Minutes 5th Run 2C specification meeting,
10th June 2021 – 16:00-17:00 (over Zoom)

Presentation: https://indico.cern.ch/event/1048272/

Present: John Farmer, Linbo Liang, Stefano Mazzoni, Patric Muggli, Rebecca Ramjiawan, Francesco Velotti, Livio Verra, Guoxing Xia

Introductory discussions

- **John:** I spoke to Patric about using a single element after the plasma to give an intuitive feel for the importance of the emittance and energy spread towards the luminosity. Emittance is likely the most important, but by how much? We could measure the luminosity with very simple optics after and this could be done with just a linear transform in python. **Francesco:** could you do this with old data? **John:** yes, we can do it with post-processing. We can compare with the Q-factor; for applications the luminosity would likely matter more. The plan is to re-visualise old data. I might be able to show something in four weeks.
- **Actions:**
  - **John:** look at old data in terms of luminosity.

Simulations: Impact of non-Gaussian transverse beam profiles to electron acceleration in AWAKE Run 2c (L. Liang)

- **Presentation**
  - Starting from V. Olsen's model and assuming matched radius. Previously, we had assumed a Gaussian distribution but if we have a deviation from Gaussian we can parameterise this with the fourth moment – kurtosis. This kurtosis in x, px will rotate, so we define a constant parameter (akin to the emittance) for the kurtosis, this is the halo parameter.
  - **See:** Linbo Liang, et al., IPAC 21, May 2021, Contribution WEPAB175.
  - Lower emittance growth seen for higher kurtosis beams, also seen for slice emittance values towards the head. Emittance growth at the head due to incomplete blowout: in the head, the focussing fields are weaker than in the bubble.
  - For higher charge, the emittance growth shows less sensitivity to kurtosis (looking at 120 pC vs. 400 pC). To see mechanism for this, look at the plasma response to non-Gaussian profiles. It generates a similar bubble for different kurtoses. The head has an incomplete blowout and dependence on kurtosis, as it has a higher peak density for higher kurtosis so a more complete and earlier blowout.
  - Look at statistics for the core of the beam, $\frac{x^2}{\sigma_x^2} + \frac{px^2}{\sigma_{px}^2} + \frac{y^2}{\sigma_y^2} + \frac{py^2}{\sigma_{py}^2} < 4$. Brightness ($\frac{I}{\epsilon_x^N \epsilon_y^N}$) of the core is pretty constant during acceleration for higher kurtosis, both for high and low charge. Higher kurtosis has higher brightness at the core. This is seen for both charge cases.

- **John:** Higher kurtosis generates a bubble more quickly. It is not as sensitive for the distribution overall, but most significant for the core.

- **Questions/comments**
  - **Francesco:** are any other parameters than kurtosis being looked at? **Linbo:** we looked at others but kurtosis seems key. Other than a centroid offset/skewness which M. Weidl is looking at. **Note from Linbo***: Simulations using skewed-Gaussian distribution (https://en.wikipedia.org/wiki/Skew_normal_distribution) are performed. The skewed-Gaussian distribution brings both skewness and kurtosis. But since in my simulations, the mean position or the centroid of the skewed-Gaussian distribution is reset to zero, i.e., no offset of the centroid, the effect of skewness is then less obvious than the kurtosis. There might be some artificial effect here.*
  - **Francesco:** so, if we inject with no tails this is beneficial? **John:** we have kept the emittance constant and changed the kurtosis, we can change the emittance easily by cutting the tails. **Francesco:** could achieve this with collimation. **Patric:** we could achieve this with collimation before plasma but, if this doesn't affect the wakefields, we could just leave it there. **John:** we could simulate this easily by having kurtosis and cutting the wings and seeing if there are any changes. **Patric:** what can be most important is the amount of charge in the skin depth. **Note from Linbo:** *the measure of the kurtosis is very sensitive to particles in the tail. The operation of trimming the tail can result in a smaller value of measured kurtosis. This operation actually happens in the process of generating the particle distribution file in the simulations but at a large radius (5-10sigma, a larger value for higher kurtosis case to include more tails while keeping the density distribution smooth) as the result of finite data sampling range. Due to this reason, the measured kurtosis of the beam distributions shown in page 3 of my slides is actually a bit of smaller than the theoretical one. But the above tail cutting doesn't affect the density distribution in the core. What we should be concerned about is still the influence of the density distribution defined by the generalized Gaussian function.*
  - **John:** L. Liang assumed so far Gaussian in px, py, and kurtosis in x, y. Could also do this the other way around.
  - **John:** to clarify, the brightness includes charge and emittance but not energy spread.
  - **Patric:** for the beamline do we want low emittance or low energy spread? **Francesco & Rebecca:** for us, low energy spread. Yes, we have detuning with amplitude effects from higher emittance, but this is largely because of the sextupoles that we had to add to compensate the chromatic effects. *N.B see https://edms.cern.ch/ui/file/2378918/0.1/AWAKE_Run2_ElectronLine.pdf for studies on the transfer line for a range of emittance and energy spreads.*
  - **Patric:** it would be interesting to know what has happened with the energy spread for higher charge. **Francesco:** energy spread becomes a problem after strong focussing, so it depends what you want the beam for. A final focus with a few percent energy spread will be difficult/impossible without higher order elements. **John:** we don't know what we need it for, a lot depends on whether we need 1 µm vs 10 µm etc. **Patric:** it's possible the energy spread is

not as important. **Francesco:** what is the energy spread here? **Linbo:** for 120 pC it is 6-7%, for 400 pC it is 10%. **John:** we can reduce this if we don't optimise to flatten the wakefields.
    - **Patric:** is this a distribution we can cut 10% can get a much better value? **John:** it's quasi-monoenergetic, yes. Usually, trimming energy spread also reduces emittance, it's often the same particles in both tails.
- **Actions**
    - **John:** study how much the tails impact the wakefields.

Simulations: Extra: Hosing induced by high kurtosis beam (L. Liang)

- **Presentation**
  - For higher kurtosis beams, the centroid displacement starts earlier. This can be minimised by adjusting the driver-witness delay. Hosing with kurtosis can cause large emittance growth later in the cell, but this can be stabilised with an increased delay.
  - Increasing the delay also brings the benefit that the phase slippage reduces the relative energy spread. The different injection points change the loading of the wakefields.
- **Questions/comments**
  - **John:** We need to check how physical it is that higher kurtosis can lead to more hosing. Hosing isn't seen in experiment as much as in simulation, we need further study on the effect of macroparticle number and how this evolves through the plasma cell. Increasing the macroparticle number better models phase mixing which would better stabilise hosing. Also, we know there is dephasing but it is possible the phase is still evolving.
  - **Patric:** we need more studies with the beamline output beam distribution. **John:** we will do that, we are trying to understand more of the underlying physics first.
  - **Francesco:** it would be good to look next at the study with the single focussing element. **John:** we may not see much energy spread dependence without any bending. **Francesco:** keep it simple and straight, or the dependence you see will be from the optics you choose.
- **Actions:**
  - **Rebecca:** provide Linbo with output beam distributions with different kurtoses.

Relevant documents

- Desired limits on the transverse offsets for Run 2 injection of the witness beam: https://edms.cern.ch/document/2427196/0.1 (M. Weidl 13-10-2020)

- AWAKE Run 2 Electron Line Parameters: https://edms.cern.ch/document/2378918/0.1 (R. Ramjiawan 26-05-2020)

- Electron Witness Constraints for AWAKE: https://edms.cern.ch/document/2588263/1.0 (J. Farmer 19-05-2021)