Simulations and numerical developments for laser-plasma acceleration at LLR

Status, projects, needs

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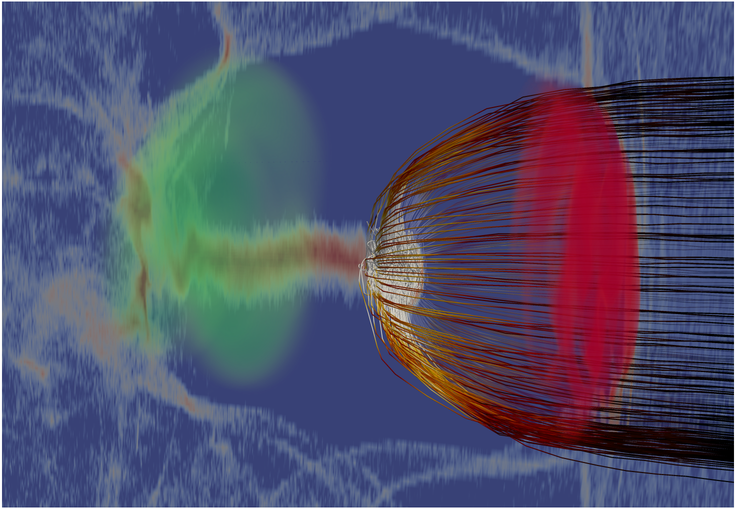
Objective : production of numerical scientific data



Outreach of numerical simulations

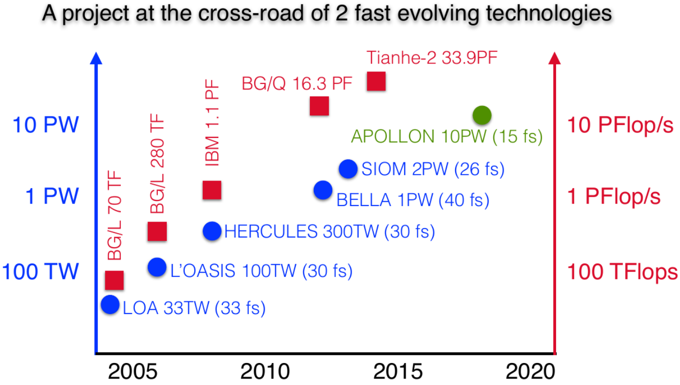
A precious tool

- Support experiences : experience and instruments design. Results interpretations.
- Support theory : access non measurable quantities during experiences, parametric studies, inspiration source source.
- Support publications : scientific communications backed up by numerical simulations are well received. Simulation is the 3rd pilar of science.

Status of laser-plasma numerical simulation in IN2P3

- Manpower
  - 1 Ingénieur de recherche. (EAAC 2015 : 257 participants).
- Particle-In-Cell codes
  - In 2013, IN2P3 depends on other institutes for simulation codes (not open source).
  - SMILEI initiative started, 2016 STILEX project (ANR, seen as the numerical CILEX).
  - Applications : laser-matter interaction, astrophysics (magnetic reconnection, collisionless shocks), accelerator sources.
- Computational resources
  - CC resources are not adapted to HPC in general and PIC codes in particular.
  - IN2P3 (S.E. GALOP) funded a local cluster for development and small productions (672 cores, 120 k€ over 3 years).
  - Real size productions use national and european resources through GENCI and PRACE projects.
  - $\sim$ 83 Mh CPU over the last 3 years, estimated at 1.5 M€ by GENCI.

Laser plasma simulation is at the strategic crossroad of TGIR “Laser” and “HPC”



Our partners : CILEX on the laser side, TGCC, CINES, IDRIS, CINECA(Italy) on the compute side.

Numerical challenges faced by laser-plasma simulations

Challenge 1 : Efficiency

- 3D simulations are COSTLY ! $\simeq 10^9$ cells, 8 particles/cell, $\simeq 10^7$ iterations ==> 10^{19} operations <==> 85 hours on 3M+ cores
- $\sim$ 255 Mh CPU with over optimistic assumptions.
- Largest PRACE allocations < 100 Mh CPU.

R. Fonseca *et al*, *Exploiting multi-scale parallelism for large scale numerical modeling of laser wakefield accelerators*, Plasma Phys. Control. Fusion (2013)
A. Beck *et al*, *Load management strategy for Particle-In-Cell simulations in high energy particle acceleration*, Nucl. Instrum. Methods in Phys. Res. A (2016)

- Reduced models.
- Extreme programming for massively parallel clusters.

Numerical challenges faced by laser-plasma simulations

Challenge 2 : Accuracy

- Numerical dispersion : the laser has to propagate at the theoretical group velocity in the plasma.
- Quantitative agreement between experiences and simulations is often not achieved for some quantities (injected charge for instance).
- Are we missing physics ? Collisions, QED, radiative loss ? As the lasers energies increase, we'll have to include this new physics at some point (already started).

- Applied mathematics, numerical analysis.
- Plasma physics.

High Performance Computing is not High Throughput Computing

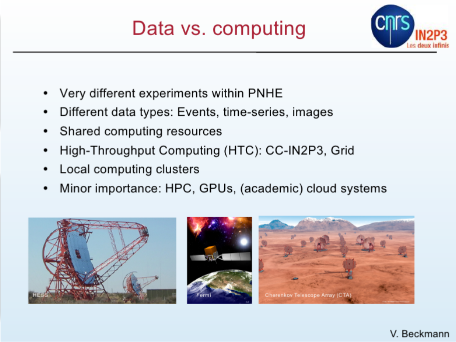
IN2P3 is running late on HPC aspects and PIC codes.
We benefit from the expertise of other institues which have been working on these topics for a long time.

HTC skills

- Network
- Dispatching

HPC skills

- Applied mathematics
- Parallel architecture and programming



«A collaborative, open-source, multi-purpose PIC code for the next generation of super-computers»

Smilei)

www.maisondelasimulation.fr/smilei

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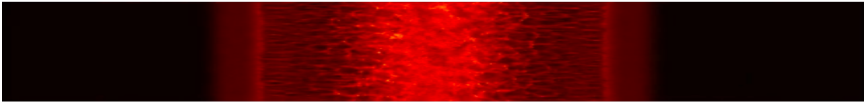


M. Grech, A. Grassi, M. Chiaramello, F. Niel, F. Pérez, T. Vinci, C. Riconda
Laboratoire d'Utilisation des Lasers Intenses (LULI, Palaiseau)

J. Dérouillat
Maison de la Simulation (Saclay)

A. Beck
Laboratoire Leprince-Ringuet (LLR, Palaiseau)

G. Bouchard
Laboratoire Interactions, Dynamique et Lasers (LIDyL, Saclay)

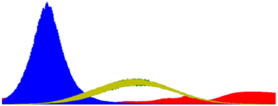
M. Flé
Institut du développement et des ressources en informatique scientifique (IDRIS, Orsay)

N. Aunai, J. Dargent, P. Savoini
Laboratoire de Physique des Plasmas (LPP, Palaiseau)

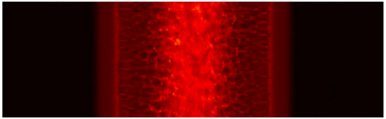
I. Plotnikov
Institut de Recherche en Astrophysique et Planétologie (IRAP, Toulouse)

5 PhD ongoing, 1 incoming

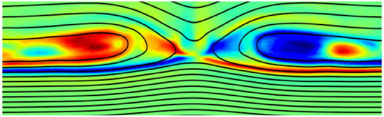
M. Chiaramello (LULI), *Amplification of short pulses using Brillouin scattering*



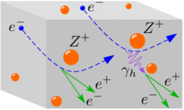
A. Grassi (LULI, Pisa), *Relativistic collisionless shocks in magnetised plasmas*



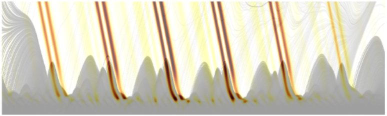
J. Dargent (LPP), *Magnetic reconnection*



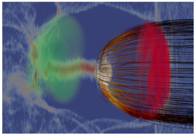
F. Niel (LULI), *QED processes in laser-plasma interaction*



G. Bouchard (LIDyL), *High-harmonic generation in laser-solid interaction*



Coming soon (LLR), *LWFA in cylindrical geometry*



Short term objectives : STILEX project

ANR project phase 2

1. Urgent R-z geometry for laser-plasma interaction. PhD student at LLR.
2. Spectral methods. Post doc, Maison de la Simulation.
3. 3D visualization toolkit. Engineer, Maison de la Simulation.