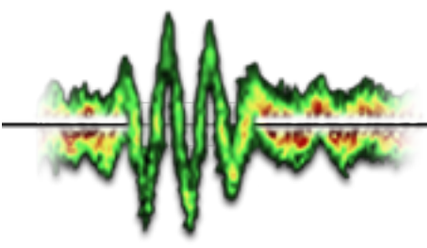


ICUIL Conference 2010

Relativistic electron dynamics in laser-nanofoil interactions:
Towards Ultra-dense Electron Mirrors

D. Kiefer

LMU München • Fakultät f. Physik
Max-Planck-Institute of Quantum Optics
Cluster of Excellence “Munich-Centre for Advanced Photonics”
(MAP)

A. Henig, R. Hörlein, P. Hilz, K. Allinger, J. Bin
W. Ma, V.Kh. Liechtenstein, X. Q. Yan, J. Schreiber, D. Habs

S. Steinke, M. Schnürer,
T. Sokollik, P. V. Nickles, W. Sandner

D. Jung, D. C. Gautier, R. Shah, SASI !??!?
S. Letzring, R. Johnson, T. Shimada, J. Fernandez, B. M. Hegelich

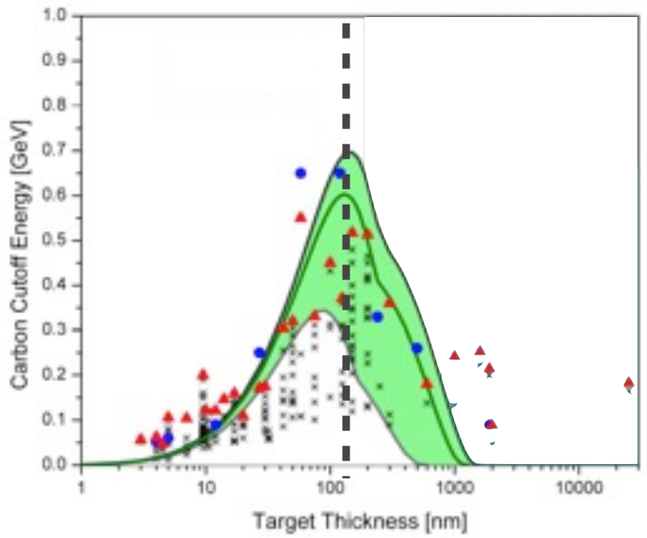
B. Dromey

Watkins Glen, NY - 09/27/2010

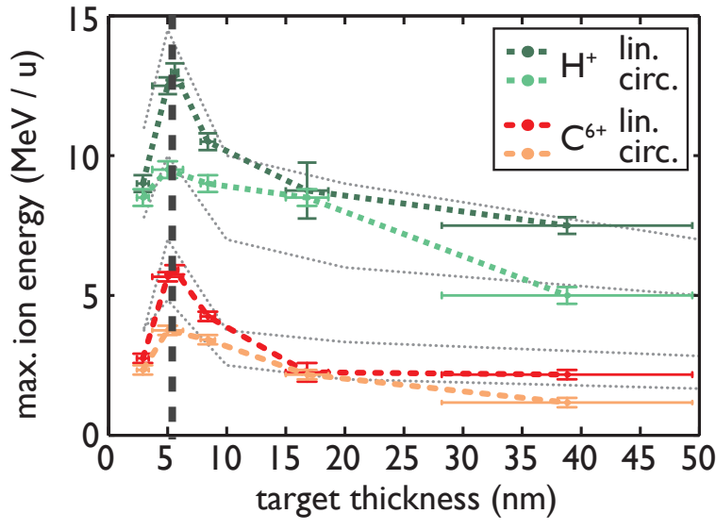
Ultra-thin targets: Why going to the limit?

max. ion energies vs target thickness

LANL: 90J, 500fs



MBI: 0.7J, 50fs



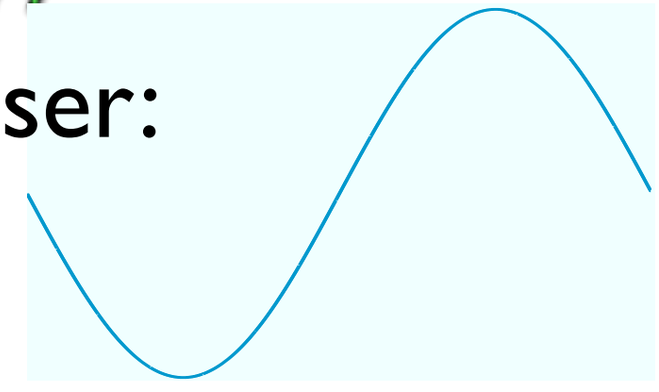
why using targets with thickness $d \ll (d_{opt})_{ion}$?

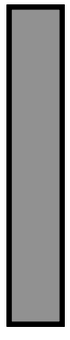
Outline

- Motivation:
  electron acceleration from solid density, ultra-thin targets
- First experimental observations:
  - Los Alamos National Lab
  - Max-Born Institute

Electron Blow-out Regime

Laser:





electrostatic charge separation field: (field of 1D capacitor)

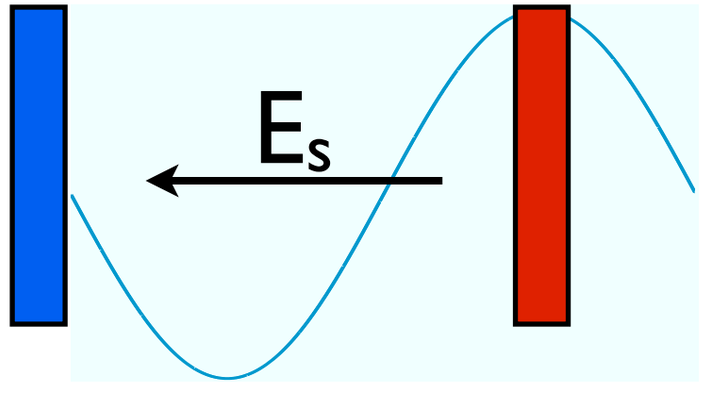
$$E_s = e\, n_e d/\epsilon_0$$

in normalized units: ($E_0 = m_e c\,\omega/e$)

laser field $\frac{E_L}{E_0} = a_0 > \frac{n_e}{n_c} k_L d = \frac{E_s}{E_0}$ electrostatic charge separation field

note: plasma skin depth (typically ~ nm) > target thickness

Electron Blow-out Regime



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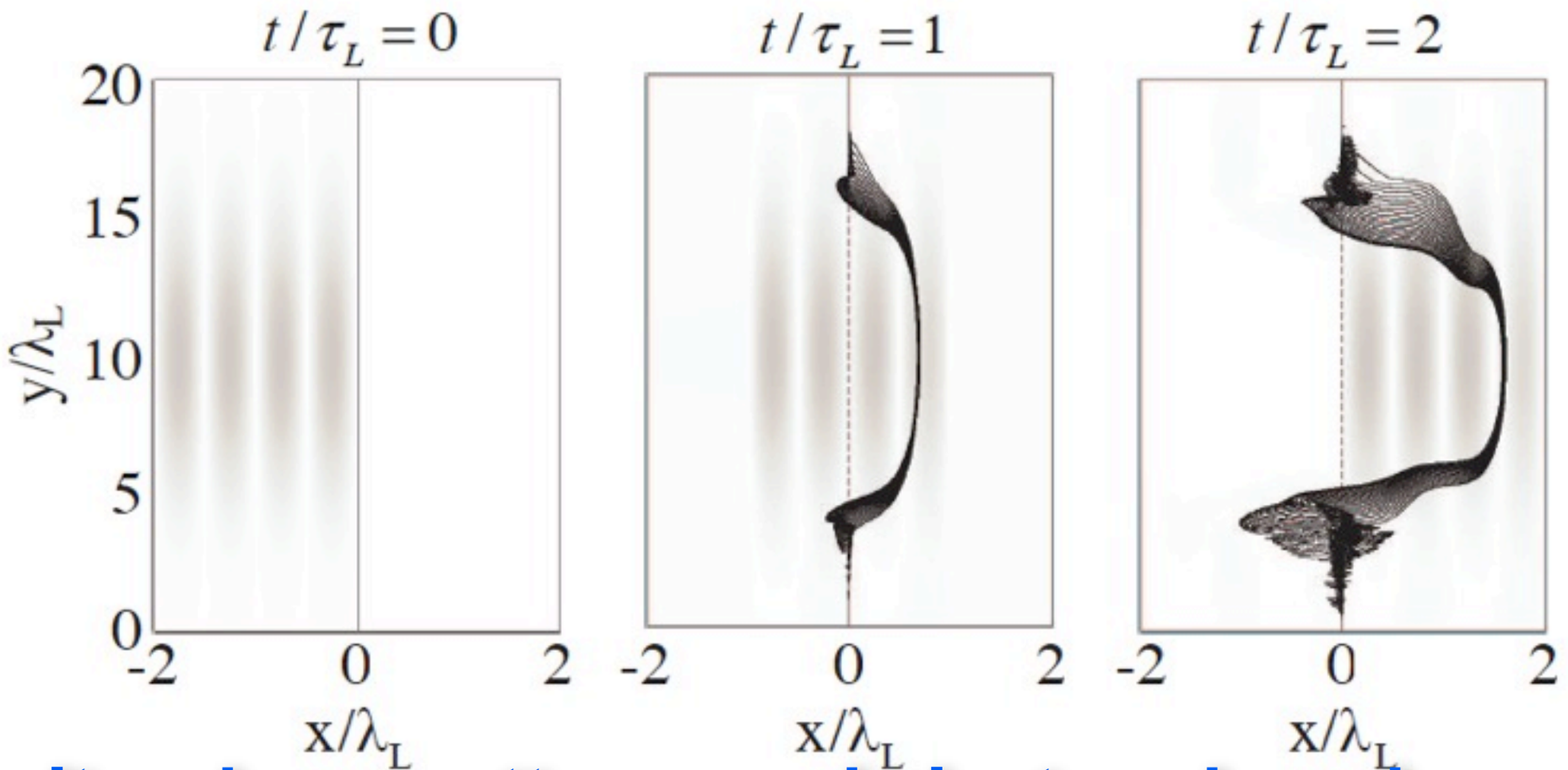
Electron Sheet Acceleration

PIC:

$$a_0 = 60$$
$$Nk_Ld = 10$$



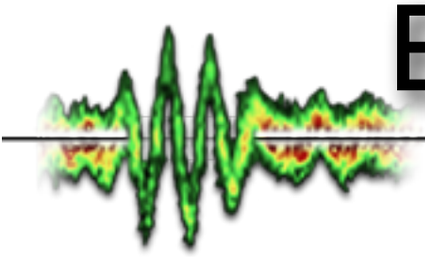
ultra-dense, attosecond electron bunch

[relativistic electron mirror]

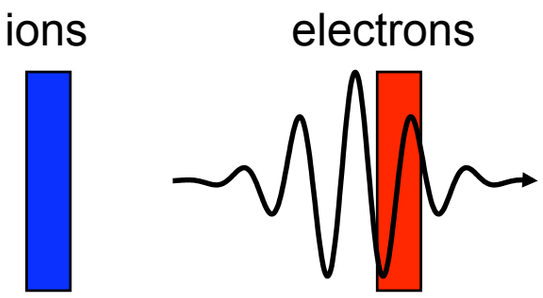
solid density target: $n_e \sim 10^{24}$ cm^{-3} >> 10^{18} cm^{-3} (gas target)
ultrathin, ~ few atom layers thick => t ~ as << fs (gas target)

*V. V. Kulagin et al., PRL **99**, 124801 (2007)*
Meyer-ter-Vehn, H. C. Wu, EPJ D (2009)

Entering the Electron Blow-out Regime

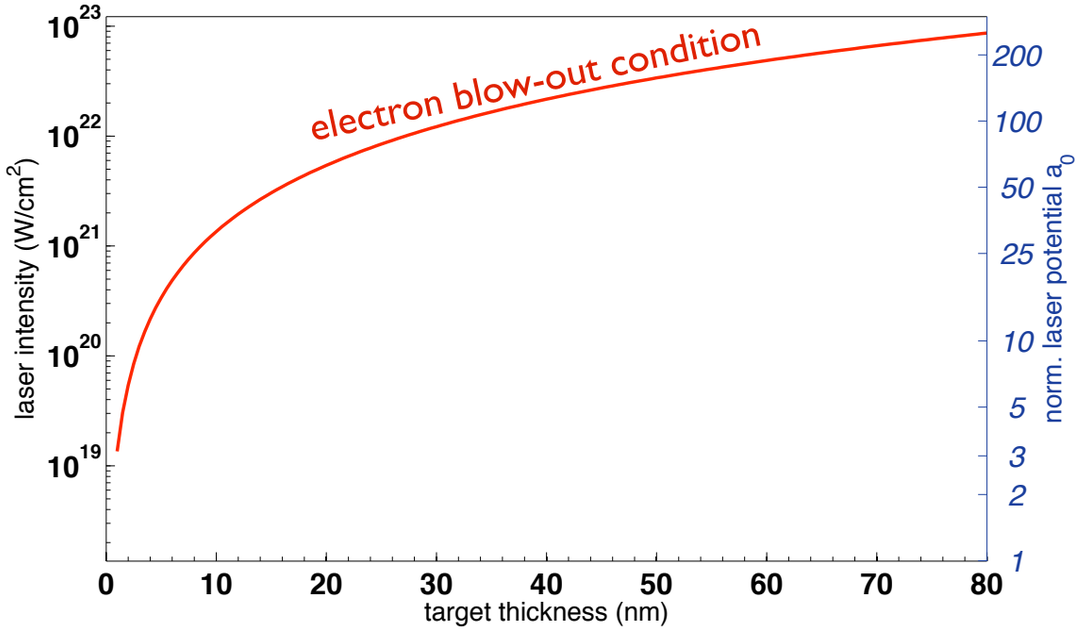


electron blow-out condition



laser field $a_0 \sim \frac{n_e}{n_c} k_L \, d$ electrostatic charge separation field

n_e: plasma density d: foil thickness



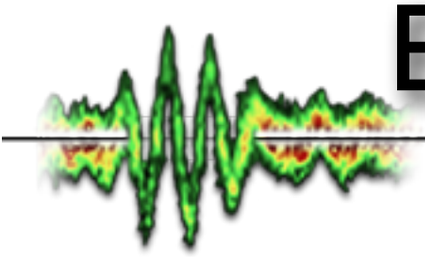
Diamond-like Carbon (DLC) foils (LMU Munich)

- ✦ free standing foils
- ✦ thickness 60nm - *3nm*
- ✦ high sp^3 bonding content: ~75%
- ✦ high mechanical strength

Kurchatow Institute

LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

Entering the Electron Blow-out Regime



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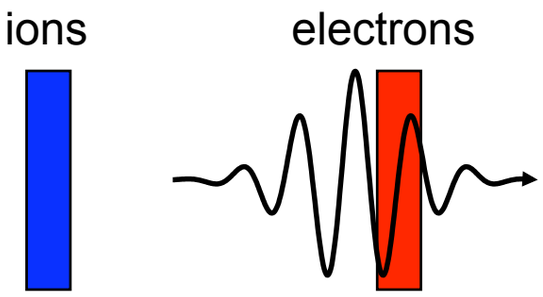

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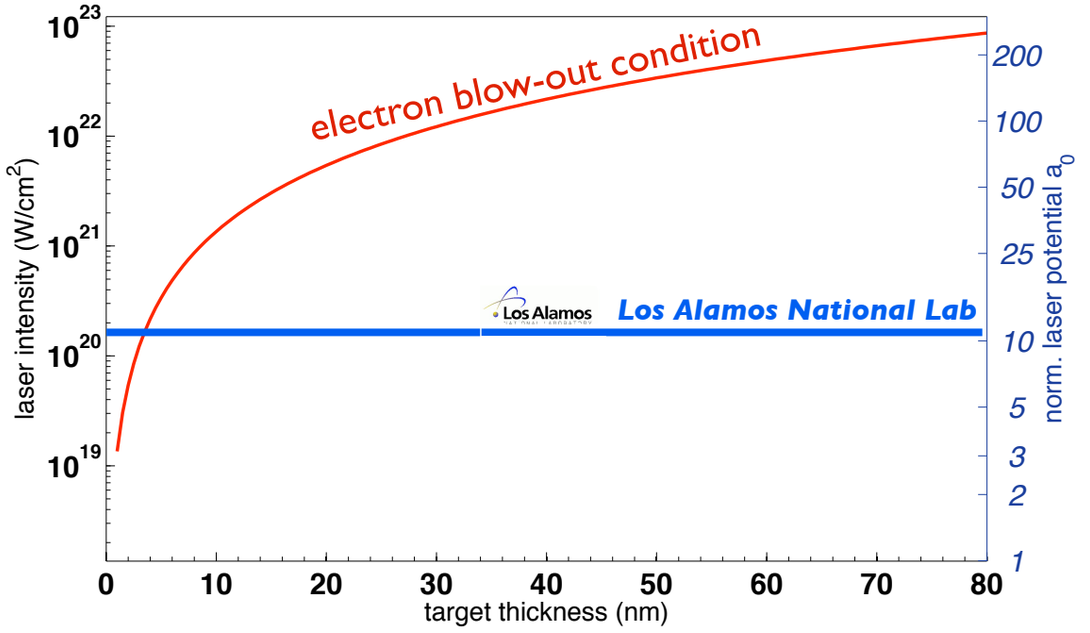

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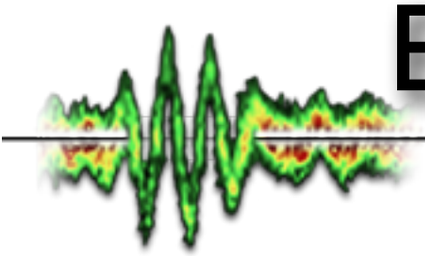

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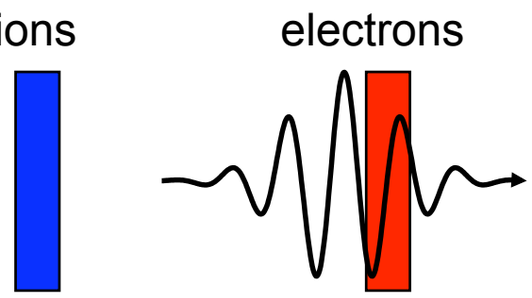

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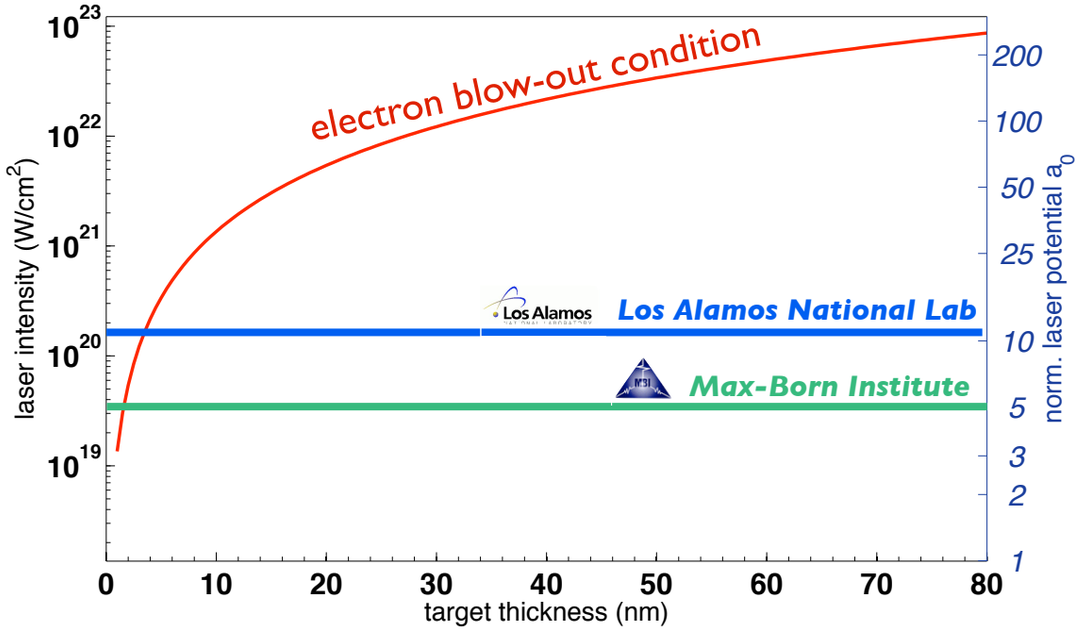

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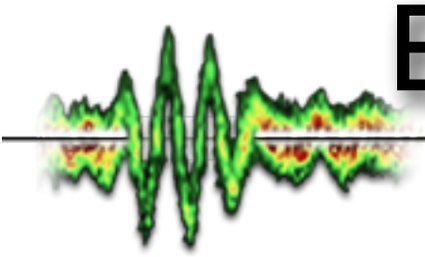

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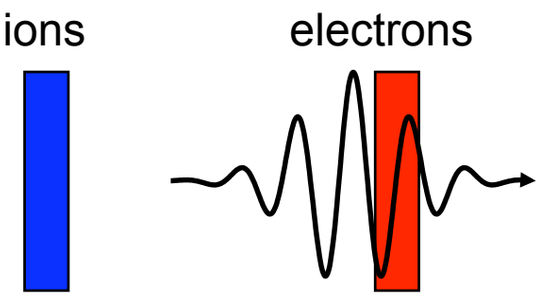

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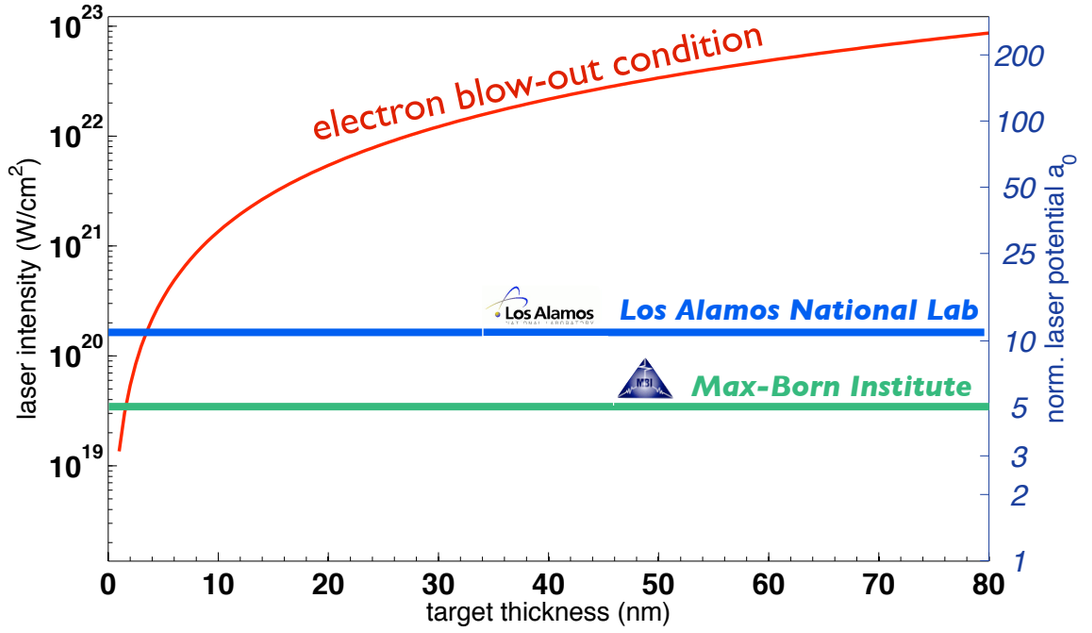

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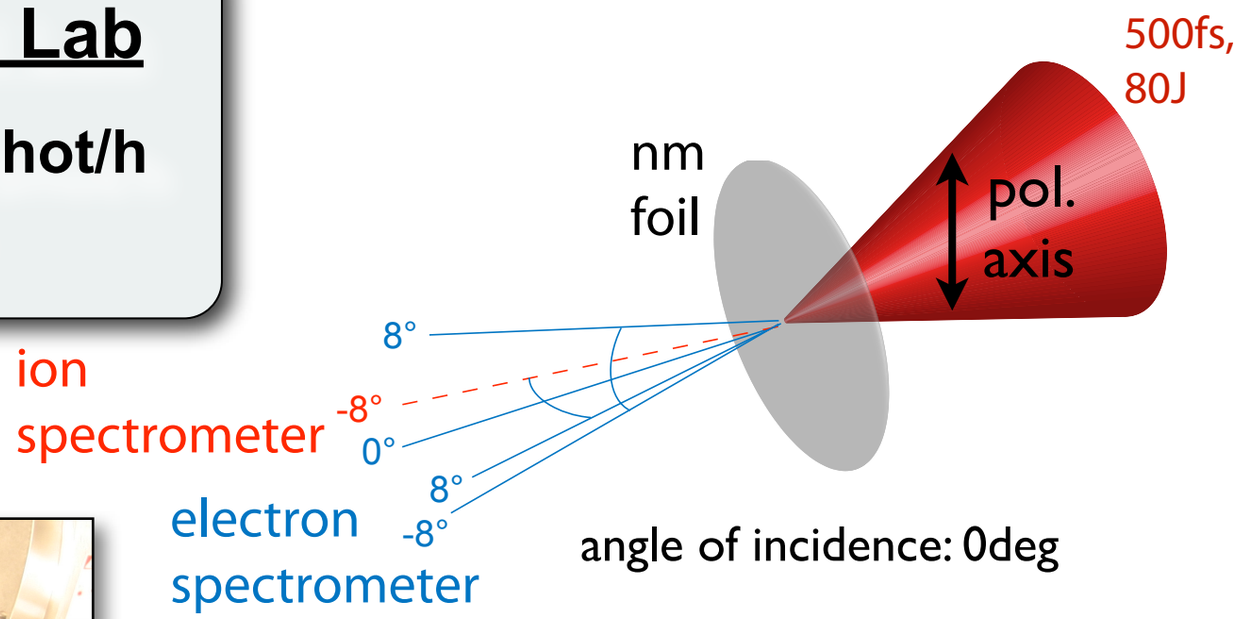
3nm foil: 100nC in focal volume of a $10\mu m$ focal spot

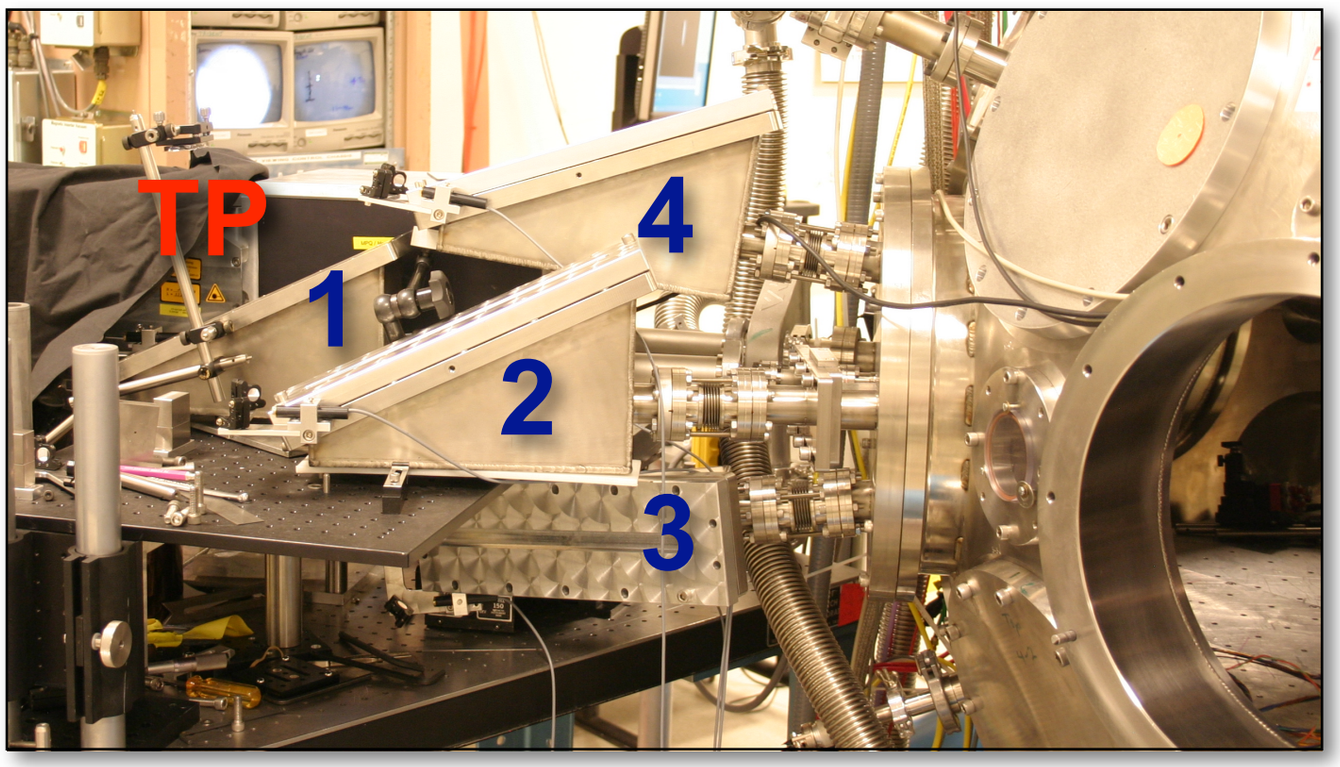
Trident - Experiments

Los Alamos National Lab

Nd:Glass, 90J, 500fs, 1Shot/h

OPCPA Pulse Cleaning

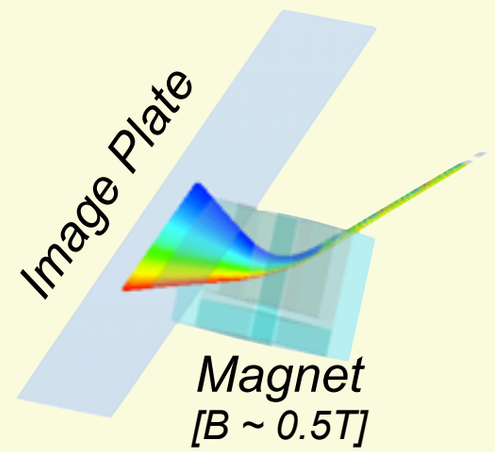




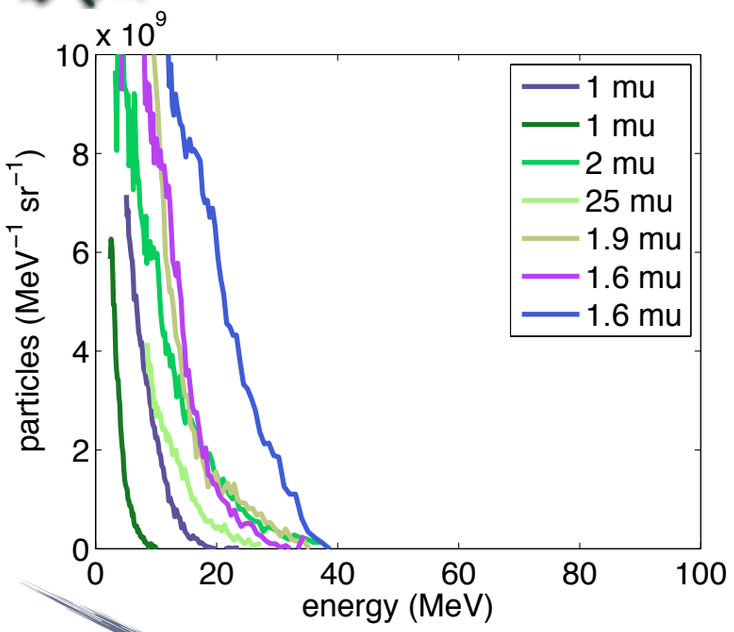
TP: Thomson Parabola @ -8deg perp. laser pol. axis

1-4: e⁻Spectrometer @ 0deg, - 8deg perp. laser pol. axis, +/- 8deg || laser pol. axis

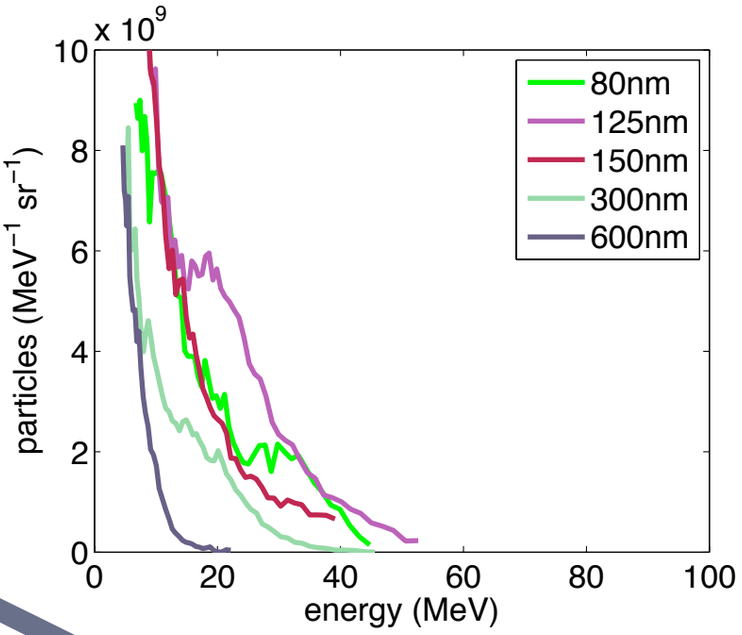
Magnetic Spectrometer



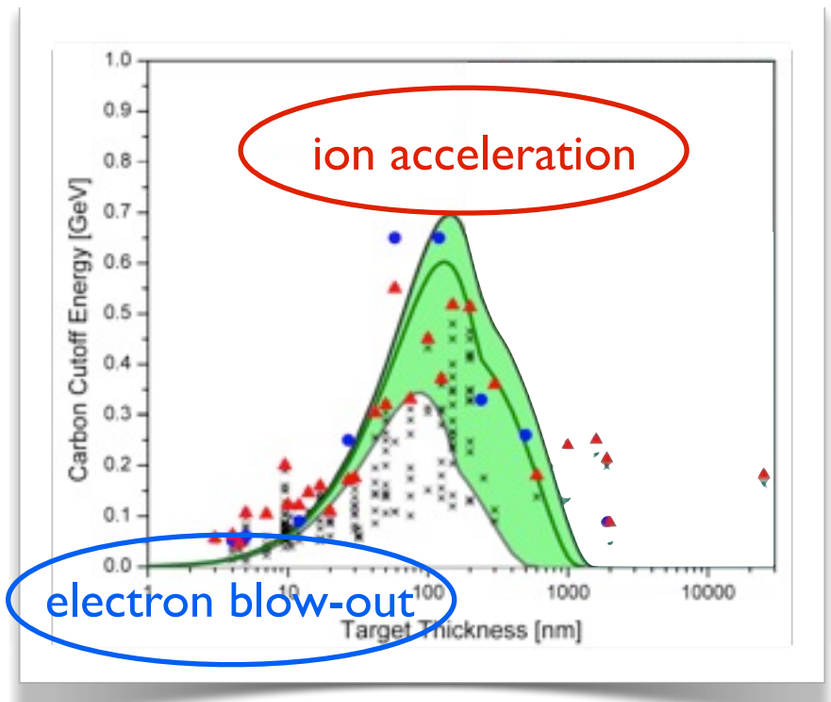
Electron blow-out from ultra-thin foils



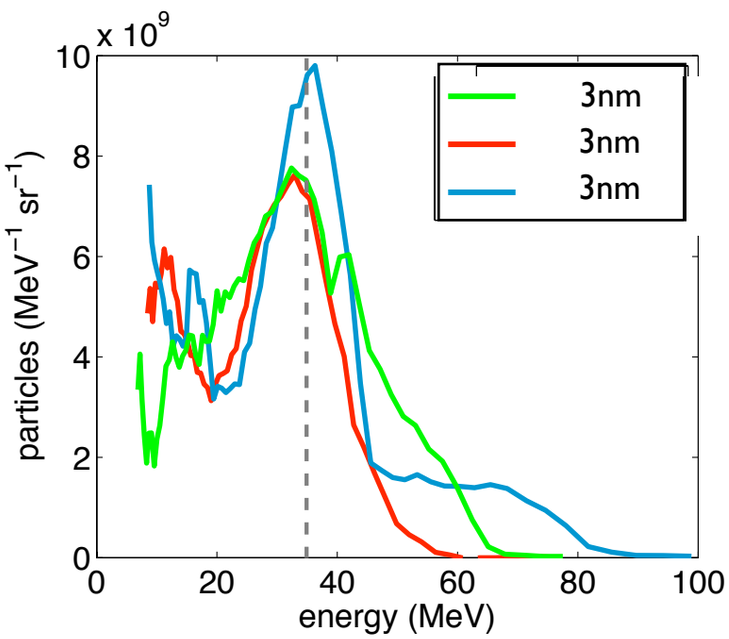
mu foils



electron distributions measured
in target normal direction (0deg)



nm foils



e⁻ Spatial Distribution

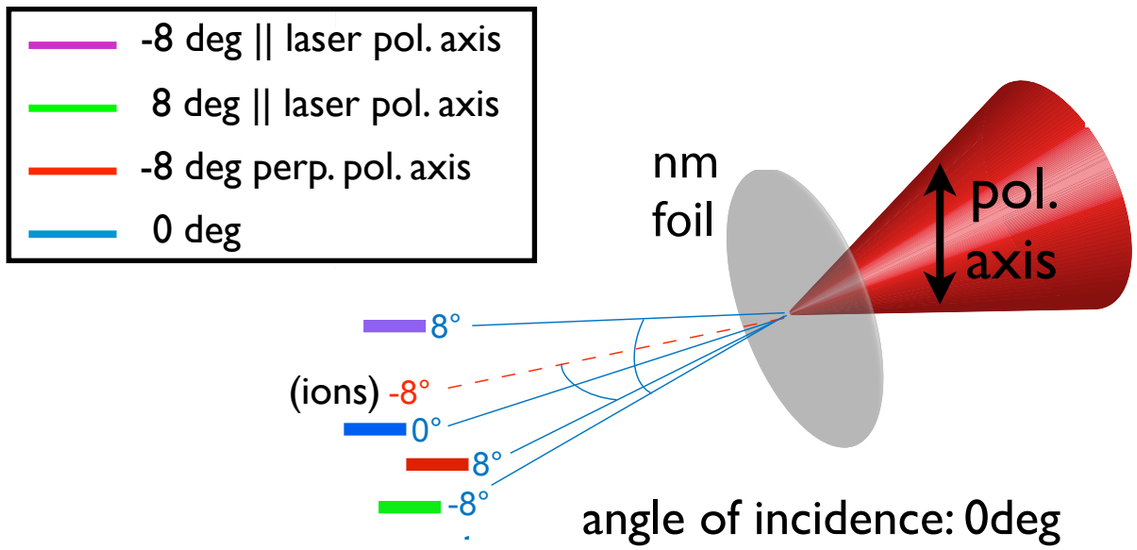
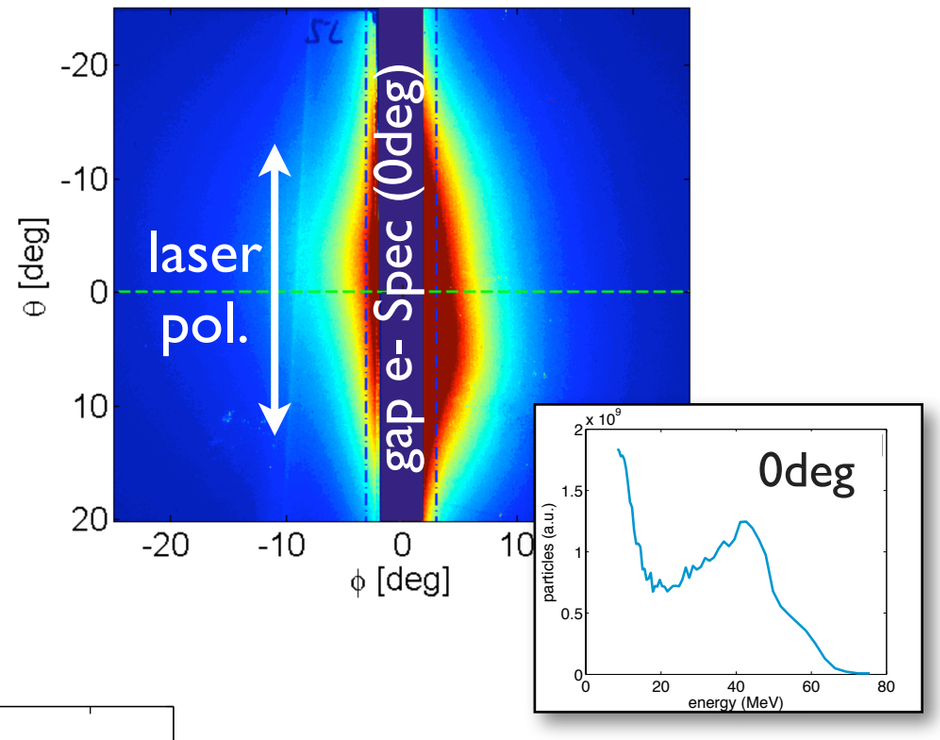
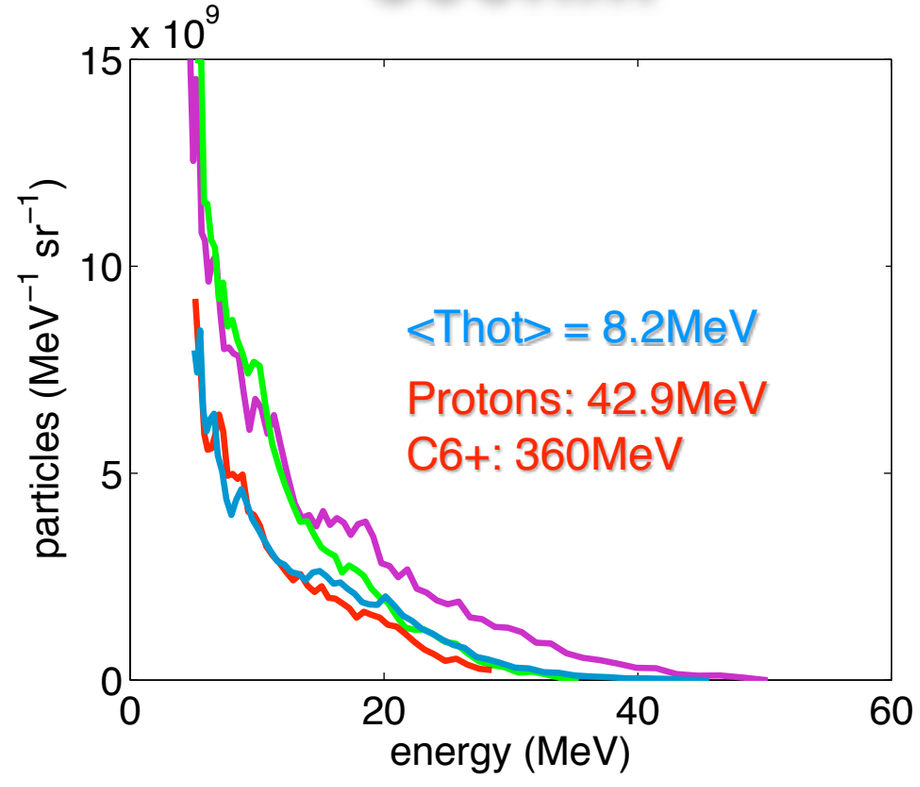


Image Plate Stack

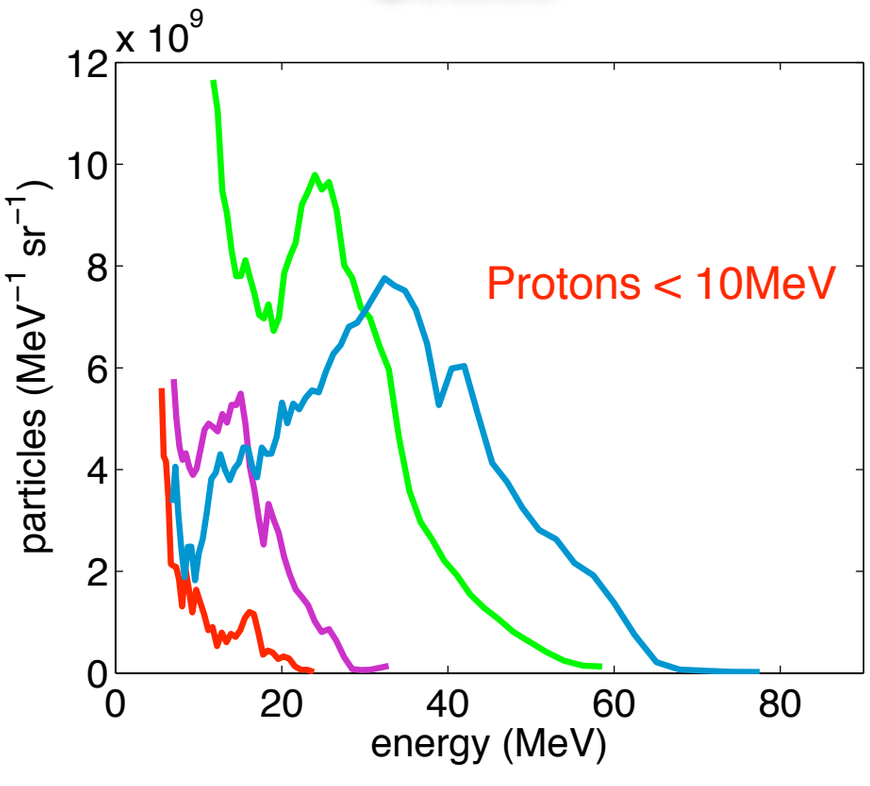
[measured behind a 46mm thick Al block]



300nm



3nm



MBI Experiment

Max Born Institut, Berlin

Ti:Sapph, 700mJ, 50fs, 10Hz
Double Plasma Mirror

thickness reduction by evaporation

- DLC foil thicknesses deduced from AFM measurements include contaminant layer of ~ nm thickness
- contaminant layer can be eliminated by target heating prior to the shot using a cw laser

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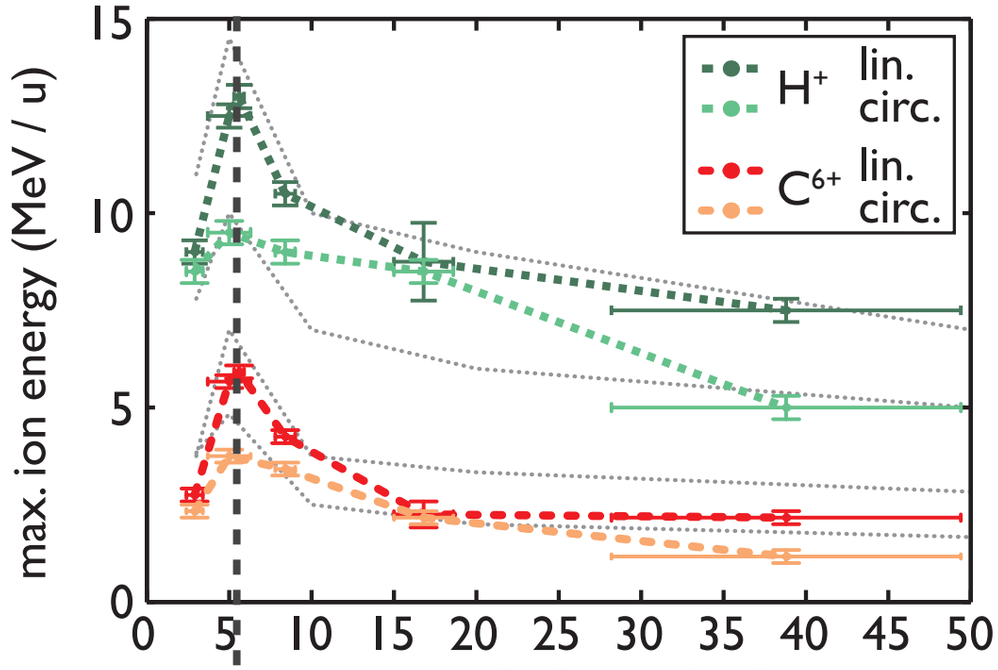

thickness reduction by evaporation

$(d_{opt})_{ion}$ target thickness (nm)

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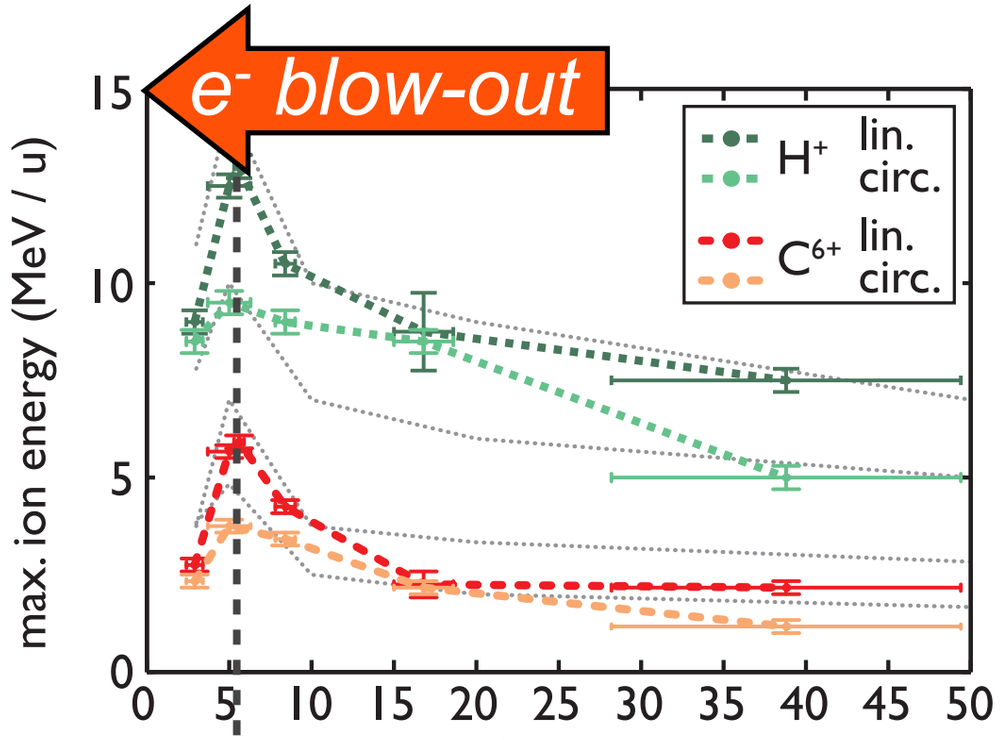

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$(d_{opt})_{ion}$ target thickness (nm)

nm
foil

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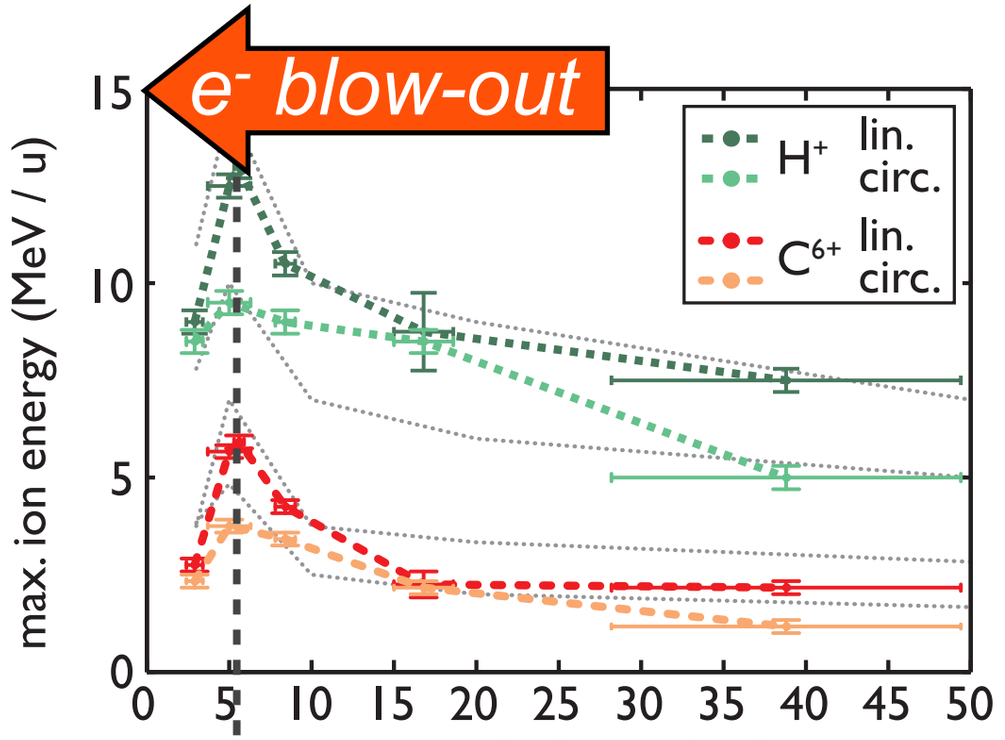

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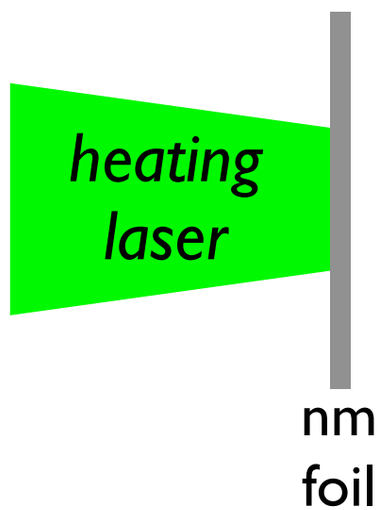

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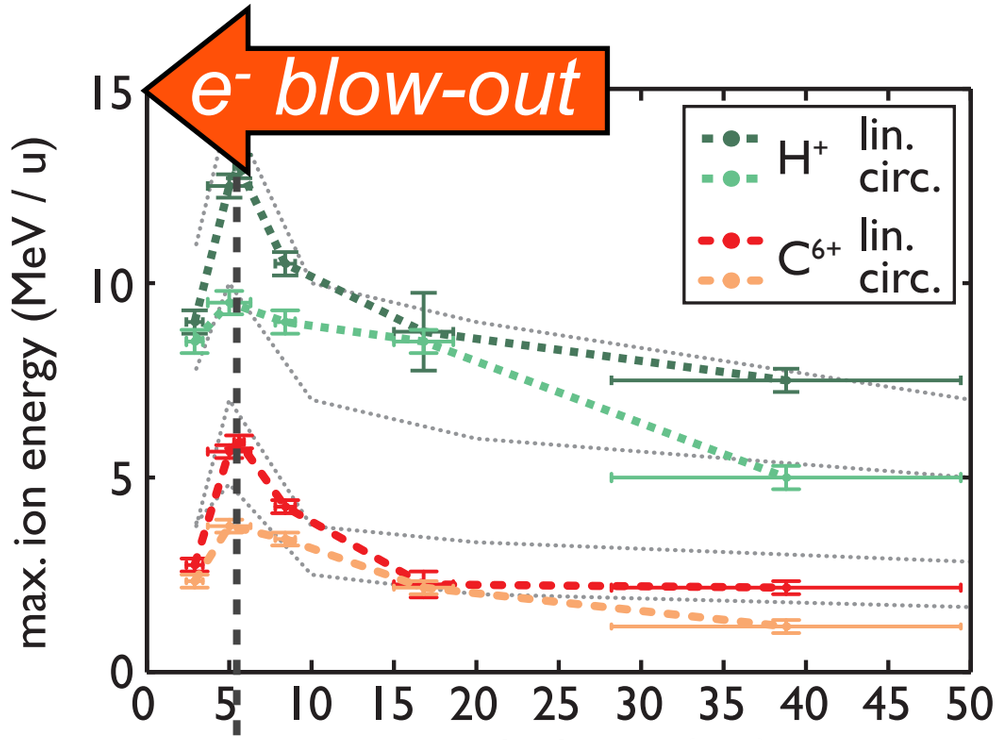

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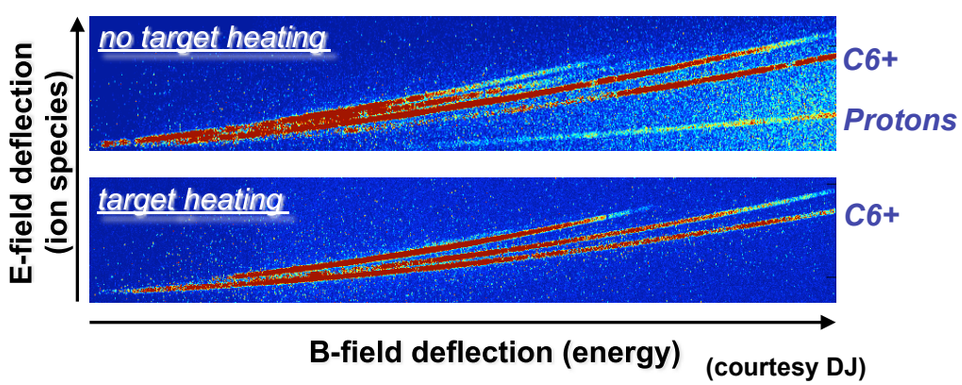
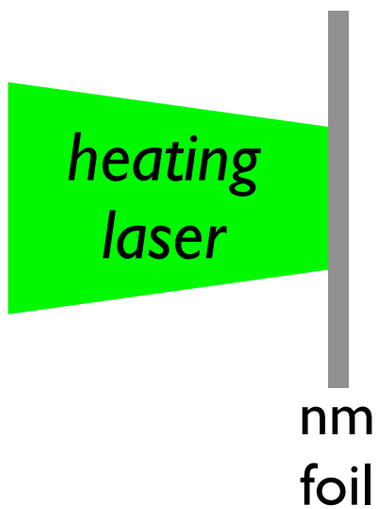
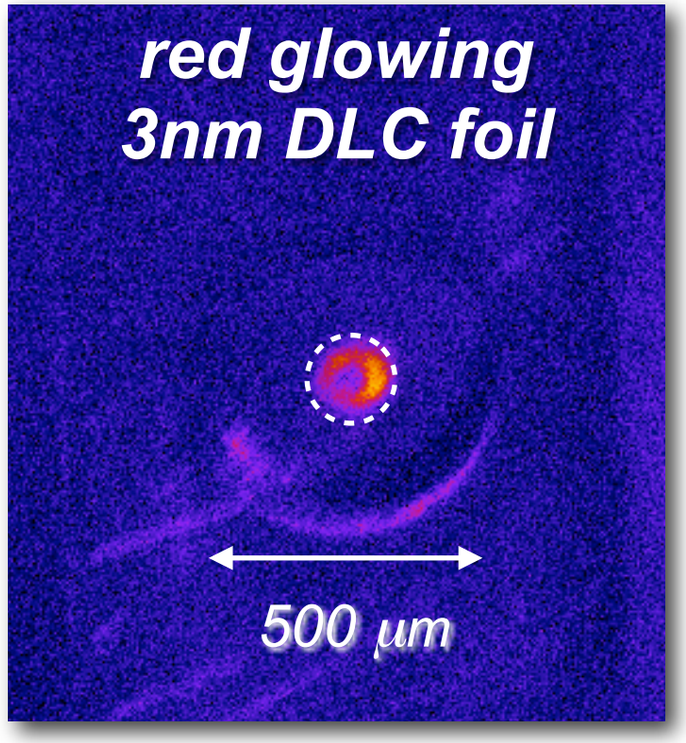
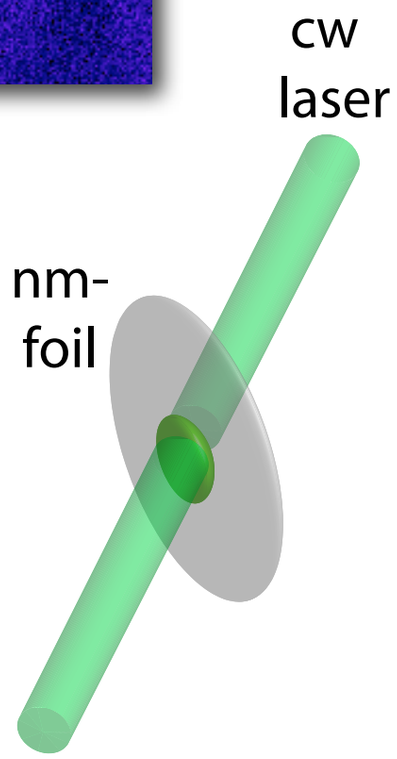


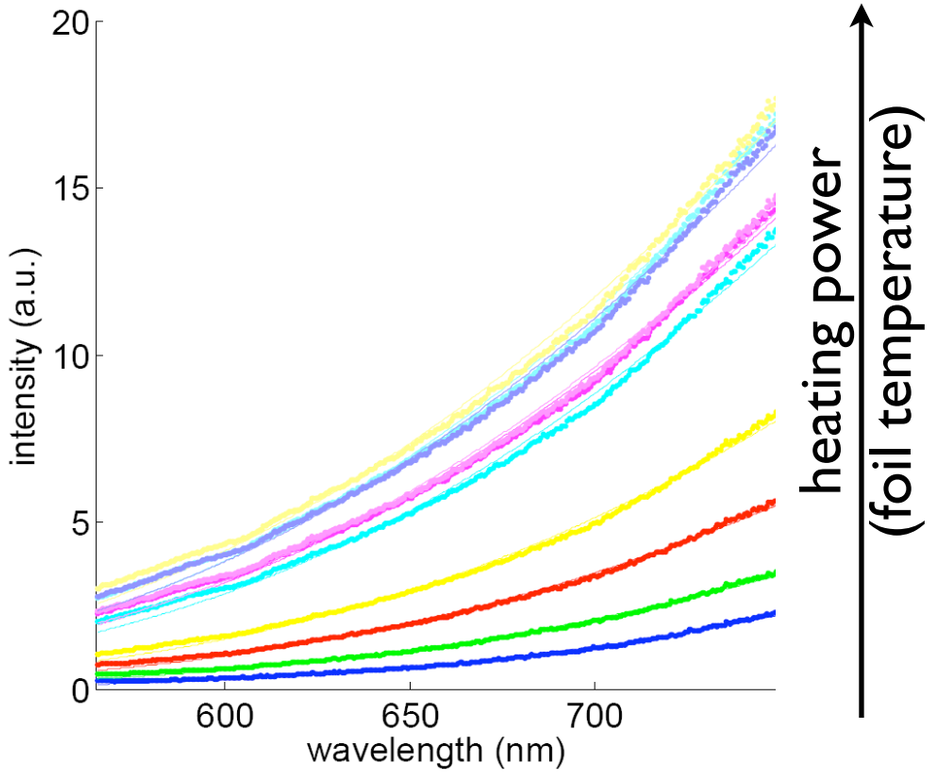


Experimental Setup





DLC foil heating
black body radiation



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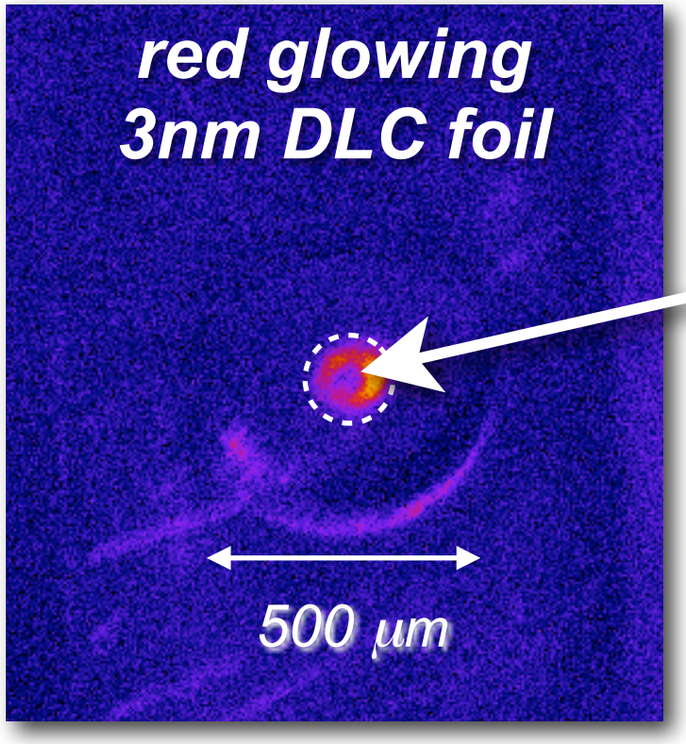
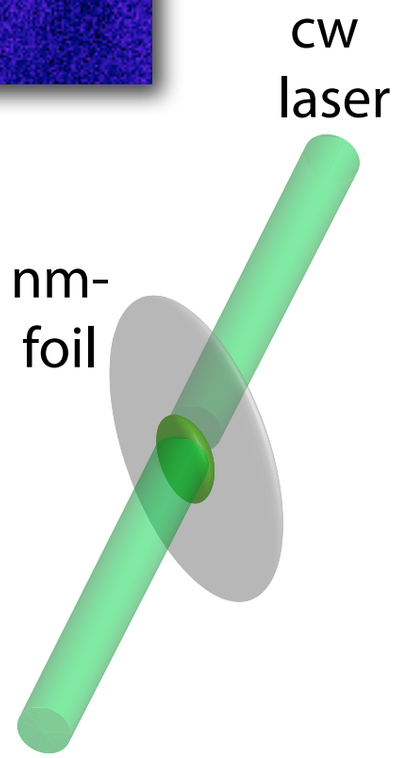


burn thru



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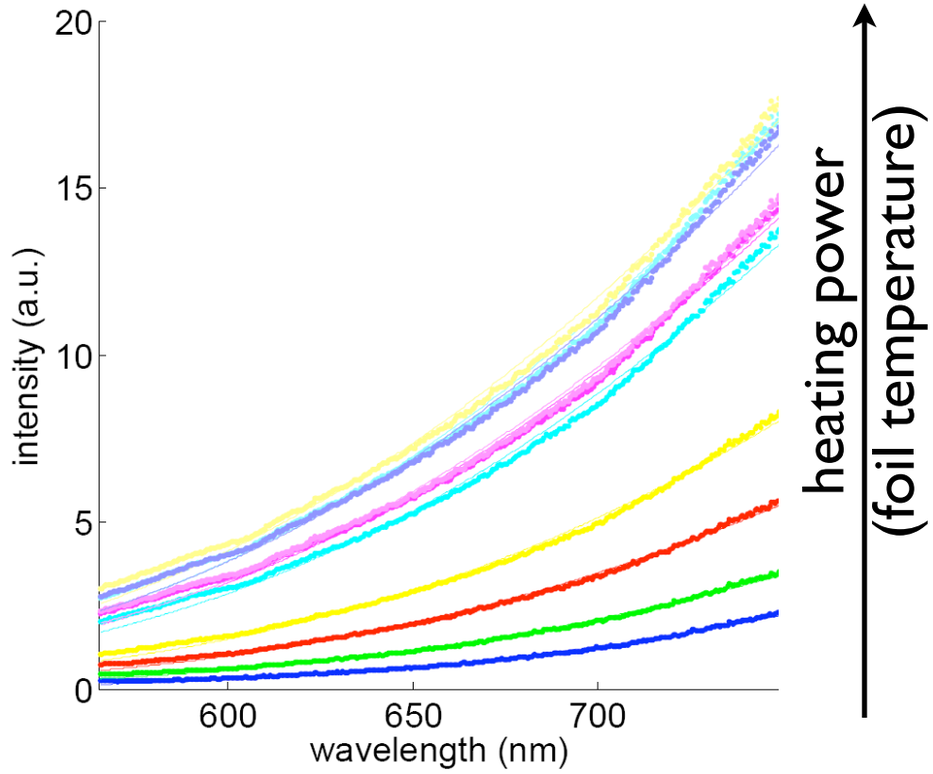

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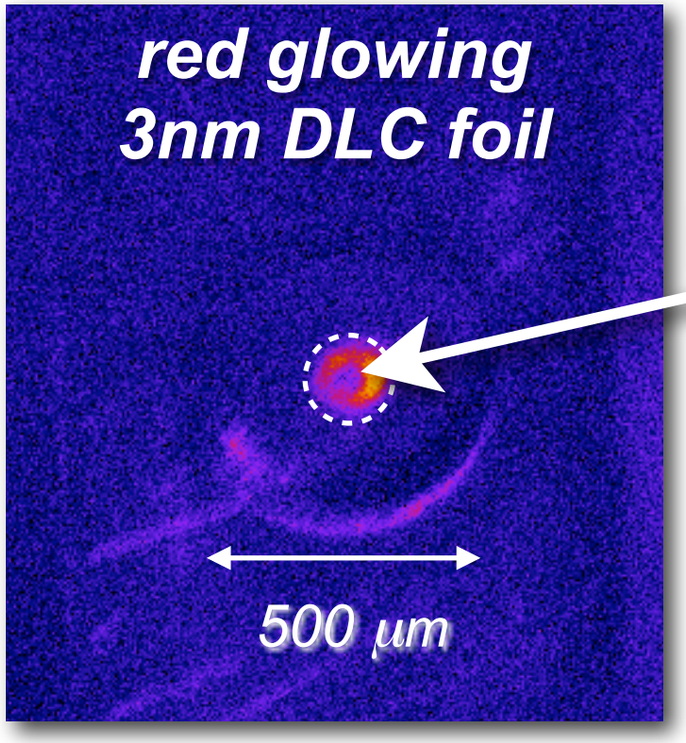

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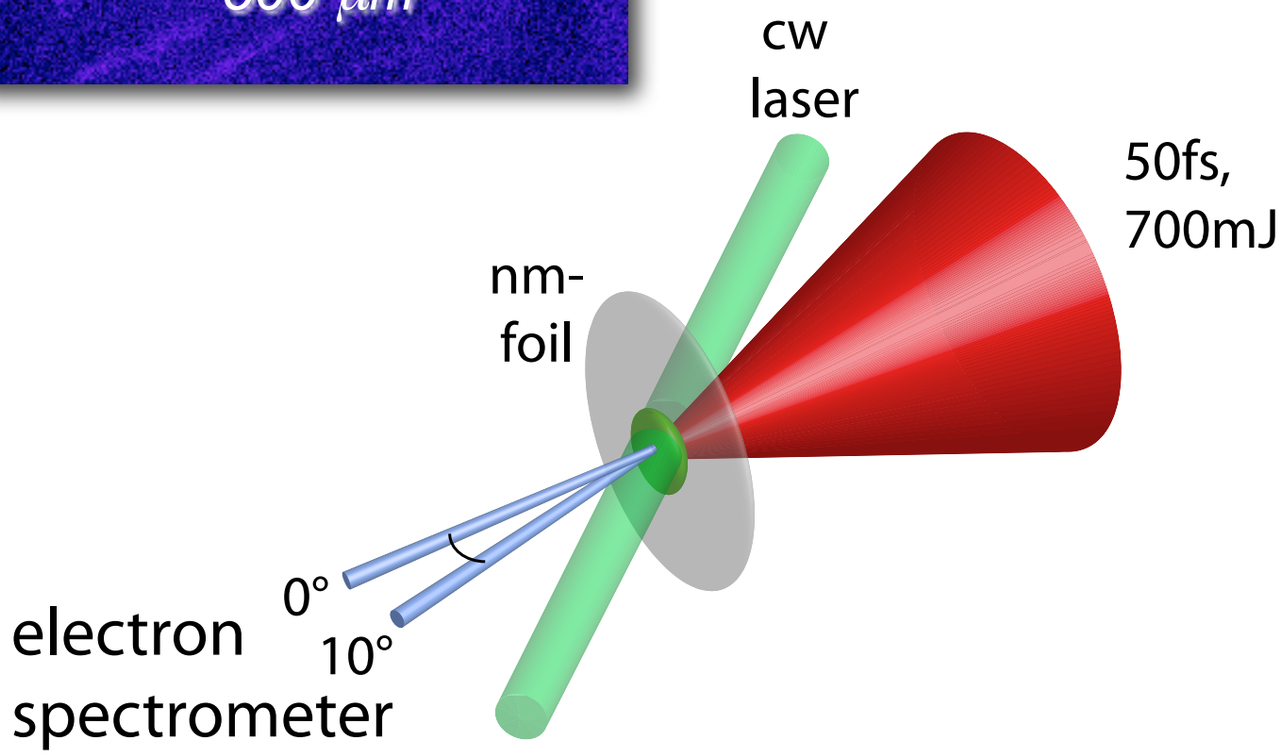

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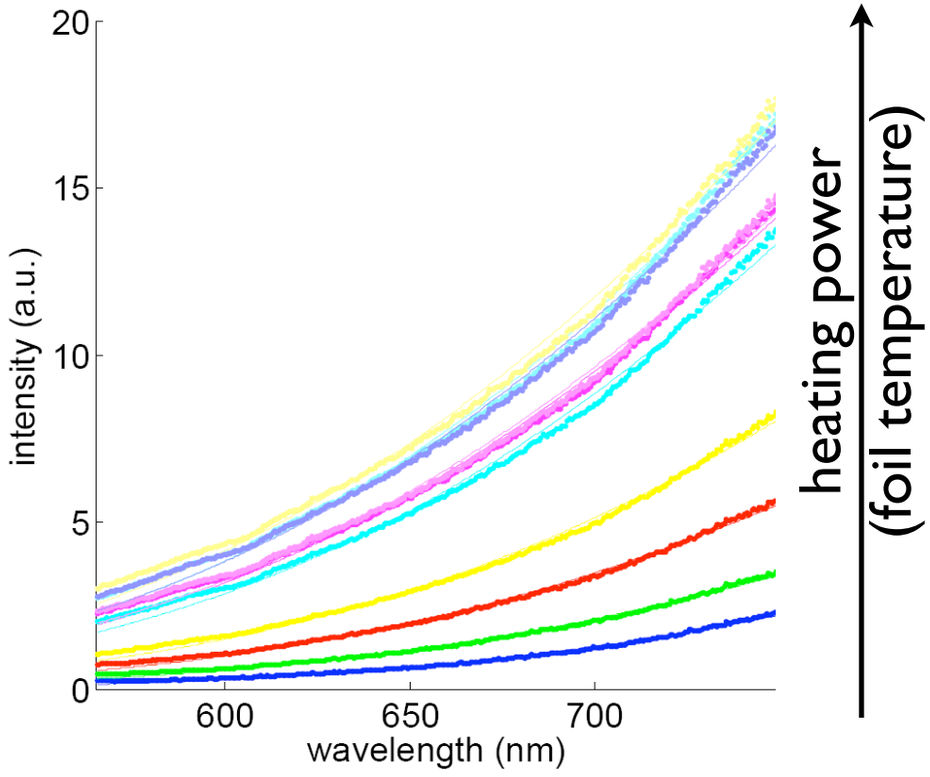
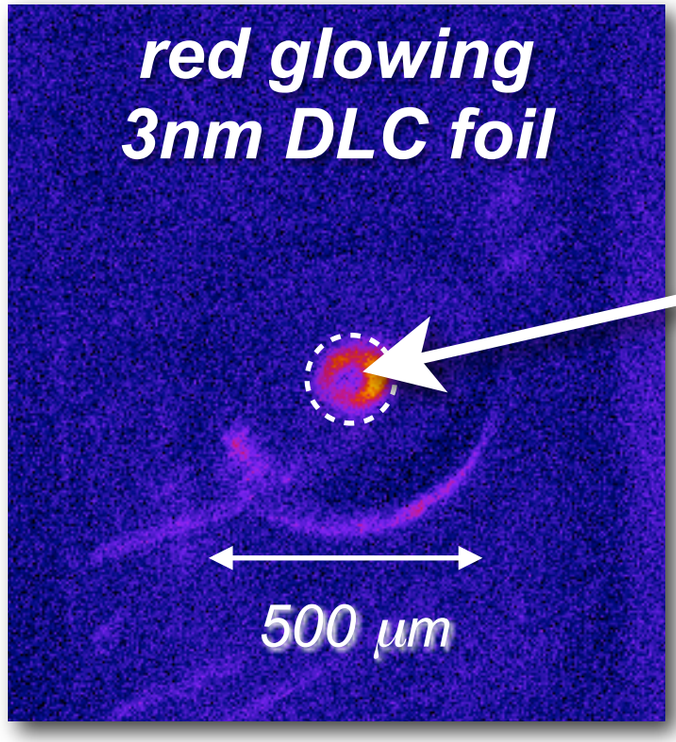
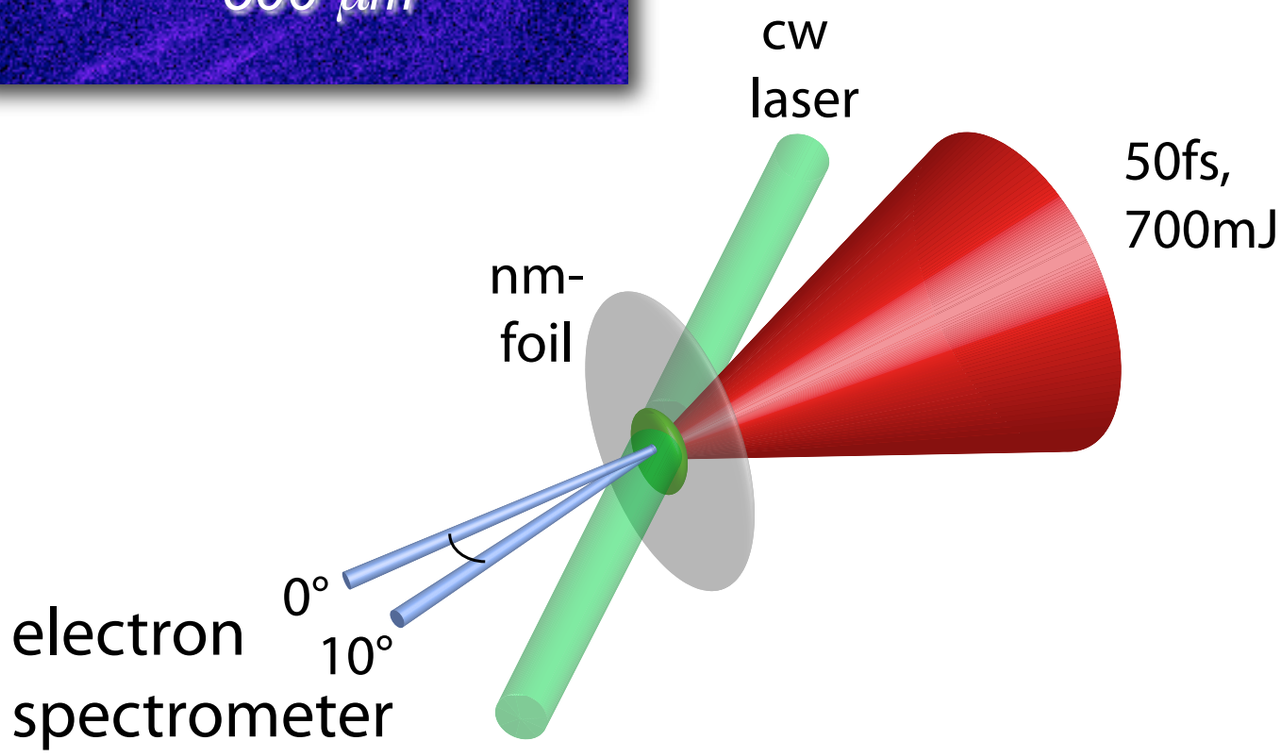


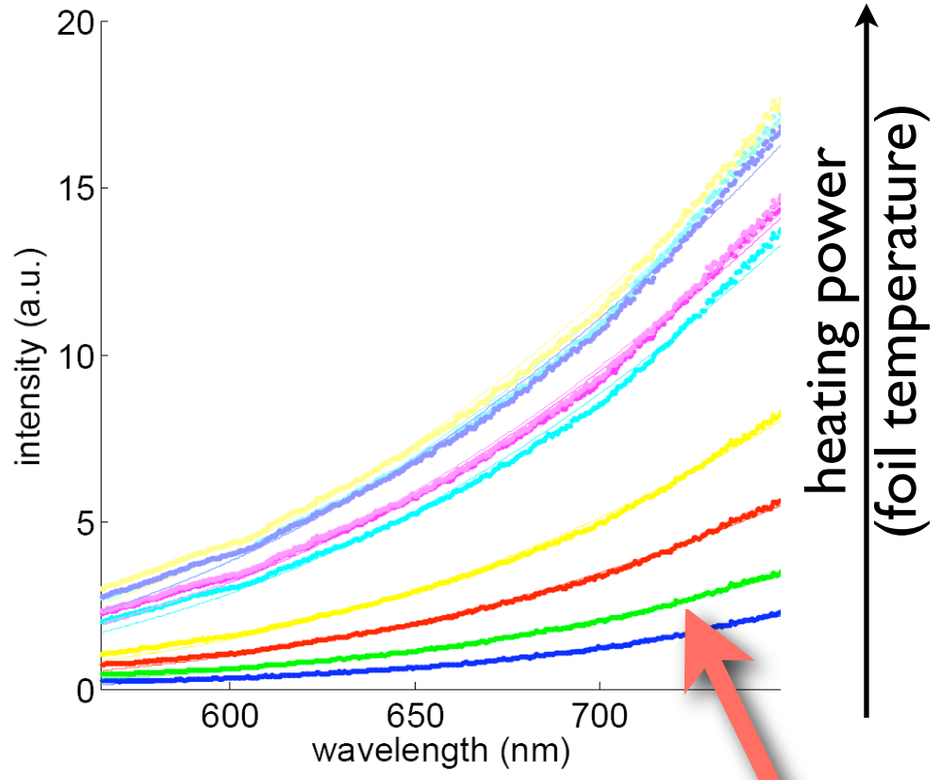
Experimental Setup



burn thru

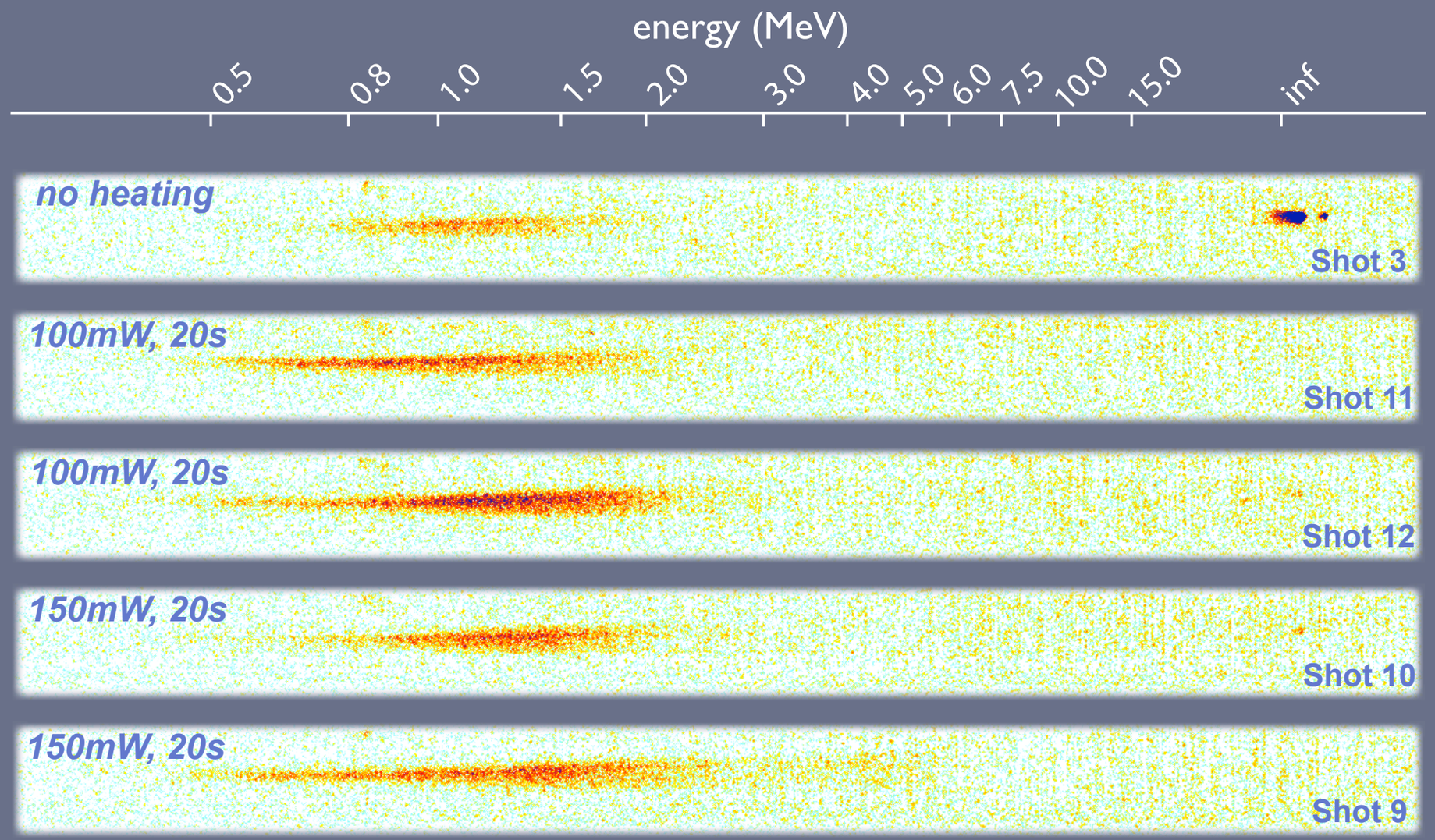


DLC foil heating
black body radiation

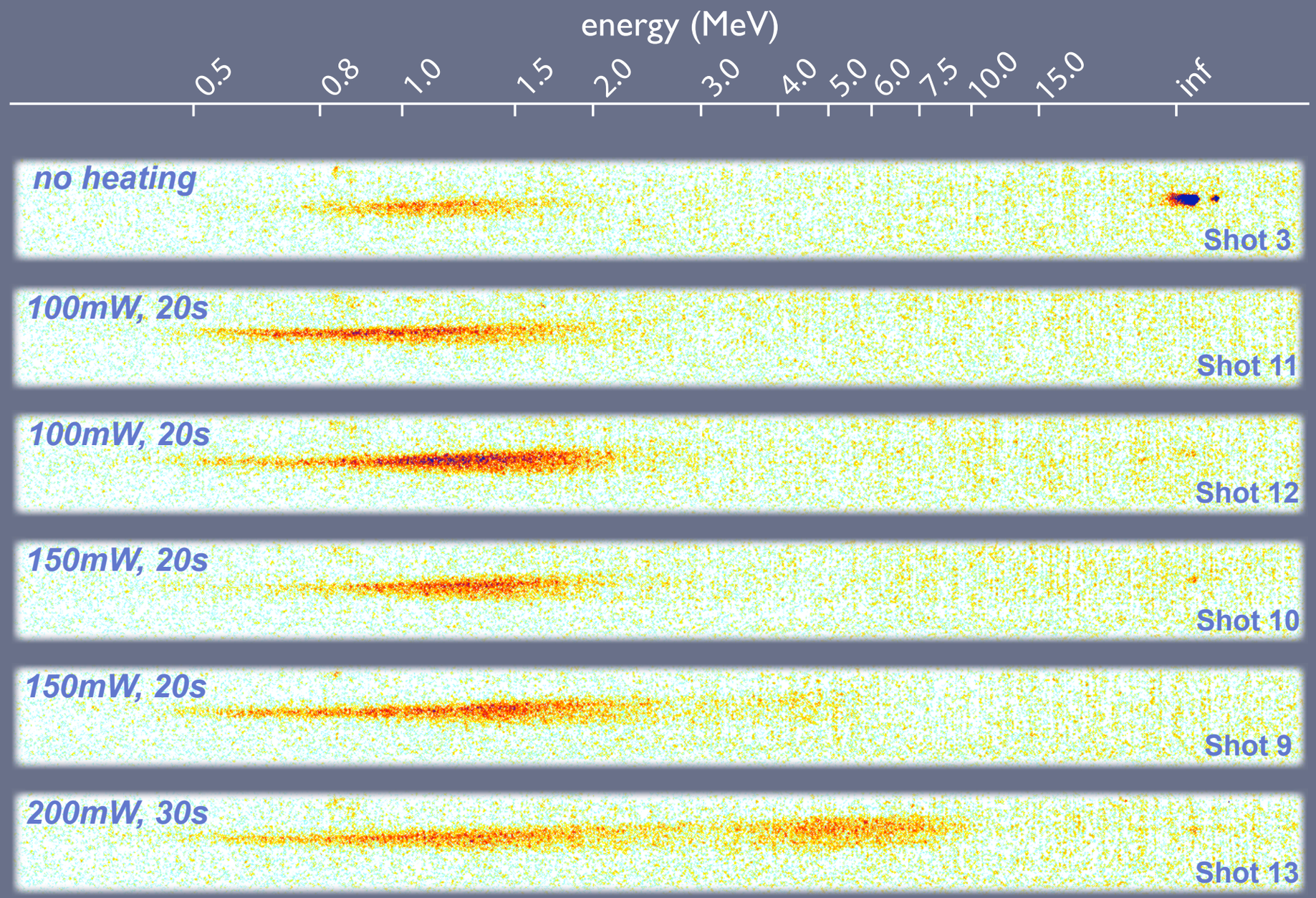


experiment

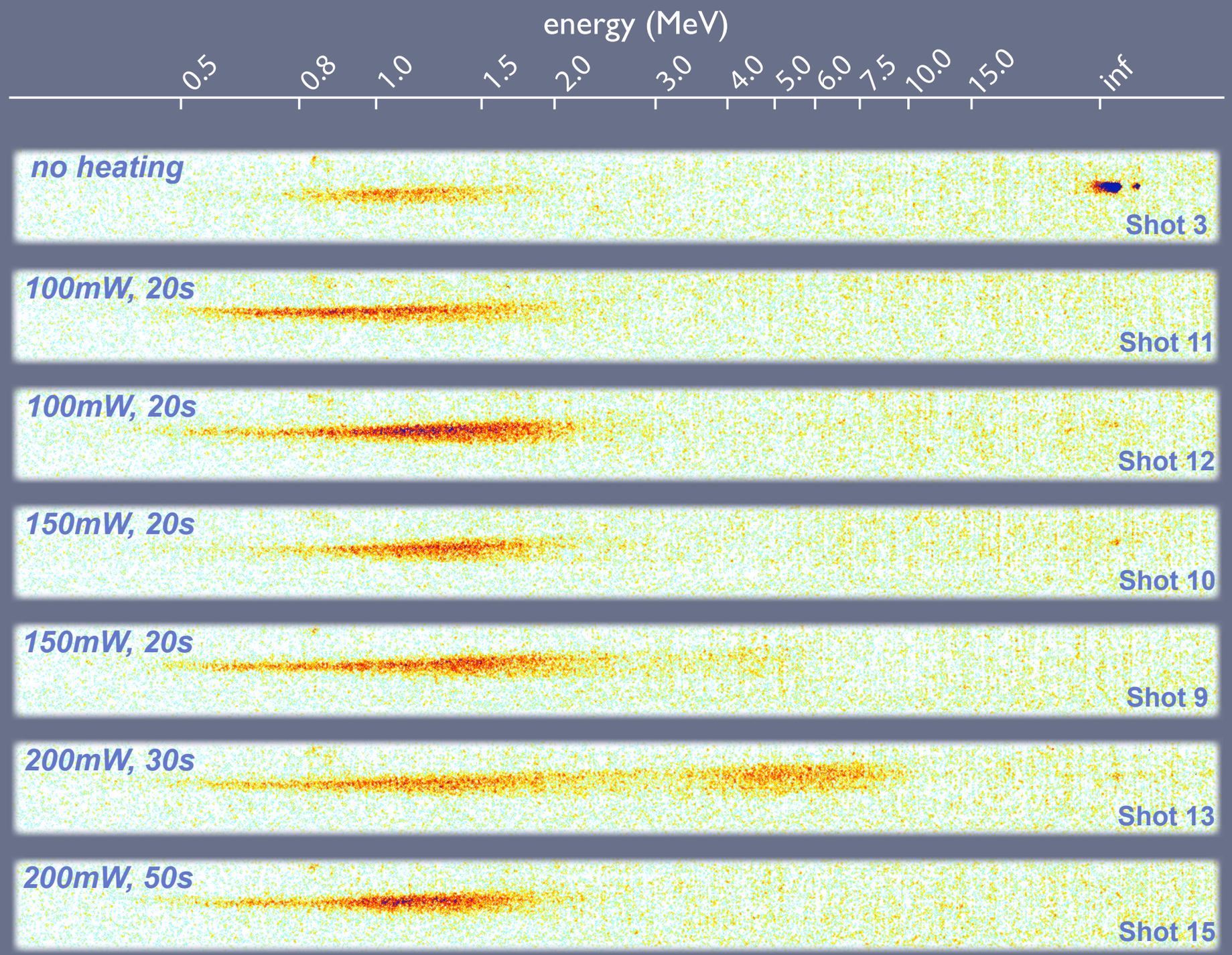
MBI - Electron Blow-Out



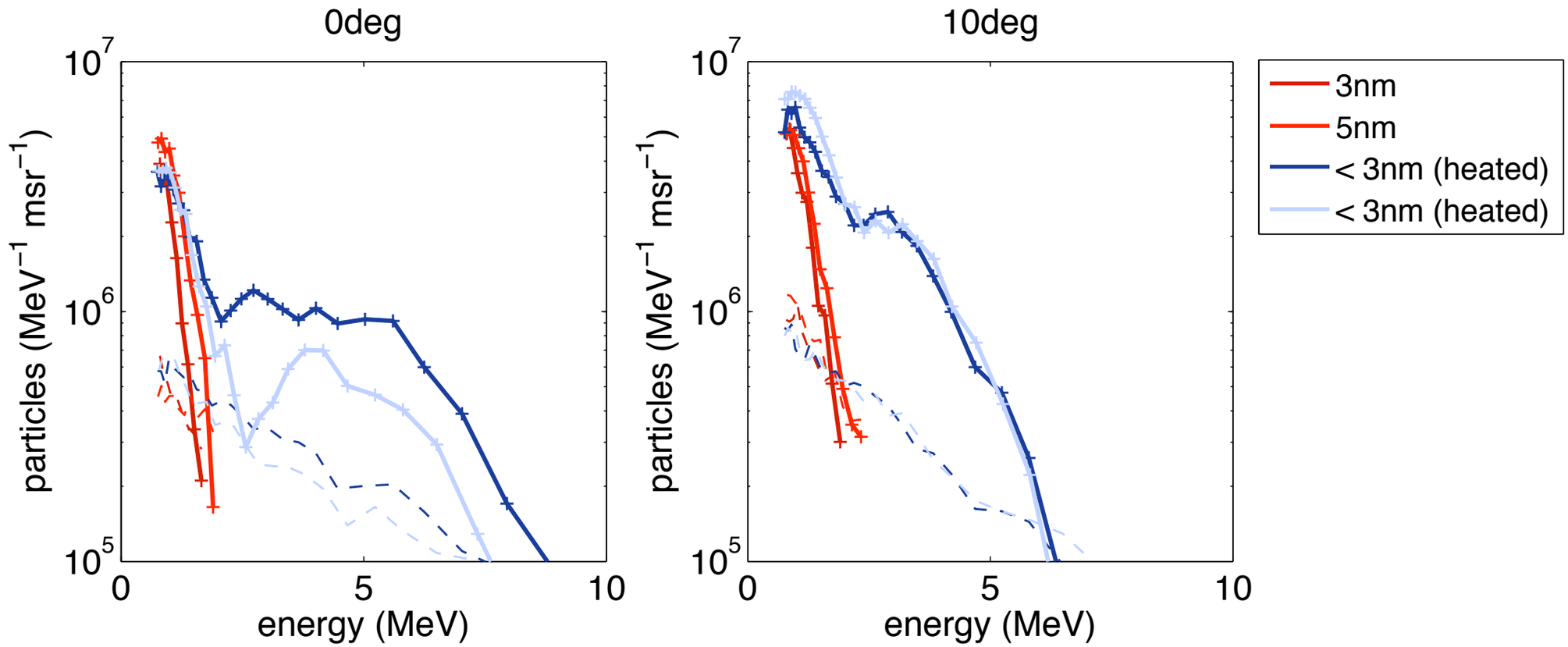
MBI - Electron Blow-Out



MBI - Electron Blow-Out



Electron Spectra



3nm/5nm thin foils:

thermal electron distribution: hot electron temperature $T_{hot} \sim 0.5\,MeV$

<3nm thin foils (target heated prior to high-intensity laser shot):

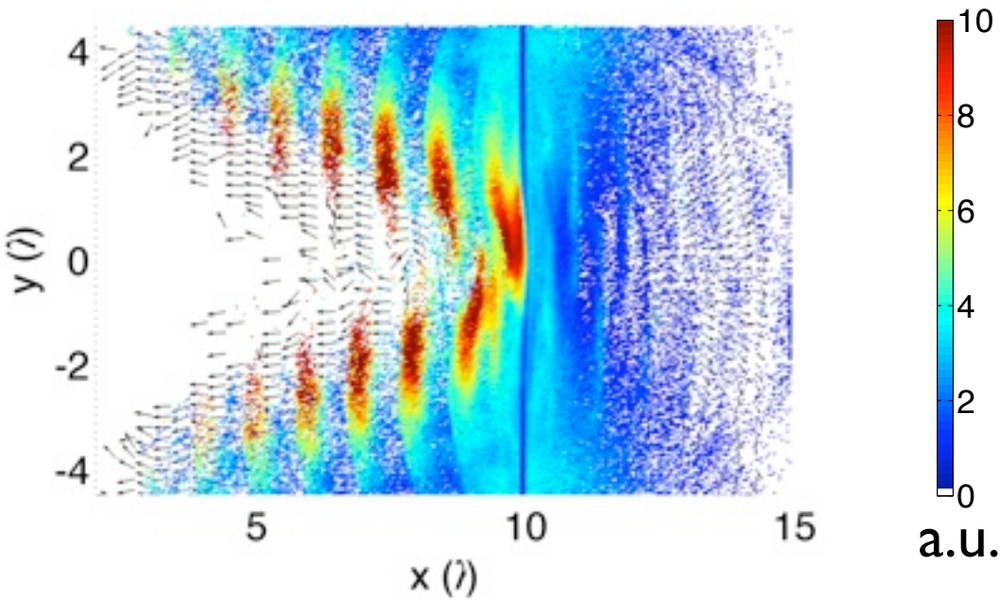
additional (peaked) spectral component *above* the thermal electron background

Particle-In-Cell Simulations

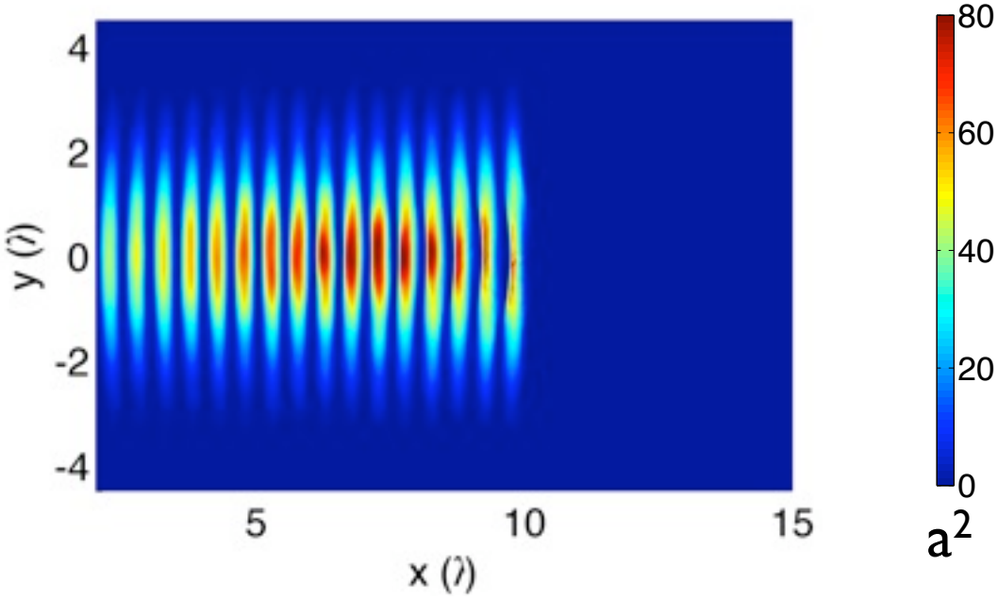
5nm target

$t=t_{peak}$

electron energy density



laser field



Particle-In-Cell Simulations

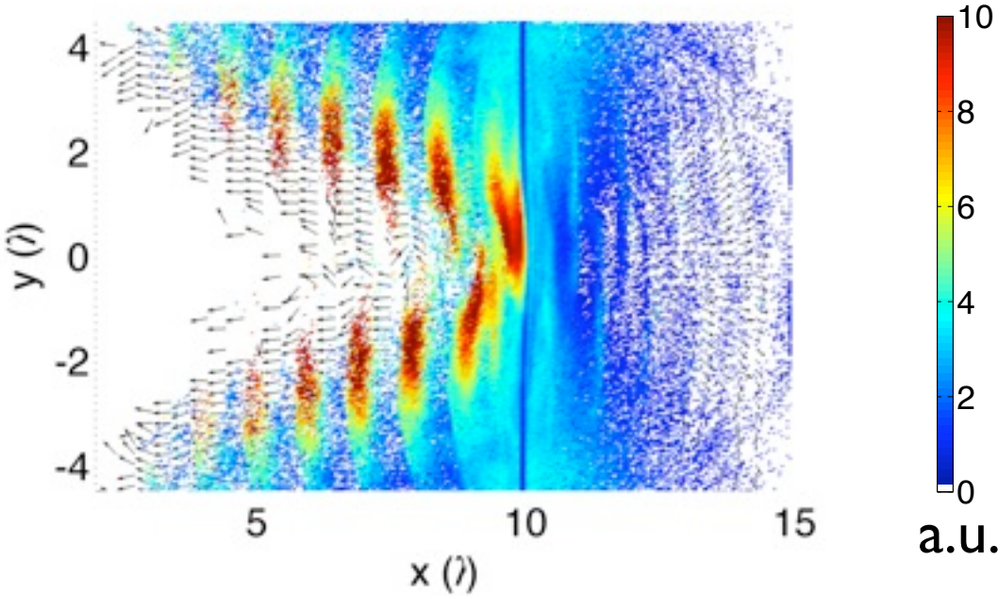
MPQ LMU www.attoworld.de

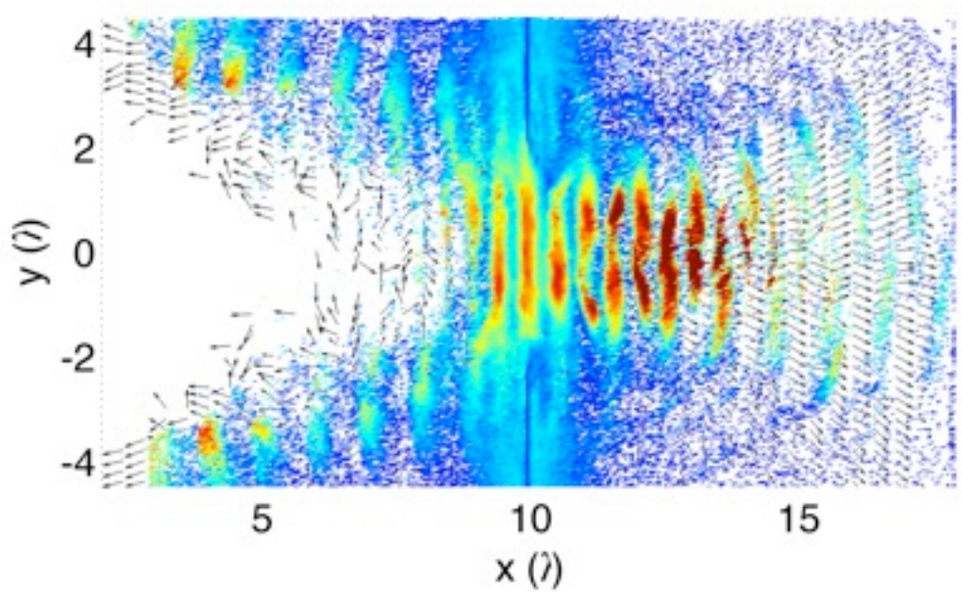
5nm target

2nm target

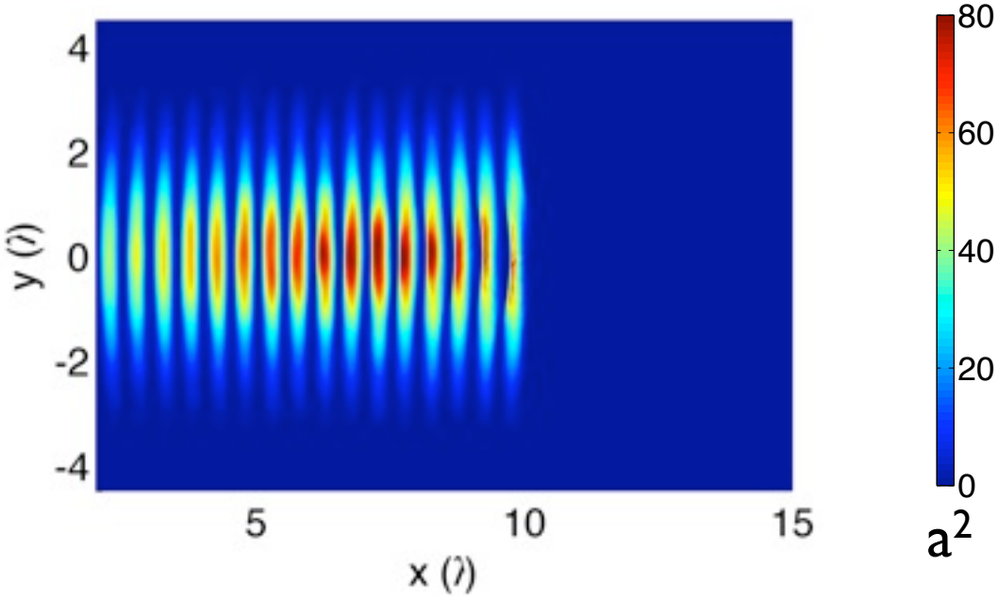
$t=t_{peak}$

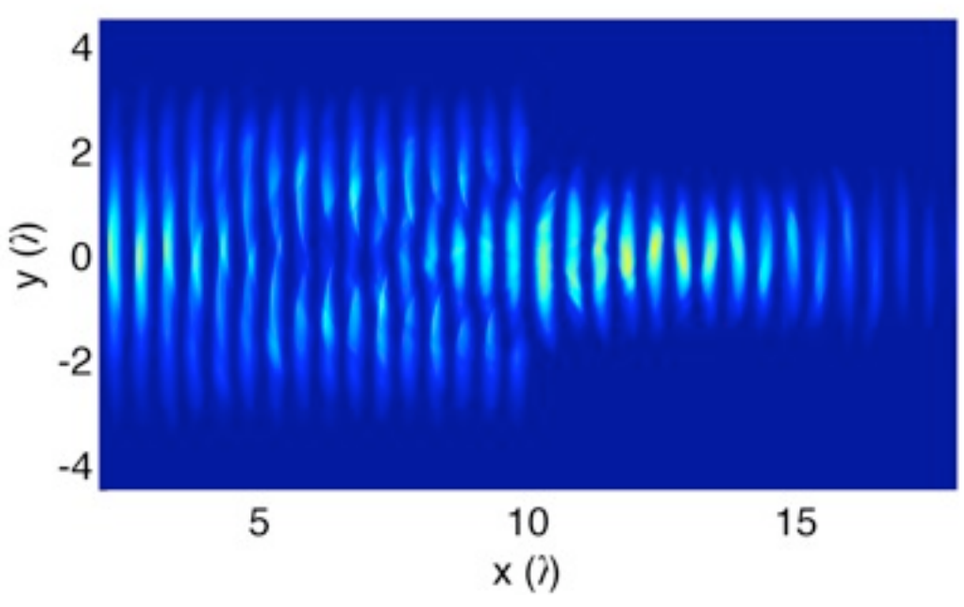
electron energy density





laser field





Particle-In-Cell Simulations

MPQ LMU www.attoworld.de

5nm target **2nm target**

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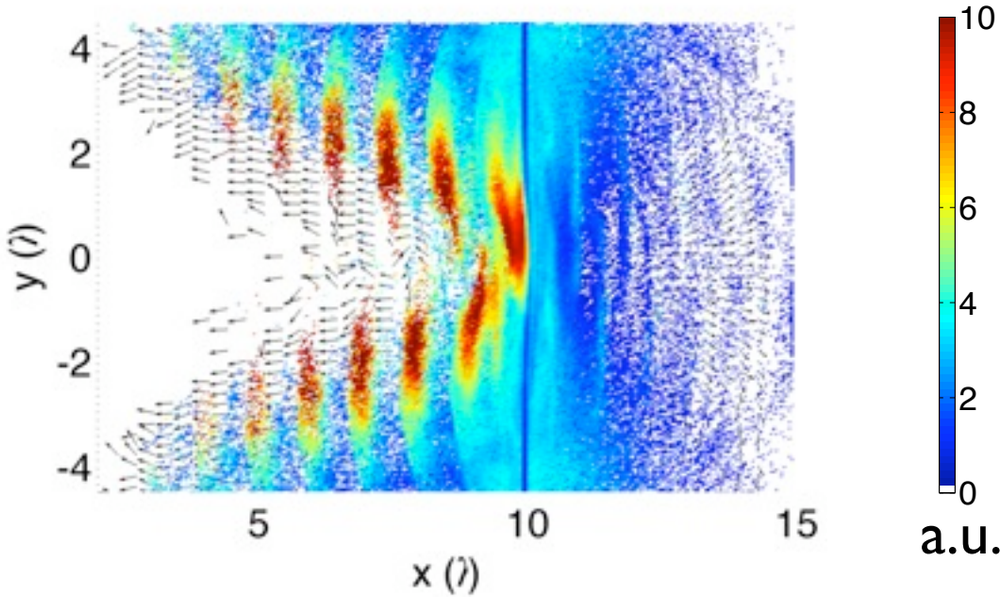
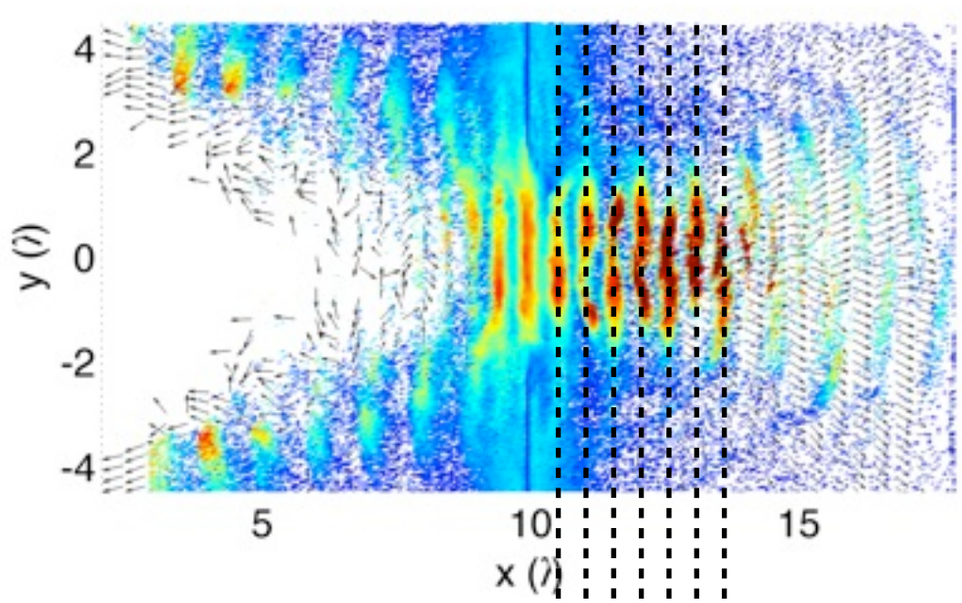
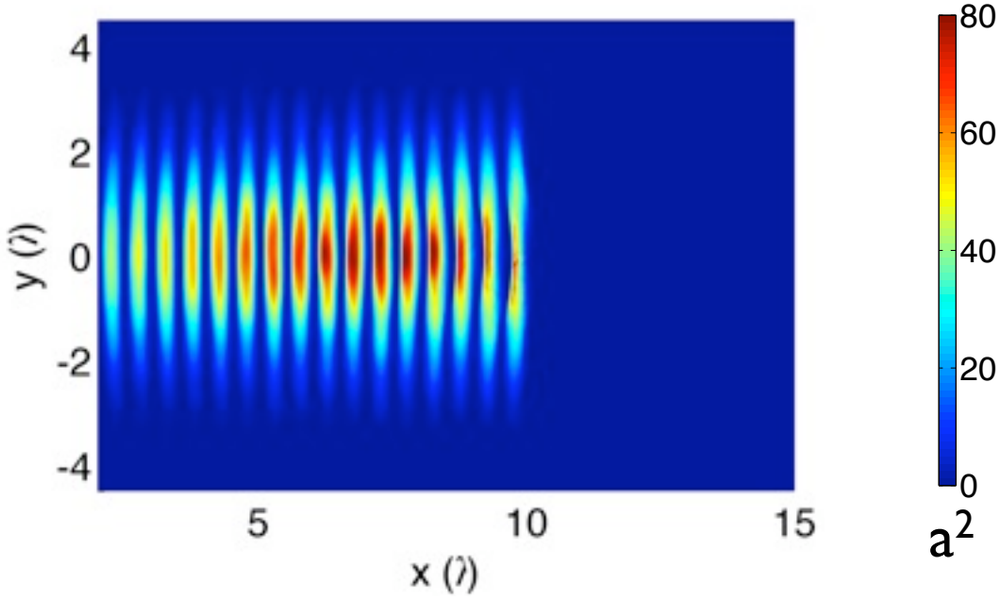
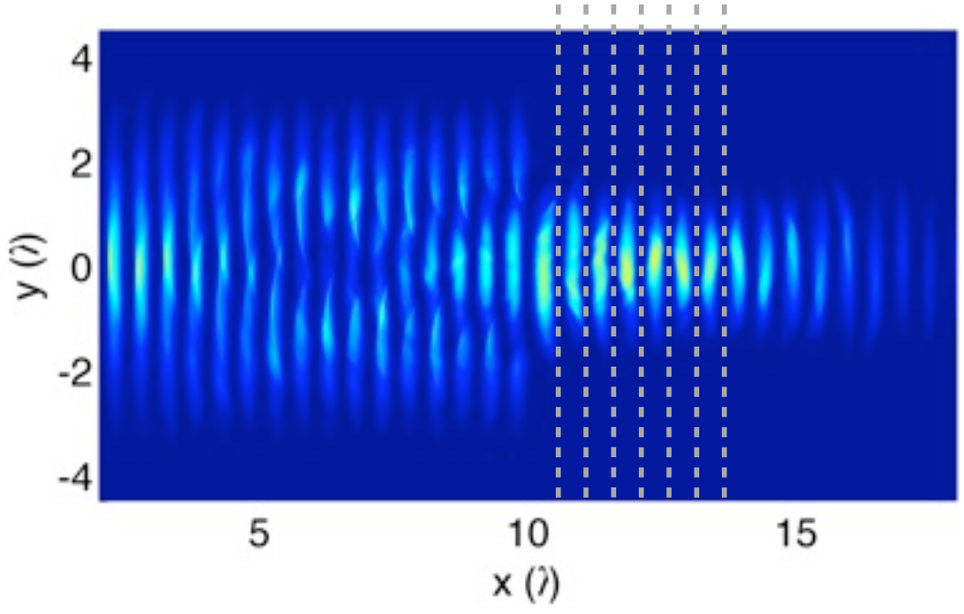




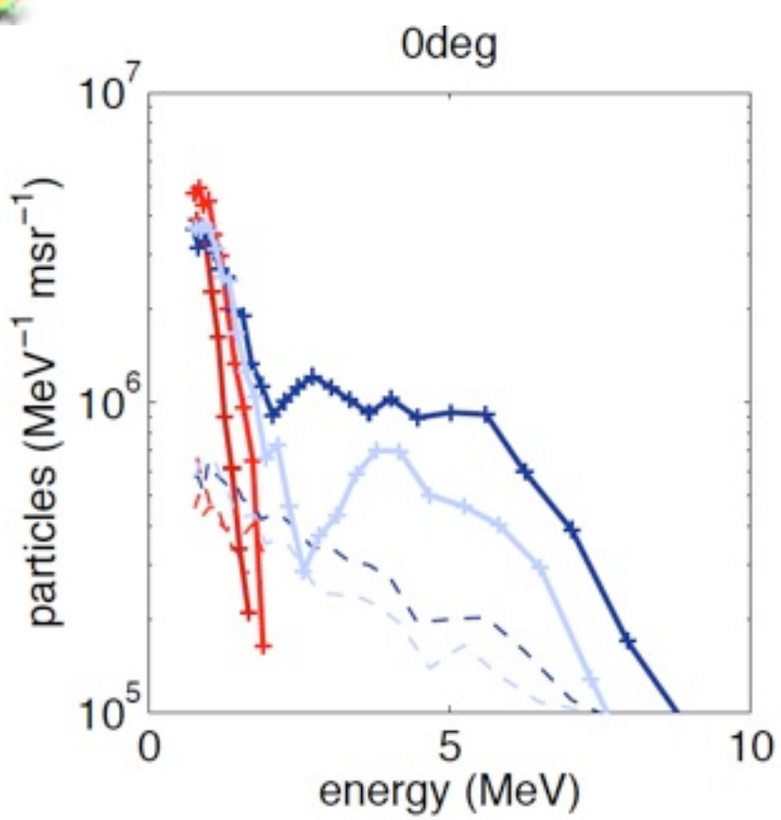
laser field

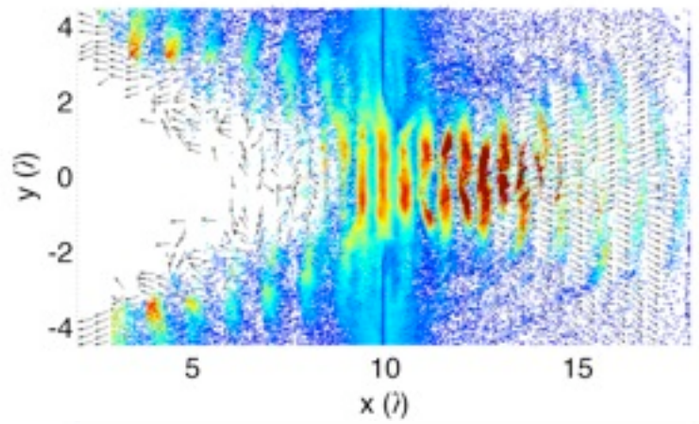


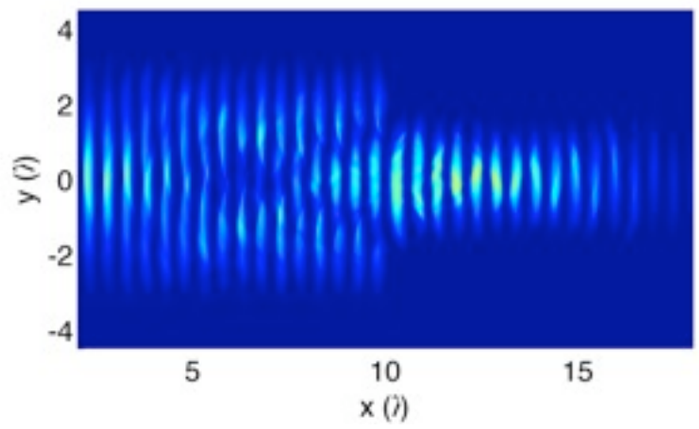


Summary

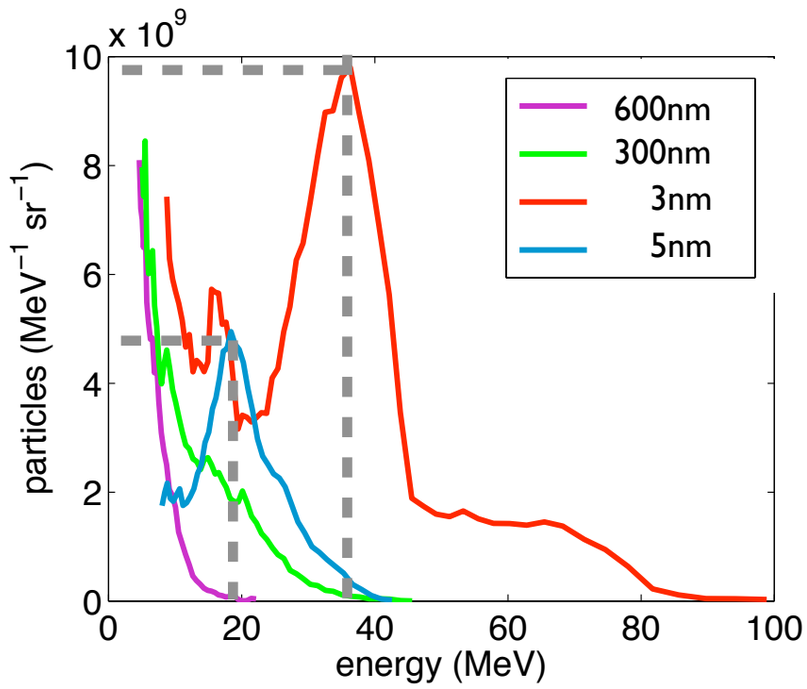
700mJ, 50fs

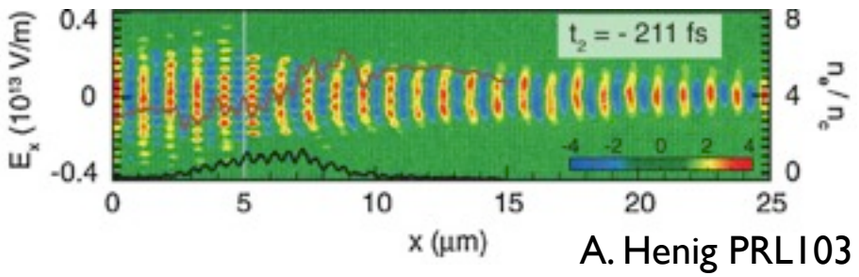






90J, 500fs





A. Henig PRL103 (2009)

Talk on Thursday (1pm):
R. Shah: *Direct Optical Signatures of Relativistic Transparency of Nanometer Foils*

Conclusions

<u>Motivation</u>: Generation of a relativistic electron mirror of solid density

- acceleration of all foil electrons in a single, dense electron bunch (Electron Sheet)

<u>Achievements:</u>

- fabrication of free-standing, ultra-thin foils down to 3nm thickness which can be used for laser plasma experiments
- first observation of electron blow-out from ultra-thin foils at two different laser systems

<u>Future Plans:</u>

- Thomson scattering of a counter-propagating probe pulse

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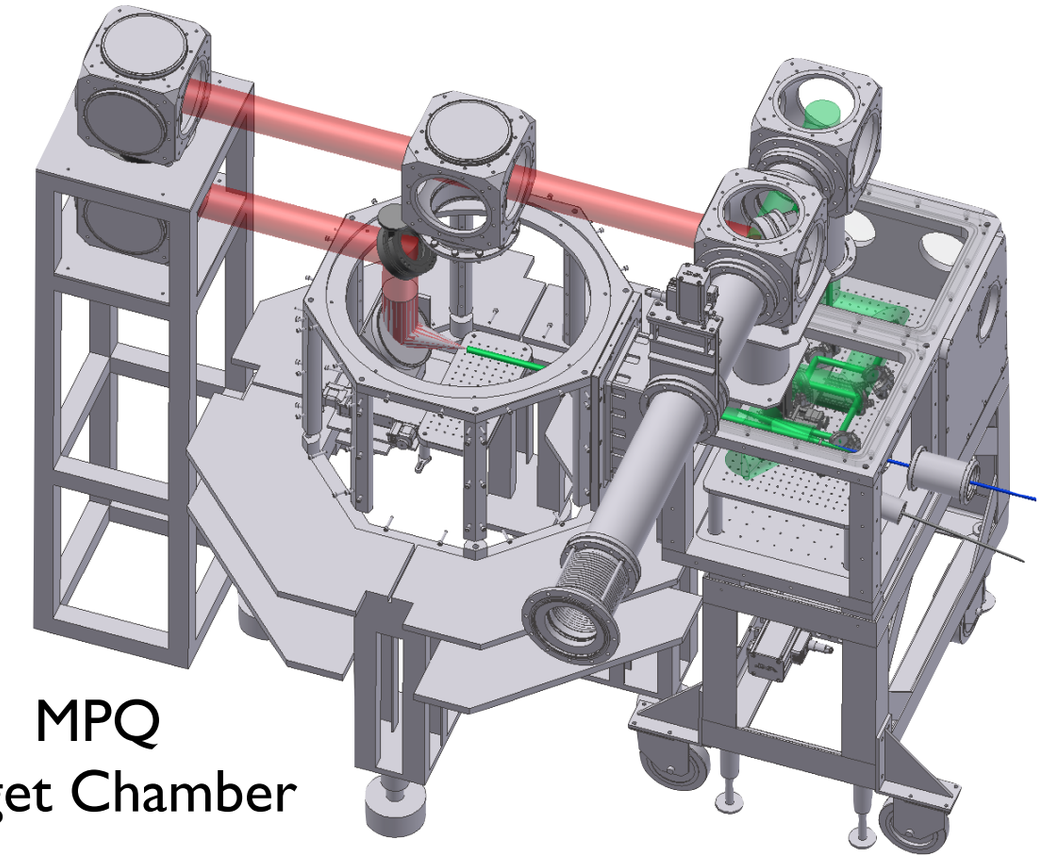

MPQ
Target Chamber

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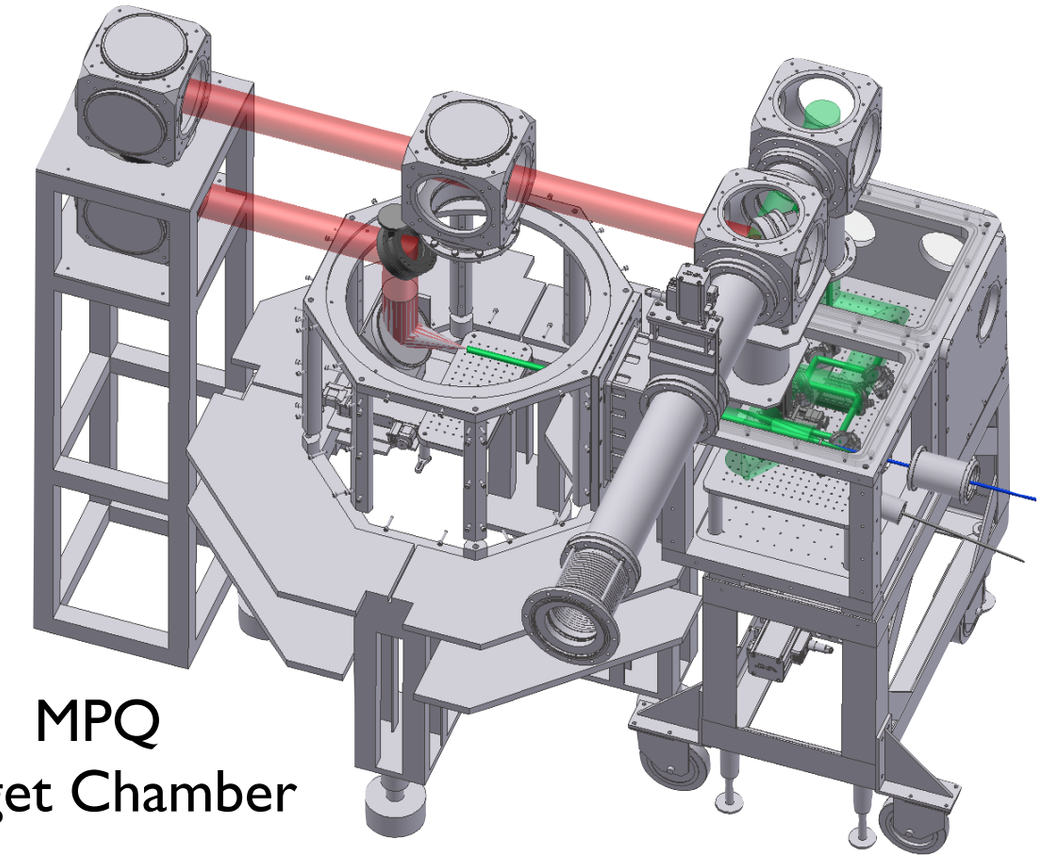
Thank you!



MPQ
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