Project: A compact plasma beam dump for next generation particle accelerators.
Supervisor: Dr. Guoxing Xia.
Duration: 24 Weeks, 2018-19.
Location: The University of Manchester,
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Week 1

- First meeting with Guoxing: Discussed project outline, necessary background reading and the `EPOCH` software. Received documents from Guoxing: LFWA PhD thesis [1], PWFA and beam dump papers [2, 3, 4, 5, 6, 7] and `EPOCH` users manual [8].
- Read theory section in Hanahoe's thesis [7].
- Weekly outline: Background reading to understand the theory of LWFA, PWFA and plasma wakefield deceleration. I will study the beam dump so no laser will feature in my simulations, however good to study LWFA to understand more about PWFA. There are several PIC softwares: QuickPIC, OSIRIS, VLPL3D, Vorpal, EPOCH, XOOPIC, OOPIC, LCODE...why use EPOCH?
- Concepts covered:
  - Gessner (2.3-2.4) - **Linear regime**: Response of a cold, non-interacting plasma, with a ultra-relativistic "delta function" particle beam by considering the electron density perturbation n_1. Compute Green's function for n_1 and then convolve the solution with a 2-D Gaussian beam to get the plasma's response of a non-point-like beam, (2.18 Gessner). I could produce 2D plot n_1/n_0 to show this response.
  - Derive wave equations for **E** and **B** fields in the plasma following the density perturbation.
  - Derive longitudinal and transverse E-fields for the ultra-relativistic delta function driving bunch, then convolve with extended Gaussian beam.
  - **Non-linear regime**: Derive accelrating and transverse fields in the blow-out regime (Gessner 2.7).
- I read Wu et al. - *Collective deceleration: Toward a compact beam dump*[5] . No yet summarised the theory section in this paper.
- Questions:
  - Should I look at LWFA theory as well, even though we won't have lasers present in the beam dump? Actually, the active scheme proposed by Bonatto et al. is laser-driven so I should look at LWFA as well, right?
  - Should I also look at positron beam dumping if I am to look at the ILC beam dump?
- Concepts to look up:
  - Bump-on-tail instability.
  - Landau damping
  - Plasma beatatron-wavelength
  - Look up current beam dumps for e-colliders and tabeltop LWFAs .

Linear regime: Perturbation due to beam $n(r,\xi) \rightarrow n(r,\xi) + \tilde{n}(r,\xi)$, use Maxwell's equations and continuity equation.
– *Density:*

$$-\frac{1}{k_p^2}\left(\frac{\partial^2}{\partial \xi^2} + k_p^2\right)\tilde{n}(r,\xi) = n_b(r,\xi) \quad , \quad \tilde{n}(r,\xi<0) = 0 \tag{1}$$

$$\mathcal{L}_\xi \tilde{n}(r,\xi) = n_b(r,\xi) \quad \Rightarrow \quad \mathcal{L}_\xi G(\xi,\xi') = \delta(\xi) \tag{2}$$

$$G(\xi,\xi') = \begin{cases} 0 & ,-\infty < \xi < 0 \\ A\sin((k_p\xi) + B\cos(k_p\xi) & ,0 < \xi < \infty \end{cases} \tag{3}$$

where the Green's function obeys the same b.c as the density perturbation, i.e it is continuous across the boundary with a discontinuous derivative across the boundary. Integrate across discontinuity at $\xi = 0$

$$\lim_{\epsilon \to 0} \int_{-\epsilon}^{\epsilon} \mathcal{L}_{\xi} G\left(\xi, \xi'\right) \mathrm{d}\xi = \lim_{\epsilon \to 0} \int_{-\epsilon}^{\epsilon} \delta\left(\xi\right) \mathrm{d}\xi = 1 \quad \Rightarrow \quad \lim_{\epsilon \to 0} \left[-\frac{1}{k_p^2} \frac{\partial G}{\partial \xi} \right]_{-\epsilon}^{\epsilon} = 1 \tag{4}$$

$$G\left(\xi, \xi'\right) = -k_p \sin\left(k_p \xi\right) \Theta\left(\xi\right) \quad \Rightarrow \quad \tilde{n}\left(r, \xi\right) = \int_{-\infty}^{\infty} G\left(\xi, \xi'\right) n_b\left(r, \xi'\right) \mathrm{d}\xi' \tag{5}$$

Week 2

References

[1] Shao-Wei Chou. Investigation of electron acceleration and deceleration in plasmas. 2016.

[2] A. Bonatto, C. B. Schroeder, J. L. Vay, C. G.R. Geddes, C. Benedetti, E. Esarey, and W. P. Leemans. Passive and active plasma deceleration for the compact disposal of electron beams. *Physics of Plasmas*, 22(8), 2015.

[3] A. Bonatto, C. B. Schroeder, J. L. Vay, C. R. Geddes, C. Benedetti, E. Esarey, and W. P. Leemans. Compact disposal of high-energy electron beams using passive or laser-driven plasma decelerating stage. *AIP Conference Proceedings*, 1777(1):0–5, 2016.

[4] W. Lu, C. Huang, M. M. Zhou, W. B. Mori, and T. Katsouleas. Limits of linear plasma wakefield theory for electron or positron beams. *Physics of Plasmas*, 12(6):1–8, 2005.

[5] H. C. Wu, T. Tajima, D. Habs, A. W. Chao, and J. Meyer-ter Vehn. Collective deceleration: Toward a compact beam dump. *Physical Review Special Topics - Accelerators and Beams*, 13(10):1–8, 2010.

[6] S. Chou, J. Xu, K. Khrennikov, D. E. Cardenas, J. Wenz, M. Heigoldt, L. Hofmann, L. Veisz, and S. Karsch. Collective Deceleration of Laser-Driven Electron Bunches. *Physical Review Letters*, 117(14):1–5, 2016.

[7] Kieran Hanahoe, Guoxing Xia, Mohammad Islam, Yangmei Li, Öznur Mete-Apsimon, Bernhard Hidding, and Jonathan Smith. Simulation study of a passive plasma beam dump using varying plasma density. *Physics of Plasmas*, 24(2), 2017.

[8] K. Bennett. EPOCH Users Manual for the EPOCH PIC codes, Ver. 4.3.4. 2015.