FUTURE CIRCULAR COLLIDER

CERN

FCC-ee Energy Calibration, Polarization and Monochromatization – Future Plans

D. Barber, M. Benedikt, A. Blondel, E. Blomley, A. Bogomyagkov, F. Carlier, E. Gianfelice-Wendt, A. Faus-Golfe, D. Gaskell, B. Härer, M. Hofer, P. Janot, H. Jiang, J. Keintzel*, I. Koop, M. Koratzinos, T. Lefevre, A. Martens, N. Muchnoi, S. Nikitin, I. Nikolaev, K. Oide, T. Persson, T. Pieloni, P. Raimondi, R. Rossmanith, D. Sagan, D. Shatilov, R. Tomàs, J. Wenninger, G. Wilkinson*, Y. Wu, and F. Zimmermann

* jacqueline.keintzel@cern.ch
* guy.wilkinson@cern.ch

6th FCC Physics Workshop
Highlights and Future Plans
27th January 2023

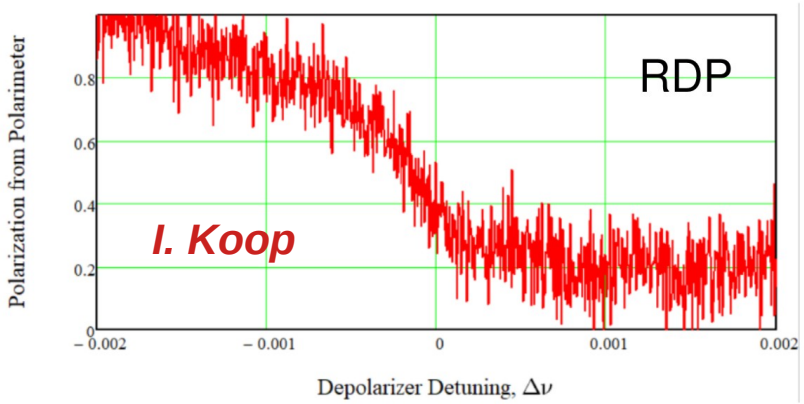
FCCIS – The Future Circular Collider Innovation Study. This INFRADEV Research and Innovation Action project receives funding from the European Union's H2020 Framework Programme under grant agreement no. 951754.

Status of the EPOL Studies

- Starting point: Polarization and Centre-of-mass Energy Calibration at FCC-ee, **arXiv:1909.12245**
- Continous updates on lattice and optics
- Close interplay with optics tuning:

  Good optics tuning – luminosity – polarization

"Status and prospects for the EPOL measurements" - Guy Wilkinson

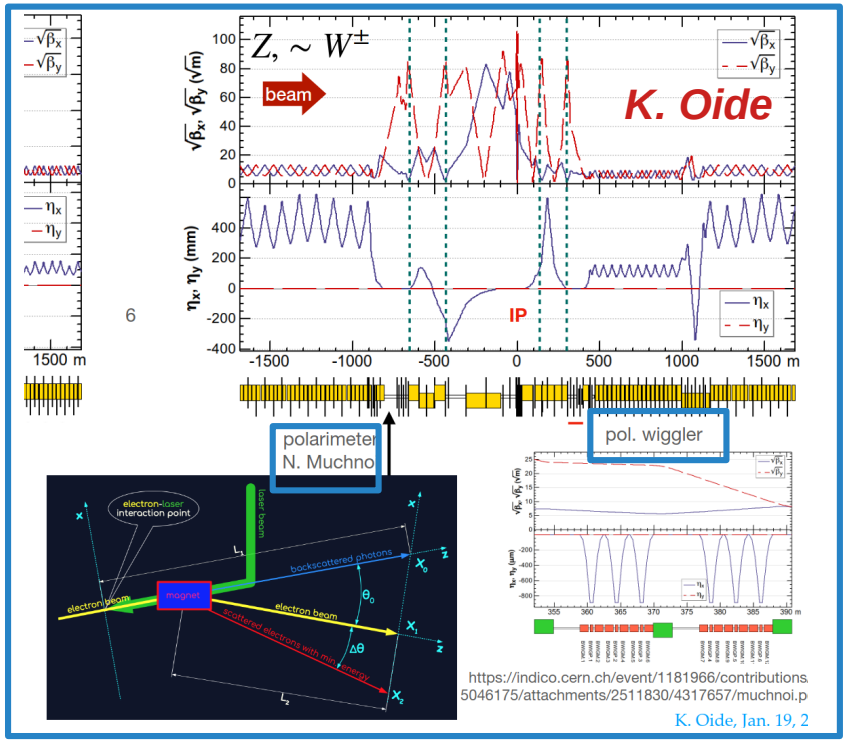


Depolarization at W-mode

Regular EPOL meetings:
https://indico.cern.ch/category/8678/

Regular optics tuning meetings:
https://indico.cern.ch/event/1226075/

New experimental interaction layout
- With wigglers
- With polarimeters



Meetings and Workshop

- Approximately bi-weekly EPOL meetings: indico.cern.ch/category 8678

- A dedicated workshop on "FCC-ee energy calibration, polarization and monochromatization (EPOL)" took place from September 19 to 30 2022 at CERN
- At this occasion there was an EIC-FCC Collaboration Working Meeting on Polarization from September 19 to 23 2022.

113 registered participants

127 contributions

Indico Event:
https://indico.cern.ch/e/EPOL2022

Structure of the EPOL Team

A- Simulations of polarization and spin-tune to beam energy relationship

-- simulations of spin polarization in realistic machine (also able to calculate emittances, luminosity)

-- res. depolarization at Z and WW threshold

-- design and integration of wigglers, RF kickers, in FCC-ee

B. Simulation of the relationship between beam energies and centre-of-mass energy

-- studies of operation scenarios

-- control of offsets and vertical dispersion

-- Impact and control of energy losses: Synchrotron rad., Beamstrahlung, impedance, etc.

C. Polarimeter design and performance

-- now working to build a global collaboration

-- Aim to provide integration of polarimeters,

-- conceptual design and cost estimate of polarimeter for FCC FS

D. Measurements in Particle Physics Experiments

-- use of dimuons and other processes to determine centre-of-mass energy spread, boost, at and within IP

E. Monochromatization

-- new ideas for monochromatization in other dimensions than horizontal (x) axis. (time, z)

-- what its the limit?

Which open questions are there to be answered by the mid-2023 and end-2025?

Spin Tune and Beam Energy

- In an ideal machine

E … energy
m … mass
c … speed of light
ν … spin tune
a … anomalous magnetic dipole moment

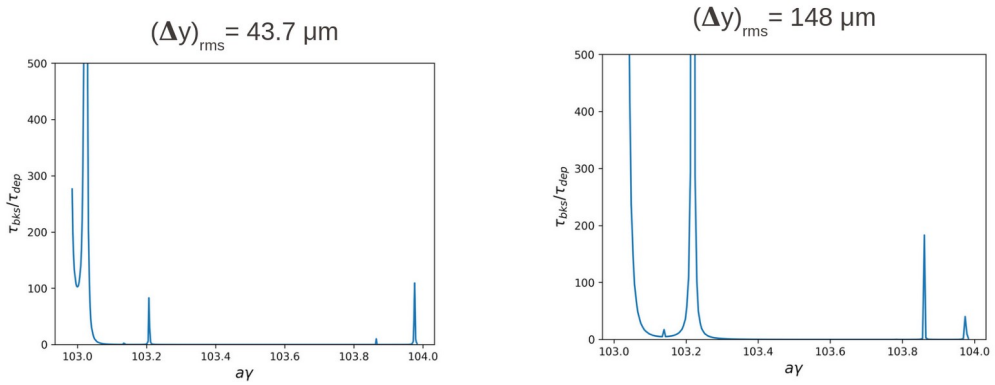
$$E = mc^2\left(\frac{\nu}{a} - 1\right)$$

Spin tune measurement might not be exact beam energy measurement, e.g. **shift due to vertical or longitudinal magnetic fields → to be studied in detail**

synchrotron oscillations	ΔE/E	$-2\ 10^{-14}$
Energy dependent momentum compaction	ΔE/E	10^{-7}
Solenoid compensation		$2\ 10^{-11}$
Horizontal betatron oscillations	ΔE/E	$2.5\ 10^{-7}$
Horizontal correctors*)	ΔE/E	$2.5\ 10^{-7}$
Vertical betatron oscillations **)	ΔE/E	$2.5\ 10^{-7}$
Uncertainty in chromaticity correction $O(10^{-6})$	ΔE/E	$5\ 10^{-8}$
invariant mass shift due to beam potential		$4\ 10^{-10}$

A. Bogomyagkov

- Lattice errors can destroy polarization
- Harmonic spin matching to reduce depolarization



Y. Wu

Open Questions:

- How well can we predict the beam energy at different energy stages?

- How does the average beam energy relate to the center-of-mass energy at the 4 IPs?

- What are the tolerances on alignment, BPMs, etc.?

A. Blondel, J. Wenninger

Dispersion and Collision Offsets

- ECM shifts due to opposite sign dispersion → obtained with BPMs around IP

  → Requires about **1 µm precision for BPMs close to IP**

$$\Delta\sqrt{s} = -u_0 \frac{\sigma_E^2 \Delta D^*}{E_0 \sigma_u^2} \quad \Longrightarrow \quad |\Delta\sqrt{s}| = 96\ |u_0|\ [\mathrm{keV/nm}]$$

for $\Delta D^* = 1$ µm, $\sigma_E/E = 0.13\%$

For **$\Delta D^* = 10$ µm**, the CM error is **~1 MeV/nm**, i.e., the uncertainty on / average separation must be below **$u_0 < 0.1$ nm to limit the systematic errors < 100 keV.**

- Even closer to 0.01 nm for σ ~ 20 nm → at the level of a % of the beam size.

- Luminosity or beam-beam (BB) deflection scan to determine collision offsets
- Disentangling of dispersion and BB offset → non-colliding bunches at different intensities?

Open Questions:

- What can we learn from non-colliding bunches with different intensities?

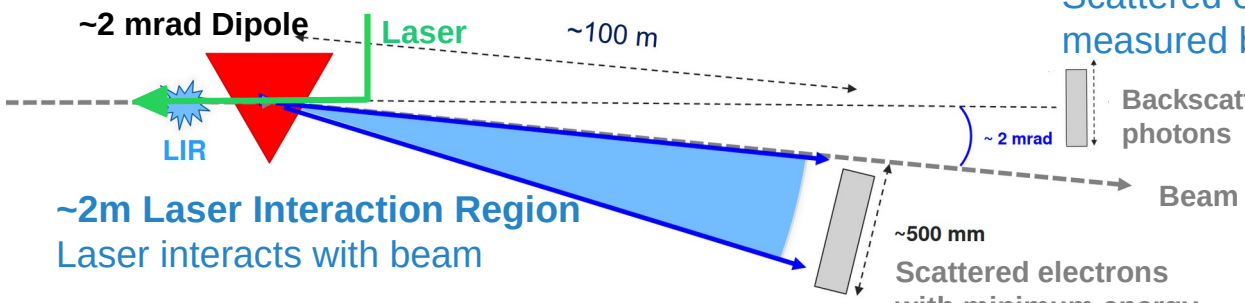
- How well can we control dispersion and collision offsets?

M. Hofer, A. Martens, N. Muchnoi, K. Oide, T. Lefevre, J. Wenninger

Polarimeter

- For now, most requirements driven by Z-pole requirements and presently studied in detail
- At least one polarimeter per beam required, goal: 1% statistical precision every second

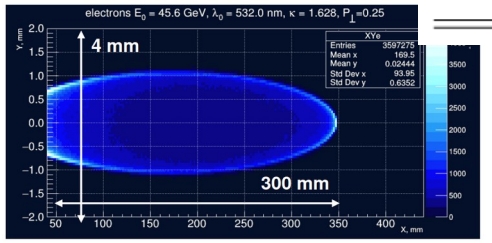
Allows measurement of three coordinates of beam polarization



~2m Laser Interaction Region
Laser interacts with beam

M. Hofer and J. Wenninger

Scattered electrons to be measured by Si pixel detector



N. Muchnoi

parameter	pilots	colliding bunches
$f_{\text{rep.}}$	3 kHz	30 kHz
U	1 mJ	10x0.5 mJ
σ_t	5 ps	5 ps
$\sigma_{x,y}$ [ps]	300 μm	300 μm
P	3 W	150 W

Laser requirements
Ytterbium mode-lock laser technology frequency doubled to provide green light at about 515 nm

Open Questions:

- What is the advantage and price of one polarimeter per IP and beam instead of one per beam?

- What are the required parameters to measure polarization of pilot bunches and colliding bunches?

I. Koop, S. Nikitin, I. Nikolaev, J. Wenninger

Depolarizer

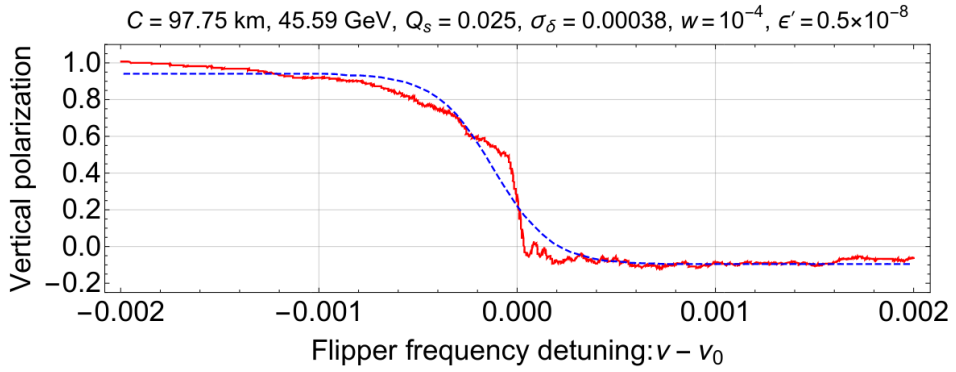
- Transverse depolarization for two pilot bunches simultaneously for polarization measurements
- Longitudinal depolarization for colliding bunches

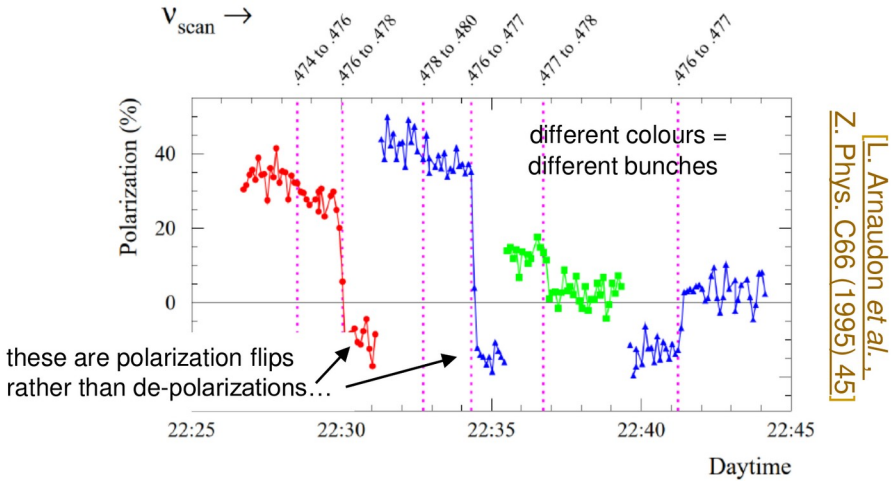
Open Questions:

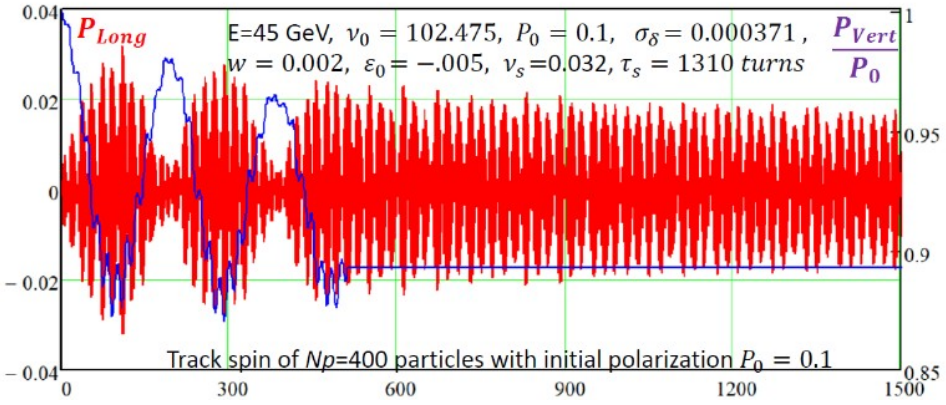
- What is the best location for the depolarizer in the lattice?

- Can we use the same pilot bunches more than once?

- Can we observe free spin precession in a realistic lattice for Z- and W-energy?







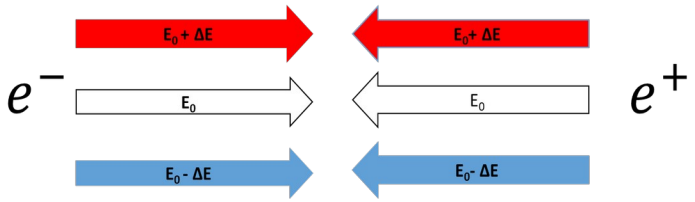
I. Koop

A. Faus-Golfe, H. Jiang, P. Raimondi, F. Zimmermann

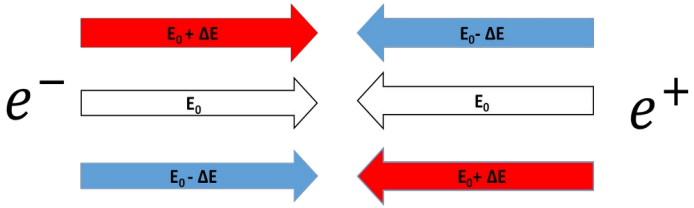
Monochromatization

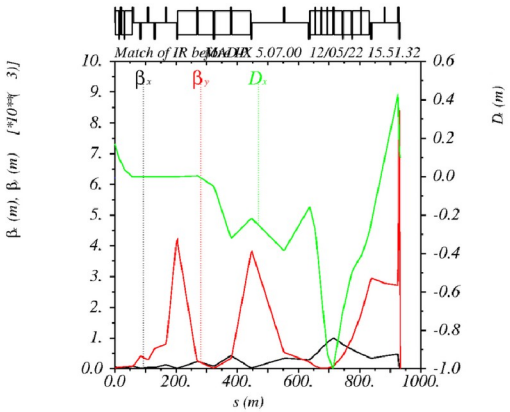
- ECM depends on many factors (collision offsets, dispersion, beamstrahlung, radiation, …)
- Monochromatization required to minimize energy spread for certain operation modes

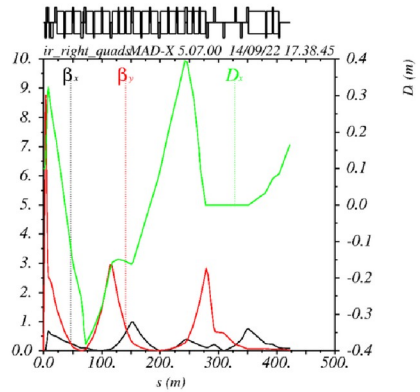
Same sign dispersion at the IP leads to change of ECM



Opposite sign dispersion helps reducing ECM spread
→ **Monochromatization**







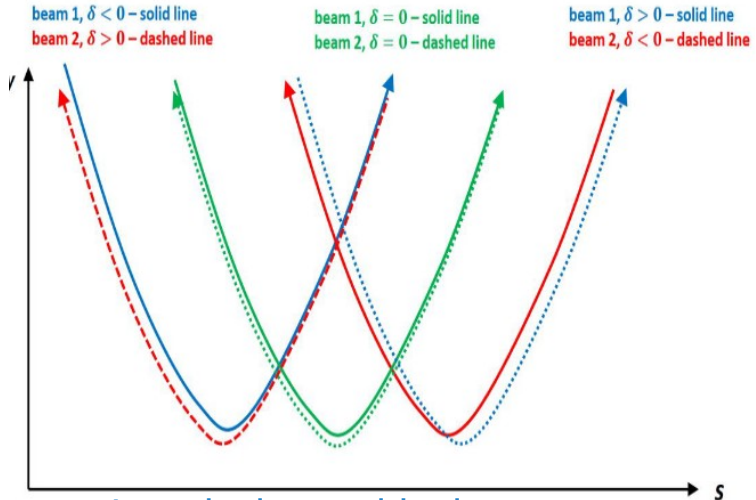
Open Questions:

- Can we have sufficient monochromatization at the Higgs-mode?

- What is the impact on luminosity?

- Can we test it somewhere, e.g. at DAFNE?

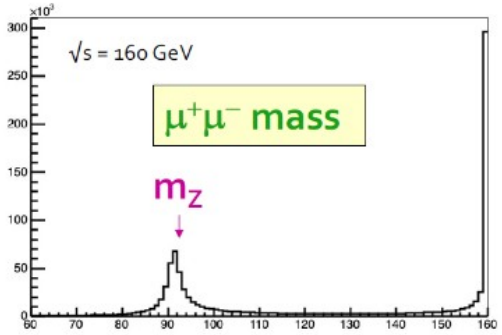
"Status and progress on monochromatisation studies" – Angeles Faus-Golfe



Introducing residual non-zero local vertical chromaticity

Experiments

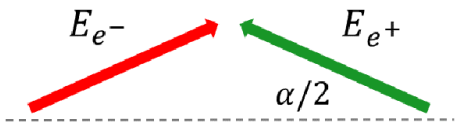
- ***Talk G. Wilkinson:*** ***Di-muon events: "The gift that keeps on giving"***
- Requires reliable and frequent logging of parameters



Radiative returns to the Z can be used to measure E_{CM} at higher energies,
with excellent statistical precision
Already exploited during LEP 2

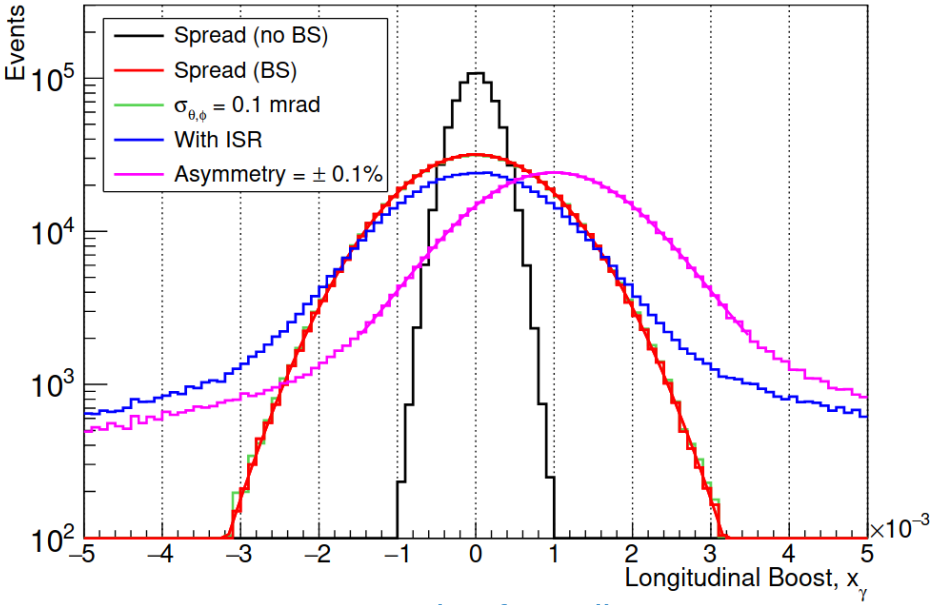
What is the real systematic uncertainty ?

Crossing angle determination from di-muon events



$$\sqrt{s} = 2\sqrt{E_{e^+}E_{e^-}}\cos\alpha/2$$

10^6 dimuon events at Z-pole: e+e- –> μ+μ- (γ)
(γ)… Initial-State-Photon (ISR)



Boost reconstruction from di-muon events

Important message / **Open questions**

All these results come from 'proof-of-principle' studies. They need to be repeated and consolidated with state-of-the-art ISR generators, proper simulation, realistic treatment of detector resolutions *etc.*, and extended to other fermion types and (in top regime) WW events. Many important & interesting studies to be performed !

A. Blondel, G. Wilkinson

Where to Start?

- ***Talk M. Dam:*** ***Projects in Detectors, MDI, EPOL***

Entry points for EPOL-related tasks (non-exhaustive list)

Experimental inputs to calibration of energy-related quantities

Di-fermion events can be used to calculate boost, energy spread, crossing angle and energy.

Almost all studies to date performed with muons, and under idealised conditions.
Should be repeated in more realistic detector and physics framework, investigating in particular the impact of QED corrections and misalignments. True systematics of radiative return events for determination of beam energy should be investigated. Need to be extended beyond dimuons.

Input on polarimeter design

FCC-ee polarimeters will be highly precise calorimeters, with a demanding high-power laser system.
Great opportunity for institute involvement !

Accelerator physicist and particle physicist input to core calibration issues

- Depolarisation and free-spin precision strategies
- Development of time-dependent energy model – impact on key observables
- Strategy for interaction-point specific corrections (in particular opposite sign dispersion studies)
- Monochromatization-related issues…
- ……

Synergies with Other Machines

- LEP: polarimeter, operation, depolarization, wigglers, di-fermion events, ...
- LHC: operation, orbit measurements

“BNL Contributions” – Marc-Andre Pleier

First joint FCC-EIC workshop on EPOL

Second joint FCC-EIC workshop on MDI

Third joint FCC-EIC workshop in spring 2023

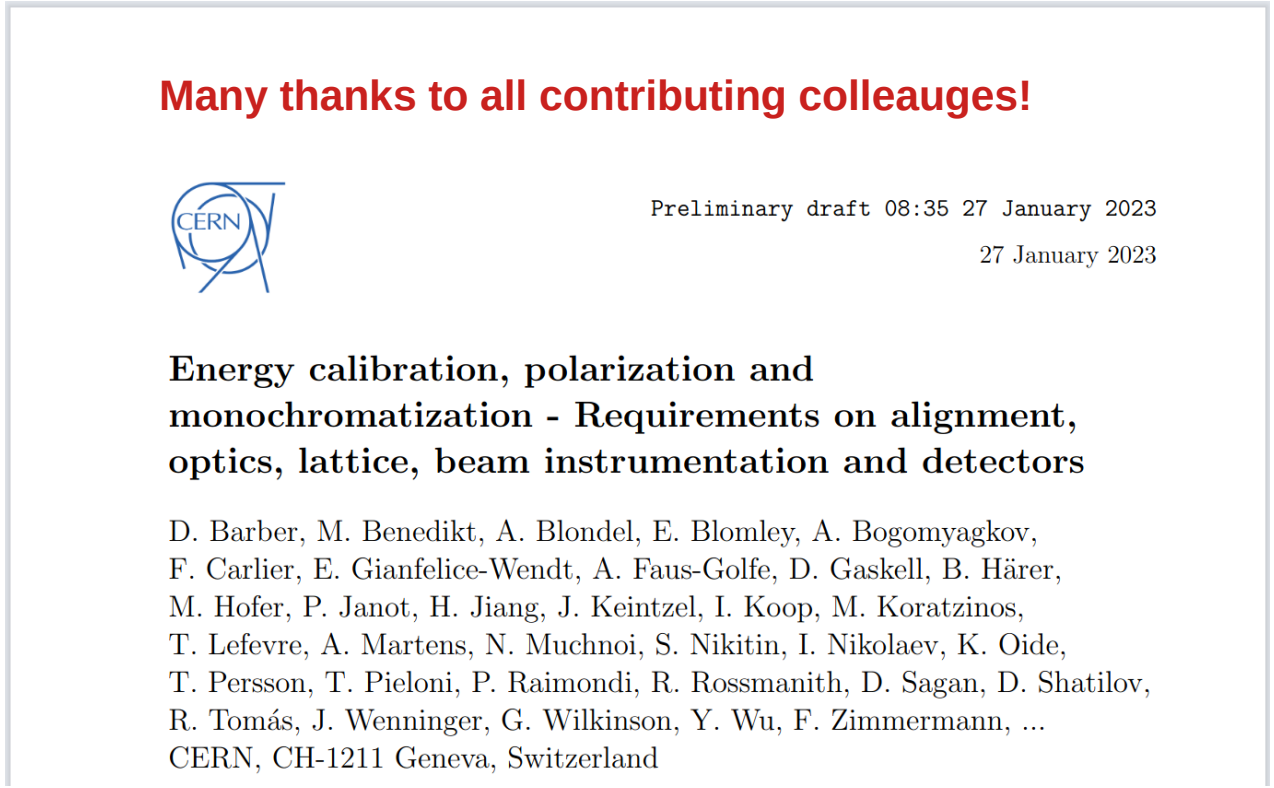
- EIC: polarimeter, spin simulations, depolarization, energy measurements, operations, …
- SuperKEKB: operations, option of polarized beams presently studied
- VEPP-4M: resonant depolarization
- ANKA-KARA: possible experiments
- EBS: possible measurements
- DAFNE: monochromatization tests
- ...

Test FCC-ee polarization concepts at existing synchrotrons with high polarization

Documentation

- Overleaf document presently being prepared and updated
- Milestones: mid-term report by mid 2023 and final version end of 2025

Many thanks to all contributing colleauges!



Preliminary draft 08:35 27 January 2023

27 January 2023

Energy calibration, polarization and monochromatization - Requirements on alignment, optics, lattice, beam instrumentation and detectors

D. Barber, M. Benedikt, A. Blondel, E. Blomley, A. Bogomyagkov, F. Carlier, E. Gianfelice-Wendt, A. Faus-Golfe, D. Gaskell, B. Härer, M. Hofer, P. Janot, H. Jiang, J. Keintzel, I. Koop, M. Koratzinos, T. Lefevre, A. Martens, N. Muchnoi, S. Nikitin, I. Nikolaev, K. Oide, T. Persson, T. Pieloni, P. Raimondi, R. Rossmanith, D. Sagan, D. Shatilov, R. Tomás, J. Wenninger, G. Wilkinson, Y. Wu, F. Zimmermann, ...
CERN, CH-1211 Geneva, Switzerland

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

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

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

FUTURE CIRCULAR COLLIDER

CERN

Questions?

FCC-ee energy calibration, polarization and monochromatization – Future Plans

D. Barber, M. Benedikt, A. Blondel, E. Blomley, A. Bogomyagkov, F. Carlier, E. Gianfelice-Wendt, A. Faus-Golfe, D. Gaskell, B. Härer, M. Hofer, P. Janot, H. Jiang, J. Keintzel*, I. Koop, M. Koratzinos, T. Lefevre, A. Martens, N. Muchnoi, S. Nikitin, I. Nikolaev, K. Oide, T. Persson, T. Pieloni, P. Raimondi, R. Rossmanith, D. Sagan, D. Shatilov, R. Tomàs, J. Wenninger, G. Wilkinson*, Y. Wu, and F. Zimmermann

* jacqueline.keintzel@cern.ch
* guy.wilkinson@cern.ch

6th FCC Physics Workshop
Highlights and Future Plans
27th January 2023

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.