Radiological Dose Rates from Laser-Target Interactions at 10^{17} W/cm^2 Irradiance

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With great support from LCLS MEC and LSTD Group

SLAC National Accelerator Laboratory

U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Lasers Generating Ionizing Radiation

Process:

- Focused tightly enough on material creates plasma
- Laser light accelerates electrons (distribution from 10's to 1000's of keV)
- Bremsstrahlung when electrons hit ions

Important Unit: Irradiance W/cm^2 [energy/time/area]

Depends on Total energy Duration Focal spot size

Currently at SLAC:

- Matters in Extreme Conditions (MEC) Instrument at LCLS
  - λ = 800 nm, 0.15 J in 40 fs on 10 µm → ~3×10^{18} W/cm^2 (at 10 Hz)
- Other SLAC lasers not used for high irradiance

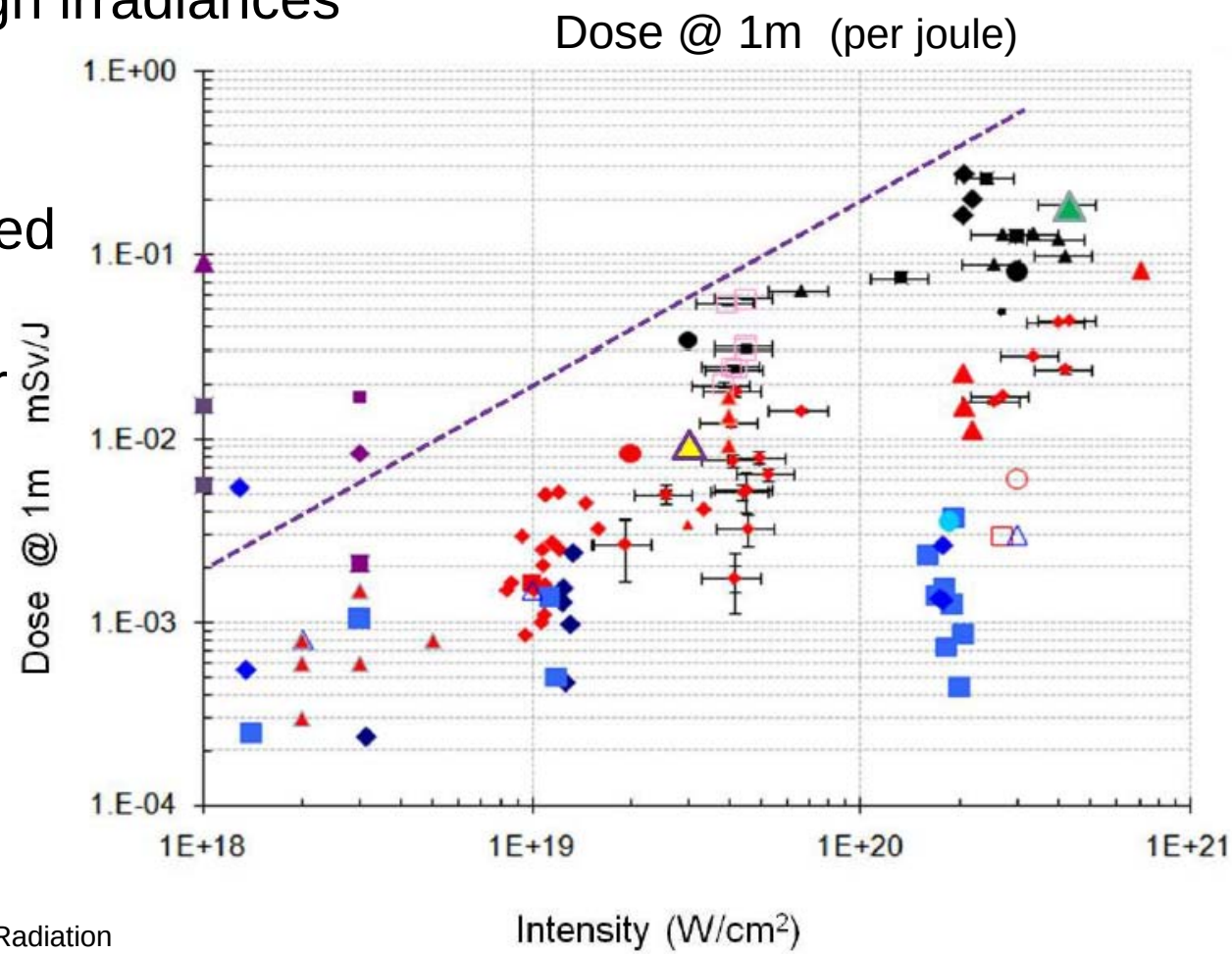
SLAC's Approach (= Outline of My Talk)

1. Review of literature and prepare model for radiation dose
2. Measurements at LLNL Jupiter Titan facility to
   - Test model
   - Test effect of Electro-Magnetic Pulse on radiation detectors
3. Measurements at SLAC MEC laser as part of commissioning
   - Test model
   - Determine hazards to determine controls

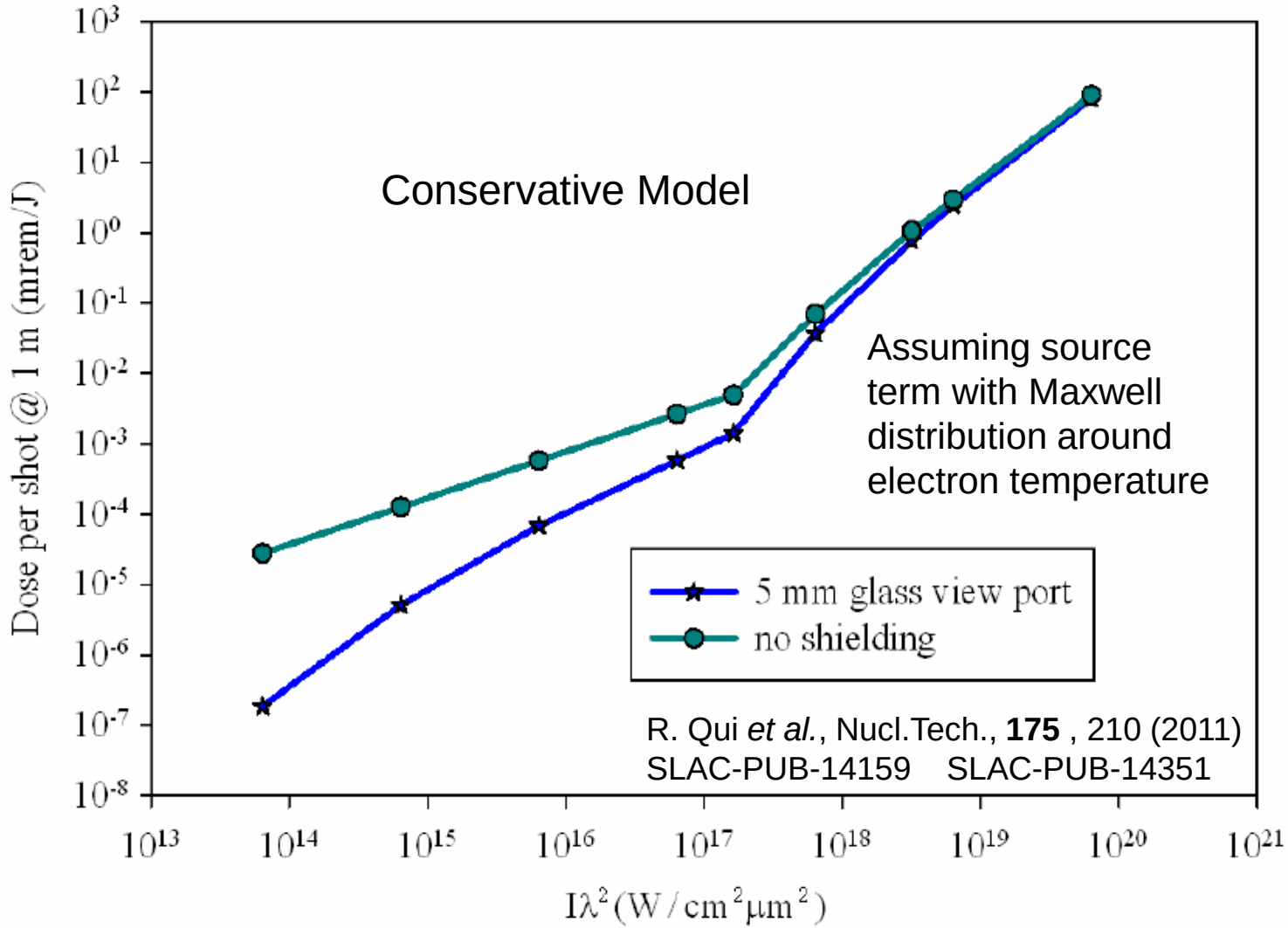
Measurements of Laser-Induced Radiation

Existing Measurements (compilation by Bob Nagler, SLAC)

- Mainly at high irradiances
- Parameters not always well-controlled or known
- Wide scatter depending material, direction, etc.



SLAC's Model of Laser-Induced X-ray Radiation



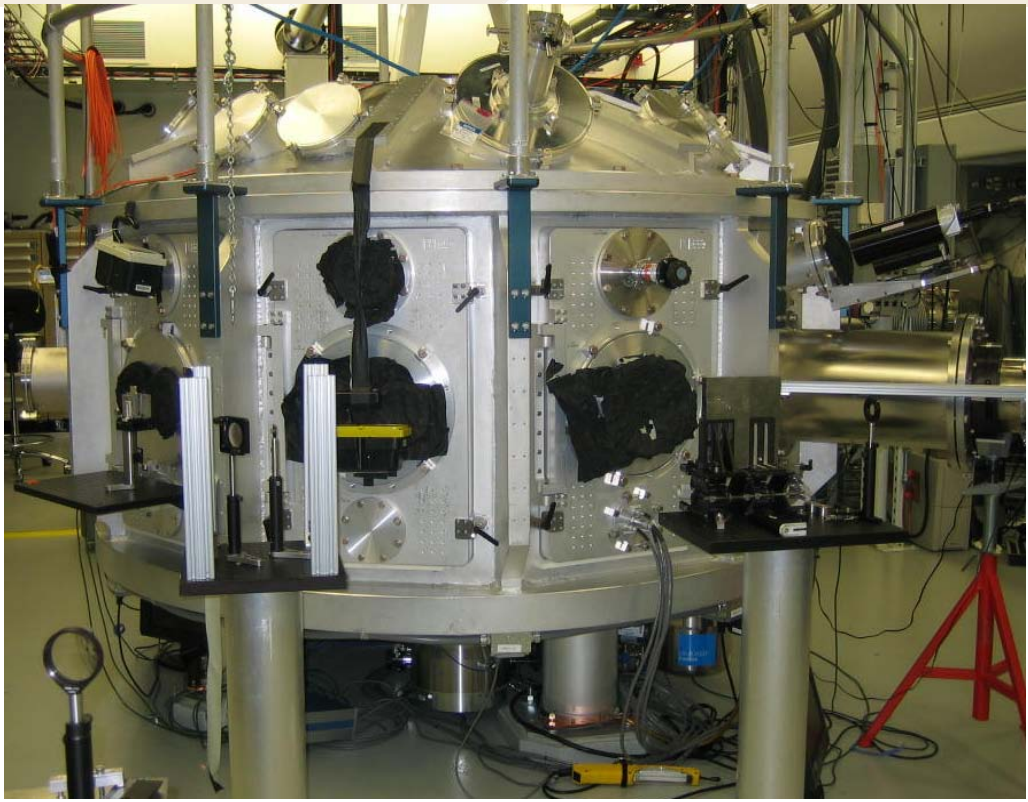
LLNL Titan Laser Facility: Setup & Parameters

Parasitic measurements during experiments by Hui Chen (LLNL)

Detectors around target chamber (1.5 inch thick aluminum walls)

Shots on Targets (once every > 30 min)

- 5 shots with hydrocarbon foam (3 to 10 mg/cm^3) + 1 mm gold
- 1 shot with hydrocarbon foam
- 1 shot with 1 mm gold

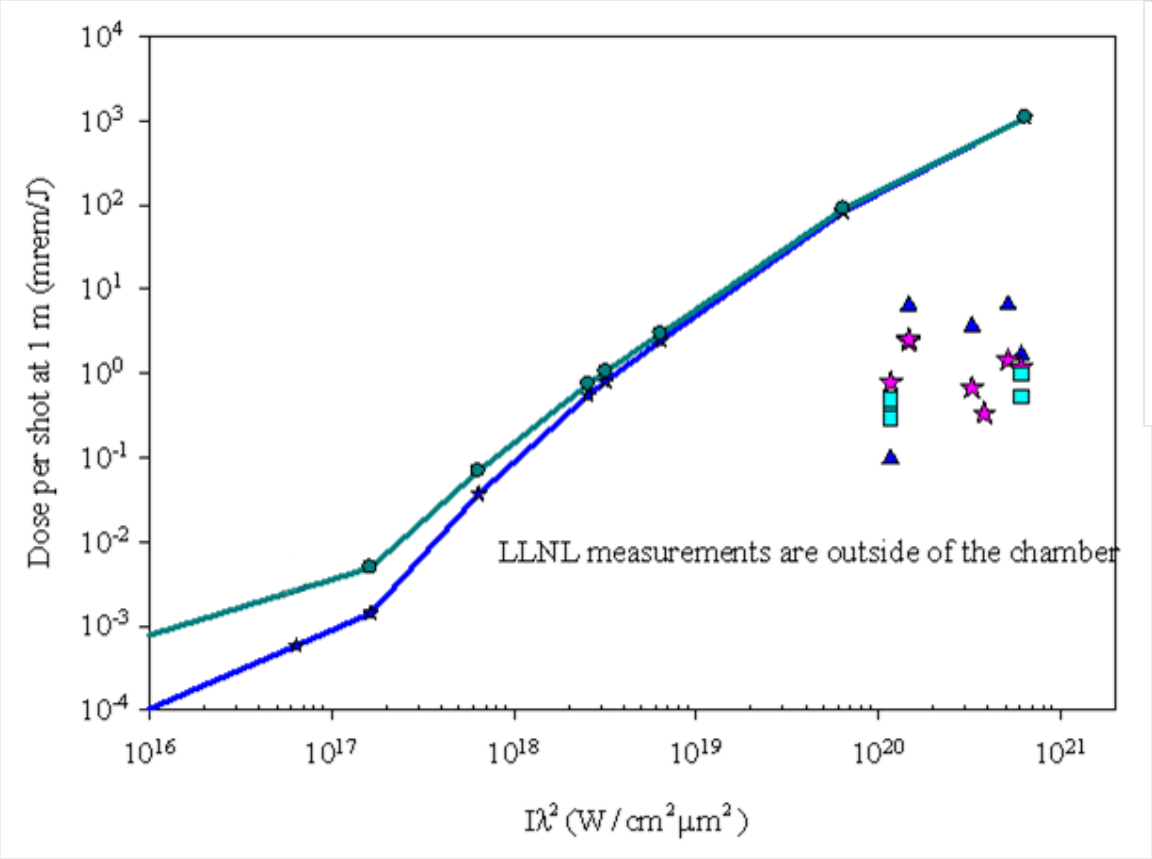


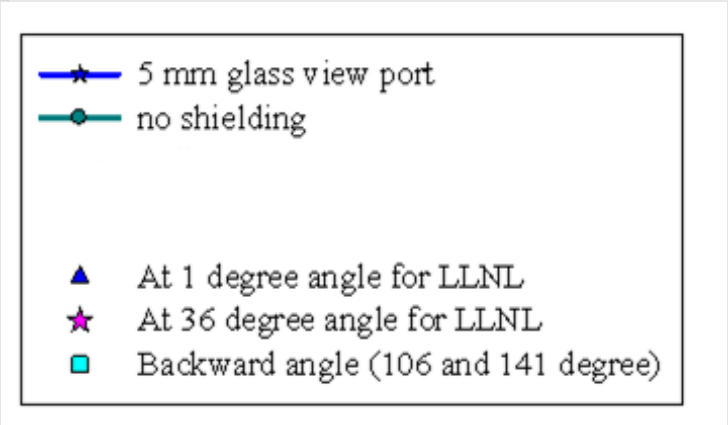
Beam Parameters:

- λ= 1 μm
- Ø = 10 μm
- 0.7 to 10 ps
- 50 to 400 J

➔ irradiance = 10^{20} to 10^{21} W/cm^2

Titan Laser Facility: Dose Results

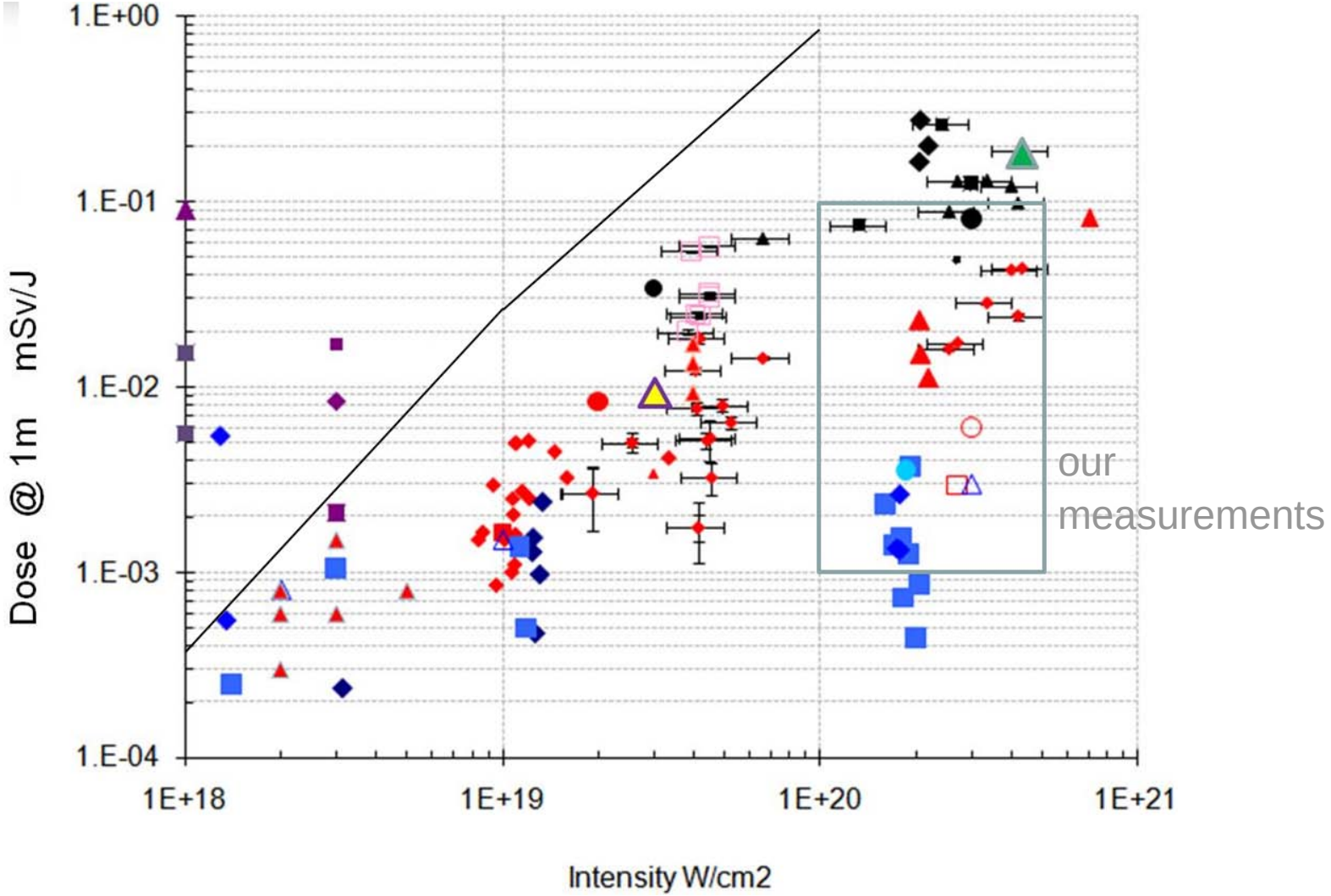




- Outside Target Chamber: up to 500 mrem/shot
- Inside chamber: ~10 x higher
- Forward angle: ~10 x higher

- Pure gold lower doses than with hydrocarbon foam

Titan Laser Facility: Dose Results (cont.)



Titan Laser Facility: Measurement Techniques

Active instruments didn't work:

- Victoreen 450 & 451 (handheld ion chamber)
- Rados RAD-60 (clip-on solid-state detector)
- HPI Meridian Remmeter (heavy portable neutron meter)

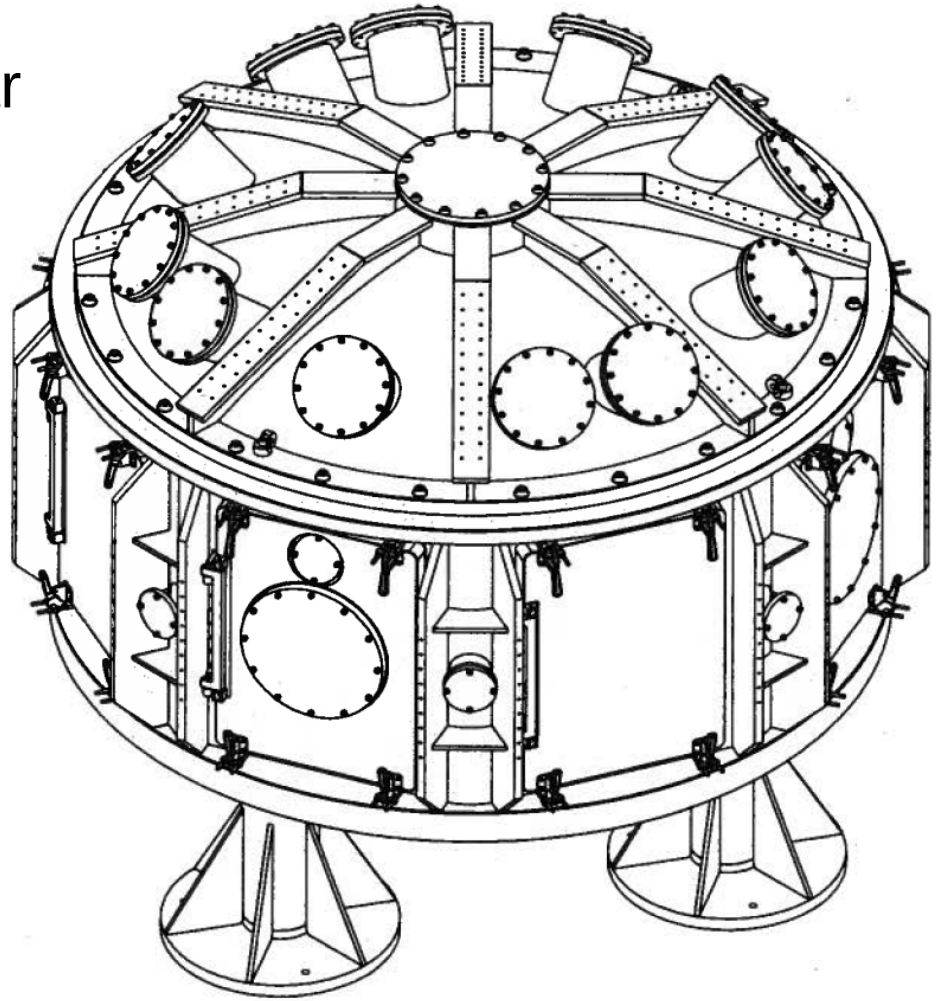
Perhaps Electro-Magnetic Pulse (EMP) or short pulse

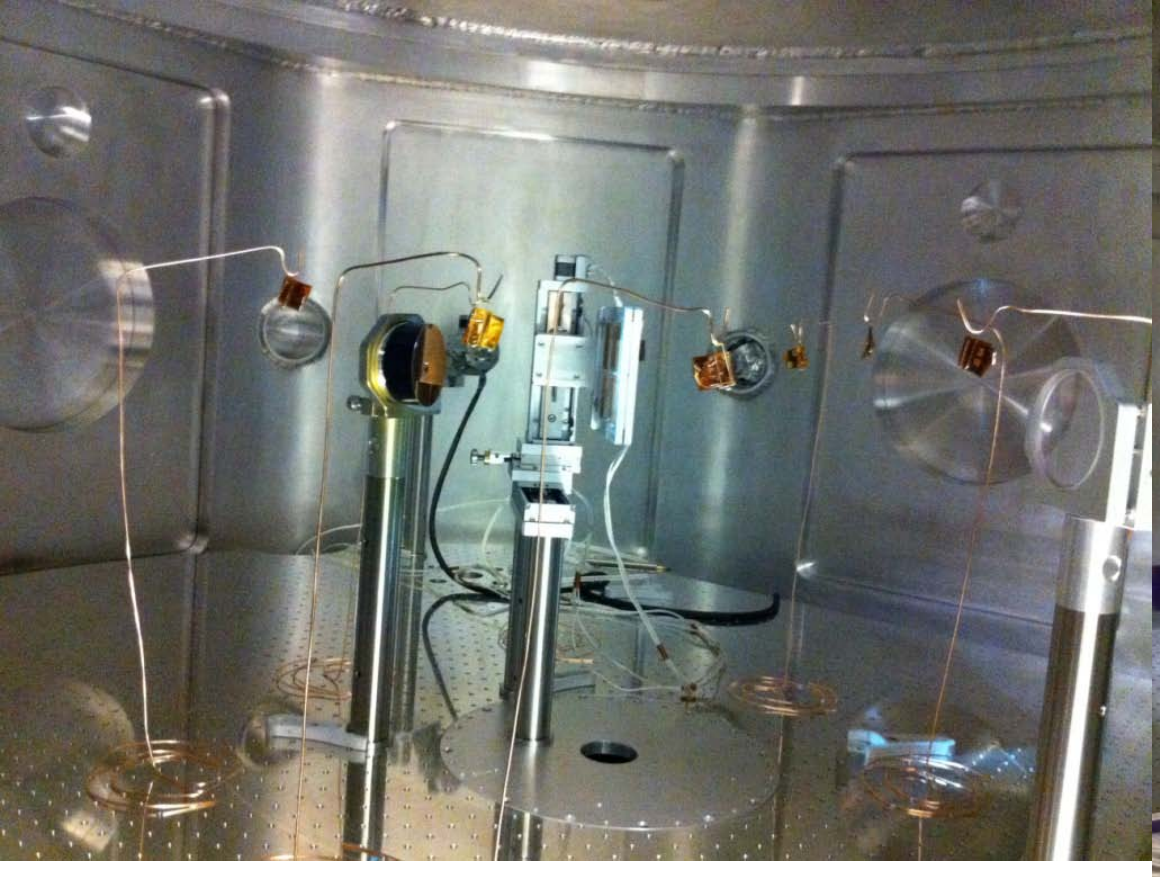
Passive dosimeters worked and consistent with each other:

- Panasonic personnel dosimeters
- Landauer Inlight
- Landauer Luxel+ (with CR-39 for neutrons)
- Pocket Ion Chambers (mechanical using electrostatic charge)

SLAC MEC Laser: Target Chamber

- Target chamber very similar to Titan's
- 1 m radius
- Al walls as shielding (~ 0.5 to 2 inch)
- Several glass viewports (0.5 to 1 inch)

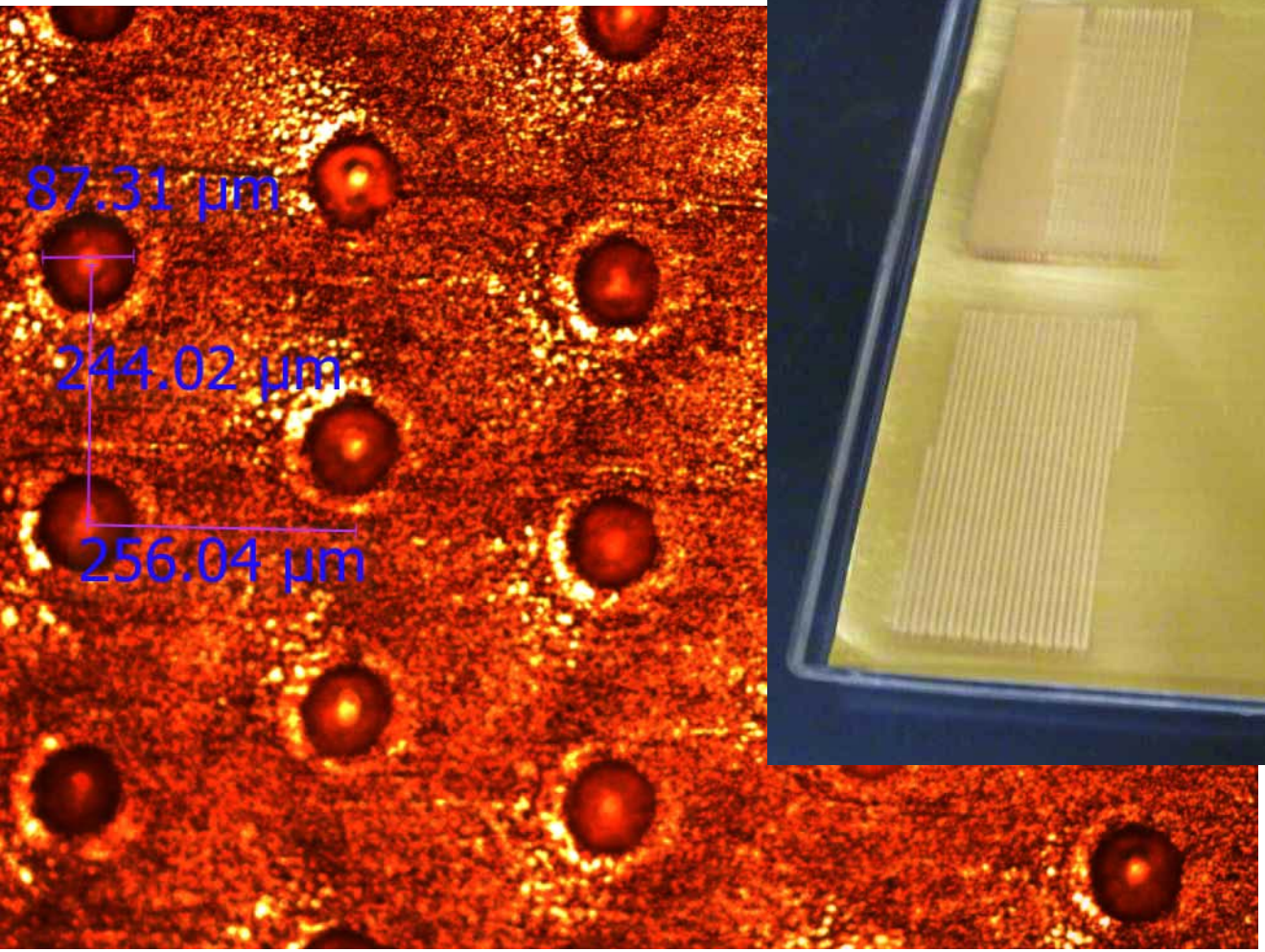


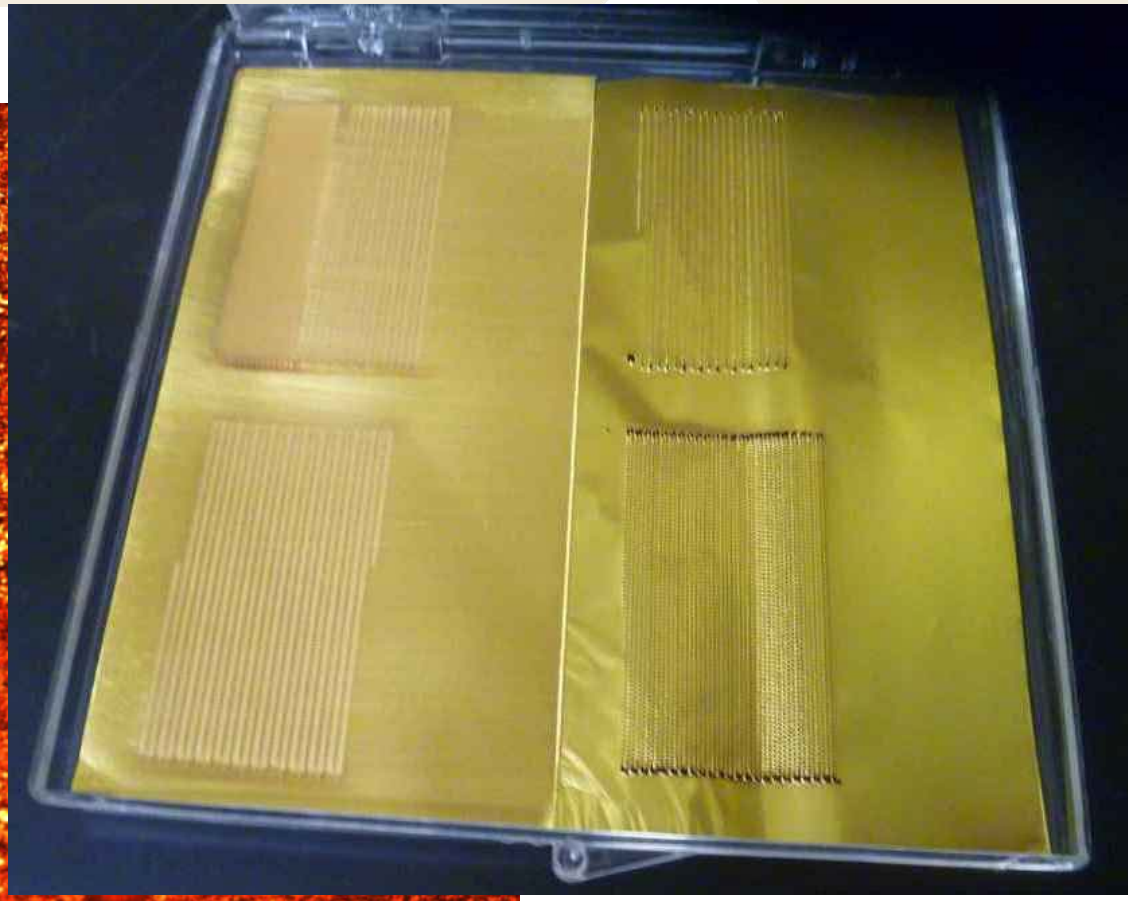


- Target in center:
  100 μm & 10 μm Au, 100 μm Kapton, 1 mm Cu
- Target moved shot-by-shot (rastering)
- Landauer “Nanodot” dosimeters inside chamber, all other outside

SLAC MEC Laser: Target Rastering

Gold foils after use

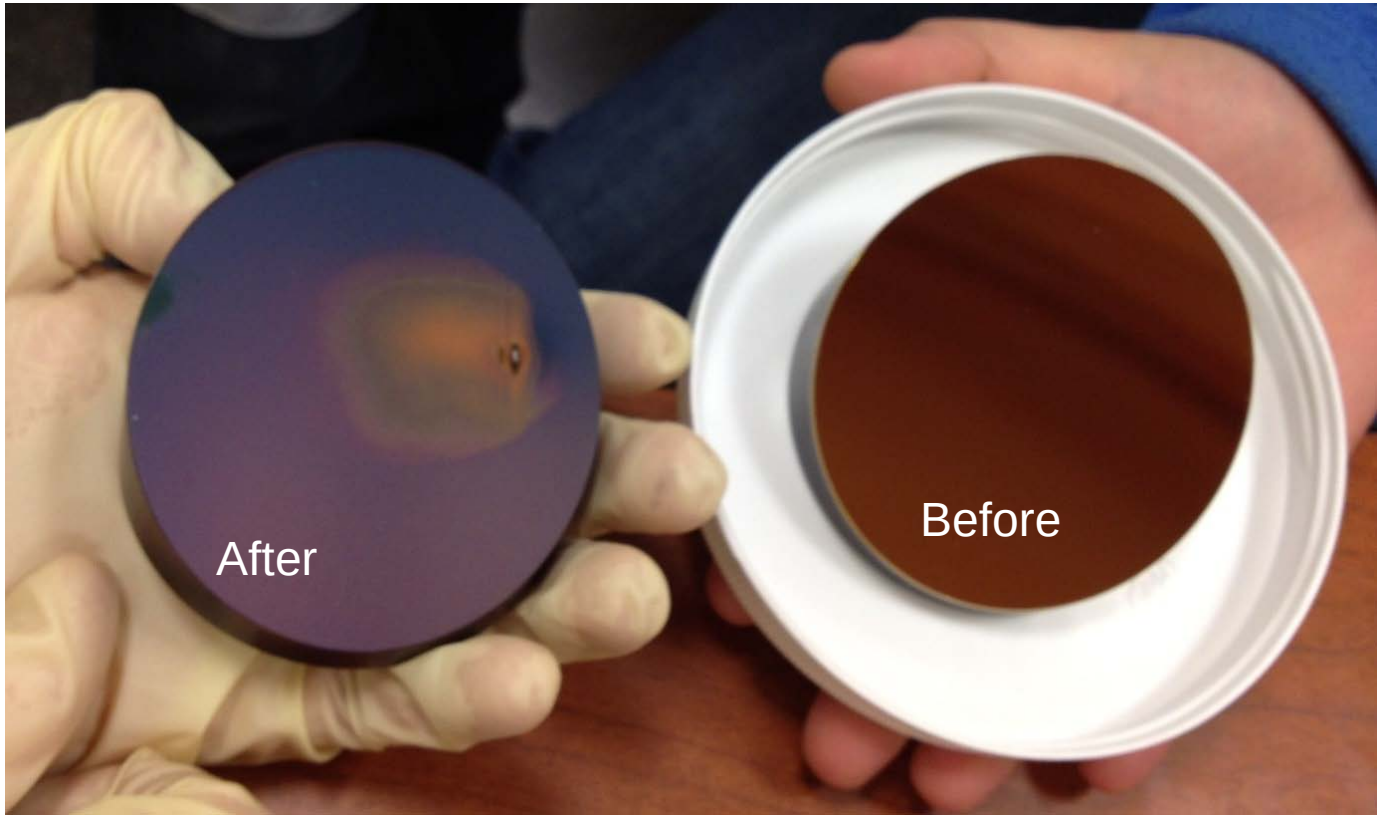




Thick and thin foils

SLAC MEC Laser: Mirror Damage

Damage to Off-Axis-Parabolic Mirror after Kapton and Gold shots

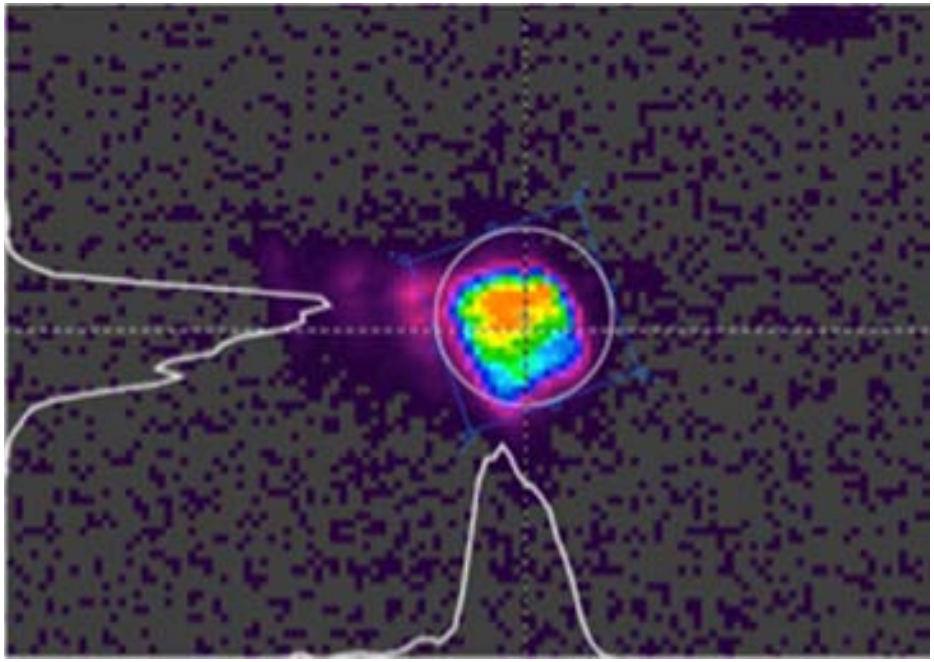


→ Mitigation is not using Kapton, moving mirror farther away

SLAC MEC Laser: Irradiance

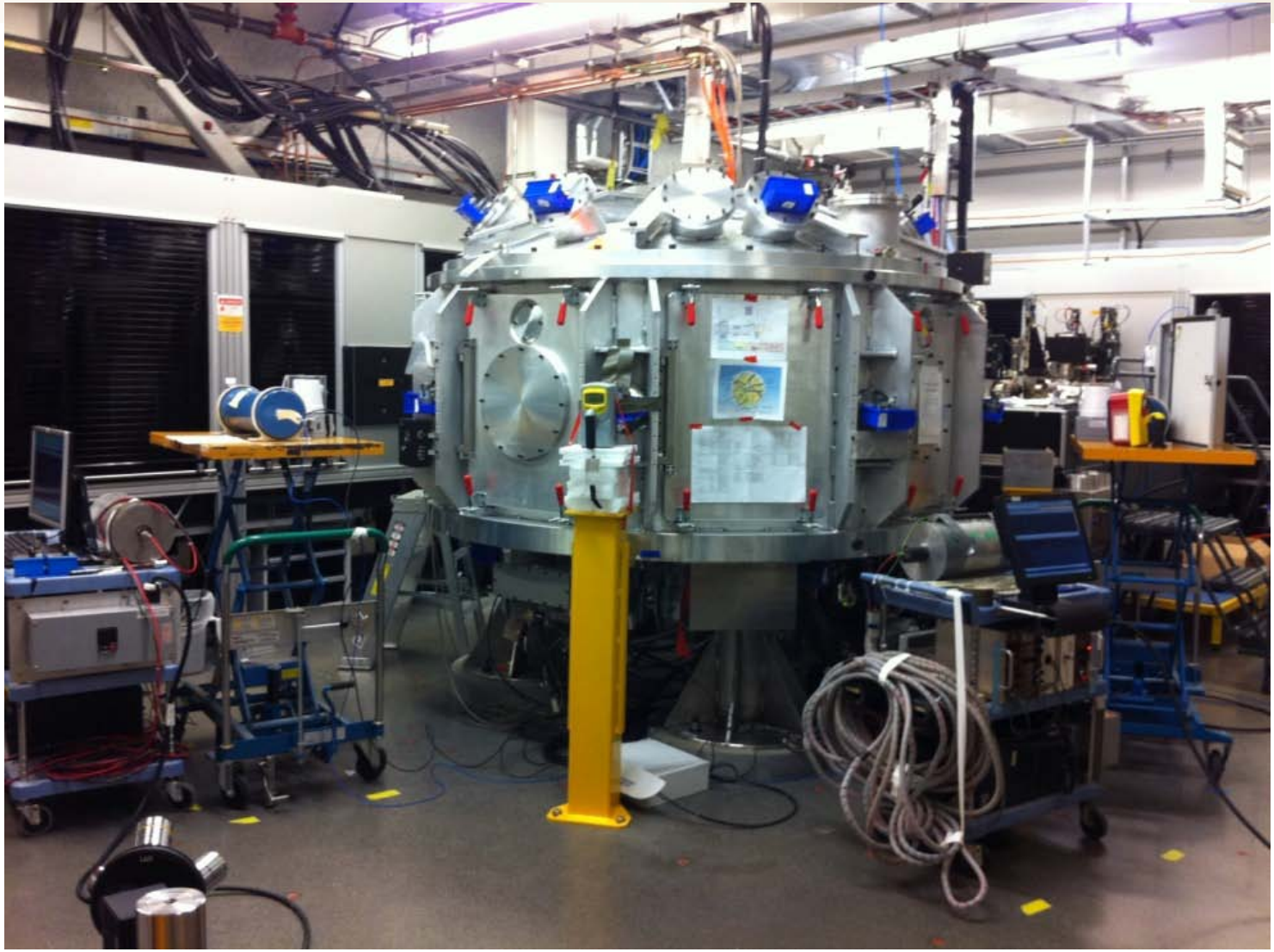
Not easy to determine irradiance for tight focus

- Measurement with cameras while attenuator in beam
- Irregularities in spot
- Mis-alignment by
  - Pumping down
  - Thermal effects
  - Rastering movement
  - Degradation of lenses (huge for Kapton, large for all others at high irradiances)

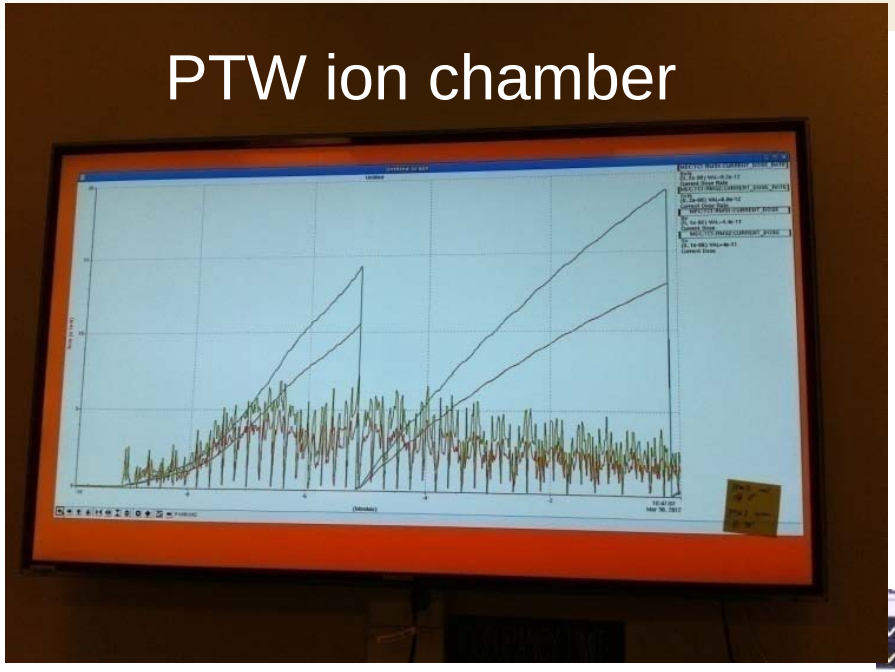


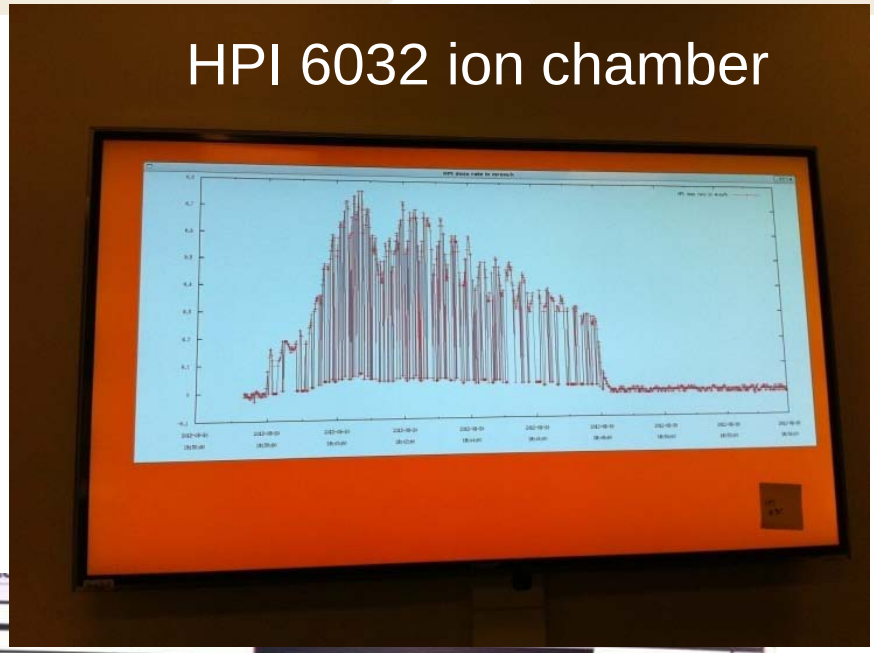
Runs at 5×10^{16}, 9×10^{16}, 2×10^{17}, 1×10^{18} W/cm^2 with factors of uncertainties in irradiance about 2 to 3

SLAC MEC Laser: Measurement Locations



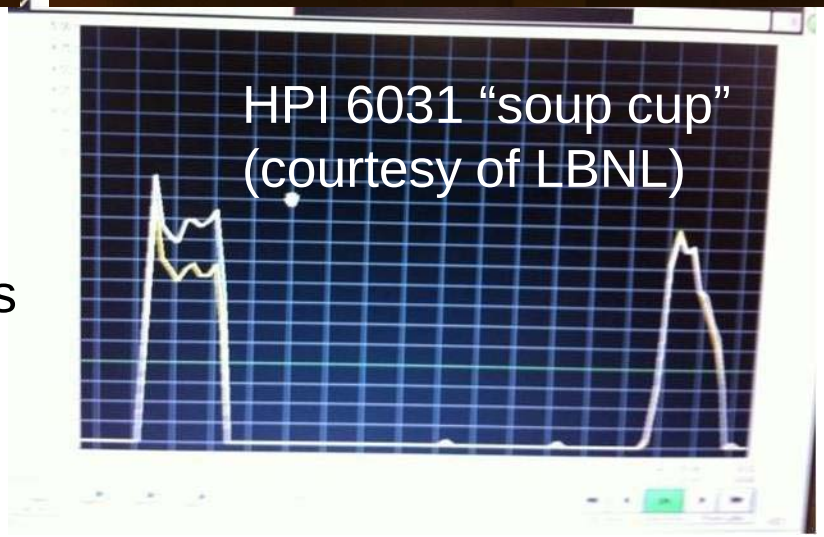
SLAC MEC Laser: Remote Readings



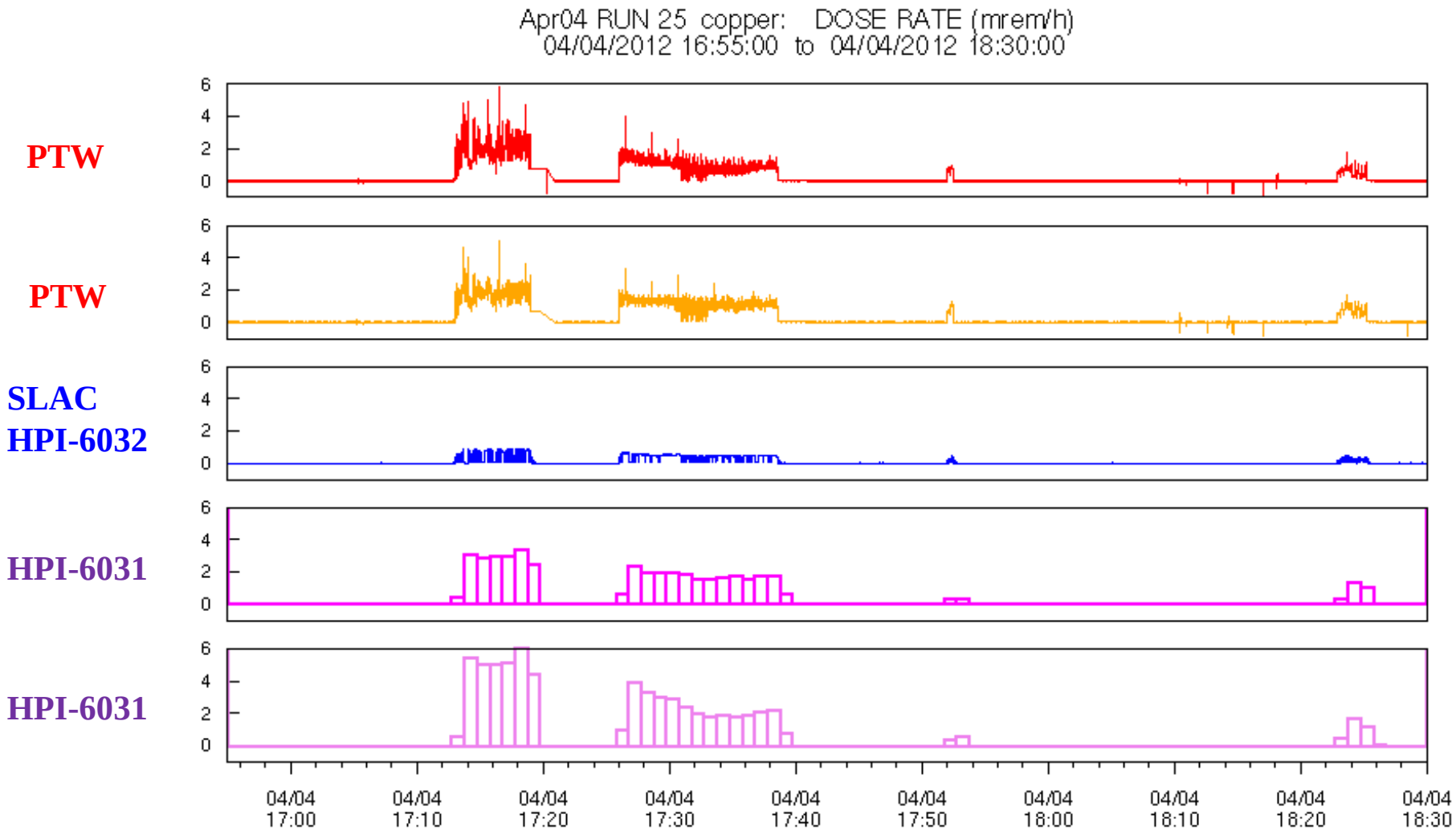


Active instruments worked

- Radiation Detectors became "tool" for laser operators
- Spikes from rastering alignments
- Showed degradation



SLAC MEC Laser: Remote Readings (cont.)



SLAC MEC Laser: Other Instruments

Outside Target Chamber also:

- 2 mR & 200 mR Pocket Ion Chambers
- Luxel+, Panasonic, Inlight dosimeters
- Rados RAD-60 electronic dosimeters (they worked!)
- Victoreen 450/451 ion chambers (they worked!)
- BF3 Neutron Detectors (no clear indication for neutrons)

Outside Hutch:

- Inlight dosimeters
- Surveys with Victoreen 450/451 ion chambers

SLAC MEC Laser: Results

Outside target chamber:

- Highest dose rate:
  40 mrem/h from RADOS on glass viewport
  [7 mrem in 8 min at $2x10^{17}$ W/cm^2]
- Active detectors: Maximum 6 mrem/h at 10^{18} W/cm^2
- Possibly very-low-level of neutrons (0.6 μrem/h) at 10^{18} W/cm^2
- At $2x10^{17}$ W/cm^2: Maximum 3 mrem/h
- At $9x10^{16}$ W/cm^2: Some radiation detected
- At $5x10^{16}$ W/cm^2: No radiation detected

Dose limit for users is 100 mrem/year

Inside target chamber:

High dose rates of low-energy electrons at 30 cm

- At $5x10^{16}$ W/cm^2: 4 rad/h
- At $1x10^{18}$ W/cm^2: 10 krad/h

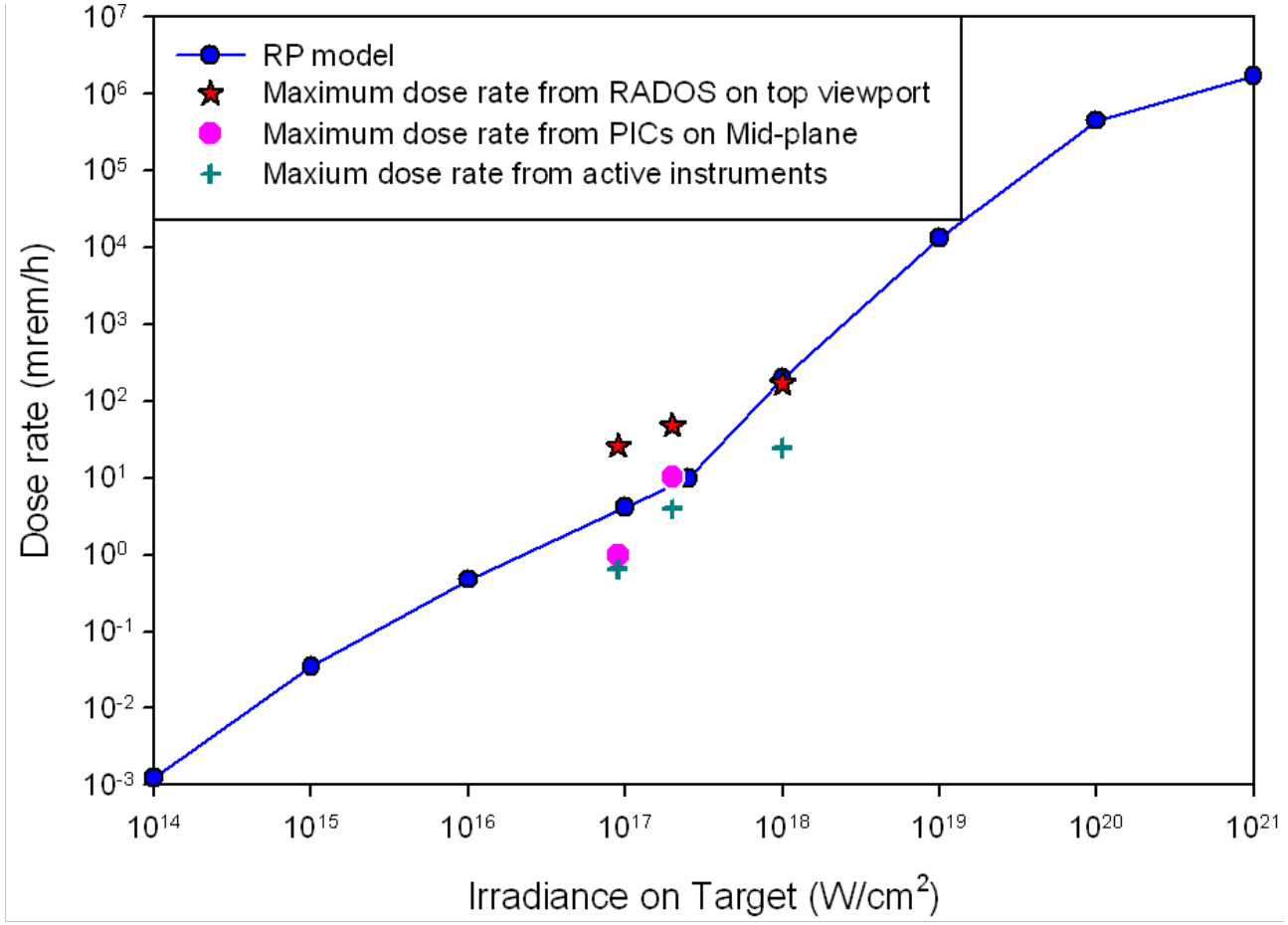
Target Z-dependence

- No large difference for different metallic targets (all within factor ~2)

SLAC MEC Laser: Results (cont.)

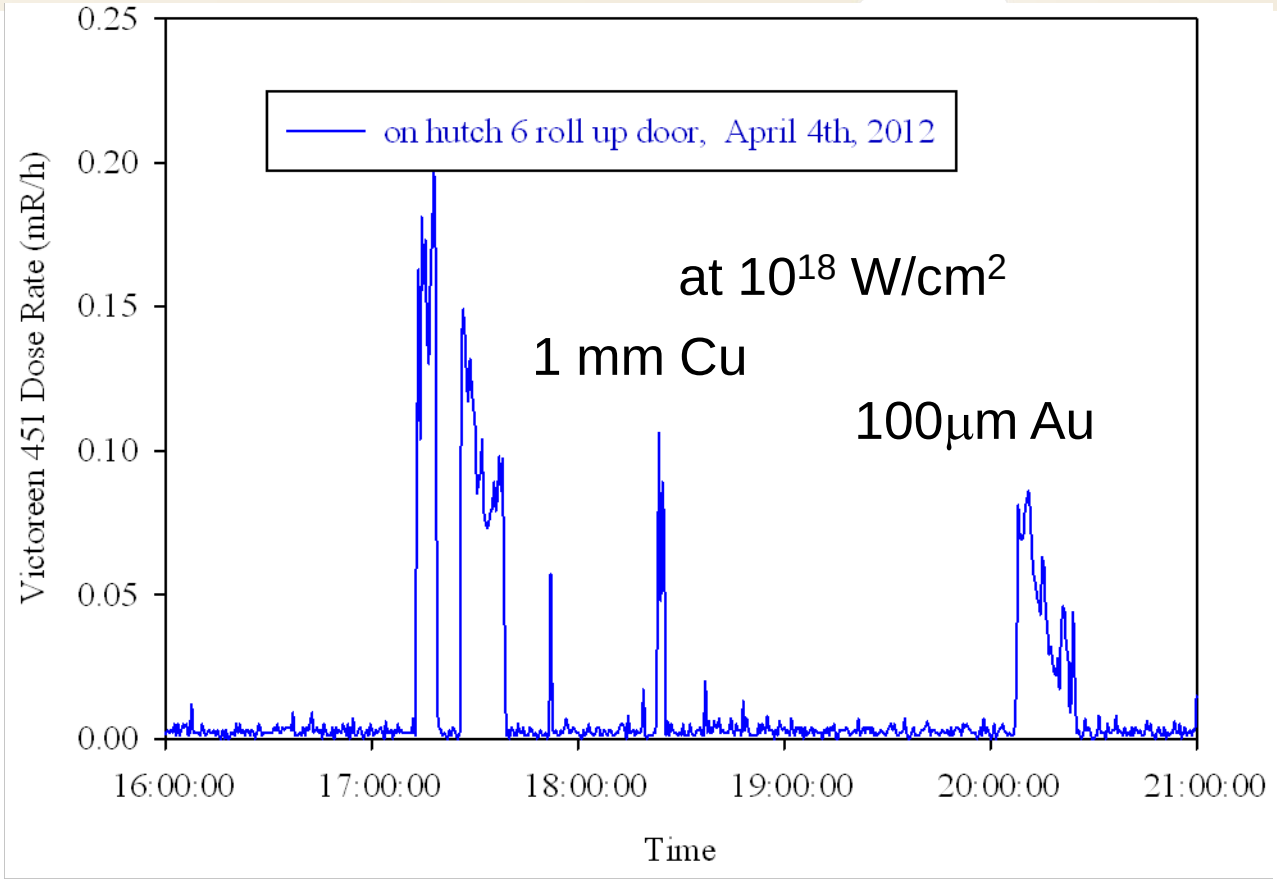
Dose results outside target chamber consistent with RP model

(large uncertainties in irradiance measurements, about factor of 2-3)



SLAC MEC Laser: Outside Hutch

No positive reading on dosimeters



Up to 0.2 mR/h with Victoreen 450 at steel roll-up door
(about 3 m from Target Chamber)

SLAC MEC Laser: Gas Target

More measurements in July/August

Test of Higher Harmonic Generation with Gas Target inside target chamber

- Argon, Xenon, Neon at 20 to 80 mbar
- Irradiances of 10^{14} to $3x10^{15}$ W/cm^2
- Concern of going into regime of Plasma Wakefield Acceleration
- From analysis expected no radiation, but still took initial measurements

SLAC MEC Laser: Gas Target (cont.)

During Full 2-Week Experiment:

Passive dosimeters and active radiation monitors (Rados; PTW and HPI 6031 ion chambers) outside target chamber

→ nothing seen, hence dose rate limit of 0.1 mrem/h

Also During Initial Shift:

Passive dosimeters inside target chamber, beam for 1 hour

→ nothing seen (dose rate limit of 10 mrem/h)

Will perform new measurements in future gas target experiments with higher irradiances

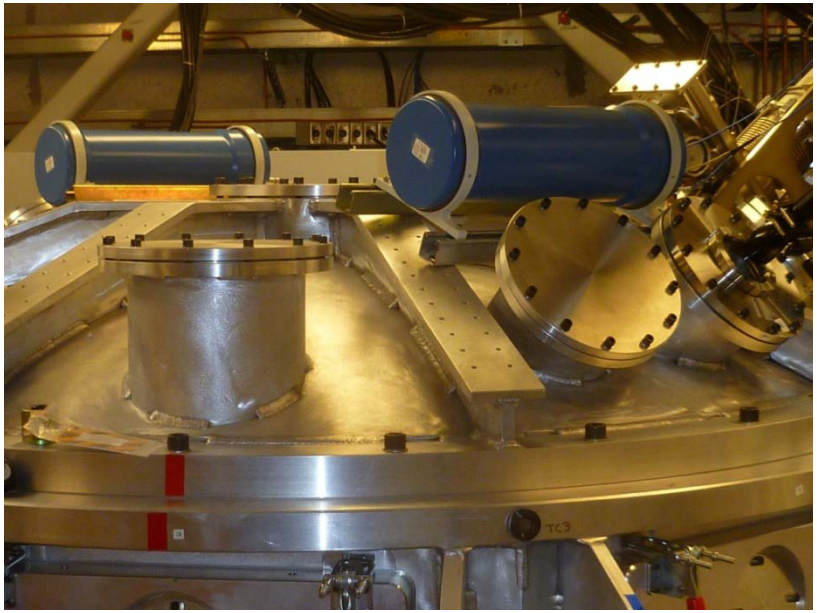
Controls for MEC Laser

Difficult alignment ➔ no ‘turn-key’ operation

- Radiation Generating Device with RGD Authorization Sheet
- Only SLAC qualified laser operators (QLOs)
- Solid targets only (or special permission)
- No deliberate enhancement of laser pre-pulse
- Controls keep irradiance low (10^{15} W/cm^2; maximal 10^{16} W/cm^2):
  - Setting of focal length, pulse length, pulse energy may allow only maximal 10^{15} W/cm^2
  - Or special conditions like no vacuum, no compressor, no focusing optics
  - Checklist signed by QLO and LCLS Safety Officer
  - Exceptions need to go to Radiation Physics

Controls for MEC Laser (cont.)

- PTW Radiation Monitor inserts shutter on high radiation
- LCLS Safety Officer informed of trips



Non-RSS system:

- Trip at 0.2 mrem/h for 5 min,
  5 mrem/h for 12 sec
- Warning (no trip) for 1 mrem in 1 day
- Monitor dose & dose rates (archive)

Two PTW Ion Chambers (5 liter at 10 bar = 50 liter effective)

PLC closes shutter in laser path on PTW trip

Computer read-out to archive, warning on daily dose

Possible Upgrade to MEC Laser Control

MEC wants laser at maximum intensity ($3x10^{18}$ W/cm^2)
when hutch in no-access mode

Update planned (still under discussion):

- Remote-controlled insertion of polarizer-waveplate-polarizer stack to reduce laser pulse energy (for maximal irradiance of 10^{15} W/cm^2)
- Interlock with hutch access state:
  Shutters open only if stack is in or hutch in no-access
- Proper Configuration Control of this device
- Radiation Monitor part of Radiation Safety System
  (i.e., fail-safe, redundant, etc.)

Control for Other SLAC Lasers

Other Lasers at SLAC:

- No research (yet) that requires high irradiance
- Keeping track of lasers and their operation parameters
- So far always below threshold for authorization
- Dosimeters to confirm no radiation (a posteriori)

New lasers being discussed to be used for plasma wakefield acceleration

Conclusion

Thanks to LCLS MEC and Laser Groups for help with measurements and controls!

- MEC Laser a Radiation Generating Device
- Inside target chamber radiation from $5x10^{16}$ W/cm^2
- Outside target chamber radiation from 10^{17} W/cm^2

New Hazard at SLAC:

- Studied the hazards (source term)
- Measurements from $5x10^{16}$ to 10^{18} W/cm^2
- Developed engineering controls