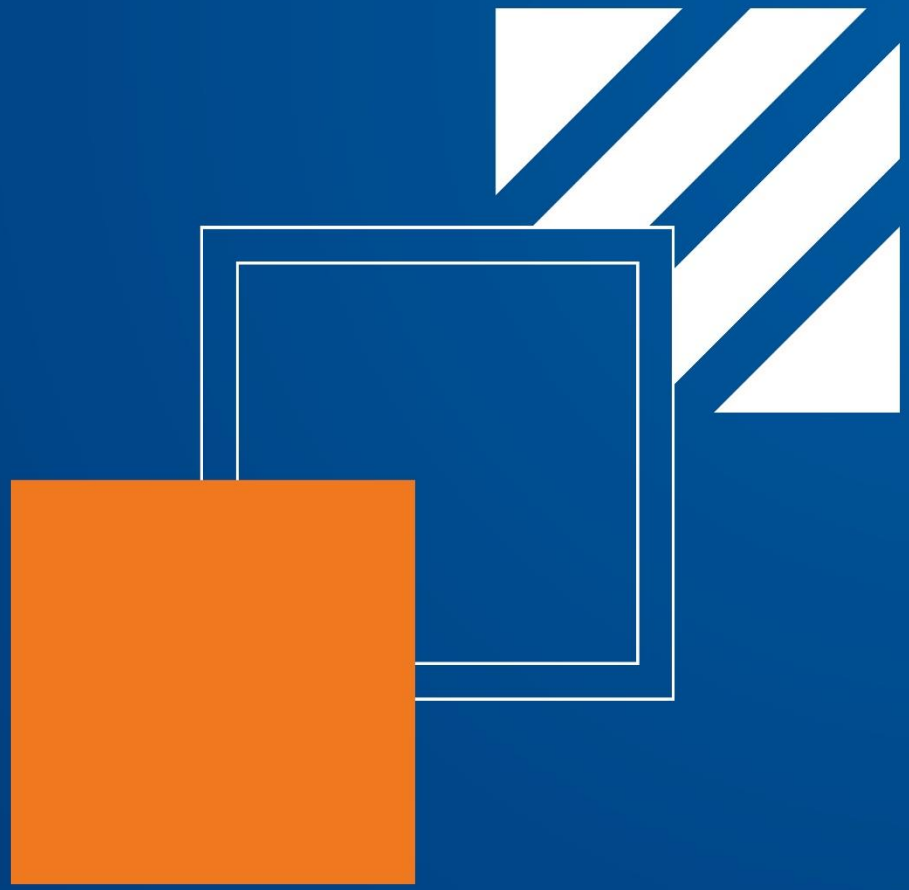
HELMHOLTZ Matter
MT DMA

HZDR
HELMHOLTZ ZENTRUM
DRESDEN ROSSENDORF

PIConGPU

Coupling HPC and AI for Laser-Plasma Simulations



Michael Bussmann · HZDR

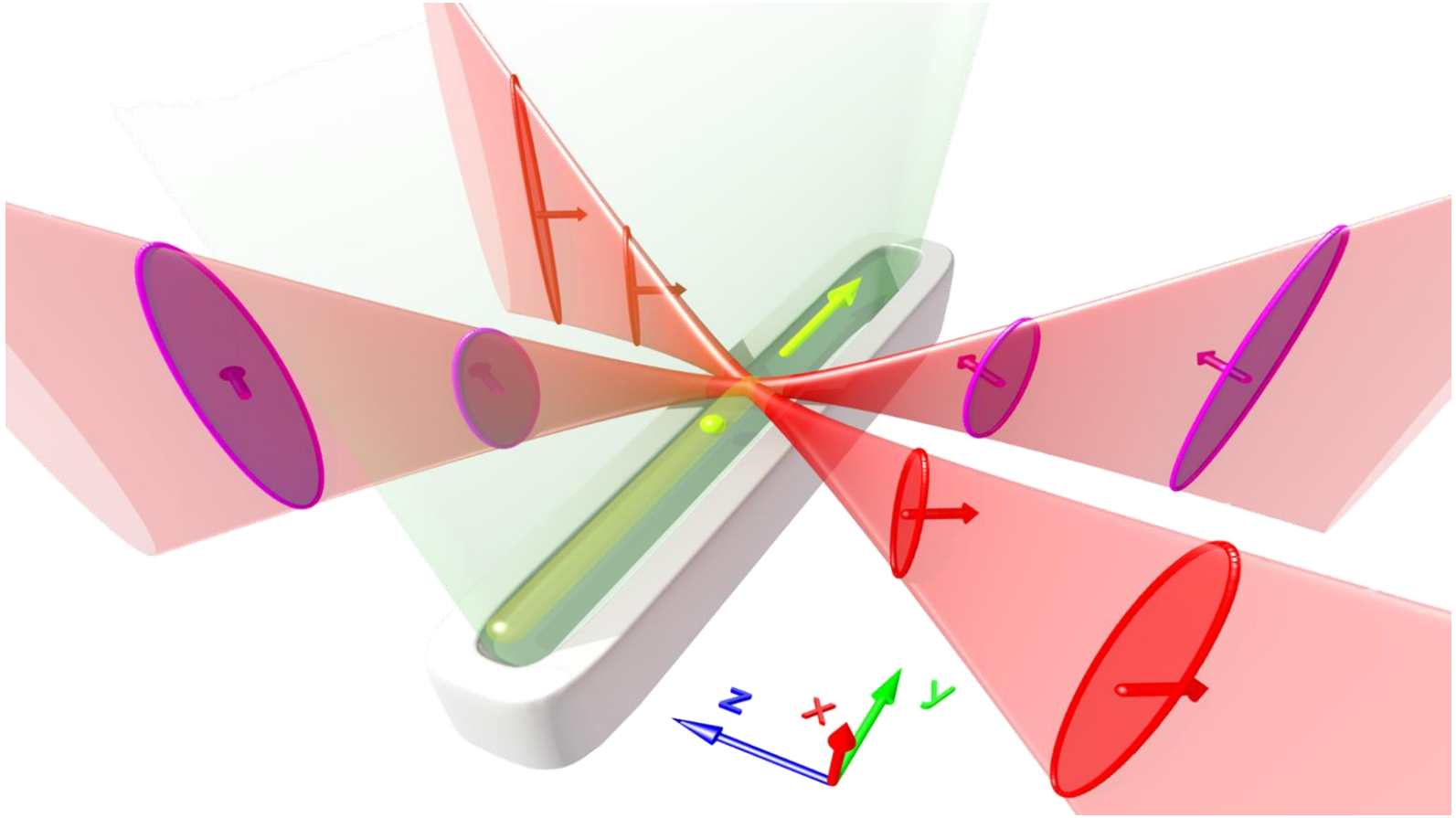
DRESDEN concept

TWEAC

Travelling **W**ave **E**lectron **AC**celeration

Travelling-Wave Electron Acceleration (TWEAC)

No dephasing, little self modulation



Travelling-Wave Electron Acceleration (TWEAC)

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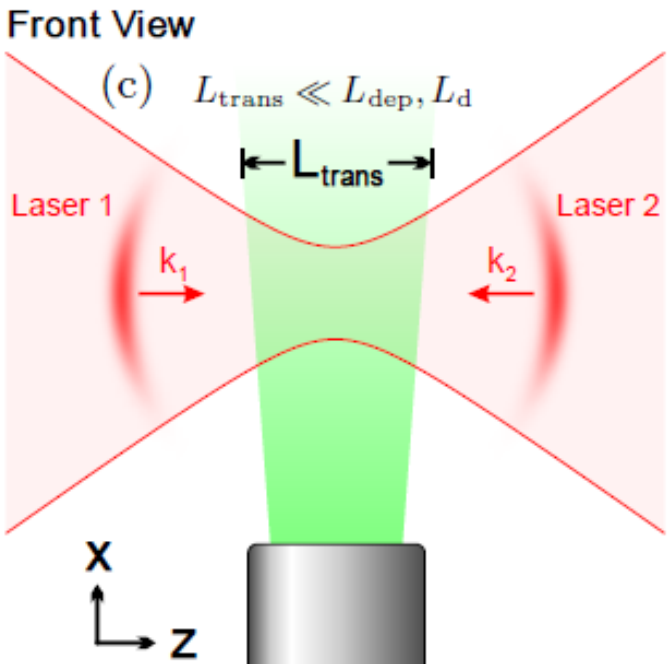

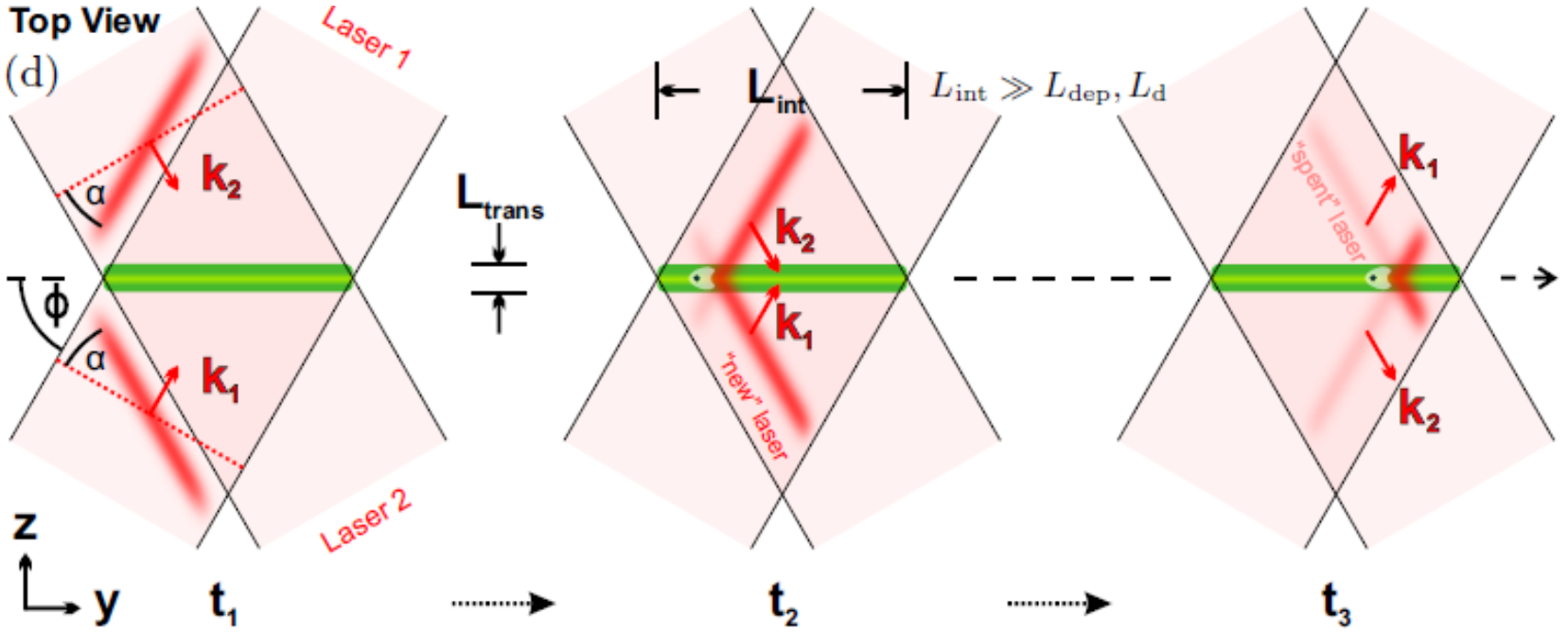

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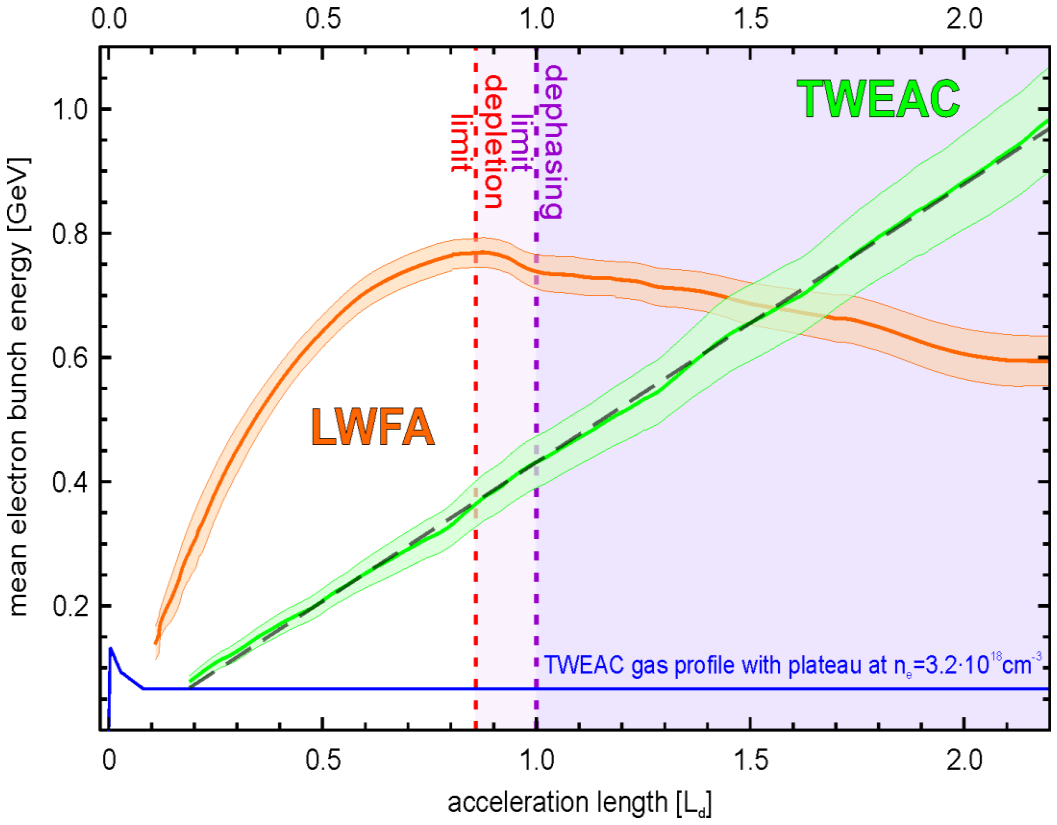

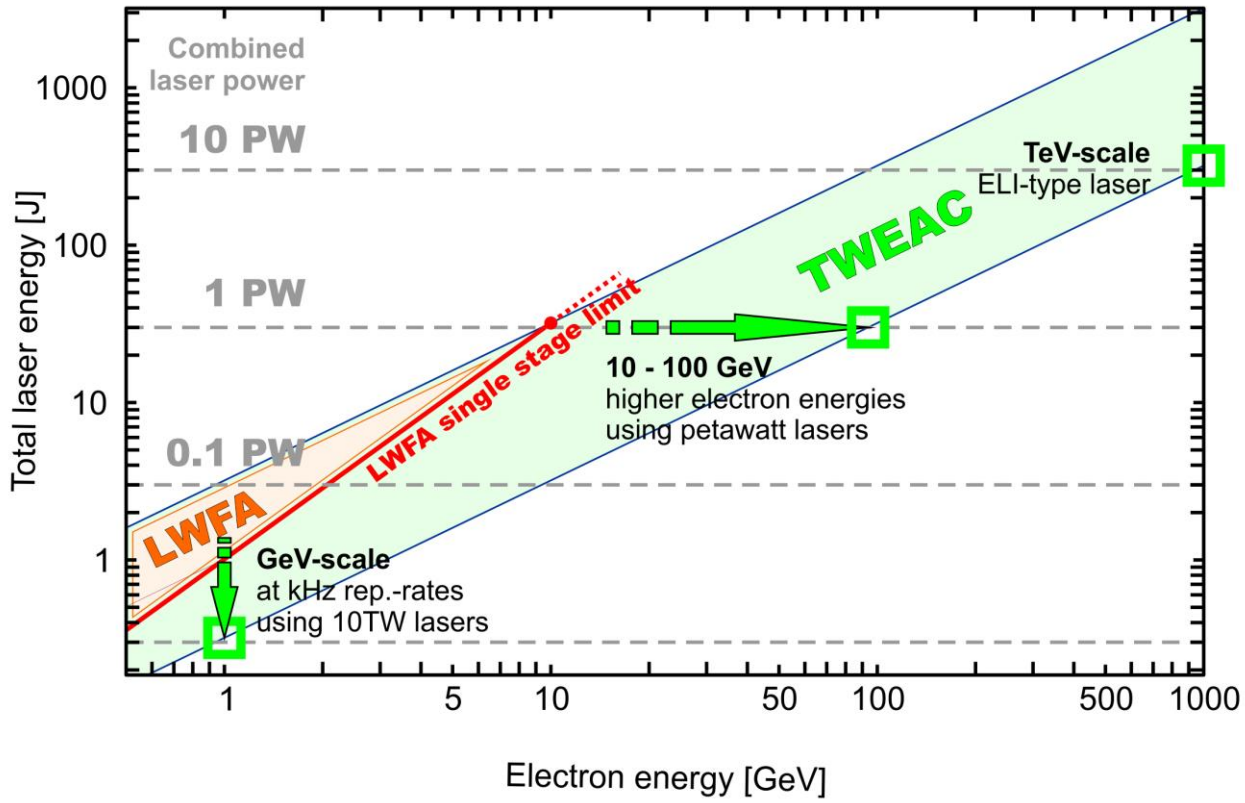

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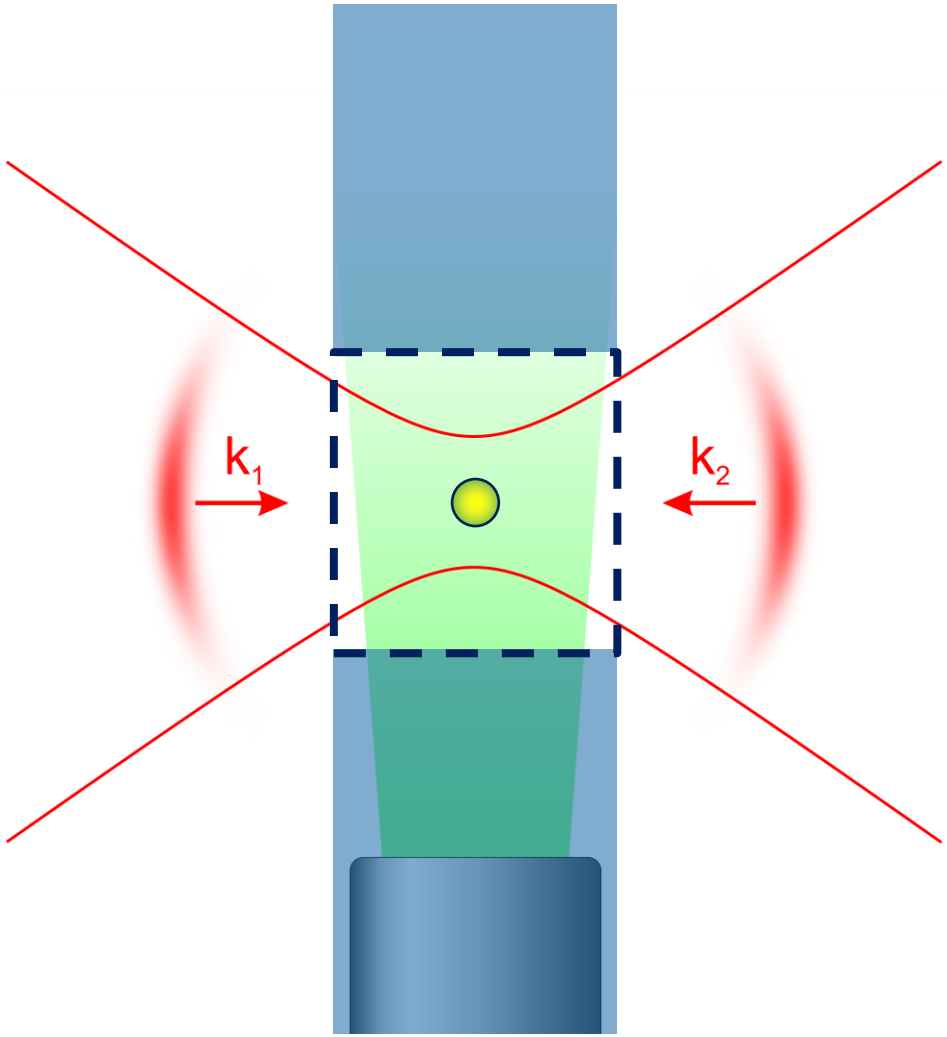
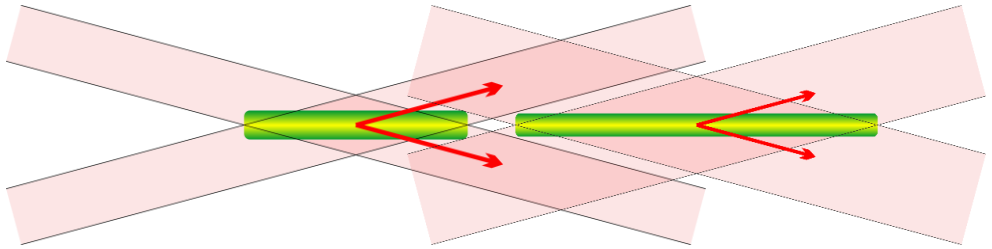


Strictly lateral, laser in- and out coupling

- ➔Stationary propagation distances to center of interaction. Geometrically enforces stationary acceleration conditions.
- ➔No geometric occlusion from gas nozzle or scrapers.
- ➔Reduces need to ionize an extended plasma volume compared to axial laser-coupling.
- ➔**Easier accelerator scaling:** Subsequent stages can be placed right after one another. Length of stages depends on available lasers.



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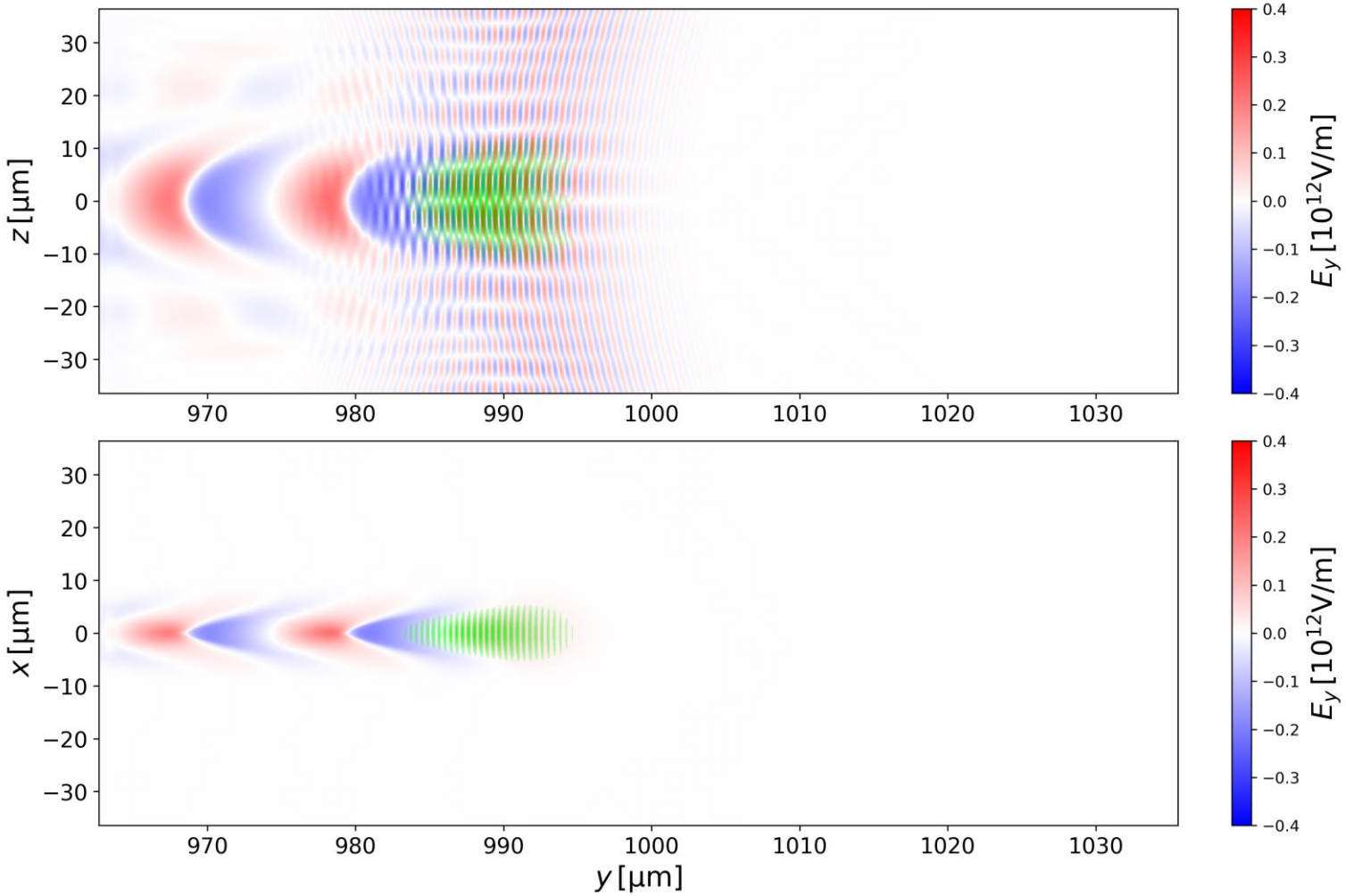
Travelling-Wave Electron Acceleration (TWEAC)

From LWFA to TWEAC Staging

Travelling-Wave Electron Acceleration (TWEAC)

EuroHPC-Application on JUPITER BOOSTER



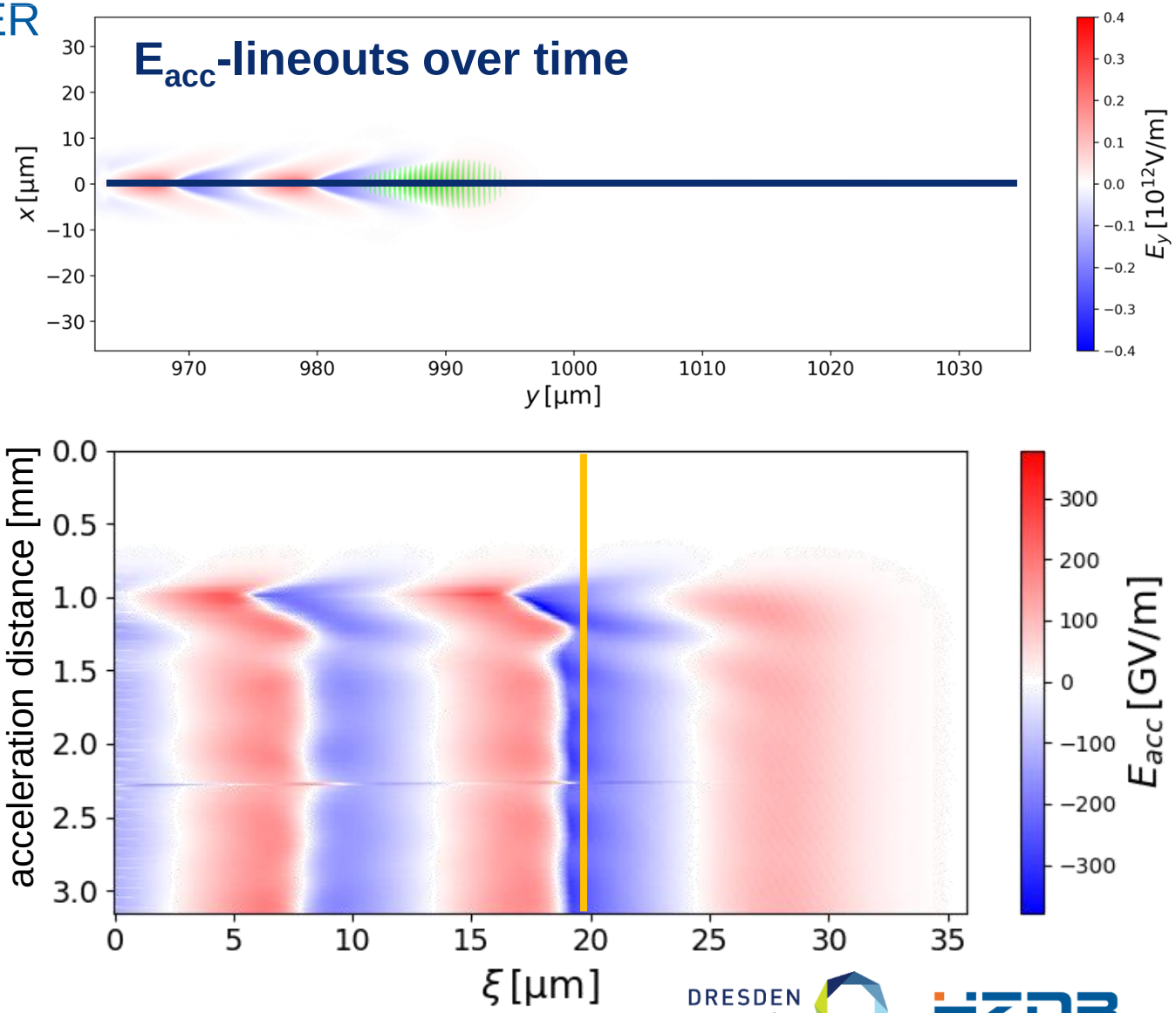
- Symmetric cavities also after extended simulation.
- Well-formed cavities without leaky-modes or parasitic injection.
- Transversely narrow cavities <20µm.
- Nonlinear wakefields with acceleration gradients of >200 GV/m and linear focusing fields.

Travelling-Wave Electron Acceleration (TWEAC)

EuroHPC-Application on JUPITER BOOSTER

- Field reaches steady-state in accelerating field after 0.75 mm and remains constant far beyond LWFA dephasing and depletion lengths.

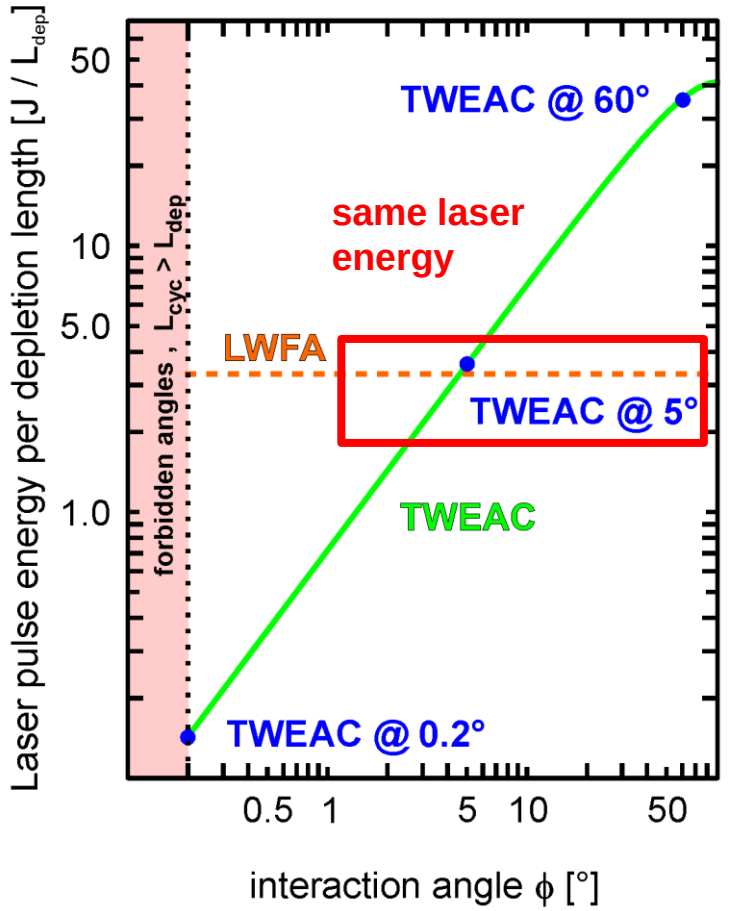
- Some reflections from boundaries still exist
  → Need to further reduce PML reflections.



Travelling-Wave Electron Acceleration (TWEAC)

Exascale LWFA simulations

- High-density plasmas have more pronounced plasma dynamics on **smaller spatial and shorter time scales**.
- Greatly **reduces simulation time** for exploring the regime.
- Benefits on controlling dephasing, depletion and diffraction are seen earlier.
- **Experimental perspective** of proof-of-principle experiments by **lower laser energy requirements**.
- Speeds up learning curve by **exposing potential problems** earlier, such as blowing up plasma dynamics, code numerics or both.

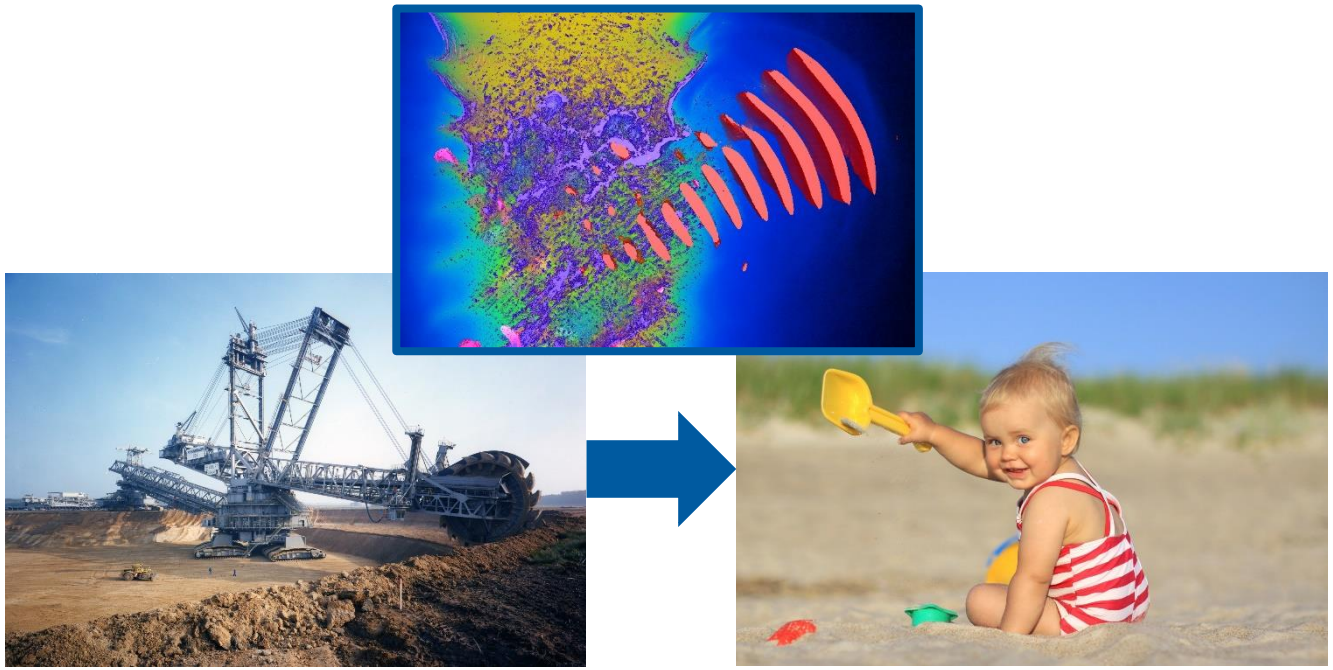


HPC + AI

Optimizing for applications, democratizing HPC simulations

Data storage is a thing of the past!

Data rates become too high, volumes too large for storage



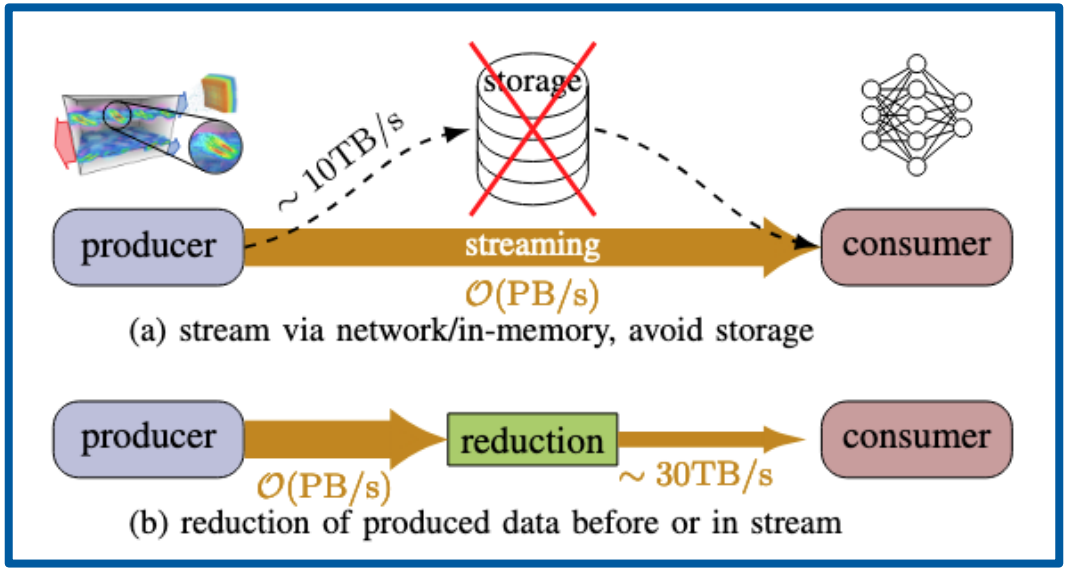
0.6 PetaByte / s

0.1TB/s GPU to GPU 16GB/s internode

file System: 679 PB

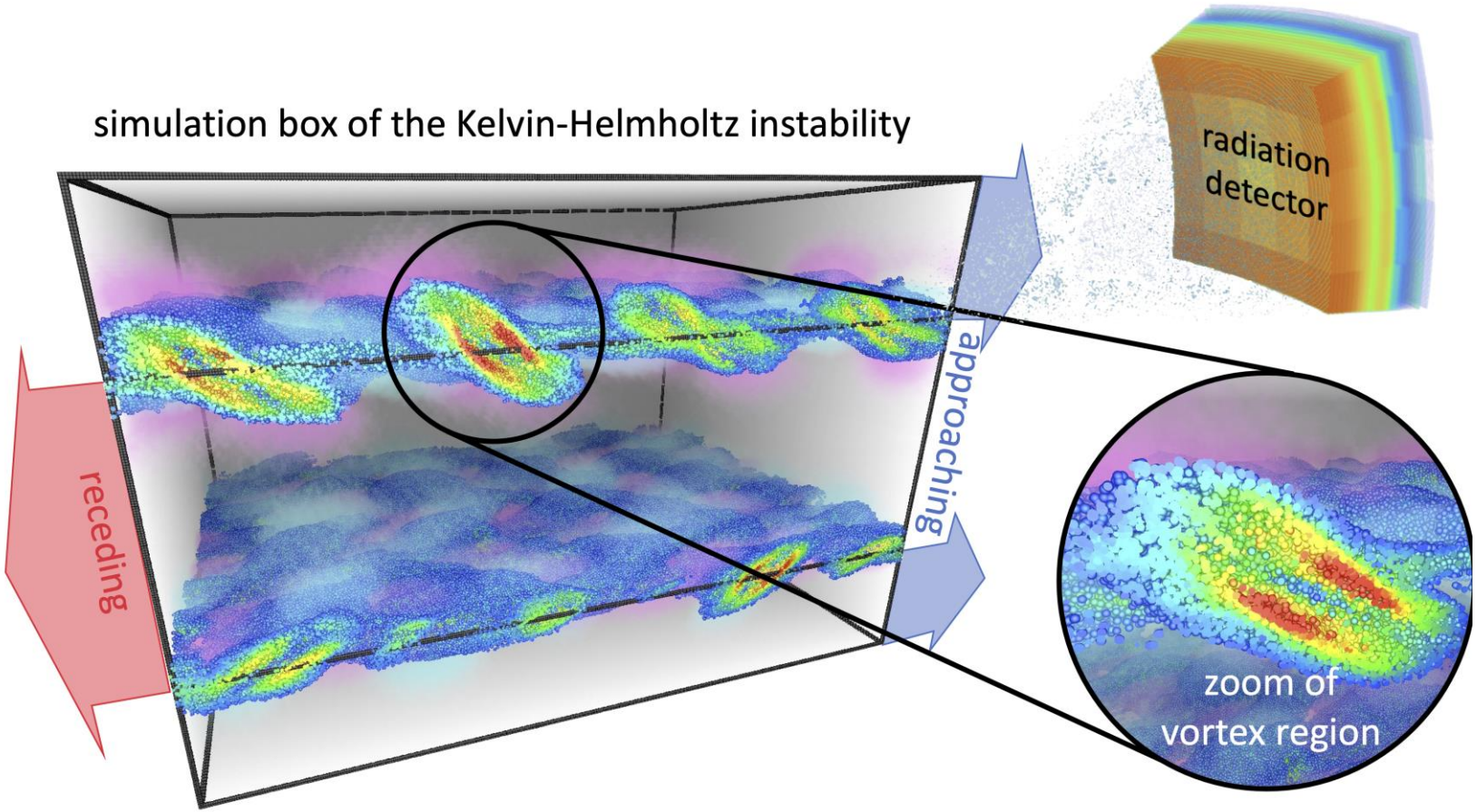
full in 100s

but simulation runs longer



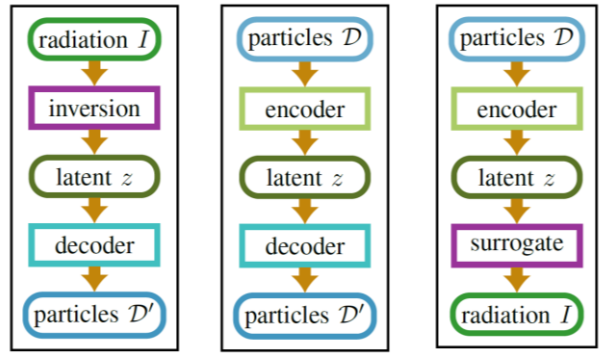
Coupling HPC with AI training at Exascale

Training of a large-scale invertible AI model with streaming simulation data



Train neural networks for:

- Forward problem:
  particle to radiation
- Compression:
  particle to particle latent space
- Inverse problem:
  radiation to particle



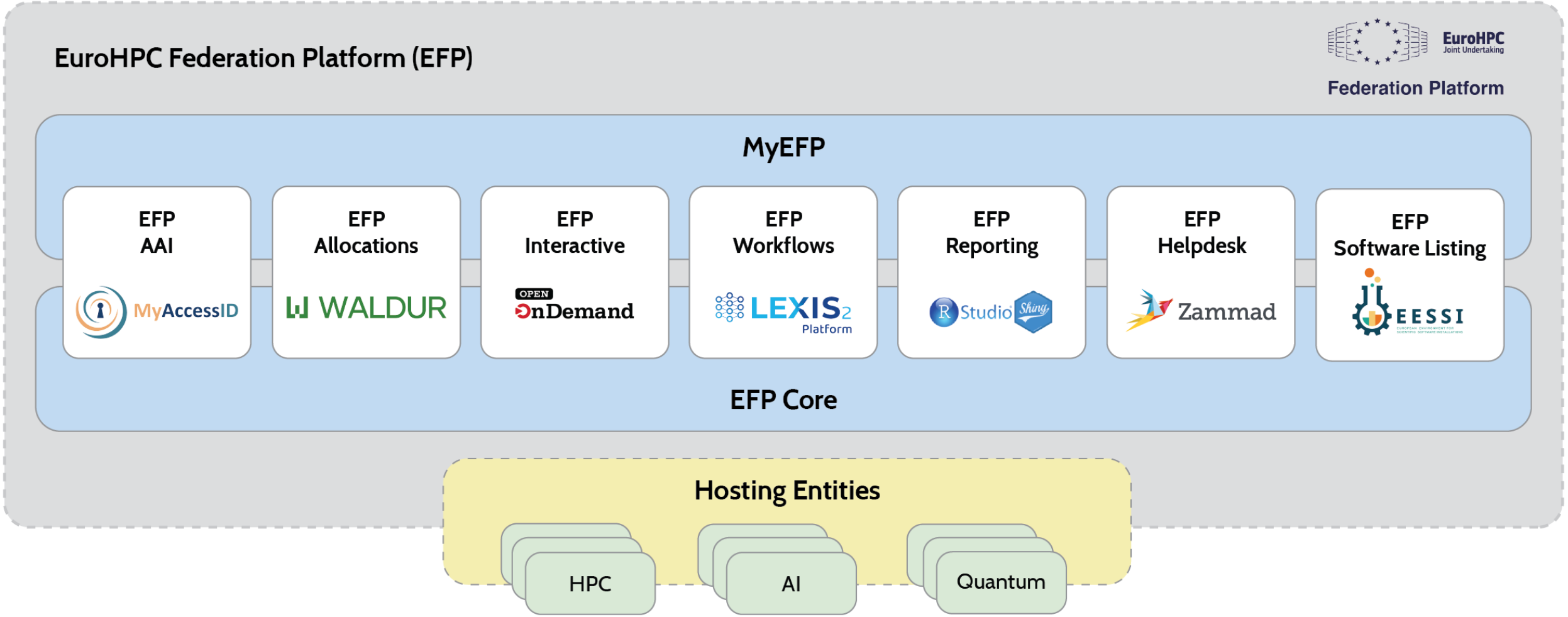
(a) inversion of physical reduction

(b) compression – decompression

(c) physical forward prediction

EuroHPC deployment and standardization

Why do we still use the shell? Ah, because OpenOnDemand DOES NOT HAVE A REST-API!!!



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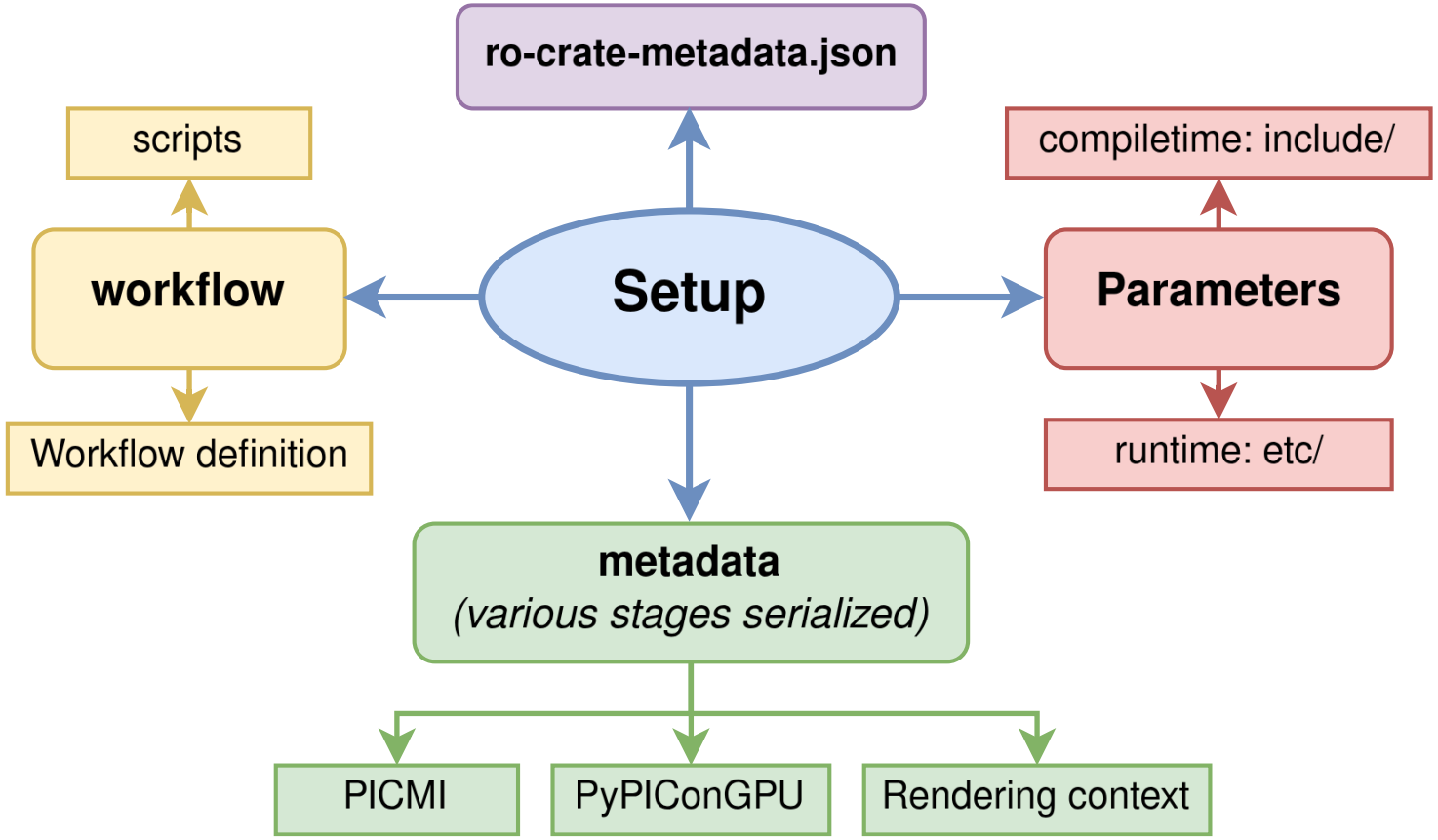
EuroHPC deployment and standardization

The power of standardization and interoperability

Input	Output	Metadata	Workflow
PICMI	openPMD	ro-crate	CWL
4 HPC PIC codes	18 Simulation codes + 11 visualisation tools + general HDF5/ADIOS tools	51 tools + 39 use cases	14 engines

EuroHPC deployment and standardization

Include all (meta)data relevant for defining and executing a simulation




```python
from picongpu import picmi

sim = picmi.Simulation(
    time_step_size=9.65531e-14,
    max_steps=1024,
    solver=picmi.ElectromagneticSolver(
        method="Yee",
        grid=picmi.Cartesian3DGrid(...)
    ),
    ...
)

sim.run()
```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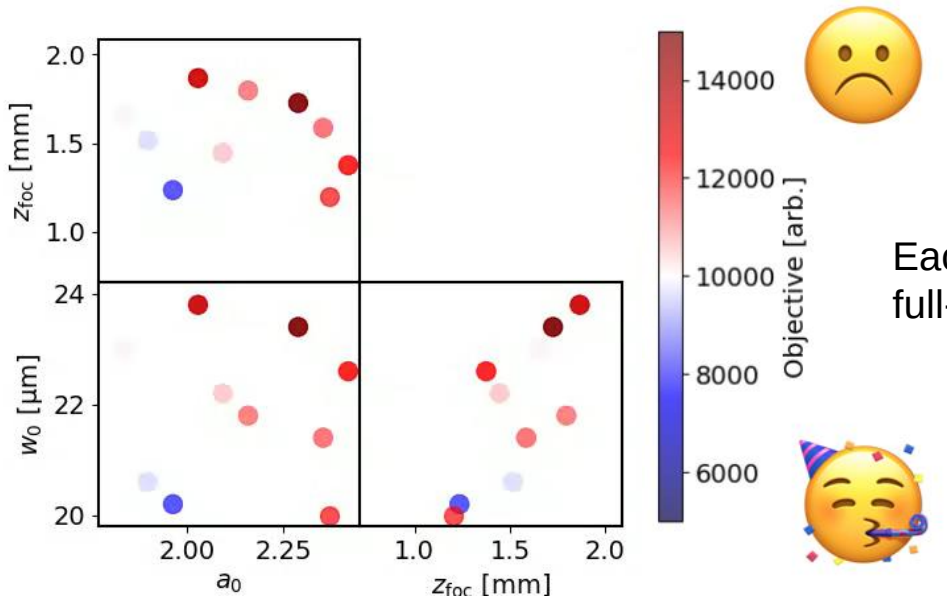
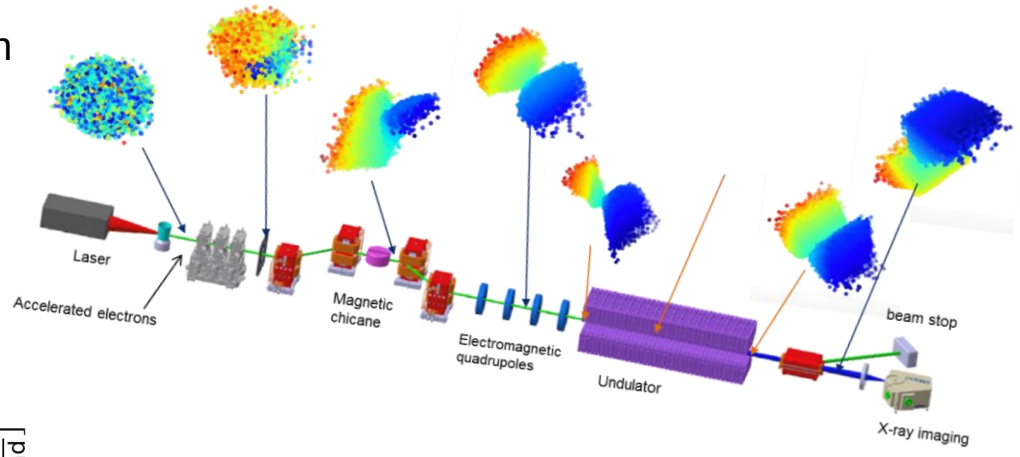
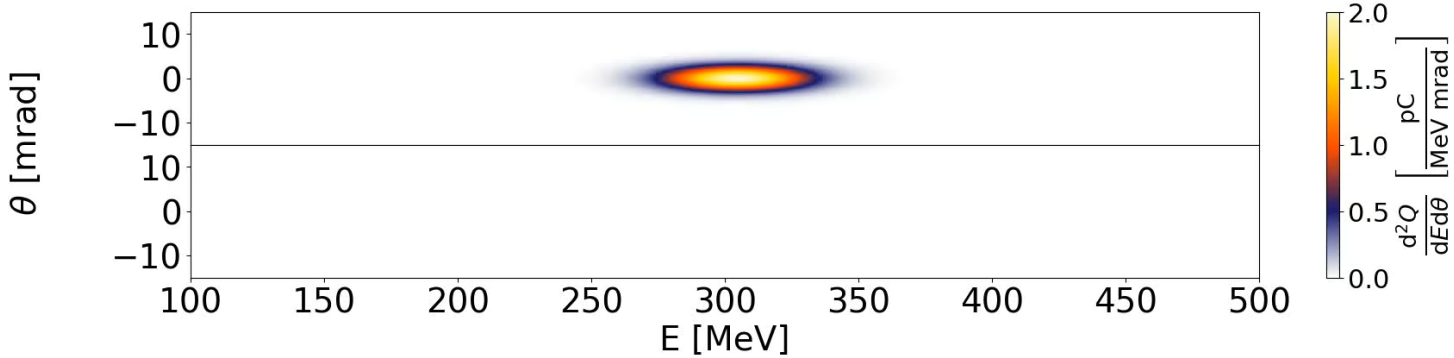
World models combining experiment and simulation

Digitalization of facility operation and experiments: Campaign-driven optimized operation



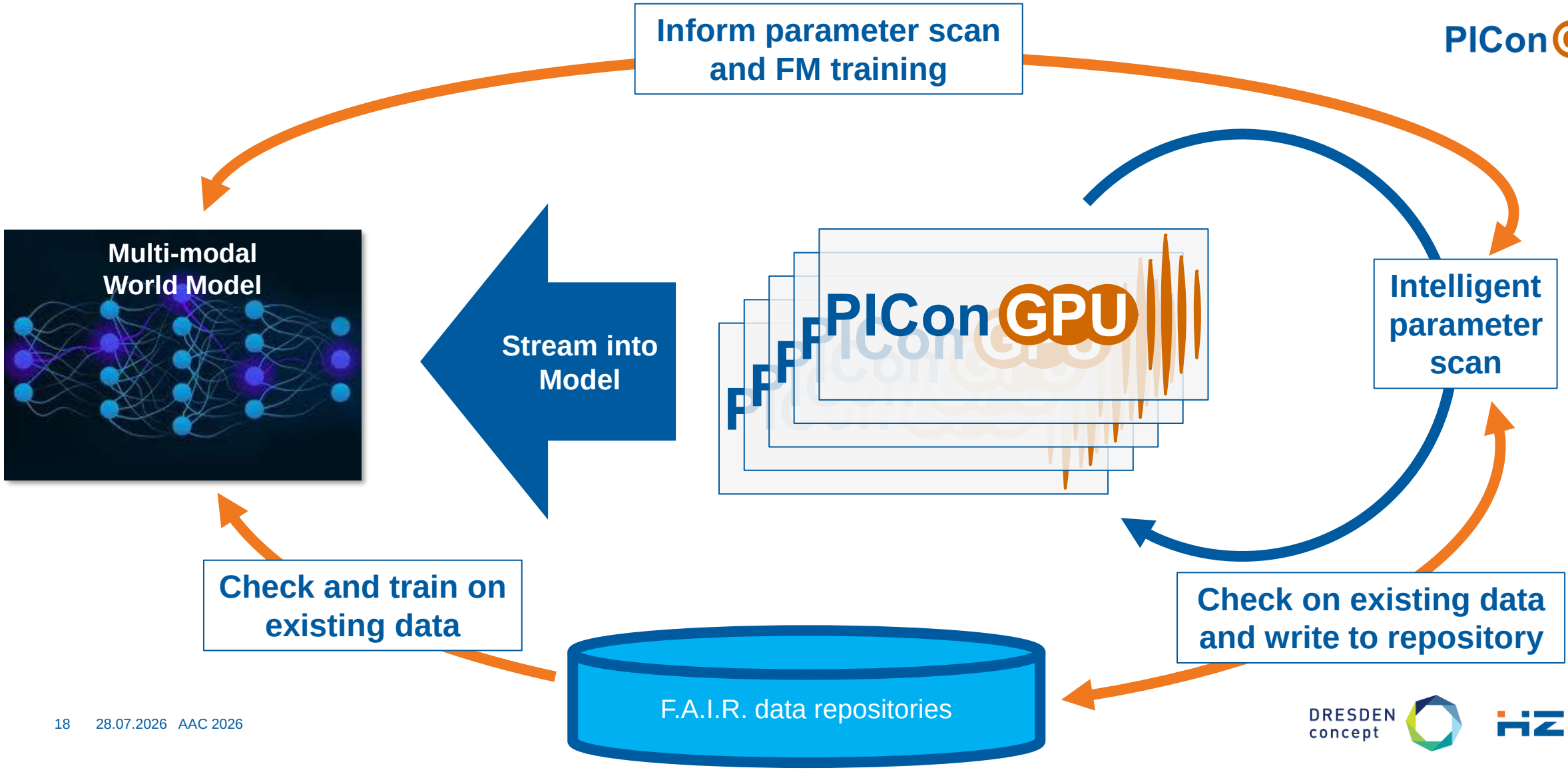
Each dot represents a full-scale HPC simulation





Online training of streaming data @ Exascale

Why use files when you have neural networks?



Frontier computing for frontier science

Joining forces in Europe, bringing together magnetic and laser-driven fusion

EuroHPC Center of Excellence for Plasma Simulations PLASMA-PEPSC

- Brings **laser fusion and magnetic fusion** community together
- Common modeling efforts for atomic physics, looking at **plasma-wall interaction** (magnetic fusion) and **radiation transport** (laser fusion)

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