



3rd European Advanced Accelerator Concepts Workshop

24-30 September 2017, La Biodola, Isola d'Elba

Timing measurement of laser-accelerated electron beams

25 Sep. 2017

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8-1-7 Umemidai, Kizugawa, Kyoto, JAPAN

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Collaborators/Acknowledgment

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Acknowledgement

ImPACT (Cabinet office)

JSPS Core-to-Core Program on International Alliance
for Material Science in Extreme States with High Power
Laser and XFEL

Core-to-Core Program





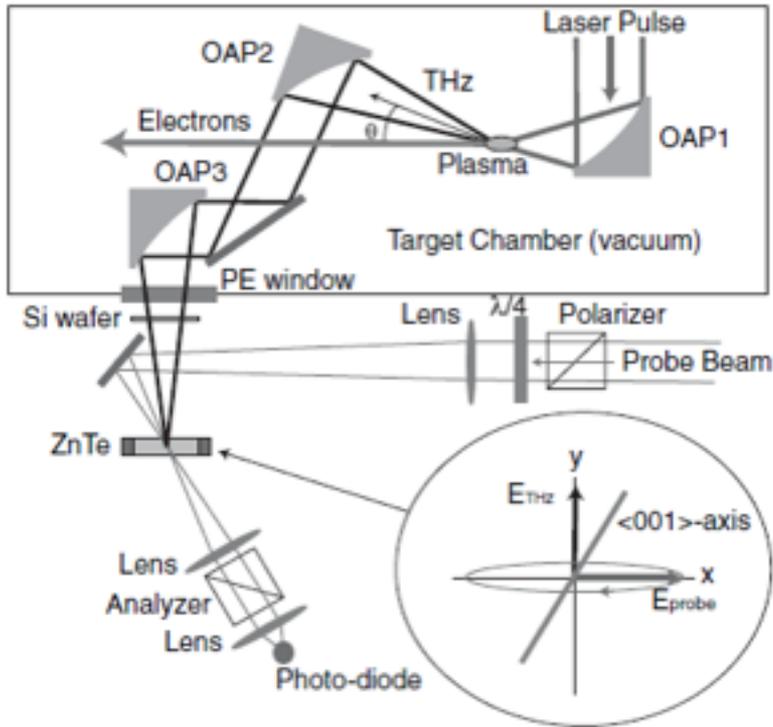
Why temporal diagnostics necessary

- **LWFA based X-ray free electron laser**
*high peak current for SASE ← high charge & **short duration***
- **Staging acceleration**
timing for beam match & short duration
- **Ultrafast pump-probe experiment using secondary sources**
resolution & jitter issues

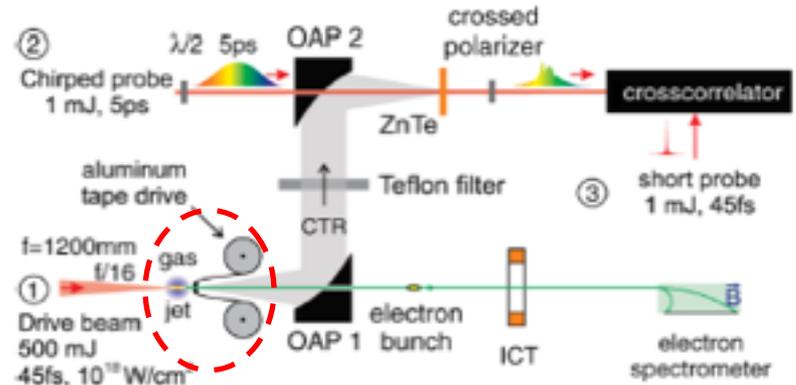
Single shot electron temporal *monitor* is necessary,
better to be **non-destructive**



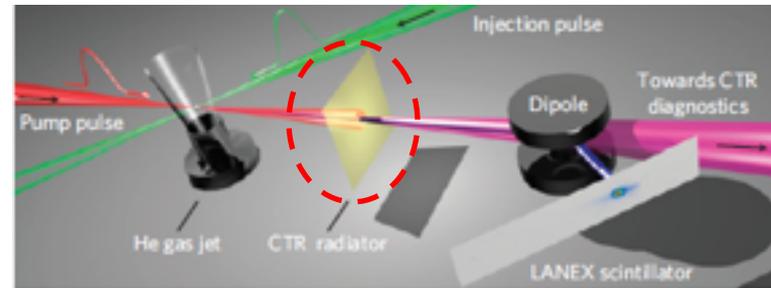
Existing electron pulse temporal diagnostics in LWFA



J. Van Tilborg et al PRL 2006 (LBNL)



A.D. Debus et al PRL 2010 (HZDR, Germany)



O. Lundh et al Nat Phys 2011 (LOA)

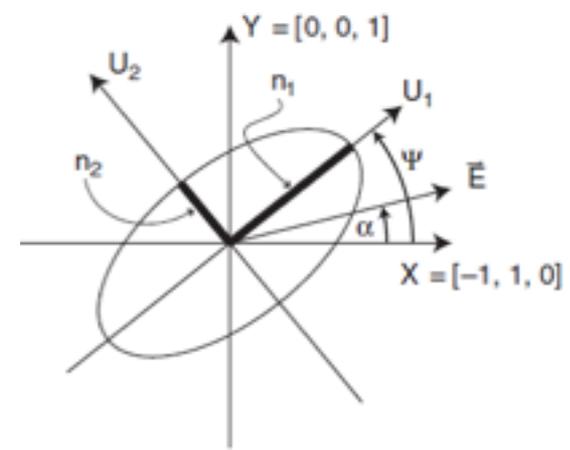
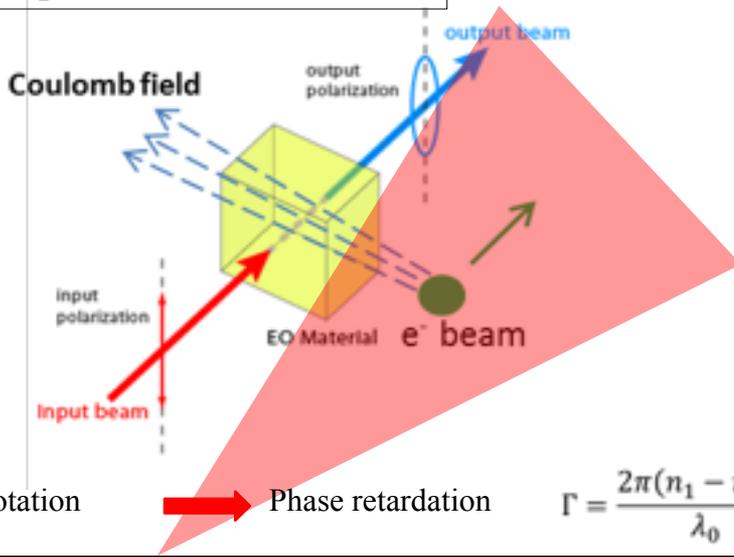
Electron pulse duration of 1.5 – 50 fs (rms) has been demonstrated

➤ *Single shot non-destructive diagnostics has NOT been reported yet*



Non-destructive real time EO crystal diagnostics

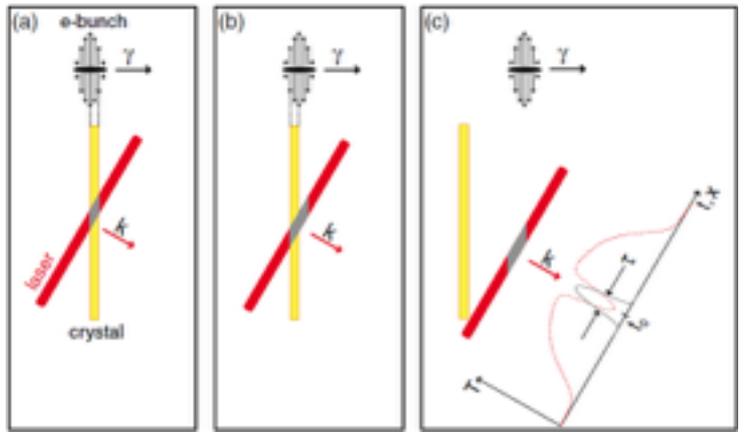
Detection principle: Pockels effect



$$\Gamma = \frac{2\pi(n_1 - n_2)d}{\lambda_0} = \frac{2\pi n_0^3 d}{\lambda_0} r_{41} E \xrightarrow{\text{Cross polarizer}} \sin^2(\Gamma/2)$$

Obliquely incidence regime (EO spatial encoding)

S. Casalbuoni et al PRSTAB 11, 072802 (2008)
A. L. Cavalieri et al PRL 94, 114801 (2005)

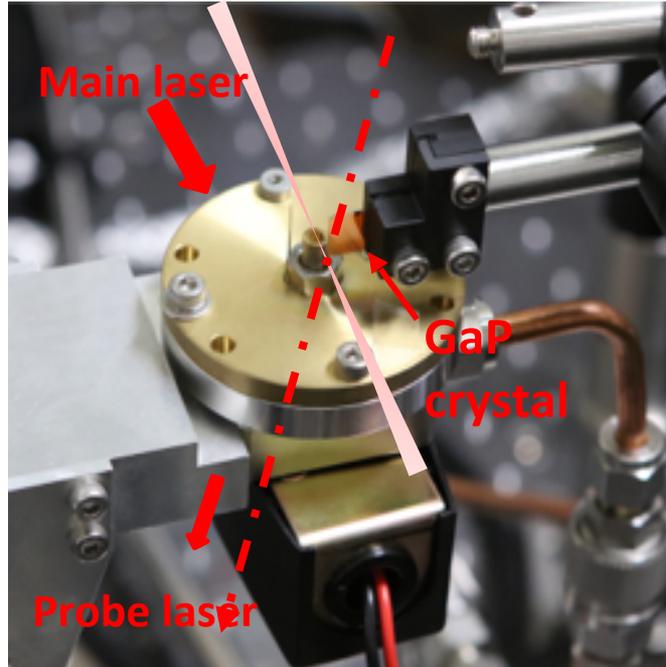


clocking relationship:

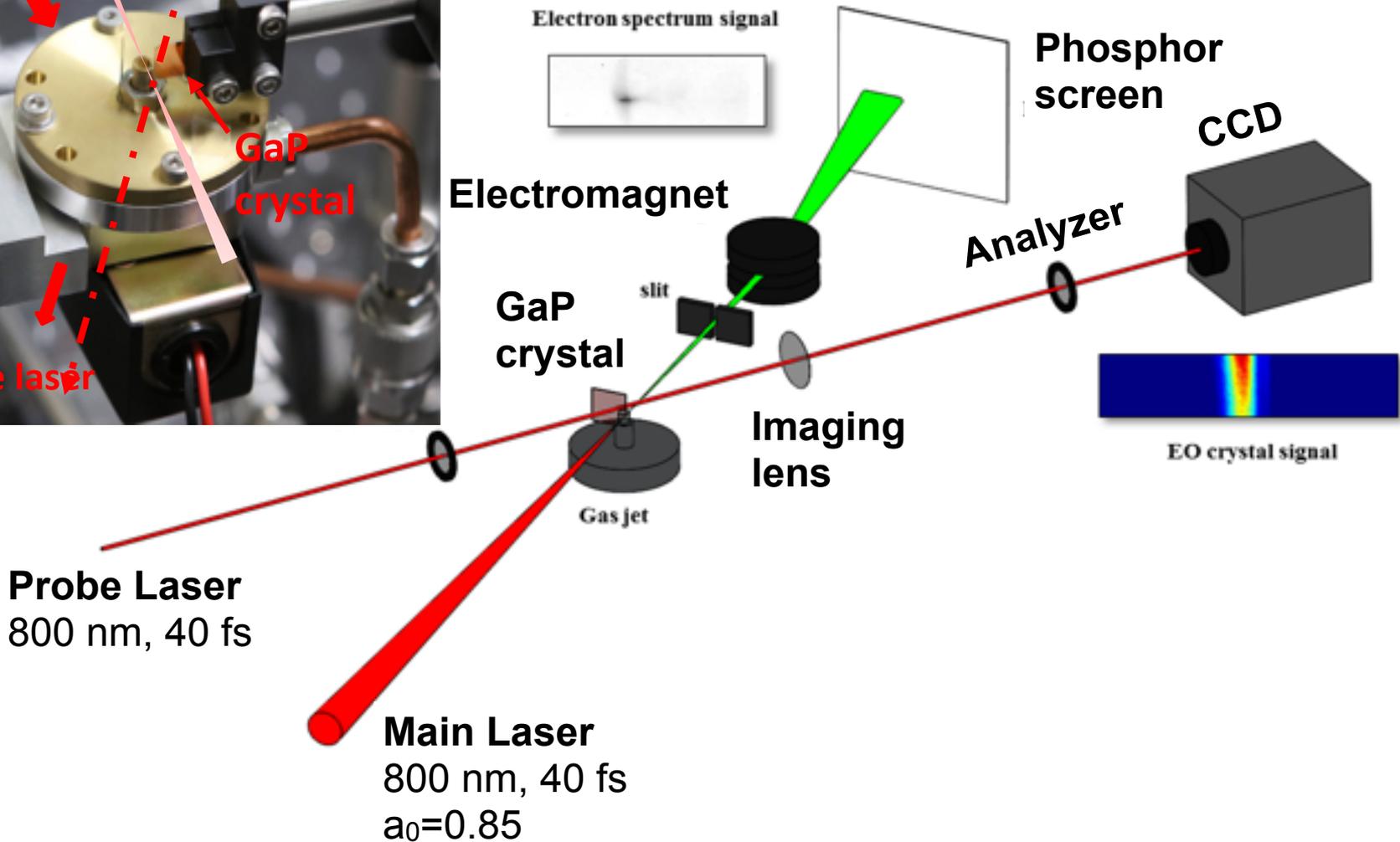
$$\Delta\tau = \Delta x \tan\theta / c$$

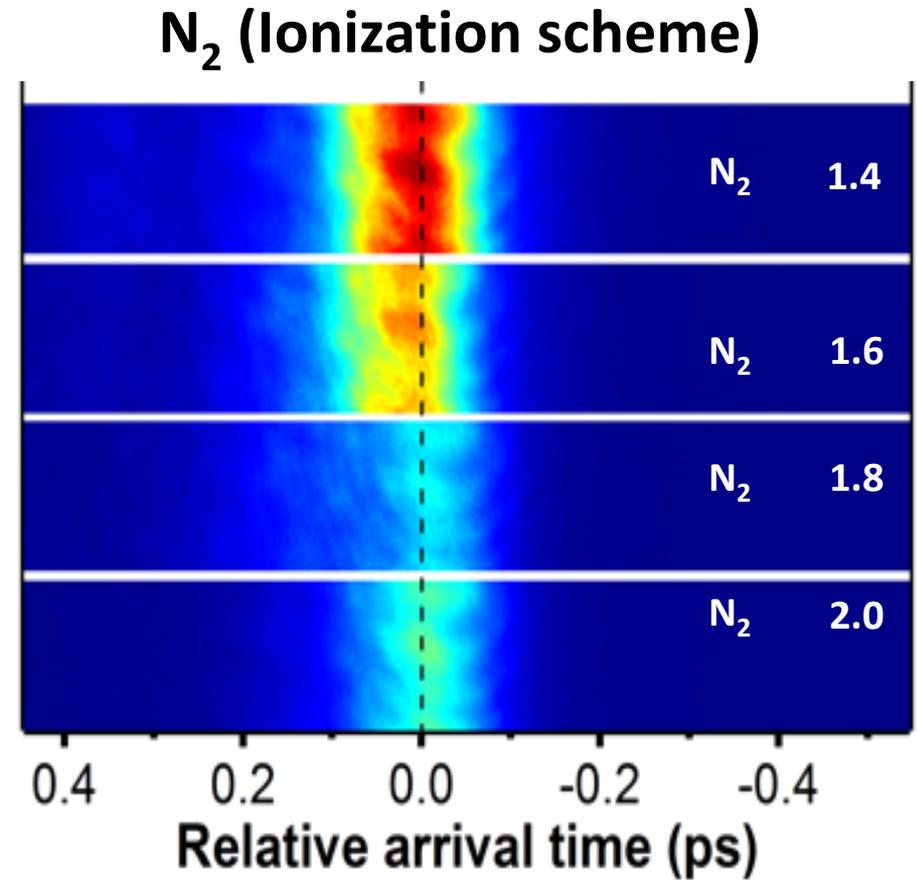
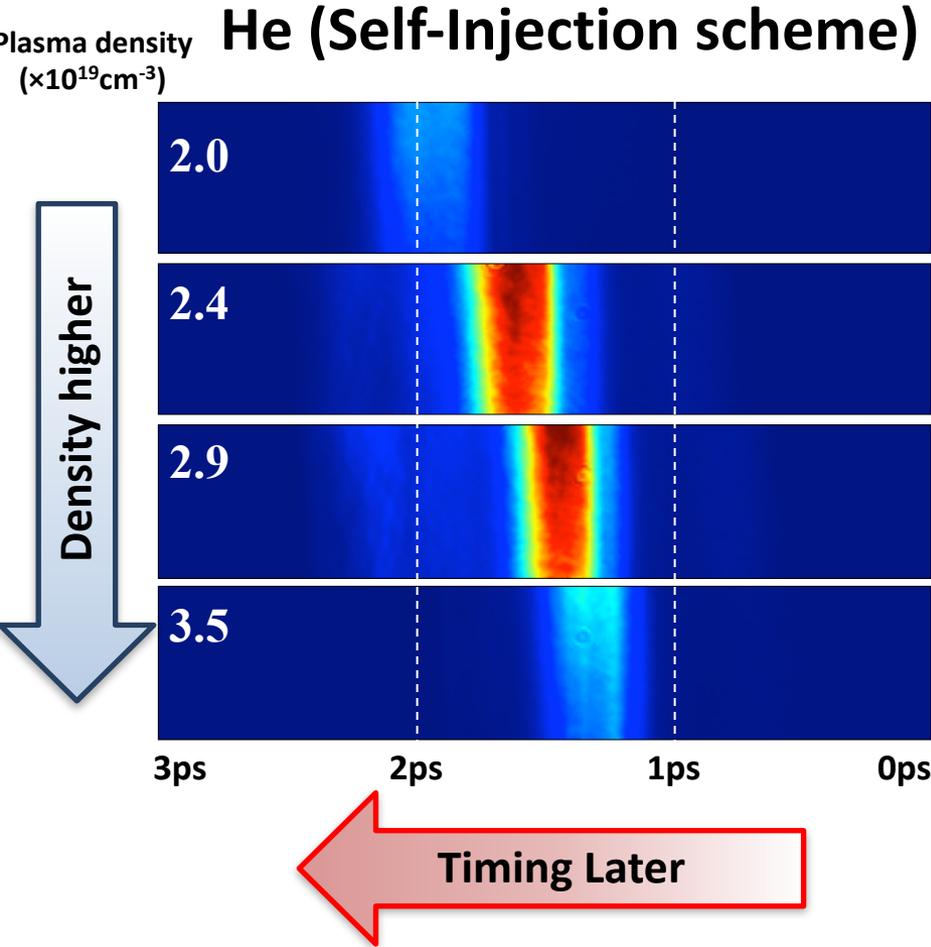
No such detection has been performed in LWFA

We applied this method in LWFA



JLITE-X 10TW laser system @KPSI QST





Propagation time difference between **50 MeV** and **10 MeV** after 2mm propagation is merely **8 fs**

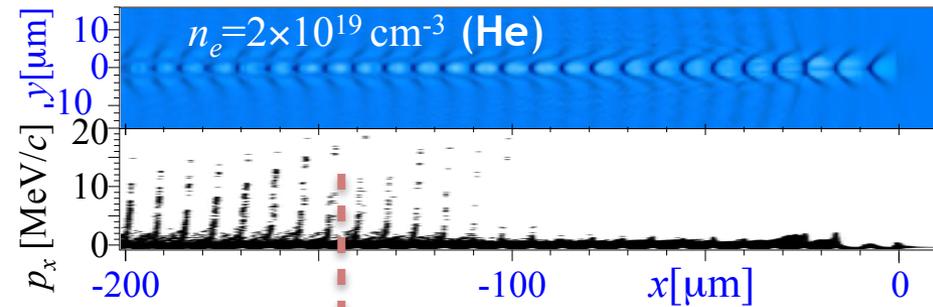
Different injection position



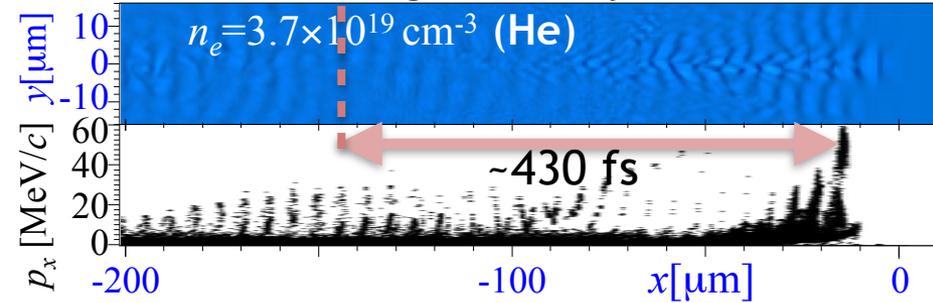
Discussion

- What is the source of observed anomalous injection timing delay (~ 1 ps) ?

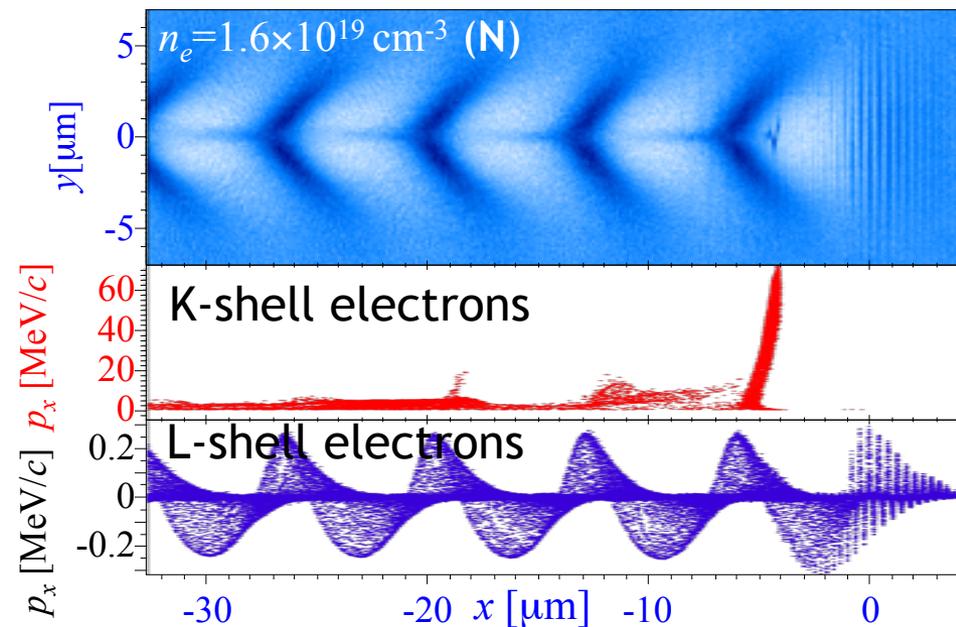
He, low density case:



He, high density case:



N_2 case:



Qualitatively the later injection is confirmed but still the observed delay looks too much.



Summary

Achieved:

- EO spatial encoding in LWFA: Non-destructive measurement on the electron beam temporal profiles
- Observation of electron beam **timing and jitter variation** dependence on plasma density in **self-injection scheme** of LWFA
Smaller variation and jitter for **ionization injection** scheme.
- Feasibility to estimate the electron bunch duration in a single shot.

Future plan:

- Further investigation of anomalous injection timing delay
- Possibility of reconstruction of original electron longitudinal information by introducing balanced detection;
- Construction of real time 3D monitor for the electron beam.