FACET

E210: Trojan Horse Injection for High Brightness Beam Generation & Diagnostic System

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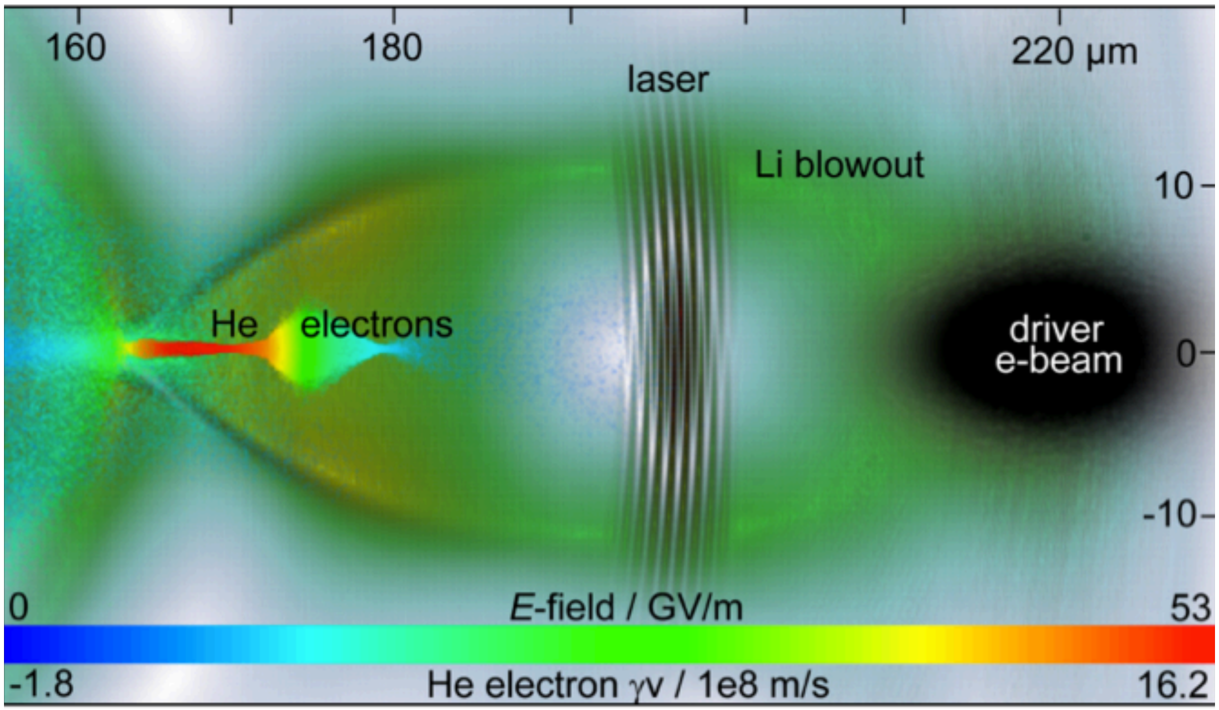
“Trojan Horse” PWFA based e-Source



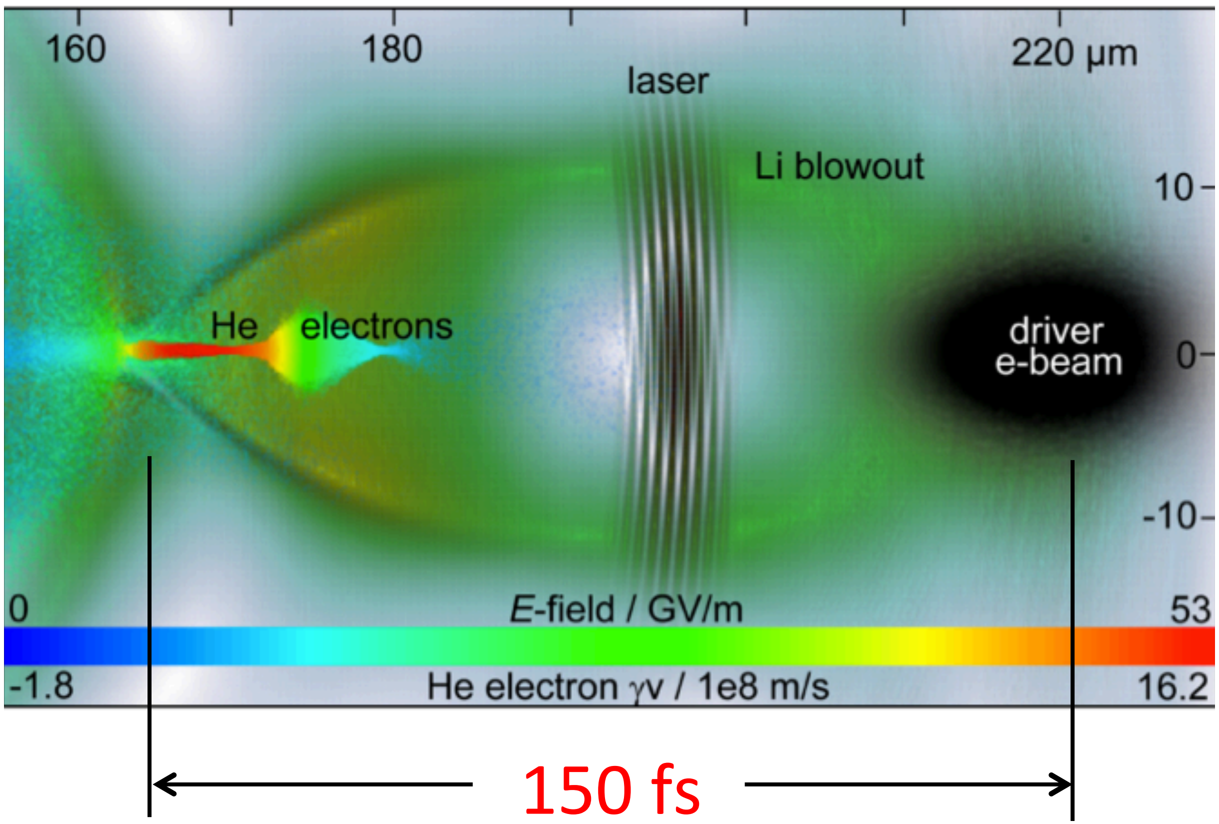
The driver electron beam with density of $n_b > n_0$ excites a plasma wake in a Low-Ionization Thresholds (LITs) background gas like H_2 or Li.

A laser-triggered ionization injection happens for a High-Ionization Thresholds (HITs) gas like He.

Trapped charge will result in a high brightness beam with emittance in order of 10^{-8} m-rad or less

B. Hidding *et al*., Phys.Rev.Lett.108.035001(2012)

Synchronization: Challenge to E210 success



B. Hidding *et al*., Phys.Rev.Lett.108.035001(2012)

5×10^{16} cm^{-3}
150 um
500 fs

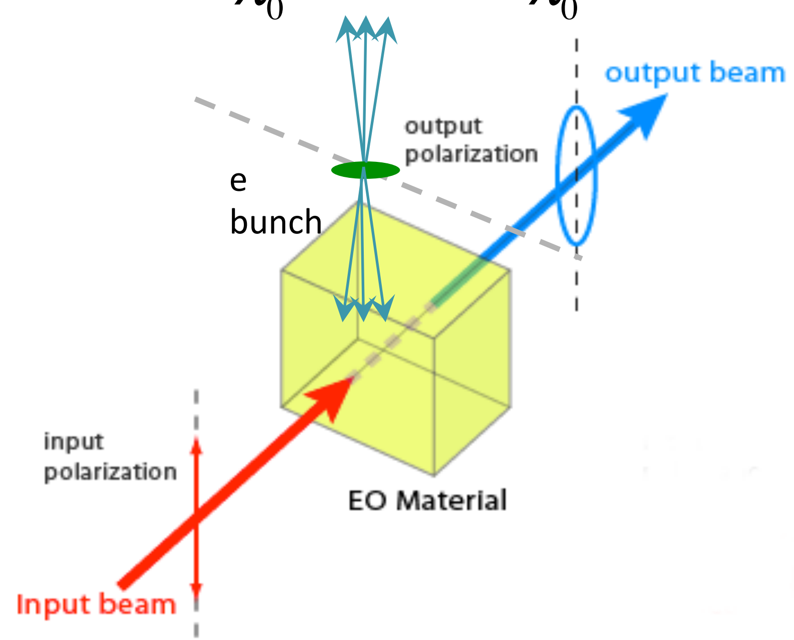
5×10^{17} cm^{-3}
47 um
150 fs

Electro-Optic Sampling (EOS)

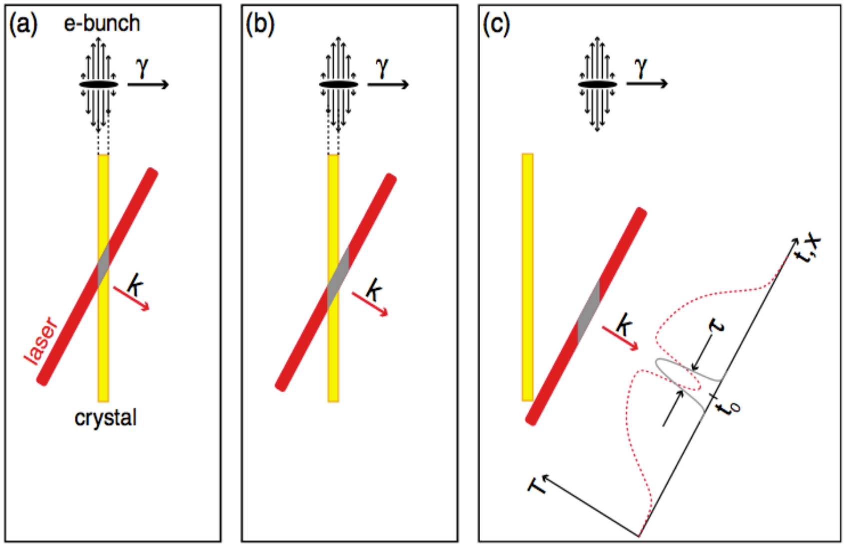
Intense electric field of e-beam induces a birefringence of the EO crystal which rotates the laser polarization.

Phase delay

$$\Gamma = \frac{2\pi(n_1 - n_2)d}{\lambda_0} = \frac{2\pi n_0^3 d}{\lambda_0} r_{41} E$$



S. Casalbuoni *et al*., Phys. Rev. ST Accel. Beams 11, 072802 (2008)

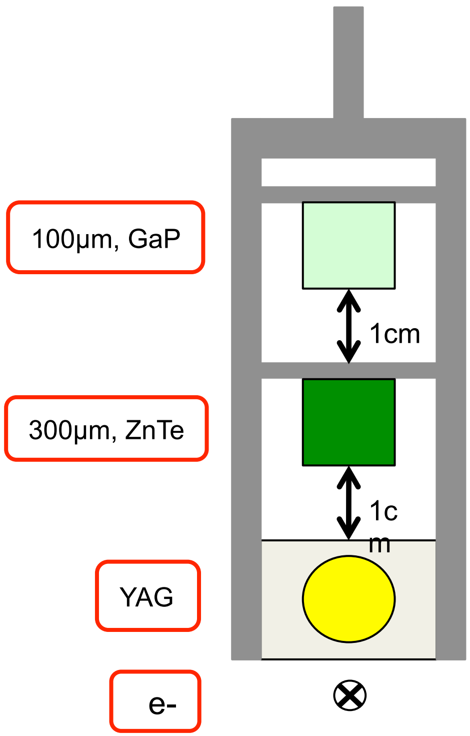


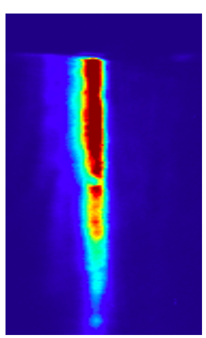
A. L. Cavalieri *et al*., PhysRevLett.94.114801(2005)

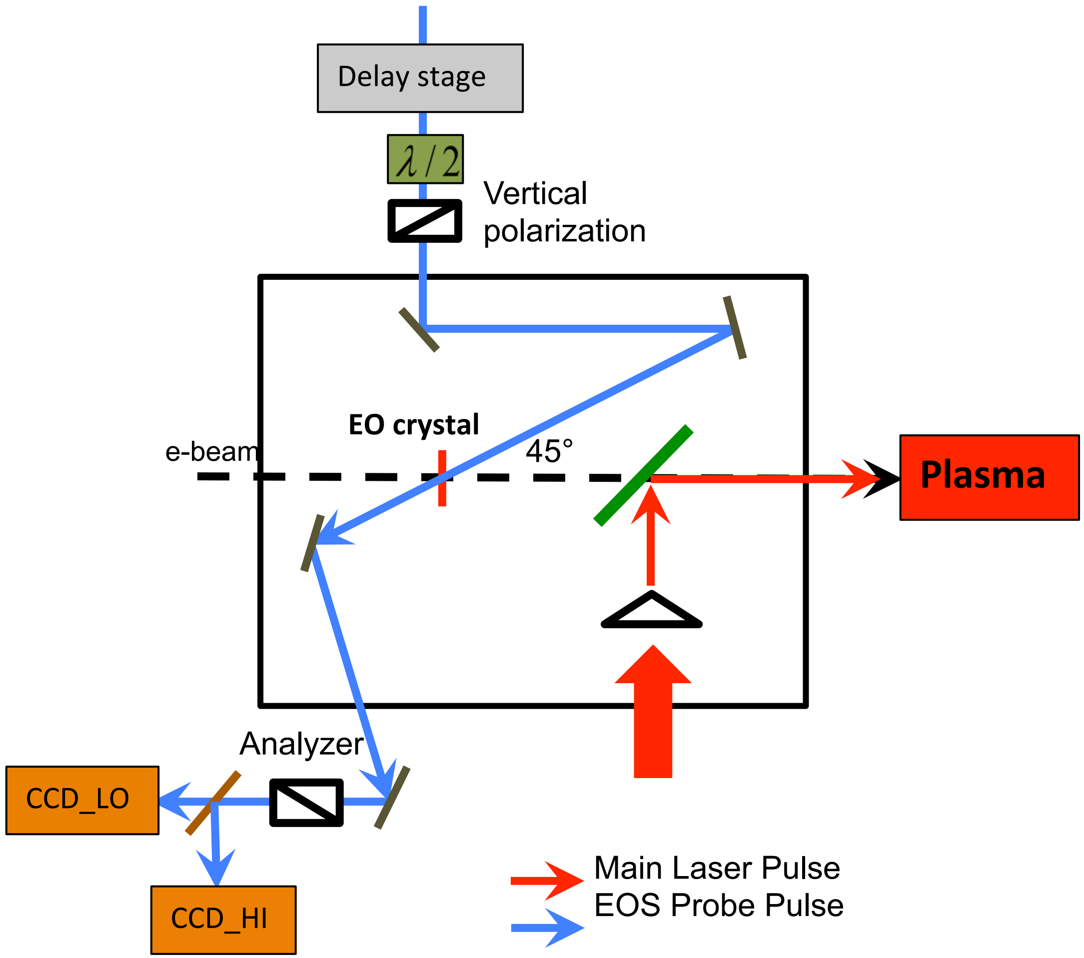
- The position of signal indicates the relative TOA.
- The width of signal is related to e-beam bunch length

Electro-Optic Sampling Setup on FACET

- Relative laser – electron beam TOA
- Non-destructive measure of single-shot bunch length, two-bunch separation, and shot-by-shot jitter

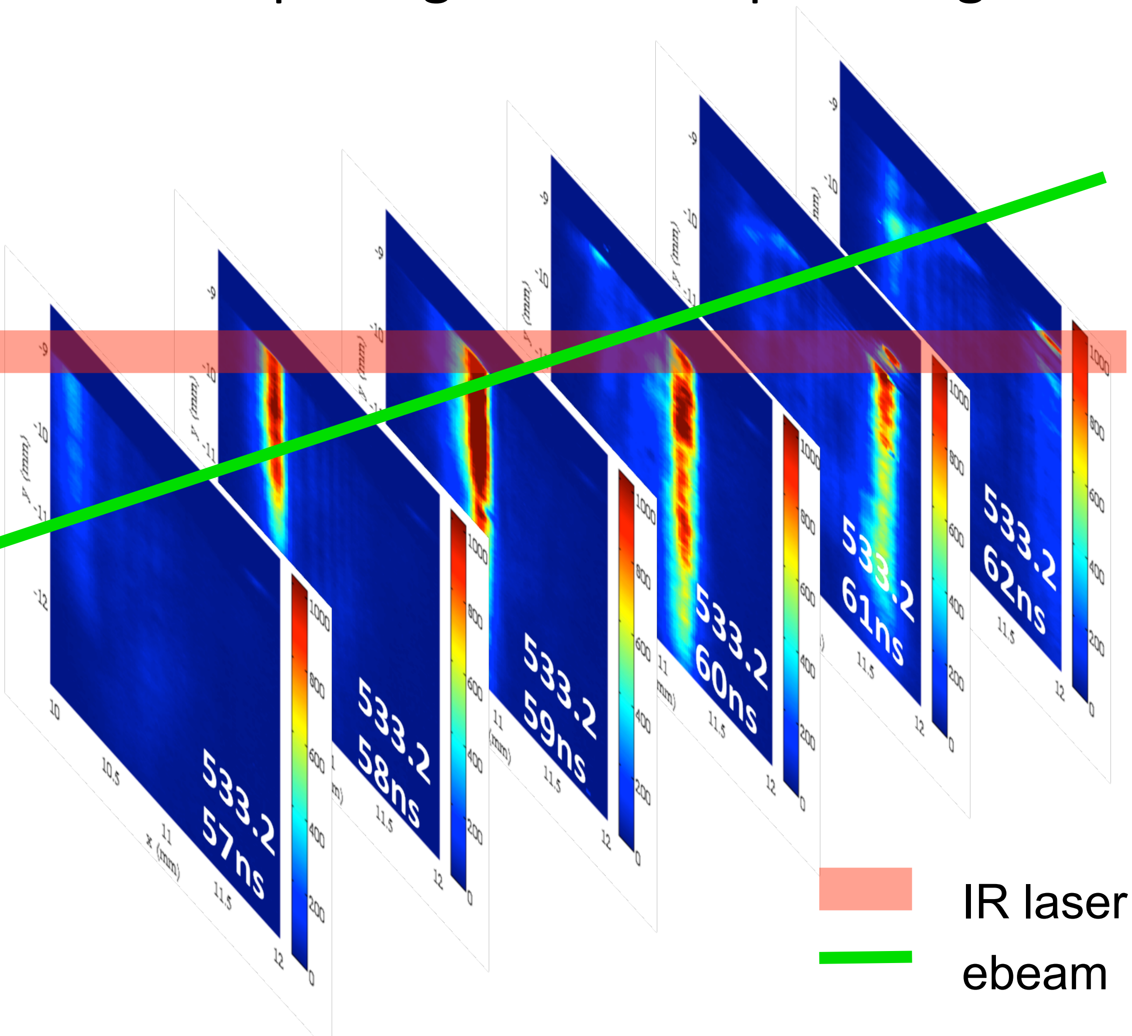


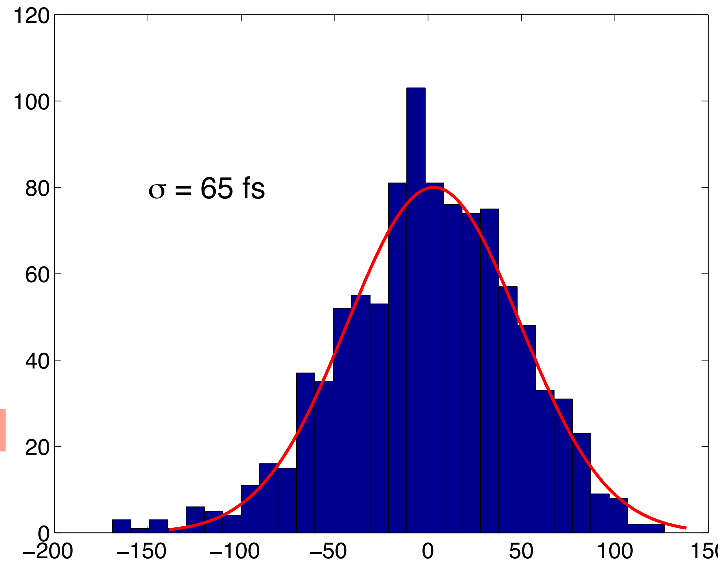




Electro-Optic Sampling

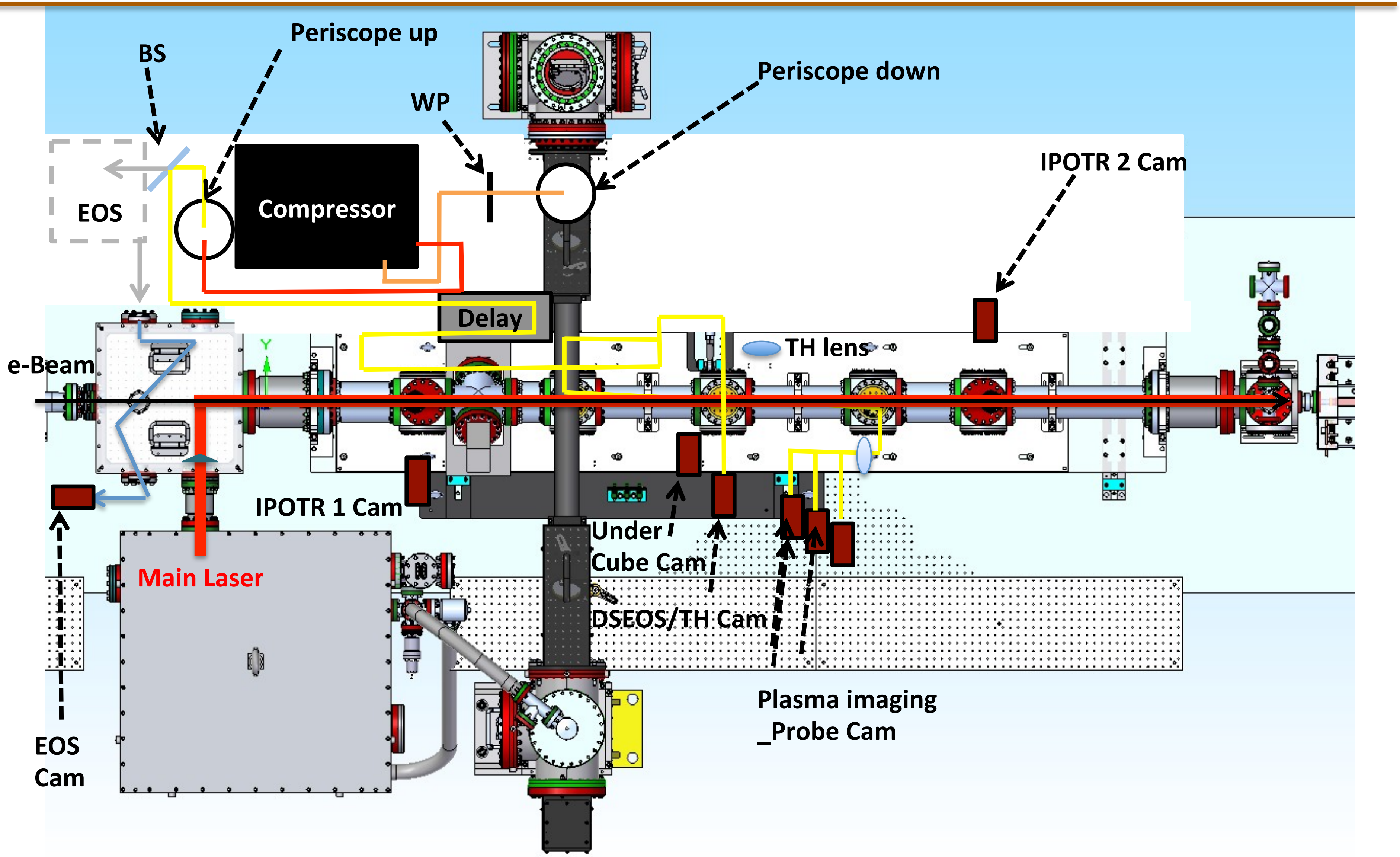
Electro-optic signal for sub-ps timing scan



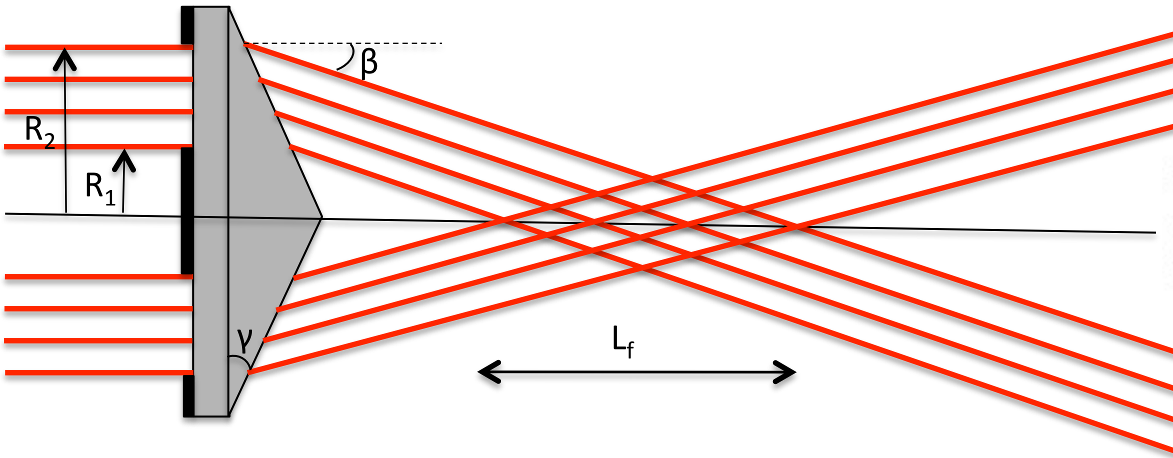


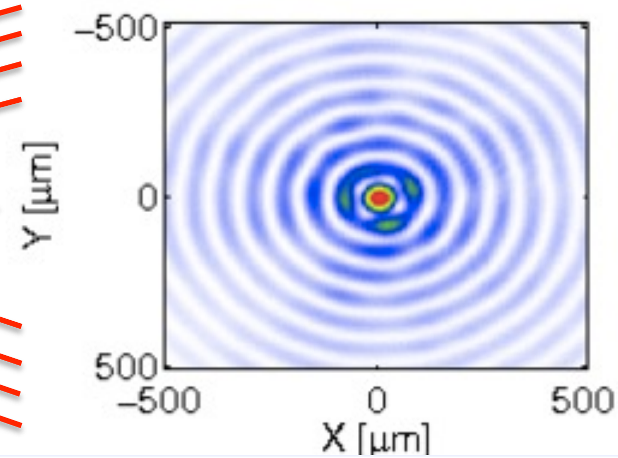
Shot-by-shot TOA jitter is ~ 65 fs (rms)

FACET Plasma Experiment Region



Plasma Column Generation with Axicon





The depth of focus L_f is given based on the geometry consideration as:

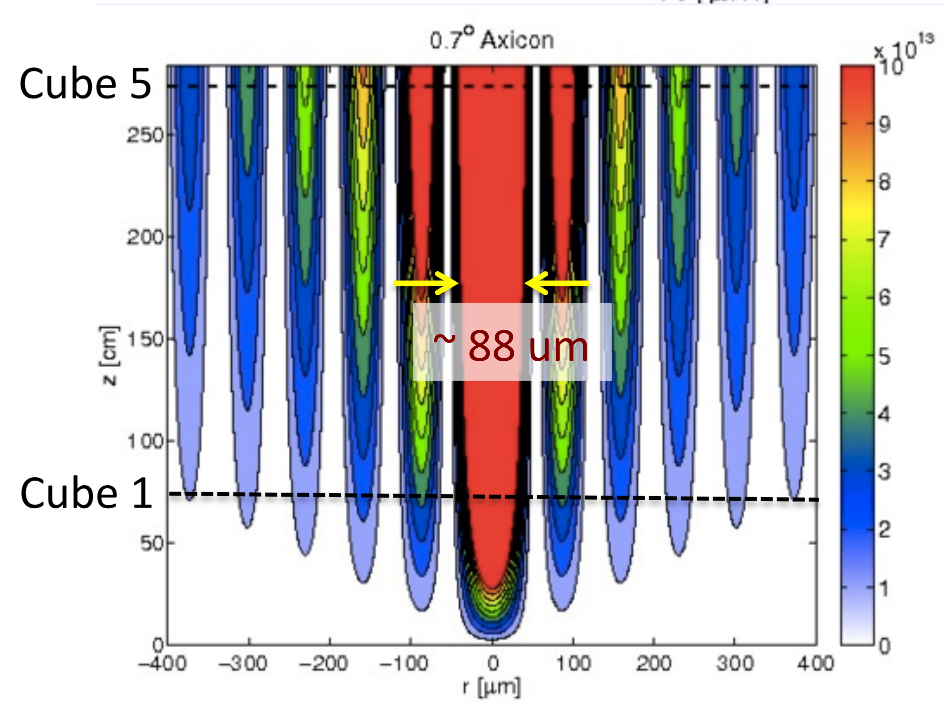
$$L_f = (R_2 - R_1)[(\tan\beta)^{-1} - \tan\gamma]$$

Where the exit angle **β** is

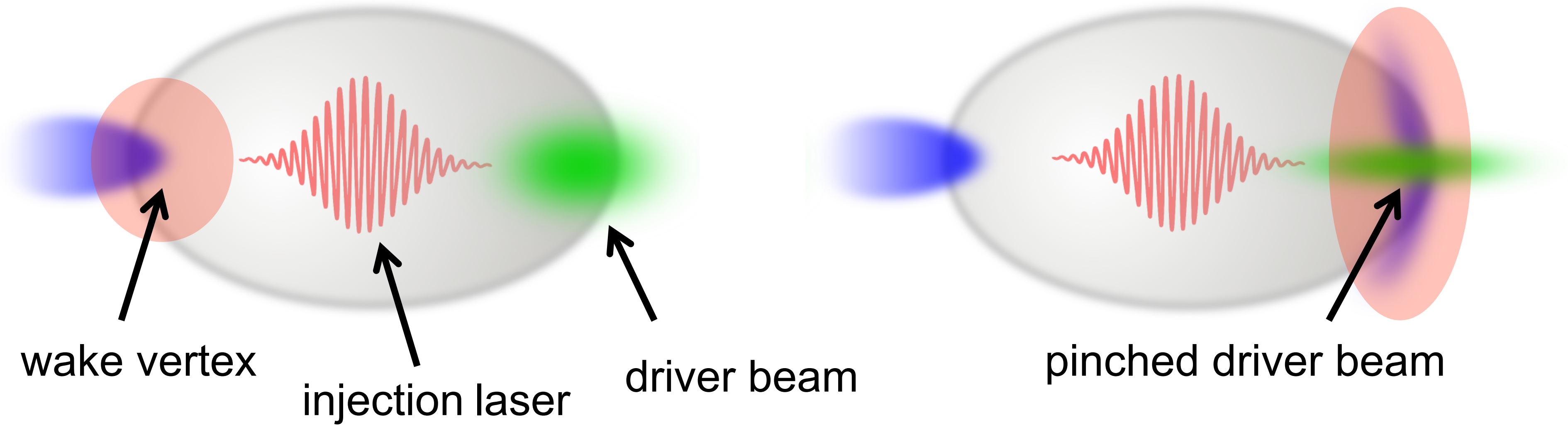
$$\beta = \arcsin(n_a \sin\gamma) - \gamma$$

The radial beam width of the focus is from zeros of Bessel functional J_0

$$R_B = 2.4048 / k_0 \tan\beta \approx 2.4048 / k_0 \beta$$



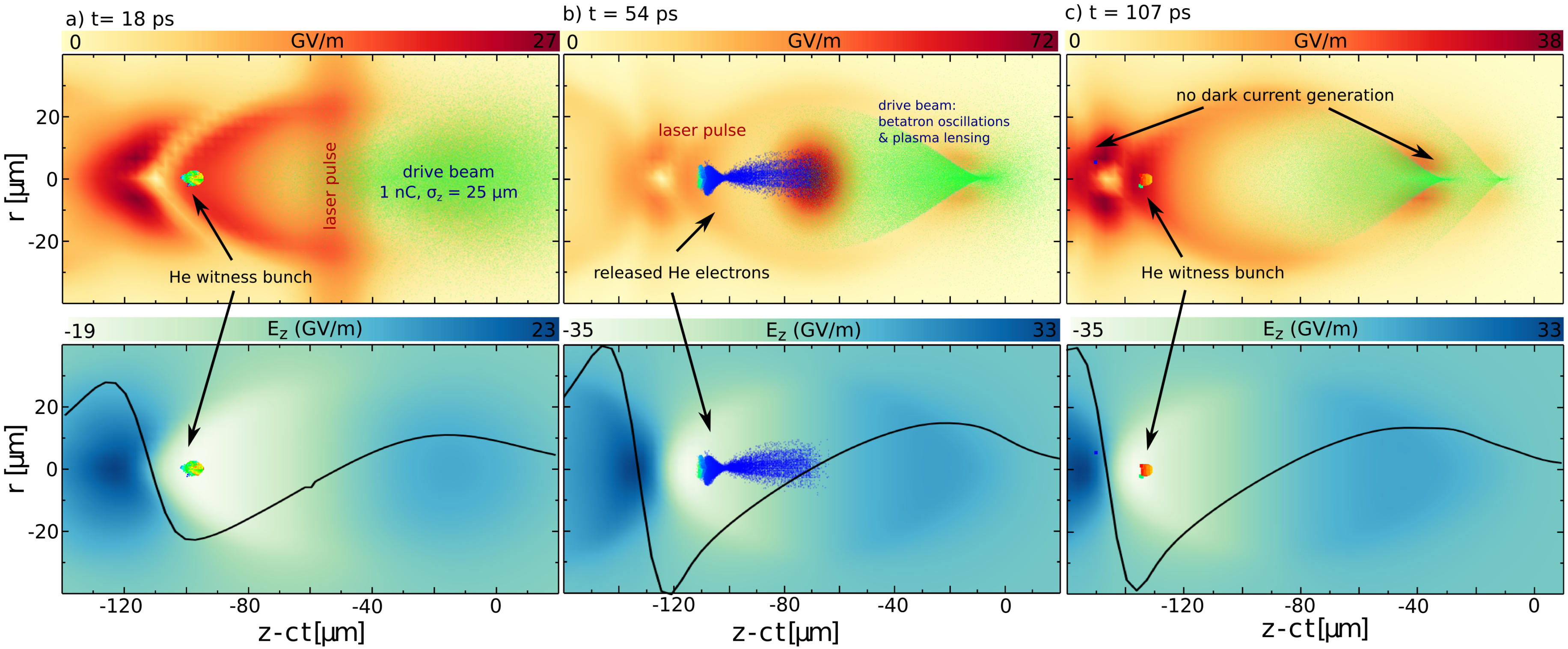
Dark Current Research



How to eliminate dark current?

- Reduce driver bunch peak current
- Lower gas pressure/density

Dark Current Free TH-PWFA



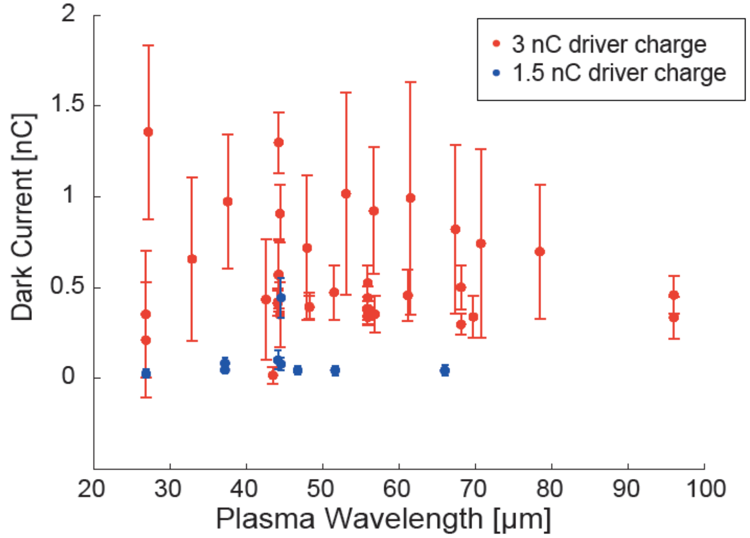
$$n_e = 1.1\times10^{17}\ \mathrm{cm}^{-3},\ \lambda_p = 100\ \mu\mathrm{m}$$ → **Match the plasma column width**

Reduce the drive bunch charge → $$Q = 1.1\ \mathrm{nC}$$

G.G. Manahan et al. submitted

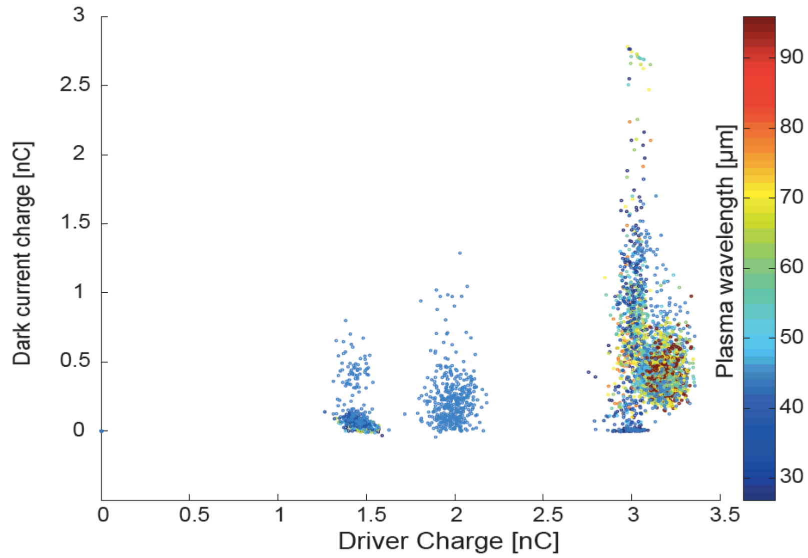
Dark Current Elimination

Dark current was suppressed successfully by reducing the driver bunch charge in the laser-ionized Hydrogen/Helium mixture plasma

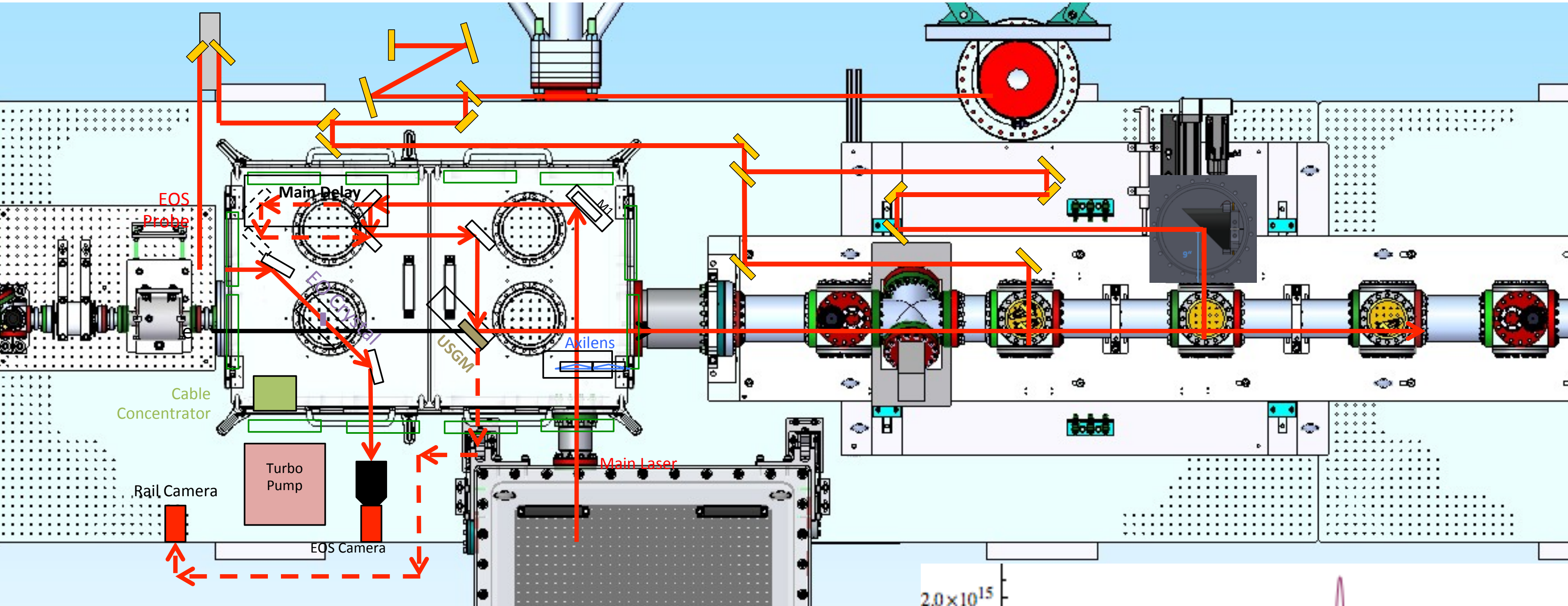


Plasma wavelength effect on dark current is ambiguous but promising;

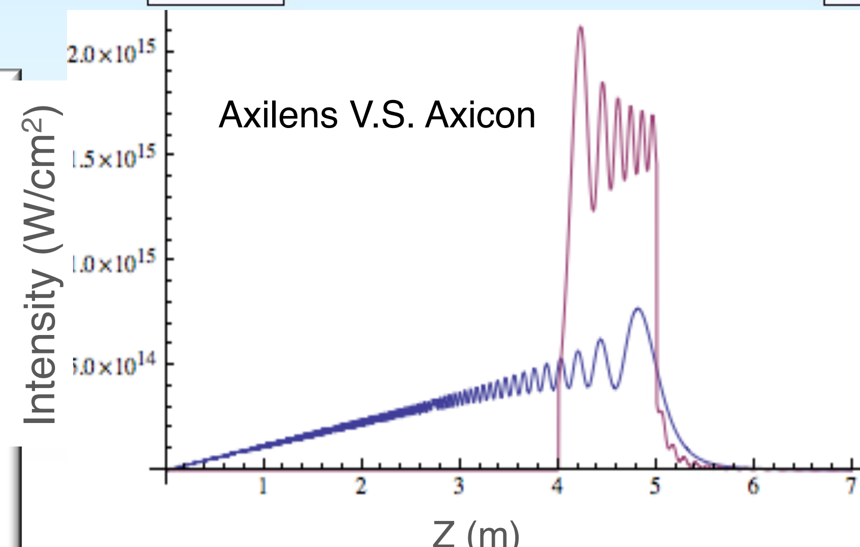
Also lower plasma density is benefit for the synchronization of injection laser and e-beam.



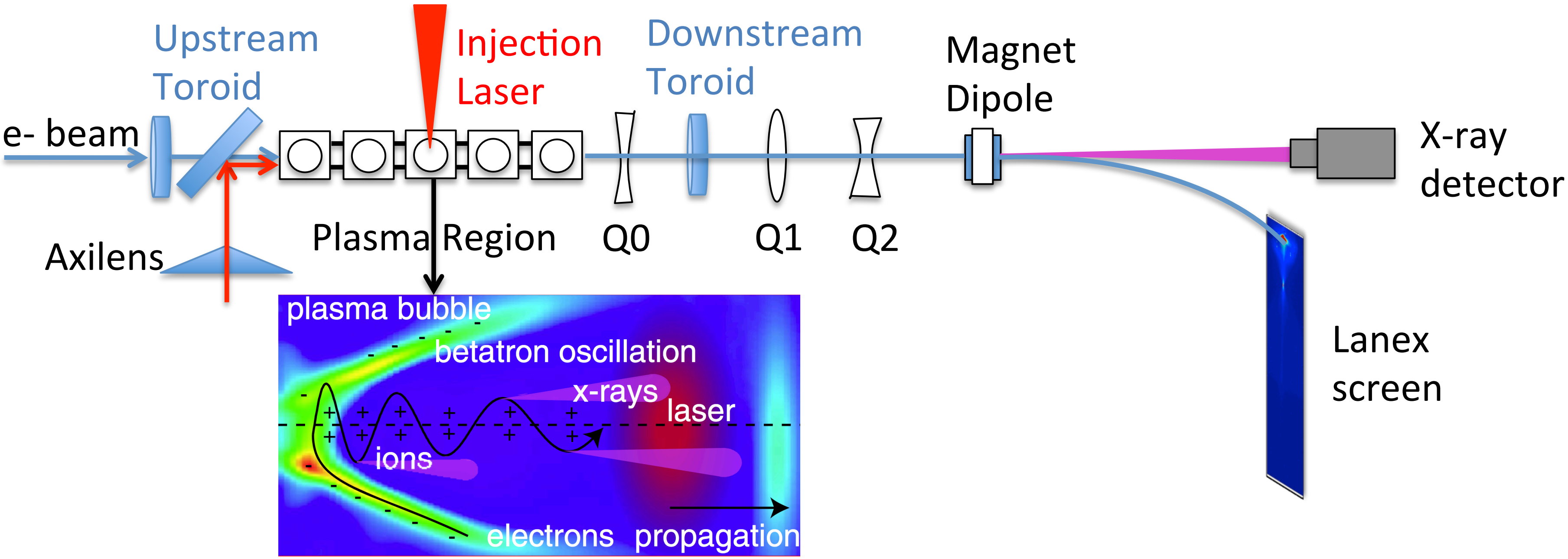
Improving E210 PWFA Setup



- Holographic Axilens is expected for a wider and stable plasma;
- OAP in vacuum will be used for injection;
- EOS systems are updated;
- Witness bunch diagnostic is being developed (phase space, bunch length etc.)



Witness Bunch Diagnostics



- Energy (E or γ) & energy spread($\Delta E/E$ or $\Delta\gamma/\gamma$)
- **Transverse Emittance (x, p_x ;y, p_y)**
- Charge Q
- Bunch length (τ)

Transverse Emittance Estimation

Rough estimation of laser contribution to normalized emittance:

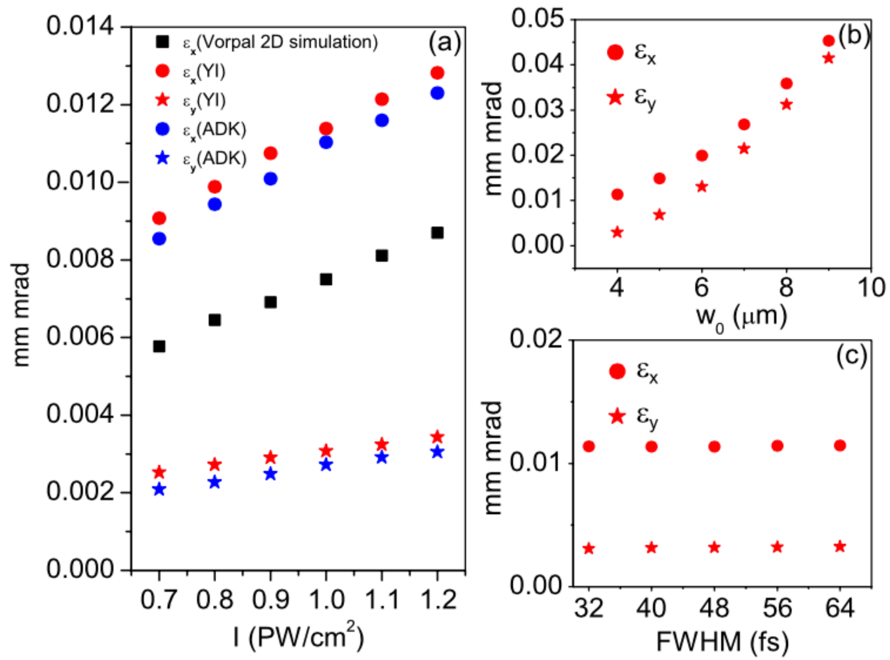
$$\varepsilon_n \approx \sigma_{rHIT}\sigma_{p_{r,HIT}}/(mc) \approx w_0 a_0/2^{3/2}$$

w_0: laser focus size
a_0 : laser potential

For He as HIT medium:

$a_0=0.03$, $w_0=15$ um

$\varepsilon_n \approx$ 0.16 um rad



Note:

* Barrier Suppression Ionization is an upper limit.

* Emittance in the non-laser-polarization plane could be smaller.

B. Hidding et al., PRL 108, 035001, 2012
Y. Xi et al., PRSTAB 16,031303, 2013

Transverse Emittance Measurement

On-axis Betatron radiation spectrum: $\frac{d^2 I}{dE d\Omega}\Big|_{\theta=0} \simeq N \frac{3e^2}{2\pi^3 \hbar c \varepsilon_0} \gamma^2 \left(\frac{E}{E_{\rm crit}}\right)^2 K_{2/3}^2\left(\frac{E}{E_{\rm crit}}\right)$

The critical energy of radiation:

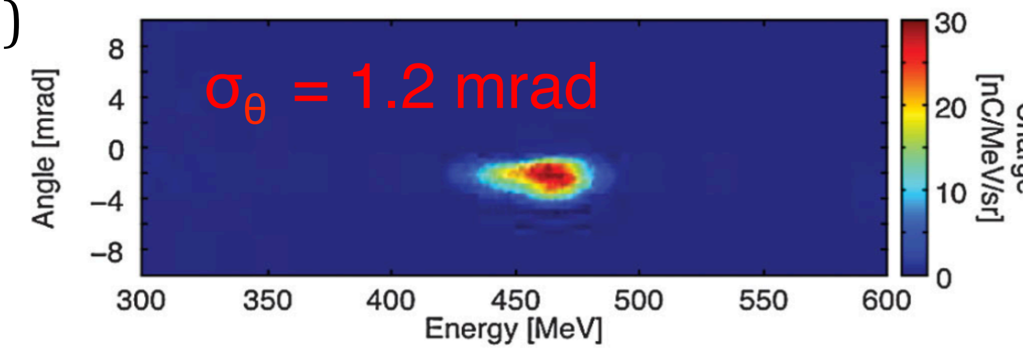
$$E_{crit}(keV) \simeq 5\times 10^{-24}\gamma^2 n_e(cm^{-3}) r_b(\mu m)$$

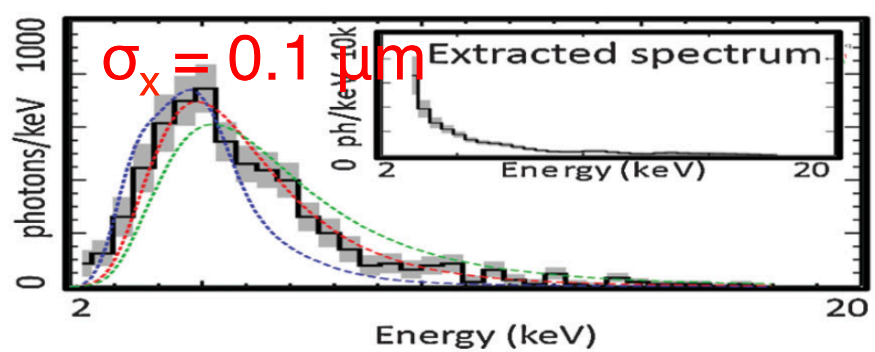
The betatron strength parameter:

$$K = 1.33\times 10^{-10}\sqrt{\gamma n_e(cm^{-3})} r_b(\mu m)$$

The normalized emittance ε_n:

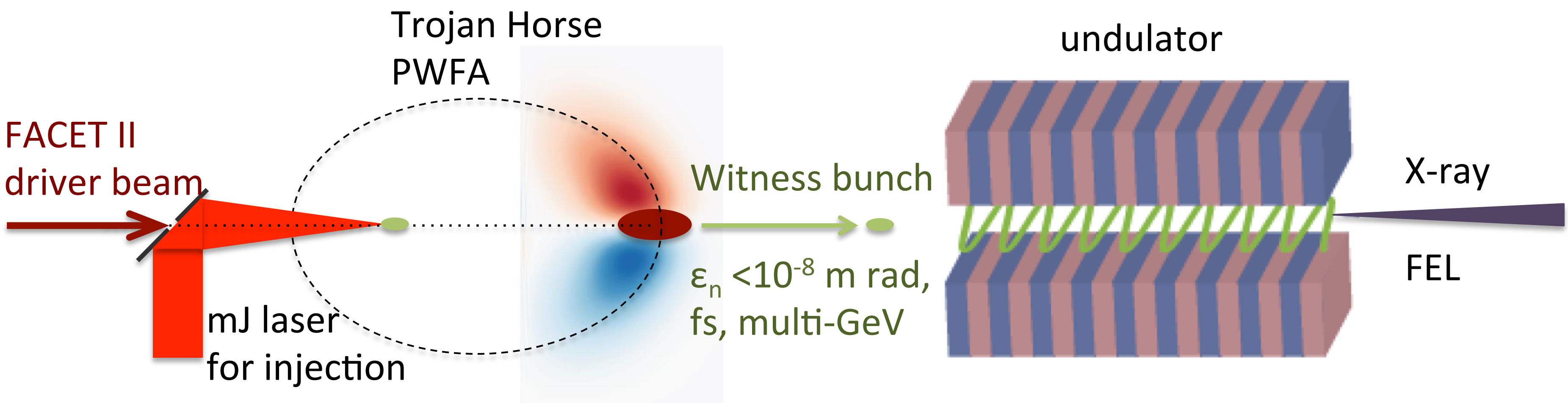
$\varepsilon_x \approx \gamma\ \sigma_\theta \sigma_x$ ≈ 0.1 um rad

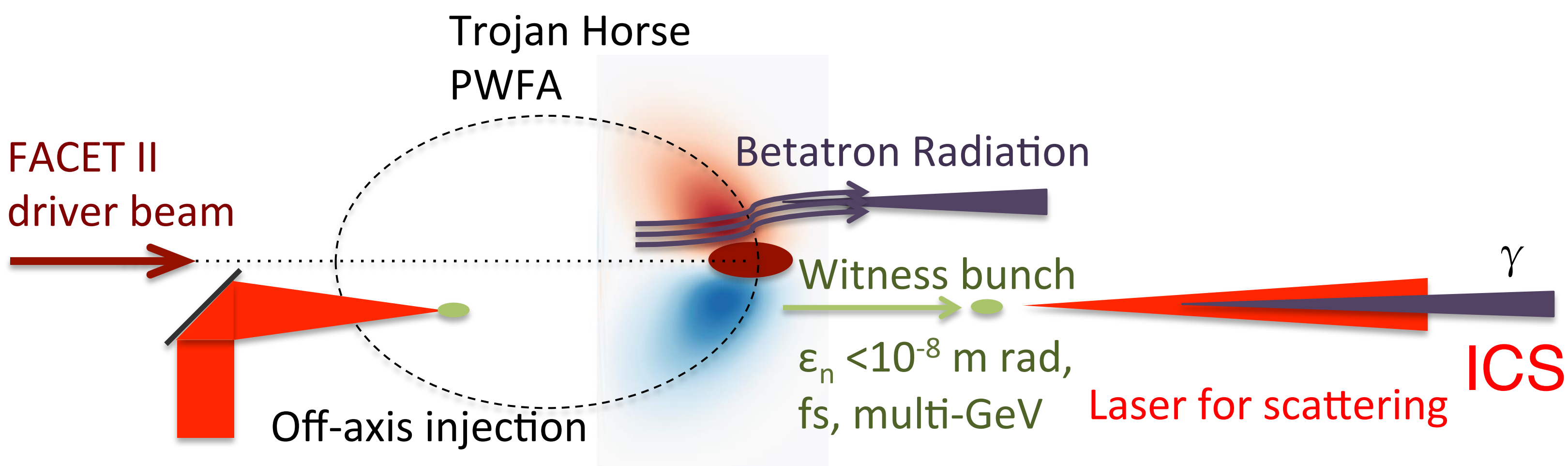




G. R. Plateau et al., PRL 109,064802 (2012)

Future scenarios and light source experiments



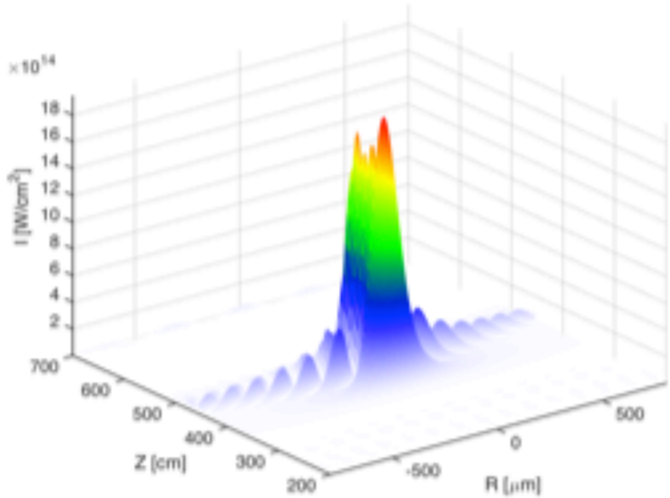


Summary and Conclusion

Challenges in Experiment

- Plasma source & profiles
- Dark current elimination
- Synchronization of laser and e-beam
- Witness bunch diagnostics (6-D phase space)
- Beam transportation and control for further applications
- …

1m Axilens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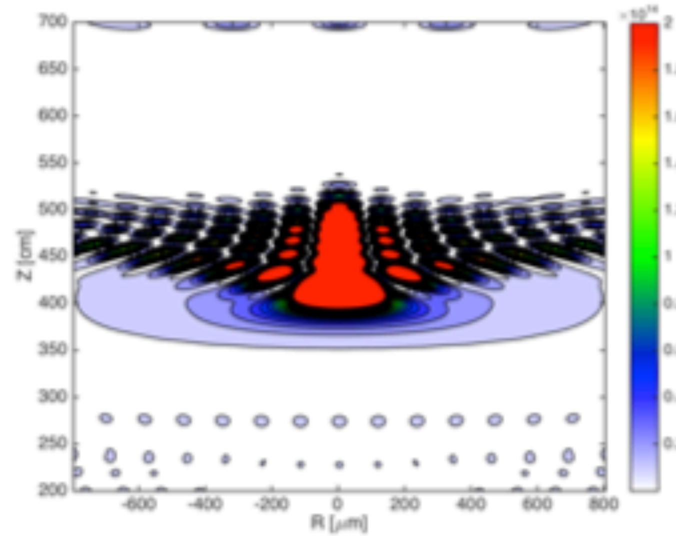
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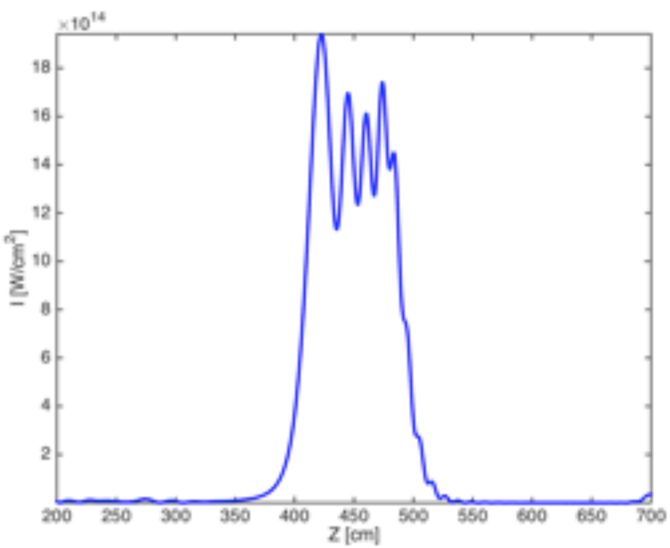
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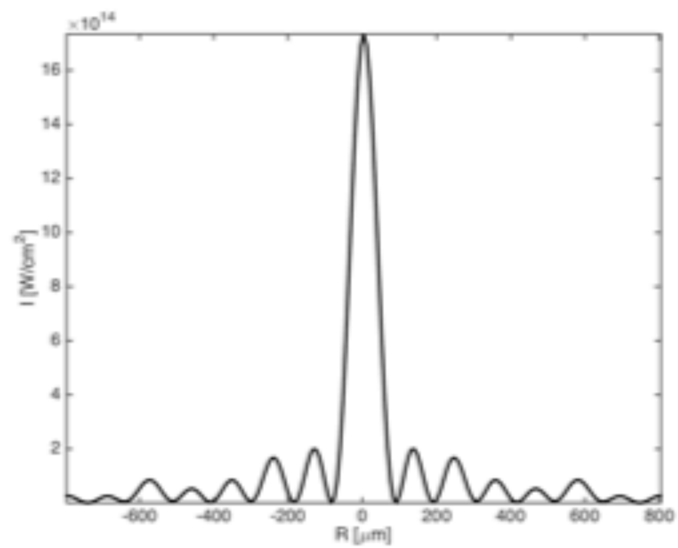
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