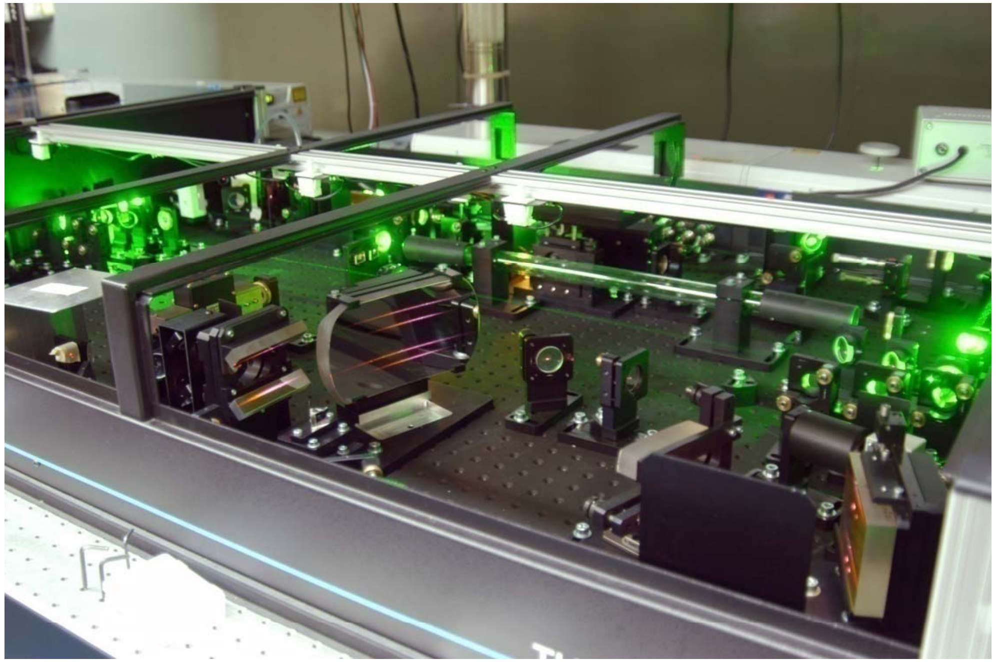
Dense, Hot Plasmas
Created by
Intense, Ultrashort Lasers

20 TW, 30 fs, 10 Hz



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ICUIL 2008, Shanghai-Tongli, Oct 2008

Coworkers

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K.A.Tanaka, H. Habara and others (ILE, Osaka)

W. M. Wang, Z.M. Sheng (Shanghai)

'Mourou -Zhang' Criterion

Some highlights of our research at TIFR (2000>>)

1. **Demonstration of Giant, Ultrashort Magnetic Pulses and proposal for a novel method for monitoring hot electron transport through dense, hot matter. (PRL 2002, PRE 2006, POP 2008)**

2. **Clarification of the role of surface structures in light absorption and devising nanostructures for enhancing absorption and hot electron generation. (PRL 2003, OL2004, AP-B 2005, PRL 2008)**

3. **First clear demonstration of electron wave breaking dynamics in plasmas (PRL 2005)**

4. **Design of new targets for laser fusion (PRL 2006 -1)**

5. **Elucidation of the role of surface magnetic fields in electron transport (PRL 2006-2)**

Ultrashort Laser Generated Hot, Dense Matter

Key physics issues

- **Enhancement of 'Hot' electrons (KeV to MeV)**
- **Transport of these electrons through dense, hot medium**

non-collisional
field (E,B) dominated
highly unstable

Hot electrons are important for laser fusion, MeV ion generation and MeV X-ray generation

Key topic 1:

Hot Electron Generation and its Control

Hot Electron Creation - 1

Plasmas reflect a large fraction of light we send in (40-50%)

This is a serious problem…

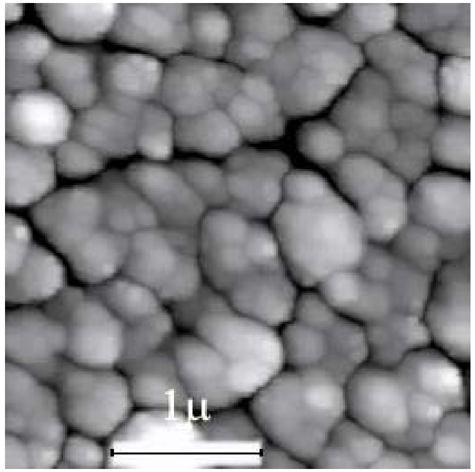
because we need

More coupling → More excitation → More x-ray emission

How do we couple more light in?

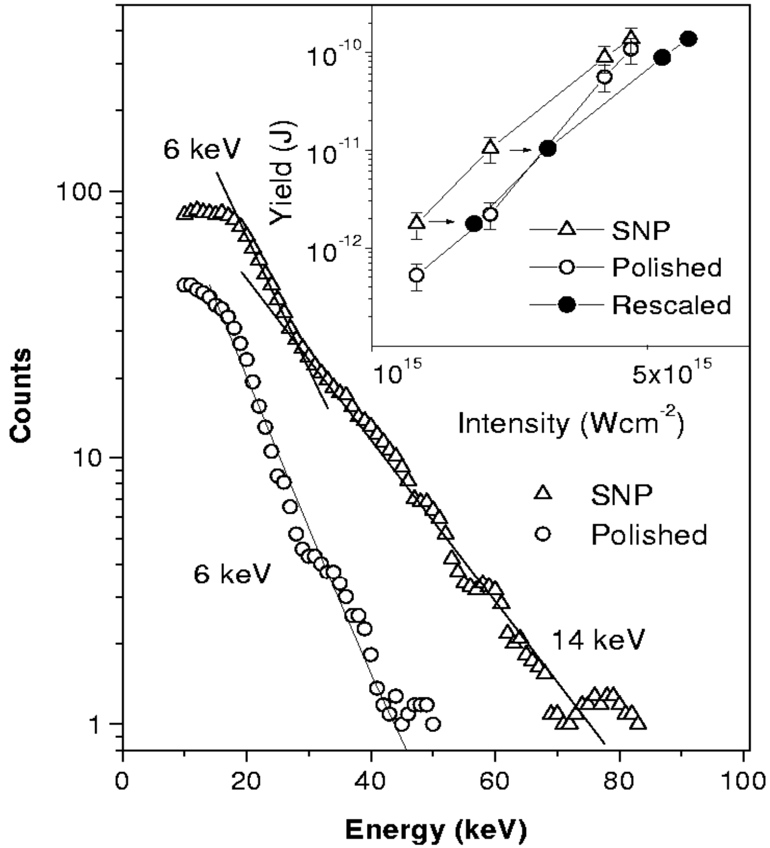
Ans: Bring in more mechanisms……..

Hot Electron Creation - 2



Metal nanoparticle coated Targets are more brilliant X-ray emitters

Order of magnitude enhancement in x-ray yield provided by "surface roughness"



Small is bountiful !

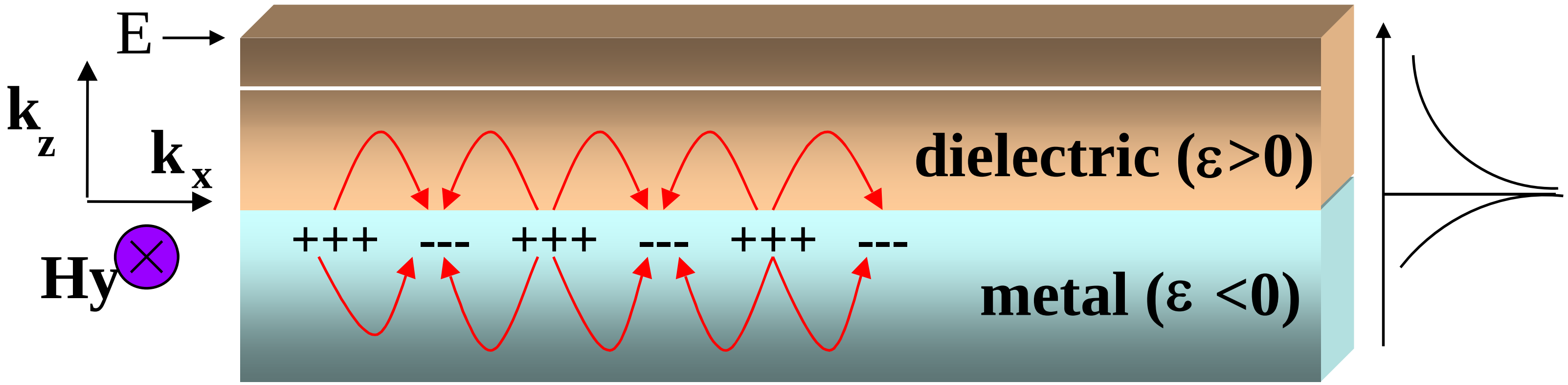
P. P. Rajeev et al., Phys.Rev.Lett. (2003); Opt.Lett. (2004)

Hot Electron Creation - 3

Rough surfaces support "Surface Plasmons"

Def: Electromagnetic surface waves ('p') which exist at the interface between 2 media whose ε have opposite signs.

$E_z \sim e^{-|k_z|z}$



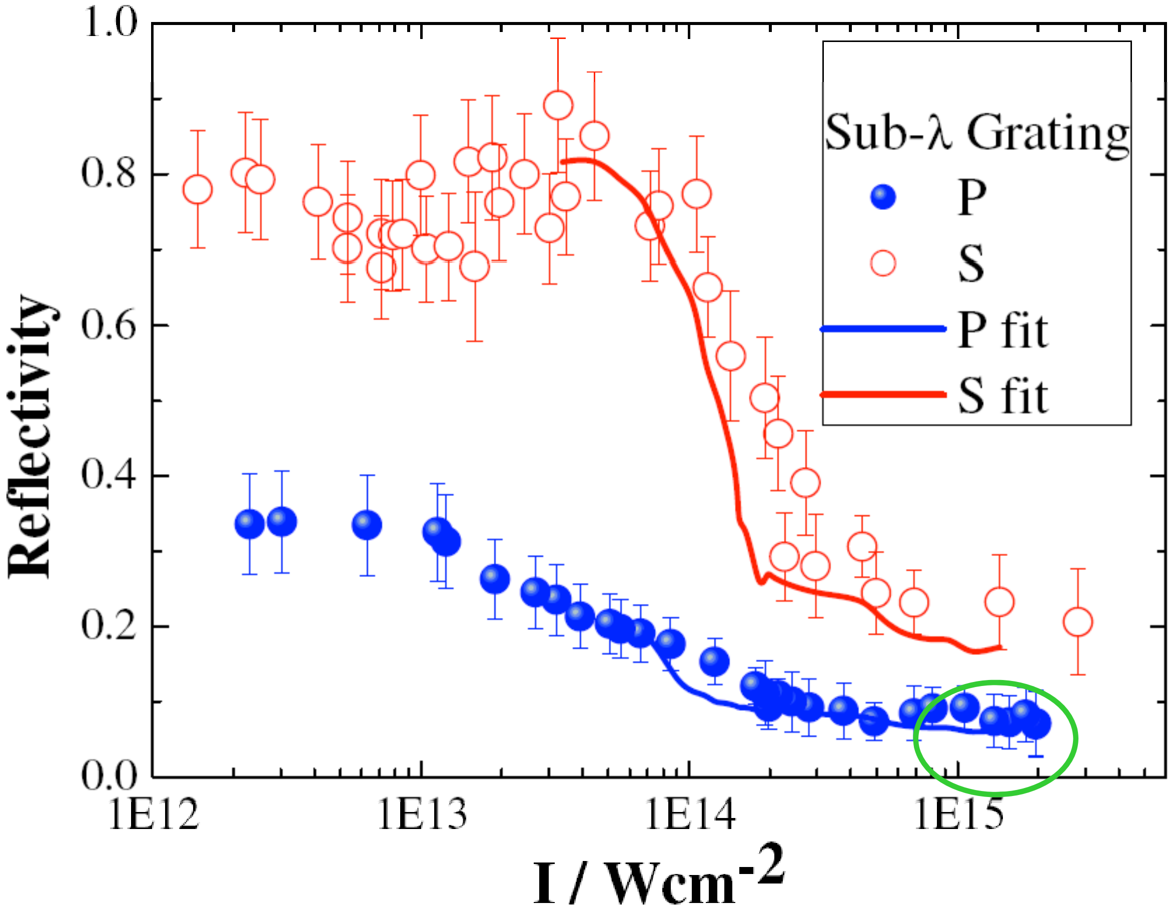
Surface plasma oscillations:

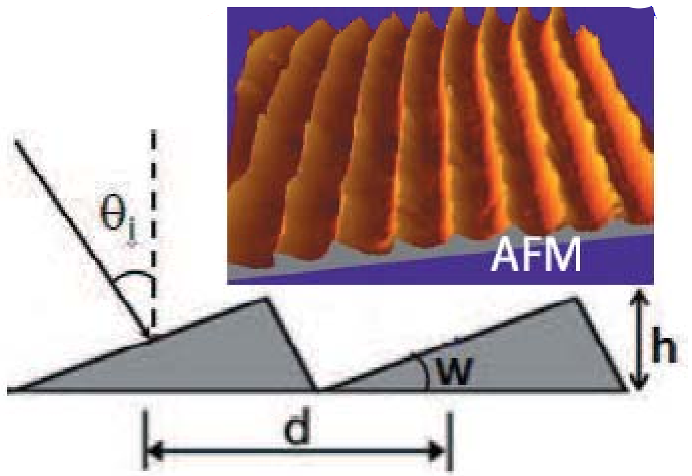
fluctuations of the charge on a metal boundary

Hot Electron Creation - 4

Good
for kHz
X-ray
Sources!

Intense light gets into the groove!





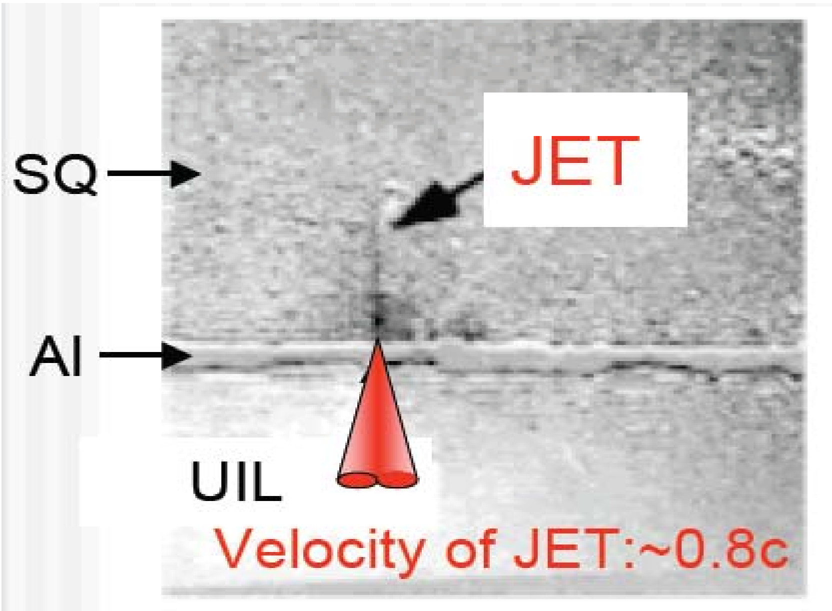
S. Kahaly et al.,
Phys.Rev.Lett.,
03 Oct 2008

Near 100 % absorption of intense light by GRATING plasma!
(Surface plasmons at work again)

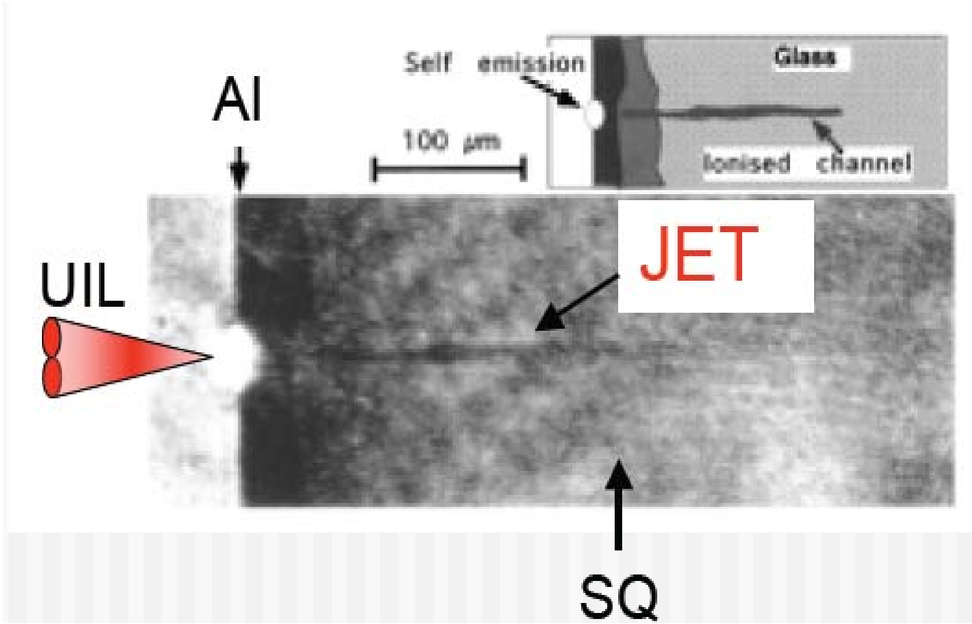
Key topic 2:

Hot Electron Transport

Hot Electron Transport - 1



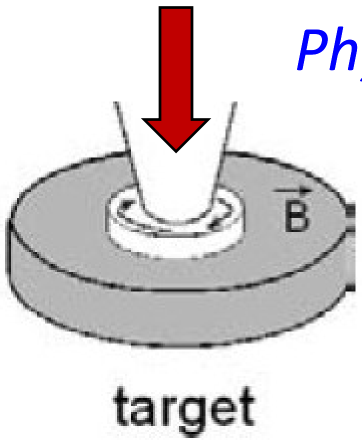
350 fs, 2 × 10^{19} W/cm^{-2}



UIL spec : 1ps, 2 × 10^{19} W/cm^{-2}

L. Gremillet et al.,
Phys. Rev. Lett. **83**, 5015 (1999)

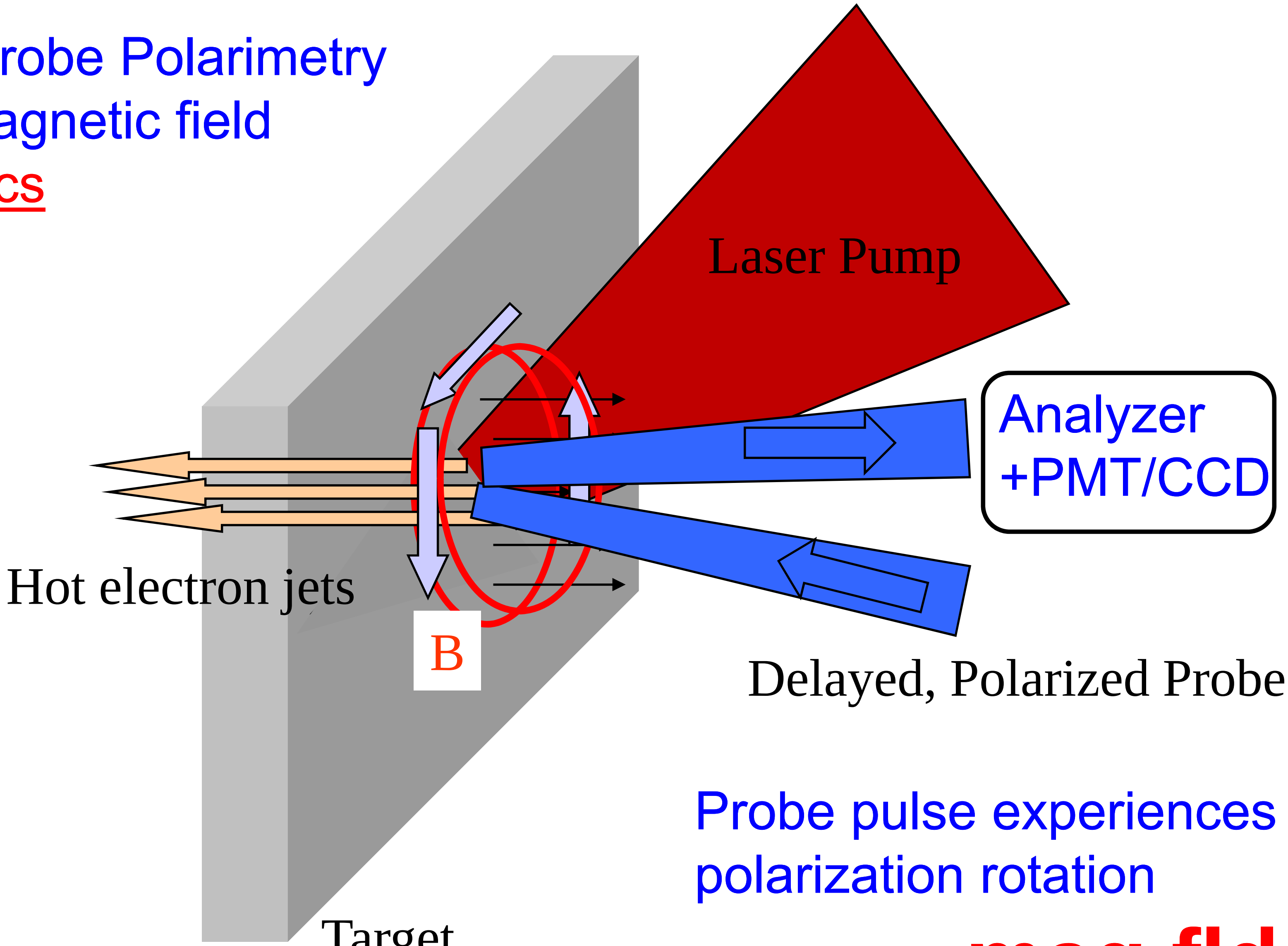
M.Borghesi et al.,
Phys. Rev. Lett. **83**, 4309 (1999)



Mega ampere currents
Megagauss fields

Hot Electron Transport - 2

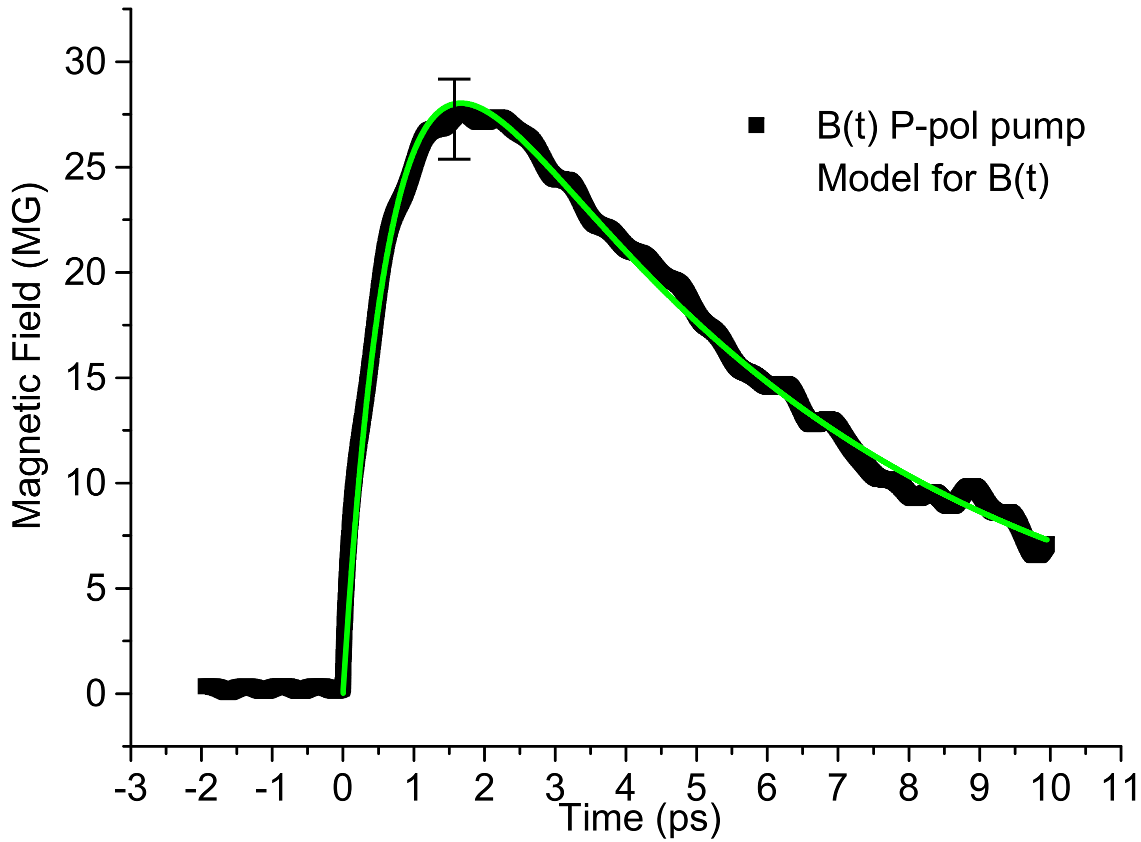
Pump-Probe Polarimetry gives Magnetic field <u>dynamics</u>



Probe pulse experiences polarization rotation induced by **mag fld**

Hot Electron Transport - 3

Giant Magnetic Pulse !



Sandhu et al, Phys.Rev.Lett. 89 (2002) 225002

Physics News Update Nov 2002

Phys Rev E (2006)

Phys Plasmas (2008)

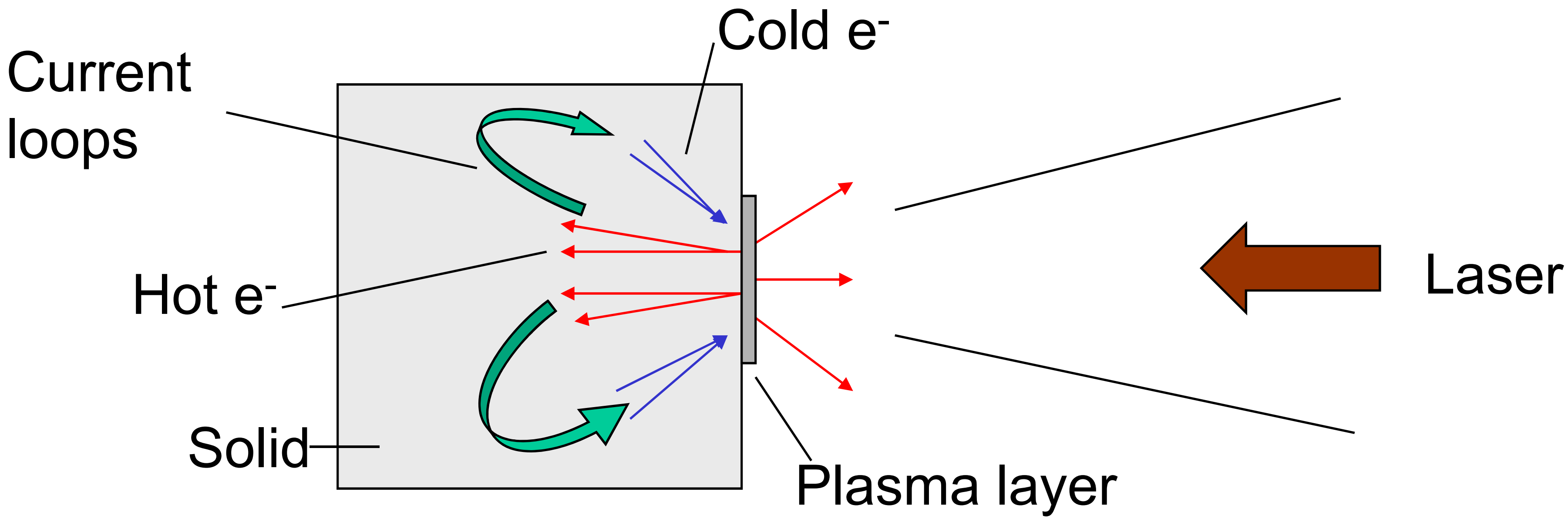
Magnetic field pulse profile for p- polarized pump at 10^{16} W cm^{-2}

Generation and damping of B

$$\frac{dB}{dt} = \frac{c}{\sigma}\left(\vec{\nabla} \times \vec{J}_{hot}\right) + \frac{c^2}{4\pi\sigma}\nabla^2\vec{B}$$

Source — Diffusion

- Hot electrons J_{hot} stream into bulk
- Return plasma currents compensate
- The electrical resistivity σ^{-1} limits buildup and determines decay of magnetic field.



Hot Electron Transport - 5

Our experiments give

$$\sigma \approx 2.5 \times 10^{14}\,\mathrm{sec}^{-1}$$

This resistivity (σ^{-1}) of Al is an order of magnitude higher than that reported Milchberg [PRL, 61, 2364 (1988)]

An indication of Magnetic field induced turbulent (anomalous) resistivity ?

The advantages of magnetic pulse method

1. Direct probing of 'actual' transport in 'actual' medium of interest

2. Crucial information – hot plasma conductivity- obtained easily

2. Looks at the total problem – forward as well as return currents

3. Dynamics readily measured

A good way to measure transport in hot, dense matter !

Spatio temporal evolution of magnetic fields

20 TW, 30 fs
800 nm, P-polarized pump
Peak intensity- 10^{19} W cm^{-2}

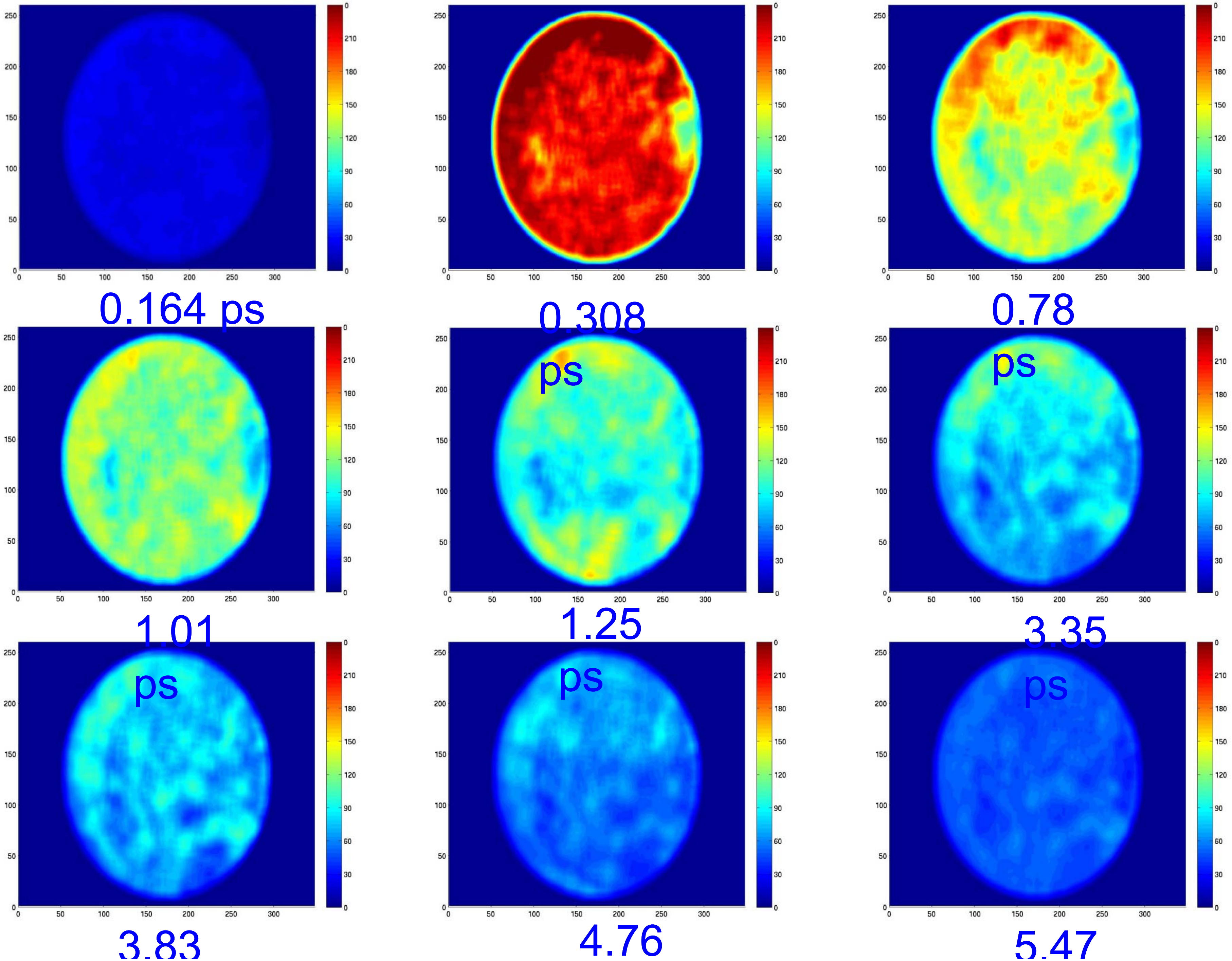
400 nm normal incidence probe

Target: metal coated glass

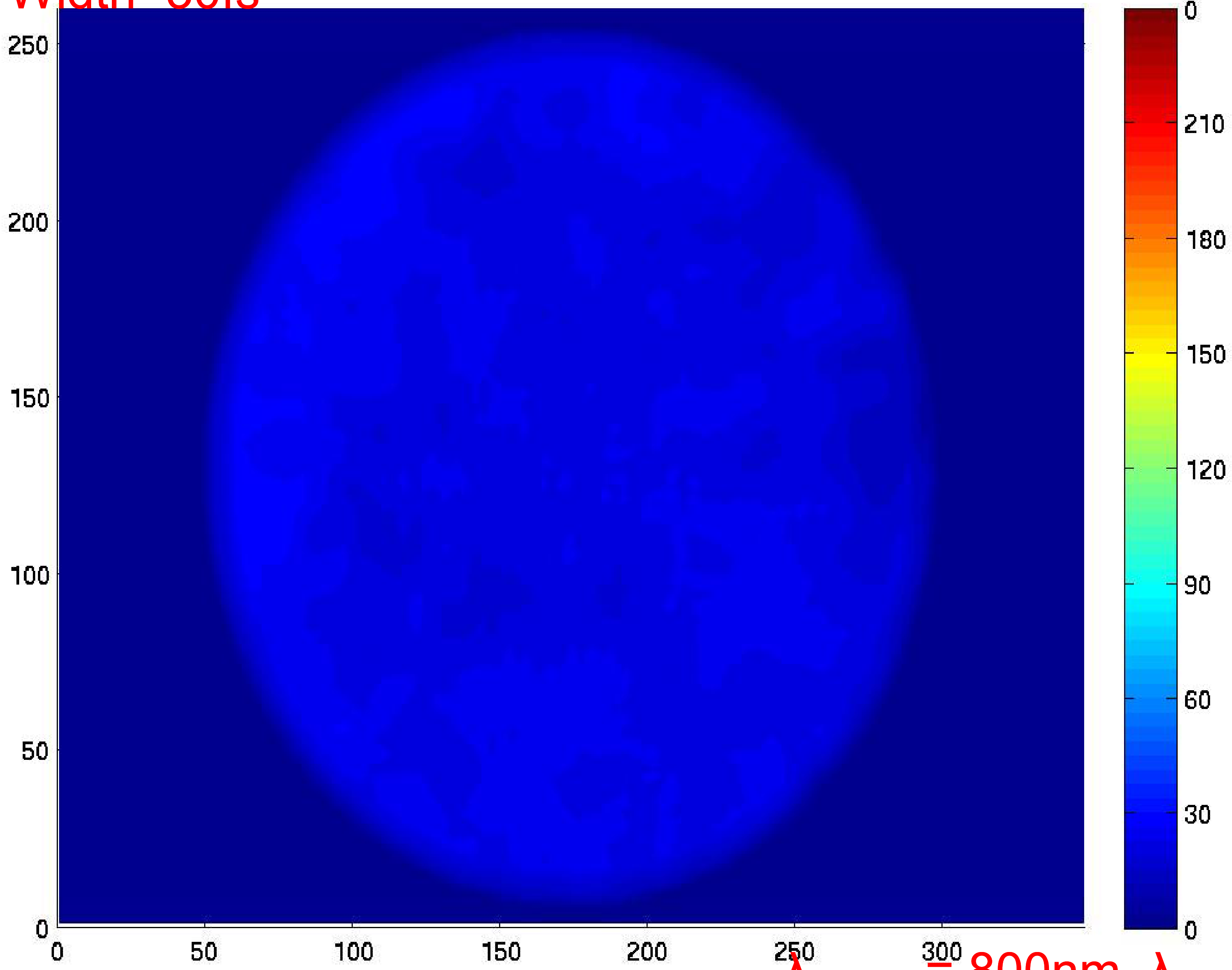
Relativistic electron currents

Fields up to 150 MG

two–dimensional images on CCD


0.164 ps
0.308 ps
0.78 ps
1.01 ps
1.25 ps
3.35 ps
3.83
4.76
5.47

Magnetic Field at Delay:0.164 ps
Pulse Width=30fs

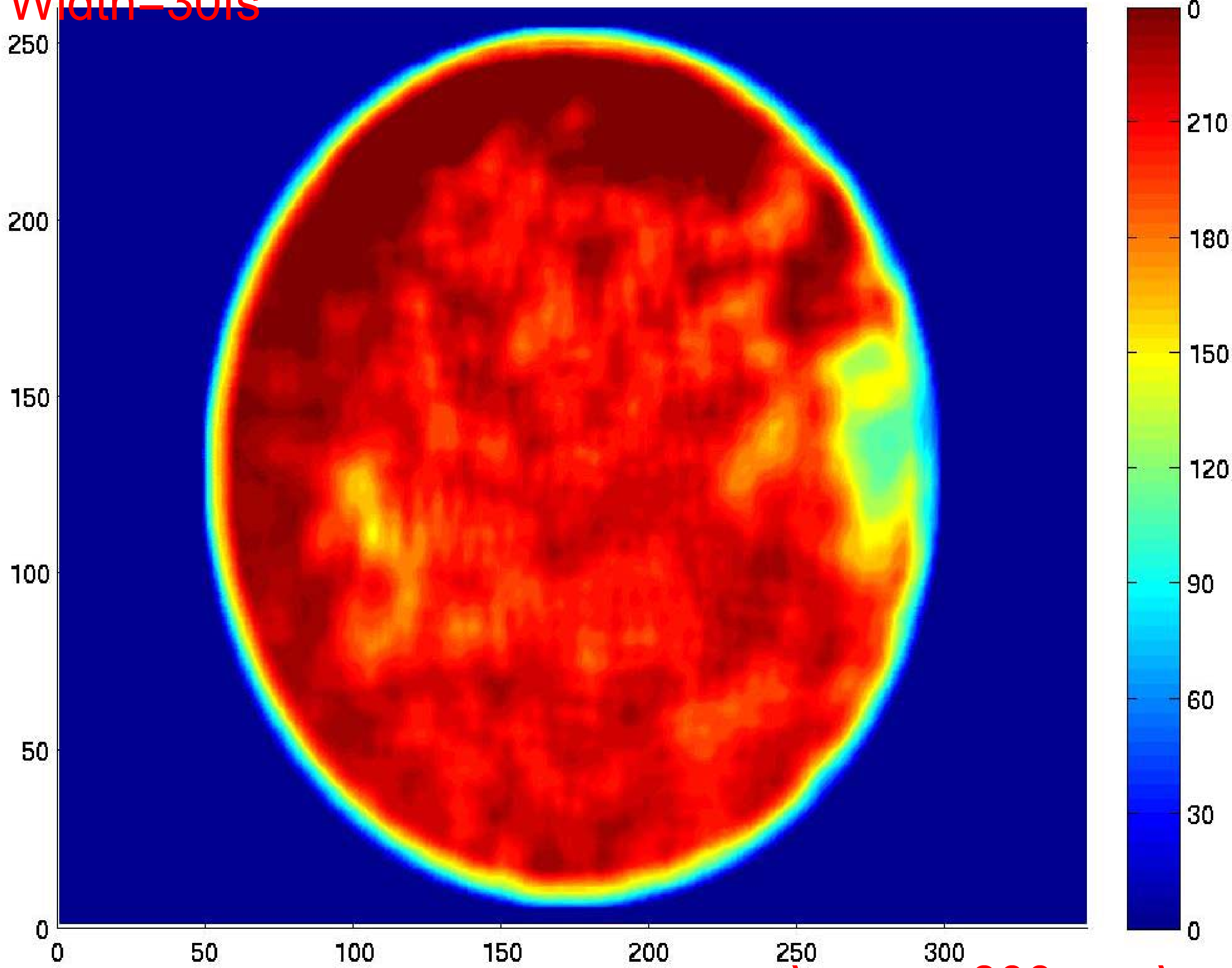


λ_{pump} = 800nm λ_{probe} =4

Target Al: Coated Glass

Pump Intensity on target =1.4

Magnetic Field at Delay:0.31ps
Pulse Width=30fs



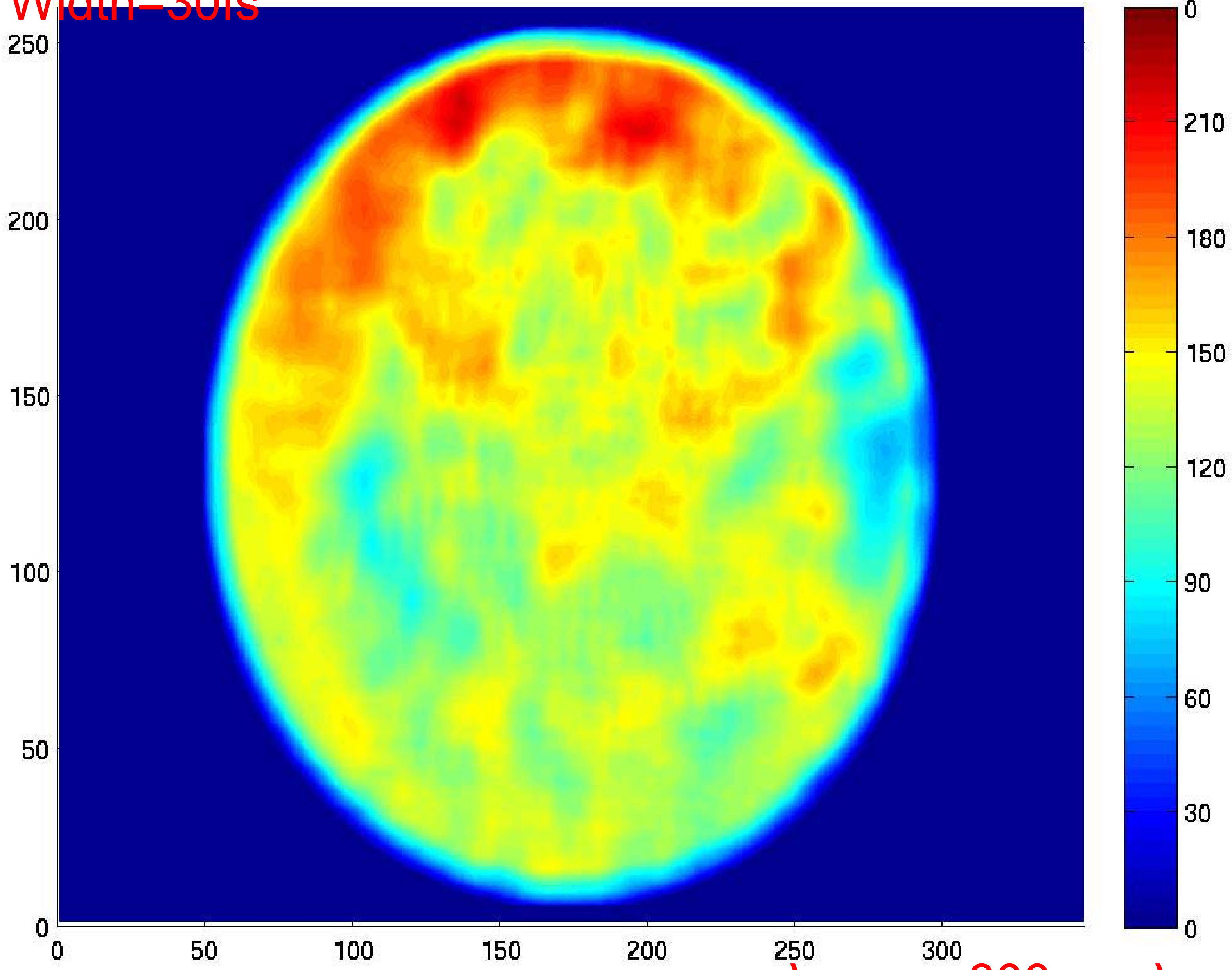
λ_{pump} = 800nm λ_{probe} =4(

Target Al: Coated Glass

Pump Intensity on target =1.4x

Magnetic Field at Delay:0.78 ps

Pulse Width=30fs

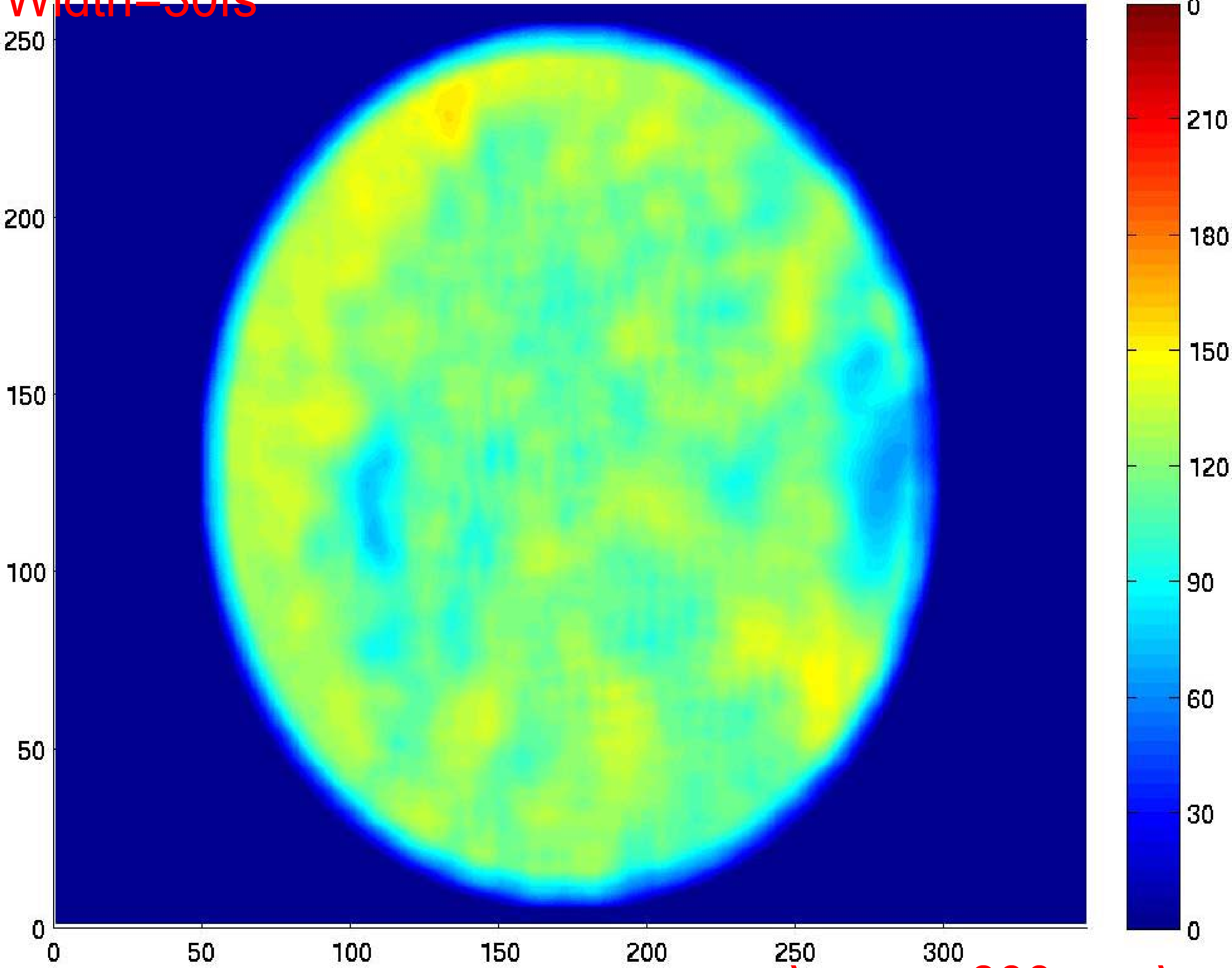


λ_{pump} = 800nm λ_{probe} =4

Target Al: Coated Glass

Pump Intensity on target =1.4

Magnetic Field at Delay: 1.01ps
Pulse Width=30fs

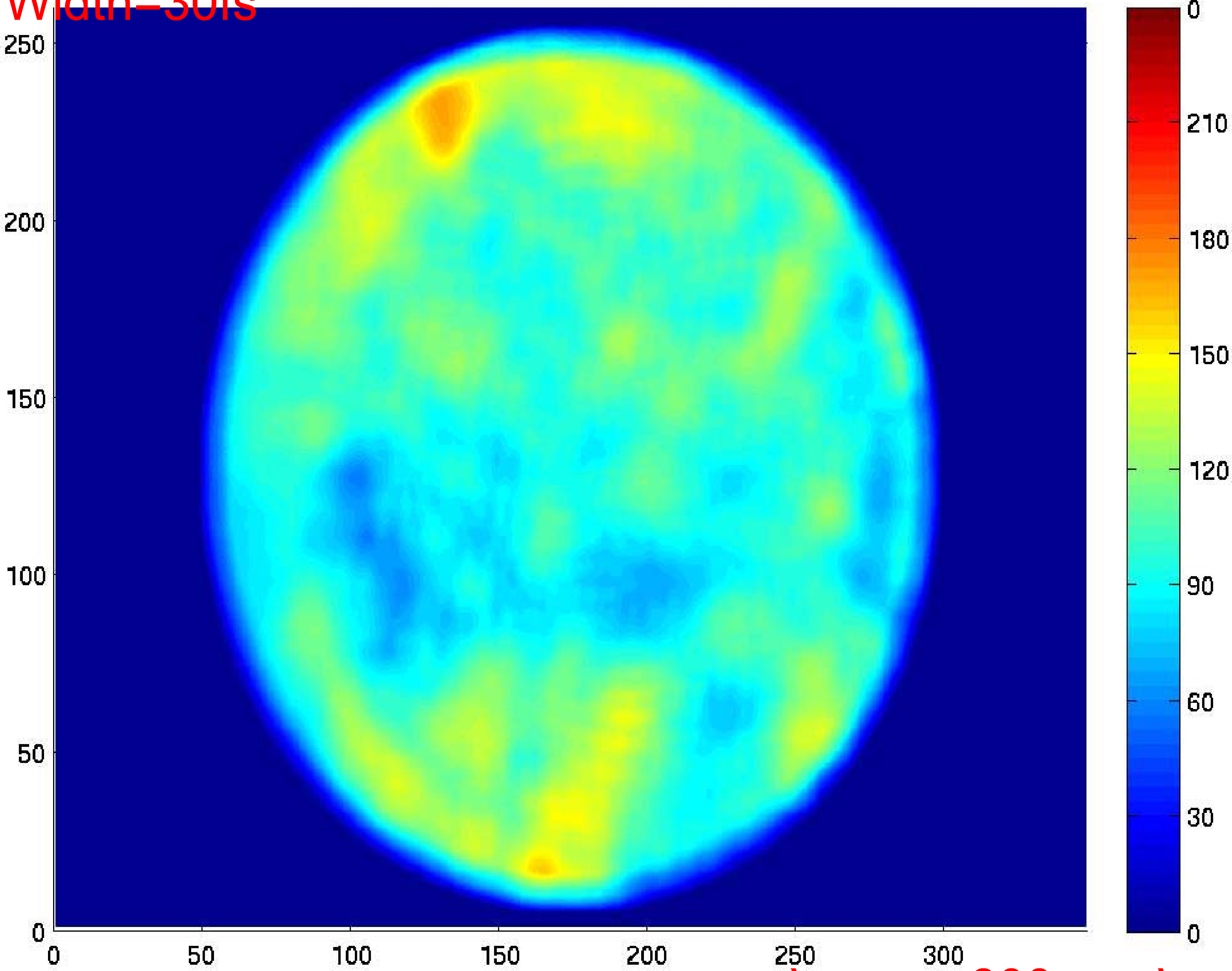


λ_{pump} = 800nm λ_{probe} =4(

Target Al: Coated Glass

Pump Intensity on target =1.4x

Magnetic Field at Delay:1.25 ps
Pulse Width=30fs

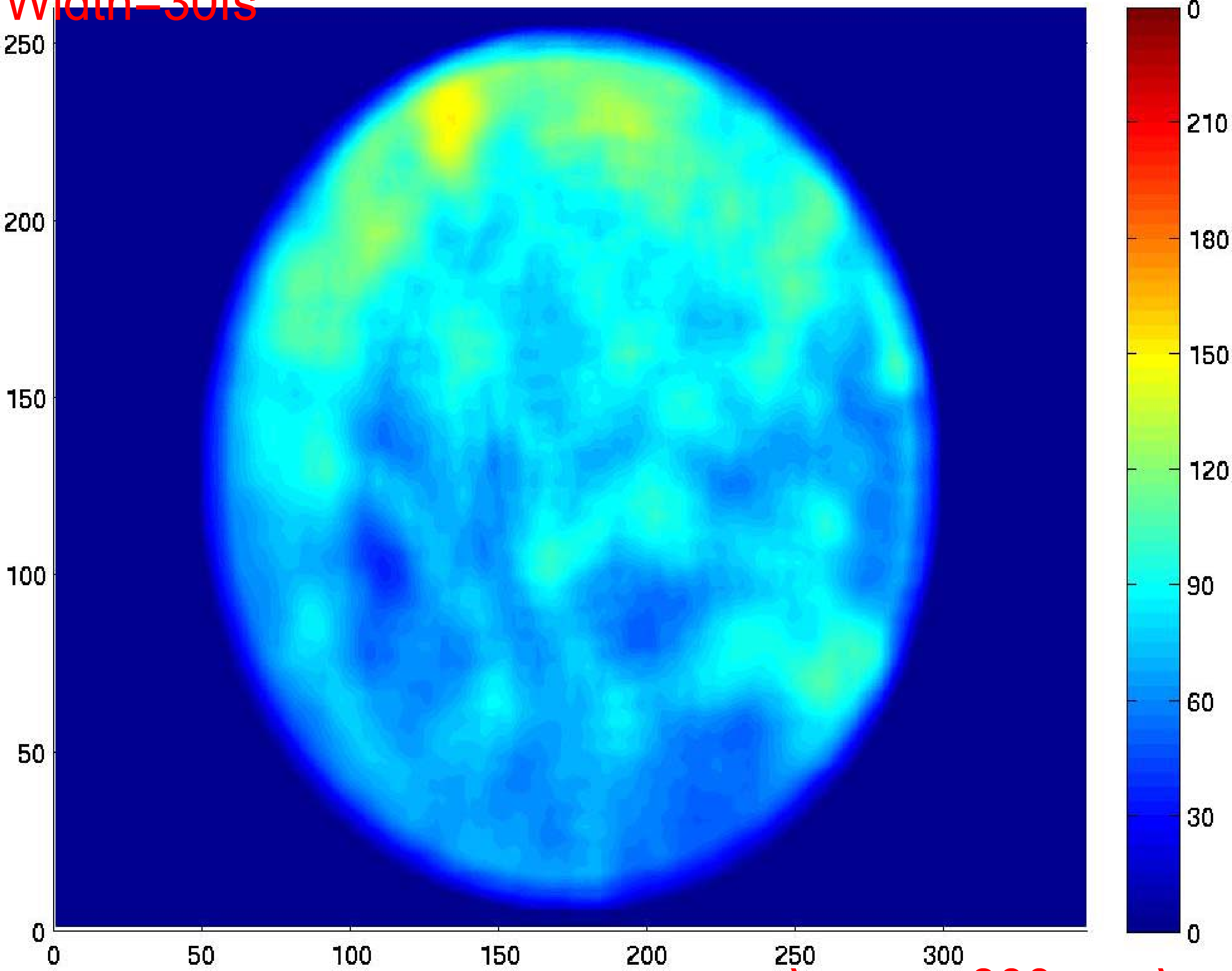


λ_{pump} = 800nm λ_{probe} =4(

Target Al: Coated Glass

Pump Intensity on target =1.4x

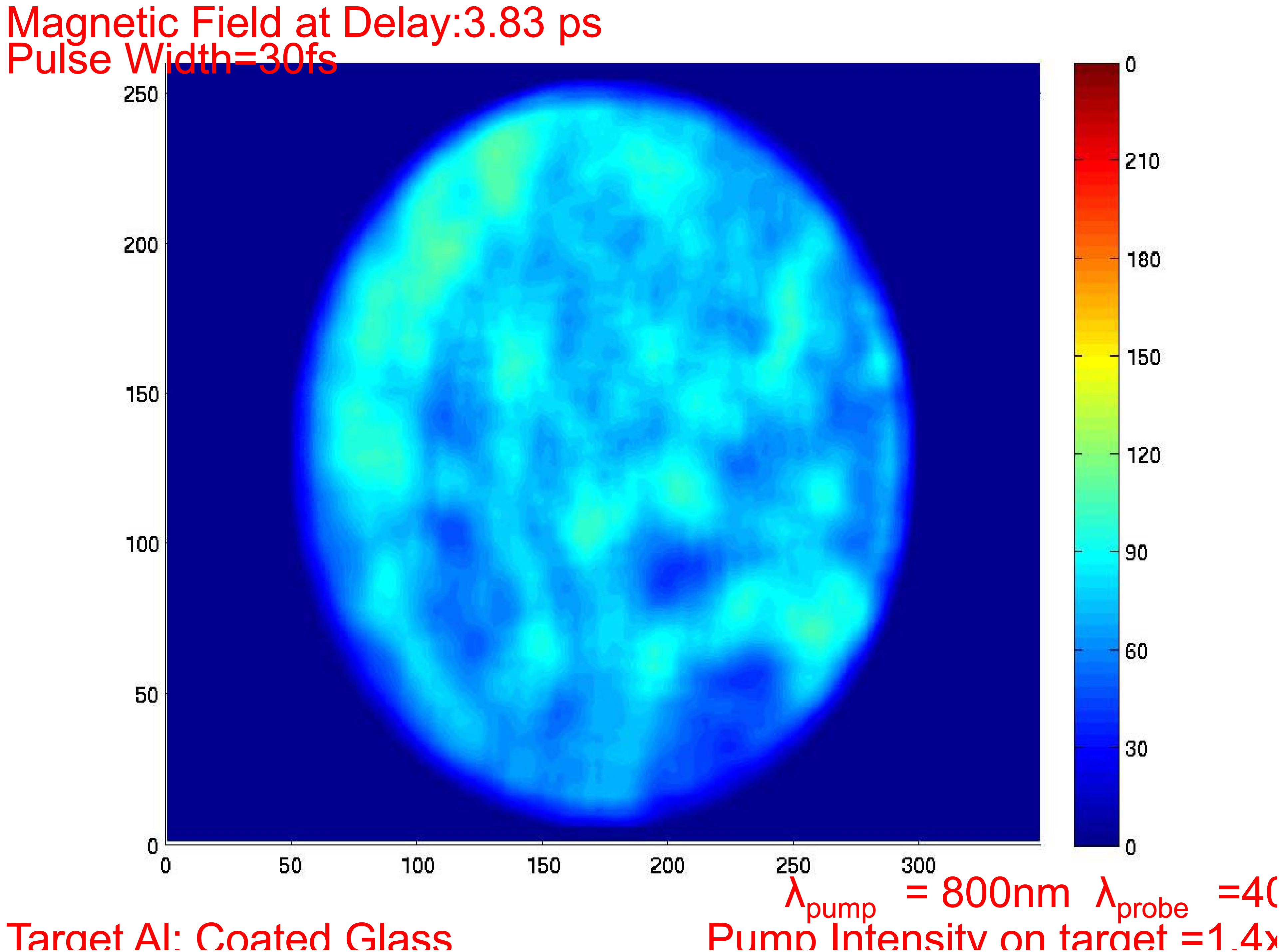
Magnetic Field at Delay:3.35 ps
Pulse Width=30fs



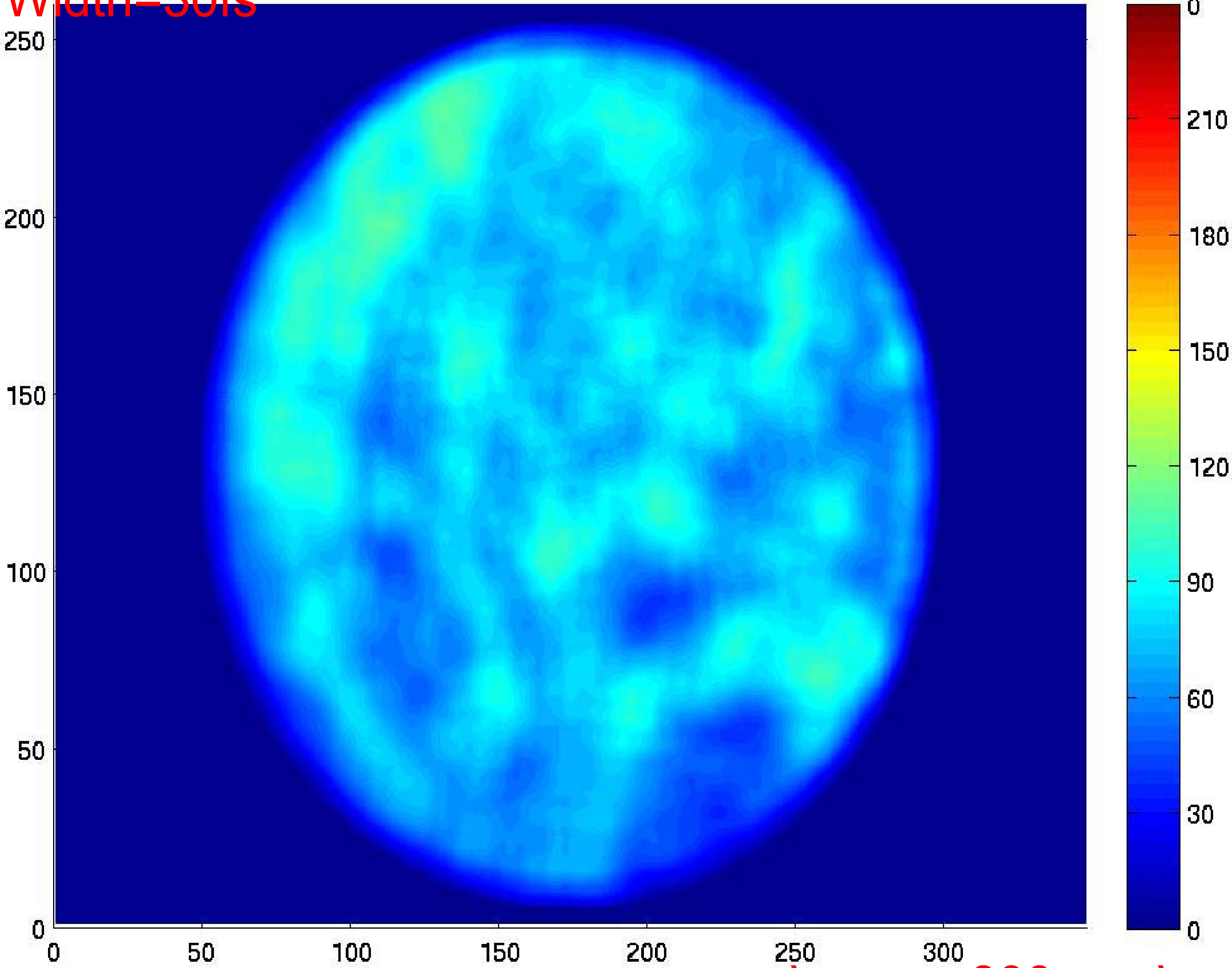
λ_{pump} = 800nm λ_{probe} =4(

Target Al: Coated Glass

Pump Intensity on target =1.4x


Magnetic Field at Delay:3.83 ps
Pulse Width=30fs
250
200
150
100
50
0
0
50
100
150
200
250
300
0
210
180
150
120
90
60
30
0
λpump = 800nm λprobe =4(
Target Al: Coated Glass
Pump Intensity on target =1.4x

Magnetic Field at Delay:4.76 ps
Pulse Width=30fs

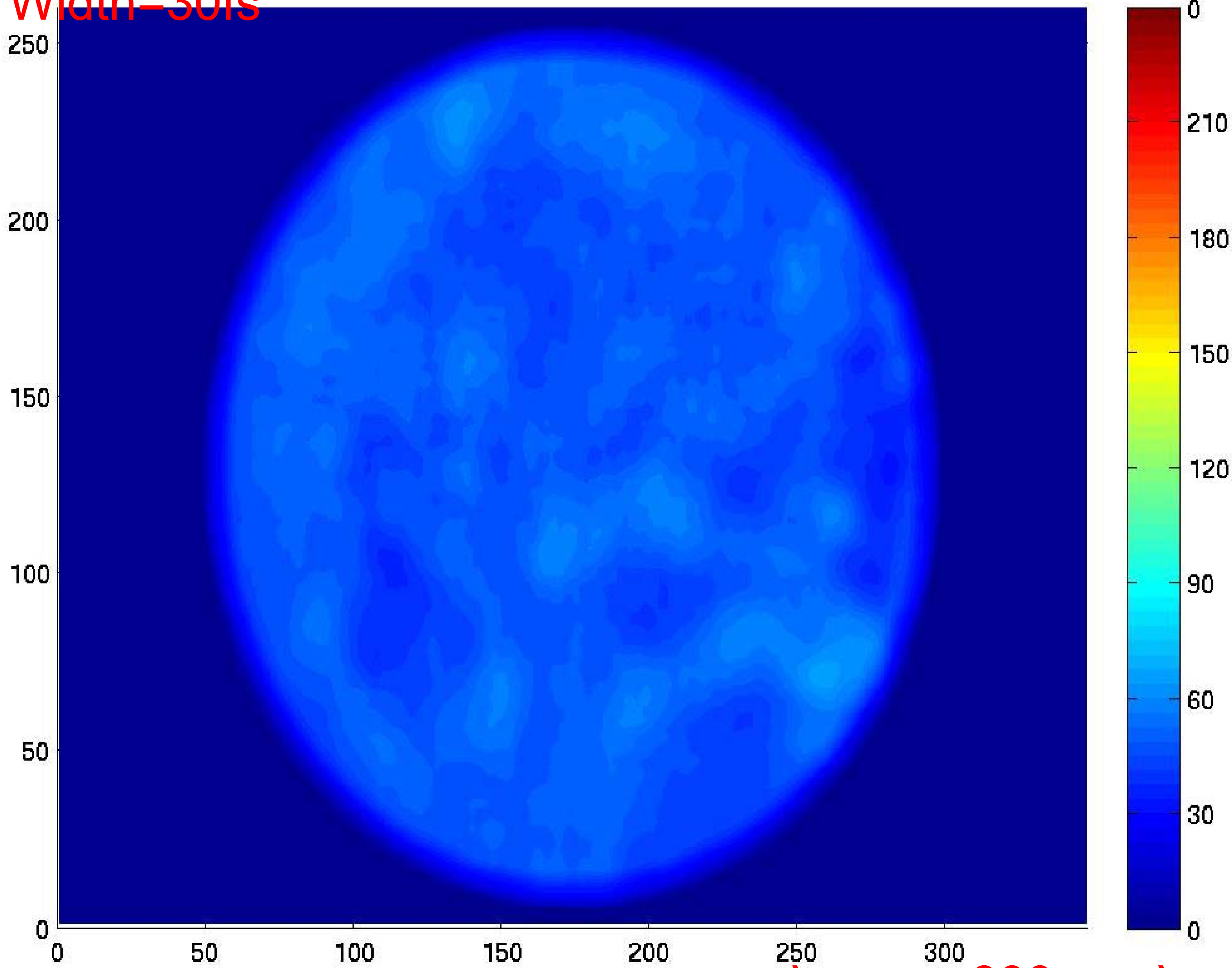


λ_{pump} = 800nm λ_{probe} =40

Target Al: Coated Glass

Pump Intensity on target =1.4x

Magnetic Field at Delay:5.47ps
Pulse Width=30fs



λ_{pump} = 800nm λ_{probe} =4(

Target Al: Coated Glass

Pump Intensity on target =1.4x

Thank you!