FLASHForward▸▸ P-9: An X-band Transverse Deflection Cavity (XTDC) for femtosecond-scale diagnostics

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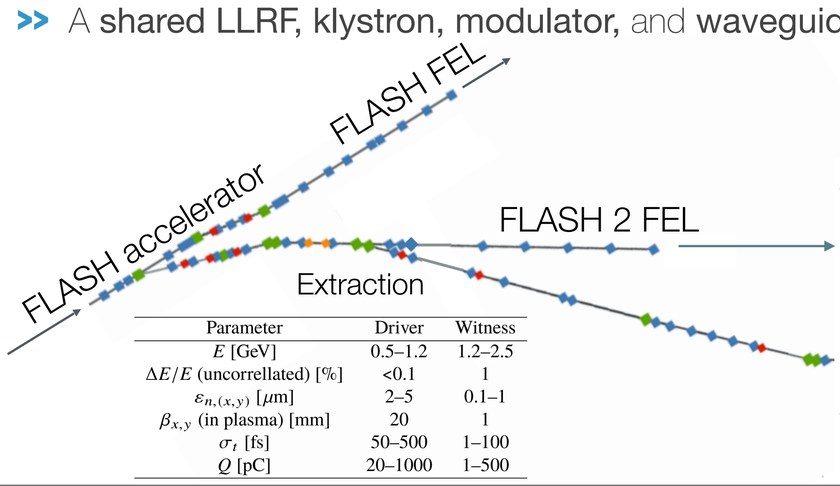
Motivation and FLASHForward background

- **FLASH**Forward▸▸ 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 driver beam**, in order to mitigate negative effects in plasma, such as **hosing** (***see T. Mehrling's talk, Weds 12:00***).
- 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.

The FLASHForward Facility and diagnostic requirements

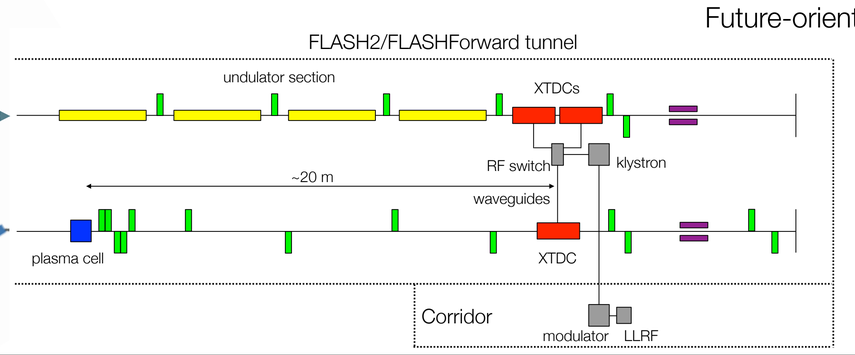
- An **X-band TDC** is the only option to longitudinally resolve **FF**» bunches with **femtosecond bunch lengths over three orders of magnitude.**
- A **shared LLRF, klystron, modulator,** and **waveguide network** will provide power to either a **single XTDC on FF**» or two XTDCs on FLASH2.

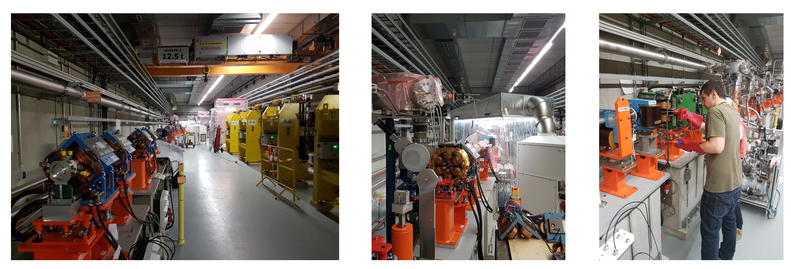


Parameter	Driver	Witness
E [GeV]	0.5–1.2	1.2–2.5
$\Delta E/E$ (uncorrellated) [%]	<0.1	1
$\varepsilon_{n,(x,y)}$ [μm]	2–5	0.1–1
$\beta_{x,y}$ (in plasma) [mm]	20	1
σ_t [fs]	50–500	1–100
Q [pC]	20–1000	1–500

See J. Osterhoff's talk, Weds WG1

FLASHForward▸▸
Future-oriented wakefield-accelerator research and development at FLASH





X-band international collaboration and FLASHForward hardware scheme

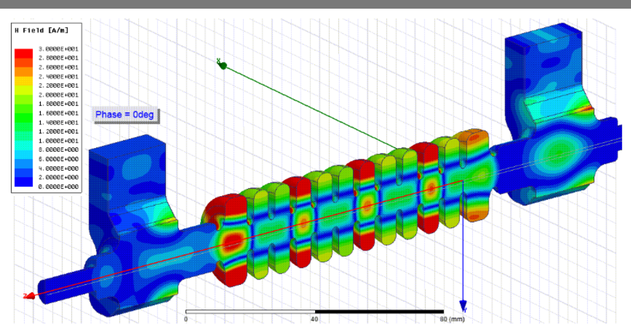


Figure 1: *A shortened version (10 cells instead of 96) of the CERN-designed dual-polarisation XTDC to be prototyped at* ***FF***». ***see A. Grudiev's talk, Fri 09:40***

- An **international collaboration between DESY, CERN, and PSI** has been set up in order to **share X-band technology** and expertise.
- CERN have designed an **XTDC with novel dual polarisation functionality**. This cavity will be manufactured at PSI and **prototyped at FF**» **in 2019.**
- With a **pulse-compressed 6 MW klystron** and a single XTDC, temporal **resolutions of <1 fs** can be expected at **FF**» for certain witness bunch cases.
- Resolutions of >1 fs are expected for the driver bunch case — **an order of magnitude higher than is currently achievable at FLASH.**

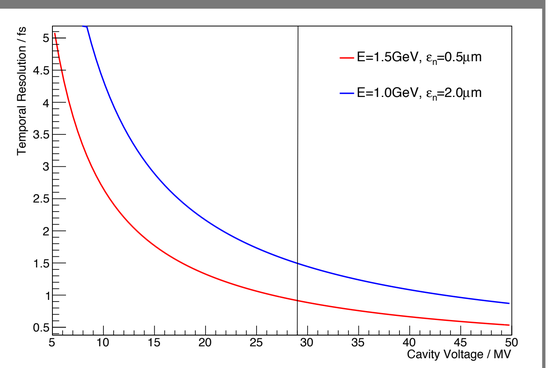
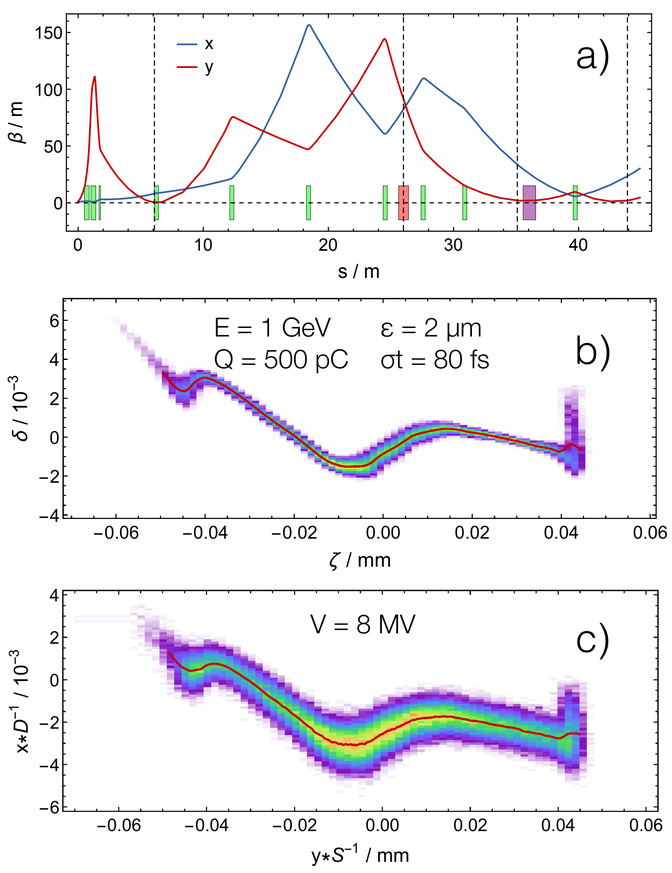


Figure 2: *Resolution limits at* ***FF***» *for the expected cavity voltage and optics.*

Post-plasma beam line design and particle tracking

DRIVER BUNCH SCENARIO



$R_t > 5.2$ fs and $R_\delta > 1.2\text{x}10^{-4}$

Figure 3: *The a) transverse beam optics, b) longitudinal phase space at the XTDC, and c) reconstructed phase space at the dispersive screen for a 'typical'* ***FF***» *driver bunch.*

- The **post-plasma beam line was designed** to accommodate and optimise the functionality of the **XTDC**.
- The optics constraints are required to measure both **transverse slice emittance** and **longitudinal phase space**.
- In the latter case the **resolutions** are defined by:

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

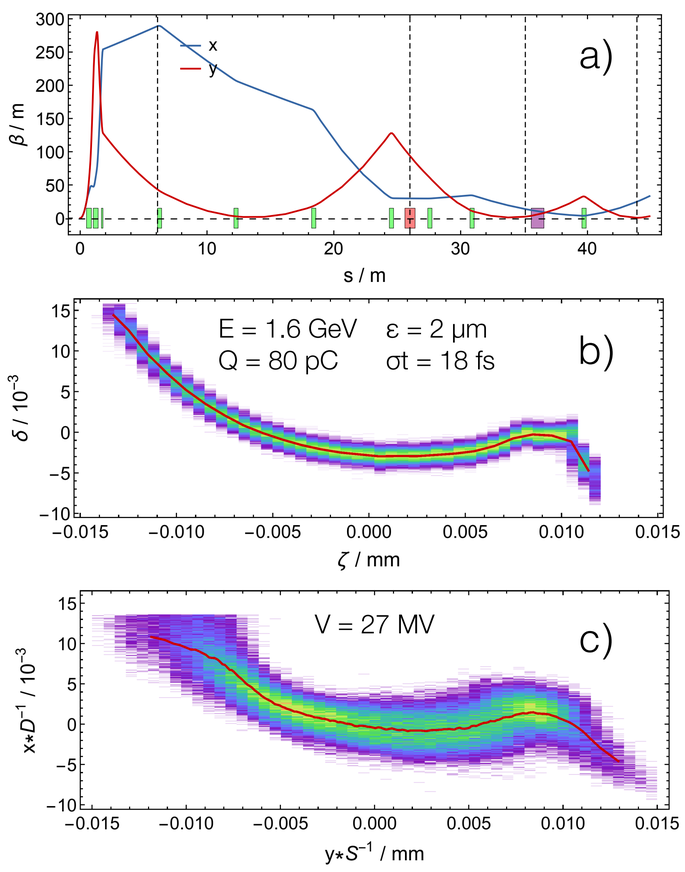
- **Particle tracking in elegant** was performed to propagate two 'realistic' bunches — one **driver** and one **externally injected witness** bunch— and reconstruct them at the dispersive screen (the final vertical dotted line in Fig. 3a and 4a).
- The **resolutions in time and energy** are calculated using the above equations and **used as bin widths**.
- The measurement suffers from **induced energy spread**, defined by

$$\sigma_\delta = \frac{eVk}{E}\,\sigma_y$$

and an **induced energy chirp**. The latter can be corrected, however the energy spread cannot.

- Despite adverse effects **bunch structure can be resolved** in each case, **with femtosecond resolution**.
- Additional effects such as **transverse and longitudinal wakefields** must be included. This suite can then be expanded to **perform a full tolerance study**. ***see V. Libov's talk, Tues WG1***

WITNESS BUNCH SCENARIO



$R_t > 1.9$ fs and $R_\delta > 1.1\text{x}10^{-4}$

Figure 4: *The a) transverse beam optics, b) longitudinal phase space at the XTDC, and c) reconstructed phase space at the dispersive screen for an externally injected* ***FF***» *witness bunch with the use of a beam scraper.*

Summary

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

FLA/Plasma Acceleration Group (http://fla.desy.de) and the FLASHForward project at DESY (http://forward.desy.de)