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TWAC : EIC PATHFINDER OPEN EUROPEAN PROJECT ON NOVEL DIELECTRIC ACCELERATION *

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Abstract

Particle accelerators are devices of primary importance in a large range of applications such as fundamental particle physics, nuclear physics, light sources, imaging, neutron sources, and transmutation of nuclear waste. They are also used every day for cargo inspection, medical diagnostics, and radiotherapy worldwide. Electron is the easiest particle to produce and manipulate, resulting in unequaled energy over cost ratio.

However, there is an urgent and growing need to reduce the footprint of accelerators in order to lower their cost and environmental impact, from the future high-energy colliders to the portable relativistic electron source for industrial and societal applications. The radical new vision we propose will revolutionize the use of accelerators in terms of footprint, beam time delivery, and electron beam properties (stability, reproducibility, monochromaticity, femtosecond-scale bunch duration), which is today only a dream for a wide range of users. We propose developing a new structure sustaining the accelerating wave pushing up the particle energy, which will enable democratizing the access to femtosecond-scale electron bunch for ultrafast phenomena studies.

This light and compact accelerator, for which we propose breaking through the current technological barriers, will open the way toward compact accelerators with an energy gain gradient of more than 100 MeV/m and enlarge time access in the medical environment (preclinical and clinical phase studies).

INTRODUCTION

The European project TWAC (Terahertz Wave Accelerating Cavity) [1] aims to build a prototype accelerator with a radically new approach to overcome several limits of the currently existing accelerator technologies in order to achieve unprecedented electron beam parameters: a very short bunch duration (femtosecond-scale) and a high number of particles per bunch in a small bandwidth (very low energy spread), thanks to a compact, light and safer machine. The technologies developed by TWAC could tackle some of the greatest challenges faced by accelerator users, both for research, medical and industrial environments, pushing compactness while keeping a high quality electron beam. For those purposes, TWAC relies on a synergy between several European research institutes and companies, with expertise in the fields of accelerator physics, electron beam diagnostics, optics and laser physics.

The TWAC project is funded by the EIC Pathfinder Open 2021 of the Horizon Europe program [2] for a duration of 4 years and started in April 2022. This program supports projects that are aimed at exploring innovative and risky ideas, likely to lead to the development of new technologies and, ultimately, disruptive innovations. The success rate for obtaining an EIC is 6.45% for the year 2021. France has 36 laureates: 6 in coordination and 30 as partners. The TWAC project is therefore one of the 6 French projects in coordination. It is also the first EIC project within the Institut National de Physique Nucléaire et de Physique des Particules of the CNRS, as well as in accelerator physics.

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DEMONSTRATING A COMPACT HYBRID ACCELERATOR FOR APPLICATIONS

The TWAC project intends to develop a prototype accelerator opening the way towards a compact (meter-scale), low-energy (≈ 10 MeV) and high peak current (≈ 1 kA) industrial electron accelerator, with an electron bunch duration at the femtosecond scale. This type of accelerator would democratize access to femtosecond-scale high peak current electron bunches, currently only available at large-scale research facilities (see Fig. 1). It is therefore highly sought after in various fields, e. g. in research for ultrafast phenomena studies, in medical applications (radiotherapy), and in industrial applications (material inspection and characterization).

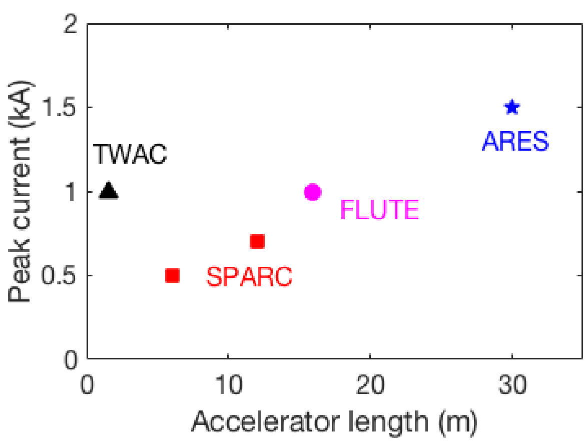

Figure 1: Compact European conventional radio-frequency electron accelerators in the parameter space peak current vs. accelerator length [3–6].

TWAC plans to simplify the infrastructure of an accelerator by substituting the well-known RF (Radio-frequency) sources powering the accelerating structures for optical-based terahertz sources (Fig. 2). A compact cm-long and mm-wide waveguide named ZITA (ZITA Is The Accelerator), driven by intense terahertz pulses, will sustain the high peak electromagnetic field needed for satisfying a meter-scale layout and an energy gain gradient of more than 100 MeV/m. TWAC will offer femtosecond-scale electron bunches with well-characterized properties and excellent repeatability (Tab. 1).

Table 1: Summary of the performance and input parameters of terahertz-driven acceleration experiments.

	Charge (pC)	Net energy gain (MeV)
THz Linac [7, 8]	0.020-0.025	0.007-0.030
CLARA [9]	1	0.009
Shanghai [10]	0.010	0.225
TWAC	**40-100**	**1.2-10**

A SYNERGISTIC EUROPEAN PROJECT

The TWAC project, coordinated by the CNRS (France), is mainly experimental and is based on a multidisciplinary environments that relies on a strong synergy between several European research institutes and companies, having expertise in the several fields required to be combined to achieve its ambitious goal: accelerator physics, high-power lasers, non-linear optics, and electron beam diagnostics.

Accelerator Physics

The prototype accelerator will be hosted at IJCLab (France), which is leading the development of the ZITA accelerating structure and the commissioning of the prototype. IJCLab has expertise in the design and manufacturing of waveguides for accelerators, in the operation of femtosecond electron sources (several accelerator facilities on-site) and high power lasers (LASERIX facility) [11, 12].

The ARES linear electron accelerator [13, 14] at DESY, a worldwide specialist in large-scale RF electron accelerators, will provide a unique and ideal benchmark platform for the development of advanced electron diagnostics.

The PhLAM laboratory [15, 16] has a long experience in optics and accelerator collaborations with laser/electrons interaction experiments on synchrotron lightsources and on laser-plasma accelerators.

THz Source

High-power THz generation is an essential part of the project. Pécs University [17] is both a pioneer and an expert in this discipline worldwide. They invented the well-known tilted-pulse front excitation scheme, and its enhancement will be used to create the extreme acceleration gradient (100 MeV/m). Besides this expertise, they also have a complete infrastructure for the characterization of extremely high-energy THz pulses.

Ultrafast Diagnostics

The femtosecond-scale bunch duration requires ultra-fast diagnostics with high resolution that fit the compactness of the prototype. Different strategies are considered such as self-reference technique and/or optical-based diagnostics. DESY will here come into play with the ARES infrastructure and the available expensive and heavy diagnostics such as X-band transverse deflecting cavity for diagnostics benchmarking. PhLAM will bring its expertise on the development of ultrafast single-shot optically-based THz and electron diagnostics [18].

Applications

The industrial partners iTEOX (France) and RadiaBeam Europe (Switzerland) will conduct investigations on the industrialization potential of the prototype accelerator developed within TWAC. CSiC [19] will be a new partner to carry out the dosimetry detectors at ultra-high dose rates, with a view to medical applications such as FLASH radiotherapy [20].

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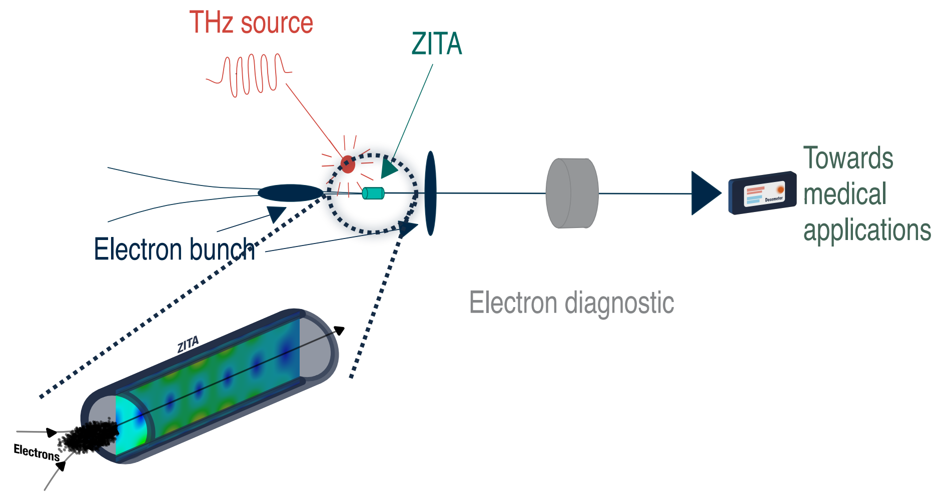

Figure 2: Schematic representation of the TWAC experiment

Recent progress in radiotherapy shows that the total dose delivered in cancer treatment is not the only parameter to take into account. Indeed, a high peak dose rate (the dose with the electron beam duration) triggers the FLASH effect, which reduces toxicity for healthy tissues. For the ultrashort electron bunches intended in TWAC, the peak dose rate is very high (even the total dose is compatible with cancer treatment), and has never been measured until now with dosimeters [21], because of the lack of commercial accelerators able to generate ultra-fast electron bunches. But, to date, the only way to have more compact accelerators is to increase the frequency of the accelerating wave, naturally leading to much shorter electron bunches than those currently used in medical installations, and then ultra-high dose rates. The first step for radiotherapy in the TWAC project is to develop accurate dosimetry devices to measure a dose rate delivery many orders of magnitude higher than on conventional radiotherapy equipment. Moreover, the radio-biological mechanisms governing FLASH irradiation [22–24] at such high dose rates as the ones expected with TWAC are unknown. Thus, such a compact accelerator can strongly ease access for pre-clinical studies to discriminate the optimal conditions of application for FLASH radio-therapy in this never explored range of dose rates. It will confirm that such accelerators based on short bunches are convenient for clinical studies.

CONCLUSION

TWAC will offer a technological breakthrough for electron acceleration and for all its applications from research accelerators to medial applications and customer products. The objectives of the TWAC project are: **(i)** the generation of high intensity THz pulses **(ii)** to drive the ZITA in order **(iii)** to reach the target energy and peak current, over a short distance.

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REFERENCES

[1] TWAC, `https://twac.ijclab.in2p3.fr/en/twac/`

[2] EIC, `https://eic.ec.europa.eu/index_en`

[3] J. Zhu *et al.*, Nucl. Instr. Meth. **A 909**, *Proceedings EEAC 2017*, 467-470 (2018).

[4] M. J. Nasse *et al.*, “Status of the Accelerator Physics Test Facility FLUTE”, in *Proc. IPAC’15*, Richmond, VA, USA, May 2015, pp. 1506–1508. `doi:10.18429/JACoW-IPAC2015-TUPWA042`

[5] D. Filippetto *et al.*, *Phys. Rev. ST Accel. Beams* **14**, 092804 (2011).

[6] T. Vinatier *et al.*, *Journal of Physics: Conference Series* **1596**, 012033 (2020).

[7] E. Nanni *et al.*, *Nature Communications* **6**, 8486 (2015).

[8] D. Zhang *et al.*, *Nature Photonics* **12** 336 (2018).

[9] Morgan T. Hibberd *et al.*, arXiv:1908.04055 (2019).

[10] Lingrong Zhao *et al.*, *Phys. Rev. Lett.* **124** 054802 (2020).

[11] D. Ros, *et al.*, *Nuclear Instrum. and Methods* A **653**, 76 (2011)

[12] C. Guyot *et al.*, “Modeling of Standing Wave RF Cavities for Tracking through Multi-Pass Energy Recovery Linac”, presented at the IPAC’23, Venice, Italy, May 2023, paper TUPL170, this conference.

[13] F. Burkart *et al.*, “The ARES Linac at DESY”, in *Proc. LINAC’22*, Liverpool, UK, Aug.-Sep. 2022, pp. 691–694. `doi:10.18429/JACoW-LINAC2022-THPOJO01`

[14] Panofski, E. *et al.*, *Instruments* **5**, 28 (2021)

[15] P. Rebernik Ribic, *et al.*, *Nat. Photonics* **13**, 555–561 (2019).

[16] M. Labat, *et al.*, *Nat. Photon.* **17**, 150–156 (2023).

[17] J. Hebling *et al.*, *Opt. Express* **10** 1161 (2002)

[18] E. Roussel, *et al.*, *Light Sci Appl.* **11**, 14 (2022).

ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-TUPA061

[19] Rafí, *et al.*, *IEEE TNS*, Vol. **67** (2020)

[20] C-L. Limoli and M-C Vozenin, *Annual Review of Cancer Biology* **7** 1 (2023)

[21] P. Jorge *et al.*, *Radiotherapy and Oncology* **139** 34 (2019).

[22] V. Favaudon *et al.*, *Science Translational Medicine* **6** 245 (2014).

[23] P. Montay-Gruel *et al.*, *Radiotherapy and Oncology* **124** 365 (2017).

[24] M. C. Vozenin *et al.*, *Clinical Cancer Research* **25** 35 (2019).