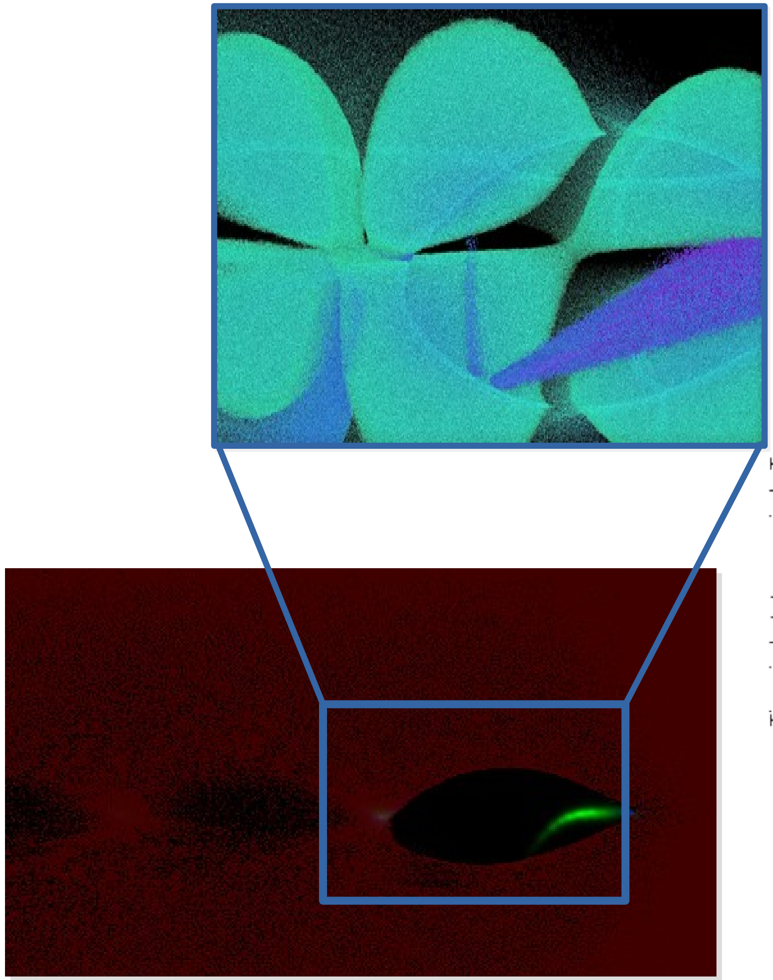

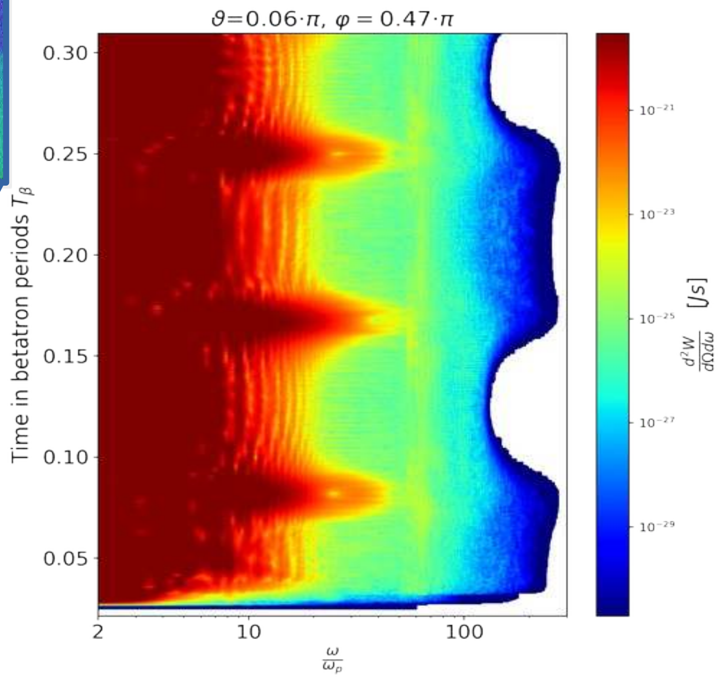

Radiation of the Hosing Instability

Preliminary Results

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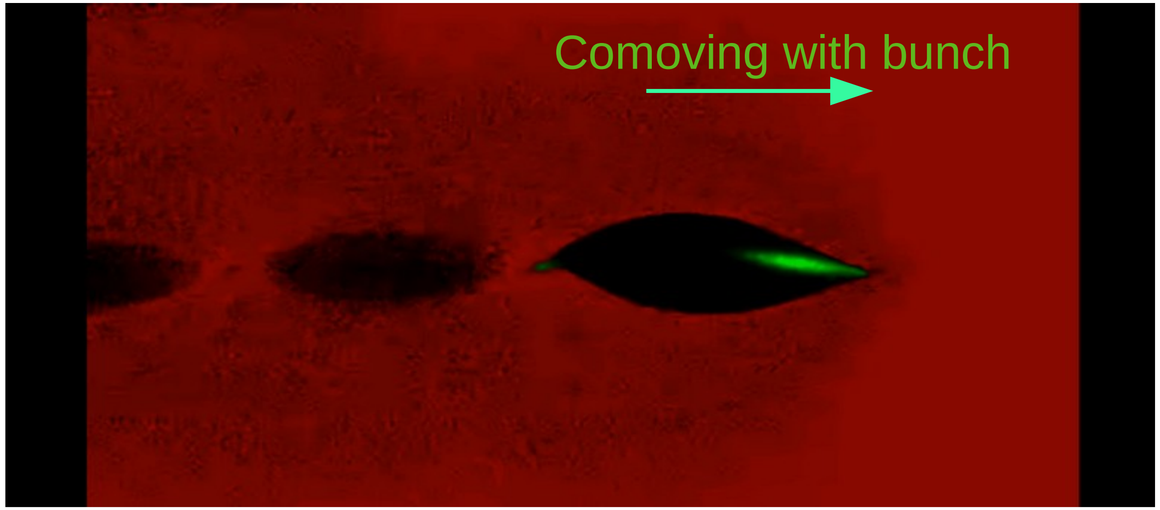
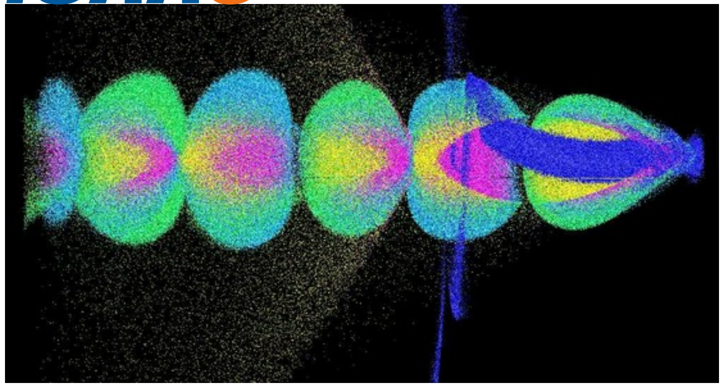
A particle cloud entering a plasma at an angle during PWFA will oscillate like a fire-hose until it breaks up

Can we characterize the process using only emitted radiation?

Goals:
- Diagnose occurrence of instability from its radiation
- Characterize the instability using the radiation signature.



ISAAC



Occurrences:
- Asymmetric particle clouds impacting a plasma [1]
- Particle jets in astrophysics [2]

[1] „*Direct Observation of the Hosing Instability of a Long Relativistic Proton Bunch in the AWAKE Experiment* “, M. Hüther, **PhD Thesis TU München, 22.12.2020**
[2] „Wave emission of non-thermal electron beams generated by magnetic reconnection“, Yao et. al. **arXiv 2107.13746v3**

Tools of the trade – PIC simulations with in-situ radiation computation

PIConGPU

Explicit 3D FDTD particle-in-cell simulation code [3]

Requires only Maxwell equations and the Lorentz force to evolve the system

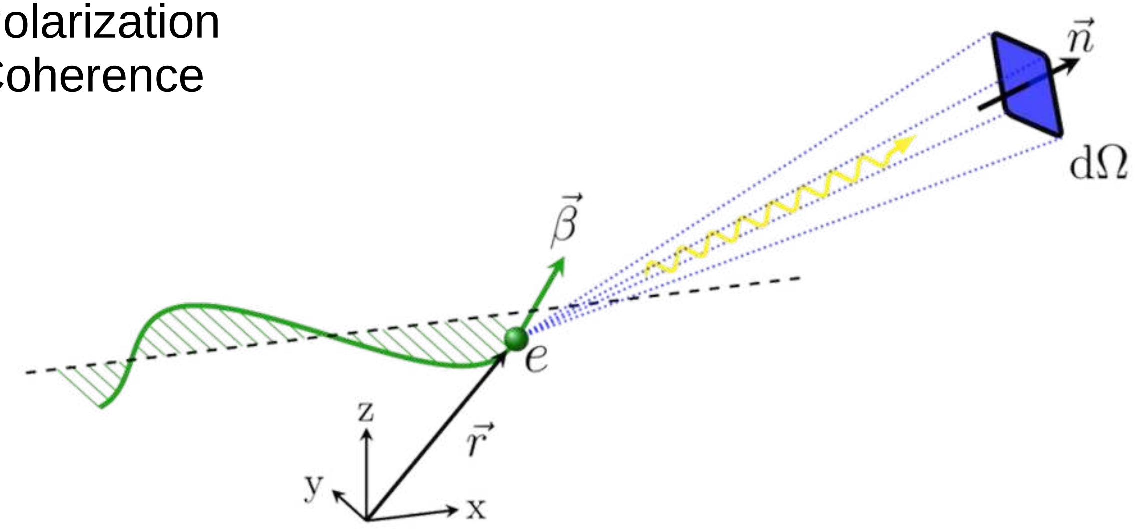
Makes no assumptions about symmetry or process time scales

$$\frac{d^2W}{d\omega\, d\Omega}(\omega,\vec{n}) \sim \left| \sum_{i=1}^{N_p} \int \frac{\vec{n}\times[(\vec{n}-\vec{\beta}_i)\times\dot{\vec{\beta}}_i]}{(1-\vec{\beta}_i\cdot\vec{n})^2} e^{i\omega(t-\vec{n}\cdot\vec{r}_i/c)}\, dt \right|^2$$

Radiation spectrum computed using Fourier transformed Lienard-Wiechert fields.

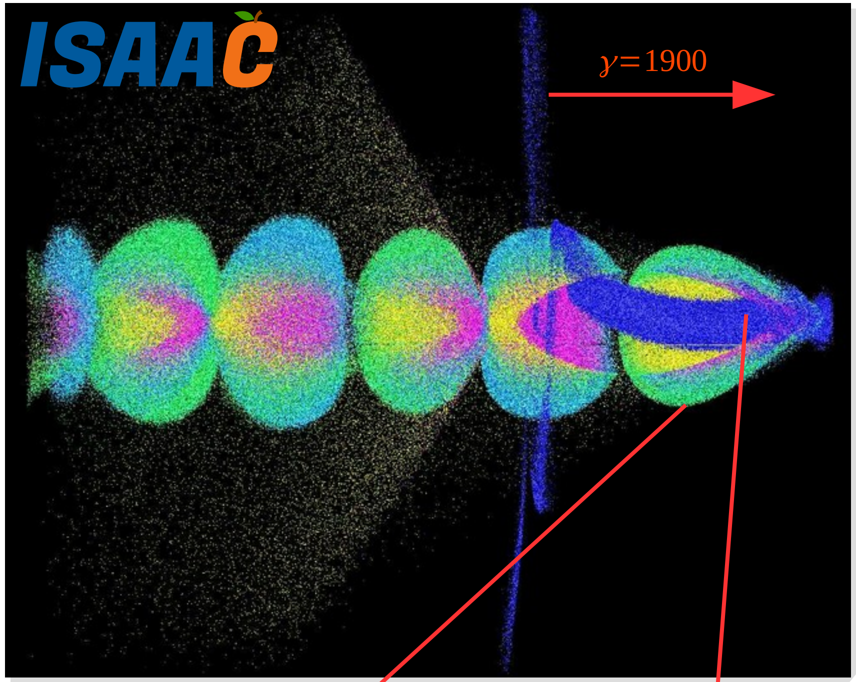
Capturing **amplitude and phase** information

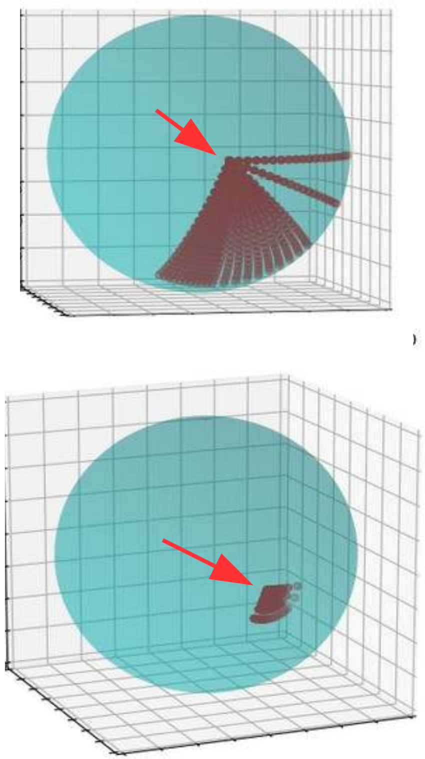
- Polarization
- Coherence



[3] *„Radiative Signatures of the Relativistic Kelvin-Helmholtz Instability“*,Bussmann et. al. In **Proceedings of the International Conference on High Performance Computing, Networking, Storage and Analysis**

The case considered isolates the hosing instability simplifying the analysis of radiation





$n_p = 4 \cdot 10^{24} [m^{-3}]$

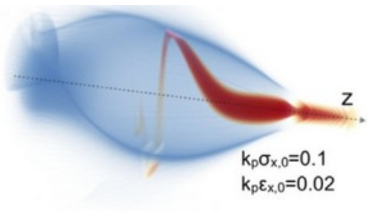
$n_b = 30 \cdot n_p$

$E_{th,b} = 0.5 [keV]$

Competition to be eliminated**:**

self-modulation instability [4]

Set-up guided by prior work [5]

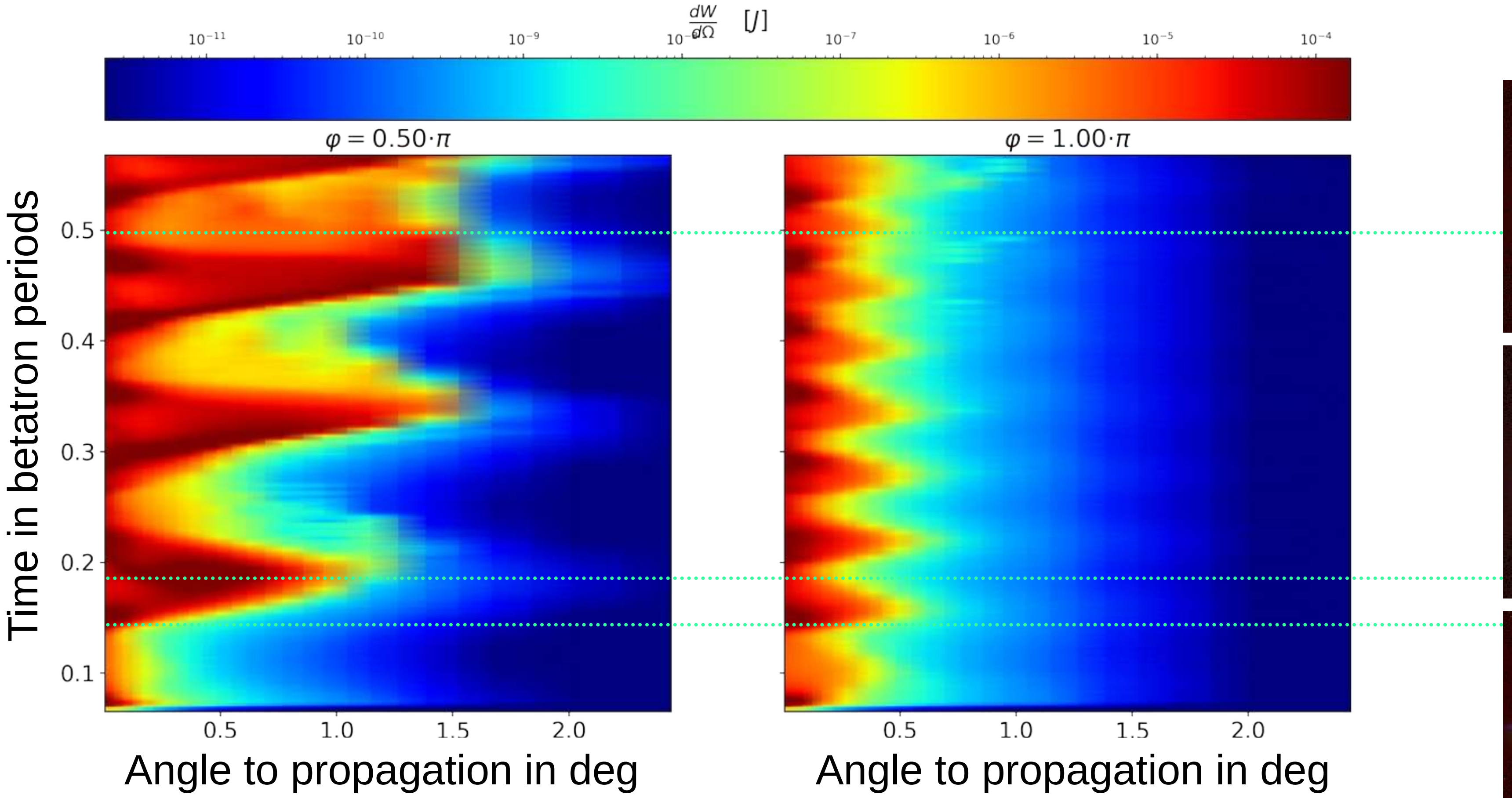


One simulation:

- 10^9 simulation particles
- 10^3 frequencies
- 440 radiation detectors
- *Runtime:* 6 days on 128 A100 GPUs

[4] „*Hosing Instability Suppression in Self-modulated Plasma Wakefields*“ Vieira et. al., **PRL 112, 205001**
[5] „*Stabilization of the Drive Beam in Plasma-Wakefield Accelerators*“, de la Ossa et. al. **PRL 121, 064803**

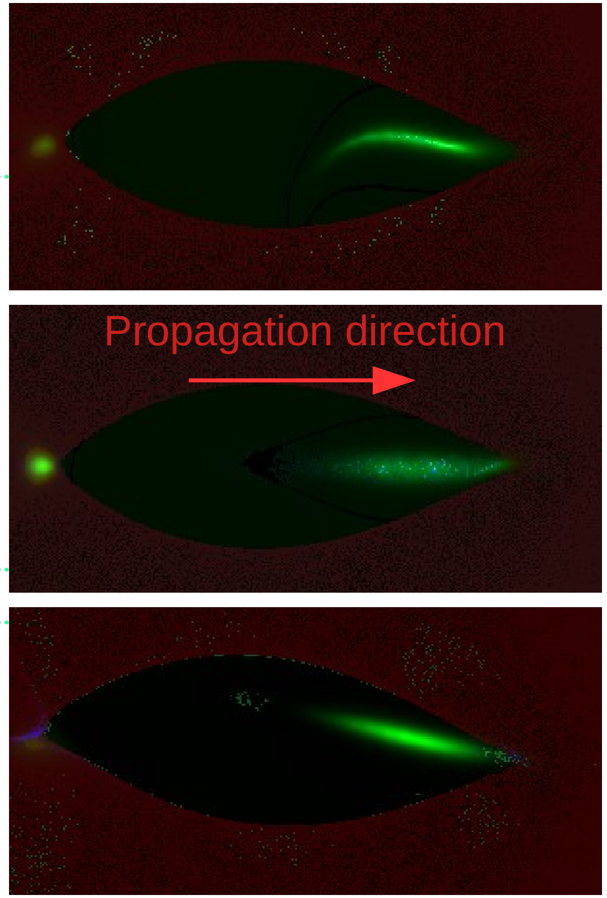
A hosing bunch produces γ - radiation bursts from bunch contractions at angles above $1/\gamma$



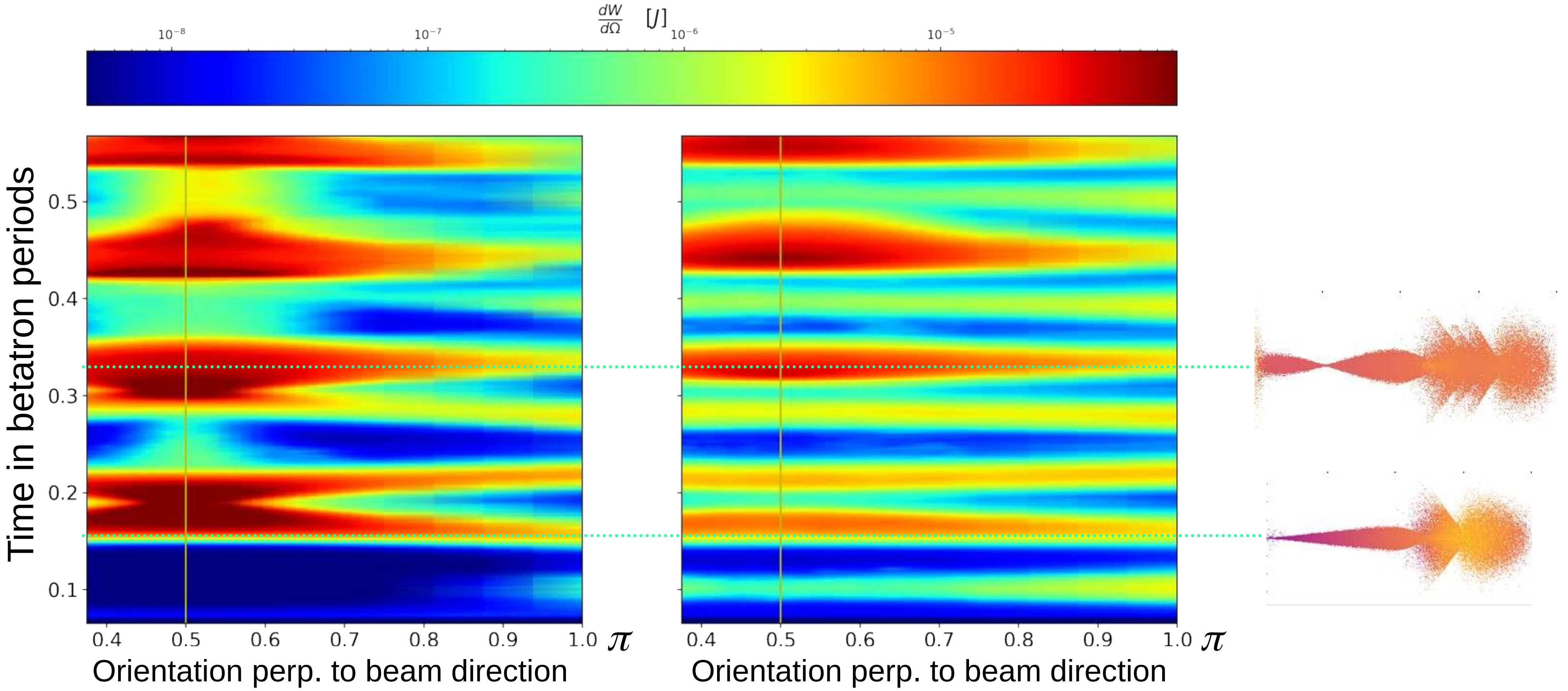
In oscillation plane

Perpendicular to oscillation plane

Bunch density in oscillation plane



Hosing modulates the amplitude of γ radiation of the bunch in plane and extends the maxima

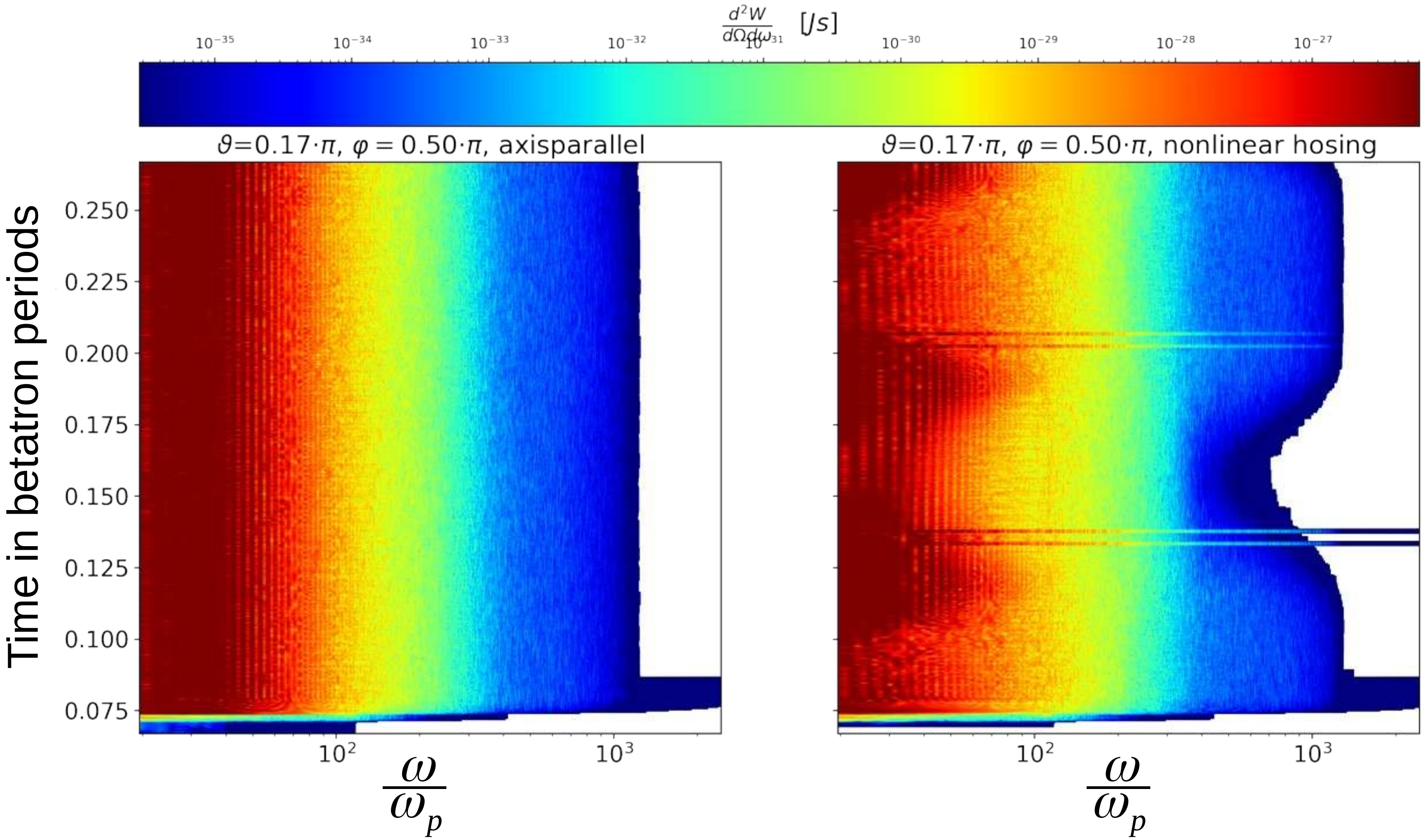


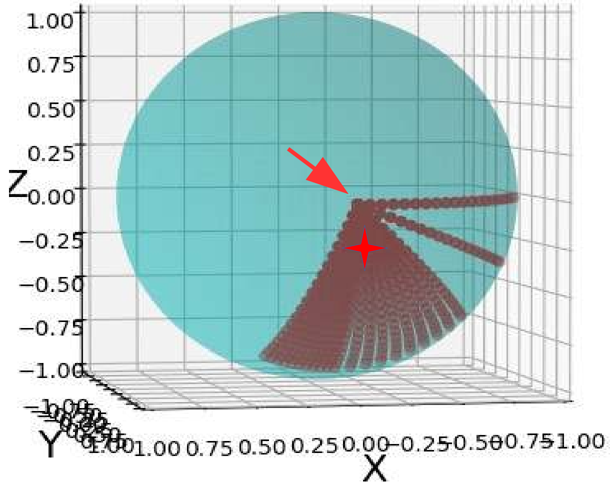
15 ° tilted bunch

4° tilted bunch

Bunch modulation

If a bunch is tilted the background plasma radiation is suppressed periodically

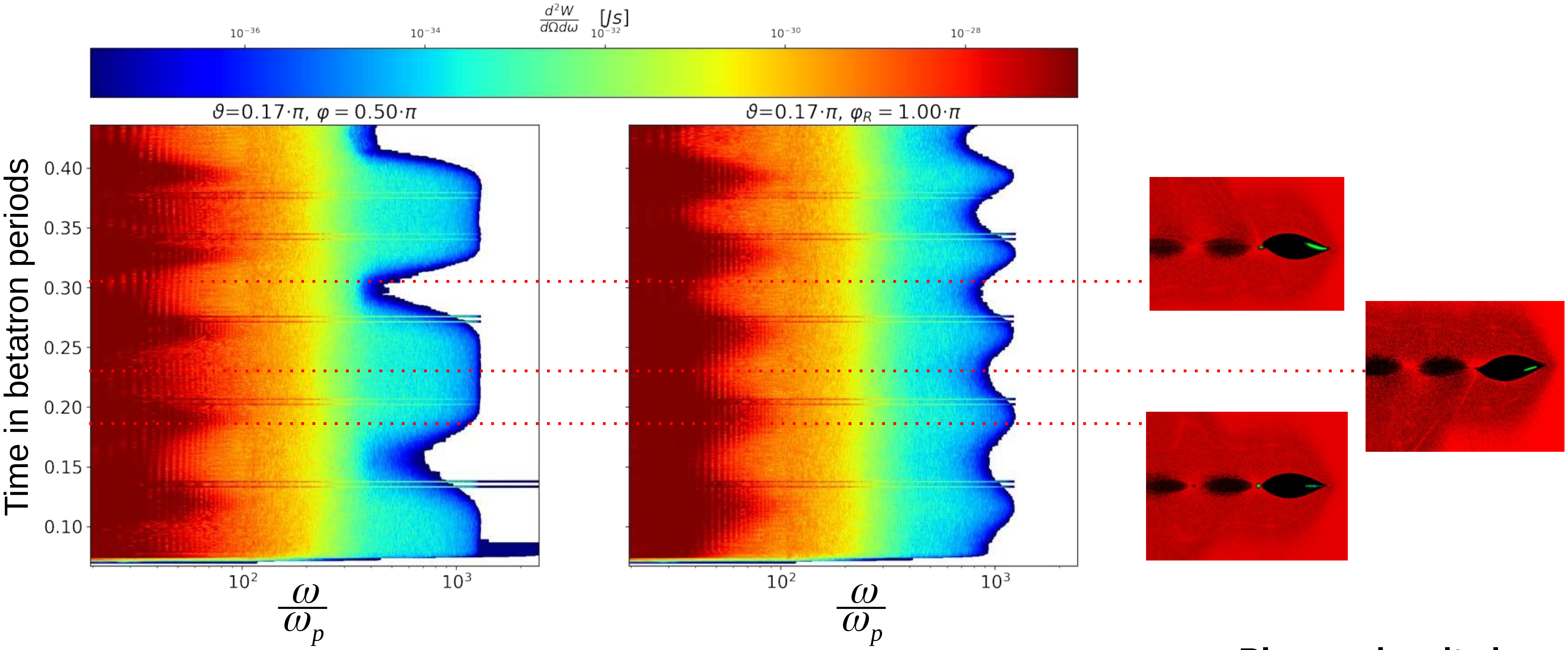




Axisymmetric bunch

15 ° tilted bunch

Hosing can be identified by comparing high-frequency ends of the spectra of two perpendicular detectors

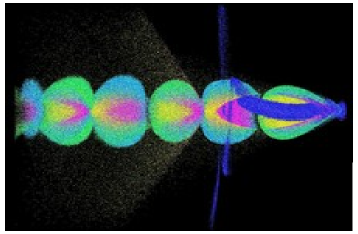


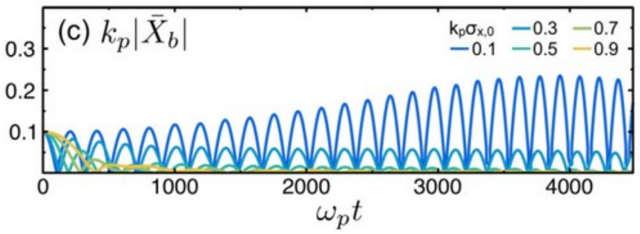
In oscillation plane

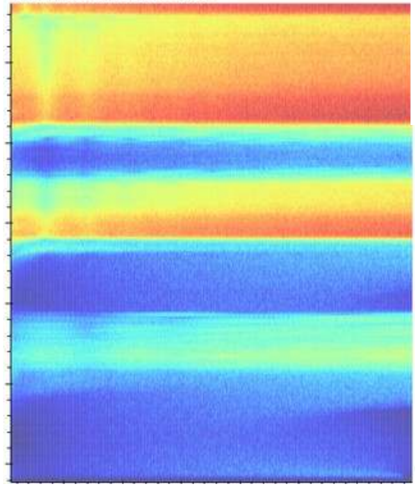
Perpendicular to oscillation plane

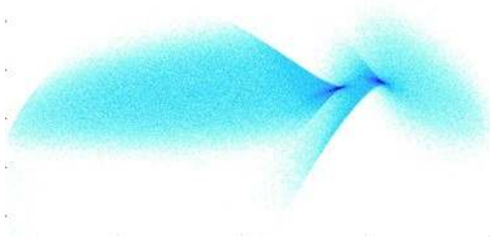
Plasma density in oscillation plane

Outlook









Ongoing information extraction from obtained radiation and particle data

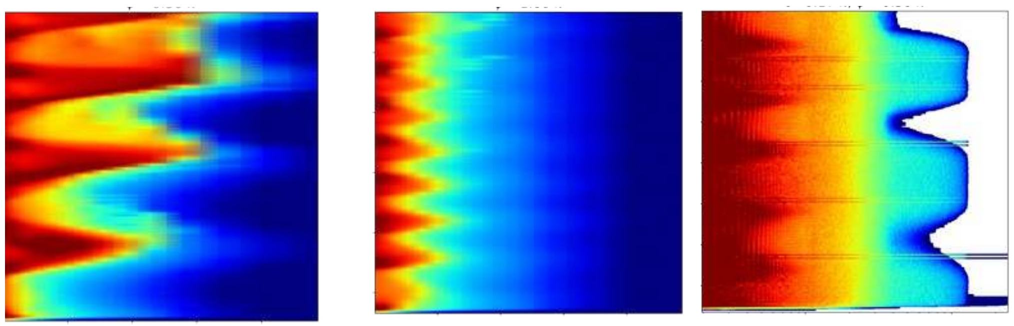
Formulation of the theoretical description of the radiation of the hosing instability

Refinement of existing simulations to capture further spectral features

Consideration of the self-modulation instability, which is in direct competition with the hosing instability

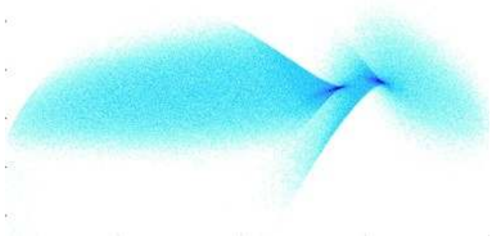
Experimental feasibility analysis

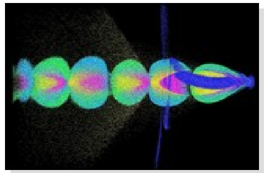
Summary



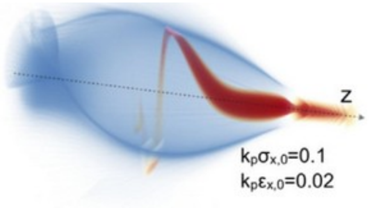
Obtained first ever synthetic radiation characteristics of the hosing instability

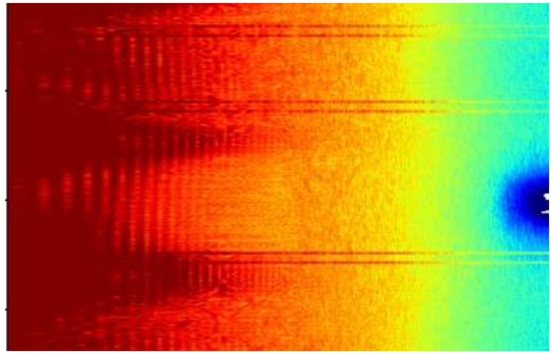
Confirmed the existence of a competing structuring process requiring explanation





Qualitatively confirmed prior results by ab-initio simulation





Require further simulations to obtain a finer resolution of spectral features

Our goal is to determine radiation signatures of the hosing and other instabilities

The large dynamic range of the radiation shows effects on multiple time scales