P B P L

University of California Los Angeles, Particle Beam Physics Laboratory

AE87: Hard X-ray ICS status report

Nonlinear ICS by a_0 ~ 1, CO_2 laser @ hv ~ 10 keV

$\rightarrow\rightarrow\rightarrow$ *Linear ICS by YAG laser @ hv ~ 100 keV*

BNL ATF user meeting
January 18, 2022yr

Yusuke Sakai, Oliver Williams, *Zhong Zhong, James Rosenzweig
UCLA, *BNL NSLS

Funding source: DOE Accelerator Stewardship Received (DE-SC0009914)
DOD DARPA GRIT Received (20204571)

BROOKHAVEN NATIONAL LABORATORY

Experiment Goals
HARD X-ray ICS at *hν* ~ 100 keV range

- ✪ Medical applications: Medicine as Photon activation (example: using a Au nanoparticle)
- ✪ Strong field physics: Bi-harmonic Compton interaction with ATF's CO_2 laser
- ✪ Hard X-ray optics developments*: DDS measurement & Focusing or Collimation

* OAM investigation ↔ Measurement of Higher order harmonics (contain OAM) spectrum by circular polarized multi TW laser

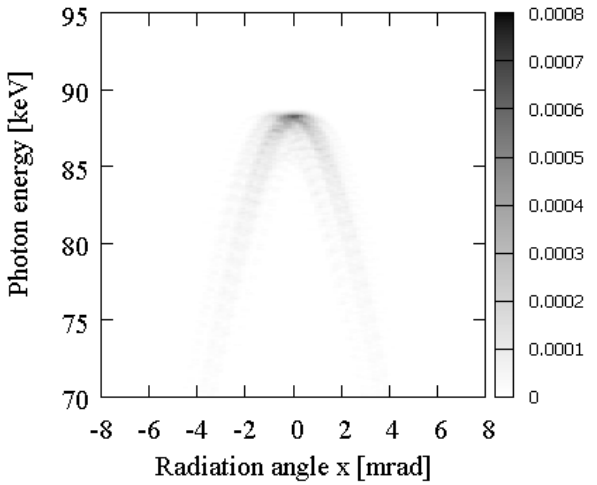
e-beam ~ 70 MeV, ~ 0.3-0.5 nC

e

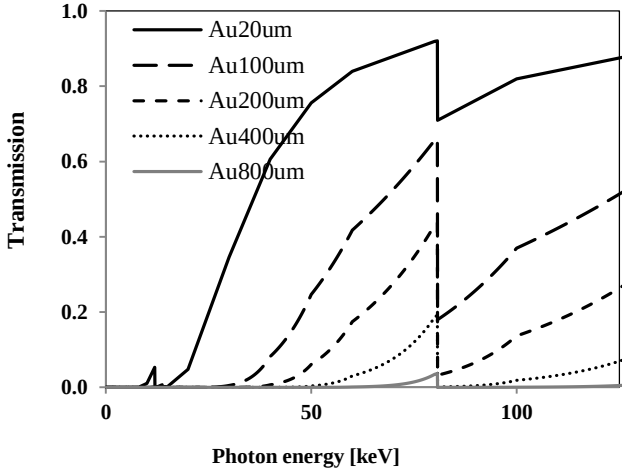
YAG laser: 1064 nm, ~ 100-200 mJ

~ 1 μJ/pulse*
@ *hν* ~ 87.5 keV

**(10^6-7 photons)×(100 keV) ×(1.6×10^-19) ~ 0.1 - 1 μJ / shot)*



2021yr : Qualitative study by Au filters ↔

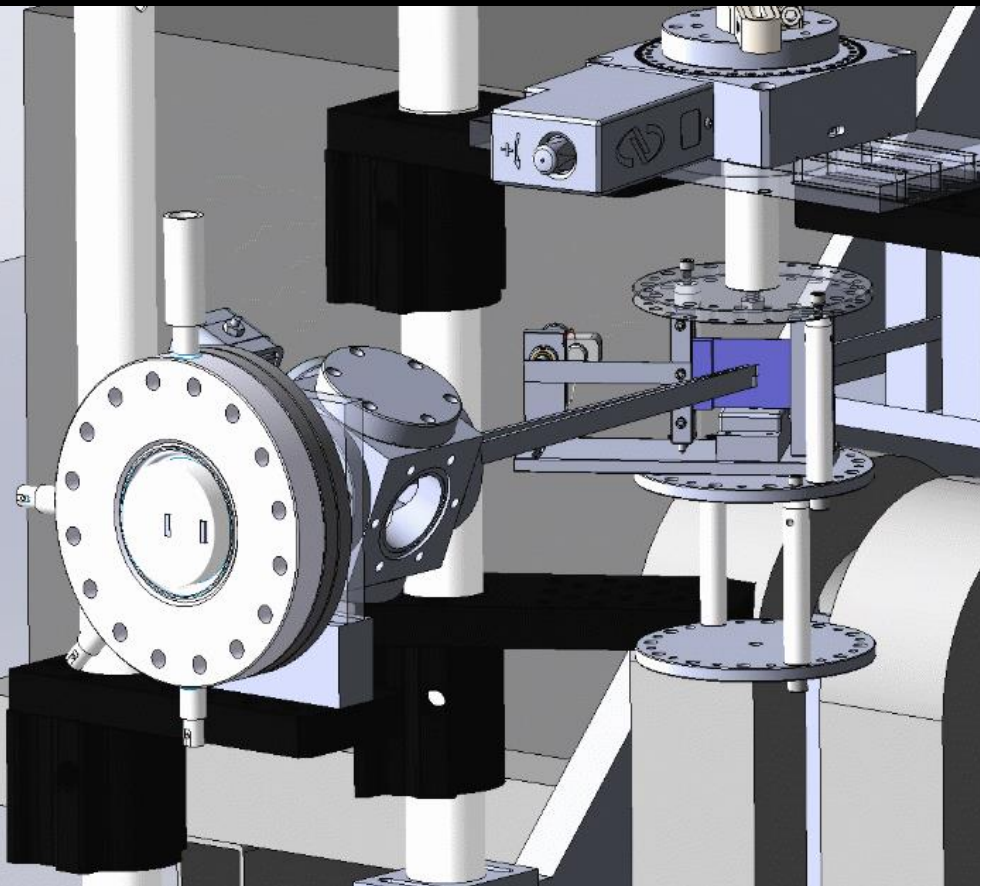


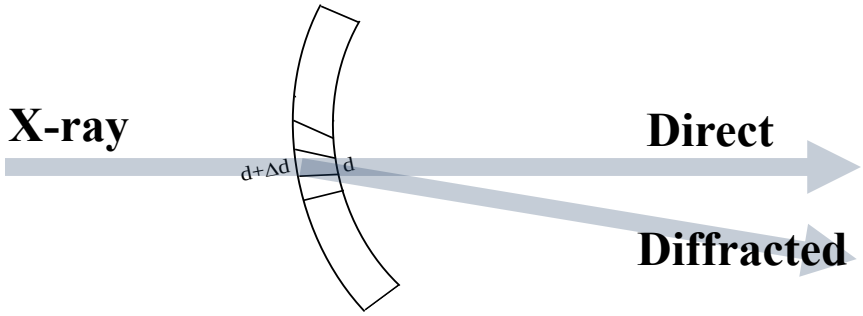
{Goals of AE87 as of now: Establish basic set up of ICS by YAG & CO_2 lasers}

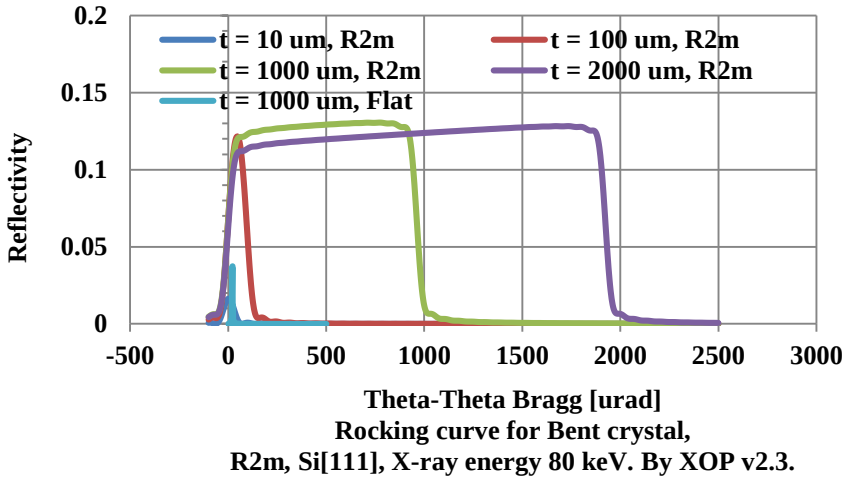
Single shot DDS measurement at X-ray energy of 87.5 keV for quantitative study

→ *Thick Laue Bent Crystal*
Efficiency > Bandwidth

Multi layer crystal: 5 – 20 keV (CO_2's ICS component)
Thick crystal: 20 keV – 200 keV (YAG's ICS component)







Rocking curve for Bent crystal,
R2m, Si[111], X-ray energy 80 keV. By XOP v2.3.

- ✶ **Radius of curvature R: 2.5 m**
- ✶ **Thickness: 1 mm**
- ✶ **Bragg angle at 85keV: ~ 22 mrad**
- ✶ **Crystal to MCP screen 0.3 m**
- ✶ **Expected dispersion at screen: 10-20 mm:**
- ✶ **Band width: ~ 10 keV**
- ✶ **Reflectivity (Efficiency): ~10%**

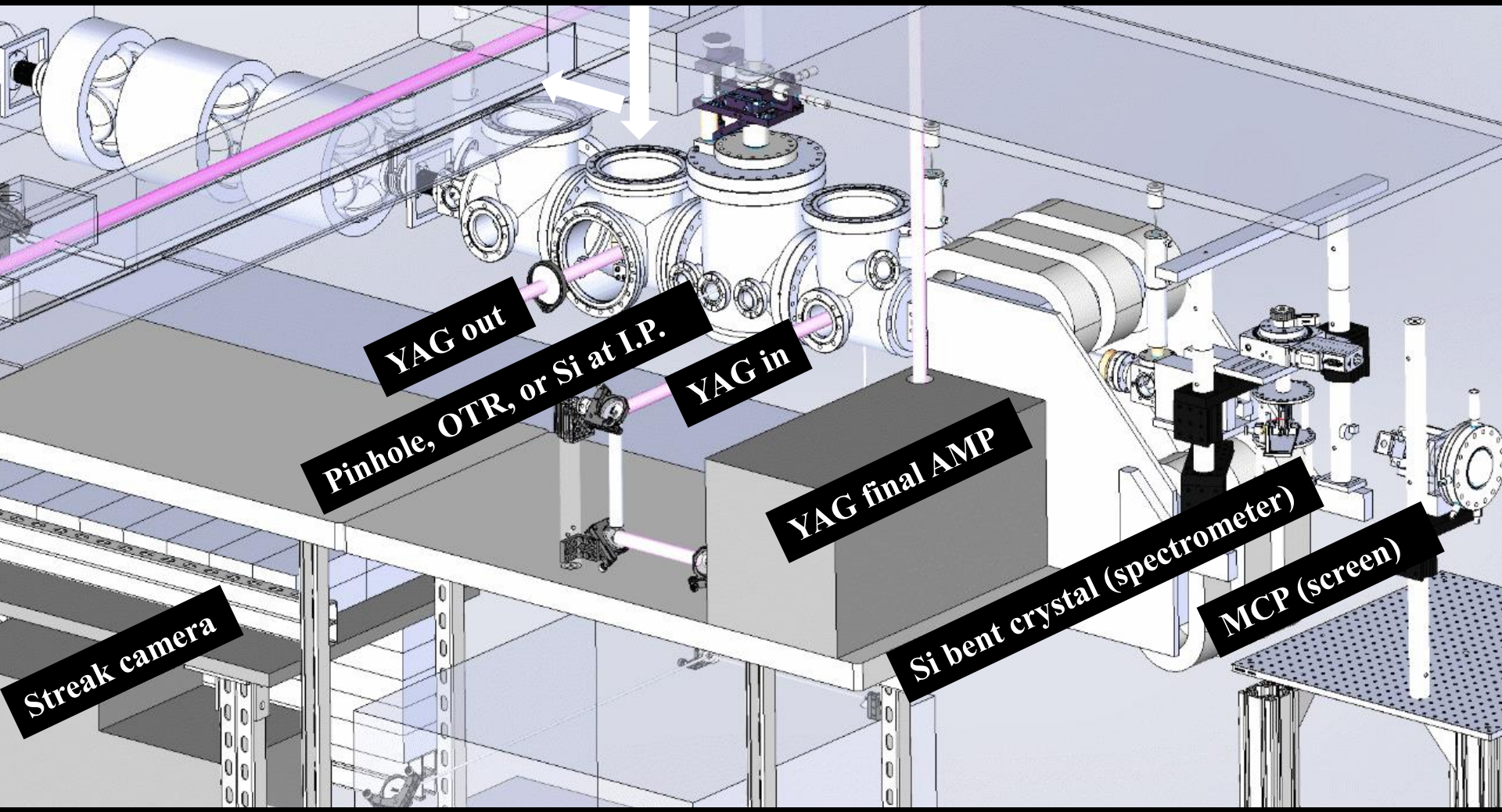
Stats: Diffraction not observed yet.

Note: This is a hard experiment as expected.

YAG ICS Set-up in BL1 as of now

2020-2021yr : ∗ Modification: Final PMQ's location is adjustable → e-beam focus down to σ20-30μm achieved.

∗ Installation of YAG laser's preamplifier (20 mJ output) has been complete → Final output 100-200mJ



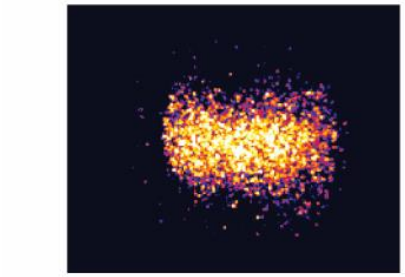
Productive run time in July 2021 ↓

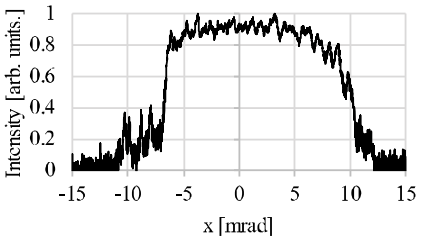
Result: Observed attenuation of 87.5 keV Hard X-ray in a single shot (10^{5}-10^{6-7} photons / shot)

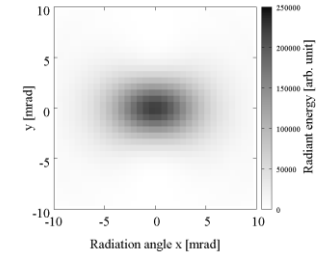
EXPERIMENTAL

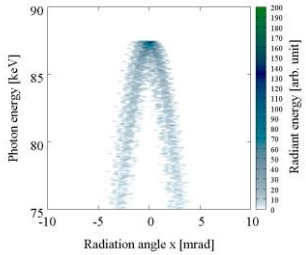
NUMERICAL

★ No-Filter

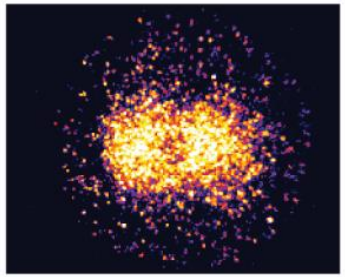


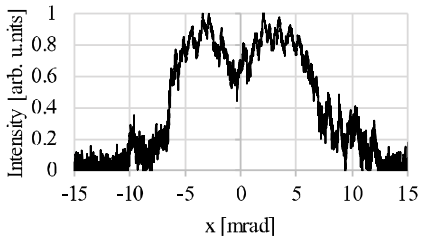


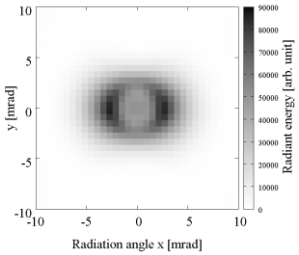


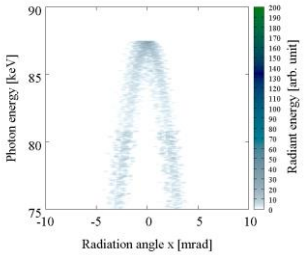


★Au-100μm

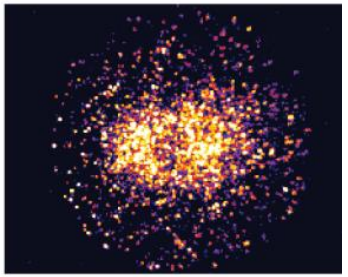


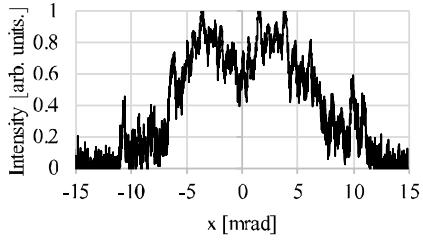


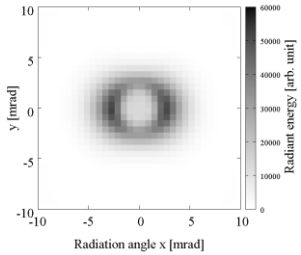


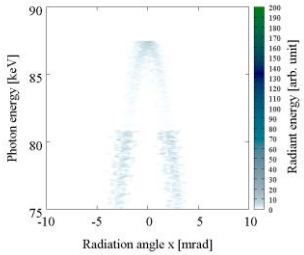


★Au-200μm





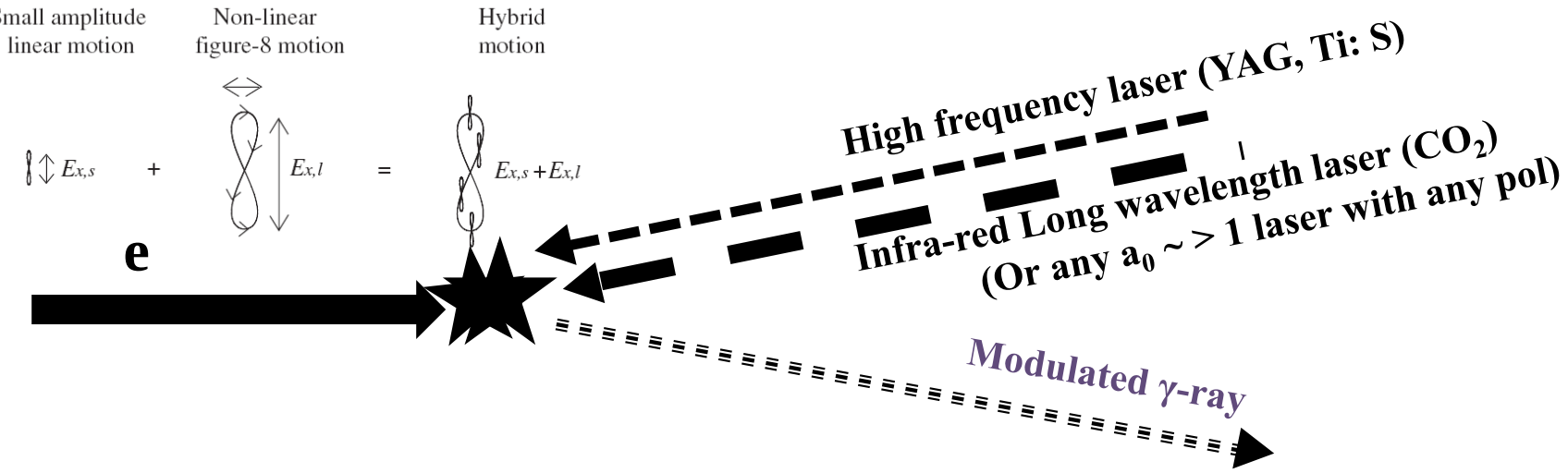




Report to be submitted as:

- **Journal of Applied Physics, Hard X-ray inverse Compton scattering at photon energy of 87.5 keV**
- **RSI or JAP, Electron beam controlled deflection of 1μm laser in Si semiconductor plasma**

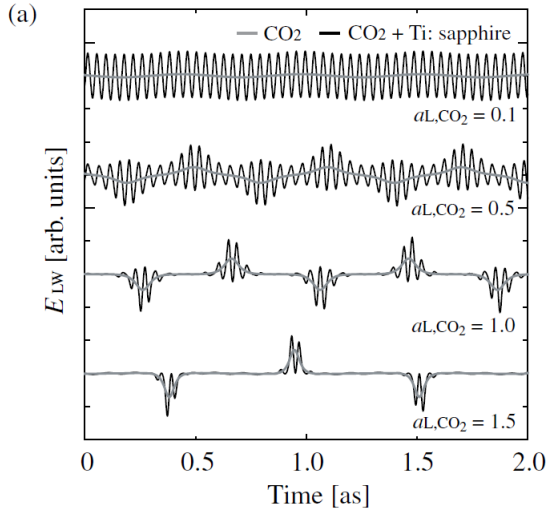
Moving forward → Preparation for Bi-harmonic nonlinear Compton experiment



Pulsed waveform modulation of Hard X-ray component

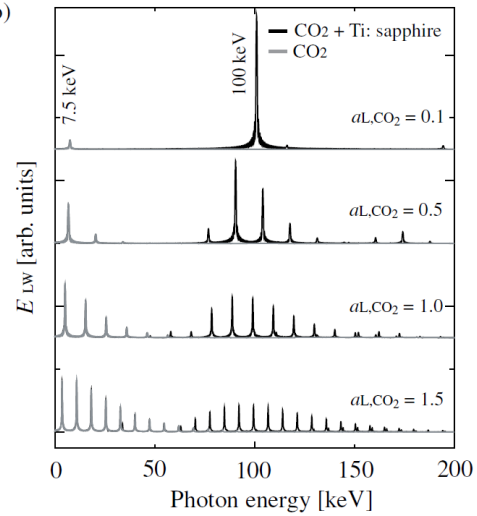
at less than < 10^{-18} s time scale

Observation of Red-Blue shifts & $h\nu_{L,YAG} \pm h\nu_{L,CO2}$

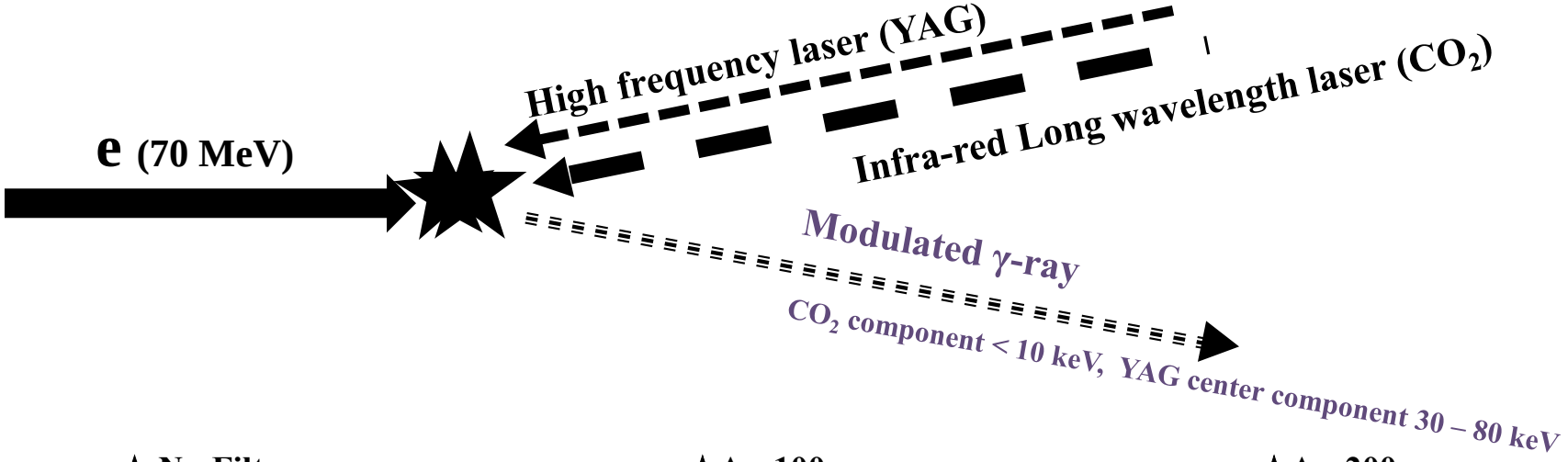


Numerically calculated Lienard-Wiechert potential $E_{LW,x}(t_{screen})$ on $(x, y, z) = (0, 0, 0)$

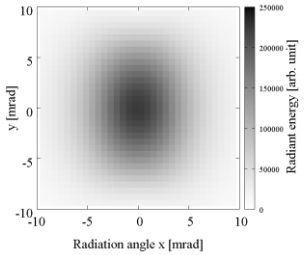
Fourier transform →



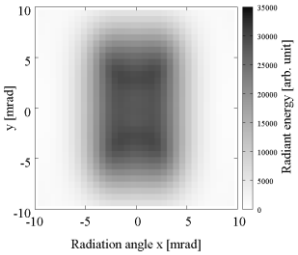
Numerical estimate of bi-harmonic spectrum by ATF parameter (Nonlinear Compton V2)



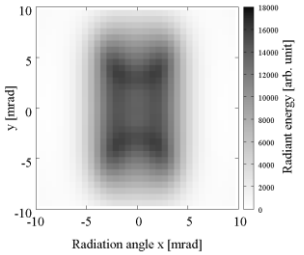
★ No-Filter

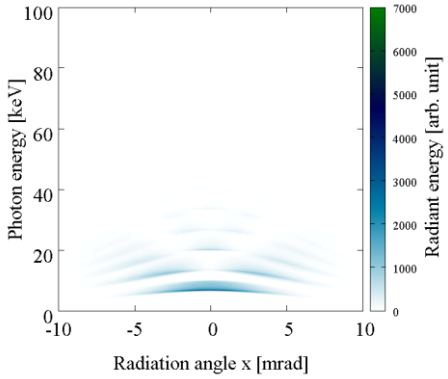


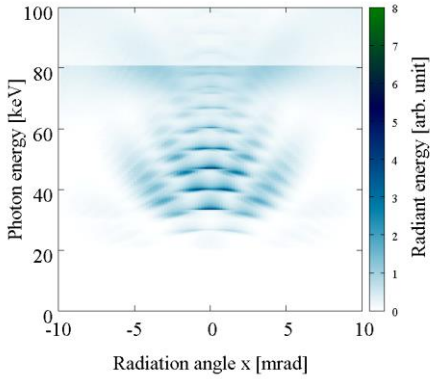
★Au-100μm

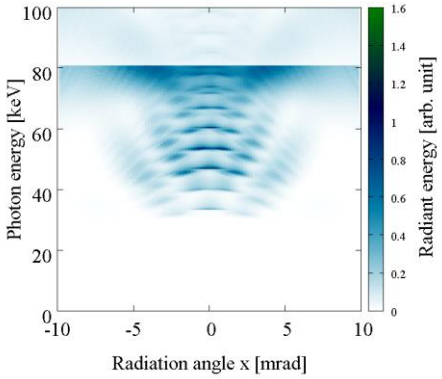


★Au-200μm









Only CO_2's component

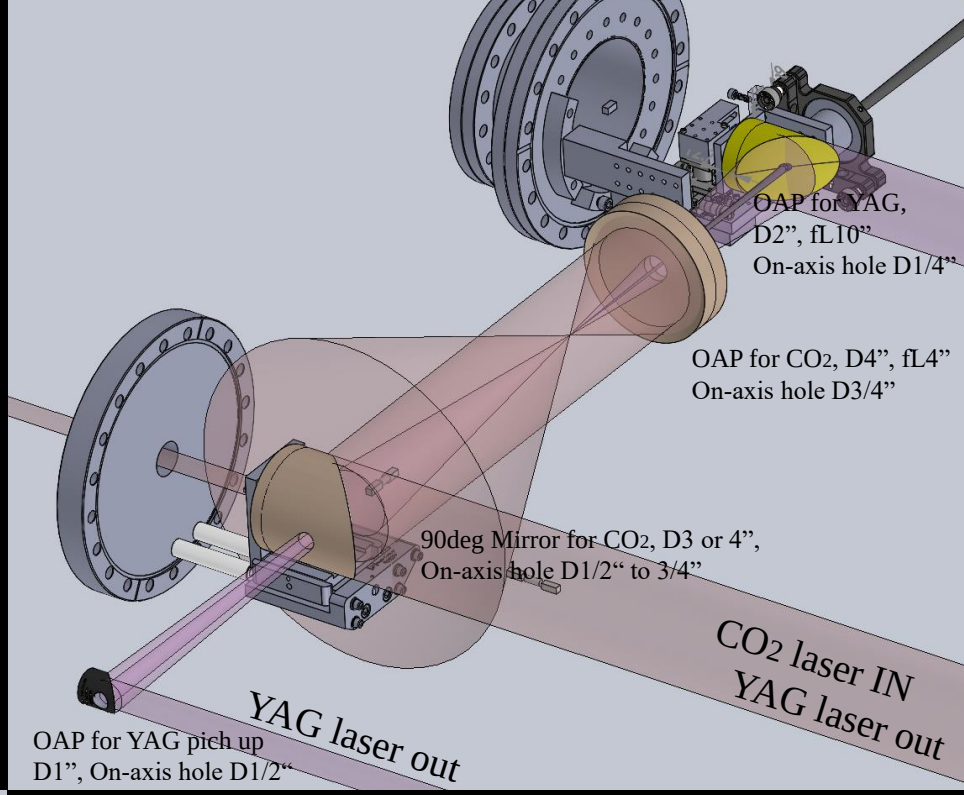
Bi-harmonic YAG's component

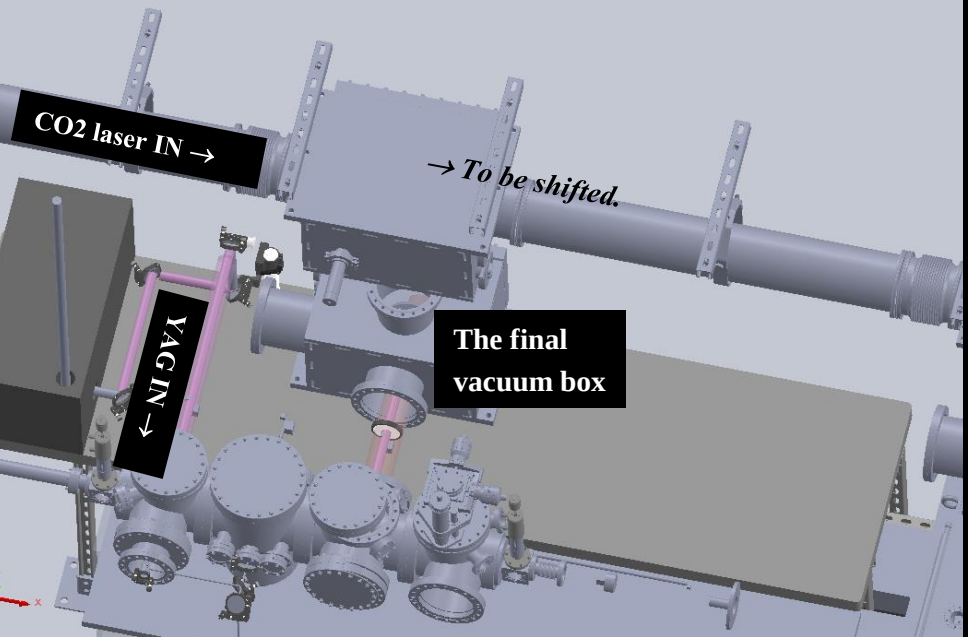
Experimental plans of AE87, year 2022

Bi-harmonic Compton laser optics set up:

Input of CO_2 laser and YAG laser are opposite direction
CO_2 laser final optics has Dia ¾" hole on axis

↔ YAG laser system should be protected by Di-electric mirrors.
↔ CO_2 laser system should be protected by plasma shutter.





← Installation of the final box
for CO_2 laser transport required asap.
(Note: The upper vacuum box needs to be shifted by an inch toward upstream.)

→Then try to recover
nonlinear Compton set-up with the 5TW CO_2 laser.

↔ Meanwhile, try to resolve the YAG ICS spectrum
by bent crystal if it is possible.
(Note: Now the final YAG OAP has been damaged,
and taking extra time to be manufactured.)

2022 PLAN

Feasibility of producing 87.5 keV Hard X-ray for applications is confirmed.

&

K-edge filter is verified to be sufficient to observe bi-harmonic Compton effect.

↓

Recover, or almost new installation of, nonlinear CO_2 ICS set up.

1. **Complete laser vacuum transport. <In March-April ?>**
2. **Installation of CO_2 laser optics. <Summer>**
3. **Reflection, Main beam power, Laser distribution measurements at low power regen signal. <Summer >**
4. **CO_2 laser high power test (Protection of YAG system & source CO_2 laser) <Autumn>**
5. **Initial a_0 measurement of upgraded 5 TW CO_2 laser through harmonic components of nonlinear ICS (~1 TW at the last nonlinear ICS experiment) <Winter>**

Single shot DDS measurement by Bent crystal At ~100 keV range by YAG ICS.

Note:

There are major restrictions, boundary conditions,

set by lead time of manufacturing custom optics recently.

THANK YOU.

Electron Beam Requirements

Parameter	Units	Typical Values	Comments	Requested Values
Beam Energy	MeV	50-65	*Full range is ~15-75 MeV with highest beam quality at nominal values*	**68 - 75 MeV**
Bunch Charge	nC	0.1-2.0	*Bunch length & emittance vary with charge*	**0.3-0.5 nC**
Compression	fs	Down to 100 fs (up to 1 kA peak current)	*A magnetic bunch compressor available to compress bunch down to ~100 fs. Beam quality is variable depending on charge and amount of compression required.* *NOTE: Further compression options are being developed to provide bunch lengths down to the ~10 fs level*	***NONE***
Transverse size at IP (s)	mm	30 – 100 (dependent on IP position)	*It is possible to achieve transverse sizes below 10 um with special permanent magnet optics.*	**~ 30 um**
Normalized Emittance	mm	1 (at 0.3 nC)	*Variable with bunch charge*	***1***
Rep. Rate (Hz)	Hz	1.5	*3 Hz also available if needed*	***1.5***
Trains mode	---	Single bunch	*Multi-bunch mode available. Trains of 24 or 48 ns spaced bunches.*	***TBD***

CO_2 Laser Requirements

Configuration	Parameter	Units	Typical Values	Comments	Requested Values
CO_2 Regenerative Amplifier Beam	Wavelength	mm	9.2	*Wavelength determined by mixed isotope gain media*	
	Peak Power	GW	~3		
	Pulse Mode	---	Single		
	Pulse Length	ps	2		
	Pulse Energy	mJ	6		
	M^2	---	~1.5		
	Repetition Rate	Hz	1.5	*3 Hz also available if needed*	
	Polarization	---	Linear	*Circular polarization available at slightly reduced power*	
CO_2 CPA Beam	Wavelength	mm	9.2	*Wavelength determined by mixed isotope gain media*	***ANY***
Note that delivery of full power pulses to the Experimental Hall is presently limited to Beamline #1 only.	Peak Power	TW	2	*~5 TW operation is planned for FY21 (requires further in-vacuum transport upgrade). A 3-year development effort to achieve >10 TW and deliver to users is in progress.*	***NORMALIZED VECTOR POTENTIAL a0 >= 1***
	Pulse Mode	---	Single		***SINGLE***
	Pulse Length	ps	2		***ANY***
	Pulse Energy	J	~5	*Maximum pulse energies of >10 J will become available in FY20*	***5***
	M^2	---	~2		***ANY***
	Repetition Rate	Hz	0.05		***100 SHOTS/DAY***
	Polarization		Linear	*Adjustable linear polarization along with circular polarization will become available in FY20*	***LINEAR FIRST (THEN CIRCULAR ♦)***

♦ ***NOTE: Circular polarization is required for reconsideration of OAM study by nonlinear Compton experiment in 2023-2025yr.***

Other Experimental Laser Requirements

Ti:Sapphire Laser System	Units	Stage I Values	Stage II Values	Comments	Requested Values
Central Wavelength	nm	800	800	*Stage I parameters are presently available and setup to deliver Stage II parameters should be complete during FY22*	
FWHM Bandwidth	nm	20	13		
Compressed FWHM Pulse Width	fs	<50	<75	*Transport of compressed pulses will initially include a very limited number of experimental interaction points. Please consult with the ATF Team if you need this capability.*	
Chirped FWHM Pulse Width	ps	≥50	≥50		
Chirped Energy	mJ	10	200		
Compressed Energy	mJ	7	100		
Energy to Experiments	mJ	>4.9	>80		
Power to Experiments	GW	>98	>1067		

Nd:YAG Laser System	Units	Typical Values	Comments	Requested Values
Wavelength	nm	1064	*Single pulse*	
Energy	mJ	5		***20 mJ AT PRE-AMP, 100-200mJ AT Final Amp***
Pulse Width	ps	14		
Wavelength	nm	532	*Frequency doubled*	
Energy	mJ	0.5		
Pulse Width	ps	10		

Special Equipment Requirements and Hazards

Any special equipment:

- None

Hazards & Special Installation Requirements:

- All items have been included in updated ESR.

Large installation (chamber, insertion device, etc.):

- Installation of CO_2 laser vacuum transport,
  especially the final box toward Compton chamber as soon as possible.

Introducing new magnetic elements:

- None

Experimental Time Request

CY2022 Time Request

Capability	Setup Hours	Running Hours
Electron Beam Only	0	0
Laser* Only (in Laser Areas)	0	0
No beams in Experimental Hall	1week (Laser vacuum box installation)	0
Only regen CO_2 laser in EH	1week (CO2 optics installation)	1week
TW CO_2 laser in EH	0	1week(CO2 laser high power test)
CO_2 Laser + Electron Beam	1week	2week(CO2 nonlinear ICS)
YAG Laser + Electron Beam	1week	1week(YAG ICS Spectrometer)

Note: Scheduling depends on custom laser optics availability.