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Emittance Growth Due to

Multiple Coulomb Scattering in a Linear Collider Based on Plasma Wakefield Acceleration

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O. Mete[1,3], K. Hanahoe[1,3], G. Xia[1,3], M. Labiche[4], O. Karamyshev[2,3], Y. Wei[2,3], C. Welsch[2,3], M. Wing[5]

[1]The University of Manchester, [2]The University of Liverpool, Liverpool, UK, [3]The Cockcroft Institute, Sci-Tech Daresbury, Warrington, UK

[4]Nuclear Physics Group, STFC Daresbury Laboratory, Sci-Tech Daresbury, Warrington, UK, [5]University College London, London, UK, DESY, Hamburg, Germany

ABSTRACT Alternative acceleration technologies are currently under development for cost-effective, robust, compact and efficient solutions. One such technology is plasma wakefield acceleration, driven by either a charged particle or laser beam. However, the potential issues must be studied in detail. In this paper, the emittance growth of the witness beam through elastic scattering from gaseous media is derived. The model is compared with the numerical studies.

Beam particles can undergo elastic and inelastic scattering by the ions and electrons forming a plasma. Elastic scattering affects the particle angles and yields an emittance growth while inelastic scattering affects both particle angle and energy.

$$\Delta\epsilon_{n,x,y} = \frac{\gamma\beta_{x,y}}{2}\mathcal{N}\langle\theta^2_{x,y}\rangle$$

EMITTANCE DIFFUSION due to the elastic scattering of the witness beam from the neutral gas.

$$\mathcal{N} = c n_{gas}\sigma \qquad \langle\theta^2_{x,y}\rangle = \frac{\int_0^{\theta_{max}}\theta^2\frac{d\sigma}{d\Omega}\,d\Omega}{\int_0^{\theta_{max}}\frac{d\sigma}{d\Omega}\,d\Omega}$$

The interaction rate in the medium and the *rms* scattering angle.

$$\Delta\epsilon_{n,x,y} = \gamma\beta_{x,y} c n_{gas}\int_0^{\theta_{max}}\pi\theta^3\frac{d\sigma}{d\Omega}\,d\theta$$

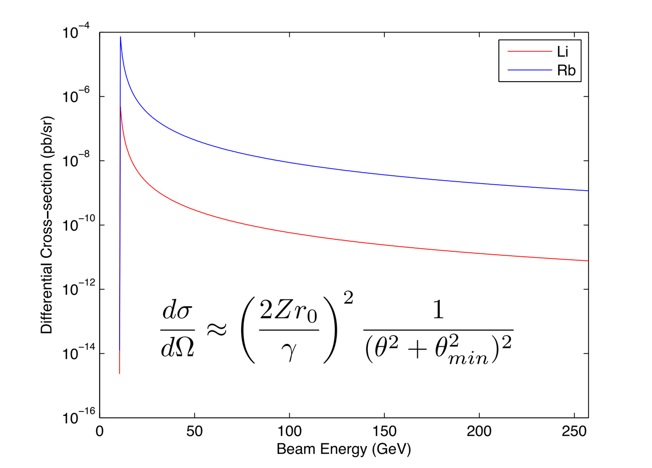
Linear energy increase during the propagation through the plasma channel. $\gamma(s) = gs + \gamma_0$

$$\Delta\epsilon_{n,x,y} = \frac{2\pi Z^2 r_0^2 c n_{gas}\beta_{x,y}}{\gamma(s)}\left(ln\left(\frac{\theta^2_{min}+\theta^2_{max}}{\theta^2_{min}}\right) - \frac{\theta^2_{max}}{\theta^2_{min}+\theta^2_{max}}\right)$$

$$\epsilon_{n,\,total} = \sqrt{\epsilon_n^2 + \Delta\epsilon^2_{n,\,scattering}}$$

Following the success of LHC's pp collisions such as the Nobel Prize winning discovery of Higgs boson, the next generation colliders for e+e− and ep collisions are vital to accomplish the tripodal scheme of discovery, precision measurements and QCD studies. Generally each successor collider should push the limits of the energy frontier further.

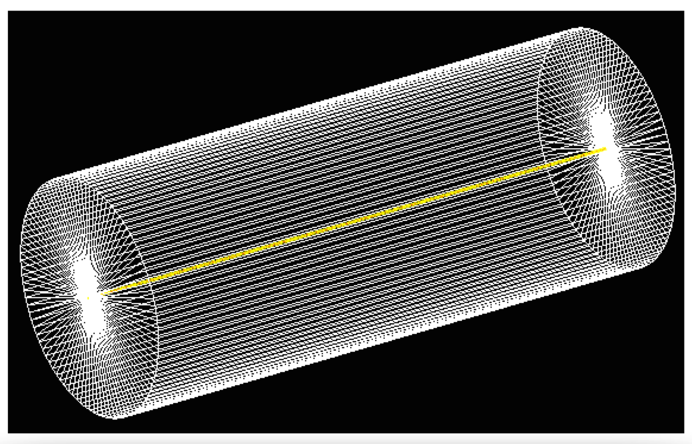
Coulomb scattering cross-section.



The concept of plasma wakefield acceleration (PWA) introduced a new technological era in high energy collider design, also proposing to employ existing infrastructure [1]. Towards the realisation of a PWA scheme, the advantages and the issues must be explored.

This study is focused on the interaction of the particles to be accelerated with the surrounding media consisting of plasma and gas. In this scope, as a first step, the growth in the emittance due to Coulomb scattering by gaseous media was studied and presented.

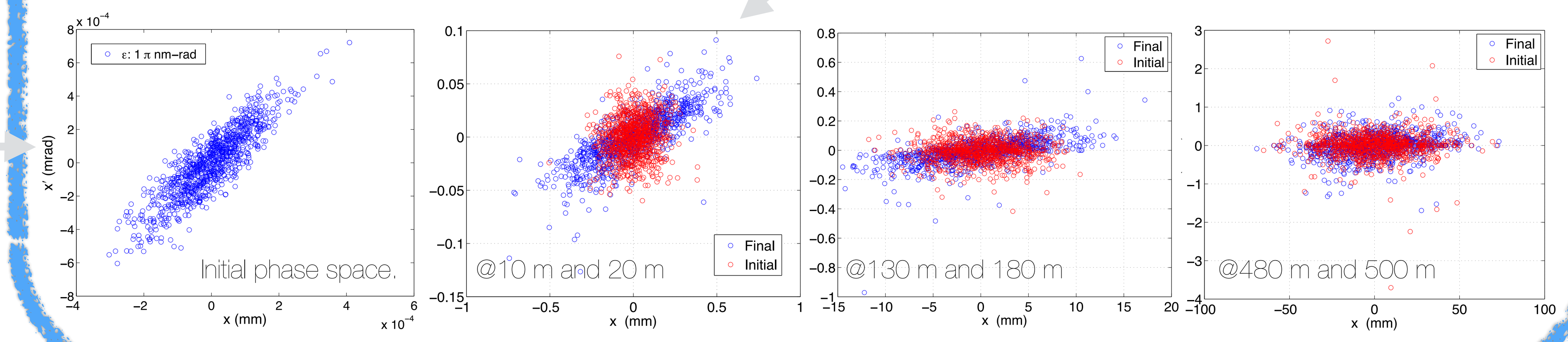
TRACKING PARTICLES THROUGH THE PLASMA AND CONSTRUCTING THE PHASE SPACE In PWA, plasma is produced by ionisation of a channel through a chamber filled with a given gas with a radius given by the ionisation laser specifications [3]. Therefore particles travelling through the centre of the chamber may interact with the plasma ions and electrons as well as the surrounding neutral gas when they are scattered out of the plasma channel.

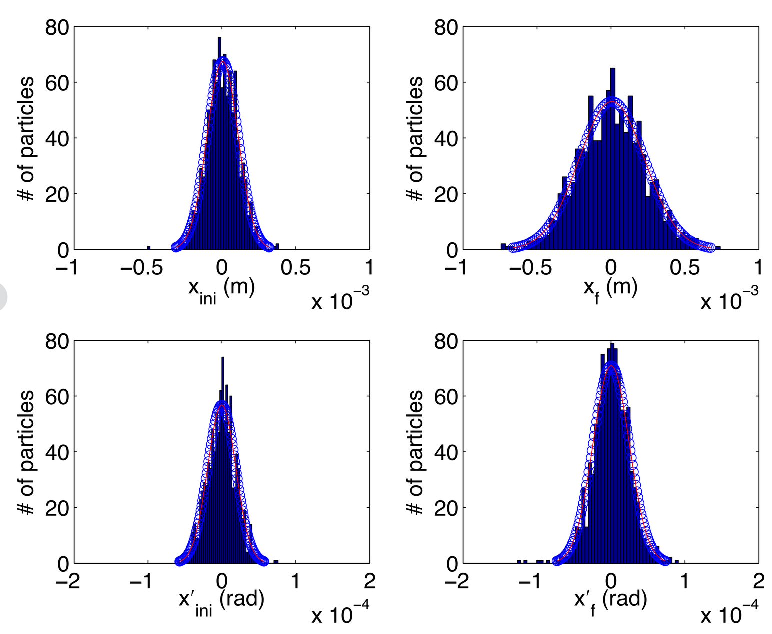


A GEANT4 [4, 5] model was produced to study the interaction of the beam particles with plasma and gaseous medium as in the example case.

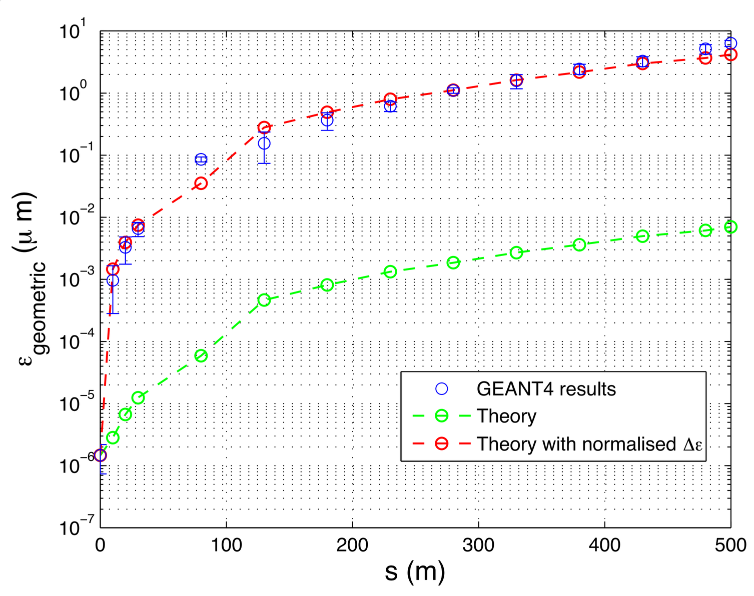
$$\epsilon = \sqrt{\langle x^2\rangle\langle x'^2\rangle - \langle xx'\rangle^2}$$

- ☑ Coulomb scattering of a beam of 1000 electrons by cylindrically shaped neutral Li gas (Z = 3, a = 6.941 g/mole) column with the radius of 100 mm,
- ☑ A plasma density of 6 × 10^{14}cm^{-3},
- ☑ Li was chosen due to its orders of magnitude low scattering cross section compared to the other candidates such as Rb (Z = 37),
- ☑ The beam was tracked through the gas column with the steps of 10 to 50 m,
- ☑ During the tracking the energy is increased linearly at each step with a gradient of 0.5 *GeV/m*,
- ☑ Phase space was reconstructed at various positions and the resulting emittance is calculated.
- ☑ The constructed phase space is fed to the next step as the initial condition.





An example initial beam distribution: Position (top) and angle (bottom) distributions of the beam, after 10 (left) and 20 m (right) travel through Li gas.



CONCLUSIONS AND OUTLOOK As an advanced accelerating technique PWA has ever-increasing prospects. Therefore, the potential issues of the scheme must be assessed carefully. This study was initiated to seek out the impact of interaction of a witness beam with the surrounding plasma formed to provide acceleration. The emittance growth induced in the beam via beam-gas elastic scattering was studied analytically based on the existing model for the beam-gas scattering in damping rings. The preliminary results of this novel study are presented in this paper. It has been shown that the beam-plasma interaction is expected to be significant in the absence of any means of focusing and the evolution of phase space can be feasibly studied by using GEANT4. In order to obtain the most realistic representation of interaction between beam and plasma and a realistic estimation on the emittance growth, several improvements to the existing GEANT4 model are in progress. Consequently, in the further studies the model will include an electric field on the beam axis to simulate the linear acceleration instead of changing the beam energy at each step of simulation. In addition a magnetic field will be introduced in a way to simulate the focusing component of the plasma wakefield. A thin plasma channel consisting of ionised gas and electrons will be simulated within a volume of gas atoms to represent the configuration in an actual plasma tank where ionisation occurs only in the inner region illuminated by a laser.

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