A **Transverse Deflecting Structure** for the PWFA experiment, **FLASHForward**

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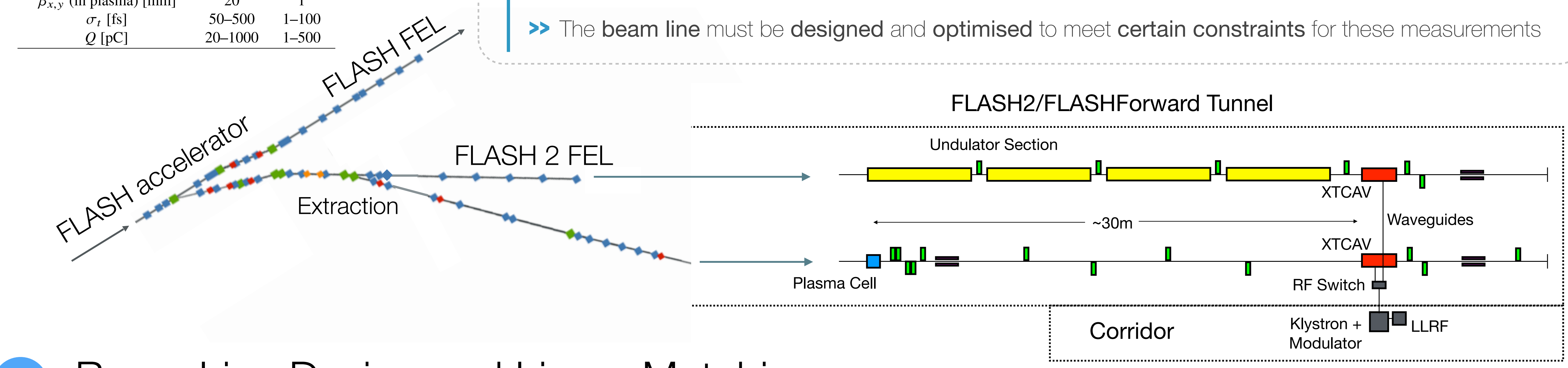
0. Motivation

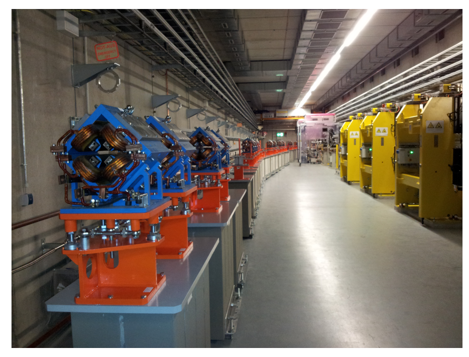
- FLASHForward aims to **accelerate electron beams to GeV energies over a few centimetres of ionised gas**. These accelerated beams must be of **sufficient quality** to be used in a **free-electron laser**
- To optimise this acceleration process it is essential to know the **longitudinal properties of the drive-beam**, in order to mitigate negative plasma effects, such as **hosing**.
- Equally as important is the ability to resolve the **longitudinal properties of the witness-beam**, both to determine the nuances of **individual injection methods**, as well as to study the quality for FEL use

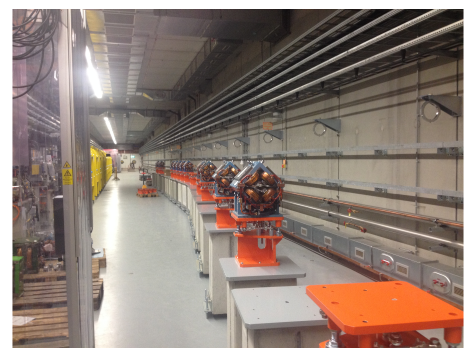
Parameter	Driver	Witness
E [GeV]	0.5–1.2	1.2–2.5
$\Delta E/E$ (uncorrellated) [%]	<0.1	1
$\varepsilon_{n,(x,y)}$ [μm]	2–5	0.1–1
$\beta_{x,y}$ (in plasma) [mm]	20	1
σ_t [fs]	50–500	1–100
Q [pC]	20–1000	1–500

1. The FLASHForward Facility

- The **FLASHForward PWFA** experiment is **driven by beams generated by** and extracted from **FLASH**
- The **beam line** must be **designed** and optimised to meet **certain constraints** for these measurements





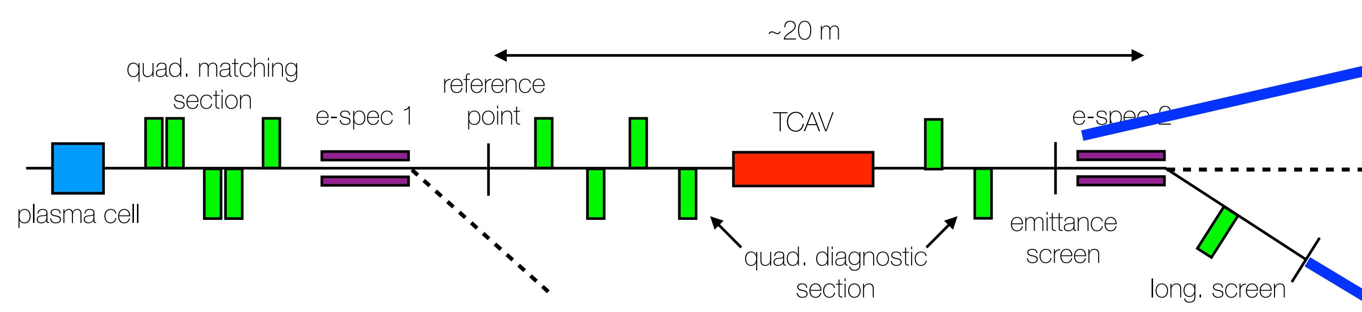


2. Beam Line Design and Linear Matching

- Two measurements are desired: **transverse slice emittance measurements** and **longitudinal phase space measurements**
- The optics constraints are dependent on the **TDS streak** and **slice emittance scan phase advance**

$$S = \sqrt{\beta_y(s)\beta_y(s_0)}\,|\sin\mu_y(s_0,s)|\,\frac{eVk}{E}$$

TDS Streak

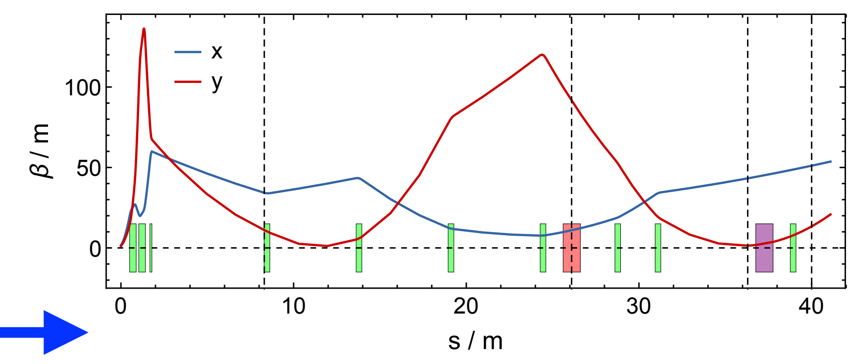


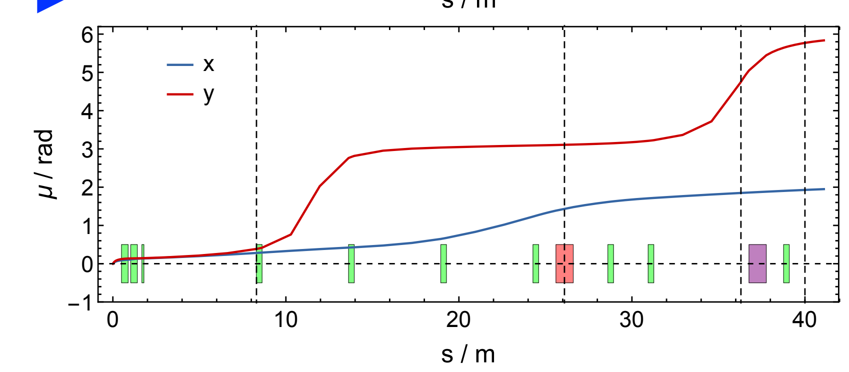
TDS: $\beta_y > 100$ m

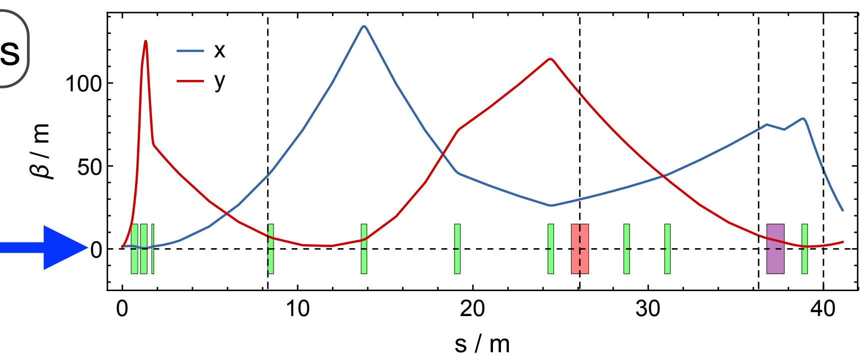
Emittance Screen:
$\beta_y < 10$ m
$\beta_x > 10$ m
$\mu_y = \pi/2$
$0<\mu_y<\pi$

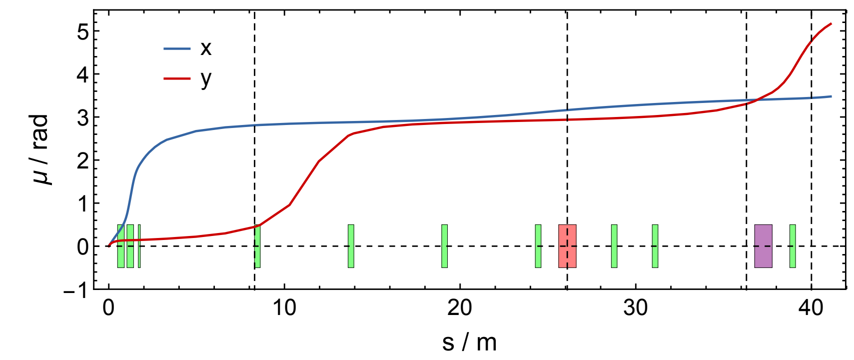
Optimisation Constraints

Dispersive Screen:
$\beta_y < 10$ m
$\beta_x < 10$ m
$D_x > 0.5$ m
$\mu_y = \pi/2$









- There are **five constraints** in each case. Therefore **at least five quads** are required. Due to availability **six quads** are added **between the reference point and emittance screen**. An additional quadrupole is added **in the dispersive** section for additional flexibility.

$$R_z = \frac{\sigma_y}{S} = \sqrt{\frac{\varepsilon_y(s)}{\beta_y(s_0)}}\frac{1}{|\sin\mu_y|}\frac{E}{eVk} \quad \Bigg| \quad R_\delta = \frac{\sigma_x}{|D_x|} = \sqrt{\varepsilon_x}\frac{\sqrt{\beta_x}}{|D_x|}$$

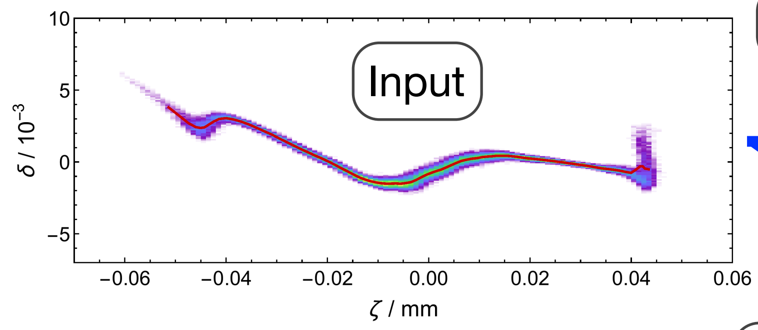
Longitudinal and Energy Resolution

- Beam line **simulations** and **matching** were performed in ***elegant***
- The **beam line was matched** in both cases, with the **quadrupole strengths** and **locations** as **matching** variables
- The **resolution** in each of these matched cases (for a **FLASHForward drive beam** with E=1GeV & ε_n=2μm, and an X-band deflecting cavity with V=30MV & f=11.99GHz) is:
  - R_z=1.37fs and R_δ=2x10^{-4}

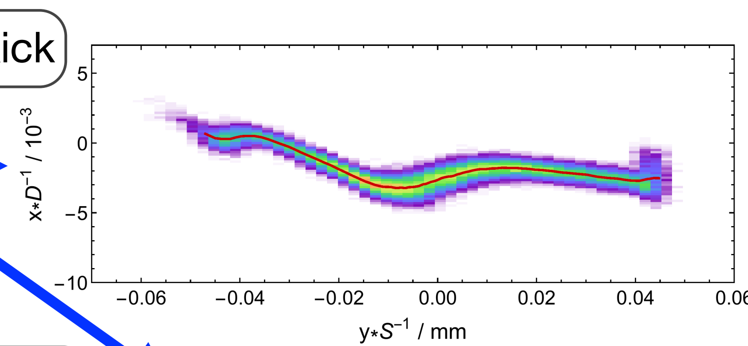
3. Particle Tracking

- A **full 3D simulation** from the **FLASH gun to the FLASHForward plasma cell** was used for **particle tracking** in ***elegant***
- The longitudinal distribution indicates **potentially harmful collective effects** from e.g. **space charge**, **coherent synchrotron radiation** in the bunch compressors, etc.
- The **TDS maps** (δ, ζ) before the TDS **onto** (x, y) at the imaging screen
- **Energy spreads** can be seen **in the reconstructed distribution**, with a larger spread for a larger streak
- **The effect can be decreased** but only with a decrease in cavity voltage i.e. **at the expense of longitudinal resolution**
- **Energy spread induced by a TDS** is defined as $\sigma_\delta = \frac{eVk}{E}\sigma_y$
- This **effect** will be **diminished for witness beams** (with emittances up to an order of magnitude smaller than for drive beams. Additionally, experimental observation and quantification will aid in **offline corrective methods**

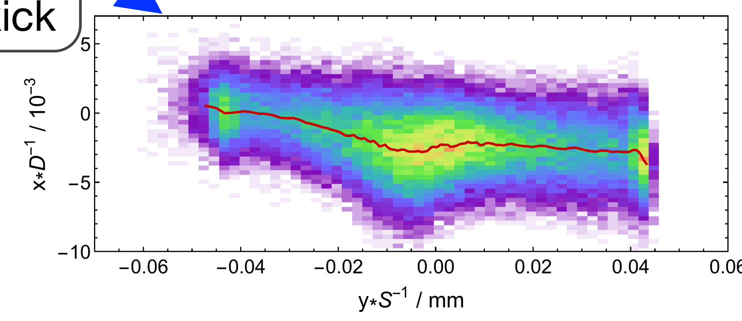
Input



6MV kick



30MV kick



4. Summary

- A **post-plasma beam line**, with the inclusion of a **TDS system** for transverse and longitudinal diagnostics, has been **designed** for FLASHForward
- Both **linear optics** and **particle tracking** demonstrate **successful TDS operation**
- The simulation package has indicated a need for **compromise between the energy and longitudinal resolution** when operating with typical FLASHForward drive beams. However, experimental benchmarking should help mitigate these limitations
- **Longitudinal resolutions** as low as **~1fs** have been demonstrated **for an X-band RF system with this optics scheme**

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