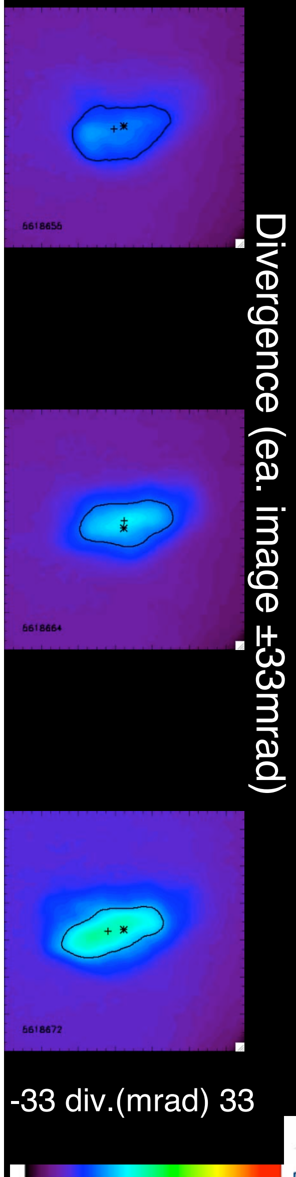


# Stable electron beams with low absolute energy spread from a laser wakefield accelerator with plasma density ramp controlled injection

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D. Bruhwiler, Tech -X
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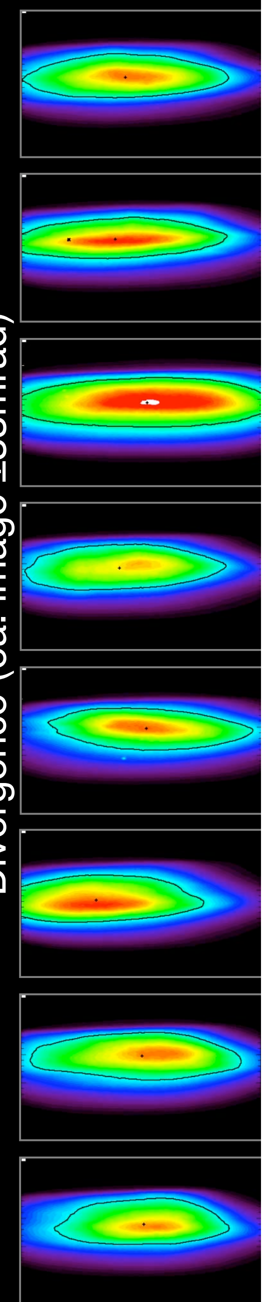
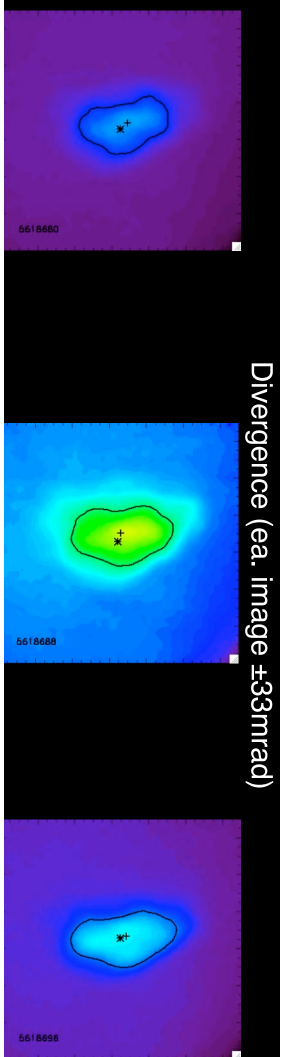
PAC, 2007



Sequential Bunch images Day#1 run #1

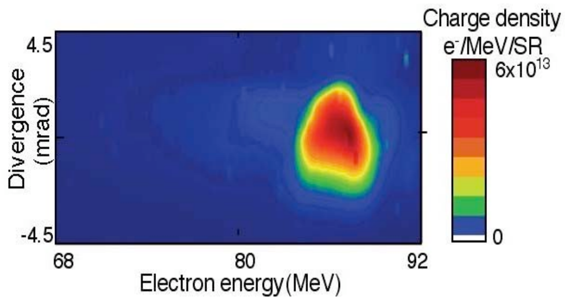



-33 div.(mrad) 33

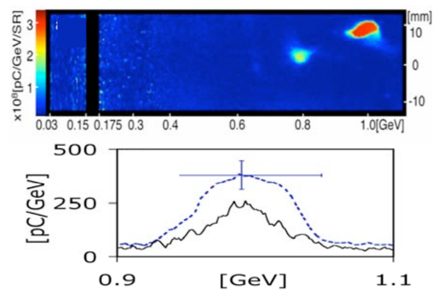
# Improve present MeV class energy spread of LWFAs, stability, E

## LBNL data

9 TW: 86 MeV/c
Δp = 4 MeV/c FWHM*

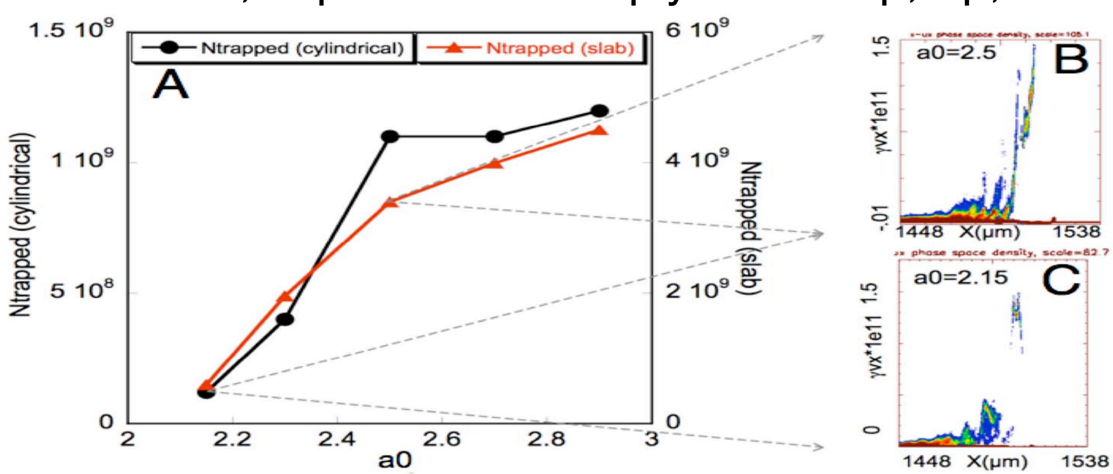



40 TW, 1 GeV/c,
Δp = 25 MeV/c rms**




Many groups report 100 MeV/c-class bunches, MeV/c Δp***.

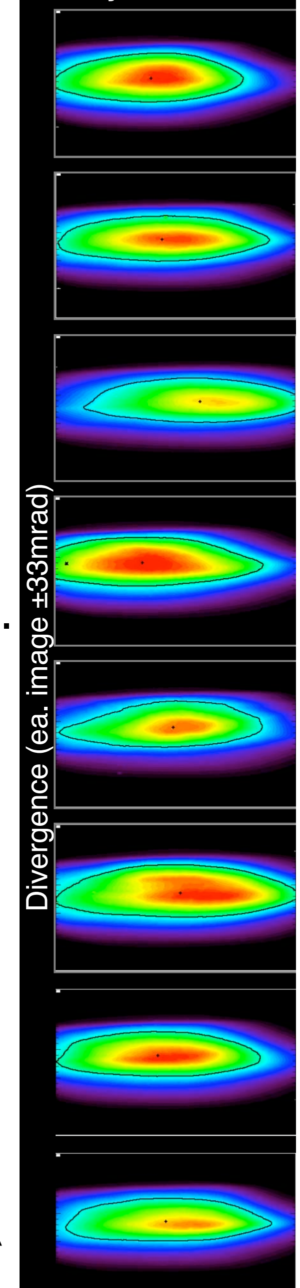
Simulations, experiments** imply tradeoff p, Δp, stability



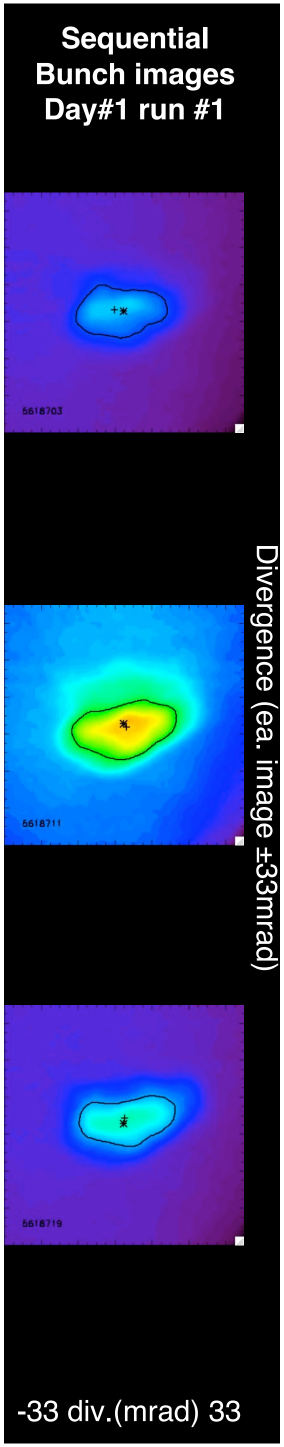

Initial optical injection\` experiments^ ⁚-stable beams, MeV/c Δp^

*Geddes et al, Nature 2004, **Leemans et al Nature physics 2006, \` Esarey et al PRL 1997
***Faure et al, Mangles et al Nature 2004, others ^Faure et al Nature 2006,⁚ Nakamura poster

Sequential Spectra Day#1 run #1




0.66 p(MeV/c)0.88




# Plasma density ramp can control trapping for stability, ΔE

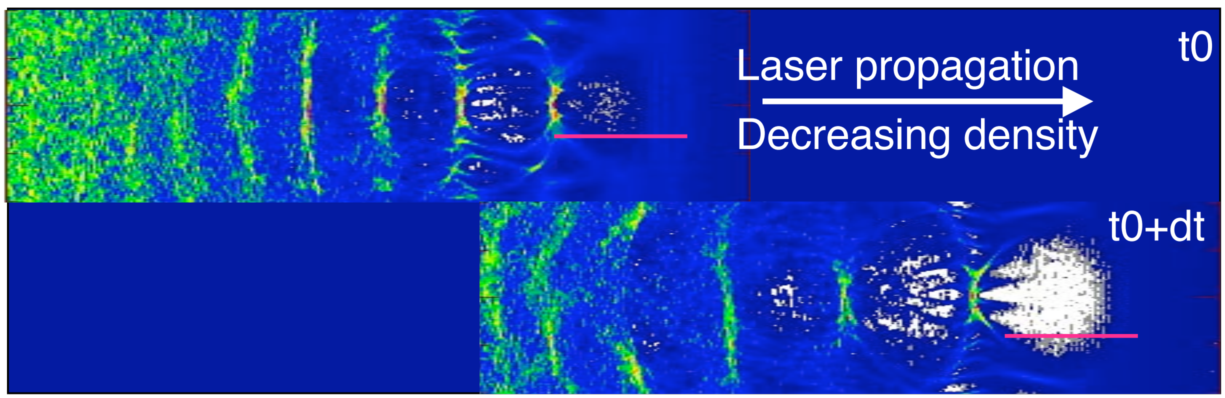
Trapping of plasma particles (1D) when -

$$(q/m)E\omega_p \sim v_{wake}$$

Decreasing plasma density (ramp) control:

plasma wavelength increases as the laser propagates

$$V_{wake} \sim V_{g,driver}(1 - d\lambda_p/dz) < V_{g,driver}$$




Decreased $V_{wake}$ and trapping threshold*

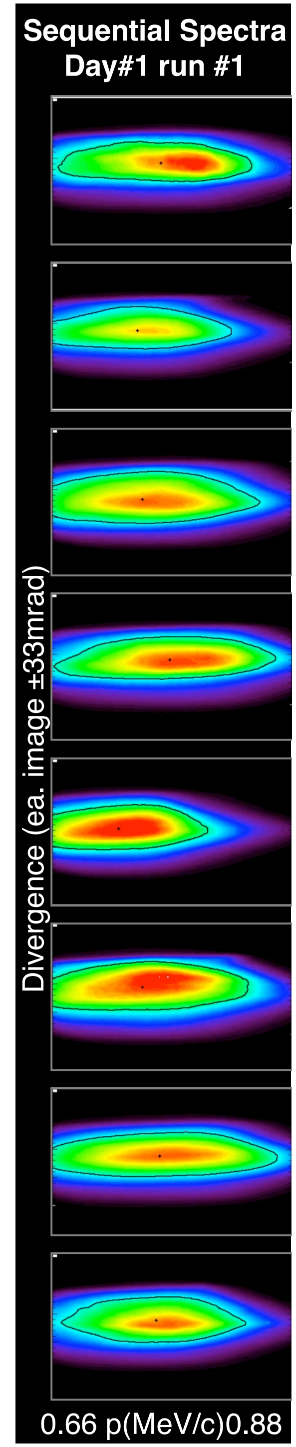
Allows operation far above trapping threshold:

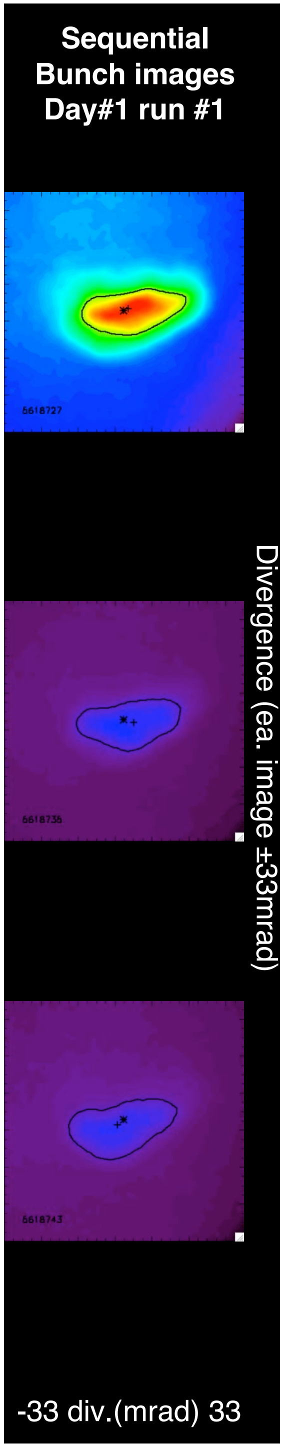
- -low energy
- -High Δp/p but low absolute Δp

NO requirement for laser modulation by plasma (unstable)

- -stable beam for staging

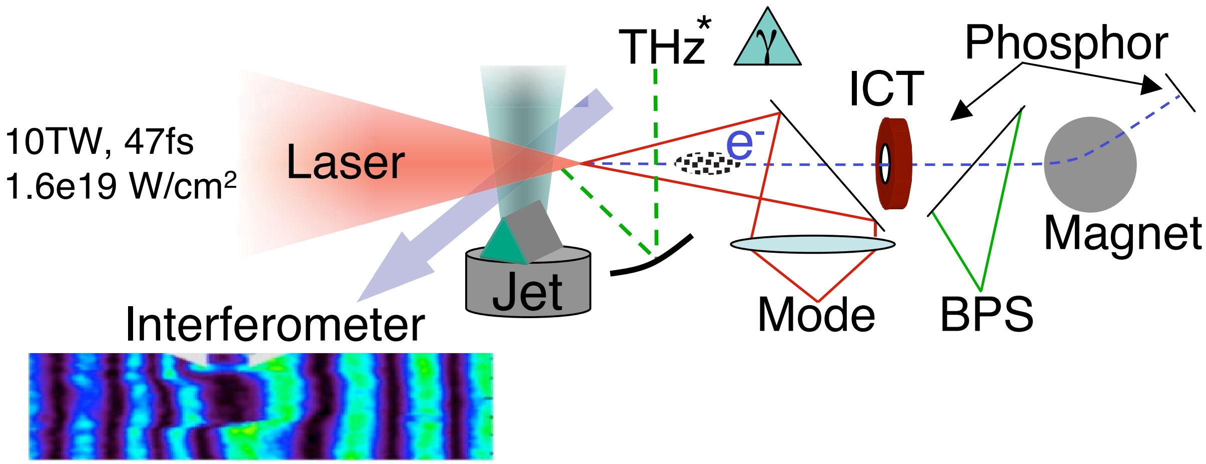
* Bulanov PRE 1998





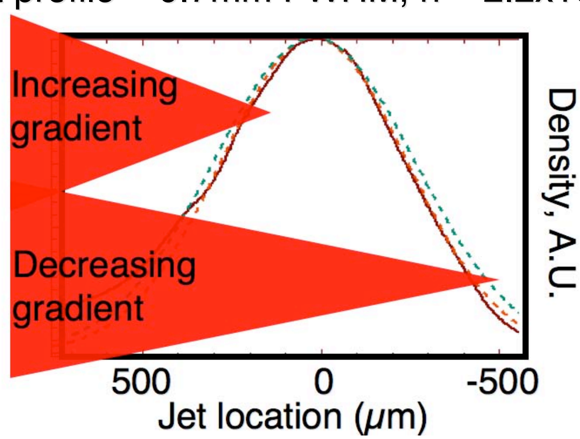

# Experiments^ select gradient using laser focal location in thin gasjet

## Experimental Setup

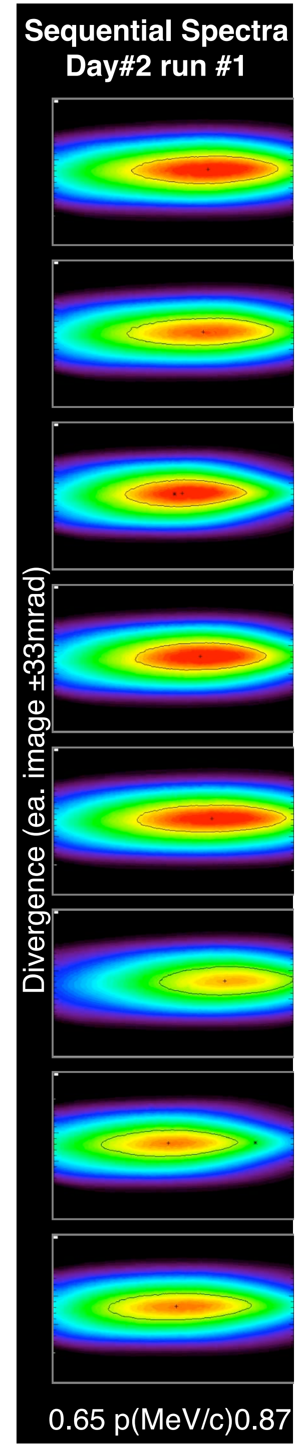



Wake only large within $Z_R \sim 200\mu m$ of focus:
Focus location determines gradient where wake excited

Plasma profile ~ 0.7mm FWHM, n = $2.2 \times 10^{19} cm^{-3}$

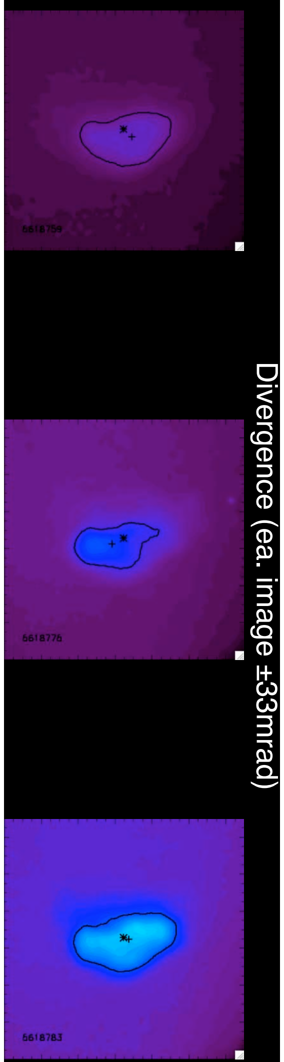



^ Geddes sub. PRL, * Leemans, Plateau poster

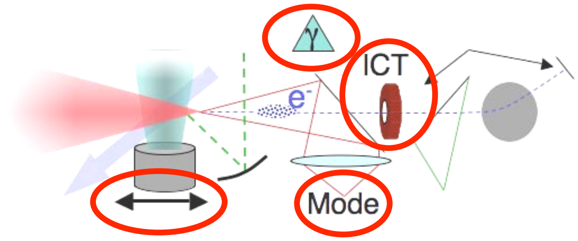


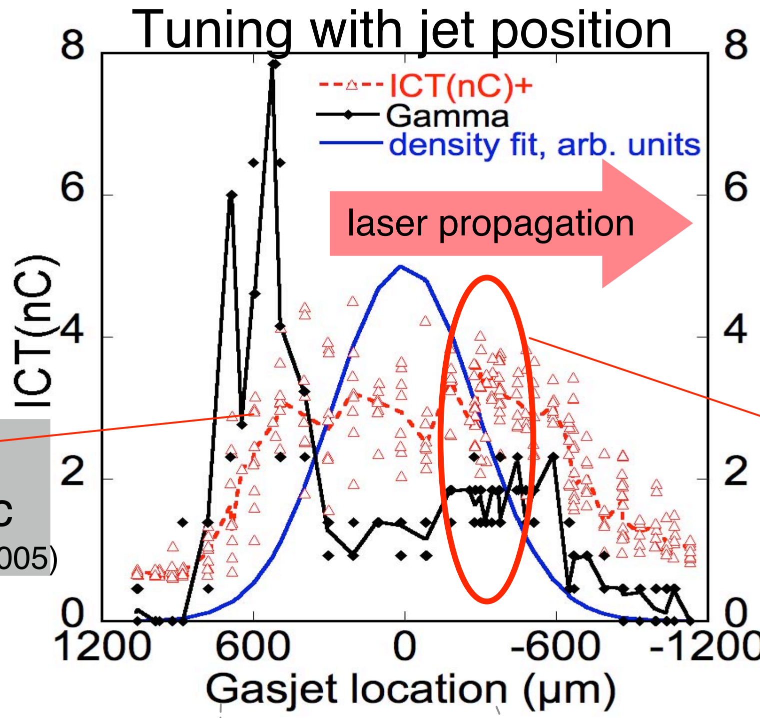
# Scanning jet with respect to focus: control of trapping and acceleration

**Sequential Bunch images Day#1 run #1**




-33 div.(mrad) 33



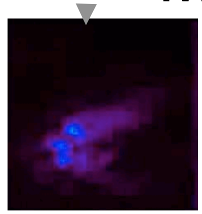



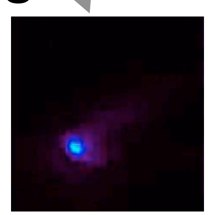

Unstable
10's MeV/c
(Geddes PoP 2005)

**Down ramp:**
Stable Q
Q±15%rms
Low γ -> low E
3 nC

## Modes

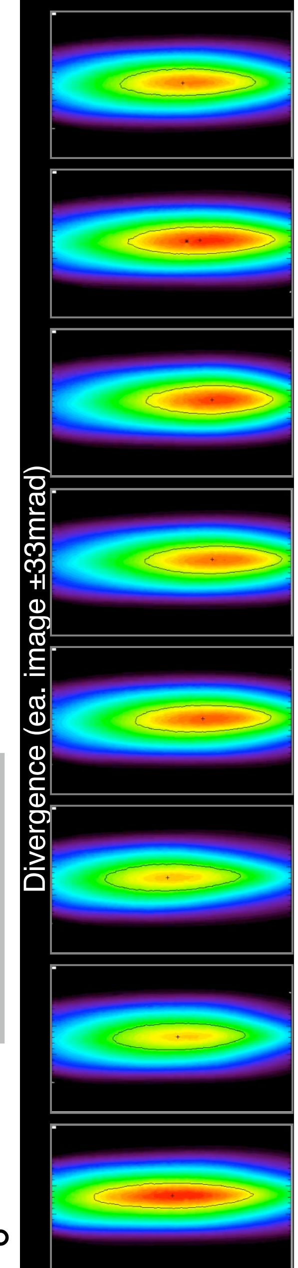
Self modulation
& filamentation
unstable





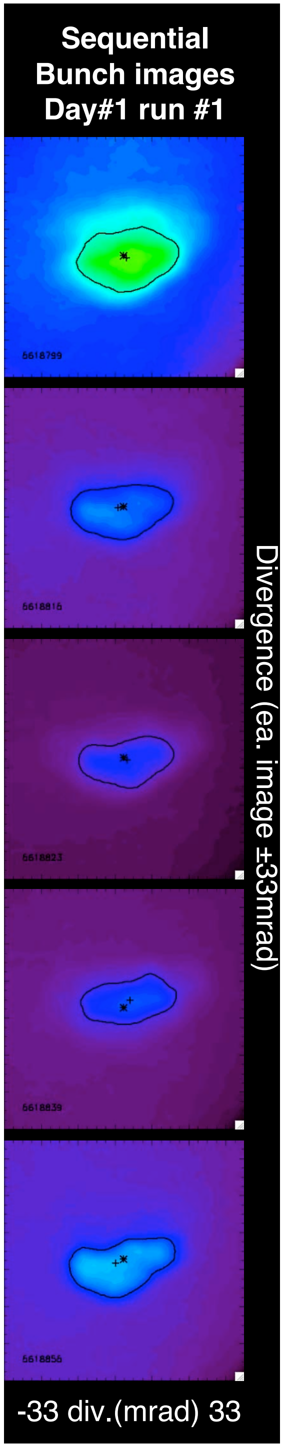
Similar to input
Transmit up to ≥70 %
stable

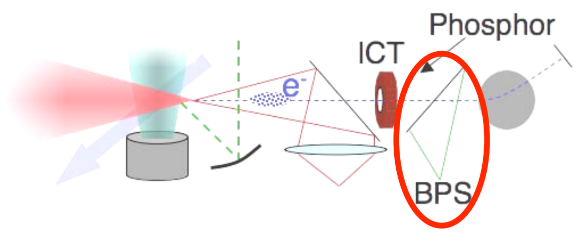
**Sequential Spectra Day#2 run #1**



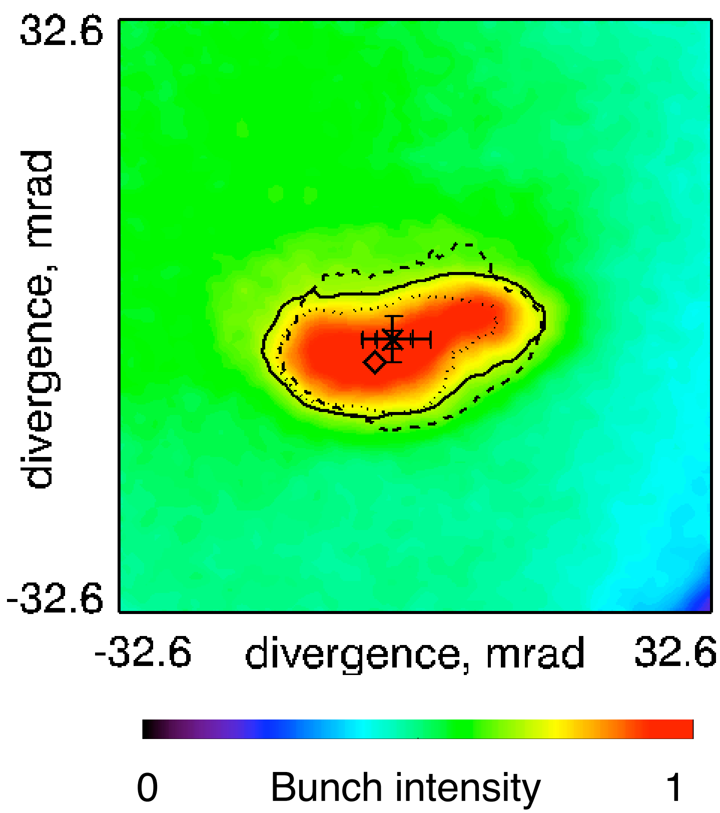

0.65 p(MeV/c)0.87

# Downramp: stable bunches with 20 keV/c transverse momentum



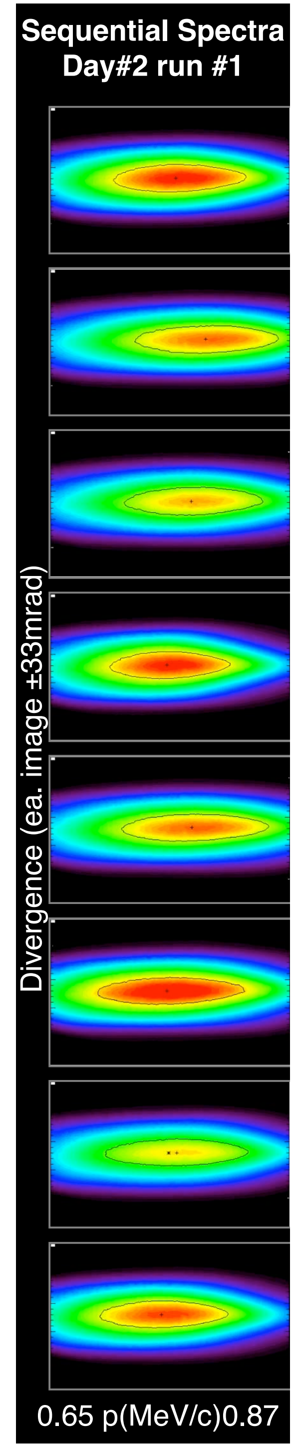

Electron beam image @ 72 cm

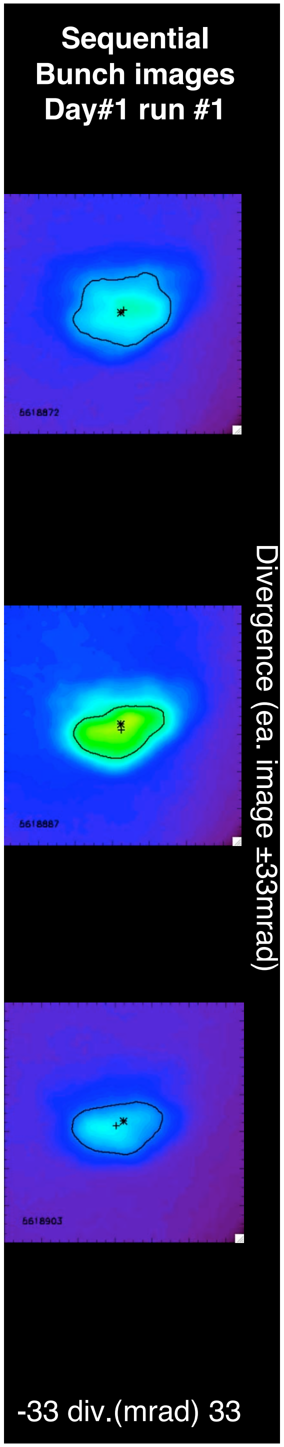



**FWHM Divergence** in X (Y)
28 (14) mrad
± 1.8 (2.5) mrad rms

**Pointing** stability in X (Y)
1.8 (1.2) mrad rms

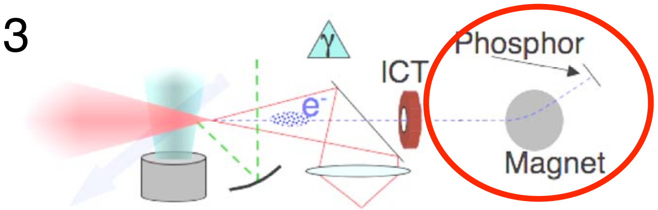
**Transverse momentum**
inferred ~ 20 keV/c FWHM






# Downramp: Stable bunches with 170 keV/c ΔP, 20 keV/c stability

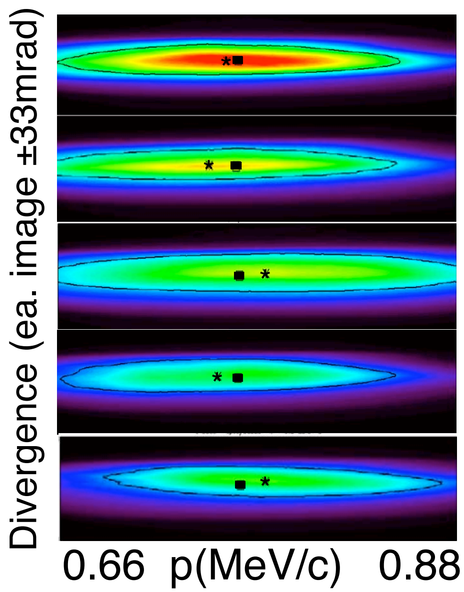
October 12-13



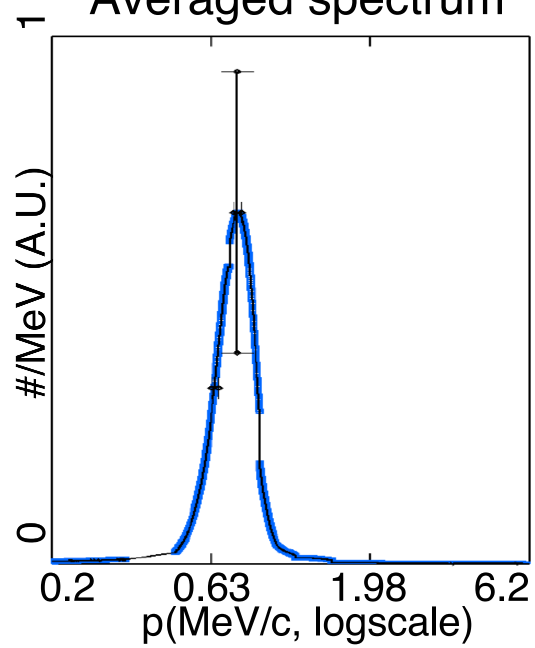

**Magnetic Spec.**

Bend angle 55º
Resolution ±5%
Range ±14%

Sequential shots




Averaged spectrum

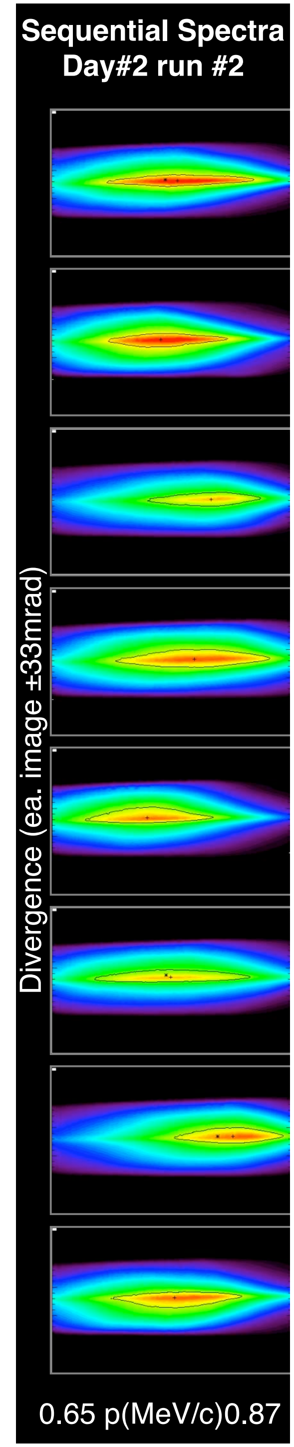


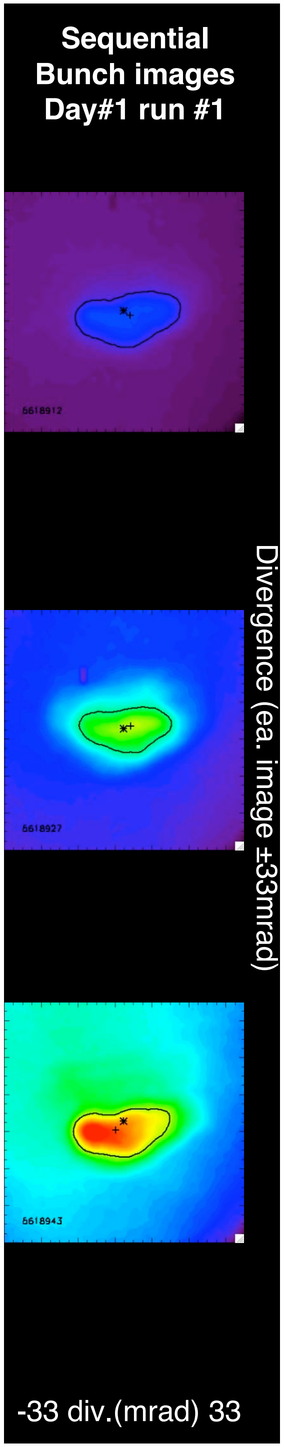

**Central momentum** 0.76 MeV/c ±20 keV/c rms

**Momentum spread** 170 keV/c FWHM ± 20 keV/c rms

**Divergence** 20 mrad FWHM (Y), pointing 1.5mrad rms

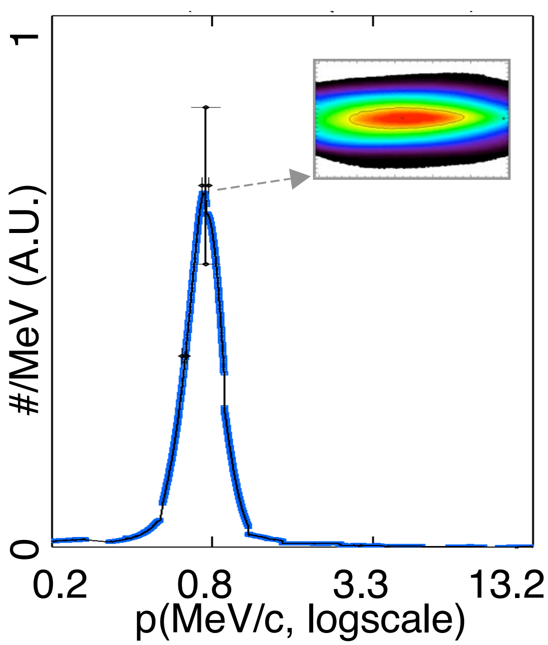
$\mathbf{Q_{bunch}}$ from correlation of phosphor & ICT ~ 0.3-1nC

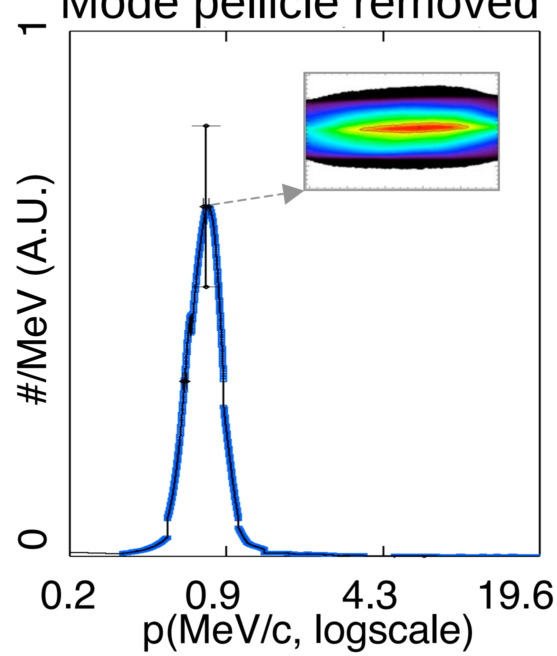





# Downramp: stability over 7 days within 20 keV/c

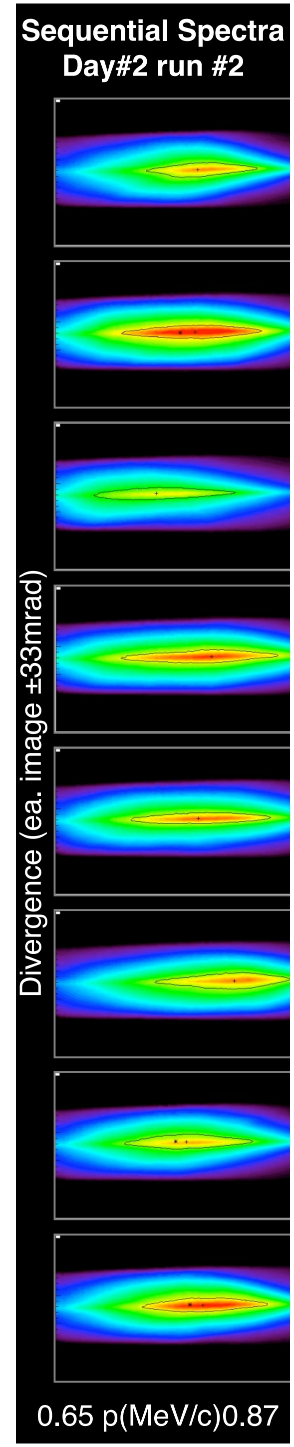
October 19




| | 0345a.m. | 0432a.m |
|---|---|---|
| **Central momentum** | 0.77 MeV/c | 0.78 MeV/c |
| **Momentum spread** | 200 keV/c | 190 keV/c |
| **Divergence** | 23 mrad (Y) | 18 mrad (Y) |
| **Charge fluctuation** | 23% rms | 21% rms |

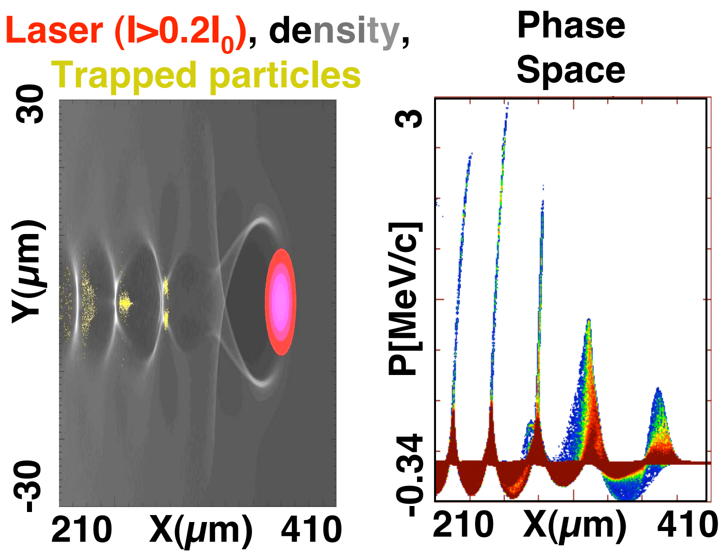
100 % injected beams w/in spec. window

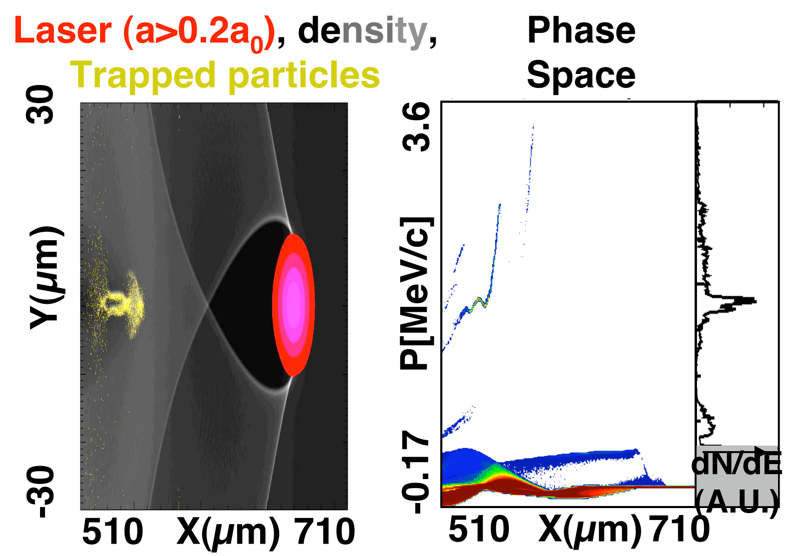


# Simulations show downramp trapping, nearly reproduce bunch

VORPAL^ particle in cell simulations, near experimental Parameters

Plasma density downramp slows wake, inducing trapping




Consistent with experimental data:

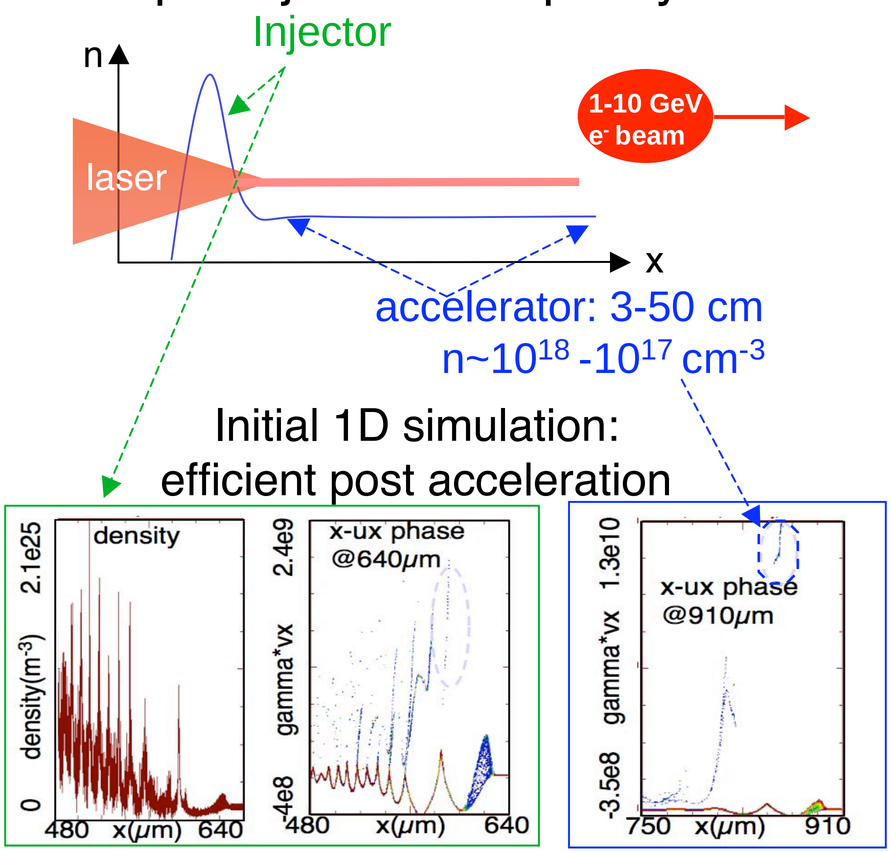
- bunches at MeV momenta, dp ~ 200 keV/c, Q ~0.2nC
- stable over physical parameter scans
- 10's of keV/c transverse momentum
- order 200 fs length at THz emission surface*

- Bunches ~ 30fs long at formation
  - suitable for LWFA injector

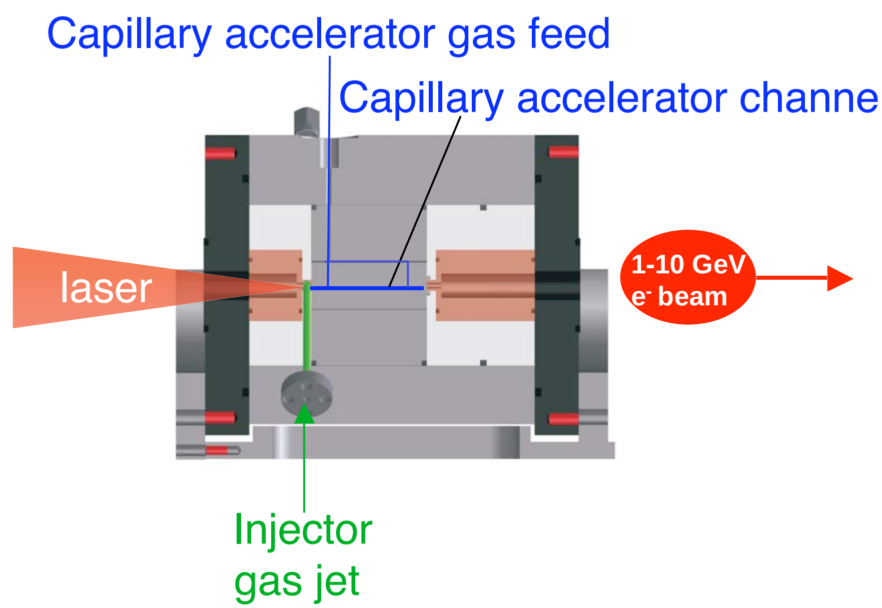
^Nieter JCP 2004, *consistent w/ experiments - W.P. Leemas,G. Plateau poster, Thursday

# Stage downramp bunch to capillary for stability, quality, 10 GeV beams

- Couple injector to capillary channel

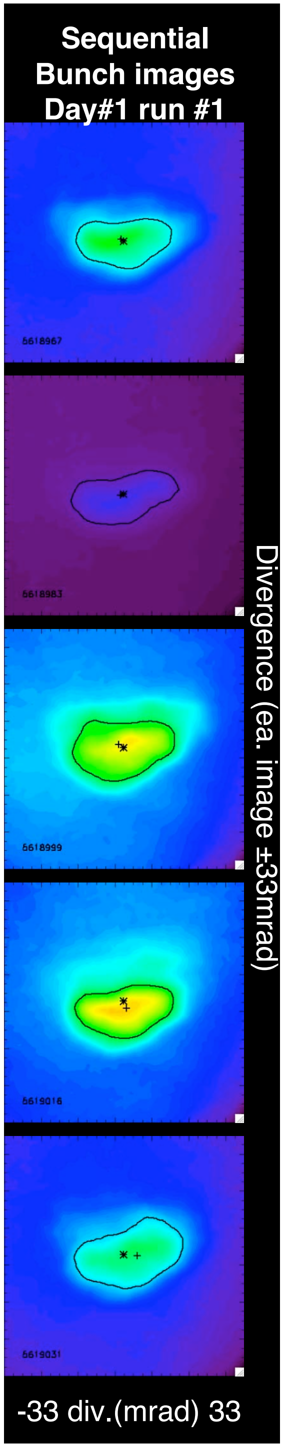



- Experimental setup




- Stage low energy injector and 1-10 GV accelerator modules
  - –Staging ~ preserves energy spread: improve emittance, stability*
  - –10 GeV using ~ PW of laser energy and meter-scale plasma

* Shadwick, BAPS, 2005




# Plasma density ramp control: stable low $\Delta p$ beams for LWFA injectors

Used plasma density gradient in gas jet to control trapping, producing bunches at 0.76 MeV

Longitudinal & transverse momentum spread, stability one to two orders improved from conventional LWFAs

- momentum spread 170 keV/c
- central momentum ±20 keV/c
- pointing ± 2mrad
- divergence implies $p_\perp \sim 20$ keV/c
- stability over 7 days, similar over 1+ year

Next: experiments and detailed simulations to:

- stage bunches to accelerator channel
- optimize injection
- optimize emittance preservation