EuCARD
EuroNNac meeting May 02–04, 2012, CERN

CILEX
Centre Interdisciplinaire de Lumiere EXtreme
Interdisciplinary Center for Extreme Light

Arnd Specka, Laboratoire Leprince–Ringuet, Ecole Polytechnique – CNRS/IN2P3, Palaiseau, France
on behalf of the CILEX collaboration

many thanks to:

F. Amiranoff, P. Audebert, J.F. Bethourné, J.P. Chambaret, S. Chen, G. Cheriaux, J. Fuchs, C. Leblanc, V. Malka, P. Martin, F. Mathieu, G. Mennerat, P. Monot, J.L. Paillard,... for supplying their slides

EuroNNAc organization committee expectations (08/04/2011)

CILEX- APOLLON

Subject: EuroNNAC workshop, session R&D plans1
From: Steffen Hillenbrand <steffen.hillenbrand@cern.ch>
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Dear All,

the program for the EuroNNAc workshop is now finished and available at
https://indico.cern.ch/internalPage.py?pageId=0&confId=115336
If you can not upload your presentation there, please do not hesitate to contact me.

Please find below a list of questions we would like to give you as guidelines for your presentations.

Thanks a lot and best regards
Steffen Hillenbrand
EuroNNAc, Scientific Secretary

Questions to be addressed in R&D plans

- Plans for development of facilities with schedule
- 5 year perspective (level of approved support: funded/proposed/idea)
- Motivation and objectives
- Acceleration goals (summary table)
- Application goals
- Possibilities for open access
- Expectations for network

- Motivation and objectives
- Acceleration goals (summary table)
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OUTLINE

- **what is CILEX**
- **scientific programme and facility design goals**
- **project organisation**
- **highlights from workpackages (selection)**
- **Ion acceleration**
- **electron acceleration**
- **conclusion**

Centre Interdisciplinaire Lumière EXtrême

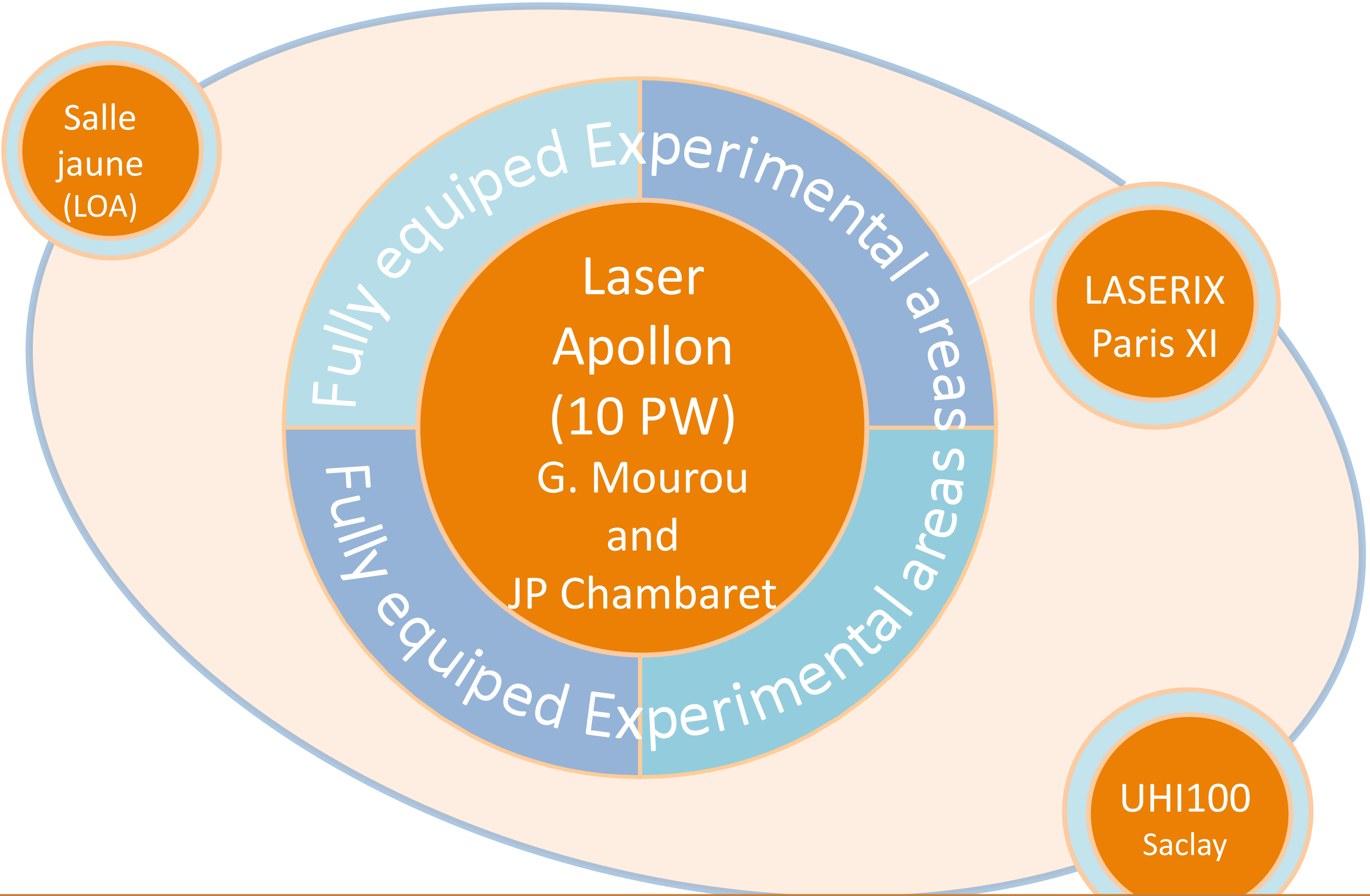
CILEX- APOLLON

CENTER dedicated to ultra-relativistic optics
Open to national and international Community

12 partner laboratories :

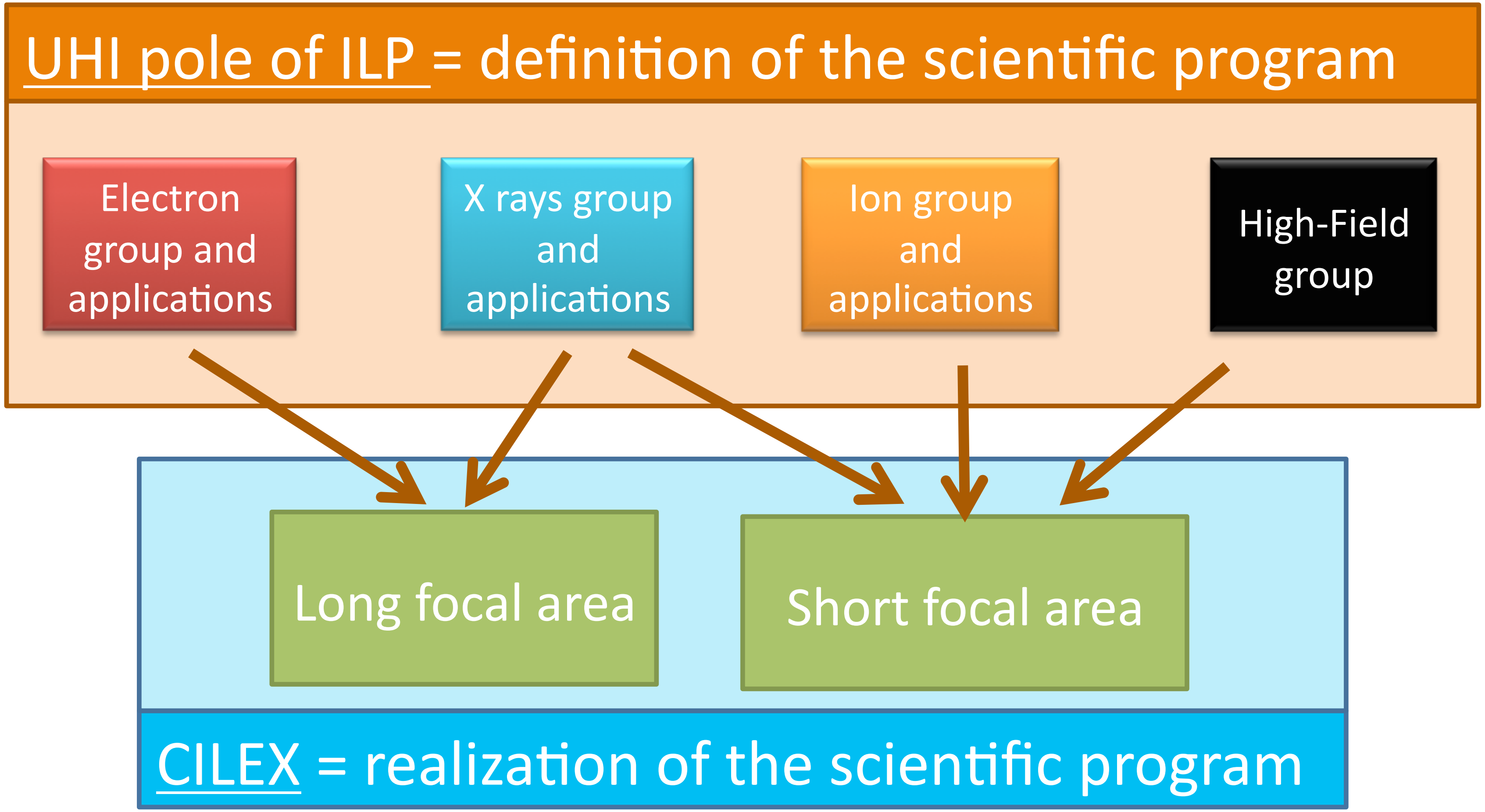
Laboratoire de Physique des Gaz et des Plasmas (LPGP)
Fédération Lumière Matière Fédération (LUMAT-LASERIX)
Laboratoire Charles Fabry de l'Institut d'Optique Graduate School (LCFIO)
Laboratoire de l'accélérateur linéaire (LAL)
Synchrotron Soleil
Laboratoire d'Optique Appliquée (LOA)
Laboratoire Leprince-Ringuet (LLR)
Centre de Physique Théorique (CPhT)
Laboratoire pour l'Utilisation des Lasers Intenses (LULI)
Institut Rayonnement Matière de Saclay (IRAMIS)
Institut de recherche sur les lois fondamentales de l'univers (IRFU)
DSM Saclay

CILEX : What's it? What's in?



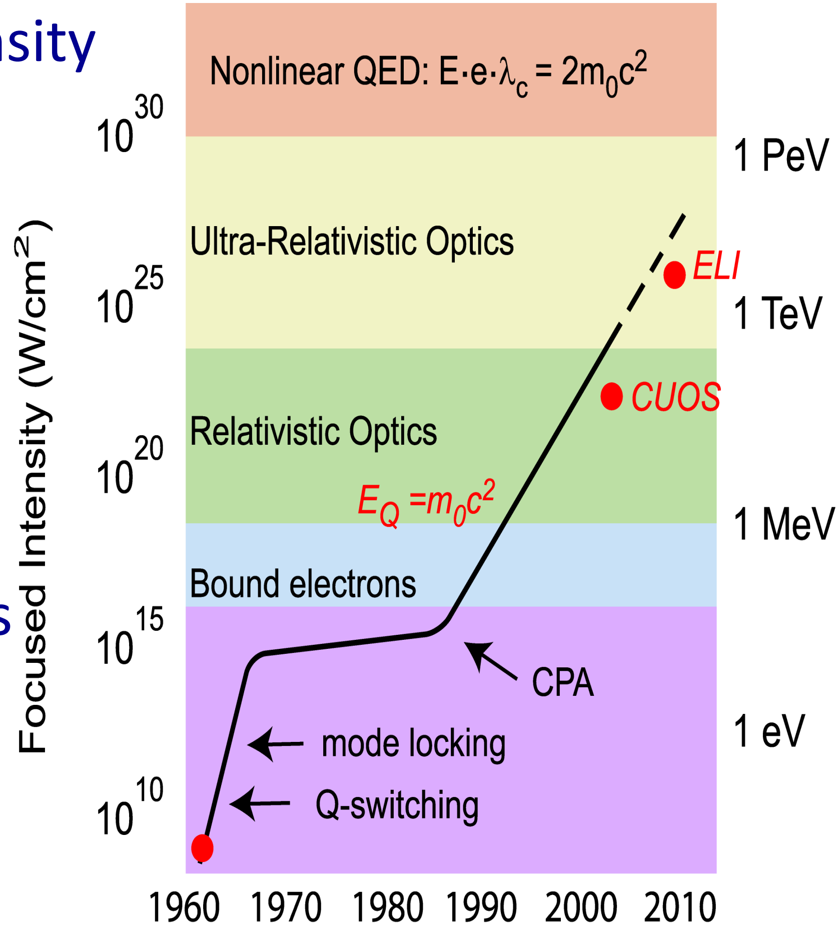
CILEX = APOLLON (20 M€) + SATELLITE FACILITIES + BUILDING REHABILITATION + EXPERIMENTAL SET-Up (20 M€)

Scientific program: definition and execution



Science Topics for CILEX

- Laser-matter interaction at high intensity
- Laser plasma electron acceleration
- Laser plasma ion acceleration
- Laser plasma x-ray sources
- Perform pump-probe experiments within a wide range of beam energies and pulse durations
- Generate sufficiently high optical intensities to open up new and unexplored areas of fundamental physics



Requirements

CILEX- APOLLON

- High laser intensity
  - $I > 10^{22}$W/cm^2 ($a_0 = (0.85\,(I_{18}\lambda^2)^{0.5}) > 100$
- Multiple laser beams
  - to perform pump probe experiments and multi stage laser acceleration
- High repetition rate
  - To adjust laser and experiment parameters
  - To have enough statistics
- High contrast
  - To be able to interact with the solid without pre-formed plasma
- Reliability and stability
- Good characterization of the beams
- Dedicated experimental set up
- Flexibility to make new experiments

Laser Beams

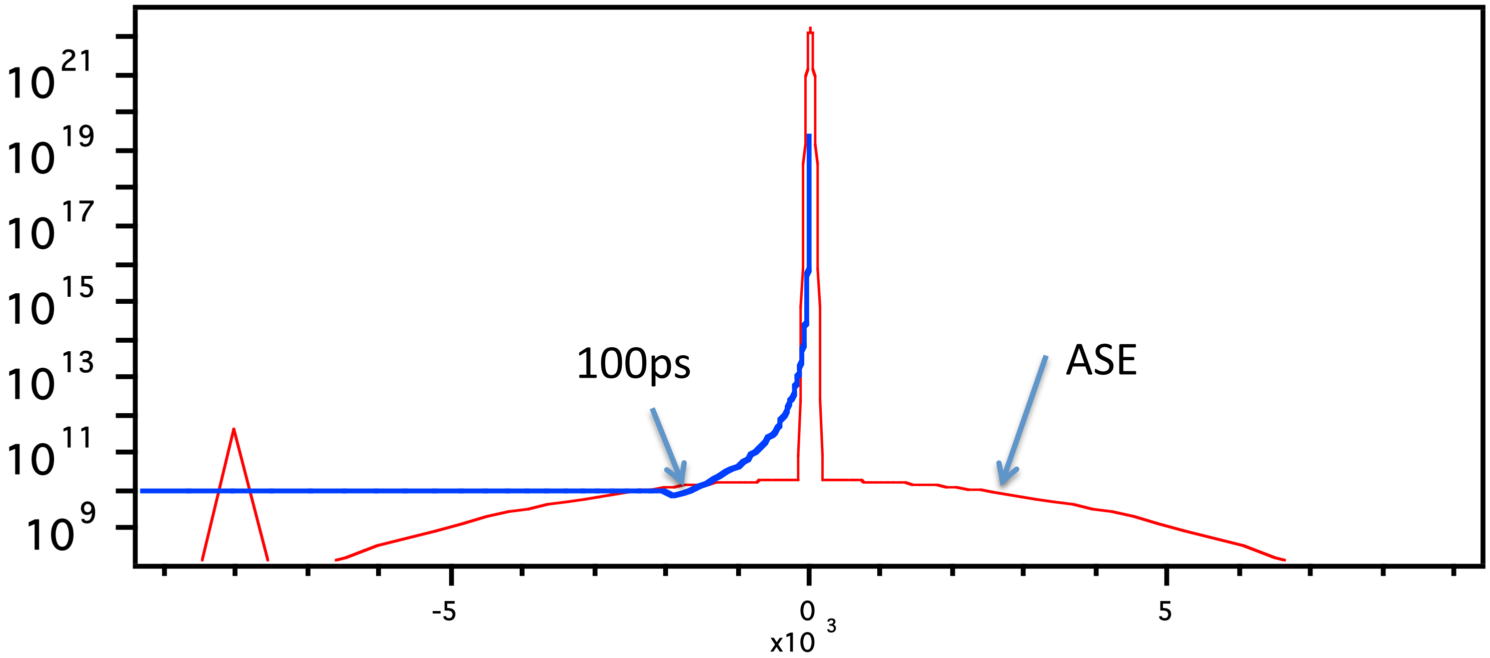
- 4 independent beams, discrete pulse energies
  - main beam 15fs-few ps / 150J, 75J 50J, 25J
  - secondary beam 15 fs-few ps / 15J, 10J, 5J, 1J
  - ns beam uncompressed 200J

  probe beam <20fs / 250mJ
- Beam pointing and stability
  - alignment on target (absolute): 1 focal spot size
  - alignment on target (relative): < 20% of focal spot size
- Synchronisation
  - delay line range ± 5ns for each
  - synchronization to < 30% of pulse duration (later <10%)
  - time step of delay < 20

Contrast

CILEX- APOLLON

- pre-pulse I < 10^9 W/cm2
- incoherent contrast I < 10^{10} W/cm2 @100ps
- coherent contrast between 100ps and the pulse maximum
  – Expansion less than a skin depth (~ t-2.9)



Operation mode

CILEX- APOLLON

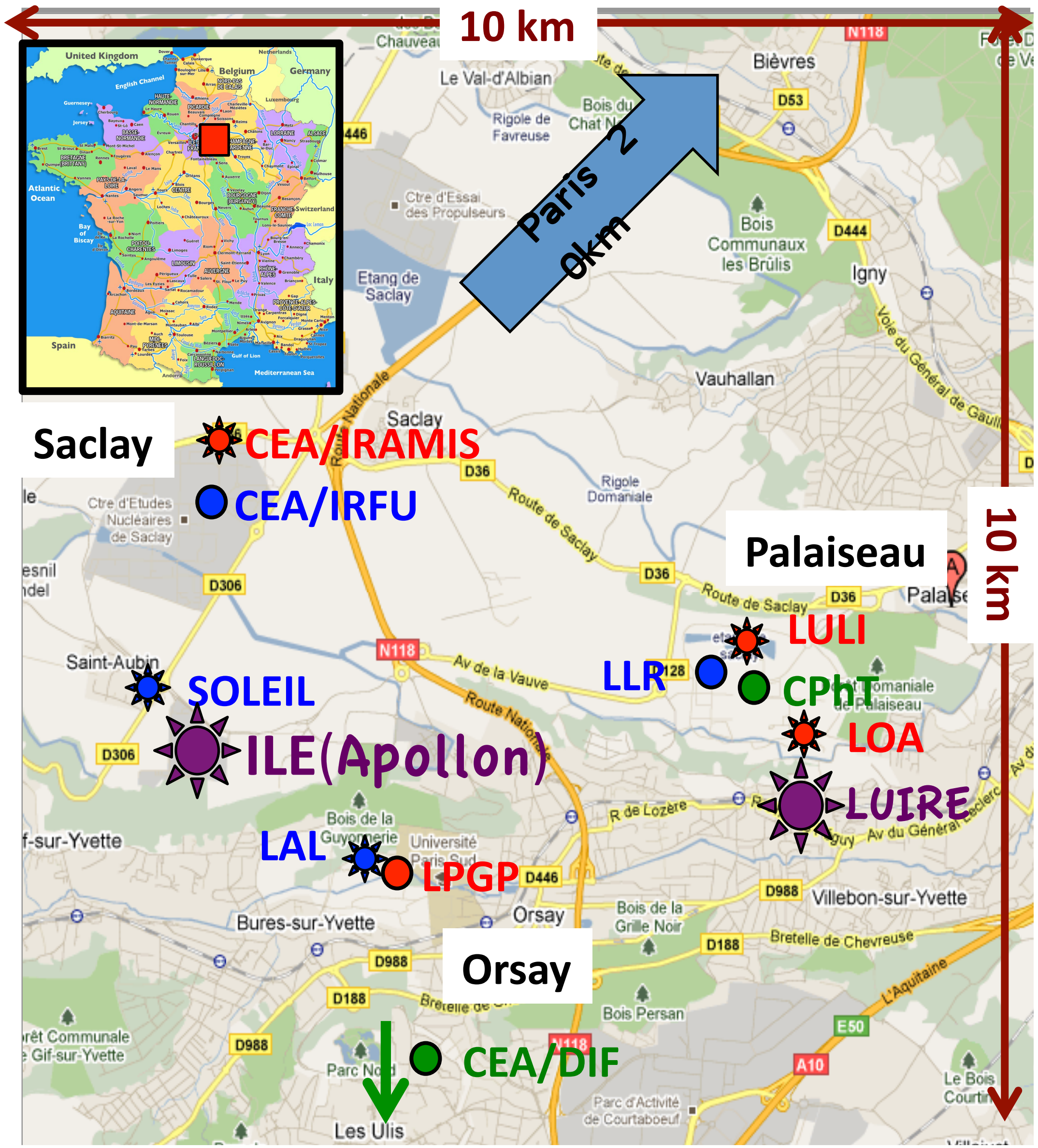
- Alignment mode at 10Hz for laser
- Alignment mode for the experimental areas
  - at 10Hz for the superposition in time and space of laser beams with an energy below any radiation risk
- Optimization mode
  - at 0,1 Hz for the superposition in time and space of laser beams and particle beams at maximum energy at this repetition rate.
- A laser characteristic measurement mode
  - the laser will be run at full energy only in the laser areas
- A laser shot mode
  - where a shot or a sequence of shots will be delivered
- A maintenance mode

The procedures for these different modes of operation will be defined taking into account laser safety, ionizing radiation and other potential hazards.

Operation of the Facility

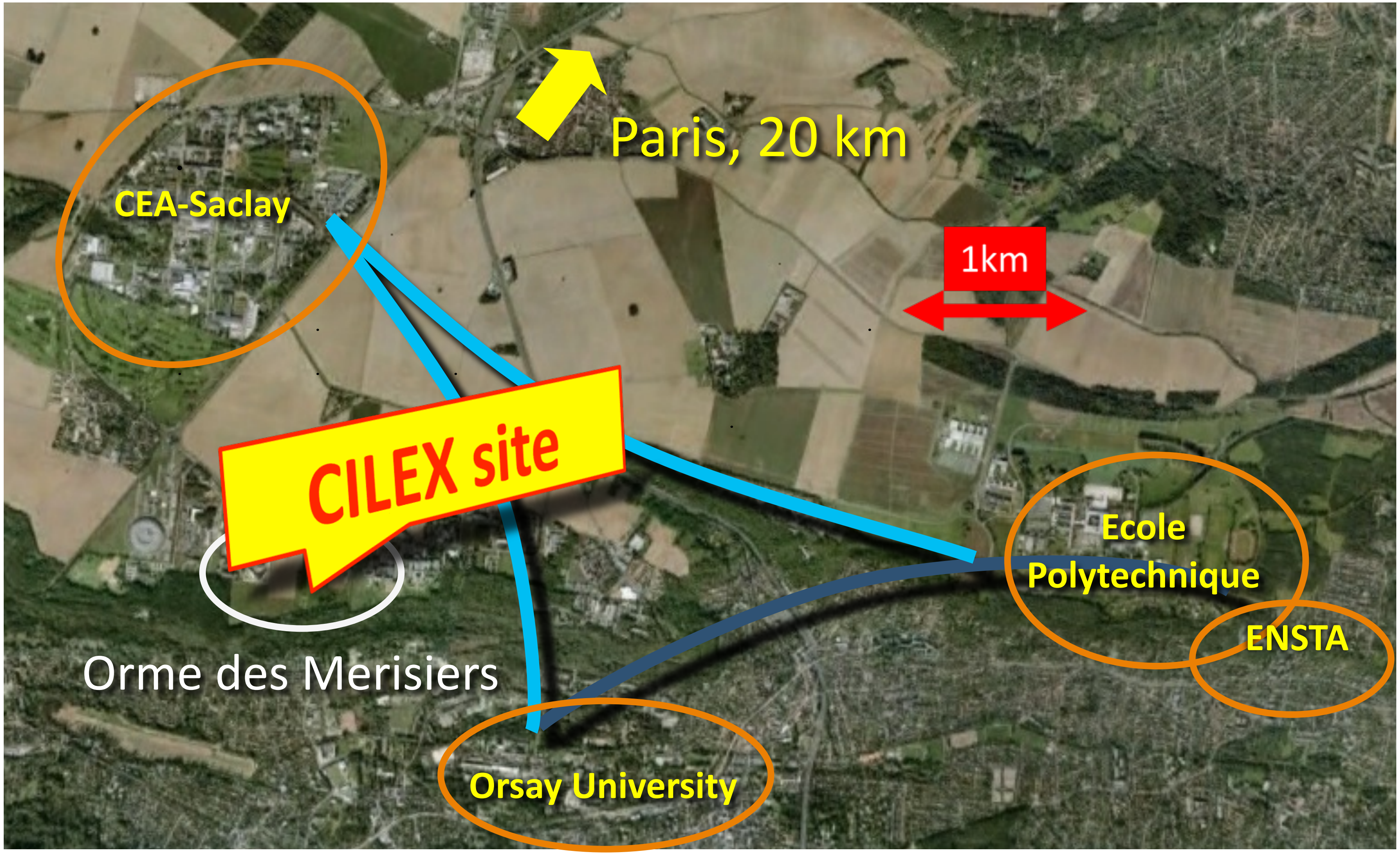
- Facility will be open to national and international scientists
  - A committee was formed to discuss on how to allocate the laser time taking into account the thematic experimental programs.
- Beam time allocation per year
  - The goal is 30 weeks for users
  - Maintenance 10 weeks
  - Development 10 weeks
- Experiments
  - Each experimental area will perform one after the other.
  - The laser will deliver pulse sequence on demand for user 6h per day.
  - At the beginning, 2 days will be used for changing configuration between experimental areas

High power – short pulse laser facilities in Paris area



High power / short pulse laser facilities in Paris area

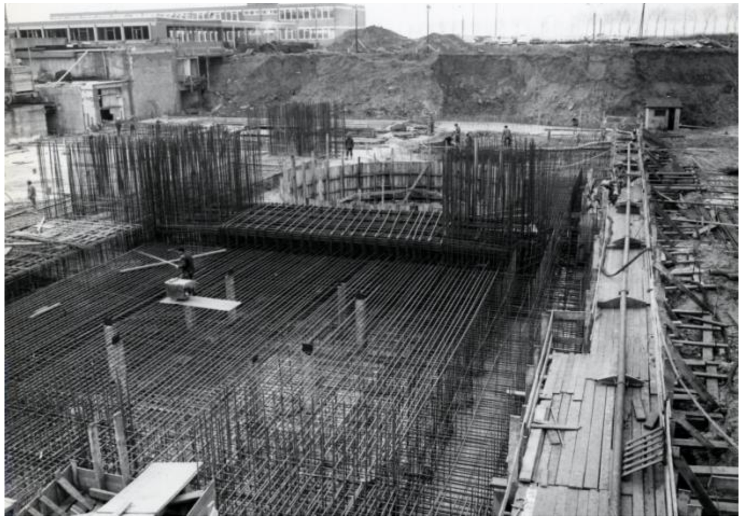
CILEX- APOLLON



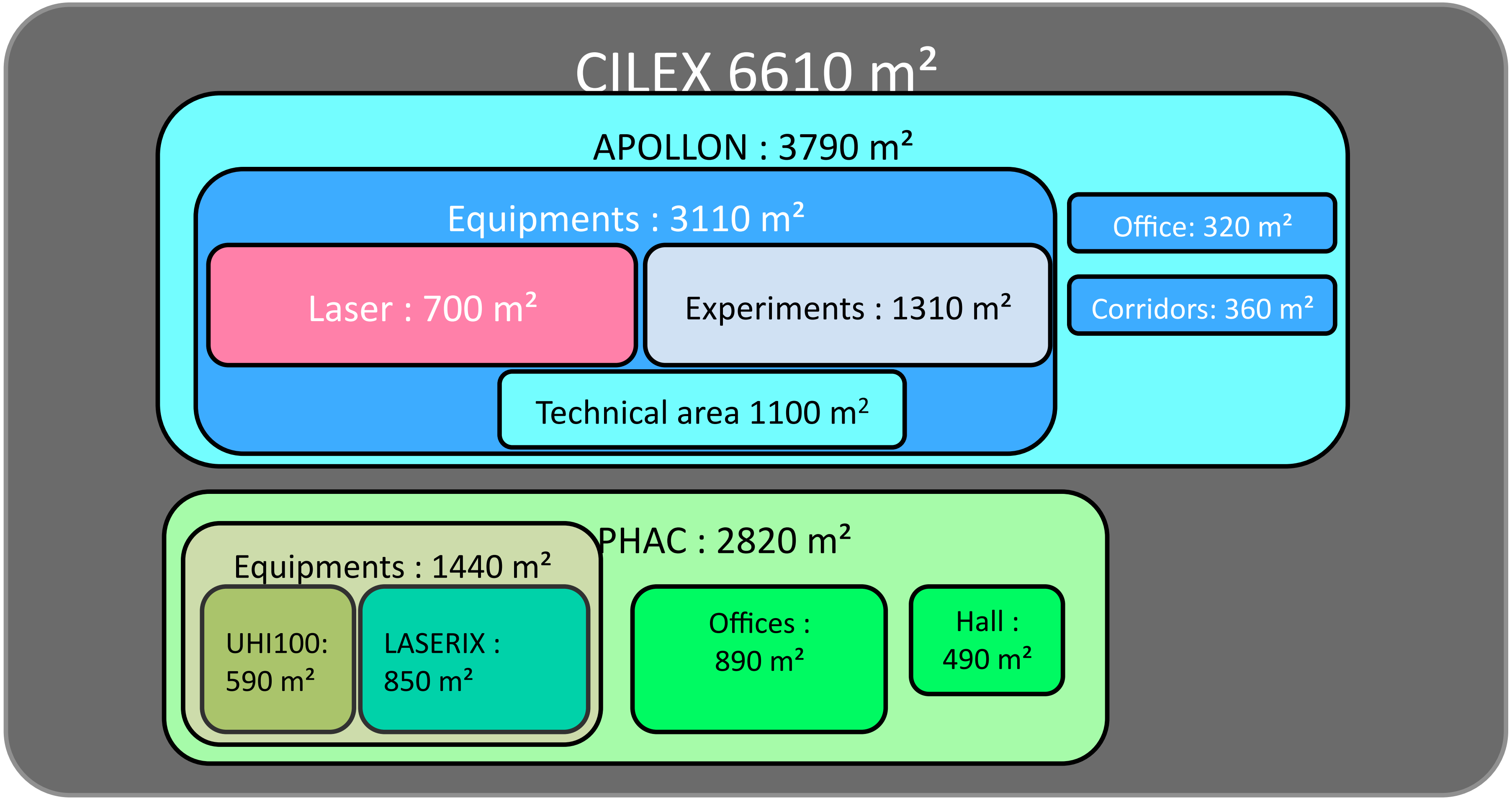
Site « l'Orme des Merisiers » (next to SOLEIL)

A renovated building dedicated to Apollon-10P will host the infrastructure
- 5000 m², radio-protected experimental areas

Decommissioned e – Linac
constructed in 1969
fully dismantled in 2006

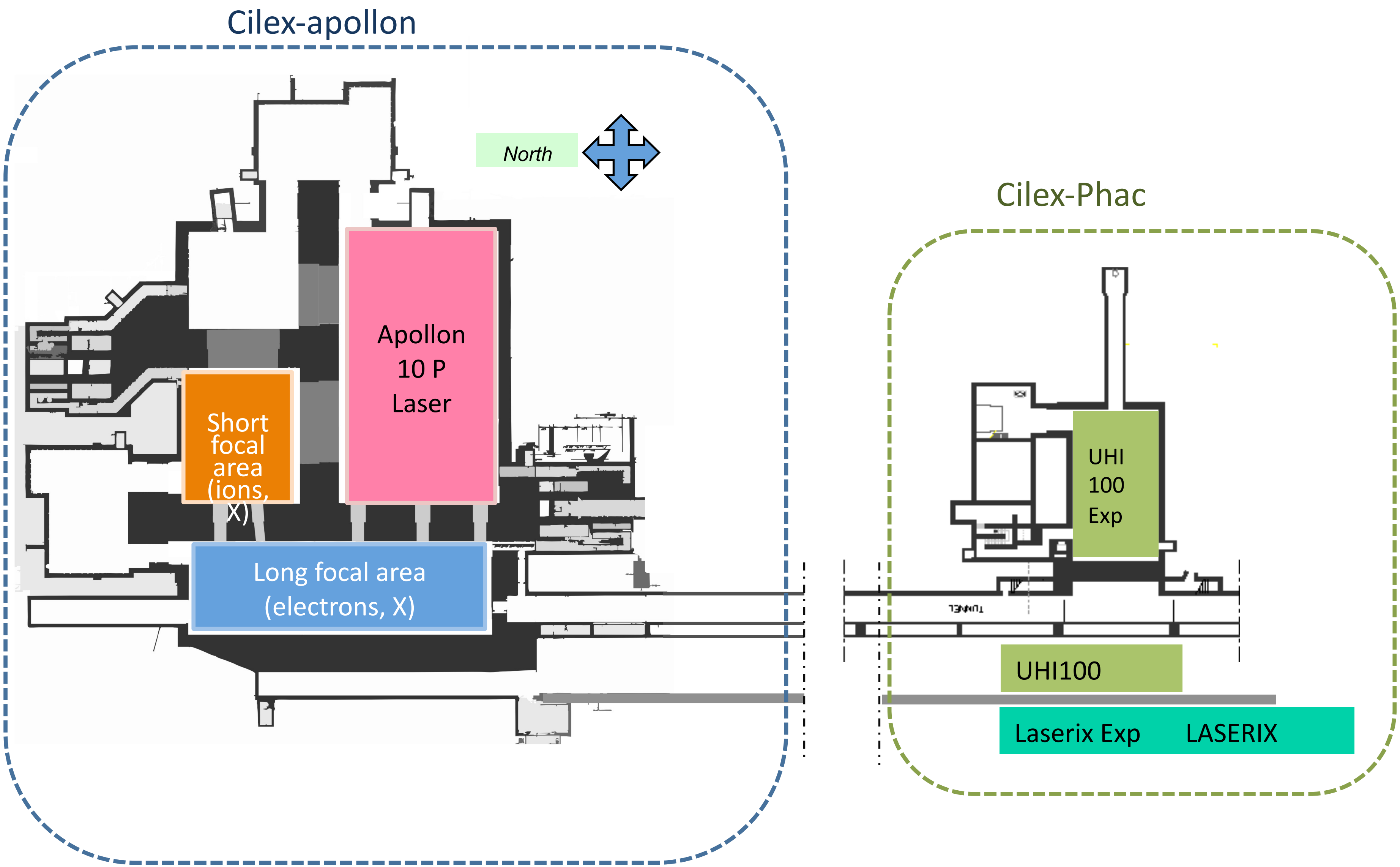


Useable Surface



Accomodation of 100 people

CILEX implantation



1 laser, 2 distinct fully-equipped rad-protected exp. halls

HE1 : short focals

- ion acceleration
- HHG, flying mirror, Xray laser (solid, gas)
- high-field physics (solid, gas, vacuum)
- **cibles solides mais non exclusivement**
- **short focals : *f=1–5 m***
- **extreme intensity: $a_0 \approx 10–10000$**
- **t contrast : ultimate**

HE3 :APOLLON LASER

- **pump1: 15fs-qq ps/ 150J-70J Ø400**
- **pump2: 15fs-qq Ps/ 15J-2J) Ø400**
- uncompressed 200J-0
- probe:1 15fs 0.2-1J

HE0 : long focals

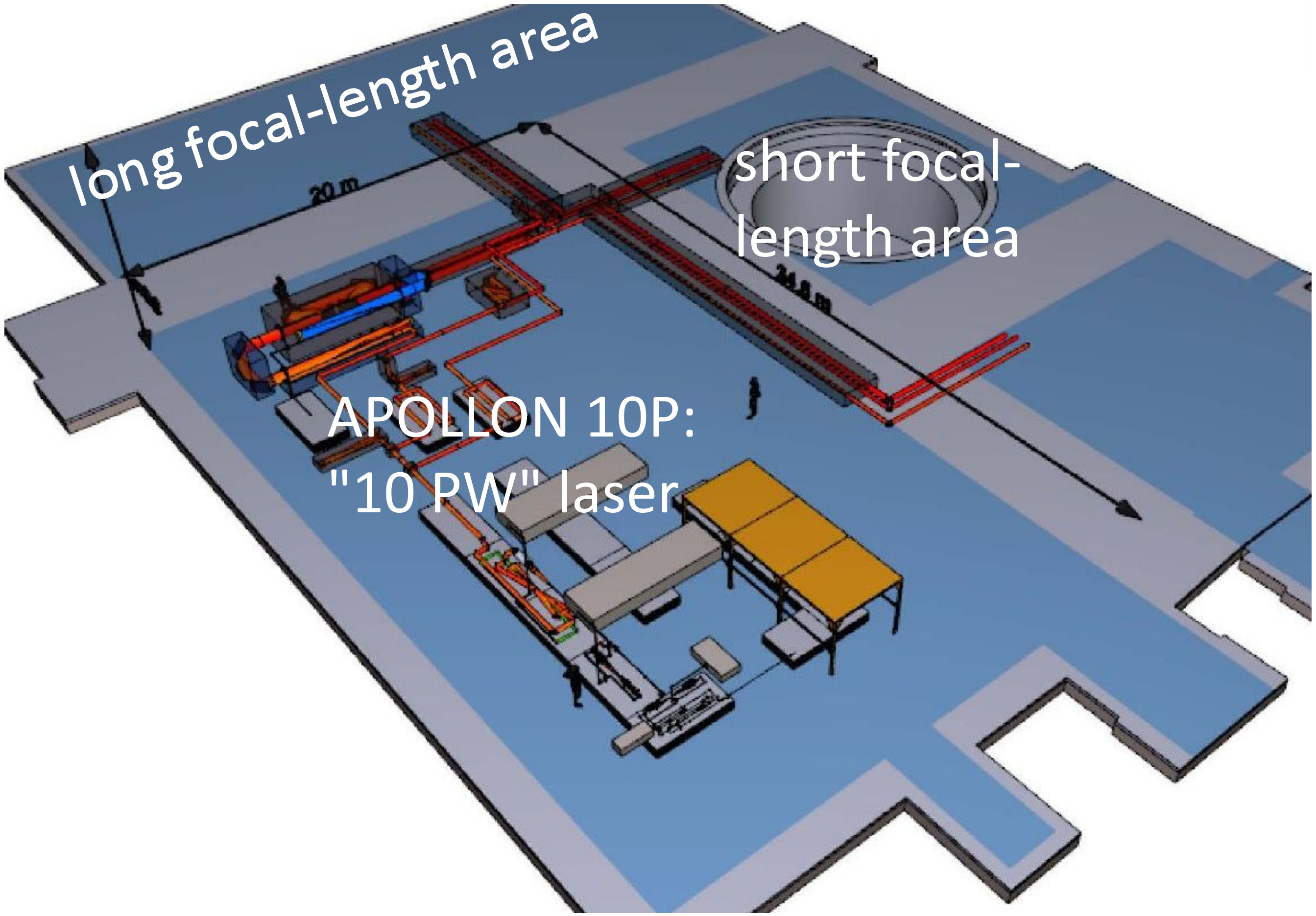
- **electron acceleration**
  - single stage and multi-stage (2)
  - blow-out and quasi-linear regime
- **direct photon production**
  - plasma undulator («betatron»)
  - magnetic undulator radiation (seeding)
  - non-lin. Thomson; Compton up-scattering
- **HHG, flying mirror** (on gas targets)

- **gaseous targets**
- **longest focals : *f=10–20 m***
- **modest intensity: $a_0 \approx 1–10$**
- **t contrast: excellent (but not ultimate)**

APOLLON: "10 PW" laser and 2 experimental areas

A "10 PW" main beam up to 150 J in 15 fs

only ≈ 75 J already funded



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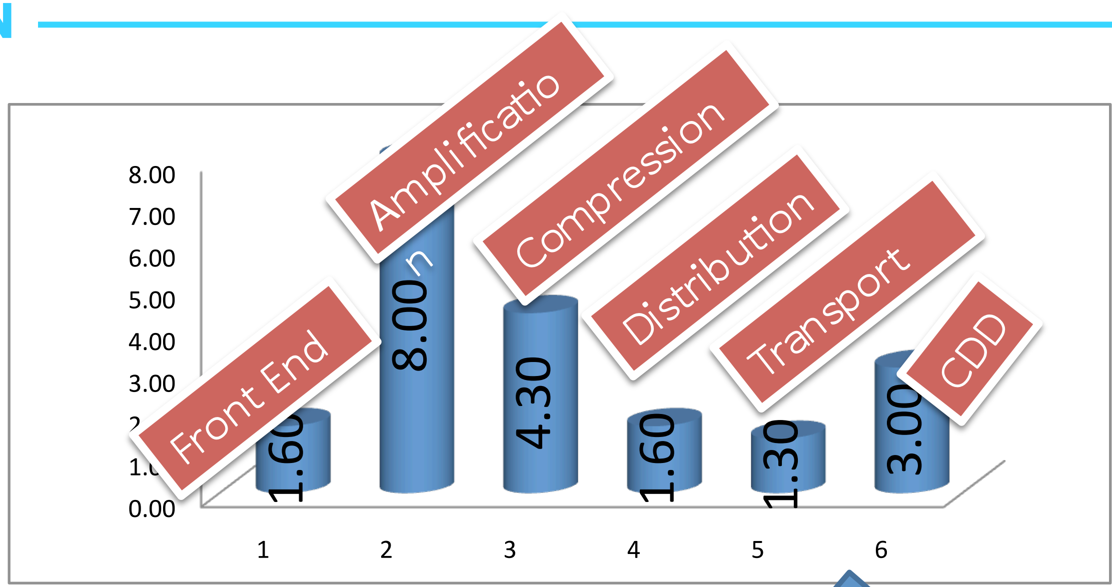
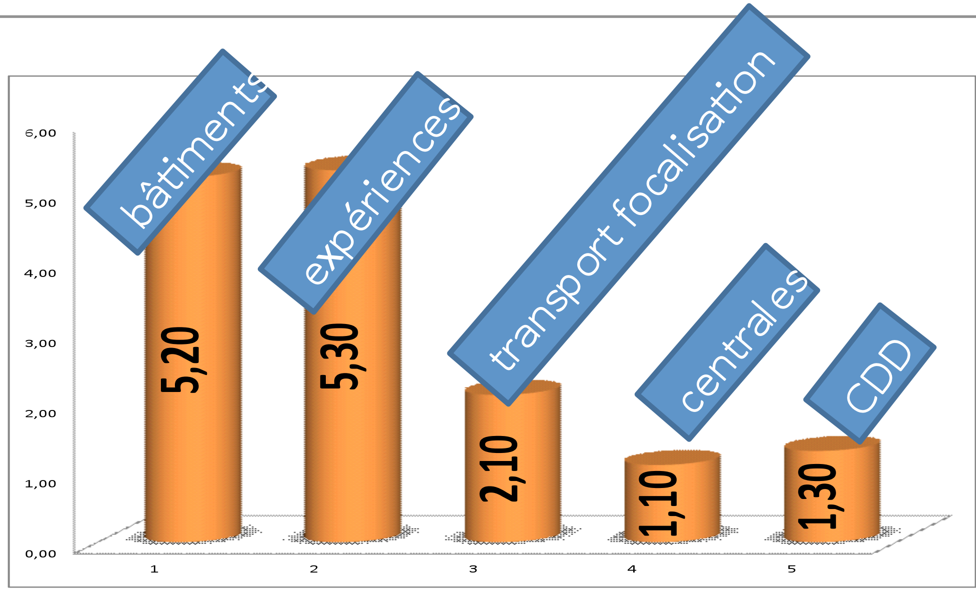
Funding

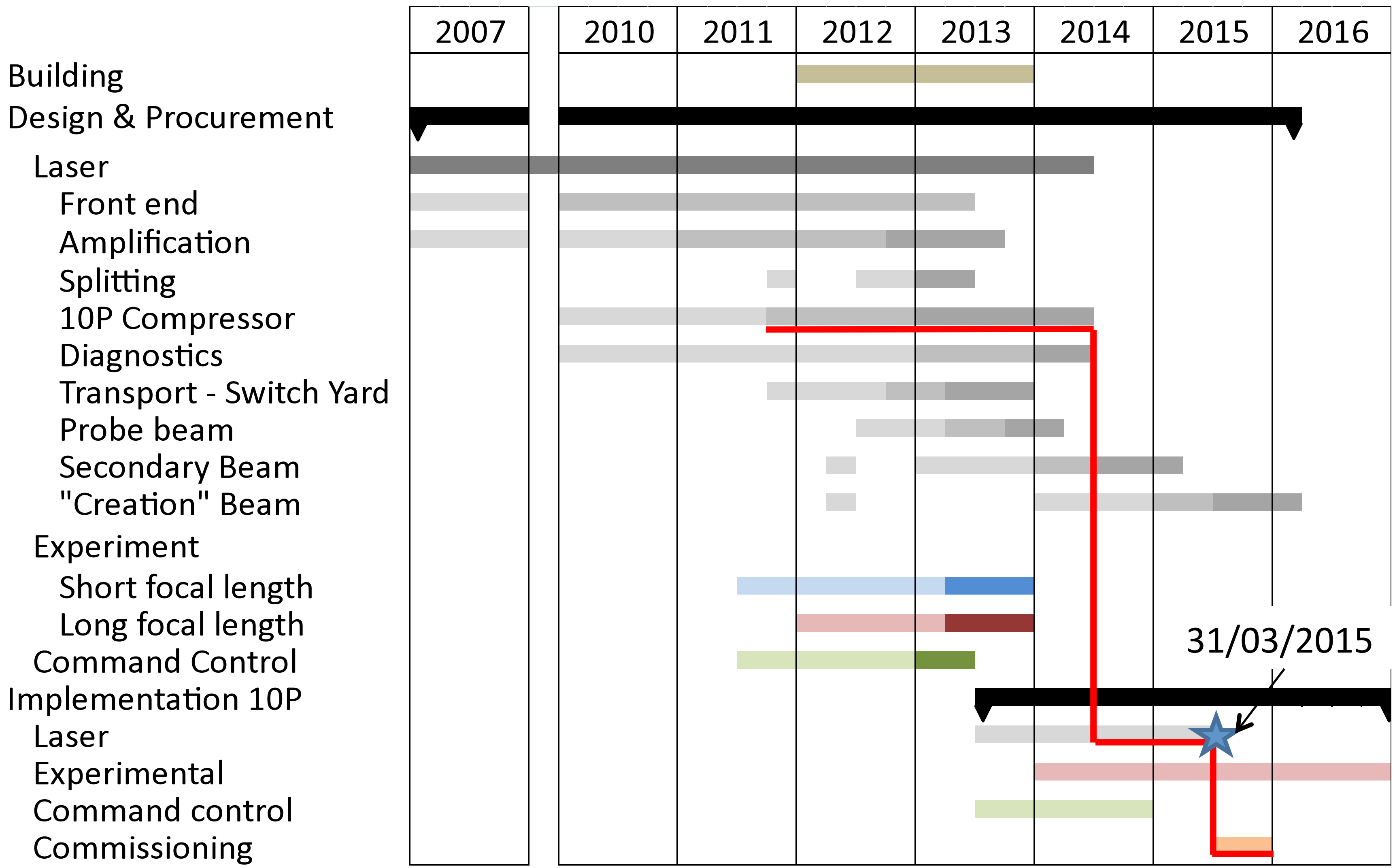
Apollon Budget
19 M€
(+5M€)



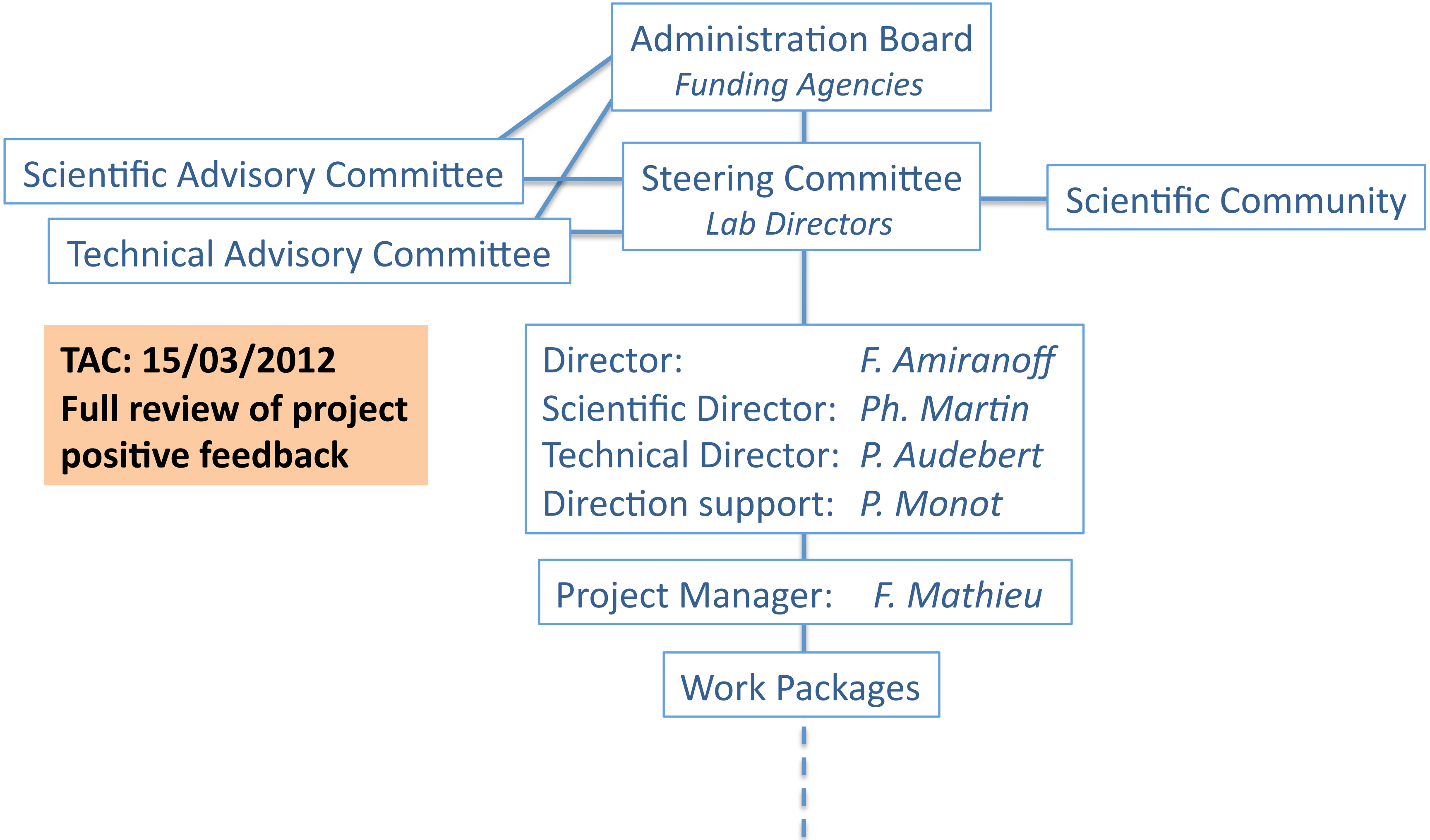
CILEX Budget
15 M€
(+5M€)



Planning GANTT



General organisation of the project



TAC: 15/03/2012
Full review of project
positive feedback

Work packages Apollon-CILEX

- Front end
- Amplification
- Strecher-compressor
- Alignement transport
- Infrastructure
- Commande control
- Experimental areas

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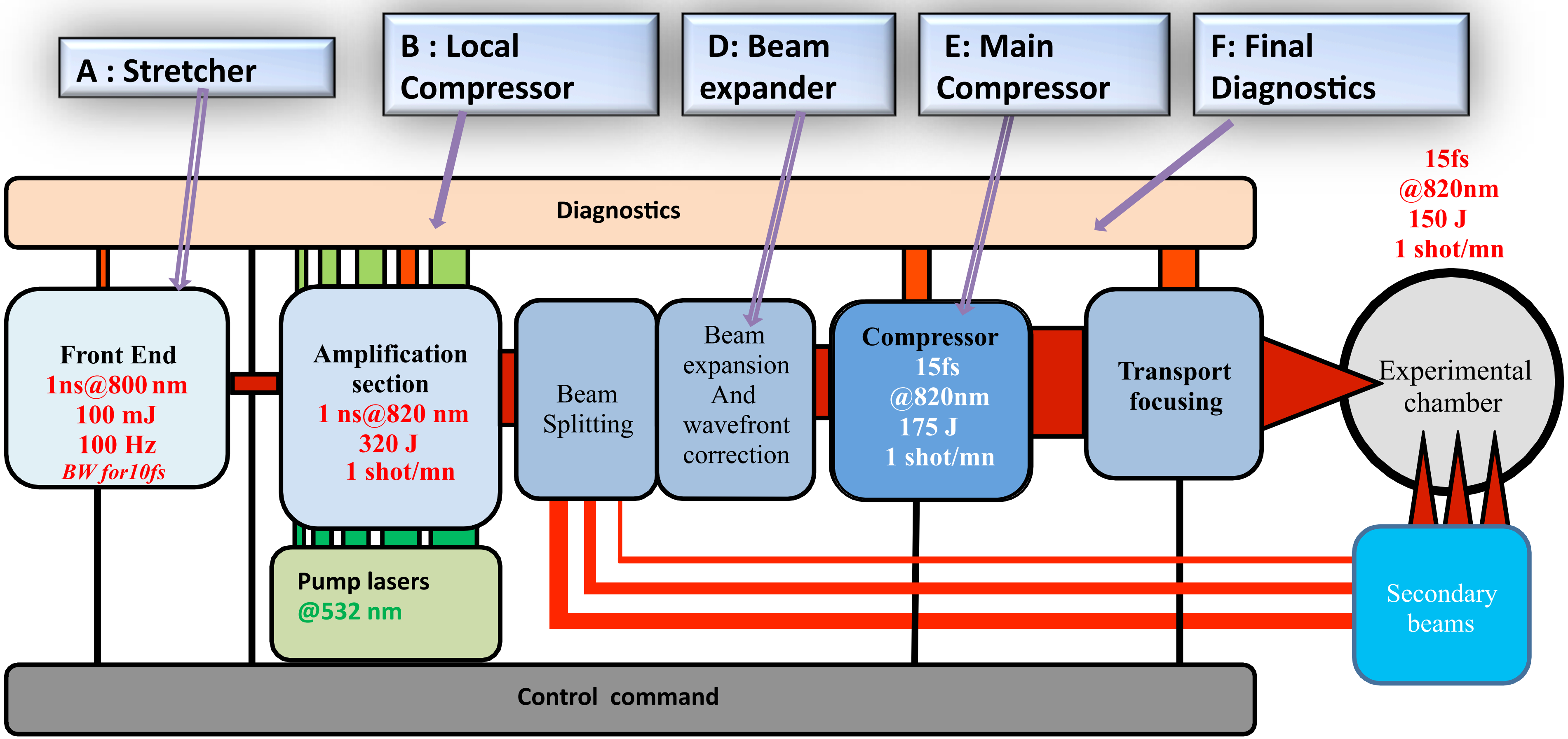
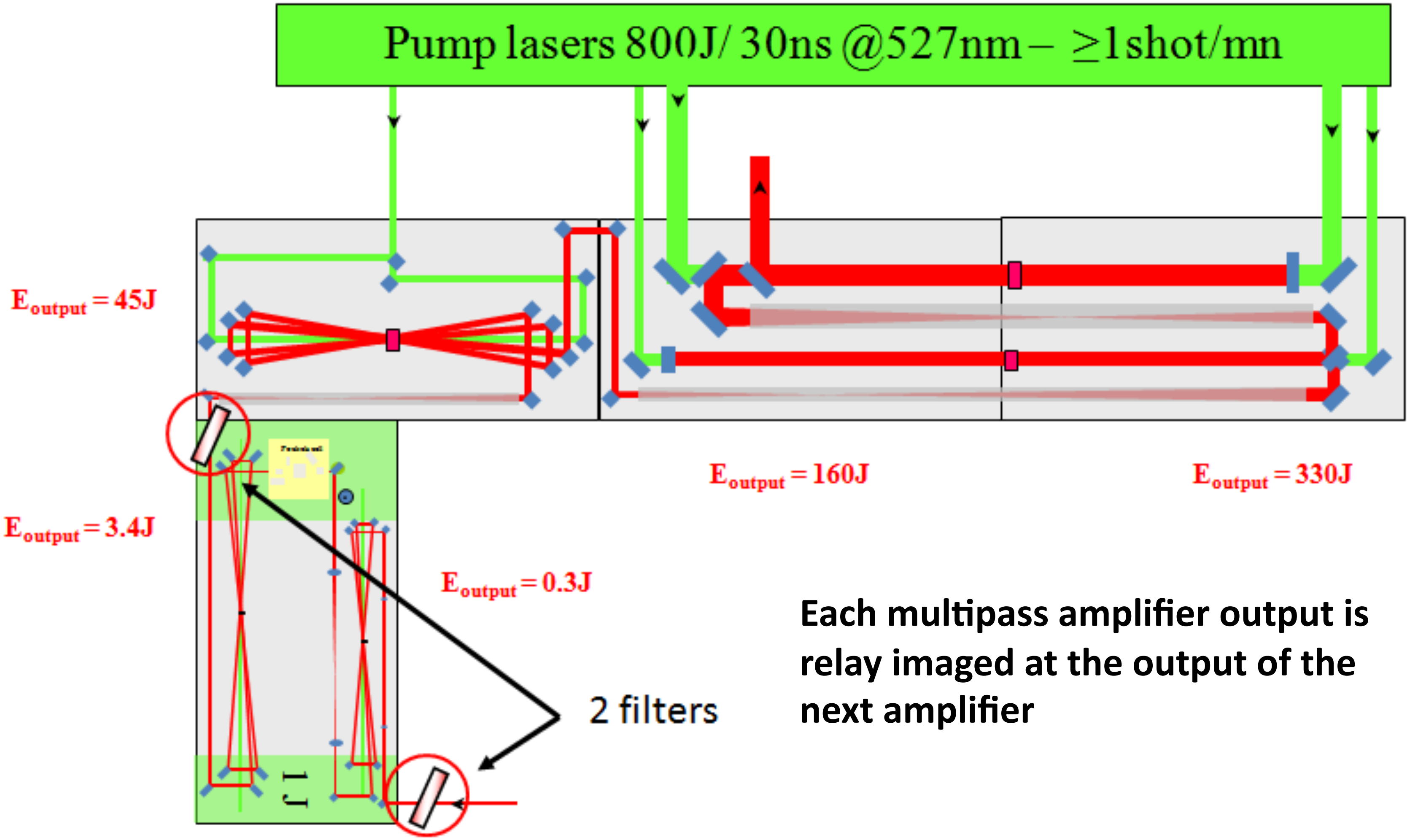
APOLLON 10 PW laser



Optical lay-out

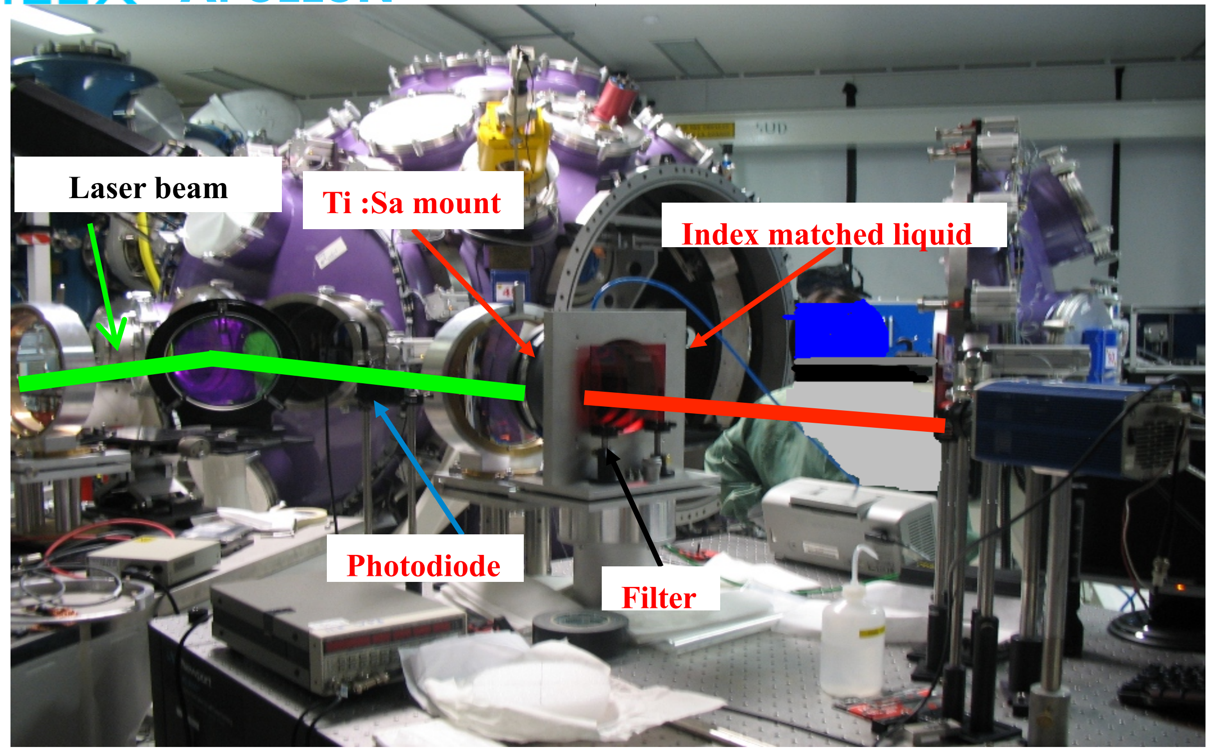
CILEX- APOLLON

5 multi-pass amplifiers based on TiSa crystals



Each multipass amplifier output is relay imaged at the output of the next amplifier

High energy and parasitic effects



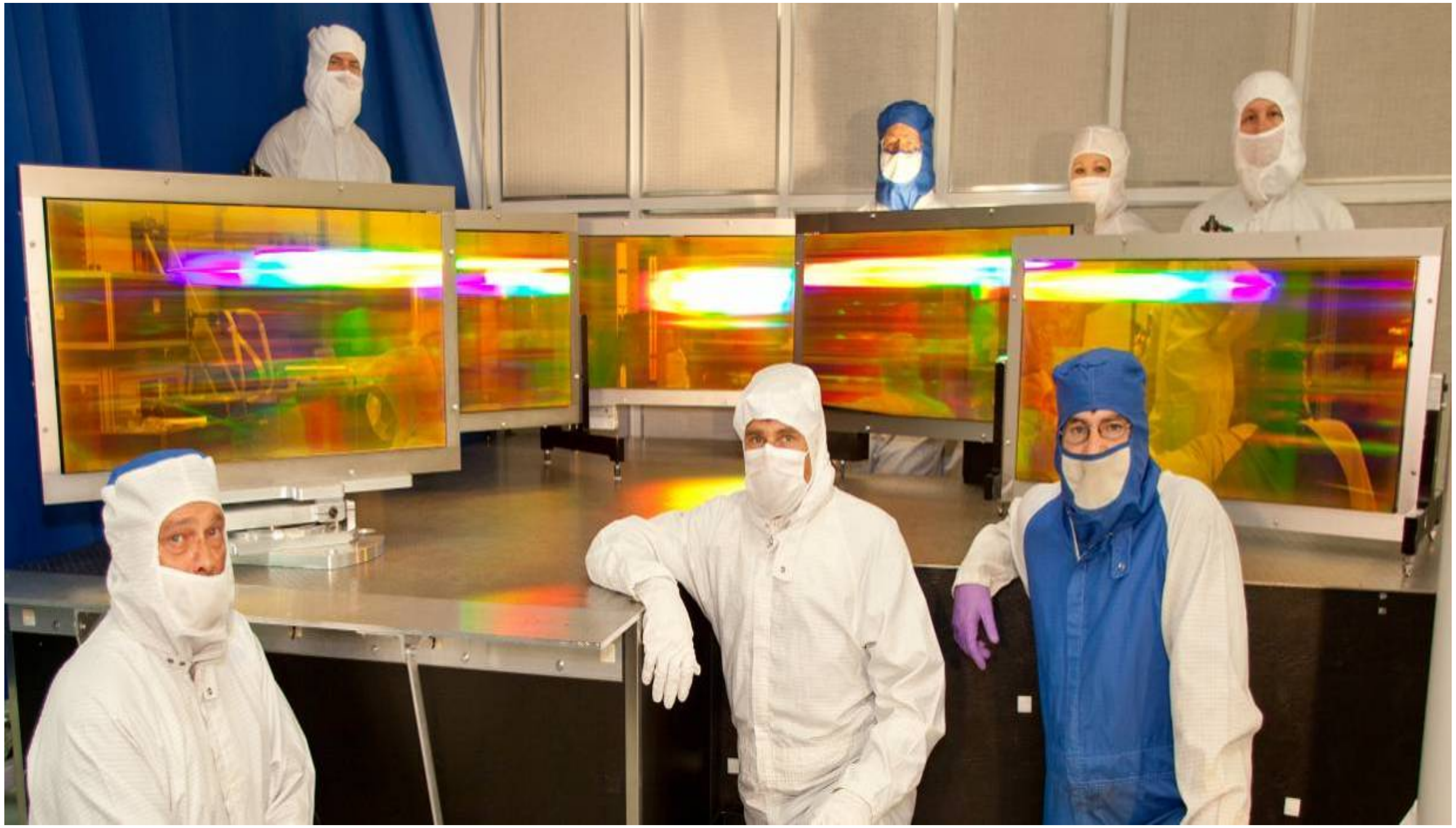
Beam diameter on TiSa : 14 cm
Quasi Gaussian beam shape
$\Delta\tau = 1.5$ ns
Pumped on one side

Two index matched liquids have been tested

- Bromonaphtalene ($C_{10}H_7Br$) with IR 140 => Threshold at **120 joules** (0.8 J/cm²)
- Diiodomethane (CH_2I_2) with HITCI => Threshold at **220 joules** (1.4 J/cm²)

<u>Simulations</u> show that with top-hat beam and index matching with $\Delta n = 5.10^{-3}$
the **transverse lasing threshold is increased <u>up to ~280 joules on each face</u>**

10PW Apollon compressor

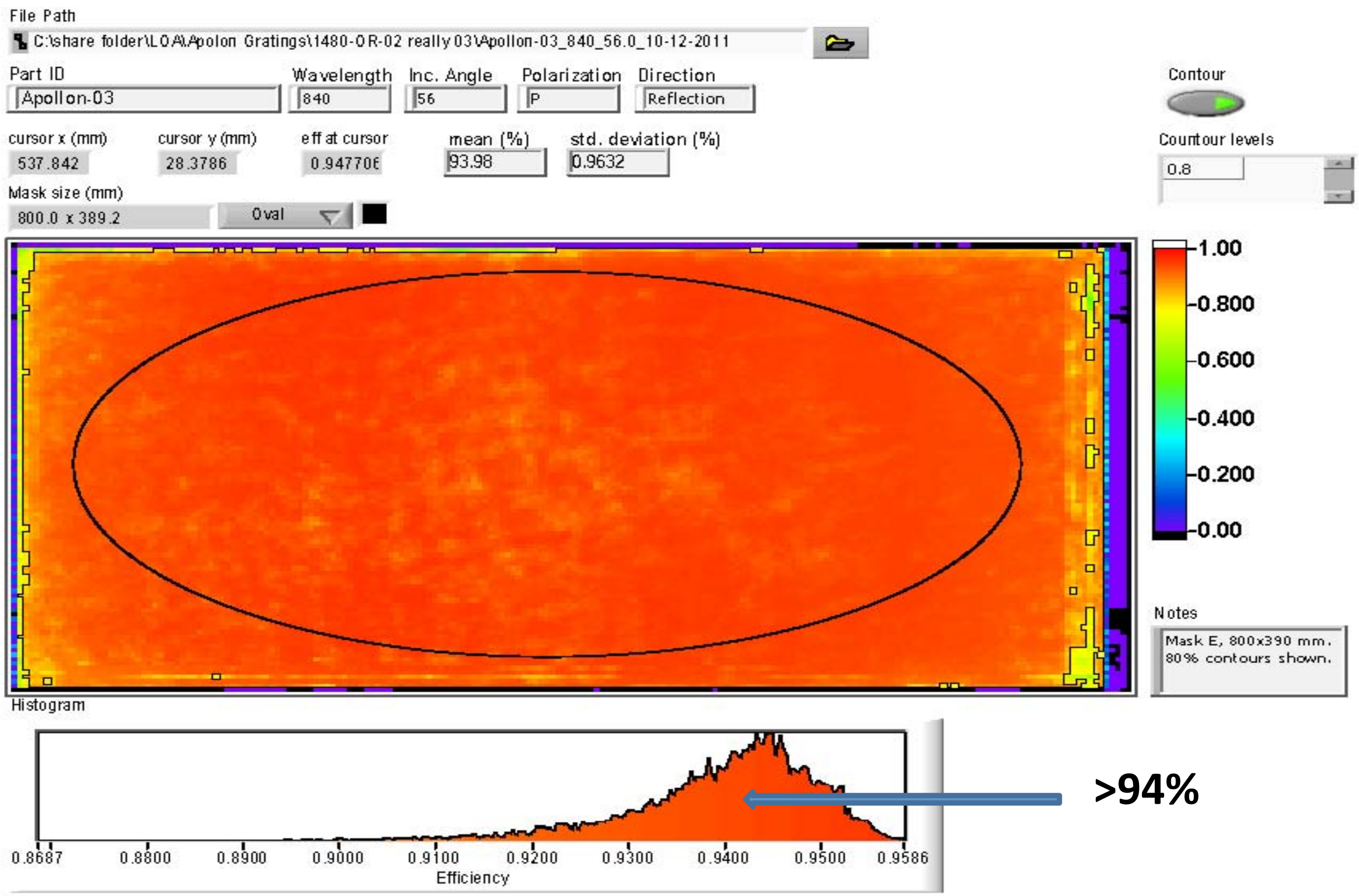


Five Apollon gratings at Lawrence Livermore National Laboratory, and the Grating lab team (Jerry Britten in the middle) (sept, 2011

10PW Apollon compressor

Livermore gold grating n°3

Efficiency map measured at 840nm, 56 degrees.



>94%

Time table

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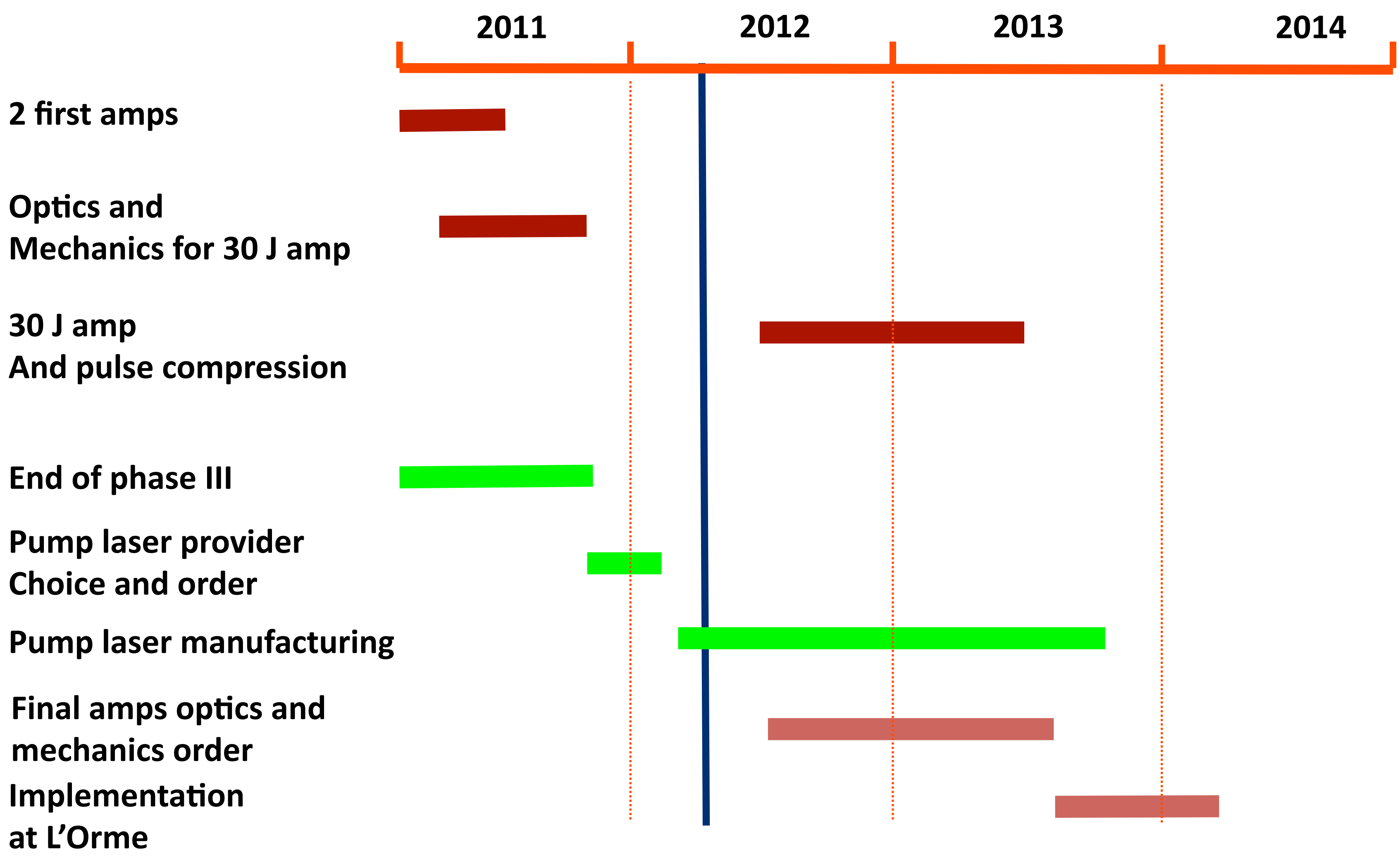

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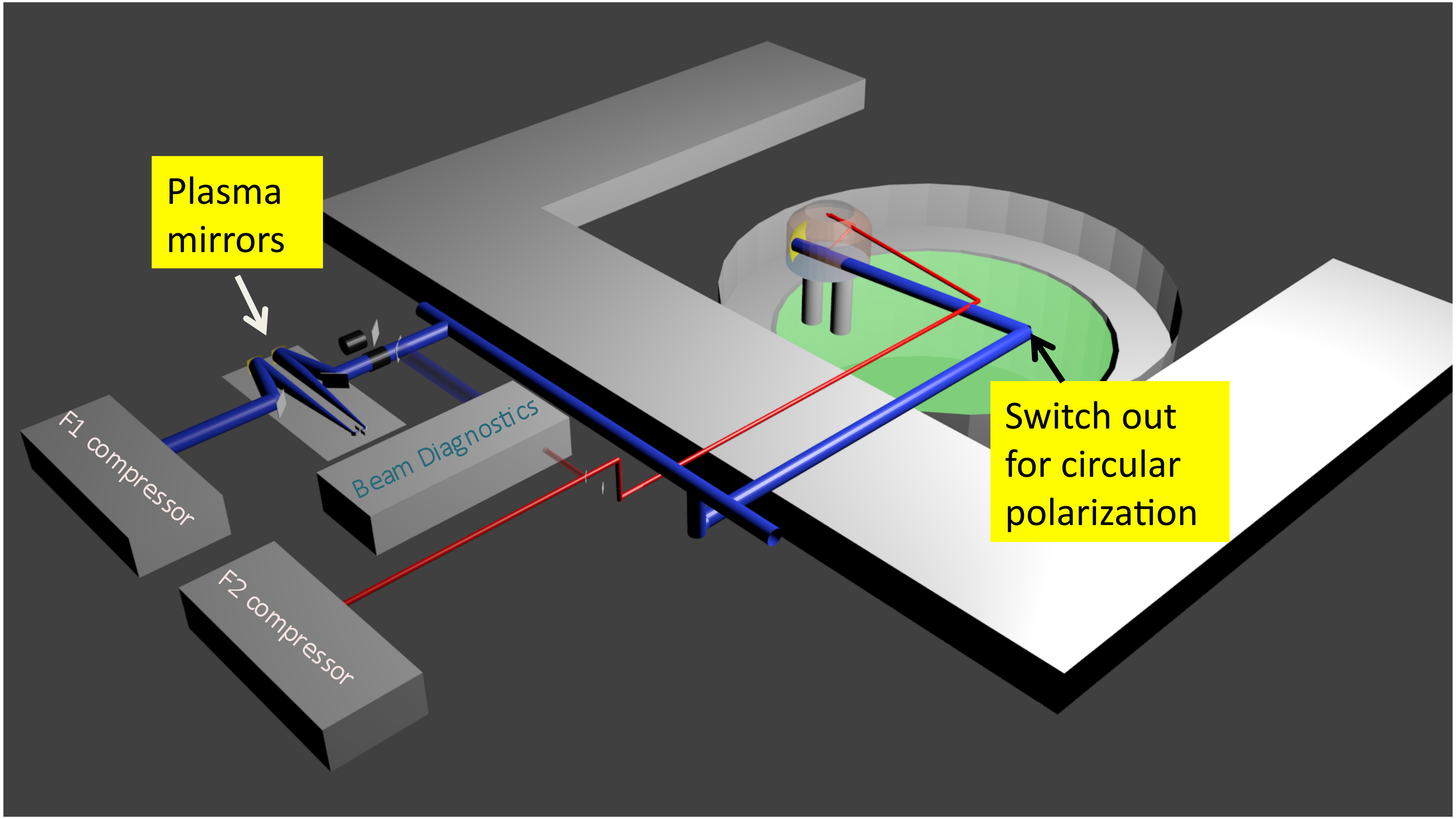
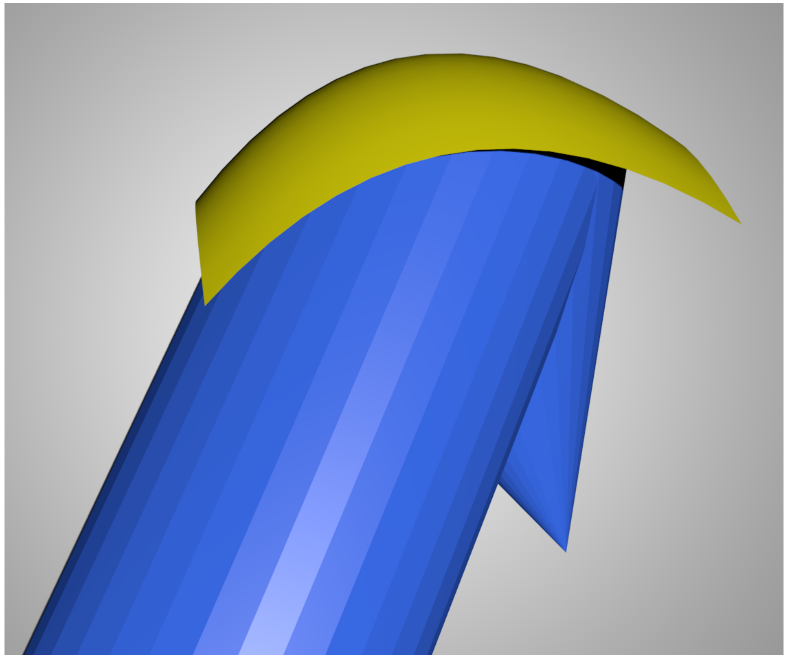
Conceptual Overview of the Laser/Experimental Hall Layout

CILEX- APOLLON

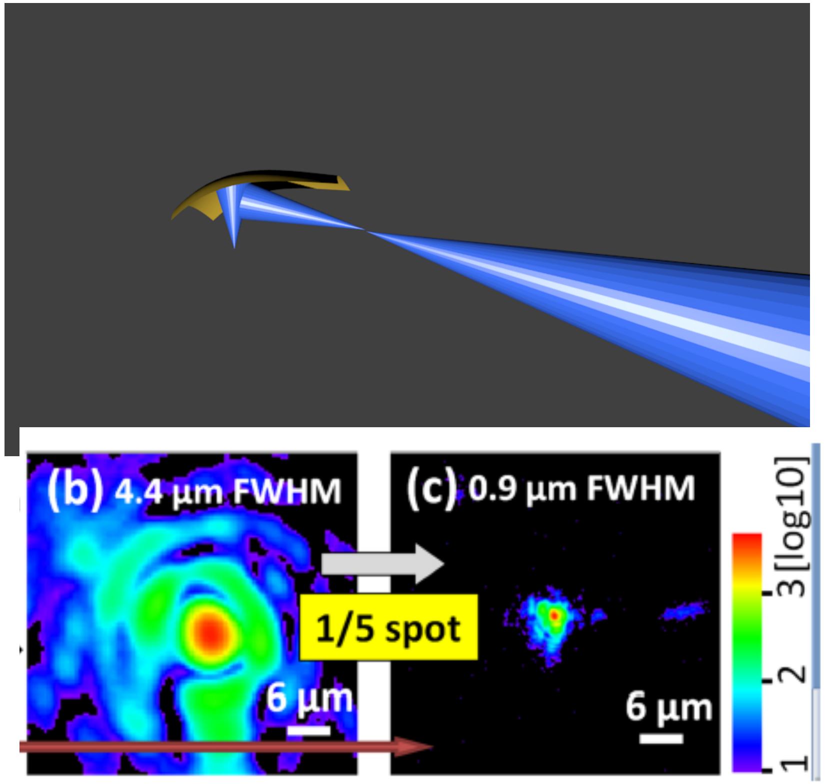


Plans to reach the highest intensity

1 x 10^{23} W/cm^2 using an f/1 OAP
BUT
•high damage probability
•high sensitivity to misalignment
•needs a very good wavefront

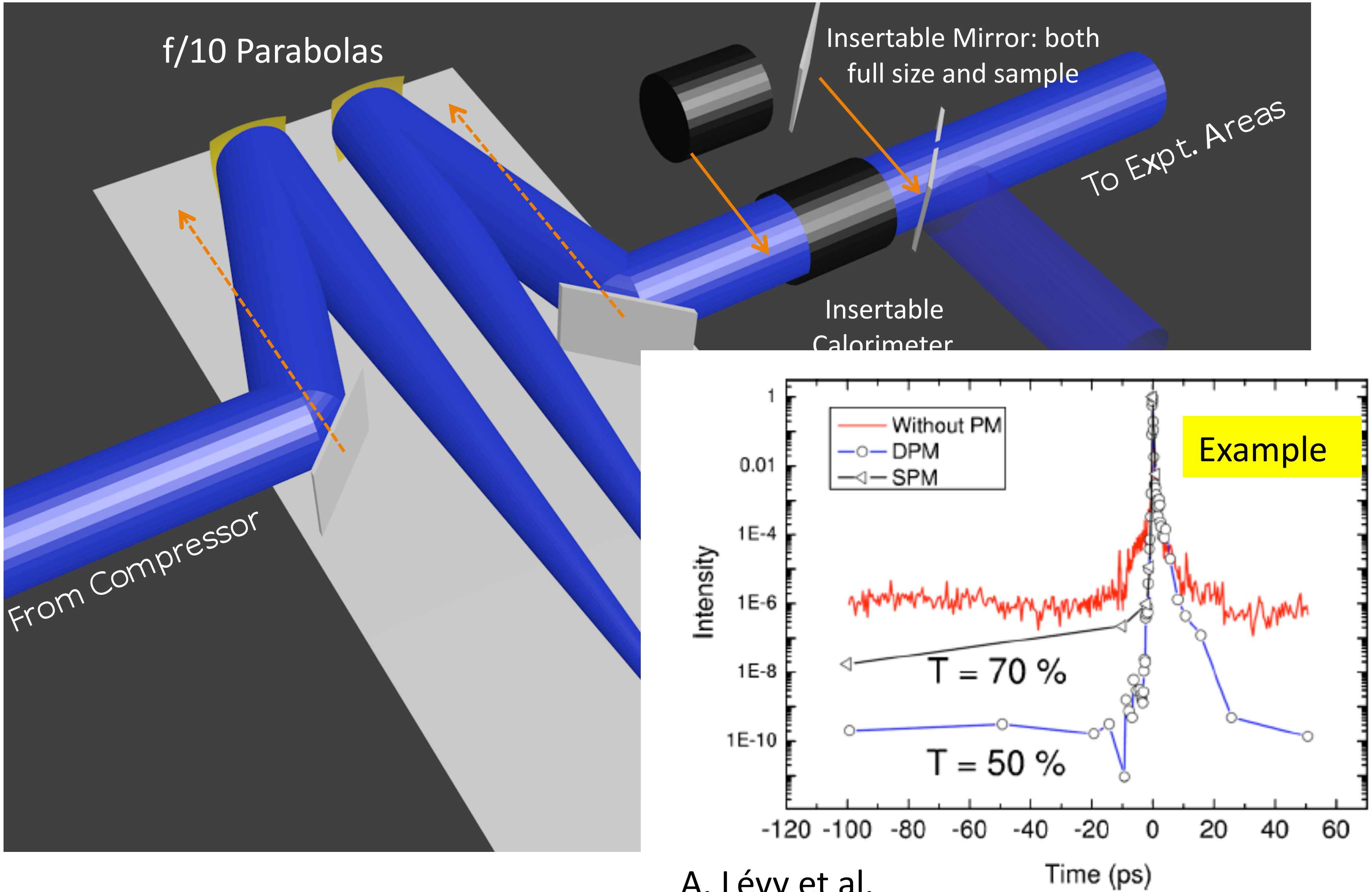


3.5 x 10^{23} W/cm^2 using Ellipsoidal Plasma Mirror after focus, safe **BUT** low rep. rate



Nakatsutsumi et al.

High t contrast: plasma mirror and beam diagnostics



A. Lévy et al.

Timeline

Project Name	2012	2013	2014
HE1 Timeline			
Experimental & Plasma Mirror Chamber			
Drawing			
Procurement & Manufacturing			
Installation			
Purchase of infrastructure			
Experimental Diagnostics			
Identify			
Design			
Purchasing and Manufacturing			
Testing			
Radiological protection			
Design			
Installation			

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HE0: electron acceleration and photon production

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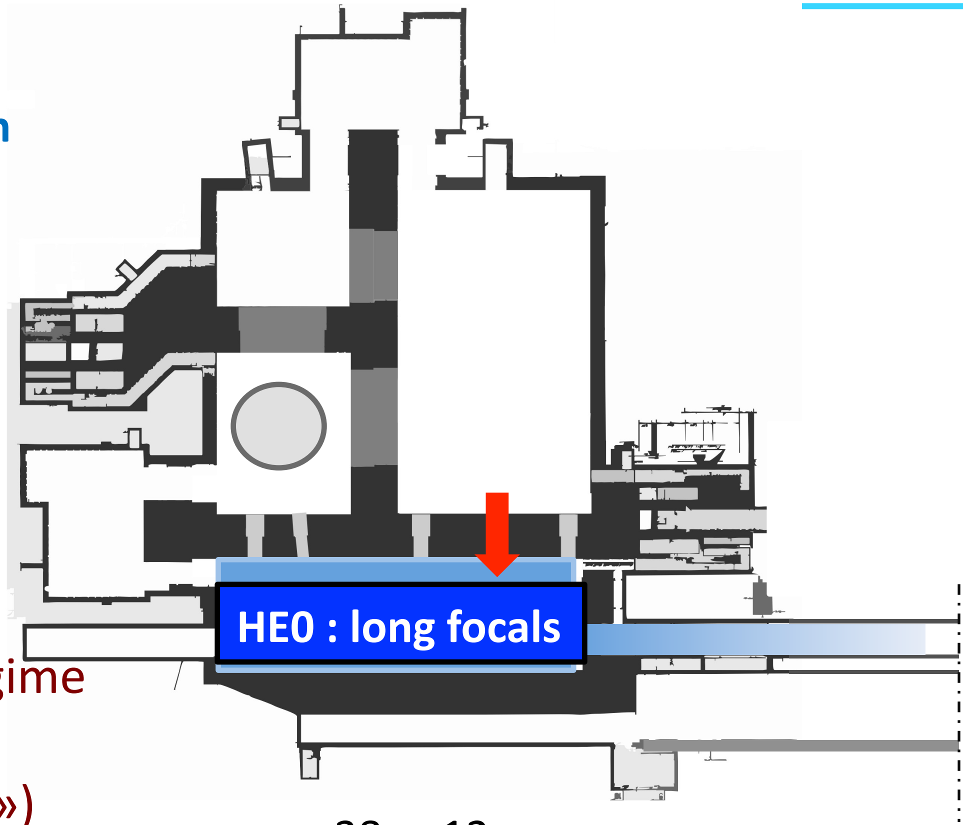
LWFA of electrons and photon production



38mx12m

- **electron acceleration**
  - single stage and multi-stage
  - blow-out and quasi-linear regime
- **direct photon production**
  - plasma undulator («betatron»)
  - magnetic undulator radiation (seeding)
  - non-lin. Thomson; Compton up-scattering
- **HHG, flying mirror** (on gas targets)

- **Gaseous targets**
- **Longest focals : *f=10–20 m***

Applications

- e– acceleration
  - investigate validity of LWFA for future high energy accelerators
  - investigate plasma wave acceleration relevant for alternative excitation
    (e.g. PWFA either e– or proton driven)
  - test beams for nuclear and HE particle detectors
  - gamma-radiography for material science
- photon production and photo science
  - time-resolved and single shot radiography (X)
  - pump beams for X ray lasers in the keV regime
  - life sciences, material science, medical diagnostics R&D

Phasing of e– acceleration experiments on APOLLON

- Phase 1 @T0 (=2015):
  - blow-out regime, 1 laser beam: 150J–70J, 15-150fs
  - homogeneous plasma, laser guiding, self injection
- Phase 2 @T0+1 (=2016):
  - colliding pulse injection, cold injection
  - 2 laser beams : 100 mJ/[150-70J], circular polarisation
- Phase 3 @T0+2 (=2017?):
  - two stage acceleration with all optical injector
  - 3 laser beams : 100mJ/6J/[10-100J]
- Phase 4 (>2019)
  - injection of e- beam into undulator

Phase 1 (2015) frontier e– acceleration

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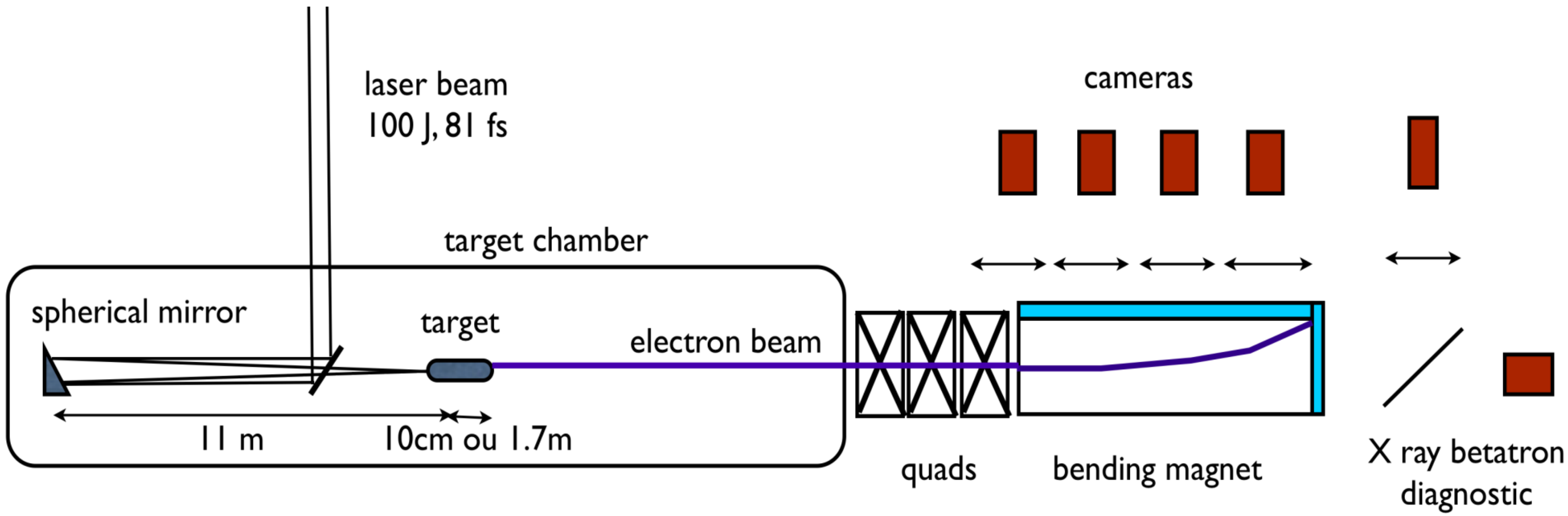
- exploration of bubble regime with full e– -characterization and betatron diagnostics
- homogeneous plasma (jet,cell) and laser guiding
- blow-out regime, 1 laser beam, 150J–70J, 15–150



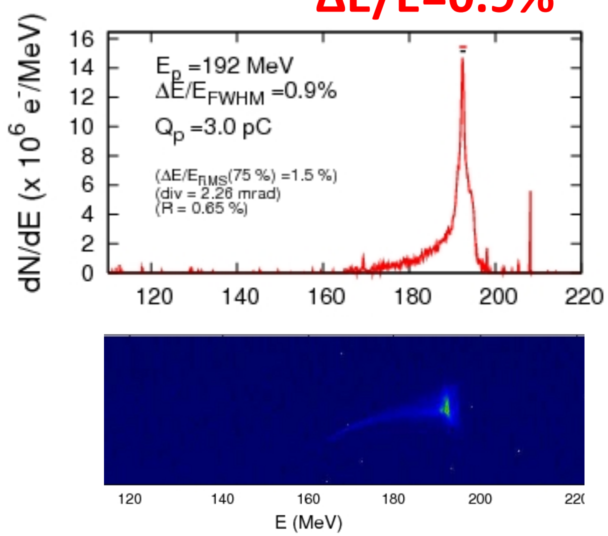
~10 GeV expected for 10 cm accelerating length and 10 m focal length

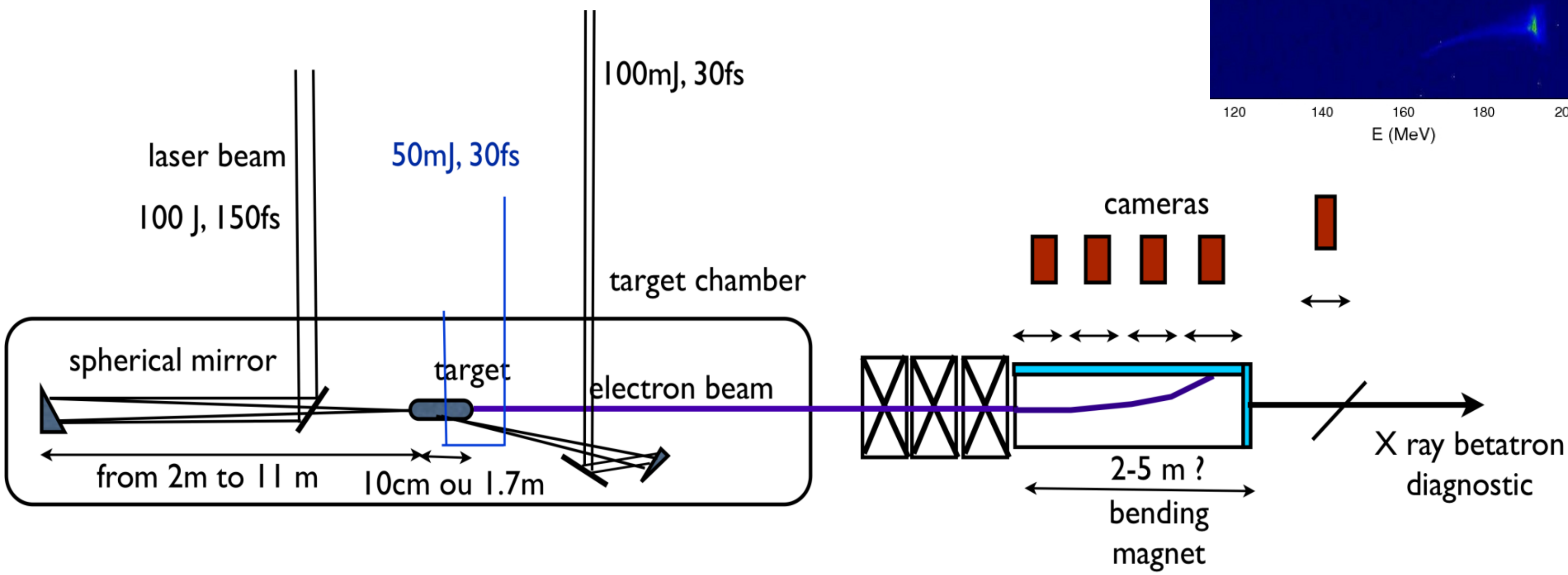
Phase 2 (2016): controlling the beam param's & stability

CILEX- APOLLON

- controlling the electron beam parameters
- colliding pulse injection, cold injection
- 2 laser beams : 100 mJ/[4J-100J], circular polarisation

ΔE/E=0.9%





Phase 3 (2017): all-optical multi-stage acceleration

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régime non-linear «bulle»

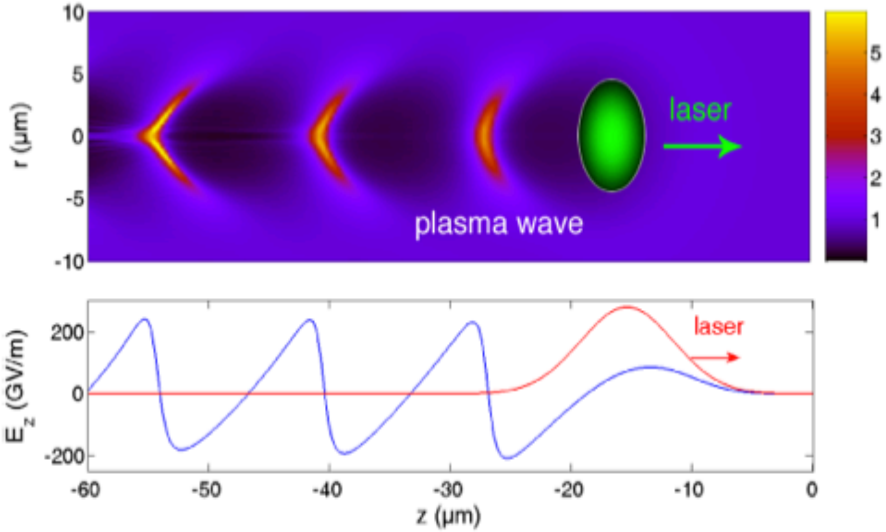
deferlement -> e– blowout

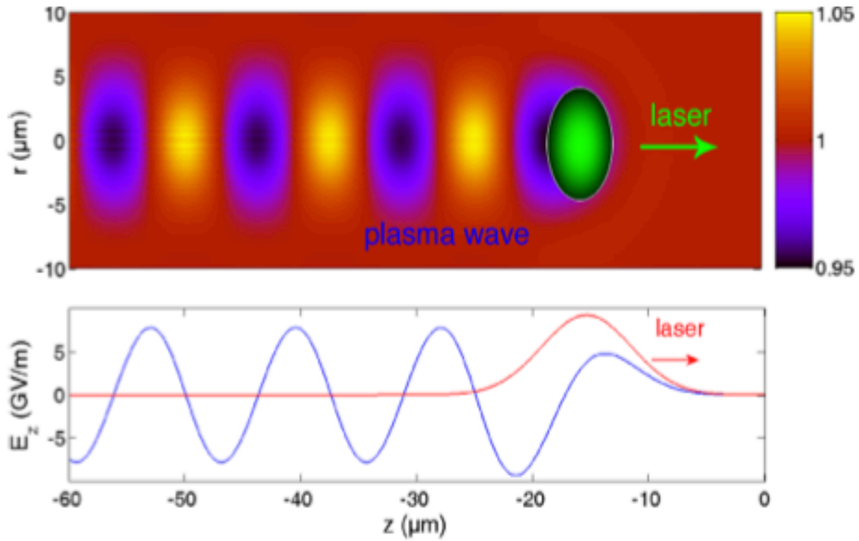
champ acc. max., focalisatº au pic du champ

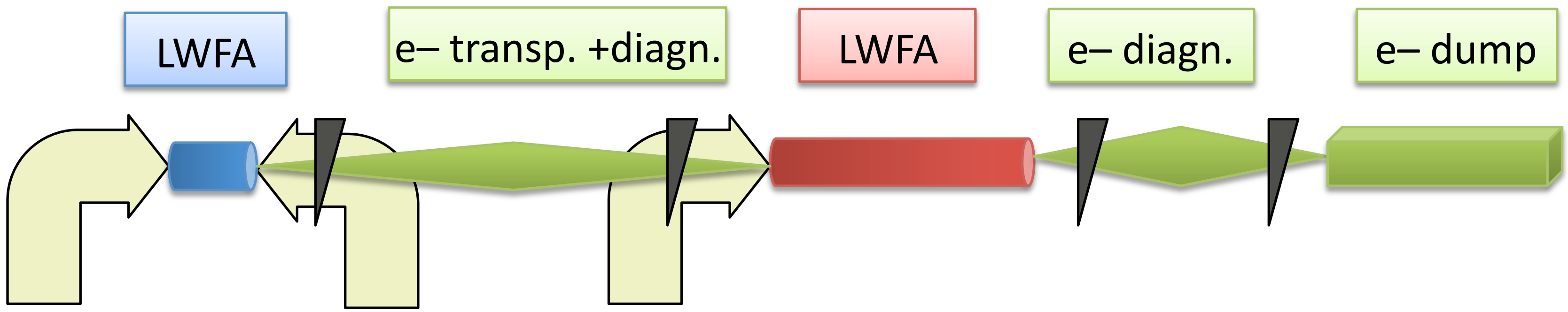
regime quasi-lineaire :

laser intensities (Wm^{-2}) plus petits

ampl. onde plasma plus faible, champ acc. moindre

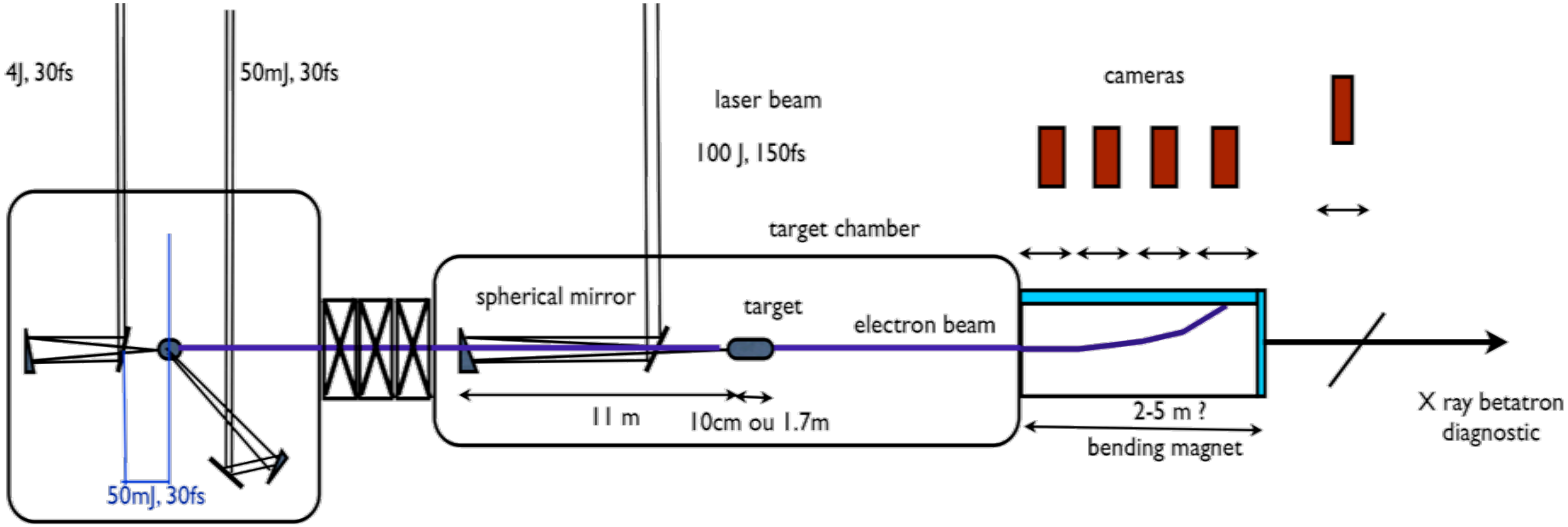






APOLLON laser: e– acceleration Phase 3 (2017)

- **two stages acceleration with all optical injector**
- **3 laser beams : 100mJ/6J/[10-100J]**

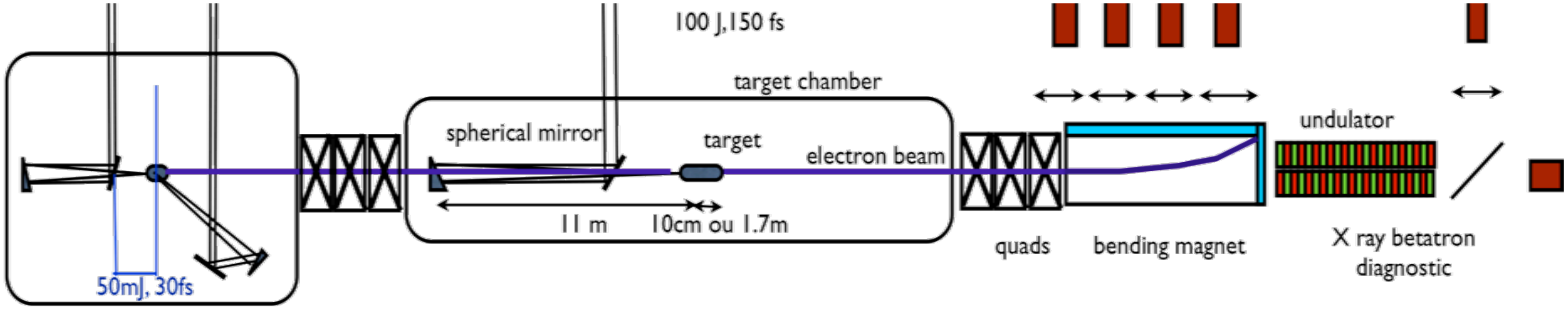


❍ **address instrumental challenges:**

- ➤ laser guiding over O(1m),
- ➤ compact electron transport («fight against gradient dilution»)
- ➤ laser & electron coupling into 2nd stage
- ➤ max. non-destructive e⁻-diag's at highest E (~20 GeV), integrated X-ray diag's
- ➤ insure beam stability and control

Phase 4: synchrotron radiation demonstration

- magnetic undulator and associated radiation diagnostics



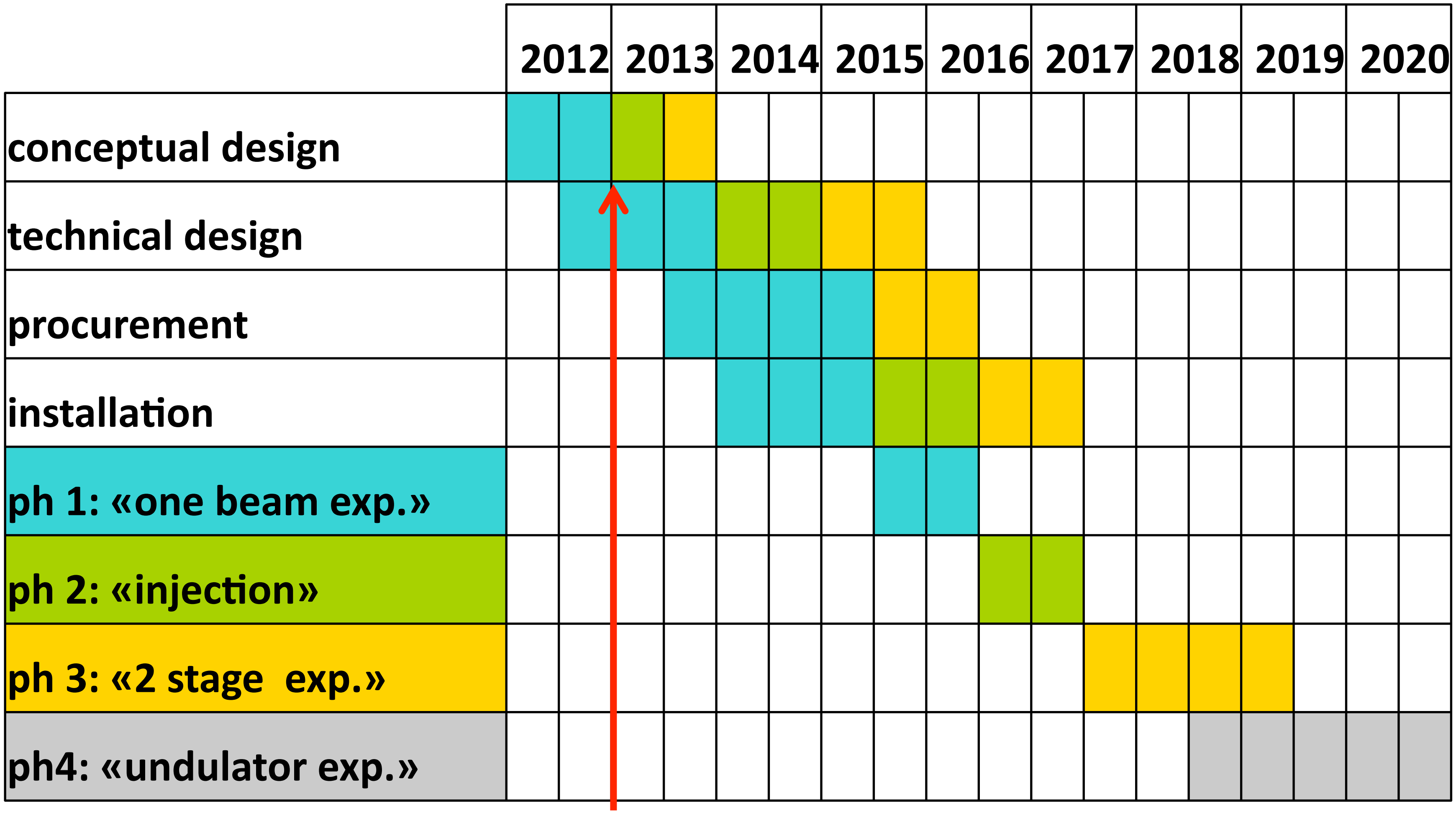
Concertation of scientific and technical program with other installations nationally (e.g. LUNEX5) and internationally (EuroNNAC)

Conceptual design objectives for LF experimental area

- fulfill experimental program defined by the UHI physics WGs e^- and X
  - ensure efficient use of available laser up-time
  - incremental design of setup (e.g. multistage e– acceleration)
  - commissioning of diagnostics in satellite facilities
- get the most of each laser shot (APOLLON 1 shot/min)
  - favor non-destructive and non-obstructive diagnostics
  - simultaneous and resident e^- and X-ray diagnostics
  - reliable and flexible data acquisition infrastructure
- flexibility of setup, openness to national and international teams
  - provide resident, operational diagnostics beam alignment system
  - accomodation of non-resident diagnostics and setups
  - provide secondary beams (e–, X, gamma) for applications

Conceptual design starting now

TIMELINE



Synchronised with the starting of rehabilitation works

EuroNNAc organization committee expectations (08/04/2011)

Subject: EuroNNAC workshop, session R&D plans1
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Dear All,

the program for the EuroNNAc workshop is now finished and available at
https://indico.cern.ch/internalPage.py?pageId=0&confId=115336
If you can not upload your presentation there, please do not hesitate to contact me.

Please find below a list of questions we would like to give you as guidelines for your presentations.

Thanks a lot and best regards
Steffen Hillenbrand
EuroNNAc, Scientific Secretary

Questions to be addressed in R&D plans

- Plans for development of facilities with schedule
- 5 year perspective (level of approved support: funded/proposed/idea)
- Motivation and objectives
- Acceleration goals (summary table)
- Application goals
- Possibilities for open access
- Expectations for network

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Conclusion

- CILEX lasers (APOLLON 10PW and satellite facilities) open field for dedicated LWFA experiments, wide range of driver param's (a0 , τ)
- APOLLON 10PW will push back major frontiers in LWFA of electrons
- Unprecedented, impressive challenges on instrumentation:
  - high intensity laser guiding over 1m x 200um (-> targetry)
  - compact, high quality e– beam transport and diagnostic (accomodate ßtron Xrays)
  - e– and laser beam alignment and synchronisation
- Fully instrumented experimental hall for e– and photon production will provide an advantage for programmatic and external uses