FCC-ee Beam Polarization and Energy Calibration

**Beam Energy measurement by Resonant depolarization**

This is a well known method, which has been used to measure particle masses such as the j/ψ at Novosibirsk, the \( m_t \) at HERA and the `T mass at DORIS (DESY). The 2 mass at LEP. It requires transverse polarization of the beams.

**Beam polarization**

In FCC-ee the e+ and e- beams polarize naturally along the magnetic field by Sokolov-Ternov effect. Excellent levels of asymmetric polarization are expected in FCC-ee at the Z and sufficient at the W.

**Polarization Wiggler**

The polarization time at the Z is slow, (250 hrs)

\[
\gamma = \frac{1}{\sqrt{1 - v^2}}
\]

It can reduced using asymmetric Polarization wigglers placed in Dispersion-free regions (HF).

8 such units per beam with

\[ B = 0.7 \times \frac{1}{(1 - \frac{43cm}{L + 20cm} + \frac{89cm}{B + 6cm} + 8atm + 45.6 GeV + \frac{80.67cm}{(E_{\gamma} = 902 keV) \text{ will provide a polarization level of } P=10\% \text{ in } 1.8H \text{ at } Eb= 45.6 \text{ GeV and } B=+0.67 \text{T (E_{\gamma} = 902 keV) }}\]

**Resonant depolarization**

A visible depolarization can be realized with a transverse kicker excited at a frequency in resonance with the spin precession frequency. The b+ beam is therefore depolarized and the bunch crossing rate at the Z is \( 1/10\).s.

The process has been simulated by I. Koop for FCC-Z with spin precession frequency a.k.a. spin tune kicker excited at a frequency in resonance with the spin precession frequency.

The spin tune is proportional to the beam energy.

**Beam energy uncertainties**

The proportionality between spin tune and beam energy is rigorously true only if the ring is perfectly planar. A certain number of effects resulting from imperfections in the ring can affect this relation and bias the beam energy calibration.

**From spin tune measurement to center-of-mass determination**

--- Synchronon radiation energy loss : 0.1% \( 9 \text{ MeV (2\% in } 4 \text{ sec) } \text{ calculable to better than } \pm 100 \text{ keV} \) per measurement. W in progress.

--- Beamstrahlung energy loss \( \pm 57 \text{ keV} \) \( 0.62 \text{ MeV per beam at } 2 \text{, compensated by RF (Shatilov)} \)

--- Beam energy spectrum without/with beamstrahlung

--- Layout of accelerator with IPs between two arcs well separated from RF

--- \( \Delta E_{\text{z}} = \frac{1}{2}(E_{\text{in}} + E_{\text{out}}) = \frac{1}{2}(E_{\text{in}} + E_{\text{out}} \cos(\Delta \theta_{\text{CM}}/2)) \)

--- E_{\text{z}} vs \( E_{\text{in}} \) asymmetries and energy spread can be measured/monitored in event, using e+ → γ → μ+ events longitudinal momentum shift and spread (Janot)

--- in two minutes at the Z the energy spread and the difference of energy between the two beams can be measured to \( \pm 40 \text{ keV} \)

--- Opposite sign dispersion

Since the two beams circulate in two independent rings it is unavoidable that there will be a residual opposite sign dispersion in both x and y planes. This can bias the center-of-mass energy.

For FCC-ee at the Z in the vertical plane we have: Dispersion of e+ and e- beams at the IP is \( \sqrt{2} \text{abc} \) (b: 28µm)

\[ \Delta E_{\text{y}} = \Delta E_{\text{y}} \text{ at } 2 \text{ in the vertical plane} \]

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