EuPRAXIA solutions
PLANS for a plasma-based accelerator
with high beam quality

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Eu Roadmap - Townhall meeting - 21st May 2021

SCOPE

EuPRAXIA optimization / simulation results
for a GeV accelerator with high beam quality
Work organization

⇩

Lessons drawn

⇩

Plans for a much more demanding accelerator:

- ❑ **Feasibility for beam quality**

  (energy, charge, emittance, energy spread, shape)
- ❑ **Staging**
- ❑ **Numerical codes**
- ❑ **Test facilities**
- ❑ **Work organization and tentative schedule**

EuPRAXIA Consortium (CDR)

16 Participants

25 Associated Partners

Private companies

Published results

Numerical simulations

1. The resonant multi-pulse ionization injection, P. Tomassini, S. De Nicola, L. Labate, P. Londrillo, R. Fedele, D. Terzani, L. A. Gizzi, Physics of Plasmas, 24 , 10, 103120, doi: 10.1063/1.5000696 (2017).
2. Single-stage plasma-based correlated energy spread compensation for ultrahigh 6D brightness electron beams, G.G. Manahan, A.F. Habib et al., Nat. Commun. 8, 15705 doi: 10.1038/ncomms15705 (2017).
3. Electron beam transfer line design for plasma driven Free Electron Lasers, M. Rossetti Conti, A. Bacci, A. Giribono, V. Petrillo, A.R. Rossi, L. Serafini, C. Vaccarezza, Nuclear Inst. and Methods in Physics Research A 909, 84-89 (2018).
4. Design of a 5 GeV Laser Plasma Accelerating Module in the Quasi-linear Regime, X. Li, A. Mosnier, P. A. P. Nghiem, Nuclear Inst. and Methods in Physics Research A 909, 49-53 (2018).
5. Toward Low Energy Spread in Plasma Accelerators in Quasi-linear Regime, X. Li, P. A. P. Nghiem, A. Mosnier, Phys. Rev. Accel. Beams, 21, 111301 (2018).
6. Plasma boosted electron beams for driving Free Electron Lasers, A. R. Rossi et al., Nuclear Inst. and Methods in Physics Research A 909, 54 (2018).
7. Optimization of laser-plasma injector via beam loading effects using ionization-induced injection, P. Lee, G. Maynard, T. L. Audet, B. Cros, R. Lehe and J.-L. Vay, Phys. Rev. Accel. Beams, 21, 052802 (2018).
8. Preserving emittance by matching out and matching in plasma wakefield acceleration stage, X. Li, A. Chancé, P. A. P. Nghiem, Phys. Rev. Accel. Beams, 22, 021304 (2019).
9. Compact multistage plasma-based accelerator design for correlated energy spread compensation, A. Ferran Pousa, A. Martinez de la Ossa, R. Brinkmann, and R. W. Assmann, Phys. Rev. Lett. 123, 054801 (2019).
10. High-quality 5GeV electron bunches with the resonant multi-pulse ionization injection, P. Tomassini, D. Terzani, F. Baffigi, F. Brandi, L. Fulgentini, P. Koester, L. Labate, D. Palla and L. A. Gizzi, Plasma Phys. Controlled Fusion, 62, 014010 (2019).
11. Hybrid LWFA|PWFA Staging as a Beam Energy and Brightness Transformer: Conceptual Design and Simulations, A. Martinez de la Ossa, R. W. Assmann, M. Bussmann, et al., Philos. Trans. Roy. Soc. A, 377, 20180175 (2019).
12. High quality electron bunches for a multi-stage GeV accelerator with the Resonant Multi-Pulse Ionization injection, P. Tomassini, D. Terzani, L. Labate, G. Toci, A. Chancé, P. A. P. Nghiem and L. A. Gizzi, Phys. Rev. Accel. Beams, 22, 111302 (2019).
13. On the use of the envelope model for down-ramp injection in laser-plasma accelerators, T. Silva, A. Helm, J. Vieira, R. Fonseca, and L. O. Silva, Plasma Phys. Controlled Fusion 62, 024001 (2019).
14. Toward a plasma-based accelerator at high beam energy with high beam charge and high beam quality, P. A. P. Nghiem et al., Phys. Rev. Accel. Beams, 23, 031301 (2020).

And others ………….

Beam quality (1)

EuPRAXIA objectives

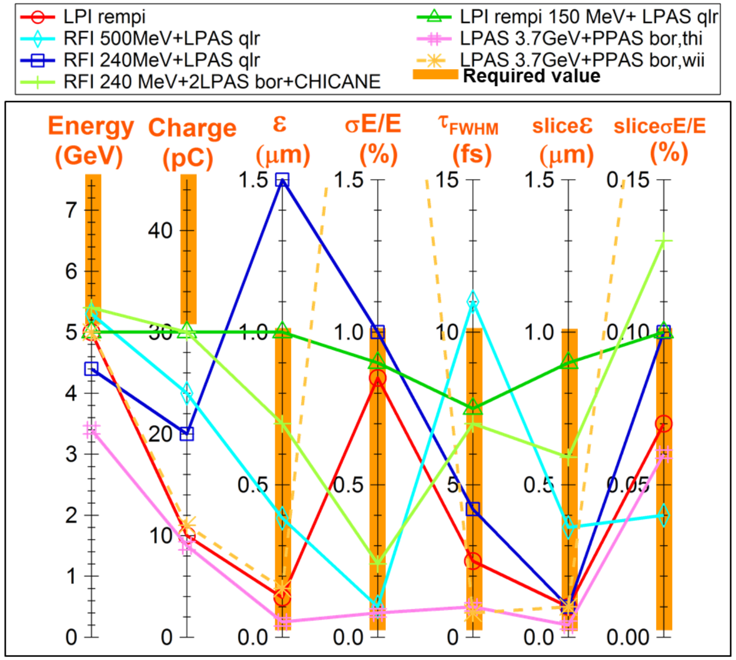
- **High beam energy ≥ 5 GeV**
- **High beam charge ≥ 30 pC**
- **Low beam emittance ≤ 1 µm**
- **Low beam en. spread ≤ 1 %**
- **Low slice emittance ≤ 1 µm**
- **Low slice en. spread ≤ 1 %**

Simultaneously!!

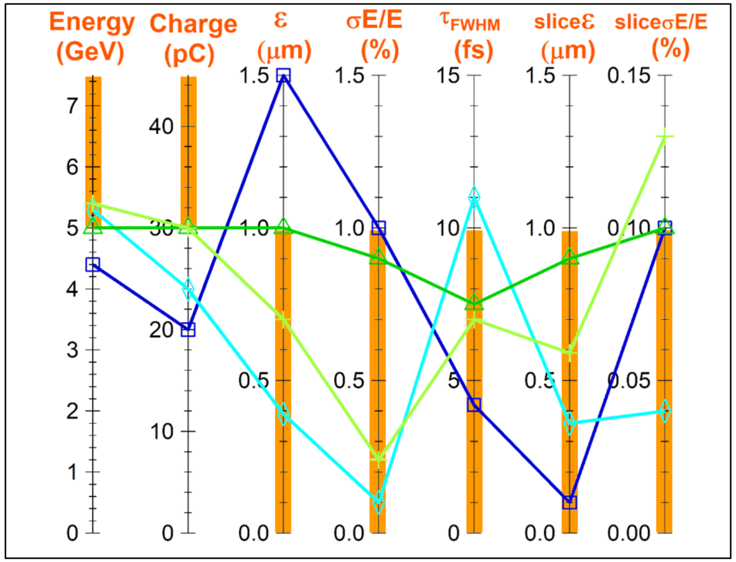
- **High reliability, reproducibility**
- **High repetition rate**
- **User area, 24/7 operation**

Not only at plasma exit
But at user's doorstep

All configurations



Configurations closest to requirements



Beam quality (2)

- ❑ Only procedures aiming to optimize <u>ALL</u> the parameters <u>AT ONCE</u> make sense

- ❑ Successful only with procedures as for conventional accelerators:
  FIRST optimize to obtain the required parameters
  THEN deduce the needed driver (laser, particle beam) and plasma parameters

<u>FEASIBILITY</u> for an HEP accelerator (only electrons)

- Energy ~ tens GeV seem OK (with staging)
- Emittance and En. spread seem OK
- Transverse beam shape could be managed by transport lines
- Beam length shorter than HEP requirements by a factor of 100 to 1000
- Beam charge remain to be improved by a factor of 10 or 100

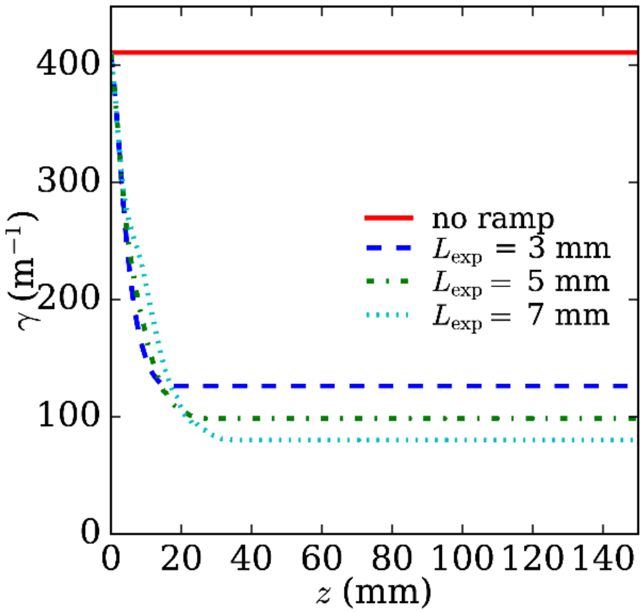
→ ? consider: an array of 10 plasma-based accelerators with beams shifted in time ?

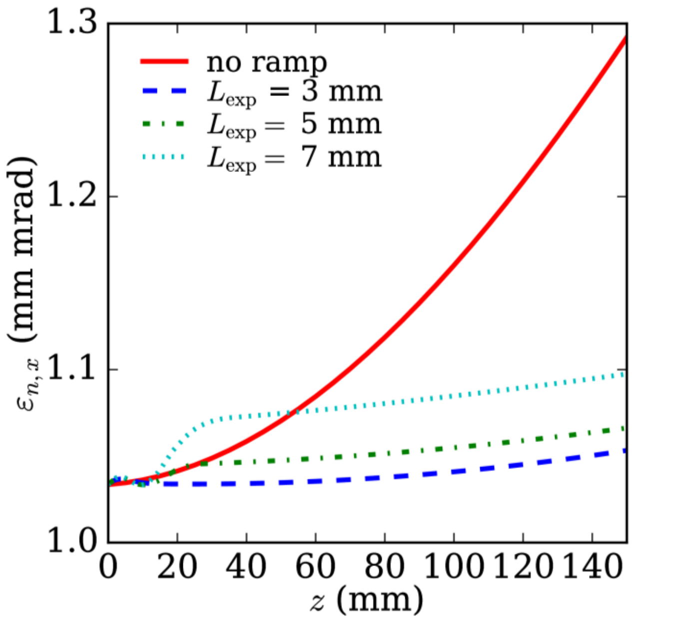
Staging and Transfer Lines (1)

To minimize emittance growth, <u>it is imperative to</u>:

1 **Tune the ramp length (whatever its shape)**

⇒ Minimizing Twiss γ ⇒ Minimizing emittance growth



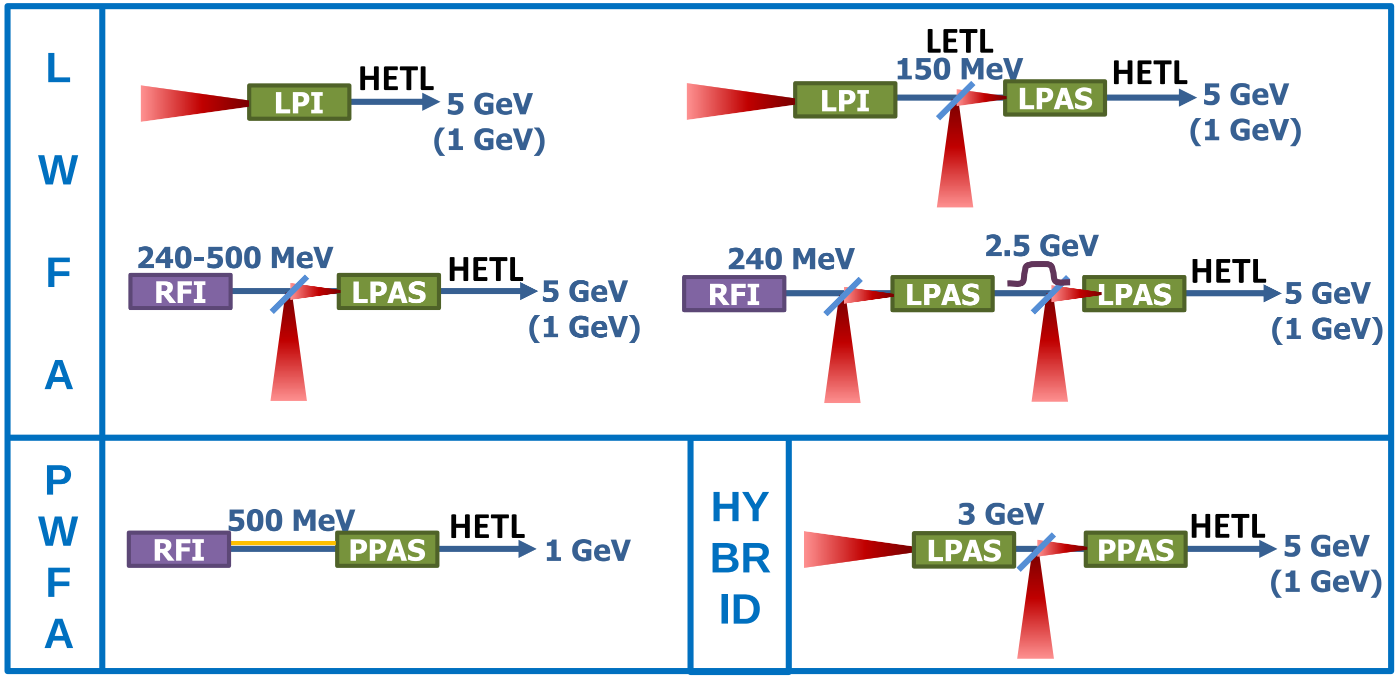


2 **Design transport lines where number of quadrupoles = number of constraints (as few quadrupoles as possible!)**

➔ **20% emittance growth through injection, acceleration, extraction and transfer to FEL users**

Phys. Rev. Accel. Beams, 22, 021304 (2019).

Staging and Transfer Lines (2)



EuPRAXIA configurations

Beam injection, acceleration, extraction and transfer can be well done only when

- **It is studied by the SAME team**
- **with DOUBLE expertise in plasma acceleration and conventional accelerator**

Numerical codes

During EuPRAXIA CDR, many numerical codes

Warp, OSIRIS, SMILEI, CALDER-C, FBIC, QFluid, ALaDYN, VSim, etc.

ASTRA, Tstep, Elegant, Architect, CSRtrack, TraceWin, etc.

used by
21 physicists
11 European institutes

- **Plasma-acceleration codes are consistent between them**
- **No problem to connect plasma-acceleration & conventional-accelerator codes**

Searching for a S2E code connecting automatically these two does not make sense :

- **their run times are totally different (weeks < > microseconds)**
- **we know what are the required parameters at the entrance and exit of each section**

In view of a plasma-based accelerator, every numerical code should offer 3 operating modes:

- **Complete, precise, and detailed mode**
- **Rapid mode, like envelope or symmetrical modes, for rapid optimizations to guide more detailed calculations in a next step**
- **Intermediate mode, like rapid mode, but with possibilities of small departures from symmetry to study errors and tolerances**

Work organization

To process plasma acceleration into plasma-based accelerator:

- **Equal involvement of the two communities, plasma and conventional accelerator**
- **Beam physics should be managed by a single team with double expertise**
- **Strong collaboration between simulators and experimenters, to make simulated and measured results consistent**

Tentative schedule

❑ **T = 0 + 3 years**

Organize studies on existing facilities or in project, so that there are equal involvement of plasma and conventional communities, equal involvement of simulations and experiments. Inventory and select the most suitable applications for an intermediate accelerator (e.g. 10 GeV energy, 100 pC charge, 1 mm.mrad emittance, 1% energy spread).

❑ **T = 0 + 6 years**

Carry out the design of an intermediate accelerator with all parameters as required above. A multiple-stage structure is recommended. An array of plasma accelerators to be considered.

Output → Deliverable for LDG

❑ **T = 0 + 9 years**

Fabricate then exploit and improve the intermediate accelerator designed previously. Serving beam to applications is the main objective, but with time reserved for machine studies.

❑ **T = 0 + 10 years**

Start carrying out the concept of an accelerator, serving HEP applications, with all the properties of beam energy and qualities as required by this ultimate application.