Design studies of the electron injector and beam transport for external injection at AWAKE Run2

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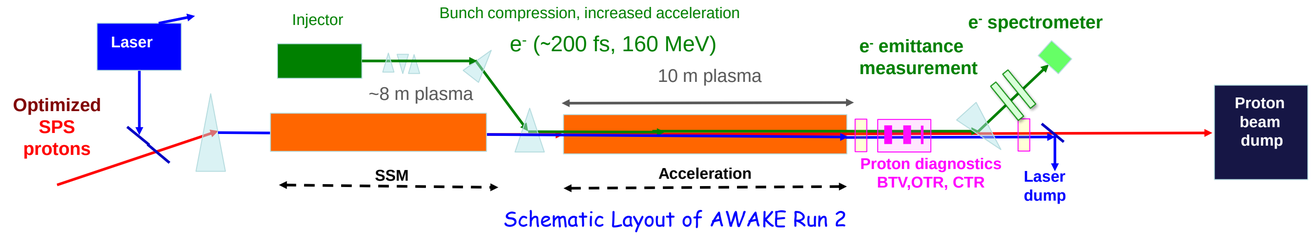
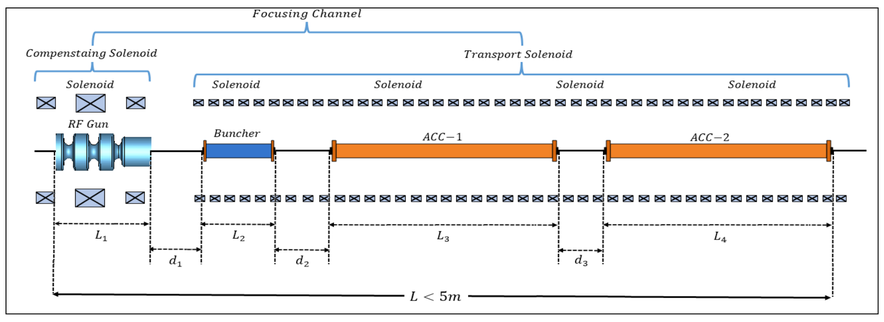
The proton driven plasma wakefield acceleration experiment AWAKE at CERN demonstrated basic electron capturing and acceleration using a rather long electron bunch spreading out over several plasma wavelengths. For the second phase of the experiment, the aim is to inject a short electron bunch with appropriate emittance and charge to achieve full capture and emittance preservation of the injected electron bunch. The correct bunch charge will load the wakefield and lower the energy spread. At the plasma entrance a bunch length of 200 fs, charge of 100 pC and transverse dimensions of 5 um are needed. The design of the injector consisting of an S-band RF-gun and X-band acceleration and velocity bunching will be presented as well as first ideas of how to transport the beam to the plasma entrance and performing the final focusing.

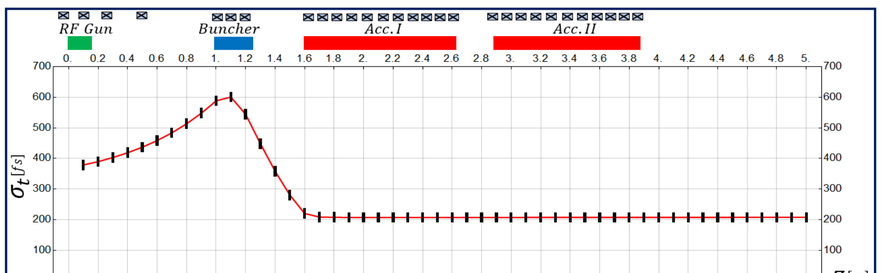


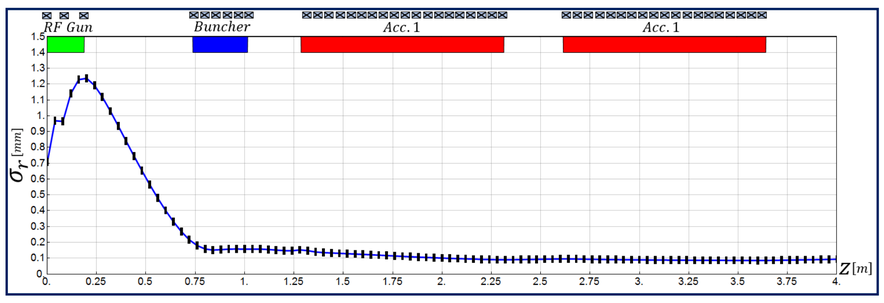
Schematic Layout of AWAKE Run 2

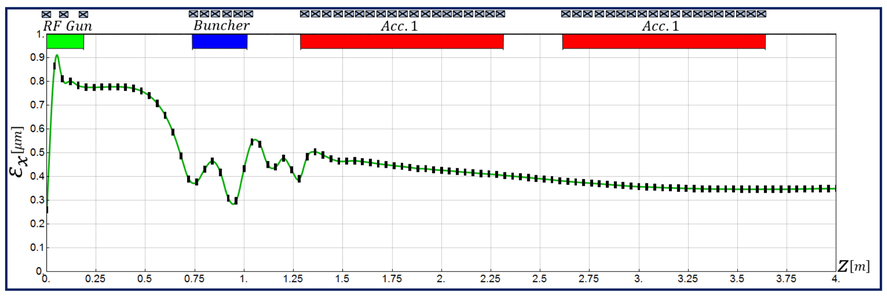
Injector

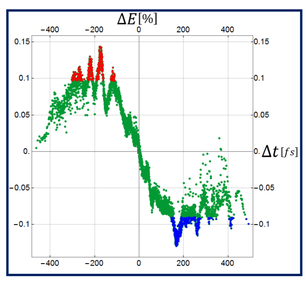
Beam Energy	Energy Spread	Energy stability	RMS Bunch Length	Bunch Charge	Emittance	Beam size plasma focus
85 – 160 MeV	0.2 %	1 x 10^{-3}	≈ 200 fs	100 pC	1 – 4 μm	~ 5 μm

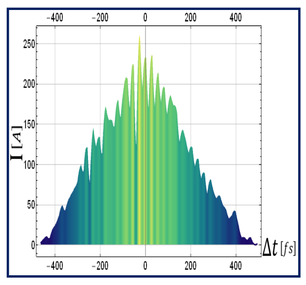






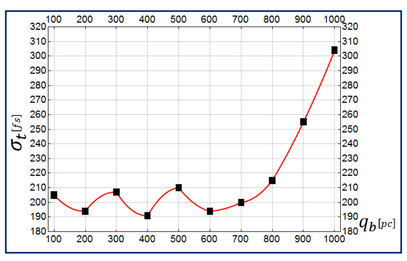


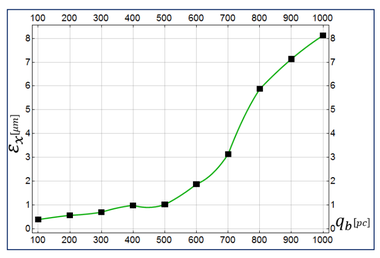


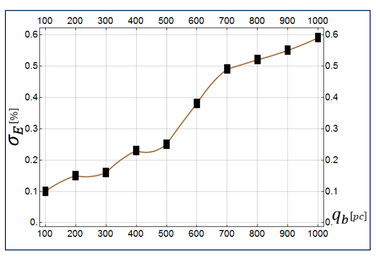


$E_k[MeV]$	$\sigma_r[mm]$	$\sigma_t[fs]$	$\varepsilon_x[\mu m]$	$\sigma_E[\%]$	$I_{av}[A]$
165	0.14	207	0.44	0.09	168

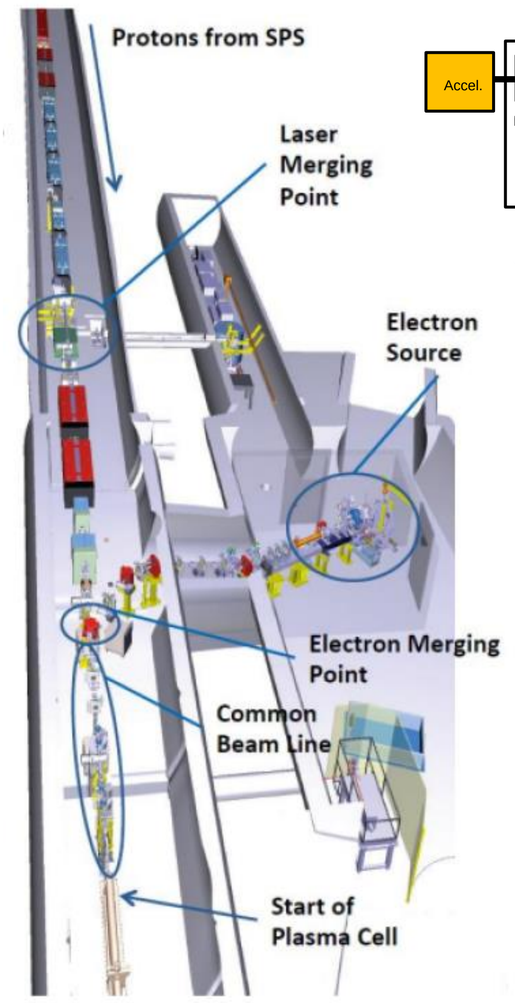
Beam dynamics simulation of the new compact injector layout using an S-band rf-gun and x-band structures for velocity bunching and acceleration. Simulations are done using ASTRA and the following parameters: Uniform distributions, laser radius 1 mm, pulse length 1 ps and a bunch charge of 100 pC. The gradient in the rf-gun is 120 MV/m and 80 MV/m for the x-band acceleration. The bunching happens with a gradient of 25 MV/m. The final optimised results can be found in the table above fulfilling the requirements of AWAKE Run 2.





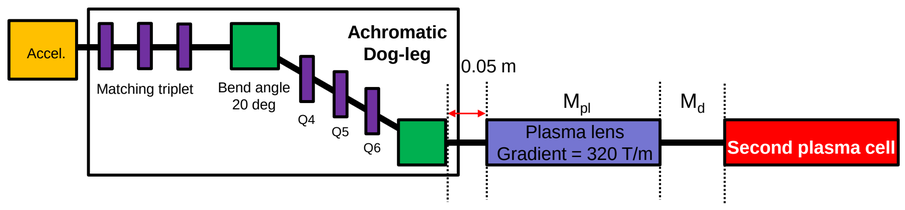


Study of important beam parameters as a function of bunch charge from 0.1 to 1 nC. One can see that the desired bunch length of 200 fs can be maintained until 700 pC at the expense of emittance and energy spread

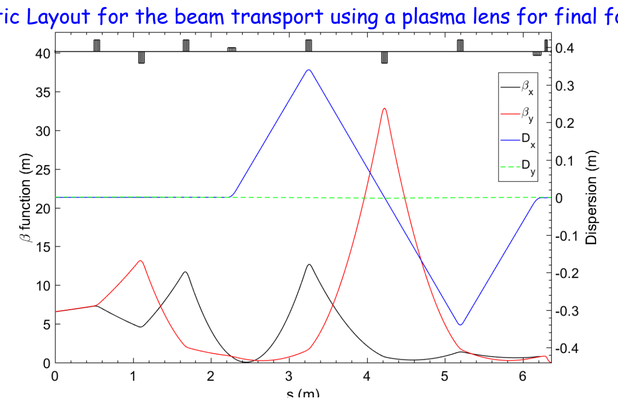


Layout of AWAKE during Run 1

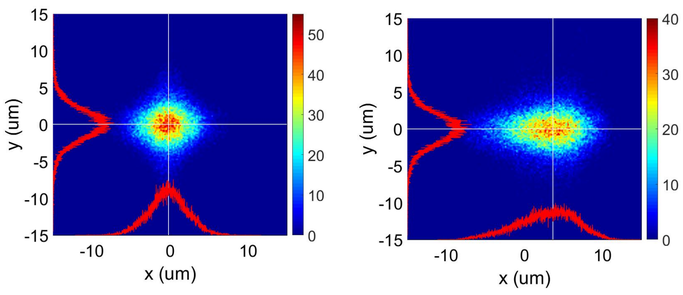
Beam transport line



Schematic Layout for the beam transport using a plasma lens for final focusing

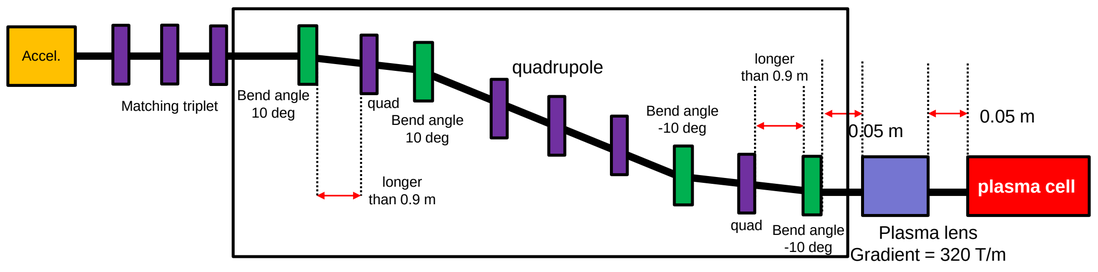


Optical functions and beam size along the beamline

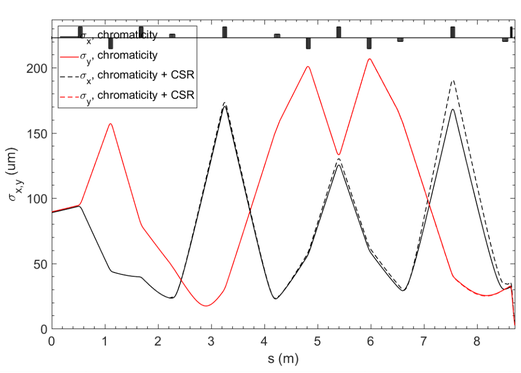


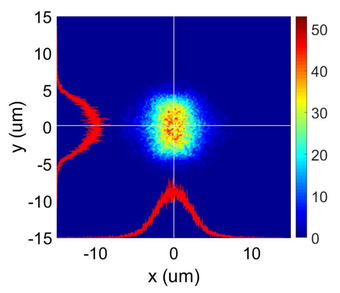
ELEGANT	σ_x (um)	σ_y (um)	ϵ_x (mm mrad)	ϵ_y (mm mrad)
Chromatic effect	2.47	2.48	0.39	0.40
Chromaticity + CSR	3.69	2.47	0.59	0.40

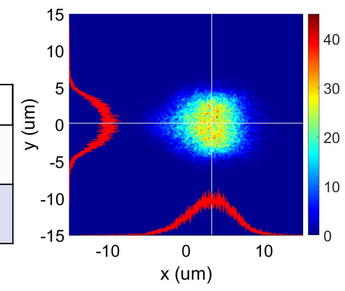
Beam spot size and distribution at the merging point taking into account energy spread and CSR



Alternative layout of the beamline using a 4 bend chicane which allows the compensation of CSR effects







ELEGANT	σ_x (um)	σ_y (um)	ϵ_x (mm mrad)	ϵ_y (mm mrad)
Chromatic effect	2.48	2.47	0.40	0.40
Chromaticity + CSR	3.06	2.45	0.52	0.39

Final beam size and distribution with a 4 bend chicane

Conclusion:
An electron injector scheme was studied to provide electron bunches with a length on the order of 200 fs with a charge of 100 pC and an energy of 160 MeV. It turns out that a combination of an s-band rf gun and x-band structures could be suitable for efficient adiabatic bunching and fast acceleration. Such a scheme would be attractive for AWAKE because of the short length of such an injector and the availability of x-band expertise and hardware from the CLIC program at CERN. This high quality electron bunch then needs to be transported to the plasma cell and focused to a beam size of 5 um to match the emittance preservation requirements. The space in between plasma cells need to be minimal to preserve the modulation of the driving proton beam. A scheme using a plasma lens for final focusing was investigated.