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TECHNISCHE UNIVERSITÄT DARMSTADT

HELMHOLTZ ASSOCIATION

Energy spectrum shaping and beam focusing of laser accelerated protons

Knut Harres

TU Darmstadt

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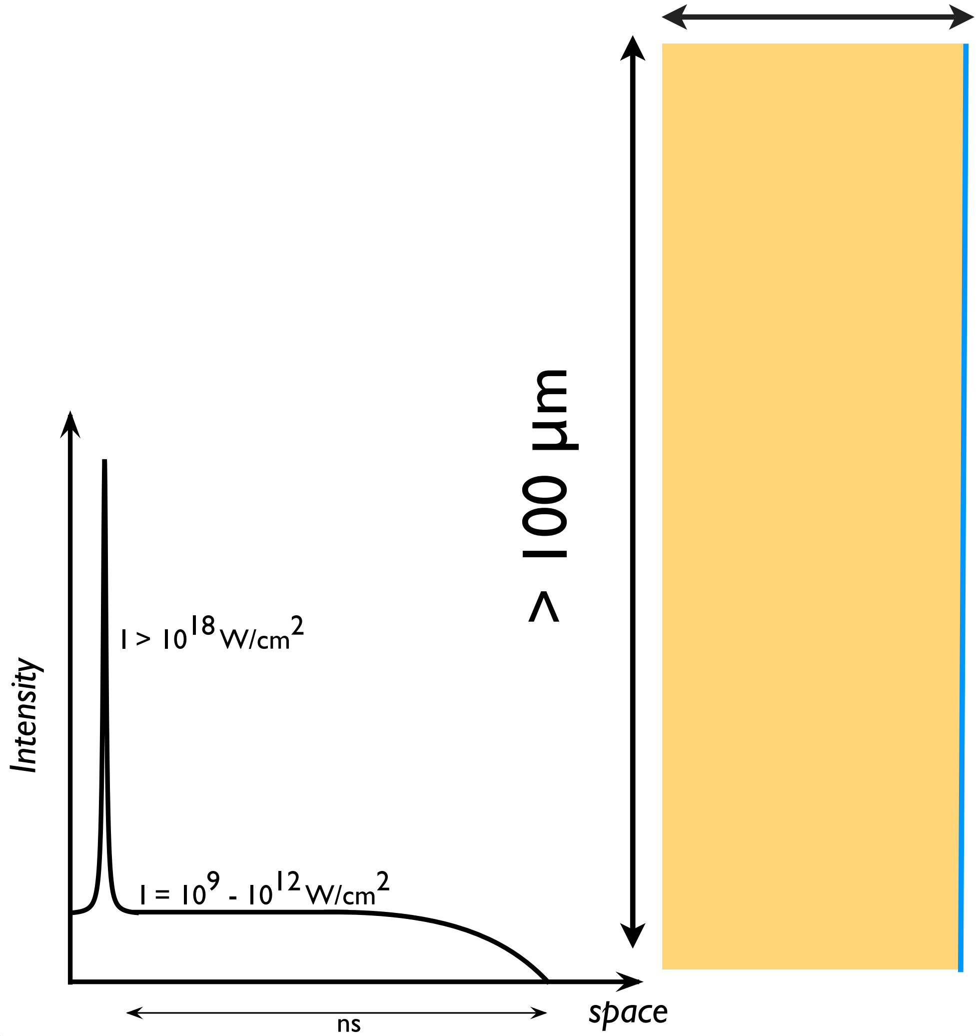
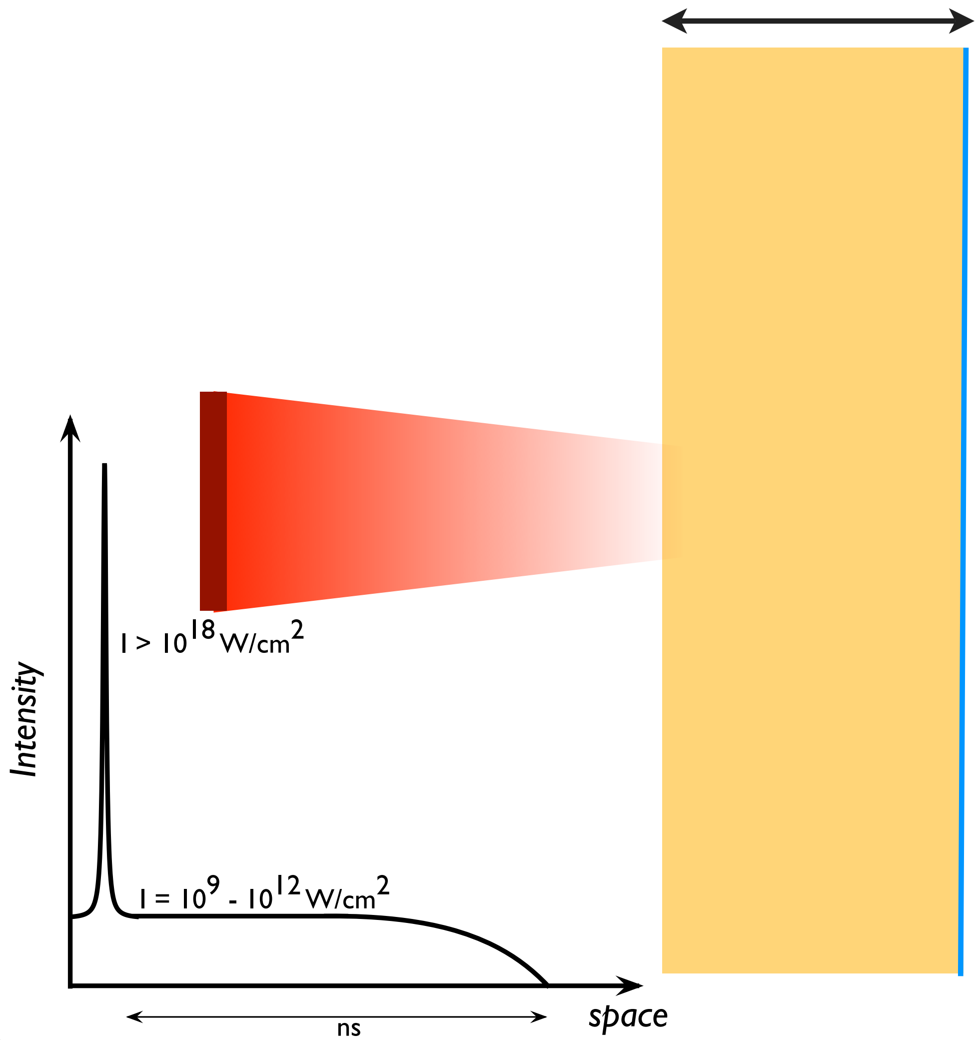
Outline

- Shaping of the energy spectrum and of the spatial energy distribution:
  - Collaboration with
- Proton focusing:
  - Collaboration with
- Conclusion and Outlook

Laser ion acceleration

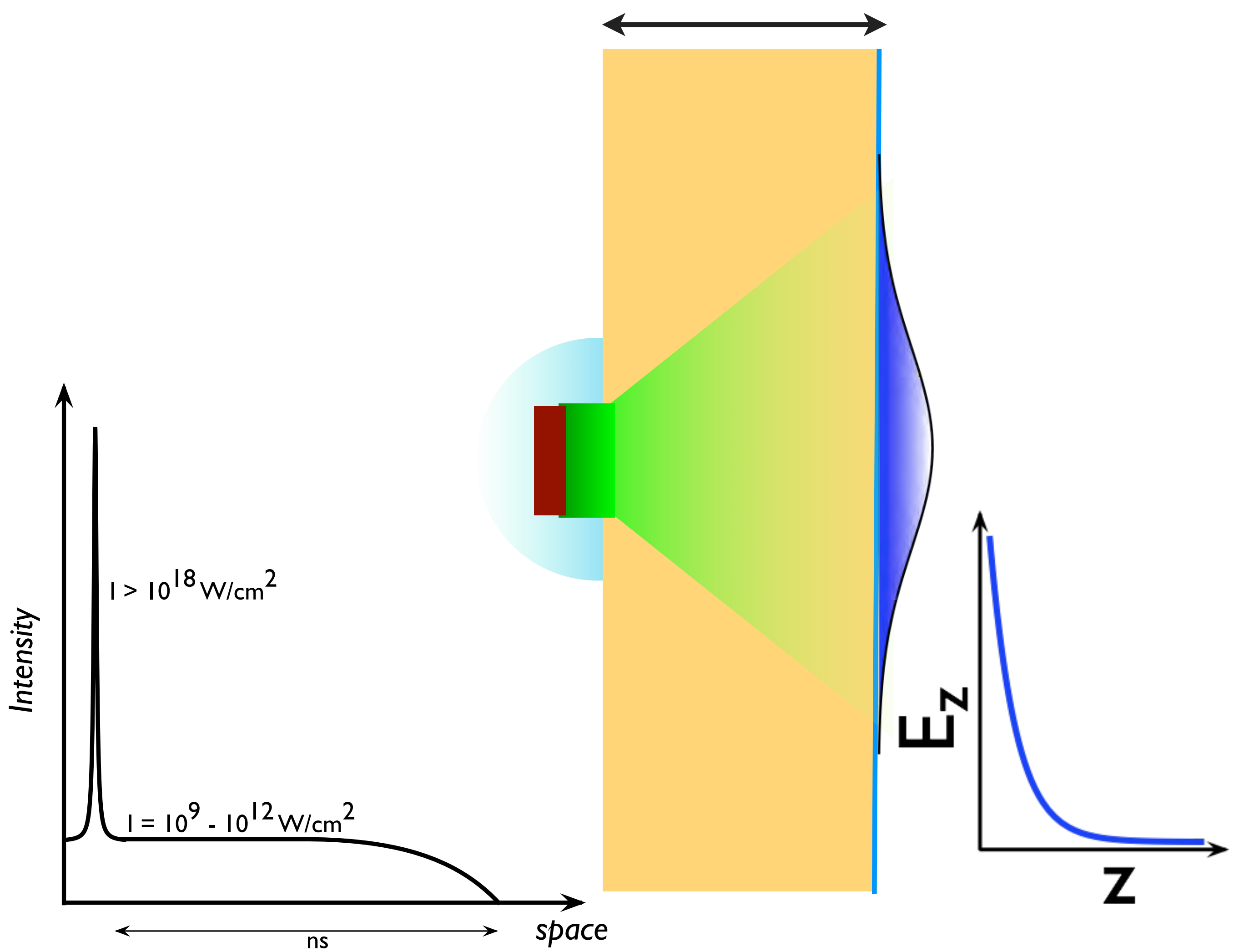


Laser ion acceleration



Laser ion acceleration

- Pre-pulse creates pre-plasma
- Main pulse accelerates electrons to MeV
- Electrons create sheath at rear side



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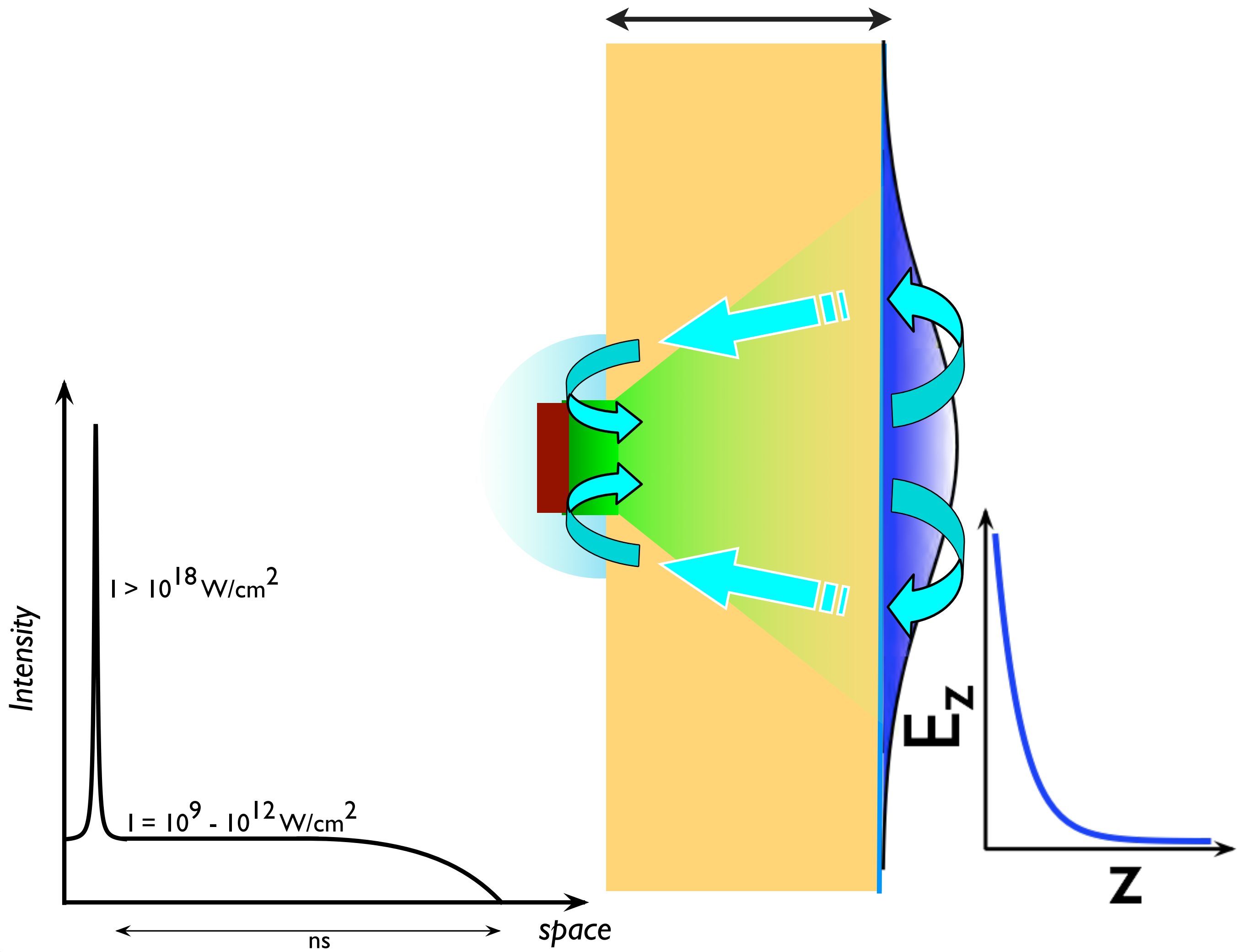
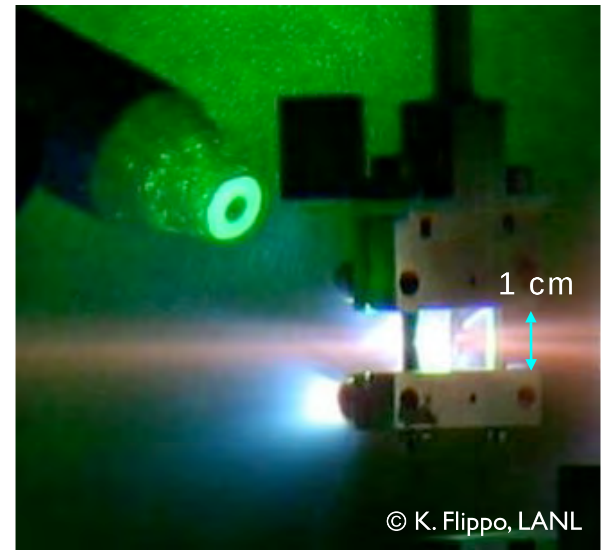
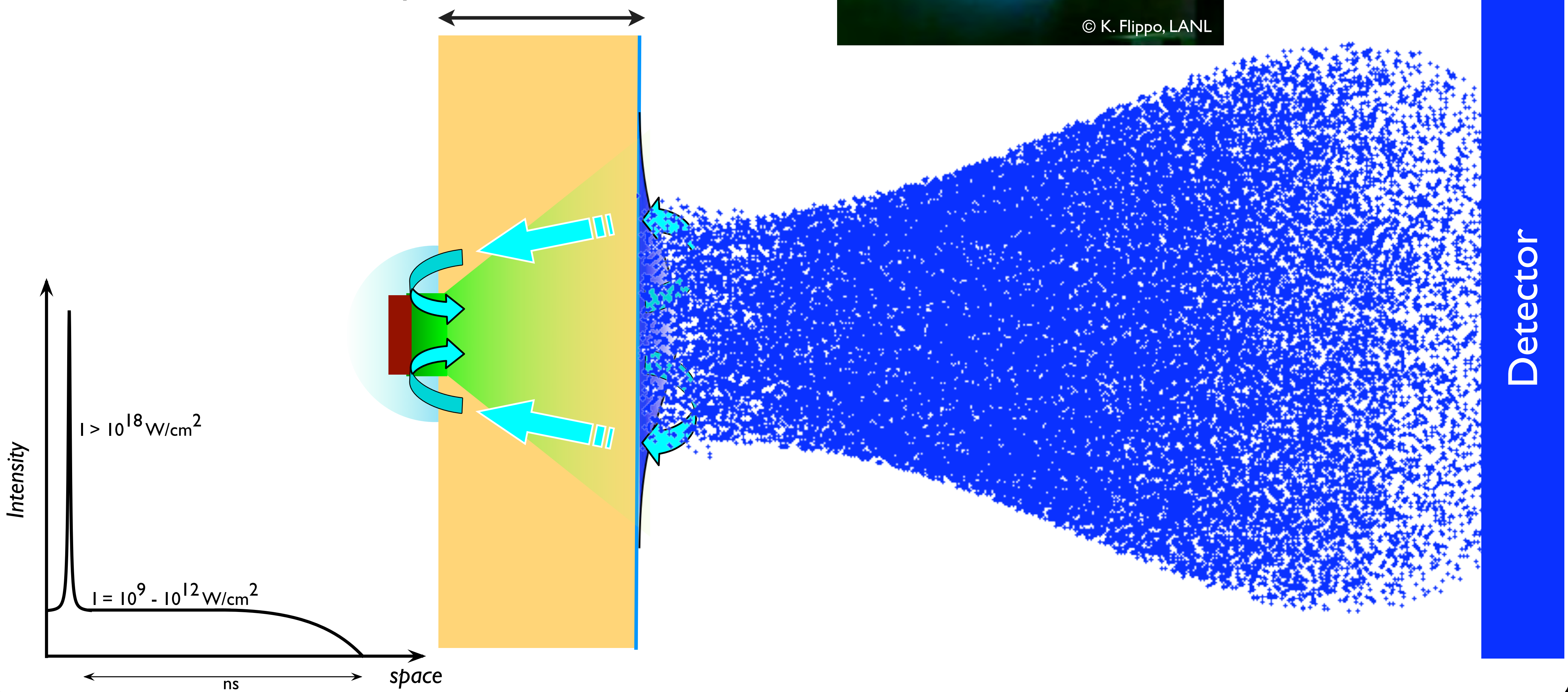
- Recirculation can enhance sheath



Laser ion acceleration

- Pre-pulse creates pre-plasma
- Main pulse accelerates electrons to MeV
- Electrons create sheath at rear side
- Recirculation can enhance sheath
- Sheath accelerates protons





Energy spectrum shaping

- Shaping of the energy spectrum and of the spatial energy distribution
  - Using an additional ns ablation laser pulse to shape the spatial energy distribution
  - Defocusing of the main pulse to increase the flux of the lower energy protons
  - Double pulse experiment with two CPA-pulses to shape the energy spectrum

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Proton acceleration with ns ablation pulse

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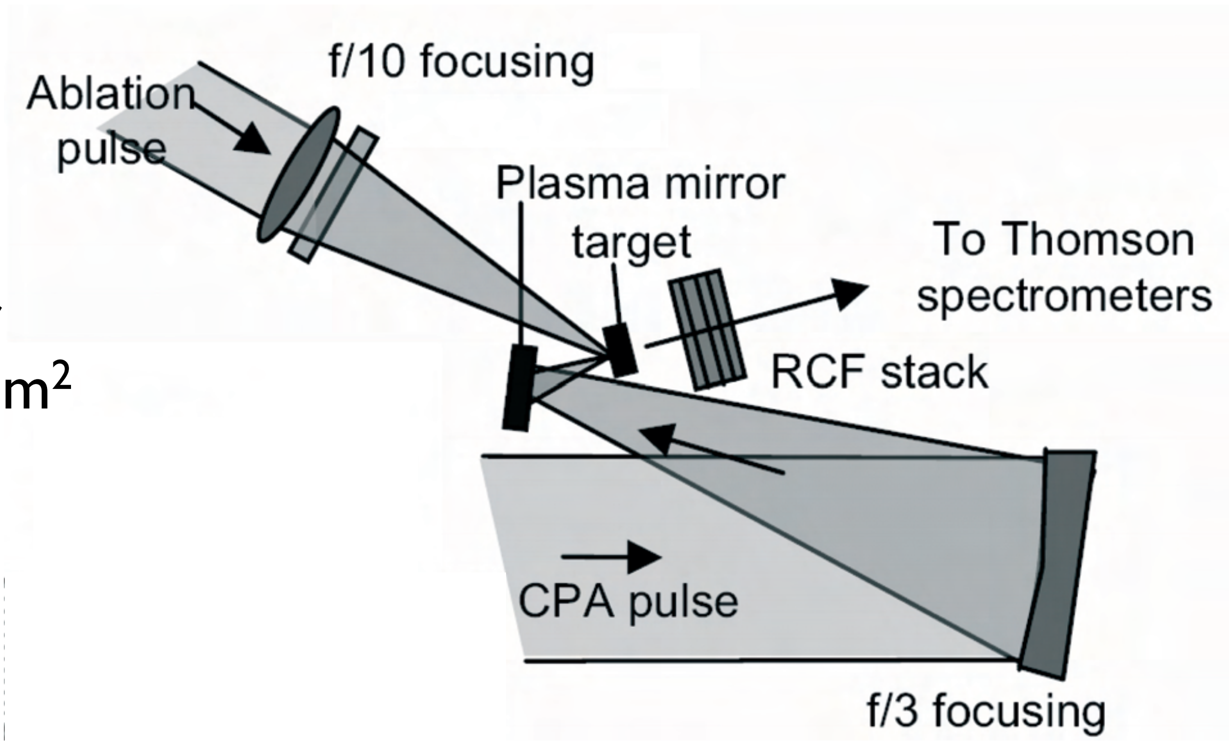

Short pulse
5 μm diameter
$I = 4\times10^{20}$ W/cm^2
τ = 600 fs

Long pulse
500 μm diameter
$I = 10^{11}$-10^{13} W/cm^2
delay = 0.5 - 6 ns

Carroll *et al.*, PRE 76 (2007)

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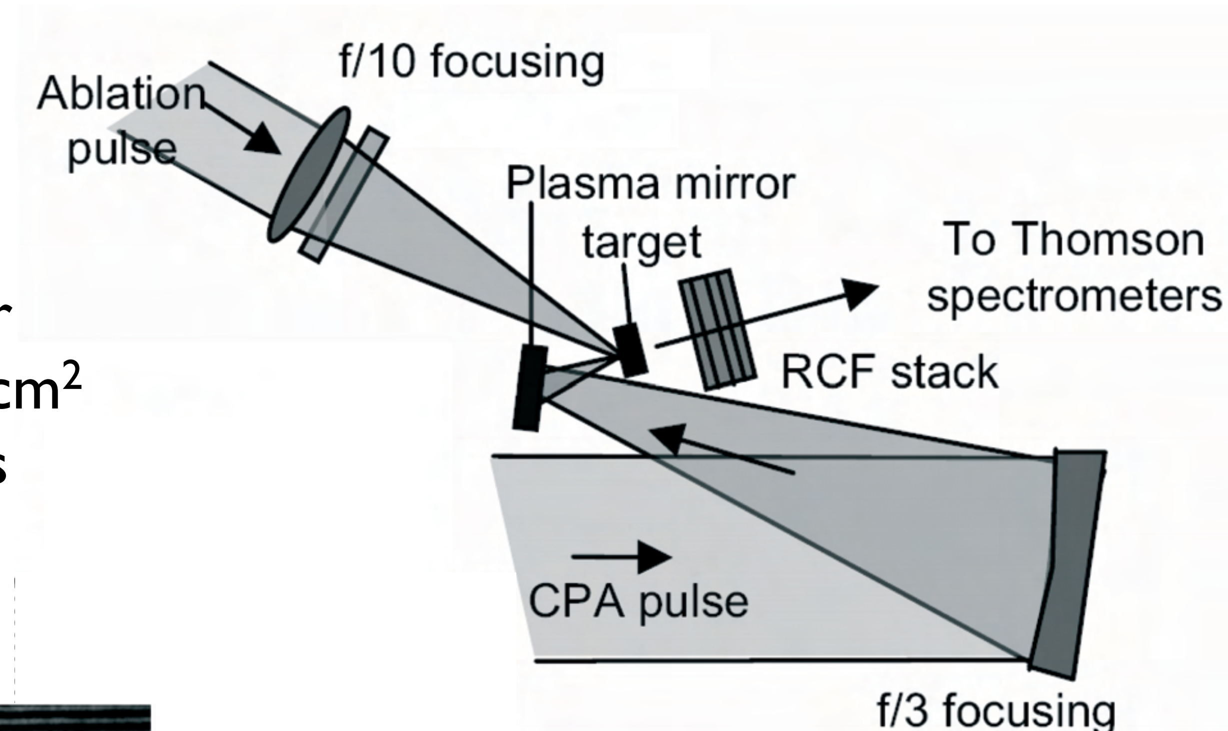

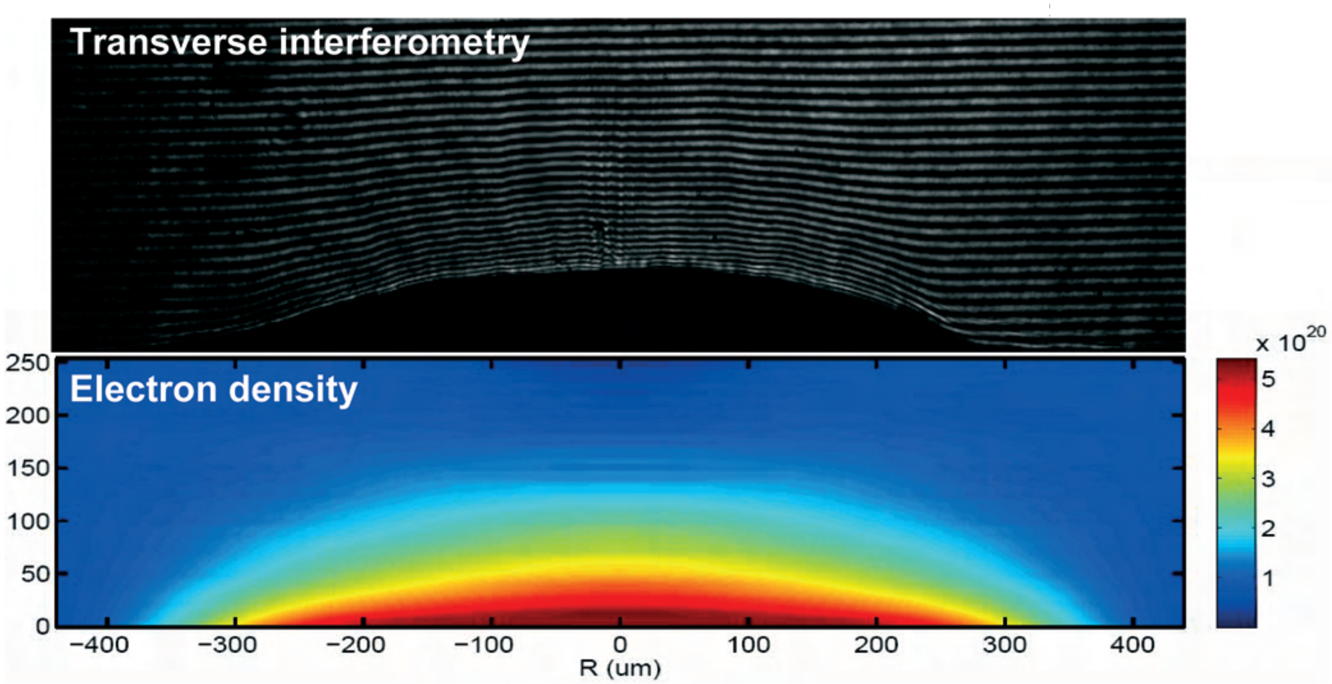

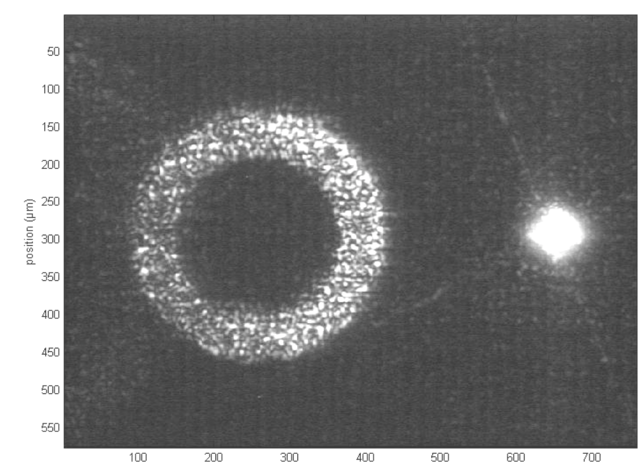

Carroll *et al.*, PRE 76 (2007)

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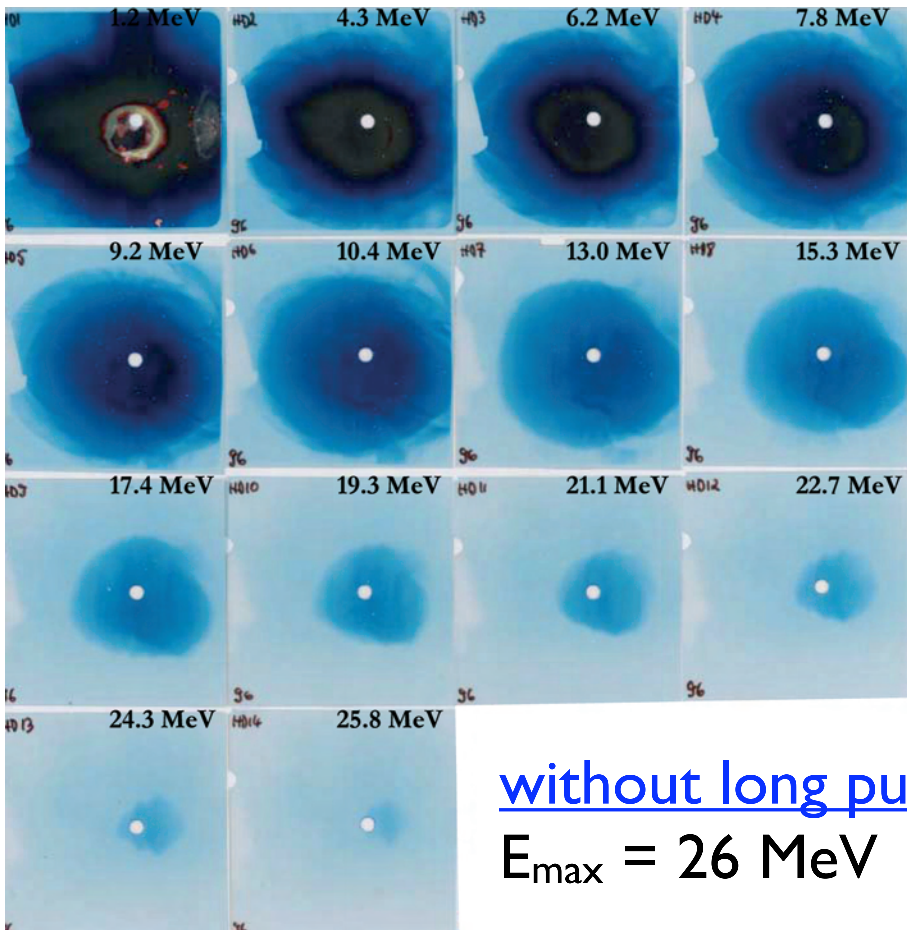
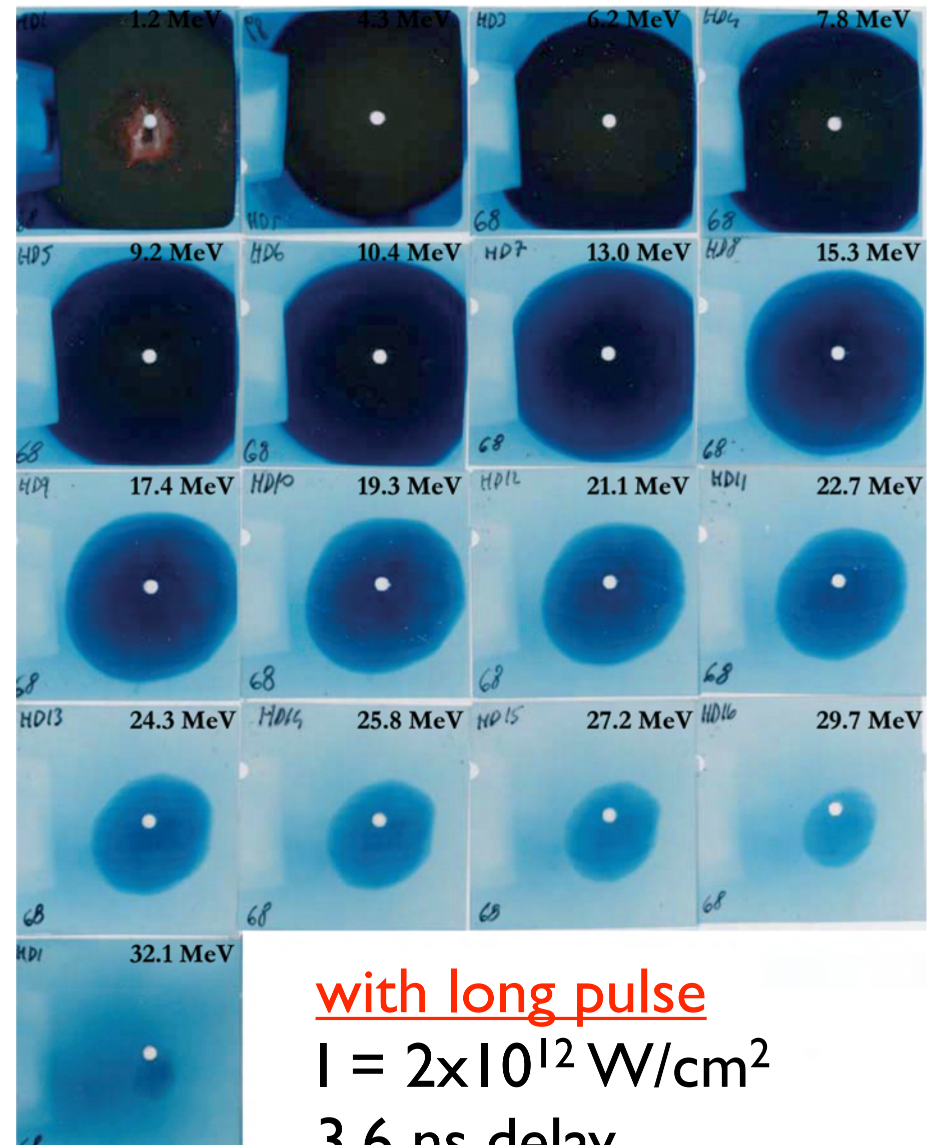
Proton beam enhancement



without long pulse

E_{max} = 26 MeV



with long pulse

I = 2×10^{12} W/cm^2

3.6 ns delay

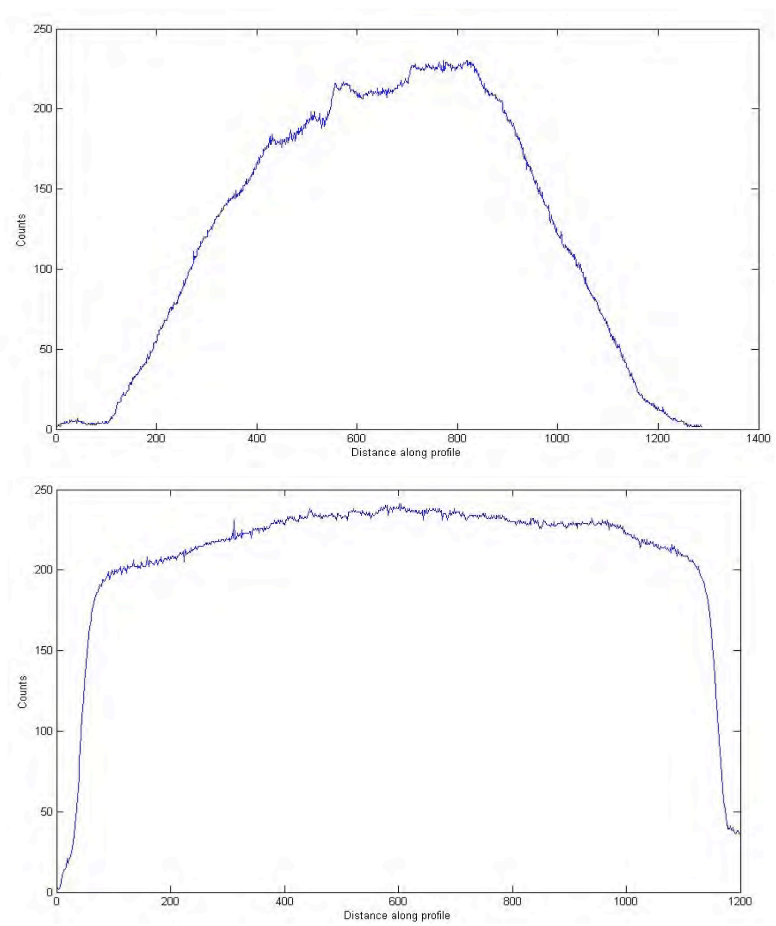
E_{max} = 32 MeV

- laser energy 512 J
- target: copper 25 μm
- > 20% increase of maximum energy
- significant improvement of the beam quality

Carroll *et al.*, PRE 76 (2007)

Proton beam enhancement

HD6 profile (10.4 MeV)



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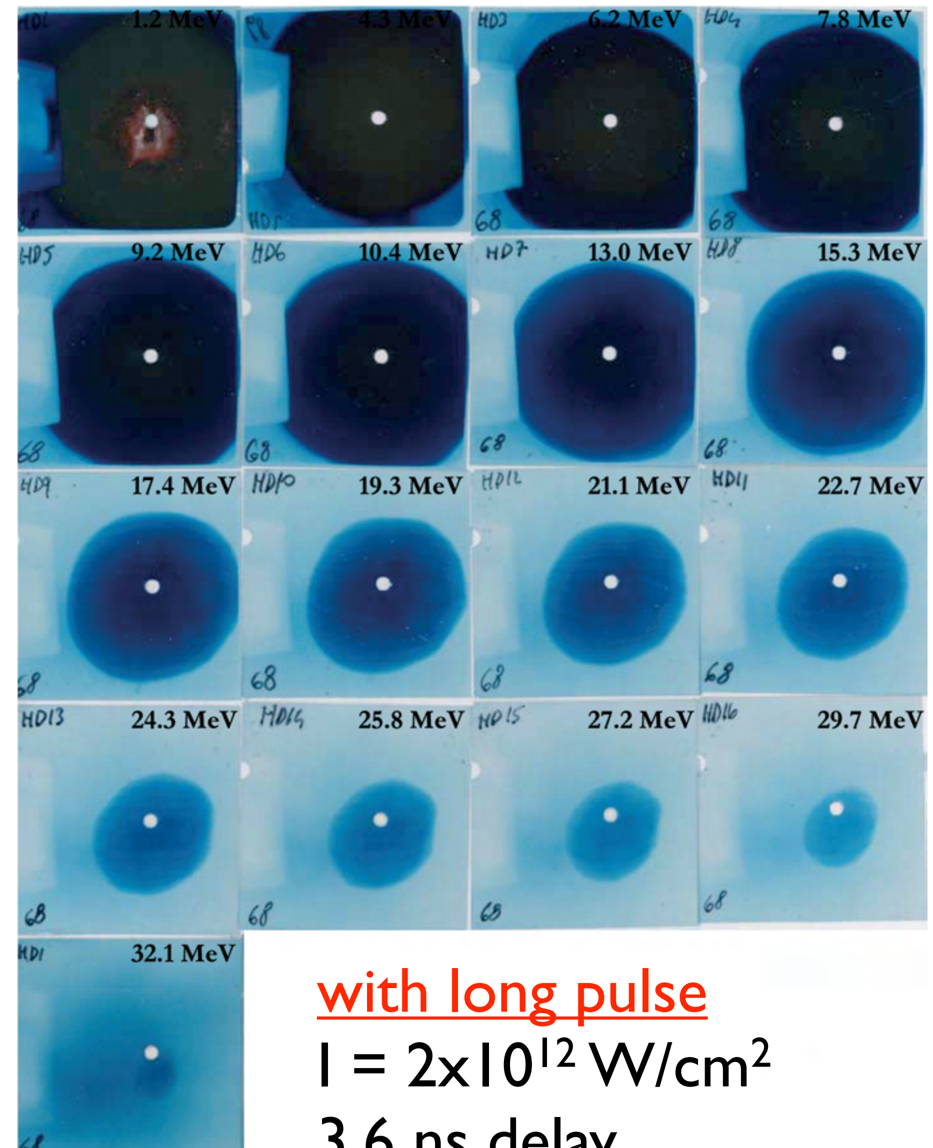

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Intensity and time scan

Time scan LP-CPA Cu targets

CPA best focus, **LP** defocused disc 470 µm

	CPA	LP	LP intensity	delay LP-CPA	max. E_{prot}
shot #97	523 J	-----	-----	-----	27.2 MeV
shot #66	540 J	31 J	1.18e+12 W/cm^2	0.5 ns	34.8 MeV
shot #67	495 J	32 J	1.23e+12 W/cm^2	1.5 ns	25.8 MeV
shot #64	461 J	34 J	1.31e+12 W/cm^2	3.6 ns	21.1 MeV

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Intensity scan LP Au targets

CPA 430 - 470 J, best focus, delay LP-CPA 0.5 ns, **LP** defocused disc 470 μm

	CPA	LP	LP intensity	max. E_{prot}	structure
shot #87	472 J	-----	-----	29.7 MeV	hole spot, up to high energies 30 MeV
shot #84	440 J	14 J	5.4e+11 W/cm^2	34.8 MeV	hole spot, up to high energies 28 MeV
shot #85	472 J	23 J	8.8e+11 W/cm^2	34.8 MeV	centre lines up to 20 MeV
shot #86	471 J	61 J	2.3e+12 W/cm^2	37.1 MeV	centre lines up to 18 MeV
shot #93	432 J	130 J	4.9e+12 W/cm^2	19.3 MeV	no lines

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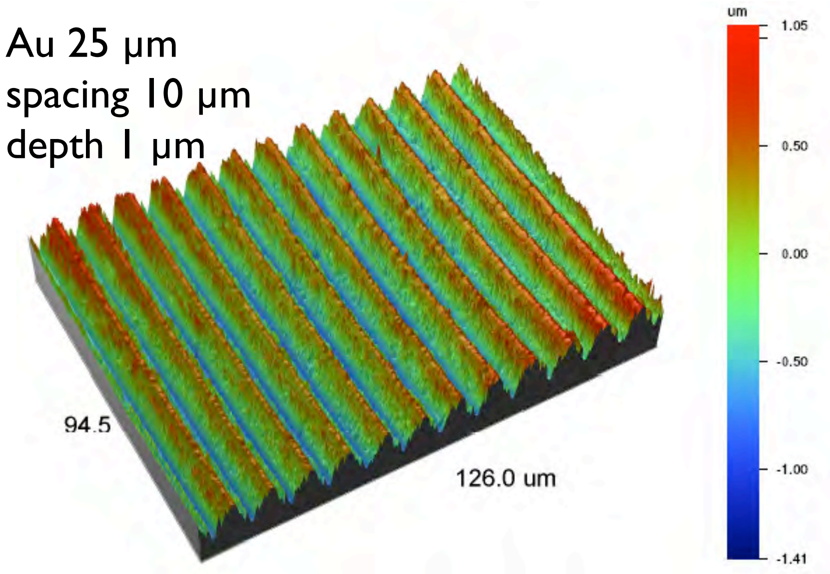
Au 25 µm
spacing 10 µm
depth 1 µm



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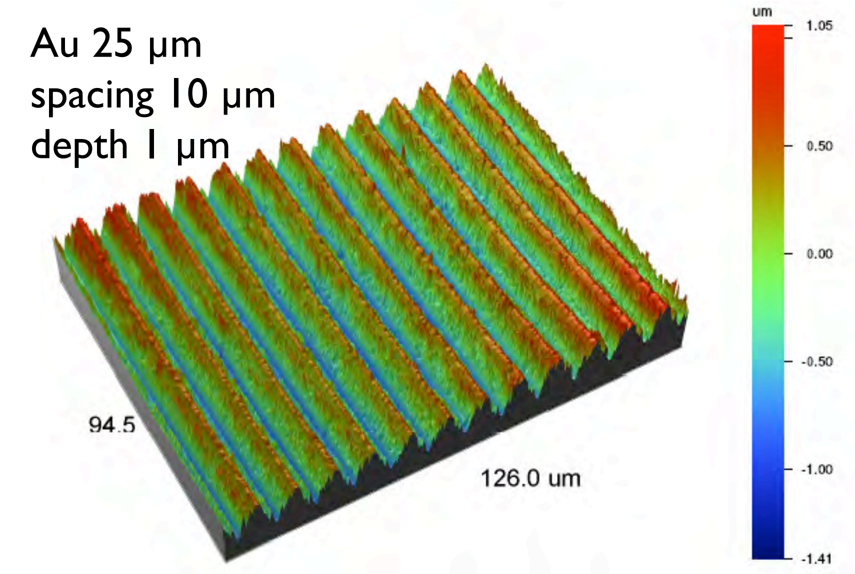

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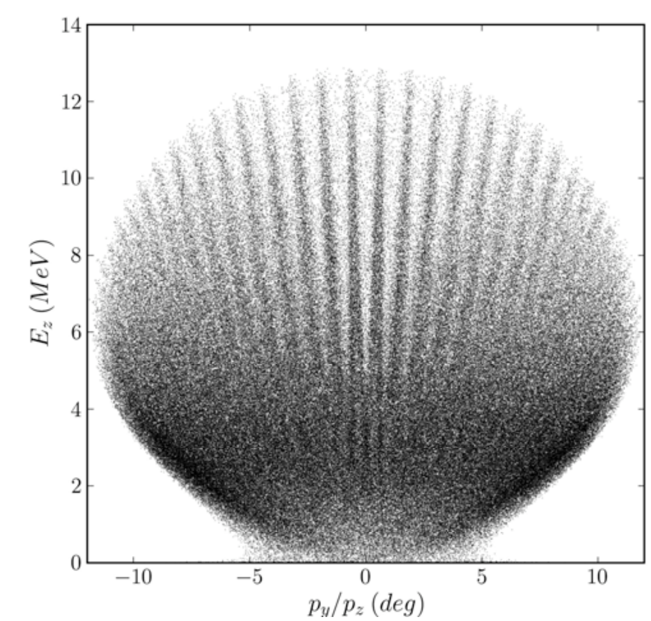

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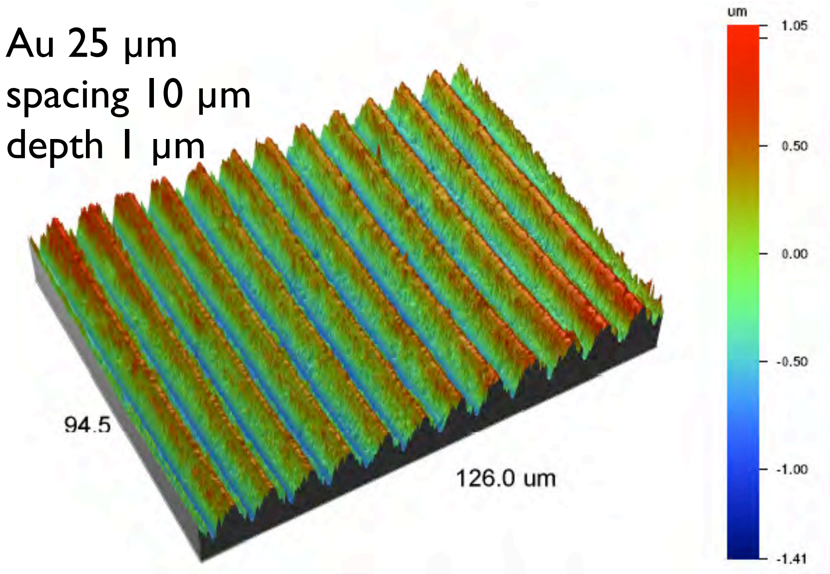

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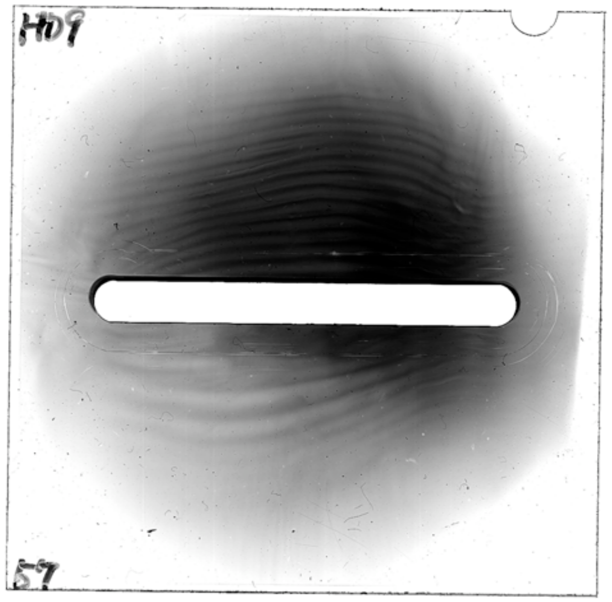
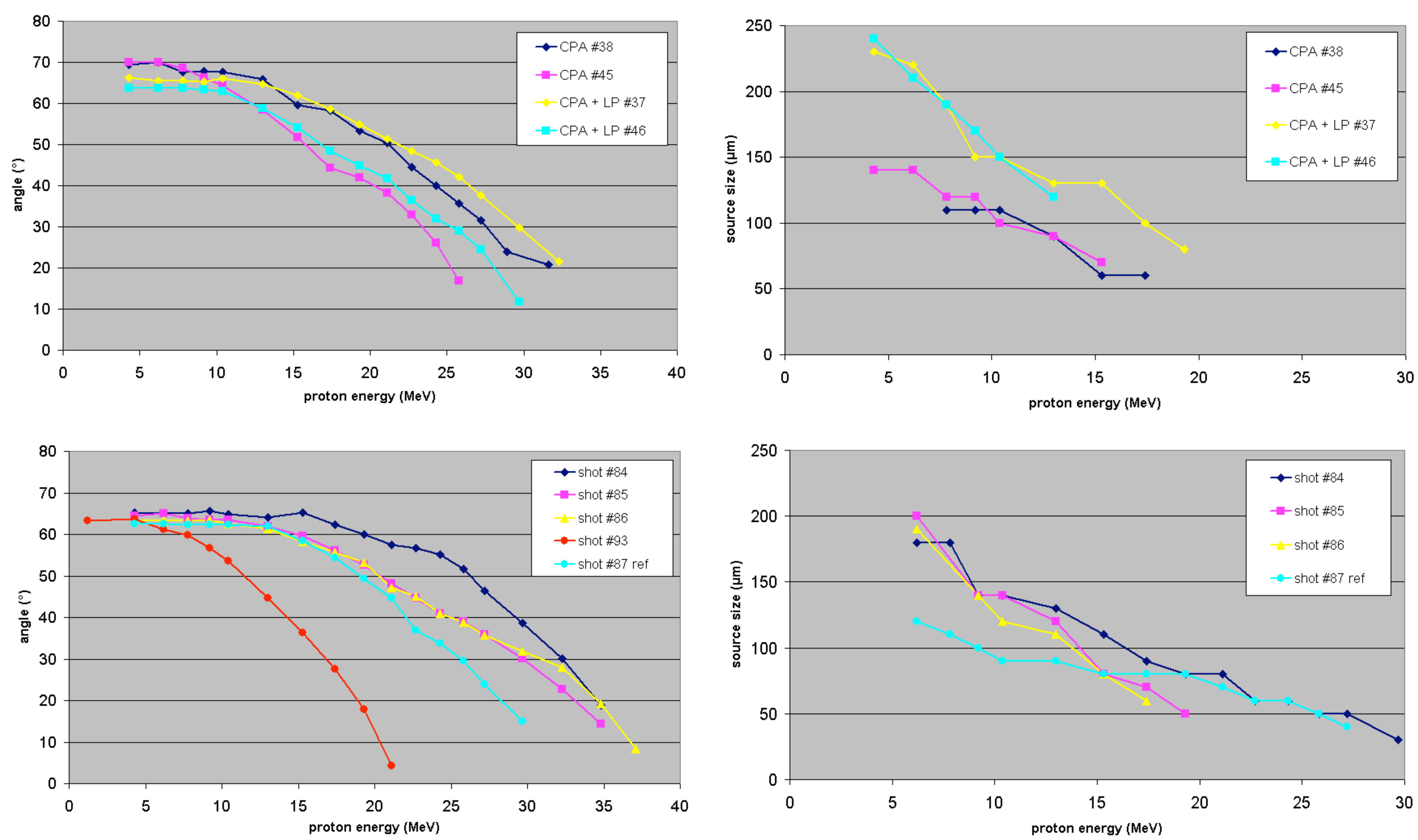
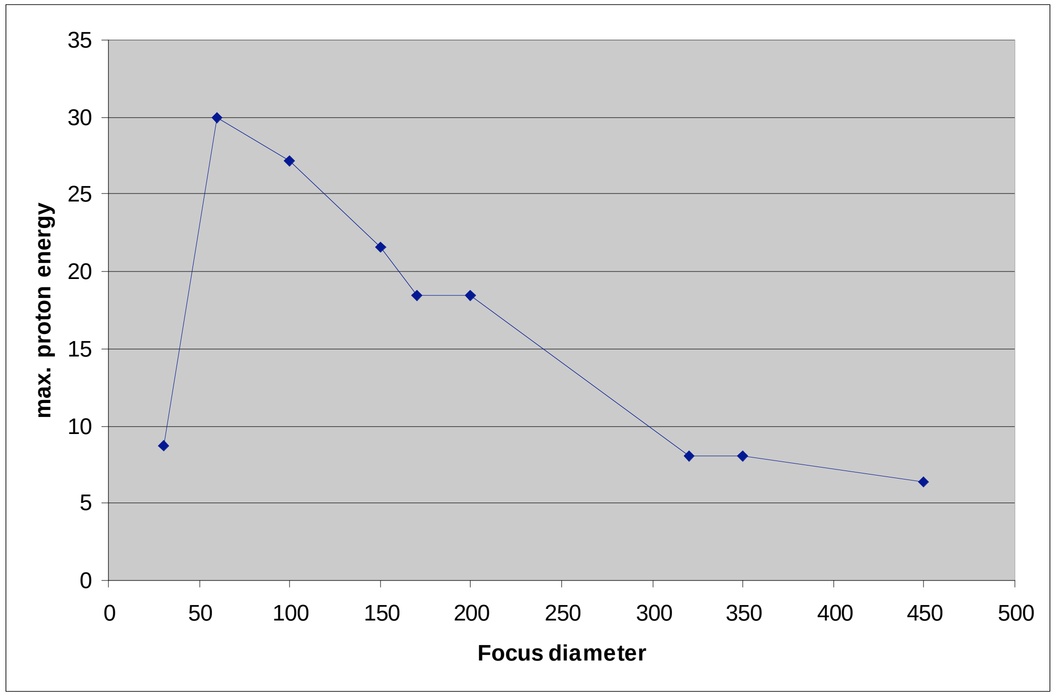


angle of beam spread and source size

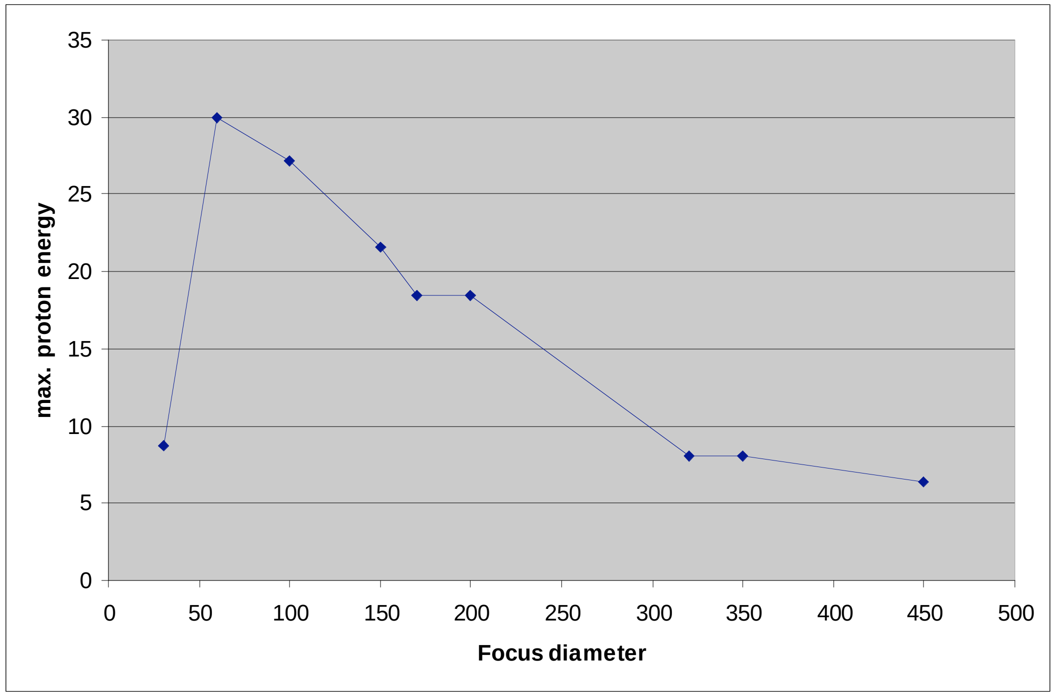


Defocusing of the CPA



focus diameter scan:
diameter: 30 - 450 µm
target: Al 2 µm

Defocusing of the CPA



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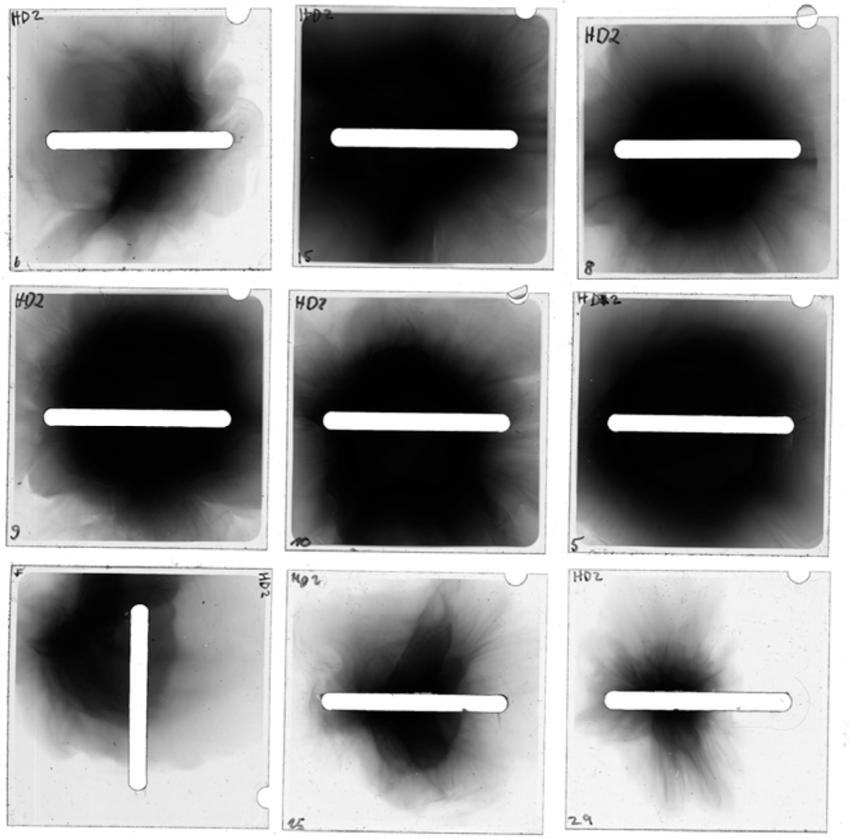
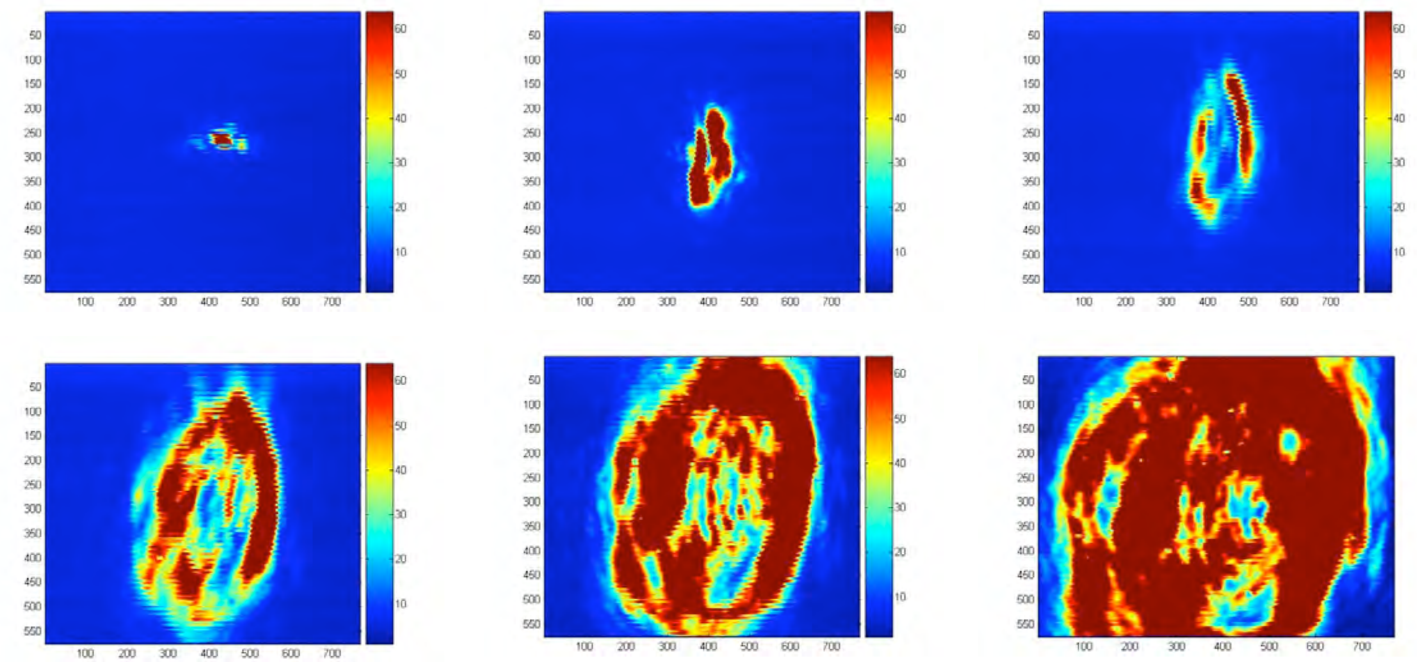


focus diameter:
30 - 60 - 100 -
150 - 150 - 170 -
200 - 320 - 350 -
450 μm

Optical transition radiation

laser focus scan:
36 - 50 - 90 - 161 - 189 - 233 µm



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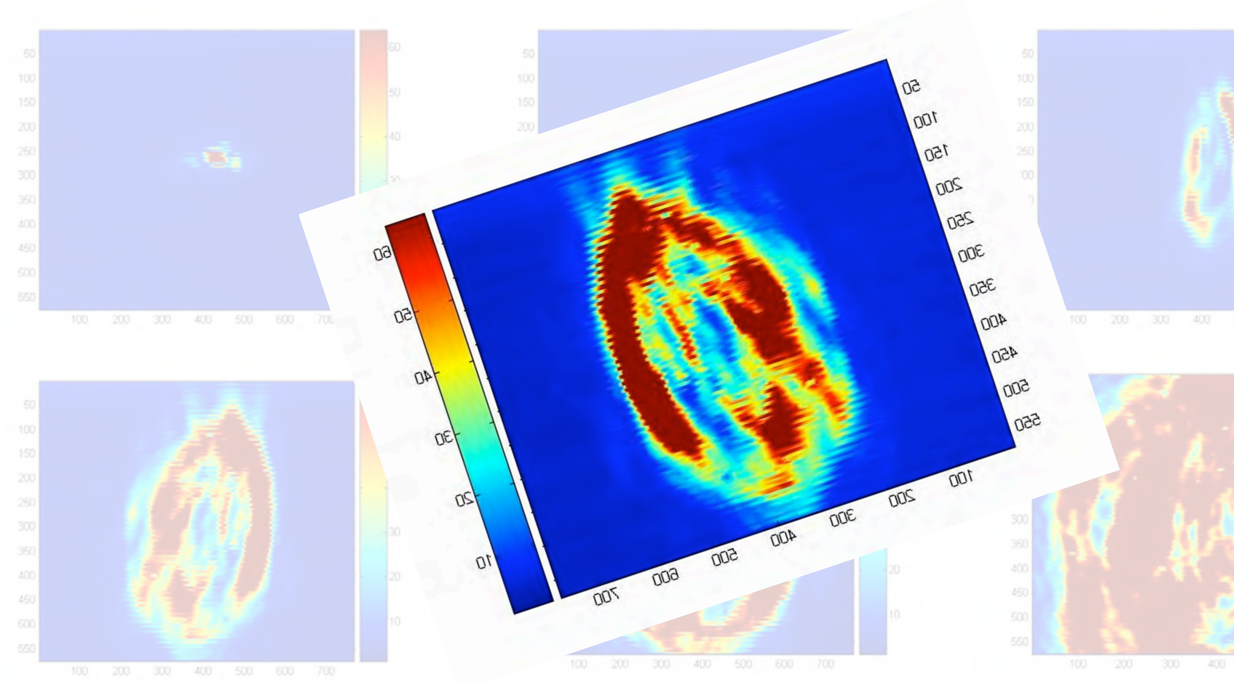
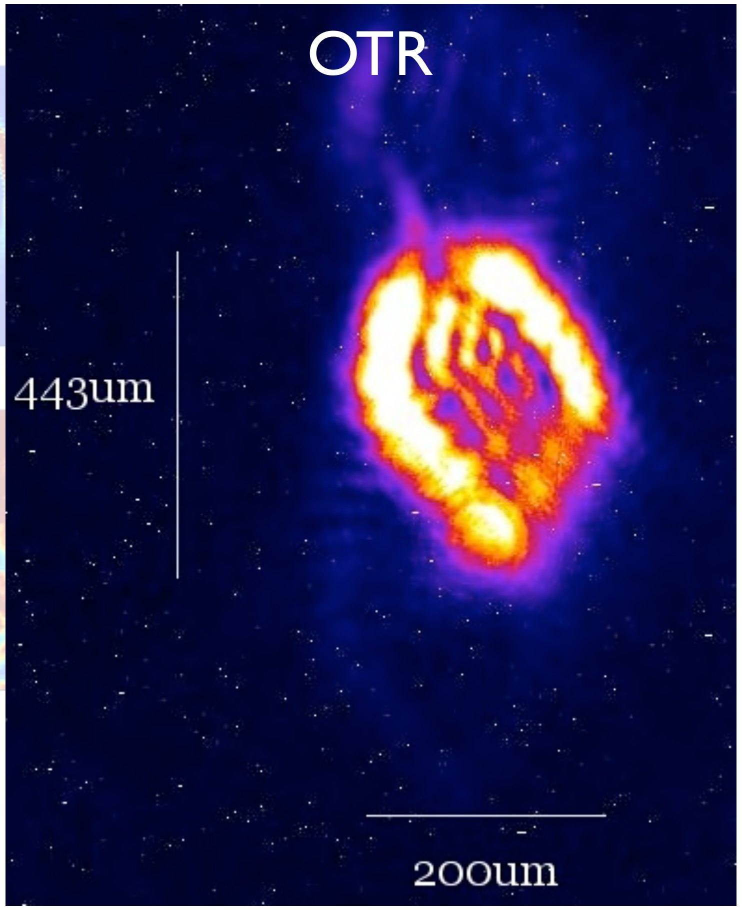
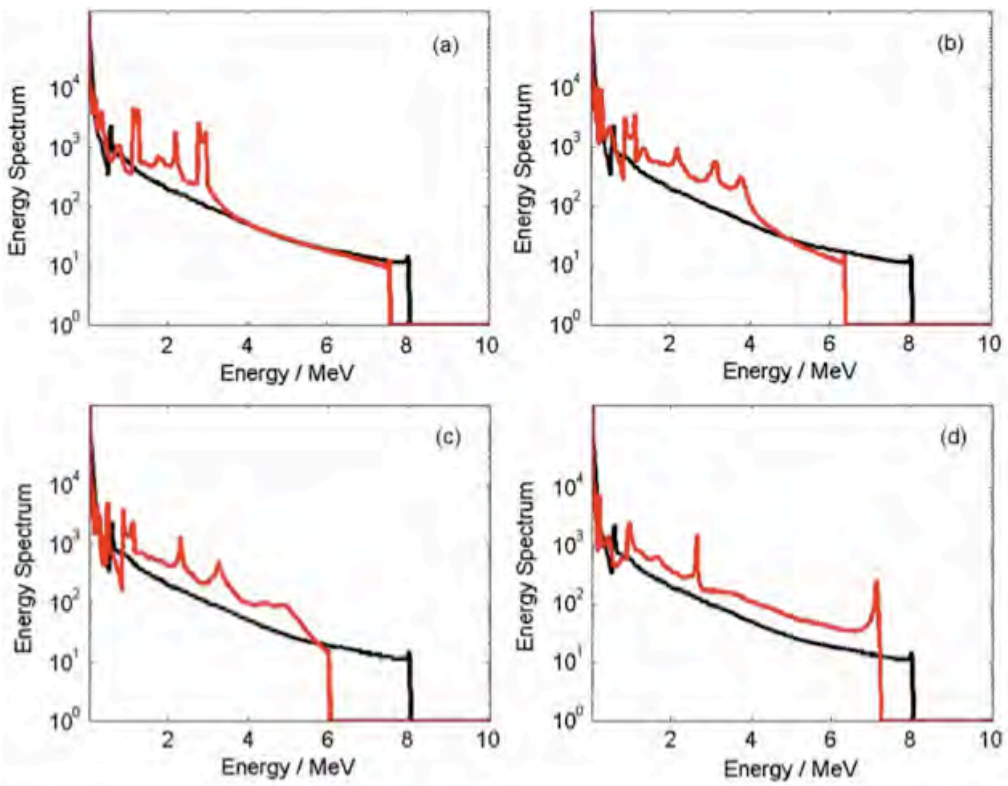




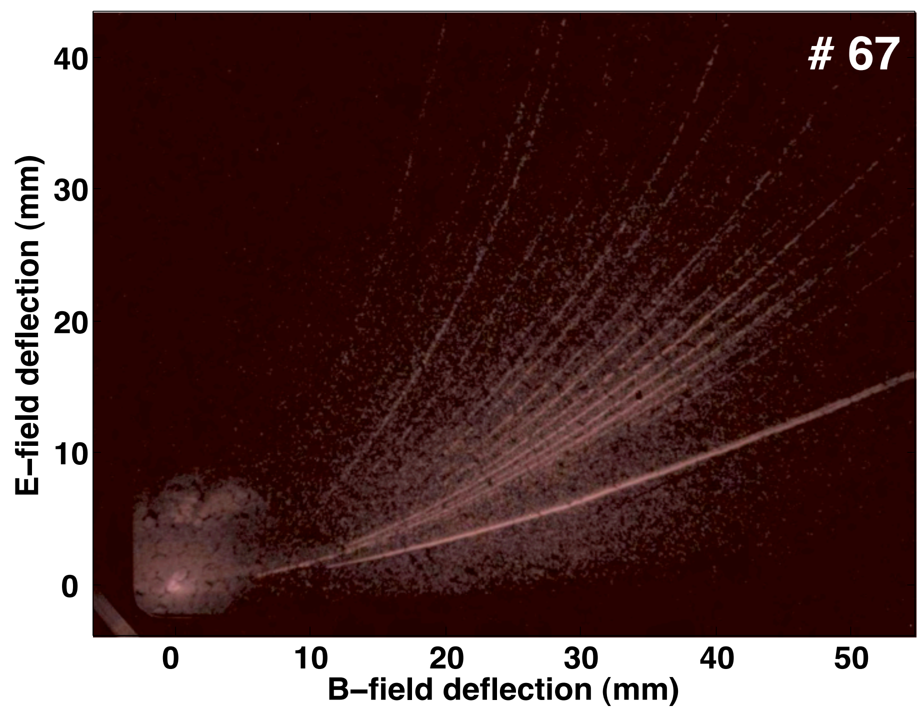
Douple pulse CPA



a_0 = 2.0, 1.5, 1.0, 0.5

Robinson *et al.*, Plasma Phys. Controlled Fusion 49, 373 (2007)

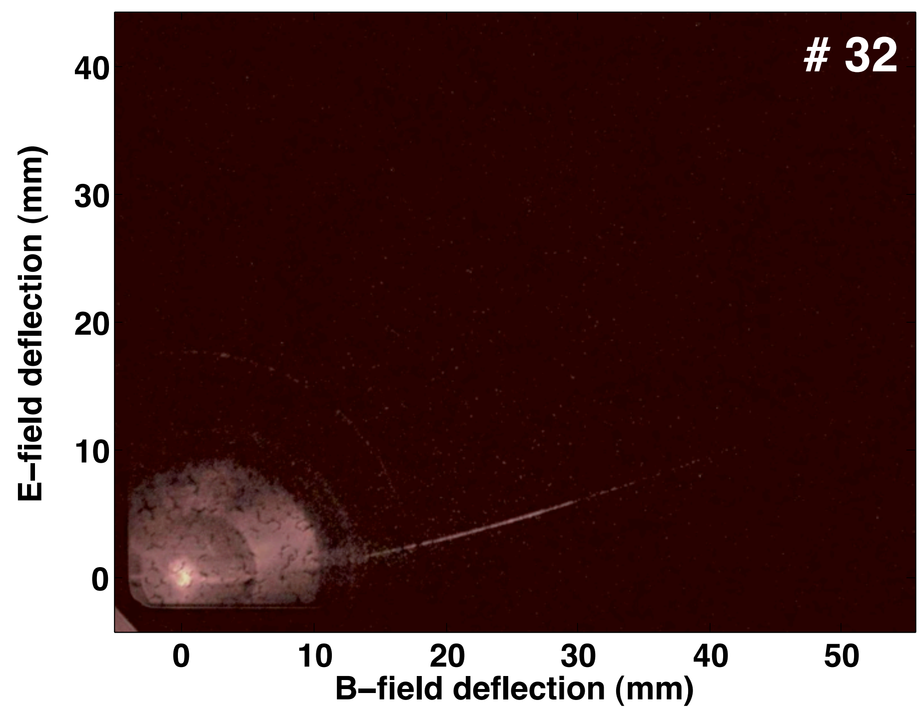
Douple pulse CPA



shot 67

target: 100μm Al

CPA: 380 J



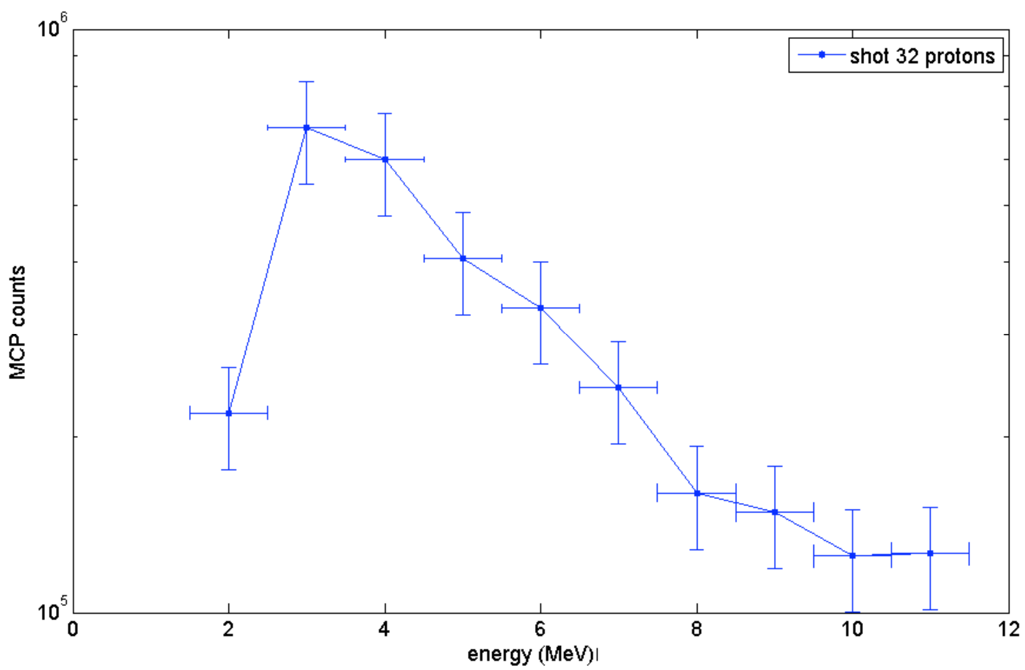
shot 32 DP

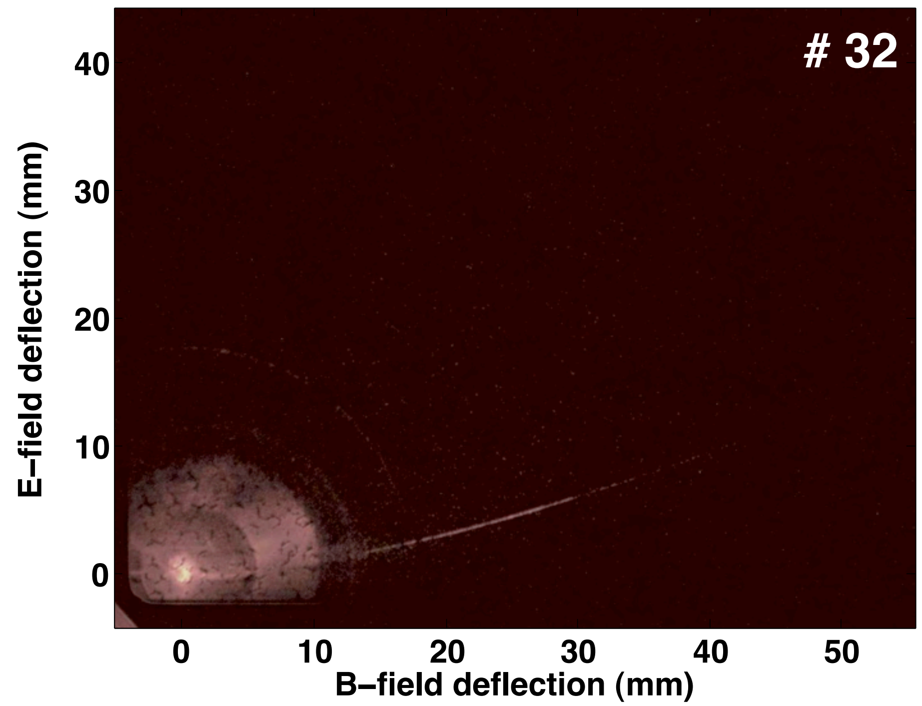
target: 25μm Au

CPA: 108 J; ratio: 1:10

delay: 1.5ps

Douple pulse CPA





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target: 25µm Au

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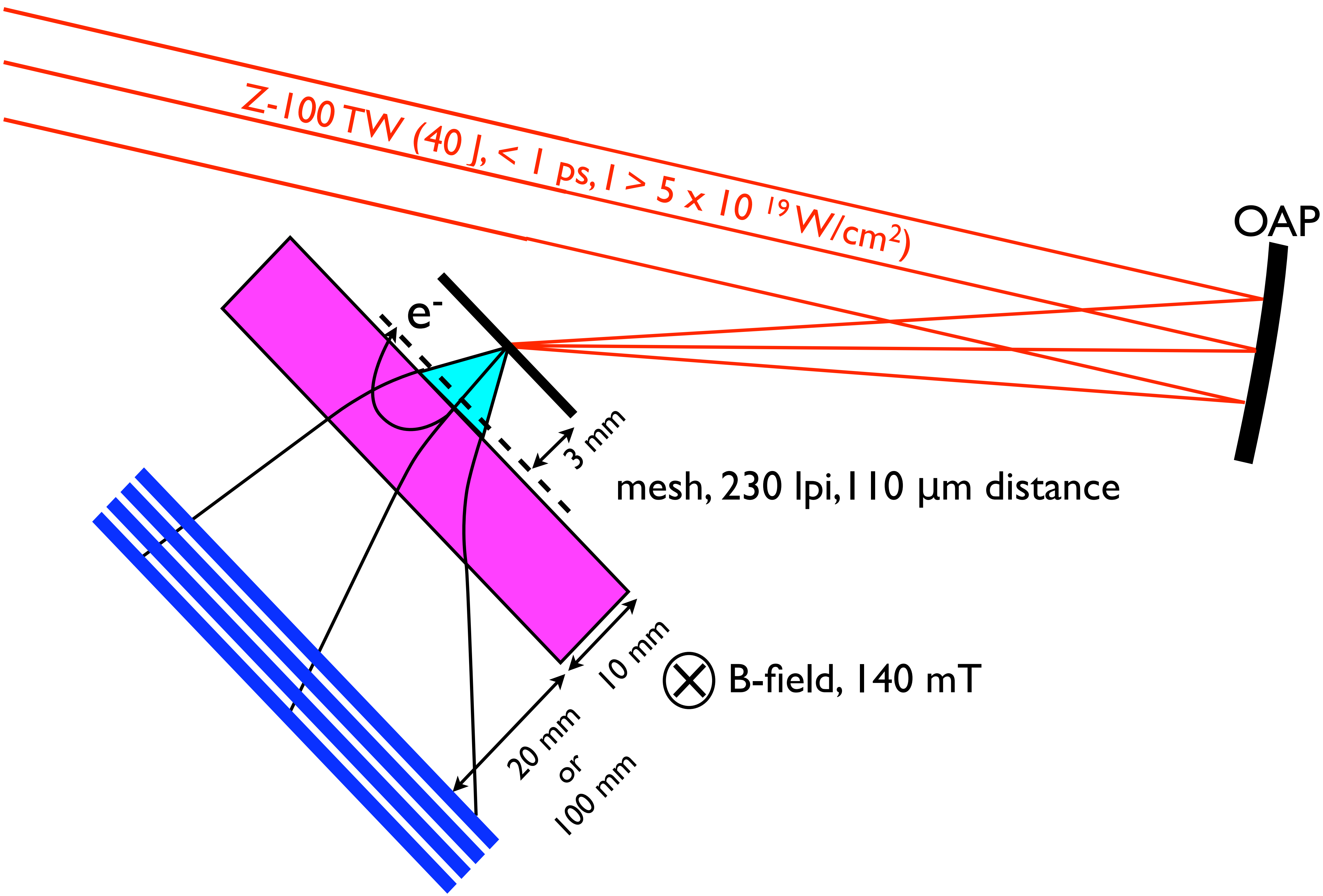
delay:1.5ps

Proton focusing

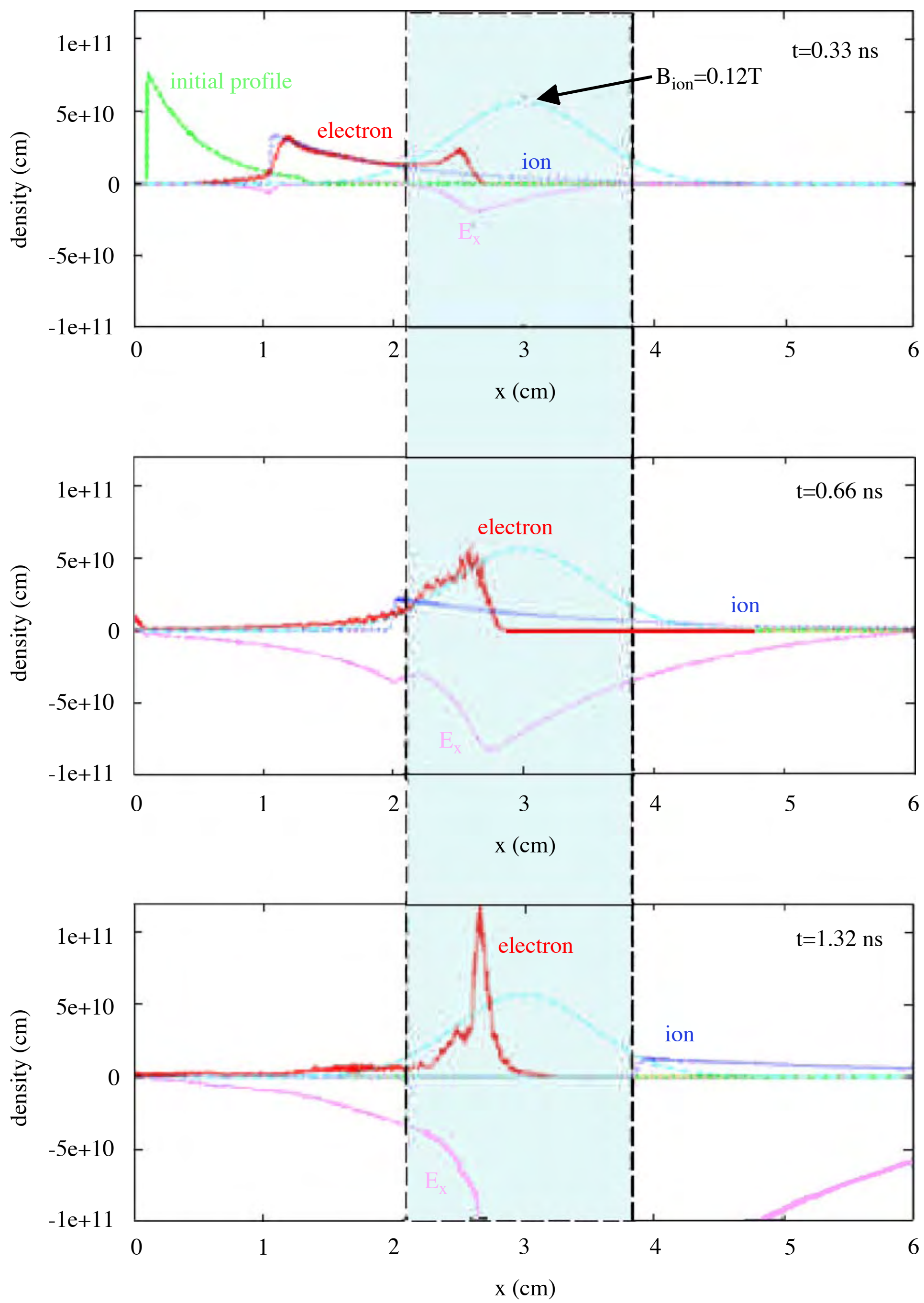
- Focusing and transport of laser-accelerated protons by mini-quadrupoles
  - Could the co-moving electrons be safely removed?
  - Experiment with MPQ's permanent magnet quadrupoles (PMQ) at the Z-100 TW laser at *Sandia National Laboratories

*Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

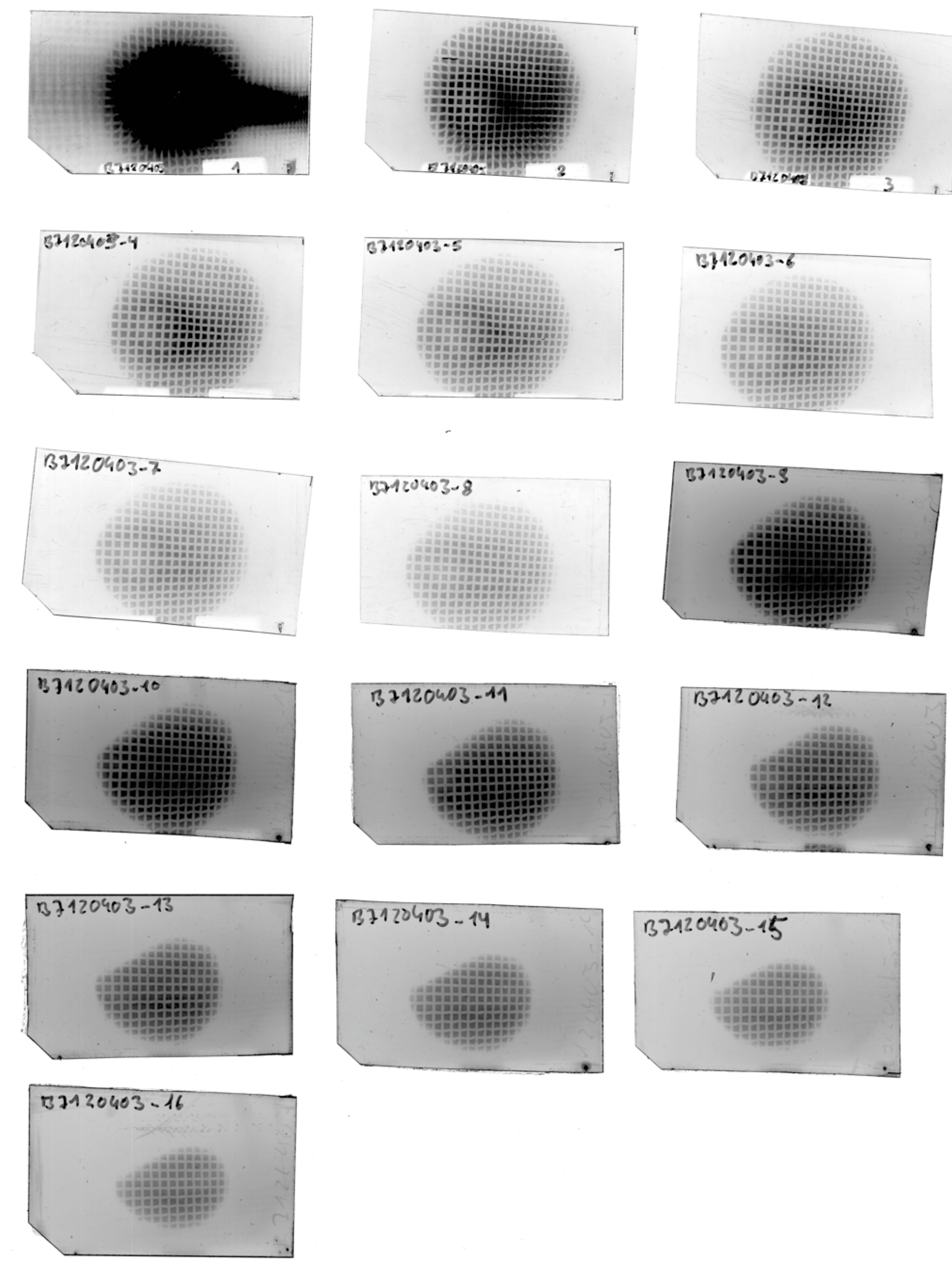
Electron stripping



Electron stripping is possible

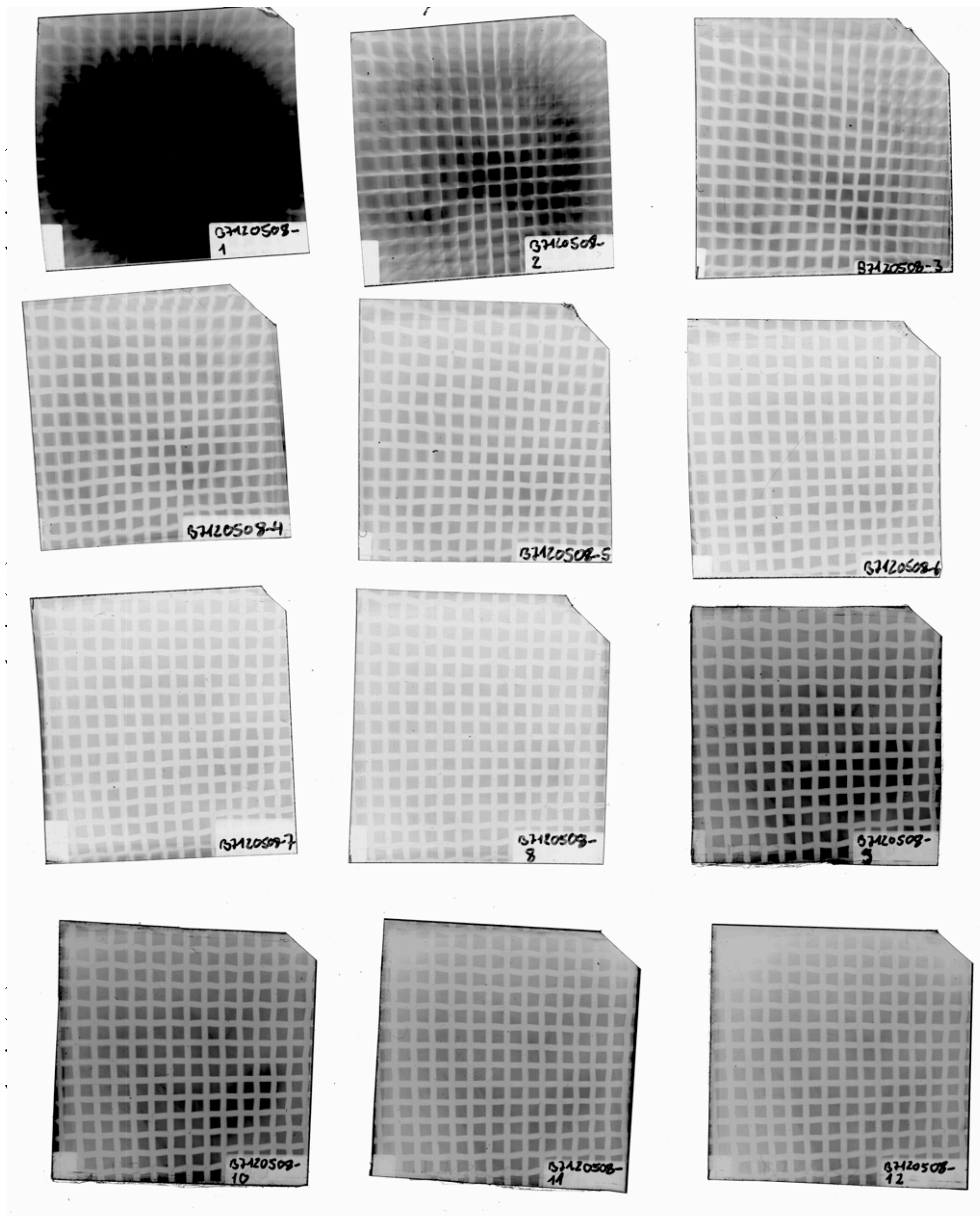


see T.E. Cowan et al, NIMA 544, p. 277 (2005)

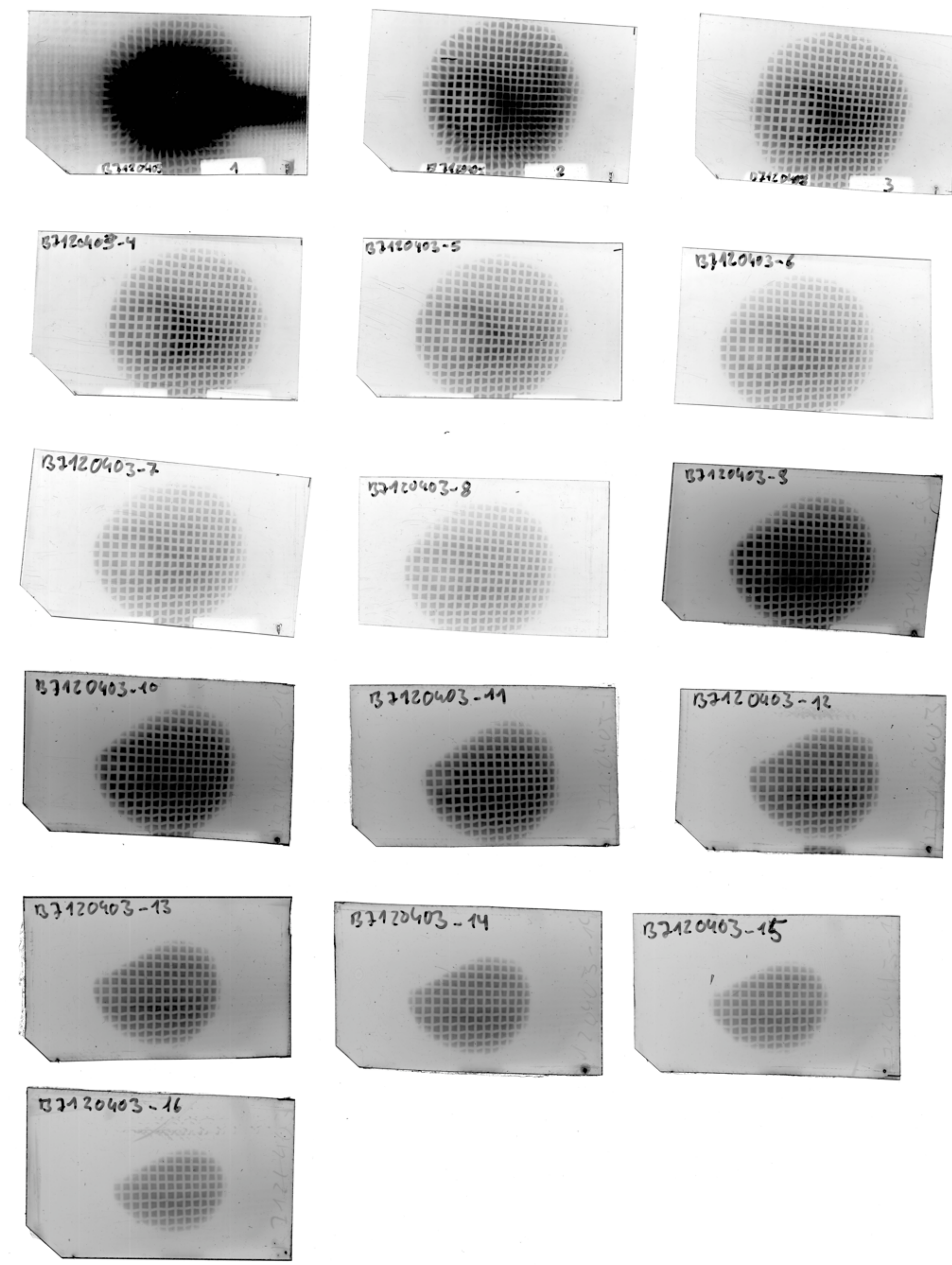


distance: 20 mm

Electron stripping is possible

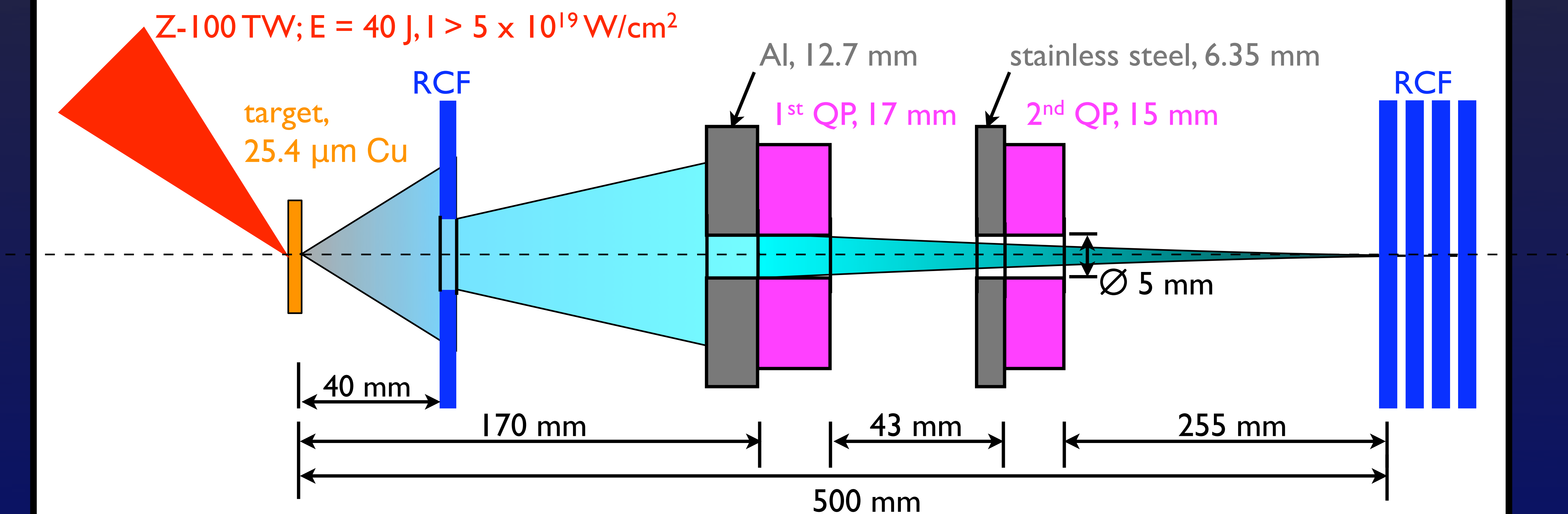


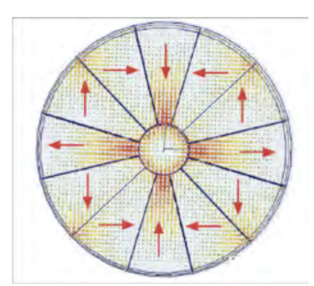
distance: 100 mm

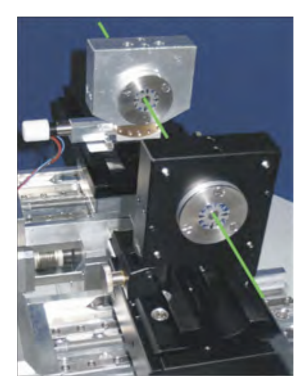


distance: 20 mm

Quadrupole focusing

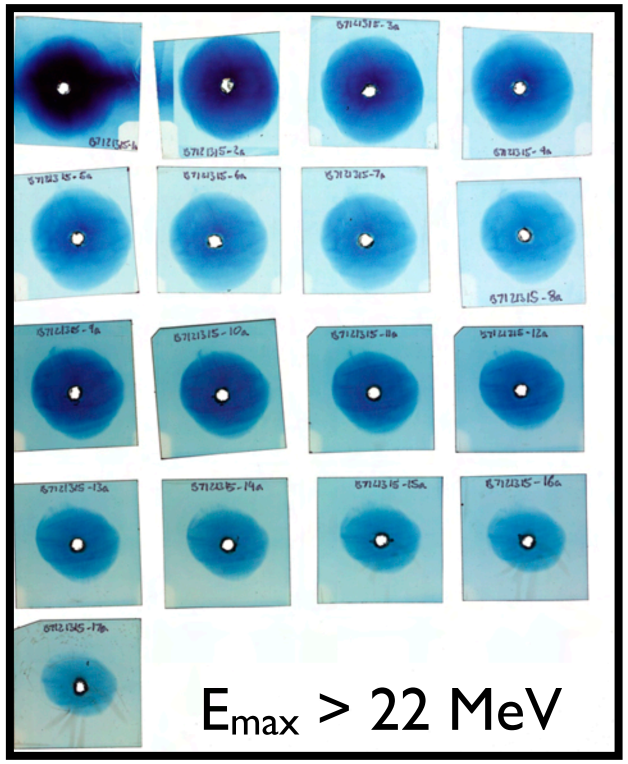


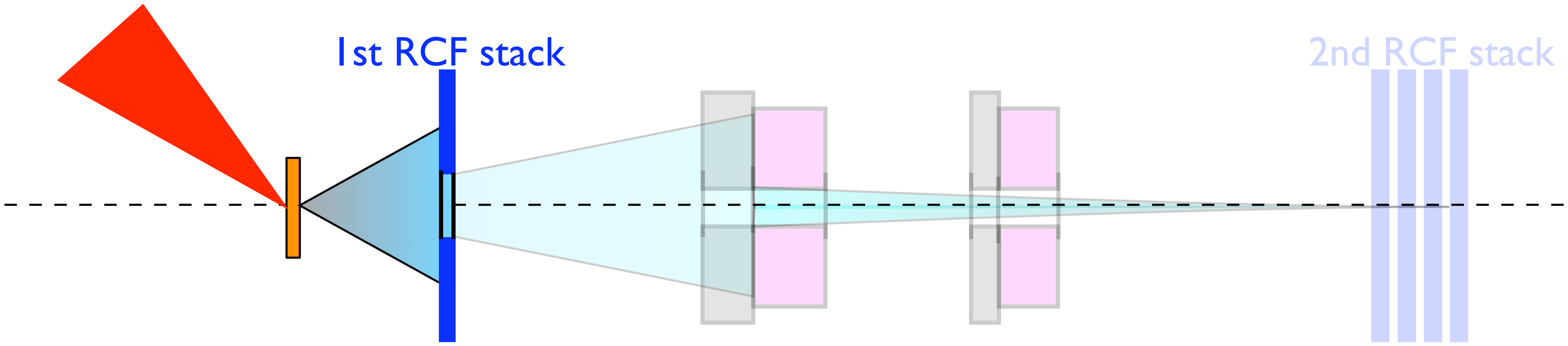




Miniaturized magnetic lens

Quadrupole focusing





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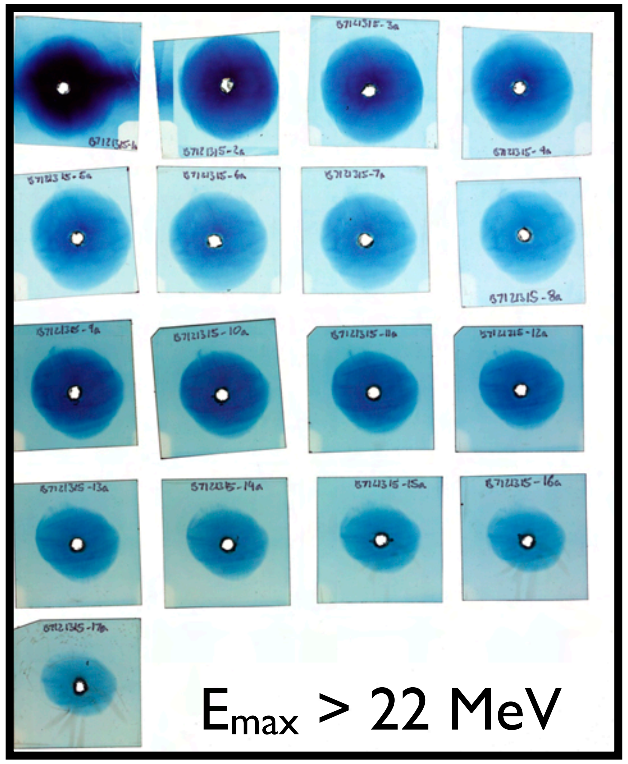

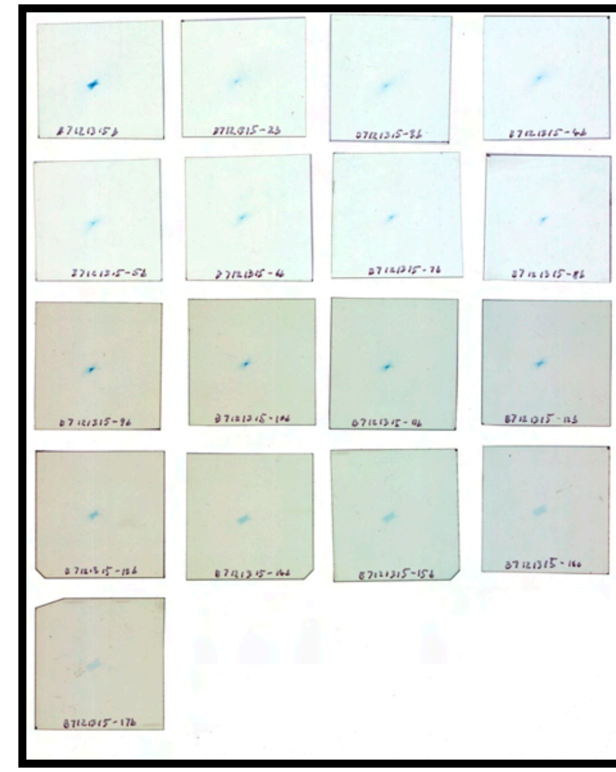

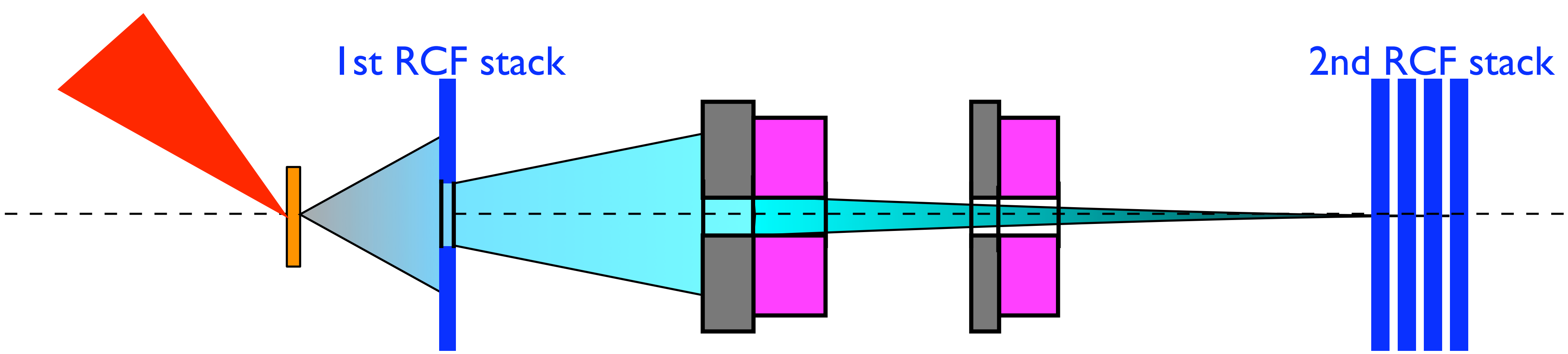

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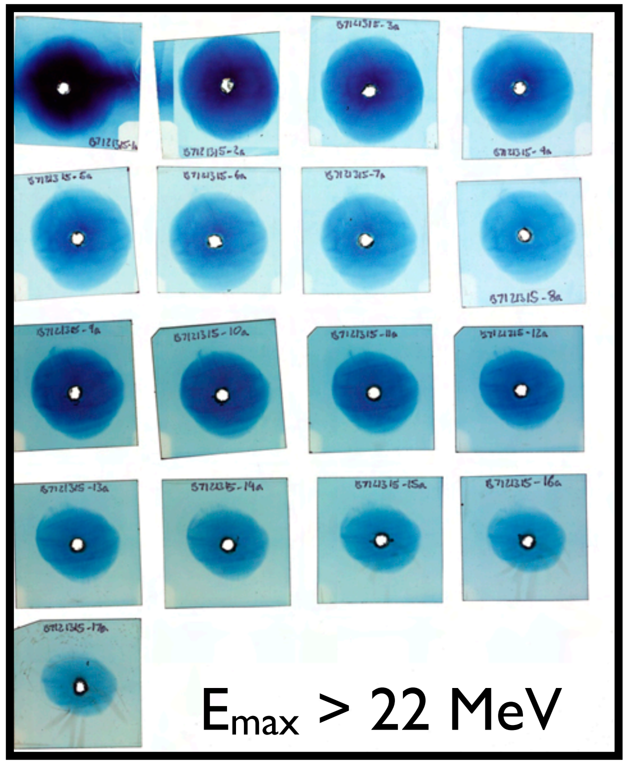
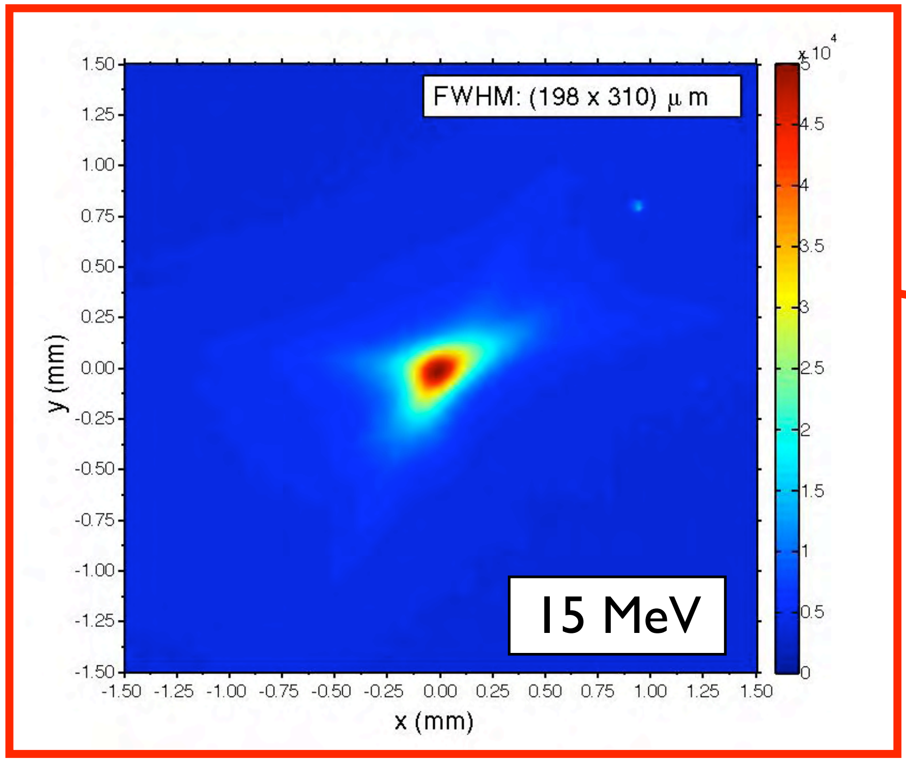
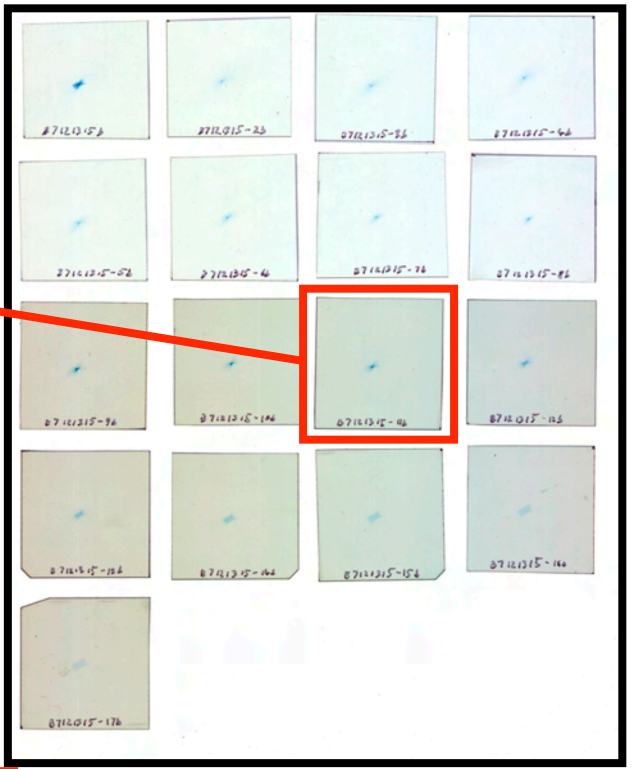
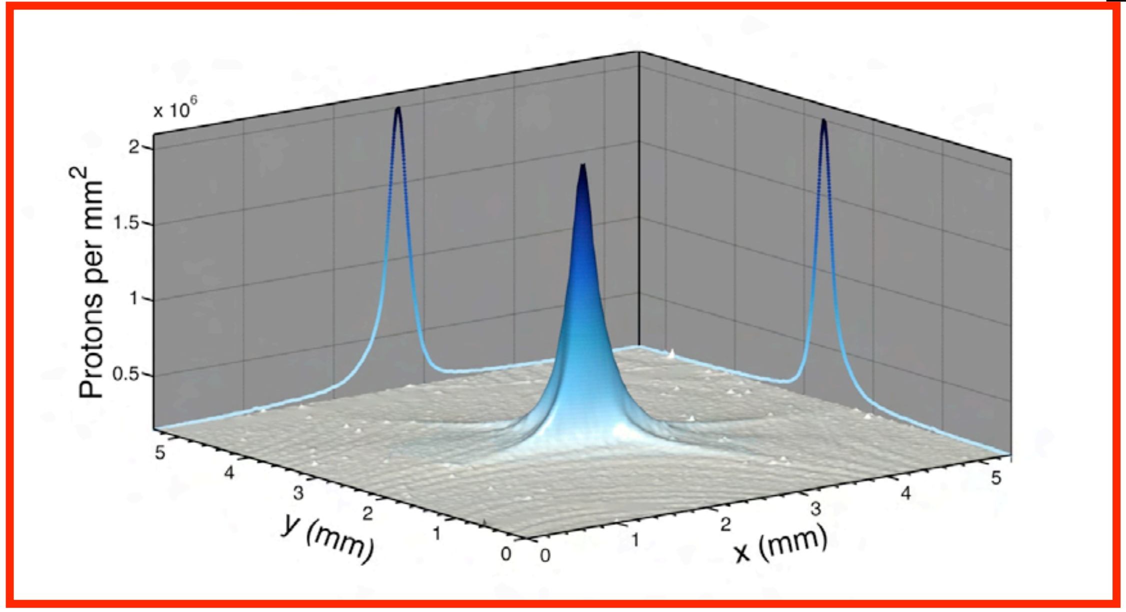
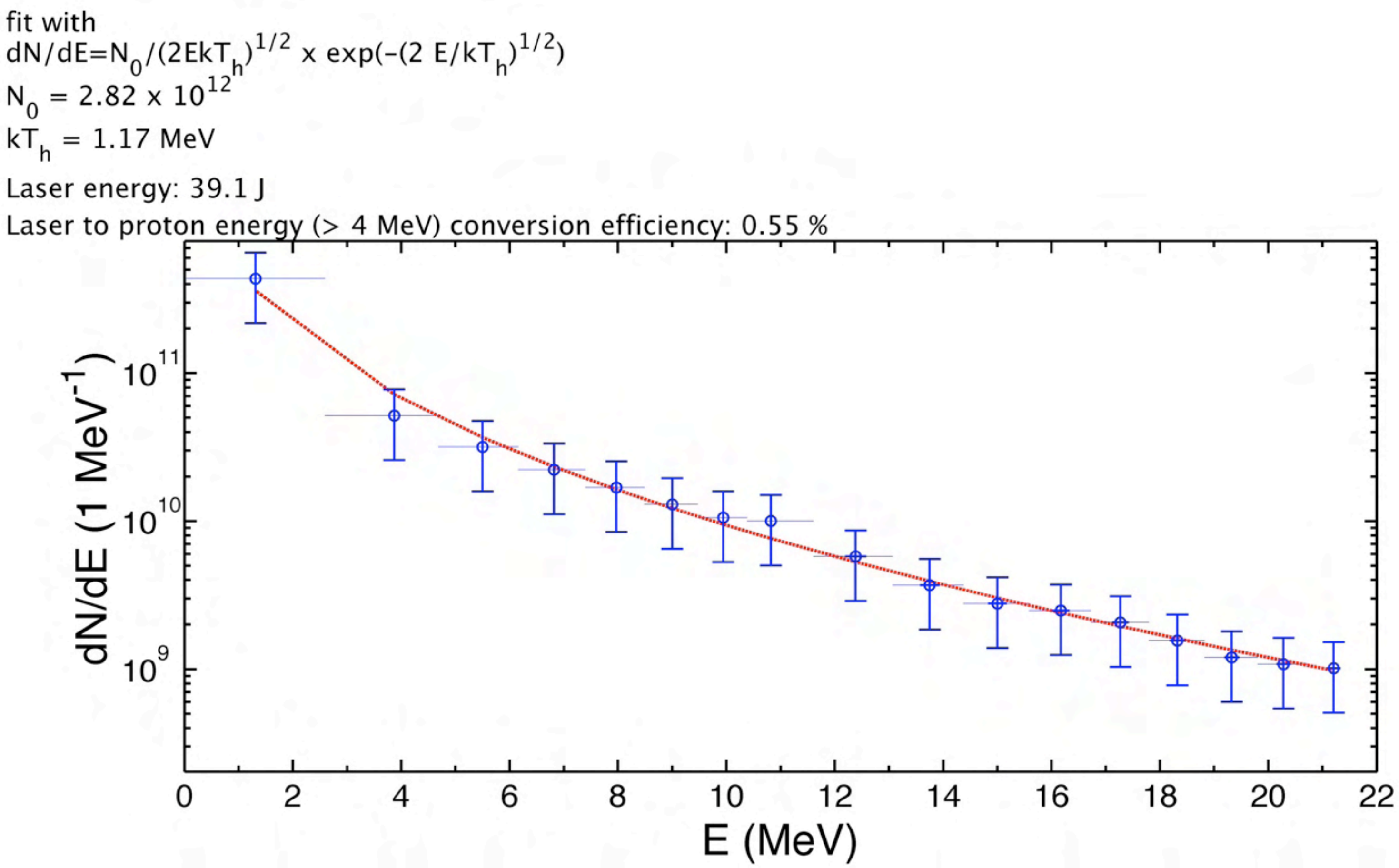


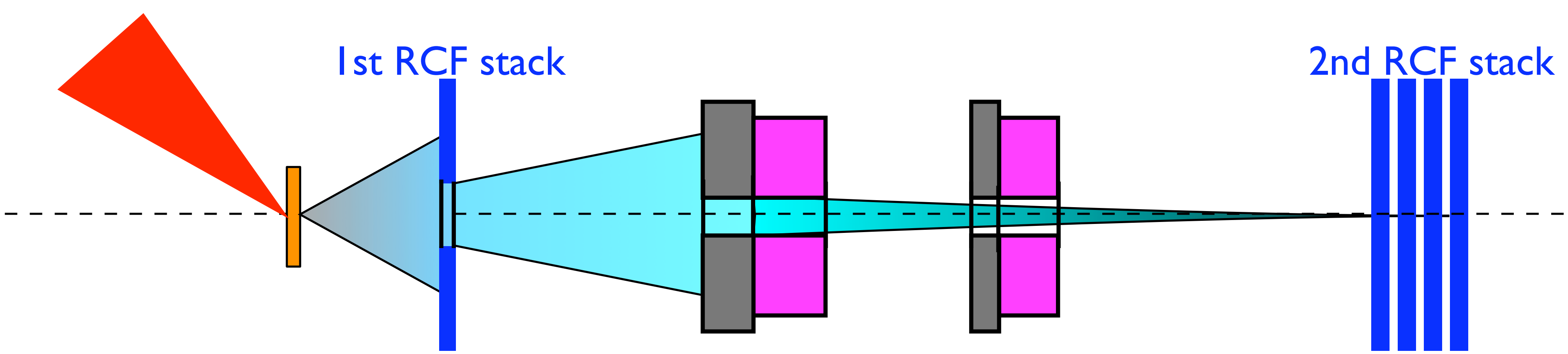




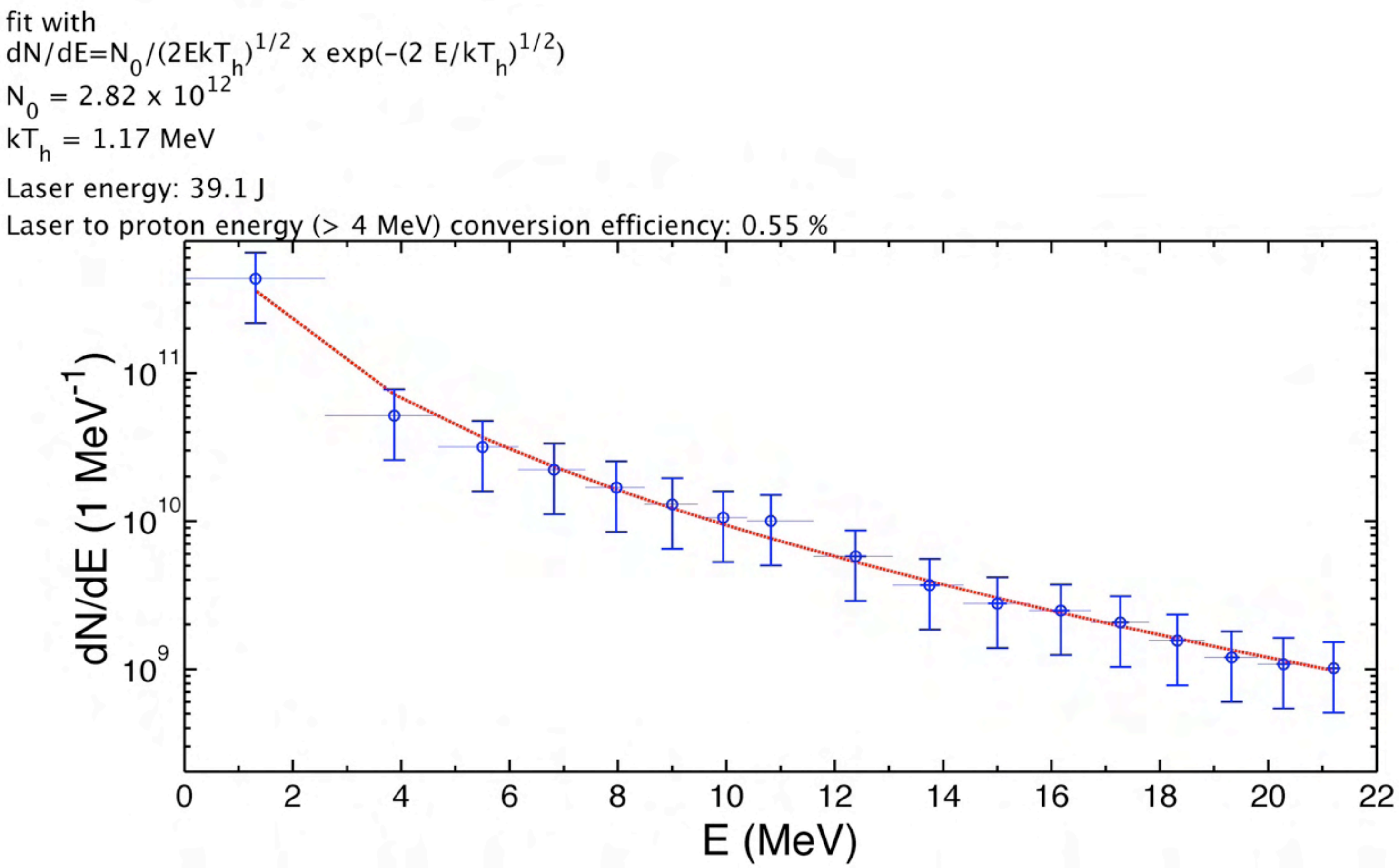


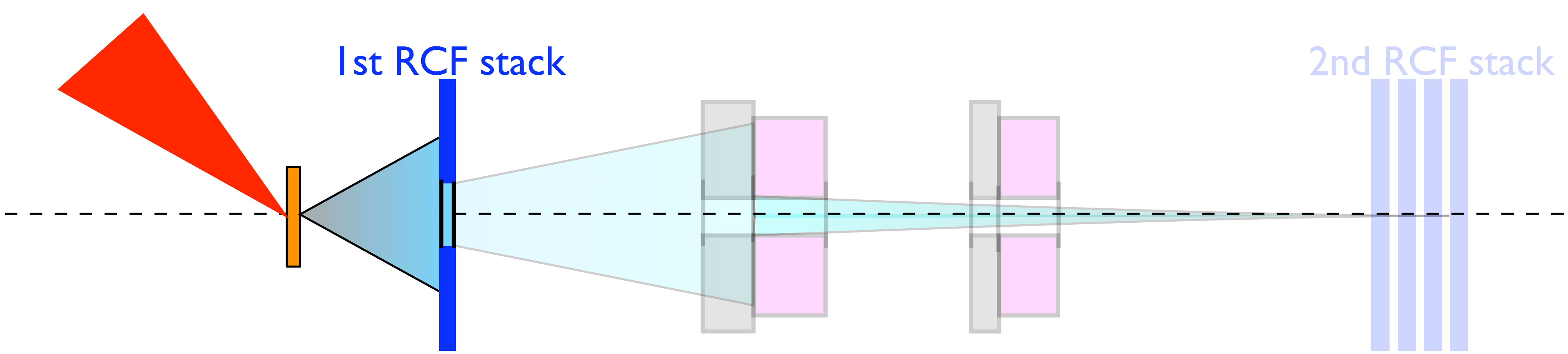
Proton flux enhancement





Proton flux enhancement





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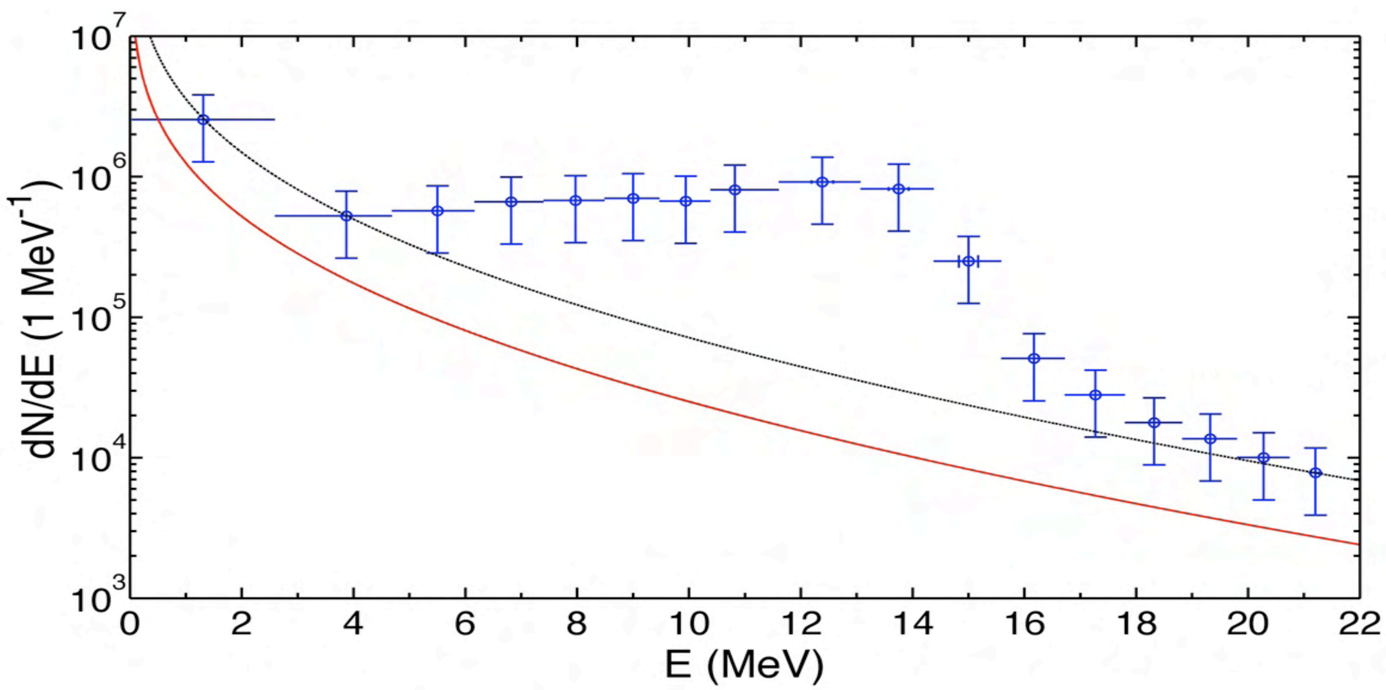
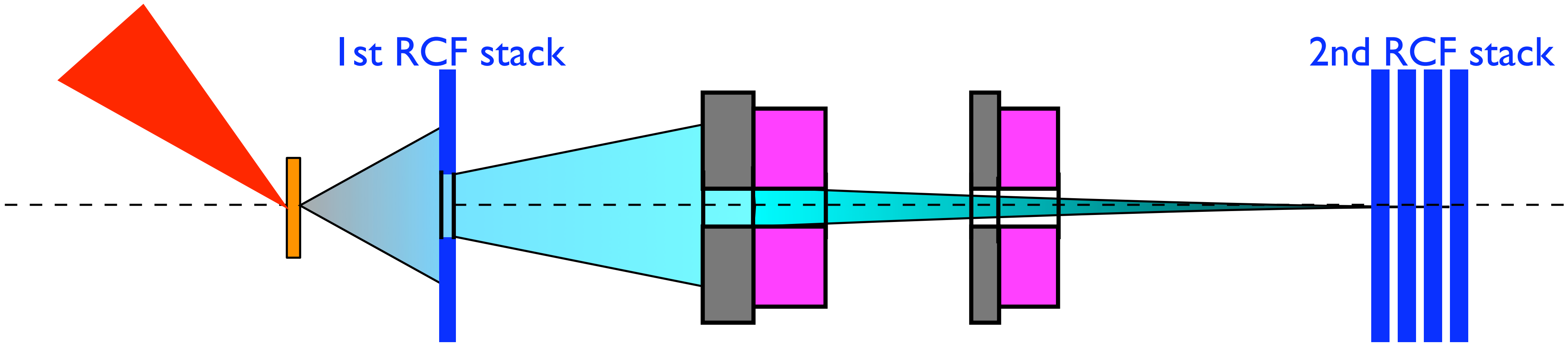
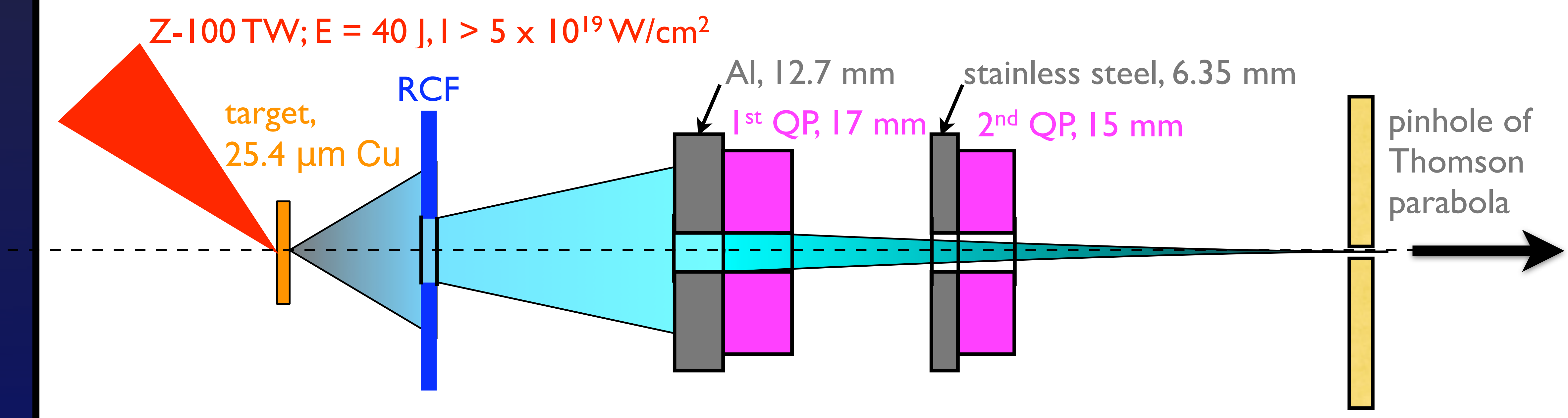
Proton flux enhancement



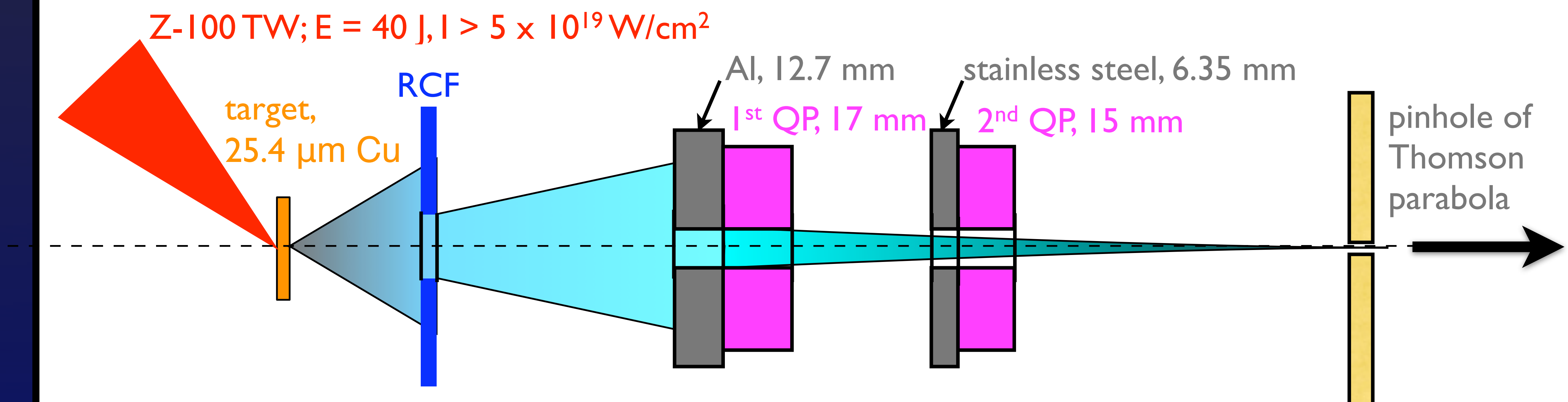
- Proton flux is increased by almost two orders of magnitude for 14 MeV protons



Energy selection (next step)



Energy selection (next step)



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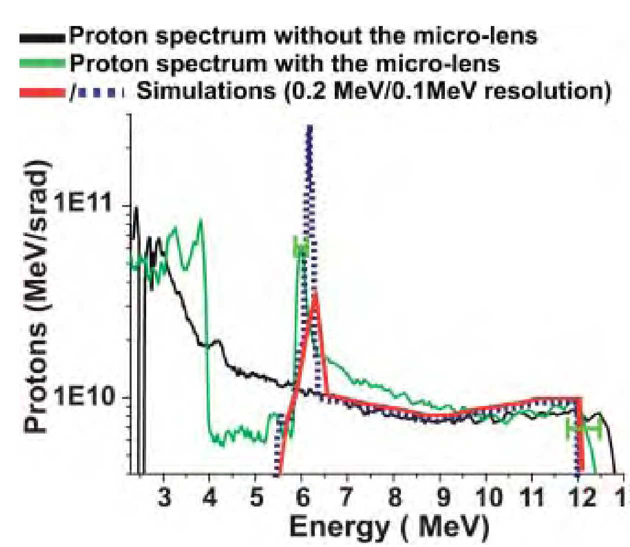
Toma Toncian, *et al.*
Science **312**, 410 (2006);
DOI: 10.1126/science.1124412



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