Laser-driven sources of ultra-relativistic positron beams

Gianluca Sarri
School of Mathematics and Physics, Queen's University Belfast, UK
g.sarri@qub.ac.uk

Main Collaborators

A. Alejo, J. Warwick, G. Samarin, T. Dzelzainis, M. Zepf

A.G.R. Thomas, W. Schumaker, K. Krushelnick

L. Gizzi, G. Grittani

J. Cole, S. P. D. Mangles, K. Poder, Z. Najmudin,

A. Di Piazza, Ch. Keitel

S. Kuschel

D. Symes and ASTRA-GEMINI technical staff

L. Romagnani

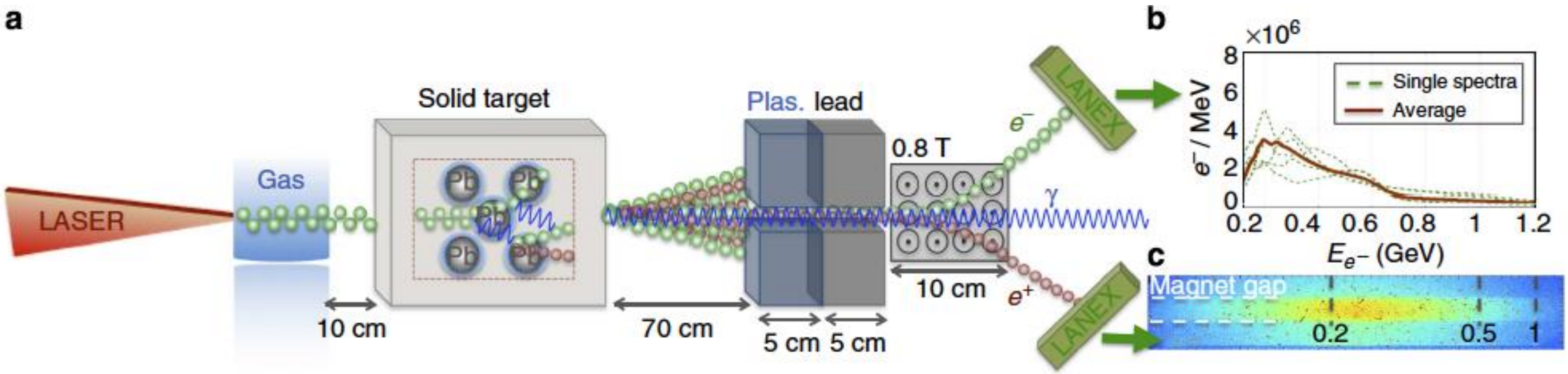
J. Vieira, N. Shukla, L. Silva

The UK Plasma Wakefield Accelerator Steering Committee (PWASC) represents UK groups working on plasma accelerators and coordinates their activities.

- Develop a **roadmap** for the development and application of plasma acceleration in the UK
- Contribute to **large international projects** and developments in the field (EuPRAXIA, AWAKE..)
- Initiate joint activities and actions supporting the **growth of the field**
- Inform and support Research Councils in the development of **targeted funding calls**

Introduction

A simple scheme



✓ **PROS**

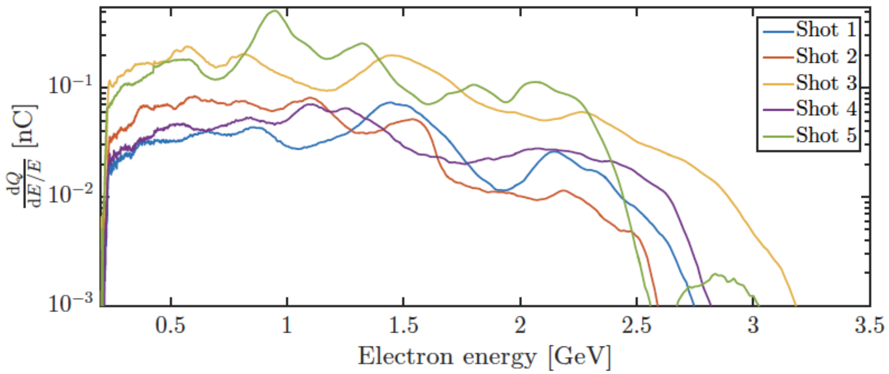
- Small source size (~ microns)
- Short duration (even a few fs)
- Relatively low divergence (~ mrad)
- Compact generation of ~ GeV-scale energies
- We don't need narrowband beams!

Would these properties map onto the positrons?

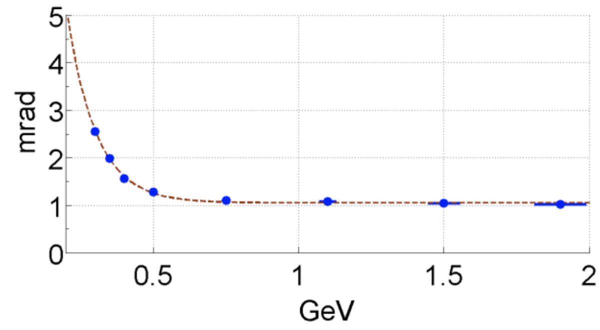
↓

GeV-scale, kAmpere positron beams with micron-scale emittance?

_aser wakefield acceleratio



- **Divergence: ~ mrad**



Shot	E_L J	Beam charge pC			Beam energy mJ		
		> 2 GeV	> 1 GeV	> 0.25 GeV	> 2 GeV	> 1 GeV	> 0.25 GeV
1	11.29	4.4	31.0	77.5	9.9	47.5	73.6
2	11.31	2.0	31.5	122.2	4.5	42.8	93.4
3	11.42	14.9	98.9	343.4	34.8	154.2	286.3
4	11.31	6.4	35.7	92.1	14.6	53.6	85.7
5	11.31	15.2	127.8	373.9	33.0	182.1	335.1

K. Poder et al., in preparation (2018)

- **Source size: ~ micron**
- **Temporal duration: ~ fs**

Current (>1GeV): 0.1 MA

Normalised emittance (1GeV): ~mm mrad

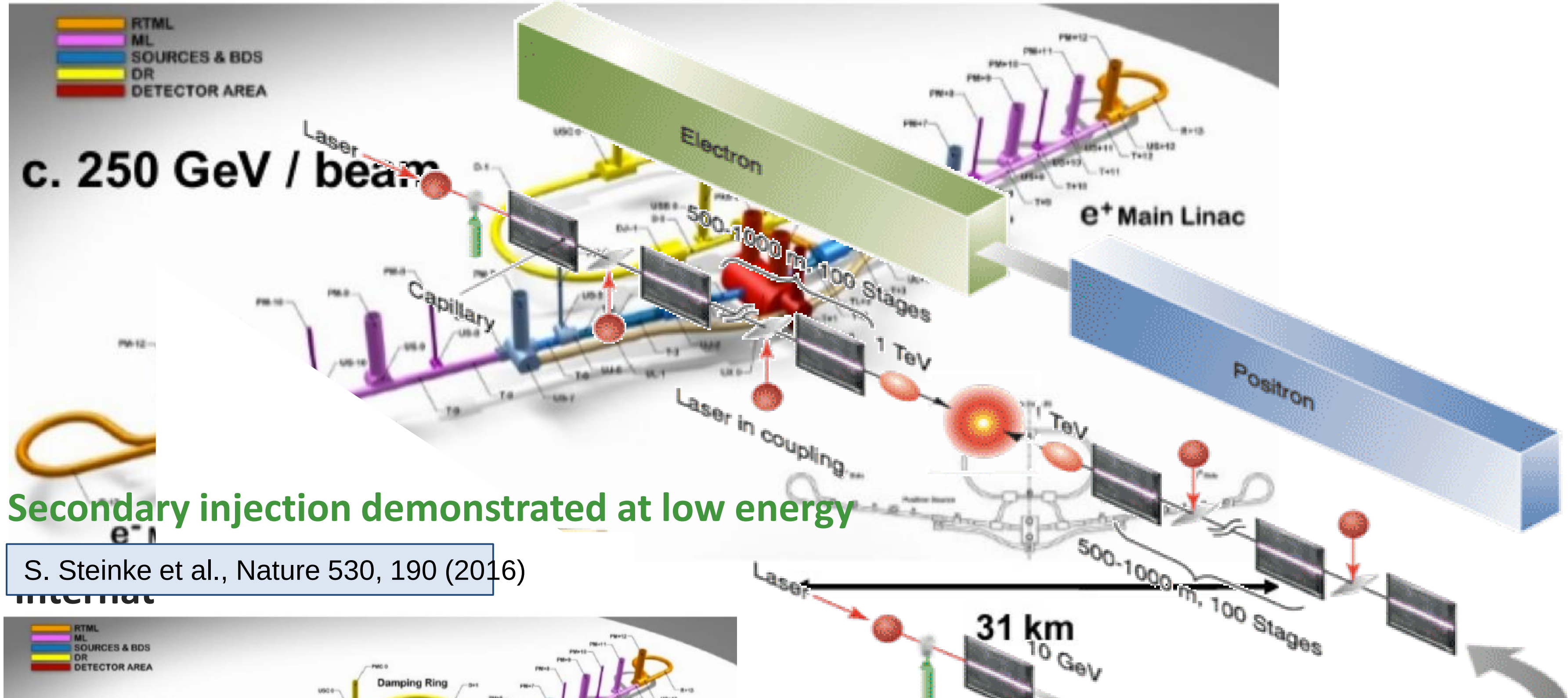
ELI-NP

Goal Specs (2019)

- E = 200 J
- d = 45 cm
- τ = 20 fs
- P = 10 PW
- F/80 focusing (36 m)

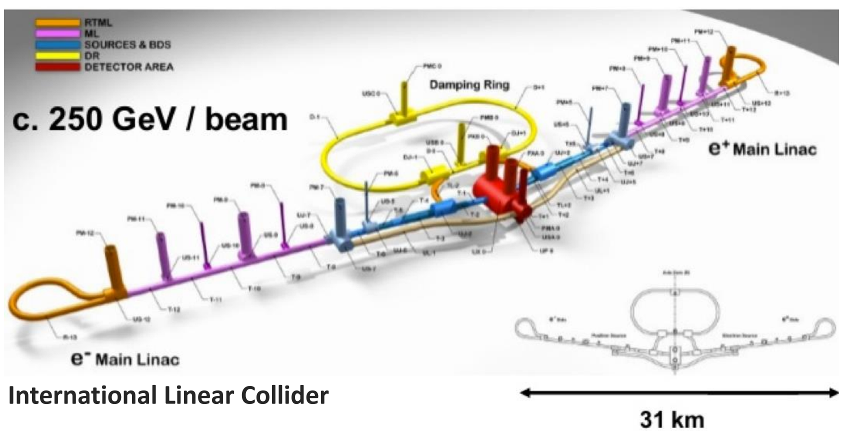
Generation of 10+ GeV electron beams within one acceleration stage

A plasma-based collider?



Secondary injection demonstrated at low energy

S. Steinke et al., Nature 530, 190 (2016)

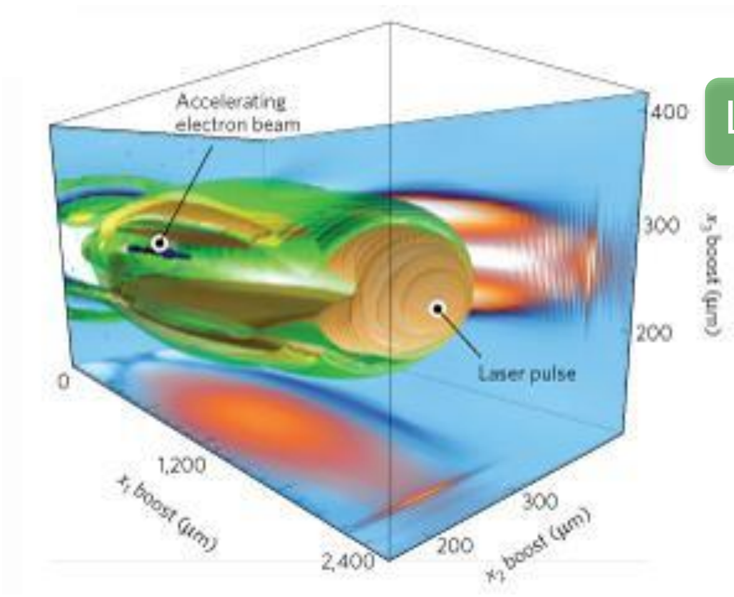


International Linear Collider

What about the positrons?

Wake-field based positron generator

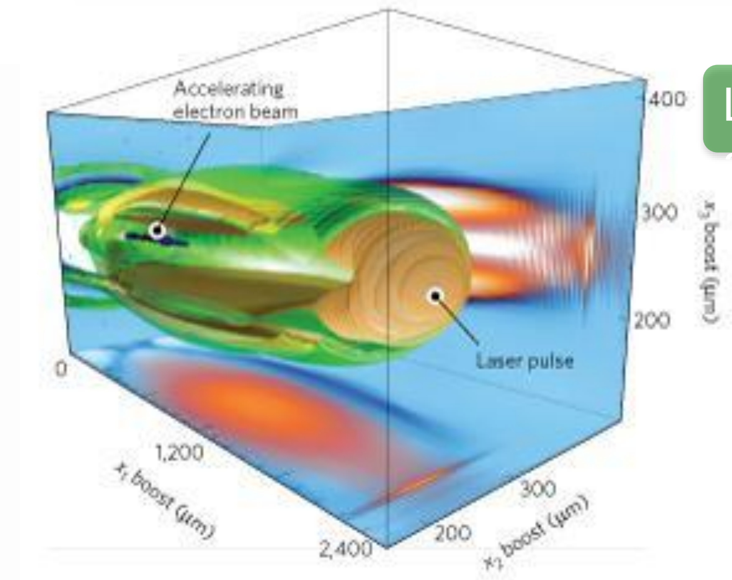
General setup



Laser-wakefield electrons to trigger the cascade in a solid

G. Sarri et al., Phys. Rev. Lett. 110, 255002 (2013).

General setup



Laser-wakefield electrons to trigger the cascade in a solid

- ✓ Divergence: 1-5 mrad (from solid: ~ 20 degrees)
- ✓ Duration: ~ 10 fs (from solid: 1 – 10 ps)
- ✓ Energy: 100s of MeV (from solid: 10s of MeV)
- ✓ Laser energy: ~1-10J (from solid: ~kJ)
- ✓ Possibility of generating neutral e^-/e^+ beams in situ

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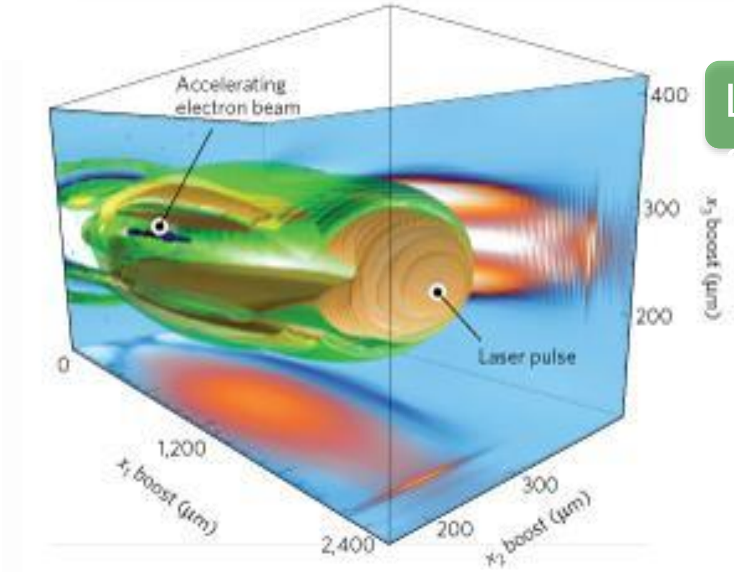

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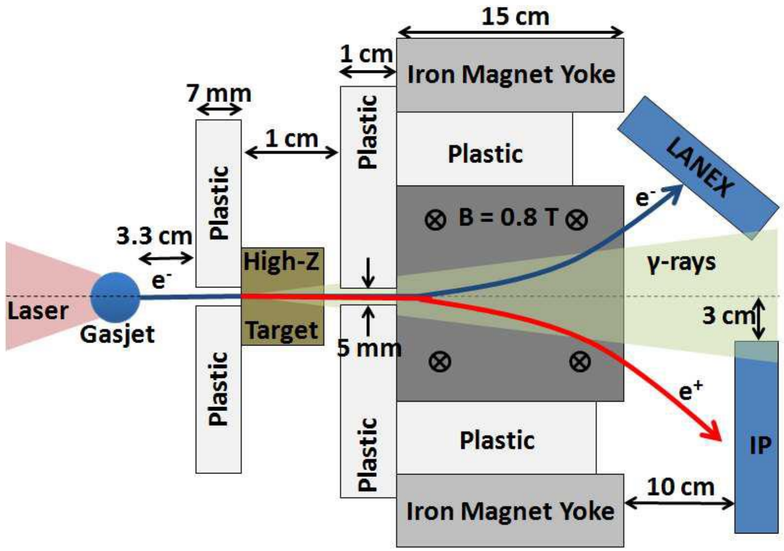

G. Sarri et al., Phys. Rev. Lett. 110, 255002 (2013).

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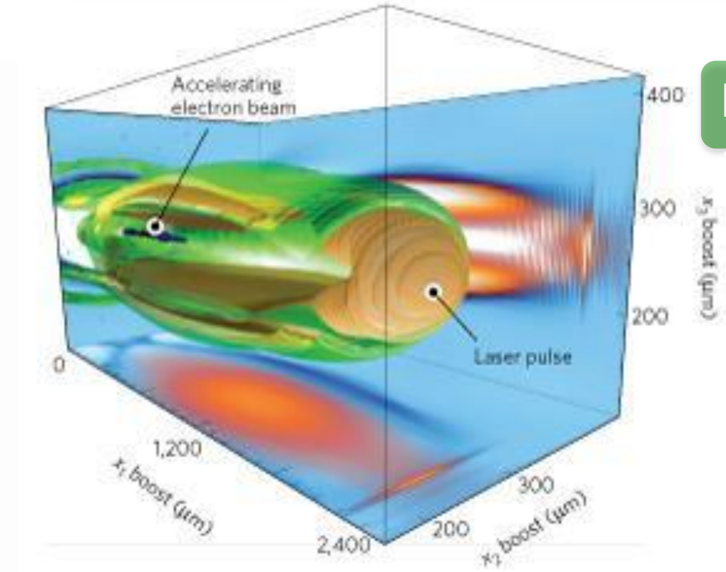

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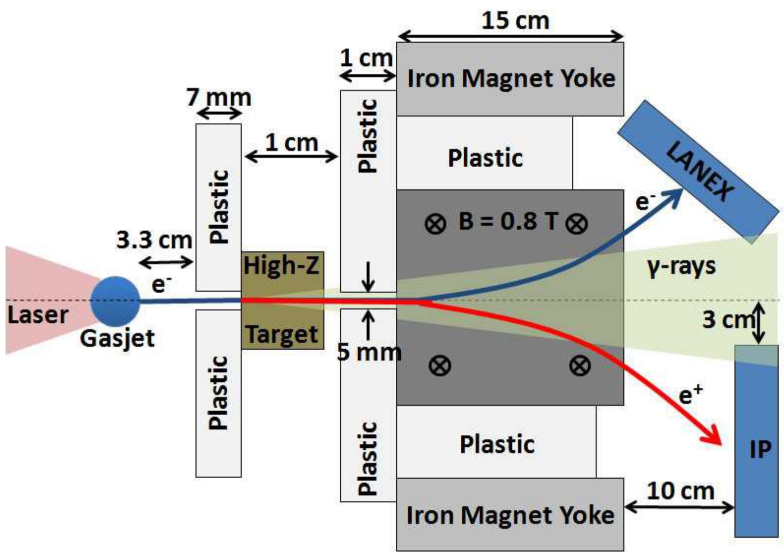
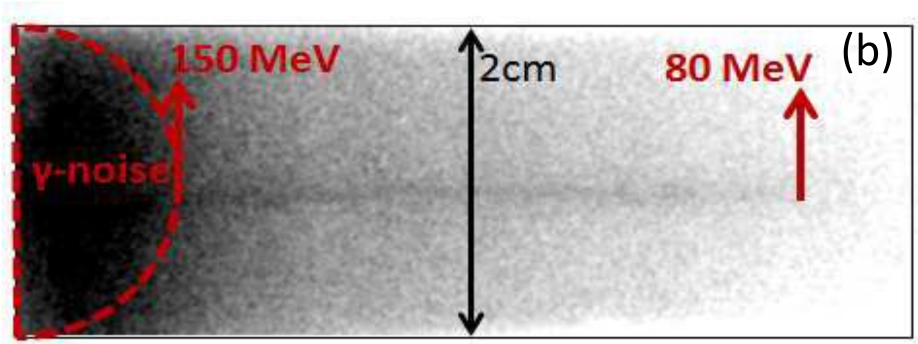
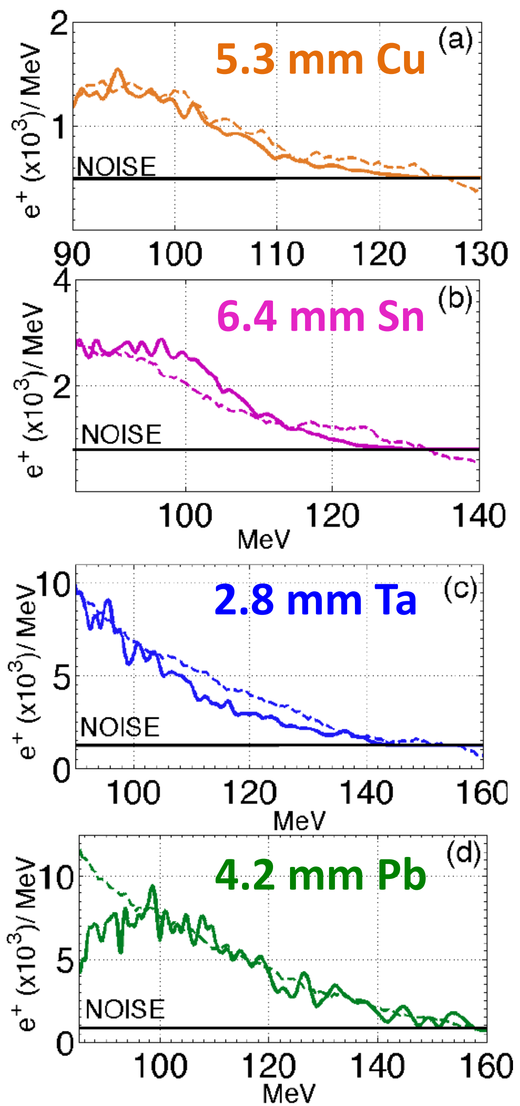


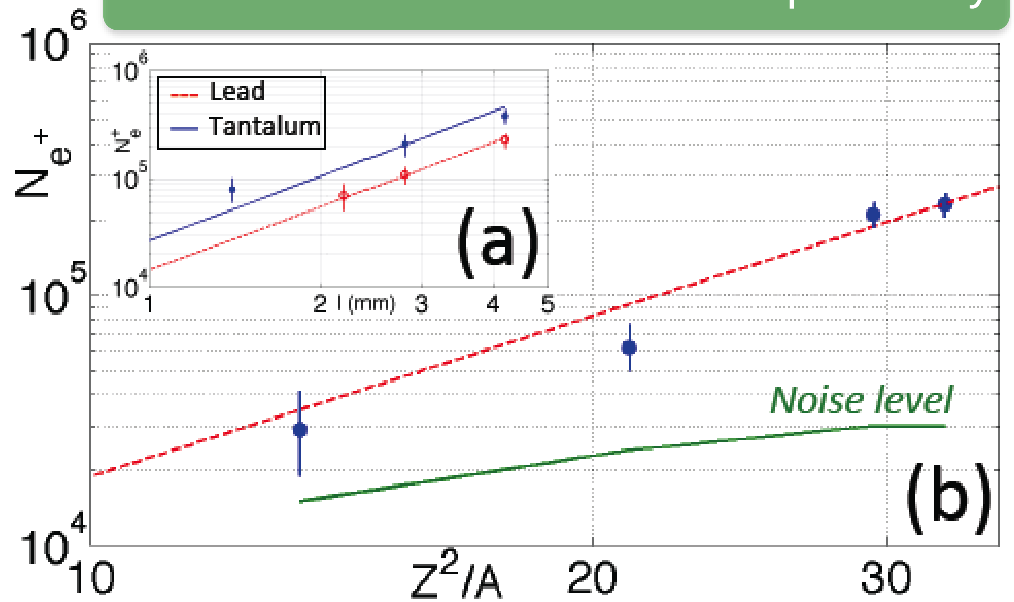


G. Sarri et al., Phys. Rev. Lett. 110, 255002 (2013).

First results: low energy



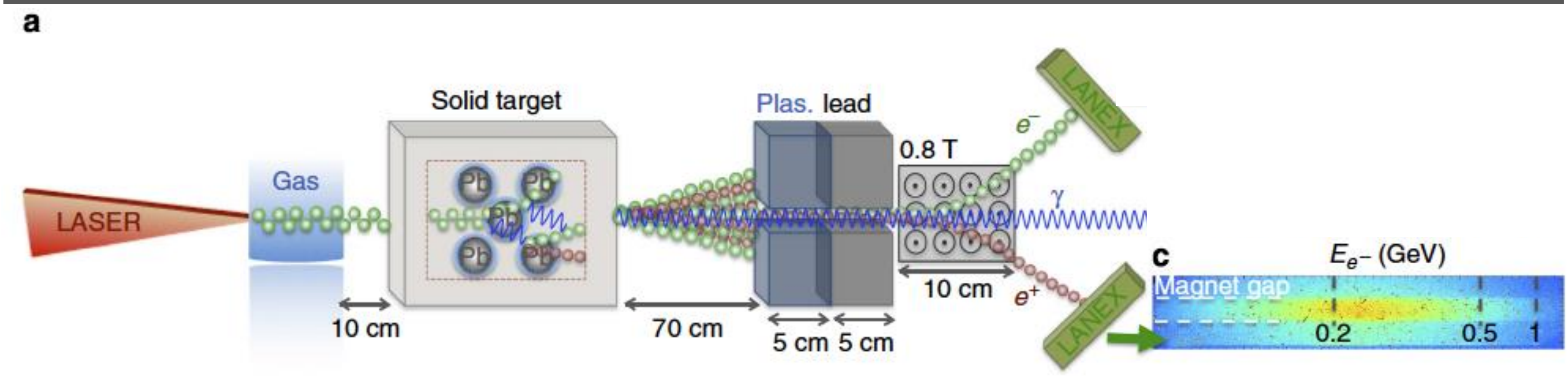
First results with a 0.8J table-top laser sys



- Overall positron yield: 3×10^{7}
- Overall lepton yield: 3×10^{8}
- Positron density: 2×10^{14} cm^{-3}
- Lepton density: 2×10^{15} cm^{-3}
- Normalised emittance: $30\ \pi$ mm mrad
- Divergence: 3 mrad

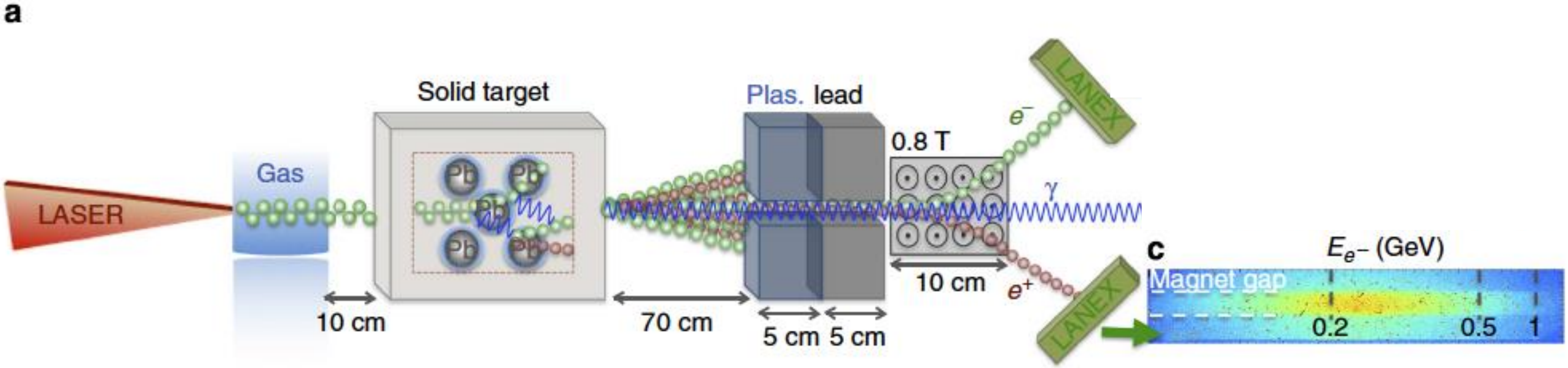
G. Sarri et al., Phys. Rev. Lett. 110, 255002 (2013).

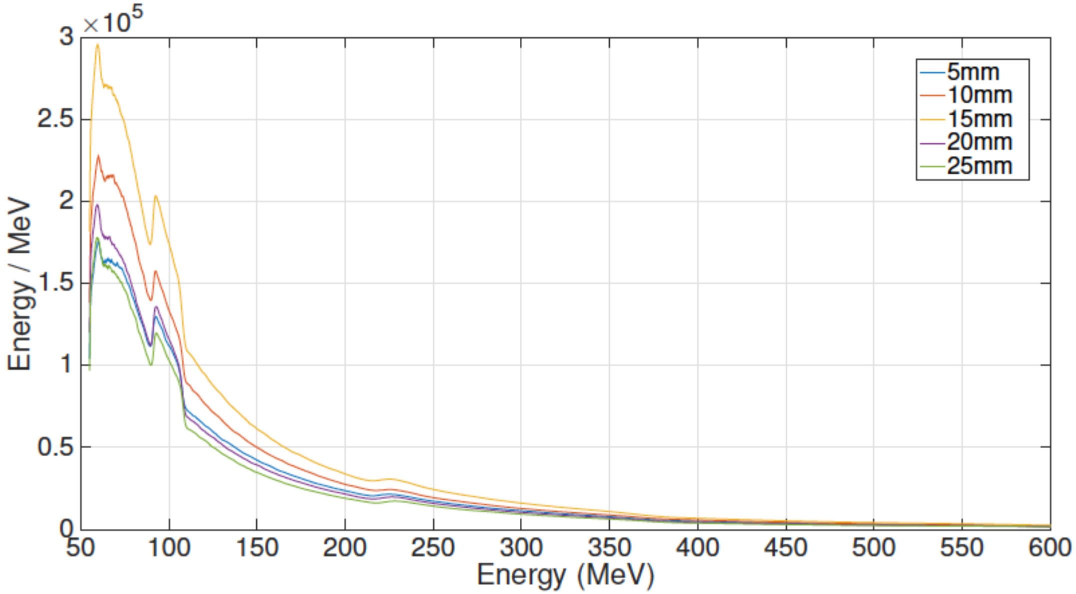
Higher electron energies

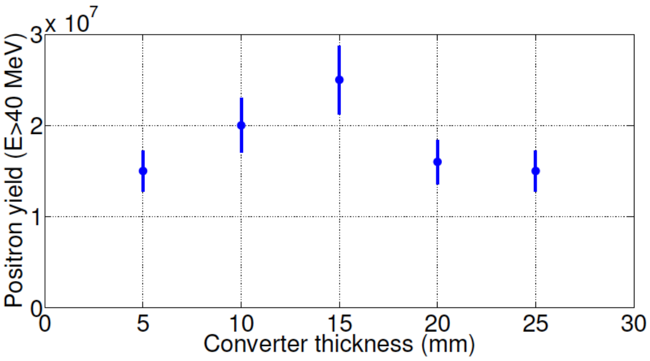


G. Sarri et al., Nature Comm. 6, 6747 (2015).

Positron spectra



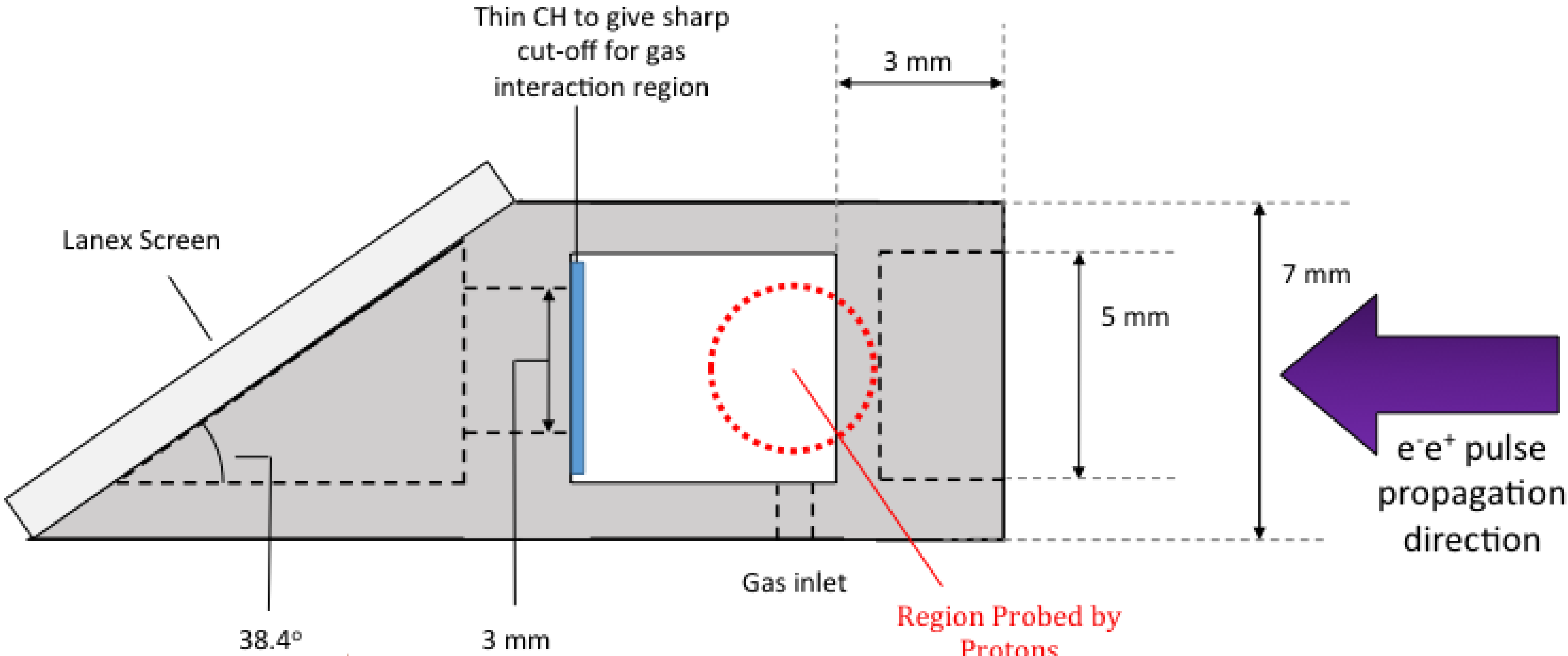


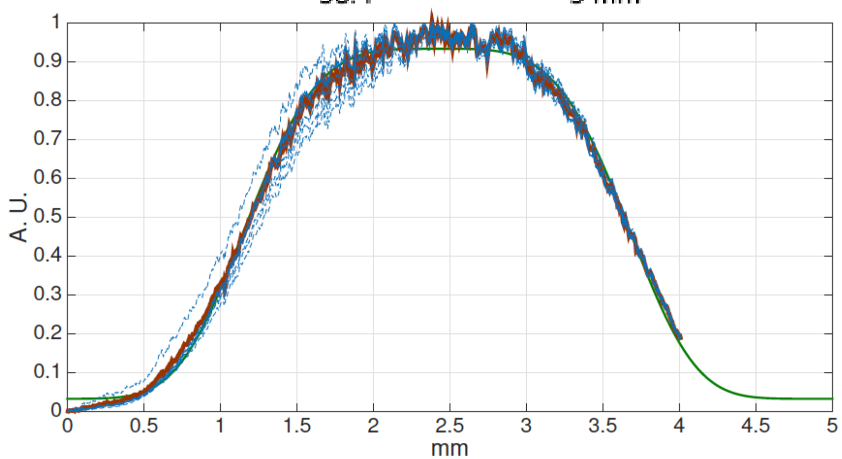


G. Sarri et al., Nature Comm. 6, 6747 (2015).

G. Sarri et al., Plasma Phys. Contr. F. 59, 014015 (2017)

Beam profile

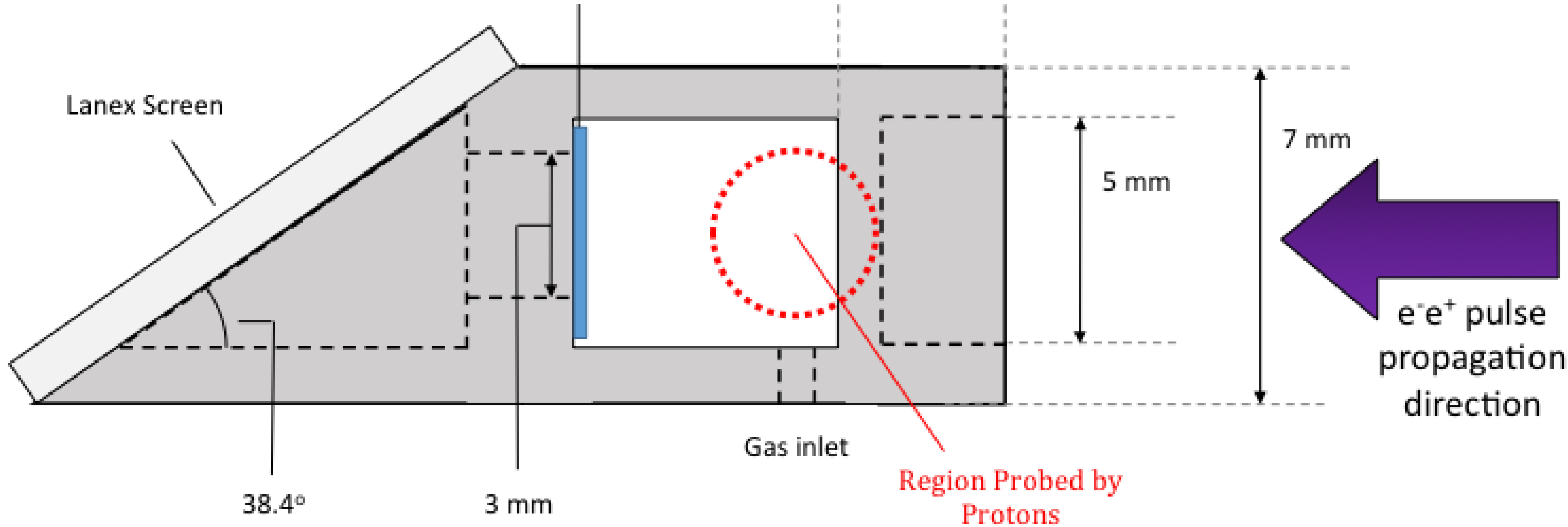


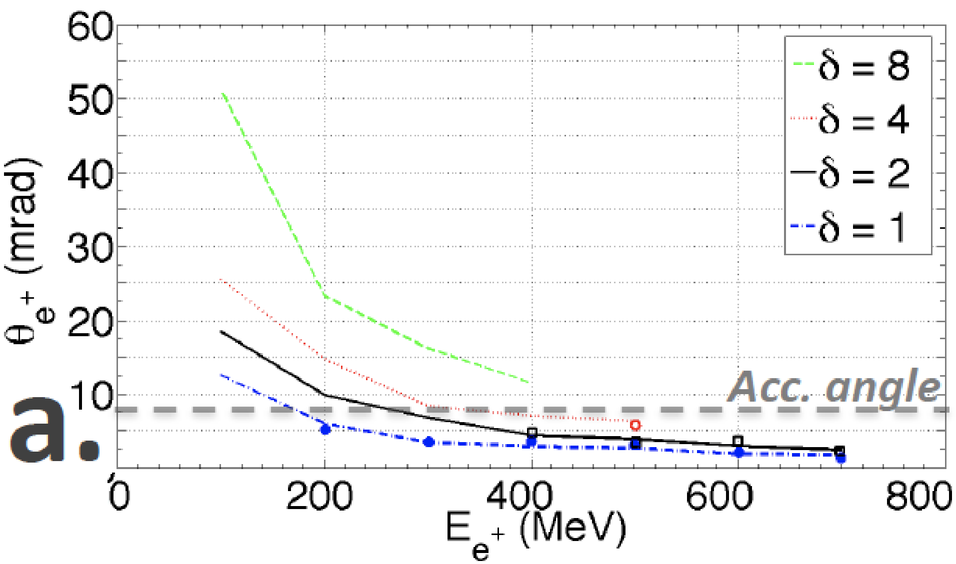


- Smooth profile after subtraction of γ-ray signa
- Stable over a significant number of shots
- Consistent with an average Lorentz factor of

G. Sarri et al., Plasma Phys. Contr. F. 59, 014015 (2017)

Beam divergence





- ✓ Energy-dependent divergence
- ✓ ~50 mrad at 5 MeV
- ✓ ~10 mrad at 200 MeV
- ✓ ~5 mrad at 500 MeV

G. Sarri et al., Plasma Phys. Contr. F. 55, 124017 (2013)

Scaling with electron energy

Initial conditions

Three cases:

Commercial laser (~ 100 TW)

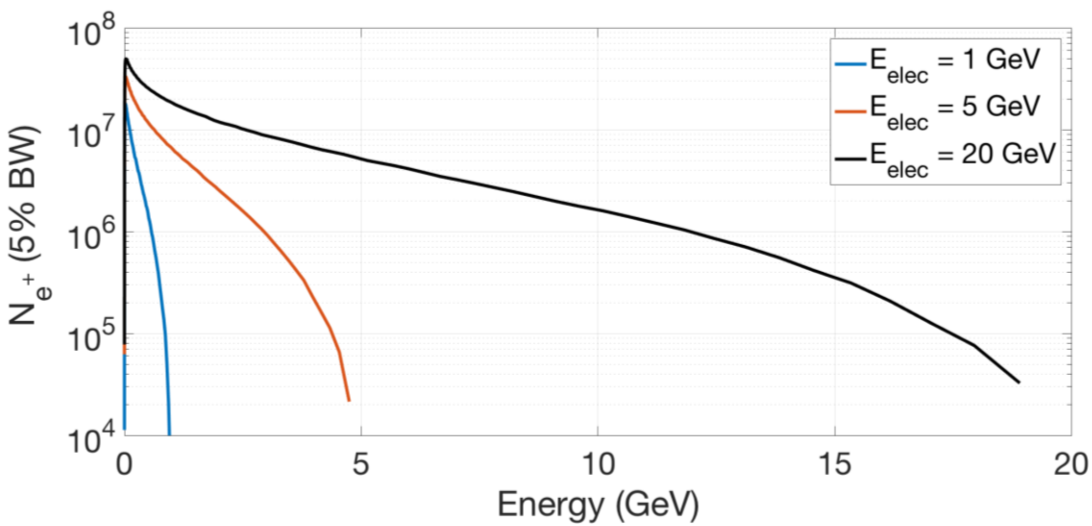
- 1 GeV electron energy
- 5% bandwidth
- 100 pC
- 5 fs duration
- 5 mrad divergence
- 2 micron source size
- 1 Hz repetition rate

EuPRAXIA

- 5 GeV electron energy
- 5% bandwidth
- 100 pC
- 5 fs duration
- 0.4 mrad divergence
- 0.4 micron source size
- 1 kHz repetition rate

ELI-NP (10 PW)

- 20 GeV electron energy
- 5% bandwidth
- 100 pC
- 1 fs duration
- 0.4 mrad divergence
- 0.4 micron source size
- **1 kHz** (1 Hz, really..)



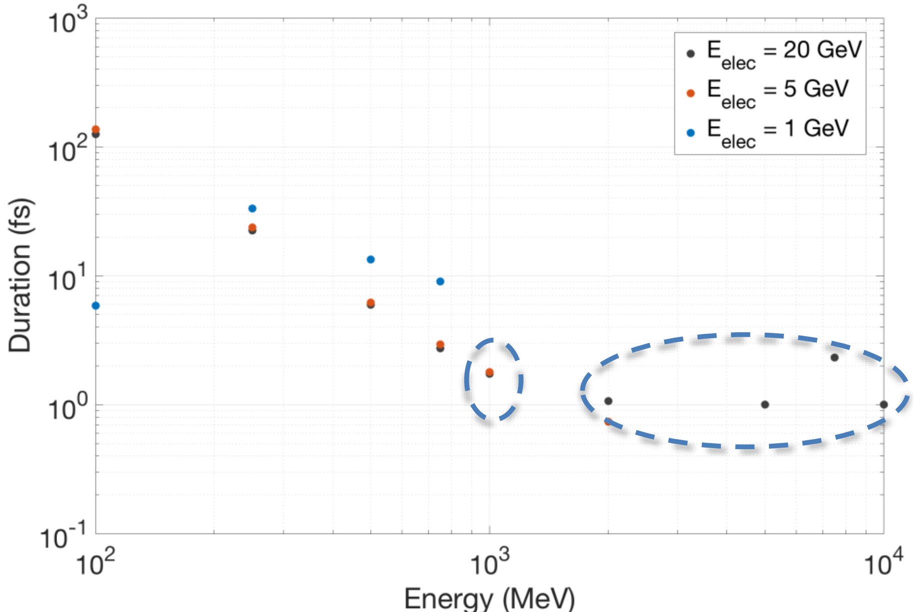
Positron spectra

For 20 GeV electrons,
up to $2x10^7$ positrons at 1 GeV

For 5 GeV electrons,
up to $6x10^6$ positrons at 1 GeV

A. Alejo and G. Sarri, in preparation (2018)

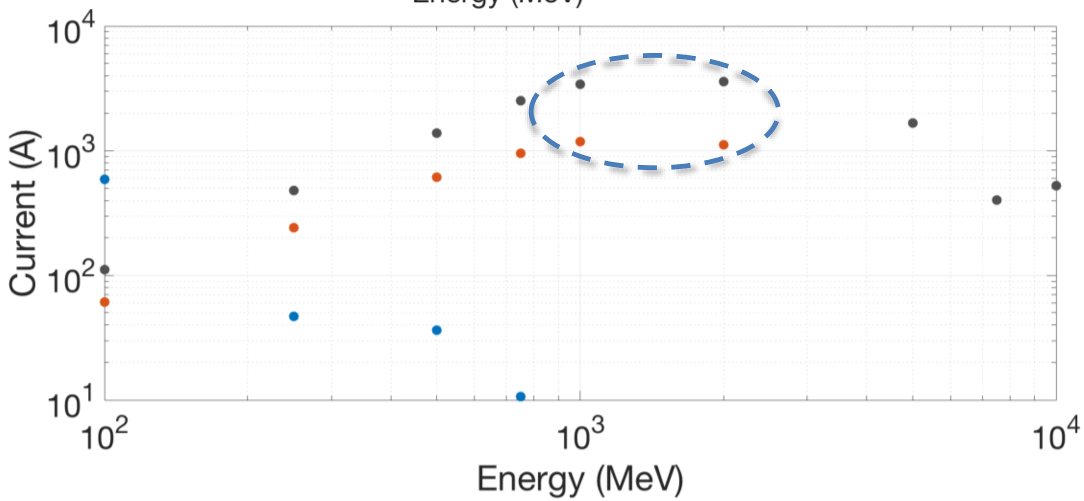
Beam duration and current



Positron duration

The 1 GeV positron beam is about 2fs longer than the primary electron beam

Above 1 GeV the positron beam is effectively as long as the primary electron beam

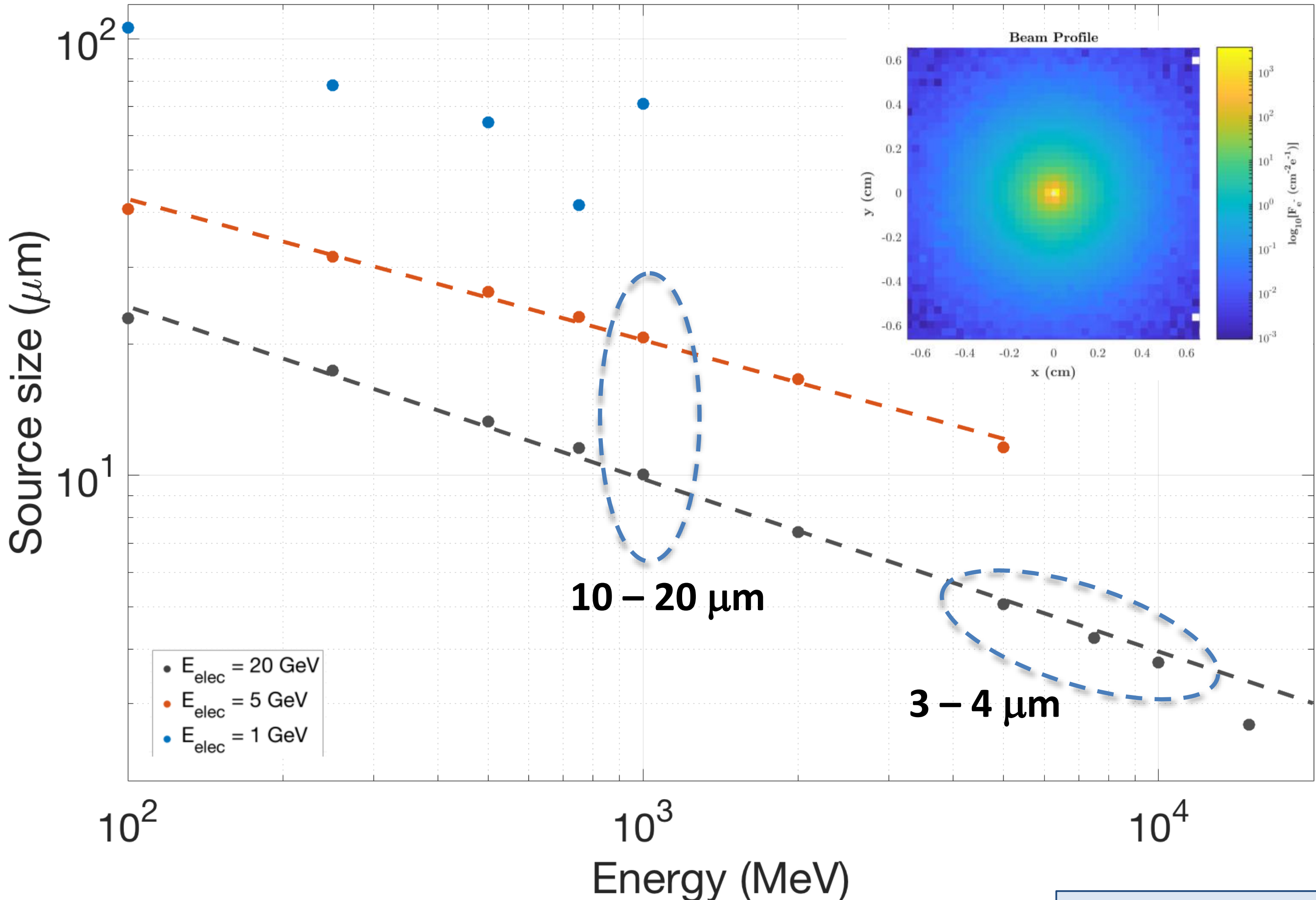


Positron current

At 1 GeV we get positron currents exceeding the kiloAmpere

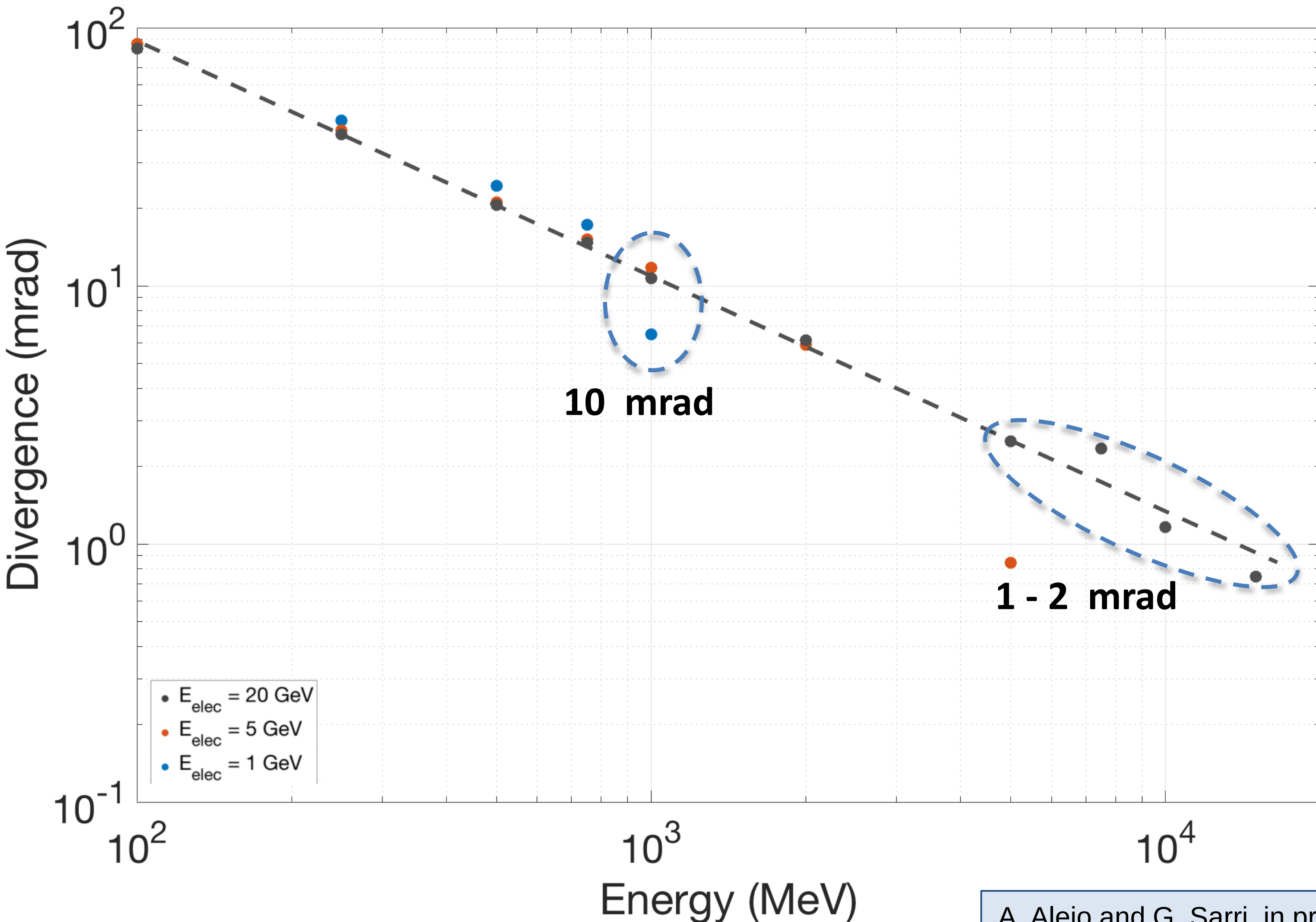
A. Alejo and G. Sarri, in preparation (2018)

Source size



A. Alejo and G. Sarri, in preparation (2018)

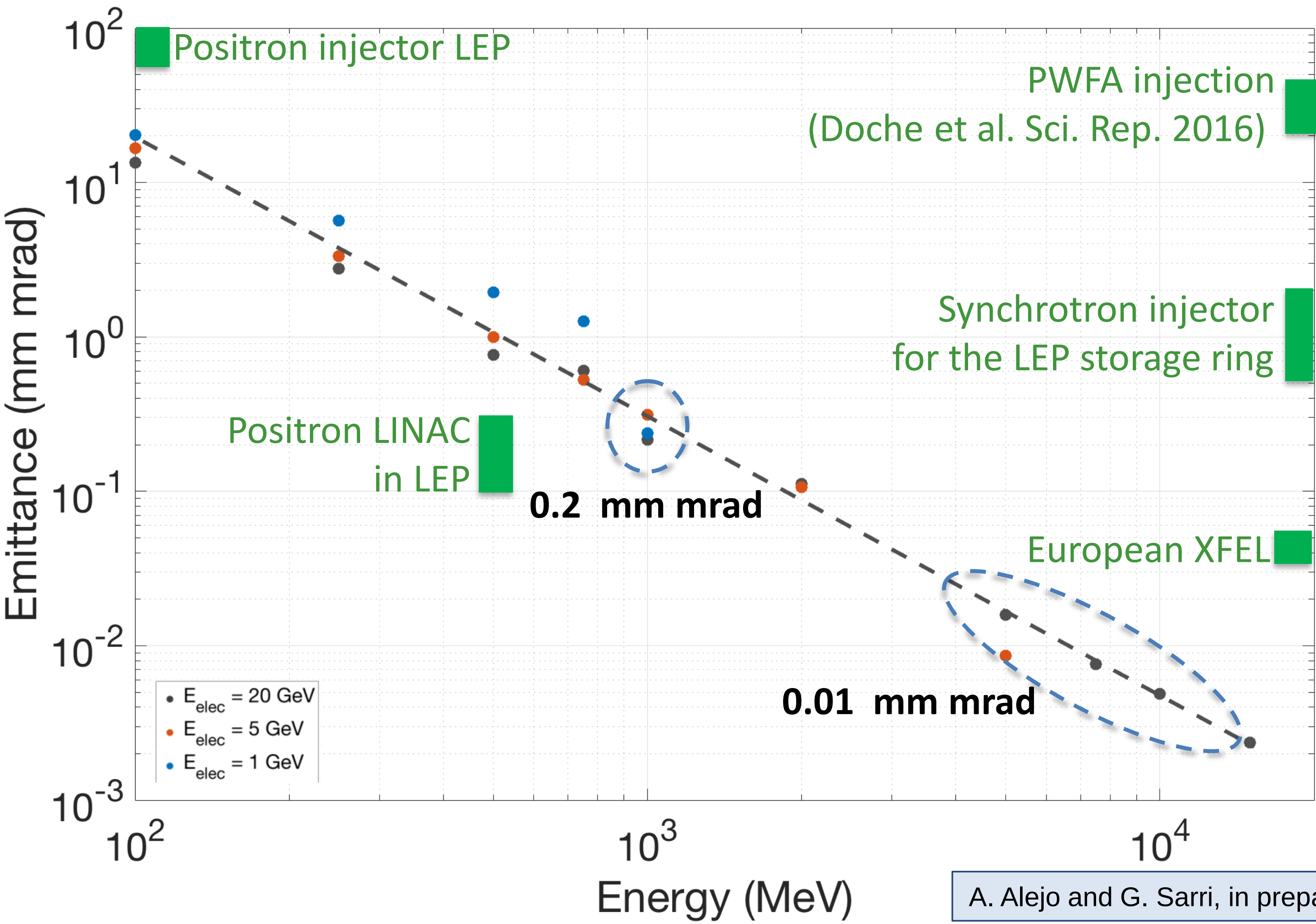
Divergence



A. Alejo and G. Sarri, in preparation (2018)

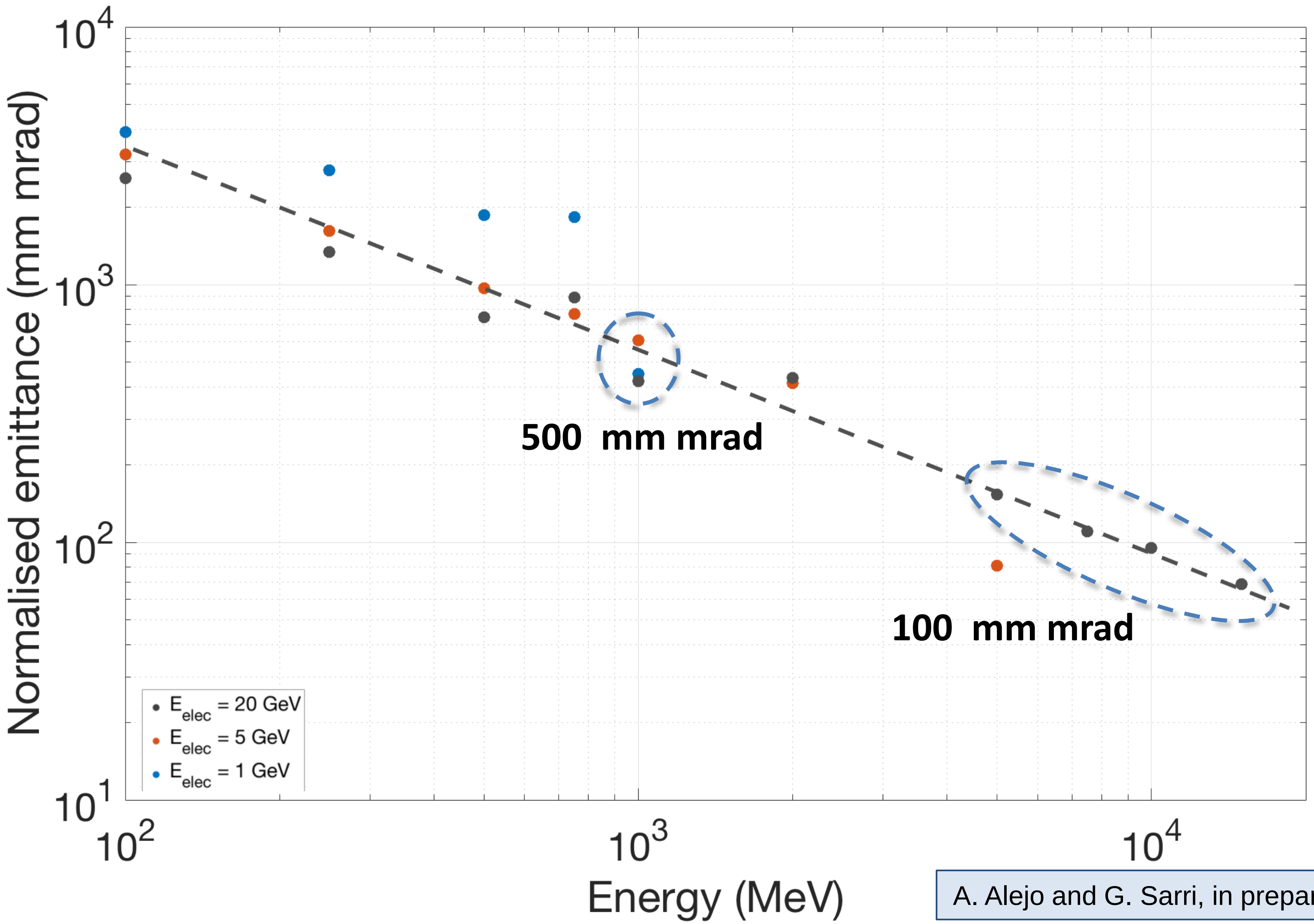
Emittance and Luminosity

Emittance



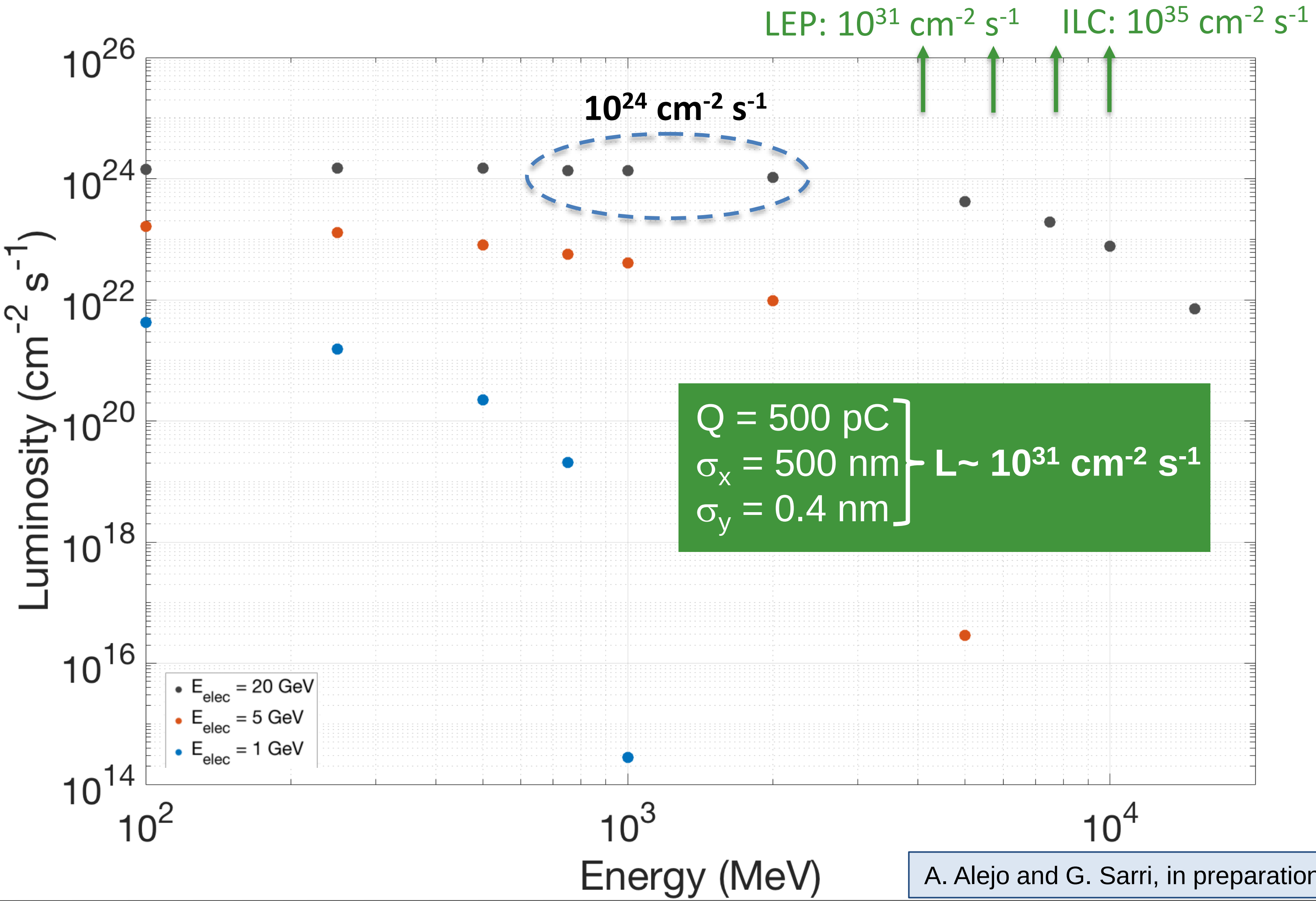
A. Alejo and G. Sarri, in preparation (2018)

Normalised Emittance



A. Alejo and G. Sarri, in preparation (2018)

Luminosity



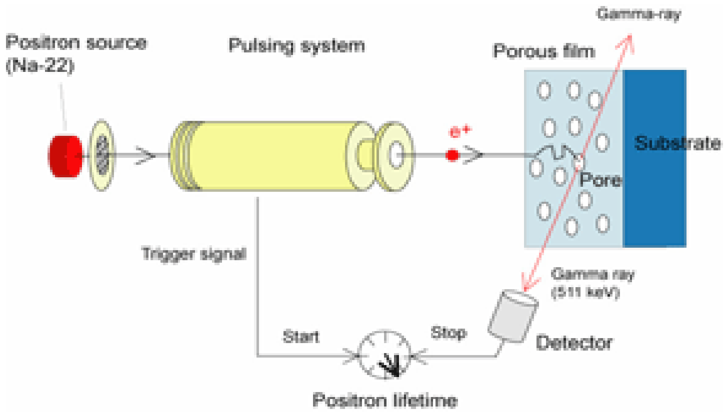
A. Alejo and G. Sarri, in preparation (2018)

Low energy positrons

Low energy source

Low-energy positrons (~ 100 keV) are useful for material testing via Positron Annihilation Spectroscopy (PAS)

Traditional PAS

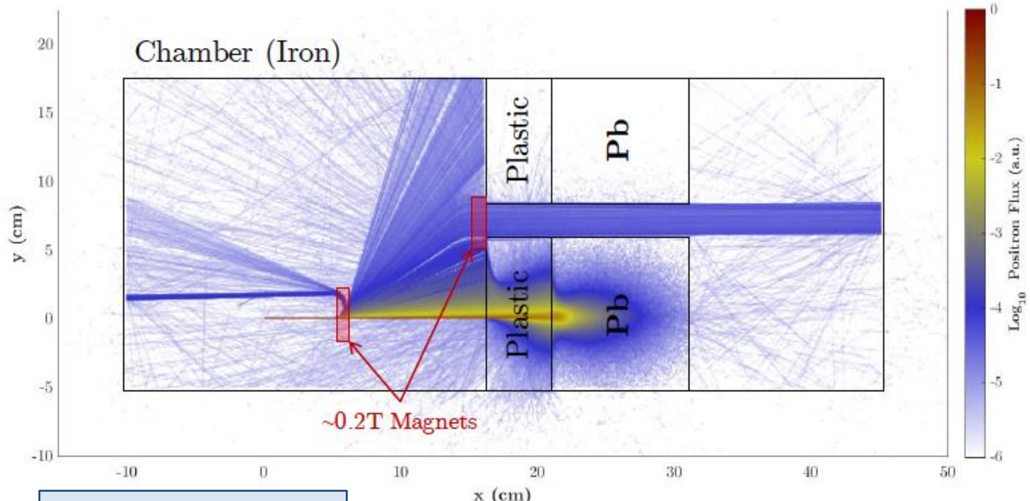


Principle of pulse-beam based PALS system

From FUJI-IMVAC Inc.

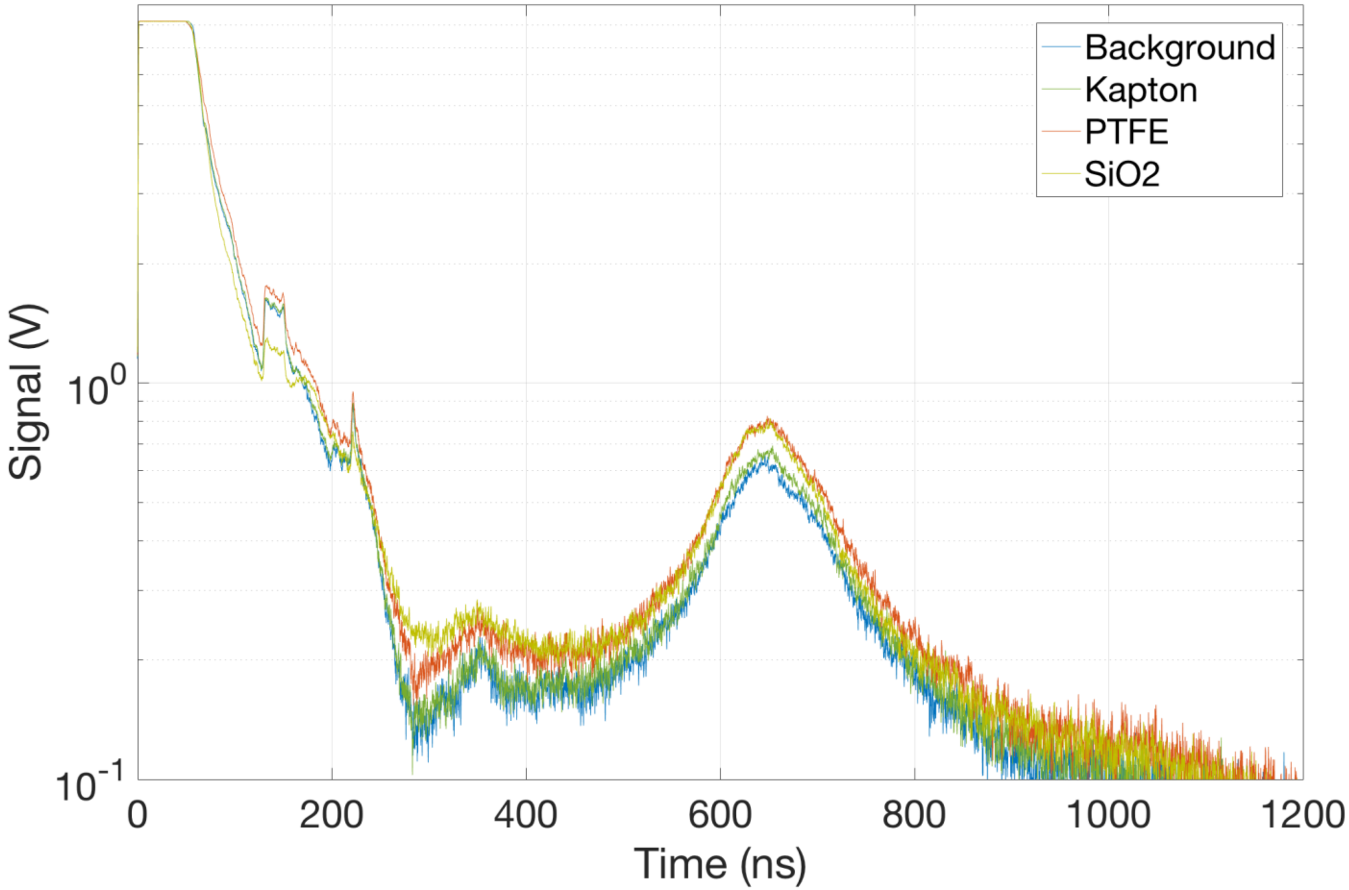
Laser-driven PAS

High-flux and short (~ ps) source of



Courtesy of A. Alejo

Spectroscopy: preliminar!

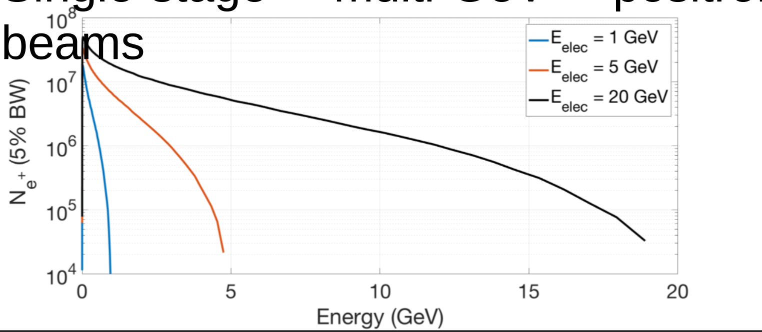


Conclusions

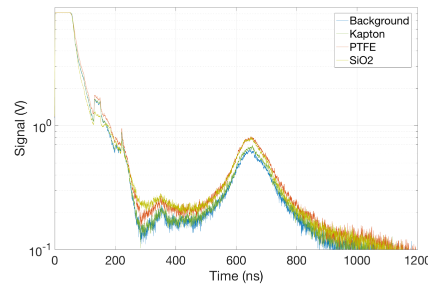
Conclusions

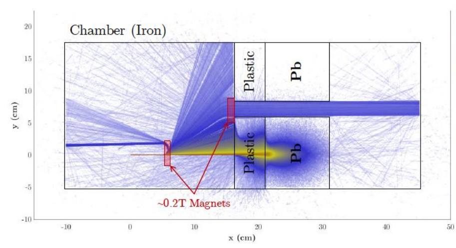
- Laser-wakefield acceleration of electrons provides a good seed for **the generation of high-quality and high-current positron beams**

Single-stage multi-GeV positron beams

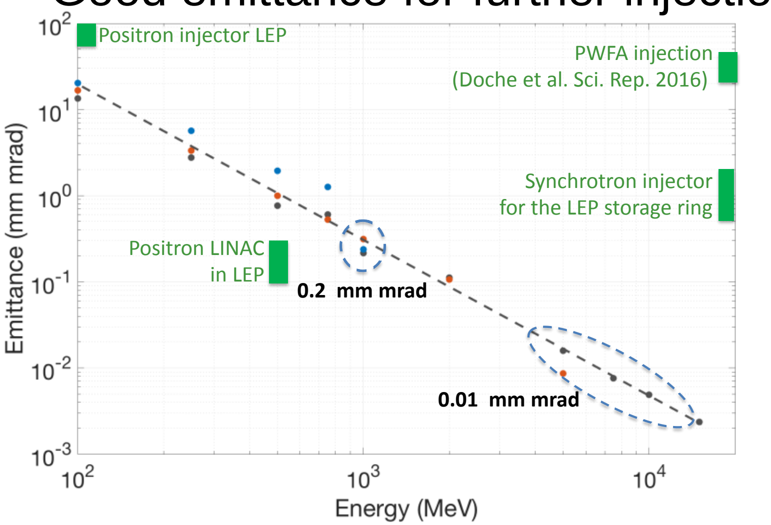


Low-energy positron populations for

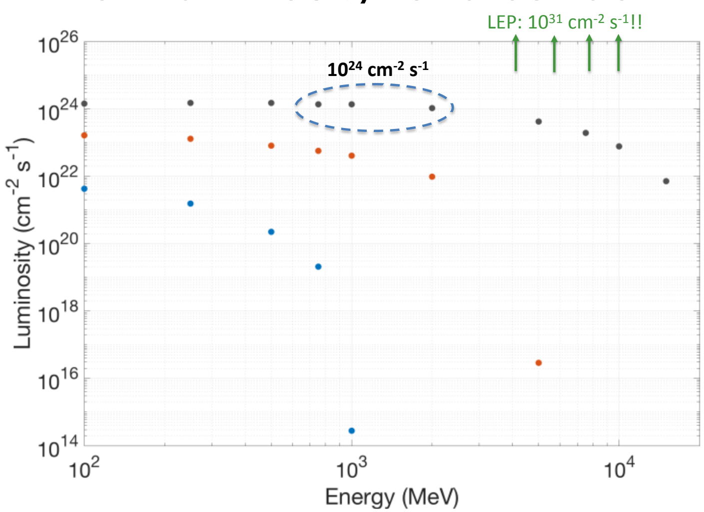




Good emittance for further injection



Low luminosity for a collider?



Thanks for your attention!

Gianluca Sarri
g.sarri@qub.ac.uk