EUROPEAN PLASMA RESEARCH ACCELERATOR WITH EXCELLENCE IN APPLICATIONS

WP6 : FEL Pilot Application

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Tasks, Milestones, Deliverables

Horizon 2020

Tasks

WP6.1 : Coordination and Communication (SOLEIL, ENEA)
WP6.2 : FEL baseline cases (SOLEIL, ENEA, CNRS-LOA, UHH, Lille Univ.)
WP6.3 : Undulator and technological development of equipments (SOLEIL, UHH, INFN, DESY, STFC)
WP6.4 : Towards scientific applications (SOLEIL, ENEA, STFC, DESY)
WP6.5 : Operational model (SOLEIL, DESY, INFN)

Milestones

MS4 : Electron beam baseline parameter for FEL application (SOLEIL) M6, published on intranet, DONE
MS5 : State-of-the-art of short period undulator (SOLEIL) M7, Activity report, DONE
MS17 : Models and scaling laws for plasma FEL dynamics (SOLEIL) M 20, Activity report

Deliverables

D6.1 : Report on state-of-the-art of short period undulators, Report, Public, M12-DONE
D6.2 : Models, scaling laws plasma FEL dynamics, Report, Public, M24
D6.3 : Diagnostic requirements and technical approaches, Report, Public, M24
D6.4 : Specific magnetic elements, Report, Public, M32
D6.5 : FEL Scientific user workshop, Report, Public, M48

1. EXECUTIVE SUMMARY

EuPRAXIA aiming at driving a Free Electron Laser (FEL) with plasma accelerator beams. Their specificities are requiring particular beam manipulation and associated magnetic elements. The most critical are the quadrupoles for handling the beam divergence, in view of the required strength for a strong focusing. The introduction presents the typical laser plasma accelerator characteristics, the issues for Laser Plasma Acceleration (LPA) beam handling, where the most critical, from the point of view of accelerator components, is the focusing elements for which different technologies can be considered. The permanent magnet quadrupoles of fixed gradient or variable strength are then reviewed, while a comparison with active plasma lens is performed at the end.

Table 1: Typical results of LPA electron bunch generation experiments

Laboratory	Max. electron energy	Divergence	Pointing	Shot-to-shot energy stability	Energy spread	LPA	Extra Detail
Lawrence Berkeley National Laboratory[11]	4.2 GeV	0.3 mrad RMS	---	---	6% RMS energy spread	self-trapping regime with capillary-discharge-guided	---
LOASIS (Lawrence Berkeley National Laboratory[12])	463 MeV	1.2 mrad rms	---	---	2.8% energy spread	---	---
The university of Texas[13]	2GeV	0.5 mrad FWHM	1.4 rms	---	5% spread FWHM	blowout regime in a gas cell filled with He	collimated quasi monoenergetic beam
Max-Planck-Institut für Quantenoptik[14]	200 MeV	2.1+-0.5 mrad FWHM	1.4 mrad and 2.2 mrad (transverse directions)	2.5% rms	---	gas cell filled with H	---
LOA[15]	178 MeV (Peaked distribution of 2.4 MeV FWHM width)	3+-1 mrad FWHM	---	---	1.3% FWHM relative	two colliding laser pulses in a supersonic gas jet	---

D6.4 Specific magnetic elements

Emittance growth due to divergence to be handled

$$\varepsilon_n^2 = \langle x\rangle^2\langle \beta^2\gamma^2 x'^2\rangle - \langle x\beta\gamma x'\rangle^2$$

$$\varepsilon_n^2 = \langle\gamma\rangle^2\left(\sigma_\gamma^2\sigma_{x'}^2\sigma_x^2 + \varepsilon^2\right)$$

$$\varepsilon_n^2 \approx \langle\gamma\rangle^2\left(\sigma_\gamma^2\sigma_{x'}^4 s^2 + \varepsilon^2\right)$$

Table 2: Typical quadrupole specifications

	LPA
Gradient G (T/m)	200
G tuneability (%)	±20
Gradient homogeneity over 5 mm	10^{-2}
Bore diameter (mm)	10.5
Magnetic axis excursion (μm)	<10
Length (cm)	30

Electromagnetic quadrupoles
Permanent magnet quadrupoles
Plasma Lenses

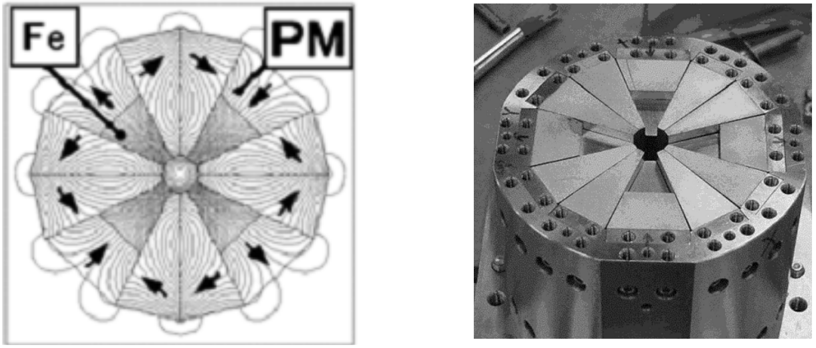
Van Tilborg, J., Barber, S. K., Benedetti, C., *et al*. Comparative study of active plasma lenses in high-quality electron accelerator *Physics of Plasmas*, 2018, vol. 25, no 5, p. 056702

D6.4 Specific magnetic elements

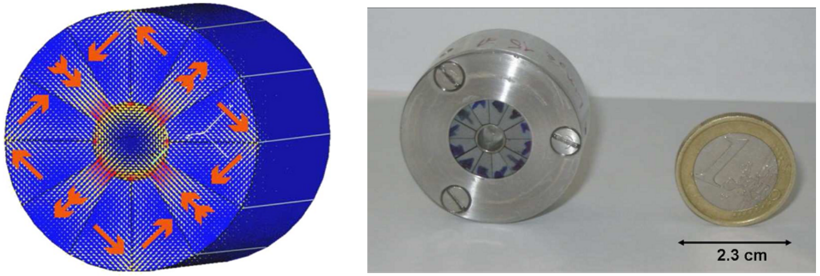
Permanent magnet quadrupoles of fixed gradient

Table 3: Characteristics of fixed gradient quadrupoles

Labs/Projects	Gradient [T/m]	bore diameter [mm]
PLEIADES ICS	550	5
FEL LPA	500	6
CLIC	575	8.25
SLAC/Kyoto	285	14
CESR	25.4	67
CESR	27.5	67
ESRF	82	24



Y. Iwashita et al, Super strong adjustable permanent magnet quadrupole for the final focus in the linear Collider. *Proceed- ing of EPAC 2006, Edinburgh, Scotland*

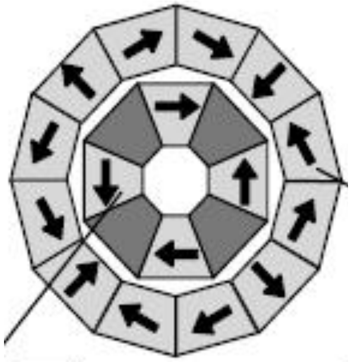


T. Eichner et al, Miniature magnetic devices for laser-based, table-top free-electron lasers. PRST Accelerators and beams 10, 082401 (2007)

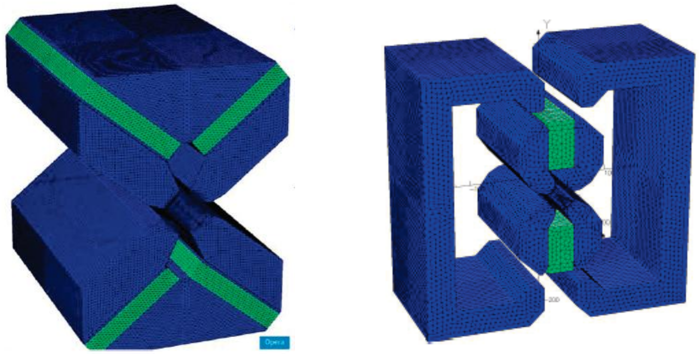
Permanent magnet quadrupoles of variable gradient

Table 4: Characteristics of variable gradient quadrupoles

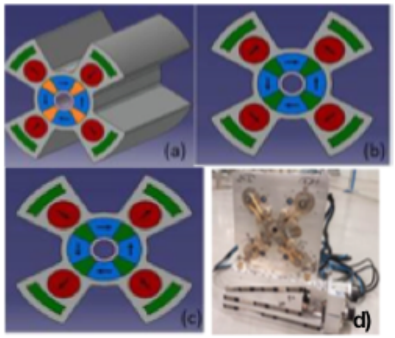
Lab/Uni	Gradient [T/m]	G [T]	Bore diameter [mm]
ILC	115	98.5	20
COXINEL	208	93	11
NLC	135	27	12.7
SLAC	115	102	13
ILC	120	98	20
CLIC beam driver	60.4	45.4	27.2



T. Mihara, Y. Iwashita et al, Super strong adjustable permanent magnet quadrupole for the final focus in the linear Col- lider. Proceeding of EPAC 2006, Edinburgh, Scotland



T. Mihara, Y. Iwashita et al, Super strong adjustable permanent magnet quadrupole for the final focus in the linear Col- lider. Proceeding of EPAC 2006, Edinburgh, Scotland



F . Marteau, A. Ghaith, P. N'Gotta, C. Benabderrahmane, M. Valléau, C. Kitégi, A. Loulergue, J. Vétéran, M. Sebdaoui, T. André, G. Le Bec, J. Chavanne, C. Vallerand, D. Oumbarek, O. Cosson, F. Forest, P. Jivkov, J. L. Lancelot, and M.E. Couprie, Variable high gradient permanent magnet quadrupole (QUAPEVA), Appl. Phys. Lett. 111, 253503 (2017)

D6.4 Specific magnetic elements

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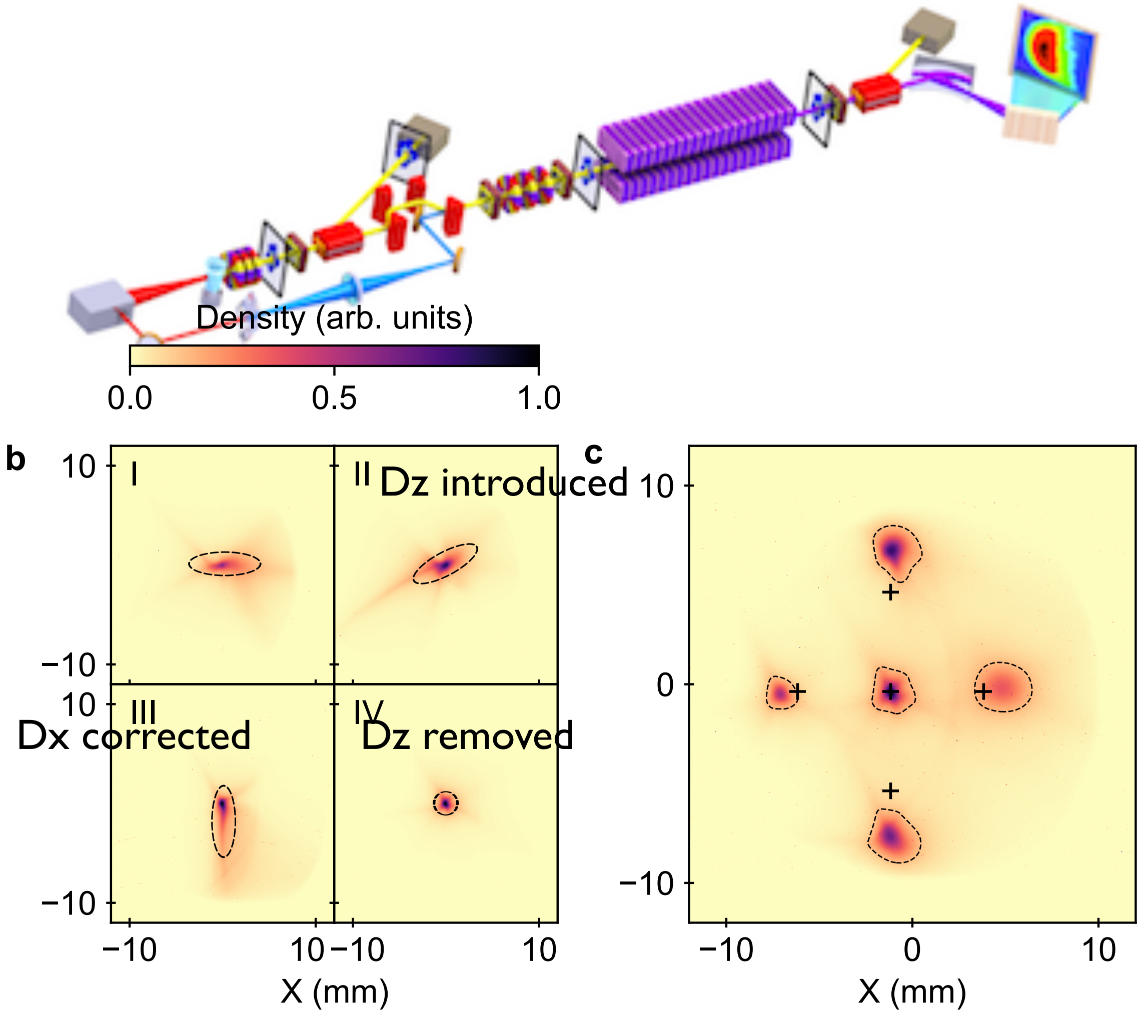
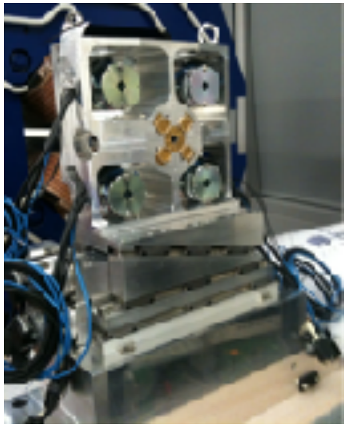
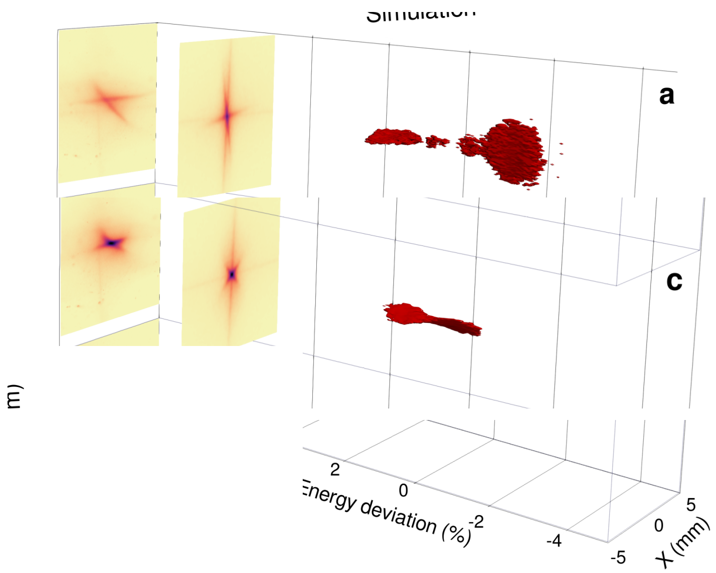
Example of application to COXINEL line







T. André et al., Control of laser plasma accelerated electrons for light sources, Nature Communications (2018) 9:1334