Compact Beam Line for Laser-Plasma Electron Characterization

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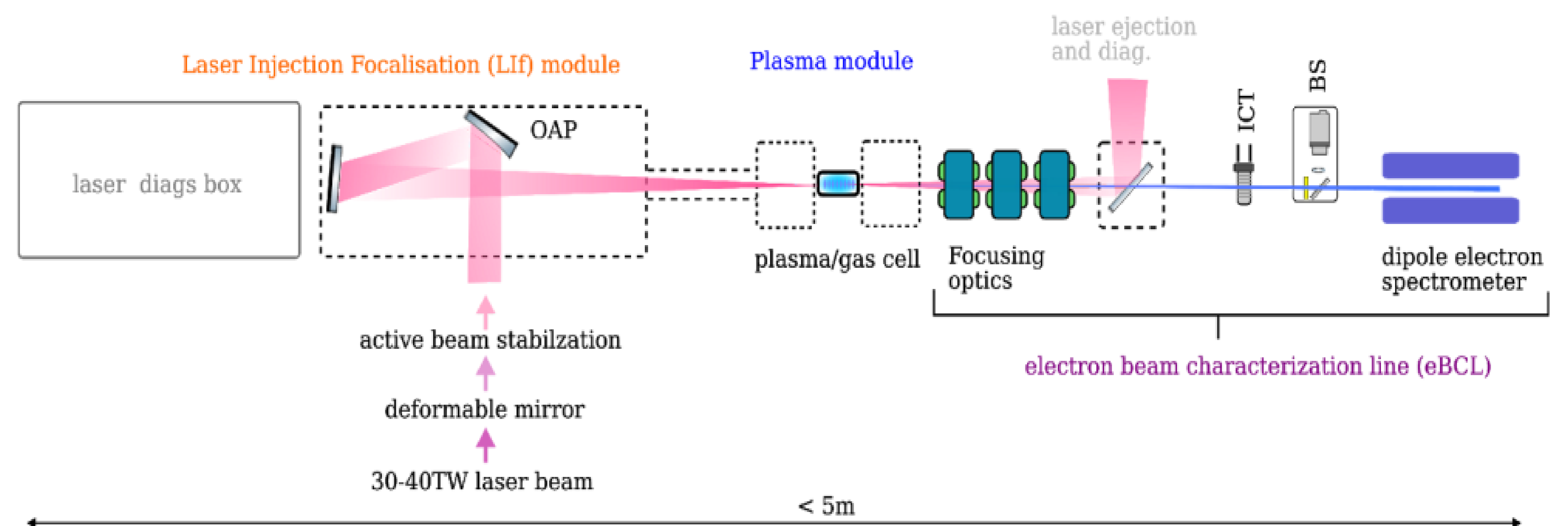
PALLAS : Advanced Parameter Control of a LPA Injector

The quest of laser plasma accelerators is of great interest for various applications such as light sources or high energy physics colliders. This research has led to numerous performance improvements, particularly in terms of beam energy versus compactness and ultra-short bunch length.

However, these performances are often reached without the achievement of sufficient **beam quality, stability** and **reproducibility**. These are the objectives of PALLAS [1], a test facility at IJCLab, that aims to advance laser-plasma from acceleration to accelerators and reduce its gap to the standards set by RF acceleration.

Main Axes of Reasearch

- Advanced Laser Control
- Plasma Target [2-3]
- Electron Capture and Characterization Beamline

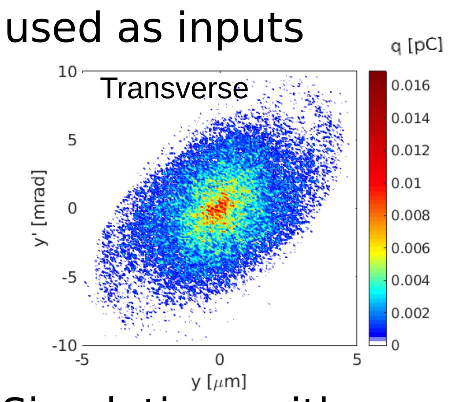


Electron Beam Target Parameters

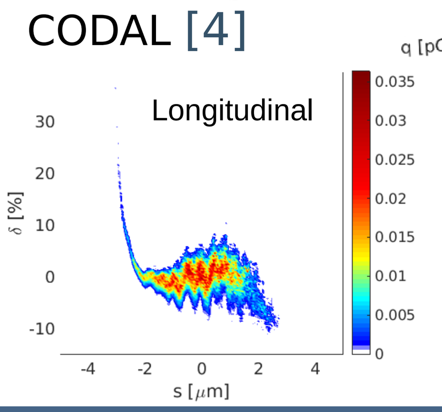
Parameter	Value
Nominal Energy E	200 MeV
Charge Q	30 pC
Repetition Rate f	10 Hz
Normalized Energy Spread (FWHM)	< 5 %
Normalized Transverse Emittance $\epsilon_{T,n}$	< 1 mm.mrad
Divergence σ_T	< 1mrad

LWFA Beam Manipulation Difficulties

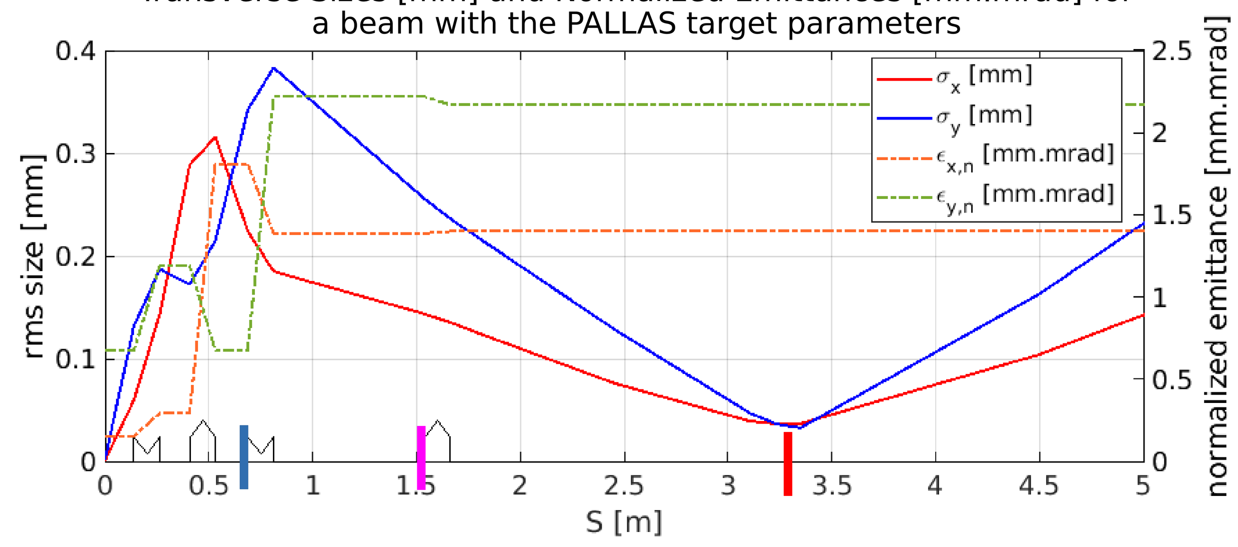
→ LWFA Simulations results [2-3] from Smeili used as inputs



→ Tracking Simulations with CODAL [4]



Transverse Sizes [mm] and Normalized Emittances [mm.mrad] for a beam with the PALLAS target parameters

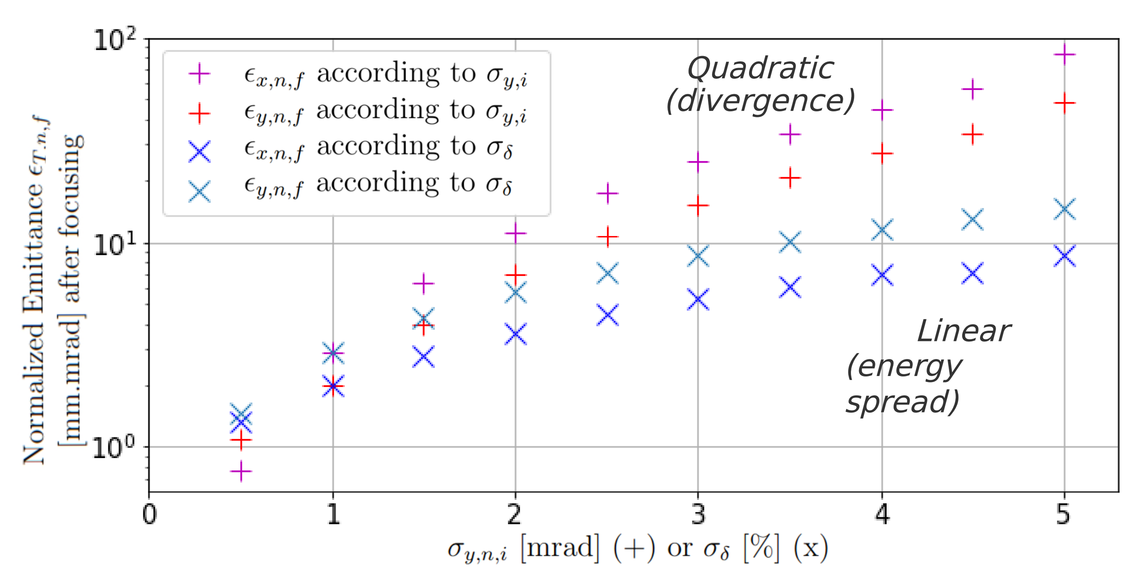


→ Emittance growth due to off-momentum particle amplified by off-axis position in the quadrupoles

→ Handling of the horizontal and vertical asymmetry induced by the ionization injection and the S linear polarization of the laser

→ Flexiblility of the focal point position to match the diagnostics needs

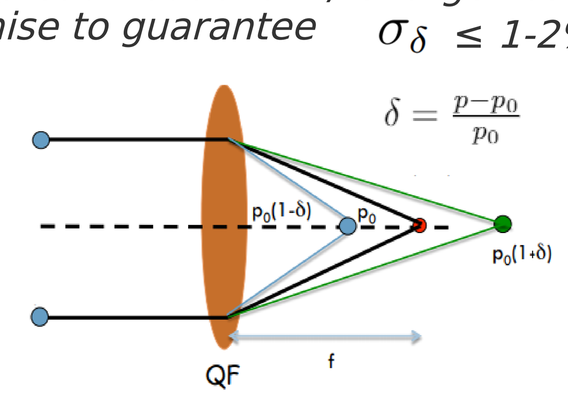
Evolution of the Normalized Emittance [mm.mrad] after the focusing as a function of either the y Initial Divergence [mrad] (+) or the Normalized Energy Spread [%] (x)



→ PALLAS source target parameters: ≤ 1 mrad divergence and a few % of energy spread

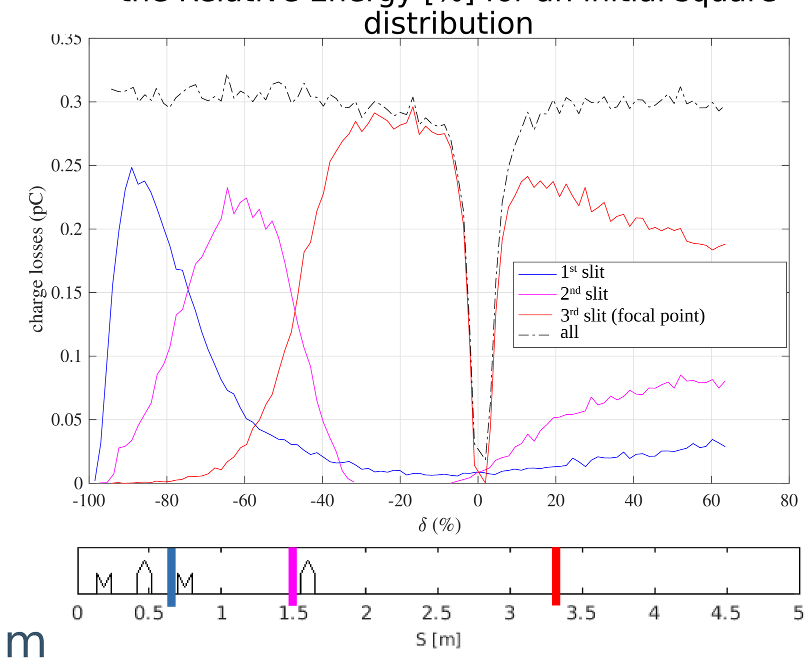
Energy Spread Reduction

Energy Spread Reduction / Charge Losses compromise to guarantee $\sigma_\delta \leq$ 1-2%



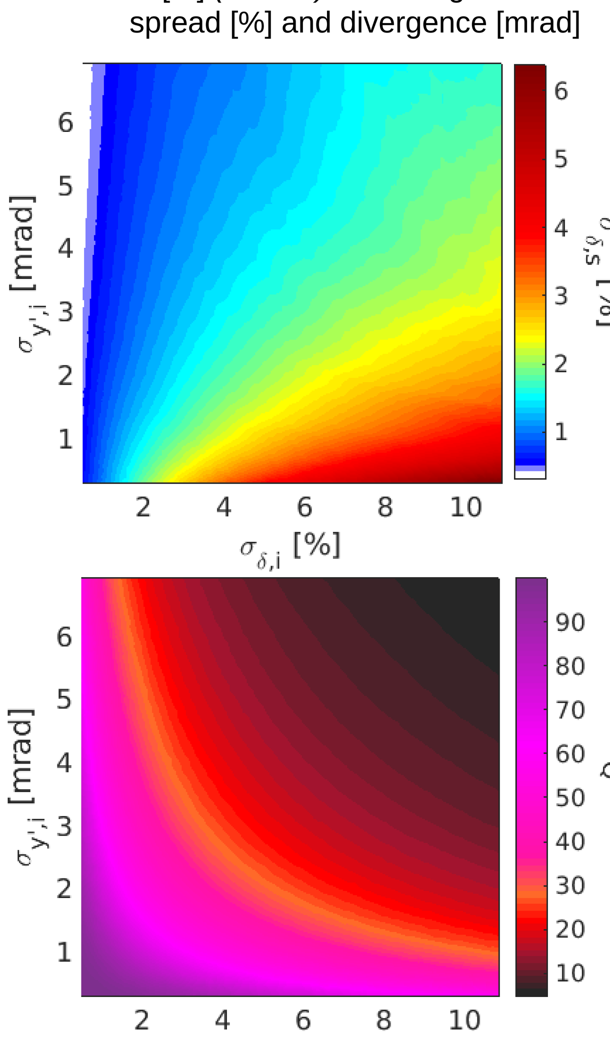
→ Energy discrimination according to the transverse positions even without a dispersive section

Charge Losses [pC] for Several Slits according to the Relative Energy [%] for an initial square distribution



- Source Parameters Influence on Output Beam

Simulated selected energy spread [%] *(top)* and charge transmission [%] *(bottom)* according to the initial energy spread [%] and divergence [mrad]



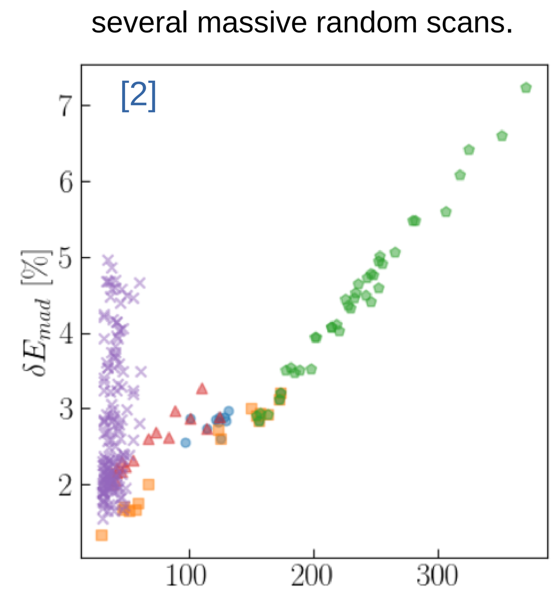
→ Energy spectrum dominated by the initial energy spread

→ Charge transmission dominated by both initial divergence and energy spread

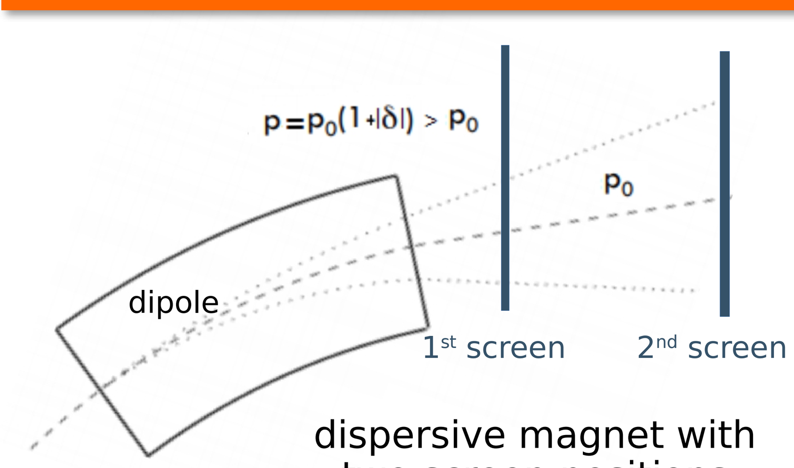
→ Low charge transmission can be associated with higher initial charge

The LWFA process is the source of correlations, including between the charge, energy spread and divergence

Energy spread [%] as function of the injected charge Q [pC] at the source. Selected simulation results obtained from several massive random scans.

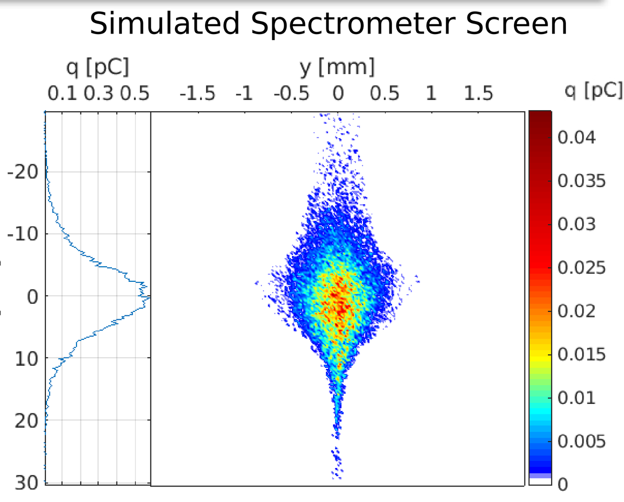


Energy Characterization



dispersive magnet with two screen positions

Simulated Spectrometer Screen

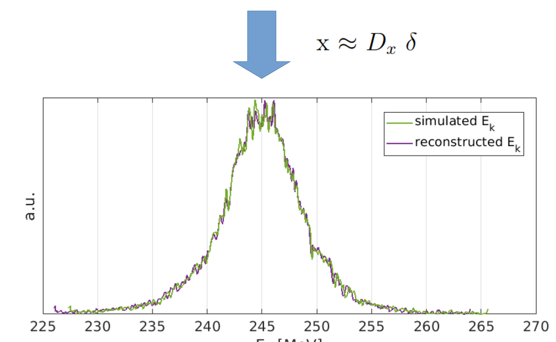


→ 1st screen: larger range

(40%: 160–240 Mev for 200MeV)

Or

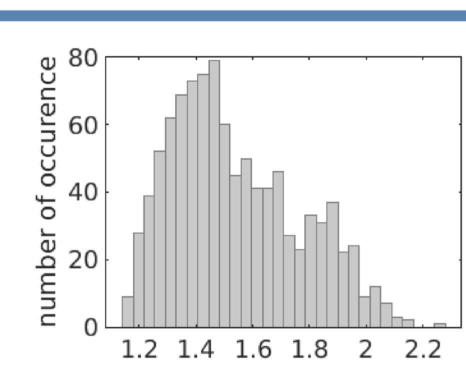
→ 2nd screen: smaller resolution



dipole of $\rho = 1.15m$ and $\theta = 17°$; screen of $60mm$ with 50x50 μm pixels; $L_{d-s} = 115cm$

- Shot-to-Shot Variation Studies

pointing angle [few mrad], divergence [few mrad], energy spread [few %], nominal energy [few MeV] ...



Example of normalized relative energy spreads [%] of the selected bunch for some uniformly random shot-to-shot variations

[1] https://pallas.ijclab.in2p3.fr/
[2] P.Drobniak, et al. Random scan optimization of a laser-plasma electron injector based on fast particle-in-cell simulations. *Phys. Rev. Accel. Beams*
[3] G.Kane, et al. Surrogate model for laser-plasma injector development. *Poster ID: 344 (Wednesday).*
[4] C.Guyot, et al. Benchmarking for CODAL beam dynamics code: laser-plasma accelerator case study. *IPAC'23 proceeding.*