# Electron acceleration in merging laser wakefields

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# Outline

#### X-ray generation and imaging applications

#### Acceleration and X-rays by intersecting wakefields



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### Ionization injection



Pak et al, Phys Rev Lett 104, 025003 (2010)



Hansson et al, Plasma Phys Control Fusion 58, 055009 (2016)

#### Betatron X-ray source



**Betatron frequency** 

$$\omega_{\beta} = \frac{\omega_p}{\sqrt{2\gamma}}$$

#### **Betatron wavelength**

$$\lambda_\beta \approx \lambda_p \sqrt{2\gamma}$$

Critical energy  $E_c = \frac{3}{2} \hbar \gamma^3 \omega_\beta^2 r_\beta / c$ 

Divergence

$$\Theta \approx \omega_{\beta} r_{\beta} / c$$

S Corde *et al*, Rev Mod Phys **85**, 1 (2013)

### X-ray polarization

Stable, elliptical X-ray beams with ionization injection



-> X-rays are preferentially polarized along laser polarization



A Döpp et al, Light: Science and Application 6, e17086 (2017)

#### X-ray spectrum



Critical energy: 2-3 keV Peak flux: 1-2 • 10<sup>11</sup> ph/sr Divergence: 30 × 40 mrad ~4 • 10<sup>8</sup> photons in FWHM



K Svendsen et al, Optics Express 26, 33930 (2018)

#### X-ray source size

#### 25 µm tungsten wires



2.8

K Svendsen et al, Optics Express 26, 33930 (2018)

#### Phase-contrast tomography



Single-shot phase-contrast image ~3 µm structures can be resolved

~10  $\mu$ m structures can be resolved in tomogram

Kristoffer Svendsen

100 µm

100 µm

K Svendsen et al, Optics Express 26, 33930 (2018)

# Fuel injection sprays

Understanding the breakup and atomization of fuel sprays is essential for improving engine efficiencies.

ChallengesFast dynamics (ns to μs)Highly scattering mediaMultiple jets in the same spray

ApproachX-ray imaging (for mass flow)2-photon light sheet LIF (for atomization)





Diego Guenot

#### Simultaneous flourescence and X-ray imaging



D Guenot et al, submitted

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# Multi-beam laser wakefield acceleration



### **Braided Light**

Mutual attraction of laser beams in a plasmas because of a mutual coupling from relativistic mass corrections



#### C. Ren et al., Phys. Rev. Lett. 10, 2124 (2000)

### Intersecting wakefields



*"Radiation emission from braided electrons in interacting wakefields"* E Wallin, A Gonoskov, M Marklund, Phys Plasmas **24**, 093101 (2017)

 See also
 M. Wen et al., Phys. Plasmas 17, 103113 (2010)

 L. Yang et al., Phys. Plasmas 20, 033102 (2013)

 J. Elle et al., New J Phys 20 093021 (2018)

#### Intersecting wakefields



#### **3D PIC simulations with ELMIS**

Laser: 1 J, 20 fs, 8  $\mu$ m spot,  $a_0$  = 5.6 Plasma:  $n_e$  = 9.5×10<sup>18</sup> cm<sup>-3</sup>

E Wallin, A Gonoskov, M Marklund, Phys Plasmas 24, 093101 (2017)

#### **Braided electrons**

# Small angles (few degrees): Braided electrons and higher radiated energy



#### E Wallin, A Gonoskov, M Marklund, Phys Plasmas 24, 093101 (2017)

#### VEGA Laser System at CLPU



www.clpu.es

ggatti@clpu.es



#### **Experimental arrangement**



## One laser beam at the time

#### Dispersed electron beams of 5 consecutive shots for each half-beam

Left half-beam

**Right half-beam** 



Energy [MeV]



#### Two laser beams





### **Collision position**

#### **Thomson scattering**



#### **Dispersed electrons**



Energy [MeV]

#### Short delay



# X-ray yield



When merged electron beams are produced, approx. x3 enhancement in the forward direction of the X-ray camera

# Interference, phase and stability



*Fluctuations in the relative phase* (e.g. by vibrations or plasma dispersion) -> impacts location of nodes in the standing wave *Solution*: crossed polarisation

## **Outlook:** Rephasing



#### **Outlook: Positron acceleration**



J Vieira et al, Phys Rev Lett 112, 215001 (2014)

#### Acknowledgment



WG1, Thursday 18:20 "Generation of a spectrally two-component electron beam in a laser-wakefield accelerator" Jonas Björklund Svensson

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	CFA: X Davoine	ELI-Beamlines/HZDR: K Falk, M, Schmid
	LPGP: B Cros et al.	MAX IV: S Thorin, E Mansten, F Curbis, S Werin et al.
	<b>CLPU:</b> G Gatti <i>et al.</i>	Chalmers: M Marklund, T Fulöp et al.
		<b>Umeå Univ:</b> L Veisz <i>et al.</i>

# Summary

#### **Betatron X-rays and imaging applications**

- ✓ Well suited for high-resolution micro-tomography
- ✓ Time-resolved studies of injection spray breakup and atomization

#### Acceleration and X-rays from intersecting wakefields

- ✓ Multi-e-beam generation with separated laser beams
- ✓ Synchronized and overlapped lasers give single electron beam along the bisector angle
- ✓ Suggests electron braiding in a common accelerating structure





