

## Answers to PAC Questions

1) Beam Evolution in Hollow Plasma Channel for Guided Positron Acceleration

**Modified title:** Can we obtain stable, high efficiency, high gradient positron acceleration in a hollow channel

2) Two Stage Cascaded High-Transformer-Ratio Plasma Wakefield Accelerator

**Modified title:** Are loaded transformer ratios  $> 2$  possible without beam shaping?

Chan Joshi, Mark Hogan and Wei Lu

# 1 Positron Acceleration in a hollow channel

1.1 What's the needed range of beam ellipticity (in emittance and beam size)?

We have simulated  $\frac{\sigma_x}{\sigma_y} = 2$  and  $\frac{\varepsilon_x}{\varepsilon_y} = 2$ .

Larger ratio of beam ellipticities are currently being investigated – may be better for larger radius channels or for reducing the stable beam formation length.

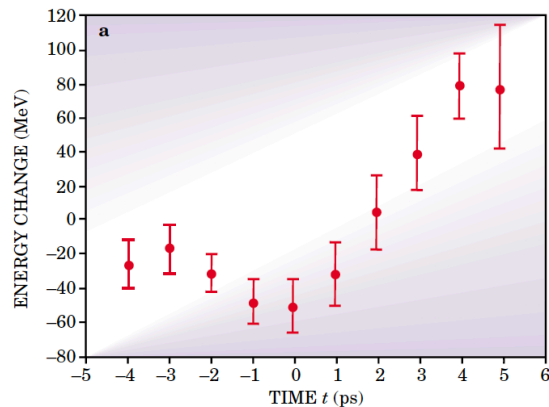
1.2 Is it easily available?

These are realistic parameters that the FACET-II is expected to achieve.

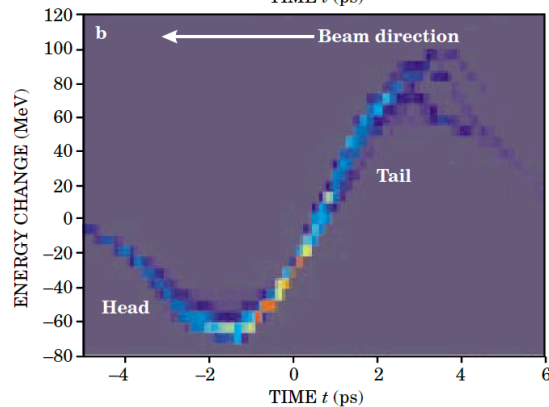
If the actual parameters are different we will adjust the channel diameter using a different kinoform optic.

## 2 Large Transformer Ratio Experiment

- 2.1: Can you give a historical perspective of TR in both **linear** and nonlinear case?

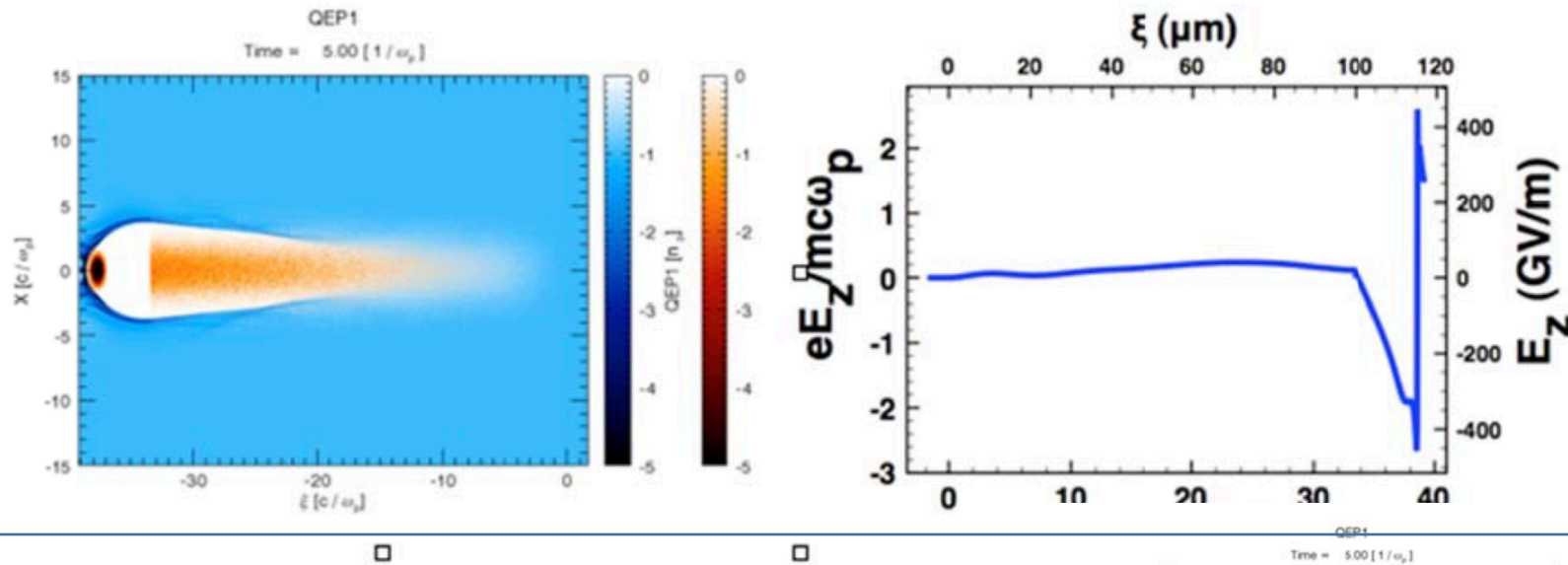


Energy gain of 80 MeV in  
Energy Loss  $40 \pm 20$  MeV  
Unloaded TR of 2 in linear-quasi-linear regime



Ref. B. Blue et al. PRL 2002, First demonstration of positron  
Acceleration in plasma wake. PRL 2002  
Expt. Done on FFTB  
@ SLAC

# High TR wake produced by a shaped and Gaussian bunch using NL-wakes



High loaded TR using a triangular Shaped pulse  
Loaded TR of  $> 7$

Loaded TR of 3 using a Symmetric Gaussian pulse

Loaded TR of 3

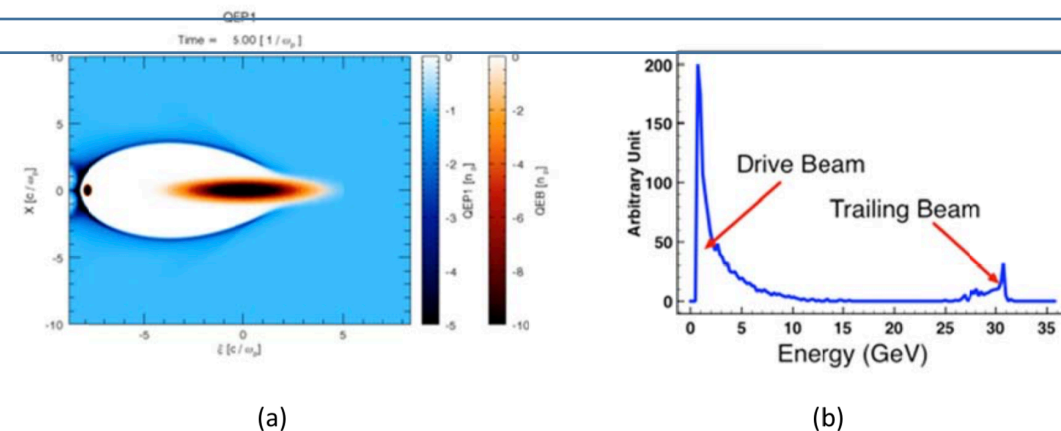
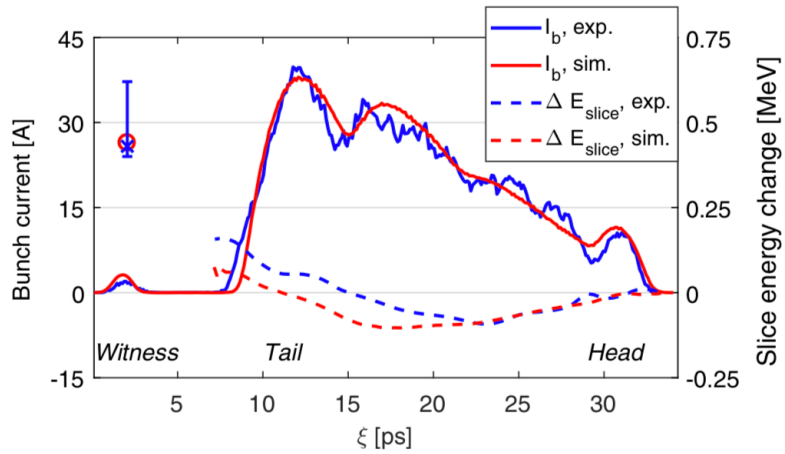
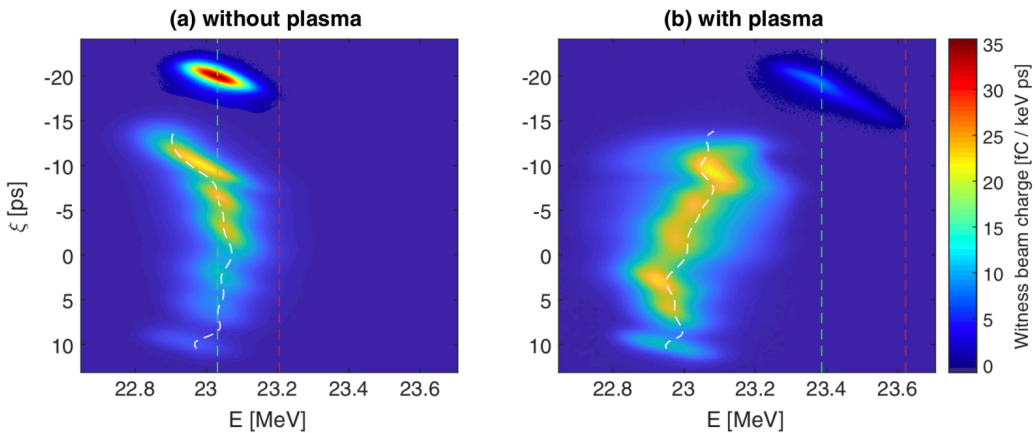


Figure 3.3. Generation of fully loaded transformer ratio wakes of 3 using the FACET-II beam. (a) shows the beams and the wake and (b) shows the energy spectrum of the two beams after just 26 cm. Drive Beam Parameters:  $Q = 4$  nC,  $\sigma_r = 5$   $\mu\text{m}$ ,  $\sigma_z = 20$   $\mu\text{m}$ ,  $\epsilon_N = 5$  mm mrad,  $E = 10.0$  GeV. Trailing Beam Parameters:  $Q = 0.288$  nC,  $\sigma_r = 2$   $\mu\text{m}$ ,  $\sigma_z = 2$   $\mu\text{m}$ ,  $\epsilon_N = 1.0$  mm mrad,  $E = 100$  MeV. Distance between two beams: 93.5  $\mu\text{m}$ . Plasma Density  $n_p = 2.0 \times 10^{17}$   $\text{cm}^{-3}$ . The beams propagate in a pre-ionized plasma. (Courtesy Weiming An, UCLA)

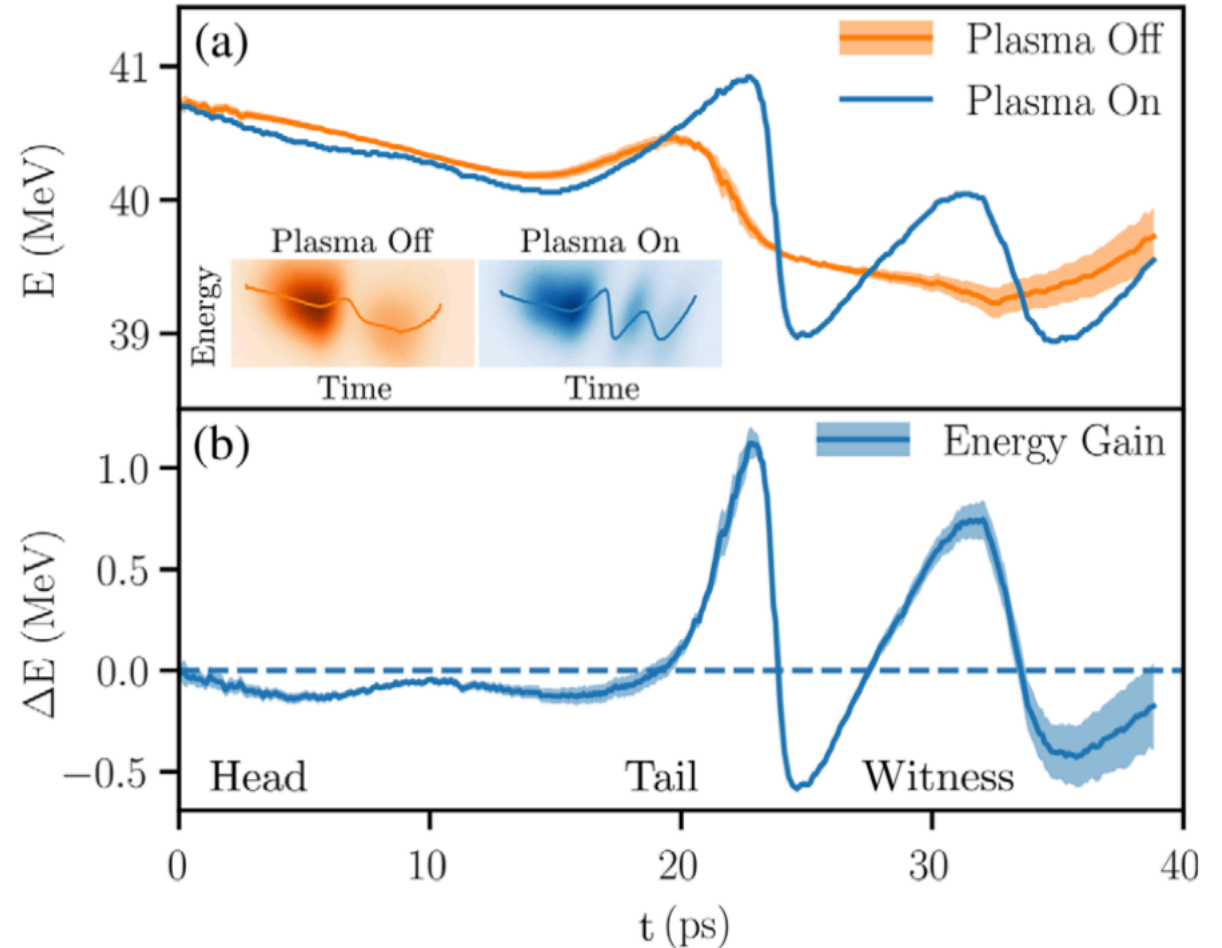
Recent work on unloaded TR using **shaped beams** at other LABS.



PHYSICAL REVIEW LETTERS **121**, 064801 (2018)

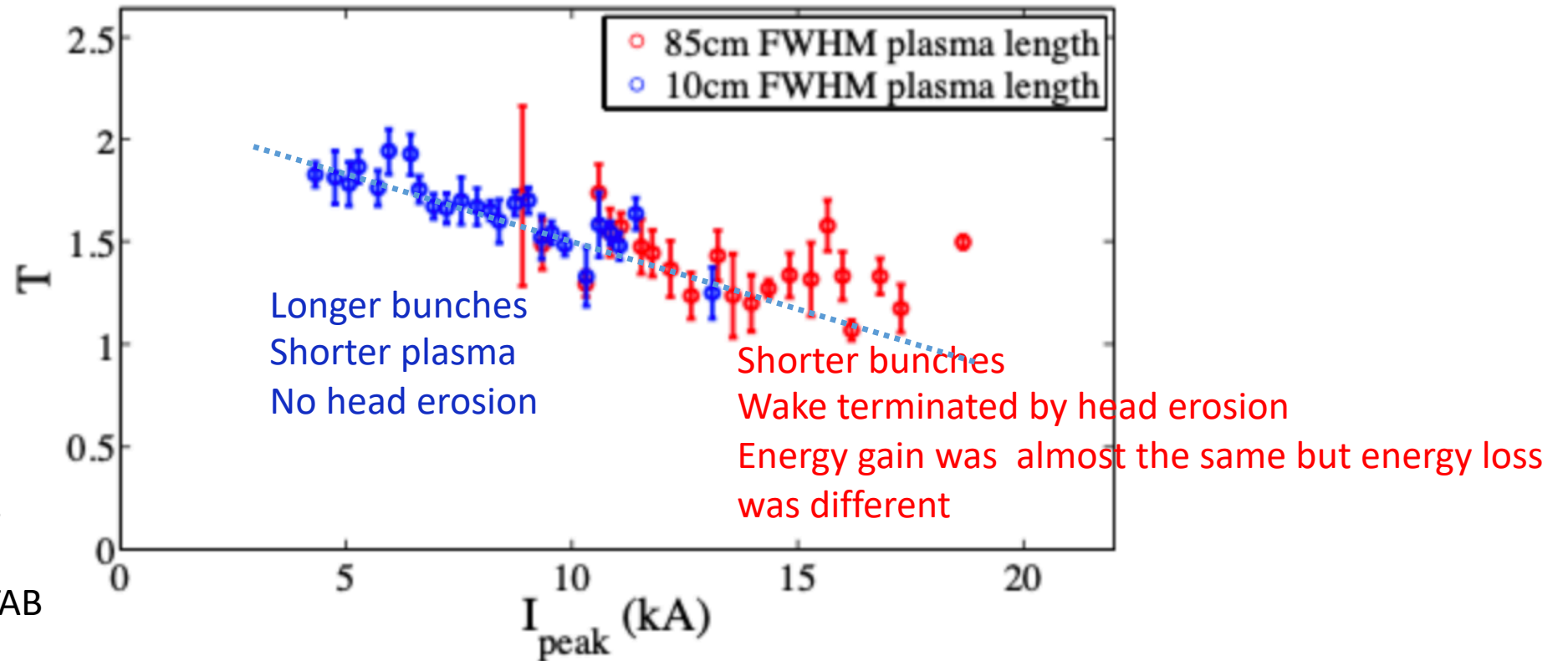


DESY Experiment



AWA/ UCLA Expt. PRL 2020

What has been seen to-date? Example E167 on FFTB  
Unloaded transformer ratio increased with longer Gaussian bunches



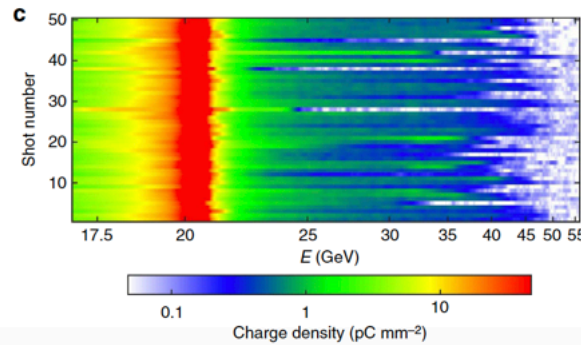
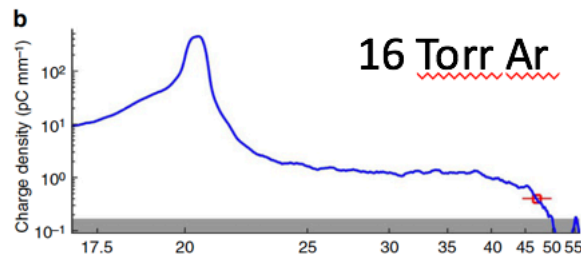
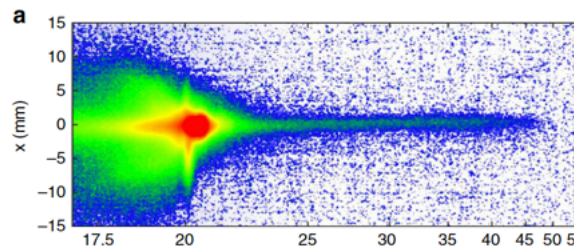
Ref. I. Blumenfeld PhD  
thesis 2008, Stanford U.

I. Blumenfeld et al. PRSTAB

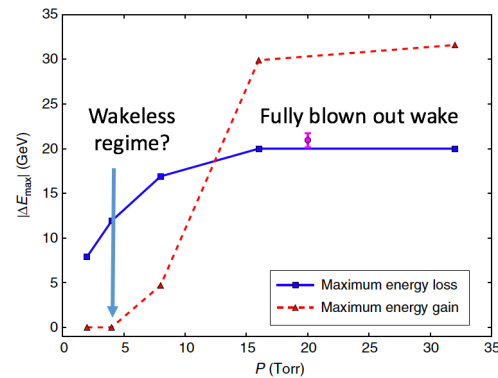
Figure 5.15: The Measured Transformer ratio vs. peak current for  $L=85\text{cm}$  and  $L=10\text{cm}$ .

# Unloaded and loaded TR work at FACET (unintentional)

## Energy Gain and Loss in Beam Ionized Ar plasma

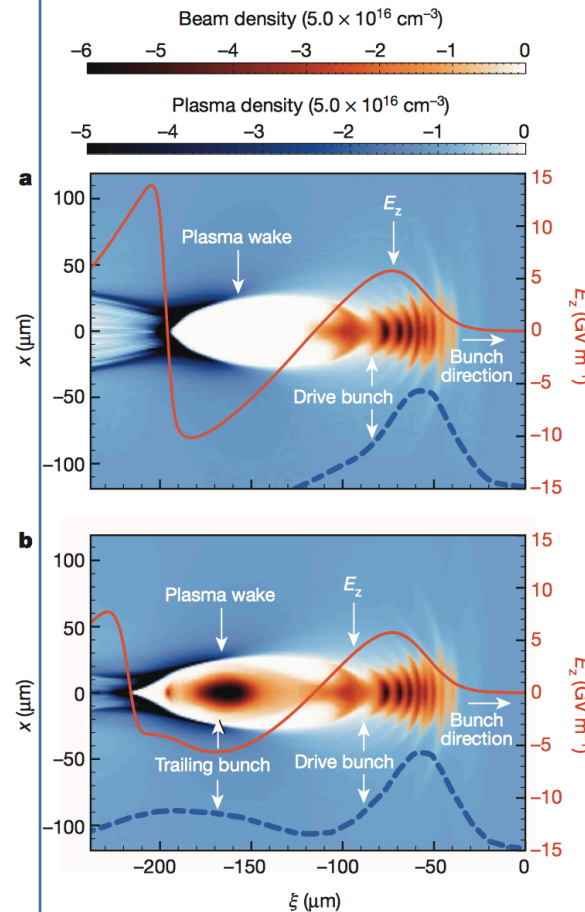


S. Corde Nature Comm

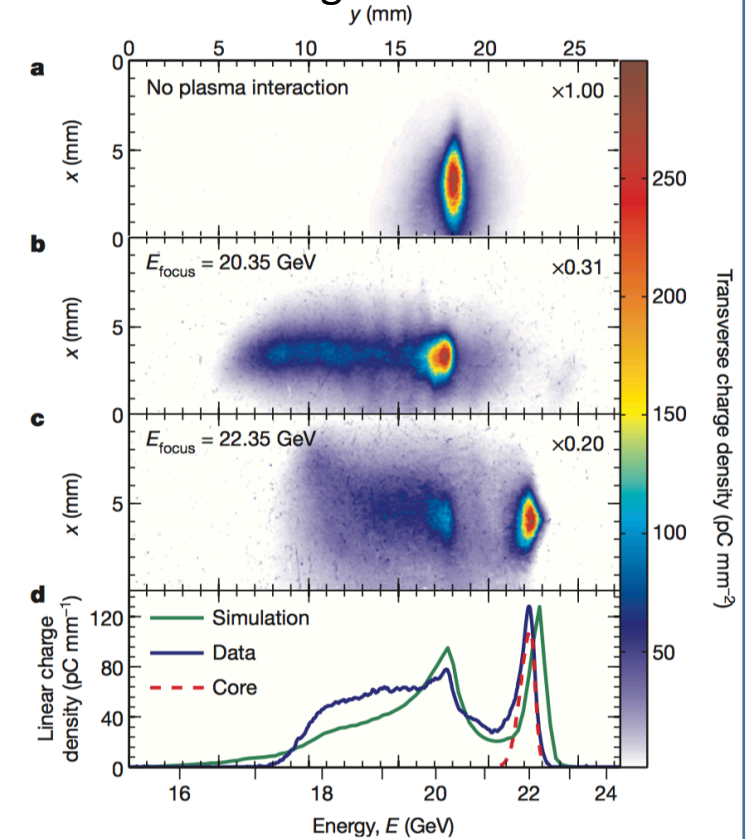


An unloaded TR of Between 1.3 and 1.5 Was observed. Possibly limited by Beam head erosion that shortens and Steepens the bunch

## Energy gain and loss in a two bunch configuration



M. Litos et al. Nature 2014



Long trailing bunch depleted the accelerating field reducing The loaded TR of  $\sim 1$

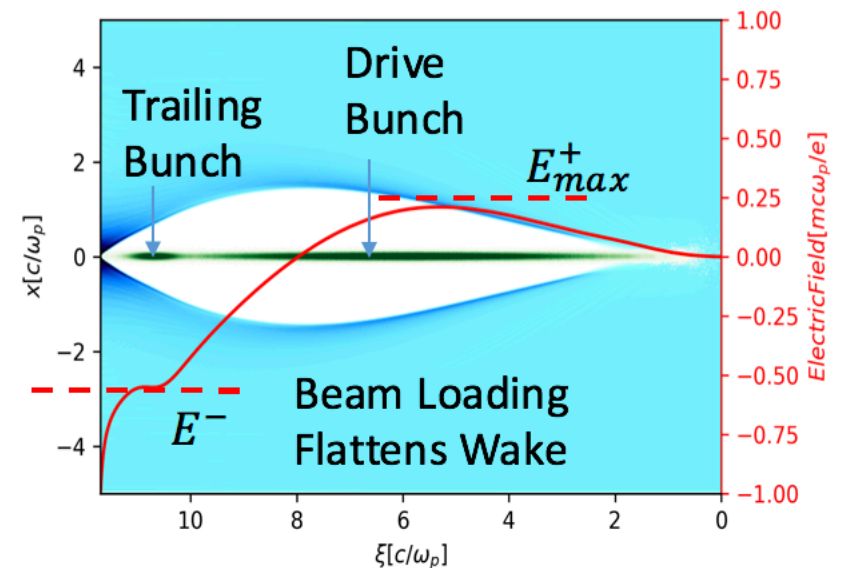
## 2.2 What TR do you want to achieve?

- In Wei's proposal he shows simulations for a loaded TR of 2.6.
- **Success** would be defined as any configuration that gives a loaded **TR of >2 with Gaussian beams.**
- i.e. the trailing beam electrons gain twice the energy compared to the maximum energy lost by the drive electrons.

$$n_{p1} = 1.765 \times 10^{16} \text{ cm}^{-3}$$

$$Q_d = 2.7 \text{ nC}, \sigma_z = 80 \mu\text{m}, \epsilon_n = 7.5 \mu\text{m}$$

$$Q_w = 250 \text{ pC}, \sigma_z = 10 \mu\text{m}, \epsilon_n = 7.5 \mu\text{m}$$



$$TR = \frac{E^-}{E_{max}^+} = 2.6$$



## 2.2 Is TR meaningful as an isolated figure of merit?

- As the noun TR implies, plasma acts as a transformer. Conservation of energy requires that- the voltage of the secondary bunch is increased at the expense of its current.
- A PWFA-LC design based on a higher loaded TR will require fewer stages to attain the same final energy thus making the overall footprint smaller and the average accelerating gradient larger.
- So it all depends on how difficult the staging turns out to be. Transverse beam instabilities due to beam alignment will lead to both a loss of energy due to betatron radiation and loss of charge due to the hosing instability.

What is the proposed experimental configuration?

Q: What is the relationship to the approved two beam experiments (E300/E301) and can this be combined with that experiment?

**See next page for the sketch**

There is synergistic relationship between E300 and E301.

Wei's initial thought was plasma and beam parameters the same as in E300 except drive beam width of 80  $\mu\text{m}$  and plasma length of 4-5 m.

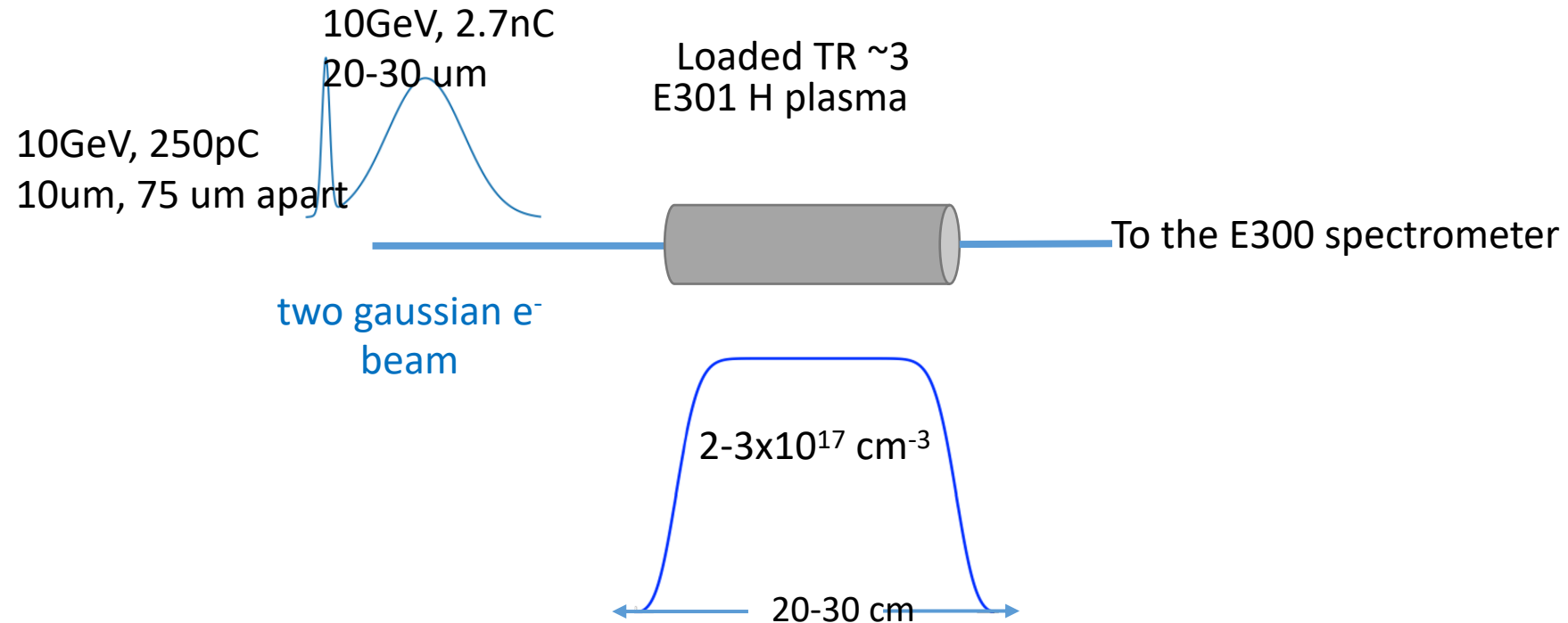
Such long bunches have not been considered as yet.

There is not enough space in FACET-II experimental hall to insert a 4-5 m long plasma oven.

So we scale the beam and plasma parameters (guided by experimental experience of E167).

# Possible Experimental set-up for stage 1 using the E301 hydrogen plasma

The revised parameters ask for a 20-30  $\mu\text{m}$  drive bunch and a  $2-3 \times 10^{17} \text{ cm}^{-3}$  plasma. Unfortunately, this design is incompatible with the E300 plasma oven design. But it is perfectly compatible with E301

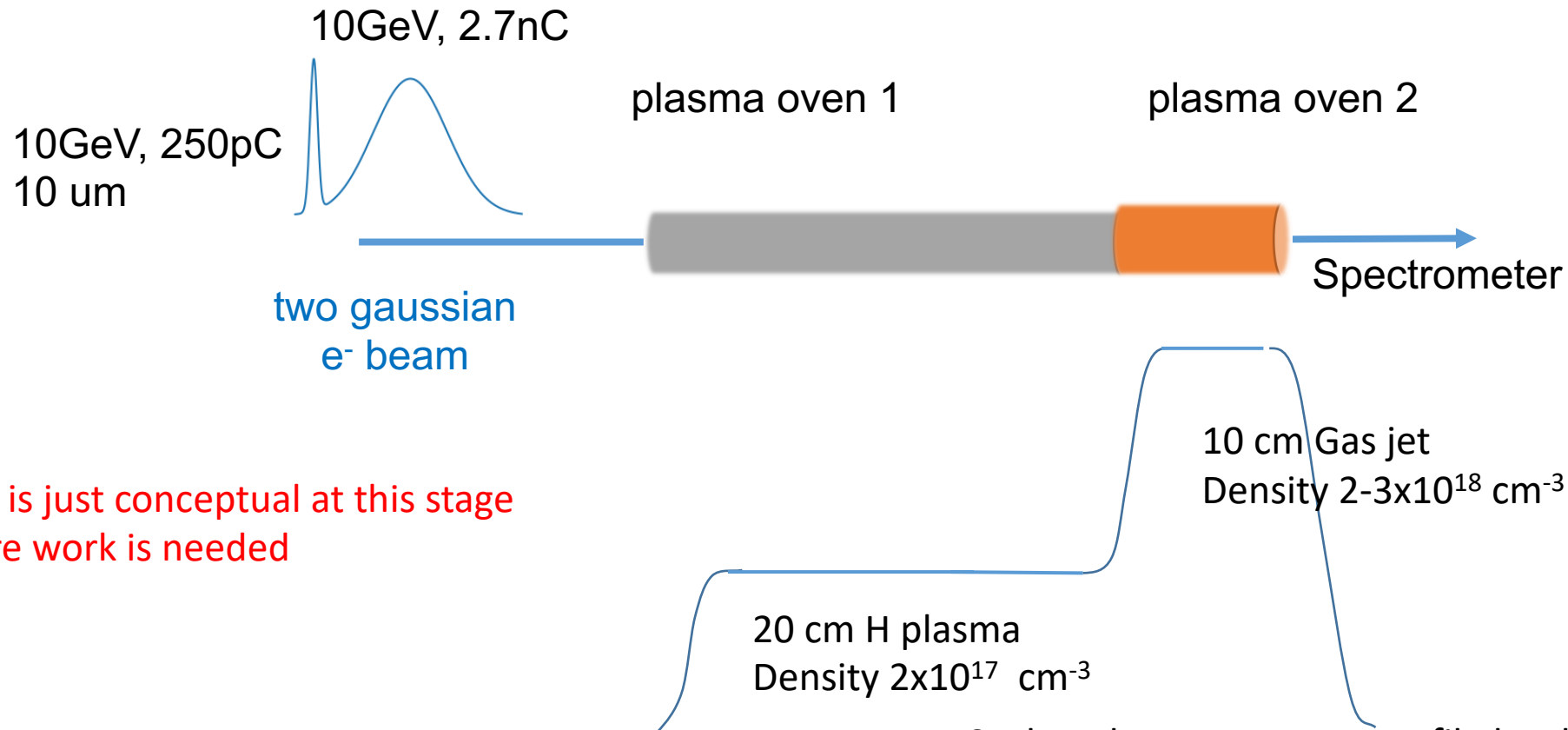


Parameters are now in the ballpark of what has been studied for E300/E301

Experimental design will be refined in optimization study between beam and plasma as was done for E300 (6-12 months)

# Two Stage Cascaded High-Transformer-Ratio Plasma Wakefield Accelerator

➤ Optional layout



This is just conceptual at this stage  
More work is needed

Such a plasma up-ramp profile has been demonstrated  
On a mm scale by Navid.