Future Circular Collider Technical and Financial Feasibility Study
2d FCC Energy Calibration, Polarization and Mono-chromatisation workshop

WP2 summary

Relationship between average beam energy and centre-of-mass energies

FCC EPOL WORKSHOP

J. Keintzel, K. Oide, J. Wenninger

19-30 September 2022 at CERN

remote participation possible

https://indico.cern.ch/e/EPOL2022

Presentations

Tuesday 20th September

15:30 **Energy sawtooth due to SR and CM energy**
Speaker: Jacqueline Keintzel (CERN)
20220920_Keintzel_...

16:00 **Energy loss due to impendance and impact on local energy and on energy differences of colliding and non-colliding bunches**
Speaker: Emanuela Carideo (Sapienza Universita e INFN, Roma I (IT))
2022_09_20_EPOL_... 2022_09_20_EPOL_...

16:30 **Energy loss due to Beamstrahlung and impact on local energy and on energy differences of colliding and non-colliding bunches**
Speaker: Dmitry Shatilov (Budker Institute of Nuclear Physics (RU))
EPOL_shatilov.pdf EPOL_shatilov.pptx

17:00 **Beam-beam offset and OSVD**
Speaker: Jorg Wenninger (CERN)
OSVD.EpolWs-Sep2... OSVD.EpolWs-Sep2...

17:30 **Dispersion at the IPs: what to expect, ways to correct**
Speaker: Michael Hofer (CERN)
MH_FCC_EPOL_dis...

Monday 26th September

15:30 **Experience of collision control using beam-beam deflection at KEKB/SuperKEKB/PEP-II**
Speaker: Yoshihiro Funakoshi (KEK)
EPOL22_Funakoshi... EPOL22_Funakoshi...

Local energy vs average energy

Local energy != average beam energy:

- **Synchrotron radiation** losses → “classical” energy sawtooth.
- Energy loss **to impedances** → impedance energy sawtooth.
- Energy loss / change due to **beam interaction at IP**.
- **RF voltage and phase errors** if more than one IP → offsets to the sawtooth in diff sections of ring.
  - Importance of single RF system at Z,
  - Can be partly “measured” with IP boosts.

Sum of local energy != centre-of-mass energy:

- IP dispersion & beam offsets

And other effects due to optics non-linearities corrections etc

Local energy – synchrotron radiation sawtooth

Can *in principle* be evaluated with high precision if the **magnetic fields** are **known accurately**:

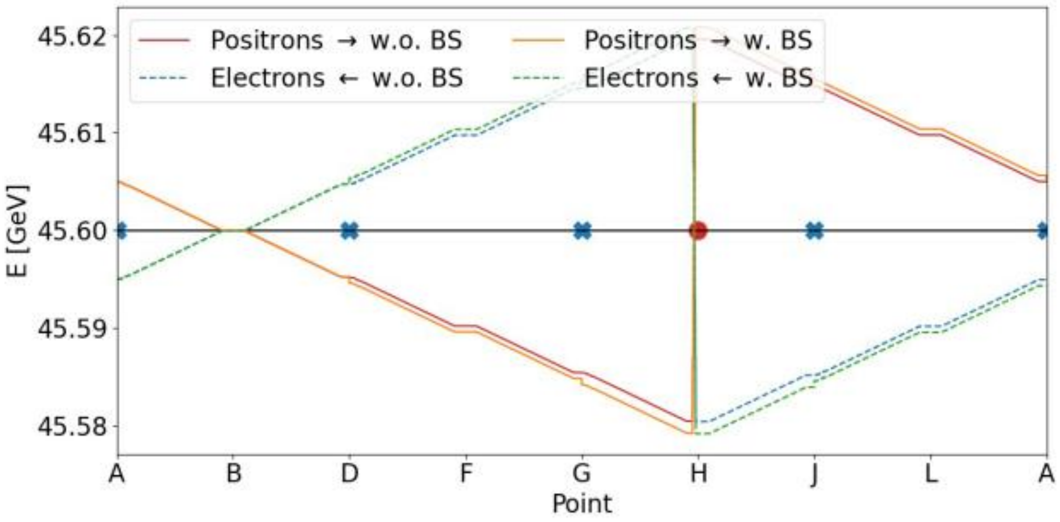
- **Dominant** contribution of **dipoles**: **requirement on field map accuracy** (also edge effects),
- Contribution of **quadrupoles, sextupoles**: require knowledge of beam offset in elements.
  - “0” in ideal tapered machine.
  - Need an **estimate** of the **uncertainty** due to BPM offsets.. for machines with errors.

$$\Delta E \propto \gamma_{\mathrm{rel}}^4$$

J. Keintzel

The absolute value of the energy loss must also be known with adequate accuracy!

- In principle *just* the sum of the contributions from individual elements.



Local energy – impedance

Overall effect less than **~10% of contribution synchrotron radiation** (@ Z).

- Contribution of **distributed sources** (RW, BPMs, bellow…) ~ **undistinguishable from SR**.
- Distributed sources known, but information on narrow band impedance source missing.

Dependance on **bunch length** and **bunch charge**:

- Non-colliding witness bunches affected differently than colliding bunches.
  - Visible as orbit difference if BPM resolution is adequate (can integrate a long time).
  - Validate impedance model by circulating bunches of different charge at the same time and observing orbit differences in dispersive sections.
- Time/bunch dependence of bunch length requires accurate tracking of longitudinal beam parameters.

@Z	Pilot bunch (3×10^{10} ppb)	Nominal intensity (2.6×10^{11} ppb)	Nominal intensity and beamstrahlung (2.6×10^{11} ppb)	SR
Energy spread	0.039 %	0.045 %	0.143 %	0.039 %
Energy loss	0.8 MeV	4.2 MeV	~ 1.6 MeV	39 MeV
Bunch length	5 mm	8.3 mm	17.2 mm	4.4 mm

E. Carideo

Constraining distributed energy losses

Boosts at the IPs – measurable with muon pairs provides 4 constraints on e+/e- difference.

Synchrotron tune: constraint on total energy loss + effective RF voltage.

High resolution orbit difference measurements:

- Bunches with different charges → impedance losses.
- Tapering on and off differences to observe the energy loss sawtooth ?
  - May not be trivial to switch on the fly with circulating beam.

Dispersion at IP

Separation between the two beams

Only the difference in dispersion matters, not the average value !

$$\Delta E_{CM} = -2u_0 \frac{\sigma_E^2(D_{u1} - D_{u2})}{E_0(\sigma_{B1}^2 + \sigma_{B2}^2)}$$

$$\sigma_{E_{CM}}^2 = \sigma_E^2 \left[\frac{\sigma_\epsilon^2(D_{u1} + D_{u2})^2 + 4\sigma_u^2}{\sigma_{B1}^2 + \sigma_{B2}^2}\right]$$

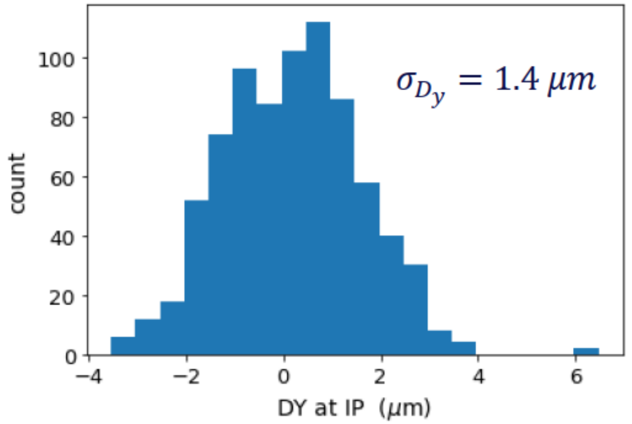
CM energy shift due **to combination of beam offsets and dispersion** @ IP.

To control the impact on ECM:

- Minimize the dispersion @ IP
- No beam offset (at least on average)

Latest set of simulations of machines with errors & corrections reach now **smaller residual D_y**:

- From rms D_y **~10 µm** to rms **~1 µm** → good news !
- Impact of solenoid (X → Y) on D_y to be considered.



Control of dispersion requires first a robust way to **measure the IP dispersion** – complex to perform on colliding beams due to the strong BB effect → need proper simulation of the process to include dynamic effects – Lifetrack etc.

Knobs to correct dispersion at IP – work started.

M. Hofer, T. Charles

Offset control

Bias-free control of IP offset at **<(<) 0.1σ** very challenging.

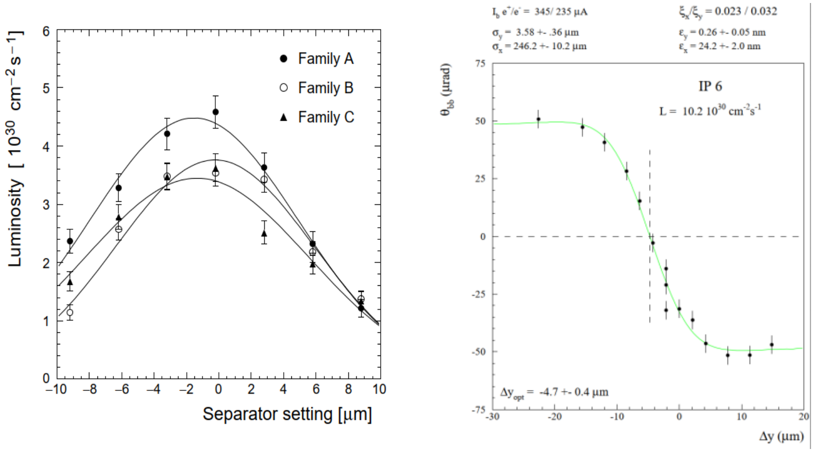
Various optimization techniques with luminosity or BB kicks.

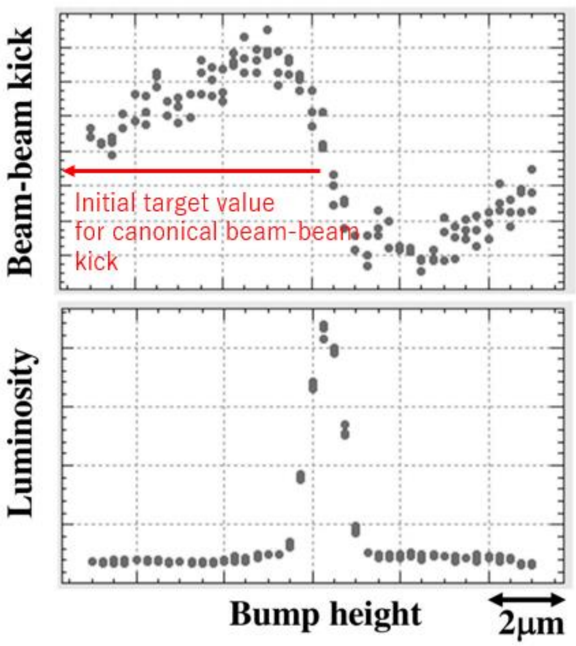
- Realistic simulation of dynamic effects during a scan @ FCCee required to progress.

(super-)KEKB IP feedbacks based on BB kick successful in controlling beam offsets and optimizing integrated luminosity.

- pre-set reference from BB scan: not accurate enough for FCCee needs?

LEP





Vertical (scan vertical offset at IP)

Y. Funakoshi

- One of annoying issues with the orbit feedback using the beam-beam deflection method is the stability and the beam current dependence of the target value of the canonical beam-beam kick.
  - We have not yet found a method to stabilize the target value.

Interaction point effects

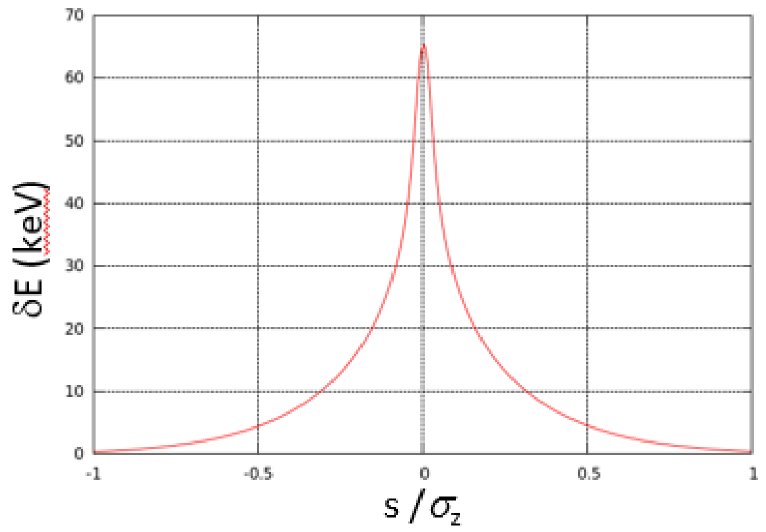
CM energy shift due to **acceleration of incoming beam** (compensated by deceleration of outgoing beam).

- Shift is function of the charges of the colliding bunch pairs → spread.
- Evaluate the uncertainty on this shift.
  - Knowledge of absolute crossing angle value etc

$$\delta E = \langle E \rangle - E_0 \qquad \langle E \rangle = \frac{\sum E_c L_c}{\sum L_c}$$

E (GeV)	45.6	80	120	182.5
δE (keV)	61	108	212	1480

D. Shatilov



There is still a lot of work to come – no time to rest !

Work on the errors, work on corrections (Dy…), work on "procedures" (beam overlap, Dy @ IP)…

Thank you to all speakers and participants !