KEK-ATF – Fermilab Collaboration Ideas

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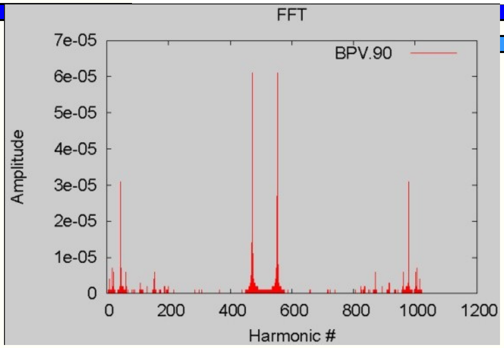
Presented at SLAC

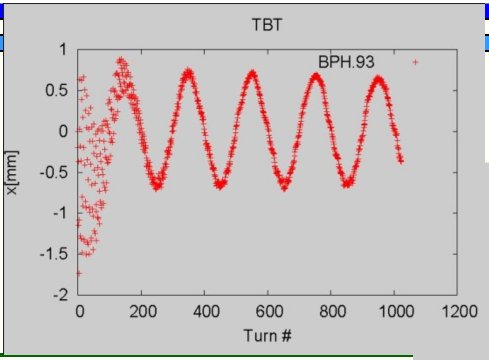
January 10, 2011

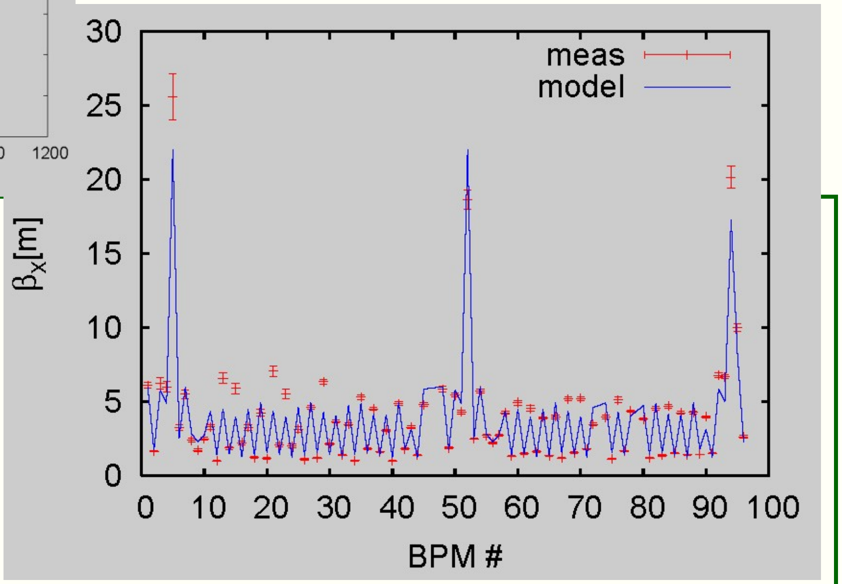
Outline

- In frame of the US-Japan HEP activities, try to find mutual interests between KEK and Fermilab on advanced accelerator R&D for e.g. ATF <-> Project X / SRF / ILCTA-NML
- Some ideas include
  - *Near-term:* Continue with BPM R&D.
  - *Mid-term:* Non-invasive beam profile measurements based on optical diffraction radiation (ODR) in the near field regime.
    OTR point spread function investigation.
  - *Long-term:* Development of high power laser systems.

BPMs & Beam Dynamics





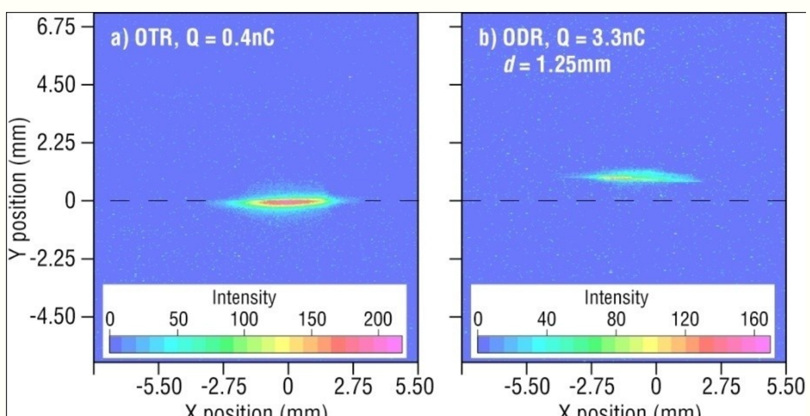


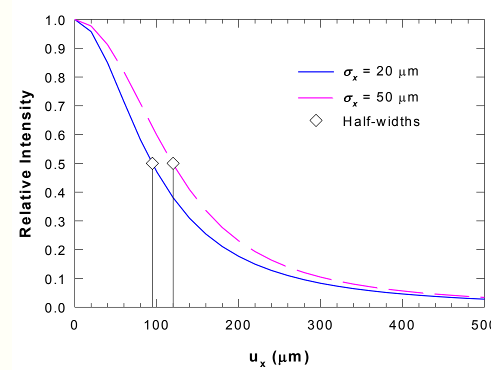
- **ATF Damping Ring BPMs**
  - **Beam Based Alignment, including pickup tilt analysis**
    - **with help of M. Woodley**
  - **Systematic TbT studies, e.g. coupling minimization**
  - **Establish / help control room tools & GUIs**
    - **TbT FFT display, beam orbit / manipulation display, use of the CAL system, resonant extraction, etc.**
- **Upgrade of injector and transport-line BPMs?**
  - **Buttons, striplines. How many?**

Investigations of Optical Diffraction Radiation on 1-GeV Beams at ATF are Relevant to ILC-TA Beams

- **ODR offers the potential for nonintercepting, relative beam-size monitoring with near-field imaging. This is an alternate paradigm to previous far-field work at KEK and INFN. This has been proposed for the 1 GeV NML at FNAL.**
- **Propose tests on ATF beams with new scientific CMOS camera by PCO/Andor with very low noise to detect ODR.**
- **Evaluate sensitivities at 10-50 μm sigma. Test ODR PSF.**

APS test at 7 GeV, 3.3 nC
Done with CCD camera,
but larger beam size case.





A.H. Lumpkin et al., Phys. Rev. ST-AB, Feb. 2007

An Analytical Model has been Developed by D. Rule for ODR Near-Field Distributions Based on the Method of Virtual Quanta

- **We convolved the electron beam's Gaussian distribution of sizes σ_x and σ_y with the field expected from a single electron at point *P* in the metal plane (J.D. Jackson)**

$$\frac{dI}{d\omega}(\boldsymbol{u},\omega) = \frac{1}{\pi^2}\frac{q^2}{c}\left(\frac{c}{\mathrm{v}}\right)^2 \alpha^2 N \frac{1}{\sqrt{2\pi\sigma_x^2}}\frac{1}{\sqrt{2\pi\sigma_y^2}} \times$$

$$\iint dxdy \;\; K_1^2(\alpha b) e^{-\frac{x^2}{2\sigma_x^2}} e^{-\frac{y^2}{2\sigma_y^2}},$$

where ω = radiation frequency, v = electron velocity ≈ c = speed of light, q = electron charge, N is the particle number, $K_1(\alpha b)$ is a modified Bessel function with $\alpha = 2\pi/\gamma\lambda$ and b is the impact parameter.

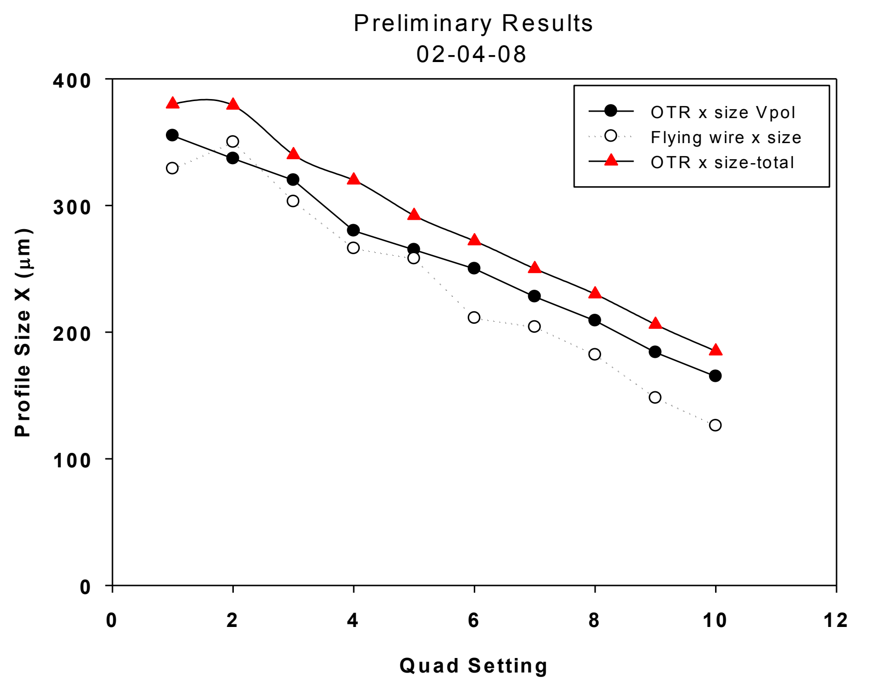
A.H. Lumpkin et al., PRST-AB, Feb. 2007

Investigations of OTR at ATF/KEK

- Mutual interest in the optical transition radiation (OTR) point spread function (PSF) and investigation of anomalous polarization effects reported in JLAB and FNAL experiments.
- Determine actual beam image size after deconvolving PSF. Perform test with beam size from 100 to 1 μm with various optical angular collection apertures.
- Subsequently apply technique to the ILC-TA beams at NML at 800 MeV.

JLAB test at 4.5 GeV: Pol. OTR image is ~20 μm smaller than total OTR image. This is ~5x more than expected from OTR PSF model.

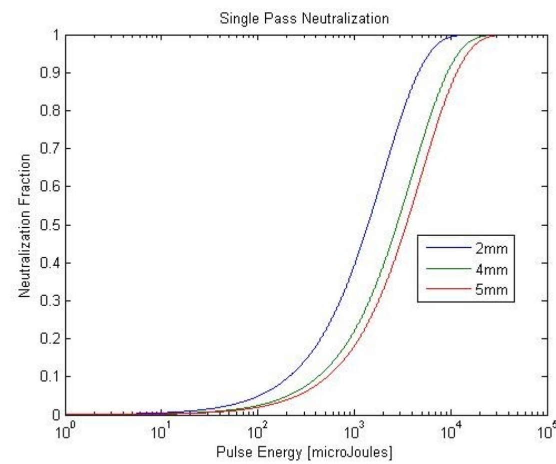
What happens below 100 μm?



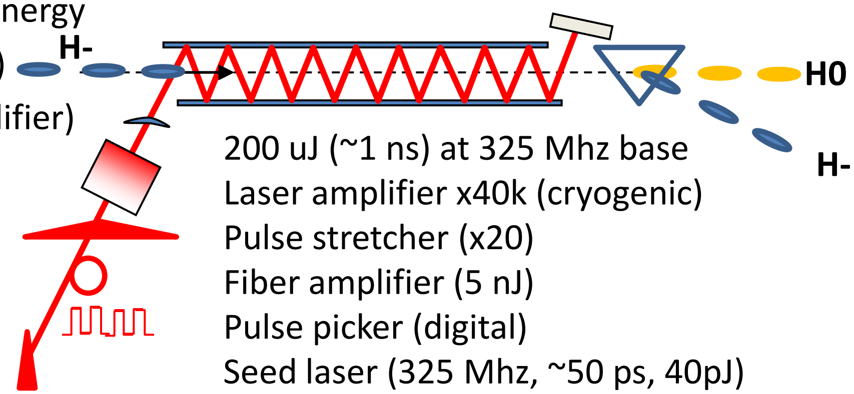
Laser Chopping

- Develop a broad band laser chopper system for 2.5 MeV H- bunches in a 325 Mhz bunch structure capable of removing arbitrary bunches to better than the 99% level.
- Depending on vertical H- beam dimensions requires tens of mJ 1 micron laser pulses at a 325 Mhz base frequency, arbitrary repetition,

  for laser systems with 10's MW avg. power.
- Multi-pass meander (zig-zag) cavity to reduce pulse energy requirement to approx 200µJ pulses and a pulse length on the order of 1 ns at 325 Mhz (65kW avg power)

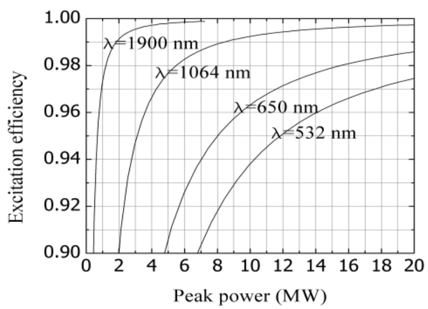


- Components for development:
  - Appropriate insertion in MEBT (~ 1 m) -> lattice design issue
  - Seed laser running at N*325 Mhz highest pulse energy
  - Digital E0 pulse picker with good rejection (40dB)
  - Fiber amplifier (and maybe a solid state pre amplifier)
  - Pulse stretcher
  - Cryogenic Laser amplifier with gain > 104
  - Zig-zag cavity design (in vacuum)
    - Cavity length 12-24 inches
    - Material and coating selection



Laser Stripping

- Stripping of 8 GeV H- requires laser wavelength of 1 to 2 microns and excitation of the n=2 atomic level. This electron in this level is removed by Lorentz stripping in downstream magnetic field.
- Laser parameters for expected H- beam conditions developed for wavelengths, laser geomerty, and magnetic field at the excitation point by T. Gorlov, SNS.



Required peak laser power for excitation of the n=2 level of hydrogen for different laser wavelengths

CASE	I	II	III	IV	V
Wavelength [nm]	1900	1900	1064	1064	1064
Incidence angle, deg	49.77	49.77	94.63	94.63	94.63
Peak power, P_0 [MW]	**1.1**	**2.1**	**6**	**6.3**	**9.7**
Micropulse energy [mJ]	0.08	0.143	0.4	0.4	0.63
Power for 325 Mhz [MW]	**0.026**	**0.046**	**0.13**	**0.13**	**0.21**
Micropulse duration, σ_τ rms [ps]	27				
x - rms size, $r_x = r_y$[mm]	2.1	2.0	8.0	2.0	2.0
y - rms size, $r_x = r_y$[mm]	2.1	2.0	1.8	2.0	2.0
x -divergence, $\alpha_x = \alpha_y$[mrad]	1.7	0	0.5	0.7	0
y -divergence, $\alpha_x = \alpha_y$ [mrad]	1.7	0	2.1	0.7	0
Magnetic Field [T]	0	1.1	0	0	1.1

Hardware

- High average power laser systems (seed lasers/amplifiers)
- Build up cavity to operate in vacuum and high radiation environment for 1 or 2 μm wavelengths with 10^3 build-up.
  - Material life time
  - Damage studies

- Case I Ho:YAG, circular laser, no magnetic field
- Case II: Ho:YAG, circular laser, in magnetic field
- Case III: Nd:YAG, elliptical laser, no mag. field
- Case IV: Nd:YAG, circular laser, no mag. field
- Case V: Nd:YAG, circular laser, in mag. field

Other Possible High-Power Laser Projects

Fermilab is in the preliminary stages of investigating other high-power laser projects such as:

1. Laser Proton Acceleration
   - For radiation therapy for cancer treatment
   - The University of Chicago and Fermilab will collaborate to set up a laser proton accelerator laboratory at Fermilab
   - The laser beam must have high peak power (tens of TW).
     - ~ 1 J with a pulse length of ~ 50 fs
     - Thin foil (aluminum or carbon), gas jet or plasma targets
2. Laser Undulator for FEL
   - The effect of the laser on the electron can be treated very similarly to an undulator
   - Use table top laser power – 10^{18} - 10^{19} W/cm^2 at NML