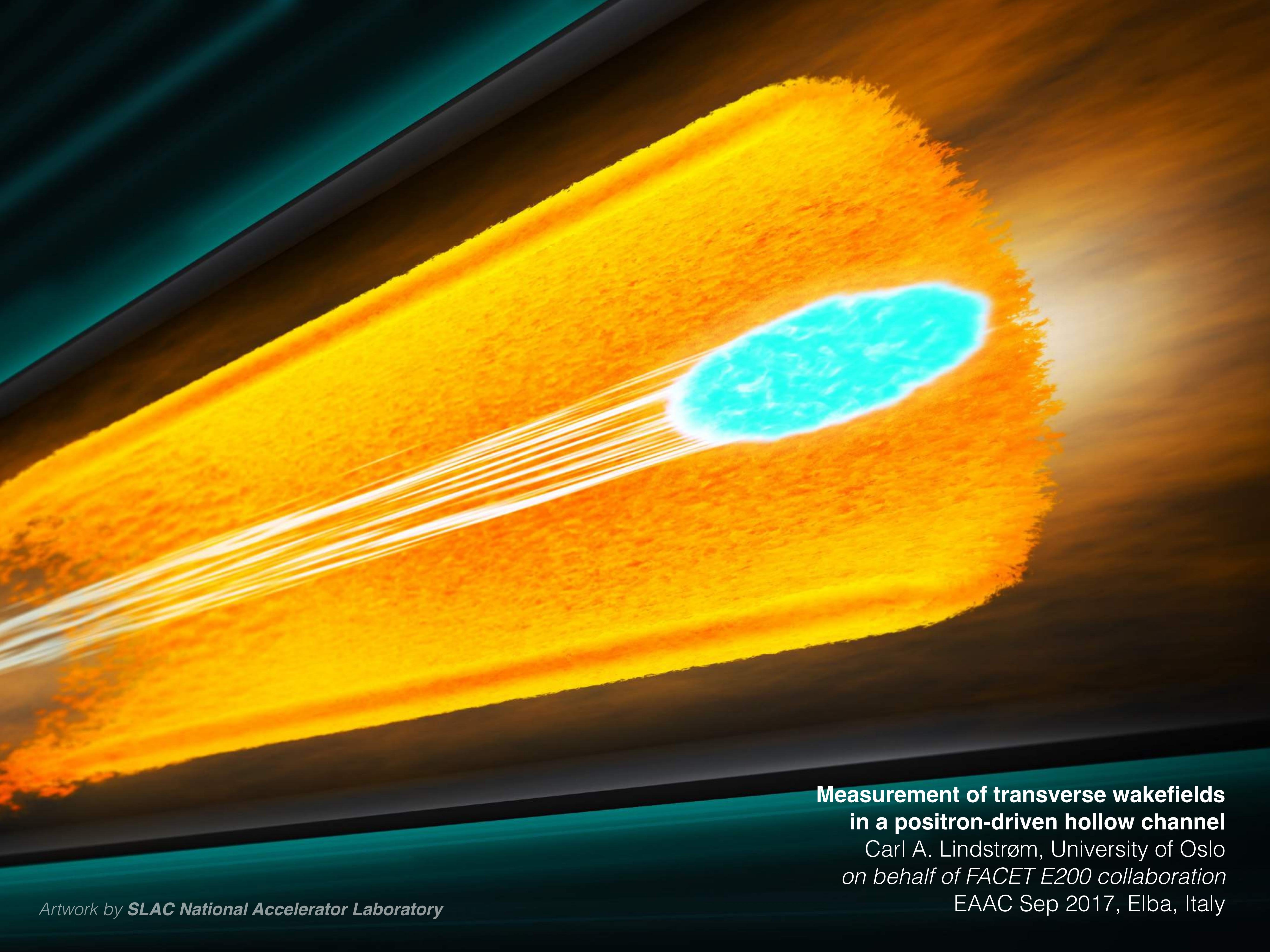

# Measurement of transverse wakefields in a positron-driven hollow channel

Carl A. Lindstrøm, University of Oslo
*on behalf of FACET E200 collaboration*

EAAC Sep 2017, Elba, Italy

*Artwork by* ***SLAC National Accelerator Laboratory***

# Measurement of transverse wakefields in a positron-driven hollow channel

EAAC 2017 – Elba, Italy – Sep 25, 2017

*on behalf of the E200 collaboration*

Carl A. Lindstrøm
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and FACET at SLAC

Supervisor: Erik Adli

# Why study the hollow plasma channel?

- Conventional plasma wakefield acceleration is promising in many respects, but it is not a complete solution for an electron-positron collider.

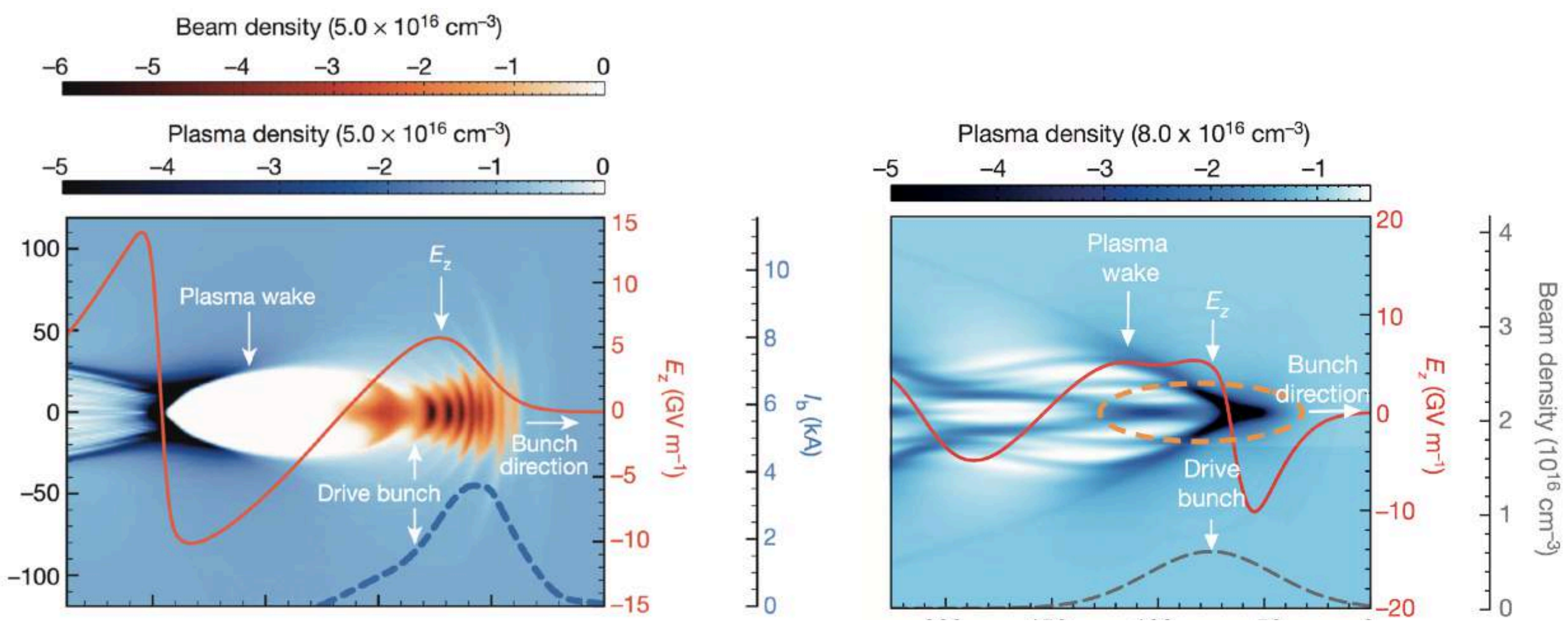



***Image source***:
M. Litos *et al.*, Nature **515**, 92-95 (2014)

***Image source***:
S. Corde *et al.*, Nature **524**, 442-445 (2015).

- Wakefields ideal for electrons cannot be replicated for positrons due to the charge asymmetry of a plasma.

- Recent work (S. Corde, FACET 2015) has shown acceleration of positrons, but emittance preservation is still a challenge.

# Why study the hollow plasma channel?

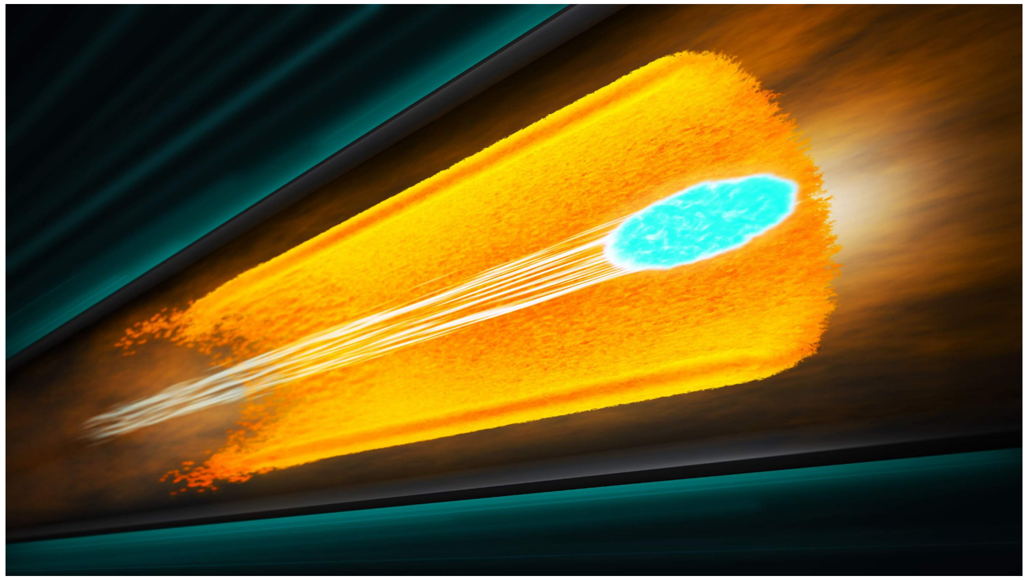


***Image source***: Artwork by SLAC National Accelerator Laboratory for Spencer Gessner.

- A hollow plasma channel is a proposed method to symmetrize the charge response and allow high gradient positron acceleration.

- Principle:
  - A positron bunch propagates <u>in the centre</u> of the hollow plasma channel
  - The channel wall is perturbed, driving an oscillating longitudinal wakefield
  - A trailing positron bunch is placed in the <u>accelerating</u> phase of the wakefield

- Benefit of hollow plasma channels: In principle, <u>no focusing forces</u> inside

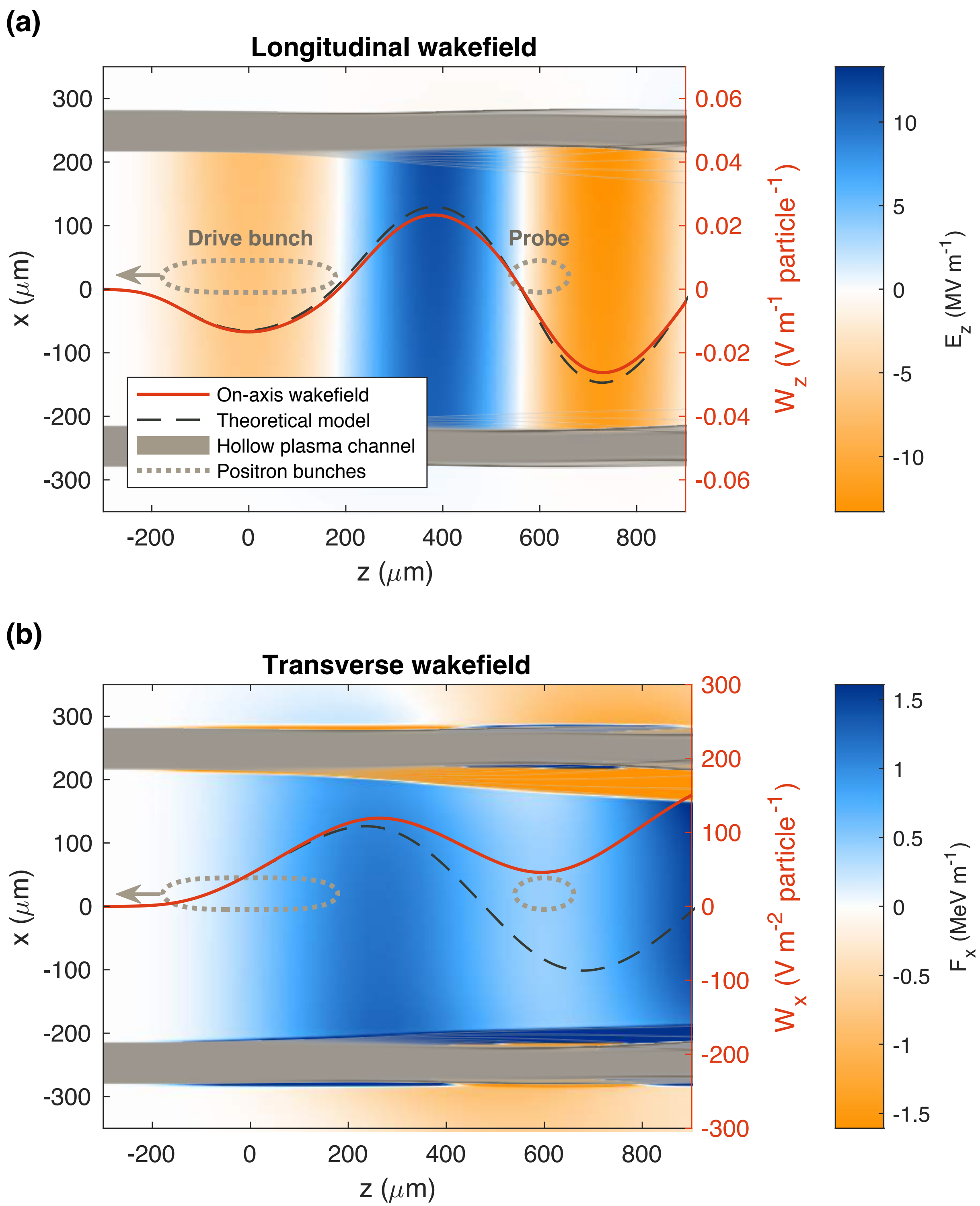
# Challenge: Misaligned beams

- Drive bunches perfectly aligned to the channel axis will give zero transverse force everywhere.
- However, misaligned drive bunches will drive **strong dipole-like (transversely uniform) oscillating transverse wakefields**.
- This leads to beam deflection and beam loss.
- This problem gets rapidly worse with stronger accelerating fields (transverse force scales faster with smaller channel radius):

| **Accelerating field per particle** | **Transverse force per particle** |
|---|---|
| $W_{\parallel} \propto \frac{1}{a}$ | $W_{\perp} \propto \frac{1}{a^3}$ |

($a$: channel inner radius)

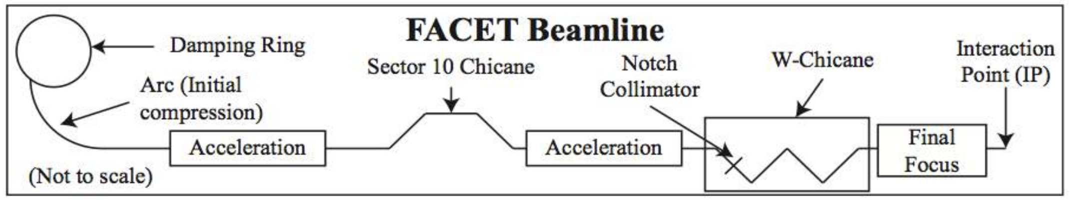
*QuickPIC simulation:*




**Note:** Linear model departs from simulation when electrons move significantly.

# FACET experiments

- The Facility for Advanced aCcelerator Experimental Tests (FACET) at SLAC operated during 2012-2016.




- – 20 GeV beam (electrons and positrons)
  – Two-bunch longitudinal structure (W-chicane)
  – Very dense: 3 nC in (20 μm)$^3$
  – ~10 TW ionization laser
  – Lithium and hydrogen/helium/argon plasma sources

- Many high impact results
  – High efficiency PWFA acceleration (Litos, Nature, 2014)
  – Multi-GeV positron acceleration (Corde, Nature 2015)
  – Trojan Horse injection (TBP, see talk by D. Ullmann)
  – Hollow channel positron acceleration (TBP, this talk)

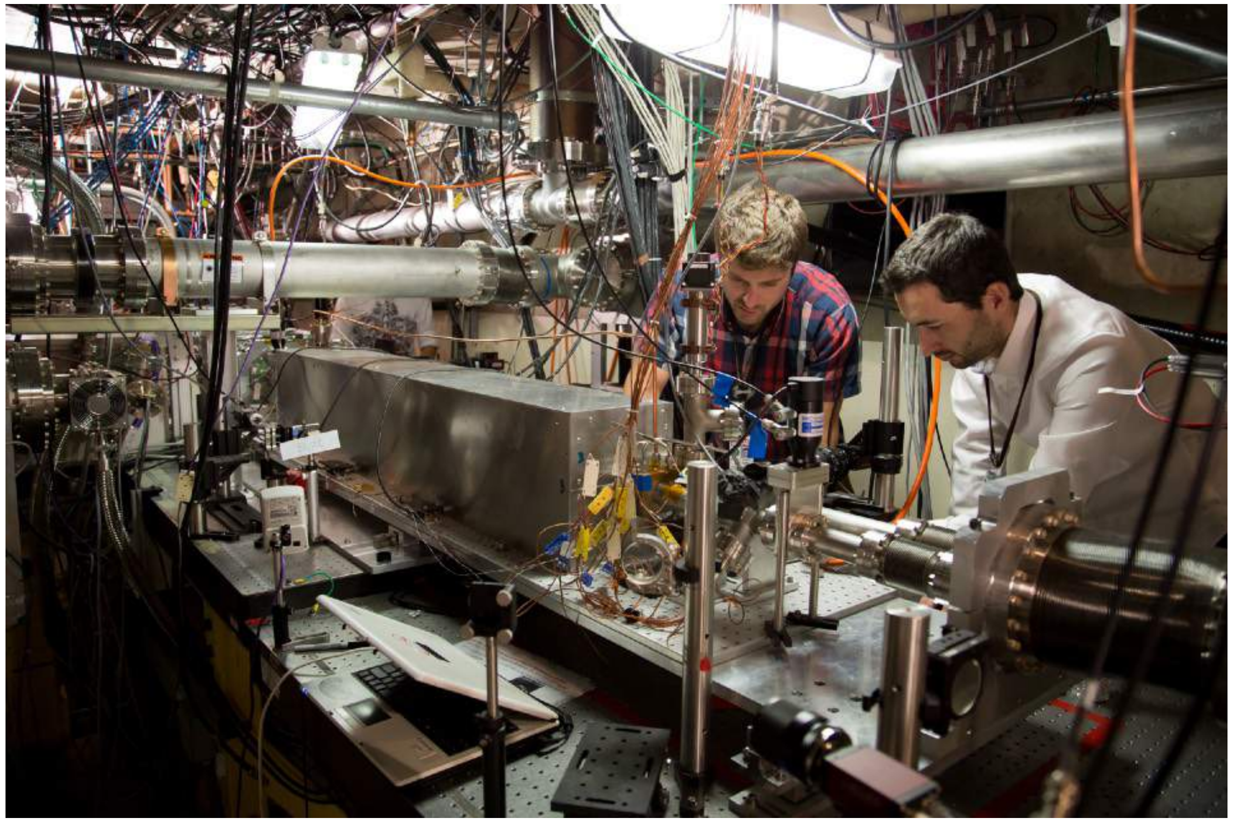
- FACET-II will continue these investigations from 2019.

FACET-II Facility for Advanced Accelerator Experimental Tests

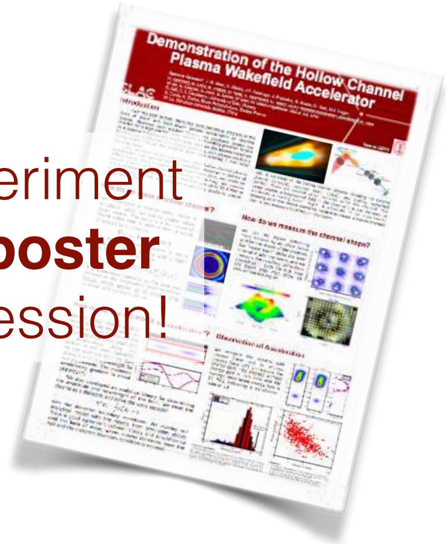

Aerial view of the SLAC linac. FACET took up the first 2 km.
***Image source:*** SLAC

# The E225 experiment

- One of these experiments was the E225 Hollow Channel experiment, **lead by Spencer Gessner**.
- **E225 successfully demonstrated acceleration** of a trailing positron bunch in a positron driven hollow plasma channel.
- Transverse wakefields were also measured in the E225 experiment.



**Spencer Gessner (left) and Sebastien Corde (right) at FACET tunnel, SLAC.**
*Image source*: SLAC National Accelerator Laboratory



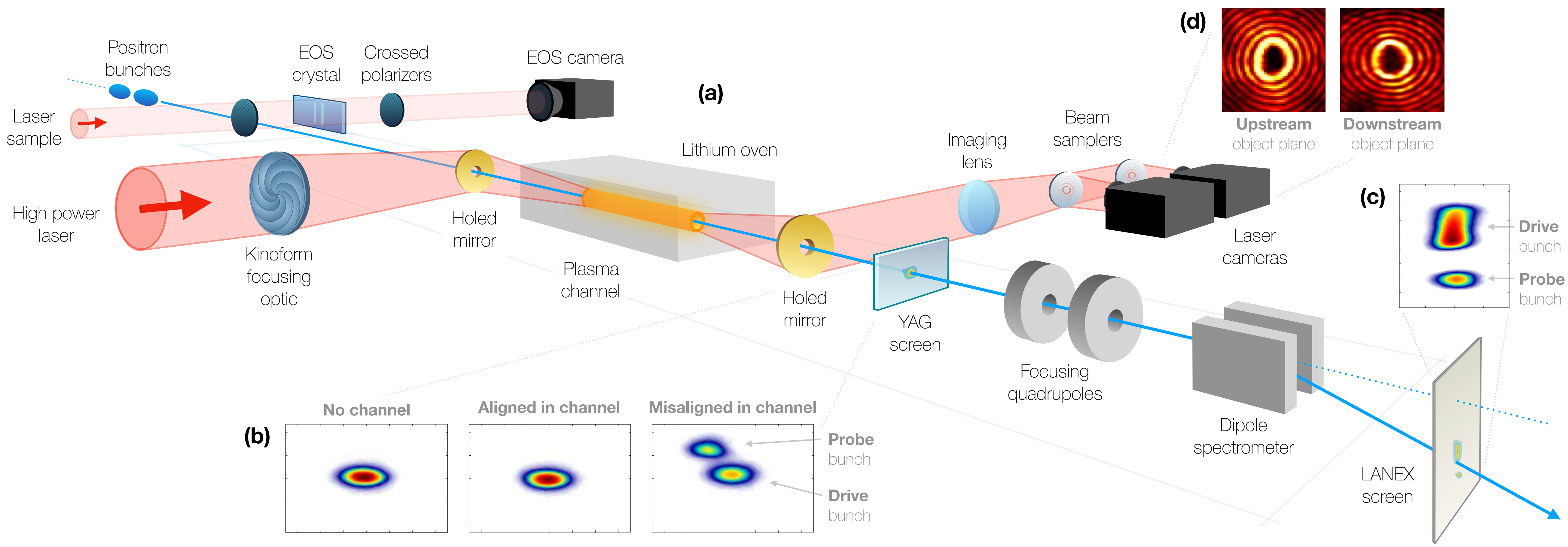

Learn more about E225 experiment from **Spencer Gessner's poster** in the **Wednesday** poster session!

# Our focus: Transverse wakefields

It is important to measure it experimentally to verify our models.

This is a starting point for designing mitigation strategies.

# E225 – Experimental setup




- The SLAC linac provided **two 20 GeV bunches**, made from one bunch using a beam notching device.
- The FACET laser (up to 10 TW, 60 fs pulses) was adjusted down to ensure **no ionisation in the channel**.
- A lithium oven was set to give a neutral gas density of $3 \times 10^{16}$ cm$^{-3}$ (but was necessarily fully ionized).

# The experiment

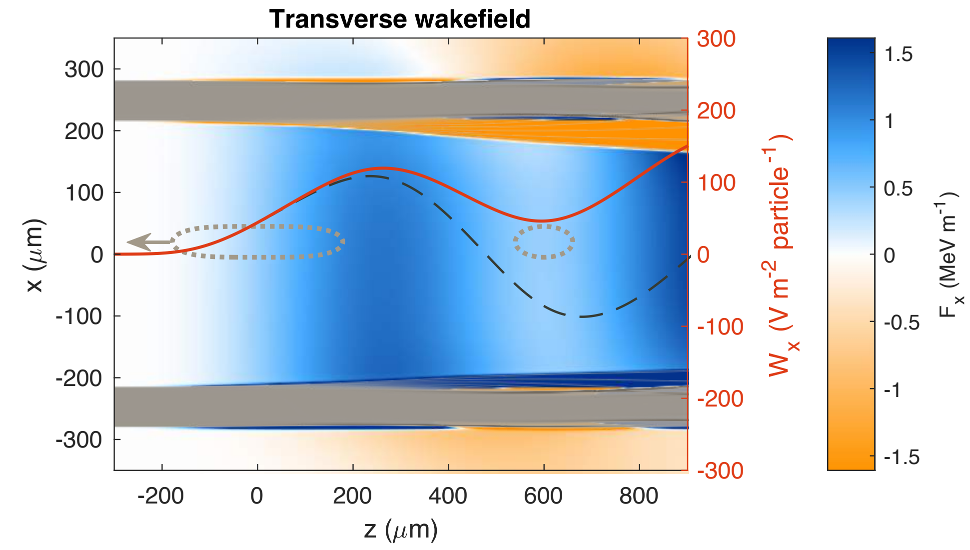
- Our **goal** was to **measure the how the transverse wakefield varied longitudinally**.

- The probe bunch observing the wakefield is deflected angularly (kicked) when the channel and the drive bunch are relatively offset.

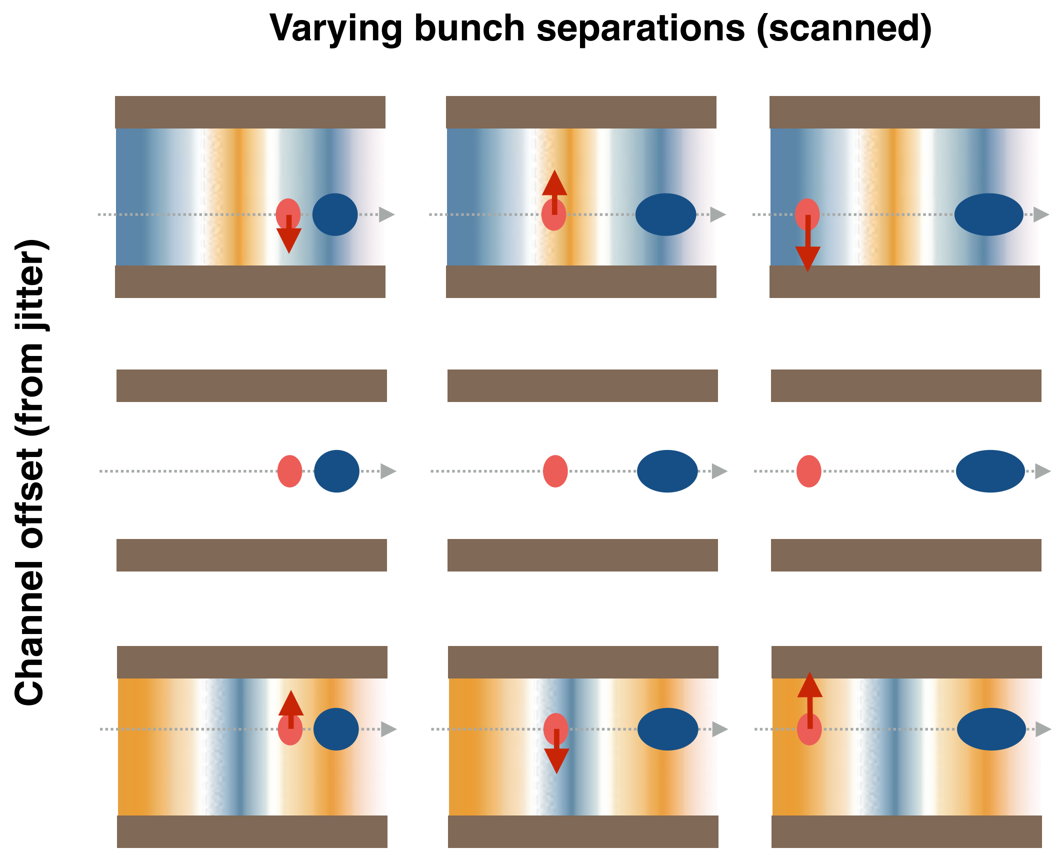
- The experiment performed was:
  **Transverse channel offsets for various bunch separations**
  – The channel (250 μm radius) was offset by transverse laser jitter (20-40 μm rms)
  – The bunch separation was varied by stretching the bunch and adjusting the notching device.

- Diagnostics:
  – Laser offset imaged downstream (**laser cameras**).
  – Probe kick measured on a **spectrometer** (in the non-dispersed plane).
  – Bunch separation measured using an **electro-optical sampler**.

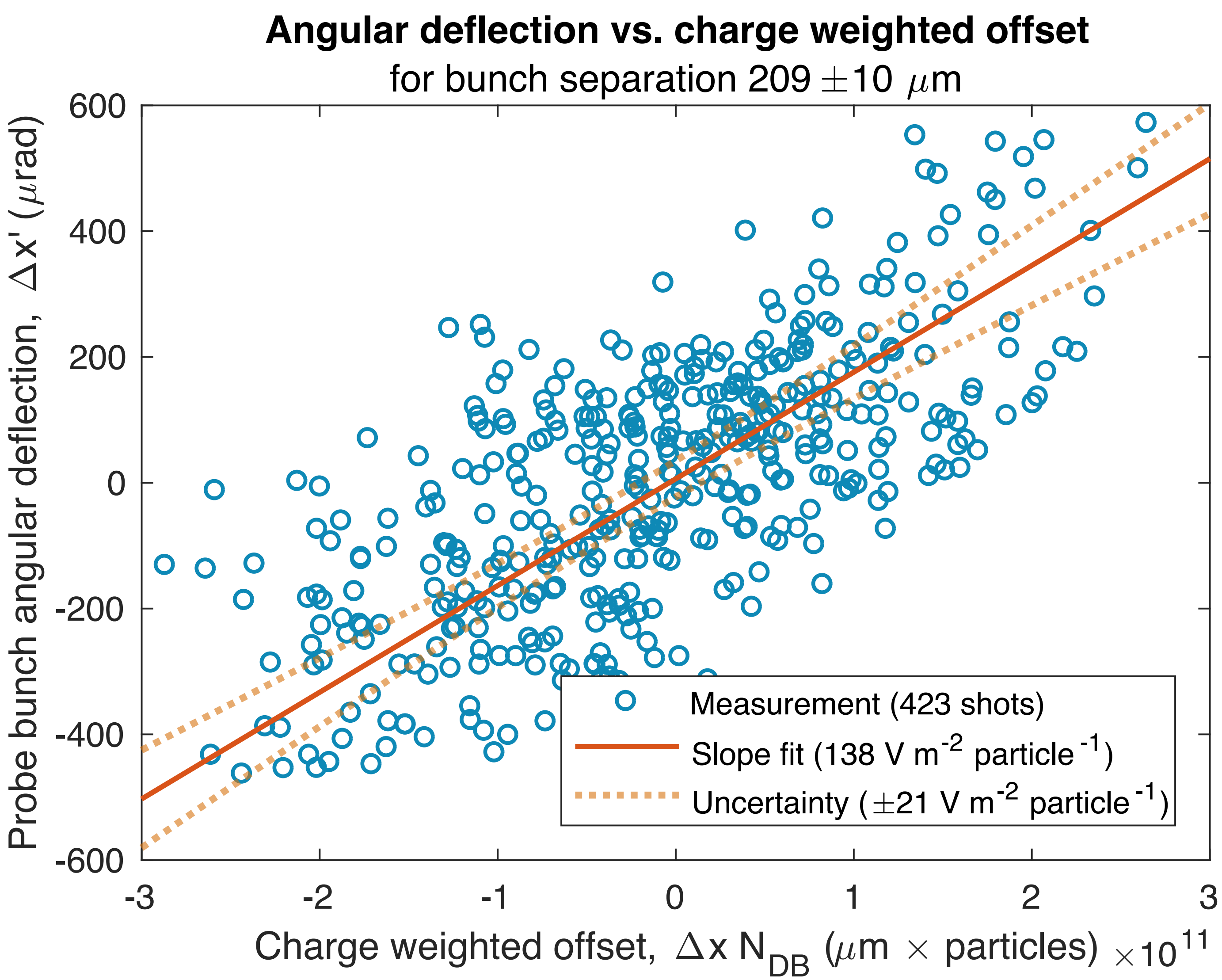
Prediction:




Experiment (2D “scan”):



# Observed data (deflection vs. channel offset)




- For each bunch separation, a correlation between channel offset and probe bunch angular deflection was observed.
- The **slope of this correlation is proportional to the transverse wakefield per offset** at the z-location of the probe bunch.

# Another independent measurement

- An independent measurement is beneficial (due to high complexity).

- It is possible to estimate the transverse wakefield per offset from the measured longitudinal wakefield, via the Panofsky-Wenzel theorem and the linear model.

*Panofsky-Wenzel theorem:*

$$\frac{\partial W_x}{\partial z} = \frac{\partial W_z}{\partial x}$$

$\xrightarrow{\text{Integrate (++)}}$

*Estimate of transverse from longitudinal wakefield:*

$$\frac{W_x(z)}{\Delta x} \approx -\frac{\kappa(a,b)}{a^2} \int_0^z W_z(z')dz'$$

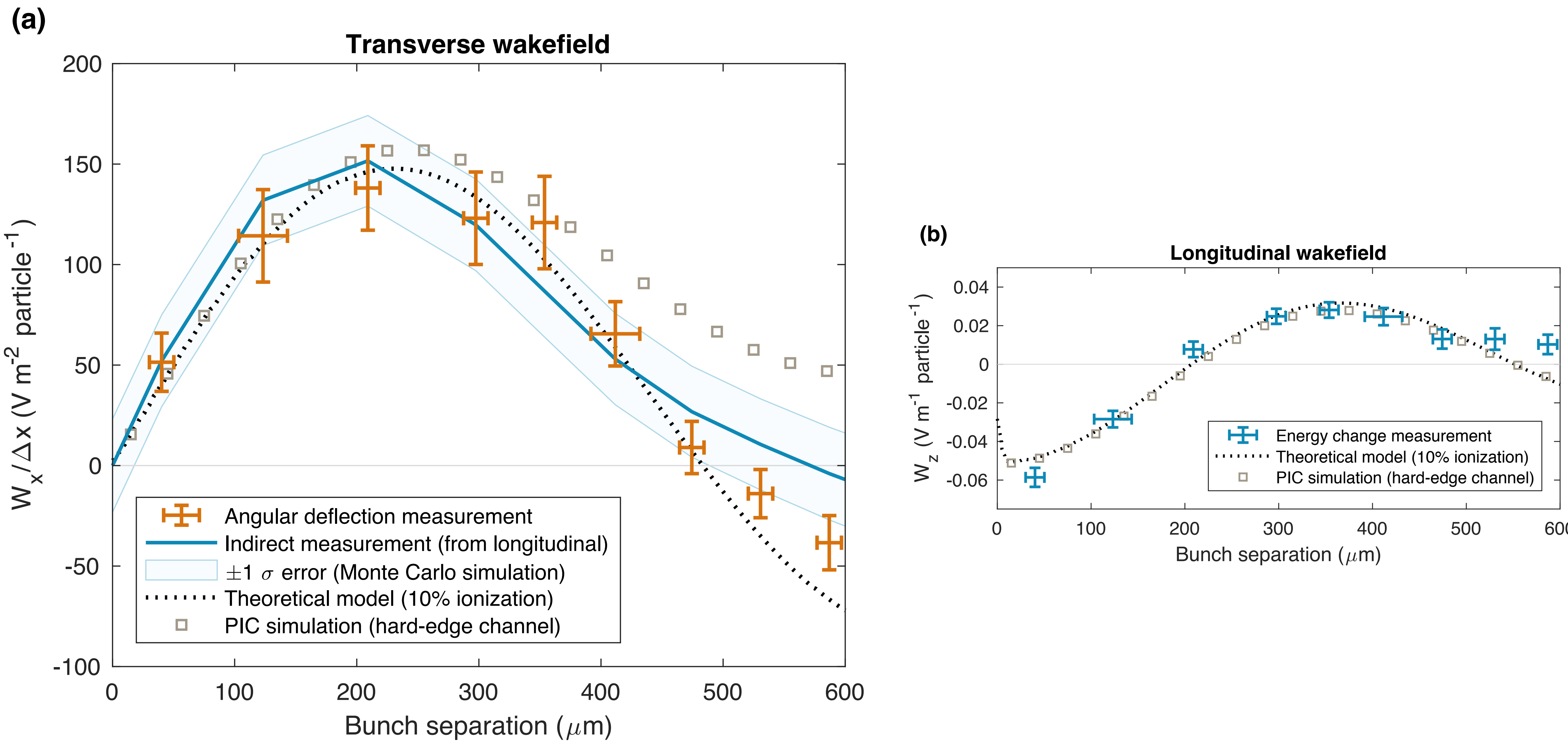
*where* $\kappa(a,b) = \frac{4\chi_\perp^2 - 2}{\chi_\parallel^2 - 1}$

- Not perfect: Assumes linear model, breaks down far behind the drive bunch.

- Provides verification of numerical calibrations, etc.

- The longitudinal wakefield was measured by the energy change of the probe bunch (on a spectrometer).

# The final results




- Plasma density determined by a wavelength fit (10% ionization = $3\times10^{15}$ cm$^{-3}$)
- Good fit, largely consistent with theory. Some discrepancy at larger separations.

# Discussion and implications

- **Overall, the measurement agrees with the theoretical models.**

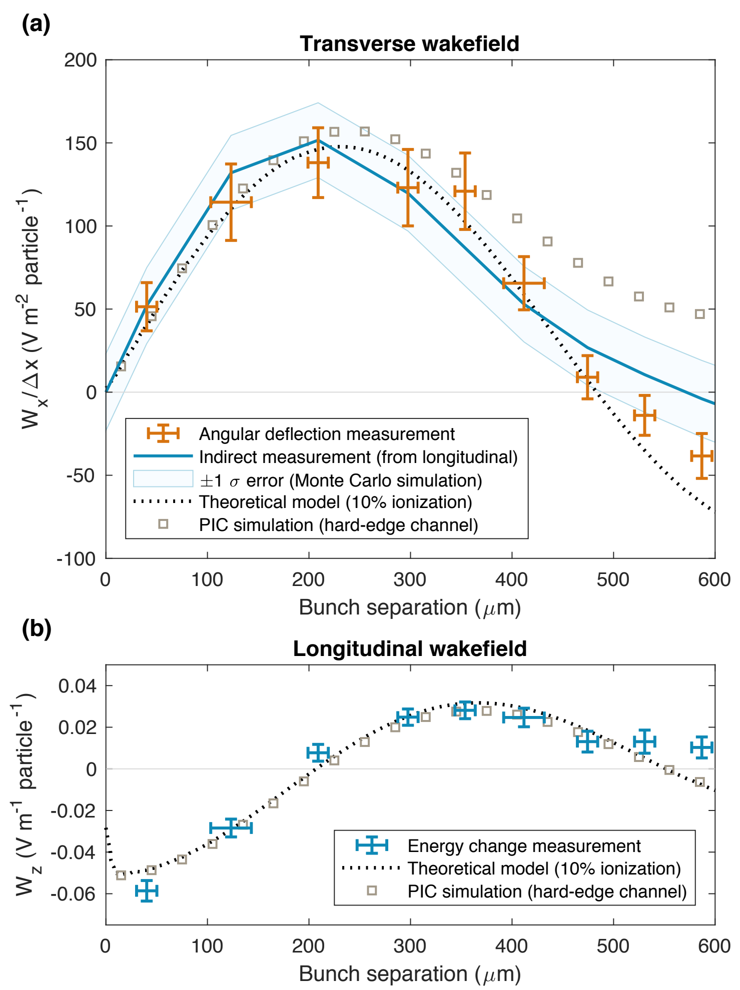
- Simulation-based parameter scans indicate that the <u>discrepancy</u> at large separations can possibly be <u>explained by using a more complex radial plasma shape</u> (not possible to exclude with our diagnostics).

- Implication: There is indeed a strong transverse wakefield.

- Exploiting plasma non-linearities may be the way forward to designing mitigation strategies. Suggestions include:
  - Nearly hollow channel
  - *Alternatively:* External focusing (BNS damping)

  (many good proposals by Schröder et al., BELLA/LBNL)

- For a more detailed report and discussion on our result: we will shortly be submitting a manuscript to PRL.



Thanks for your attention!