Plasma-based positron sources R&D: current status and next steps

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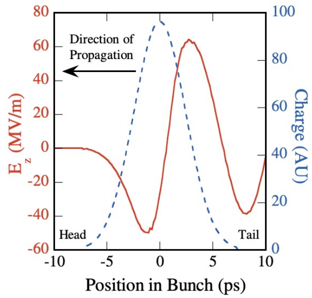
Plasma-based acceleration of positron is a challenging task, due to the asymmetric structure of wake-fields.

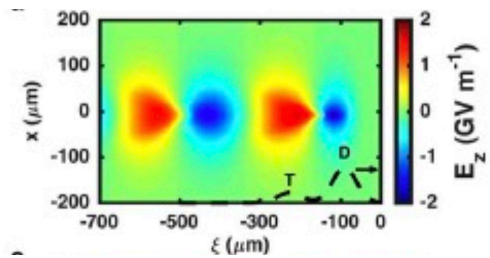
Several schemes and regimes have been proposed:

1. Quasi - linear



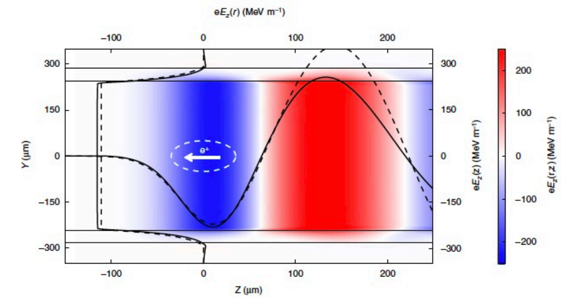
B. E. Blue et al., Phys. Rev. Lett. 90, 214801 (2003).

2. Non – linear



A. Doche et al., Sci. Rep. 7, 14180 (2017)

3. Hollow - channel



S. Gessner et al., Nat. Commun. 7, 11785 (2016).

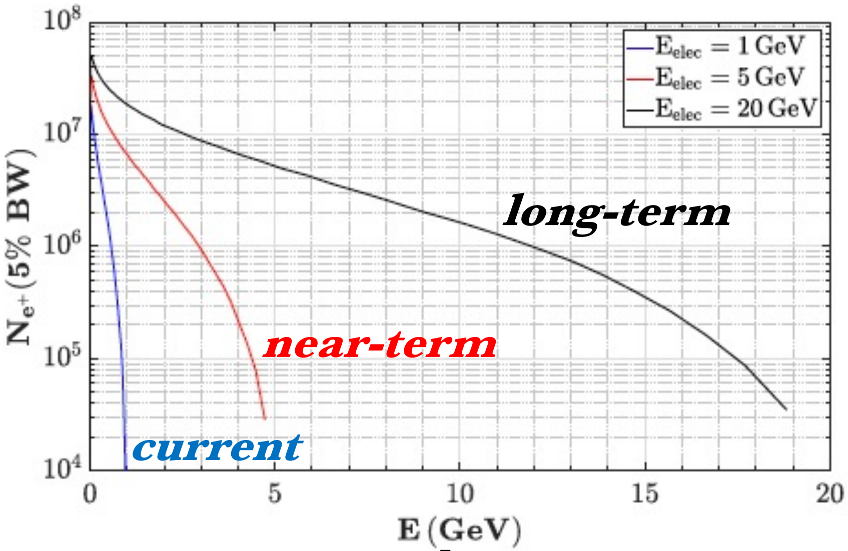
Parameters required

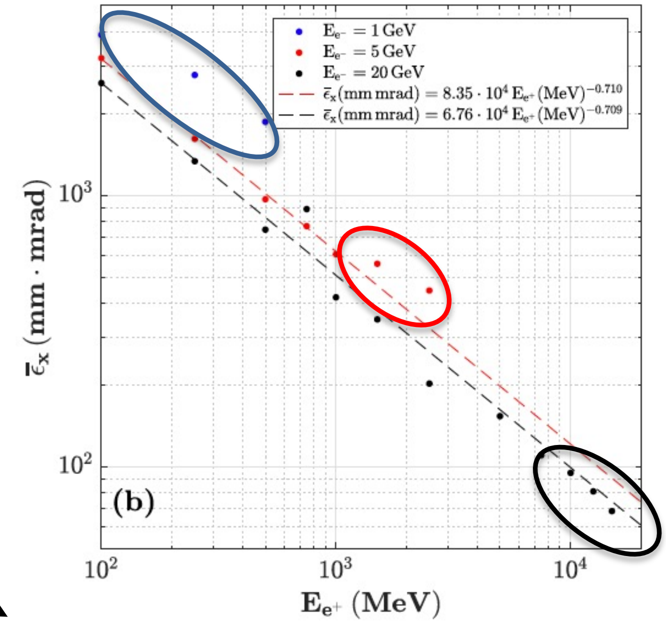
- $>$ pC of charge.
- $\geq$ GeV energy
- $\sigma_z \sim 10 - 100$ μm (30 – 300 fs)
- $\sigma_x, \sigma_y \sim$ 10s of microns
- $\varepsilon_n \sim$ 10s μm

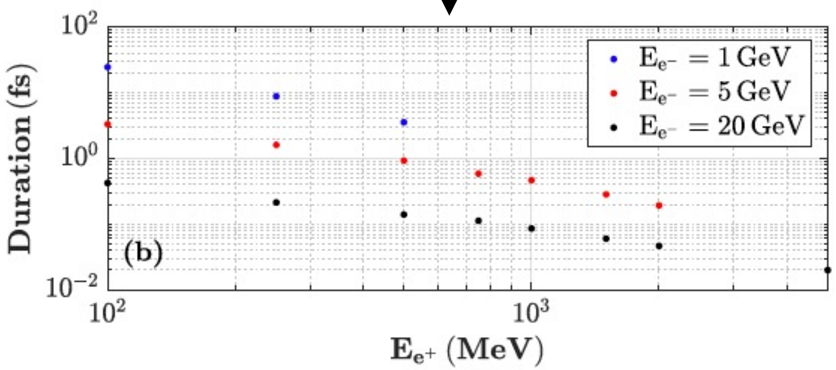
	Units	FACET-I	FACET-II
E	GeV	21	10
P	W	7.4	9.6
Q_e	pC	350	500
σ_x	μm	30	4
σ_y	μm	30	4
σ_z	μm	50	6.4
$\bar{\varepsilon}_{xx}$	mm mrad	200	7
$\bar{\varepsilon}_y$	mm mrad	50	3
ΔE	%	1.5	1
f	Hz	1	1

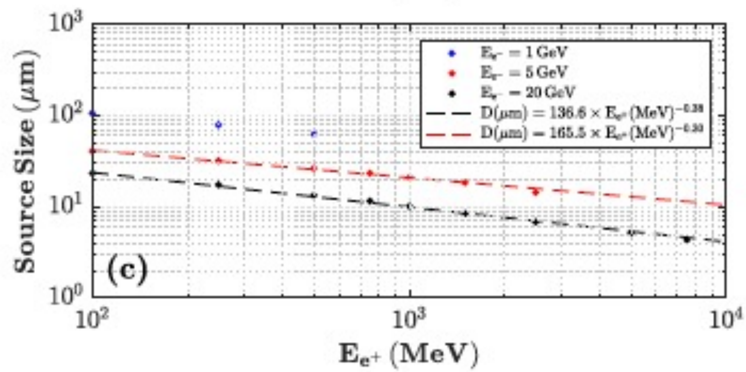
Laser-driven positrons

Laser-driven positron beams allow for experimental studies of plasma-based positron acceleration





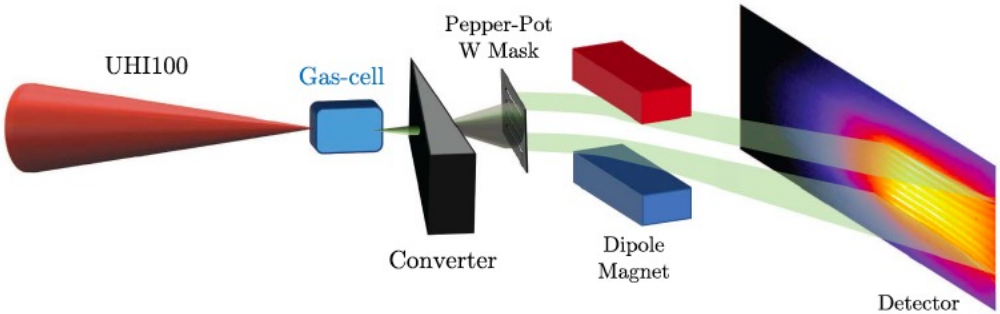


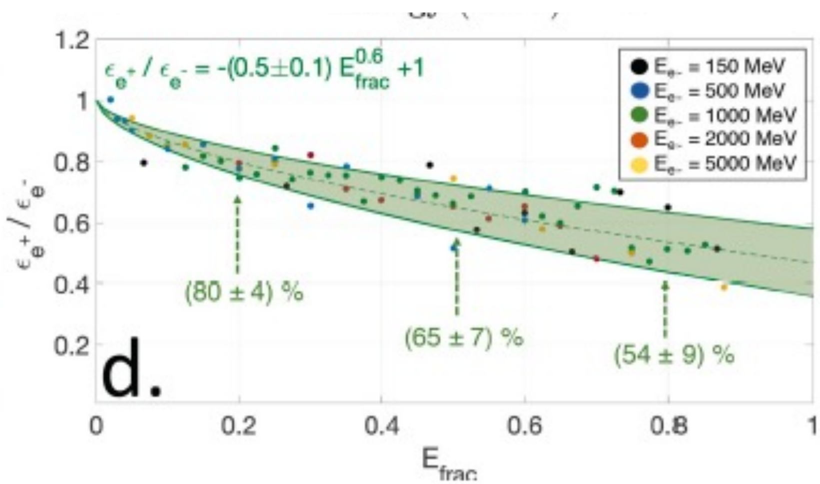


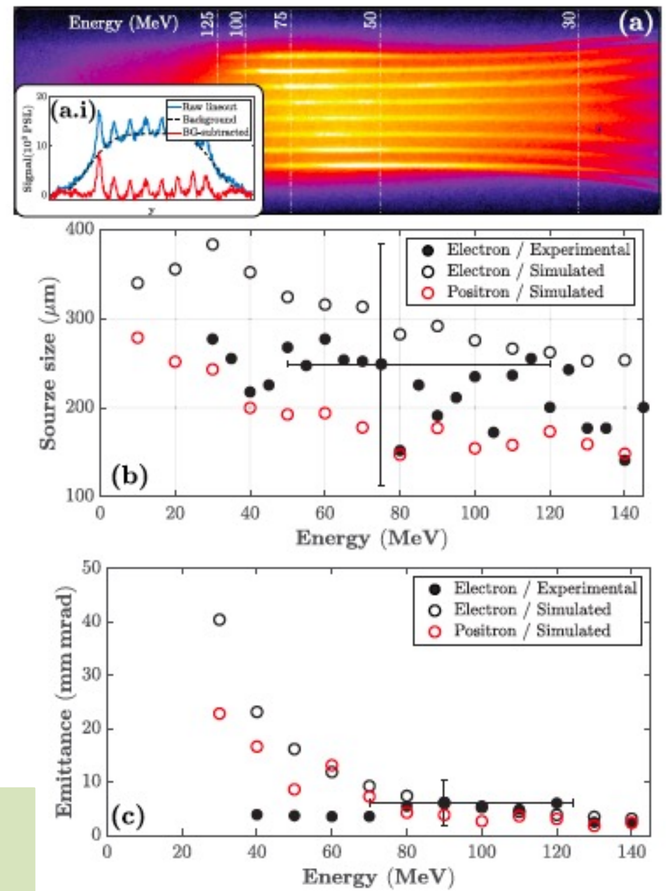
A. Alejo et al., Sci Rep. 9, 5279 (2019)

Exp. results (~100 MeV)

First proof-of-principle experiments with ~ 50 TW laser producing ~ 100 MeV positrons







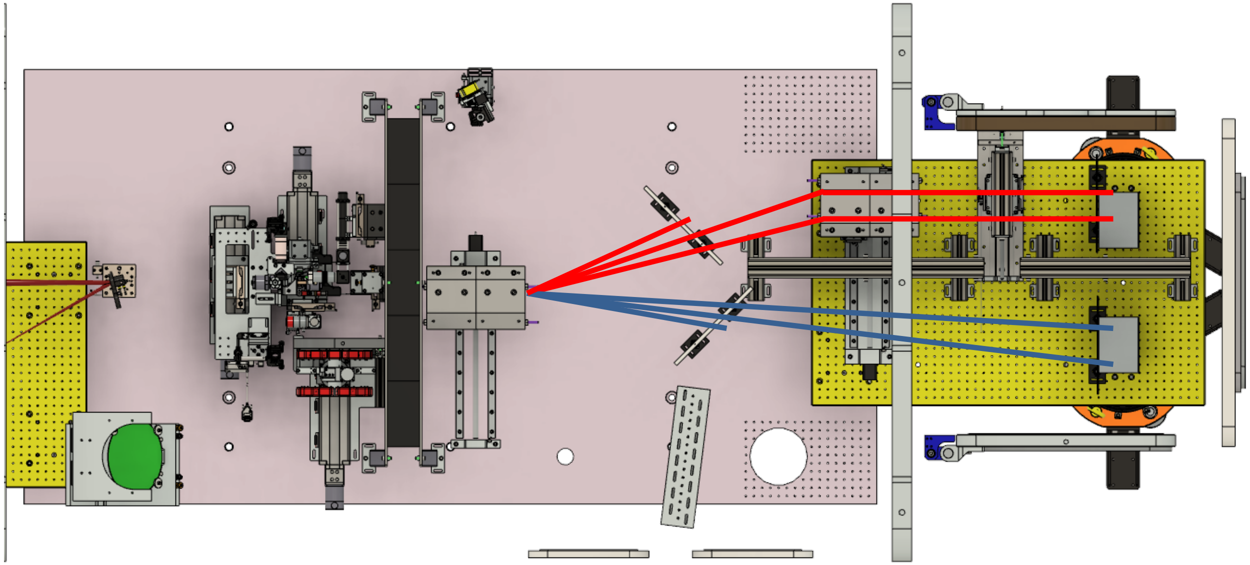
- Close correlation between e^- and e^+ properties
- **Live, simultaneous, and non-invasive** measurement of spectrum, source size, total charge, and energy-resolved emittance

A. Alejo et al., PPCF 62, 055013 (2020)

Exp. results (~500 MeV)

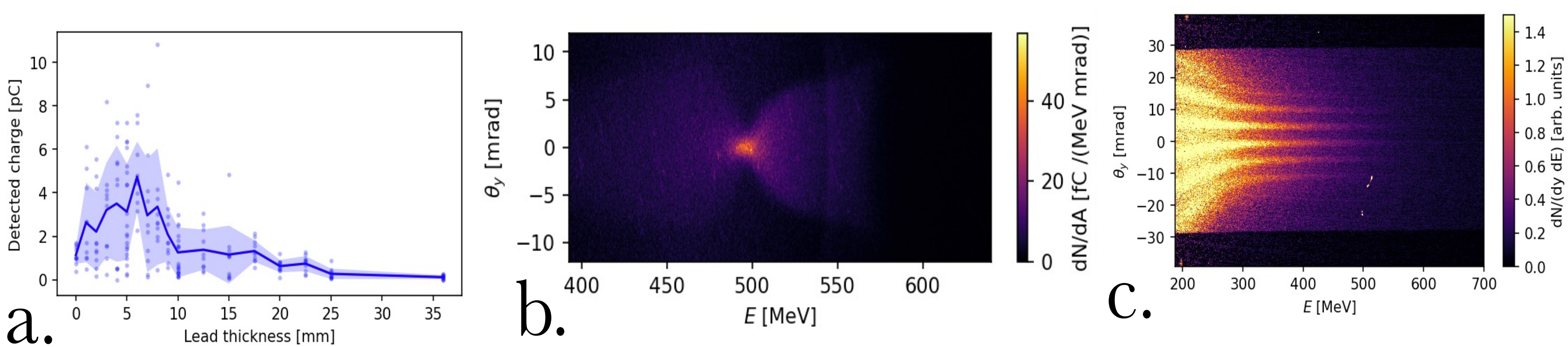
QUEEN'S UNIVERSITY BELFAST — EPSRC — central laser facility

Follow-up experiments with ~ 300 TW laser (Astra-Gemini) producing ~ 0.5 GeV positrons



Positron beam properties

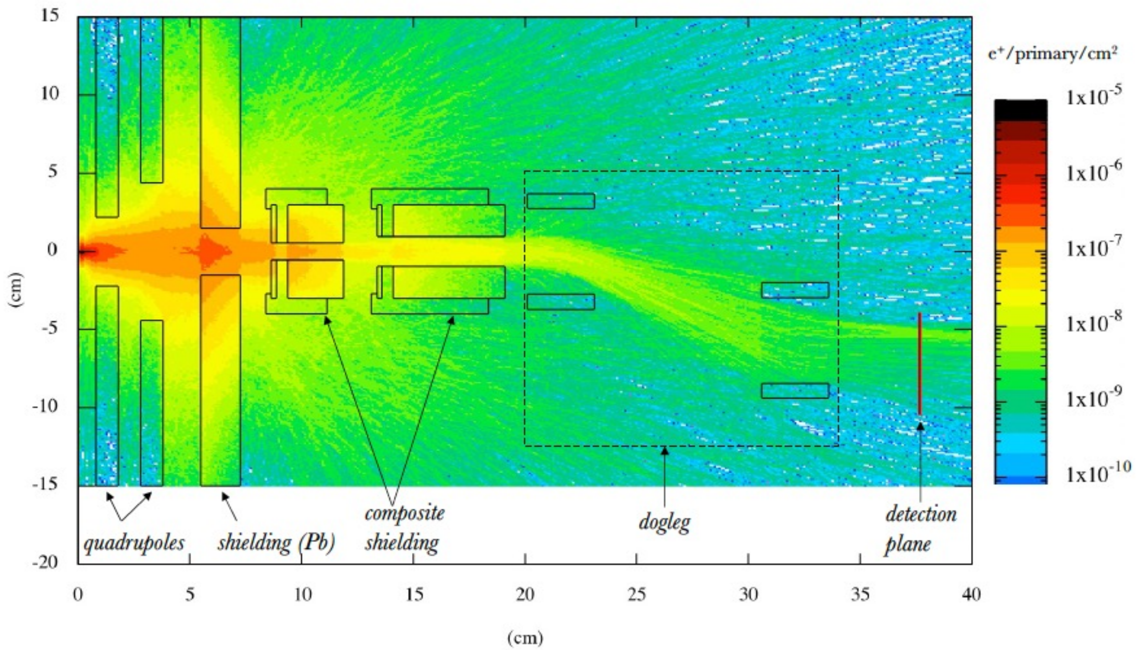
- Charge: ~ pC
- Energy: 500 MeV
- Bandwidth: ΔE/E ~ 2%
- Divergence: 0.5 mrad
- Duration: ~30 fs
- Emittance: ~ μm

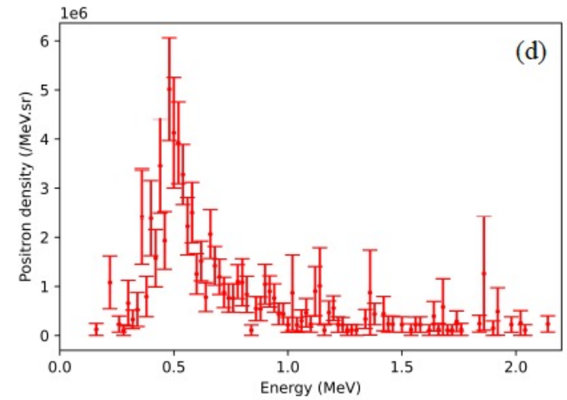


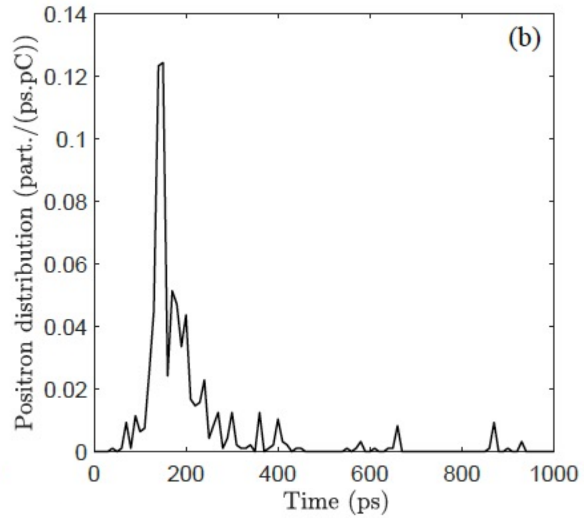
CLF campaign, Feb-March 2021, *in preparation* (2021)

Low energy positrons (~MeV)

Low-energy positrons (~ MeV) can also be collected in a similar fashion for industrial applications







Positron source	Positron flux (e^+/s)	Beam duration FWHM (ps)	Positron energy (keV)
Our work	10^5 - 10^6	50 - 60	0 - 10^3
ELBE [5]	10^6	250	0.5 - 15
NEPOMUC [6]	10^9	/	1
PLEPS [7]	0.5 - 1×10^4	260-280	0.5 - 20
PALS-200A (Fuji) [34]	5×10^2	300	0.5 - 15
NANOPOS [8]	10^5	/	0.25 - 25
PULSTAR [9]	10^6 - 10^9	300	0.5 - 10

A. Audet et al., Arxiv: 2009.05521 (2021)

Main questions

1) Where do you see HEP applications of advanced accelerators in 30 years?

- There are better people in the meeting to answer this!
- However, I am sure anyone would like an e^+ - e^- collider in the range of 0.1 – 1 TeV…

2) What intermediate physics applications/steps do you see until a HEP linear collider?

- In my opinion, it is **vital** to have several test beams available worldwide **(e.g., EuPRAXIA)**
- **The transition to ~ 5 - 20 GeV** electron beams will allow demonstration of high-quality positron beams for PWFA and LWFA studies
- Similar electron beams will also allow for the generation of **high-quality muon beams** (no time to talk about it here, but happy to discuss off-line…)

3) What is the synergy with related fields?

- Laser-driven positron sources can complement existing efforts, by providing ultra-short and synchronised beams. Possibility of having several test-beam facilities with complementing characteristic.

Main questions

1) What are the important milestones for the next 10 years to get there from today?

- Completion of dedicated facilities for plasma-based acceleration **(e.g., EuPRAXIA, ELI, EPAC…)**
- Realisation of high average power and high intensity laser systems (>100 Hz)

2) What additional support is needed to achieve these?

- Continuing and strengthening synergy between plasma and accelerator physicists, via specific international networks, large-scale projects, and doctoral training centers.

3) What should be proposed as deliverables until 2026? Please list in order of priority.

- Demonstration of high-charge electron beams with maximum energy > 10 GeV
- Demonstration of high-quality positron beam from a wake-field at the multi-GeV level
- Demonstration of plasma-based acceleration at high repetition rate (100 Hz)

4) Is the R&D work for each of those deliverables already funded and, if not, what additional resources / support would be needed?

- National support obtainable (and obtained!) but usually fragmented and group-specific
- We also need to form the scientific base for the future (doctorate centers, fellowships…)

Main questions

1) What key R&D needs can be achieved in existing R&D facilities?

- Mainly proof-of-principle. Lack of **dedicated** facilities world-wide.

2) What is the role of the already planned future facilities in Europe and world-wide?

- **Transformational and indispensable**, in my opinion. Need to start working on the technical aspects (reliability, high rep-rate…), impossible without dedicated facilities.

3) Is a completely new facility needed?

- Facilities currently planned or under construction will provide a step-change advancement in the field allowing to transition from proof-of-principle experiments to reliable and stable test beams (EPAC, DESY, EuPRAXIA, ELI…).
- As a matter of priority, funding should be first secured for the full blossoming of these facilities, before proceeding to the next step?

4) Are additional structures needed beyond existing networks and projects, e.g. a design study for a collider or an advanced accelerator stage?

- It would be ideal to form **large-scale consortia** to start working on conceptual designs. However, this should go alongside dedicated and structured support to fund staff-time and PhD studentships.

Thanks for your attention!

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