A Dielectric Wakefield Streaker for Longitudinal Bunch Profile Measurements

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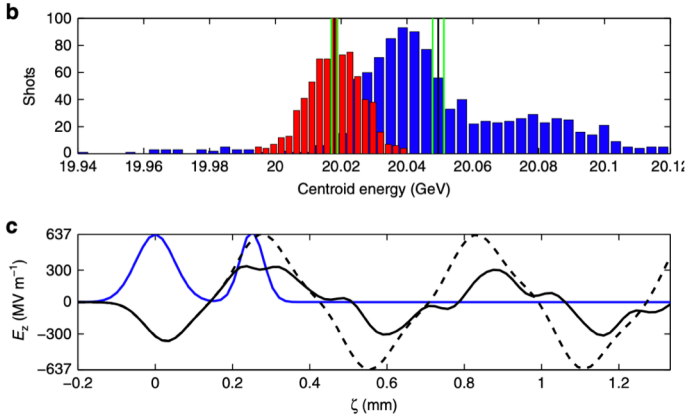
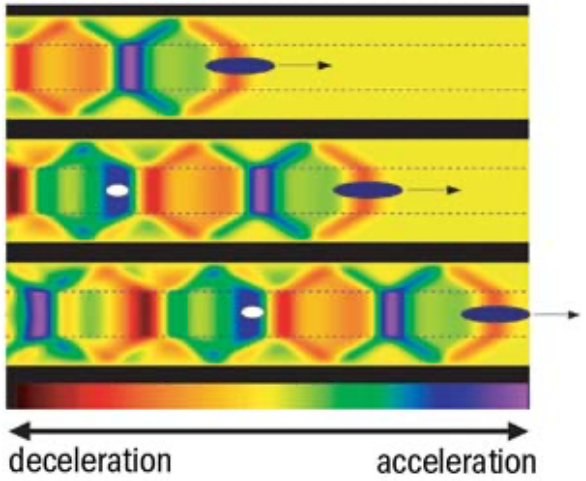
Dielectric Wakefield Acceleration

- Cherenkov radiation produced by electron beams in a DLW:
  - Trailing witness/main bunch accelerated by the wakefield produced
  - Structures can sustain ~800 MV/m accelerating gradients
- Area of large focus internationally (Snowmass, ESPP)
  - Aim to show the technology can work over large distances



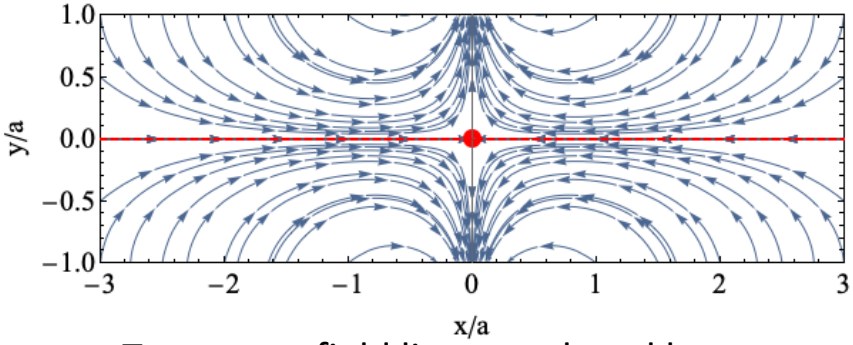
300 MV/m accelerating gradient for electron bunch at SLAC (O'Shea et.al 2016 Nature)



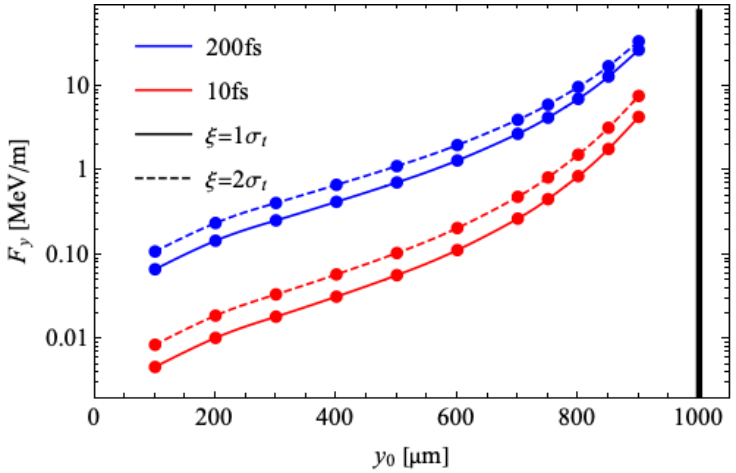
Longitudinal field produced by a drive electron bunch, accelerating a trailing bunch

Transverse Fields in DLWs

- Fields can be approximated as quadrupole-like with dipole term growing with offset
- Field strength grows exponentially with distance from axis
- We have shown the streaking effect and behavior with offset at CLARA

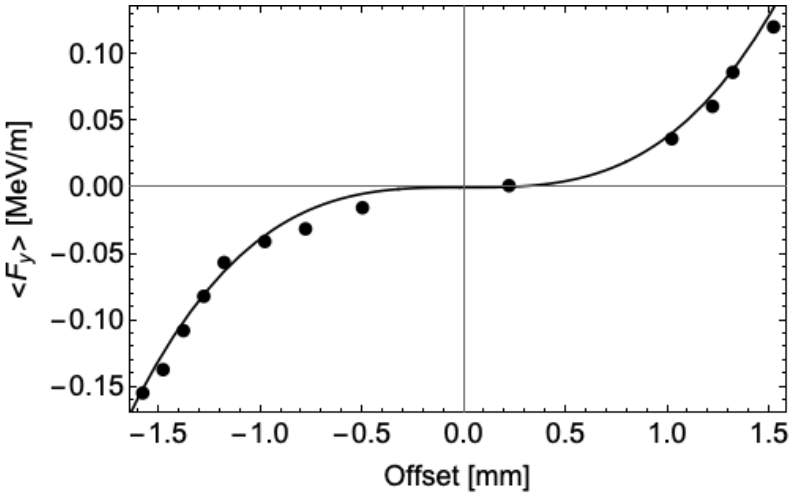


Transverse field lines produced by an electron bunch on-axis

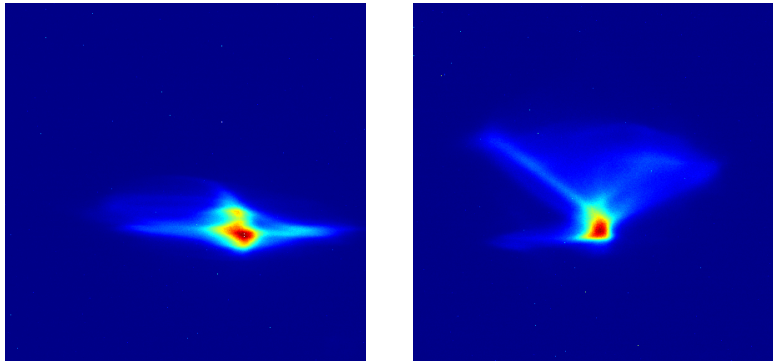


Transverse field vs. offset for 250 pC bunches at 2 longitudinal positions

- Measurements at CLARA using 35 MeV, ~100 pC, 800 fs bunches
- DLW had a 200um thick quartz layer, with a 2mm half-gap

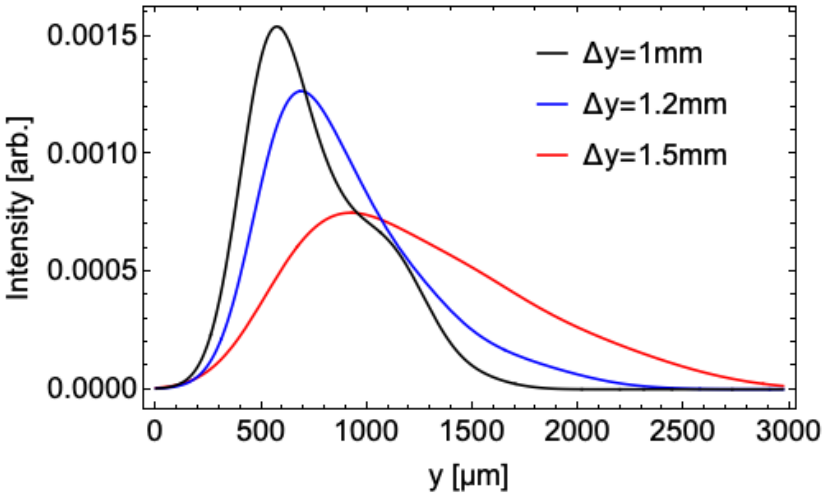


Average vertical streaking force vs. offset



Beam on-axis

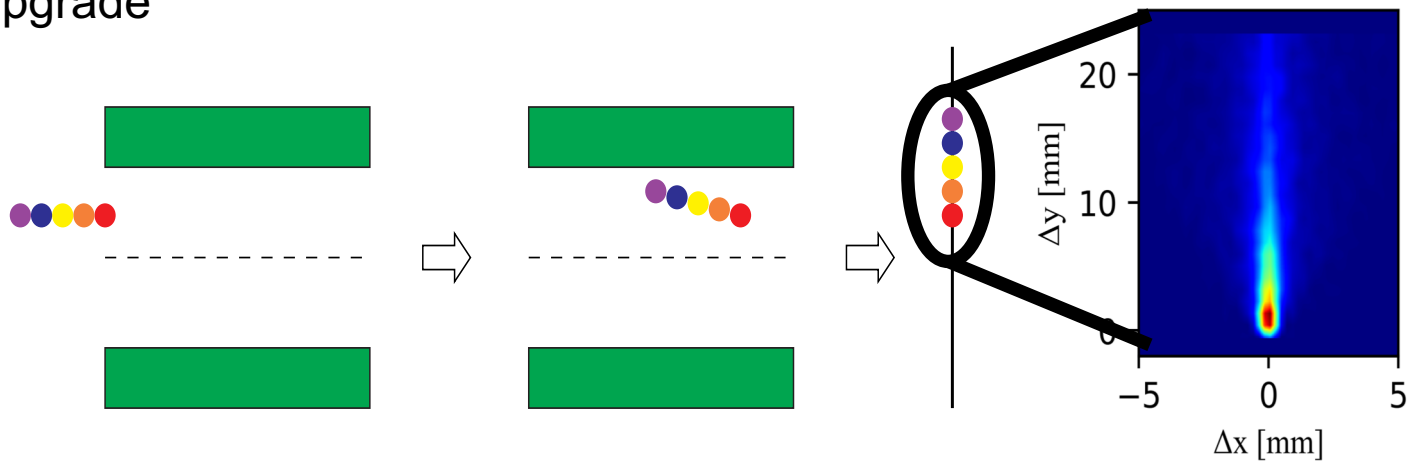
Beam off-axis



Measured longitudinal profile for streaked bunches at 3 offsets

Passive Diagnostics with Dielectrics

- So long as the streak is monotonic:
  - Self-synchronised -> fields independent of beam-to-beam variation
  - Longitudinal profile converted to transverse profile
  - Small physical and energy footprint
- Diagnostic for a wide range of facilities
  - Focus on either ‘novel accelerator’ type beam or facility like CLARA FEBE upgrade



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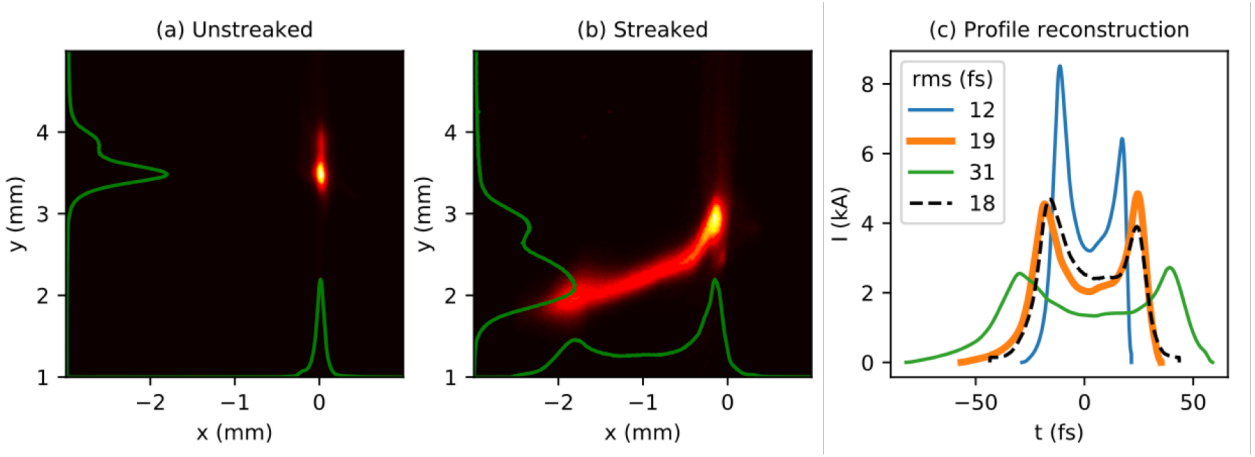
Dielectric Streakers

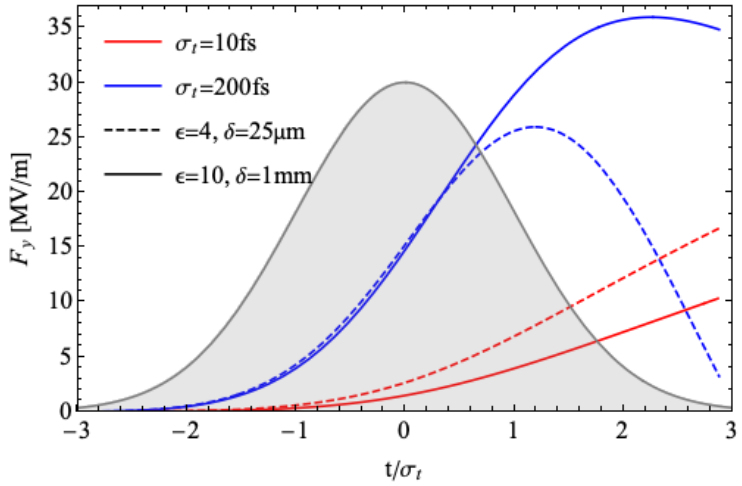
- Other facilities have explored the potential of dipole wakefields for streaking
  - Corrugated structure at SwissFEL for bunch reconstruction and FEL power profile reconstruction
  - Femtosecond resolution obtained for bunches with rms bunch length 10-30 fs



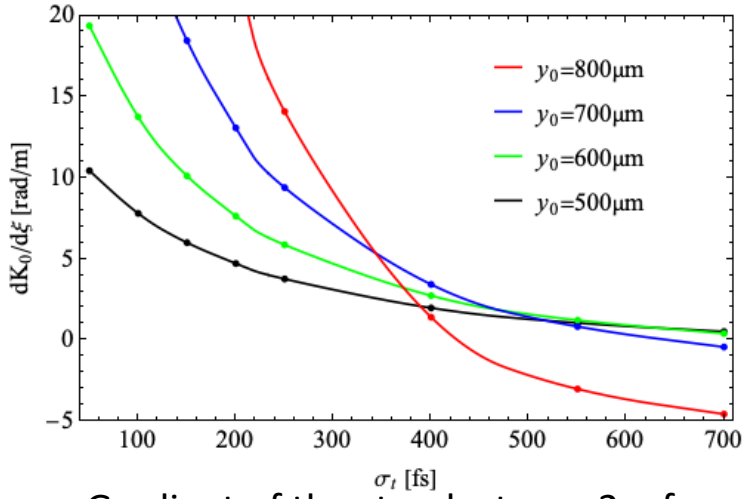
Example streaked/unstreaked beam and reconstructed profiles at SwissFEL (Dijkstal 2022 Physical Review Research)

Streaker Optimisation

- Shorter bunches:
  - Always monotonic so maximise the streak only
    - Very thin, quartz layer
- Longer bunches:
  - Need to increase wavelength for monotonic profile
    - Thicker plate, higher permittivity
- For even longer bunches reduce the offset for longer wavelength



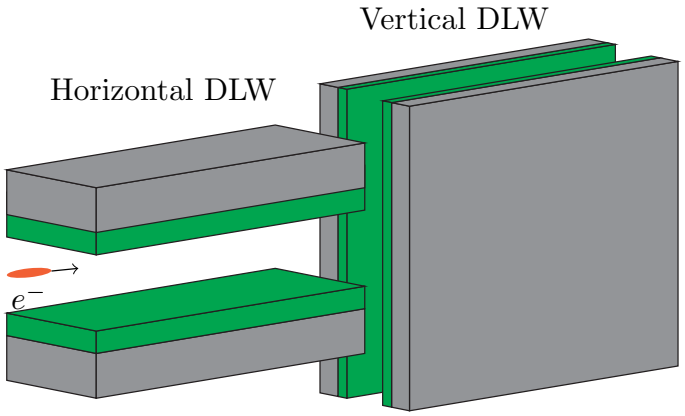
Vertical streaking field with the 2 streakers offset 900um from axis

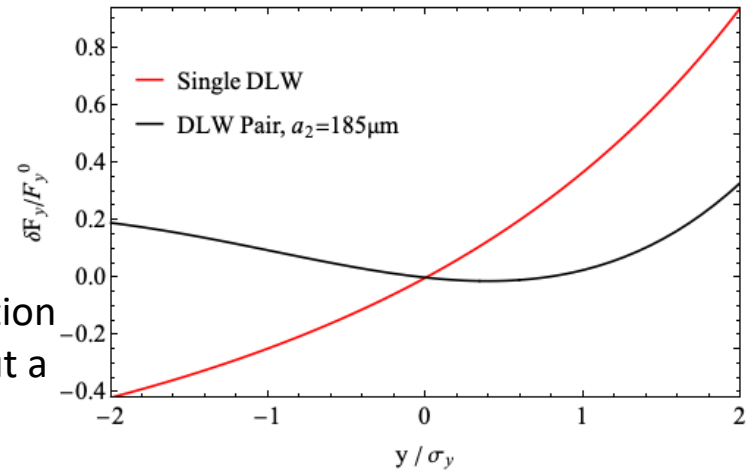


Gradient of the streak at $z = +2\sigma_t$ for varying offsets and bunch lengths

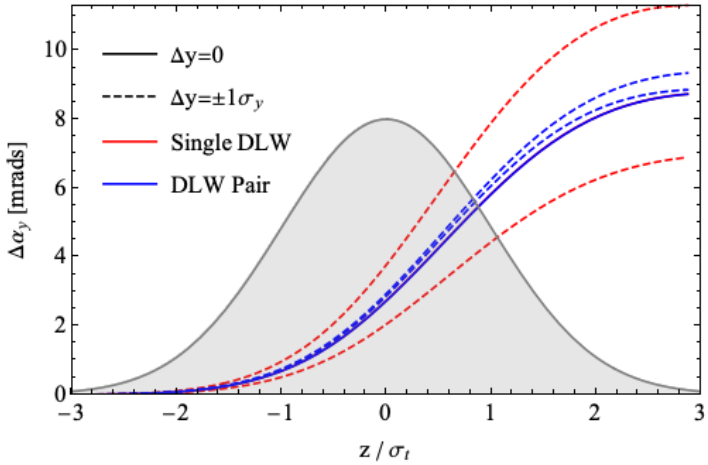
Minimising Transverse Streak Variation

- Take advantage of the quadrupole-like fields to cancel streak variation
- Electron beam on-axis through second shorter DLW
- Reduction from 120% variation to 30% variation
- More monotonic streak





Transverse streak variation with/without a second DLW



Angular kick along the bunch with/without a second DLW

Expected Resolution

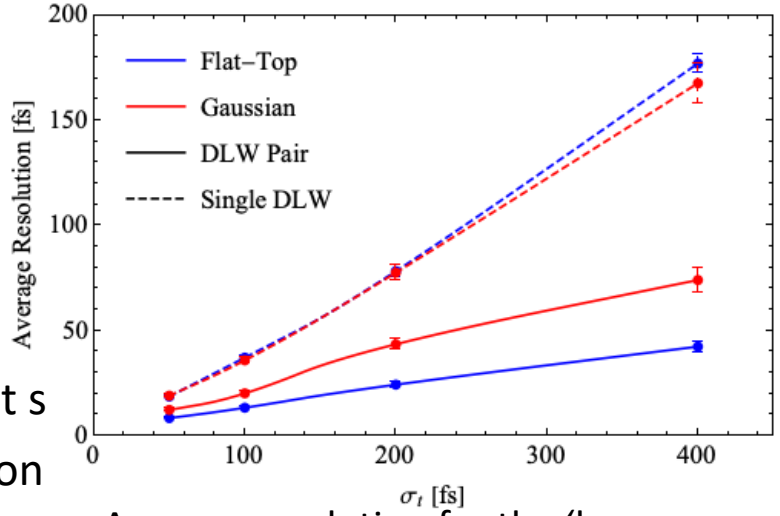
- Resolution is given by:

$$r(s) = \frac{\sigma_Y(s)}{R_{12}\frac{dK_0(s)}{ds}}$$

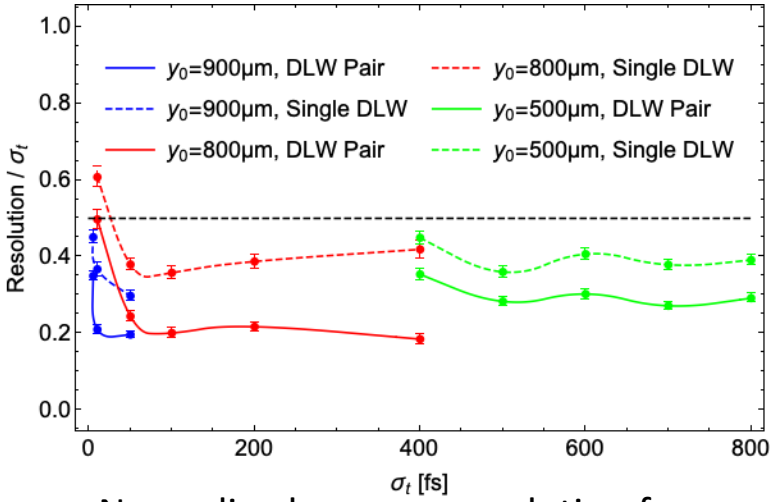
Transverse beam size at s

Longitudinal variation in streak

- Average is the instantaneous resolution weighted by charge
- Resolution is enough for reconstruction across 5 to 800 fs

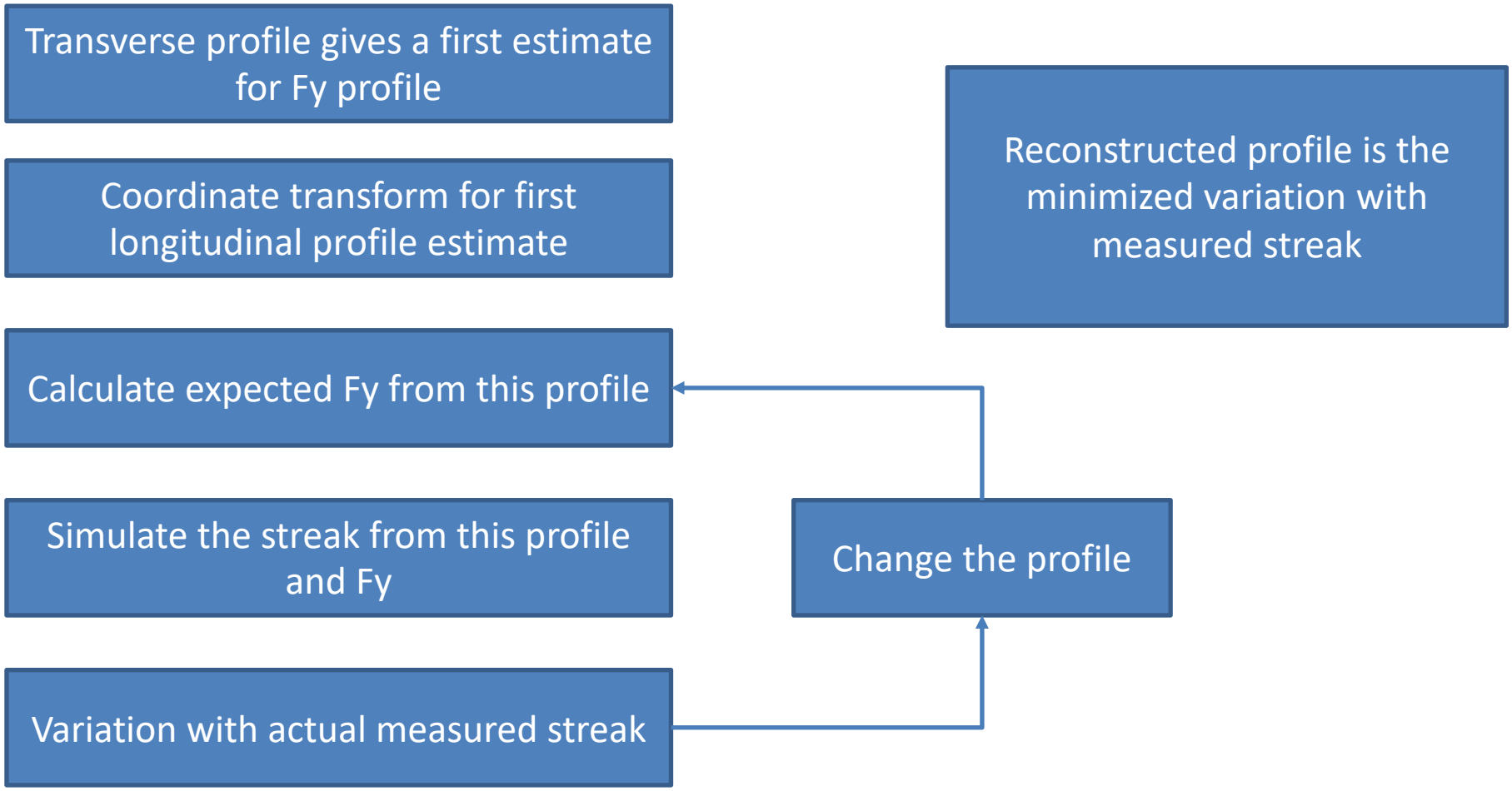


Average resolution for the 'long bunch' streaker with bunch length



Normalised average resolution for varying streaker type and offset

Bunch Profile Reconstruction



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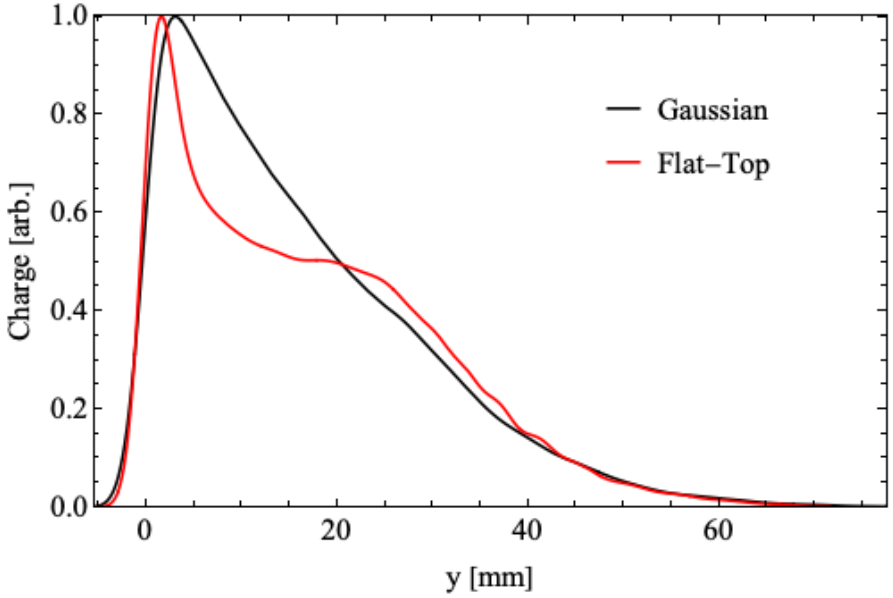
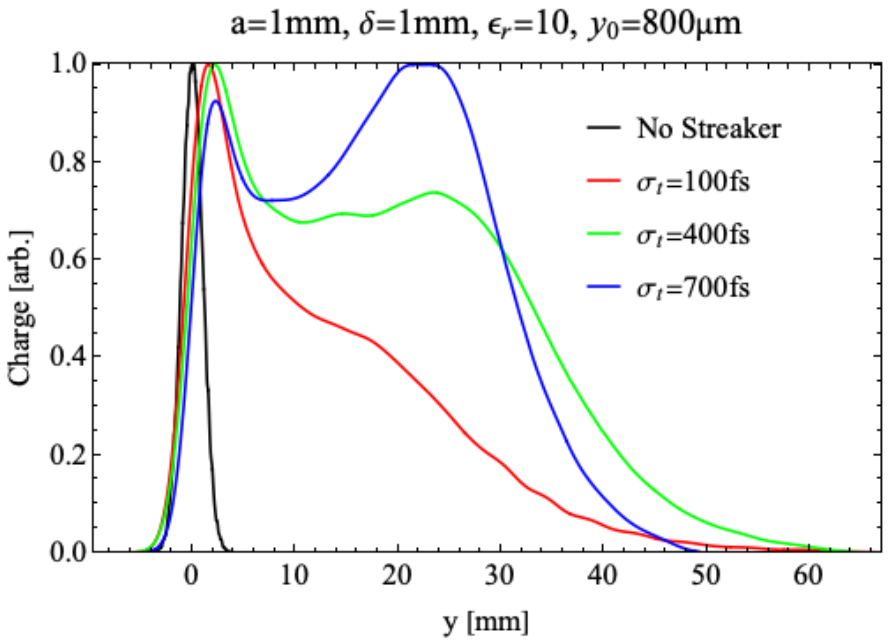
Conclusions and Outlook

- Dielectric streaker can be used to effectively convert longitudinal bunch profile to a transverse profile on screen
- Two ways to make this diagnostic work across a ‘broadband’ bunch length range
  - High frequency and low frequency streaker together
  - Reduce the offset for longer bunches
- Need to show reconstruction will work experimentally, especially with very short bunches
  - Upcoming experiments at the Gemini facility to test streaker and streak reconstruction

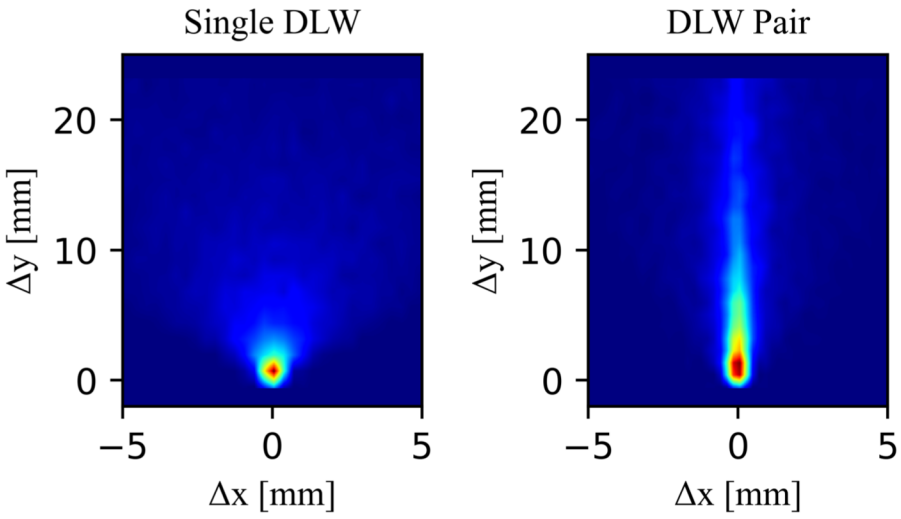
Additional slides

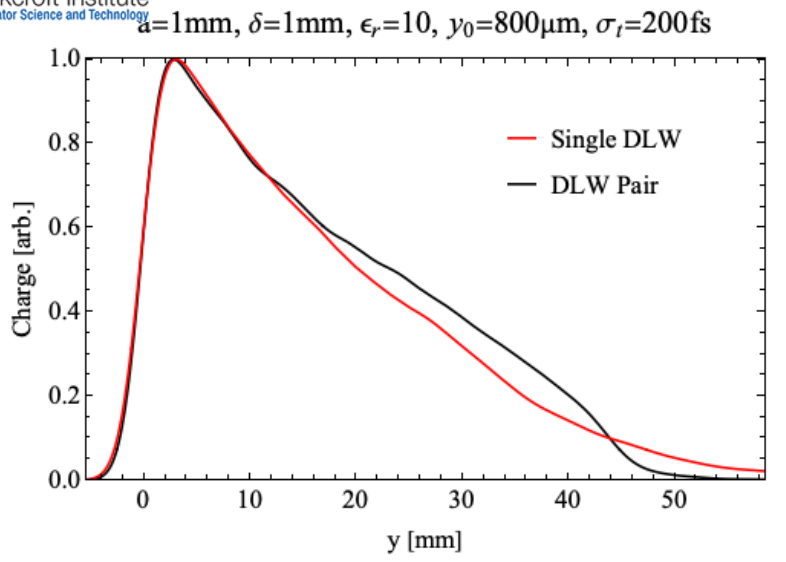
Varying Bunch Profile

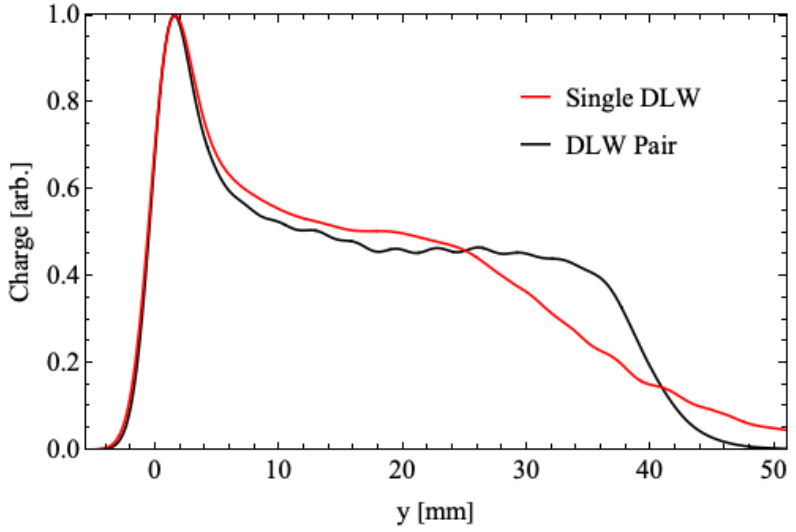




DLW Pair


Single DLW
DLW Pair
Δy [mm]
Δx [mm]
20
10
0
−5
0
5


a=1mm, δ=1mm, ϵr=10, y0=800μm, σt=200fs
Single DLW
DLW Pair
Charge [arb.]
y [mm]
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
50


Single DLW
DLW Pair
Charge [arb.]
y [mm]
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
50