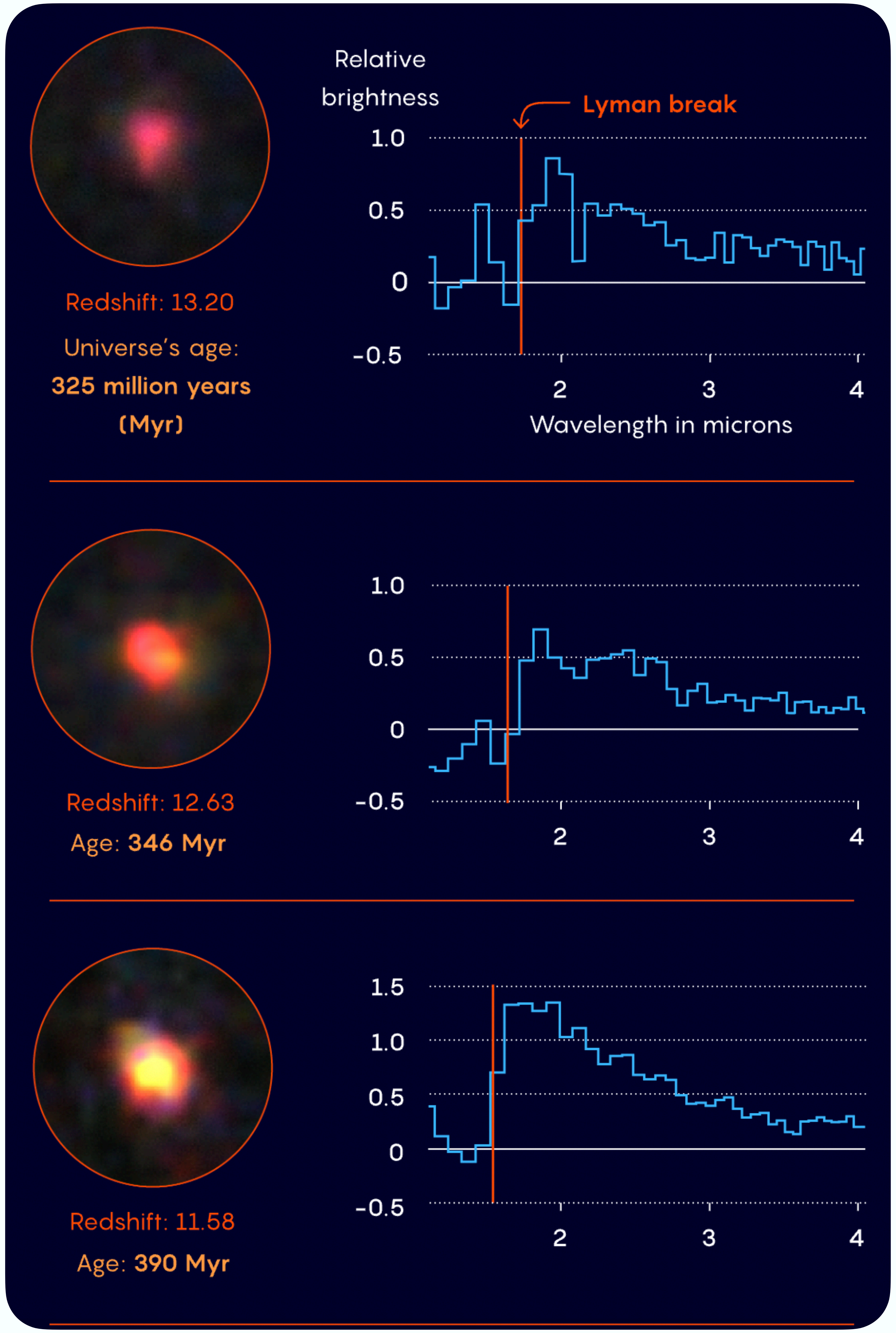
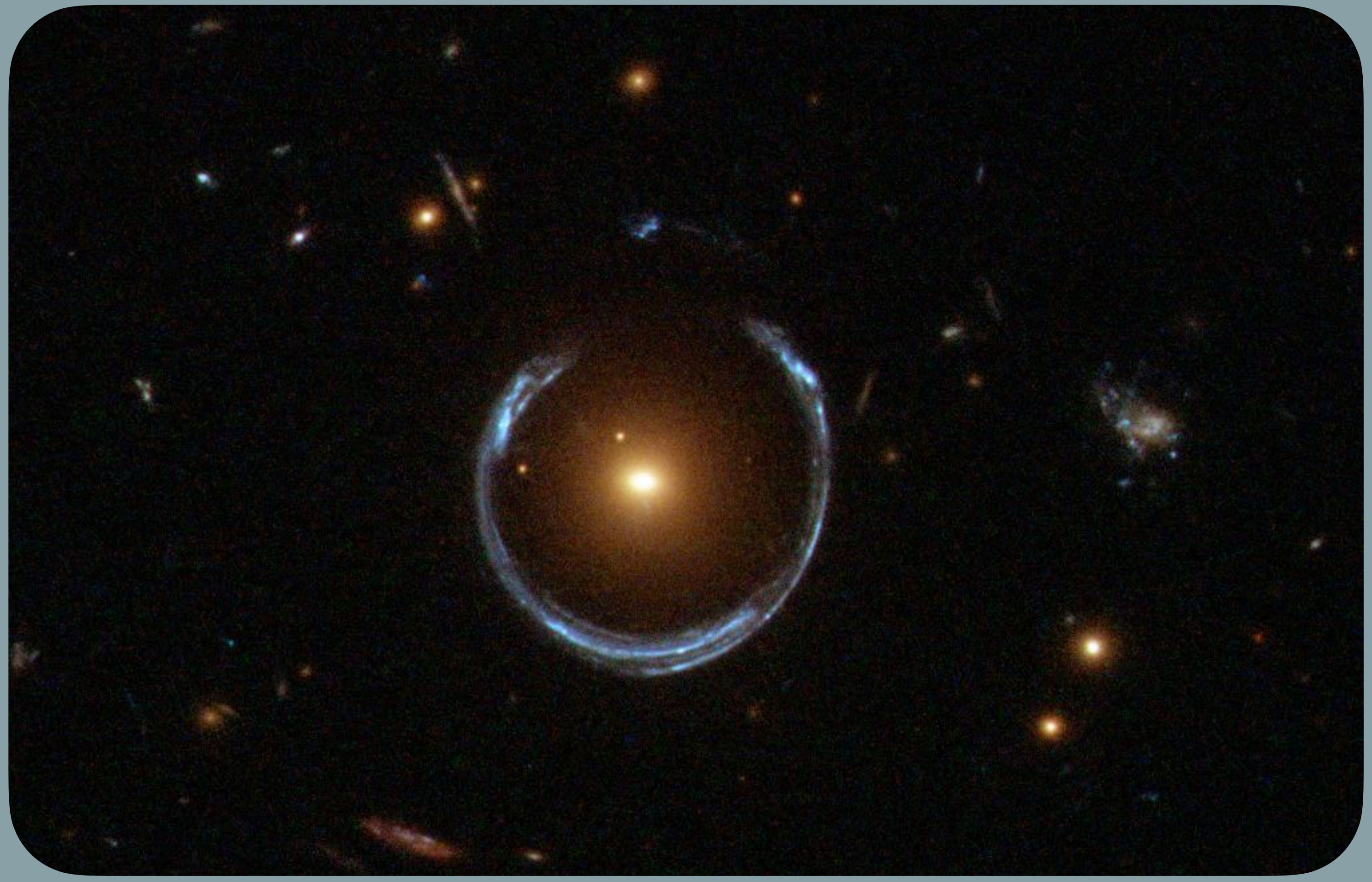
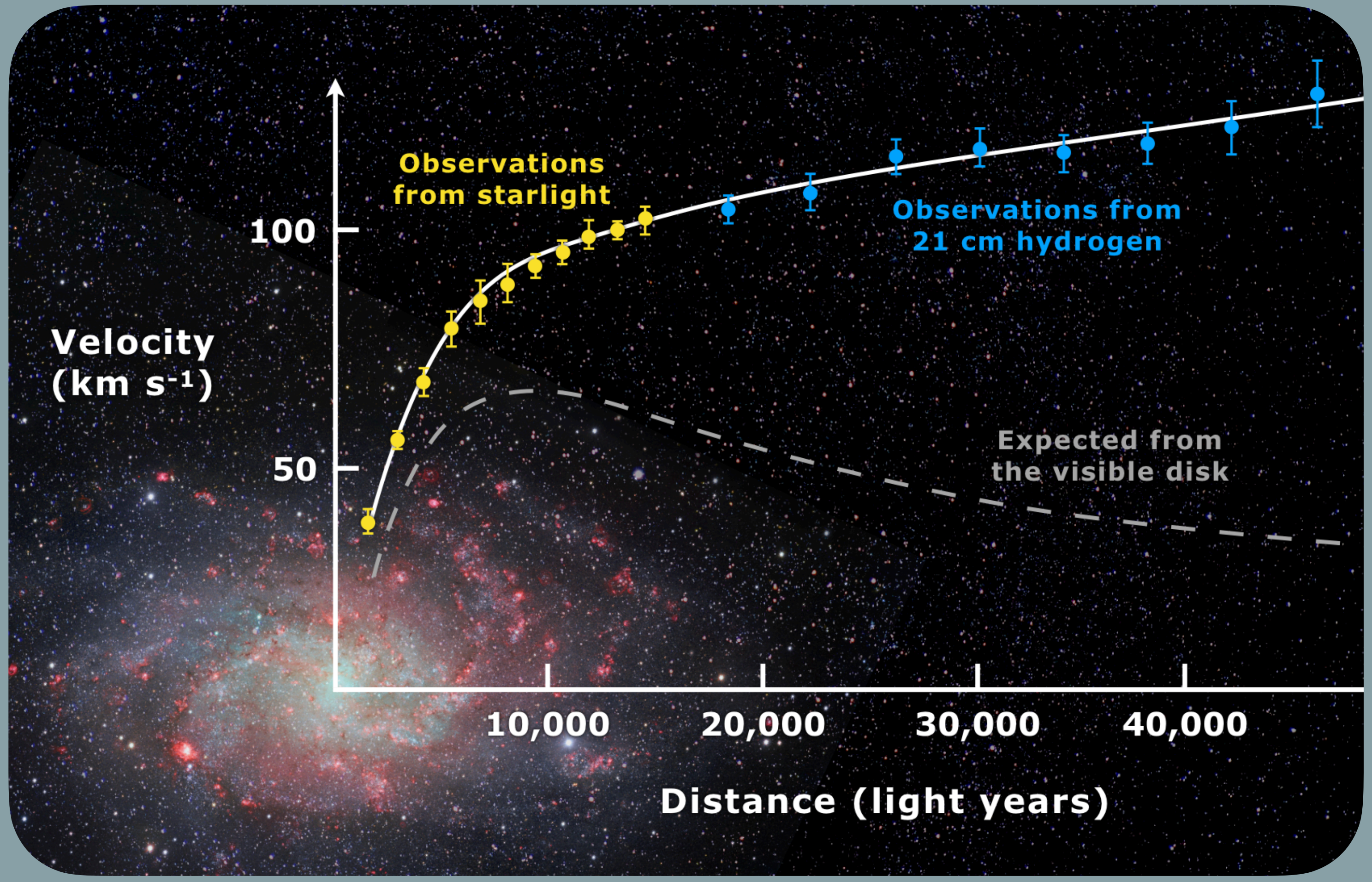
Exploring Dark Matter with Dielectric Laser Acceleration

Raziyeh Dadashi Motlagh, 22 July 2024

Massimiliano Ferro-Luzzi, Rasmus Ischebeck, Richard Jacobsson, Mieczyslaw Witold Krasny, Tatiana Latychevskaia, Uwe Niedermayer, Frank Zimmermann, Mike Seidel

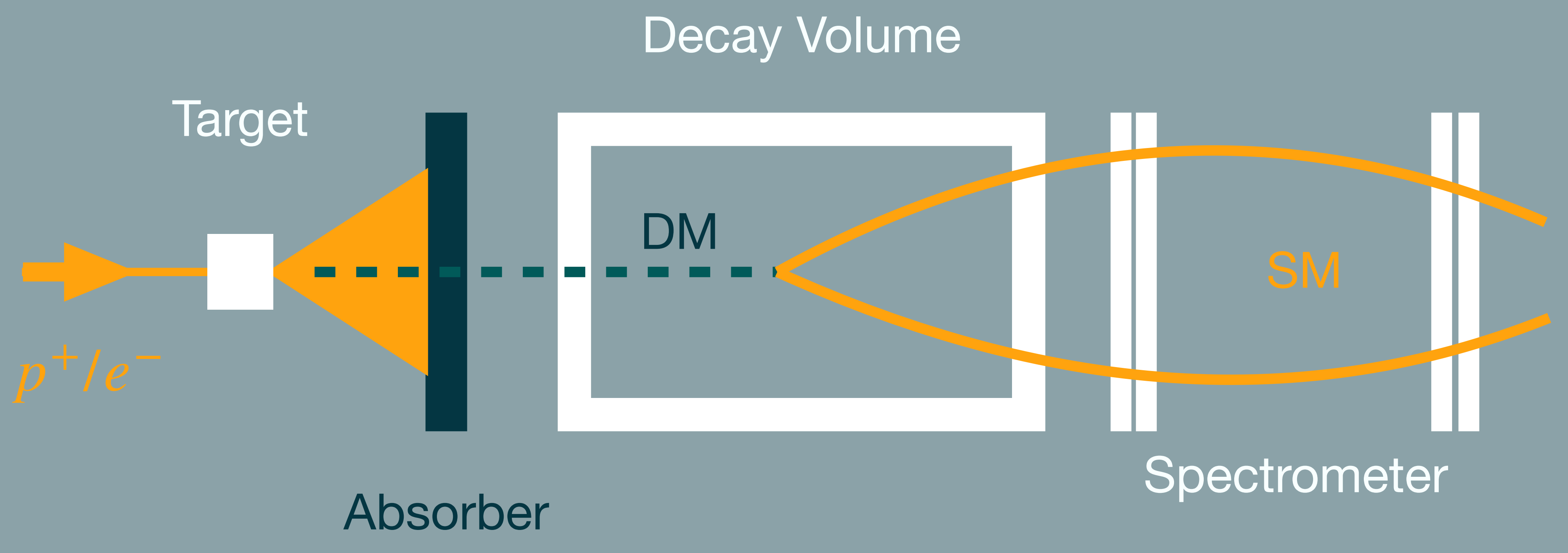




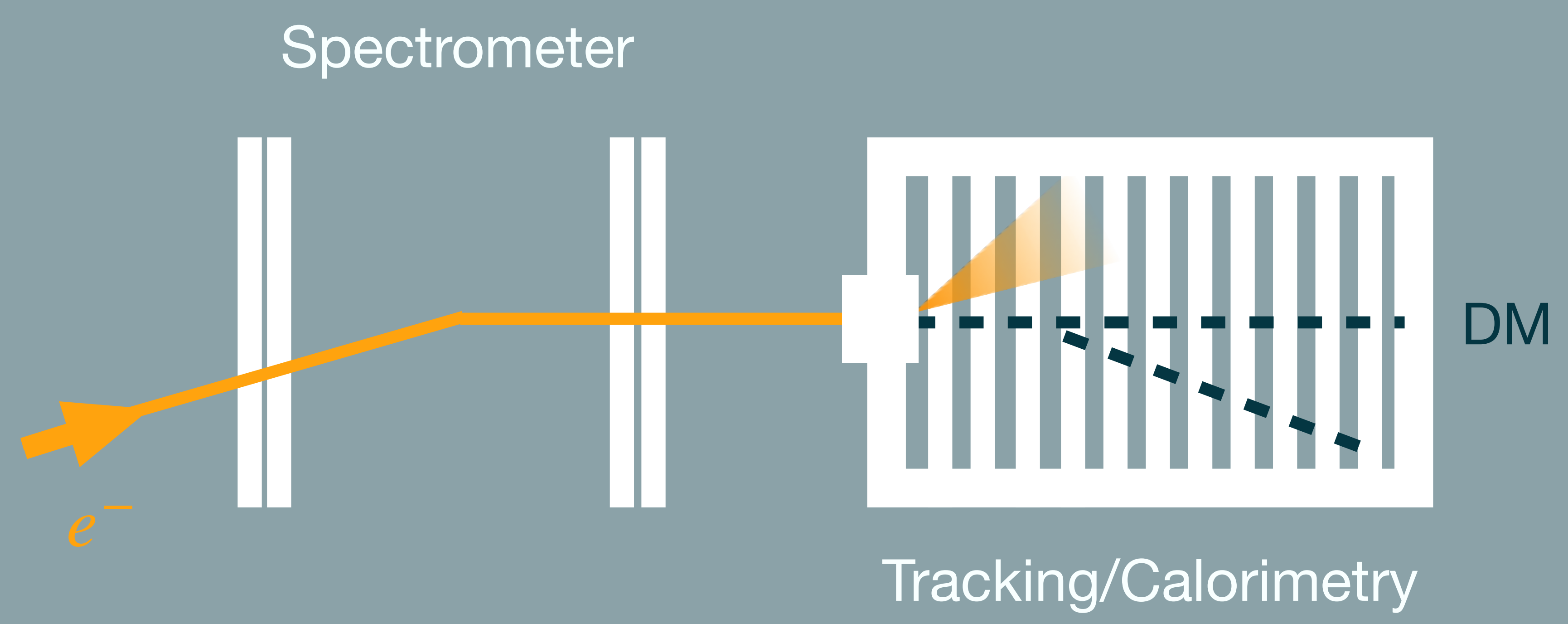


Dark Matter Evidence

- Galaxy Rotation Curves
- Gravitational Lensing
- Supermassive Dark Star candidates seen by JWST



Direct Search



Indirect Search

- Interaction probability ~ ϵ^4
- Need a very large number of primary particles (10^{20} electron on target)

- Interaction probability ~ ϵ^2
- Need a clean initial state (i.e. single electrons with high repetition rate)

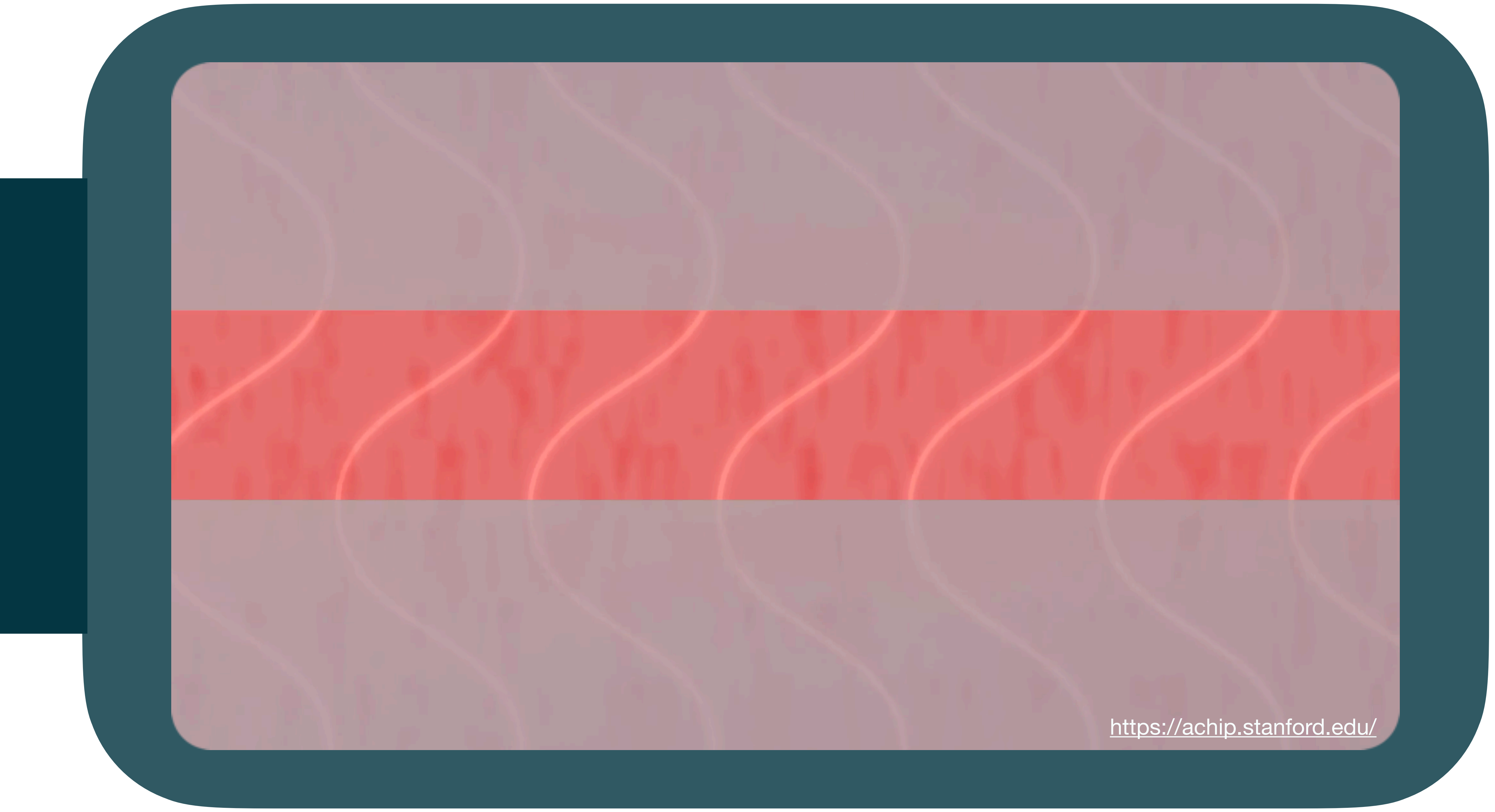
Requirements for Indirect Dark Matter Studies

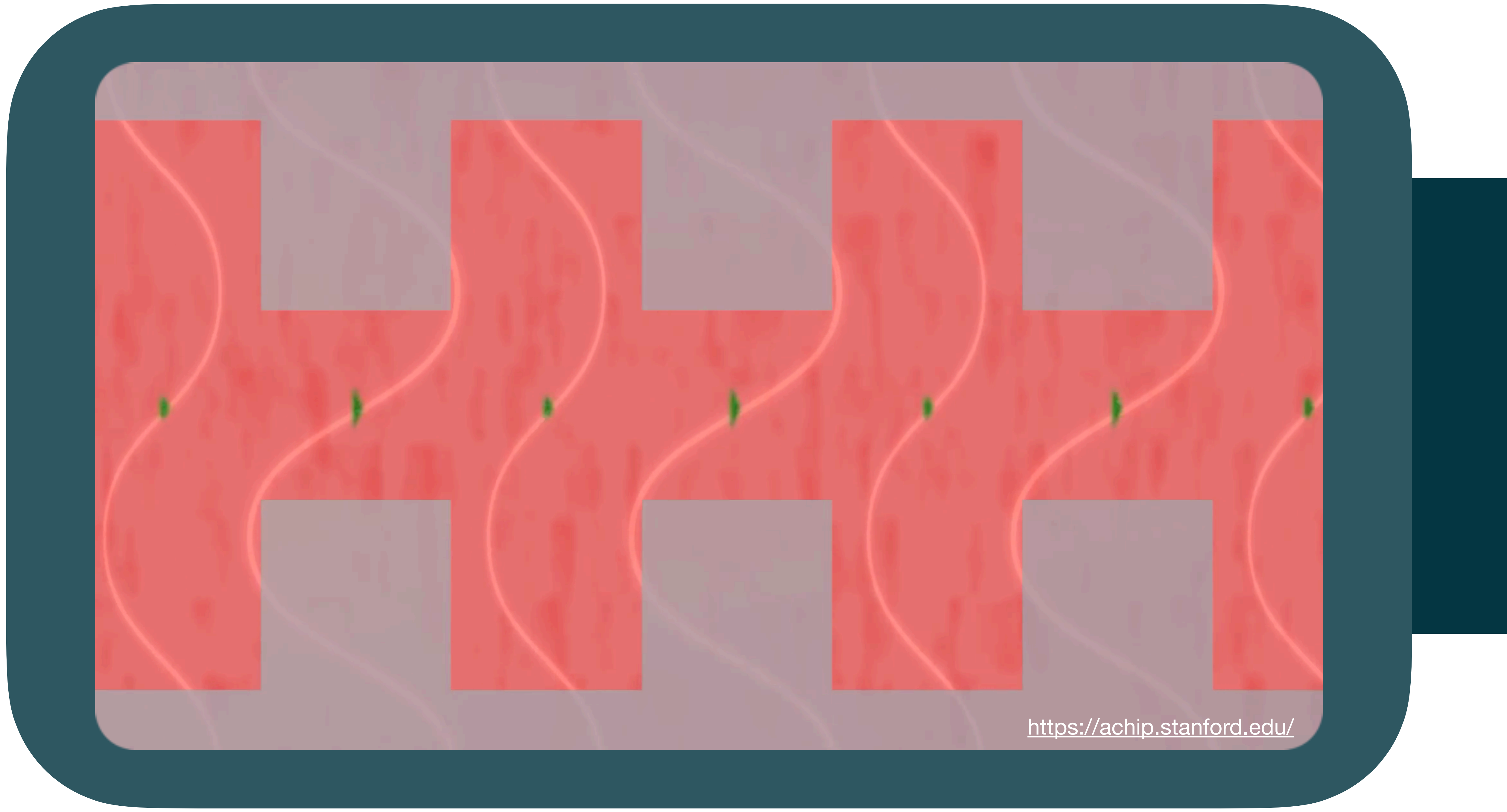
Beam Energy: 10-20 GeV

Beam repetition rate: 10 GHz
Beam of single electrons

Energy Efficiency

Dielectric Laser Acceleration





How DLAtrack6D works?

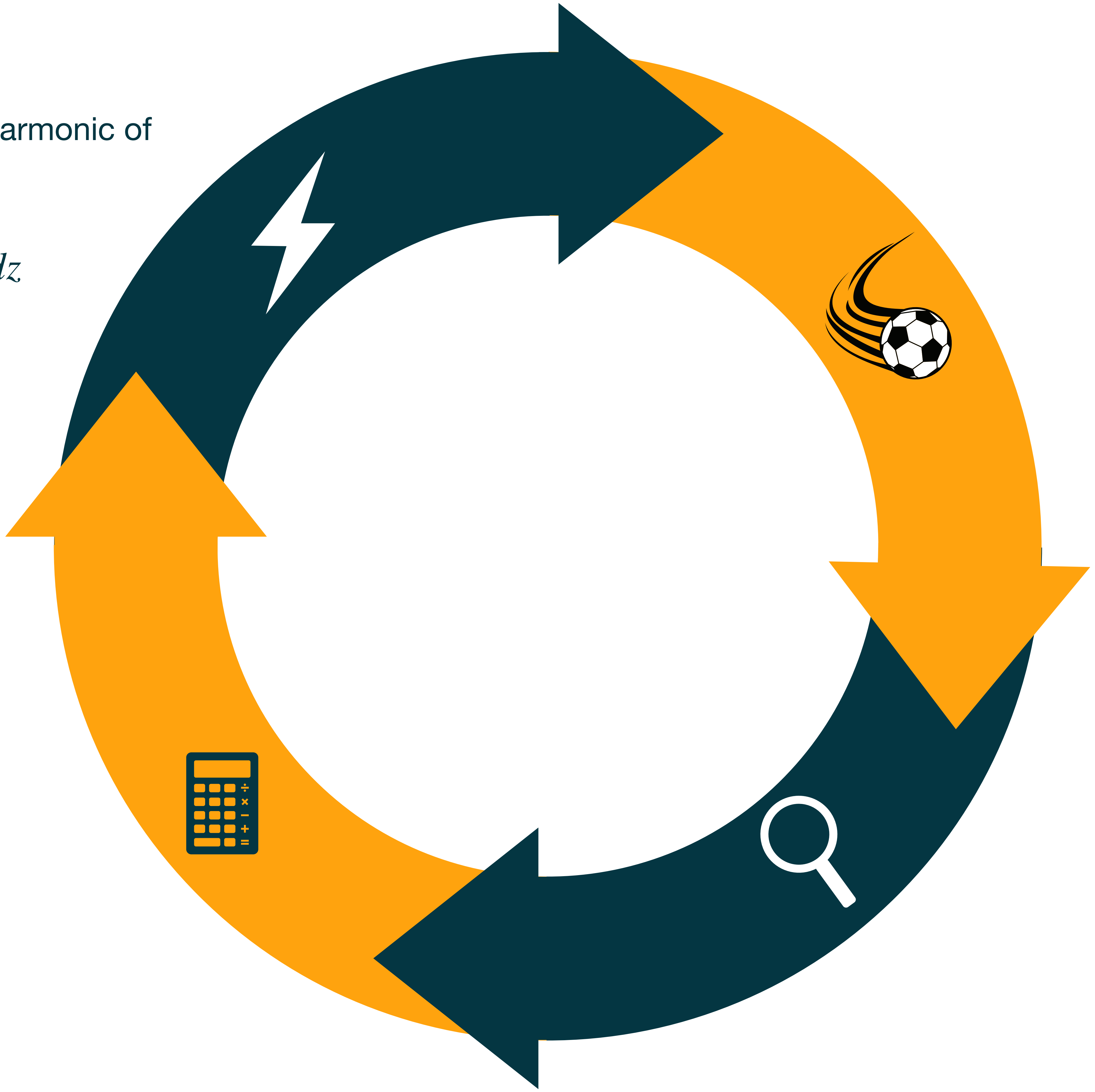
Electric Field Calculation

If $\lambda_{gz} = m\beta\lambda_0$, the synchronous spatial harmonic of the electric field is given by

$$e_m(x,y) = \frac{1}{\lambda_{gz}} \int_{-\lambda_{gz}/2}^{\lambda_{gz}/2} E_z(x,y,z) e^{im2\pi z/\lambda_{gz}} dz$$

If assume $m = 1$,

$$e_1(x,y) = e_1(0{,}0) cosh(ik_y y) cos(ik_x x)$$



Kick Calculation

$$\Delta x' = -\frac{k_x q \lambda_0 \lambda_{gz}}{2\pi p_{z0} c} sin(k_x x) cosh(ik_y y) Re\{e_1 e^{i\phi}\}$$

$$\Delta y' = -\frac{-ik_y q \lambda_0 \lambda_{gz}}{2\pi p_{z0} c} cos(k_x x) sinh(ik_y y) Im\{e_1 e^{i\phi}\}$$

$$\Delta\delta = \frac{q\lambda_{gz}}{\gamma m_e c^2} Re\{e_1 cos(k_x x) cosh(ik_y y) e^{i\phi} - e^{i\phi_z}\}$$

Calculating Beam Parameters

Particle loss

Energy Spread

Emittance,…

Tracking Scheme

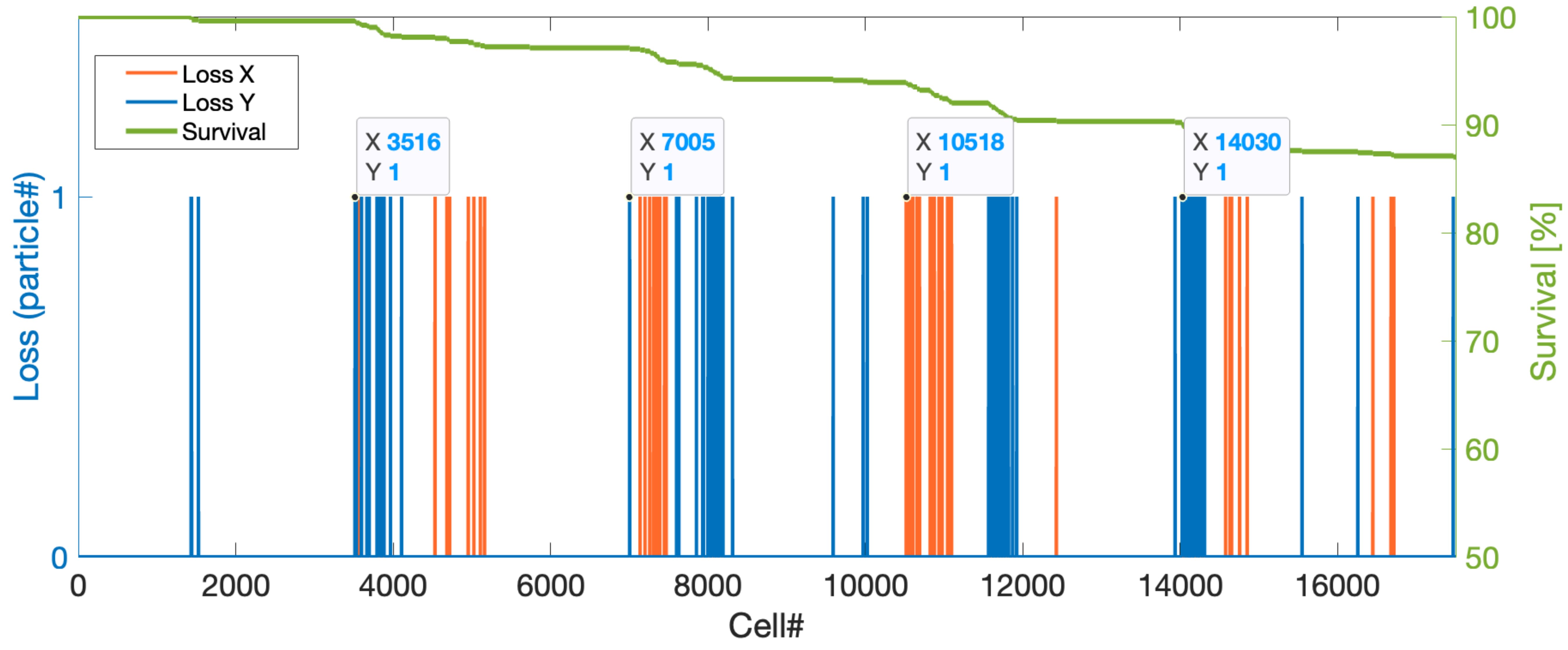
$$\begin{pmatrix} x \\ x' \\ y \\ y' \\ \phi \\ \delta \end{pmatrix}^{(n+1)} = \begin{pmatrix} x \\ Ax' + \Delta x'(x,y,\phi) \\ y \\ Ay' + \Delta y'(x,y,\phi) \\ \phi \\ \delta + \Delta\delta(x,y,\phi;\phi_{sync}) \end{pmatrix}^{(n)} + \begin{pmatrix} L_{APF} x'(x,y,\phi) \\ 0 \\ L_{APF} y'(x,y,\phi) \\ 0 \\ -\frac{2\pi L_{APF}}{\beta^3\gamma^2\lambda_0}\delta(x,y,\phi) \\ 0 \end{pmatrix}^{(n+1)}$$

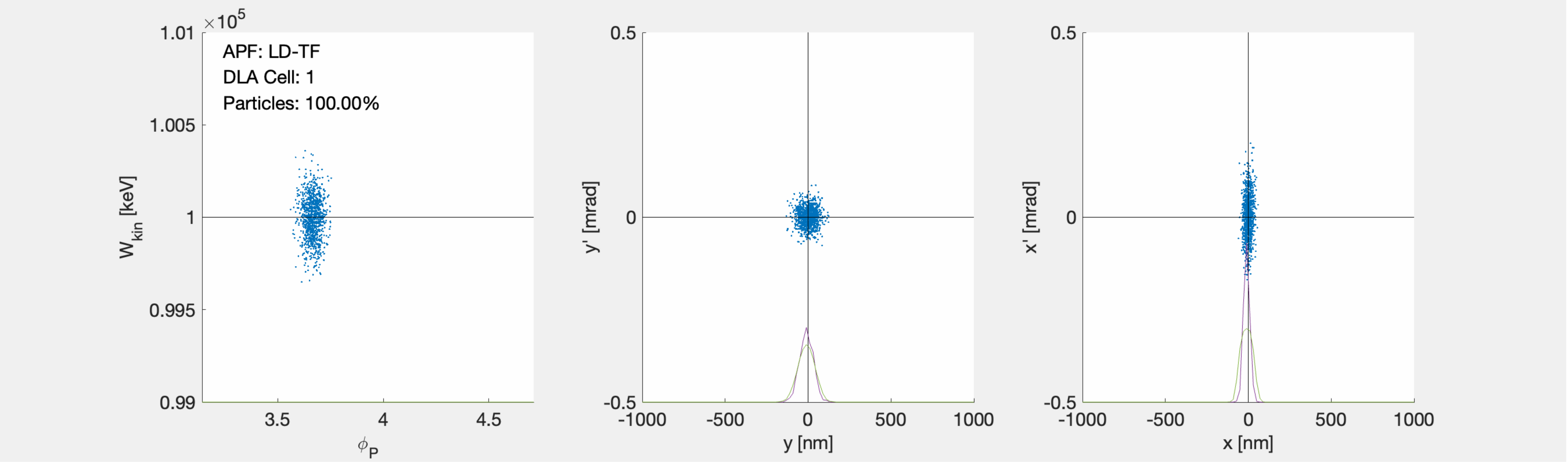
Requirements for Indirect Dark Matter Studies

Beam Energy: 10-20 GeV

Beam Dynamics

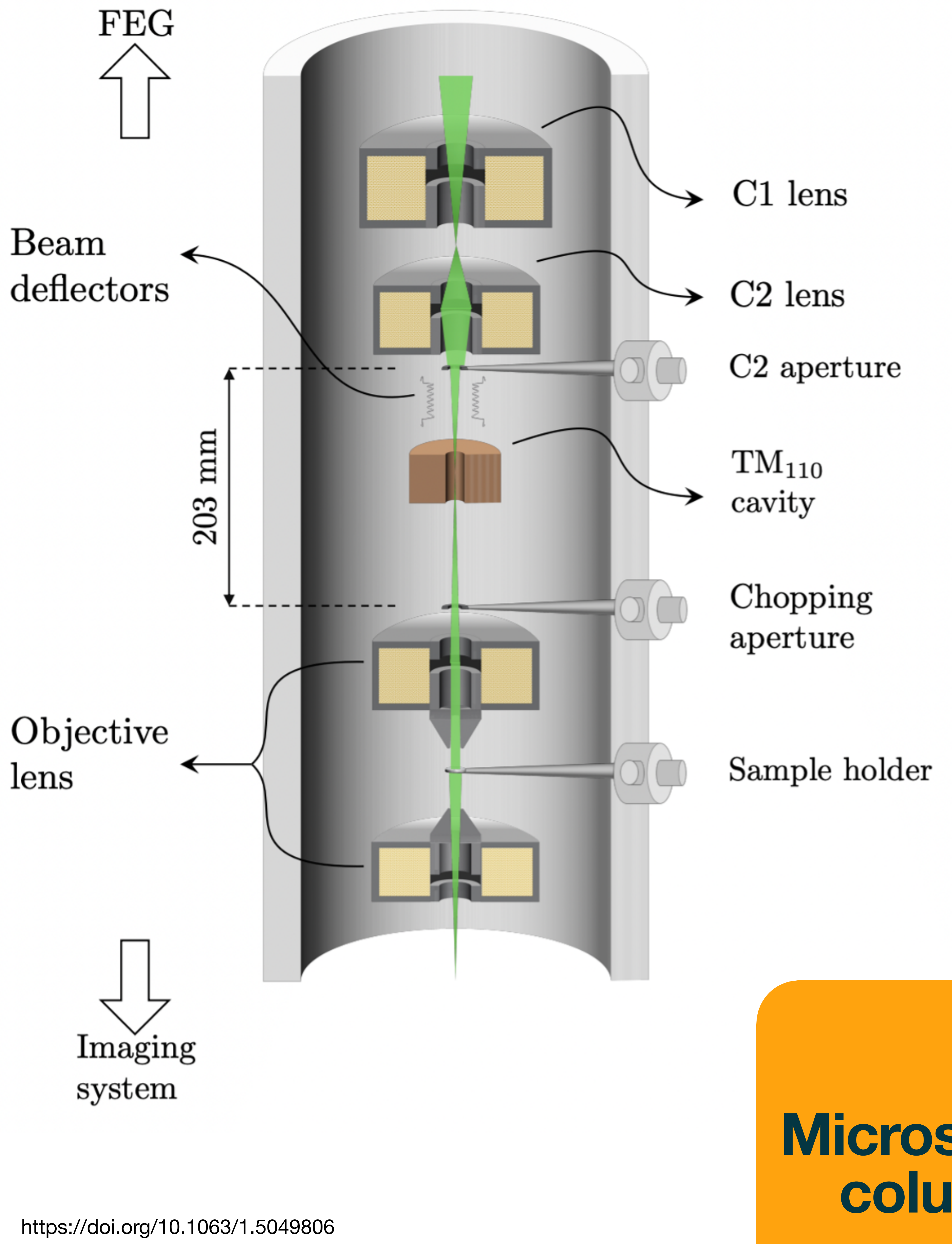
- Beam energy: 100 MeV
- Laser energy: 1 GV/m
- Energy gain: 7 MeV
- Number of macro-cells: 5×30
- Number of micro-cells: 5×3500
- Structure length: $5 \times 7mm$

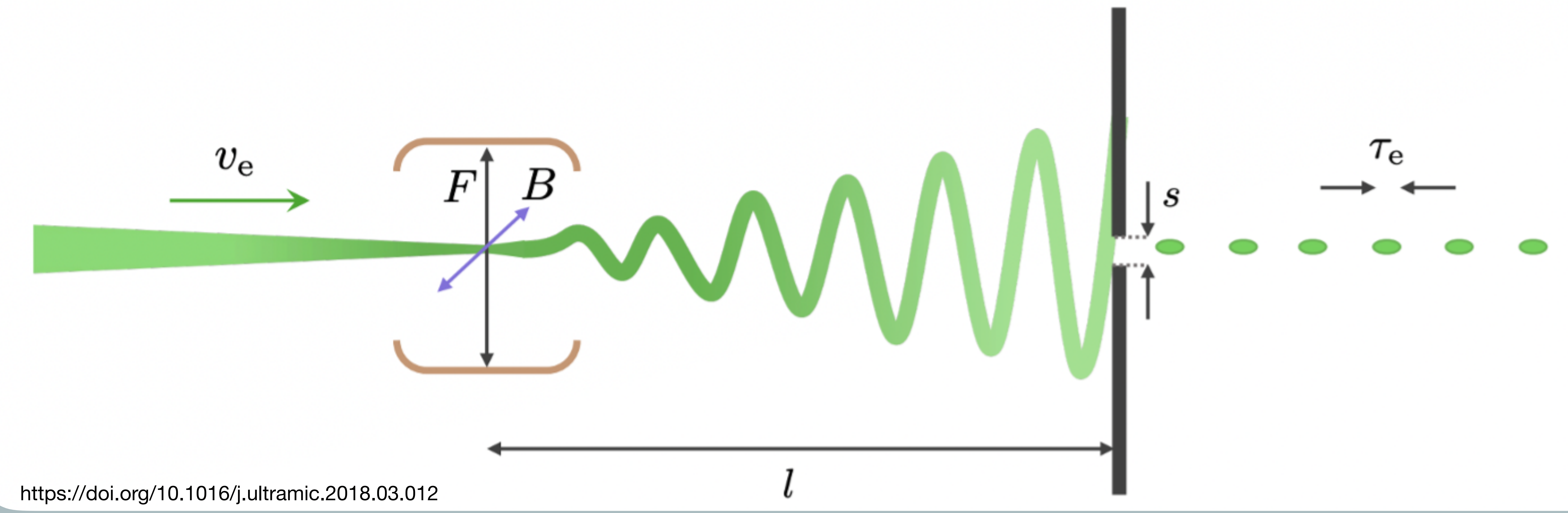




Requirements for Indirect Dark Matter Studies

Beam repetition rate: 10 GHz
Beam of single electrons





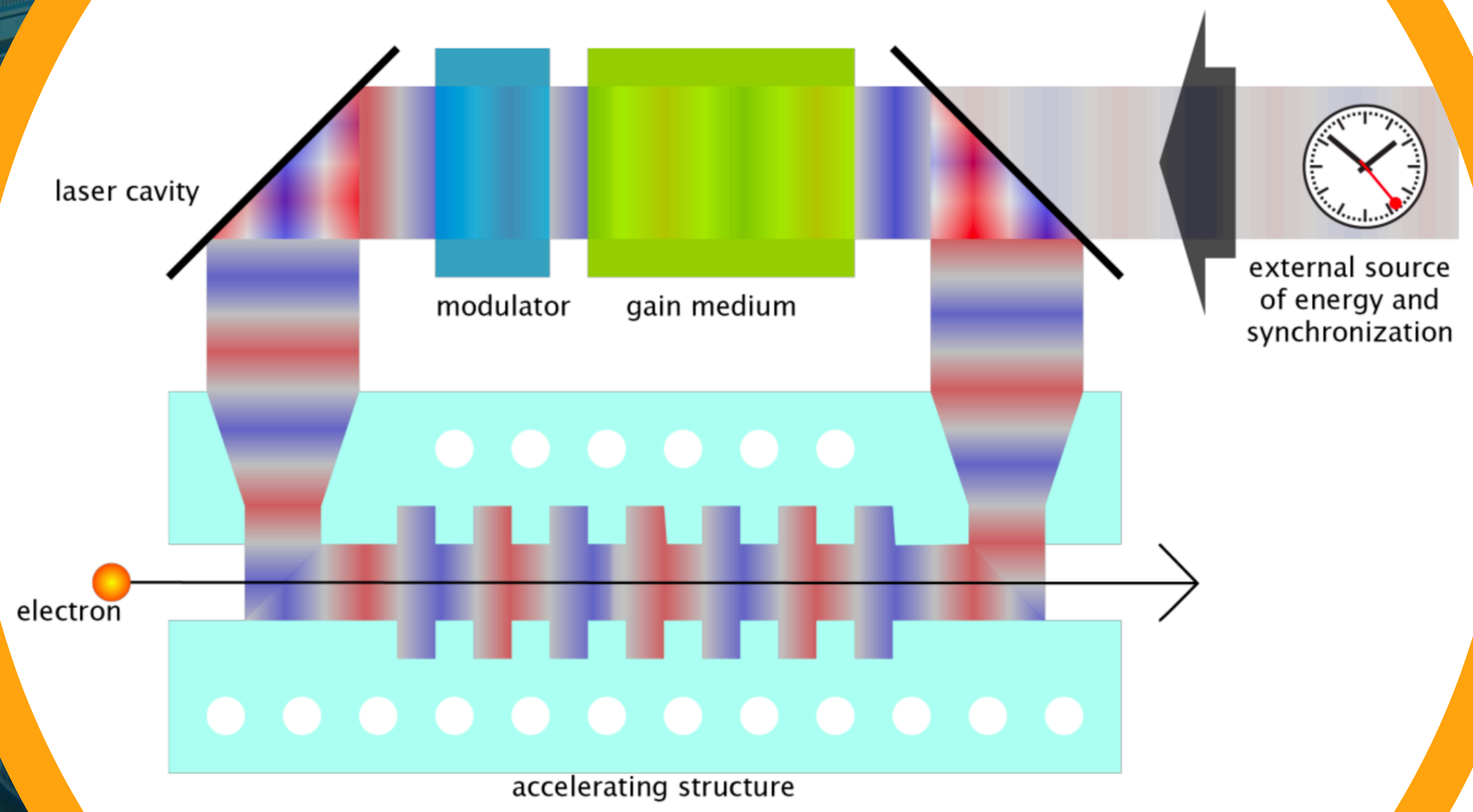
Microscope column

Electron Microscope Type Sources

- Beam repetition rate: 3 GHz
- Beam of single Electrons
- Beam emittance: 10 pm-rad (suitable for the sub-400 nm aperture and field uniformity)

Requirements for Indirect Dark Matter Studies

Energy Efficiency



Accelerator in Laser Cavity

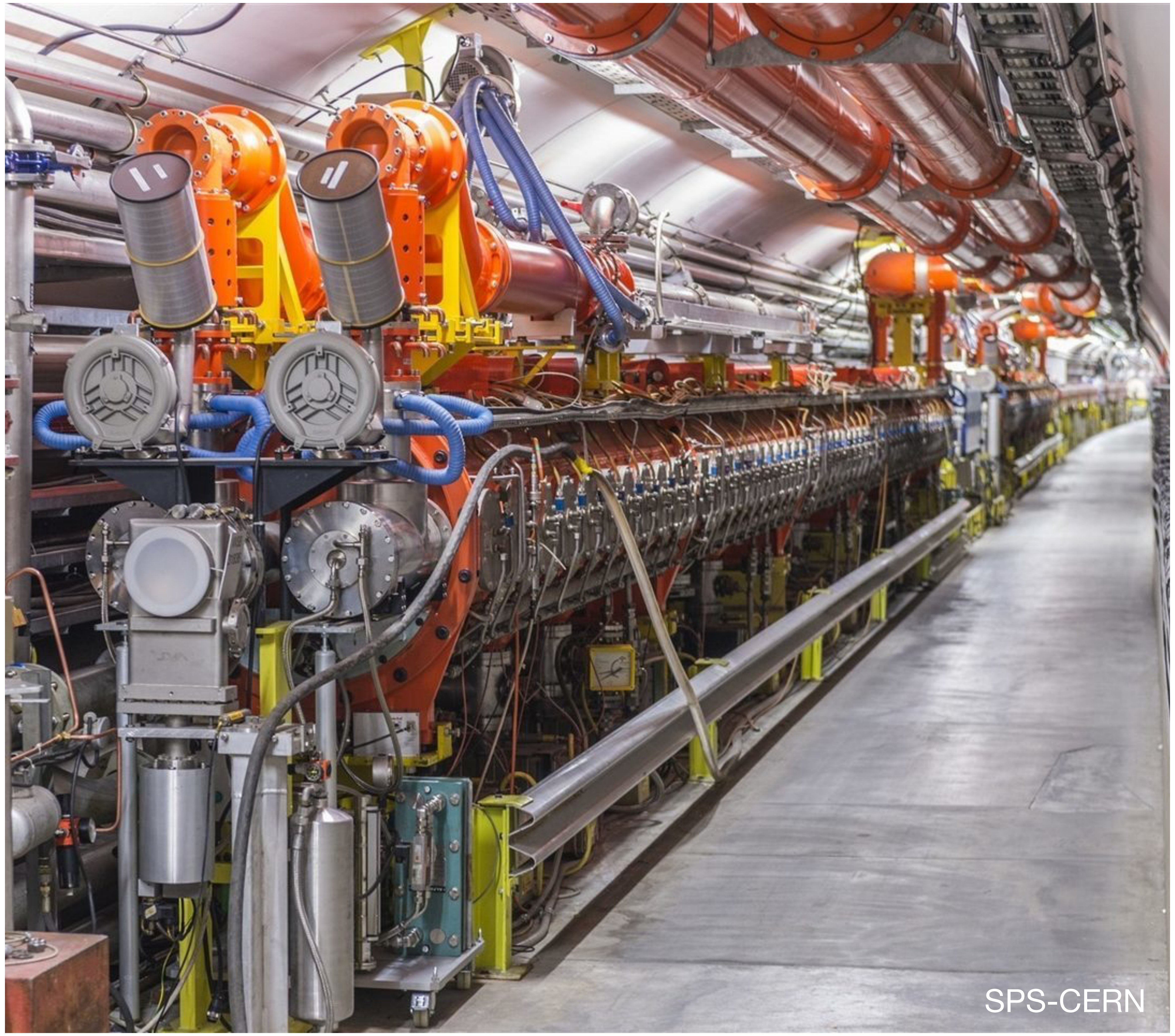
- Enables the recycling of laser energy,
- Facilitates energy-efficient acceleration of high-repetition-rate beams,
- Requires efficient couplers to direct the laser into the accelerating structure.

THANK YOU!


BACKUP
SLIDES

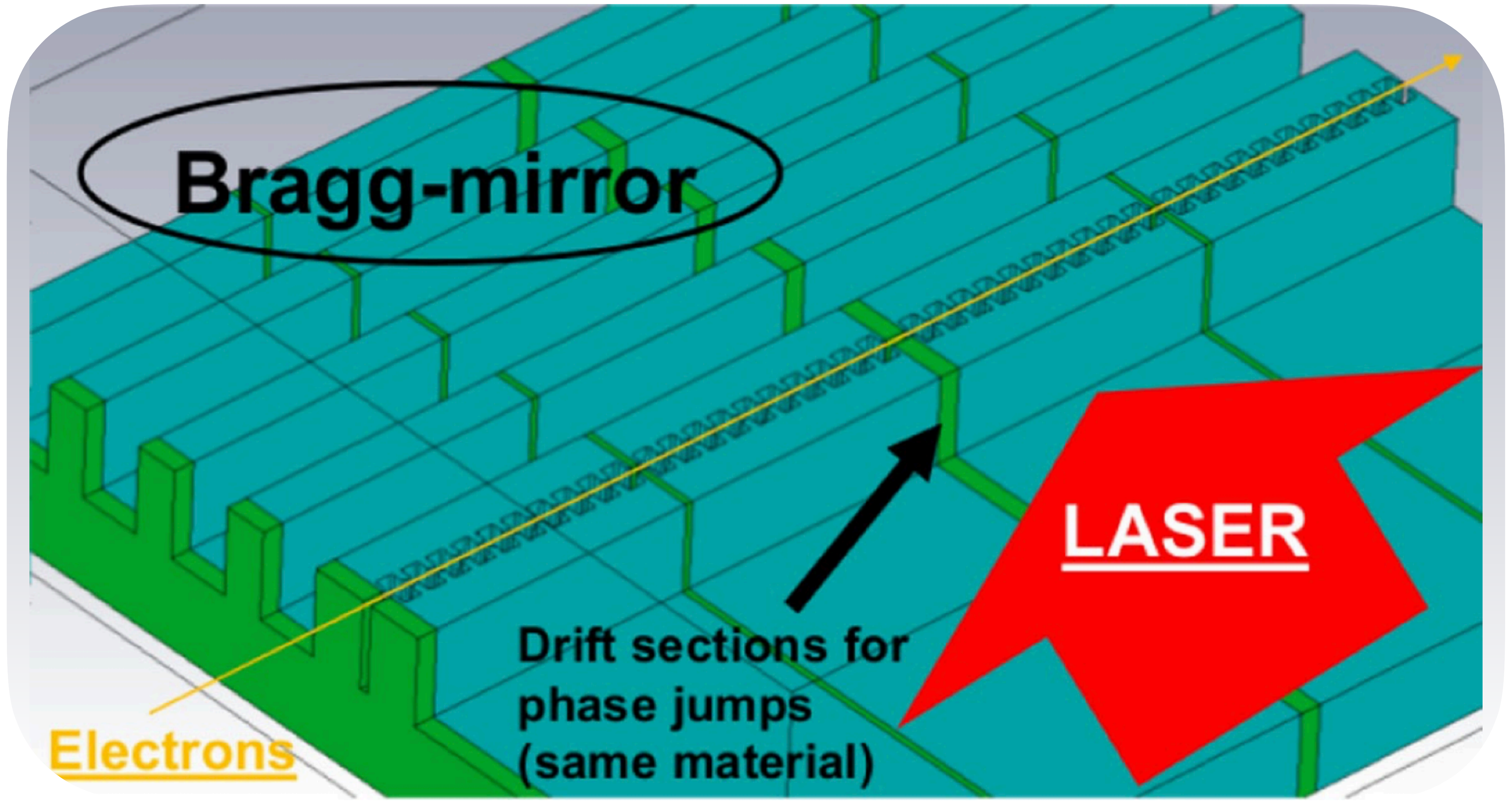
OPTIONS TO GENERATE THE ELECTRON BEAM

Extraction from a storage ring

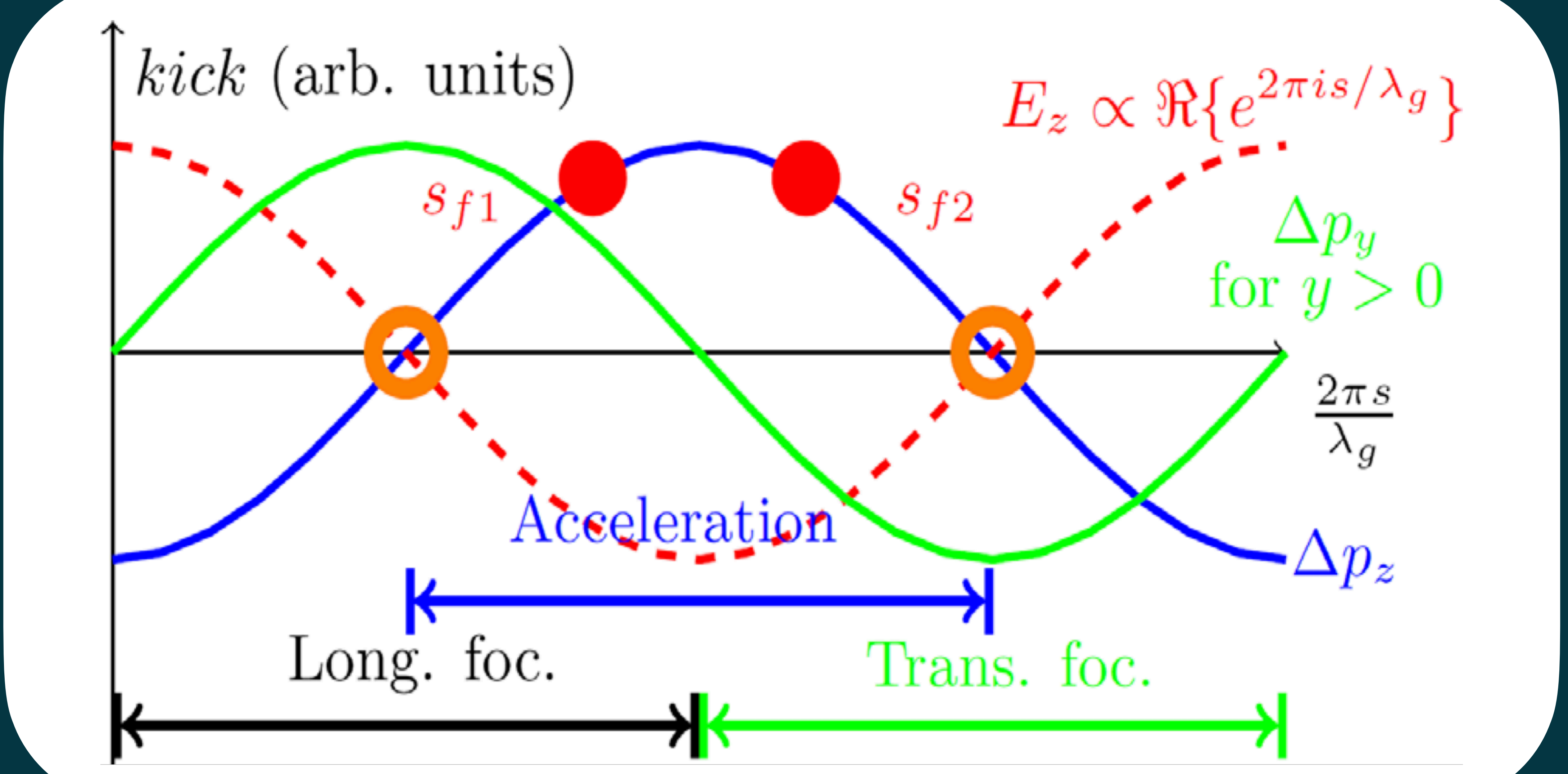


Superconducting accelerator

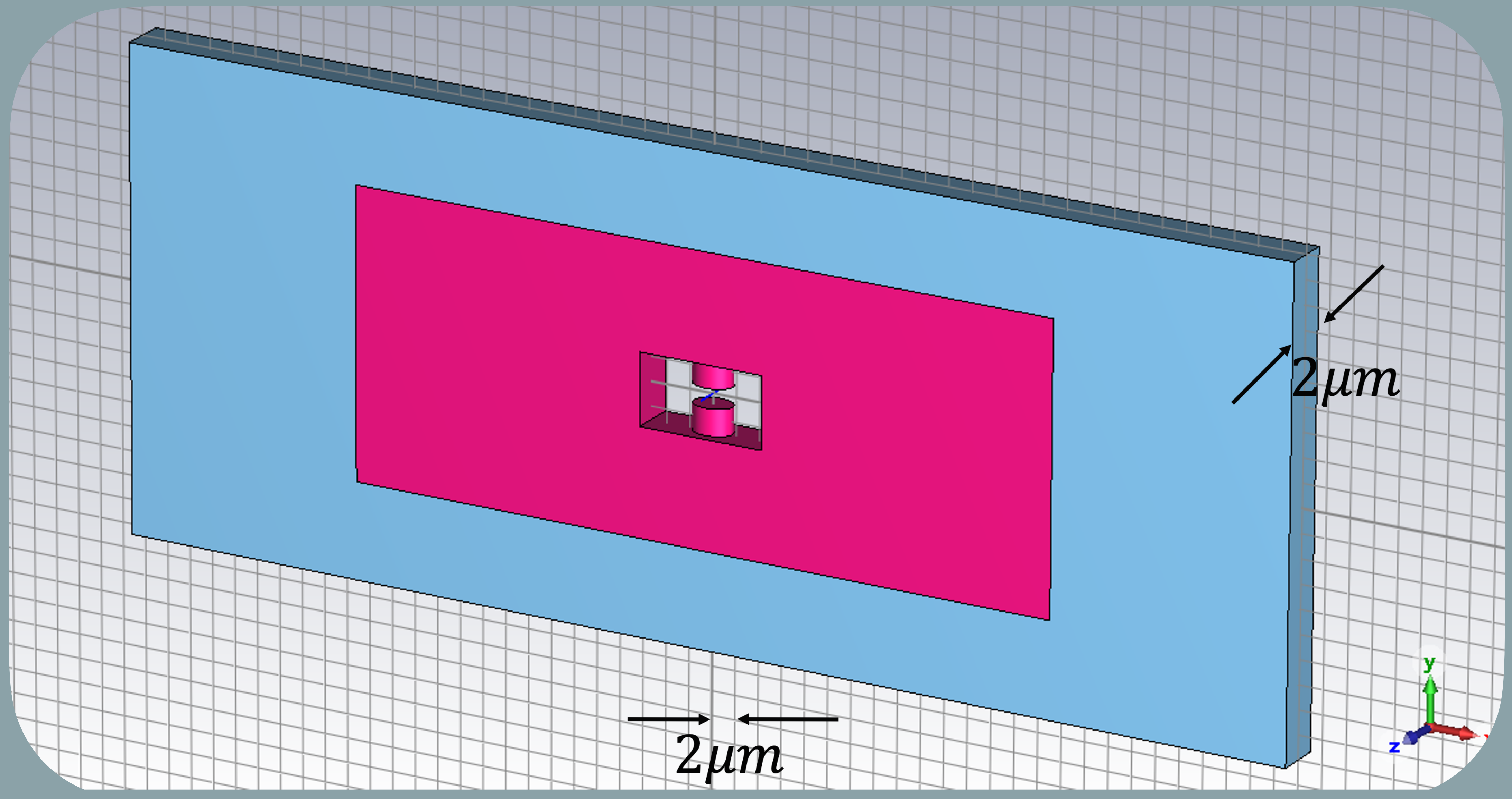
Alternating-Phase Focusing



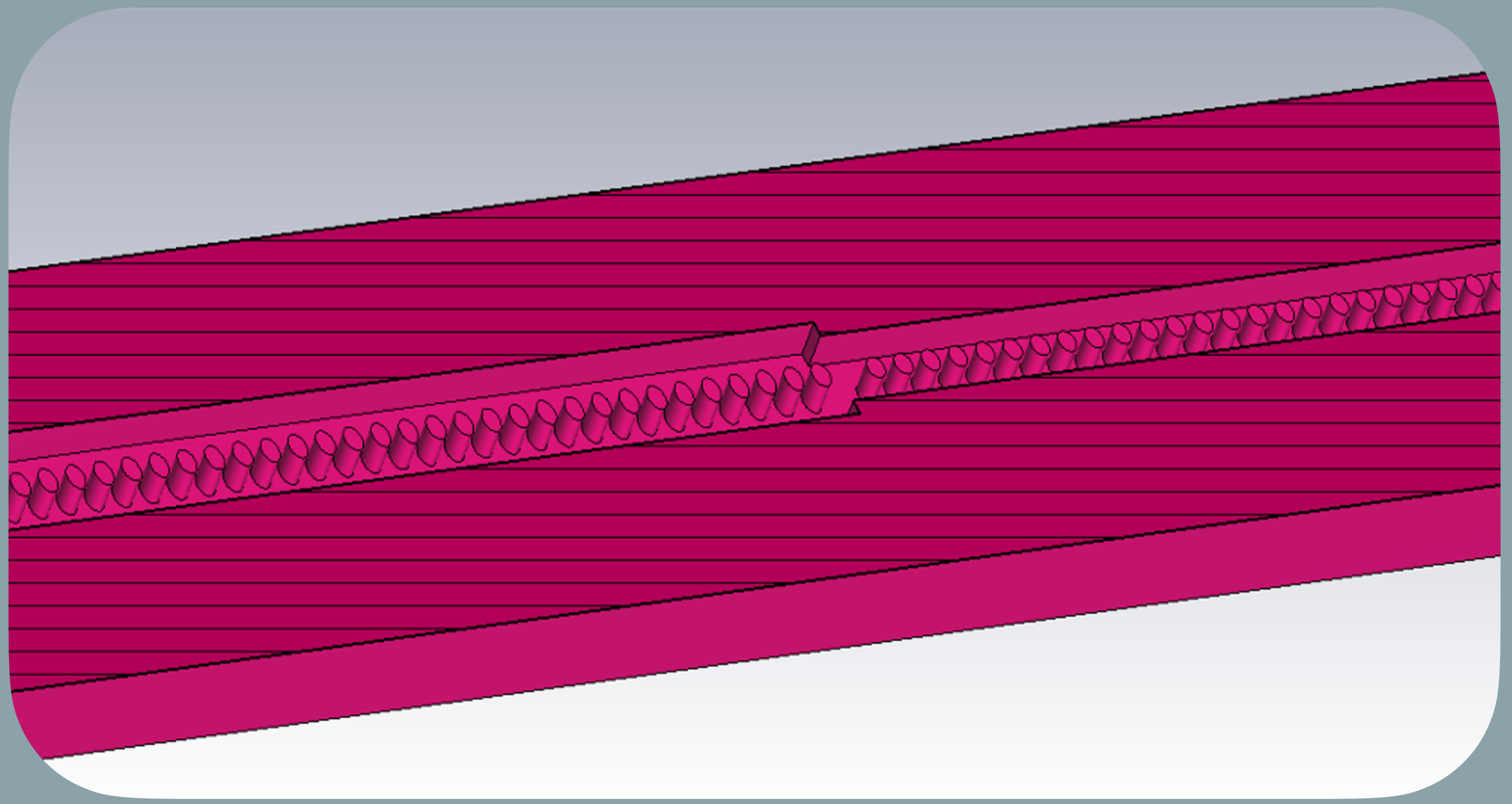
https://doi.org/10.1103/PhysRevAccelBeams.20.111302



https://doi.org/10.1103/PhysRevLett.125.164801



Single Cell



Half-view of the Structure

- The parameters k_x, k_y, and e_1 can be calculated for a single cell using CST Studio Suit (or vice versa).
- These parameters can change along the structure (homogenous structure) or stay identical (non-homogenous structure).

- Beam energy: 10 MeV
- Laser energy: 200 MV/m
- Number of macro-cells: 2×30
- Number of micro-cells: 2×3500
- Structure length: $2 \times 7mm$
- Initial energy spread: 0.001

Beam Dynamics