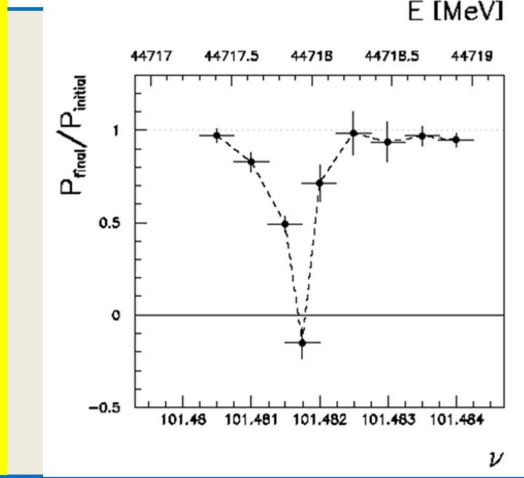
FCC-ee Beam Polarization and Energy Calibration



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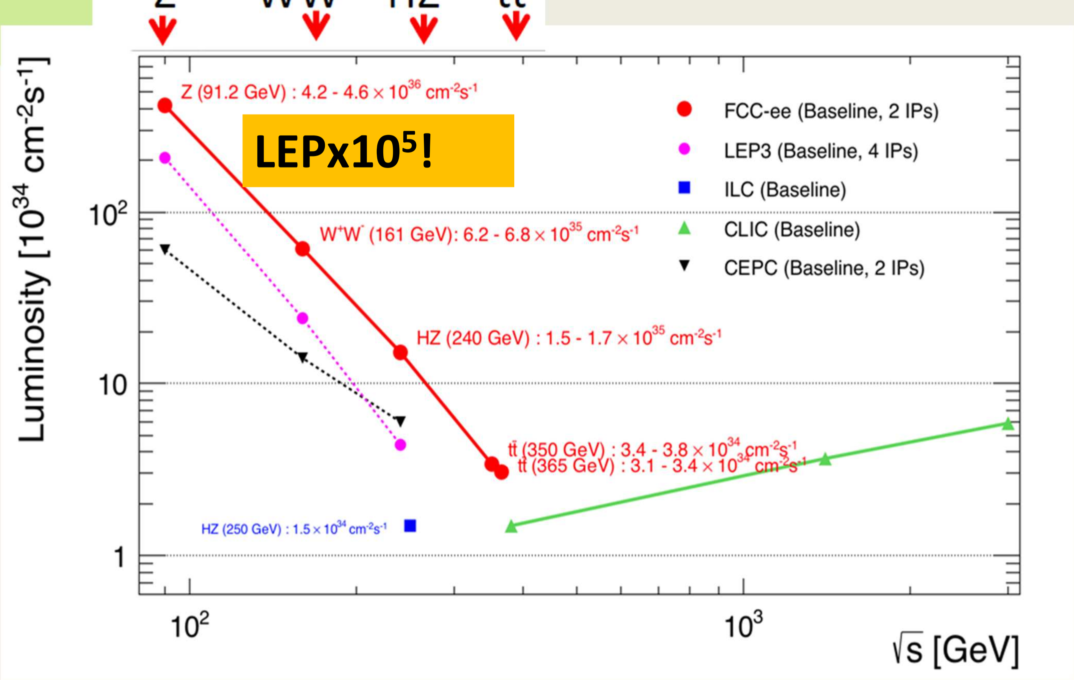
Electroweak Factory

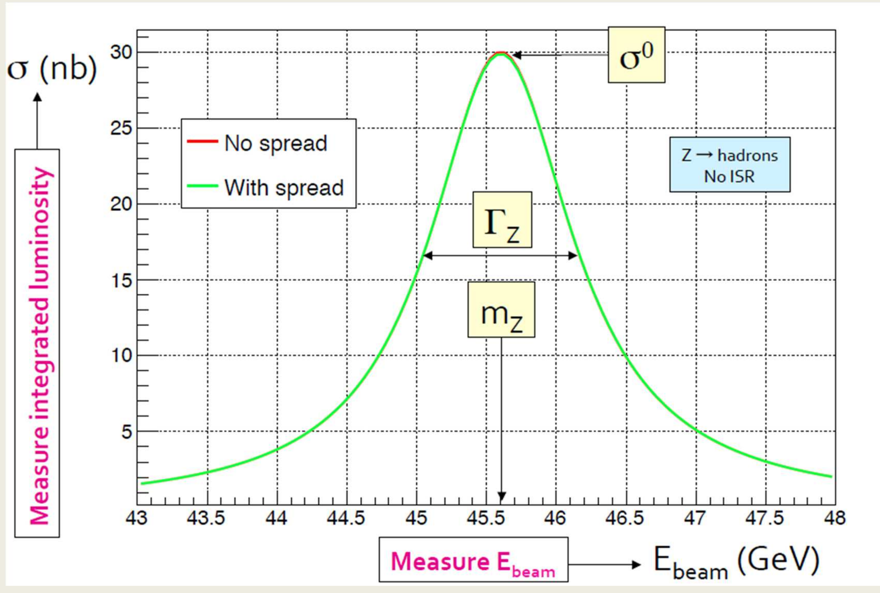
Z WW HZ tt

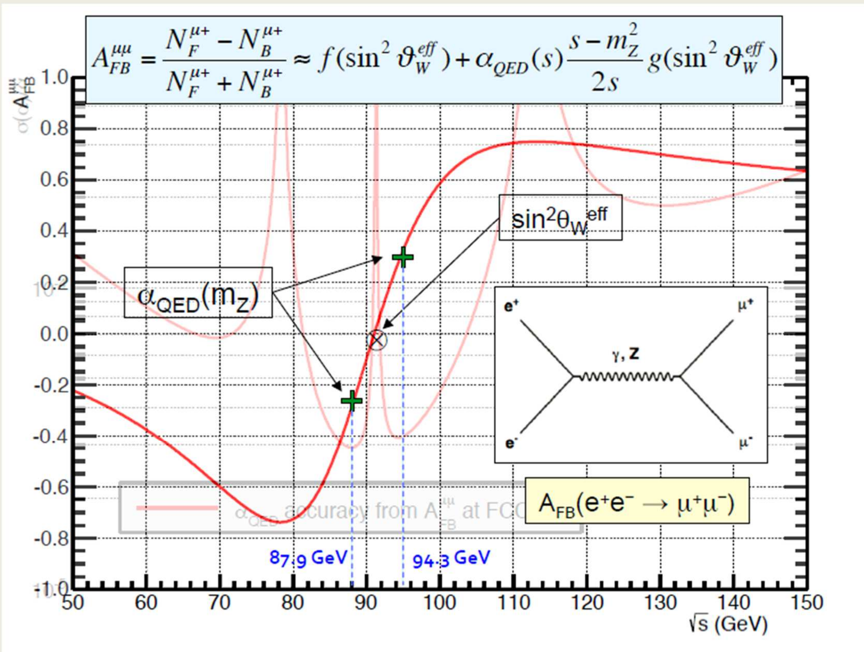


$5\ 10^{12}$	Z
10^8	WW
10^6	ZH
10^6	tt

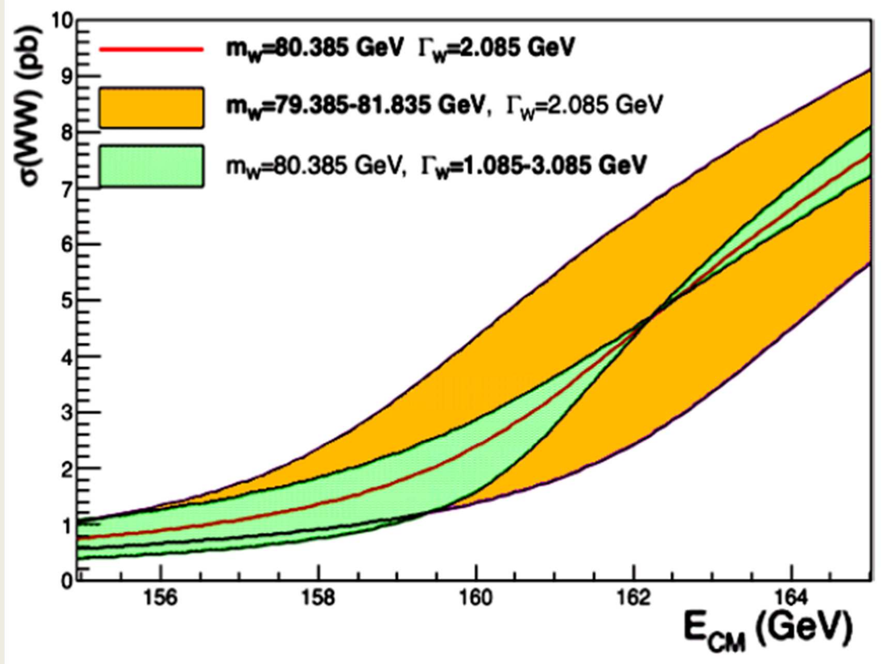
FCC-ee will produce huge statistics of Z and Ws and millions of Higgs and tops.
This is an opportunity to perform extremely precise measurements of many electroweak bservables, such as mass and width of the Z, Z pole asymmetries, the W, & top quark masses, and Higgs mass and width. The quatities are **sensitive to new physics up to 10-100 TeV** (decoupling) or possibly much more (non decoupling)

This requires an extremely precise knowledge of the beam energy,
UNIQUE TO THE CIRCULAR e+ e- COLLIDERS





Physics priorities scan points



Scans using the half integer spin tunes have been designed for the FCC-ee running across the Z line shape and at the W W threshold. In order to avoid extrapolation errors, a set of 200 'pilot' bunches – having no colliding counterpart, will be stored

at the beginning of fills with polarization wigglers ON, for about 1.5 hour to develop about 5-10% transverse polarization, then, after a first Energy calibration is performed, the full luminosity run will take place with regular calibration on the 'pilot' bunches.

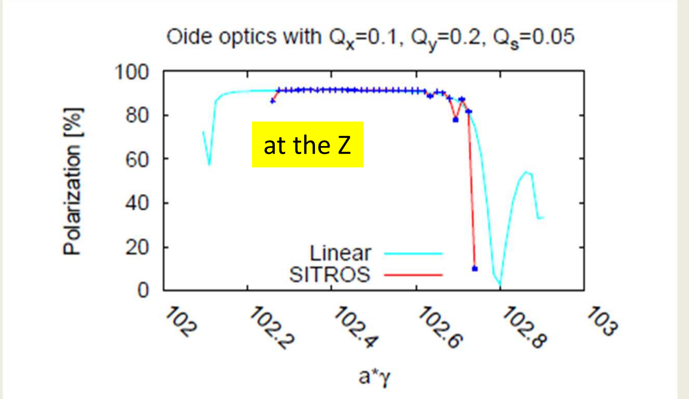
Goal precisions; uncertainties on
m_Z, Γ_Z : ±100 keV , m_W : ±300 keV – or better.

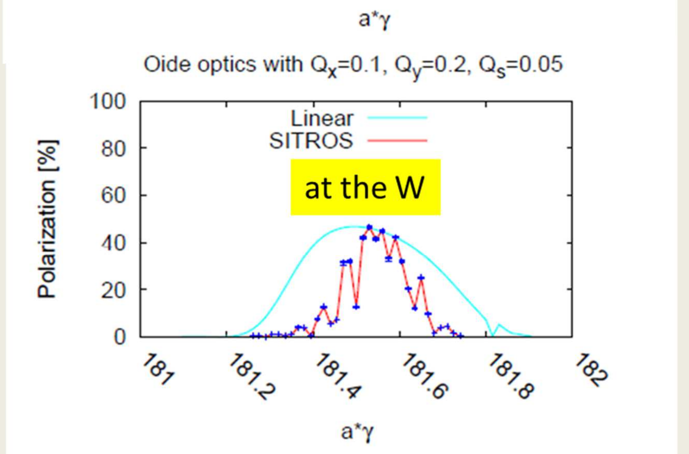
Beam Energy measurement by Resonant depolarization

This is a well known method, which has been used to measure particle masses such as the J/ψ à Novosibirsk, the τ mass at IHEP Beijing, the ϒ mass at Doris (DESY), the Z 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 asymptotic polarization are expected in FCC-ee at the Z, and sufficient at the W.



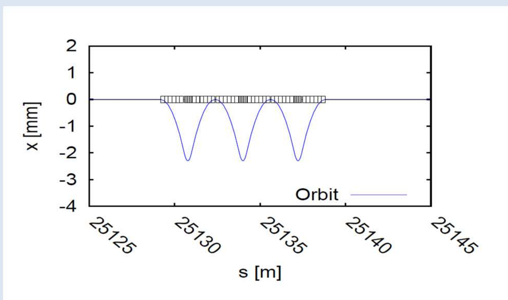


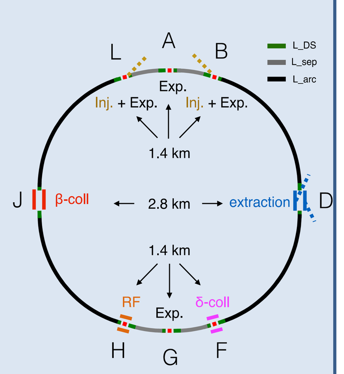
Polarization Wigglers

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

$$\tau_p = \left(\frac{5\sqrt{3}}{8}\frac{\hbar r_e E_{beam}^5}{m_e^6 \rho^3}\right)^{-1}$$

It can reduced using asymmetric **Polarization wigglers** placed in dispersion-free regions (H,F)





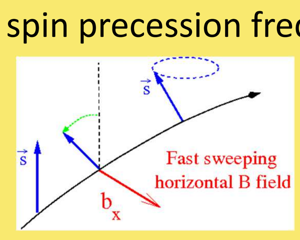
8 such units per beam with

B+=0.7 T L+ = 43cm L-/L+ = B+/B- = 6
at Eb= 45.6 GeV and B+= 0.67 T (E_{crit}=902 keV)

will provide a polarization level of P=10% in 1.8H while increasing the energy spread within a reasonable value of σ_{Eb} = 60 MeV

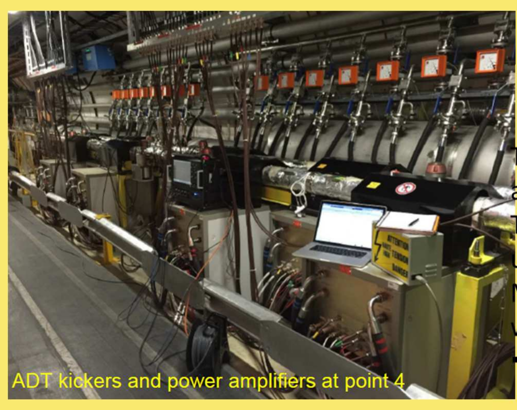
Resonant depolarization

A visible depolarization can be realized with a transverse kicker excited at a frequency in resonance with the spin precession frequency a.k.a. spin tune ν



$$\nu = a_e\gamma = \frac{g_e - 2}{2}\frac{E_{Beam}}{m_e c^2} = \frac{E_{Beam}}{0.4406486(1)}$$

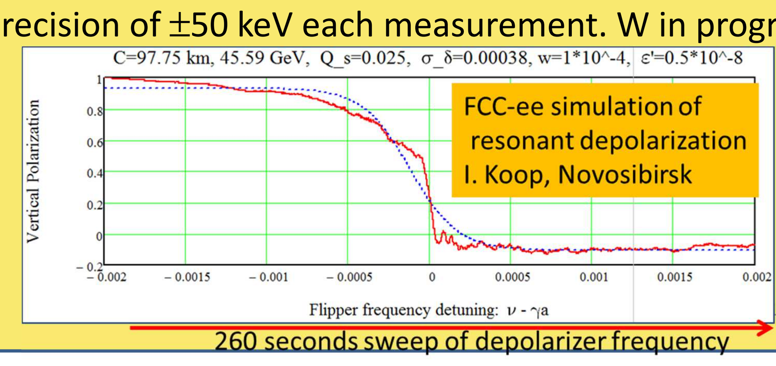
The spin tune is proportional to the beam energy



The bunch crossing rate at the Z is 1/10ns.

The LHC TF system works essentially on a bunch by bunch basis for 25ns. They would provide a transverse kick of up to ~20 mrad at the Z peak with ~10 MHz bandwidth. This is 10x more than what we may need-
➔ **a priori OK !**

The well known plot shown in banner of this poster shows the precise location of the resonance (in that case 100keV)
The process has been simulated by I. Koop for FCC-Z with a precision of ±50 keV each measurement. W in progress.



260 seconds sweep of depolarizer frequency

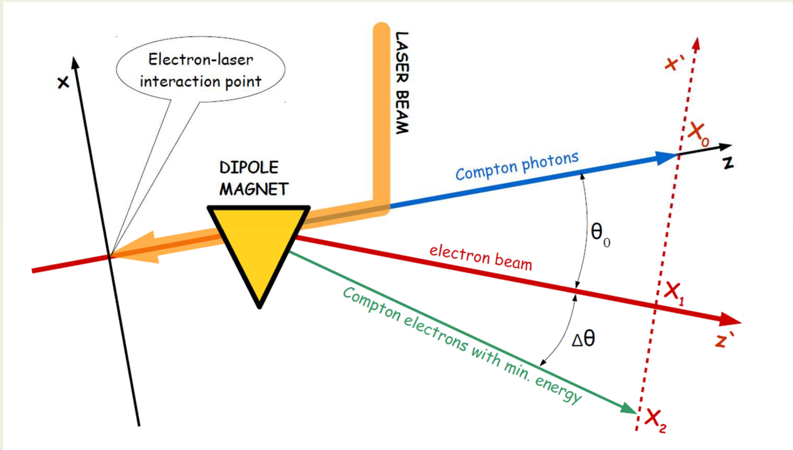
Beam energy uncertainties

The proportionality between spin tune and beam energy is rigourously 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.

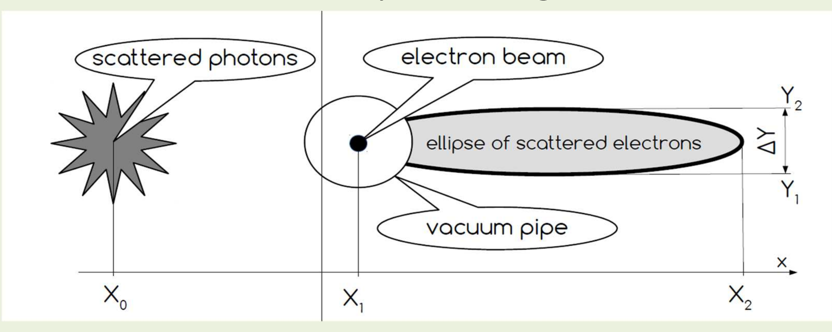
source	ΔE/E
synchrotron oscillations	$2\ 10^{-14}$
Energy dependent momentum compaction	10^{-7}
Solenoid compensation	$2\ 10^{-11}$
Horizontal betatron oscillations	$2.5\ 10^{-7}$
Vertical betatron oscillations	$2.7\ 10^{-7}$
Horizontal correctors	$2\ 10^{-7}$
Uncertainty in chromaticity correction	$5\ 10^{-8}$

Polarization measurement

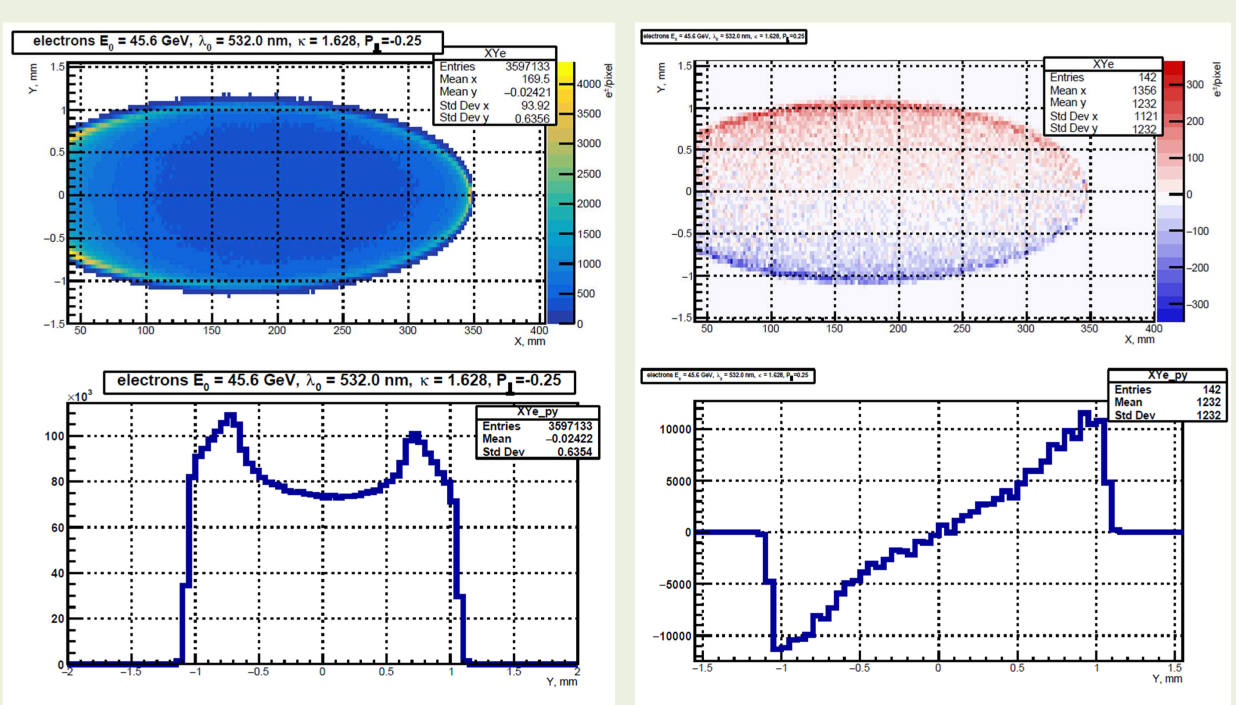
The electron or positron beam polarization can be measured with a compton backscattering polarimeter. This technique was already used at LEP, where only the backscattered photons were detected. The FCC-ee polarimeter, designed by Muchnoy, proposes to use also of the recoil electron to increase the sensitivity.



There will be two polarimeters, for e+ and e-, using the dispersion suppressor magnet, as the beam enters points H and F on the locally outer ring.



The polarimeter is sketched above. The e-γ IP is situated upstream of a ring magnet with suitable optics, so that the backscattered photon beam is centered on X_o, in the direction of the original beam, while the recoiling electrons are defelected by the magnet and measured between X_1 (the unscattered beam) and X_2 (for the slowest electrons). For a 45 GeV beam and a distance of the detection plane of 100m from the e-γ IP, X_2 - X_o = 638 mm. The end point moves by 2.4 microns for a variation of energy of 10^{-5}. **The polarimeter thus acts as a spectrometer, capable of constantly monitoring the beam energy with a sensitivity of a few 10^{-5}.**

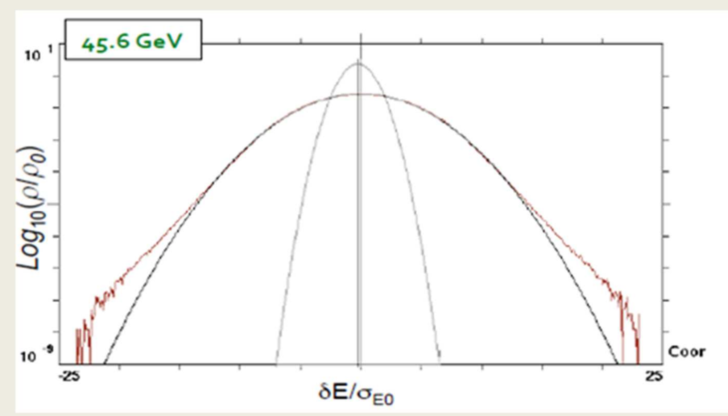


The measurement of polarization will be made, as in LEP, by observing changes in the recoil electron and photons, upon reversing the circular polarization of the incoming laser beam. The beam spot of the photon beam will move by about ± ***P** x1.4 mm* at a distance of100 m. If the polarization is small this movement can be mistaken with a movement of the beam. The change for the electron recoil is more distinctive: the change in the relative population of the outer ring of the electron recoil spot is unmistakable. It was concluded that the beam polarization can be measured with a precision of ±1% per second.

From spin tune measurement to center-of-mass determination

-- Synchrotron Radiation energy loss: ±9 keV
9 MeV @Z in 4 'arcs') calculable to < permil accuracy

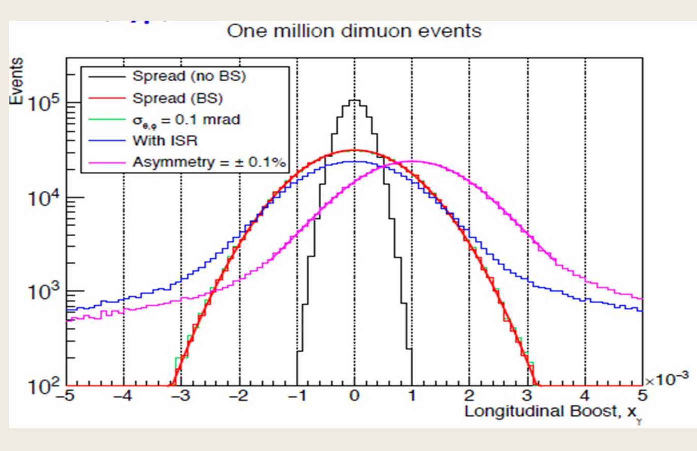
-- Beamstrahlung energy loss ±7 keV
0.62 MeV per beam at Z, compensated by RF (Shatilov)



Beam energy spectrum without/with beamstrahlung

-- layout of accelerator with IPs between two arcs well separated from RF
➔ 0.5 (E_{CM}^A + E_{CM}^G) = (E_b^+ +E_b^-) cos($\alpha_{crossing}$/2)
the average of the two experiments remains correct.
but more to do on phases and alignment, unless all RF is on one side of the ring.

-- E_b^+ vs E_b^- asymmetries and energy spread can be measured/monitored in expt, using e+e- ⟶ μ+ 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 ± 40 keV.

Opposite sign dispersion

$$\Delta E_{CM} = -\frac{1}{2}\cdot\frac{\delta y}{\sigma_y^2}\cdot\frac{\sigma_{E_b}^2}{E_b}\cdot\Delta D_y^*$$

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 O(20um)
➔ $\Delta D_y^* = 28\mu m$.
Sigma_y is 30nm
Sigma_E is 60MeV
Delta_ECM is therefore 4MeV for a 10% offset offset of the beams
Assume each Vernier scan accurate to 1% sigma_y
We need 100 Van der Meer scans to get an E_{CM} accuracy of 40keV, this will require a Vernier scan every hour to be performed and recorded.
further analysis of the problem is underway.

CONCLUSIONS

We are well on track to achive center-of-mass Energy calibration systematics at the level of 100 keV at the Z and 300 keV at the W.

There remains a number of issues
-- -- Opposite sign vertical dispersion : size of effect, correction strategy
-- anti correlation of ECM between expts due to RF
-- correlation matrix of sum and difference between experiments
-- Depolarization for W
-- general issue of software codes: polarization and orbit corrections are not integrated.