Ultra-intense Pair Creation using the Texas Petawatt Laser (TPW)

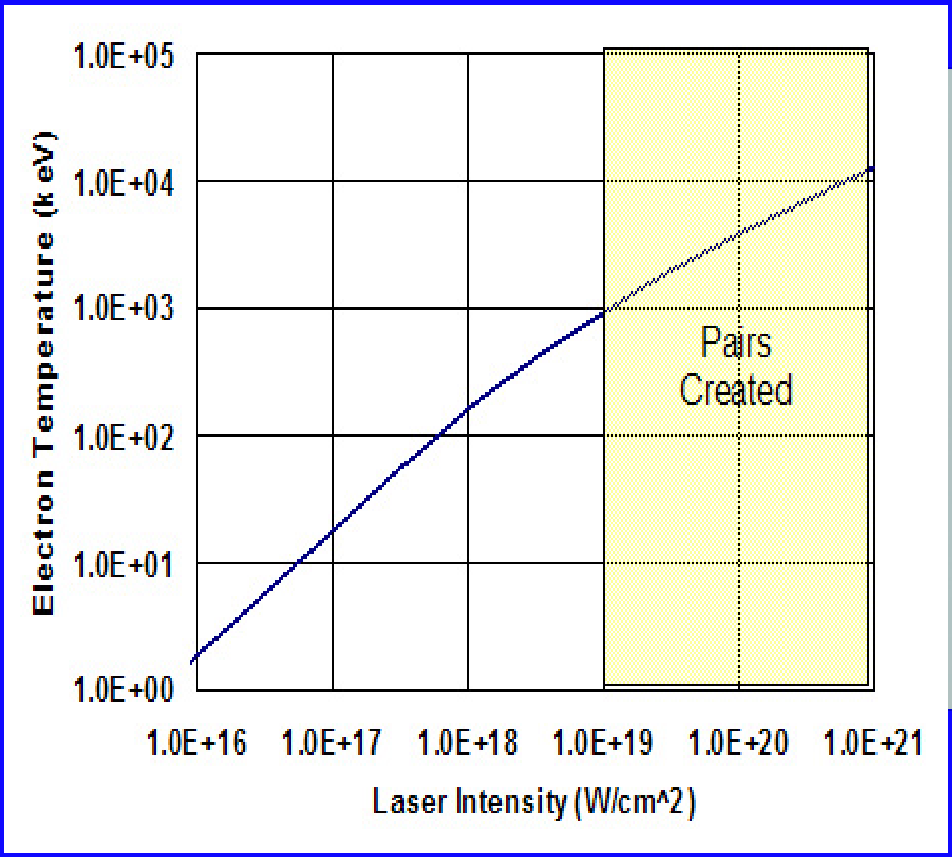
PI: Edison Liang, Rice University
Co-PI: Todd Ditmire/Manuel Hegelich, UT Austin

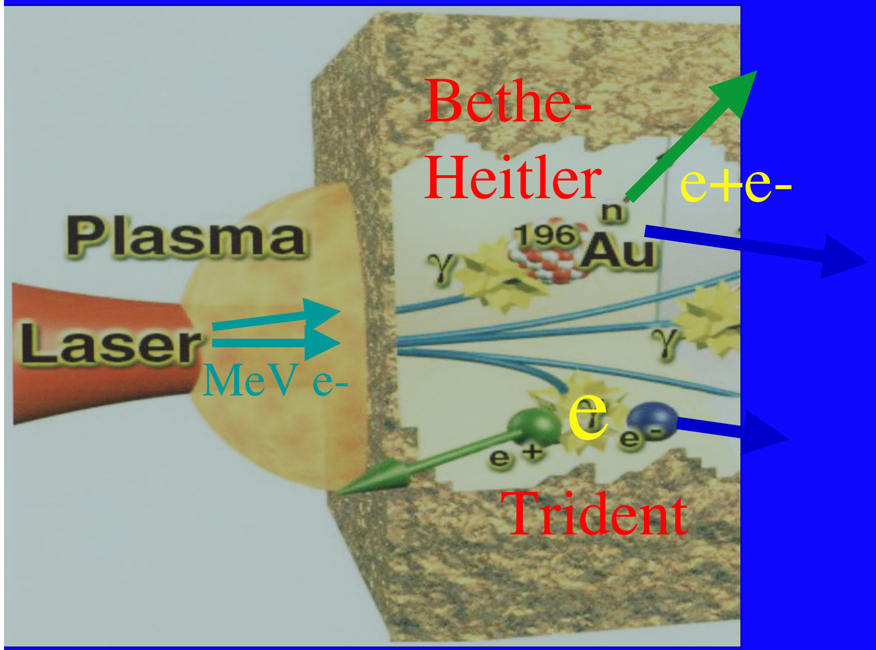
Rice Team Members: Devin Taylor, Taylor Clarke, Alexander Henderson, Steve Zhou, Petr Shagin, Xin Wang. Xinyi Cen, Yi Hua, Willie Lo, Wen Fu.

UT Team Members: Gilliss Dyer, Kristina Serratto, Nathan Riley, Michael Donovan

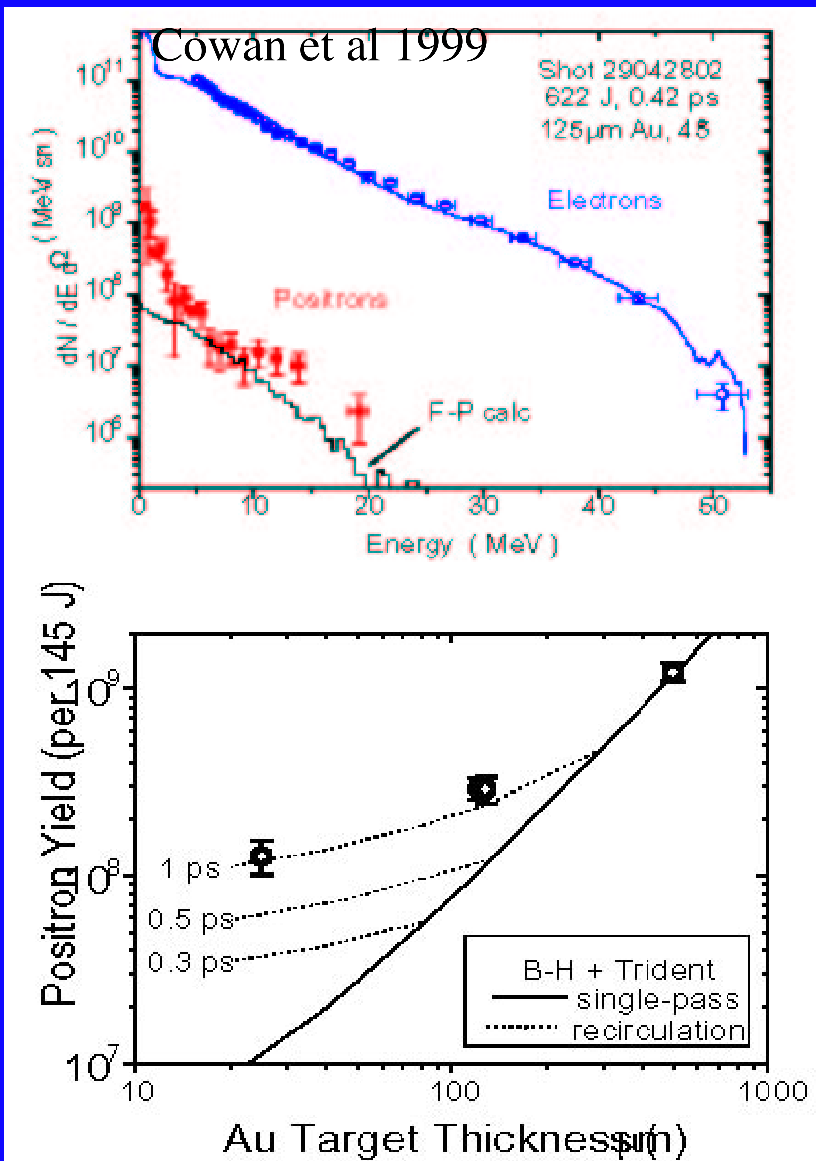
Work Supported by DOE DE-SC-000-1481 and Rice U. FIF

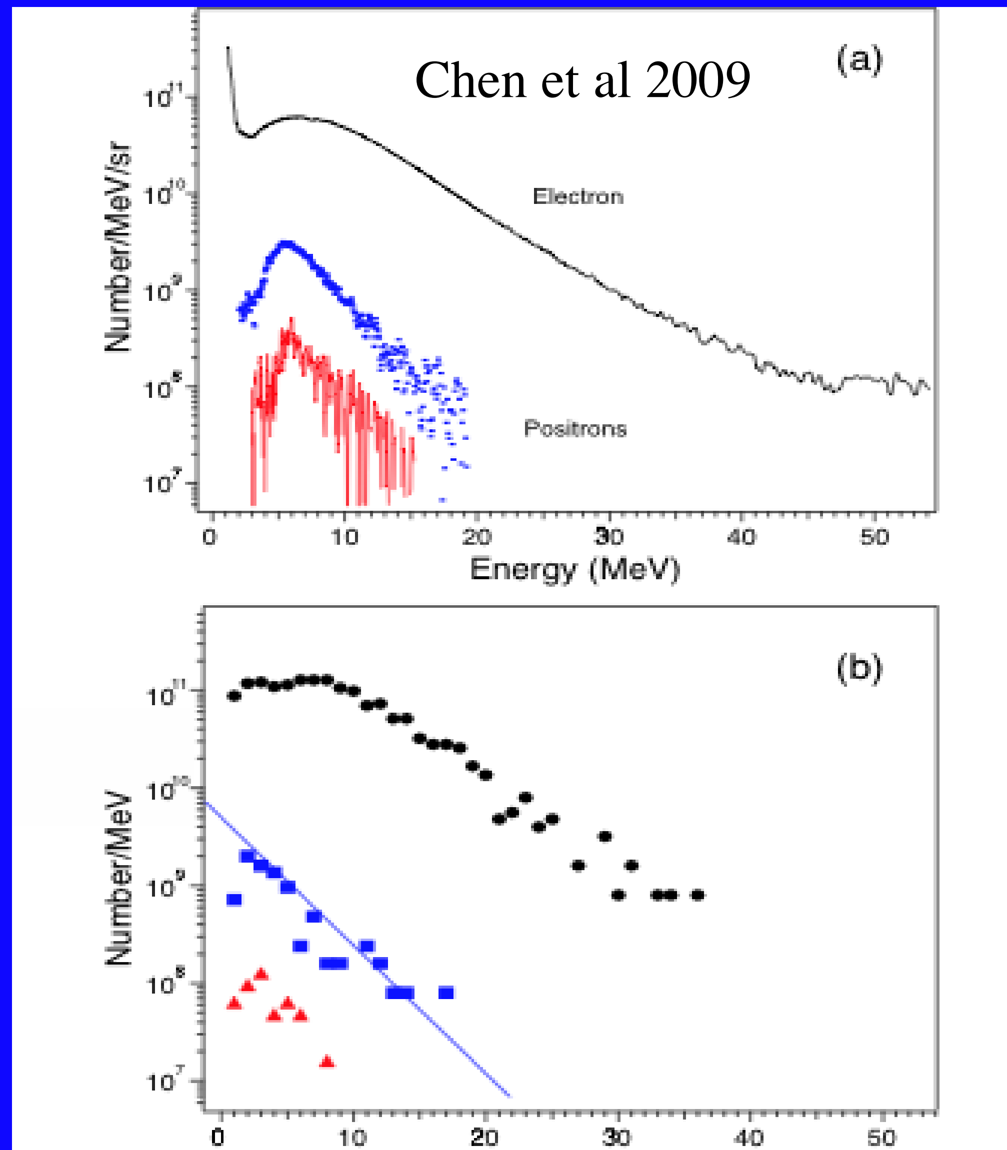
Ultra-intense Laser is the most efficient tool to make copious dense e+e- pairs in the laboratory



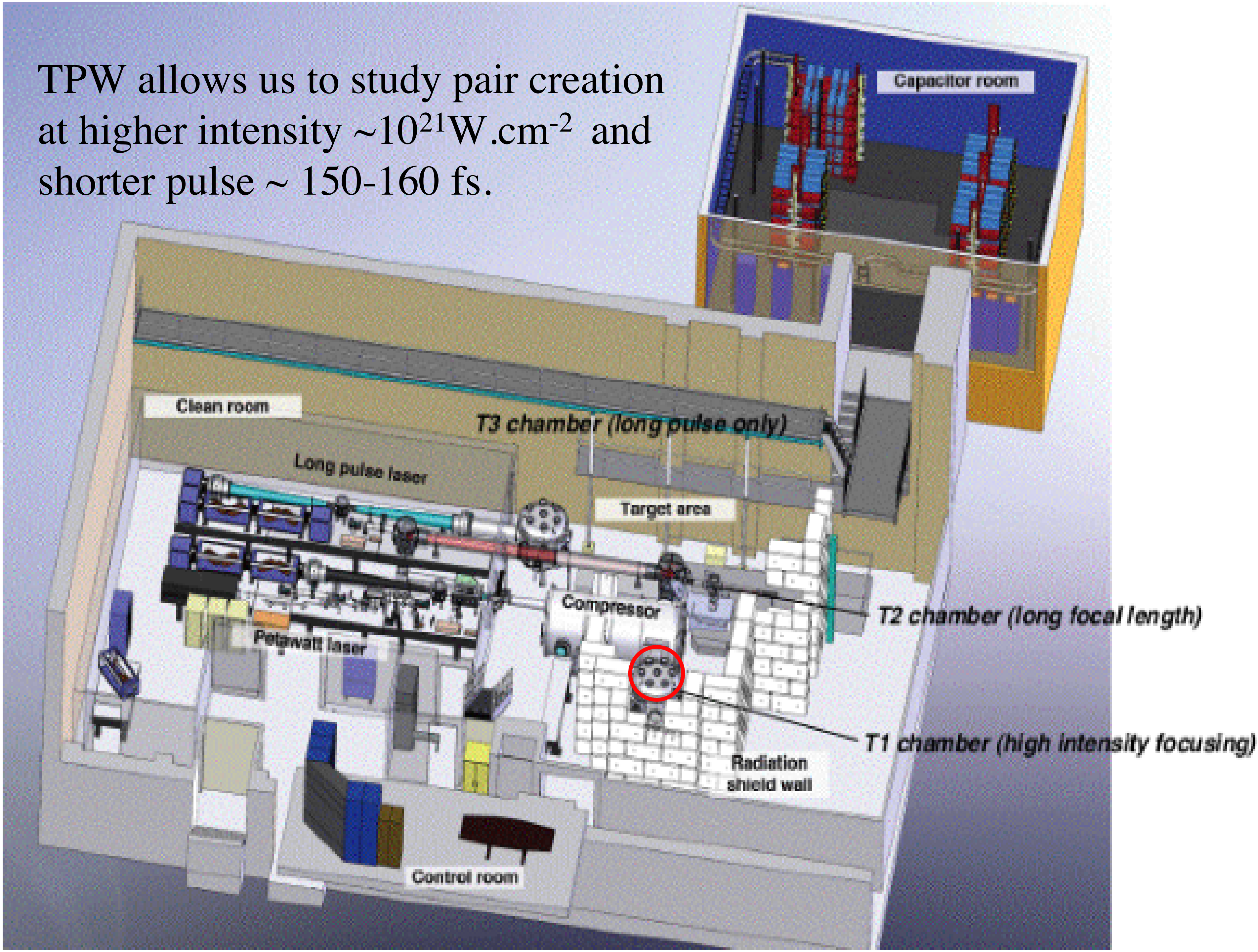


Laser pair creation was demonstrated by Cowan et al (1999) and Chen et al (2009, 2010) at laser intensities ~ few x10^{19} - 10^{20} W.cm^{-2}.



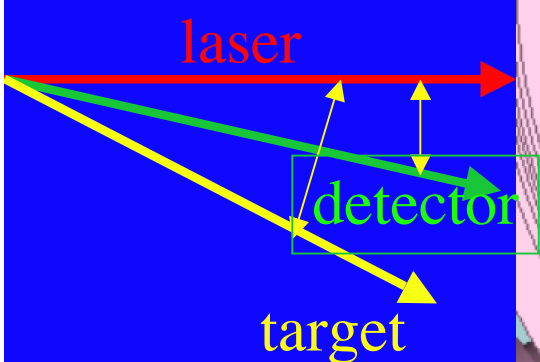


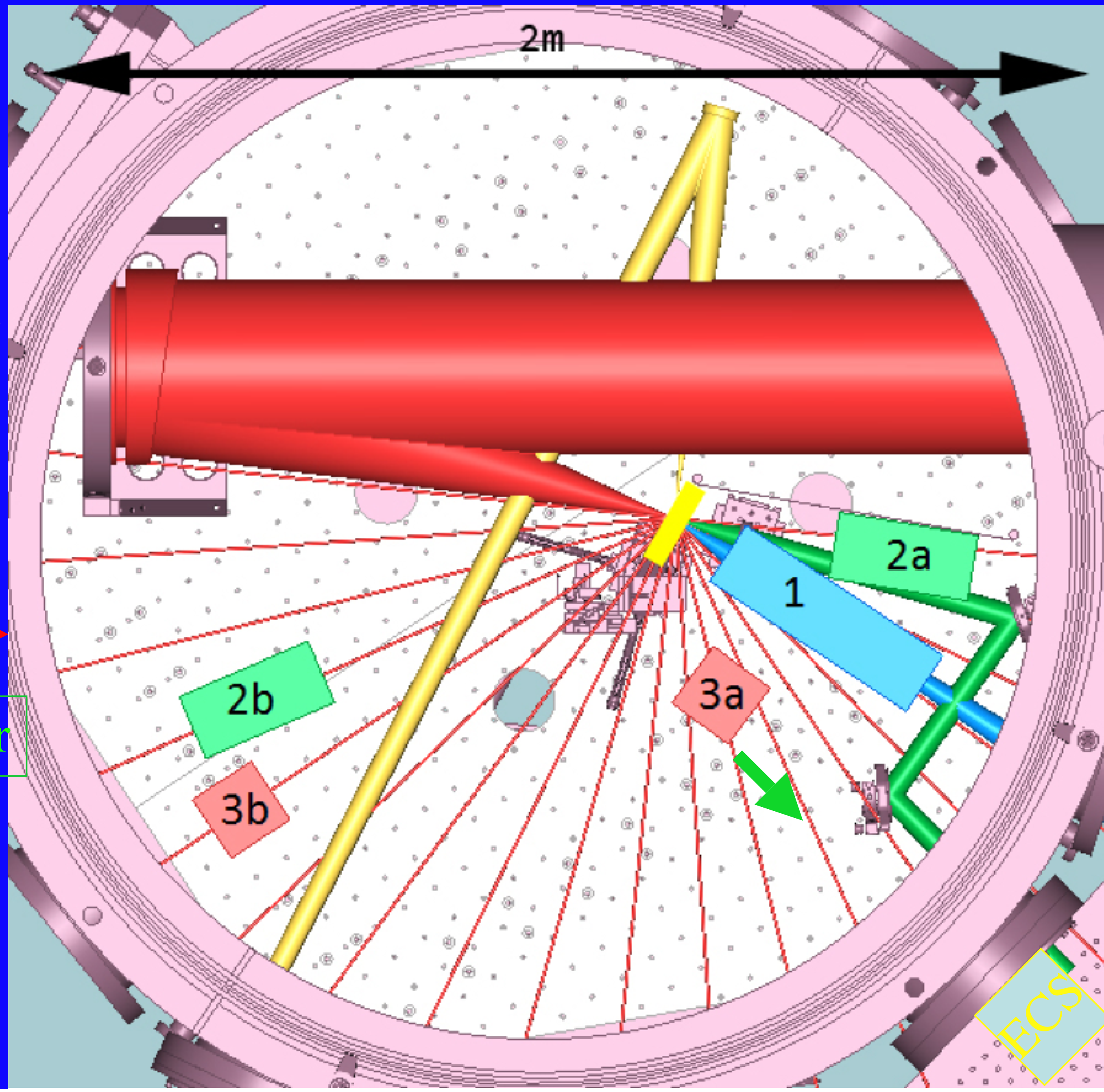
TPW allows us to study pair creation at higher intensity ~10^{21}W.cm^{-2} and shorter pulse ~ 150-160 fs.



Diagnostics and target setup

TC1 with f/3 mirror





TPW Performance for the 2012 Experiments

1. E = 81 -130 J , <E> ~ 100 J
2. ΔT = 128 - 245 fs, <ΔT> ~ 160 fs
3. P = 450 - 800 TW, <P> ~ 650 TW
4. %E in 10 μm circle = 40 - 80%, <%E> ~ 65%
5. Peak I = 3×10^{20} - 1.9×10^{21} W.cm^{-2}, <I> ~ 7×10^{20}

   25% of shots had I ≥ 10^{21} W.cm^{-2}

2012 Experiment: 65 Au Targets

1. Flat Disks: 0.2 - 4 mm thick
2. Thin Rods: 2-3 mm diameters, 4 mm - 1cm long.
3. Angles between laser and target normal: 25 -45 degrees

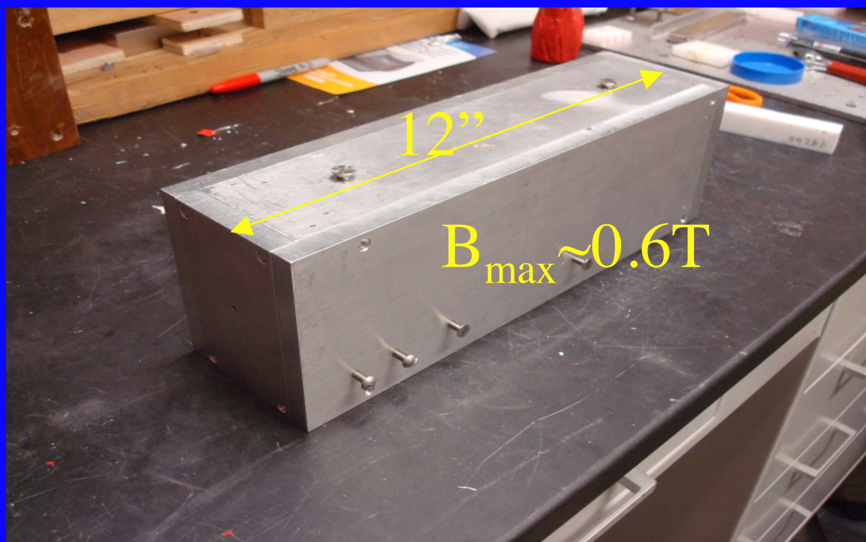
e+e- Magnetic Spectrometers

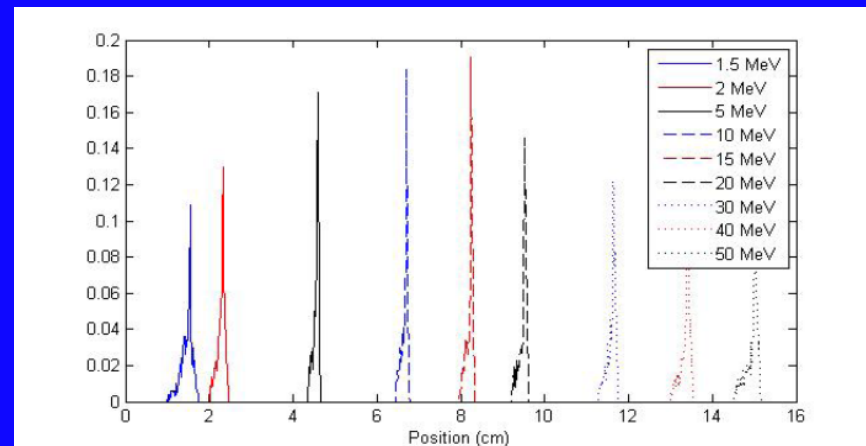
1. 10 inch magnet: 2 MeV - 130 MeV
2. 6 inch magnet: 2 MeV - 55 MeV
3. 4 inch magnet: 0.4 - 6 MeV

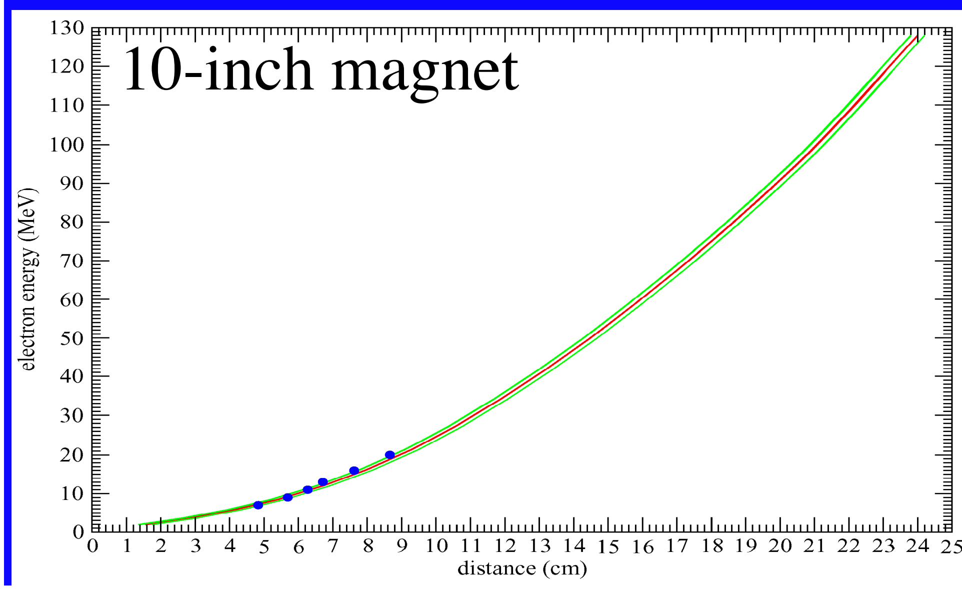
Gamma Detectors

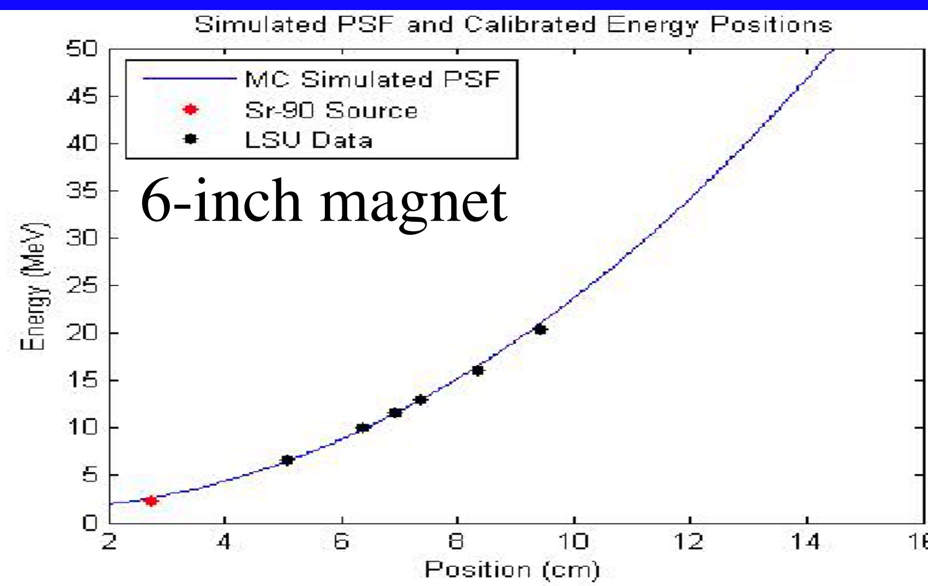
1. Filter-stack spectrometers: up to 1.5 MeV
2. Forward Compton spectrometer: 2 - 50 MeV
3. 30 dosimeters per day: up to 40 MeV

We used 3 magnetic e+e- spectrometers: 1 low-E (<7 MeV), 1 medium-E (2-50 MeV) and 1 high-E (1-120 MeV), calibrated with LSU e-beams

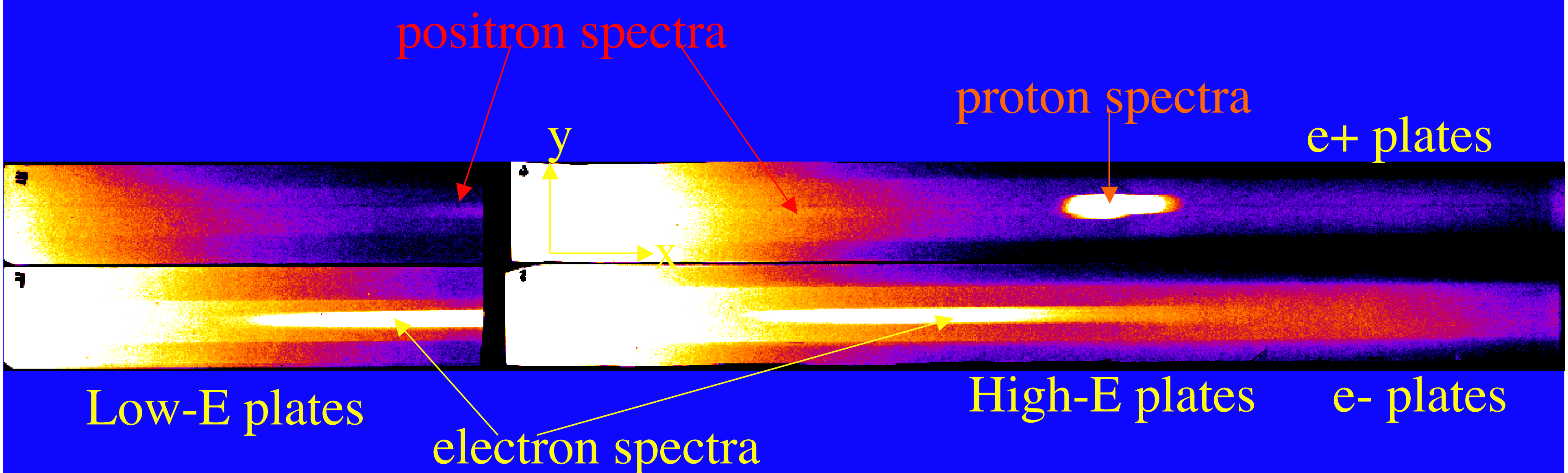








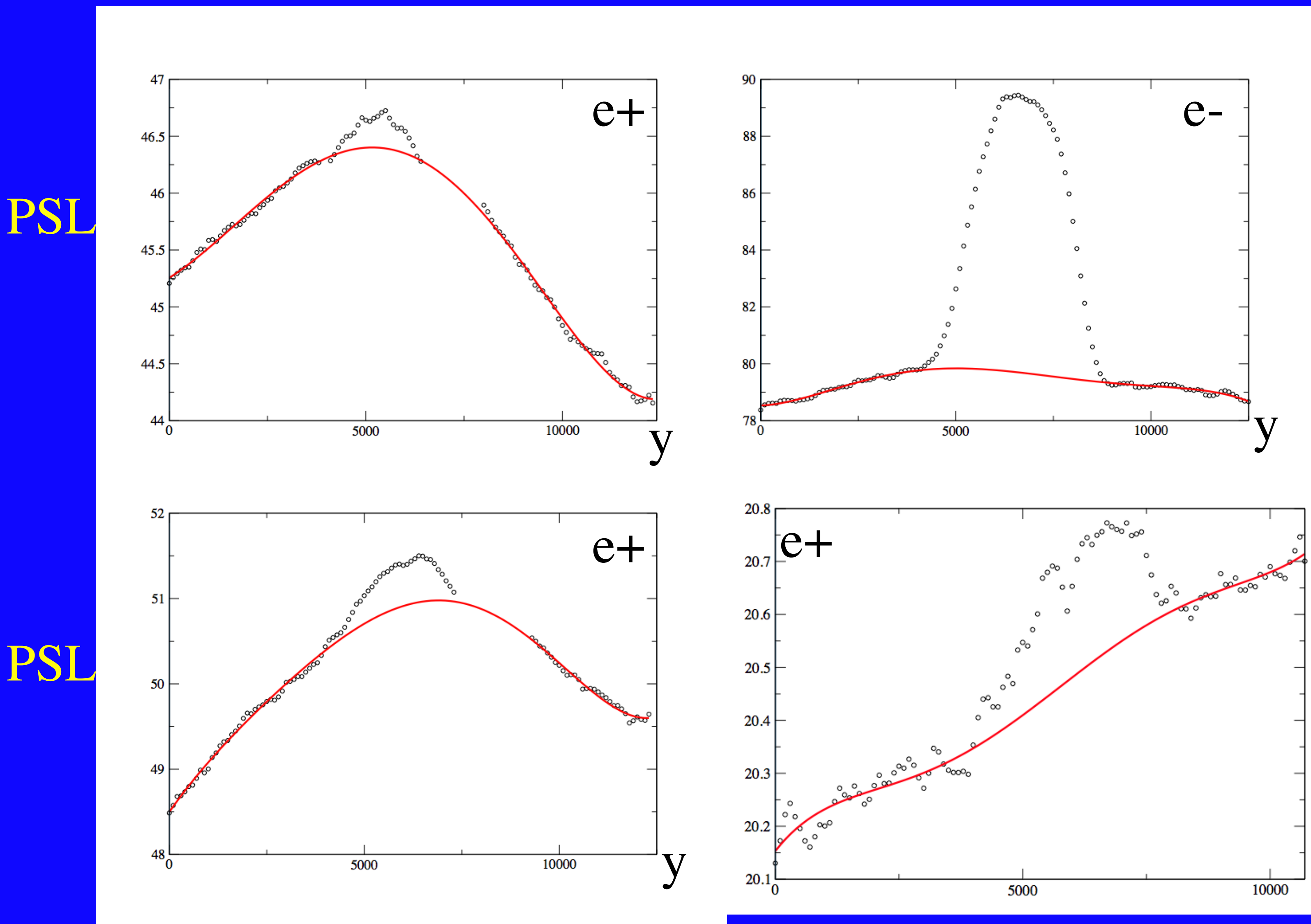
Typical e+e- Image Plate images after conversion to PSL



Internal x-ray background is high due to many factors

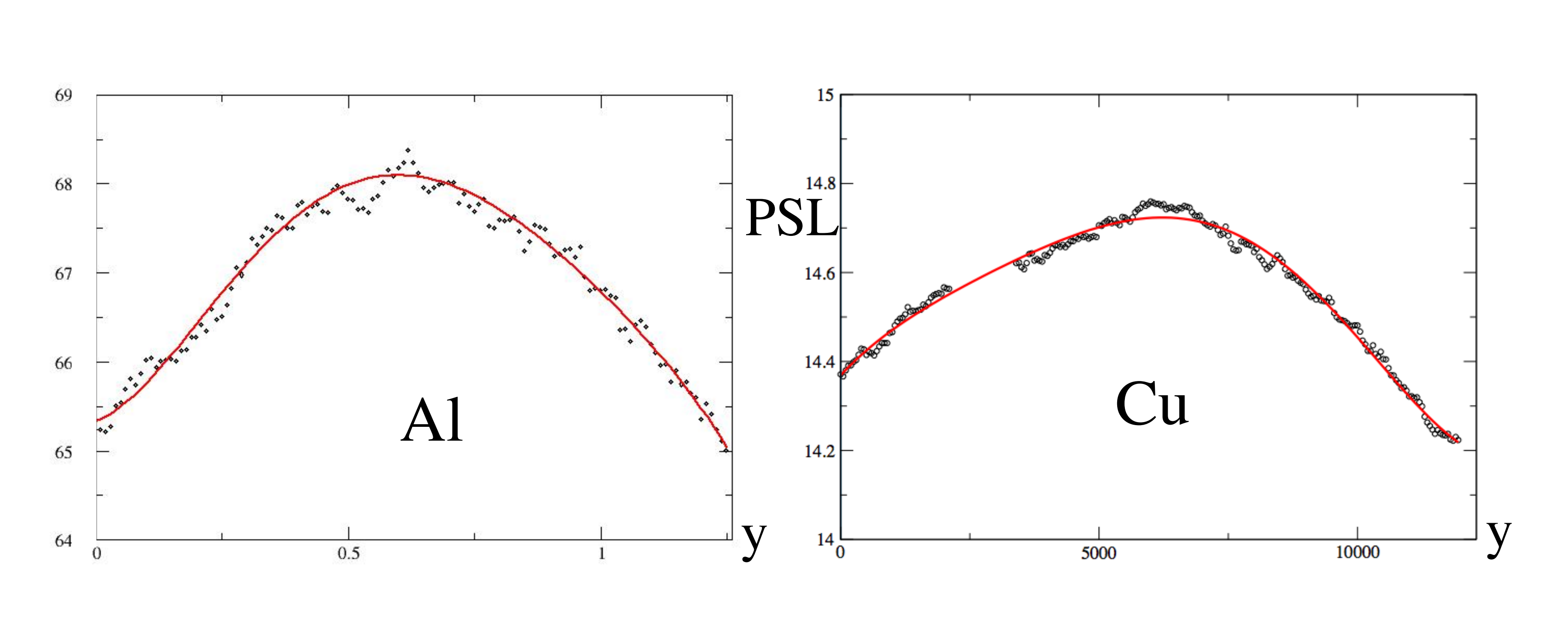
Proton signal measures target sheath potential (1.5 - 4 MeV)

Sample e+e- y-scan profiles for Au Shots

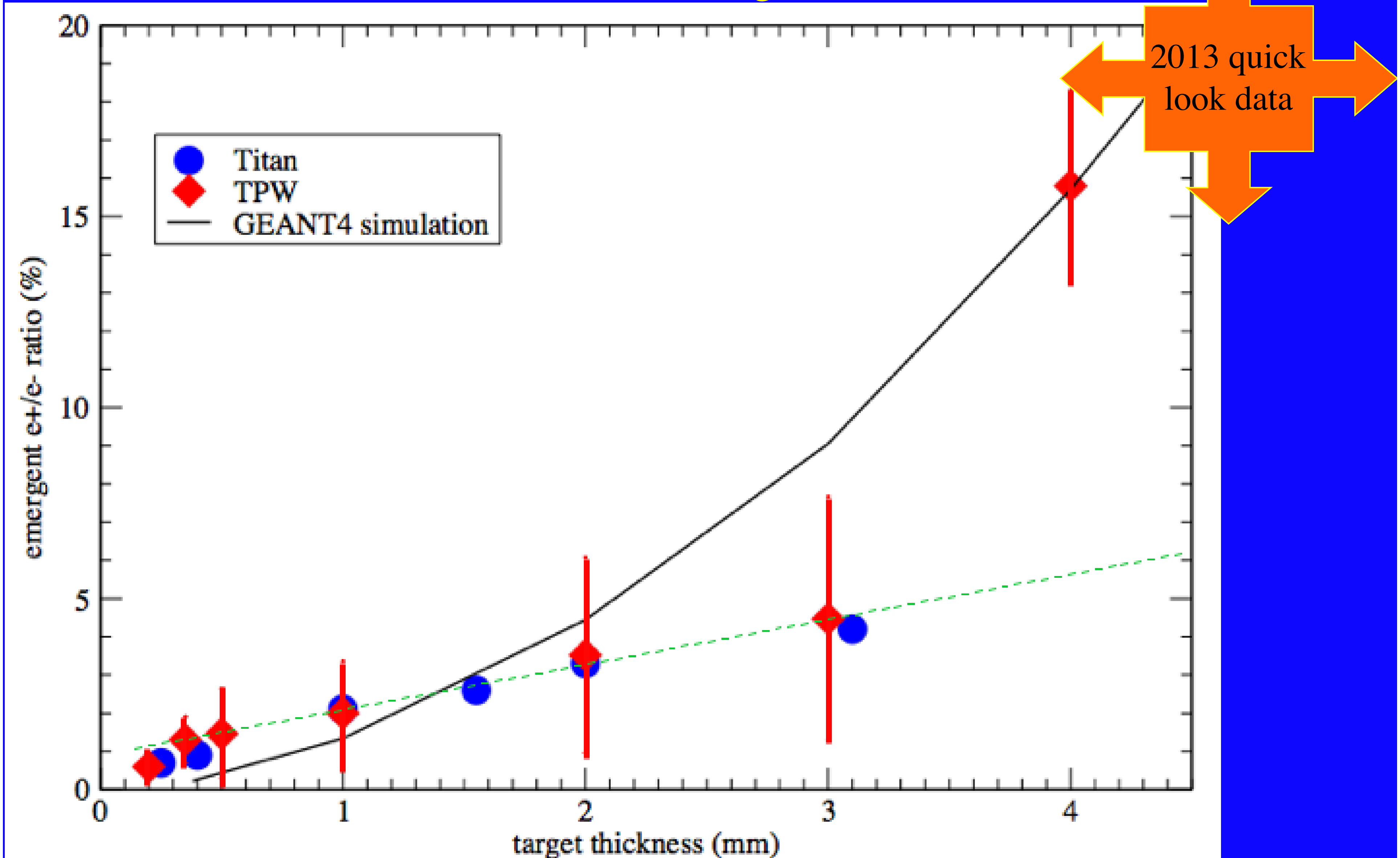


Red Line is best 5th-order polynomial fit to background with central ~ 4mm pixels removed

The above procedure applied to Al,Cu and e-beam shots gives null results for any e+ signal above background. These fits also provide an estimate of the systematic error (1-sigma) for this method.

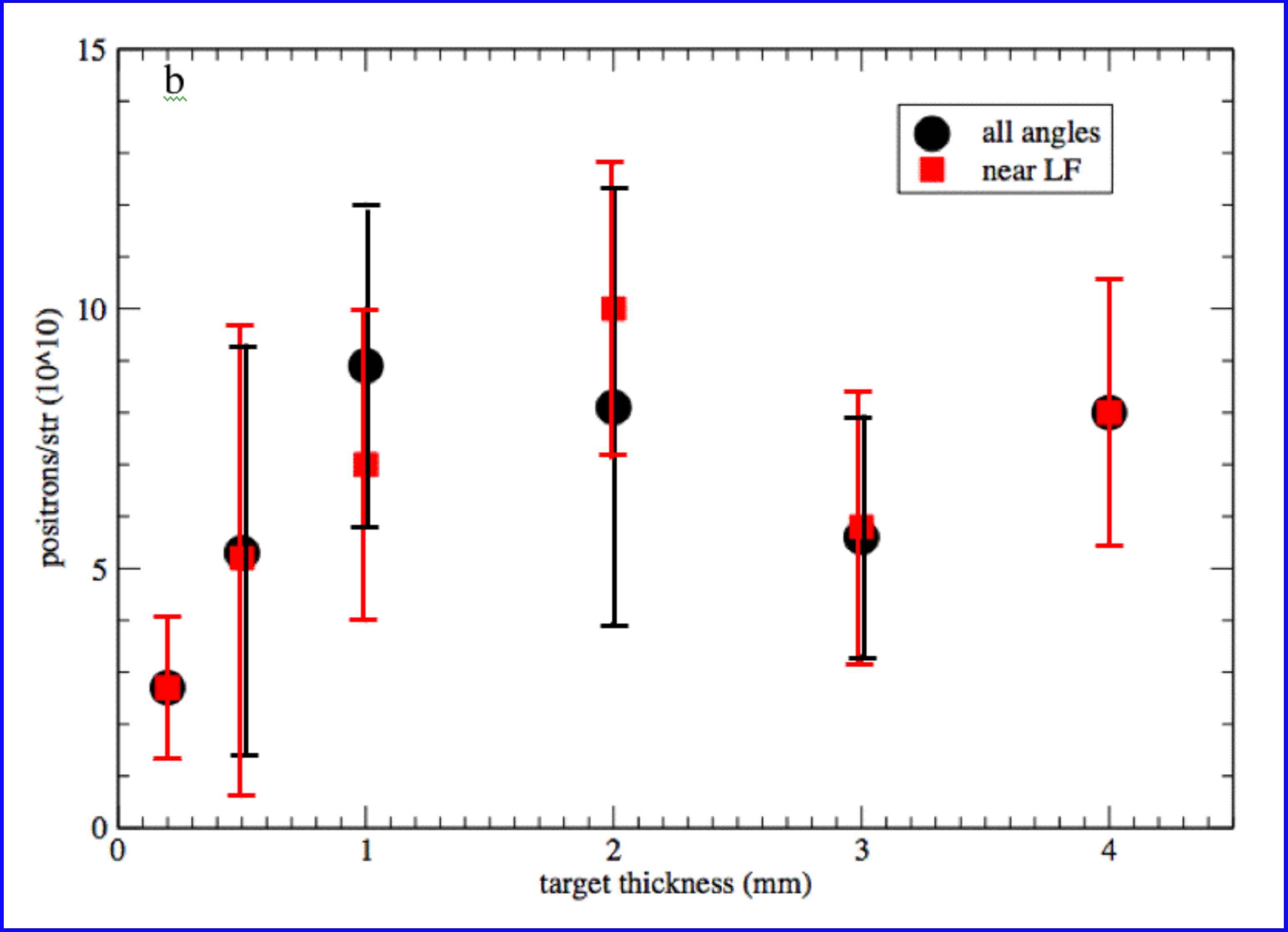


Red Line is 5th-order polynominal fit to data with central ~4 mm wide pixels removed e+/e- ratio vs. target thickness

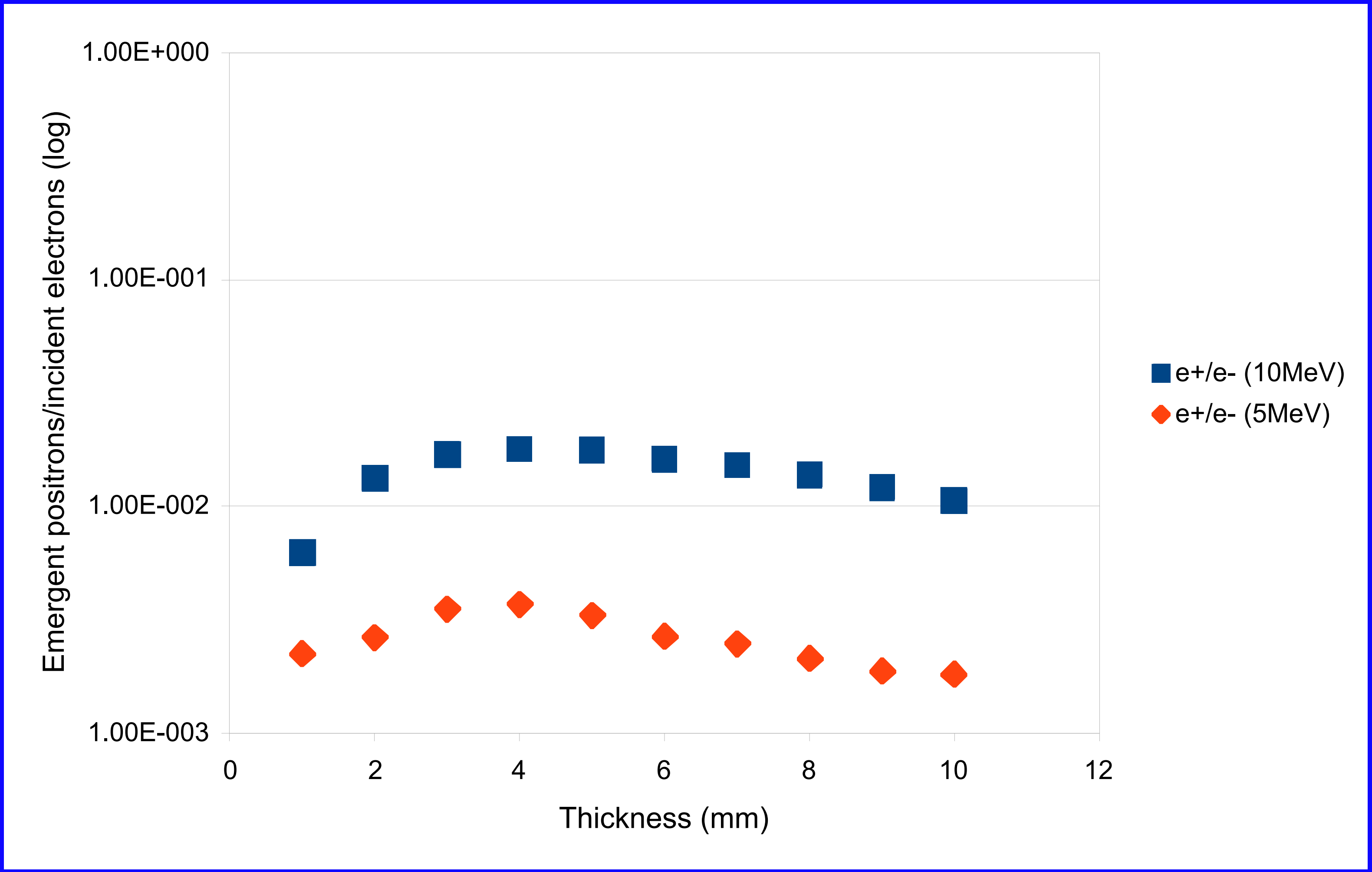


≥ 4 mm data shows clear deviation from linear trend.
It agrees with GEANT4 Monte Carlo predictions.

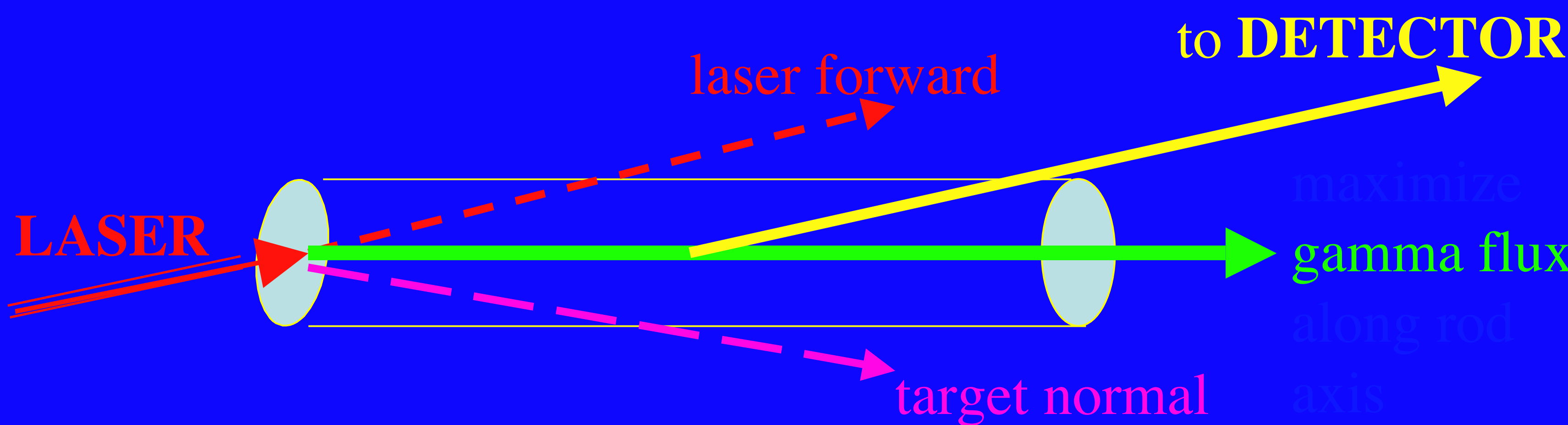
e+ yield/str peaks around 2mm and levels off above that



GEANT4 simulations suggest similar trends though the peak yield sits ~ 3 - 4 mm

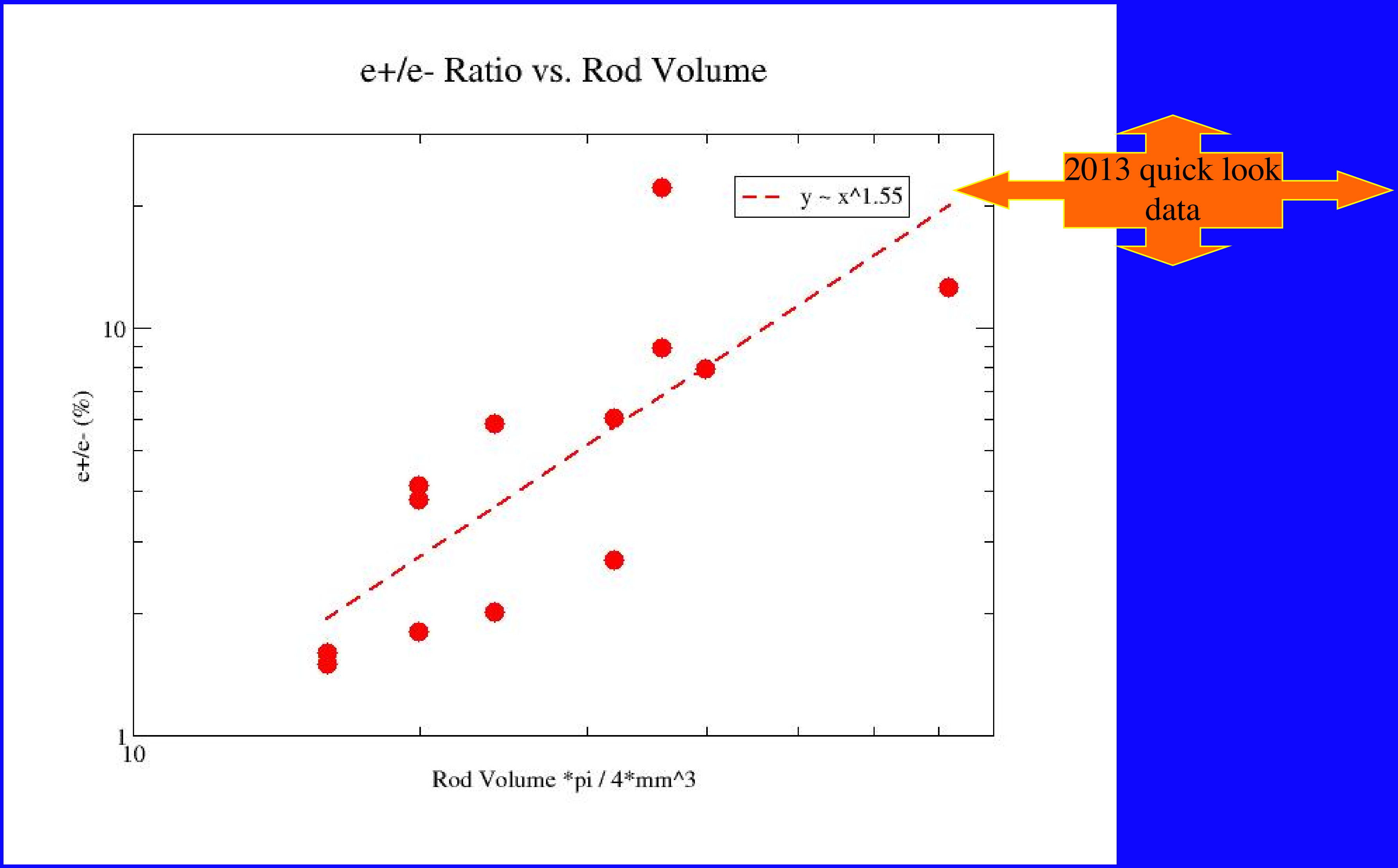


We also explored using long narrow rods to optimize emergent e+/e- ratio by maximizing gamma-->pair optical depth along rod axis, with encouraging results.

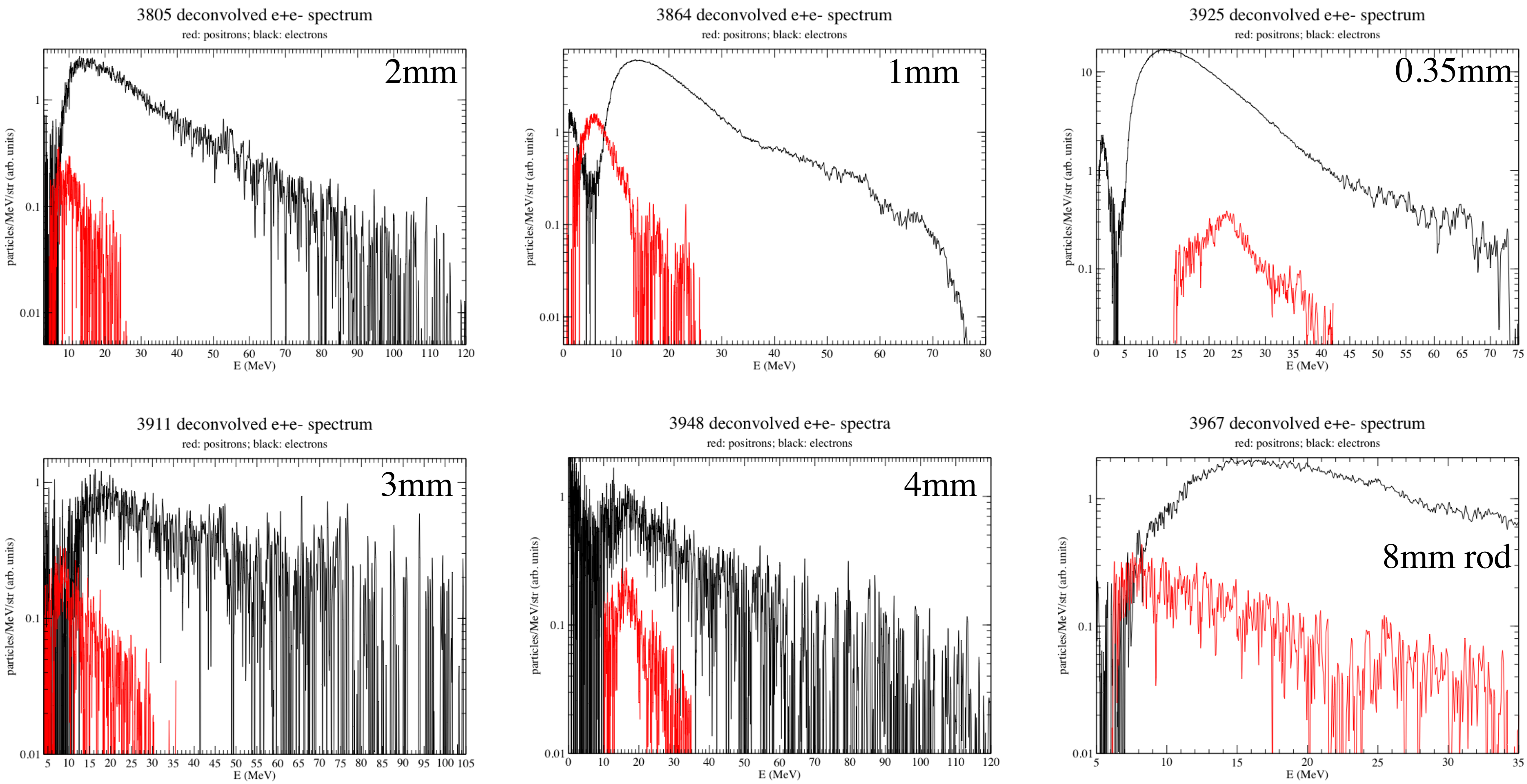


Detector needs to be positioned so as to maximize solid angle of entire rod visible by the detector pinhole

We confirm that e+/e- ratio increases with rod volume for rod lengths up to ~ 6 mm and diameters up to ~ 3mm

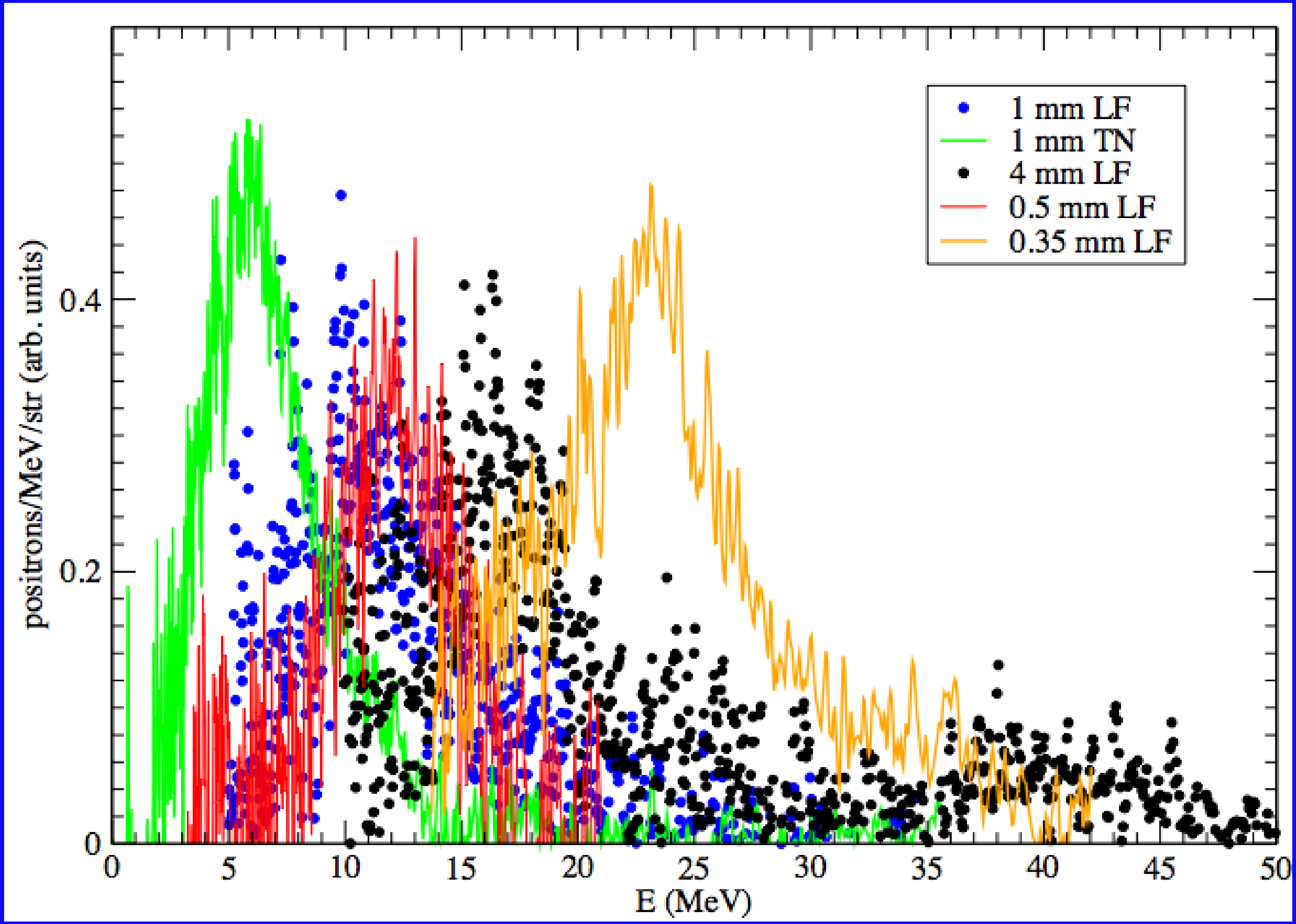


e- spectra always peak ~ 12-15 MeV, e+ peaks vary from ~ 6 - 23 MeV
e- spectra show 1 or 2 distinct slopes, $kT > (I/I_o)^{1/2}$, many extend > 100 MeV

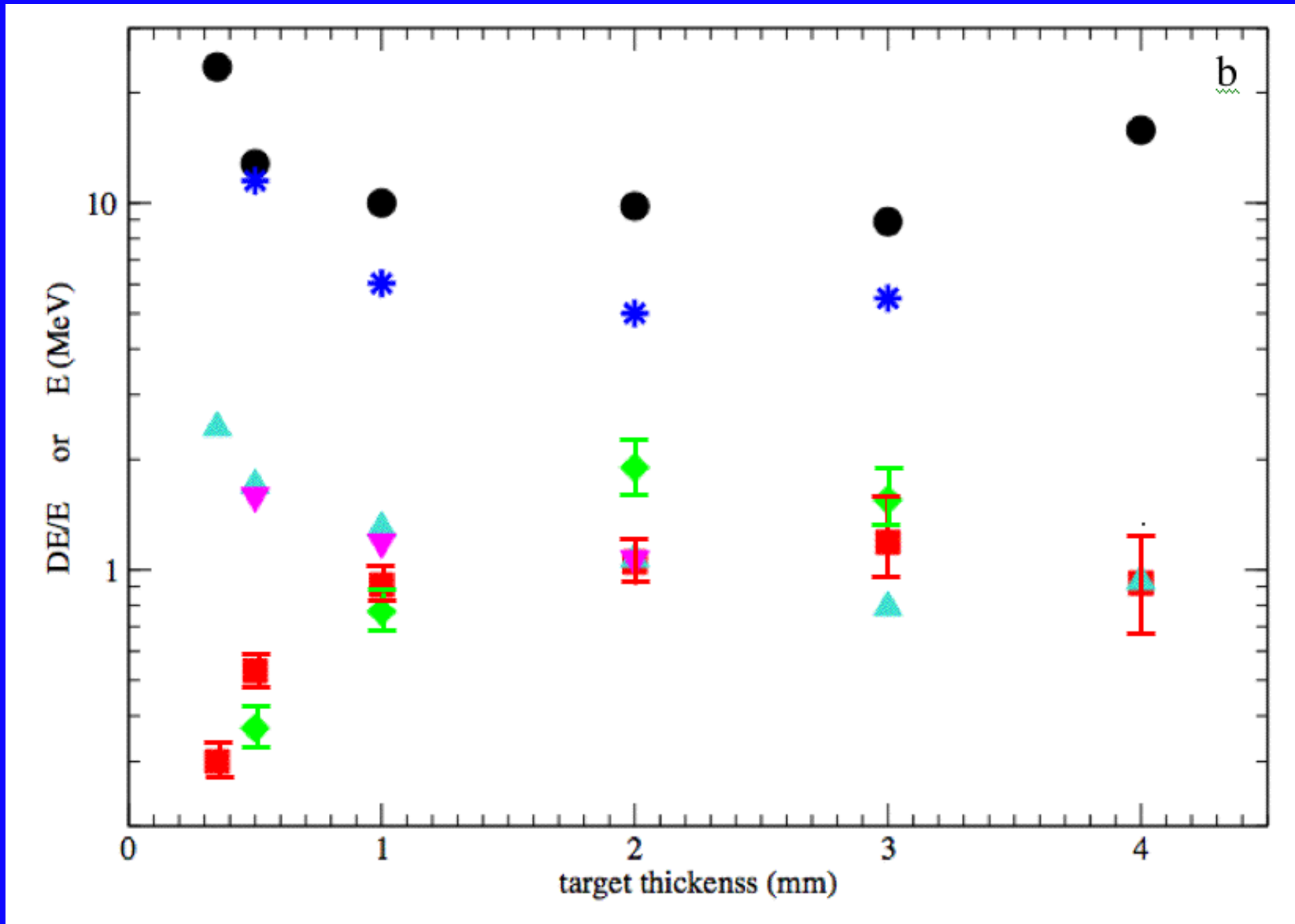


positron spectra are narrow and soft for disks,
but broad and hard for long rods

Positron energy peaks lie between ~ 6 and 23 MeV



Positron peak energy and width scaling with target thickness



black dot = E_+(LF), blue star = E_+(TN), red square = $\Delta E/E_+$ (LF), green diamond = $\Delta E/E_+$ (TN), up cyan triangle = E_{proton} (LF), down magenta triangle = E_{proton} (TN)

Summary of positron peak energy data

1. E_+ is lowest for 2 - 3 mm targets
2. E_+ at LF is higher than at TN for each thickness
3. E_{proton} is highest for thinnest targets
4. E_+ and E_{proton} are correlated for thin targets with $E_+ \sim 10\ E_{proton}$

2013 July-August Experiment

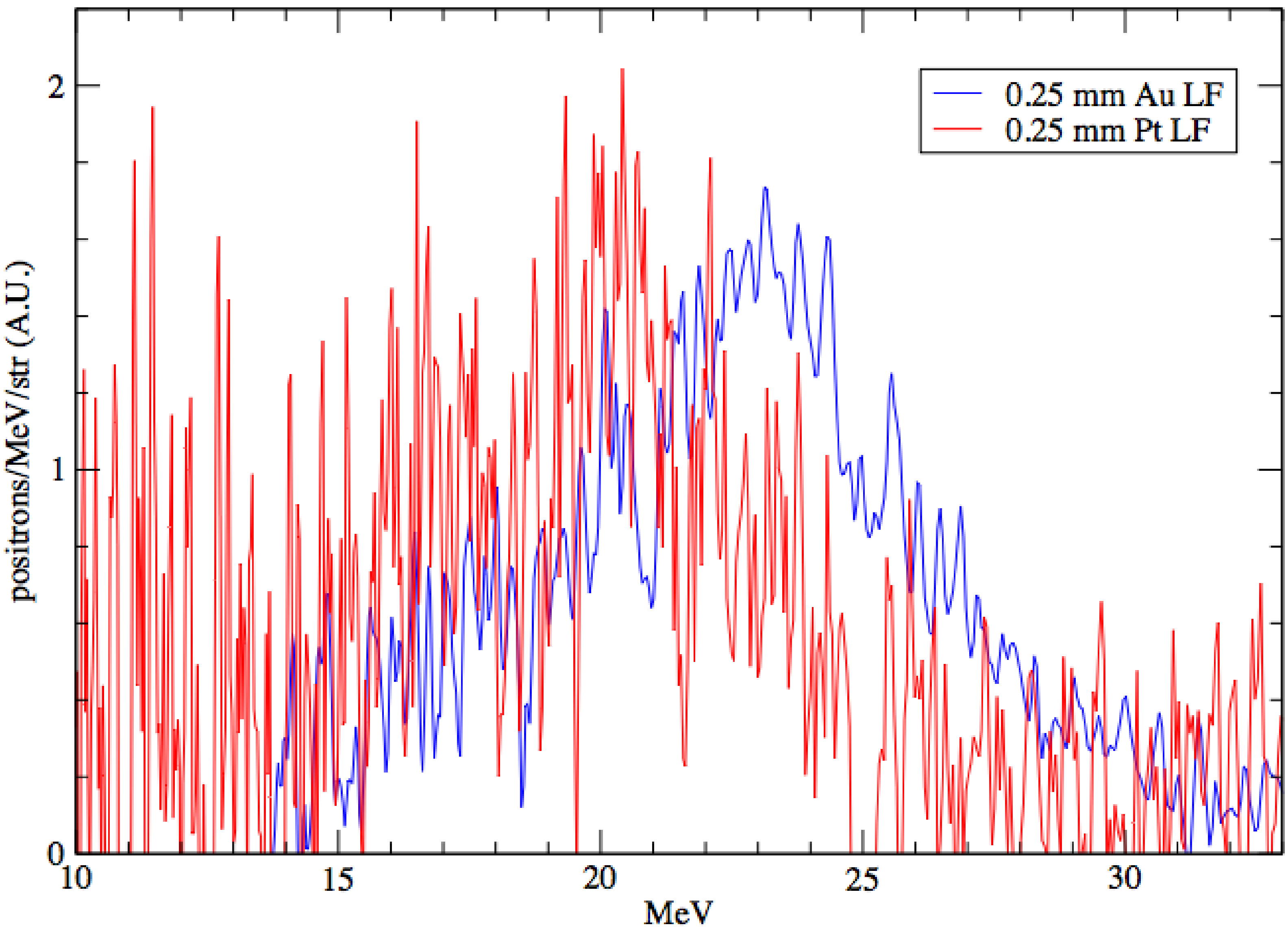
62 Shots total: 27 Pt targets, 35 Au targets

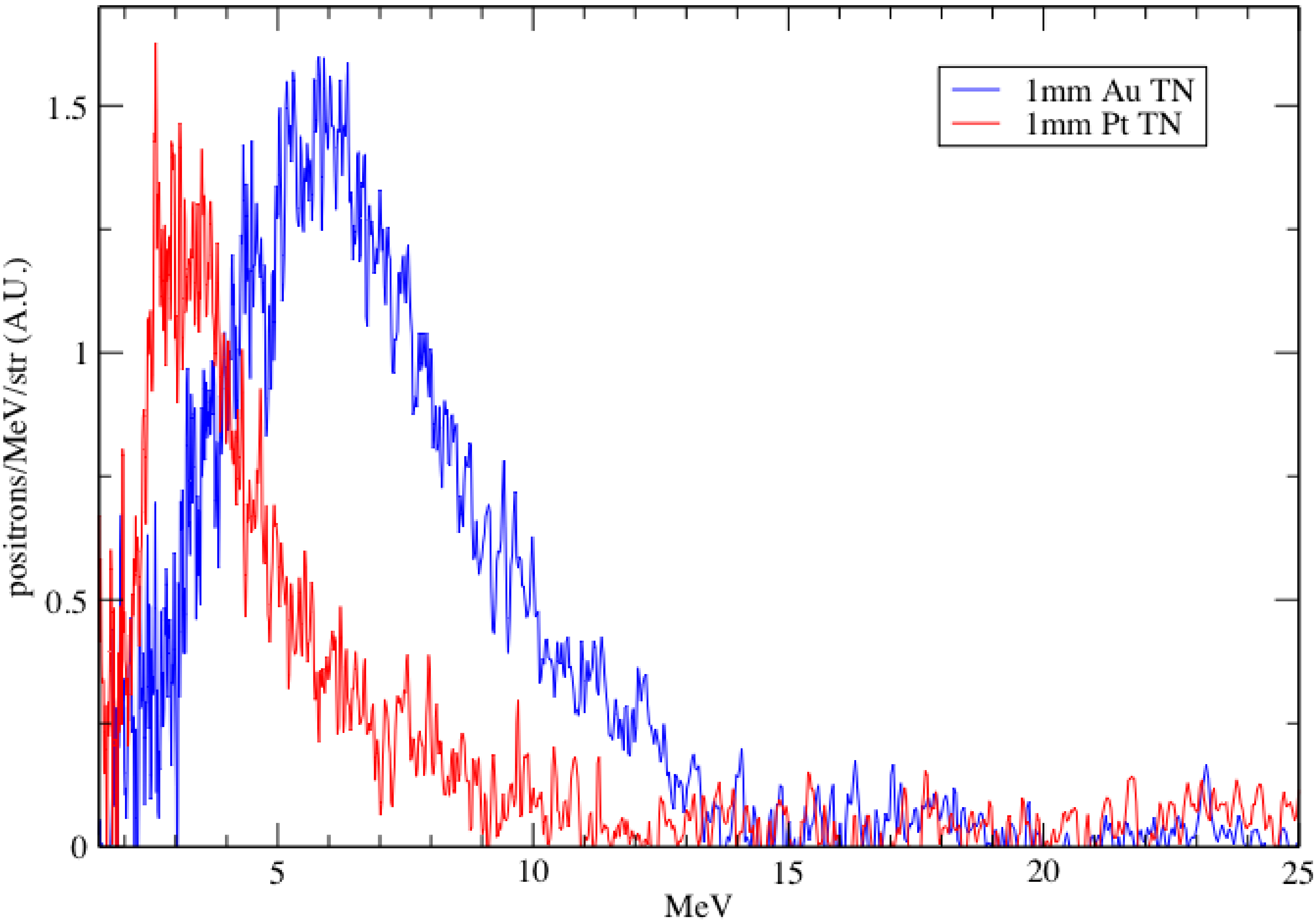
1. TPW performance similar to 2012, with slightly higher average E, but lower peak I (only a few shots were above 10^{21} W.cm^{-2})

2. Quick look Au data consistent with 2012 results.
   e+/e- curve levels out for around 5 mm thick disks and 6 - 7 mm long rods of 2-3mm diameters.

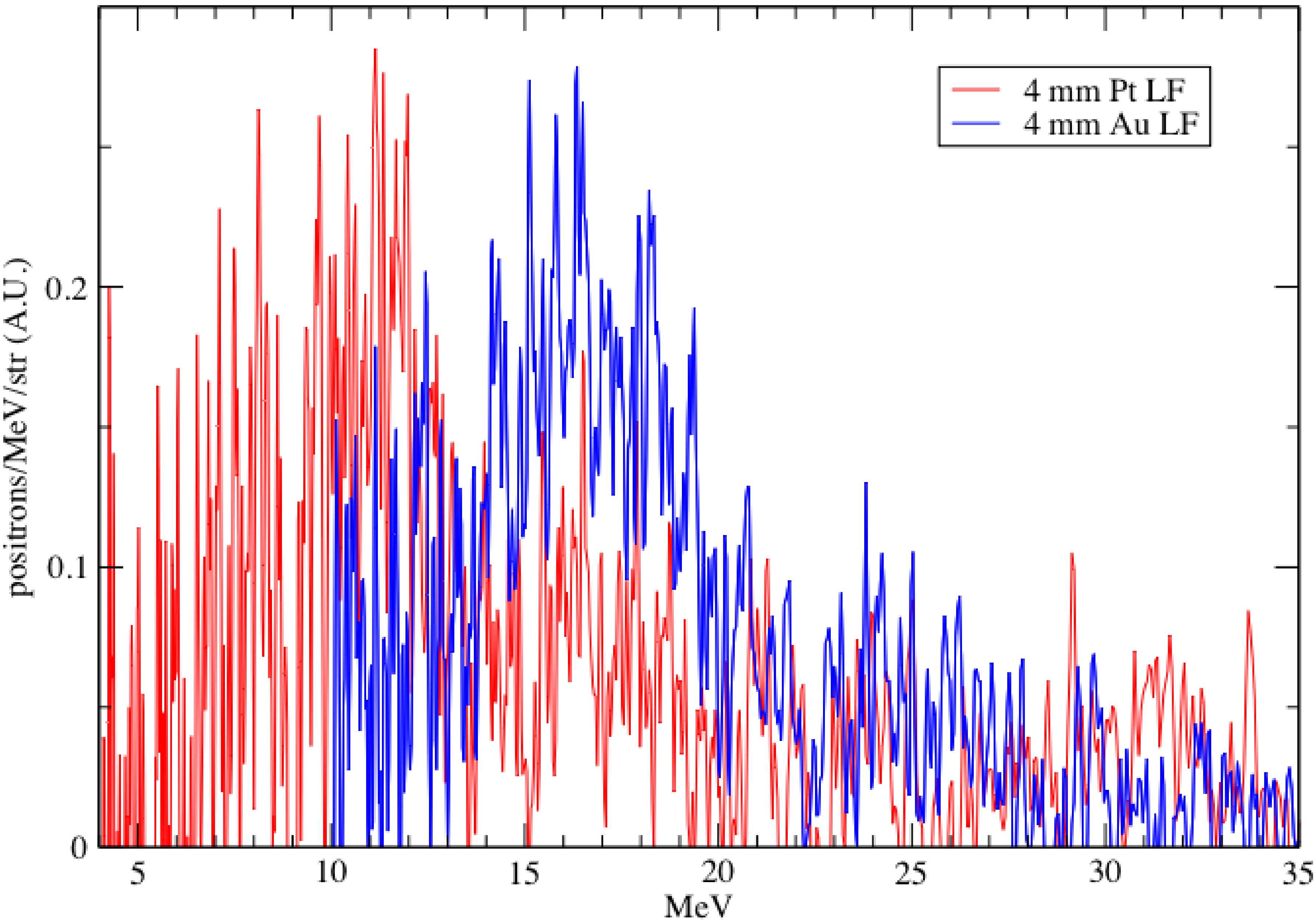
3. Quick look Pt data suggest that e+/e- ratio and e+ yield are comparable to Au. But the Pt e+ energy is lower.

Pt e+ peak energy lower than Au by ~ 3 MeV





1mm Au TN
1mm Pt TN
positrons/MeV/str (A.U.)
MeV
0
0.5
1
1.5
5
10
15
20
25



4 mm Pt LF
4 mm Au LF
positrons/MeV/str (A.U.)
0
0.1
0.2
5
10
15
20
25
30
35
MeV

Summary

1. We confirmed copious pair creation using TPW, with maximum e+yield up to ~10^{11}e+/str for ~100 J laser energy
2. Inferred e+ emergent density >10^{15}/cc
3. e+/e- ratio shows nonlinear increase from 3 to 4 mm thickness, with max. ratios exceeding 20 %
4. Rod targets tend to produce higher e+/e- ratios when viewed off-axis.
5. Narrow-band positrons up to ~ 23 MeV are detected for thin targets (0.1-0.35 mm).
6. Pt e+ energy peaks are ~ 3 MeV lower than Au.
7. e+ peak energy ~ 10 times higher than proton energy for Au
8. e- peak energy ~ 12 - 15 MeV for all Au shots, with kT > ponderomotive temperature

For Gamma-Ray Results of TPW Experiments, Please See Poster No. YP8.00049 by A. Henderson et al.

Our results confirm that the maximum positron yield is

~ 10^{12} e+ per kJ of laser energy
when the Au target ~ 5 - 6 mm

The emergent e+ density may reach > $10^{17}/cm^3$

The peak e+ current may reach 10^{24}/sec

(This is 10^{10} higher than conventional schemes
using accumulators and electrostatic traps)