Polarimeter for FCC-ee
(and other options and instruments)

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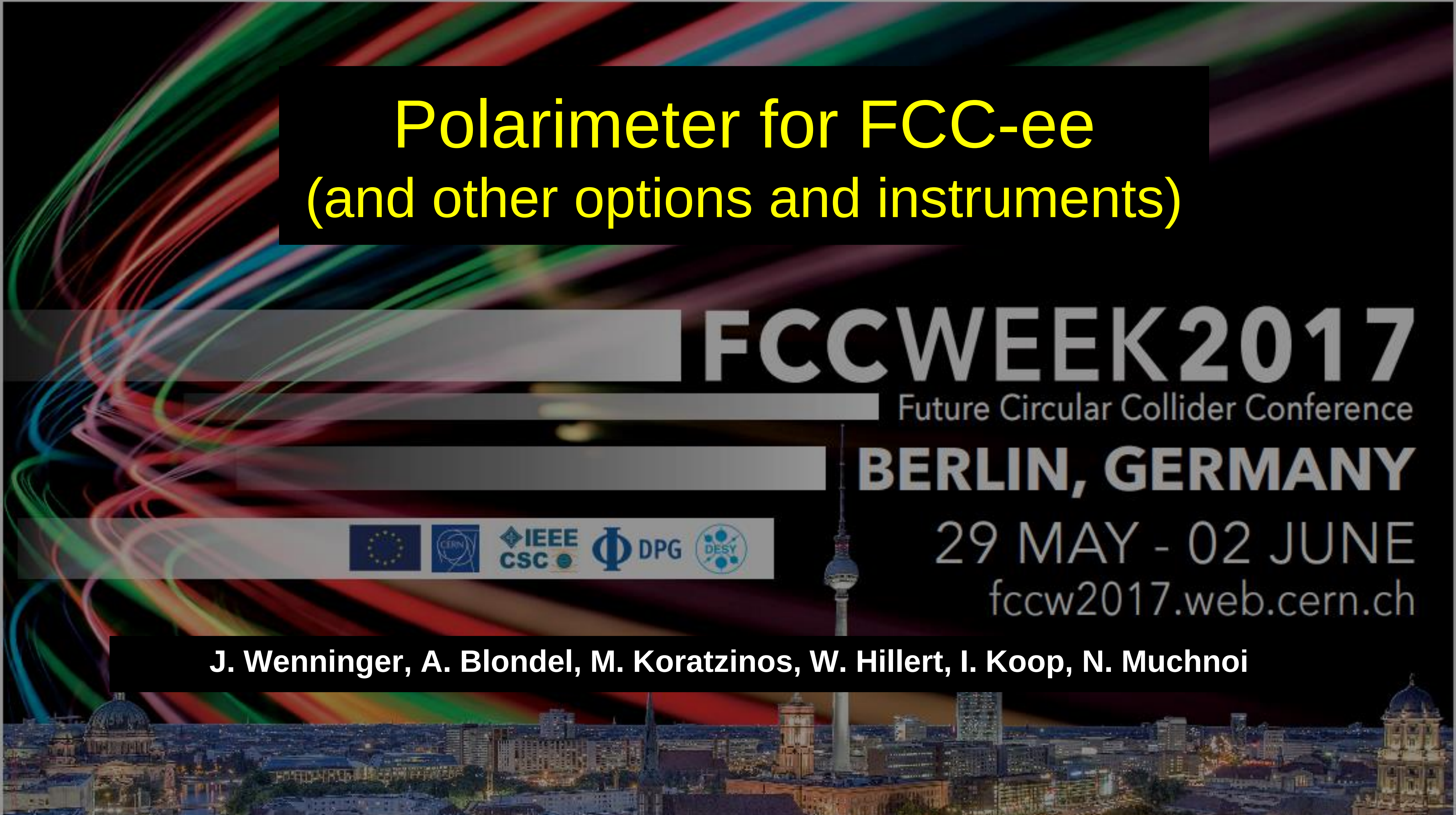
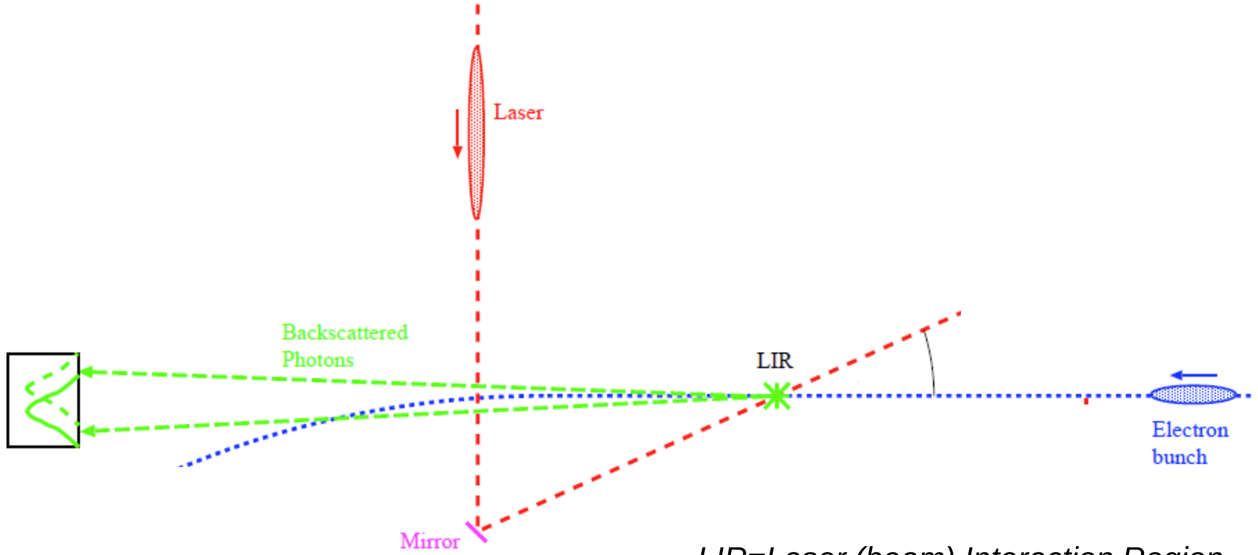


Polarimeter principle

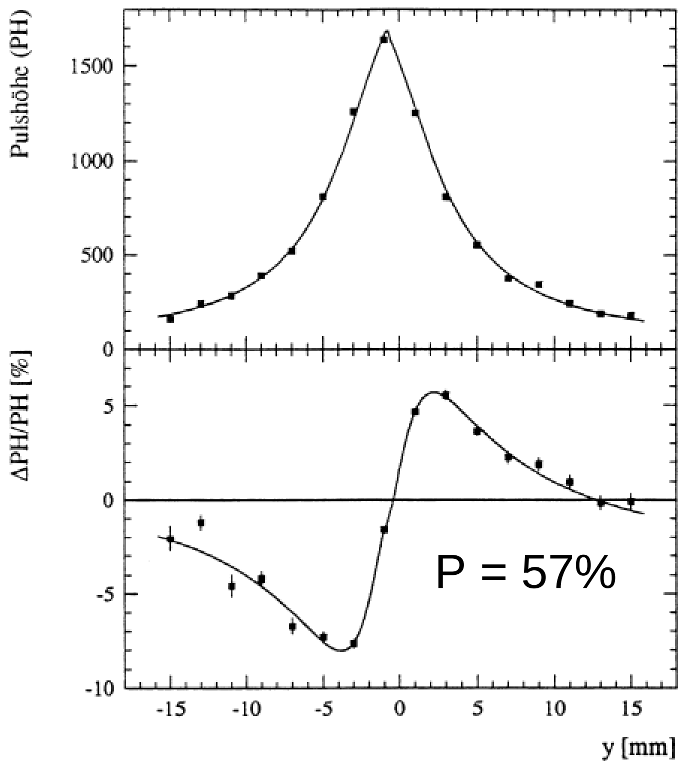
- Scattering circularly polarized light on a transversely polarized e-/c+ beam (assume vertical P_T) generates a polarization depend shift of the out-coming photon profiles.
  - The beam polarization can be assessed from the scattered photon distribution.

- Typical sensitivities at the Compton photon detector: $\Delta y = S \times P_T$
  - *S ~ 5 – 10 μm / % (depends on lever arm LIR – detector).*
  - *By flipping the laser helicity one only has to measure a relative shift.*



LIR=Laser (beam) Interaction Region

γ profile and asymmetry (R/L laser helicity) at LEP

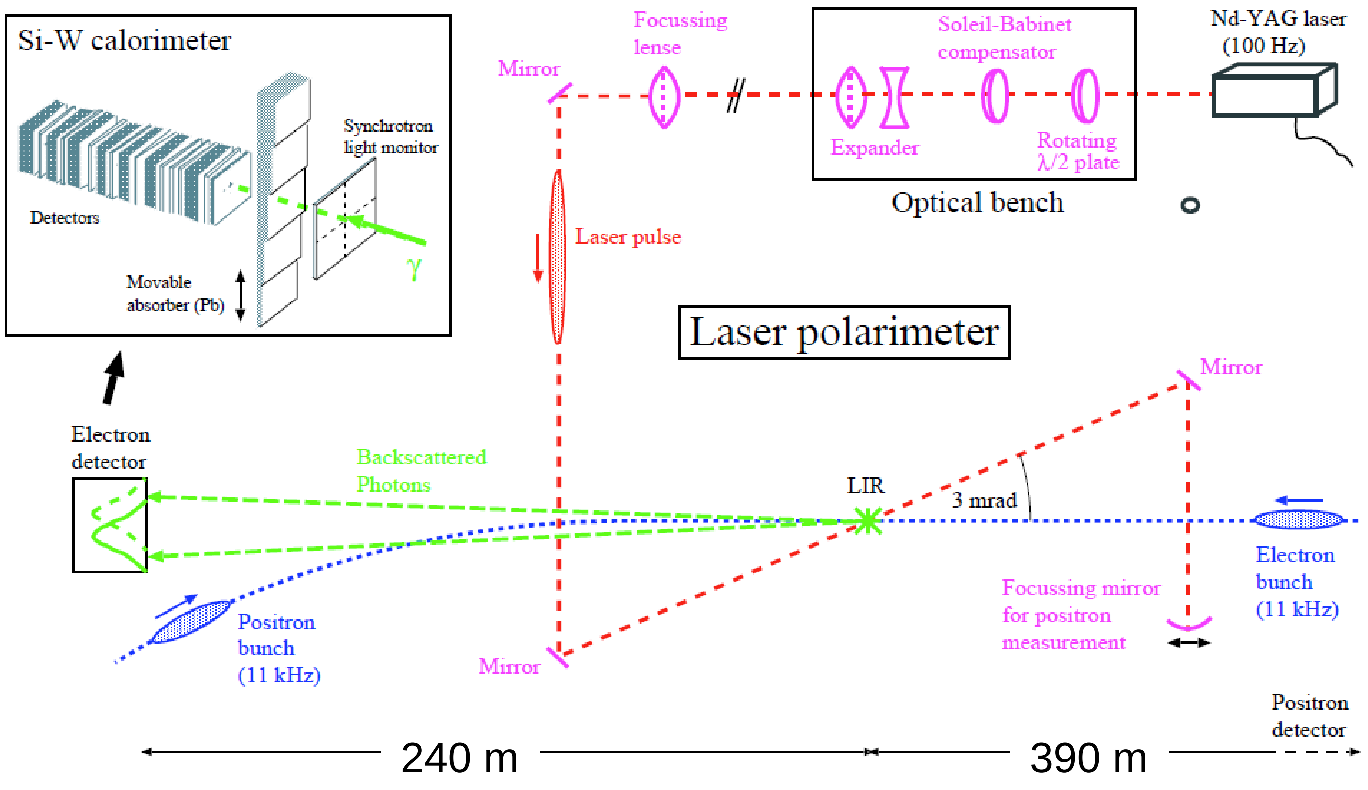


R. Assman (PHD)

The LEP polarimeter

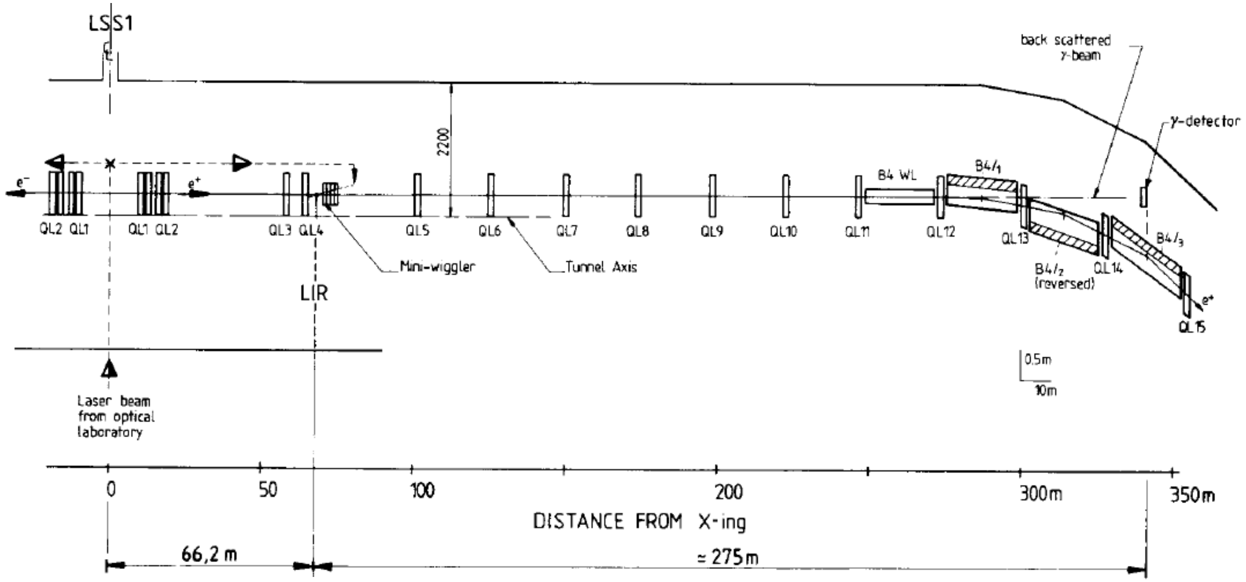
- The LEP polarimeter was installed in LEP point 1 (now in the middle of the ATLAS detector).
  - ND-YAG laser @ 100 Hz, interleaved right / left circularly polarized laser light (optical bench),
  - Laser light path into the LEP vacuum chamber, in vacuum mirrors,
  - Si strip detector (2 mm strips) for gamma profile measurement.

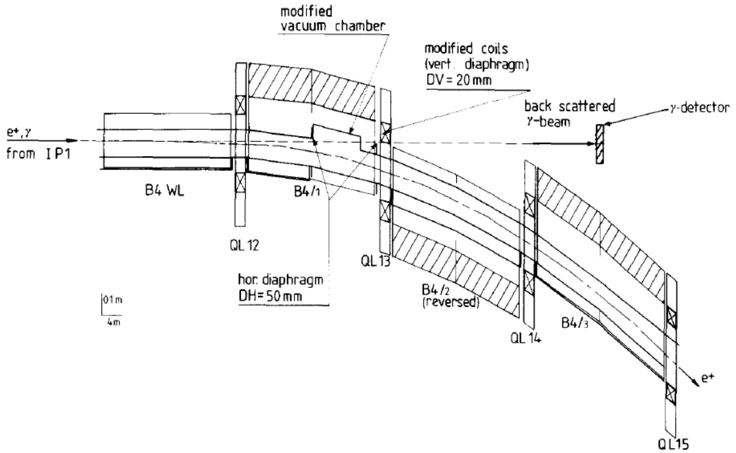
- Both e- (primary) and e+ polarizations could in principle be measured.
  - e+ measurement difficult due to mirror vibration issues, performed only 2-3 times during the entire LEP area.
- Distances to photon detectors of 240m and 390m.



The LEP polarimeter (2)

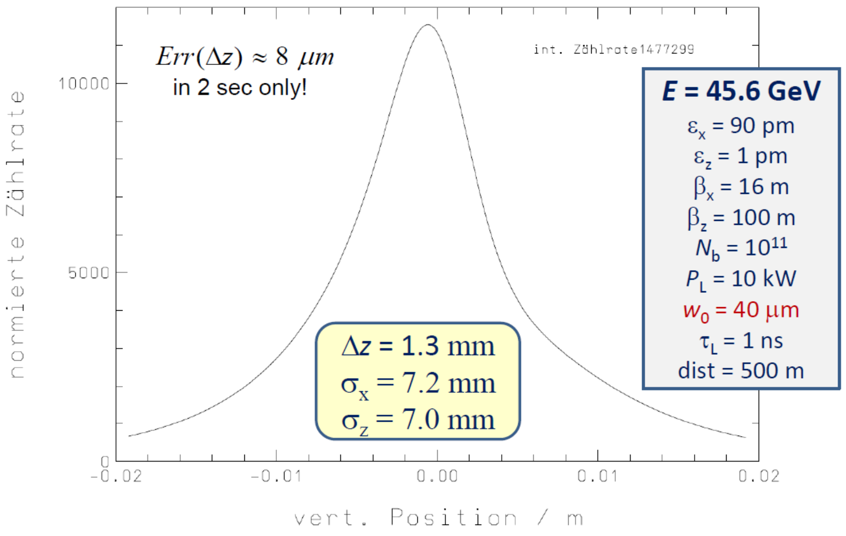
- The backscattered Compton photons were extracted at the entrance of the arc (Al window in the vacuum chamber ~ 50 x 25 mm^2).
  - Note that the actual layout was actually reversed (design drawing !).
  - β functions at LIR (Laser-beam IR) ~40-120 m, beam sizes ~0.4 -1 mm.

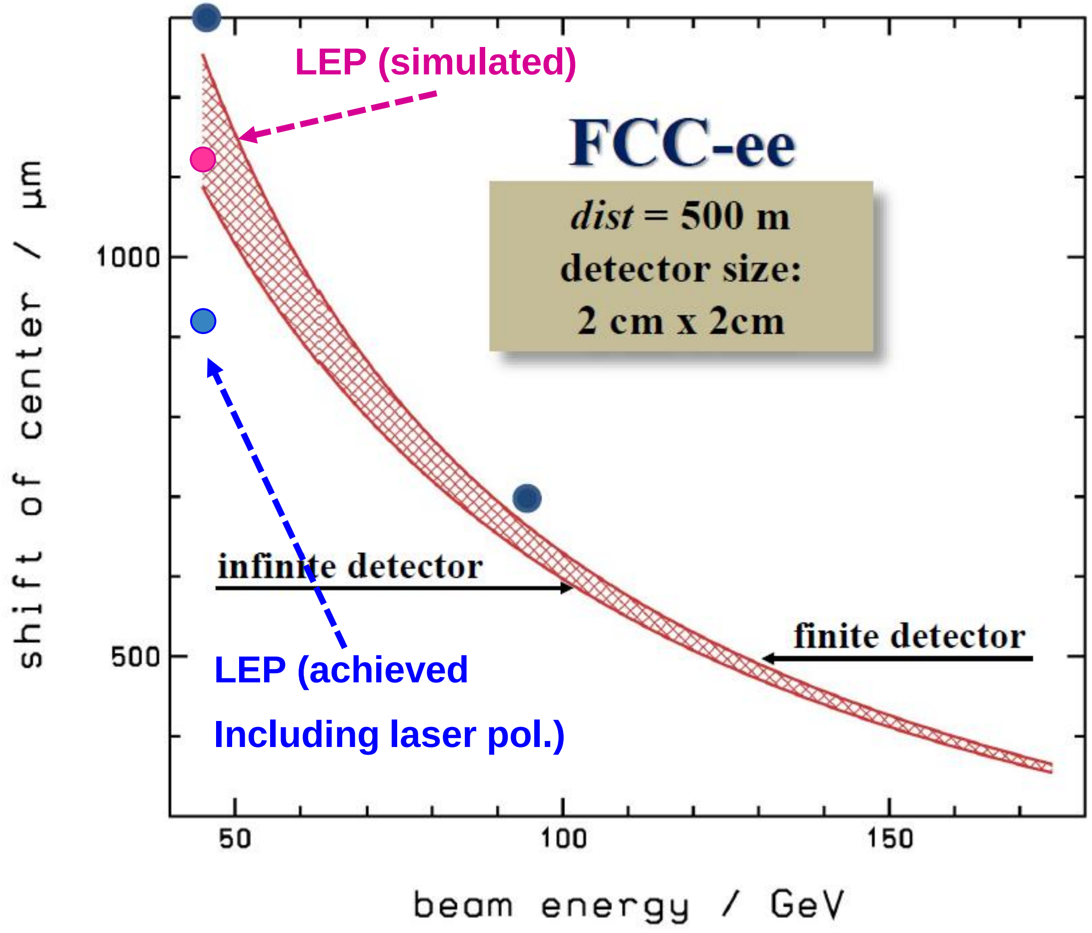




Detector simulation for FCC-ee

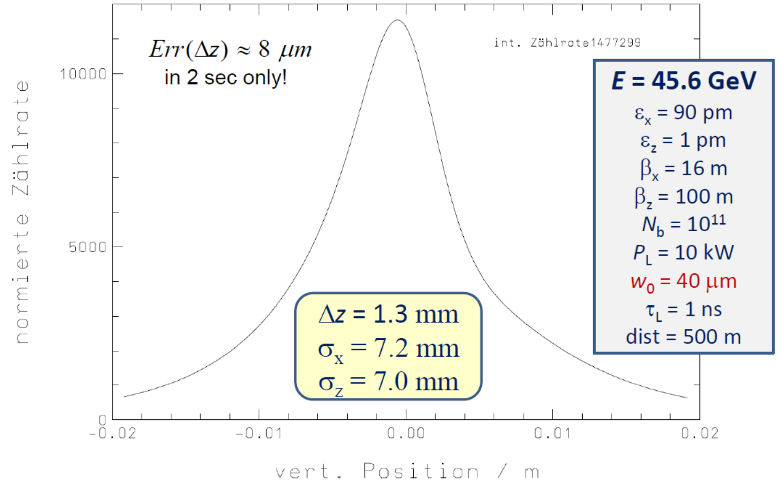
- Photon recoil distributions for FCC-ee were recently simulated by W. Hillert for a distance of 500 m between LIR and detector.
  - Detector & shower effects were not taken into account.
- The photon profile properties depend only weakly on the optical functions at the LIR: dominated by the geometry.
  - Eases the integration of the polarimeter into the lattice.
  - The LEP polarimeter sensitivity scaled to a distance of 500 m is in line with the simulations.

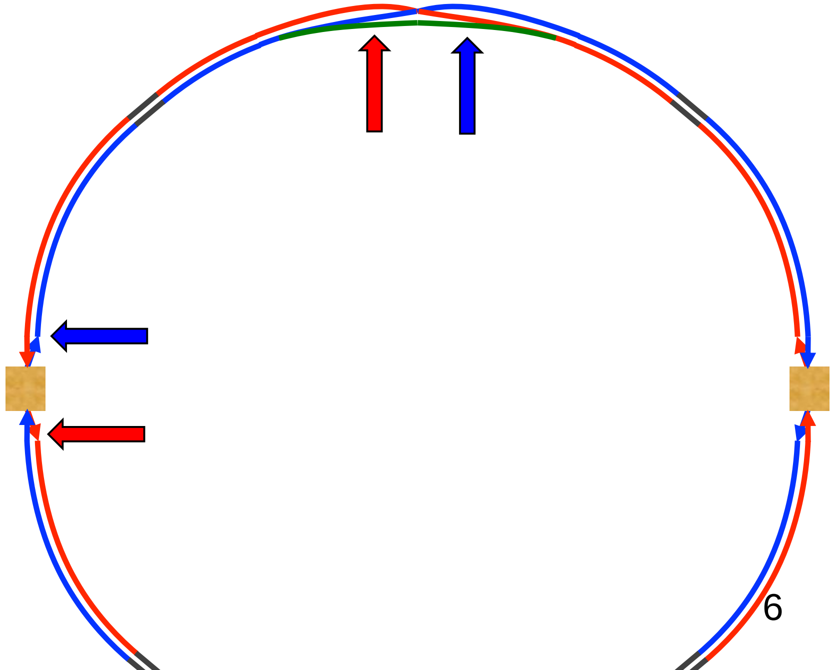




Polarimeter for FCC-ee – detector & LIR

- The width of the photon distributions will be in the range of ~5-10 mm (rms) depending on the distance to the LIR.
  - The maximum distance may be partly dictated by the photon extraction window / vacuum chamber size.
- A pixel detector with pixel sizes of **50x50 to 100x100 μm^2** should be adequate.
- The sensitive area should be around **50x50 mm^2**.
  - Photon converter installed in front of a few pixel layers / pixel converter sandwich.
- The LIR should be located close to a bend at the end of a straight section for photon extraction.
  - Likely to require magnet(s) with special yoke/coil.
- The e+ and e- LIRs & detectors should be independent for parallel measurements of e+ and e-, and located at the same access point (efficiency).
  - RF straight sections where beams cross over.
  - Experiments IRs on the outgoing beam lines.
  - Dispersion suppressor



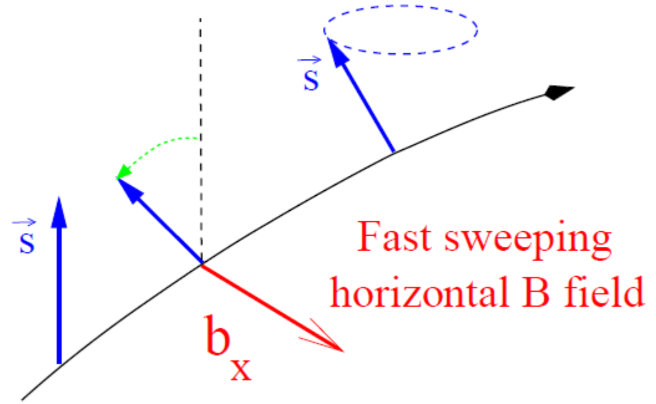


Laser & optical system

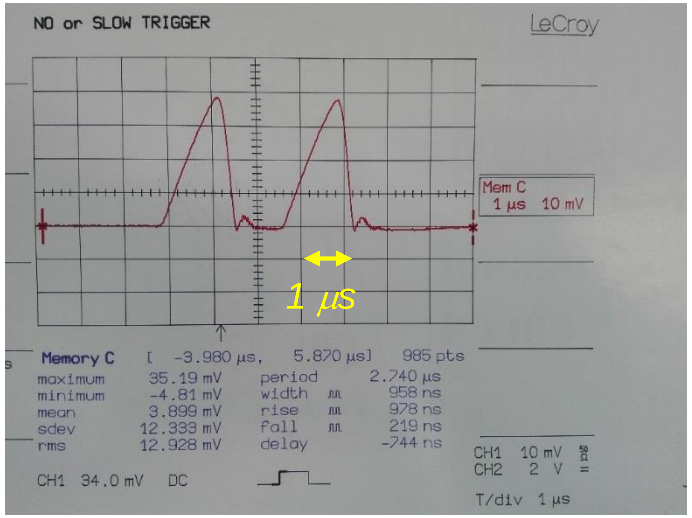
- Lasers available on the market (i.e. Nd-YAG) provide adequate pulse power and pulse width:
  - Pulse energies 100-200 mJ @ 100 Hz,
  - Synchronized with one selected bunch at a time,
  - Pulse width < 15 ns – shorter would be better:
    - **more efficient, non-colliding polarized bunch separation can be reduced**.
- For comparison the LEP laser provided 125 mJ pulses at 100 Hz, pulse length of ~5 ns.
  - With such laser parameters the bunch lifetime could be lowered to ~4 hours.
  - The **LEP** statistical accuracy on the transverse polarization was **~ 0.5%/min**. Recent simulations by W. Hillert indicate that much better values could be achieved (by more than 2 orders of magnitude).
- The laser could be installed at a distance of ~100-200 m from the tunnel / interaction region with a laser light path into the vacuum and grazing incidence on the beam.
  - Optical bench with polarizing elements and frequent polarization flipping to minimize systematic errors.

Depolarizer

- The beam is depolarized with a fast transverse RF pulse.
  - Frequency sweep during the pulse.
- The bandwidth of the LEP RF- depolarizer was uncritical because the bunch spacing was large.
  - RF pulse width ~1 μs, BL ~ 2×10^{-4} Tm (~1 μrad transverse kick to the beam, ~100 μrad kick to the spin at Z).
- At FCC-ee we plan to use **dedicated non-colliding ecal bunches**: to limit the loss of luminosity at the Z where ~100's bunches will be dedicated to energy calibration, the RF pulse must be short to allow for closely packed ecal bunches.
- The new SPS wideband / FCC-hh transverse feedback systems could provide a baseline with ~ adequate deflection (~ equivalent to the LEP device) with much reduced pulse width (< 25 ns - tbc).
  - Only one pulse per revolution period is required, therefore low average power.

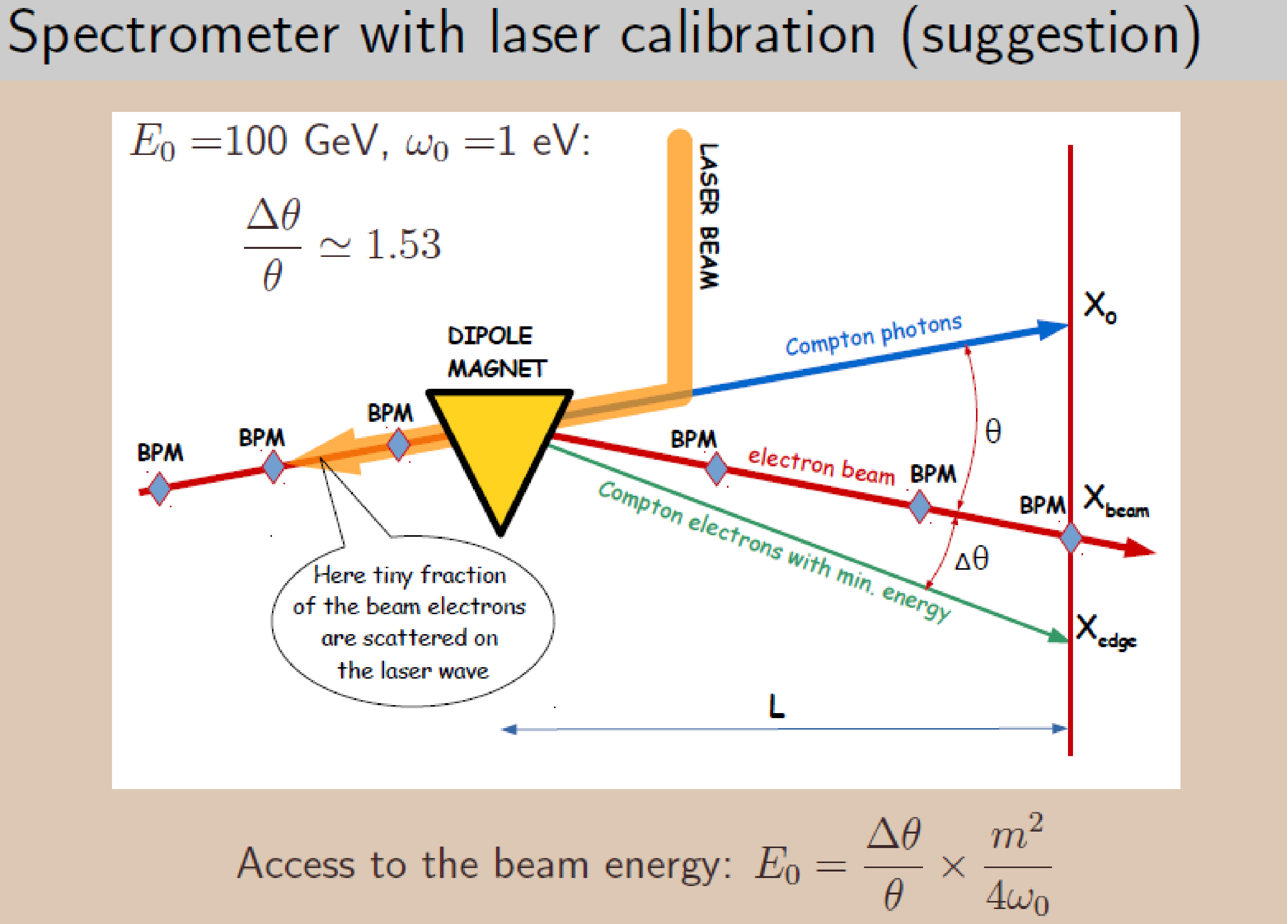


LEP depolarizer pulse (L. Arnaudon)



Enhanced polarimeter

- Concept proposed by N. Muchnoi et al. to detect the Compton scattered electrons in addition to the photons to obtain the energy independently of the beam polarization by reconstructing the direction of the scattered electrons wrt beam direction.
  - Similarities with an integrated spectrometer (as was the case at LEP).
  - **Local energy !**
- This concept could be integrated into the polarimetry layout.
  - Requires a long (~ 100 m) field free region,
  - High precision beam position monitors (BPMs),
  - High precision on the reconstruction of the Compton photons and electrons (~ µm).
- This method could provide an independent check of the energy determined by RDP + local energy model.

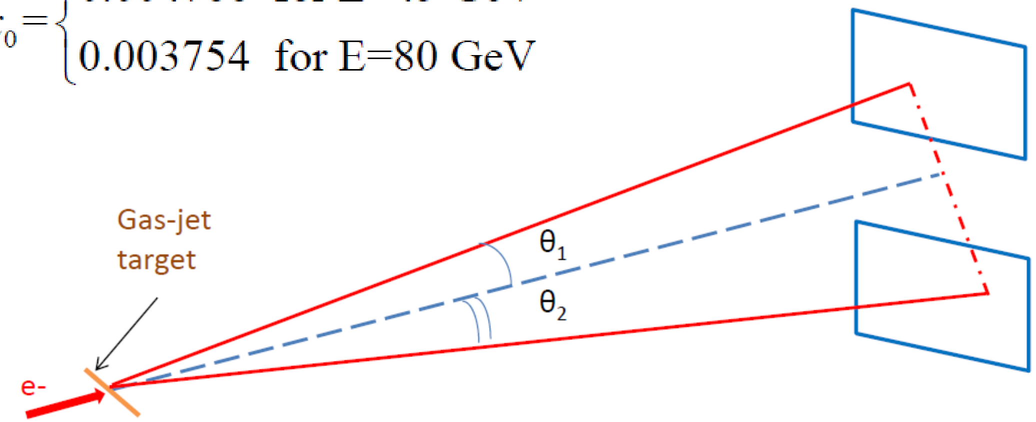


Moeller polarimetry

- I. Koop et al. recently proposed Moeller scattering as an alternative to measure the **beam energy locally** without the need of polarized beams.
- The idea is based on measuring the minimum scattering angle of the outgoing electrons:
  - min (θ1+θ2) ~ **9.4 mrad @ 45 GeV** → with 20 m lever arm the separation is ~ **20 cm**.

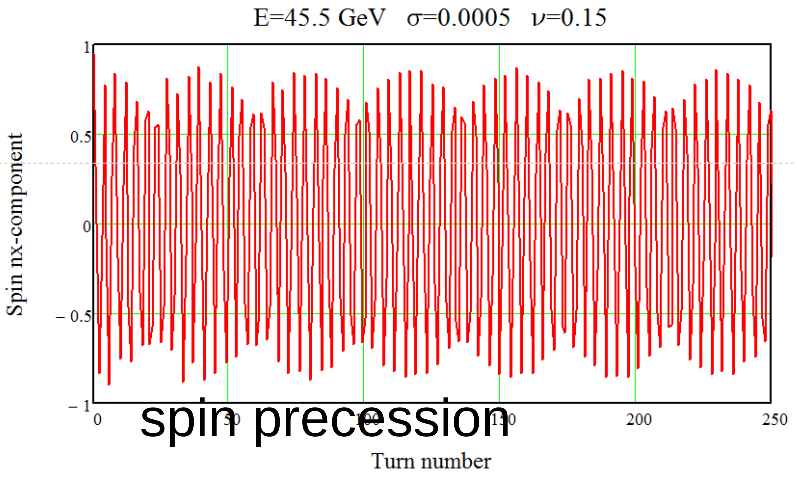
$$\frac{\tan(\theta_1)+\tan(\theta_2)}{2} \rightarrow x_0 = \frac{1}{\gamma_{cm}} = \sqrt{\frac{2}{\gamma+1}} \qquad x_0 = \begin{cases} 0.004766 & \text{for E=45 GeV} \\ 0.003754 & \text{for E=80 GeV} \end{cases}$$

- Achieving a relative accuracy of 10^{-6} requires sub-micron resolution and alignment of the detectors.
  - Other biases to be evaluated (local fields, energy spreads, etc).
- Even if an accuracy of only 10^{-5} is achieved, it could provide an independent energy measurement – similar to the proposal on previous slide.
  - Probes RDP energy (mean) and local energy model.

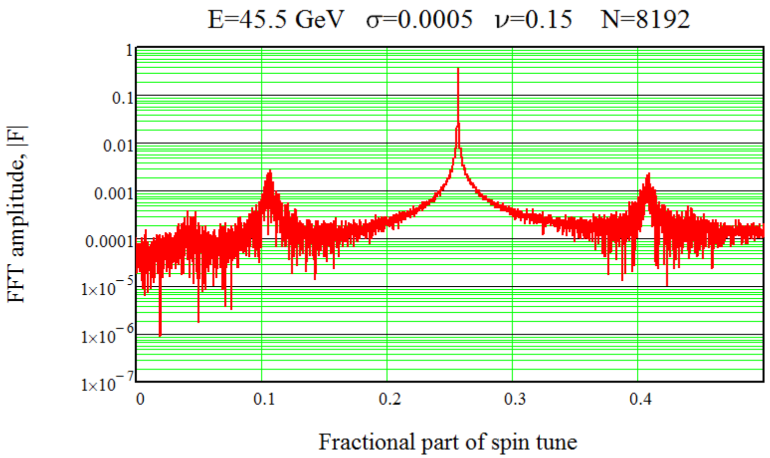


Longitudinal spin precession

- A concept of accelerating polarized beams and injecting them into the ring with spins oriented in the horizontal plane to determine the energy just after injection from the longitudinal precession also requires polarimetry – but this time on a **turn-by-turn basis – 3 kHz**.
- This may require a (quasi) continuous laser pulse over N thousand turns (up ~few seconds) with sufficient power to resolve the precession frequency with high accuracy.
- Besides the fact that it requires quite some HW in the injection chain, the measurement concept (laser power) has to be analysed in detail.



spin precession



Some other measurements and instruments

- The **energy spread** must be known to **~10^{-4}** : extremely challenging need.
  - Very accurate longitudinal profile measurements coupled to precise synchrotron tune and momentum compaction factor information.
- **Magnetic field monitoring with NMRs** in a sample of magnets (~2 per arc and per beam) to track the field (in)stability.
- **Precise BPMs** (~for free, ~ μm in relative) to model the energy sawtooth, RF voltages and phases.
- **RF voltage and phase measurements** (precision to be defined) to model the energy sawtooth for local energy prediction.
- **Residual dispersion at the IP** to monitor c.m. energy shifts due to opposite sign dispersion of the two beams.
  - Changes (lowers) the c.m. energy spread, induces c.m. energy shifts in conjunction with transverse beam offsets at the IP.

Summary

- There is no fundamental issue to design a polarimeter for the measurement of the transverse polarization.
- A more detailed layout should be developed in the coming months, possibly integrating one or more of the alternative options.
- Independent polarimeters must be foreseen for e+ and e- beams – we have to measure both beams continuously and efficiently.
- Monitoring / modelling of the local c.m. energy and c.m. energy spread adds additional needs for instrumentation and measurements – this must not be overlooked.