preliminary

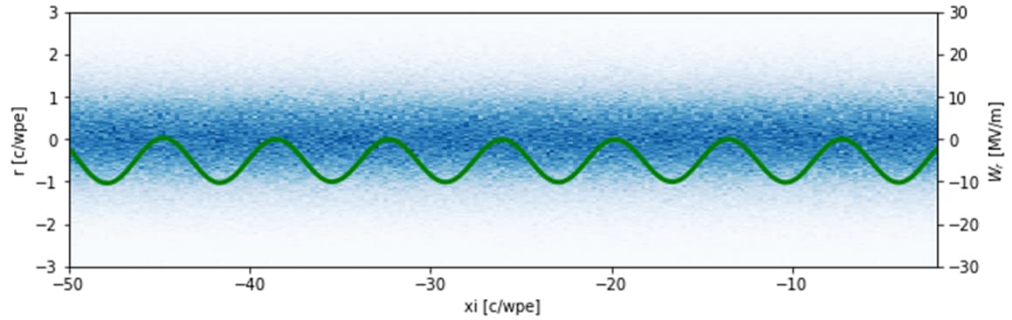
Suppression of the SM Process

M. Turner, J. Mezger, A. Clairembaud, N. Z. van Gils, F. Pannell, L. Ranc, M. Bergamaschi and P. Muggli

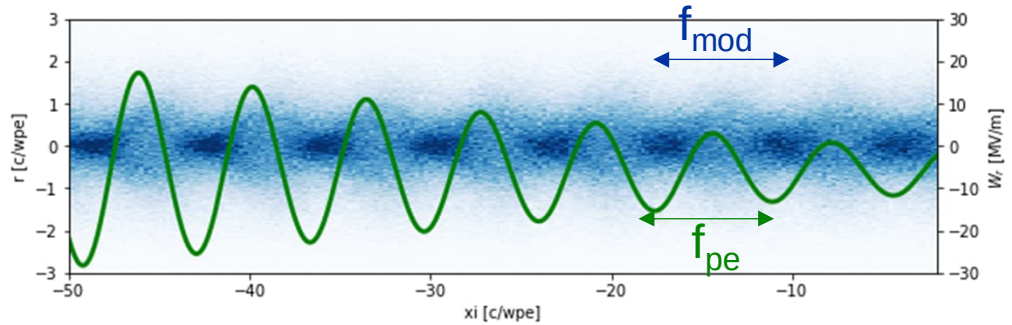
Self-Modulation Instability Suppression

Self-modulation is an instability
→ requires feedback loop

Seed wakefields → modulate bunch density



Bunch with modulated density drives stronger wakefields



Uniform n_{pe} : $f_{mod} \cong f_{pe}$

P. I. Morales Guzmán *et al.* (AWAKE Collaboration), PRAB 2021

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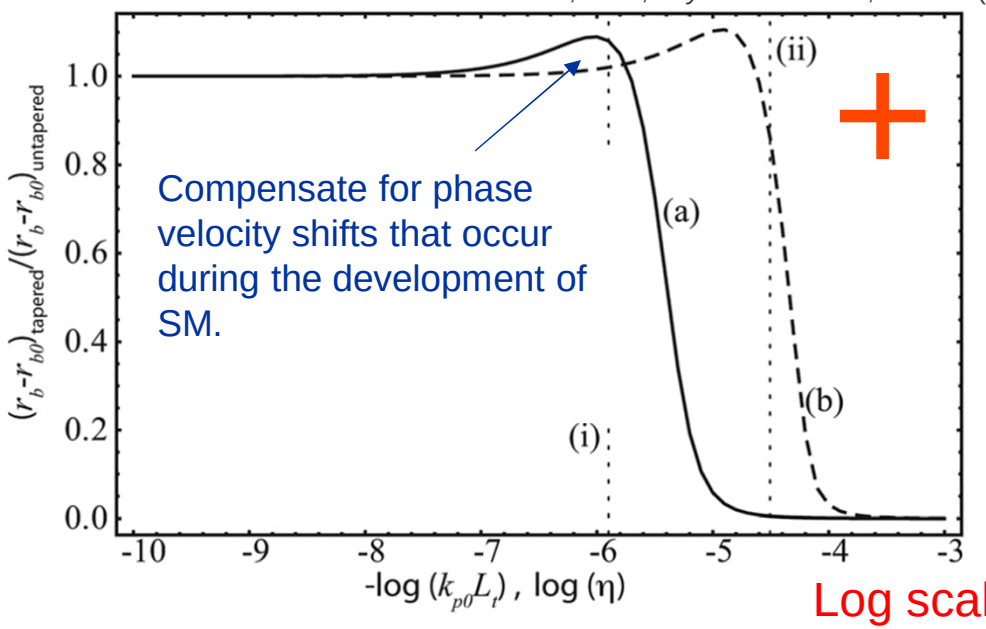
Prediction from theory: for sufficiently large **positive** plasma density gradients, SM growth is suppressed

C. B. Schroeder, et al., *Phys. Plasmas* 19, 010703 (2012)



- relative radial modulation of the bunch vs. linear density gradient (log scale) ∝ Wakefields
- SM suppression at large (>1e6) gradient because ⟷ feedback loop affected

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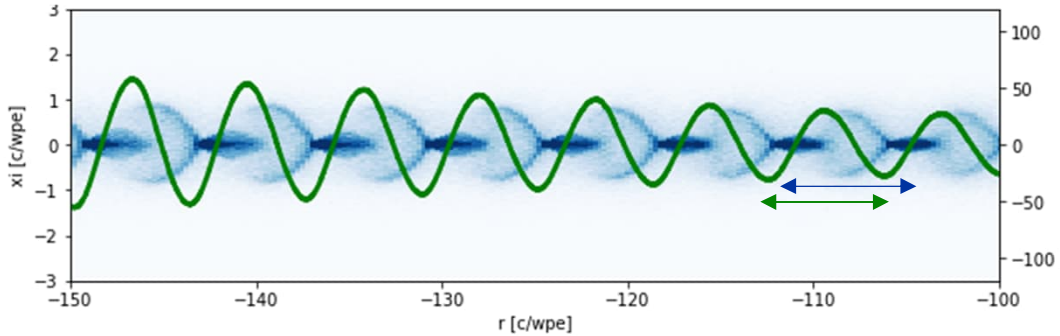
Seed wakefields → modulate bunch density



With gradient → changing n_{pe} along z: $f_{mod} \neq f_{pe}(z)$

→ Impose f_{mod}, then change f_{pe}

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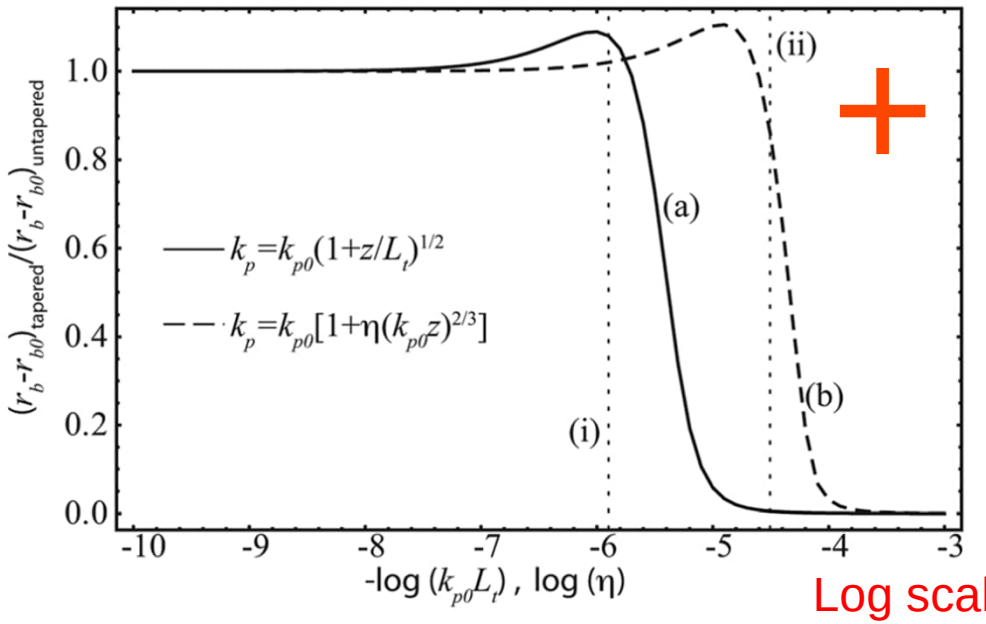
C. B. Schroeder, et al., *Phys. Plasmas* 19, 010703 (2012)



Log scale

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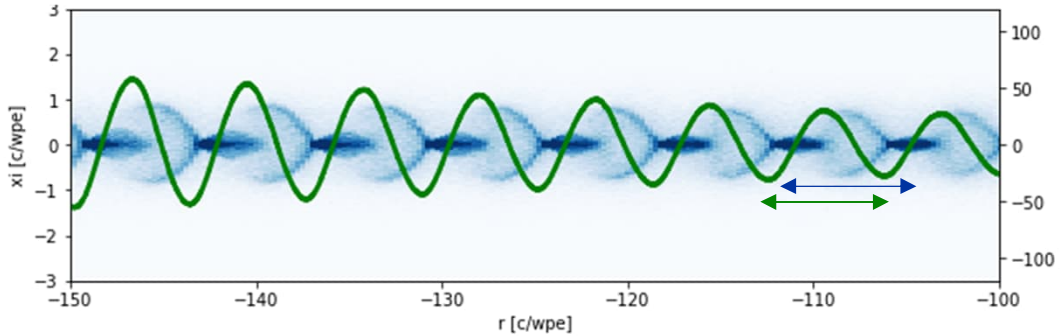

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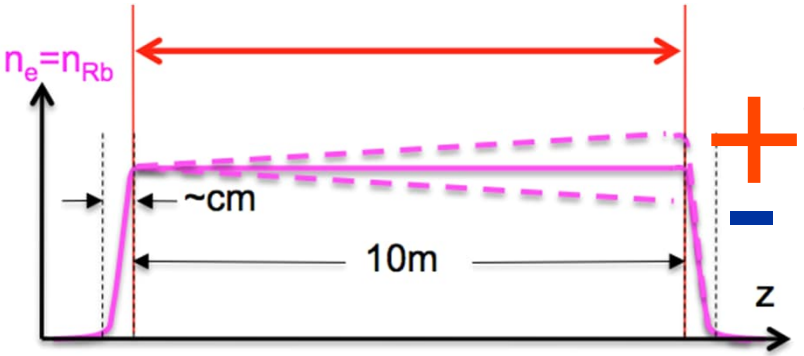
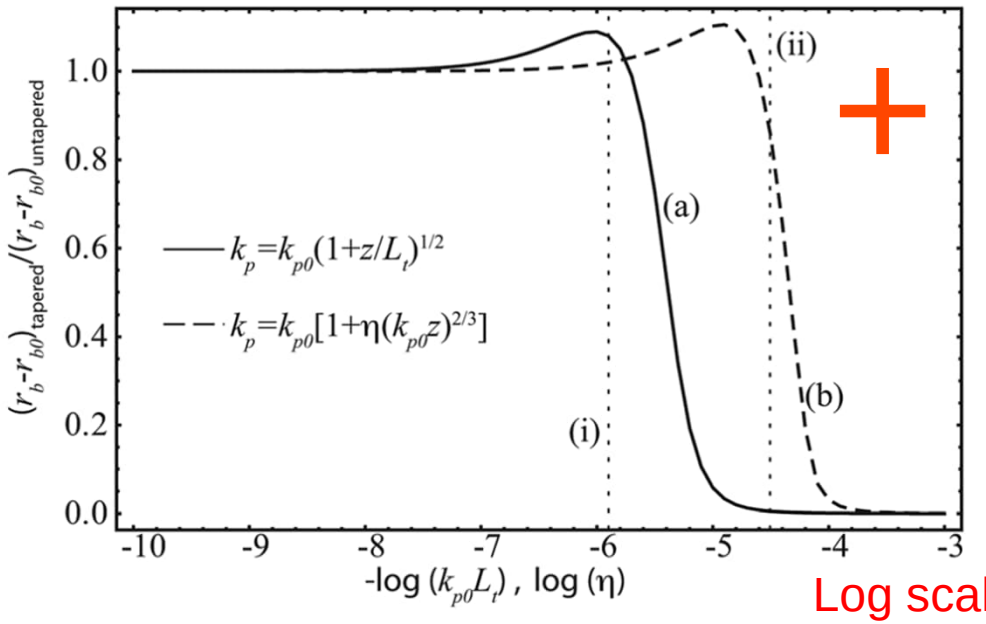


- vapor source allows for linear density gradients

Prediction from theory: for sufficiently large **positive** plasma density gradients, SM growth is suppressed

C. B. Schroeder, et al., *Phys. Plasmas* 19, 010703 (2012)



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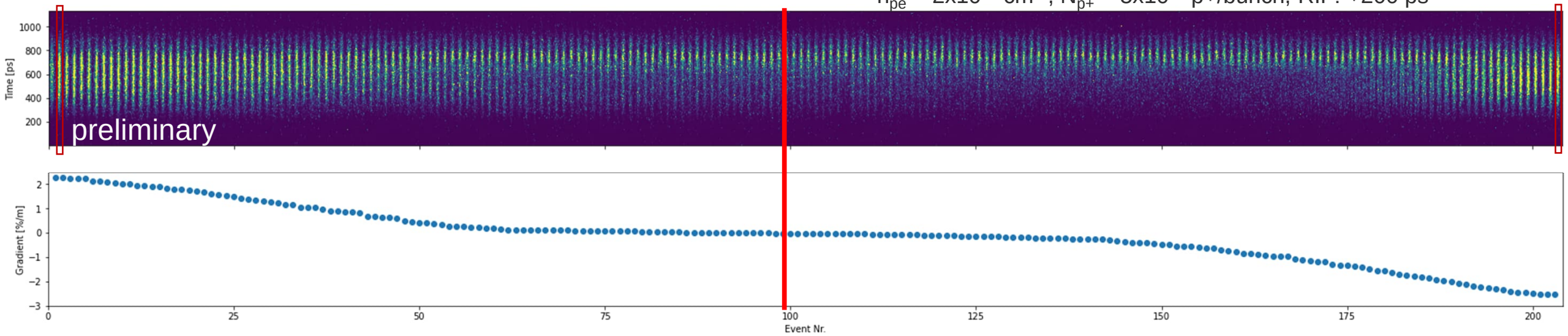
Gradient Scan

Wakefield suppression signatures on streak camera images and plasma light

+ 0 −

n_{pe} = 2x10^{14} cm^{-3}, N_{p+} = 5x10^{10} p+/bunch, RIF: +200 ps



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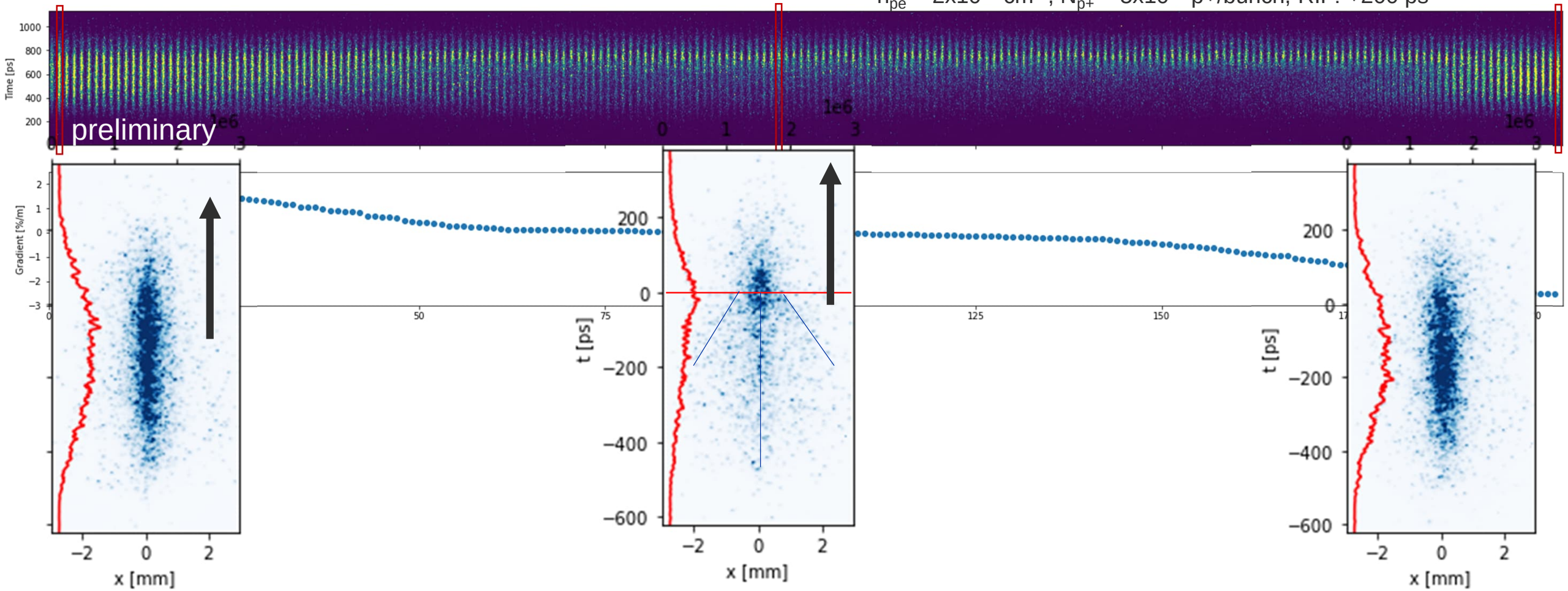

Gaussian long. profile

Successful SM

Gaussian long. profile

Gradient Scan

Wakefield suppression signatures on streak camera images and plasma light

+

0

−

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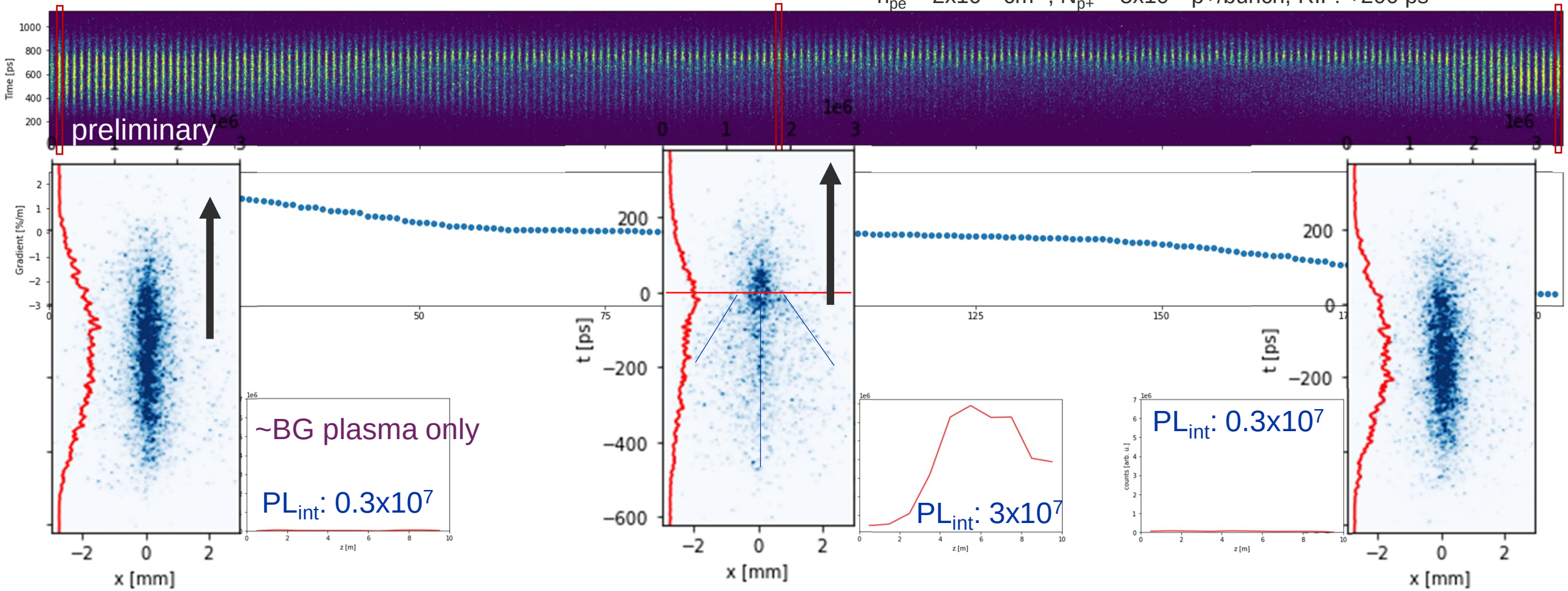


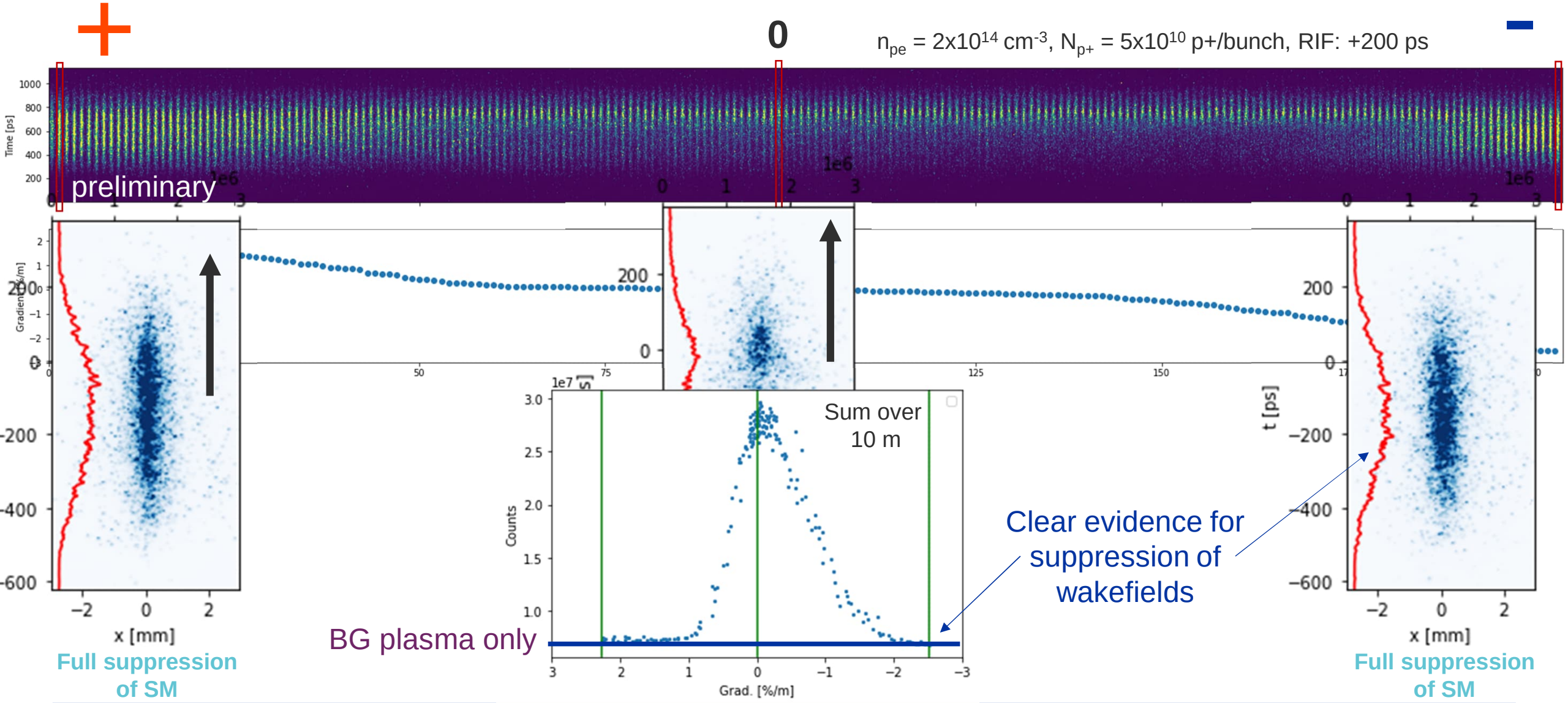
Gaussian long. profile

Successful SM

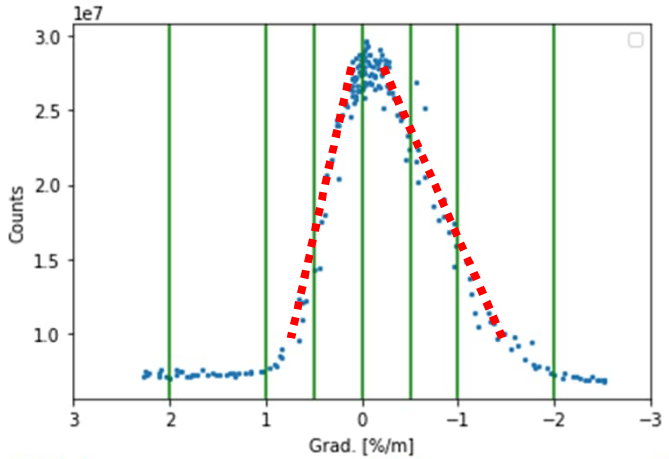
Gaussian long. profile

Gradient Scan

Wakefield suppression clear on streak camera images and plasma light



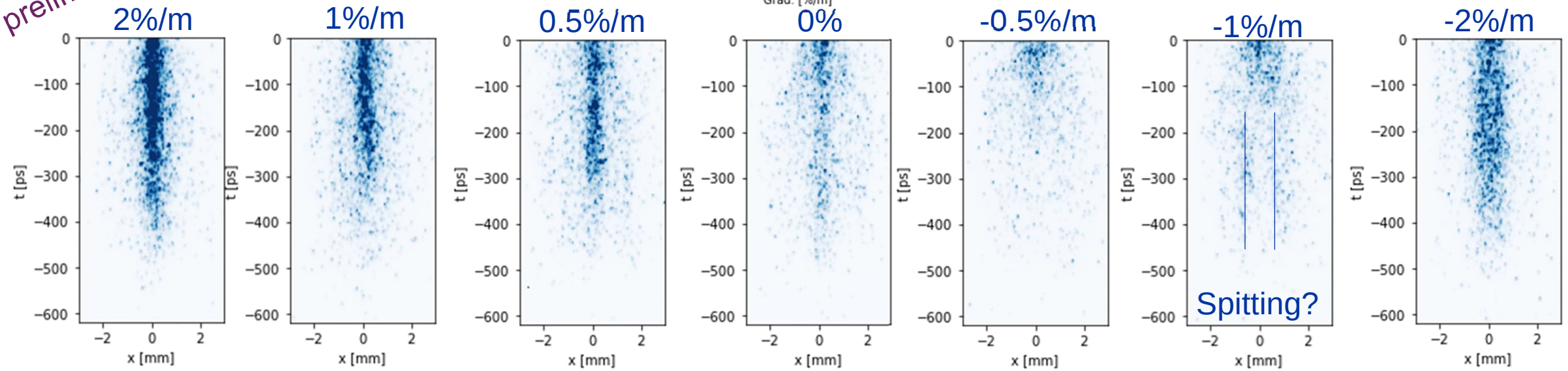
Plasma Light & Streak Camera Measurements



→ Slopes for +,- asymmetric

n_{pe} = 2x10^{14} cm^{-3}, N_{p+} = 5x10^{10} p+/bunch,
RIF: +200 ps

preliminary

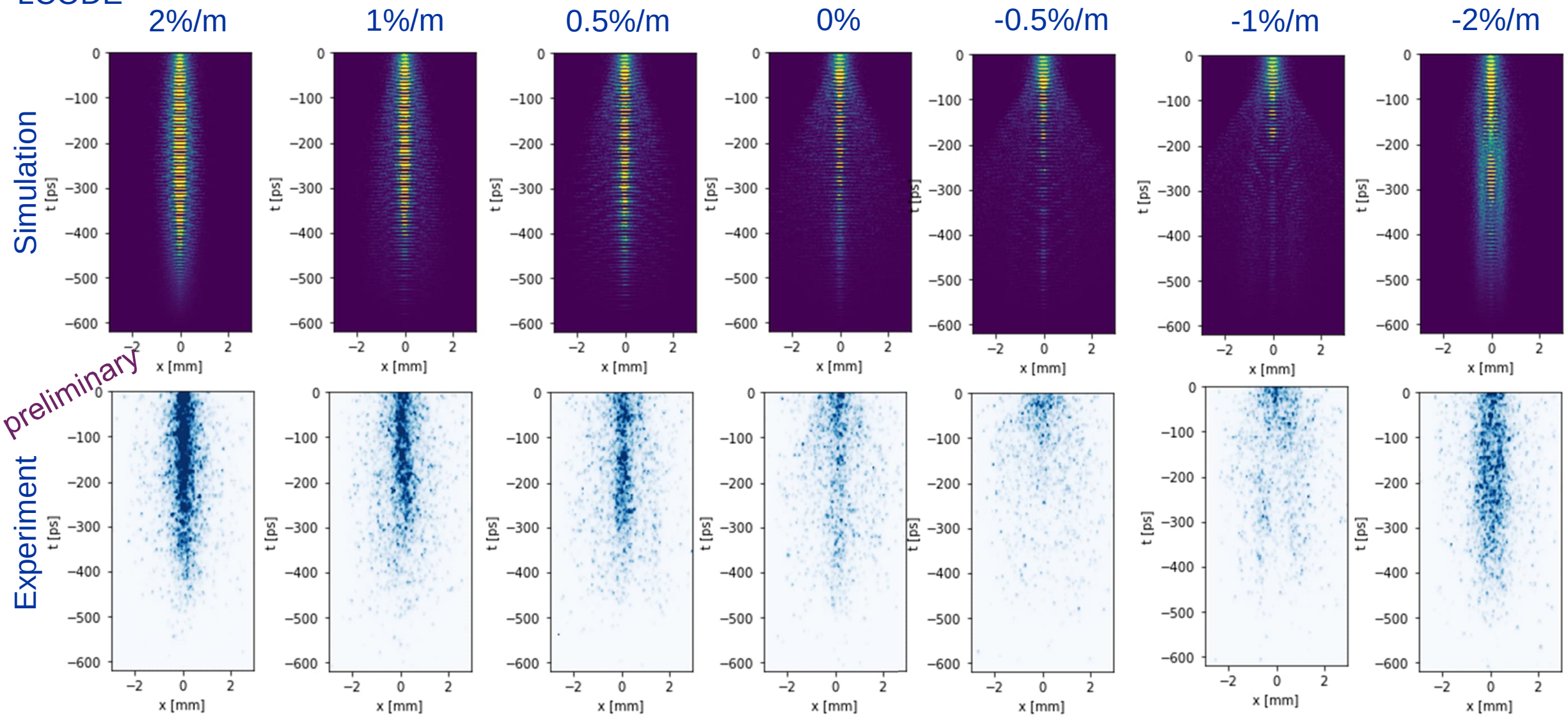


core more intense

core shorter

Comparison Simulation / Measurement

LCODE



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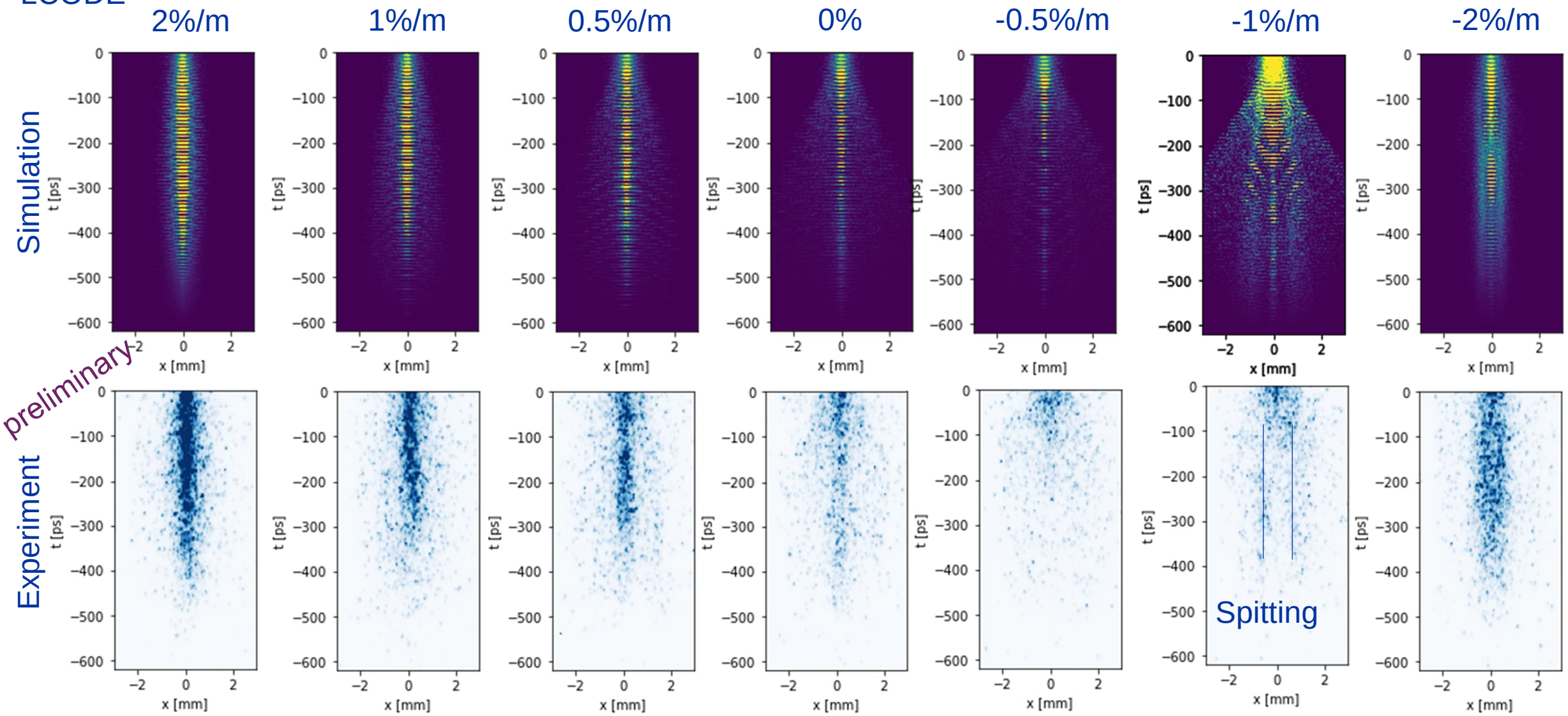

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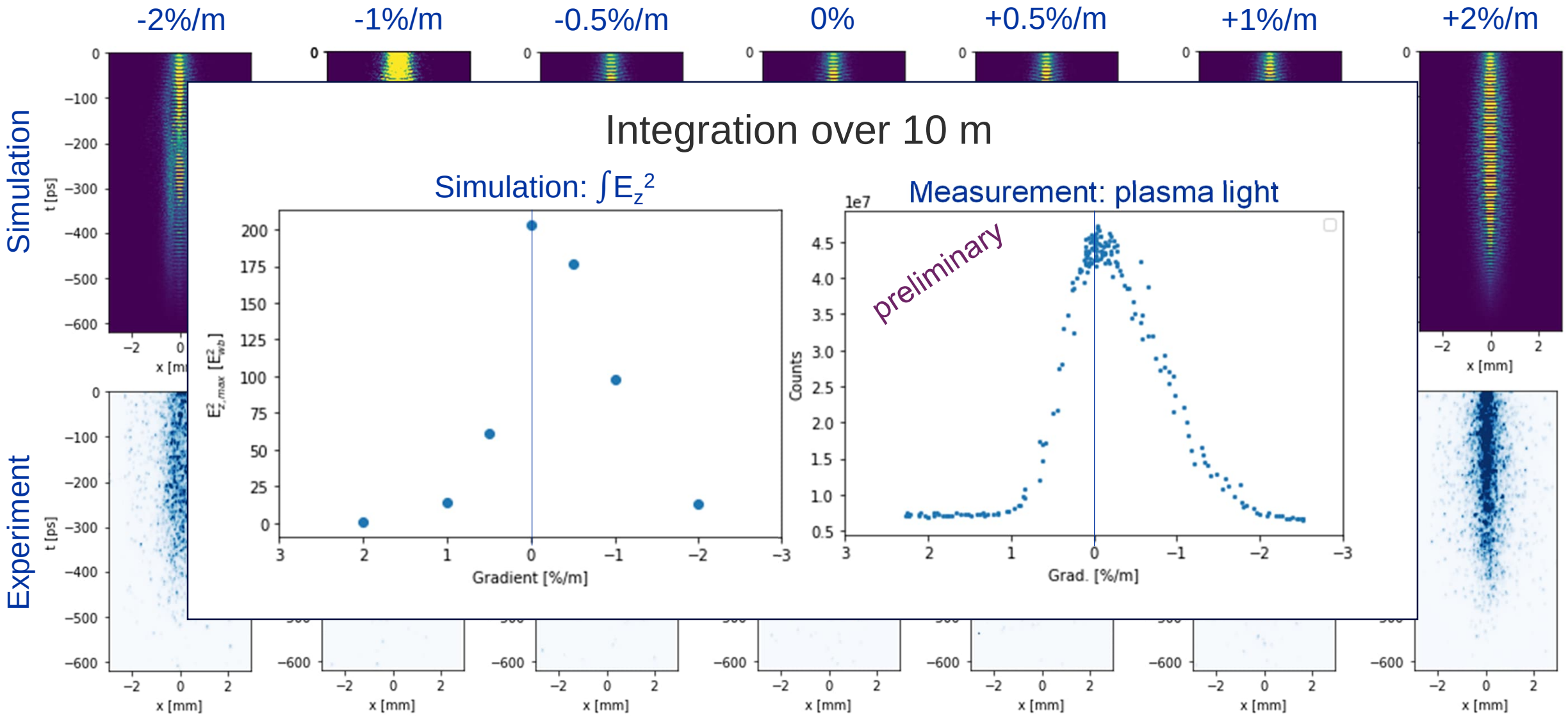

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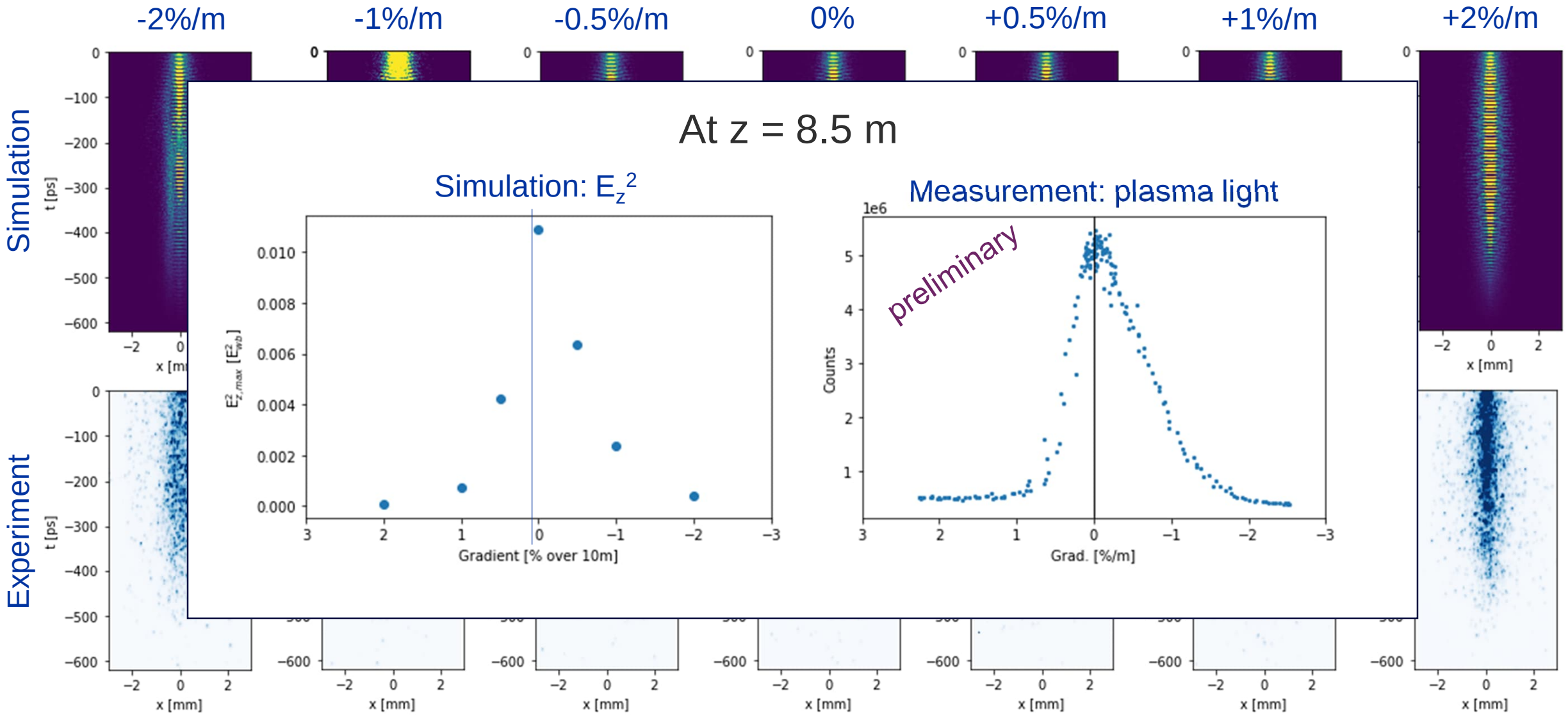
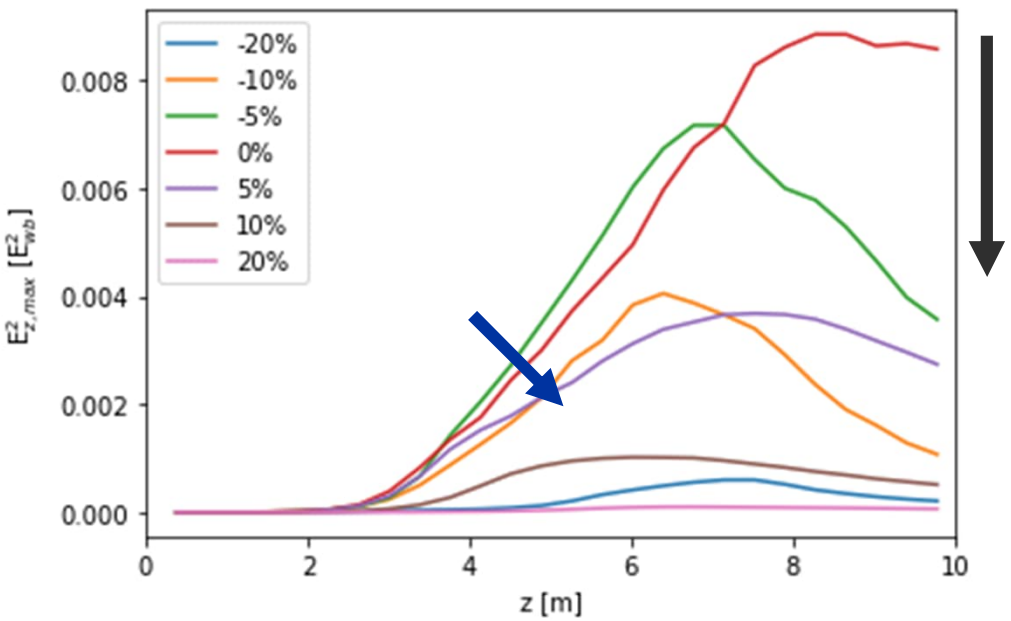
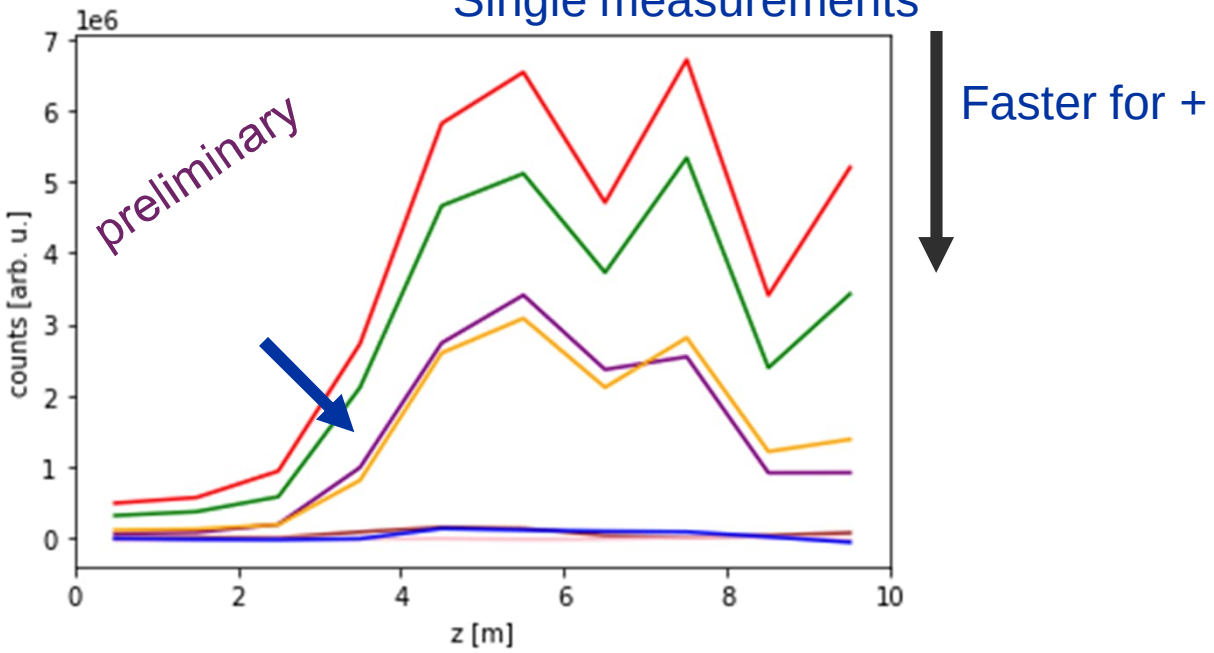


Comparison Simulation / Measurement

Regime where plasma light ‘likely local’



Single measurements



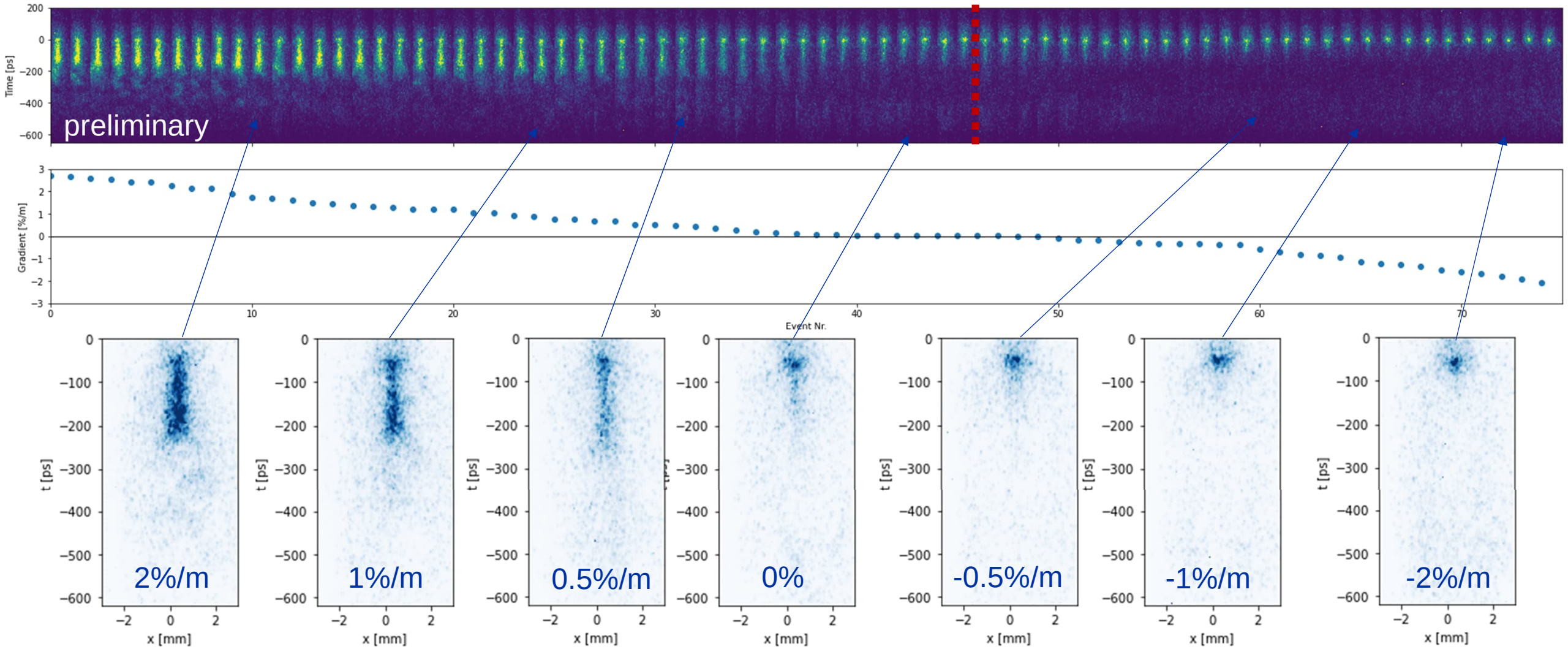
Faster for +

Similarities:

- E_z^2 decreases with + and – gradients → clear signature of suppression
- Decrease is faster for positive than negative gradients
- Next step: compare plasma light to energy deposited

Measurement at High N_{p+}

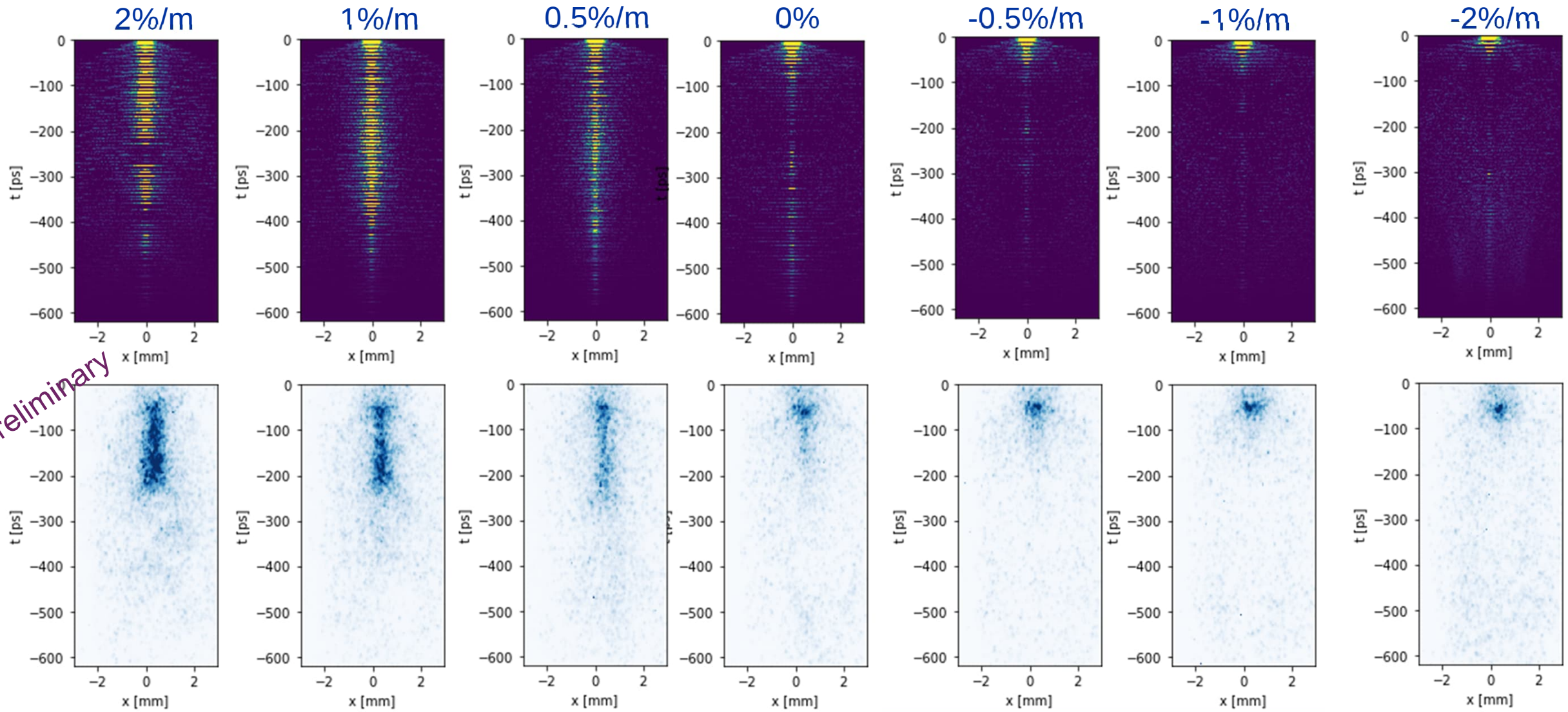
n_{pe} = 2x10^{14} cm^{-3}, N_{p+} = 3x10^{11} protons/bunch, RIF: +200ps



→ Reachable gradient (3%/m) no longer sufficient to reach full suppression

Measurement at High N_{p+}

LCODE



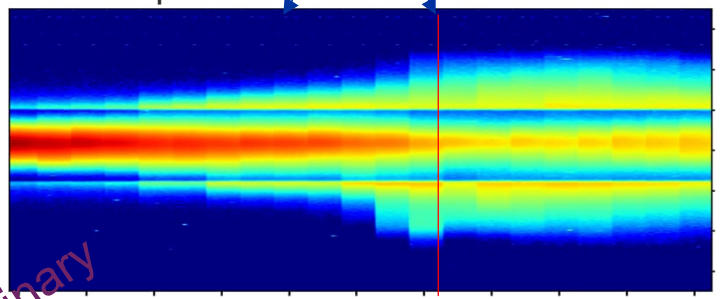
Plasma Light Increases for Small Positive Gradients

Consistent with theoretical expectation

Asymmetry in halos

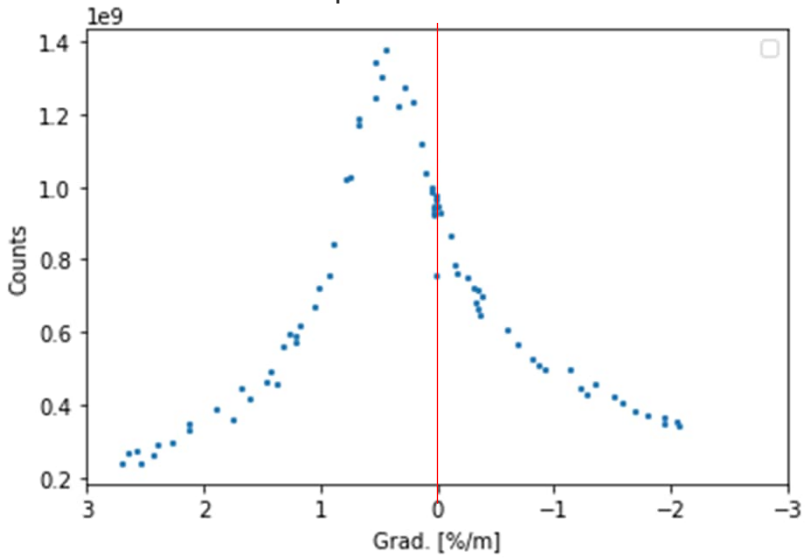
Microbunch formation supressed

Microbunches formed, defocused



preliminary

\+ $N_{p+} = 3x10^{11}$ −



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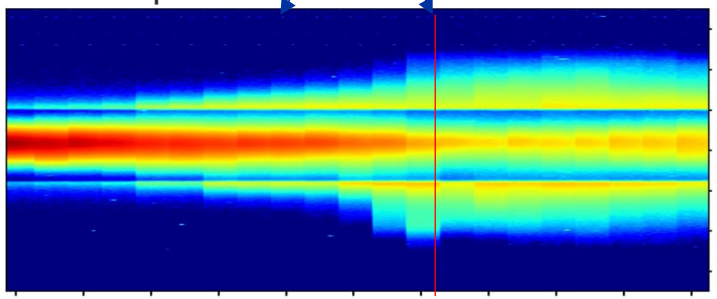

+

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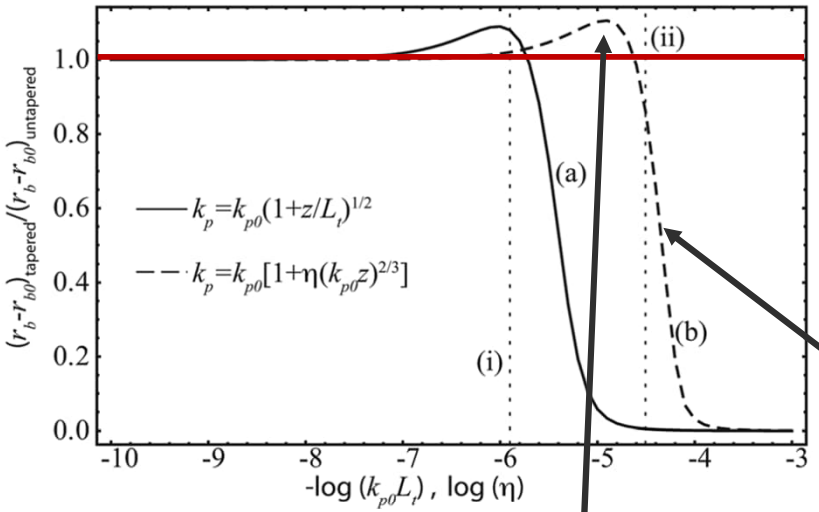
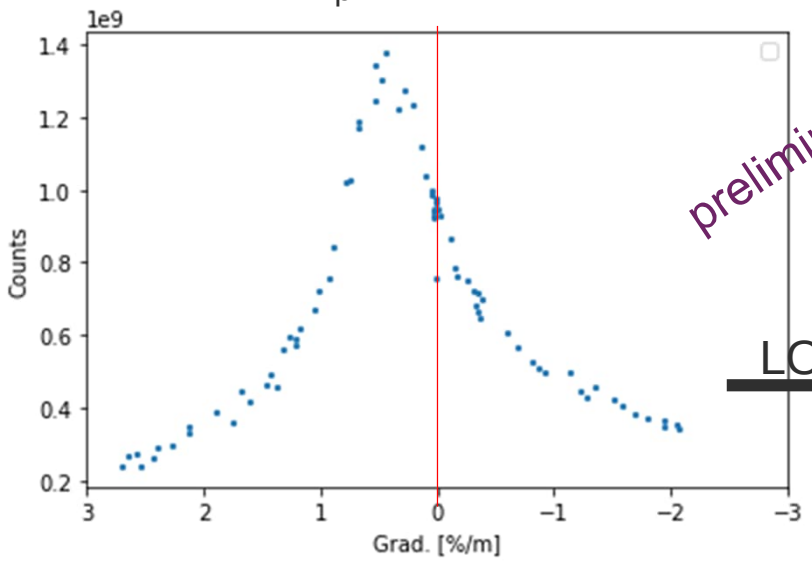
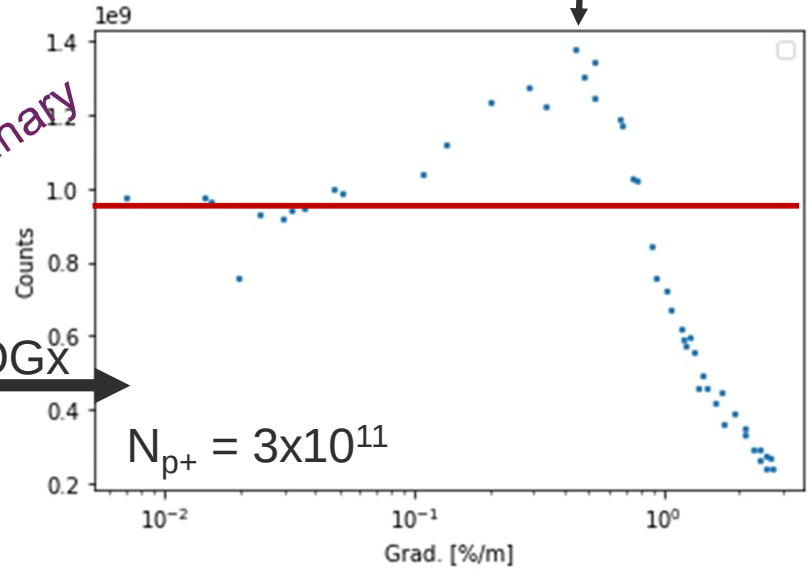


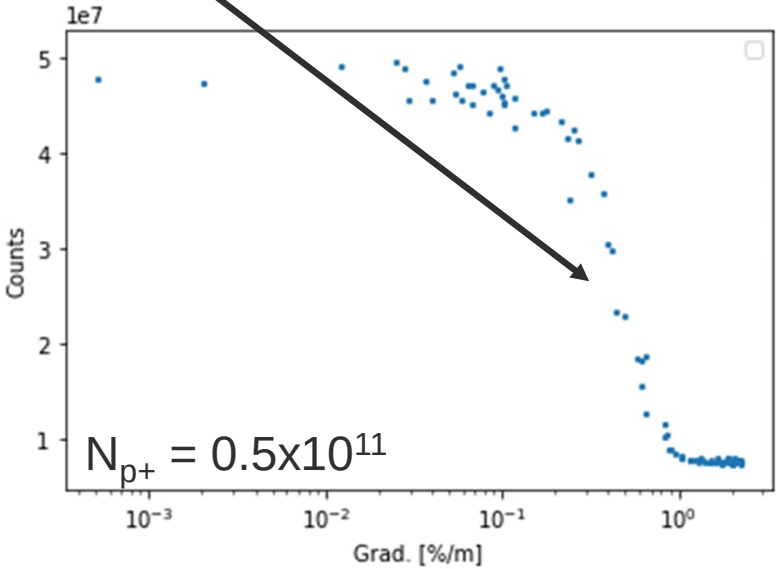
Transition

preliminary

LOGX







Summary & Conclusions

- **Theoretical prediction:** Large positive n_{pe} gradients suppress the development of the self-modulation (SM) process.
  C. B. Schroeder, et al., *Phys. Plasmas* 19, 010703 (2012)
  - This occurs as changes in the plasma wavelength impact the instability's feedback loop
  - Experimentally observed, including for negative gradients
  - Process is asymmetric, faster for the positive gradients
  - Suppression observed with 5×10^{10} protons/bunch and gradients of ±2%/m.

  - **"Small" positive gradients**: predicted to increase the wakefield amplitude by compensating for wakefield phase shifts occurring during self-modulation.
    - Observed with a bunch population 3×10^{11} protons/bunch
    - Consistent with larger energy gains observed with small + gradients in 2018