PhD Open Days

Cherenkov Radiation from Superluminal Plasma Quasi-particles

Technological Physics Engineering

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Attosecond Sources

- **Electrons move on attosecond timescales** (1 as = 10^{-18} s). That motion governs photoionisation, charge migration and electron transport in atoms, molecules, solids and plasmas [1].
- **Attosecond pulses let us watch and control it.** They are used for:
  - time-resolved spectroscopy [2]
  - strong-field and plasma interactions [3, 4]
  - future petahertz electronics [5]
- Sources of attosecond pulses:
  - **High Harmonic Generation** – conversion efficiency is low, limited by phase matching
  - **Free Electron Lasers** – brightest sources but expensive
- **Malaca et al. [6]** have shown through simulations that **superluminal plasma quasi-particles** can be used as FEL-like bright sources of attosecond pulses

Plasma Quasi-particles

- The **electron density peak** at the rear of a non-linear bubble is shape invariant (approximately) – regarded as a **plasma quasi-particle**
- Plasma quasi-particles achieve **superluminal velocities** in **tailored gas density** profiles
- Radiate coherently at a preferred angle: $\theta_C \cong \arccos(c/v_{QP})$
- The cone is "sharper" if the quasi-particle velocity is constant

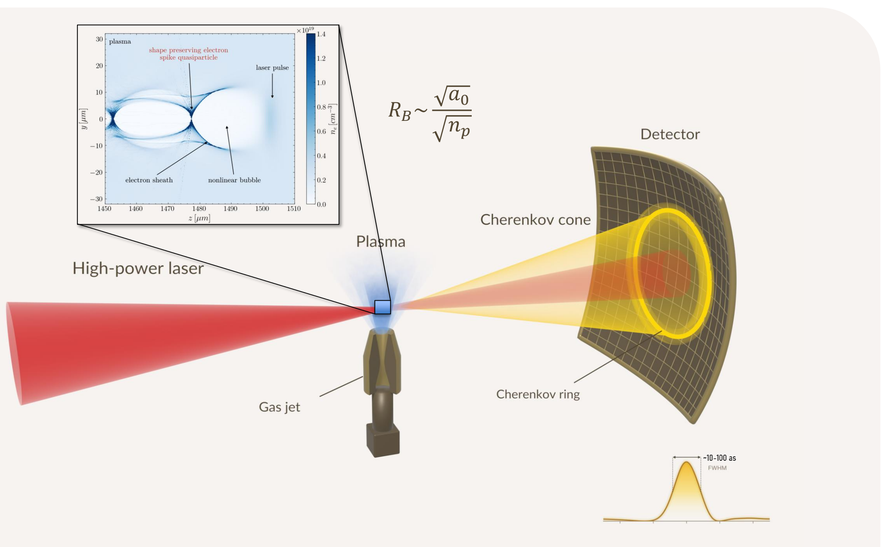


Figure 1: Laser-driven plasma quasi-particle radiation source concept schematic.

Optimizing Laser and Jet Parameters

- **Goal:** optimize laser and gas density profile parameters to achieve constant velocity quasi-particle propagation, in experimentally achievable ranges (CoReLS, South Korea)
- **Laser Parameters**: wavelength, energy, pulse durations, spotsize, focus position
- **Plasma Parameters**: initial density, up-ramp slope (controlled by CFD simulations)
- Balance between laser intensity and plasma density required to achieve **stable velocity**
- Shown that for a given focusing geometry (spotsize)
  - Laser energy ("coarse knob")
  - Laser focus position ("fine knob")

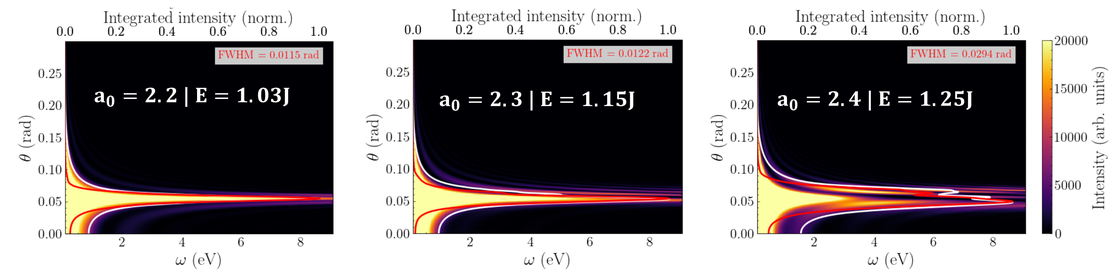


Figure 2: Cherenkov spectra for different laser energies

Jet Tilt Angle to Tune Cherenkov Angle

- Laser parameters fixed
- Gas jet backing pressure fixed at 2.6 bar
- Rotating the gas jet allows probing different longitudinal density profiles (gradient and baseline density)
- Simulations showed that the Cherenkov angle can be varied by 35 mrad for experimentally achievable tilt angles

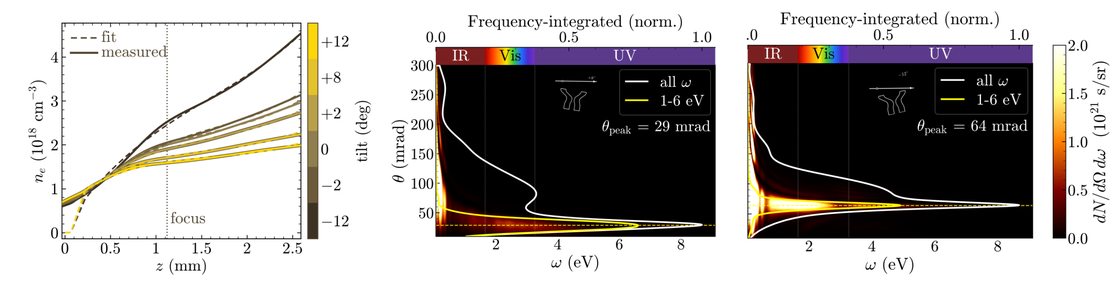


Figure 4: a) Longitudinal density profiles for different tilt angles. b) and c) Cherenkov spectra for two different gas jet tilt angles (+8° and -12°)

Conclusions & Future Work

- For a given focusing geometry (focal distance and focal spotsize) the laser energy can be varied to optimize the quasi-particle trajectory (aim at constant velocity)
- The gas jet tilt angle can be used to tune the Cherenkov angle (a single experimental parameter allows to test a signature of this radiation mechanism
- Next Steps: experimental setup design

Acknowledgments

- Supported by FCT – Fundação para a Ciência e Tecnologia, I.P. through project UID/50010/2025- Instituto de Plasmas e Fusão Nuclear
- Supported by FCT – Fundação para a Ciência e Tecnologia, I.P. through projects 2024.07091.CPCA and 2026.01836.BD

References

[1] M. Hentschel, et al., Attosecond metrology, Nature 414, p509 (2001) DOI: https://doi.org/10.1038/35107000
[2] M. Schultze, et al., Delay in Photoemission, Science 328, p1658 (2010) DOI: https://doi.org/10.1126/science.1189401
[3] F. Krausz et al, Attosecond Physics, Review of Modern Physics 81, p163 (2009), DOI: https://doi.org/10.1103/RevModPhys.81.163
[4] A. Sävert, et al., Direct Observation of the Injection Dynamics of a Laser Wakefield Accelerator Using Few-Femtosecond Shadowgraphy, Physical Review Letters 115, p055002 (2015)DOI: https://doi.org/10.1103/PhysRevLett.115.055002
[5] A. Schiffrin, et al., Optical-field-induced current in dielectrics, Nature 493, p70 (2013)DOI: https://doi.org/10.1038/nature11567
[6] B. Malaca, et al., Coherence and superradiance from a plasma-based quasiparticle accelerator,Nature Photonics 18, p39 (2024) DOI: https://doi.org/10.1038/s41566-023-01311-z

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