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ML Feedback for HI Jena Laser plasma accelerators

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High Energy Lasers

JETi200

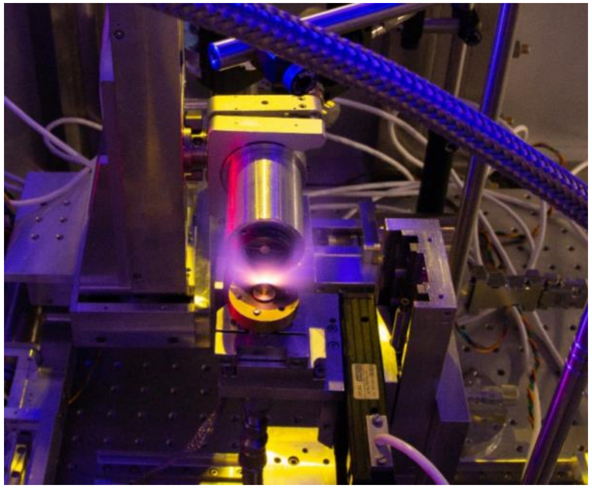
Wavelength: 800 nm
Medium: Ti:Sapphire
Energy on target: up to 5 J (4 J typical)
Pulse duration: 17 fs (20 fs typical)
Peak power: 300 TW
Repetition rate: 5 Hz
Probe beam: 5 fs

POLARIS

Wavelength: 1030 nm
Medium: Yb:CaF2, Yb:Glass
Energy on target: up to 20 J (Comp. limited)
Energy uncompressed: 54 J
Pulse duration: >90 fs
Peak power: >200 TW
Repetition rate: 1/40 Hz

Optimizing LWFA

Laserparameters for optimization
- Energy
- Focussing (shape, position)
- pulse duration (chirp)
- temporal intensity contrast



Experimentalparameters for optimization
- target gas
- target length
- focus position

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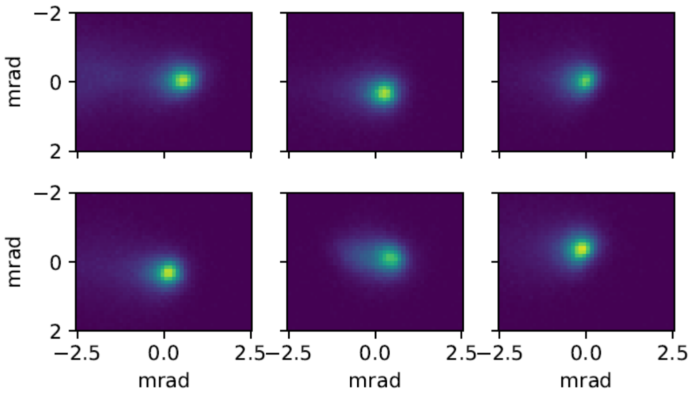
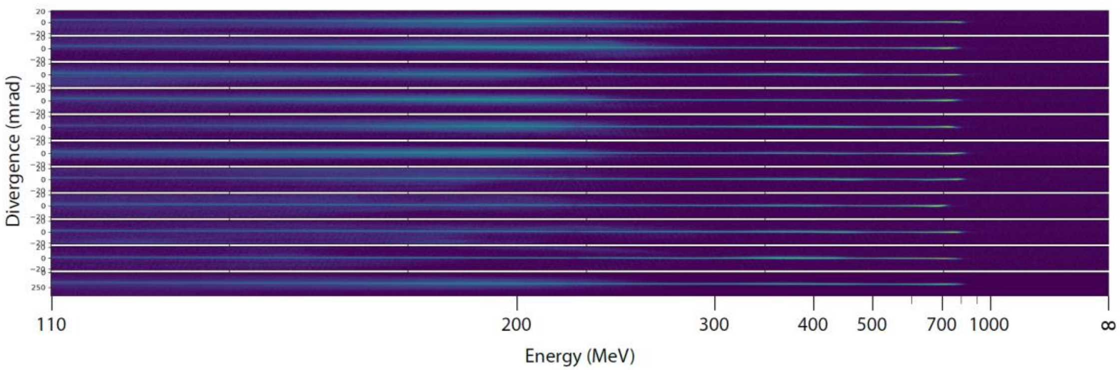
GeV electron bunches

Electron bunch profile



Electron bunch spectrum



pointing fluctuations on same order as divergence

GeV beams with ultra low beam divergence < 0.5 $mrad^2$

Optimization parameter

- peak energy
- bandwidth
- charge
- pointing

Diagnostic ready anyway ;)

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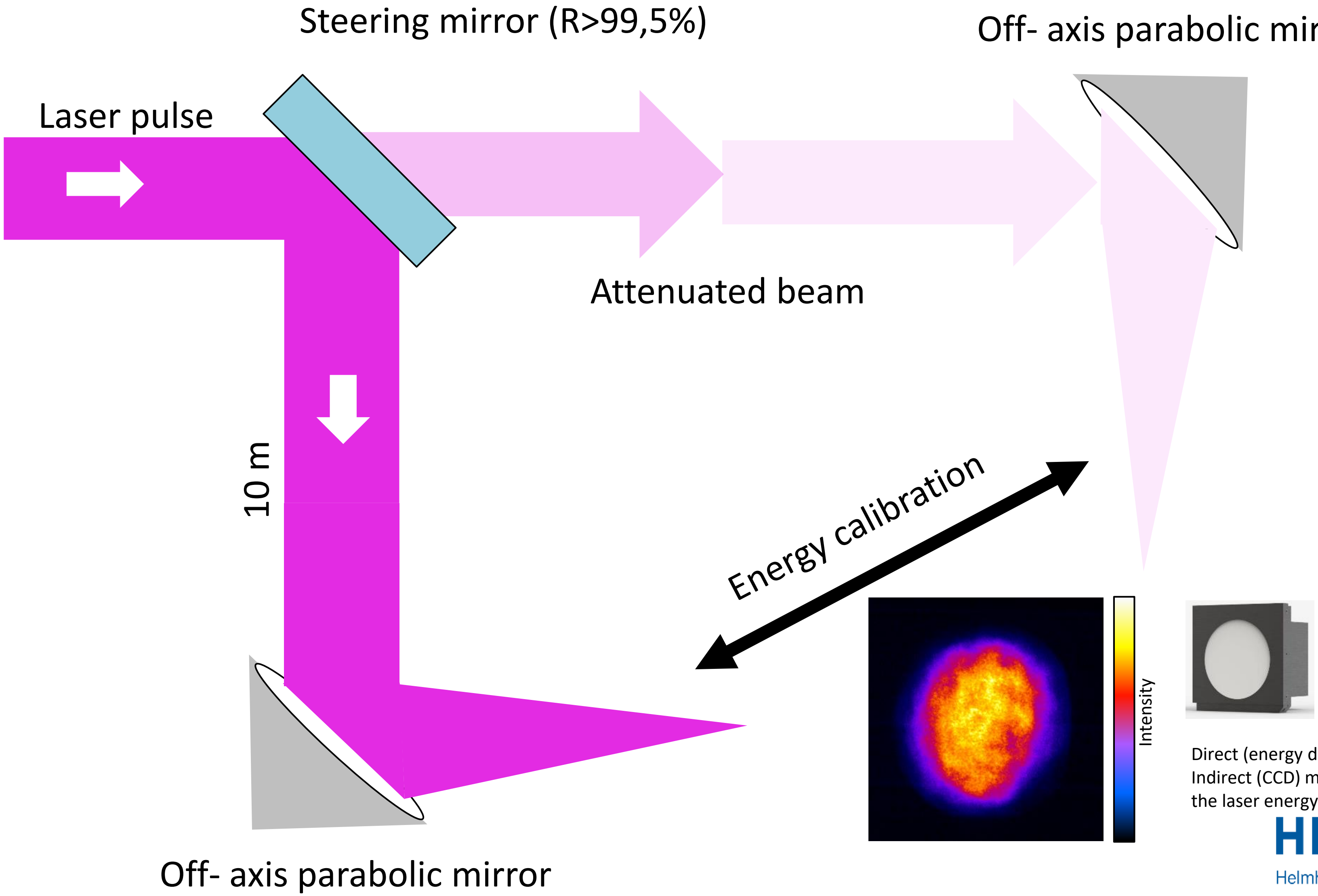
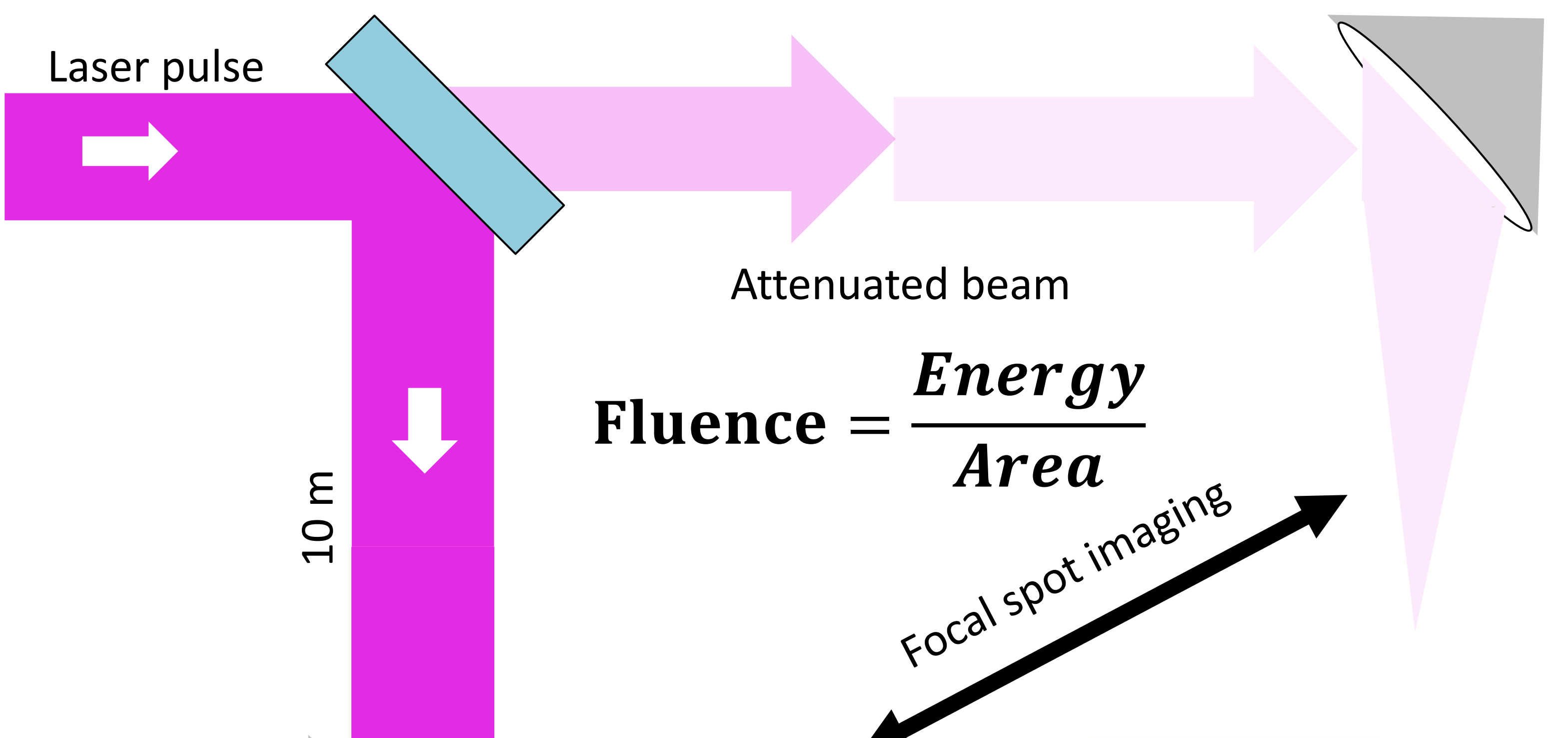
Pulse characterization @ full power

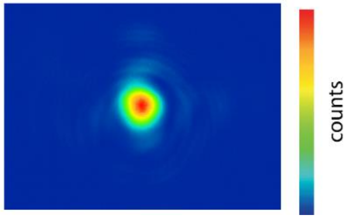


Direct (energy detector) or Indirect (CCD) measurement of the laser energy.

Pulse characterization @ full power



$$\mathbf{Fluence} = \frac{\boldsymbol{Energy}}{\boldsymbol{Area}}$$



Online evaluation of the focal spot (area, position energy content) .

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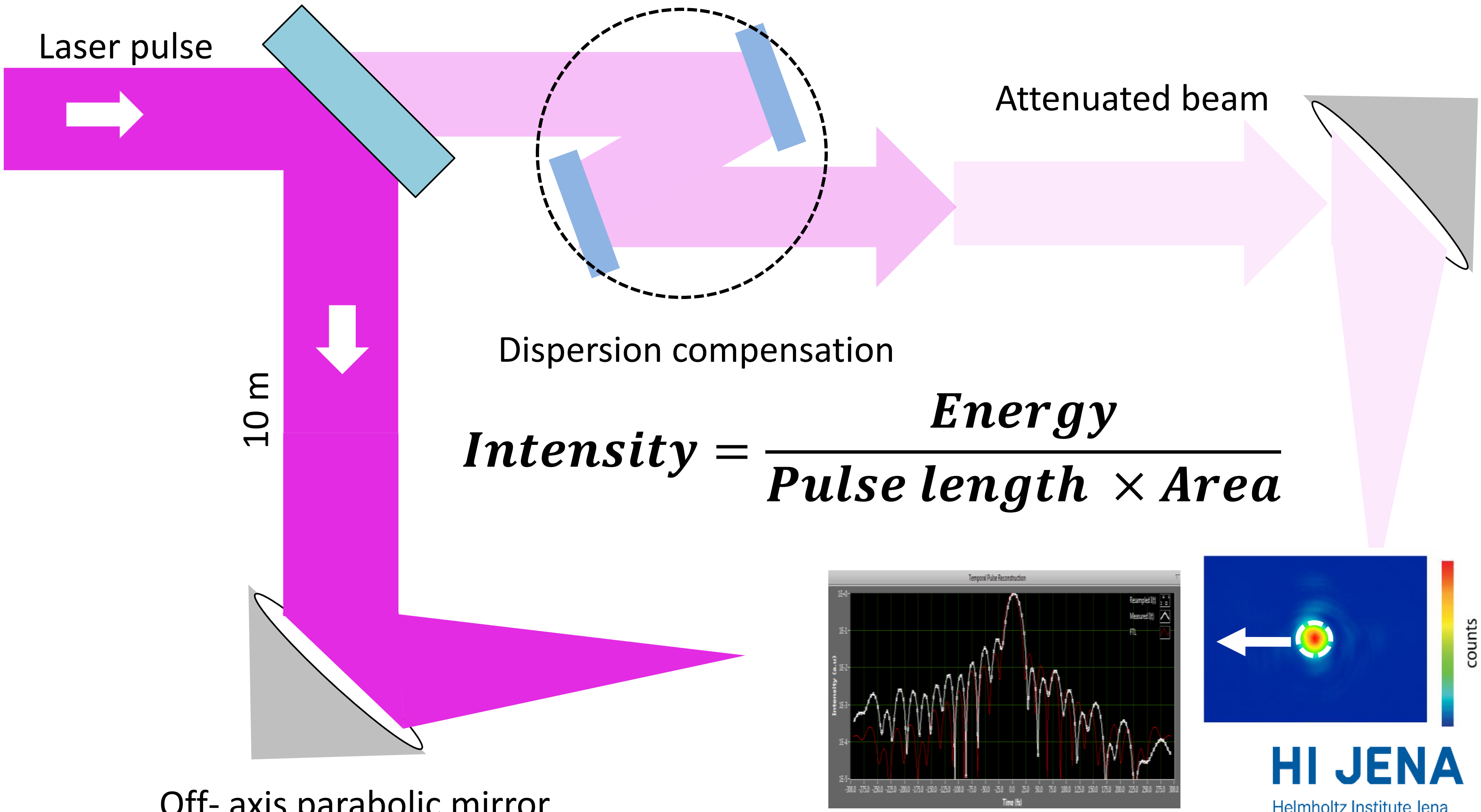
Pulse characterization @ full power



$$\boldsymbol{Intensity} = \frac{\boldsymbol{Energy}}{\boldsymbol{Pulse\ length} \times \boldsymbol{Area}}$$

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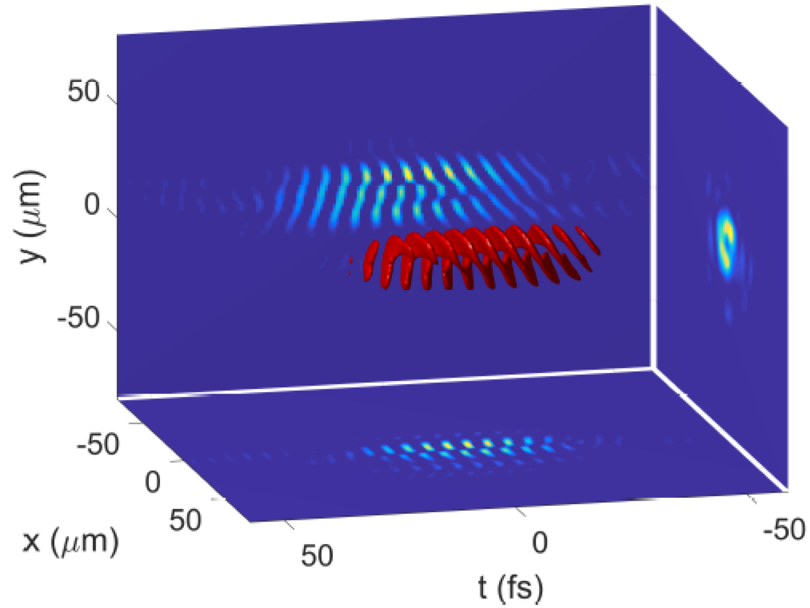
Full recontruction of the focal spot intensity

A. Borot & F. Quéré, Opt.Express 26 26444 (2018)

Using INSIGHT technique to gather full information about the focal spot.



Measured/retrieved spatio-temporal E-Field

Input for simulations.

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Model development

PHYSICAL REVIEW LETTERS **126,** 174801 (2021)

Optimal Beam Loading in a Laser-Plasma Accelerator

Manuel Kirchen,[1,*] Sören Jalas,[1] Philipp Messner,[2,1] Paul Winkler,[3,1] Timo Eichner,[1] Lars Hübner,[3,1] Thomas Hülsenbusch,[3,1] Laurids Jeppe,[1] Trupen Parikh,[3] Matthias Schnepp,[1] and Andreas R. Maier[3,1]
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Applications of laser-plasma accelerators demand low energy spread beams and high-efficiency operation. Achieving both requires flattening the accelerating fields by controlled beam loading of the plasma wave. Here, we optimize the generation of an electron bunch via localized ionization injection, such that the combination of injected current profile and averaged acceleration dynamics results in optimal beam loading conditions. This enables the reproducible production of 1.2% rms energy spread bunches with 282 MeV and 44 pC at an estimated energy-transfer efficiency of ~19%. We correlate shot-to-shot variations to reveal the phase space dynamics and train a neural network that predicts the beam quality as a function of the drive laser.

PHYSICAL REVIEW LETTERS **126,** 104801 (2021)

Bayesian Optimization of a Laser-Plasma Accelerator

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Generating high-quality laser-plasma accelerated electron beams requires carefully balancing a plethora of physical effects and is therefore challenging—both conceptually and in experiments. Here, we use Bayesian optimization of key laser and plasma parameters to flatten the longitudinal phase space of an ionization-injected electron bunch via optimal beam loading. We first study the concept with particle-in-cell simulations and then demonstrate it in experiments. Starting from an arbitrary set point, the plasma accelerator autonomously tunes the beam energy spread to the subpercent level at 254 MeV and 4.7 pC/MeV spectral density. Finally, we study a robust regime, which improves the stability of the laser-plasma accelerator and delivers sub-five-percent rms energy spread beams for 90% of all shots.

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standing on shoulder of giants ;)

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