IGS: Inverse (Compton scattering) Gamma-rays Source

Alex Murokh
RadiaBeam Technologies, LLC.

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IGS Collaboration:
R. Agustsson, S. Boucher, P. Frigola, A. Ovodenko, M. Ruelas, R. Tikhoplav (RadiaBeam Technologies);
M. Babzien, T. Shaftan, V. Yakimenko (BNL);
I. Jovanovic (Penn State University).
• 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 2\textsuperscript{nd} 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 $\gamma^2$; 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

<table>
<thead>
<tr>
<th>Pulse duration</th>
<th>10 ps</th>
<th>1 ps</th>
<th>100 fs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimized RMS spot sizes at IP</td>
<td>~ 15 µm</td>
<td>~ 5 µm</td>
<td>~ 1.5 µm</td>
</tr>
<tr>
<td>Beam charge</td>
<td>500 pC</td>
<td>300 pC</td>
<td>100 pC</td>
</tr>
<tr>
<td>Laser peak power</td>
<td>50 GW</td>
<td>200 GW</td>
<td>1 TW</td>
</tr>
<tr>
<td>Number of Compton photons</td>
<td>3x10^8</td>
<td>6x10^8</td>
<td>1x10^9</td>
</tr>
<tr>
<td>Efficiency (# photons/electron)</td>
<td>0.1</td>
<td>0.3</td>
<td>1.5</td>
</tr>
<tr>
<td>Level of Difficulty</td>
<td>Moderate</td>
<td>Hard</td>
<td>Very hard</td>
</tr>
</tbody>
</table>

- 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 $\sim 5$ GW, we expect about 1 \% ICS efficiency (photons per electrons), which at 500 pC implies $3 \times 10^7$ 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.
• Motivation
• IGS Project Overview
• Project Status
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

\[ x_0 = y_0 = 2\sigma \]
\[ x_0 = y_0 = \sigma \]
\[ x_0 = y_0 = \sigma/2 \]
Diagnostics

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