IGS: Inverse (Compton scattering) Gamma-rays Source

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IGS Collaboration:

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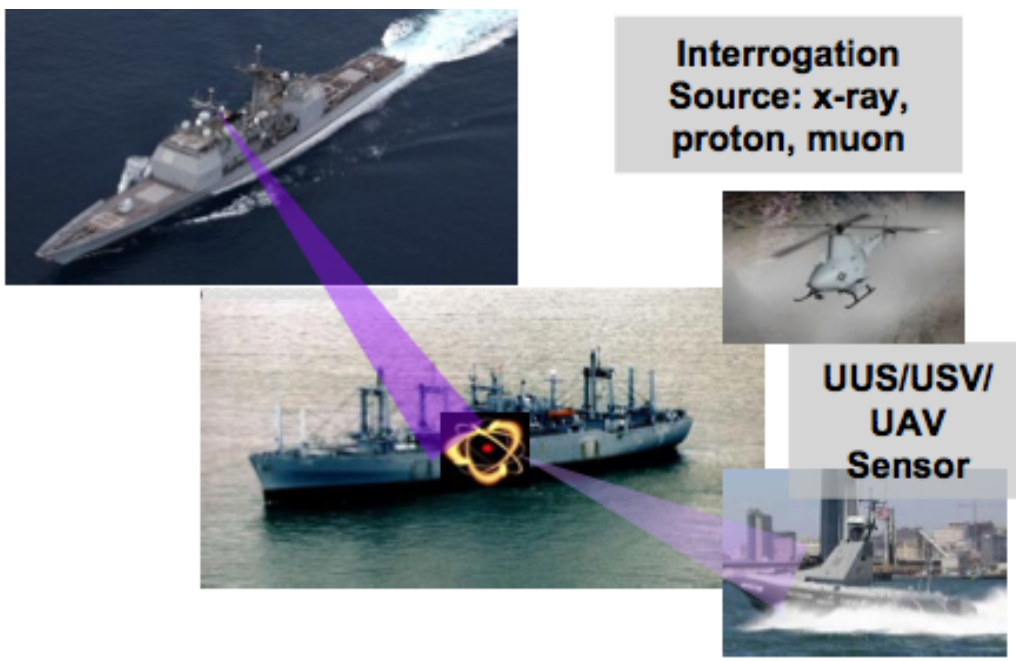
- **Motivation**
- IGS Project Overview
- Project Status

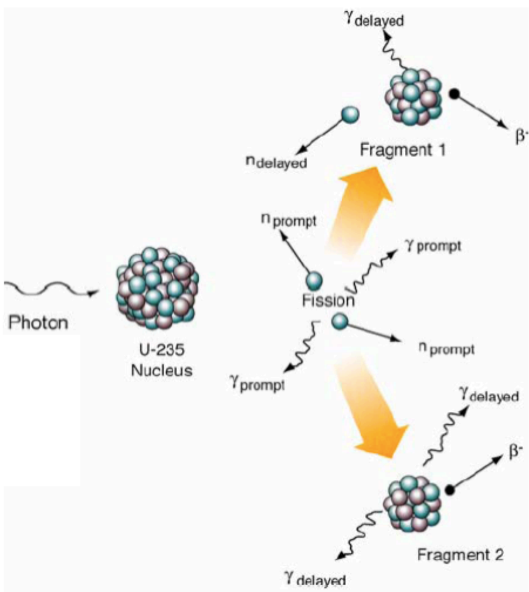
Detection of Loose Nuclear Materials

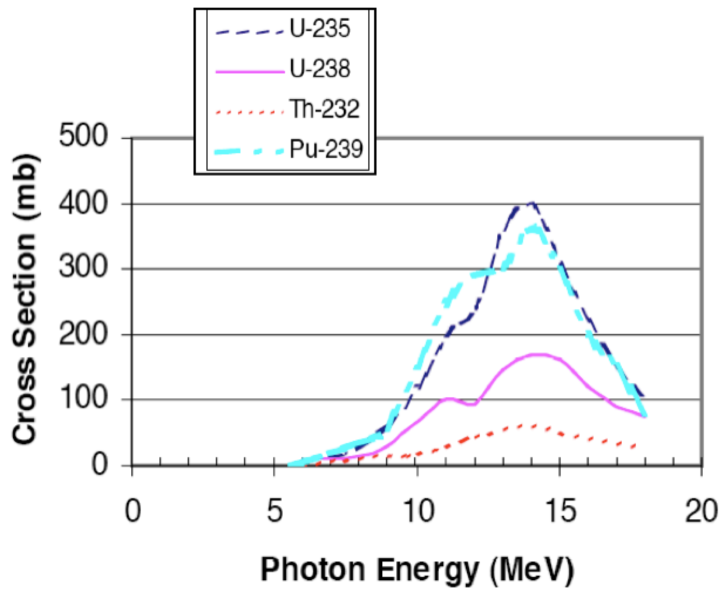
- Developing long-range Special Nuclear Materials (SNM) stand-off detection capabilities (i.e. maritime interdiction) is an important goal of DOD R&D program;
- Passive detection has limited range for SNM, especially U-235;
- Active detection (i.e. with photo-fission or NRF) scheme has to be developed.



Photofission

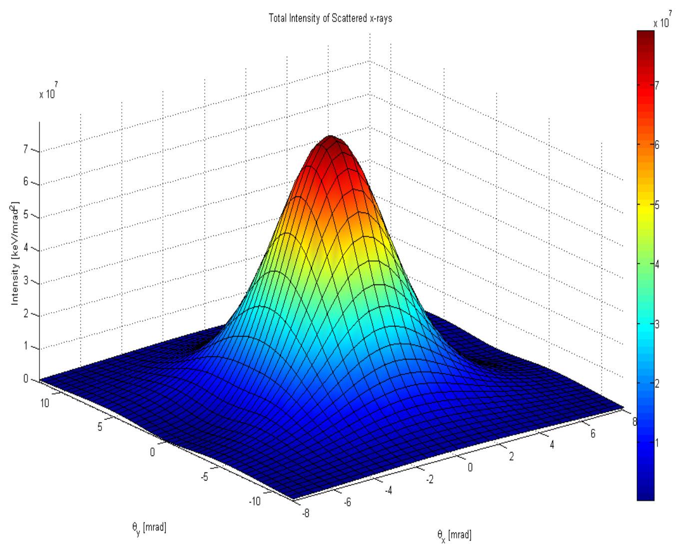
- Photon-induced fission produces signals of prompt neutrons and gammas (from initial fission) and delayed neutrons and gammas (from daughter nuclei)
- Delayed neutrons/gammas are a characteristic signal of SNM

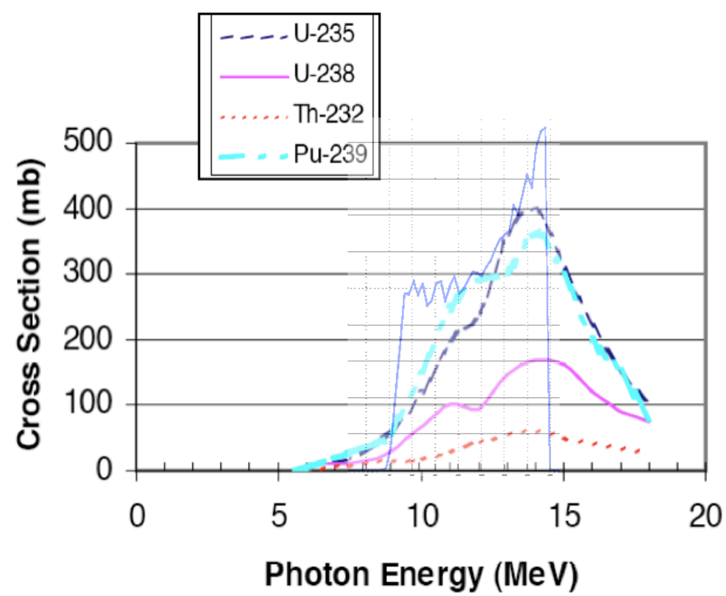




Inverse Compton Scattering

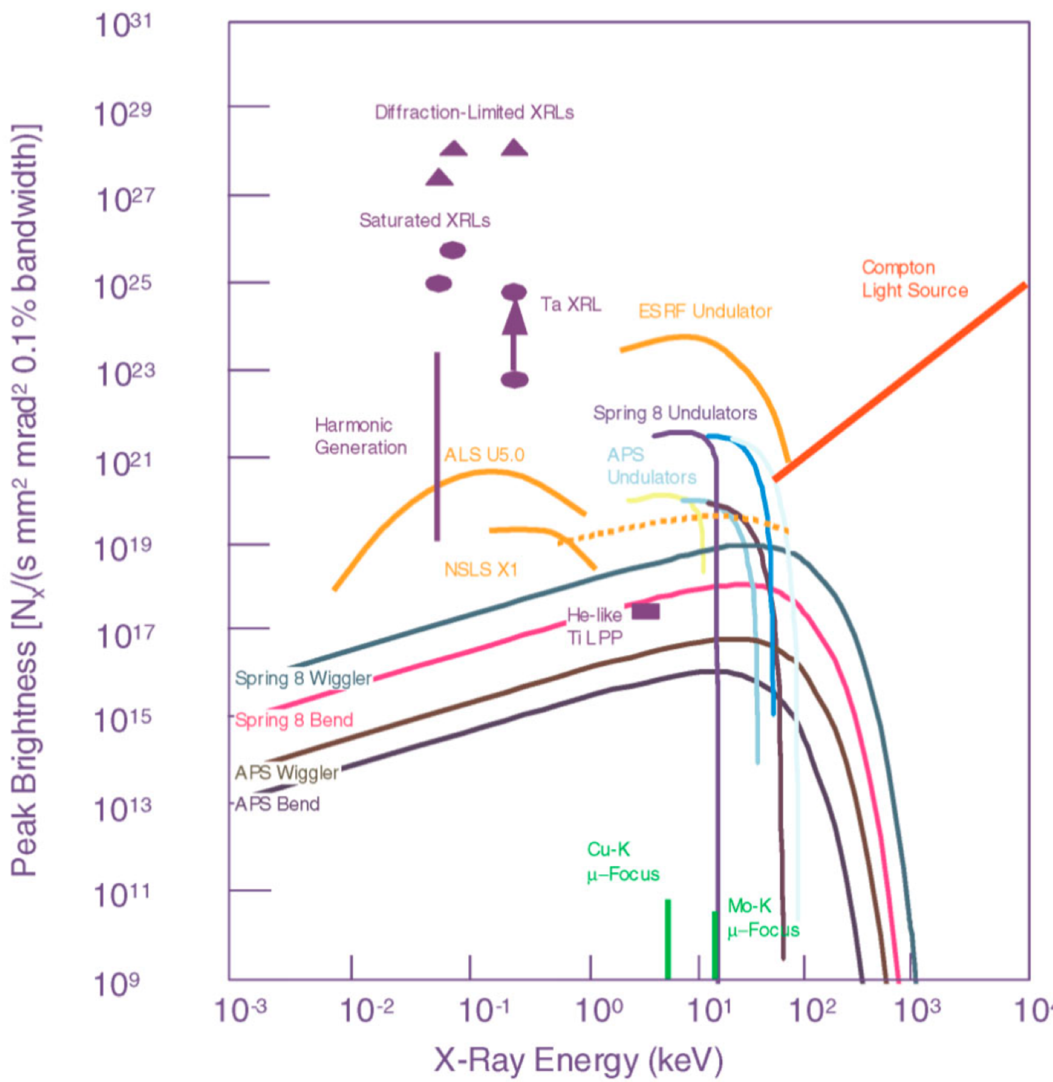
- Inverse Compton Scattering (ICS) process using 2nd harmonic (green) laser and 750 MeV e-beam generates gammas in the photofission range.
- Opening angle of ~ 1 mrad: 1 meter diameter beam at 1 km!



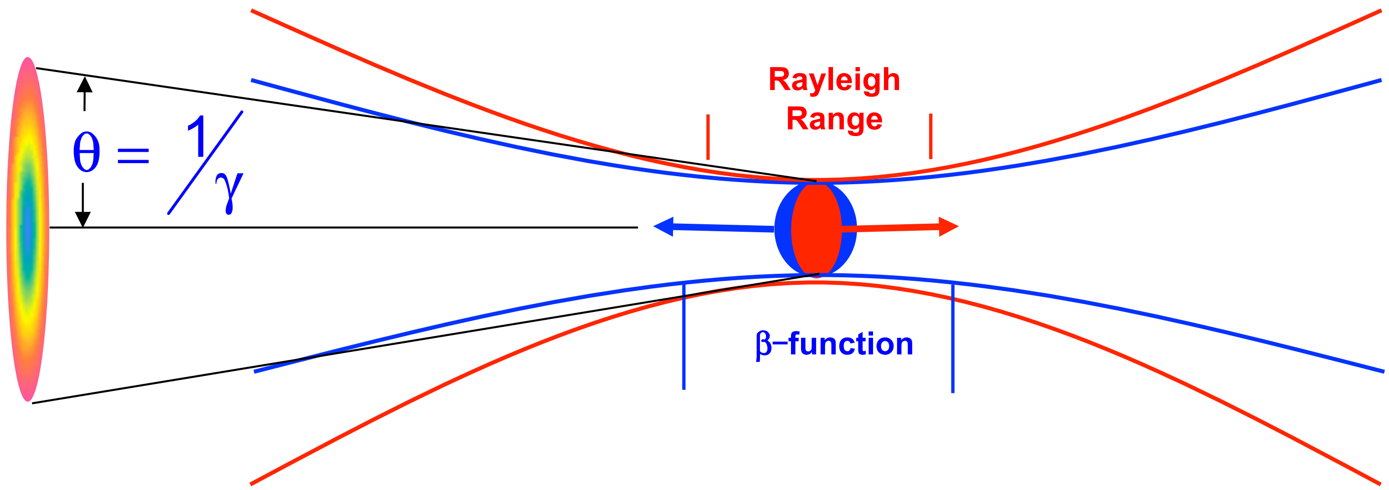


ICS gamma source potential

- ICS energy efficiency scales like γ^2; which makes 500-800 MeV ICS system a very efficient source (**as high as 1 % energy extraction**);
- **Small opening angle of the ICS source** makes it a highly promising technology for long distance stand-off detection.
- Can we get $>10^{11}$ photons per second?



ICS Efficiency



- Compton cross-section is nearly flat
- At reasonable laser intensities the process is linear, and ICS efficiency depends on:
  - beam matching and optimized overlap;
  - precise and stable 3-D alignment;
  - good emittance, low energy spread, quality optics.

ICS Efficiency

Pulse duration	10 ps	1 ps	100 fs
Optimized RMS spot sizes at IP	~ 15 μm	~ 5 μm	~ 1.5 μm
Beam charge	500 pC	300 pC	100 pC
Laser peak power	50 GW	200 GW	1 TW
Number of Compton photons	3×10^8	6×10^8	1×10^9
Efficiency (# photons/electron)	0.1	0.3	1.5
Level of Difficulty	Moderate	Hard	Very hard

- Most of the academic/national lab R&D efforts are directed towards shorter bunches.
- RadiaBeam goals are to demonstrate **higher average power** (this project), **compact geometry** (elsewhere) and **lower cost** (Phase III) of the IGS system.

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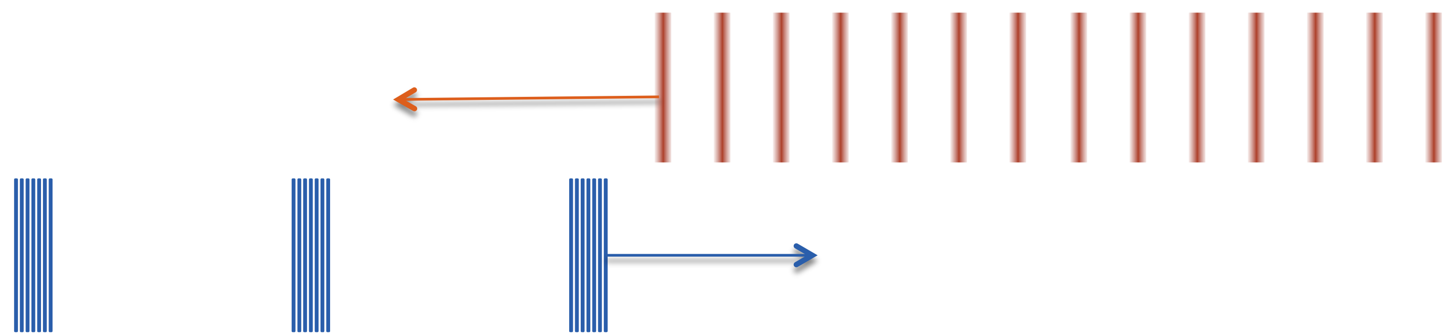
ICS Average Power

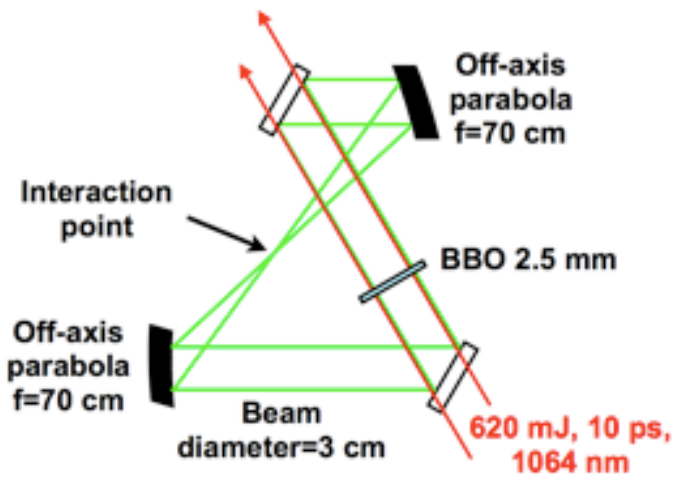
- State-of-the-art laser operate in a single pulse mode but at a relatively high repetition rate (up to few 100 Hz);
- State-of-the-art electron beam is a burst mode (bunch train per each RF pulse, but only up to 50 Hz repetition rate);

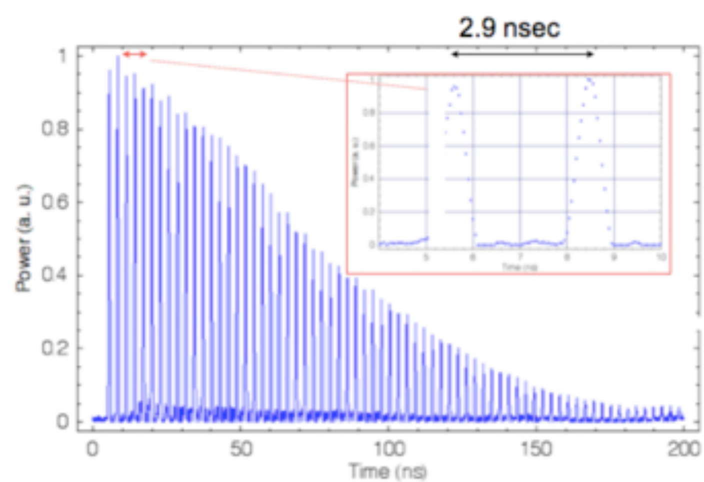


- Interaction defaults to ~ 50 Hz, 2 orders of magnitude below target;
- There are two ways to improve the interaction rate:
  - increase the repetition rate of the RF photoinjector;
  - recirculate the laser to interact with the pulse train.

Laser Recirculation

- Several different techniques were studied; we chose:
  - Recirculation Injection by Nonlinear Gating (RING)
    - Developed at LLNL [I. Jovanovic et al]
- Advantages: simple, inexpensive, can handle high power
- Disadvantage: "ring-down"
- Challenges: timing, alignment, maintaining good laser focus through many recirculations



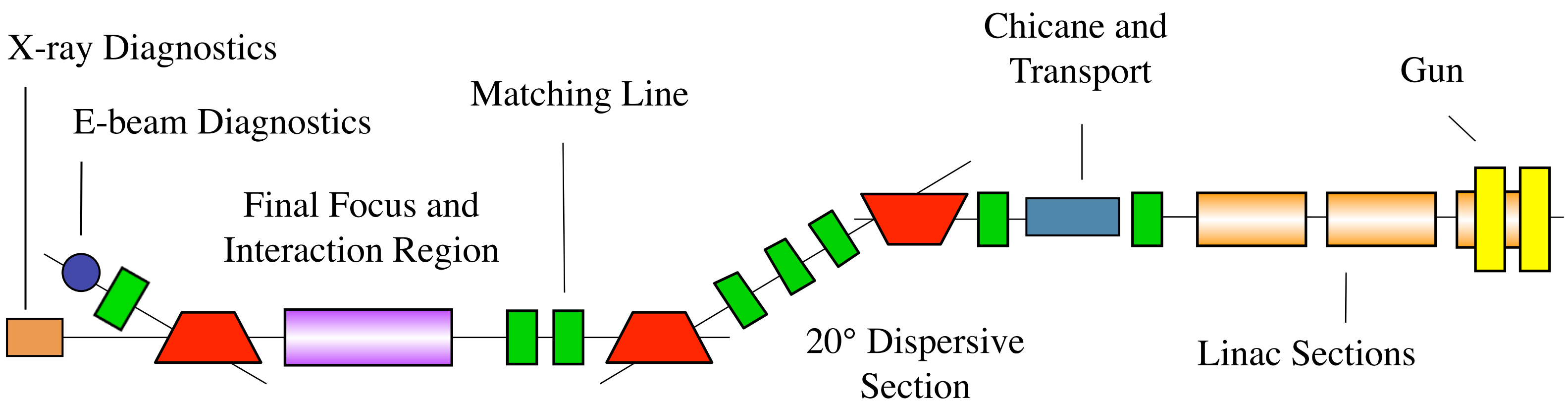


Phase II Experimental Program at ATF

- There are two experimental objectives:
    1. Optimize photon flux per single shot. With the available laser power of ~ 5 GW, we expect about 1 % ICS efficiency (photons per electrons), which at 500 pC implies 3×10^7 photons (in 1/gamma cone). Examine efficiency scaling with charge.
    2. Optimize ICS with the bunch train. Initial goal is to use 20 bunches train, and achieve order of magnitude enhancement with RING. Final objective is a 50 bunches train and a factor of 20 enhancement.
- Both objectives primarily require rigid timing, alignment, beam quality and matching control.

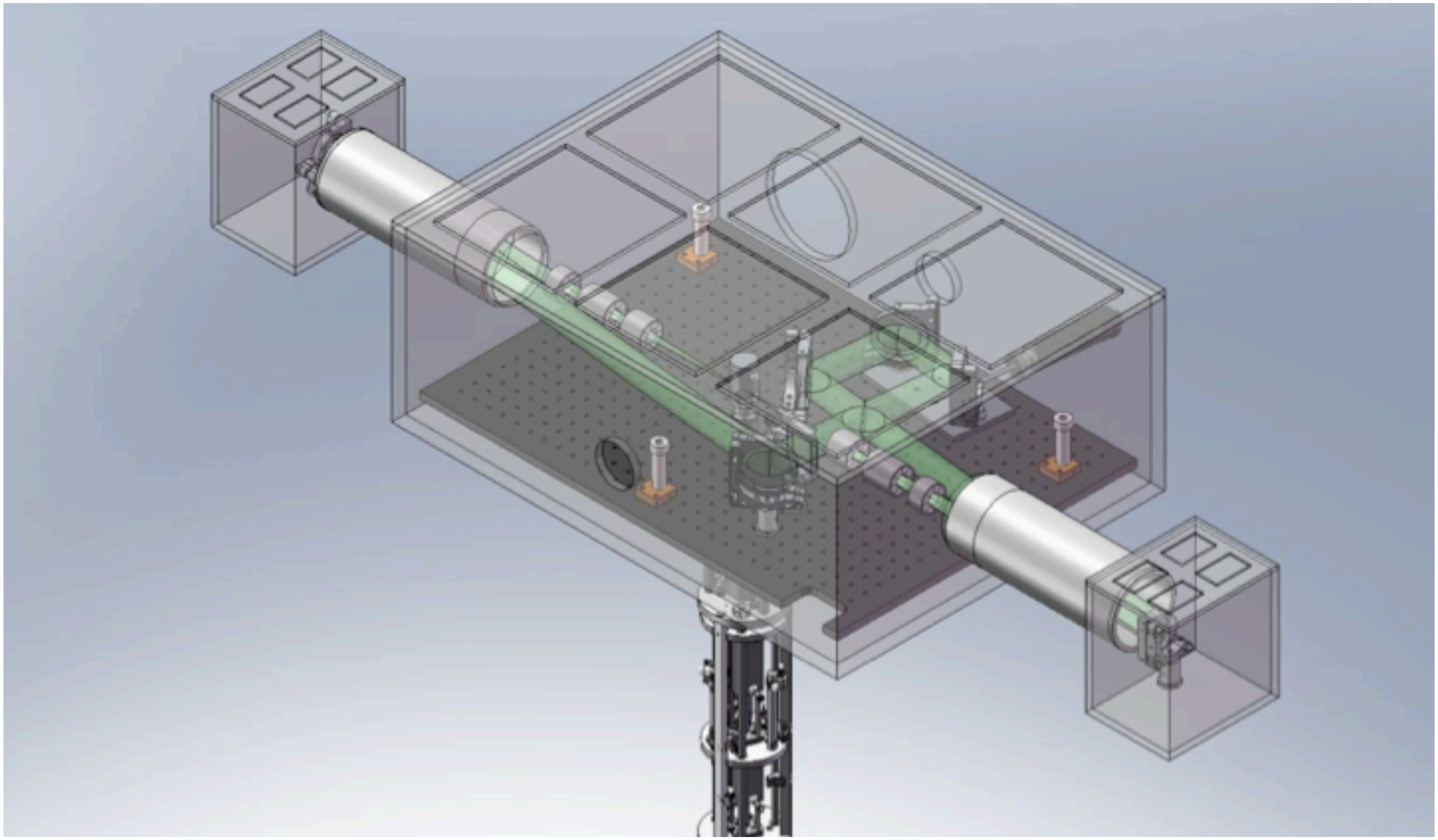
Project overview

- Interaction Box footprint ~ 2 m
- X-ray detector is located ~2 m away from the IP (~ 2 cm beam size)
- Careful e-beam management after IP is critical for good signal to noise measurement.



Project overview

- RING will be implemented inside the vacuum box. Electron beam is focused to the IP with PMQs.



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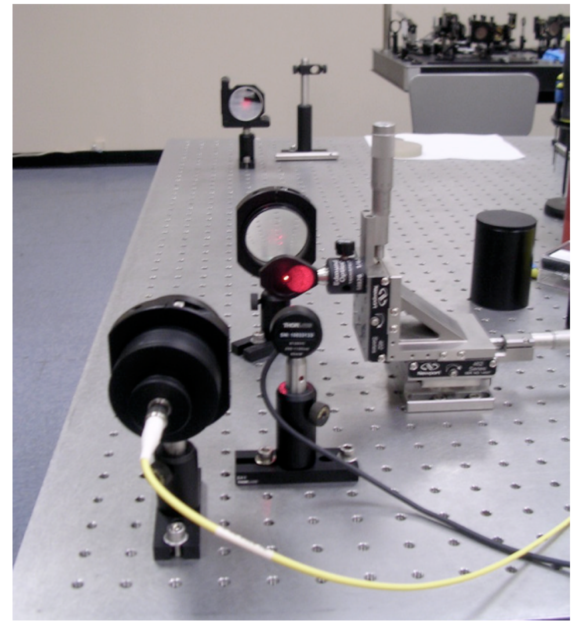
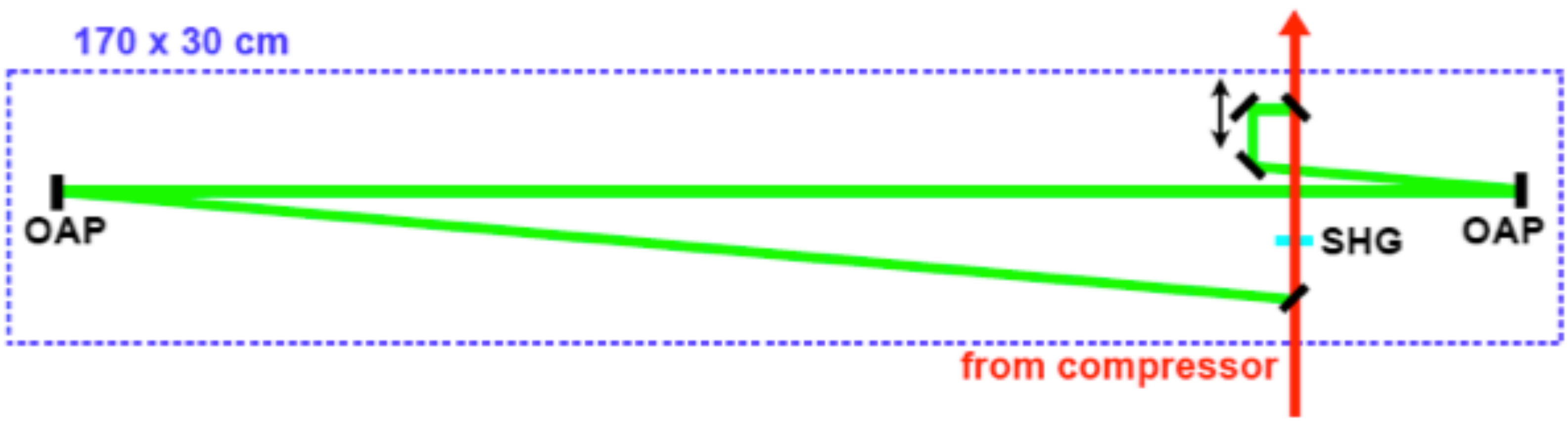
Interaction Laser RING

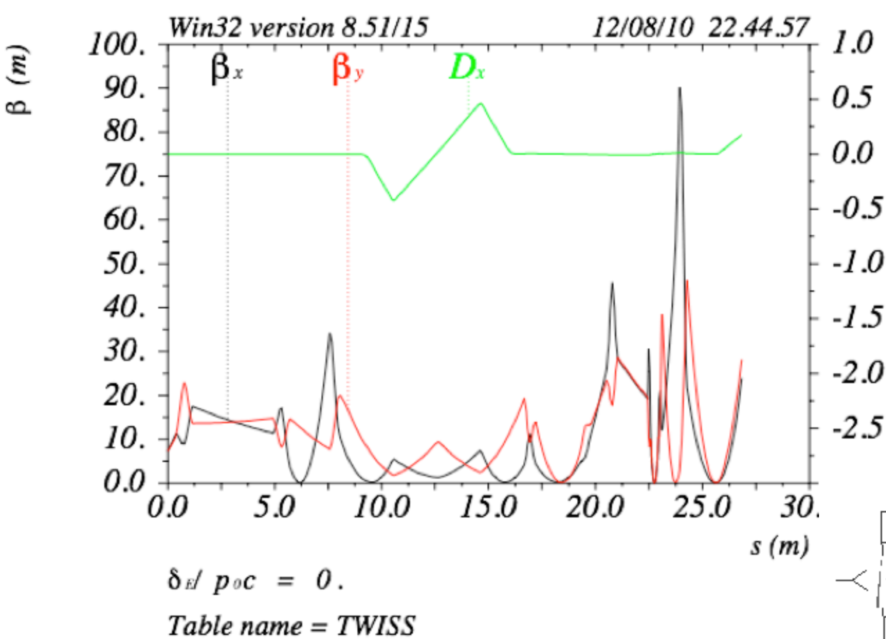
- RING was redesigned to allow path length adjustment
- Currently preparing for test of aberrations with spherical mirrors
- Plan to assemble full RING system at ATF in November 2010.

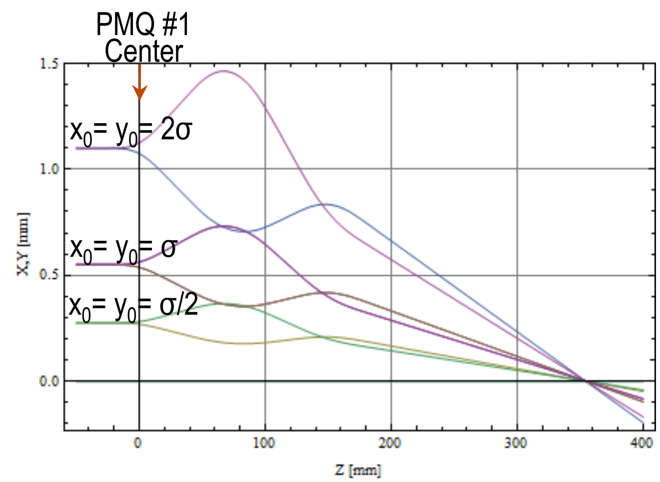


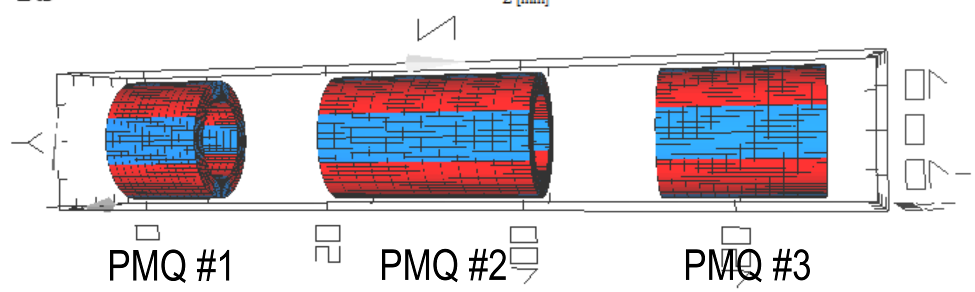


Electron Beam Final Focus

- Fitting the final focus magnets into the region around the IP more difficult than anticipated
  - Several different layouts were simulated
- PMQ's have been designed, currently starting fabrication

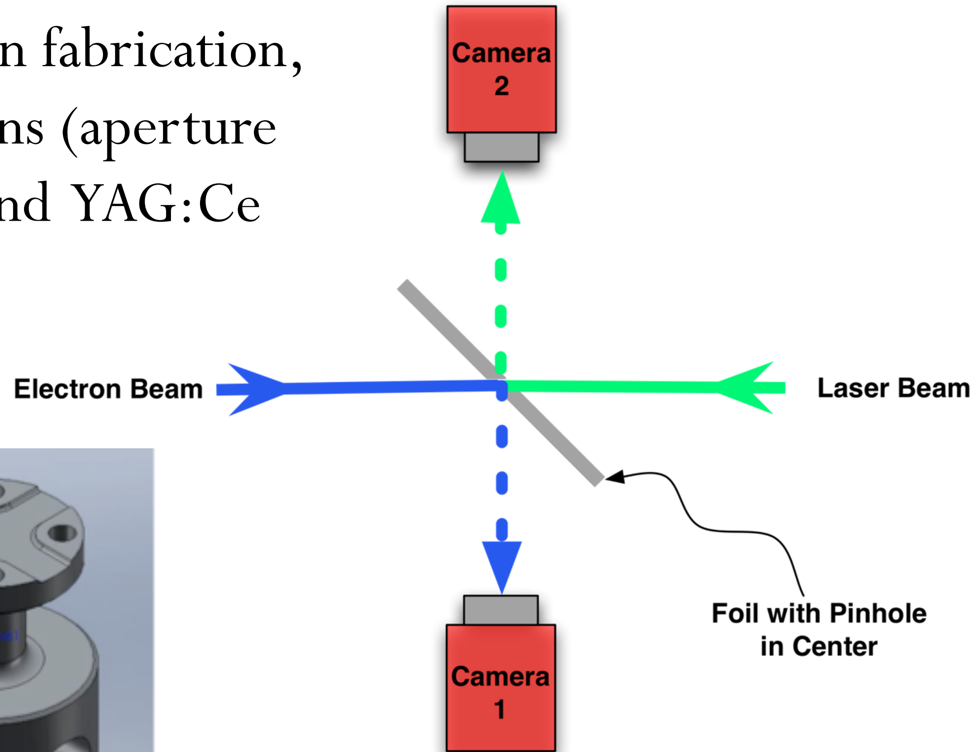


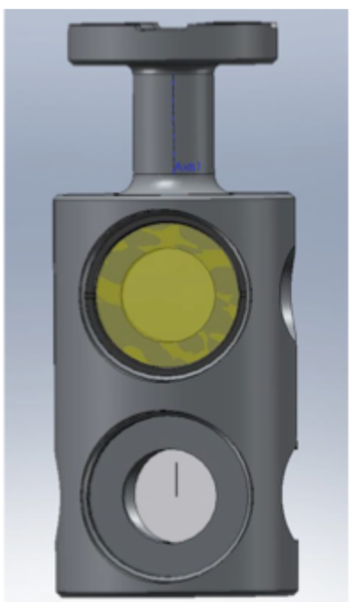


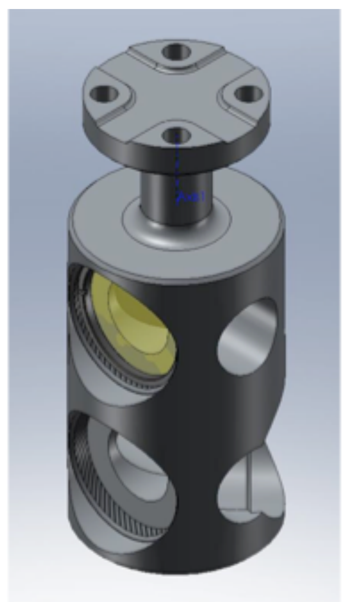


Diagnostics

- IP beam profile monitor is in fabrication, including two active positions (aperture for beam-laser alignment, and YAG:Ce scintillating screen).

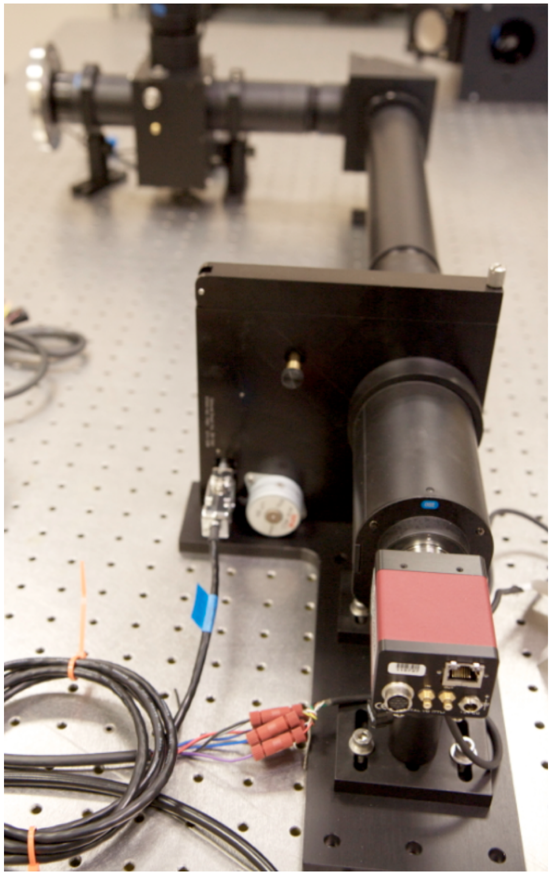


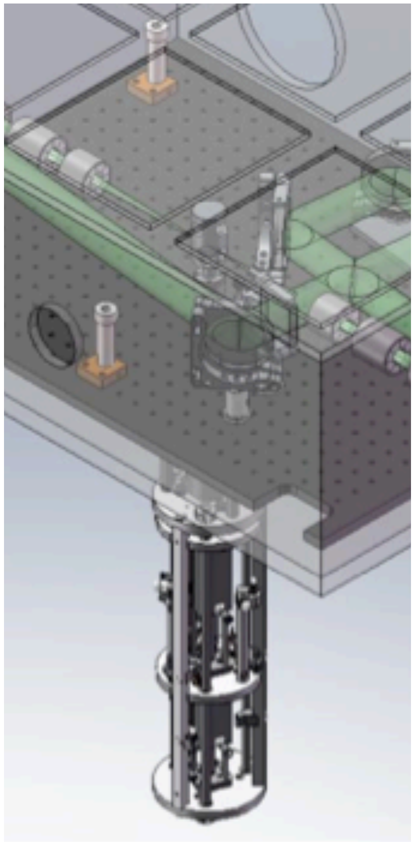




Diagnostics

- To achieve required beam resolution in the zoom-in position an in-vacuum field lens may be required.

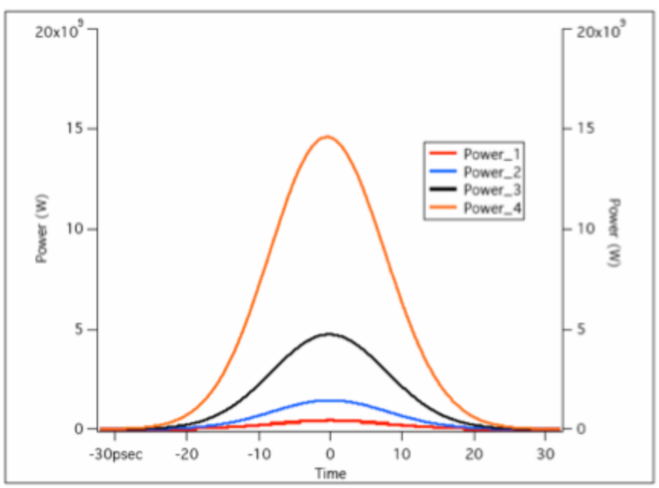




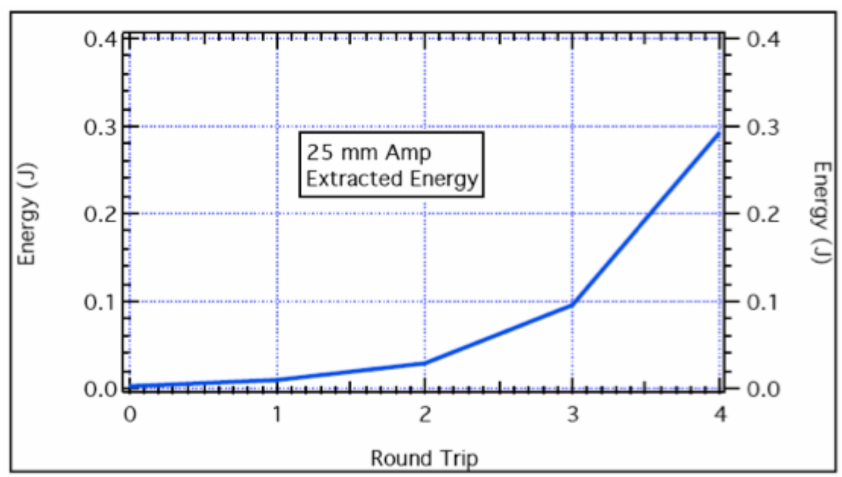
ATF Laser System

- Laser upgrade to 300 mJ in green costs more than originally estimated (both gratings and amplifier)
- Due to budget limitations and operational simplicity, decided to eliminate gratings for now (possible future upgrade)
- Amplifier purchased from Continuum, to be delivered ~1/1/11
- Pockels cells drivers delivered; cells themselves arrive in Sept.

Amplification of pulse on each pass

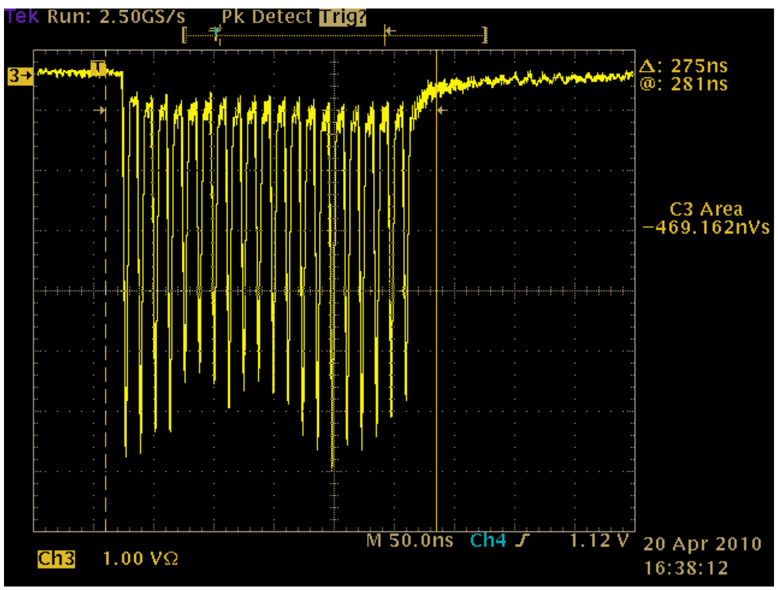


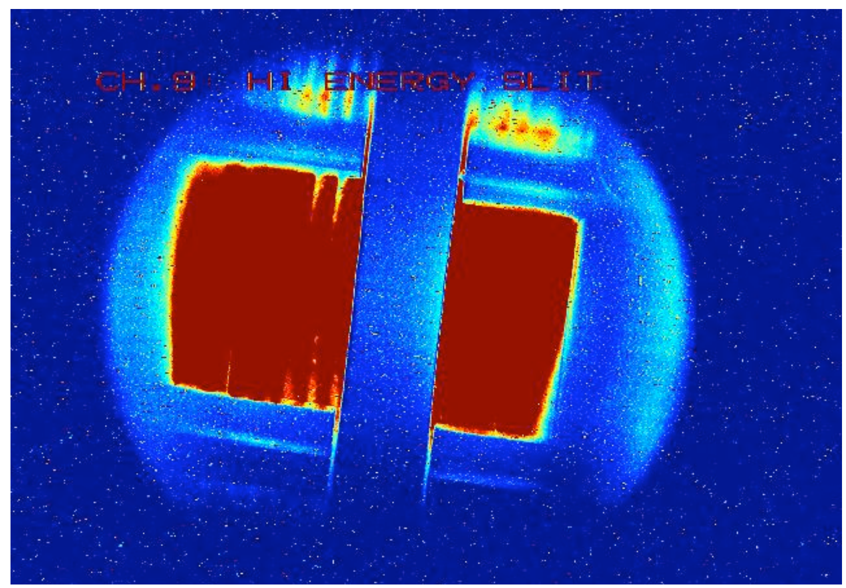
Energy per pass



Bunch Train Generation

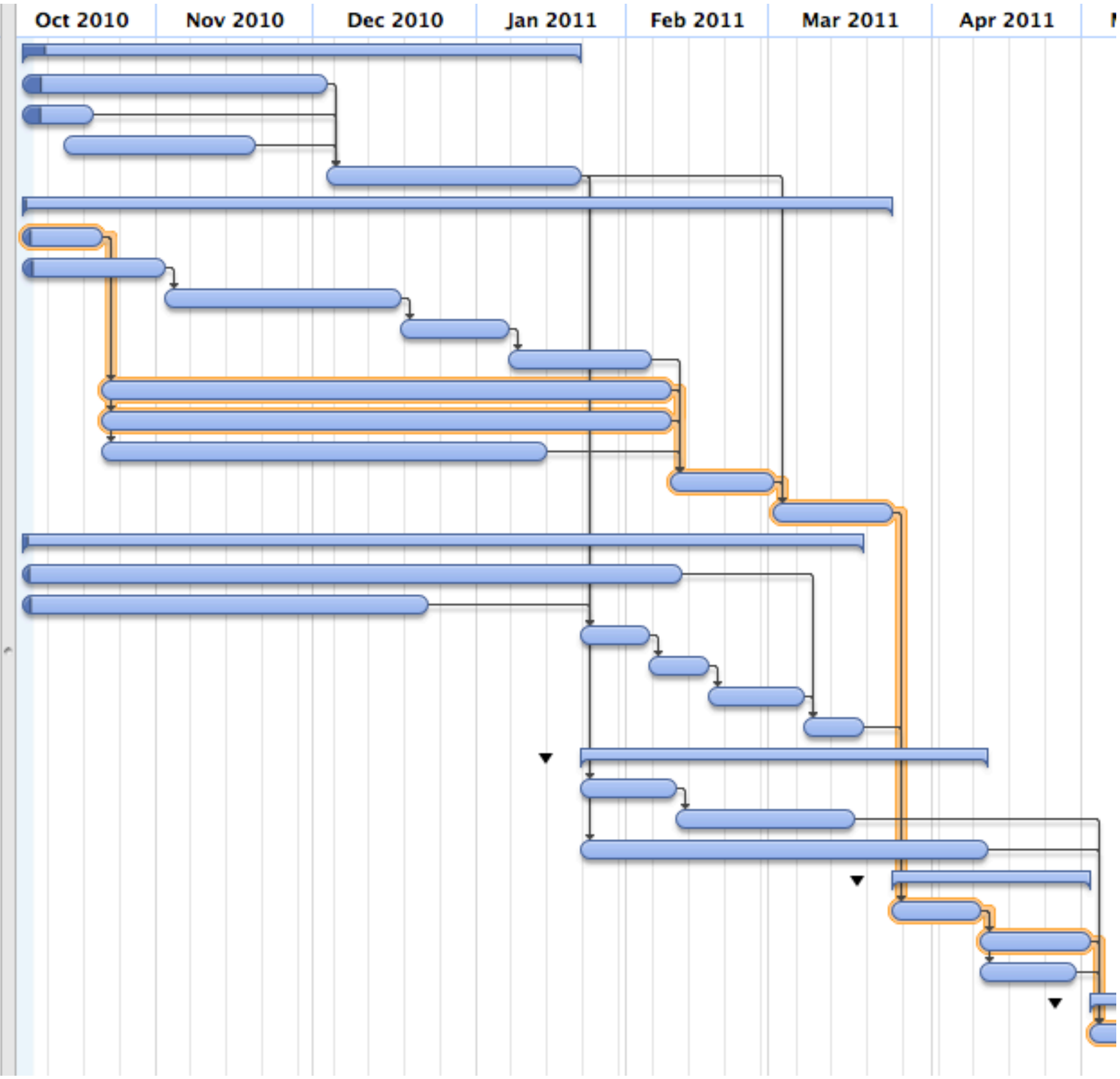
- In preparation 20 pulses bunch train, 300 pC each beamlet has been generated (April 2010).
- Next experimental run will focus on beam loading mitigation and radiation hardening test of the RING dielectric mirrors.





Schedule

Task	Effort
1) RING	8w 1d
• 1.1) Radiation hardness test	3w
• 1.2) Mirror aberrations test	3d
• 1.3) RING bench top alignment test	1w 3d
• 1.4) RING bench top ring-down test	3w
2) Interaction Box	9w 4d 1h
• 2.1) I-box design freeze	1d 1h
• 2.2) PMQ place order	1d
• 2.3) PMQ procurement	1d
• 2.4) PMQ testing	3d
• 2.5) Final beam dynamics simulations	2d
• 2.6) I-box chamber procurement	1w 3d
• 2.7) I-box components procurement	1w 3d
• 2.8) IBIS fabrication	1w
• 2.9) I-box vacuum test	2w
• 2.10) I-box vacuum test w/components	2w
3) ATF laser upgrade	> 7w 1...
• 3.1) Amplifier procurement and...	> 2w 3...
• 3.2) Spatial filter fabrication	4d
• 3.3) Transport line design (beamline)...	1w 1d
• 3.4) Transport line components...	2d
• 3.5) Transport line installation	1w 1d
• 3.6) Laser testing and stabilizer decision	1w
4) Experimental system development	4w 4d
• 4.1) detector design	2d
• 4.2) detector procurement	2d
• 4.3) control system development	4w
5) System Integration	5w 2d
• 5.1) Beamline installation	3w
• 5.2) RING optimization	2w
• 5.3) e-beam optimization	2d
6) Experimental Phase	34w
• 6.1) Single shot optimization	12w
• 6.2) 20 pulse optimiztion	20w



Conclusions

- IGS project is aimed at optimizing "practical" efficiency and average power of the ICS.
- Experimental plans have two steps: single shot ICS optimization, and multi-shot output flux optimization.
- Key sub-systems are in fabrication and procurement stage.
- Installation plans: February-April 2011.
- Experimental phase: May-October 2011.
- The project is supported by DTRA (DOD) Phase II SBIR contract No. *HDTRAI-10C-0001*