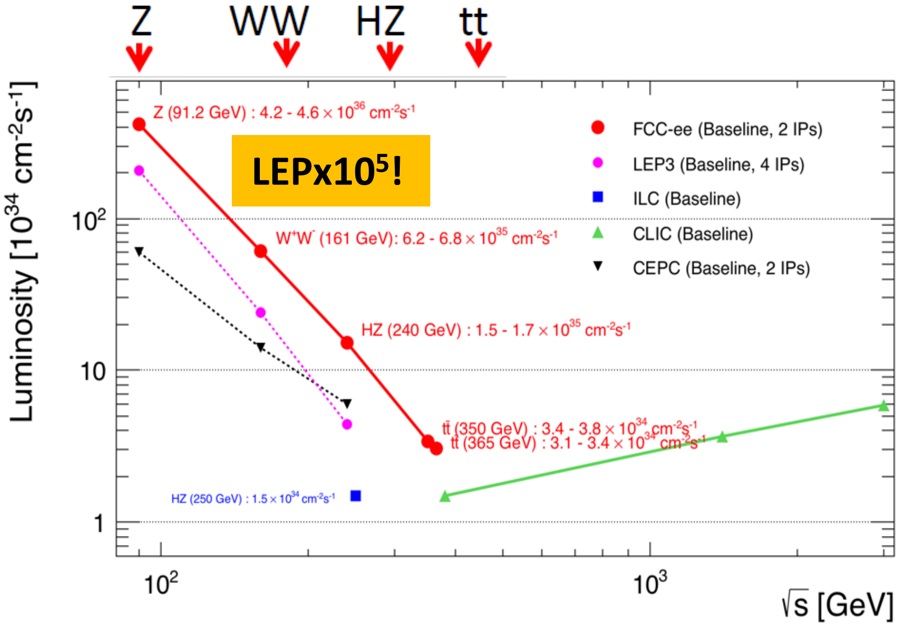
FCC-ee beam polarization and centre-of-mass energy calibration

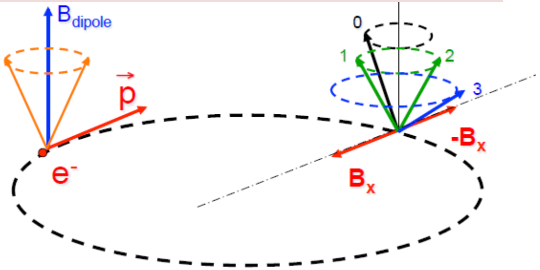
arXiv:1909.12245

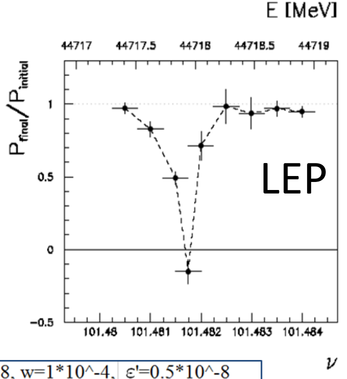


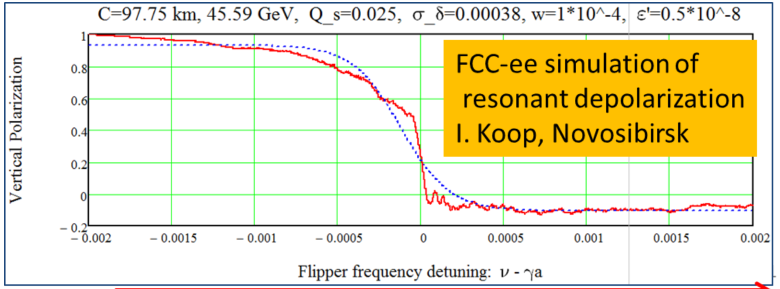
Higgs and Electroweak Factory

$5\ 10^{12}$	Z
$3\ 10^{8}$	WW
10^{6}	ZH
10^{6}	$t\bar{t}$

Resonant depolarization





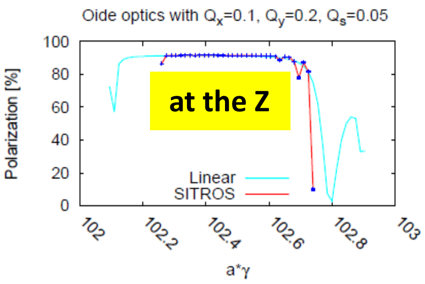


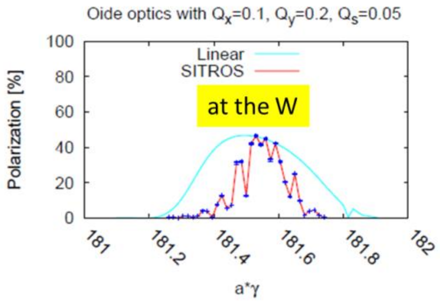
260 seconds sweep of depolarizer frequency

$$\nu_s = \frac{g-2}{2}\frac{E_b}{m_e} = \frac{E_b}{0.4406486(1)} = 103.5 \text{ @ Z}$$

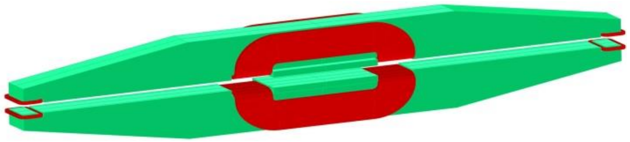
Beam energy determination with 10^{-6} accuracy

HAVING WAT WE NEED

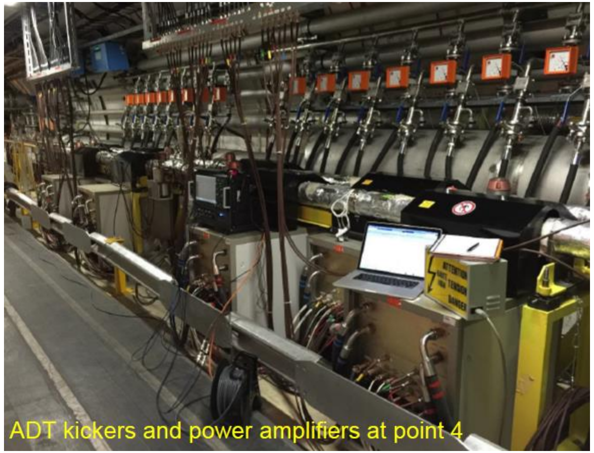




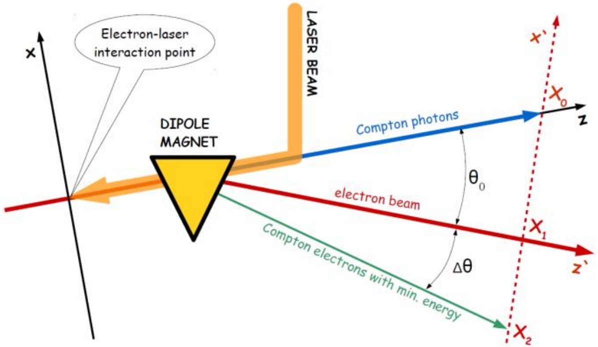
e+ and e- beam polarization will be available up to at least the W pair threshold



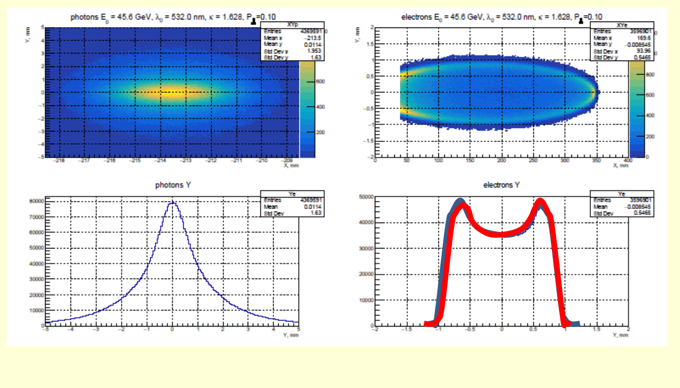
polarization wigglers will speed up polarization at the start of fills, for ~200 (out of 16500) bunches/beam



RF Kickers similar to LHC will have the required qualities



Laser polarimeter and spectrometer
(one for each e+ and e- beams)
measure both recoil photon spot and scattered electrons and positron



From beam energy to E_{CM}

$$\sqrt{s} = 2\sqrt{E_b^+ E_b^-}\cos\alpha/2, \quad \approx E^+_b + E^-_b$$

Energy gain (RF) = losses in the storage ring
Synchrotron radiation (SR)
beamstrahlung (BS)

$\Delta_{RF} = 2\Delta_{SRi} + 2\Delta_{SRe} + 2\Delta_{BS}$

at the Z (O of mag.):

$\Delta_{SR} = 2\Delta_{SRi} + 2\Delta_{SRe}$ =36 MeV

$\Delta_{SRe} - \Delta_{SRi} \approx \alpha/2\pi\ \Delta_{SR}$ = 0.17 MeV

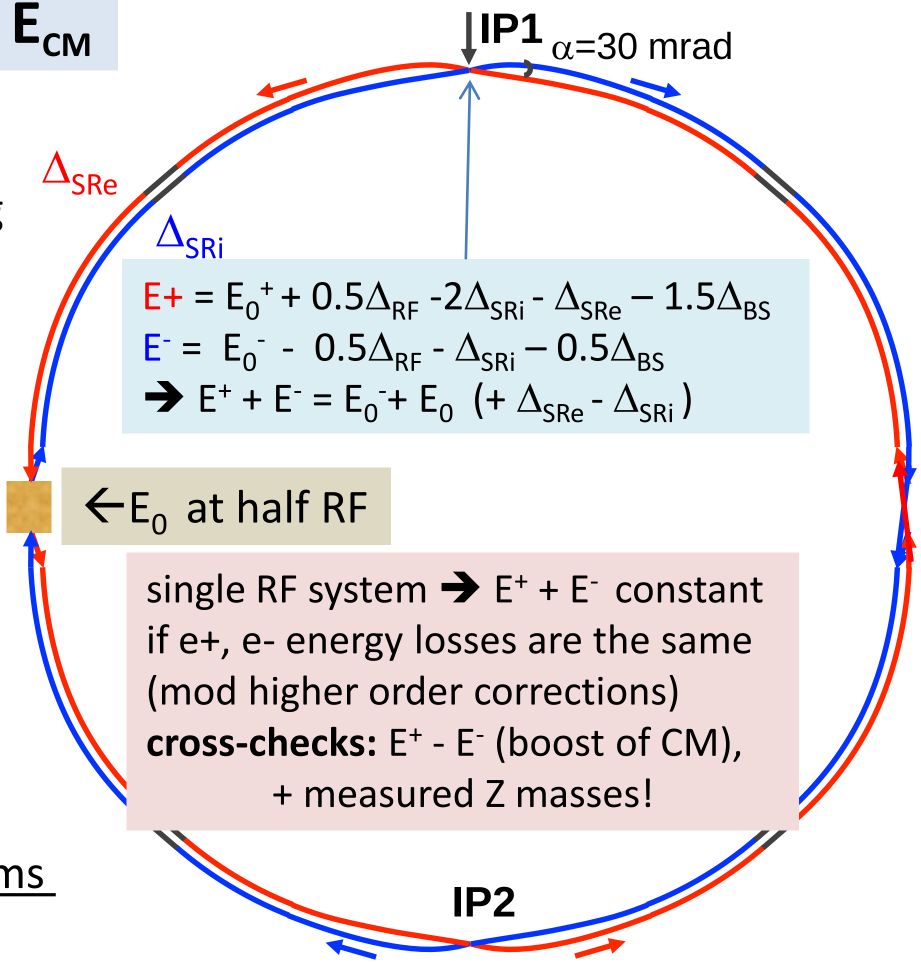
Δ_{BS} = 0 up to 0.62 MeV

the average energies E_0 around the ring
are determined by the magnetic fields

➔ same for colliding or non-colliding beams

-- measured by resonant depolarization

-- can be different for e^+ and e^-

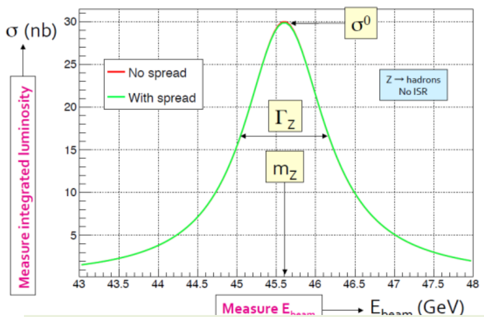


$E+ = E_0^+ + 0.5\Delta_{RF} - 2\Delta_{SRi} - \Delta_{SRe} - 1.5\Delta_{BS}$
$E^- = E_0^- - 0.5\Delta_{RF} - \Delta_{SRi} - 0.5\Delta_{BS}$
➔ $E^+ + E^- = E_0^- + E_0$ $(+\Delta_{SRe} - \Delta_{SRi})$

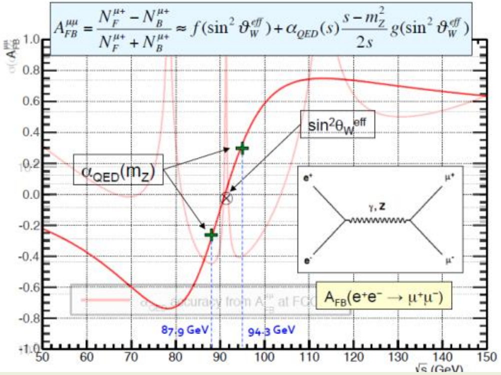
← E_0 at half RF

single RF system ➔ $E^+ + E^-$ constant
if e+, e- energy losses are the same
(mod higher order corrections)
cross-checks: $E^+ - E^-$ (boost of CM),
+ measured Z masses!

Physics: scan points and output quantities



Z line shape → m_Z and Γ_Z



at the same time $A_{FB}^{\mu\mu}(\sqrt{s})$

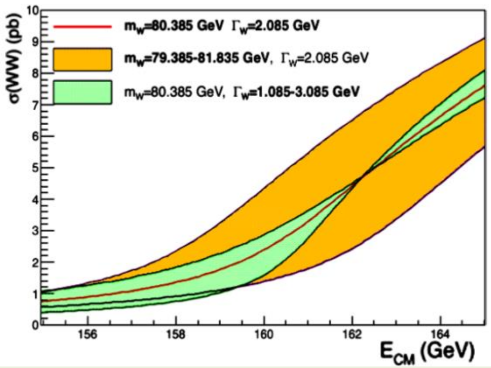
→ $\sin^2\theta_W^{eff}$, $\alpha_{QED}(m_Z)$

Use half integer spin tune energies
for Z line shape, lucky:
ν= 99.5, 103.5, 106.5/107.5
and
W W threshold ν= 178.5, 184.5

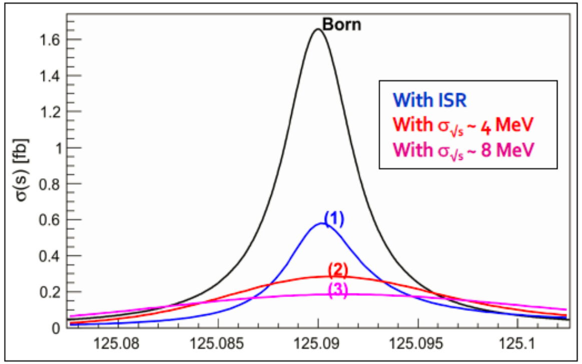
for the Higgs, bad luck!
$\nu = m_H/2/.4406486\ (1) = 141.95$
--too close to integer for polarizazion–
→ 141.48 for e+ and 142.47 for e-

200 'pilot' bunches will be stored at the beginning of fills with polarization wigglers ON, for about 1 hour to develop about 5-10% transverse polarization.

After a first energy calibration, the full luminosity run will comprise regular calibrations (1/10 min) on pilot bunches.



WW threshold→ m_W and Γ_W



Higgs s-channel production need to know E_{cm} σ_{ECM}

Beam energy uncertainties

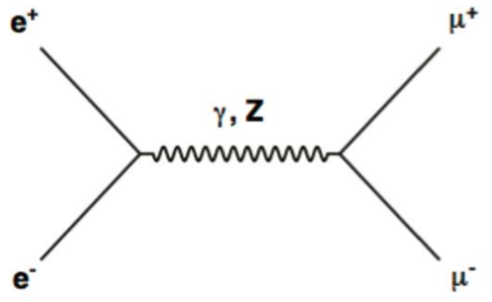
Absolute: The proportionality between spin tune and beam energy is rigourously true only if the ring is perfectly planar. A certain number of effects resulting from imperfections in the ring can affect this relation and bias the beam energy calibration. Other effects such as opposite sign dispersion at the IRs also need to be considered and tackled
At this point 100keV (300keV) uncertainty a Z (WW) can be expected, but experiments can be devised to reduce it. This mostly affects the Z and W masses.

Relative ptp (Energy point to Energy point): The Z width, and $A_{FB}{}^{\mu\mu}$ depend on relative uncertainties between the scan points. When considering only errors that can be different between scan points a relative error of ~±20keV at the Z is inferred. Experimental verification either with the polarimeter-spectrometer or using muon pairs can be made at **±40 keV** on a daily basis.

Energy spread. knowledge of energy spread is critical for the Z width measurement and fo the s-channel Higgs production. It is extracted from the muon pairs with sufficient precision.

A thousand recipes to use up dimuon events at the FCC-ee

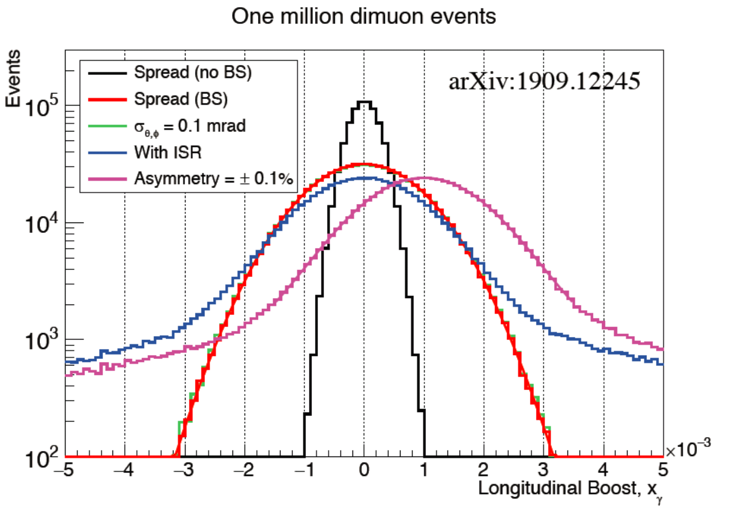
P. Janot



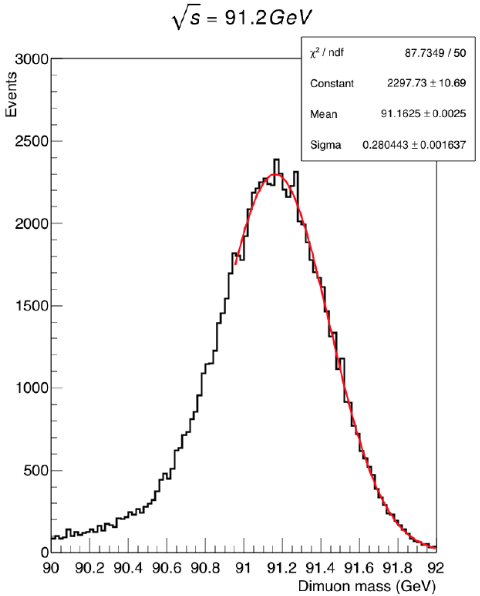
E,P conservation –>
allow E_{CM} and P_{CM}
on event-per-event basis.

10^6 evts/5 min/expt @Z

→Determine ECM, ECM spread and collision angle,
in addition to $A_{FB}^{\mu\mu}(\sqrt{s})$!
(also: control of ISR spectrum)



The measurement of CM boost distribution allows control of beam energy spread (including beamstrahlung), as well as the difference between e+ vs. e- energies.



±2.5 MeV ECM meast
in 30 seconds of data
~40keV per day at
each scan point….

challenge for QED calculations!

Main results and .. more to do!

Table 15. Calculated uncertainties on the quantities most affected by the centre-of-mass energy uncertainties, under the final systematic assumptions.

Observable	statistics	$\Delta\sqrt{s}_{abs}$ 100 keV	$\Delta\sqrt{s}_{syst-ptp}$ **40 keV**	calib. stats. 200 keV$/\sqrt{N^i}$	$\sigma_{\sqrt{s}}$ 85 $\pm$ **0.05** MeV
m_Z (keV)	4	100	**28**	1	–
Γ_Z (keV)	4	2.5	**22**	1	**10**
$\sin^2\theta_W^{eff} \times 10^6$ from $A_{FB}^{\mu\mu}$	2	–	**2.4**	0.1	–
$\frac{\Delta\alpha_{QED}(m_Z^2)}{\alpha_{QED}(m_Z^2)} \times 10^5$	3	0.1	**0.9**	–	**0.1**

<u>There remains much to do:</u>

-- integration of spin code in optics codes

-- diagnostics to measure directly beam-beam offsets and local dispersion to control Opp. Sign Vert. Dispers

-- improve precision at the W threshold to match 200keV stat.

-- Wiggler implementation esp. synchrotron radiation handling

-- further reduction of point to point errors:

-- energy model, logging and diagnostics

-- spectrometer stability

-- expt magnet and momentum scale stability

-- automatization and logging of all procedures!