Metrology of picosecond laser driven ion bursts

Brendan Dromey

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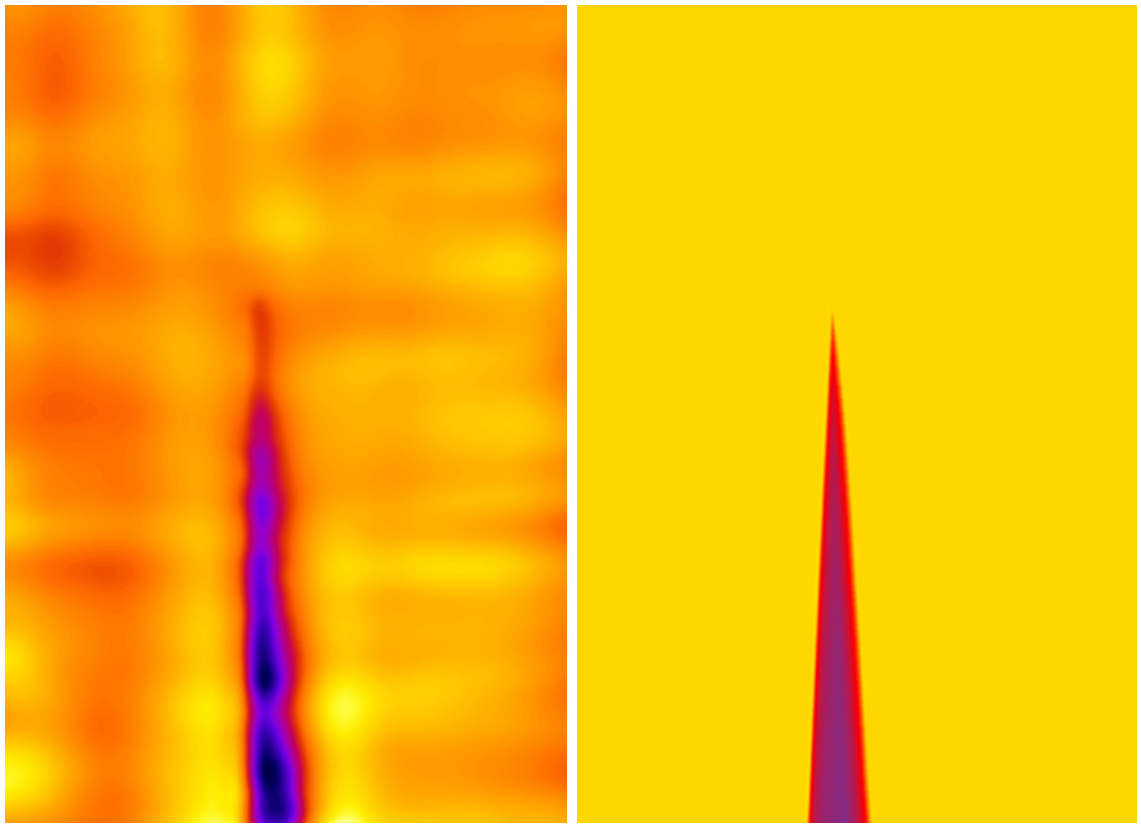

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- C. L. S. Lewis
- M. Zepf

- L. Senje
- C-G Wahlström

Outline

- Nanostructured dose distribution and few picosecond ion pulses
- Target normal sheath acceleration
    - Fundamental mechanism
    - Temporal structure
- Ion Bandwidth selection in SiO_2
- Ultrafast response in SiO_2
- Temporally resolved ion induced damage – optical streaking method
- First measurement of ps ion pulse duration
- New Horizons
- Outlook

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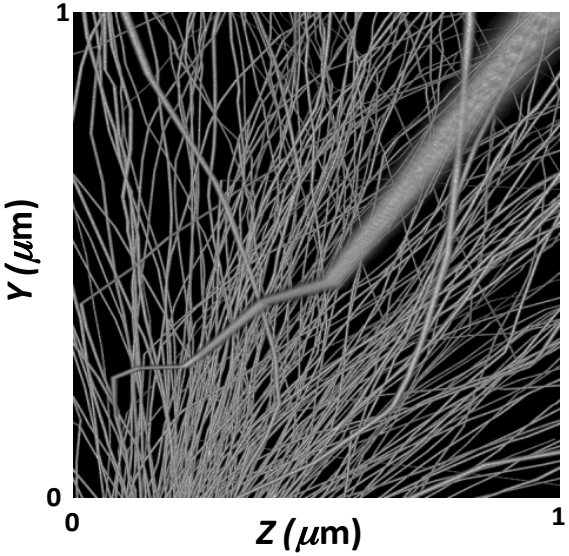
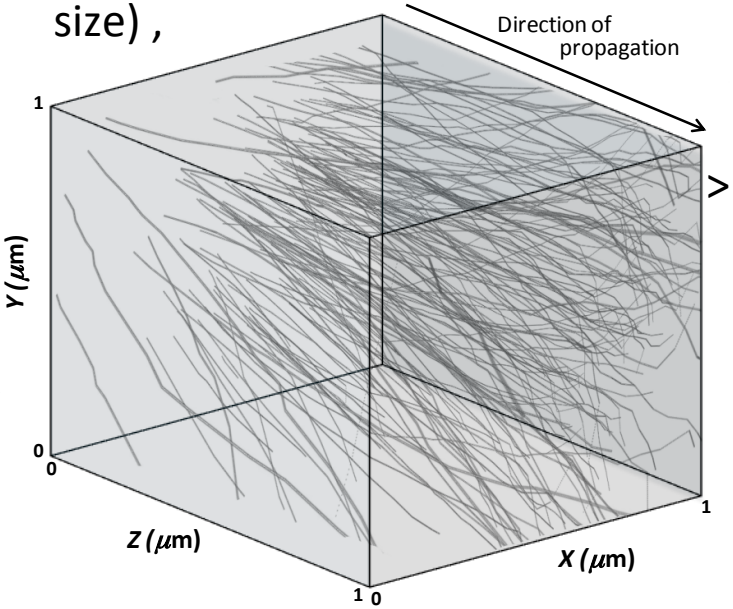
Nanostructured dose distribution



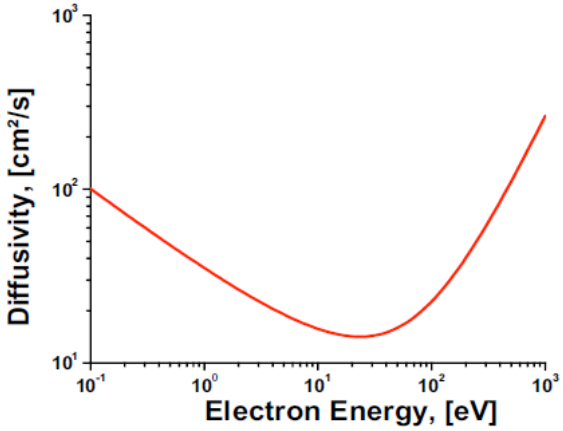
Nanoscale tracks of ion damage from a combination of TRIM calculations (trajectories) and FLUKA simulations (track size) ,



> 10^{21} cm^{-3} per track

However, this only the instantaneous picture…..

Nanometer scale energy density gradients drive rapid diffusion over picoseconds



Resolving this evolution is

Osmani et al., e-J. Surf. Sci. Nanotech. Vol. 8 (2010) 278-282

Critical for understanding early stage diffusion driven dynamics and isochoric heating

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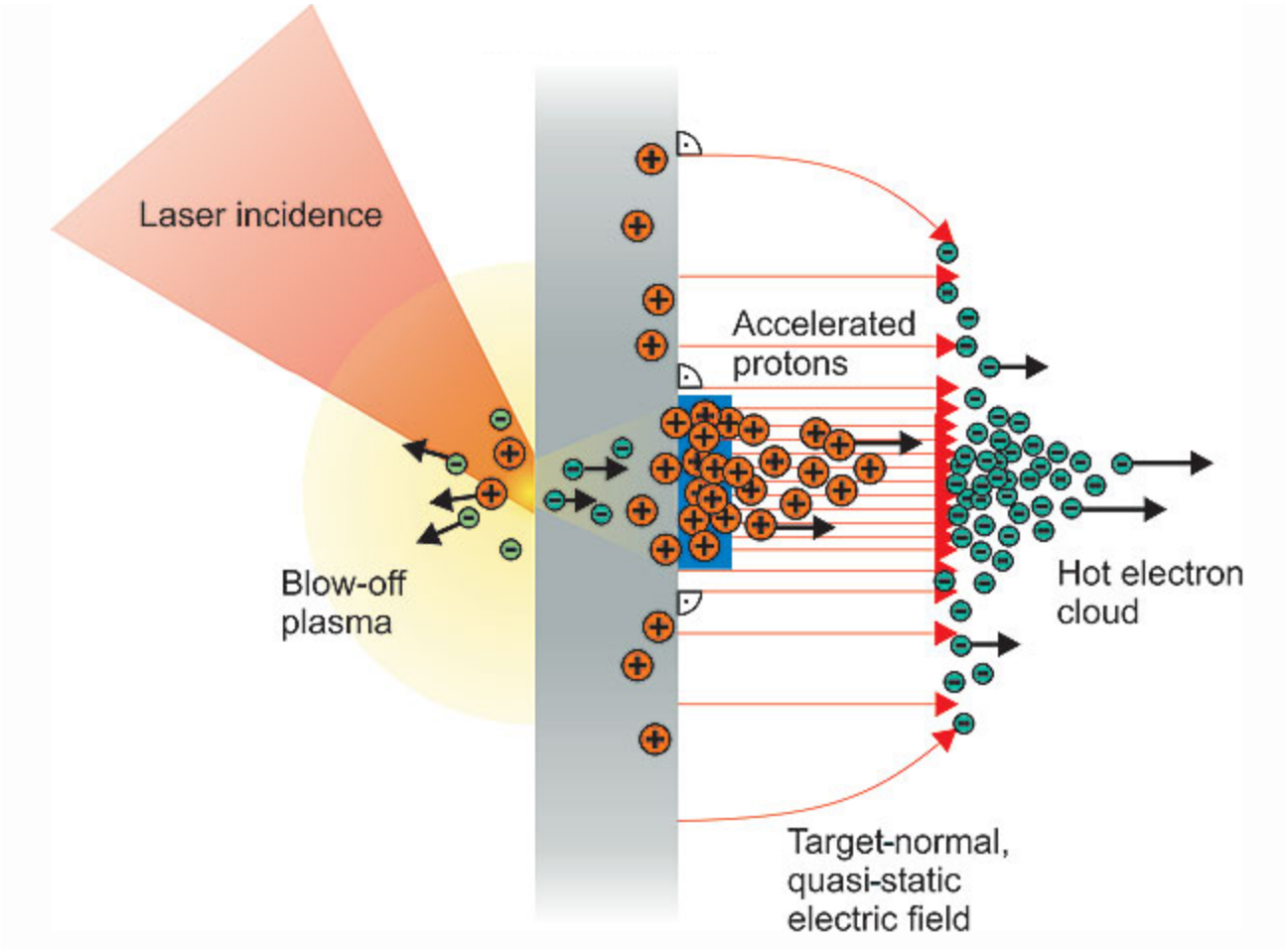
Target Normal sheath acceleration



Schwoerer et al., Nature, 439, 26 (2006)

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Few picosecond ion pulses

Radiofrequency cavity pulsed ion sources

Rely on hot cathode seed sources – large thermal spread

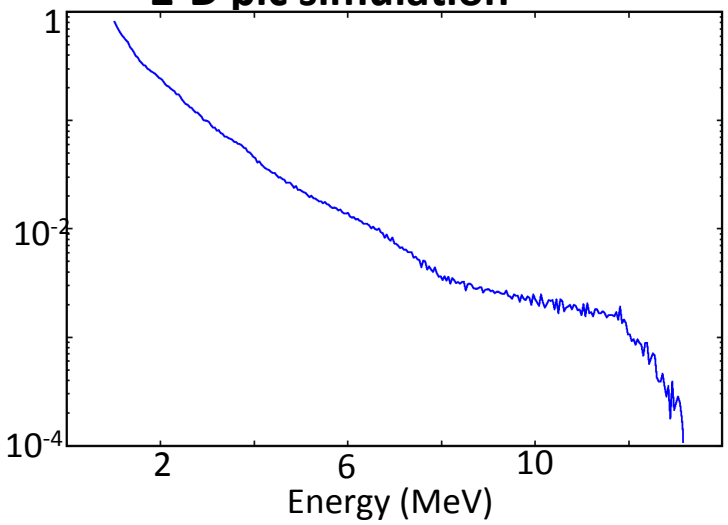
> 100 ps , 10^{-2} eV s longitudinal emittance

Laser driven Target Normal Sheath Acceleration

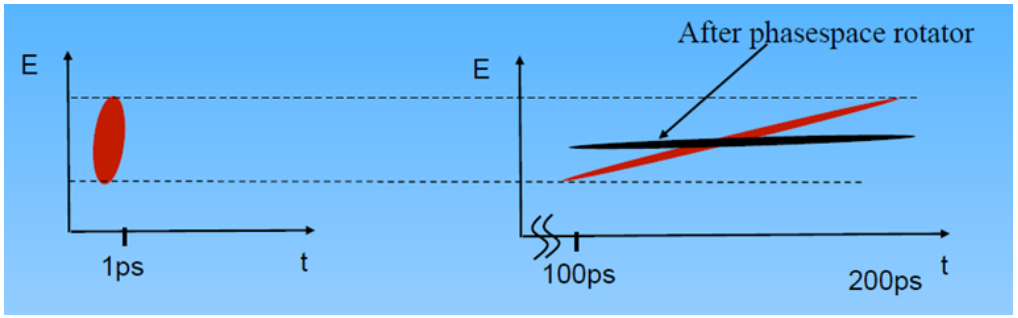
Cold cathode source with low thermal spread

Rapid acceleration phase < 1 ps ,

2-D pic simulation



Velocity dispersion dominated pulse durataion



< 10^{-5} eV s inherent longitudinal emittance

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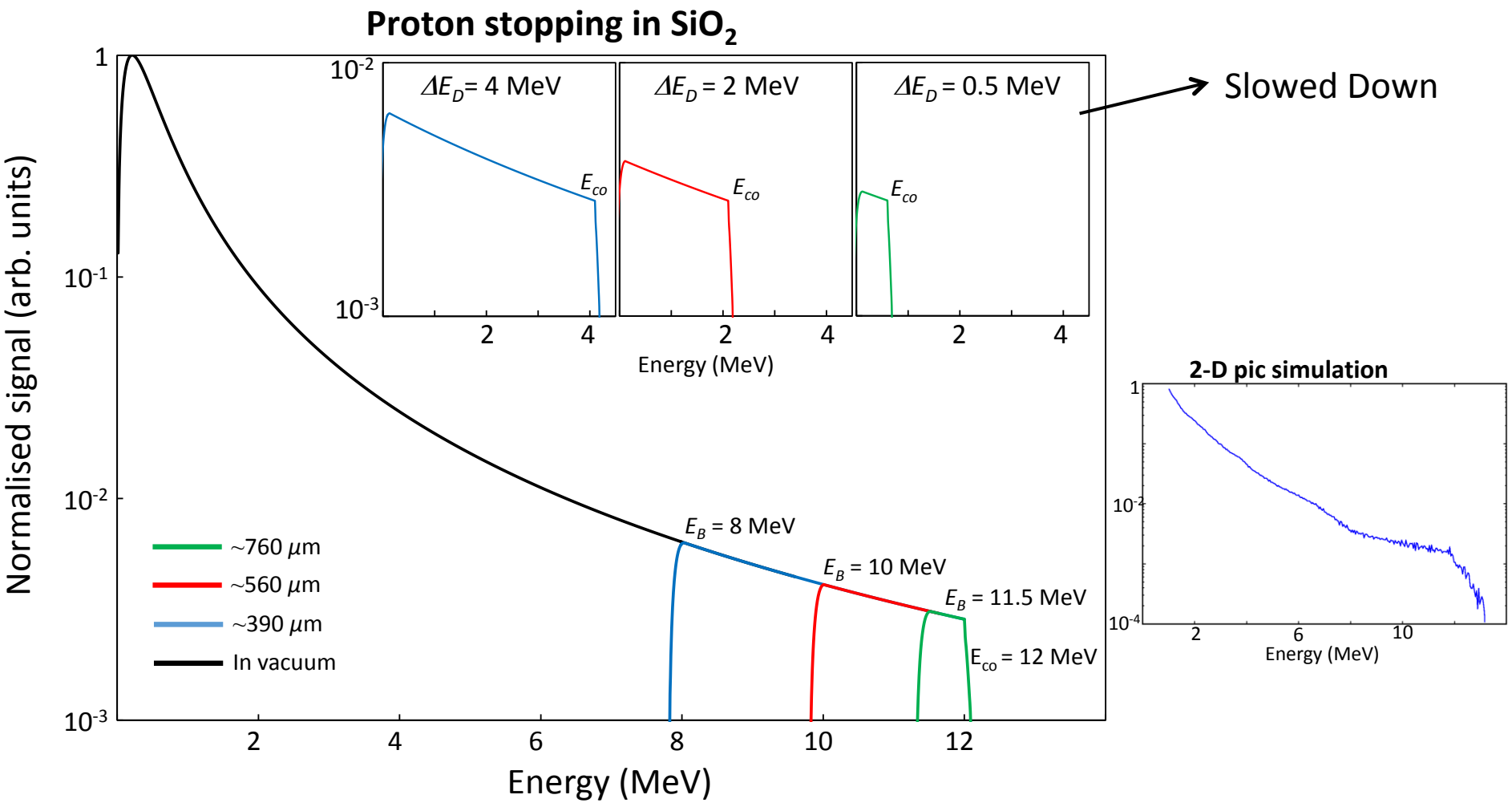
Bandwidth selection in SiO_2



Combination of rapid temporal response and spectral filtering – Spectro-temporal metrology

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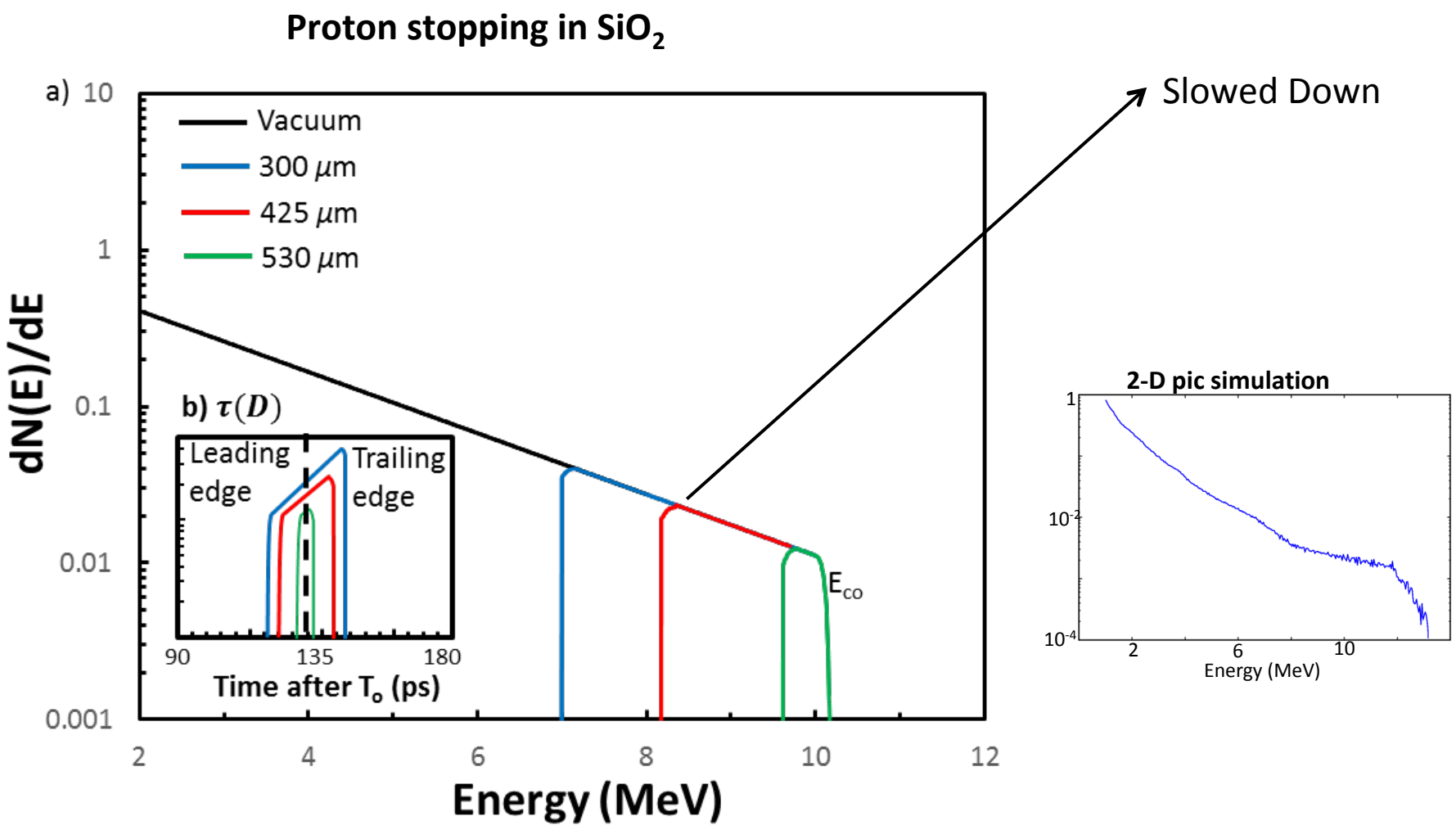
Bandwidth selection in SiO_2



Combination of rapid temporal response and spectral filtering – Spectro-temporal metrology

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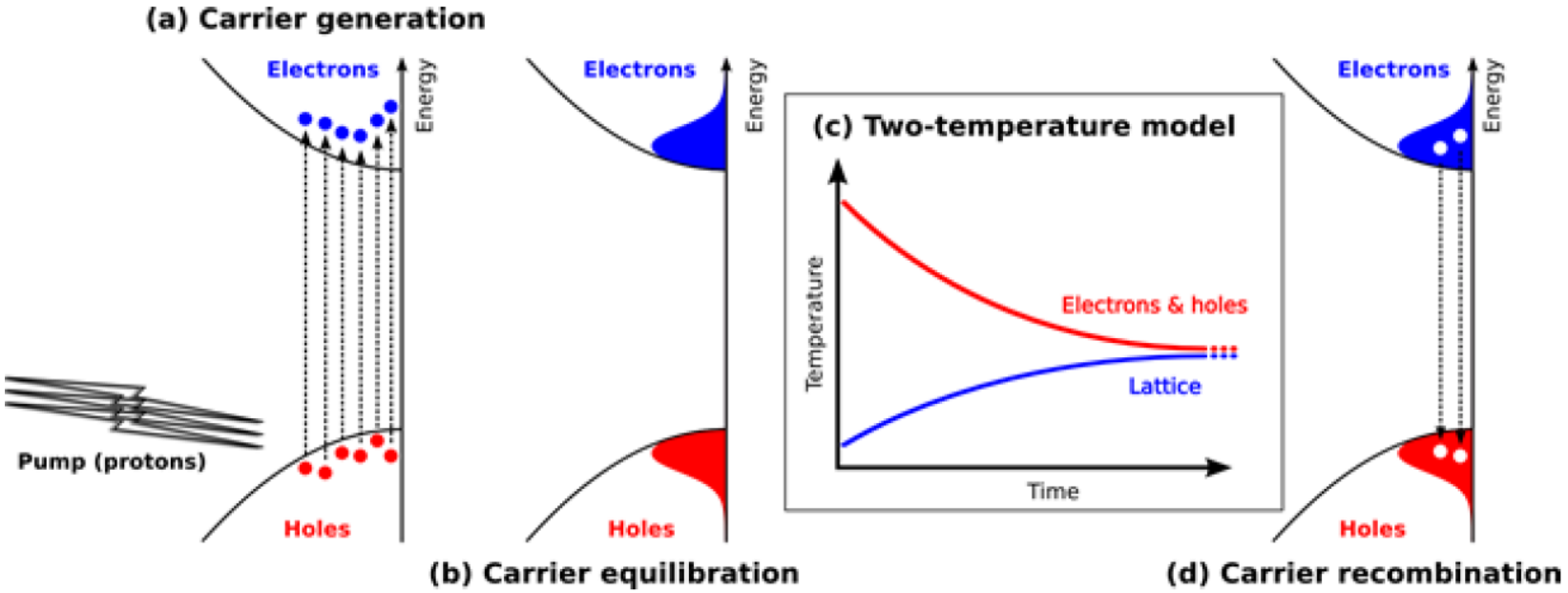
Ion induced damage in materials

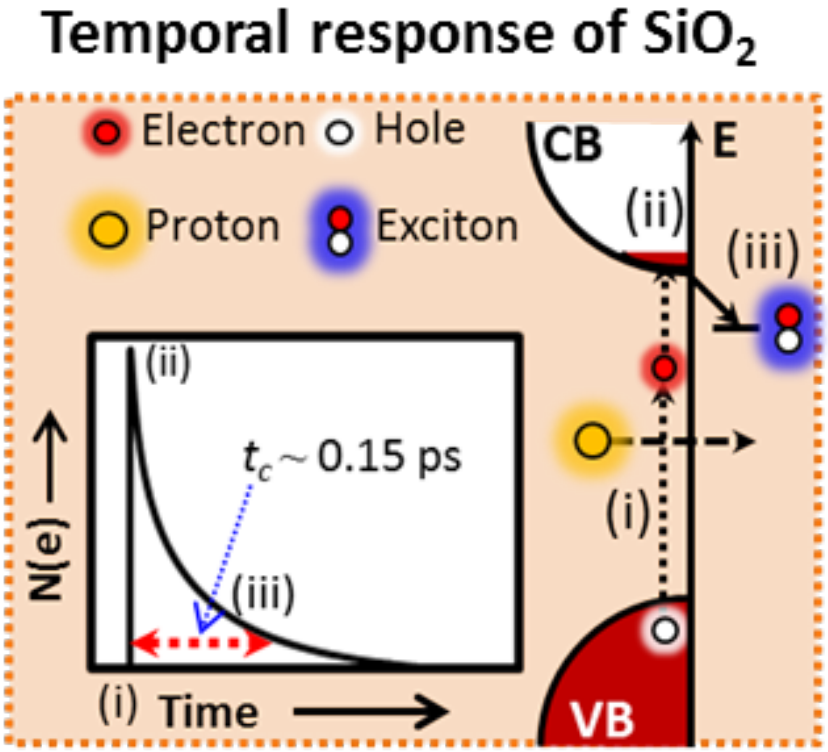


< Few femtosecond

> 1 - 10 picoseconds

>> 10 picoseconds

Ultrafast response SiO_2



SiO_2 - Rapid decay channel possible:

Exciton formation can limit the upper state lifetime to ~ 150 fs

Guizard J Phys Cond Matt 8 1281-1290 1996 "Time resolved study of colour centre formation SiO2"

Audebert, P., et al., Space–time observation of an electron gas in SiO2. *Phys. Rev. Lett*. **73**, 1990–1993 (1994)

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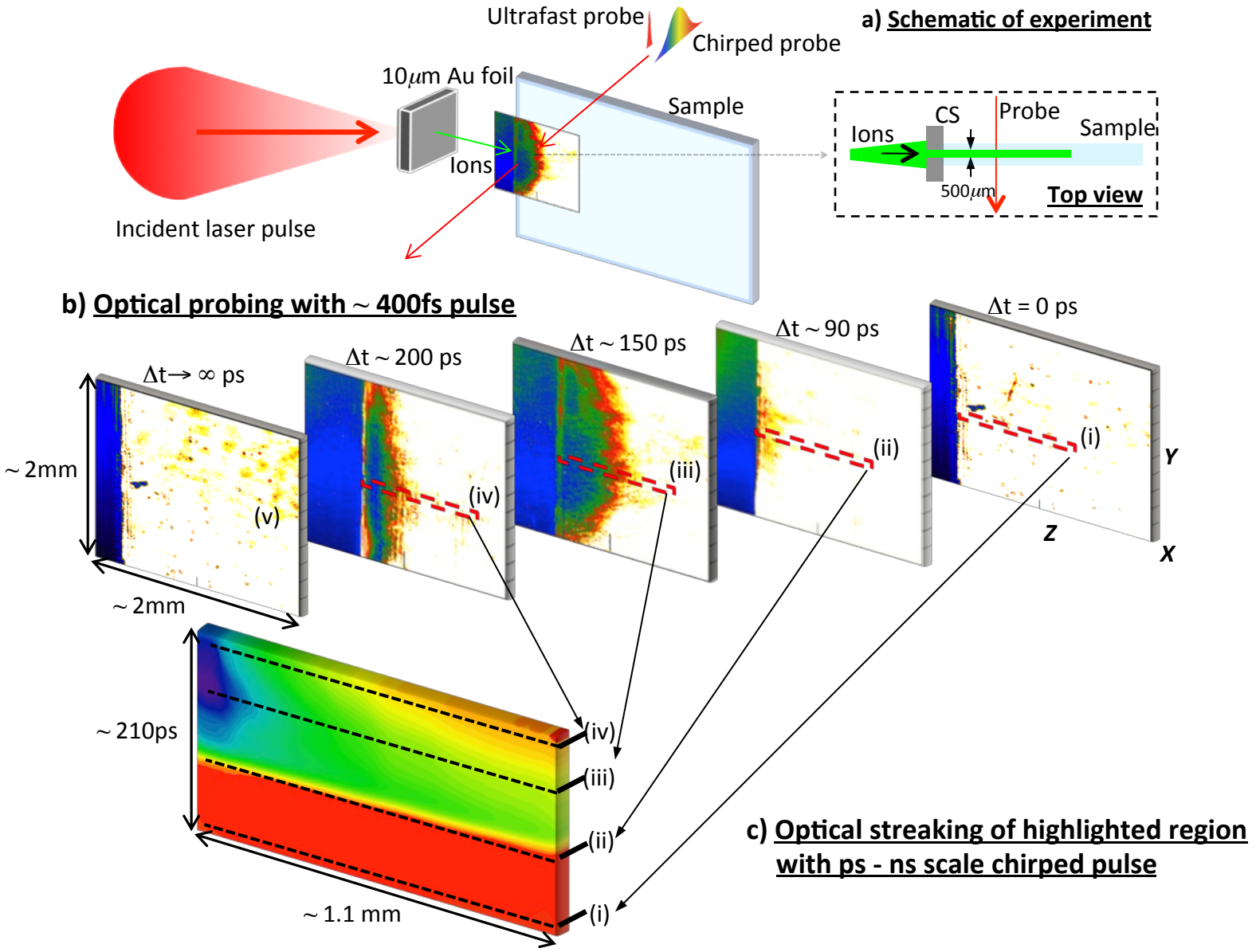
Experimental method overview



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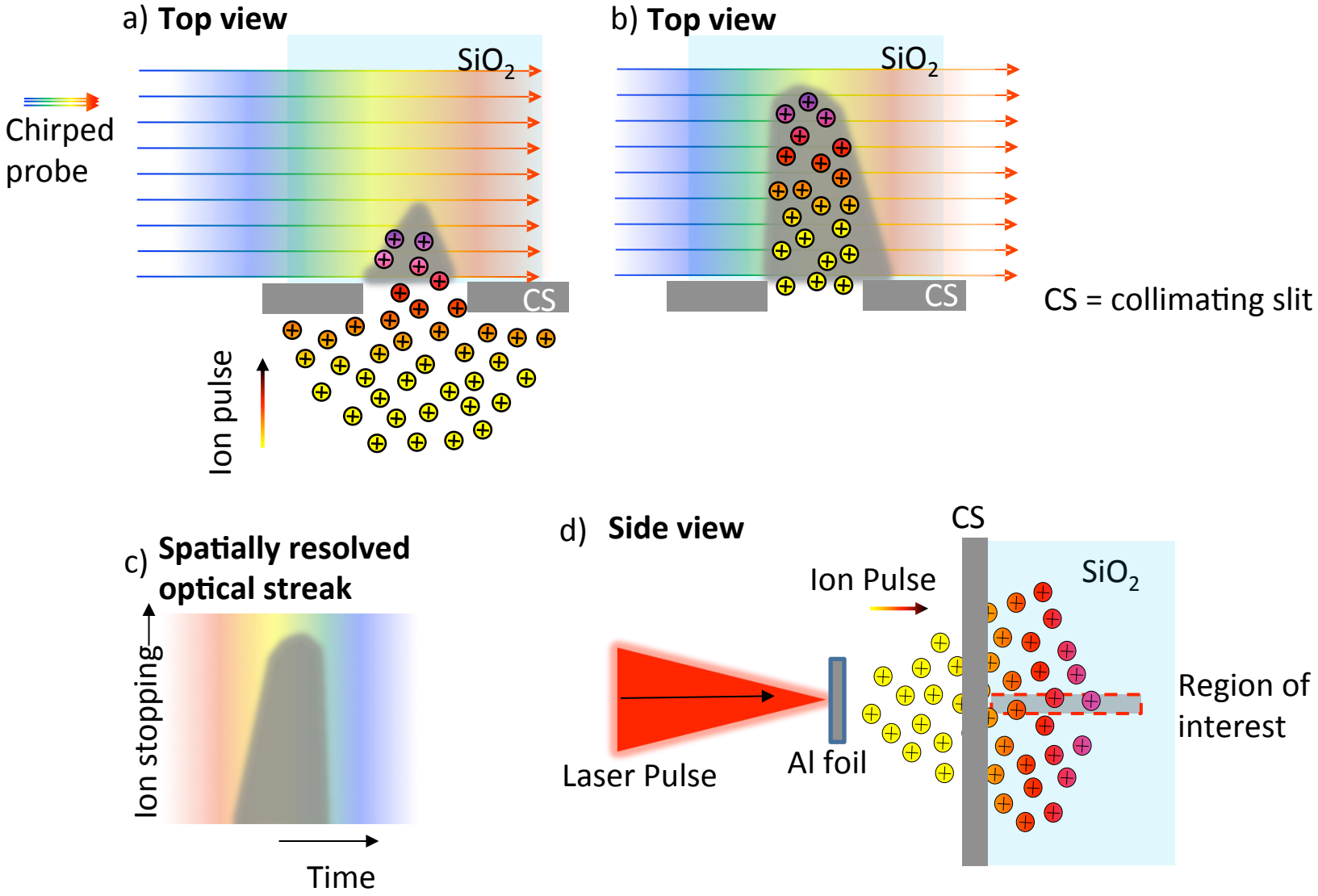
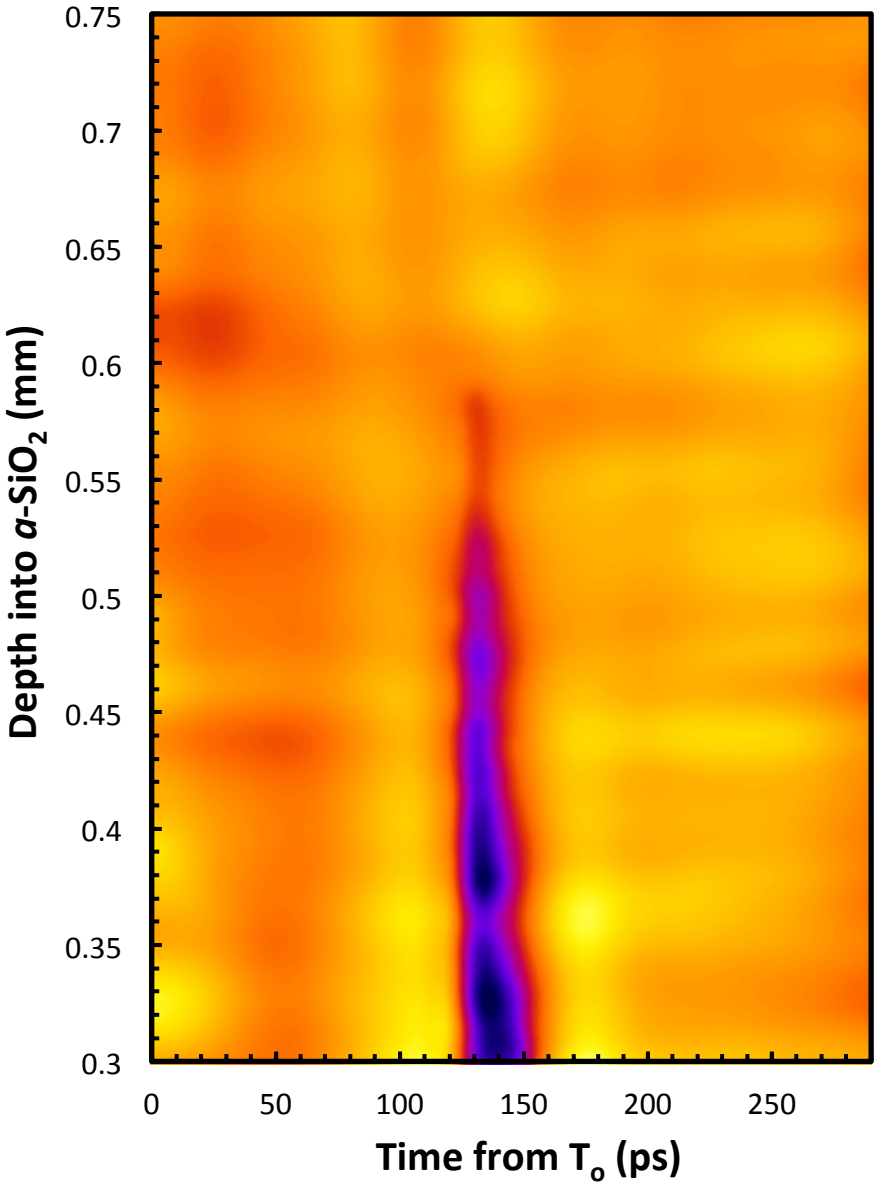
Schematic of optical streaking method



Results: Optical streak of opacity in SiO_2



Filtered to remove high frequency noise

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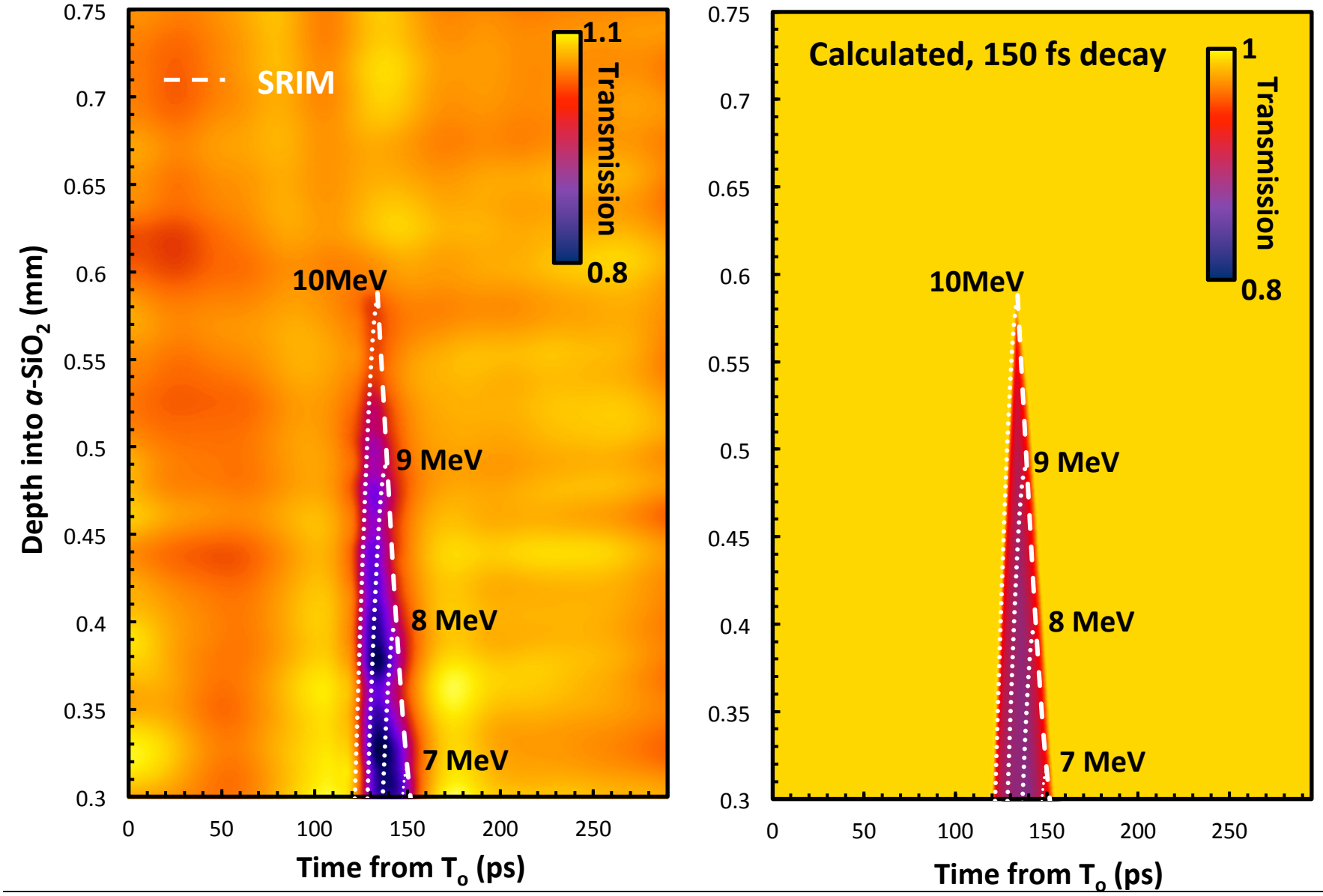
Results: Optical streak of opacity in SiO_2



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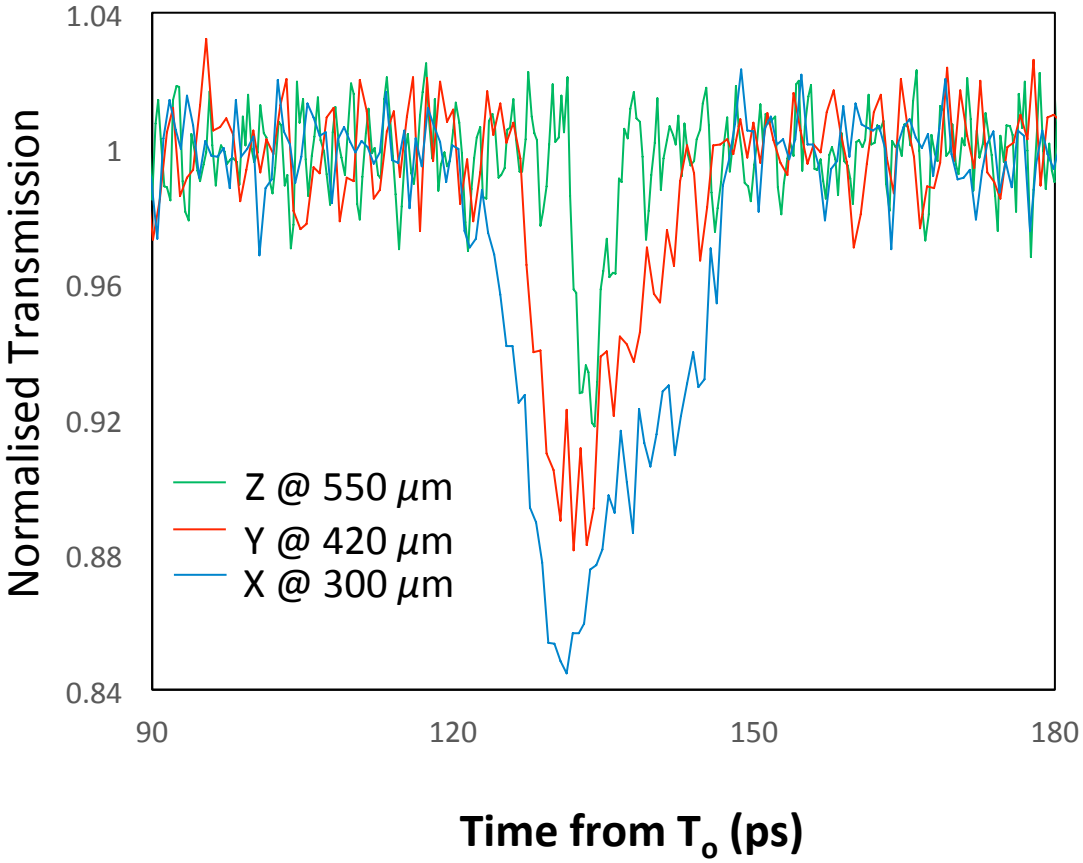
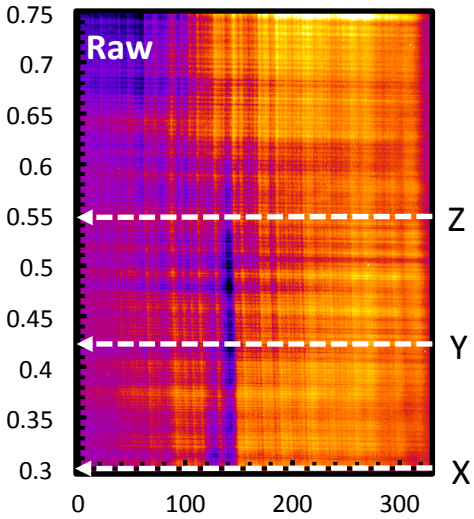
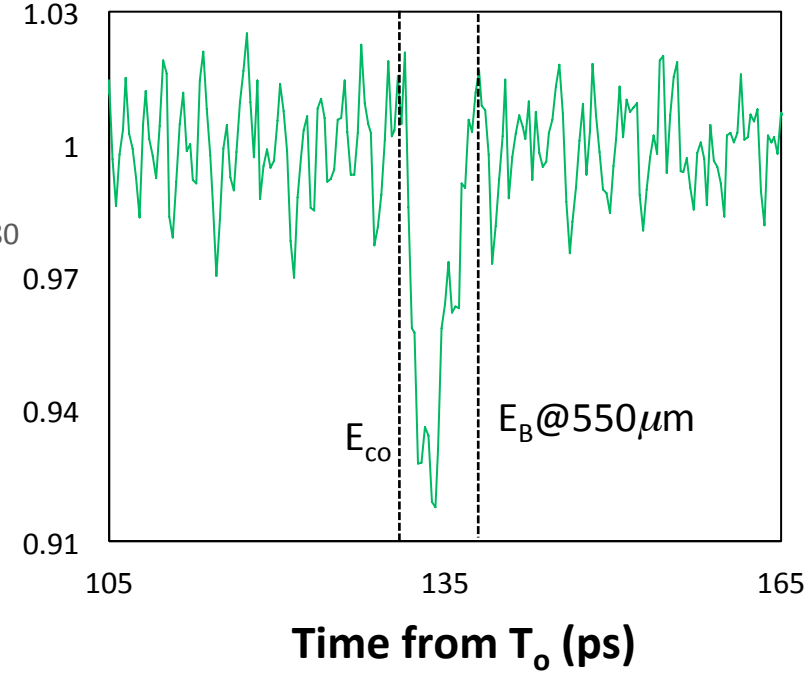
Picosecond proton pulse duration







Note: Successively shorter pulses with respect to depth in SiO_2

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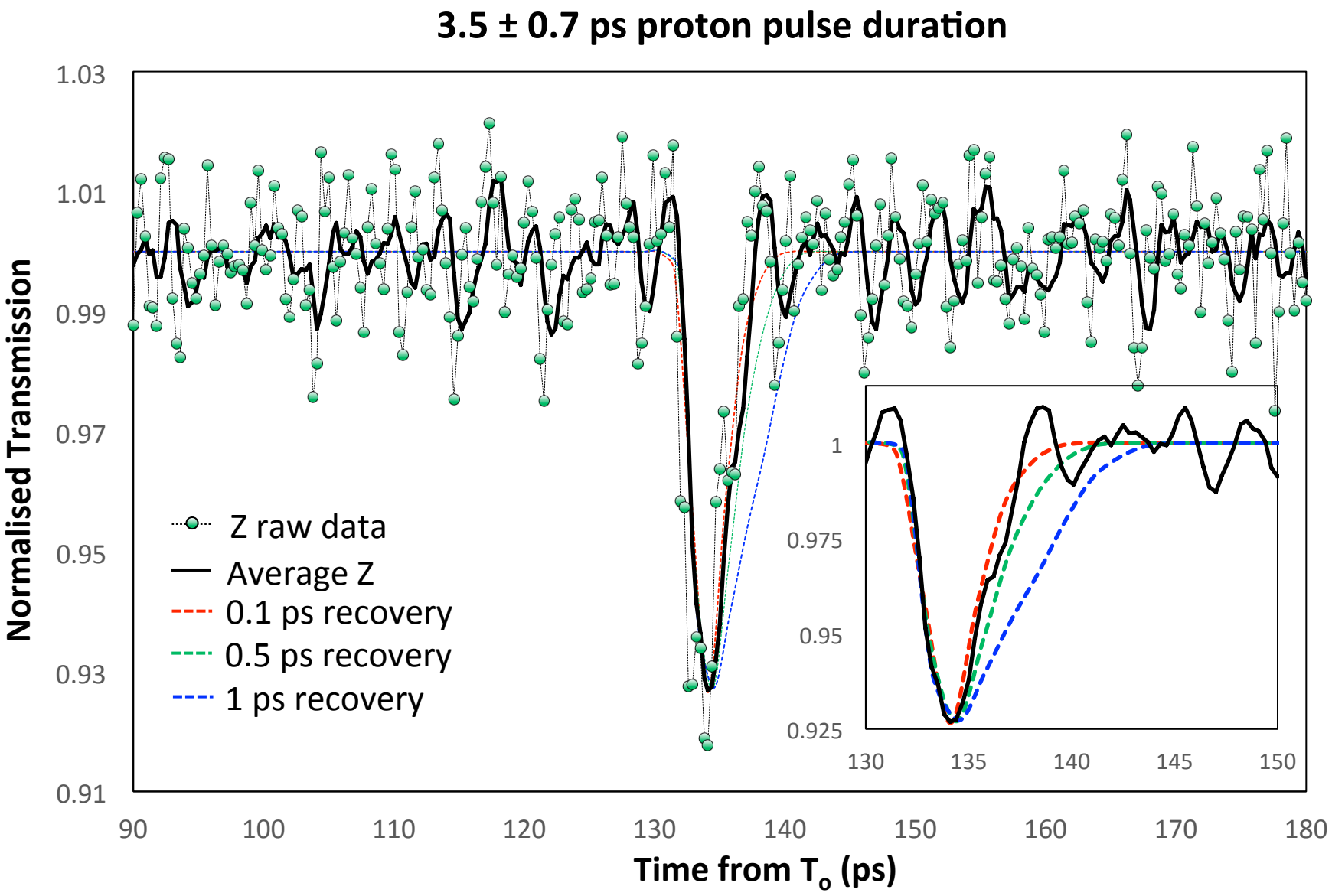
Picosecond ion pulse duration



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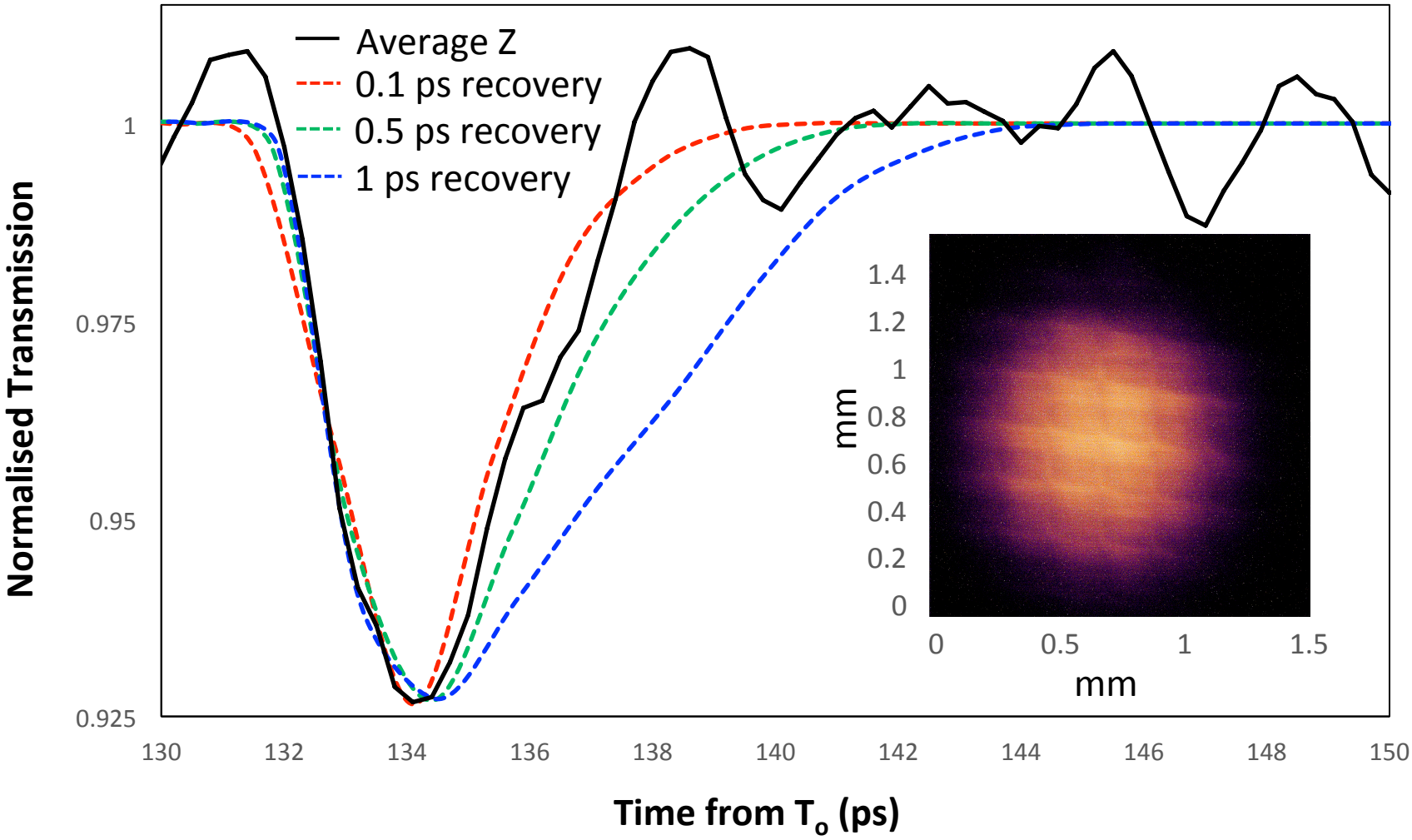
Self trapped exciton decay

Spatially resolved ionoluminescence in 400 nm – 600 nm

Suggests density: 10^{18} - 10^{19} cm^{-3} (electron hole plasma conditions supress exciton formation)



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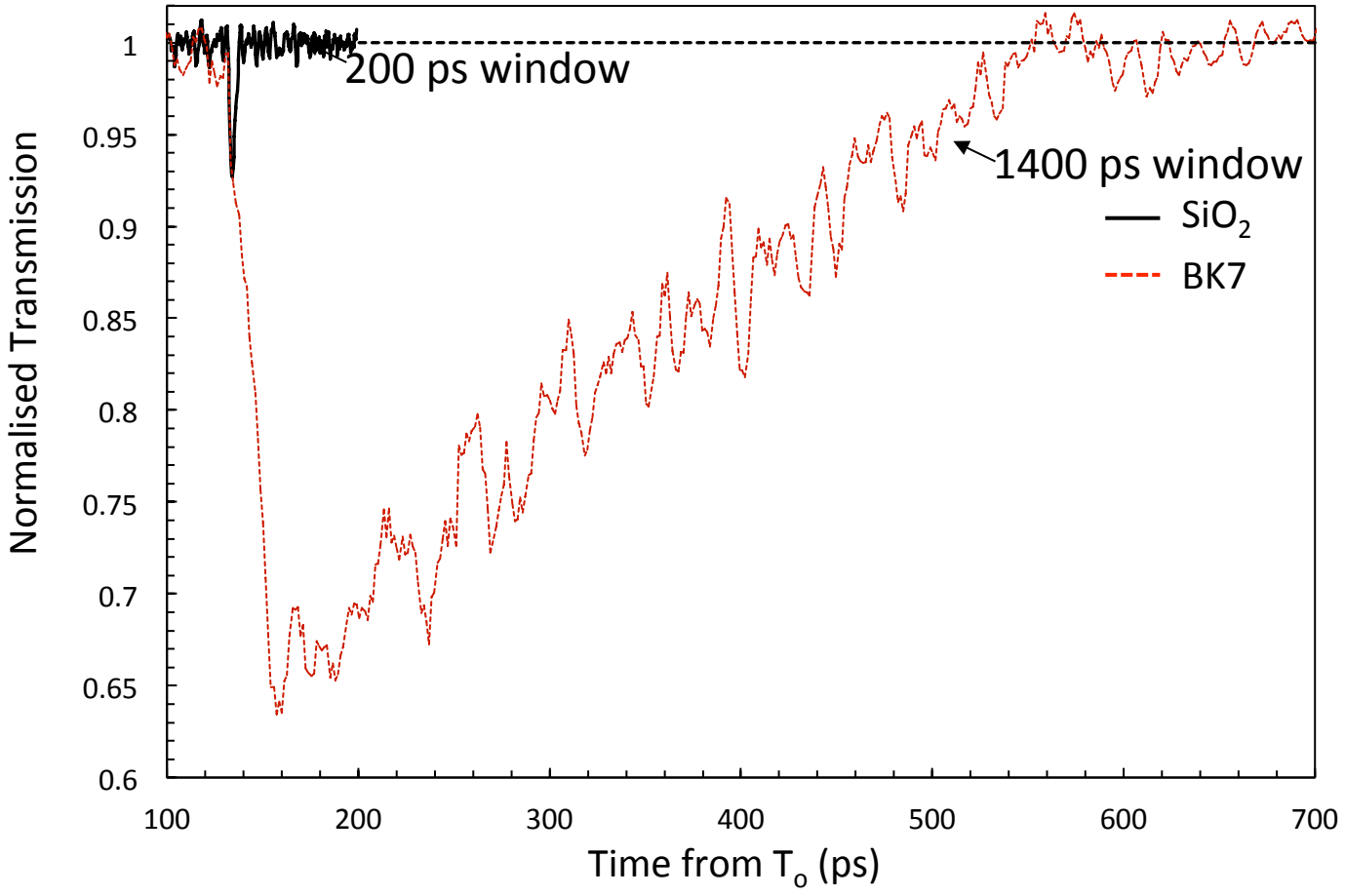
Example: SiO_2 vs BK7



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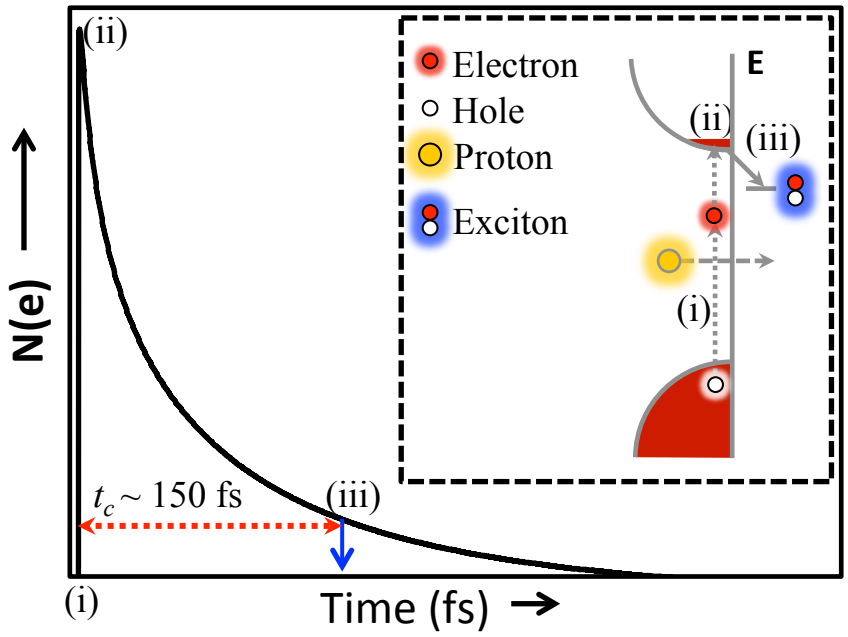
Why is the SiO_2 response fast?



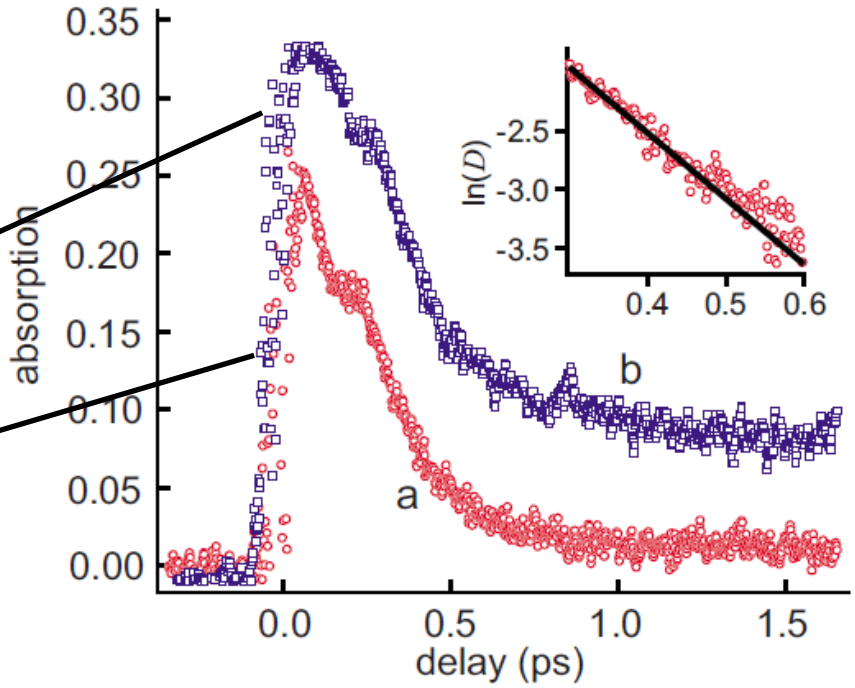
Possible explanation: Transition from free electron gas to electron hole plasma

>10^{20} cm^{-3}

~10^{18} cm^{-3}

"Dual speed" decay

D. Grojo "Exciton-seeded multiphoton ionization in bulk SiO2" PHYSICAL REVIEW B 81, 212301 (2010)



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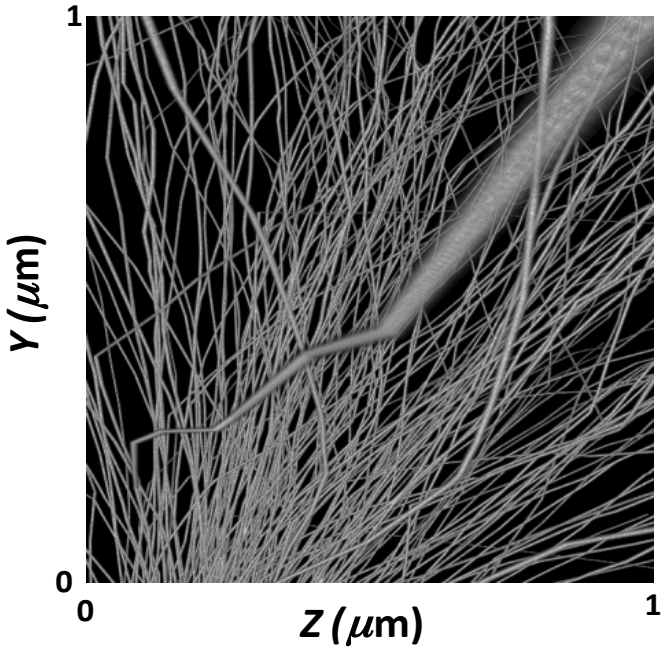
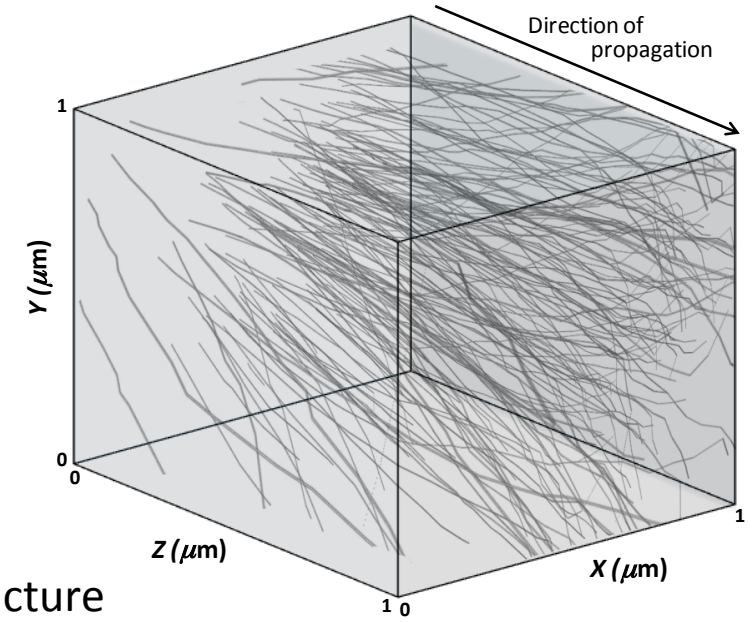
Nanostructured dose distribution



Nanoscale tracks of ion damage for our flux conditions – combination of TRIM calculations (trajectories) and FLUKA simulations (track size)



However, this only the instantaneous picture

Nanometer scale energy density gradients drive rapid diffusion over picoseconds

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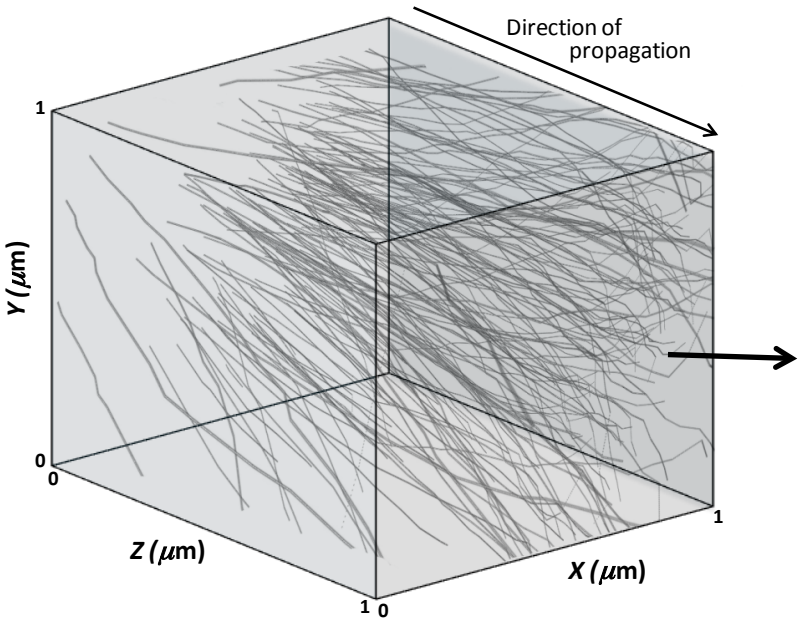
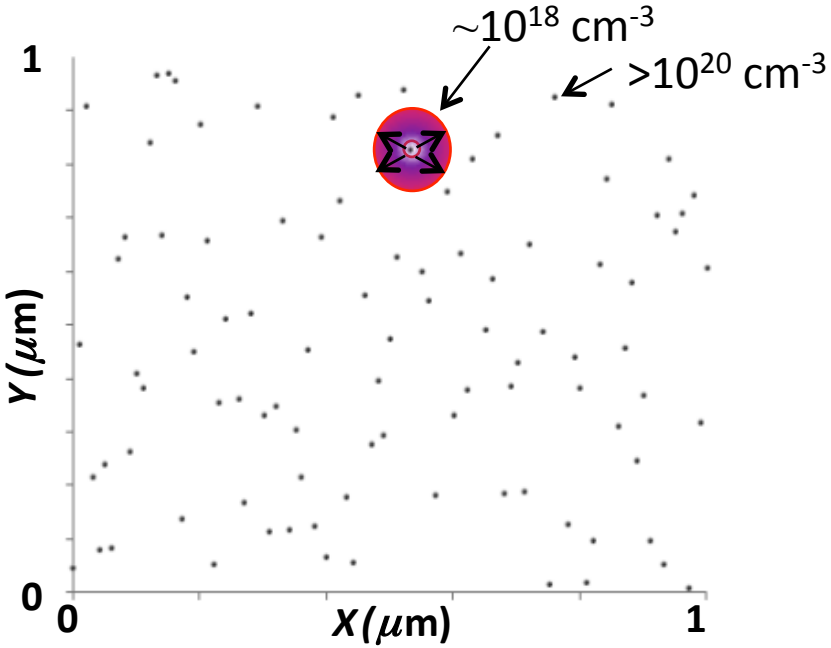
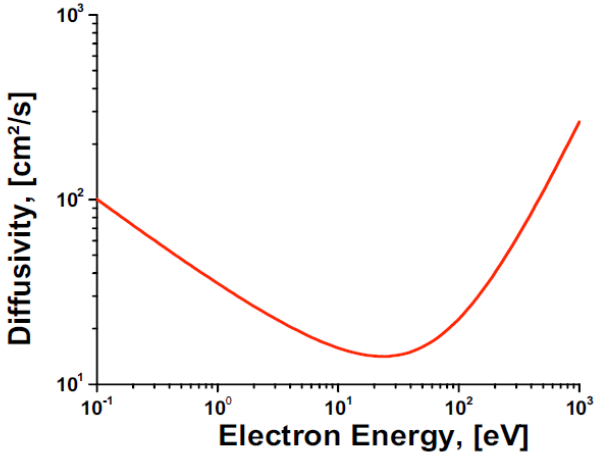
Rapid evolution of density





This evolution is consistent with predictions from Monte Carlo simulations for electron diffusivity



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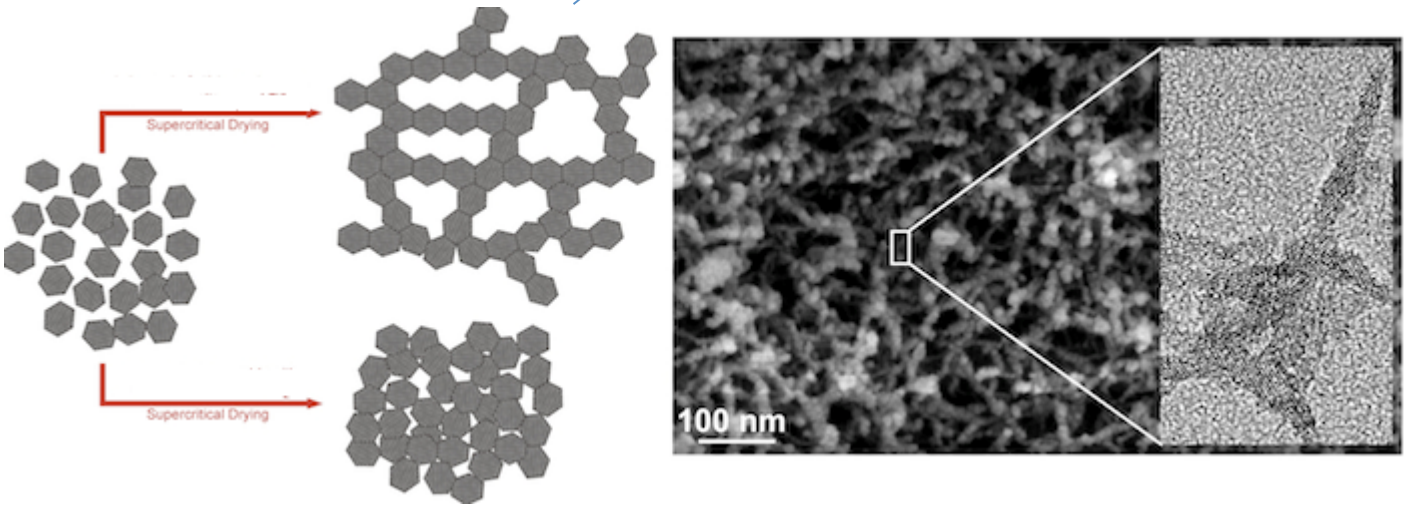
SiO_2 Aerogel – reduced dimensionality

Tortuous nanostructured matrix of SiO_2



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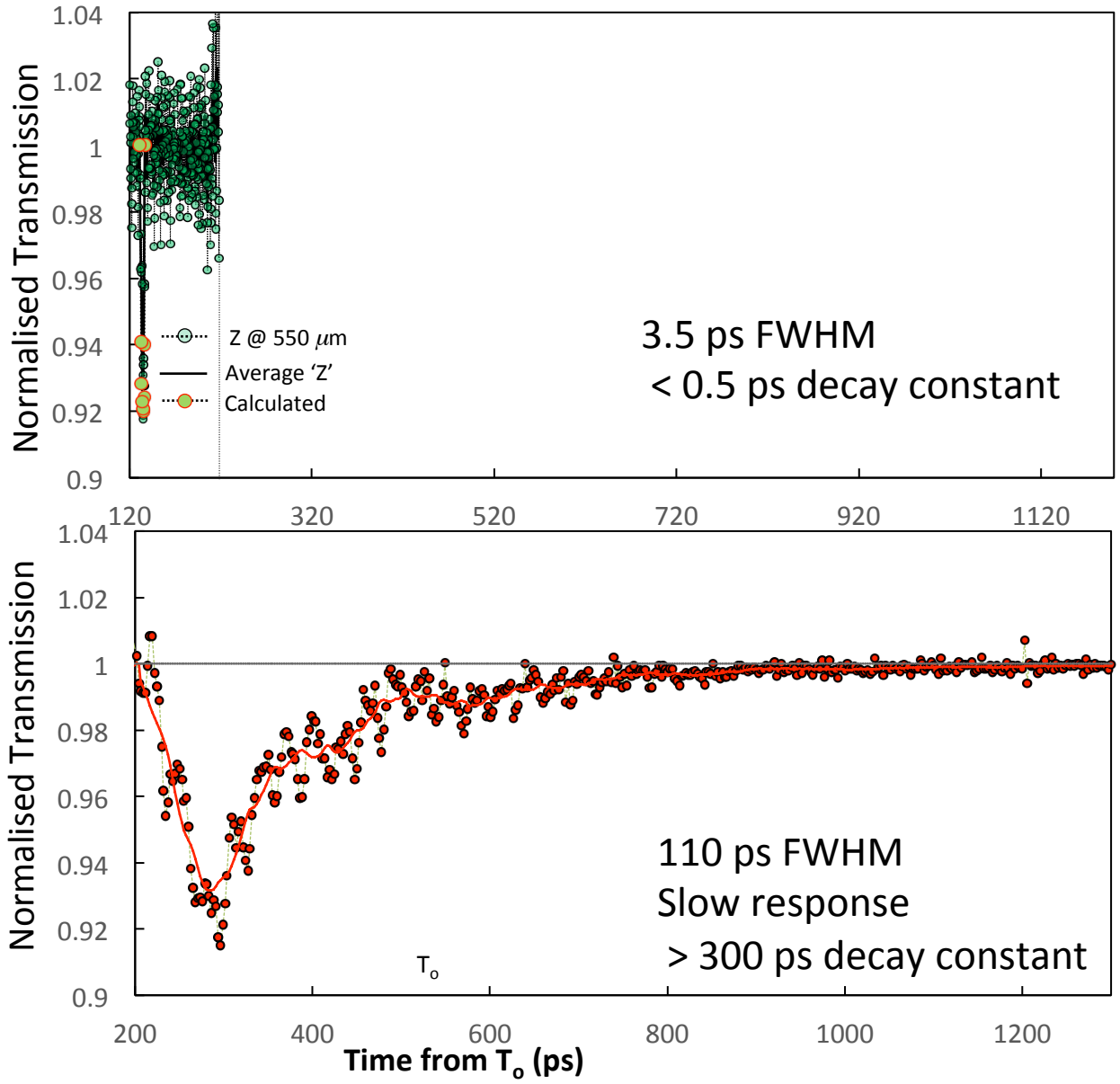
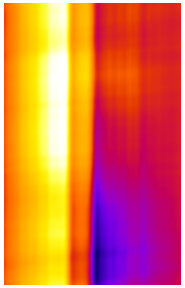
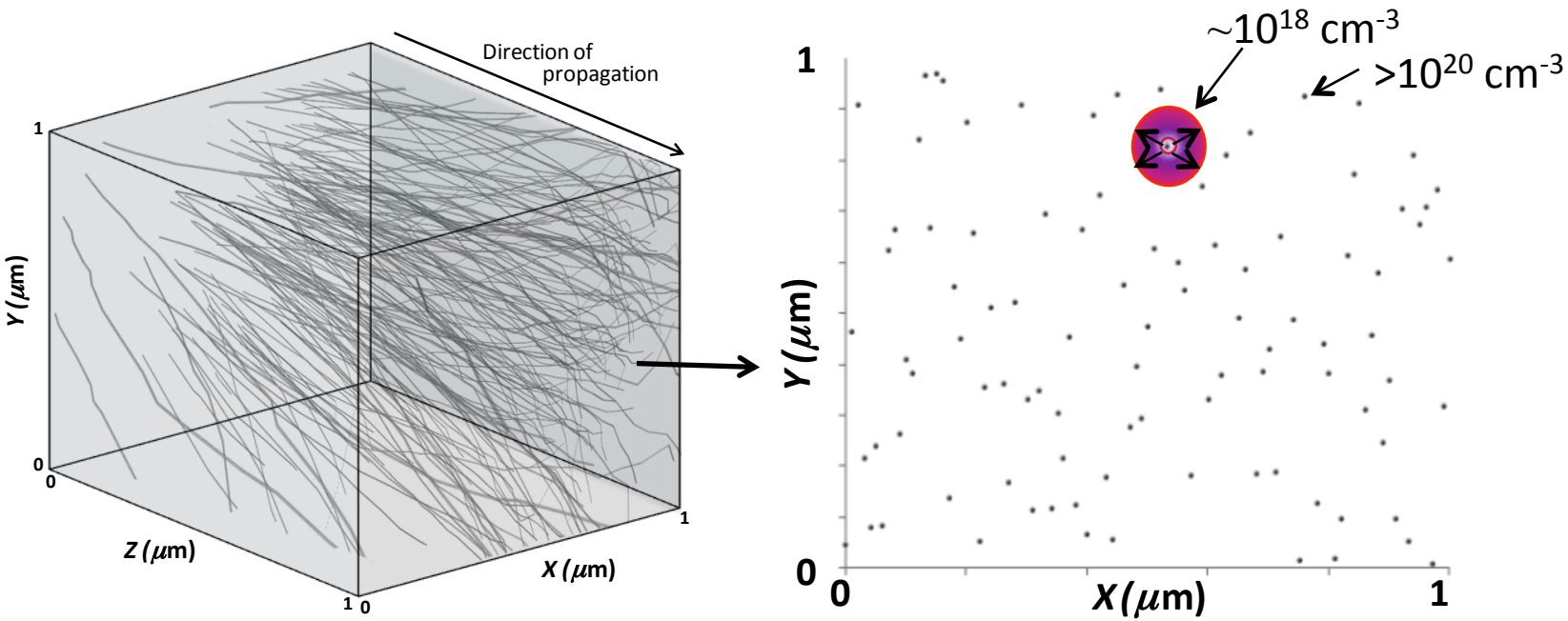
Inhibition of diffusion in Aerogel





Rapid evolution of density



The nanostructured network inhibits the rapid evolution of density

This implies that electron hole plasma conditions are maintained –

Thermal energy too great to allow long lived exciton states

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Outlook

- First ion pulse duration measurements – single shot basis
- Building and testing ab-initio models of reaction of time-resolved response to radiation damage may be possible
- A broadband probe can look at reaction time histories in water etc.
- This technique is also applicable to electrons/X-rays
- Clear diagnostic for ps pulses of protons
- Sheds new light on proton interactions in matter
- A possible tool to perform the first absolute study of the emergence of ultrafast processes.

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