Modélisation des expériences LWFA au LOA avec des techniques de simulation modernes.

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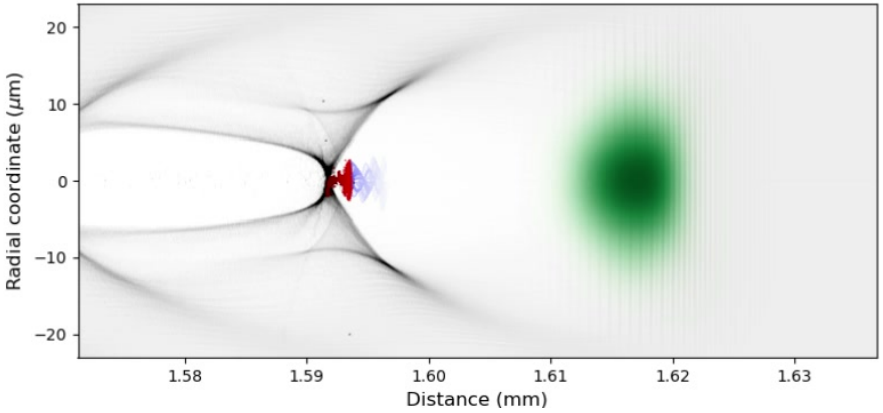
Laser plasma acceleration

Unique source features

- compact (table-top)
- ultra-fast $\sim fs$
- multi-kA current
- jitterless synchronization



High repetition rate systems (mJ@kHz)

- high compression (few-cycles)
- sharp focusing ($w_0 \sim 1\,\mu$m)
- low e^- energy (few MeVs)
- high average flux
- stable operation
- e^- diffraction, Compton X-rays

High power lasers (TW-PW)

- laser guiding
- multi-GeV electrons
- controllable injection
- low-divergence $\lesssim 1$ mrad
- monoenergetic
- future XFELs and colliders

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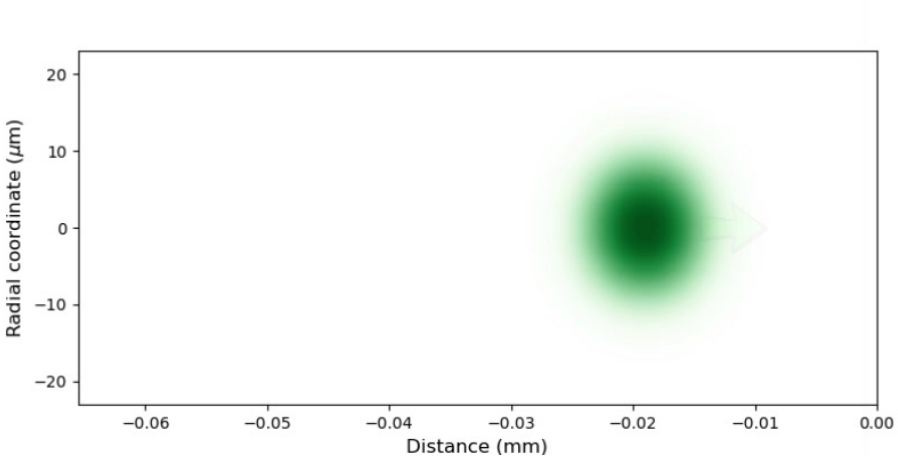

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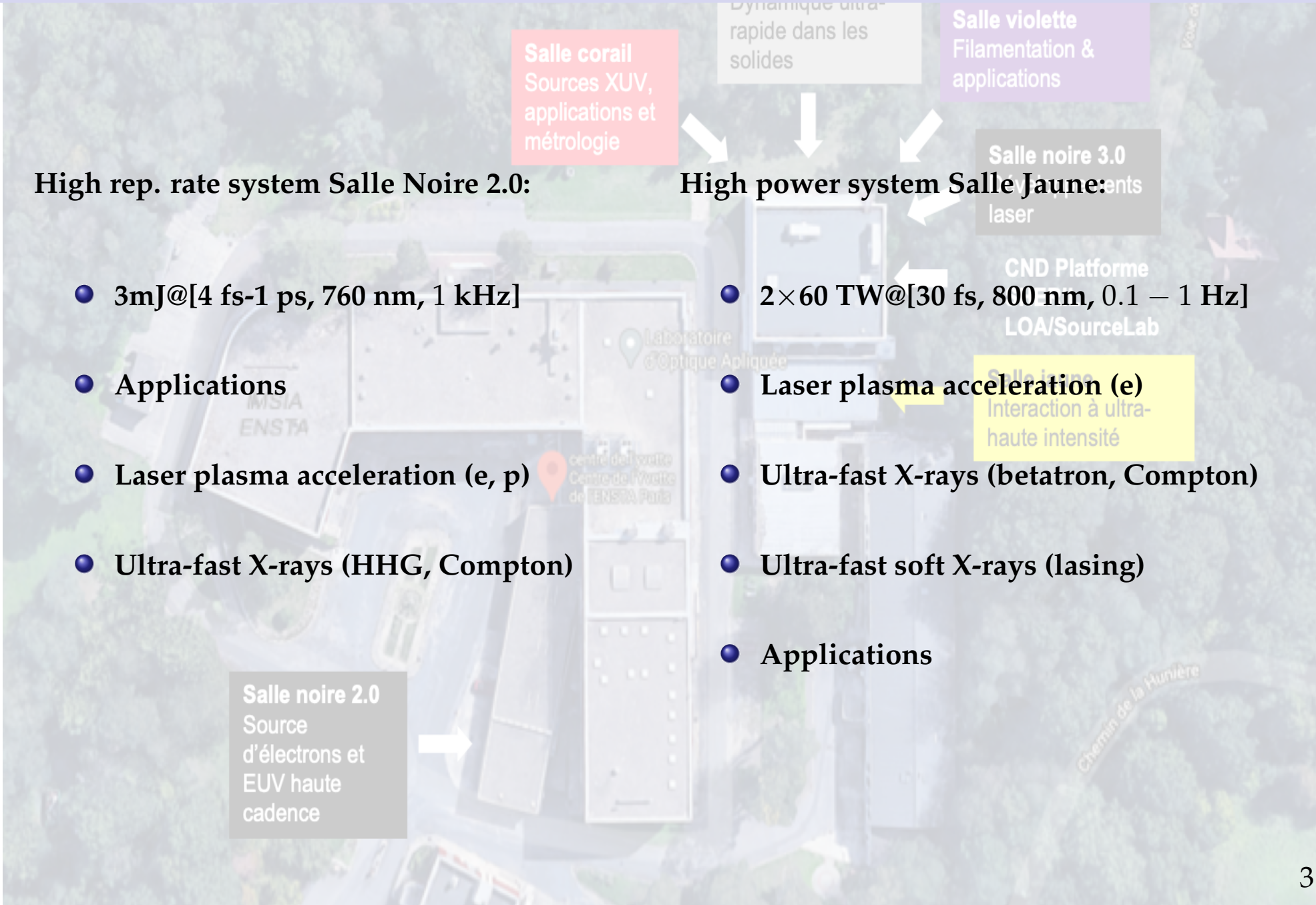
Relativistic laser plasma at LOA



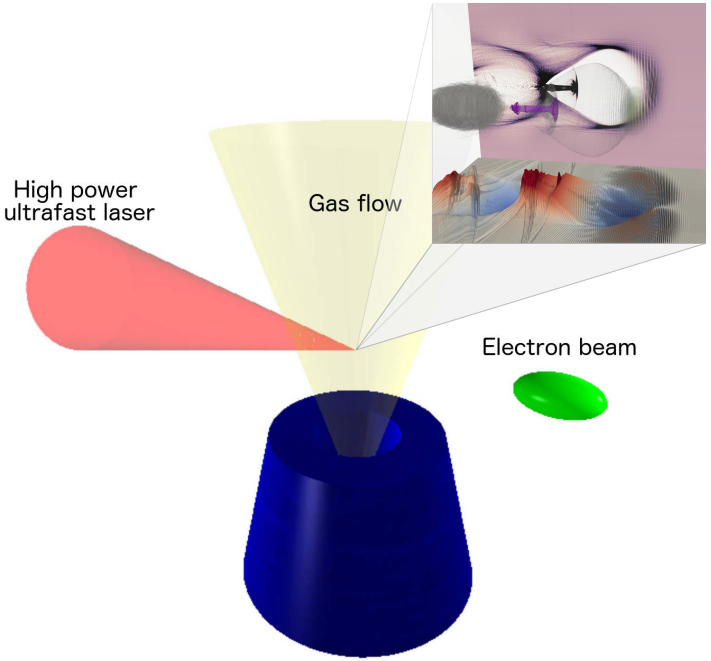
High rep. rate system Salle Noire 2.0:

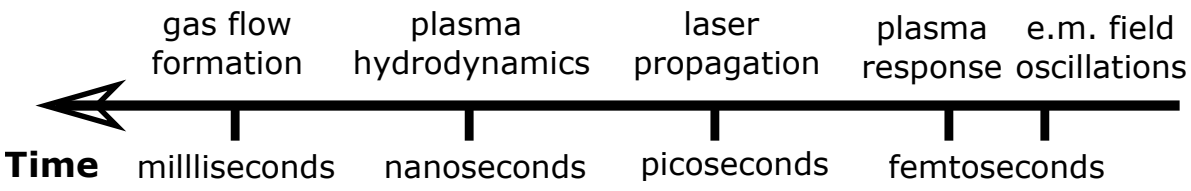
- **3mJ@[4 fs-1 ps, 760 nm, 1 kHz]**
- **Applications**
- **Laser plasma acceleration (e, p)**
- **Ultra-fast X-rays (HHG, Compton)**

High power system Salle Jaune:

- **2×60 TW@[30 fs, 800 nm, $0.1-1$ Hz]**
- **Laser plasma acceleration (e)**
- **Ultra-fast X-rays (betatron, Compton)**
- **Ultra-fast soft X-rays (lasing)**
- **Applications**

Time-scales in LWFA





- gas flow: (super)sonic, transient/steady-state, turbulent, viscosity
- plasma hydro-dynamics and heat transport: channel/shock formation
- laser spot formation, measurements interpretation
- LWFA: e.m. field, plasma response, propagation

Open-source/on-request solutions

PIC codes

- WARPX[multi-/solv, port]
- Smilei[multi-/solv]
- PIConGPU[multi-/solv, port]
- EPOCH [multi-/solv]
- FBPIC[RZ, PSATD, GPU]
- ChimeraCL[RZ, PSATD, GPU]
- HiPACE++[QSA]
- QuickPIC[QSA]
- WAND-PIC[QSA]
- Architect[RZ, Fluid]
- PICLS
- Piccante/ALaDyn
- VPIC
- iPic3D

Hydrodynamics

- OpenFOAM
- COOLFluiD

Plasma MHD

- FLASH
- CASTRO
- FRONT3D

Bunch Transport

- ELEGANT[ALL]
- ASTRA[RK,SC,SCR]
- OCELOT[MTRX,SC,SCR]
- AT[MTRX]
- Beta[MTRX]
- Synergia[PIC]

SR

- SynchRad[SR,GPU]
- AxiProp[Prop,GPU]
- SRW[SR,Prop]
- XRT[SR,Prop,GPU]
- CHIMERA[SR]
- Shadow3 (OASYS)*
- OPC[Prop]

FEL

- GENESIS[3D,TD]
- PUFFIN[3D,TD, unav]
- CHIMERA[3D,PSATD,TD, unav]
- FEL Booklet (PARSIFEL)

Particle-In-Cell modeling

$$\partial_t \boldsymbol{\varepsilon} = \boldsymbol{\nabla} \times \mathbf{b} - \mathbf{j}\,, \quad \partial_t \mathbf{b} = -\boldsymbol{\nabla} \times \boldsymbol{\varepsilon}\,,$$
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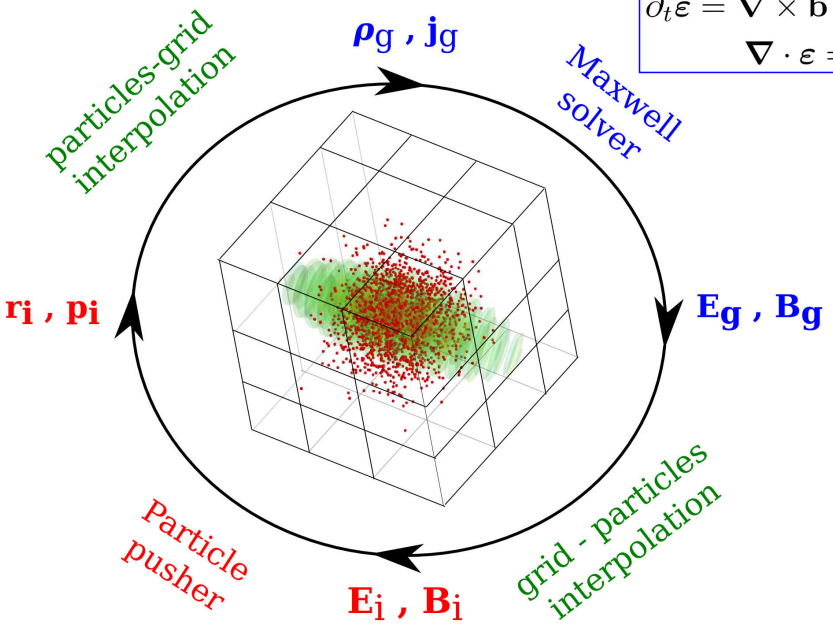

Challenges: typically $10^5 - 10^6$ steps, numerical artefacts

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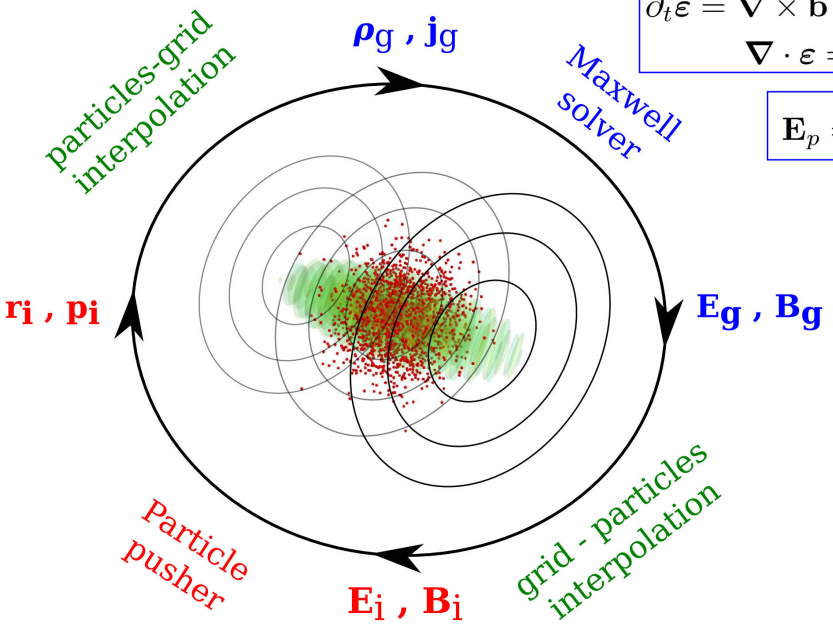

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$$\mathbf{E}_p = \sum_m \mathrm{e}^{im\theta_p} \mathbf{E}_p^{(m)}$$

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- Quasi-cylindrical: $\times 2\, N_\perp / N_m$

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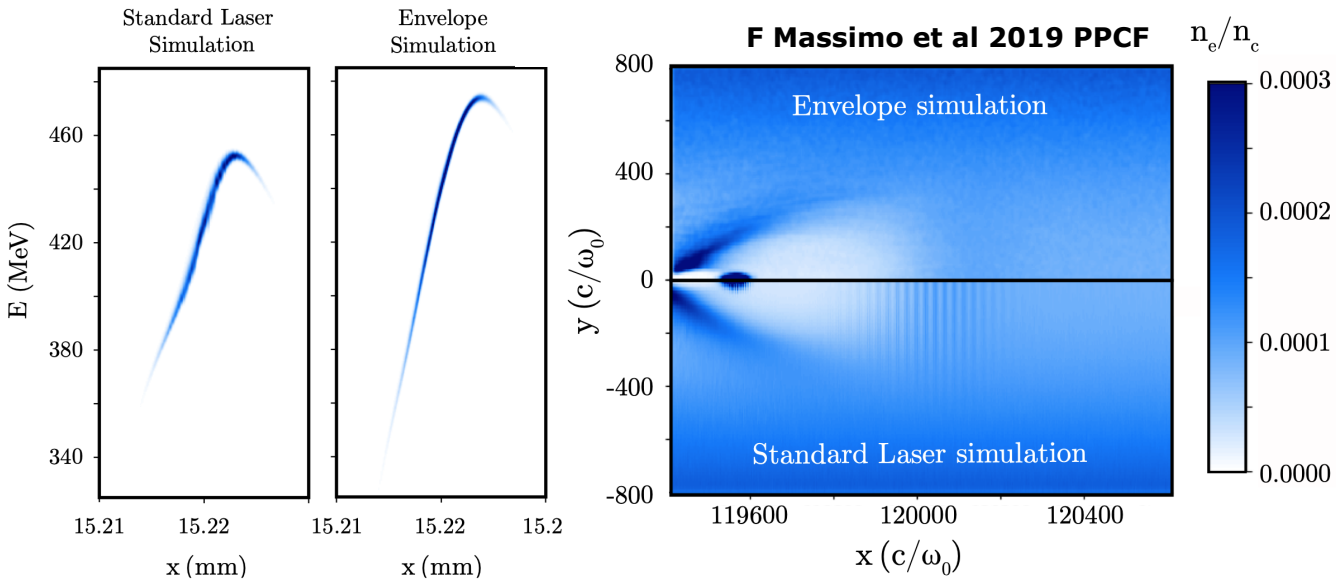

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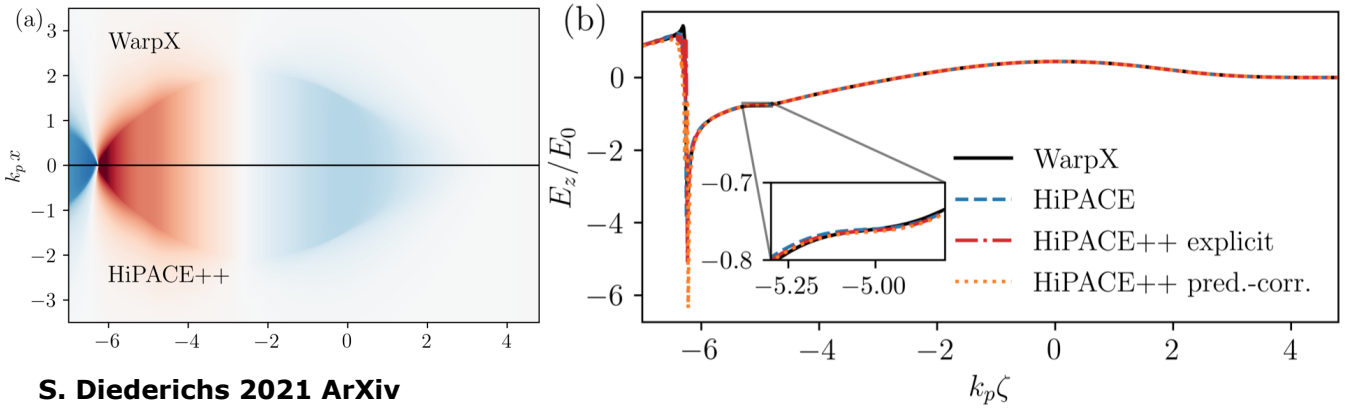

S. Diederichs 2021 ArXiv

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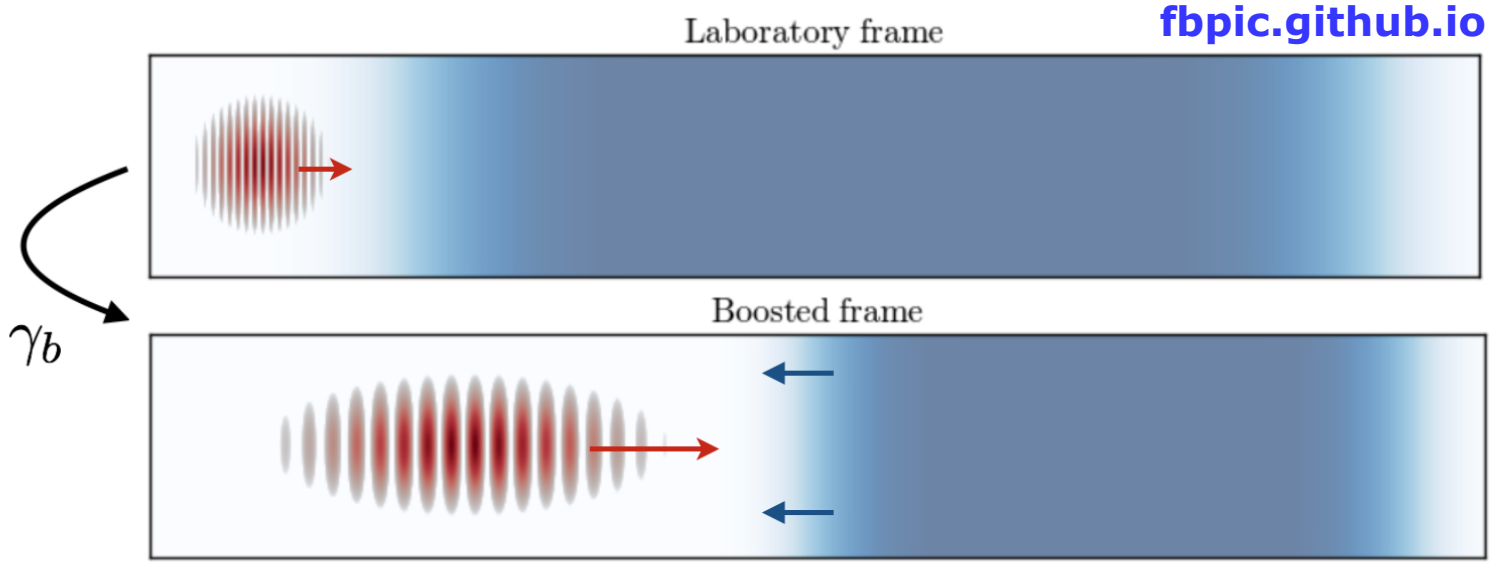

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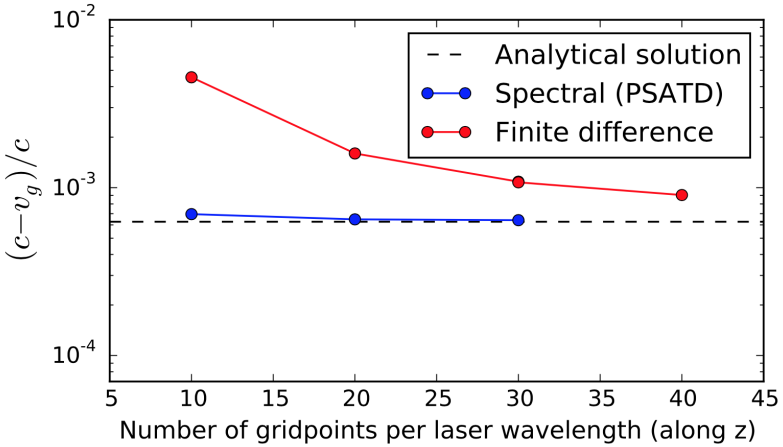

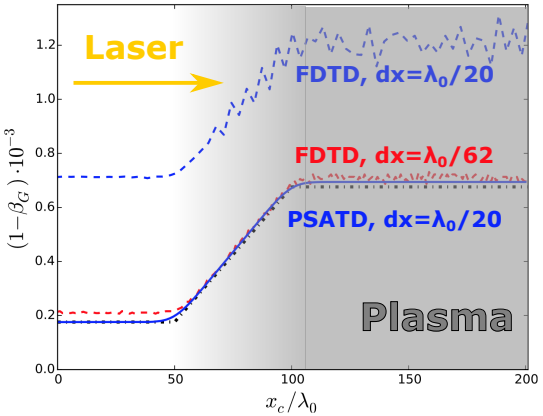

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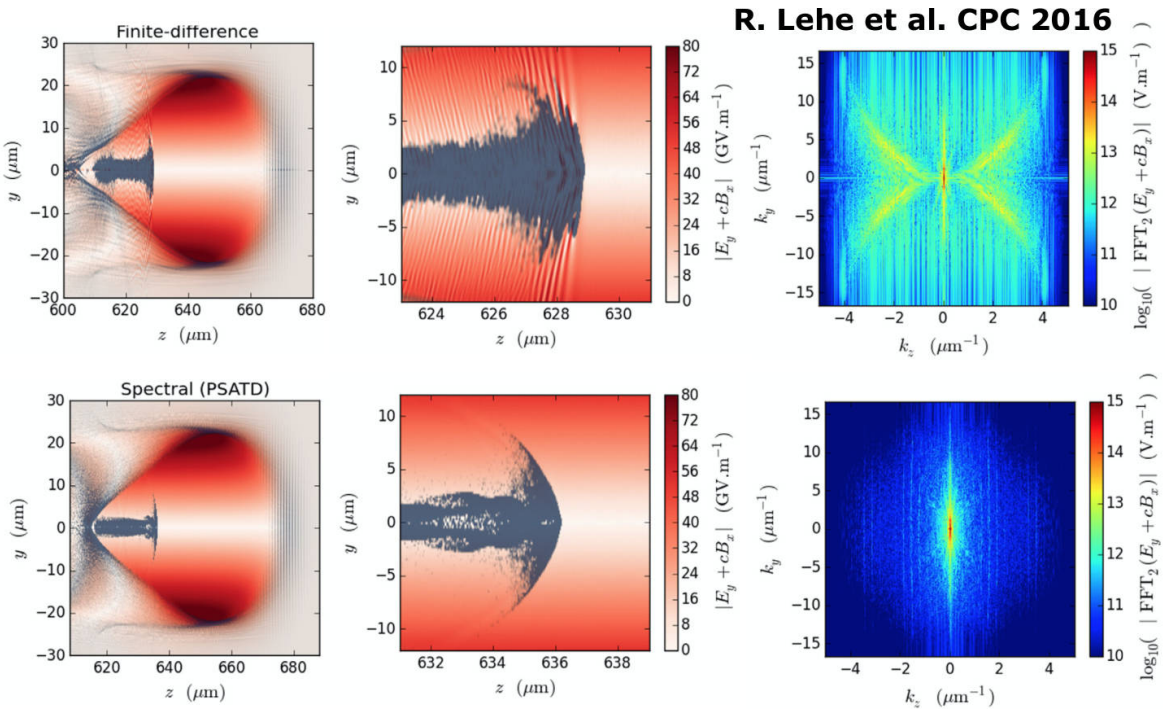

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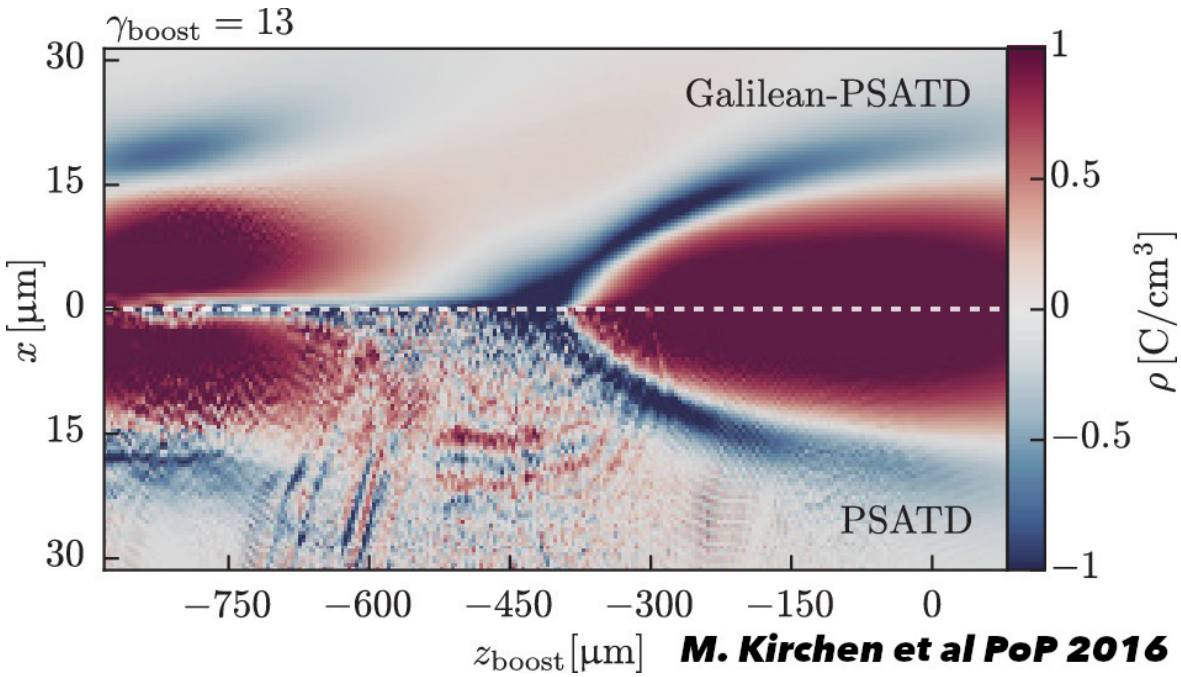

M. Kirchen et al PoP 2016

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- Streaming plasma instability: Galilean frame

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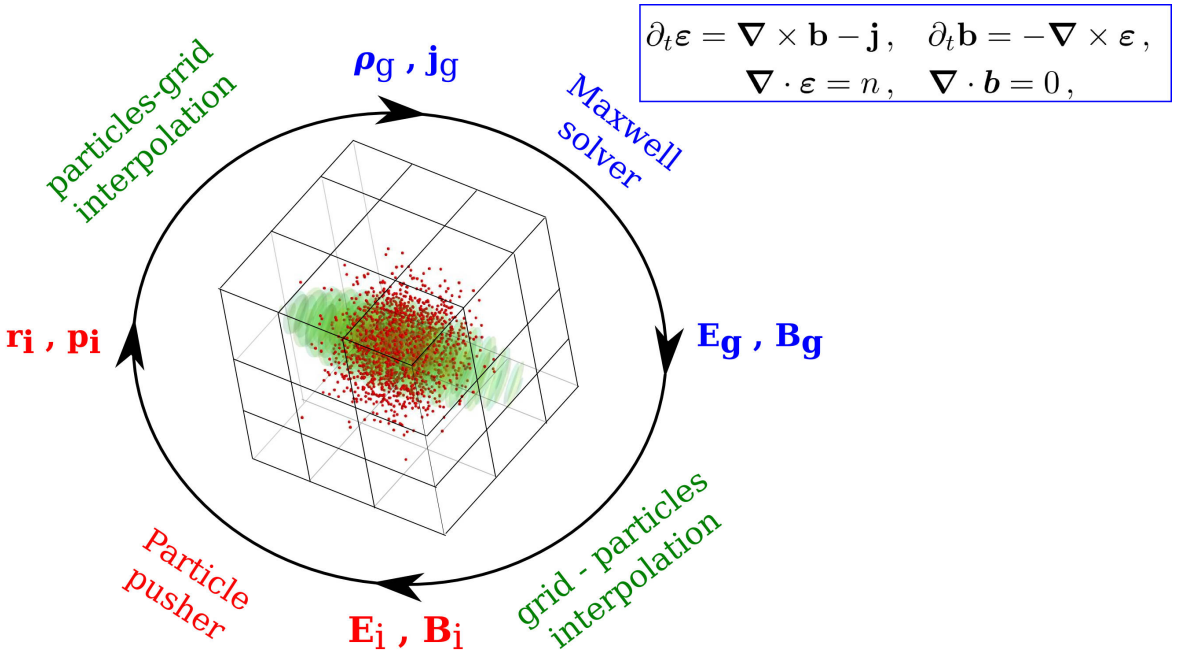
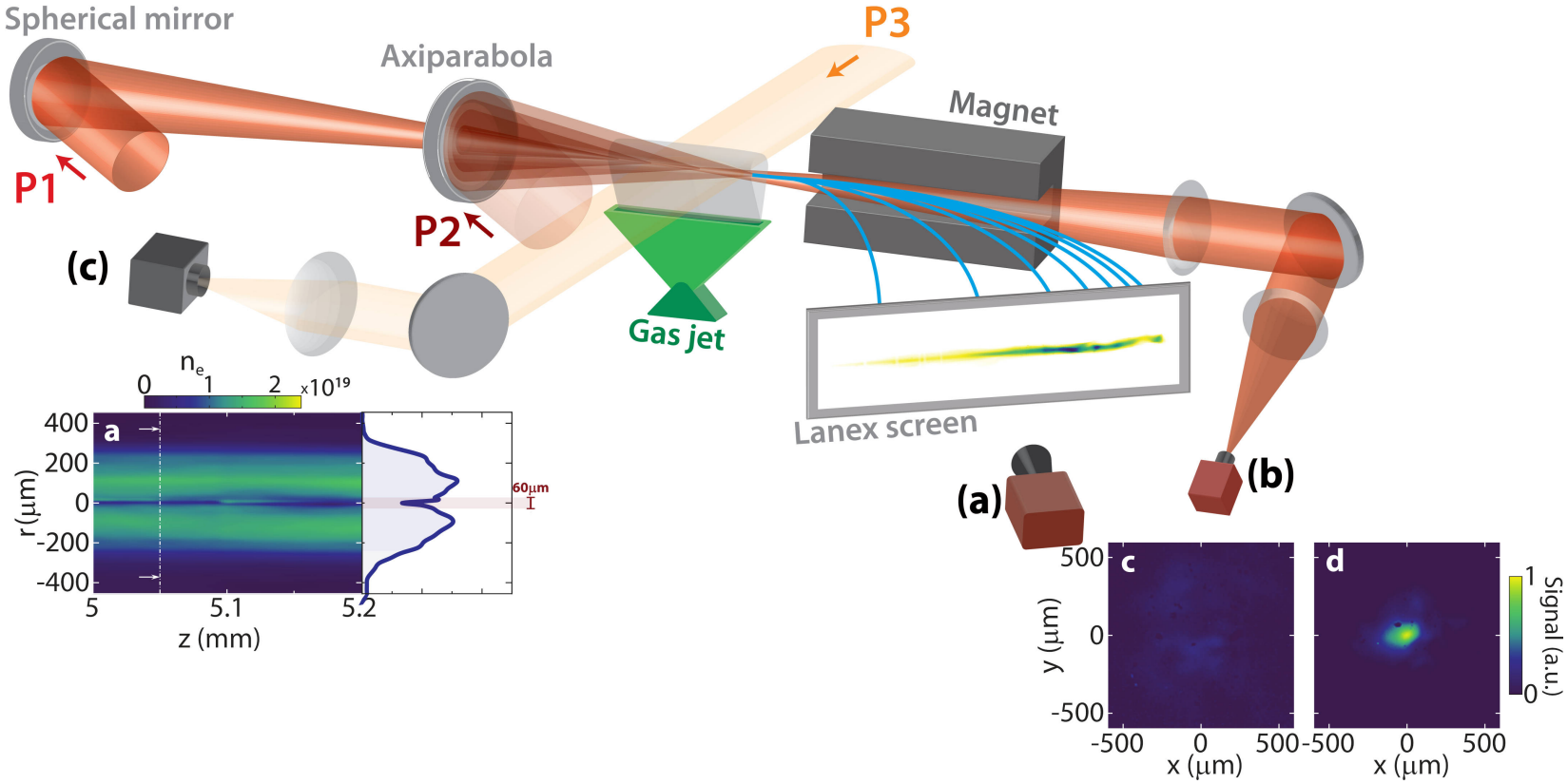


Challenges: typically $10^5 - 10^6$ steps, numerical artefacts

- 2D/3D, Quasi-cylindrical
- FDTD: Yee, NDFX, DS, CKC
- PSATD: FFT2D/3D, FFT+Hankel
- current deposition: direct, Esirkepov, ZigZag
- pushers: Boris, Vay, Higuera-Cary
- QSA: predic-corr, explicit
- Envelope: 3D/RZ

Guided LWFA at LOA: Experiment

[Oubrerie et al Light Sci. Appl. 2022]



Laser, 30fs, 810 nm

- P2: $f_0 = 200$ mm, axiparabola $\delta = 30$ mm, 1.46 mJ
- P1: $f_0 = 1.5$ m, 1.7 J (60% in main peak), + 2ns

Target

- Slit nozzle 15mm 40 bars $\rightarrow$ $n_{pe} = 1.4 \times 10^{19}$ cm^{-3}
- Injection: ionization (H_2+1%N_2), shock (H_2)
- motorised blade to produce shock

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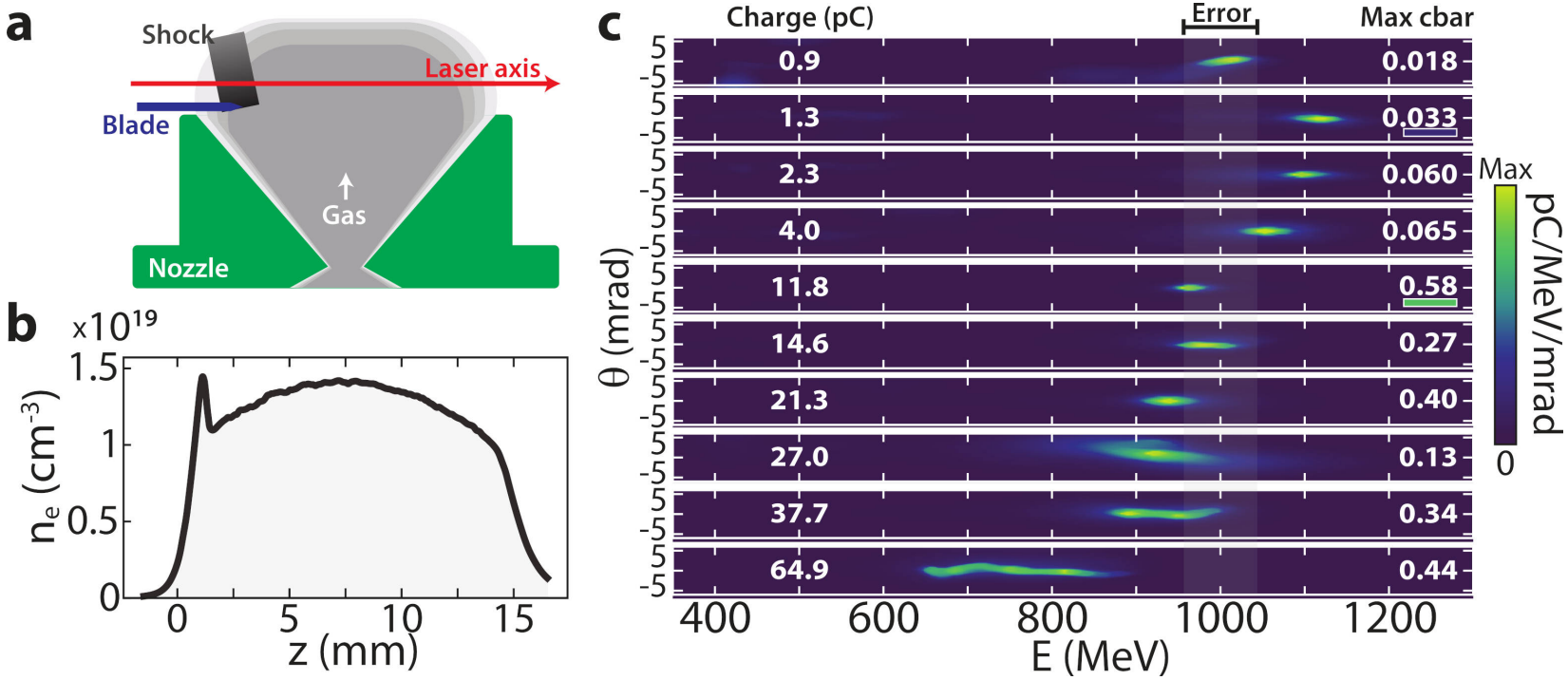

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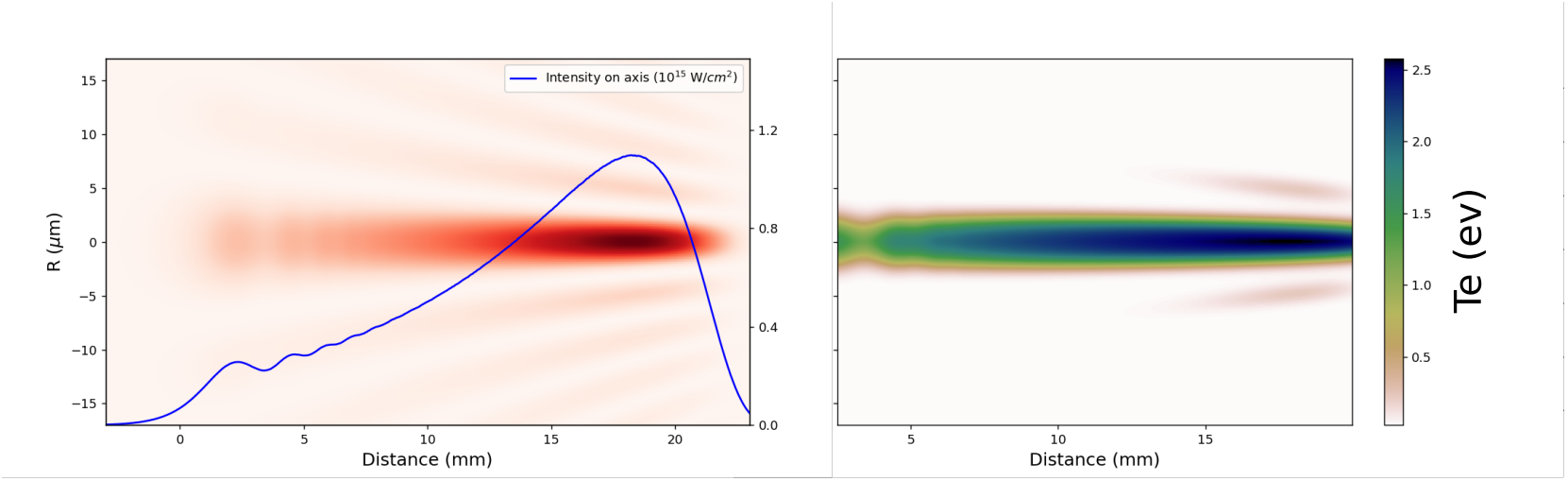
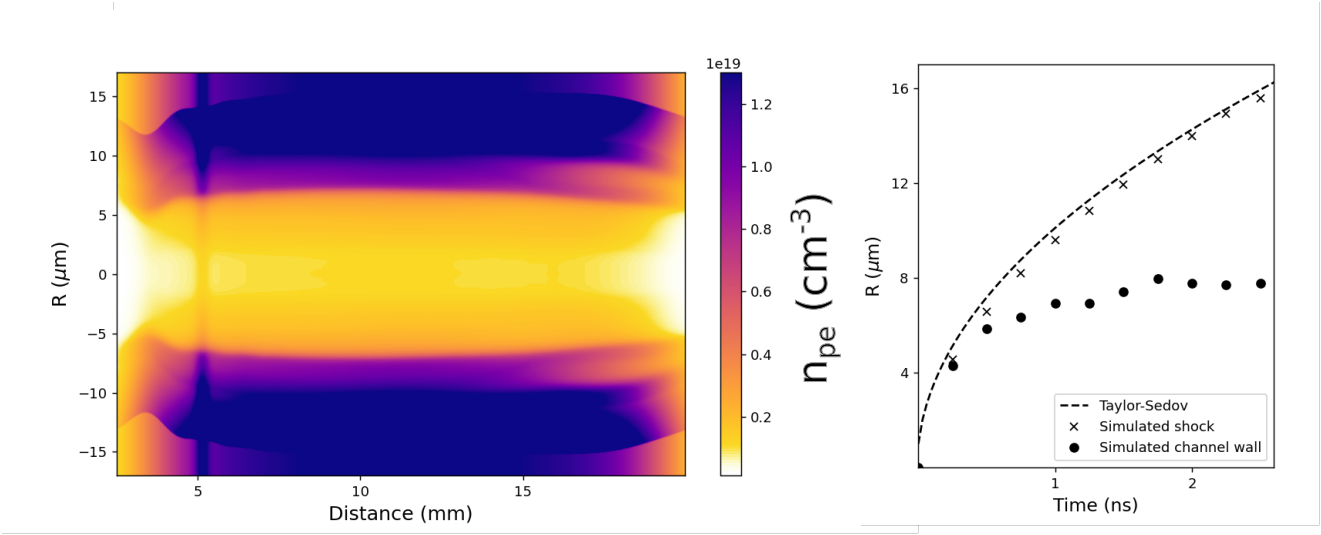
Guided LWFA at LOA: Modeling

- Optical propagation (`AxiProp`) → OFI heating (`home-made`)



- Channel formation (`FRONT3D`)



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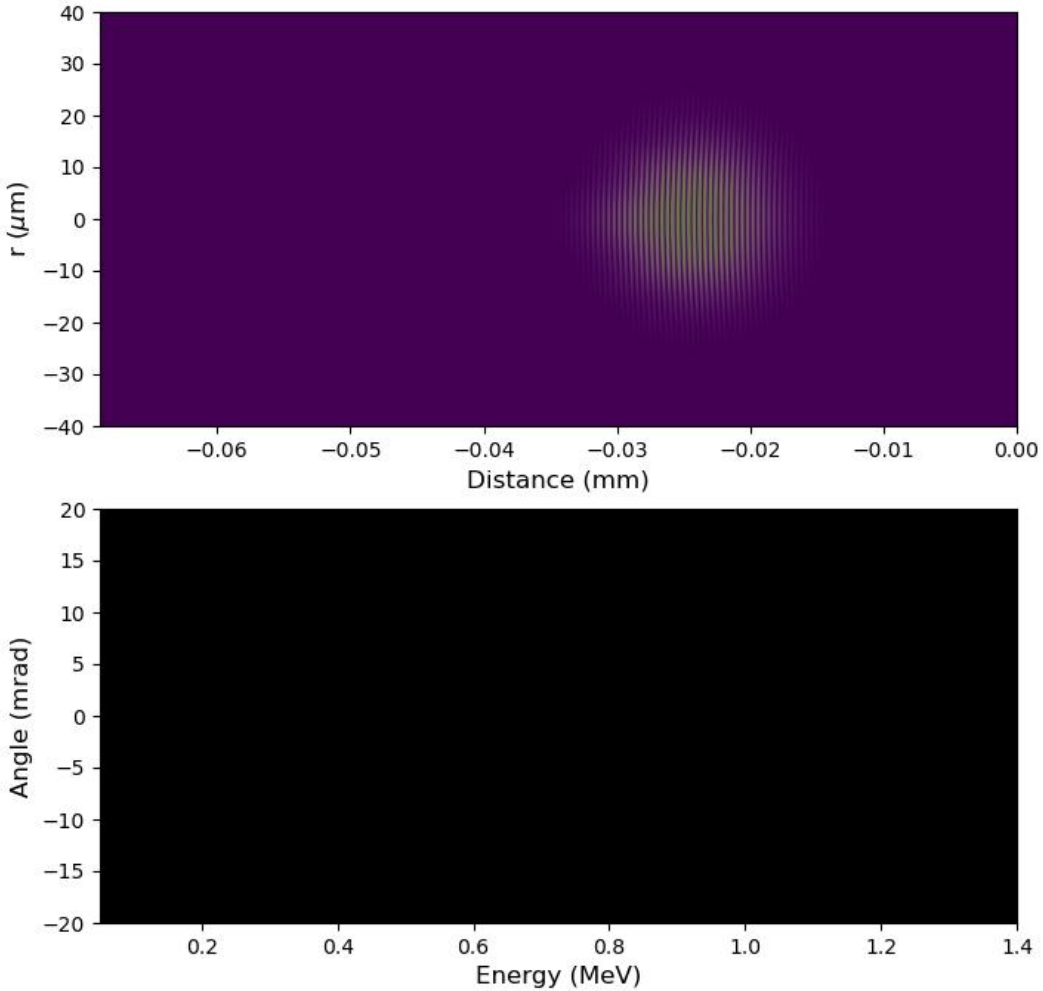

- Lorentz-boosted PIC (`FBPIC`)

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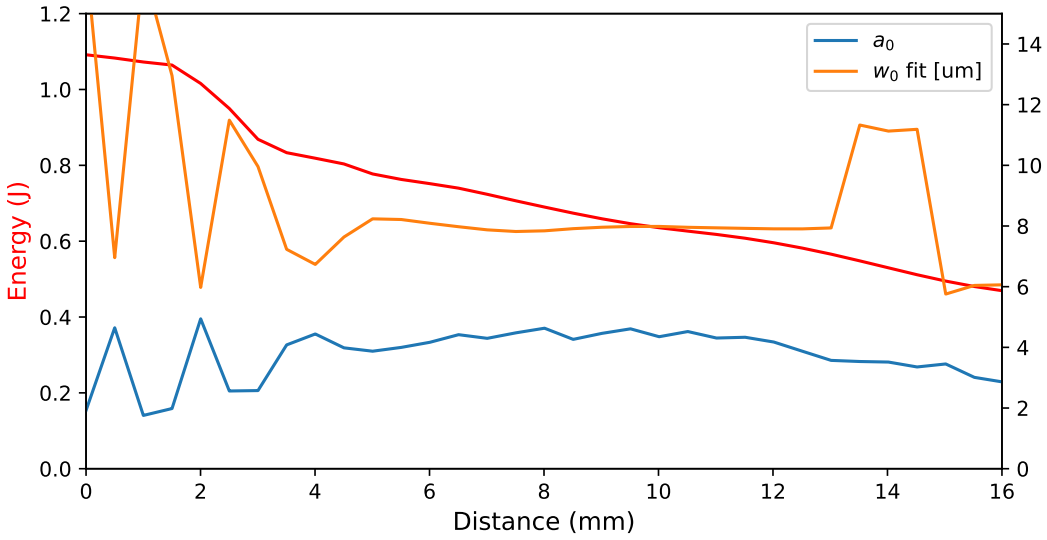

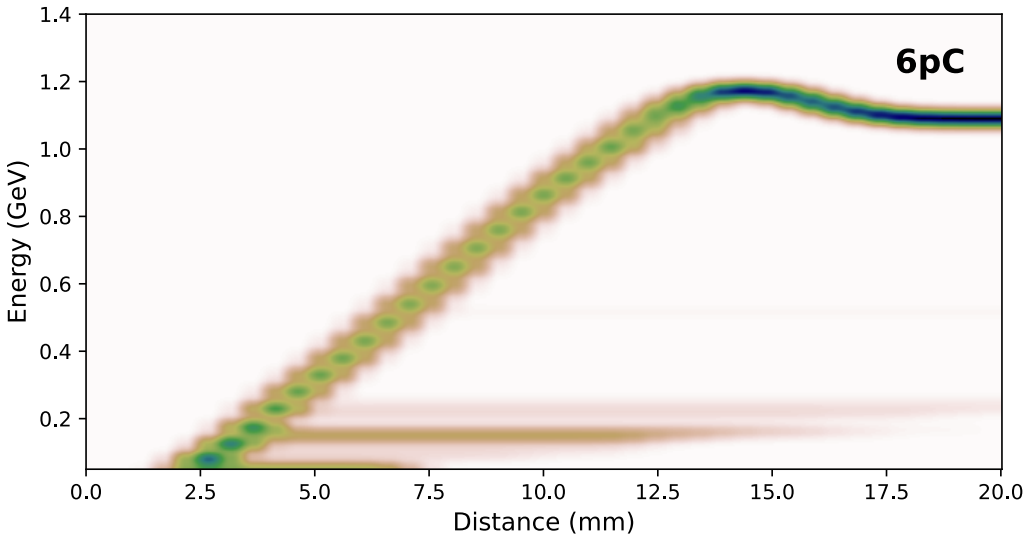

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Questions