

Light Emission of Dissipating Wakefields

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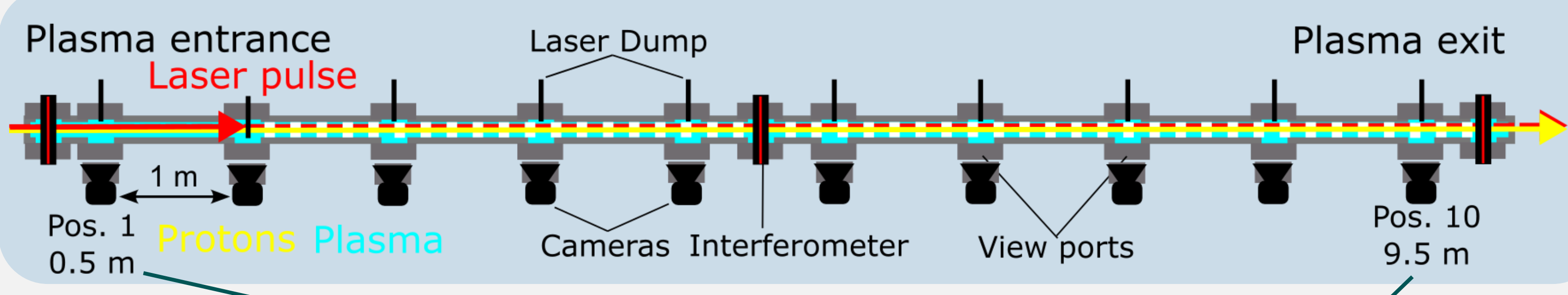
ABSTRACT

In plasma wakefield acceleration, energy is transferred from a driver to a witness bunch through the wakefields. Energy lost by the driver is stored in wakefields as kinetic energy of the oscillating electrons, and as potential energy of the electric and magnetic field. A witness bunch can be accelerated by the longitudinal electric field. Wakefield energy is eventually dissipated in the plasma. A part of this energy is emitted as light. We discuss the proportionality between emitted light, deposited energy and wakefield amplitude. We utilize this relation with the light diagnostics and showcase how it is used to investigate the longitudinal evolution of wakefields driven by a long relativistic proton bunch at AWAKE.

Setup

IONIZING LASER

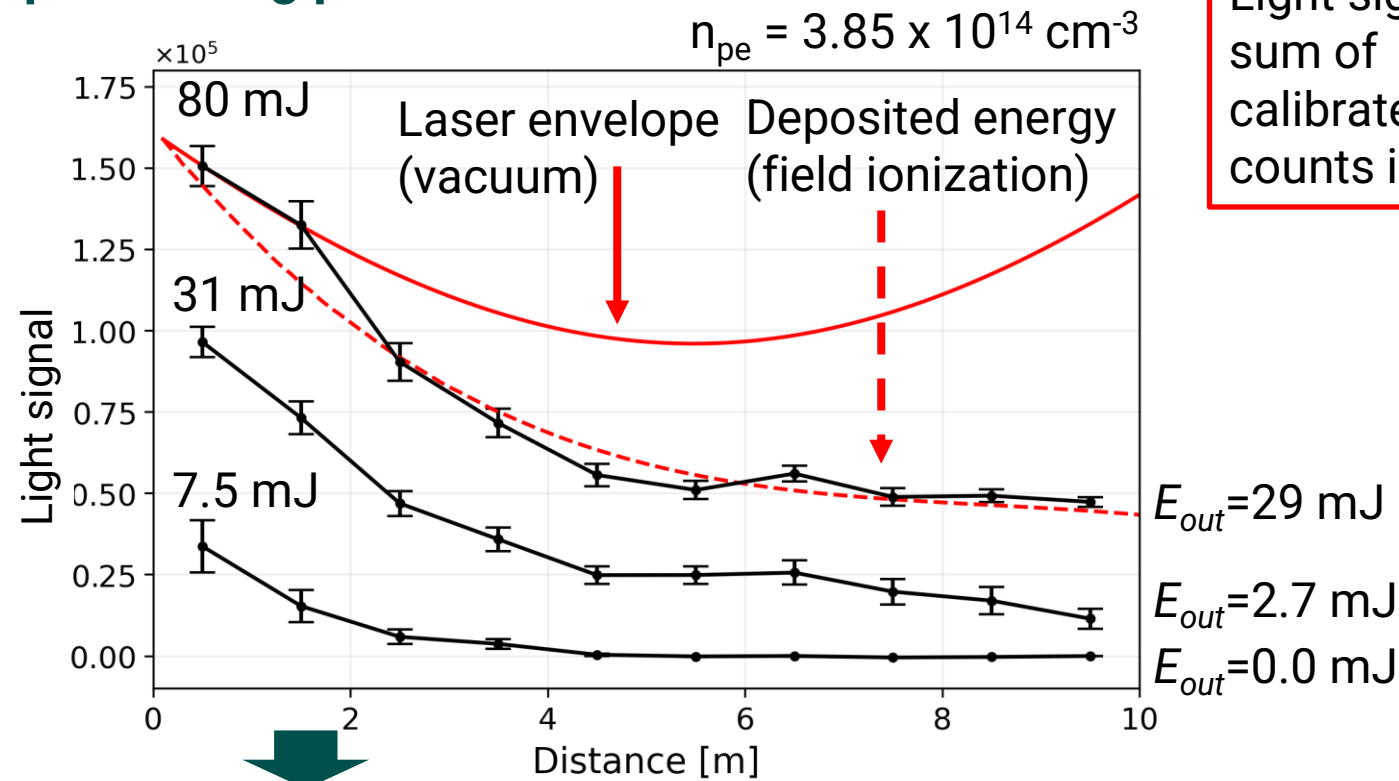
- 780 nm Ti:Sa – laser pulse
- Pulse duration ~ 100 fs
- Pulse energy: 0 – 120 mJ
- Peak intensity ~ 10 TW/cm²
- Field ionization (Rb vapor 100 % singly ionized)
- Ionization front moves near c
- RIF (Relativistic Ionization Front)



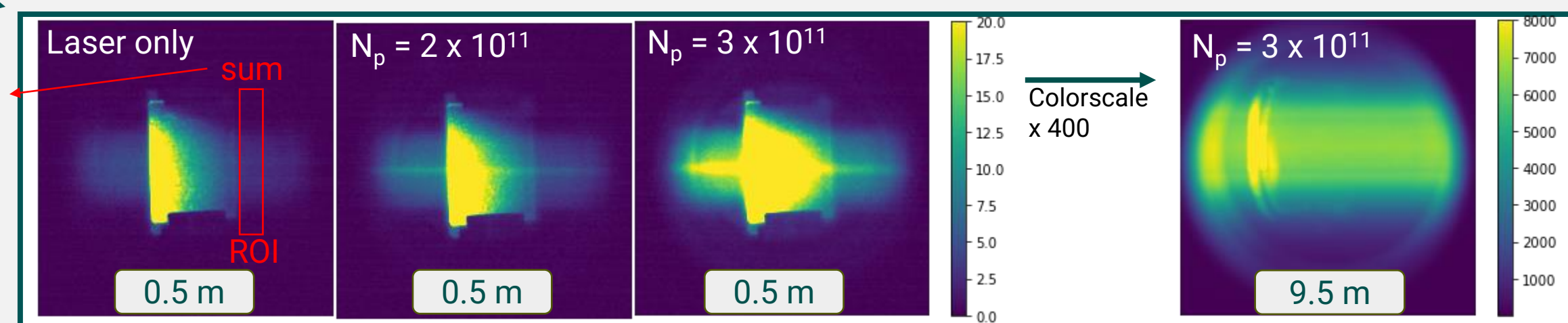
PROTON BUNCH

- Drive bunch
- CERN SPS - 400 GeV
- “Gaussian” distribution
- $\sigma_z \sim 180$ ps (5.4 cm)
- $\sigma_r \sim 200$ μ m (at plasma entrance)
- $\gamma \sim 427$
- $N_p = (0.5 - 3) \times 10^{11}$ protons

Light signal of the laser pulse along plasma source



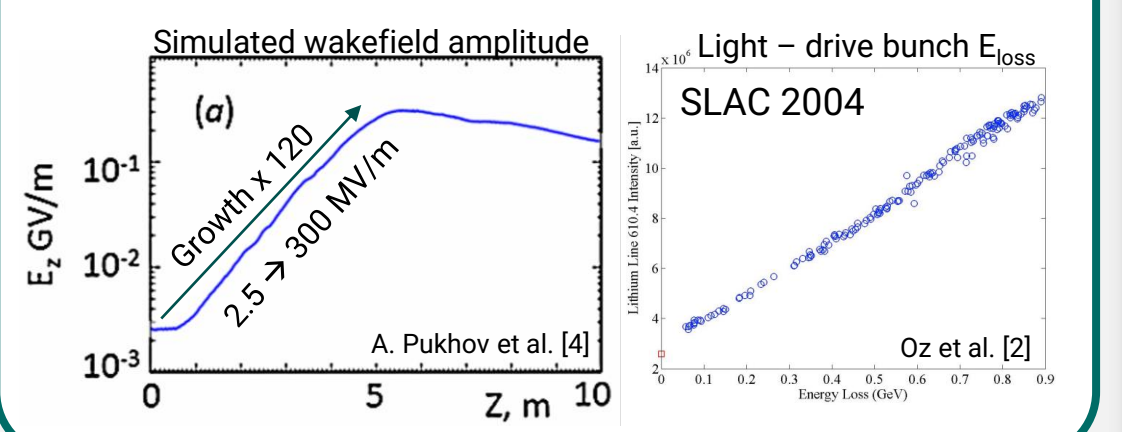
Light signal: sum of calibrated counts in ROI



Motivation

p+ bunch → Self-modulation → micro-bunch train

Wakefields evolve as the p+ bunch self-modulates
→ Light emission of plasma as measurement of wakefield amplitude along plasma?



OBJECTIVE

Diagnostic for the Wakefield Amplitude

Verify Assumptions

Test with Established Wakefield Physics

Explore New Wakefield Physics

Assumption

Emitted light proportional to energy deposited

How to verify?

- Use laser pulse!
- Pulse energy measured at entrance and exit
- Correlate measured light with energy loss

Conclusion

Light emitted proportional to energy deposited
Verified for 0-12 mJ/m with laser pulse

$n_{pe} = 1.05 \times 10^{14} \text{ cm}^{-3}$
→ Low density for large ratio of wakefield signal to laser signal

Assumption

Wakefields deposit energy proportional to $W_{z,r}^2$

How to verify?

- Use seed wakefields!
- Wakefields calculated from linear theory
- Correlate with measured light

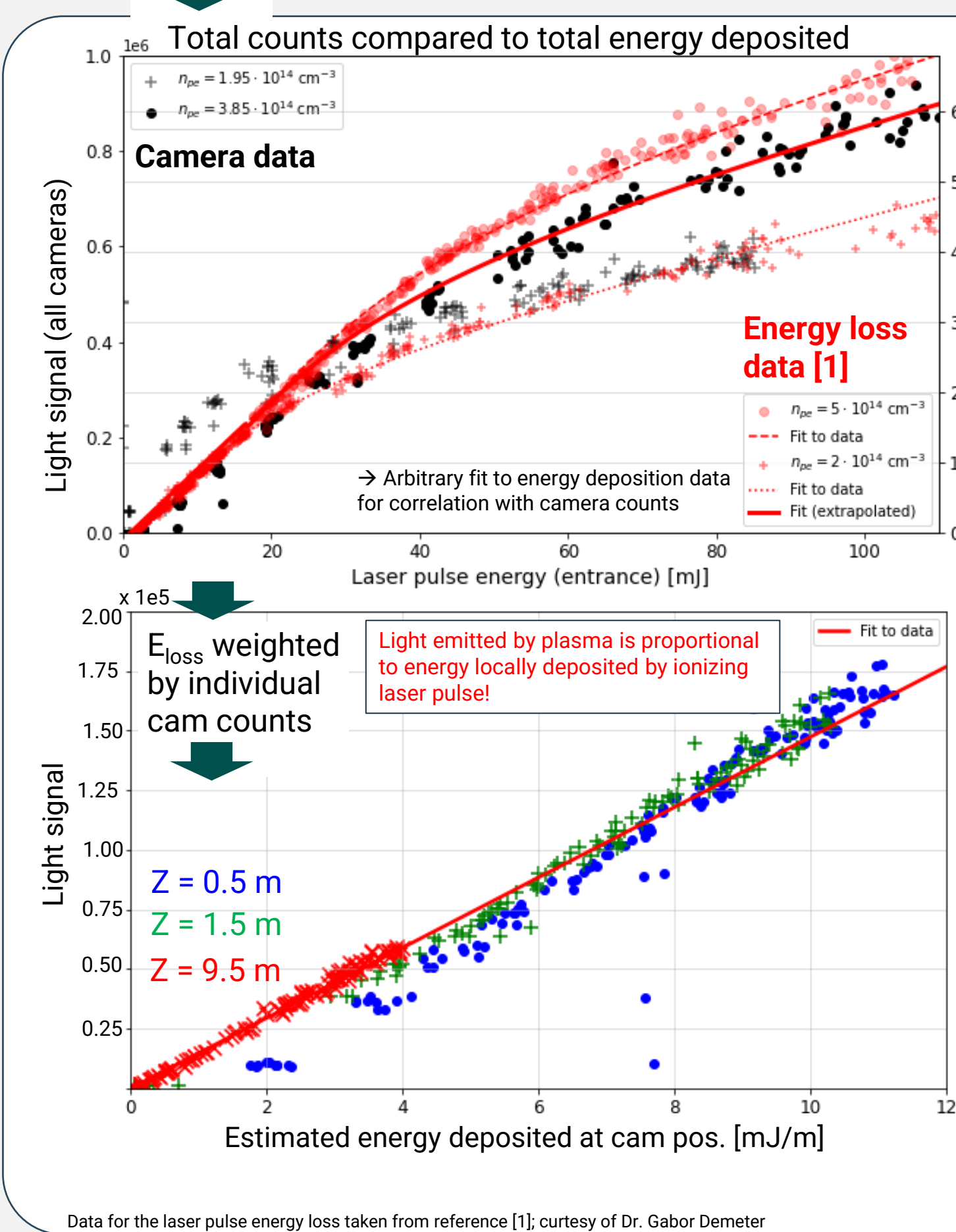
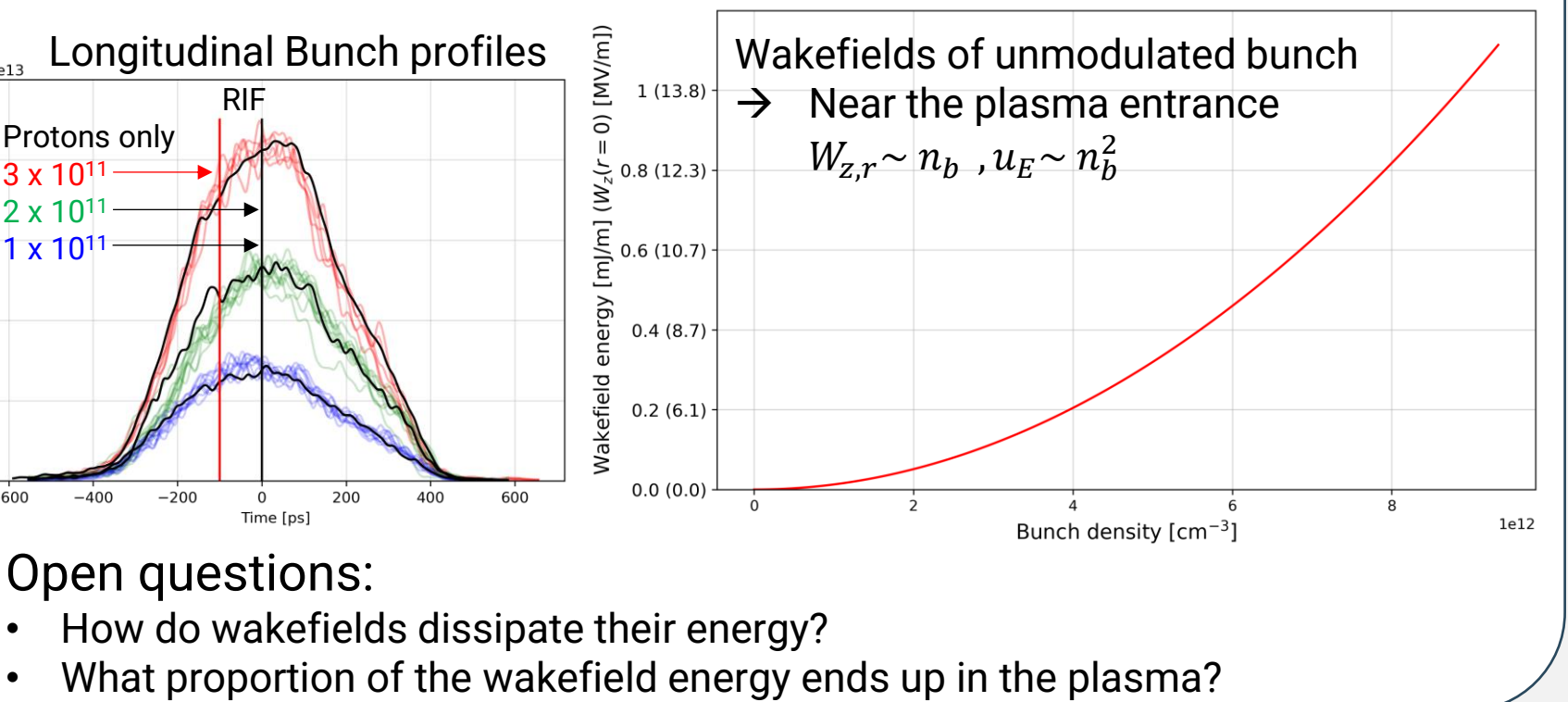
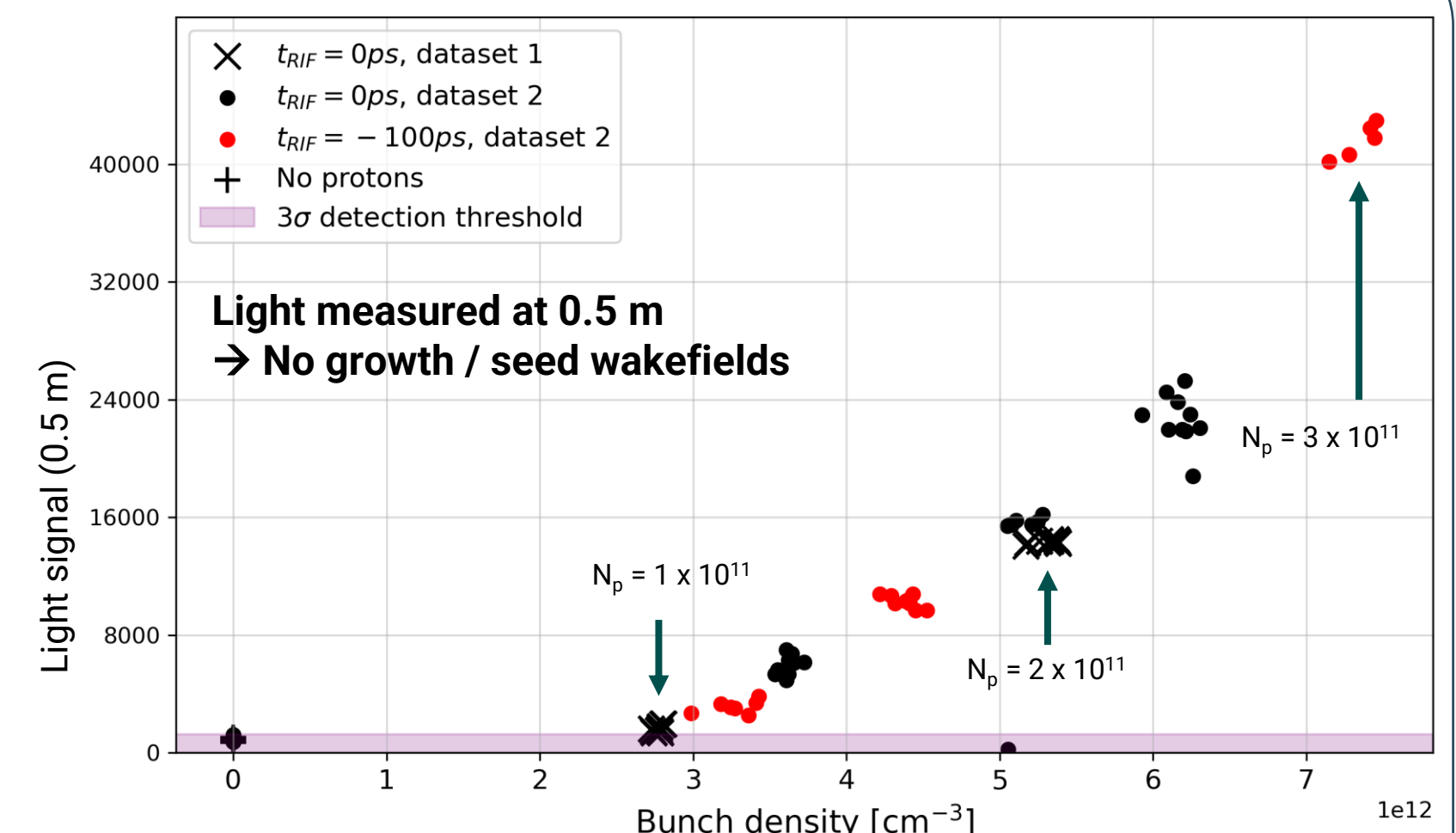
Conclusion

Some proportionality (larger $W_{z,r}$ → more light)
No strong evidence for strictly squared relation
→ Ongoing research topic

Findings at SLAC: Light proportional to e⁻ bunch energy loss [2]

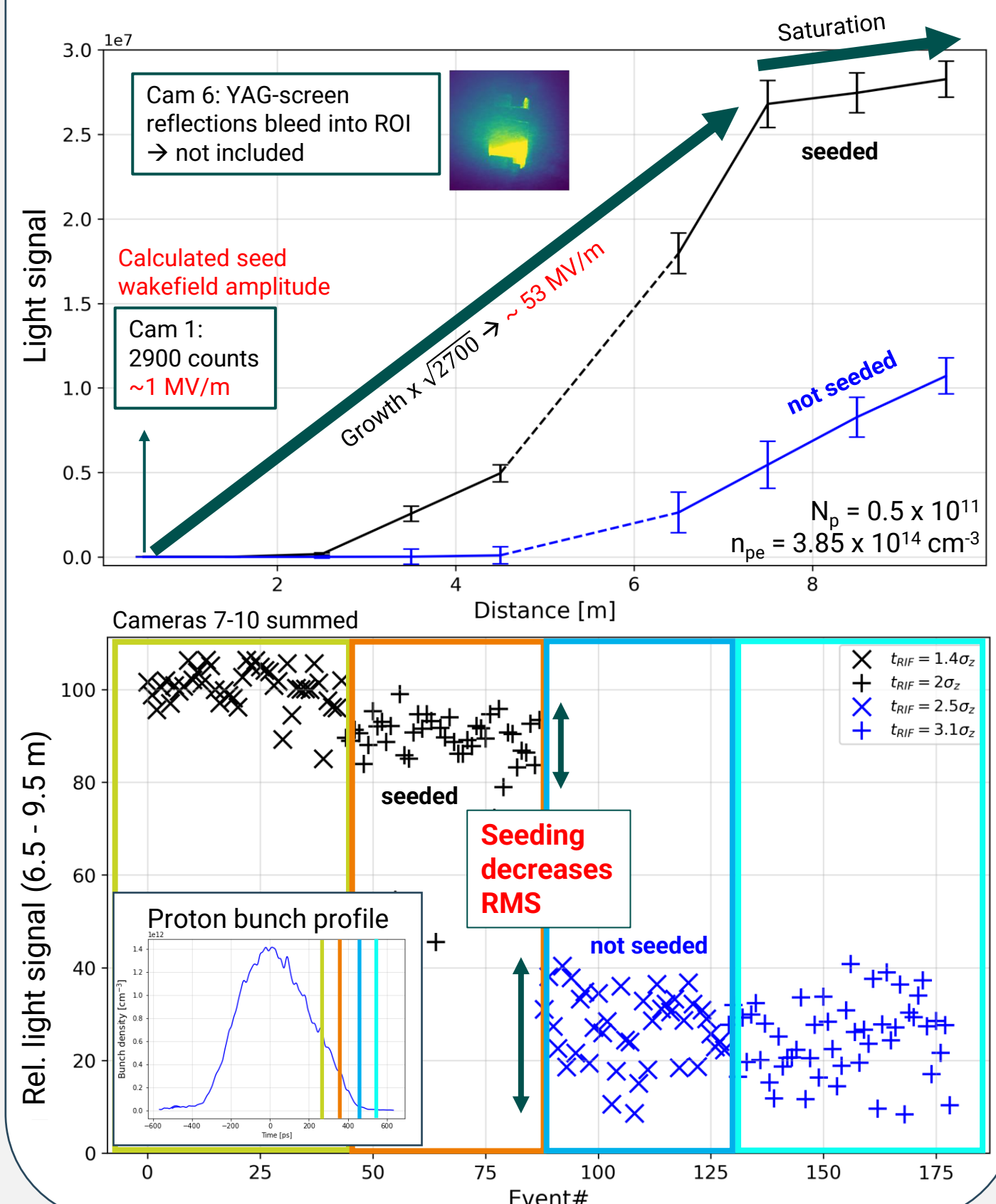
Not practical to measure energy loss of 400 GeV p⁺ bunch

→ Here: Light proportional to laser pulse energy loss



Self-Modulation Studies

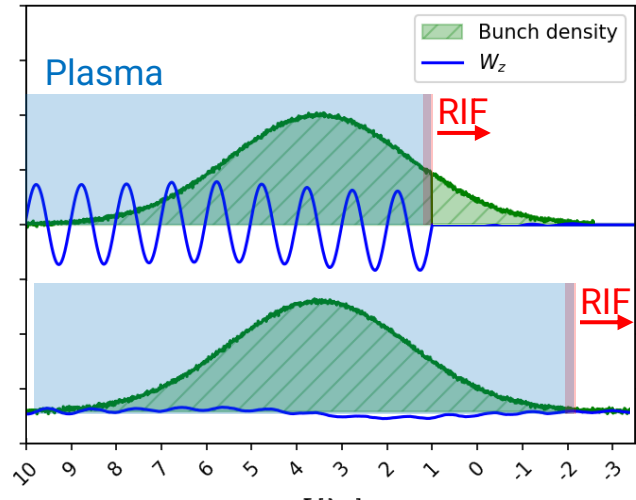
SELF-MODULATION GROWTH AND SEEDING



Expectations

- ✓ Wakefield amplitude grows along z
- ✓ Wakefield amplitude saturates
- ✓ With seeding growth starts earlier
- ✓ With seeding better reproducibility

RIF SEEDING



SELF-MODULATION

- Initial wakefields (1-15 MV/m)
- Focusing / defocusing fields
- Modulated bunch distribution
- Micro-bunch train
- Large amplitude wakefields (100s MV/m)

GROWTH SUPPRESSION

Low charge / large density gradient along z:

- Increasing / decreasing ω_{pe} causes phase shift
- Micro-bunch frequency does not match ω_{pe}
- Disrupts feedback loop ✗

High charge & small density gradient:

- $V_{ph} < V_{group}$
- Phase shift compensates lower V_{ph}
- More charge in micro-bunch train ✓

First experimental observation of this effect predicted by reference [3]

