AE 70: Nonlinear Inverse Compton Scattering Status Report 2016

1. ICS double differential spectrum analysis
2. RUBICONICS (Double pulse ICS/IFEL)
3. Future plan: Use of YAG(or Ti:S) ICS

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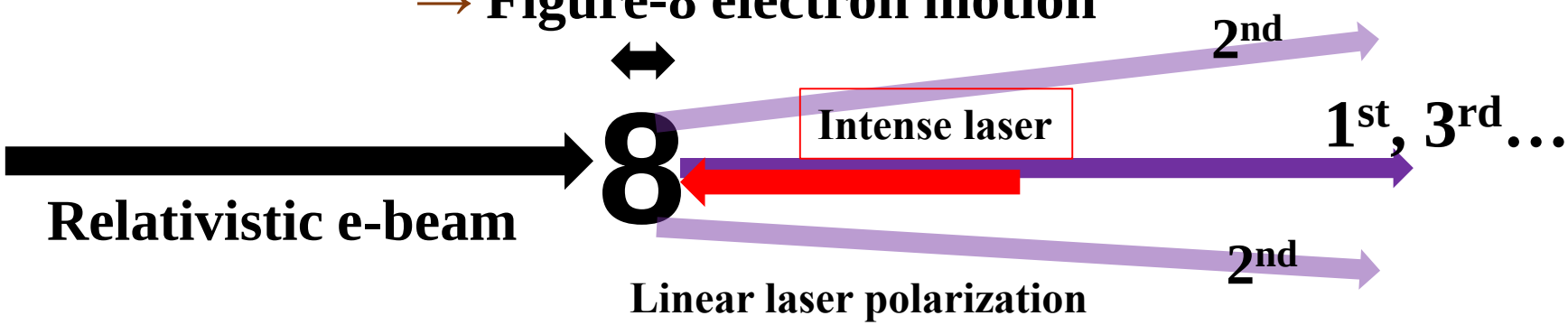
Nonlinear ICS physics in high intensity (E_L^2), long λ_L (high a_L) laser field.

High brilliance, Luminosity/pulse

$N_\gamma = \sigma_T L = \sigma_T N_e N_L / 4\pi\sigma_x^2 \approx 10^9$ per pulse →

→ **Figure-8 electron motion**



Nonlinear ICS: a_L~1, transverse motion relativistic, nontrivial longitudinal oscillation

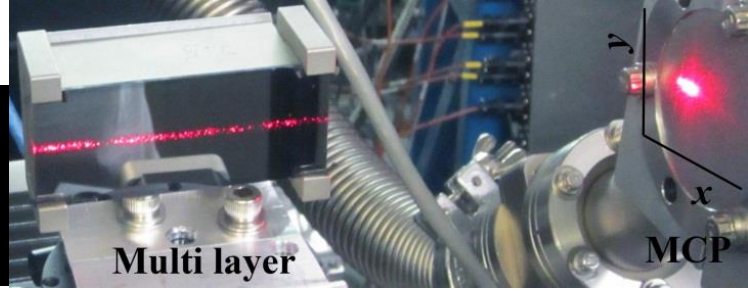
★**Red-shifting *and* BW increase:**

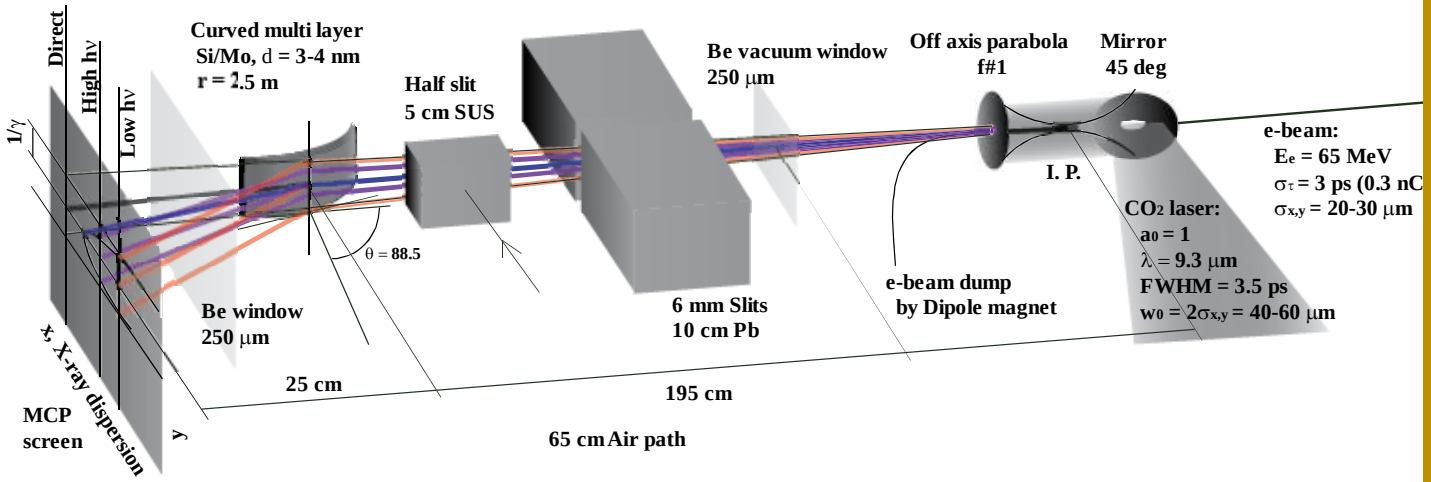
$$h\nu_{X\text{-ray}} \Rightarrow h\nu_{X\text{-ray}} / (1+a_L^2/2)$$

Electron slow down or "Mass Shift"

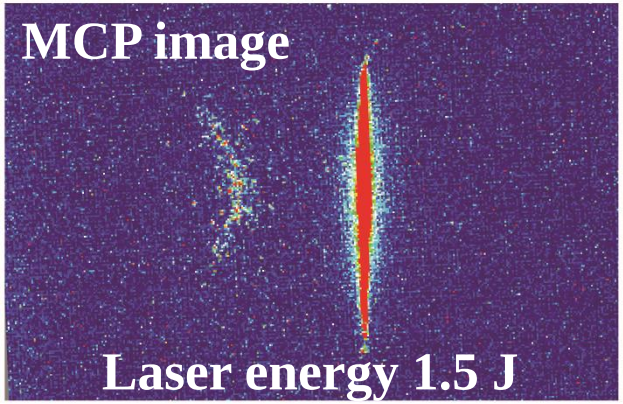
Details of the ICS X-ray spectrum:

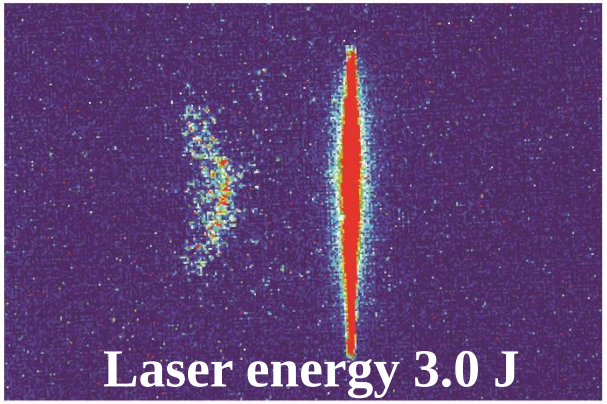
Mo/Si curved Multi-layer spectrometer





- ✡ Mo-Si Multi (45) layer thickness: $d \approx 3.3$ nm
- ✡ Bragg angle: ~ 25 mrad
- ✡ Angle acceptance : ~ 50 mrad
- ✡ Reflectivity ~ 15% @ NSLS X15A

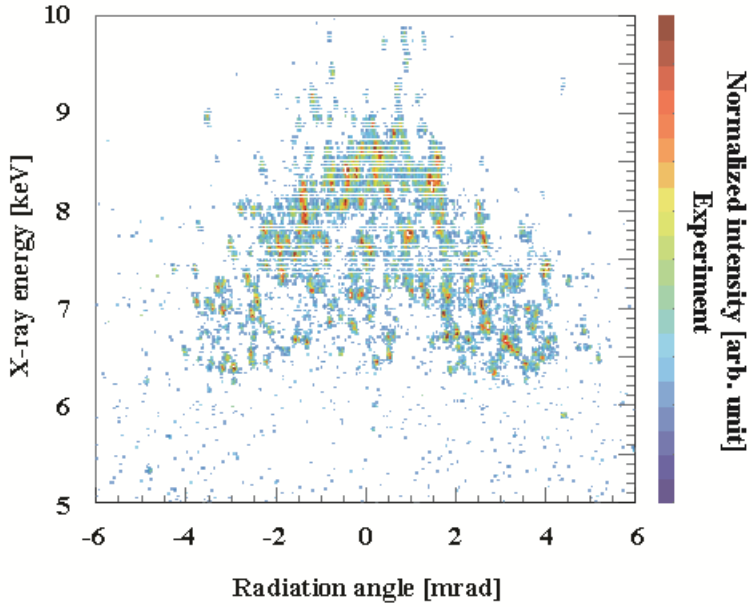




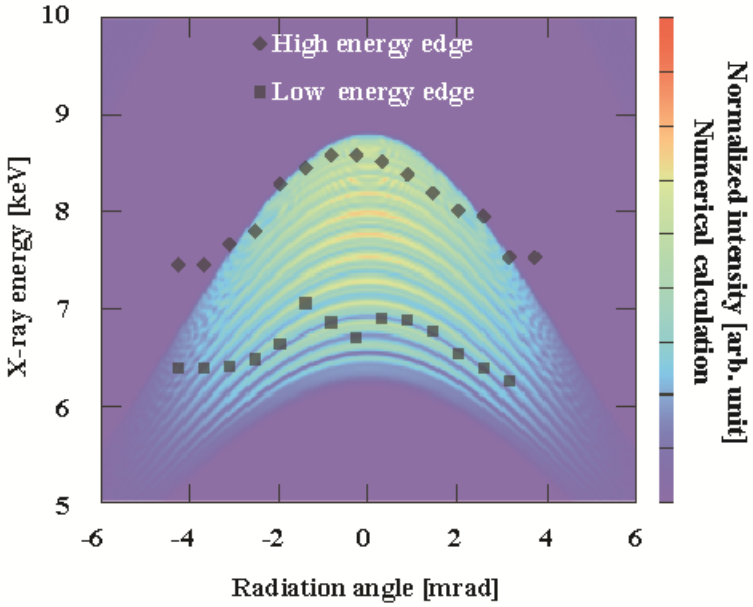
Y. Kamiya, T. Kumita and P. Siddons et al., X-ray spectrometer for observation of nonlinear Compton scattering, Proc. Joint 28th Workshop on Quantum Aspects of Beam Physics (World Scientific), 103 (2003)

Single shot, double differential spectrum
a_0 = 1 case

Experiment



L.W. Simulation



<u>After a few years discussion…</u>

<u>It figured out that Spectrum shape changes by e-beam & laser spot size significantly:</u>

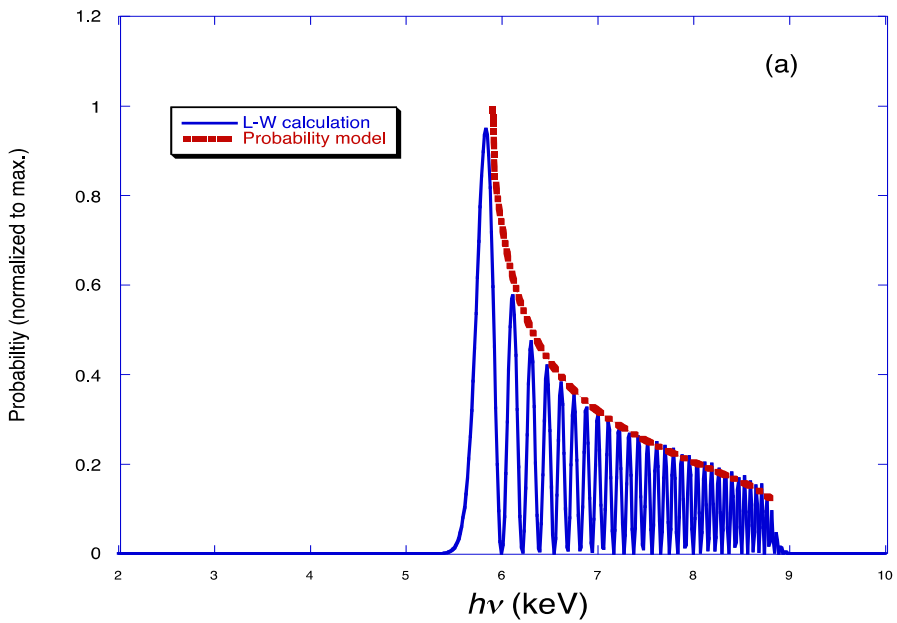
Analysis : on-axis spectral structure
Broadening in nonlinear ICS

- ★ ***Temporal artifacts: high red-shift emphasized,***
- ★ ***Self-interference effects by electron's oscillation?***
- ★ ***Transverse effect gives low red-shift***

$$P_1(\Delta\lambda) = \frac{C_1}{\sqrt{ln(\Delta\lambda_{max}/\Delta\lambda)}}$$

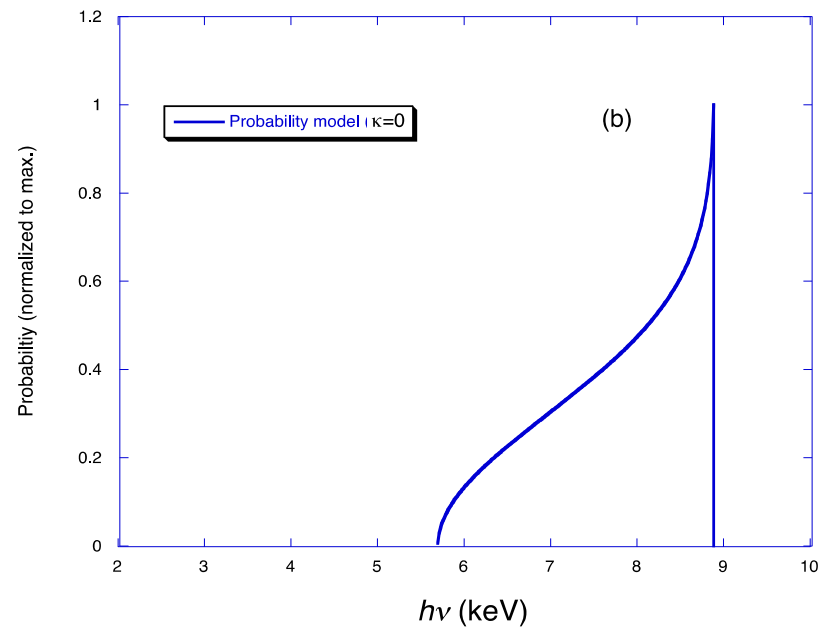
$$P_2(\Delta\lambda) = C_2\left(\frac{\Delta\lambda}{\Delta\lambda_{max}}\right)^{\kappa-1}$$

$$\kappa = \sigma_L/\sigma_e$$



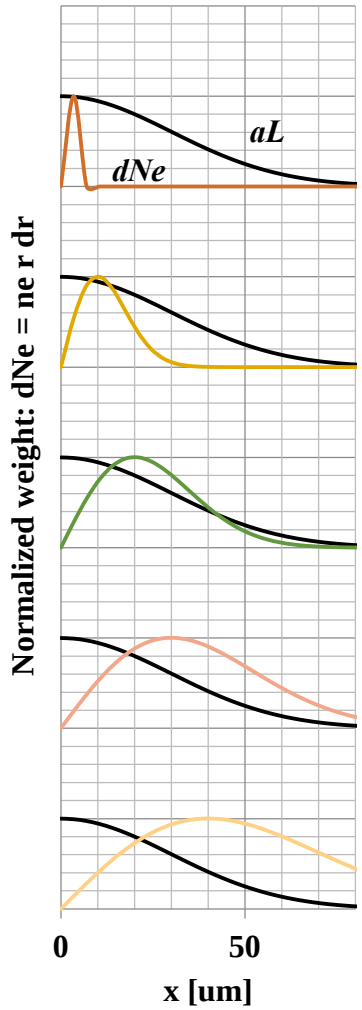
Temporal shift alone

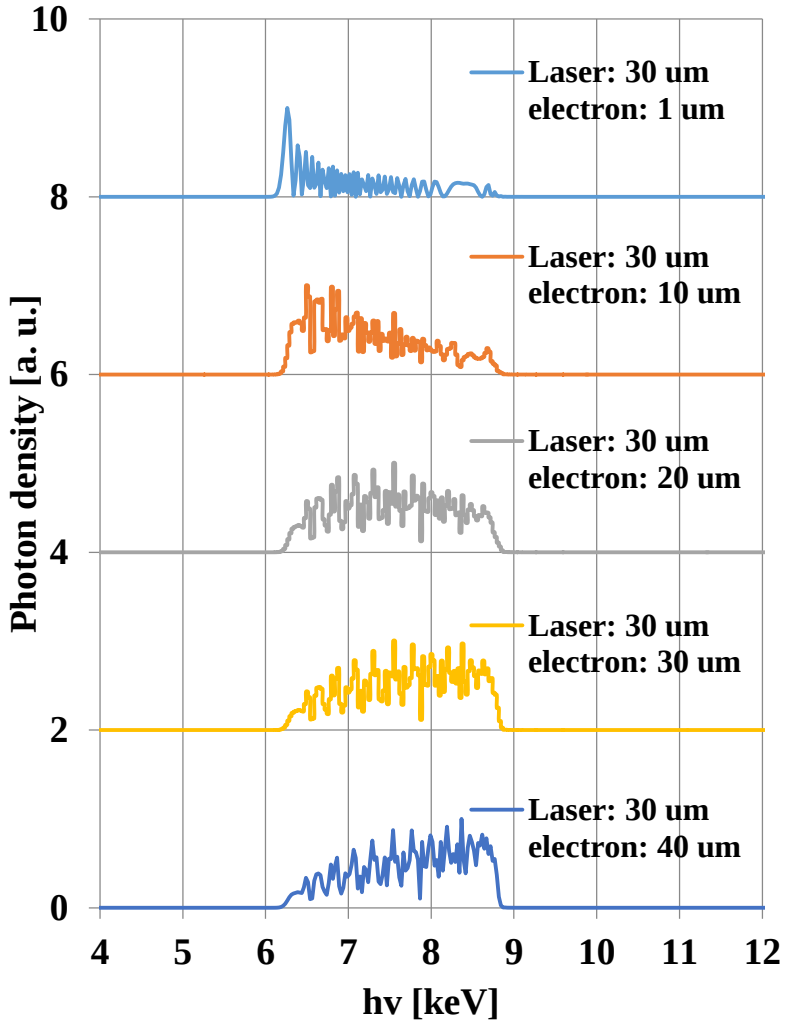
(Note: L-W numerical model shows interference)



Transverse shift alone

Numerical example
<u>beam size effect</u>:





Weight factor:

$I_{x\text{-}ray}(r) \propto a_L^2(r)\, N_e$

$N_e \propto n_e\, r\, dr$

Note:

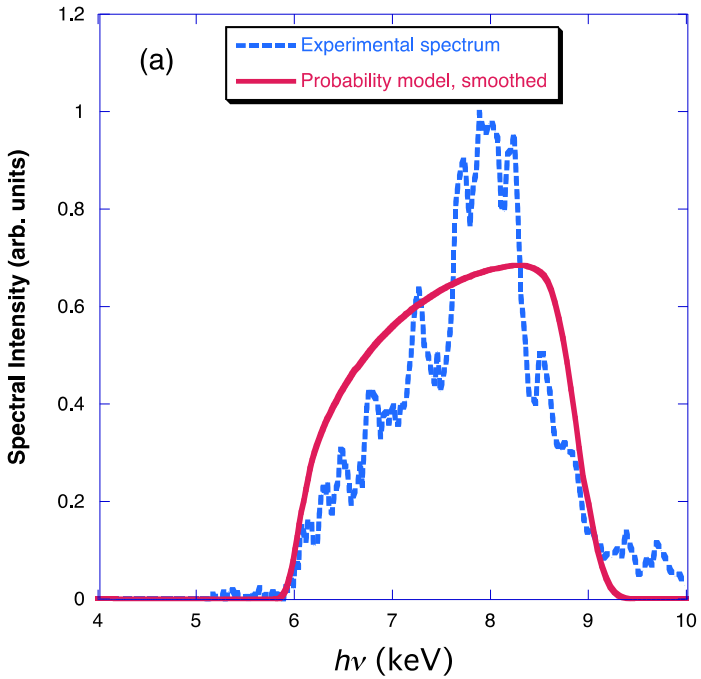
$\beta = 3$ *cm* >>

$Z_R = 0.5$ *mm*

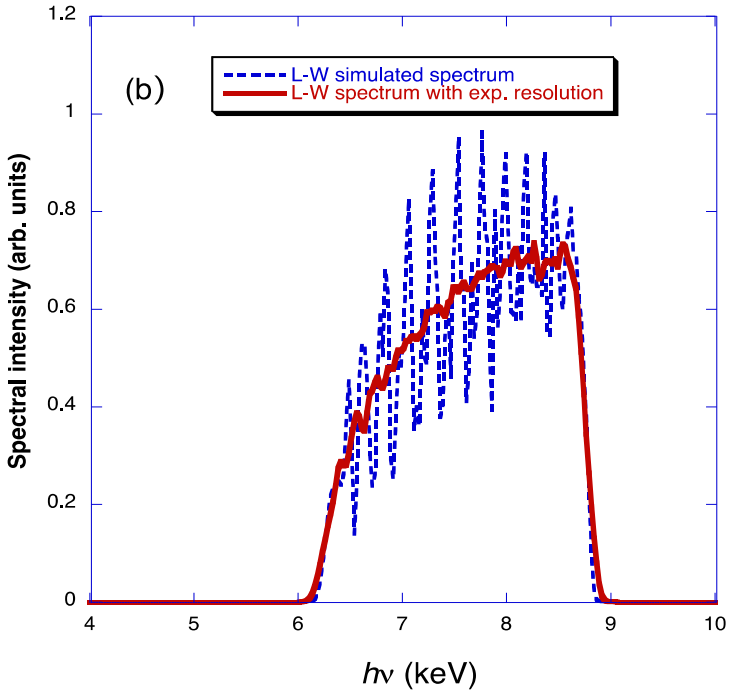
longitudinal effect is neglected.

Conclusion of on-axis spectrum analysis :

★ **Spectral shape agrees with model, deduce $\sigma_e \approx \sigma_L \approx 20\text{-}30\mu m$**
★ **On-axis emission; Total BW=33% with $a_0 = 1$.**

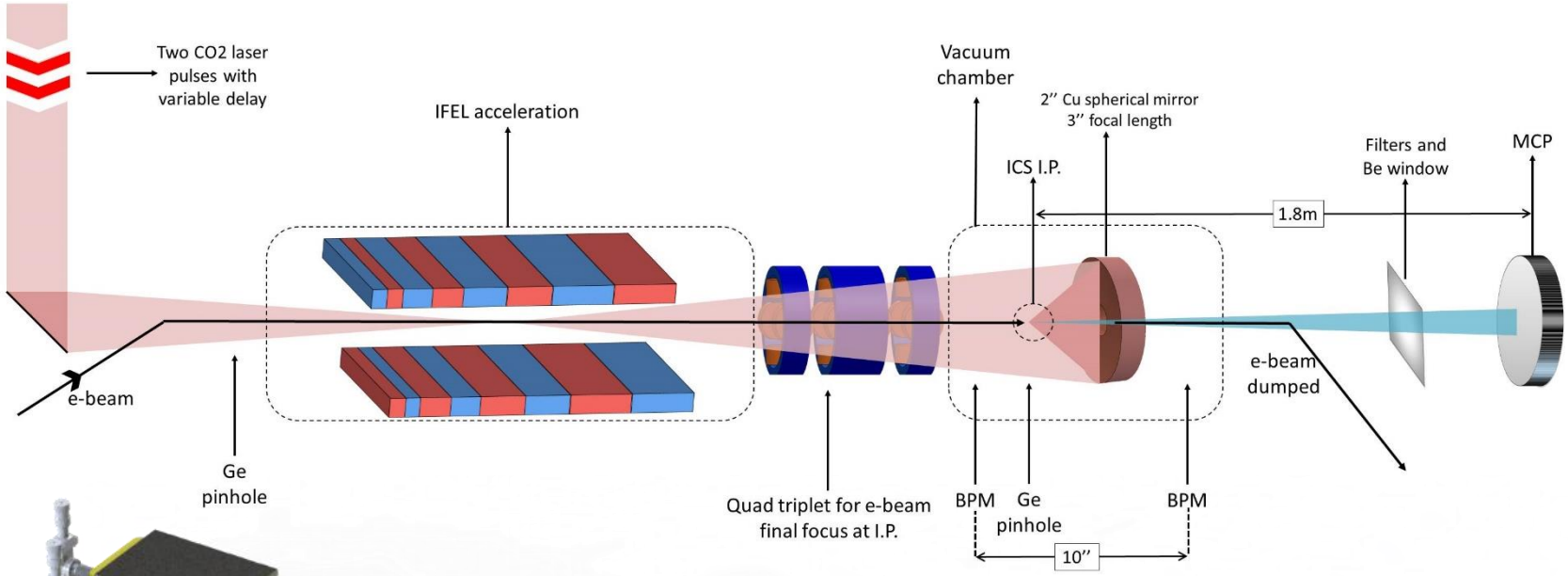


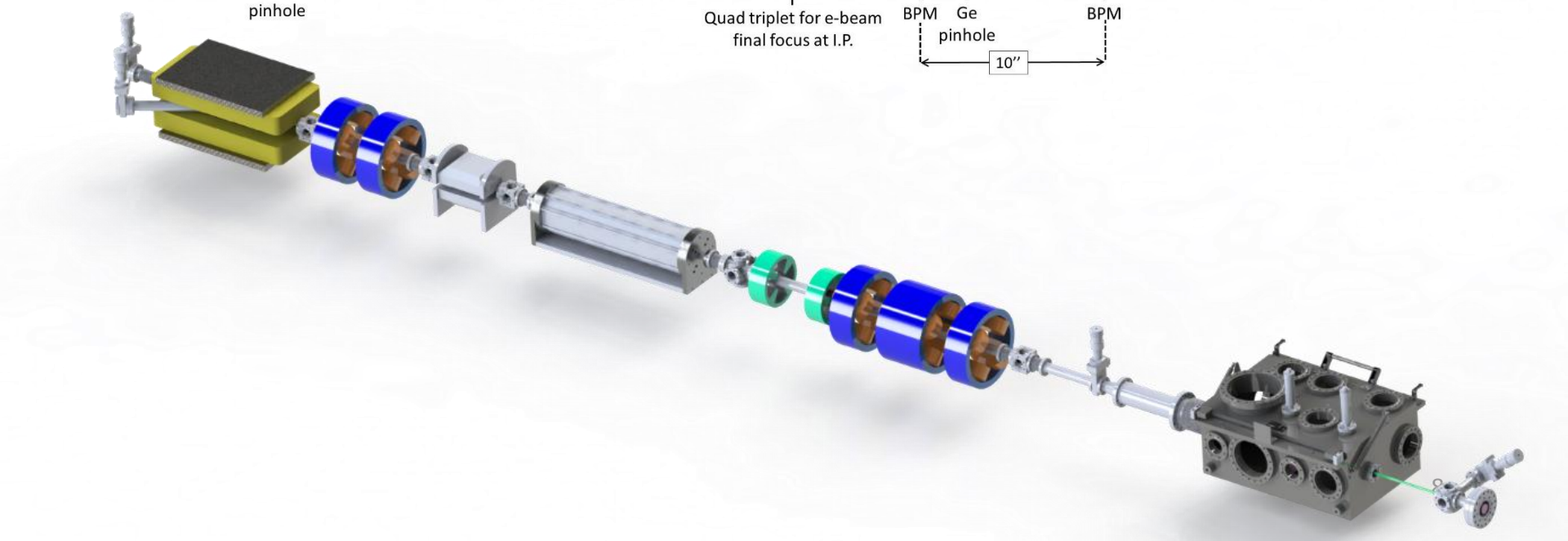
Data and analytical probability model



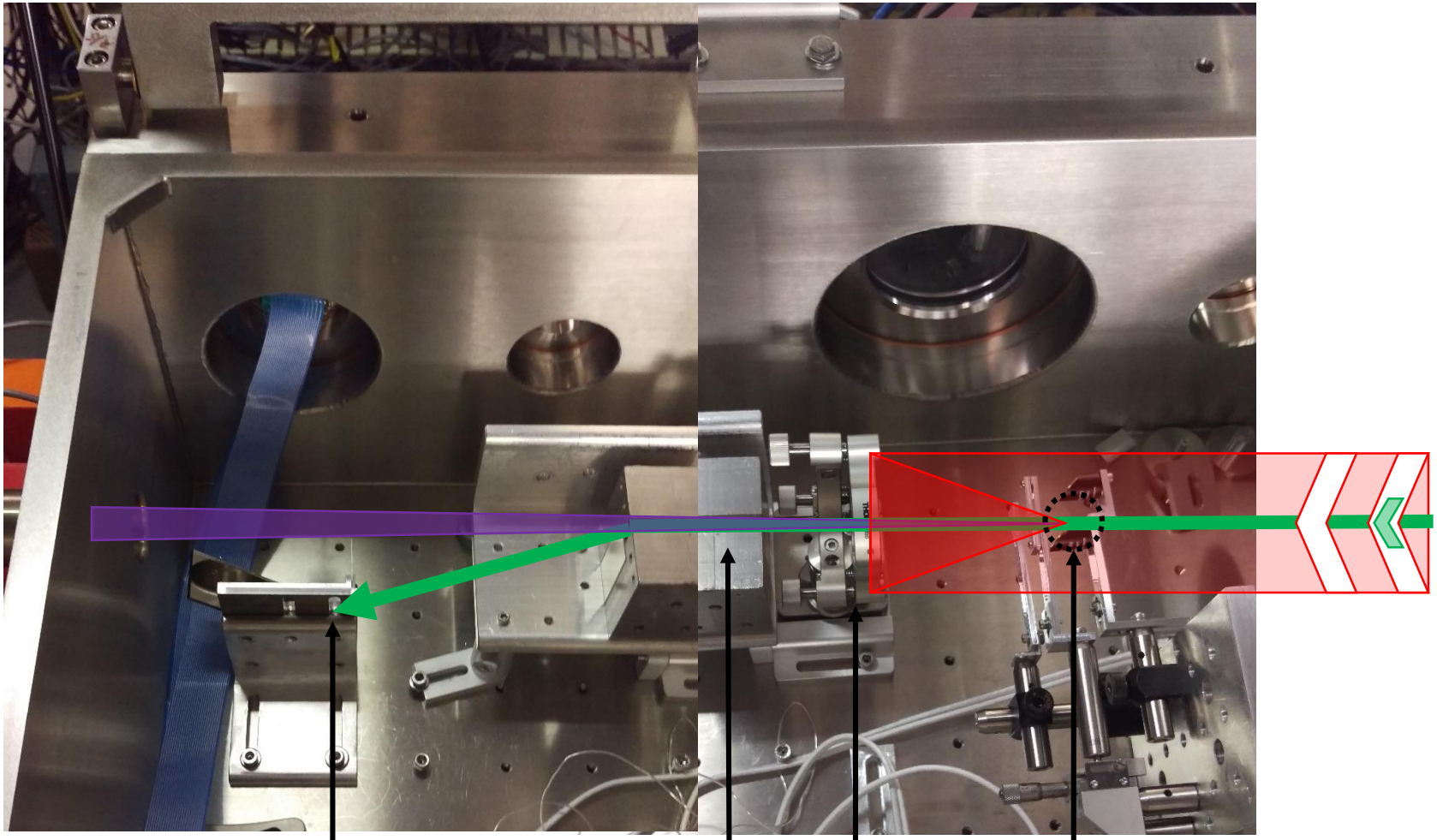
Lenard-Wiechert model (showing interference)

IFEL-ICS setup at ATF

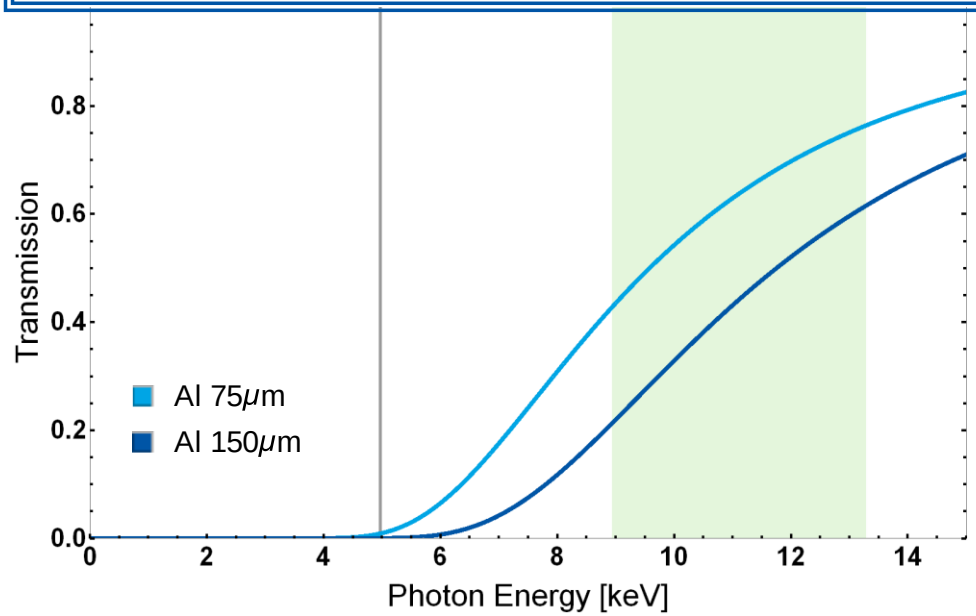


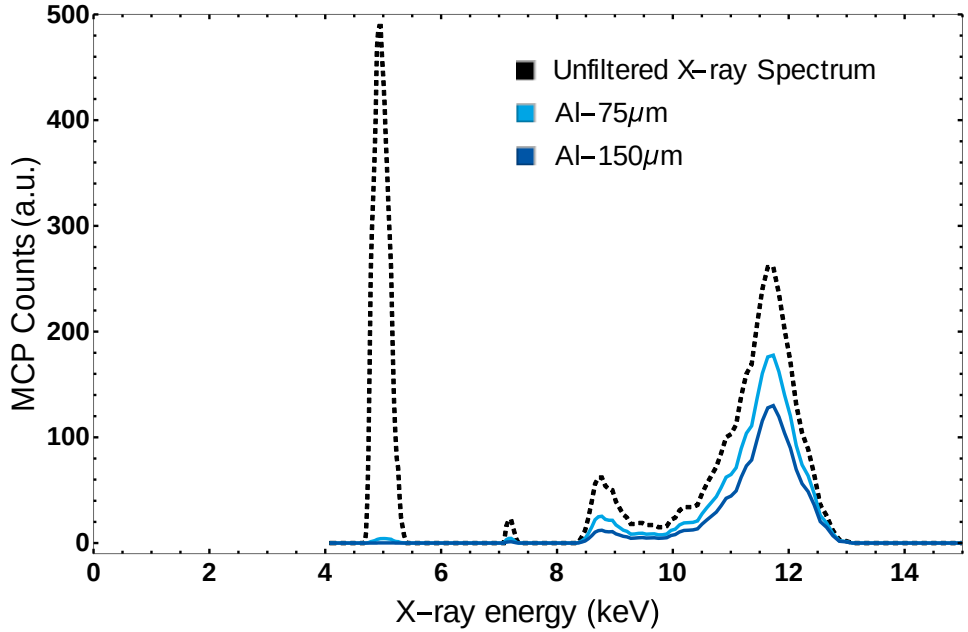


ICS IP + e-beam spectrometer



RubiconICS X-ray Spectrum and Filtering





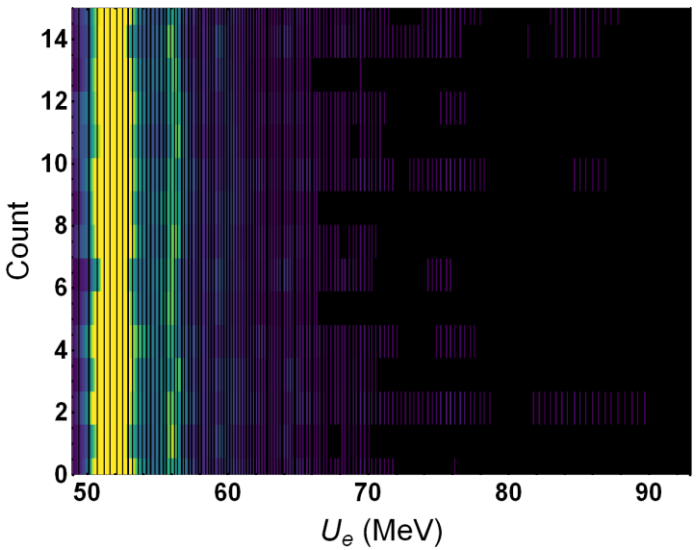
Relative MCP Counts

	4 – 6 keV	8 – 13 keV	ratio
No Al	165	357	2
Al 75μm	2	227	146
Al 150μm	0	159	4149

RubiconICS Results - June 2016

- Achieved interaction of the electron beam with both CO2 laser pulses
- ICS X-rays produced by the IFEL accelerated beam were successfully detected
  - 10^6 x-ray photons per shot
    - Bunch charge = $300pC$
    - Laser energy = 1J
- $< 5\%$ of electron beam was accelerated above $65\ MeV$
- Bremsstrahlung background too high

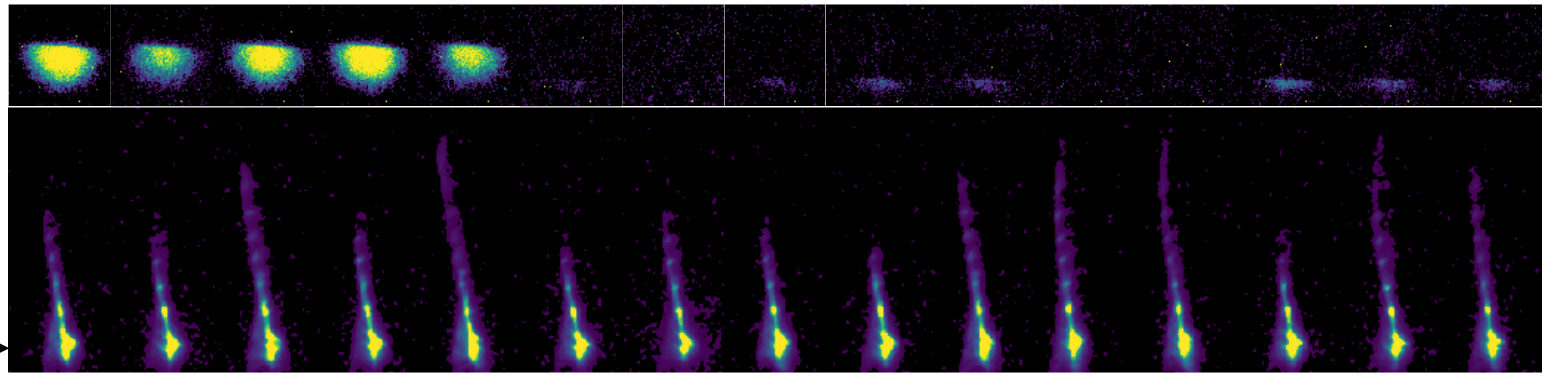
IFEL acceleration



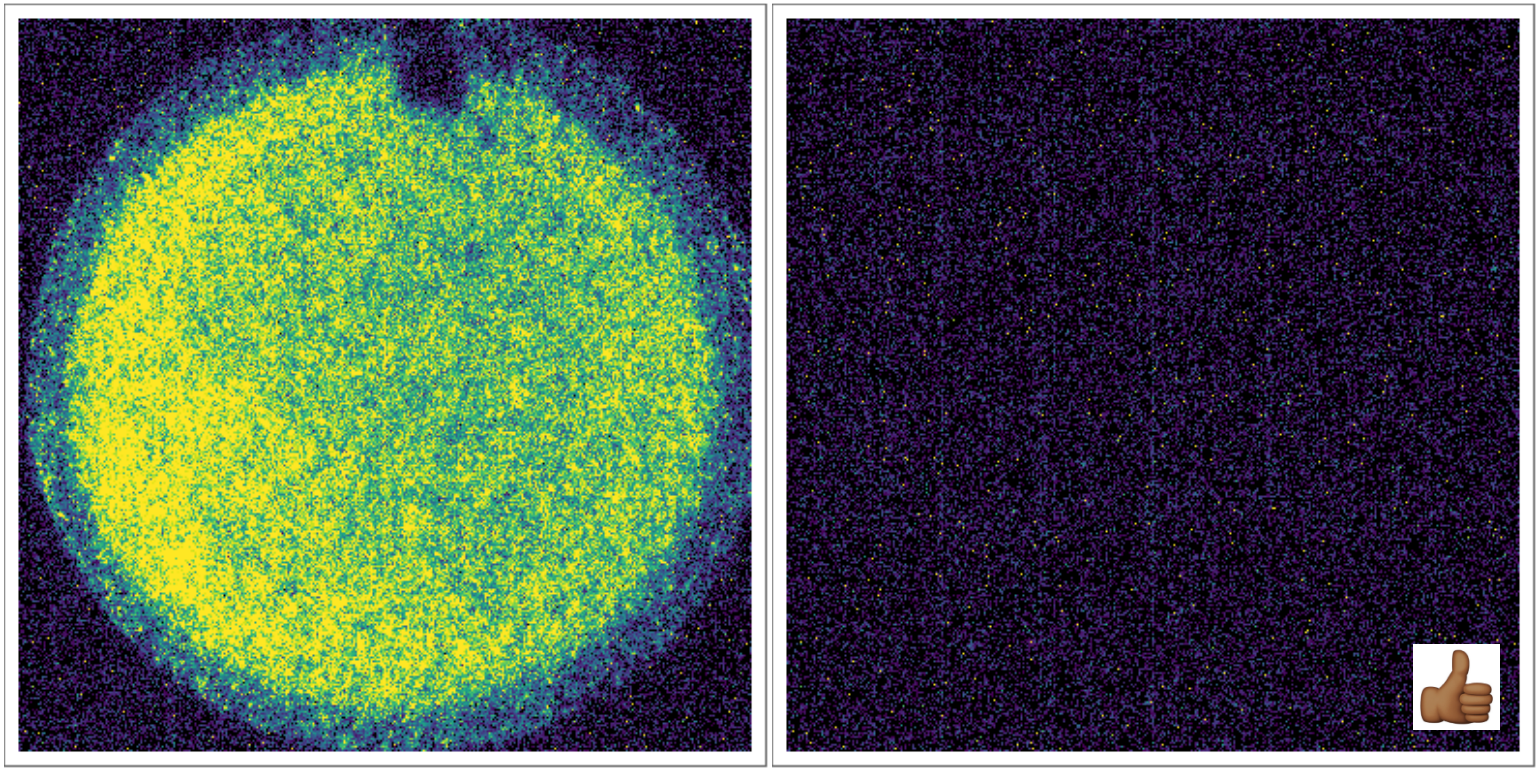
MCP – Al $75\mu m$

e-beam spectrometer

$U_e = 52\ MeV$



Bremsstrahlung Background



Representative images of the Bremsstrahlung background before and after re-alignment of the permanent dipole

RubiconICS Results – August 2016

Achievements

- Stable operation of the IFEL driven ICS X-ray source
- 30% of each electron bunch were accelerated to 80MeV
- $5 \cdot 10^6$ - # of X-ray photons per shot at $11(\pm 2)$ keV
- Focused accelerated beam at ICS IP (scaling of quads)

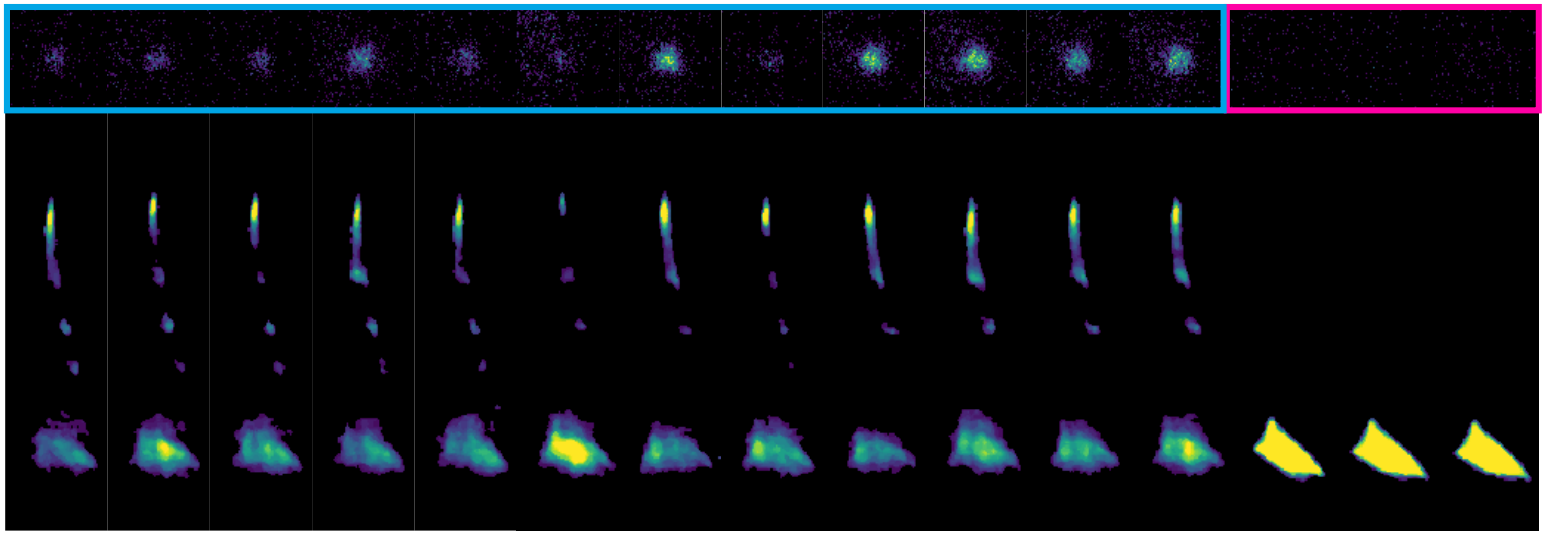
When IFEL acceleration is ON, higher energy X-rays are detected

$150\mu m$ thick Al foil extinguishes X-rays from lower energy electrons

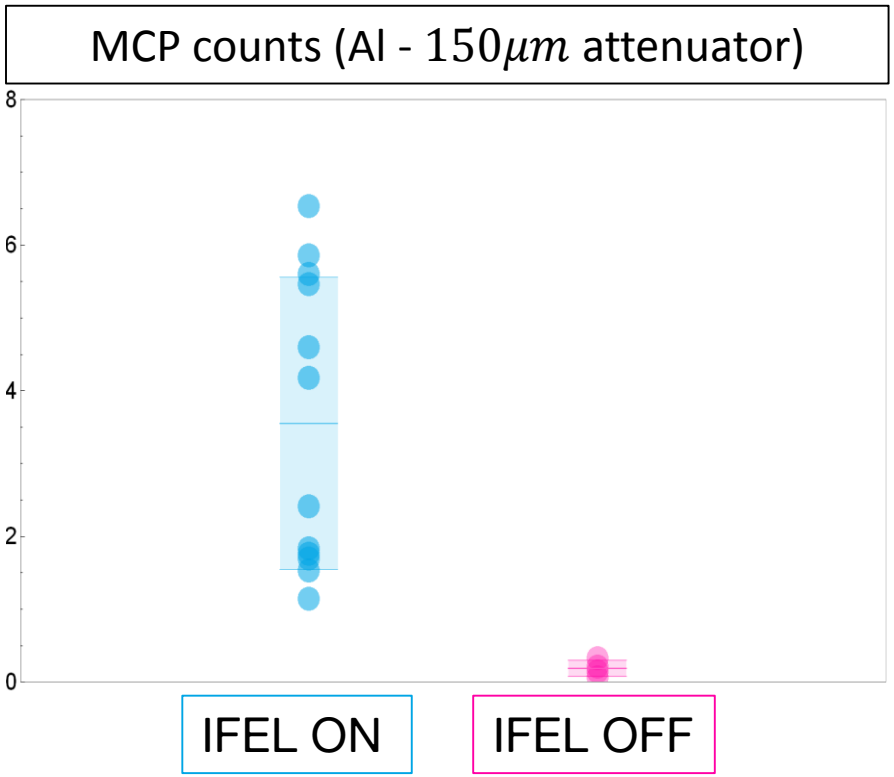
MCP – Al $150\mu m$

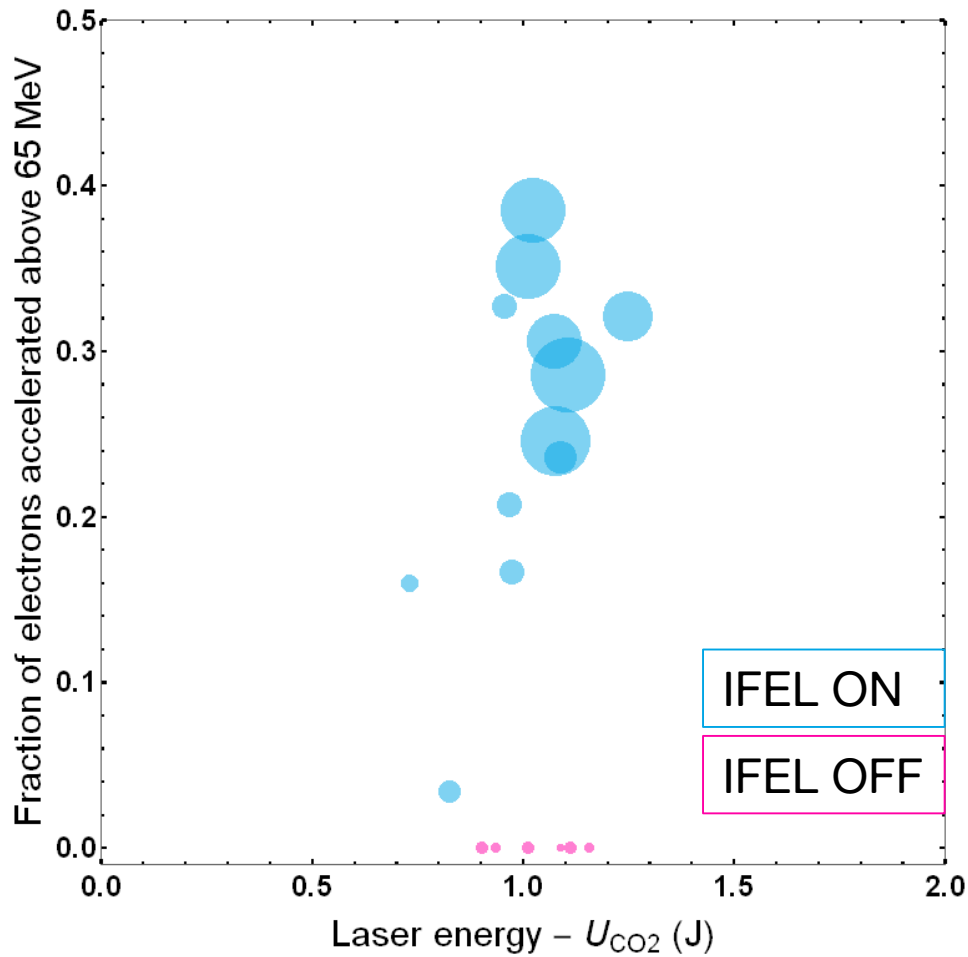
$U_e = 82\ MeV$

$U_e = 52\ MeV$

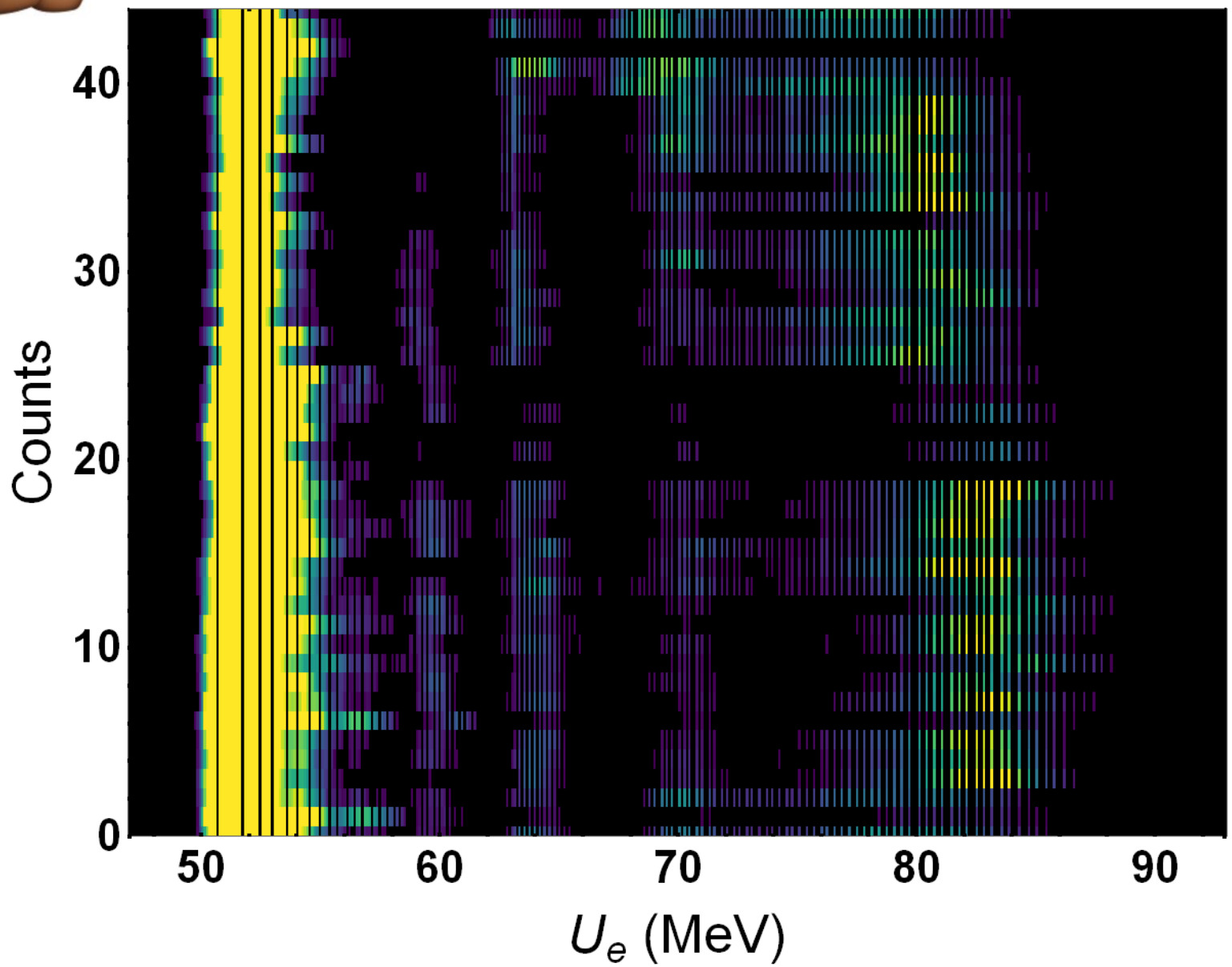


RubiconICS Operation – August 2016





IFEL Stability – August 2016



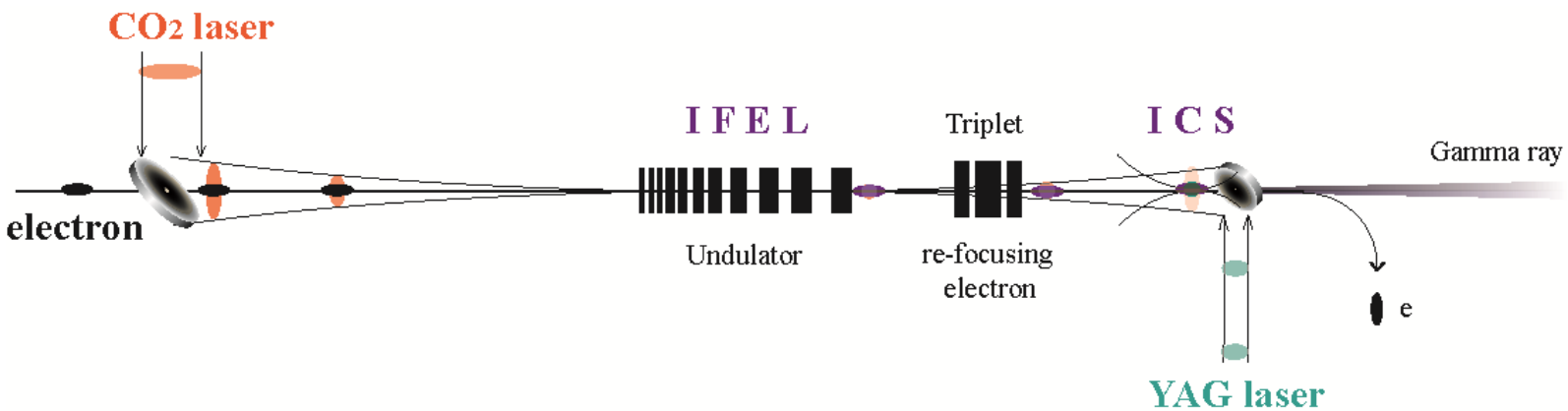
Future plan

YAG ICS for

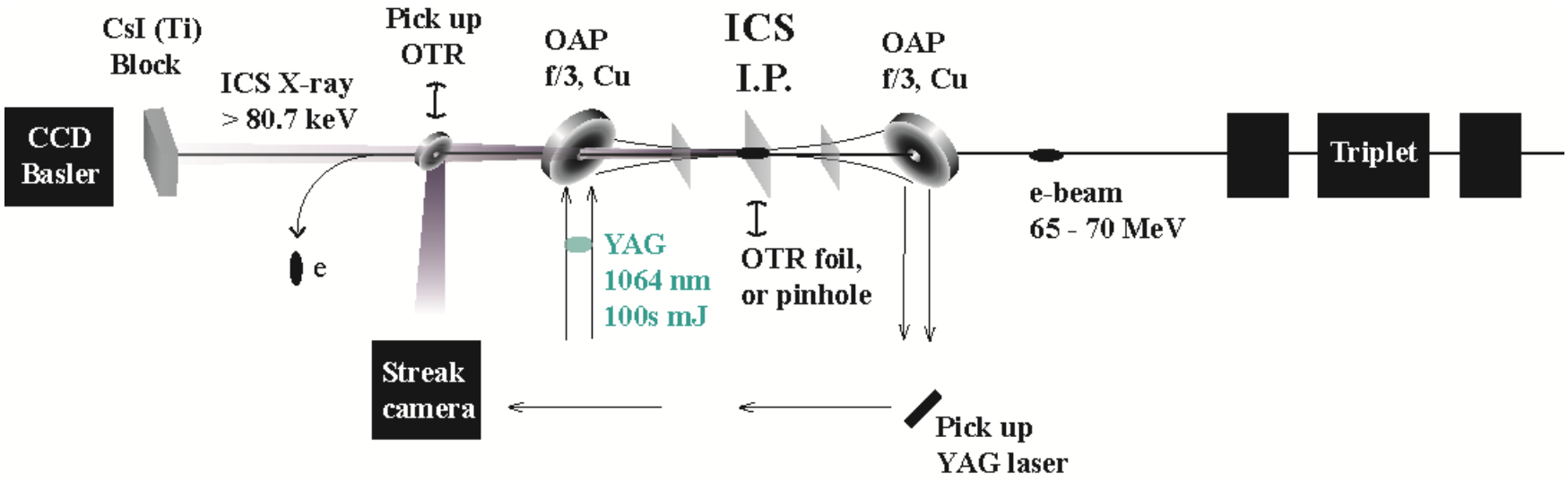
- ✪ Preparation for Two wavelength harmonic mixing (or polarization mixing) at Gamma ray regime at ATF II.

- ✪ Photon activation therapy at $h\nu$ > 80.7 keV
  (using Gold nano particle etc.)

- ✪ ICS(YAG) / IFEL (CO_2) at E_e > 250 MeV, $h\nu$ > MeV



Linear ICS experiment using YAG laser in BL1



Initial goal of 2016-17 yr:

1. Set up synchronization system (Streak camera, or EOS)
2. Observe > 81 keV photons through Au k-edge, then measure X-ray flux ~10^6 photons/shot.

Thank you!

UCLA

Nick Sudar, Yusuke Sakai, Joe Duris, Oliver Williams, Pietro Musumeci, James Rosenzweig

ATF @ BNL

Igor Pogorelski, Mikhail Fedurin, Mikhail Polyanski, Karl Kushe, Marcus Babzien, Christina Swinson