STATUS OF E-157:

METER-LONG PLASMA WAKEFIELD EXPERIMENT

Presented by Patrick Muggli

for the E-157 SLAC/USC/LBNL/UCLA Collaboration

OUTLINE

- Basic E-157 Acelleration, Focusing
- Plasma Source
- Diagnostics: Beam, OTR, Cherenkov
- First run results Focusing
- Summary

E-157 Goal: Accelerate e^- by 1 GeV over 1m, and …

LWFA:	$\varphi \approx 100$ GeV/m	$n_e \approx 10^{18}$ cm^{-3}	$L \approx 1$ mm
PBWA:	$\varphi \approx 3$ GeV/m	$n_e \approx 10^{16}$ cm^{-3}	$L \approx 1$ cm
PWFA:	$\varphi \approx 1$ GeV/m	$n_e \approx 10^{14}$ cm^{-3}	$L \approx 1$ m

30 GeV SLC-FFTB*:

- The head of the beam excites the 1 GeV/m plasma wake.
- The tail of the beam experiences the 1 GeV/m acceleration.
- The plasma is 1-m long.
- $\lambda_{pe}/4 \approx \sigma_z$

*Stanford Linear Collider-Final Focus Test Beam

Particle In Cell (PIC) Simulations

1) Longitudinal Field Acceleration

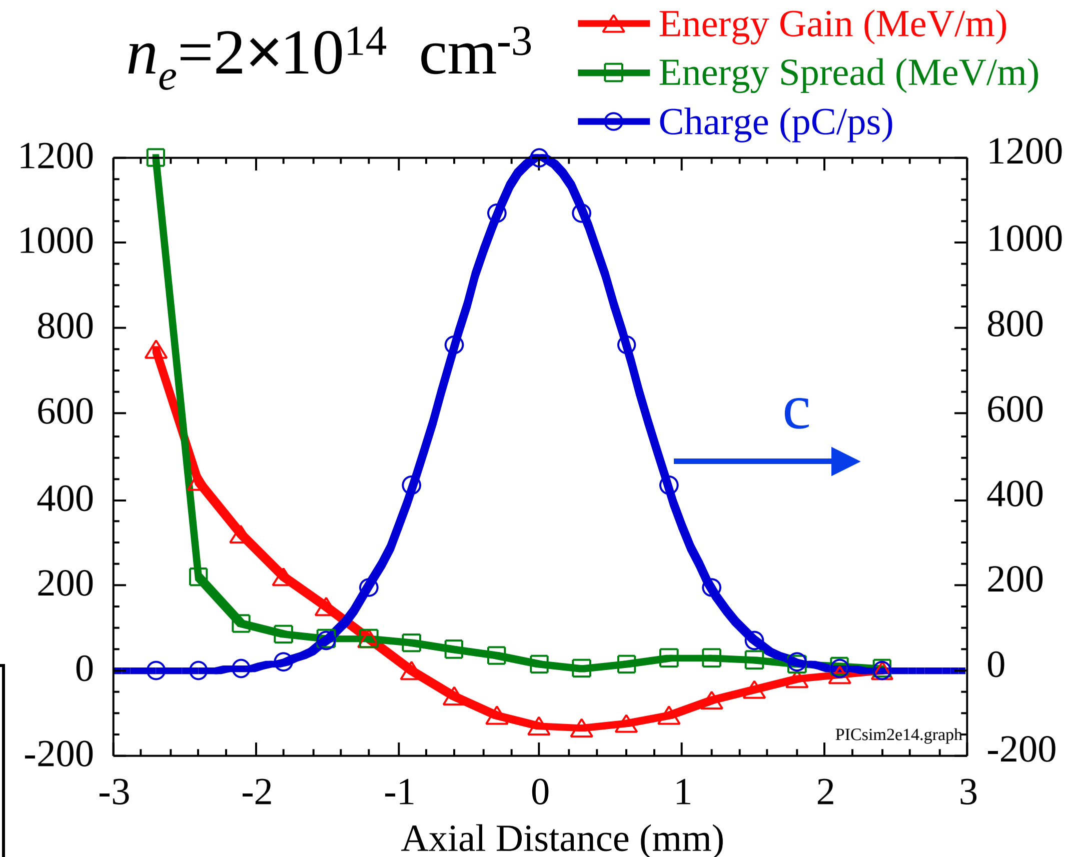
SLAC-FFTB* parameters:

Number of Electrons	N_e	$3.5\text{-}4.0 \times 10^{10}$
Initial Energy	E_0	30 GeV
Bunch Length	σ_z	0.6 mm
Bunch Size	σ_x	75 µm
	σ_y	75 µm
Emittance	$\gamma\varepsilon_x$	60 mm-mrad
	$\gamma\varepsilon_y$	15 mm-mrad

Plasma parameters:

Plasma Density	n_e	$2\text{-}4 \times 10^{14}$ cm^{-3}
Plasma Length	L	1 m
Density Uniformity	$\Delta n_e/n_e$	<25%
Ionization Fraction	n_e/n_0	>15%
Radius	r	>400 µm

$n_e=2\times10^{14}$ cm^{-3}



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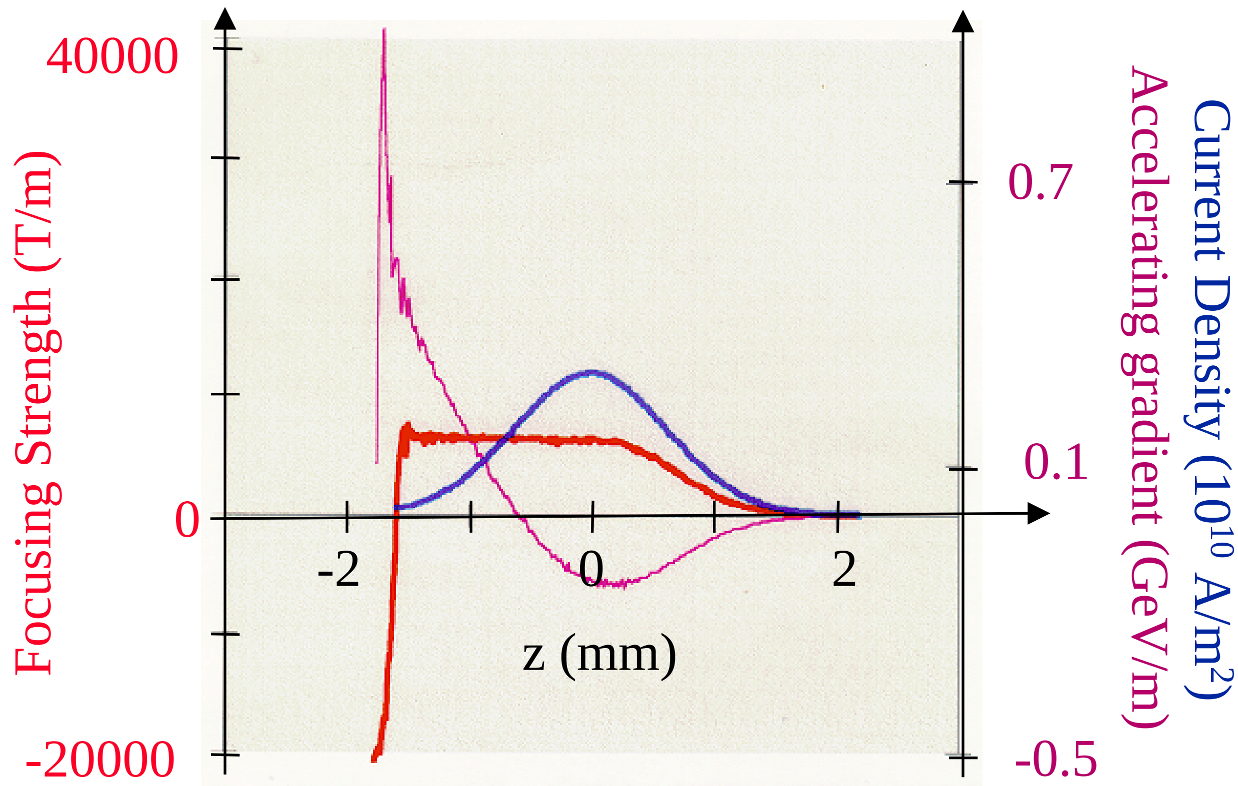
2) Transverse Fields Focusing, Betatron Motion



- Large focusing force in the blowout regime

Need to match $L=m\lambda_b/2$, m=3, 5, … or $n_e^{1/2}L$ fixed

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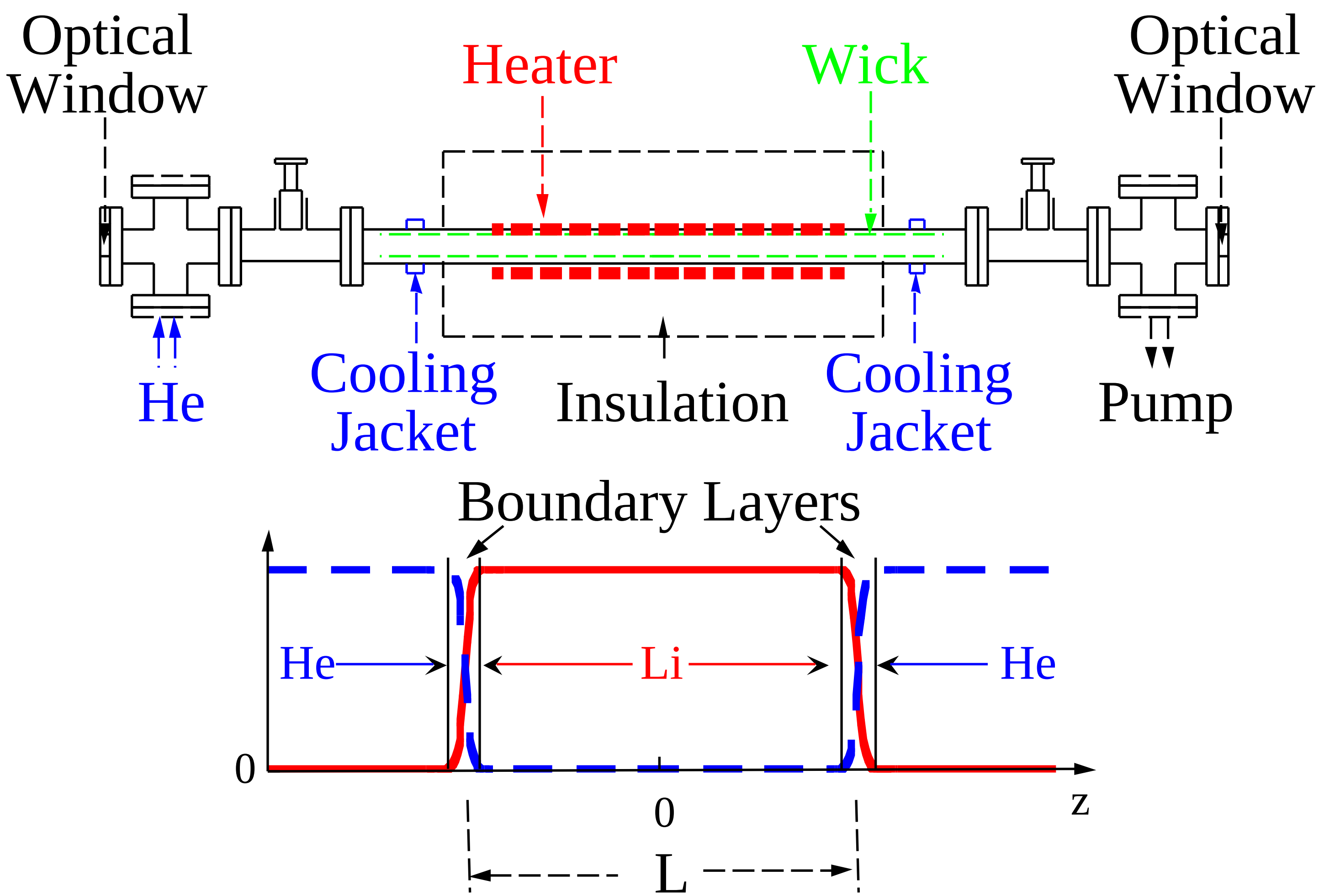
Li Vapor Source



- n_0(Li) ↔ P_{He}
- L ↔ Heating Power

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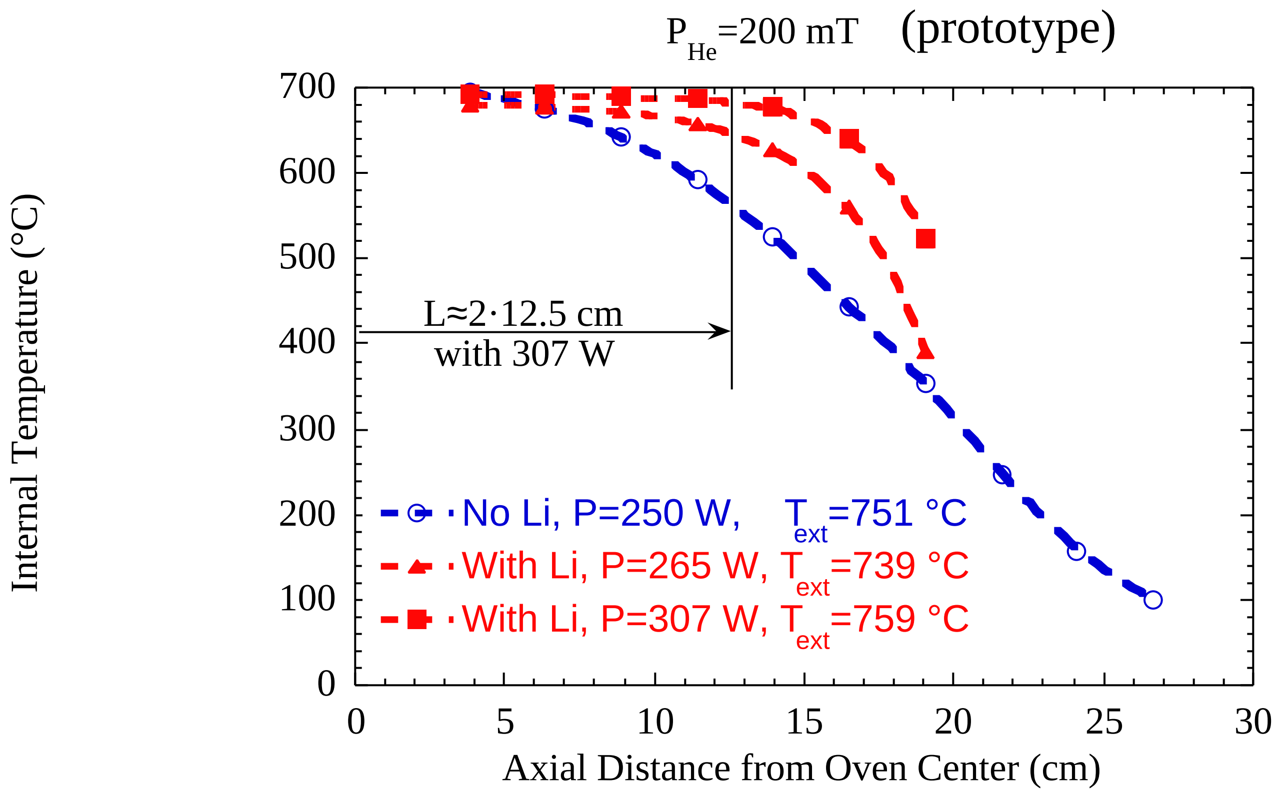
Li Vapor



- Obtained neutral density $n_0=2\times10^{15}$ cm^{-3}, $L=80$ cm, 130 cm

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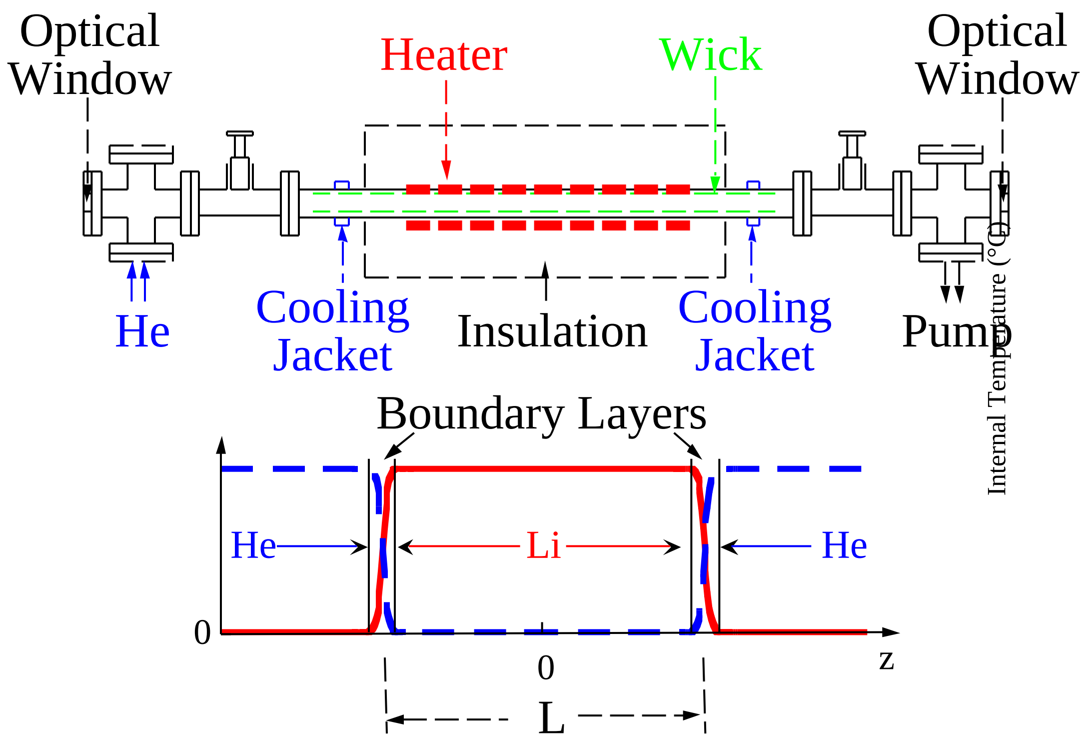
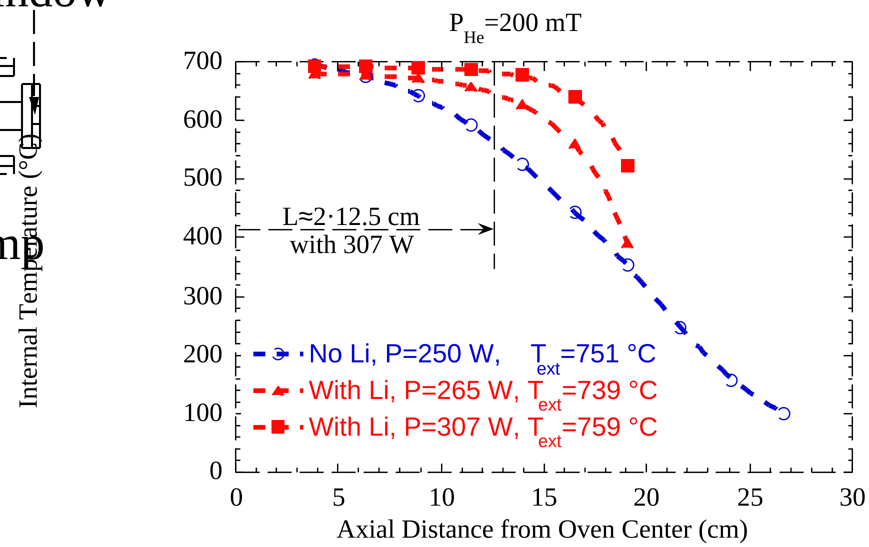
Li Vapor Source





- n_0(Li) ↔ P_{He}
- L ↔ Heating Power

- Obtained neutral density $n_0=2\times10^{15}\ cm^{-3}$, $L=80\ cm,\ 130\ cm$

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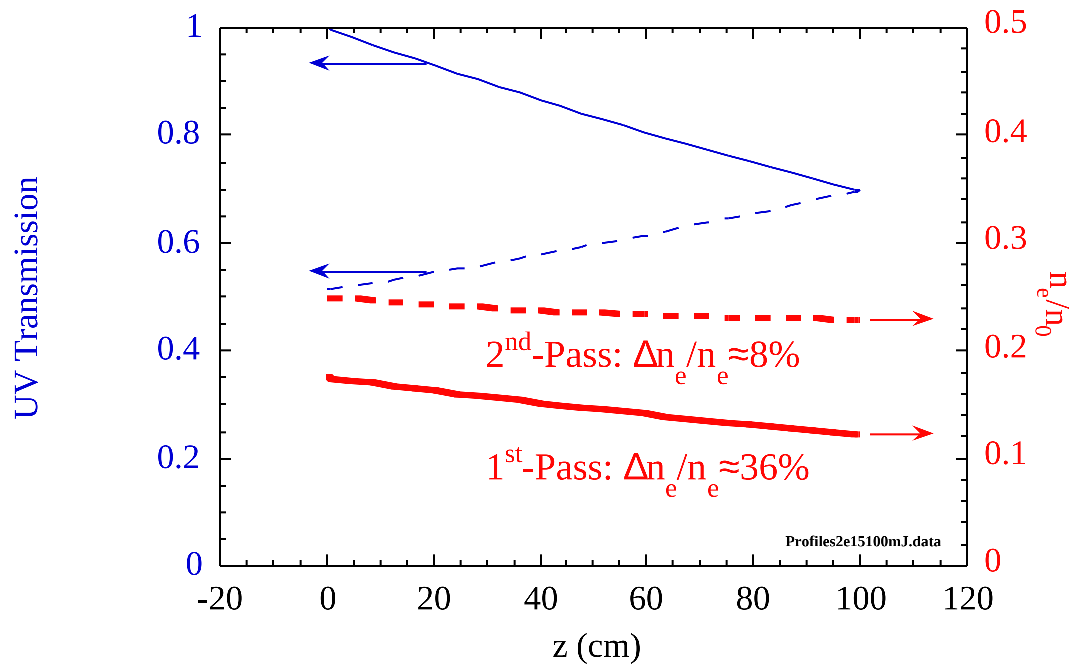
Li Plasma

Ionize Li with 6.45 eV uv photons (ArF laser, 193 nm)



- $n_0 = 2\times10^{15}$ cm^{-3}, L= 1m,100mJ/cm^2

  (alternative: cylindrical focusing of the beam)

2 passes: $n_e \approx 4.8\times10^{14}$ cm^{-3}
$n_e/n_0 \approx 24\%$
$\Delta n_e/n_e \approx 8\%$

- Obtained plasma density $n_e = 2.9\times10^{14}$ cm^{-3}, $L = 25$ cm *(prototype, 1-pass)*

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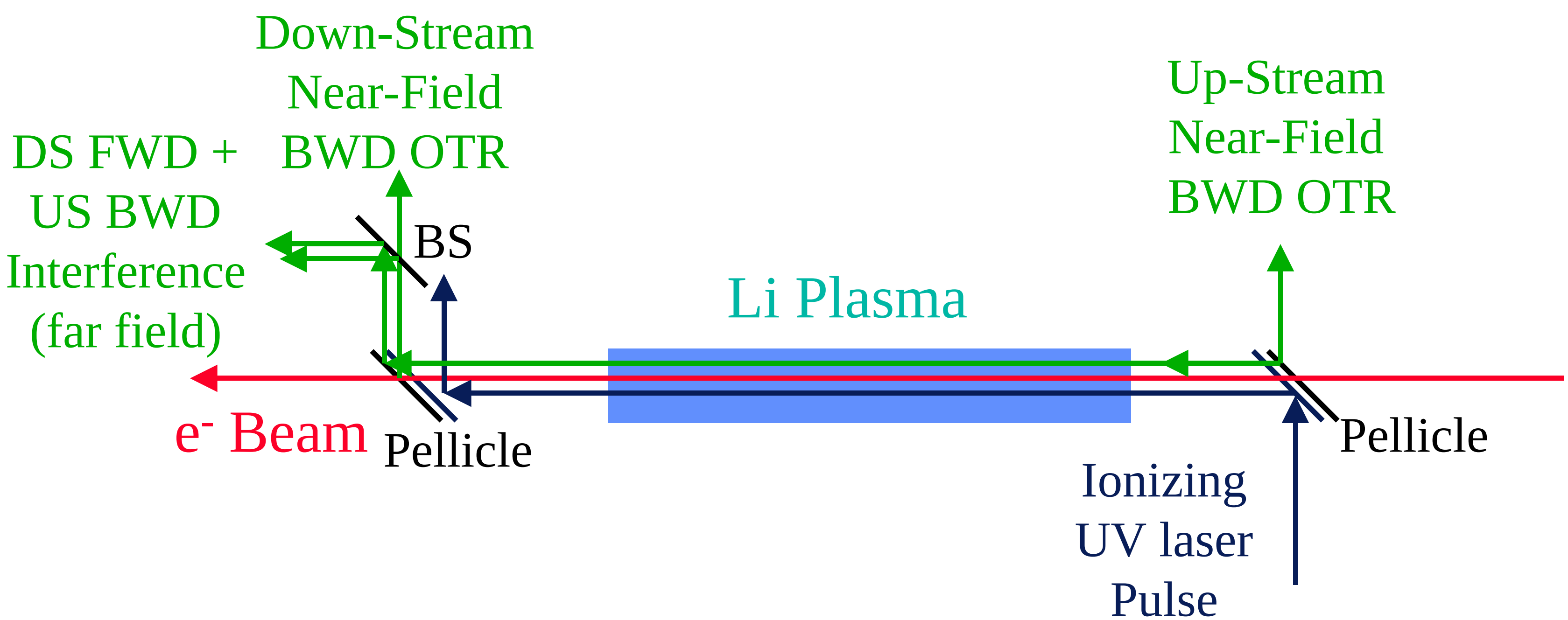
Diagnostics

1) e^- beam: - Beam Position Monitors (BPM), SLC diagnostics

(energy, emitance, beam size, …)

2) Optical Transition Radiation (OTR)



- Near field: beam position (alignment), and size before/after plasma
- Far field: beam divergence/emitance (interference between fwd and bwd OTR)

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E-157 Plasma Wakefield Acceleration
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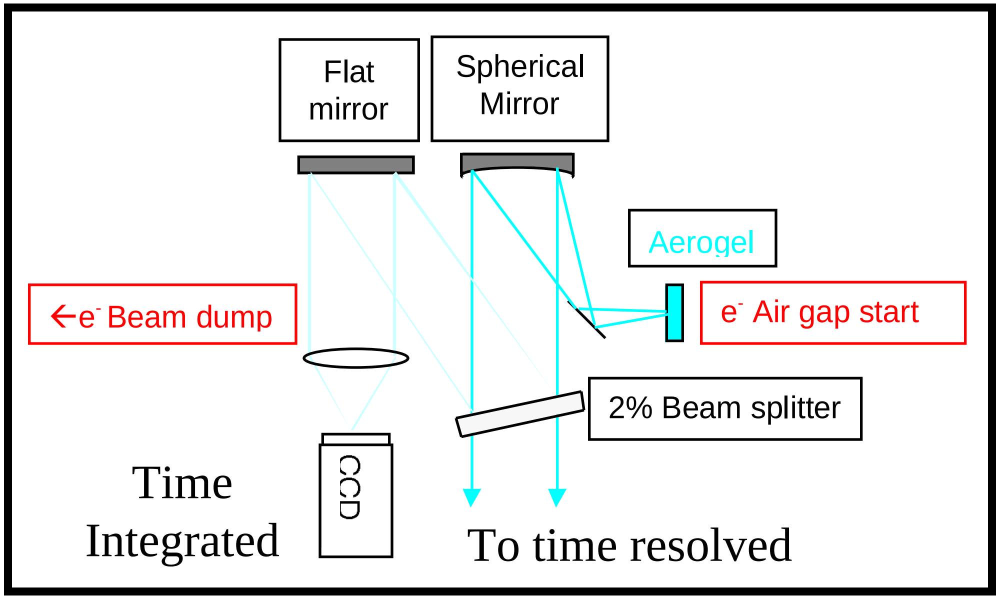
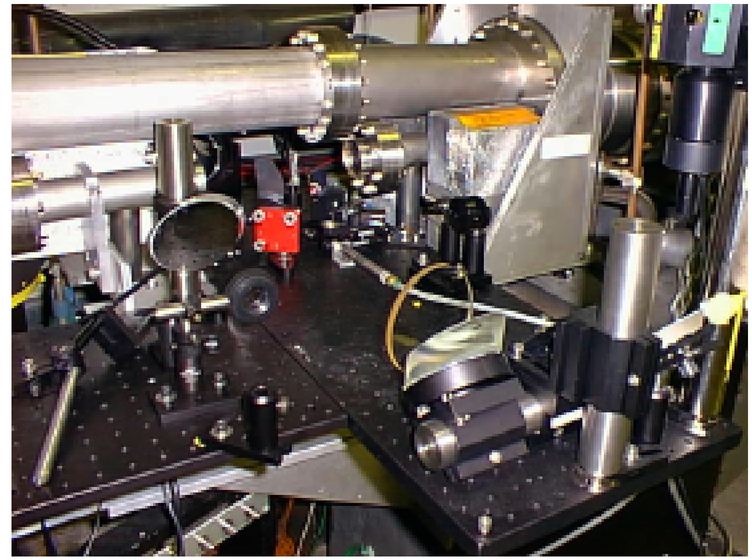
3) Cherenkov radiation:





- **<u>Why choose aerogel?</u>**
  - **$\cos\theta_c = 1/\beta n$, n=aerogel index of refraction**
  - **Energy Resolution: ΔE_{res} $L\theta_c \leq 150$ µm**
  - **# photon/e-: N_γ $L\theta_c^2$ $\Delta\varepsilon_{res}\theta_c$ --> want as large a Cherenkov angle as can collect**
- **<u>Aerogel parameters:</u>**
  - **$n_{aerogel}$ = 1.008 - 1.012 --> θ_c =7.2-8.8 deg.**
  - **$N_{g\ Cherenkov}$ (photons/e-mm) = 1.4 >> $N_{g\ OTR}$ = 1/100**

- Time integrated: energy spectrum, x-size
- Streaked : energy, x-size as a function of *t* or z-slice

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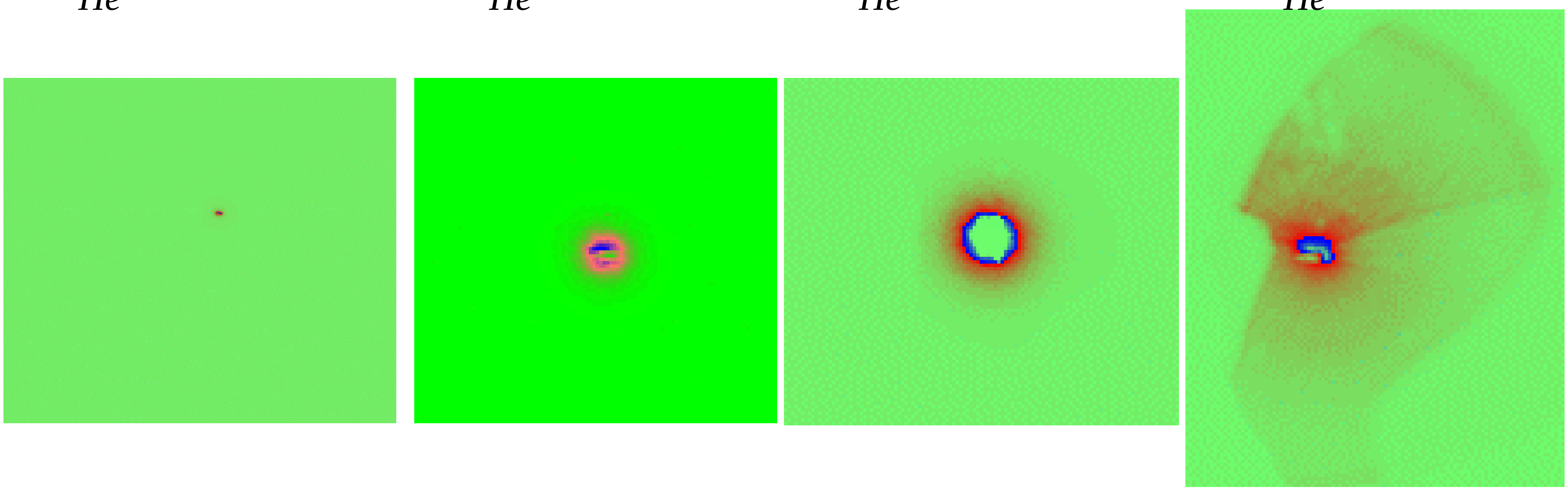
First Run Data (preliminary)

- He (buffer gas) Impact Ionization, downstream OTR

N=2×10[10] e[-], ΔE≈3% n_e/n_0≈1.5% @ 0.25T (estimate), L≈2.2 m

P_{He}=0.0-0.25 T P_{He}=6 T P_{He}=15 T P_{He}=250 T



- No Impact Ionization Effect @ Operating Pressure
- At higher pressure: plasma lensing

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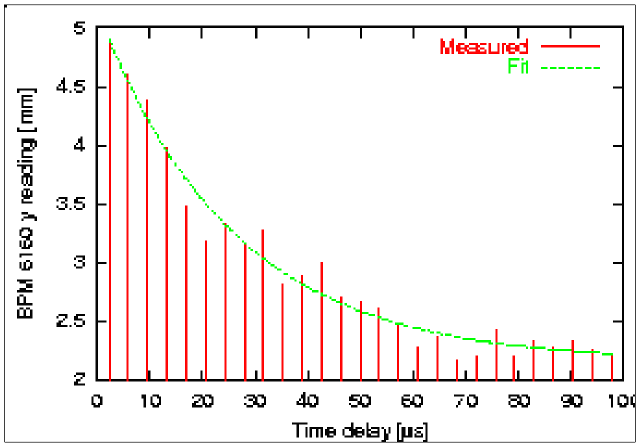
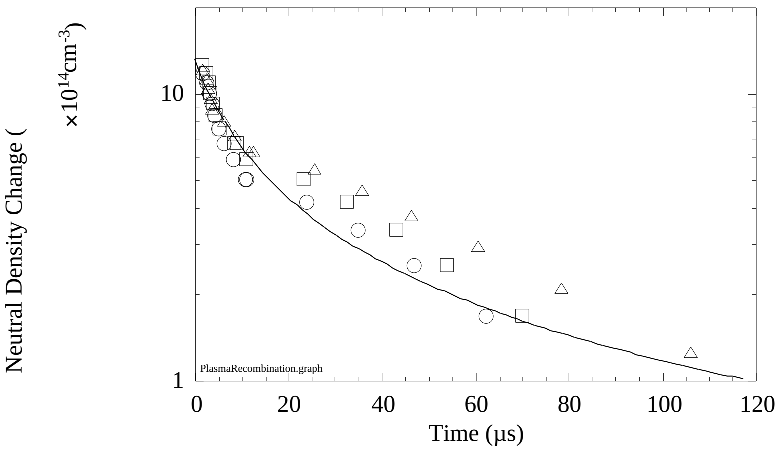
- Plasma Induced Beam Motion (BPM 6160, 12.0 m)

N=2×10^{10} e$^-$, ΔE≈3%





n_e≈e$^-$ pulse-laser pulse delay

- Vertical motion of the beam centroid as a function of ionizing laser-e$^-$ beam delay i.e., plasma density
- $n_e \approx n_{e,max} e^{-t/\sigma}$, $\sigma \approx 27\ \mu s$

- Time evolution of the plasma density as measured by laser visible interferometry
- n_e decreases by a factor of 2 in ≈12 µs

- The plasma kicks around the beam tail ⇔ observe centroid motion
- Beam tail due to wake fields in the accelerator

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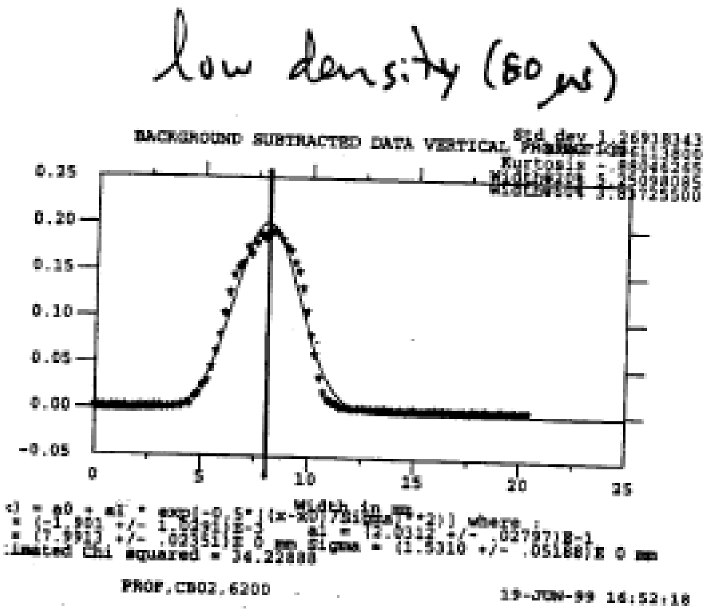
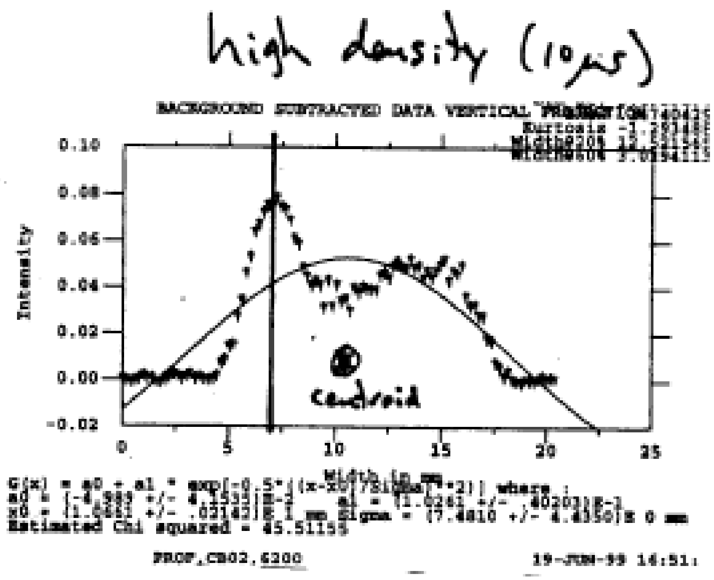
- Plasma Induced Beam Motion

Beam Dump Image Line-Out





- The plasma does kick around the beam tail

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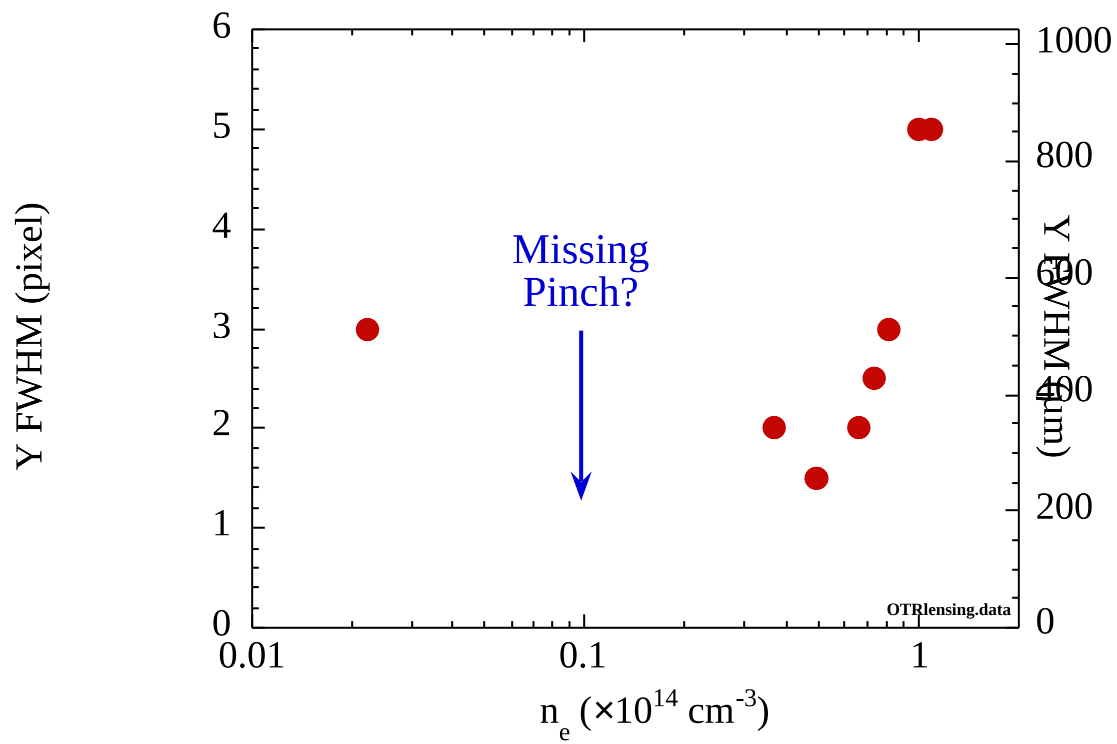
- Plasma Lensing

Downstream OTR images

N=2×10^{10} e$^-$, ΔE≈3%, σ_z≈500 μm



- The beam pinches by a factor of 2!
- Consistent with $n_{e,max}$≈1.1×10^{14} cm^{-3}, L≈0.8 m, if 2nd pinch

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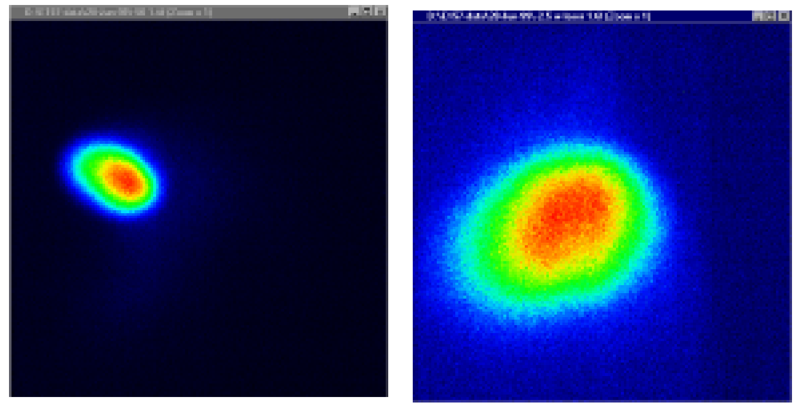
Time Integrated Cherenkov Images, (focus mode)

N=2×10^{10} e^-, ΔE≈3%, σ_z≈500 μm

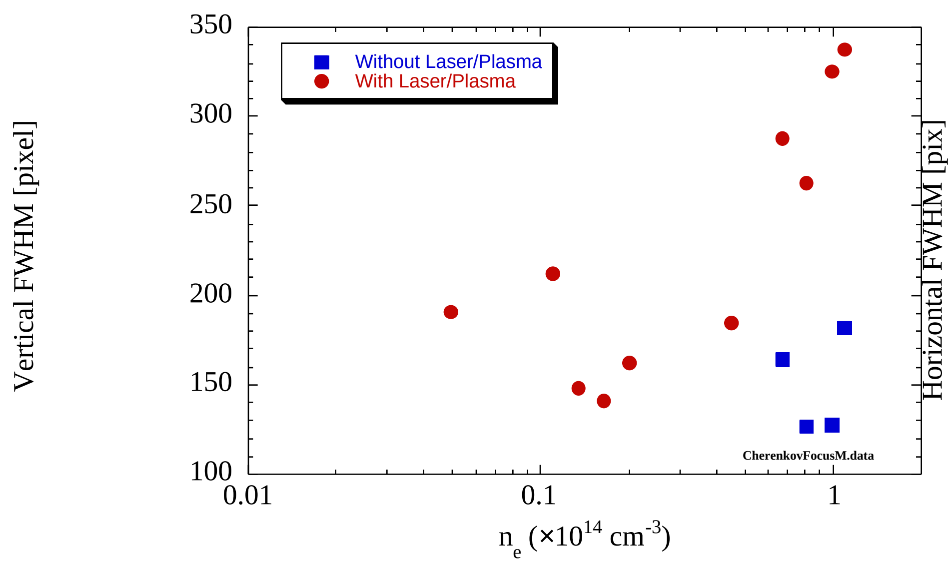
E

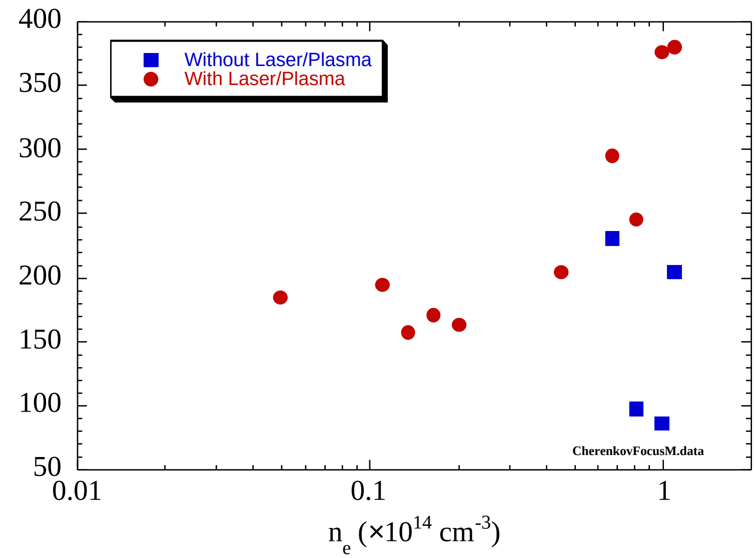
No Plasma



n_e≈1.1×10^1 cm^{-3}

x





- The beam only expands at the Cherenkov location

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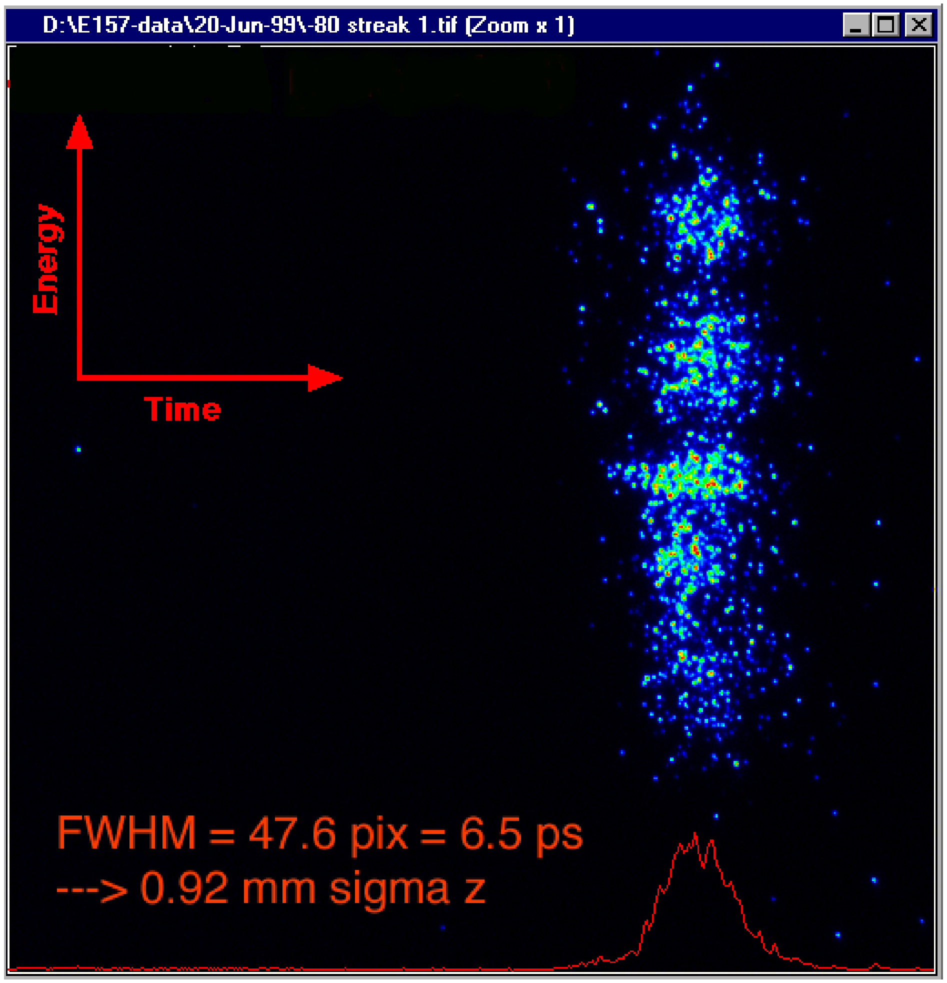
• e^- Bunch Length (streak mode)



- **Streak camera measurement of dispersed electron beam**
- **Image 8mm (2.7 GeV) field of view @ streak camera 15m away**
- **Reflective optics for:**
  - **Large bandwidth = more sensitivity**
  - **Low dispersion = 1ps resolution**
- **SLAC streak camera (SLC and GTF experience):**
  - **Intrinsic resolution = 0.5 ps**
  - **125 μm slit contribution = 0.86 ps**
  - **Total resolution = 1 ps**
  - **Charge resolution ~ 10^6 e^-**

Summary of the First Run Data

- The experiment is young
  - Most diagnostics/data acquisition debugged.
- Clear evidence of beam-plasma interaction:
  - Focusing due to impact ionization in He.
  - Focusing (Li plasma) observed at the plasma exit with OTR.
  - De-focusing (Li plasma) observed with Cherenkov radiation in the dispersion plane.
- Next runs:
  - July 12 to August 2
  - August 17 to August 31
  - ???