EPOL Summary

Jacqueline Keintzel, Eric Torrence and Guy Wilkinson

On behalf of the
FCC-ee EPOL working group

FCC Week 2024
San Francisco, California, USA
14 June 2024

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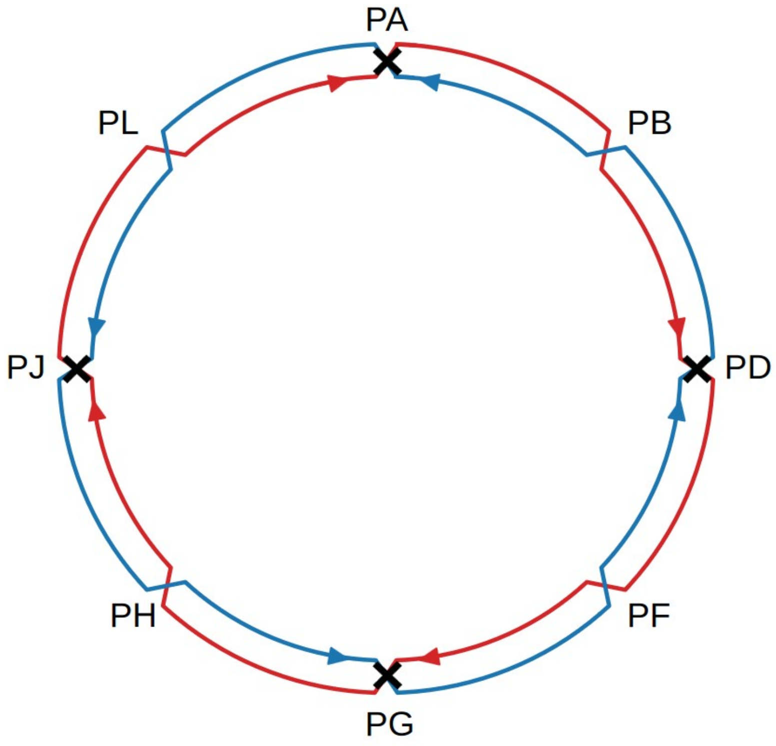
FCCIS – The Future Circular Collider Innovation Study. This INFRADEV Research and Innovation Action project receives funding from the European Union's H2020 Framework Programme under grant agreement no. 951754.

FCC-ee Overview

Particle Physics:

- Higgs and electro-weak factory
- 4 baseline beam energies and diverse particle physics program
  - 45.6 GeV: Z-pole
  - 80 GeV: W-pair-threshold
  - 120 GeV: ZH-production
  - 182.5 GeV: top-pair-threshold
- High number of statistics

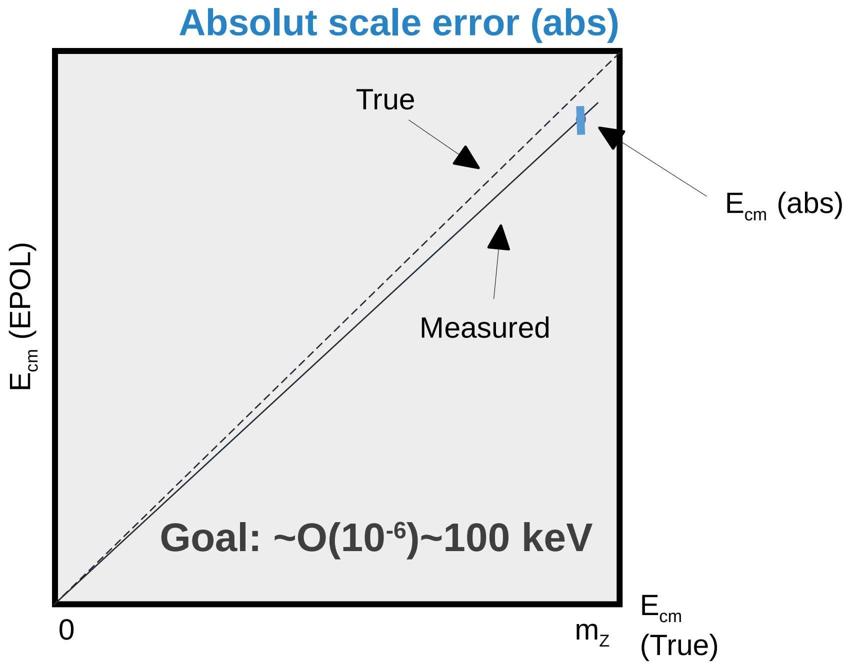


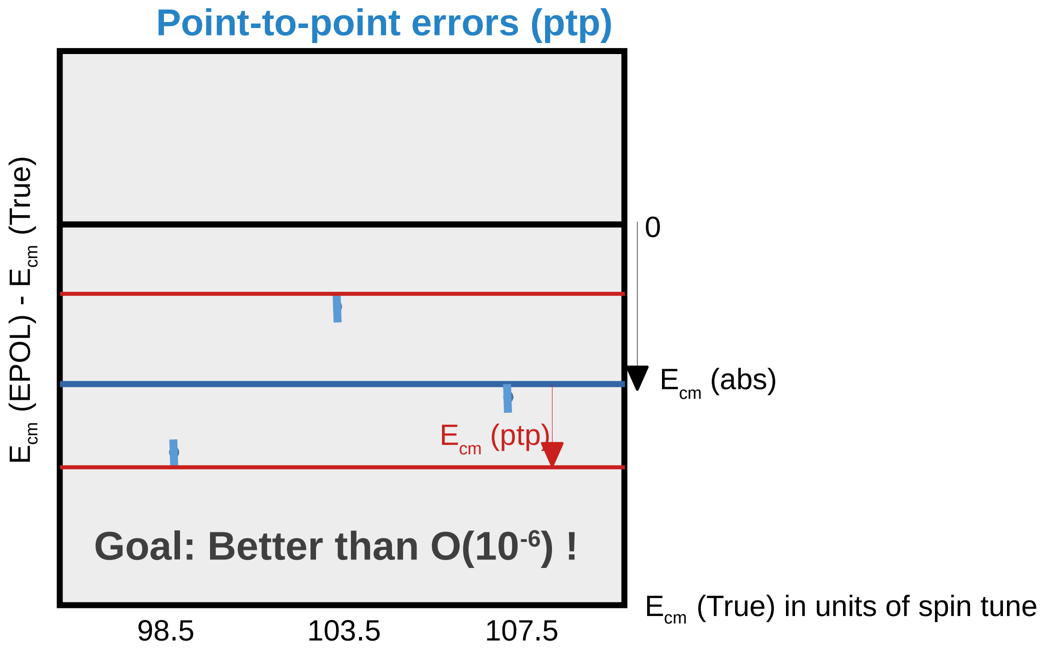
Accelerator Physics:

- 4-fold super-symmetric layout
  - Up to 4 Interaction Points (IPs)
  - 1 RF-section per beam
  - 1 collimation section
  - 1 section for injection and dump
- Nanometer beam size at IPs
- Strong synchrotron radiation

Precision particle physics experiments ⟺ Center-of-mass energy determination

Center-of-mass Energy Uncertainty





Error between measured and true E_{cm}

- Large effect on mass measurement
- Stems from systematic errors

Fluctuation between measurements

- Large effect on resonance width measurements
- Stems from variability of measurement conditions

Courtesy: A. Blondel

Expected Precision

Quantity	statistics	ΔE_{CMabs} 100 keV	$\Delta E_{CMSyst-ptp}$ **40 keV**	calib. stats. 200 keV/$\sqrt{(N^i)}$	σE_{CM} (84) $\pm$ **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	–
$\frac{\Delta\alpha_{QED}(M_Z)}{\alpha_{QED}(M_Z)} \times 10^5$	**3**	0.1	**0.9**	–	**0.05**

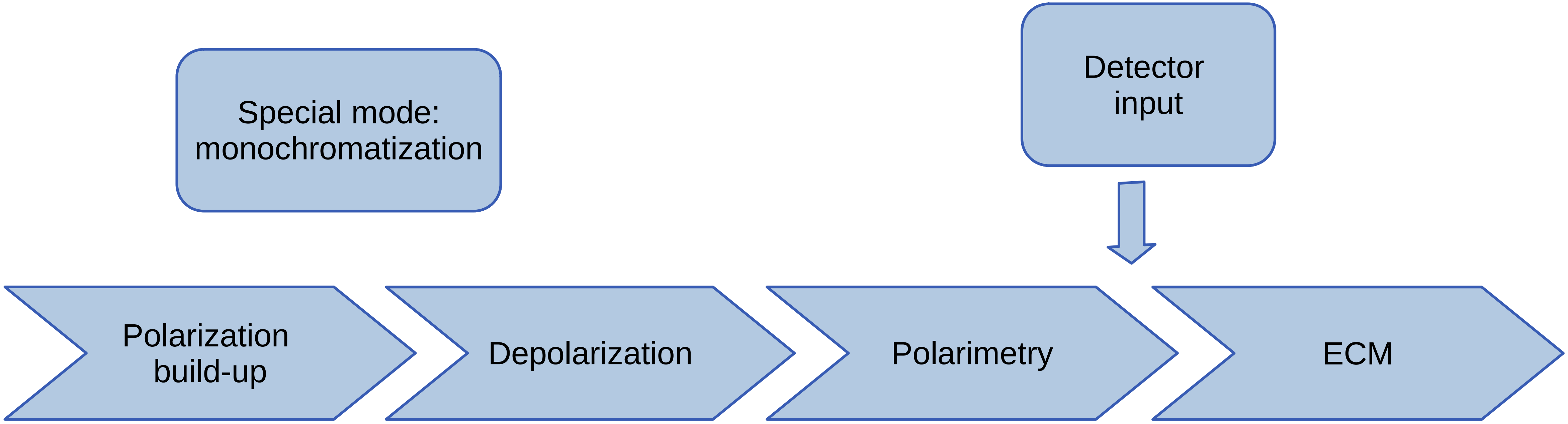
Huge statistics → small statistical error of a **few keV for Z and W-boson**

Aim to achieve same order of magnitude for systematic **(ptp)** errors → Scope of the **EPOL working group**

EPOL: Energy calibration, polarization and monochromatization

arXiv:1909.12245

How to?



- Resonances
- Wigglers
- Beam tests

- Resonant depolarization
- Free spin precession

- Polarimeter incl. laser, Si-detectors
- e.g. EIC experience

- Systematic errrors
- Statistical errors
- Accurate models

Sessions Overview

Thursday 13:30 – 15:00

Introduction and overview
Speaker: Guy Wilkinson

Polarized positron production
Speaker: Joseph Grames

Experiments at existing facilities
Speaker: Jacqueline Keintzel

The EIC polarimeter and lessons for the FCC
Speaker: Dave Gaskell

Thursday 15:30 – 17:00

Simulation polarization studies at the FCC
Speaker: Yi Wu

Polarized electrons at the EIC, lessons for the FCC
Speaker: Georg Hoffstaetter

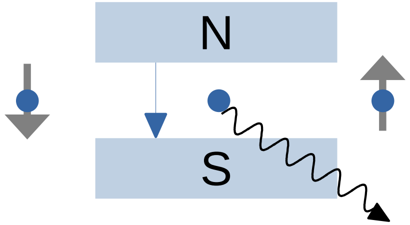
The FCC polarimeter
Speaker: Robert Kieffer

First thoughts on the FCC depolarizer
Speaker: Wolfgang Höfle

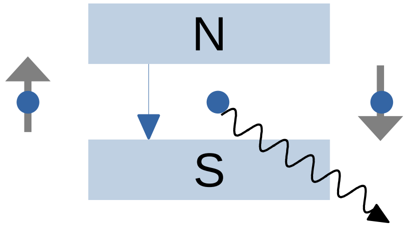
Lessons from LEP and final steps towards the final report of the FS, Speaker: Eric Torrence

Polarization Build-Up

More likely
(by factor ~25)



Less likely



- Statistically every 10^{10th} emitted synchrotron photon flips the spin
- Probability depends on the initial spin orientation

- Leads to a natural **polarization build-up** over time
- Orientation is **anti-parallel** to the guiding magnetic field

- Maximum theoretical polarization of **92.4 %**
- Spin precesses through the lattice → Spin tune

$$\nu = a * \gamma_{Rel}$$

a … gyro-magnetic anomaly
γ_{Rel} … Lorentz-factor

Tasks for Remainder of FS

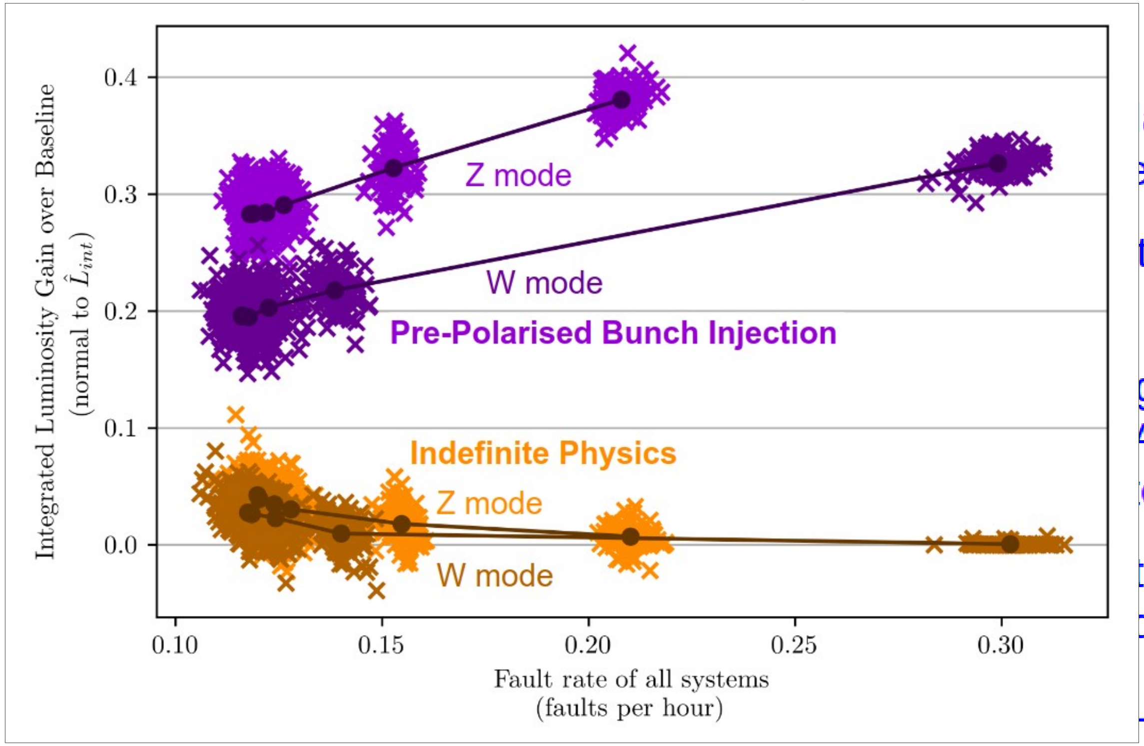
Introduction and Overview
Speaker: Guy Wilkinson

- Ensure sufficient polarisation in optics, including HSM studies at Z & WW
- Procedure, systematics and ultimate precision on RDP & FSP measurements
- Inform studies through series of measurements at KARA (and other accelerators)
- Arrive at full conceptual design of polarimeter, including infrastructure
- Full costing of EPOL related items
- Wigglers vs polarisation ring (injecting polarised e^-/e^+ increasingly attractive possibility – is it feasible ?)
- Requirements on depolariser and agreement on depolarisation procedure for pilot and physics bunches
- Deepen understanding of IP-specific corrections, in particular dispersion and offset effects
- Improve understanding of input from experiments, *e.g.* effect of higher-order corrections and detector resolutions *etc.* in $e^+e^- \rightarrow$ffbar(γ) studies
- Establish feasibility and expected performance of monochromatisation scheme for electron Yukawa run

Tasks for Remainder of FS

Introduction and Overview
Speaker: Guy Wilkinson

Courtesy: J. Heron



arisation in optics,
es at Z & WW

tics and ultimate
FSP measurements

gh series of
ARA
ors)

tual design
ding infrastructure

. related items

Injection of polarized beams could increase integrated luminosity by up to ~35%

- Wigglers vs polarisation ring (injecting polarised e^-/e^+ increasingly attractive possibility – is it feasible ?)

- Requirements on depolariser and agreement on depolarisation procedure for pilot and physics bunches
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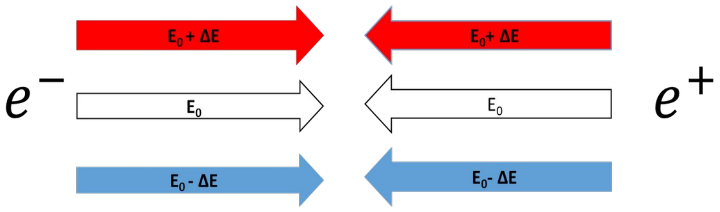
Monochromatization

FCC accelerators: Optics alternatives & lessons
Tuesday, 11 June, 10:30 – 12:00

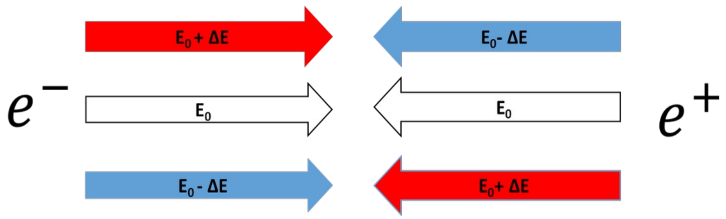
Monochromatization optics for FCC-ee
Speaker: Angeles Faus-Golfe

- 62.5 GeV beam energy → peak of Higgs-production
- For minimization of collision energy spread –> monochromatization
- Trade-off between collision energy spread and luminosity production

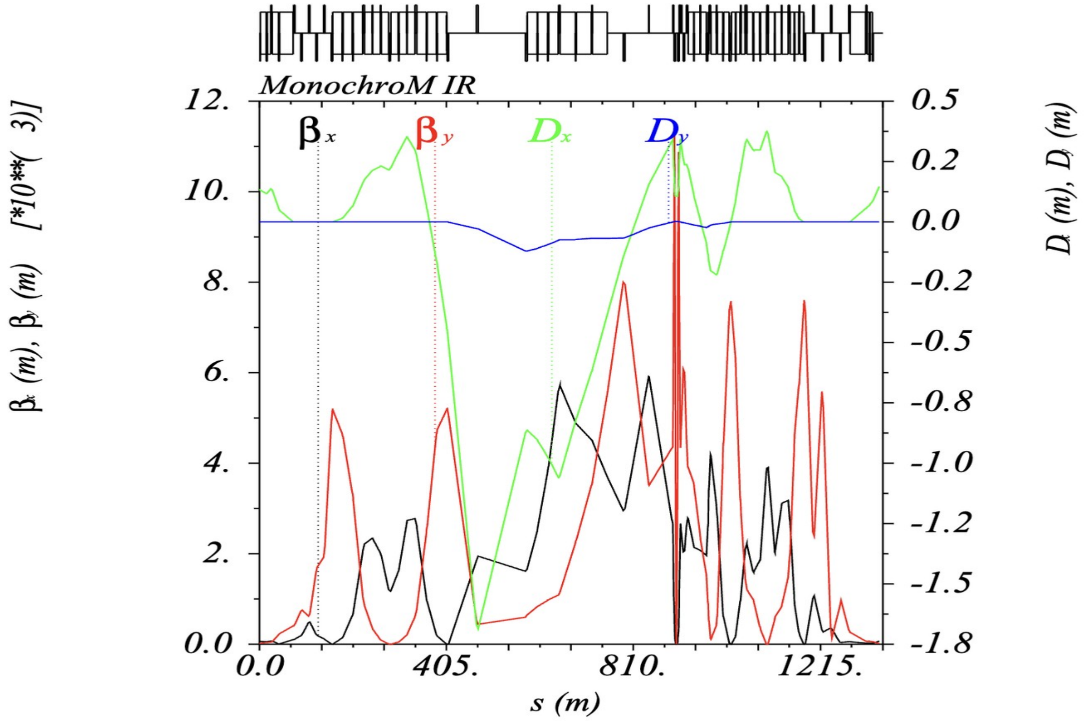
Introducing dispersion



Same sign dispersion at the interaction point leads to change of E_{CM}



Opposite sign (horizontal) dispersion helps reducing E_{CM} spread



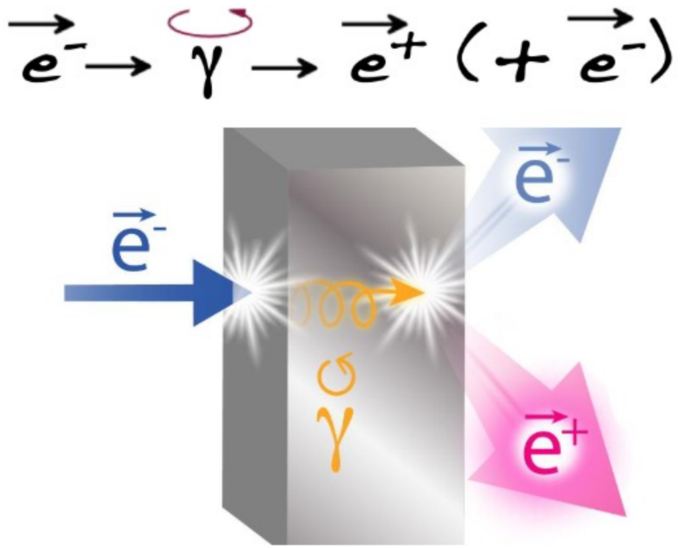
4 MeV spread ↔ 18 x 10^{34} $cm^{-2}s^{-1}$, possible optimization

Polarized Positron Source

- **P**olarized **E**lectrons for **P**olarized **Po**sitrons (PEPPo)
- Designed for CEBAF
- Polarized electrons based on GaAs
- Polarized positrons from polarized electrons

Parameter	CEBAF 12 GeV Electron Beam	Proposed 12 GeV Positron Beam
Experiment Intensity	10 nA - 170 μA	> 50 nA (pol) > 1 μA (unpol)
Duty Factor	100% (cw)	same
Bunch Frequency	249.5/499 MHz	same
Spin Polarization	>85%	>60%
Rapid Spin Reversal	30 – 2000 Hz (Pockels cell)	same

Polarized positron production
Speaker: Josef Grames

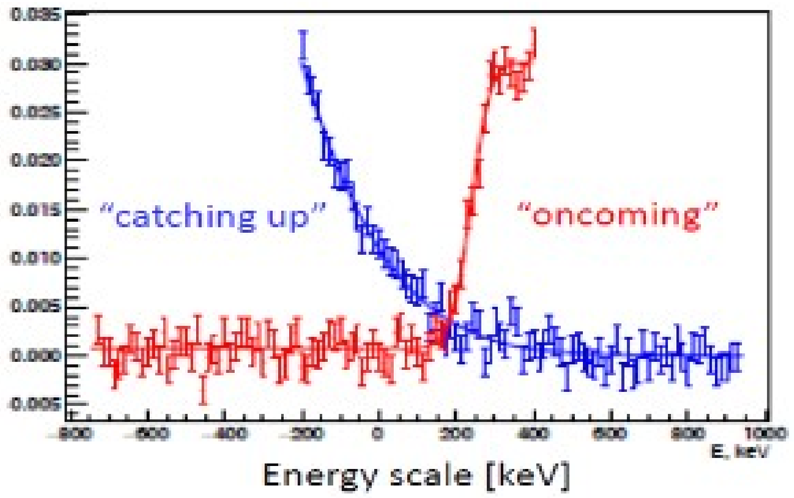


When a longitudinally polarized e^- beam strikes matter, e^+ produced in the shower carrying >50% of the e^- beam energy are significantly longitudinally spin polarized…

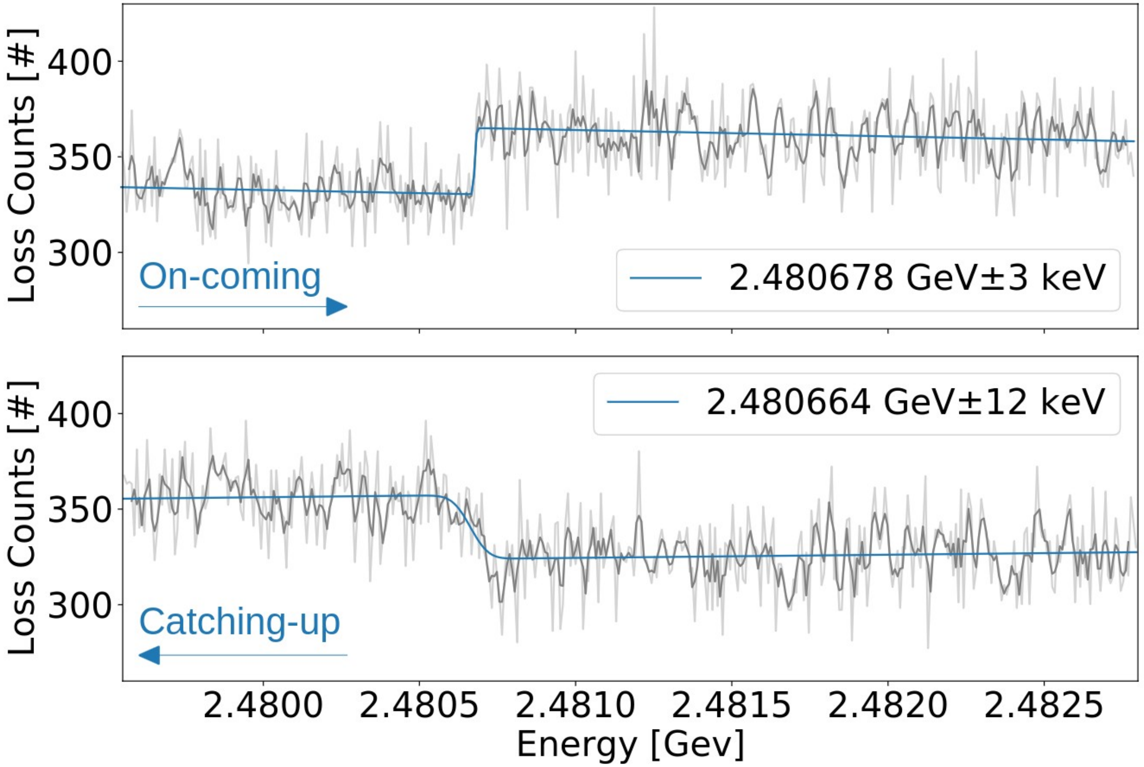
Experience at KARA

- RDP measurement campaign at KARA
- Findings consistent with simulations for FCC
- Low measurement fit error of a few keV

Experiments at existing facilities
Speaker: Jacqueline Keintzel

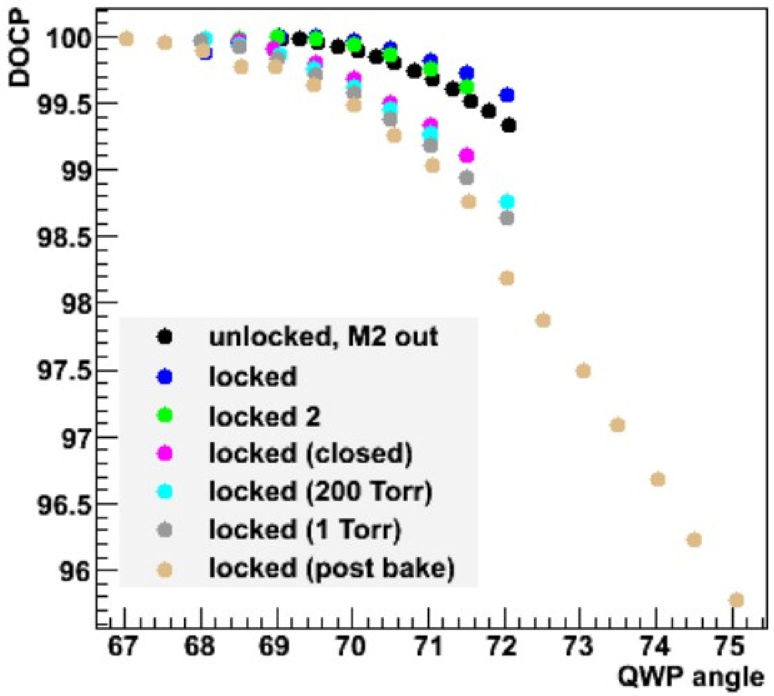


Courtesy: S. Nikitin, I. Koop

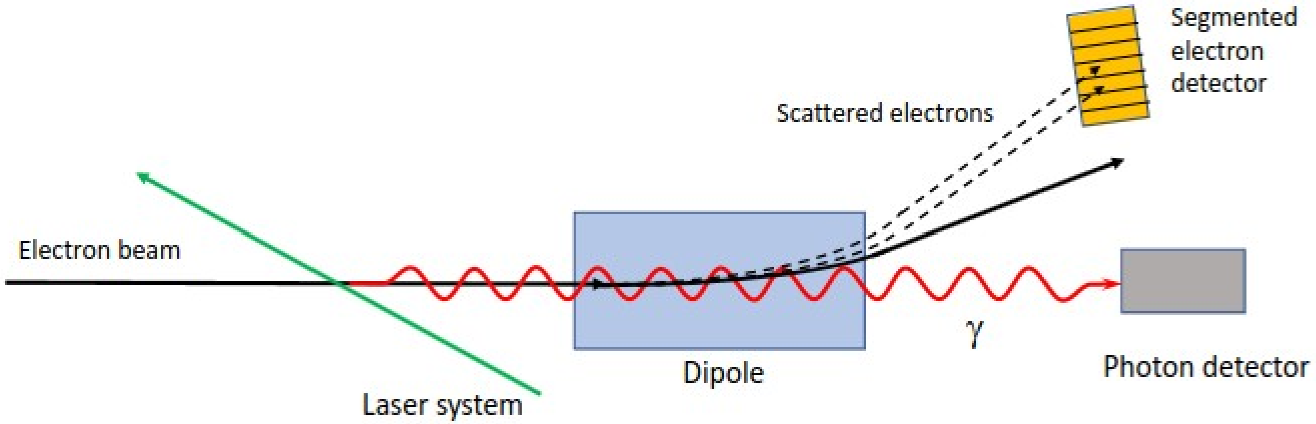


EIC and FCC Polarimeters

The EIC polarimeter and lessons for the FCC
Speaker: Dave Gaskell



- Common issues:
  - Beam structure: short times between bunches
  - Synchrotron radiation issues
  - Laser diagnostics



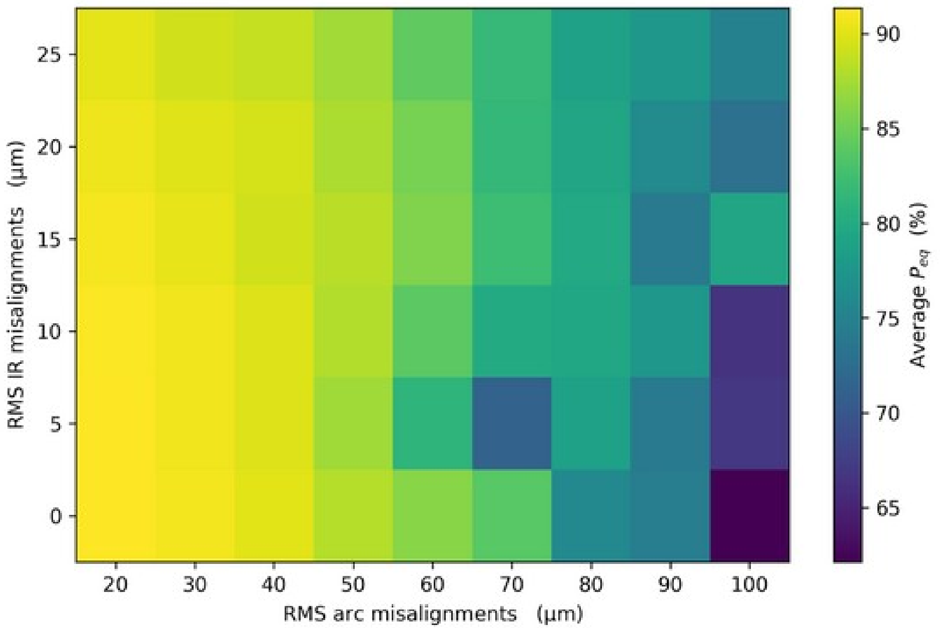
Polarization and Misalignments

- Element misalignments increase vertical orbit and decrease theoretical achievable polarization
- Large fluctuations between various error seeds

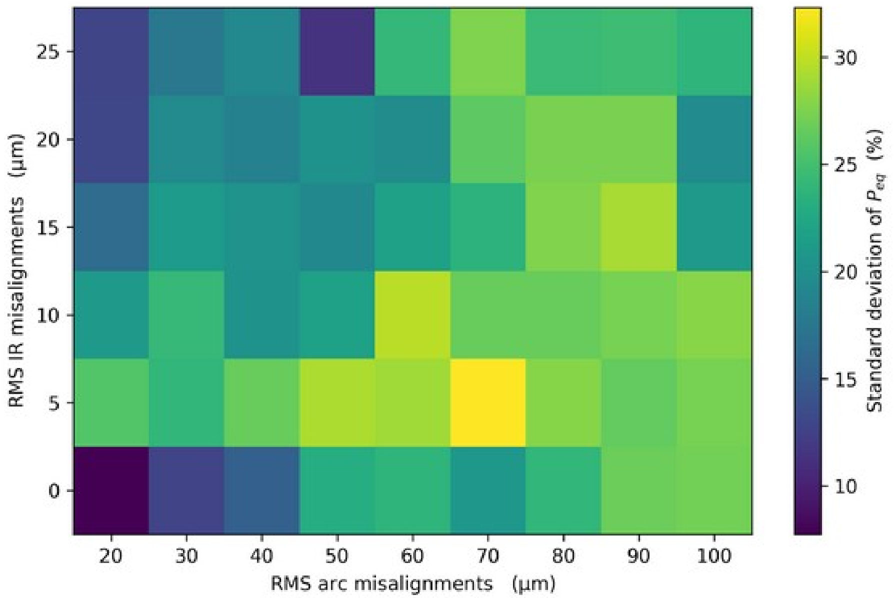
Orbit correction and polarization studies
Speaker: Yi Wu

- 100 / 10 μm in arcs / IRs → 70 ± 25 % polarization

average P_{eq} (%)



standard deviation of P_{eq} (%)



Polarization Lessons from EIC

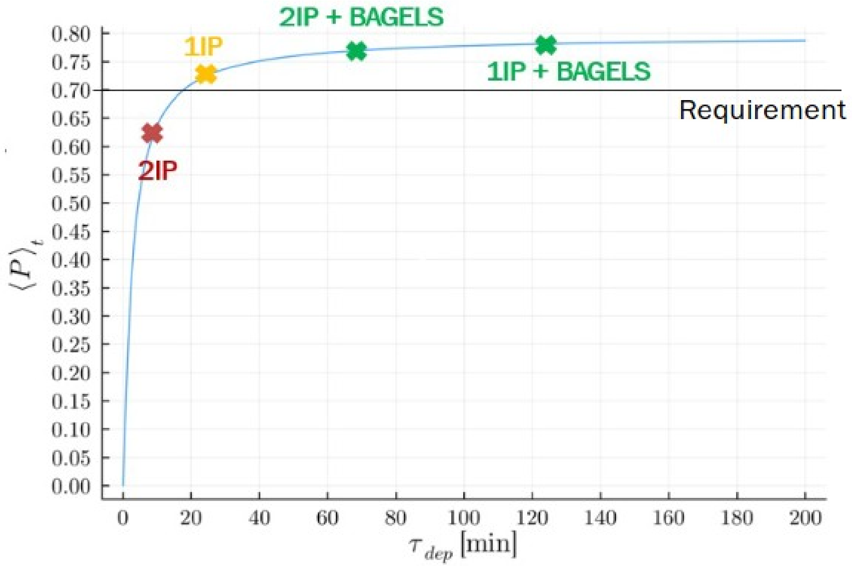
Polarized electrons at the EIC, lessons for the FCC
Speaker: Georg Hoffstaetter

- Better polarization with errors observed
- → **B**est **A**djustment **G**roups for **EL**ectron **S**pin (BAGELS)

$$\begin{pmatrix} \partial\hat{n}/\partial\delta_1 \\ \vdots \\ \partial\hat{n}/\partial\delta_n \end{pmatrix}_f = \begin{pmatrix} \partial\hat{n}/\partial\delta_1 \\ \vdots \\ \partial\hat{n}/\partial\delta_n \end{pmatrix}_0 + \begin{pmatrix} \frac{\partial(\partial\hat{n}/\partial\delta)_1}{\partial\theta_1} & \cdots & \frac{\partial(\partial\hat{n}/\partial\delta)_1}{\partial\theta_m} \\ \vdots & \ddots & \vdots \\ \frac{\partial(\partial\hat{n}/\partial\delta)_n}{\partial\theta_1} & \cdots & \frac{\partial(\partial\hat{n}/\partial\delta)_n}{\partial\theta_m} \end{pmatrix} \begin{pmatrix} \theta_1 \\ \vdots \\ \theta_m \end{pmatrix} + \ldots$$

n bends

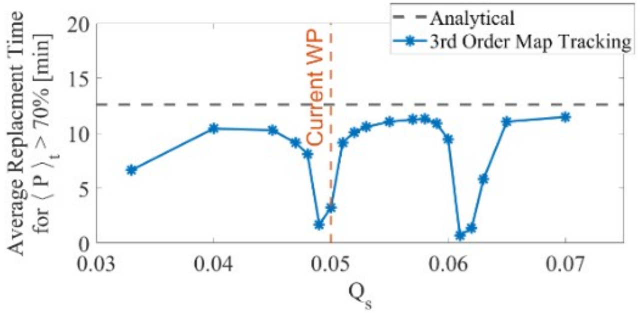
m unit bumps



- "Eigenvectors" with **largest** "eigenvalues" have **maximum** impact on $\partial\hat{n}/\partial\delta$
- "Eigenvectors" with **smallest** "eigenvalues" have **minimum** impact on $\partial\hat{n}/\partial\delta$

Polarization studies have changed many important features of today's ESR

- 10 GeV Lattice Correction of 1IP/2IP Operating Energies
- ESR v5.3: Nonlinear Resonance Identified, Tunes Changed
- ESR v5.6: Partial Longitudinal Spin Match by solenoid polarity change



FCC Polarimeter

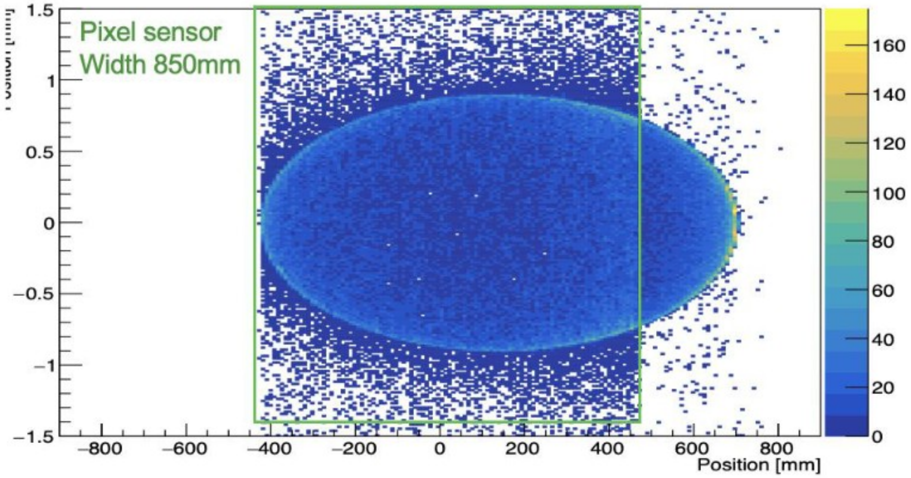
The FCC polarimeter
Speaker: Robert Kieffer

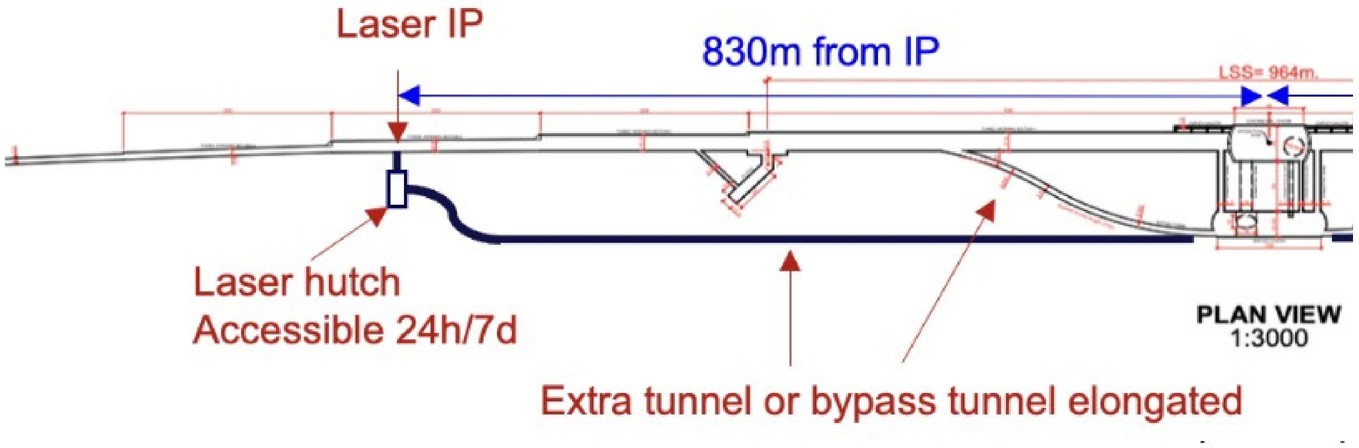
- Laser should be accessed at all times
- Baseline would require additional CE
- Separation chamber length optimized
- Extraction window optimization:

  Angle and material thickness

Base line: a single polarimeter per beam (2 total)

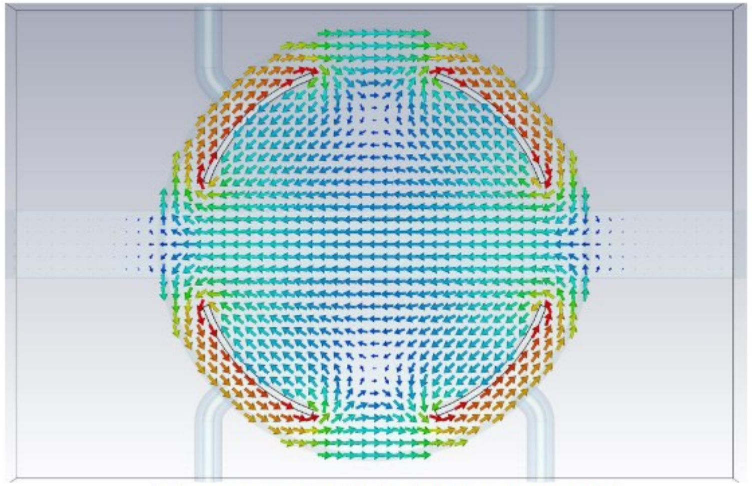
- Instrument location: both ends of LSS on each experimental **IP A.**
- Laser room should have a **24/7 access to insure availability**.
- **Needs dedicated laser hutch and access tunnels.**
- Energy at IPs is inferred from one measurement point.
- Energy loss (Tapering), along the ring **induce systematic errors** on the energy inferred at each IP.

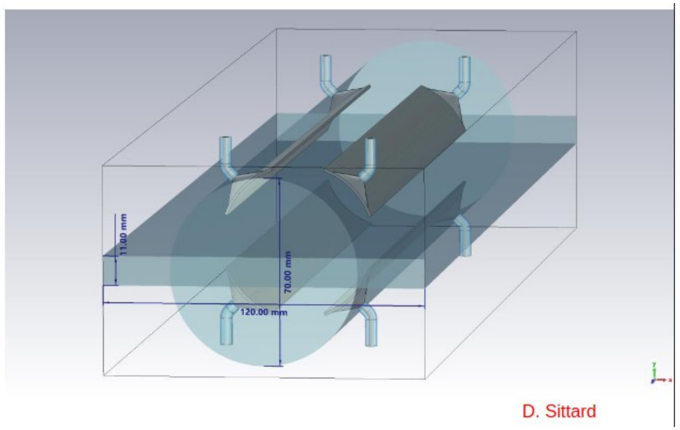




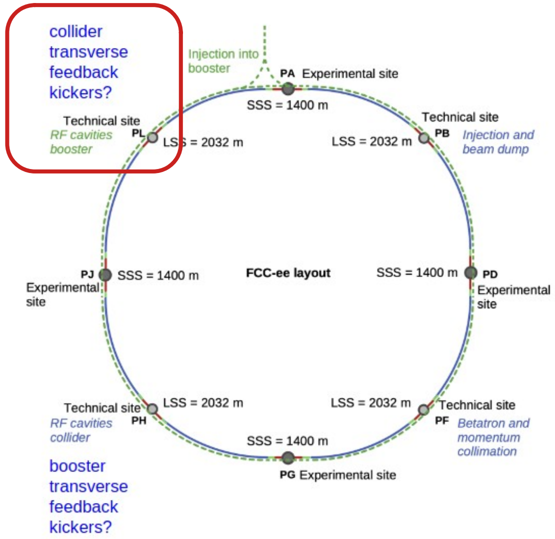
Depolarizer

First thoughts on the FCC depolarizer
Speaker: Wolfgang Höfle





- First detailed thoughts on depolarizer design have started
- Combined with transverse feedback system
- Minimum 3 location required to generate closed orbit bumps
- Optimum location to be found
- 10 µrad kick at 45.6 GeV required
  - → challenging
  - → Closer to the beam
  - → Multiple depolarizers
  - → Best locations?



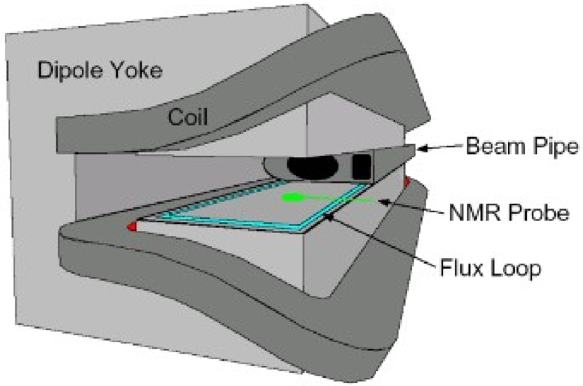
From LEP to the End of the FS

Lessons from LEP and final steps towards the final
Speaker: Eric Torrence

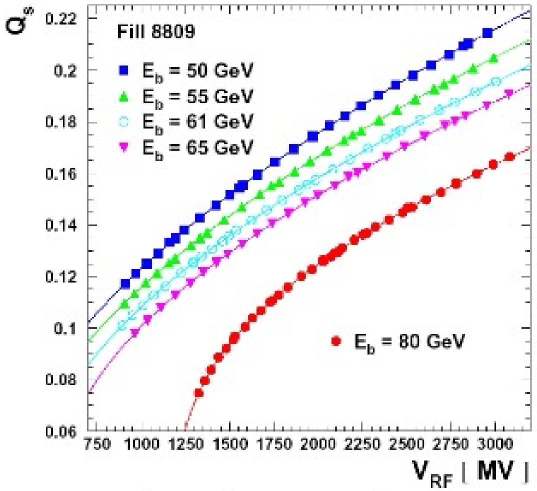
- Redundancy for beam energy measurements
- Especially at higher energies when RDP is more challenging
- RDP, physics measurements, free spin precession

- LEP2 used 3 separate methods to extrapolate RDP

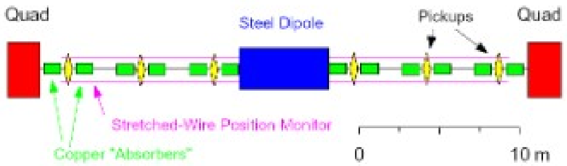
Flux loop



Synchrotron tune vs V_{RF}



In-line spectrometer



Agreement lead us to believe dE_b/E_b = 10 MeV uncertainty

Outlook

- Presently aimed to achieve *a few keV* systematic (ptp) uncertainty at the *Z- / W- modes –> EPOL*

- Important questions aimed to be investigated in the future, for example:
  - Could/should we aim to inject already polarized bunches?
  - What are the best locations for the depolarizer and the polarimeter?
  - ...

Regular EPOL meetings:
indico.cern.ch/category/8678/
Typically every third Thursday 16:30-18:30

Mailing list:
fcc-ee-PolarizationAndEnergyCalibration@cern.ch

Self-subscription from:
https://e-groups.cern.ch/e-groups/EgroupsSearch.do

Any help is welcome!

FUTURE CIRCULAR COLLIDER

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Thank you!

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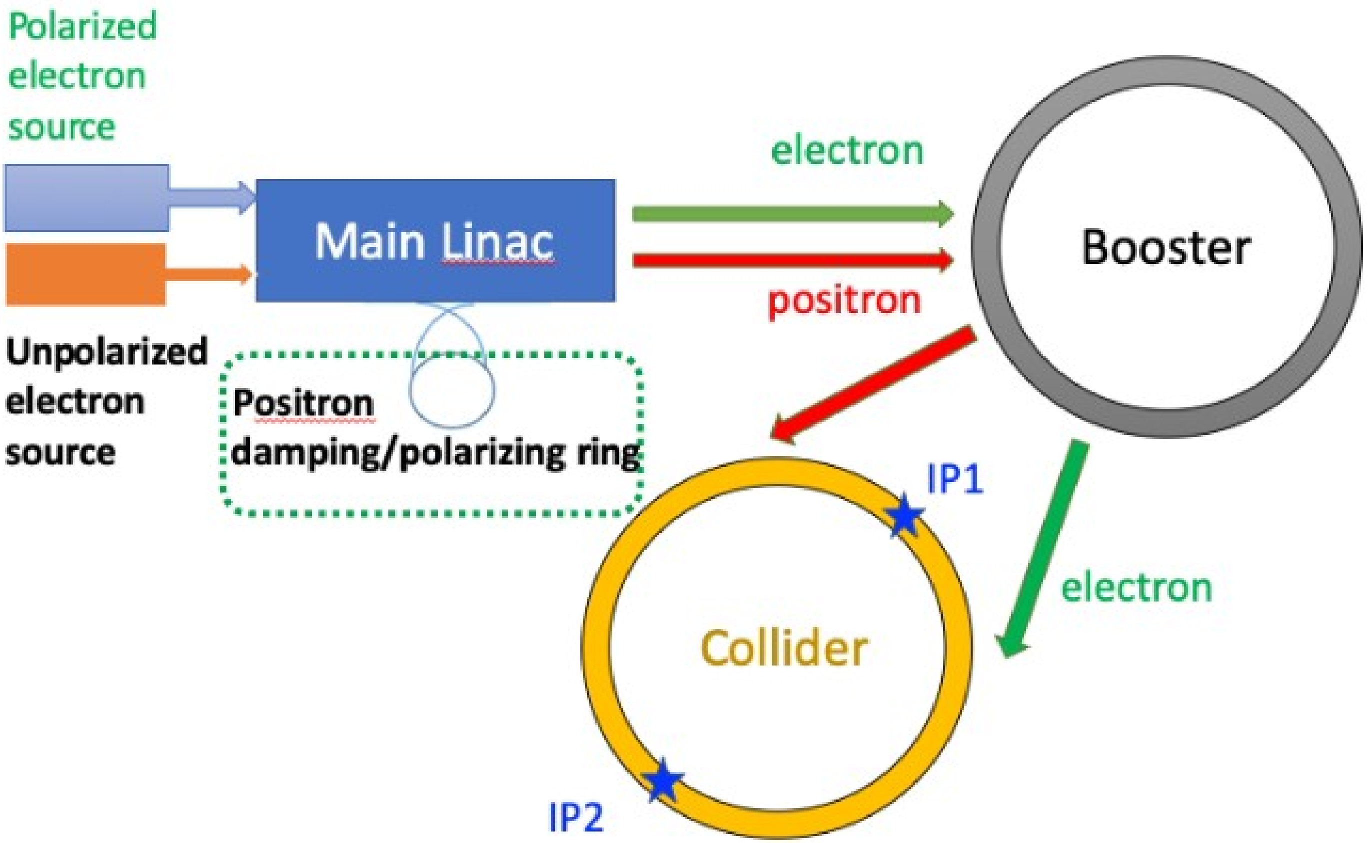
CEPC Polarization Scheme

Courtesy: Zhe Duan



- Injection of polarized electrons and positrons in collider rings at Z and W
  - Longitudinal polarization for physics bunches
  - Transverse polarization for pilot bunches
  - More time for physics
- Possibly also polarized beams at H