Beam hosing - pseudophysical effects in simulations

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Pseudophysical effects

Pseudophysical effects are caused by nonphysical effects, but mimic or couple to physical effects.

For example: Numerical artefacts may introduce additional simulation noise. This nonphysical noise can act as a seed for hosing, which then grows in a physical way.

Untangling the two is difficult.
Characterising Hosing

We “see” hosing in density-step simulations (carried out at low resolution)

Can we attach a number to this?
Characterising Hosing

No density step
Characterising Hosing

With density step
Characterising Hosing

Beam centroid alone is misleading
Characterising Hosing

Beam centroid alone is misleading

Spot size $\sim q/\sigma_x \sigma_y$ – statistical measure of current density
Characterising Hosing

Turns out, hosing without step is comparable!

Main difference is bunch charge
Characterising Hosing

Effect grows from noise
Effect grows from noise – every shot is different
Effect grows from noise – every shot is different
Characterising Hosing

Effect grows from noise – every shot is different
Characterising Hosing

Effect grows from noise – every shot is different
Simulation convergence

No density step
Simulation convergence

Noise seen in simulations due to wavebreaking *transverse phase crossing* in 3d

What is it?

Toy model based on Dawson sheet treatment. Consider harmonic cylindrical oscillations.
Transverse phase crossing
Transverse phase crossing

In the model, phase crossing occurs due to random perturbations in velocity.

These mimic numerical errors.

In 3d, this can act as a seed for hosing.
Transverse phase crossing

However, the real system is weakly anharmonic – phase crossing may also occur.

\[ F_r \sim \frac{(r_0 - \Delta r)^2 - r_0^2}{r_0 + \Delta r} n_e + \frac{\sigma_r^2 (1 - \exp\left(\frac{(r_0 + \Delta r)^2}{2 \sigma_r^2}\right))}{r_0 + \Delta r} n_b \]

How to distinguish physical and numerical effects?
Transverse phase crossing

Look for simulation convergence
• Higher resolution reduces effect

Look for simulation bugs
• Found one! Squashed

Look for simulation limitations
• Numerical accuracy
• Particle pusher

Make analytical estimates
Transverse phase crossing

Not only relevant to hosing.

Phase crossing damps wakefields (Konstantin, James)

Noise will spoil witness emittance

Understanding this is vital for AWAKE simulations