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APPLICATIONS

EuPRAXIA

Parameters for the EuPRAXIA beamlines

(towards advanced linear collider)

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Questions asked

- What future facilities could be considered as the next milestones towards building a future collider?
- Could a machine based on an EuPRAXIA design be such facility?

Outline of the presentation

- EuPRAXIA in few words
- ILC toy model to set the scene
- Beam parameters we need in comparison to what was achieved so far (LWFA)
- EuPRAXIA beam parameters
- EuPRAXIA as the next milestone towards a future collider

Consortium

16 Participants

24 Associated Partners

(as of December 2017)

EuPRAXIA; focus on beam quality

- Plasma accelerator; 5 GeV electron beam @ 20 to 100 Hz rep rate; industrial quality
- 2 user areas: FEL and HEP & Other Pilot Applications (HOPA)
- Injectors: LPWA, RF including multiple bunches
- Accelerating structures: LWFA (possibly also MP-LWFA), PWFA (including trains of electron bunches) and Hybrid LWFA-PWFA
- 3 lasers: 5 to 7J (30 to 20 fs), 15 to 30J (30 to 20 fs), 50 to 100 J (60 to 50 fs)

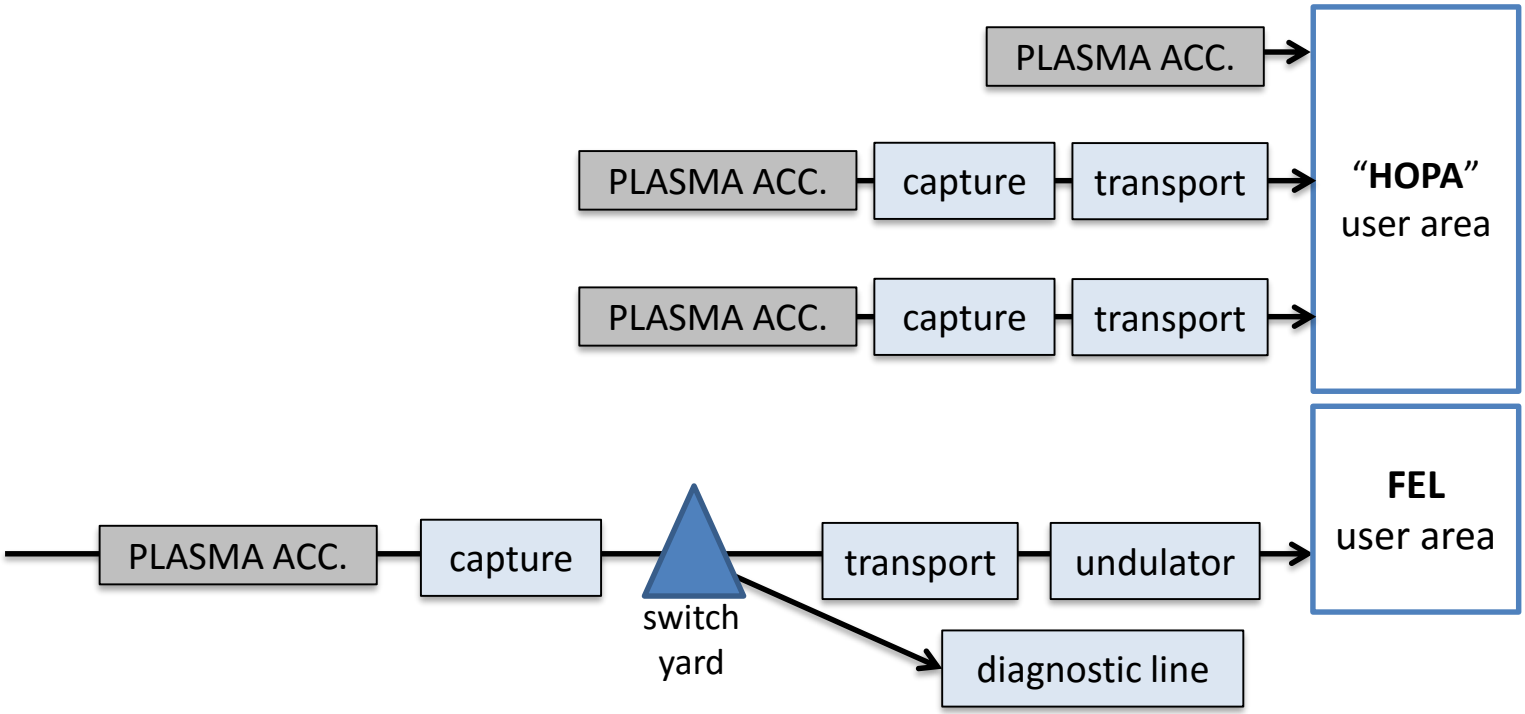
EuPRAXIA calendar

- EuPRAXIA design study, supported by EU and participating institutions, is 4 year project concluding with CDR in November 2019
- 2019 application to ESFRI roadmap for 2020 update
- >2021 – 2025 construction
- >2025 – 2035 operation
- Bridging funding for further R&D foreseen between 2020 and the operation

How to position user areas?

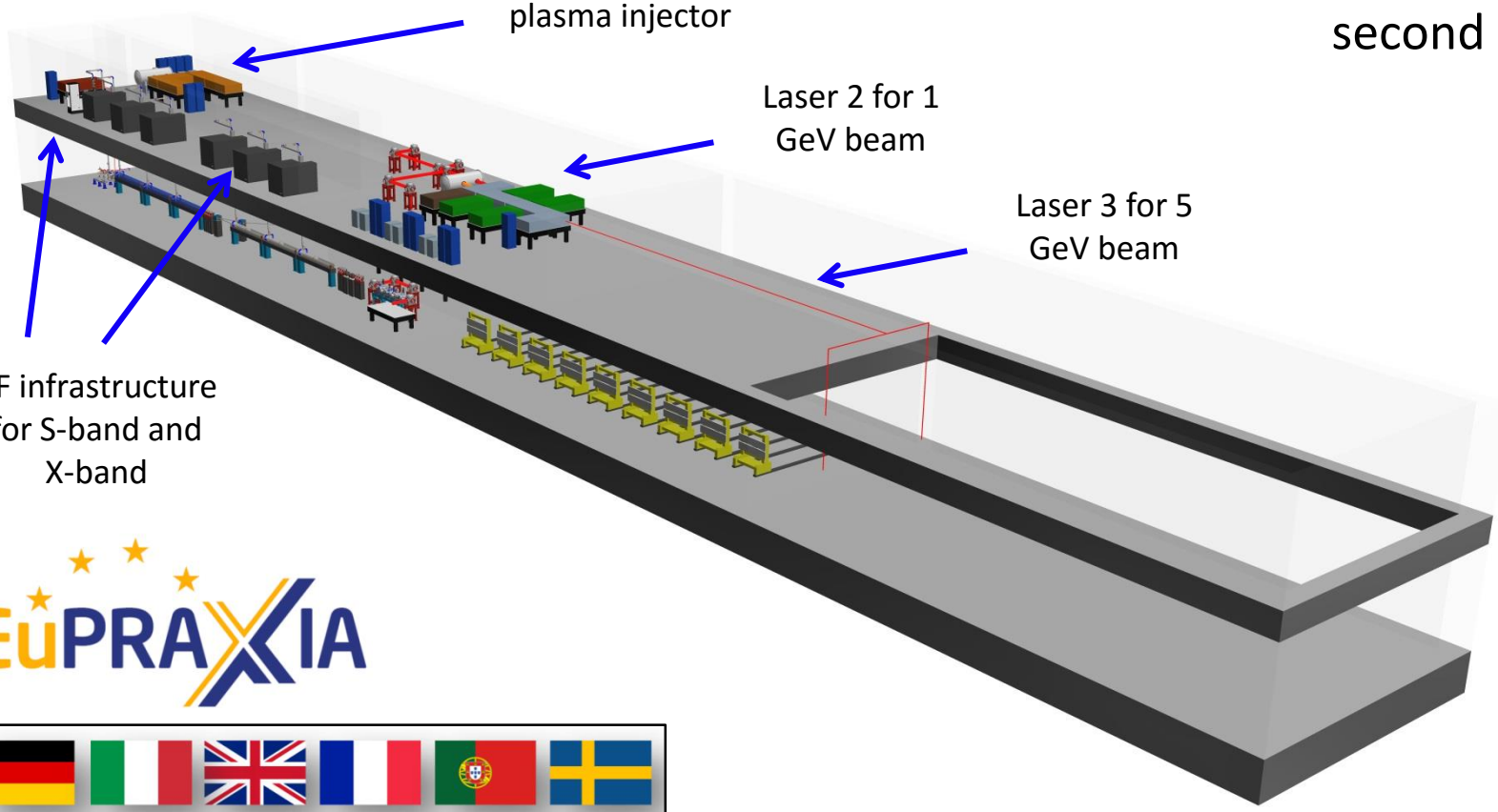
There will be **at least 2 user areas:** FEL and HOPA

Options 2: several LWFA stages



… with 1st floor for laser/RF infrastructure

RF and laser infrastructure on second level



What does particle physics need?

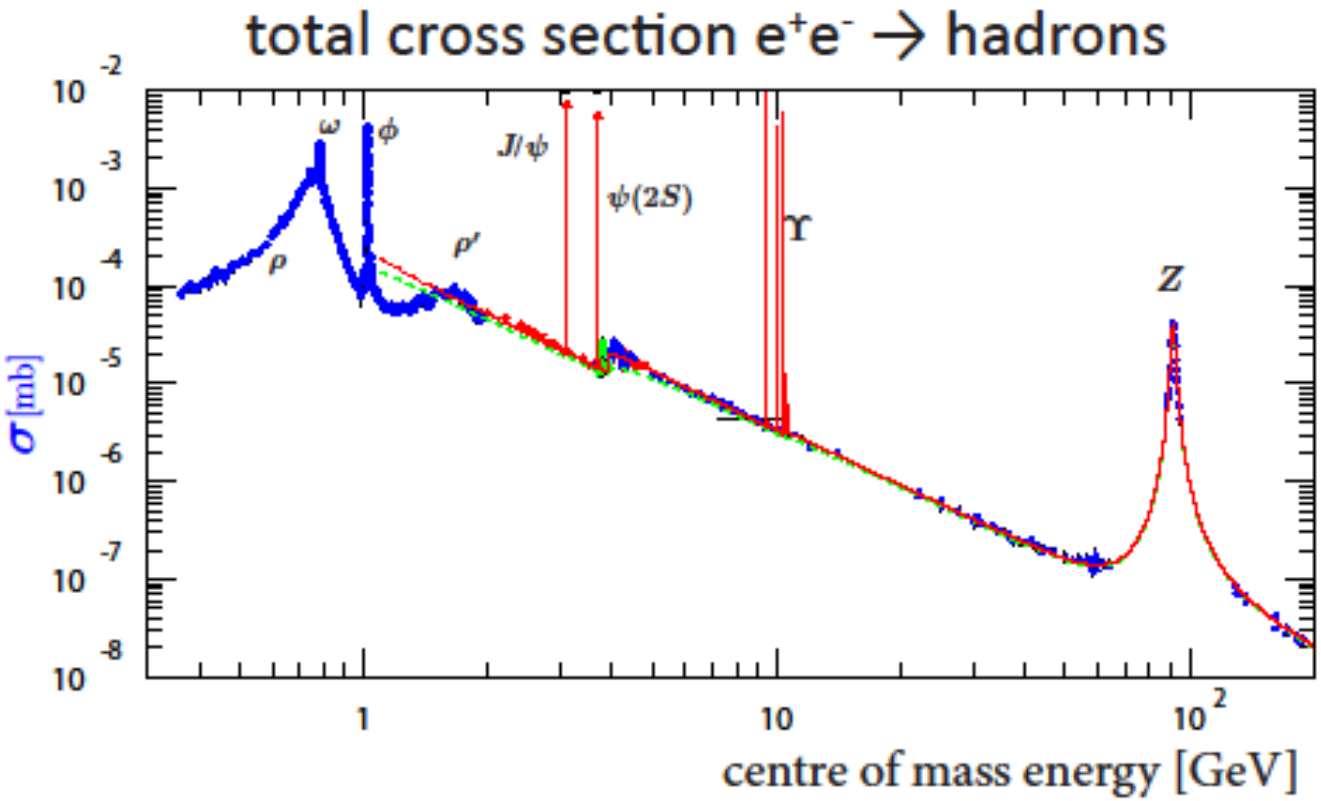
- Energy E
- Luminosity L
- No background at IP

E: significant progress in recent years 10 GeV per stage should be reached soon; 4.2 GeV achieved as well as the first demonstration of multistage acceleration.

L: is being addressed now by improving beam quality

Background at IP: we are not there yet to extrapolate from where we are.

Why L is important for colliders?



PDG

Beyond resonances, the cross section goes down as (the centre of mass energy)^2. L has to grow with the centre of mass energy the same way. We also have to know (from LHC or FCC or ?) what is the energy where there is something interesting to measure. Otherwise, there is no point.

ILC toy model

- For orders of magnitude estimates of L

$$L = \frac{bf}{4\pi}\frac{N^2\gamma}{\sqrt{\epsilon_{Nh}\beta_h^*\epsilon_{Nv}\beta_v^*}} = \left[\frac{bf}{4\pi}\right]\left[N^2\gamma\right]\left[\frac{1}{\sqrt{\epsilon_{Nh}\beta_h^*\epsilon_{Nv}\beta_v^*}}\right]$$

where
b is the number of bunches, f is the rep rate,
N is the number of electrons (positrons) i a bunch,
γ is the the ratio of the electron energy over its mass,
ϵ_{Nh} and ϵ_{Nv} are normalized horizontal and vertical emittances,
β_h^* and β_v^* are horizontal and vertical β functions at the IP.

As there is substantial energy spread and angular spread, the paraxial approximation which is used doesn't work well but should be ok for orders of magnitude estimations.

ILC – beam energy 250 GeV

$$\mathrm{b} = 1320,\ \mathrm{f} = 5\ \mathrm{Hz},$$
$$\mathrm{N} = 2 \cdot 10^{10} \text{ at IP and at 5 GeV},$$
$$\epsilon_{Nh} = 10\mu\mathrm{m} \text{ at IP and } \epsilon_{Nh} = 5.5\mu\mathrm{m} \text{ at 5 GeV},$$
$$\epsilon_{Nv} = 35 \text{ nm at IP and } \epsilon_{Nv} = 20 \text{ nm at 5 GeV},$$
$$\beta_h^* = 11 \text{ mm and } \beta_v^* = 0.48 \text{ mm}.$$

$$L = \left[\frac{6560}{4\pi}\right]\left[4 \cdot 10^{20}\gamma\right]\left[7.7 \cdot 10^{8}\right]\frac{1}{\mathrm{m}^2\mathrm{s}} = 7.8 \cdot 10^{34}\frac{1}{\mathrm{cm}^2\mathrm{s}}$$

This is about factor 5 bigger than properly calculated luminosity; ok for orders of magnitude estimates. Taking parameters at 5 GeV one would get the luminosity 1.8 times bigger: 7.7 -> 13.9

LWFA 5 GeV stage

Taking Bella parameters for 4.2 GeV stage:

b = 1, f = 1 Hz, N= $3.8 \cdot 10^7$,

assuming:

$\epsilon_{Nh} = 1\mu\text{m}$, $\epsilon_{Nv} = 1\mu\text{m}$,

$\beta_h^* = 1$ mm and $\beta_v^* = 1$ mm.

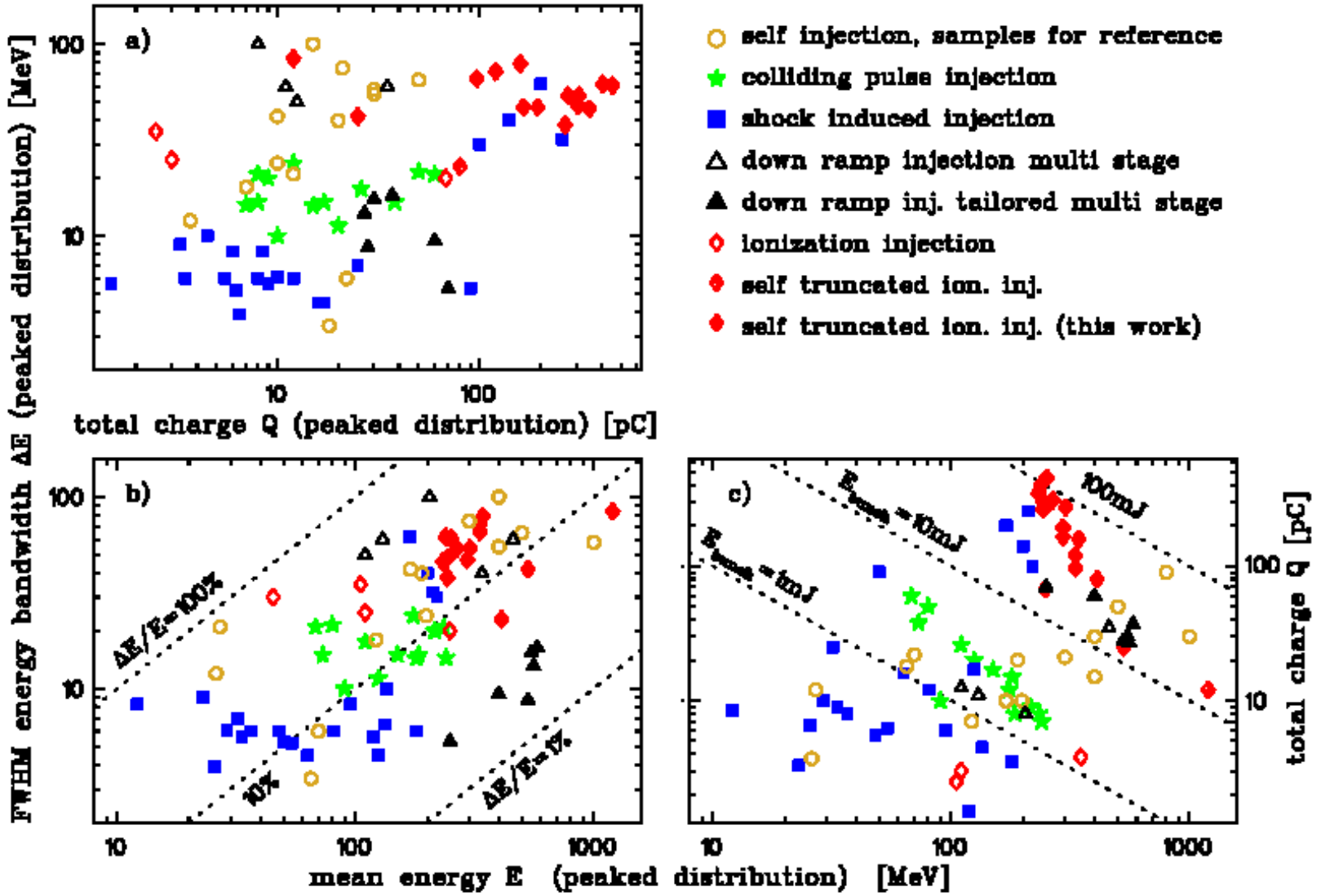
$$L = \left[\frac{1}{4\pi}\right]\left[3 \cdot 10^{14}\gamma\right]\left[10^9\right]\frac{1}{\text{m}^2\text{s}}$$

which is $1.2 \cdot 10^{10}$ smaller than ILC L calculated taking 5 GeV parameters:

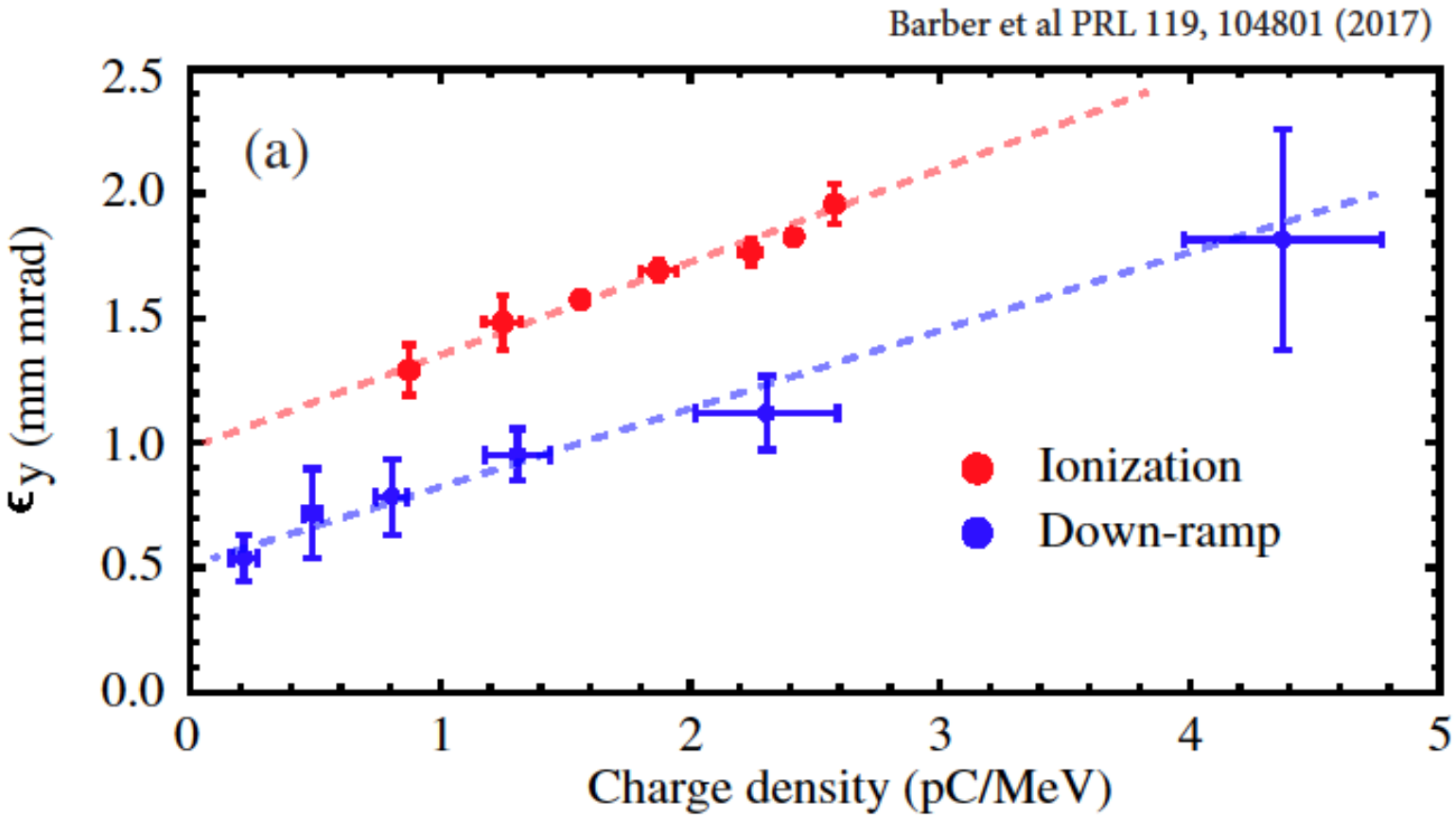
$$L = \left[\frac{6560}{4\pi}\right]\left[4 \cdot 10^{20}\gamma\right]\left[1.4 \cdot 10^9\right]\frac{1}{\text{m}^2\text{s}}$$

LWFA bunch charge

Plasma Phys. Control. Fusion **60** (2018) 044015 A Irman *et al*



Emittance and charge



EuPRAXIA LWFA injector

Quantity	Required value (entrance of accelerator)	[range]
Energy	150 MeV	[100 – 200 MeV]
Charge	100 pC	[30 – 100 pC]
Bunch length	5 fs (rms)	[3 – 20 fs]
Repetition rate	10 Hz	[1 – 100 Hz]
Total energy spread	5 % (rms)	[1 – 5 %]
Transverse normalized emittance	1 mm.mrad	
Transverse beam size	0.58 µm (rms)	[0.5 – 0.71 µm]
Transverse divergence	5.8 mrad (rms)	[5 – 7.1 mrad]

EuPRAXIA RF injector

Quantity	Baseline INFN	Baseline DESY
E	~540 MeV	240 MeV
Q	30 pC	30 pC
τ (FWHM)	12 fs	~5 fs
σ_E/E	0.06 %	0.27%
$\sigma_{E,S}/E$		0.23%
$\varepsilon_{N,x}$, $\varepsilon_{N,y}$	0.4 mm mrad	0.81/0.46 mm mrad
$\varepsilon_{N,x,S}$, $\varepsilon_{N,y,S}$		0.59/0.34 mm mrad
$\sigma_{x,y}$	1 μm	2 μm

EuPRAXIA beam parameters

3.6.2. Case 3B: acceleration to 5 GeV

Quantity	Symbol	Baseline value	Range of exploration	
			Lower limit	Upper limit
5 GeV beam at exit of plasma 2				
Energy	E	5 GeV	5 GeV	
Charge	Q	100 pC	30 pC	100 pC
Bunch length	τ	5 fs	3 fs	20 fs
Peak current per bunch	I	20 kA	5-20 kA	
Total energy spread (RMS)	σ_E/E	5%	1%	10%
Transverse normalized emittance	$\varepsilon_{N,x}$, $\varepsilon_{N,y}$	1 mm mrad	1 mm mrad	10 mm mrad
Transverse norm. slice emittance	$\varepsilon_{N,x,S}$, $\varepsilon_{N,y,S}$	tbd	tbd	
Alpha function	α_x, α_y	0	0	
Beta function	β_x, β_y	1 mm	1mm	
Transverse beam size (RMS)	σ_x , σ_y	0.32 µm	0.32 µm	1 µm
Transverse divergence (RMS)	$\sigma_{x'}$, $\sigma_{y'}$	0.32 mrad	0.32 mrad	1 mrad
Jitter, beam to global reference (RMS)	$\sigma_{\Delta t}$	10 fs	10 fs	

EuPRAXIA LWFA 5 GeV

Taking EuPRAXIA parameters, one gets

$$L = \left[\frac{20}{4\pi}\right]\left[4 \cdot 10^{17}\gamma\right]\left[10^{9}\right]\frac{1}{\mathrm{m}^2\mathrm{s}}$$

which is $4.5 \cdot 10^5$ smaller than ILC L calculated taking 5 GeV parameters:

$$L = \left[\frac{6560}{4\pi}\right]\left[4 \cdot 10^{20}\gamma\right]\left[1.4 \cdot 10^{9}\right]\frac{1}{\mathrm{m}^2\mathrm{s}}$$

This is almost 5 orders of magnitude improvement in comparison to the first try.

Can EuPRAXIA do even better?

- The rep rate might go up to 100 Hz and future upgrade of EuPRAXIA to kHz range is considered.
- High charge beamline to make positron source in HOPA user area should lead to bunches with nC charge; 2 orders of magnitude higher than considered above.
- RF injector can provide trains of electron bunches which might lead to increase luminosity by factor 10 or so.

There is a prospect of getting there!

Quality beams and staging

- EuPRAXIA' s main goal is the quality of the beams and this will keep beam emittance low as well as low energy spread and angular divergence.
- The multistage acceleration is at the core of EuPRAXIA program. This, together with the focus on beam quality, should lead to high efficiency and quality of beam transport from stage to stage. There is almost no degradation of beam parameters from 5 to 250 GeV at the ILC! This is the serious challenge which EuPRAXIA takes on board.
- Quality needs diagnostics! Required instruments will be developed/installed.

We need positron beam

- LWFA produced positrons come in short bunches with significant charges and relatively low emittance see talk by Gianluca Sarri at the WG8 meeting.
- Positron source will be available in EuPRAXIA HOPA user area for both: low energy positron spectroscopy and for studies to create high energy positron beam for particle physics applications. This opens an opportunity for a dedicated project on high energy positron beams to work together with EuPRAXIA team. If you are interested, please say it now!

Summary

- Using luminosity as the figure of merit one can see that EuPRAXIA would be a milestone in developing technology towards particle physics applications.
- Simultaneously, EuPRAXIA would be also a milestone for other applications, such as FEL, positrons, X-ray imaging etc.
- One can see that this is the same powerful idea which Bjørn Wiik had proposing superconducting technology for XFEL and a Linear Collider: merging applied with fundamental.