PAUL SCHERRER INSTITUT

Rasmus Ischebeck
Uwe Niedermayer

with contributions by the ACHIP collaboration

DIELECTRIC LASER ACCELERATORS

LASER-BASED ACCELERATORS

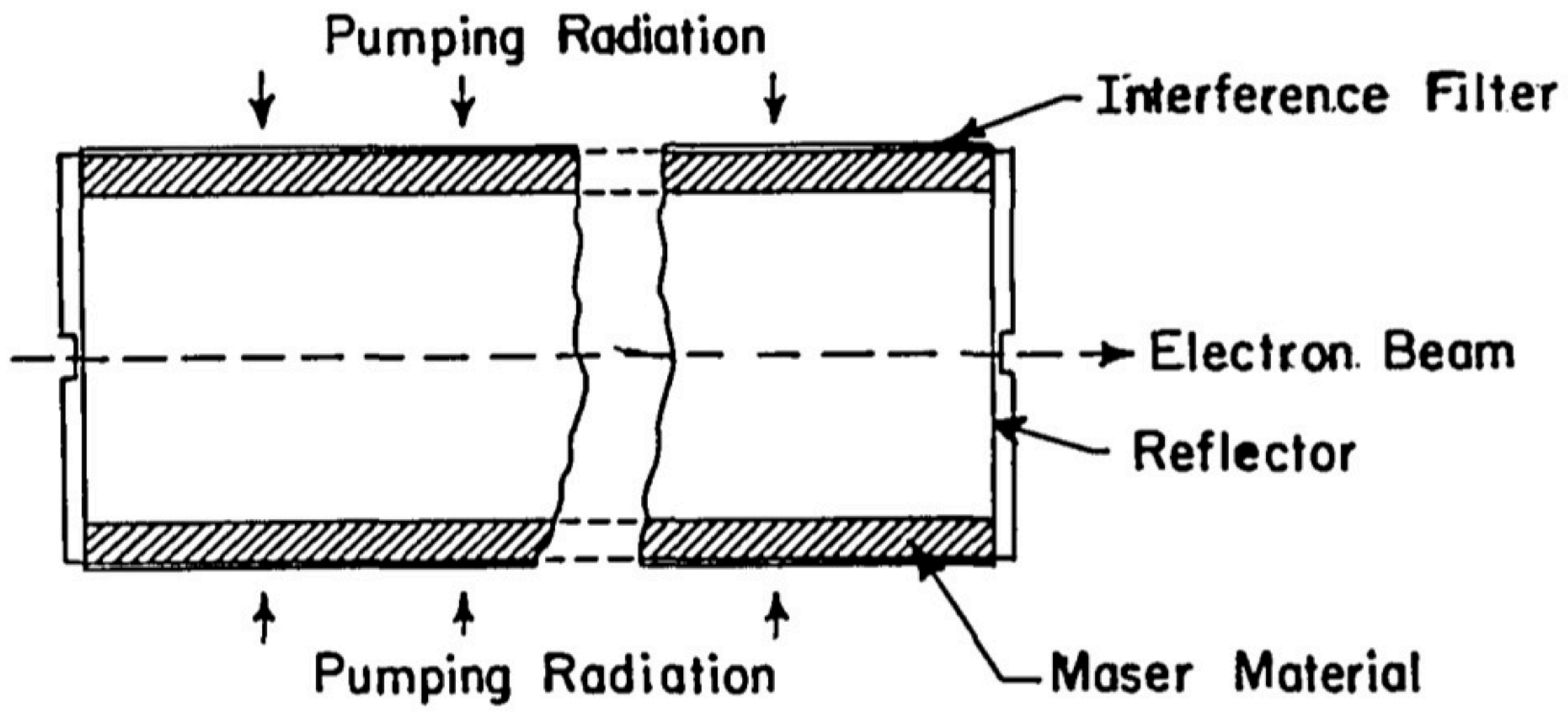
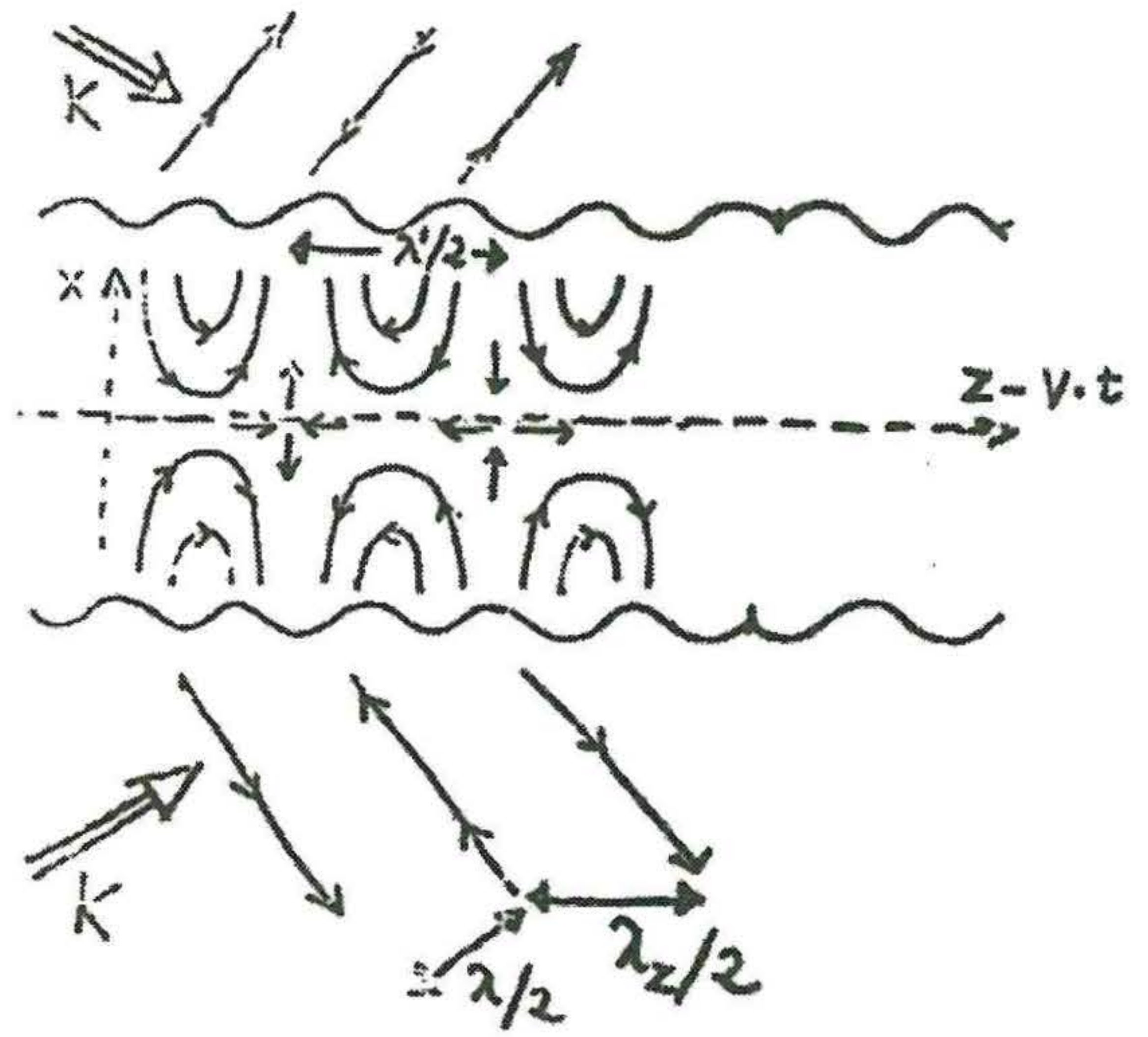


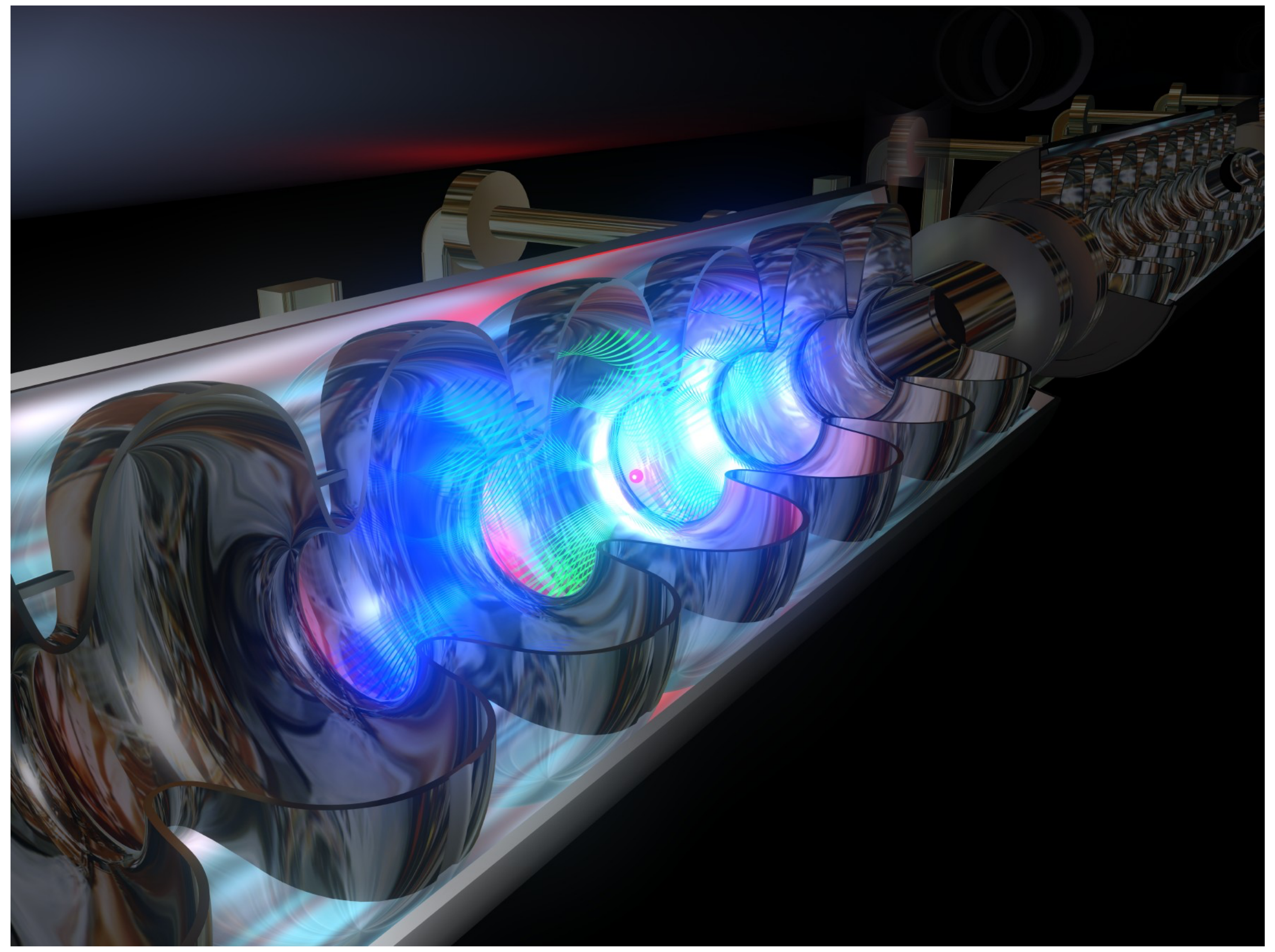
Fig. 1. Schematic diagram of an electron linear accelerator by optical maser.

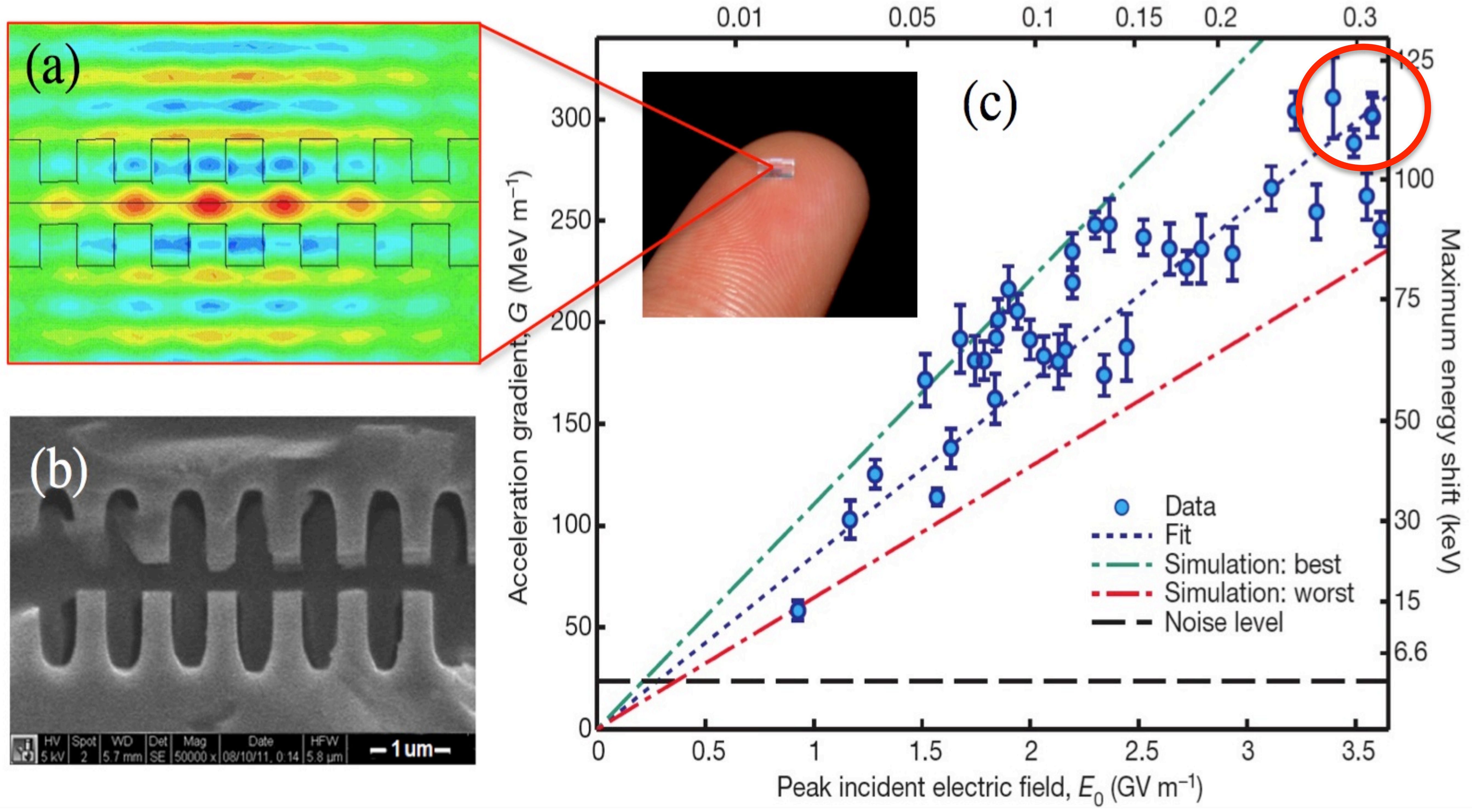
- Shimoda, Appl. Opt. 1 (1), 33 (1961)



- Lohmann, IBM TN-5, 162 (1962)

ACCELERATING STRUCTURES





- Peralta et al., Nature 503, 91 (2013)

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

LASERS

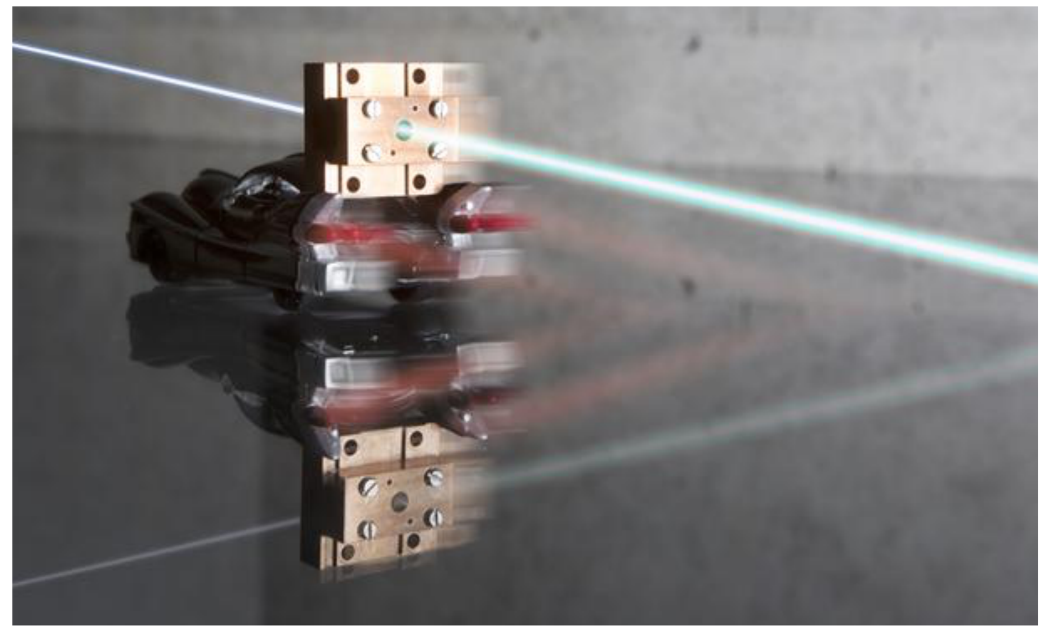
- Suitable lasers
  - MHz repetition rate
  - low pulse energy ~ 10 μJ
  - high wallplug efficiency ~ 30%

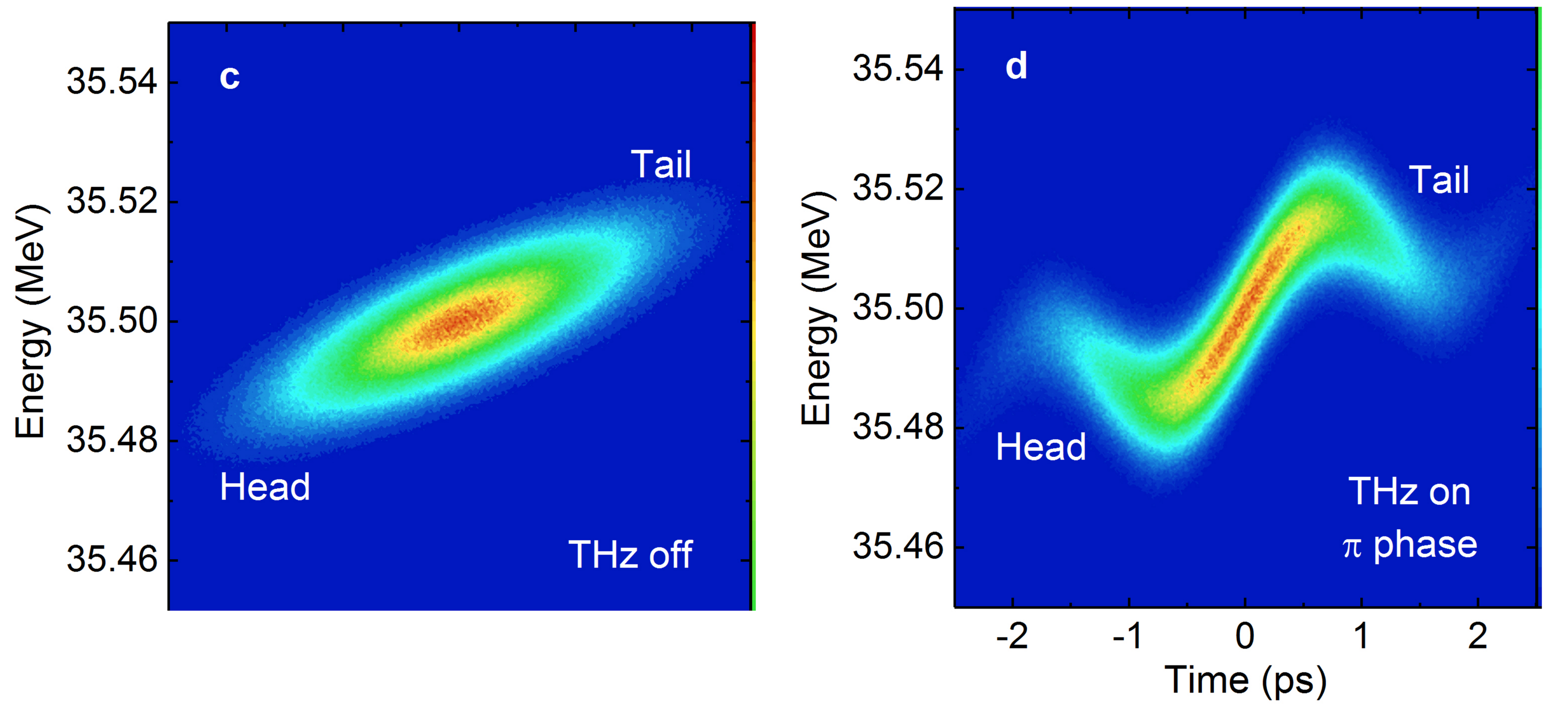
COMPARISON TO RADIO FREQUENCY ACCELERATORS

Parameter	DLA	RF
Power Source	Commercial IR Laser	Microwave Klystron
Wavelength	1-10 µm	2-10 cm
Bunch Length	10-100 attosec	1-5ps
Bunch Charge	1-10 fC	0.1- 4 nC
Required Norm. Emittance	1-10 nm rad	0.1-1 µm rad
Rep Rate	10-200 MHz	1-1000 Hz
Confinement of Mode	Photonic Crystal (1D, 2D, 3D)	Metal Cavity
Material	Dielectric	Metal
Unloaded Gradient	1-10 GV/m	30-100 MV/m
Power Coupling Method	Free-space/Silicon WG	Critically-coupled metal WG

OTHER ADVANCED ACCELERATION CONCEPTS

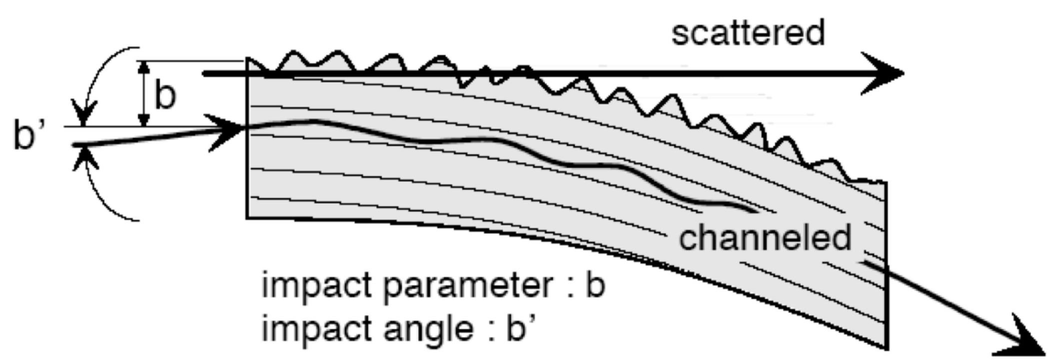
- Terahertz accelerators





  - Zhang et al., Nature Photonics 12, 336–342 (2018)
  - Hibbert et al., Nature Photonics 14, 755–759 (2020)

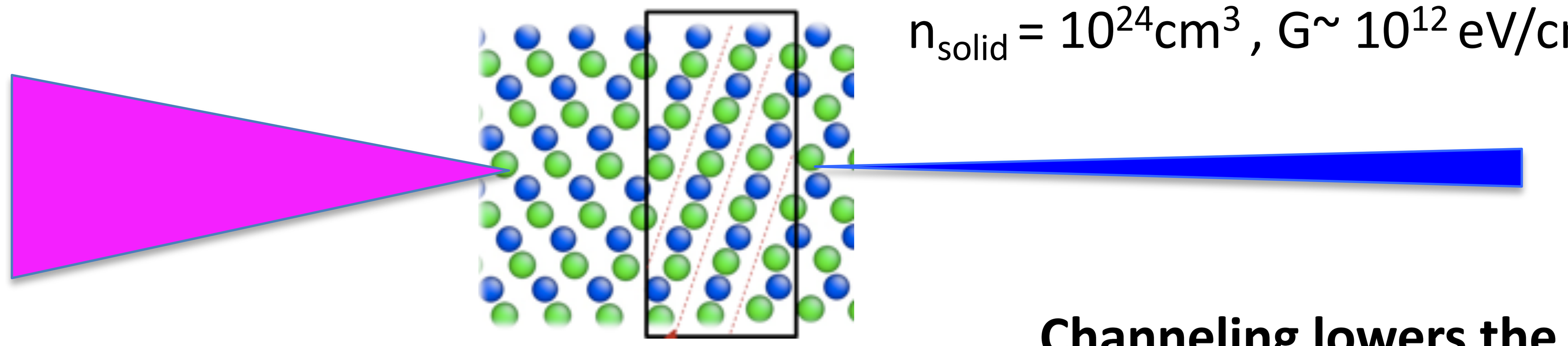
- Crystal accelerators and collimators



- Plasma from solid state material

Atto-zepto, X-ray Driver, Solid, *Tajima et Cavenago 1987*

$n_{solid} = 10^{24}cm^{3}$, $G\sim 10^{12}$ eV/cm, TeVcm

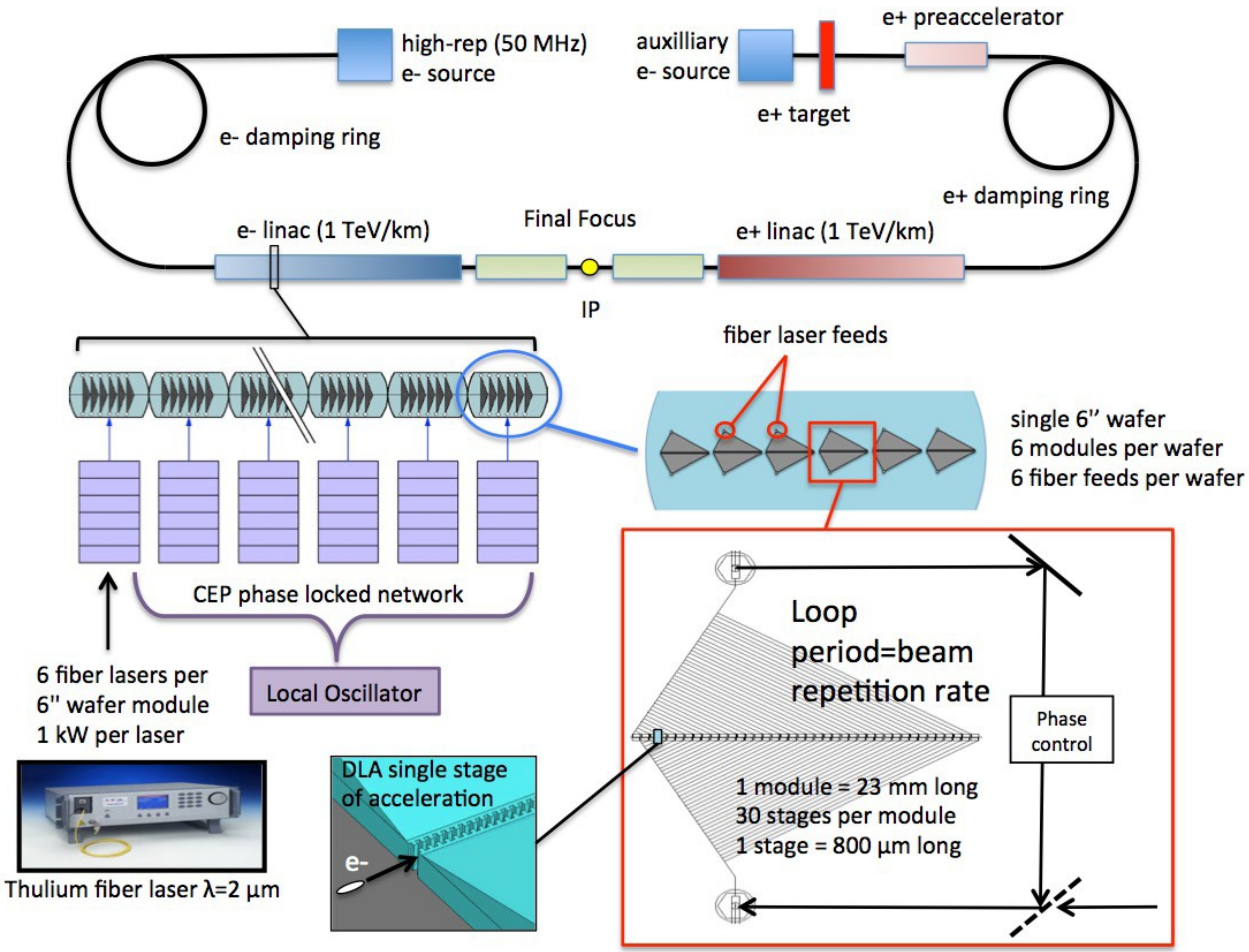


Drive pulse X-Ray, 600zs
+ as electron pulse

Channeling lowers the emittance
Valid for electrons, muons, heavy ions

07/10/2019 Corkum, RECOLLISION

DLA-BASED COLLIDER CONCEPT — ALEGRO / ANAR



STUDIES FOR A 3…30 TeV COLLIDER — ALEGRO

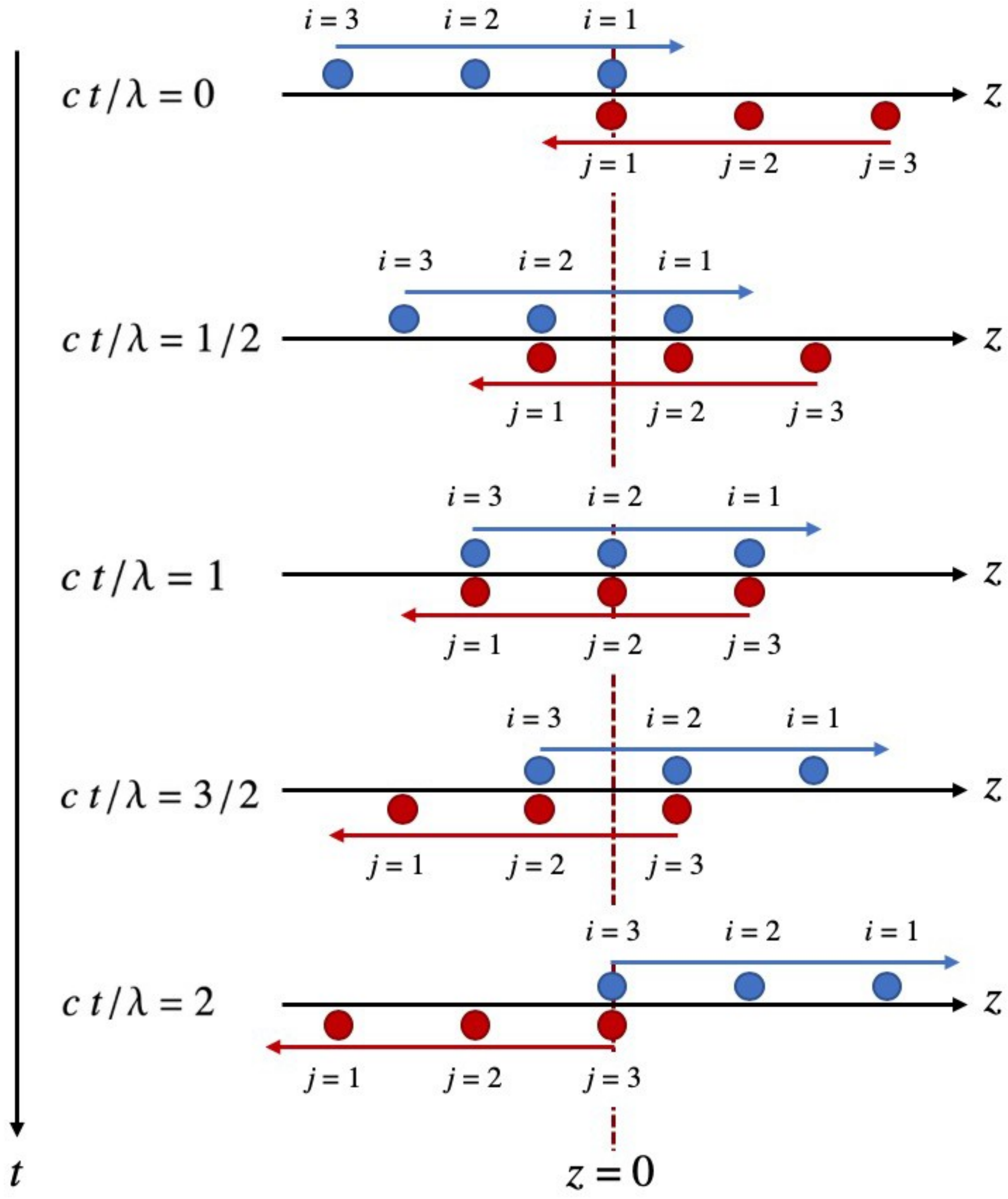
Towards an Advanced Linear International Collider

ALEGRO collaboration

TABLE 3. Electron-Positron Collider Parameter Comparison

Beam Parameters	Units	DLA 250 GeV	DLA 3 TeV	DLA 30 TeV
Center of mass Energy	GeV	250	3000	30000
bunch charge	e	3.8E+04	3.0E+04	3.0E+04
# bunches/train	#	159	159	159
# parallel beamlines	#	1	1	10
train repetition rate	MHz	20	20	20
final bunch train length	psec	1.06	1.06	1.06
single bunch length	micron	2.78E-03	2.78E-03	2.78E-03
Drive wavelength	micron	2	2	2
IP X Emittance	micron	0.0001	0.0001	0.0010
IP Y Emittance	micron	0.0001	0.0001	0.0010
IP X Spot Size	nm	2	1	1
IP Y Spot Size	nm	2	1	1
Length of beam delivery	m	2321	2304	2304
Effective L*	m	5	5	5
Total Length	km	5.0	8.4	42.1
Geometric Luminosity	**/cm^2/s**	**1.46E+33**	**3.63E+33**	**3.63E+35**
Enhanced Luminosity	**/cm^2/s**	**1.84E+34**	**3.19E+34**	**3.19E+36**
Beam Power (per beam)	MW	2.4	22.9	2292.5
Total Wall Plug Power	MW	88.1	360.3	30487.4
Wall Plug Efficiency	%	5.5	12.7	15.0

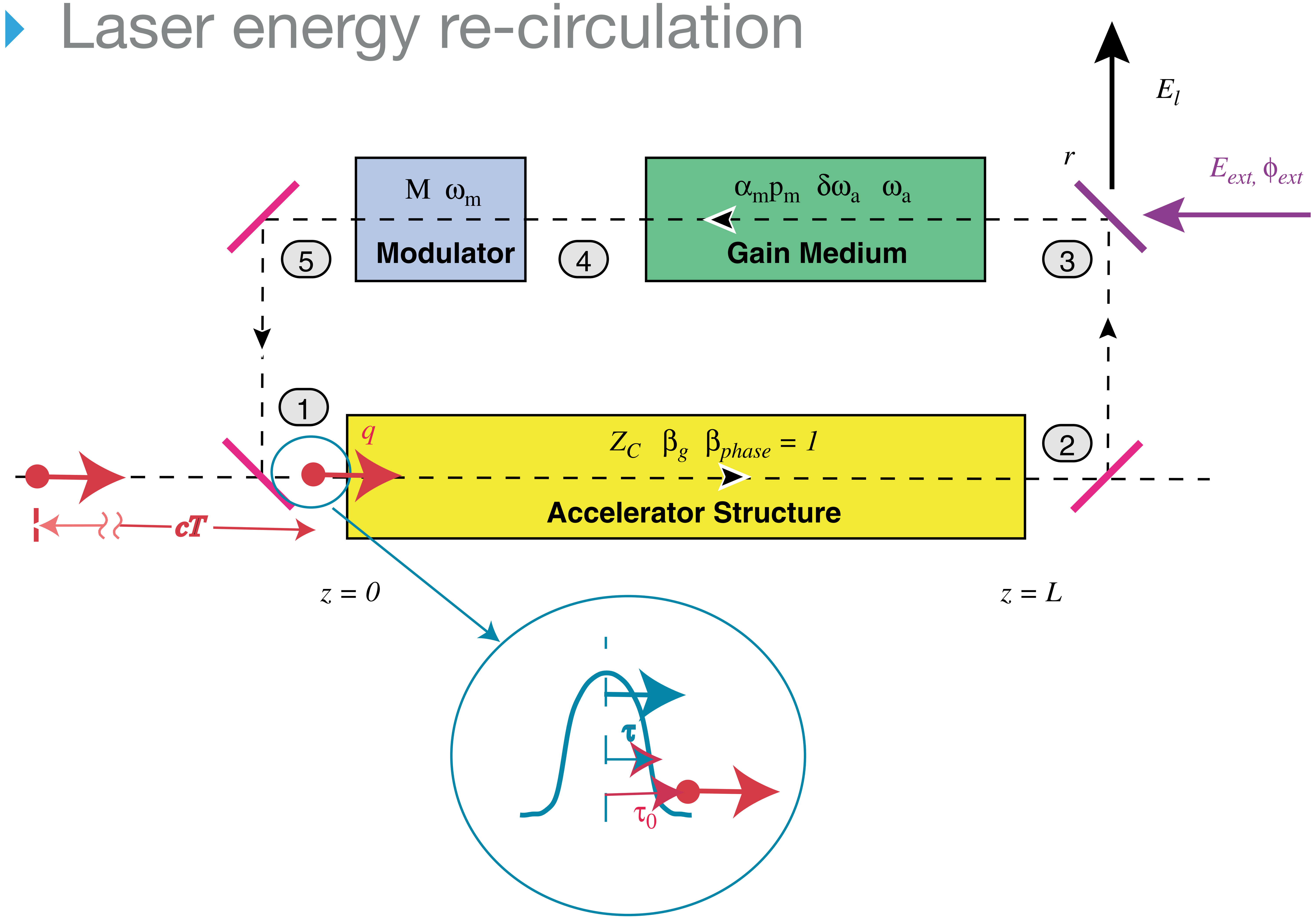
COLLISION OF BUNCH TRAINS



- Joel England, Levi Schachter, work in progress

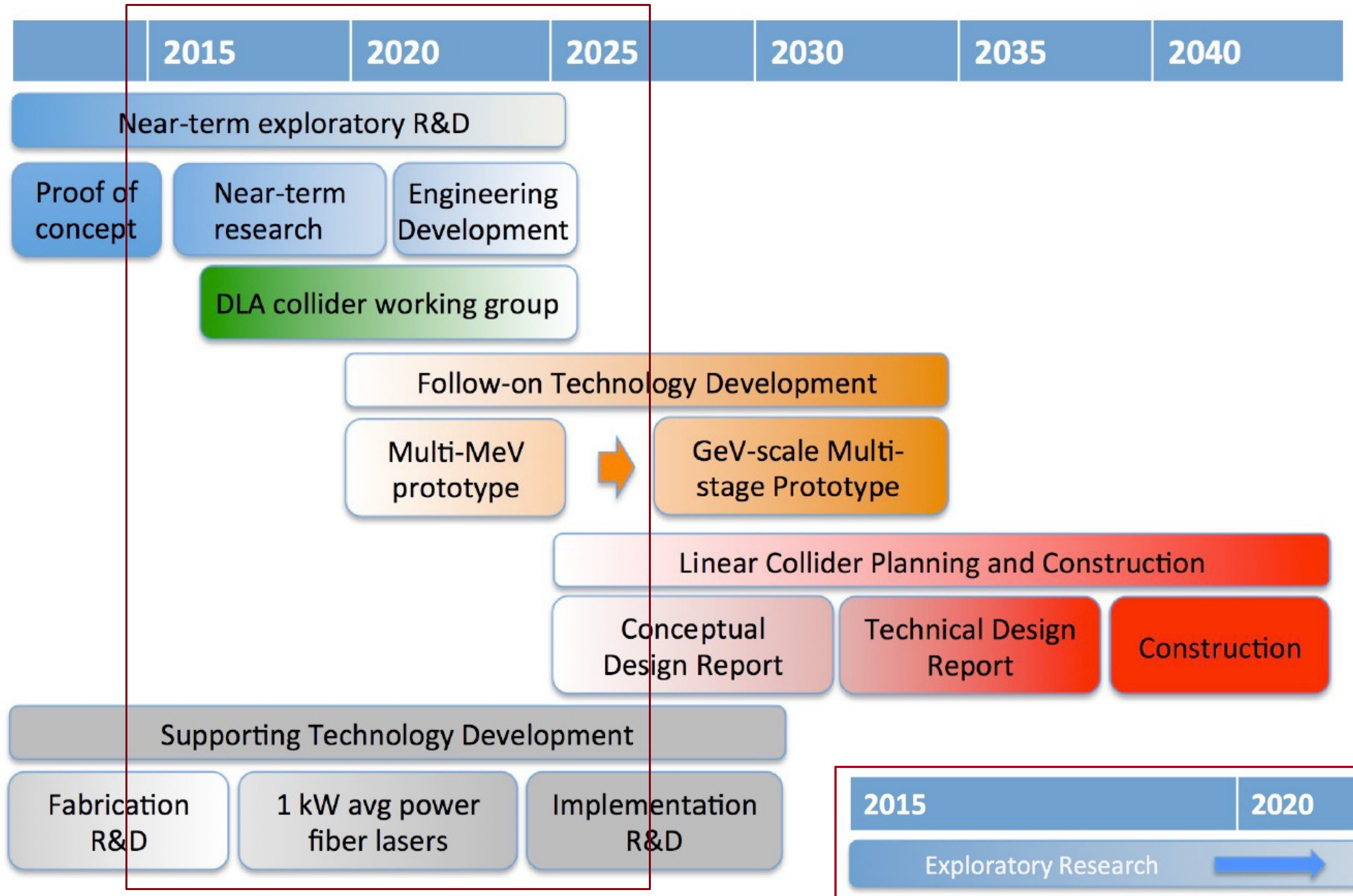
EFFICIENCY OPTIMIZATION

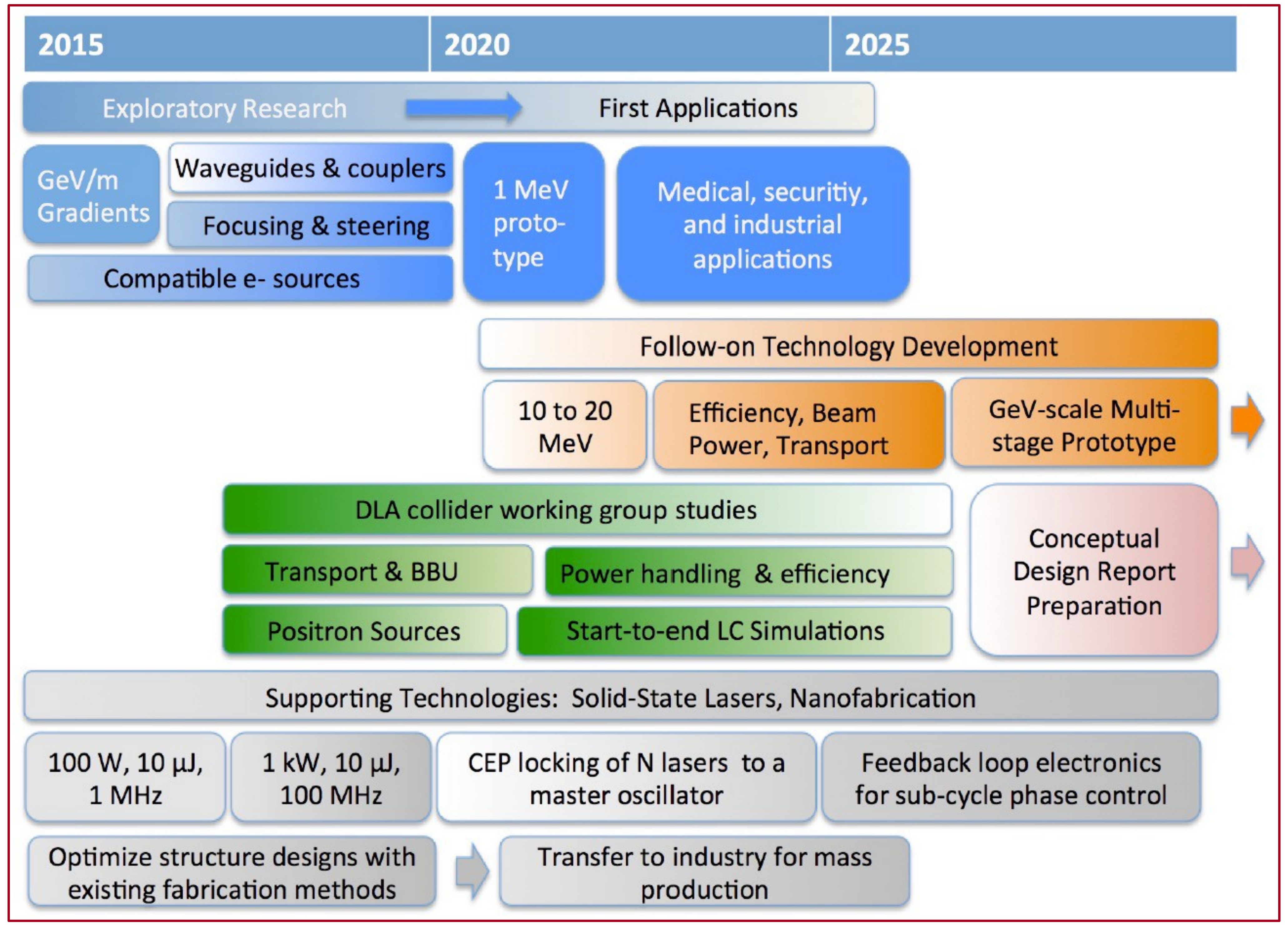
- Traveling wave structures
- Laser energy re-circulation



- Siemann, Phys. Rev. ST Accel. Beams 7, 061303 (2004)

30-YEAR ROADMAP (ANAR 2017)





KEY ADVANTAGES

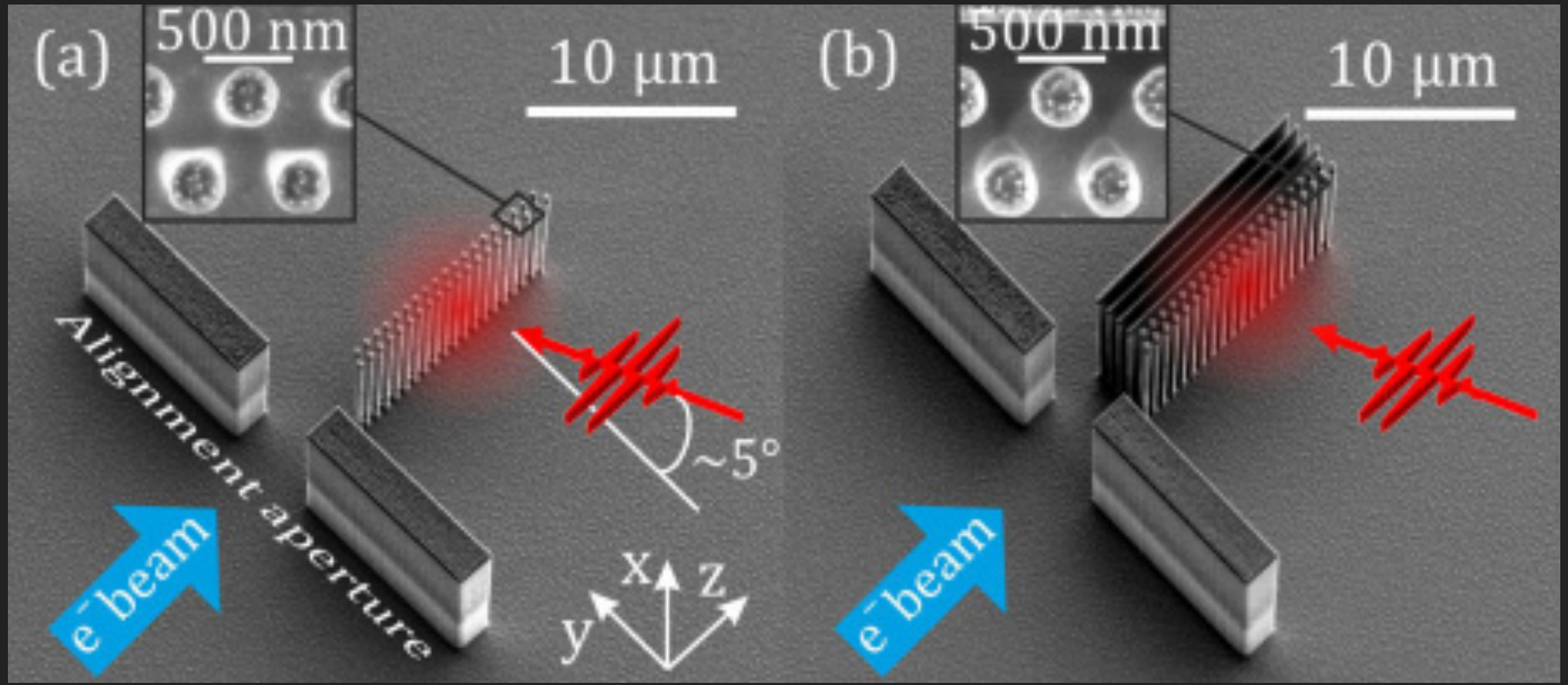
- Linear acceleration in a static nanostructure with vacuum channel
- Underlying technologies well-developed, and with considerable funding
  - Lasers
  - Nano-fabrication
- High efficiency of fiber lasers
- Unique bunch format with beamstrahlung loss ~ 1%

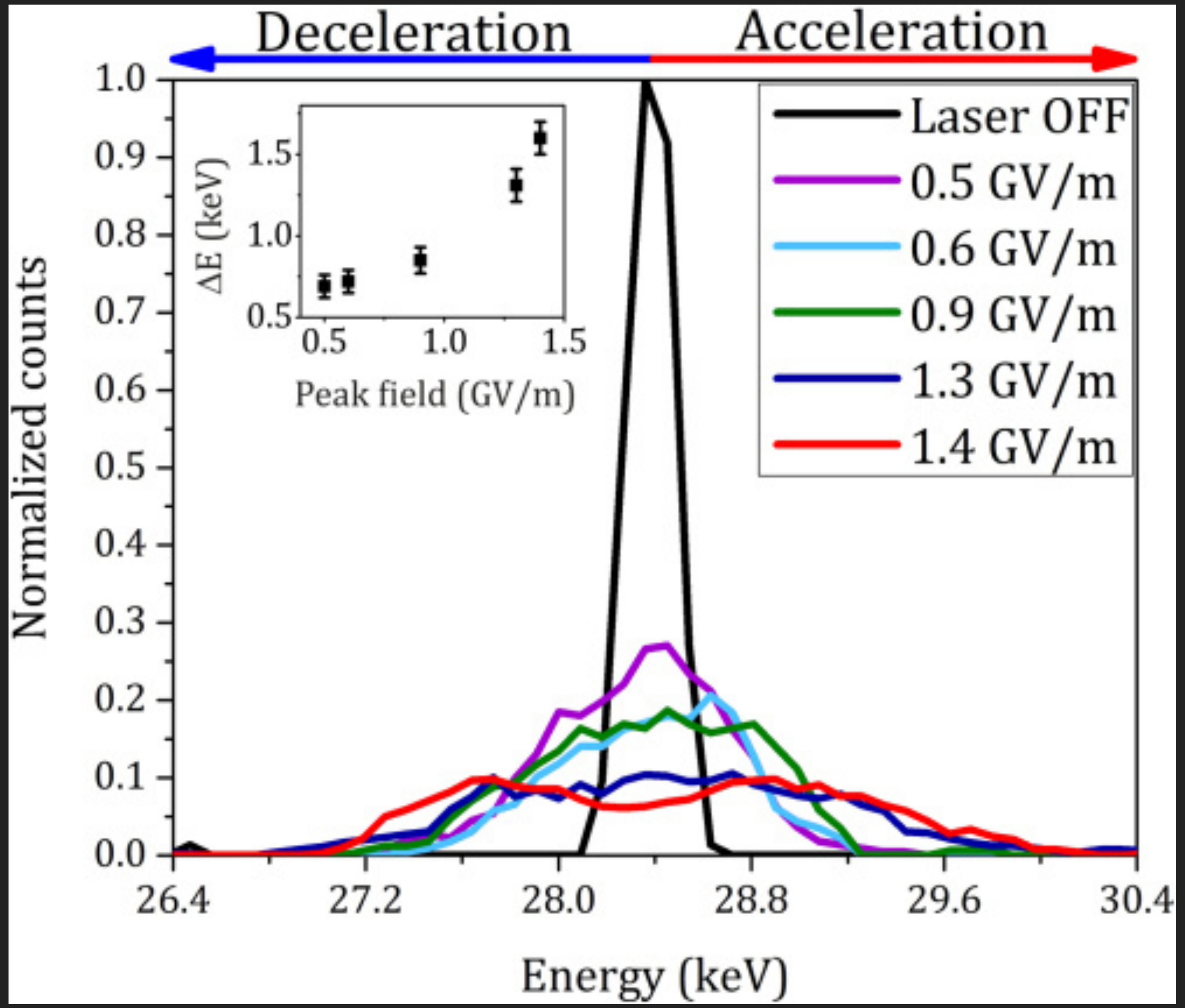
PRIMARY CHALLENGES FOR A DLA COLLIDER

- Small beam apertures
  - Wakes
  - Halo
  - Long-distance transport
- Need high-rep rate e^+ and e^- sources
- Current funding for this area of research is not directly focused on HEP applications

RESULTS FROM THE ACHIP COLLABORATION

ACCELERATION

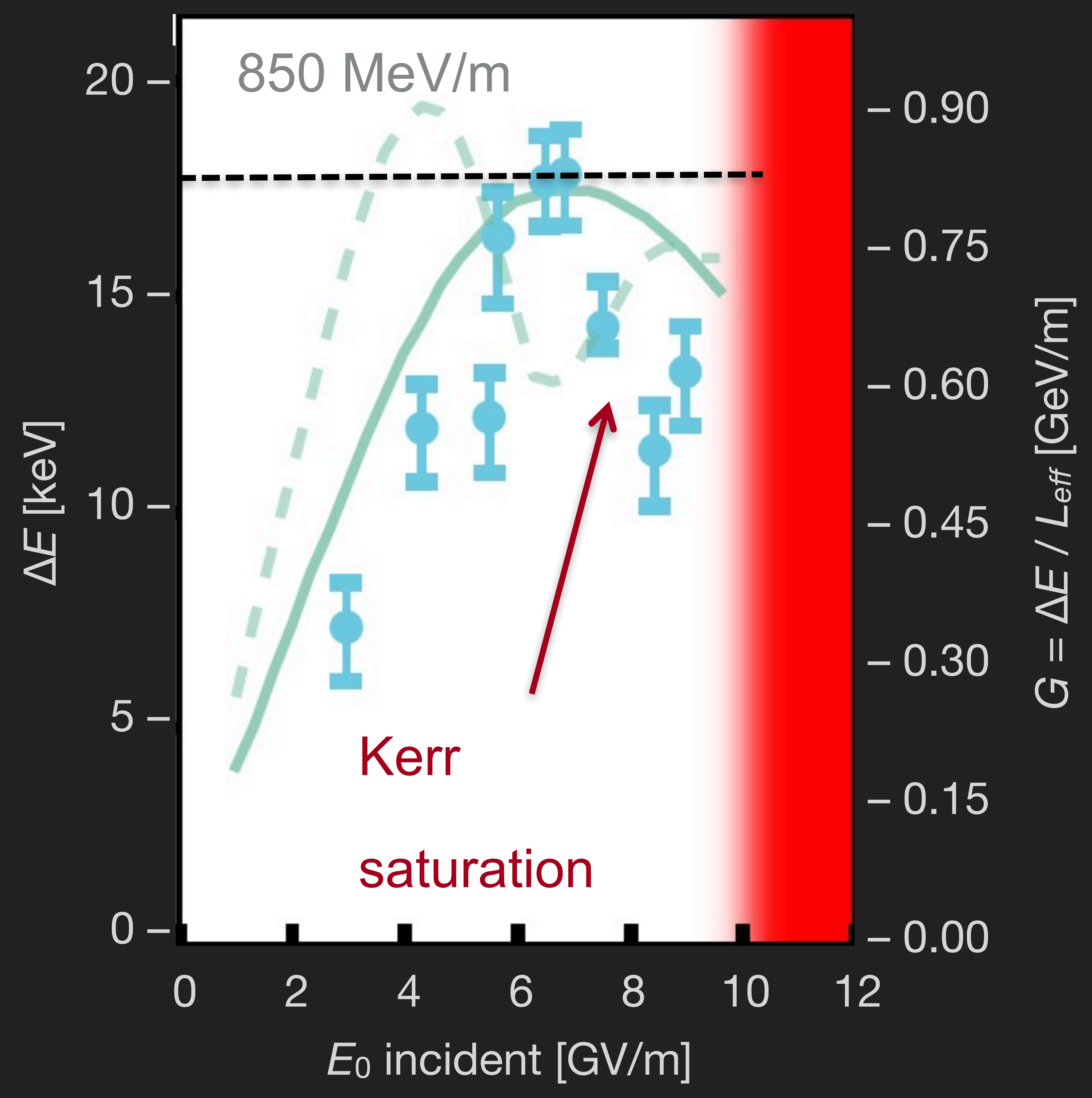




- Yousefi et al., Opt Lett 44, 1520 (2019)

ACCELERATION

Energy gain vs. incident laser field

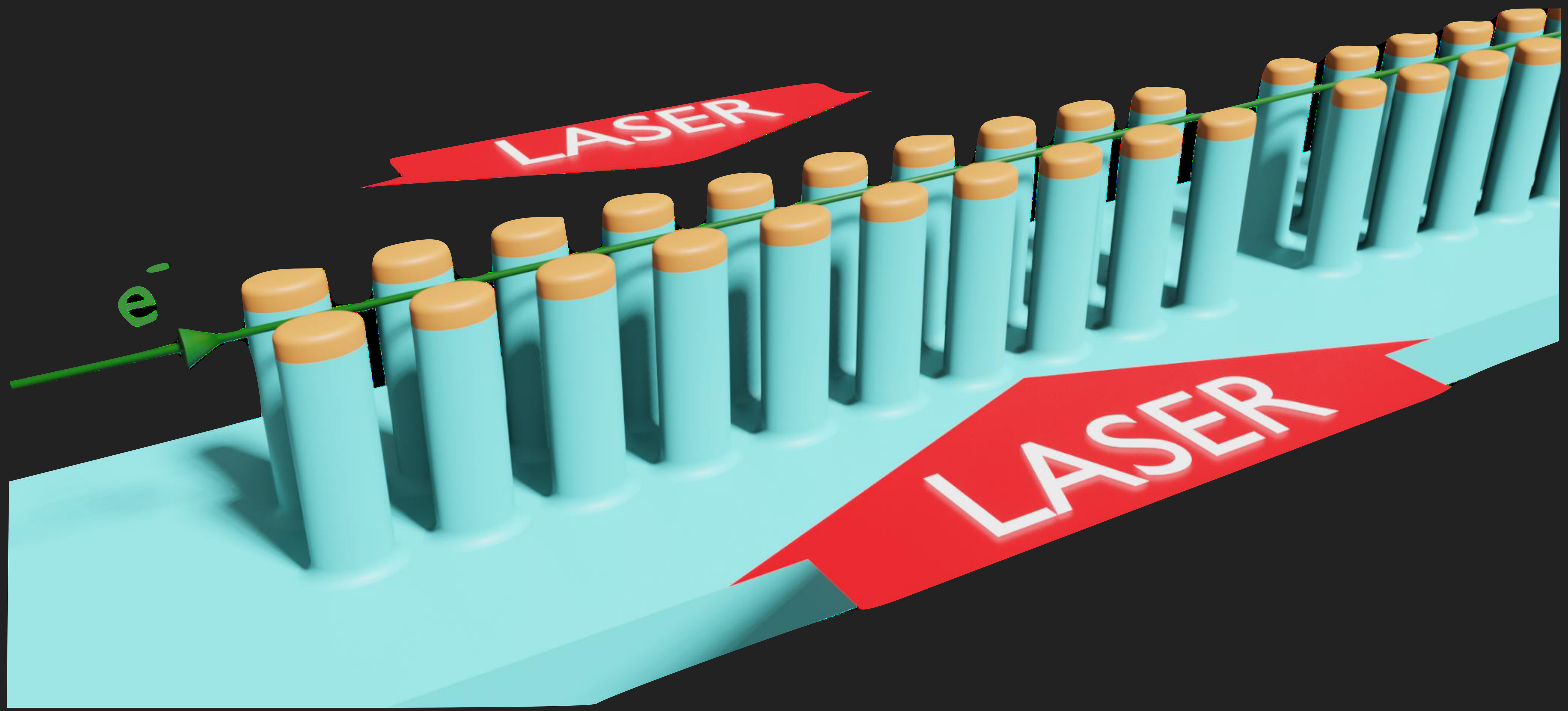


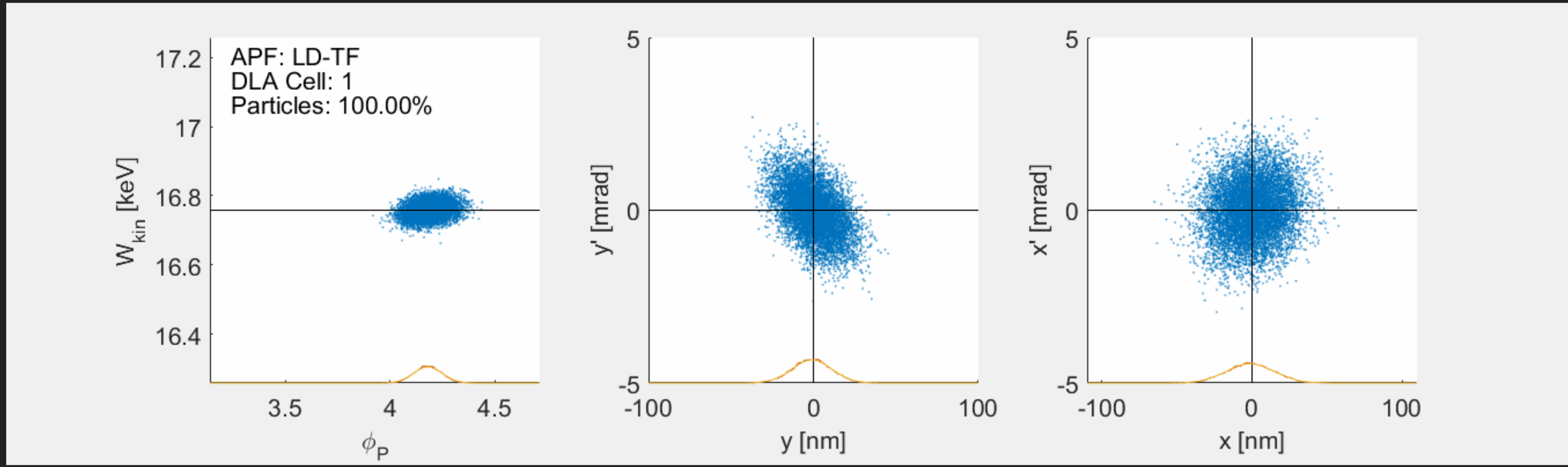
- Cesar et al., Communications Physics 1(1), 46 (2018)

A COLLIDER IS MUCH MORE THAN ACCELERATING STRUCTURES

- Focusing and beam transport
- Longitudinal Phase Space Control
- Power delivery
- Instrumentation and feedbacks
- Halo control

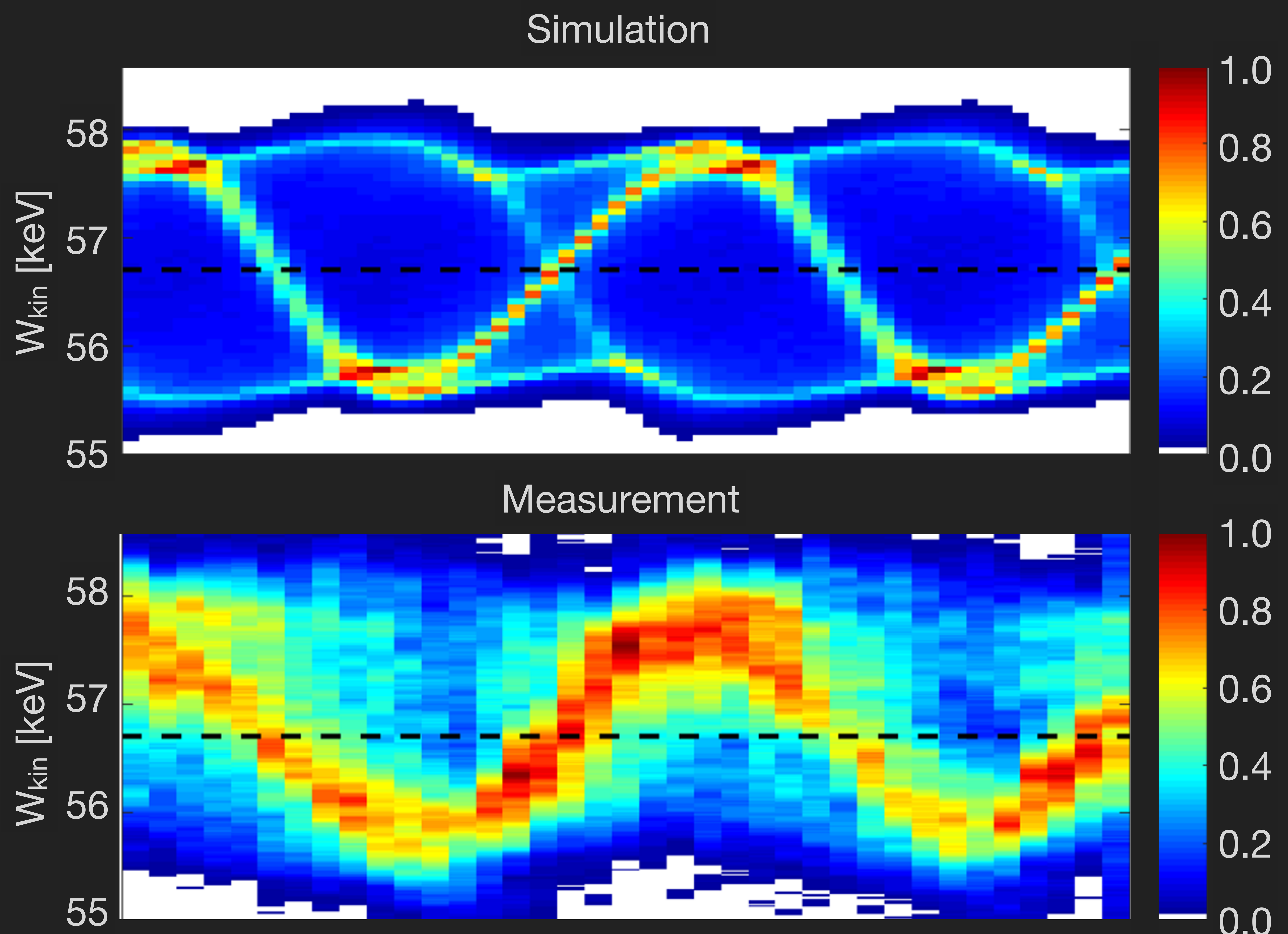
LASER-BASED FOCUSING





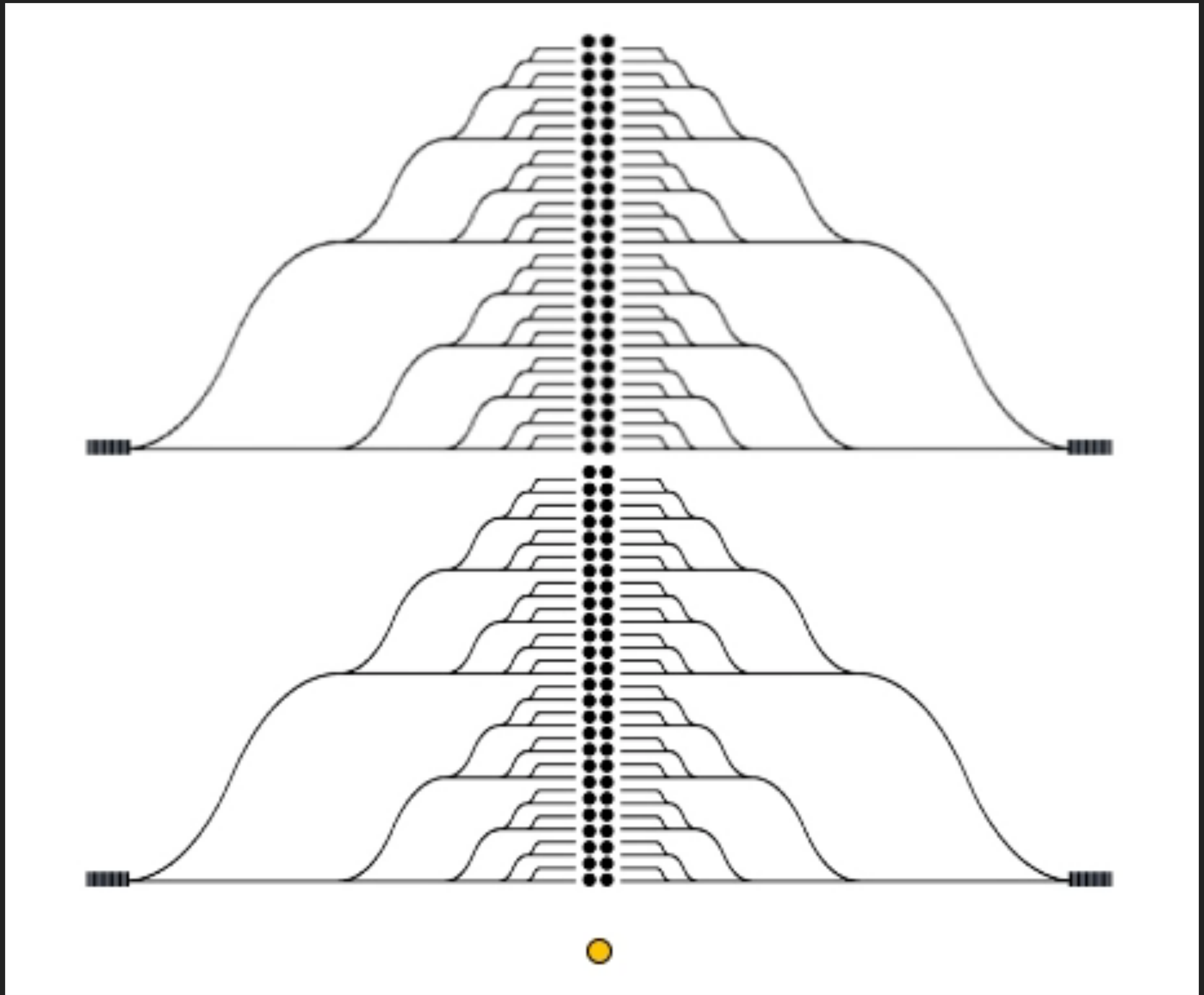
- Niedermayer et al., Phys. Rev. Lett. 125, 164801 (2020)

LONGITUDINAL PHASE SPACE CONTROL



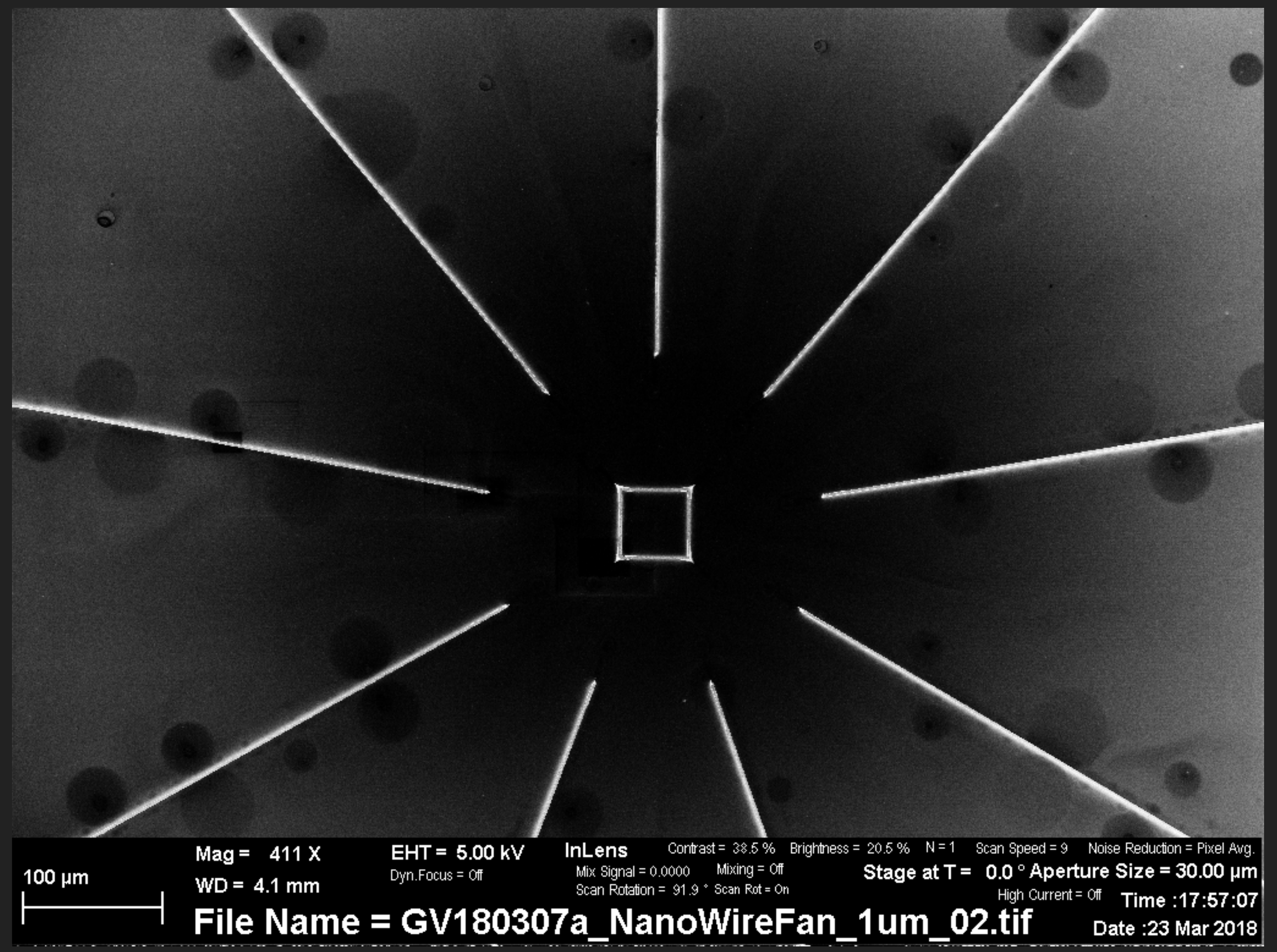
- Black et al., Phys. Rev. Lett. 123, 264802 (2019)
- Schönenberger et al., Phys. Rev. Lett. 123, 264803 (2019)
- Niedermayer et al., Phys. Rev. Applied 15, L021002 (2021)

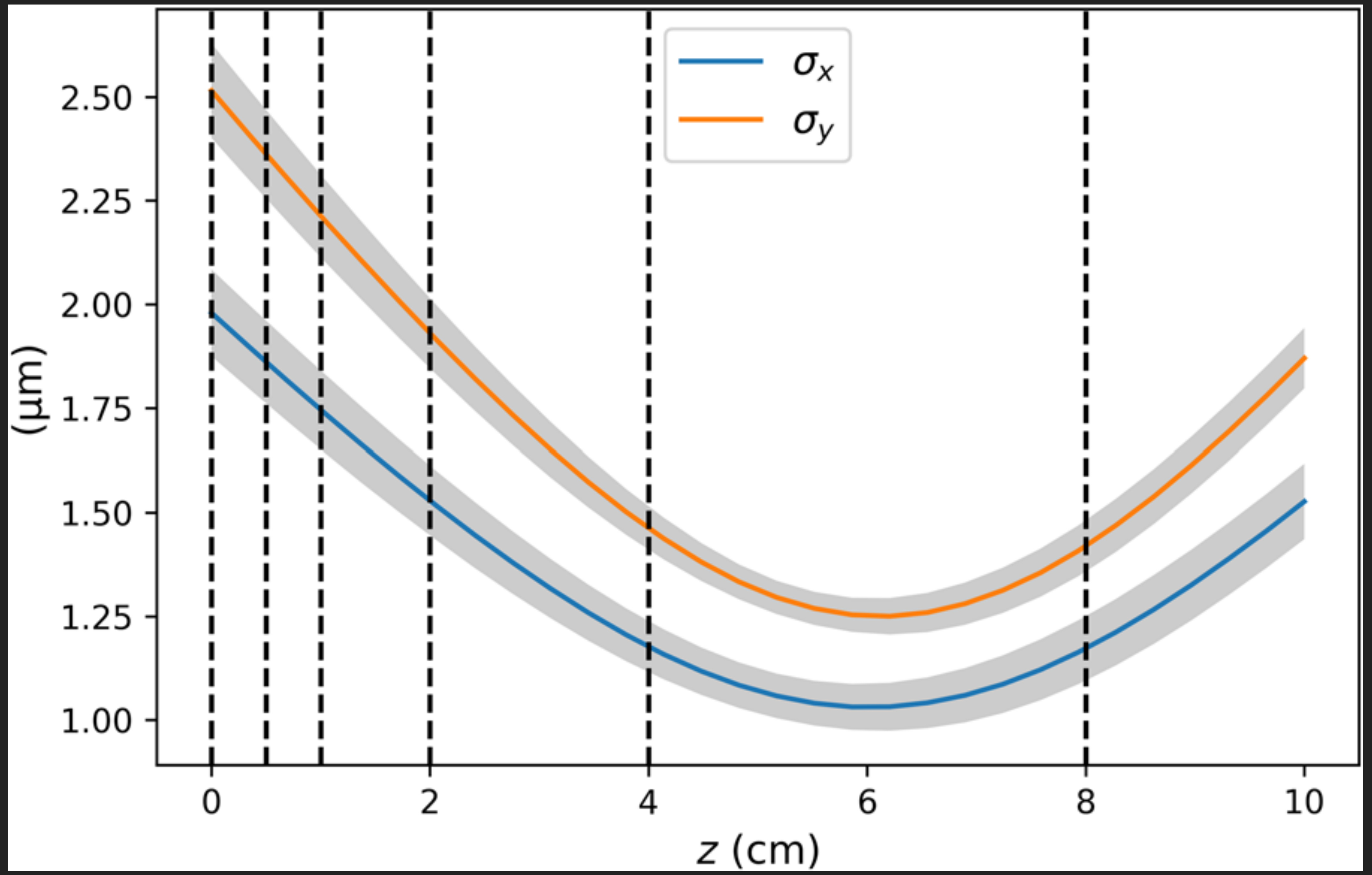
POWER DELIVERY



- Hughes et al., Phys. Rev. Applied 9, 054017 (2018)

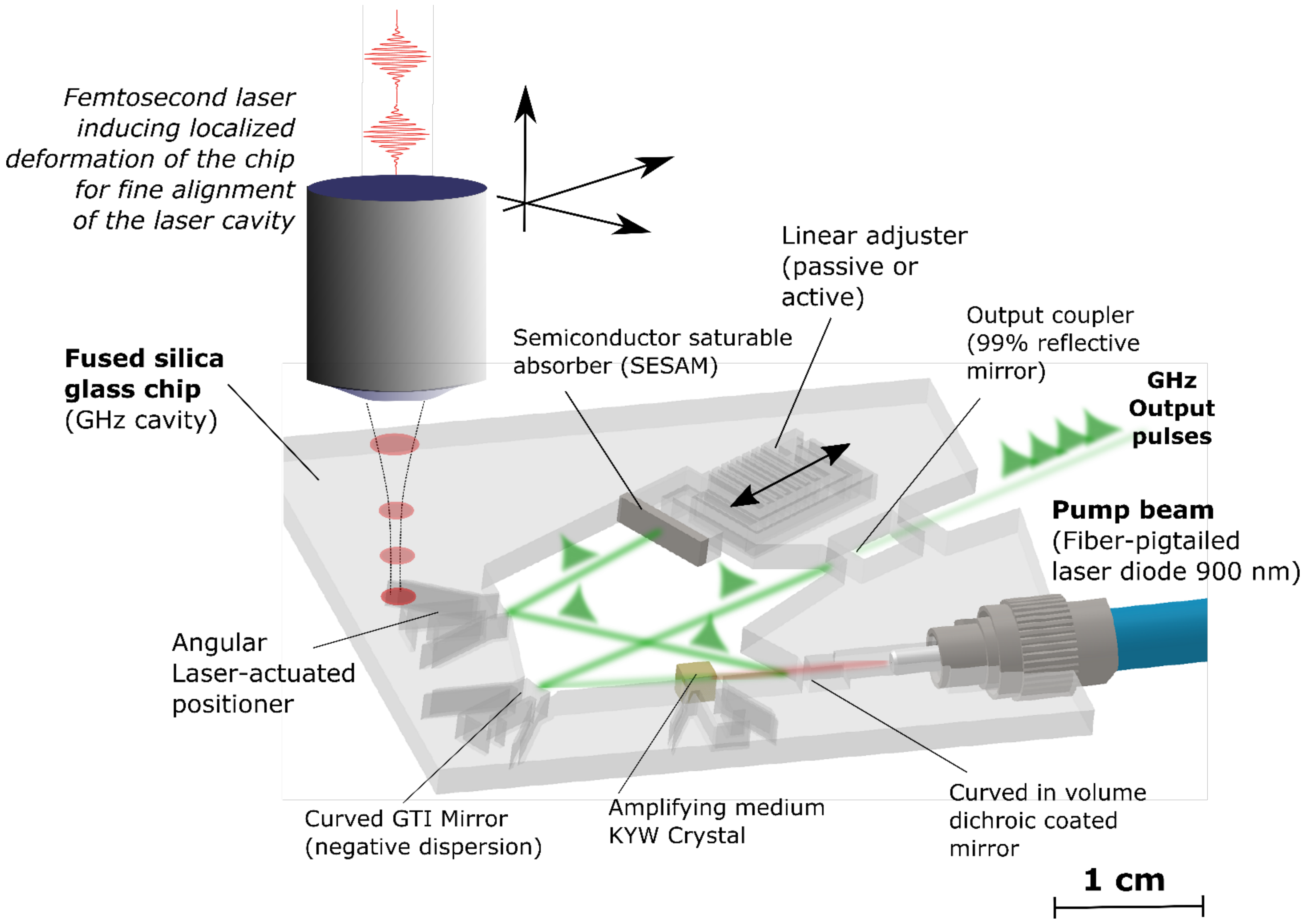
INSTRUMENTATION AND FEEDBACKS





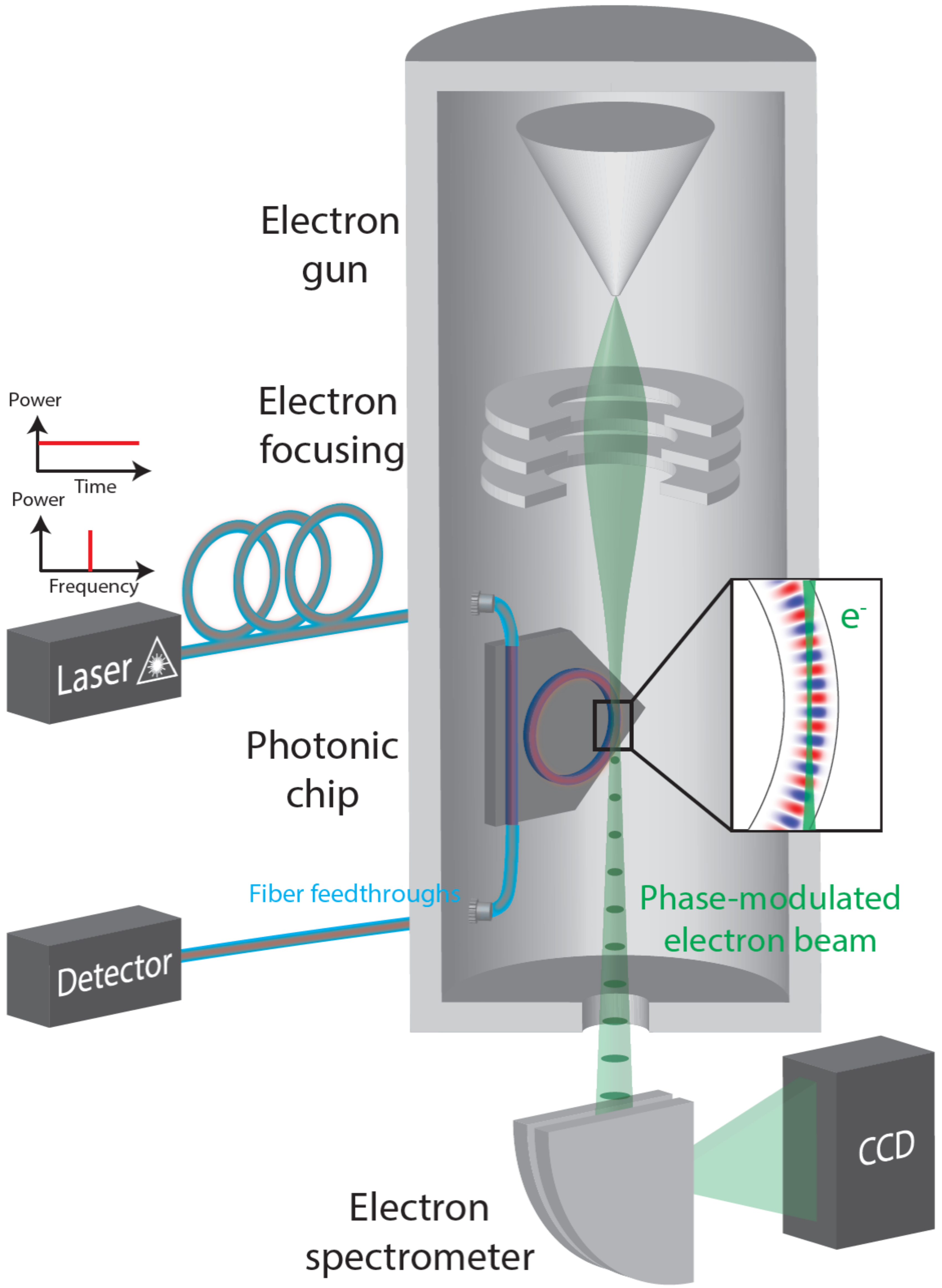
- Hermann et al., Phys. Rev. Accel. Beams 24, 022802

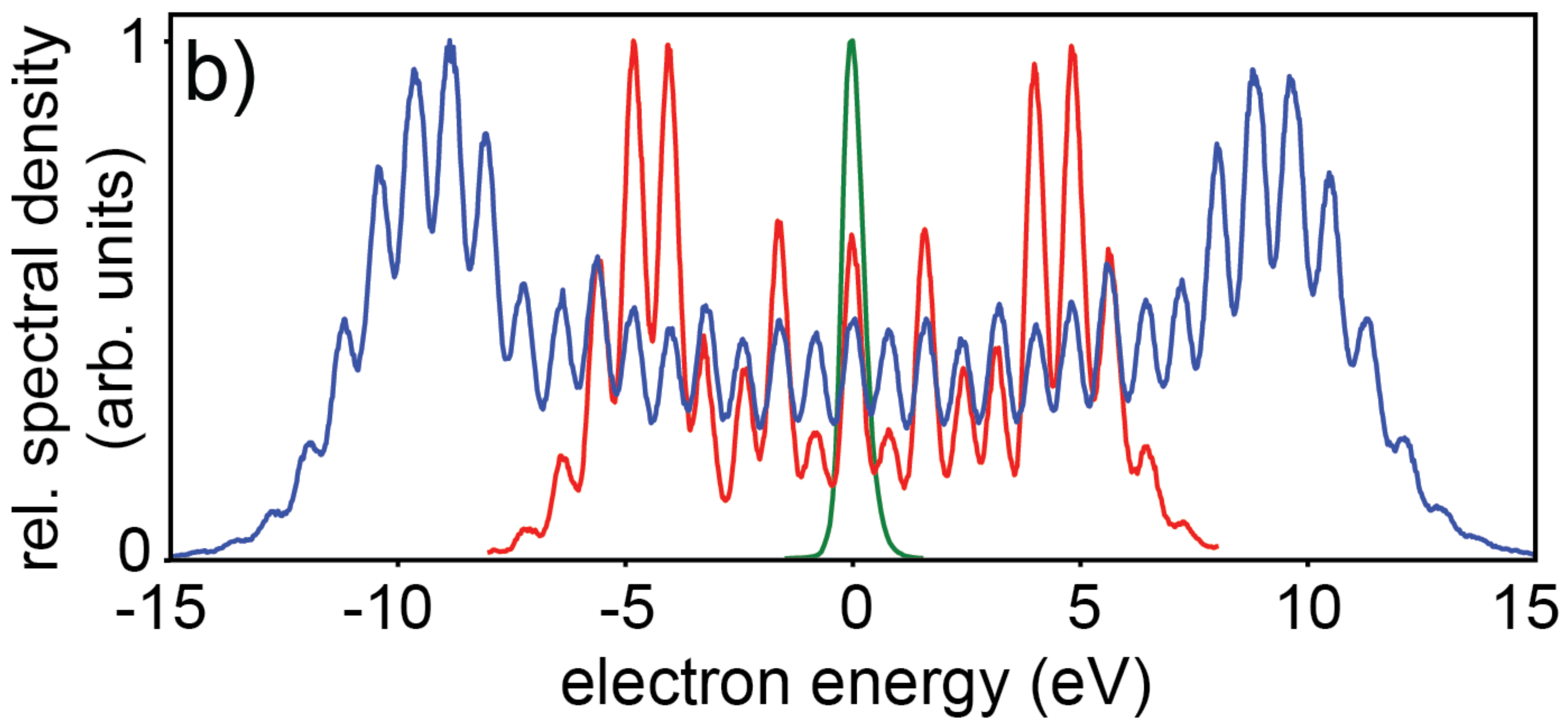
ILLUSTRATION: GHZ CAVITY CONCEPT

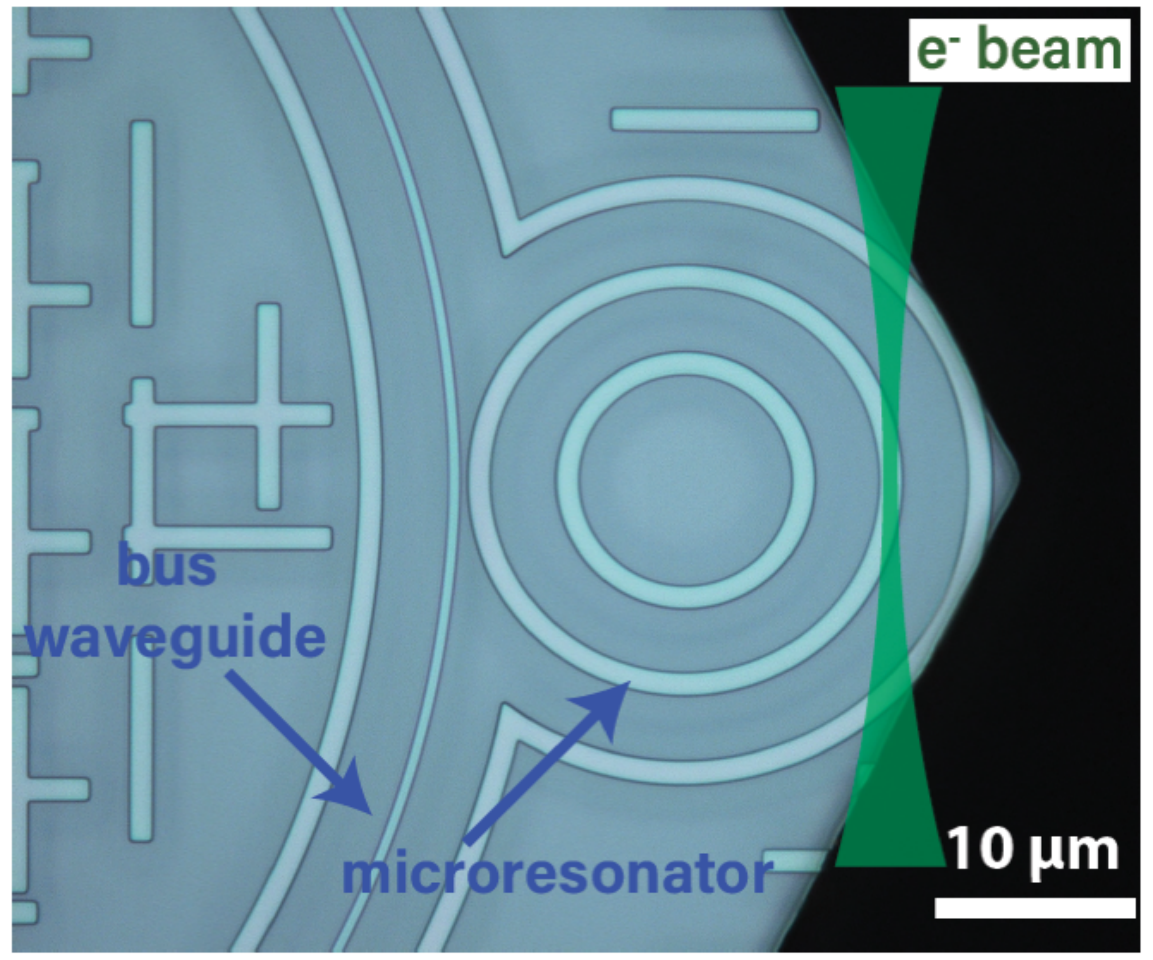


- Yves Bellouard, EPFL

COHERENT CONTROL OF ELECTRONS WITH INTEGRATED OPTICAL MICRORESONATORS

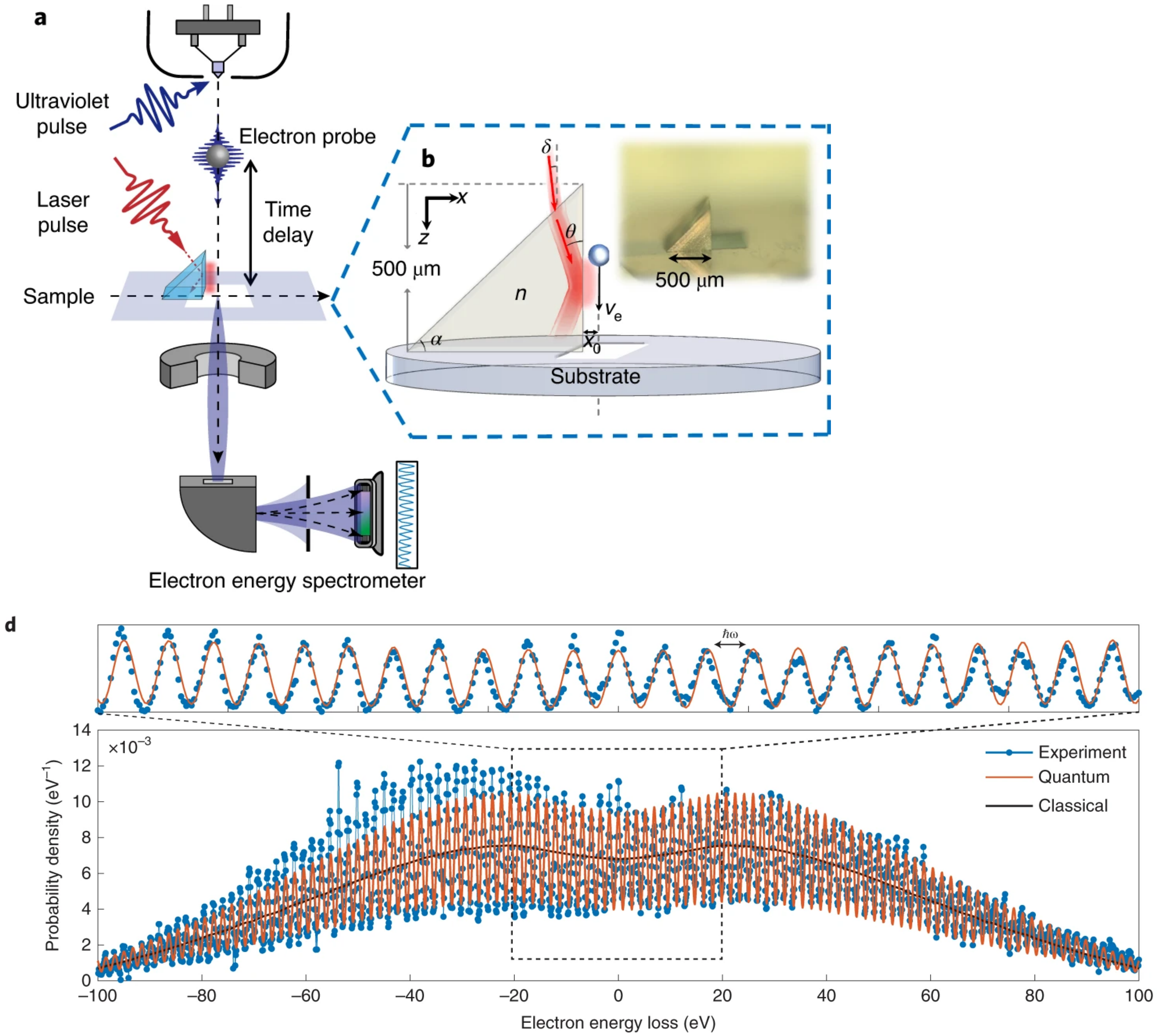






- Tobias Kippenberg, EPFL, and Claus Ropers, Uni Göttingen

QUANTUM ACCELERATION



- Dahan et al., Nature Physics 16, 1123–1131(2020)

TAKE-HOME MESSAGES

- DLA has compelling advantages that position it as a competitive LC technology
- DLA's challenges are distinct from other concepts, but not necessarily less surmountable
- recent work on DLA shows promising results, nonwithstanding a relatively modest funding
- Integrated photonics is a very active field of research, with applications in industry

Thank you to Ralph Aßmann, Yves Bellouard, Joel England, Benedikt Hermann, Peter Hommelhoff, Tobias Kippenberg, and Niels Quack