EPOL Summary

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On behalf of the
FCC-ee EPOL working group

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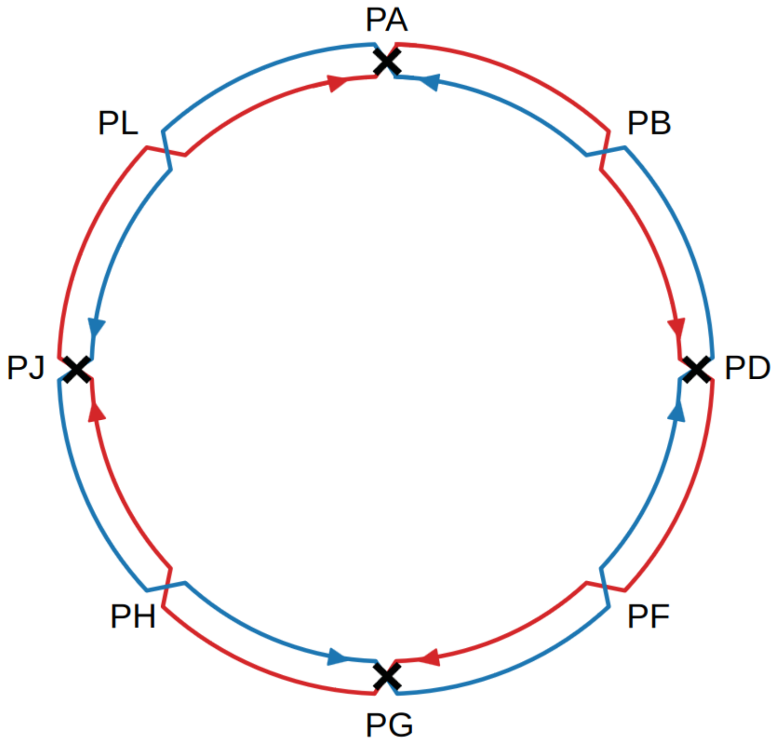
FCCIS – The Future Circular Collider Innovation Study. This INFRADEV Research and Innovation Action project receives funding from the European Union's H2020 Framework Programme under grant agreement no. 951754.

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

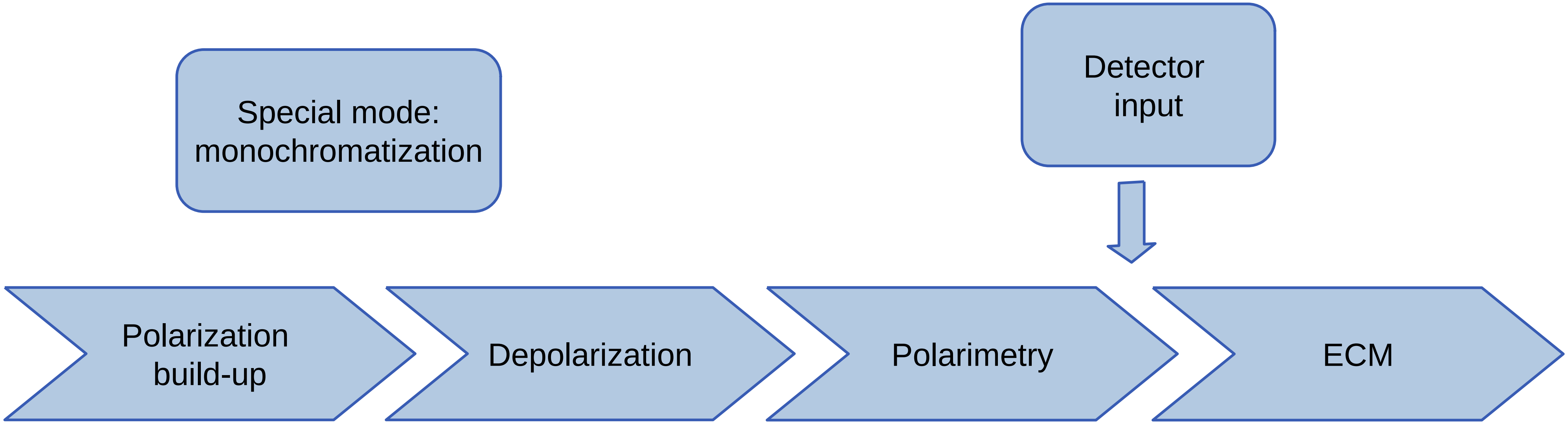
Expected Precision

	Quantity	statistics	ΔE_{CMabs} 100 keV	$\Delta E_{CMSyst-ptp}$ **40 keV**	calib. stats. 200 keV/$\sqrt{(N^i)}$	σE_{CM} (84) ± **0.05** MeV
Z	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**
WW	Further clarification ongoing			300 keV	150 keV	
	m_W(MeV)	**0.200**	**(?)**	75 keV?		
	Γ_W (MeV)			(75?)	small	OK

- Large expected luminosity → huge statistics → small statistical error: **4 / 100 keV per Z / 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

How to?



- Resonances
- Wigglers
- Beam tests

- Resonant depolarization
- Free spin precession

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

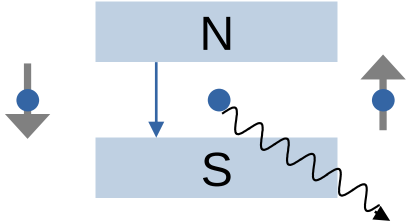
- Systematic errrors
- Statistical errors
- Accurate models

Sessions Overview

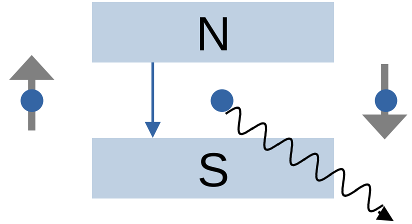
Wednesday 13:30 – 15:00	**Thursday 08:30 – 10:00**
Compton Polarimeter Speaker: Aurelien Martens	Depolarizer for the FCC-ee Speaker: Ivan Koop
Polarization studies Speaker: Yi Wu	The challenge of E_{CM} calibration above the Z-pole Speaker: Guy Wilkinson
Spin based beam energy measurements Speaker: Edmund Blomley	Monochromatization optics for the FCC-ee lattice Speaker: Zhandong Zhang
Centre-of-mass energy shifts Speaker: Alain Blondel	The roadmap to the final report Speaker: Jacqueline Keintzel

Polarization Build-Up

More likely
(by factor ~25)



Less likely



- Statistically every 10^{10} 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

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

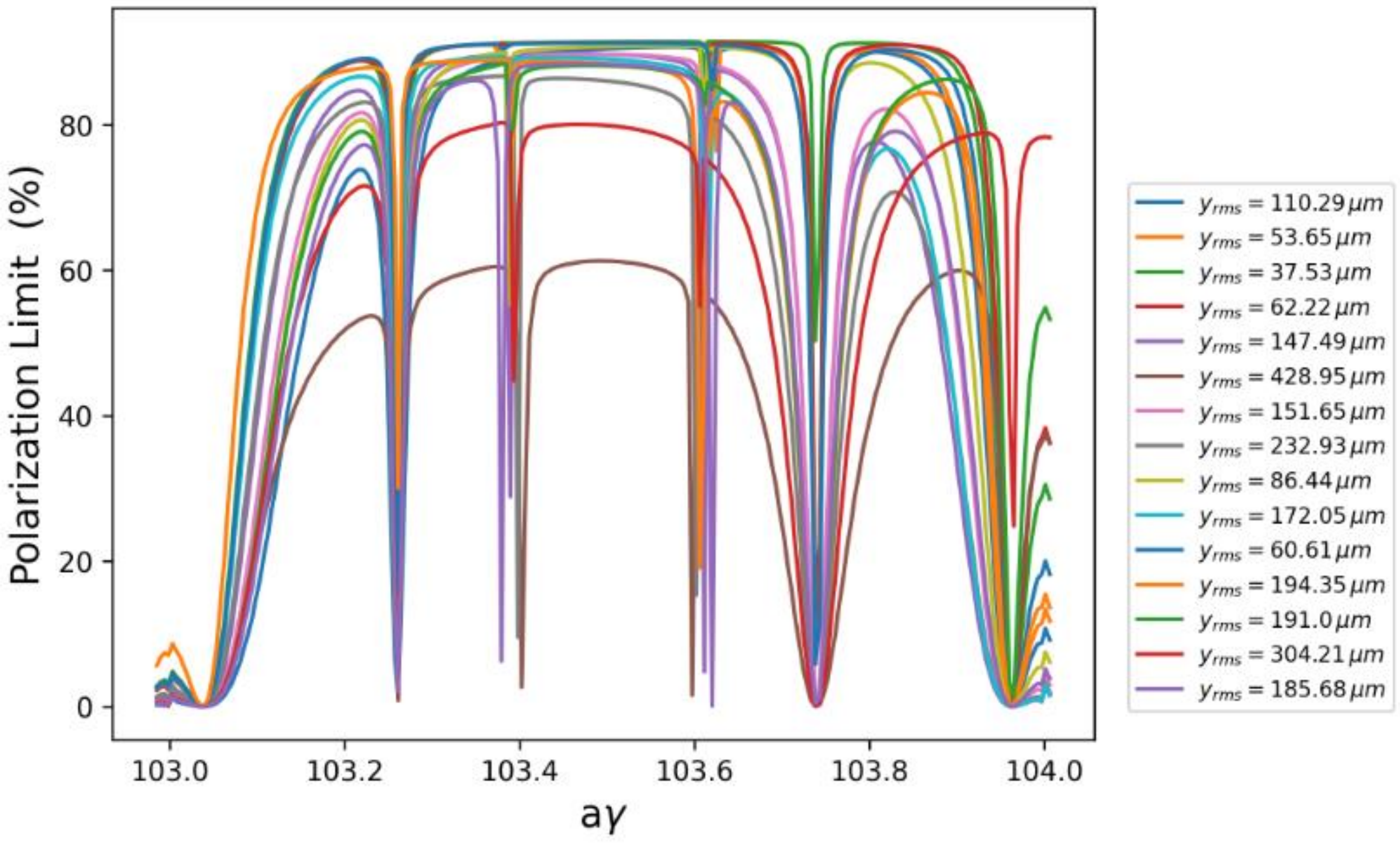
a … gyro-magnetic anomaly
γ_{Rel} … Lorentz-factor

What are the advantages of wigglers or a dedicated polarization ring?

Resonances and Misalignments

Polarization studies
Speaker: Yi Wu

- Large vertical closed orbits reduce polarization level
- *What is the maximum allowed orbit for sufficient polarization?*



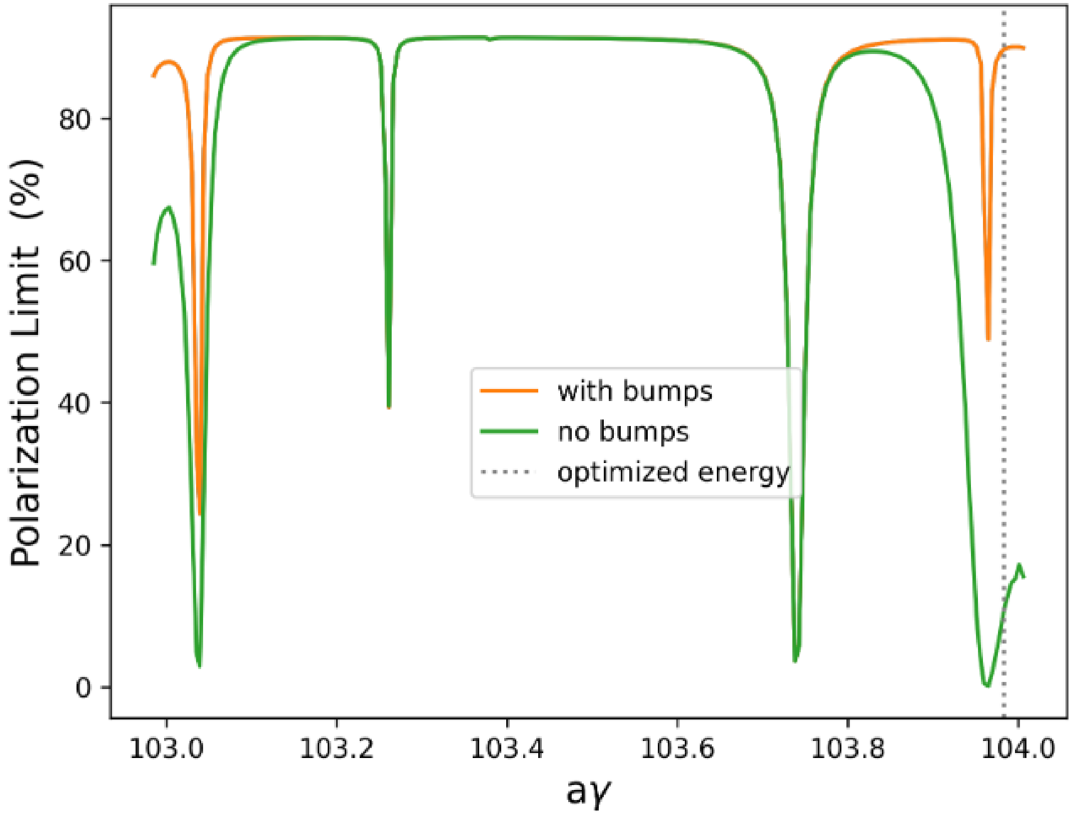
Resonances and Orbit Bumps

- Techniques to improve polarization level studied
- 3 different schemes applied and explored for the FCC

Polarization studies
Speaker: Yi Wu

- Based on 4 closed orbit bumps placed in arcs
- Could require BPMs next to arc dipoles

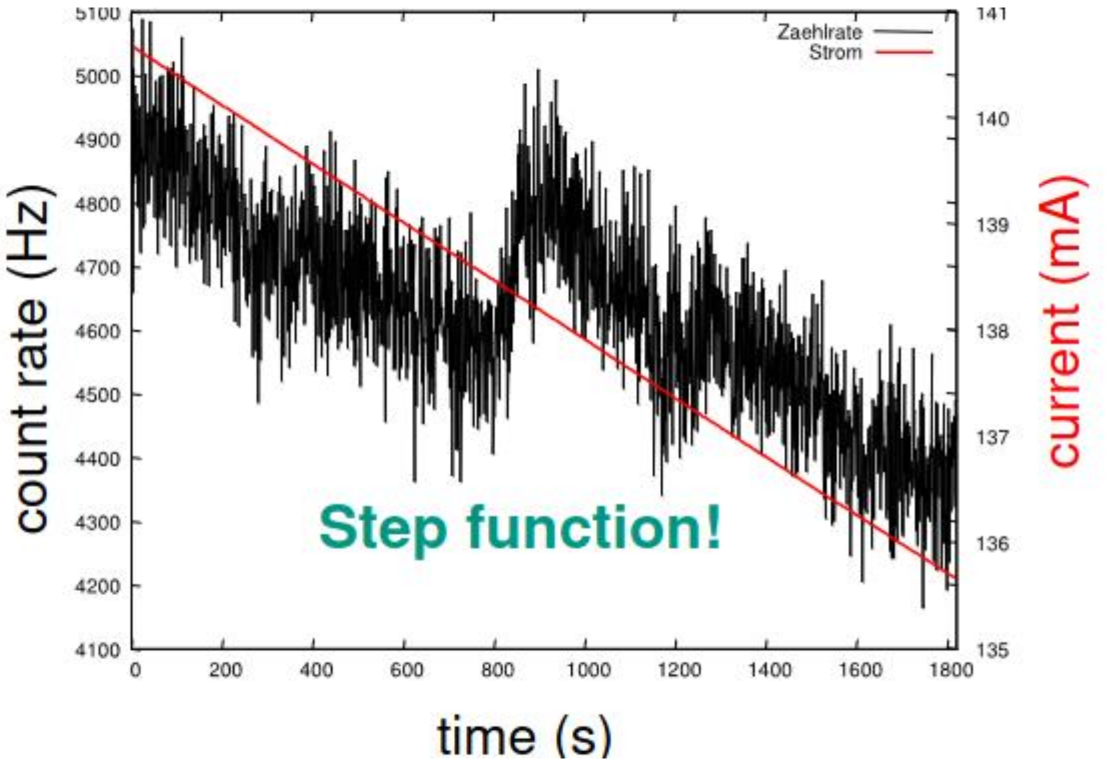
- *What is the most effective scheme for the FCC?*
- *How many BPMs are required, where, with which errors?*
- *Can this be tested somewhere?*



Measuring Polarization

- KARA at KIT, polarization time ~ 10 min at 2.5 GeV
- Polarization measurements via Touschek lifetime change

Spin based beam energy measurements
Speaker: Edmund Blomley



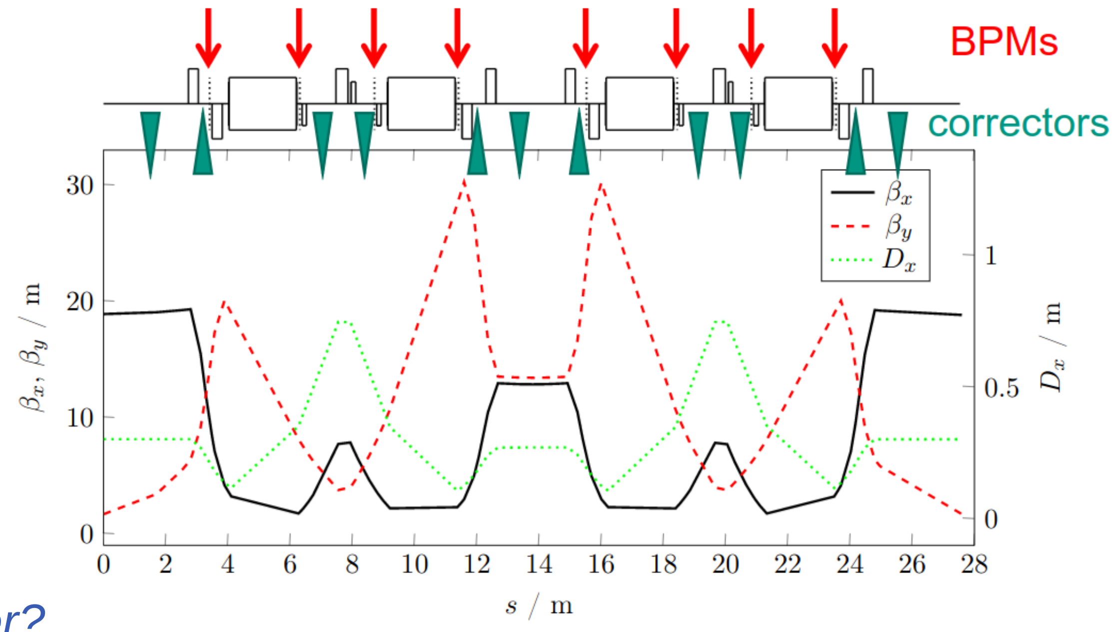
Beam Test Polarization and Bumps

Spin based beam energy measurements
Speaker: Edmund Blomley

- KARA at KIT, polarization time ~ 10 min at 2.5 GeV
- Polarization measurements via Touschek lifetime change

- Possible beam test with:
- Generate strong depolarizing source and orbit bumps
- Find minimum polarization level and how to measure

- *What can we learn from KARA?*
- *Possible long term idea: Is it possible to install a polarimeter?*



sector 1 (one quarter)

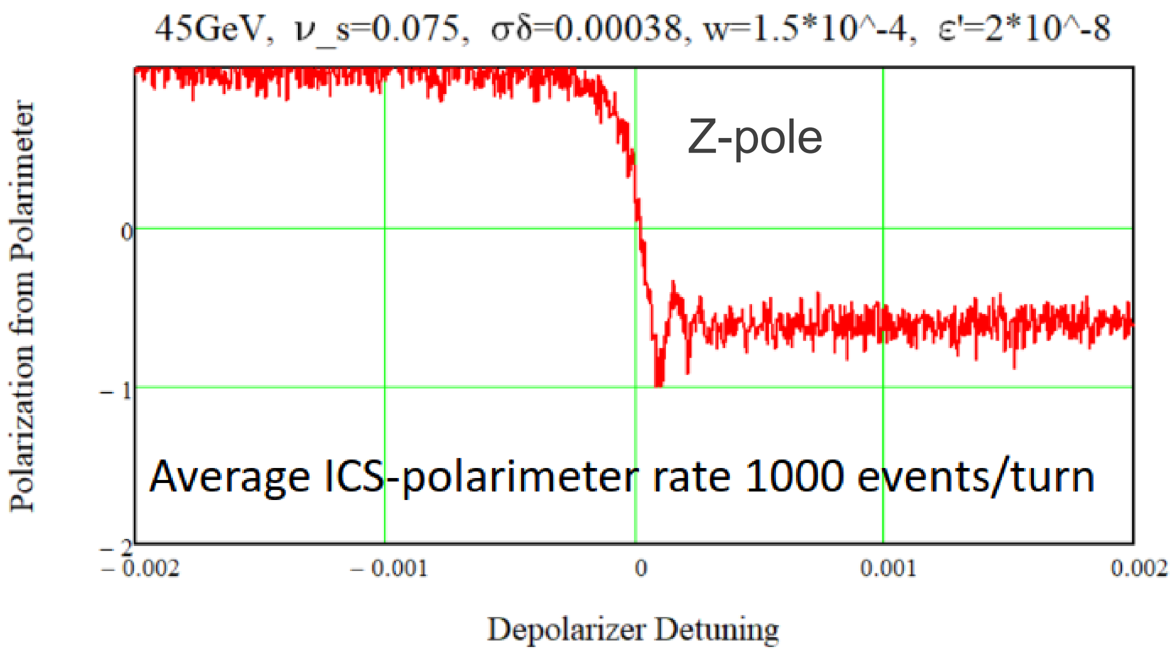
Resonant Depolarization

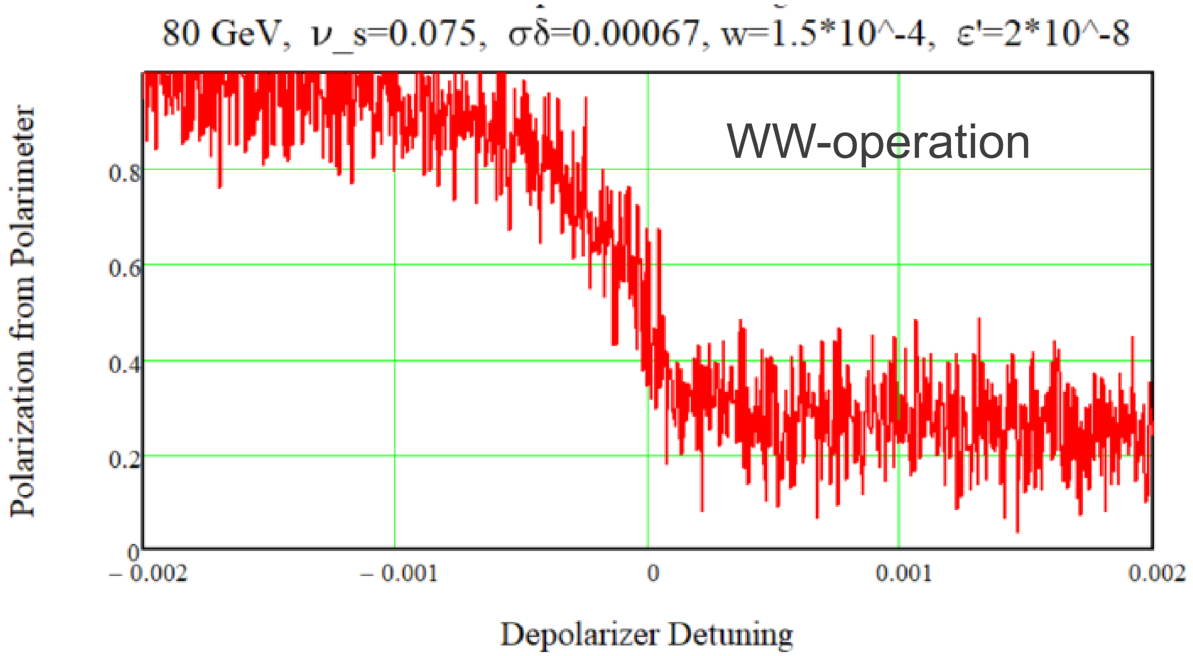
- Independent depolarizers per beam
- Varying exciting frequency

- Exciting frequency = spin tune = depolarization

Depolarizer for the FCC-ee
Speaker: Ivan Koop

- *Where is the best location for the depolarizers?*
- *Can they be combined with other hardware?*





Colliding Bunches Polarization

Depolarizer for the FCC-ee
Speaker: Ivan Koop

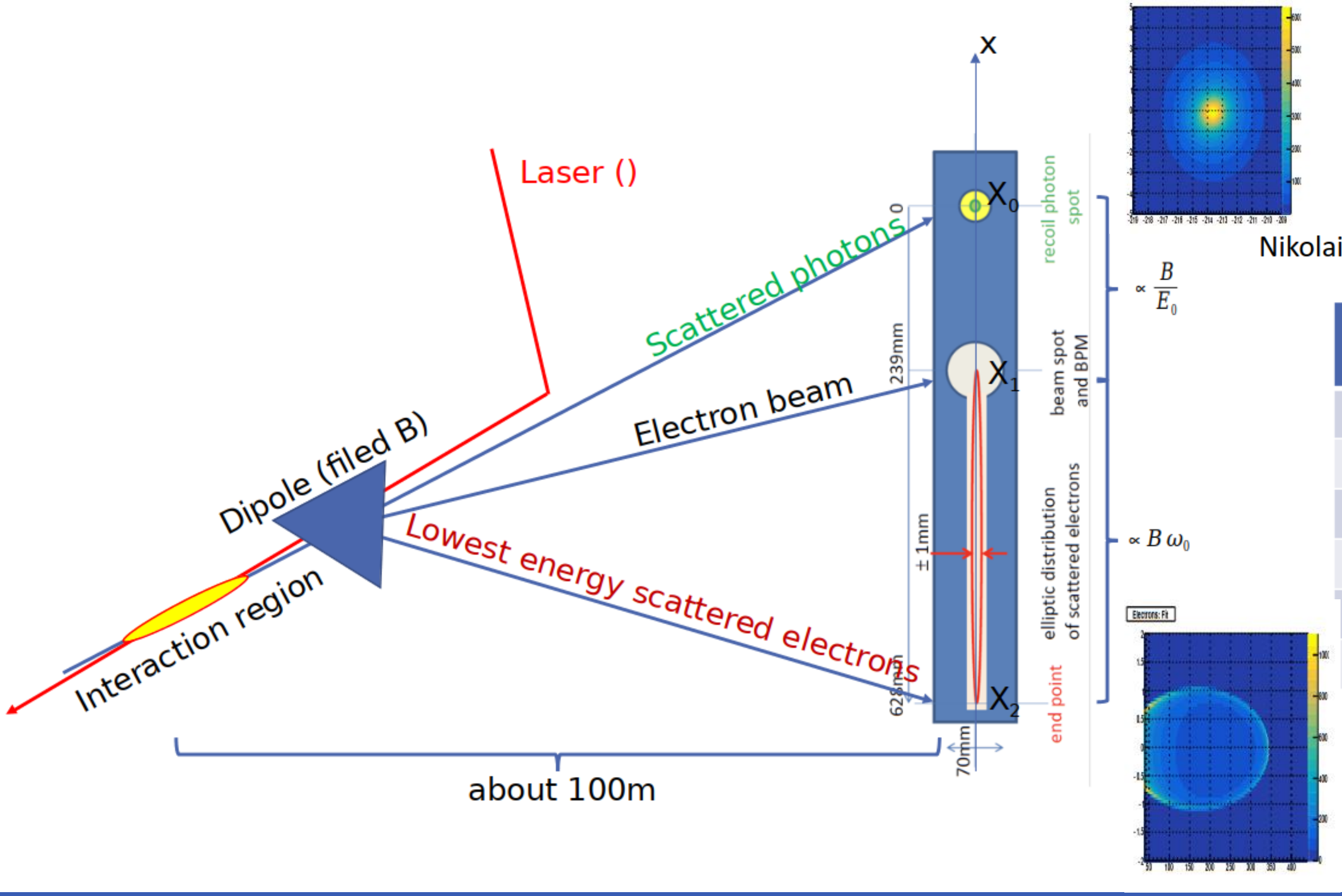
- **Take away message:**
- **Longitudinal** polarization could spoil measurements and must be **< 10-5**
- Depolarizers must also act on colliding bunches → Consider closed-orbit bumps to avoid impact at IP
- To be measured also with polarimeters

- *What could be the impact of kickers acting on colliding bunches?*
- *Which depolarizer and polarimeter design is the most suitable for pilot and colliding bunches?*

Polarimeter

- *Can we extract the beam energy from the polarimeters?*
- *What are the advantages of more than 1 polarimeter per beam?*

Compton Polarimeter
Speaker: Aurelien Martens



Nikolai's baseline (Q-switch Nd-YAG)

Versatile Yb system

Laser param.	1 pilot	1 pilot v2	All colliding bunches (at Z)
Repetition rate	3 kHz	3 kHz	30 kHz
Pulse energy	1 mJ	1 mJ	10x0.05mJ
Pulse duration	3 ns	30 ps (**)	30 ps
Average power	3 W	3 W	15 W (***)
Scattering rate	$3x10^5/s$ (*)	$3x10^5/s$ (****)	$4x10^7/s$ (****)
Scattering rate per bunch	$3x10^5/s$ (*)	$3x10^5/s$	$4x10^5/s$

adaptable

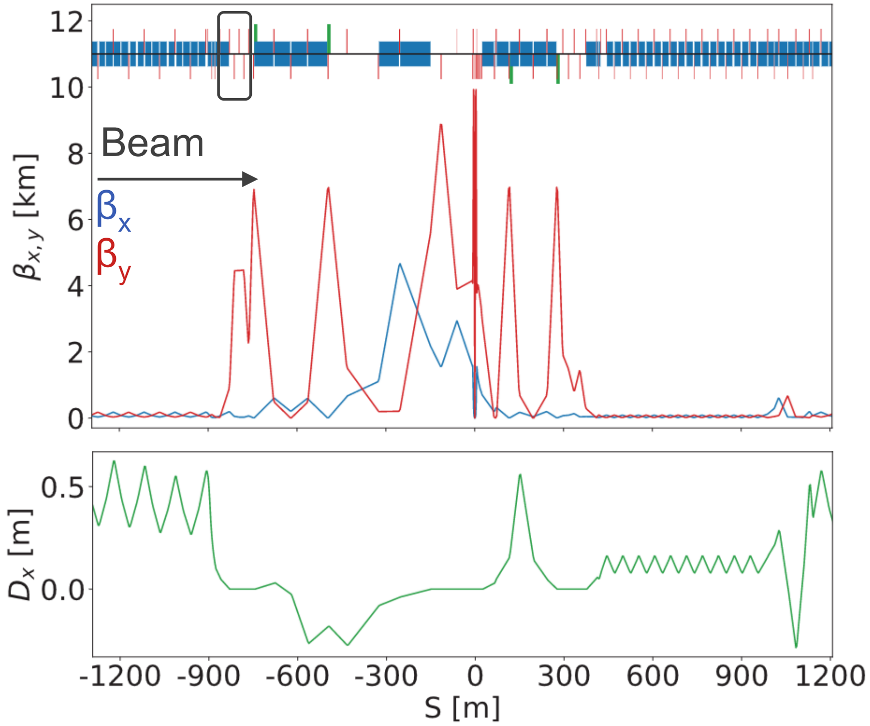
Same oscillator may be used but two different amplification schemes

Polarimeter

- *Where is the best integration point for the polarimeters?*

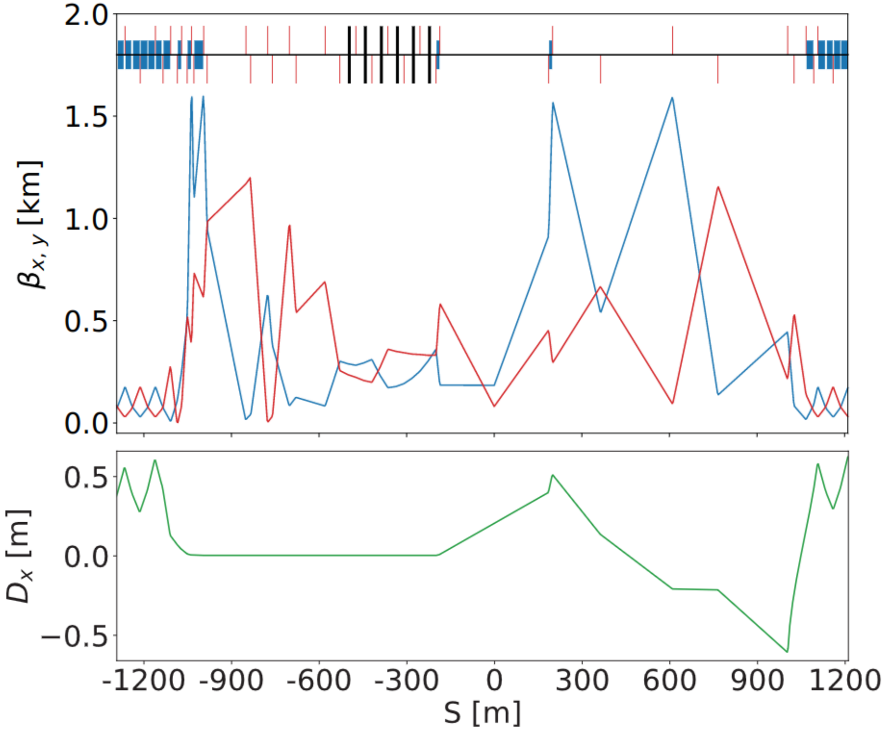
Compton Polarimeter
Speaker: Aurelien Martens

Blue: Dipoles; Red: Quadrupoles



EIR

Blue: Dipoles; Red: Quadrupoles



RF-Section

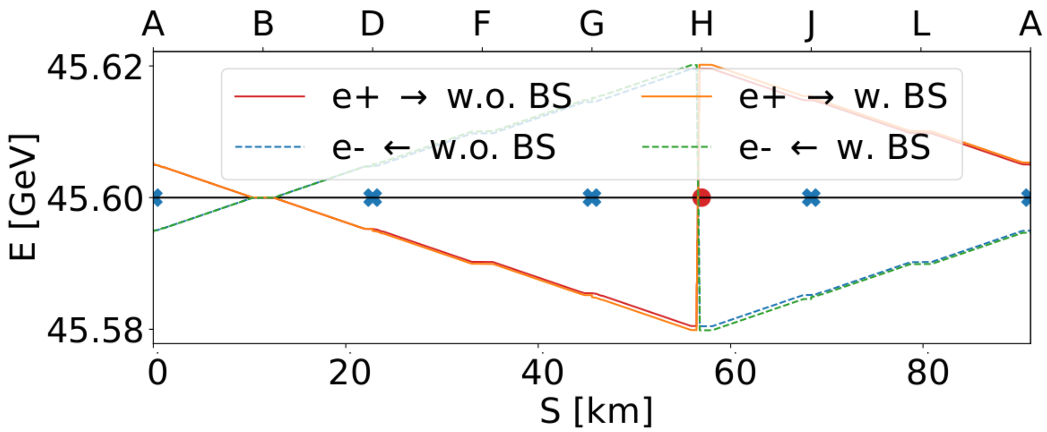
ECM Energy Shifts

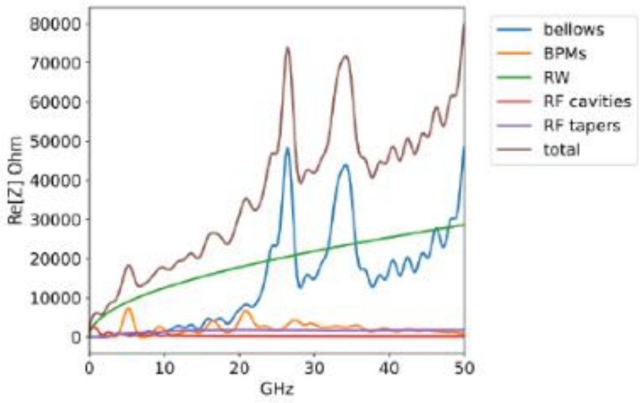
Center-of-mass energy shifts
Speaker: Alain Blondel

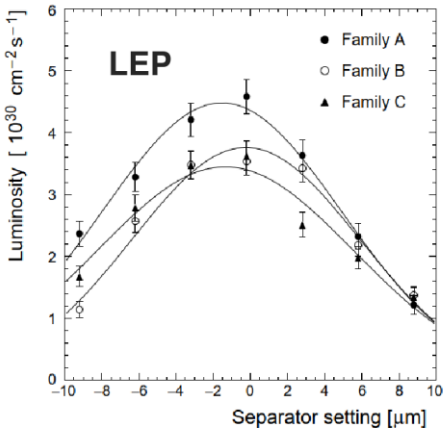
- Beam energy depends on
  - Pilots: Synchrotron radiation, impedance losses, ...
  - Colliding: Synchrotron radiation, impedance losses, beamstrahlung, …
- Center-of-mass energy depends on
  - Opposite sign dispersion at the IP, collision offsets, ...
- *How can we go from the found resonant frequency to the beam energies to the center-of-mass energy?*

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

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





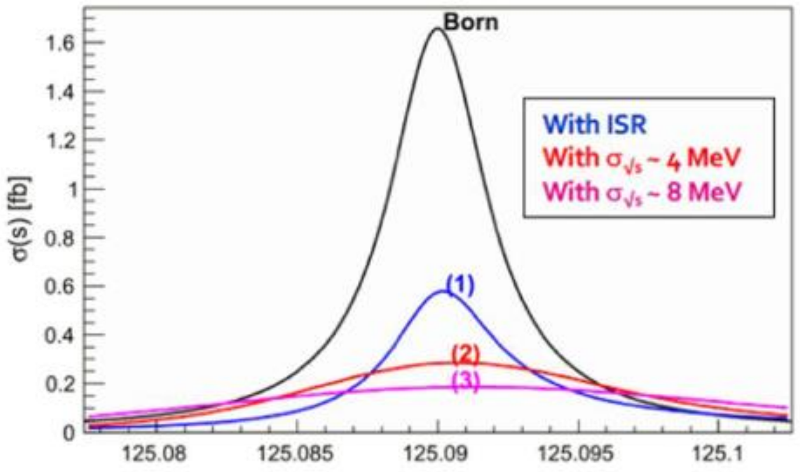


ECM Calibration Above the Z-pole

- *What must be included in reliable energy models at all energy stages?*

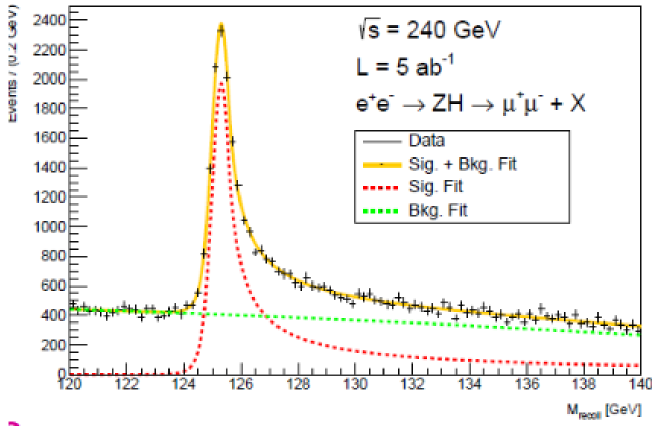
The challenge of E_{CM} calibration above the Z-pole
Speaker: Guy Wilkinson

E_{cm} = 125 GeV



RDP in principle possible, however:
v_s = 142.12 +/- 0.19 far away from half integer resonance
–> possible energy assymmetry with 150 MeV boosts

E_{cm} = 240 GeV

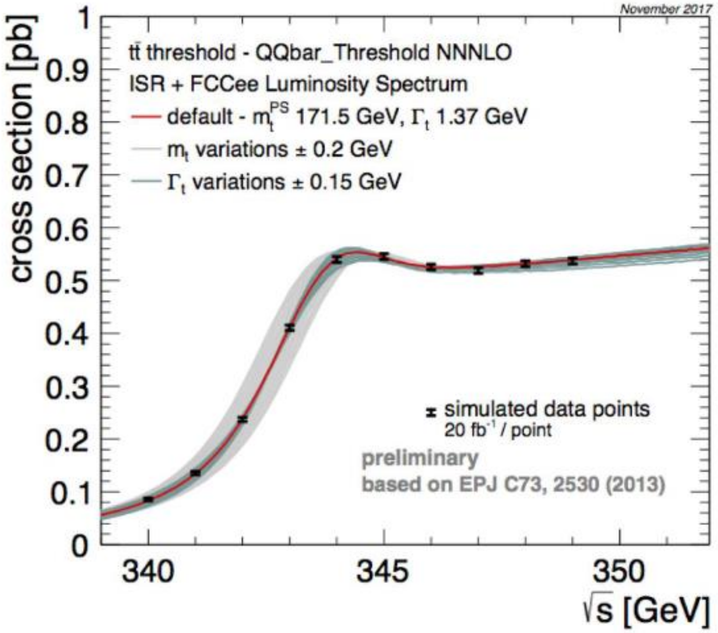


RDP not possible; m_H ~ 10 MeV

RDP only possible for spin modulation index:

$$B = \frac{\upsilon_0 \sigma_E}{Q_S} < 1.5$$

E_{cm} = 340 – 350 GeV

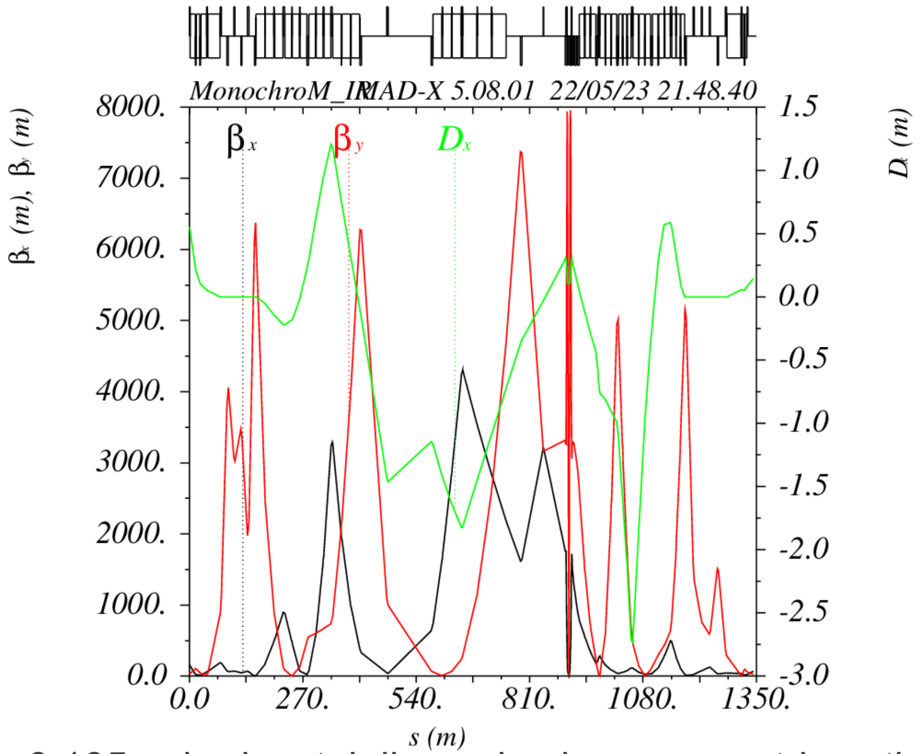


RDP not possible; m_t ~ 3 MeV

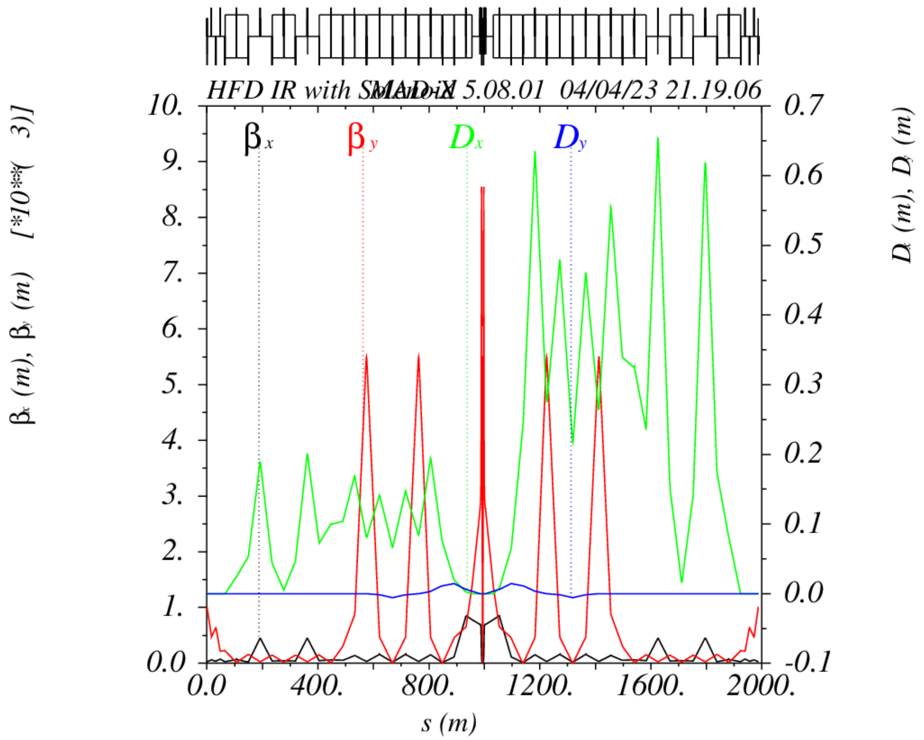
Monochromatization

Monochromatization optics for the FCC-ee lattice
Speaker: Zhandong Zhang

- 62.5 GeV beam energy → peak of Higgs-production
- For minimization of collision energy spread –> monochromatization via dispersion –> optics designed
- *What is the most suitable way for monochromatization and what is the trade-off with luminosity?*



0.105 m horizontal dispersion in assymmetric optics



0.001 m vertical dispersion in symmetric optics

Outlook

The roadmap to the final report
Speaker: Jacqueline Keintzel

- Presently aimed to achieve *4 / 100 keV* systematic uncertainty at the *Z- / W- modes –> EPOL*
- Many questions aimed to be answered until the end of the feasibility study, for example:
  - What is the most efficient way for polarization and depolarization needs?
  - What can be gained from one polarimeter per beam and IP? At which cost?
  - Can we test e.g. orbit bumps at KARA?
  - What are the systematics energy shifts between pilot bunches and colliding ones?
  - ...

Regular EPOL meetings:
indico.cern.ch/category/8678/
Typically every second 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

Thank you!

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