EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

EuPRAXIA

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

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 653782.

- 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

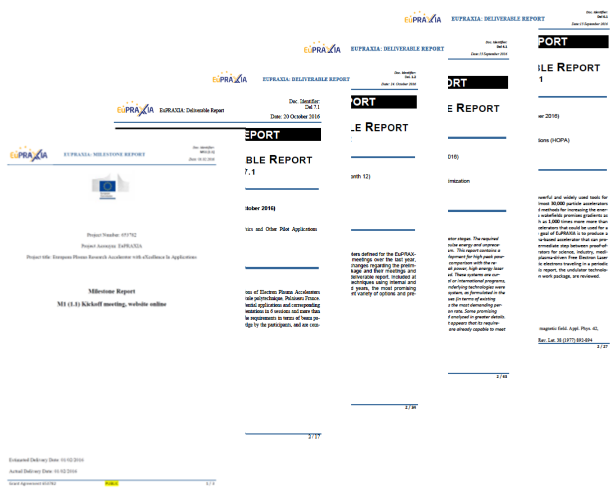
- EuPRAXIA is an EU Horizon 2020 project
  - One of two accelerator related design studies funded, other is EuroCirCol (FCC) from CERN

- Develop plasma technology for user readiness:
  - Incorporate established accelerator technology for optimal quality
  - Combine expertise from accelerator and laser labs, industry, and international partners

European Plasma Research Accelerator with eXellence In Applications

Horizon 2020

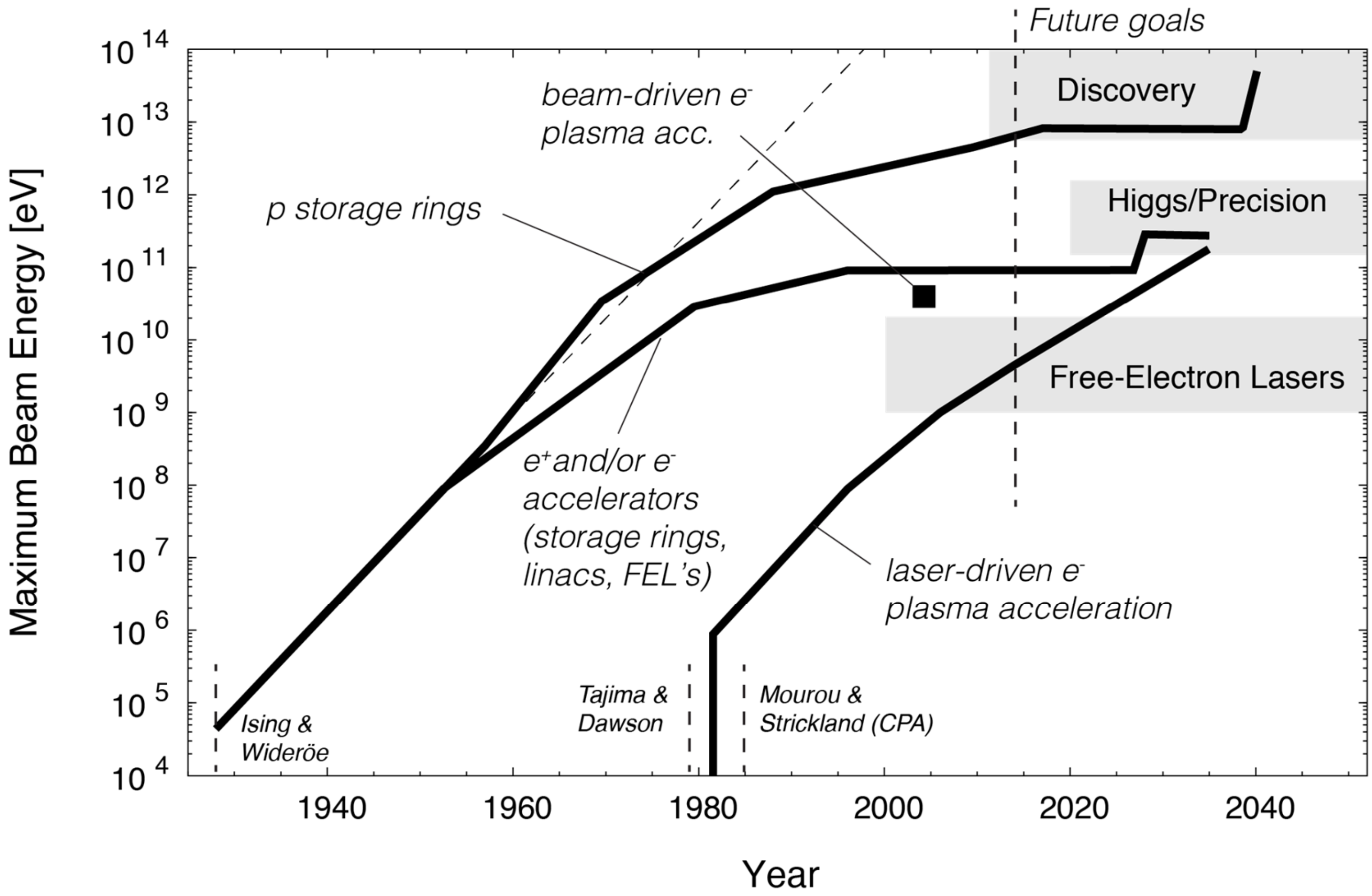
- 15 scientific reports produced in first 18 months



- Final **Conceptual Design Report** published in **October 2019**

Livingston Curve

EuPRAXIA as stepping stone to users readiness



R. W. Assmann
F3iA, 12/2016

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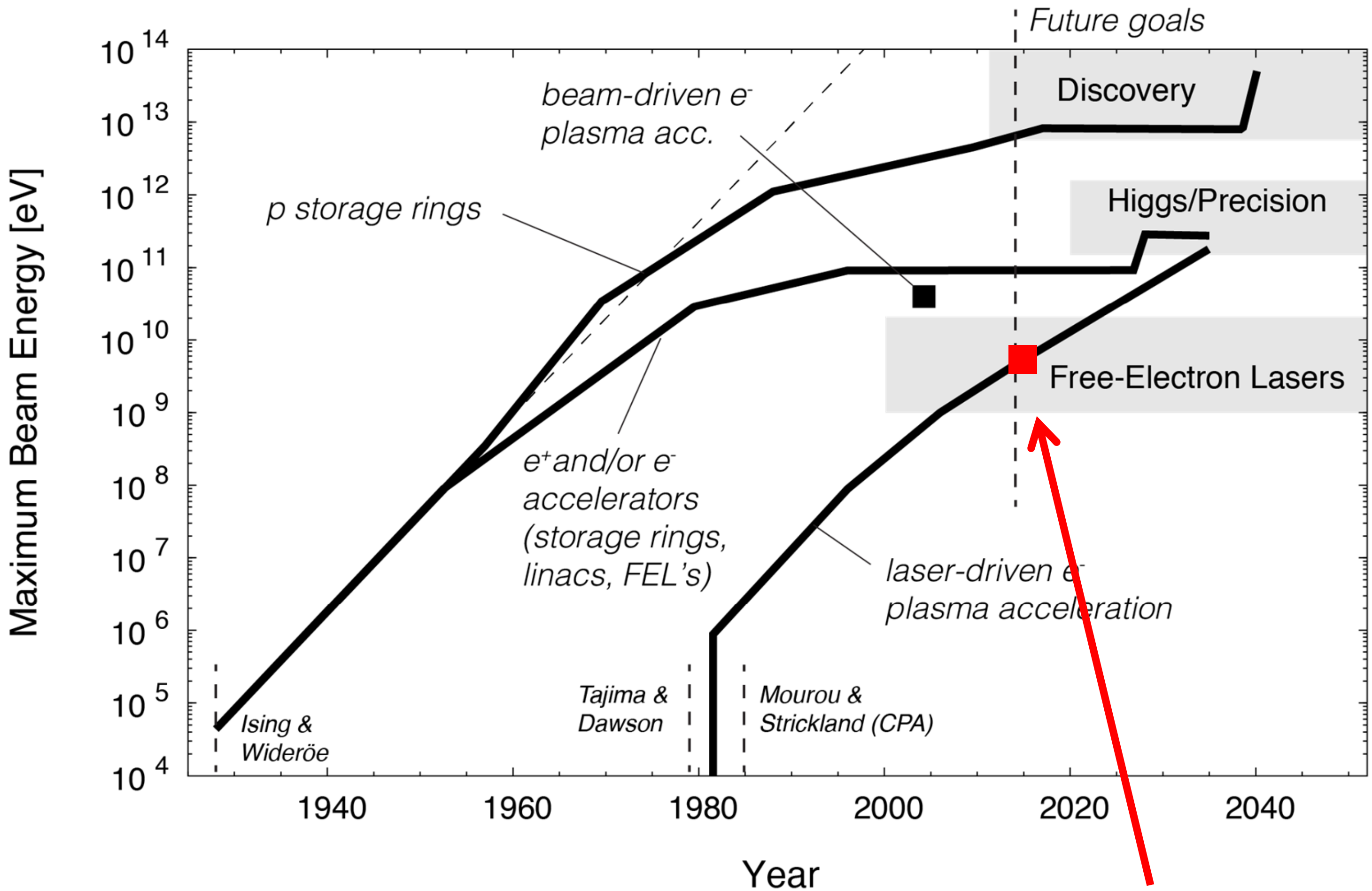

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- Plasma accelerators reach energy regime of ongoing construction projects
- Acc. length of 9 cm instead of 100 m for multi GeV e^- beams [1]
- EuPRAXIA is **required stepping stone** to bring plasma accelerators to user readiness

[1] Leemans et al., Phys. Rev. Lett. 113, 245002 (2014)

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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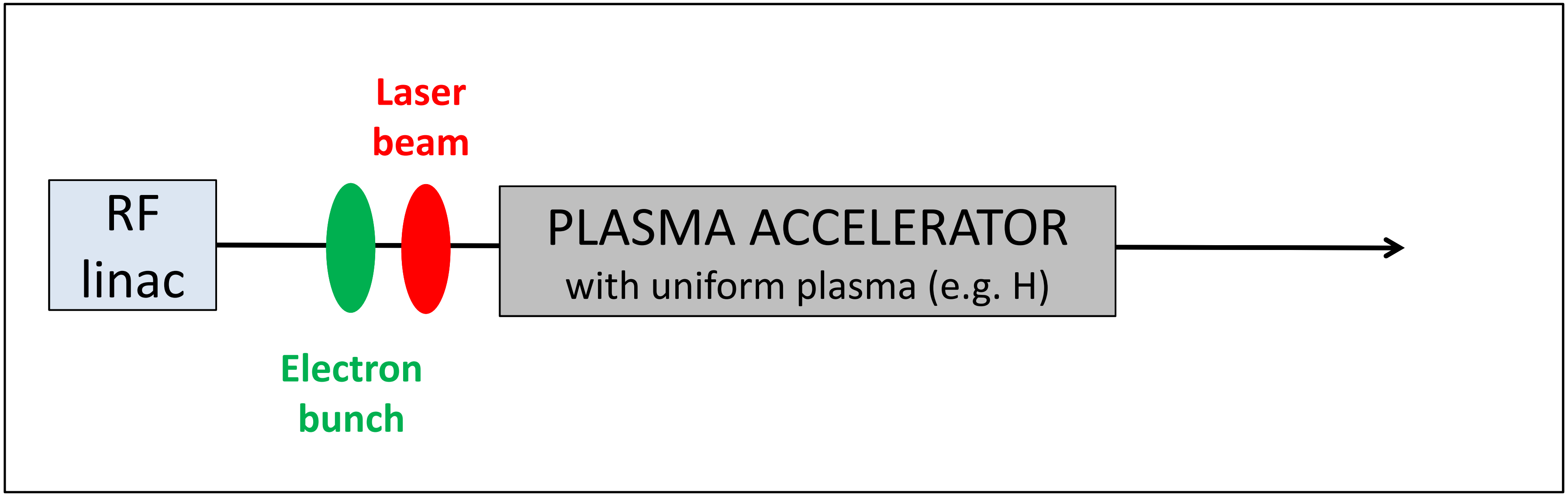

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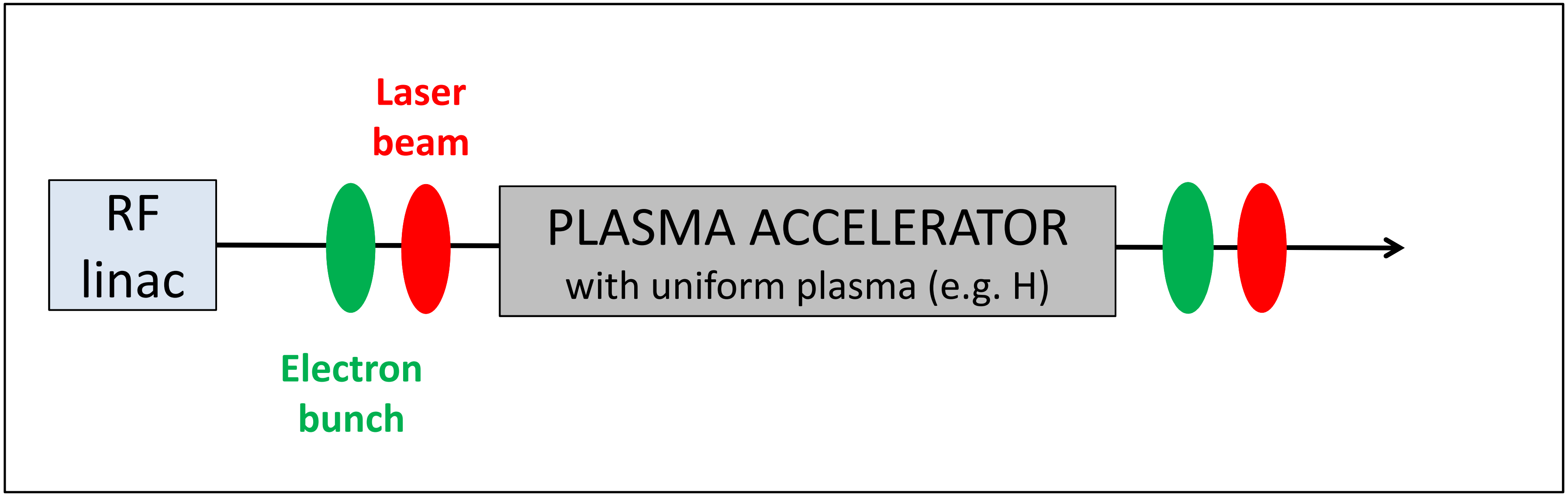

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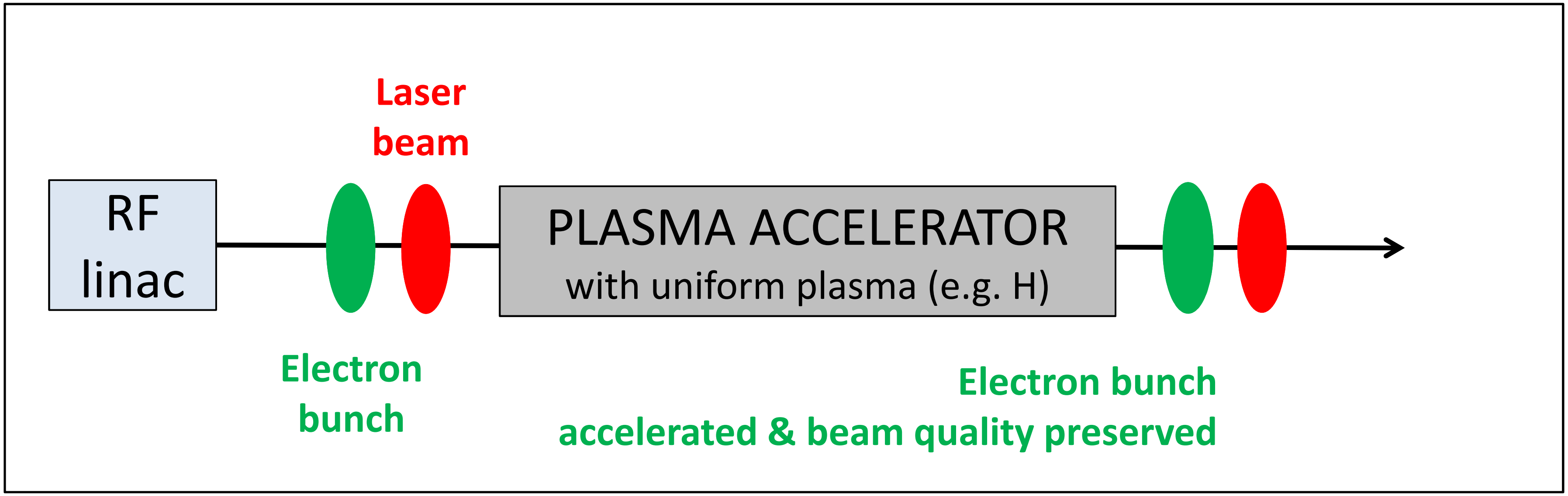

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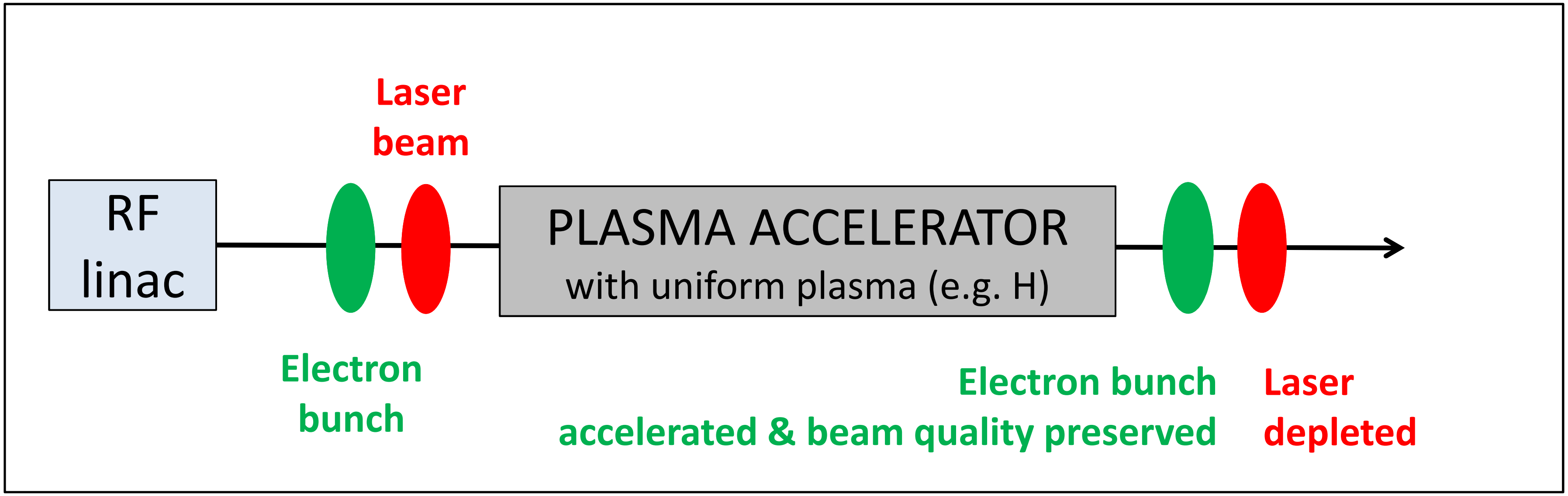

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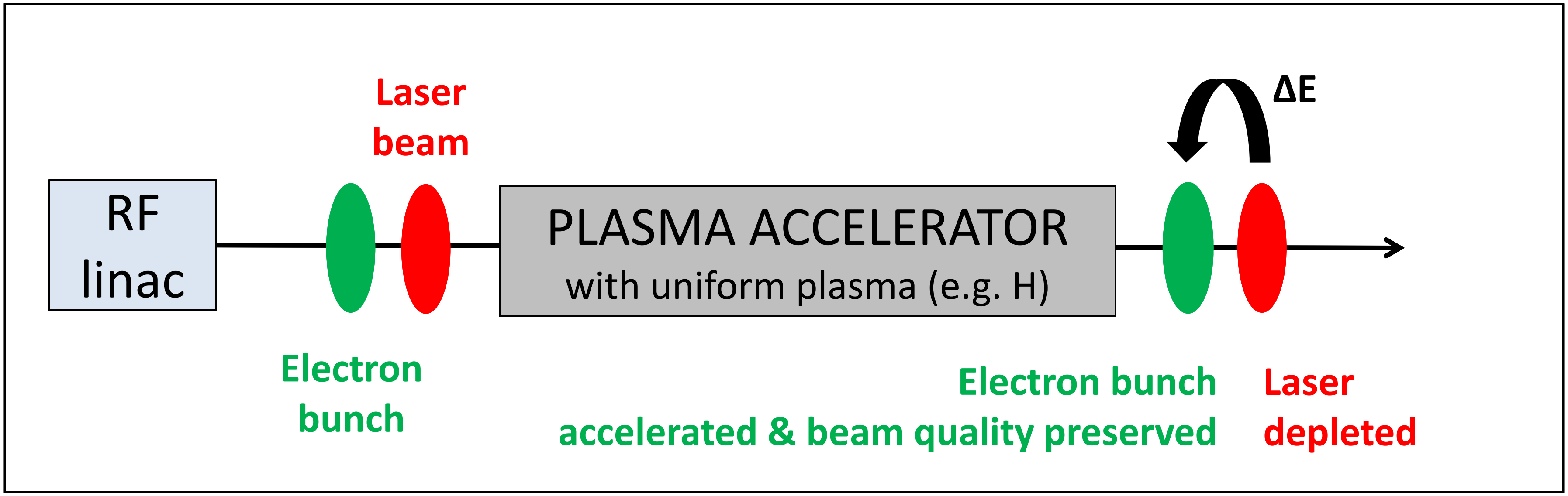
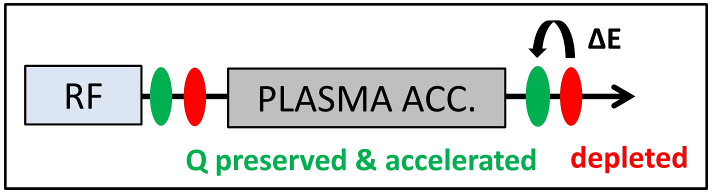
100 GV/m



1) RF electron injector + laser plasma accelerator (LPA)
(LWFA with external injection from an RF accelerator)



Laser beam Electron beam

The 5 EuPRAXIA configurations

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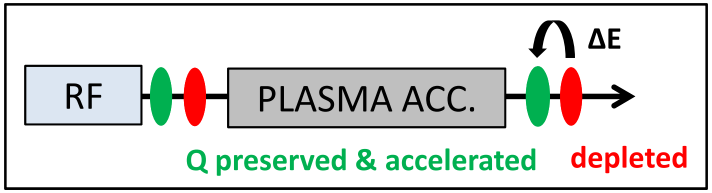
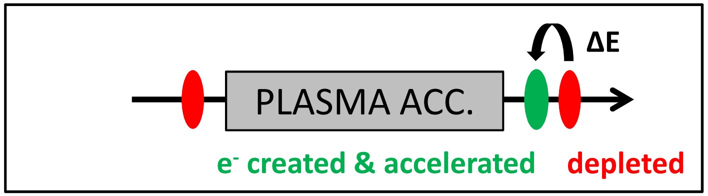


2) LPA with electron bunch created in plasma directly
(LWFA with internal injection)



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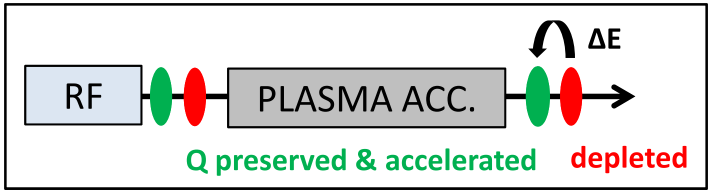

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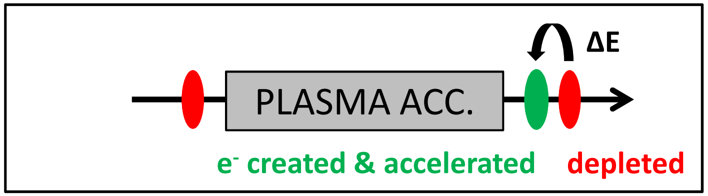

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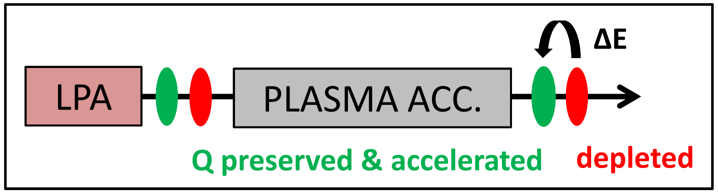

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EuPRAXIA Plasma Accelerator Scheme

The 5 EuPRAXIA configurations

Horizon 2020

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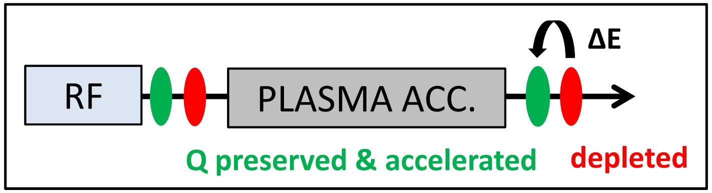

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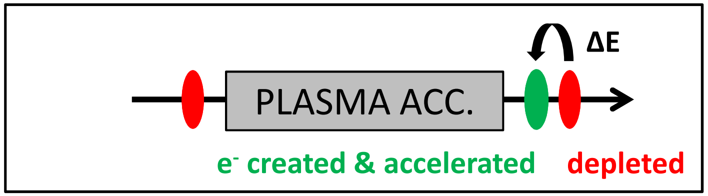

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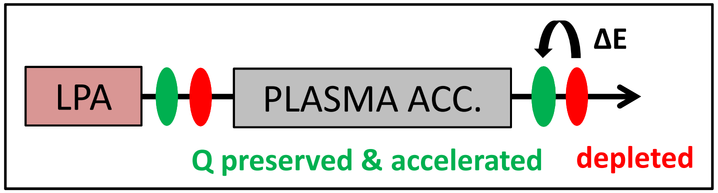
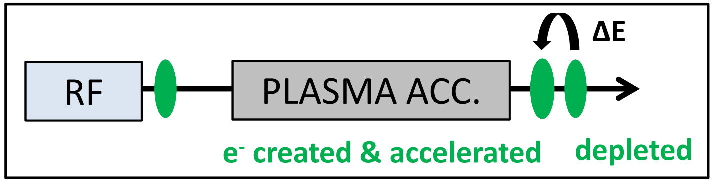


4) RF electron bunch as beam driver in LPA

(PWFA with an RF electron beam)



Laser beam Electron beam

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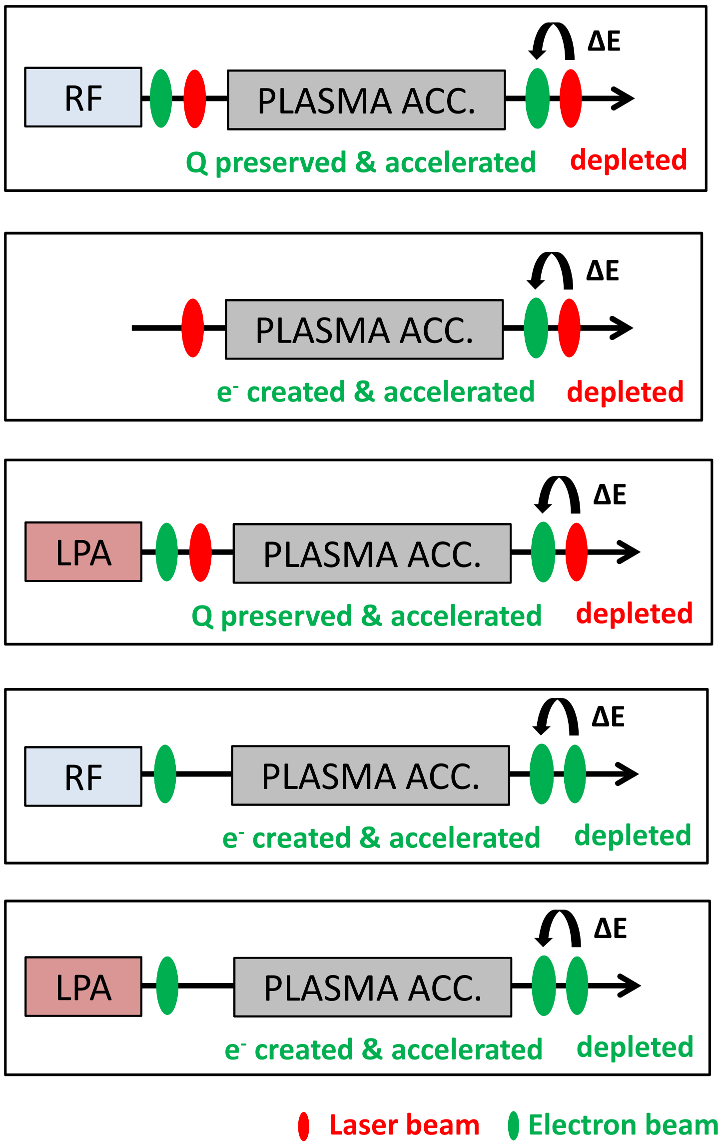
(LWFA with external injection from an RF accelerator)

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)

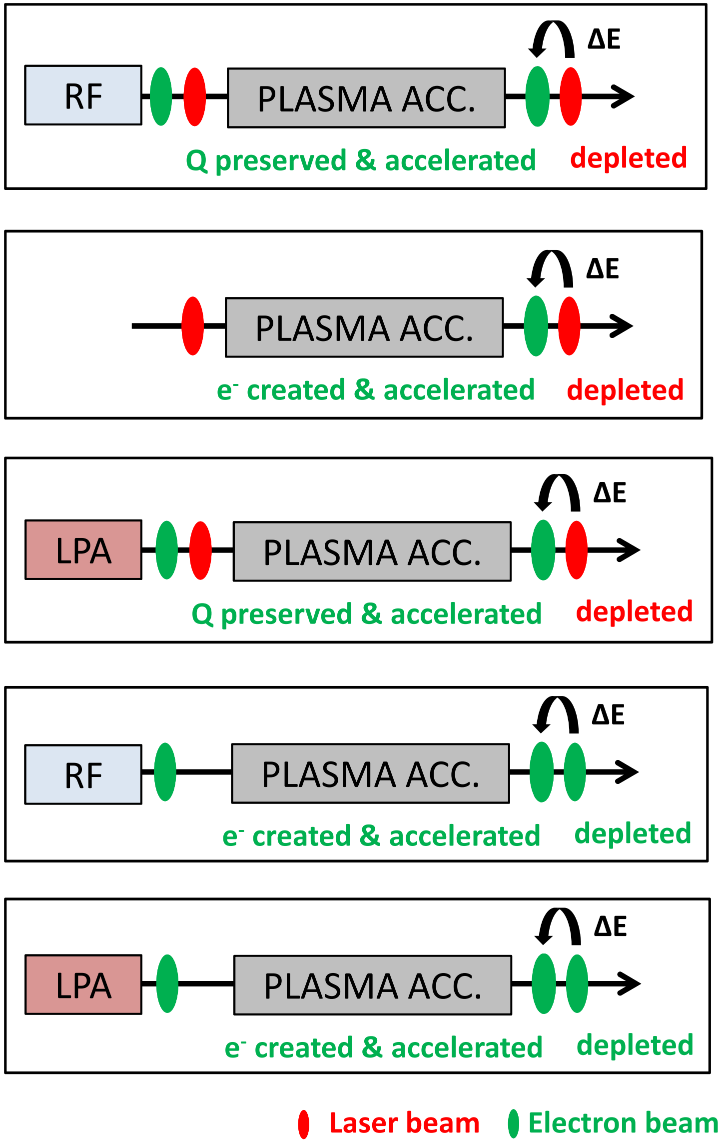
4) RF electron bunch as beam driver in LPA
(PWFA with an RF electron beam)

5) RF electron bunch as driver in a hybrid stage
(PWFA with LWFA produced electron beam or Trojan Horse scheme)



The 5 EuPRAXIA configurations

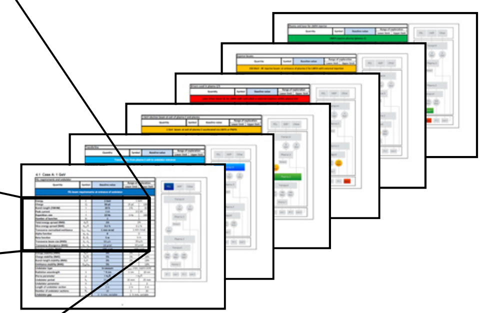
- Science & practical considerations will determine final choice of configuration(s)
- EuPRAXIA layout is being optimized for best synergy of lasers & RF technology



Target study parameter for electron and X-ray beams

- 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

Quantity	Symbol	Baseline value	Range of exploration	
			Lower limit	Upper limit
Particle type	e-	Electrons	Electrons	
Energy	E	5 GeV	5 GeV	
Charge	Q	30 pC	15 pC	100 pC
Bunch length (FWHM)	τ	10 fs	3 fs	30 fs
Peak current	I	3 kA	3-5 kA	
Repetition rate	f	10 Hz	1 Hz	100 Hz
Number of bunches	N	1	1	
Total energy spread (RMS)	σ_E/E	1%	1 %	
Slice energy spread (RMS)	$\sigma_{E,S}/E$	0.1 %	0.1 %	
Transverse normalized emittance	$\varepsilon_{N,x}$, $\varepsilon_{N,y}$	1 mm mrad	1 mm mrad	



- EuPRAXIA will be a low power accelerator aiming at high quality (later higher rep. rate)

EuPRAXIA Deliverable Report 1.2 “Report defining preliminary study concept”, 30. October 2016

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

PIC code used	Users
OSIRIS	IST, DESY
WARP	CNRS/LPGP, CEA
CALDER-Circ	LOA
SMILEI	CNRS/LLR
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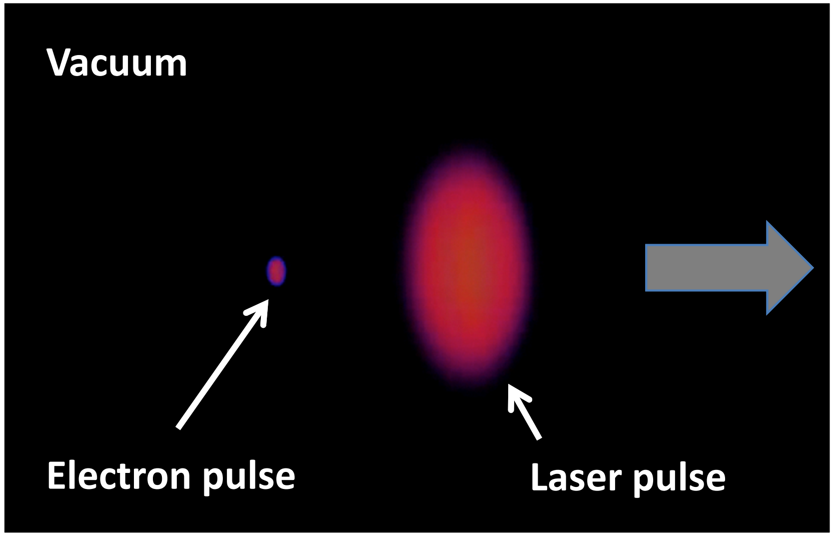
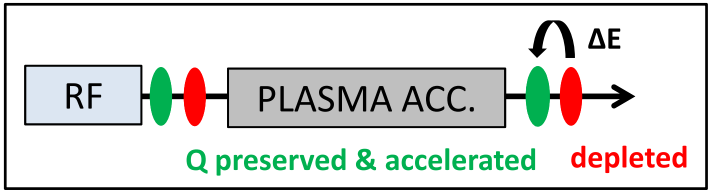
PIConGPU	DESY





*Á. Ferran Pousa, R. Assmann, A. Martinez de la Ossa. IPAC17 paper **TUPIK007**.*

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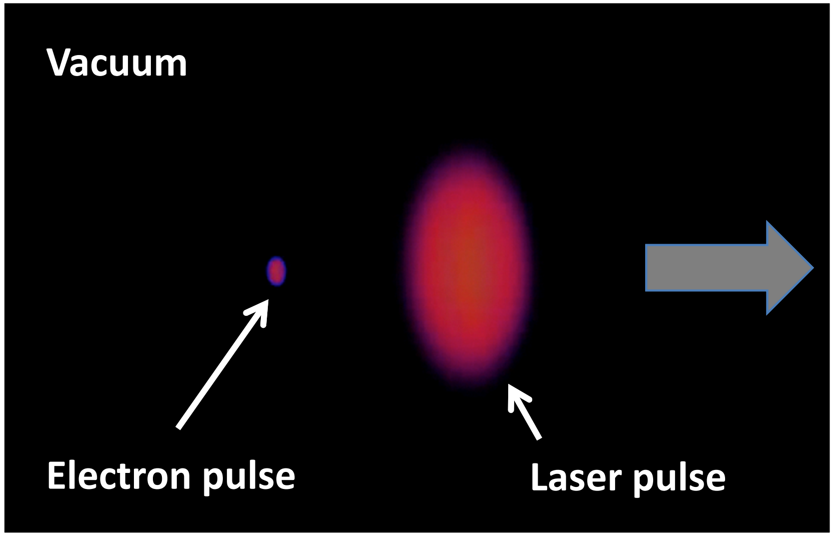

Initial electron beam:
E = **100 MeV**,
Relative energy spread = **0.1 %**
Norm. trans. emittance = **1 mm mrad**
Q = 1 pC, τ = 3.3 fs (rms), σ_x = 1.3 µm

Laser pulse:
a_0 = 3.1, λ = 800 nm, I_{FWHM} = 100 fs,
w_0 = 54 µ m, E = 100 J, 1 PW peak power

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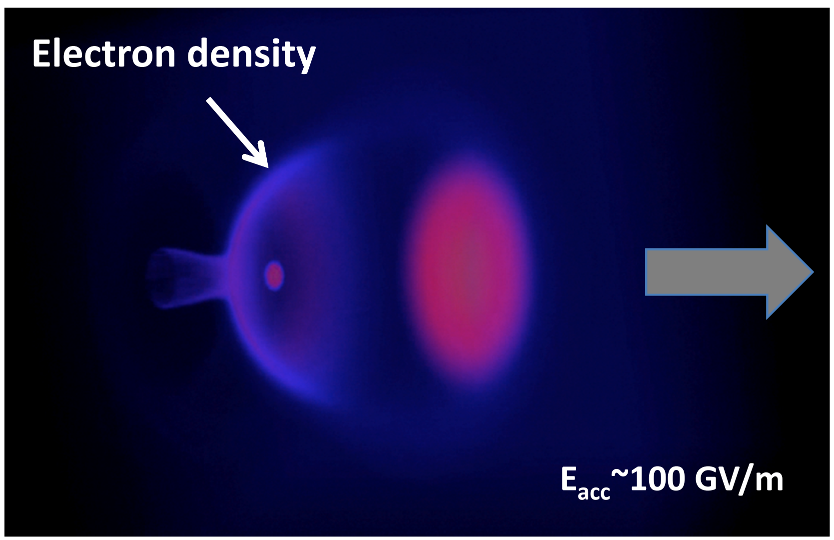

The acceleration regime:
close to blowout
2D simulation: the 3D animation was made assuming cylindrical symmetry

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

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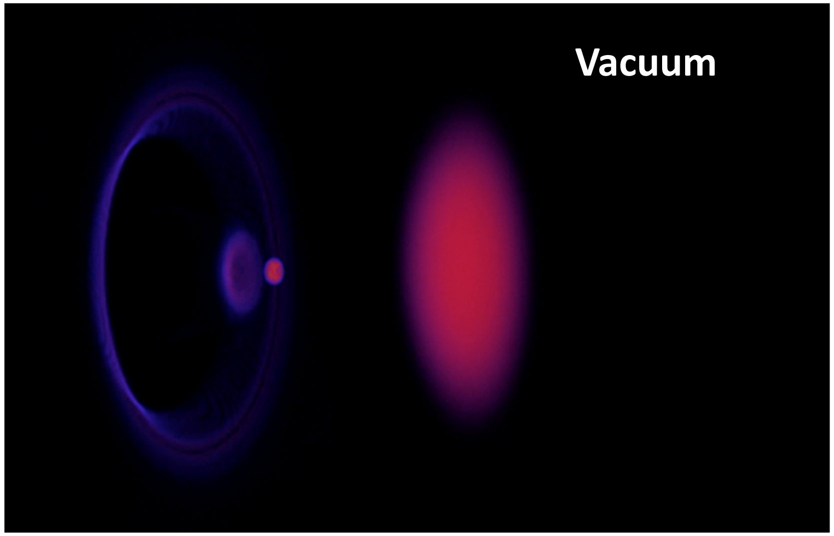
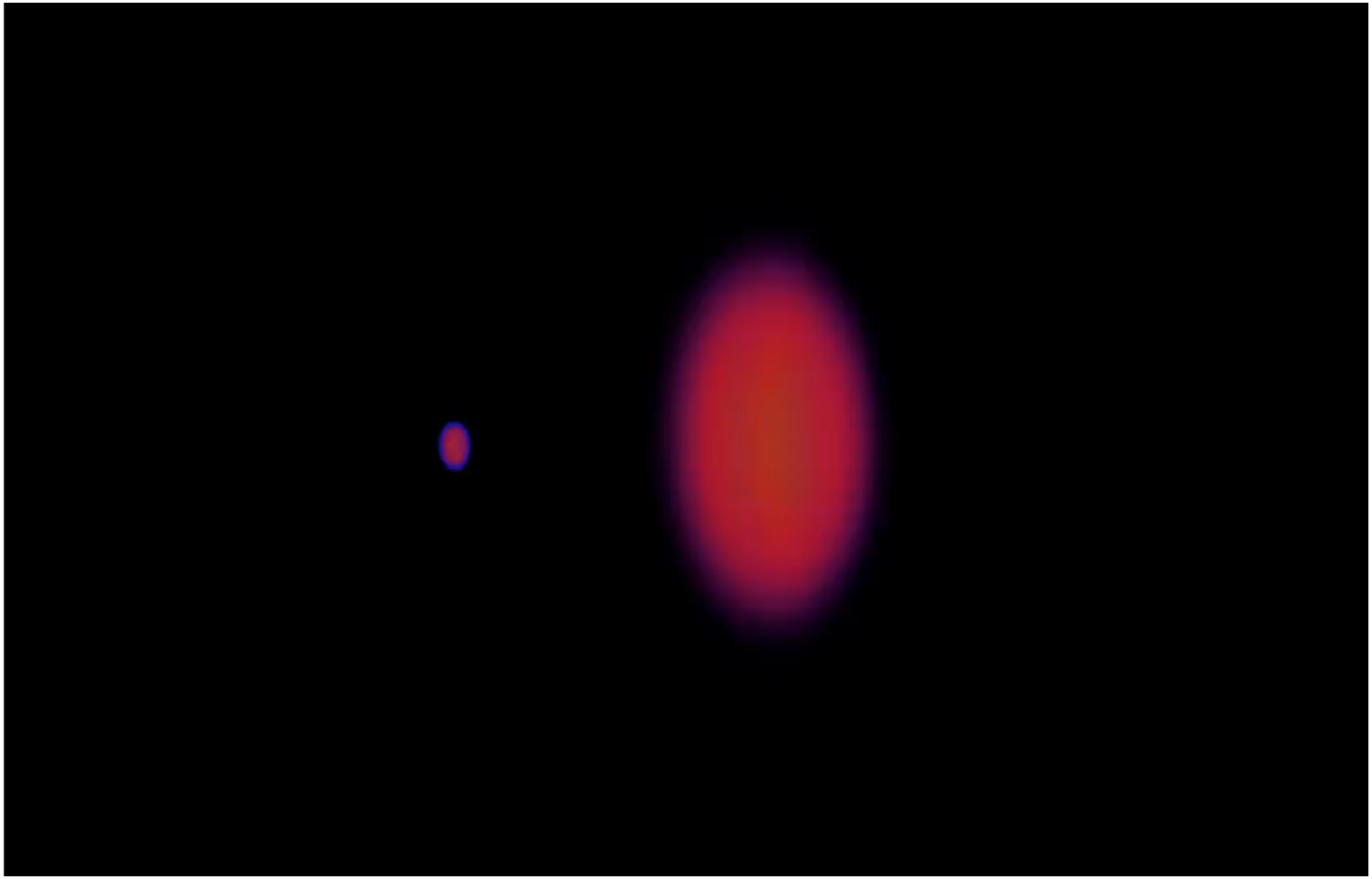


Electron beam after plasma:
Energy = **1 GeV** (initial 100 MeV)
Relative energy spread **= 1.5%** (initial 0.1 %)
Normalized emittance = **0.995 µrad m** (initial 0.99 µrad m)

Á. Ferran Pousa, R. Assmann, A. Martinez de la Ossa. IPAC17 paper ***TUPIK007***.

One example



Á. Ferran Pousa, R. Assmann, A. Martinez de la Ossa. IPAC17 paper ***TUPIK007***.

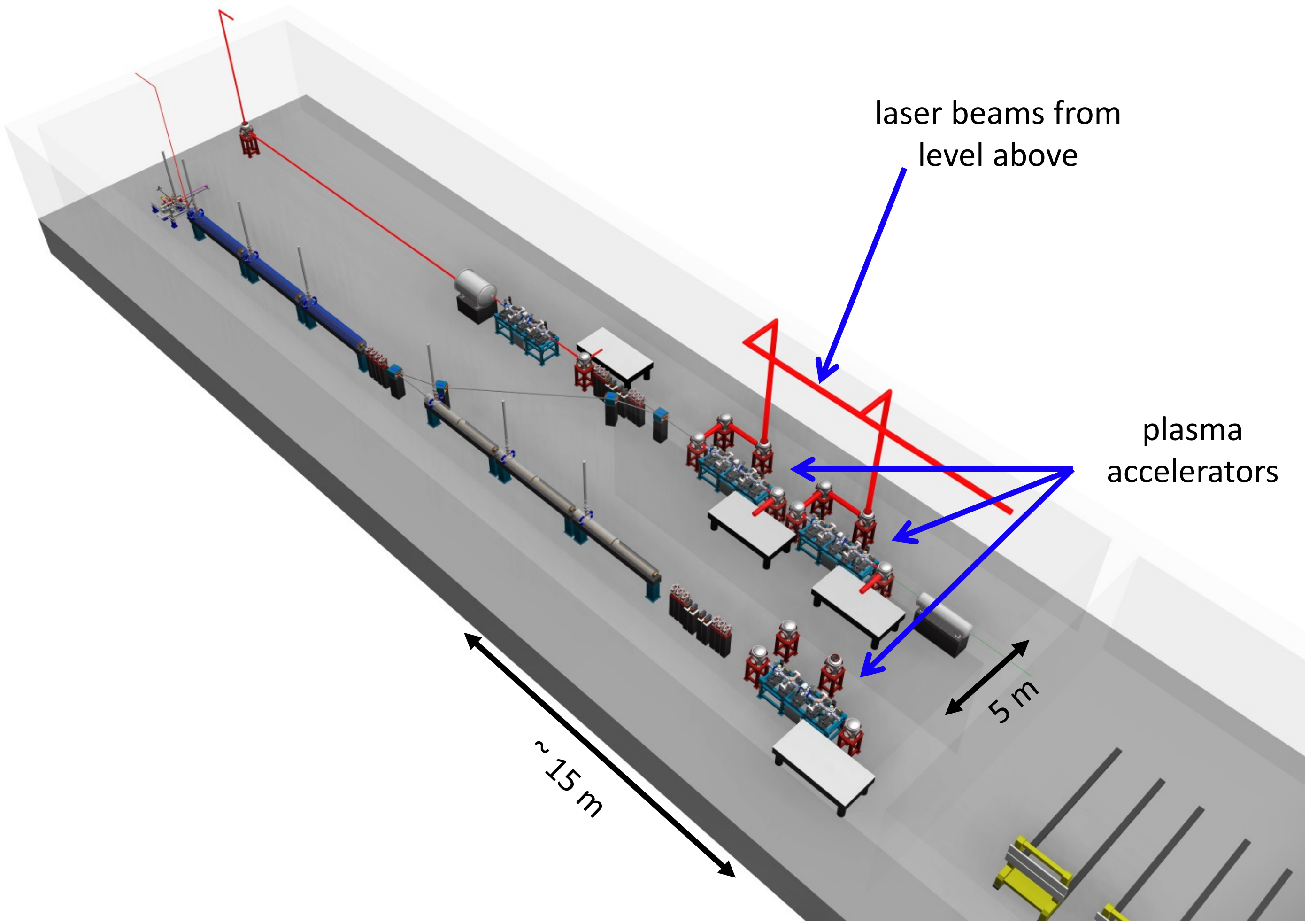
- Of particular importance is the sensitivity to **initial fluctuations**
  - plasma density
  - alignment
  - particle beams
  - laser pulses

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

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

I = laser intensity, $\boldsymbol{\rho}$ = distance ,
w = transverse size , α = 2 (Gaussian),
α > 2 (“top-hat”)

Layout proposal
combining all configurations



3D design by Dariusz Kocoń (ELI-Beams)

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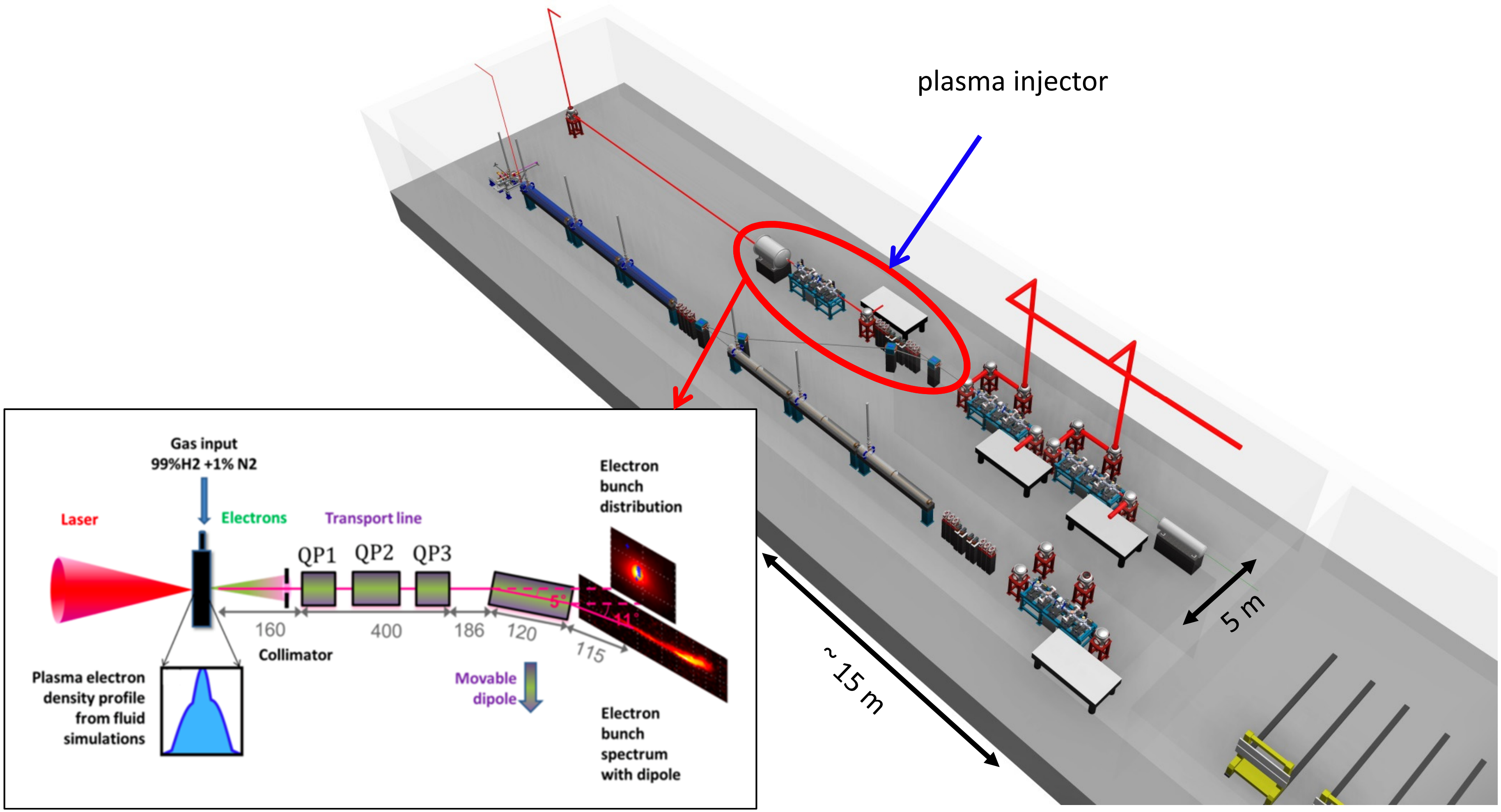

See poster: B. Cros et al., ‘Electron injector for multi-stage laser-driven plasma accelerators’, IPAC’17, **WEPVA001**

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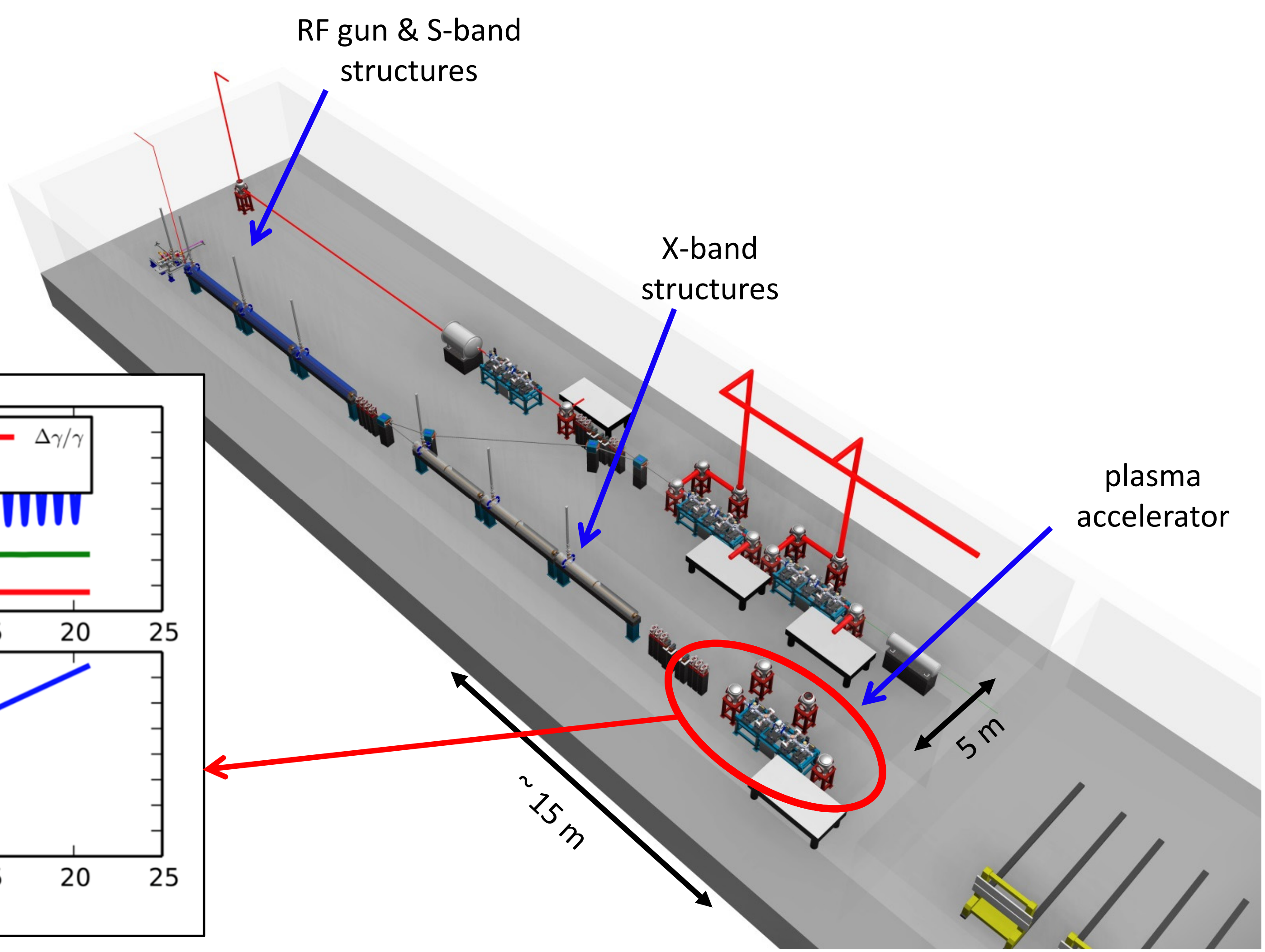

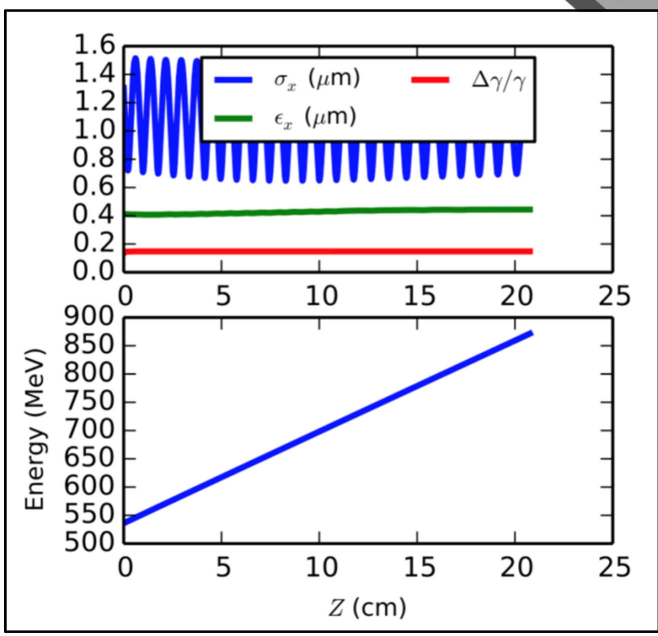

A. Marocchino et al., simulations with hybrid code Architect, Nucl. Instr. Meth. Phys. Res. vol. 829, 2016.

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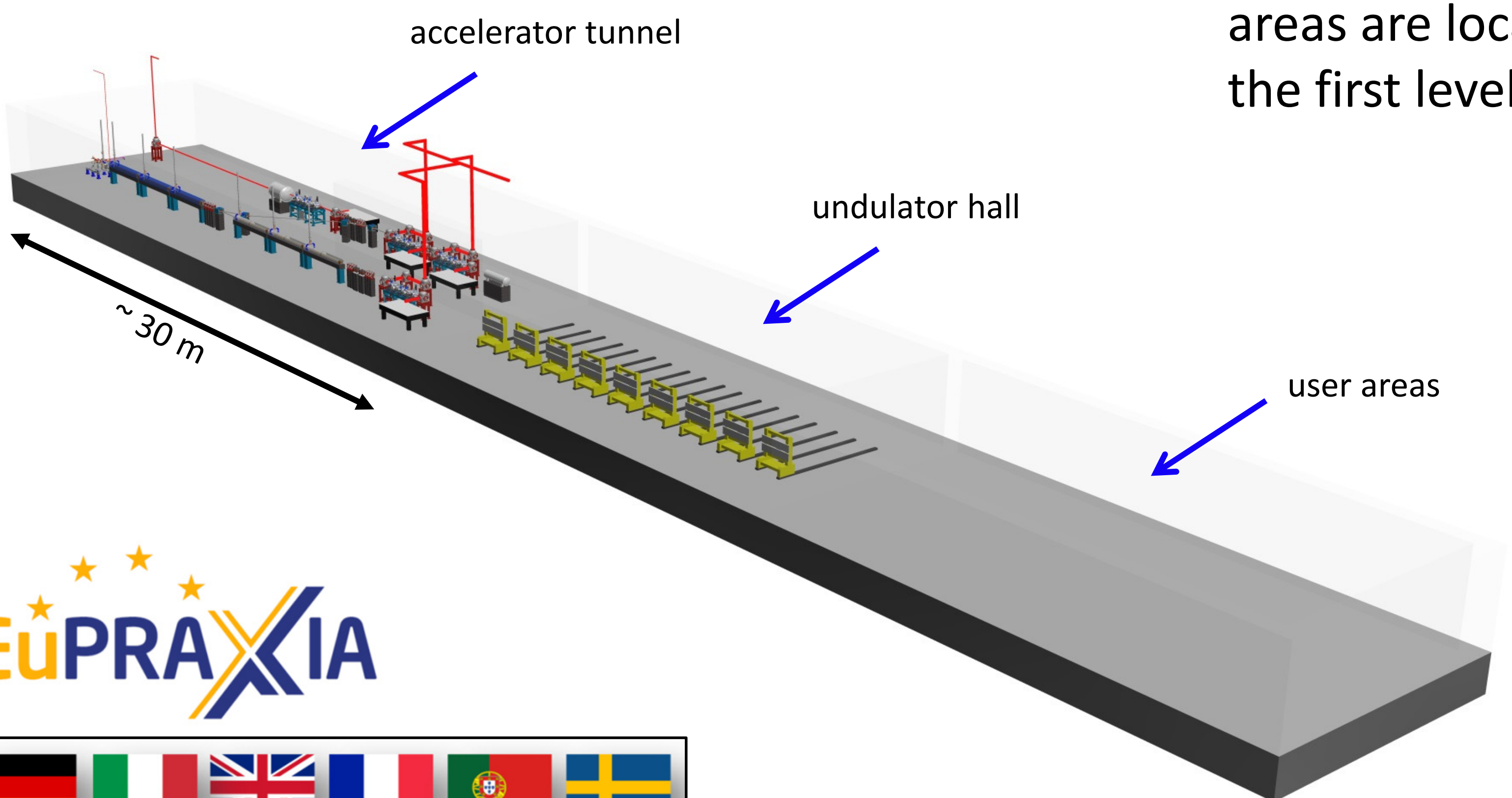
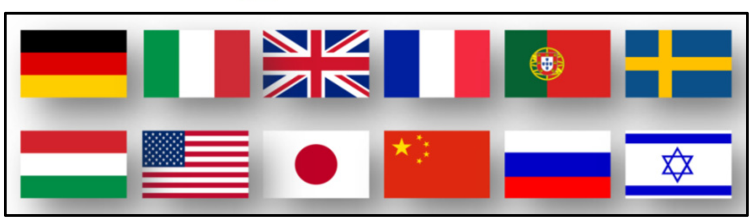
Layout proposal

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



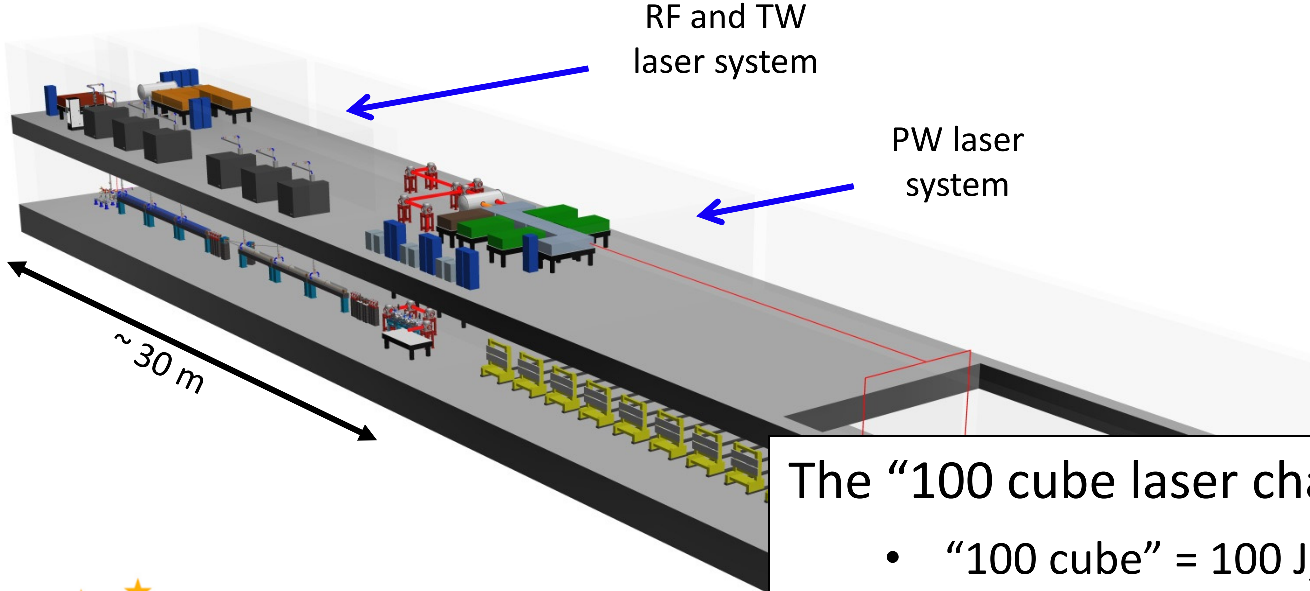


See poster: P.A.Walker et al., ‘Layout and space considerations for EuPRAXIA’, IPAC’17, **TUPIK012**

Layout proposal

Horizon 2020

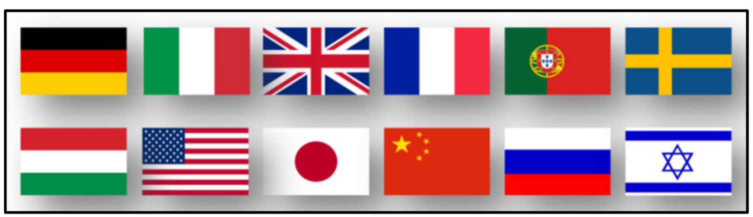
RF and laser infrastructure on second level



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?

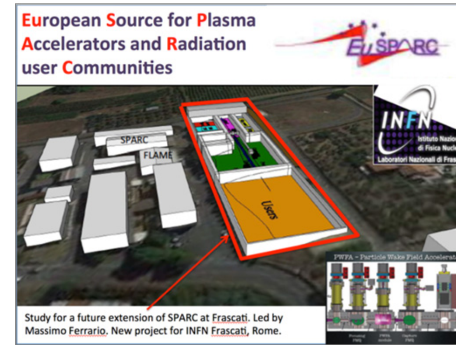
Horizon 2020

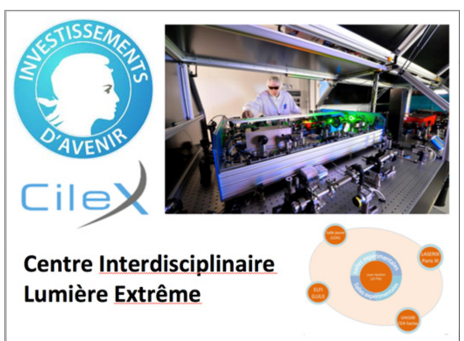
- Detailed estimates of required space are ongoing:
  - Acc. tunnel **+** infrastructure **about 300 – 600 m^2 for 5 GeV** (depending on conf.)
  - Potential **factor of 5-10 footprint reduction** compared to RF based electron linac
  - Reduced footprint has potential to open many additional applications
- **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

[3] S. Van der Meer, CLIC Note No. 3, CERN; PS, '85-65
[4] R. Brinkmann et al., arXiv:1603.08489, accepted for publication in PRL

Site study

- EuPRAXIA design study is site independent
- Five possible sites have been discussed so far
- We invite the suggestions of additional sites





Eli Beamlines
Prague, Czech Republic

Central Facility
Didcot, UnLaser ited Kingdom

Conclusion

- 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**

Thank you for your attention

Horizon 2020

The EuPRAXIA team

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