EPOL WG: status and prospects

Jacqueline Keintzel and Guy Wilkinson, with many thanks to colleagues in EPOL Working Group !

FCC Physics Week, CERN, 13/1/25

Outline

- Remit of EPOL group, and reminder of baseline E_{CM} calibration strategy
- Recent achievements, and things to look out for this week
- Current estimates of achievable precision
- Tasks for pre-TDR phase
- Conclusions

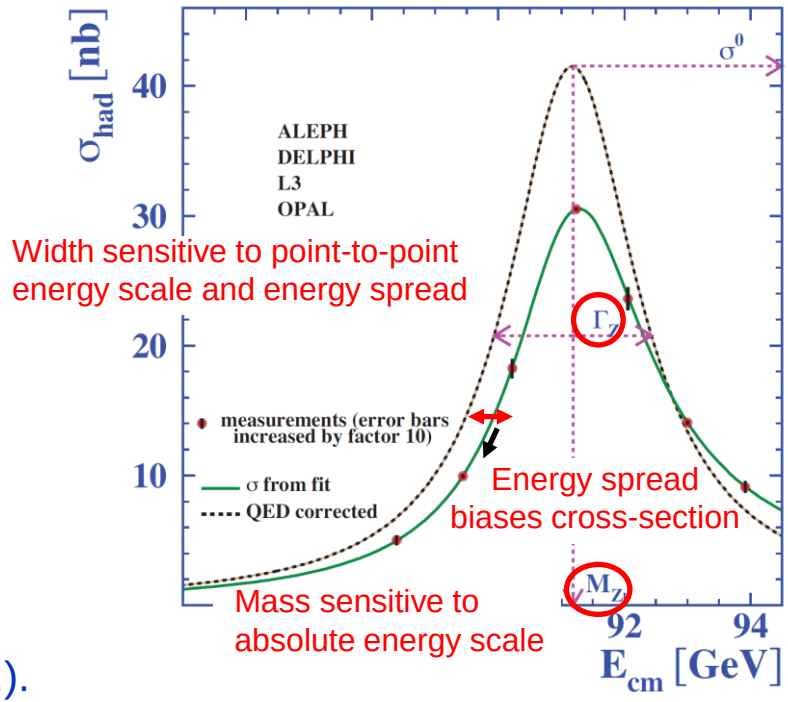
Remit of EPOL group

Calibration of E_{CM}, a critical systematic for Z lineshape parameters and W mass. (and needed at higher energies also).

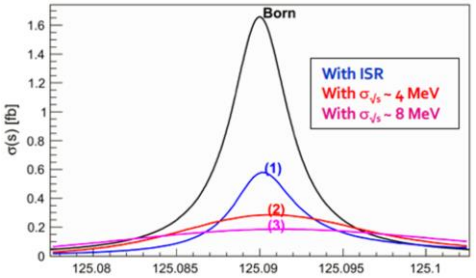
Also needed: measurement of $\sigma_{E_{CM}}$.

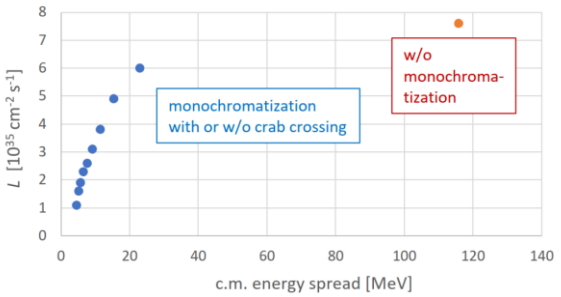
Primary tools:

- E_b calibration from resonant depolarisation (RDP), (at least up to W^+W^- threshold);
- Measurements from *e.g.* $e^+e^- \rightarrow$ ffbar(γ);
- Measurements needed for IP-specific corrections to go from E_b to E_{CM} (RF sawtooth, dispersion, crossing angle *etc*.).



Investigation of a viable monochromatisation scheme for possible Higgs-pole run.





Reminder of baseline strategy (Z^0 example)

- Start of fill: inject ~160 non-colliding pilot bunches with wigglers on.
- Wait 60-100 mins for polarisation to grow (exact time requirement under study).
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- Perform (essentially) continuous Resonant Depolarisation (RDP) measurements of E_b for both e^+ and e^- pilot bunches (Free Precession Frequency (FSP) measurements a complementary option).
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- Monitor longitudinal polarisation levels in physics bunches (must be ~zero!); depolarise if necessary.
- Continually adjust f_{RF} to keep beams centred in quads (minimise tide effects).
- Monitor and log all machine parameters ! Track E_b evolution between measurements with model à la LEP.
- Auxiliary procedures and measurements required to suppress and account for dispersion-related IP-specific effects in going from E_b to E_{CM}. Also necessary: corrections for RF sawtooth, measurements of / corrections for crossing angle and energy spread from $e^+e^- \rightarrow$ ffbar(γ) events… *etc.*

Talks this week, highlighting areas of recent progress and activity

4/3-006 - TH Conference Room

11:00 → 12:30 **EPOL**

Convener: Jacqueline Keintzel (CERN)

- 11:00 **FCC Polarimeter**
  Speaker: Dr Robert Kieffer (CERN)
- 11:20 **FCC Polarimeter (Laser and Fitting Procedures)**
  Speaker: Aurelien Martens (Université Paris-Saclay (FR))
- 11:40 **Considerations for the design of the FCCee depolarizer kicker system**
  Speaker: Wolfgang Hofle (CERN)
- 12:00 **Thoughts on injecting polarized beams**
  Speaker: Jorg Wenninger (CERN)

500/1-001 - Main Auditorium

11:00 → 12:30 **EPOL**

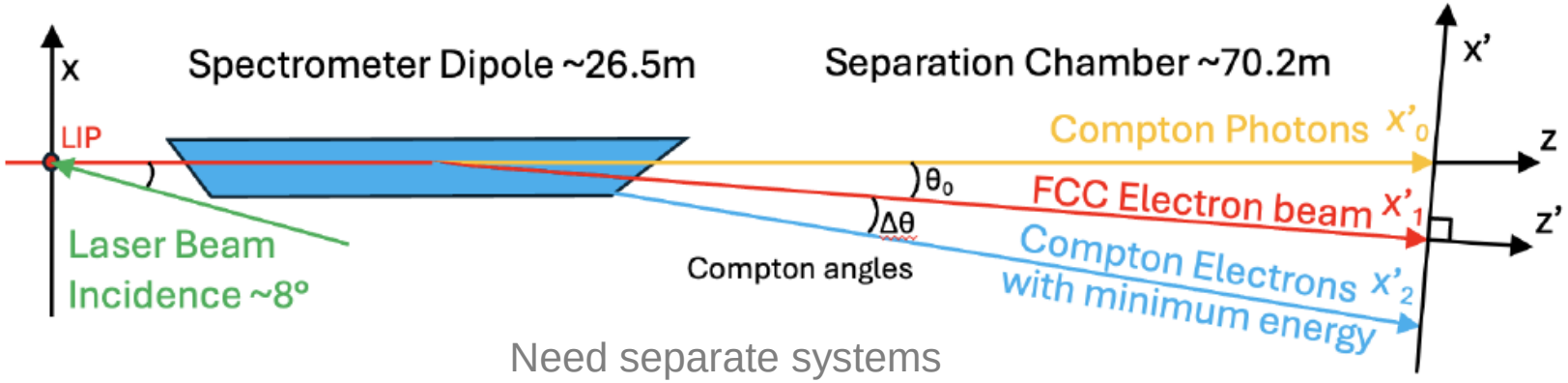
Convener: Guy Wilkinson (University of Oxford (GB))

- 11:00 **Point-to-point calibration with dimuons**
  Speaker: Emmanuel Francois Perez (CERN)
- 11:20 **Monochromatisation IP optics simulations for the eeH run**
  Speaker: Dr Angeles Faus-Golfe (IJCIab IN2P3 CNRS-Université Paris-Saclay (FR))
- 11:40 **Spin tune shifts**
  Speaker: Yi Wu (EPFL - Ecole Polytechnique Federale Lausanne (CH))
- 12:00 **Outlook and next steps for the pre-TDR phase**
  Speakers: Guy Wilkinson (University of Oxford (GB)), Jacqueline Keintzel (CERN)

Polarimeter progress

E. Granados, R. Kieffer, T. Lefevre, A. Martens, S. Mazzoni *et al.*

Determine beam polarisation through inverse Compton scattering. Detect both backscattered photons & electrons (positrons) to obtain full polarisation vector.



Need separate systems for e^- and e^+ beams

Tasks of polarimeter:

- Monitor transverse polarisation level of pilot bunches for RDP
- Direct measurement of precession frequency, *i.e.* FSP (under study);
- Set constraints on residual longitudinal polarisation of physics bunches;
- Real-time energy measurement from scattered electron kinematics.

Require ~95% availability during Z and W^+W^- operation.

Polarimeter progress

Great progress in investigating practical realisation of polarimeter concept !

Location

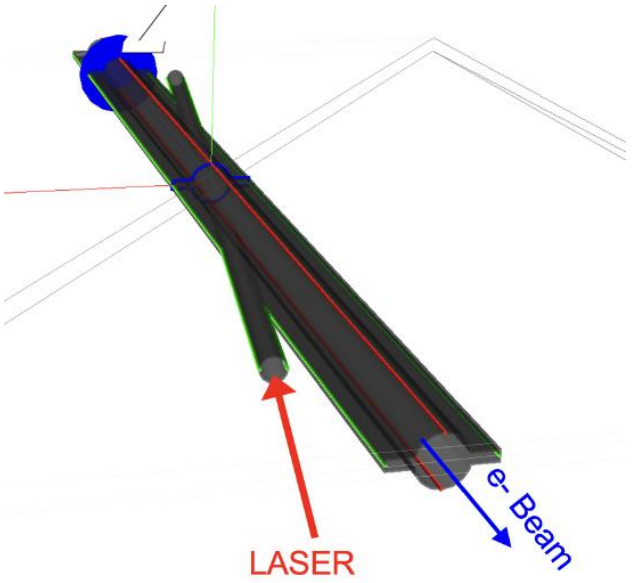
Current preferred place in in straight section 830 m upstream of experimental IP. Dispersion suppression dipole can double as Compton spectrometer magnet, and there is ~100 m of field-free propagation space….

…however, impractical to excavate long access tunnel to laser hutch, so system must be reliable (a demonstrator will be evaluated during pre-TDR phase). Good argument, therefore, for equipping > 1 region, to give redundancy.

Laser specifications:

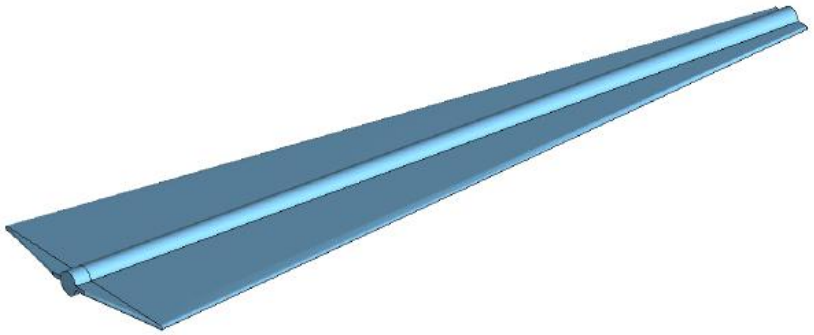
Technology	Q-switch	Modelock Yb	Modelock Yb
Bunch type	Pilot	Pilot	Colliding
Repetition frequency	3 kHz	3 kHz	3 kHz
number of targeted bunches	1	1	10
Pulse energy	3 mJ	3 mJ	50 μJ
Average power	9 W	9 W	1.5 W
Pulse duration	3 ns	30 ps	30 ps
Beam width ($\sigma_{x/y,l}$)	1 mm	1 mm	1 mm
Crossing angle	2 mrad	8 deg	8 deg
Scatters per bunch crossing	260	290	94
Scatters per second	8 10^5/s	9 10^5/s	28 10^5/s

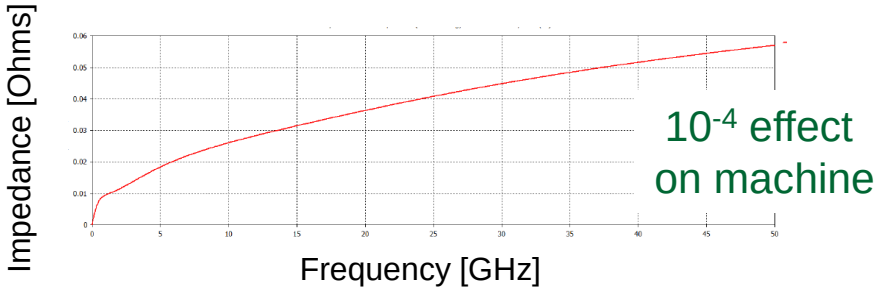
(two technologies under consideration)



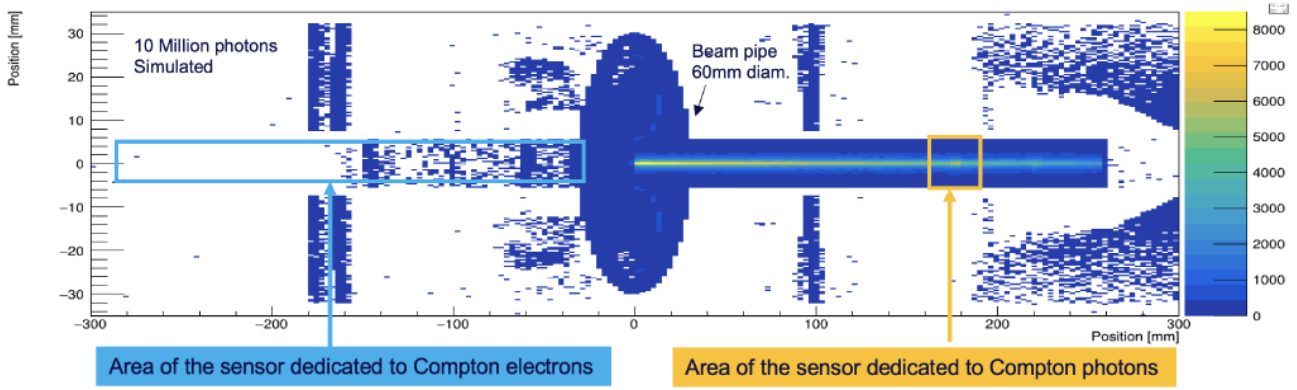
Polarimeter progress

Preliminary design of separation chamber, and impedance studies:





Evaluation of synchrotron radiation background:



+ studies of:

- detector technology and granularity;
- fitting methods;
- systematics *etc.*

See talks by Robert Kieffer and Aurelien Martens on Tuesday morning.

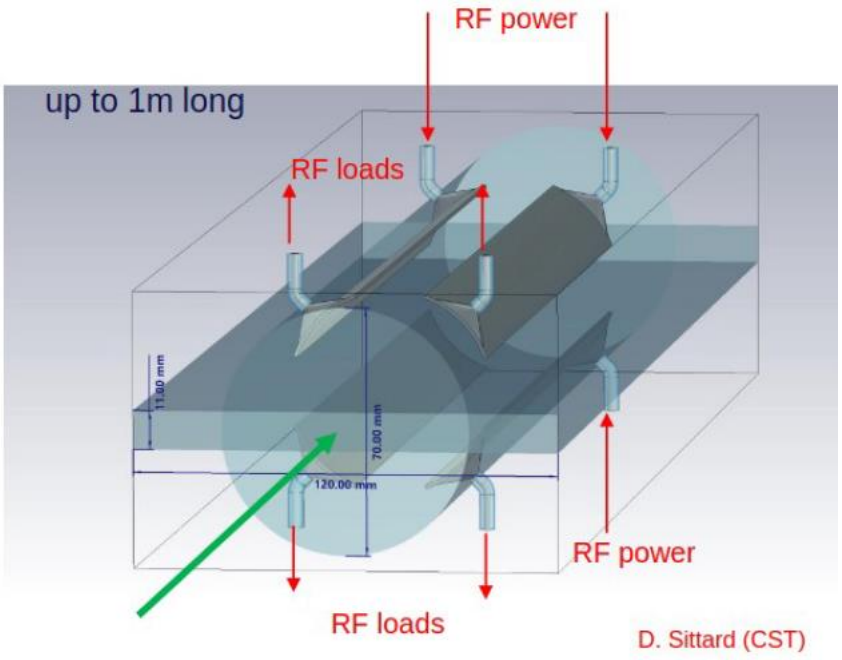
RF kicker for RDP

W. Hofle

Preparations advancing on realistic design of RF kicker for performing RDP.

- Require 2 RF kickers, which between them will achieve closed orbit bunch.
- Must be integrated in regular arc structure
- Foreseen kick will lead to deflections of ~1mm - implications for aperture / lifetime ?
- Design could cope with ~160 pilot bunches, separated by 100 ns (recall, must kick bunches one at a time).
- Currently independent of feedback system.

Four 1m long structures per RF kicker.

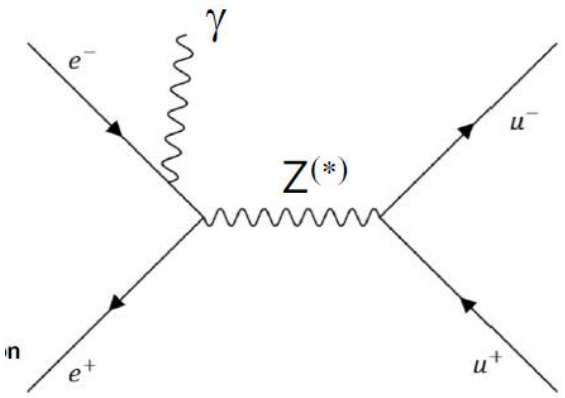


Consequences for impedance under study.

See Wolfgang Hofle talk on Tuesday morning.

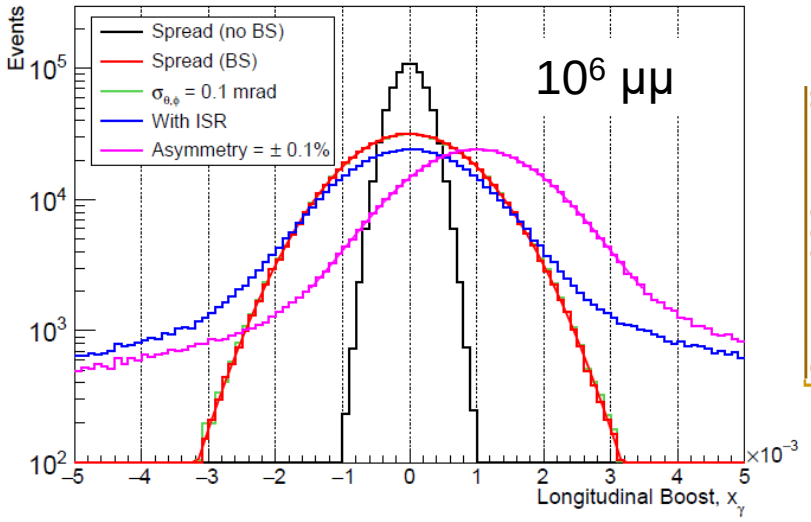
Input from the experiments

Physics events, in particular di-muons, can be harnessed to provide information on many E_{CM} related quantities, *e.g.* longitudinal boost, energy spread, crossing angle…. Basic techniques & potential of these studies established at time of CDR.



At Z expect 10^6 events every ~5 minutes

Reconstructed longitudinal boost ($x_\gamma = p^\gamma_z/E_{CM}$) under various scenarios



[Shatilov, Perez, Janot arXiv:1909.12245]

Recent work from Michal Kazanecki and Marcin Chrzaszcz has shown that energy-spread determination remains robust even in presence of ISR/FSR uncertainties.

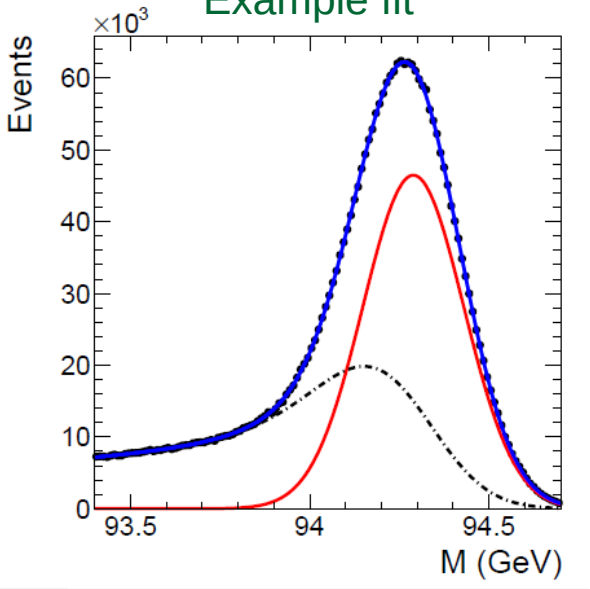
Relative E_{CM} calibration with di-muons

E. Perez

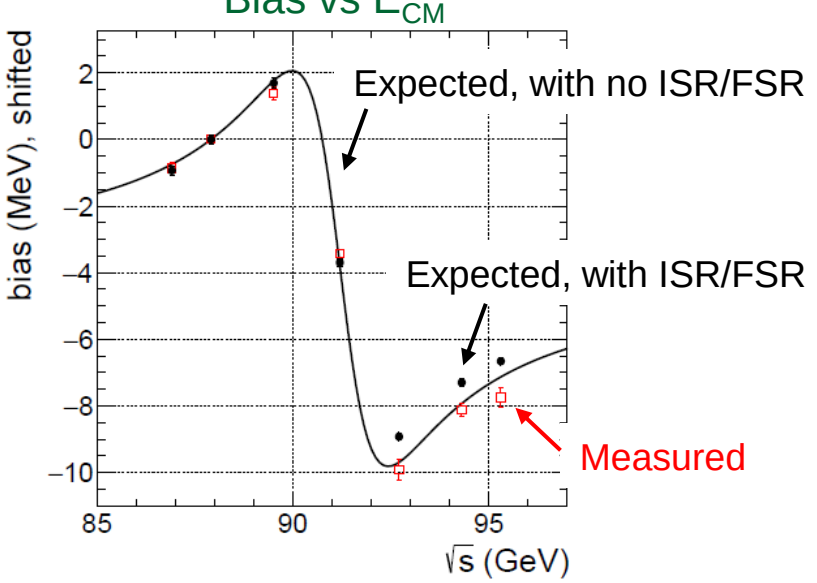
Fit to di-muon invariant mass provides a proxy for E_{CM}, and so change between off-peak points gives a measure of energy difference needed for Γ_Z measurement.

However, in any fit there are energy-dependent biases even in perfect case.

Example fit



Bias vs E_{CM}



Momentum resolution important – results assume IDEA-like performance.

Stat precision around 20 keV at 87.9 GeV or 94.3 GeV, summed over 4 IPs.
→ uncertainty on Γ_Z of 11 keV, assuming ISR/FSR & detector biases controllable.

Seems achievable for ISR/FSR (bias needs to be known to ~1%). Detector effects under investigation. See talk by Emmanuel Perez on Thursday morning..

E_{CM} uncertainties on EW precision observables

E_{CM}-related uncertainties on selected EWPOs, as quoted in Final Report. These numbers are *neither* the last word (we may do better), *nor* are they easily achievable (they assume further hard work, and excellent control of *e.g.* detector biases).

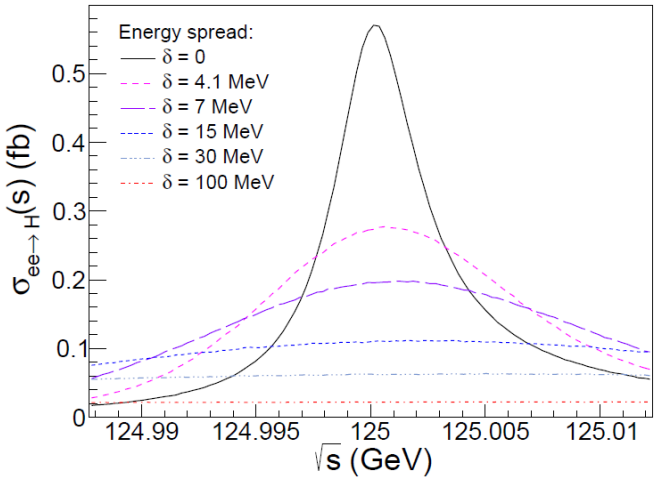
	Observable				
Uncertainty	m_Z [keV]	Γ_Z [keV]	$\sin^2\theta_W^{\text{eff}}$ [$\times 10^{-6}$]	$\frac{\Delta\alpha_{\text{QED}}(m_Z^2)}{\alpha_{\text{QED}}(m_Z^2)}$ [$\times 10^{-5}$]	m_W [keV]
Absolute	100	2.5	/	0.1	150
Point-to-point	14	11	1.2	0.5	50
Sample size	1	1	0.1	/	3
Energy spread	/	5	/	0.1	/
Total $\sqrt{s}$ related	101	12	1.2	0.5	158
FCC-ee statistical	4	4	2	3	180

- Absolute energy scale most important for m_Z and m_W. Current estimates set by confidence we have in going from RDP measurement to E_b. In particular, m_W warrants renewed and closer studies during the pre-TDR phase.
- 'point-to-point' and energy spread most relevant for Γ_Z. Quoted numbers based on what can be done with di-muons, assuming detector effects can be controlled. For 'point-to-point' we will work on machine-based cross checks.
- We are approaching regime where Γ_Z may not be E_{CM}-systematics limited !

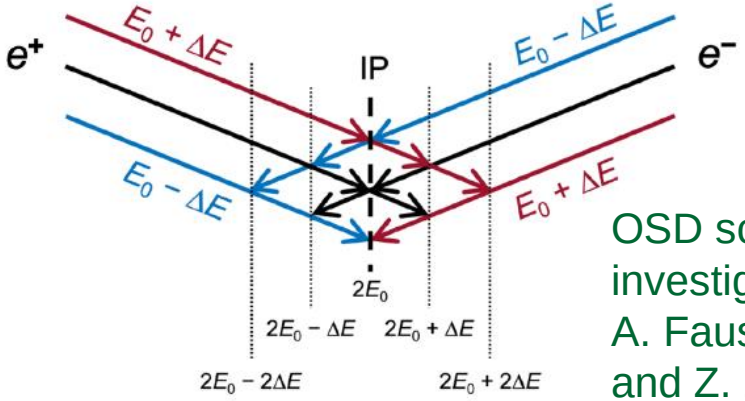
Electron Yukawa and the monochromatisation challenge

D. Enteria,
A. Faus-Golfe,
Z. Zhang

Higgs pole run gives unique opportunity to measure the electron Yukawa. To make this feasible, need to reduce E_{CM} spread from ~70 MeV, ideally towards Higgs width (~4 MeV). Such monochromatization generally brings lumi reduction.



Monochromatisation can be achieved through introducing opposite sign dispersion (OSD).



OSD schemes investigated by A. Faus-Golfe and Z. Zhang.

With best performance obtained so far, four experiments could set an upper limit at the 95% CL at about 2.5x SM in one year (*c.f.* 4x without monochromatisation).

Promising, but more work to be done ! See talk by Angeles F-G on Thursday.

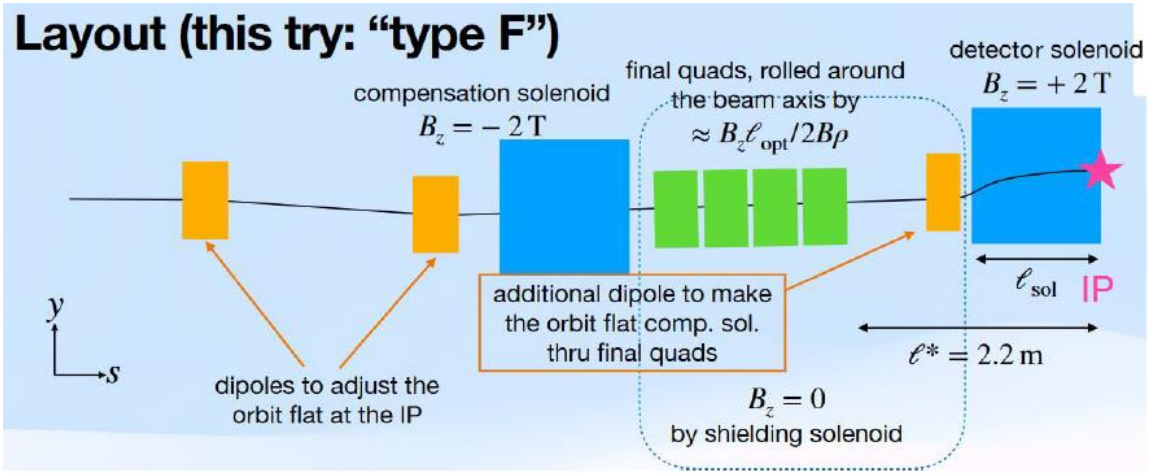
Tasks for the pre-TDR phase

There are many, such as:

- Consolidation of designs for polarimeter and depolariser;
- Deeper studies of relationship between spin tune and E_b;
- Closer attention to be paid to RDP in W^+W^- regime;
- More attention to be paid to local ECM effects, *e.g.* opposite sign dispersion;
- Further exploration of possible monochromatisation schemes;
- Examination of detector requirements for E_{CM} related measurements;
- and two that I will briefly discuss…

Impact of non-local solenoid compensation

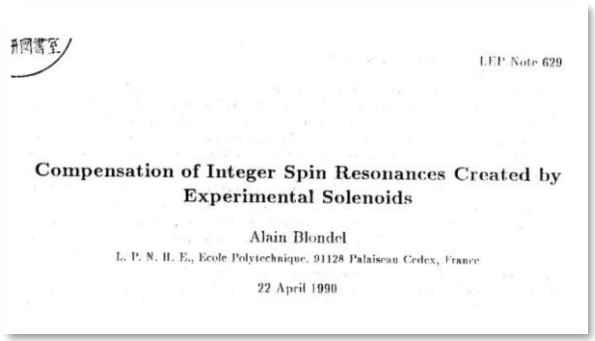
New layouts of the IR proposed (K. Oide), in which compensation solenoid displaced from inner MDI region to ~10 m from the IP. Allows for lower field.



Brings several advantages… but for EPOL makes life more challenging. Preliminary indication is that it introduces spin rotation that will reduce asymptotic polarisation to ~1 % (sic), and possibly introduce other nasty systematic effects.

In principle, can be combatted by introducing orbit bumps either side of IP. This was done at LEP.

Studies have begun (Jorg Wenninger), but no firm conclusions yet. Watch this space !


LEP Note 629

Compensation of Integer Spin Resonances Created by Experimental Solenoids

Alain Blondel
L. P. N. H. E., Ecole Polytechnique, 91128 Palaiseau Cedex, France

22 April 1990

Injection of polarised beams

Reminder of baseline strategy:

- Start of fill: inject ~160 non-colliding pilot bunches with wigglers on.
- Wait 60-100 mins for polarisation to grow (exact time requirement under study).
- Turn off wigglers and inject physics bunches.
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An alternative strategy would be to inject pre-polarised beams, as is proposed for CEPC. This is not straightforward ! See talk by Jorg Wenninger on Tues.

Conclusions

- A successful and high-performance energy-calibration strategy is mandatory for many of the key physics goals for FCC-ee
- Much progress over the recent year, in particular with several components moving from conceptual to design phase;
- Many tasks remain open for the pre-TDR phase. Help very welcome !

  Sign up to e-group fcc-ee-PolarizationAndEnergyCalibration@cern.ch
  Meetings can be found under https://indico.cern.ch/category/8678/
- See summary and outlook talk by Jacqueline Keintzel on Thursday !