Center-of-mass Energy Calibration, Polarization and Monochromatization of the Future electron-positron Circular Collider

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On behalf of

The FCC-ee EPOL working group

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BE Seminar

CERN, Geneva, Switzerland

12 April 2024

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.

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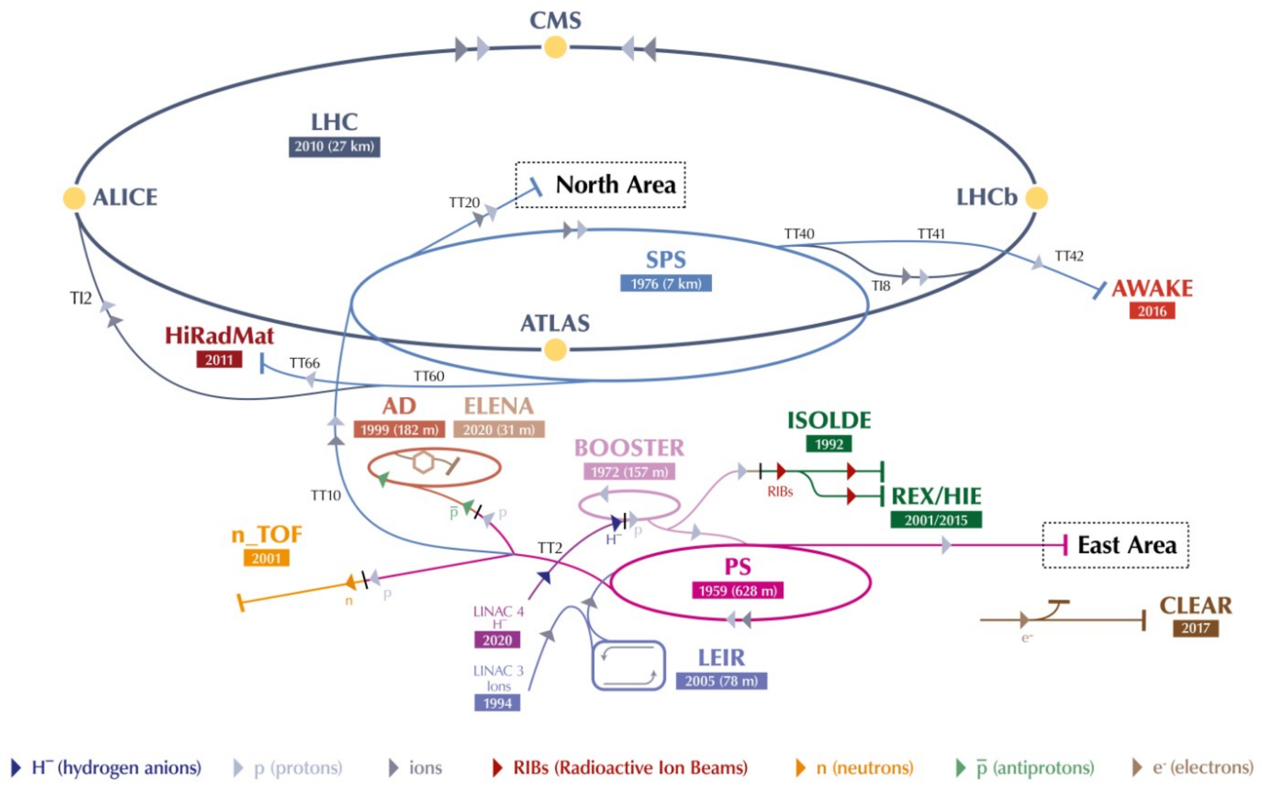
CERN Accelerator Complex



LHC - Large Hadron Collider // SPS - Super Proton Synchrotron // PS - Proton Synchrotron // AD - Antiproton Decelerator // CLEAR - CERN Linear Electron Accelerator for Research // AWAKE - Advanced WAKefield Experiment // ISOLDE - Isotope Separator OnLine // REX/HIE - Radioactive EXperiment/High Intensity and Energy ISOLDE // LEIR - Low Energy Ion Ring // LINAC - LINear ACcelerator // n_TOF - Neutrons Time Of Flight // HiRadMat - High-Radiation to Materials

- Large Hadron Collider (LHC)
  - Biggest collider in the world
  - Presently in Run 3
  - 6.8 TeV beam energy achieved
  - 2 x 10^{34} $cm^{-2}s^{-1}$ luminosity

- High Luminosity LHC (HL-LHC)
  - Aims at 7 TeV per beam
  - Up to 5 – 7.5 x 10^{34} $cm^{-2}s^{-1}$
  - Collisions until ~ 2040

And then?

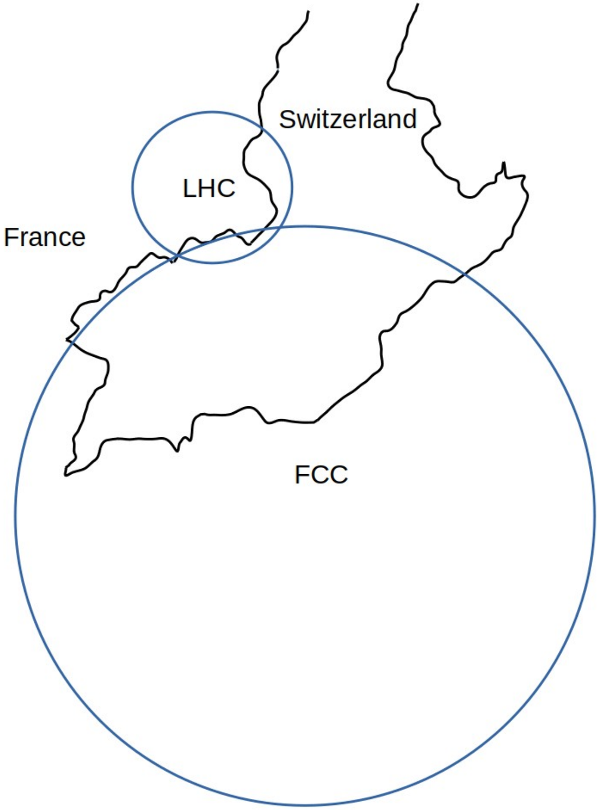
Particle Physics Future

- In 2020 the **European** strategy upgrade of particle physics (ESPP) expressed the long-term plan for particle colliders:
  - An **electron-positron Higgs factory is the highest-priority** next collider.
  - Europe, together with its international partners, should investigate the technical and financial feasibility of a **future hadron collider at CERN** with a center-of-mass energy of at least 100 TeV and with **an electron-positron Higgs and electroweak factory as a possible first stage**.
- Particle Physics Project Prioritization Panel **(P5)** published recommendations in 2023, high priority projects:
  - Exploitation of LHC and HL-LHC
  - Off-shore **Higgs and electroweak factory**

Future Circular Collider

Inspired by LEP-LHC programm

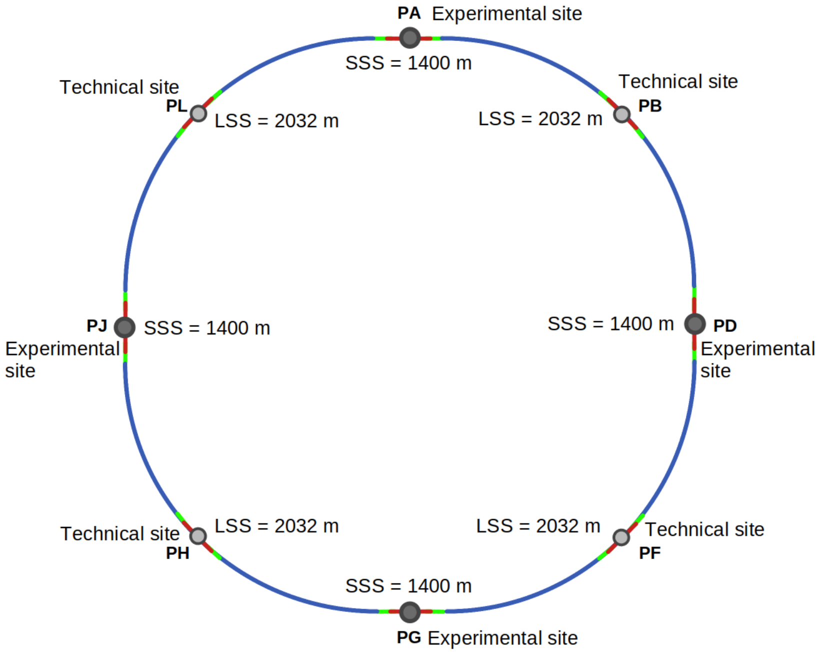
Re-using CERN infrastructure



Compatible lattice designs

FCC-ee

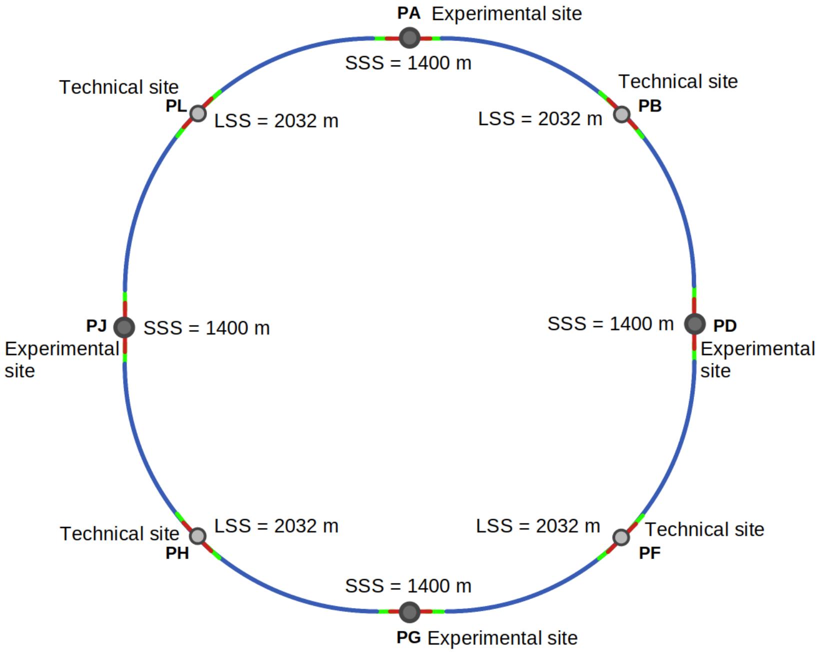
Electron-positron collider



~ 2045 - 2060

FCC-hh

Proton-proton collider



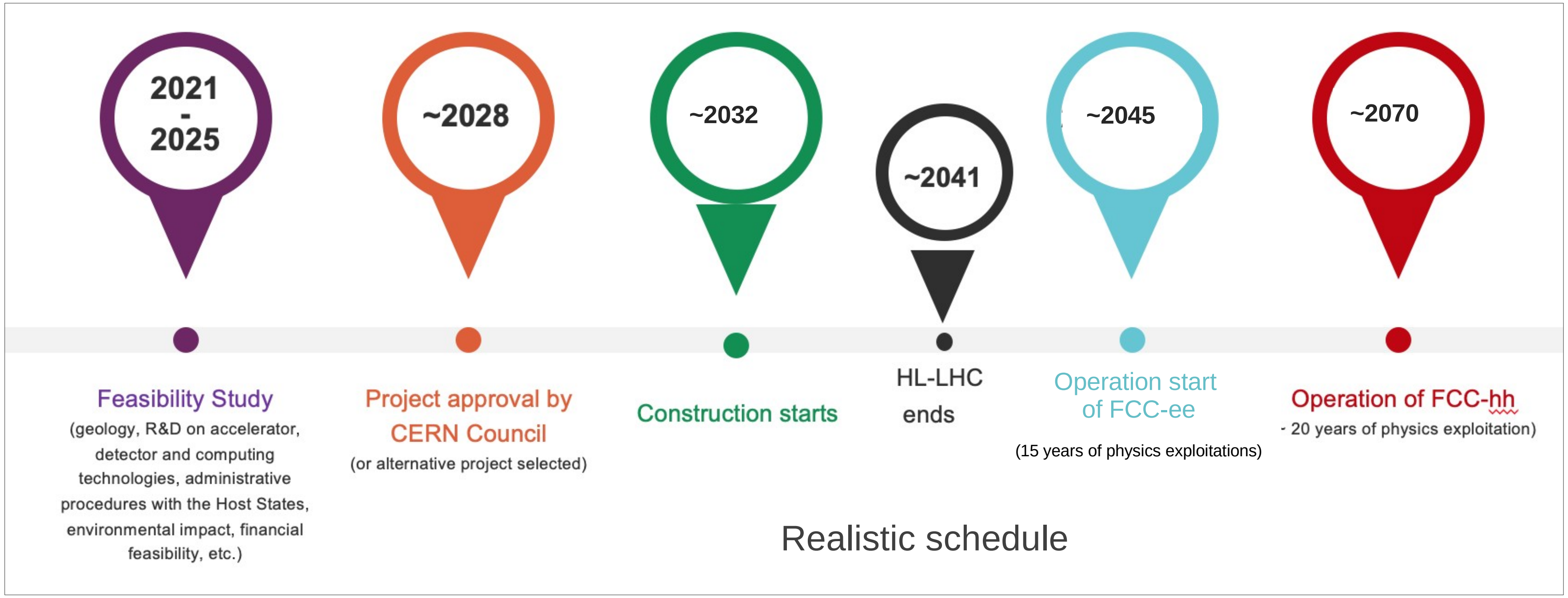
~ 2070 - 2090

FCC Collaboration

Long-Term Goal: World-leading high energy physics infrastructure for 21st century to push particle-physics precision and energy frontiers far beyond present limits → international collaboration essential

Feasibility Study and Schedule

- **Goal:** Demonstration of the geological, technical, environmental, financial and administrative feasibility of the FCC-ee, including its optimisation
- Project preparatory phase with adequate resources immediately after Feasibility Study



Mid-Term Report

- **MTR Goal:** Asses progress of feasibility study towards the final report; published February 2024

Future Circular Collider
Midterm Report

February 2024

Edited by:
B. Auchmann, W. Bartmann, M. Benedikt, J.P. Burnet, P. Craievich, M. Giovannozzi, C. Grojean, J. Gutleber, K. Hanke, P. Janot, M. Mangano, J. Osborne, J. Poole, T. Raubenheimer, T. Watson, F. Zimmermann

This project has received funding under the European Union's Horizon 2020 research and innovation programme under grant agreement No 951754.

This document has been produced by the organisations participating in the FCC feasibility study. The studies and technical concepts presented here do not represent an agreement or commitment of any of CERN's Member States or of the European Union for the construction and operation of an extension to CERN's existing research infrastructures.
The midterm report of the FCC Feasibility Study reflects work in progress and should therefore not be propagated to people who do not have direct access to this document.

8 Chapters
~ 700 pages
~ 16 editors
~ 300 contributors

Executive Summary of the
Future Circular Collider
Midterm Report

February 2024

Edited by:
B. Auchmann, W. Bartmann, M. Benedikt, J.P. Burnet, P. Charitos, P. Craievich, M. Giovannozzi, C. Grojean, J. Gutleber, K. Hanke, P. Janot, M. Mangano, J. Osborne, J. Poole, T. Raubenheimer, A. Unnervik, T. Watson, F. Zimmermann

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8 Chapters
~ 45 pages
~ 16 editors

Courtesy: F. Gianotti

FCC Physics Potential

- Integrated FCC offers multi-stage facility with broad and diverse physics potential

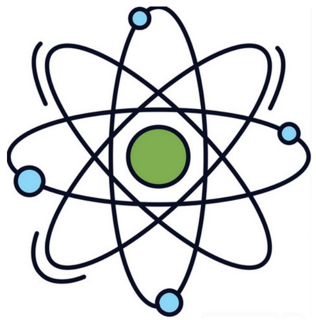
	$\sqrt{s}$	L /IP ($cm^{-2} s^{-1}$)	Int L/IP/y (ab^{-1})	Comments
e^+e^- FCC-ee	~90 GeV Z 160 WW 240 H ~365 top	182 x 10^{34} 19.4 7.3 1.33	22 2.3 0.9 0.16	2-4 experiments Total ~ 15 years of operation
pp FCC-hh	100 TeV	5-30 x 10^{34} 30	20-30	2+2 experiments Total ~ 25 years of operation
PbPb FCC-hh	$\sqrt{s_{NN}}$ = 39TeV	3 x 10^{29}	100 nb^{-1}/run	1 run = 1 month operation
ep Fcc-eh	3.5 TeV	1.5 10^{34}	2 ab^{-1}	60 GeV e- from ERL Concurrent operation with pp for ~ 20 years
e-Pb Fcc-eh	$\sqrt{s_{eN}}$ = 2.2 TeV	0.5 10^{34}	1 fb^{-1}	60 GeV e- from ERL Concurrent operation with PbPb

- FCC-ee:
  - Highest luminosities at Z, W and H of all proposed Higgs and electro-weak factories
  - Indirect discovery potential up to 70 TeV
- FCC-hh:
  - Direct exploration of next energy frontier (~10x LHC)
  - Also heavy ion collision experiments possible
- FCC-eh:
  - Possibly also electron-proton (ion) collisions

Courtesy: F. Gianotti

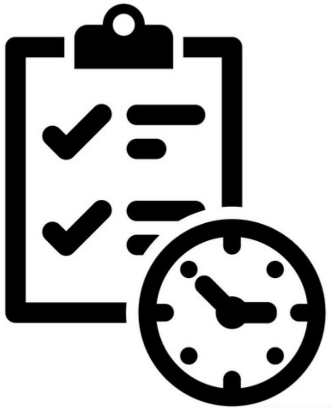
Why FCC?

Physics



- Immense physics potential for lepton and hadron colliders
- Luminosity frontier: Precision physics experimements
- Energy frontier: Discovery potential thanks to 100 TeV E_{cm} for FCC-hh

Timeline



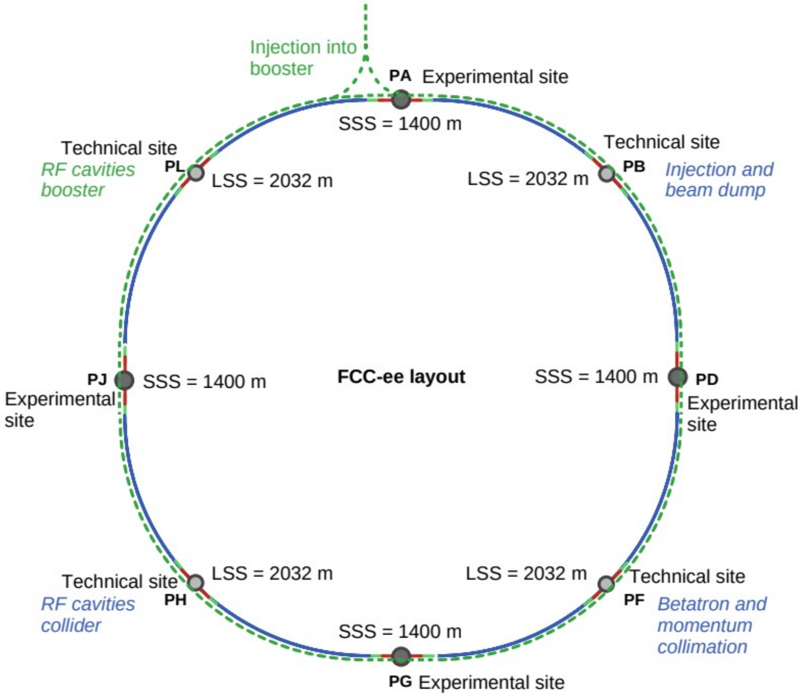
- FCC-ee technology is mature; collisions could start few years after HL-LHC
- Integrated FCC project allows for ~20 more years magnet R&D
- Optimized overall investment

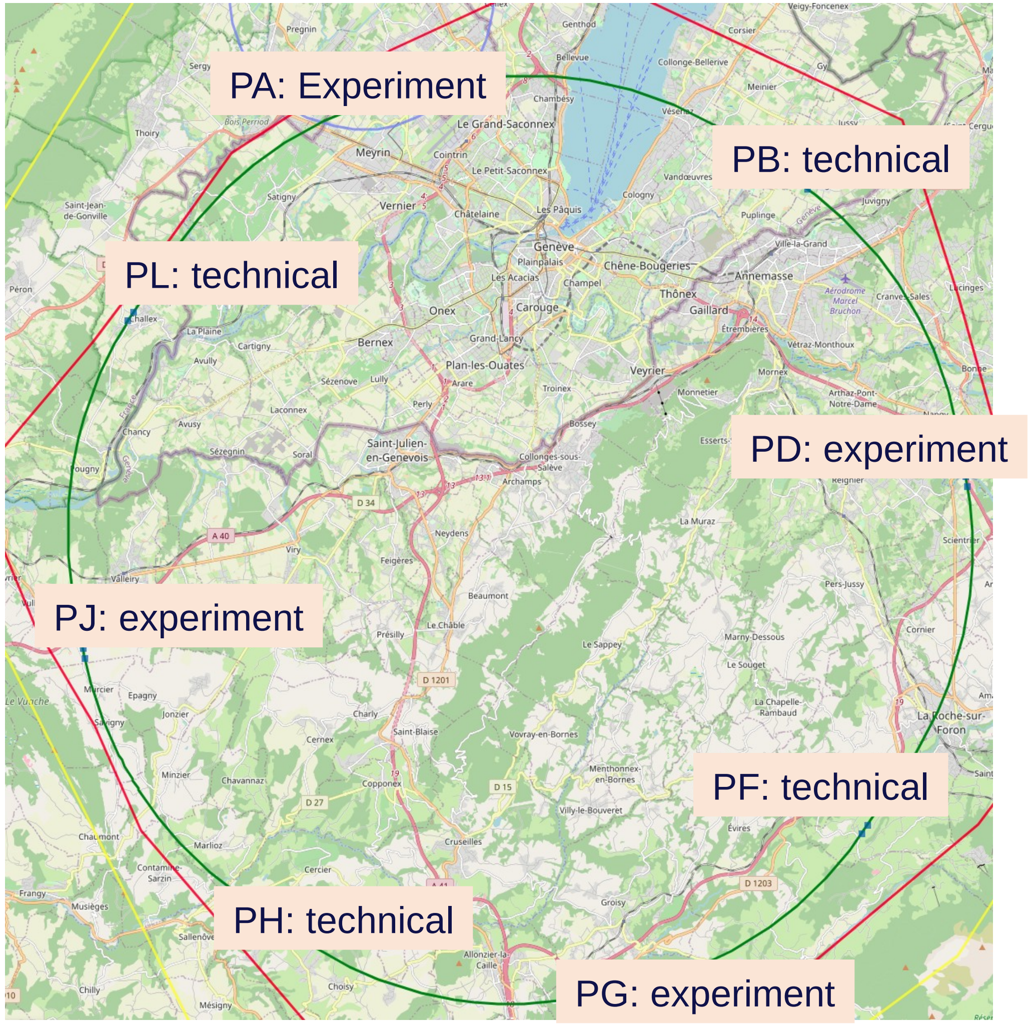
Community

- 4 collision points for high-energy physics experiments
- Many other possibilities (fixed-target, use of beam dump, ..)
- Only facility to commensurate the size of the CERN community

Optimized Placement

- Optimized considering constraints on geology and surface
- **90.7 km** circumference with **8 surface points**
- **High Energy Booster** in addition to main rings

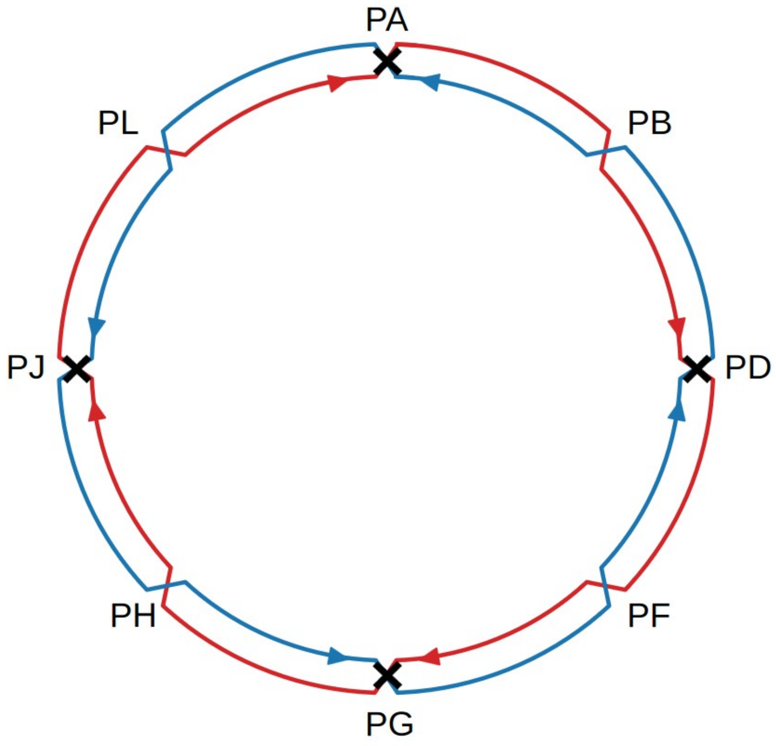




FCC-ee Overview

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
- Huge 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

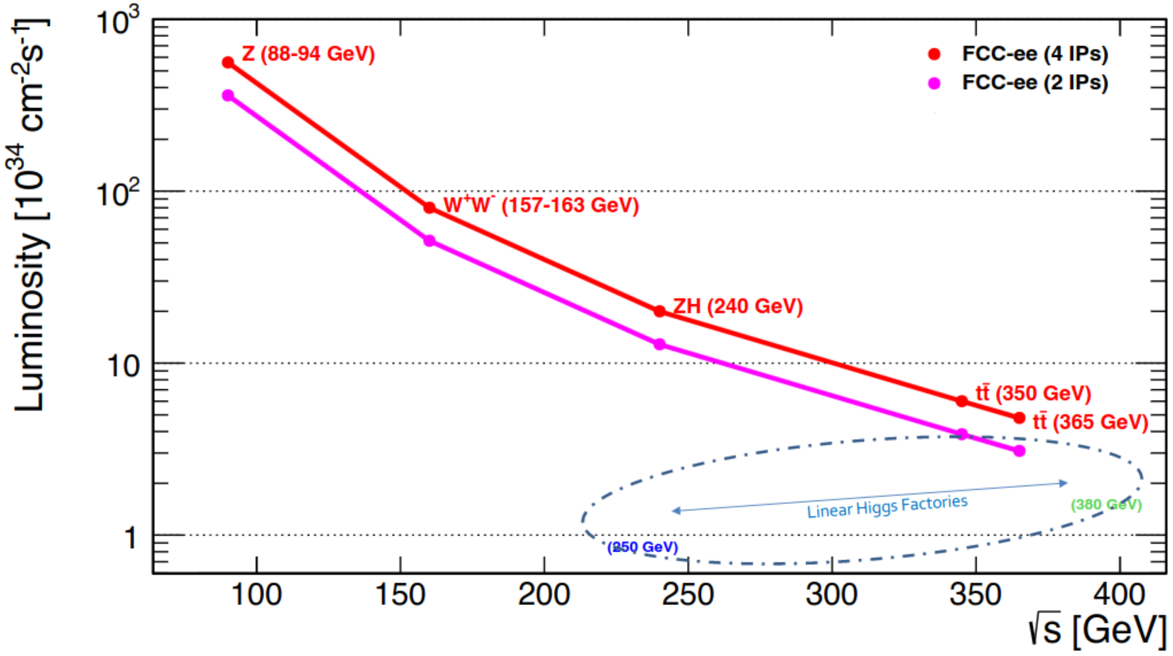
Center-of-mass Energy

Calibration, Polarization and Monochromatization of the Future electron-positron Circular Collider

Courtesy: C. Grojean

FCC-ee Run Plan

- In principle 4 different energy stages
  - Z-pole
  - W-pair-production
  - ZH-production
  - top-pair threshhold

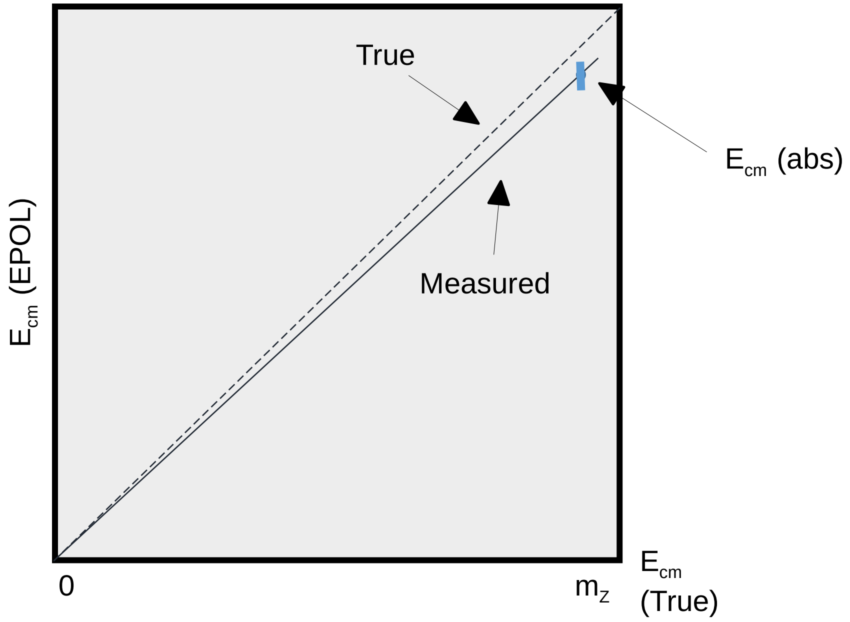


Working point	Z, years 1-2	Z, later	WW, years 1-2	WW, later	ZH	$t\bar{t}$	
$\sqrt{s}$ (GeV)	88, 91, 94		157, 163		240	340–350	365
Lumi/IP ($10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$)	70	140	10	20	5.0	0.75	1.20
Lumi/year (ab^{-1})	34	68	4.8	9.6	2.4	0.36	0.58
Run time (year)	2	2	2	–	3	1	4
Number of events	6×10^{12} Z		2.4×10^{8} WW		1.45×10^{6} ZH + 45k WW $\to$ H	$1.9 \times 10^{6}\, t\bar{t}$ +330k ZH +80k WW $\to$ H	

Number of events are for the current baseline with 4 Interaction Points

Center-of-mass Energy Uncertainty

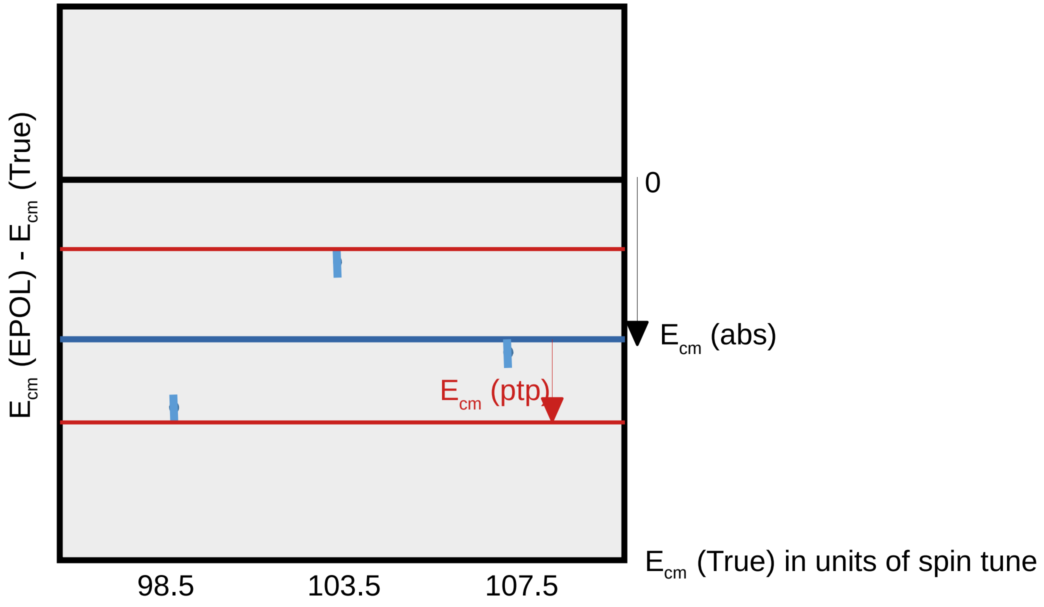
Absolut scale error (abs)



Error between measured and true E_{cm}

- Large effect on mass measurement
- Stems from systematic errors

Point-to-point errors (ptp)



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**
$sin^2\theta_W^{\rm eff} \times 10^6$ 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**

Large expected luminosity → huge statistics → small statistical error of a **few keV for Z and W-boson**

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

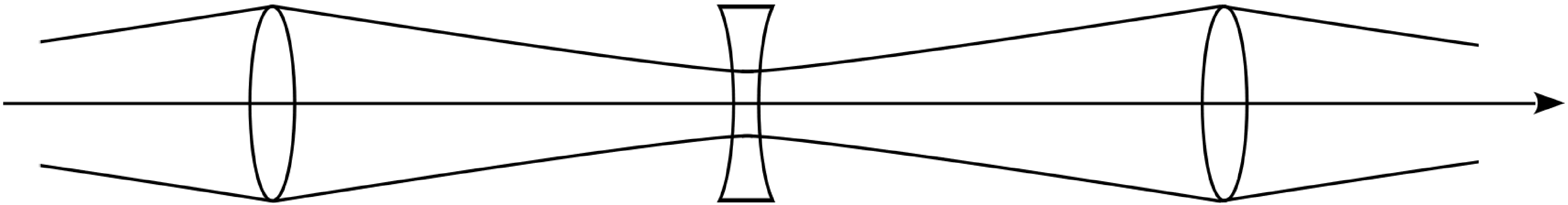
EPOL: Energy calibration, polarization and monochromatization

arXiv:1909.12245

Center-of-mass Energy Calibration, Polarization and Monochromatization of the Future electron-positron Circular Collider

Part I: Introduction to beam optics

Linear Beam Optics in a Nutshell

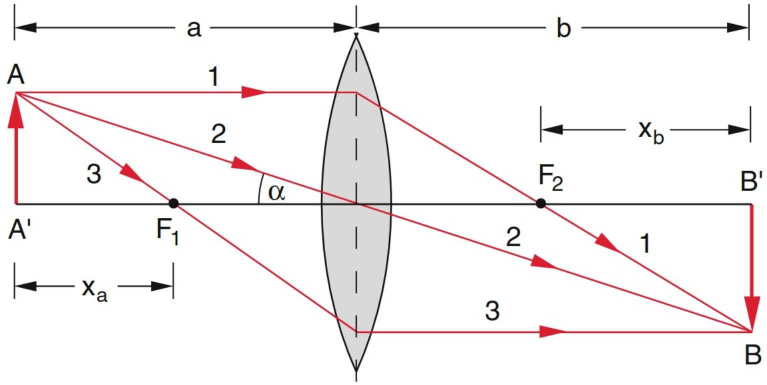


Focusing structure (F)
Converging lens

Defocusing structure (D)
Diverging lens

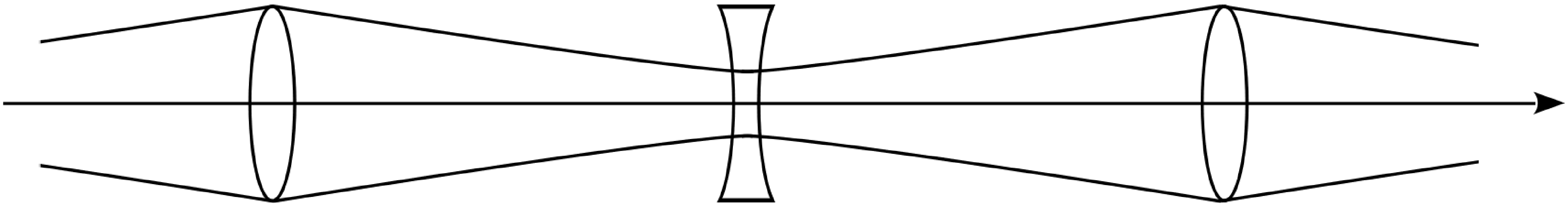
Focusing structure (F)
Converging lens

- Optical lenses focus and defocus light

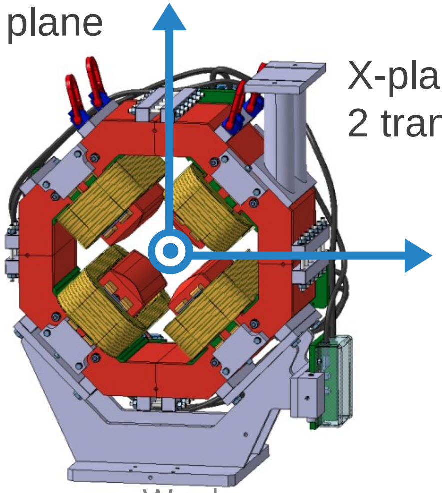


W. Demtröder, Experimentalphysik 2

Linear Beam Optics in a Nutshell



- Optical lenses focus and defocus light
- Magnetic lenses focus charged particle beams
  - Dipoles for circular path
  - Quadrupoles for focusing
  - Many higher order magnets

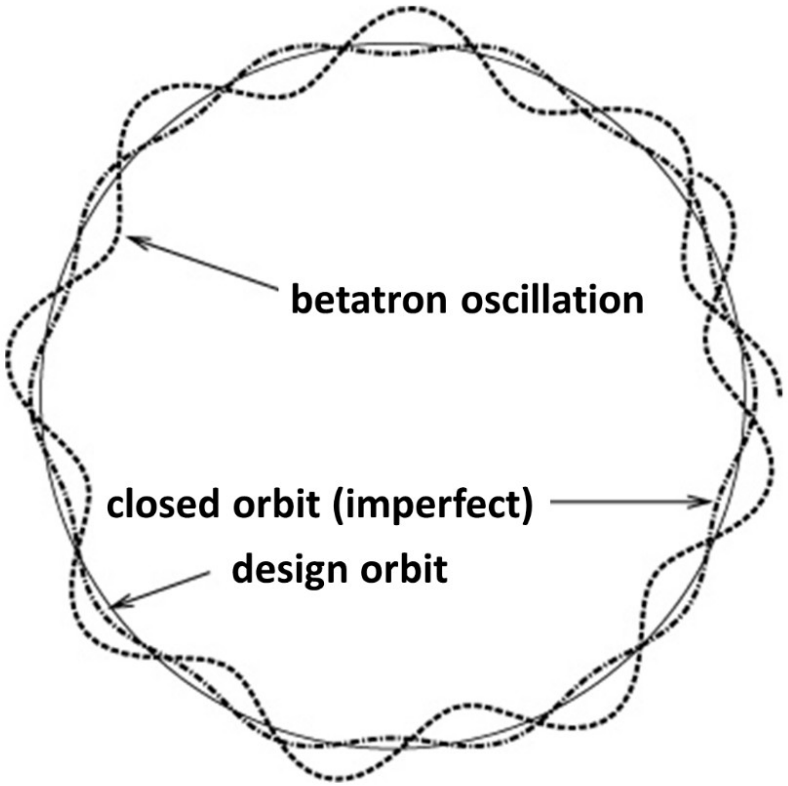


Wordsun.com

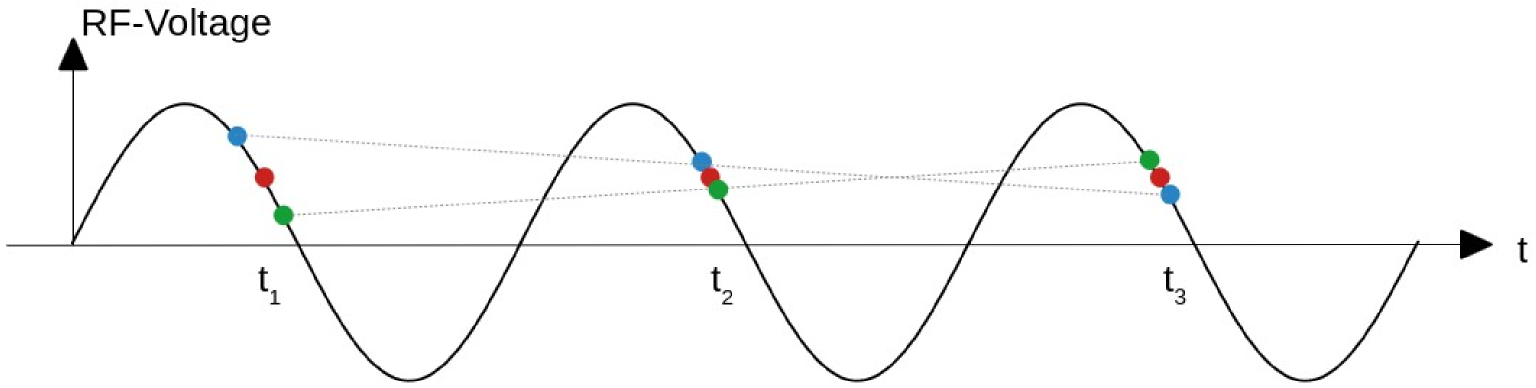
Tune

- Transverse focusing and defocusing leads to betatron oscillations
- Tune Q_x, Q_y: Number of betatron oscillations per turn

- Longitudinal focusing with RF-cavities leads to synchrotron oscillations
- Synchrotron tune Q_s: Number of synchrotron oscillations per turn



Reports on Progress in Physics, 68 Vol. 9, p. 1997-2265



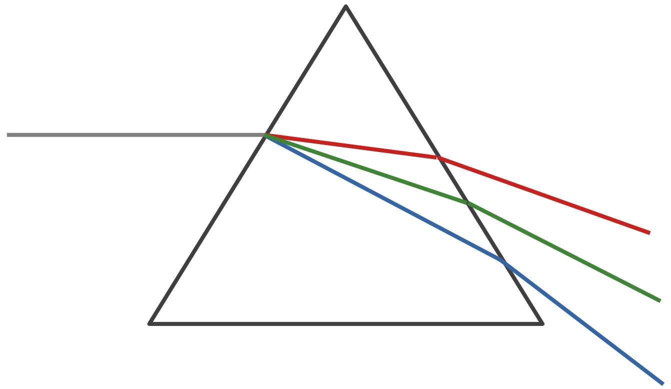
Off-momentum (chromatic) particles (blue and green) oscillate around the nominal energy (red)

Chromatic Effects

Off-momentum particles have different beam optics

Dispersion

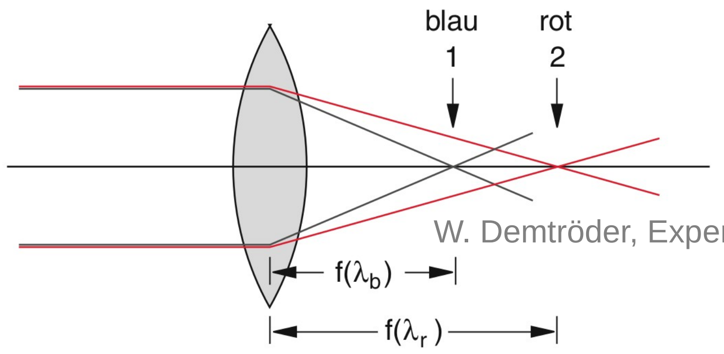
- Generates a shift of transverse position for off-momentum particles
- Stems from dipoles and quadrupoles



Classical optics: path length depends on wavelength

Chromaticity

- Generates a betatron tune shift for off-momentum particles
- Change in focusing for different momenta



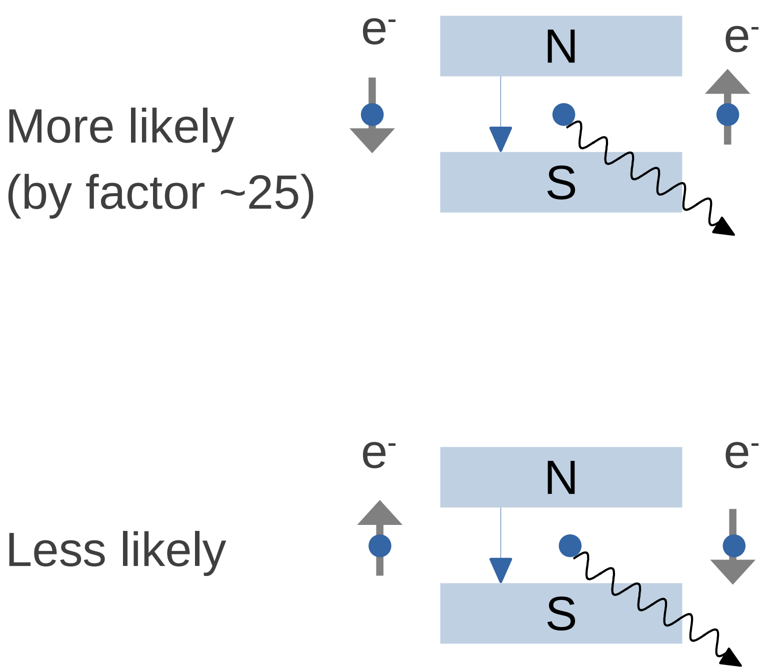
W. Demtröder, Experimentalphysik 2

Classical optics: focal length depends on wavelength

Center-of-mass Energy **Calibration, Polarization and** Monochromatization of the Future electron-positron Circular Collider

Part II: Polarization

Polarization Build-Up



- 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 for e^-
- In a flat synchrotron only vertical bending → vertical spin orientation
- Known as Sokolov-Ternov-Effekt

- Maximum theoretical polarization of **92.4 %**
- In real accelerator max. polarization depends on various factors

Spin Tune

- Spin precesses through the lattice
- Spin tune ν: Number of spin precessions per turn

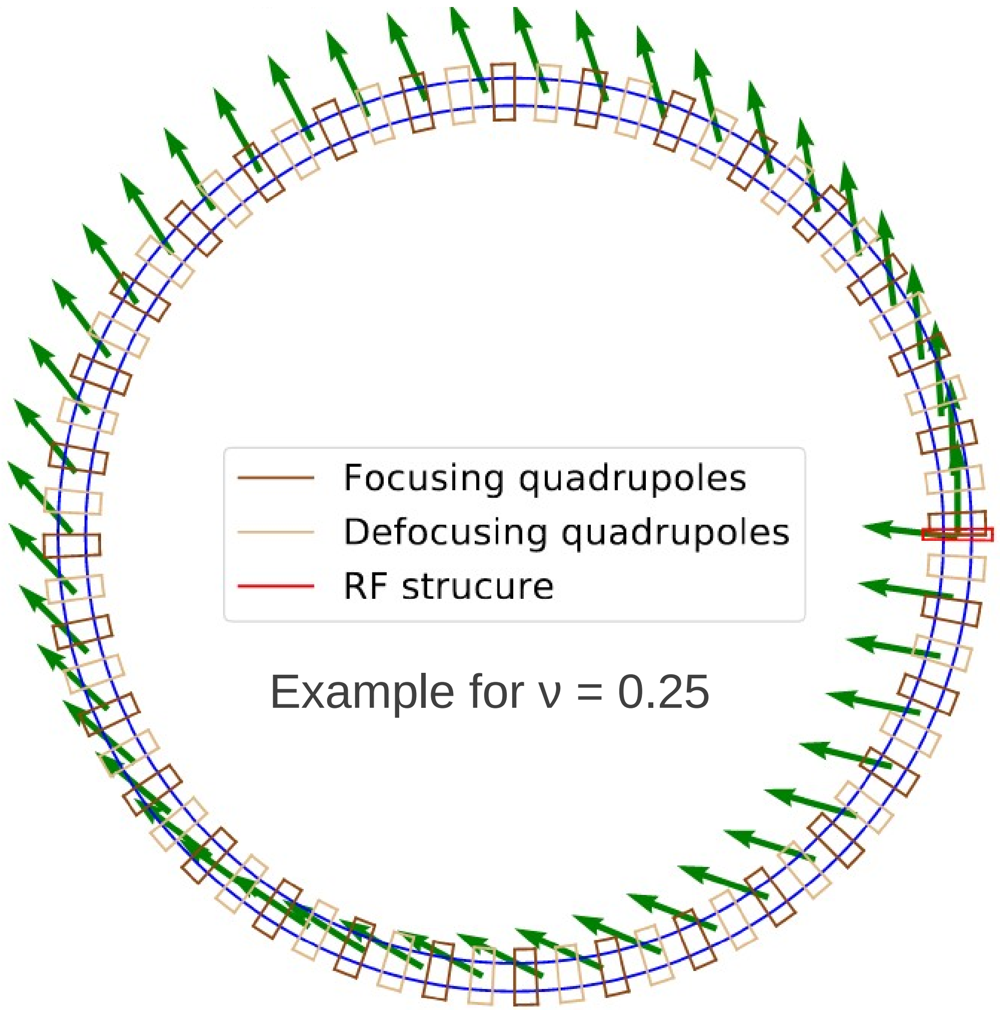
- In an error-free flat machine without solenoids:
- 45.6 GeV e^+/e^- –> 103.5 spin tune
- Purely vertical spin orientation

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

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

Principle:

Spin tune measurement ⟺ **Beam energy determination**



Courtesy: V. Caudan

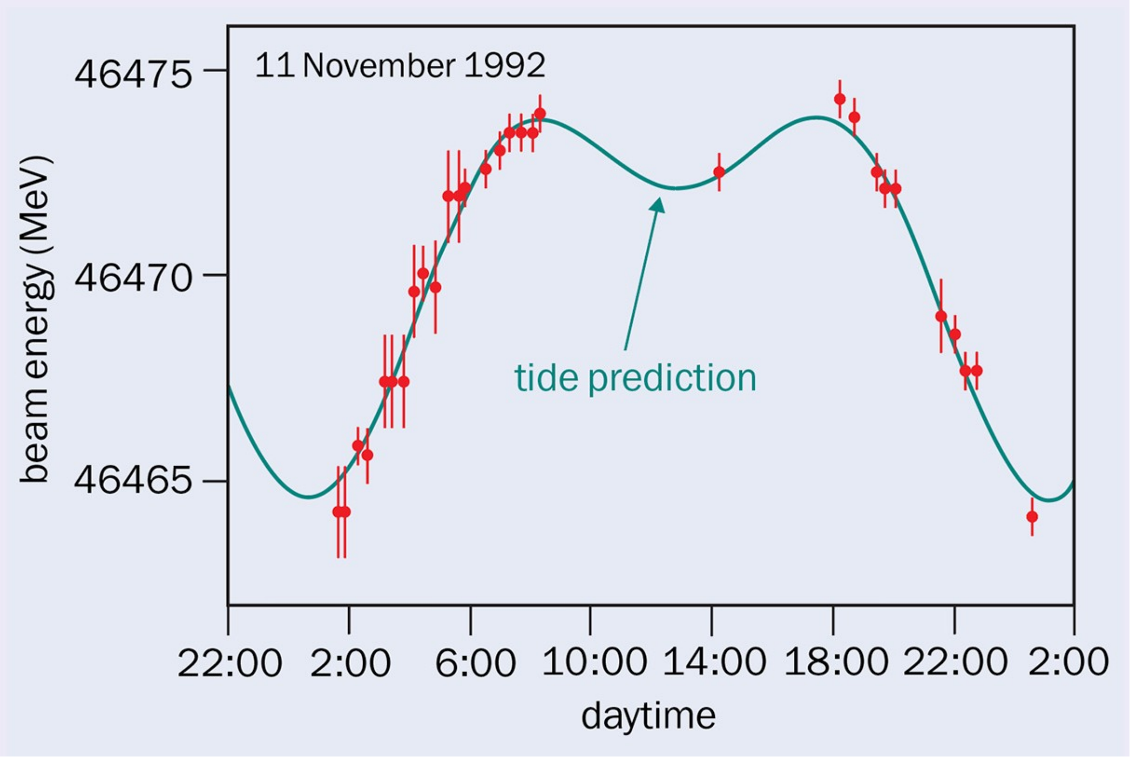
Contributions to the Beam Energy

~4 keV at 45.6 GeV beam energy measurement –> ambitious goal of ~ **10^{-7}** statistical and systematic **errors**

Selected impacts on the beam energy

- Synchrotron radiation losses
- Earth Tides, energy followed by RF-cavities
- Chromaticity uncertainty ~ 10^{-6}: $\Delta E/E \sim 10^{-8}$
- Energy dependent path length: $\Delta E/E \sim 10^{-7}$
- Betatron oscillations: $\Delta E/E \sim 10^{-7}$
- Orbit corrections: $\Delta E/E \sim 10^{-7}$
- …

Beam energy change due to Earth tides at LEP



Courtesy: A. Bogomyagkov

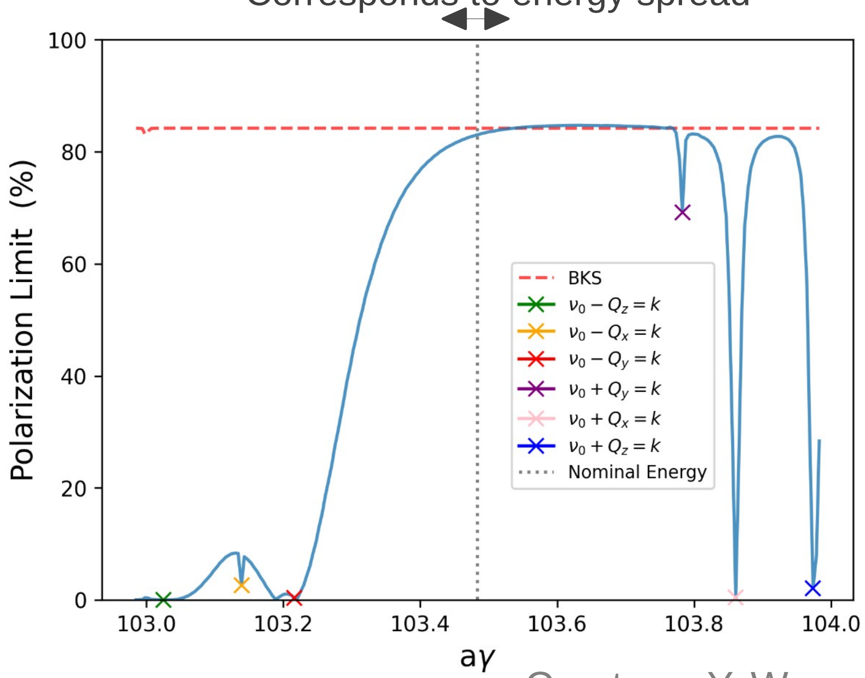
Courtesy: J. Wenninger

Resonances

Spin tune for ideal machine $\left\{ a\gamma + \underbrace{m_x Q_x + m_y Q_y}_{\text{Transverse planes}} + \underbrace{m_s Q_s}_{\text{Longitudinal plane}} = k \right.$

$m_x, m_y, m_s, k \in \mathbb{Z}$

Corresponds to energy spread



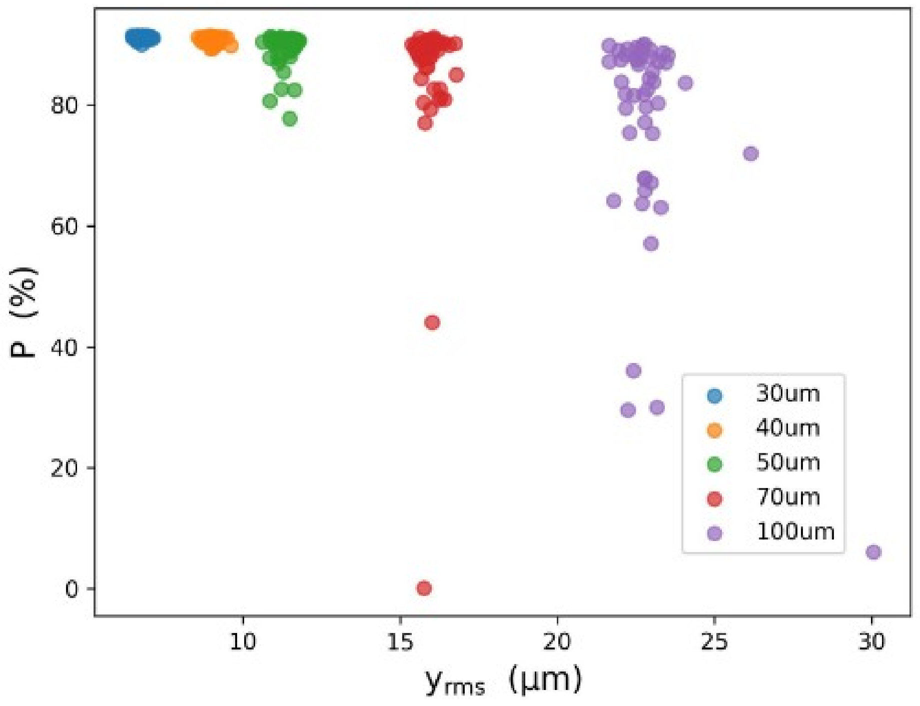
Courtesy: Y. Wu

- Resonances
  - Lead to particle loss
  - Lead to polarization loss
- Origins
  - Misalignment and multipole errors
  - Enhance with larger closed orbit and errors

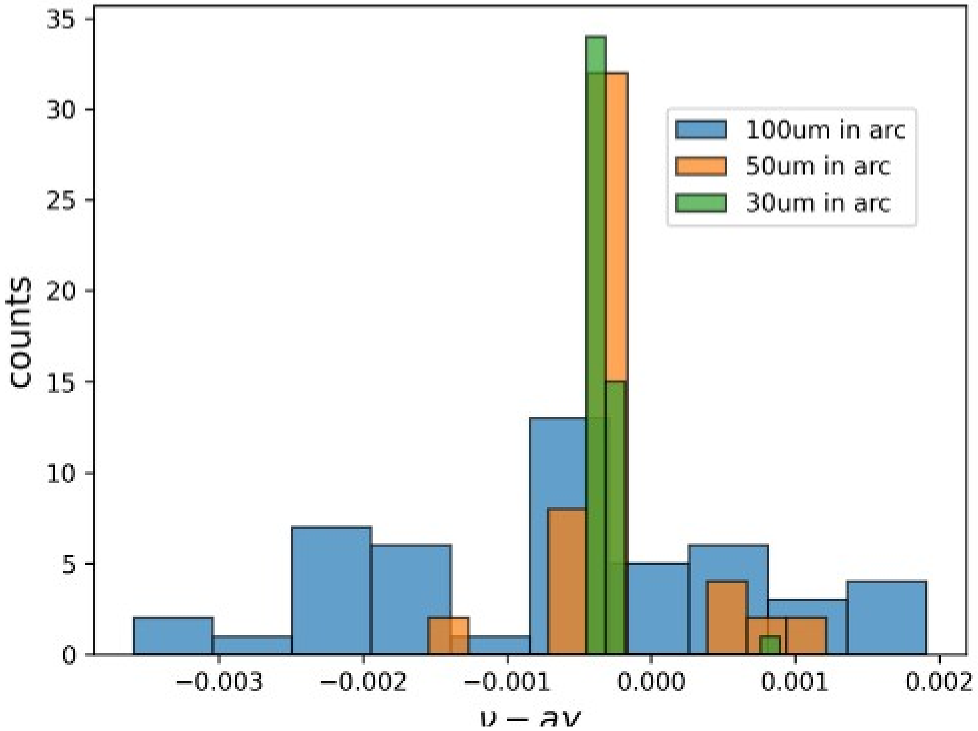
Requires excellent beam optics tuning, measurements and corrections

Tuning and Polarization

Courtesy: Y. Wu

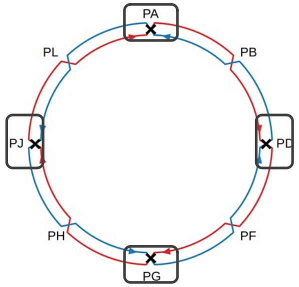


- Misalingment errors applied in the arcs and corrected
- Maximum polarization calculated
- Spread of max polarization significantly increased

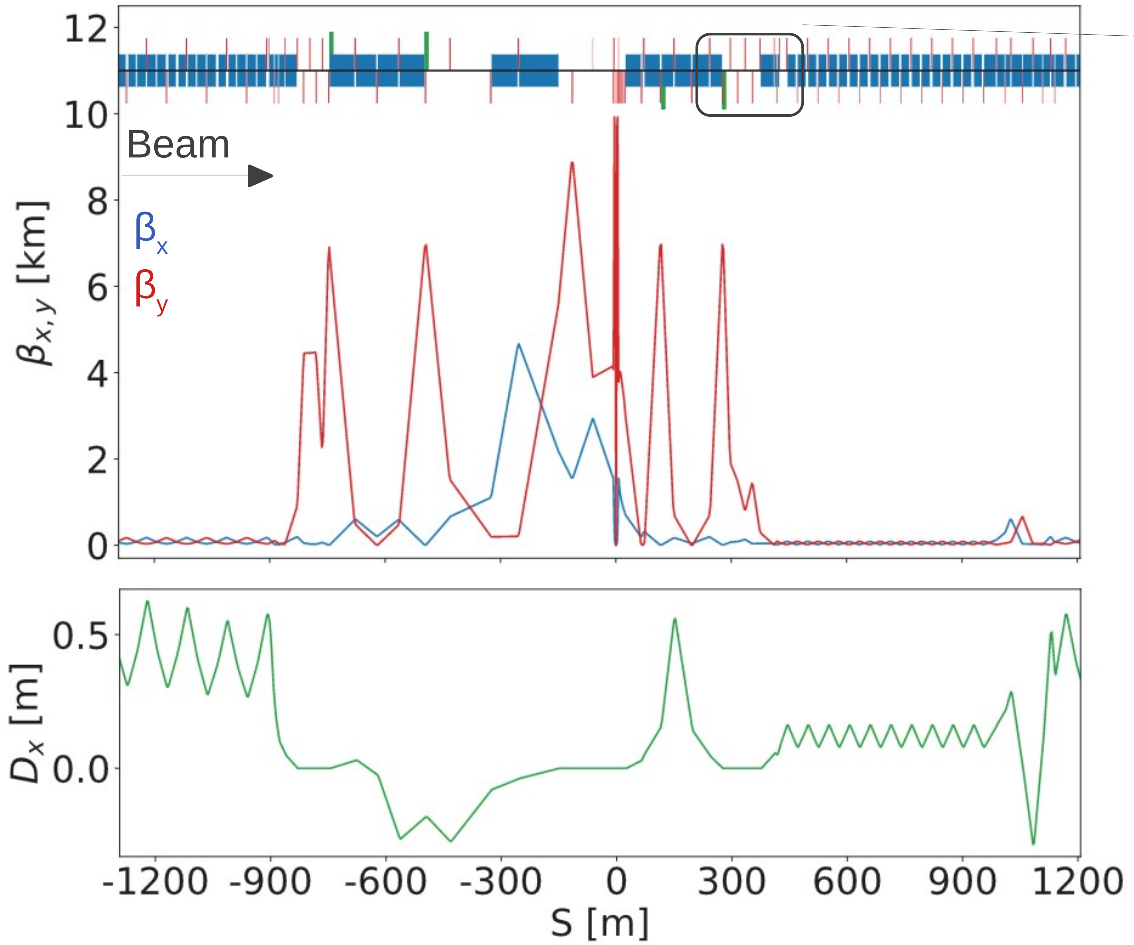


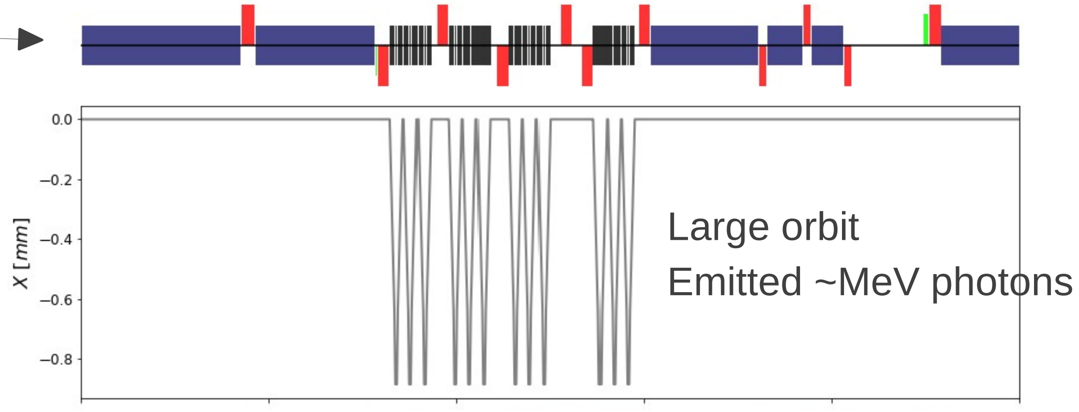
- Polarization possibly improved by harmonic spin matching
- Shift of spin tune with misalignments to be evaluated

Wigglers



Blue: Dipoles; Red: Quadrupoles



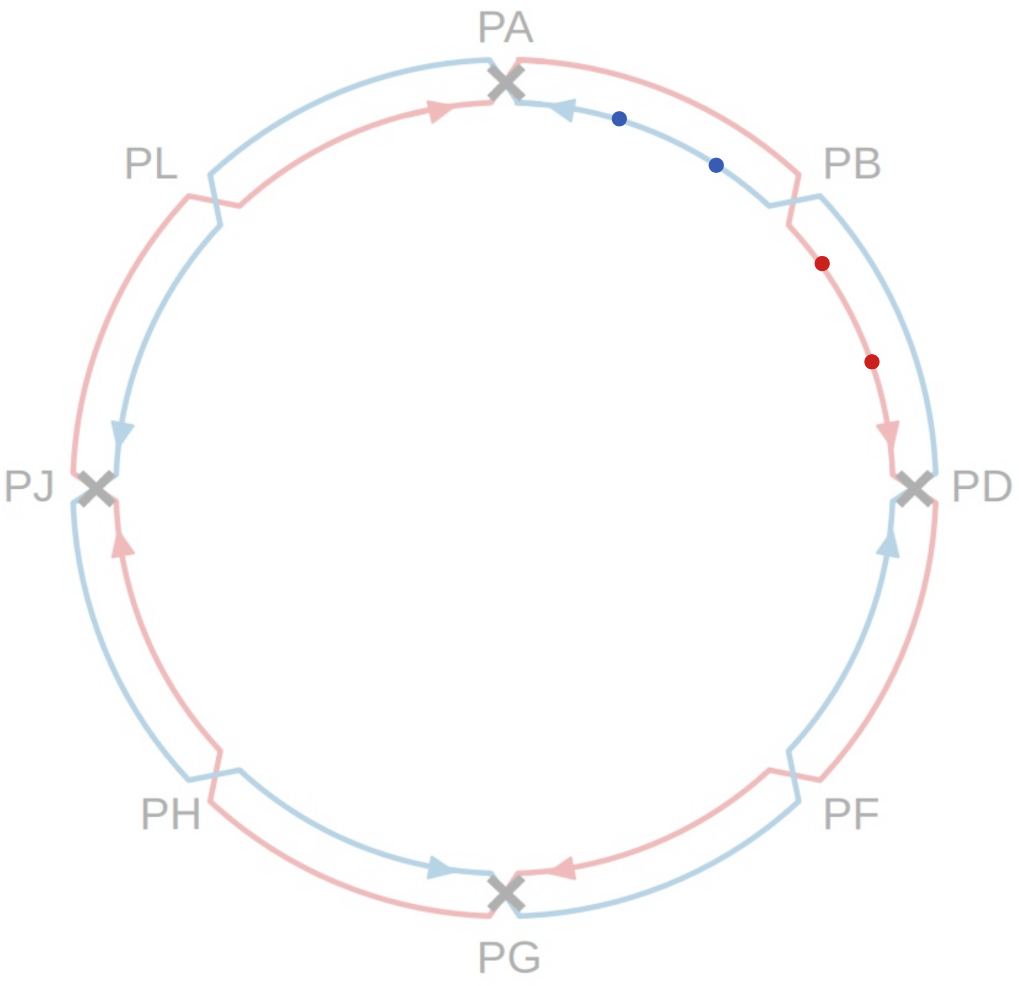


Courtesy: M. Hofer

- At 45.6 GeV energy: Polarization time of 248 h
- Solution: wiggler magnets
  - Reduce polarization time to 12 h
  - Increase energy spread by factor ~ 3.5

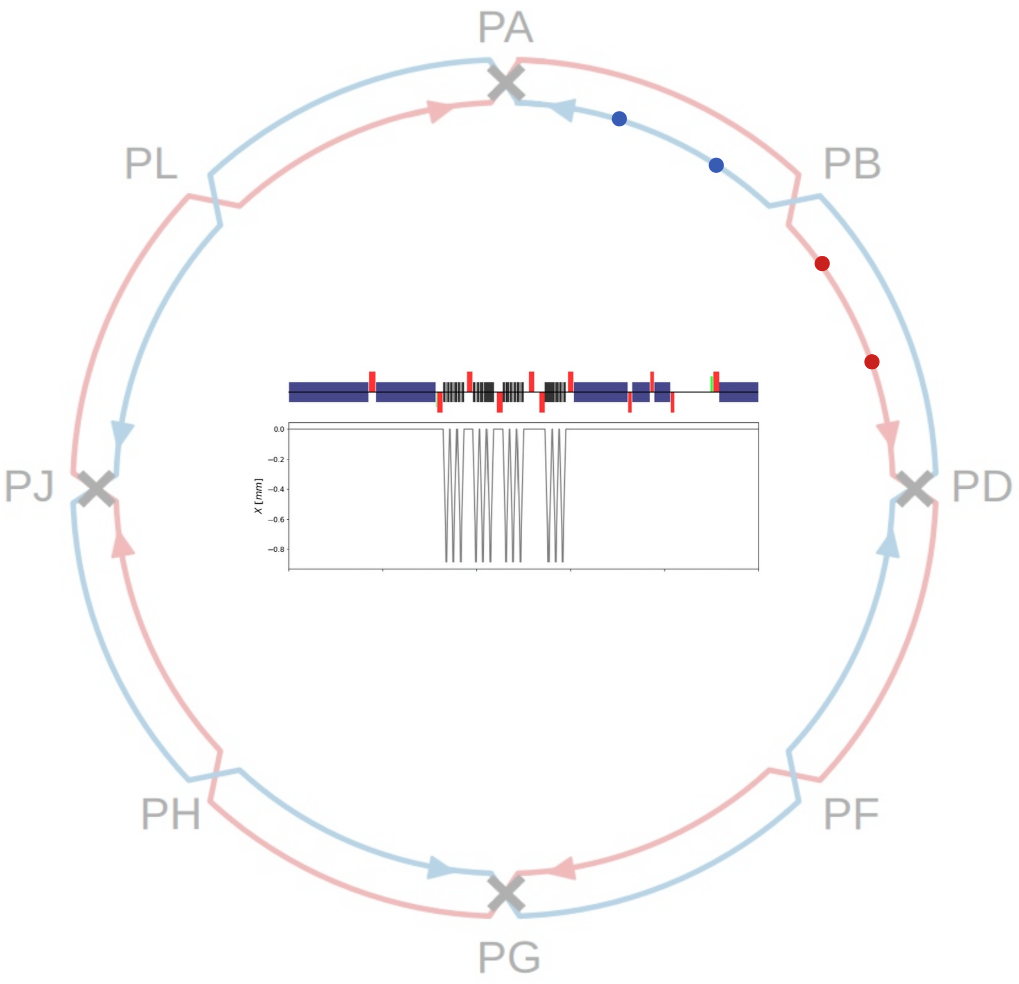
Operational Scenario

- Inject a few (100-200) non-colliding pilot bunches (~10^{10} ppb)



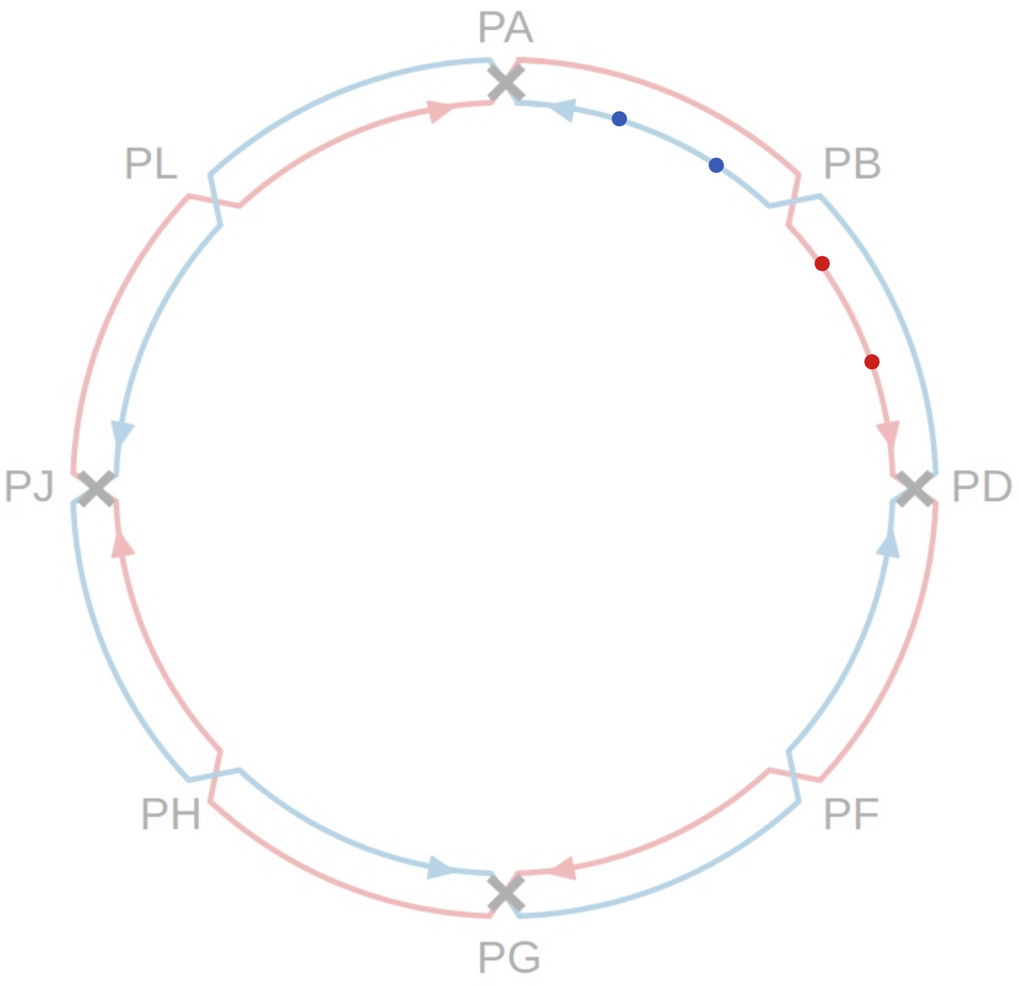
Operational Scenario

- Inject a few (100-200) non-colliding pilot bunches (~10^{10} ppb)
- Use on wigglers until ~5-10 % **vertical polarization** reached



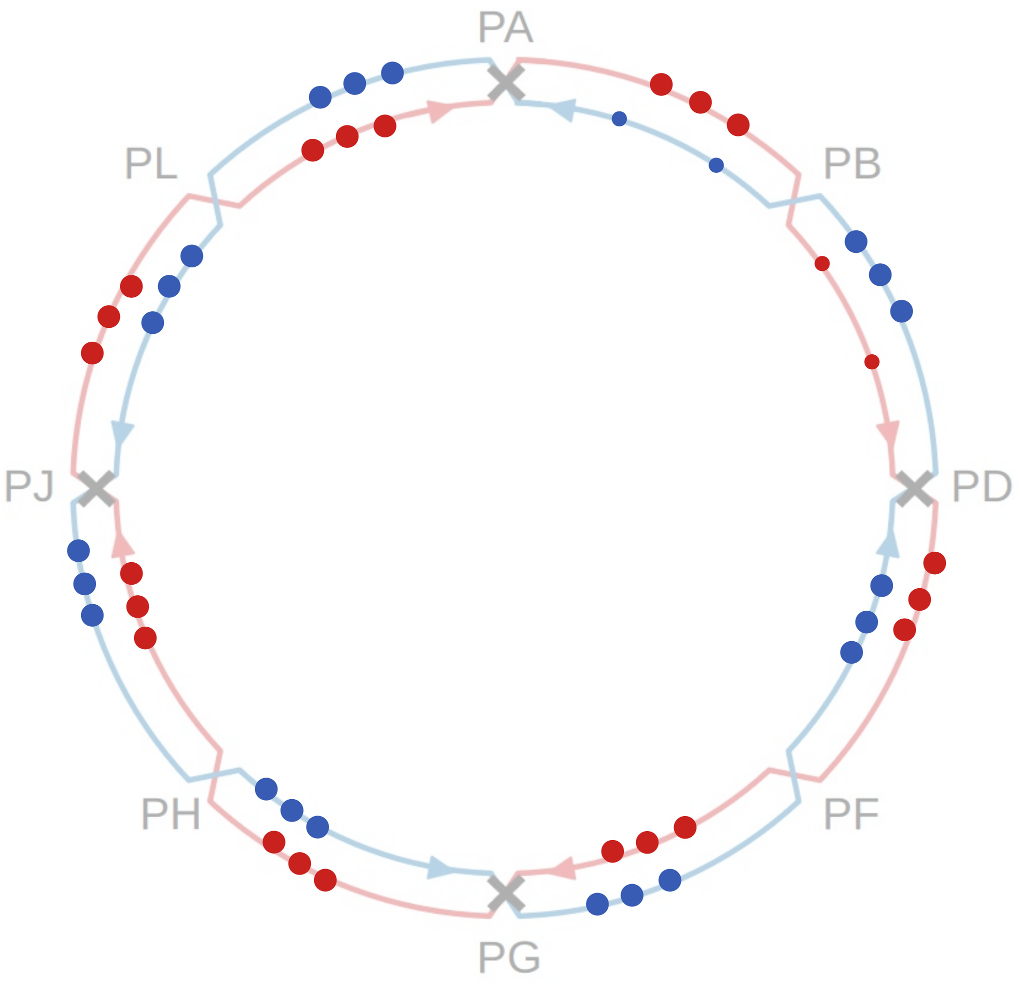
Operational Scenario

- Inject a few (100-200) non-colliding pilot bunches (~10^{10} ppb)
- Use on wigglers until ~5-10 % **vertical polarization** reached
- Switch wigglers off



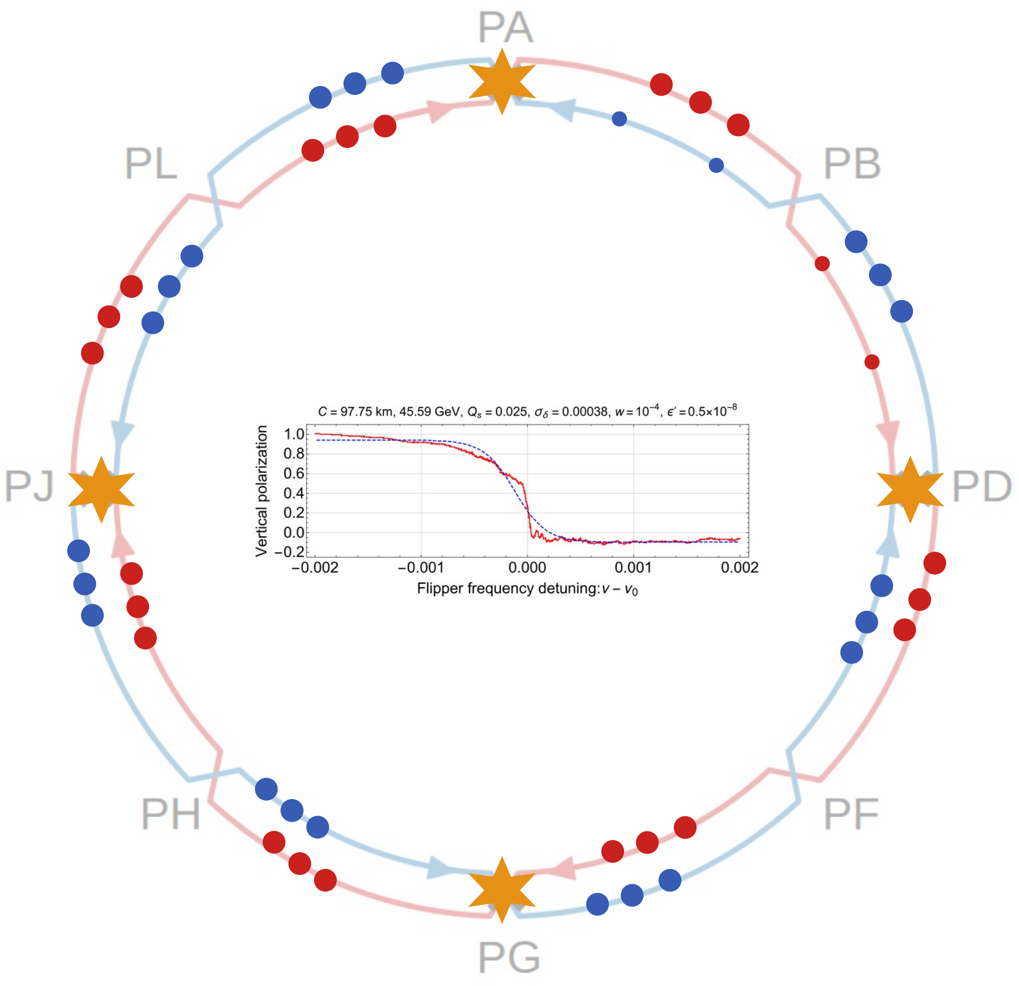
Operational Scenario

- Inject a few (100-200) non-colliding pilot bunches (~10^{10} ppb)
- Use on wigglers until ~5-10 % **vertical polarization** reached
- Switch wigglers off
- Inject ~10000 colliding bunches (~2 x 10^{11} ppb)

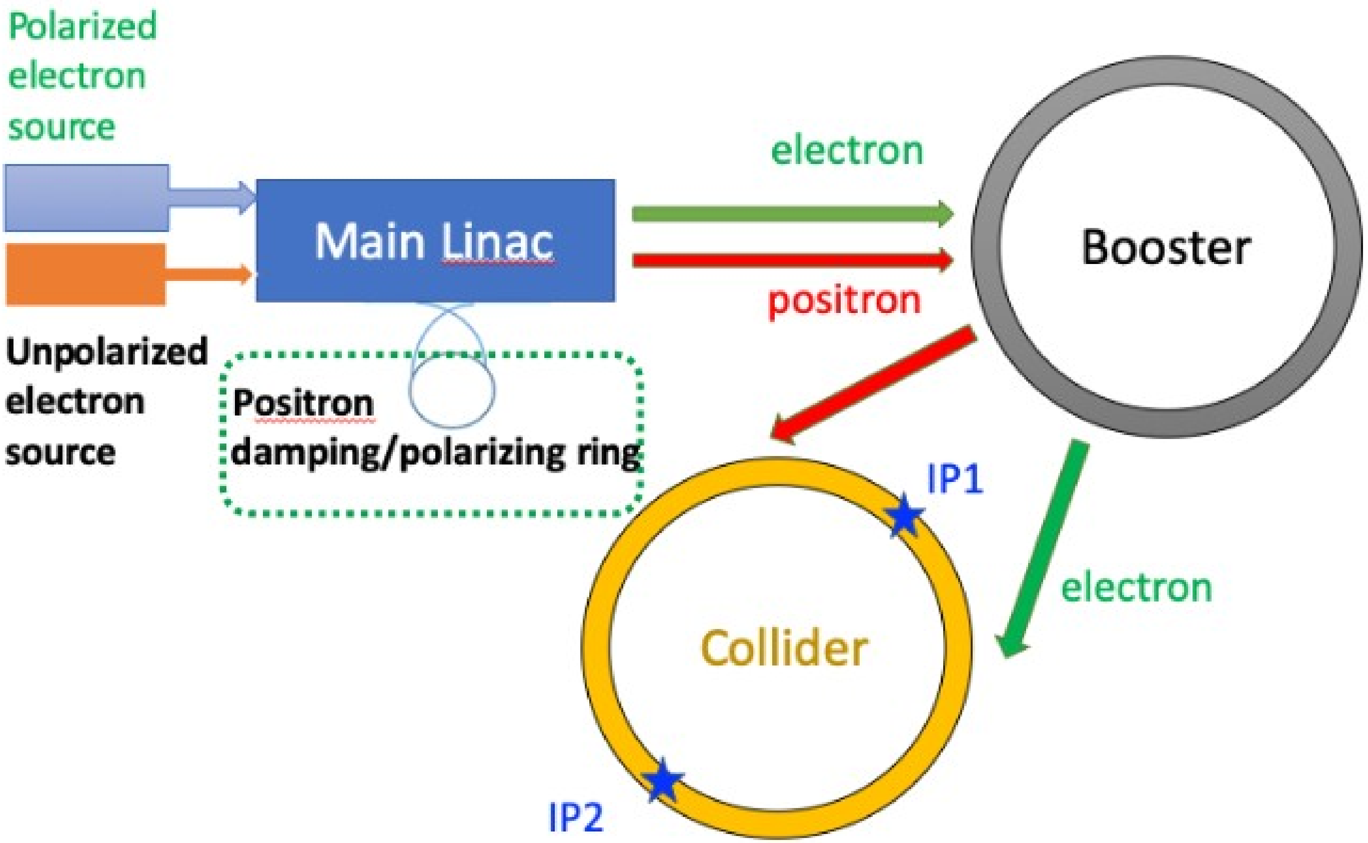


Operational Scenario

- Inject a few (100-200) non-colliding pilot bunches (~10^{10} ppb)
- Use on wigglers until ~5-10 % **vertical polarization** reached
- Switch wigglers off
- Inject ~10000 colliding bunches (~2 x 10^{11} ppb)
- Measure beam energy with pilots while collisions take place



CEPC Polarization Scheme



- 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

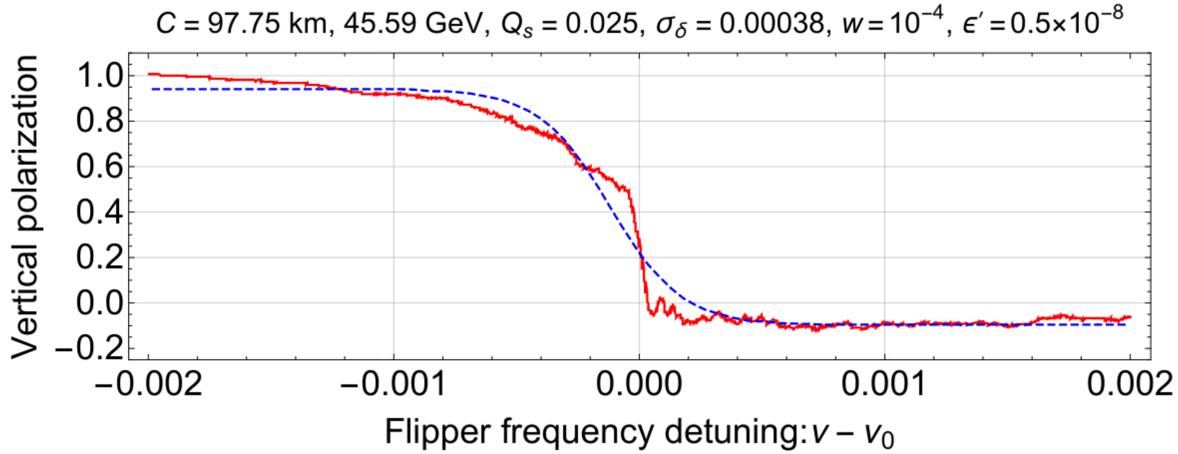
Courtesy: Z. Duan

Center-of-mass Energy Calibration, Polarization and Monochromatization of the Future electron-positron Circular Collider

Part III: Depolarization and energy measurement

Resonant Depolarization

Simulations for Z-pole



Courtesy: I. Koop

Natural width ~ 200 keV at Z

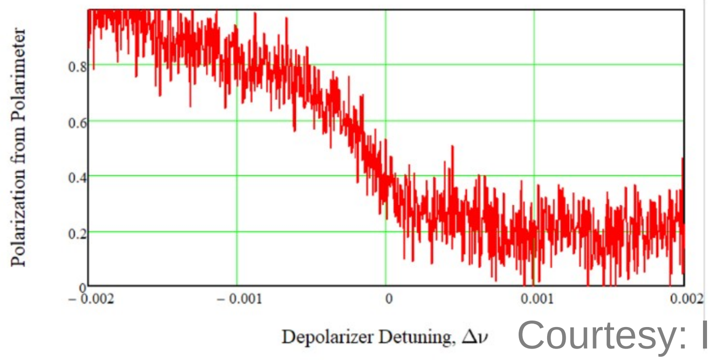
Suggestion: Alternating scanning directions

Simulations achieved better than 10 keV

- Independent depolarizers per beam
- TEM wave propagating towards a pilot bunch
- Varying exciting frequency

Exciting frequency = spin tune = depolarization

Simulations for W-pair-threshold

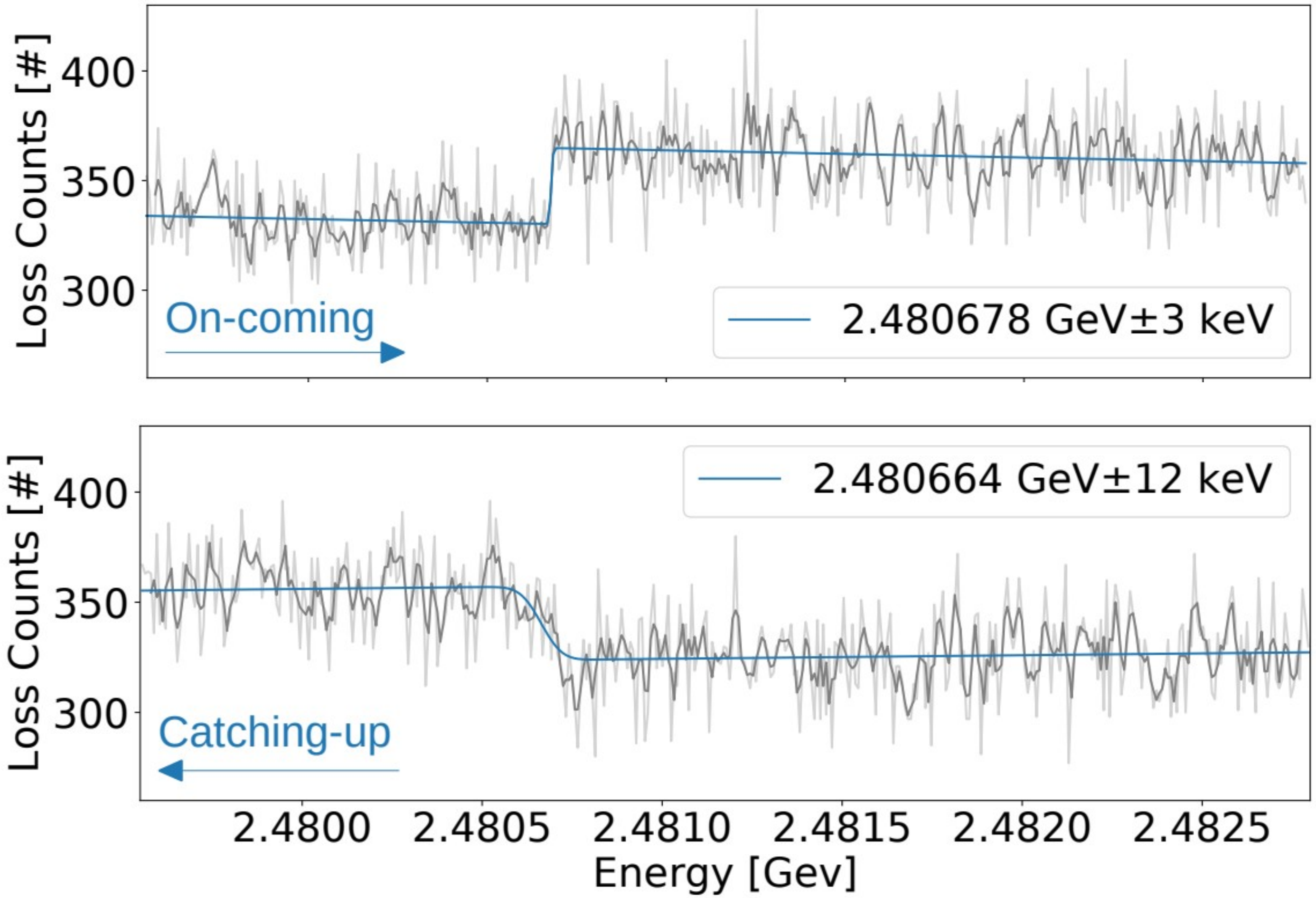


Courtesy: I. Koop

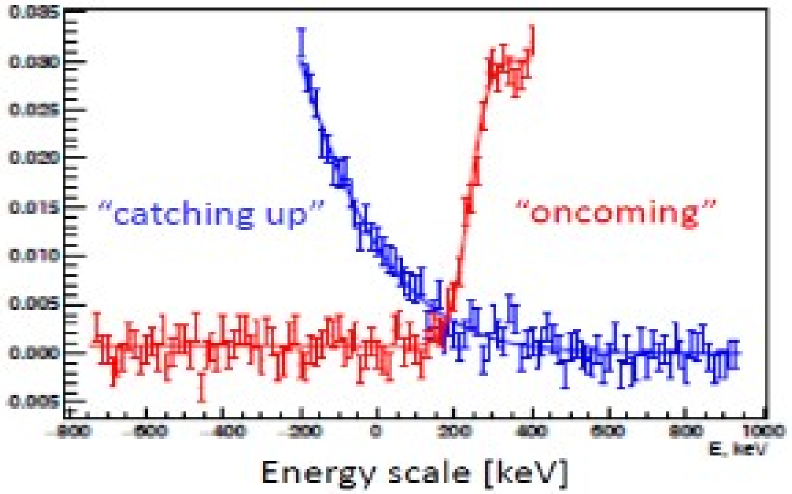
Natural width ~ 1.4 MeV at W

Beam Tests at KARA

Excitation frequency ↔ Beam energy



- Losses depend on polarization
- Findings consistent with FCC simulations
- Suggests negative engergy drift

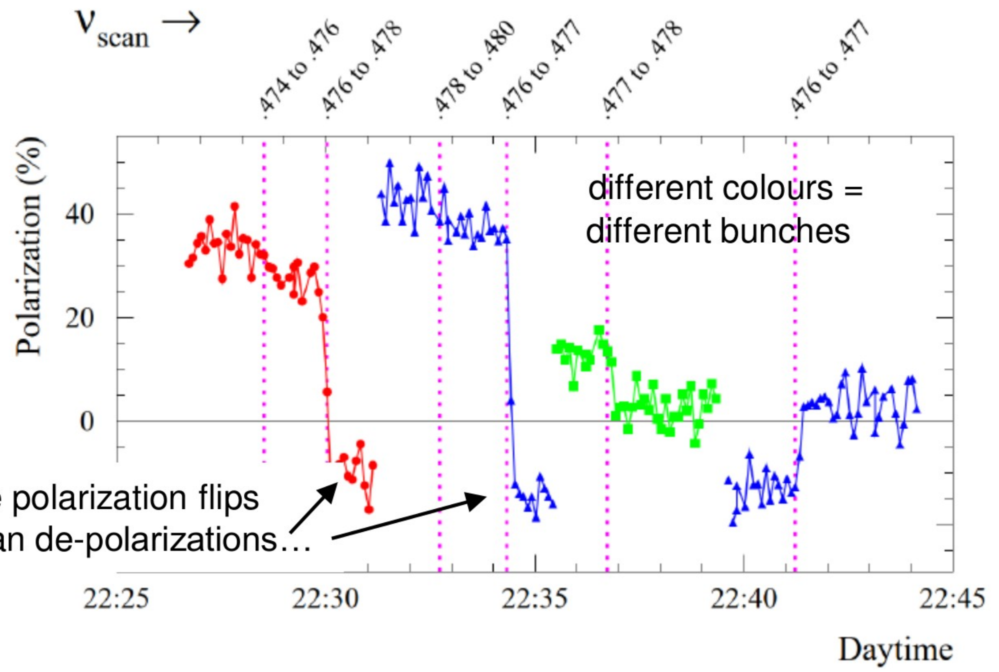


Courtesy: S. Nikitin, I. Koop

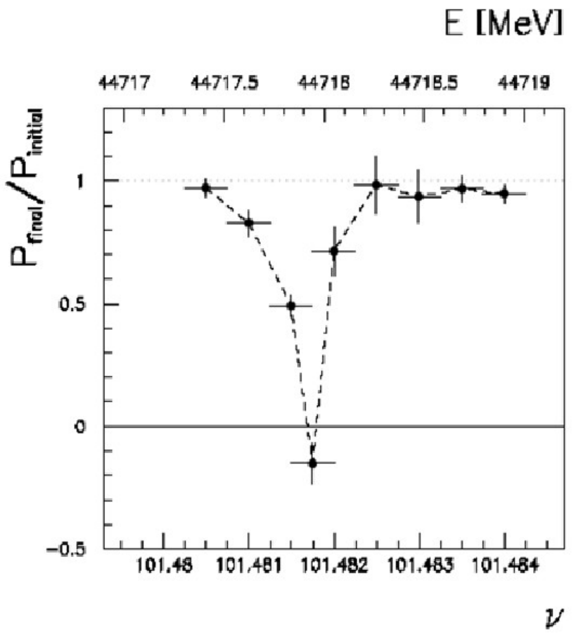
Experience from LEP

- Resonant depolarization also used at LEP

- Strong depolarizers have lead to polarization flips
- Possibly re-use of the same pilot bunches



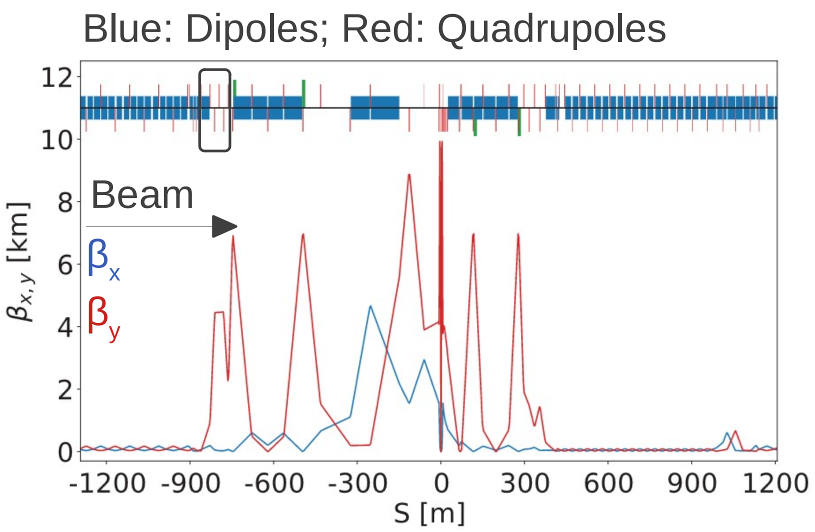
[L. Arnaudon *et al.*, Z. Phys. C66 (1995) 45]



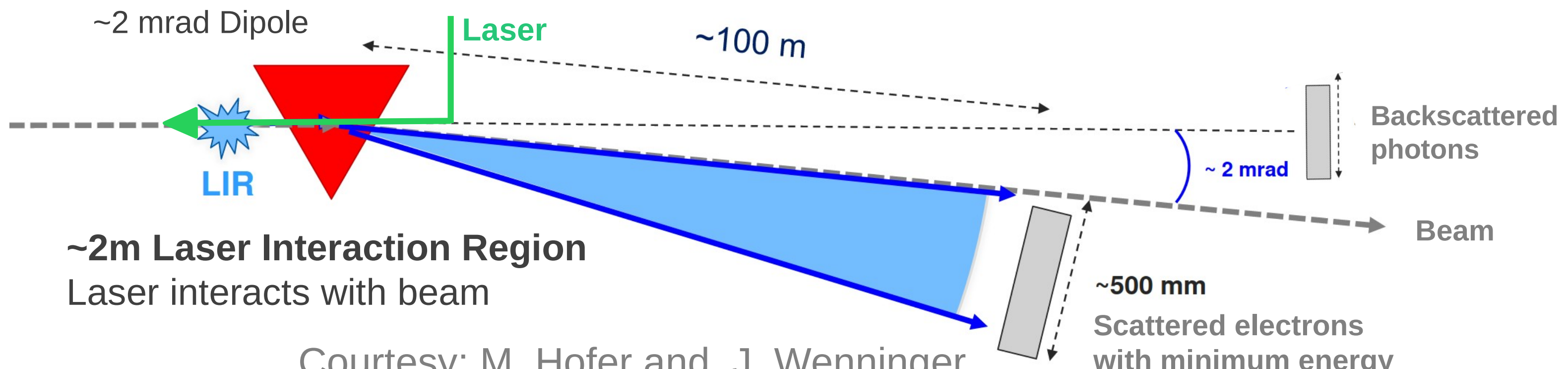
- At LEP resonant depolarization not feasible for W
- Several shorter depolarization steps at discrete frequencies

Polarimeter

- ~ 520 nm circular **polarized laser** interacts with beam
- **Back-scattered photons** sufficient for resonance measurement
- Additional measurement of **scattered electrons** for 3D spin vector
- At least 1 polarimeter per beam

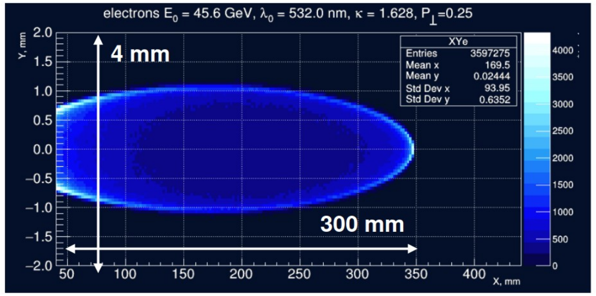


Spin tune ⟺ **Beam energy measurement**



Courtesy: M. Hofer and J. Wenninger

Scattered electrons to be measured by Si pixel detector



Courtesy: N. Muchnoi

Colliding Bunches Polarization

Consider forward-backward asymmetry of $b\bar{b}$ at Z pole: $A_{\rm FB}^b = \frac{3}{4}\mathcal{A}_e\mathcal{A}_b$

where in the SM $\mathcal{A}_e \approx 0.15, \quad \mathcal{A}_b \approx 0.95 \Longrightarrow A_{\rm FB}^b \approx 0.11$

Now, if there is longitudinal polarisation, asymmetry becomes: $\left(A_{\rm FB}^b\right)' = \frac{3}{4}\mathcal{A}_e'\mathcal{A}_b$

where $\mathcal{A}_e' = -\left(\frac{\mathcal{A}_e - P}{1 - \mathcal{A}_e P}\right)$ with $P = \frac{(P_z)_{e^-} - (P_z)_{e^+}}{1 - (P_z)_{e^-}(P_z)_{e^+}}$

and $(P_z)_{e^\pm}$ the longitudinal polarisation of the $e^\pm$.

So, if $(P_z)_{e^-} = (P_z)_{e^+}$ (no reason to be so) = 10^{-5} (ballpark guess)

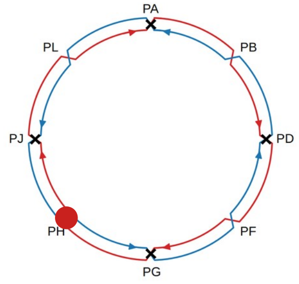
$$P = 2 \times 10^{-5} \quad \Longrightarrow \quad \frac{\left(A_{FB}^b\right)' - A_{FB}^b}{A_{FB}^b} = 1.3 \times 10^{-4}$$

Take away message:

- **Longitudinal** polarization could spoil measurements and must be **< 10-5**
- To be measured also with polarimeters
- Depolarizers must also act on colliding bunches

G. Wilkinson: Requirements for polarization measurements

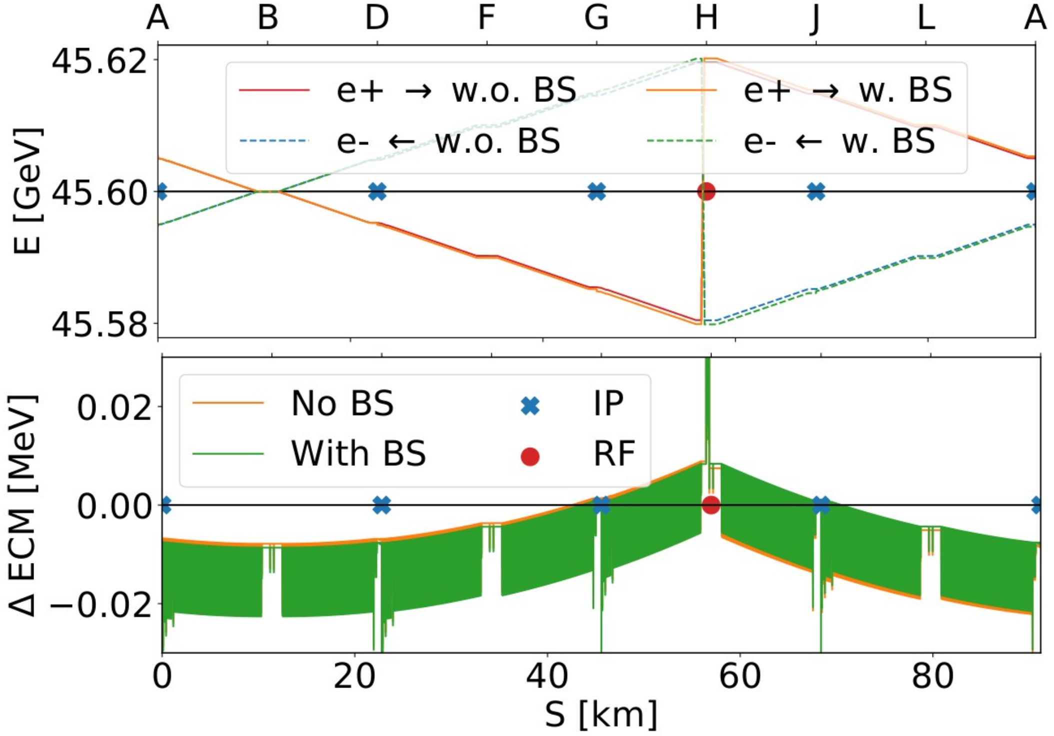
From Beam Energy to E_{CM}



- 40 MeV synchrotron radiation losses per turn
- Additional beamstrahlung (BS) (synchrotron radiation due to field of colliding bunch) ≲ 0.62 MeV/beam/IP

- **Same RF-section for both beams** to compensate losses
- ΔE_{cm} ~ -8 keV (PA, PD) and ~0.7 keV (PG, PJ)
- Boosts ~ +/- 10 MeV (PA, PD) and ~ +/- 30 MeV (PG, PJ)

- Pilot and colliding bunches have different local energy
- **Accurate models essential**



Dispersion and Collision Offset

$$\Delta\sqrt{s} = -u_0 \frac{\sigma_E^2 \Delta D^*}{E_0 \sigma_u^2}$$

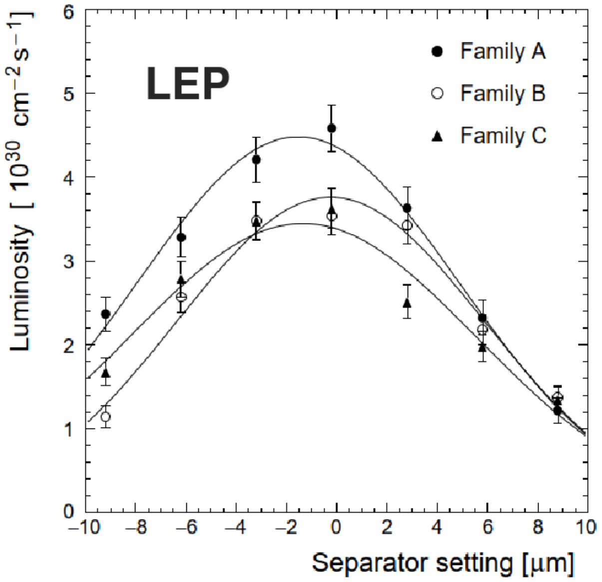
$$|\Delta\sqrt{s}| = 96\ |u_0|\ [\mathrm{keV/nm}]$$

D… Dispersion
σ_u … transverse beam size
u_0 … collision offset

for $\Delta D^* = 1\ \mu\mathrm{m}$, $\sigma_E/E = 0.13\%$

For **ΔD* = 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.**

- Only relevant for colliding bunches
- Measurement and control of dispersion at collision point essential
  - **ΔD < 1 μm** relaxes requirements on collision offsets
- Collision offsets determined with e.g. luminosity scans
  - Presently collision offsets must be demonstrated to be controlled to **$\sim 0.1\sigma_y$**



J. Wenninger: Beam-beam and OSVD

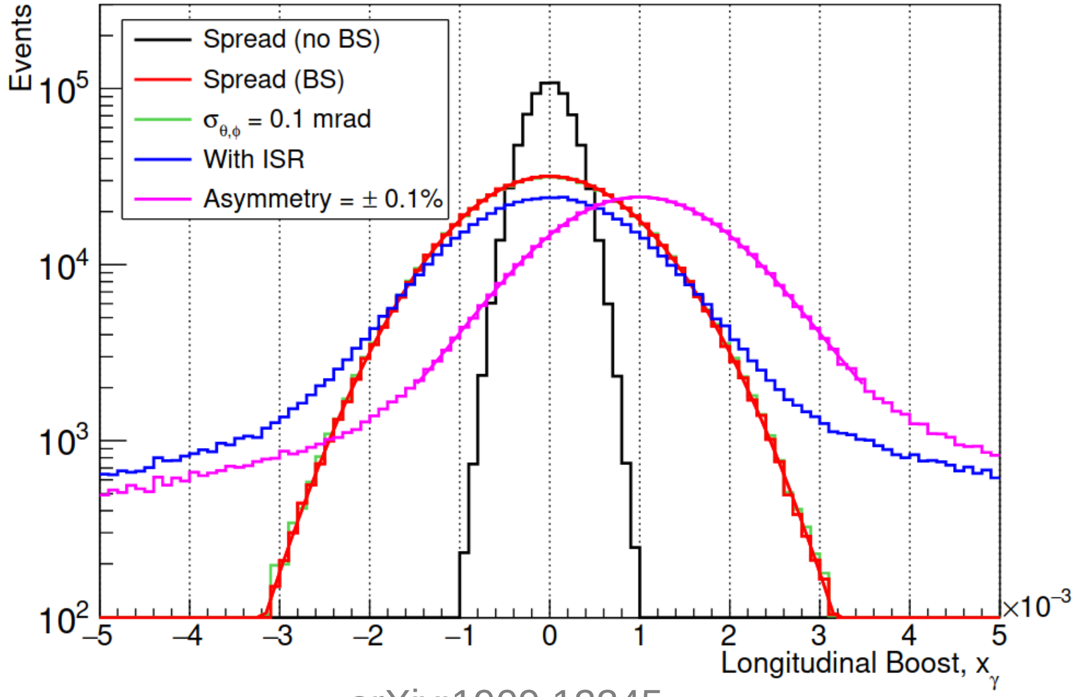
Experiments

- G. Wilkinson: *Di-muon events - "The gift that keeps on giving"*
- Reliable and frequent logging of parameters essential
- Possibility to measure Z-bosons from higher E_{cm} events

One million di-muon events per 8h shift
~ 5 keV statistical precession achievable

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

Boost reconstruction from di-muon events



arXiv:1909.12245

Important message

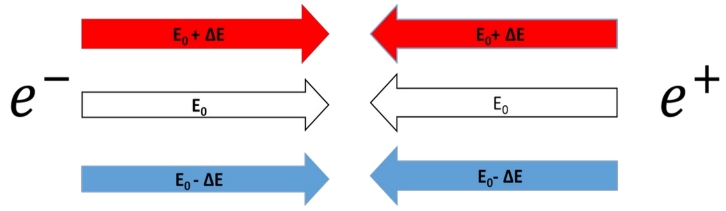
All these results come from 'proof-of-principle' studies. They need to be repeated and consolidated with state-of-the-art ISR generators, proper simulation, realistic treatment of detector resolutions *etc.*, and extended to other fermion types and (in top regime) WW events. Many important & interesting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

Center-of-mass Energy Calibration, Polarization and **Monochromatization of the** Future electron-positron Circular Collider

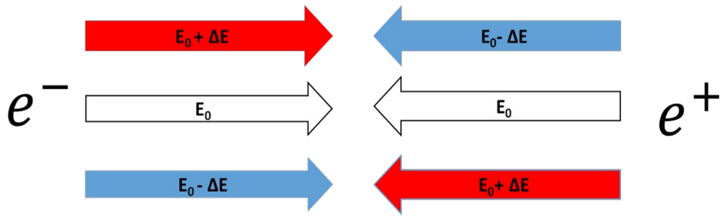
Monochromatization

- 62.5 GeV beam energy corresponds to the peak of Higgs-production with narrow width of 4.2 MeV
- For minimization of collision energy spread –> monochromatization techniques required

Introducing dispersion



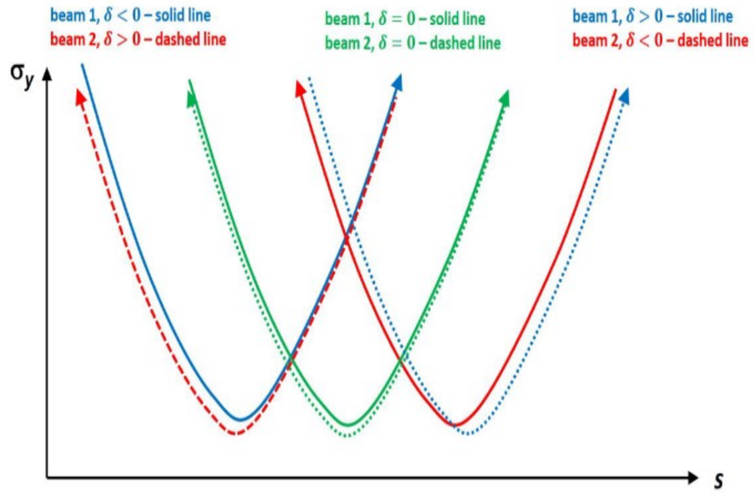
Same sign dispersion at the IP leads to increase of E_{CM} spread



Opposite sign dispersion helps reducing E_{CM} spread

Courtesy: A. Faus-Golfe, H. Jiang and P. Raimondi

Introducing chromaticity



Non-zero local vertical chromaticity to reduce collision energy spread presently explored

Center-of-mass Energy Calibration, Polarization and Monochromatization of the Future electron-positron Circular Collider

We made it through the title!

Summary

- **Higgs and electroweak factory** highest priority **next collider** after completion of HL-LHC
- High precision particle physics experiments require **excellent determination of E_{cm} and collision boosts**

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

Any help is welcome!

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

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

Summary

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- First half of **FCC Feasibility Study** successfully completed with the **mid-term review**
  - Placement and layout defined, entire project adapted to new geometry
  - Dialogue with local-regional actors and stakeholders for implementation established and ongoing
  - All deliverables met, list of recommendations from committees towards final Feasibility Study

Outlook

- Completion of FCC Feasibility Study by **March 2025** and **set-up structure for preparatory phase**
  - Complete **technical work for FCC FS by end 2024** including implementation of recommendations
  - Further development of affordable funding model and related governance implications (with Council)

- **By 2027-2028: Project approval and start of civil engineering design contracts**
  - Requires overall integration study, refined input for environmental evaluation and project authorisation
  - Specifications to enable tender design to start from 2028 (underground) and 2029 (surface)

- **By 2031-2032: Start of civil engineering construction**
  - TDR to enable prototyping, industrialization towards component production

FCC-Week 2024

Future Circular Collider (FCC) Week 2024
at the
Westin St. Francis in San Francisco
from
Monday 10 June to Friday 14 June 2024

Registration is open:
https://fccweek2024.web.cern.ch/

We look forward to welcoming you in San Francisco for what promises to be an exciting and informative event!

Thank you!

Jacqueline Keintzel and Guy Wilkinson

On behalf of

The FCC-ee EPOL working group

jacqueline.keintzel@cern.ch

guy.wilkinson@cern.ch

BE Seminar

CERN, Geneva, Switzerland

12 April 2024

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.