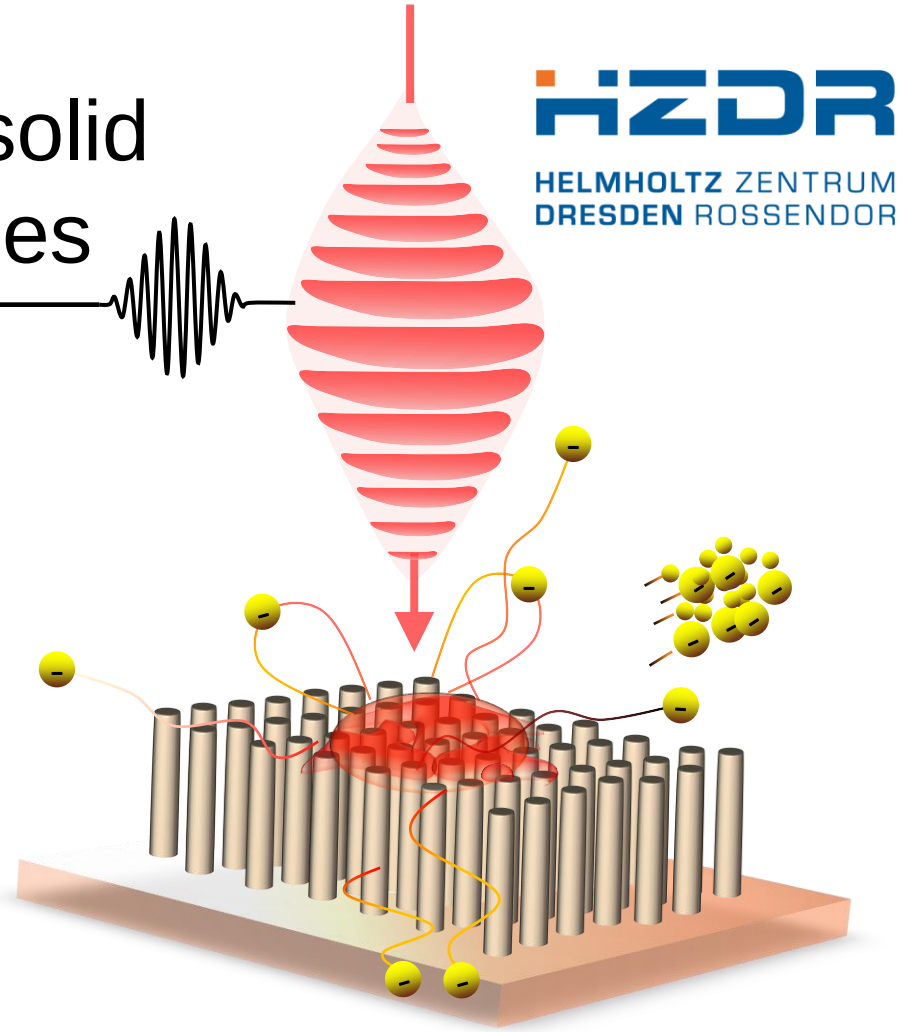
Optical probing of nanostructured solid interacting with intense laser pulses



Ankit Dulat

21-27 September, 2025, Elba, Italy

EAAC2025 7th European Advanced Accelerator Conference

HZDR HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

VANLIFE

DRESDEN concept

Acknowledgements

A. Dulat[1], S. Assenbaum[1,2], C. Bernert[1], M. Bussmann[1], T. E. Cowan[1,2], T. Kluge[1], F. Kroll[1], J. Metzkes-Ng[1], F. Paschke-Brühl[1,2], M. Rehwald[1], J. Schilz[1,2], H.-P. Schlenvoigt[1], U. Schramm[1,2], M.E. Umlandt[1,2], M. Vescovi[1], K. Zeil[1], T. Ziegler[1]

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[2]TUD Dresden University of Technology, Dresden, Germany

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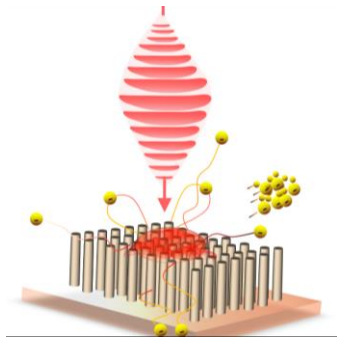


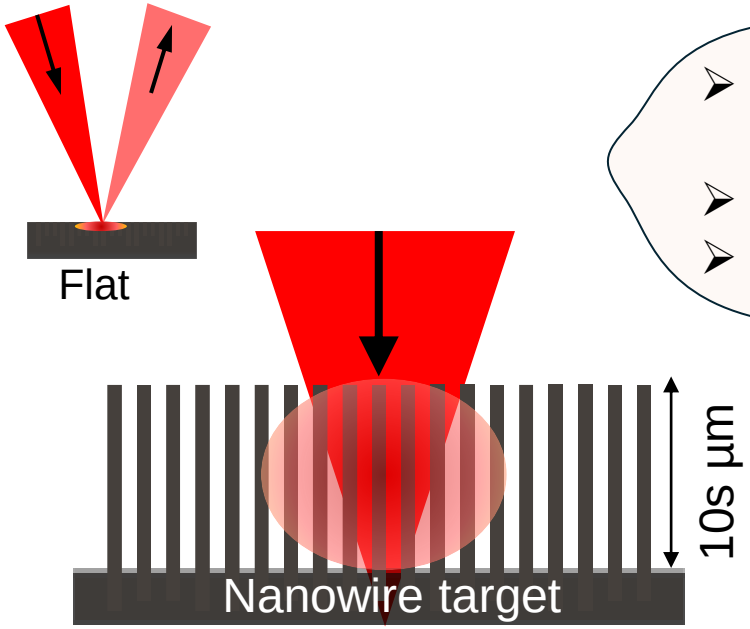
HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

MarvelFusion

DRESDEN concept SCIENCE AND INNOVATION CAMPUS

HZDR

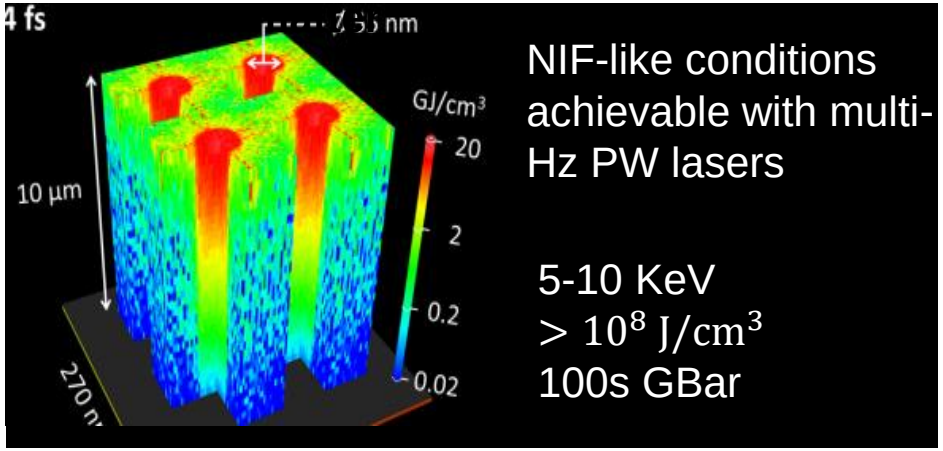
What so special about nanowire targets?



- Enables large surface area of interaction
- Volumetric heating (~ 10s µm)
- Lightening rod effect

Very efficient coupling of laser energy to particles/plasma

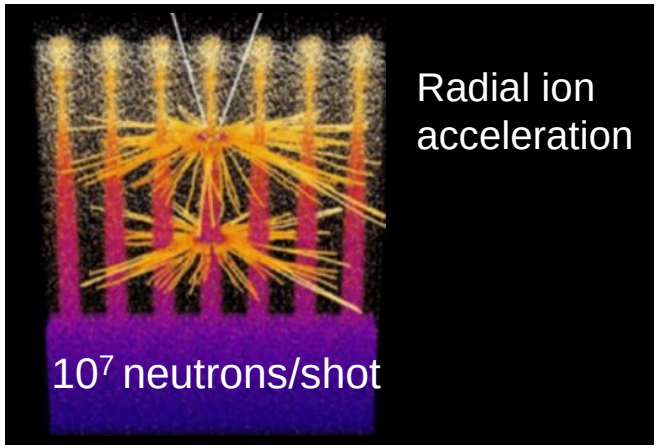
[1]Ultrahigh-energy density (UHED)



NIF-like conditions achievable with multi-Hz PW lasers

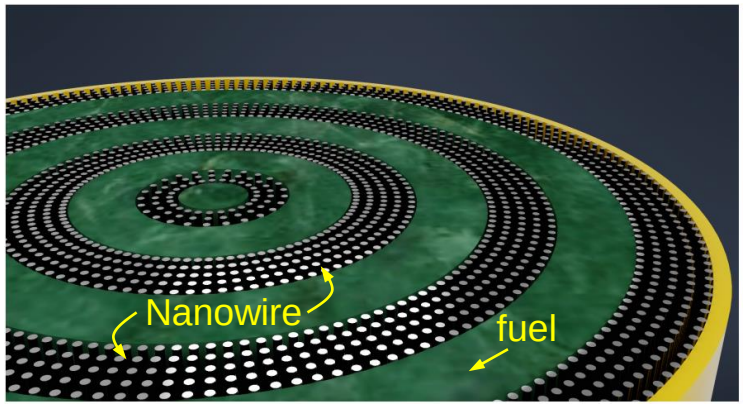
5-10 KeV
$> 10^8$ J/cm^3
100s GBar

[2]D-D fusion with compact lasers



Radial ion acceleration

[3]Nanorod based target design for fusion



[1]Bargsten et al. Sci. Adv. 2017;3: e1601558
[1]M.A. Purvis Nat. Photonics 7, (2013)
[1]R. Holligner et al., Nat. Photonics 14, (2020)
[1,2]J.J. Rocca et al., OPTICA 11, (2024)
[2]A. Curtis et al., Nat. Comm.| (2018) 9
[3]H. Ruhl et al. arXiv 2306.03731v4
[3]H. Ruhl et al., arXiv:2212.12941v1

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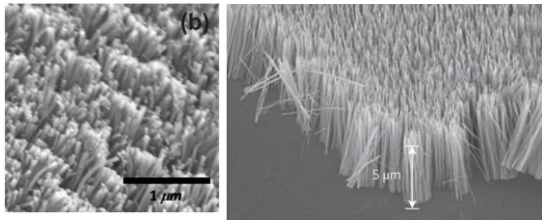
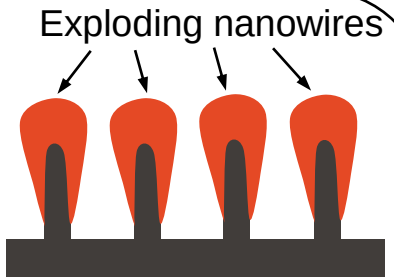
Do the nanowires really survive upto the peak of the pulse?

Fragile nano-structures

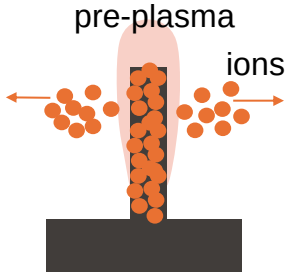


What do we investigate?

- **Time-resolved pre-plasma dynamics of exploding nanowires**



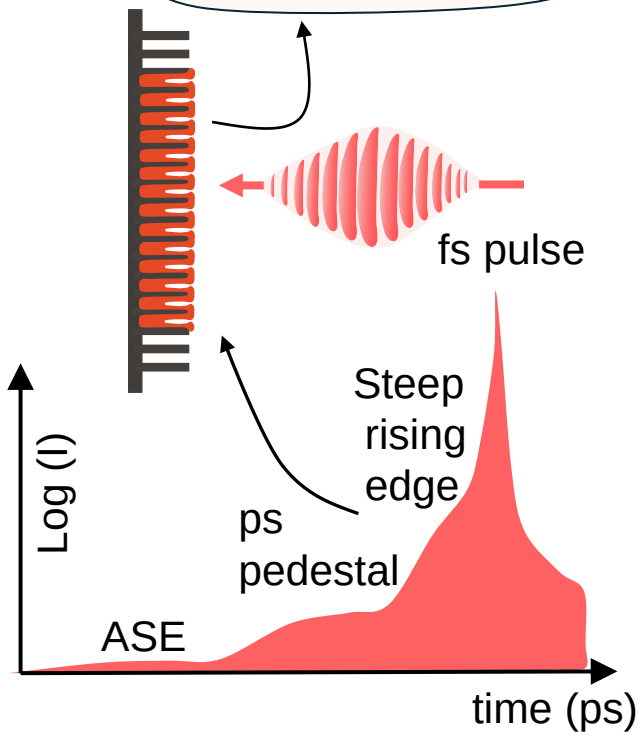
- **Radial ion acceleration**
  TNSA/ Columb explosion/ Ambipolar expansion ?



Importantly

nm to **µm** levels of pre-plasma.

Critically effect
1. laser absorption
2. particle acceleration



❑ Remain unmeasured

- Time-resolved pre-plasma expansion of nanowires
  Extremely challenging to simulate
- Effect of pre-plasma expansion on volumetric heating and ion acceleration

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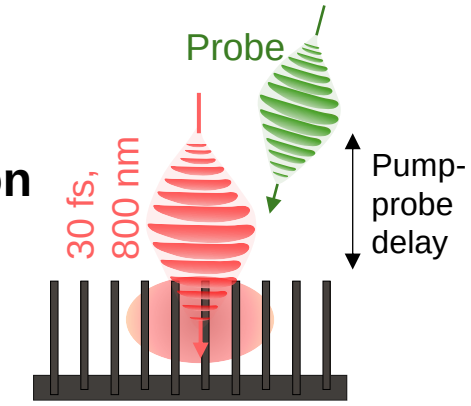
Measurement Challenges & Technique

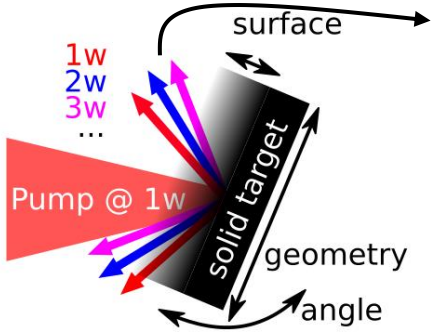
Challenges

- **Femtosecond time-resolution**

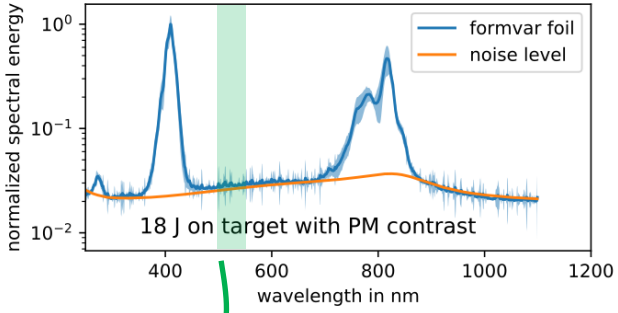
  Pump-probe technique



- **Strong Plasma emission → pump, harmonics & self-emission**



Reflected light from 300nm Formvar



Off-harmonic probing

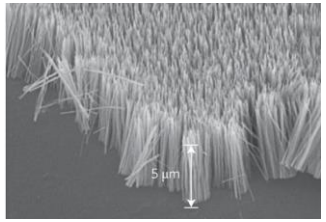
Probe
515 nm
160 fs

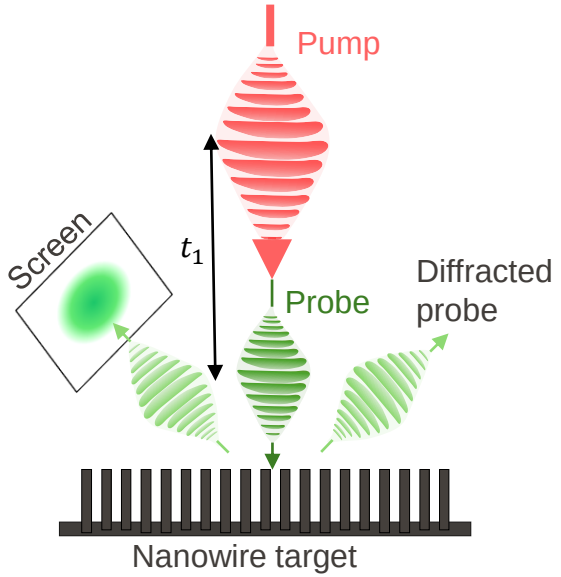
Dedicated laser system (Yb:CaF2) for off-harmonic probing

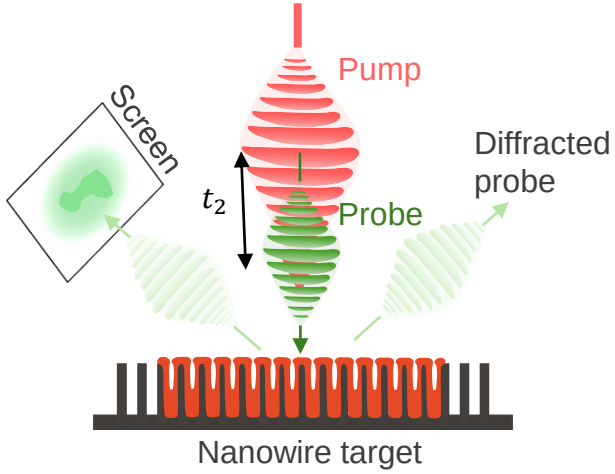
C. Bernert et al., Sci. Reports 12 (2022)
Loeser et al Opt. Expr. 29 (2021)

- **Nanometric spatial resolution**

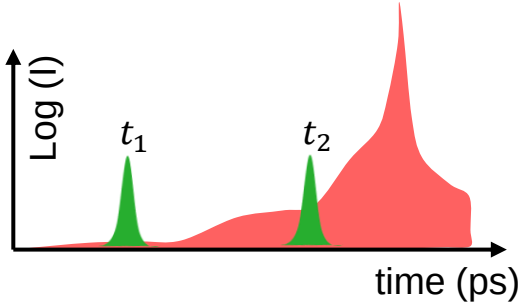
  Scattering based measurement







- Diffraction efficiency is sensitive to 'nm-' level changes in the target's parameters



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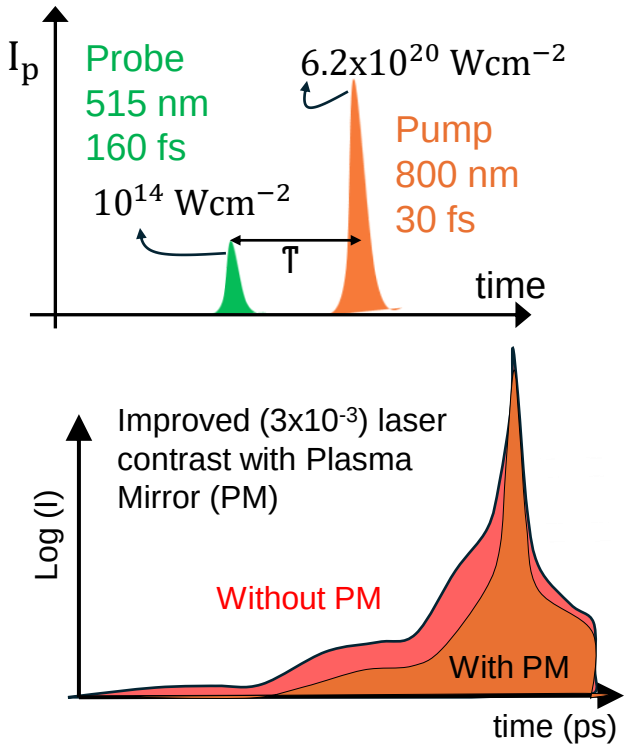
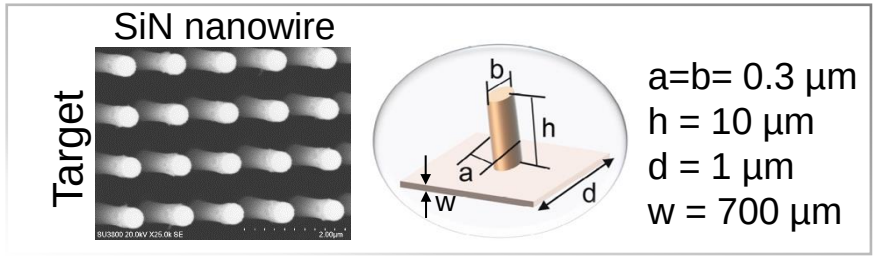
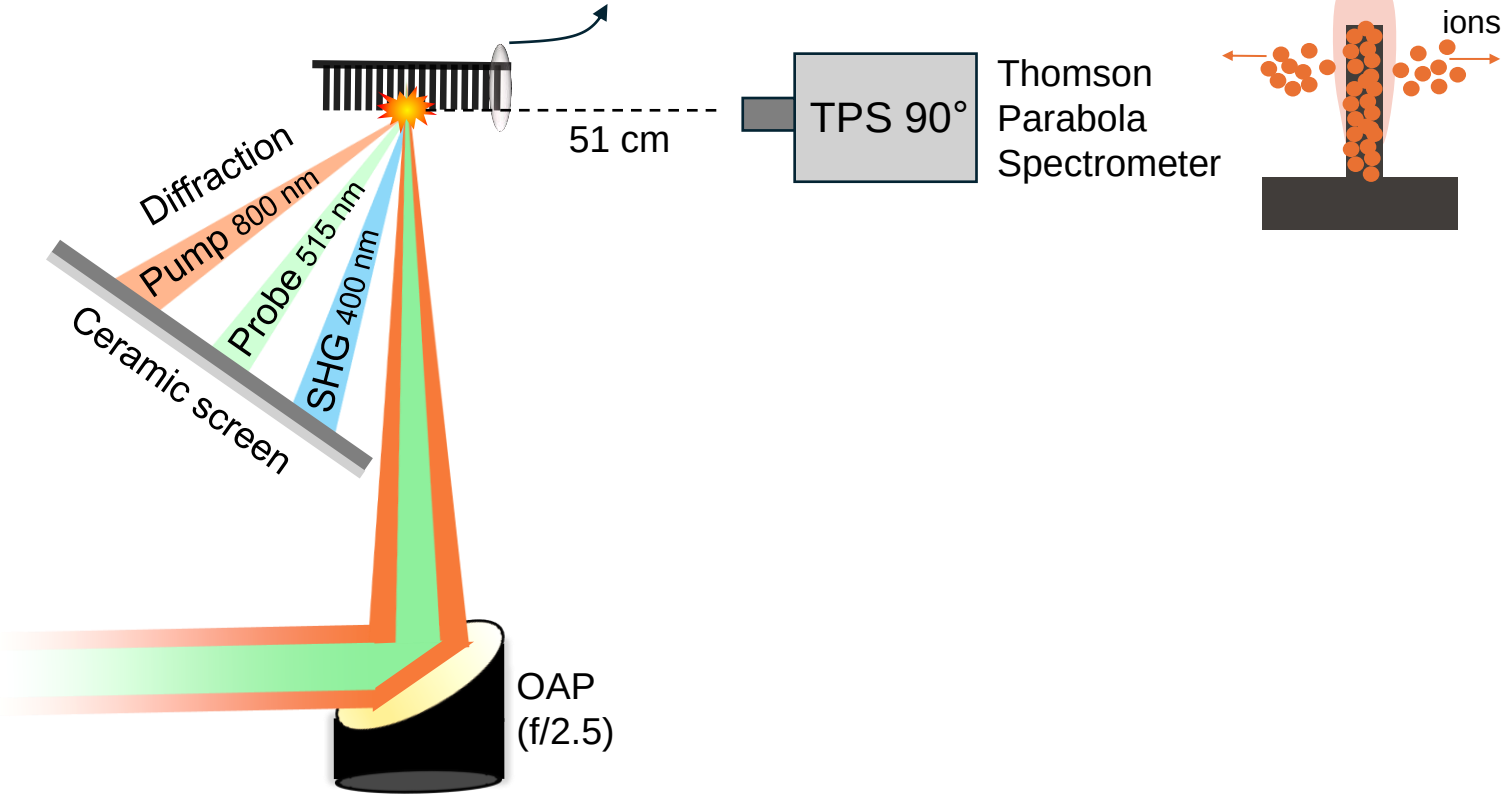
Schematic of the Experiment & Diagnostics

Investigating →

1) pre-plasma expansion of nanowires
2) radial ion acceleration







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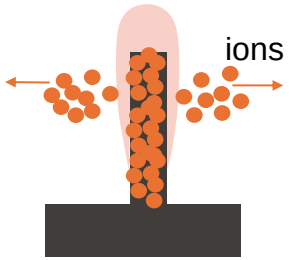
Results: Radial Ion acceleration



- Multiple charged states of Si accelerated to multi-MeV

?

- Si ions accelerated preferentially

- Laser penetrates in NW → heat electrons on NW surface → set up TNSA fields → ion accelertion?

The concept is working.
Can we optimize the acceleration performance?

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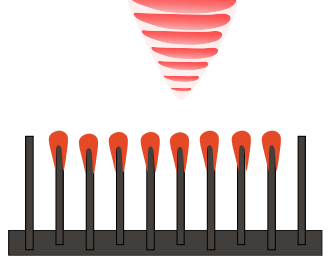
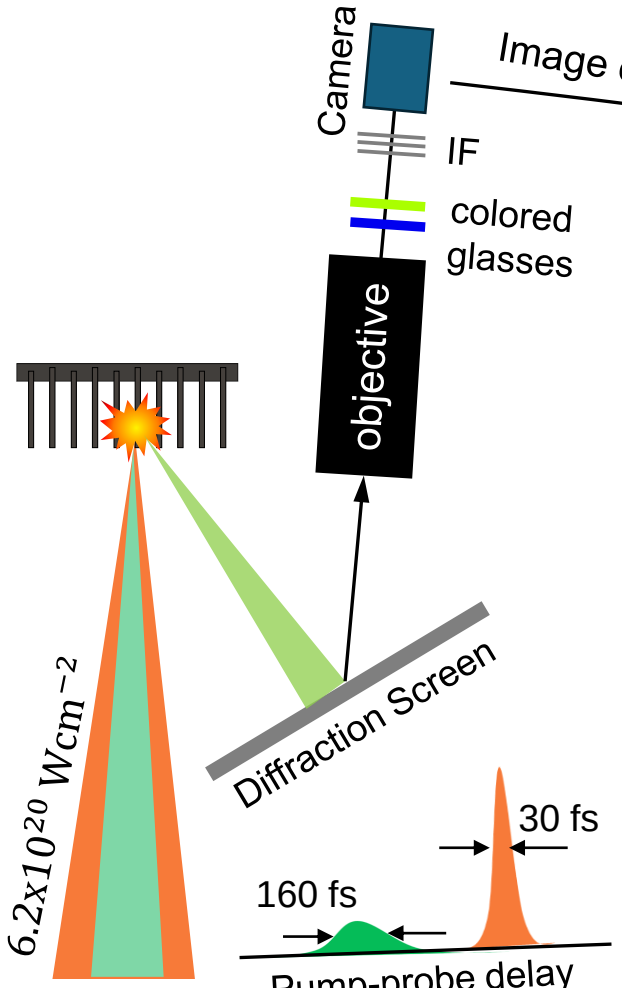
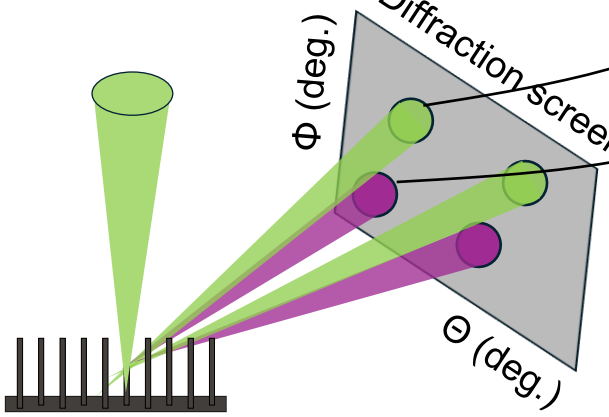
Results: Off-harmonic probing of exploding nanowires



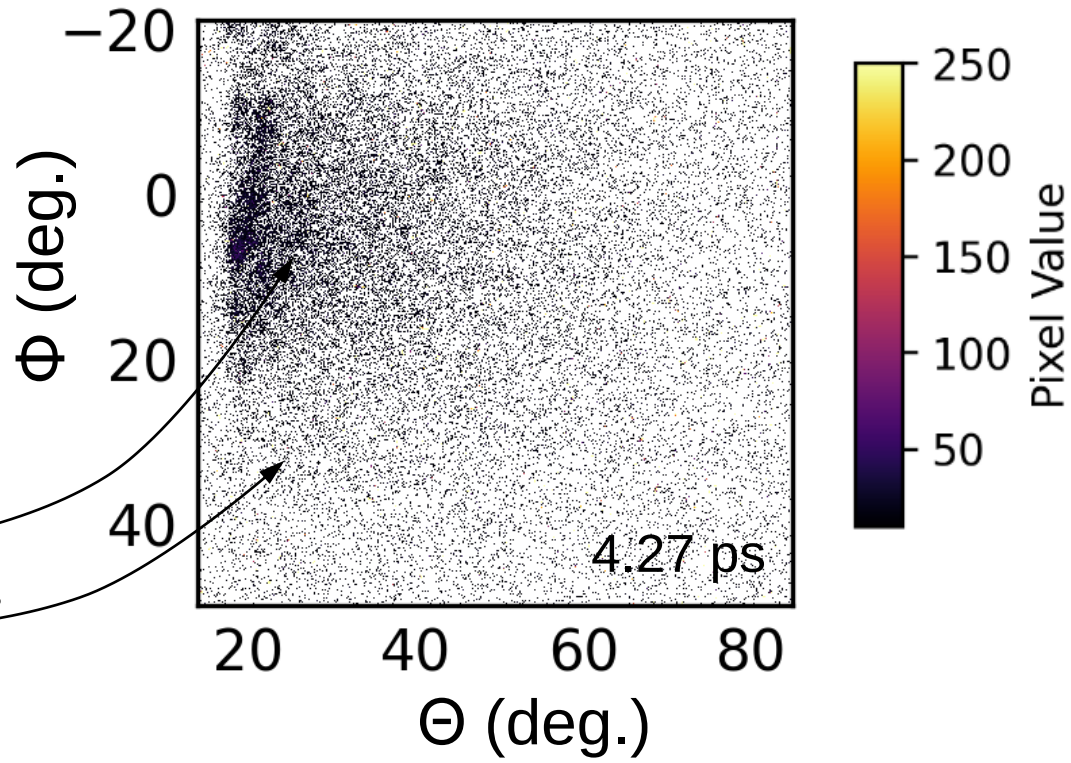
Exploding nanowires



- Strong filtering to reduce plasma emisson → 3 interference filters + Colored glasses
- Two diffraction order captured



Probe difraction signal



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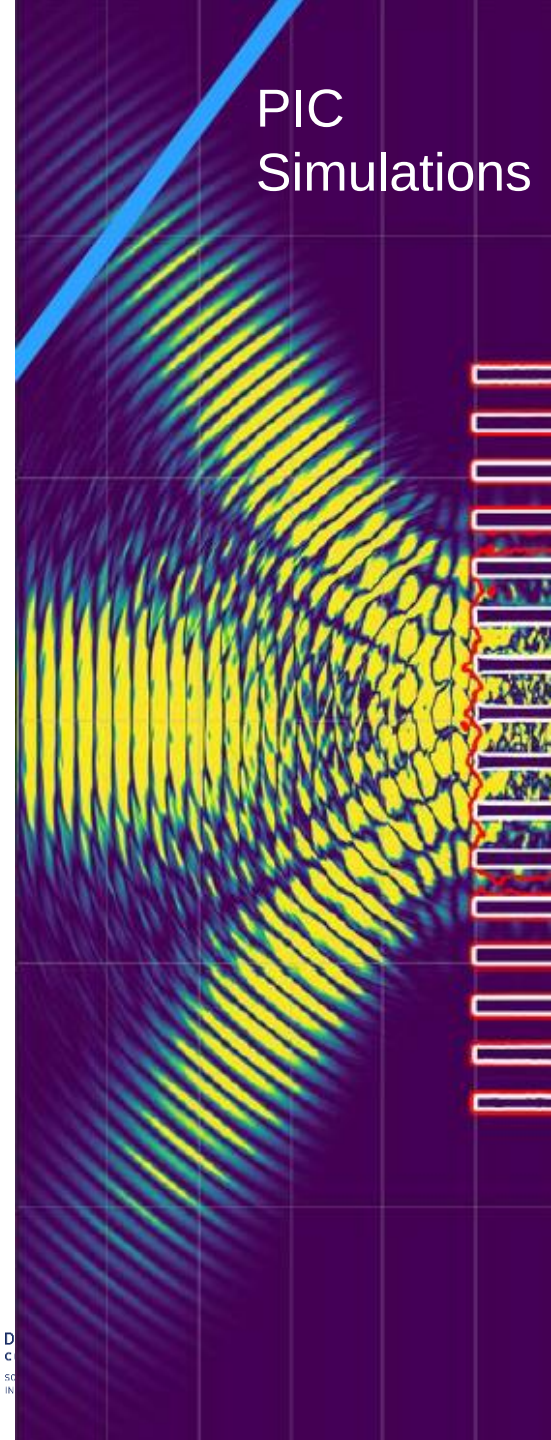
Results: Off-harmonic probing of exploding nanowires

?



- PIC Simulations undergoing for better understanding

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Thank you for you attention!

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