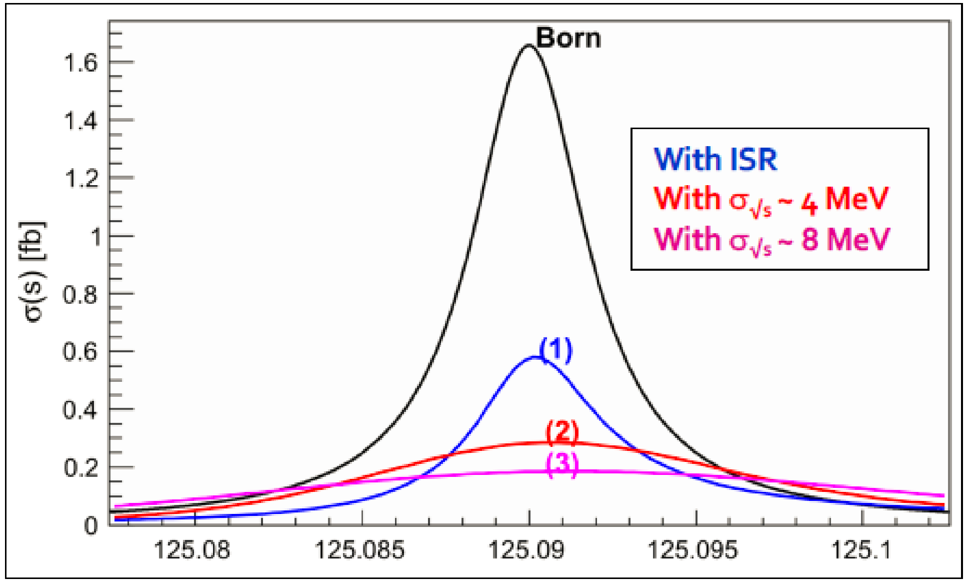
A first look at beam energy monitoring issues for the ee→ H run



Basic requirements (to be spelled out more precisely)

At any moment during the run:

-- run at nominal centre-of-mass energy that is stable well within Higgs width (±4 MeV OK?)

-- know the nominal center of mass energy to much better precision (±1 MeV OK?)

-- know the centre-of-mass energy spread with similar precision (±1 MeV OK?)

reference **arXiv:1909.12245**

-- know the centre-of-mass energy spread with similar precision (±1 MeV OK?)

➔ this requires use of the transverse polarization and resonant depolarization.

One condition is that the beam energies should be located around the half integer spin tune $\nu_s = E_b / 0.4406486$

if $m_H = 125.09$ GeV, then: $\nu_s = (m_H/2) / 0.4406486 = 141.938$ which is too close to integer.

-- A possibility is to shift the energies of the two beams in opposite way by $\Delta\nu_s$ = + and - 0.5, to 141.438 and 142.438 (Oide)

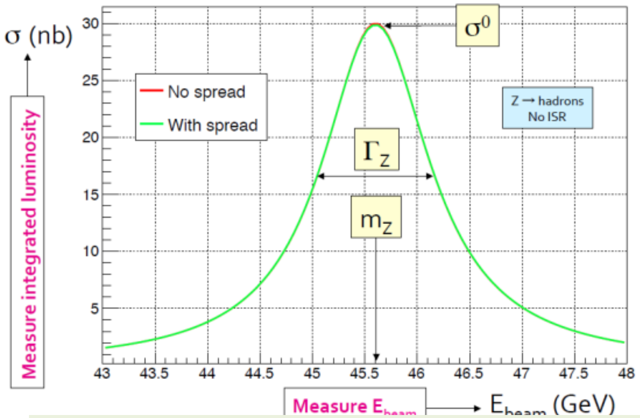
(There might be an elegant way to combine this with OSVD)

➔ then we should use the same method as for the Z run which should be somewhat easier since the **polarization time is ~5 times shorter (125/91)^5**

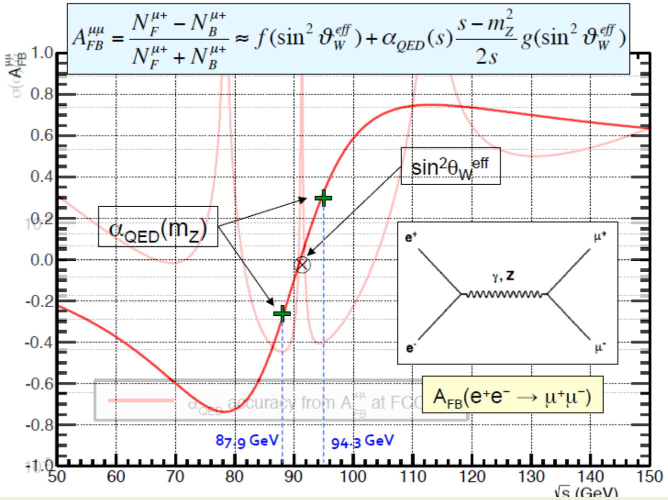
Precision at time of measurement will be similar (±100 keV) as for the Z run and should be sufficient

However it is important that it is tracked very well....

Physics: scan points and output quantities



Z line shape → m_Z and Γ_Z



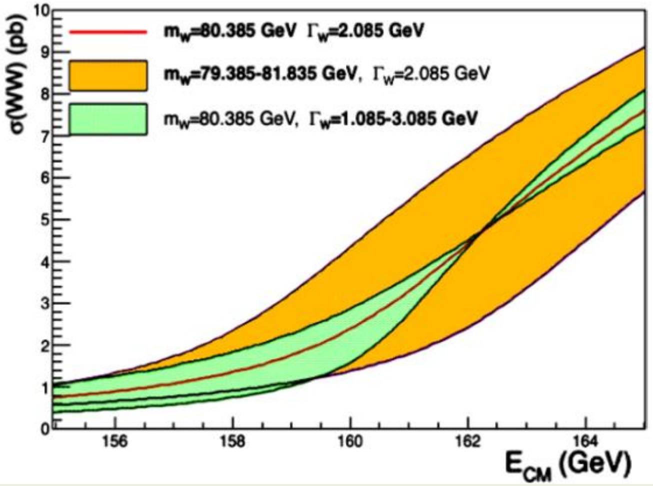
at the same time $A_{FB}^{\mu\mu}(\sqrt{s})$
→ $\sin^2\theta_W^{eff}$, $\alpha_{QED}(m_Z)$

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

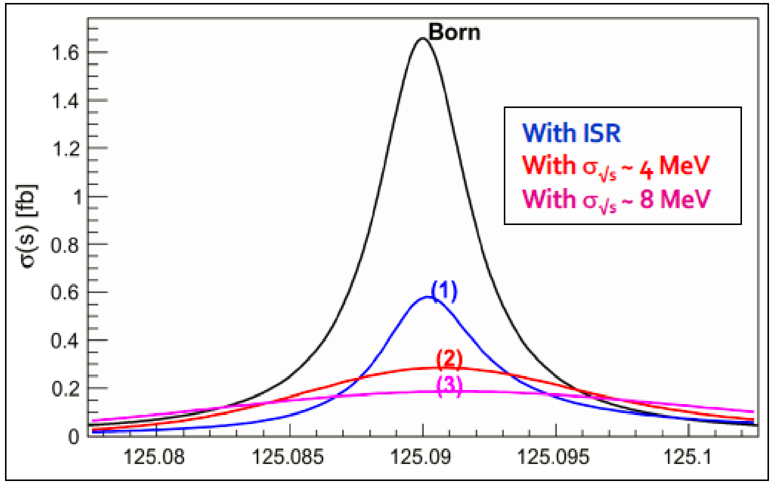
for the Higgs, bad luck!
ν = m_H/2/.4406486 (1) = 141.94
--too close to integer for polarizazion–
→ 141.44 for e+ and 142.44 for e-

at Z: 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} → $y_e = m_e$?

At any moment during the run:

-- run at nominal centre-of-mass energy that is stable well within Higgs width (±4 MeV OK?)

Large machines like FCC-ee will be subject to earth tides with circumference changes by $\Delta C \simeq \pm 2\,\mathrm{mm}$ for C of 100 km [22, 66, 67]. For a momentum compaction factor of $\chi \simeq 10^{-5}$ the corresponding energy changes reaches $\pm 2 \cdot 10^{-3}$ or $\pm 90\,\mathrm{MeV}$ around the Z

This requirement is more stringent than that for the Z line shape scan where the requirement is well within the center-of-mass energy spread (so that it does not worsen it) of O(80 MeV)

The full swing at the Higgs will be ±125 MeV... for each beam, i.e. ±250 MeV for E_{CM}
This corresponds to a maximum variation of 125 MeV per hour, or ~2 MeV per minute.

This will require a good model of the FCC-ee machine and its energy variations
-- benchmarked at the Z pole with great precision
and a correction mechanism using the RF frequency, based on e.g. beam position monitors, that is valid at that precision.
Must also use the 'spectrometer' function of the polarimeter in an operational way.

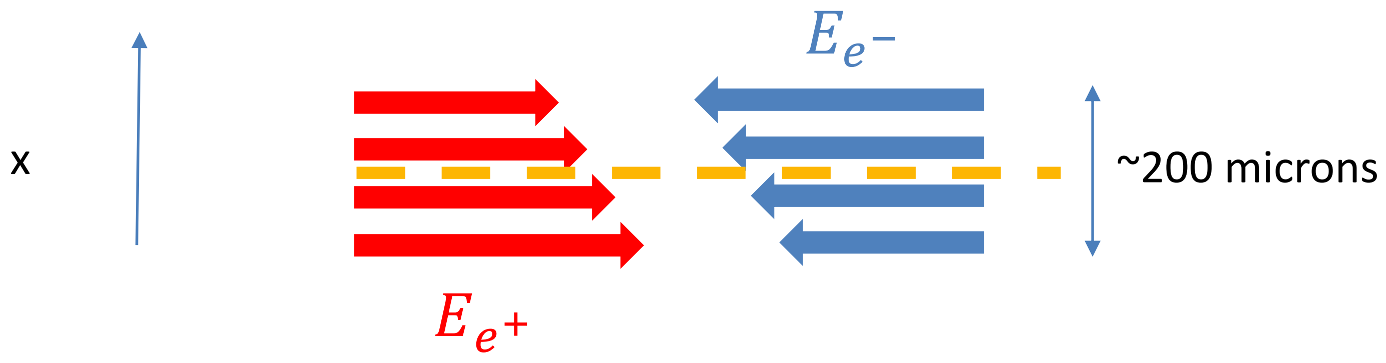
The beam energy measurements by RDP might need to be performed more often than every 10 minutes.
➔ it is essential that the ee➔ H measurement is performed after the Z line shape run

Measuring the centre-of-mass energy spread

A discussed in arXiv:1909.12245 the centre-of-mass energy spread σ_{ECM} cannot be measured from the bunch length when using crab-waist crossing.
A method was therefore devised to measure σ_{ECM} from the resulting spread in the measured boost of $\mu^+\mu^-$ pairs.

However that analysis was made without taking into account the possibility of horizontal dispersion. In this scheme for monochromatization the average boost varies with horizontal position and
integrating it leads to a measurement of the centre-of-mass energy spread in absence of monochromatization. Not good.

We are saved by the fact that the beam is artificially spread around for the monochromatization ($\sigma_x \sim \pm 100\ \mu$m) and that the detector should be able to measure the production point of each event with a precision of $\pm 3\mu$m.



Monochromatization **$D_x(e+) = - D_x(e-)$**

<ECM>(x) ~constant

σ_{ECM} (x)~constant ~ <σ_{ECM} (x)>

Boost measurement:

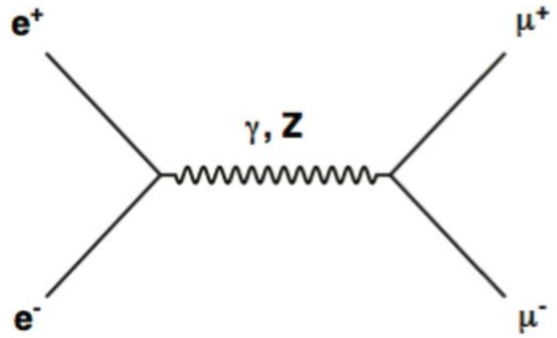
<(E(e+)-E(e-)> $\propto$ x (D_x(e+)-D_x(e-))

rms((E(e+)-E(e-))(x) ~constant << <rms((E(e+)-E(e-))>

this is very elegant: we can measure from the {boost of the muon pairs vs. x} the true energy spread *and*
verify the variation of boost across the beam crossing point -- this is the very principle of monochromatization.
NB we can and should also maybe verify the ECM is constant vx x. Detailed analysis is needed to ascertain the errors.

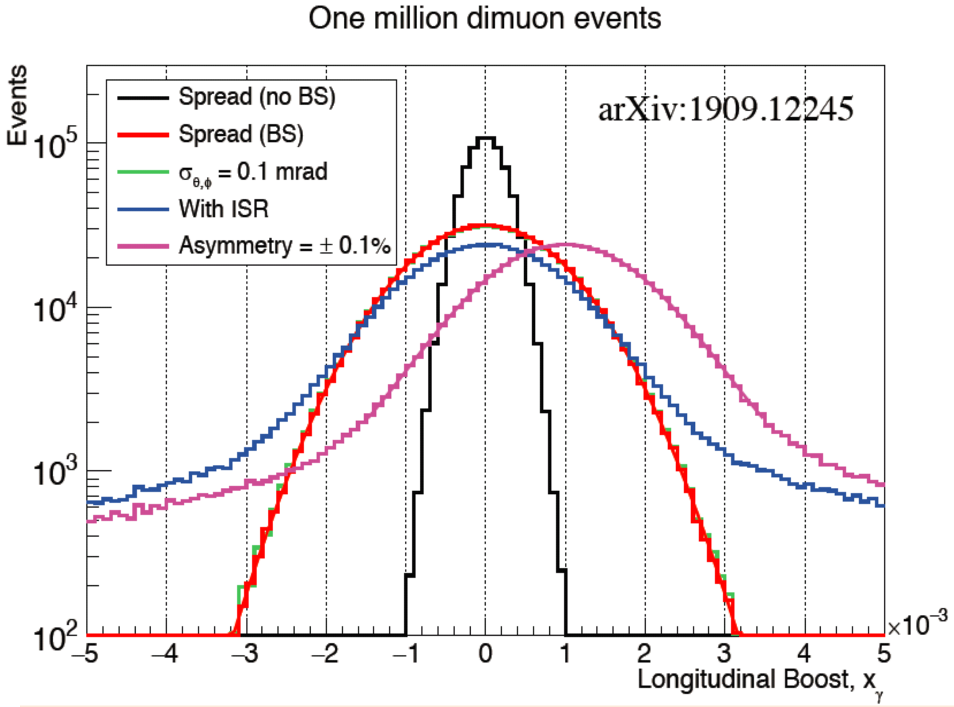
A thousand recipes to use up dimuon events at the FCC-ee

P. Janot

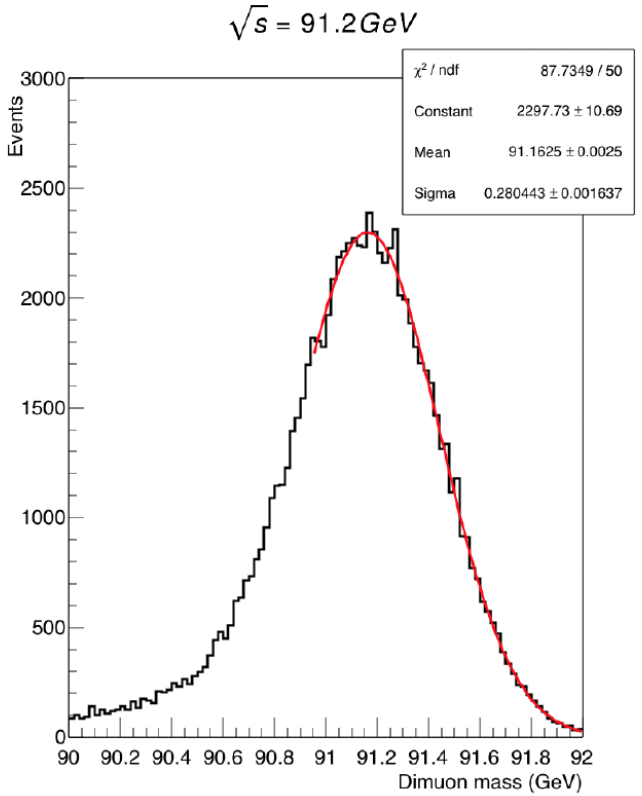


E,P conservation –>
allow E_{CM} and P_{CM}
on event-per-event basis.

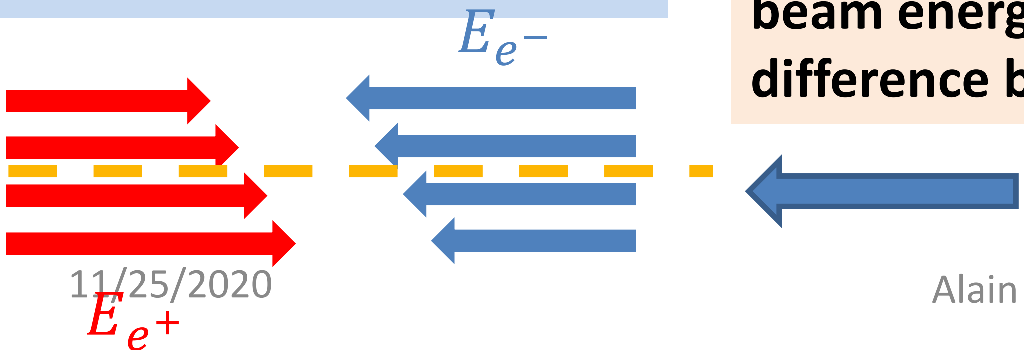
10^6 evts/5 min/expt @Z
~10^4 evts/5 min/exp @H
→Determine ECM, ECM spread
and collision angle,
in addition to $A_{FB}^{\mu\mu}(\sqrt{s})$!
(also: control of ISR spectrum)



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

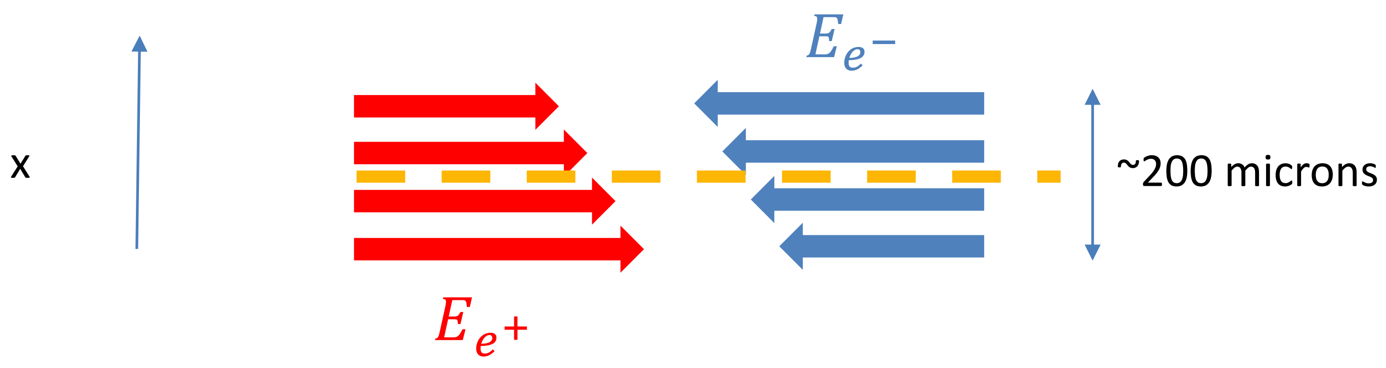


±2.5 MeV ECM meast
in 30 seconds of data
~40keV per day at
each scan point….
challenge for QED calculations!



Very useful also for control of Monochromatization!

For the s-channel Higgs production



Monochromatization

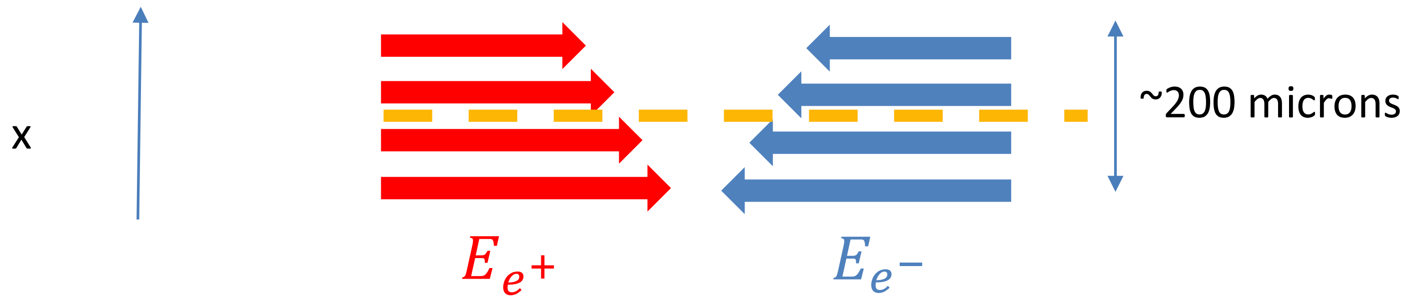
<ECM>(x) ~constant

σ_{ECM} (x)~constant ~ <σ_{ECM} (x)>

Boost measurement:

<(E(e+)-E(e-)> $\propto$ x (D_x(e+)-D_x(e-))

rms((E(e+)-E(e-))(x) ~constant < <rms((E(e+)-E(e-))>



Chromatization along x axis:

across the x axis:

<ECM>(x) ~ x (Dx(e+)+Dx(e-))

σECM (x)~constant < <σECM (x)>

Boost measurement:

<(E(e+)-E(e-)> (x)

Rms((E(e+)-E(e-))(x) ~constant ~<Rms((E(e+)-E(e-))>

"Measure" ECM on evt by evt basis

Measurement uncertainty in x for muon pairs ≈ 3microns/sin(phi)
Investigate other variables (z or time coordinates)

MORE TO DO

Specify the requirements from the experiment on
-- ECM stability,
-- ECM measurements and
-- Centre-of-mass energy spread measurement

It seems possible (but not easy) to get in the right ball park with the techniques used for the Z pole see **arXiv:1909.12245;** but we should go through the exercise to make sure we are not forgetting anything.

Also the muon-pair analysis needs to be investigated, taking into account the large amount of radiative Z-return to see how many of the events are really useable.