Heavy ions and X/γ ray diagnostics used in PW laser-plasma experiments

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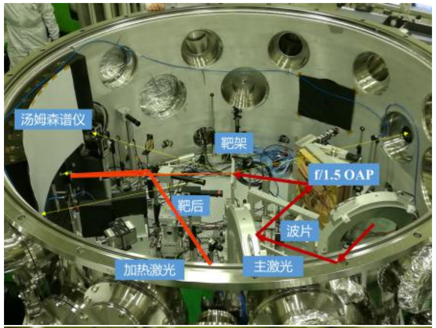
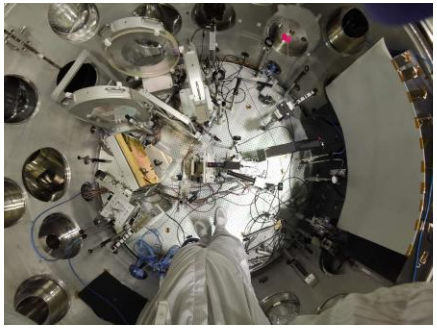
2 experimentnal campaigns performed in GIST in 2019

Laser Parameters (On targets)

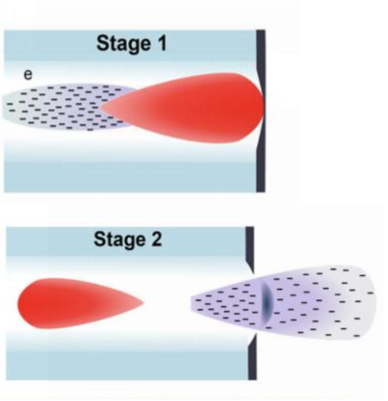
Laser Energy: 15-18 J (f/1.6, f = 450 mm)
25-30 J (f/5.6, f = 1600 mm)
Pulse Duration: ~20 fs
Focus Spot(FWHM): 1.5-1.7 um, 5.8-7.1 um
Contrast Improvement: double PMs
Intensity: ~1X10^{22} W/cm^2 (f/1.6)
~1X10^{21} W/cm^2 (f/5.6)





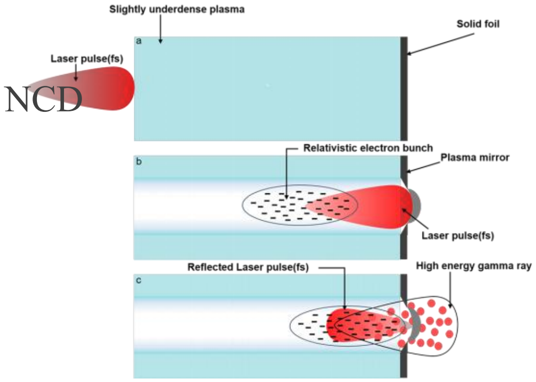
Goal 1: very heavy ion acceleration from ultrathin & double-layer targets

- ion acceleration using ultrathin targets
- cascaded acceleration from double-layer targets



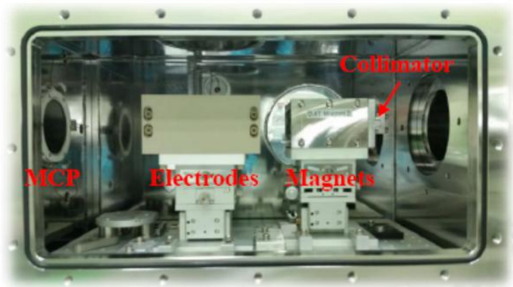
Goal 2: X/γ ray from near-critical targets at intensity over 10^{21} W/cm^2

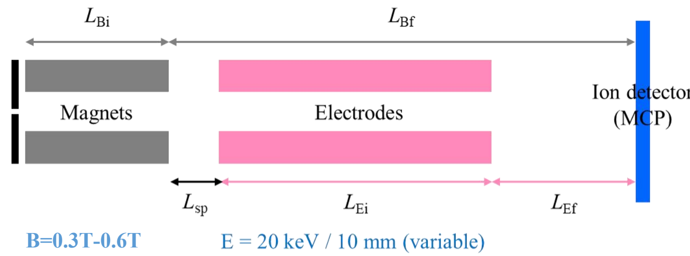
- betatron radiation from NCD plasma
- Compton γ ray from double-layer targets

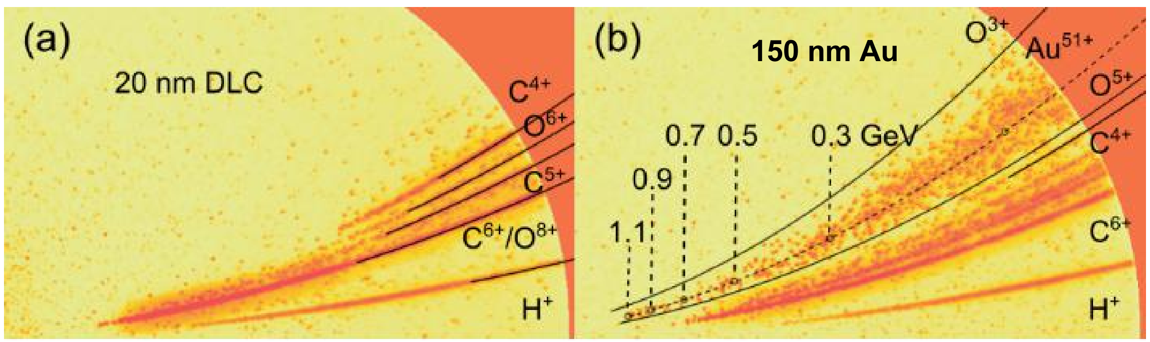


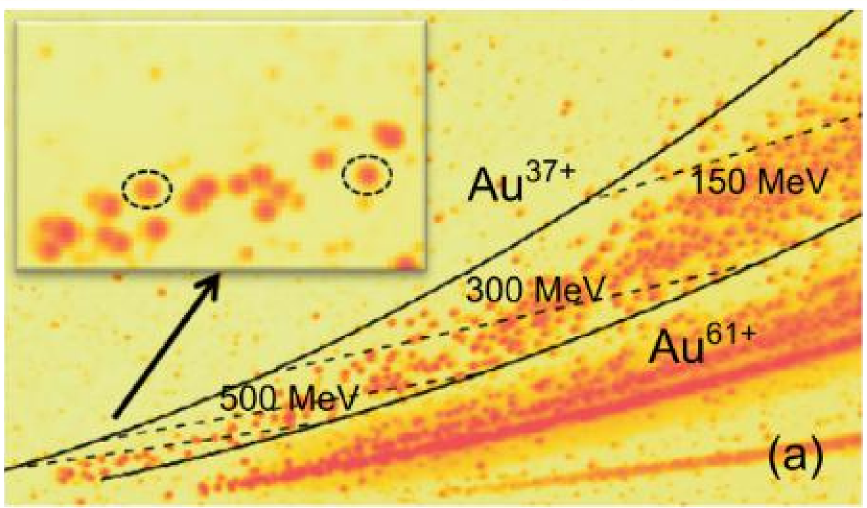
Thomson Parabola used for heavy ions: campaign 1

Setup:



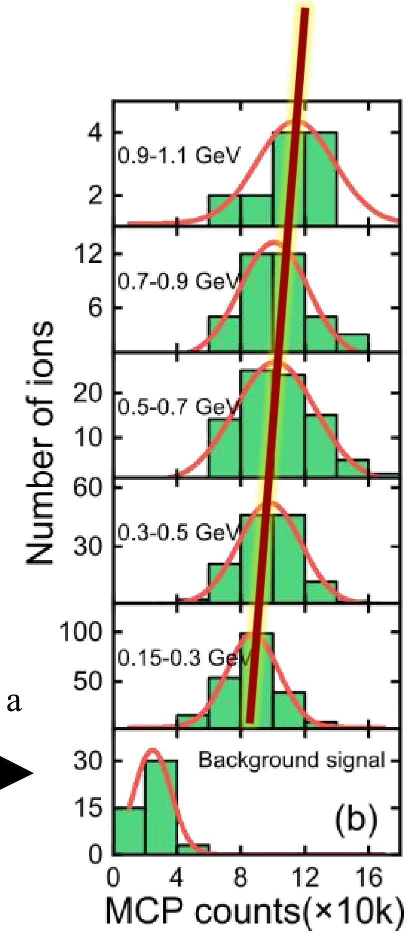






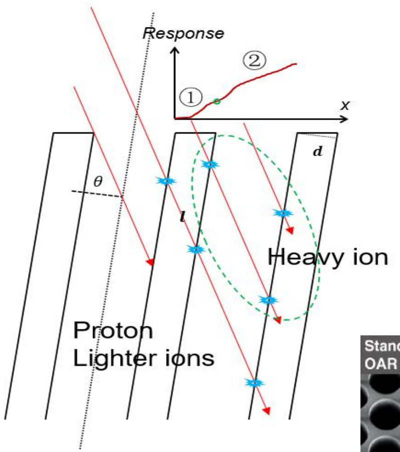
0.4 nc/80 um CNT
150 nm Au foil

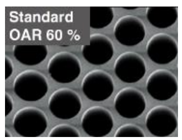
Each of clusters comes from a single Au ion.



Thomson Parabola used for heavy ions: campaign 1

Theoretical response of heavy ions on MCP:





$$Response \propto \frac{1}{cos\theta}\left(\frac{dE}{dx}\right)_e \sum_i P_i \cdot g_i$$

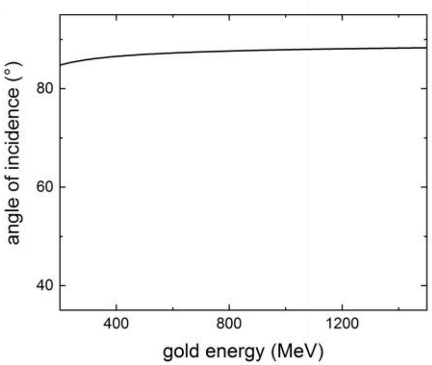
$$\bar{g} = e^{k(L-\bar{x}_L)/L}$$

P =1 if the ion hit a inside surface of a channel

The number of channel surfaces that a ion hits depends on its incident angle, incident position, and its energy.

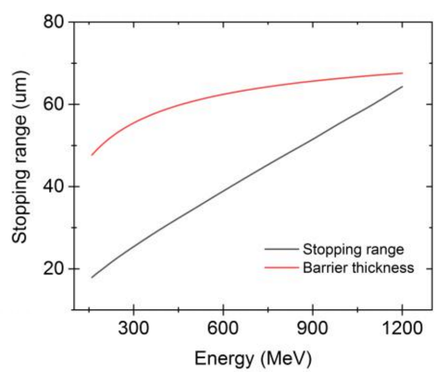
R. Prasad. et.al., NIMA 623.2 (2010): 712-715
Tae Won Jeong. et.al., Review of Scientific Instruments 87, 083301 (2016)

Insident angles on MCP:

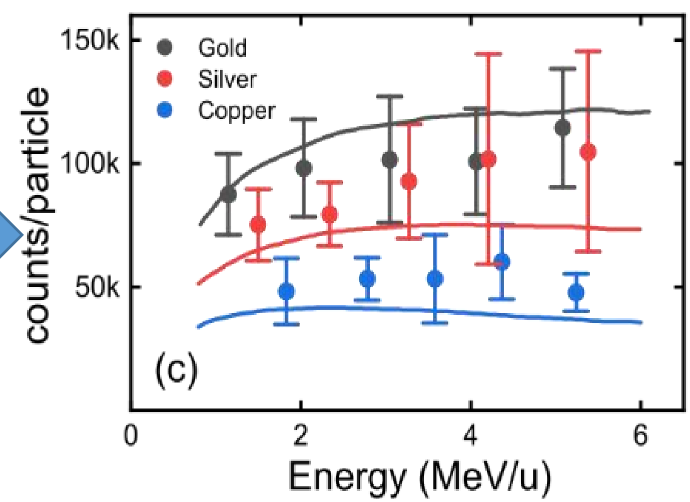


\+

Stoping range of heavy ions in MCP:



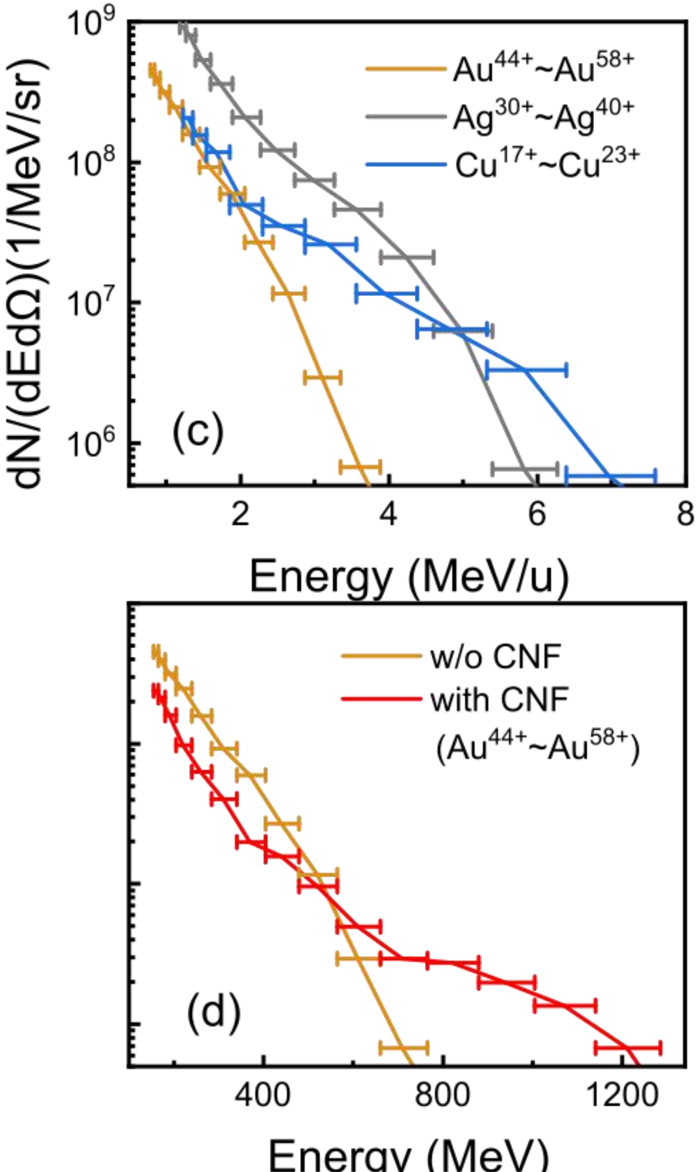
The ***first*** calibration of heavy ions' response on MCP



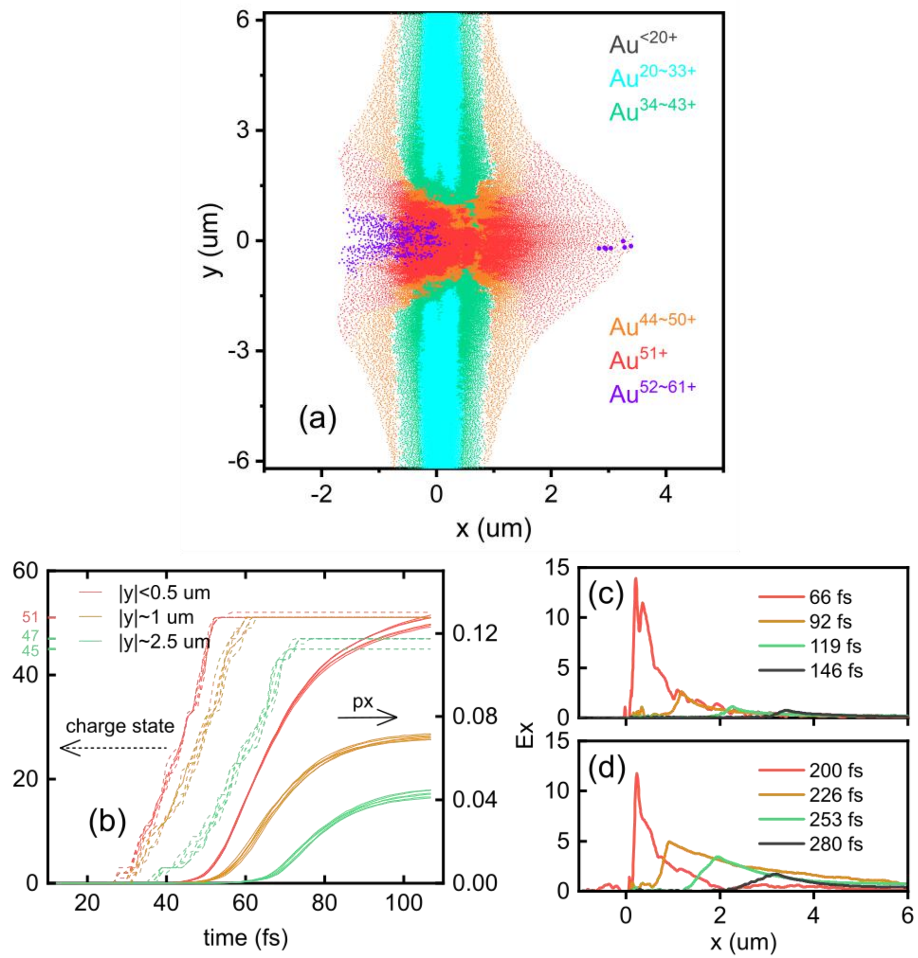
Simulated responses for Au, Ag, and Cu well fit the experimental results.

Thomson Parabola used for heavy ions: campaign 1

Spectra for multi-type ions:

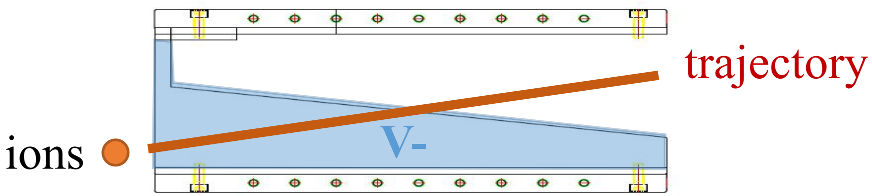


PIC simulation:

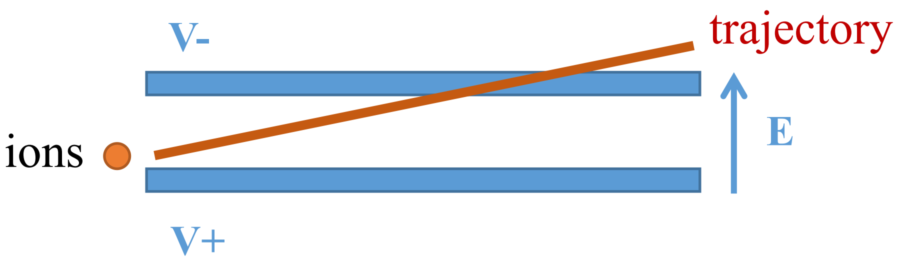


Thomson Parabola used for heavy ions: campaign 2

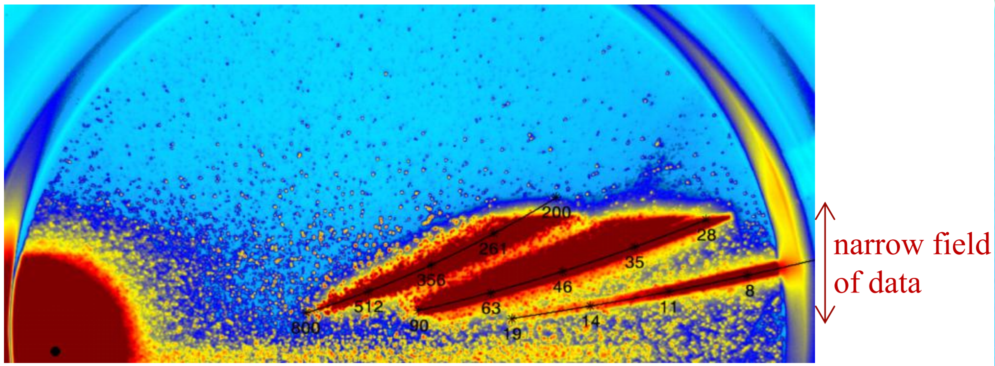
The new design of the Electrode Plate（Top view）：



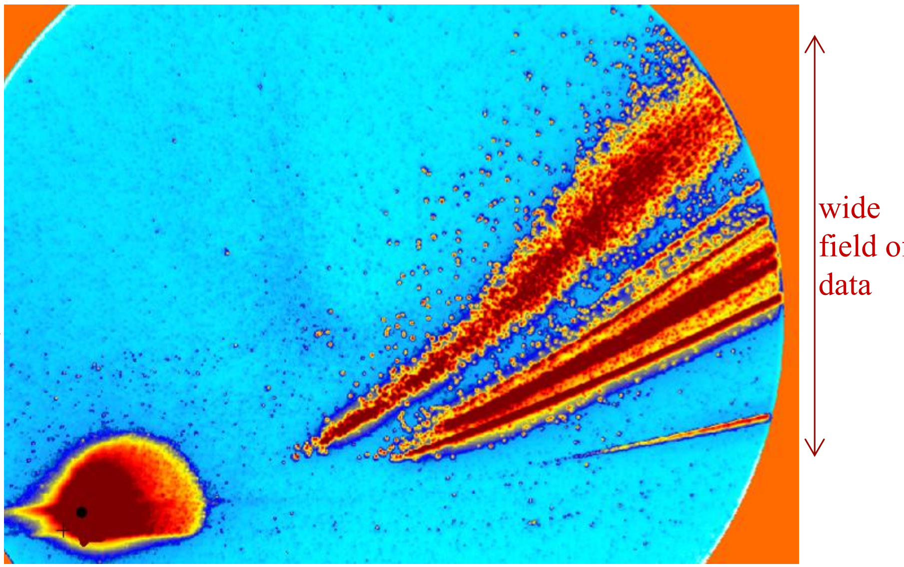
The new design of the Electrode Plate(Side view):



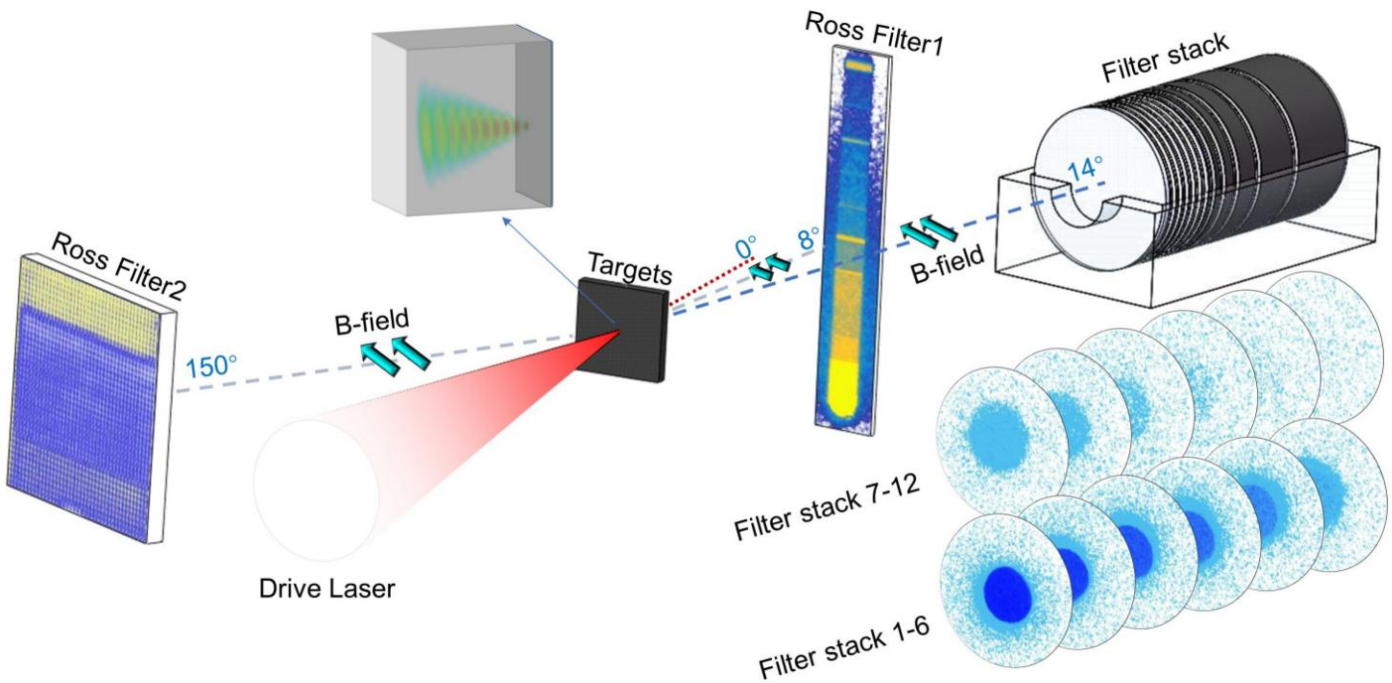
raw data from old TP:



raw data from new TP:



X/γ ray diagnostics



Used diagnostics:

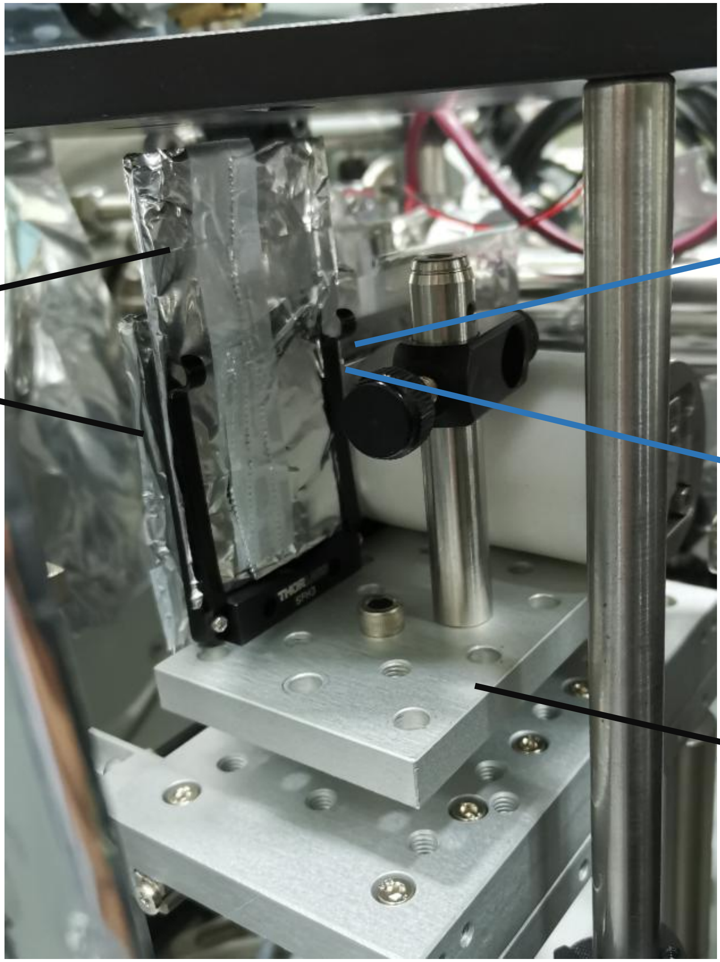
- **Ross filter + IP (9 - 88 keV)**
- **Ross filter + scintillator (30-88keV)**
- **Filter stack (20-1000 keV)**

Targets:

- **single-layer CNT: 80um,1nc**
- **double-layer targets:**

  40um,0.4nc/10nm DLC

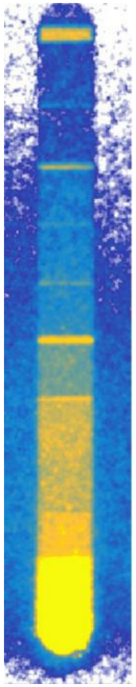
Ross Filter + Image Plate : setup



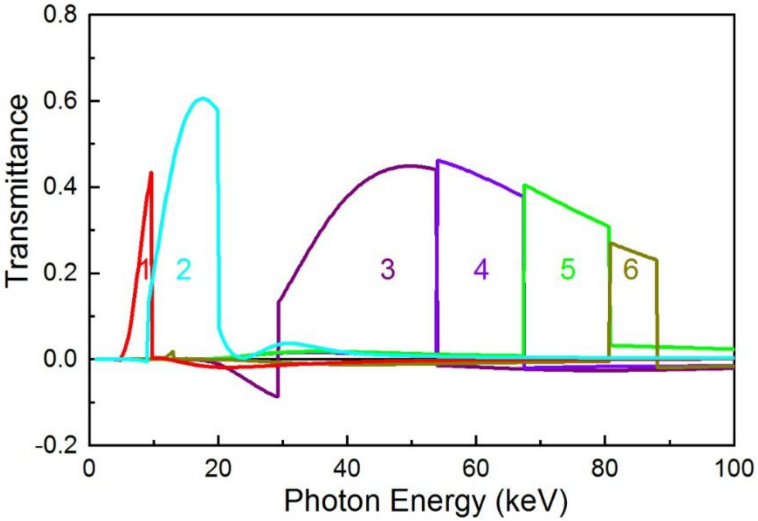
Ross pair	Filter1	Filter2
1	Zn (20μm)	Ti (70μm)
2	Mo (15μm)	Cu (50μm)
3	Dy (100μm) Cu (50μm)	Sn (220μm) Cu (25μm)
4	Ta (45μm) Cu (15μm)	Dy (100μm) Cu (50μm)
5	Au (29μm) Cu (15μm)	Ta (45μm) Cu (15μm)
6	Pb (50μm)	Au (29μm) Cu (15μm)

Ross Filter + Image Plate : data and results

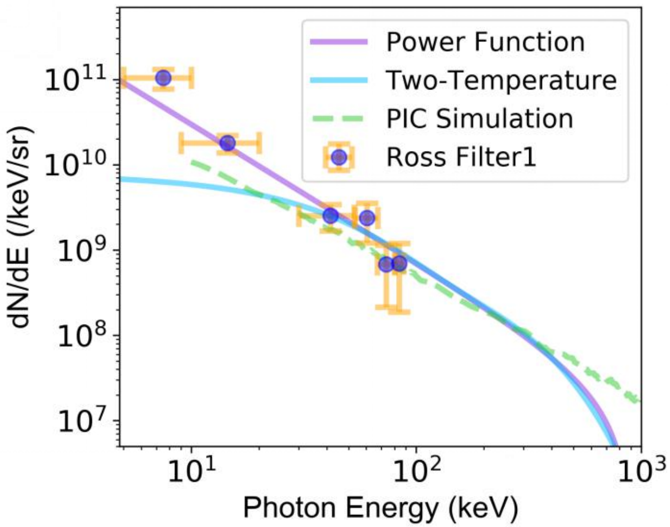
Raw data



Transmission of the filters



Spectra



$$\frac{dN}{dE} = \frac{\Delta S}{\bar{T} \cdot \bar{R} \cdot \Delta E}$$

ΔS the signal difference between two filters of pair

$\bar{T}$ mean transmittance of the pair window

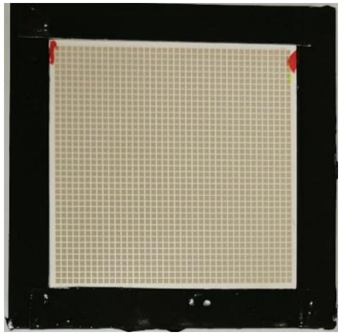
$\bar{R}$ mean response of Image Plate considering time decaying

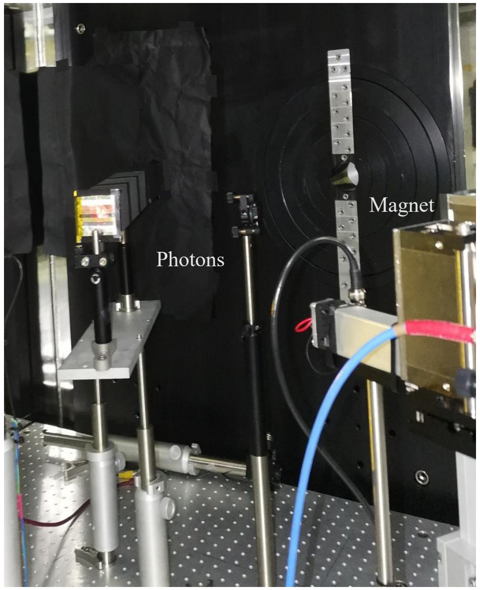
ΔE bandwidth of the pair window

Ross Filter + Scintillator

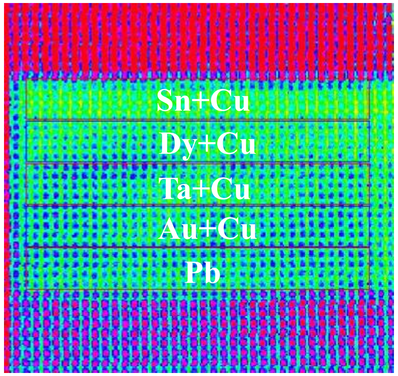
Filters

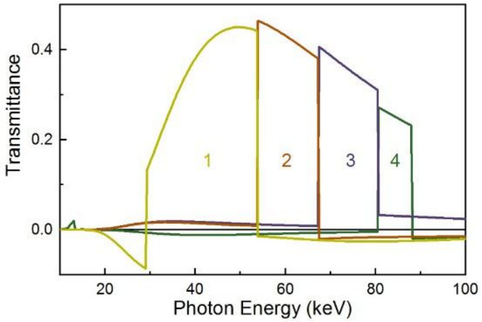
Scintillator array
1mm*1mm, 50*50





Raw data

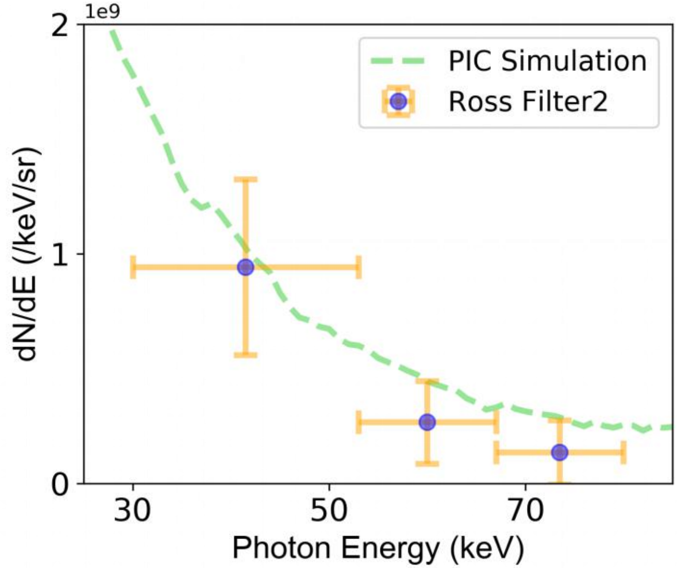




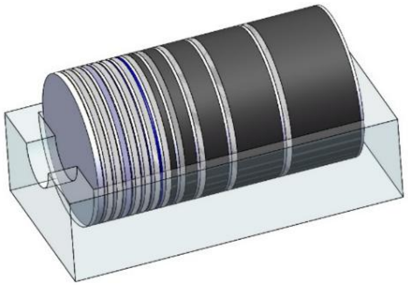
Ross pair	Filter1	Filter2
1	Dy (100μm) Cu (50μm)	Sn (220μm) Cu (25μm)
2	Ta (45μm) Cu (15μm)	Dy (100μm) Cu (50μm)
3	Au (29μm) Cu (15μm)	Ta (45μm) Cu (15μm)
4	Pb (50μm)	Au (29μm) Cu (15μm)

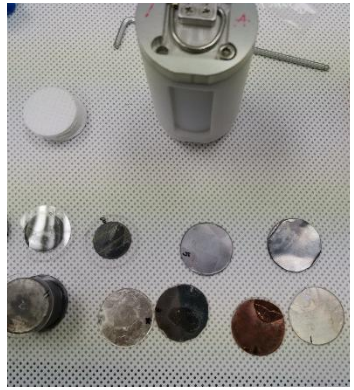
Realization of real-time measurement

Spectra



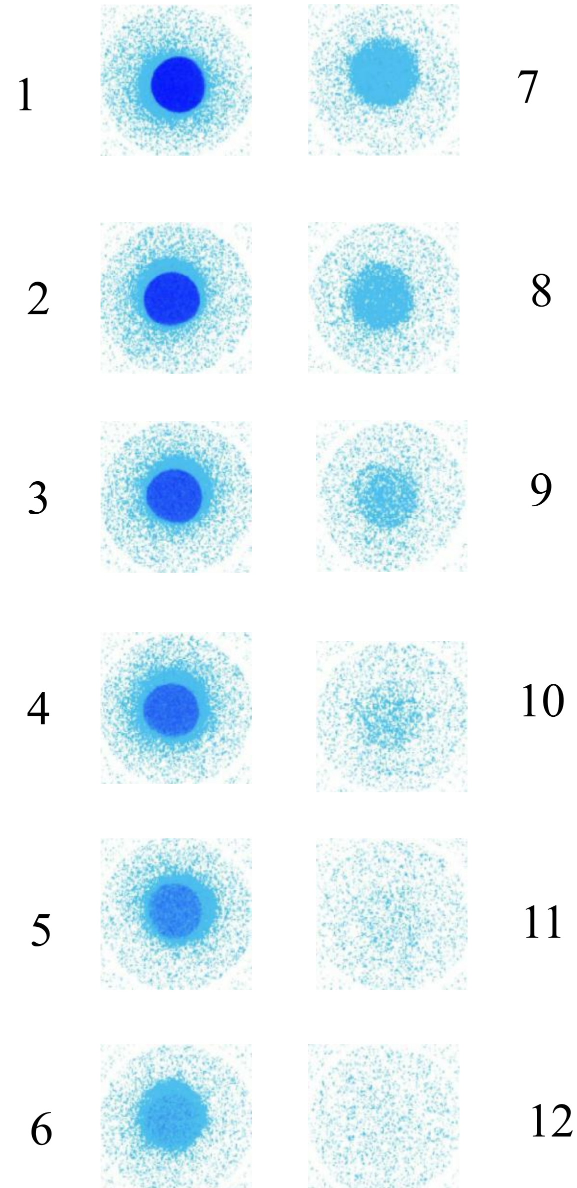
Filter Stack : setup and raw data





Order	Material	Thickness（mm）
1	Ti	0.1
2	Cu	0.1
3	Mo	0.1
4	Ag	0.15
5	Ta	0.15
6	Ta	0.2
7	Ta	0.4
8	Pb	1
9	Pb	2
10	Pb	4
11	Pb	8
12	Pb	12

Raw data



Filter Stack : spectra deconvolution

$$\Delta S_i = \frac{S_i - f(E) \cdot R_i(E)}{S_i}$$

least square $\sum_i (\Delta S_i)^2$

S_i PSL value of Image Plate layer i

$f(E)$ supposed spectrum

two-temperature and power function model were employed

$$f(E) = C[a \cdot e^{-\frac{E}{T_1}} + (1-a) \cdot e^{-\frac{E}{T_2}}]$$

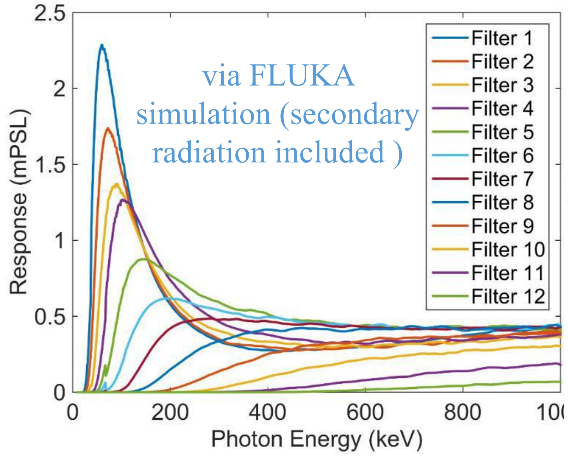
$$f(E) = a \cdot e^{-b} + c$$

$R_i(E)$ calculated response curve of image plate layer i

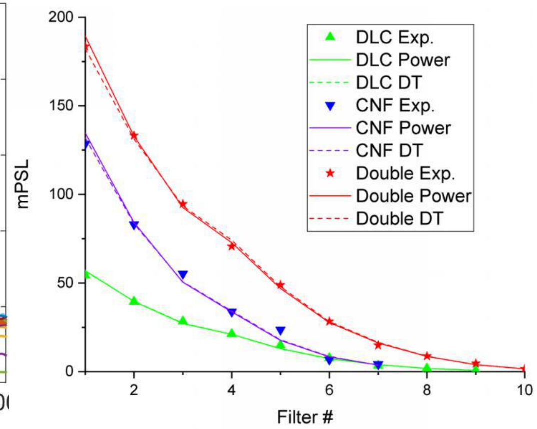
transmittance of Al window and air from XOP

energy deposited in the Image Plate layers considering the effect of secondary electrons from FLUKA

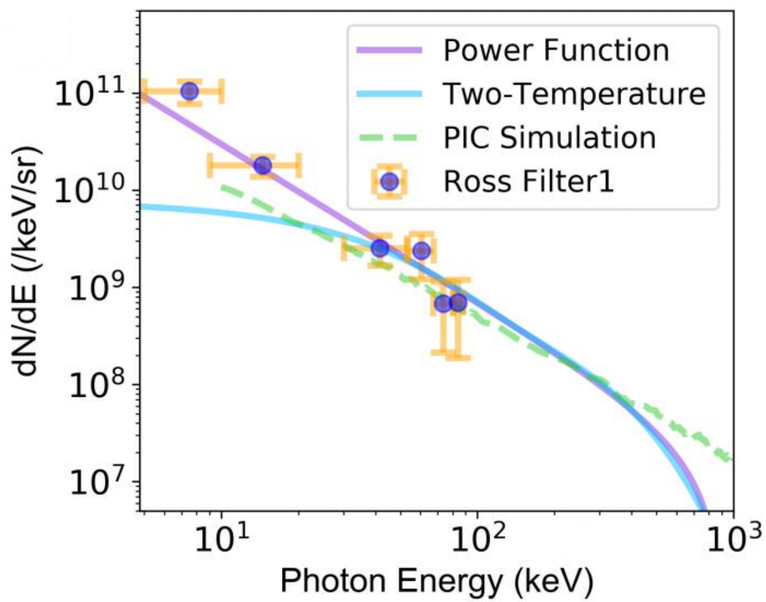
relationship between deposited energy and PSL value from Rev. Sci. Instrum. 84, 103510 (2013)



Fitted experimental retults

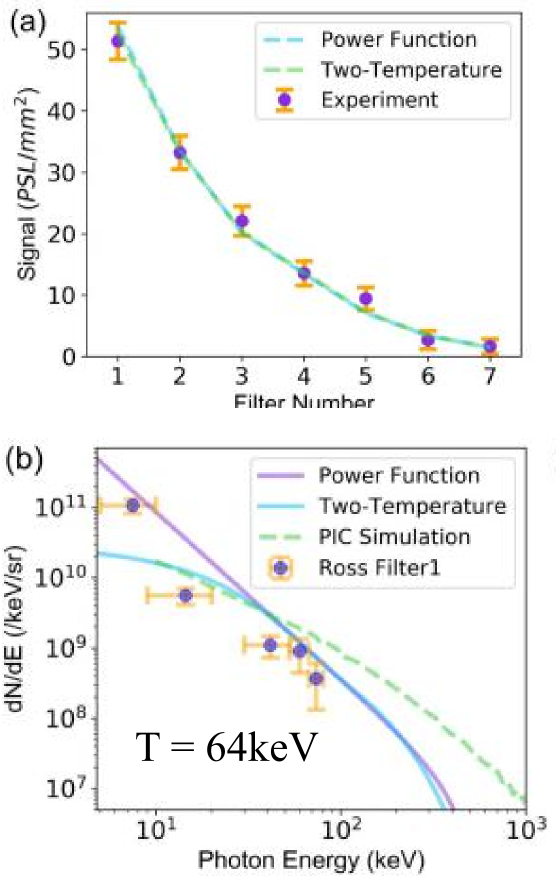


Spectra

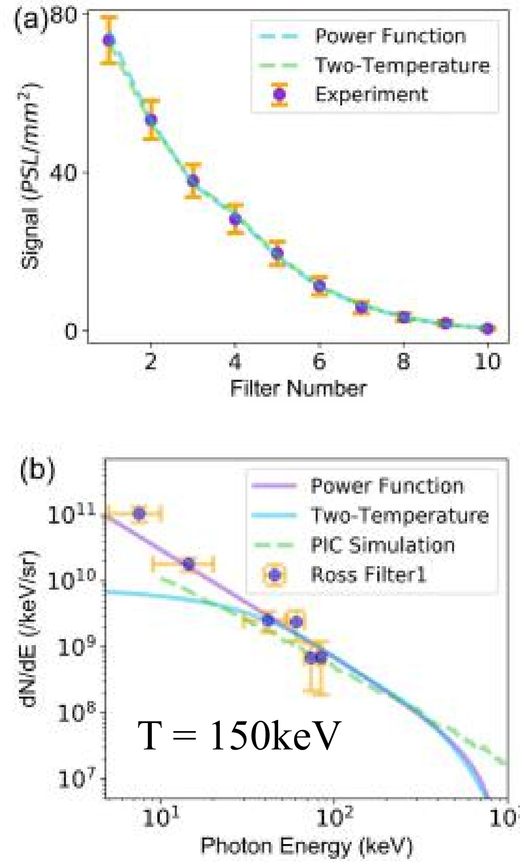


single-layer targets *vs* double-layer targets

single-layer CNT targets



double-layer CNT targets



Thank you

The slides are for sharing in BLIN4 workshop and on the website later on