Photonuclear Reactions using Gamma-Rays Created by A High-Energy Petawatt Laser and Applications

Edison Liang, Rice University*

*On behalf of the Rice, UTA, LLNL and LANL collaboration:

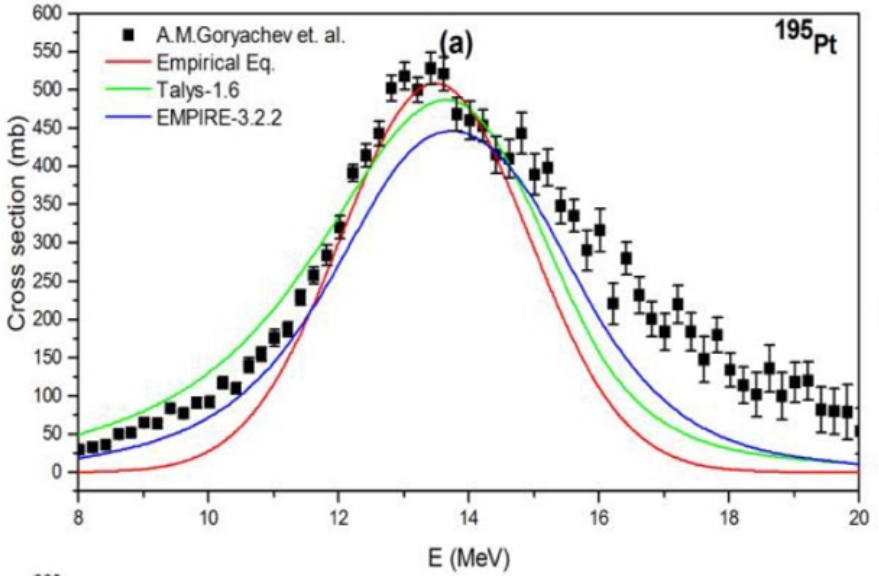
E.Liang[1], W.Lo[2], B.Cage[1], S.Arora[1], K.Q.Zheng[1], E. Fang[1], M. Weiss[1]. L. Simon[1],H.Quvedo[2], S.A.Bruce[2], M. Spinks[2], E. Medina[2], A. Helal[2], T. Ditmire[2], S. Libby[3], S. Willks[3], A. Nikroo[3], J. Nguyen[3] , T. Mix[4]

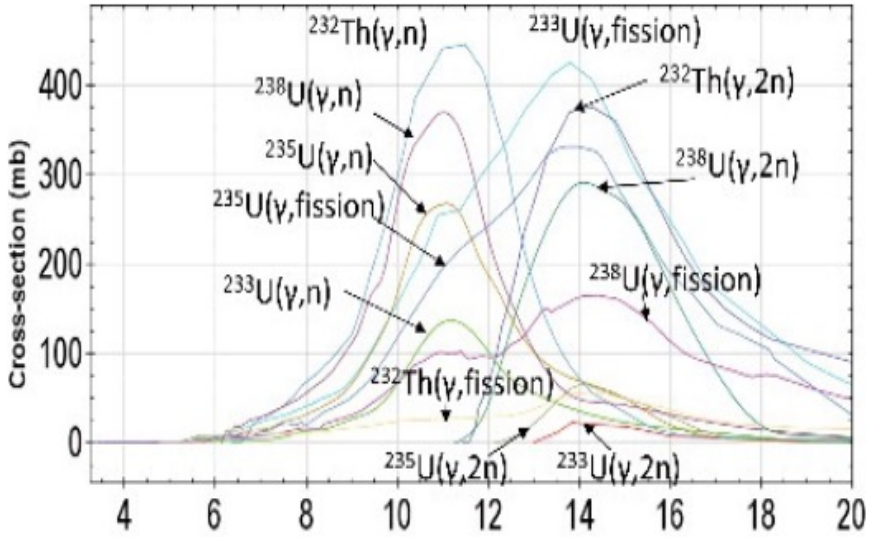
[1] Rice University, [2] University of Texas at Austin, [3] LLNL, [4]LANL

Rice Research Supported by US DOE DE SC0024874

Invited talk at the 2026 ECT Workshop 8/10-14/2026, Trento, Italy

Most Photonuclear cross-sections peak at 8 MeV – 26 MeV due to Giant Dipole Resonance (GDR). Hence we need narrow-band gamma-rays of these energies to facilitate the study and applications of these reactions.





GDR cross-sections for (γ, n), (γ, 2n) and (γ, fission) reactions mostly span ~8 – 25 MeV. Hence photoneutron and photo-fission yields are highly sensitive to the gamma-ray fluence in this energy band.
.I will refer to gamma-rays of these energies as “GDR gamma-rays”

- This talk is divided into 3 Sections

- 1. Creation and diagnotics of “GDR gamma-rays” (8 – 25 MeV) excess using an HEPW laser to irradiate dense high-Z targets.

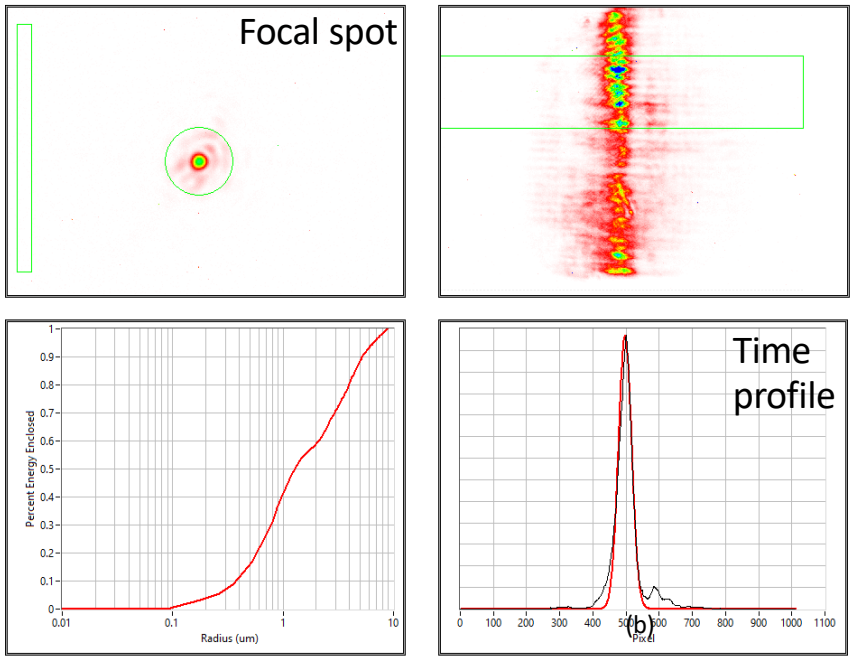
- 2. Production mechanism of “GDR gamma-rays”

- 3. Applications

1. TPW gamma-ray experiments (2016-2023)

- Over the past decade, using the 130J, 130ps TPW laser in Ausiin TX to irradiate dense high-Z targets (W. Re, Pt, Au..), we discovered that the gamma-rays consist of two separate components: (a) hot electron bremsstrahlung with quasi-exponential spectrum of kT~MeV, plus (b) a band-limited "bump" peaking at ~10-20 MeV. Component (b) is only observed near laser forward (LF) directions. This discovery was achieved using our new SAS gamma-ray spectrometer developed jointly with MDACC in Houston.
- In 2022 we used 3 independent diagnostics to crpss check the SAS gamma-ray data: positron yield and spectrum, photoneutron yield, and transmutation of actinides. All three diagnostics confirm the gamma-ray excess >~ 8 MeV discovered by the SAS.
- We measured up to few x 10^{12} GDR gamma-rays > 8 MeV (~ 3-4 % of laser energy), (b) up to ~ few x 10^{10} photoneutrons per shot.

SHOT# 014897 2022-06-23



Energy
135 J

Pulse Duration
138 fs

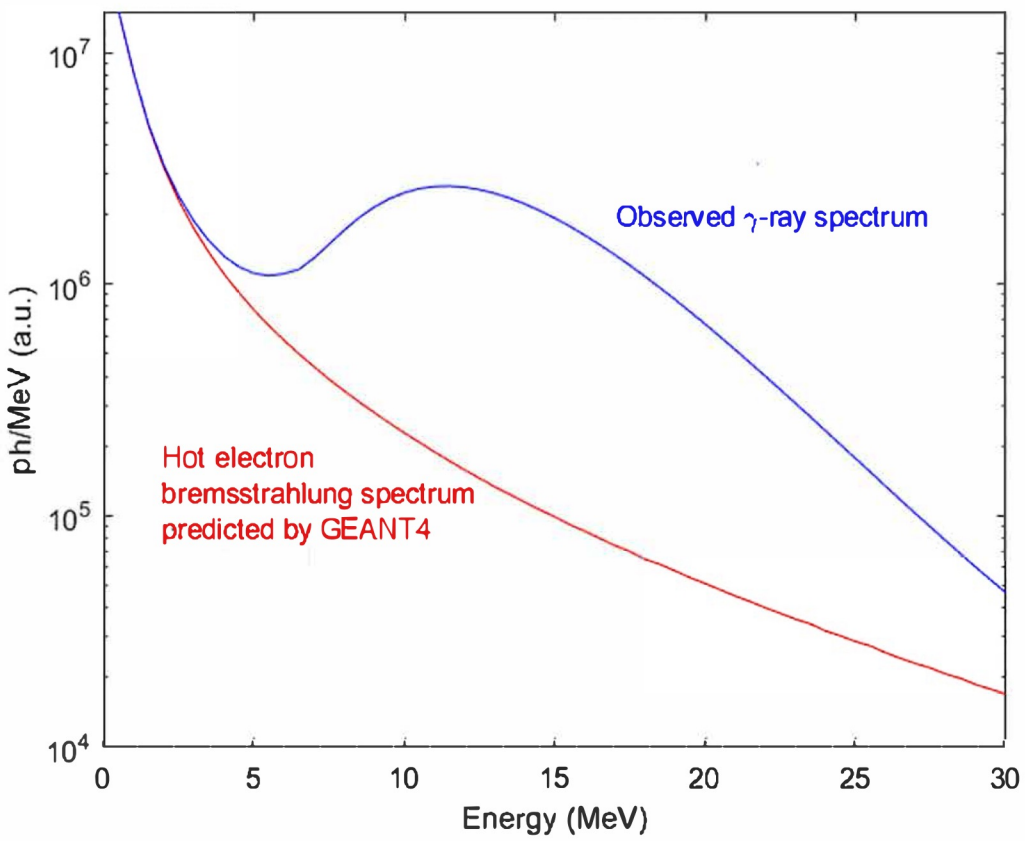
Power
980 TW

I = 4.7e+21 W/cm2

6/23/2022 4:22:12 PM

TPW laser parameters of our 2022 60-shot run

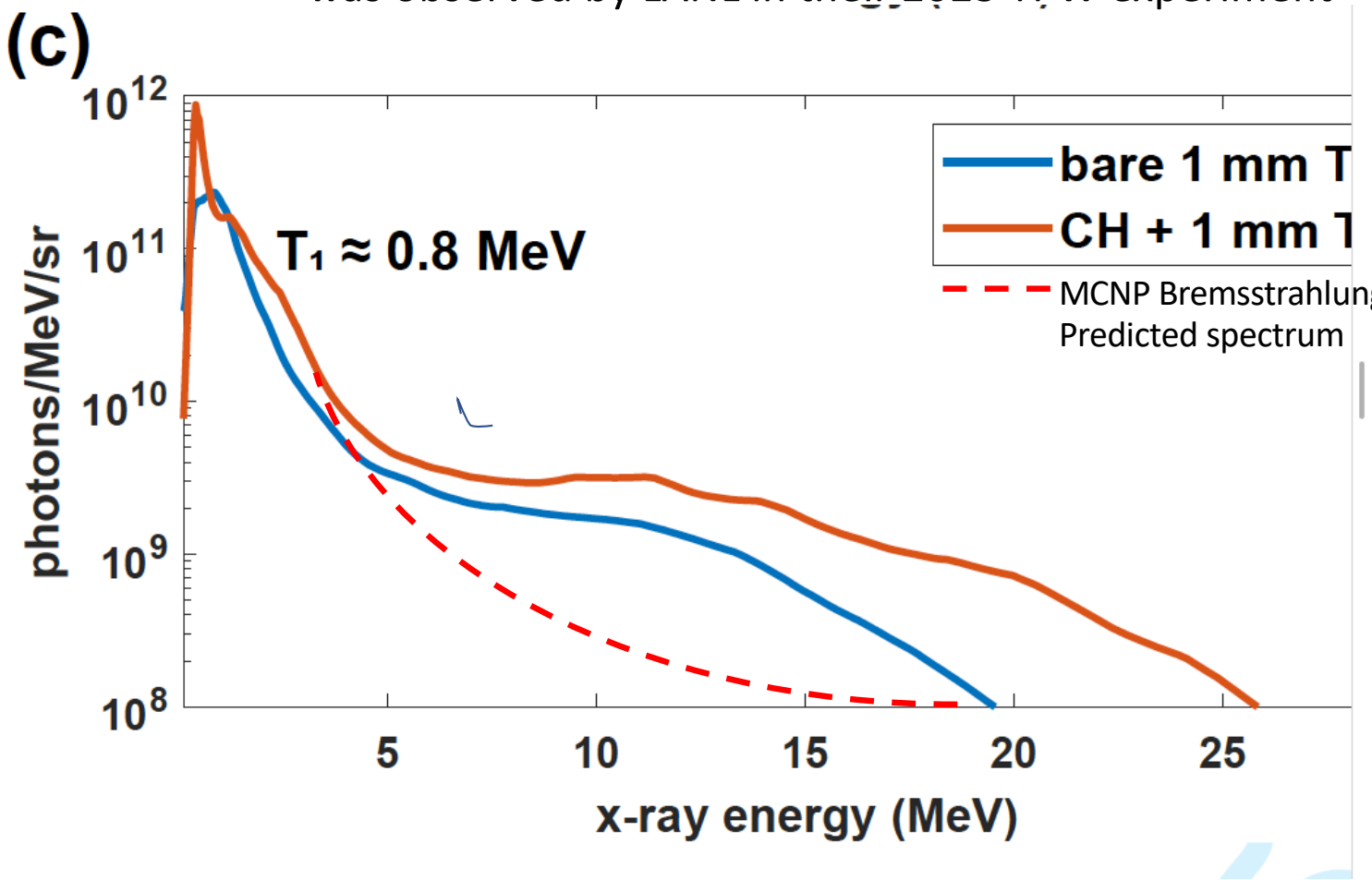
	Energy	Pulse Duration (fs)	Peak Power (TW)	closed Radius with 50% (u	ak Intensity (W/cm	Strehl
AVERAGE	123.25	161.05	781.82	3.8	2.96E+21	0.68
MEDIAN	122.57	158	794.12	3.72	2.89E+21	0.7
MIN	104.2	128	531.29	2.42	1.85E+21	0.46
MAX	139.18	216	1060.68	5.39	4.68E+21	0.82



Pure hot electron bremsstrahlung would predict ~50 times less gamma rays > 8 MeV than we observed at LF

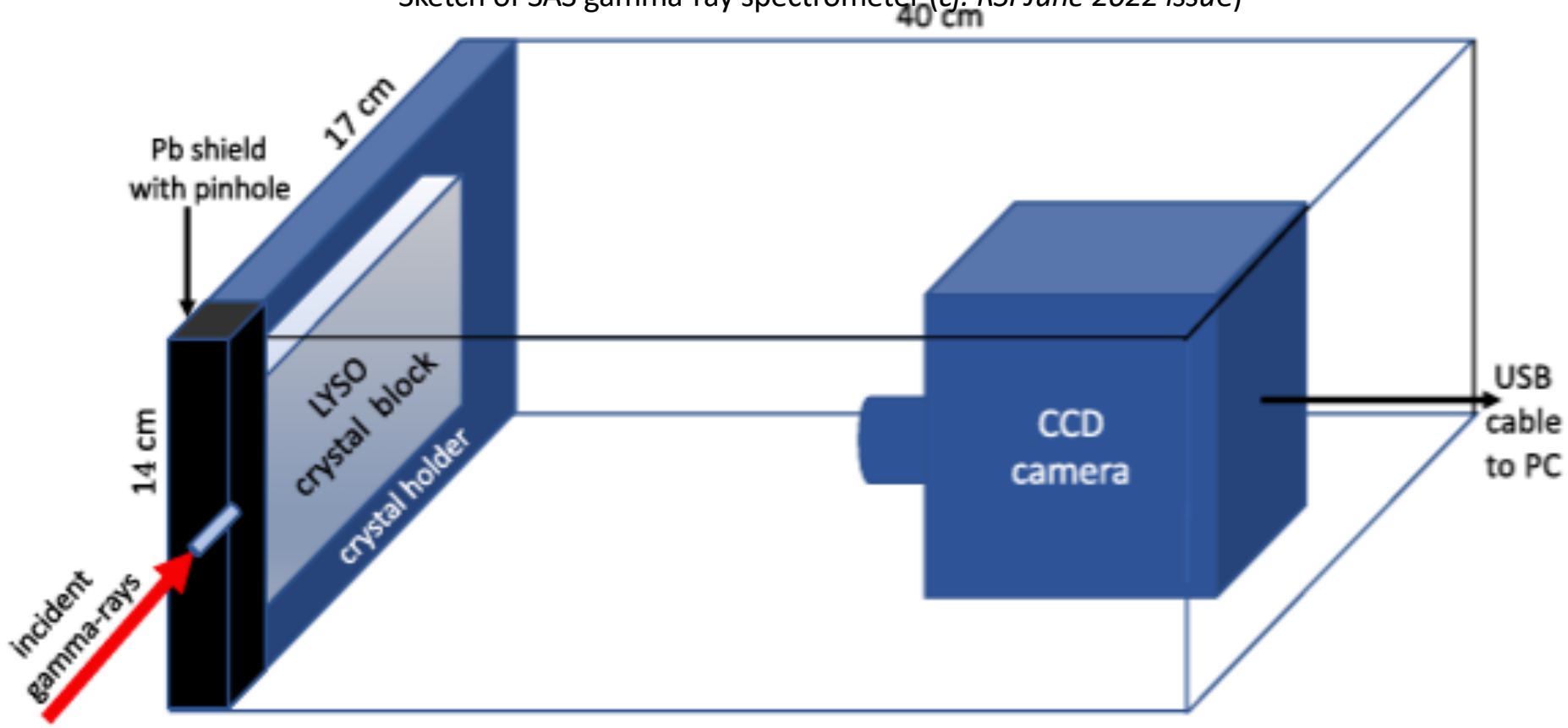
TPW gamma-ray excess broadly coincides with GDR peak

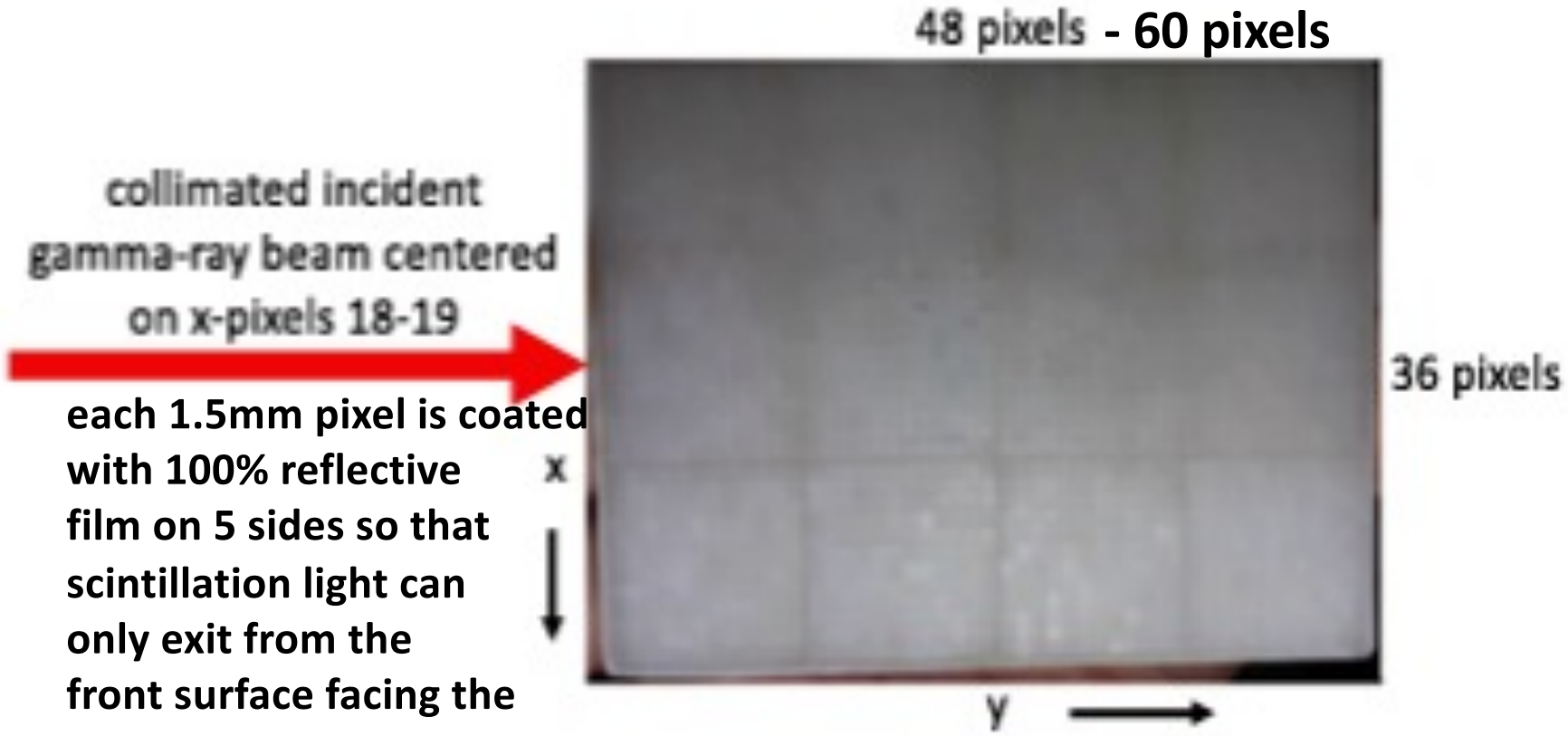
Similar Gamma-Ray excess above bremsstrahlung prediction was observed by LANL in their 2023 TPW experiment



(Adapted *from Strolhow et al PoP 2025)*

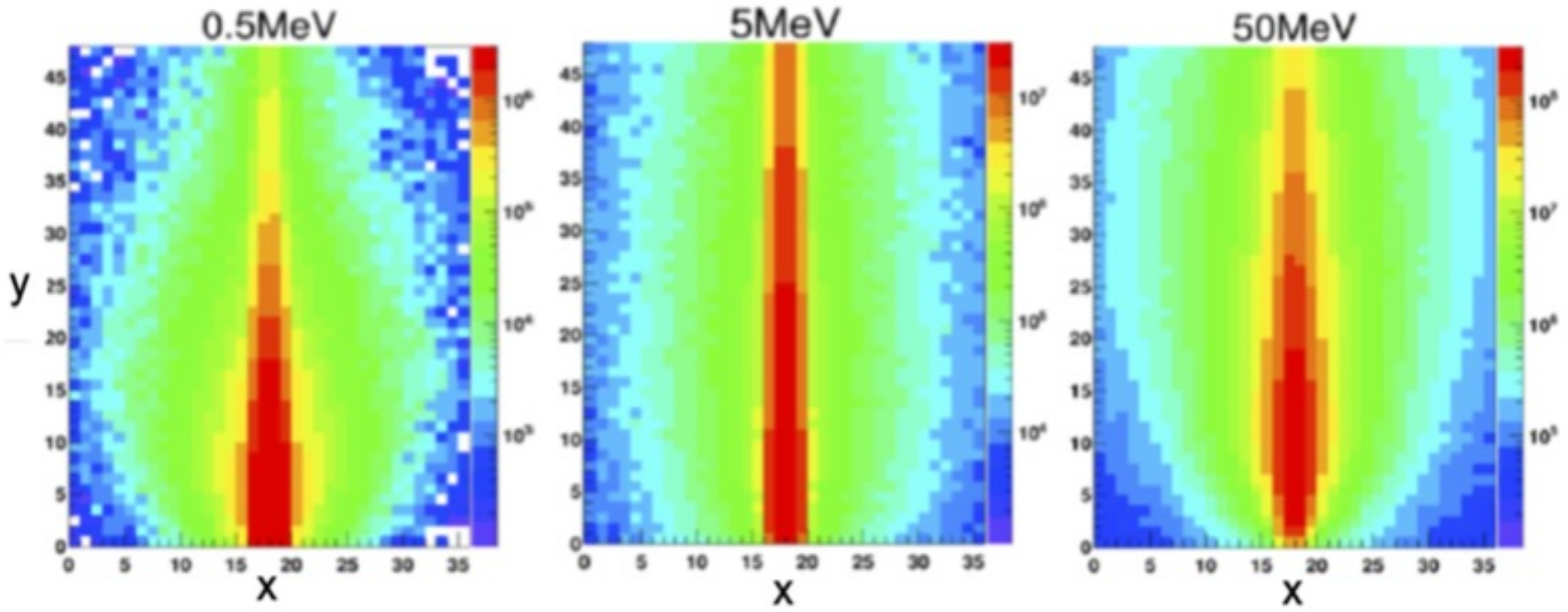
Sketch of SAS gamma-ray spectrometer (*cf. RSI June 2022 issue*)





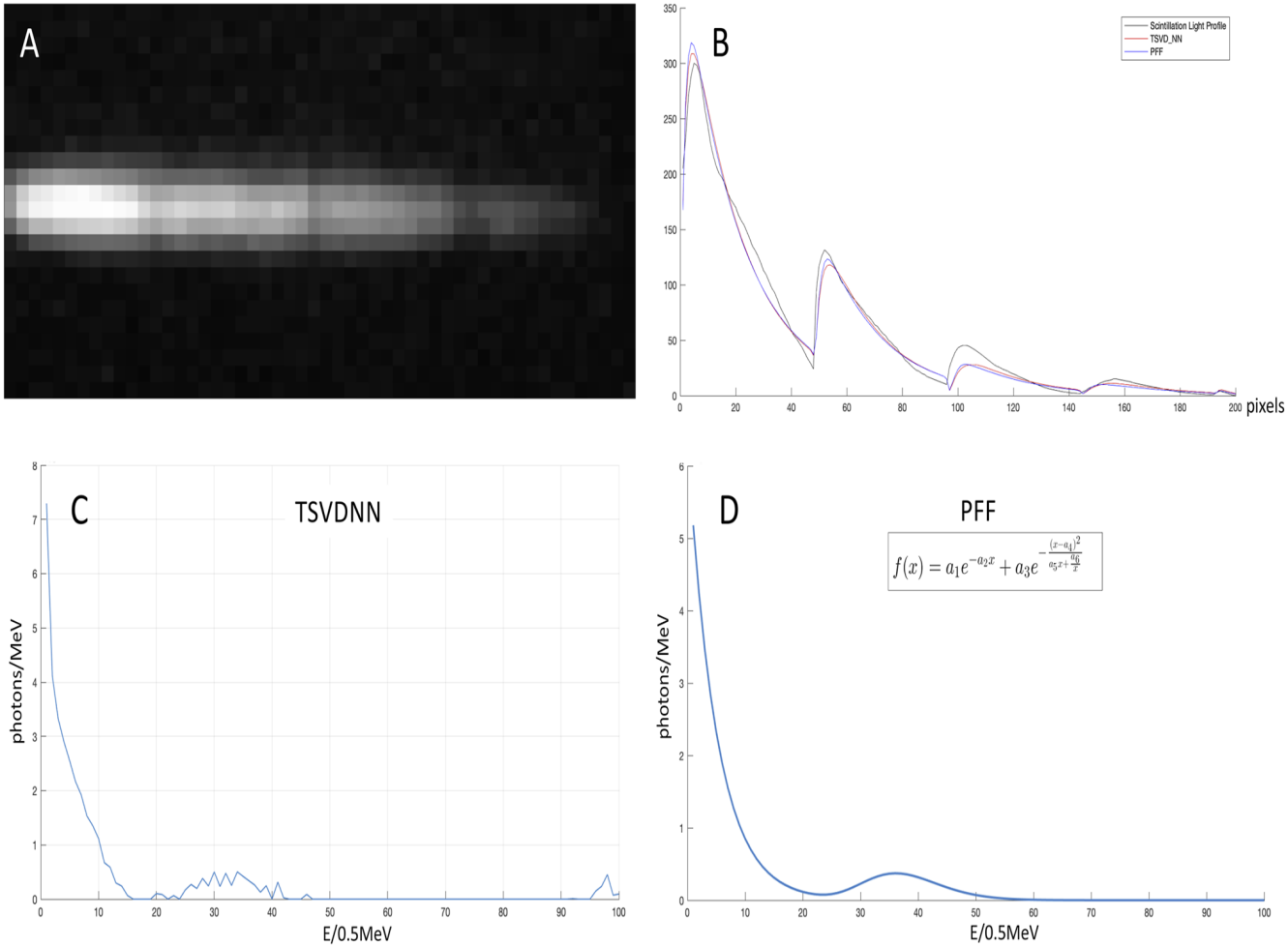
each 1.5mm pixel is coated with 100% reflective film on 5 sides so that scintillation light can only exit from the front surface facing the camera

light patterns from different monoenergetic gamma-rays are clearly distinguishable

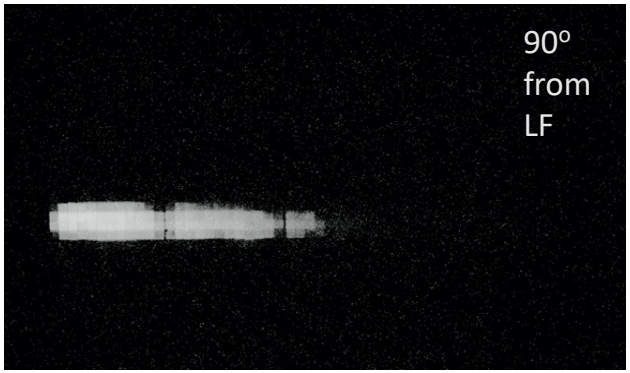


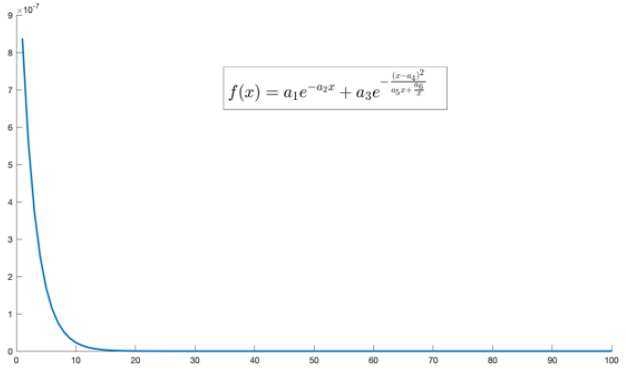
Shot 10084, LF
2016

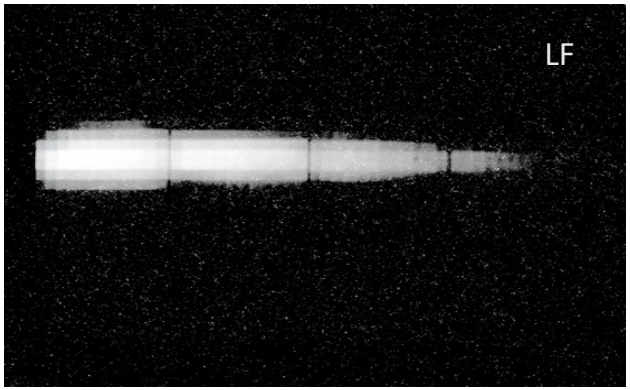
From RSI June 2022

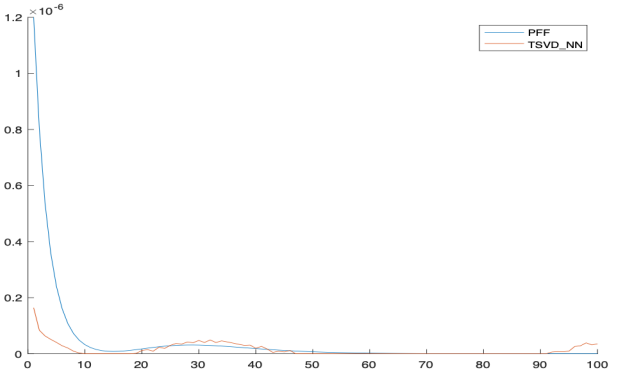


Shot 14833





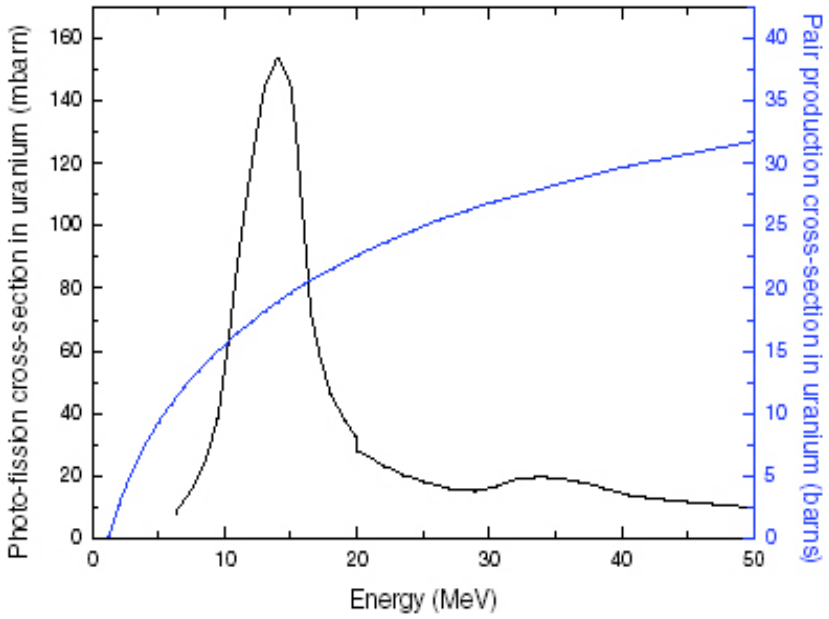




To confirm or dismiss SAS results

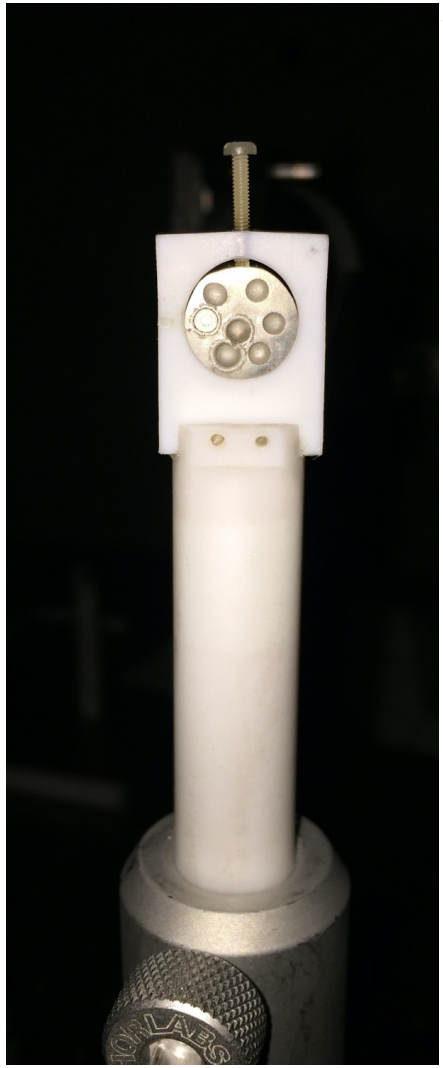
In 2022 we employed 3 independent diagnostics

1. Positrons
2. Photoneutrons
3. Actinide transmutation

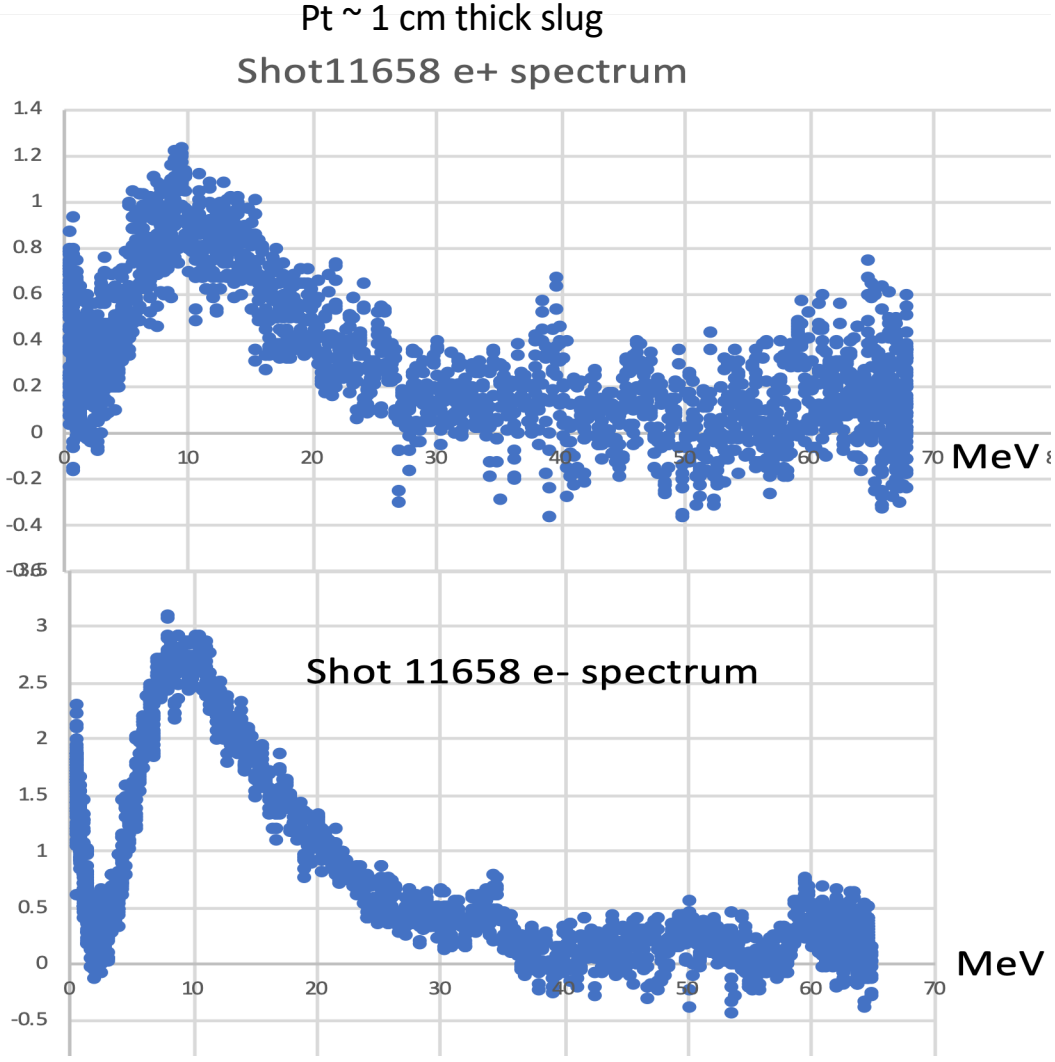


Pair creation and GDR cross sections differ in energy dependence, hence e+/n ratio provides sensitive test of gamma—ray spectrum independent of absolute normalization. Our data was consistent with excess gamma-rays peaking between 10-20 MeV.

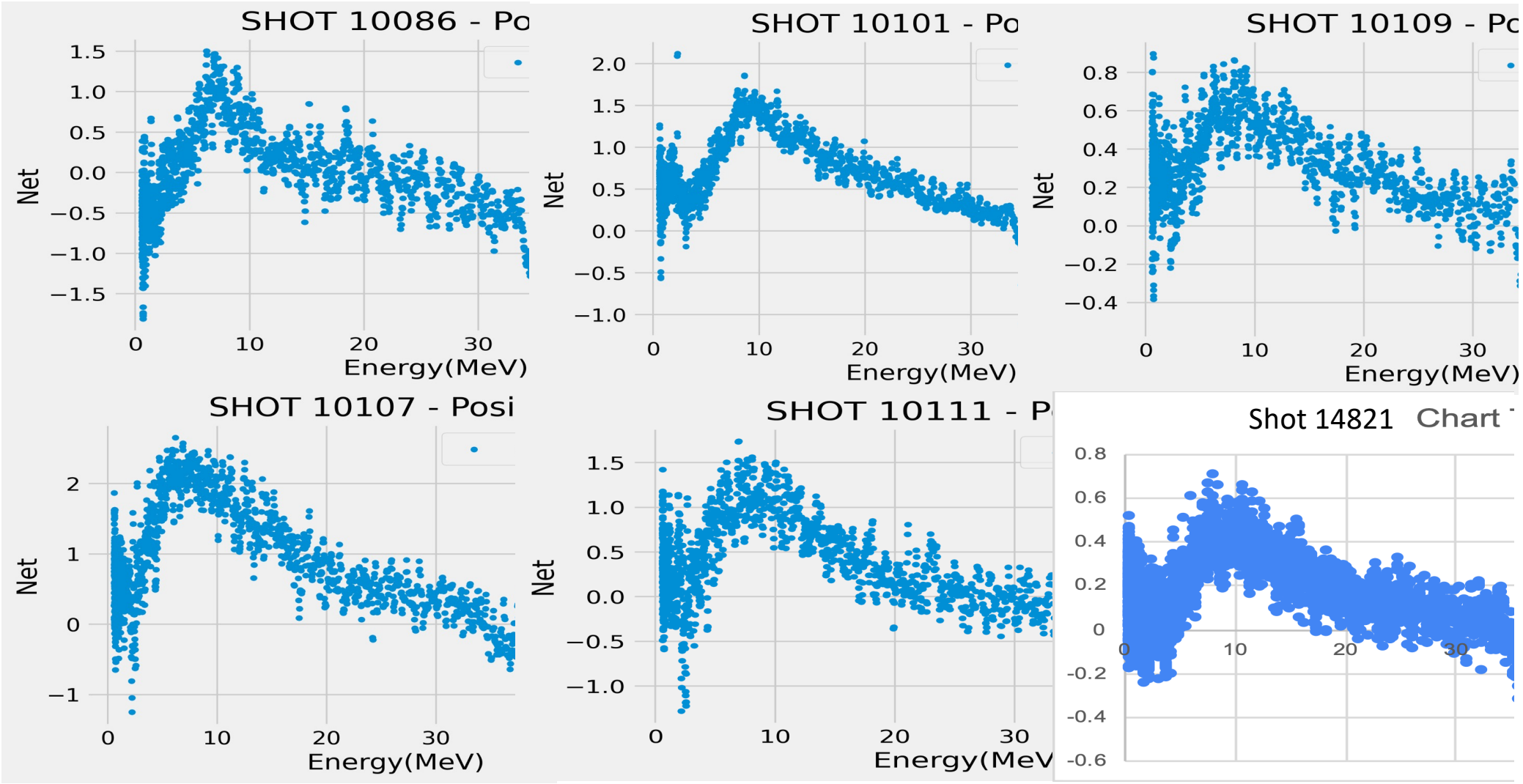
For very thick (~ cm) targets, e+e- spectra almost Identical, dominated by pairs created within ~1 mfp of target back surface. Equal peak energies suggest that sheath fields did not affect the peak energy. Hence Epeak must come from gamma-ray spectrum



Pt ~ 1 cm thick slug

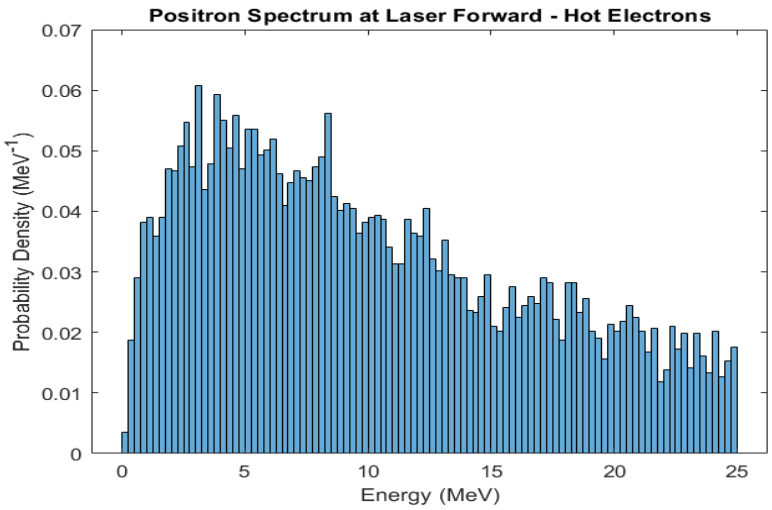


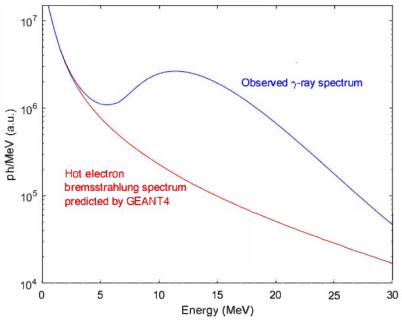
Positron spectra of thick targets all peak at 7.5 MeV +/- 1.5 MeV



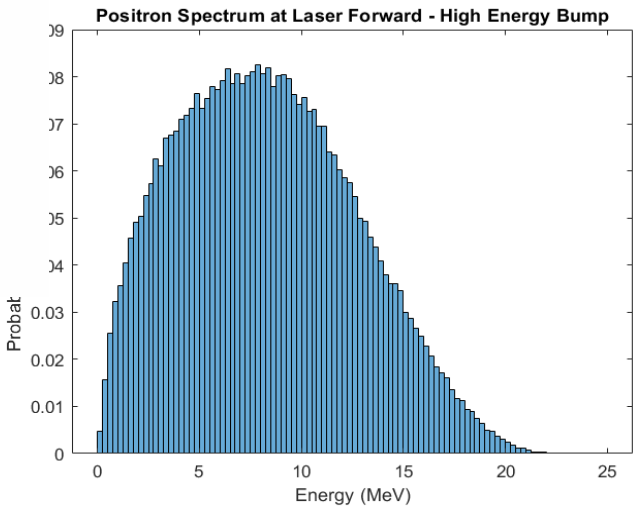
Hot electrons +

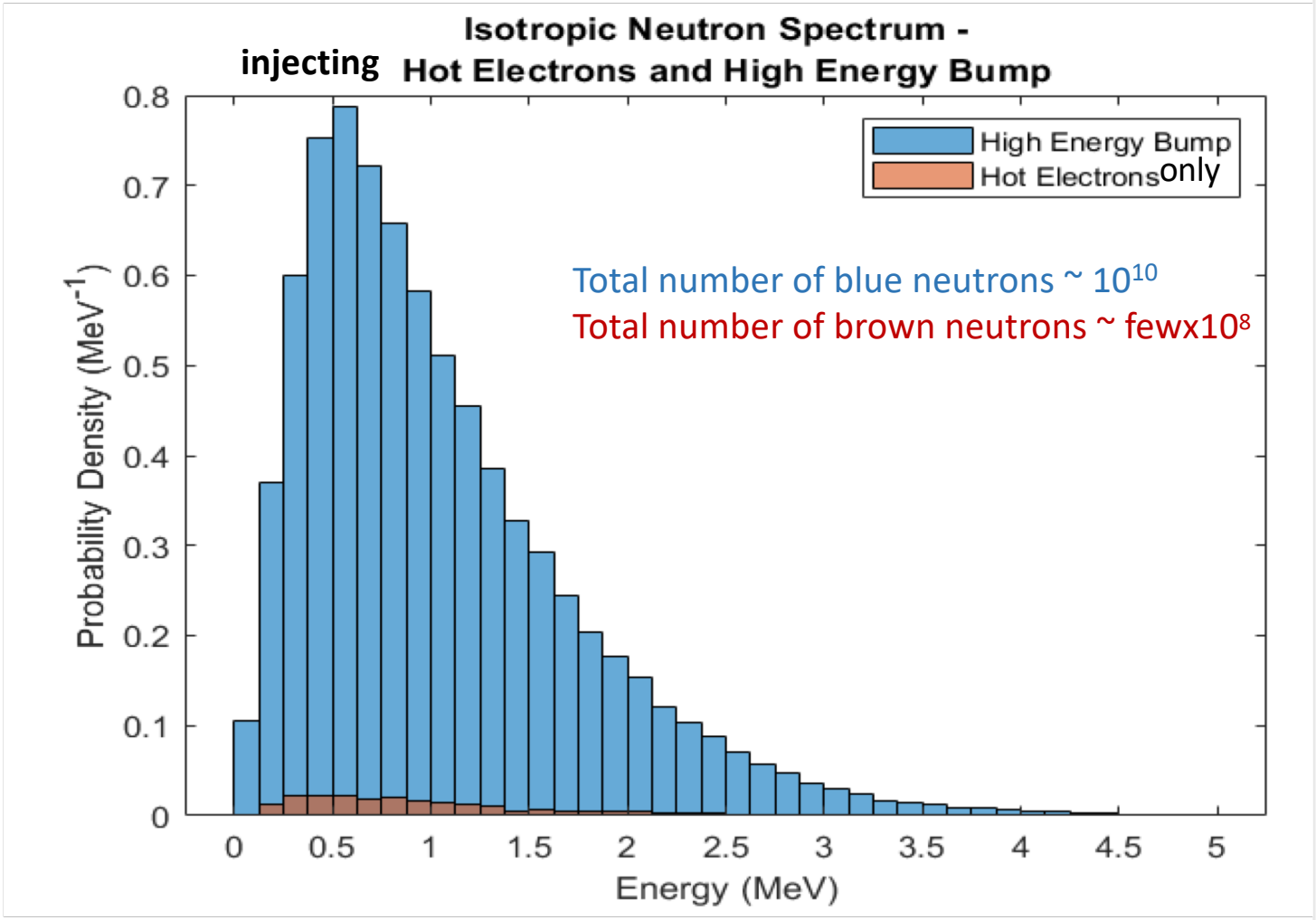
e+ peak energy too low
with only bremsstrahlung

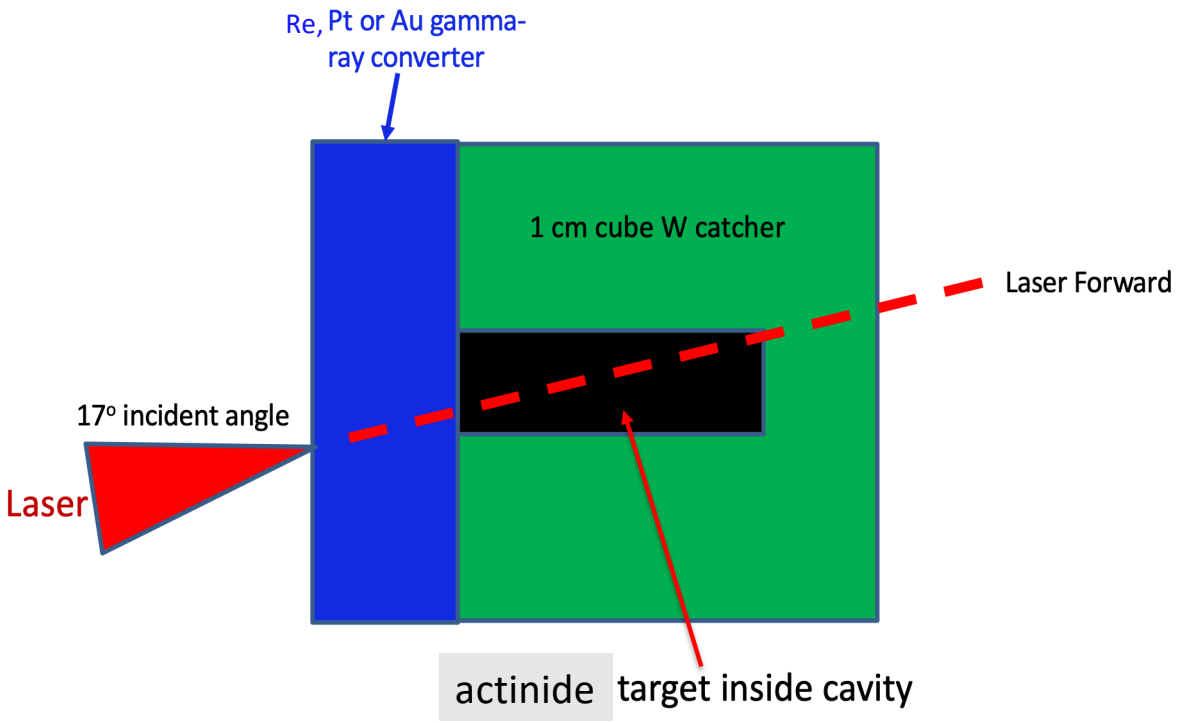


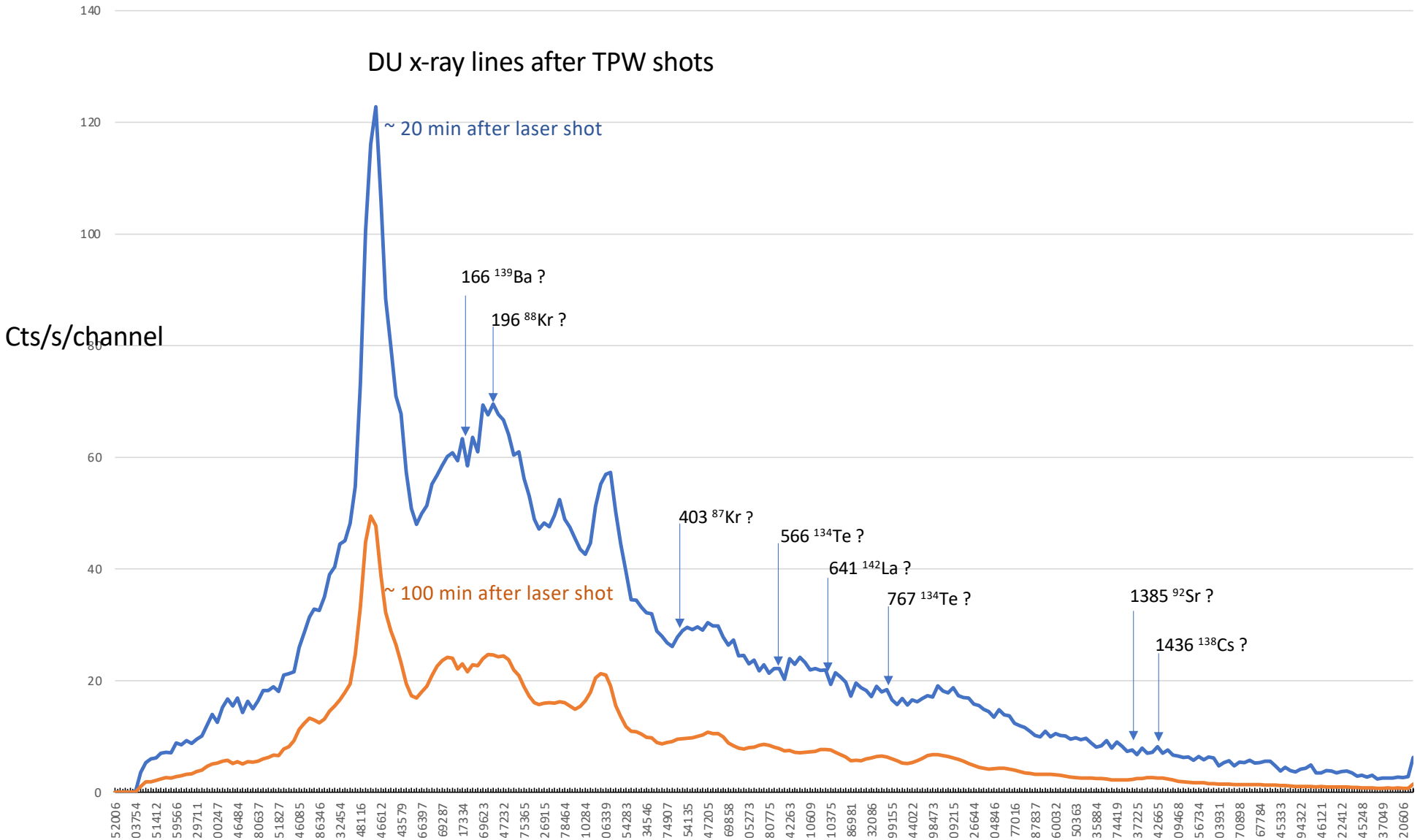


e+ peaks at observed
energies

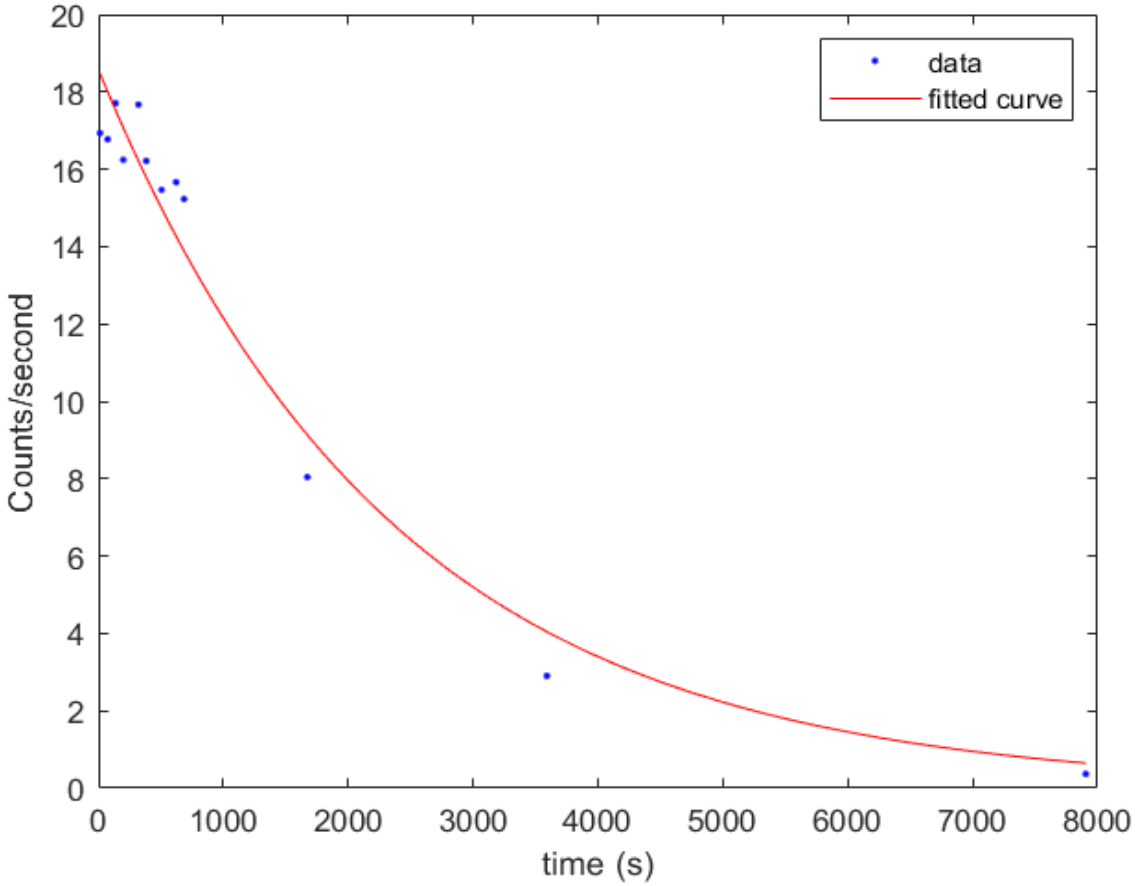



Isotropic Neutron Spectrum -
injecting Hot Electrons and High Energy Bump
High Energy Bump
Hot Electrons only
Total number of blue neutrons ~ 10^10
Total number of brown neutrons ~ fewx10^8
Probability Density (MeV^-1)
Energy (MeV)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5


Re, Pt or Au gamma-ray converter
1 cm cube W catcher
Laser Forward
17° incident angle
Laser
actinide target inside cavity


DU x-ray lines after TPW shots
~ 20 min after laser shot
~ 100 min after laser shot
166 139Ba ?
196 88Kr ?
403 87Kr ?
566 134Te ?
641 142La ?
767 134Te ?
1385 92Sr ?
1436 138Cs ?
Cts/s/channel
140
120
100
80
60
40
20
0
52006
03754
51412
59566
29711
00247
46484
80637
51827
46085
86346
32454
48116
46612
43579
66397
69287
17334
69623
47232
75365
26915
78464
10284
06339
54283
34546
74907
54135
47205
69858
05273
80775
42263
10609
10375
86981
32086
99155
44022
98473
09215
26644
04846
77016
87837
60032
50363
35884
74419
37225
42665
09468
56734
03931
70898
67784
45333
94322
46121
22412
45248
37049
20606

Decay curve of beta-decay bremsstrahlung continuum is consistent with (γ,n) isotope yield produced by ~10^{12} gamma-rays



Prelim Results of 2022 Actinide Experiemnt

1. Decay Data from all lines and continuum are fully consistent with ^{238}U irradiated by ~ 10^{12} GDR gamma-rays and ~ 10^{10} photoneutrons per shot.

1. Photofission products remain to be identified and quantified.

2. What mechanism(s) can produce the gamma-ray "bump" > 8 MeV?

Beaming along Laser forward hints at Compton scattering since forward Compton Scattering by relativistic electrons can easily boost ~keV x-rays into multi-MeV gamma-rays.

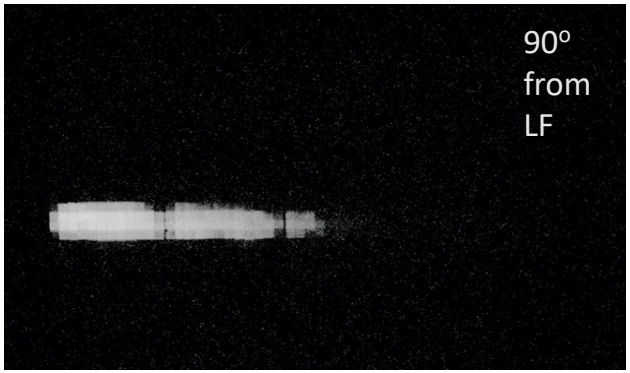
But CS does not work because:

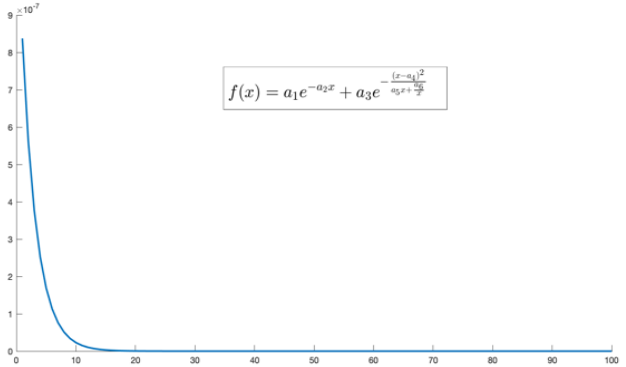
1. **Compton cross section is too small to get $P_{scatt} \geq 10\%$ for hot electrons.**

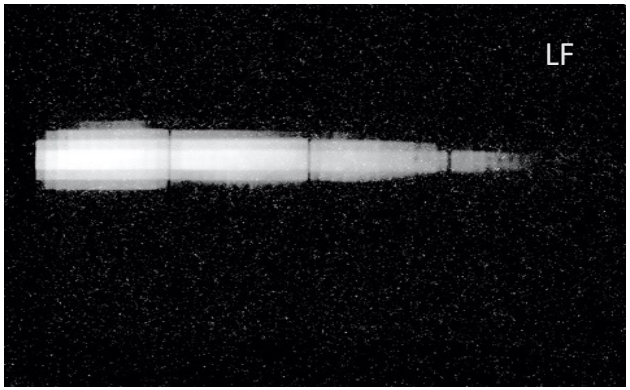
2. **C ompton upscattered spectrum should be relatively flat, not concentrated in the GDR (8-25 MeV) band.**

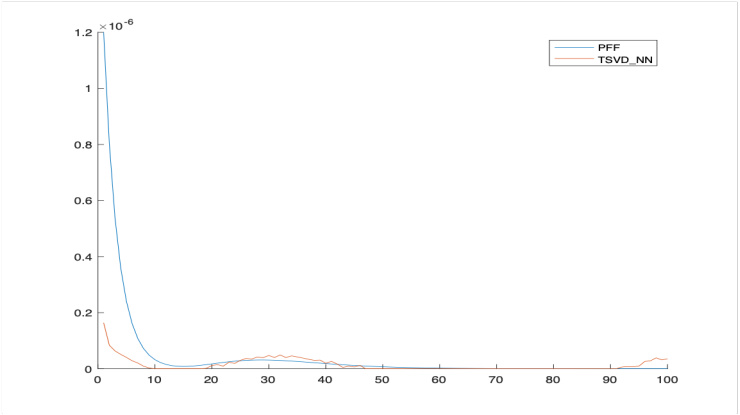
Gamma-ray Excess > 8 MeV is only observed near Laser Forward directions

Shot 14833





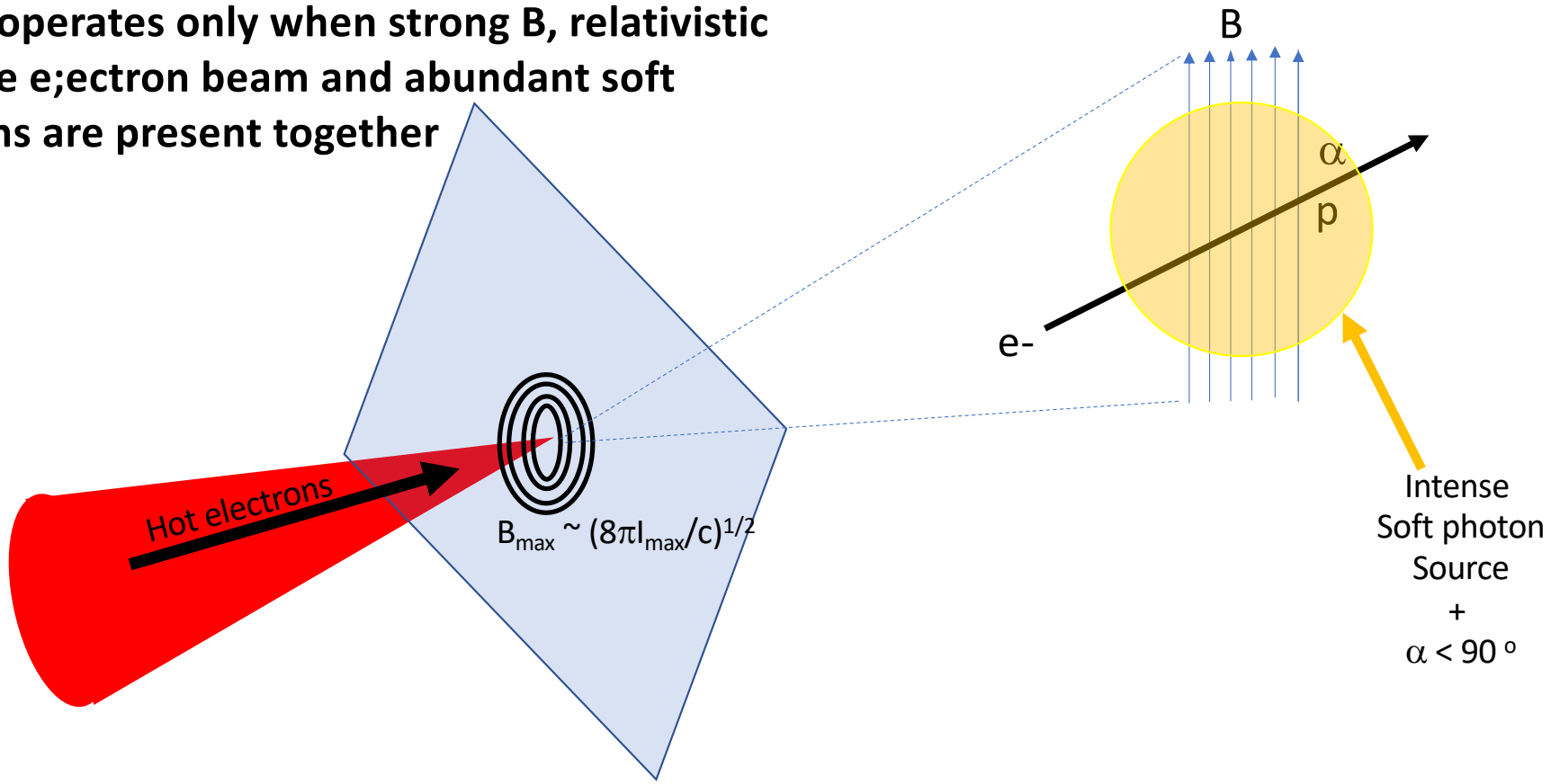




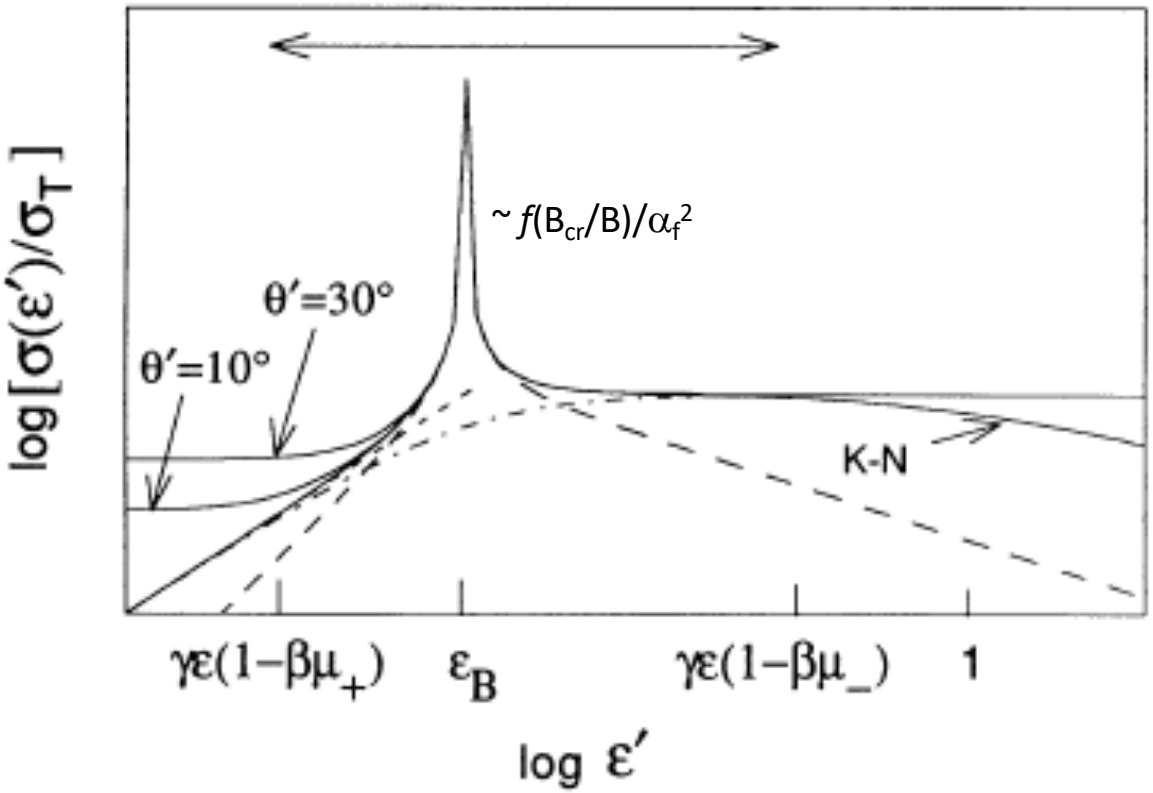
- **It turns out a well-known radiation mechanism in astrophysics works very well in this case**

It is called Magnetic Compton Resonant Scattering (MCRS) which has been widely used (for over 30 years) to model gamma-ray emission from strongly magnetized neutron stars.

MCRS operates only when strong B, relativistic oblique e;ectron beam and abundant soft photons are present together

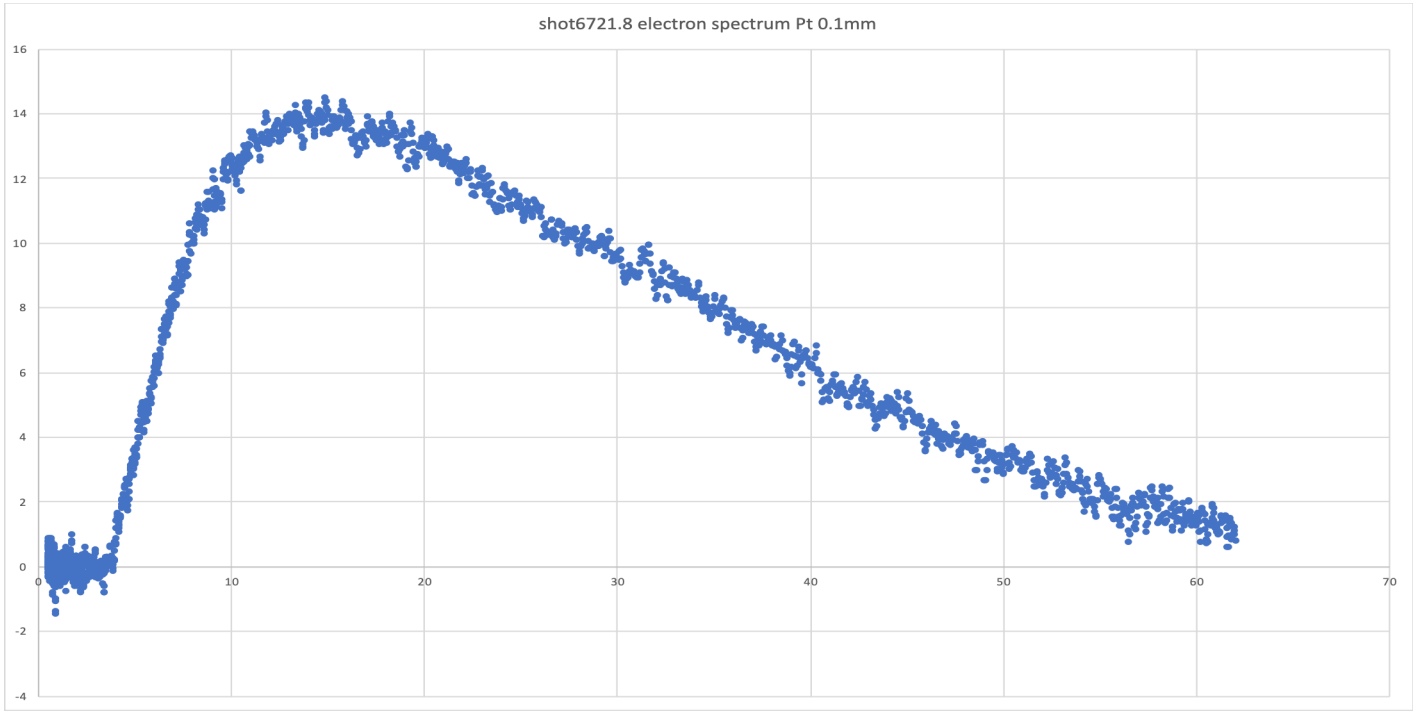


MCRS Cross Section in strong B fields



This cross-section applies only to electrons initially in the Landau ground state

ω_B (cyclotron energy in electron rest frame)= $\omega_{o*}\gamma_{||}(1-\beta\cos\theta)$



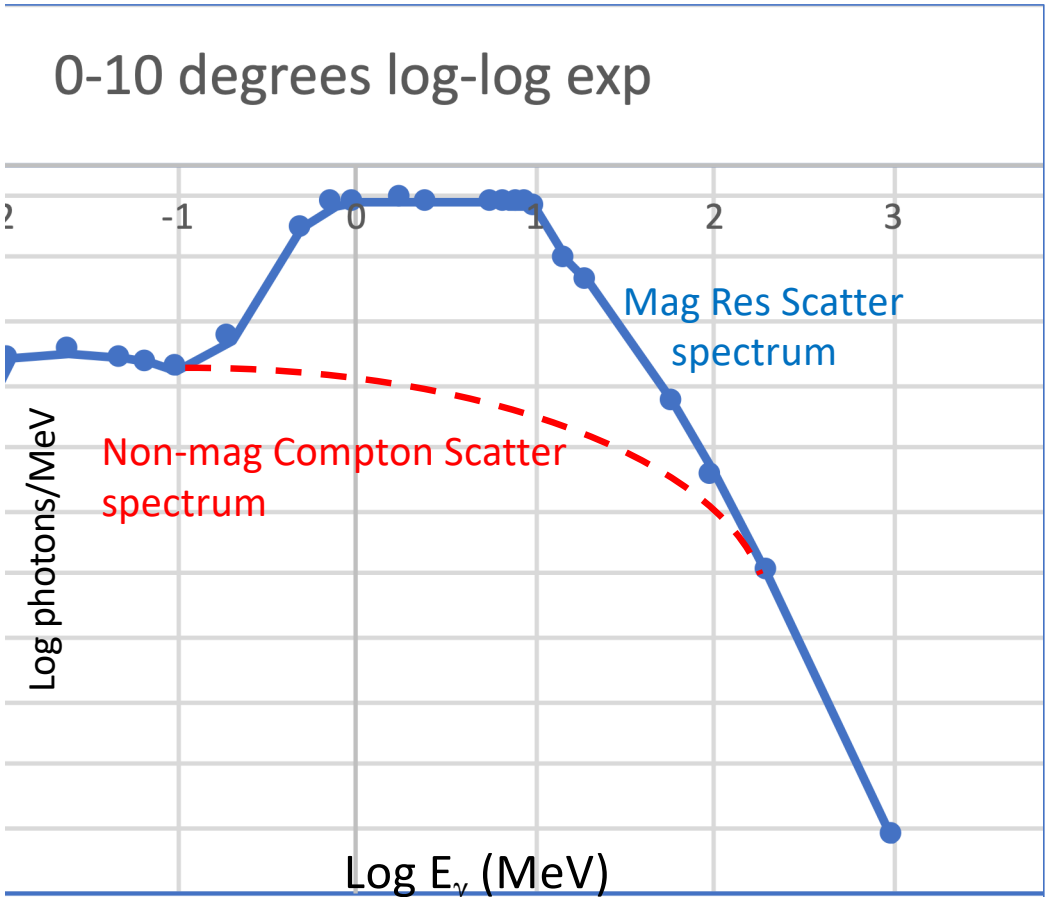
Hot electrons spectra from TPW experiments

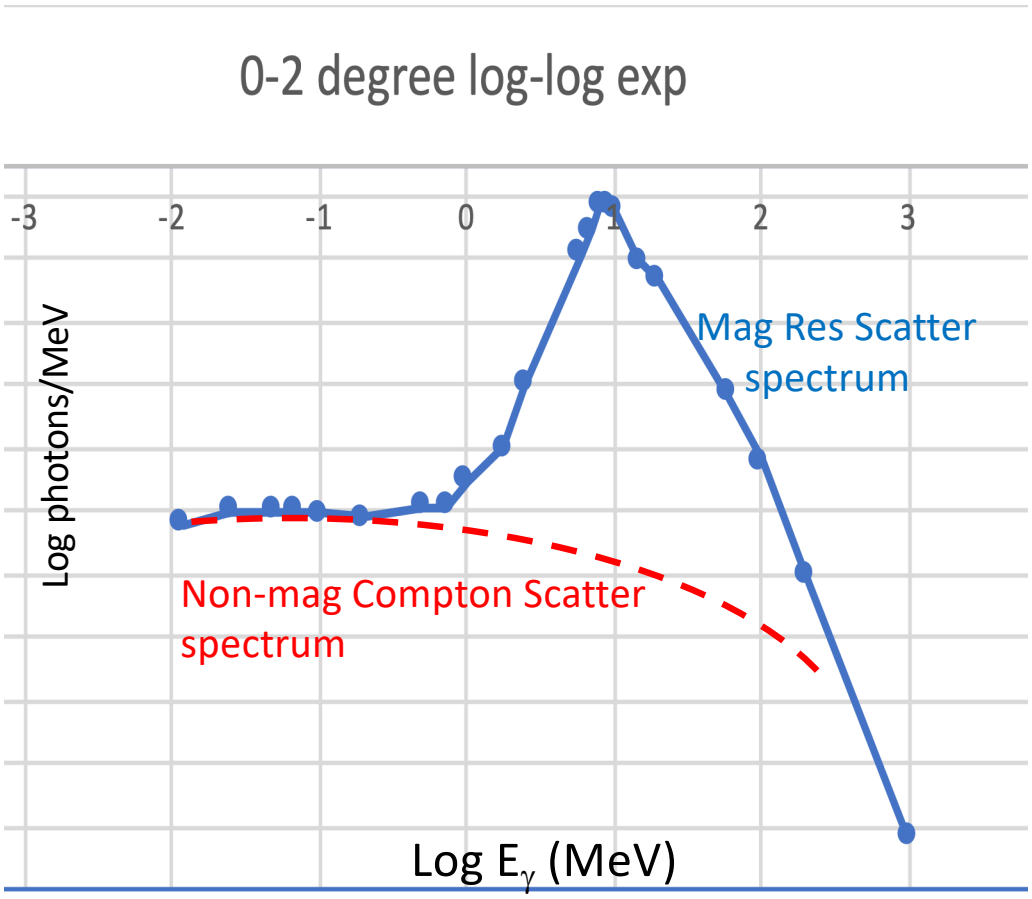
used in our MCRS simulations

MCTS produces narrow-band beamed gamma-rays many orders of magnitude higher than Non-magnetic Compton Scattering

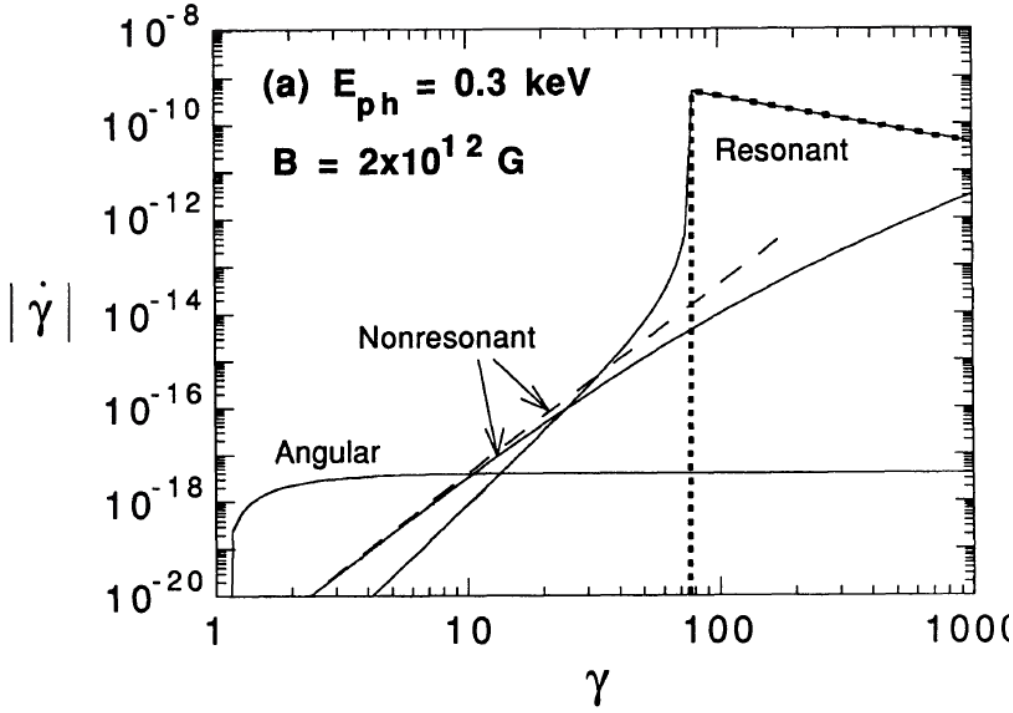
B_o=5x10^9 G, ω_B= 60 eV, pitch angle = 70°, $f_e(E)$ ~ exp(-E/20 MeV)

Mag Res Scatt Spectrum





Hot electron energy loss jumps when resonance is satisfied



(*from Dermer ApJ 1990*)

Summary

MCRS can producing narrow-band high energy beamed gamma-rays at HEPW laser focal spots under favorable conditons.

1. Laser must be high-intensity and high energy per pulse

2. Highest energy gamma-rays are beamed along hot electron direction

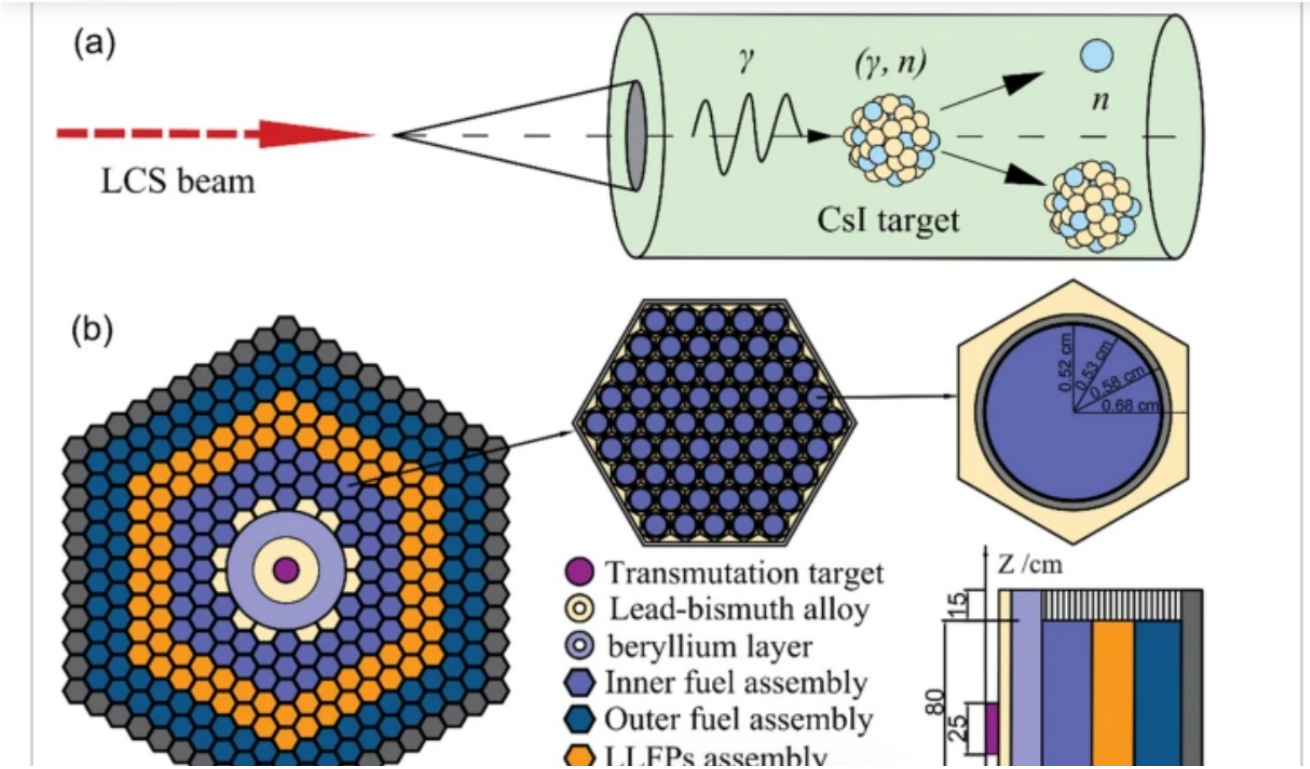
3. Peak gamma-ray intensity can be many orders of magnitude higher than from non-magnetic Compton scattering.

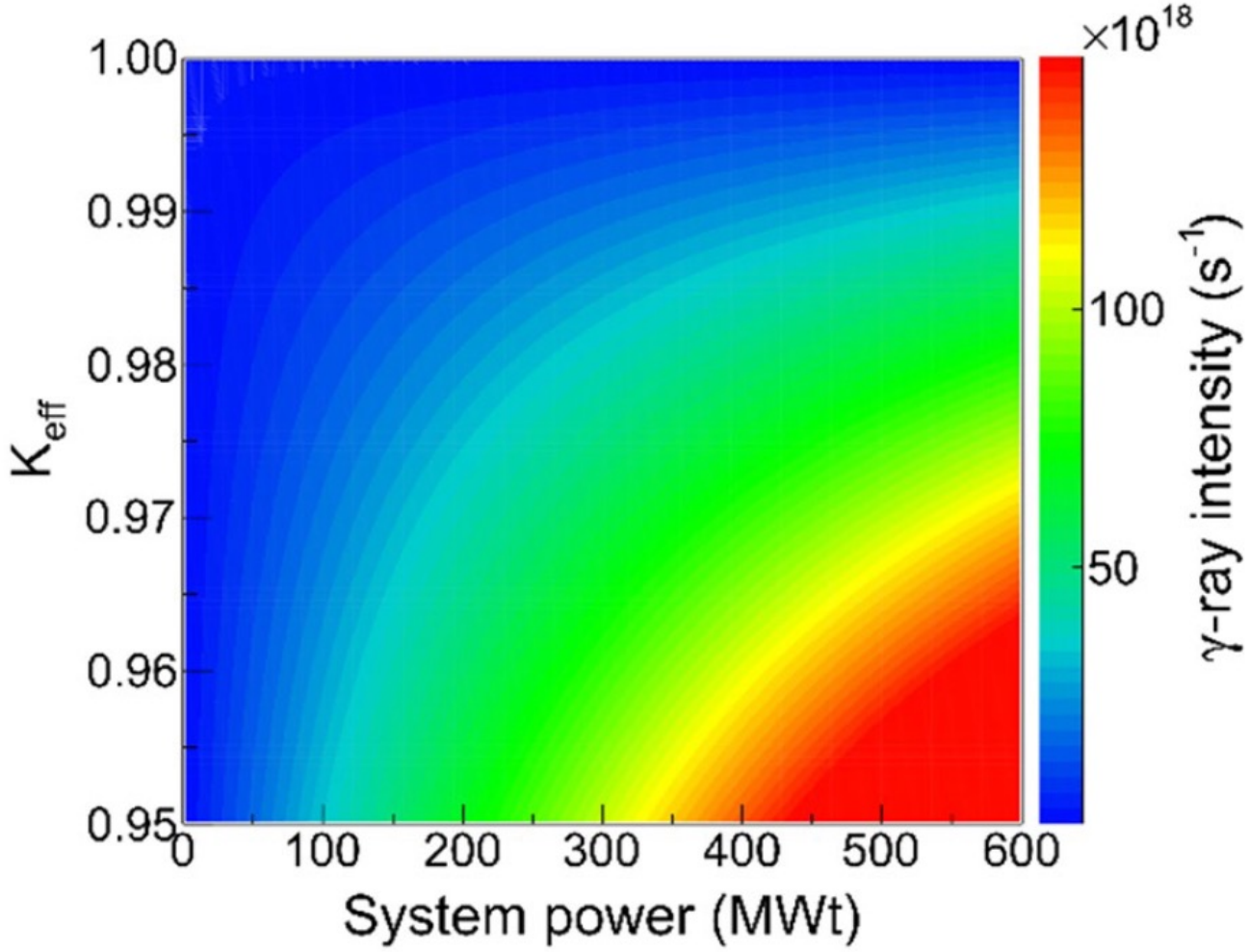
4. We expect total gamma-ray yield to scale with laser pulse energy ~ E_l^n where n >2

1. Transmutation: for nuclear waste treatment

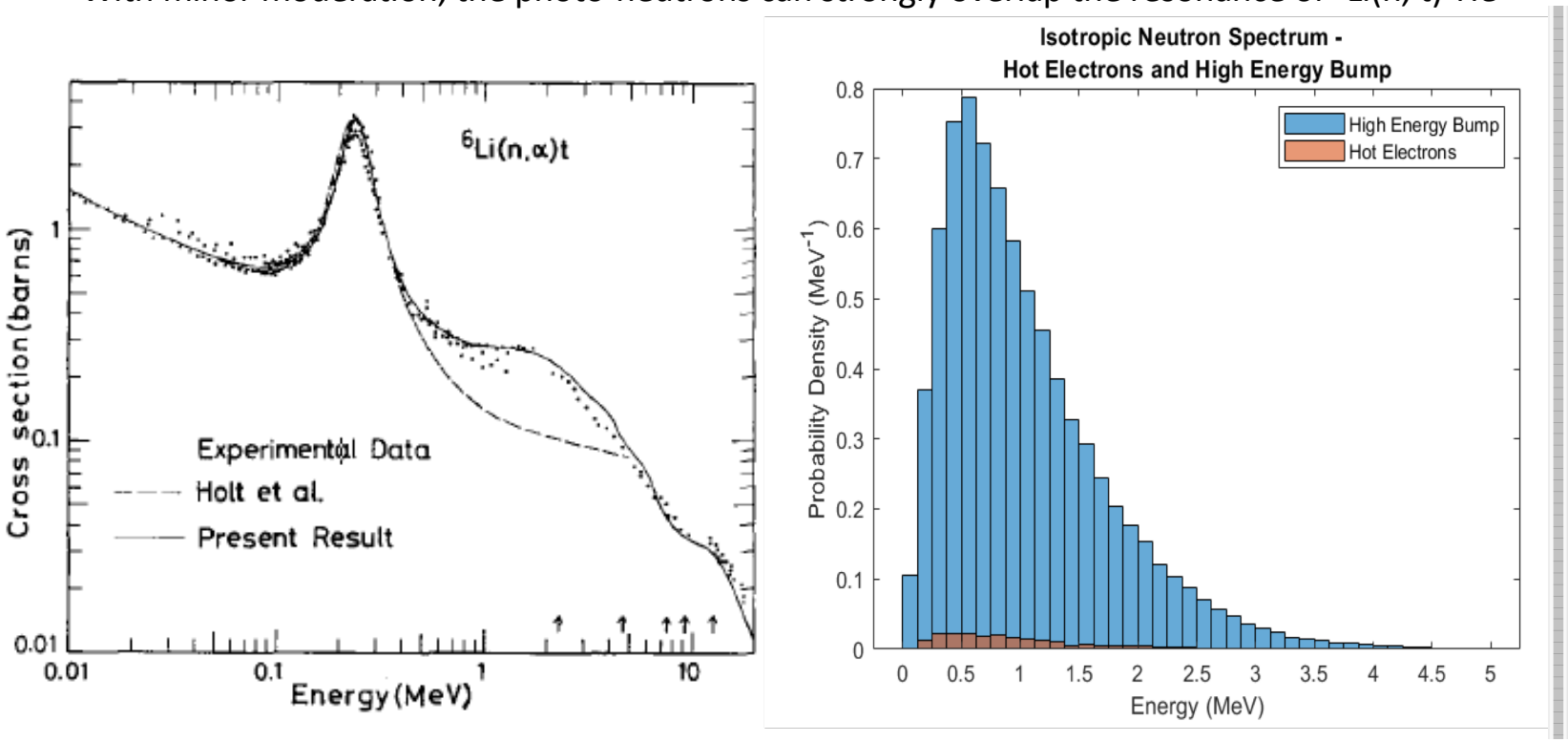
2. Isotope Production using resonances

nuclear waste: Transmutation of long-lived fission products in an advanced nuclear energy system
by *X. Y. Sun, et al, Sci. Rpt.* ***12****, 2240 (2022)*




1.00
0.99
0.98
0.97
0.96
0.95
K_{eff}
0
100
200
300
400
500
600
System power (MWt)
×10^18
100
50
γ-ray intensity (s^-1)

With minor moderation, the photo-neutrons can strongly overlap the resonance of $^{6}Li(n, t)^{4}He$



Photuneutron peak overlaps with $^{5}Li(n,t)\alpha$ resonance

Conclusion

High-Energy PW laser can produce GDR gamma-rays with high efficiency, ideal for studying and applications of photnuclear reactions.

MCRS is a new radiation mechanism worth exploring using both HEPW lasers and other platforms.