Stand-off Detection of Nuclear Materials Using Inverse Compton Scattering Generated Gamma-Rays

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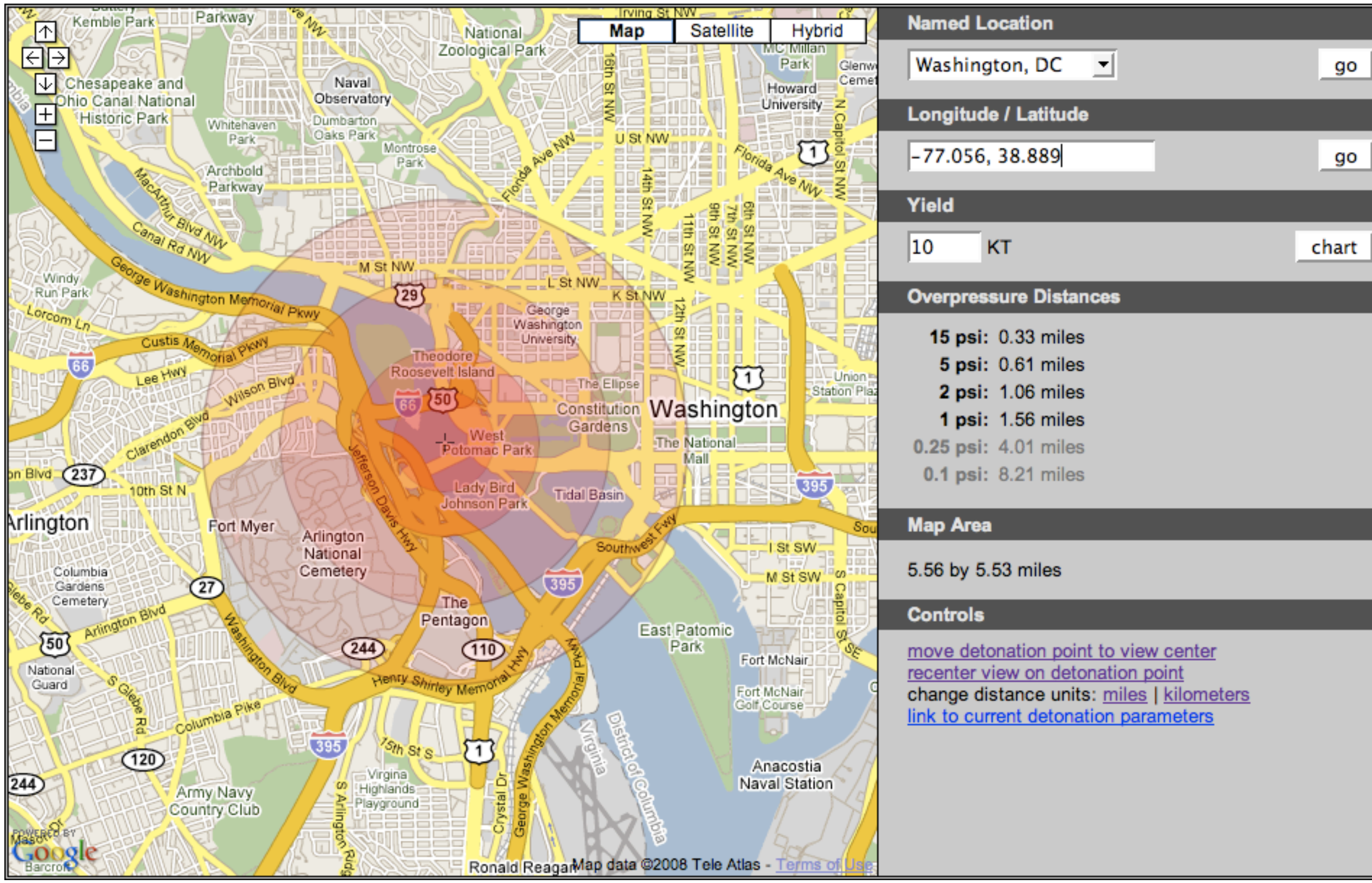
Abstract

Special Nuclear Materials (e.g. U-235, Pu-239) can be detected by active interrogation with gamma-rays (> 6 MeV) through photofission. For long-range detection (~1 km), an intense beam of gamma-rays (~10^14 per second) is required in order to produce a measurable number of neutrons. Production of such fluxes of gamma-rays, and in the pulse formats useful for detection, presents many technical challenges, and requires novel approaches to the accelerator and laser technology. RadiaBeam is currently designing a gamma-ray source based on Inverse Compton Scattering from a high-energy electron beam. To achieve this, improvements in the photoinjector, linac, final focus, and laser system are planned. These enhanced sub-systems build on parallel work being performed at RadiaBeam, UCLA and elsewhere. A high-repetition rate photoinjector, a high-gradient S-band linac, and laser pulse recirculation will be used. The proposed system will be a transportable source of high-flux, high-energy gamma-rays for active interrogation of Special Nuclear Materials.

"Evil doers" obtaining Special Nuclear Materials (SNR) is considered a high likelihood.



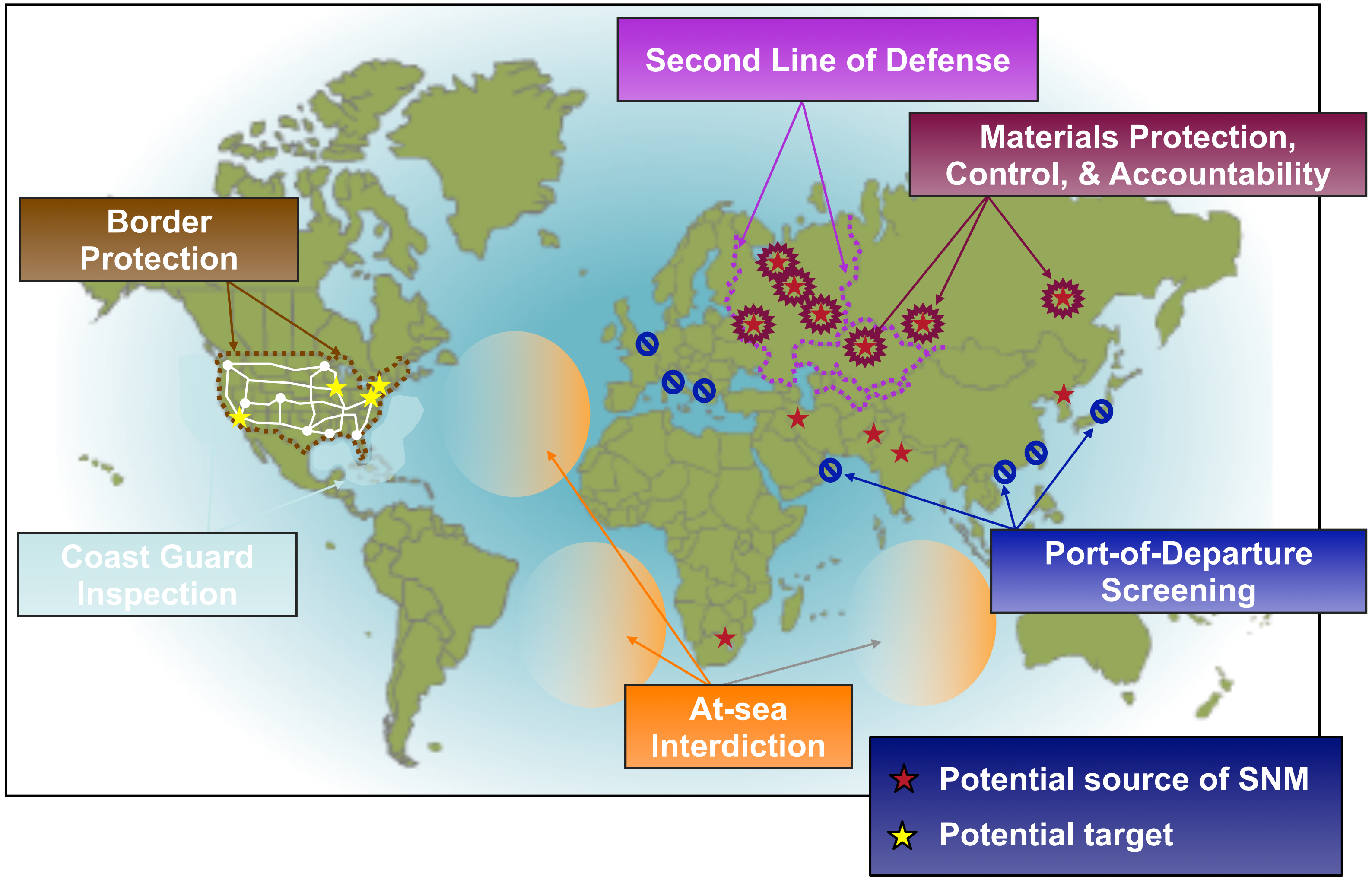
In this post-Cold War world, nuclear terrorism may be the single most catastrophic threat that any nation faces - we must do everything we can to ensure against its occurrence.

-- Joseph Krol, Associate Administrator, NNSA

The detection and tracking of SNM is a global, multifaceted effort

...nuclear materials detection is but one tool in the broad array of ongoing activities and emerging capabilities, systems, and architectures that comprise an overall strategy to counter nuclear terrorism.

-- Joseph Krol, Associate Administrator, NNSA



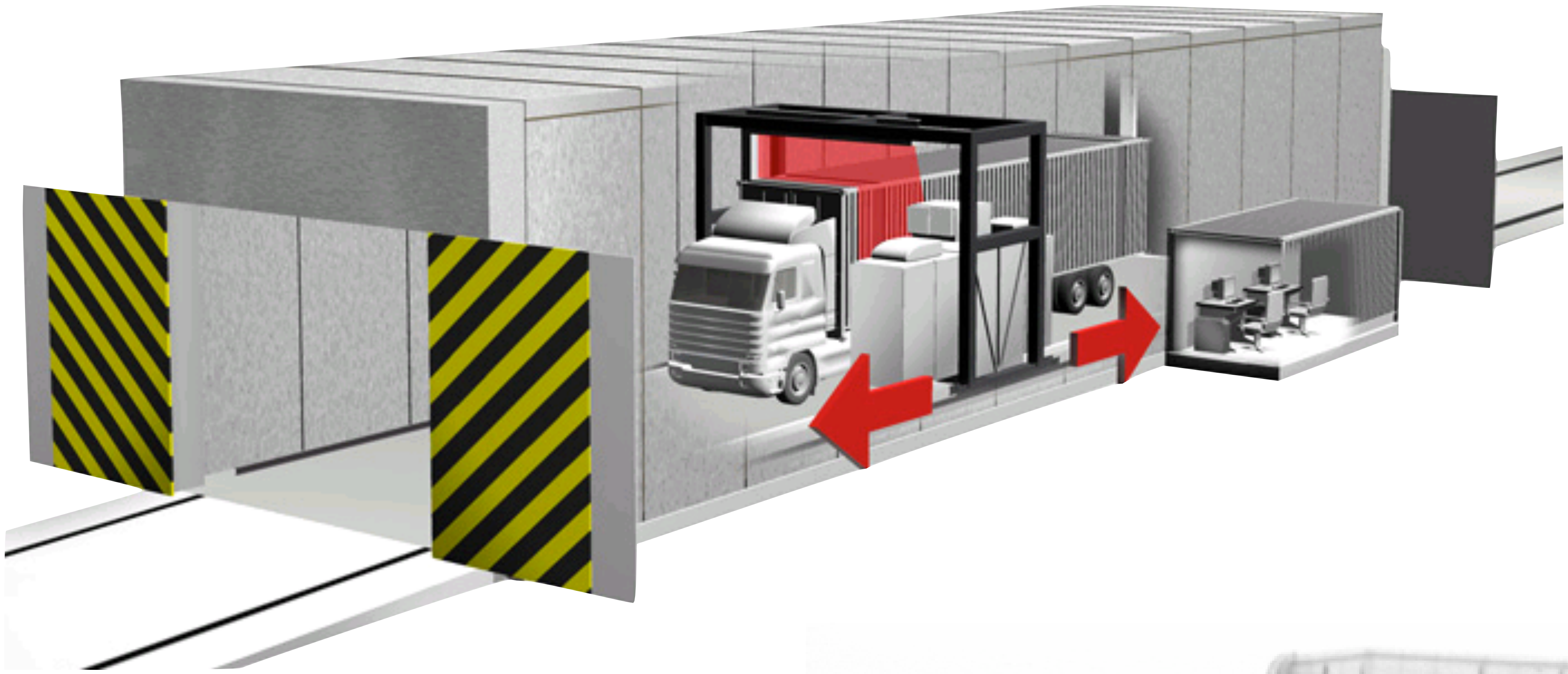
From "Progress in Nuclear Detection", Abu Bowman, DNDO, 3/23/2007

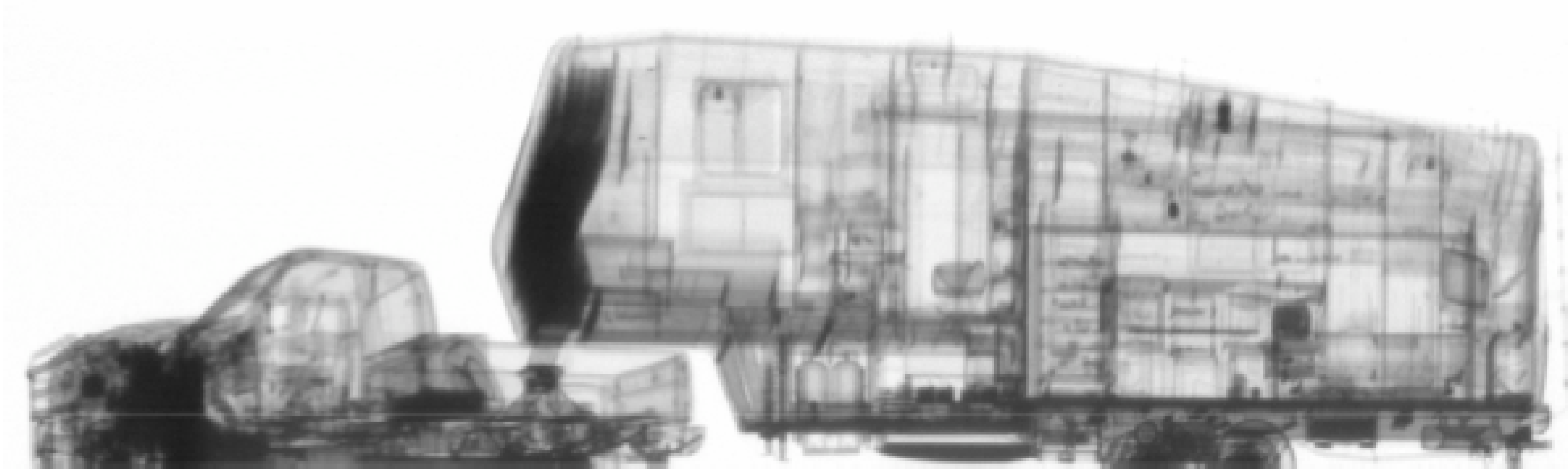
Currently employed methods of passive detection of SNM can easily be defeated

portal screening

Easy to negate with shielding
Can be masked with other isotopes
Low signal-to-noise at long-range

Radiography addresses some of the shortcomings of passive detection but is unsuited to stand-off detection





Standoff detection of SNM requires active interrogation

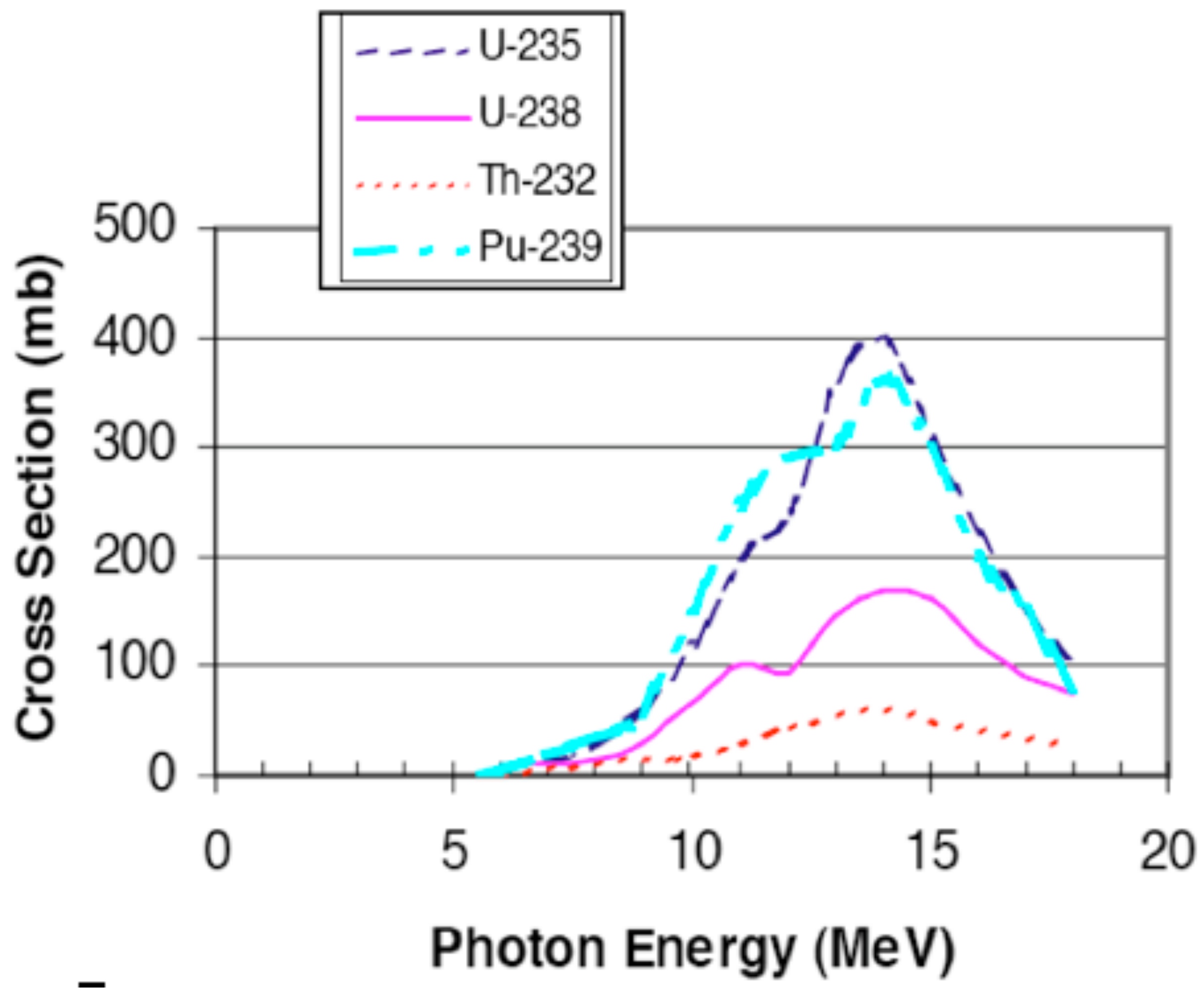
At long distances, Signal-to-Noise Ratio is low
Increasing detector size/efficiency only increases amplitude of signal, not SNR
Some tricks can be played to increase SNR, but still do not work beyond 10's of meters
Neutrons can be shielded with hydrogenous material, gammas with high-Z material

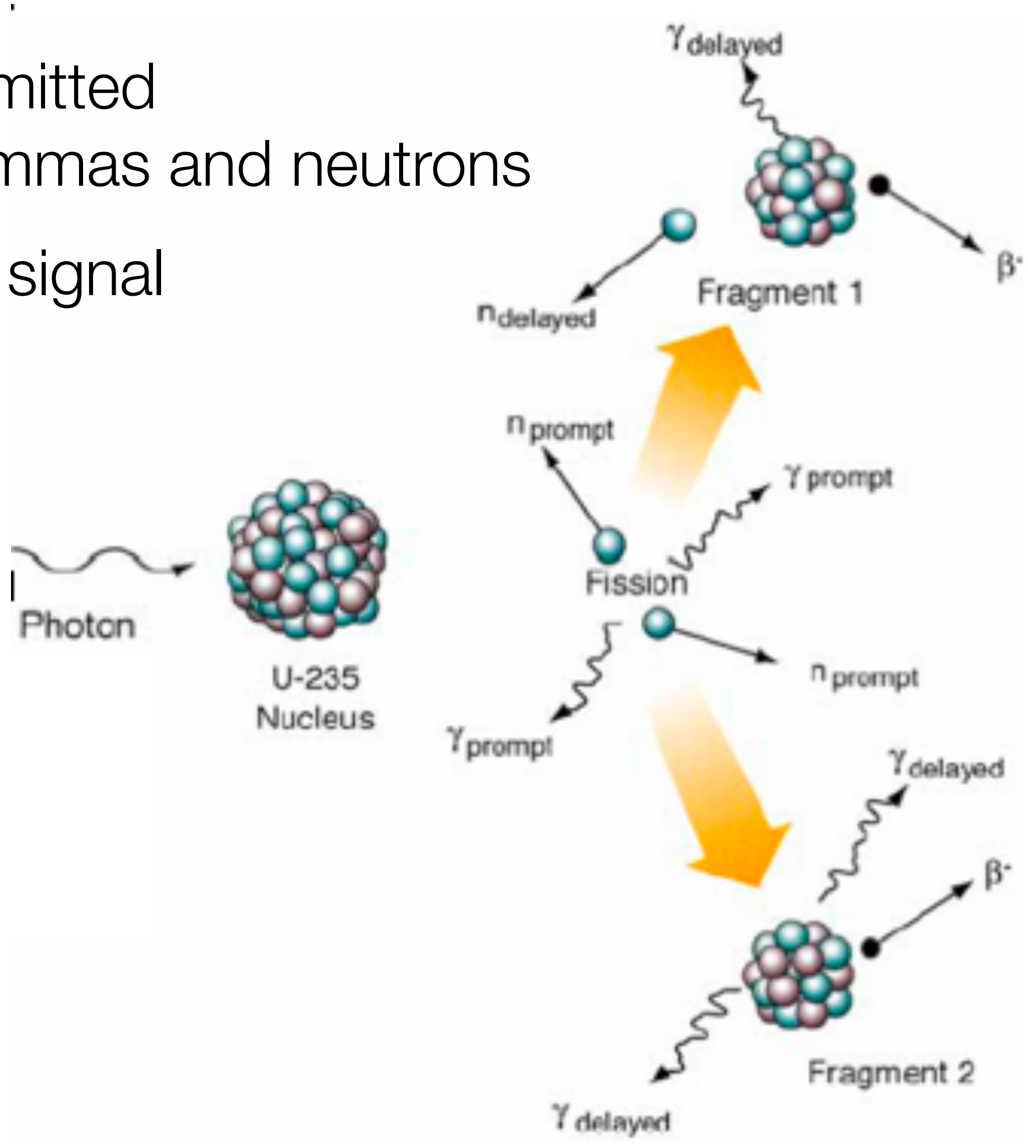
Passive	**Active**
Low S/N & Limited range	Flux determines S/N
Limited targeting	With directed source (ICS), long range and target pin pointing possible
Easy to shield against	Very difficult to mask and can be combined with neutrons
Difficult to identify materials	Specific materials can be identified

Photofission is a promising means of detecting SNM with high confidence.

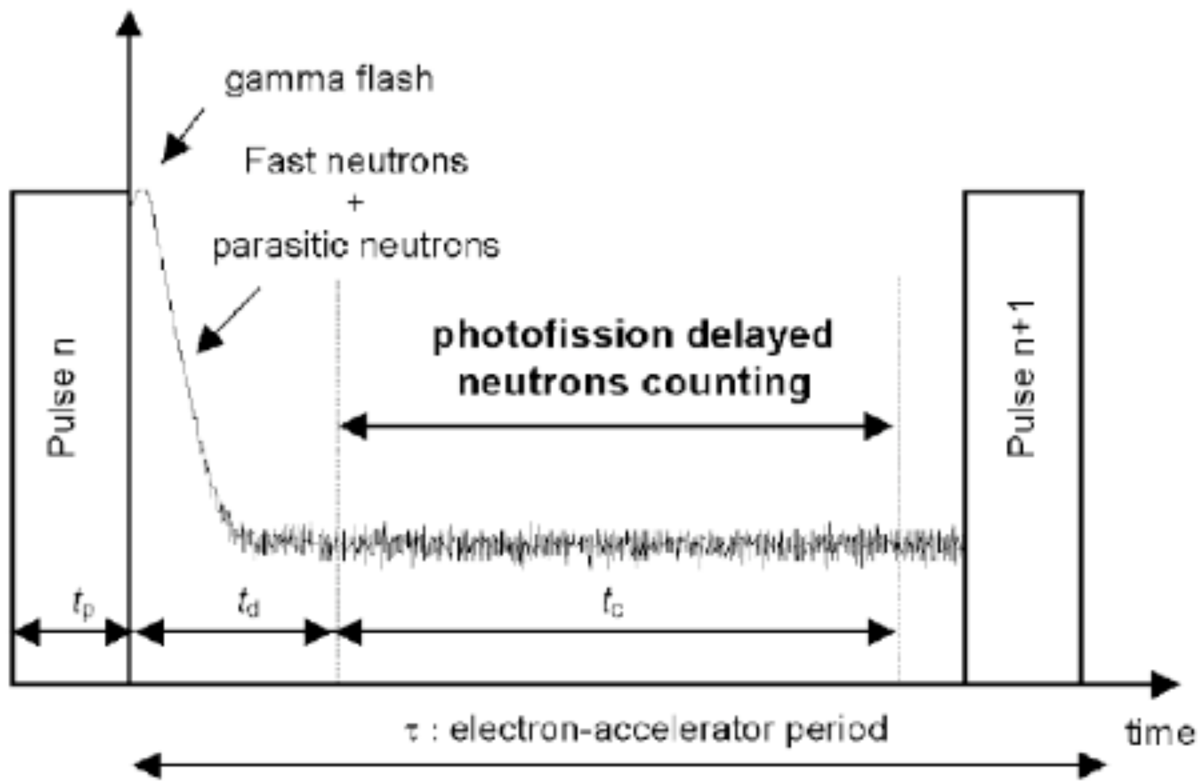
❶ 6+ MeV gammas induce fission in actinides
❷ Prompt neutrons and gammas immediately emitted
❸ Fission fragments decay, emitting delayed gammas and neutrons

➟ Delayed gammas and neutrons are a positive signal

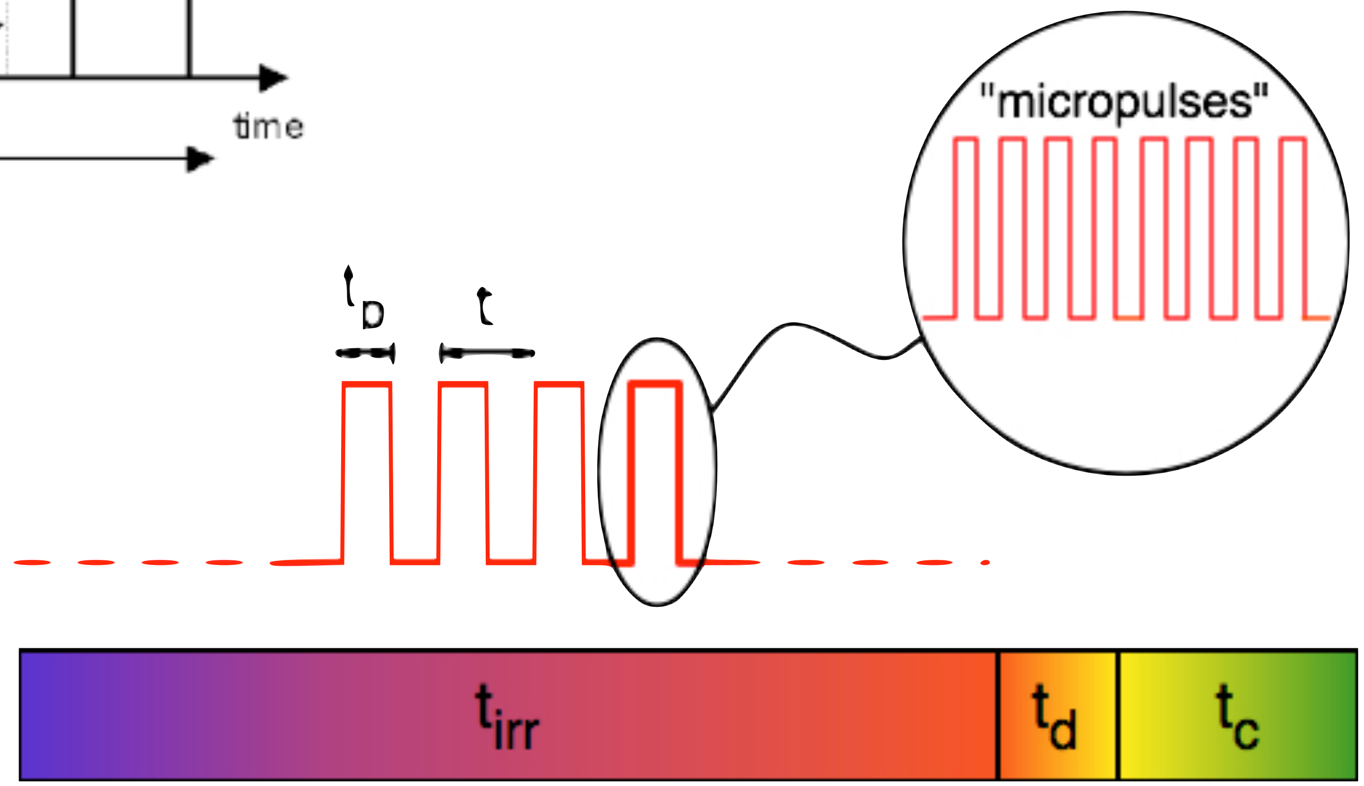




Active interrogation requires time intervals to count delayed products



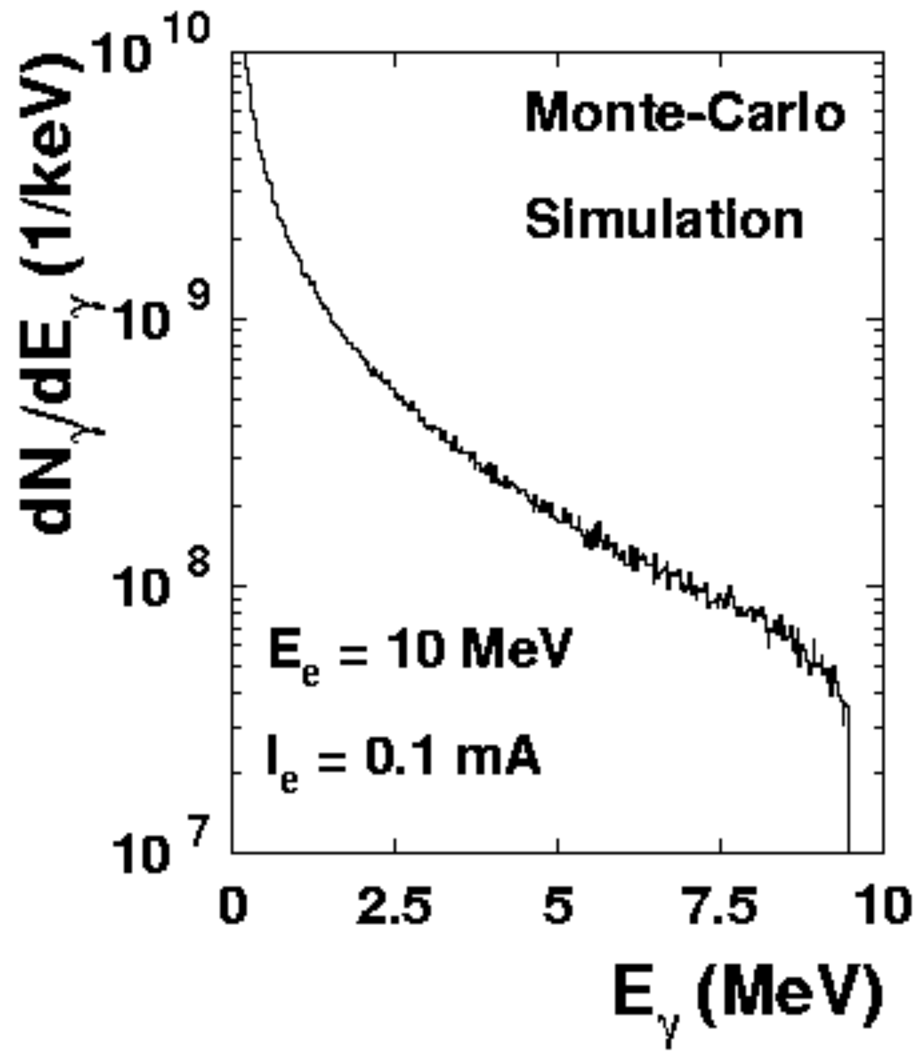
t_{irr} = 10 s
t_d = 5 ms
t_c = 250 ms



Producing gammas for photofission is easy; Producing a source with good S/N is hard

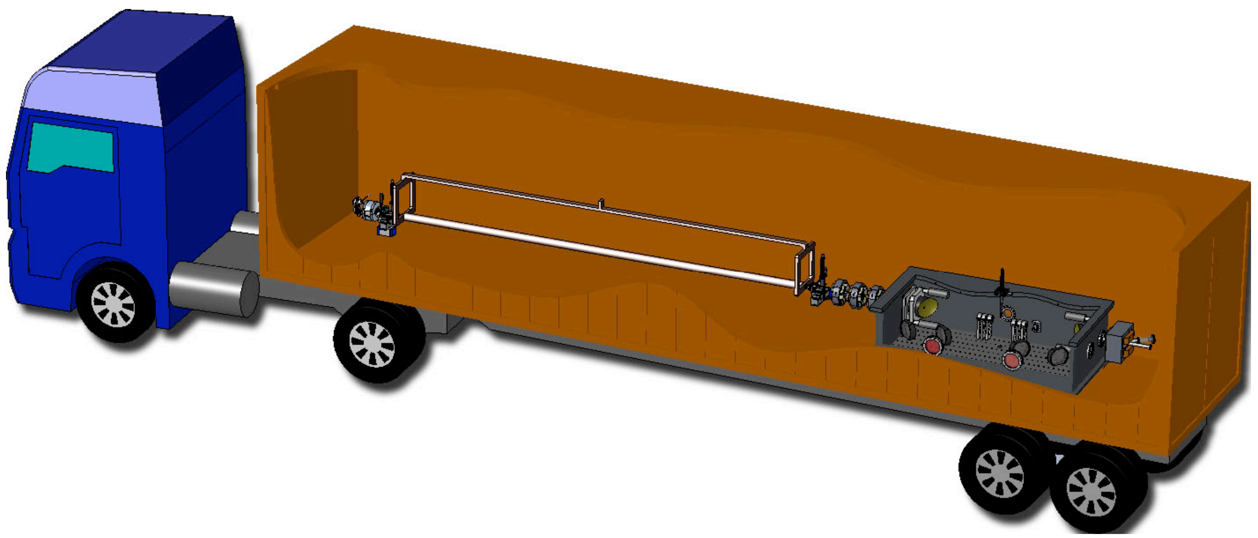
bremsstrahlung is ill suited

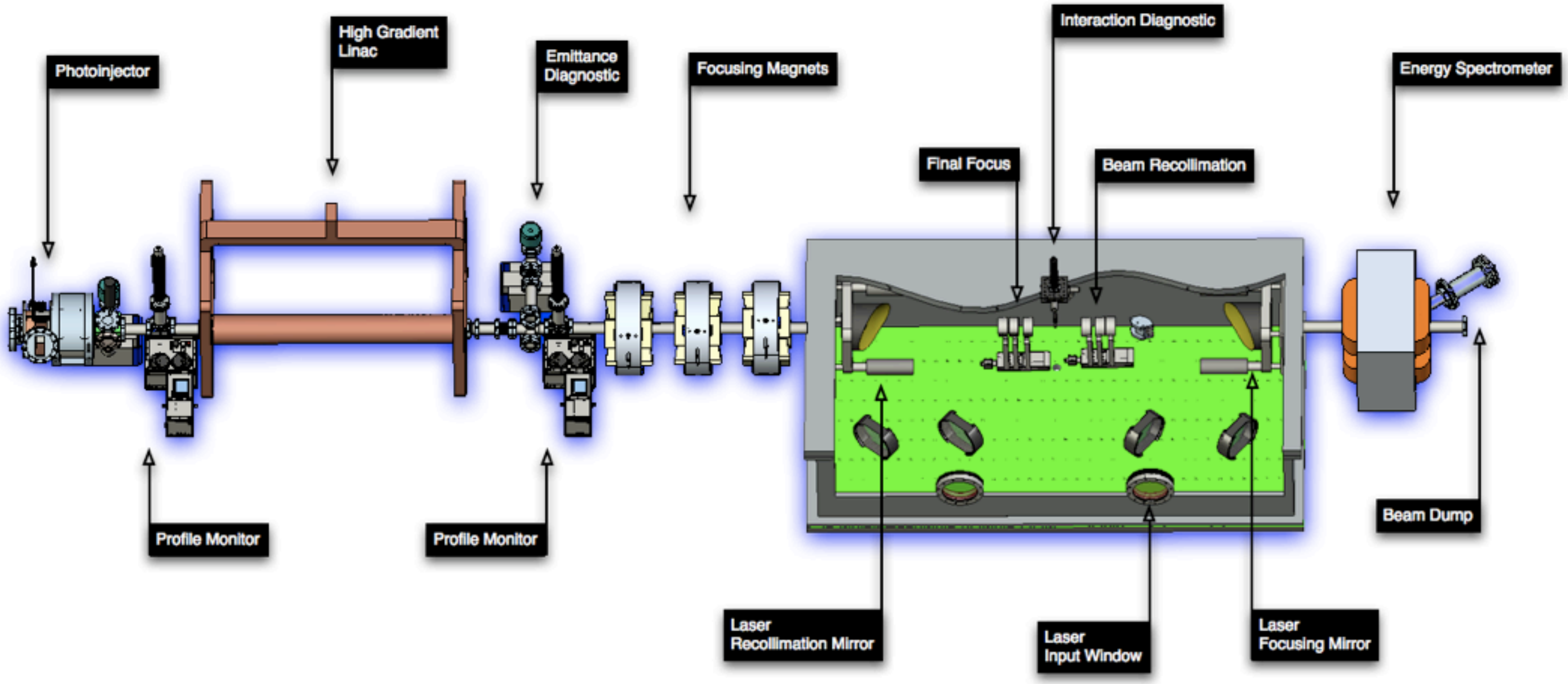
Bremsstrahlung	**ICS**
Local (target) radiation	Directed radiation beam
Low spectral density	High spectral density & brightness
High background signal	Excellent S/N
Easy to do	**Hard to do**



An ICS Gamma Source (IGS) is the best path for photofission standoff detection

fieldable source of
bright
monoenergetic
beam of photons

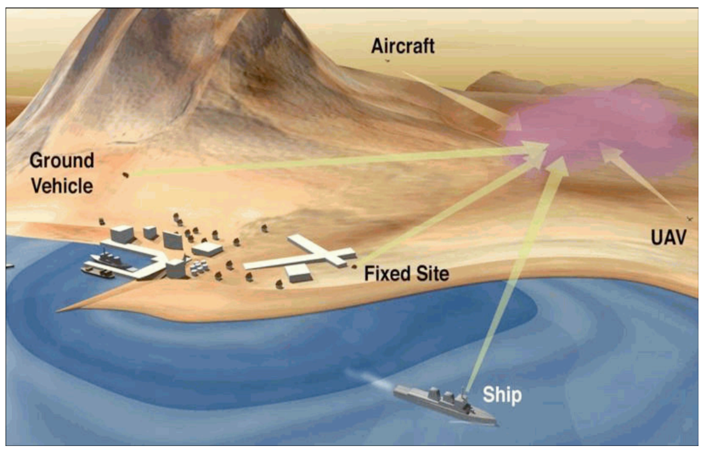


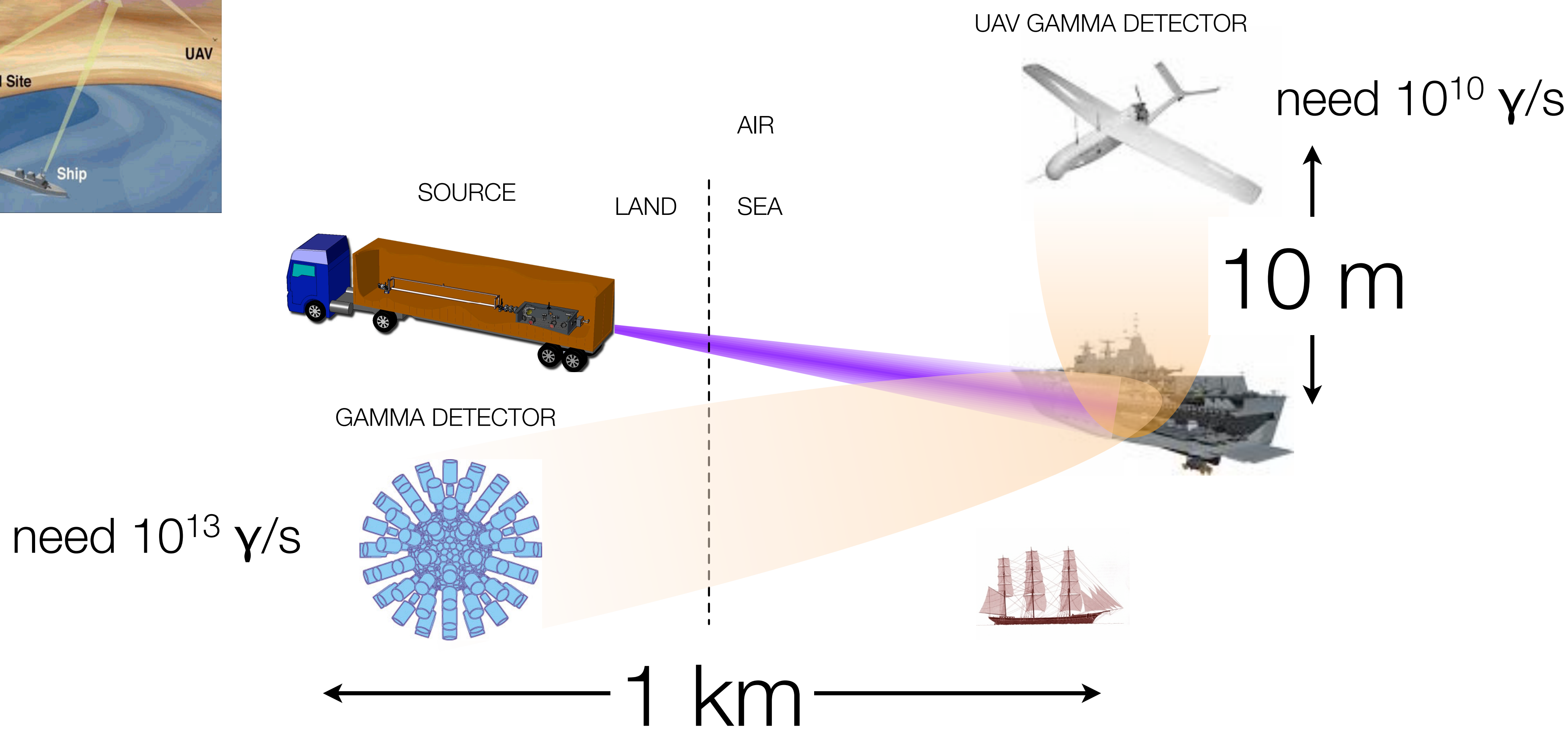


The IGS performance requirements are severe

Up to 10^{13}, 10 MeV gammas/sec

Producing 10 MeV gammas requires
~500 MeV electrons
(assuming green drive laser)



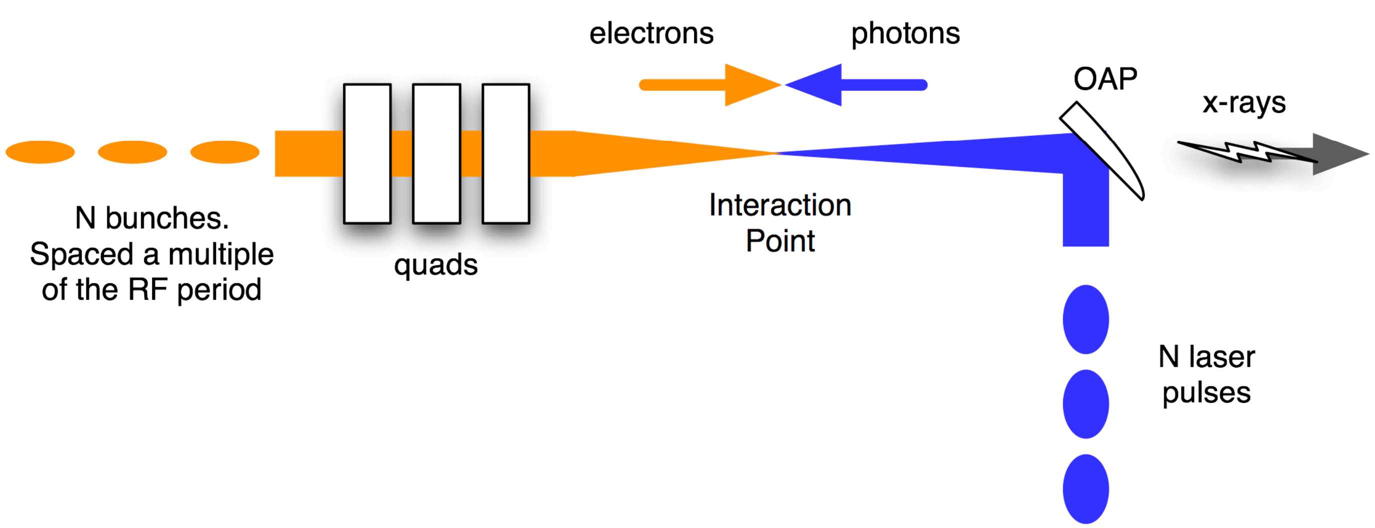


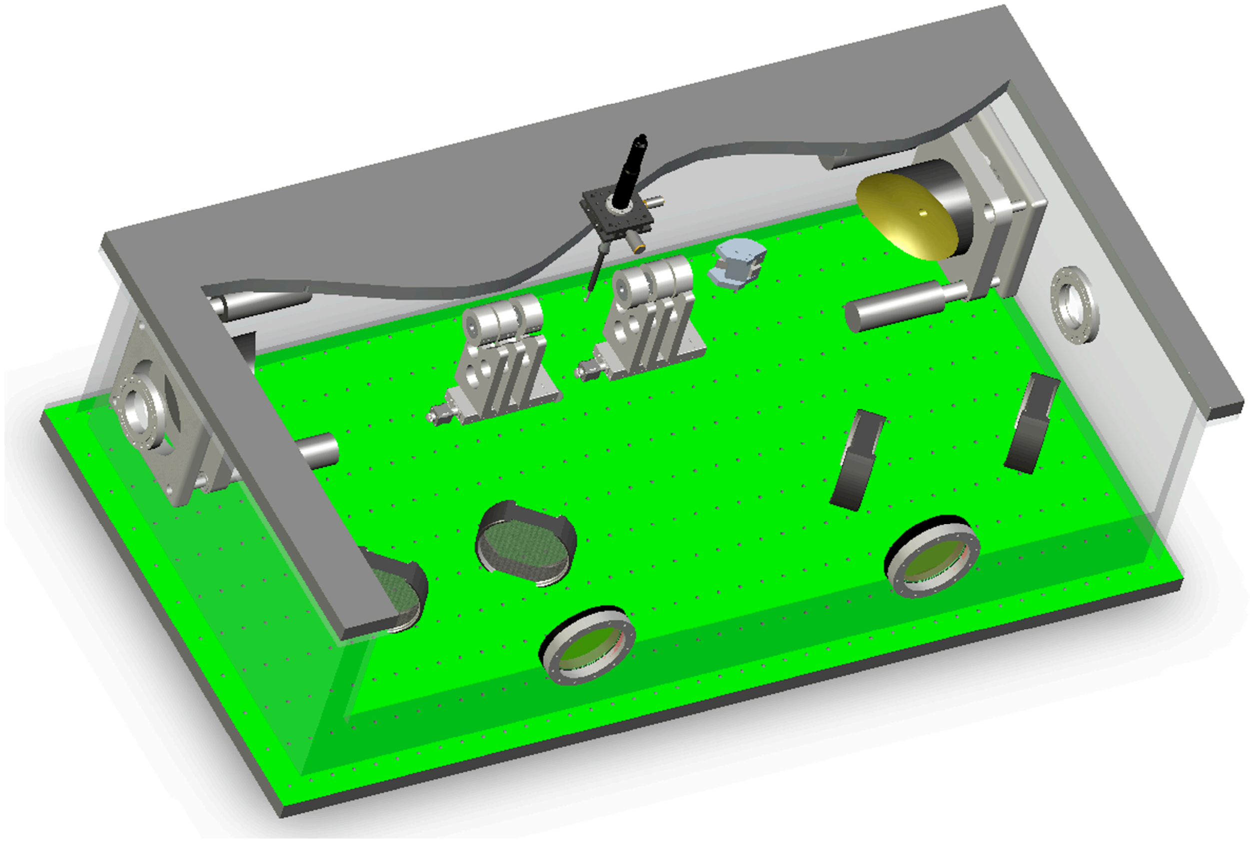
The IGS specifications are ambitious and demand advancements in several areas

Parameter	**Value**
Laser Pulse Length (FWHM)	10 ps
Laser Wavelength (frequency doubled)	532 nm
Laser Pulse Energy	620 mJ
Laser Strength Parameter (a_0)	0.06
Laser Rayleigh Range	1.28 mm
Laser/E-beam Spot Size (rms)	7.4 μm
E-beam Energy	547 MeV
E-beam Beta Function	29 mm
Number of Gammas per Micropulse	**1.0×10^9**
E-beam Charge	1 nC
E-beam Emittance	2 μm
Number of Photons per Micropulse	2.0×10^9
Number of Photons per Macropulse	2.0×10^{11}
Peak flux at 1 km stand-off [m^{-2}-s^{-1}]	8.9×10^{15}
Average flux at 1 km stand-off [m^{-2}-s^{-1}]	8.9×10^{12}

Multibunch operation is critical to high flux, but puts demands on the various subsystems

1kHz rep rate
100 e-bunches
100 laser recirculations
Total cavity power = 62 kW



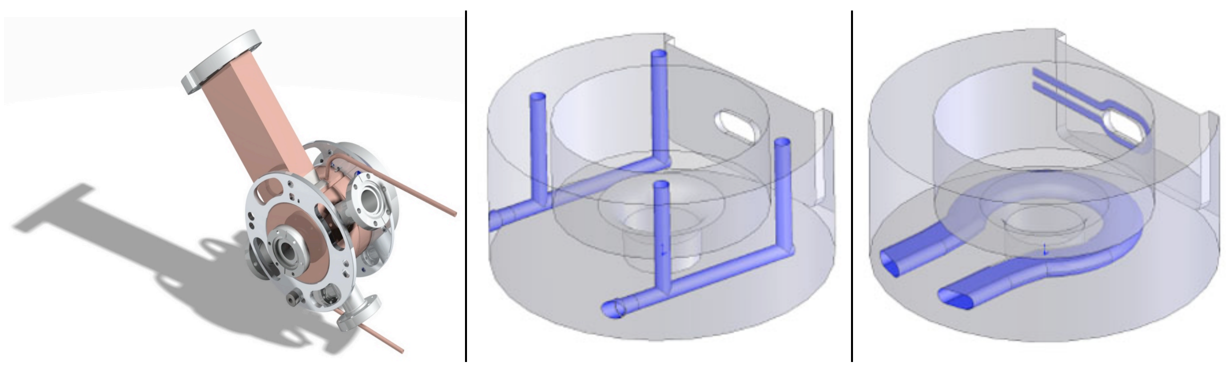


Final focus combines electron and laser optics with feedback diagnostics

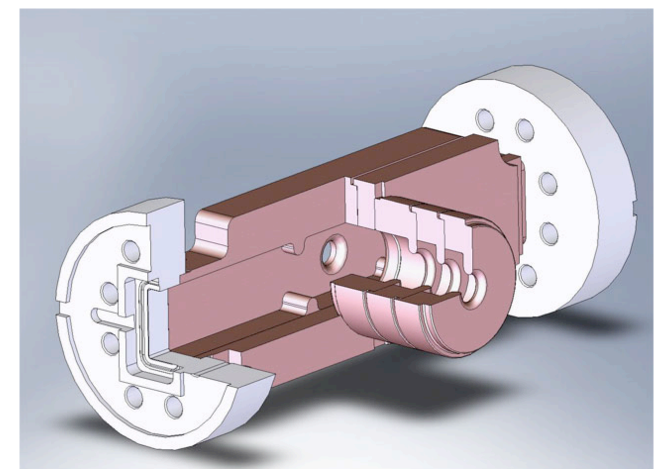
The IGS effort at RadiaBeam and UCLA involves developing four core technologies

see poster

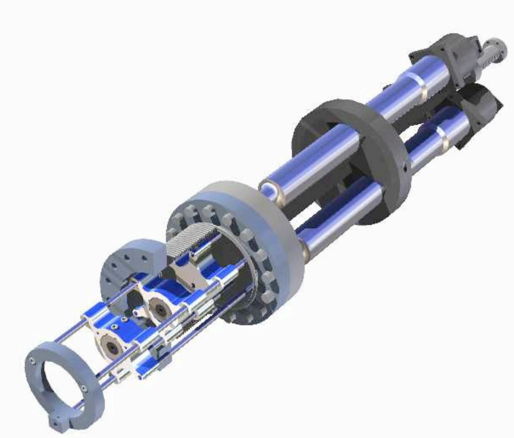
high repetition rate photoinjectors

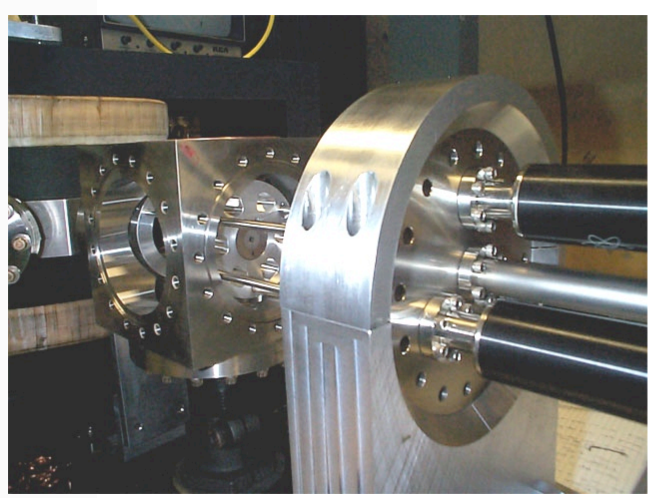


high gradient accelerator structures

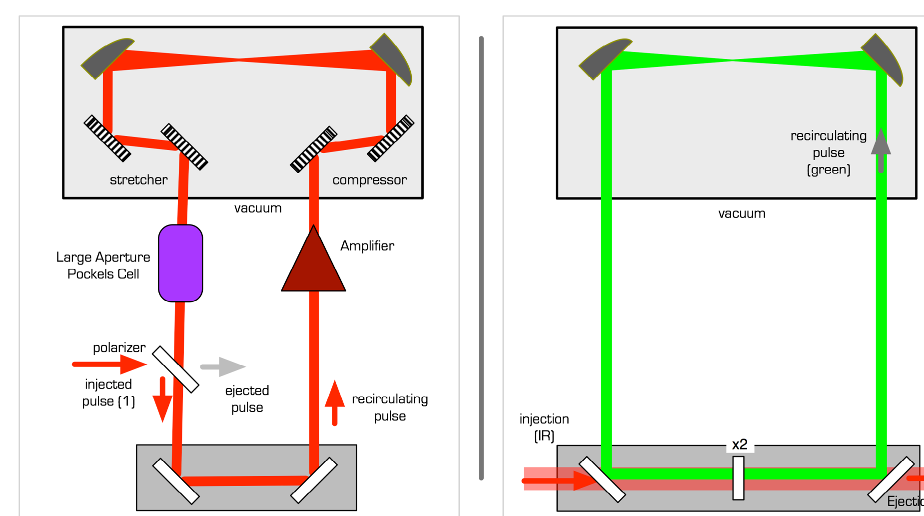


final focus systems





Multibuch interaction schemes



SNM standoff detection in general and the IGS specifically present many beam and laser technology challenges

- Inverse Compton Scattering is the ONLY way to produce the flux on target required for long-range active interrogation detection;
- RadiaBeam is working on high gradient accelerating structures and final focus technologies;
- RadiaBeam and UCLA are working collaboratively on high repetition rate photoinjectors;
- Igor Jovanovic (Purdue) is working with us on laser and laser recirculation issues; and,
- RadiaBeam is funded through a DTRA Phase I SBIR to study the IGS.

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