PAUL SCHERRER INSTITUT

EUROPEAN NETWORK FOR NOVEL ACCELERATORS

NPACT supported by EU via I-FAST

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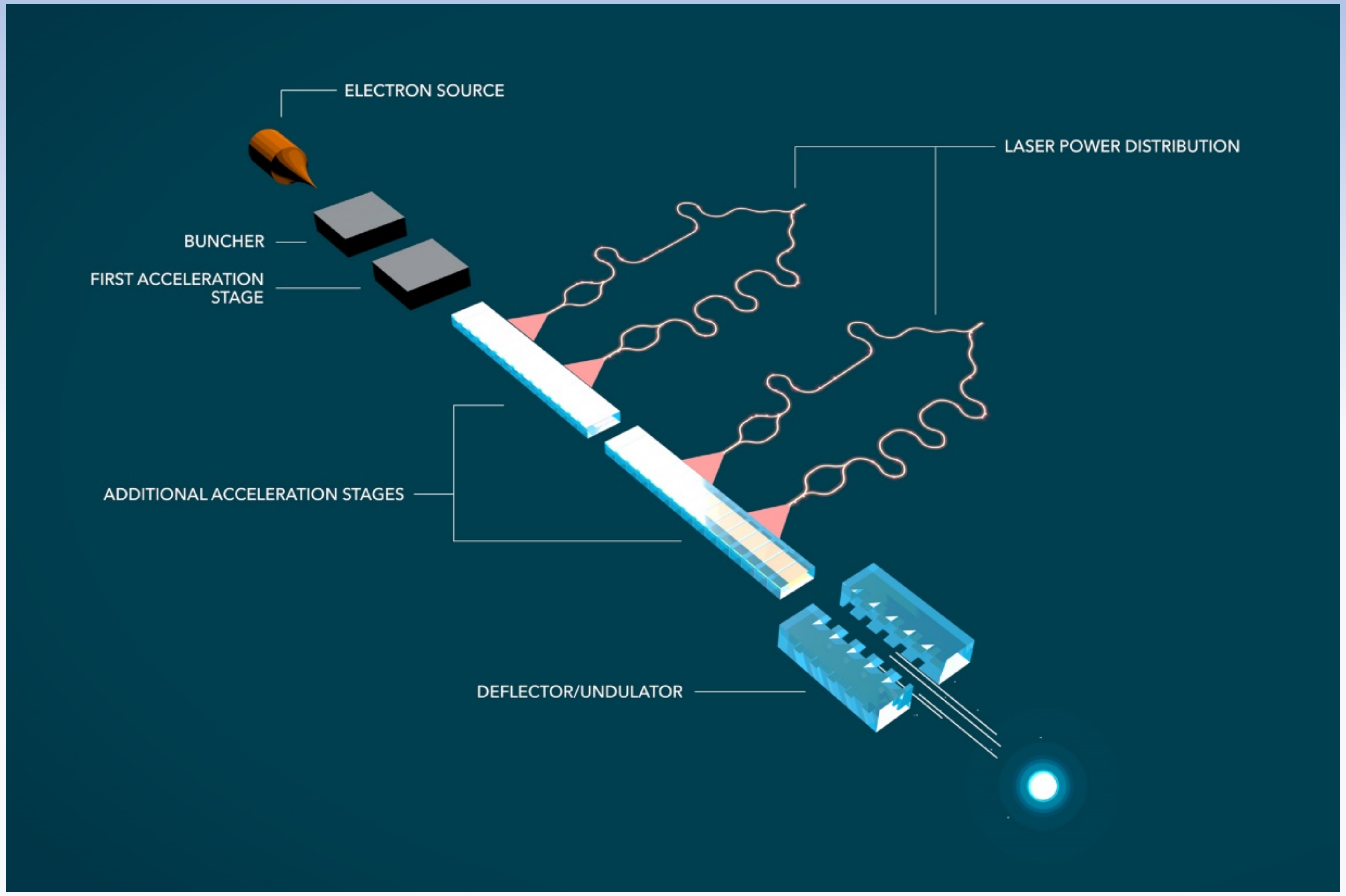
STRUCTURE-BASED NOVEL ACCELERATORS

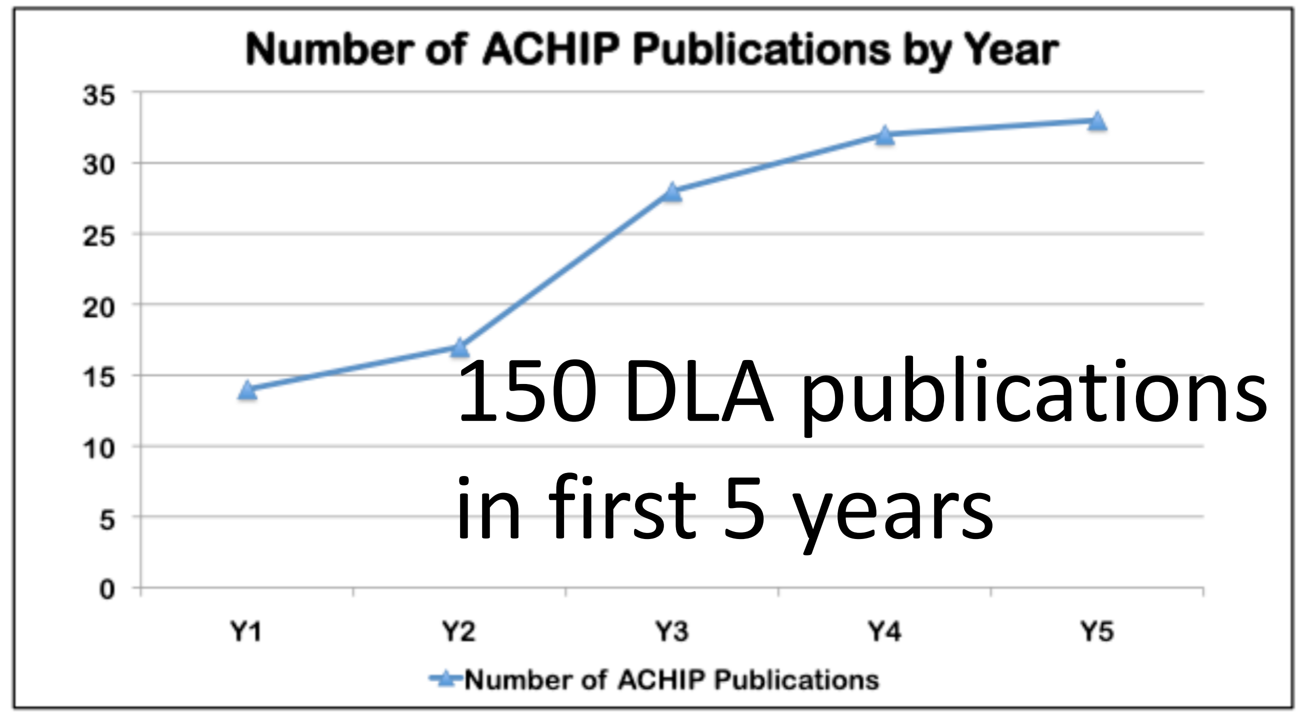
A 7-Year initiative in DLA was funded by the Gordon and Betty Moore Foundation (2015 – 2022)

From SLAC newsroom: “Moore Grant to Develop Working ‘Accelerator on a Chip’ Prototype” (November 19, 2015)

$19.5M / 7 years
6 universities, SLAC, DESY, PSI, 2 industry partners

60 grad students/postdocs funded by the grant
20+ Ph.D. awarded





150 DLA publications in first 5 years

LETTER nature
doi:10.1038/nature12664

Demonstration of electron acceleration in a laser-driven dielectric microstructure

E. A. Peralta[1], K. Soong[1], R. J. England[2], E. R. Colby[2], Z. Wu[2], B. Montazeri[3], C. McGuinness[1], J. McNeur[4], K. J. Leedle[3], D. Walz[2], E. B. Sozer[4], B. Cowan[5], B. Schwartz[5], G. Travish[4] & R. L. Byer[1]

REVIEWS OF MODERN PHYSICS

Dielectric laser accelerators

R. Joel England *et al.*
Rev. Mod. Phys. **86**, 1337 – Published 23 December 2014

COMMUNICATIONS PHYSICS
a natureresearch journal

High-field nonlinear optical response and phase control in a dielectric laser accelerator

D. Cesar, et al., Comm. Phys. 1, 46 (2018)

Hirano et al., “A compact electron source for the dielectric laser accelerator”, Appl. Phys. Lett. (2020)

Schonenberger et al., “Generation and Characterization of Attosecond Microbunched Electron Pulse Trains via Dielectric Laser Acceleration”, Phys. Rev. Lett. 123, 264803 (2019)

Black et al., “Net Acceleration and Direct Measurement of Attosecond Electron Pulses in a Silicon Dielectric Laser Accelerator”, Phys. Rev. Lett. (2019)

Niedermayer et al., “Three Dimensional Alternating-Phase Focusing for Dielectric-Laser Electron Accelerators”, Phys. Rev. Lett., 125, 164801 (2020)

Sapra et al., “On-chip integrated laser-driven particle accelerator”, Science, 367, 6473 (2020)

What are DLA useful for?

US High energy physics panel (2015) recommends to “reduce funding for direct laser acceleration activities considering them not a viable solution for future lepton collider.

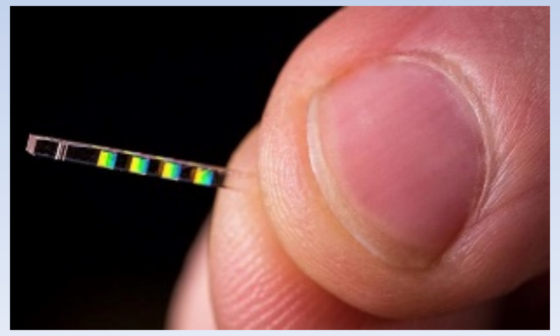
Coherent radiation applications required large charge per bunch which is incompatible with the small aperture.

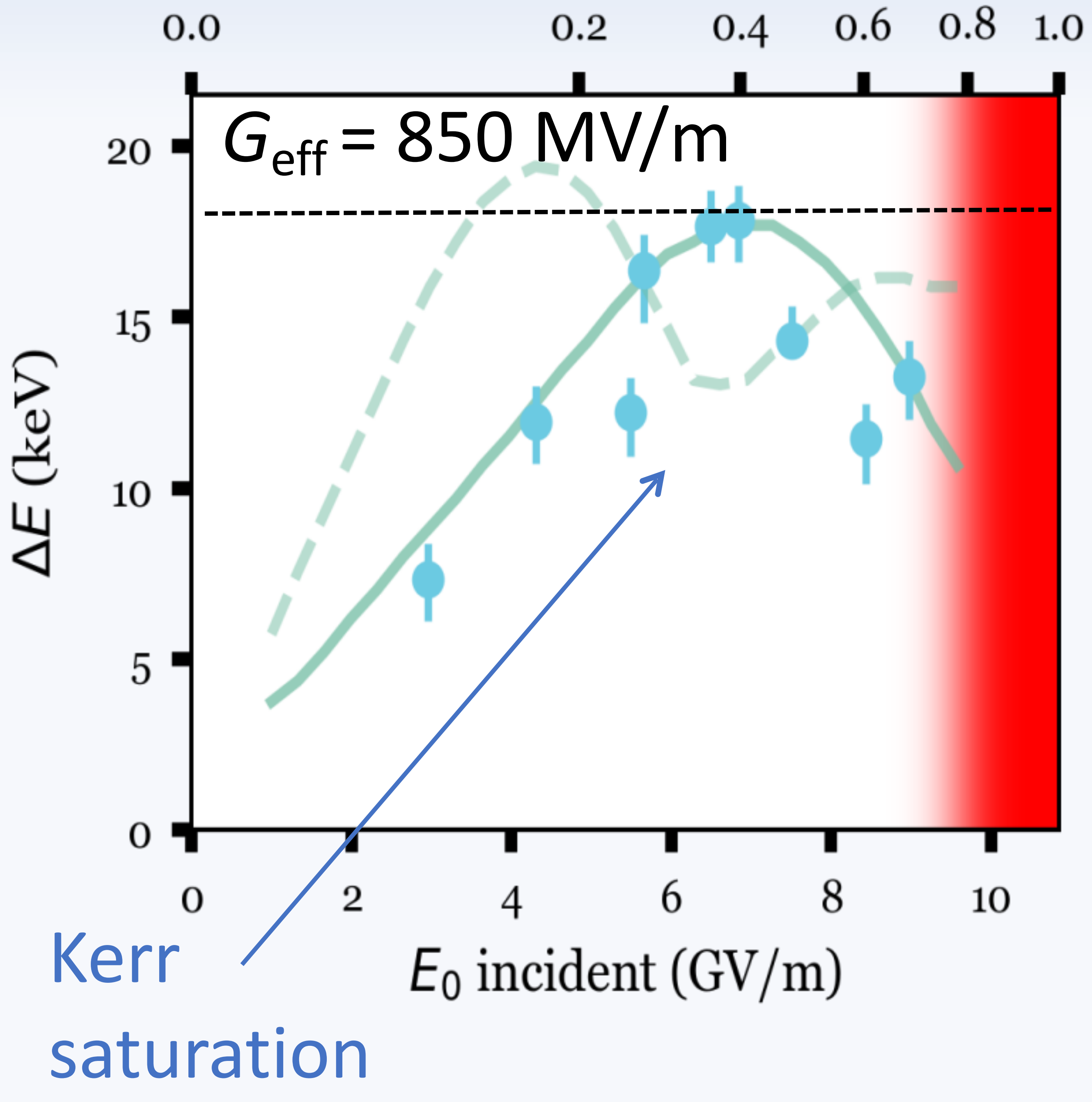
Still, DLA has an important advantage in terms of development path for accelerator mass production (comm. laser and nanofab)

Application	Field	Time-Scale	Kinetic Energy	Species	Beam Power
Radiobiology, Endoscopic RT	**Medical**	**5 yrs**	**100 keV to 10 MeV**	**e-**	**1-5 mW**
UED/UEM and Attosecond Science	**Science**	**5 yrs**	**1-5 MeV**	**e-**	**10 to 50 µW**
Radiation Sources (EUV, IR, THz)	**Industry**	**5-10 yrs**	**10 to 100 MeV**	**e-**	**0.5 W**
Compton X-ray Source	Medical	5-10 yrs	10 to 60 MeV	e-	20 to 60 mW
Proton/Hadron Therapy	Medical	10-20 yrs	70 to 250 MeV	p+	3-400 mW
Compact XFEL	Science	10-20 yrs	1 GeV	e-	1.5 kW
Multi-Axis Tomography	Science	10-20 yrs	1 GeV	e-	1.5 kW
Colliding Beam Fusion	Industry	20+ yrs	15 keV to 1 MeV	p+	1 MW
Linear Collider	HEP	20+ yrs	1 to 10 TeV	e-/e+	10 to 200 MW

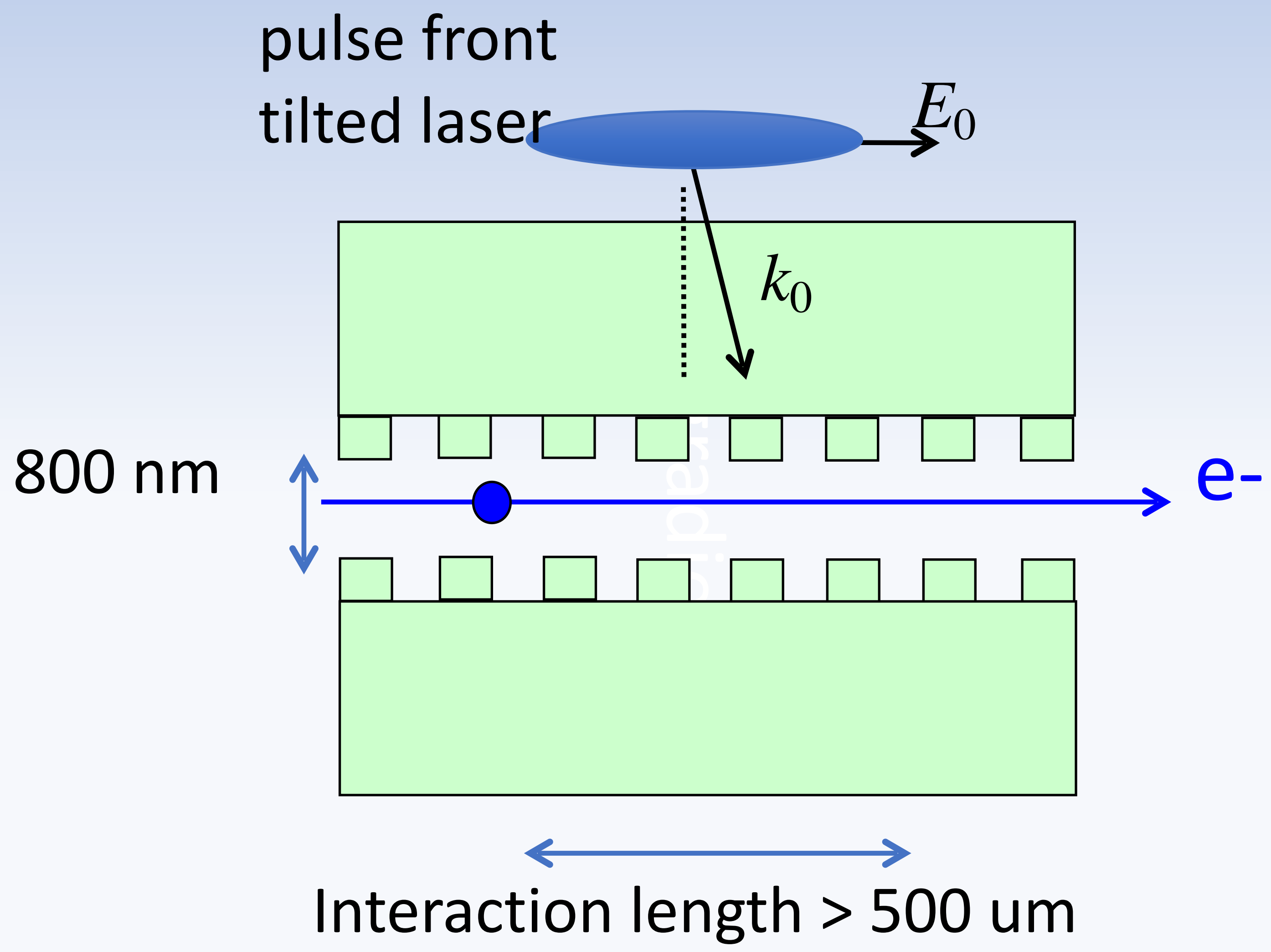
Experiments with relavistic beams have demonstrated record gradients and energy gain.

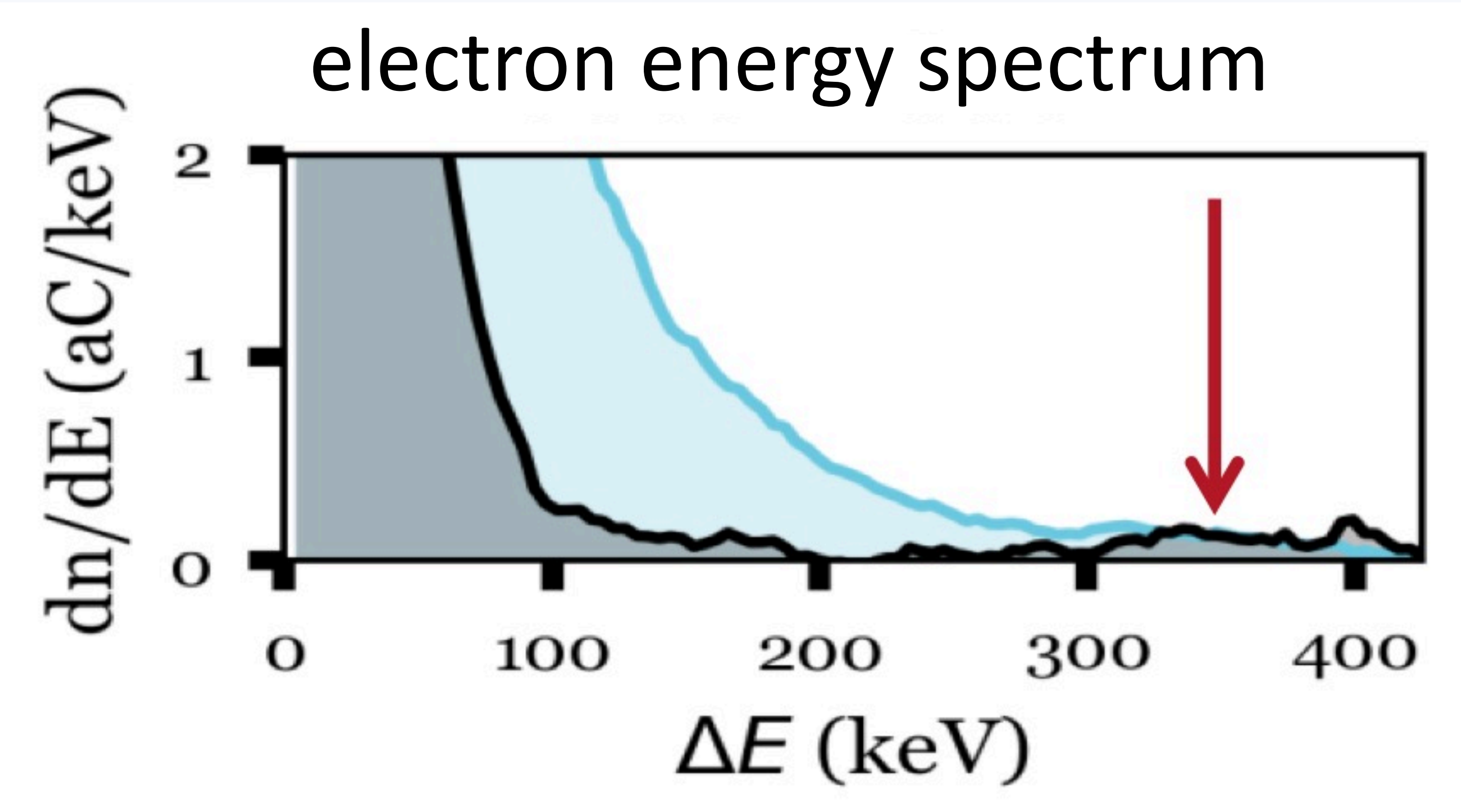
SLAC/UCLA: 0.85 GeV/m*





SLAC/UCLA: 0.3 MeV energy gain**





* D. Cesar et al, Communications Physics 1(4), 1-7 (2018)

** D. Cesar et al, Optics Express 26 (22), 29216 (2018)

Pietro Musumeci

Experimental setup

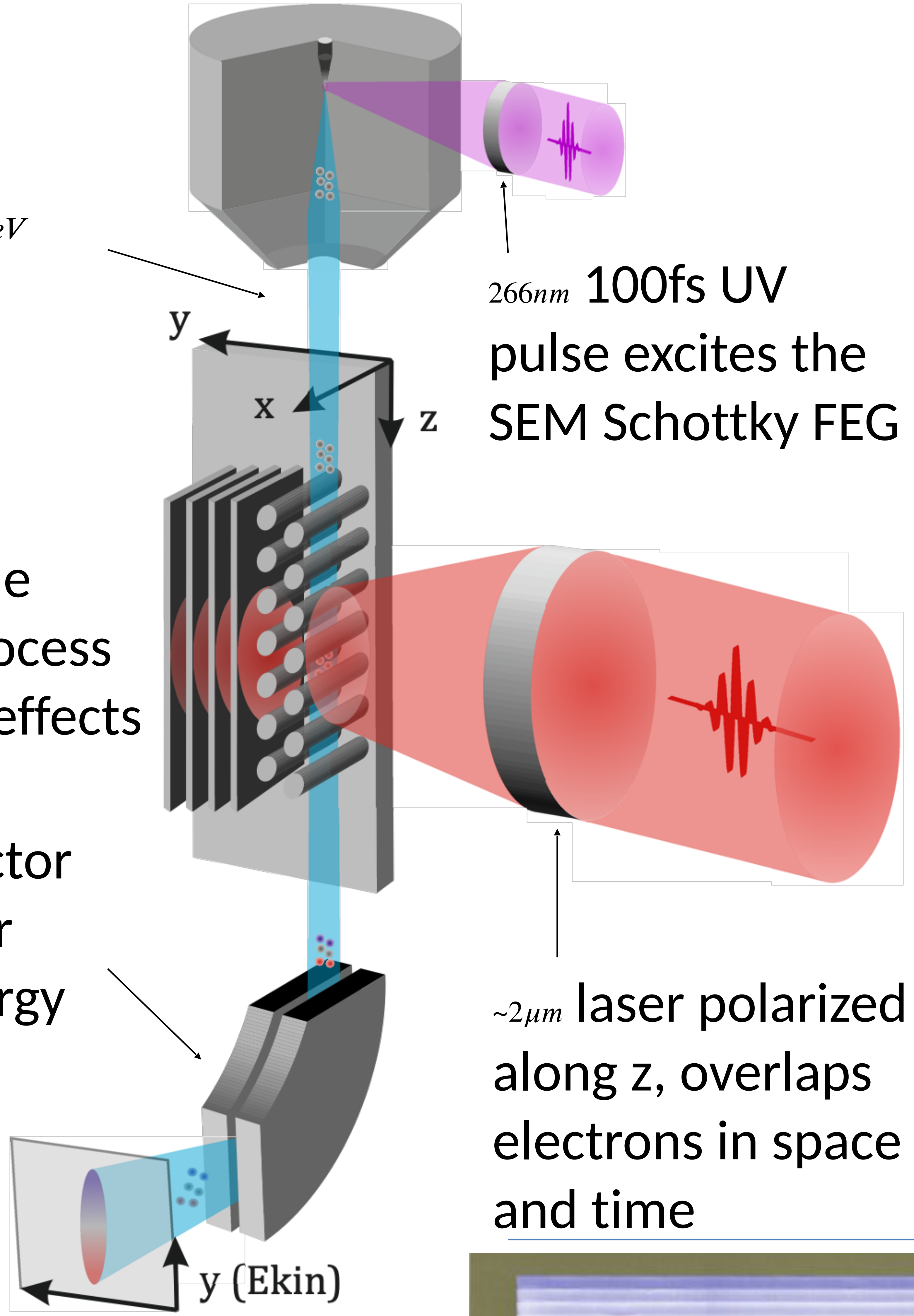
Kozák, M., McNeur, J., Schönenberger, N., Illmer, J., Li, A., Tafel, A., ... & Hommelhoff, P. (2018). *Journal of Applied Physics*, *124*(2), 023104.

Electron energy: ~$30keV$

„Dual pillar" structure:

✓ Symmetric field profile
✓ Simple fabrication process
✓ No nonlinear optical effects

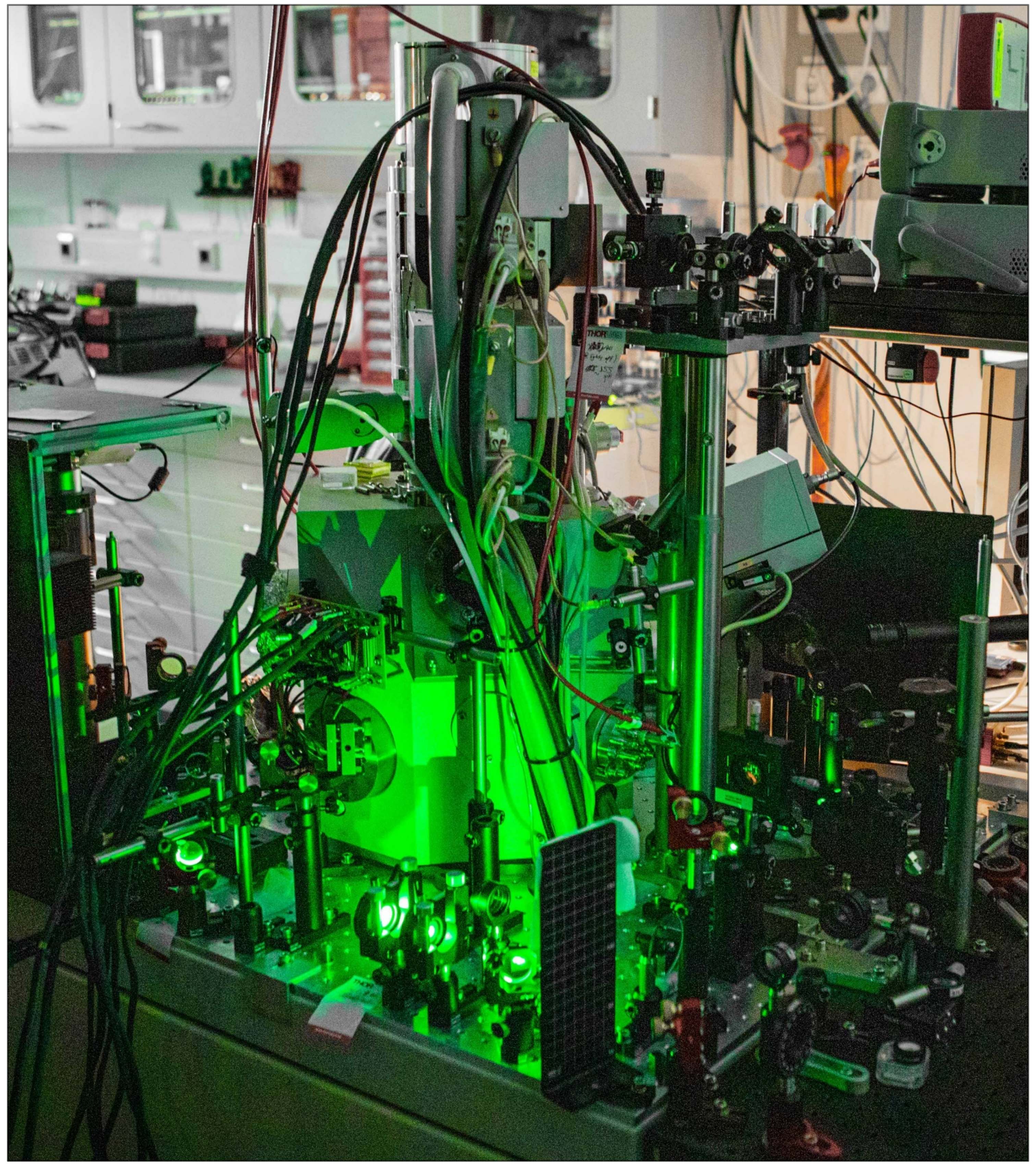
Magnetic sector spectrometer analyzes energy spectra



$266nm$ 100fs UV pulse excites the SEM Schottky FEG

$\sim 2\mu m$ laser polarized along z, overlaps electrons in space and time

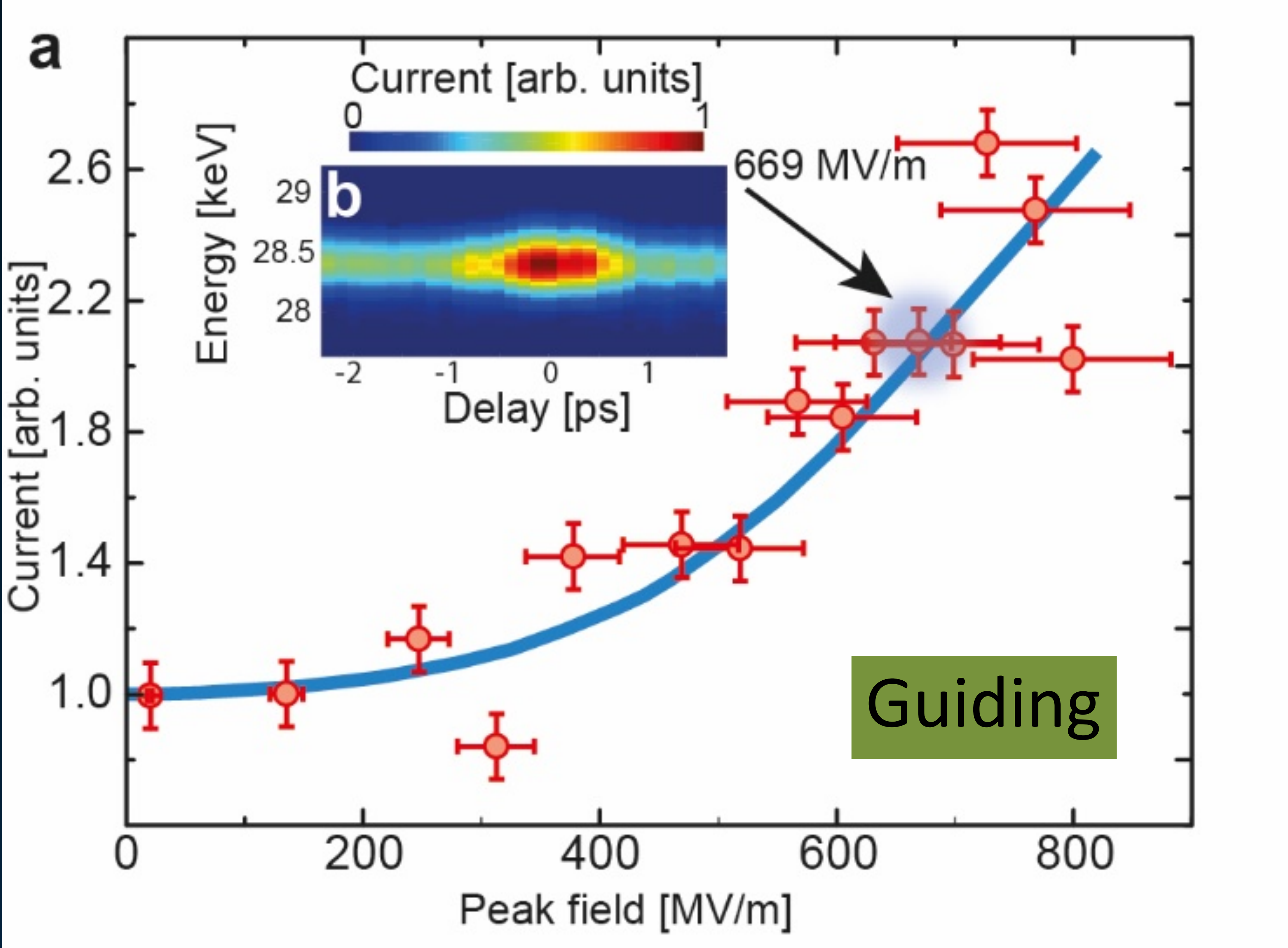
Ultrafast scanning electron microscope



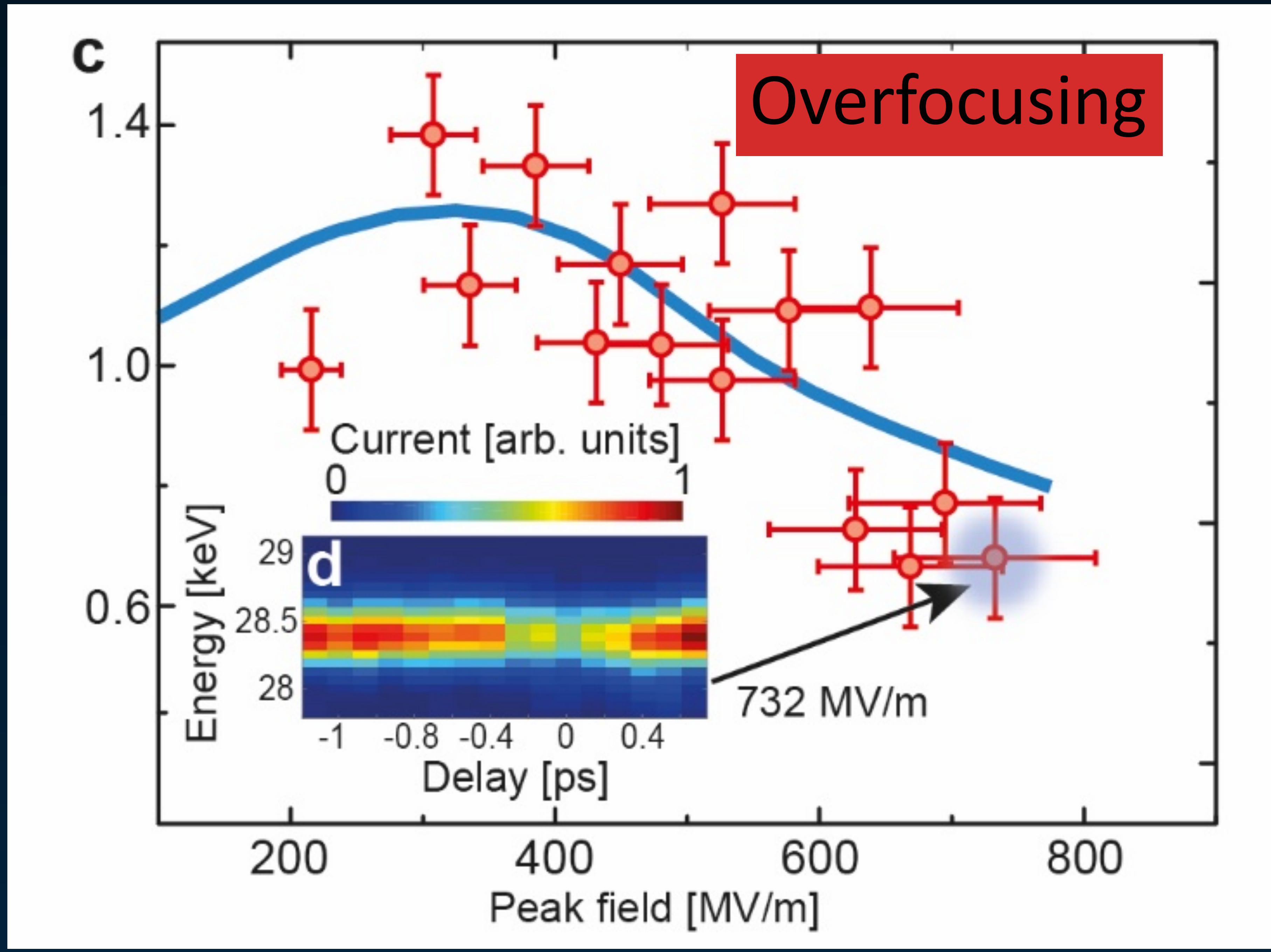
$77\mu m$

Yousefi et al., Opt. Lett. 44, 6 (2019)

Alternating phase focusing effect: proof of principle

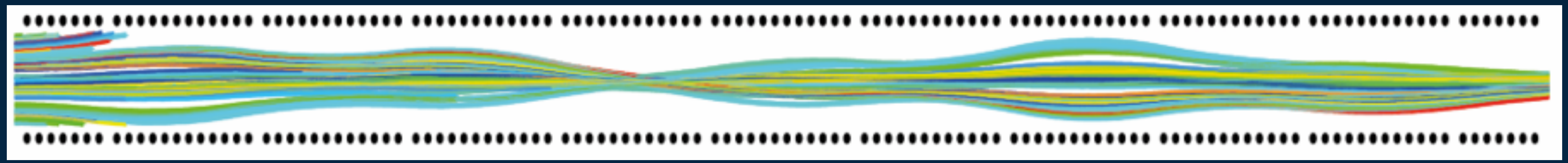


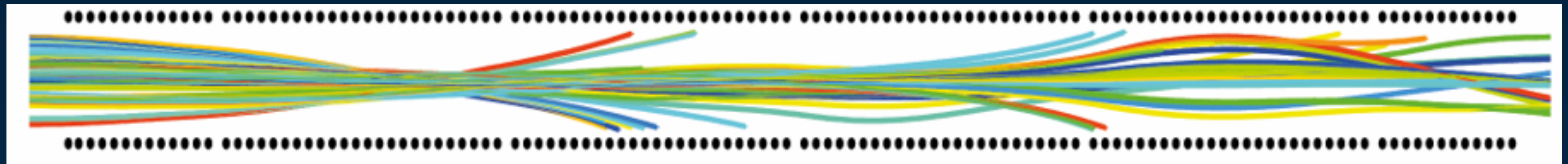
2.7 larger electron current at optimal transport field strength (~700 MV/m)



Overfocusing effect (>400 MV/m)

Different structure geometry with larger macrocells here





R. Shiloh, J. Illmer, T. Chlouba, P. Yousefi, N. Schönenberger, U. Niedermayer, A. Mittelbach, P. Hommelhoff, Nature 597, 498 (2021)

Niedermayer, U., Egenolf, T., Boine-Frankenheim, O., Hommelhoff P., *Physical review letters* 121.21 (2018): 214801.

Next step: Acceleration AND guiding

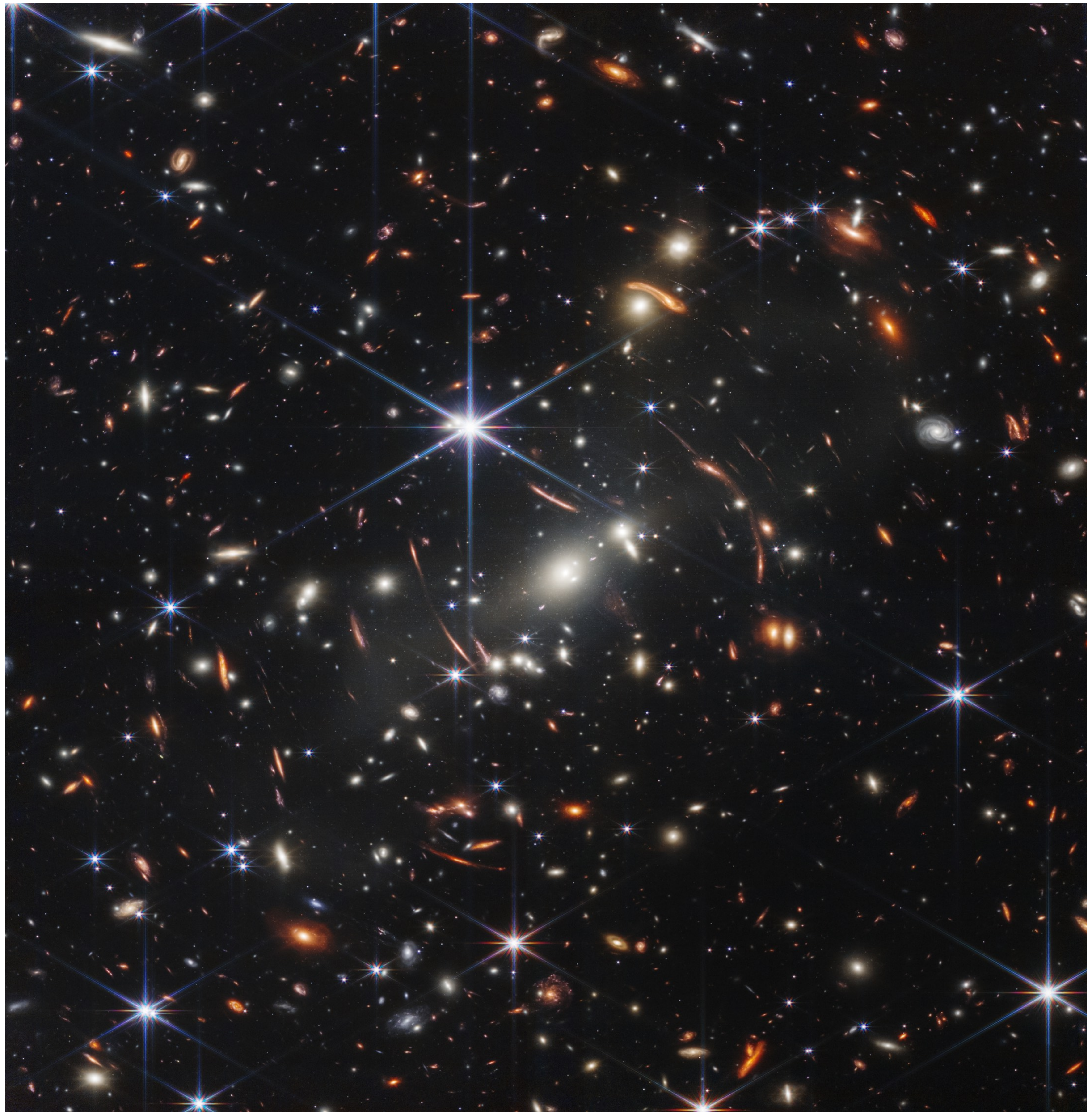
What is Dark Matter?

Dark Matter Properties

1. Dark matter does not interact with electromagnetic forces.(No absorption or emission)

2. It is matter.

3. Dark matter interacts weakly with standard model particles and itself. (As weakly as weak nuclear forces or even weaker)

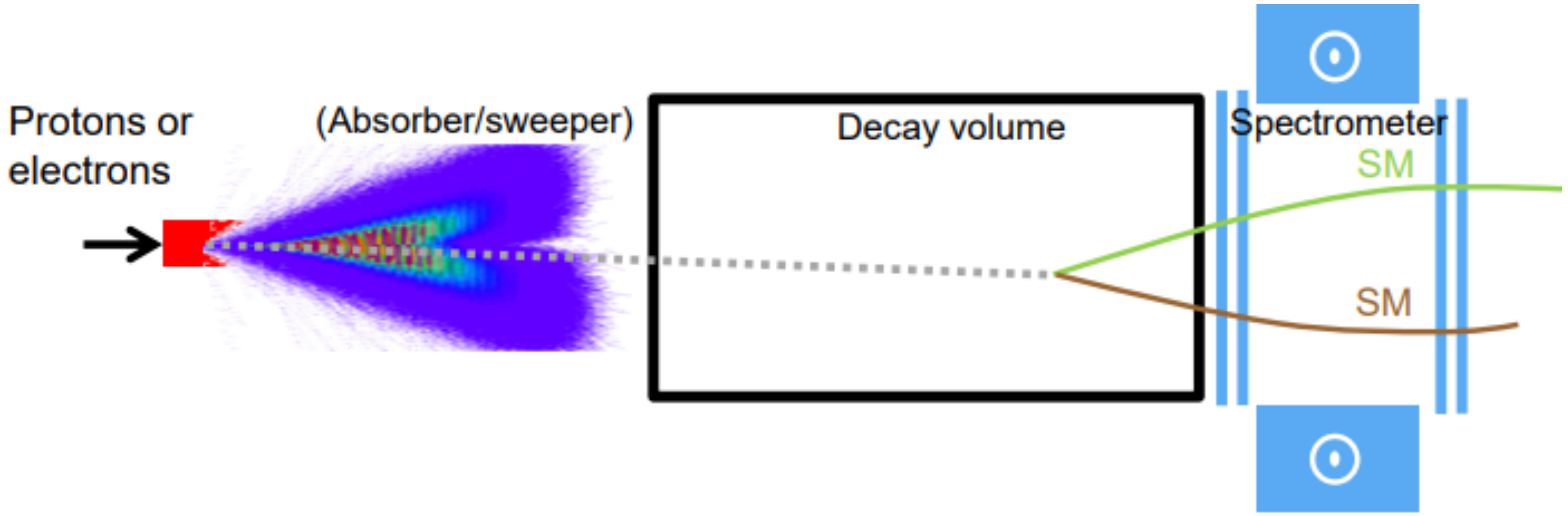


https://www.nasa.gov/webbfirstimages

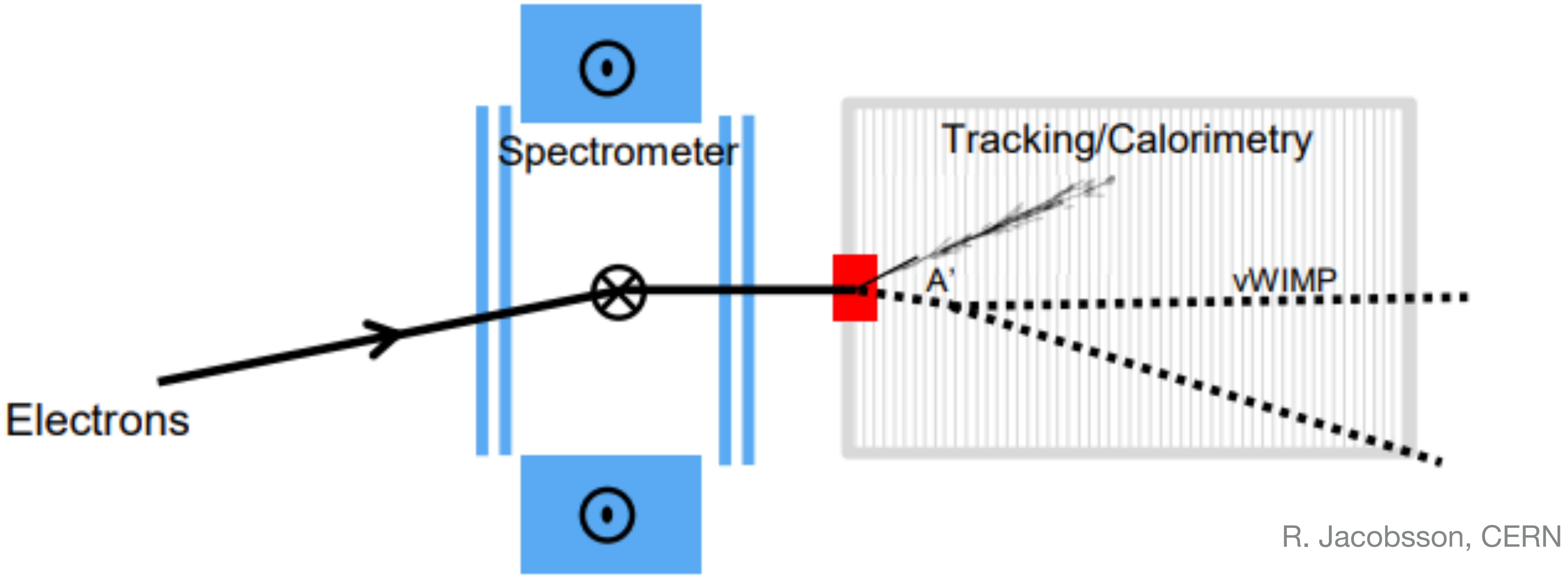
DARK MATTER SEARCH

- Proposed experiments to search for dark matter in the laboratory

  - Direct search: visible decay to Standard Model particles



  - Indirect search: Missing energy/momentum



R. Jacobsson, CERN

- Interaction probability ~ ε^4

  ⇒ need a very large number of primary particles $\mathcal{O}(10^{20})$

- Interaction probability ~ ε^2

  ⇒ need a clean initial state (i.e. single electrons with high repetition rate)

  ⇒ possibility to use a dielectric laser accelerator?

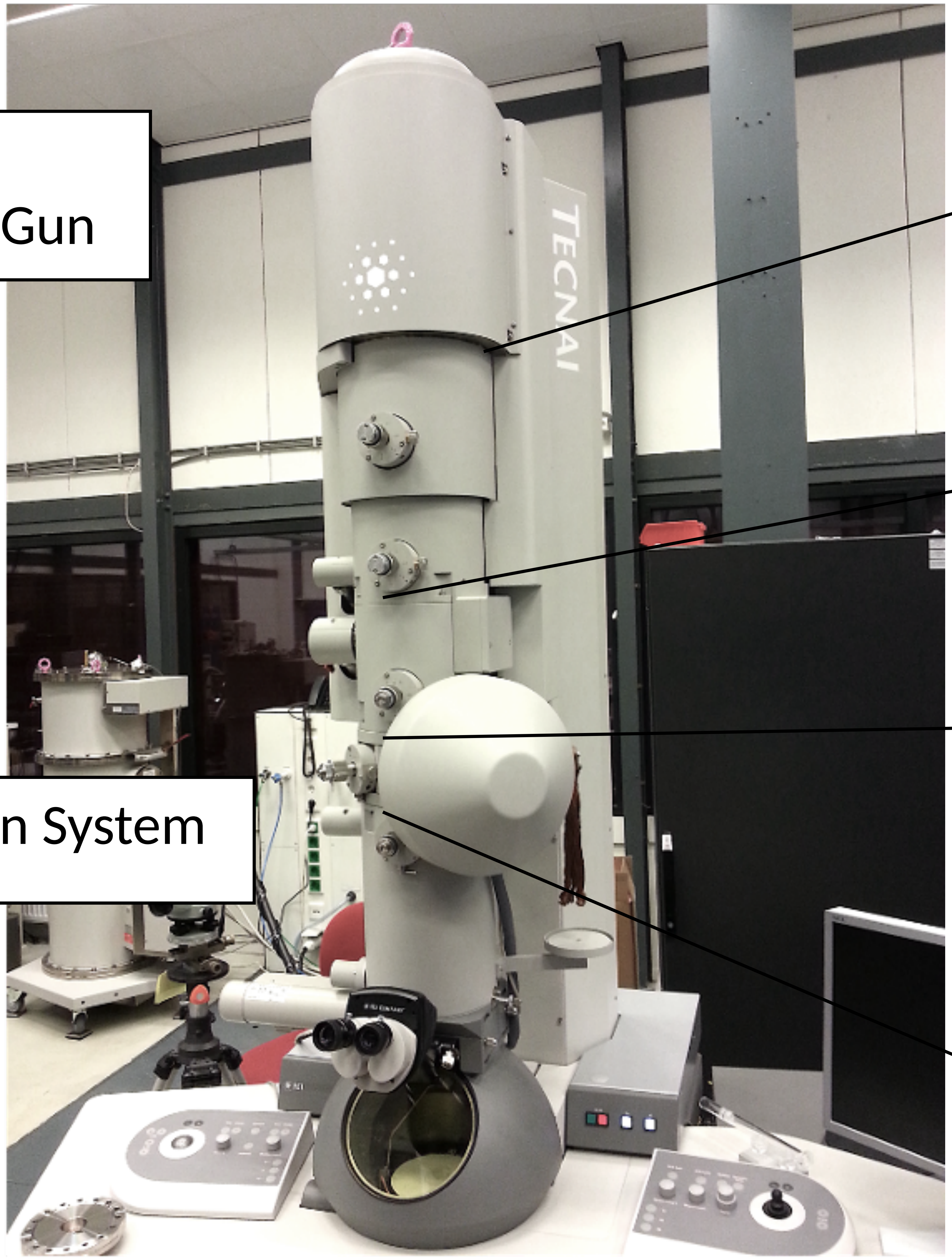
  ⚠ Need to bring dielectric laser acceleration technology to the GeV scale.

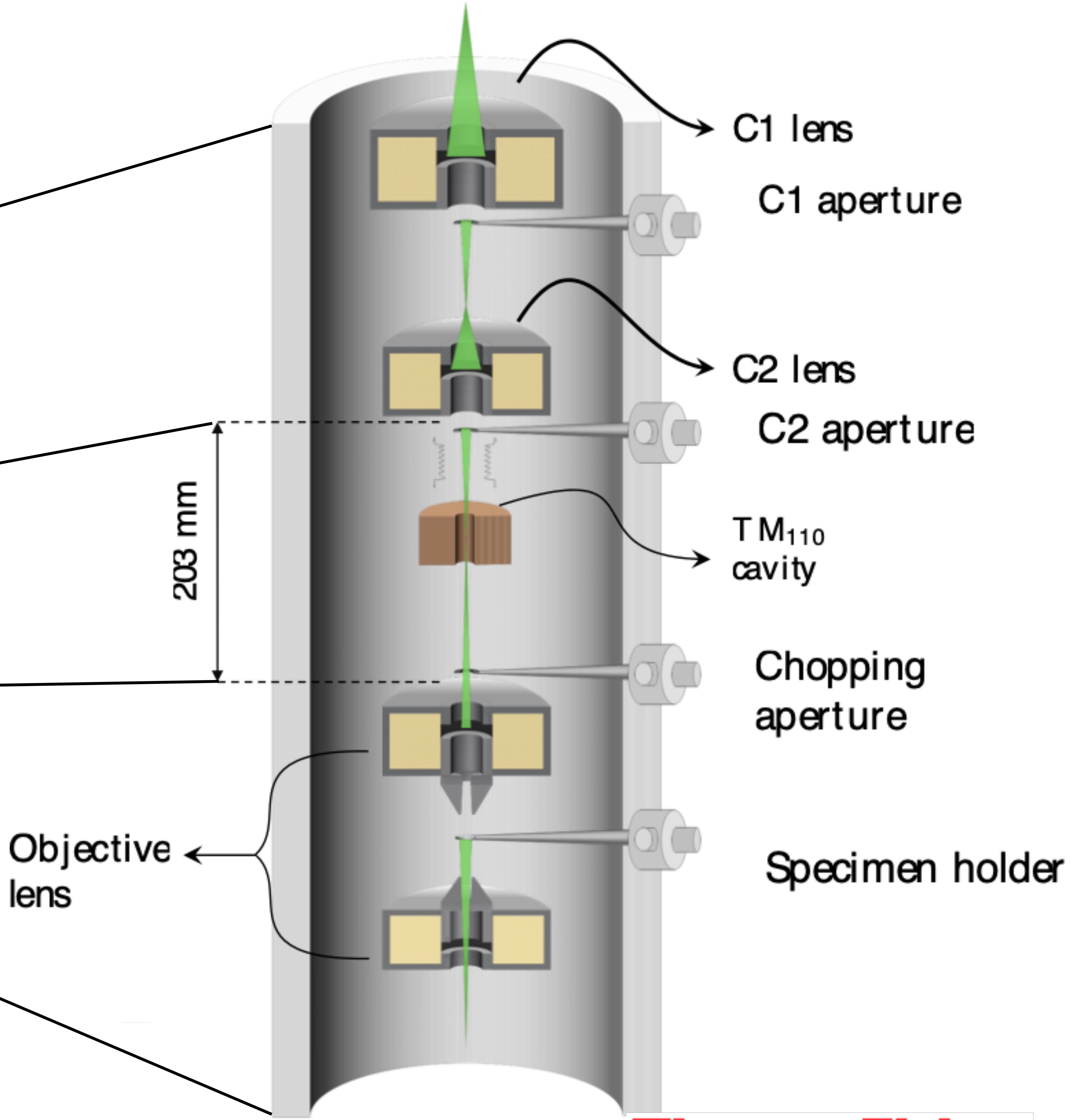
RF-Cavity-Based Ultrafast Transmission Electron Microscope

Schottky
Field Emission Gun

200 keV Tecnai TF20
Pulsed electron beam

Projection System





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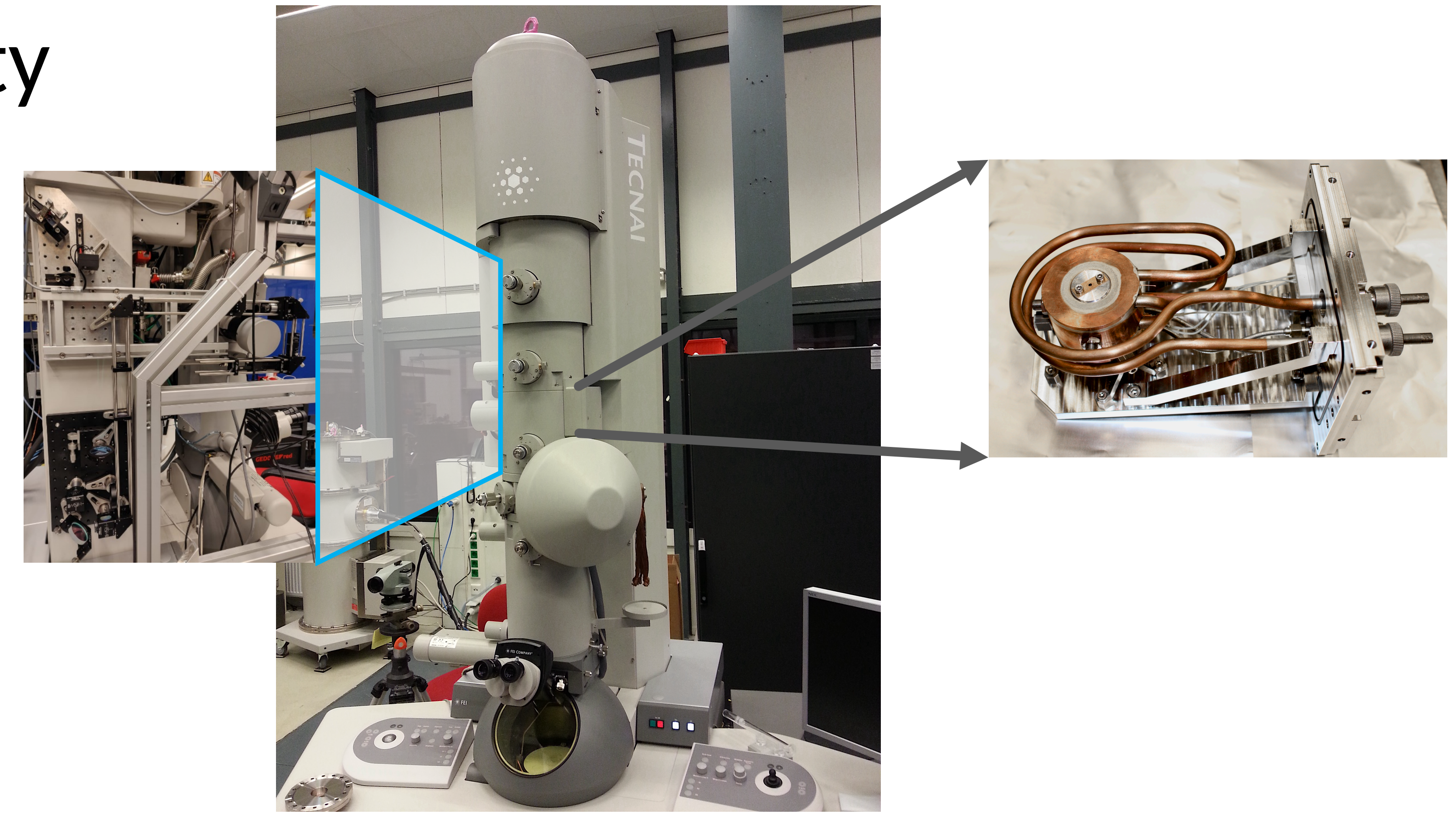
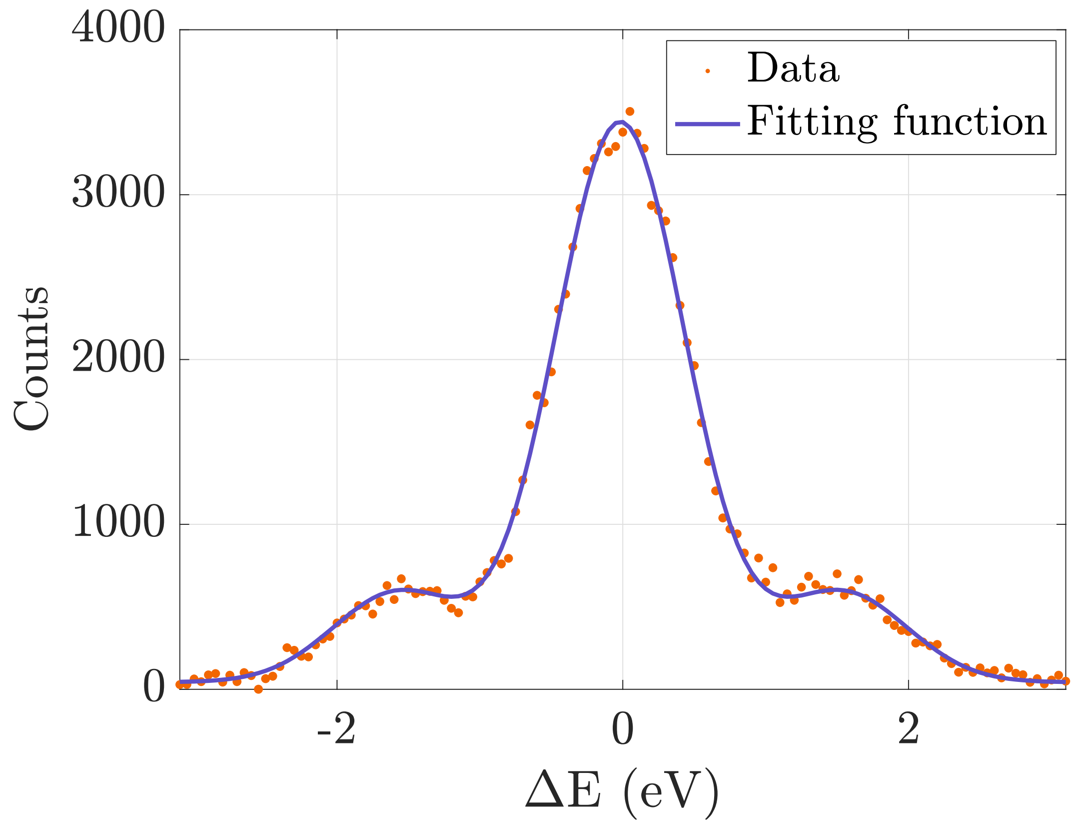
Wrap-up

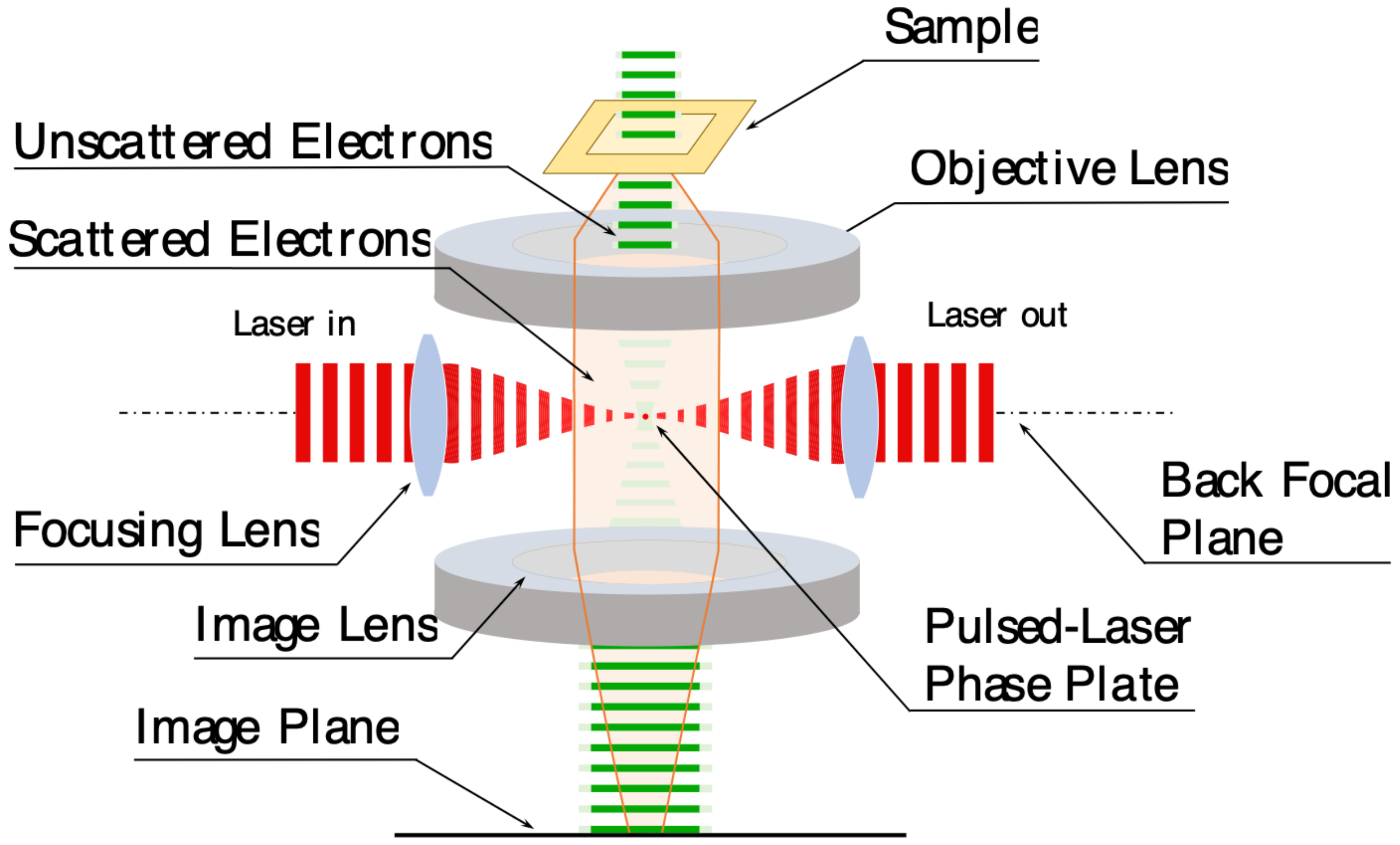
- Pulse generation by beam chopping with miniaturized TM_{110} RF-cavity
- 100 fs pulses @ rep rate 3 GHz or 75 MHz
- Fast switching between continuous and pulsed mode operation
- High Brightness ($\sim 10^{7}$ A/m2 sr V) and energy spread (0.9 eV)
- fs-laser oscillator integrated into the microcope





- Photon-Induced Near-field Electron Microscopy for electron pulse length measurements

- Shaping of the electron wavefunction with fs laser pulses for Zernike phase contrast microscopy



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- Neil Sapra et al., Science 367 (6473), 97-83