Rooting out the gremlins - stable LWFA operation at the PW frontier

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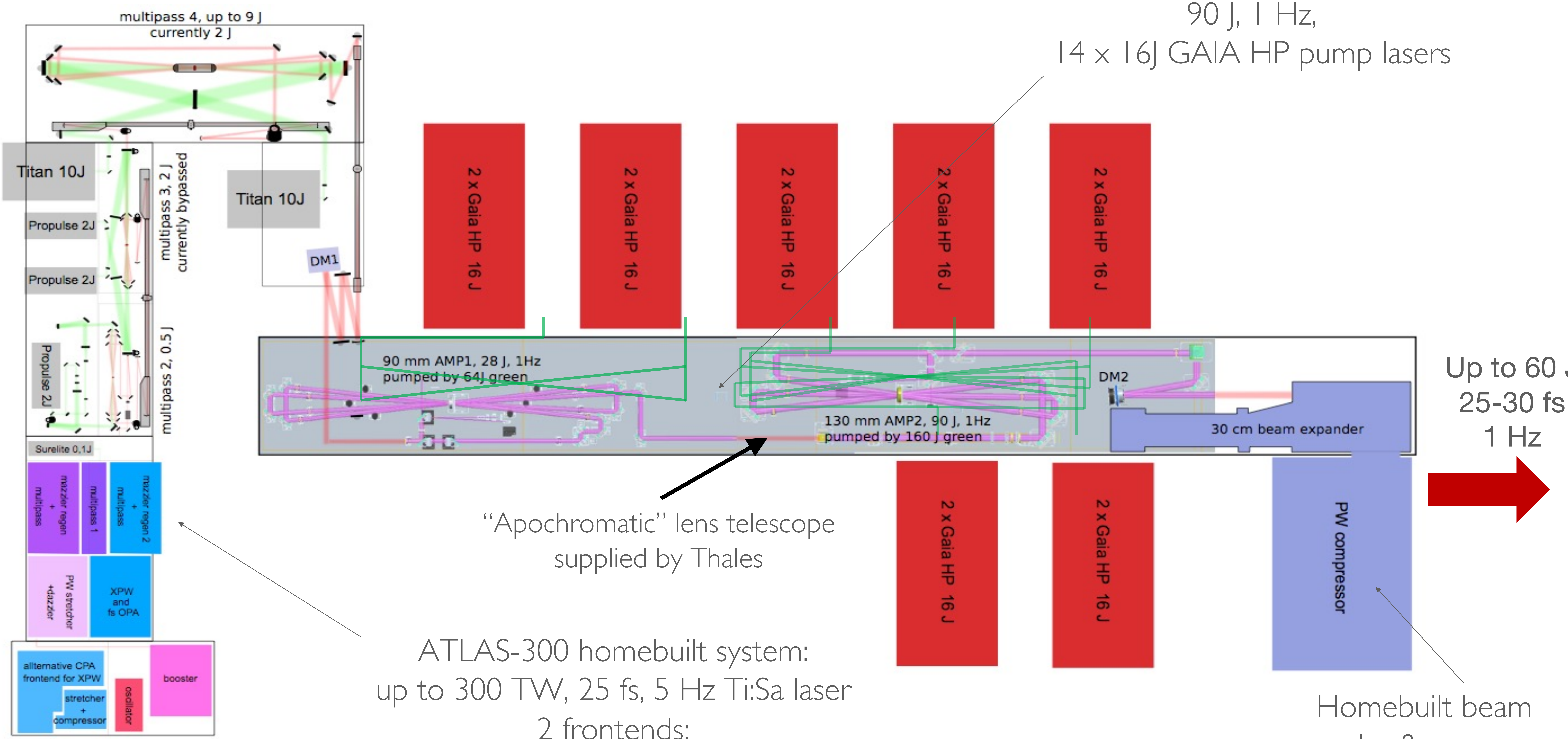
ATLAS-3000 at CALA: Schematic system layout

ATLAS-3000 main amplifier
by THALES LAS
90 J, 1 Hz,
14 x 16J GAIA HP pump lasers



Up to 60 J
25-30 fs
1 Hz

"Apochromatic" lens telescope
supplied by Thales

ATLAS-300 homebuilt system:
up to 300 TW, 25 fs, 5 Hz Ti:Sa laser
2 frontends:

- ps booster, sat. absorber + Amplitude stretcher & regen
- double CPA, XPW + fs-OPA + Amplitude stretcher & regen

Homebuilt beam
expander & compressor

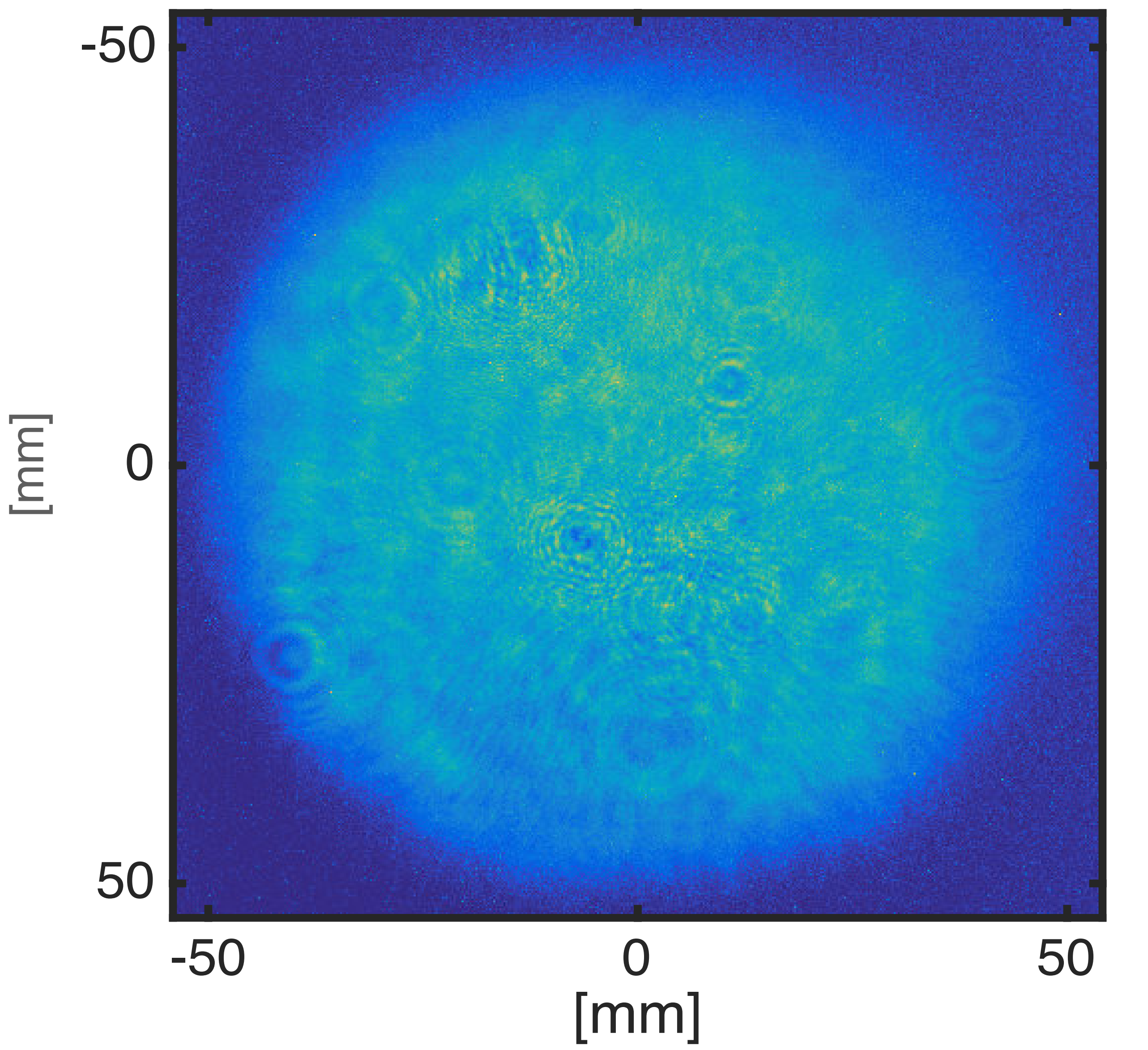
ATLAS-3000: on-paper performance

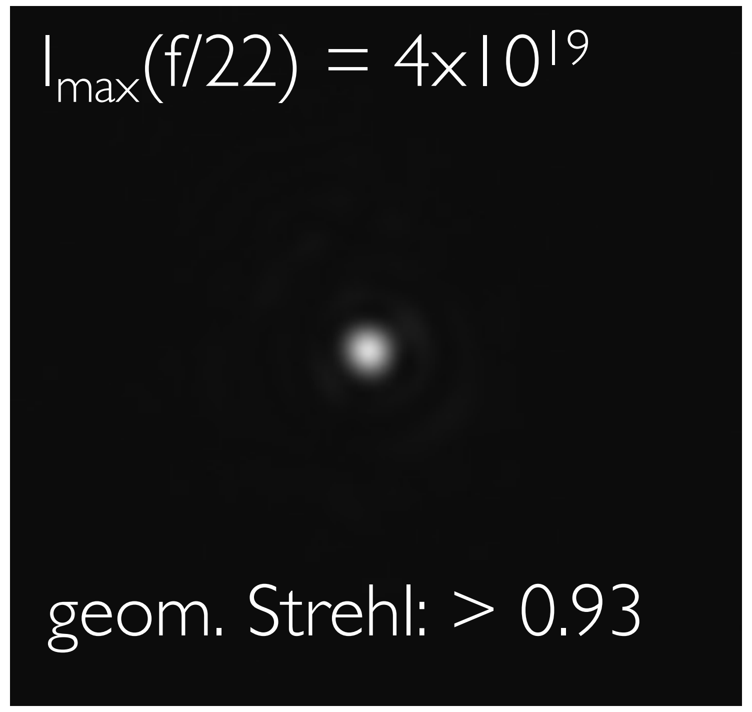
near field

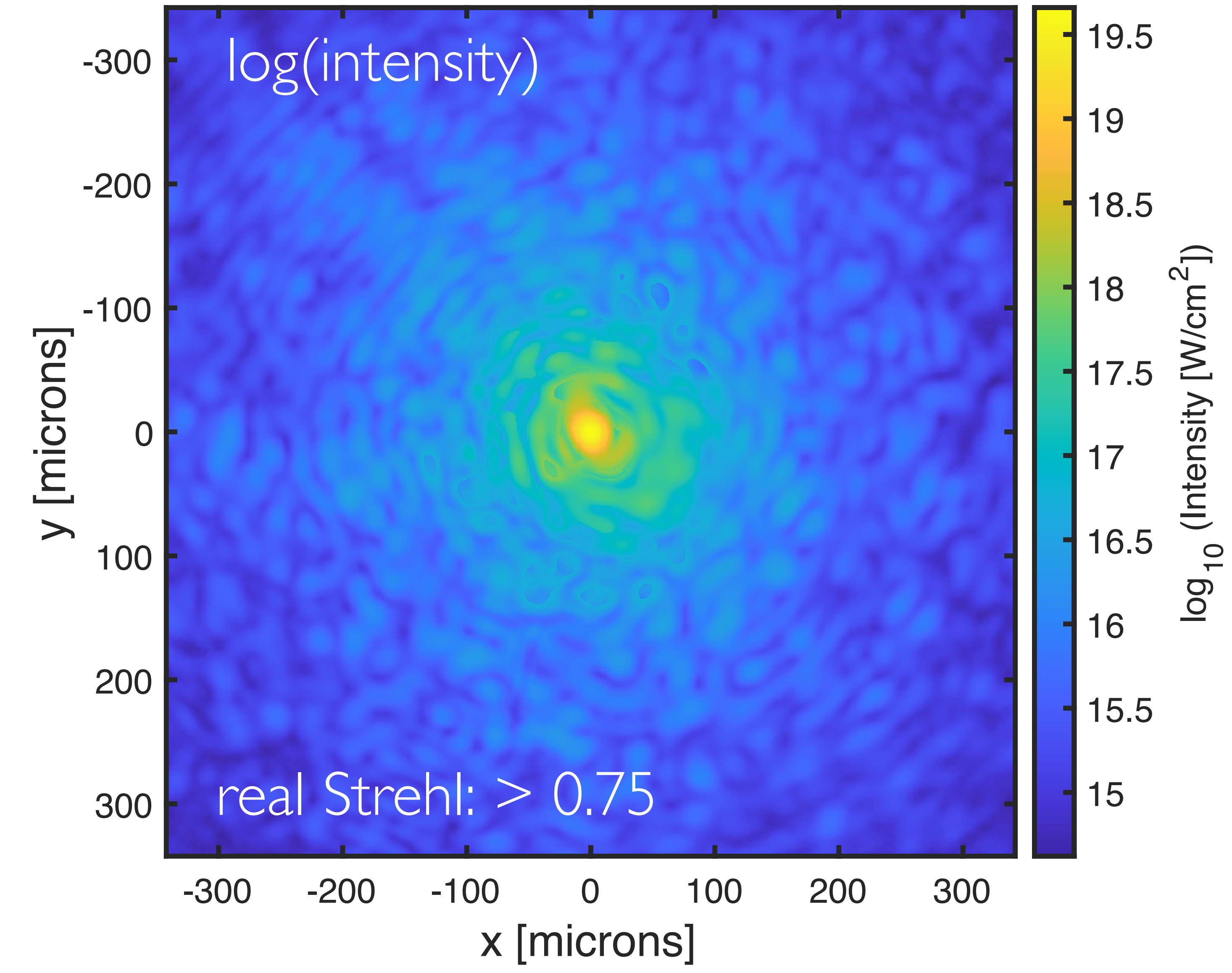
far field

contrast

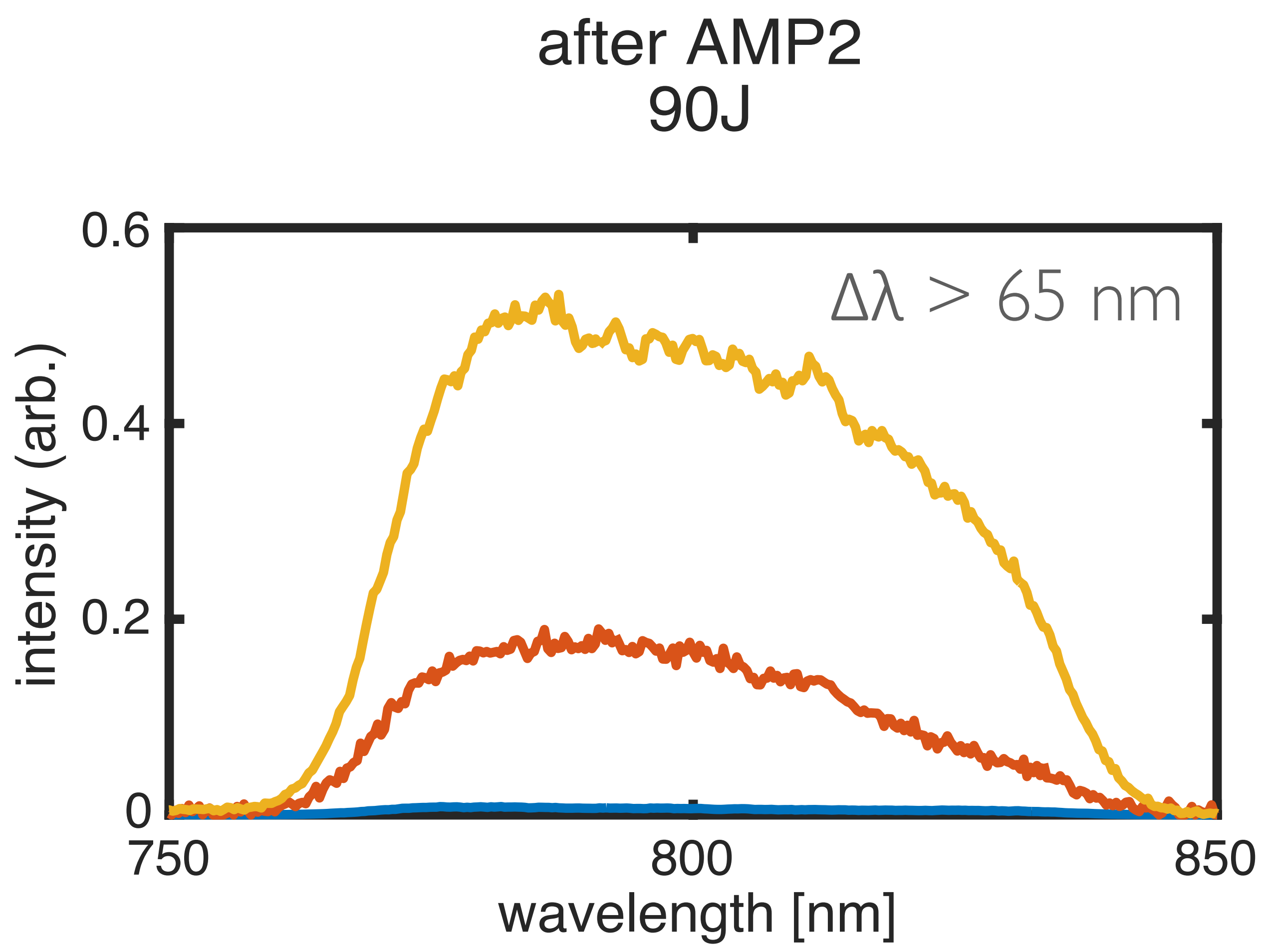
spatial

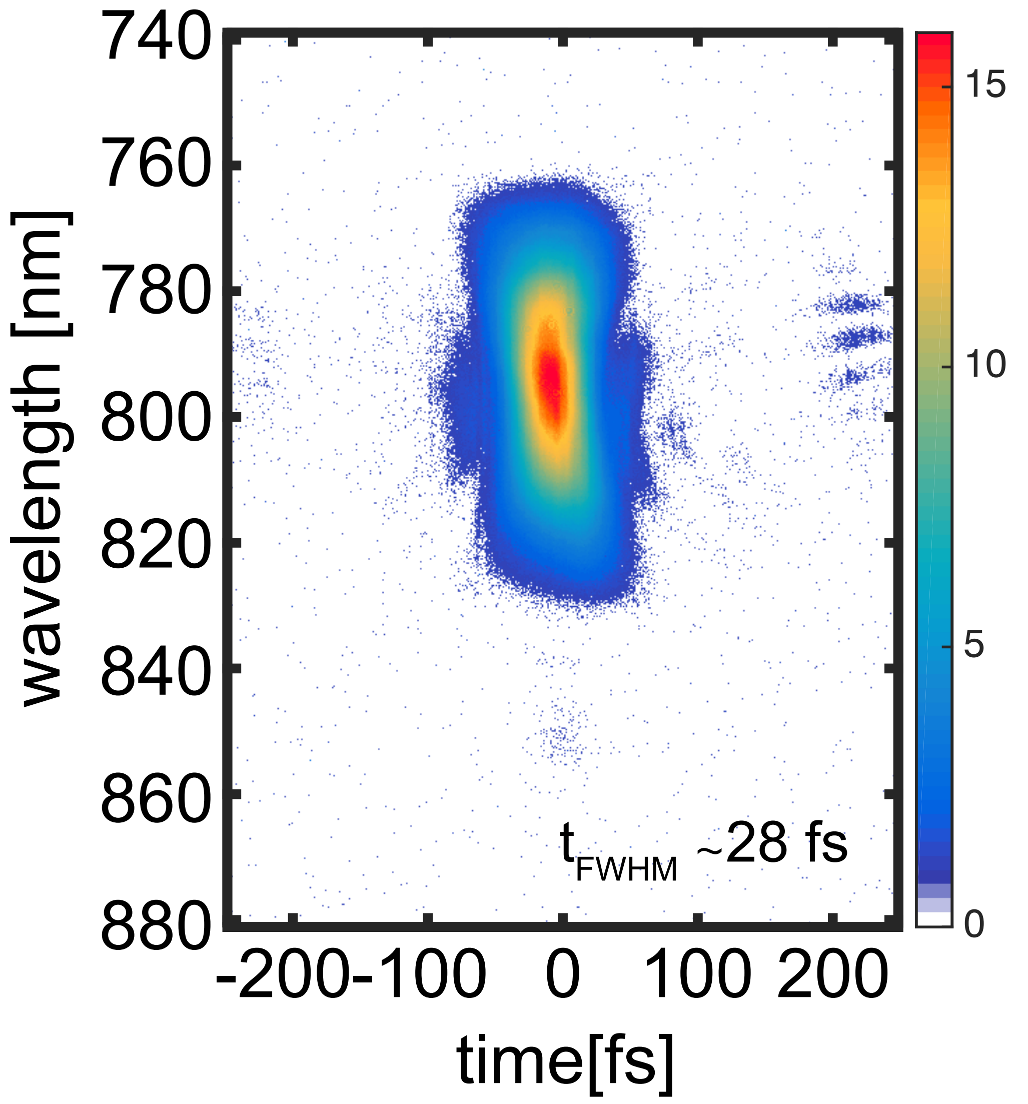


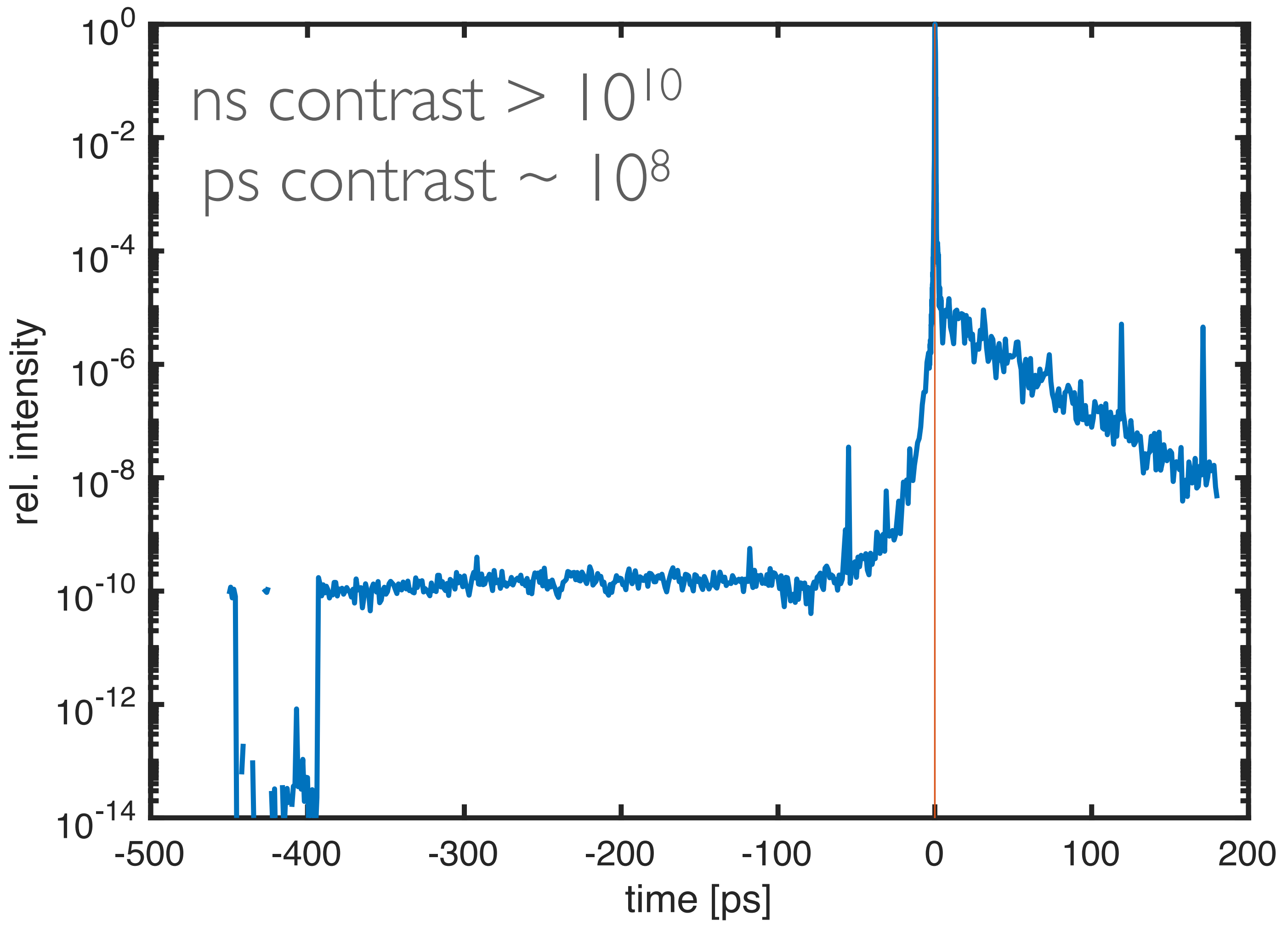




spectro-temp.

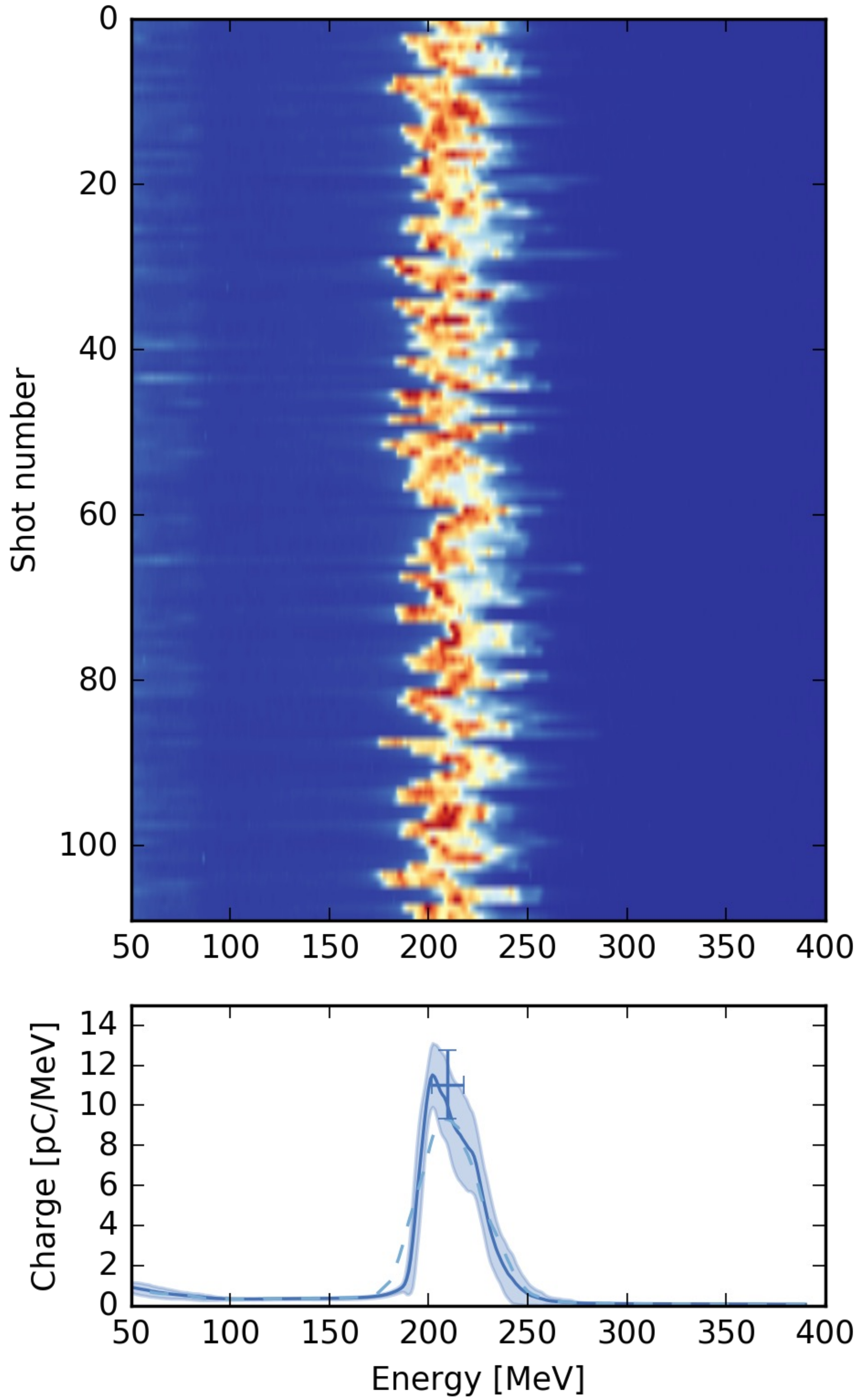






First laser wakefield acceleration results: LWFA by shock-front injection

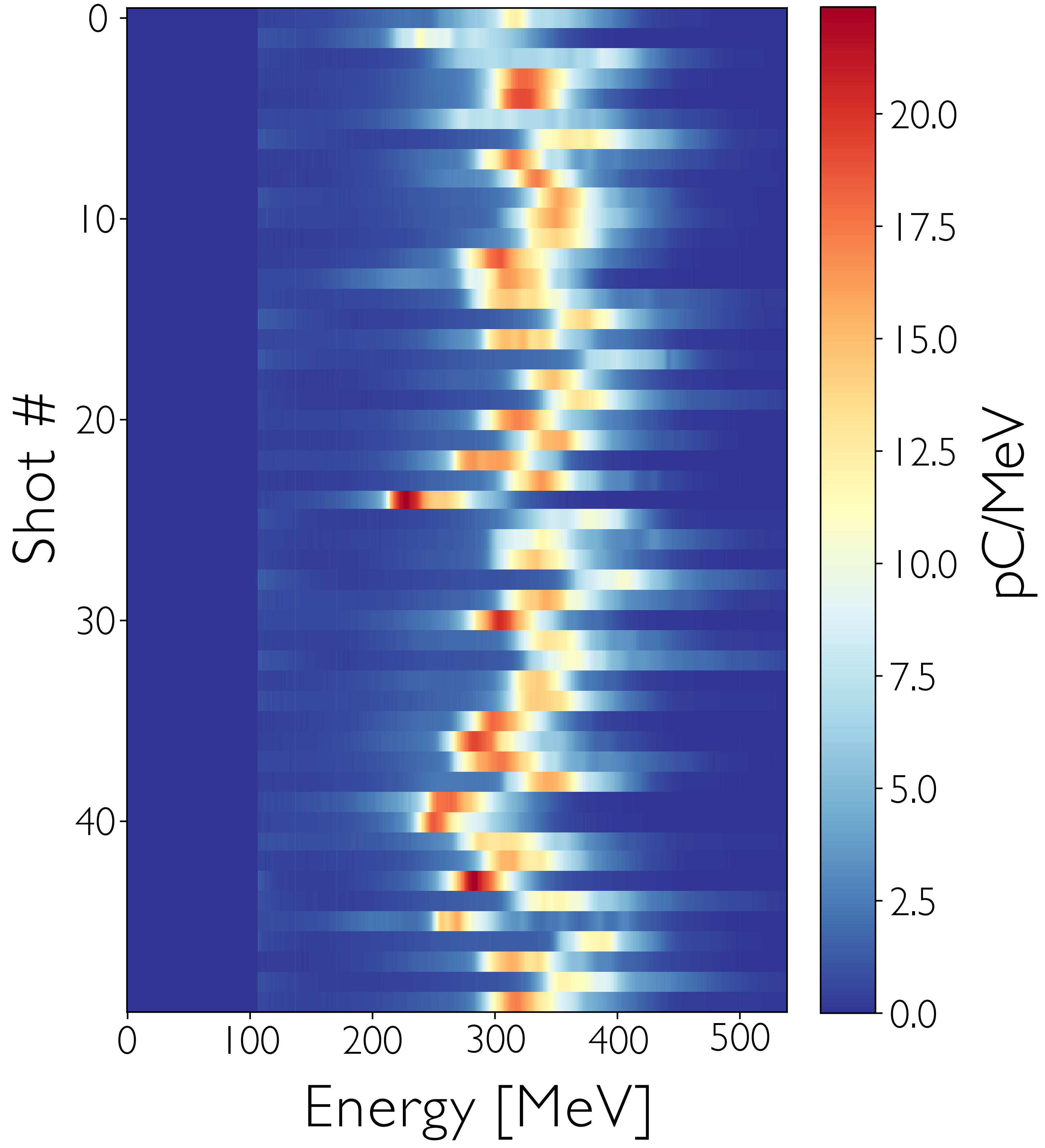
old laser, 80 TW on target
f/22, 5 mm gas jet



Similar experiment

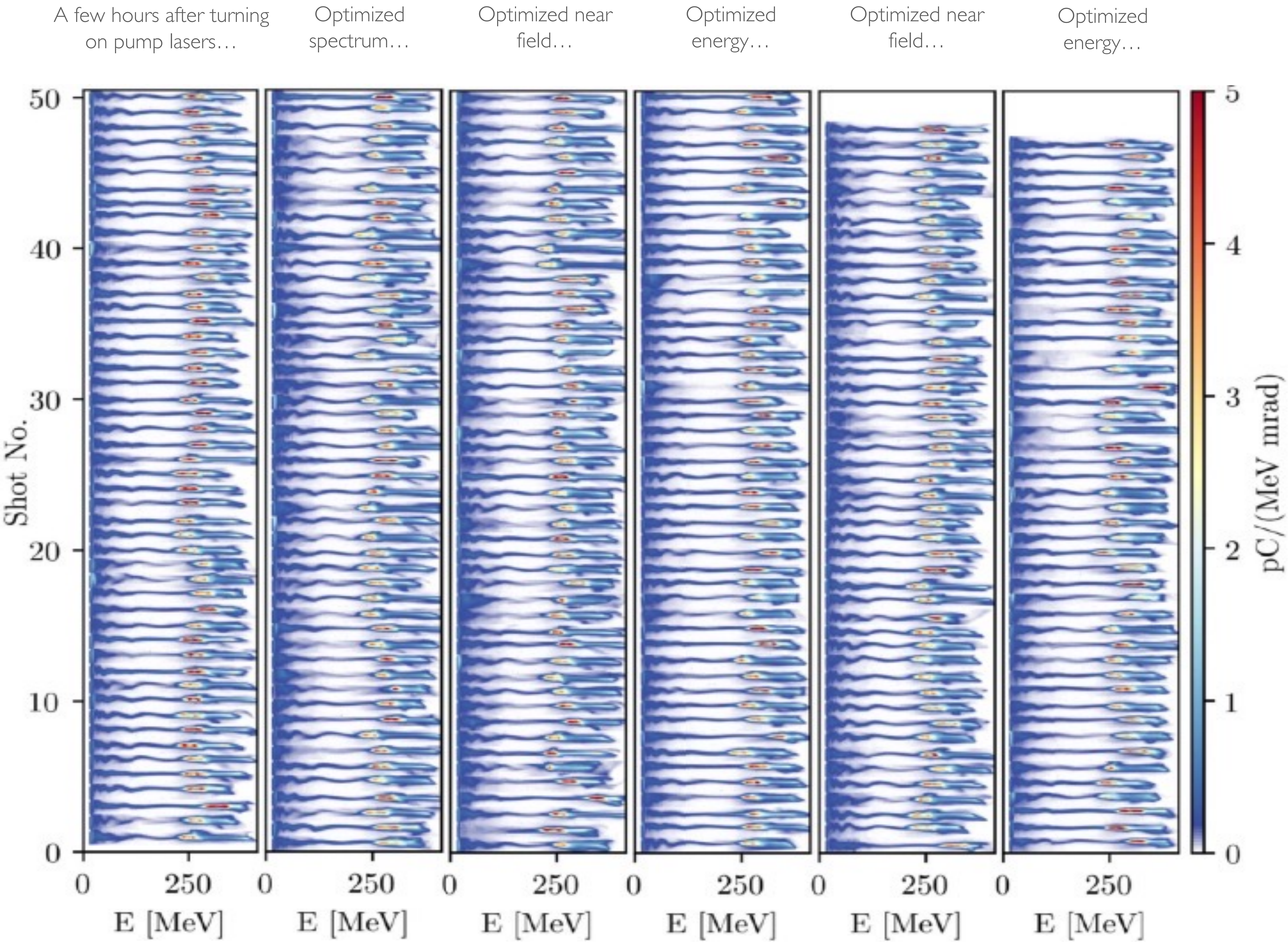
Stability ?

upgraded laser, 250 TW on target
f/22, 5 mm gas jet

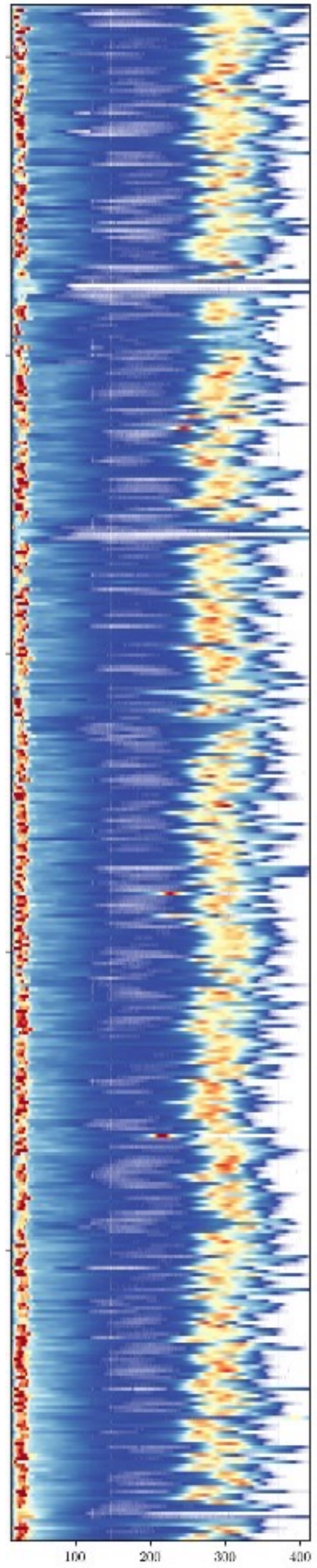


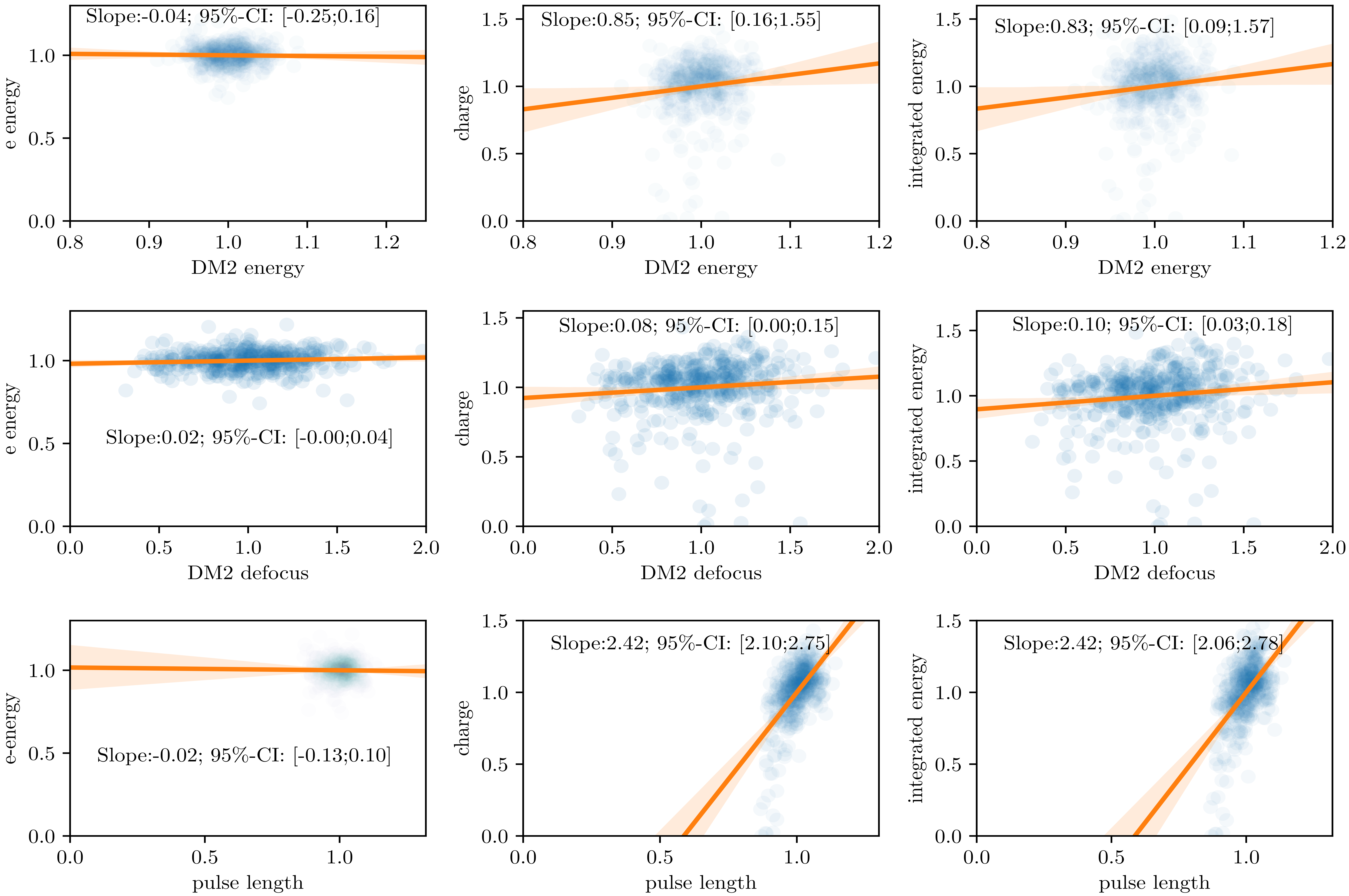
First step:

- f/33
- Cheap trick: mixed gas for ionization-assisted shock injection



Correlations ? … not clear

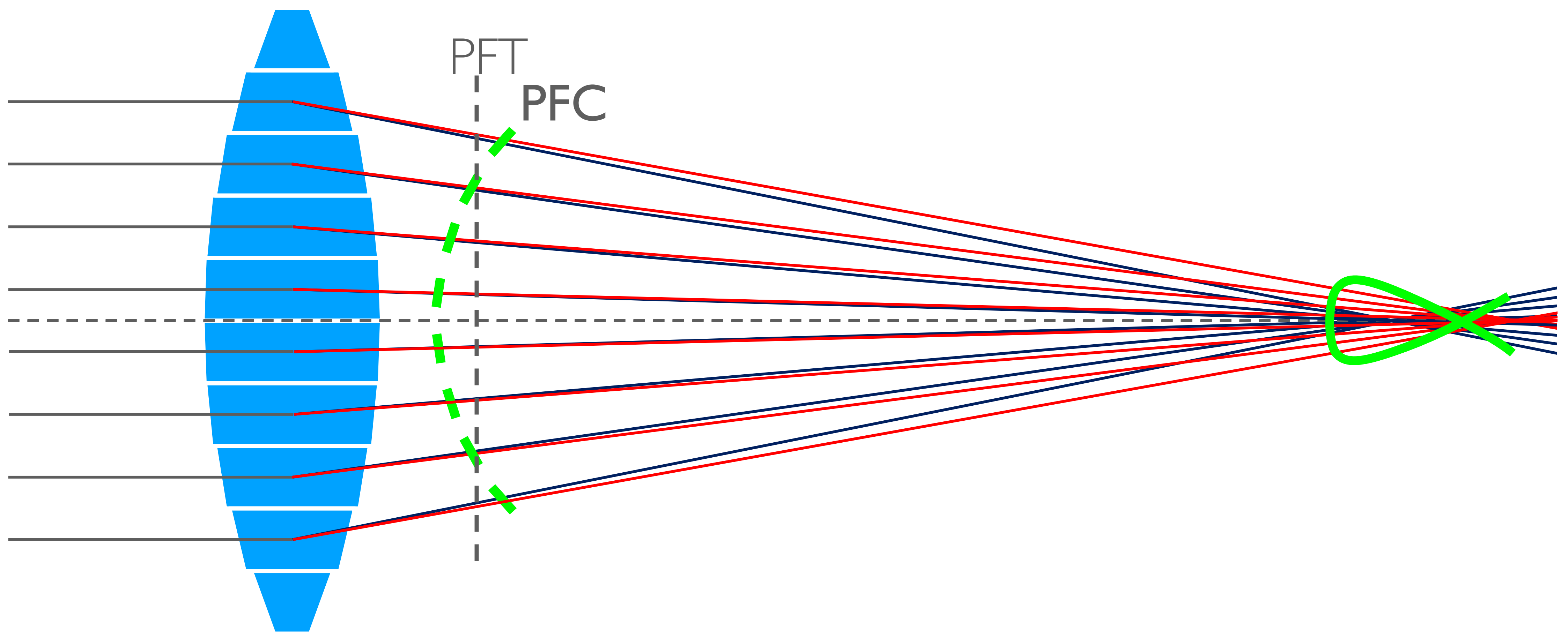




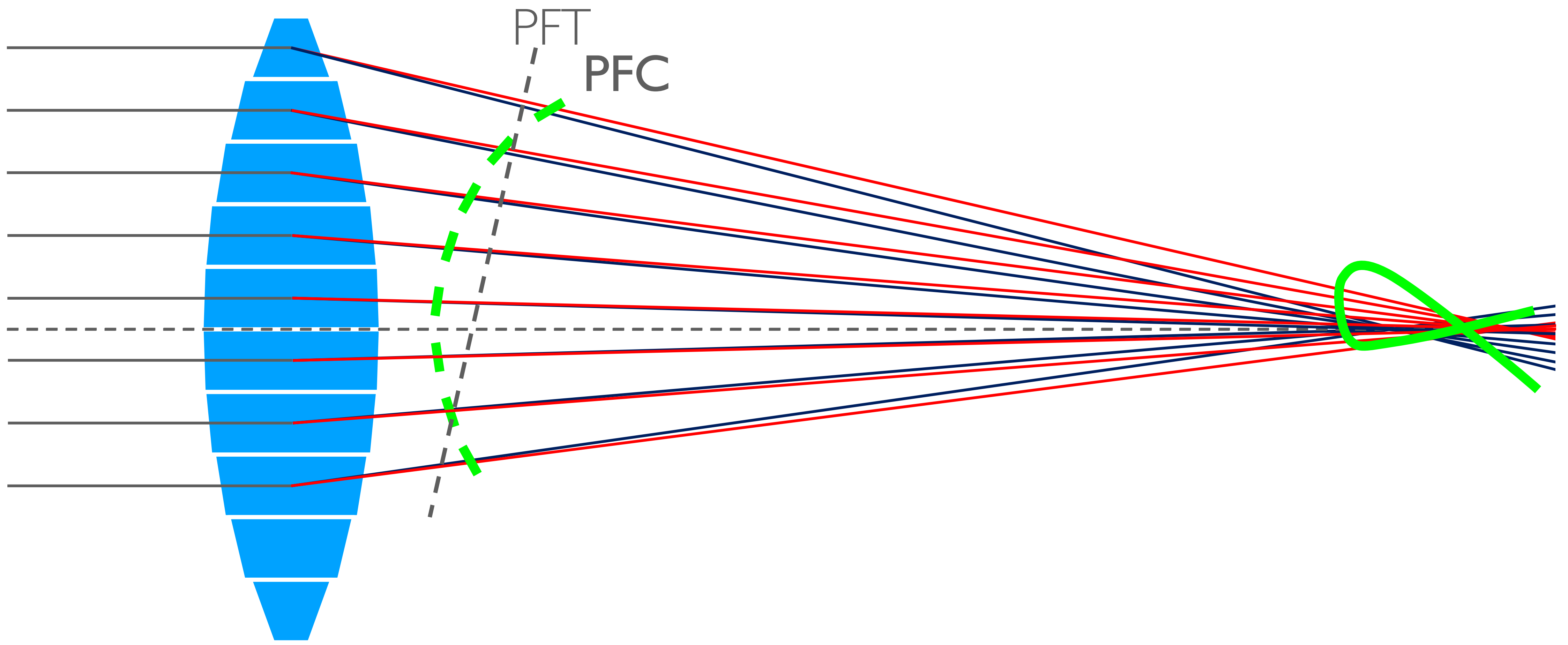
Hidden parameters?

Spatio-Temporal Couplings (STCs) by chromatic optics (beam expander telescopes)

Chromatic lens causes pulse front curvature (PFC)



Off-center bundle in chromatic lens causes PFC and pulse front tilt (PFT)

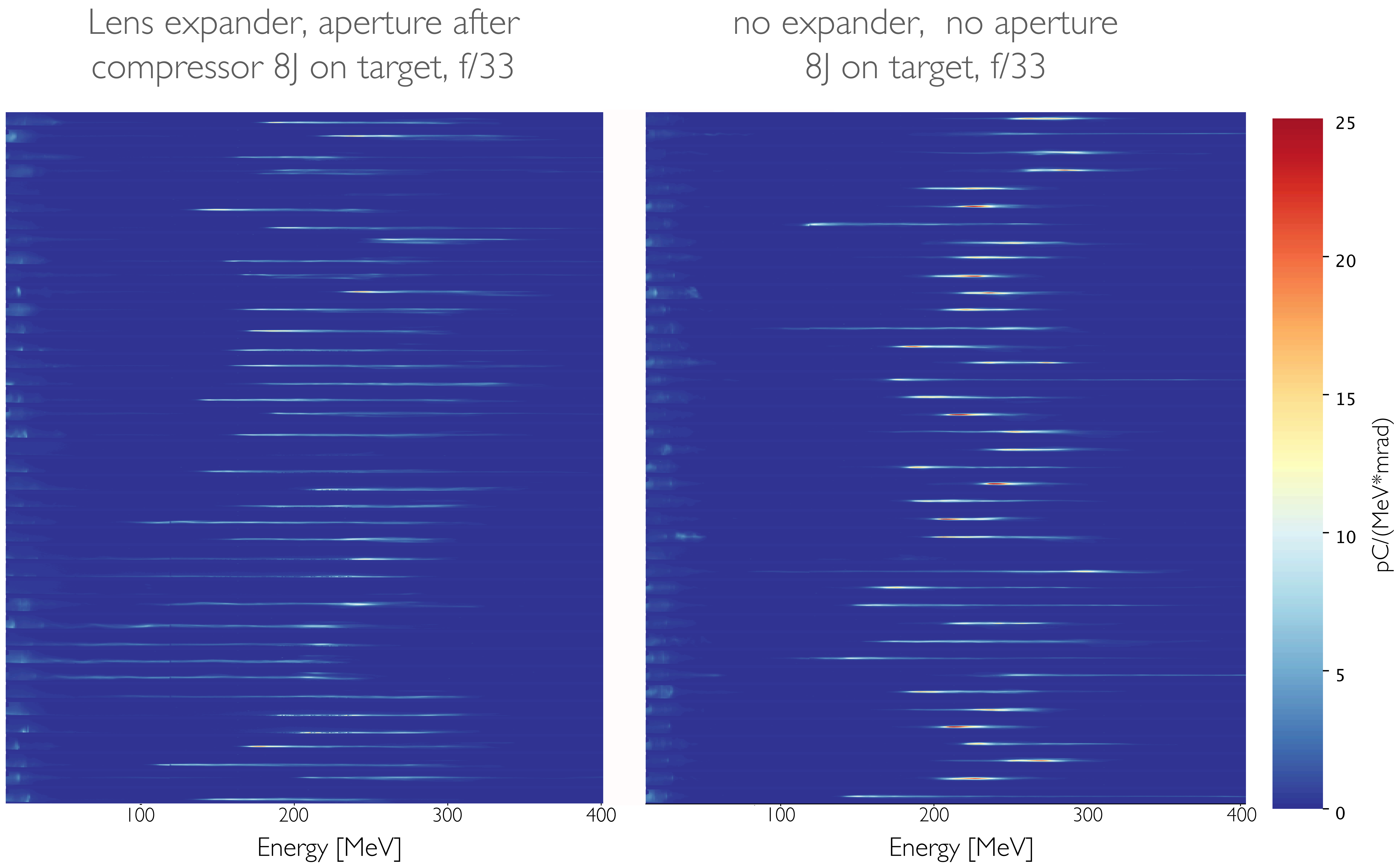


“A(po)chromatic lenses are free from PFT/PFC“ ⇒
Triplet lens expander between AMP1 and AMP2 is designed apochromatic within lambda/50

Yet still detect PFT after beam shift ⇒ expander in practice is not free from STCs

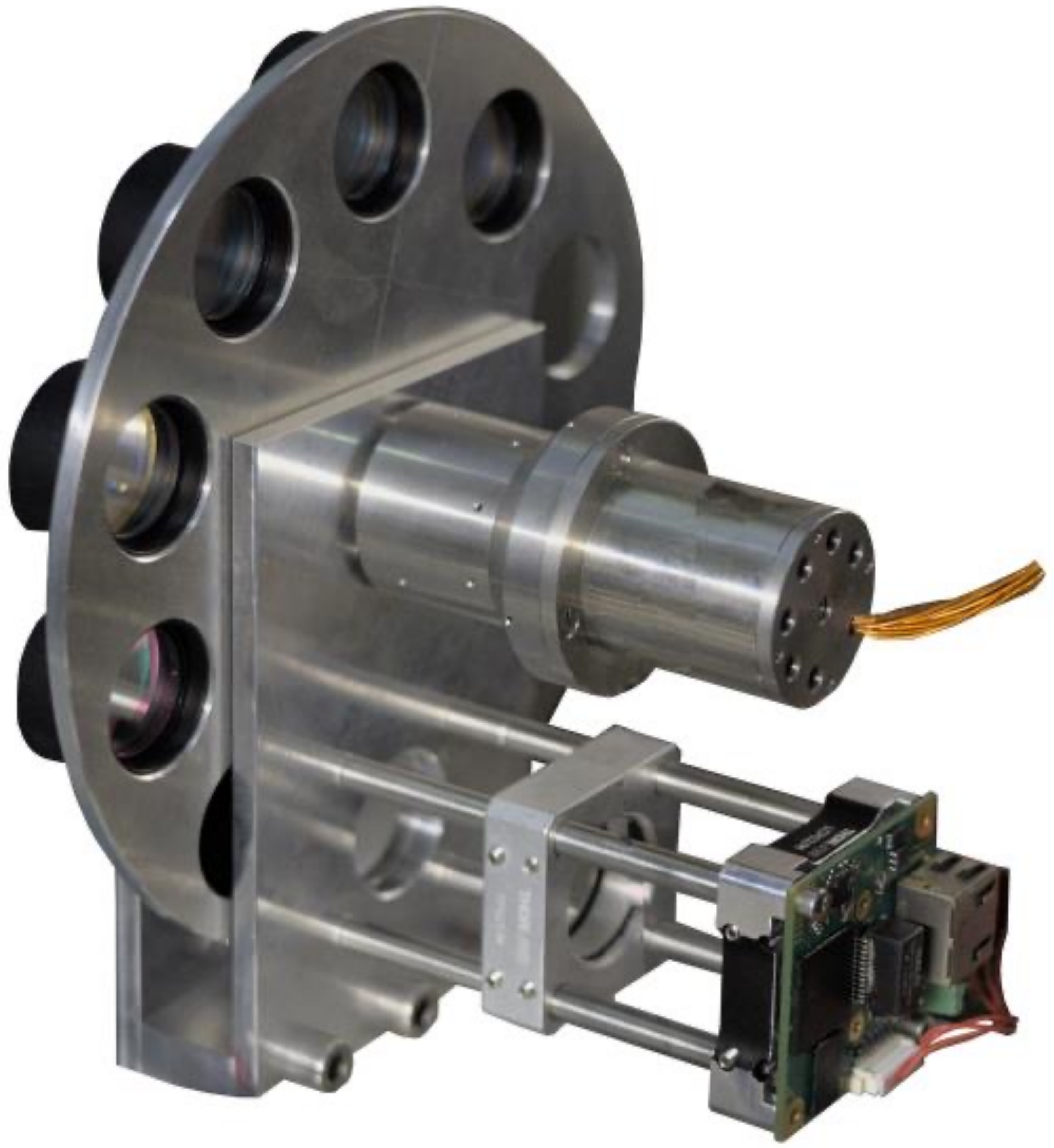
Replace “perfect“ lens telescope by reflective expander

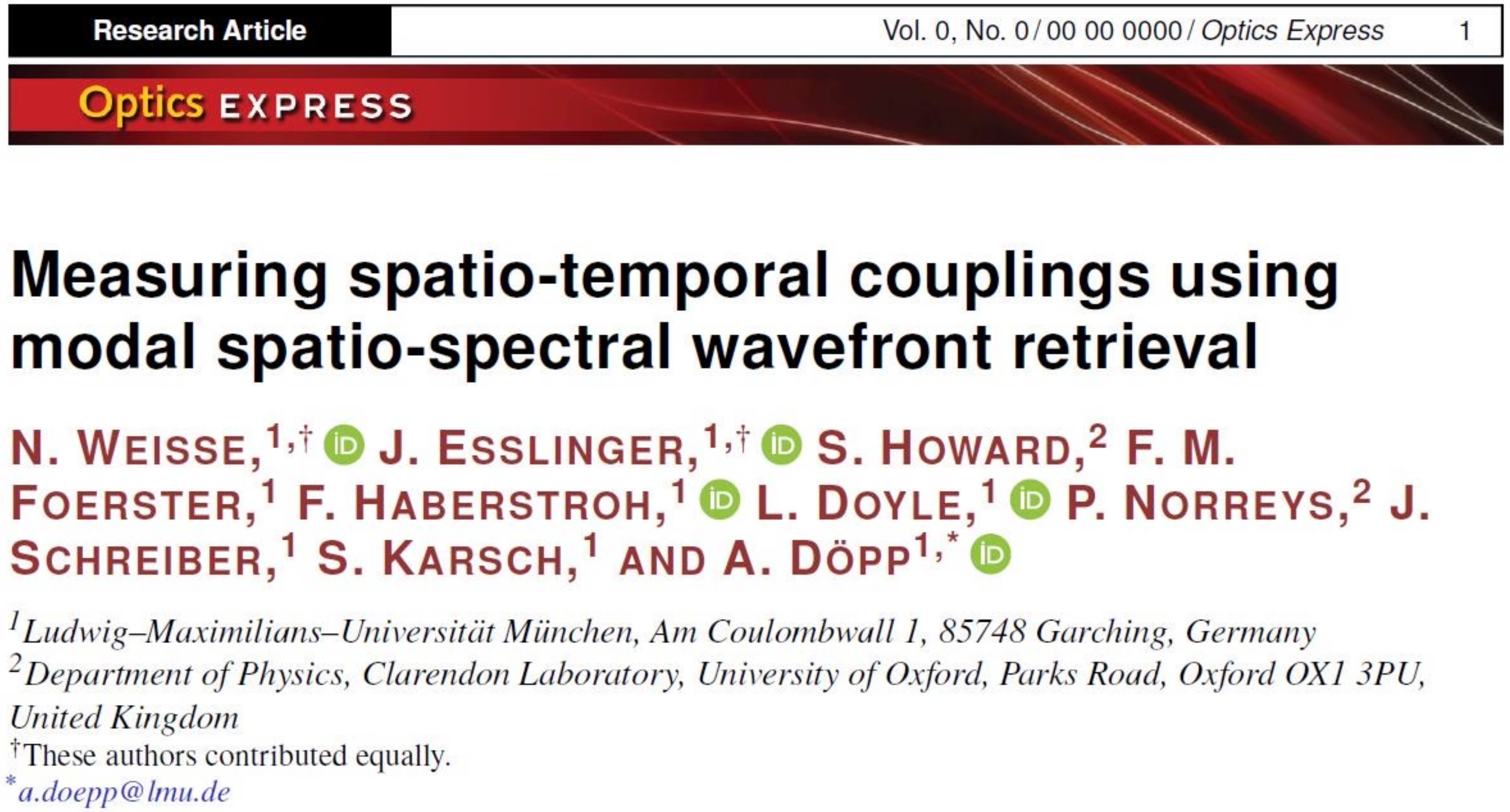
Suppression of STCs improves electron performance (pure hydrogen)



Falcon device:

- Spectrally resolved Shack-Hartmann-wavefront sensor
- Measurement of Spatio-Temporal Couplings by spectral wavefront retrieval
- Take 10 images per filter position to average out pointing jitter





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Optics EXPRESS

Measuring spatio-temporal couplings using modal spatio-spectral wavefront retrieval

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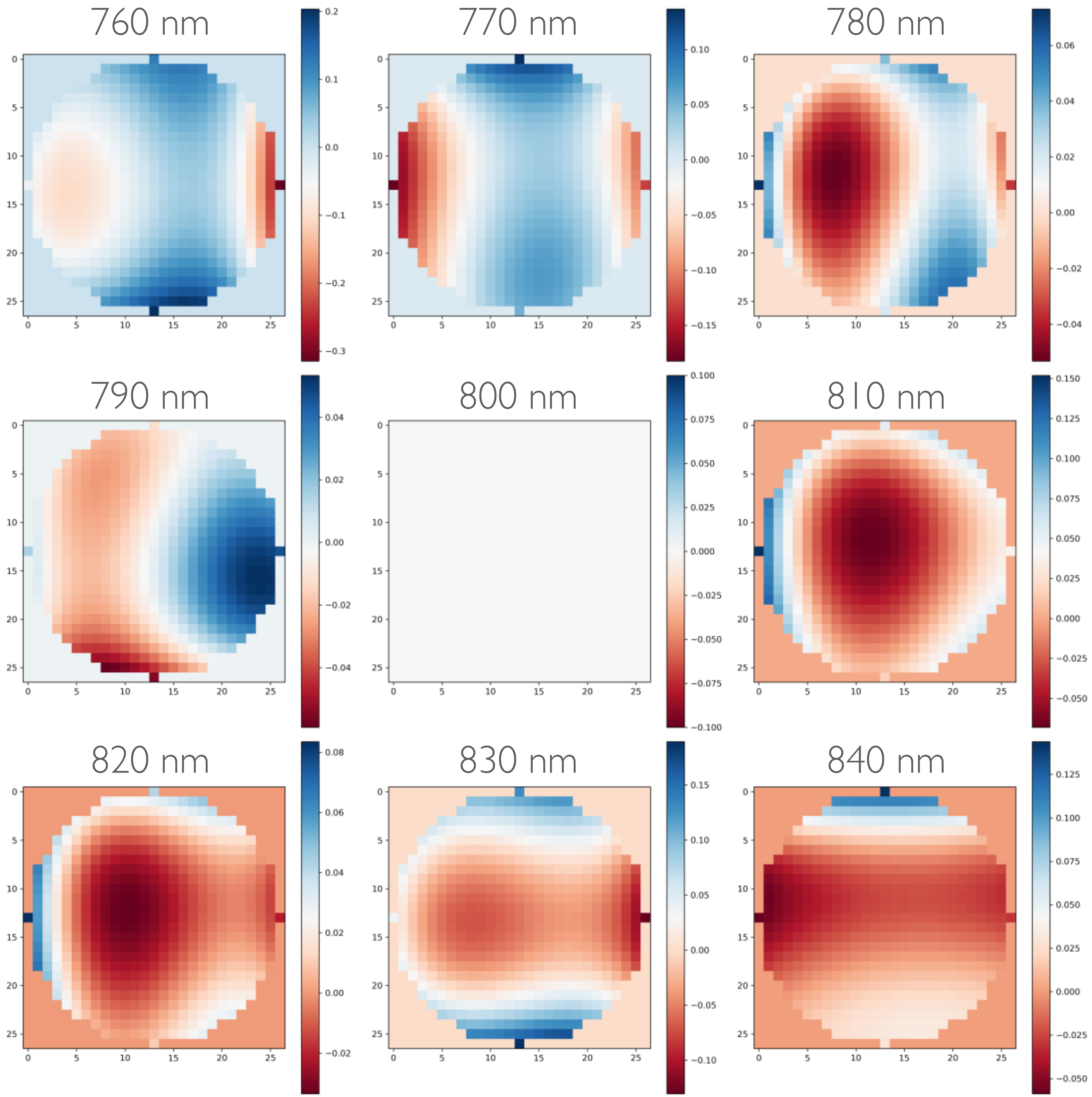
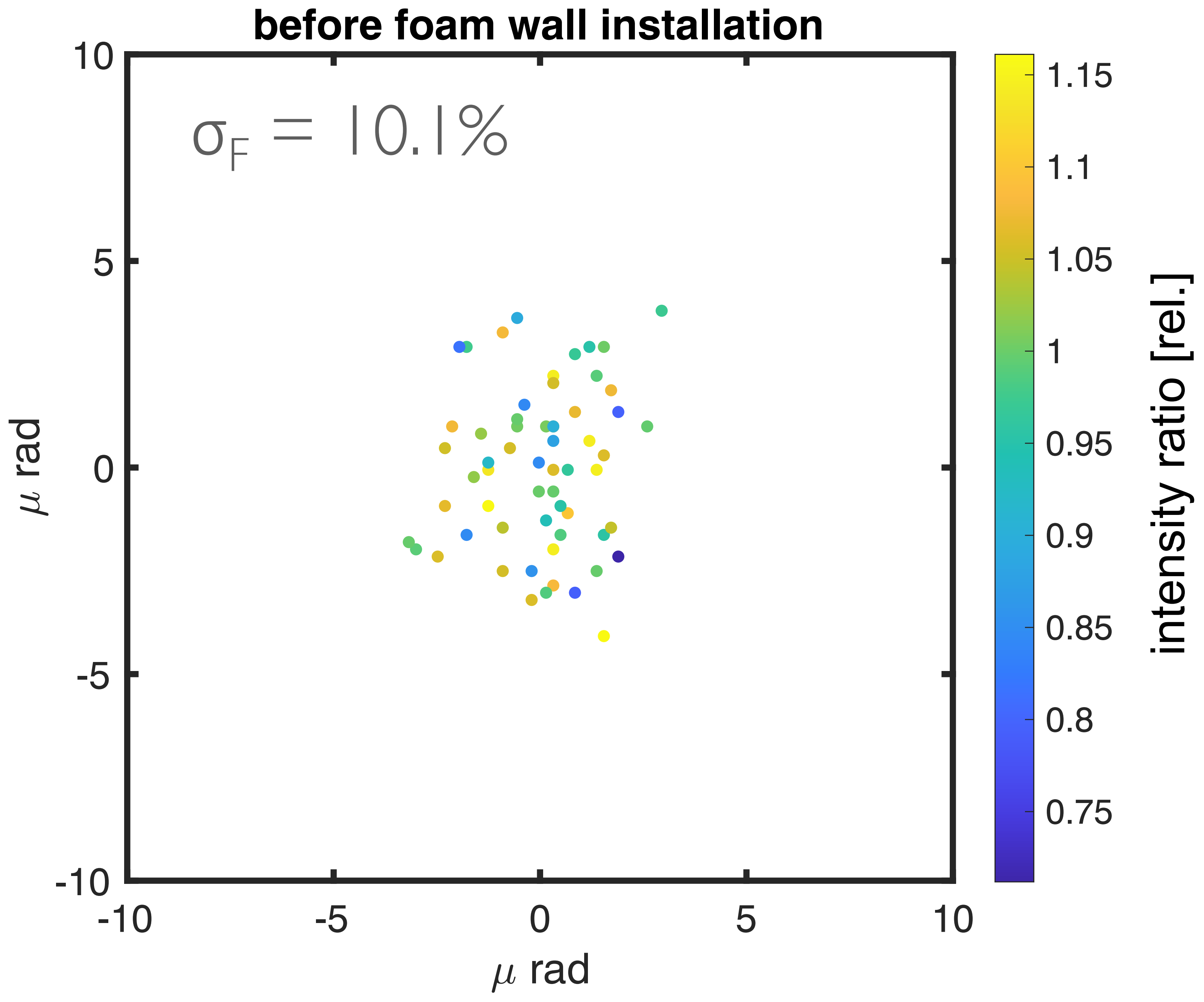


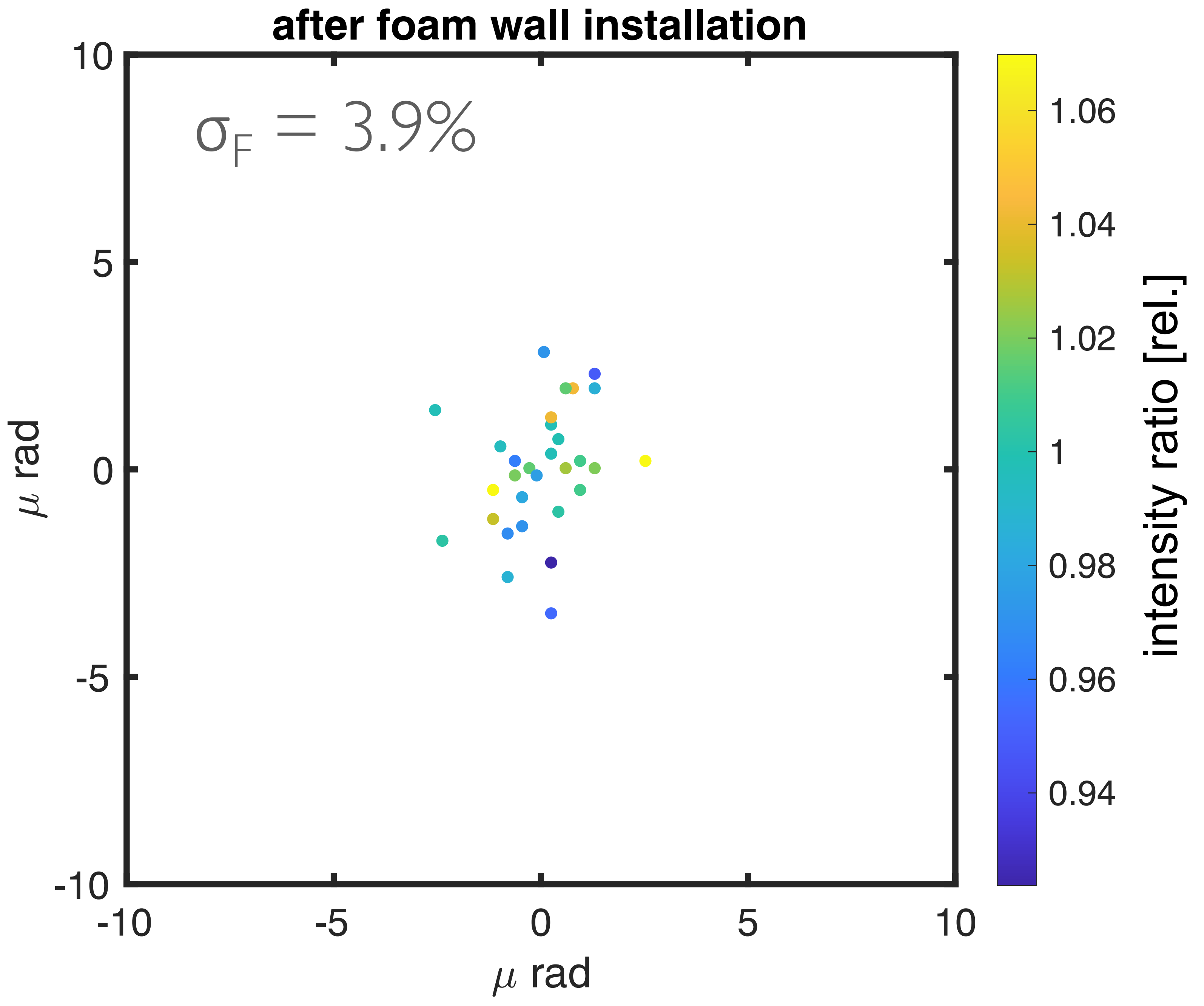
PtV <0.2 λ

	8.5.23	11.5.23	15.5.23
Pulse front tilt µrad/nm	-2.6e-6	-2.0e-5	-7.7e-6
Pulse front tip µrad/nm	-7.7e-6	-6.2e-5	-1.1e-4

Pointing and fluence variations by air turbulence (after eliminating heat sources):

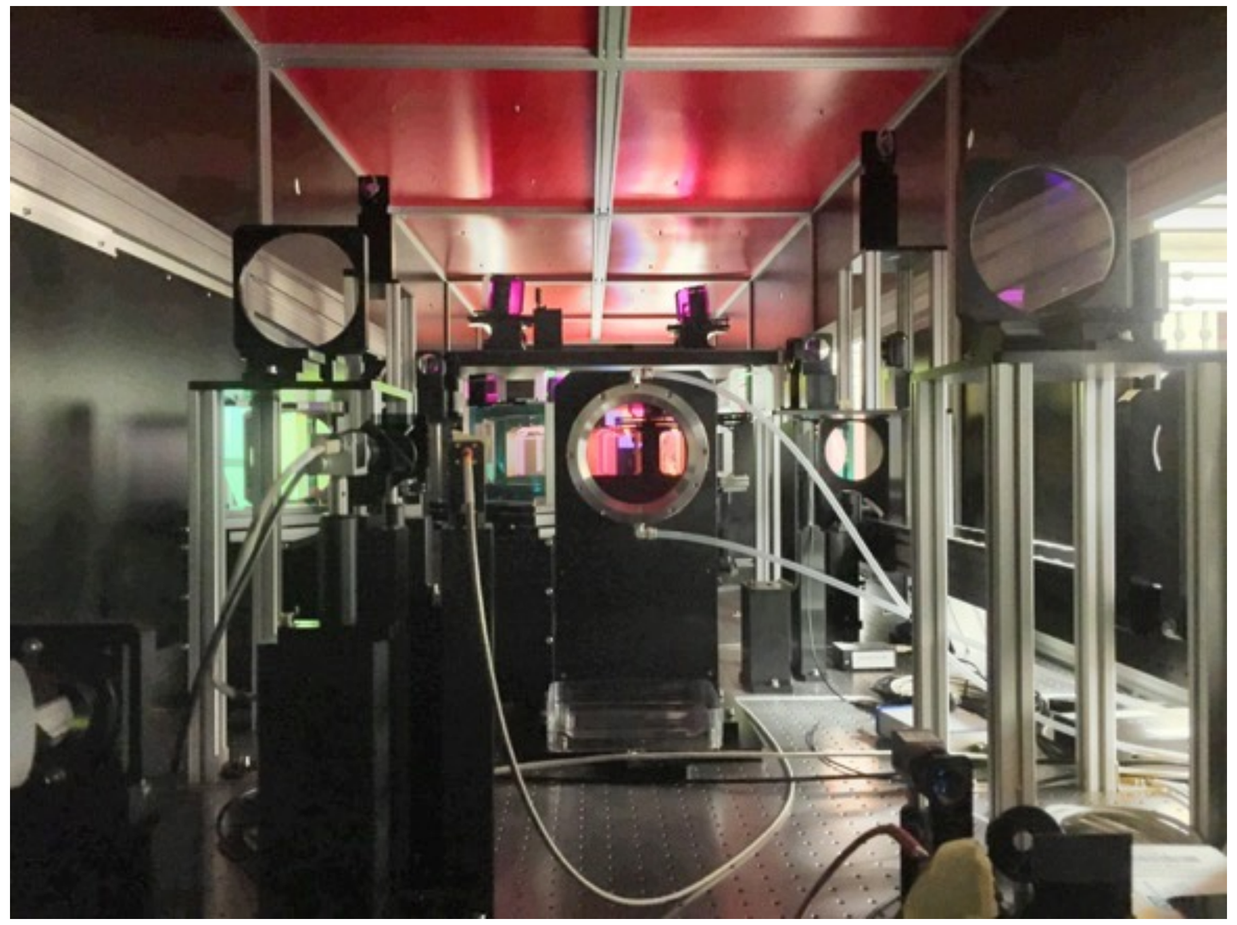
Moving from 100 TW to PW: as beam size and optical path increase, so does susceptibility to air turbulence.

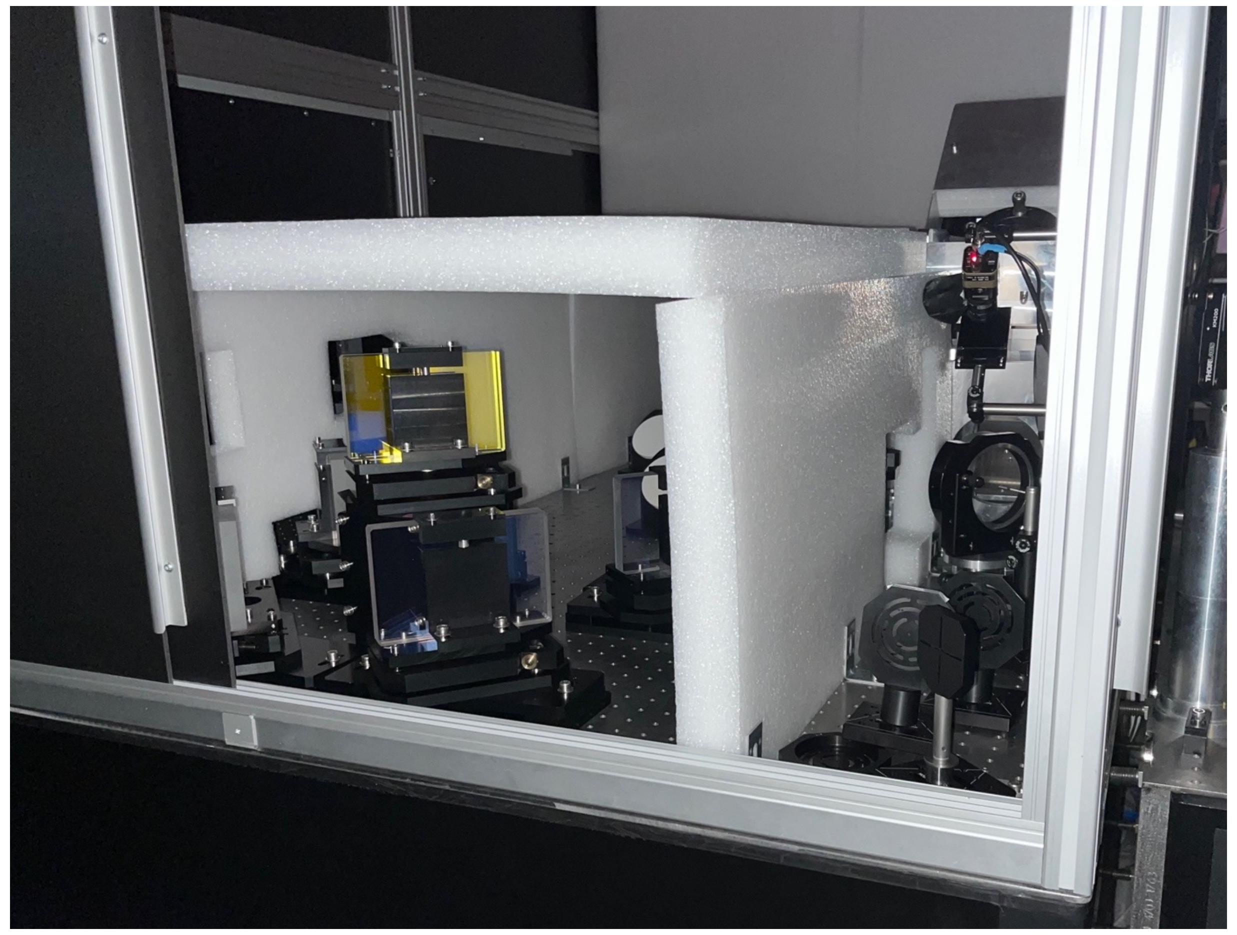




Recently: more foam walls:

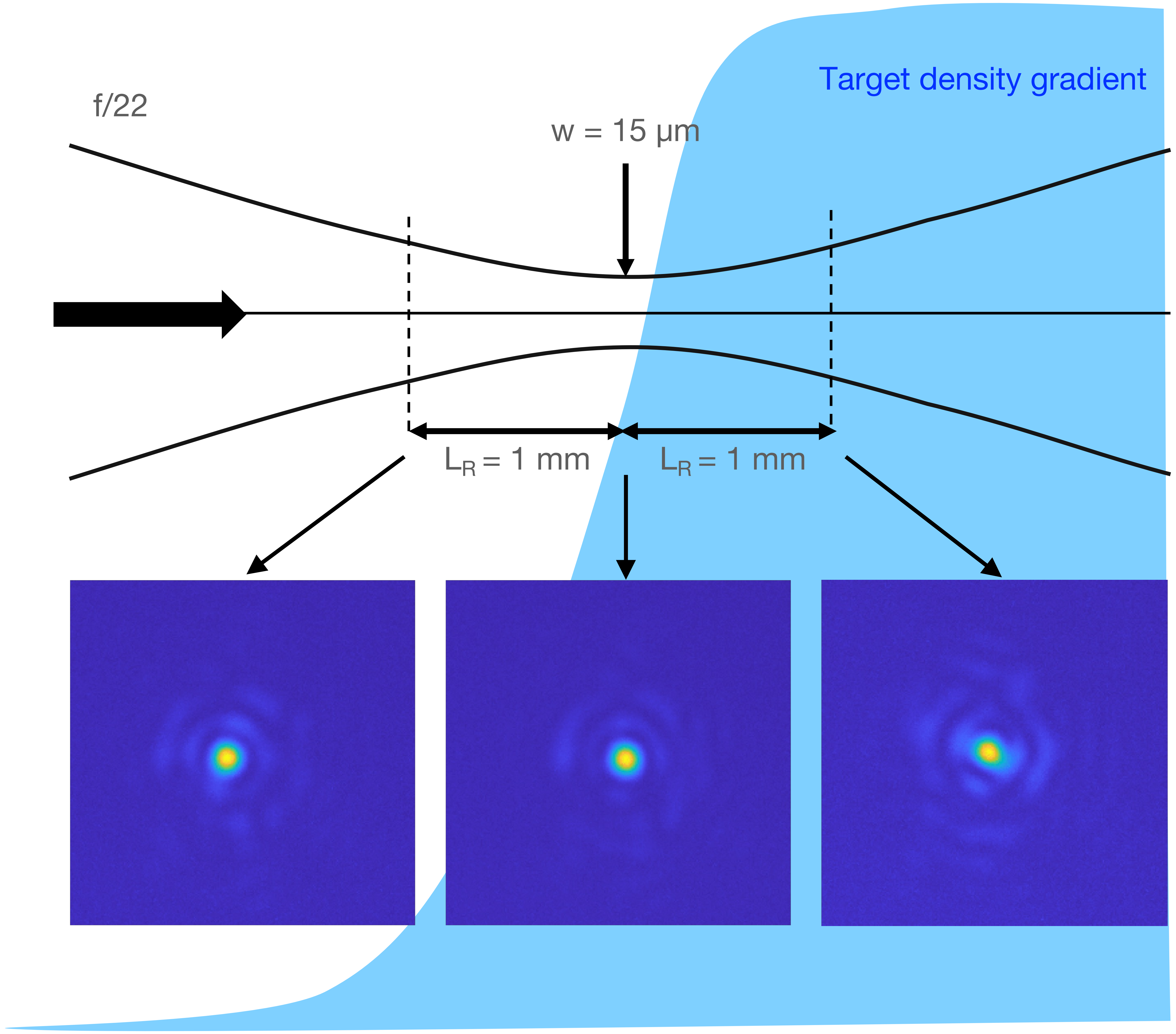
$\Longrightarrow \sigma_F = 2.8\%$

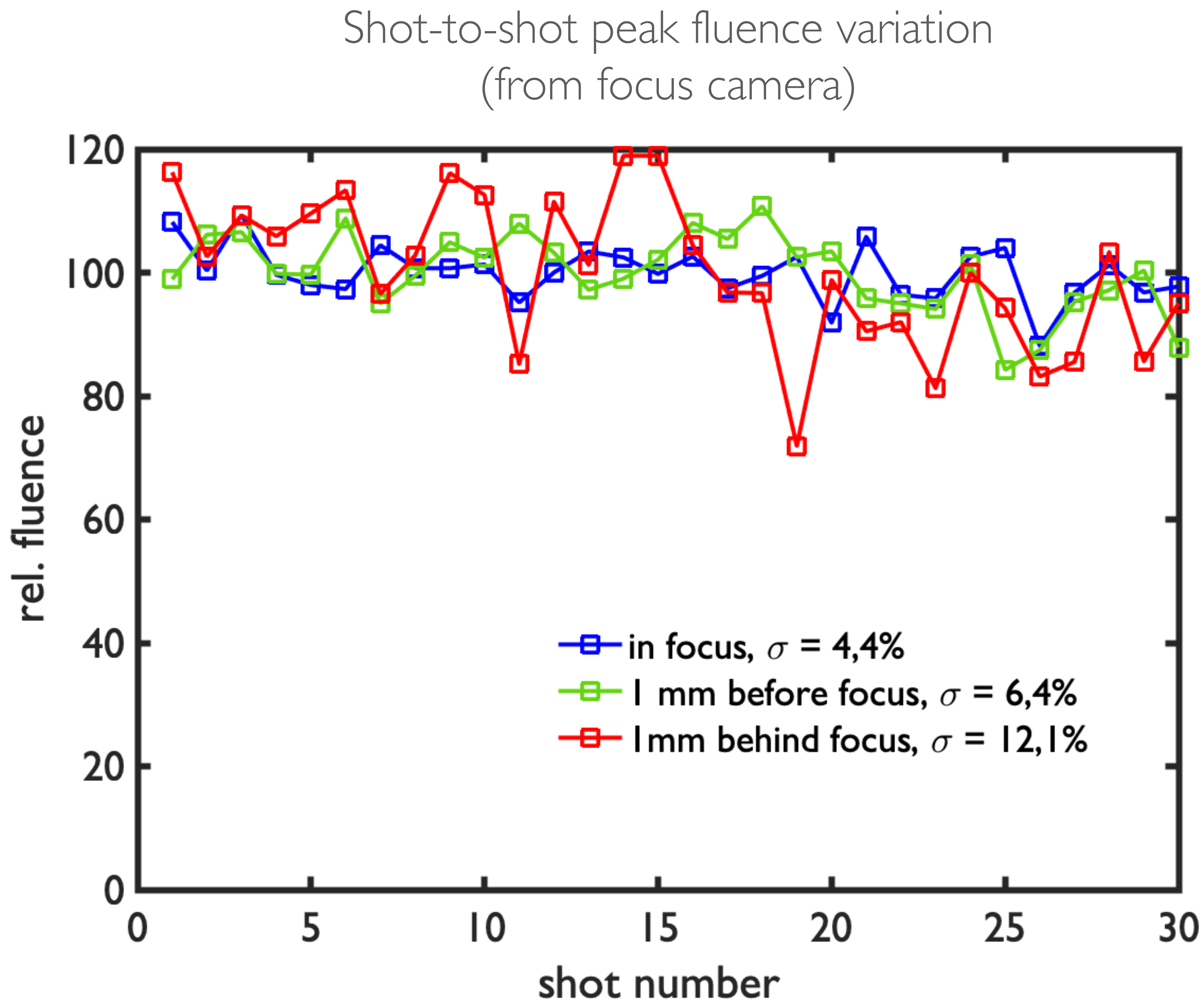




(shot-to-shot energy variation < 1%)

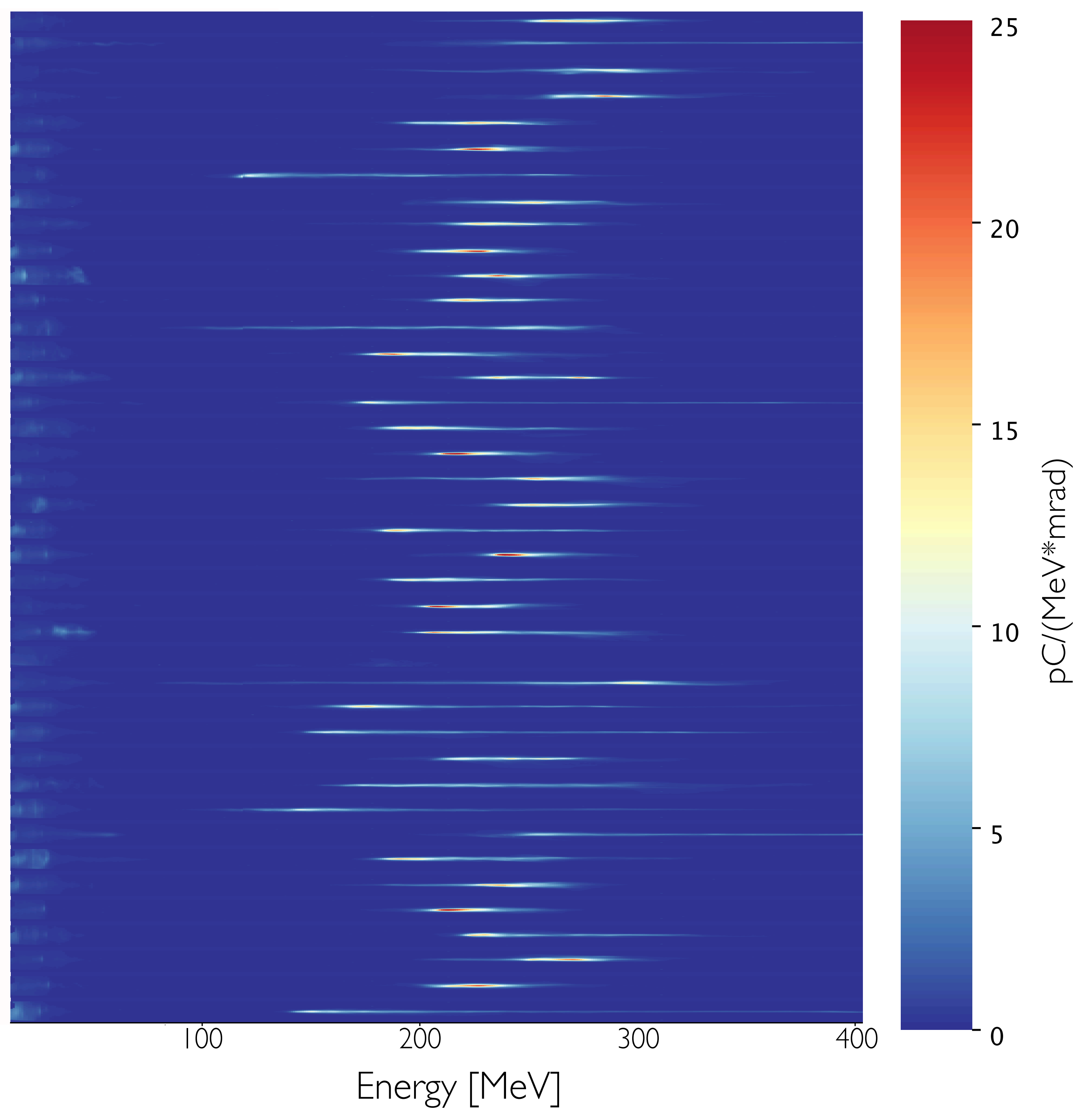
Out-of-focus, fluence variations increase:

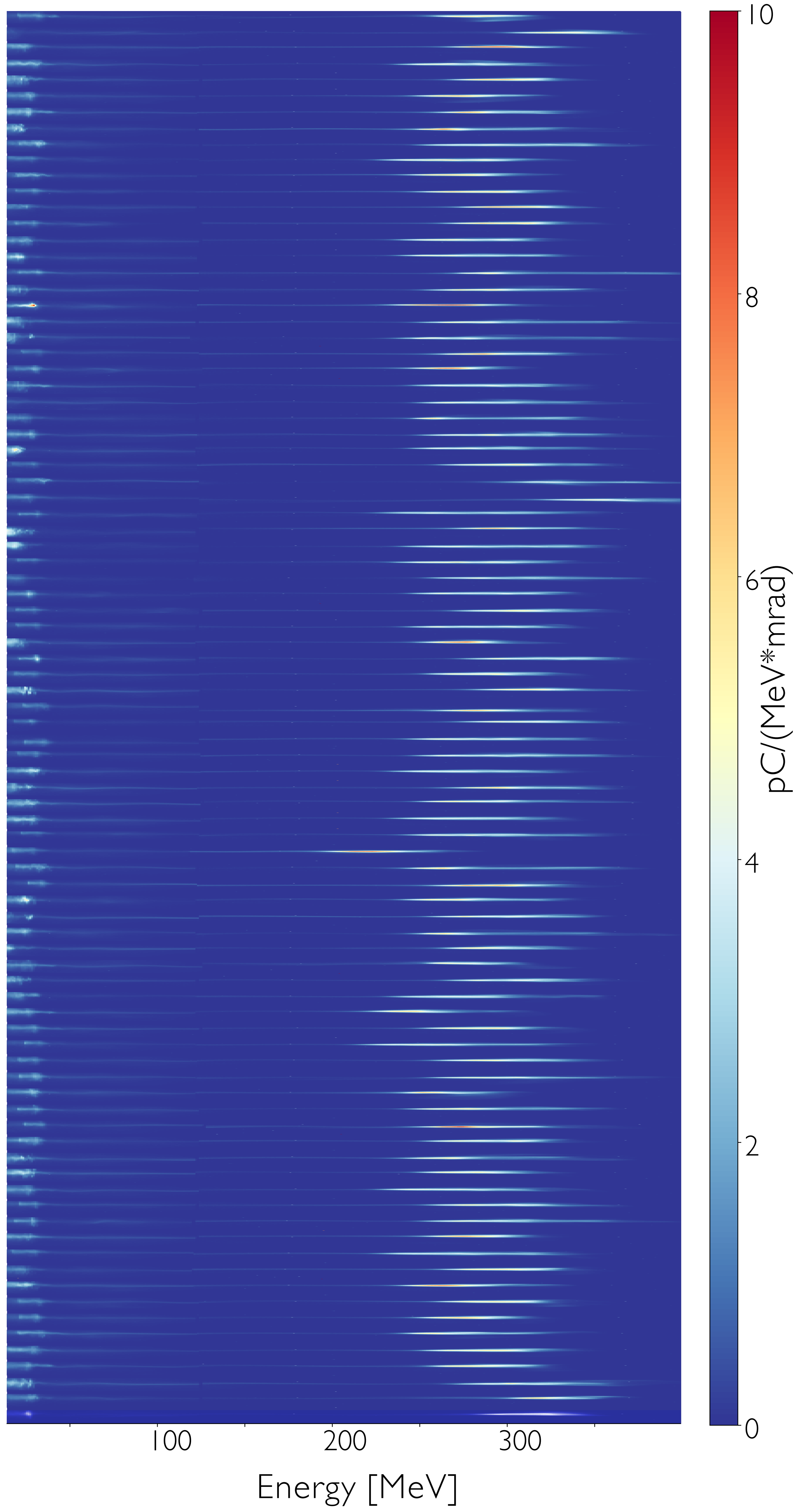


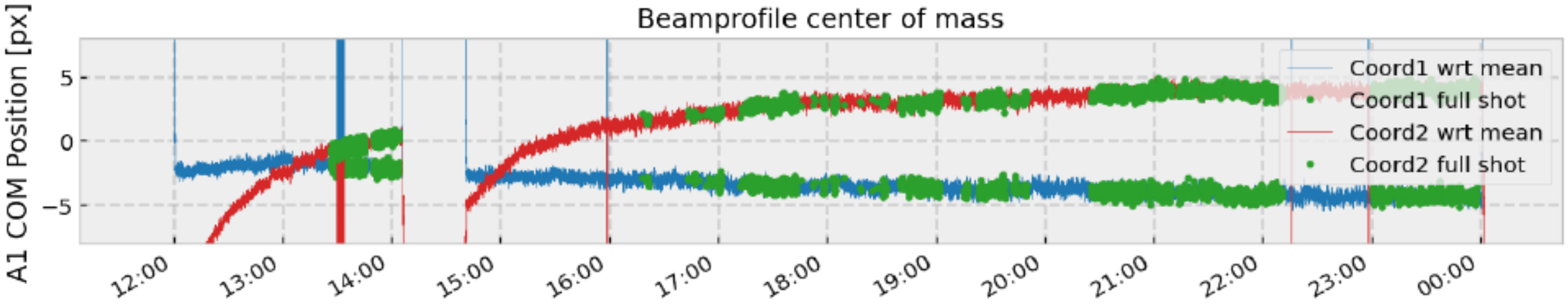


- fluence fluctuates much stronger out-of-focus than at focus
- Self-focusing at target gradient is sensitive to intensity fluctuations
- Probable cause: air turbulence in laser housing

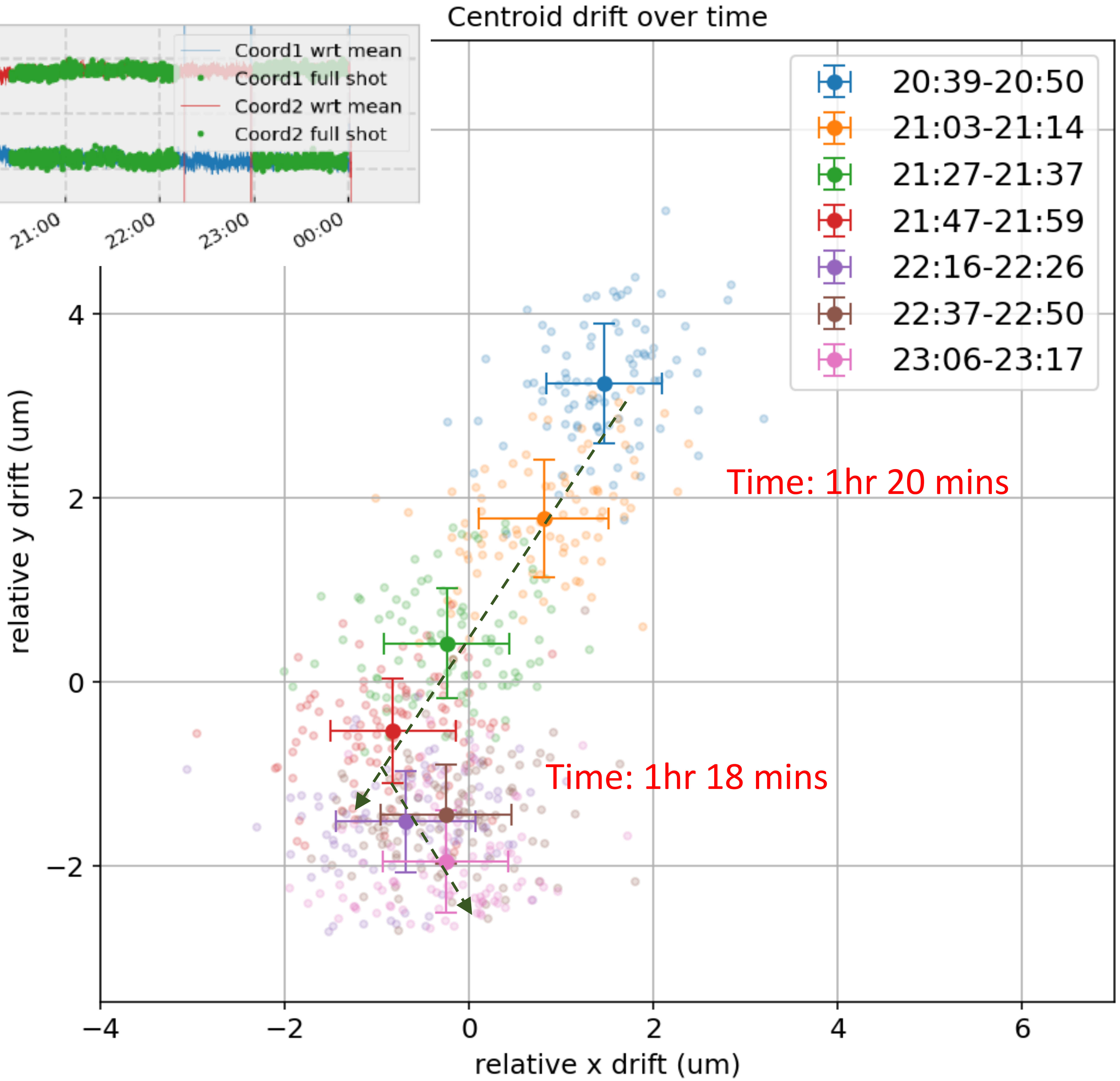
Going from 6m focal length, f/33 to 10 m focal length, f/55:







Long term focus drift seems to saturate after several hours after pump laser start



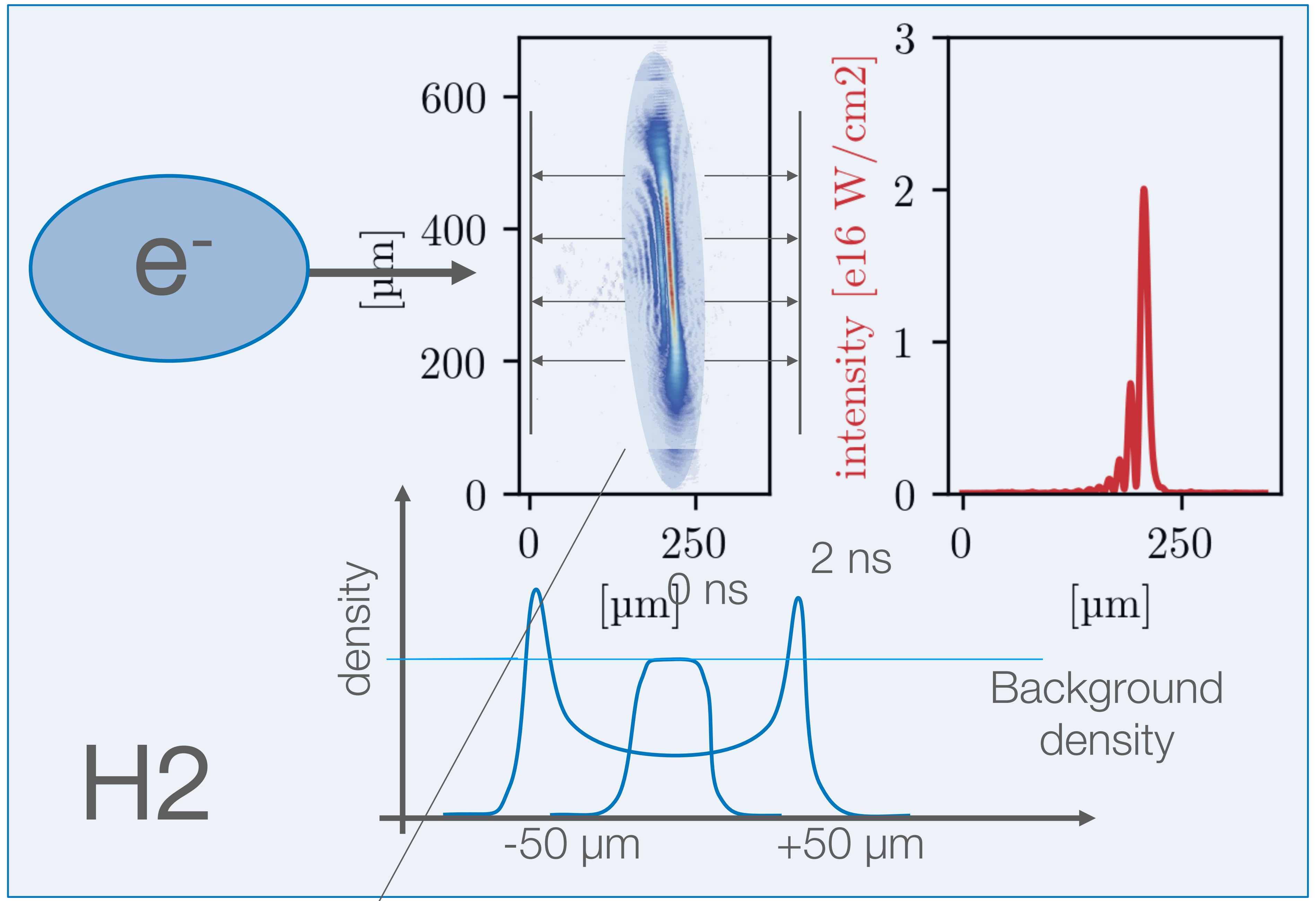
- Homemade active stabilization ongoing (A. Döpp)
- Shot-to-shot pointing will take a bit longer…

f = 50 cm → 1 μm = 2mrad

Better injection control: Hydrodynamic optical field ionized shocks

Independent control of:

- injection position → final energy
- shock height → charge
- plateau density → acceleration gradient



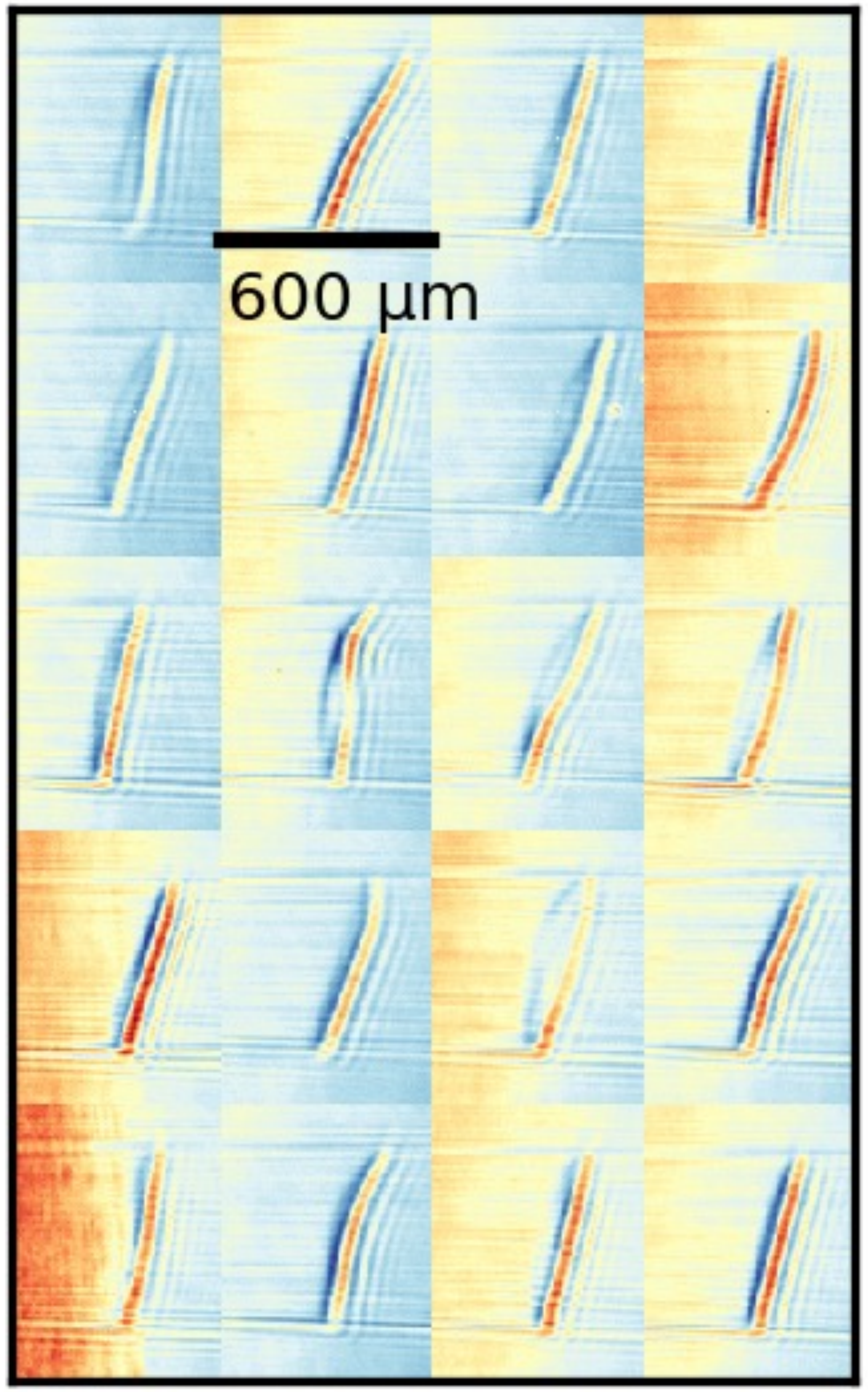
Plasma simulation support from Oxford

M. Foerster

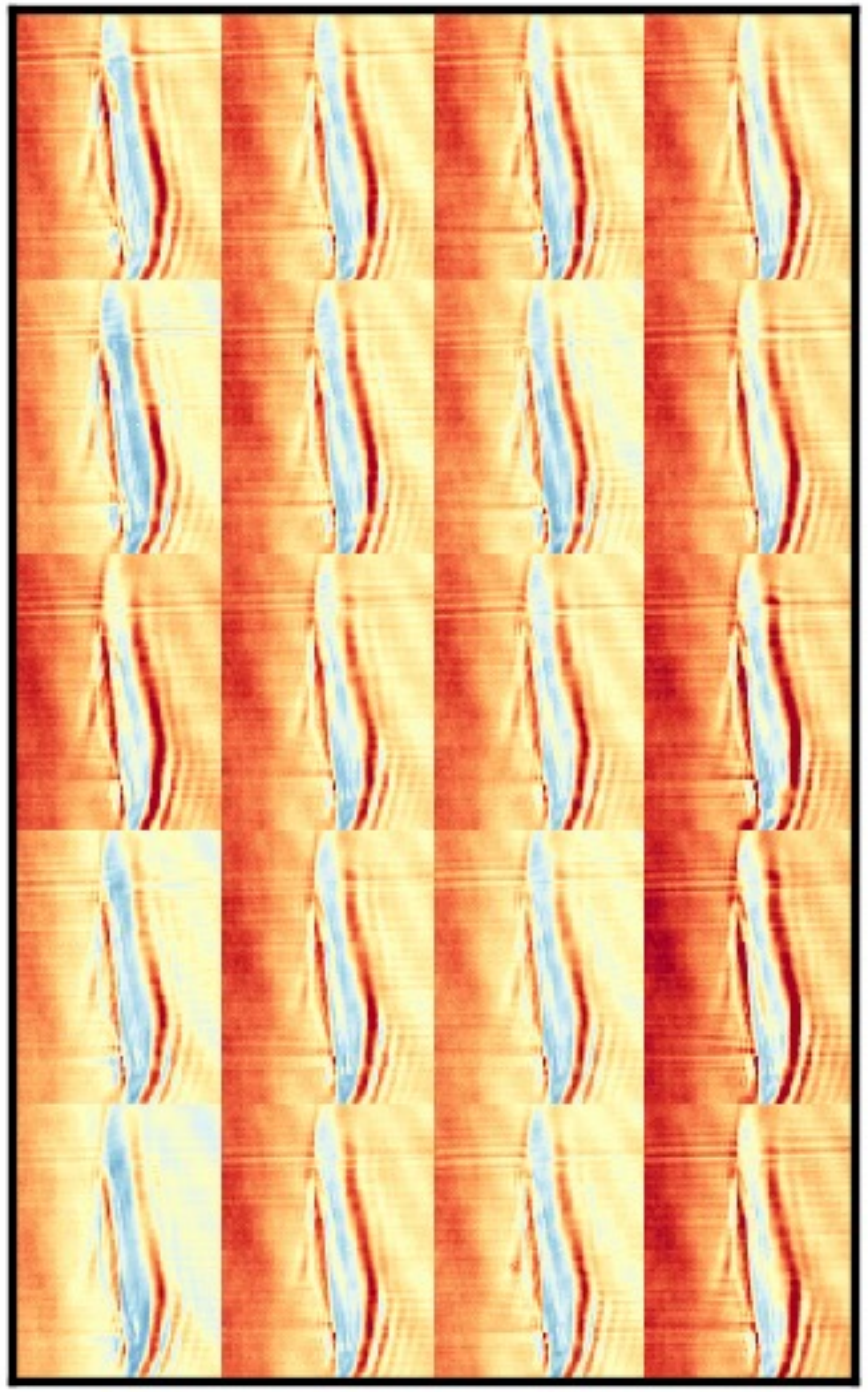
(A. Ross)

HOFI shock stability

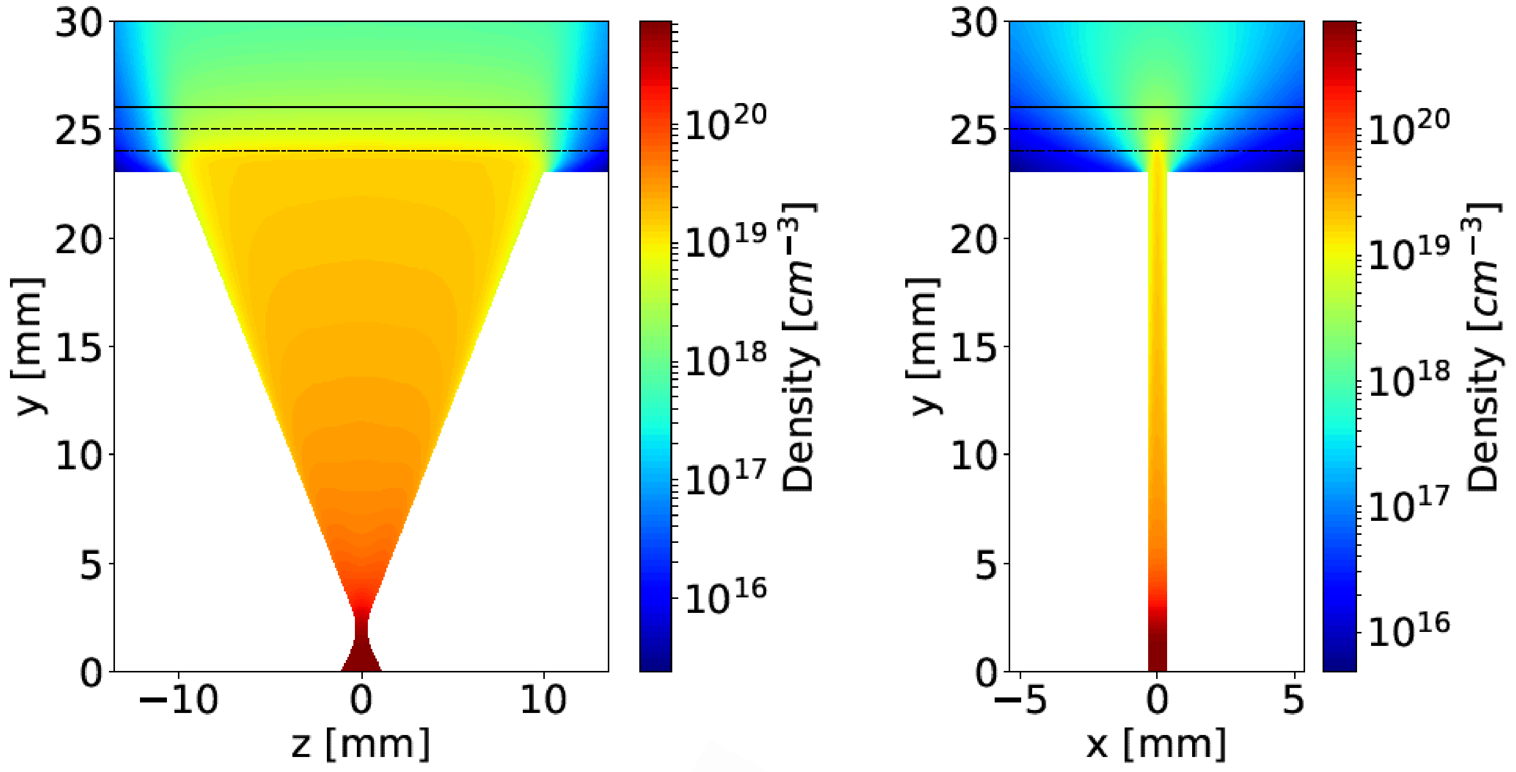
Supersonic wire shocks

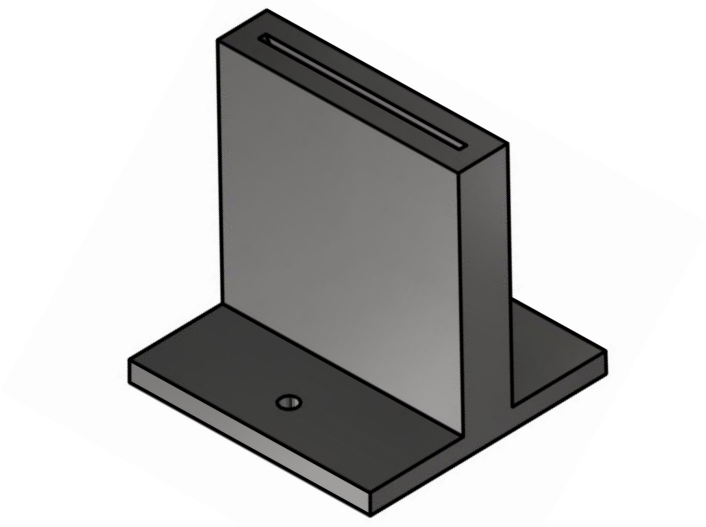


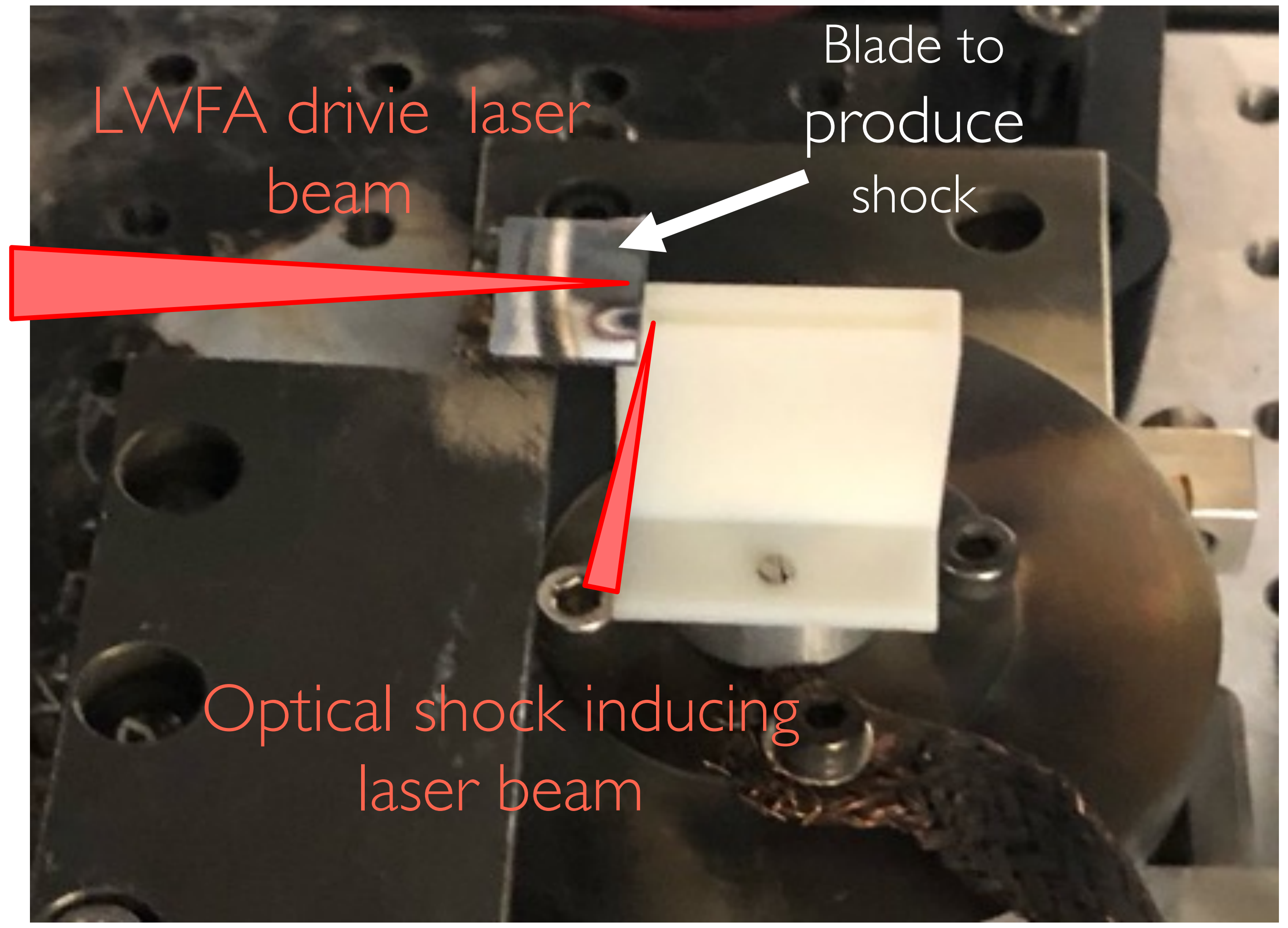
HOFI shocks

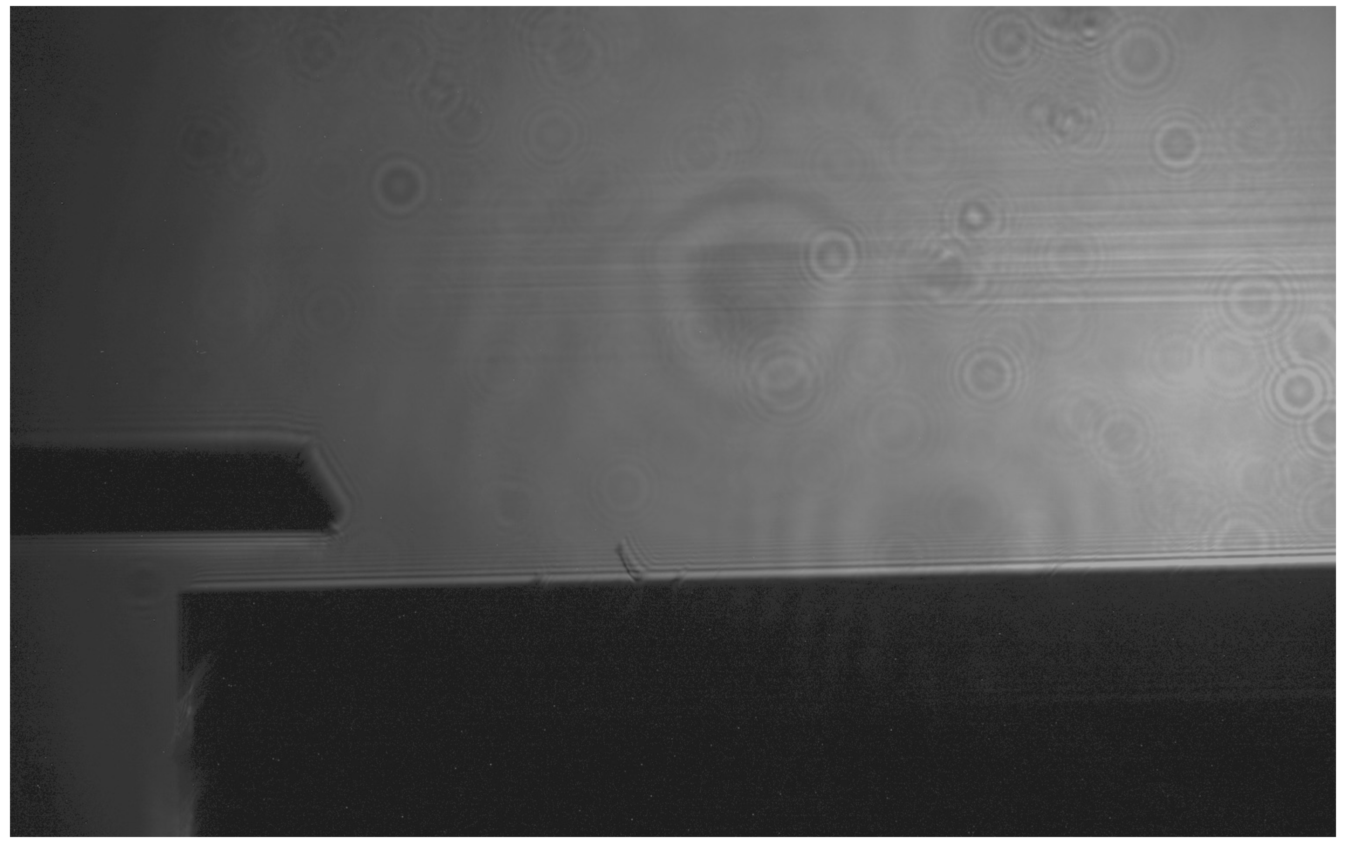


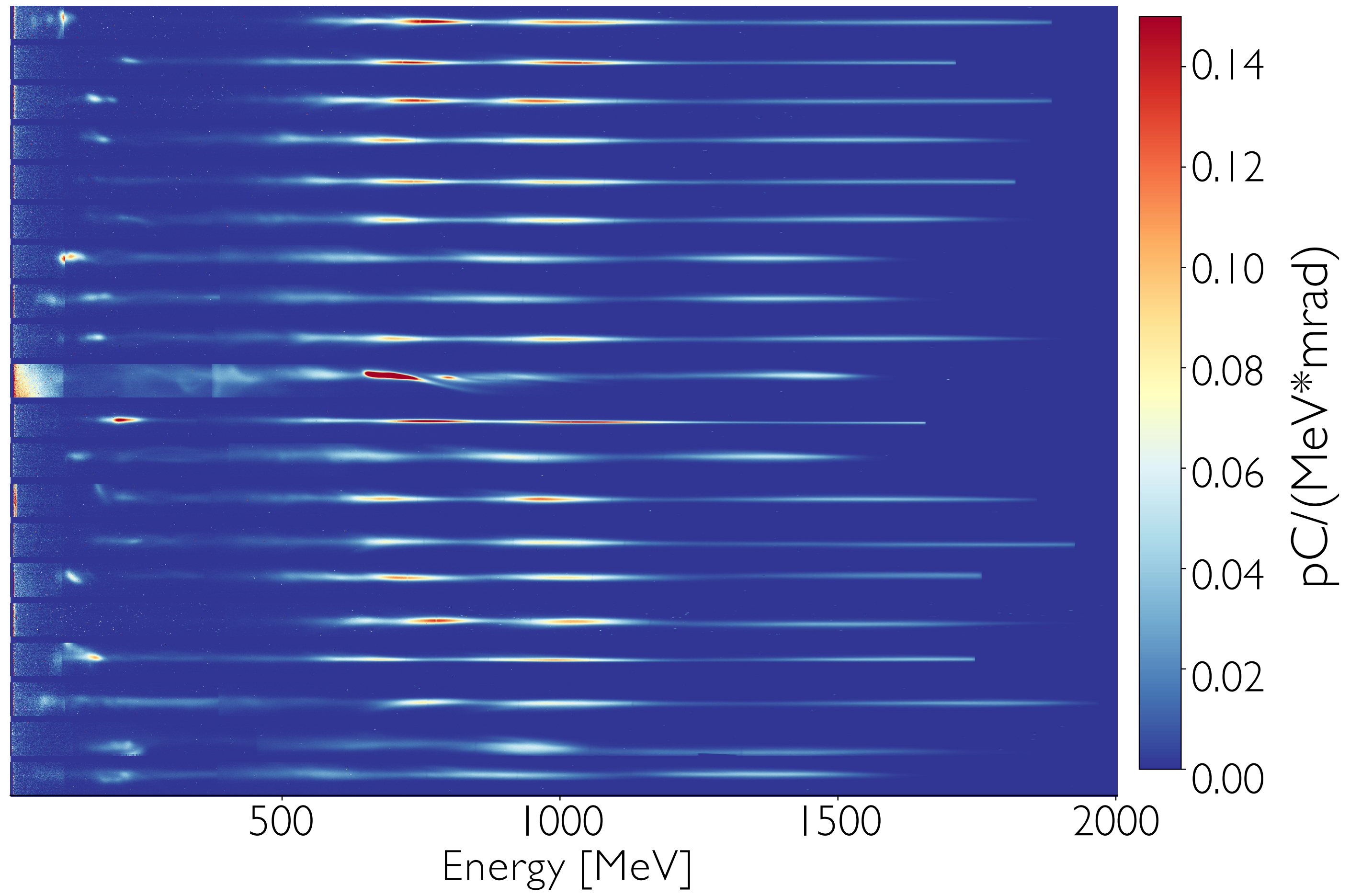
Monoenergetic GeV beams
20 mm slit nozzle target, f/55

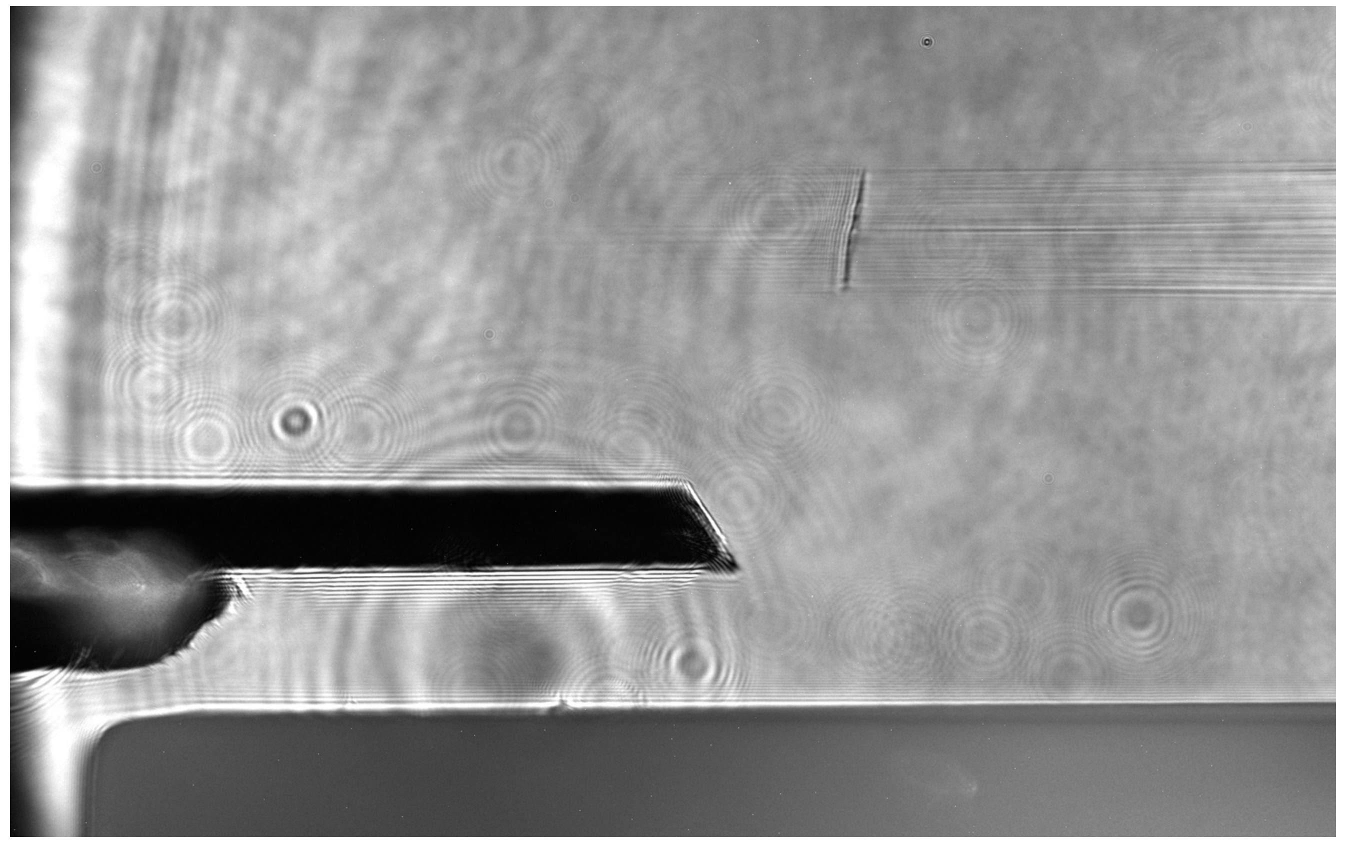


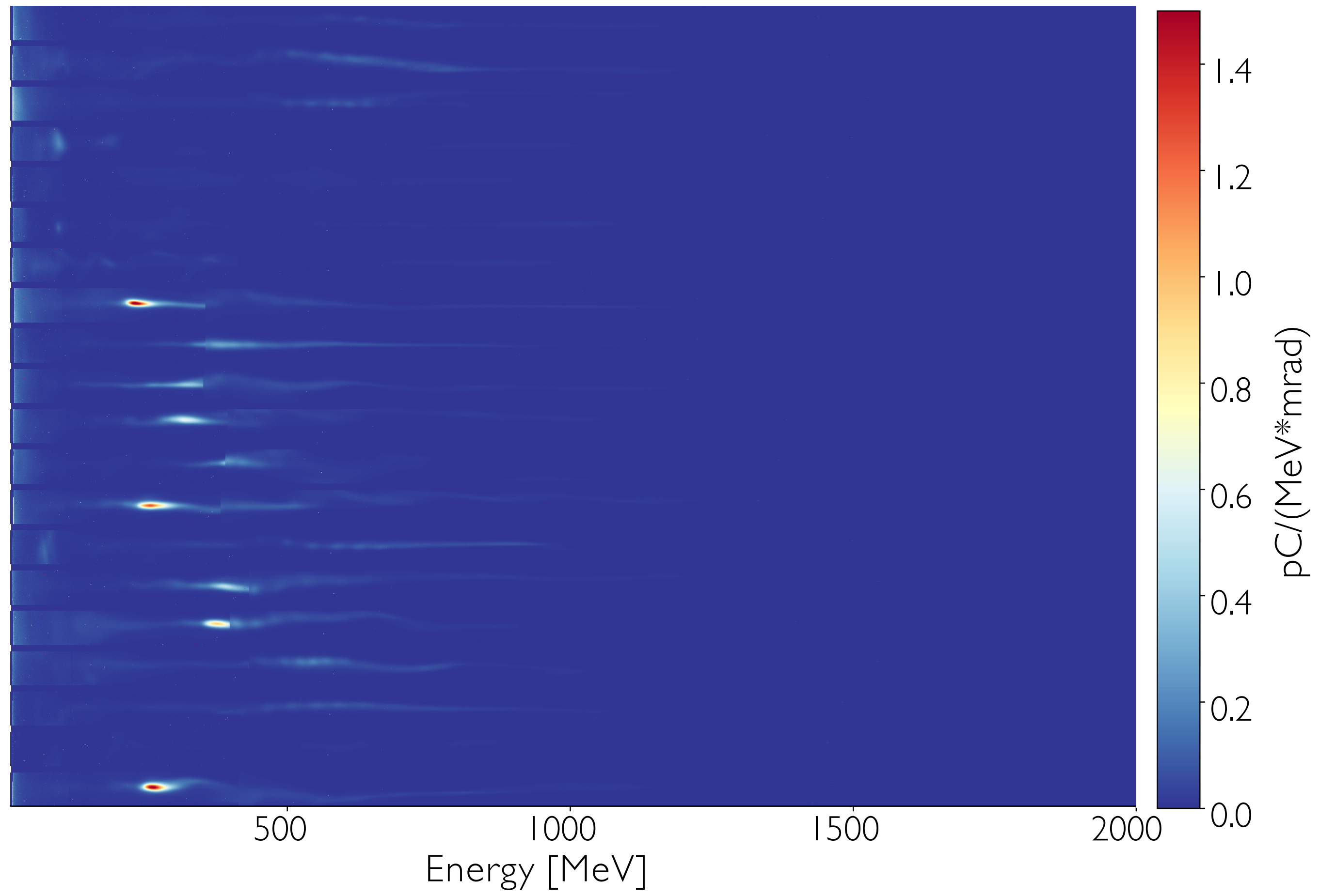


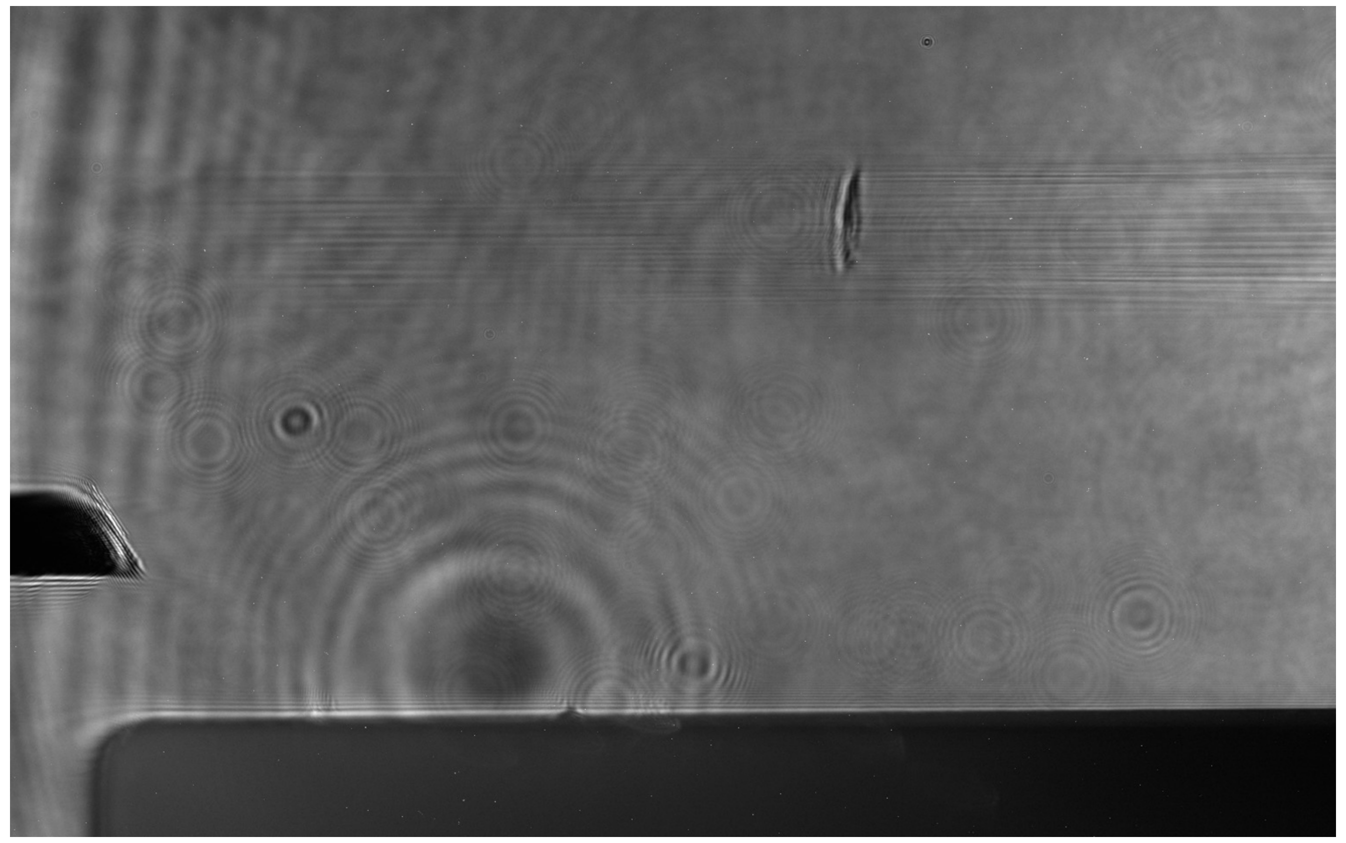


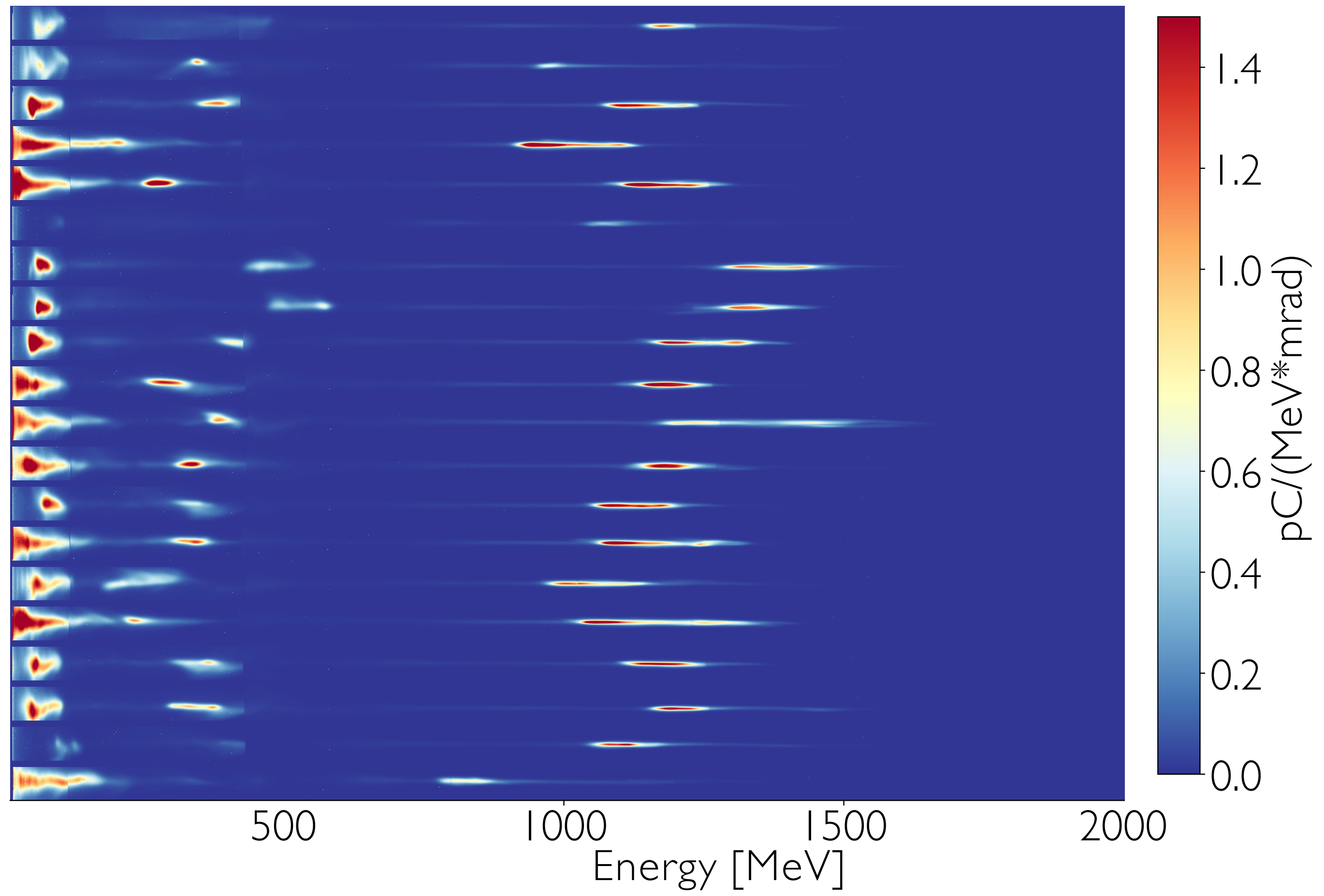




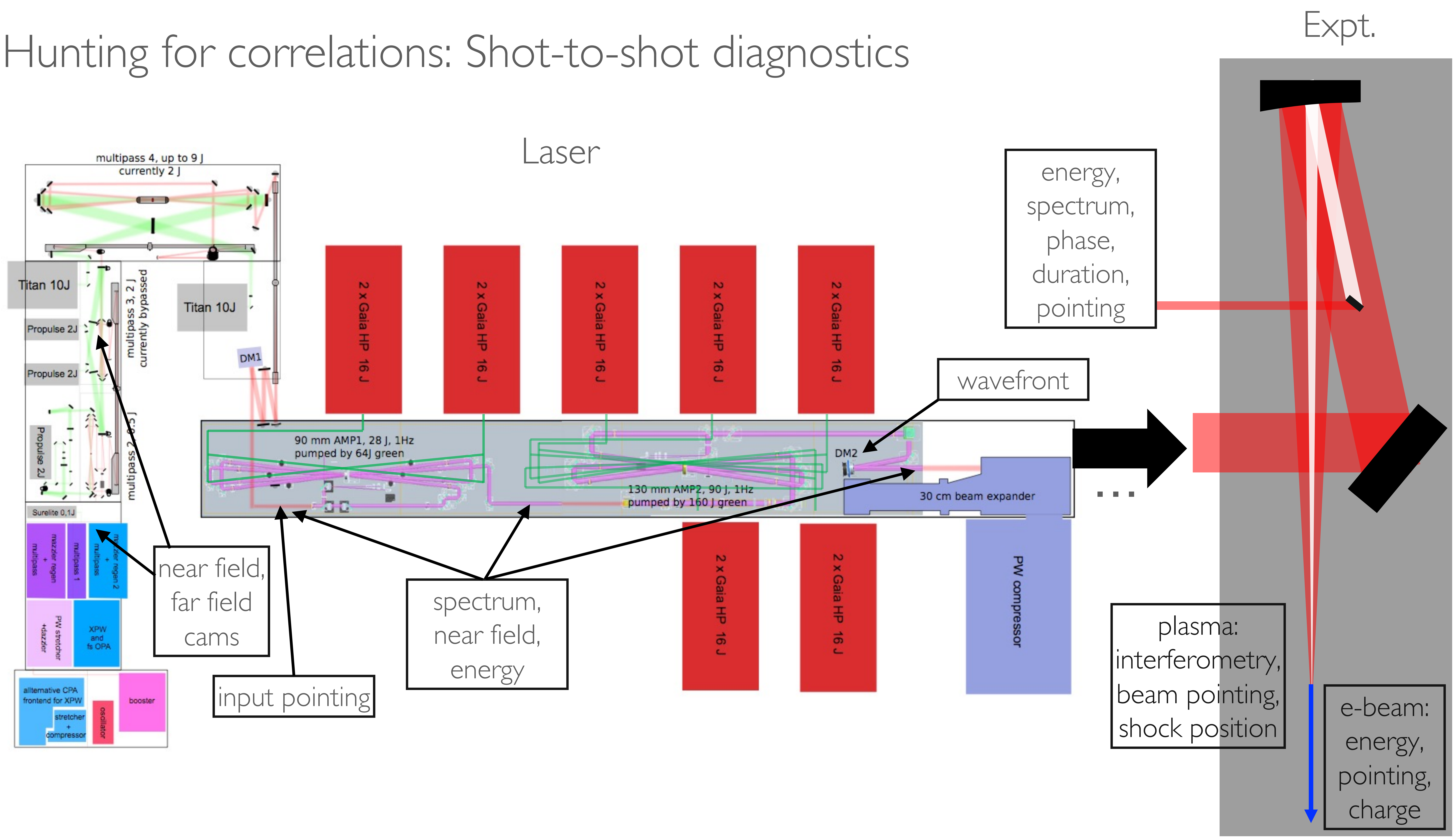








Hunting for correlations: Shot-to-shot diagnostics

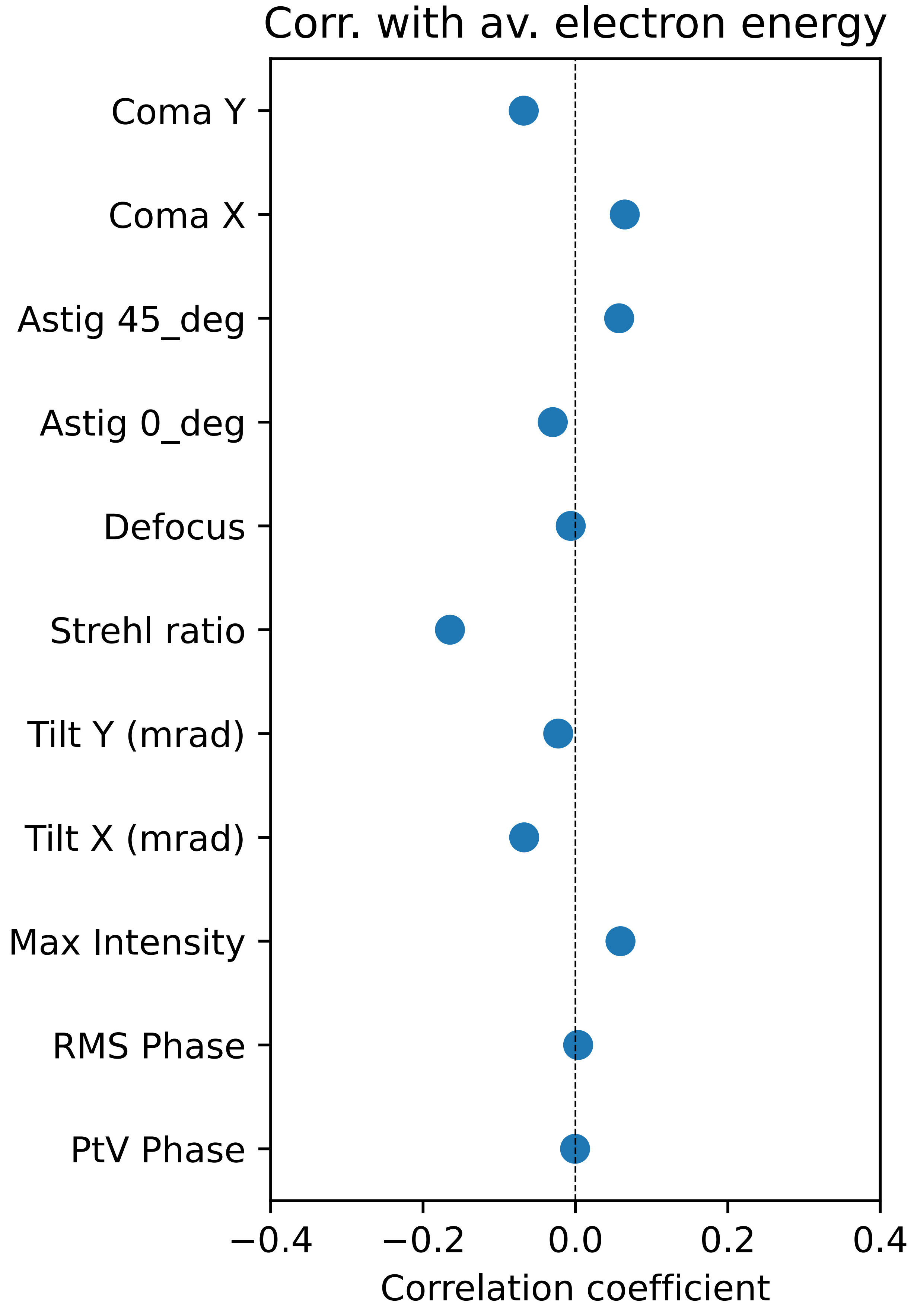


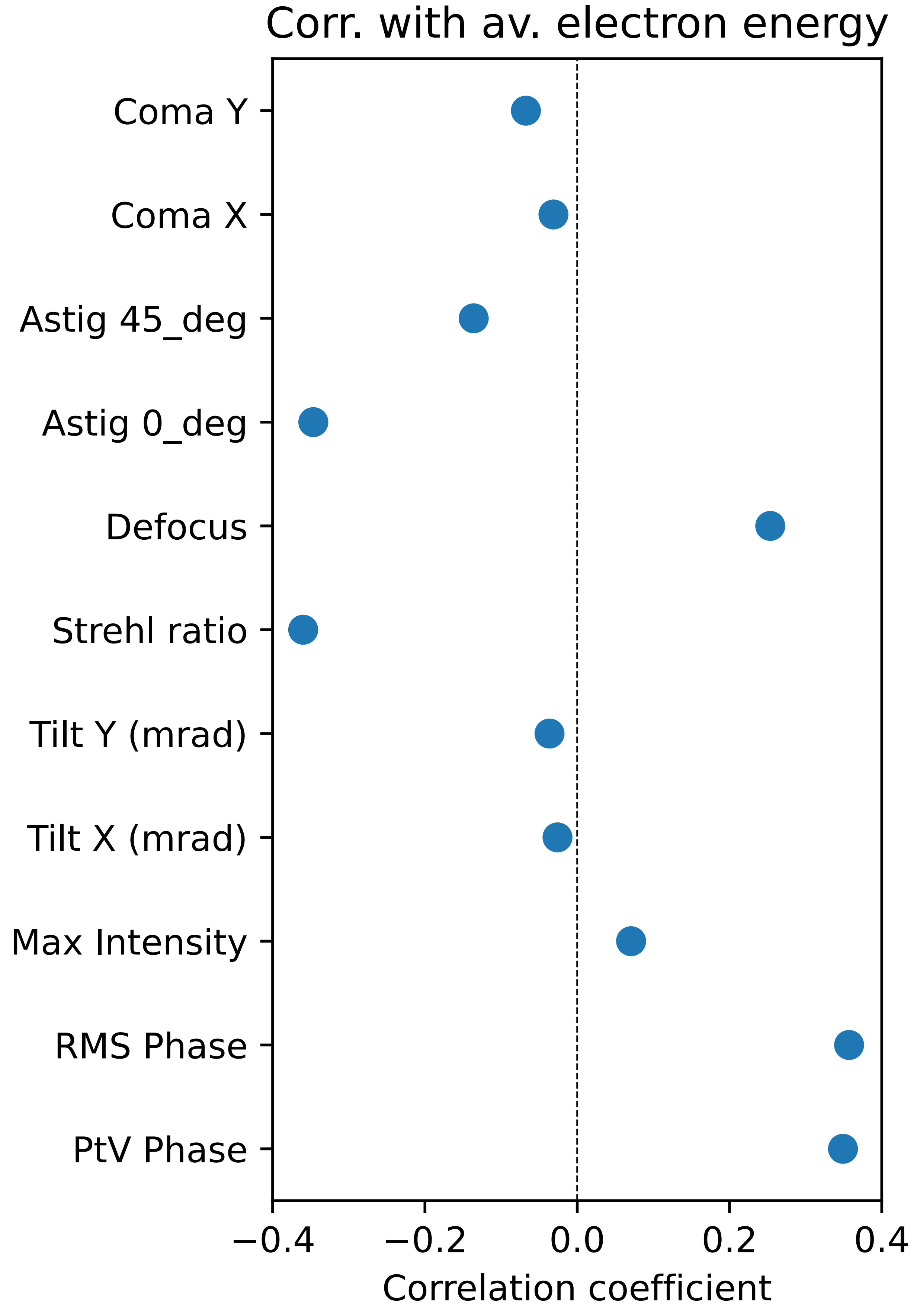
Hunting for correlations: Analysis ongoing…

electron energy vs. wavefront

Run 13

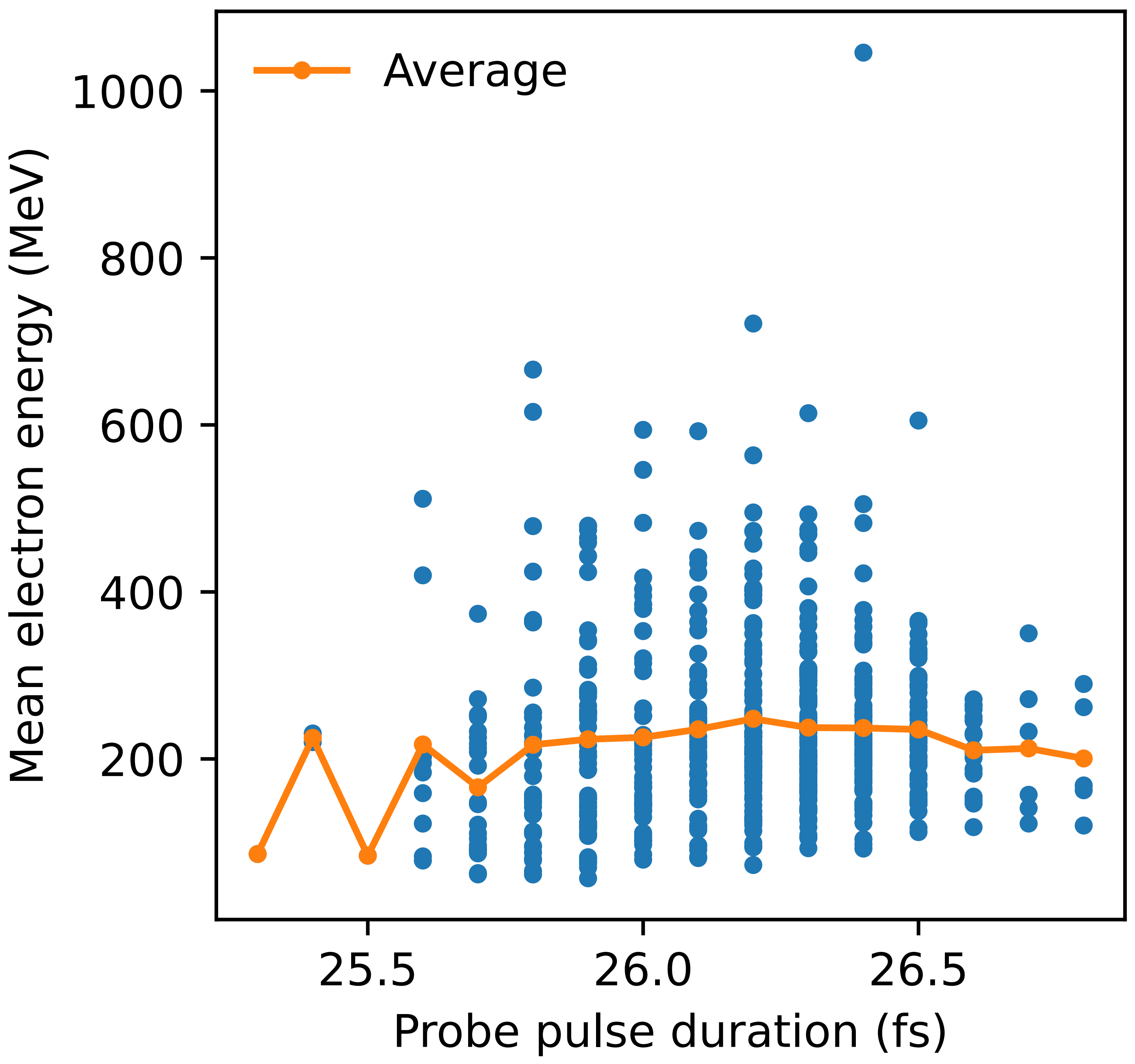
Run 19
target moved downstream
by 400 μm = 1/3 Z_R





400 shots each, relying on statistical fluctuations

electron energy vs. pulse duration



Thank you for your attention!

CALA

Stefan Karsch, Andreas Döpp, Moritz Foerster, Hao Ding, Max Gilljohann, Johannes Götzfried, Sabine Schindler, Florian Haberstroh, Katinka v. Grafenstein, Faran Irshad, Enes Travac, Albert Schletter

Hybrid Data

DESY. HZDR HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

loa University of Strathclyde Glasgow

We are hiring :

- CALA postdoctoral fellowship (see https://pulse.physik.uni-muenchen.de)
- PHD positions

Thank you for your attention!

Btw: We are hiring, too…

PHYSICAL REVIEW RESEARCH **5**, 013063 (2023)

Multi-objective and multi-fidelity Bayesian optimization of laser-plasma acceleration

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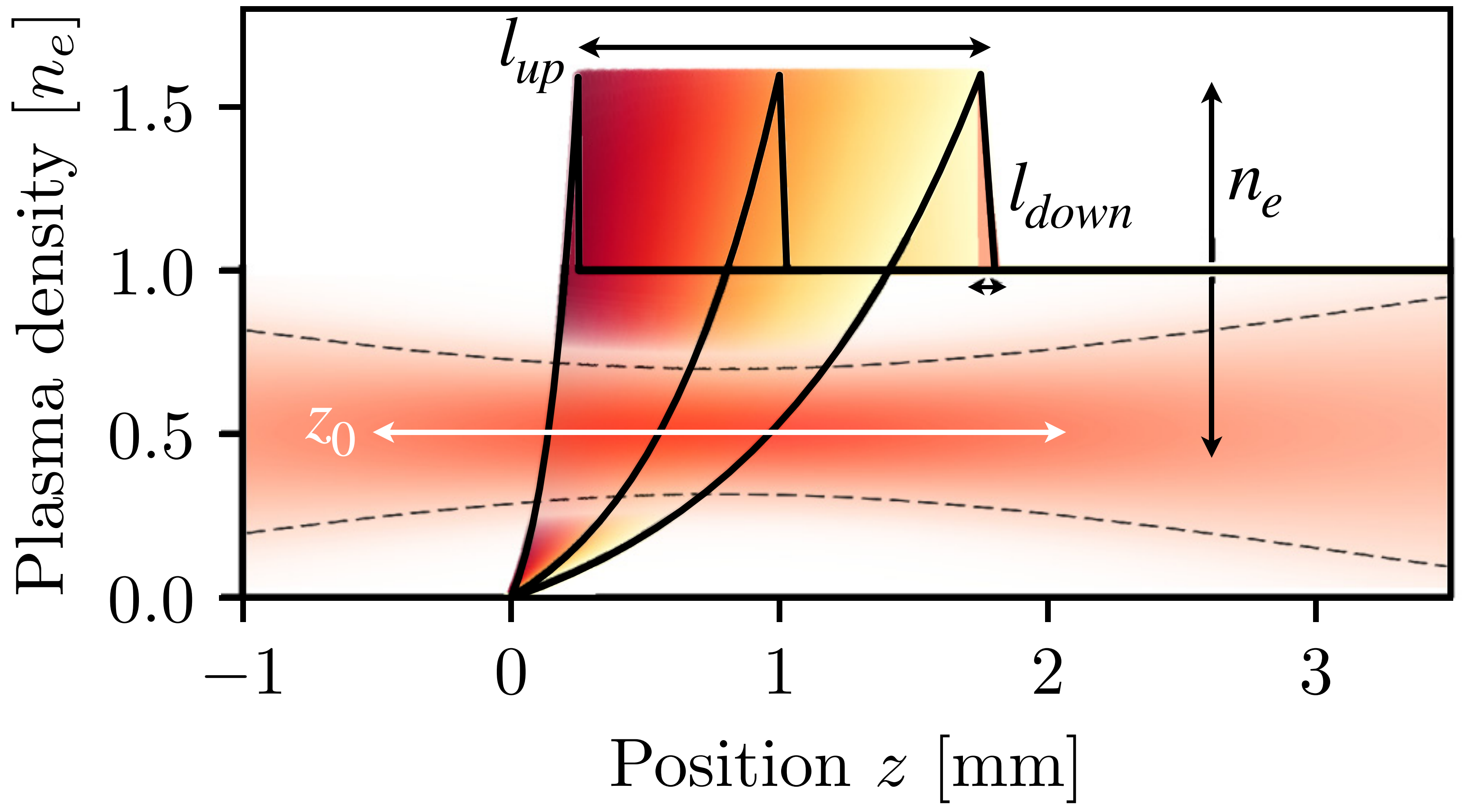
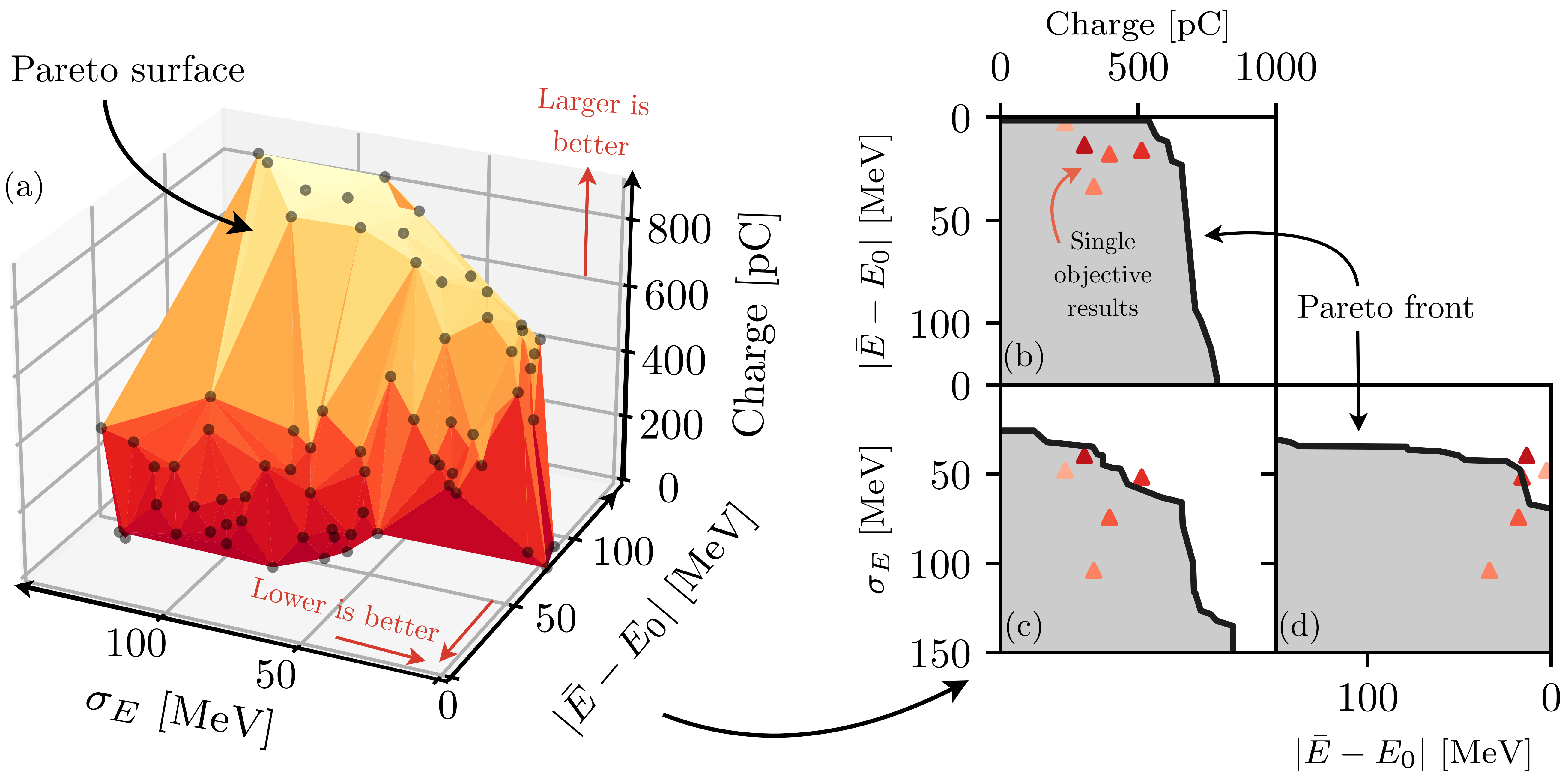
(Received 2 October 2022; accepted 17 January 2023; published 31 January 2023)

Optimization parameters



Pareto front vs. single objective optimization

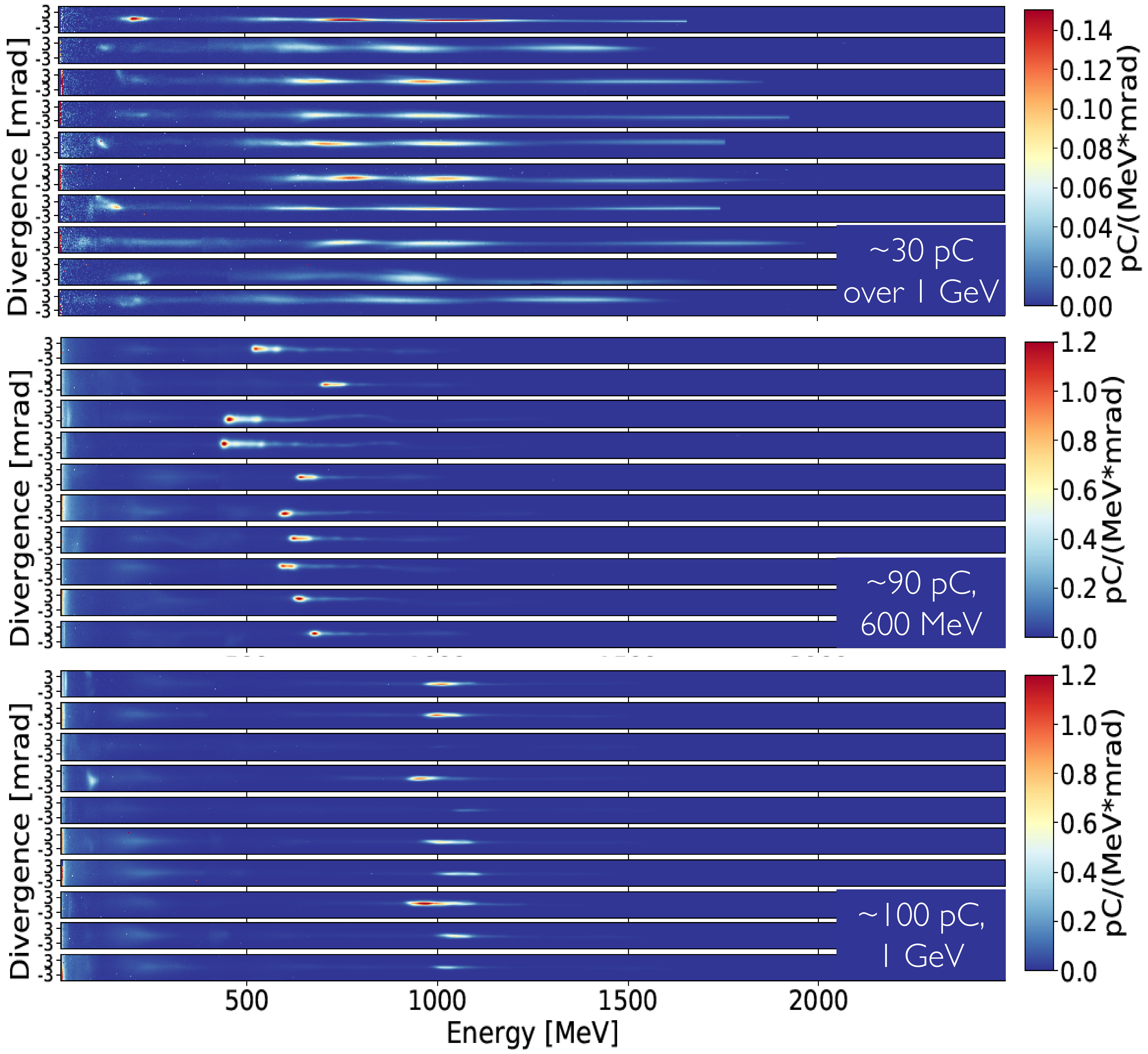


…currently successfully implemented in the experiment… stay tuned!

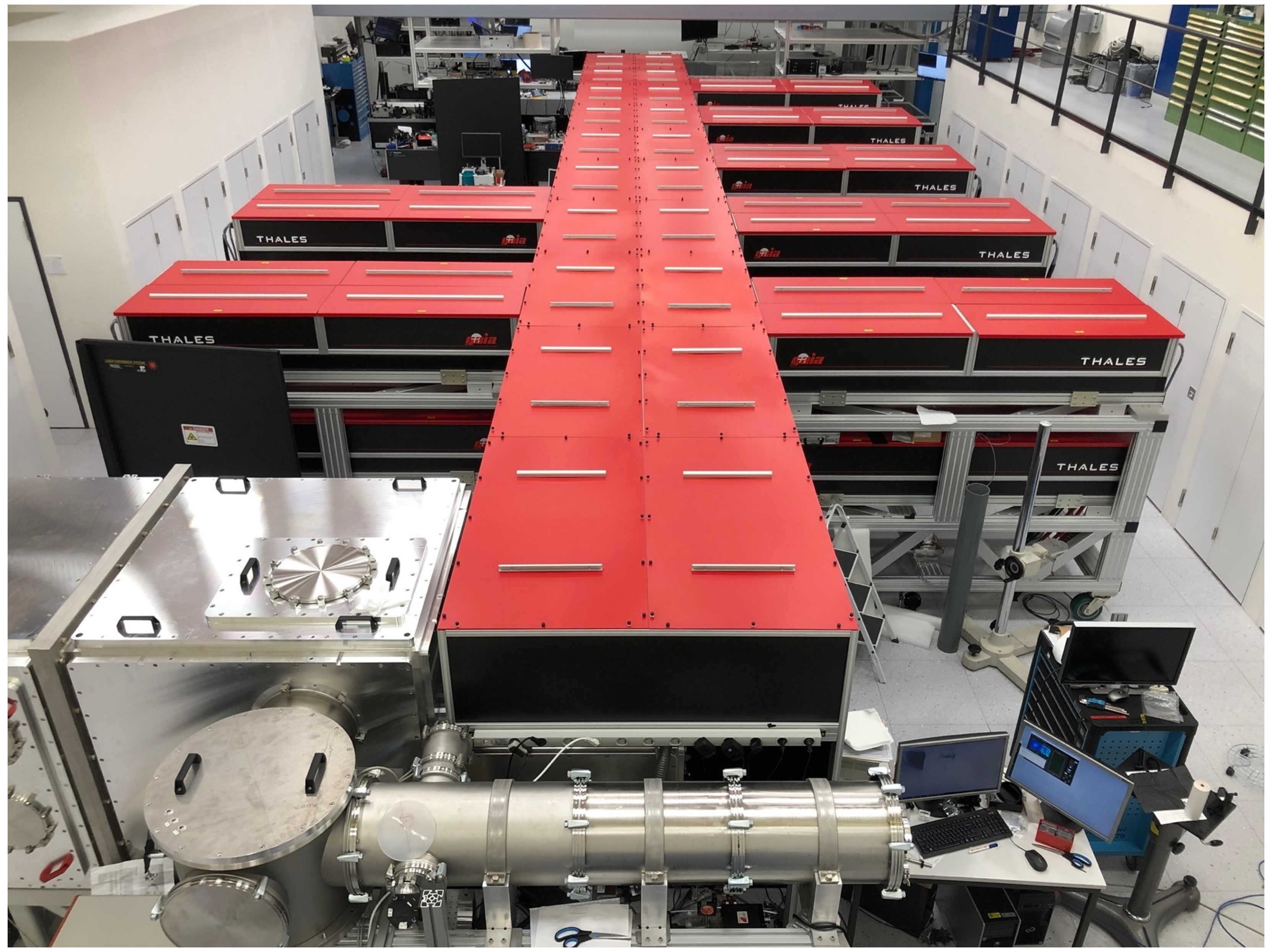
Self injection

Blade induced shock injection

Optically induced shock injection



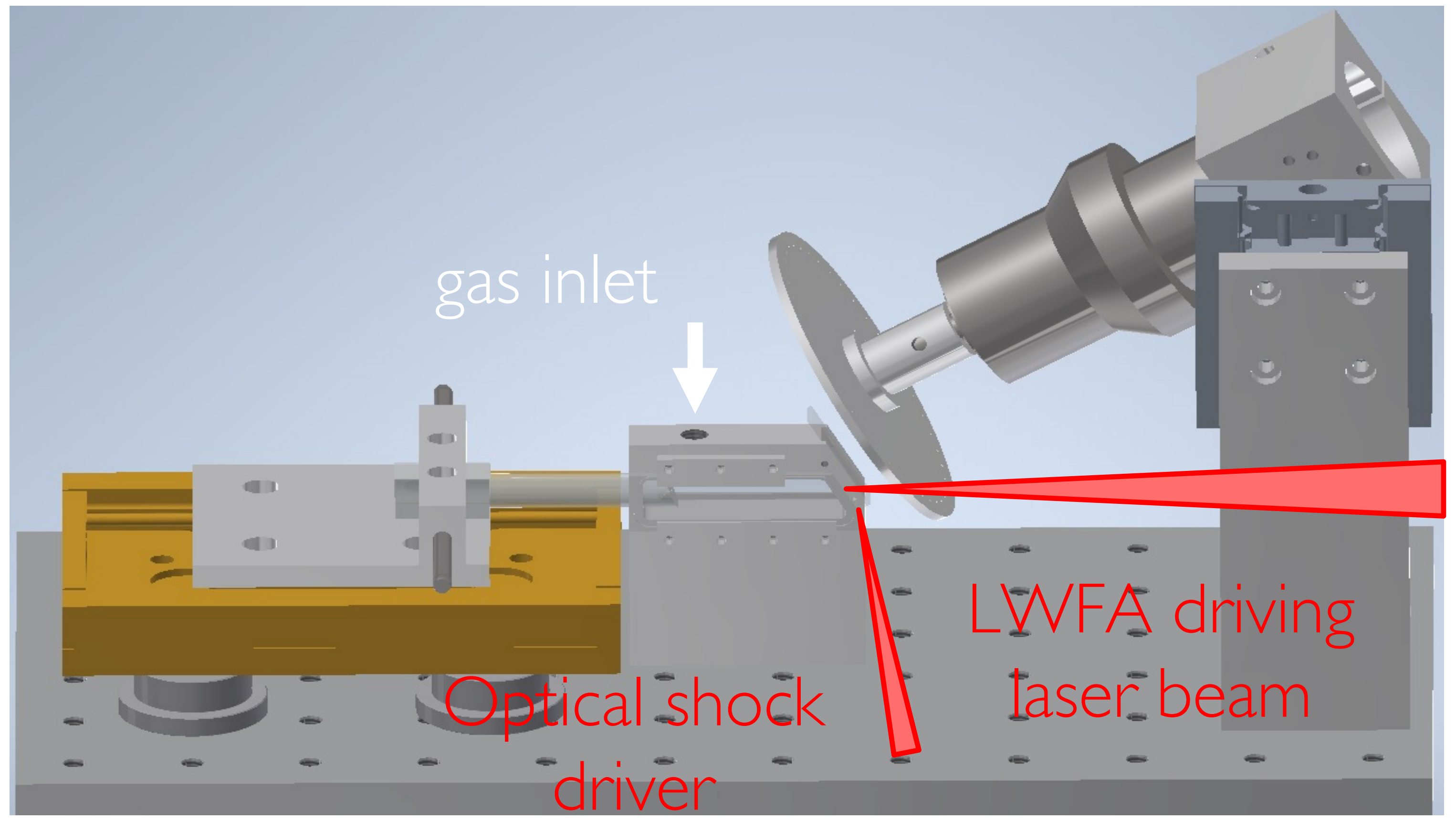
Centre for Advanced Laser Applications (CALA)…



…is operated by the Ludwig-Maximilians-Universität München (LMU)
… serves three university user groups
… hosts approx. 40 staff members

… houses two laser systems, ATLAS-3000 and PFS-pro
… and five experimental beamlines

Multi-GeV beams
25 mm gas cell target, f/55

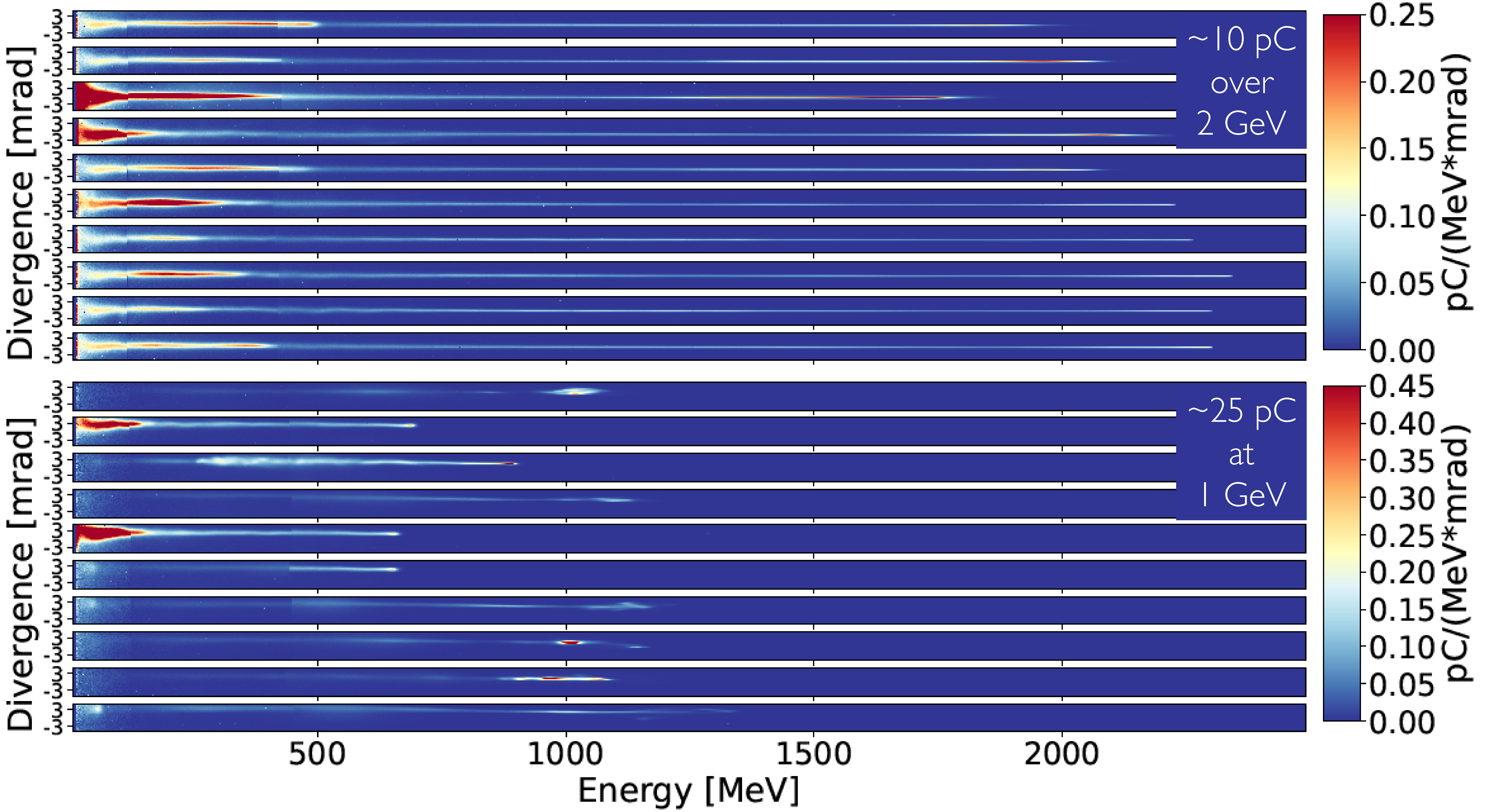


K. v. Grafenstein

Self injection

f/37

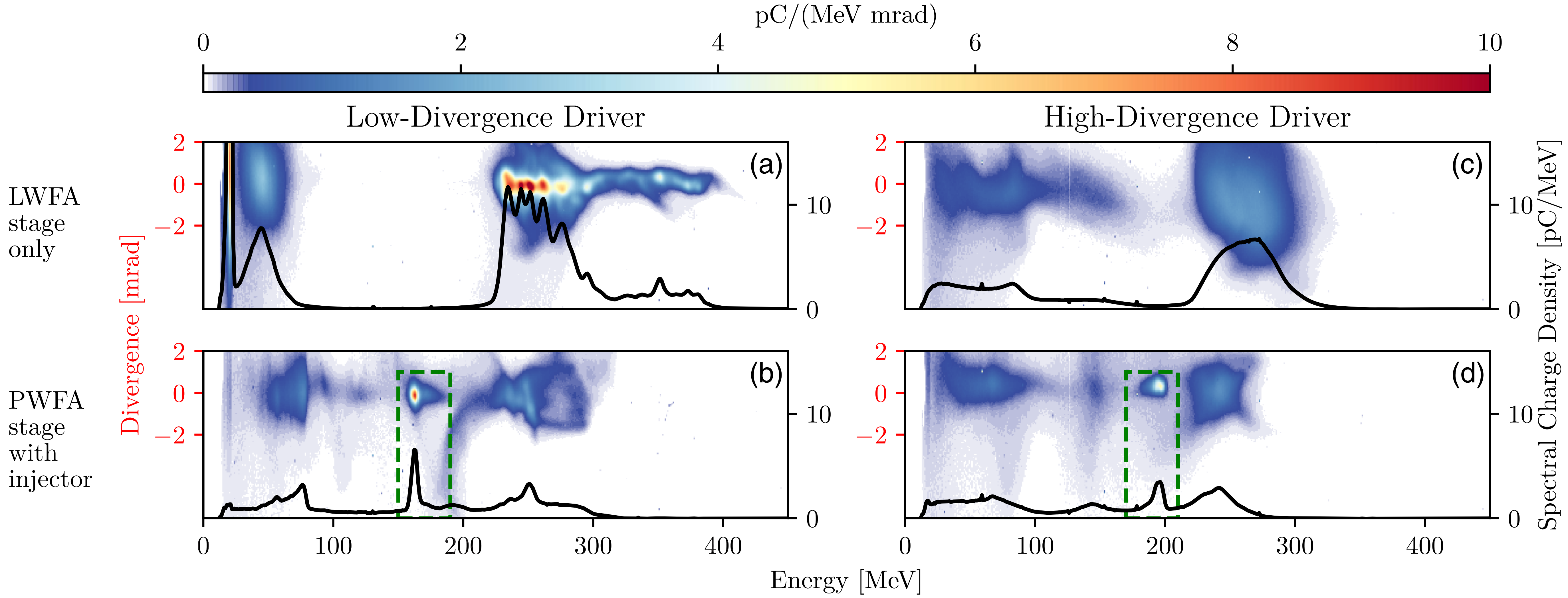
Optically induced shock injection



Hybrid LWFA-PWFA

- First experimental clues (ca. 2010):
- Hybrid accelerator & plasma photocathode concept
- nC LWFA electron bunches
- Plasma waves driven by LWFA electrons
- Dual bunches from a single LWFA
- External injection of witness beam
- Internal injection of witness beam (supersonic shock)

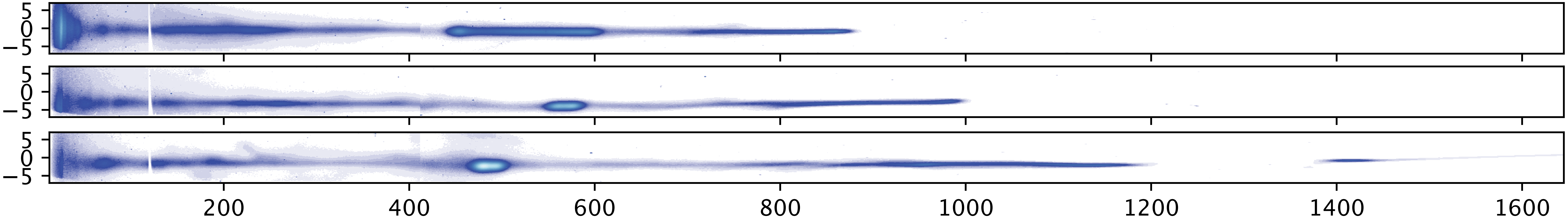
HOFI shocks: High stability and beam quality from hybrid accelerator



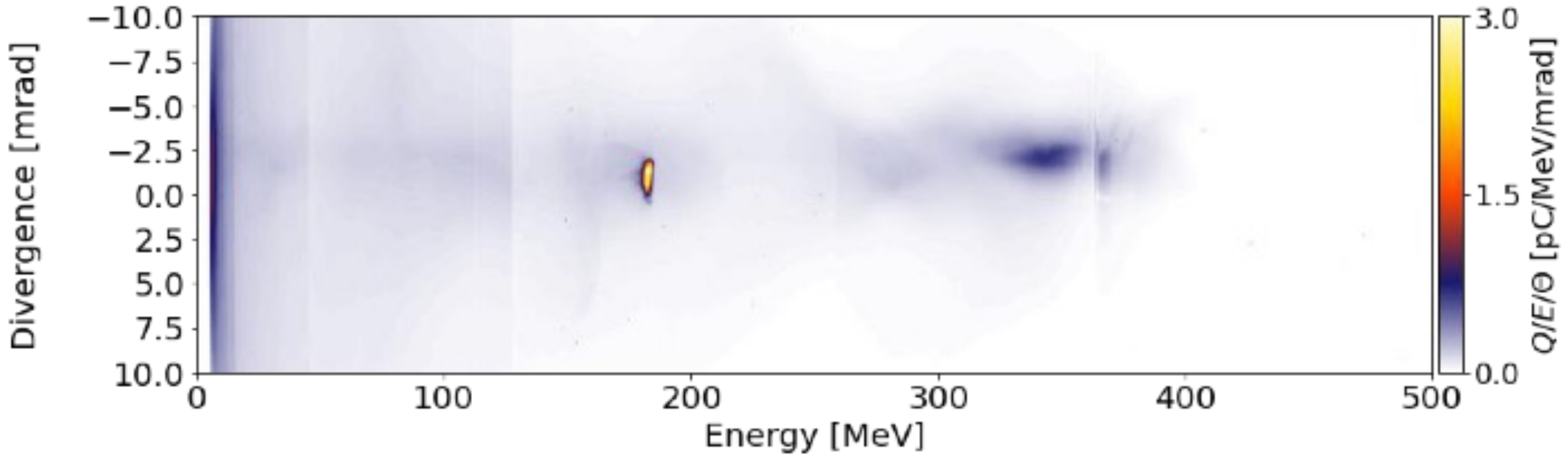
M. Foerster et al. Phys.Rev.X **12**, 041016 (2022)

Latest preliminary results:

- GeV-scale hybrid



- Implementation of Trojan horse scheme (HZDR)



Simulation: laser wakefield acceleration (LWFA)