Summary
Theory and simulations (roadmap)

J. Vieira, M. Thévenet

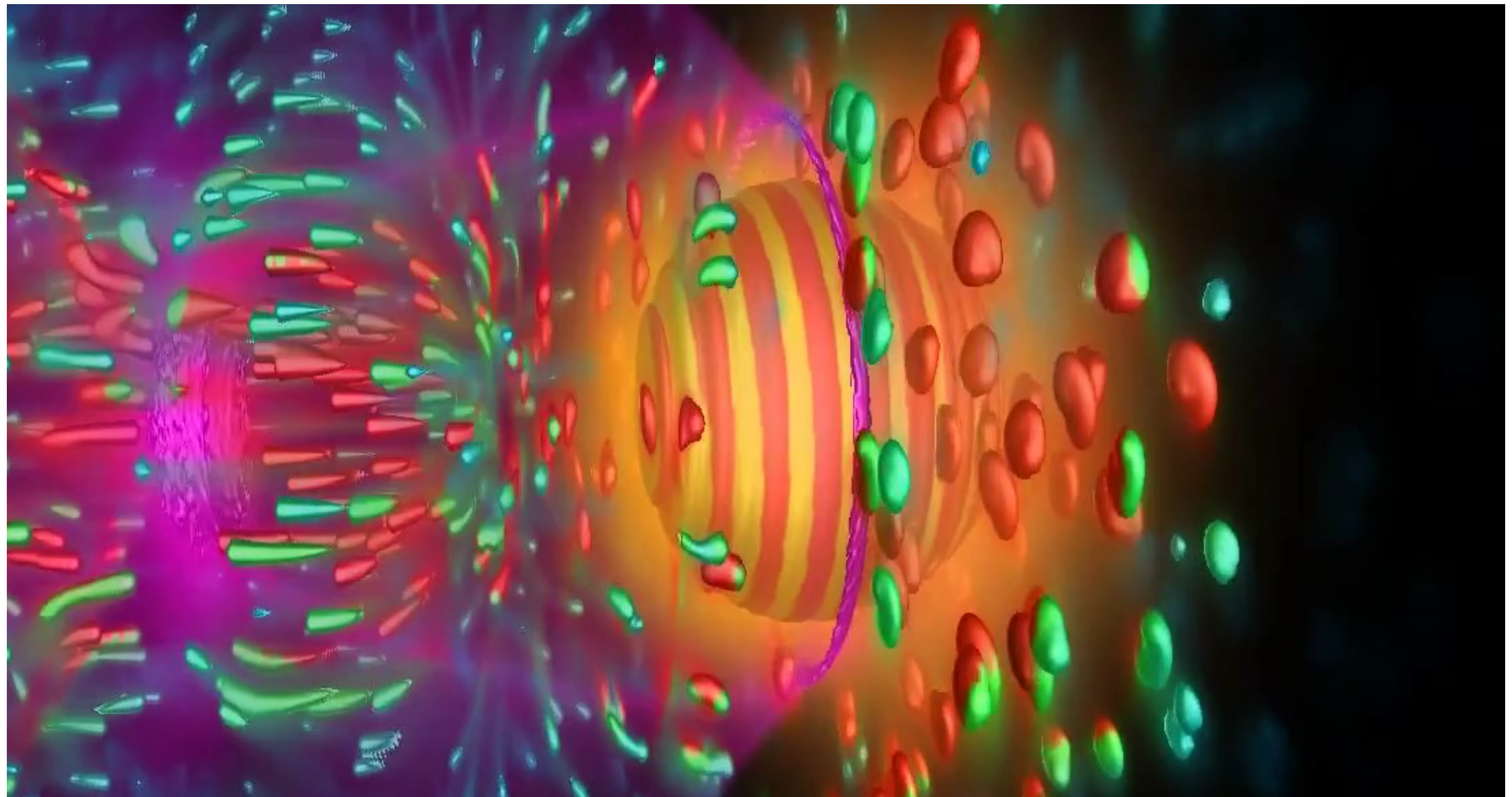

Image:
PIC simulation computed by PIConGPU
2nd prize Helmholtz Imaging Best Scientific Image Contest 2022

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TÉCNICO LISBOA

Session summary

Applications of machine learning on plasma accelerators

Remi Lehe

Limits of PIC simulations for modelling plasma accelerators and applications

Xavier Davoine

QED effects in reduced PIC simulations and applications to positron acceleration

Bertrand Martinez

Reduced PIC models: Quasi-static approximation

Severin Diederichs

Common standards for numerical simulations - OPENPMD

Franz Poeschel

Machine learning in plasma accelerators

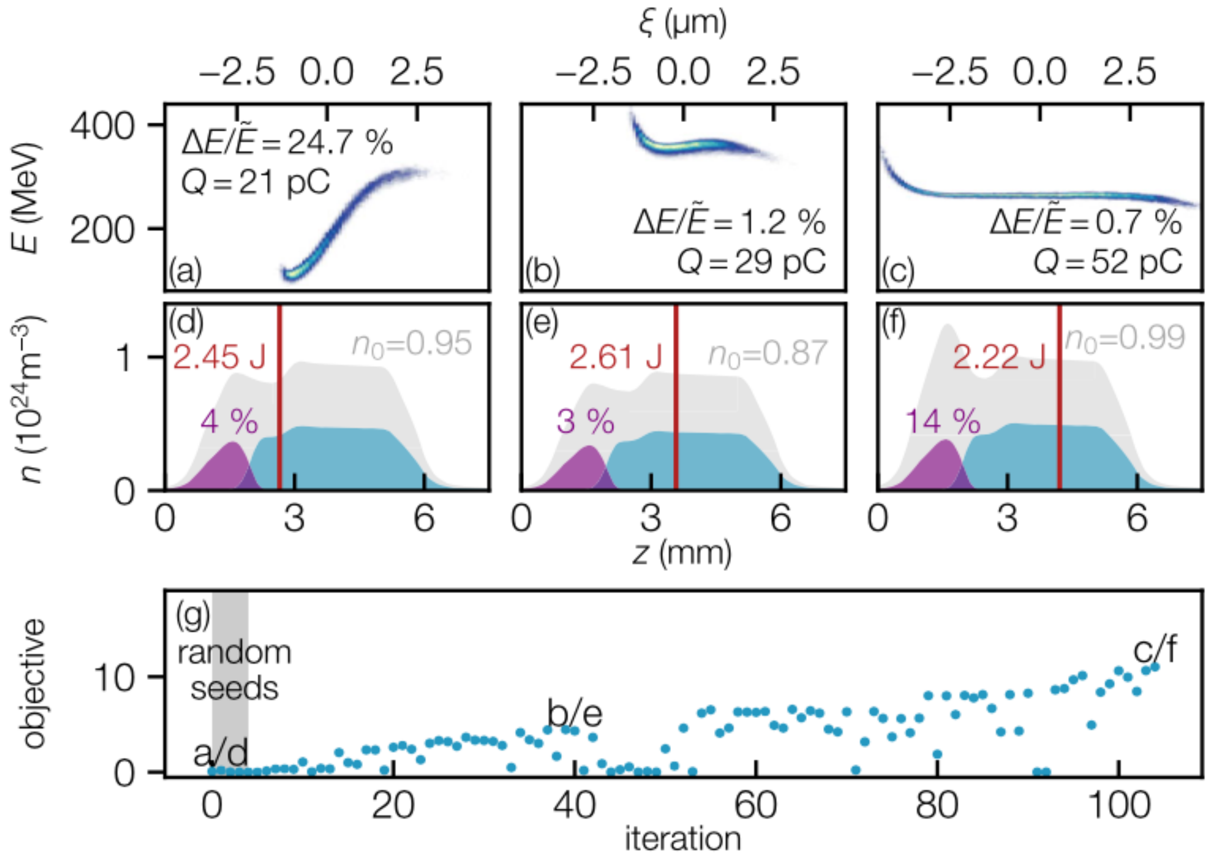
Remi Lehe

Optimization

Optimization:
The (uncontrolled) properties of the system do not change (e.g. negligible drift).

e.g.
- Design study (simulations)
- Experimental setup,
  over relatively short timescales

Aim: “exhaustively” search the parameter space to find x_{best}.

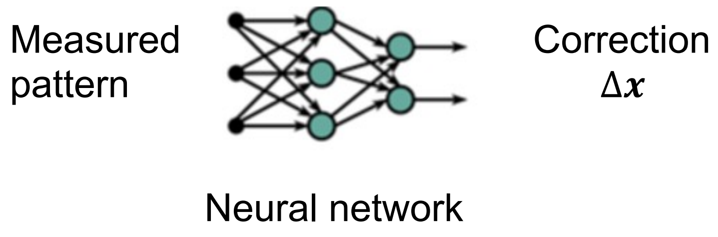


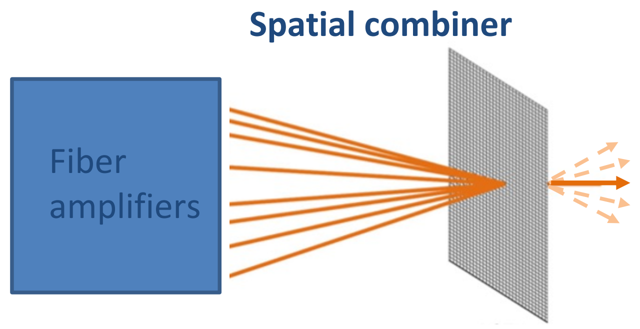
S. Jalas et al., PRL (2021)

Stabilization

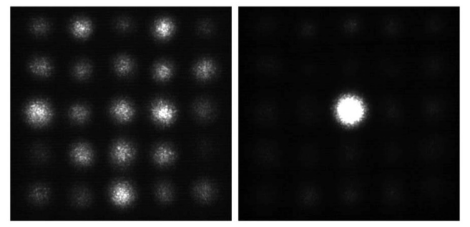
Stabilization algorithm based on machine learning:

Can recognize “patterns” in the system and directly apply the right correction.





The phases of the incident laser beams need to be such that they **interfere destructively** in **all but the forward direction**.



But the phase of each beam is drifting and is not measured directly (only the resulting intensity pattern is).

Outlook

1) Future developments needed and planned as seen from the speakers and their groups

- More applications of ML for stabilization of in experiments
- Better evaluation of uncertainty from ML methods
- Combine simulations of different fidelities for design optimization

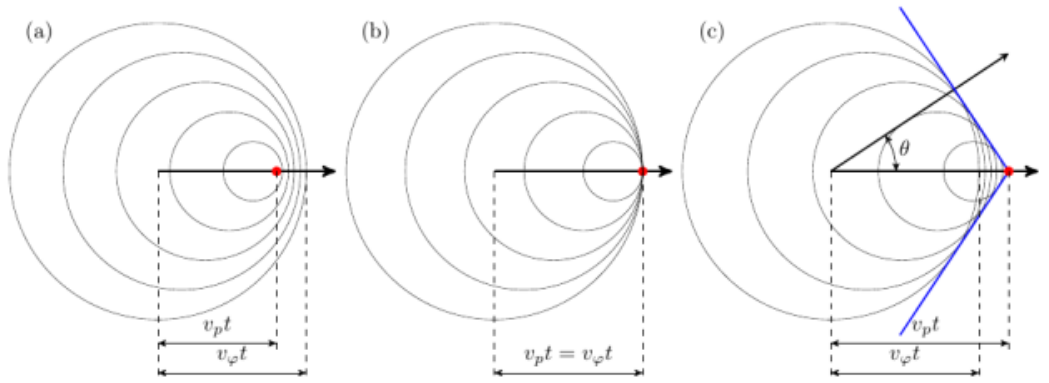
2) Do the planned activities address the requirements from funded projects (AWAKE, EuPRAXIA, …) and from various roadmaps for plasma accelerators? Are there urgent holes?

There is sometimes a gap between **proof-of-concept machine learning application** and robust solution that can run autonomously at the right rep. rate.

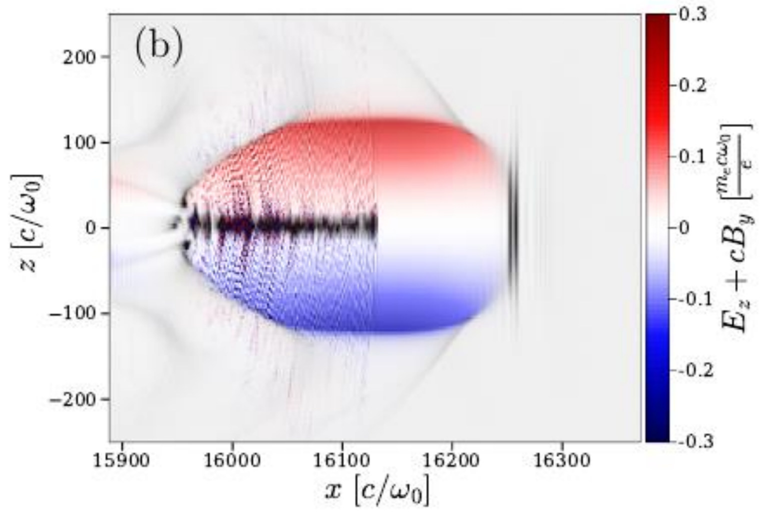
Numerical Cherenkov in PIC simulations and high fields

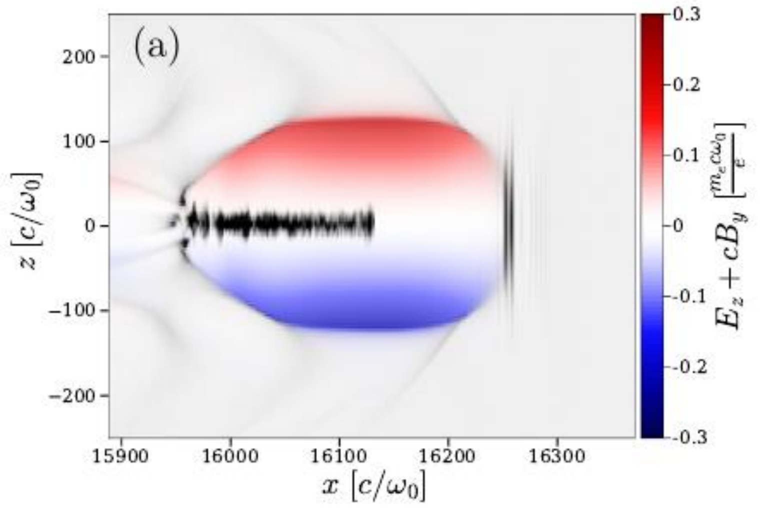
Xavier Davoine

Numerical Cherenkov



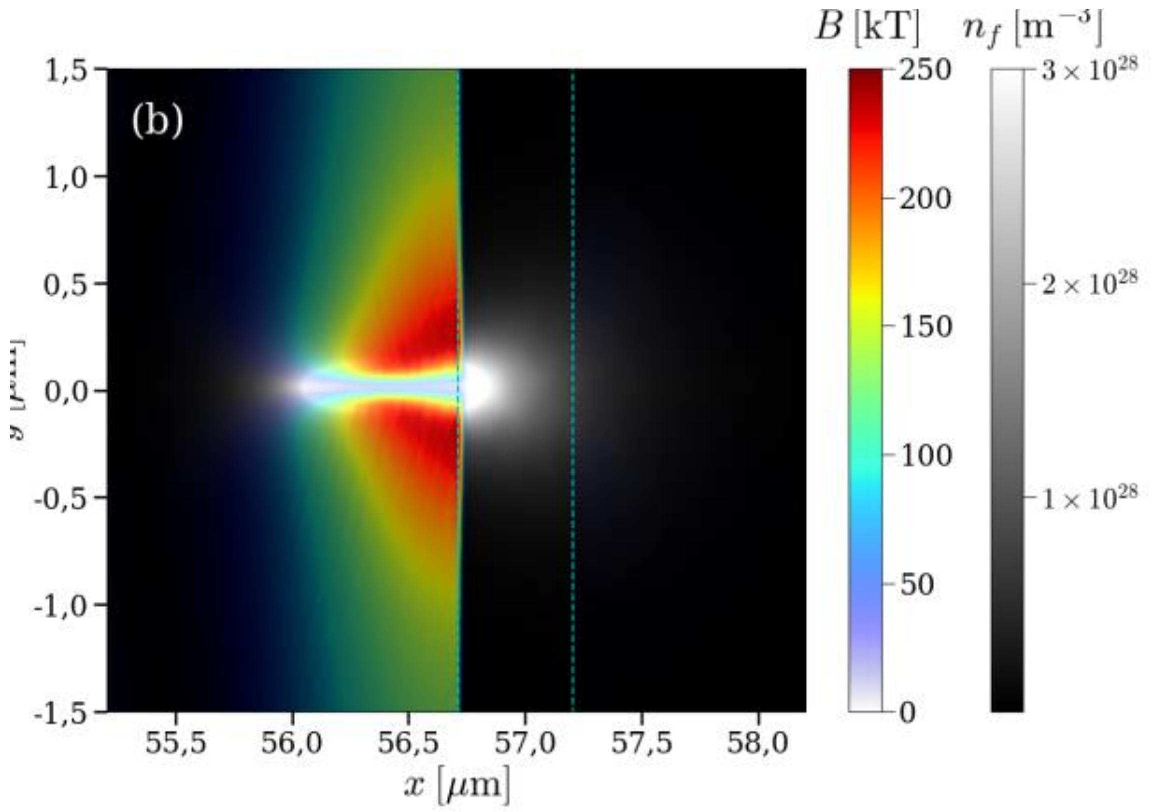
$$\cos(\theta) = \frac{c}{v_p n(\omega)} \qquad \omega = \boldsymbol{v_p} \cdot \boldsymbol{k}$$





Physics at the interaction point

- PIC code developments help to foster accelerator applications
  - radiation sources
  - **Beam interaction with EM fields or target/plasma. (beams from conventional accelerators, PWFA, LWFA)**
  - Needs for code developments



Outlook

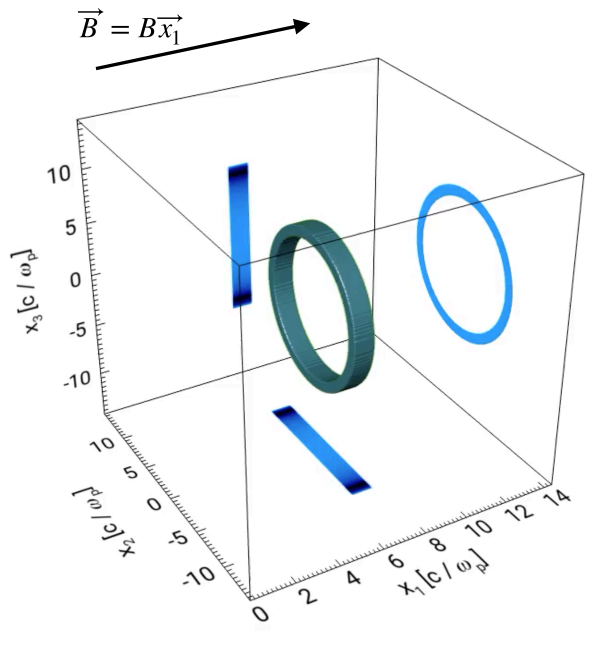
- In addition to reduced code development, it is still important to further increase the precision of full PIC codes (e.g. solve the NCI problem)
- Good practices: give all numerical details in papers and reports to allow for reproducibility and better acceptance
- Code development should be better recognised and funded in the context of current actives such as EuPRAXIA, AWAKE, etc

QED effects in reduced PIC simulations

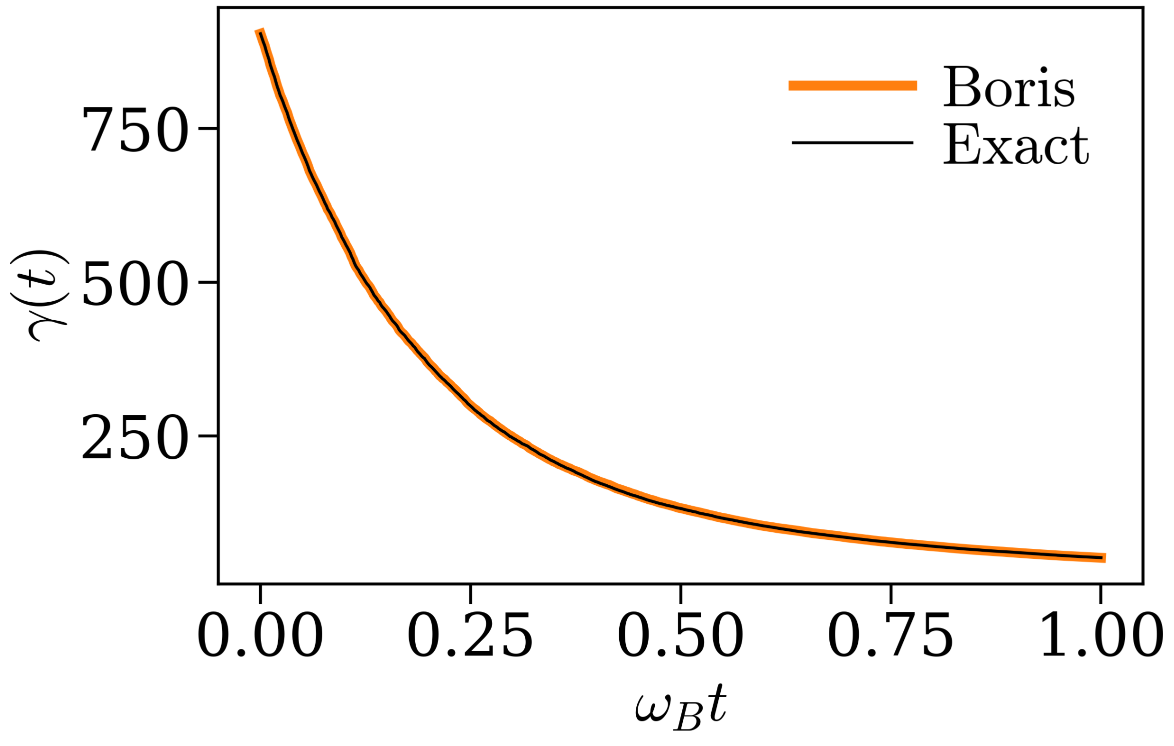
Bertrand Martinez

Exact quantum pusher

e^- rotating in a uniform B field



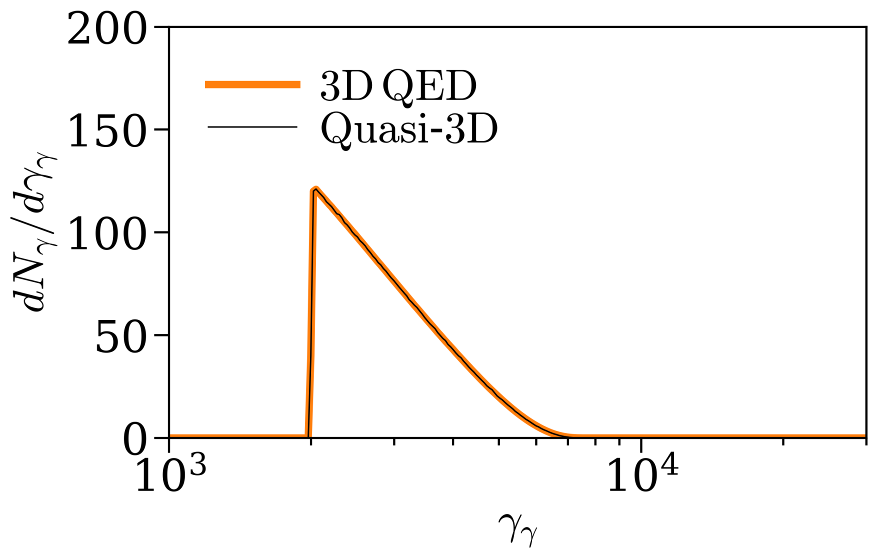
e^- energy for $\chi = 1$



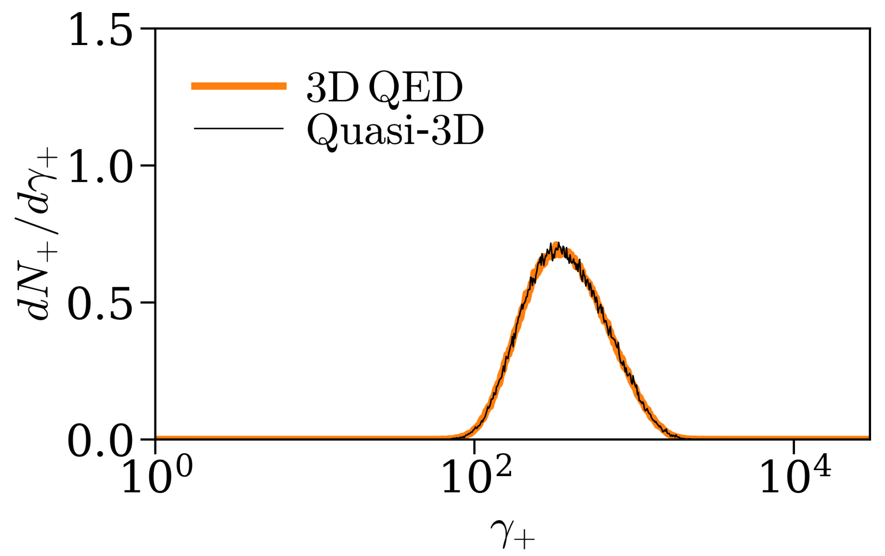
QED effects in Quasi-3D PIC

Quasi-3D simulations can be several orders of magnitude faster than full PIC

Energy spectrum of photons



Energy spectrum of positrons



Outlook

What future developments are needed ?

- Take advantage of new parallelisation methods (GPU, vectorisation)
- Particle pushers to handle high-amplitude fields
- Implement and handle more radiative/QED processes and particles

Does simulation/theory require its own roadmap ?

- Yes, multi-scale physics requires more developments
- It requires a roadmap, and also dedicated programs/fundings

Quasi-static PIC simulations

Severin Diederichs

TÉCNICO LISBOA

Motivation

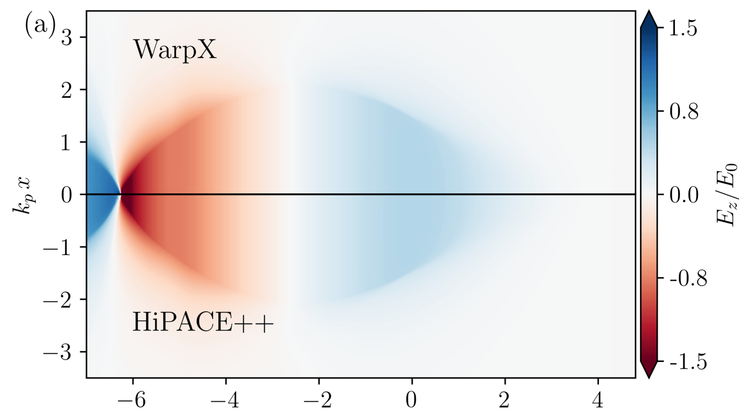
PIC simulations are **essential**
- validating experiments
- design studies
- new concepts

and ~~**affordable**~~

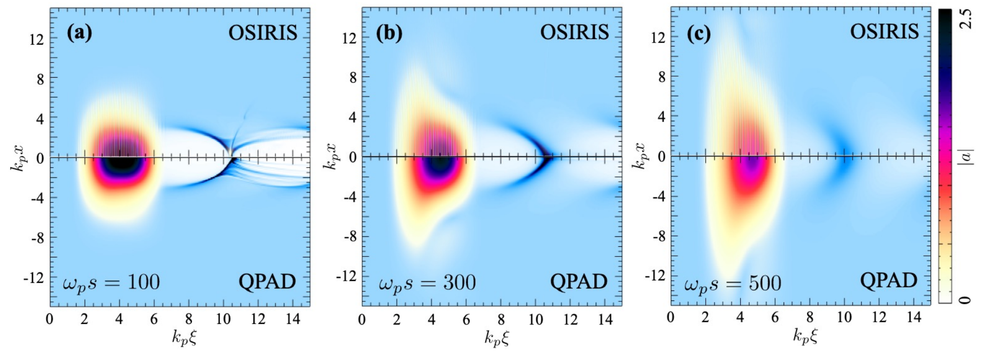
ESPP Accelerator R&D Roadmap including a "***feasibility study**, mostly theory and **simulation driven***"

at 190 GeV, with ≤135 nm emittance, and 833 pC charge

QED effects in Quasi-3D PIC



- Laser envelope solver[5]: $> 10^4$ **speedup**



Simulation costs must be reduced by orders of magnitude!

Outlook

1) Future developments needed and planned

Sustained, future-oriented code development needed: ***Open source, automated testing, community standards (openPMD), portability***
Focus on achieving roadmaps: ***mesh refinement***

2) Do the planned activities address the requirements from funded projects (AWAKE, EuPRAXIA, …) and from various roadmaps for plasma accelerators? Are there urgent holes?

Yes, simulation activities are designed to meet these requirements!

3) Does simulations and theory require its own roadmap or is work adequately driven/supported through funded projects and through overall plasma accelerator roadmaps?

***Yes**, otherwise we will soon need another "positron miracle"*

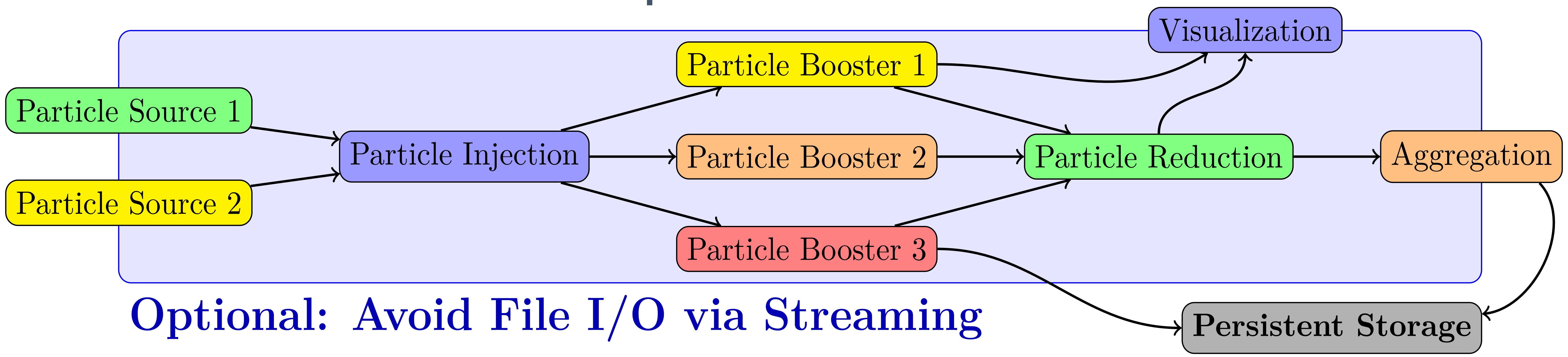
"The needs for simulating (…) nm emittance bunches (…) require further development in this area."

Adoption of common standards: OpenPMD

Franz Poeschel

TÉCNICO LISBOA

Particle accelerators are complex:



openPMD standard
for **p**article-**m**esh **d**ata
as communication layer

open PMD

Documents:

- **openPMD standard** (1.0.0, 1.0.1, 1.1.0)
  the underlying file markup and definition
  A Huebl et al., doi: 10.5281/zenodo.33624