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Annual report WP18
Very High Gradient Acceleration Techniques (VHGAT)

Apr 21, 2021, ZOOM once more

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Contributions from and thanks to:
A. Chancé, J. Schwindling, B.Bolzon, F. Lemery, C. Thaury, J.Vieira

JRA VHGAT : WP tasks

4 (physics) tasks, largely independent

- T18.1 Coordination and Communication

  (A.S., CNRS[1)])

- T18.4 Laser driven dielectric accelerator (DLA) ***in vacuum***

  completed (F. Lemery, DESY, Erlangen)

- T18.2 Enabling multi-stage LWFA

  reformulated (A. Chancé, CEA[2)], CNRS[3)])

- T18.5 Pushing back the charge frontier

  extended (C. Thaury, CNRS[5)], U Lund)

- T18.3 LWFA with exotic laser beams

  completed (J. Vieira, Lisbon, CEA[4)])

(T18.2, T18.5, T18.3): ***in plasma*** *(LWFA)*

[1)]LLR Ecole Polytechnique; [2)]IRFU/SACM; [3)]LLR Ecole Polytechnique, 3)LULI Ecole Polytechnique, LPGP U Paris Sud; [4)]IRAMIS/LIDYL; [5)]LOA ENSTA

JRA VHGAT : Deliverables and Milestones

MS18.1	**exotic beams**	Setup simulation framework for acceleration and radiation generation in wakefields driven by lasers with orbital angular momentum	**M6**	✓
MS18.2	**exotic beams**	Setup of experimental facilities for laser wakefield acceleration experiments using laser drivers with orbital angular momentum	**M12**	✓
D18.1	**multistage**	Report containing a detailed design of a compact dogleg transport systems for use in plasma accelerators	**M18**	✓
MS18.3	**dielectric**	Final design of the ARIES dielectric structure for relativistic beams	**M30**	✓
D18.4	**dielectric**	Design & construction of an ARIES dielectric structure for acceleration of relativistic electron beams	**M35**	✓
MS18.4	**multistage**	Start of commissioning interstage line	**M36**	⛔
D18.3	**exotic beams**	Report on simulations of particle acceleration in plasma waves driven by exotic lasers with orbital angular momentum with corresponding radiation signatures and experiments on particle acceleration and radiation generation using intense vortex light beams	**M36**	✓
D18.5	**charge frontier**	Experimental demonstration on a plasma acceleration test stand of a substantial charge density increase obtained by improving injection techniques, and/or develop new techniques for increasing the beam charge	~~**M45**~~ **M54**	⏰
D18.2	**multistage**	~~**Component procured, inter-stage transport line assembled, elements tested characterized and integrated in the CILEX facility, first beam tests completed**~~	~~**M46**~~ **M54**	⏰

Publications and conference contributions

DLA

- L. Genovese et al.: Tolerance studies and limitations for photonic bandgap fiber accelerators, Proc. IPAC'19 (DOI: 10.18429/JACoW-IPAC2019-THPGW014)
- F. Mayet et al.: Status report on the dielectric laser acceleration experiments at the SINBAD/ARES linac, Poster Presentation, EAAC'19
- F. Mayet et al.: Simulation of a passive longitudinal phase space synthesizer concept based on 3D-printed dielectric-lined waveguides, Poster Presentation, EAAC'19
- W. Kuropka et al.: Parameter studies on dielectric gratings as electron accelerators, Poster Presentation, EAAC'19
- M. Kellermeier et al.: Towards additive manufacturing of dielectric accelerating structures, EAAC'19

Exotic beams:

- J. Vieira, M. Pardal, J.T. Mendonça, R.A. Fonseca, Generalised superradiance in diluted media, **Nature Physics** (under review)
- J. Vieira, J.T. Mendonça, F. Quéré, Phys. Rev. Lett. 121, 054801 (2018)
- J. Vieira et al, *Superradiant nonlinear Thomson scattering*, contributed oral, 61st APS-DPP meeting October (2019).
- J. Vieira et al, Radiation emission from twisted plasma acceleration, contributed poster, 46th EPS Conference on Plasma Physics (2019).
- J. L. Martins et al, Radiation emission in laser-wakefields driven by structured laser pulses with orbital angular momentum, Scientific Reports **9**, 9840 (2019).

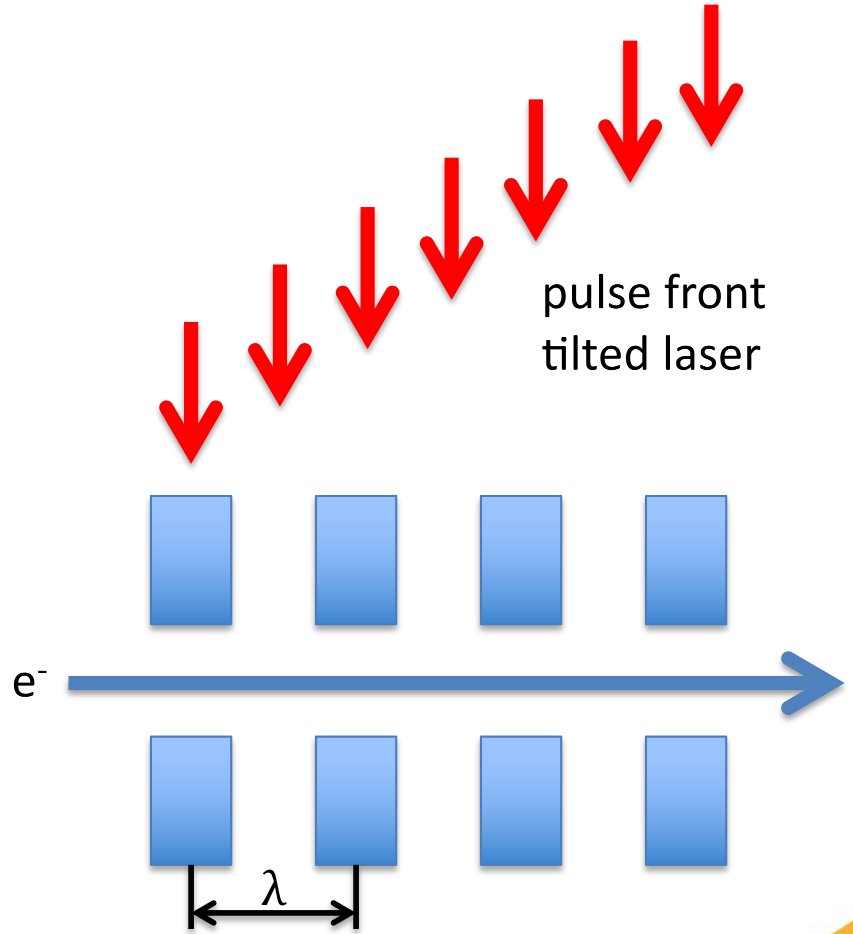
Charge Frontier:

- Slava Smartsev, Clément Caizergues, Kosta Oubrerie, Julien Gautier, Jean-Philippe Goddet, Amar Tafzi, Kim Ta Phuoc, Victor Malka, and Cédric Thaury, "Axiparabola: a long-focal-depth, high-resolution mirror for broadband high-intensity lasers," Opt. Lett. **44**, 3414-3417 (2019)
- A. Döpp, C. Thaury, E. Guillaume, F. Massimo, A. Lifschitz, I. Andriyash, J. -P. Goddet, A. Tazfi, K. Ta Phuoc, V. Malka, «Energy-chirp compensation in laser wakefield accelerators Phys. Rev. Lett. 121, 074802 (2018)
- Adeline Kabacinski1, Kosta Oubrerie, Jean-Philippe Goddet, Julien Gautier,Fabien Tissandier, Olena Kononenko, Amar Tafzi, Adrien Leblanc, Stéphane Sebban, Cédric Thaury, "Measurement and Control of Main Spatio-TemporalCouplings in a CPA Laser Chain", accepted in Journal of Optics ,2021

Dielectric Laser Acceleration (DLA)

- Estimated achievable parameters for fused silica structure

Laser params	Value
wavelength λ	2050 nm
Pulse length, rms	0.2 ps
Pulse energy	0.7 mJ
Rep. rate	1 kHz
DLA params	
Horizontal focus, rms	1.0 mm (3.3ps)
Vertical focus, rms	50 um
E_{acc}/E_{in}	0.25
Fluence	1.4 J/cm²
Damage Fluence (SiO_2)	~2 J/cm²
using pulse front tilt	
Particle energy gain	~ 1 MeV
Effective gradient	~ 1 GV/m

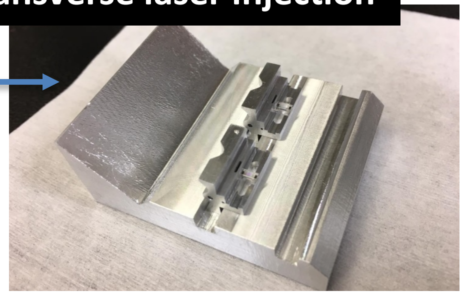


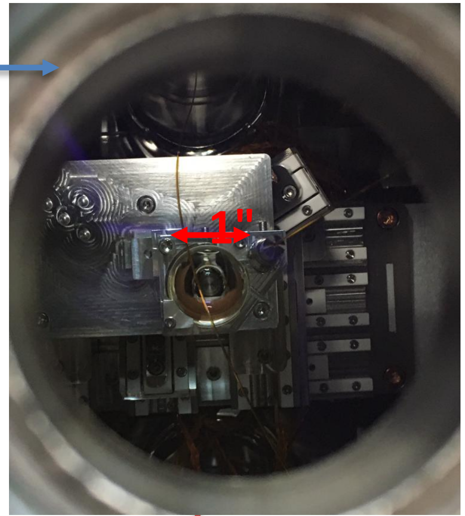
DLA: Y4 activity and progress (François Lemery,DESY)

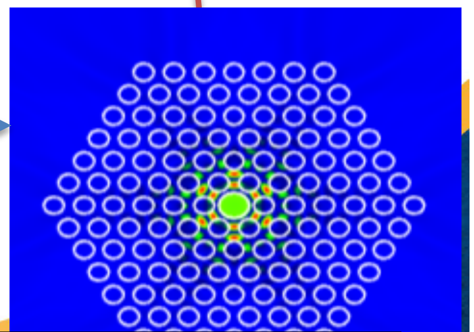
- Reminder: Deliverable D 18.4 delivered (M35: march 2020)
  Design & construction of an ARIES dielectric structure for acceleration of relativistic electron beams
  - Grating structures have been designed, fabricated and acquired.
  - Grating structures have been mounted for installation in vacuum chamber
  - Bulk and structure damage tests ongoing in laser lab
- Priority of DLA on ARES reconsidered at DESY, reduced person-power now
- Slow progress on machine dev. of ARES and first DLA experiments:
  ARES: High gun dark current -> reduced field
- Long ARES shutdown foreseen : installation of bunch compressor and TDS
- 2nd beam time of beam time on grating-DLAs to be scheduled soon
  aiming for transmission and acceleration!

- First hollow fibre received from Erlangen
- First coupling experiments in laser lab to be done soon
- Backed by “exciting” theoretical/simulation results (tbp in PRAB)
- Fibre studies scheduled after grating DLA experiments

Transverse laser injection







longitudinal laser injection

Enabling multi-stage

Amendment (sept 2020)

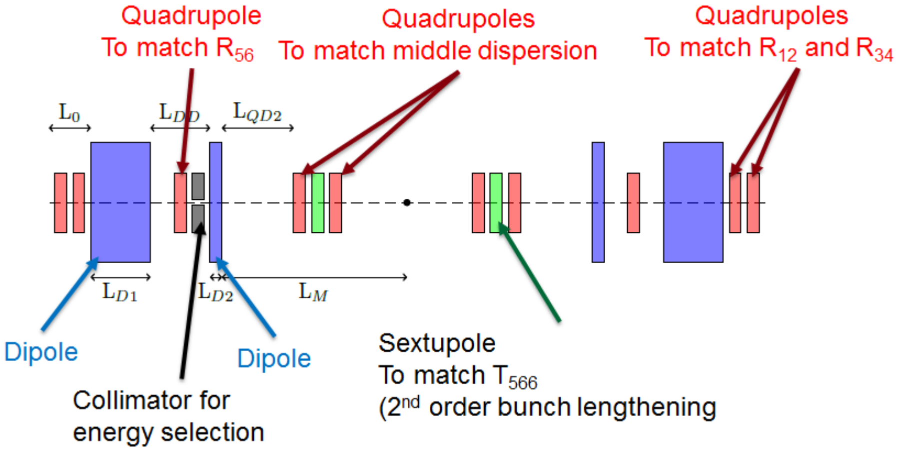
Task leader: Antoine Chancé (CEA Saclay)

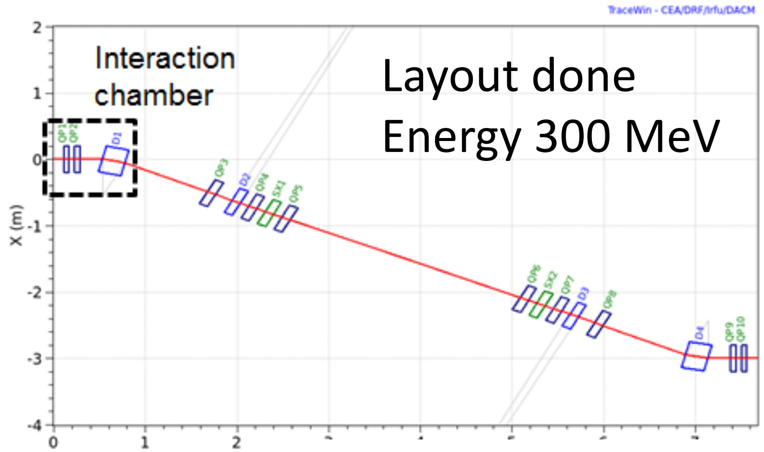
Proposed Accepted Replacement text for task description

In Laser-Wakefield Accelerators (LWFA) dephasing and beam-depletion make the use of multiple acceleration stages necessary in order to reach multi-GeV electron beams. Besides, on the low energy end, a first injection stage before further acceleration allows to uncouple the injection mechanism from the acceleration and consequently a better tuning of the plasma structures. Such 2-stage acceleration experiment is being considered at the multi-petawatt laser facility APOLLON, with transport of electrons from an all-optical injector in the non-linear (blowout) regime to a booster in the linear regime. The compact transport line has to be sufficiently achromatic, isochronous, and astigmatic which is a challenge at an energy around ranging from 200 to 300 MeV. In contrast to very compact interstage transport schemes, this project focuses on the control and characterization of the electron beam produced in the injector stage. A detailed design of the study of this line will be performed. A beam-dynamics study will focus on optimizing the preservation of emittance and bunch duration. The a design will be proposed for two energies (200MeV and 300MeV). A tolerance analysis will quantitatively assess the sensitivity alignement and field errors. A first mechanical implementation design study will be performed, including beam pipe, vacuum chambers and supports. A product break-down structure of the full line will be provided. A comprehensive study of beam diagnostics for this line will be provided, and an implementation in the mechanical design will be suggested.

Modified deliverable description D18.2 (M54=oct 2021 : Design and tolerance analysis of interstage transport and diagnostics line for 200 and 300 MeV completed. *Alignment and component tolerance study completed. Mechanical design completed, and documented in writing and drawing. Product breakdown structure documented. Beam diagnostics study and specification completed.*

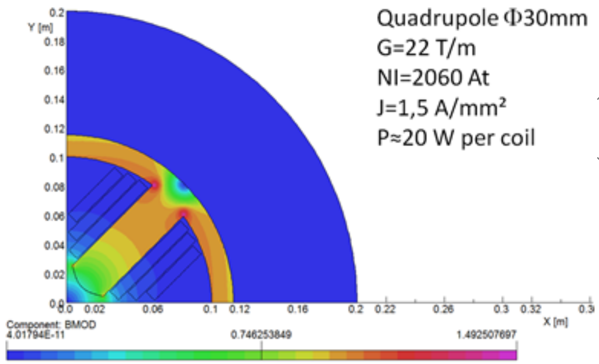
Two stage LWFA experiment at APOLLON :



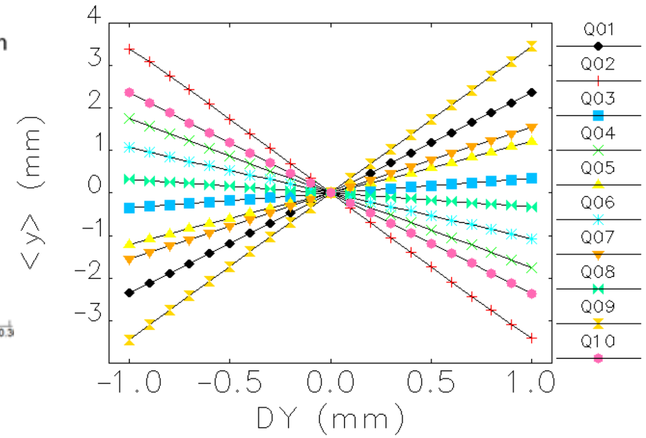


Magnet	Length	Max Strength
D1	250 mm	1,7 T/26°
D2	100 mm	0.15 T/1°
QP1	60 mm	206 T/m (PM)
QP2	60 mm	102 T/m (PM)
QP3/4/5	100 mm	15 T/m (EM)
SX1	1	M)

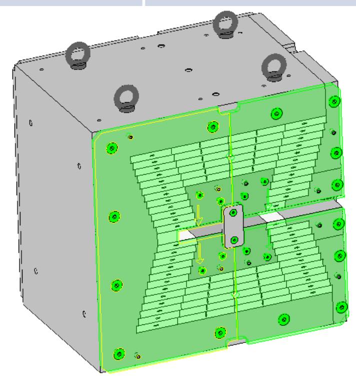
List of mag

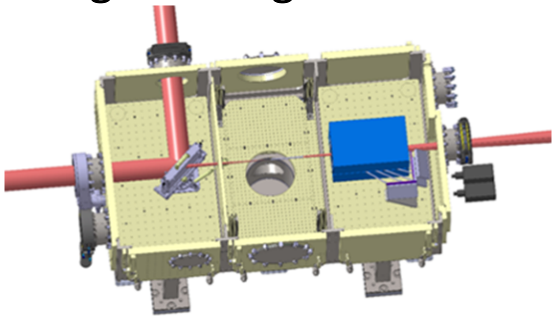


Design of magnets done



Tolerance analysis begun





First permanent dipoles
Should be delivered
in May

Towards 18.2 deliverable report

- Purpose: Transport baseline design of instrumented dogleg as starting point for potential future implementation
- Workplan towards deliverable 18.2
  - *Alignment and component tolerance study*
  - *Mechanical design in writing and drawing*
  - *Product breakdown structure document.*
  - *Beam diagnostics study and specification*
- Backward schedule of DR editing
  - *02-7-2021: first draft of DR available to WP Coordinator*
  - *13-7-2021: first feedback from WP Coordinator*
  - *24-8-2021: final DR ready for WP coordinator review*
  - *24-9-2021: submission of DR to Project Management*
  - *22-10-2021: submission of DR to Eu portal*

Continuous progress monitoring, MONTHLY meetings with CEA

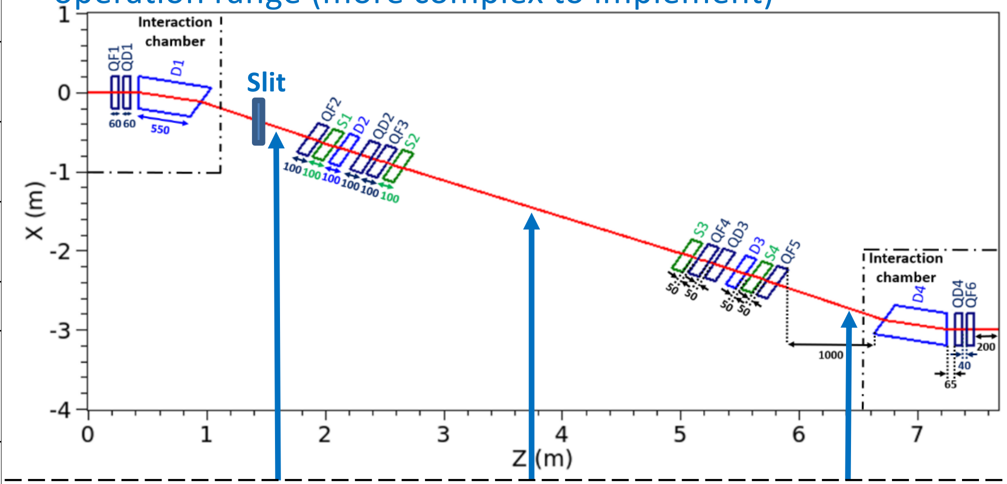
Identification of suitable beam diagnostics

Due to the difference in complexity and resolution of some methods of diagnostics, commissioning foreseen to be conducted in 2 steps (some methods have been excluded because too expensive, too complex or too imprecise):

Beam parameters to be measured		Type of diagnostics	Number of diagnostics	Location of diagnostics
Charge		Turbo ICT	Minimum 2	Just downstream the slits and at the end of the transfer line
		Possibly Faraday Cup	1	At the end of the transfer line
Position	1st step	Imaging system: Lanex, YAG, OTR	Minimum 3	At the beginning, at the middle, and at the end of the line
	2nd step	BPMs (cavity or stripline, TBD)	Minimum 3	At the beginning, at the middle, and at the end of the line
Transverse profile		Use of the same systems as for position measurement at 1st step		
Mean Energy / energy spread		Variable dipole + large 1 inch' screens (stage)	Minimum 1	Middle of the transfer line (in the drift)
Transverse emittance	1st step	Energy-scan: use of the same system as for energy measurement + 2 quadrupoles (magnets already existing in the conception of the line)		
	2nd step	Multiple OTR screens or Pepper-Pot, … TBD	1? (cumbersome)	Middle of the transfer line (in the drift)
Longitudinal profile	1st step	Coherent transition; Pyroelectric detector	Minimum 3? (cost)	In front of a screen of each translation stage
	2nd step	Electro-Optic Sampling	TBD	TBD

- **1st step:** require more robust and wide-range diagnostics
- **2nd step:** require more accurate diagnostics and a restricted operation range (more complex to implement)

TraceWin - CEA/DRF/Irfu/DACM

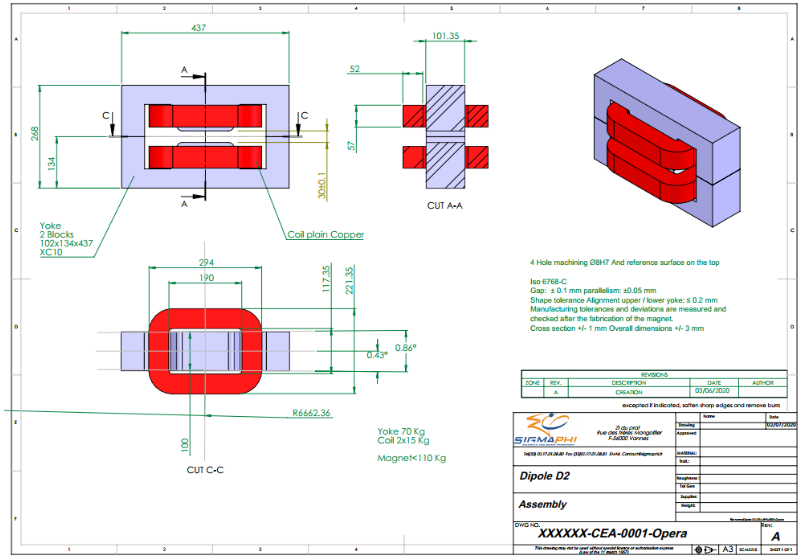


1st step	Turbo ICT 1 Imaging system 1 *(Pyroelectric detector)*	*(Turbo ICT 2)* Imaging system 2 *(Pyroelectric detector)*	Turbo ICT 3 Imaging system 3 *(Pyroelectric detector)*
2nd step	BPM 1	BPM 2 Multi OTR, Pepper Pot… Electro-Optic Sampling	BPM 3

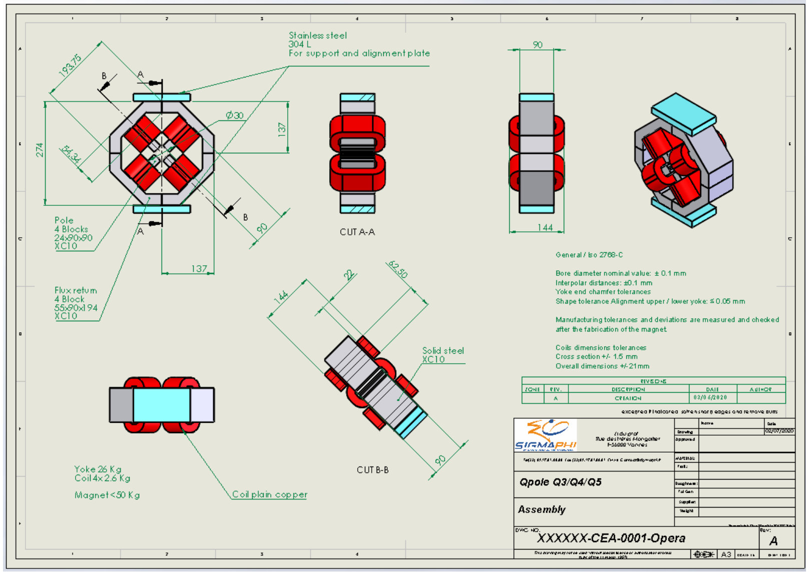
CEA benefits from counselling by Synchrotron SOLEIL

Design of the magnets

- Provided by the SigmaPhi company (CEA thanks!)
- Mechanical (CAD files) + electrical characteristics



Dipoles



Quadrupoles

CEA benefits from preorder counselling by SigmaPhi

Detailed Workplan towards deliverable 18.2

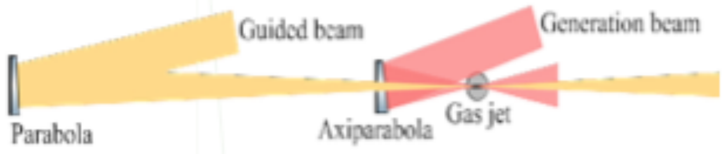
	Alignment and tolerance studies	Diagnostics	Mechanical design	Product Breakdown Structure
March 25th	Effect and correction of wrong average energy (AC) (✓)	Gather information on diagnostic chambers and off-the-shelf diagnostics (BB) ✓	Summarize the magnet design (OD) ✓ Gather information on interfaces (AD) Drawing of the line with magnets in place (AD)	
April 15th	Effect and correction of displaced magnet (AC) (✓)	Information on diagnostics precision, range, etc (BB)		First level breakdown (JS) (✓)
May 20th			Drawing of the line with diagnostic chambers (AD)	
June 17th	Summary of the studies in the document (AC)	Summary of the diagnostics in the document (BB)	Drawing of the line with supports (AD)	
July 15th			Final drawing of the line (AD)	Final PBS (JS)

Charge frontier: Work done so far

- Proposed and demonstrated a laser « dechirping » technique
  => *spectral charge increased*
- Détailed numerical study of injection sharp density gradient
  => *determined optimal conditions for maximizing injection*
- Tested two-supersonic nozzle scheme (one ultra-short)
  => *difficult experimentally, unsuccessful*
- Tested a novel long nozzle (dielectric) with integrated gradient step, in collaboration with FTMC (Vilnius, Lithuania), *ongoing*
- Suppressed presumed culprits « 4th order spectral phase » and « pulse front tilt » in LOA laser :
  => *no effect on charge density observed (other benefits)*
- 3 journal publications, 4th to come

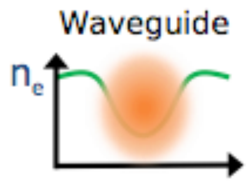
Pushing back the charge frontier:

Electron acceleration in a laser-plasma waveguide

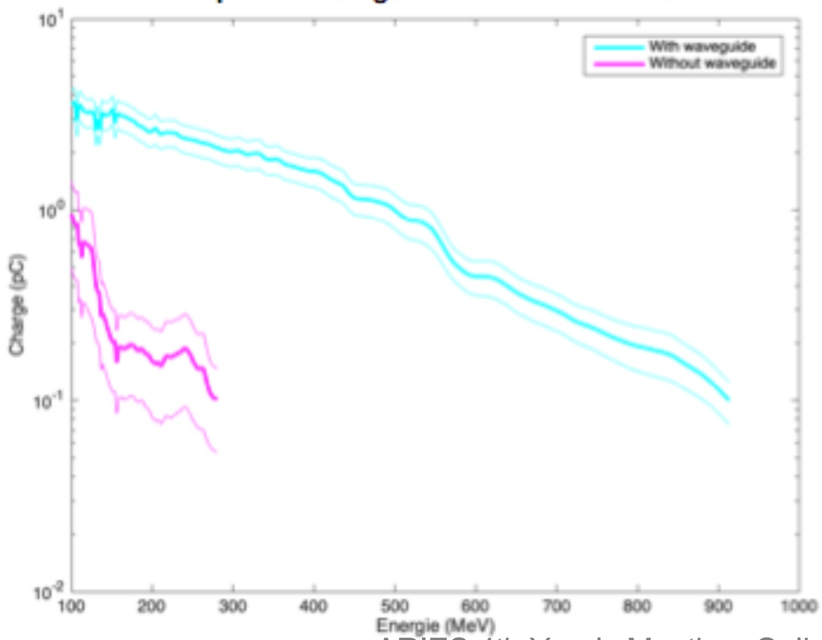


Two laser pulses

- One to create the waveguide
- One to accelerate electrons



Electron spectra averaged over 50 consecutive shots



Guiding improves the energy transfer from the laser to the plasma.

→ **Charge at 200 MeV increases by a factor 13** (from 0,15 pC/MeV up to 2 pC/MeV for a 1 J laser pulse).

→ **Total charge above 100 MeV increases by a factor 18,** up to an average value of 800 nC (for 1 J laser).

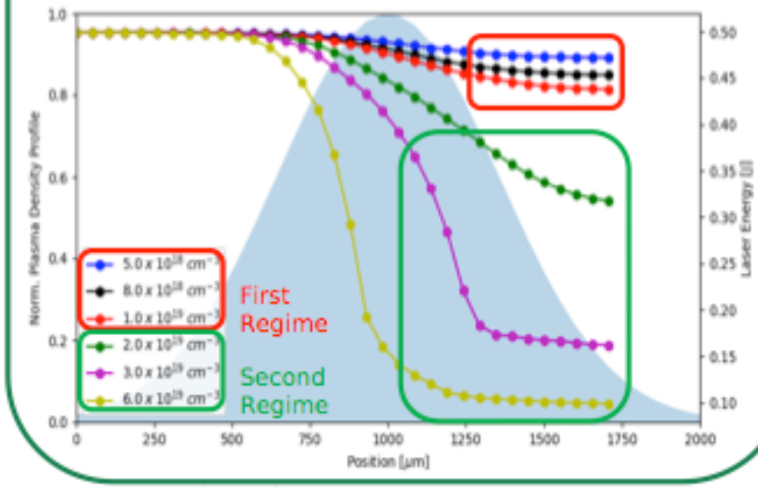
Pushing back the charge frontier

Increase of the charge at low energy

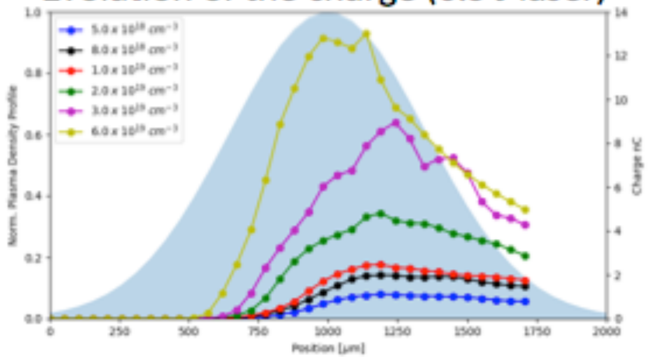
Motivation : increase the charge below 10 Mev for industrial (security at border, radiography) or radiobiology and radiotherapy applications

→ **systematic numerical study**

Density scan → 2 regimes (low or high laser depletion)



Evolution of the charge (0.5 J laser)



→ High depletion regime: high charge but high divergence + loss of charge

→ Low depletion regime: lower charge, but better divergence

◆ One of the two regimes cannot be ruled out at this time.

◆ To do next : energy, intensity, focal position scans, optimization of the density profile, laser shaping

◆ First experiment planed in September 2021

Charge frontier summary/Outlook

- Also progress on the energy frontier through laser guiding experiments
- Interferometric studies of supersonic gaz jets with dielectric nozzles ongoing
- Useful synergy with low energy (10mJ), high repetition rate applications
- Collaboration with FTMC Vilnius to be continued in iFAST

Summary & Perspectives

- Task 18.4: Dielectric Laser Acceleration (DESY)
  - ARES Linac commissioning takes longer than foreseen
  - DLA grating experiments still scheduled (experiment ready)
  - Simulation of DLA in hollow fibres to published soon
- Multistage:
  - Rescheduled. Redefined activity and deliverable accepted in amendment
  - Efforts by CEA to complete substitute delivery T18.2 have started are being intensified.
  - CEA gratefully benefits from help by third parties.
  - Engineer person power allotted to mechanical design
- Charge frontier:
  - Many approaches check to eliminate culprits for low charge density at LOA
  - New, dielectric gaz nozzles with integrated density downramp being tested in low P_{peak} and high P_{peak} lasers
  - Optical laser guiding in long gas jet reaches ~O(1GeV) AND increases total charge.
  - 2 runs still foreseen (may/june) and September 2021 (low E)
  - agenda towards deliverable report defined

Thanks to task leaders and
WP members who contributed so far!