E301: PWFA with Laser Ionized Gas Plasma Source (& Friends)

Oct. 30, 2019

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- Ecole Poly.: S. Corde, P. Claveria, others...
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- U. Texas: M. Downer, R. Zgadzaj, others...
- Others...

PWFA in Laser-Ionized, Room Temperature Gas Plasma Source

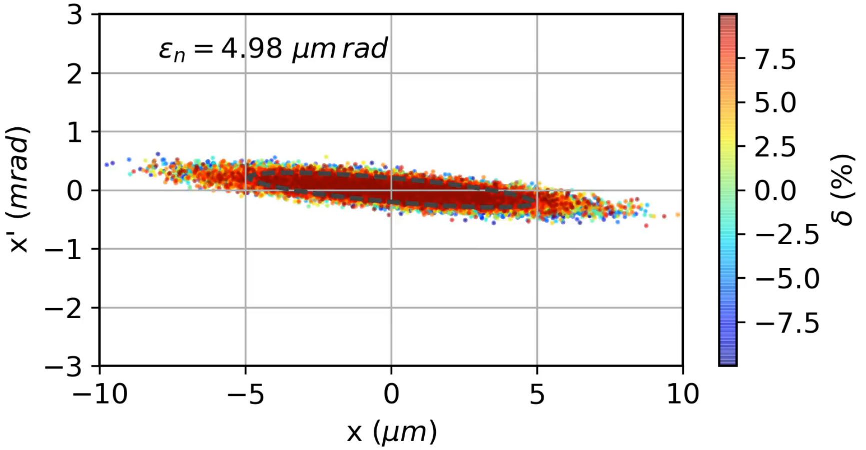
E301: Motivations

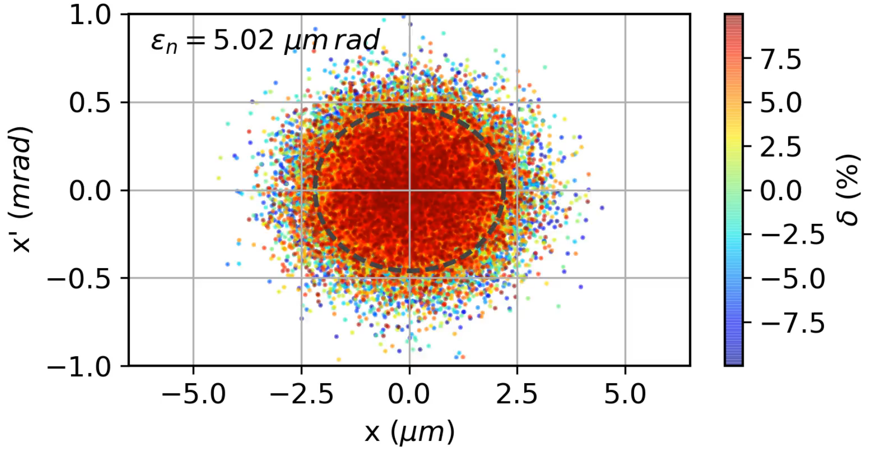
Laser-Ionized, Room Temperature Gas Plasma Source

- Improved emittance preservation
- Greater & faster tunability
- Higher rep. rate, especially with flowing gas
- Mixed gas species for injection
- Room temperature: no thermal expansion of hardware
- Optically accessible for diagnostics

Chromatic Emittance Growth

Chromatic phase spread causes projected emittance growth in an ion column.





Motion in an ion column:

$$x'' + k_\beta^2 x = 0$$

Oscillation frequency depends on particle energy:

$$k_\beta \propto 1/\sqrt{\gamma_b}$$

Mismatched beam:

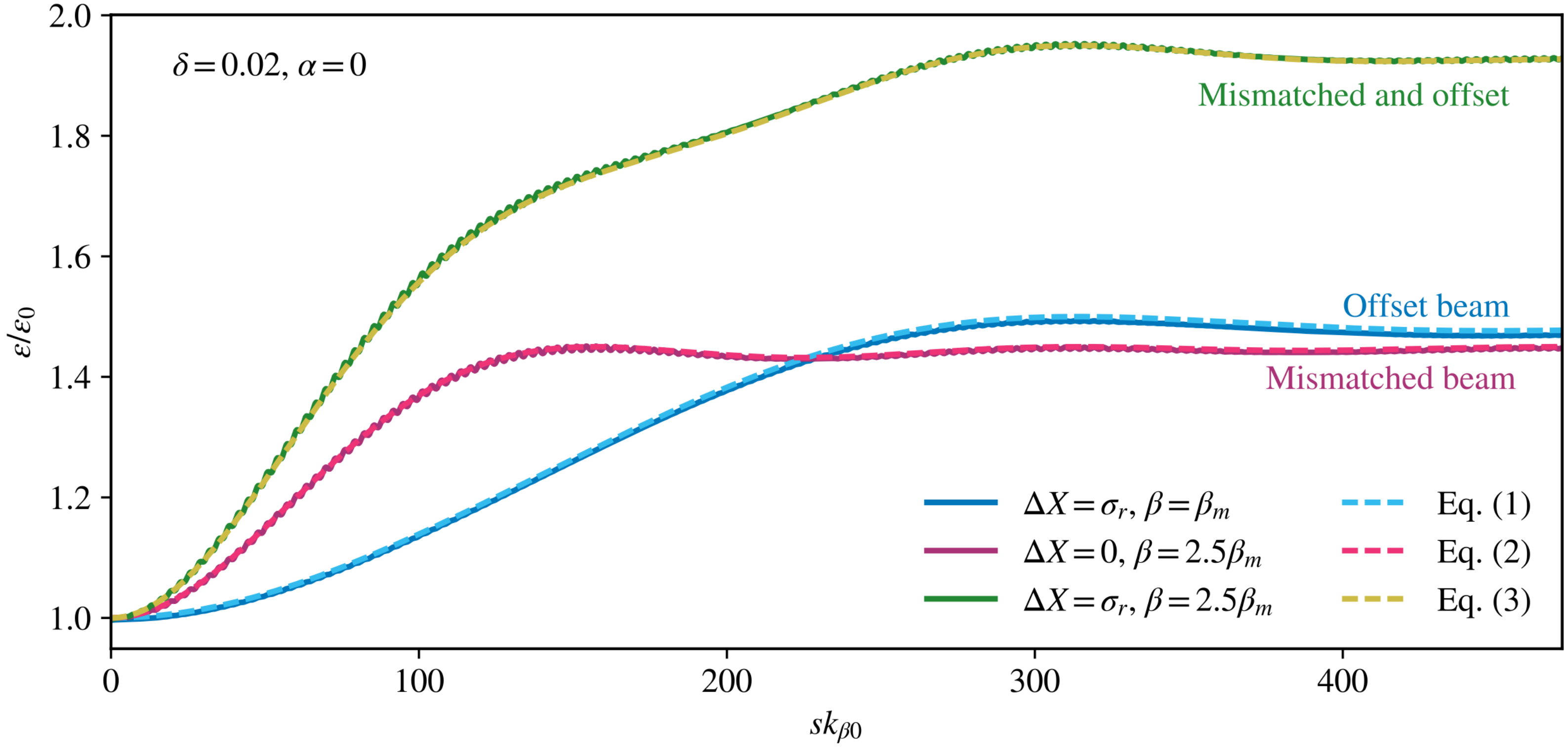
Saturated, projected emittance is given by:

$$\frac{\epsilon}{\epsilon_0} = \frac{1}{2}\left(\beta\gamma_m - 2\alpha\alpha_m + \gamma\beta_m\right)$$

Emittance Growth Rate

Saturated emittance for a witness beam that is both mismatched and offset:

$$\frac{\epsilon}{\epsilon_0} = \frac{1}{2}\left(\beta\gamma_m + \gamma\beta_m + \frac{\Delta x^2}{\beta_m \epsilon_0} + \frac{\beta_m}{\epsilon_0}\Delta x'^2\right)$$



(1) $$\epsilon = \epsilon_{sat}\sqrt{1 - \frac{(\gamma\beta_m + \beta/\beta_m)^2 - 4}{(\gamma\beta_m + \beta/\beta_m)^2}\left(\frac{\sin\Delta\Phi}{\Delta\Phi}\right)^2}$$

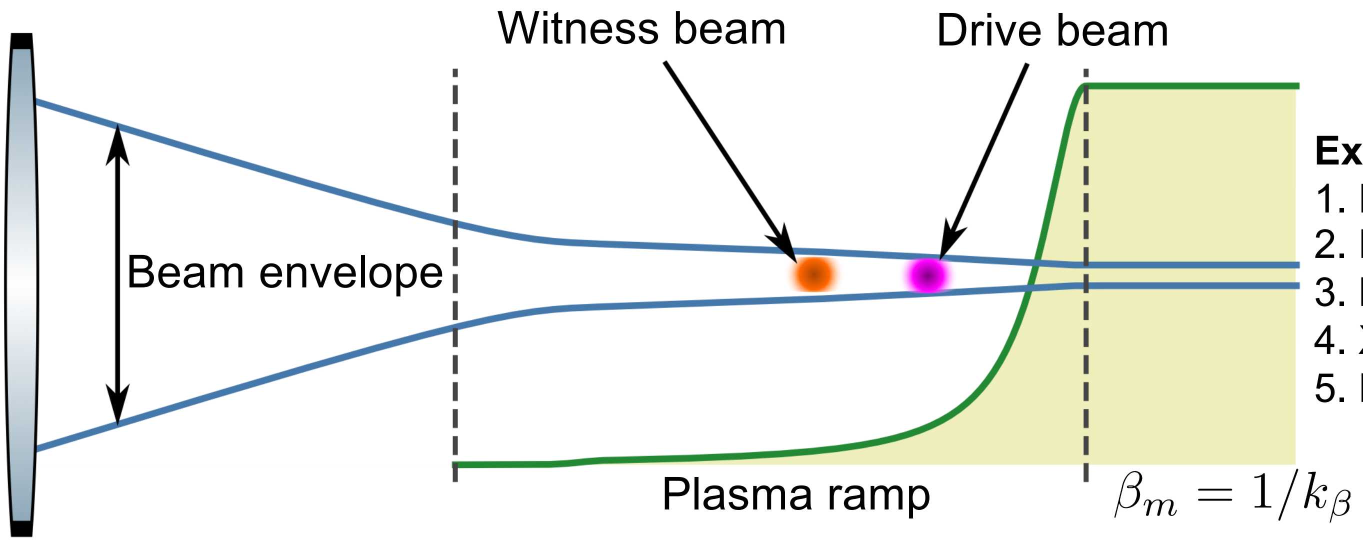
(3) Is a bit too big for the slide

(2) $$\epsilon = \epsilon_{sat}\sqrt{1 - \frac{Y^2}{2+Y^2}\left(\frac{Y^2}{2+Y^2}\mathrm{sinc}\Delta\Phi\left[\mathrm{sinc}\Delta\Phi - 2\mathrm{sinc}^2\Delta\Phi/2\right] - 2\mathrm{sinc}^2\Delta\Phi/2\right)}$$ where $$Y = \frac{\Delta x^2}{\beta_m \epsilon_0}$$

Matching with a Ramp

Matched CS parameters: $\alpha_m = 0 \rightarrow \beta_m = 1/k_\beta, \quad \gamma_m = k_\beta$

The beam can be focused to the matched size using a tailored plasma density.



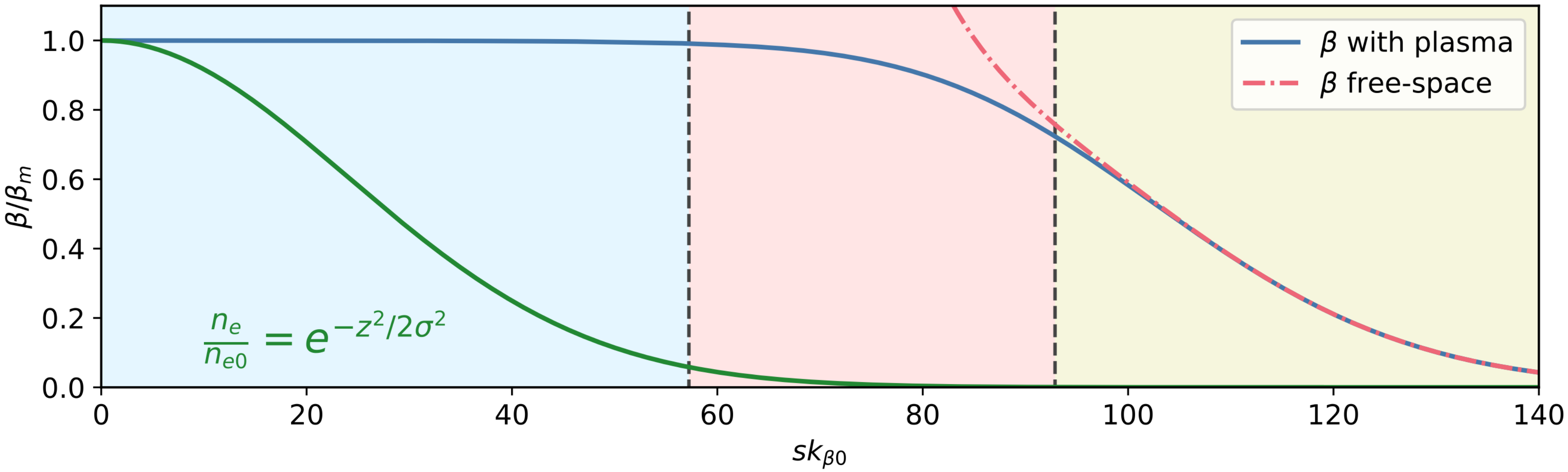
Examples in the literature:

1. P. Chen *et al*. 1990
2. N. Barov, J. Rosenzweig 1994
3. K. Floettmann 2014
4. X. Xu *et al*. 2016
5. R. Ariniello *et al.* 2019

Gaussian shape: not adiabatic, but it works

Three Types of Beam Evolution

Example: Gaussian Plasma Ramp



Adiabatic Region:

Matched beam size changes slowly.

Beam remains matched to local plasma density.

Non-adiabatic Region:

Beam departs from matched size.

Perturbative Region:

Total amount of plasma is small.

Vacuum propagation perturbed by plasma.

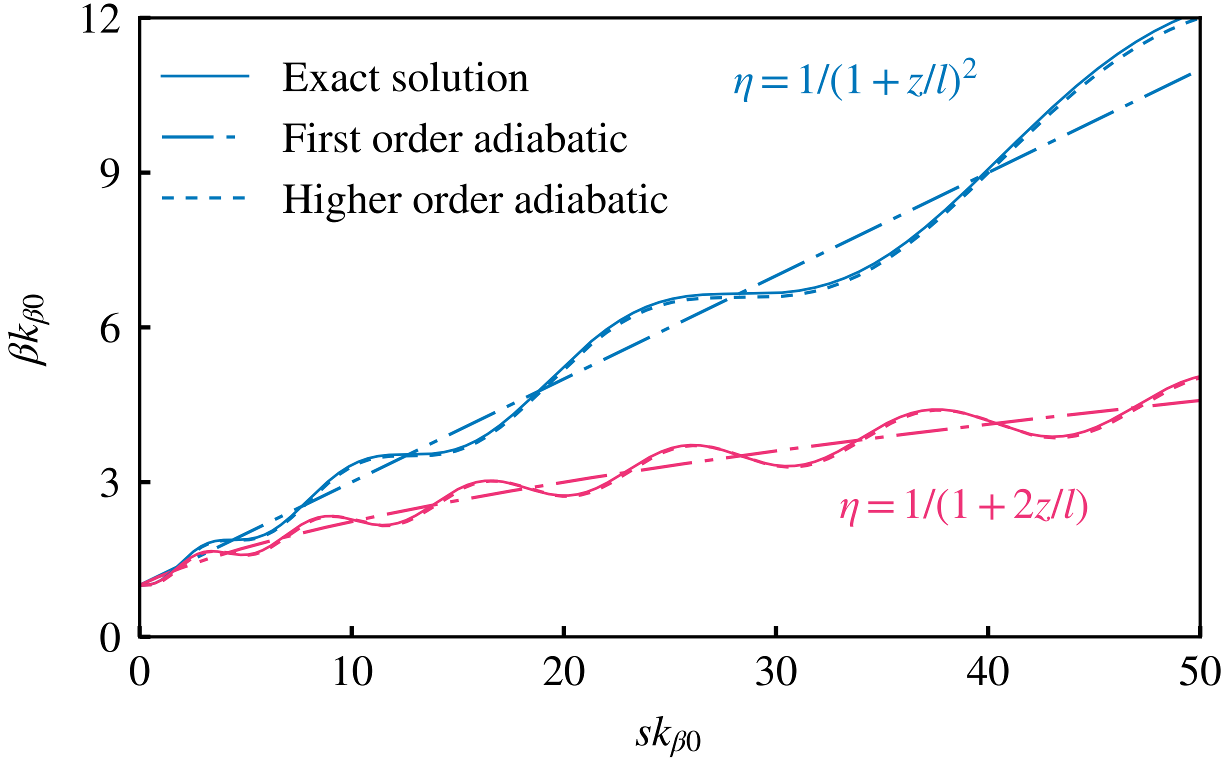
Complete description of beam evolution in all three regions:

R. Ariniello, et al. Phys. Rev. Accel. Beams **22** 041304 (2019)

Adiabatic: First Order vs. Higher Order

Previous literature: Only first order. Incorrect for mismatched beams!

Higher order solution predicts beam evolution for matched and mismatched beams with great accuracy!



$$\eta = \frac{n}{n_0}$$

Adiabatic Region

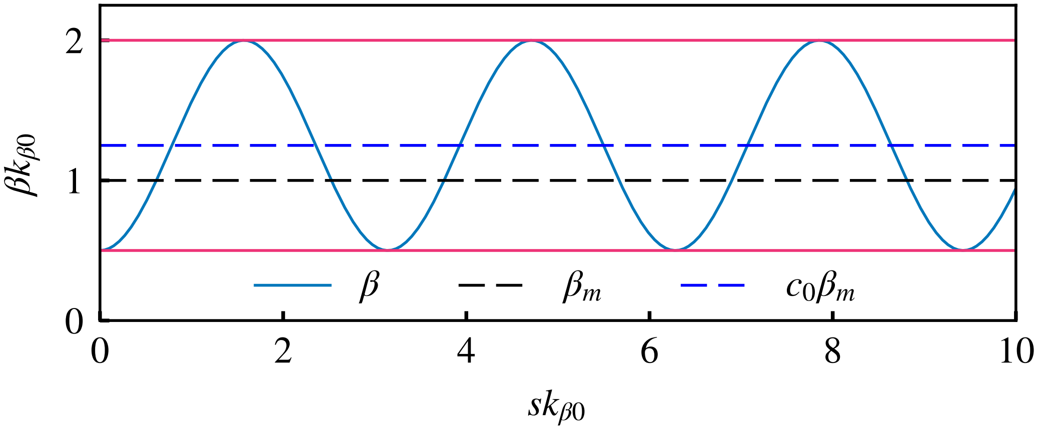
Adiabatic condition:

$$|\alpha_m| = \frac{1}{4nk_\beta}\left|\frac{dn}{ds}\right| \ll 1$$

Matched beam condition:

$$\beta_m(s) = 1/k_\beta(s)$$

$$\alpha_m(s) = -\beta_m'(s)/2$$



Adiabatic beam evolution:

$$\beta(s) = \beta_m\left(c_0 + c_1\cos 2\theta + c_2\sin 2\theta\right)$$

$$\theta = \int_0^s \frac{d\xi}{\beta_m(\xi)}$$

$$c_0 = \frac{1}{2}\left(\frac{\beta_0}{\beta_{m0}} + \beta_{m0}\gamma_0 - 2\alpha_0\alpha_{m0}\right)$$

$$c_2 = -\alpha_0 + \frac{\alpha_{m0}\beta_0}{\beta_{m0}}$$

$$c_1 = \frac{1}{2}\left(\frac{\beta_0}{\beta_{m0}} - \beta_{m0}\gamma_0 + 2\alpha_0\alpha_{m0}\right)$$

New

For details see R. Ariniello *et al.* PRAB 2019

Perturbative Region

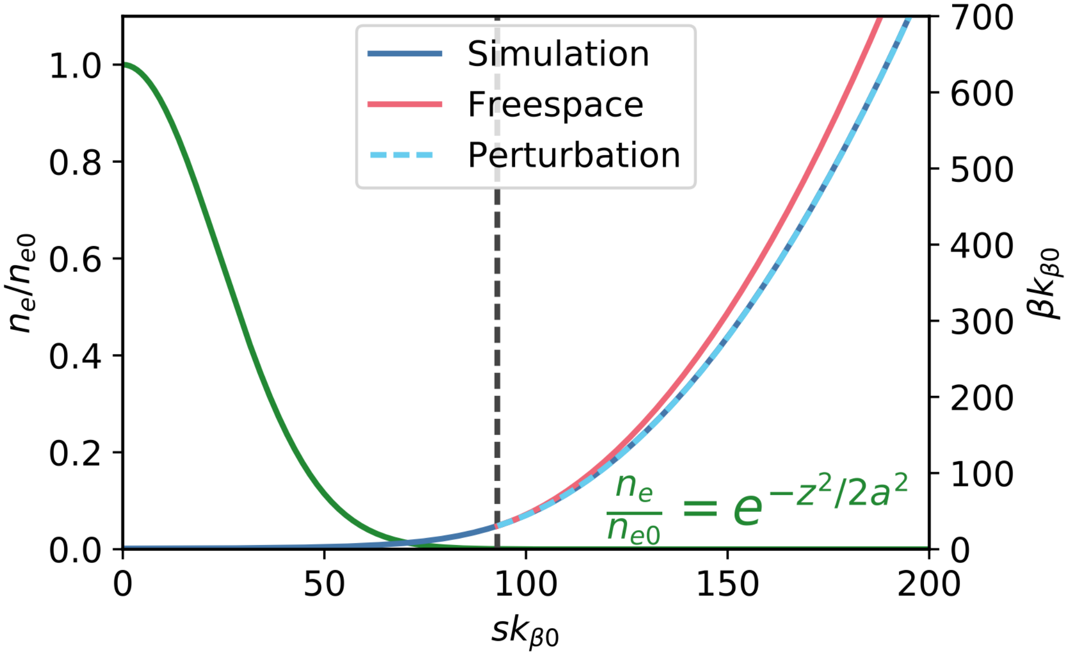
The small amount of plasma at the end of the ramp perturbs the beam evolution.

The beam behaves as if it is coming from a vacuum waist of:

$$\beta^* = \frac{1}{\gamma_0 + 2(\alpha_0 I_0 - \gamma_0 I_1)}$$

Requirement: $I_0 \ll 1, \quad I_1 \ll 1$

The vacuum waist can only be changed by a small amount



The beam evolves according to $M = \begin{pmatrix} 1 - I_0 s + I_1 & s - I_1 s + I_2 \\ -I_0 & 1 - I_1 \end{pmatrix}$

where

$$I_m = \int_0^\infty (s - s_0)^m n(s - s_0)\, ds$$

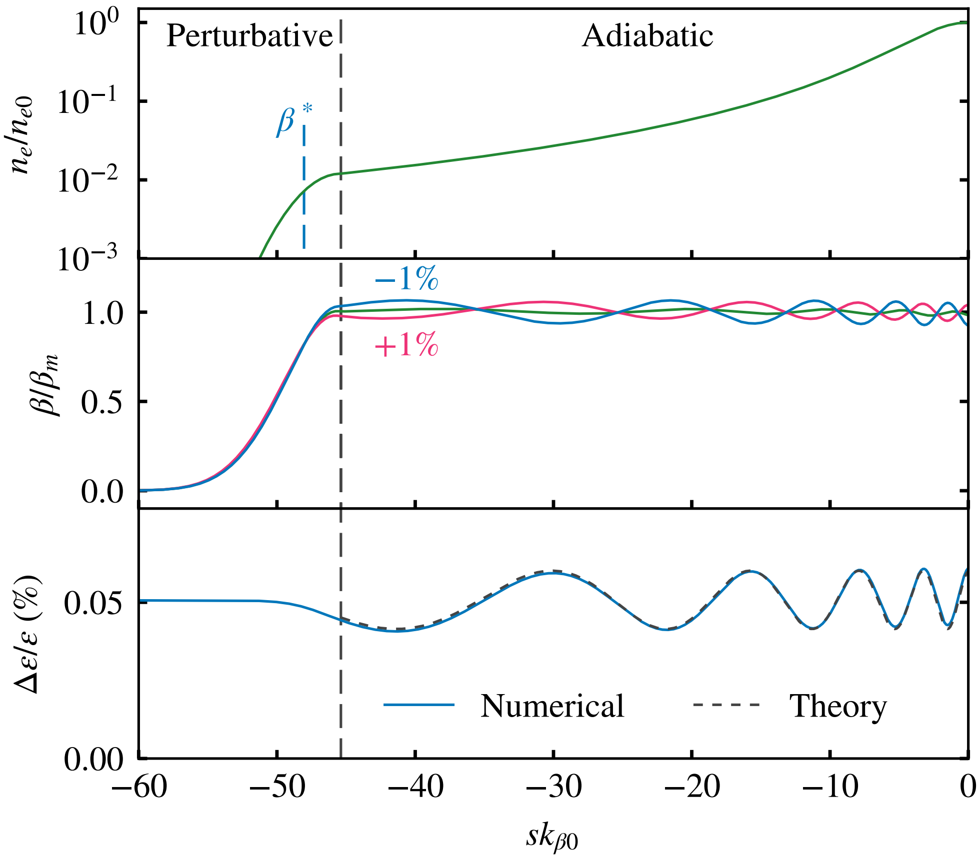
All New

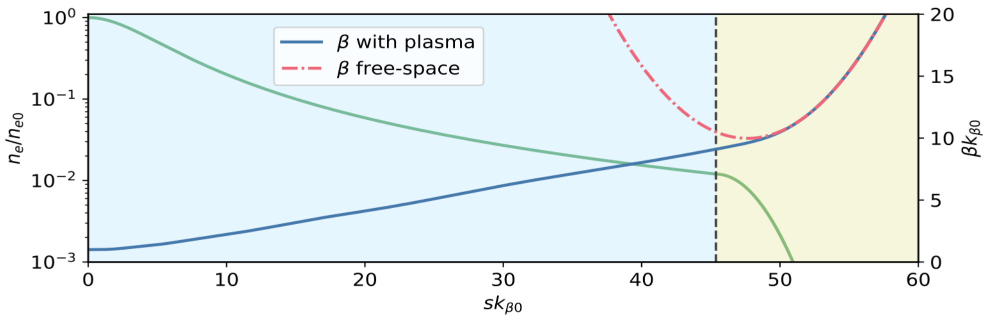
For details see R. Ariniello *et al.* PRAB 2019

Idealized Ramps

Fast transition from perturbative to adiabatic:

- Can be described completely analytically.
- Virtually no emittance growth in ramp.
- Relatively insensitive to errors.





Corresponding exit ramp produces virtual vacuum waist that can match back into magnetic optics.

Gaussian Ramps Also Work

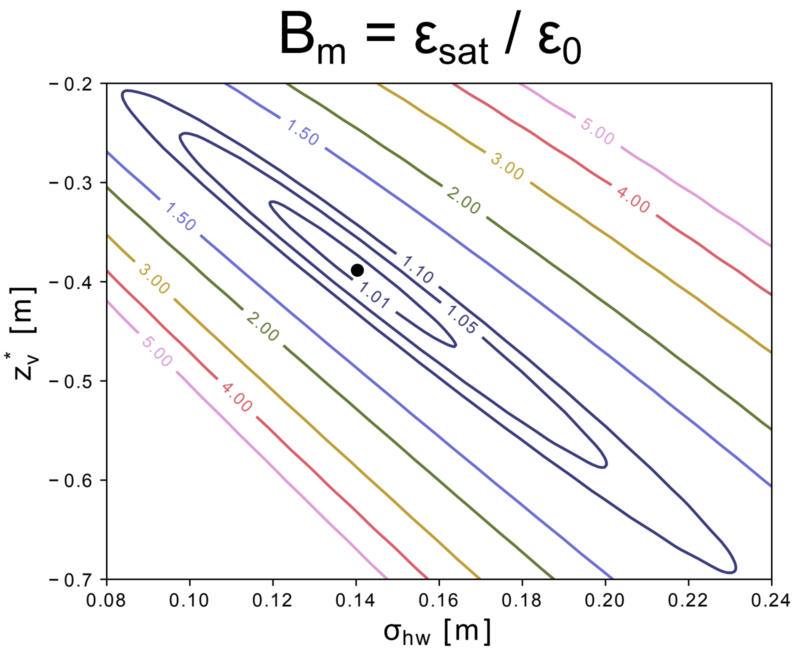
Numerically determined prescription for matching with a Gaussian ramp from M. Litos, et al., Phi. Trans. R. Soc. A **377** 20180181

ramp half-width: $\tilde{\sigma}_{\mathrm{hw}} = 1.55 \times 10^{-3}\, \tilde{\beta}_v^{*\,2} + 1.54\, \tilde{\beta}_v^{*} - 3.61$

β_v^* : vac. waist

waist location: $\tilde{z}_v^{*} = -1.57 \times 10^{-2}\, \tilde{\beta}_v^{*\,2} - 4.47\, \tilde{\beta}_v^{*} + 19.1$

(normalized to k_β at start of flat-top)

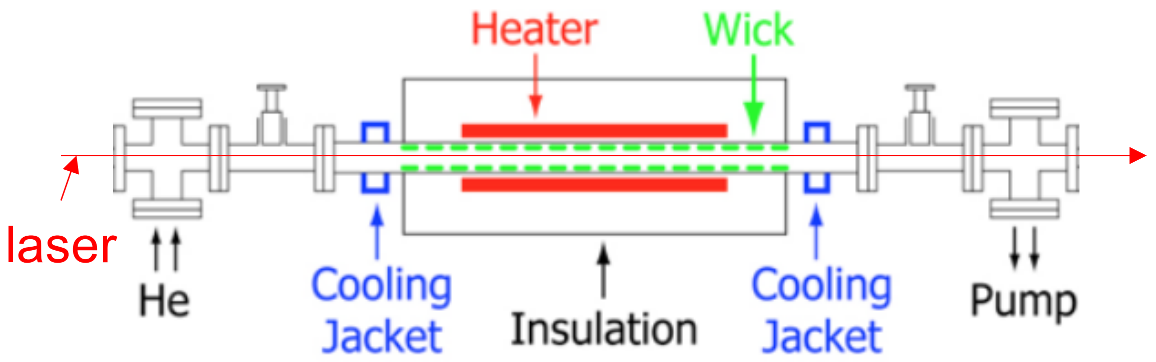


$B_m = \varepsilon_{sat} / \varepsilon_0$

Numerical tolerance studies show comfortable range of waist placement and ramp length for <1% emittance growth.

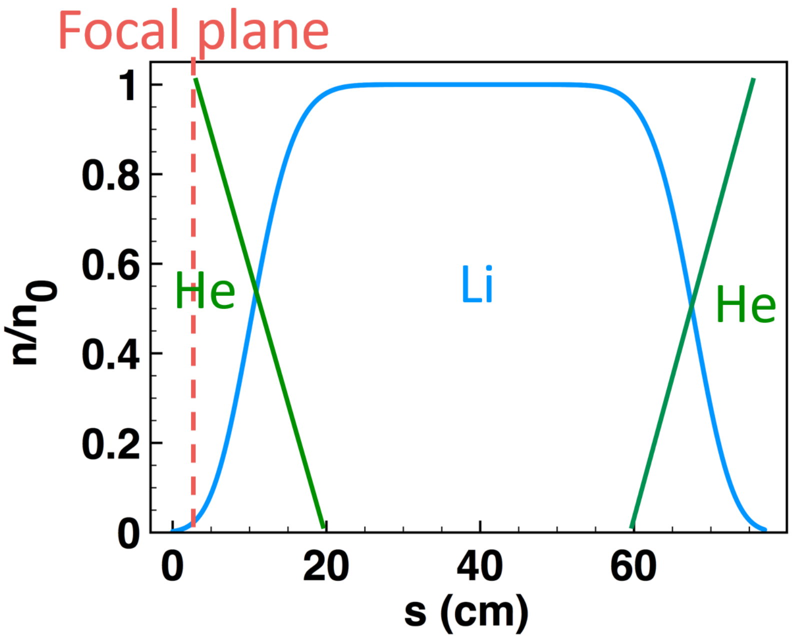
Similarly shaped ramps should have similarly comfortable tolerances.

Lithium Oven Plasma Source



Used to great success in FACET:

- High wake-to-beam efficiency (Nature, 2014)
- Record energy gain of 9 GeV
- Positron PWFA



Laser ionize the Li to minimize head erosion and maximize total efficiency.

Must ionize the full length: 80 cm

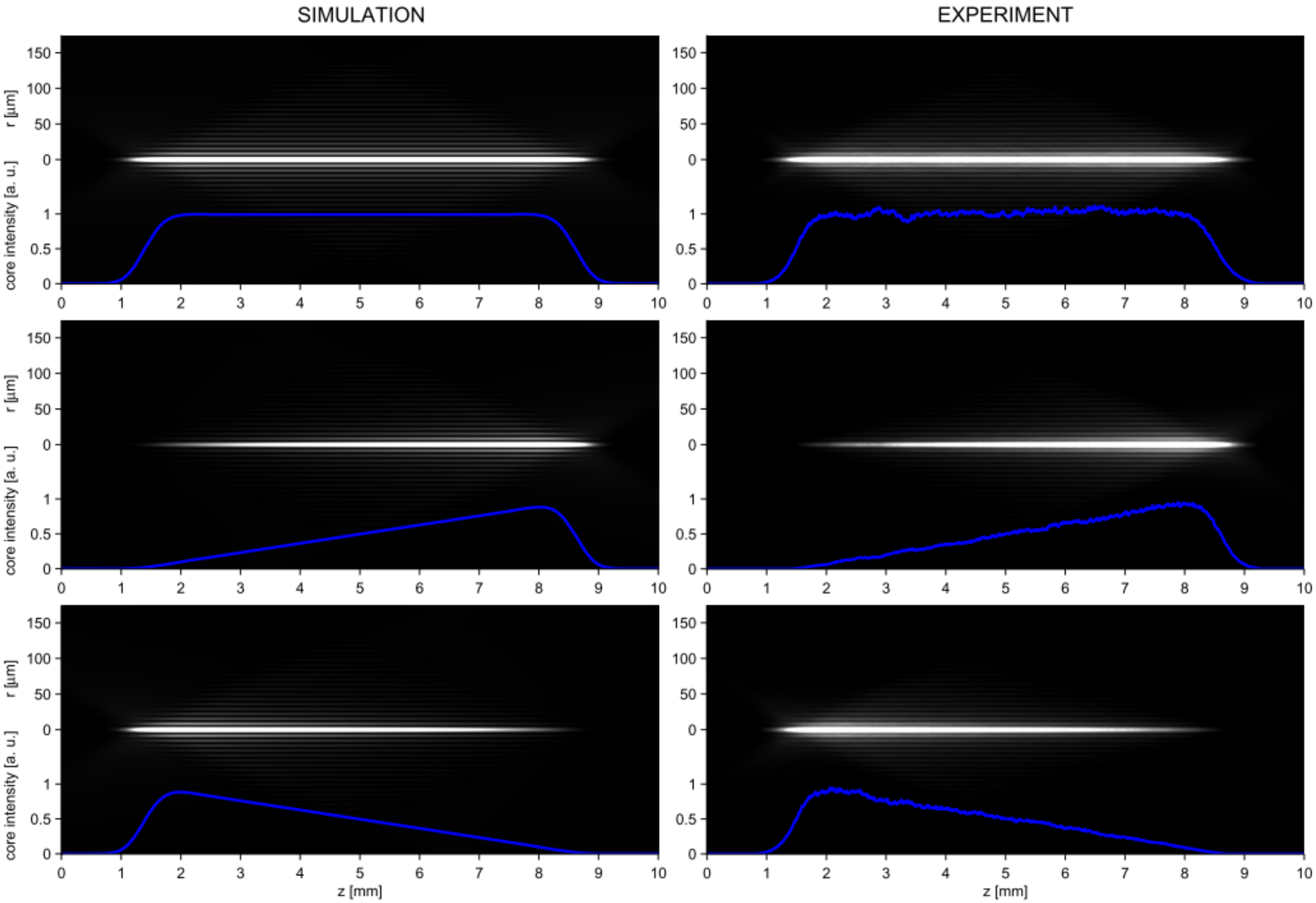
Must create a wide plasma >300 μm.

Must not ionize the He buffer.

Not trivial...

Semi-Arbitrary Axial Intensity Profile

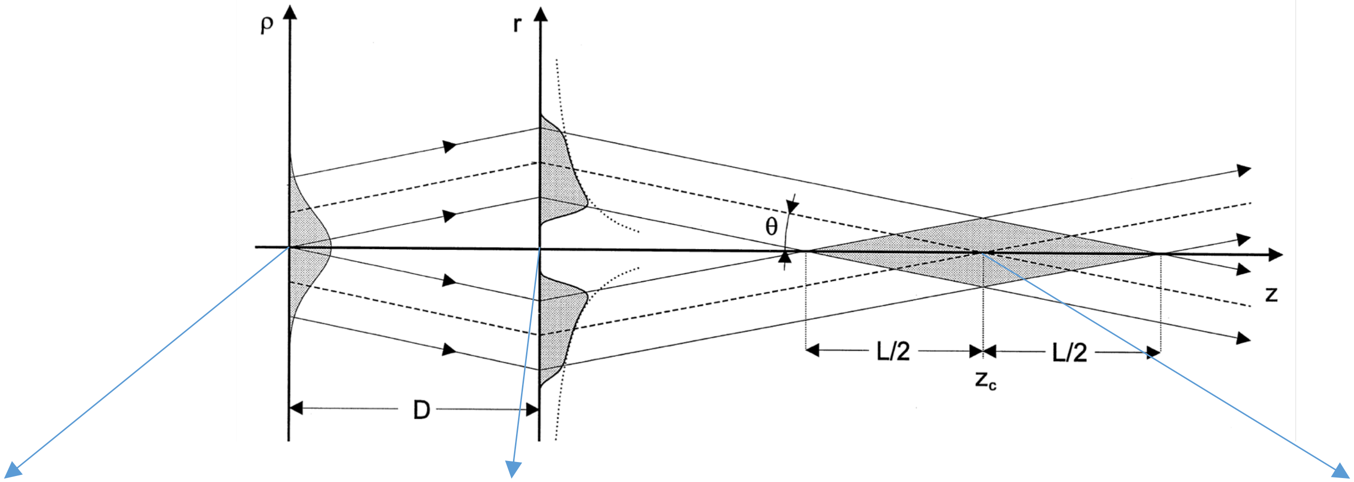
1) Manipulate initial intensity profile
2) Add axicon-like phase profile
3) Result: semi-arbitrary axial intensity profile


SIMULATION

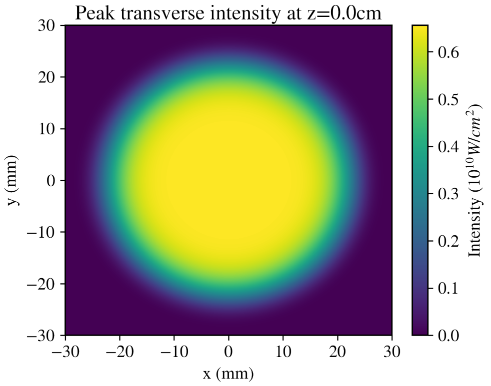
EXPERIMENT

T. Cizmar, K. Dholakia 2009 *Optics Express* **17** 18

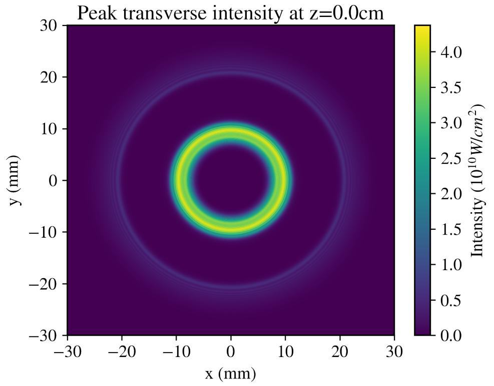
Tandem Lens Laser Focusing



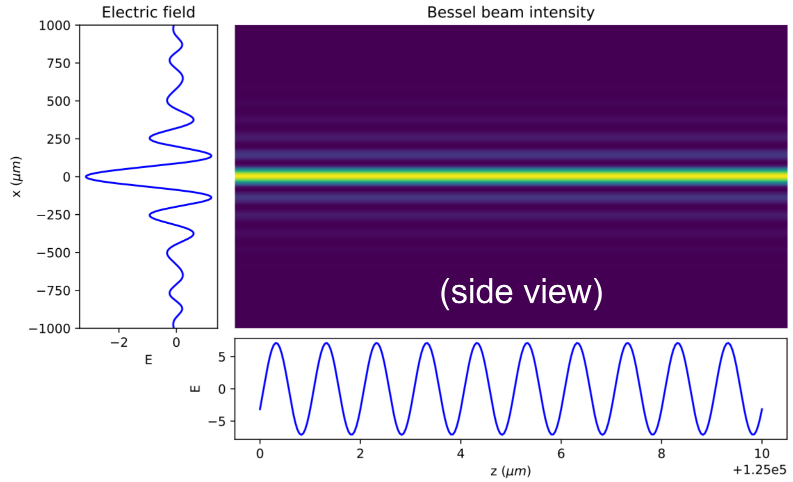
First Lens



Second Lens



Focus Region

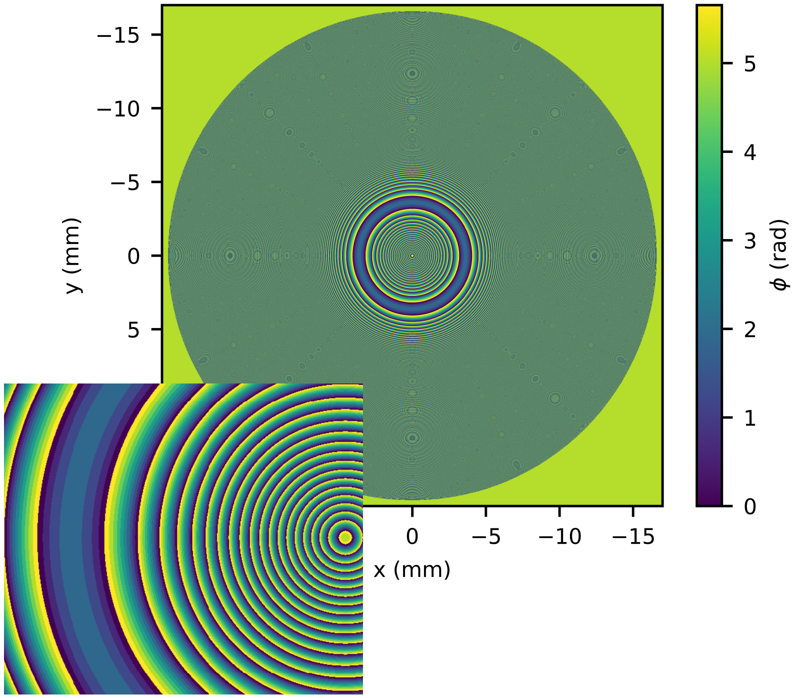


Tandem Lens Scheme

First Lens: Shapes intensity profile at second lens.

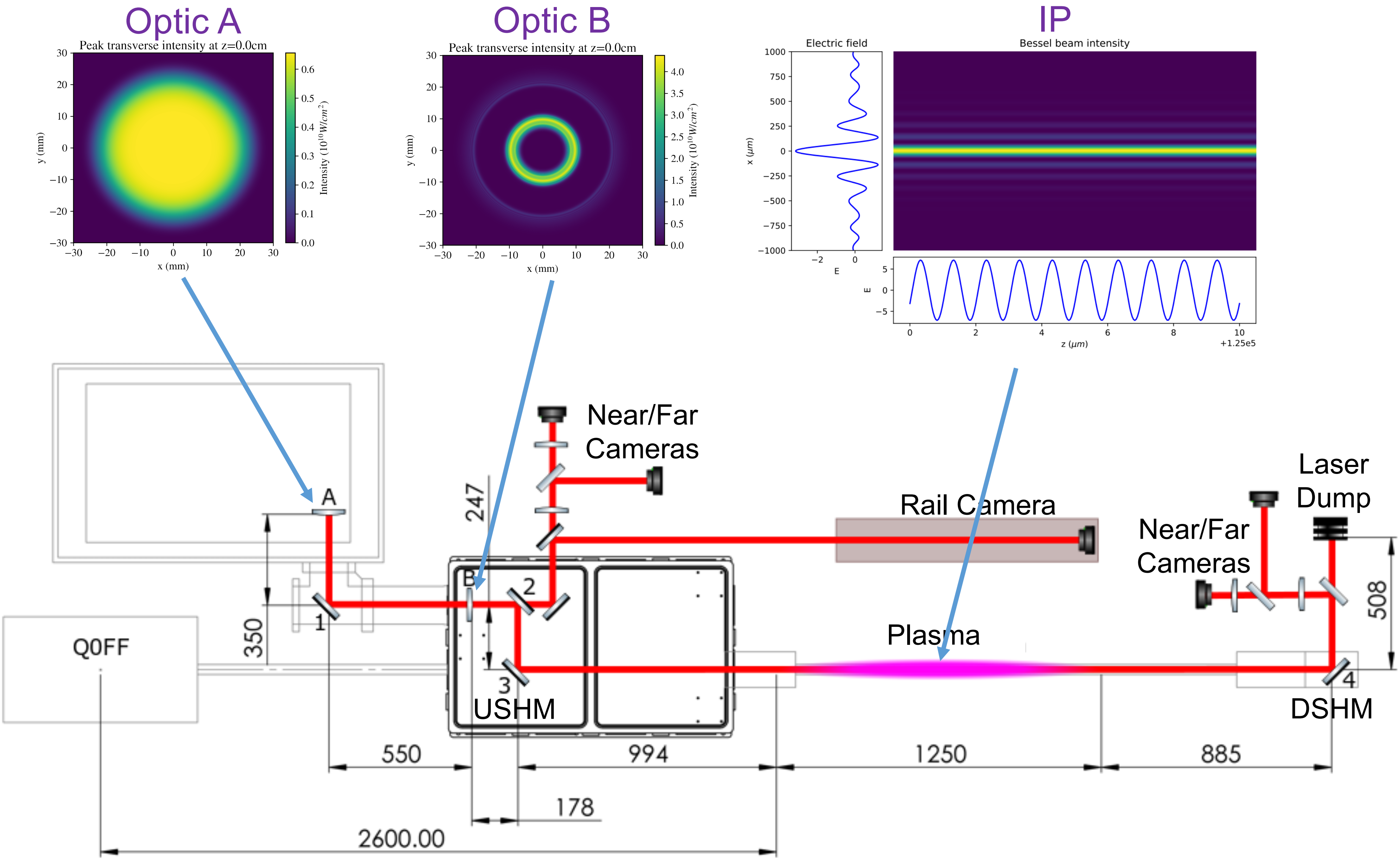
Second Lens: removes residual phase from first lens and adds axicon-like phase profile to generate Bessel-beam downstream.

Tandem Lens Fabrication

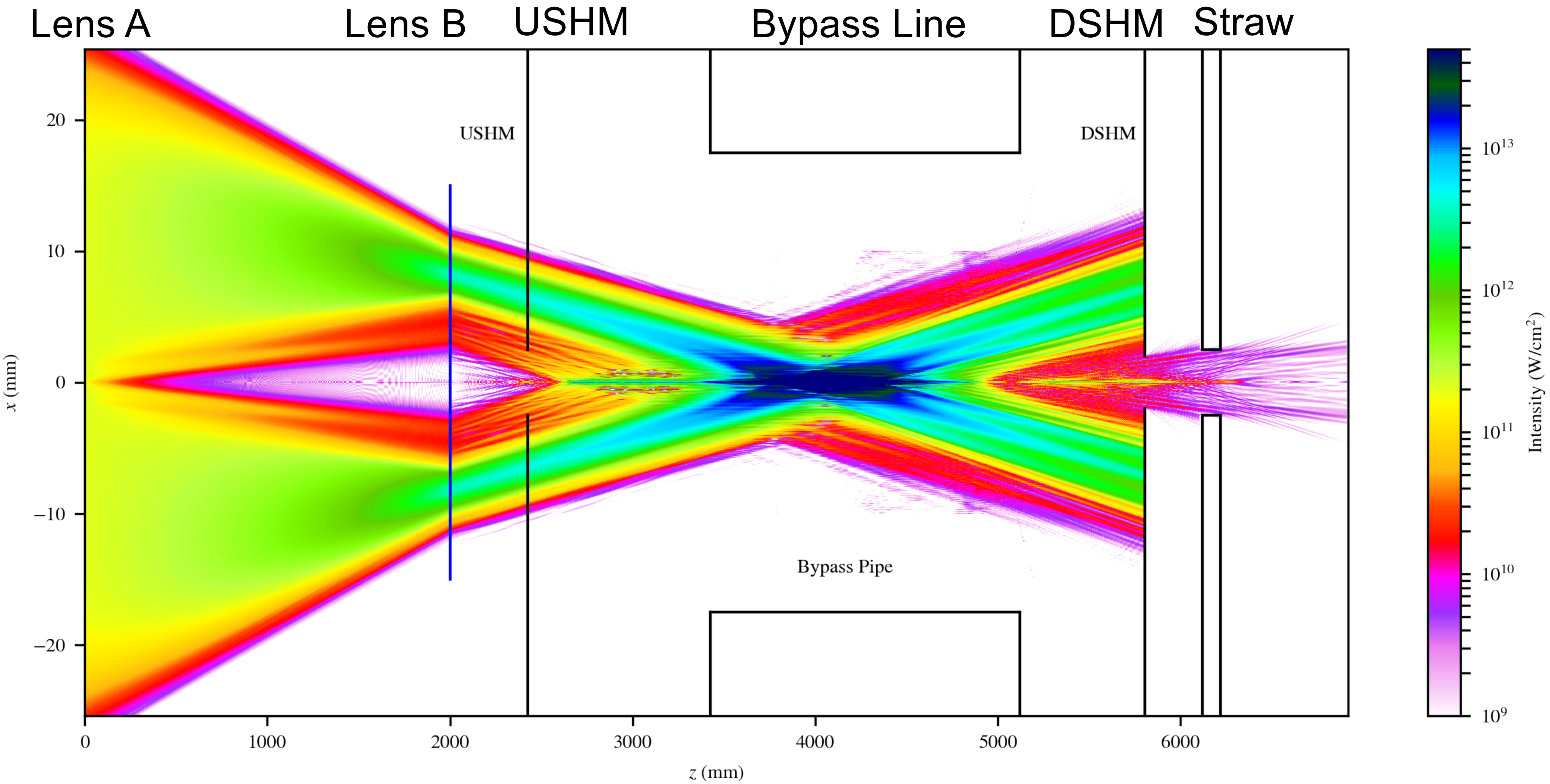


Tandem lens pair: diffractive optics (kinoforms)
Etched into thin (100 μm – 1mm) fused silica wafers
Made in university nanofab lab by students...
...so far, just Robert!

E300 & E301 Experimental Layout (Run 1)



Laser Intensity Profile for E301



Near to damage threshold at USHM. Now testing optic durability at CU.

Axicon Li Plasma (E300)

Laser Parameters

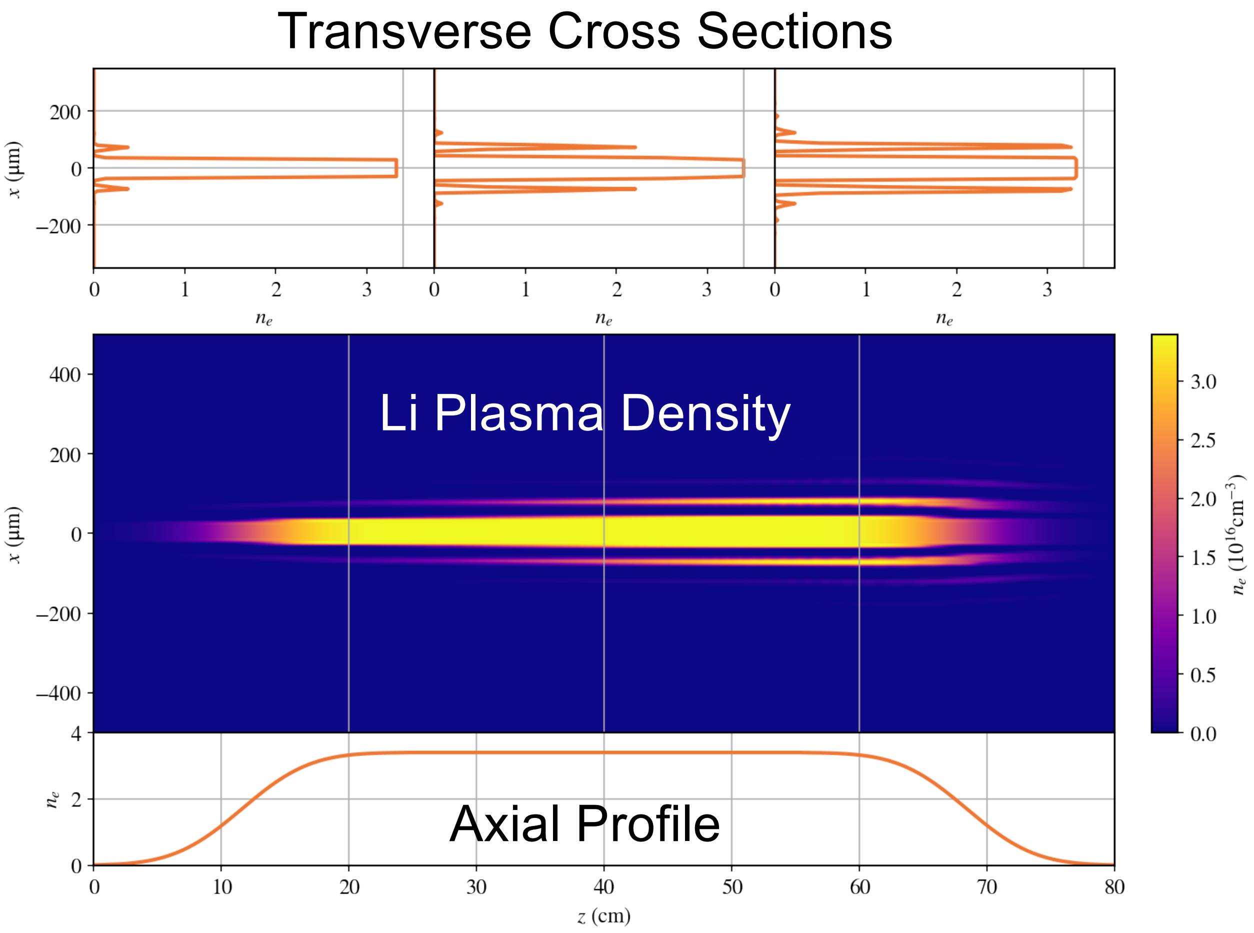
Laser energy: 13mJ
Pulse duration: 70fs
Wavelength: 796nm
Beam width: 40mm
Beam profile: Super Gaussian

Beam Energy

Energy to ionize: 0.15mJ
Plasma heating energy: ~0.1mJ
Energy after optics: 9.0mJ
Optics efficiency: 80%
Energy before optics: 11.25mJ
Lost to aberrations: 1.5mJ
Lost to aperture: 0mJ
Required energy: 12.8mJ

Laser refraction simulation

Split step Fourier based code.
Energy loss due to ionization.
No dispersion, no self-focusing.


Transverse Cross Sections

Li Plasma Density

Axial Profile

Simulation includes TDSE ionization rate, refraction from gas & plasma, and Kerr effect.

E300: Tandem Lens Li Plasma

Laser Parameters

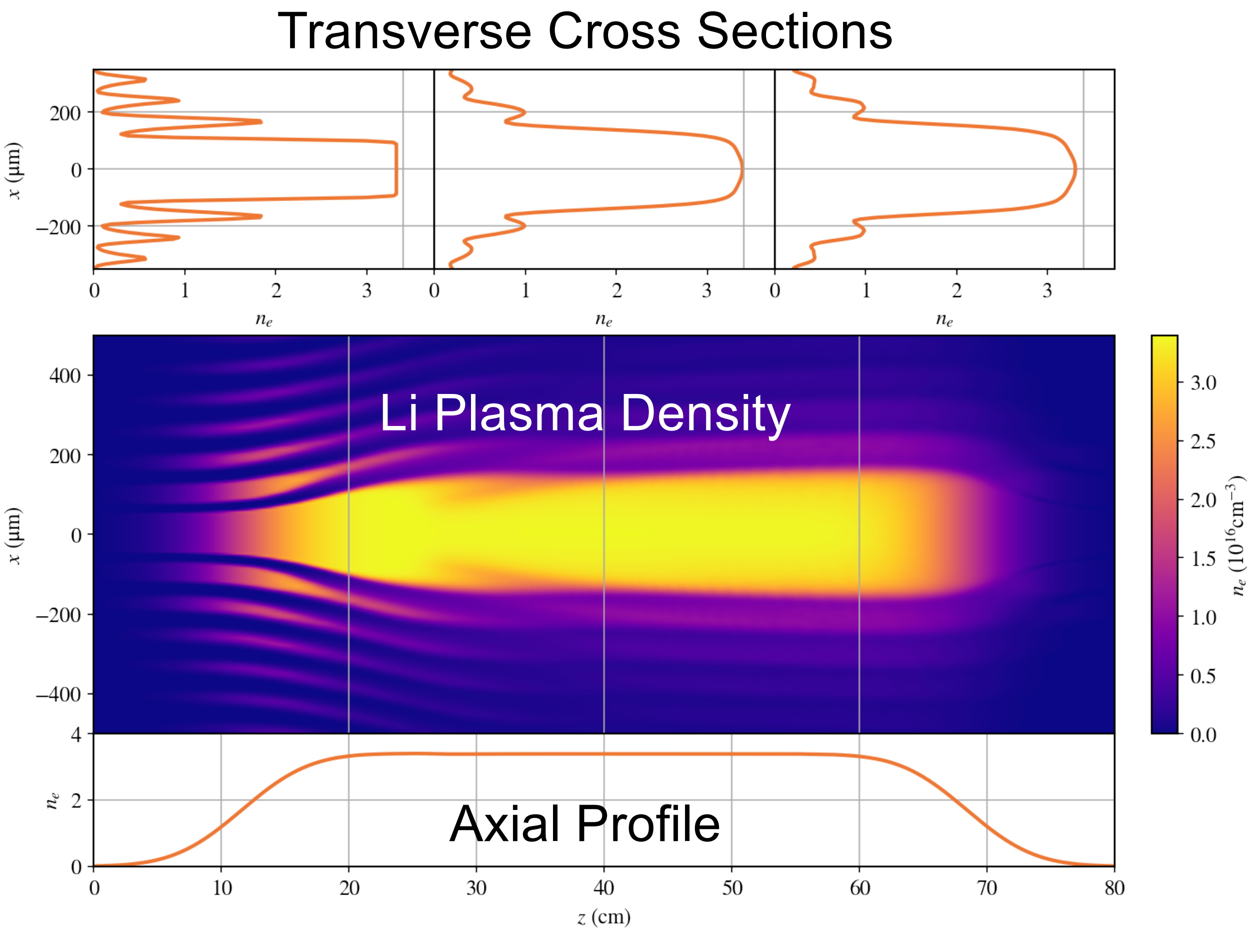
Laser energy: 20mJ
Pulse duration: 70fs
Wavelength: 796nm
Beam width: 40mm FWHM
Beam profile: Super Gaussian

Beam Energy

Energy to ionize: 2.84mJ
Plasma heating energy: ~2mJ
Energy after optics: 7.28mJ
Optics efficiency: 80%
Energy before optics: 9.1mJ
Lost to aberrations: 2.5mJ
Lost to aperture: 6.5mJ
Required energy: 18.1mJ

Laser refraction simulation

Split step Fourier based code.
Energy loss due to ionization.
No dispersion, no self-focusing.



Transverse Cross Sections

Simulation includes TDSE ionization rate, refraction from gas & plasma, and Kerr effect.

E300: Tandem Lens He Plasma

Laser Parameters

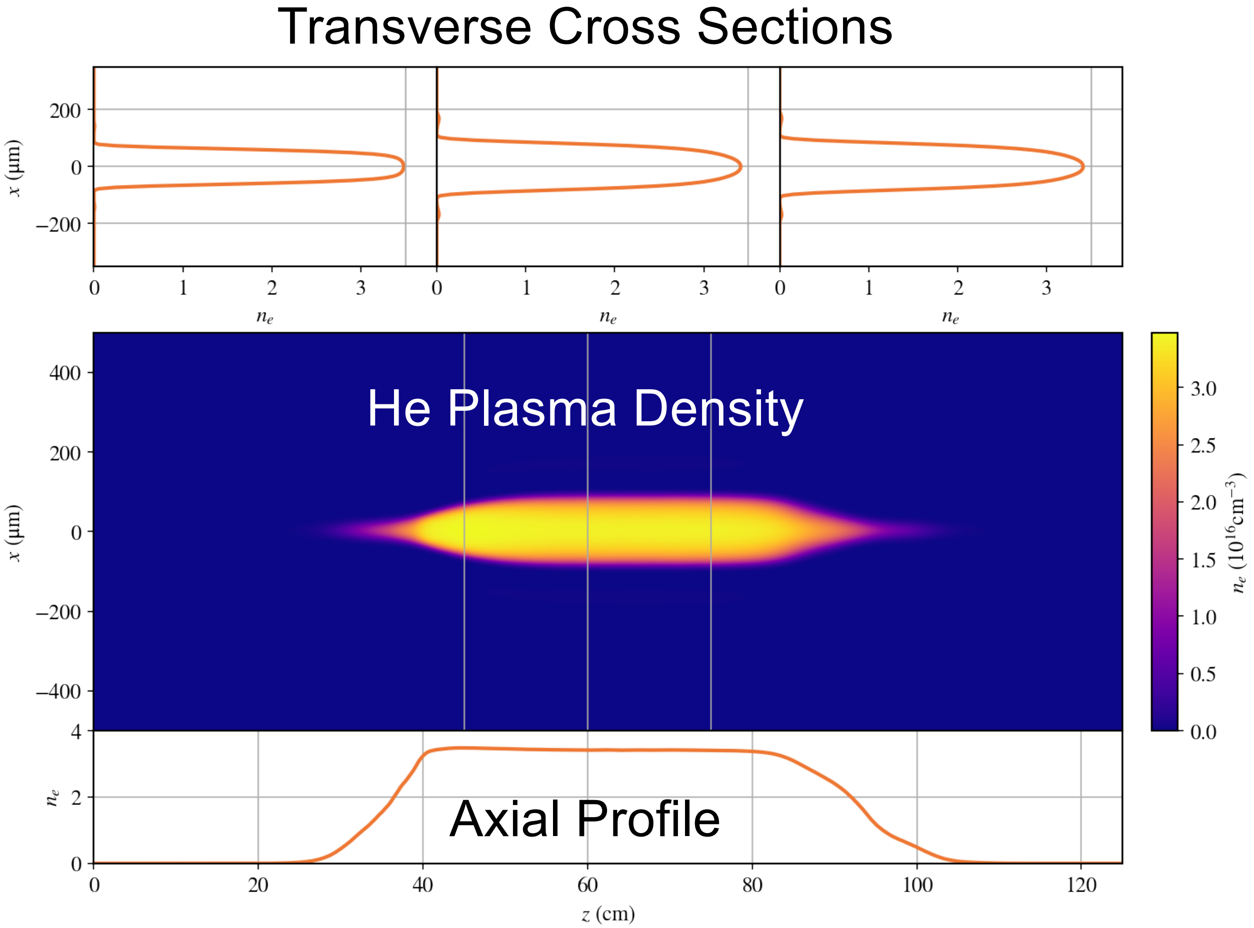
Laser energy:	350mJ
Pulse duration:	70fs
Wavelength:	796nm
Beam width:	40mm FWHM
Beam profile:	Super Gaussian

Beam Energy

Energy to ionize:	1.05mJ
Plasma heating energy:	~1mJ
Energy after optics:	222mJ
Optics efficiency:	80%
Energy before optics:	278mJ
Lost to aberrations:	50mJ
Lost to aperture:	0mJ
Required energy:	328mJ

Laser refraction simulation

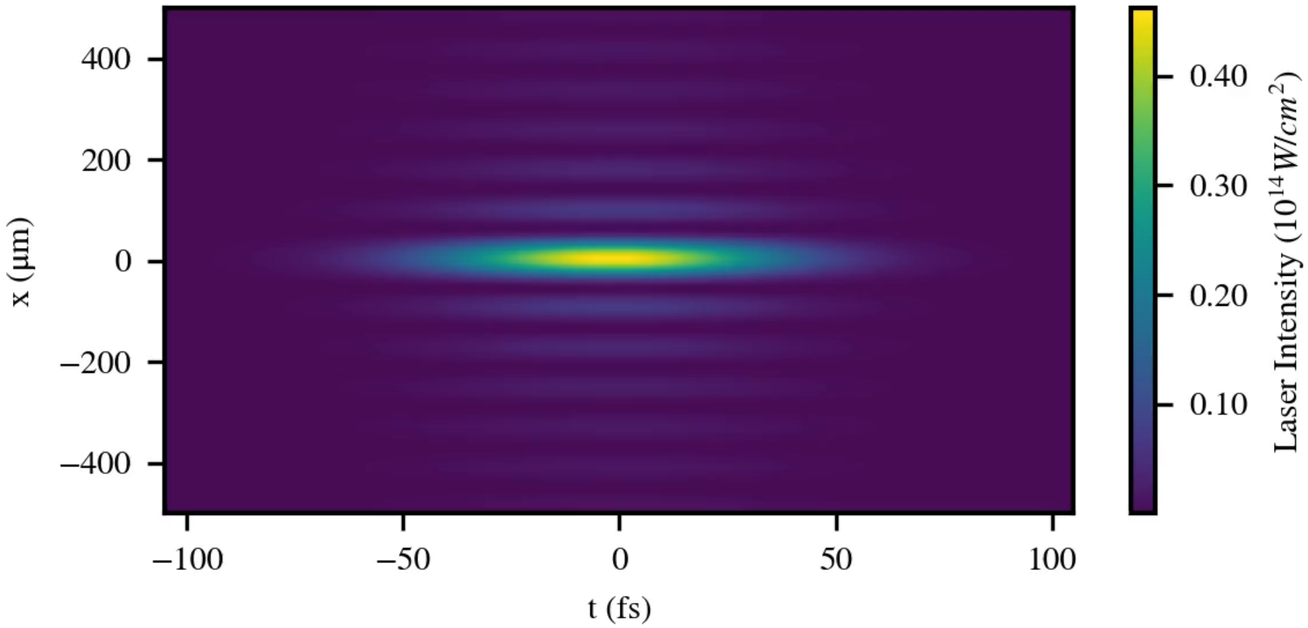
Split step Fourier based code.
Energy loss due to ionization.
No dispersion, no self-focusing.



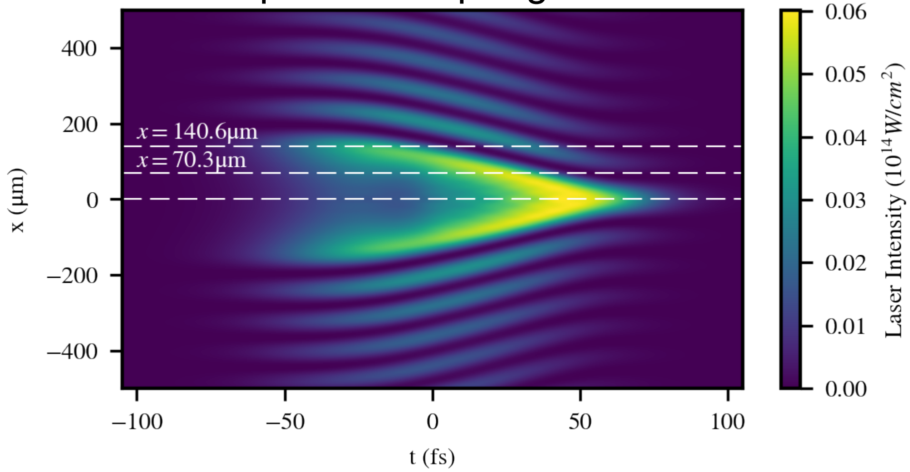
Simulation includes Gen. PPT ionization rate, refraction from gas & plasma, and Kerr effect.

Refraction is Your Friend!

Movie: Evolution of laser pulse as it propagates, forms plasma (not shown), and refracts.



Characteristic cone shape in flat-top region.

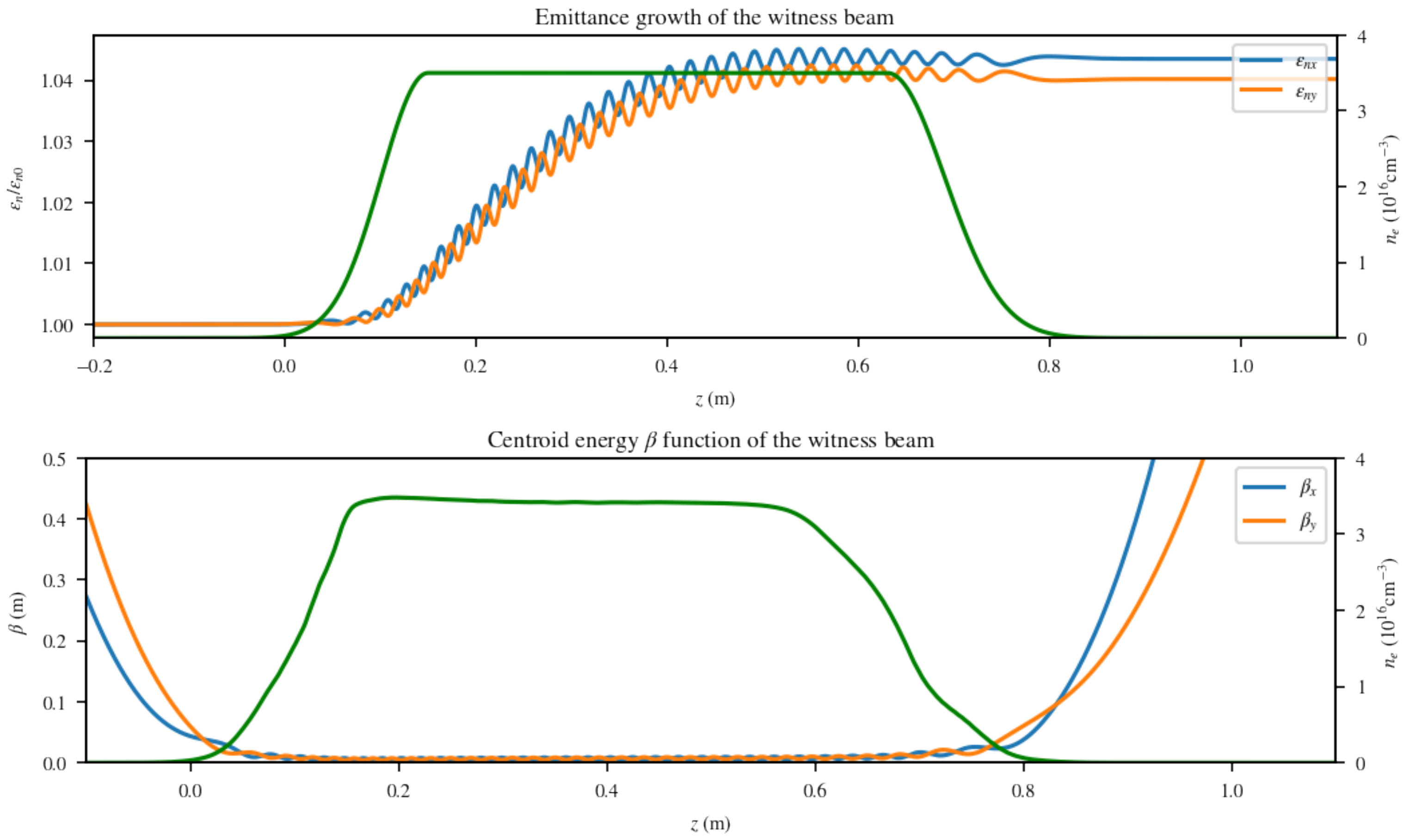


We take advantage of refraction from plasma to spread the laser out transversely. This leads to a wider ionization profile!

Predicted Performance

Using CU's WARGSim particle tracking code:

- Includes energy gain, but not loading (yet)
- Assumes energy spread of 2% → from VSim PIC sims
- Assumes linear focusing everywhere (blowout)

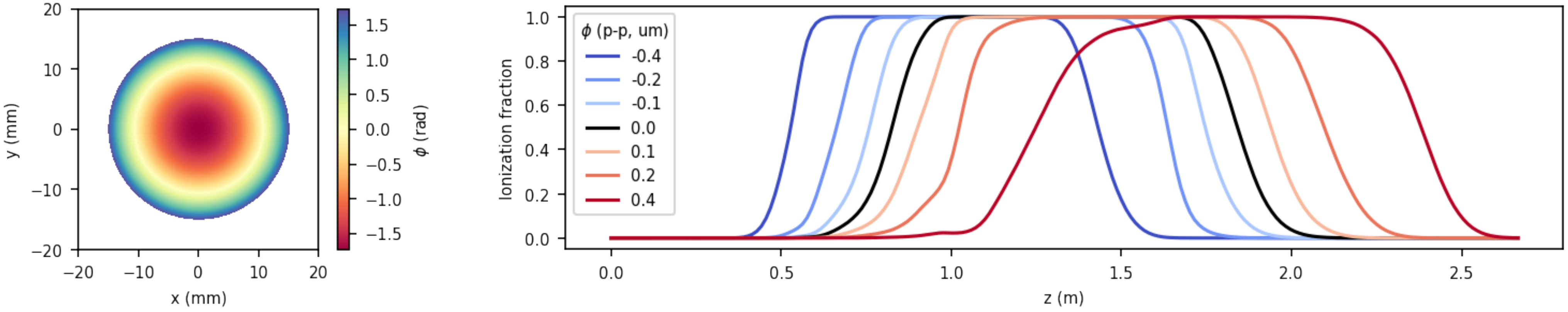


Projected emittance grows by about 4%.

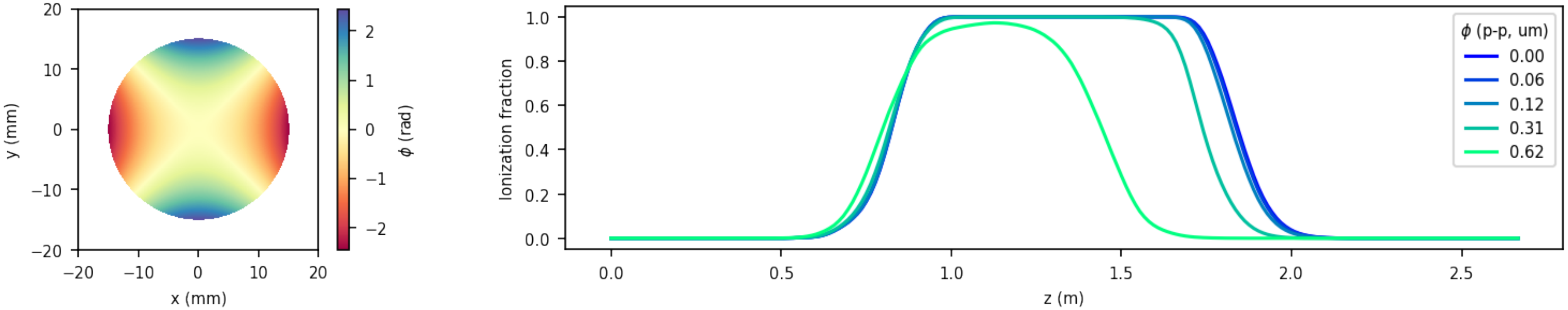
Virtual exit waist beta function of about 4.5 cm.

Plasma Tuning

Defocus

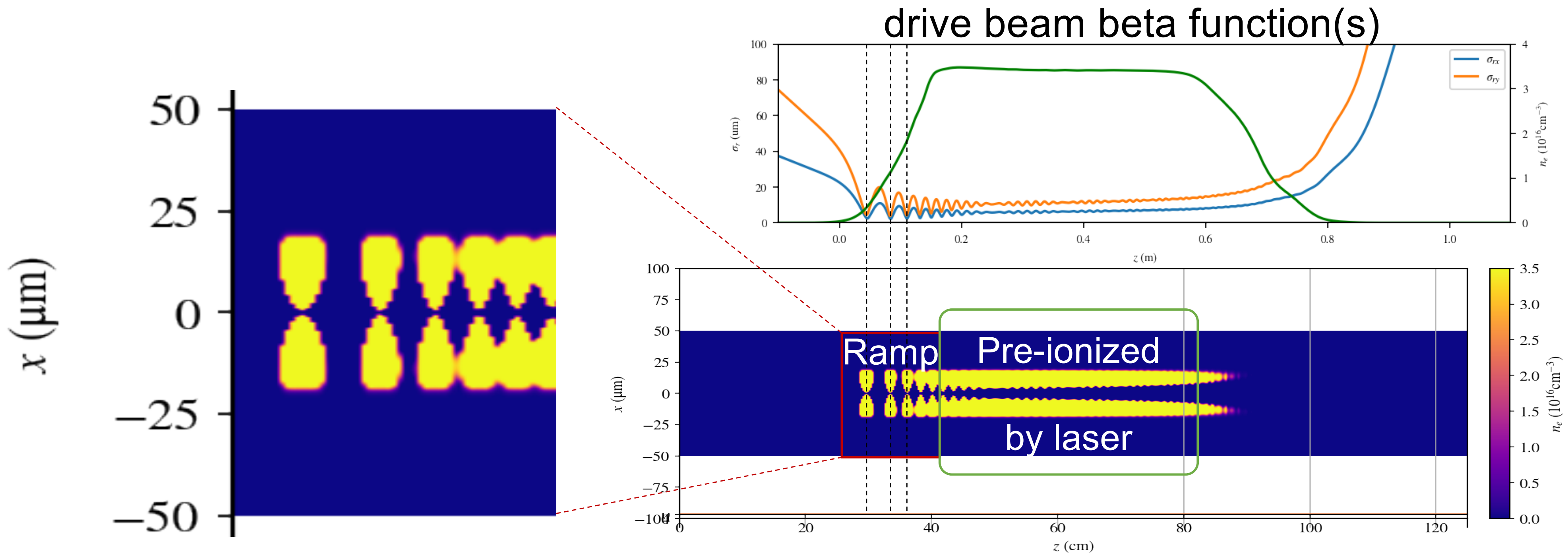


Astigmatism



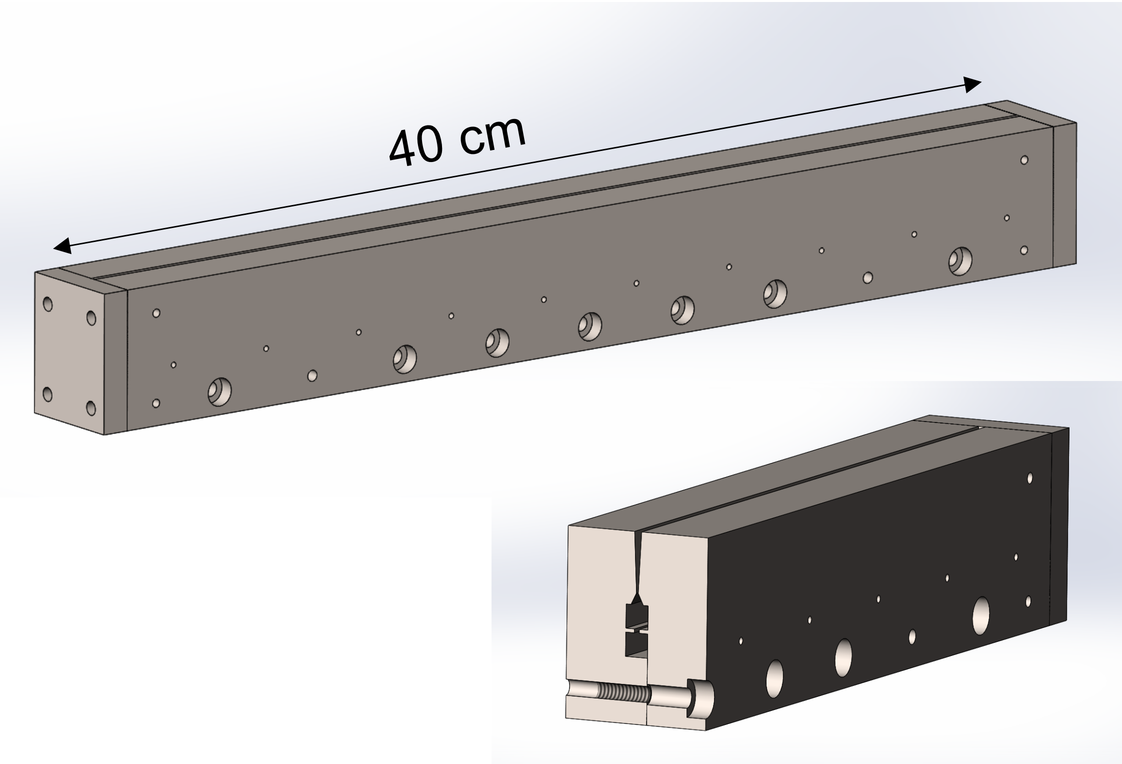
Using the deformable mirror, we can actively change the plasma shape by introducing aberrations. Gives possibility of feedback.

He Beam Ionization Estimation

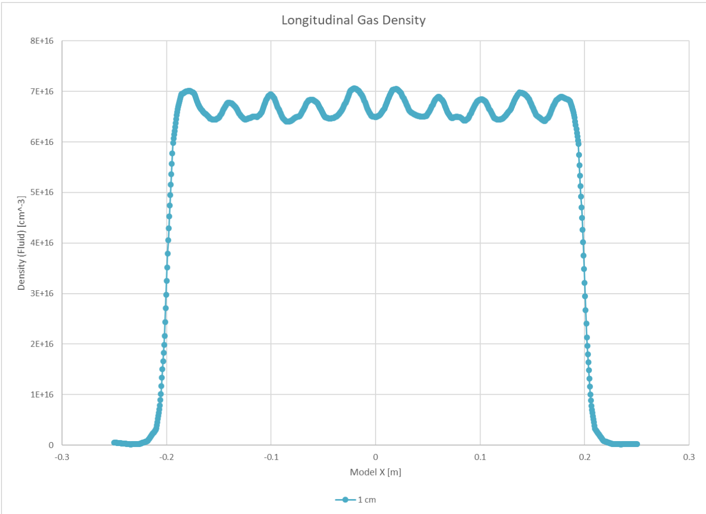


- Vacuum waist location optimized for witness beam.
- Drive beam is severely mismatched.
- Creates “hourglass” rings of 100% singly-ionized He.
- Witness size is small enough that it can thread the needle.
- Investigation ongoing, but effects are unlikely to be significant for FACET-II experiments in Run 1.

Elongated Gas Jet (Run 2)



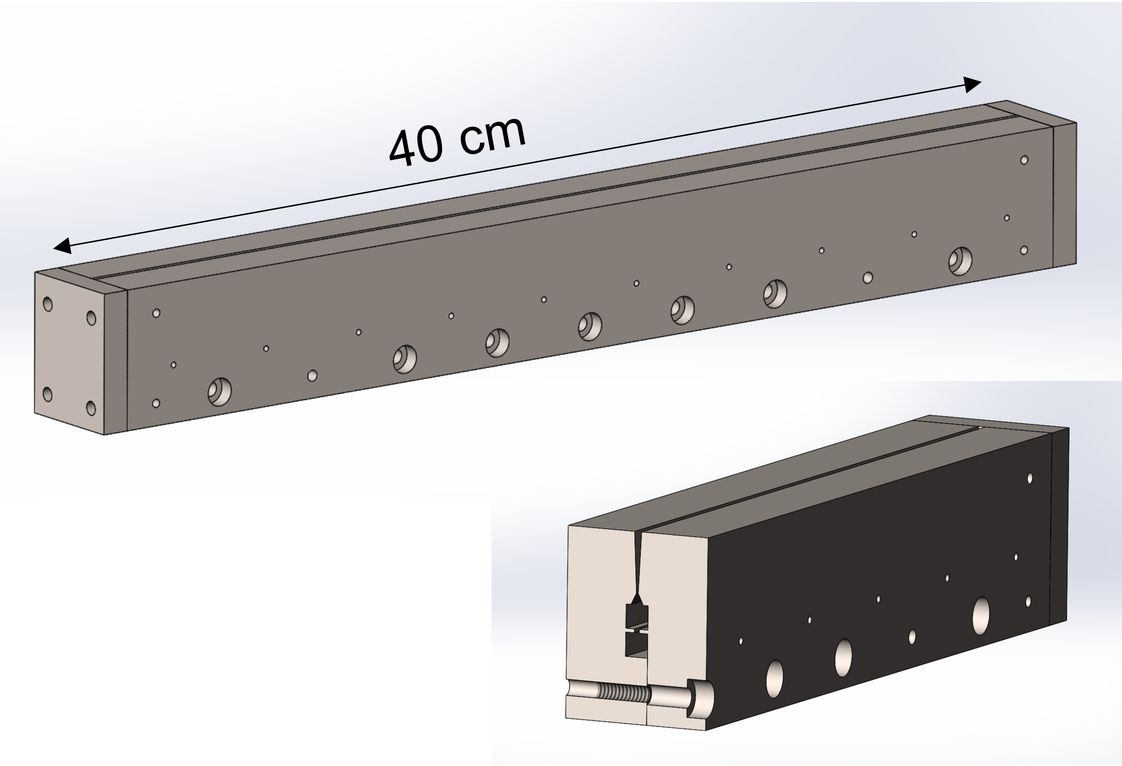
Axial Density



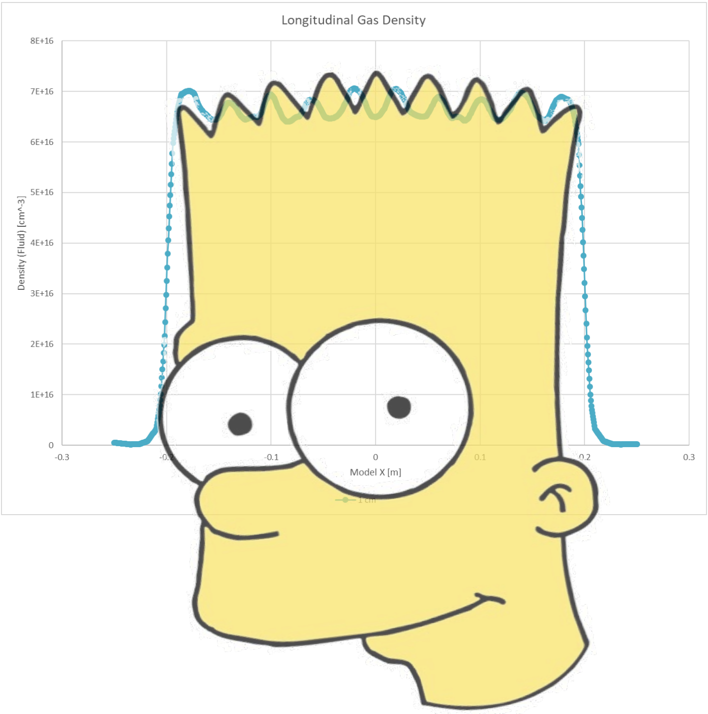
That shape
looks familiar...

Hydrogen gas 100% ionized by laser; no beam ionization.
Plasma density is determined by the gas jet profile.
Similar to Li oven, but room temp. and no buffer gas.
First pass design gives usable profile: lumps are adiabatic.
Challenges remain, e.g. gas removal from chamber.

Elongated Gas Jet (Run 2)



Axial Density



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Similar to Li oven, but room temp. and no buffer gas.
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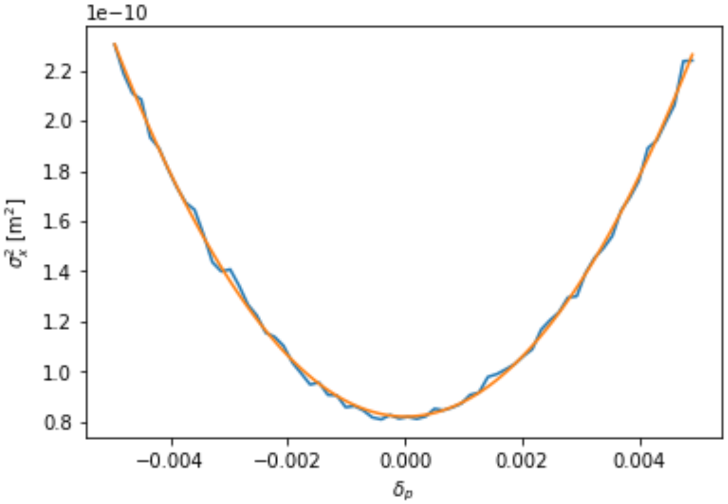
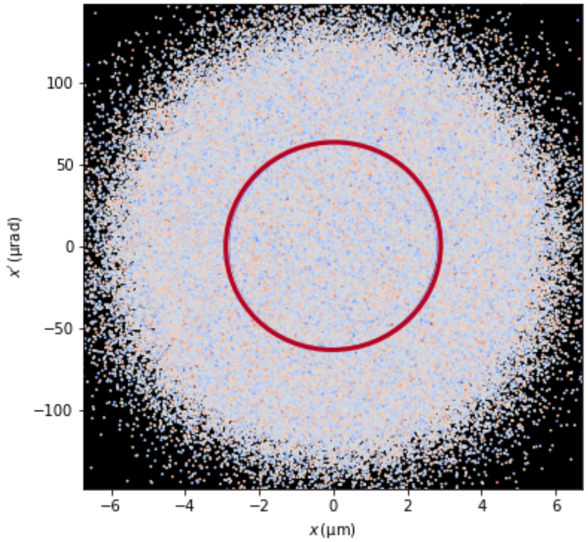
Butterfly Measurement: Matched Case

Using WARGSim particle tracking code.

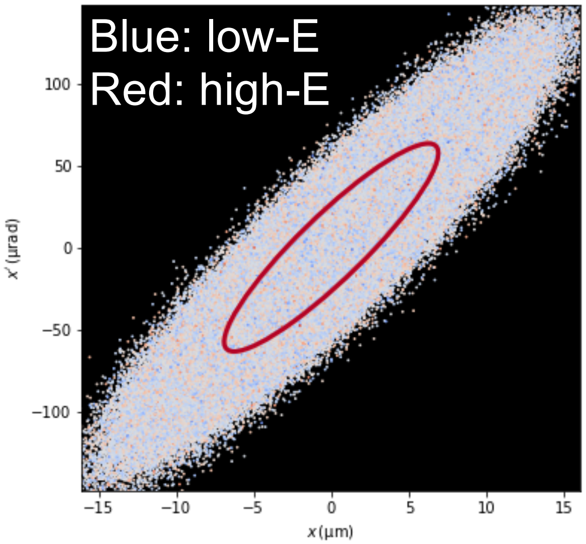
Matching Value	B_{mag}	1.00
Emit. Before PWFA	$\varepsilon_{n,init}$	3.00 mm-mrad
Emit. After PWFA	$\varepsilon_{n,final}$	**2.98 mm-mrad**
Butterfly Value	$\varepsilon_{n,bfly}$	**3.15 mm-mrad**



Virtual Exit Waist

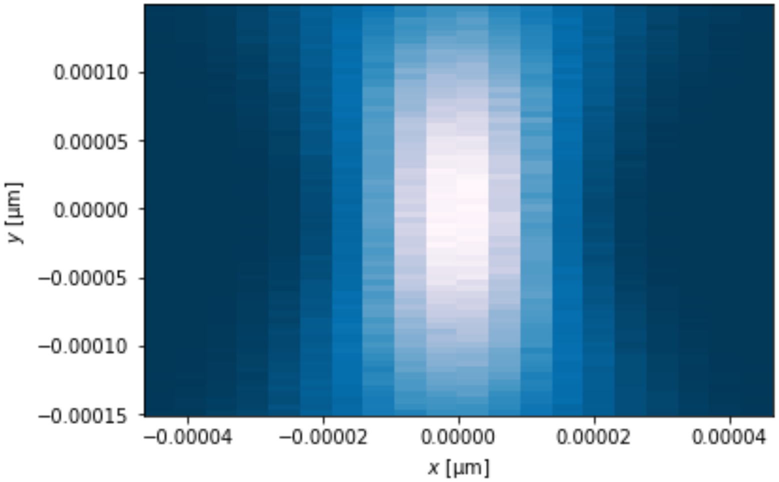


QS0 Entrance



Blue: low-E
Red: high-E

Butterfly Image

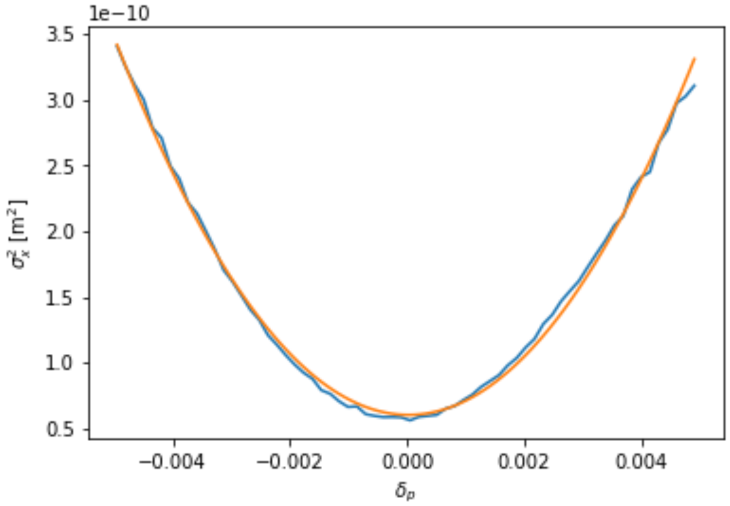


[note: x-axis range]

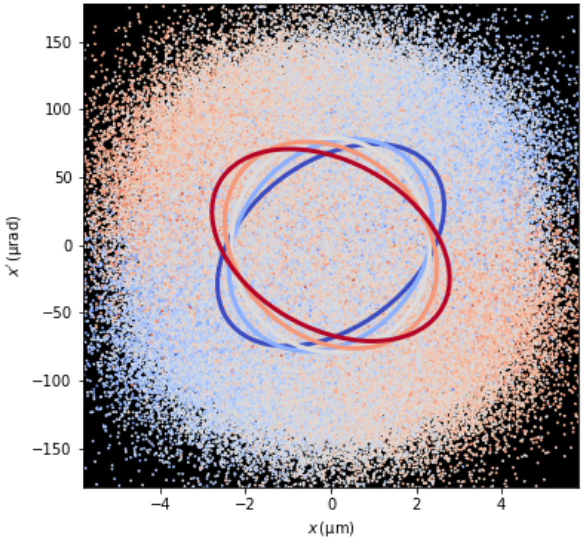
Butterfly Measurement: Near-Matched Case

Using WARGSim particle tracking code.

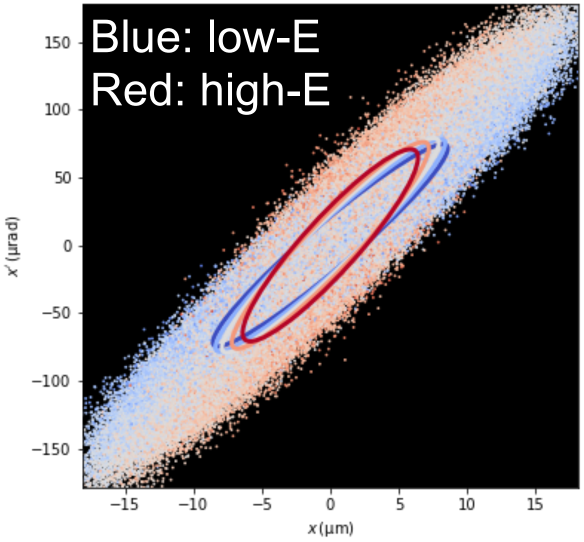
Matching Value	B_{mag}	1.10
Emit. Before PWFA	$\varepsilon_{n,init}$	3.00 mm-mrad
Emit. After PWFA	$\varepsilon_{n,final}$	**3.10 mm-mrad**
Butterfly Value	$\varepsilon_{n,bfly}$	**3.70 mm-mrad**



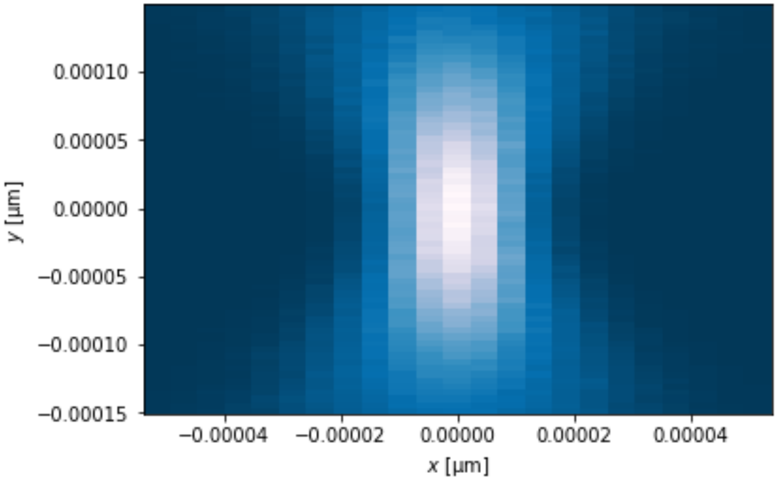
Virtual Exit Waist



QS0 Entrance



Butterfly Image

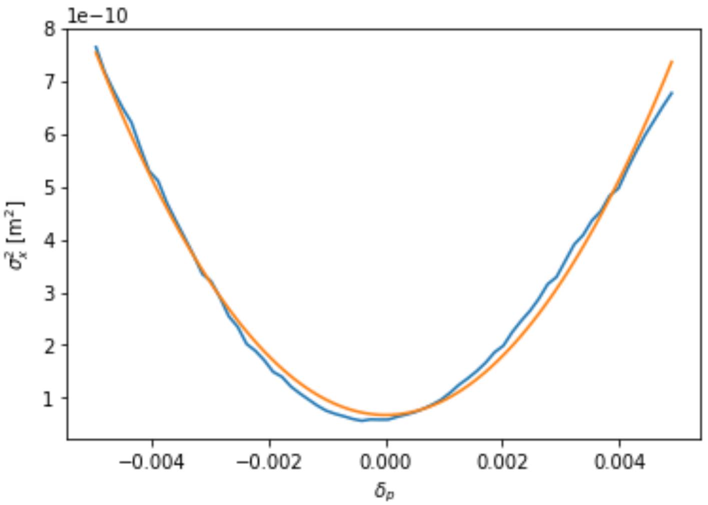


[note: x-axis range]

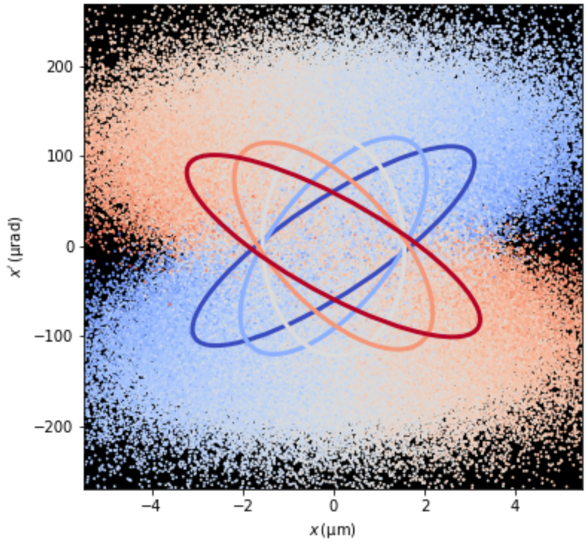
Butterfly Measurement: Mismatched Case

Using WARGSim particle tracking code.

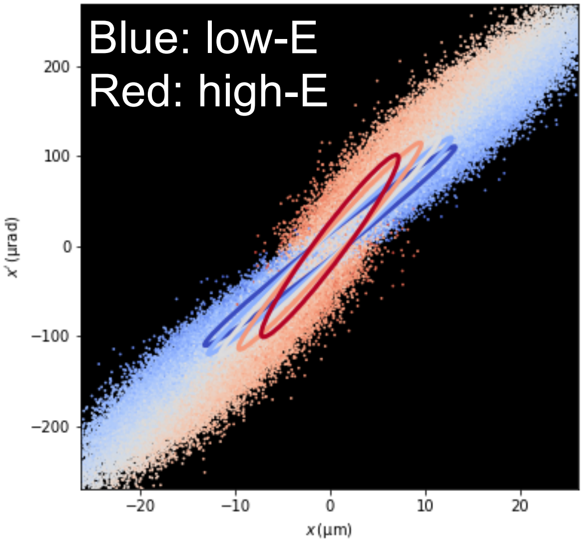
Matching Value	B_{mag}	2.00
Emit. Before PWFA	$\varepsilon_{n,init}$	3.00 mm-mrad
Emit. After PWFA	$\varepsilon_{n,final}$	**4.42 mm-mrad**
Butterfly Value	$\varepsilon_{n,bfly}$	**6.14 mm-mrad**



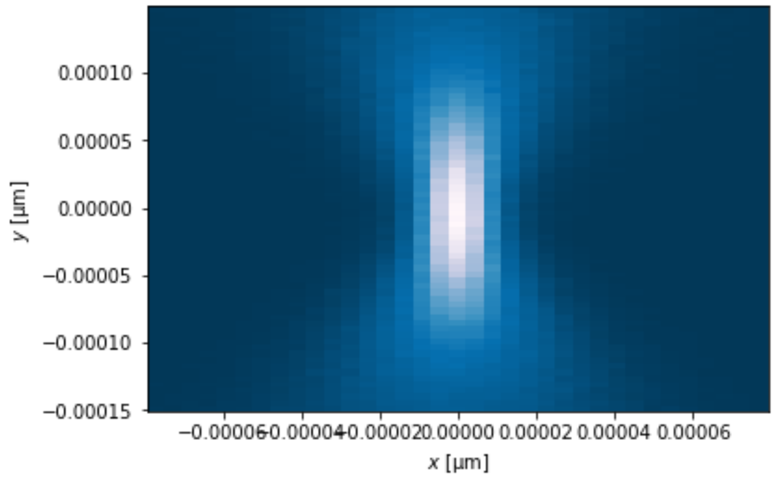
Virtual Exit Waist



QS0 Entrance


Blue: low-E
Red: high-E

Butterfly Image



[note: x-axis range]

Chromatic Quad Scanning

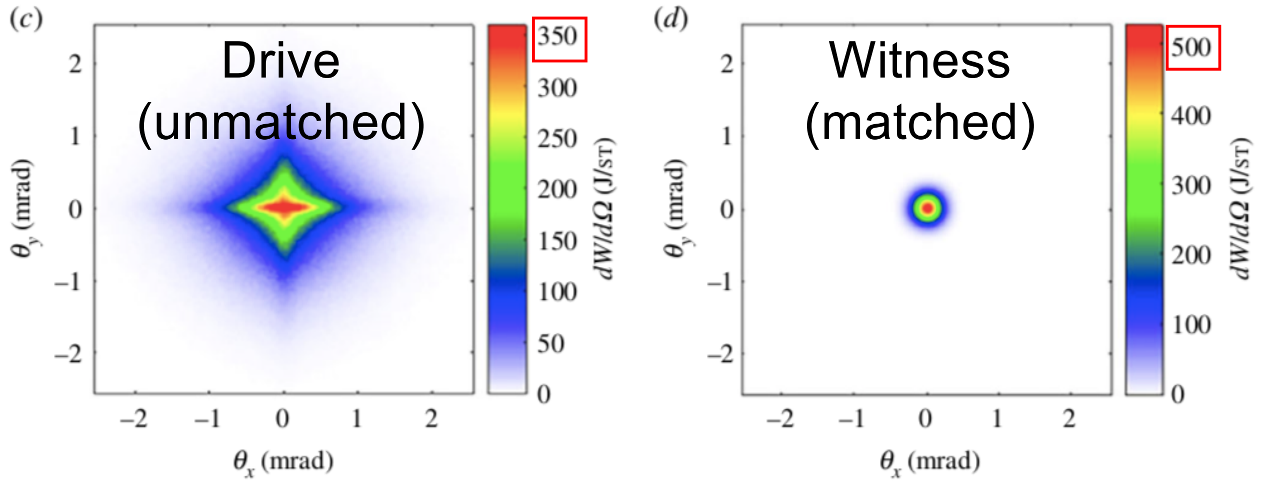
- **Single-shot butterfly grossly overestimates projected emittance** when there is chromatic phase spreading (as in PWFA)

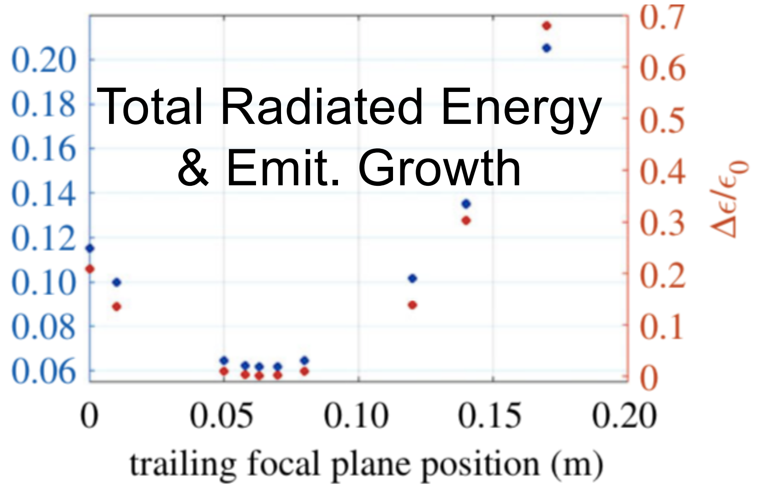
- **Solution: perform quad scan at several energies**
  - statistical measurement of beam
  - maps transverse phase space of each energy slice independently
  - combine to calculate projected emittance

- **Chromatic quad scan time** (example):
  - 5 energy slices
  - 5 quad settings per slice
  - 10 shots per step
  - 5x5x10 = 250 shots
  - **~1 minute at 10 Hz**
  - **~10 minutes at 1 Hz**

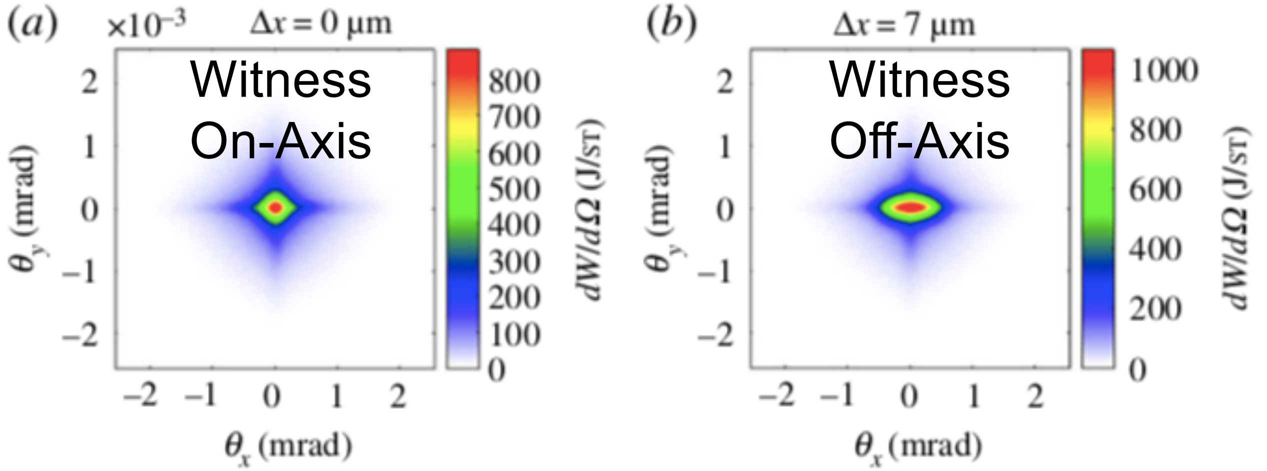
- **Emittance measurement error will depend on stability of the beam**

Betatron Radiation





Betatron radiation energy and transverse profile provide information about beam matching. Challenge: deconvolve drive from witness.



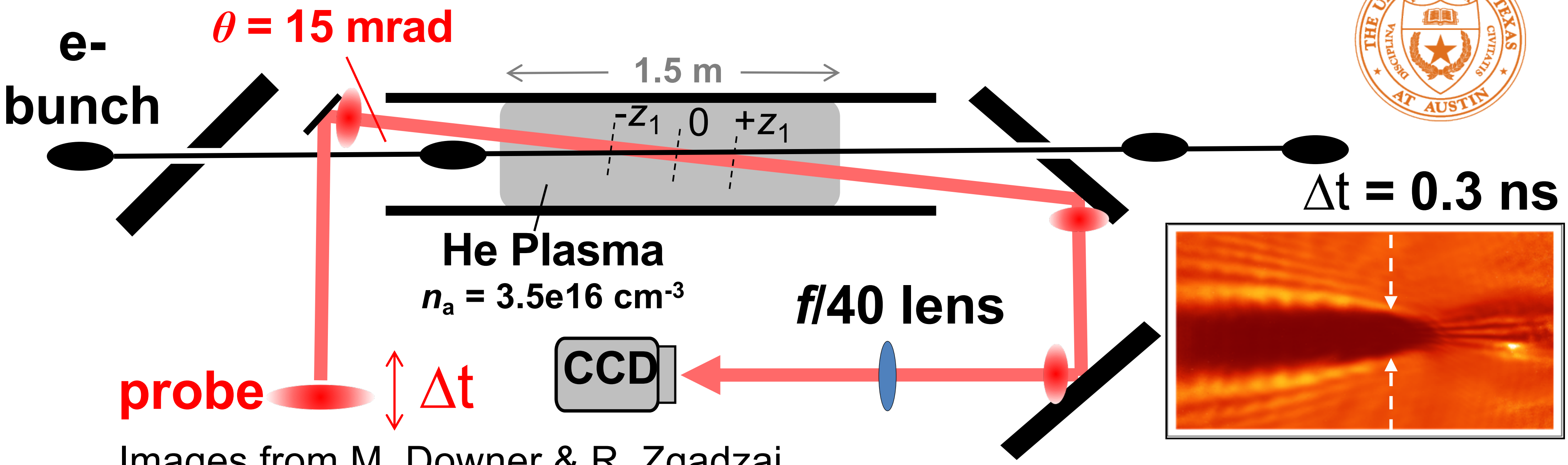
P. Claveria, et al., Phil. Trans. R. Soc. A **377** 20180173 (2018)

Long-Term Goal:

Use WARGSim to generate large MC database of butterfly & betatron to train machine learning algorithm → single shot diagnostic.

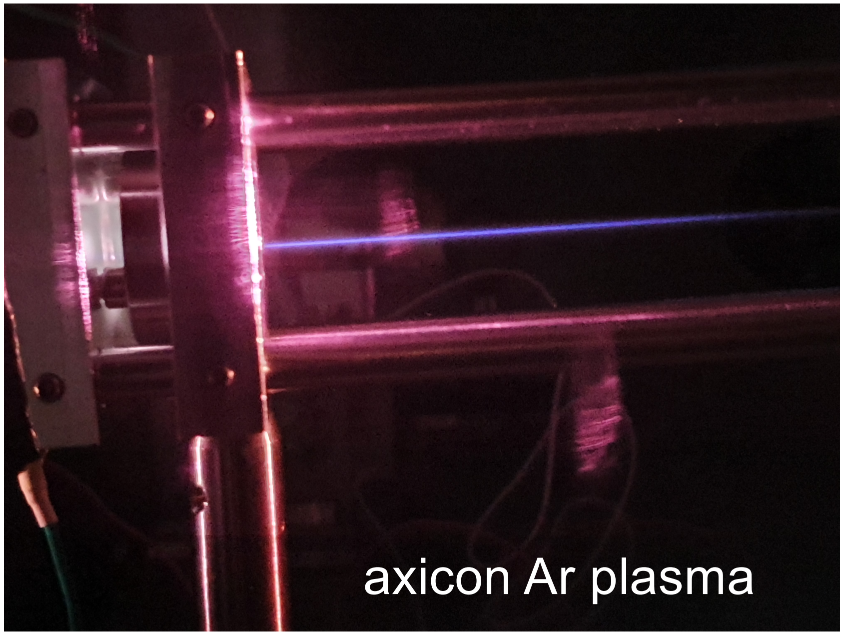
Plasma Diagnostics: E324

- These laser-ionized plasmas are hard to diagnose:
  - Non equilibrium, short lived, and partially ionized
  - Low densities (~3×10^{16} cm^{-3})
  - Small (~100s μm) and cold (~1 eV)
- Probe-based ptychography allows for plasma wake to be reconstructed from phase information



Images from M. Downer & R. Zgadzaj

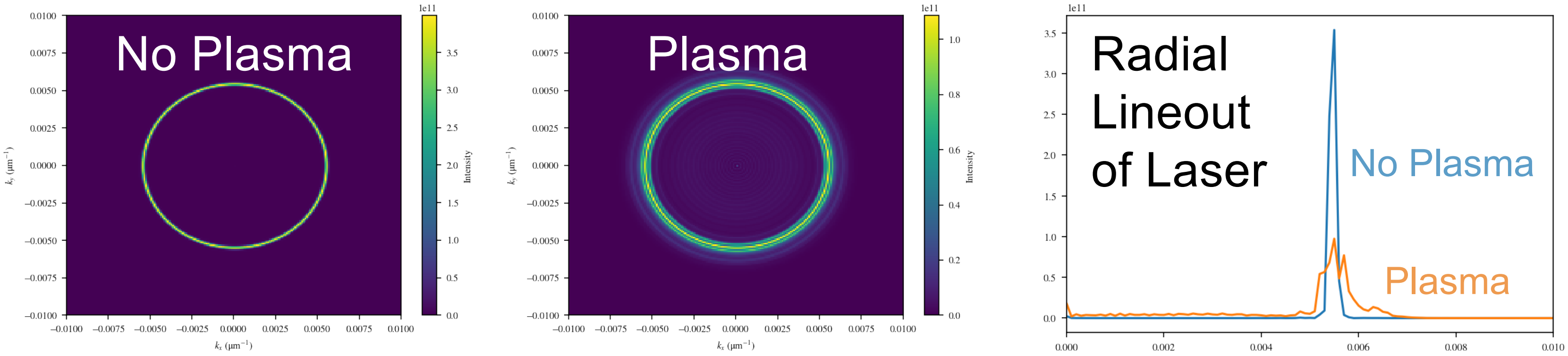
Plasma Diagnostics: CU



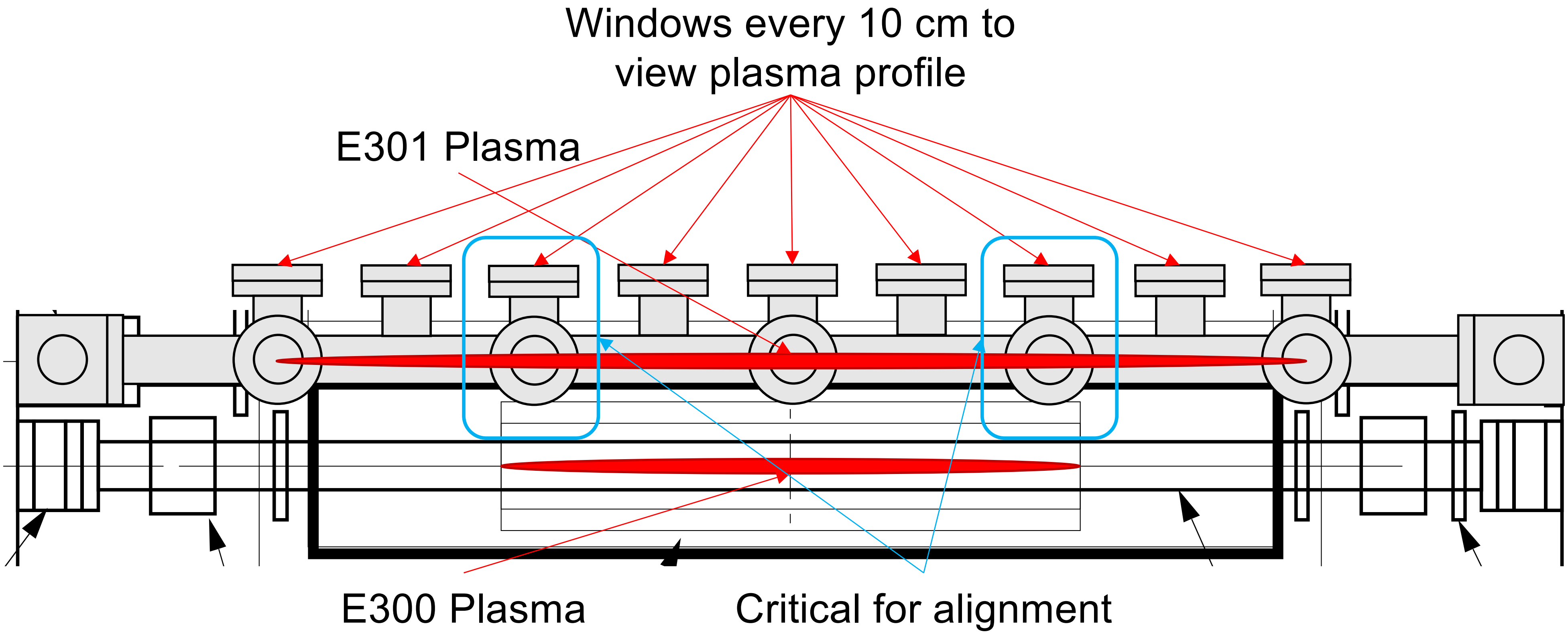
We have been working on other plasma diagnostics at CU...

Triple Langmuir probe (left):
- measures temperature well
- probe tips quickly destroyed
- work in progress

Diffraction of main laser: pattern observed from presence of plasma at DSHM



Bypass Line Design



- Oven thermal jacket constrains bypass line design.
- Concept: multiple ports for windows and OTRs.
- E300 & E301 **require** two identified OTR ports.
- More windows increase view of plasma: important!
  → **cameras are the most reliable plasma diagnostic we have**

PWFA Experimental Procedure

1. Optimize 2-bunch beam (TCAV, EOS-BPM, spectrometer, etc.)
2. Align laser through transport at low power
3. Optimize Bessel quality using rail camera system
4. Align laser to e-beam path using bypass line OTRs
5. Fire laser at high power and observe plasma
6. Send electron beam through plasma
7. Begin tuning, starting with e-beam waist position, 2 cm steps
8. At given set point, perform chromatic quad scan
9. Rinse and repeat...

E301: Status

- Conceptual design: **complete**
- Numerical design optimization: **complete**
- Fast particle tracker WARGSim: **complete, improving**
- Detailed PIC simulation: **ongoing, due: Nov.**
- Optics design: **complete**
- Optics fabrication: **ongoing, due: Nov.**
- CAD design: **complete**
- Order all parts for SLAC: **Nov.**
- Prototype test at CU: **Nov.-Dec.**
- Prototype test at SLAC (E300 & E301 optics): **2020**
- Perform E300: **2020**
- Perform E301: **2020, after E300**

E301: Experimental Priorities

First priority: E300 (Li oven plasma source PWFA)
- Laser ionization of Li to maximize total efficiency

After E300: Install E301 optics and test plasma generation

Single bunch commissioning:
- Optimize laser alignment & timing
- Test reproducibility & stability
- Compare deceleration to model; adjust gas pressure

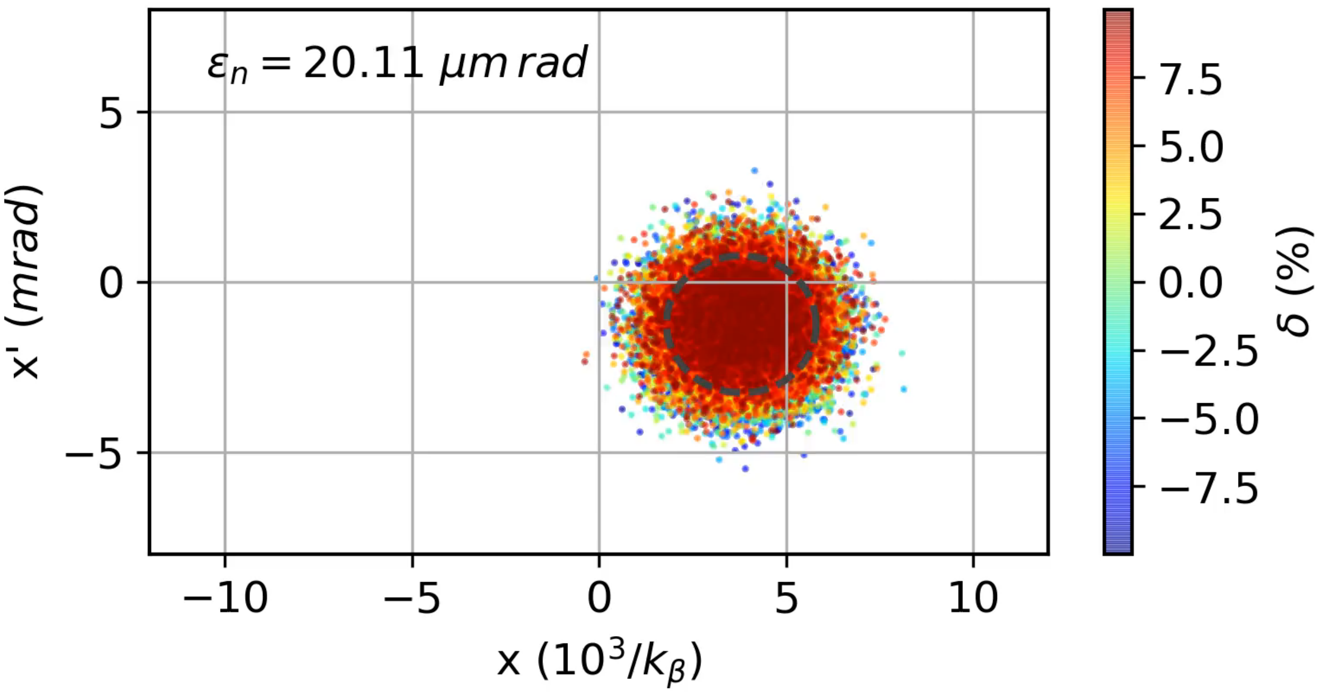
Two-bunch commissioning:
- Optimize witness acceleration; adjust gas pressure
- Optimize witness matching; adjust vacuum waist

Two-bunch experiment:
- Perform chromatic quad scan to measure emittance
- Scan vacuum waist position to vary matching conditions
- Perform plasma profile scans using deformable mirror

Electro-Optic Sampling Beam Position Monitor: EOS-BPM

EOS-BPM: Motivation

Chromatic phase spread causes projected emittance growth in an ion column.



Offset witness beam:

Saturated, projected emittance is given by:

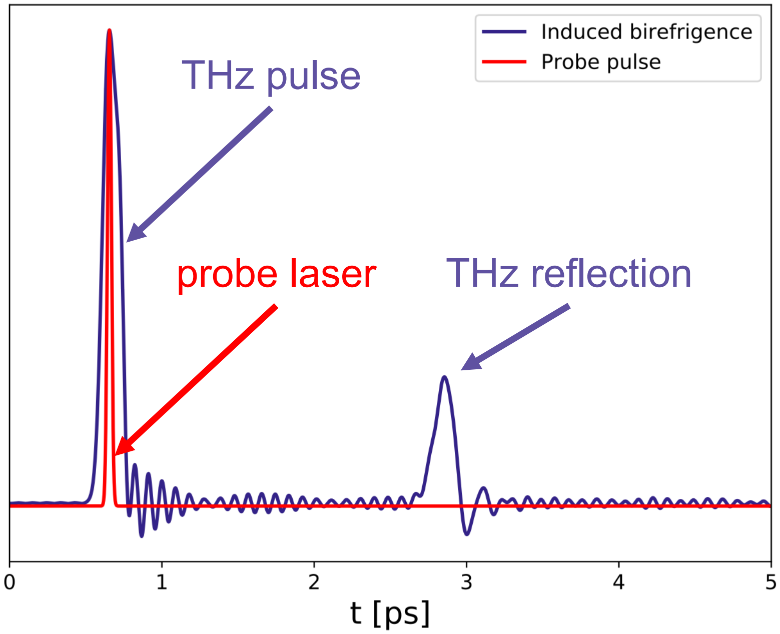
$$\frac{\epsilon}{\epsilon_0} = 1 + \frac{1}{2}\left(\frac{\Delta x^2}{\beta_m \epsilon_0} + \frac{\beta_m}{\epsilon_0}\Delta x'^2\right)$$

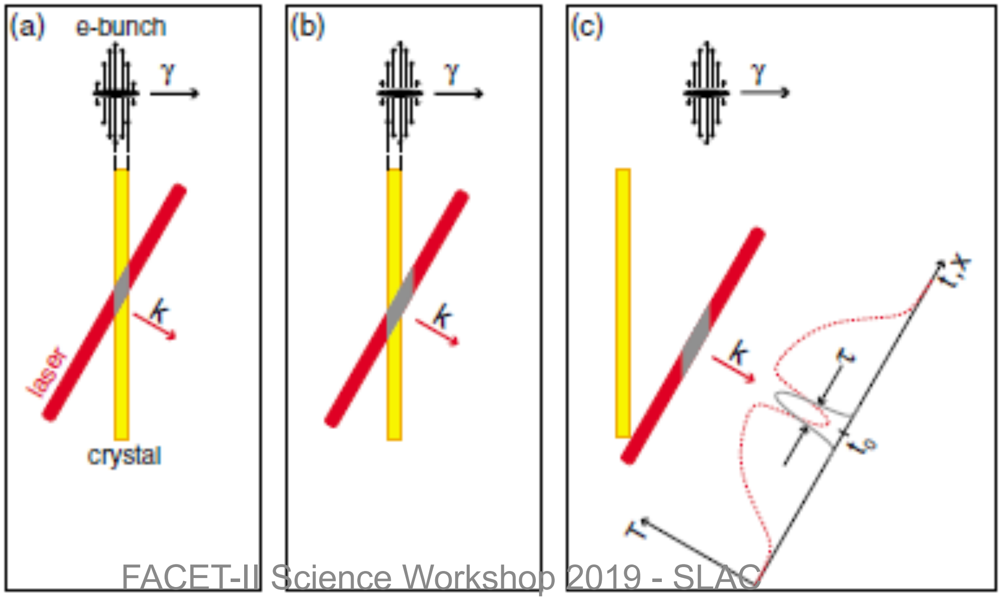
Matched witness bunch will still undergo emittance growth if it is transversely offset!

EOS: Spatial Encoding

Electro Optic Signal:

- e-beam passes by EO crystal; resembles transient THz pulse travelling through crystal.
- THz field induces birefringence
- Phase retardation occurs between polarization components of a probe laser pulse
- Result: polarization rotation when probe is coincident with e-beam





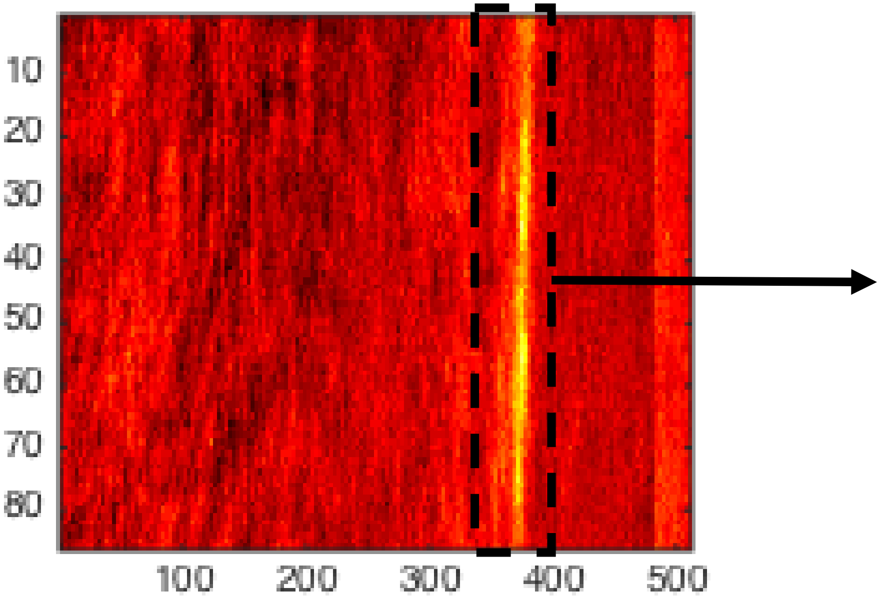
Cavalieri *et al* PRL 2005

Spatial encoding:

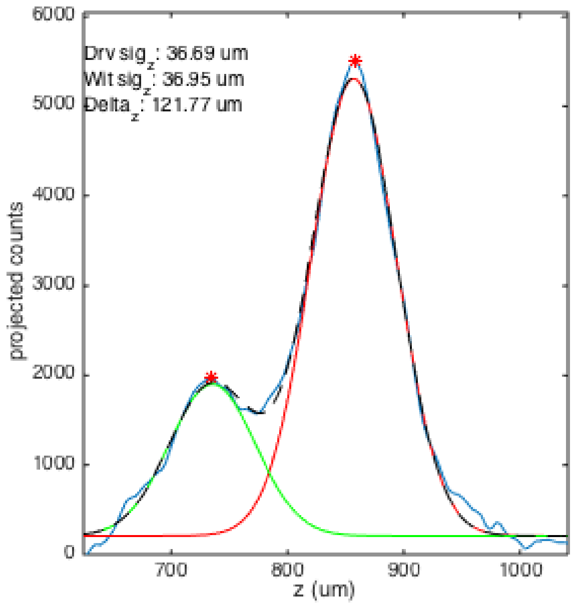
Ultrashort probe pulse crosses crystal at an angle; time is mapped into transverse spatial dimension.

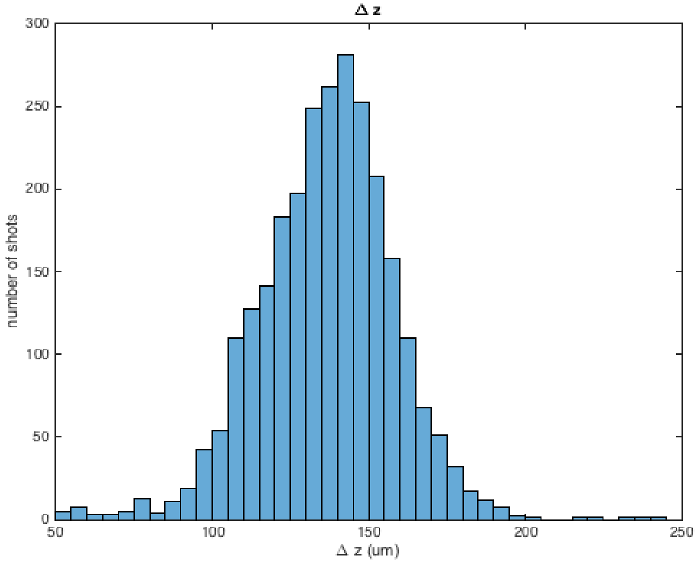
EOS: FACET Data

Spatial Encoded EOS Signal



Analyzed Signal





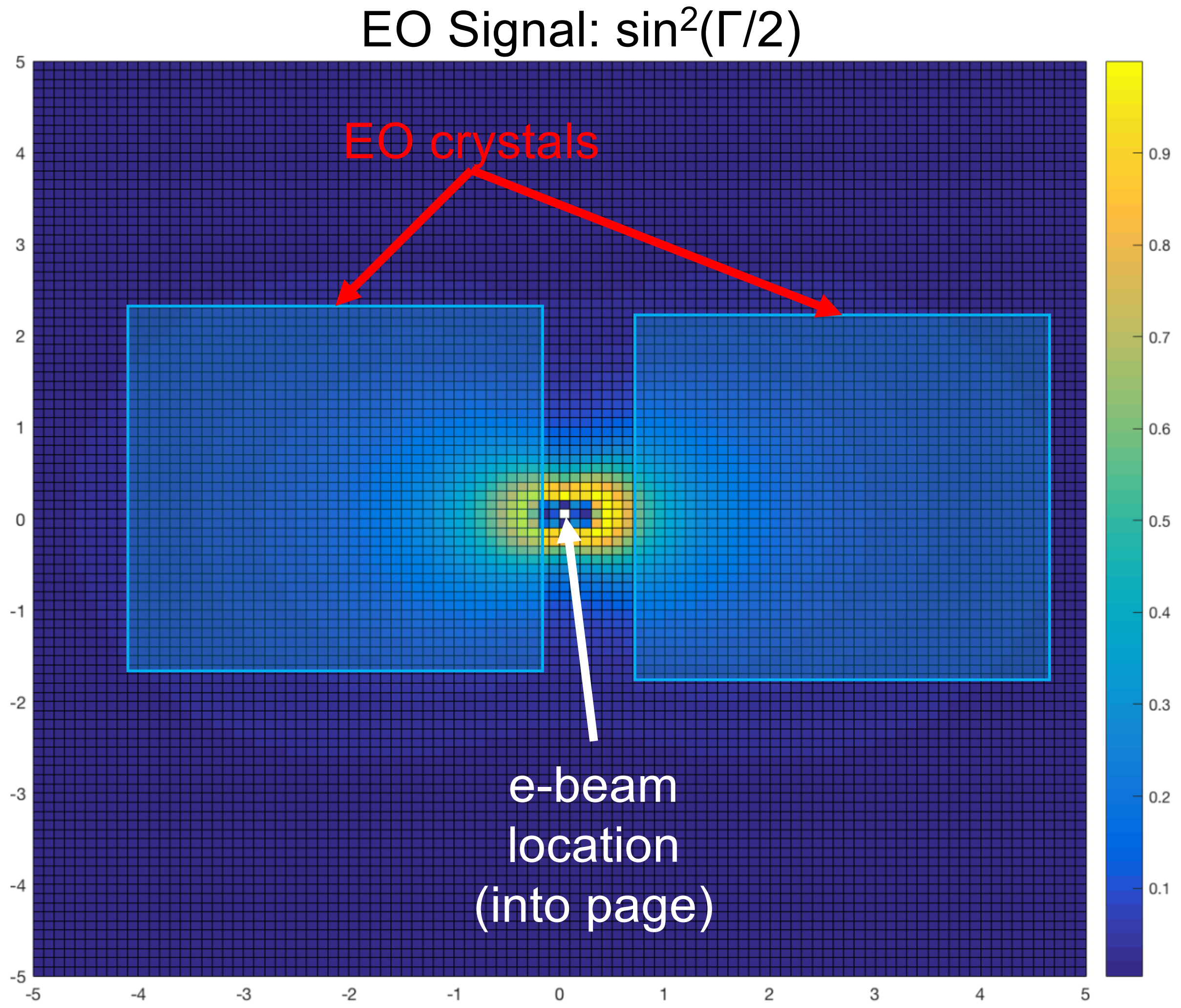
EOS used to great effect at FACET.

Calibrated against X-TCAV.

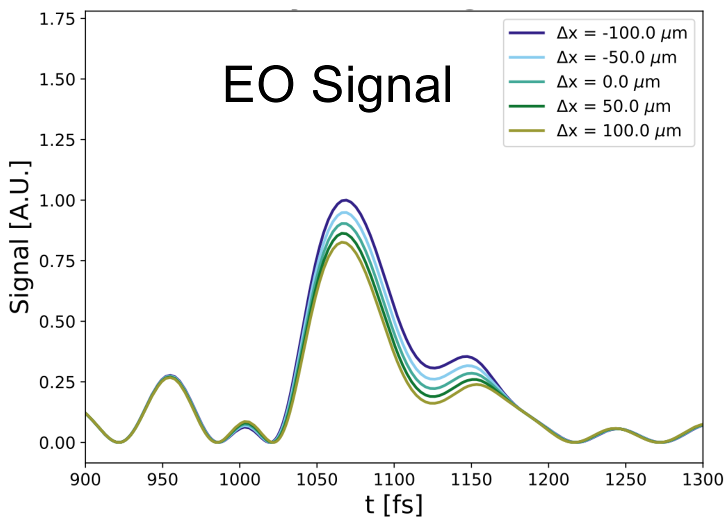
Measured drive / witness separation and e-beam / laser timing jitter with O(10 fs) resolution.

Current profile was less well resolved.

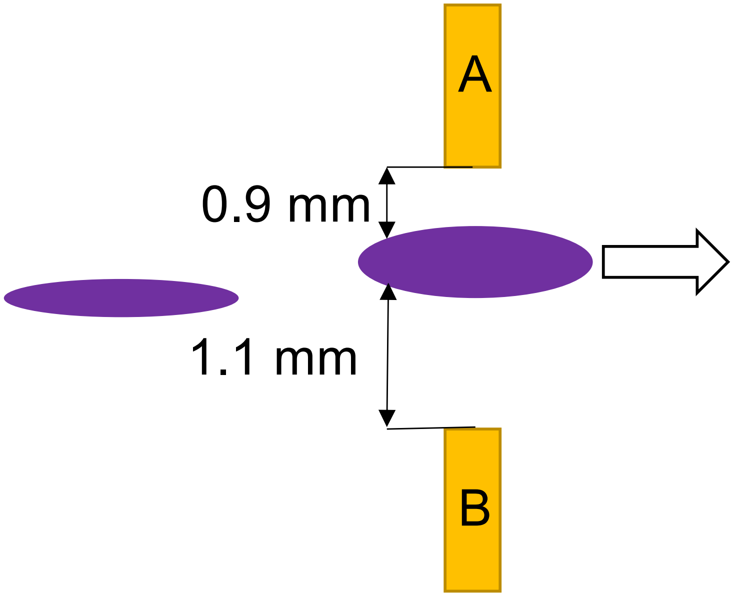
EOS: Spatial Dependence of Signal

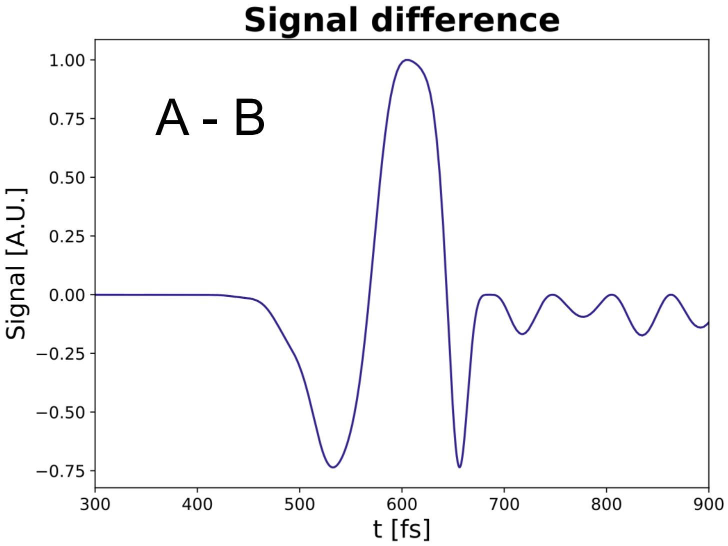


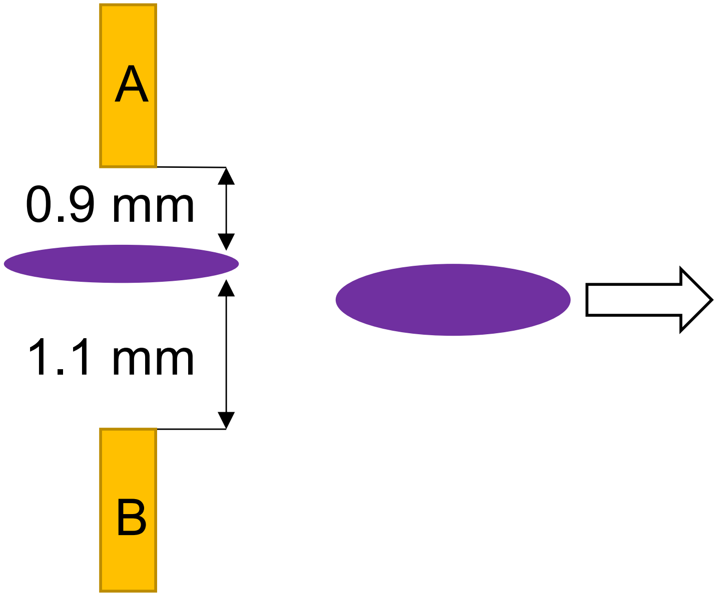
Strength of signal is stronger when beam is closer to crystal and vice versa.

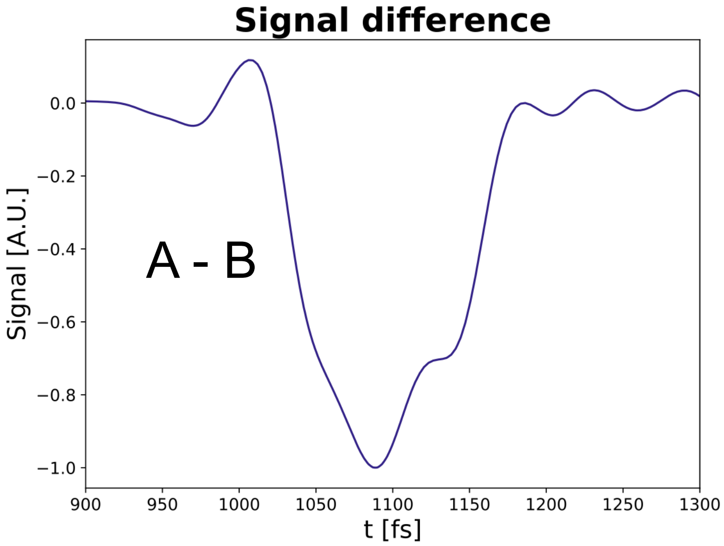


EOS-BPM: Signal Difference

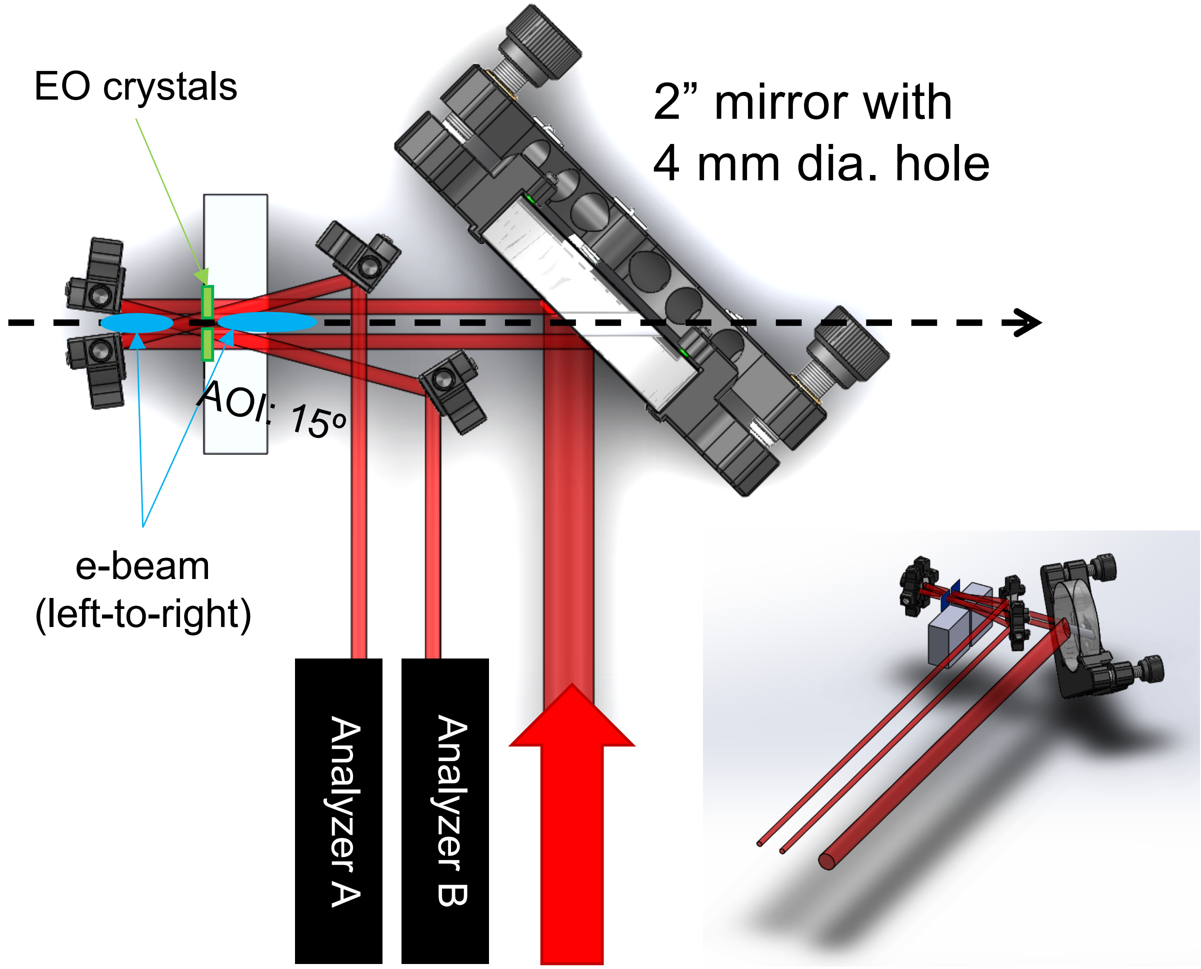




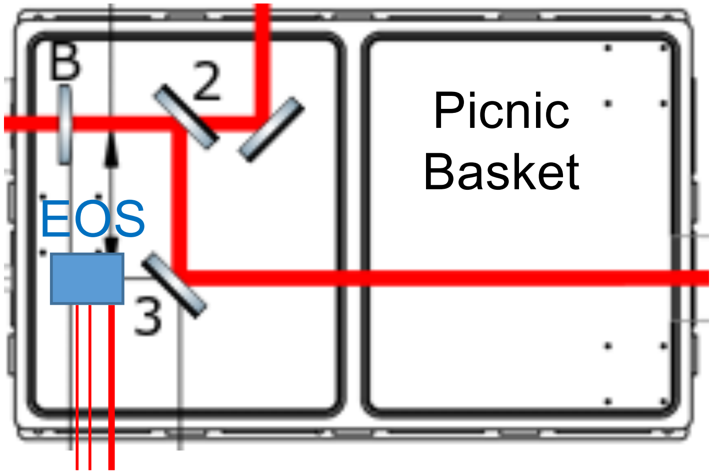




EOS-BPM: Experimental Layout



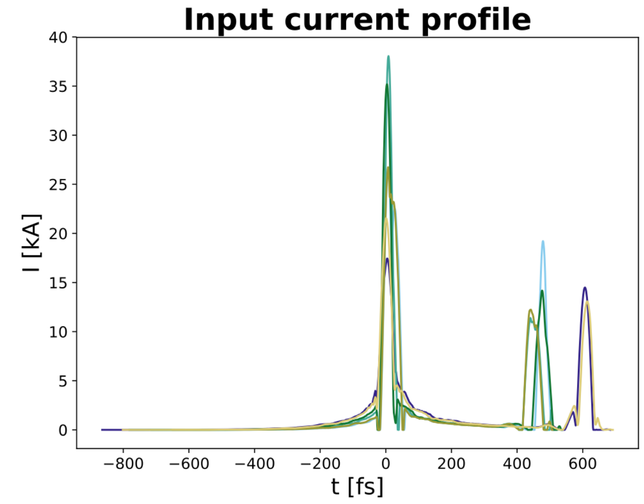
Compressed Probe
Laser, 1 cm diameter

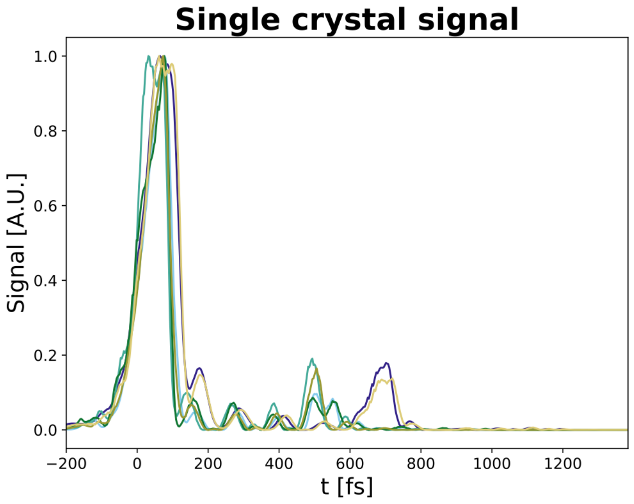


EOS-BPM sits just upstream of USHM

Footprint in PB: 5”x7”

EOS-BPM: Simulated Response


Input current profile


Single crystal signal

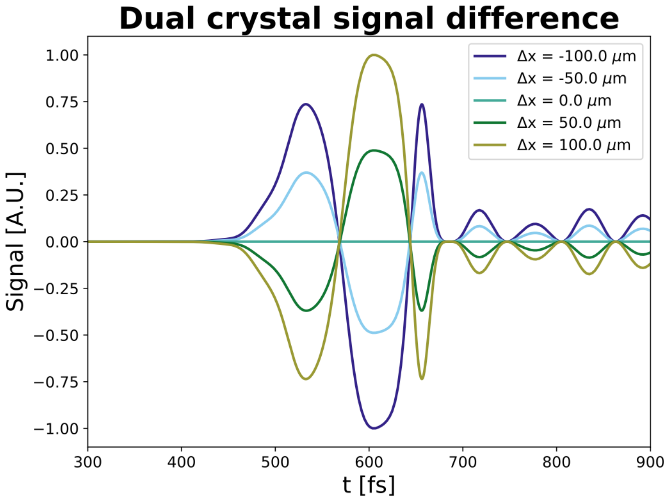
Estimated **peak-to-peak** resolution: **~10 μm, 30 fs**

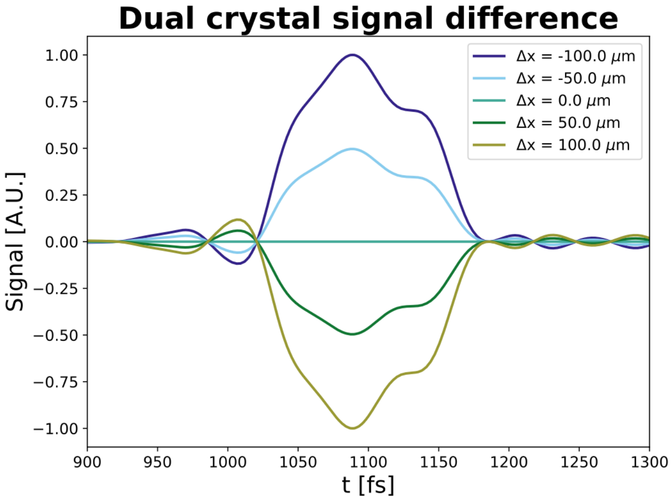
Single drive peak: ~30 fs

<u>FACET Values</u>

Peak resolution: ~30 fs

Laser/e$^-$ jitter: ~110 fs


Dual crystal signal difference


Dual crystal signal difference

Estimated **transverse** sensitivity: 1% / μm

→ 10% sensitivity: 10 μm

→ 5% sensitivity: 5 μm

→ 1% sensitivity: 1 μm

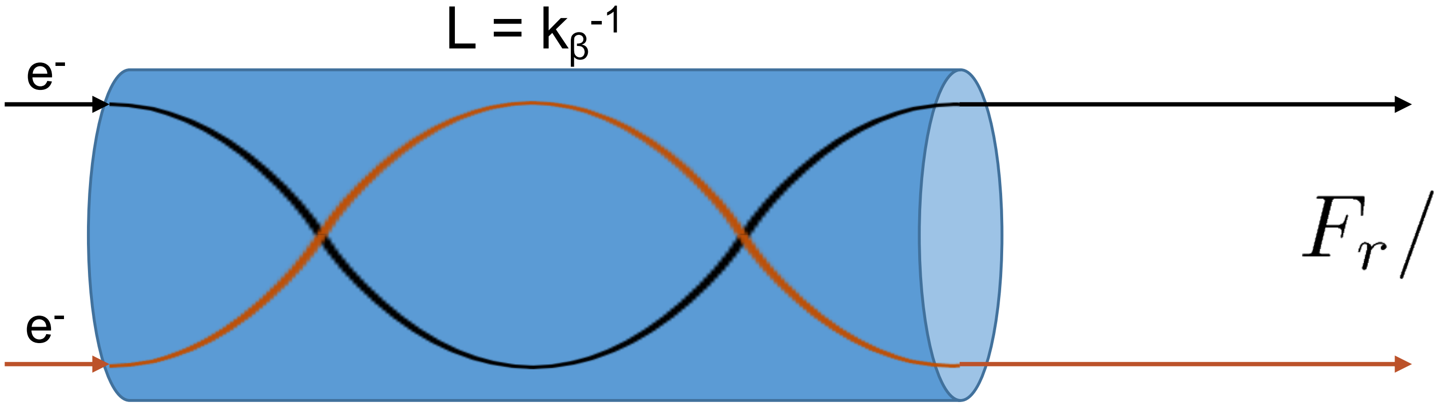
EOS-BPM: Status

- Conceptual design: **complete**
- Numerical design optimization: **complete**
- Simulated response: **complete**
- CAD design: **complete**
- Order all parts for SLAC: **Nov.**
- Prototype test with laser-THz source at CU: **Nov. – Dec.**
- Installation at SLAC: **2020**
- Commission with single bunch & BPMs + TCAV: **2020**
- Commission with two bunches & BPMs + TCAV: **2020**
- Use with any/all experiments: **May 2020 onward**

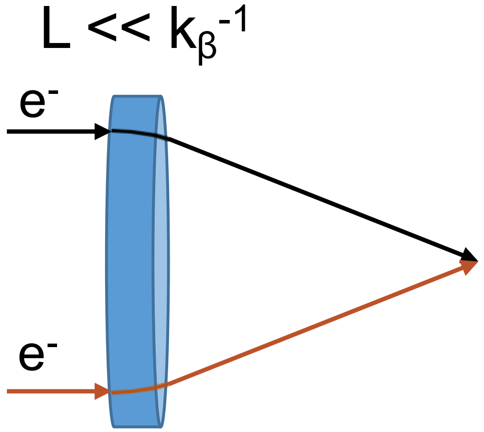
TPL

Laser-Ionized,
Beam-Driven,
Underdense,
Passive
Thin Plasma Lens:
TPL

TPL: Short Ion Column



$$F_r/r = 2\pi n_p e^2$$



$$f = \frac{1}{KL} \simeq \frac{\gamma_b m_e c^2}{2\pi e^2 n_p}\frac{1}{L}$$

Concept: use a laser to ionize the plasma lens
→ control plasma profile with optical precision.
Use blowout regime to produce linear focusing.

TPL: Analytic Formulae

Thin Lens requirement: $\Delta\psi = \sqrt{K}L \ll 1$ where $K = 2\pi r_e n/\gamma_b$

Can predict waist size and location:

$$\widetilde{\beta}^*_{thin} = \frac{1}{\widetilde{\beta}_0\widetilde{L}^2 + 2\alpha_0\widetilde{L} + \widetilde{\gamma}_0} \qquad \widetilde{z}^*_{thin} = \frac{\widetilde{\beta}_0\widetilde{L} + \alpha_0}{\widetilde{\beta}_0\widetilde{L}^2 + 2\alpha_0\widetilde{L} + \widetilde{\gamma}_0}$$

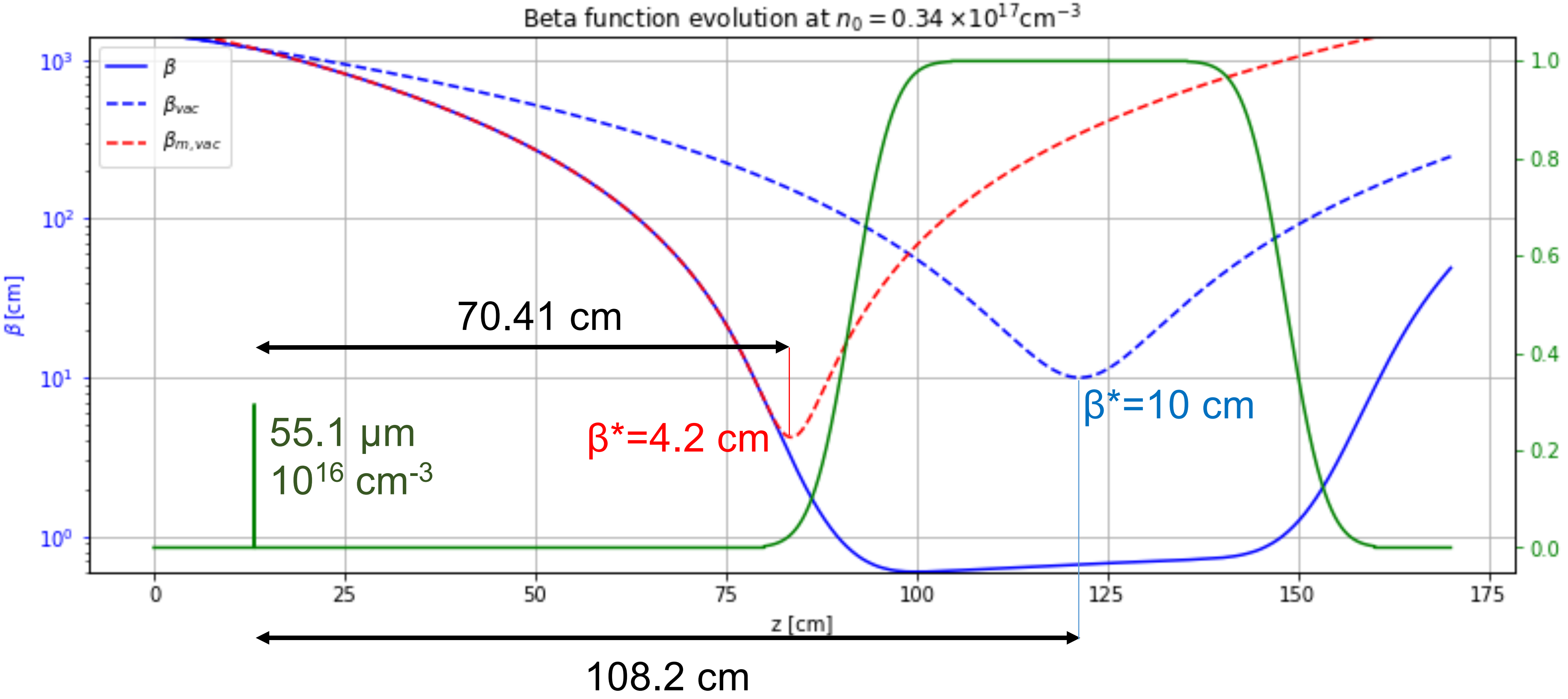
normalized to $\sqrt{K}$

Thin lens comparison against conventional electromagnet quad. and permanent quad. for $\Delta\psi = 0.1$, E=10 GeV.

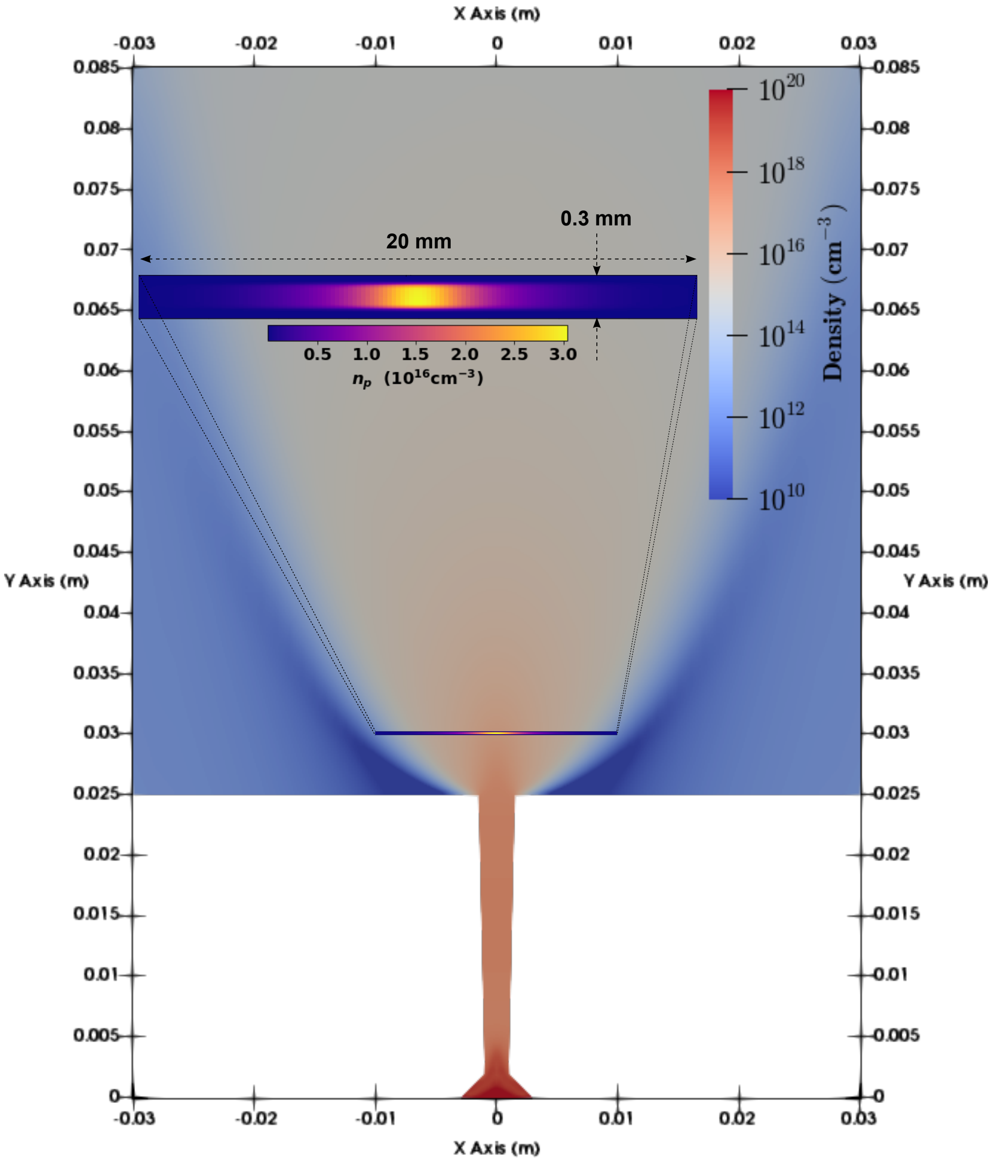
Focusing Element	**G [T/m] or n_p [cm^{-3}]**	**K [m^{-2}]**	**L [mm]**	**f [cm]**
Quadrupole	1	0.3	180	1000
PMQ	500	150	8.2	81
TPL	**10^{17}**	**88400**	**0.34**	**3.3**

PWFA Matching Conceptual Example

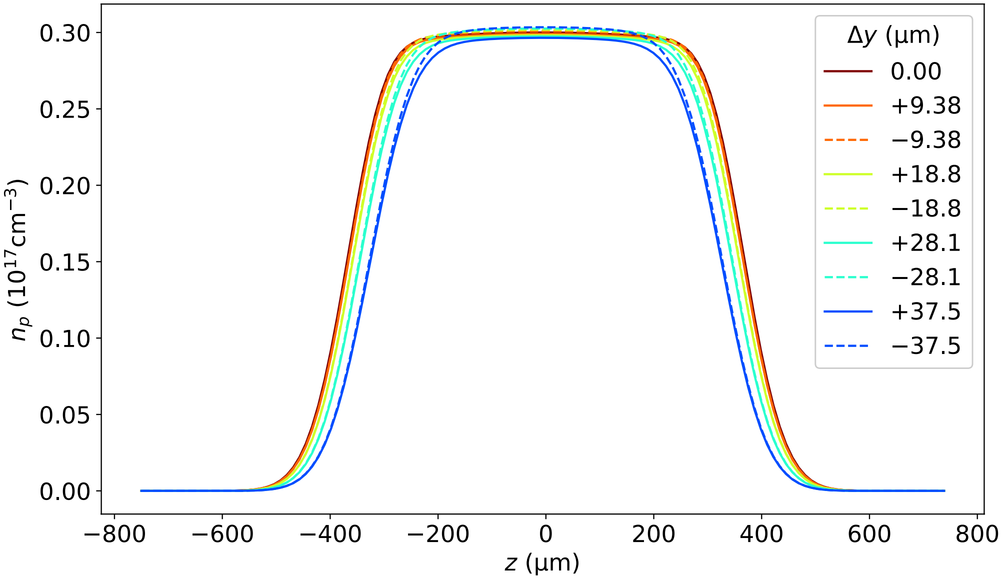
If PWFA ramps cannot provide sufficient focusing, TPL can provide extra focusing "boost" to match beam.



Ideal Ionized Gas Jet Profile

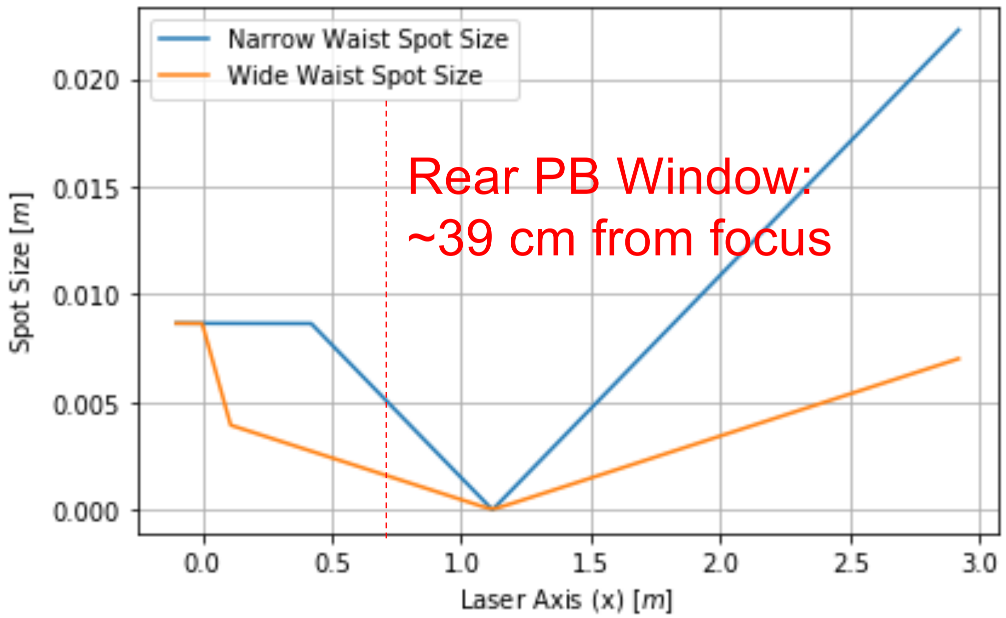


- OpenFoam sim. of gas jet profile
- Split-step Fourier sim. of laser ionization
- Goal: uniform density profile in center
- No appreciable horizontal variation
- Slight vertical variation (below)
- Effective TPL length varies by few percent over height of 100 μm

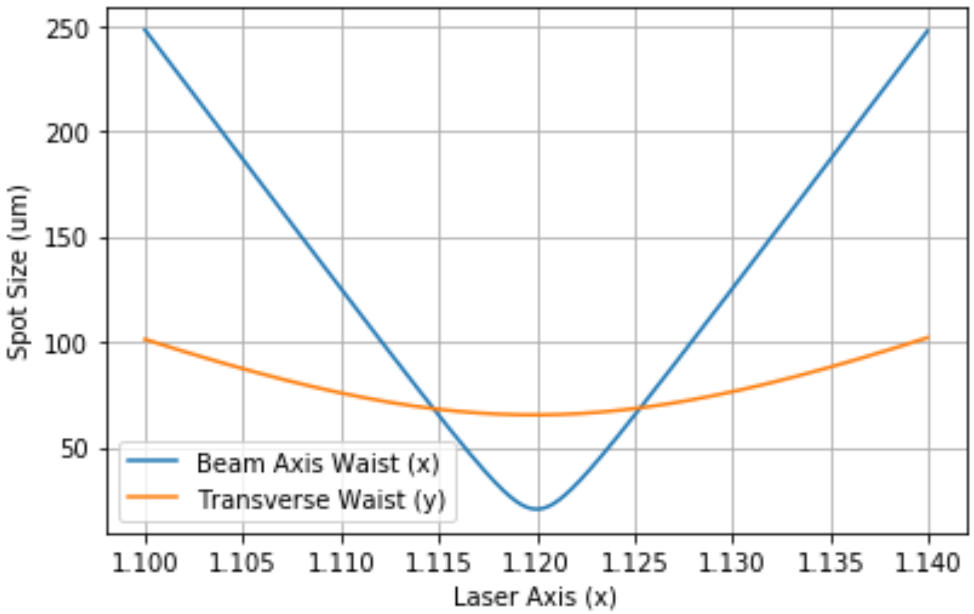


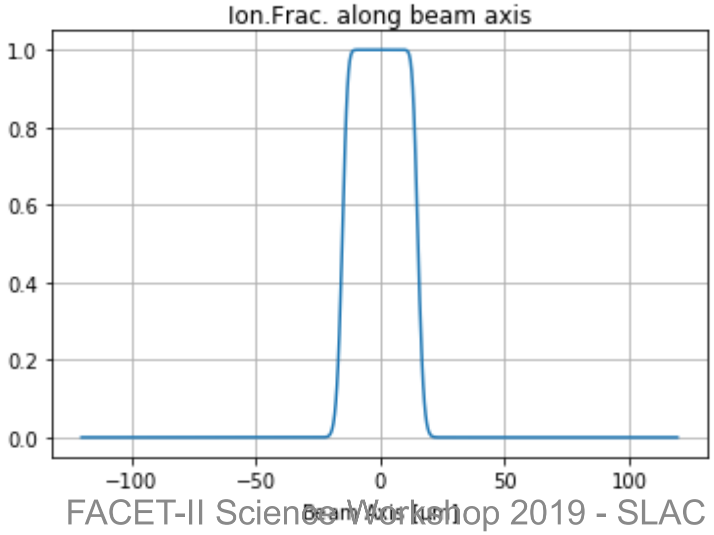
FACET-II Optics Mk. 1

Optics: Crossed cylindrical lenses → one wide and one narrow waist



Rear PB Window:
~39 cm from focus





- **Limiting factor: intensity at window**
- Max TPL length: only 31 μm
- Produces weak focusing at 3.5 x 10^{16} cm^{-3}
- Solution: Increase density and put witness in second bucket of wake

Second Bucket Operation: Example

TPL density: 5.1×10^{17} cm^{-3} → Highest blowout density

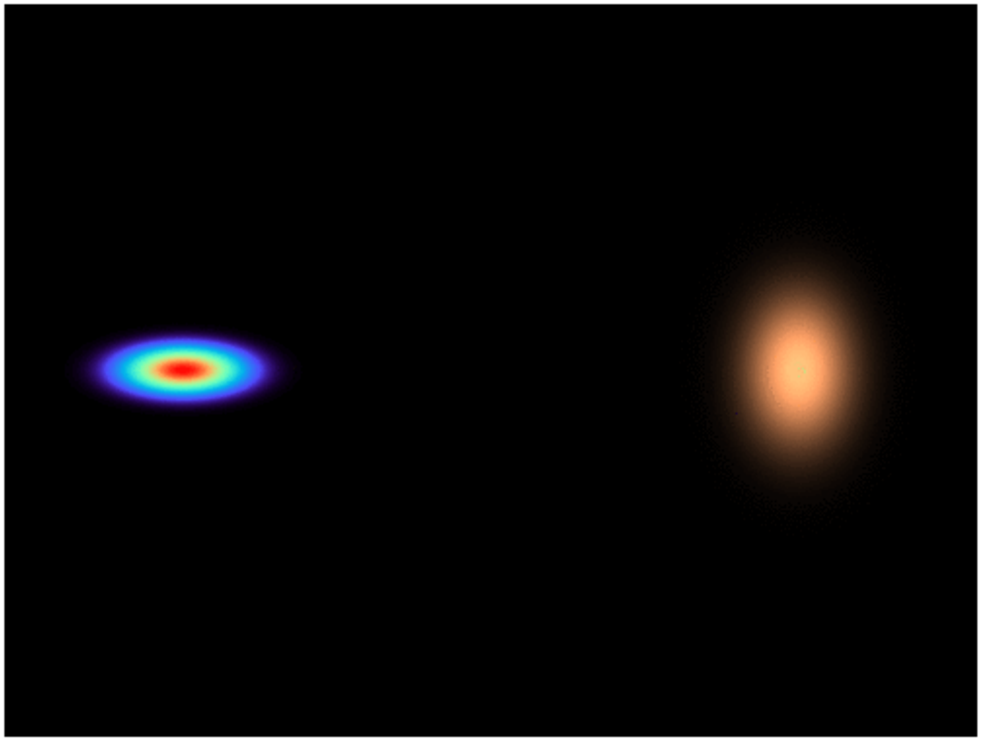
TPL length: 48.3 μm → $\Delta\psi = 0.03$

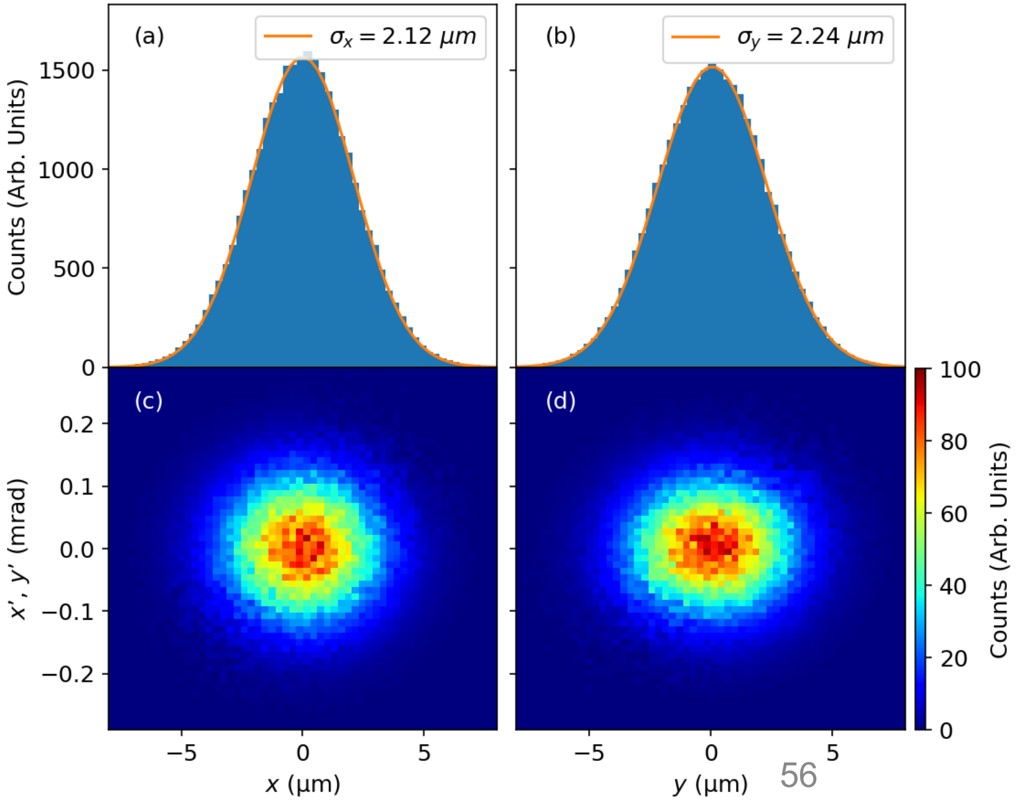
Drive-witness spacing: 90 μm → Witness in 2nd bucket

Beta function reduction: from 5 cm to 2.75 cm

Waist location: 2.5 cm after TPL

Emittance growth: 1.25% in both dimensions





Afterglow Plasma Source TPL

TPL density: 5×10^{17} cm^{-3}

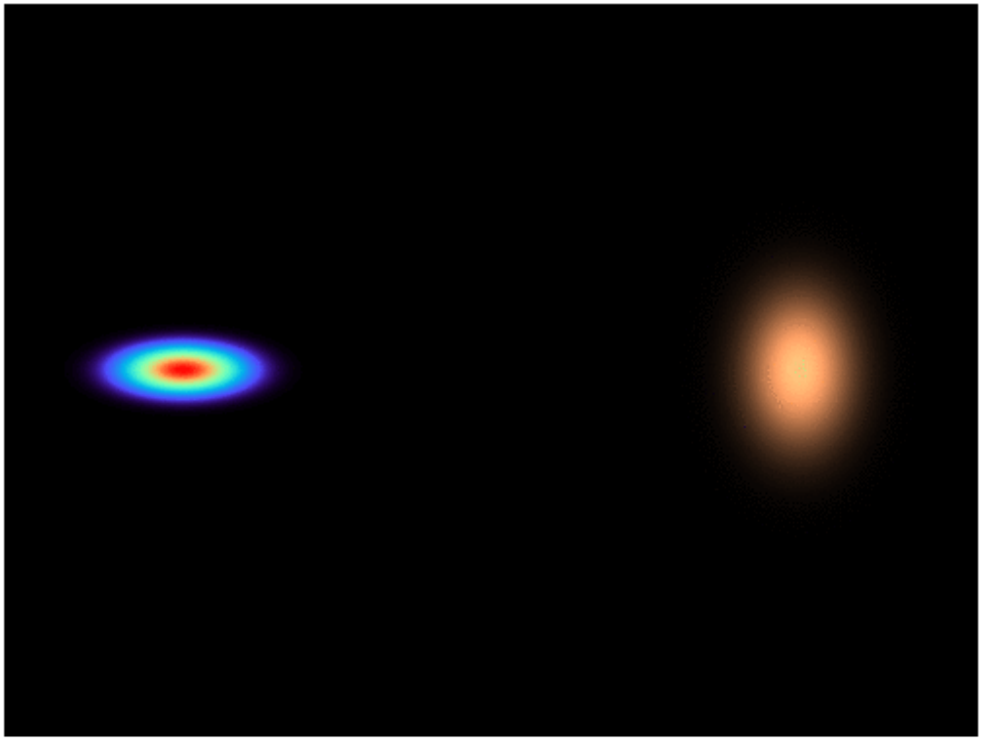
TPL y-z plane diameter: 75 µm (hard edge in simulation)

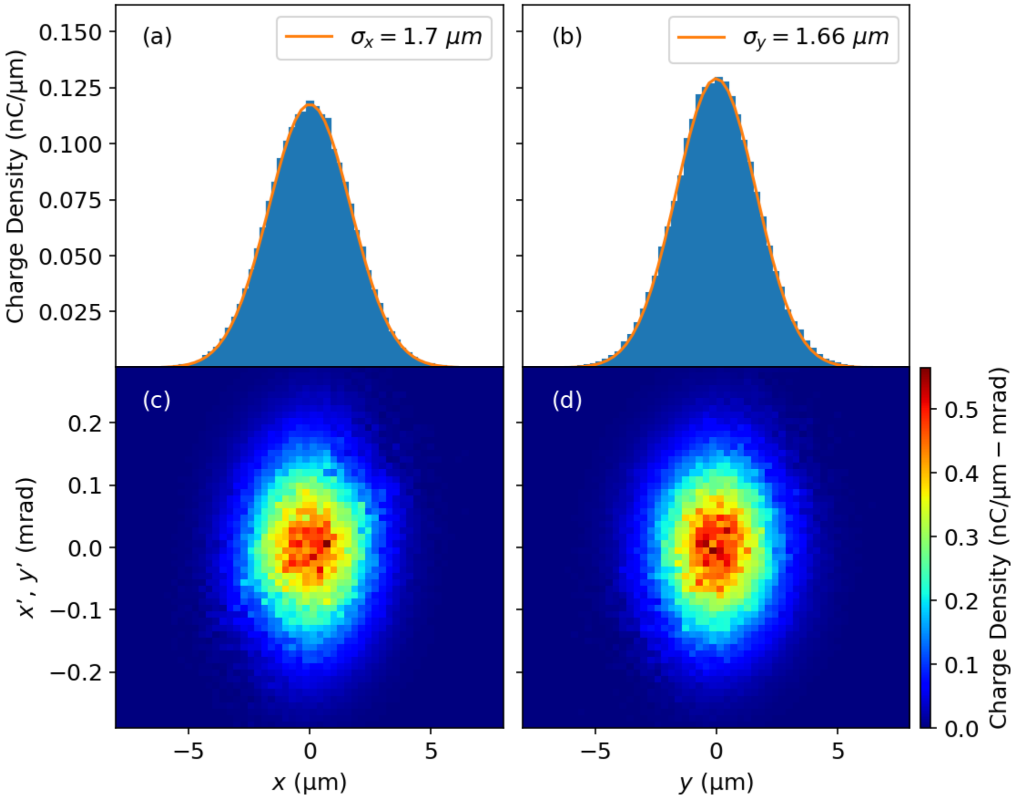
Drive-witness spacing: 90 µm → Witness in 2nd bucket

Beta function reduction: from 5 cm to 1.75 cm

Waist location: 2.34 cm after TPL

Emittance growth: 2% in both dimensions

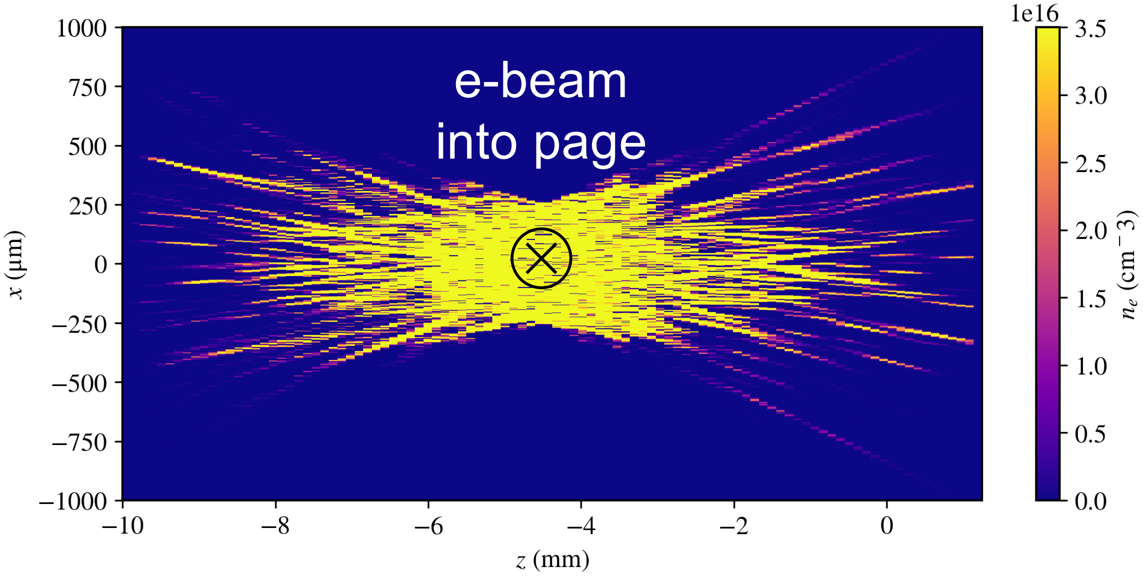


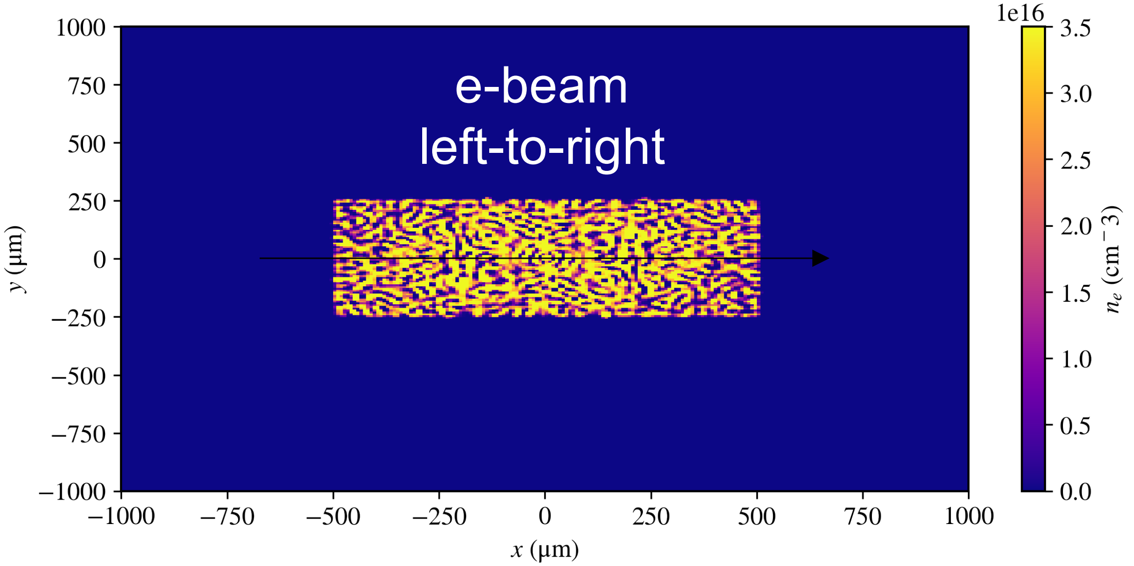


Experimental Challenges

- Experimental constraints make optics challenging for ideal TPL
- Second bucket operation could permit much smaller TPLs
- Could use Afterglow optics to form reasonable first pass TPL
- Axial focusing like Filamentation could produce good TPL, but incompatible with E300 and E301
- Transverse laser propagation is ideal: critical for compactness!
- Possible improvement: diffractive optics...

TPL from Diffractive Optics





First pass at diffractive optic simulation for rectangular focus.

Creates TPL with length 1mm, width 2mm, and height 0.5 mm.

Not bad for first try!

Work in progress...

TPL: Experimental Measurements

Early tests would not reduce beam size below measurable size for imaging spectrometer
→ use large incoming beta functions

Ideal: scan density from first bucket operation to second bucket operation and compare to models

For stronger focusing, need more sophisticated diagnostics. Examples: matching into plasma (E301 plasma source), laser scattering (SFQED laser?)

More work required to plan measurements of beams focused to less than a few microns

TPL: Status

- Conceptual design: **ongoing**
- Numerical design optimization: **ongoing**
- Simulated response: **ongoing**
- CAD design: **Dec.**
- Order all parts for SLAC: **Dec.**
- Prototype test at CU: **Jan. – Feb. 2020**
- Installation at SLAC (afterglow?): **early 2020**
- Test with single bunch: **early 2020**
- Test with two bunches: **early 2020**
- Focusing in vacuum experiments: **mid-2020**
- Focusing into plasma experiments: **mid-2020**

Thanks!

Work supported by
US DOE grant number DE-SC0017906
and NSF award number 1806053.

Live footage of CU Boulder...