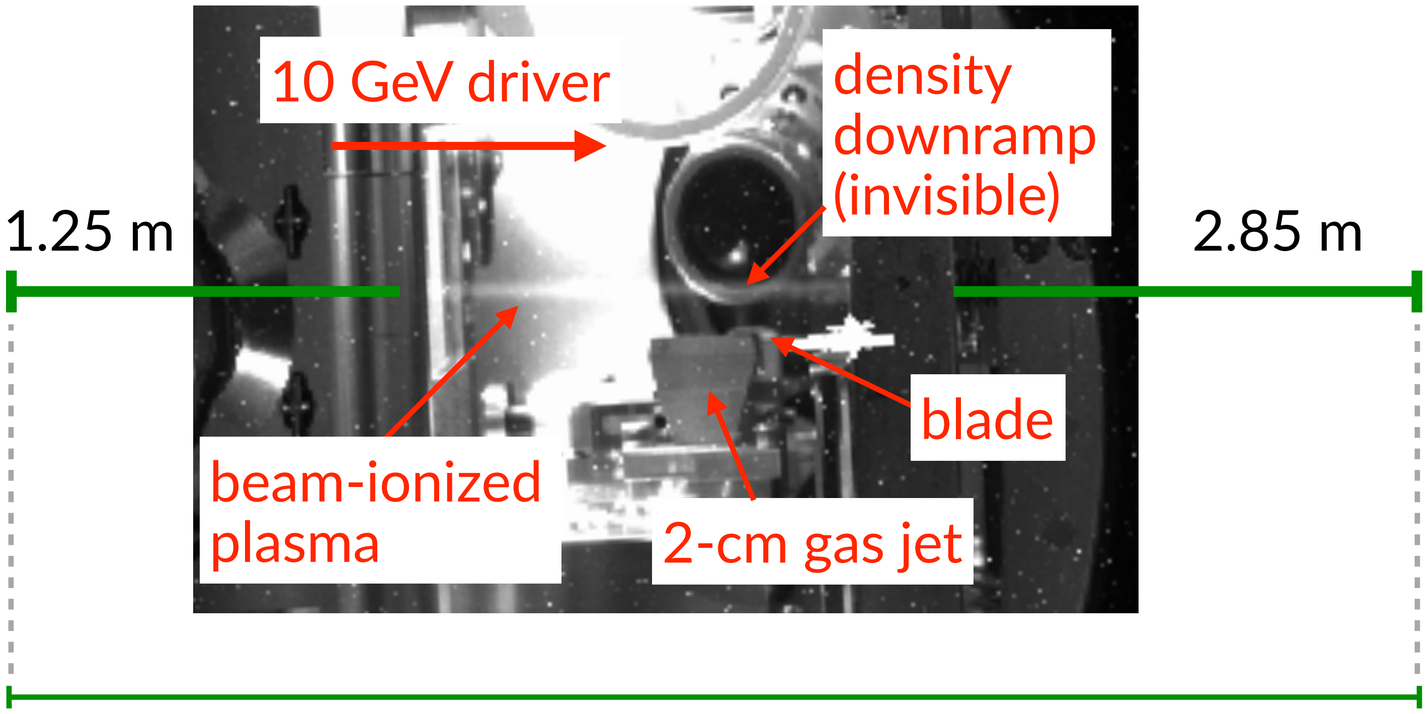
E304 discussion

Chaojie Zhang
(E300 collaboration)

Aug 22, 2024

Experimental setup

1-4 Torr H2 static fill, gas jet backing pressure 100 psi



March run:

First saw downramp injected electrons

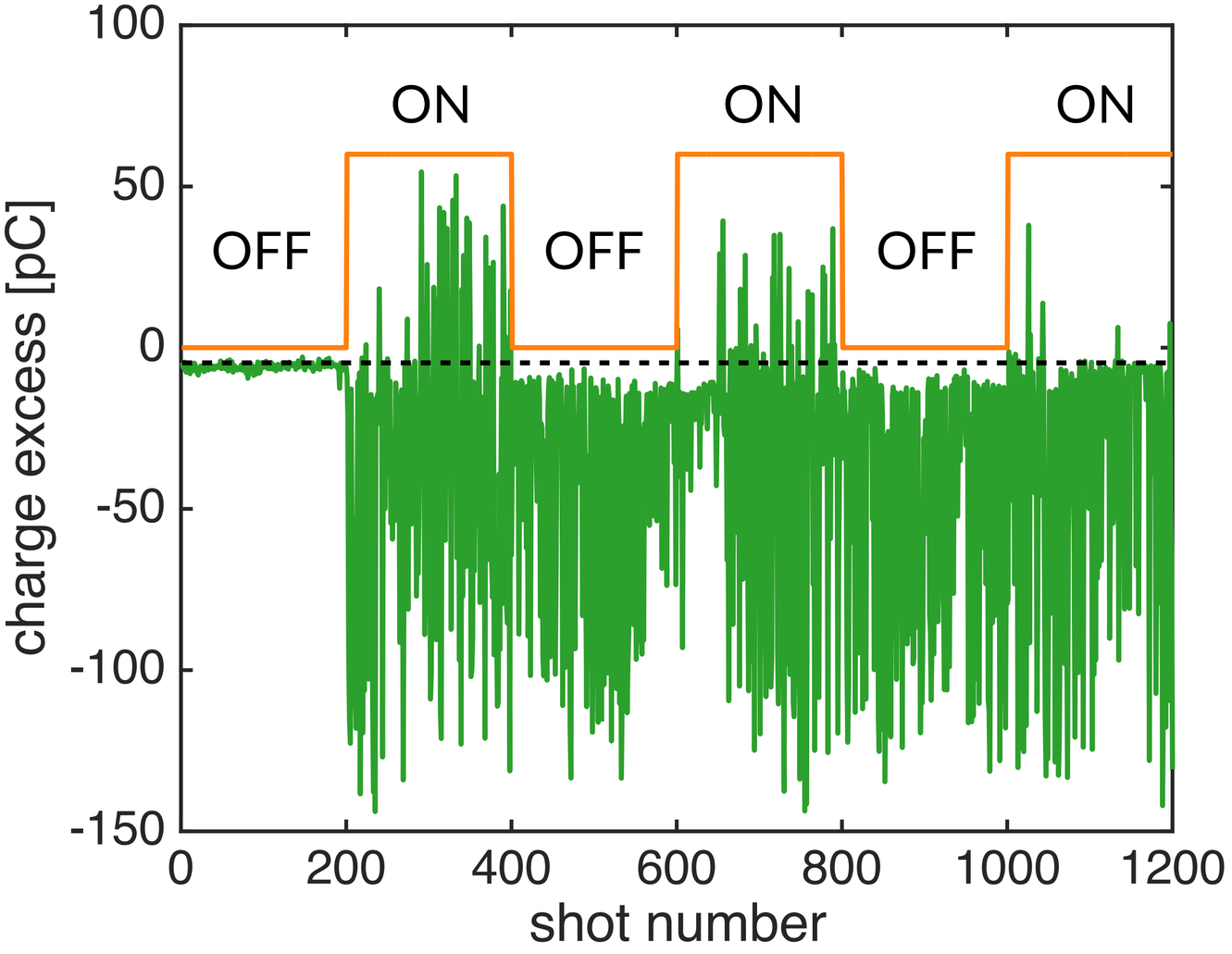
June run:

More systematic optimization + Higher energy gain + emittance measurement + more data

From the measurements what we would like to understand

- Loaded transformer ratio
  - Drive beam energy depletion
  - Highest energy gain (with small energy spread)
  - To what extent is the wake loaded
- Small emittance
  - may have saturated after >100 betatron cycles
- Brightness booster
  - emittance (measured)
  - peak current of the injected bunch

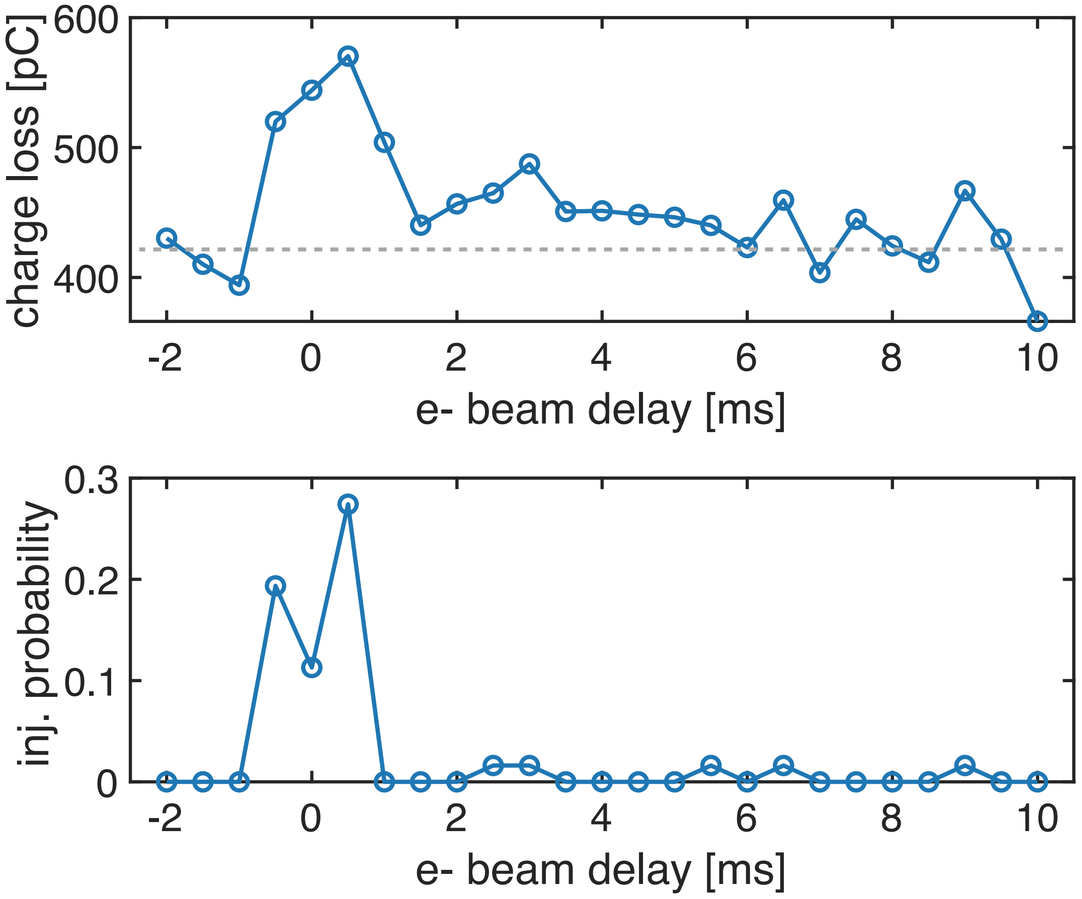
Confirm it's downramp injected bunch



- max charge loss ~140 pC (due to drive bunch energy depletion)
- 57 shots show charge excess
- charge excess means injection
- measured charge excess is the lower limit of injected charge due to charge loss of the driver

E304_06335, static fill 3.4 Torr, gas jet backing pressure 100 psi, e- beam height 2 mm. Quad 1.8 GeV, Dipole 3.5 GeV, OFF/ON scan

Gas jet delay scan



The delay of the e- beam with respect to the gas jet firing time was scanned from -2 to 10 ms (negative: e- beam arrives earlier).

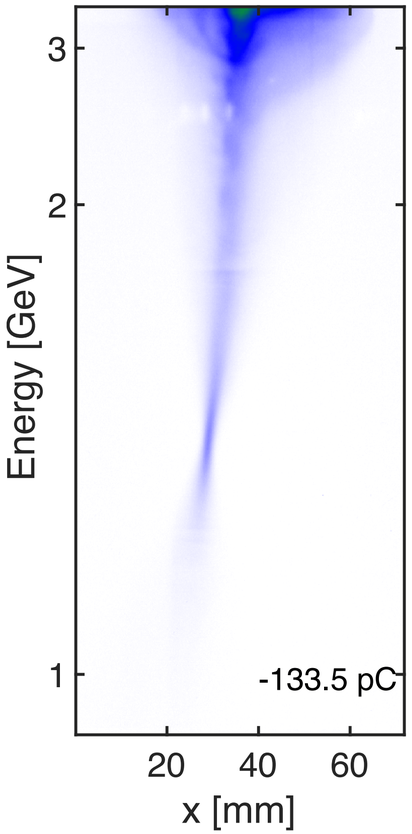
The opening time of the gas jet is 1 ms (to limit gas load).

Only when the timing is right, we saw downramp injection signals- another piece of evidence for attributing the observed signals to downramp injection.

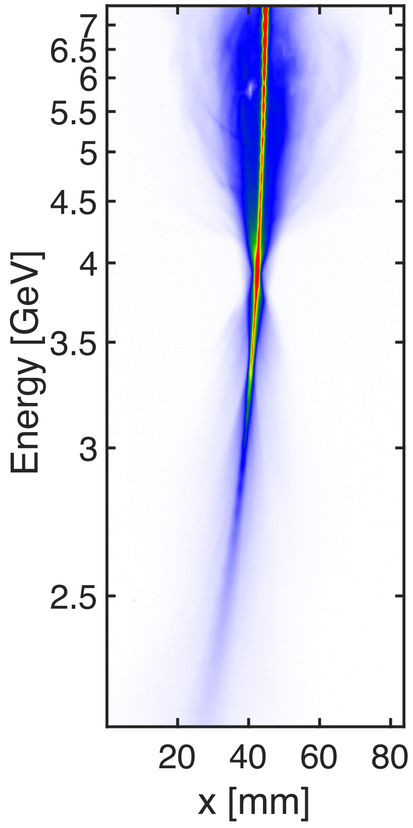
Drive beam energy depletion

- direct evidence: energy down to 2 GeV
- indirect evidence: large charge loss

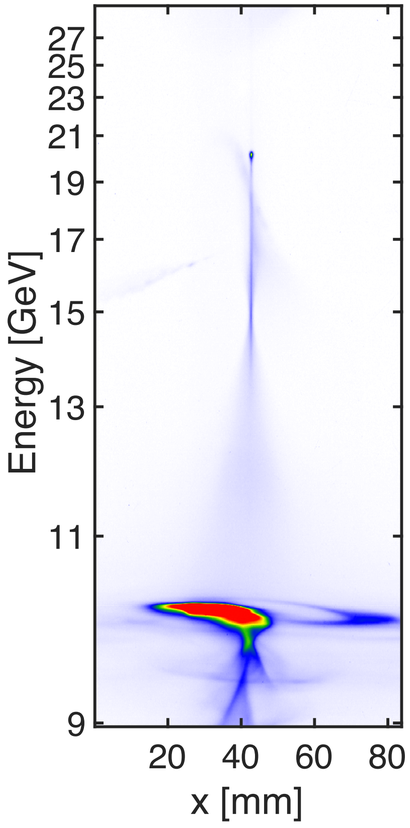
20240319 data
3.4 Torr



20240603 data
1.6 Torr



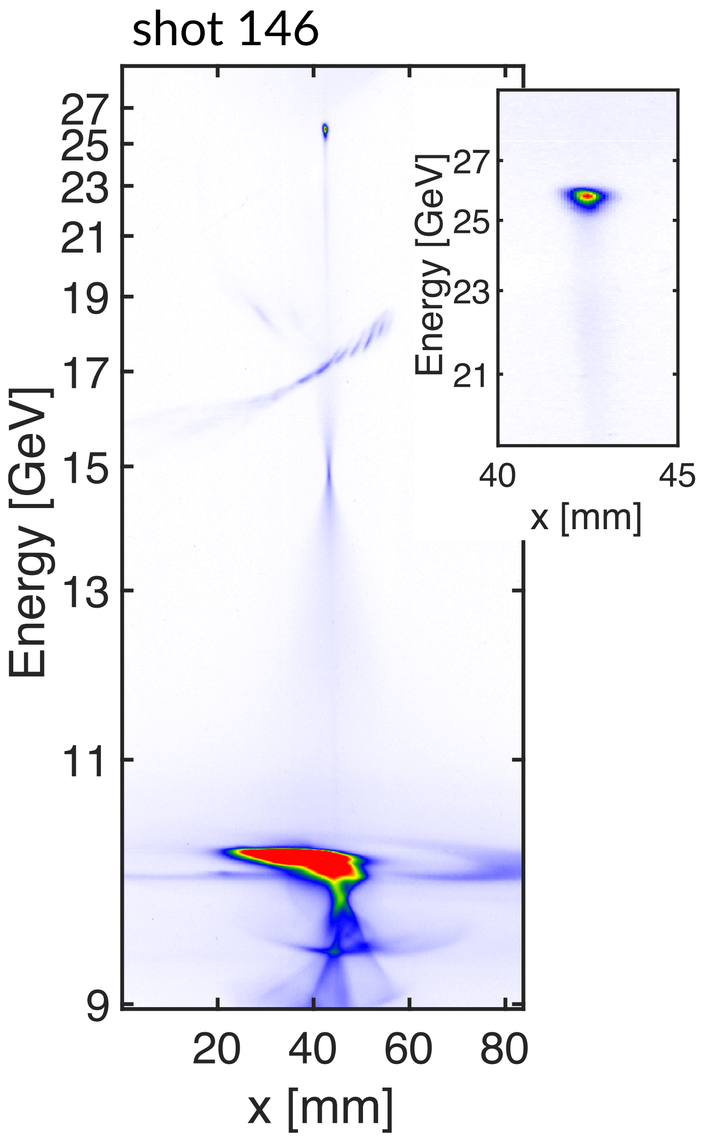
20240603 data
4.0 Torr



	March	*June*	*June with injection*
Pressure	***3.4 Torr***	***1.6 Torr***	***4.0 Torr***
min energy (spectrometer limited)	***1 GeV***	***2 GeV***	***N/A***
charge loss	***~150 pC***	***~300 pC***	***~500 pC***

From the measured min energy and charge loss data at lower pressures, we can infer that in the higher pressure datasets where we saw injection, pump depletion must have occurred.

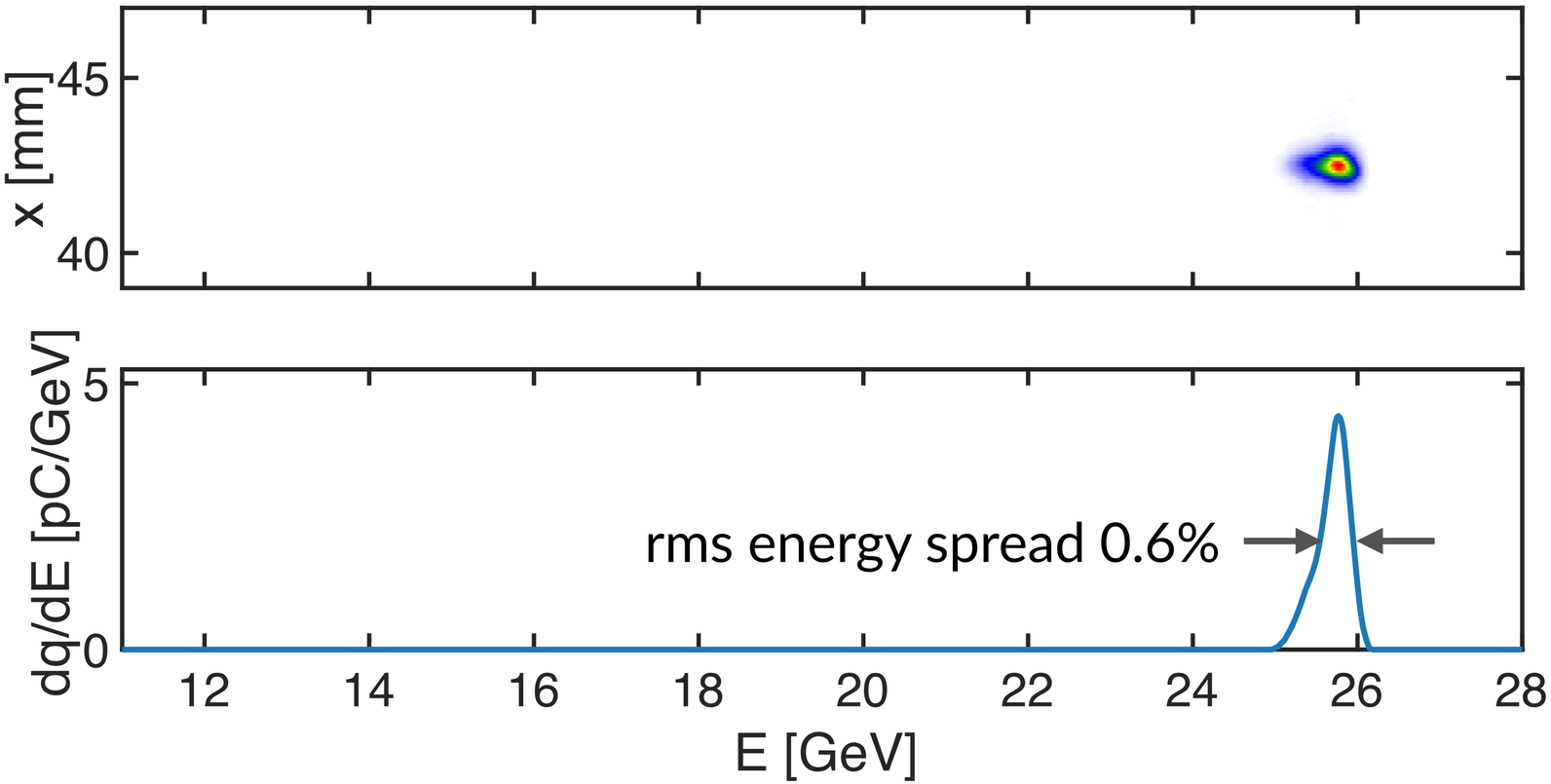
Accelerated beam parameters- Highest energy gain (26 GeV)



Accelerated bunch:

Energy gain: 25.8 GeV, rms energy spread 0.6%

Charge: 2.0 pC

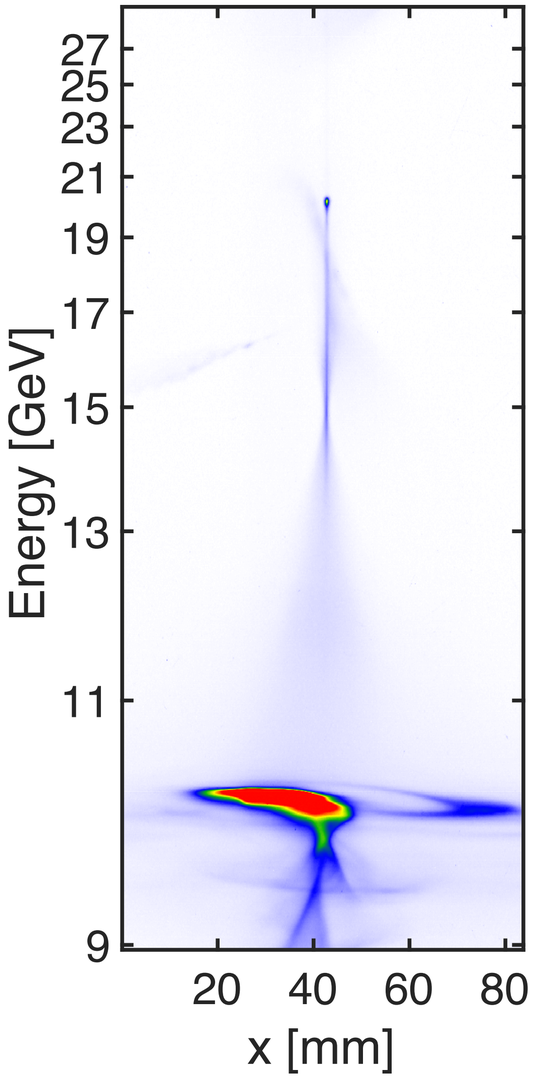


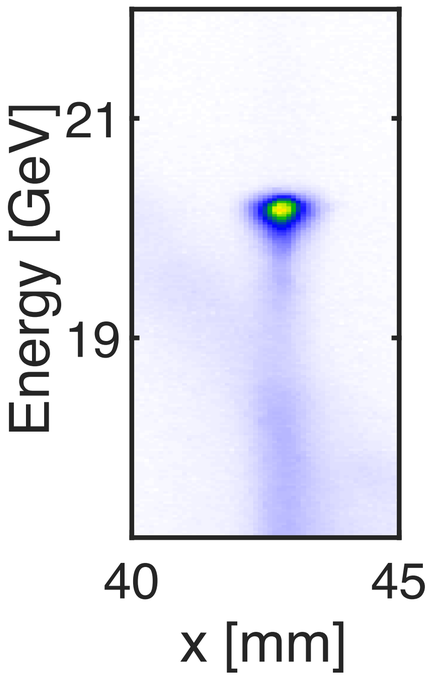
E304_08878, 4 Torr, 100 psi, beam height 2 mm. 50 cm beta at FILG+100 cm, Quad 15 GeV FILG+3m to LFOV, Dipole 25 GeV

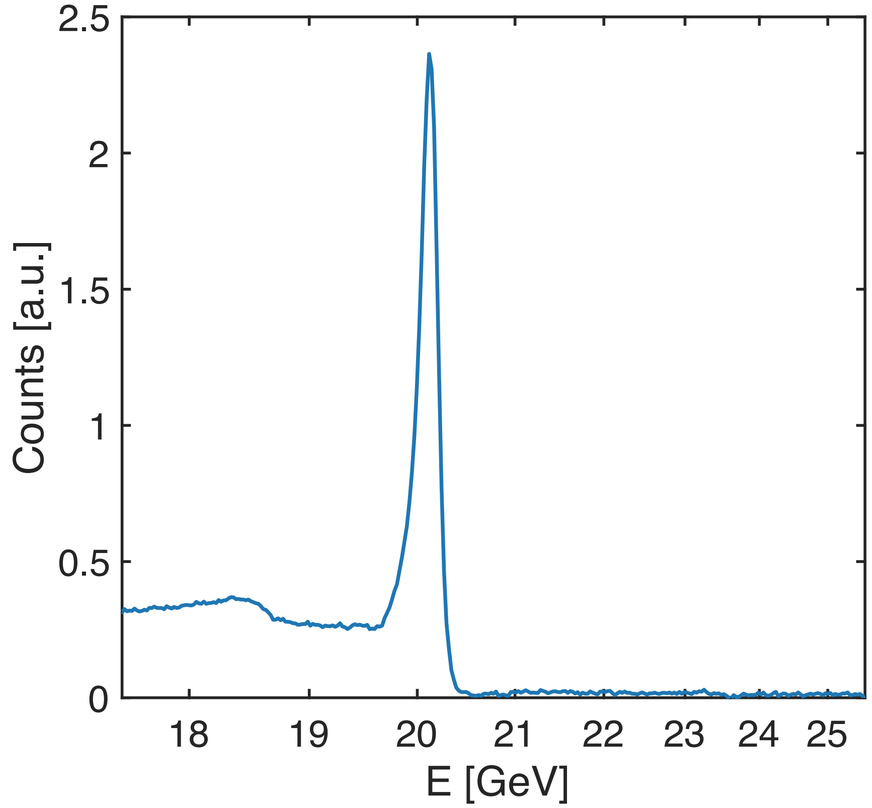
Accelerated beam parameters- Smallest energy spread

Accelerated bunch:

Energy gain: 20 GeV, energy spread (rms): 0.47%, Charge: ~2.5 pC

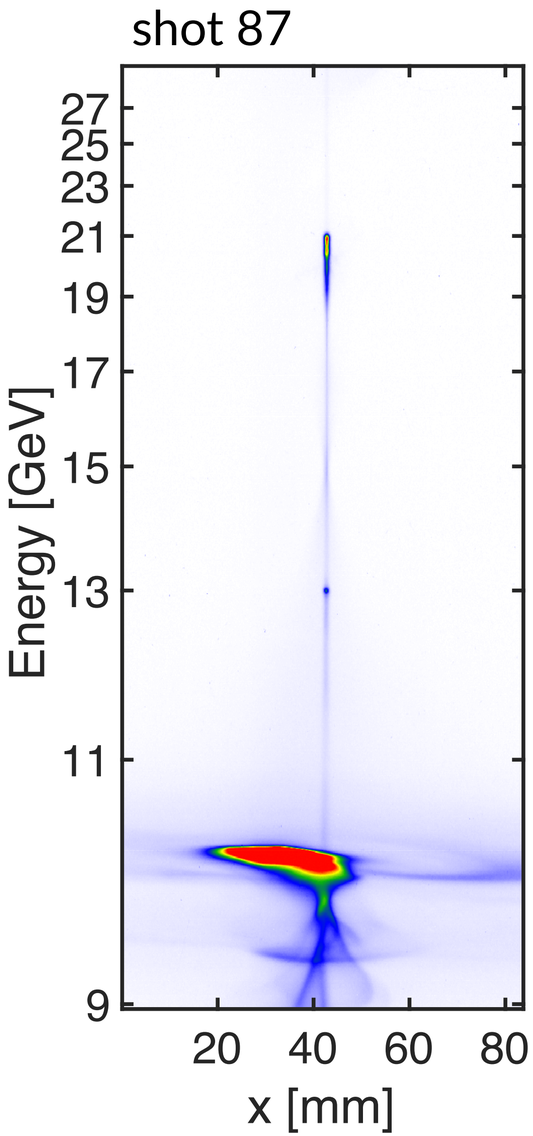






E304_08877, 4 Torr, 100 psi, beam height 2 mm. 50 cm beta at FILG+75 cm, Quad 15 GeV FILG+3m to LFOV, Dipole 25 GeV

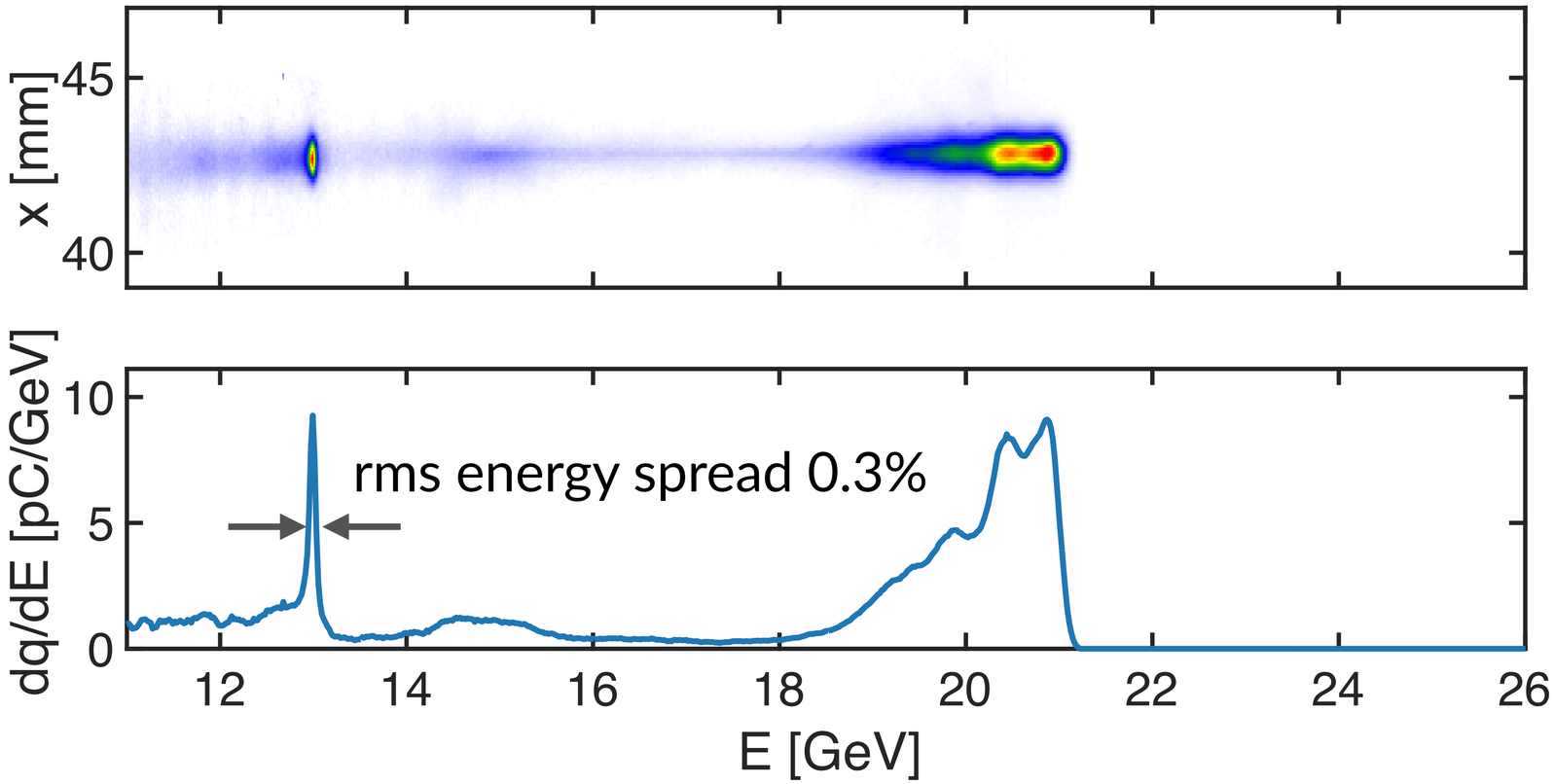
Accelerated beam parameters- Smallest energy spread



Accelerated bunch:

Energy gain: 13 GeV rms spread 0.3%, 21 GeV

Charge: 17.8 pC

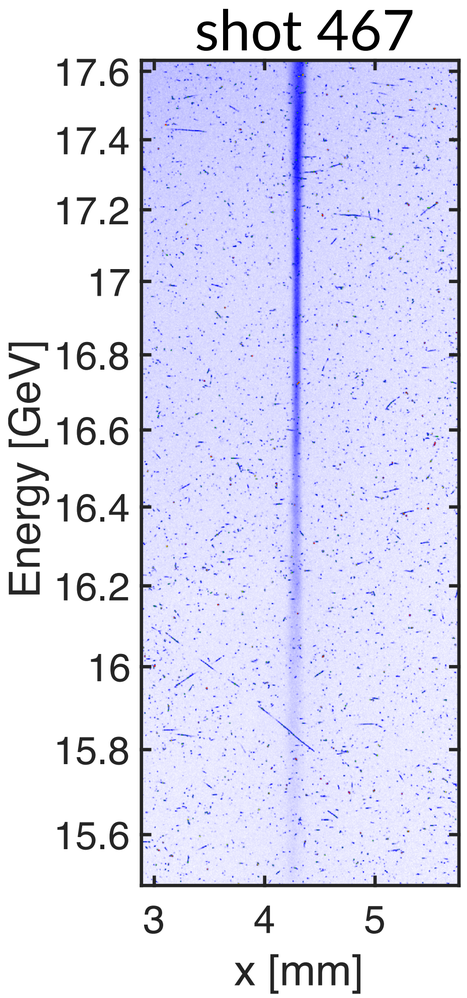


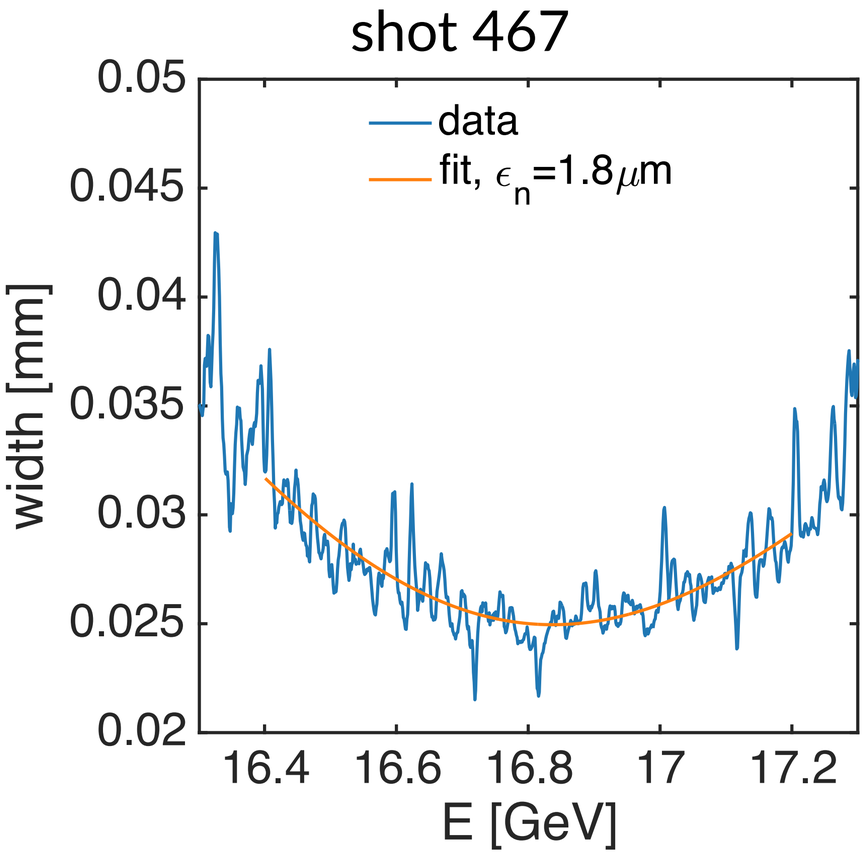
E304_08877, 4 Torr, 100 psi, beam height 2 mm. 50 cm beta at FILG+75 cm, Quad 15 GeV FILG+3m to LFOV, Dipole 25 GeV

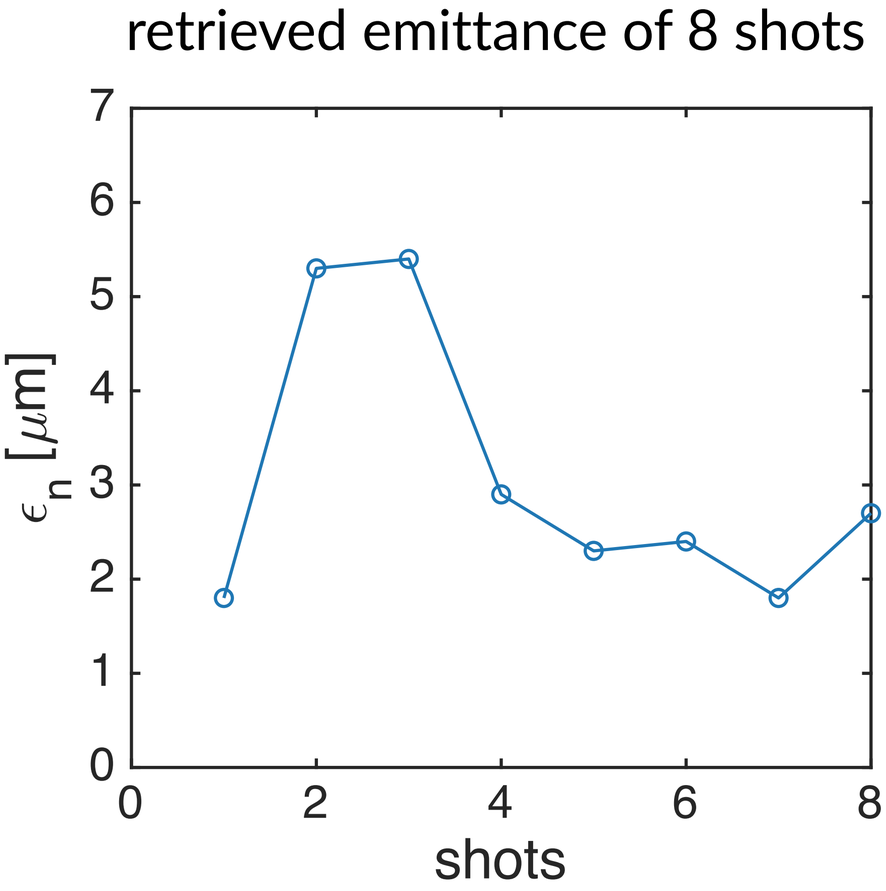
Accelerated beam parameters- emittance

low-emittance injected beam formed a butterfly structure with very narrow waist on a high resolution (3.6 μm) OTR screen

minimum emittance 1.8 μm

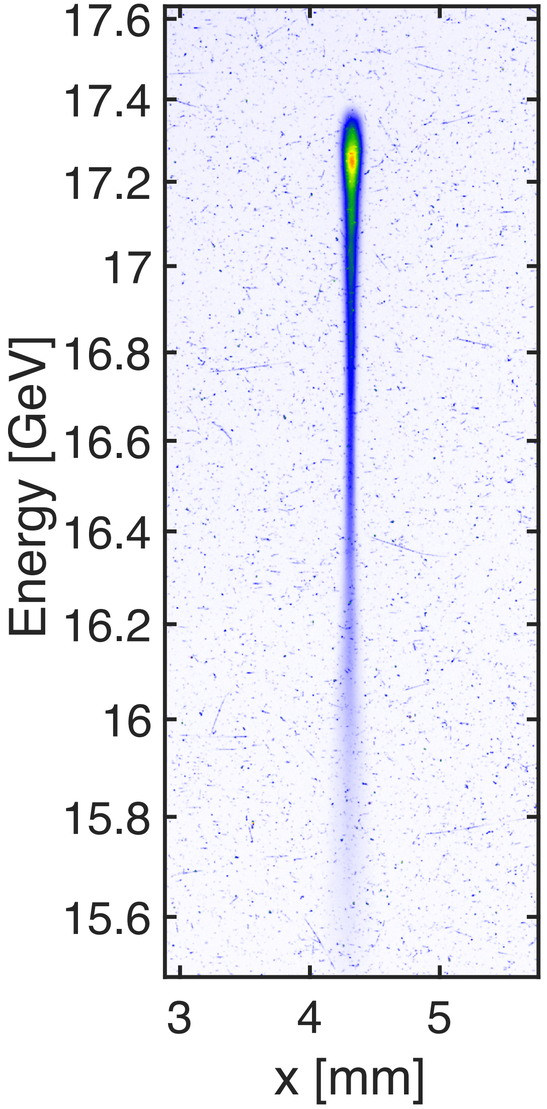




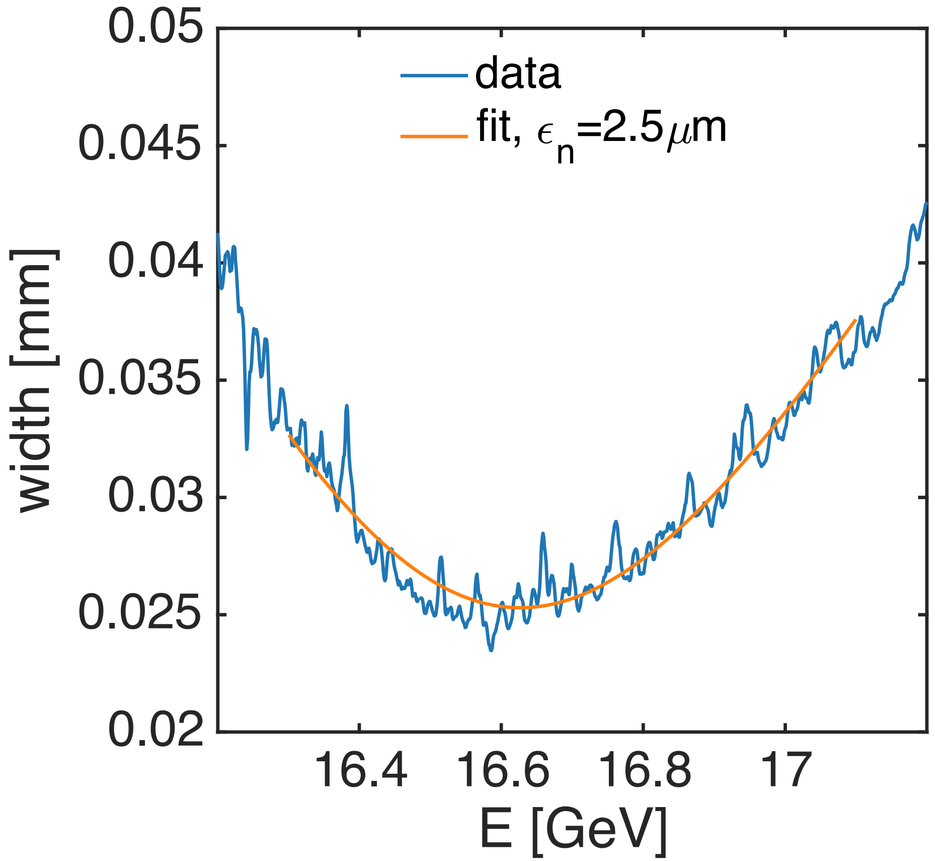


E304_08900, 4 Torr, 100 psi, beam height 2 mm. 50 cm beta at FILG+75 cm, Quad 17 GeV BeWin2 to DTOTR, Dipole 17 GeV

Accelerated beam parameters- emittance



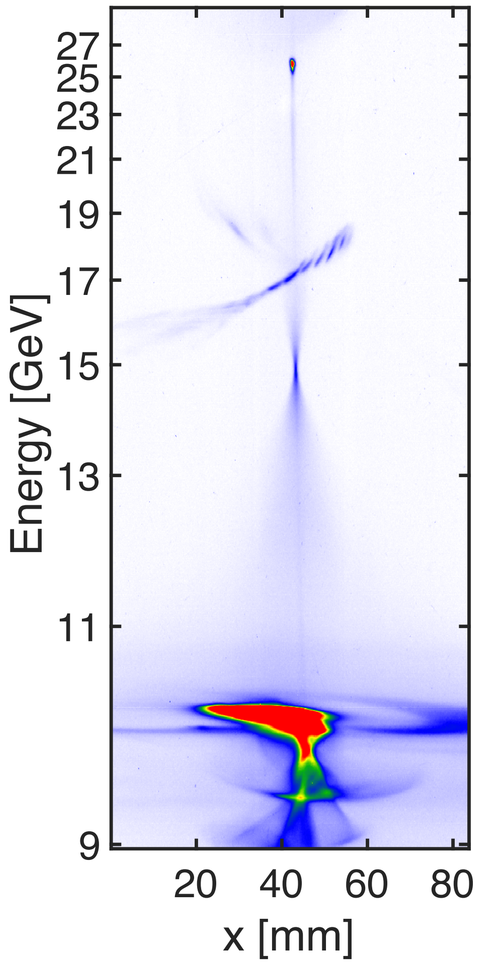
17.25 GeV, dE(FWHM)=0.17 GeV, 0.42% (rms)

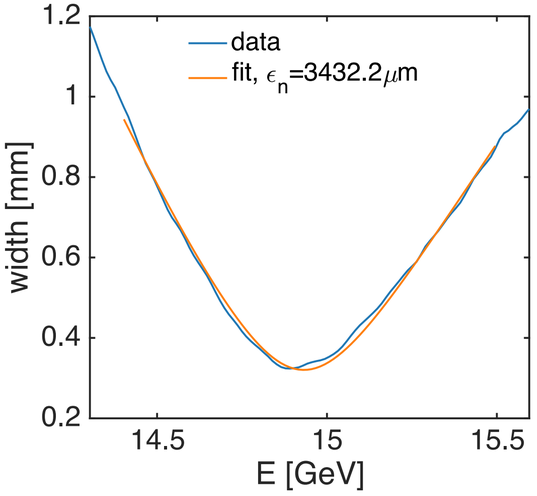


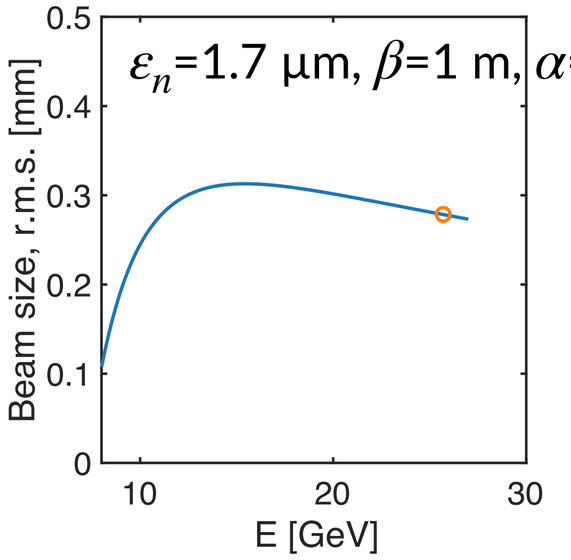
E304_08901, 4 Torr, 100 psi, beam height 2 mm. 50 cm beta at FILG+75 cm, Quad 17 GeV BeWin2 to DTOTR, Dipole 17 GeV

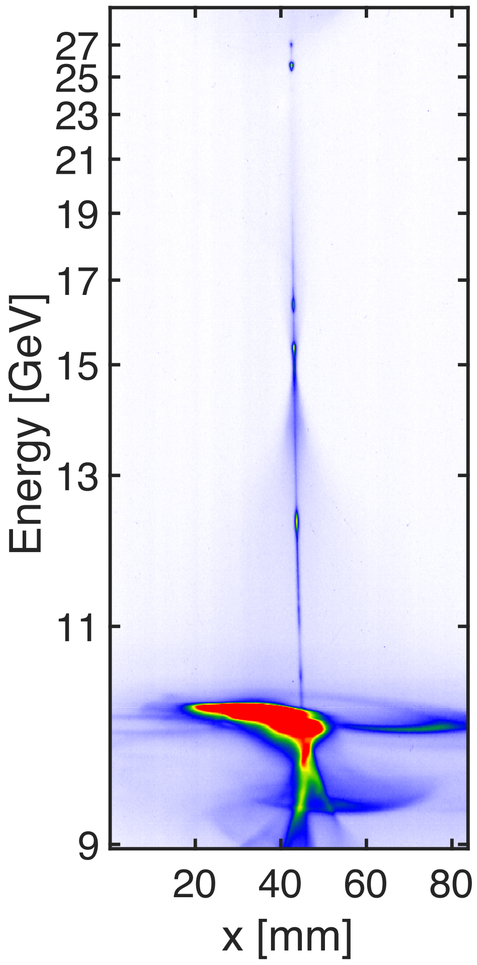
Emittance estimate from the divergence of the beam

drive beam emittance: >100x growth



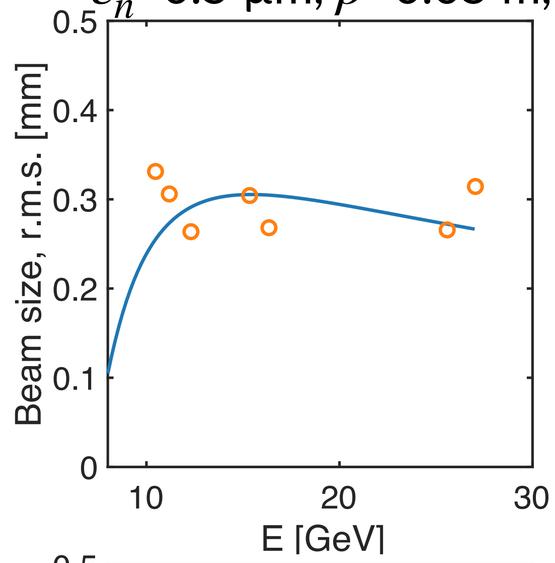


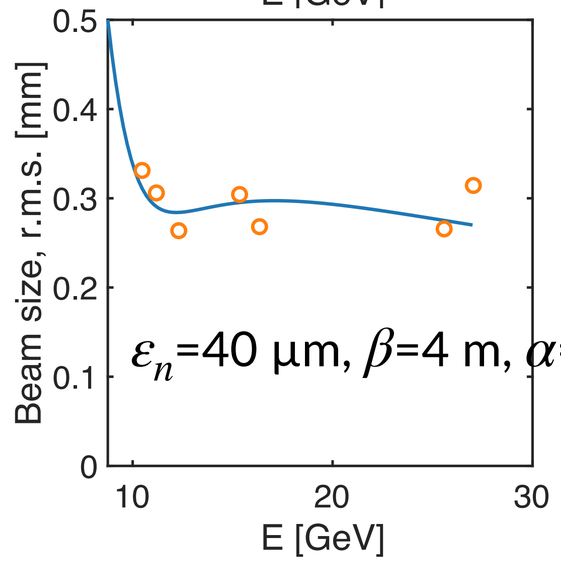




ε_n=1.6 µm, β=1 m, α=2.4

ε_n=0.5 µm, β=0.05 m, α=0

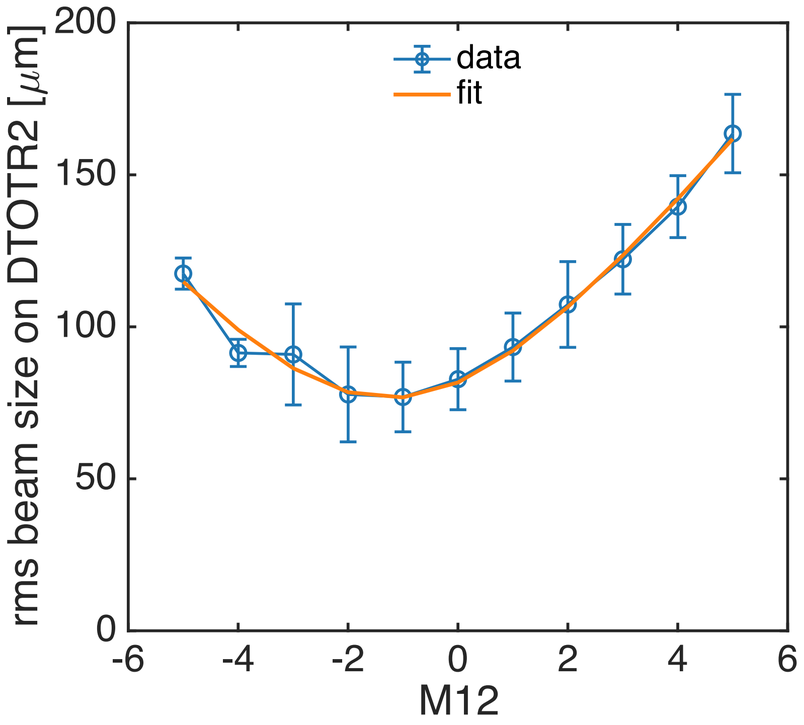




Emittance of the drive beam

at the beginning of the shift (6:10 PM)

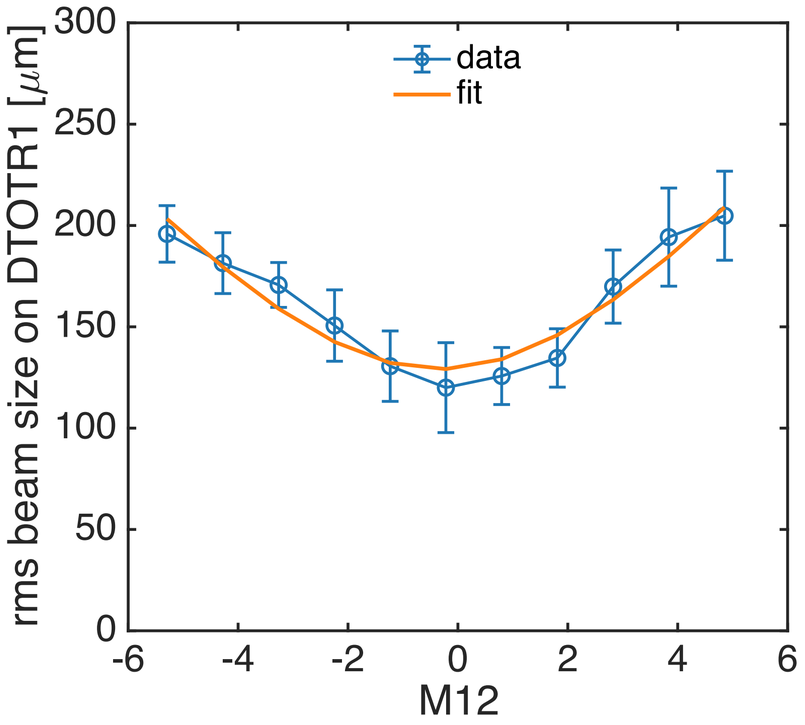
$$\varepsilon_n = 9.7\ \mu\text{m}, \beta \approx 1.09\ \text{m}$$



dataset E304_08860

at the end of the shift (1:40 AM)

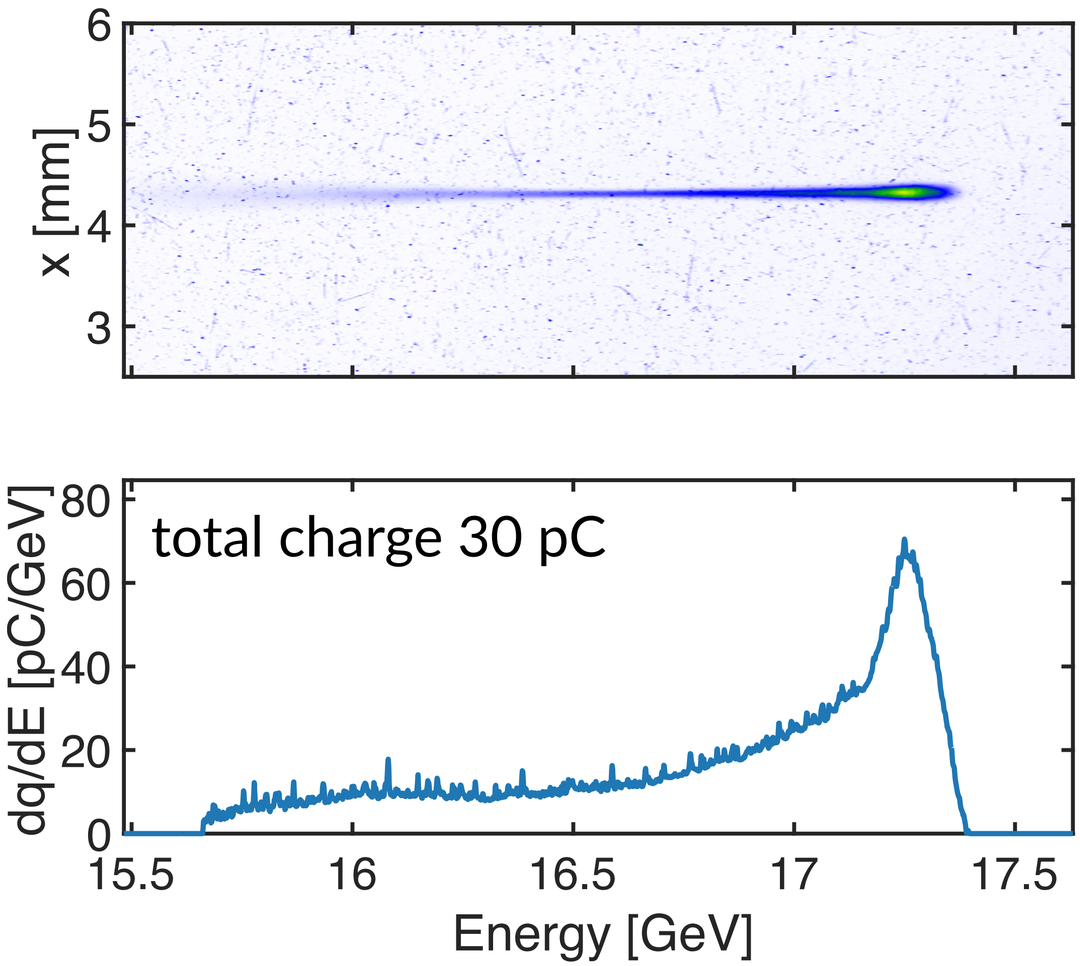
$$\varepsilon_n = 22.8\ \mu\text{m}, \beta \approx 1.17\ \text{m}$$



dataset E304_08910

pixel size 3.6 μm

Current profile- work in progress



driver $\Lambda \approx 1.124$ $k_p R_b \approx 2\sqrt{\Lambda} \approx 2.12$

Idea:

Known drive bunch parameters and plasma density —>

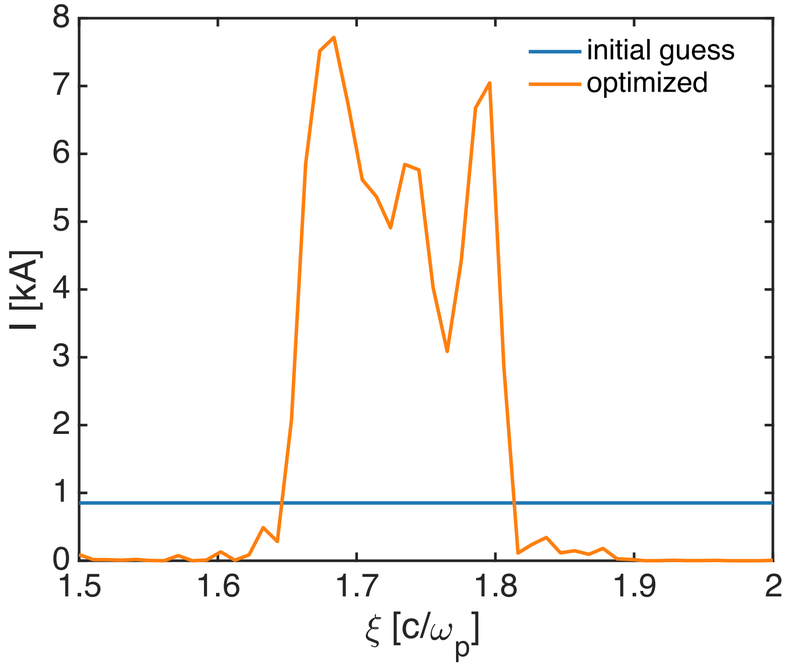
Unloaded wake using PIC simulation/ theoretical model —>

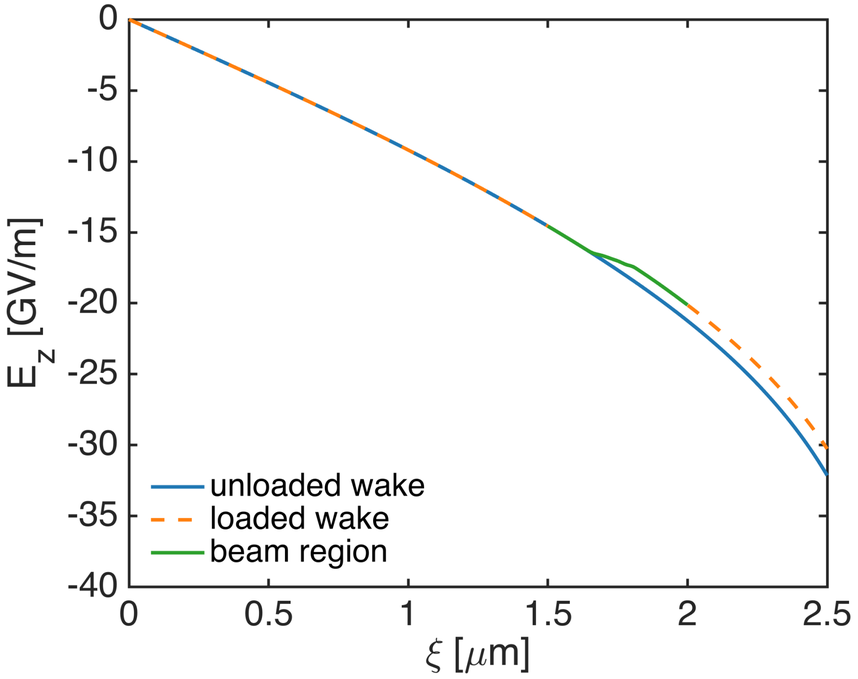
Iteratively change current profile of the injected bunch to load the wake —>

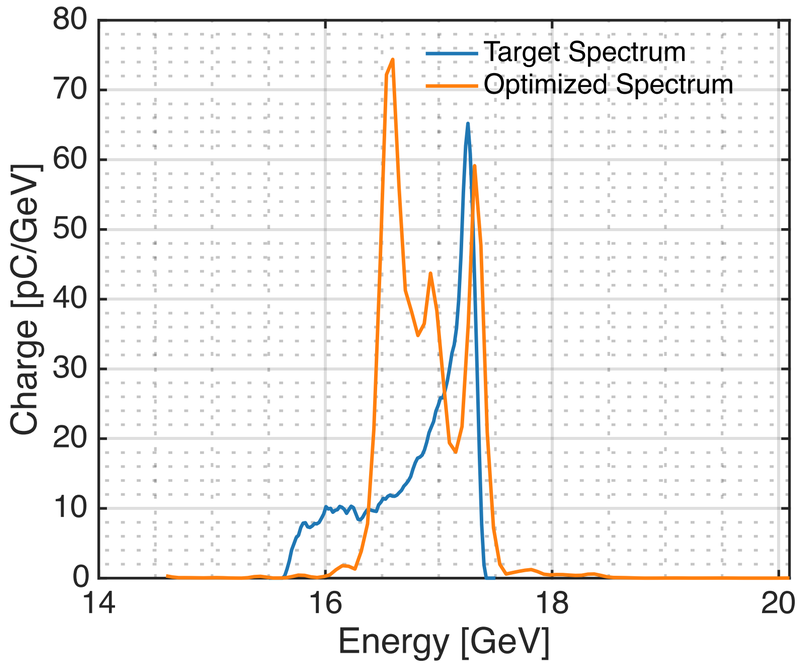
Until the resulting energy spectrum matches the measured one

Current profile- work in progress

optimized (not fully) current profile using genetic algorithm
tried ~270,000 possible current profiles

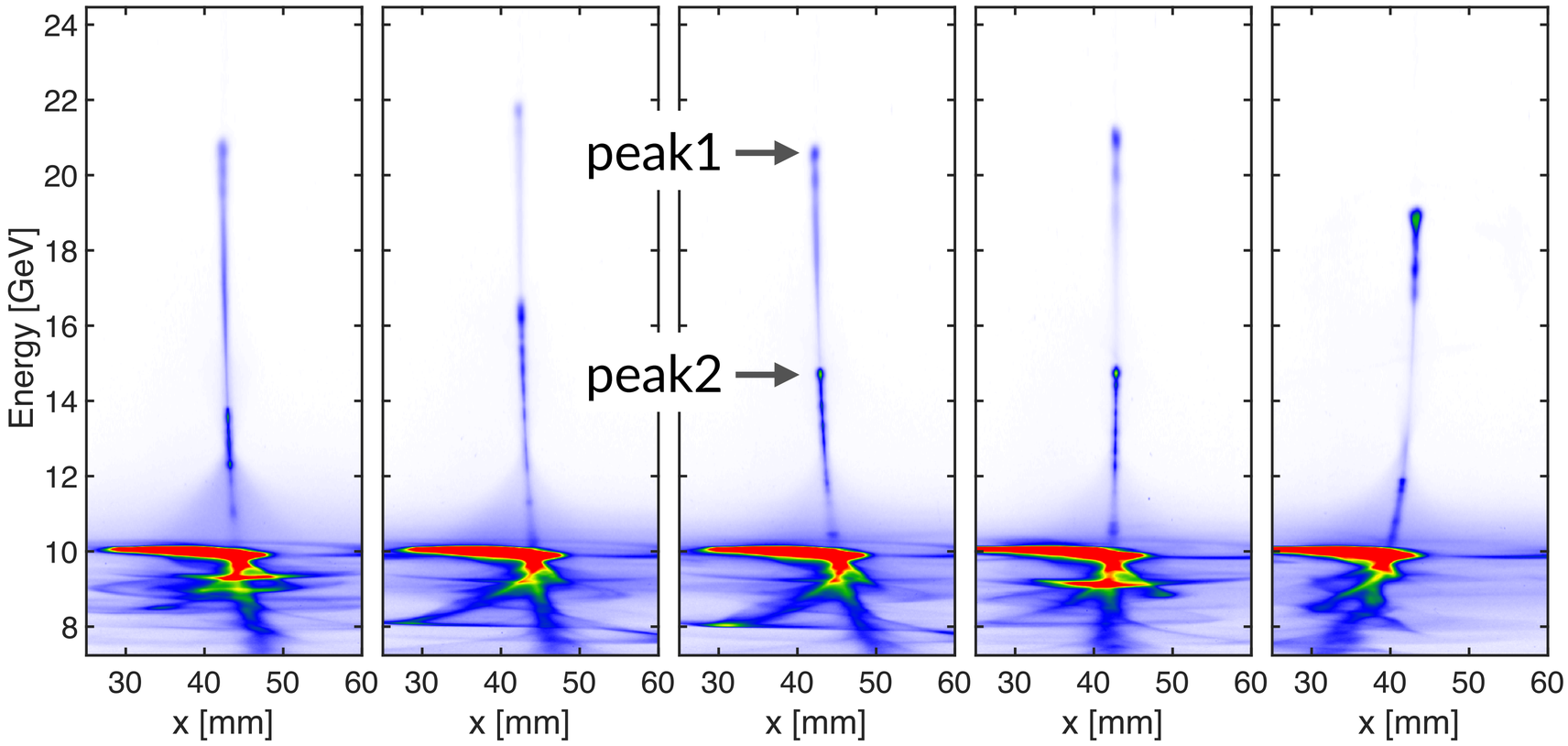


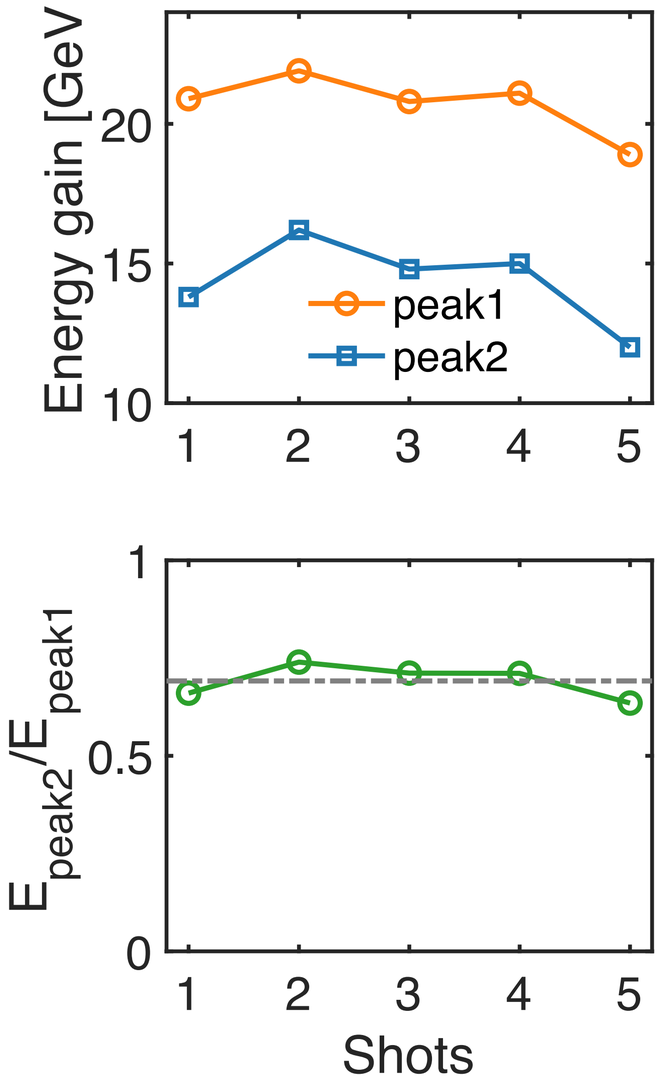




Two bunches injected into the first and second bubbles

Many shots show two distinct bunches with large energy differences but fixed energy ratios

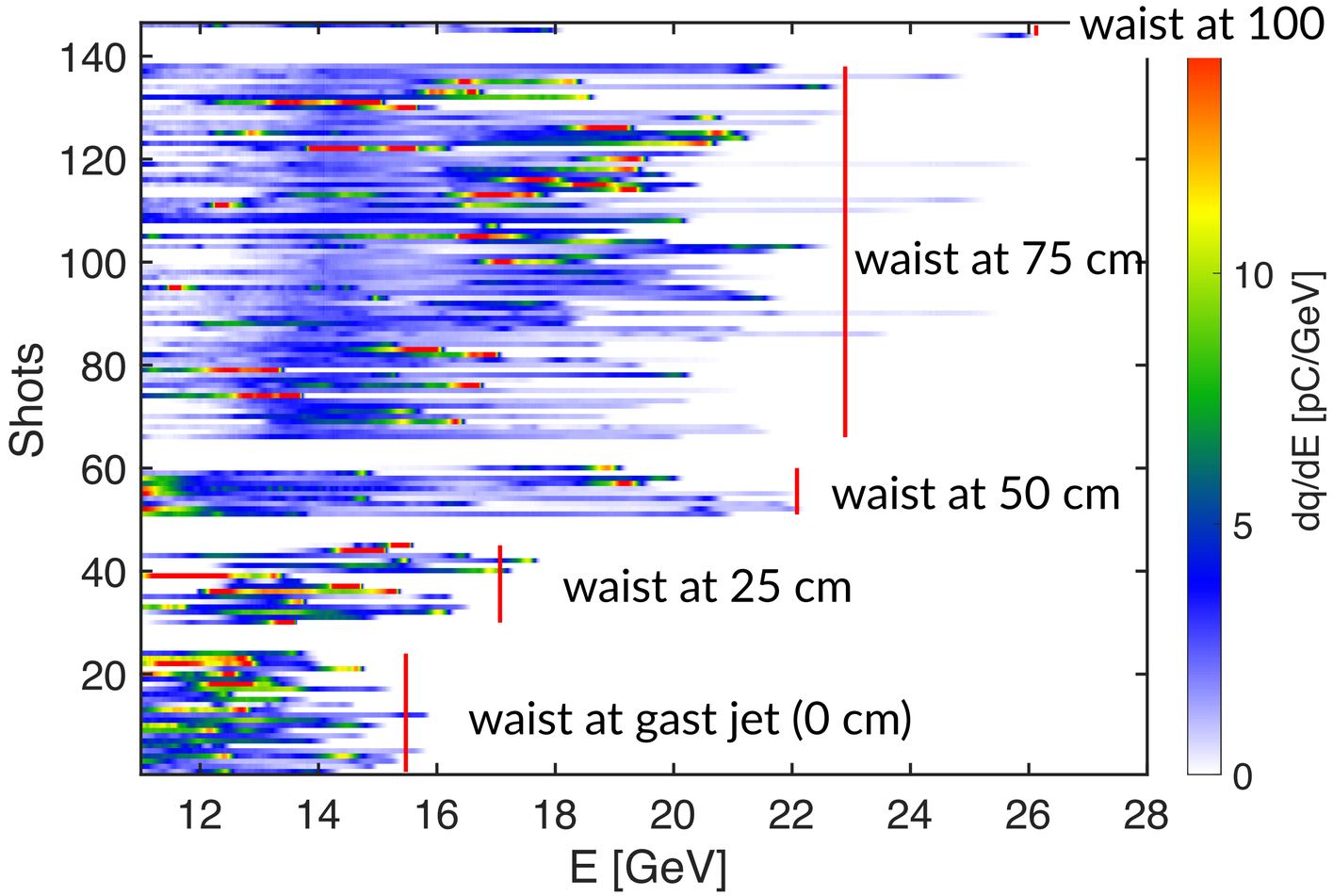


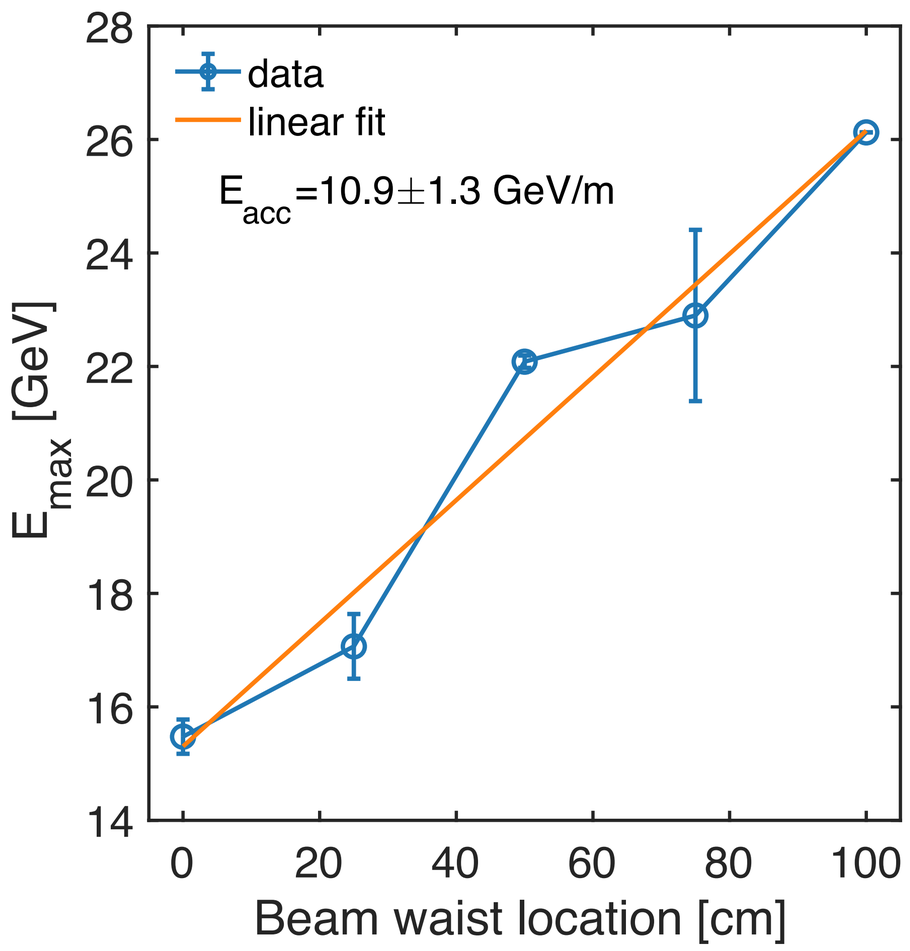


E304_08873, 4 Torr, 100 psi, beam height 2 mm. 50 cm beta at FILG50 cm, Quad 13 GeV FILG+2m to LFOV, Dipole 20 GeV

Accelerating gradient retrieved from plasma length scan

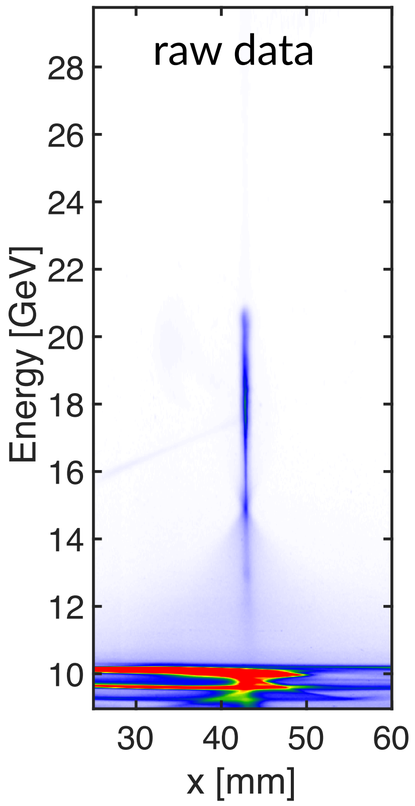
- Plasma length increases by moving the beam waist location in vacuum towards downstream
- Max energy scales linearly with plasma length, giving an average gradient of 10.9±1.3 GeV/m

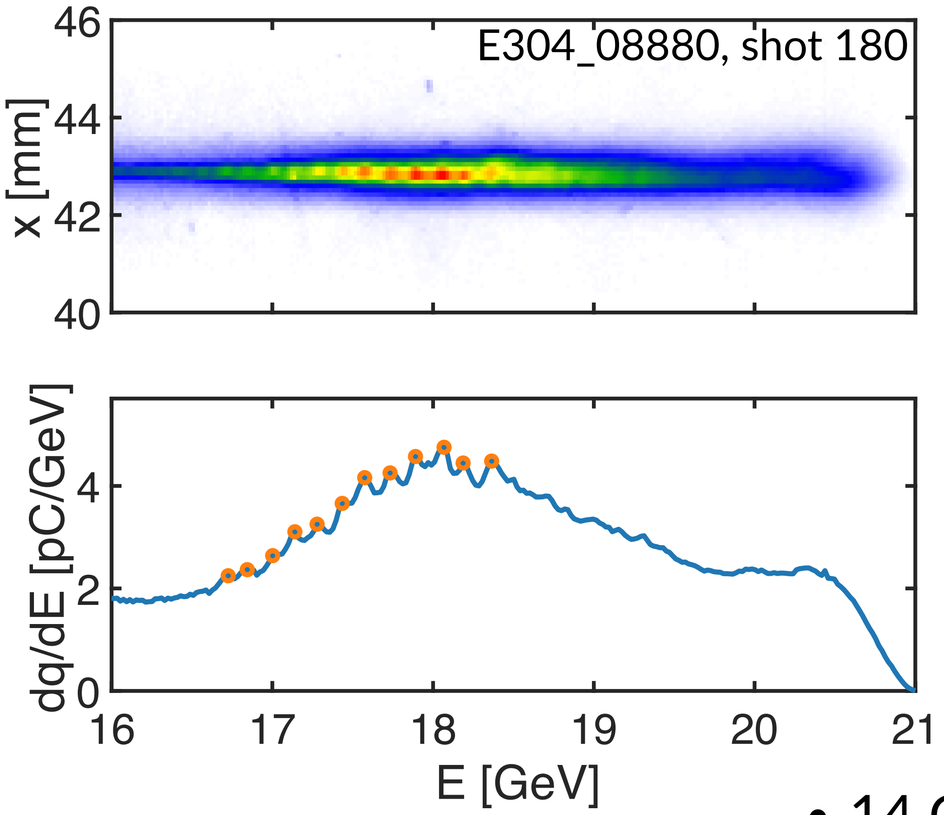


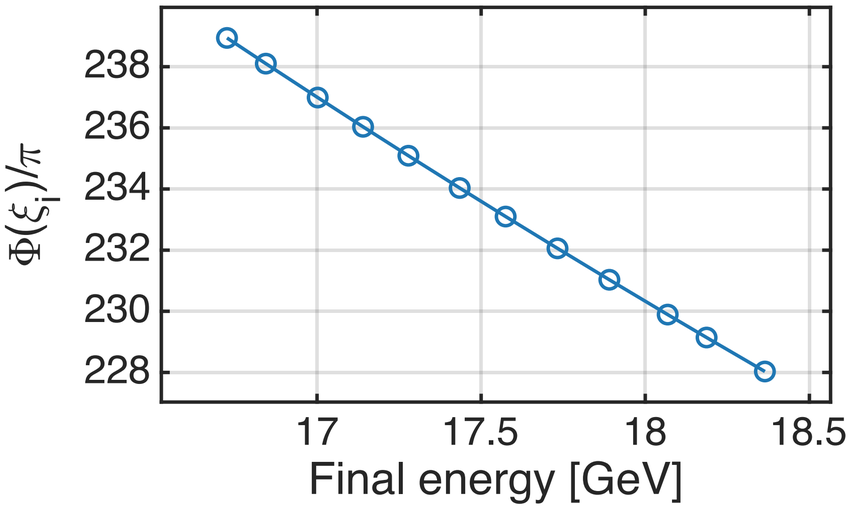


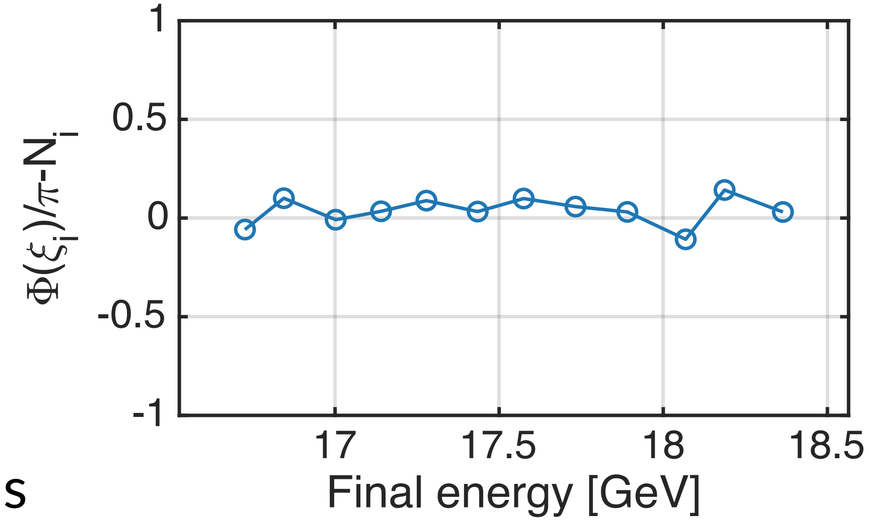
Plasma length calculated using betatron analysis of unmatched beam

UCLA









- 14 GeV/m

- Betatron analysis of the drive beam gives Leff ~ 1.42 m
- The beam has undergone more than 110 betatron oscillations

E304_08880, 4 Torr, 100 psi, beam height 2 mm. 50 cm beta at FILG+75 cm, Quad 15 GeV FILG+3m to LFOV, Dipole 25 GeV

Issues

drive beam characterization- we measured sigma_z 11 μm, is that real?

DAQ/Camera issues

unknown plasma length, density profile

difficult to align DTOTR1 when measuring small emittance (depth of focus of the camera is small)- put markers on the foil to help focus the camera?

currently heavily rely on the jittery current spikes in the beam to initiate ionization, leading to unstable results

2-cm gas jet, 5 Hz, 100 psi backing pressure, equilibrium pressure at IP is ~4 Torr
how to remove the static-fill gas when we want to do the gas-jet only configuration (instead of the gas-jet in static fill configuration)

Drive beam parameters

charge 1.6 nC n_b~5e16 cm^{-3} n_p~1.4e17 cm^{-3} (4 Torr)

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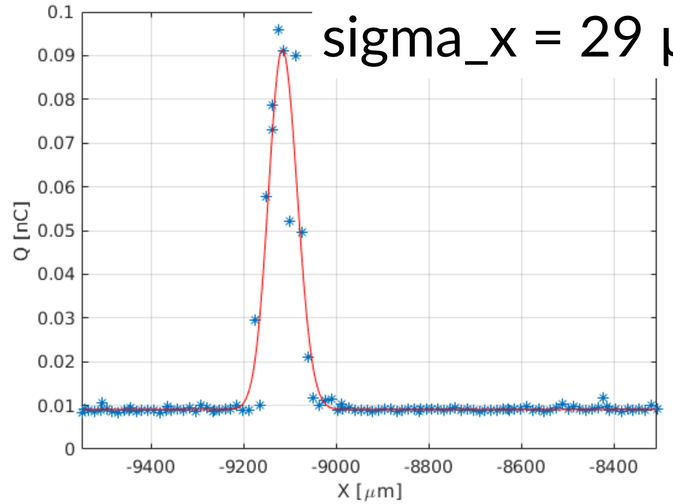
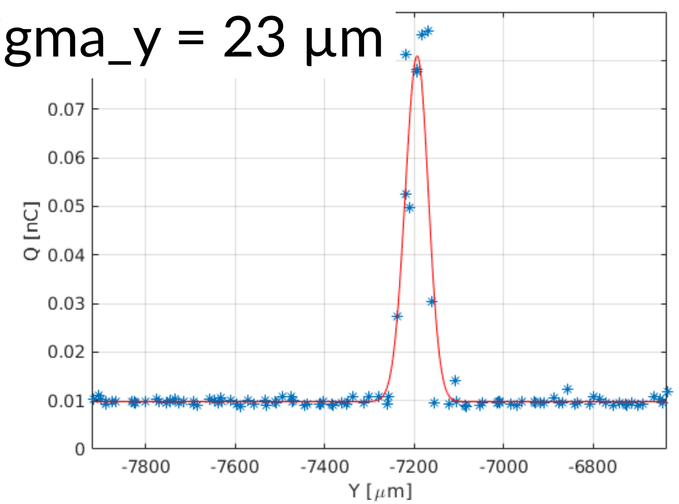
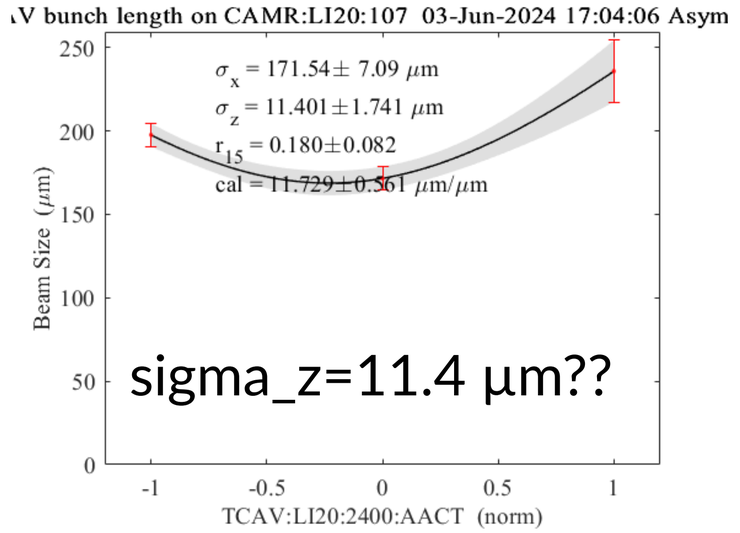
June 3, before the shift



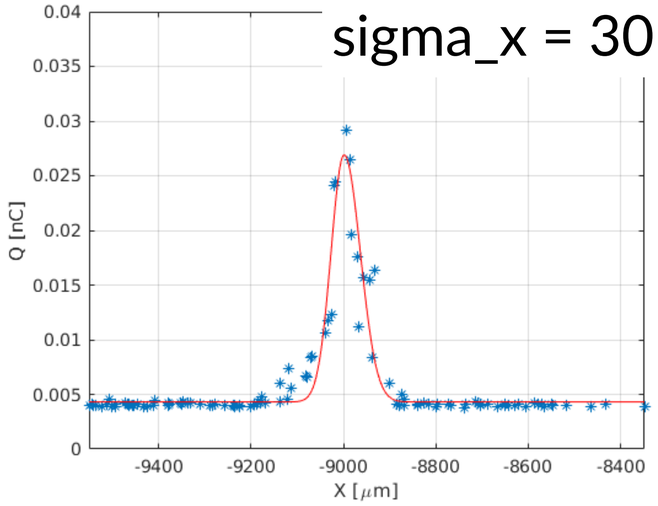
sigma_x = 29 μm sigma_y = 23 μm



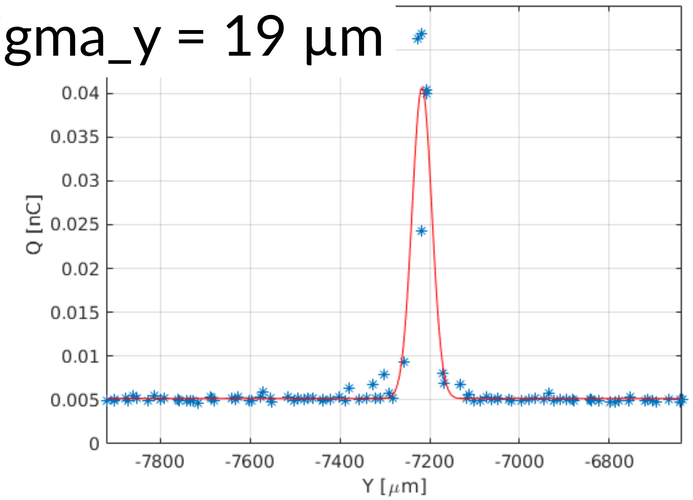


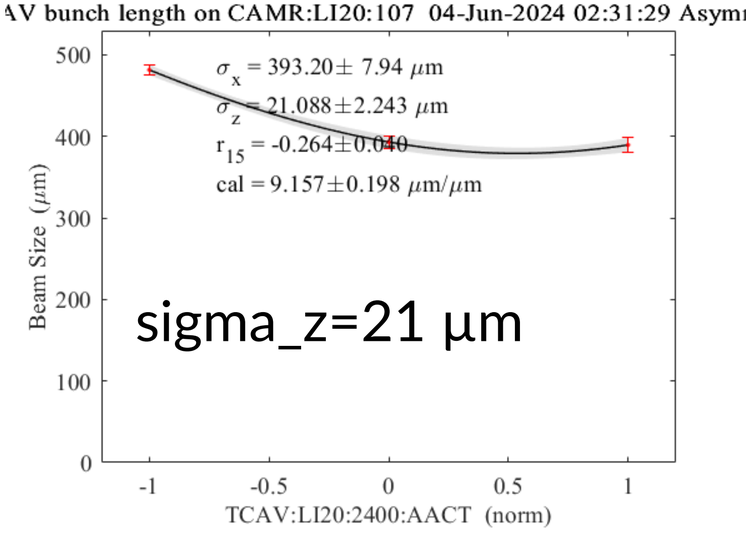
sigma_z=11.4 μm??

June 3, after the shift



sigma_x = 30 μm sigma_y = 19 μm





sigma_z=21 μm