Mitigation of transverse wakefields in hollow plasma channels

CERN – Feb 9, 2018

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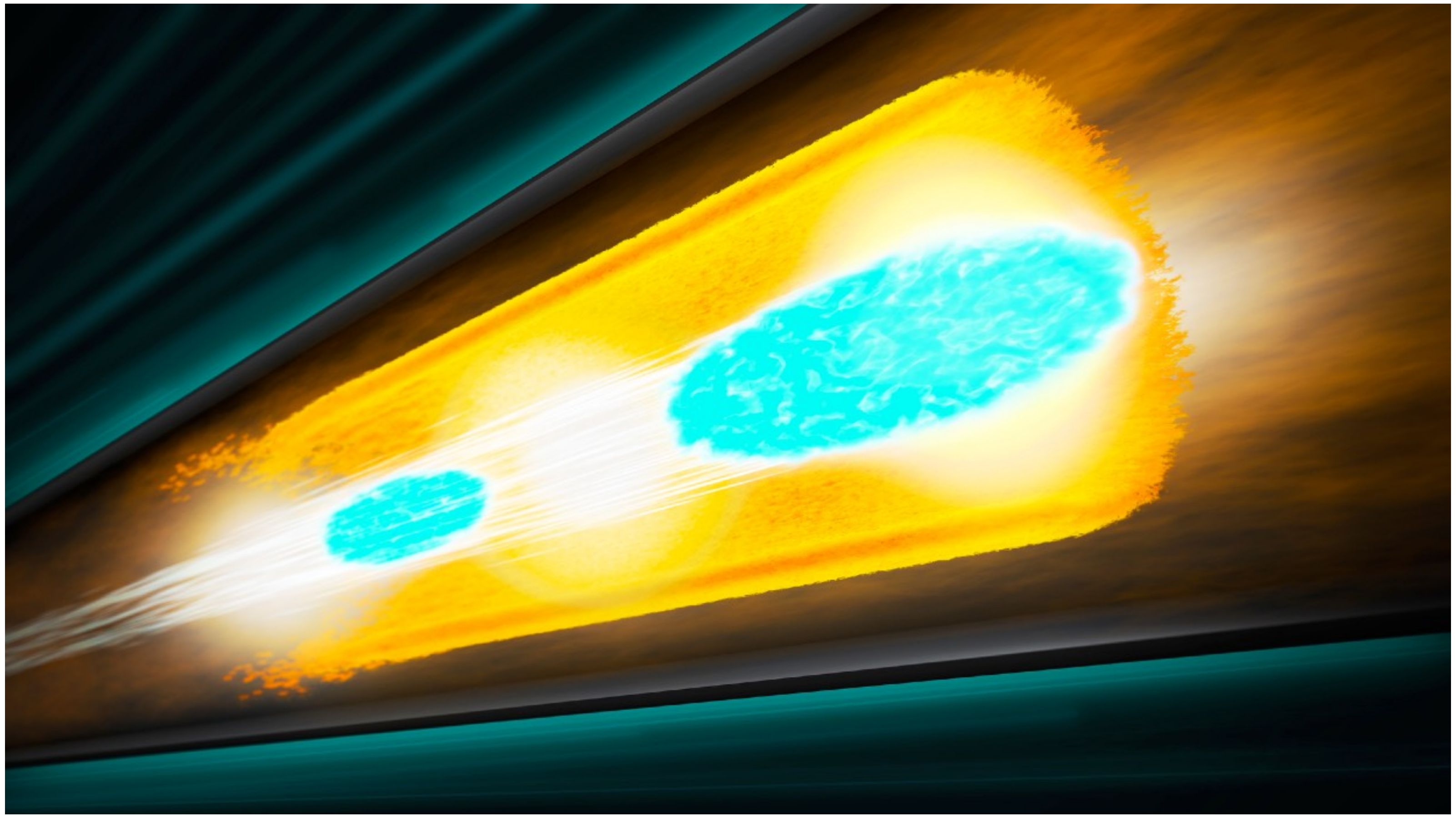
Introduction to hollow channels

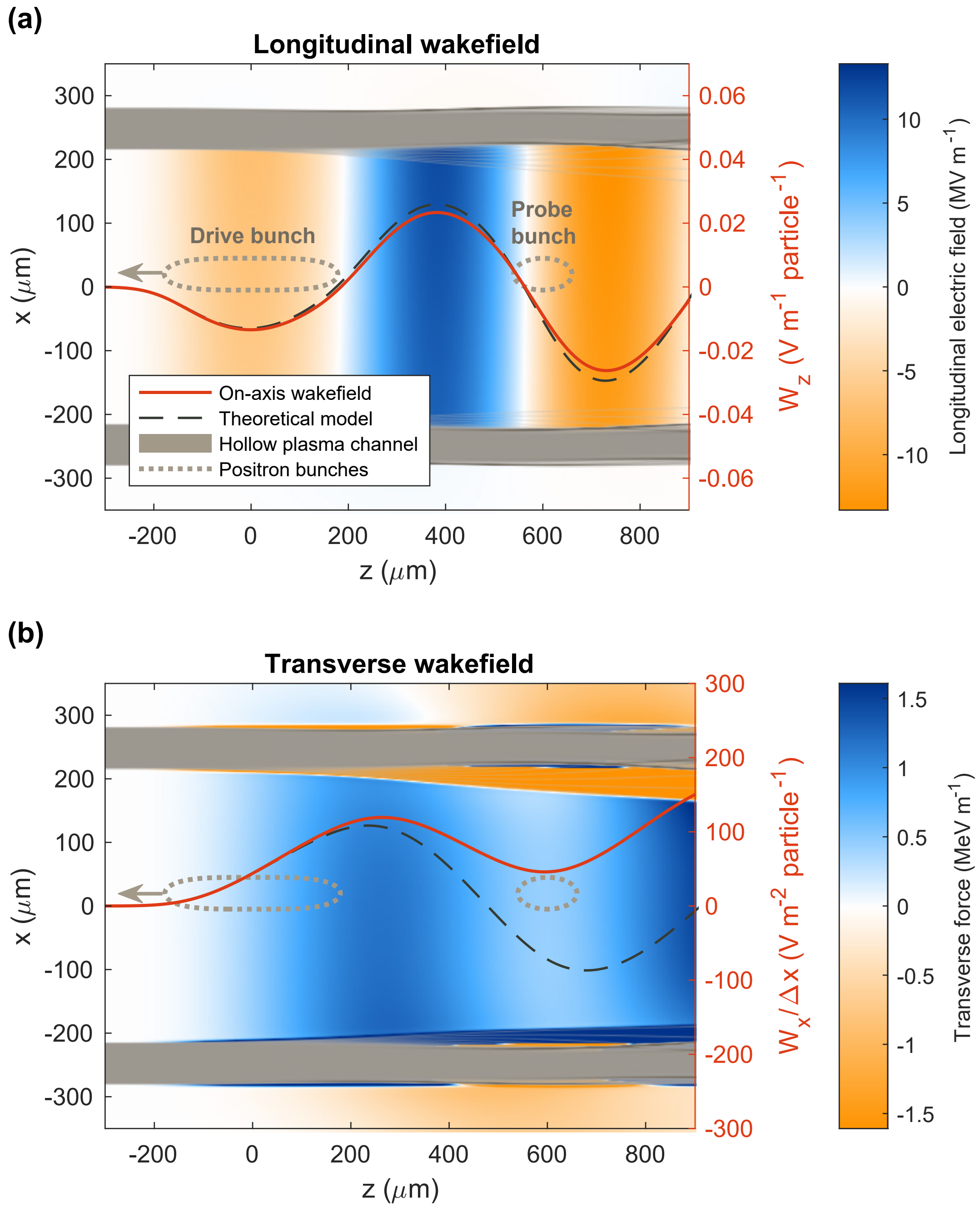
Hollow channels – what and why?

- Hollow channels are in principle **charge-asymmetric** – can accelerate positrons.
- Thin, long tube of plasma with an accelerating wakefield **driven by a beam** (or laser).
- **No focusing fields** on axis!



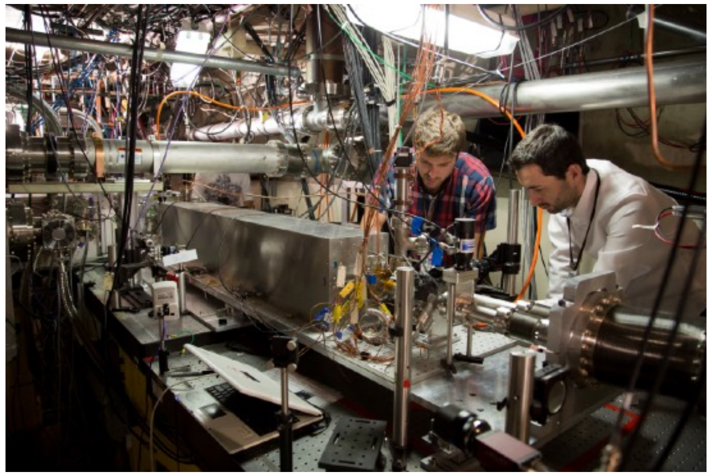
Strong transverse wakefields from misalignment

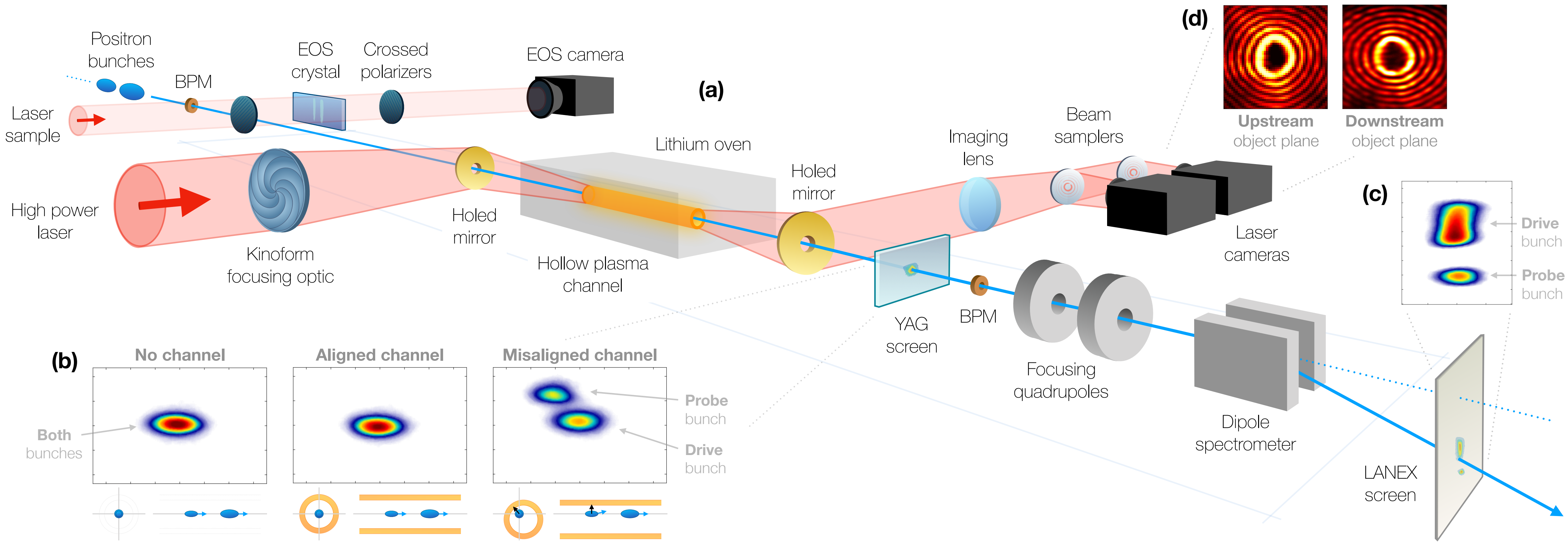
- A **misaligned beam** inside the channel will drive a very strong transverse wakefield.
- Dipole-like and deflects away from axis.
- Leads to positive feedback loop: **beam-breakup instability** and very rapid beam loss.
- Typical **CLIC** transverse wakefields per offset in structures: **~1-100 V/pC/m/mm**
- **Hollow channel** (500 µm diameter at 3 x 1015 cm-3): **~1 000 000 V/pC/m/mm**



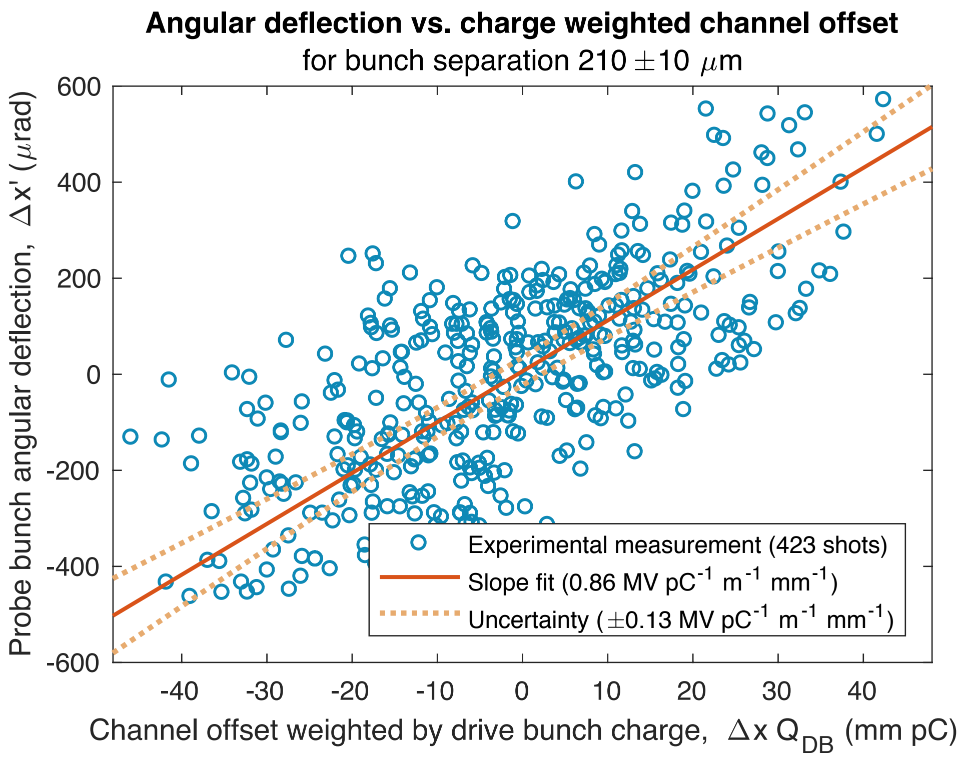
Experiments at FACET

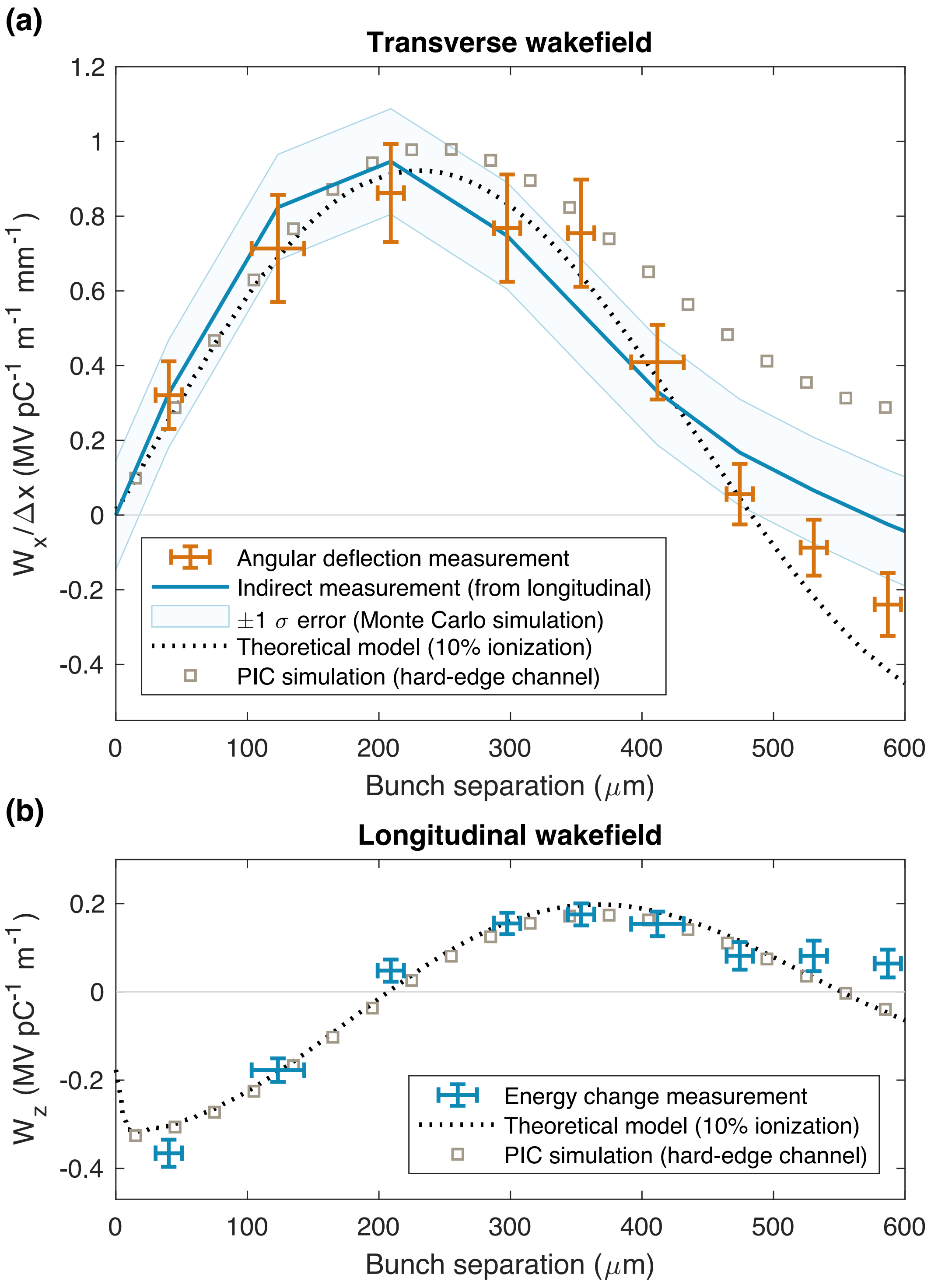
- E225 hollow channel experiment at SLAC, spearheaded by Spencer Gessner.
- Demonstrated acceleration of positrons!
- Also measured transverse wakefields.





Experiments verify presence of strong transverse wakefields





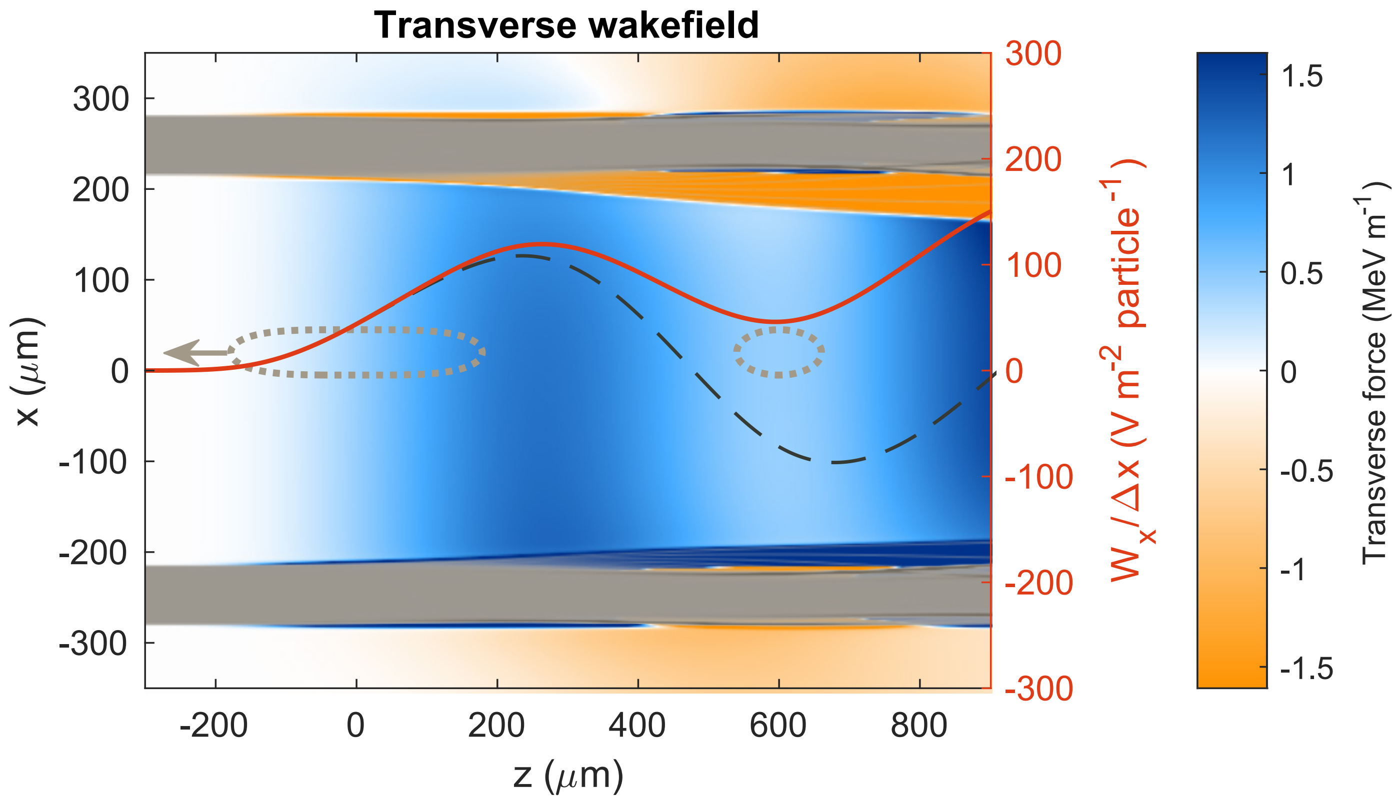
Mitigation strategies for the transverse wakefield

Distinction: interbunch vs. intrabunch wakefields

- Important distinction between the wakefield seen by a bunch
  – made by bunches ahead (inter)
  – made by itself (intra)

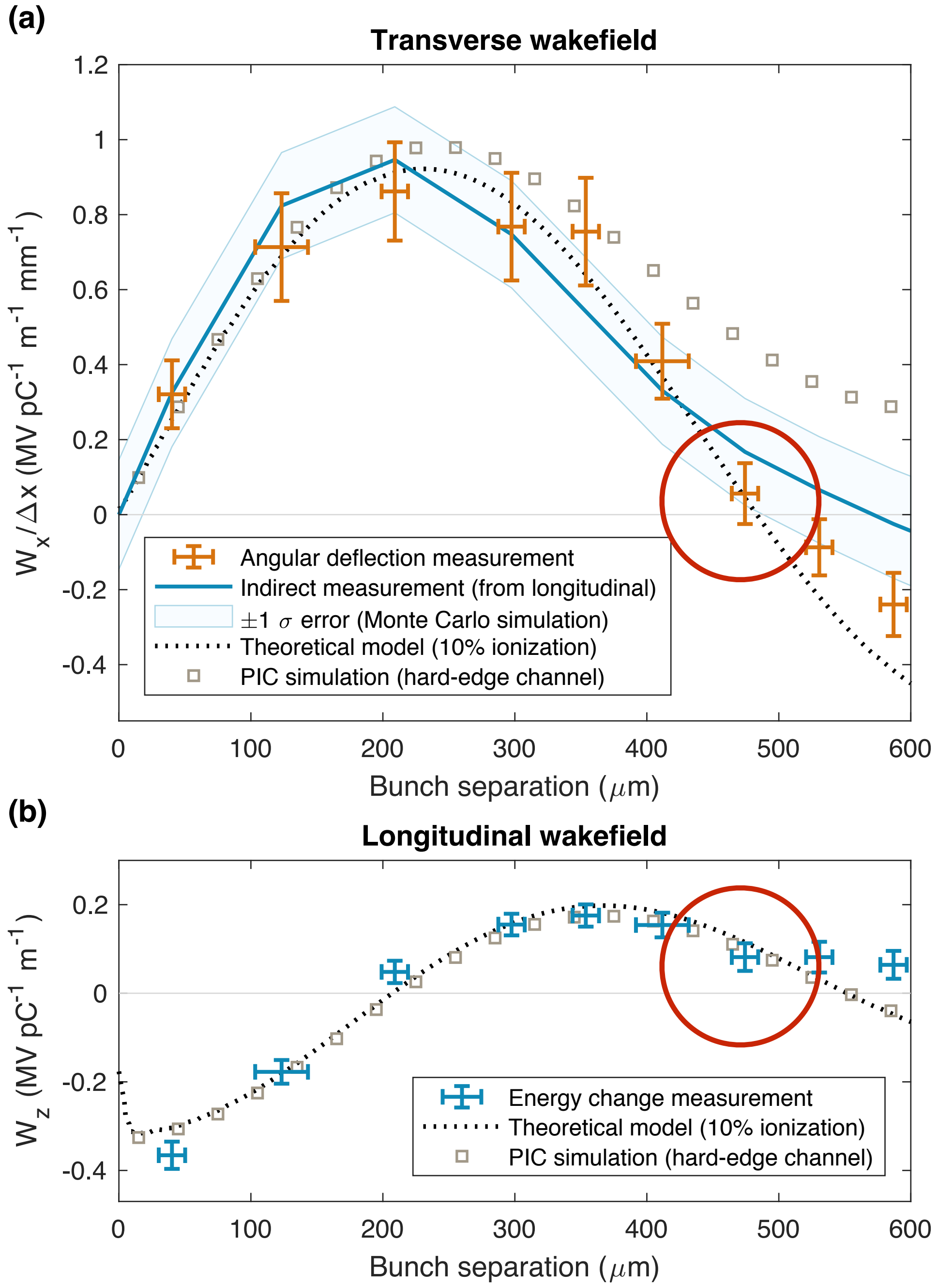
- Interbunch:
  The wakefield from bunches ahead will lead to dipole deflection: a linear growth.

- Intrabunch:
  However, a self-wakefield will depend on the bunch offset, and therefore lead to (quasi-)exponential growth.



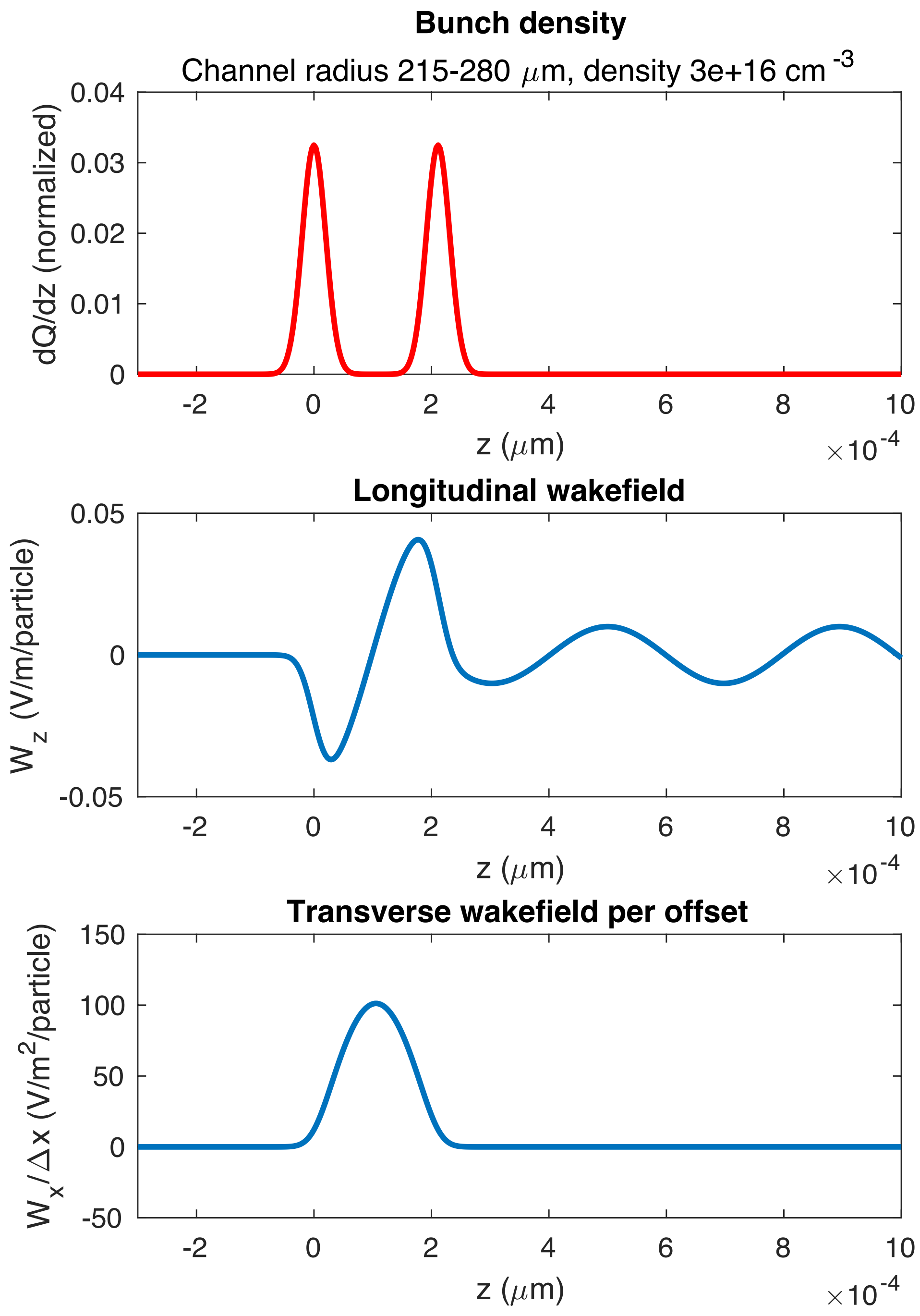
1. Choosing the right phase

- Place the witness beam on the zero-crossing of the transverse wakefield
- Still a remaining longitudinal wakefield.
- Not perfect cancellation for finite length beams.
- Does not cancel witness intra-bunch wakefield.



2. Multi-bunch cancellation

- Transverse and longitudinal wakefields have slightly different wavelengths.
- Can cancel the transverse wakefield, but not the longitudinal wakefield!
- However, still problematic for offset drive bunches.
- Still does not cancel witness intra-bunch wakefield.



3. Low-Q damping of transverse wakefields

- Tailored transverse plasma density profiles will induce resonances in the (soft) plasma wall. (thesis by Gennady Shvets)

- This can be used to damp the transverse (and longitudinal) wakefield.

- Vast parameter space to search! (channel "shape")

4. Conventional solution: External focusing

- With an energy spread, external focusing can cancel out the transverse wakefield (BNS damping).

- This is the only known way to cancel also the intra-bunch instability.

- However, since the wakefields are very strong, this would require an impractically large energy spread or focusing strength.

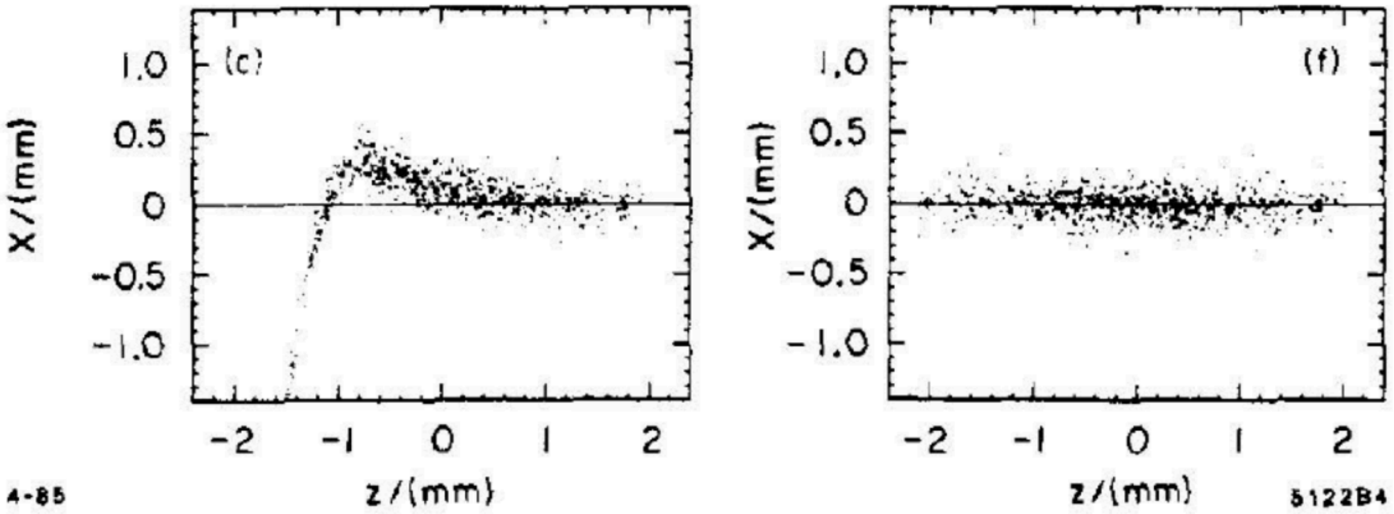
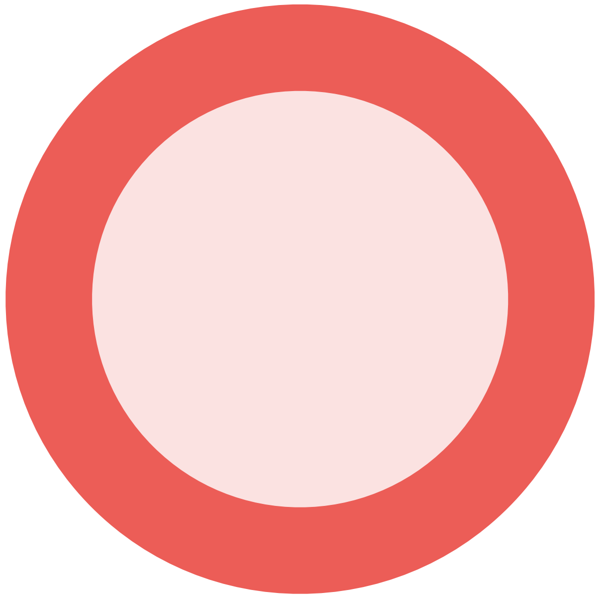


Figure 34: Multiparticle simulation of a particle bunch passing through the SLAC linac without (left) and with BNS damping (right) [36].

Image source: Sergei Nagaitsev, FACET-II Workshop

5. Unconventional solution: Near hollow channels

- (C. B. Schroeder, E. Esarey, C. Benedetti, and W. P. Leemans, 2013)
- Hollow channel with low density plasma on axis.
- Claims focusing of electrons and positrons alike
- However, not self-consistent:
  For intense low emittance beams, there is transverse beam-loading and blowout/suck-in occurs.



(6. Ultra-good alignment)

- Even an exponential growth can be controlled if the seed is small enough!

- Perhaps with LIGO-like alignment techniques, it is possible to reach sub-nm alignment jitter?

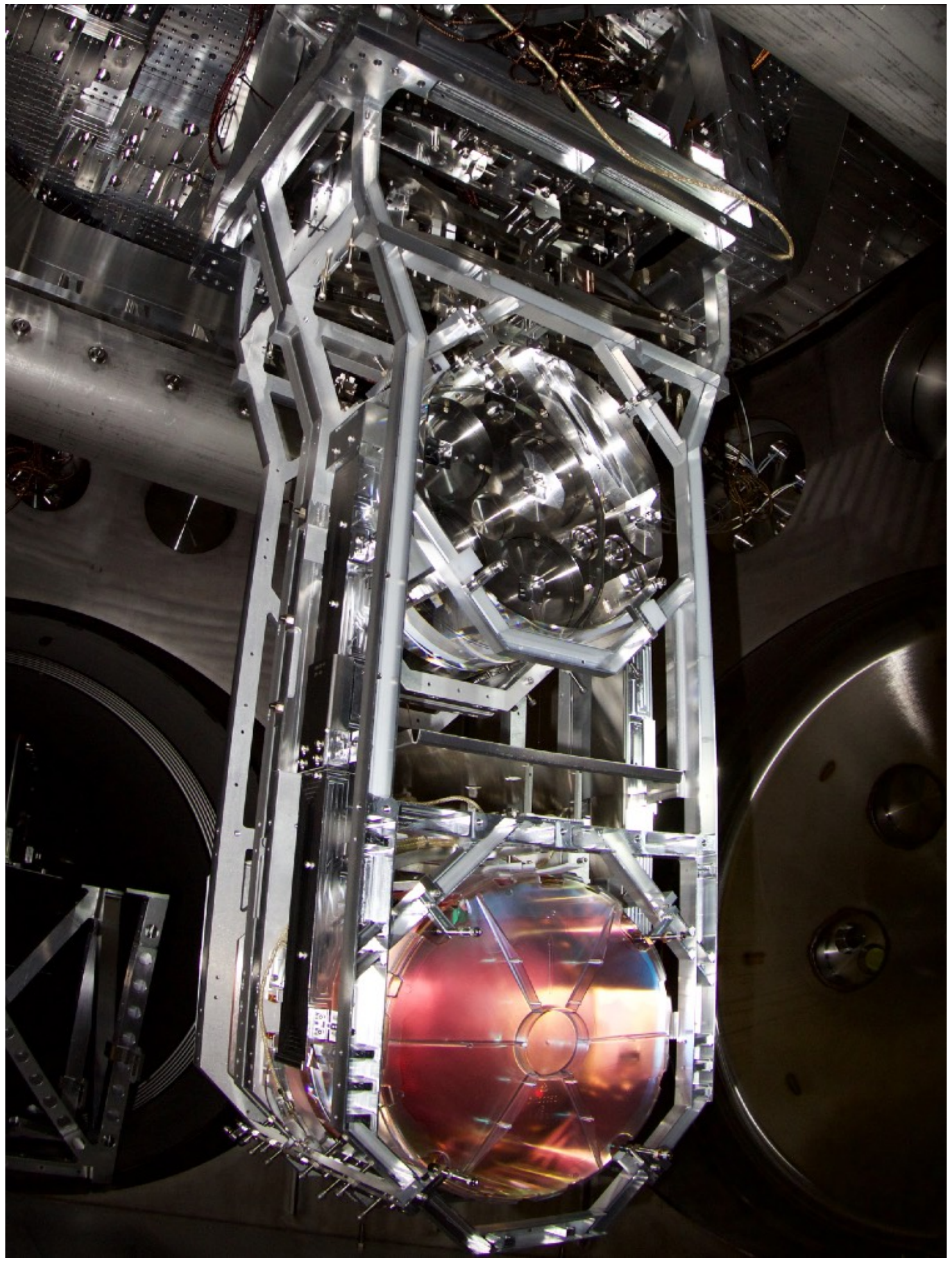


Image source: LIGO

Status quo and way forth

- No obvious solution
- Proposal: **a general staged hollow channel collider feasibility study should be attempted**, in order to actually quantify the alignment tolerance.
- This will indicate (a) how far from state-of-the-art the required tolerances are and (b) whether each of the mitigation methods help and if it is sufficient.
- Maybe a combination of all mitigations can fix it?

Thanks for listening!