DE LA RECHERCHE À L'INDUSTRIE

Studies on LWFA Injector for AWAKE run 2

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LWFA4AWKAE2 meeting- April 11, 2022

An LWFA injector for AWAKE 2

IRFU-DACM

CNRS-LPGP

WF acceleration & HEP: great scientific interest
An LWFA injector for AWAKE 2 : exciting project
Challenging task

Beam physics
Beam diagnostics

Plasma design & test
Plasma-Laser experiments

Beam Physics

Beam physics → mastering all the beam parameters

- Design phase
- Beam commisioning phase
- Operational phase

Recommended:

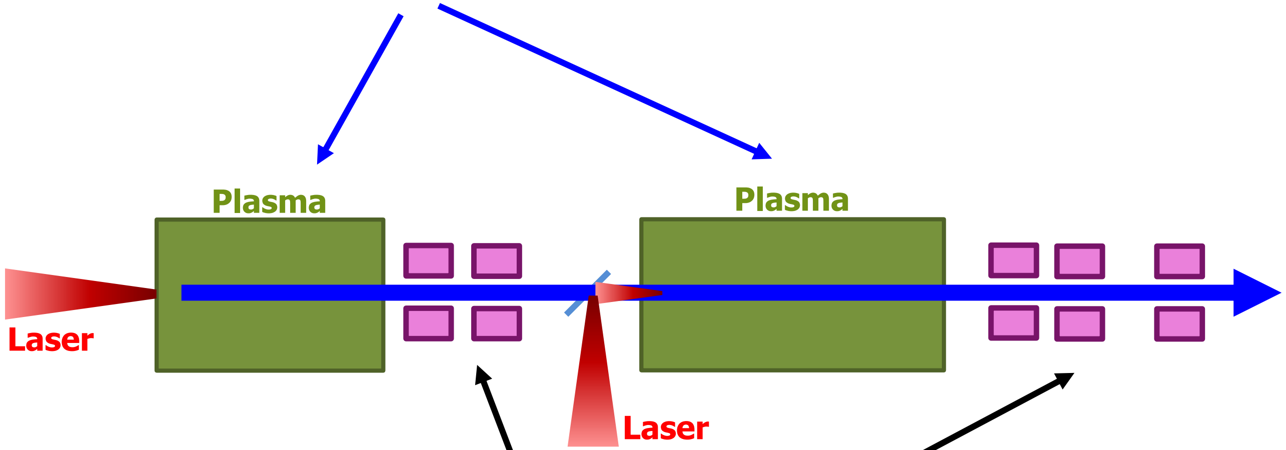
Done by a single person

or by a team cordinated by a single person

→ - persons working in parallel on different sections
- should expect many back & forth between the sections

ELECTRIC field, MAGNETIC field

Electric field $\vec{F} = q\vec{E}$ could be accelerating, guiding, focusing



Magnetic field $\vec{F} = q\,\vec{v} \wedge \vec{B}$ only guiding or focusing
cannot give or take (kinetic) energy to/from a particle

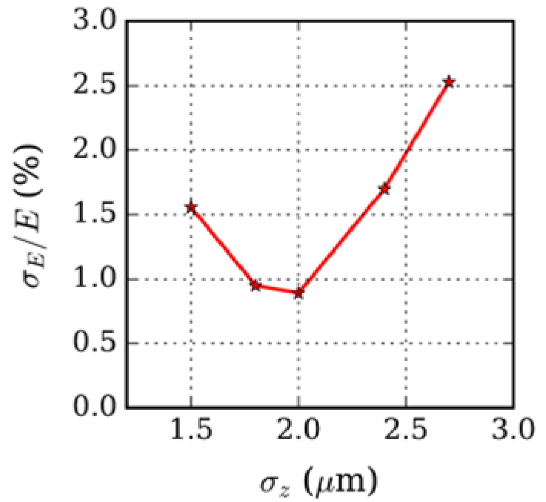
➡ Given beam parameters can only be mastered in specific sections

$(\sigma_E/E) \rightarrow$ only in plasma stages

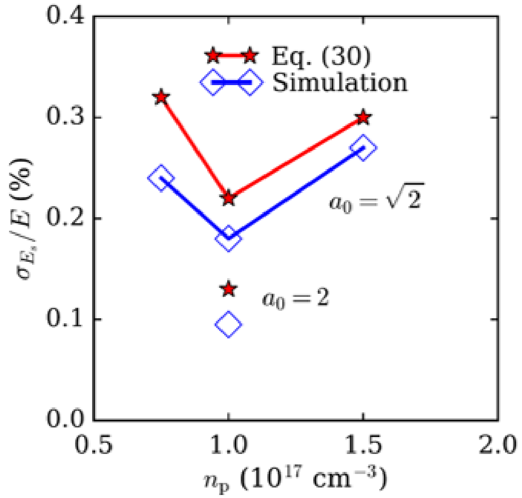
High beam quality and high charge

For acceleration: minimize energy spread in the presence of high charge

In the presence of significant beam loading



Minimizing energy spread by optimizing the bunch length



Minimizing slice energy spread by optimizing jointly the plasma density & the laser strength

Bunch charge ↓

Wakefield & bunch length — **energy spread** — Beamloading field & bunch radius

Bunch charge ↓

$\frac{\sigma_{E,s}}{E_0}$ — Beamloading field ↗ $\sqrt{n_p}$ and ↘ a_0

— Av. energy gain by wakefield ↘n_p

X. Li, P. A. P. Nghiem, A. Mosnier, Phys. Rev. Accel. Beams, 21, 111301 (2018)

Minimizing ε growth: in which section?

It is well known: beam extraction and transport → important emittance growth
Floettmann, PRAB 2003; Dornmair, Floettmann & Maier, PRSTAB 2015, …
Xu et al. PRL 2016 …

But: only solutions of downramp without space charge nor beam loading

And: three pending questions without explicit answer

1- Which emittance? (Phase or Trace emittance?)

2- In which circumstances? (Drift or Focusing element?)

3- Which parameters govern the emittance growth?

→ **Answer ≡ Know how to mitigate emittance growth**

X. Li, A. Chancé, P. A. P. Nghiem, Phys. Rev. Accel. Beams, 22, 021304 (2019)

Minimizing ε growth: the 3 key roles

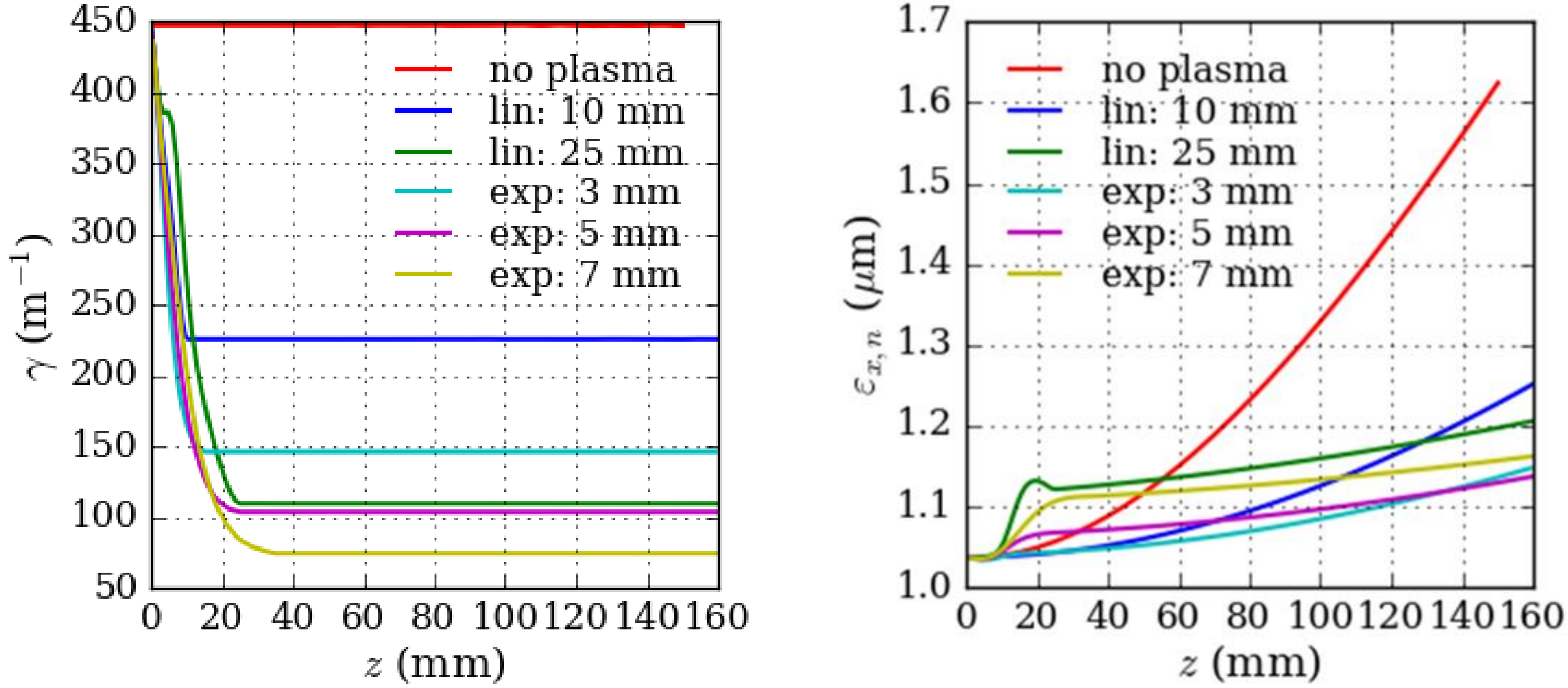
In the plasma: minimize Emittance and Energy Spread
(as done previously)

In the downramp: minimize γ
by tuning the ramp length (whatever its shape)

In the transfer line: minimize the first drift and use the smoothest focalization
→ use as few quadrupoles as possible (~6)

Minimizing ε growth: example at 5 GeV

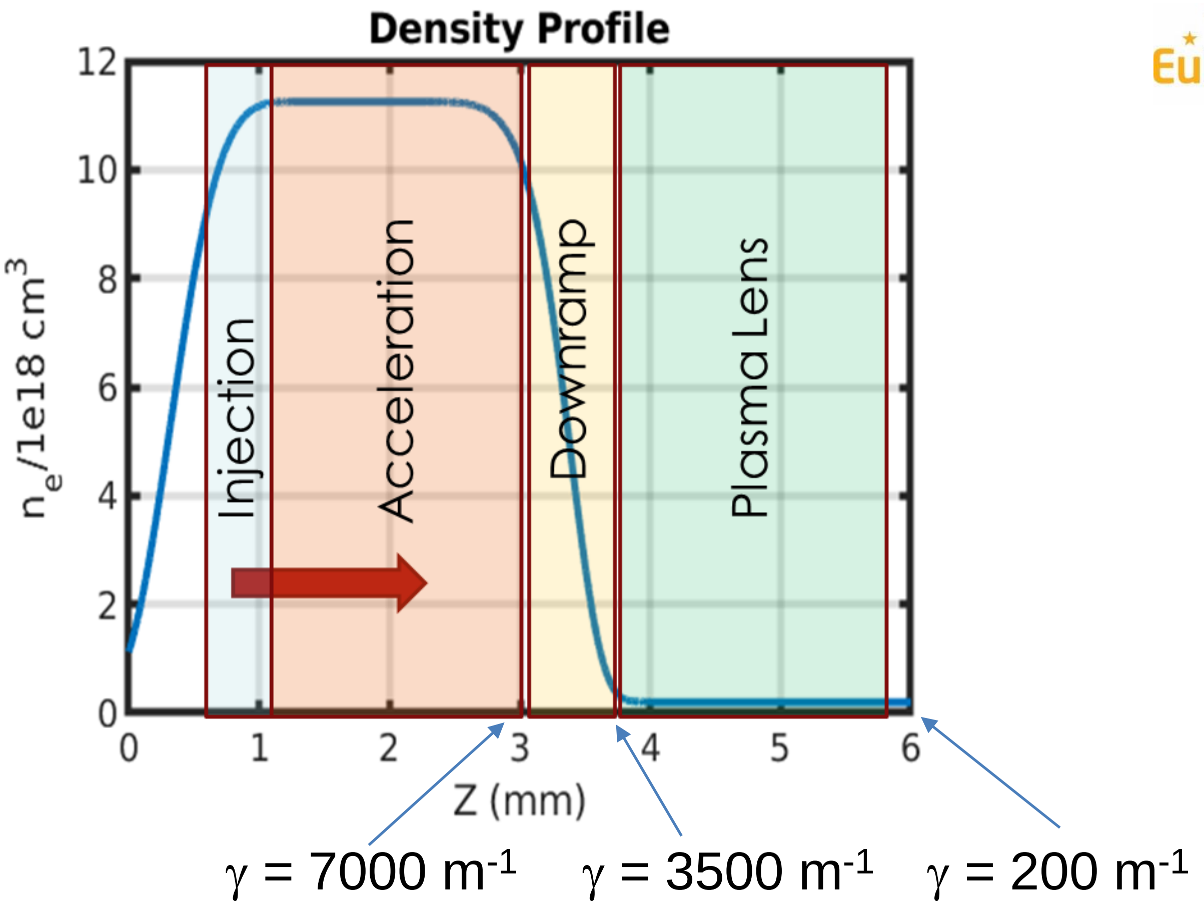
Plasma exit 5 GeV

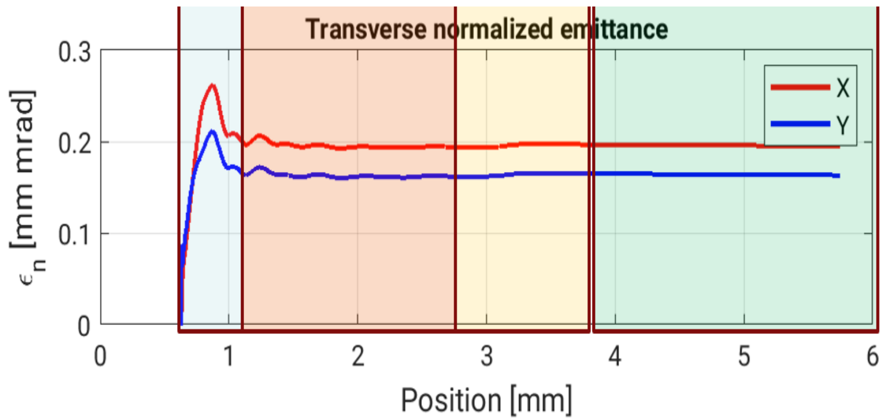


Tuning the ramp length (whatever its shape)
⇒ Minimizing γ_0 ⇒ Minimizing emittance growth

Minimizing ε growth: example at 150 MeV

Plasma exit 150 MeV

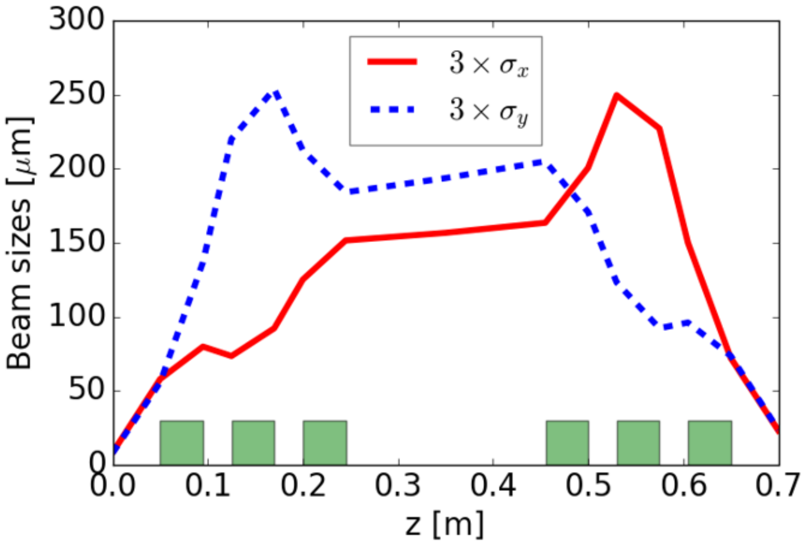


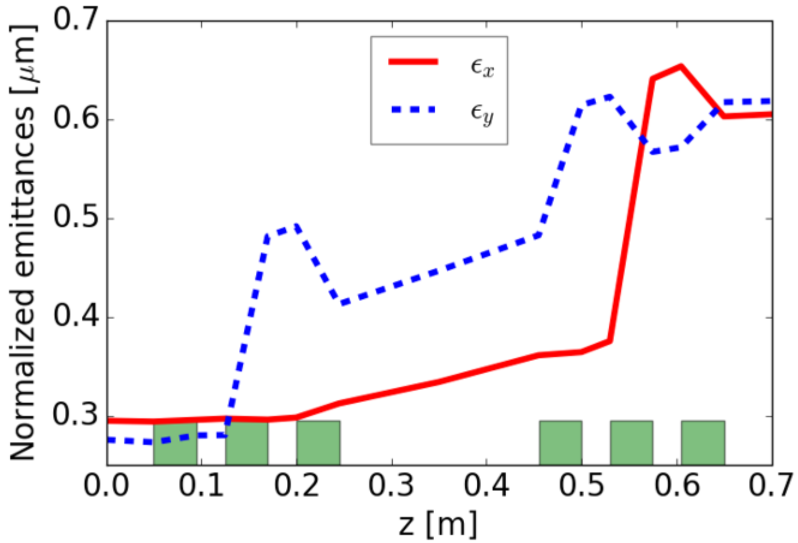


Minimiser émittance : ligne de transport

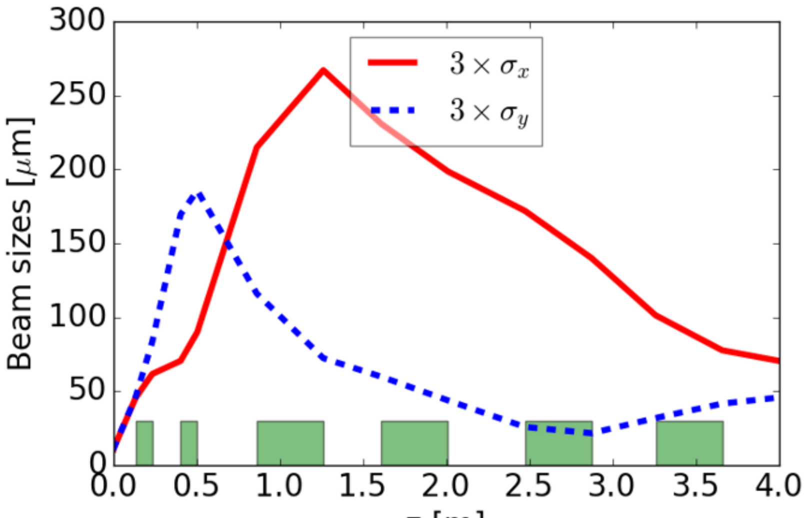
Rule: smoothest focusing → number of quadrupoles= number of constraints (~6)

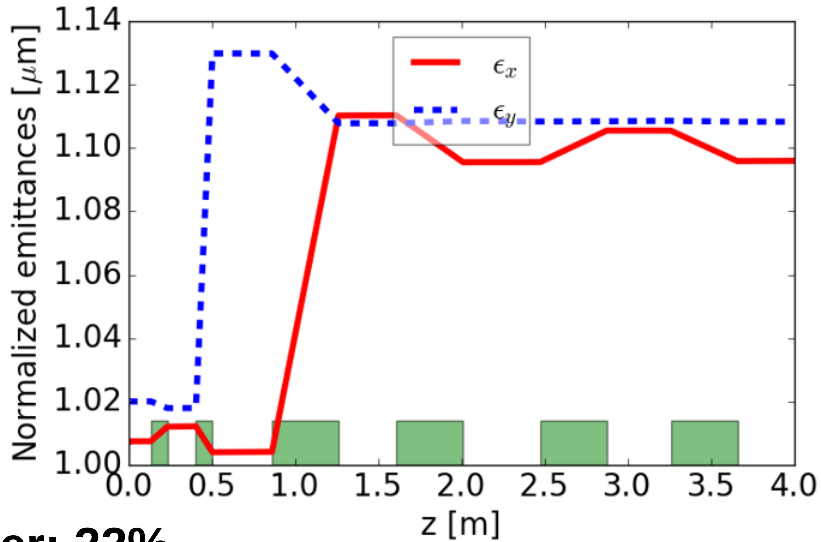
LETL 150 MeV





HETL 5 GeV





Total emittance growth from LPAS injection to end user: 22%

Component performances needed

Error and tolerance calculations

Heavy simulations!!! To be completed

Errors ≡ Jitters

The most critical points are:

In the plasma stages: For laser and electron beams,

- Position vibrations should be a small fraction of their size
  - → consistency of error simulations
  - → stability of the selected schemes, no surprising error amplification
- Departure to cylindrical symmetry should be very tightly controlled

  Strong effects on final emittance and slice energy spread

In the transport lines:

Magnet position vibrations in the capture section should be < μm

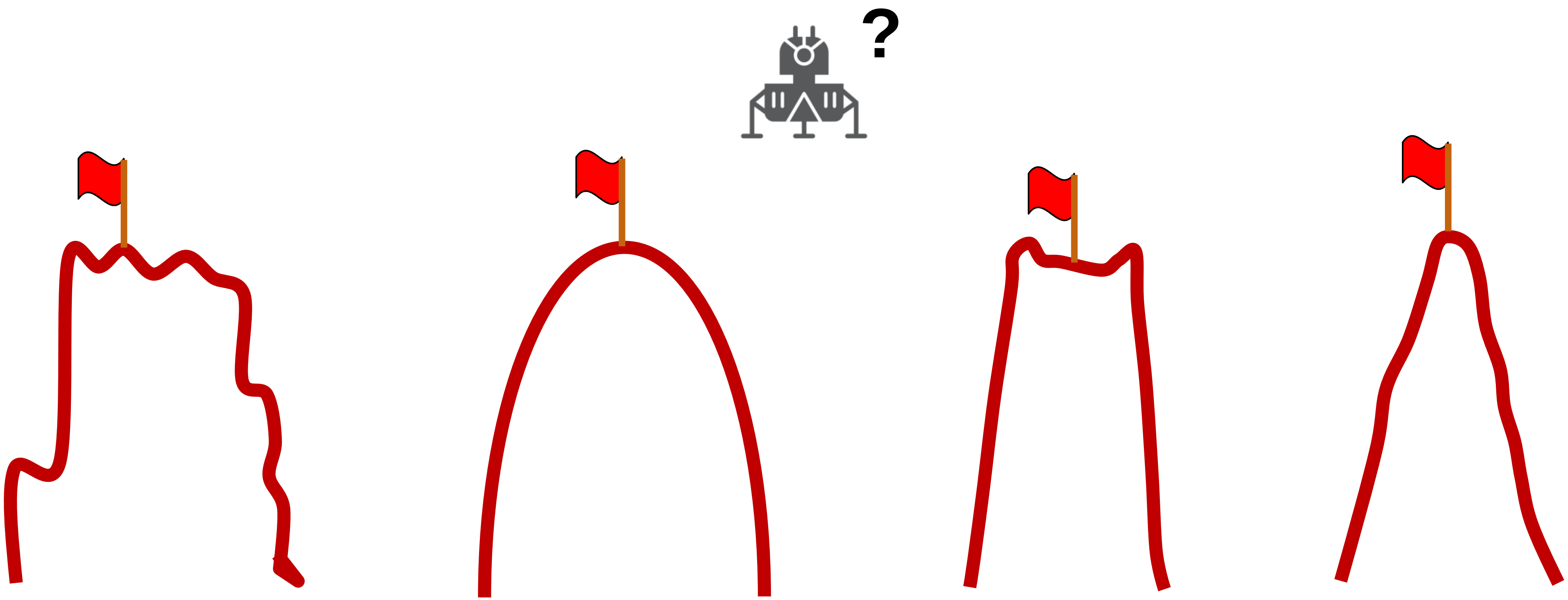
Strong effects on final electron beam position

→ vibration dampers to mitigate low-frequency vibrations

→ fast feedback to compensate high-frequency vibrations

Beam physics: Phase I

Landing in unknown territory



1 Many series of simulations to know not only the different optimum points but also the "landscape" around (NO one-shot simulations)

→ Errors/tolerances simulations 2

→ Prepare
- the tuning/correction procedures
- the measurements/diagnostics

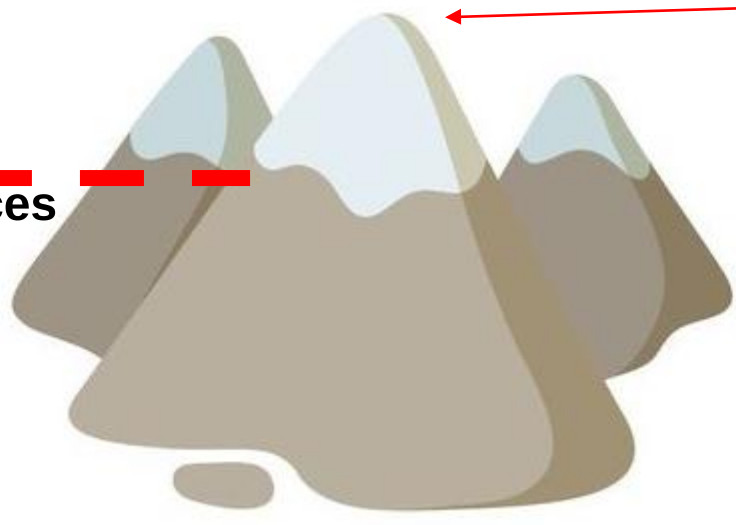
to get to the targeted point 3

Beam physics: Phase II

Unreachable

Limit due to out-of-tolerances

Reachable



Best
- energy
- charge
- emittance
- energy spread
- reproducibility
- reliability
- efficiency
- …..

The objective is to understand
- the unreachable/reachable limit
- how to move from a position to another one
- how to get to a given position day after day

→ As many series of experiments/simulations as necessary to make experiment/simulation as close as possible

Real machine   Numerical avatar

Landing in known territory

(NO one-shot experiments)
(NO one-shot simulations)

Beam physics

Two phases

PHASE I : Simulations … and components ⟸ **Design, Preparation**

PHASE II : Experiments … and simulations ⟸ **Beam commisioning, operation**

Beam physics → Mastering all the beam parameters

PHASE I

1. Optimizations in view of obtaining the desired beam parameters
2. Explore the 'landscape' of the 6D phase space
3. Determine the needed components and their tolerances
4. Determine the needed beam measurements and their résolutions

PHASE II

5. Workout the beam commissioning scenario
6. Implement the beam commissioning
7. Determine routine operating points
8. Set up the theoretical model of the real machine

An LPInj for AWAKE 2 (1)

1. Optimizations in view of obtaining the desired beam parameters
2. Explore the 'landscape' of the 6D phase space

} 1 year

- Assess the beam features to be obtained at the injection point of AWAKE.
-Estimate the most appropriate configuration(s) for LPInj, including the plasma structure, the electron injection procedure, the acceleration regime, the general shape of the transfer line.
- Launch massive simulations/optimizations of the electron injection and acceleration within the plasma in order to obtain the desired beam features at the plasma exit.
- Study the plasma structure and the magnetic structure capable of extracting then capturing the electron beam with minimum beam deterioration.
- Study, simulate and optimize the rest of the transfer line, so that the beam delivered at the injection point of AWAKE meets the requirements.

The outputs of this phase are:
- The requirements for the laser system: power, energy, w_0, a_0, and pulse duration.
- The requirements for the plasma structure: density and longitudinal density profile.
- The requirements for the transfer lines: strength, length and position of its magnetic elements.

An LPInj for AWAKE 2 (2)

At the end of the first year, rough idea:
- size
- cost
- feasibility
- …

➡ General assessment CERN, IRFU-DACM, CNRS-LPGP to decide on to continue or not the project

An LPInj for AWAKE 2 (3)

If decision to go on:

3. Determine the needed components and their tolerances
4. Determine the needed beam measurements and their résolutions

} 1 year

- Simulate and estimate tolerance to errors, highlighting the critical elements to which particular care should be devoted during the fabrication and implementation.
- Estimate and describe the tuning procedures and the corresponding measurements that should be planned for commissioning and routine operation.

The outputs of this phase are:
- Tolerances for all the laser, plasma, and transfer line parameters whose nominal values were defined in Phase 1.
- The needs in terms of photon and electron measurement types (beam position, size, profiles, etc.) at dedicated positions of LPInj (these measurements remain to be properly designed by experts in diagnostics).

An LPInj for AWAKE 2 (4)

<u>These two first years</u> can be performed by

DACM-IRFU: Damien MINENNA + hopefully 1 post-doc
assisted by P.A.P. Nghiem & A. Chancé

CNRS-LPGP: Brigitte Cros + 1 permanent researcher being recruited

Total CPU needed: 5 Mhours

For the following phases (5, 6, 7, 8)
we are interested to implement
or at least to participate