FCC

# DISPERSION AT THE IPS:
# WHAT TO EXPECT, WAYS TO CORRECT

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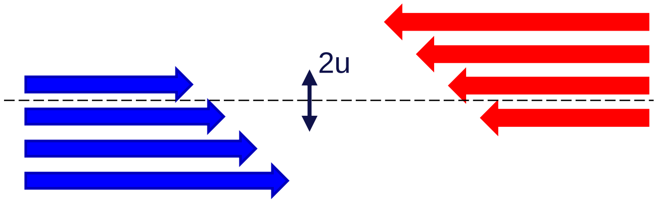
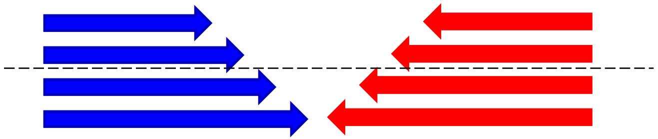
# Effect of dispersion at the IP

- Dispersion at the IP changes collision energy spread and, together with orbit offset $u$, leads to a shift of $E_{com}$
  - Studied in LEP where vertical bumps were used to avoid parasitic collisions, leading to vertical dispersion at IP [Ref]
  - For Gaussian beams with the same $\sigma_u = \sqrt{\beta_u^* \varepsilon_u}$, $\sigma_{u,Bx} = \sqrt{\sigma_u^2 + \left(D_{u,Bx}\sigma_\epsilon\right)^2}$ shift of centre-of-mass energy $\Delta E_{com}$ and $\sigma_{E_{com}}^2$ are:

$$\Delta E_{com} = -2u\,\frac{\sigma_E^2\left(D_{u,B1}-D_{u,B2}\right)}{E_0\left(\sigma_{u,B1}^2+\sigma_{u,B2}^2\right)} \qquad \sigma_{E_{com}}^2 = \sigma_E^2\left[\frac{\sigma_\epsilon^2\left(D_{u,B1}+D_{u,B2}\right)^2+4\sigma_u^2}{\sigma_{u,B1}^2+\sigma_{u,B2}^2}\right]$$



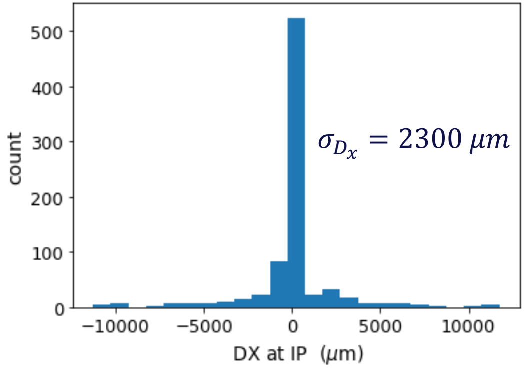

$D_{u,B1} \neq D_{u,B2}$

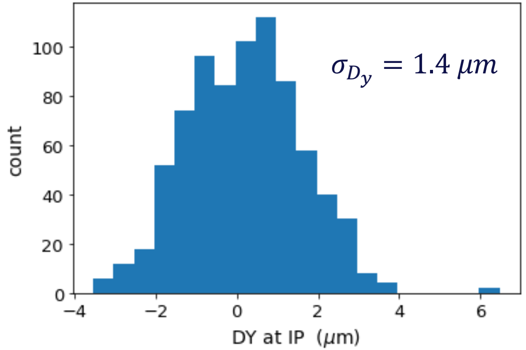


$D_{u,B1} = D_{u,B2}$

# Dispersion at the IP after correction

- Optics correction studies performed by T. Charles (see presentation next week)
  - Studies performed with 4 IP lattice and $t\bar{t}$ operation, applying a global correction scheme
  - In $Z$ operation, smaller $\beta^*$ and higher $D_x$ in the arcs, increasing sensibility to errors

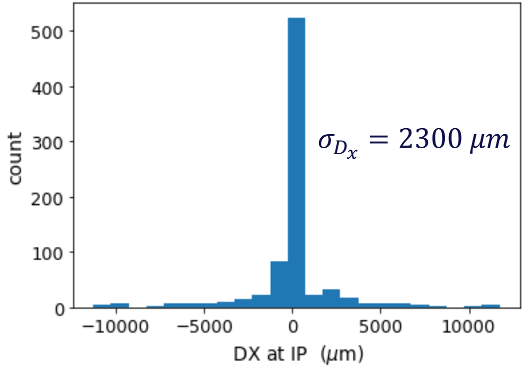


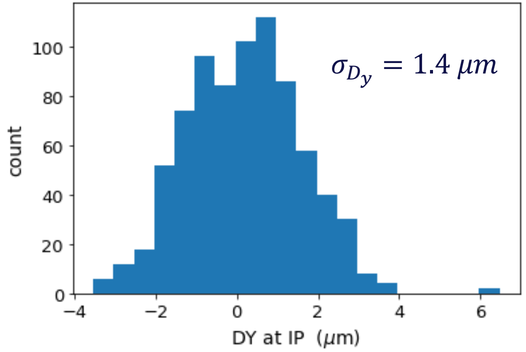




T. Charles

# Impact on $\Delta E_{com}$

- Assuming $\Delta E_{com} < 100\ keV$ together with design parameters for $Z$ and $\Delta D_y = 2.8\ \mu m$, we get $\Delta y < 0.5\ nm$ [cf. $\Delta y < 0.1\ nm$ and $\Delta D_y = 10\ \mu m$ in arXiv:1909.12245]
  - Relaxed in horizontal plane, $\Delta D_x = 4\ mm$ leads to $\Delta x < 20\ nm$ [cf. $\Delta x < 300\ nm$ and $\Delta D_x = 0.2\ mm$ in arXiv:1909.12245]

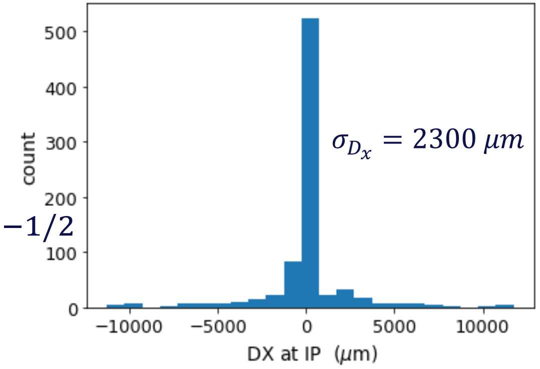


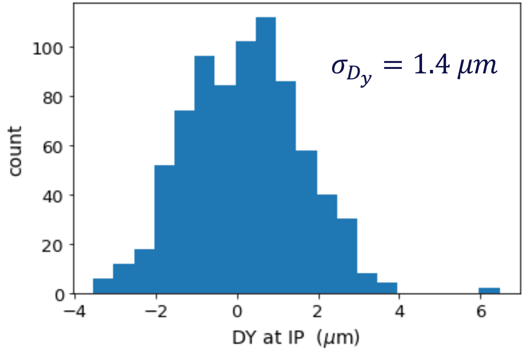




T. Charles

# Impact on $\sigma_{E_{com}}$

- Energy spread $\sigma_{E_{com}}$ affected by sign between beams
  - For $(D_{u,B1} = D_{u,B2})$ → $\sigma_{E_{com}} = \sqrt{2}\sigma_E$
  - In case $(D_u = D_{u,B1} = -D_{u,B2})$ → $\sigma_{E_{com}} = \sqrt{2}\sigma_E \left(1 + \left(\frac{D_u \sigma_\epsilon}{\sigma_u}\right)^2\right)^{-1/2}$
  - In vertical plane, difference between $(D_{y,B1} = D_{y,B2})$ and $(D_y = D_{y,B1} = -D_{y,B2})$ negligible and $\sigma_{E_{com}} = 85MeV$
  - In horizontal plane, $\sigma_{E_{com}} = 85MeV$ $(D_{x,B1} = D_{x,B2})$ to $\sigma_{E_{com}} = 80MeV$ $(D_{x,B1} = -D_{x,B2})$

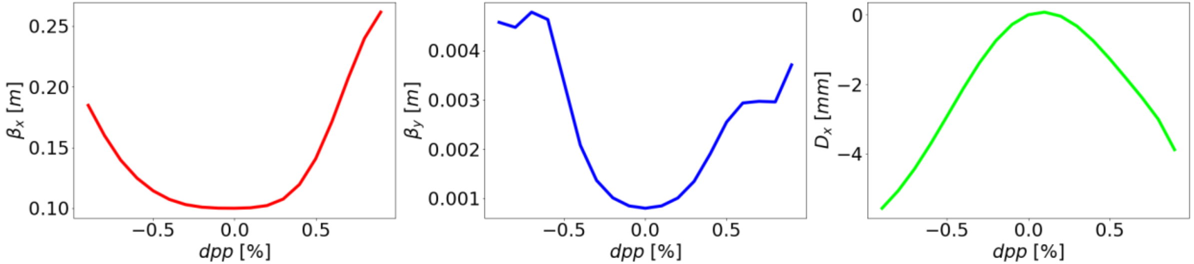



T. Charles

# Control of Dispersion at the IP

- Perform Vernier scans for different RF frequencies to obtain $\Delta D_y$
  - Measurement of luminosity for different separations $u$ of colliding bunches
  - Chromatic optics ($\beta_u^*(\delta), D_u^*(\delta), ..$) at IP may result in slight bias
    - Impact of misalignments to be studied

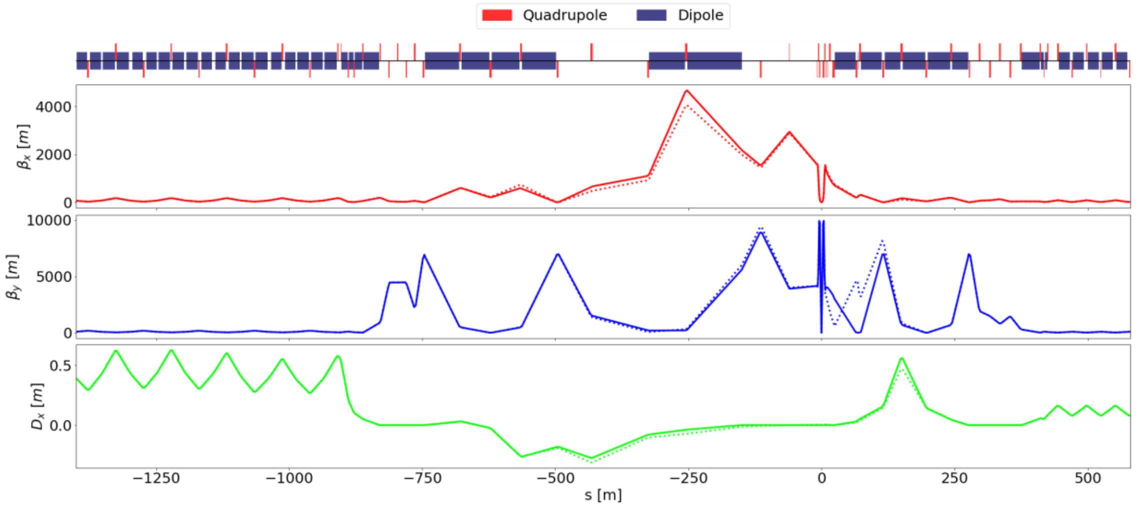



Chromatic optics at IP for latest 4-IP layout

  - Preceded by rough tuning via fast measurements with pilots and using IP BPMs (?)
    - Assuming equal distance between BPM and IP on either side and drift space between BPMs: $D_u^{ip} = 0.5\left(D_u^{bpm1} + D_u^{bpm2}\right)$
    - Complication due to Solenoid (see later)

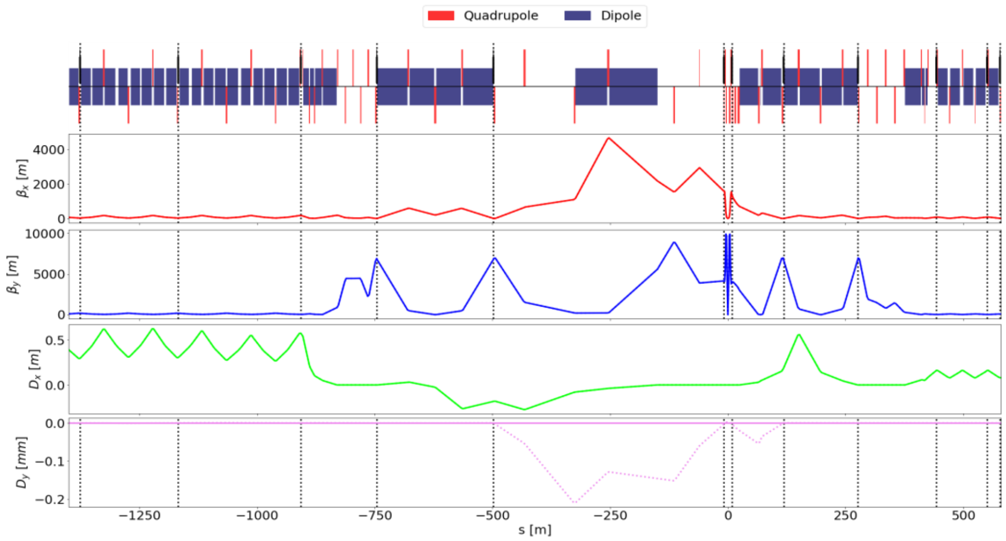
# Horizontal dispersion knob

- For control of horizontal dispersion (in order of ~mm) while keeping same linear optics at IP, knob constructed using final focus quadrupoles and quadrupoles next to crab sextupole
  - Some (unavoidable?) issues:
    - Phase constraints $\mu_{ip \to crab\ sextupole}$ broken and slight difference in linear optics between crab sextupole pair affecting cancelation of geometric sextupole terms
    - Impact on DA to be studied
    - No knob found with less quadrupoles



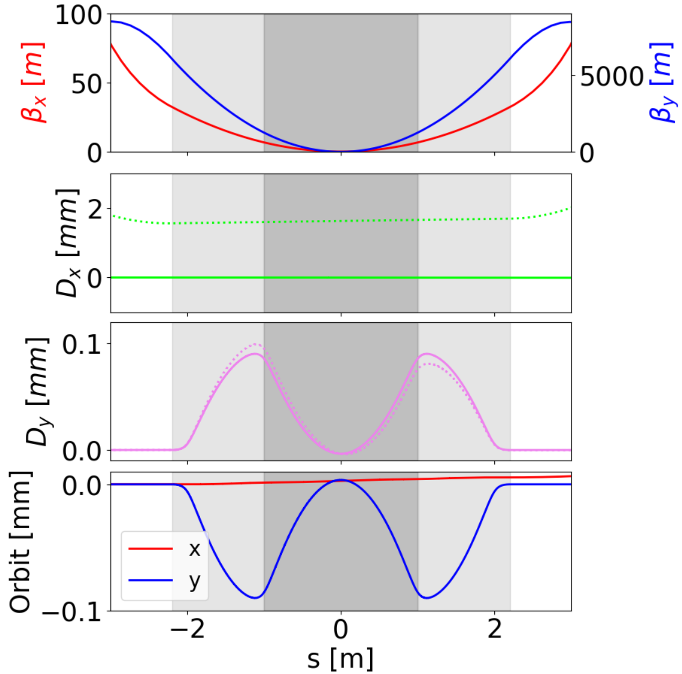
# Vertical dispersion knob

- To induce vertical dispersion at the IP,
  skew quadrupoles in final focus and next to crab sextupoles and arc sextupoles installed
  - For $D_y$ of $\sim\mu m$, no perturbation of linear optics and linear coupling induced at IP
    - Impact on chromatic properties to be checked



# Tilted Solenoid

- So far, drift space around IP assumed
  - Tilted solenoid affects orbit and introduces coupling
- Field map implemented by H. Burkhardt in MAD-X as thin solenoid slices and orbit correctors [Ref]
  - Solenoid generates $D_{x,y} \cong 3\ \mu m$ at IP, even in the ideal case
  - In test case, residual $D_x = 1.5\ mm$ at solenoid entrance adds $\Delta D_y = 0.2 \mu m$ at IP



# Conclusions

- Dispersion at the IP affects energy spread and, together with offset between bunches, the centre of mass energy

  - Latest tuning studies yield lower vertical dispersion at the IP compared to last report, without dedicated local correction

  - Knobs for control of dispersion at IP constructed, adverse side effects to be studied
    - Tilted Solenoid creates additional dispersion, model (and uncertainties) should be included in correction procedure

  - Next steps: add prelim. Knobs to IP correction suite and perform correction in lattices with errors

# Thanks for your attention!