Energy Spectrometer Studies for Proton-Driven Plasma Acceleration

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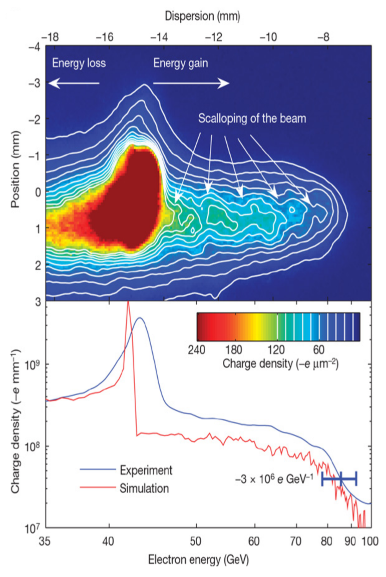
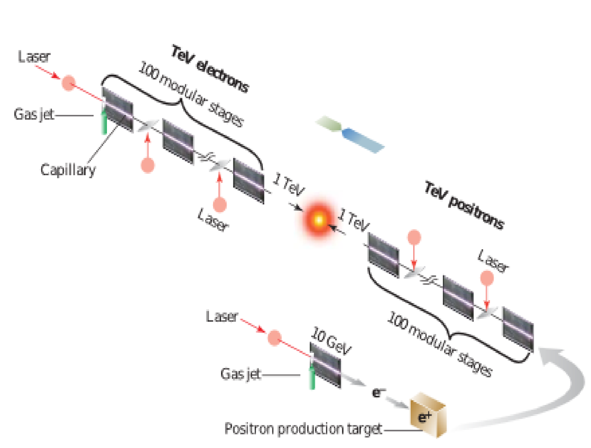
Physics Motivation



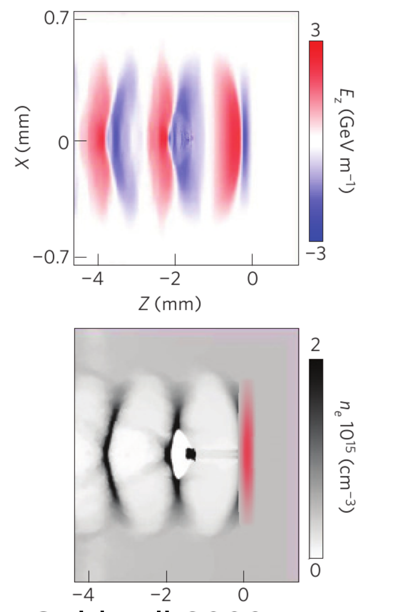
Blumenfeld 2007,
doi: 10.1038/nature05538

- To complement the LHC, a next generation Lepton collider with TeV energy is required.
- Plasmas can sustain very high fields and could yield acceleration gradients of several 100GeV/m.
- At SLAC, the energy of 42GeV electrons has been doubled in a 85cm plasma cell (see left).



Leemans 2009,
doi: 10.1063/1.3099645

BUT:
- The energy stored in a Laser / electron beam is not very high.
- This directly determines the maximum possible energy gain per cell.
- Therefore, staging of many cells is necessary to acquire TeV energies (see left).
- This makes the setup and operation very complex.



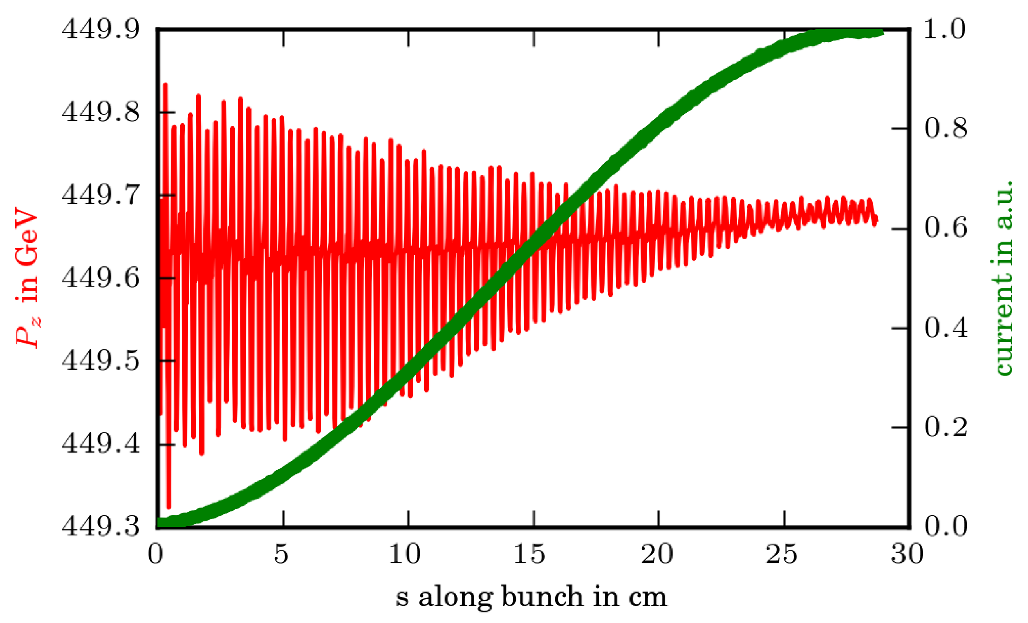
Caldwell 2009,
doi:10.1038/nphys1248

- Protons, on the other hand, can be accelerated to very high energies using Synchrotrons.
- A plasma could transfer this energy to a witness bunch.
- This way, TeV electrons could be generated in one single, long plasma cell.
- Studies to use CERN's SPS beam have started (see left).

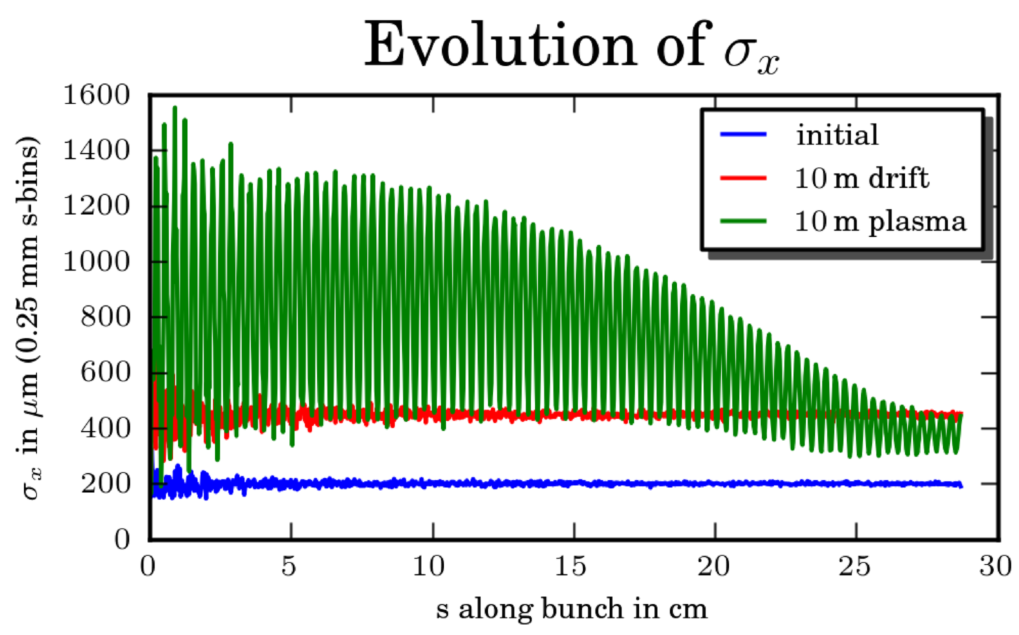
Possible Experimental Setup:

- A proton beam will be extracted from the SPS and fired into a Lithium oven.
- A co-propagating Laser will generate a plasma in the middle of the proton bunch.
- This way the plasma sees a proton bunch with a very sharp current flank (hard cut).
- The instability seeded by this flank modulates the density of the proton bunch.
- The modulated proton bunch creates plasma wakes.
- The resulting fields will be used to accelerate particles.

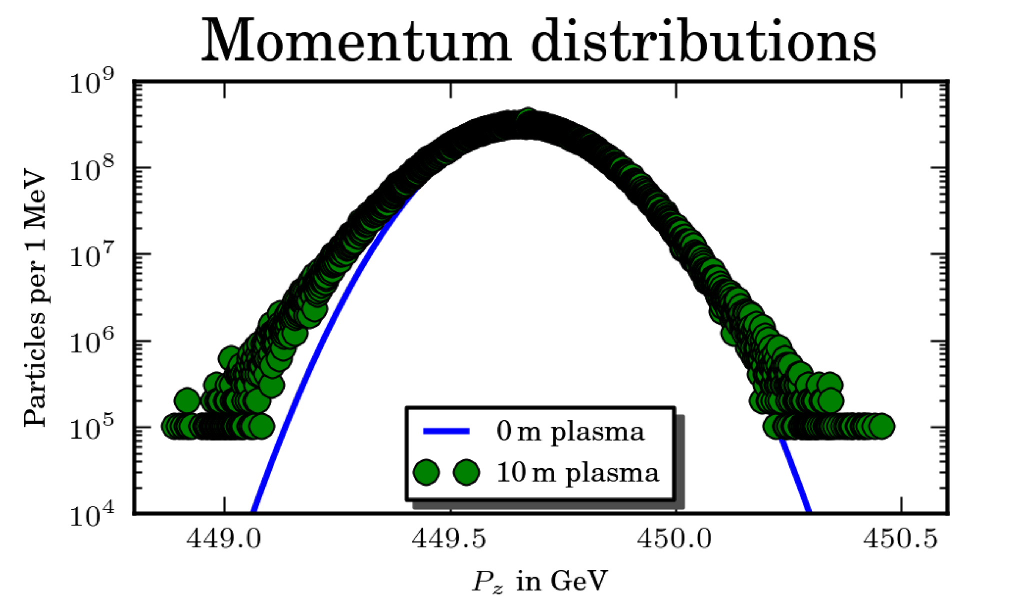
Evaluation and Spectrometer estimates based on Beam-Plasma Simulations by Konstantin Lotov, Budker Institute of Nuclear Physics, Russia



The green curve shows the so called hard cut proton beam, as described above. The red curve shows the longitudinal energy modulation of the proton bunch. The modulation is strongest at the end of the bunch (the region of lowest current).

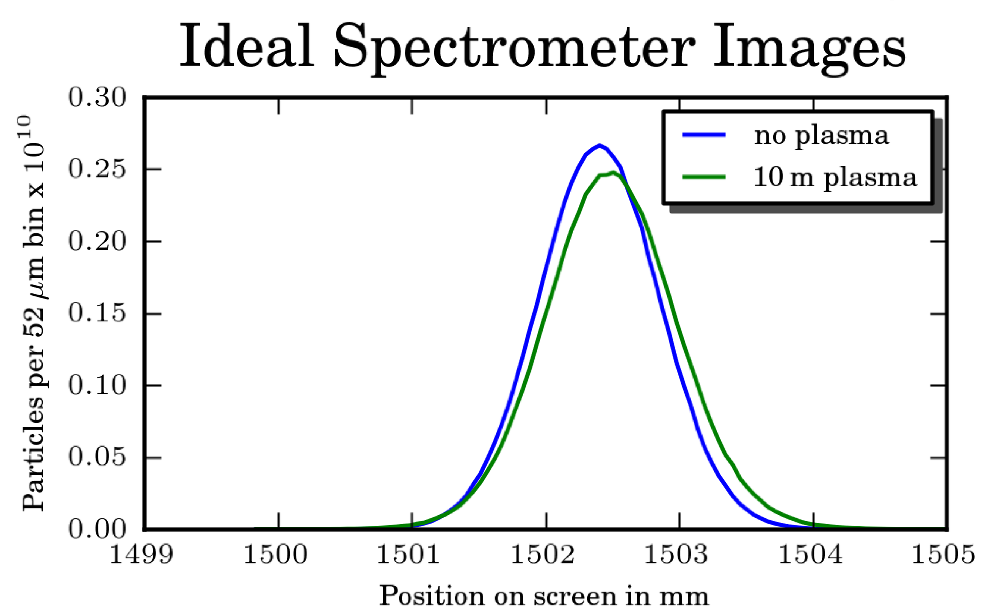


The blue curve shows the initial binned transverse beam size, in green the distribution after 10m of plasma. The beam blows up dramatically in the region of the strongest energy modulation (see left). The beam size after 10m of ballistic propagation is shown in red for comparison.

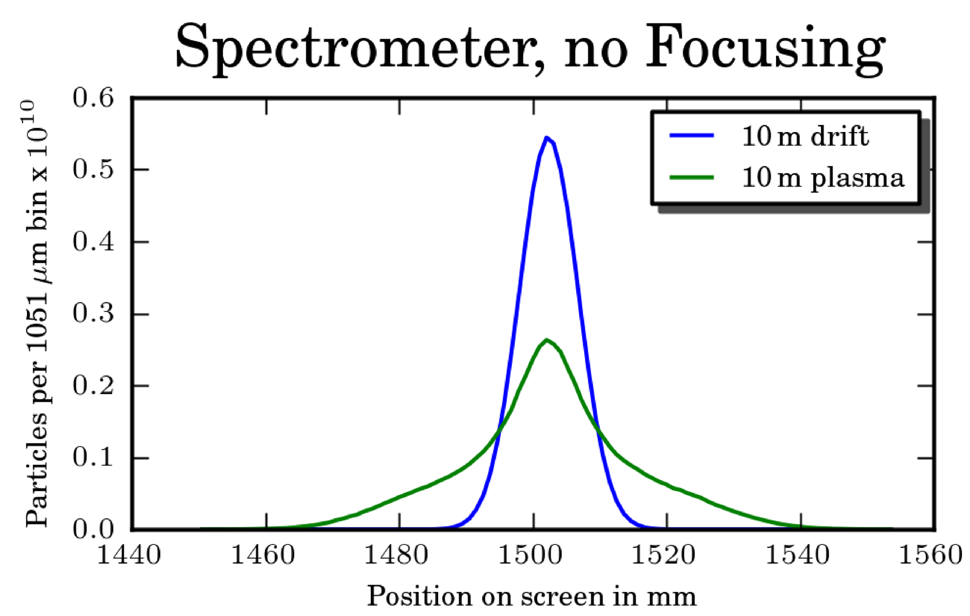


Shown is the longitudinal energy distribution before and after the plasma. The energy spread increases from ~135MeV to ~150MeV at an average energy of 450GeV. 1 macro particle corresponds to ~10^5 protons.

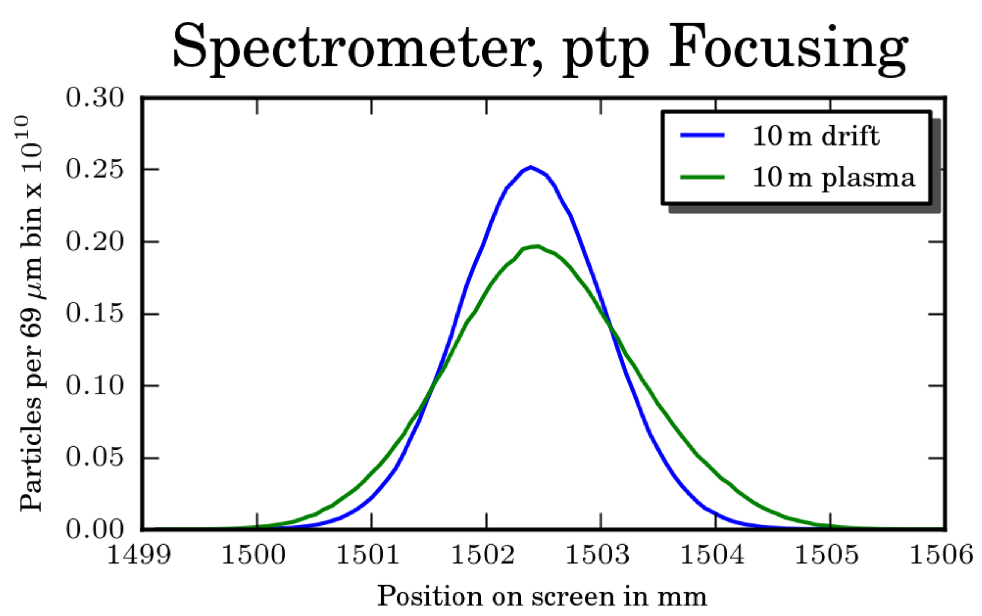
Estimation of possible Spectrometer Images for the Proton Beam (20m dipole, 1.5T, 100m drift):



The effect one would like to see. The position on the spectrometer screen is only determined by the longitudinal momentum. The particle distribution after 10m of plasma is compared to the initial distribution before the plasma.

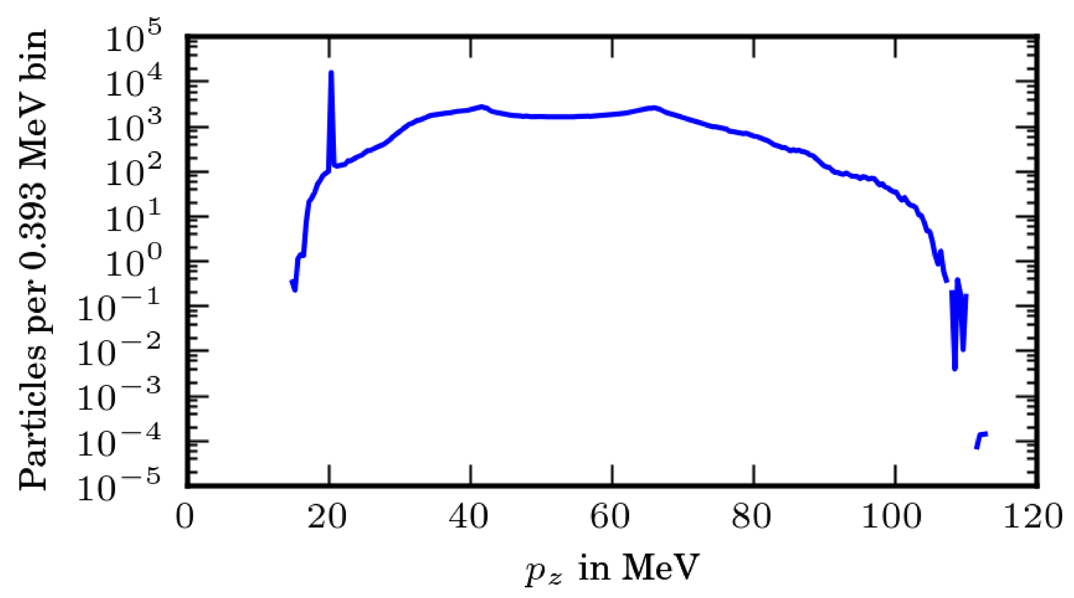


The estimated spectrum including the transverse position and momentum before the spectrometer dipole. Their effect completely overshadows the effect of the energy modulation. (See x-axis)



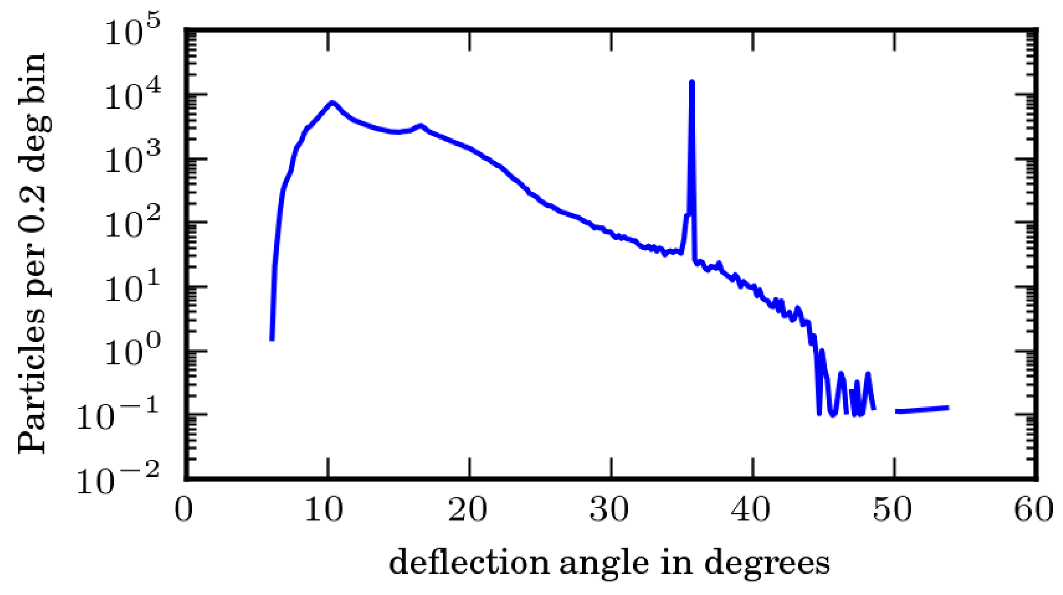
A spectrometer with point-to-point focusing can remove the dependency on the transverse momentum and improve the resolution dramatically.

Based on Beam-Plasma Simulations by Alexander Pukhov, Heinrich-Heine-University of Düsseldorf, Germany



Left:
Longitudinal energy spectrum of an injected electron beam after 7m of plasma. The bunch is much longer than the plasma wave length and therefore samples all phases of the wake, leading to a broad spectrum.

Right:
Deflection angles after a spectrometer dipole, taking the transverse momentum into account. The energy gain is easy to observe (dipole with 0.04Tm integrated field strength).



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