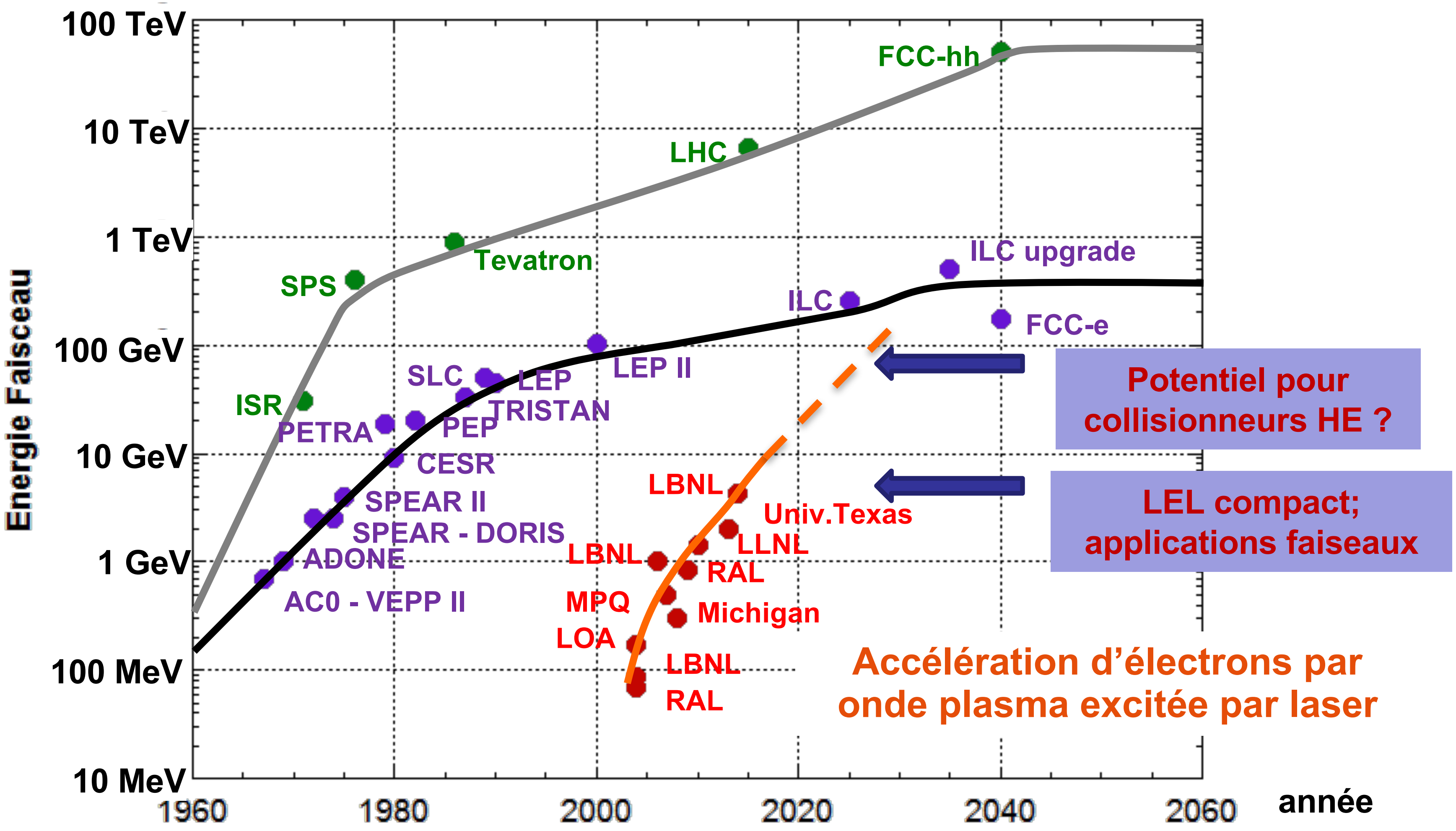
MATERIEL ADDITIONNEL

Collaborations et visibilité

- **Collaborations locales:**
  - CILEX: LULI, CEA/IRFU, CEA/IRAMIS, LAL, LPGP, LOA (ENSTA), SOLEIL
  - DACTOMUS: CEA/IRAMIS, LPGP (Orsay), LAL
  - LULI, CEA/IRFU, CEA/IRAMIS, LAL, LOA (ENSTA), LULI
- **Collaborations européennes:**
  - EuPRAXIA: WP HEP applications
    DESY, U OXFORD, CEA/IRFU
  - ARIES: WP Very High Gradient Acceleration Techniques
- **Stratégie internationale:**
  - Berkeley Plasma collider workshop (2016)
  - ANAR2017
    (ICFA Adavanced and Novel Accelerator for HEP Roadmap) (2017)

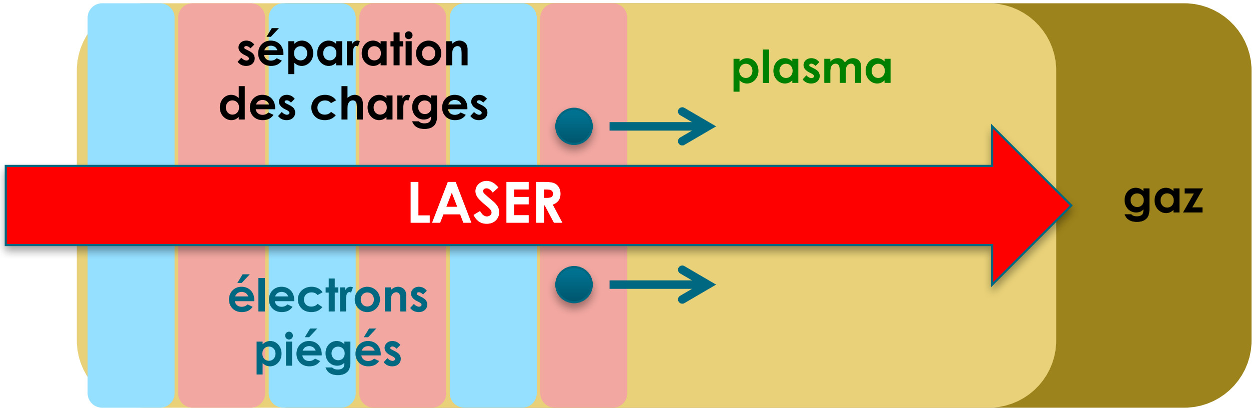
Evolution des énergies obtenues en accélération laser-plasma



- **gradients en ALP 10 à 100 fois supérieurs aux LINAC RF**
- **évolution des énergies maximales plus rapide**

Principe physique d'accélération laser de particules ALP: électrons

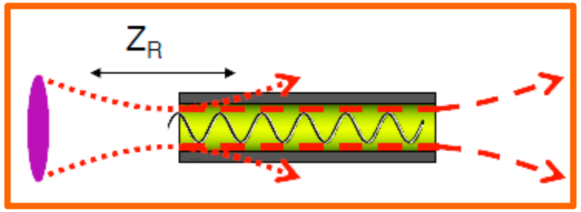
- laser de puissance à impulsion courtes: >50TW, 20-100fs, >1 J, focalisé



- accélération d'électrons: *laser wakefield acceleration* (LWFA)
  - cible gazeuse (plasma sous-dense)

    densité électronique: $n_e \sim 10^{16} - 10^{19}$ cm^{-3}
  - ionisation par effet de champ
  - séparation des charges => onde plasma: $\lambda_P \sim 300\mu m - 10\mu m$
  - v_{PH} (onde) = v_G (laser) => onde relativiste

Accélération laser-plasma d'électrons : limitations



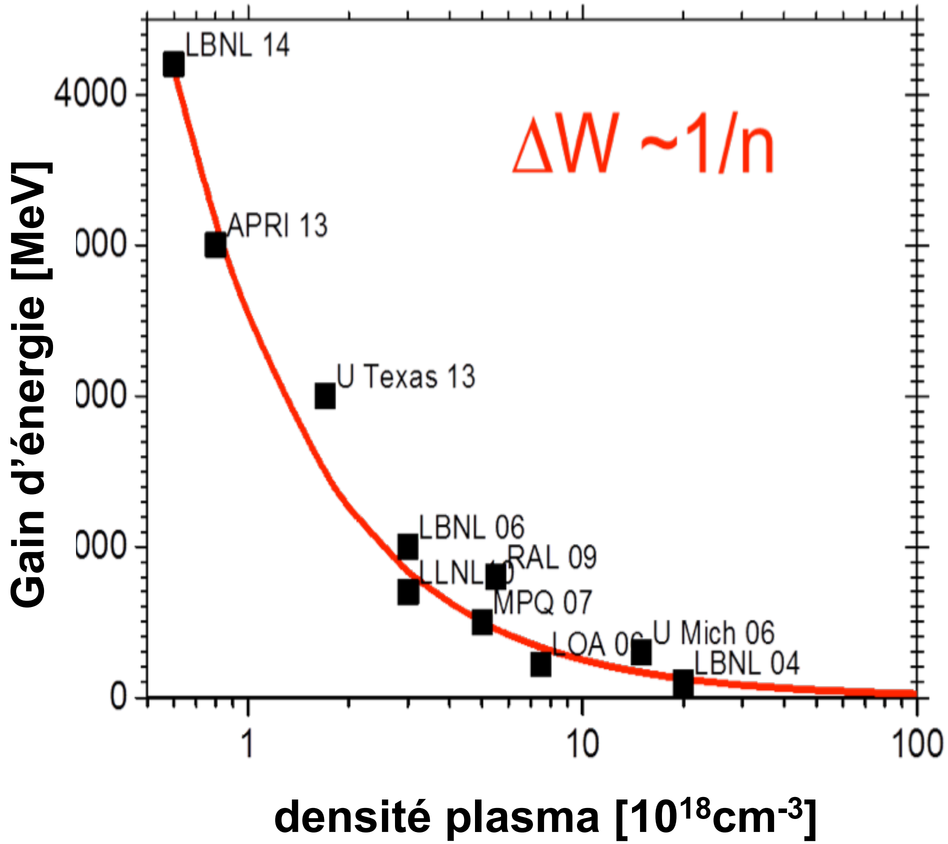
- **Diffraction du laser: longueur de Rayleigh**
  - **remède: (auto-focalisation), guidage par capillaire, décharge**
- **Déphasage du paquet et de l'onde plasma ($\gamma_{el.}$>γ_{onde})** $L_{max} \propto {n_0}^{-3/2}$
  - **remède : rampe de densité d'électrons décroissante, multi-étage**

- **Epuisement du laser (*depletion*)**

$$L_{deplete} \propto {\lambda_p}^3/{\lambda_L}^2 \propto {n_0}^{-3/2}$$

- **gradient acc.:** $G \sim E_0 = mc\omega_p/e \propto \sqrt{n_0}$
- **gain d'énergie:** $W = G \times L_{acc} \propto 1/n_0$
- **puissance crête laser:** $P_{laser} \propto 1/n_0$

augmenter le gain d'énergie (par étage)
=> baisser la densité plasma
et augmenter la puissance laser



Current Status of LWFA Electron Bunch Properties

Property	State of Art*	Reference	Remarks
Energy	**2 GeV** (± 5%, 0.1 nC) **3 GeV** (±15%, ~0.05 nC) **4 GeV** (±5%, 0.006 nC)	Wa Ki Leen	
Energy Spread	**1%** (@ .01 nC, 0.2 GeV) **5-10%**	Rech more t	
Normalized Trans-verse emittance	**~ 0.1 π mm-mrad**	Ged Brunet Plat	
Bunch Duration	**~ few fs**	Kaluza (2010) – Jena (**Faraday**) Lundh (2011) – LOA; Heigoldt (2015) – MPQ/Oxford (**OTR**) Zhang (2016) – Tsinghua	Measurements at resolution limit
Charge	**0.02 nC** @ 0.19 GeV ±5% **0.5 nC** @ 0.25 GeV ±14%	Rechatin (2009b) – LOA Couperus (2017) - HZDR	Beam-loading achieved. FOM: **Q/ΔE** ?
Repetition Rate & Repeatability	**~ 1 Hz** @ > 1 GeV **1 kHz** @ ~ 1 MeV	Leemans (2014) - LBNL He – UMIch ('15); Salehi ('17) – UMd; Guénot ('17) -- LOA	Limited by lasers & gas targets

ICFA Workshop: Advanced and Novel Accelerators for HEP Roadmap
april 2017, CERN

* No one achieves all of these simultaneously!

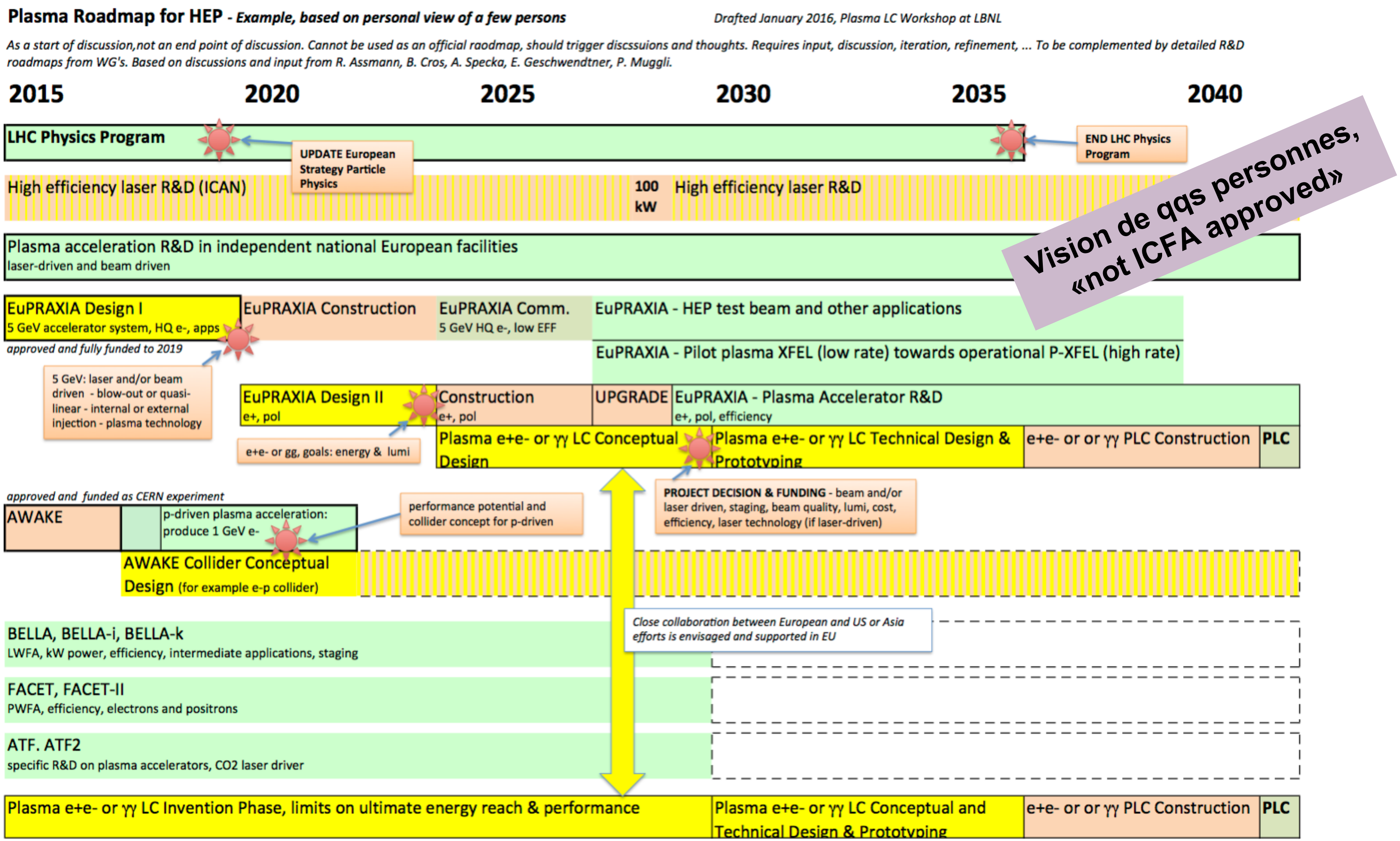
• Couperus, *submitted* ('17)
• Geddes, *PRL* **100**, 215004 ('08)
• He, *Nat. Comms* **6**, 7156 (2015)
• Heigoldt, PR-STAB **18**, 121302 ('15)
• Kaluza, *PRL* **105**, 115002 ('10)
• Kim, *PR*
• Leemans, *PRL* **113**, 245002 (2014)
• Lundh, *Nat. Phys.* **7**, 219 (2011)
• Rechatin, *PRL* **103**, 194804 ('09b)
• Salehi, *Opt. Lettt.* **42**, 215 ('17)
• Wang, *Nat. Comms* **4**, 1988 (2013)

Current Status of L

Summary report available (90 pages)
http://www.lpgp.u-psud.fr/icfaana/ana-publications-2017

Des expériences d'accélération vers des accélérateurs

- ***roadmap* vers un collisionneur** [Plasma Collider WS, Berkeley, jan 2016]
- **nécessite d'une étape intermédiaire: accélérateur plasma à qqs GeV**



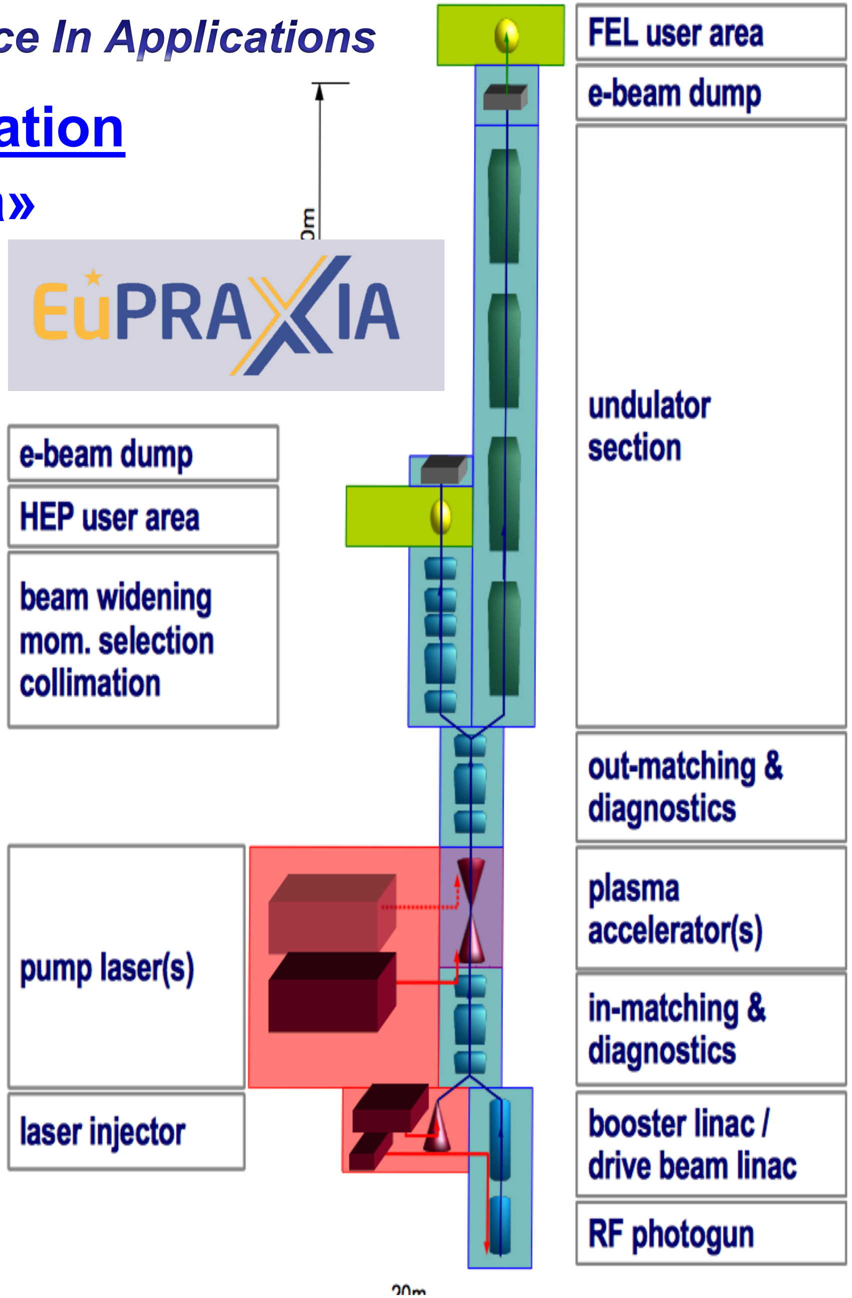
EuPRAXIA: Etude de conception d’un accélérateur plasma européen

European Plasma Research Accelerator with eXcellence In Applications

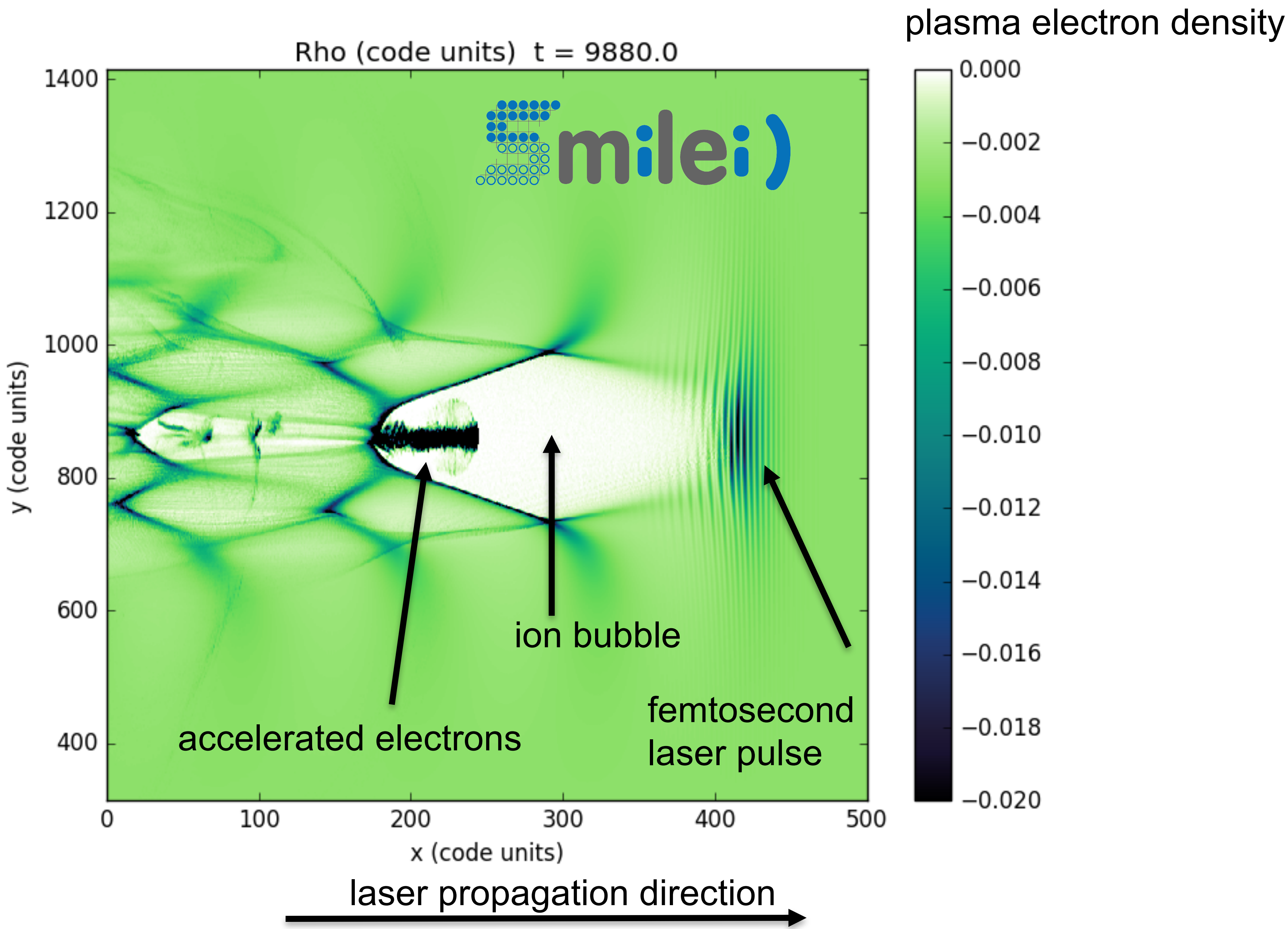
Concevoir, proposer et réaliser une <u>installation</u> «accélérateur d’électrons par laser-plasma» européenne, pour R&D <u>et</u> applications

- 2019: *conceptual design study (3M€)*
- 2020: se placer sur la ESFRI *roadmap*
- 2023: financer et construire l’installation

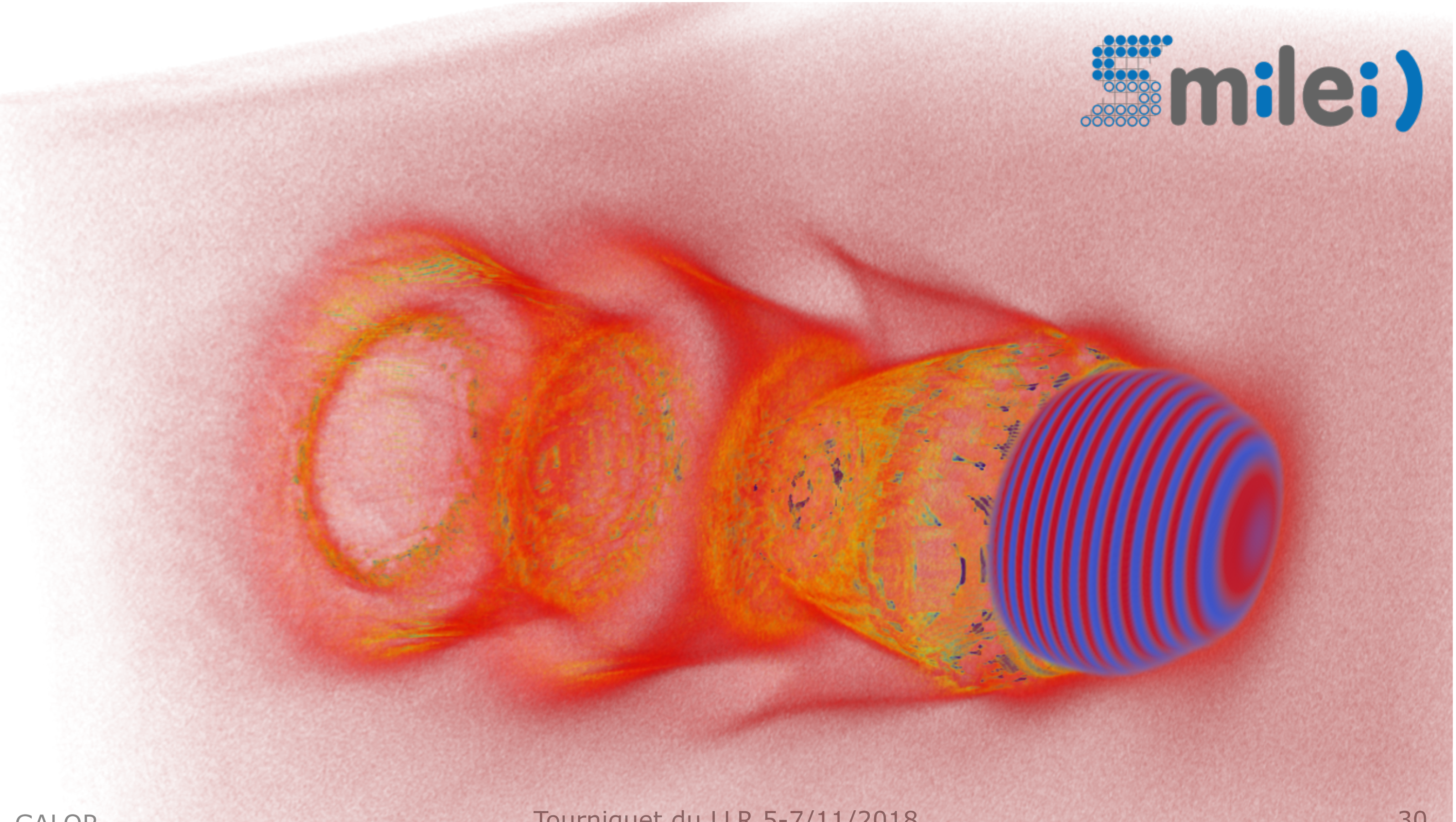
Electron beam energy	1-5 GeV
Charge per bunch	1 – 100 pC
Repetition rate	10-100 Hz
Bunch length	0.01 – 10 fs
Peak current	1 – 100 kA
Energy spread	0.1-1%
Norm. emittance	0.01 – 1 µm



Simulation of laser plasma acceleration of electrons: SMILEI



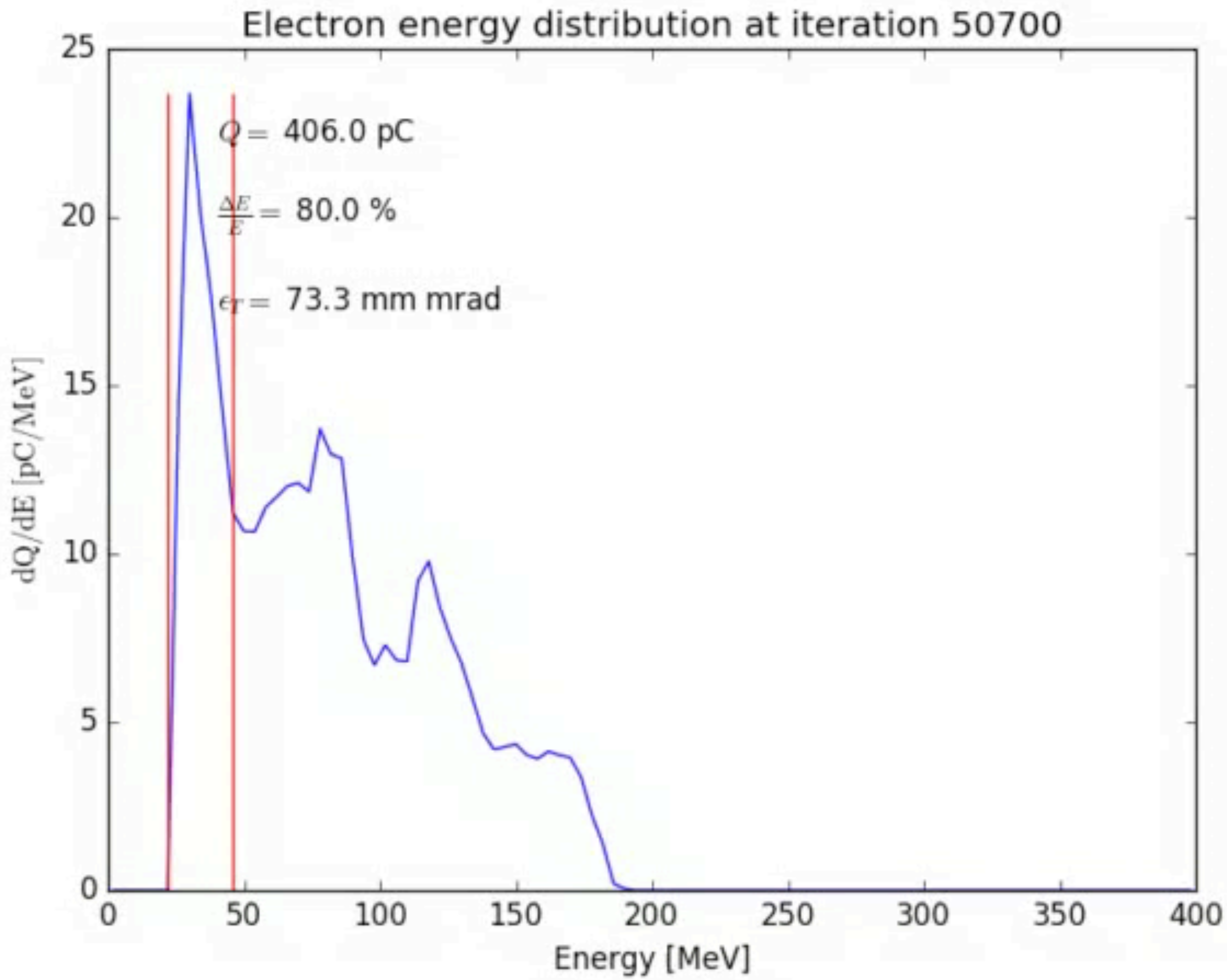
Production Scientifique
- Analyses de Physique -



A. Beck (LLR)

- **3D PIC Simulation (SMILEI code)of unguided, unassisted acceleration in O(1mm) gas jet -> high yield injector w/ F2 (1PW)**

- $\lambda_0 = 0.8\ \mu m$
- $a_0 = 2.56$
- $\tau_L = 20$ fs
- $w_0 = 40\ \mu m$
- $E = 7.5$ J
- $P = 350$ TW
- $n_0 = 5.0 \times 10^{18}\ cm^{-3}$
- $L_{ramp} = 0.1$ mm
- $L_{tot} = 1.65$ mm



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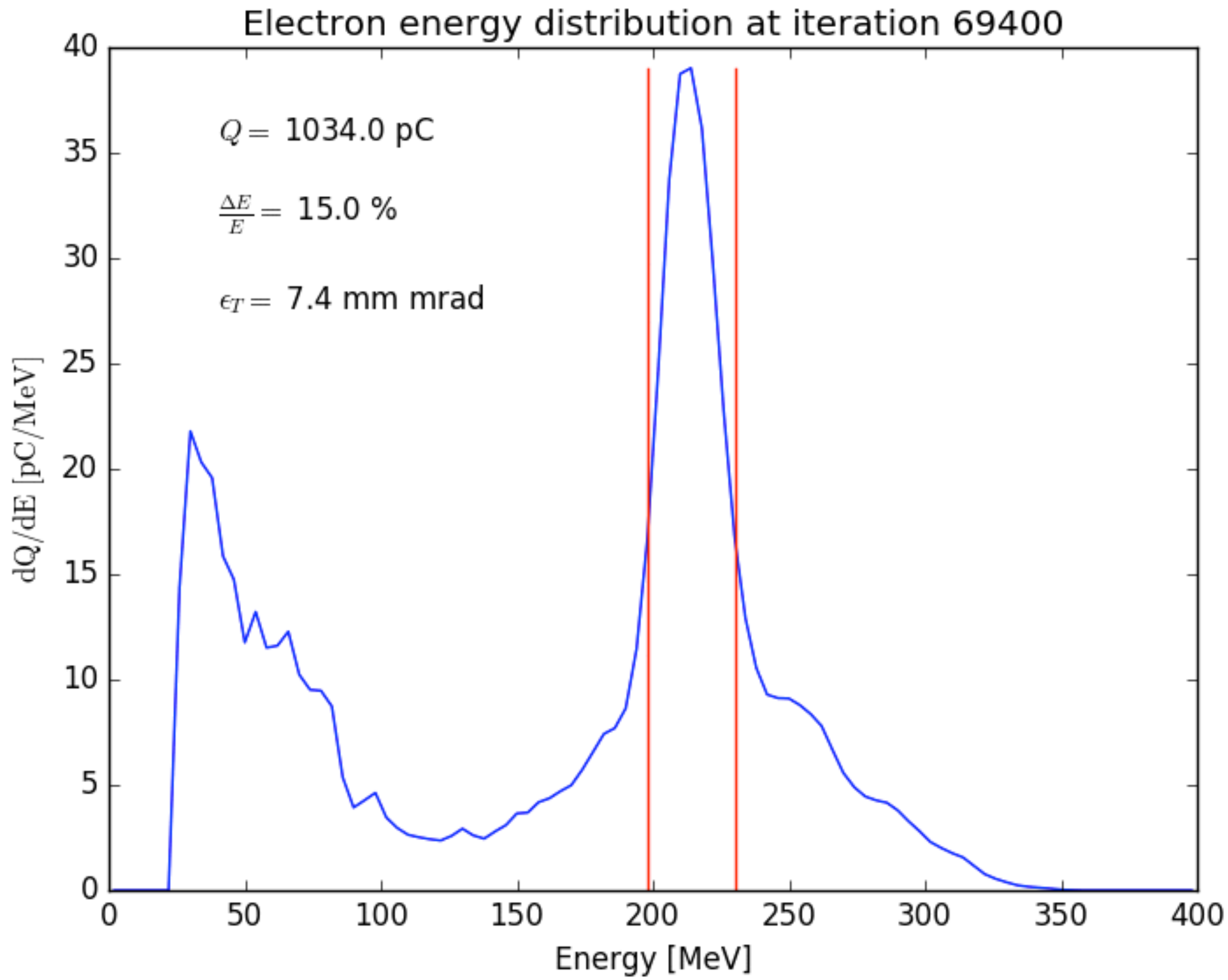
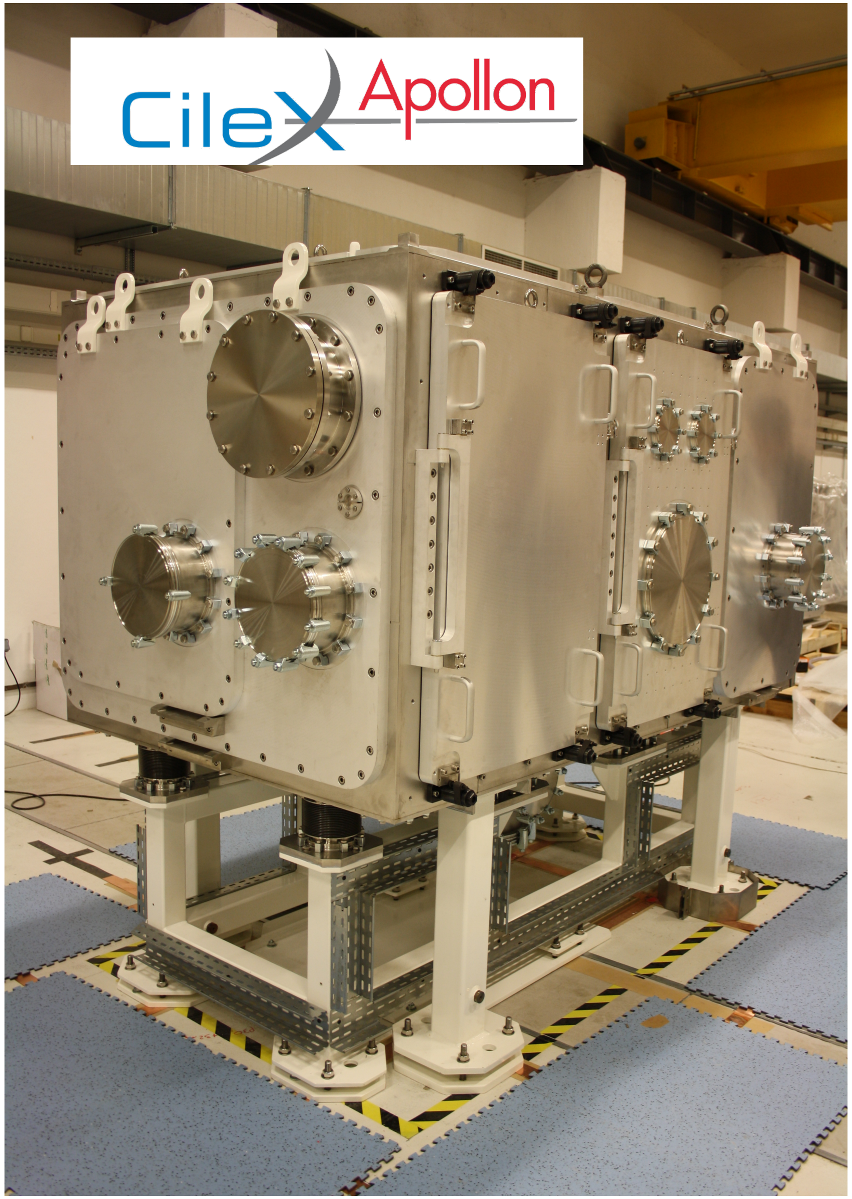
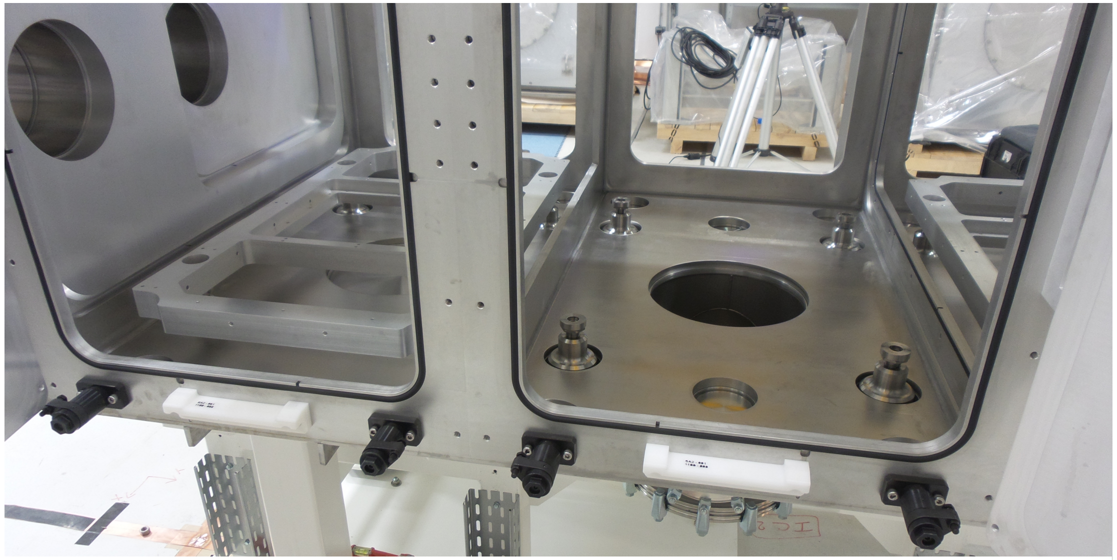


CILEX-APOLLON: installation of interaction chambers (Aug. 2017)



interaction vacuum chamber

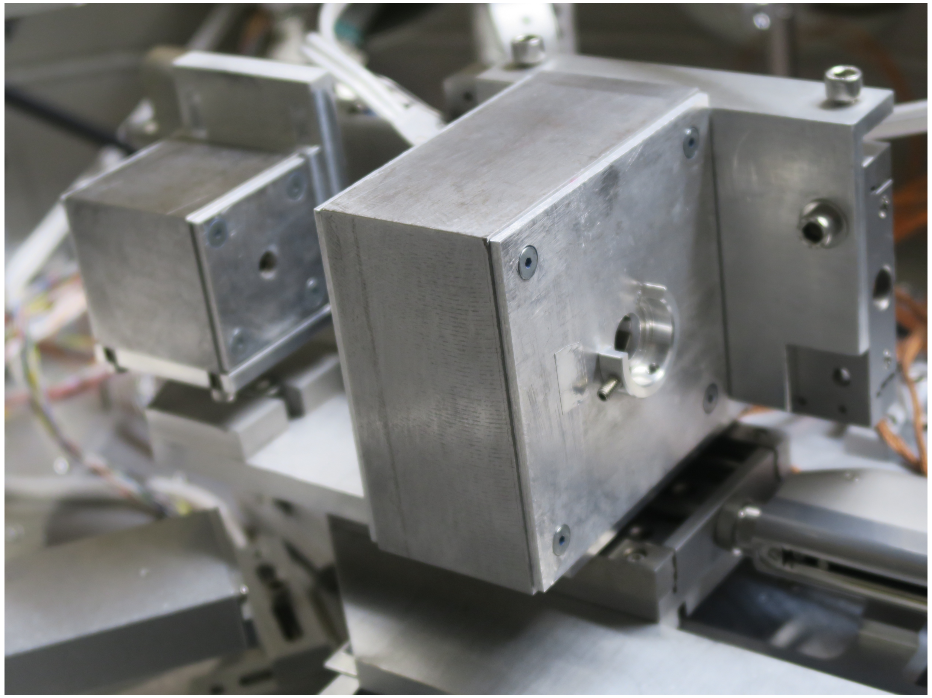


Interior of interaction vacuum chamber

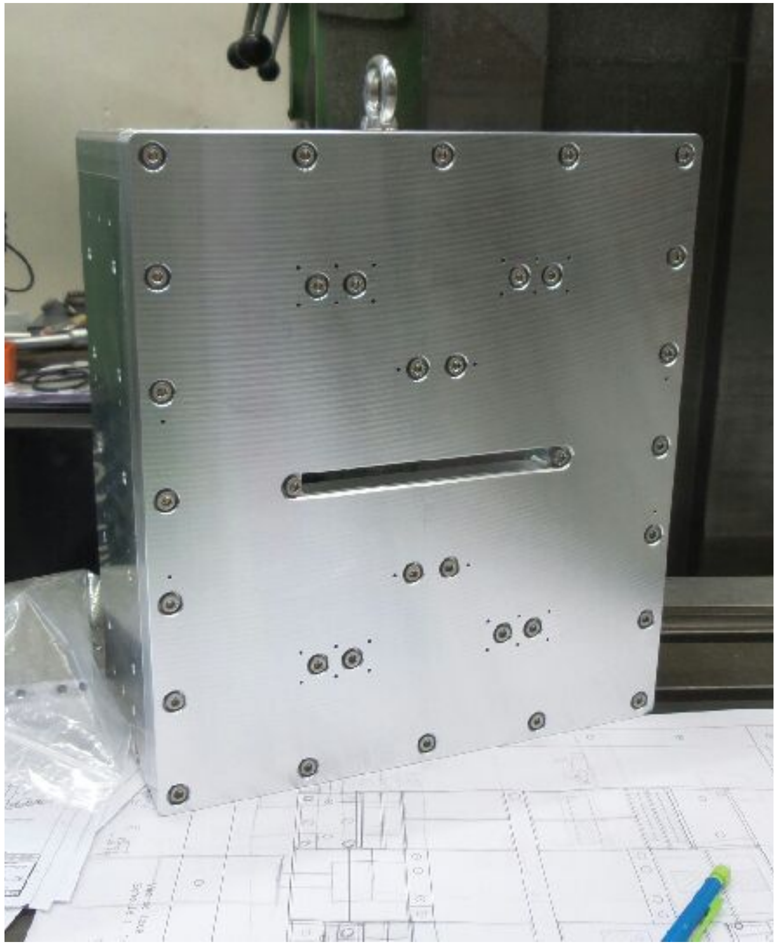
Long-focal experimental area dedicated to high-energy electron acceleration and X-ray generation

CILEX-APOLLON: compact electron diagnostics

- magnetic zoom objective
- tested on 100TW laser UHI100 (Saclay) (jan 2017)
- goal: compact electron transport



- construction of 2.1 Tesla permanent dipole magnet
- prototype being characterized
- goal: measure highest energies



3 main tasks identified for Phase 2 and preparation of phase 3

scientific advisory committee 2015, B. Cros

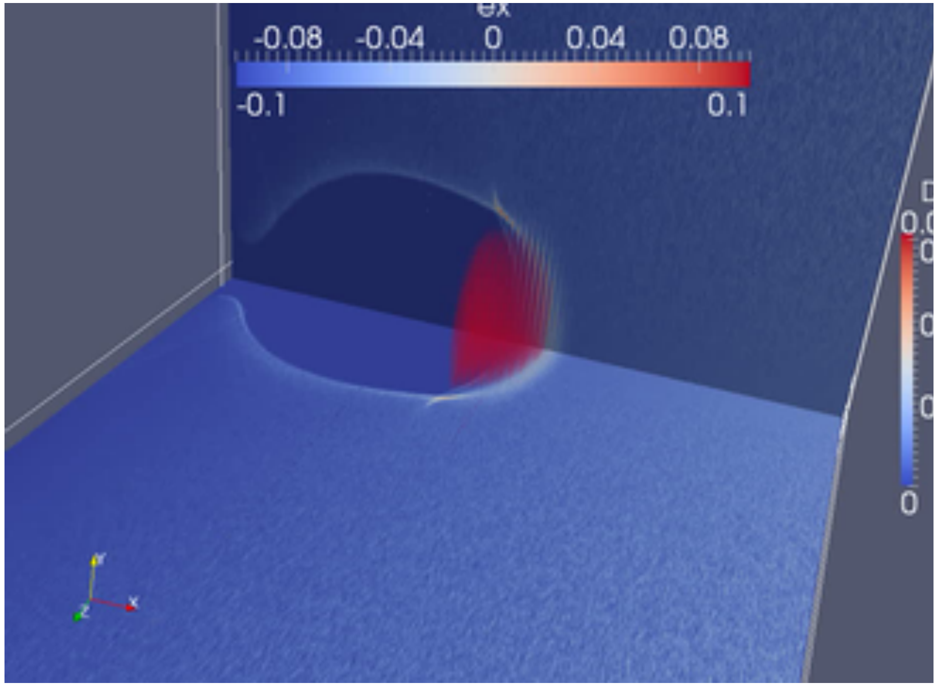
- **T1. Exploratory experiments using a single beam**
  - Validate scaling laws & commission the facility (laser parameters, experimental area)
  - Explore new regimes to produce high quality electron beams in the few GeV range
- **T2. Optimize injector (1PW):**
  - >100pC charge electron bunches in the range 50-300MeV, that can be focused at the entrance of the 2nd stage.
- **T3. Develop and implement the equipments necessary to**
  - Characterize electron bunches (energy and spatial distribution)
  - Synchronize electron bunch and laser beam
  - Transport electron bunches at the entrance of the second stage
  - Guide the laser beam over large distances (0.1-1 m)

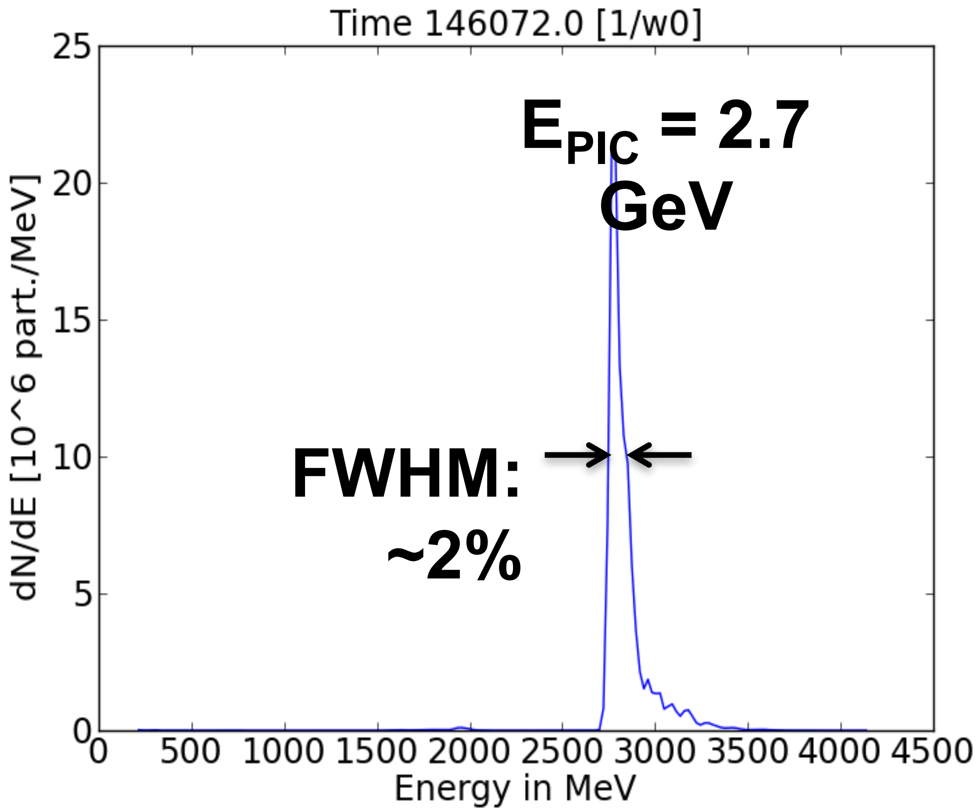
Blow-out regime LWFA : selfinjection and acceleration

- (**CILEX/Apollon 1PW startup**
- laser: 600TW 25fs w0=30µm
- comoving window over 18mm
- bubble shrinks, then expands

A. Beck et al., NIM A 740 (2014).

energy spectrum of self-injected electrons

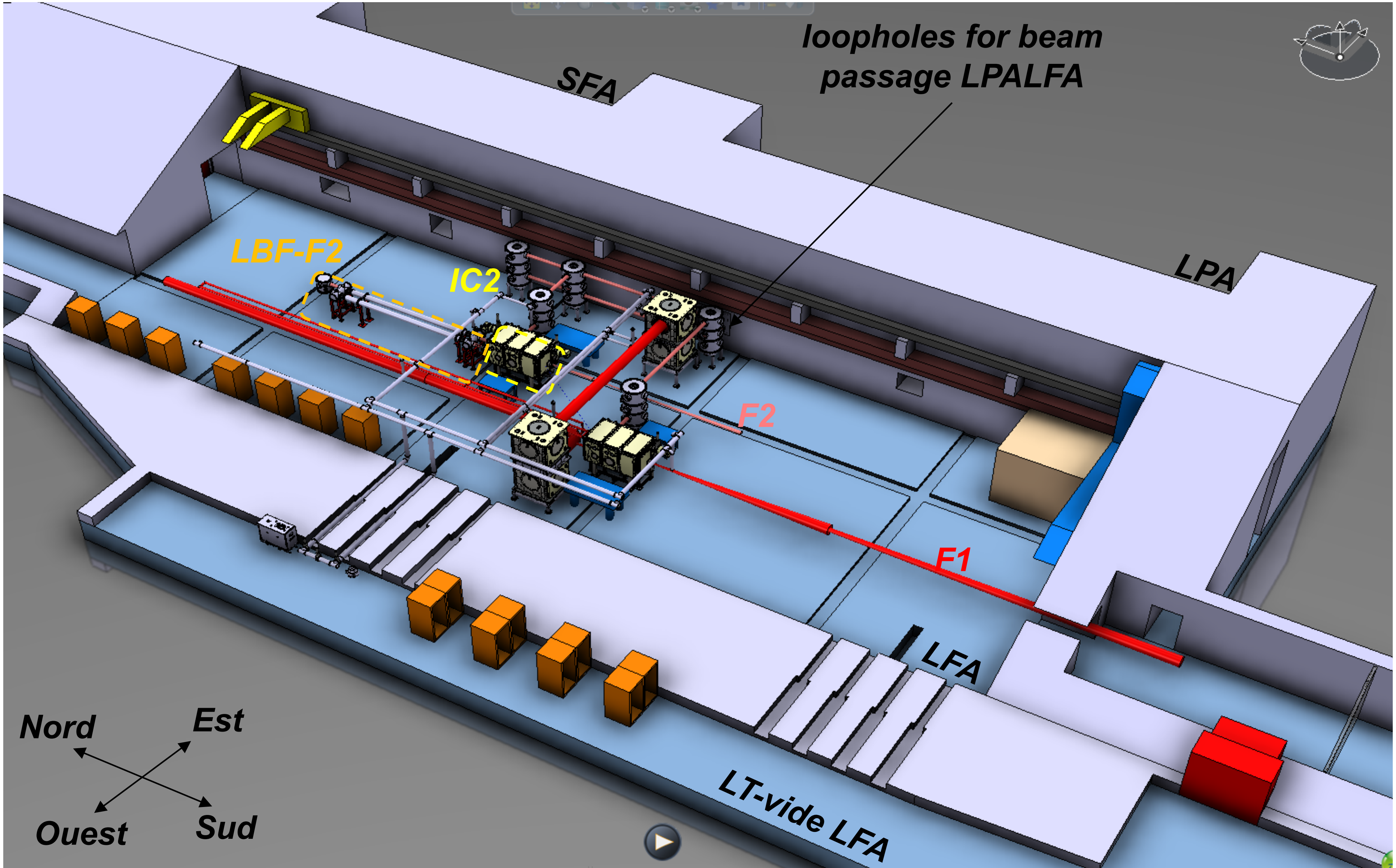




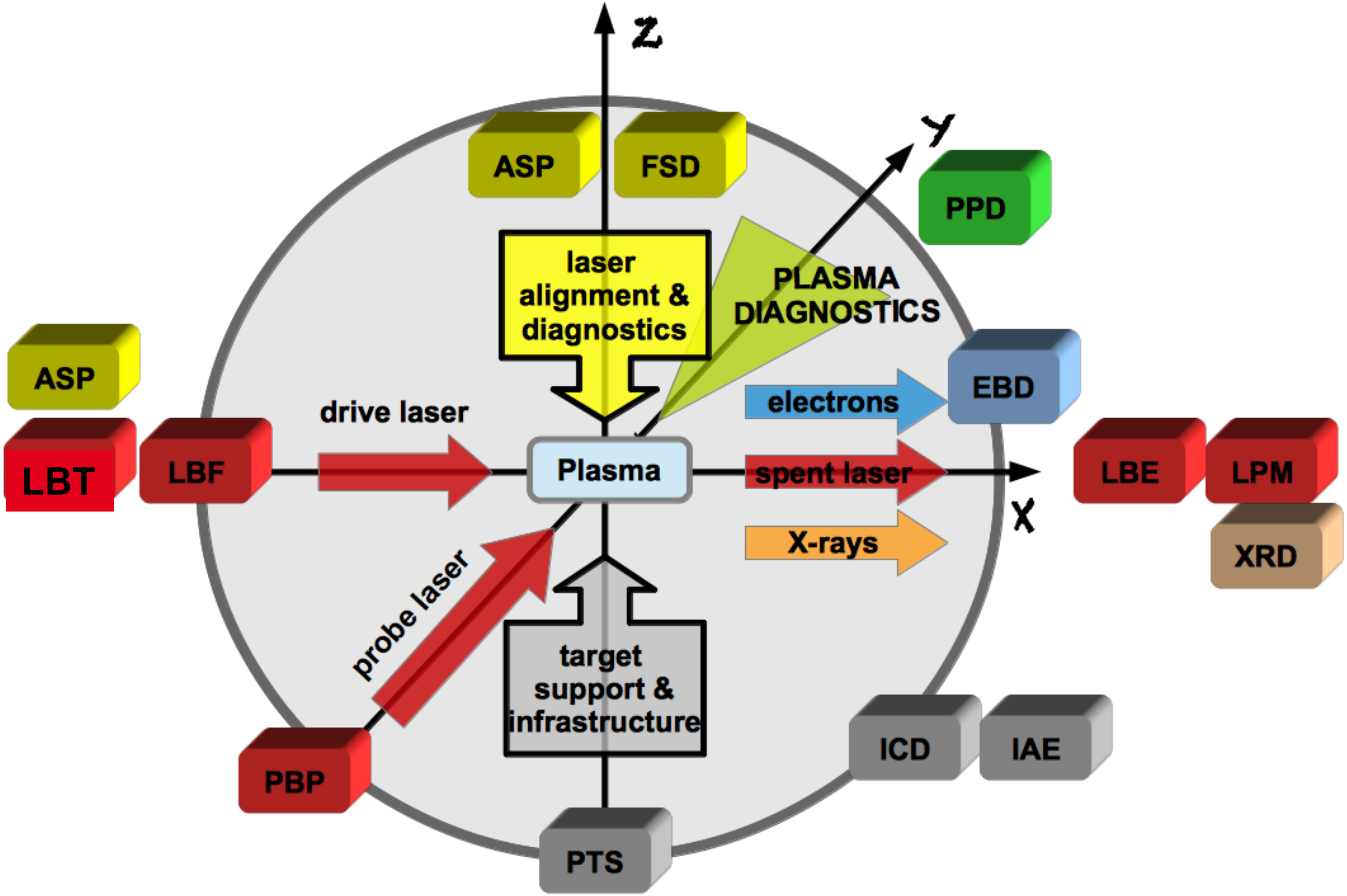
- simulation shows stable acceleration even without guiding
- peaked energy spectrum around 3GeV after ~20mm

Long Focal Area

LFA

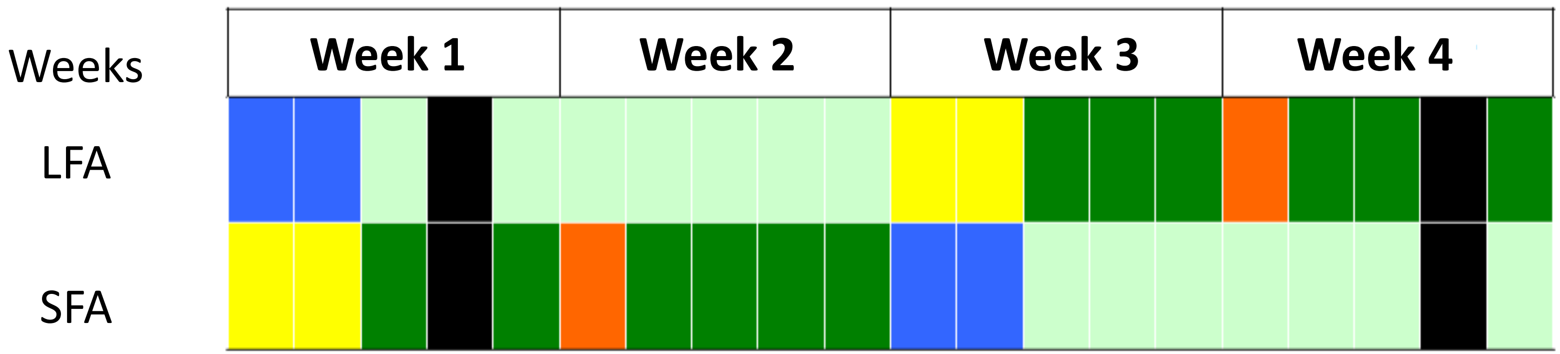


Reminder: space occupation around each IP



Campaign model on 4 weeks basis

- Each block corresponds to 1 day
- Experimental assembly without laser (**7 days**)
- Holidays and contingency 2 days
- Switch of laser configuration (2 days)
- Experiences (**6 days** : 1 800 shots)
- Laser Maintenance (1 day every 2 weeks)
- Experimental dismantling (2 days)



Dispositif envisagé pour les premières expériences