The PETAL+ project
X-ray and particle diagnostics for plasma experiments at LMJ - PETAL

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for the PETAL+ project

Outline

1) The LMJ – PETAL facility

2) Basic science at LMJ – PETAL

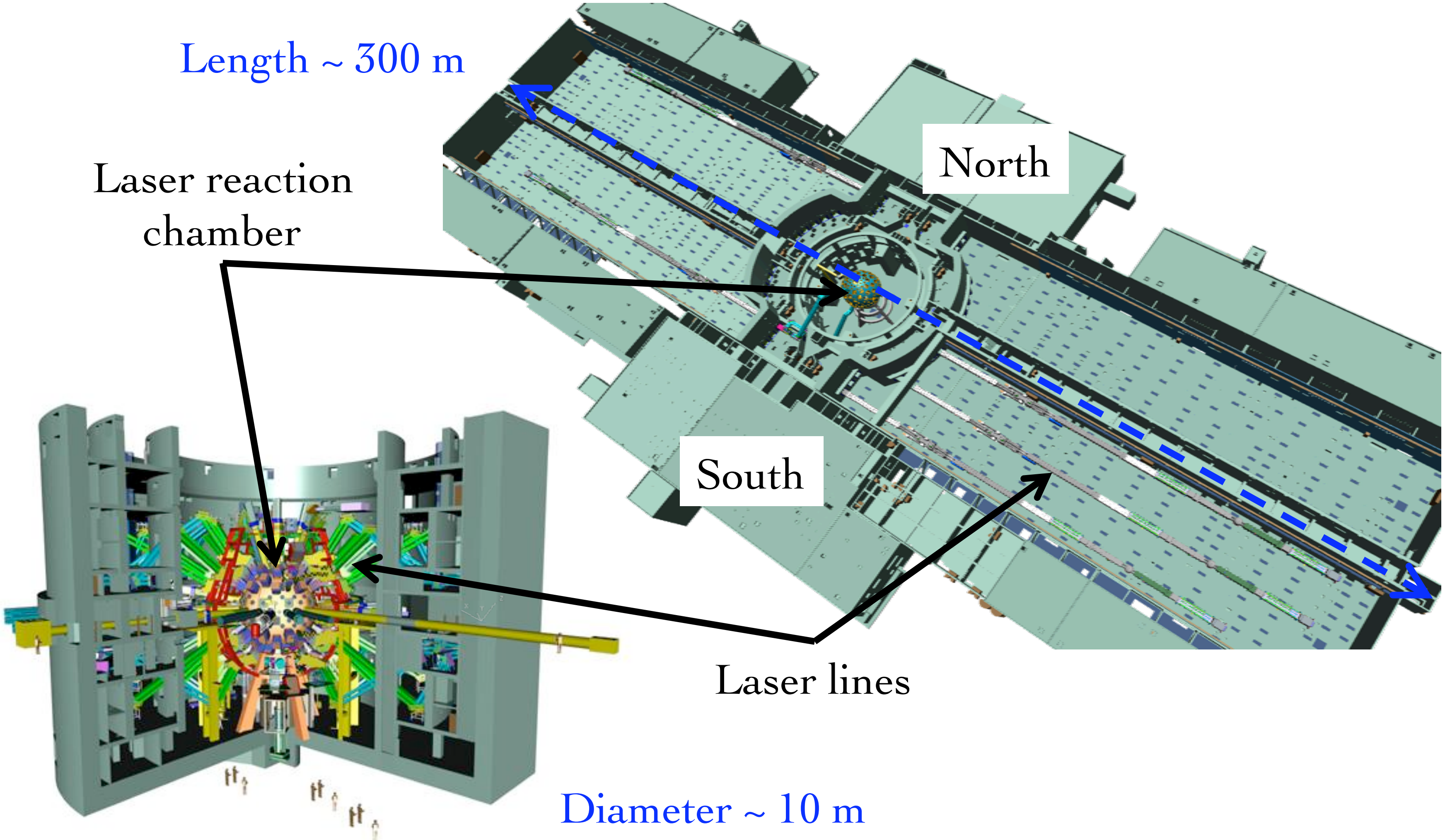
3) Measuring the properties of a laser plasma

4) The PETAL+ project

5) The proton/ion diagnostic

The LMJ – PETAL facility

The facility (le Barp – Bordeaux, France)



The LMJ – PETAL facility

The laser system

40 quads (4 laser beams)

$$E(quad) \geq 30\ kJ$$
$$\lambda = 351\ nm$$
$$L_{pulse} \simeq a\ few\ ns$$
$$I_{TARGET} \geq 10^{15}\ W/cm^2$$

1 Petawatt beam

$$E(PW) \geq 3.5\ kJ$$
$$\lambda = 1053\ nm$$
$$L_{pulse} \simeq 0.5 - 10\ ps$$
$$I_{TARGET} \geq 10^{20}\ W/cm^2$$

Petawatt laser

PETAL

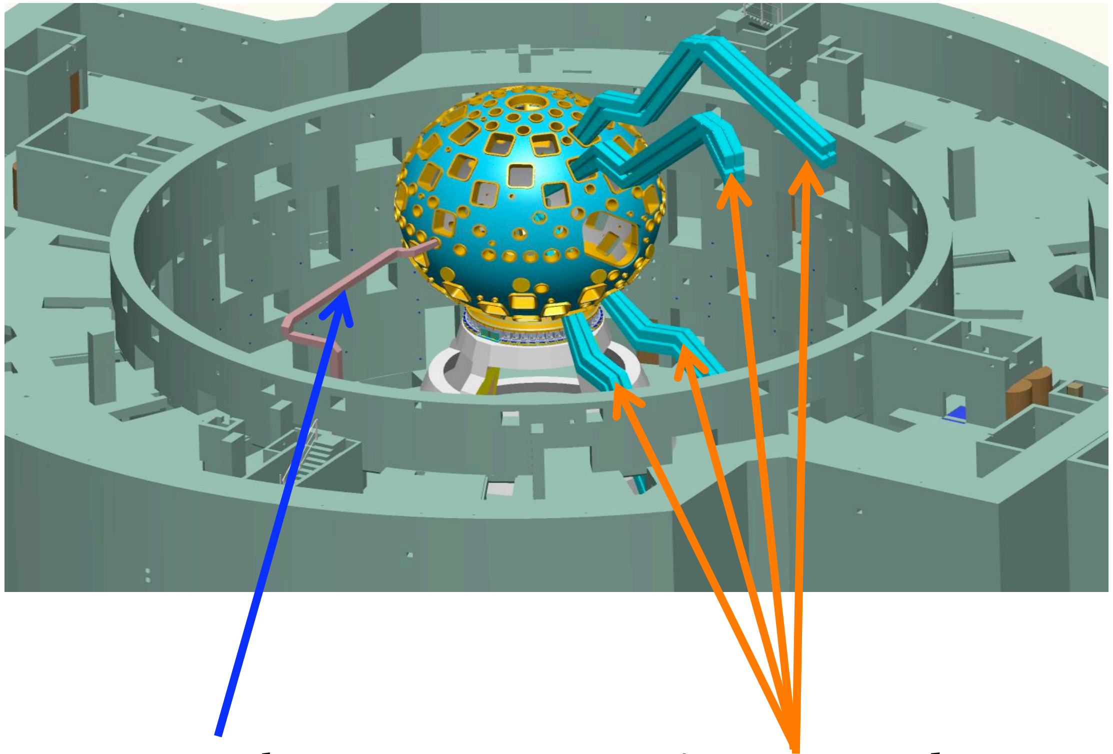
Petawatt Aquitaine Laser
funded by the Région Aquitaine

54.3 M€ of total budget for PETAL

The LMJ – PETAL facility

The laser system

Configuration in 2014 – 2015: 4 quads + 1 PW



Laser amplification lines

Basic science with LMJ – PETAL

1) Plasmas for inertial confinement fusion

i. Basic plasma physics
ii. Fast ignition
iii. Shock ignition

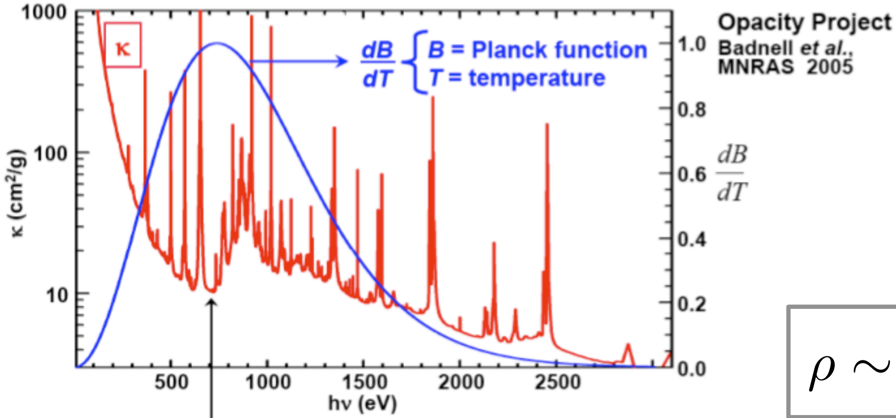
HiPER

2) Plasmas for astrophysics (laboratory astrophysics)

i. Hydrodynamics for astrophysics: shocks to simulate violent events in the Universe (SN, accretion disks…)
ii. Planet interiors: highly compressed matter
iii. Stellar physics: absorption/emission of photons within stellar matter conditions
iv. Nucleosynthesis in plasma conditions (electron – screening, Gamow window)

Basic science with LMJ

Spectral opacities of ^{56}Fe for blue giant star physics



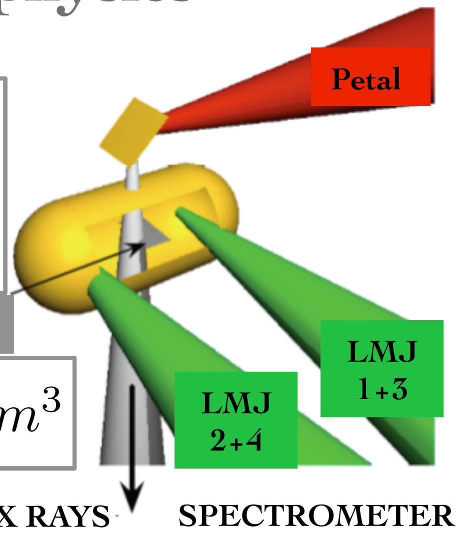
Photons transport through opacity "windows"

$$\frac{1}{\kappa_R} = \int d\nu \frac{1}{\kappa(\nu)} \frac{dB}{dT} \Big/ \int d\nu \frac{dB}{dT}$$

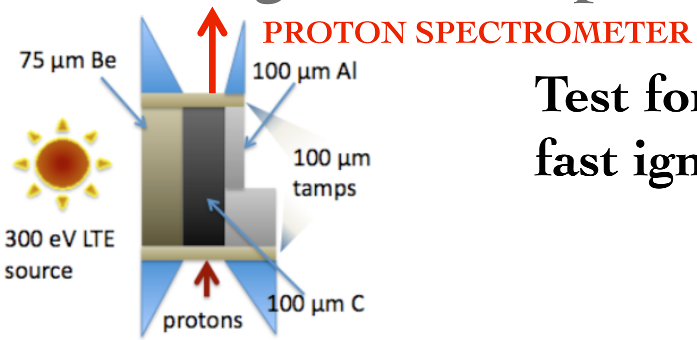
$$\langle Z_{Fe} \rangle \sim 12$$
$$T \sim 100\ eV$$

TARGET

$$\rho \sim 10^{-3} - 10^{-4} g/cm^3$$



Measuring dE/dX of protons within plasmas



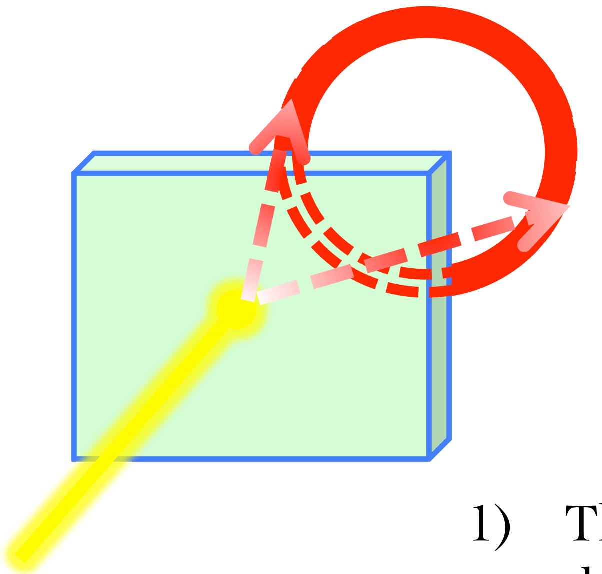
Test for feasibility of proton-triggered fast ignition (alternative to electrons)

R. Shepherd et al., NIF proposal (courtesy of J. Fuchs)

Measuring the properties of a laser plasma

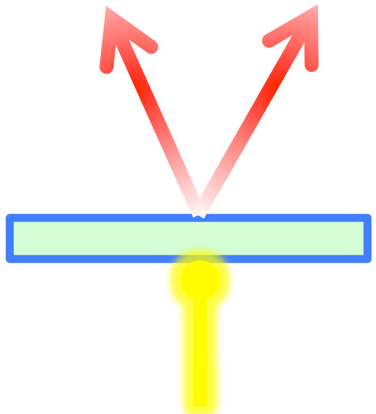
1) Detection of the radiation emitted by the plasma
   i. X-ray photon spectra of ionised atoms (emission lines, X- - ray imaging of the plasma)
   ii. γ – ray detectors (GRH, fusion rates)
   iii. Neutrons or ions from nucleosynthesis (rates, neutron imaging of the plasma)
2) Probing the plasma with a secondary source of radiation
   i. Radiography of the plasma
      a. X – ray photon absorption
      b. Proton / electron radiography
   ii. Particle production from a high – power short pulse laser → **PETAL**

Particle acceleration with a laser



Short – pulse laser (< ps)

High – contrast (> 10^{5-6})



1) The short – pulse laser instantaneously ionises the target (the electrons are emitted in the laser direction from the target back plane)
2) The protons / ions are accelerated in the E field hence created
3) High divergence (± 10°)
4) Up to high energies (a few 100 MeV)

The PETAL+ project

Design & construction of diagnostics realisation for PETAL

(Project between the French ANR and the University of Bordeaux)

Budget ~ 9 M€

Realisation of the first three plasma diagnostics related to PETAL

Proton Spectrometer, Electron Spectrometer, X-ray spectrometer

Detection mostly based on passive removable detectors to avoid effects of large EMP induced by PETAL. They will also be designed to work in a nuclear environment (tritium pollution, neutron activation…)

Realisation of diagnostic insertion systems (DIS)

The DIS for PETAL will be different from the standard LMJ DIS because the extraction of detector components (e.g. CR39 and RCF films, IP detectors) is required & the positioning accuracy is lower

The PETAL+ project

The proton spectrometer

- Proton spectral range: 0.1 - 200 MeV $\delta E/E \sim 10\%$
- Thomson Parabola to distinguish the charge states
- Observation field on target: 1 - 10 mm
- Transversal spatial resolution: 10 - 100 µm

The electron spectrometer

- Electron spectral range: 300 keV - 50 MeV $\delta E/E \sim 5\%$
- Permanent magnets and Imaging Plates
- Signal dynamics 10^5
- + activation measurements

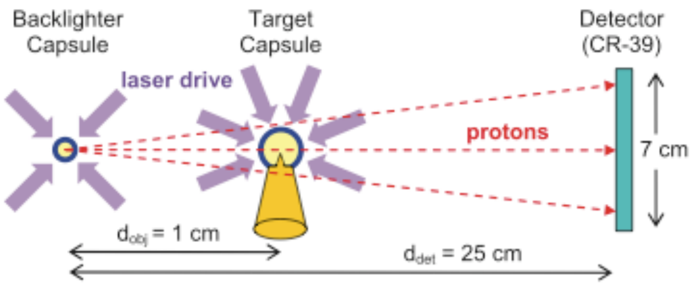
The X-ray spectrometer

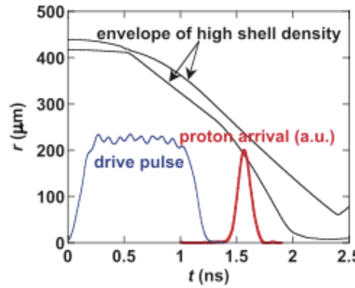
- X-ray spectral range: 5 keV- 120 keV $\delta(h\nu)/h\nu \sim 1/300$
- based on a crystal in transmission (Laue diffraction, Cauchois geometry)
- Detection with Imaging Plates

The proton/ion diagnostic

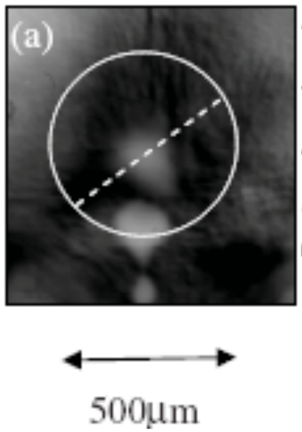
Proton radiography of plasma implosion

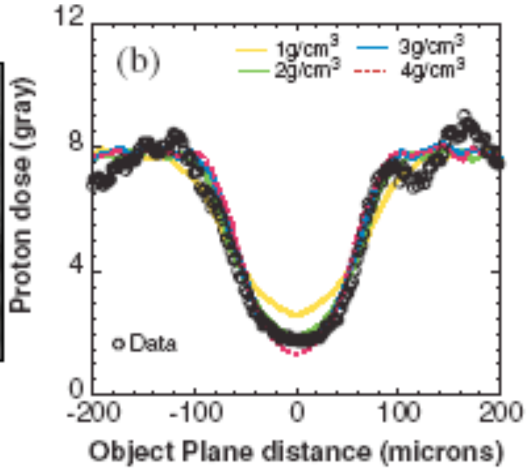
→ plasma central density



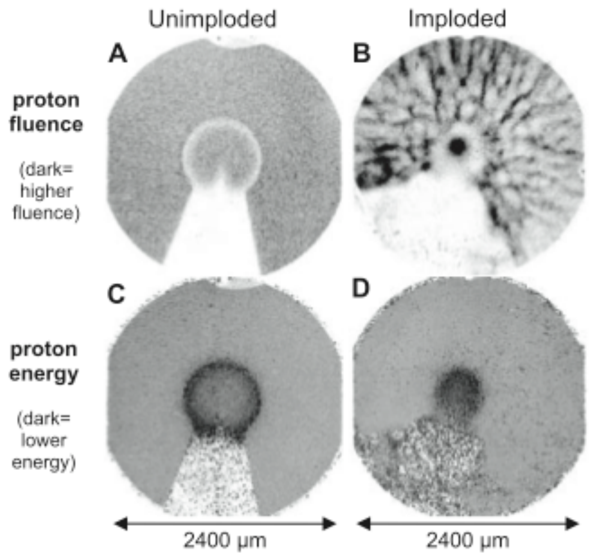


7 MeV protons





A. Mackinnon *et al.*,
Phys. Rev. Letters 97, 045001 (2006)

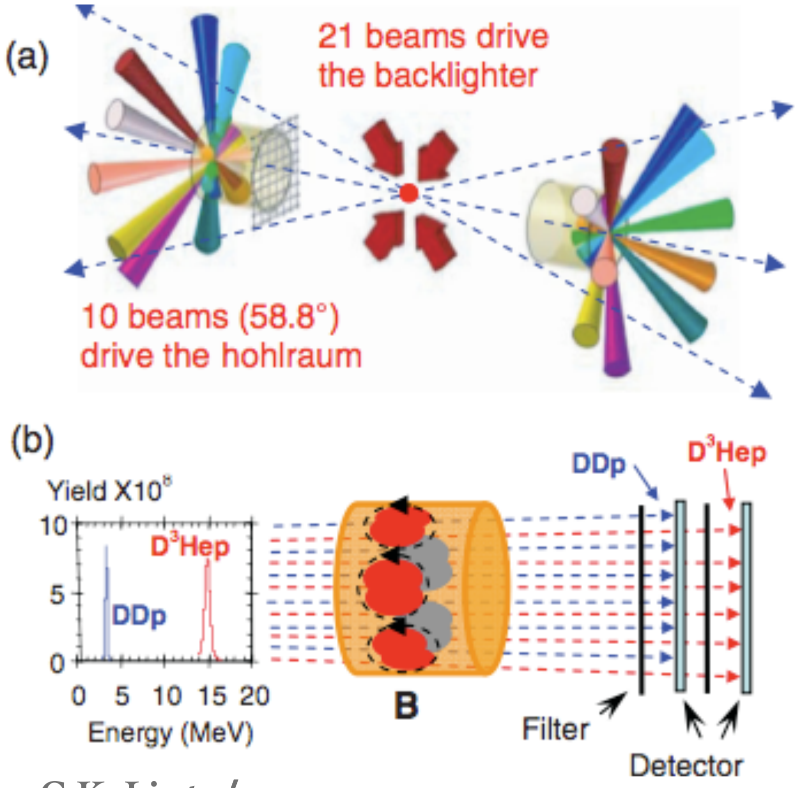


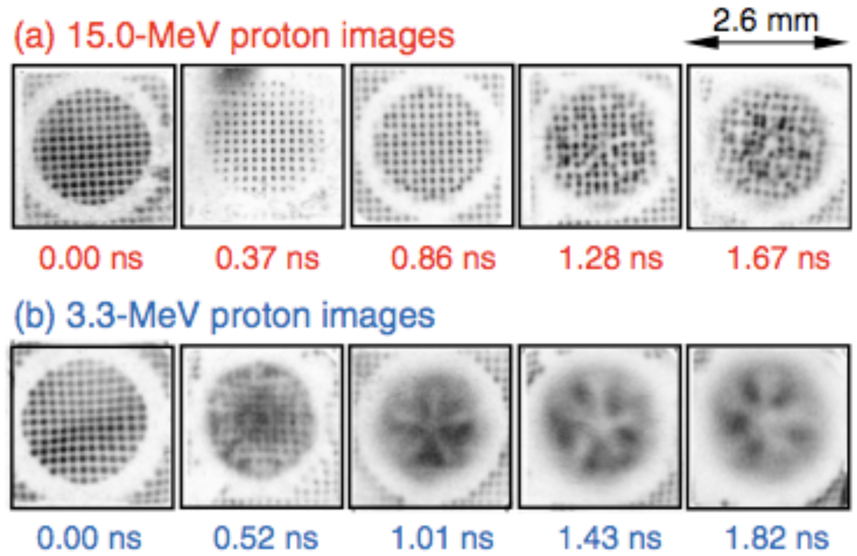
J. R. Rygg *et al.*
Science 319, 1223 (2008)

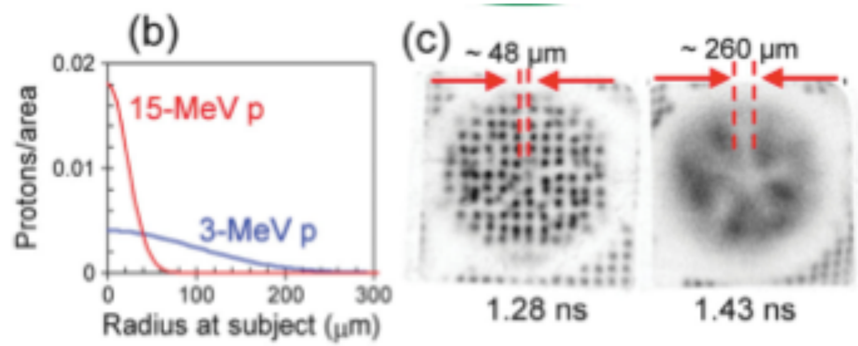
The proton/ion diagnostic

Proton radiography of plasma implosion

→ plasma magnetic field (~ GG)



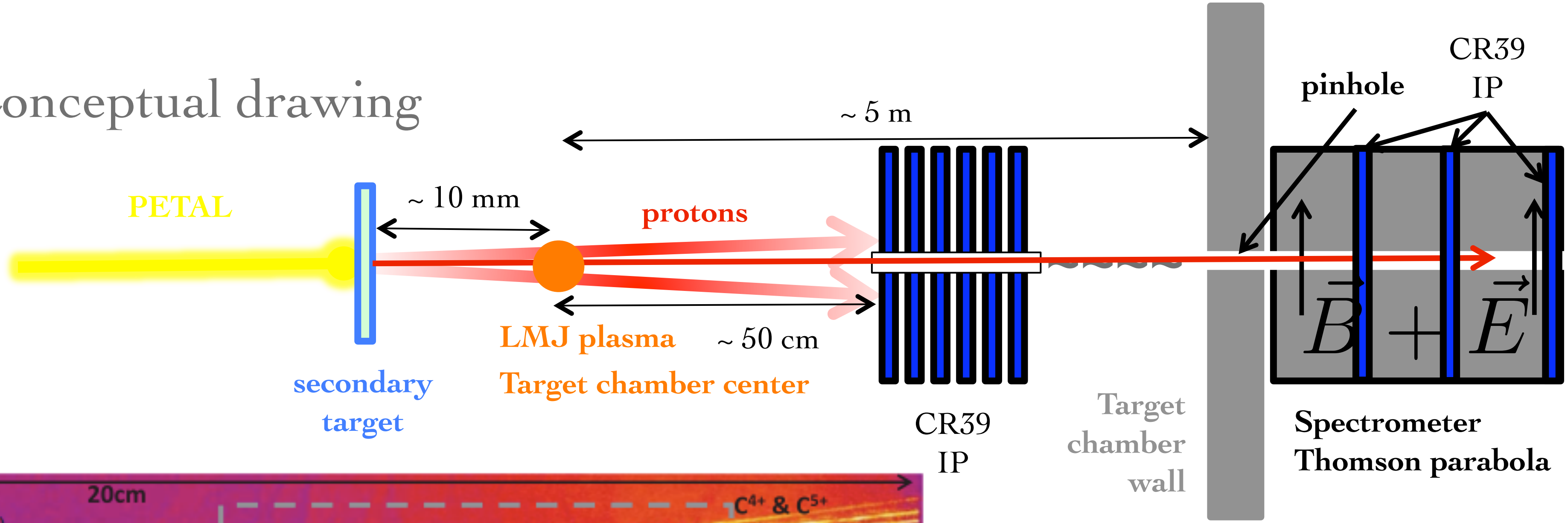


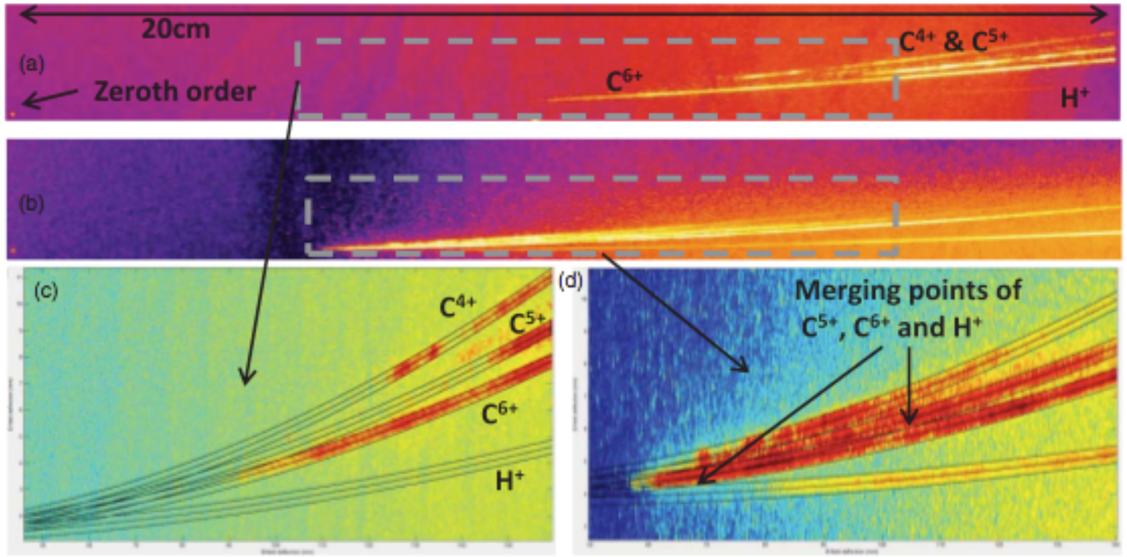


C.K. Li *et al.*,
Phys. Rev. Letters 102, 205001 (2009)

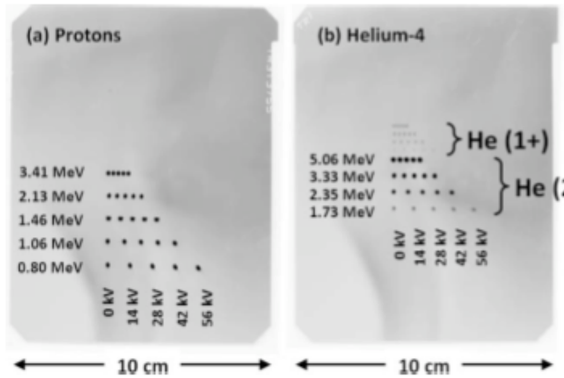
The proton/ion diagnostic

Conceptual drawing





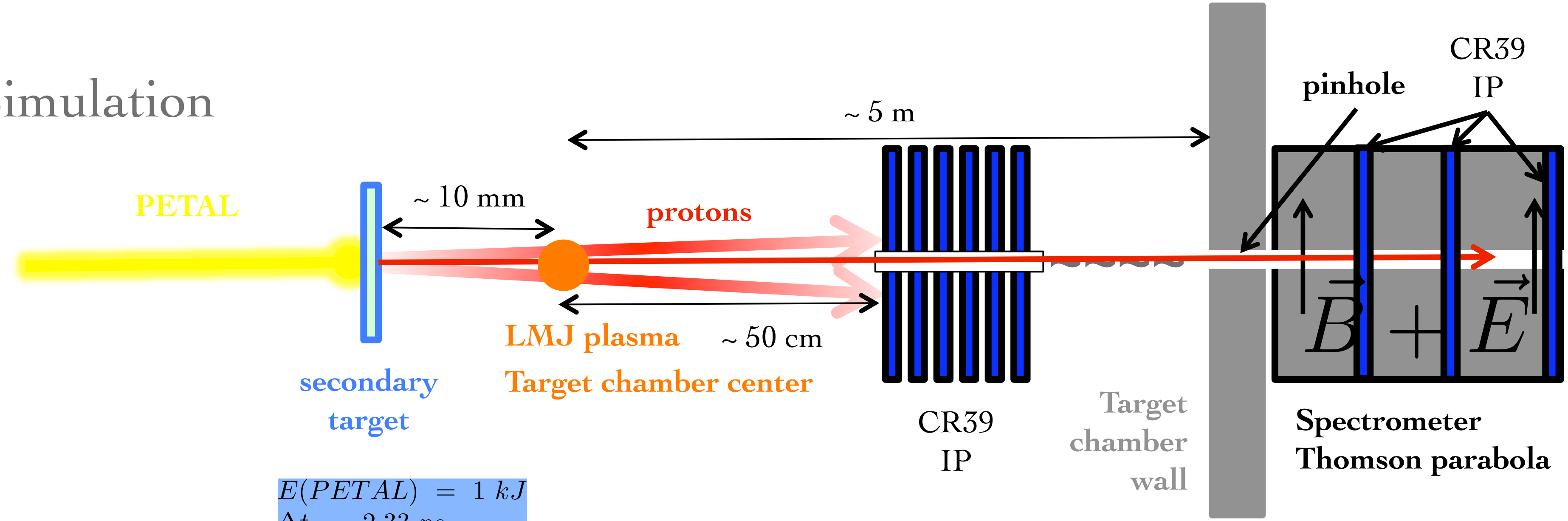
D. Jung *et al.*, Rev. Scient. Instrum. 82, 013306 (2011)



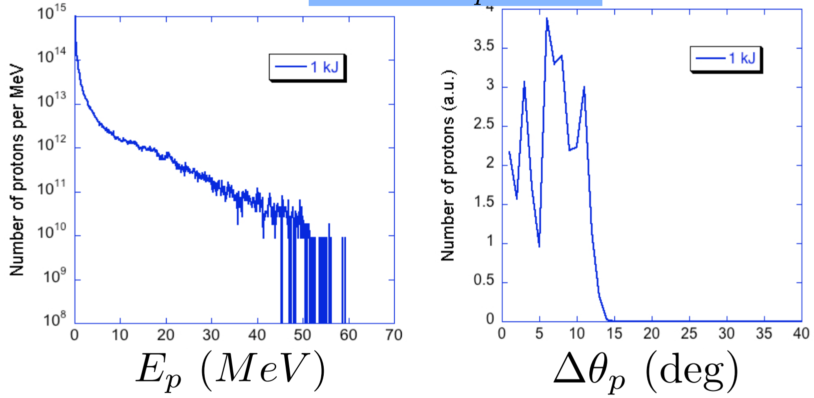
C.G. Freeman *et al.*,
Rev. Scient. Instrum. 82, 073301 (2011)

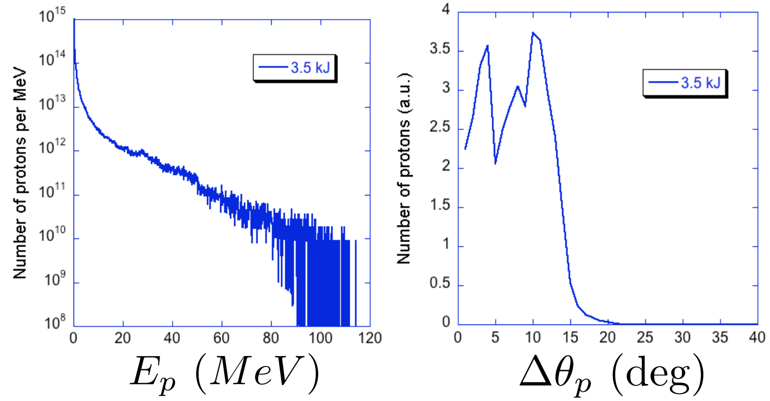
The proton/ion diagnostic

Simulation



$E(PETAL) = 1\ kJ$
$\Delta t = 2.33\ ps$



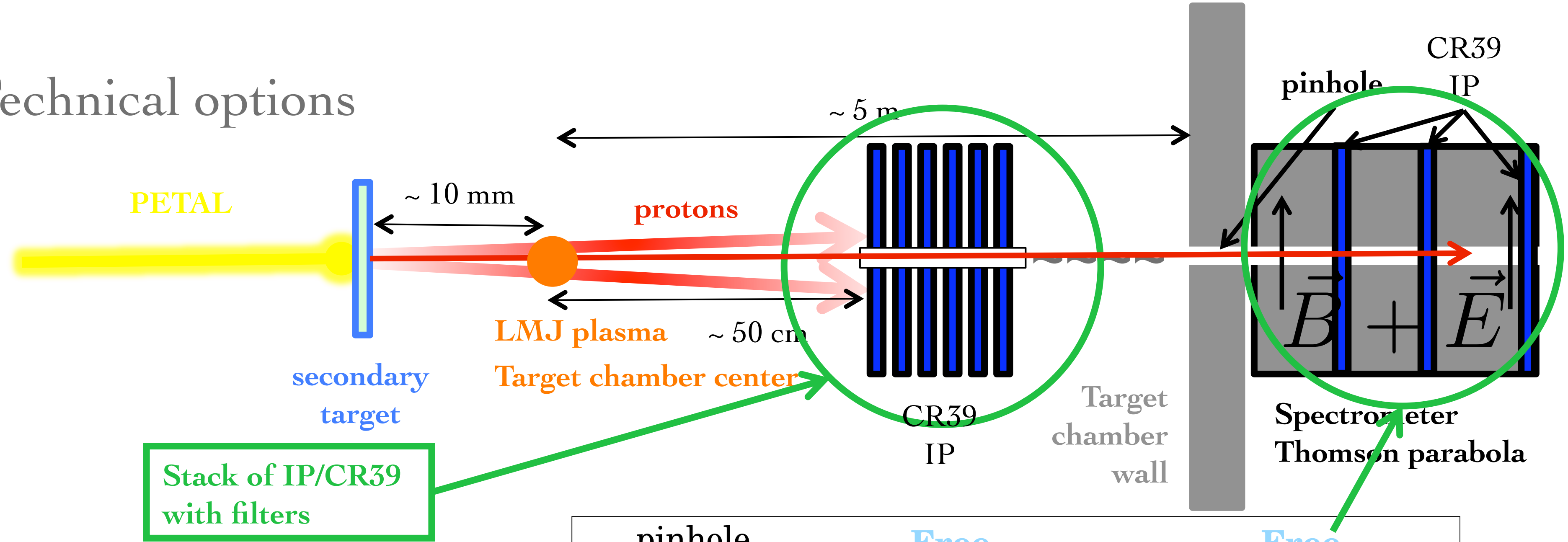


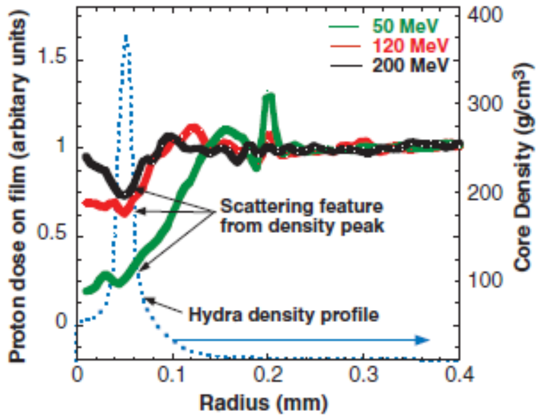
$E(PETAL) = 3.5\ kJ$
$\Delta t = 1.94\ ps$

Courtesy of E. d'Humières (CELIA, U. Bordeaux), PIC simulation for the PETAL+ project (2011)

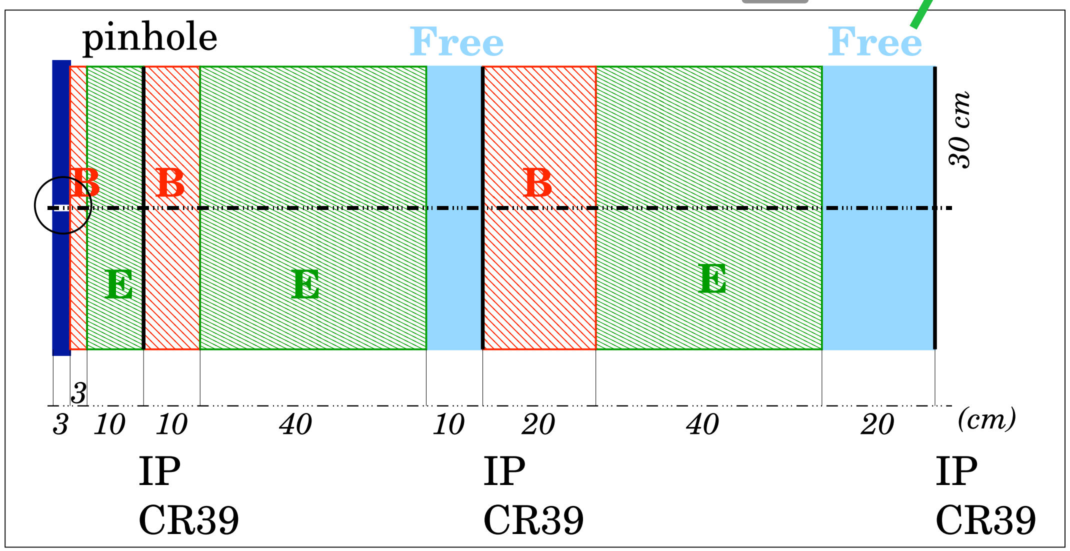
The proton/ion diagnostic

Technical options



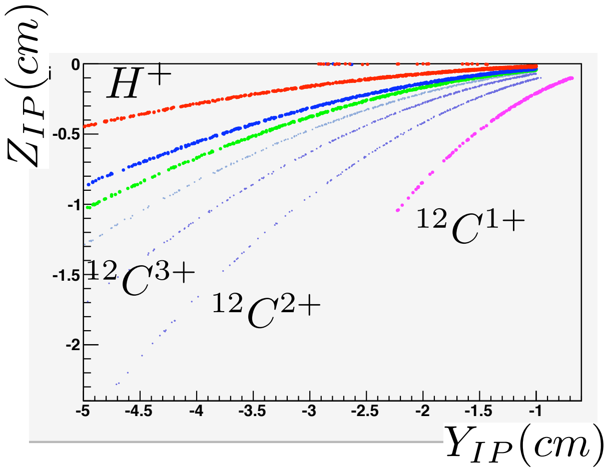


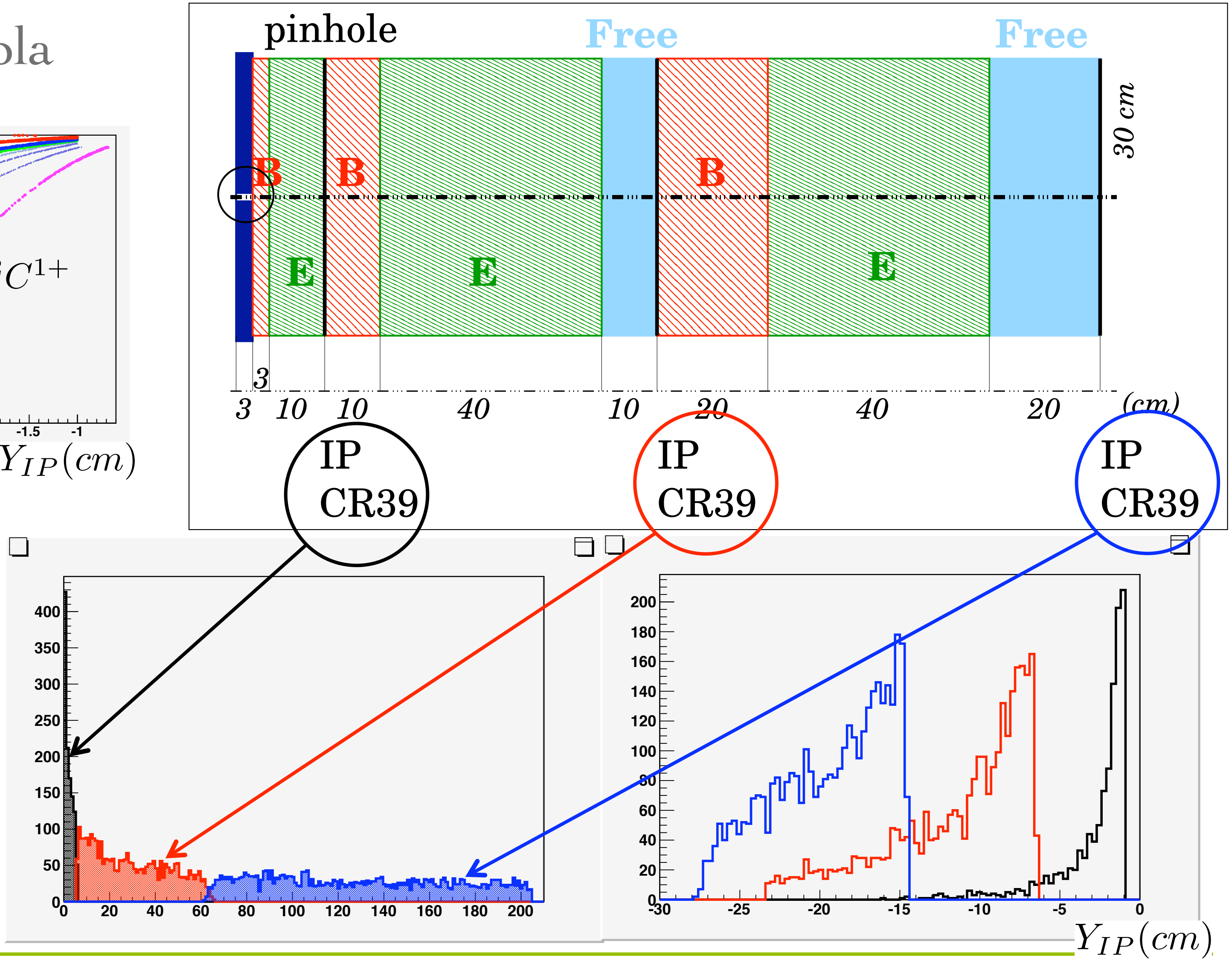
A. Mackinnon *et al.*,
Phys. Rev. Letters 97, 045001 (2006)



The proton/ion diagnostic

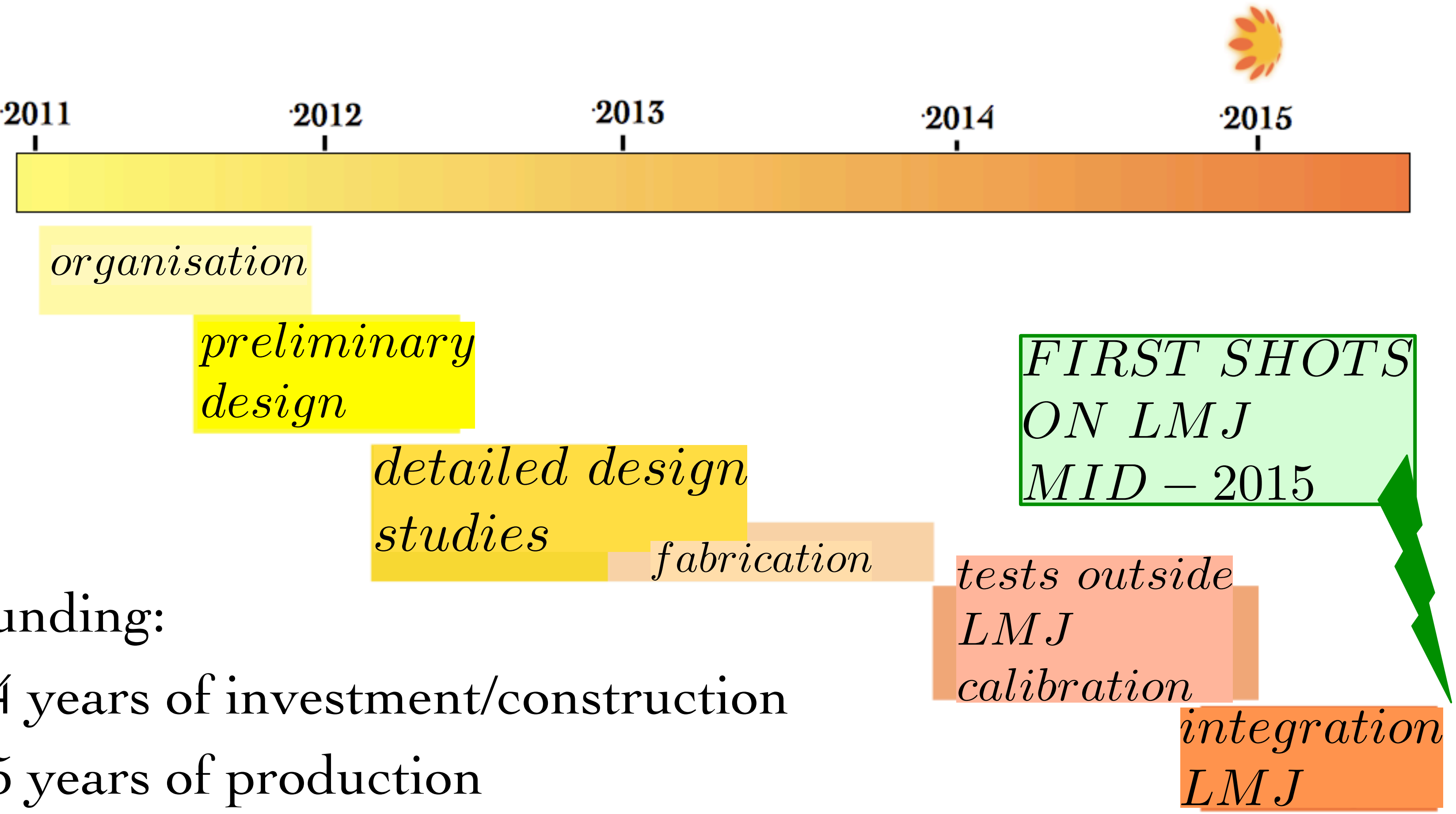
Thomson parabola





Planning of the project

Planning



Funding:

- 4 years of investment/construction
- 5 years of production

Summary

• On the LMJ facility, the installation of the Petawatt laser PETAL will provide the opportunity to perform physics well beyond the scope of LMJ, which is the French programme for the simulation of the atomic bomb: inertial fusion with different ignition schemes, astrophysics, planetary science…

• Used with secondary targets, PETAL will generate different probes of the LMJ plasmas for the academic research effort on what is basically a military facility

• The PETAL+ project is aiming at constructing the first three diagnostics to be used with PETAL. Given the particularly unfriendly environment of the laser shots at LMJ (radiations of many types, giant EMP, activation…), **the choice is made for known and robust diagnostic techniques**. Other steps will follow once experience has been gained on such a device.

With a little help from…

D. Batani, S. Hulin, É. D'Humières, V. Tikhonchuk CELIA - Bordeaux

T. Ceccotti, S. Dobosz, F. Thais, S. Turck-Chièze, J.P.Chièze CEA-Saclay

J.R. Marquès, S. Bastiani, S. Baton, M. Koenig LULI - Palaiseau

C. Reverdin, I. Thfoin-Lantuéjoul, A. Duval, R. Wrobel
CEA-DAM Bruyères-le-Châtel

M. Tarisien, F. Gobet, L. Sérani CEN Bordeaux Gradignan

With PETAL & PETAL+,
the French academic research community
is investing on the LMJ **with the hope of triggering**
the scientific interest of the European academic research

Workshop on the physics with PETAL & PETAL+
8th of December, Hôtel de région, Bordeaux – France
http://petal.aquitaine.fr/Workshop-PETAL-Reunions-HiPER.html