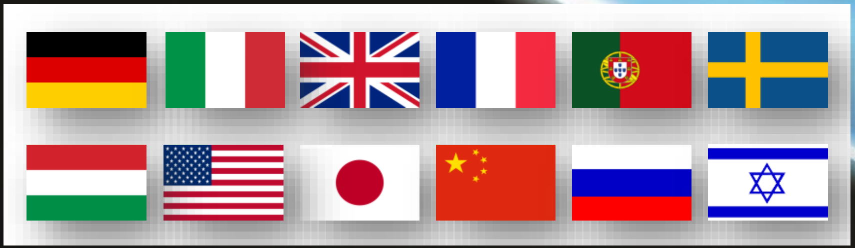
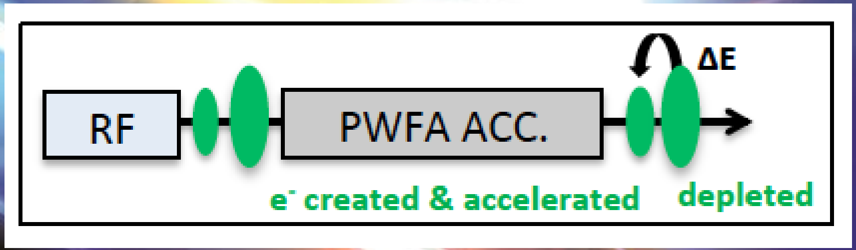
EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

WP9 - Beam Driven Plasma Acceleration
Status Report

Massimo Ferrario (INFN) & Jens Osterhoff , Pardis Niknejadi (DESY)

2nd yearly meeting, November 21rst, 2017, Lisbon





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

WP9 Deliverables

- Del 9.1. Baseline design report including electron beam optics, plasma modules, plasma diagnostics and beam transport to applications [May 2018].

- **Del 9.2.** Staging analysis (DESY) [**May 2019**].

- **Del 9.3**. Tolerance analysis (DESY, INFN) [**May 2019**].

- Del 9.4. Full design report EUPRAXIA, contribution from WP9 [October 2019].

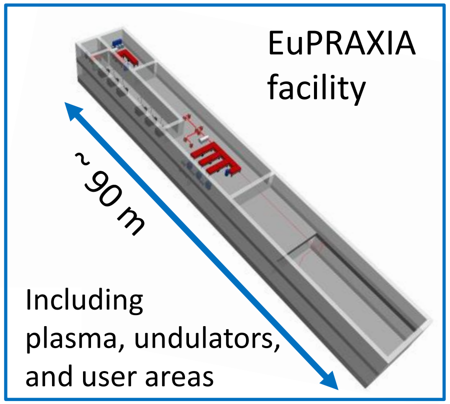
FLASHForward & SPARC_LAB Contributions to EuPRAXIA

- Baseline studies for plasma and FEL simulation codes
  - 1 GeV case: complete optimized start to end simulation with transformer ratio of 2
  - 5 GeV case: in progress
  - Dedicating Millions of Core hours from Maxwell (Hamburg) and JuQUEEN/JuWELS (Jülich) high performance computers
  - Benchmarking of reduced model codes against full physics codes
- Cross-examining of technical challenges
  - Experimental generation of two spatially close high-brightness beams, driver + witness
  - Development of active plasma lenses for compact high gradient focusing
  - Tailored, windowless plasma sources
  - SRF injectors with high rep-rate, high average power for PWFA
- Conventional and novel diagnostics for
  - Precise measurement of plasma density
  - Transverse and longitudinal beam properties

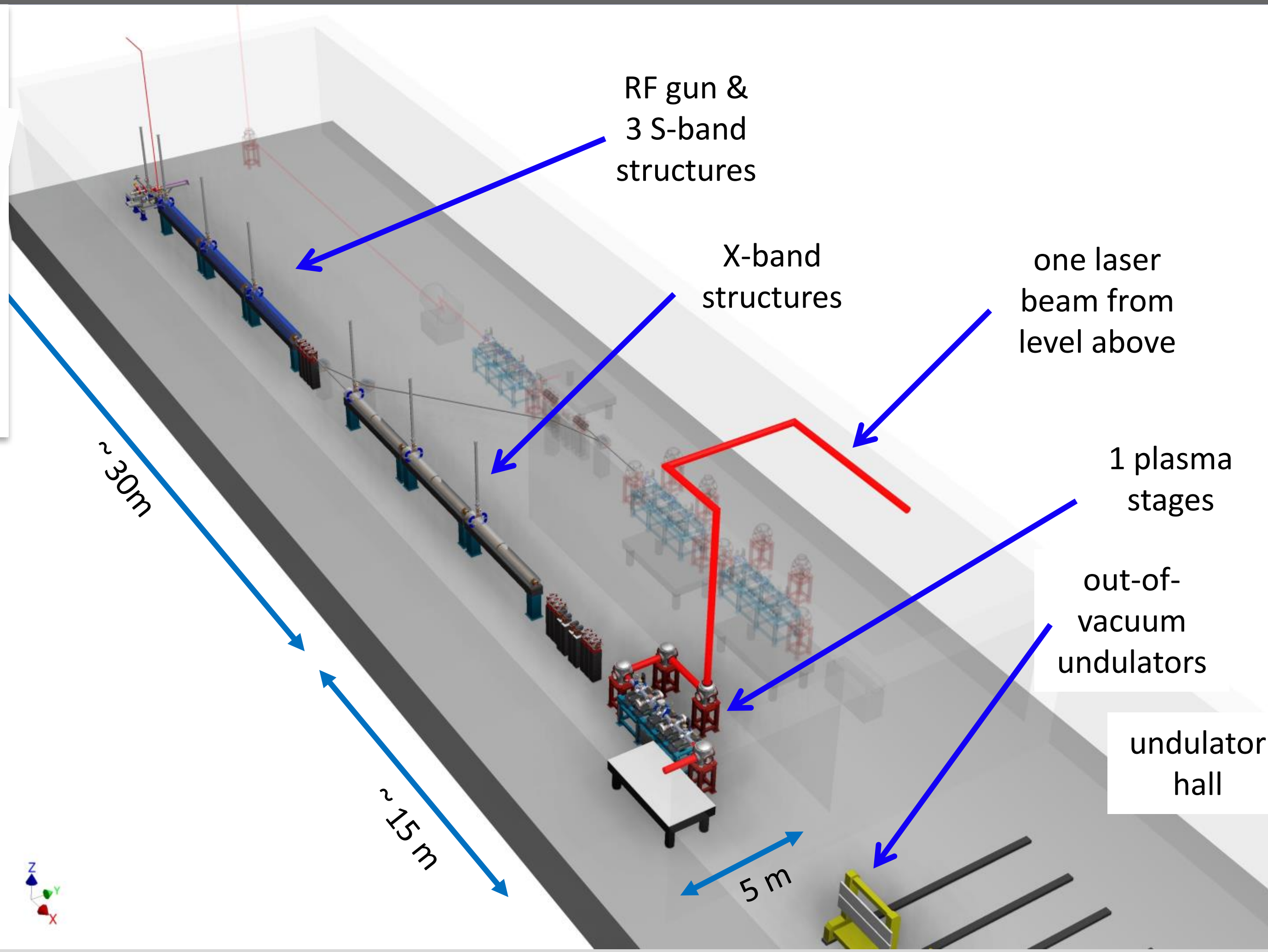
FLASHFORWARD

SPARC LAB

Possible EuPRAXIA Beam Driven layout



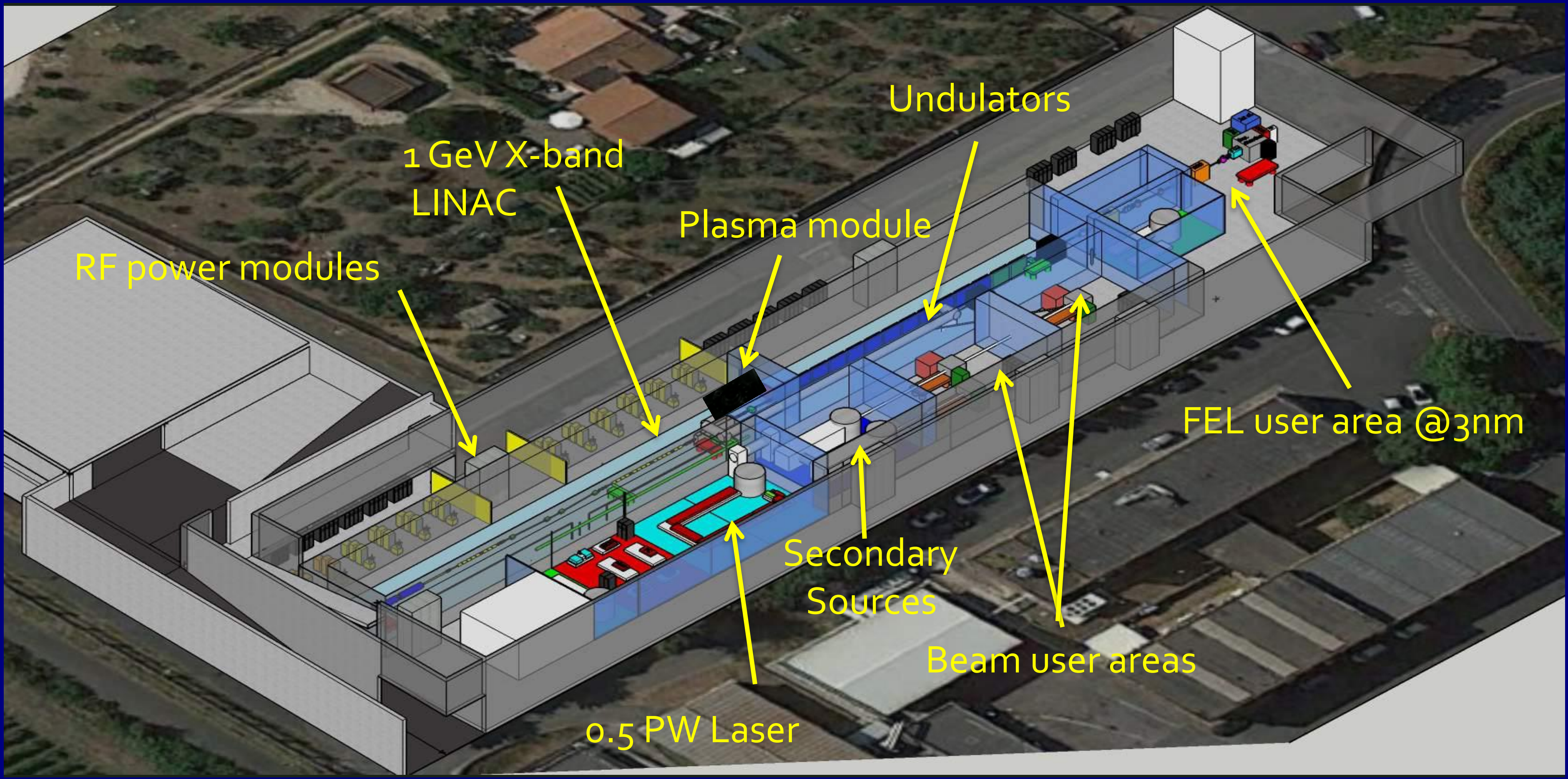
- PWFA uses electron beam as driver in one plasma stage
- RF structures consist of S-band and X-band
- Laser needed for pre-ionization of plasma



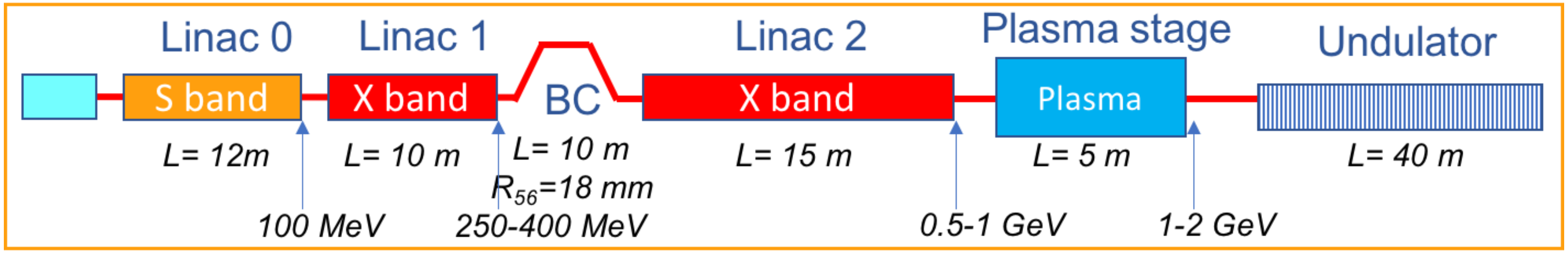
A = 45 x 5 m² = 225 m²

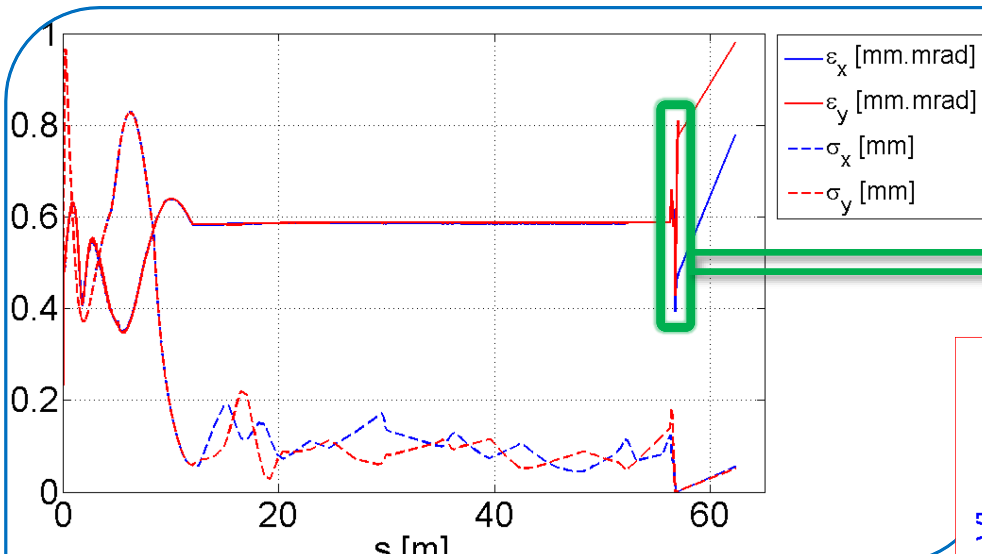
3D layout by Dariusz Kocoń and Paul Andreas Walker

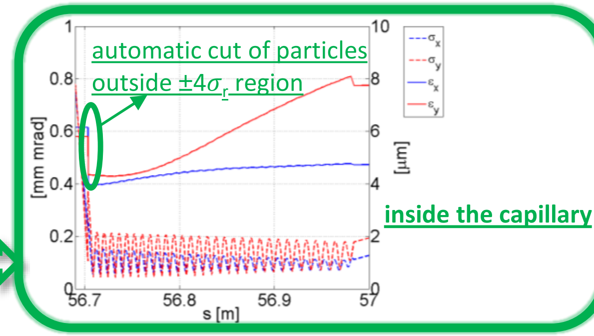
EuPRAXIA@SPARC_LAB

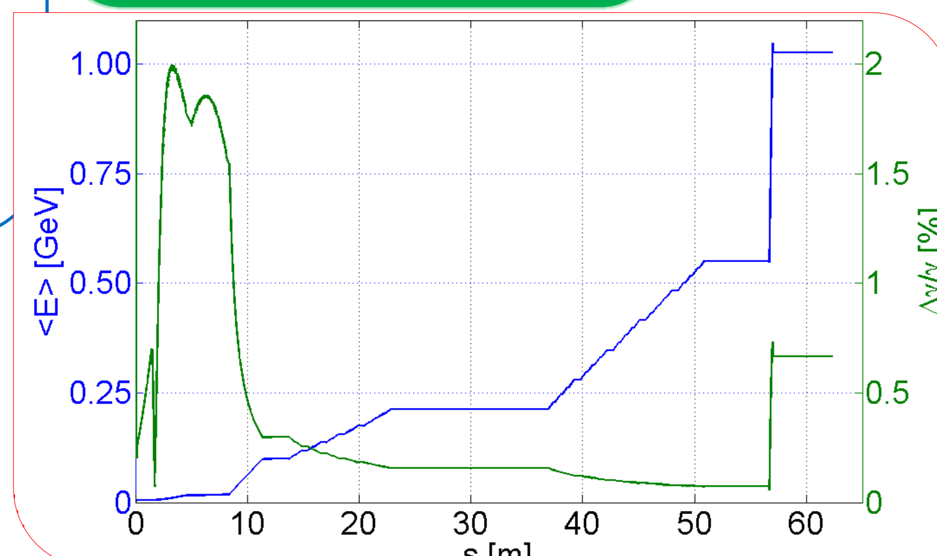


30 pC beam Start To End Simulations

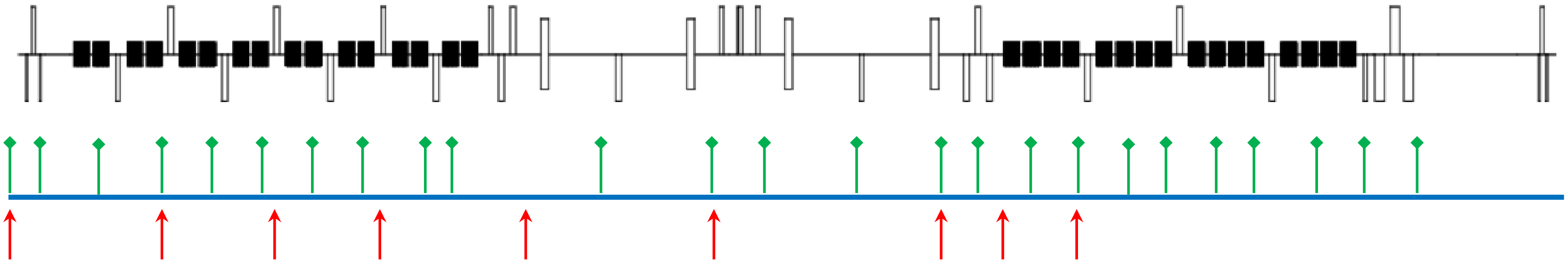








Static and dynamic errors simulation:



Steerer + BPM

Beam error kick (girder to girder)

- ✓ Static errors:
  - 100 (20) μm (x ,y) random misalignment on RF's structures and magnetic elements
  - 0.05 (0.01) μrad tilt on magnetic elemts
  - 100 μm misalignment kick to the beam, ex. girder to girder
  - 100 random simulated machines
- ✓ Dynamic errors:
  - Quad strength errors 0.1% rms
  - Sterer kick errors 0.01% rms (0.4 μrad rms)
  - RF Acc Grad 0.1% rms
  - RF phase 0.5°
  - 100 random machine for each static arrangement

Static plus dynamic errors summary table

	WP1 (@capillary in) witness	WP1(@capillary in) driver	Previous WP3(@undulator in) with no RF jit
Q (pC)	30	30	200
E (GeV)	0.5	0.5	1.0
σ_{Cx} (μm)	6	5	10
σ_{Cy} (μm)	2	5	30
σ_x (μm)	2.1	7	30
StDevσ_x (μm)	0.04	0.1	10
σ_y (μm)	1.6	8	40
StDevσ_y (μm)	0.02	0.2	5
σ_{δ} (%)	0.07	0.2	.14

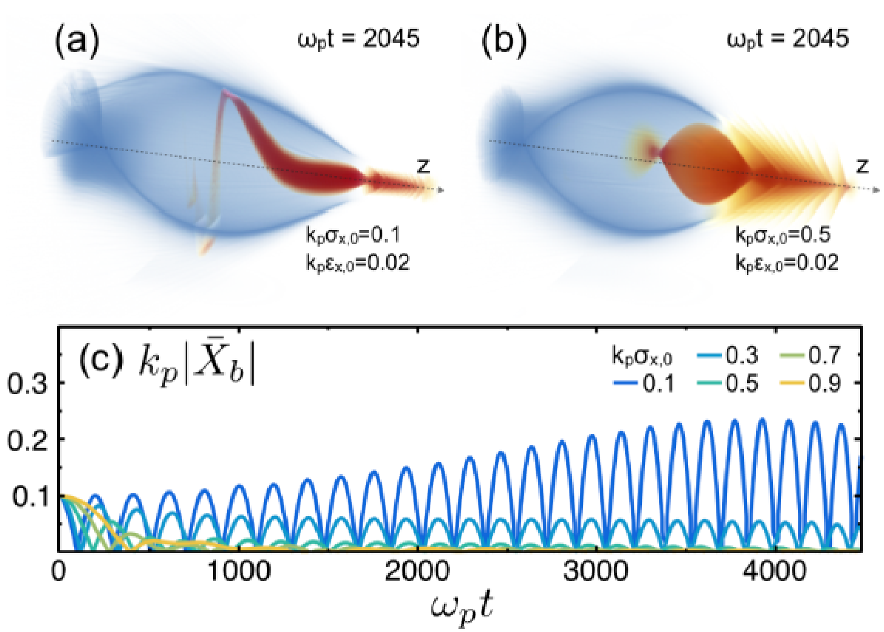
* No dispersion free steering

Physics study: hosing growth rates and mitigation

START-TO-END SIMULATIONS SHOW EXCITATION OF THE HOSING INSTABILITY - EXPERIMENTS DO NOT YET

collaboration between DESY, U Hamburg, and IST Lisbon

- Full start-to-end simulations incl. CSR predict hosing modes can be excited
- Measurement of growth rates & hosing saturation vs. beam parameters one of next steps at FLASHForward
- No sign of hosing so far in experiments
- Suppressed owing to large focal size? (current diagnostic resolution limited at ~20µm…)



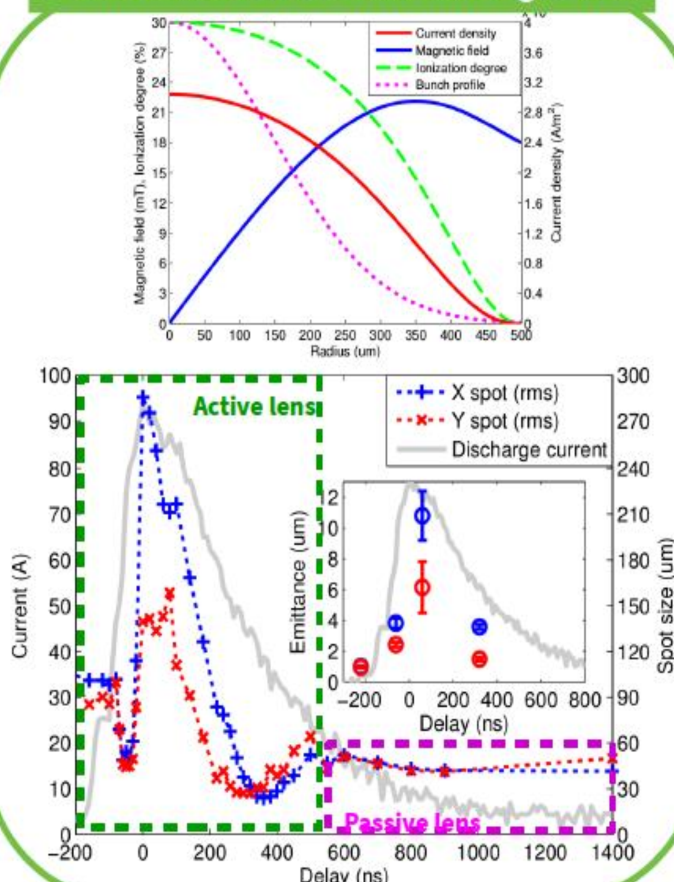
Hosing mitigation

- T. J. Mehrling *et al.*, Phys. Rev. Lett. 118, 174801 (2017)
- T. J. Mehrling *et al.*, Phys. Plasmas 25, 056703 (2018)
- A. Martinez de la Ossa *et al.*, Phys. Rev. Lett. 121, 064803 (2018)

Experimental results

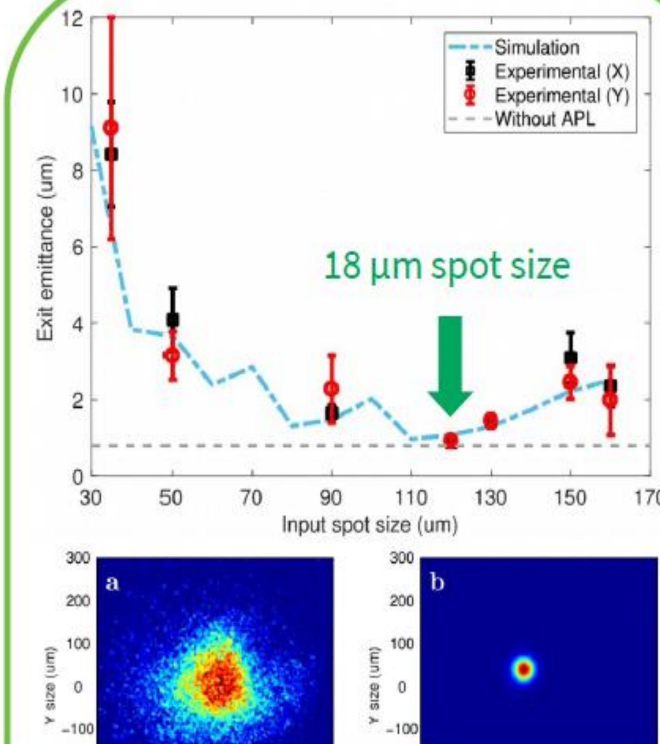
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

Demonstration of emittance growth



Pompili, R., et al. Applied Physics Letters 110.10 (2017): 104101.
Marocchino, A., et al. Applied Physics Letters 111.18 (2017): 184101.

Demonstration of emittance preservation



PHYSICAL REVIEW LETTERS

Accepted Paper

Focusing of high-brightness electron beams with active-plasma lenses

Phys. Rev. Lett.

R. Pompili et al.

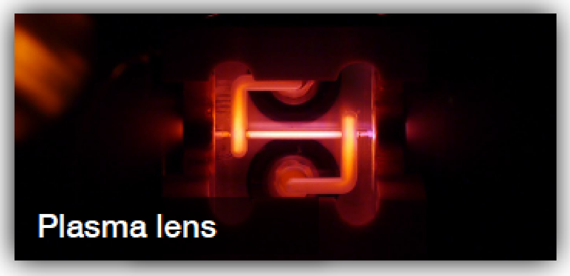
Accepted 11 October 2018

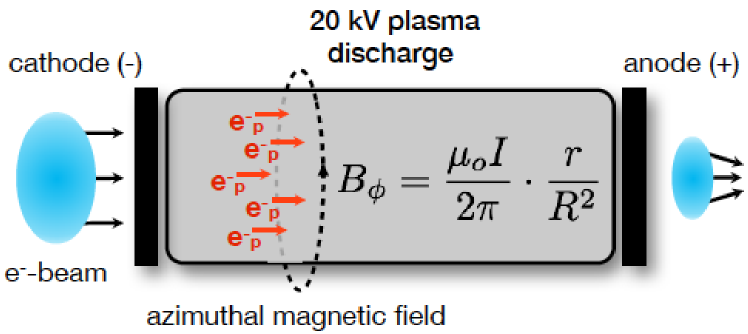
Prototype R&D: aberration-free active plasma lenses

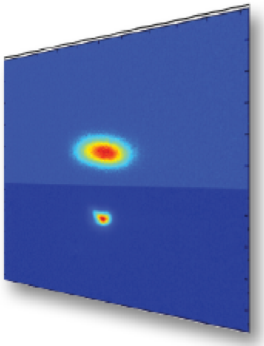
First measurements revealed non-linear focussing fields

in collaboration between

- Strong focussing optics are desirable for emittance-preserving beam capturing after release into vacuum
- Active plasma lenses are a promising technology providing up to 3 kT/m symmetric fields

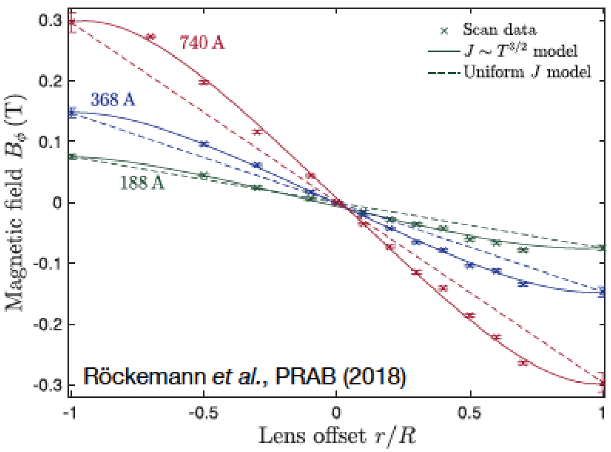




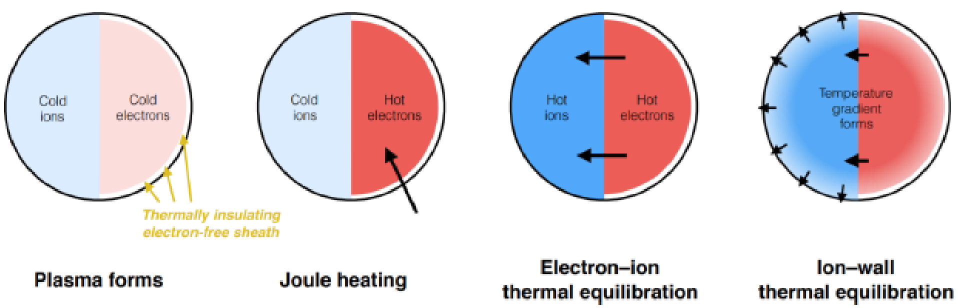


F = I x B, tunable and symmetric focussing force for e⁻-beam

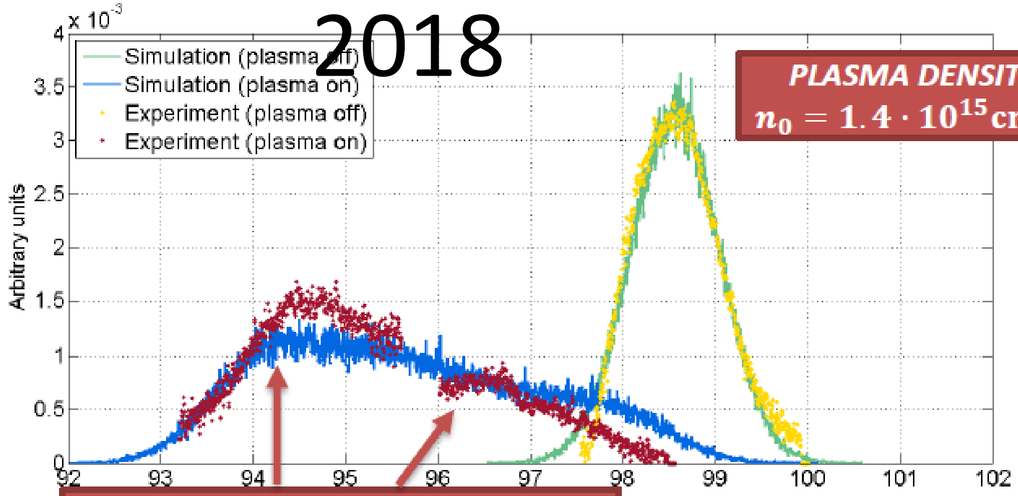
J. van Tilborg et al., Phys. Rev. Lett. ***115****, 184802 (2015)*



- **Field measurements revealed non-linearity consistent with measured emittance growth**
- **Likely cause: temperature gradients**



Deceleration test - July 2018



PLASMA DENSITY

$$n_0 = 1.4 \cdot 10^{15} \mathrm{cm}^{-3}$$

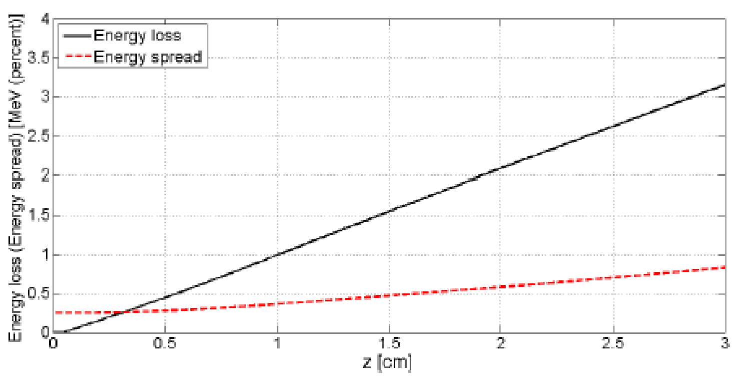
Measurements performed with same bunch and plasma density
Different dipole currents

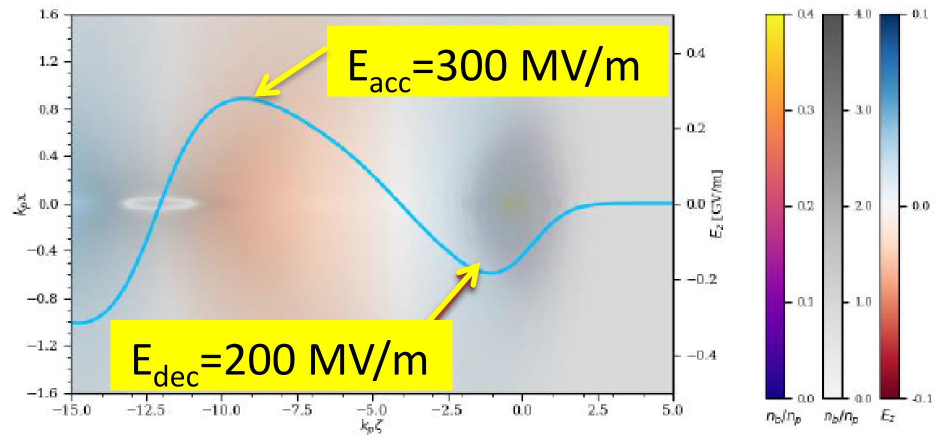
Experimental data at injection

$\sigma_{x,(y)} = 24(33)\mu\mathrm{m}$
$\sigma_z = 50\mu\mathrm{m}$
$\varepsilon_{x,(y)} = 1.7(1.8)\mathrm{mm\ mrad}$
$\sigma_E = 0.5\%$

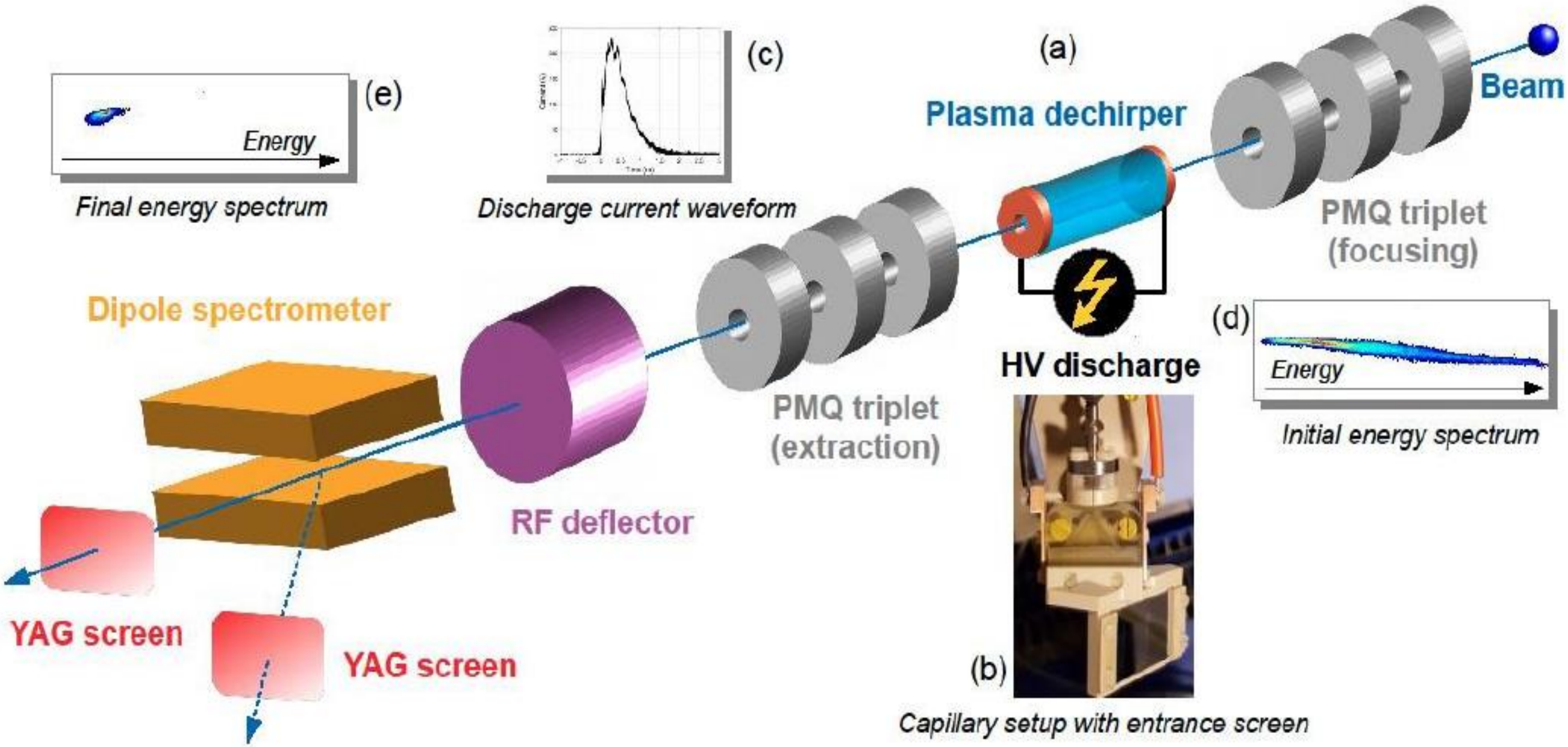
Simulation parameters

$\sigma_{x,y} = 28.3\mu\mathrm{m}$
$\sigma_z = 50\mu\mathrm{m}$
$\varepsilon_{x,y} = 1.75\mathrm{mm\ mrad}$
$\sigma_E = 0.5\%$





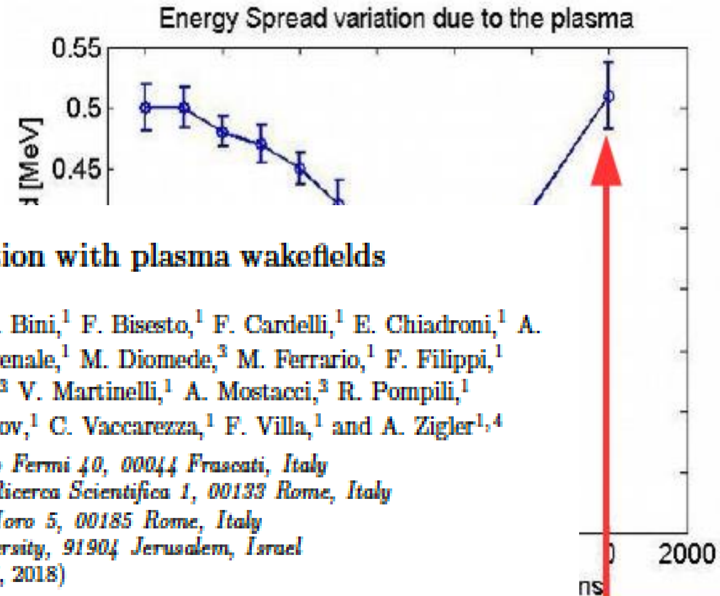
Experimental setup



Preliminary results

Beam parameters

- 200 pC
- Emittar
- Spot si

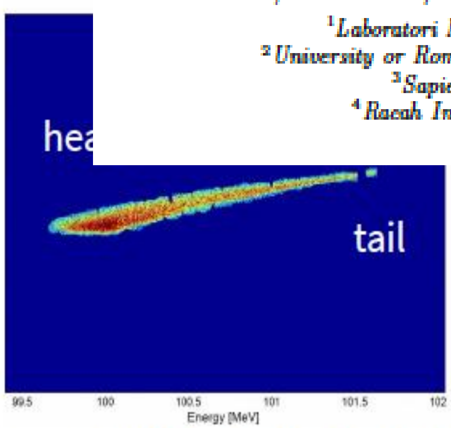


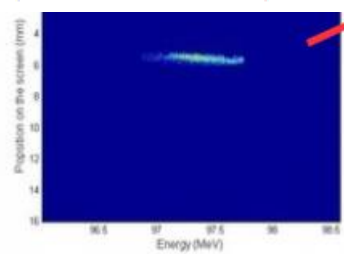
Longitudinal phase-space manipulation with plasma wakefields

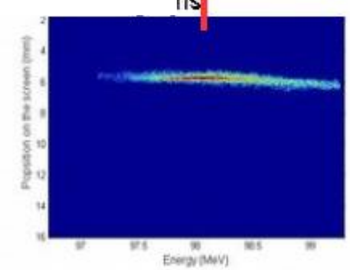
V. Shpakov,[1,*] M.P. Anania,[1] M. Bellaveglia,[1] A. Biagioni,[1] S. Bini,[1] F. Bisesto,[1] F. Cardelli,[1] E. Chiadroni,[1] A. Cianchi,[2] G. Costa,[1] M. Croia,[1] A. Del Dotto,[1] D. Di Giovenale,[1] M. Diomede,[3] M. Ferrario,[1] F. Filippi,[1] A. Giribono,[1] V. Lollo,[1] A. Marocchino,[1] M. Marongiu,[3] V. Martinelli,[1] A. Mostacci,[3] R. Pompili,[1] L. Piersanti,[1] G. Di Pirro,[1] S. Romeo,[1] J. Scifo,[1] V. Shpakov,[1] C. Vaccarezza,[1] F. Villa,[1] and A. Zigler[1,4]

[1]*Laboratori Nazionali di Frascati, Via Enrico Fermi 40, 00044 Frascati, Italy*
[2]*University or Rome Tor Vergata and INFN, Via Ricerca Scientifica 1, 00133 Rome, Italy*
[3]*Sapienza University, Piazzale Aldo Moro 5, 00185 Rome, Italy*
[4]*Racah Institute of Physics, Hebrew University, 91904 Jerusalem, Israel*

(Dated: October 27, 2018)







Under condition, that the beam has a positive chirp at the injection, the energy spread was reduced in more than ×2.5, from 0.51 to 0.19 MeV

→ A. Aschikhin *et al.*, NIM A **806**, 175 (2016)

FLASHFORWARD▸▸

FUTURE-ORIENTED WAKEFIELD ACCELERATOR RESEARCH AND DEVELOPMENT AT FLASH

> ***a next-generation experiment for beam-driven plasma wakefield accelerator research***

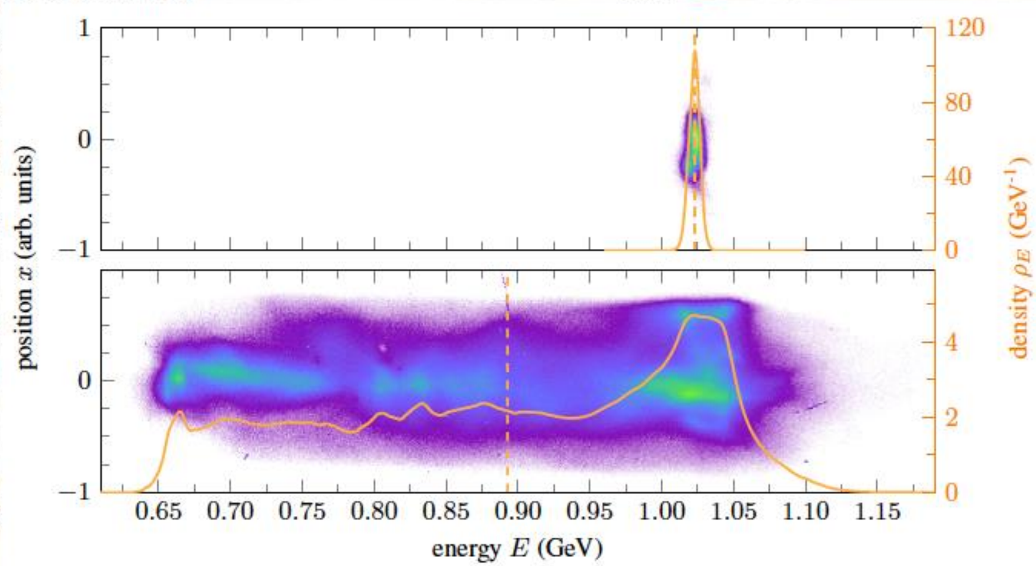
> **FLASH superconducting accelerator front-end based on ILC/XFEL technology. Typical beam parameters:**
  - 1.25 GeV energy with 500 pC, ~100 fs rms bunch duration, ~2 µm trans. norm. emittance

> **unique FLASH facility fe**
  - differentially pumped,
  - 3rd harmonic cavity fo → shaping of beam c
  - *2019:* X-band deflect (collaboration with FL
  - *future:* up to 800 bun macro-pulse rate, few

1.2 GEV BEAMS FROM FLASH

CHRONIZED 25 TW LASER

CENTRAL INTERACTION AR



> **(12.3 ± 1.7) GV/m wakefield generated in 30 mm plasma cell**
  → plasma cell scale length ~100 mm for GeV energy gain confirmed

> **12.7% total energy loss to plasma wakefield**

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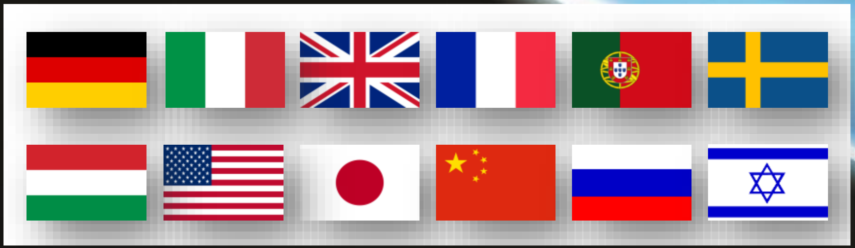
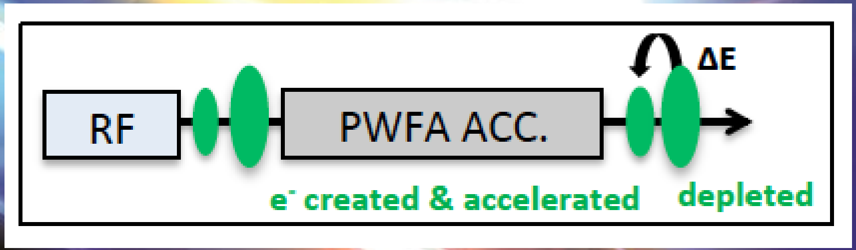
EuPRAXIA

Thank for your attention





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