Horizon 2020 EuPRAXIA design study

Paul Andreas Walker (DESY)
On behalf of the EuPRAXIA collaboration team
8th International Particle Accelerator Conference
May 16th, 2017, Copenhagen, Denmark
EuPRAXIA is a **conceptual design study** for a **5 GeV electron plasma accelerator** as an European research infrastructure.

- 125 scientists work in 38 international partners
  - 16 EU laboratories are beneficiaries
  - 22 associated partners contribute in-kind

EuPRAXIA is an EU Horizon 2020 project

- One of two accelerator related design studies funded, other is EuroCirCol (FCC) from CERN

Develop plasma technology for user readiness:

- Incorporate established accelerator technology for optimal quality
- Combine expertise from accelerator and laser labs, industry, and international partners
• 15 scientific reports produced in first 18 months

• Final Conceptual Design Report published in October 2019
Livingston Curve
EuPRAXIA as stepping stone to users readiness

Future goals
- Discovery
- Higgs/Precision
- Free-Electron Lasers

Maximum Beam Energy [eV]

- beam-driven e⁻ plasma acc.
- p storage rings
- e⁺ and/or e⁻ accelerators (storage rings, linacs, FEL's)
- laser-driven e⁻ plasma acceleration

Year

- Ising & Widerøe
- Tajima & Dawson
- Mouro & Strickland (CPA)

R. W. Assmann
F3iA, 12/2016

P. A. Walker (DESY) - IPAC 2017 - Copenhagen, 16th May 2017
Plasma accelerators reach energy regime of ongoing construction projects
Acc. length of 9 cm instead of 100 m for multi GeV \( e^- \) beams [1]
EuPRAXIA is **required stepping stone** to bring plasma accelerators to user readiness

Why use plasma accelerators?

• RF accelerators are an amazing success story: 30,000 accelerators are in use all over the world (started by R. Widerøe 90 years ago)
• Many further applications imaginable but some are constrained by practical concerns such as size and cost
• Plasma accelerator techniques offer an innovative path to reduced size and cost with applications such as:
  • Ultra-compact FEL’s at universities
  • Laser-driven electron beams as medical imaging sources in hospitals
  • Compact electron irradiation
  • Portable industrial appl. for X-ray inspections
  • HEP table-top test beams
  • Compact plasma HEP collider
• “Compact/table-top” sources = 10’s of meters rather than a kilometer (fits on a trailer of a truck)
Plasma accelerator concepts: example one

- Plasma accelerators can be driven by lasers or electron beams
- EuPRAXIA studies 5 different approaches
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![Plasma Accelerator Diagram]
Plasma accelerator concepts: example one

- Plasma accelerators can be driven by lasers or electron beams
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Plasma accelerators can be driven by lasers or electron beams

EuPRAXIA studies 5 different approaches
1) RF electron injector + laser plasma accelerator (LPA)  
(LWFA with external injection from an RF accelerator)
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2) LPA with electron bunch created in plasma directly  
(LWFA with internal injection)
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3) LPA electron injector + LPA  
(LWFA with external injection from a LPA)  

4) RF electron bunch as beam driver in LPA  
(PWFA with an RF electron beam)  

Laser beam  ➜ Electron beam
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(LWFA with external injection from an RF accelerator)

2) LPA with electron bunch created in plasma directly  
(LWFA with internal injection)

3) LPA electron injector + LPA  
(LWFA with external injection from a LPA)

4) RF electron bunch as beam driver in LPA  
(PWFA with an RF electron beam)

5) RF electron bunch as driver in a hybrid stage  
(PWFA with LWFA produced electron beam or Trojan Horse scheme)
• Science & practical considerations will determine final choice of configuration(s)
• EuPRAXIA layout is being optimized for best synergy of lasers & RF technology
• Electron and X-ray parameter in a nutshell:
  • 5 GeV electron beam
  • 1 – 0.1 nm FEL radiation
• Detailed tables of electron and X-ray parameter exist

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Symbol</th>
<th>Baseline value</th>
<th>Range of exploration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Lower limit</td>
</tr>
<tr>
<td>Particle type</td>
<td>e-</td>
<td>Electrons</td>
<td>Electrons</td>
</tr>
<tr>
<td>Energy</td>
<td>E</td>
<td>5 GeV</td>
<td>5 GeV</td>
</tr>
<tr>
<td>Charge</td>
<td>Q</td>
<td>30 pC</td>
<td>15 pC</td>
</tr>
<tr>
<td>Bunch length (FWHM)</td>
<td>τ</td>
<td>10 fs</td>
<td>3 fs</td>
</tr>
<tr>
<td>Peak current</td>
<td>I</td>
<td>3 kA</td>
<td>3-5 kA</td>
</tr>
<tr>
<td>Repetition rate</td>
<td>f</td>
<td>10 Hz</td>
<td>1 Hz</td>
</tr>
<tr>
<td>Number of bunches</td>
<td>N</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Total energy spread (RMS)</td>
<td>σ₁/E</td>
<td>1%</td>
<td>1 %</td>
</tr>
<tr>
<td>Slice energy spread (RMS)</td>
<td>σₑₑ₁/E</td>
<td>0.1 %</td>
<td>0.1 %</td>
</tr>
<tr>
<td>Transverse normalized emittance</td>
<td>$\varepsilon_{N,x}$, $\varepsilon_{N,y}$</td>
<td>1 mm mmrad</td>
<td>1 mm mmrad</td>
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• EuPRAXIA will be a low power accelerator aiming at high quality (later higher rep. rate)
EuPRAxIA simulations

- It is a design study:
  - Simulations and design work at the core of this project
  - Goal is start to end simulations, demonstrating required performance
  - Various codes being used

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Á. Ferran Pousa, R. Assmann, A. Martinez de la Ossa. IPAC17 paper TUPIK007.
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Initial electron beam:
- \( E = 100 \text{ MeV} \),
- Relative energy spread = 0.1 %
- Norm. trans. emittance = 1 mm mrad
- \( Q = 1 \text{ pC}, \tau = 3.3 \text{ fs (rms)}, \sigma_x = 1.3 \text{ \mu m} \)

Laser pulse:
- \( a_0 = 3.1, \lambda = 800 \text{ nm}, l_{\text{FWHM}} = 100 \text{ fs}, \)
- \( w_0 = 54 \text{ \mu m}, E = 100 \text{ J}, 1 \text{ PW peak power} \)

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The acceleration regime:
close to blowout
2D simulation: the 3D animation was made assuming cylindrical symmetry

**Plasma:**
Density = 1.2 x 10^{17} \text{ cm}^{-3}
Length = 2.5 \text{ cm}

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Electron density

\[ E_{\text{acc}} \approx 100 \text{ GV/m} \]

Á. Ferran Pouza, R. Assmann, A. Martinez de la Ossa. IPAC17 paper TUPIK007.
EuPRAKXI simulations

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Electron beam after plasma:
Energy = 1 GeV (initial 100 MeV)
Relative energy spread = 1.5% (initial 0.1 %)
Normalized emittance = 0.995 μrad m
(initial 0.99 μrad m)

Á. Ferran Pousa, R. Assmann, A. Martinez de la Ossa. IPAC17 paper TUPIK007.
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• Of particular importance is the sensitivity to **initial fluctuations**
  • plasma density
  • alignment
  • particle beams
  • laser pulses

• **Use of realistic profiles**
  • Simulation work package is identifying the role of non-standard laser profiles such as non pure Gaussean beams:

\[
I(\rho) = I_0 \exp\left[-\left(\frac{\rho}{w}\right)^\alpha\right]
\]

I = laser intensity, \(\rho\) = distance, \(w\) = transverse size, \(\alpha = 2\) (Gaussian), \(\alpha > 2\) (“top-hat”)
Layout proposal combining all configurations

3D design by Dariusz Kocoń (ELI-Beams)

P. A. Walker (DESY) - IPAC 2017 - Copenhagen, 16th May 2017
Layout proposal combining all configurations

See poster: B. Cros et al., ‘Electron injector for multi-stage laser-driven plasma accelerators’, IPAC’17, WEPVA001

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Accelerator research, undulators and user areas are located on the first level.

See poster: P.A.Walker et al., ‘Layout and space considerations for EuPRAXIA’, IPAC’17, TUPIK012
The “100 cube laser challenge”:

- “100 cube” = 100 J, 100 fs, 100 Hz
  => 1PW @ 100Hz
- Not a complete Ti:Sa laser system
- Diode-pumped solid-state laser scheme
- 2nd laser system (Ti:Sa) operates at lower energy and shorter pulse length
Is EuPRAXIA Accelerator Really Compact?

- Detailed estimates of required space are ongoing:
  - Acc. tunnel + infrastructure **about 300 – 600 m² for 5 GeV** (depending on conf.)
  - Potential **factor of 5-10 footprint reduction** compared to RF based electron linac
  - Reduced footprint has potential to open many additional applications

- **Sufficient beam quality** required which is **central goal of EuPRAXIA**
  - Improve energy spread ("beam loading" [3] or "modulated plasma density" [4])

- **EuPRAXIA will initially be low power and low wall-plug power efficiency**
  - Efforts with industry and laser institutes to improve rep. rate & efficiency of currently used laser systems (also incorporate fiber-based lasers with 30 % eff.)

- **EuPRAXIA report will be technical design report and project proposal:**
  - Performance, required tolerances, footprint and cost will be assessed
  - We **hope for significant cost benefit** from this new technology

• EuPRAXIA design study is site independent

• Five possible sites have been discussed so far

• We invite the suggestions of additional sites
• EuPRAXIA is preparing **conceptual design for a European research facility** with applications in science, industry & medicine.

• Provide a **5 GeV electron beam** based on a laser and/or a beam driven **plasma acceleration** approach.

• Design will include user areas for **FEL radiation**, “table-top” **test beam for HEP detectors tests**, and **compact X-ray source** for medical imaging.

• This is a Horizon 2020 project and we acknowledged the essential support from the EU.

• Please visit posters for more details:
  • Á. Ferran Pousa, “Visualization code”, **TUPIK007**
  • P. A. Walker, “EuPAXIA Layout”, **TUPIK012**
  • F. Filippi et al., “Gas-filled capillaries” **TUPIK023**
  • B. Cros et al., ”Electron injector”, **WEPVA001**
The EuPRAXIA team


www.eupraxia-project.eu