UCLA

Particle Beam Physics Lab

Hard X-ray ICS

2017 BNL ATF user meeting

Yusuke Sakai, Atsushi Fukasawa, Oliver Williams
Youming Yang, Ke Sheng, James Rosenzweig

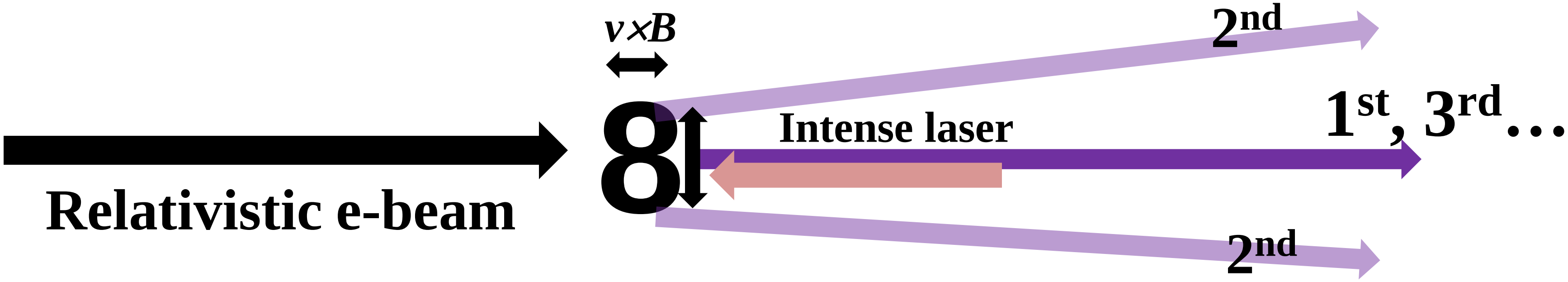
University of California, Los Angeles

BROOKHAVEN NATIONAL LABORATORY

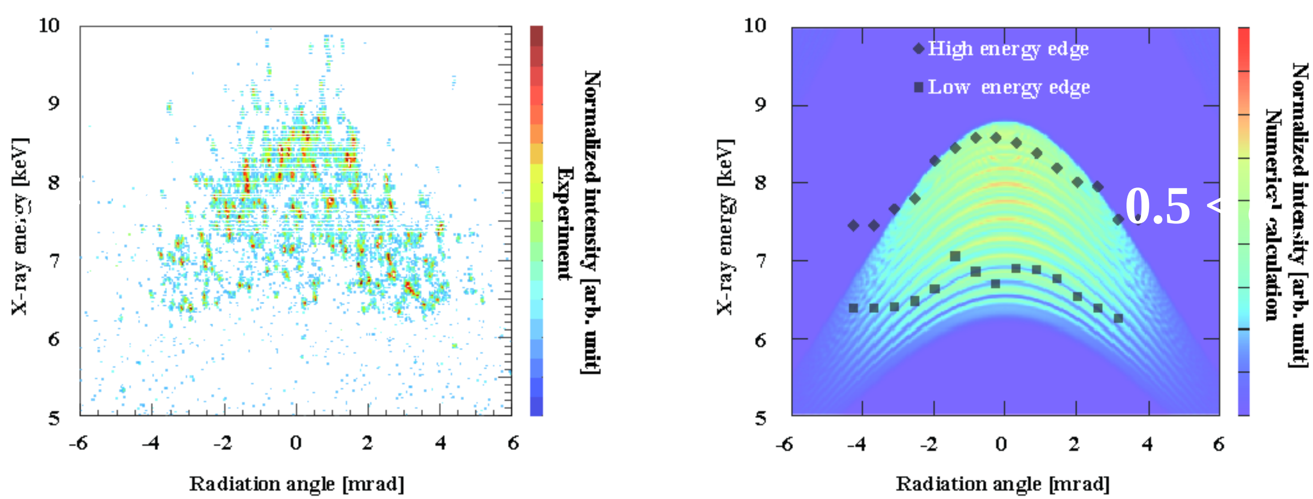
Previous study

Nonlinear Compton scattering *by long wavelength laser*

Long wavelength CO_2 laser effectively induce nonlinear motion



Nonlinear ICS: $a_L > 1$: Transverse motion induce nontrivial longitudinal oscillation
→ Redshift (mass shift)

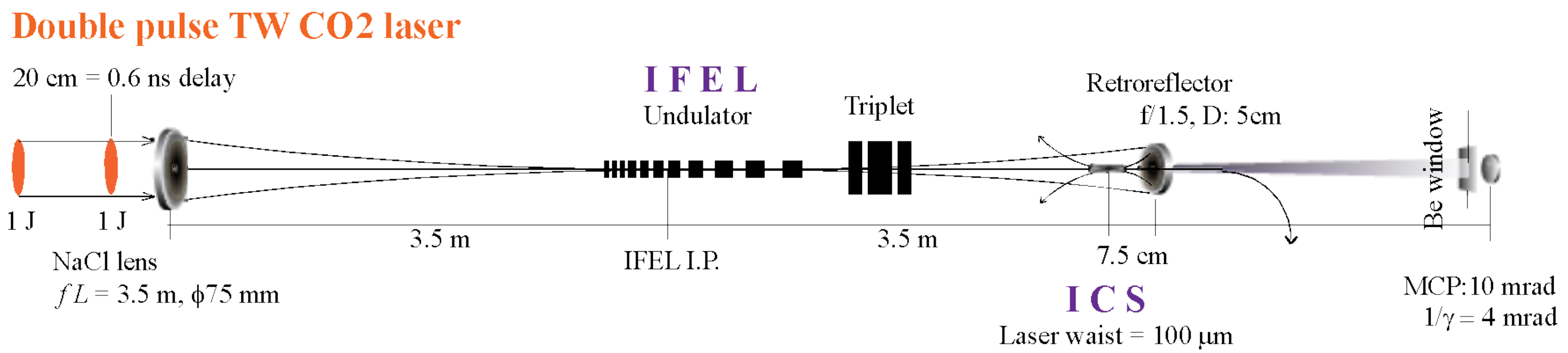


Measured double differential spectrum

Previous study

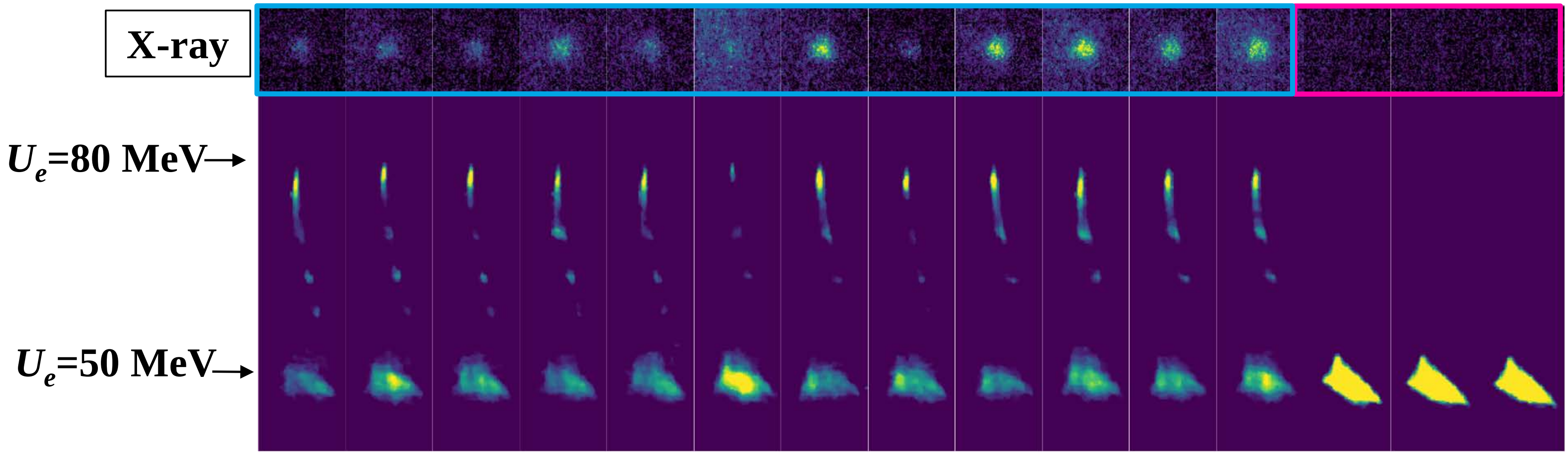
Double pulse IFEL driven ICS

Compact 5th generation light source at higher photon energy



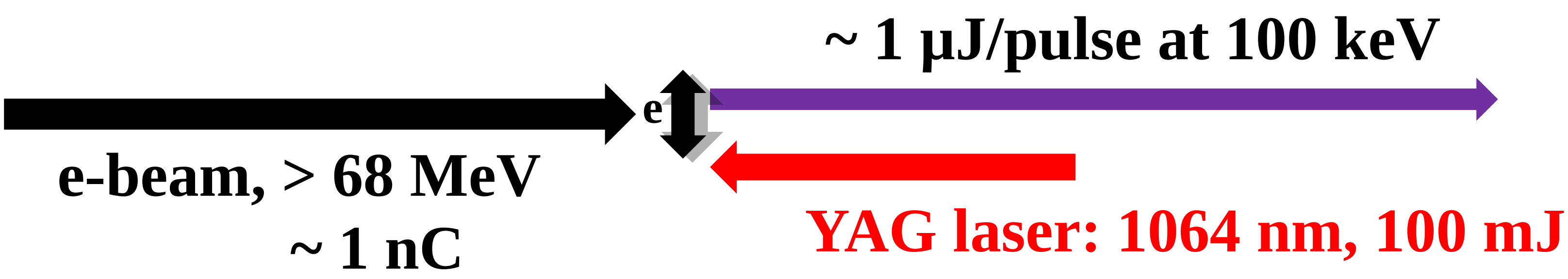
★ 30 % of each electron bunch were accelerated from 50 to 80 MeV

★ ~10^7 X-ray photons per shot at 11(±2) keV (↔ Al higher energy filter is used)



I. Gadjev et al., An inverse free electron laser acceleration-driven Compton scattering X-ray source,, submitted to Nature Communications (2017)

Monochromatic ICS at > 10 keV (high penetration depth) for actual applications



$h\nu_{ICS} = 2\times2\gamma^2\nu_L$ > 82 keV, K-edge of Au (82.5 keV) and Pb (87 keV) k-edge

I. Photon activation therapy using Gold nano particle (GNP) in 2018

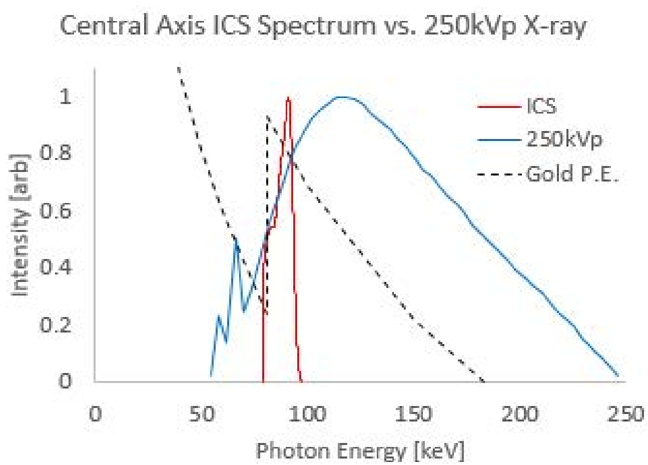
II. Bi-harmonic Compton scattering (To be re-submitted.)

- - Future extension - -

III. IFEL driven ICS for MeV Gamma-ray generation

200 MeV electron, 532nm Nd: YAG → > 1MeV Gamma-ray (D.N.D.O).

Photon Activated Therapy by ICS with non-reactive GNP (Au *K*-edge = 81 keV)



ICS spectrum: 81 keV < *hv* < 95 keV

Enhanced does with ICS monochromatic photon:

<u>Hard X-ray absorption by Gold K-shell (inner shell) electron</u>

↓

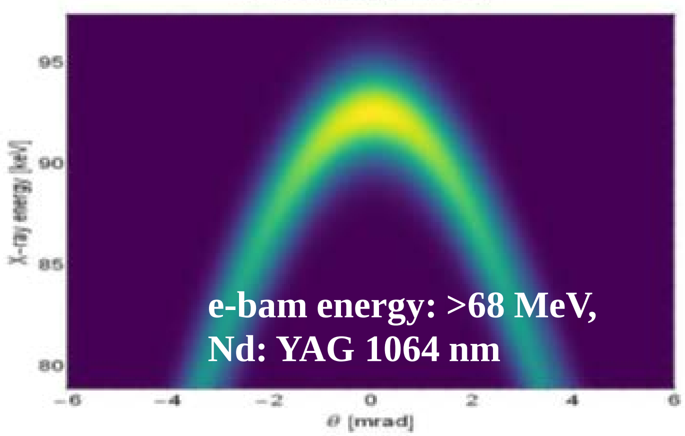
<u>Emission of Auger electron from outer shell,</u>

<u>Dose enhancement around surface of nano particle.</u>

GNP size ~ 10 nm

Penetration depth of Auger electron ~ 10 μm? (function of hv_{ICS})

Linear ICS Spectrum



[by I. Gadjev]

Au nanoparticle is a *diagnostic*

for only > 81 keV photons

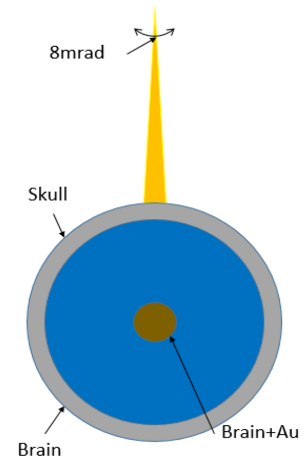
Transparent for surrounding low *Z* material:

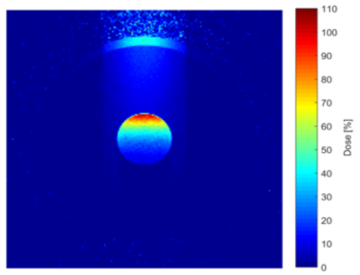
(*K*-edge (resonant energy) for C, O, H is lower << 10 keV)

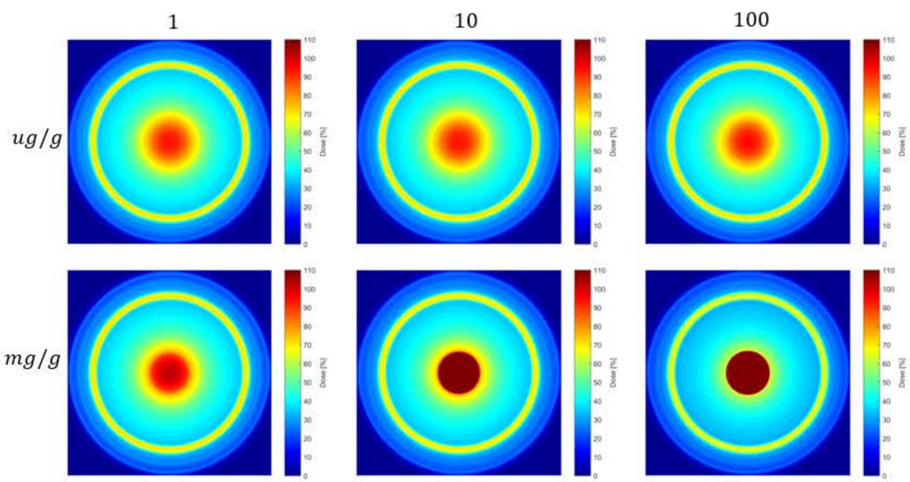
Example of dose enhancement by ICS source
Monte Carlo simulation

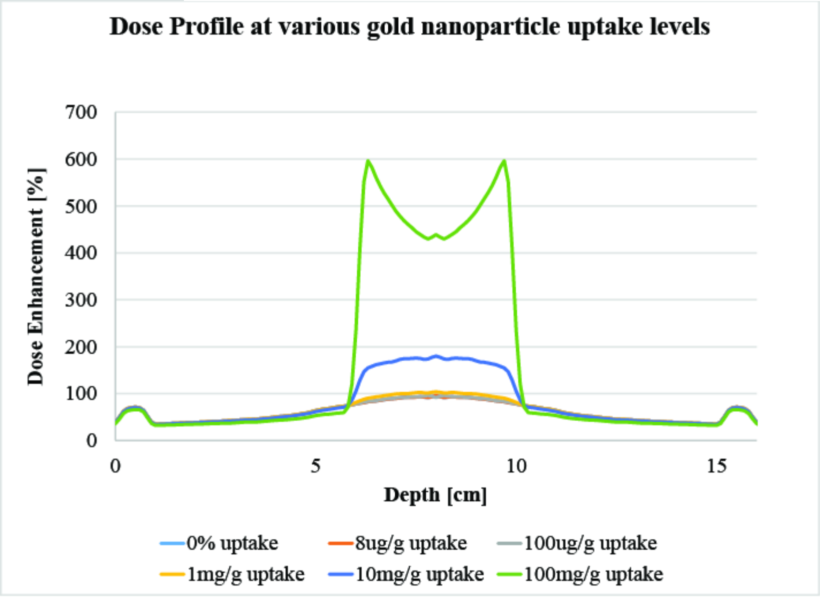
GNP 100 mg/g uptake (< 1% volume ratio) for cm size target shows dose saturation.

- ✪ **Density of Au: 19.7 g / ml**
- ✪ **Corresponds to 100s μm Au filter**



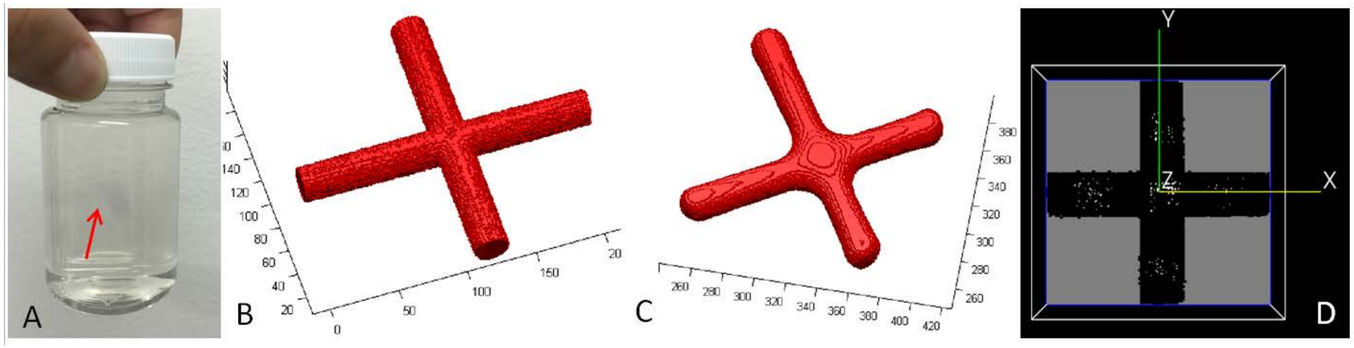






[by Y. Yang, K. Sheng]

3D gel dosimetry validation test, with optical CT scanner in UCLA medical school



3D gel dosimetry validation test:

Two pairs of 5 mm circularly collimated orthogonal beams were projected on a 3D gel dosimeter. The change in optical density is visible as a purple hue in the irradiated gel bottle (A) and quantified by an optical CT scanner. After conversion to dose using a calibration curve, the measured dose (C) was compared against the calculated dose (B). (D) Gamma calculation.

[K. Sheng et. al.]

Expected photon flux: 10^7 photons / shot

$\rightarrow (10^7) \times (85\ \text{keV}) \times (1.6\times10^{-19}) = 0.1\ \mu\text{J}$ / shot.

Assuming target dimension of $(L_{I.P.\ to\ target} \times 1/\gamma)^2 = 1\ \text{cm}^3$,

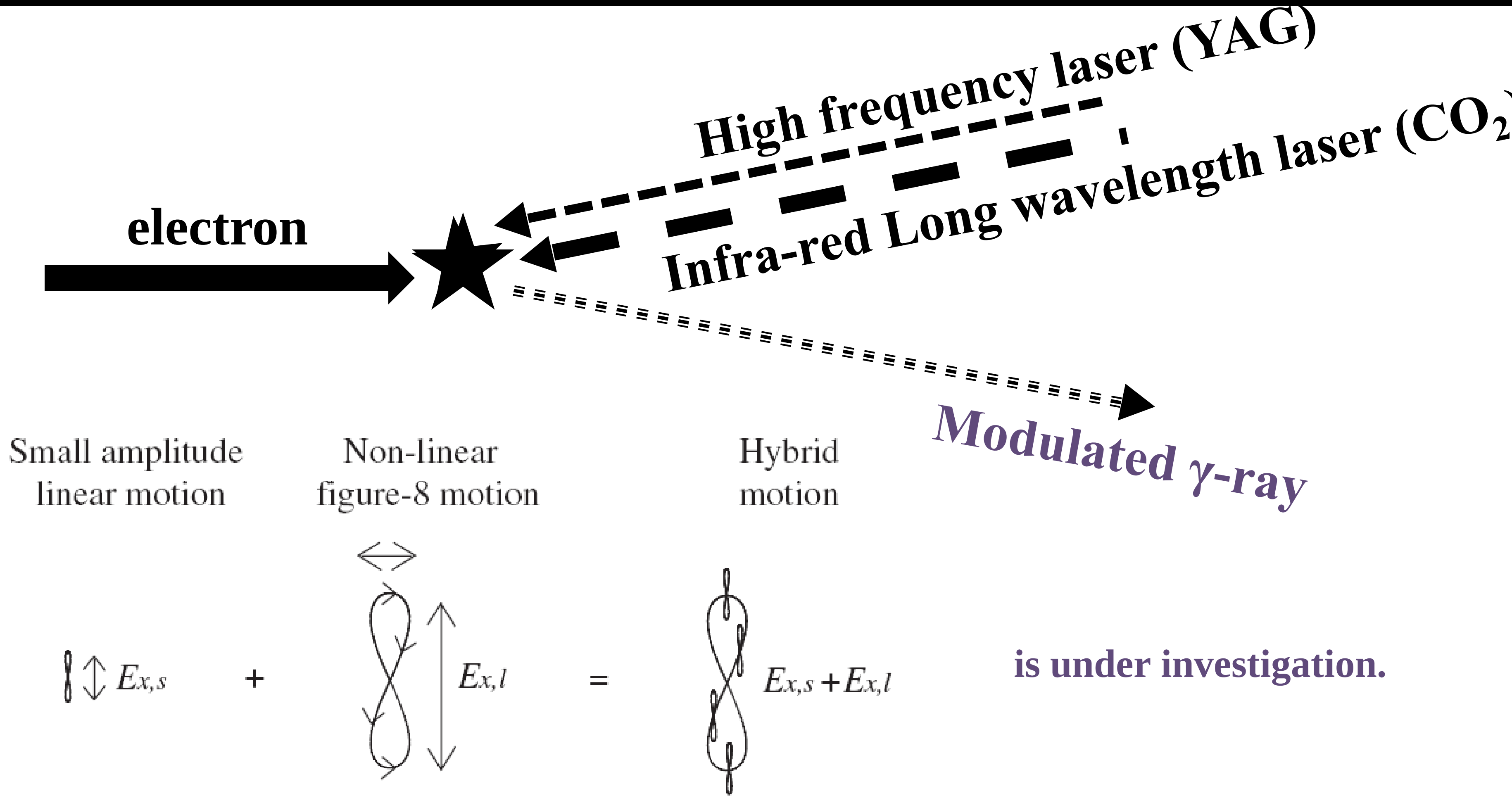
(1 m away from I.P.)

Radiation dose per kg of water per shot is equivalent to be 1 [Gy = 1 J / $(10\ \text{cm})^3$] $\leftrightarrow$ 1 mJ / $(1\ \text{cm})^3$.

Total irradiation time required: 1 mJ / 0.1 μJ = 10.000 shot

$\leftrightarrow$ > 1 Hz × 60 min × 3 hour? run time.

Extension of nonlinear Compton experiment: Interaction in multiple photon fields.

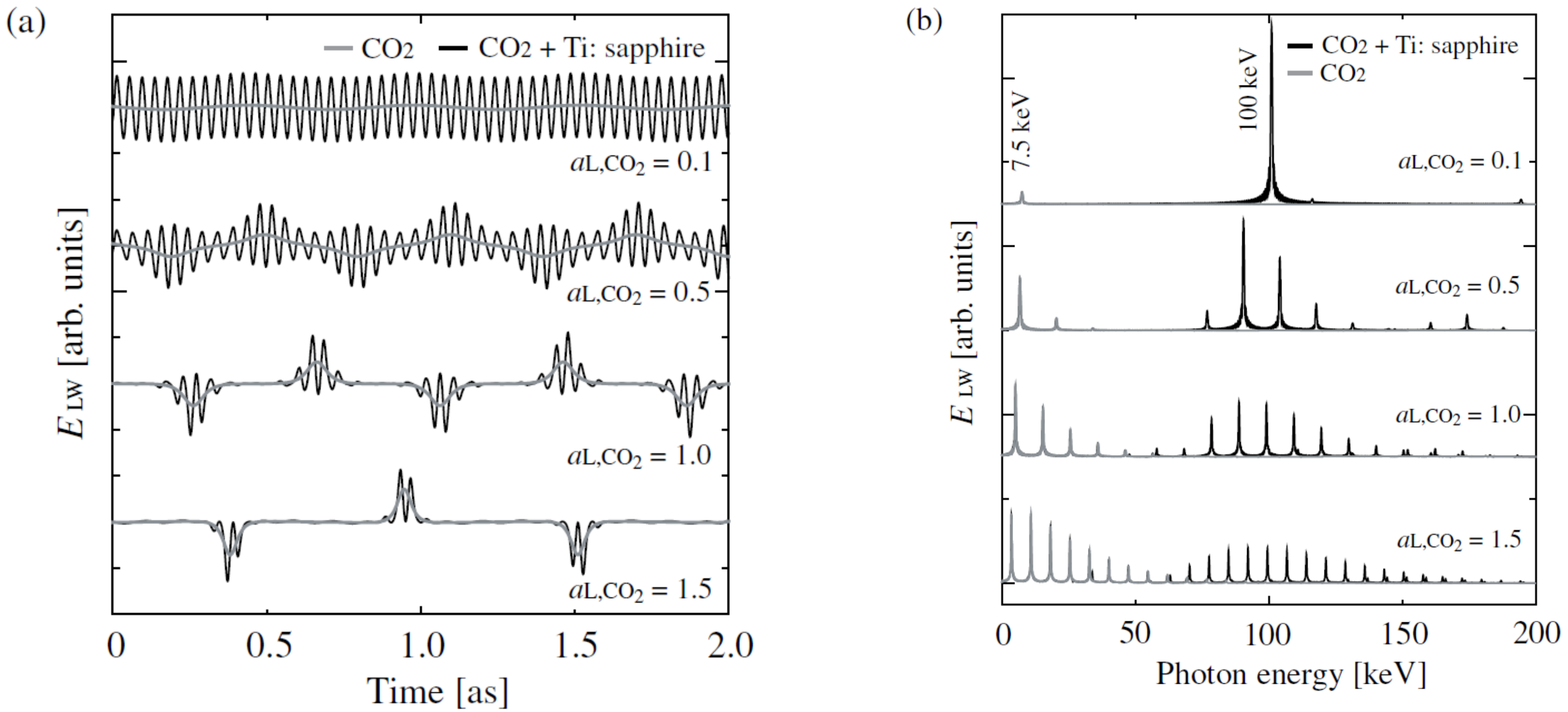


is under investigation.

Controlling radiation kinetics at $h\nu$ = 100s keV

Pulsed waveform modulation at < 10^{-18} s time scale

Harmonic spectrum:
$$h\nu_{ICS} = 4\gamma^2 h(\nu_{L,Short} + n\nu_{L,Long})$$

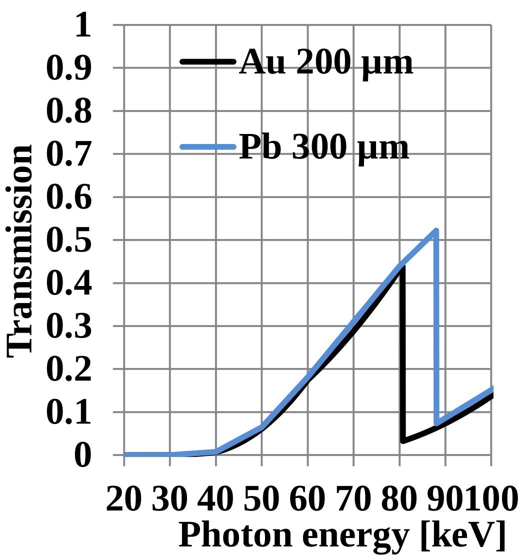


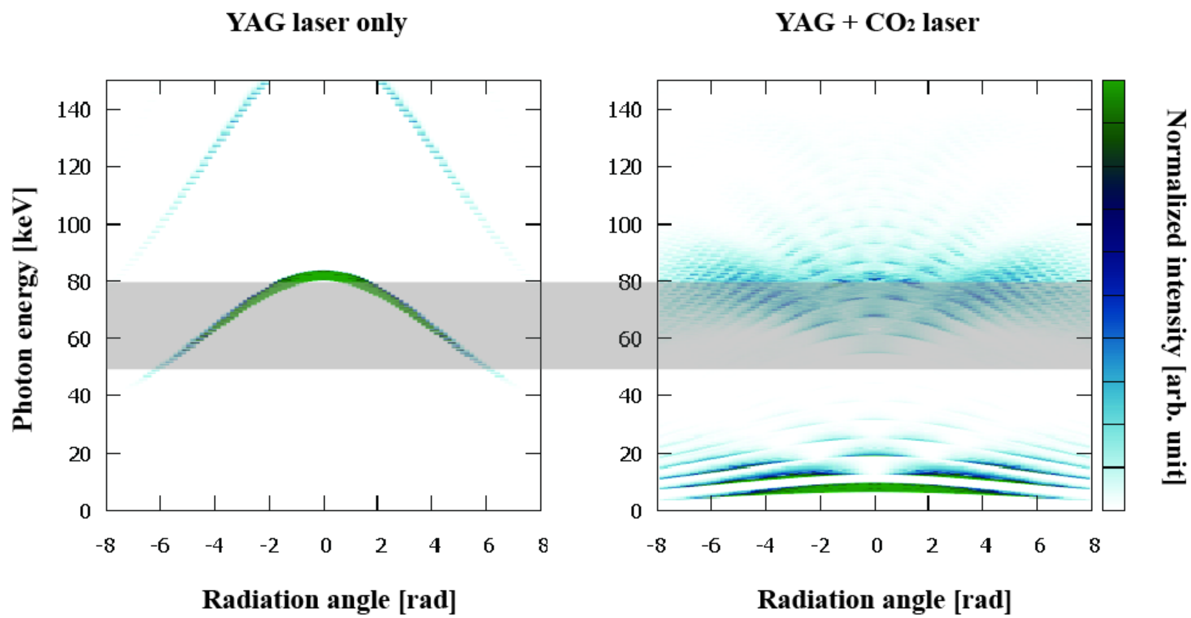
Numerically calculated Lienard-Wiechert potential $E_{LW,x}(t_{screen})$ on $(x, y, z) = (0, 0, 0)$

Measurment of bi-harmonic spectrum in ATF

Bi-harmonic spectrum:

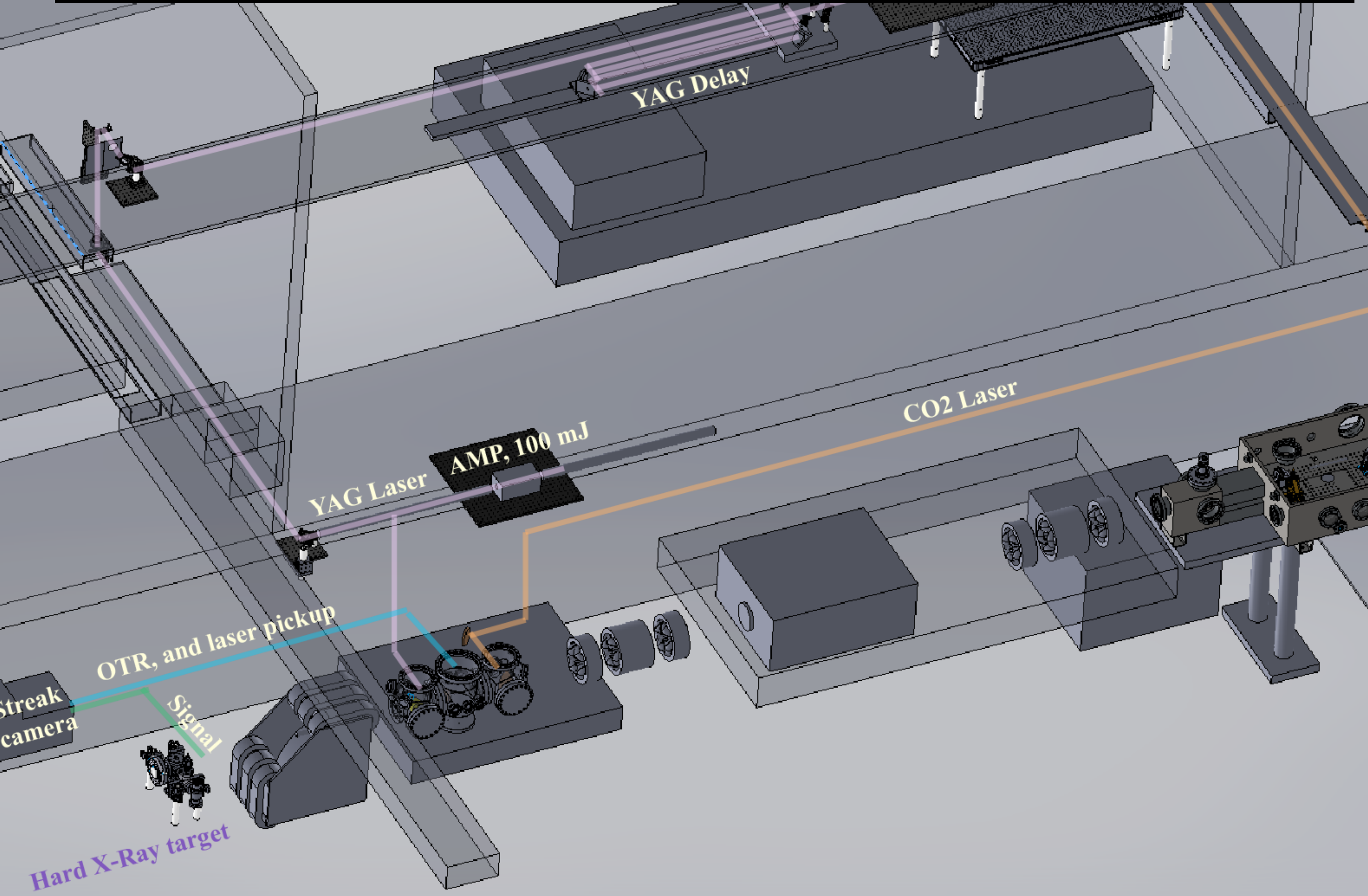
$$h\nu_{ICS} = 4\gamma^2 h(\nu_{L,YAG} \pm n\nu_{L,CO2})/(1+a_0^2/2)$$





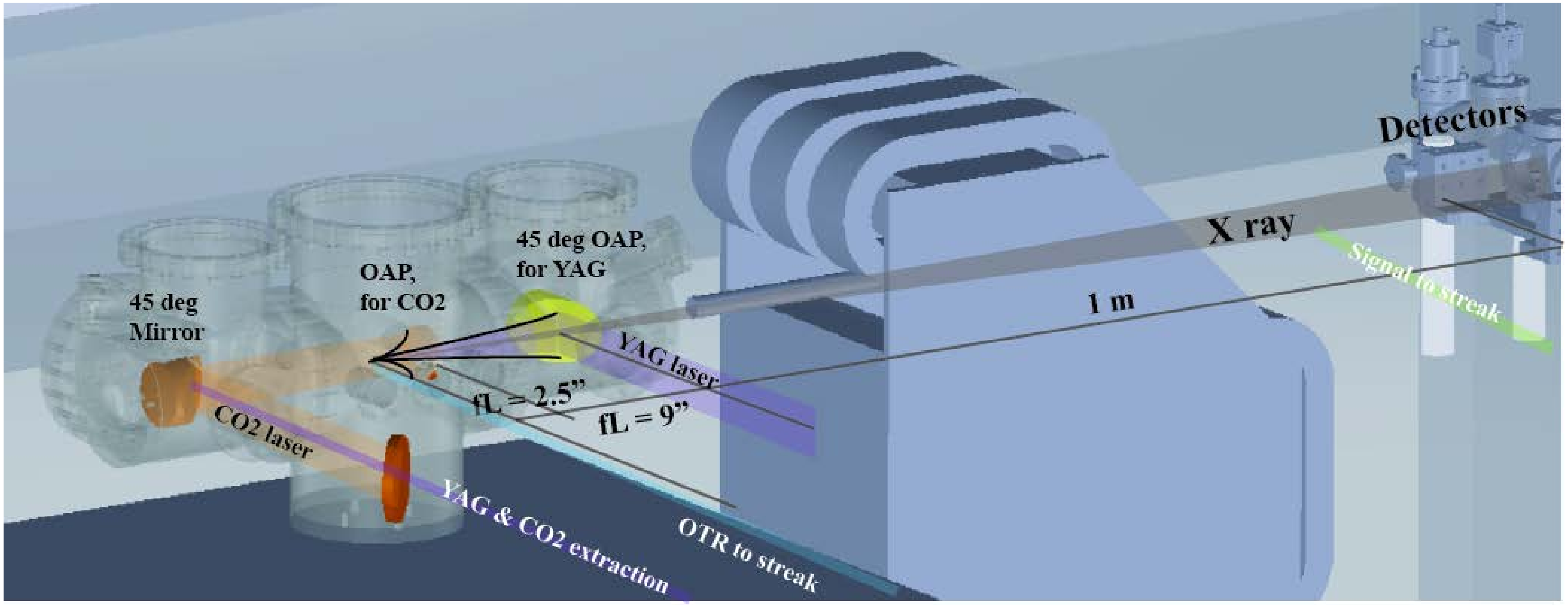
Observation of Redshifting & $h\nu_{L,YAG} \pm h\nu_{L,CO2}$?

Experimental layout: Laser transport, streak camera, I.P., Hard X-ray measurment and target response:



Optical paths

- ✪ YAG optics: From downstream with 45 deg OAP
- ✪ CO_2 optics: From upstream with Retro reflecting OAP
- ✪ Hard X-ray detectors: Voxel CsI scintillator with CCD, Streak camera, MCP and Si detecter.
  (located from ~1m from I.P., Radiation angle < 7 [mrad] at > 68 MeV)



- ✪ Optics inside Compton chamber will have Dia 1/4" on-axis hole
- ✪ Center of Compton chamber can be open for experiments such as μUndulator and PWA

PLAN

2018

Dec-Feb:

1. Installation of Compton chamber with YAG optics.

2. YAG laser transport, streak camera and Nd: YAG amp re-location to EH.

March-April:

3. Measurments of OTR by streak camera, and Si plasma switch testing etc.

4. Synchronization of e-beam with Nd: YAG laser

June-August:

5. Hard X-ray generation and characterization at *hv* > 81 keV, by > 68 MeV e-beam.

6. Initial testing of GNP gel target by irradiation (10.000 shot, several hours run time)

<u>2018</u> Experiment Time Estimates

Run Hours (include setup time in hours estimate):

Number of electron beam only hours:

< 40 hours (a few days X several times).

Number of **<u>YAG</u>** laser hours, + **<u>ebeam</u>**, delivered to electron beam experiment hall:

120 hours (3 weeks.)

Overall % setup time: > 50 %.

Hazards & installation requirements:

Large installation (chamber, insertion device etc…): Yes

Laser use (other than CO_2): Nd: YAG laser at 100 mJ

Cryogens: Y/N

Introducing new magnetic elements: maybe Yes: PMQ before I.P.

Introducing new materials into the beam path: Yes: GNP target, Aerogel, OTR, YAG

Any other foreseeable beam line modifications: Maybe Yes.

Electron Beam Requirements

Parameter	Nominal	Requested Experiment Parameters
Beam Energy (MeV)	68-70 to 75 MeV	*Full range is ~ 15-75 MeV with highest beam quality at nominal values*
Bunch Charge (nC)	0.3-0.5 nC	*Bunch length & emittance vary with charge*
Compression	none	*A magnetic bunch compressor available to compress bunch down to ~ 100 fs. Beam quality is variable depending on charge and amount of compression required.*
Transverse size at IP (sigma, um)	< 30 um at BL1 Compton chamber (10 um may be required)	*It is possible to achieve transverse sizes below 10 um with special permanent magnet optics.*
Normalized Emittance (um)	1 (at 0.3 nC)	*Variable with bunch charge*
Rep. Rate (Hz)	3 Hz is better.	*3 Hz also available if needed*
Trains mode	Single bunch	*Multi-bunch mode available. Trains of 24 ns spaced bunches.*

Special Equipment:

Very stable Nd: YAG laser & Continuous electron beam run time for > several hours. Thank you.