radiation (analytic)
  - ATF parameters
    - Dose ~0.7kGy per shot
  - For 1 hr operation
    - Dose ~100MGy
- Crosstalk (simulations)
  - Monte Carlo (GEANT4)
  - SiO_2 fibers
  - No significant crosstalk for up to 1mm
  - Avg. dose = 1.37×10^{-6} Gy per e^-
  - Total dose ~ 2kGy per shot
- FMD is viable in lab environment

$$\langle E_0 \rangle = \mu(z) = \frac{\mu d \gamma m_e c^2}{\sqrt{2}\sin(\theta_C)}$$

Energy deposited by single e^-

$$\Gamma_0 = \frac{\langle E_0 \rangle N \sin^2(\theta_C)}{\pi d^2 \sigma_x \rho} \approx \frac{\mu}{\rho}\frac{\sin(\theta_C)}{4\pi\sigma_x^2} E_b$$

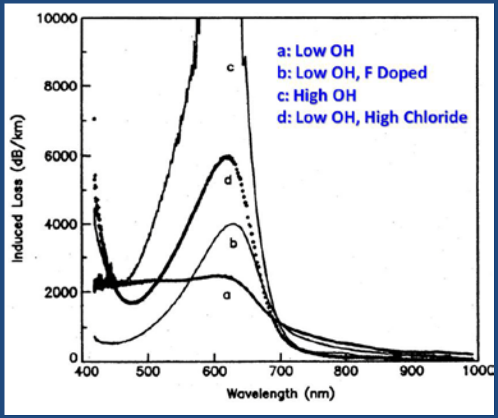
Dose rate per shot per area



100µm thick fiber (left) and 1mm thick fiber (right). Red lines are e^- trajectories.

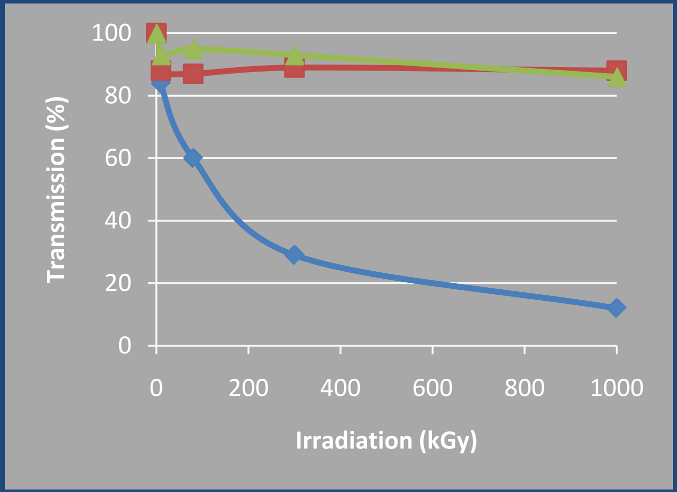
Fiber selection

- Resolution
  - core <10µm
  - cladding 80-125µm (industry standards)
  - Coating unnecessary
- Chemical content
  - Doping (low OH preferred)
  - Improved transmission
  - Life expectancy (F-doped)
- Irradiation expt results
  - Fujikura rad-resistant fibers
    - 50µm core, 125µm cladding
  - Sterigenics (San Diego, CA)
    - Exposures from 10kGy-1MGy
  - 3 wavelengths tested
    - 658nm (blue curve)
    - 808nm (red curve)
    - 1313 (green curve)



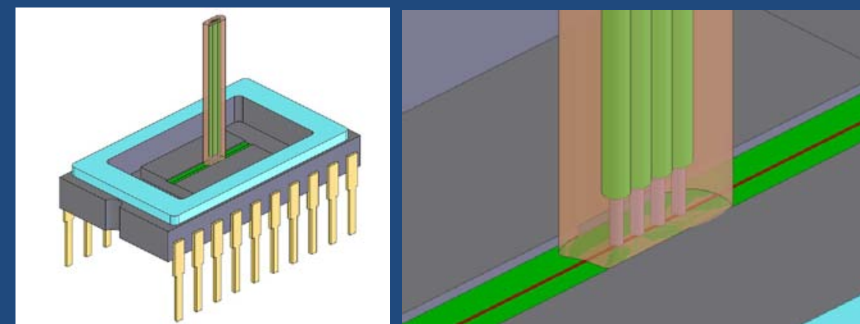
Fiber losses vs wavelength D. Griscom

Fiber Irradiation results



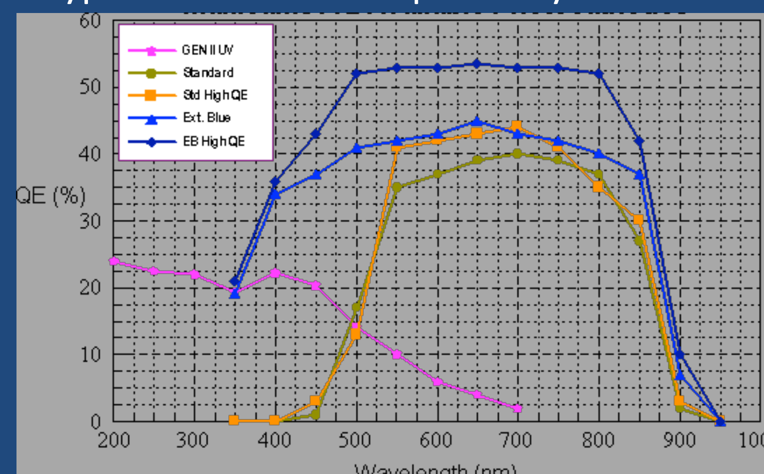
Detector

- Linear CCD
  - Coupling
  - Reduce crosstalk
  - Pixel size~10µm
    - Adjacent pixels stay dark (cladding ~125µm)
- Fiber preparation
  - Fiber coatings must be stripped
  - Fiber ends polishing
  - Epoxy adhesive
- Single fiber detectors considered, but costly
  - PMTs
- Proof-of-concept test at UCLA Pegasus
  - 125µm core, 250µm cladding
  - Center Spacing 250µm
  - Only one dimension



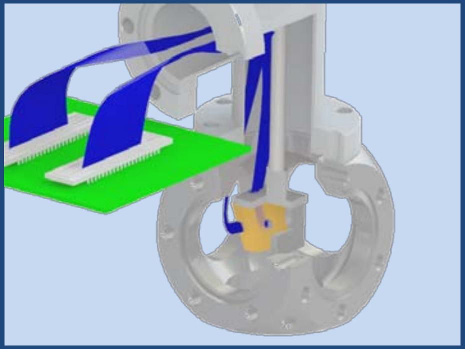
Coupling scheme renderings

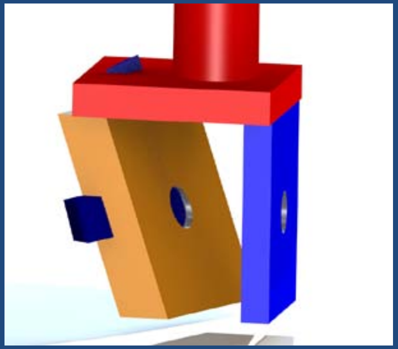
Typical linear CCD responsivity

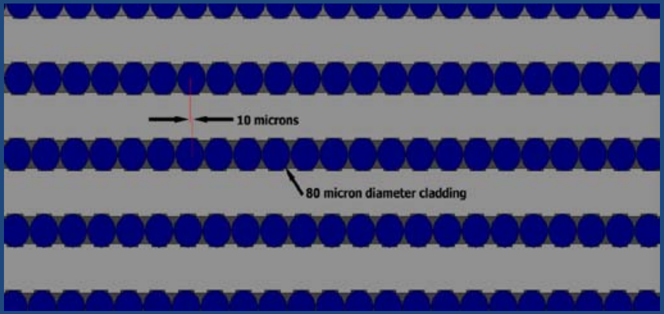


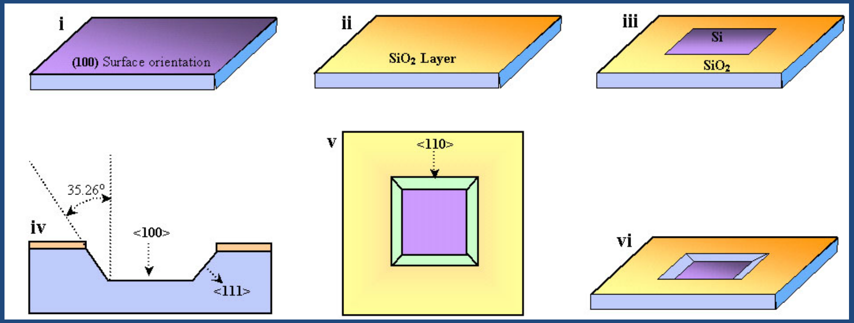
Fabrication

- Fiber holder
  - Nanofabrication techniques
  - Fiber core 8.6µm, cladding 80µm
  - Need ~10µm shift
  - Need 8 layers
  - Both x and y axes
- Coupling out of UHV to CCD board
  - Problem unsolved
- Precision angular alignment of holders
  - Tip/tilt stage



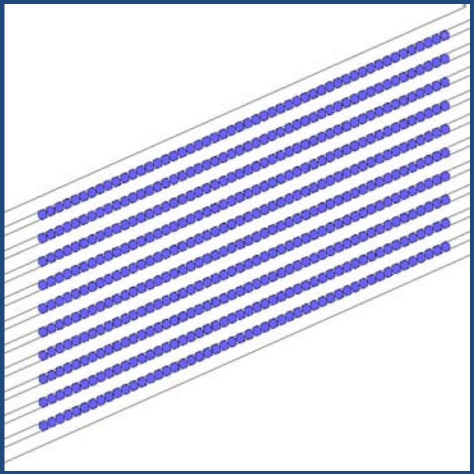






Testing at ATF

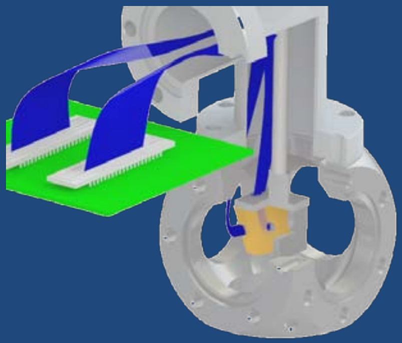
- Time scale ~ FY2012
- Dependent on other milestones
  - Irradiation results
  - Fabrication procedures
  - POC test in UCLA
  - Maintain UHV levels >5x10^{-8}
- Goal: Demonstrate sub-10µm resolution in both transverse planes
  - Fiber 8.6µm core



Fiber layout with ~10µm shifts between layers

BNL ATF Parameters	
Energy	50-90 MeV
Charge	< 1nC
Emittance	2 mm-mrad
Rep. rate	1.5 Hz

Conclusions



- FMD is an innovative idea
  - Still in its infancy
  - Advances in fiber size and radiation hardness
  - Nano-fabrication techniques allow further exploration
  - Irradiation results imperative
  - POC milestone
- Competitive to current profile measurements
  - ATF has long history of testing beam profile monitors
  - Need to demonstrate lifetime
  - Cost