Summary and outlook to the pre-TDR phase

Jacqueline Keintzel and Guy Wilkinson

FCC Physics Workshop 2025
CERN, Geneva, Switzerland
16 January 2025

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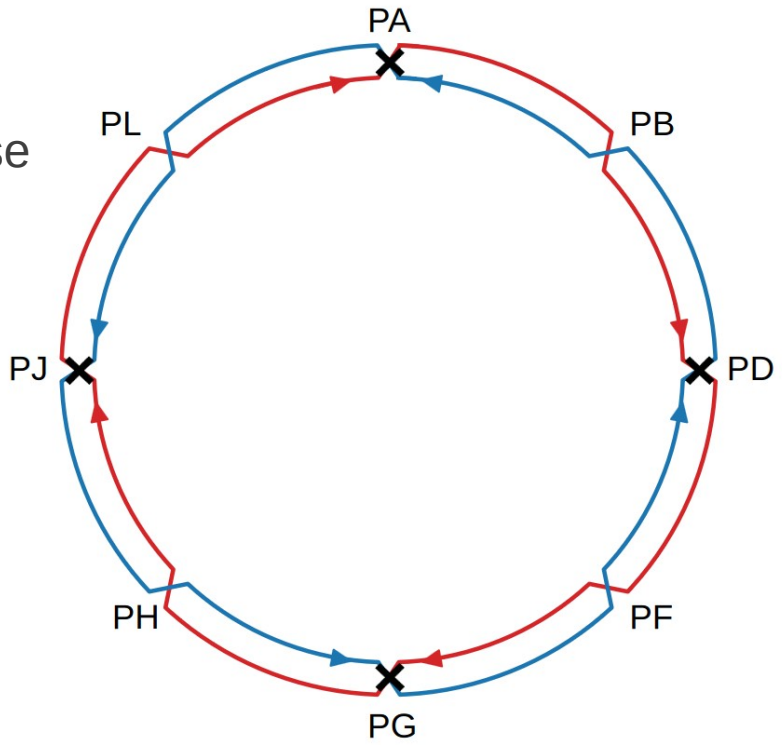
Reminder: FCC-ee Overview

Particle Physics:

- Higgs and electro-weak factory
- Various beam energies and diverse particle physics program
  - 45.6 GeV: Z-pole
  - 62.5 GeV: H-peak
  - 80 GeV: W-pair-threshold
  - 120 GeV: ZH-production
  - 182.5 GeV: top-pair-threshold

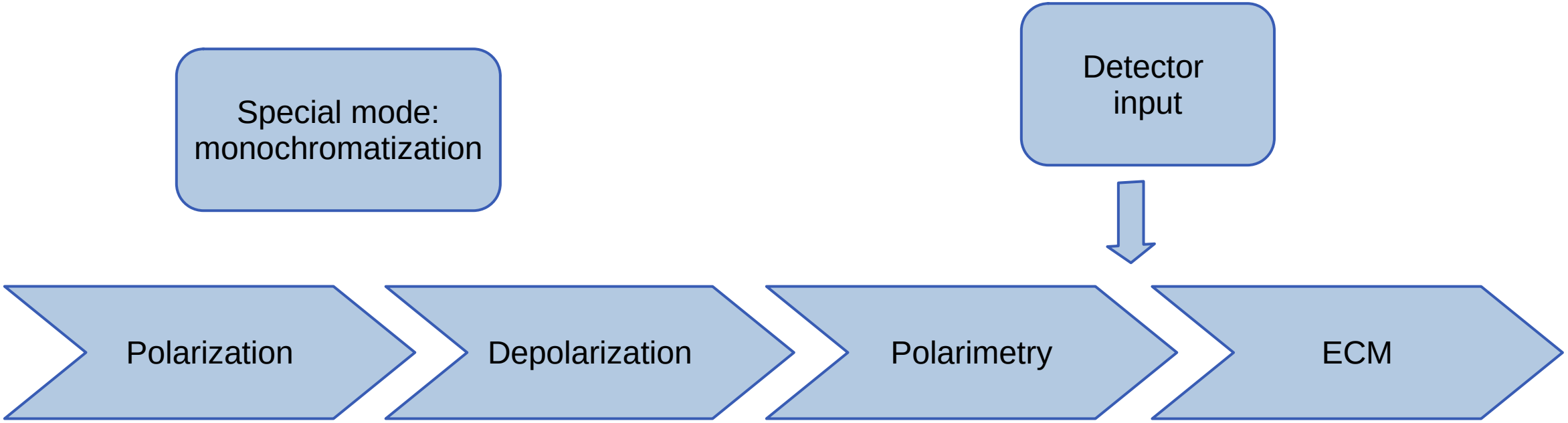


Accelerator Physics:

- 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

How to?



- Polarization level
- Beam optics

- Resonant depolarization
- Free spin precession
- RF-kicker design

- Polarimeter incl. laser, Si-detectors

- Systematic errrors
- Statistical errors
- Accurate models

Sessions Overview

Tuesday 11:00 – 12:30

FCC Polarimeter I
Speaker: Robert Kieffer

FCC Polarimeter II
Speaker: Aurélien Martens

Considerations for the design of the FCCee depolarizer kicker system Speaker: Wolfgang Höfle

Thoughts on injecting polarized beams
Speaker: Jorg Wenninger

Thursday 11:00 – 12:30

Point-to-point calibration with dimuons
Speaker: Emmanuel Perez

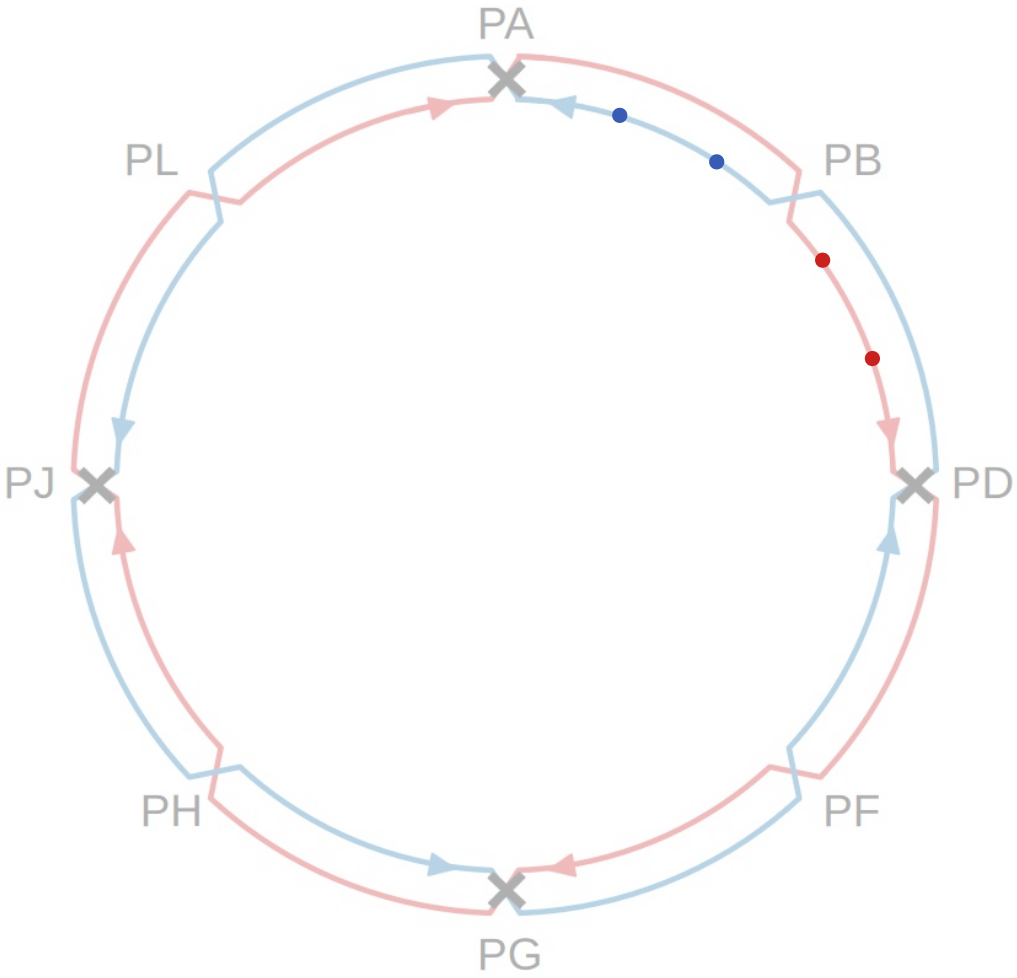
Monochromatisation IP optics simulatons for the eeH run studies; Speaker: Angeles Faus-Golfe

Spin tune shifts
Speaker: Yi Wu

Outlook and next steps for the pre-TDR phase
Speaker: Jacqueline Keintzel

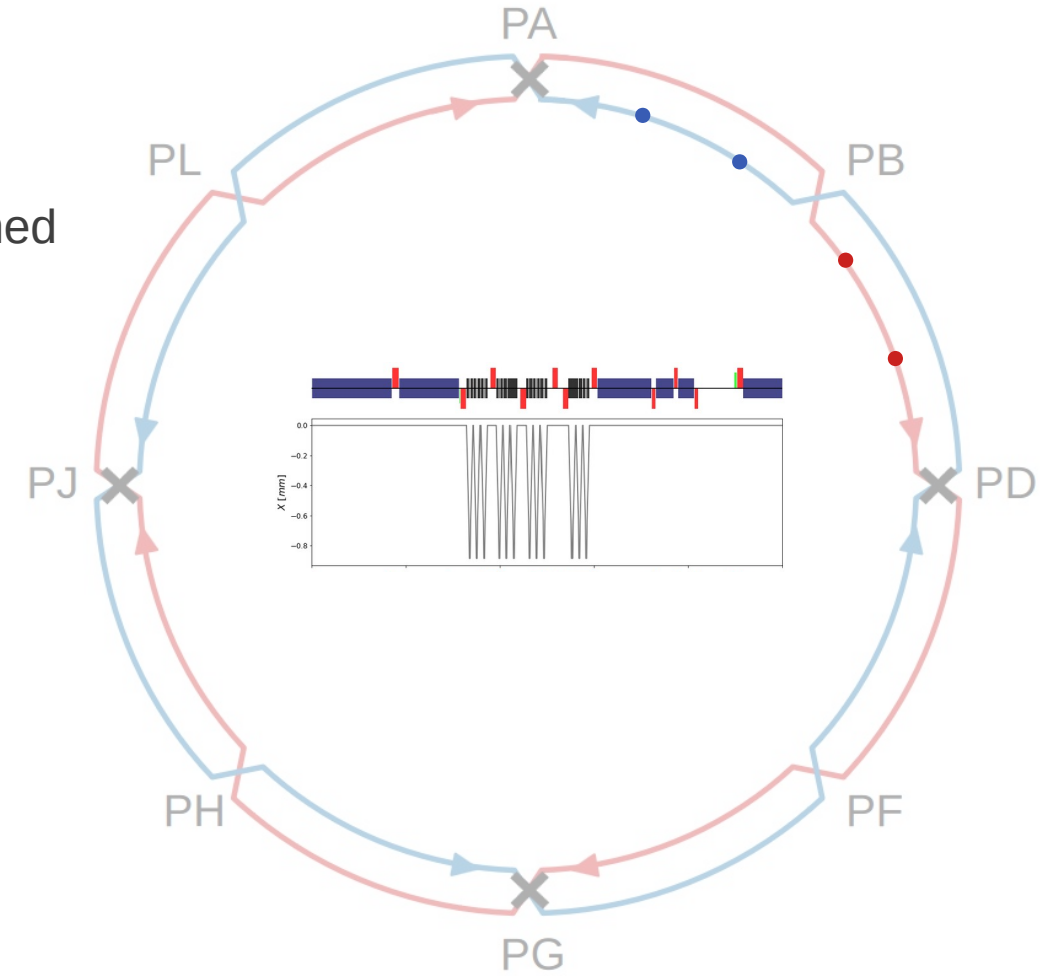
Baseline Scenario

- Inject a few (~160) non-colliding pilot bunches (~10^{10} ppb)



Baseline Scenario

- Inject a few (~160) non-colliding pilot bunches (~10^{10} ppb)
- Switch on wigglers until ~5-10 % **vertical polarization** reached



Baseline Scenario

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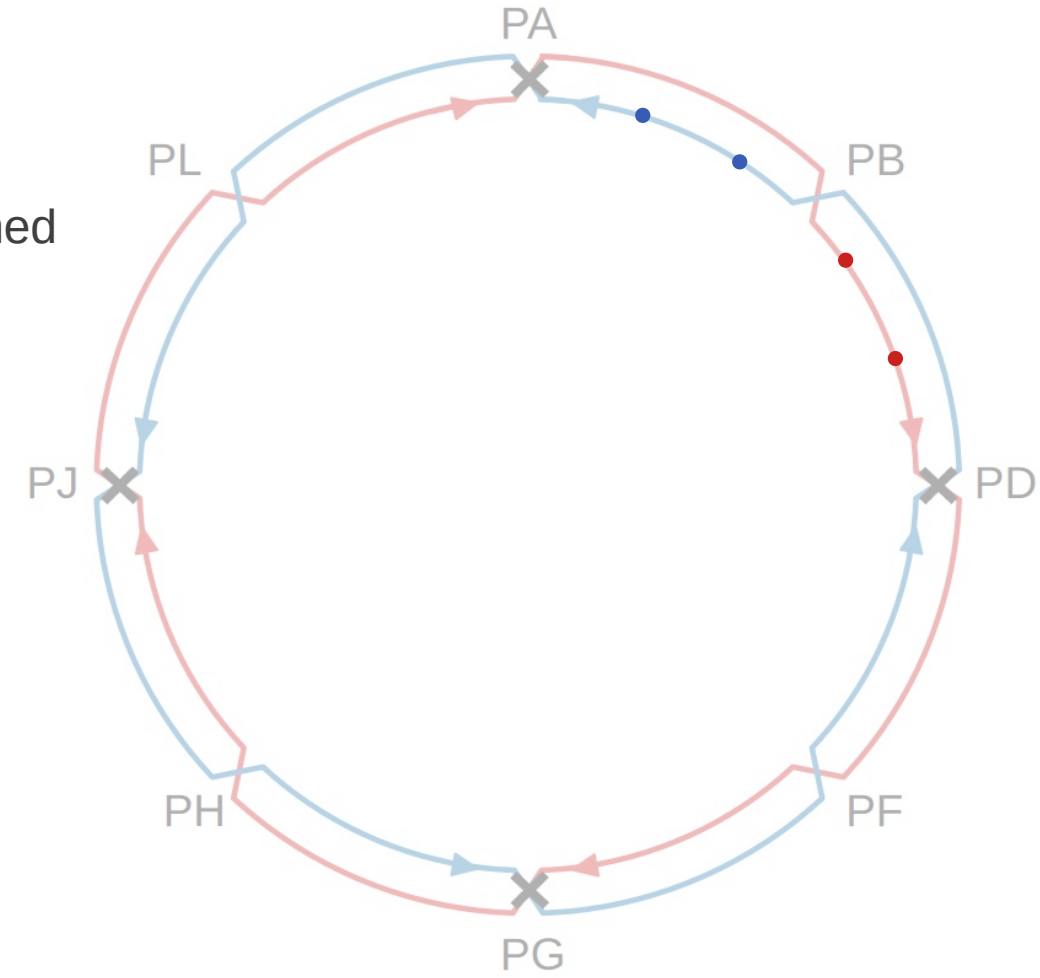
- Switch on wigglers until ~5-10 % **vertical polarization** reached
- Switch wigglers off



Baseline Scenario

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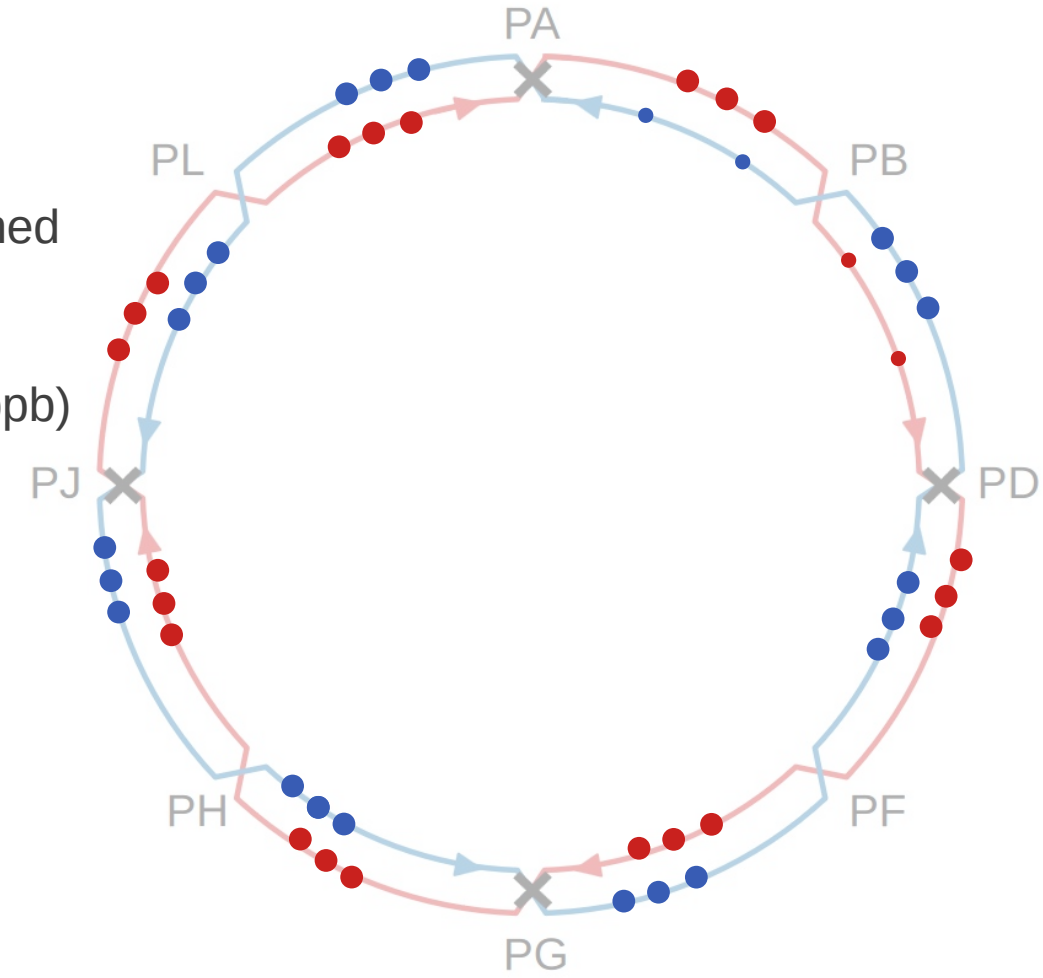

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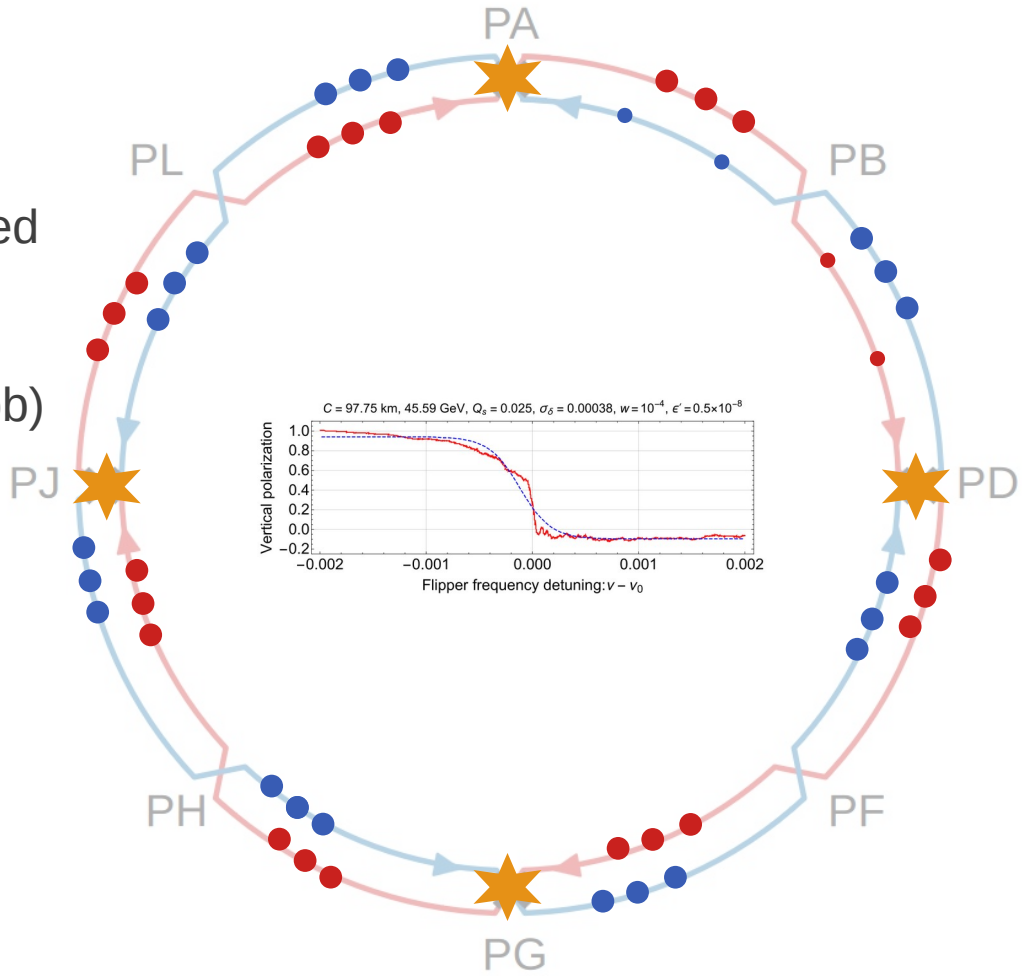
- Measure beam energy with pilots while collisions take place



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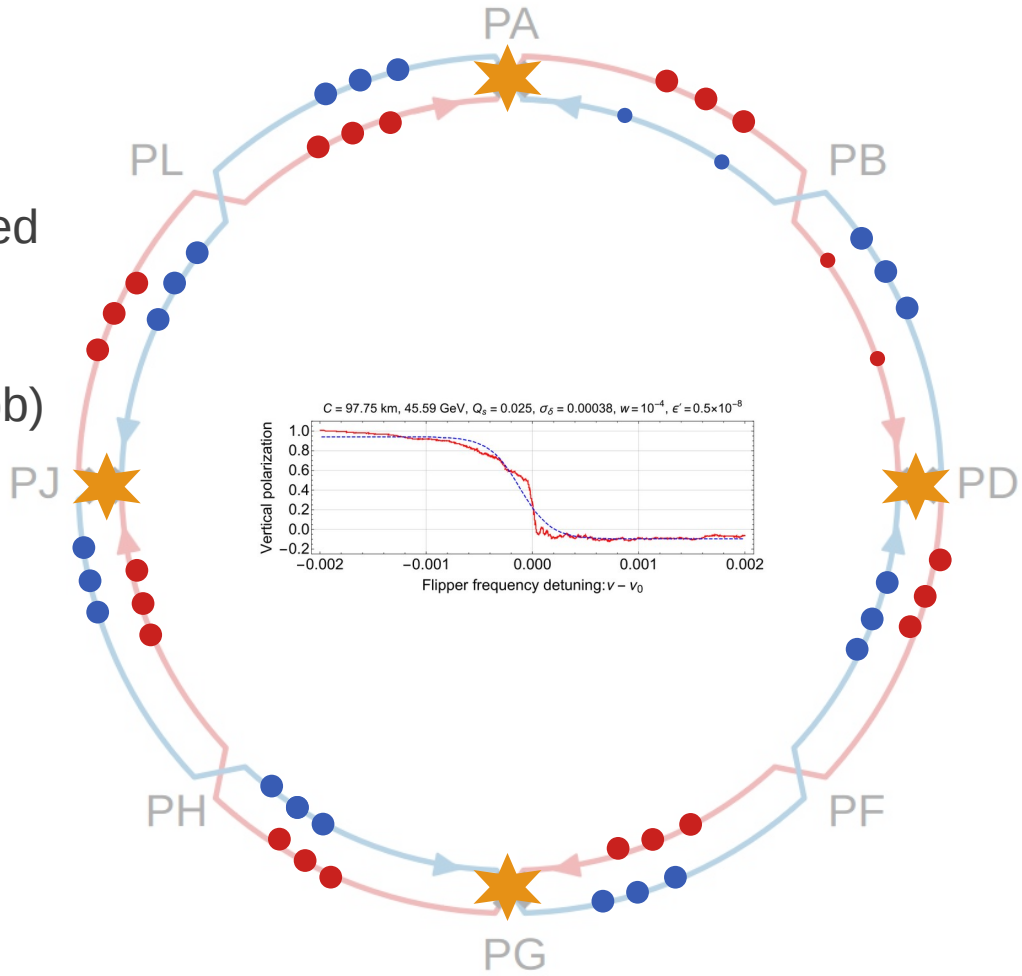
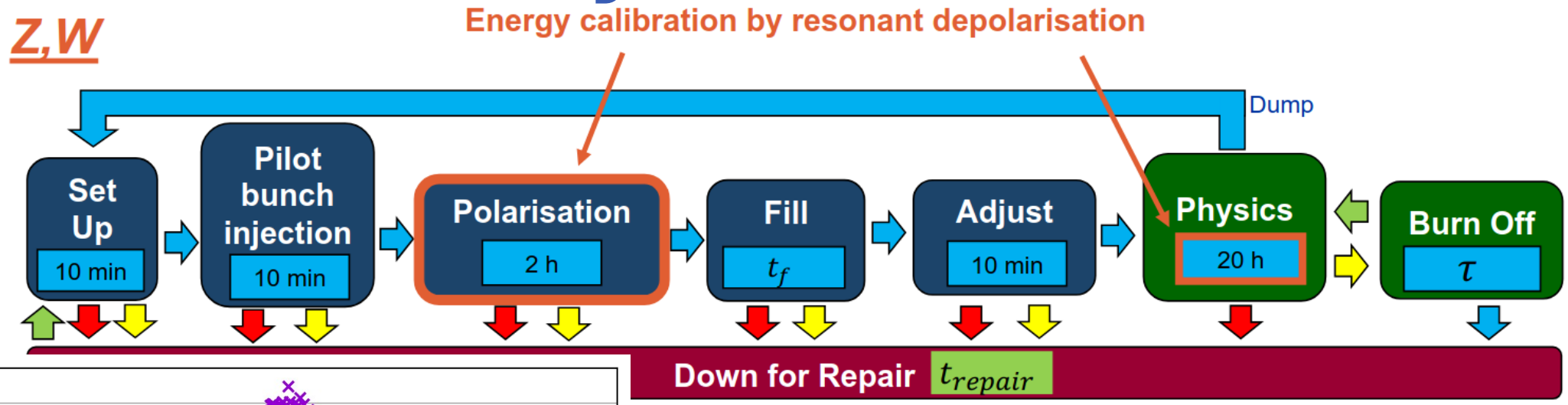
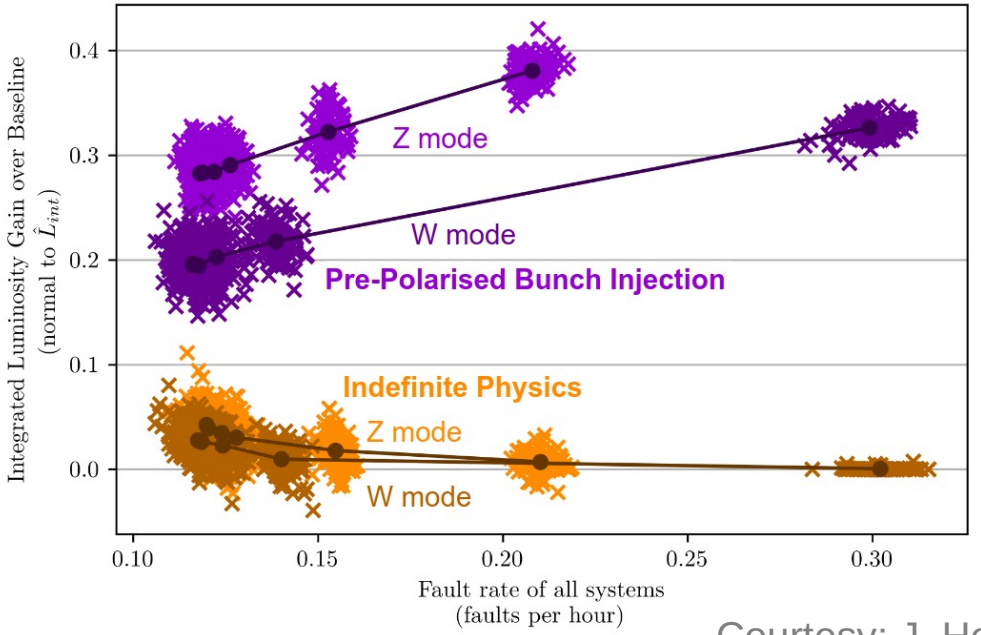
- Measure beam energy with pilots while collisions take place
- Caveats:
  - Machine availability due to time for polarization build-up
  - Optimized design with sufficient equilibrium polarization



Operational Cycle



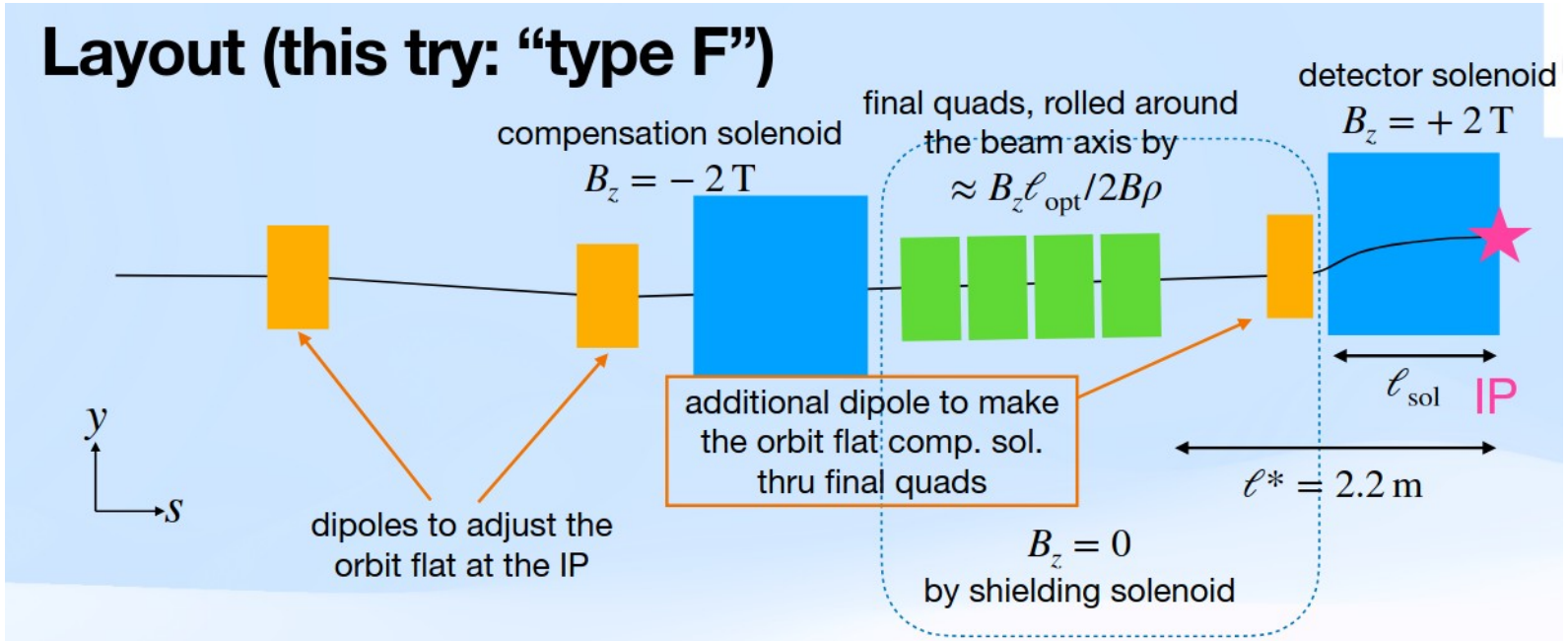


- Increased integrated luminosity with increasing failure rate if polarized bunches are already injected
- Injected polarized beams could lead to huge improvement in machine availability

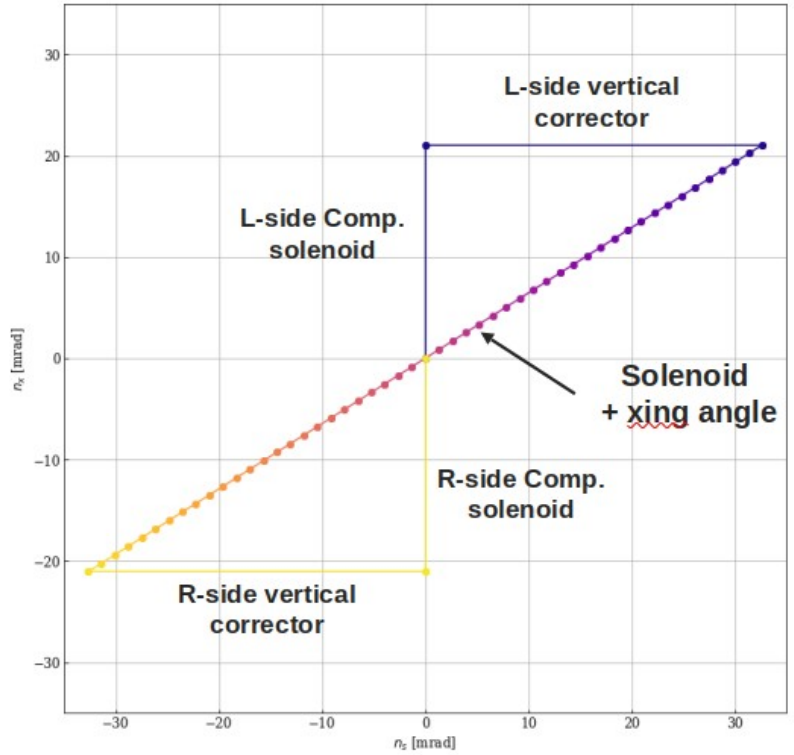
Courtesy: J. Heron

Polarization Build-Up

- New non-local solenoid compensation scheme after final focus quadrupoles
- Equilibrium polarization of ~1% in ideal lattice from ~10 µrad spin deviation over the interaction region
- Could probably be improved with dedicated spin bumps as in LEP



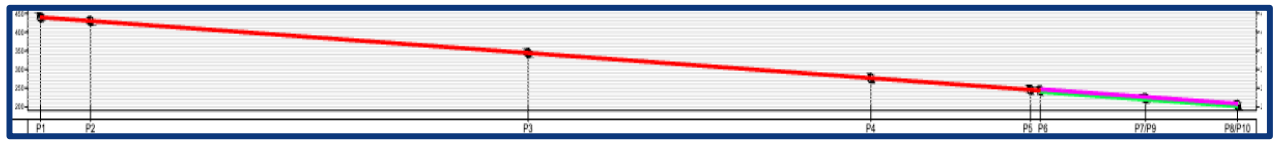
Courtesy: K. Oide

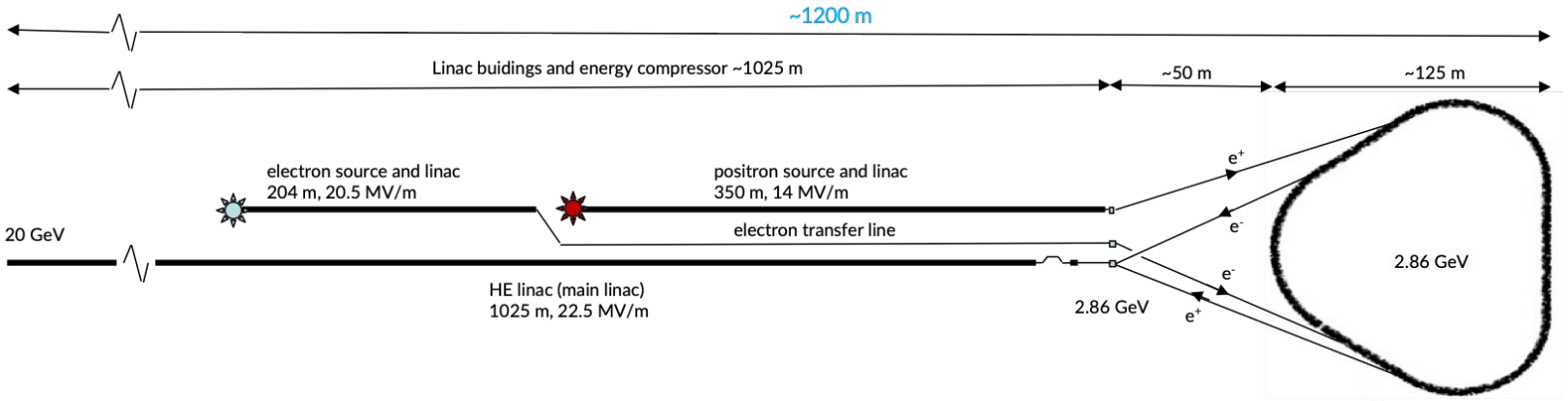


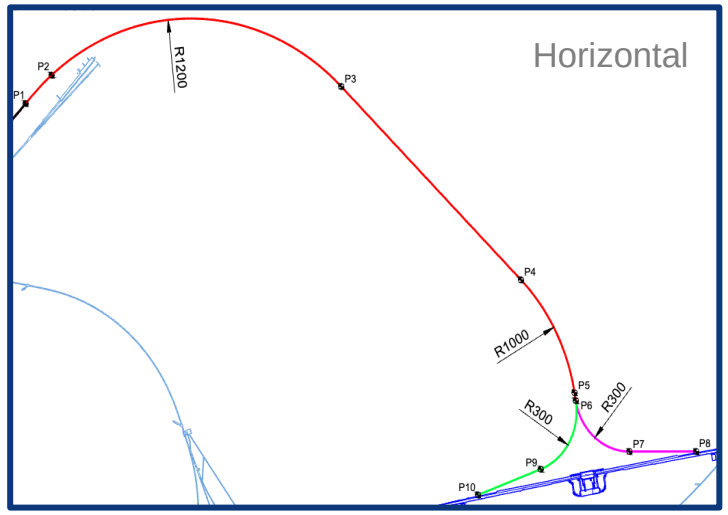
Courtesy: J. Wenninger

Polarized Beam Injection

- Possibly modifications of injectors and to enhance polarization transport
- Could require multipole polarimeter systems over whole complex to ensure polarization transport







- *Which is the preferred technique and the costs to achieve polarized pilot bunches for energy calibration?*
- *Which are the required modifications in the complex?*

Thoughts on injecting polarized beams
Speaker: Jorg Wenninger

Spin Tune

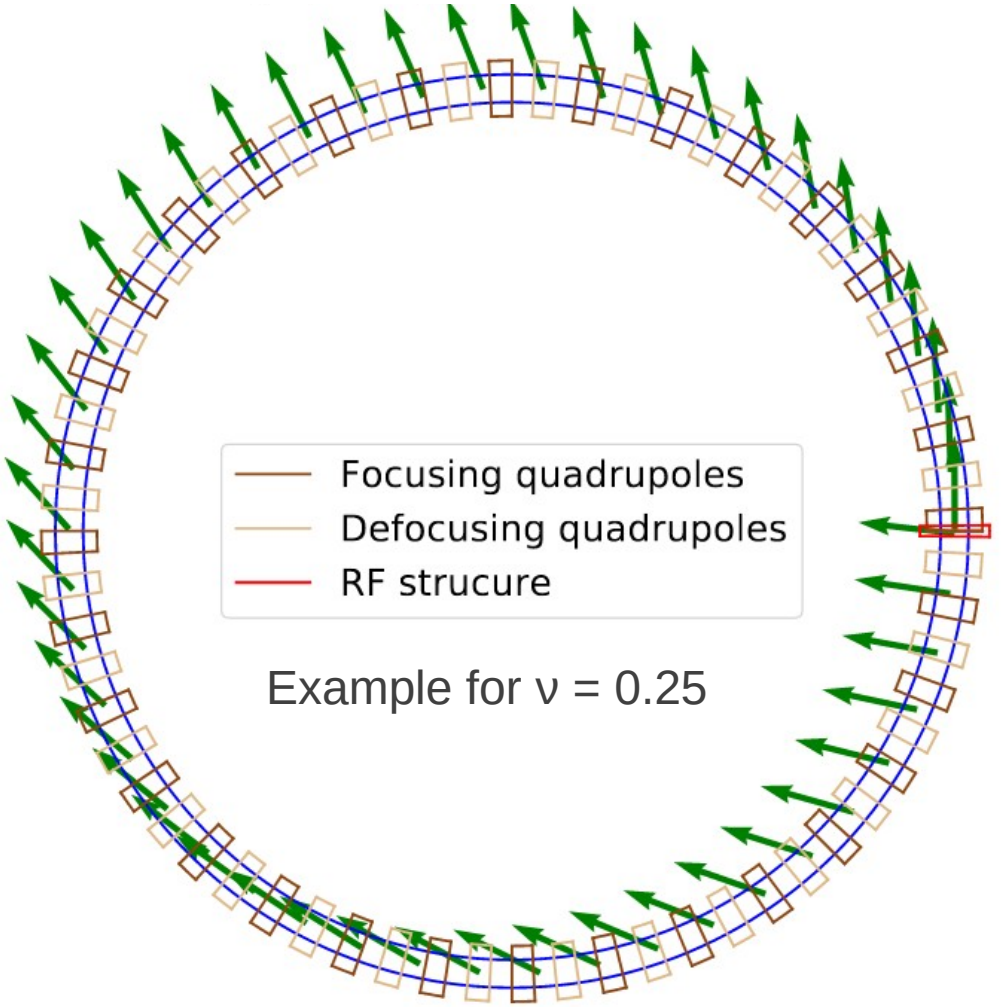
Polarization → Depolarization

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

- In an error-free flat machine without solenoids
- Purely vertical spin orientation

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

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

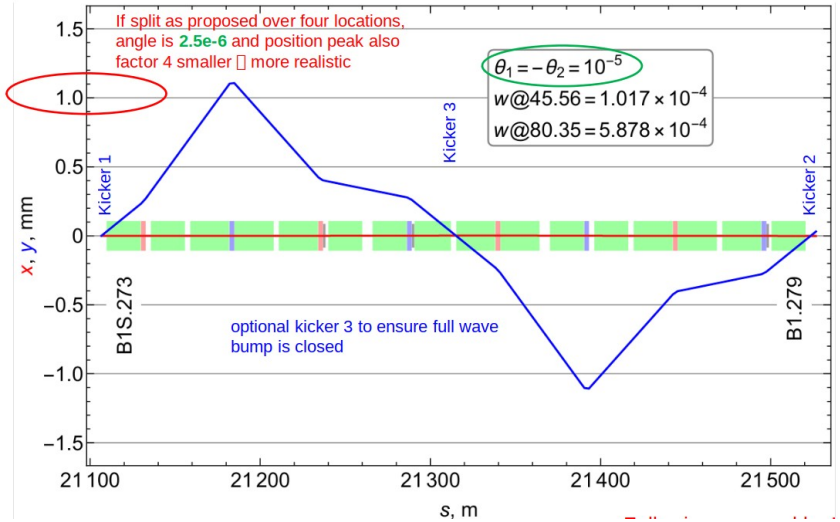


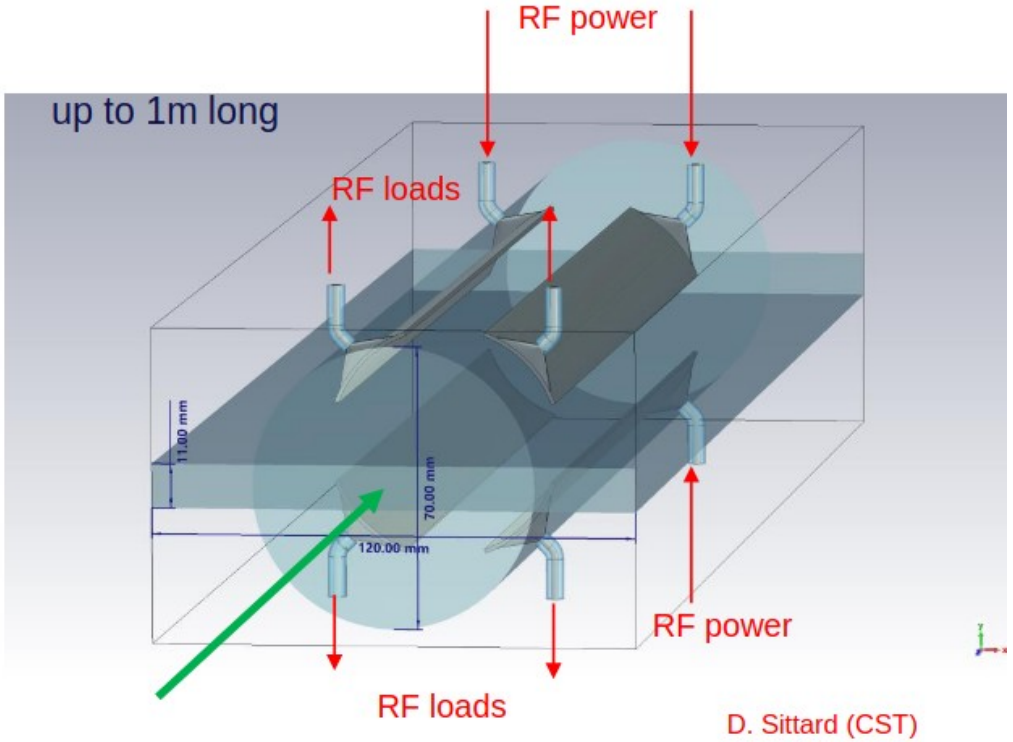
Spin tune measurement ⟺ Beam energy determination

Courtesy: V. Caudan

RF-Kicker Design

- Space for ~160 pilot bunches per beam with 100 ns bunch separation
- Currently not combined with feedback system
- Distribute power over multiple kickers over lattice
- Kicker 3 could potentially be weaker



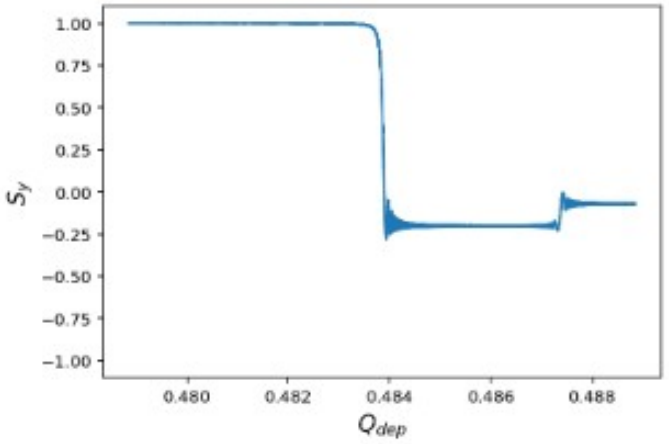


- *What are the specifications for colliding bunches?*

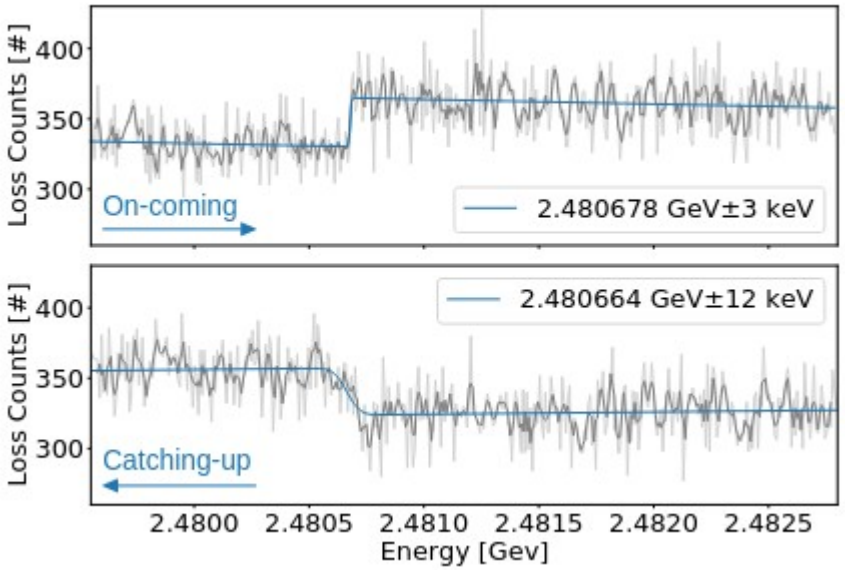
Considerations for the design of the FCCee depolarizer kicker system Speaker: Wolfgang Höfle

Parameter Scan

- Best parameters for resonant depolarization technique to be determined
  - Simulations with increasing complexity to fully understand interplay of aspects
  - Beam tests at existing machines to benchmark results (e.g. SLS, KARA, ...)

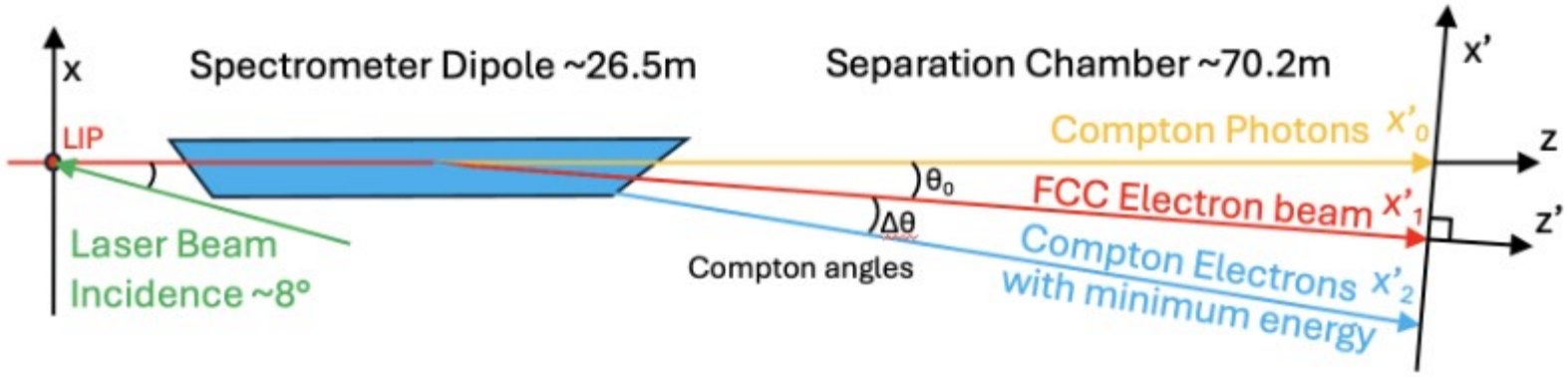


Courtesy: C. Kiel



- *What is the best scan velocity, step-size etc.?*
- *What can we learn from machines using resonant depolarization for energy measurements?*

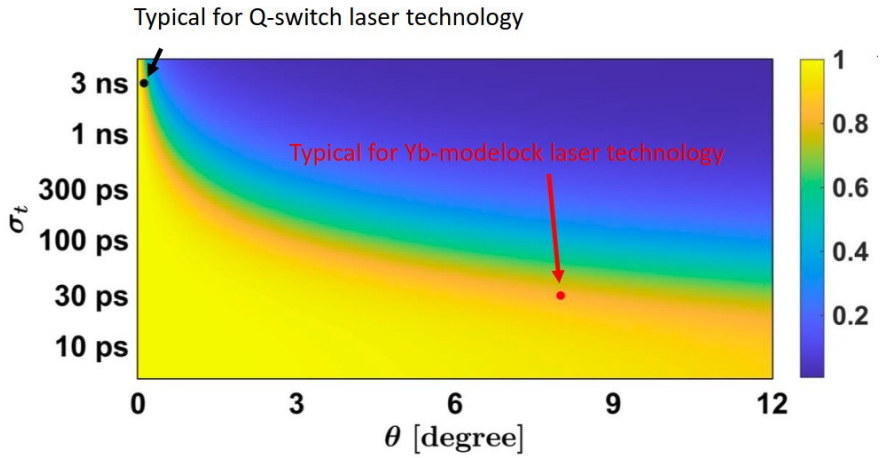
Polarimeter I



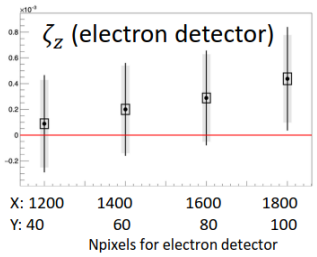
- Laser currently not accessible 24/7 → choice for 2 polarimeters per beam for redundancy
- Laser circular polarization must be controlled to 10^{-3} for pilot bunches and 10^{-4} for colliding ones
- Temporal jitter and systematic timing error must be controlled to the time of the laser pulse duration

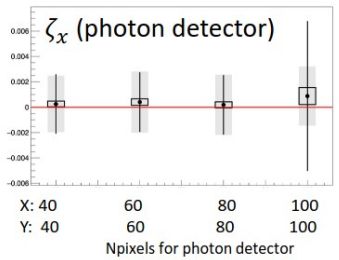
- *Prove of principle for fully remote control of laser control, tuning and laser polarization preservation*
- *Specifications for the spectrometer dipole*

Polarimeter II

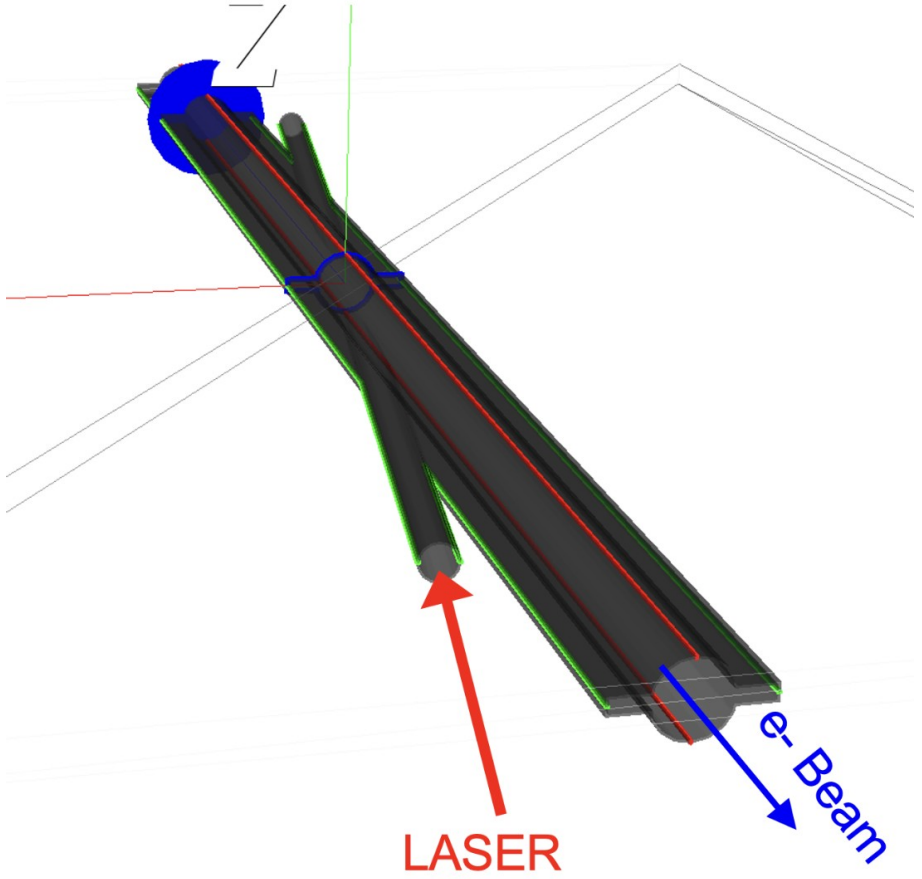


- Optimisation of laser interaction region and laser choise
- Many advances on fitting procedures and sensor dimensions



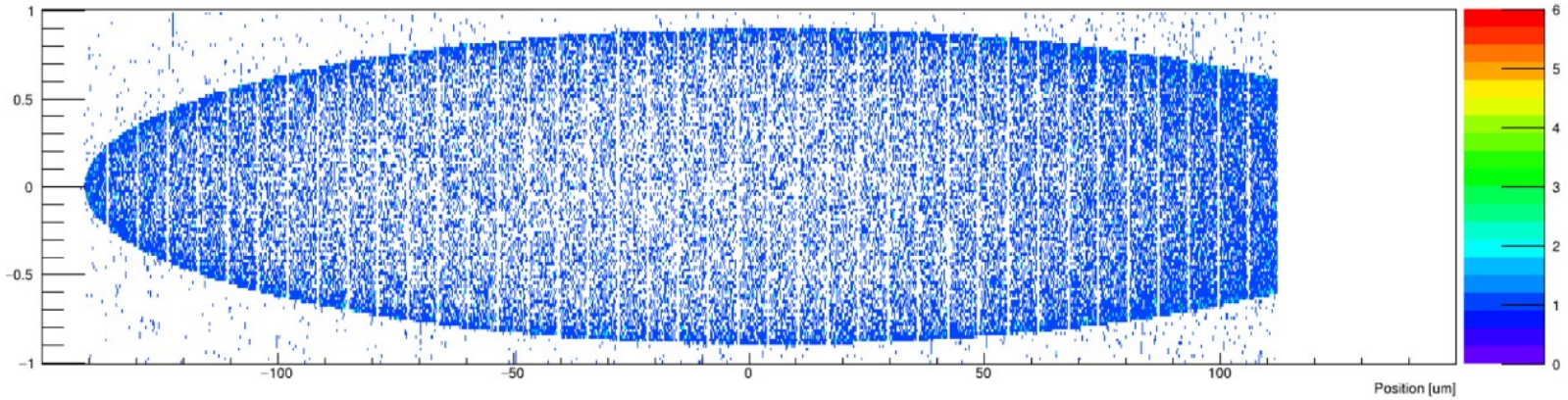


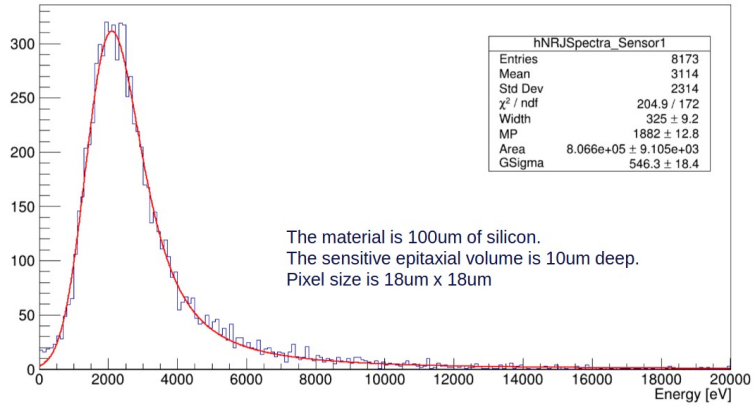
- *Aim to directly extract beam energy from fitting for redundancy*



FCC Polarimeter II
Speaker: Aurélien Martens

Polarimeter III





- Simulation and optimisation of Si-sensors for Compton electron detection
- Evaluation of synchrotron radiation background on sensors

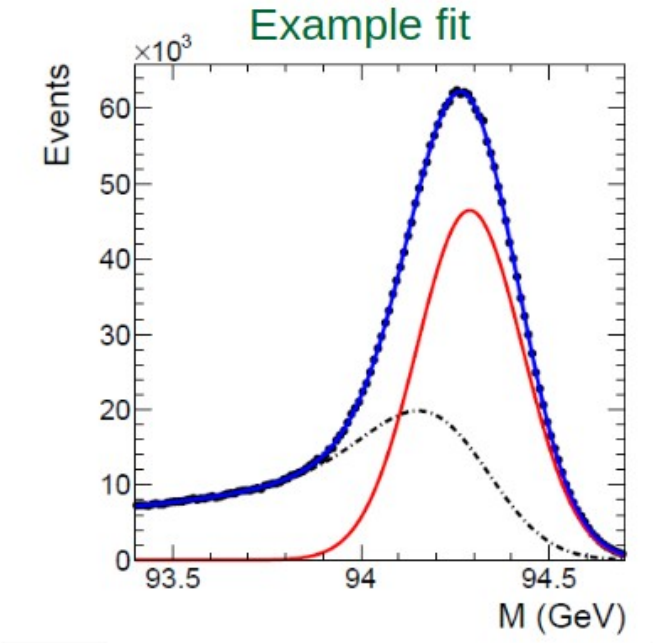
- *Technical design of the full polarimeter system which achieves an availability of 95 %*
- *Towards a complete front-to-end simulation*

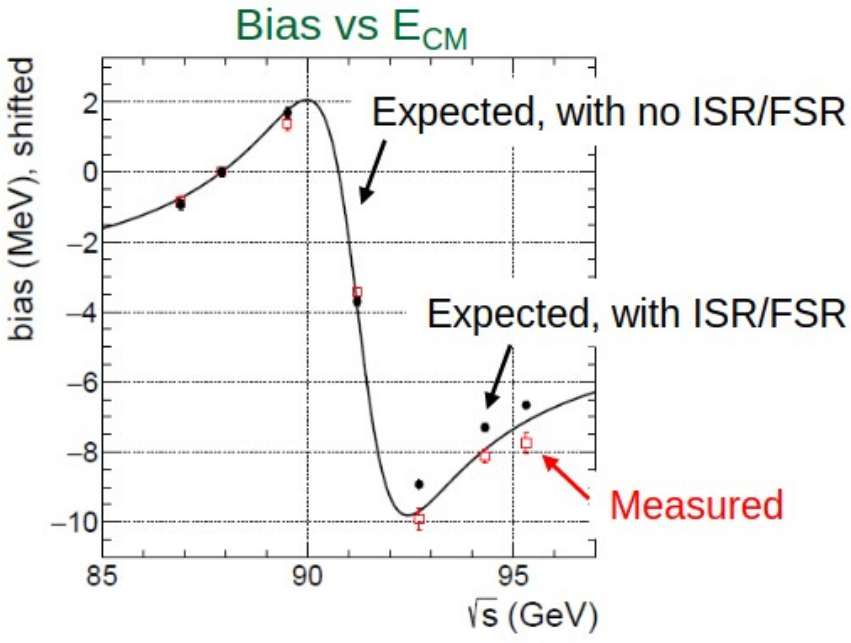
FCC Polarimeter I
Speaker: Robert Kieffer

Detector Input

Di-Fermion Events

- Physics events, in particular di-muons, can be harnessed to provide information on many quantities
- Energy spread determination remains robust even in presence of ISR/FSR uncertainties





- *What are the effects from the detectors?*
- *How can we fully exploit that knowledge?*

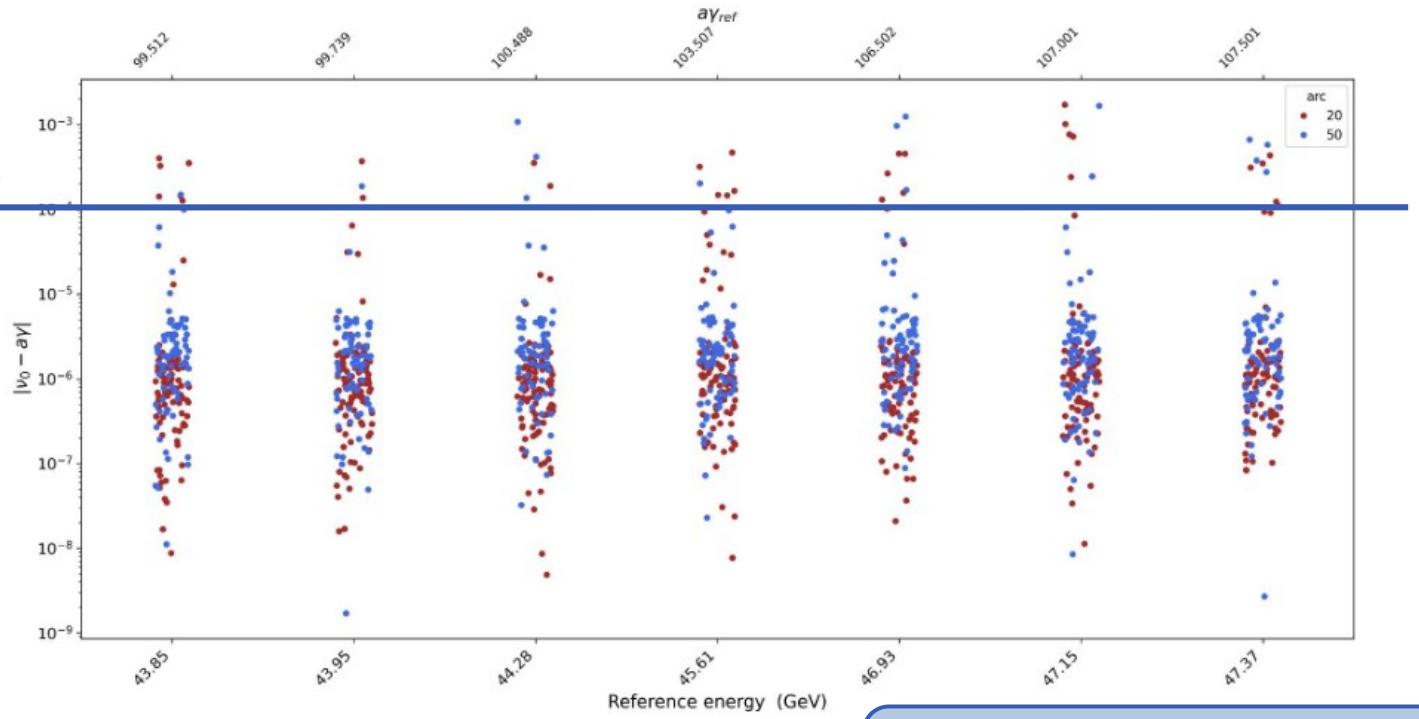
Point-to-point calibration with dimuons
Speaker: Emmanuel Perez

ECM

Spin Tune Shifts

- Average beam energy obtained from RDP scans for pilot bunches in both beams every ~10 mins
- Measured beam energy deviates from a*γ depending on error seeds and beam energy

Total limit on systematic errors



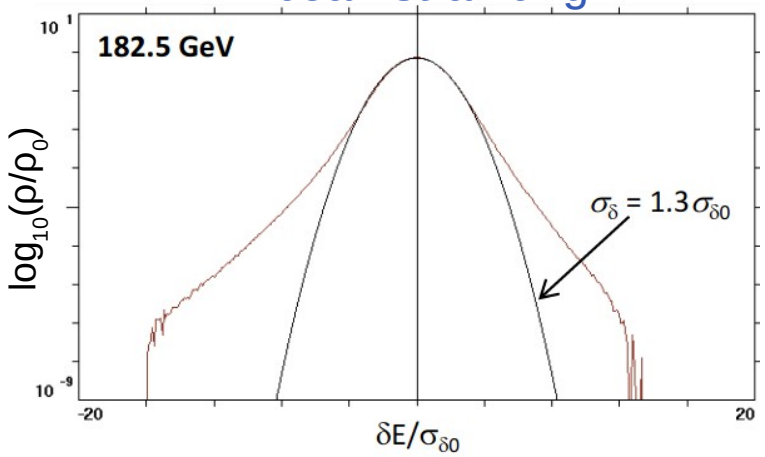
- *To which accuracy corresponds the measured frequency to the beam energy?*

Spin tune shifts
Speaker: Yi Wu

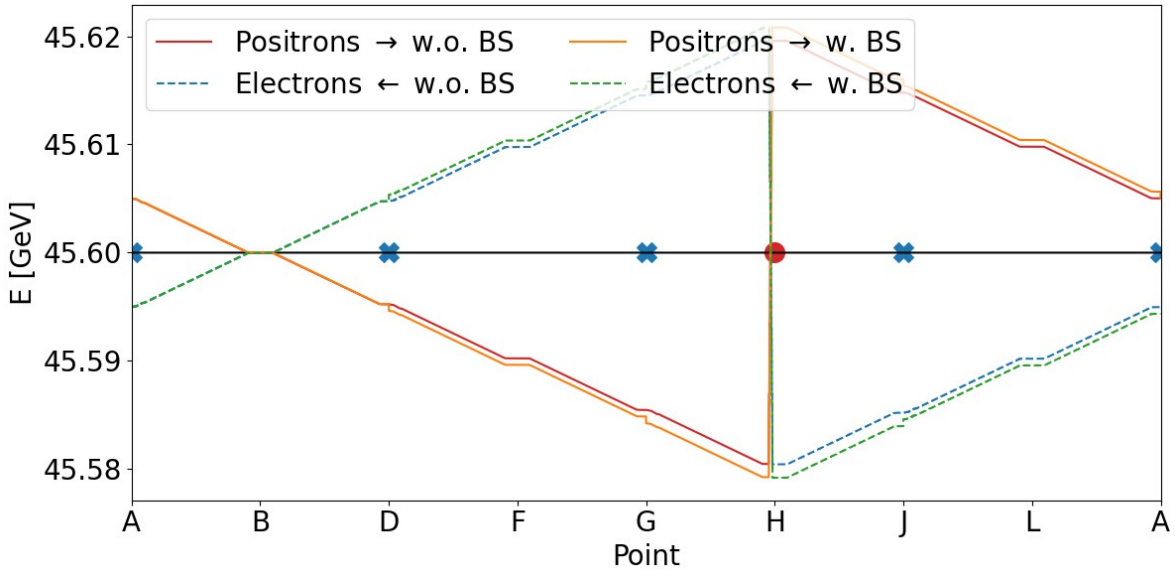
From E_{beam} to E_{CM}

- Average beam energy obtained from RDP scans for pilot bunches in both beams every ~10 mins
- Measured beam energy deviates from a*γ depending on error seeds and beam energy
- Systematic offset between pilot and colliding bunches from bunch charge, orbit, beam-beam

beamstrahlung



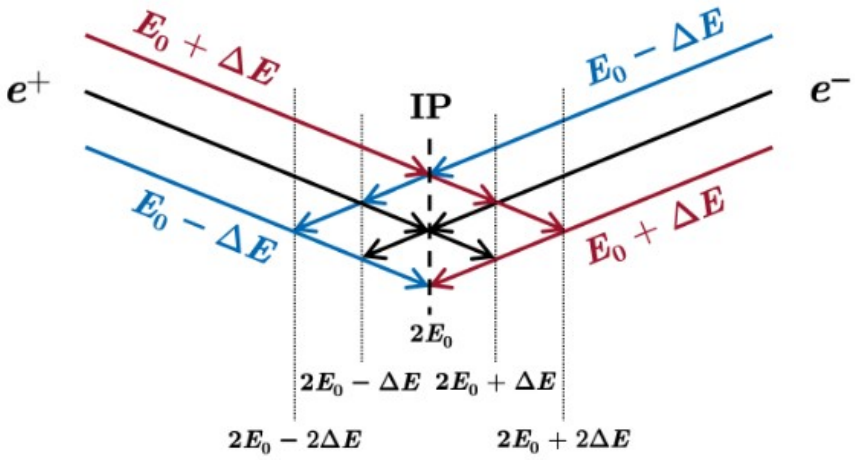
Courtesy: D. Shatilov

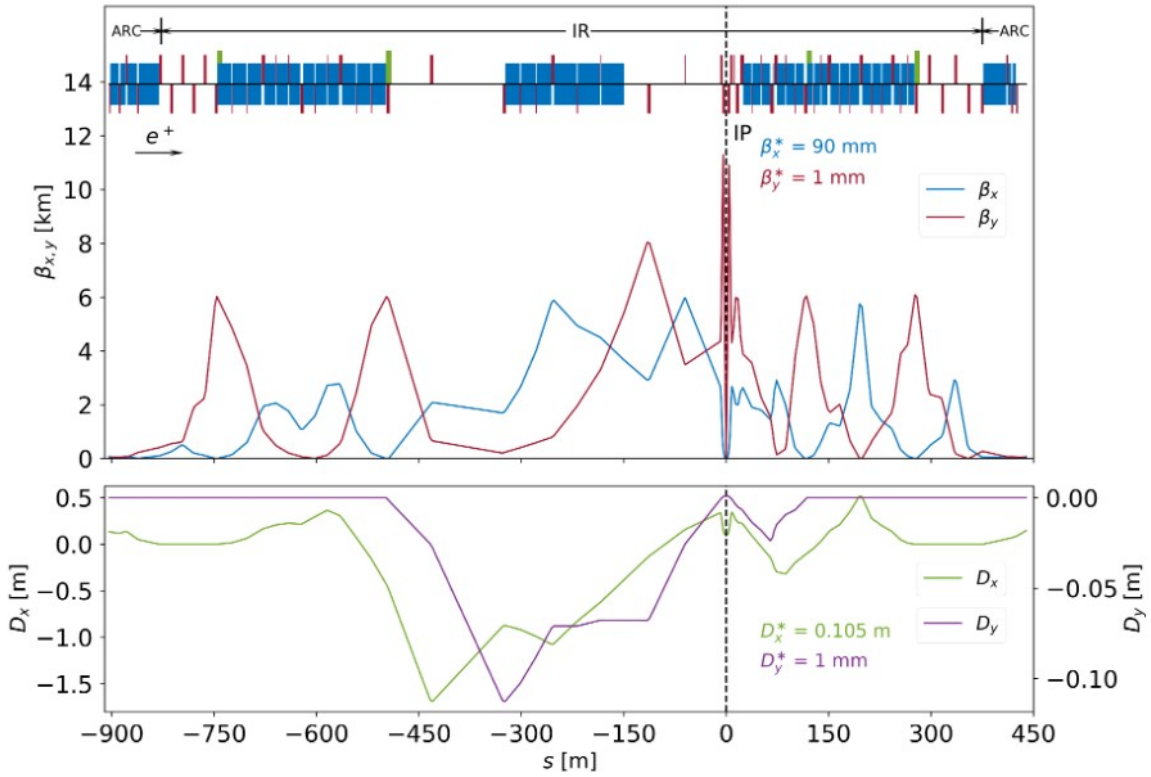


- *Generate dynamic model to relate measurements from RDP and detectors to E_{cm} and boosts at IPs*

Monochromatization

- Lattice and optics designed to reduce E_{cm} spread for collisions at 125 GeV
- New chicane inserted close to the IP

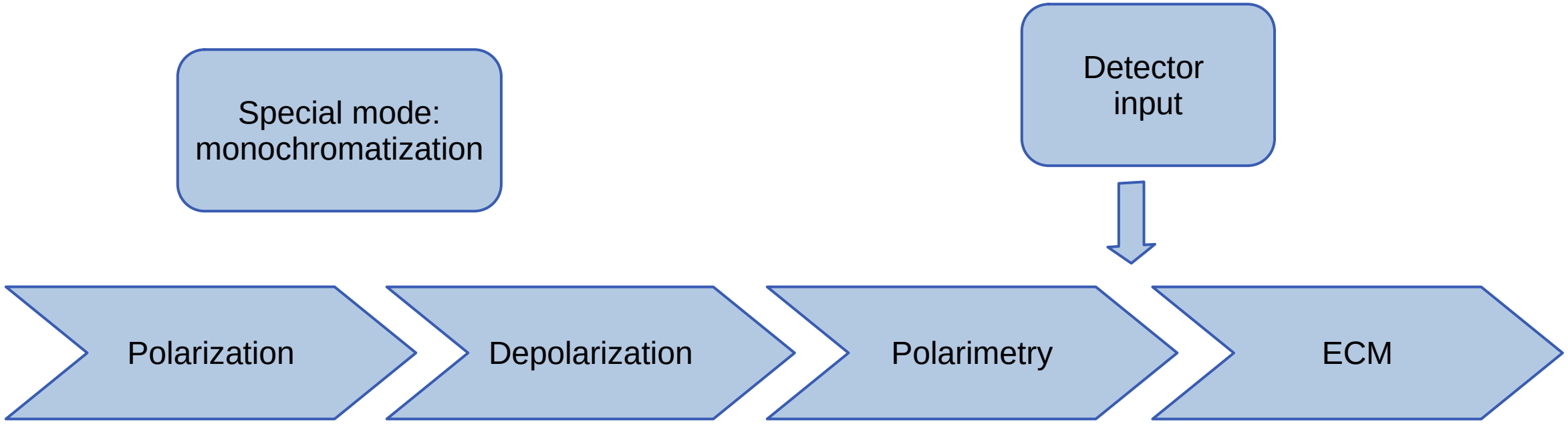




- *Develop measurement and operation of monochromatization*
- *Can monochromatization be combined with baseline lattice?*

Monochromatisation IP optics simulatons for the eeH run studies; Speaker: Angeles Faus-Golfe

Summary



Impressive progress on all EPOL aspects

Outlook and Open Questions

- Define technique to achieve polarized pilot bunches
  - Self-polarization or polarized bunch injection
- Define parameters for resonant depolarization scans
  - Scan velocity, step size, strengths, etc.
- Show optics compatibility of orbit and spin bumps from RF-kicker
  - Dynamic aperture, etc.

Outlook and Open Questions

- Demonstrate remotely controlled polarimeter-laser system with 95% availability
  - Laser control and tuning, backgrounds, etc
- Develop dynamic model to track E_{cm} and exploit detector input
  - Earth tides, results from RDP scans, detector inputs, etc.
- Investigate monochromatization scheme
  - Integration, operation, possible longitudinal polarization

Thank you!

Jacqueline Keintzel and Guy Wilkinson

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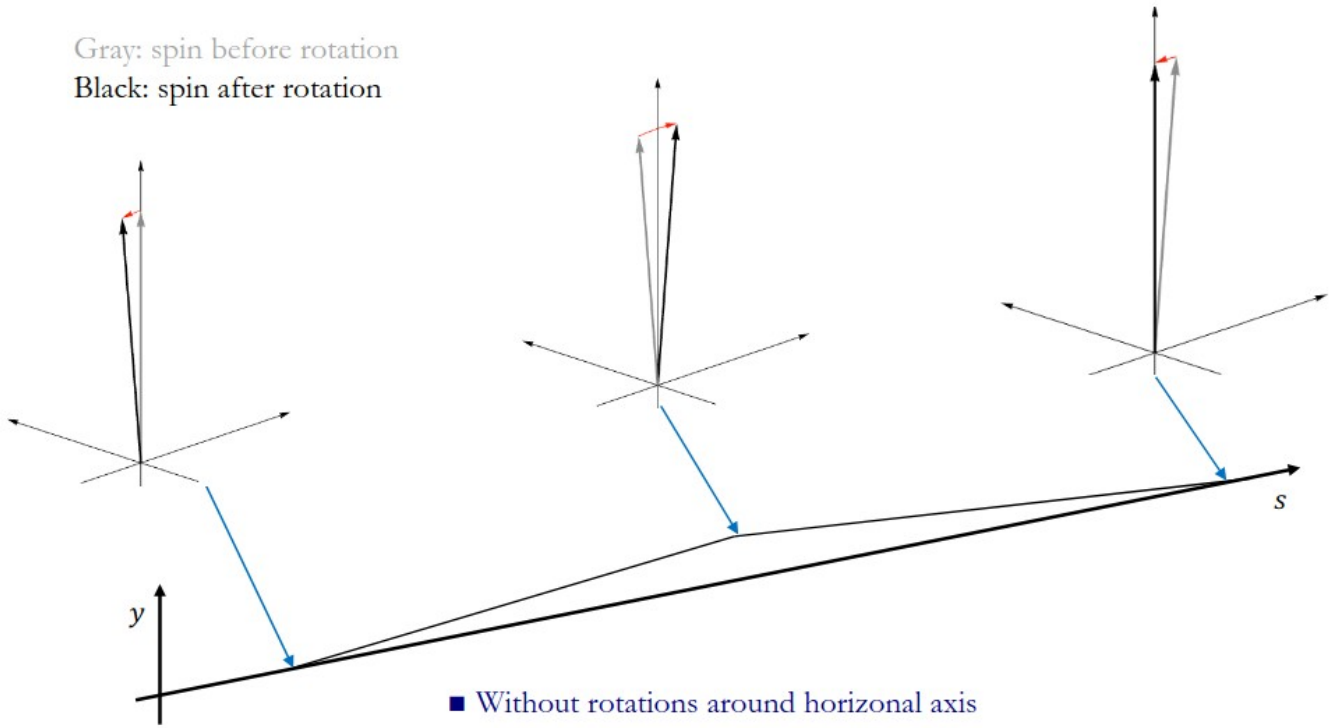
RF-Kicker Location

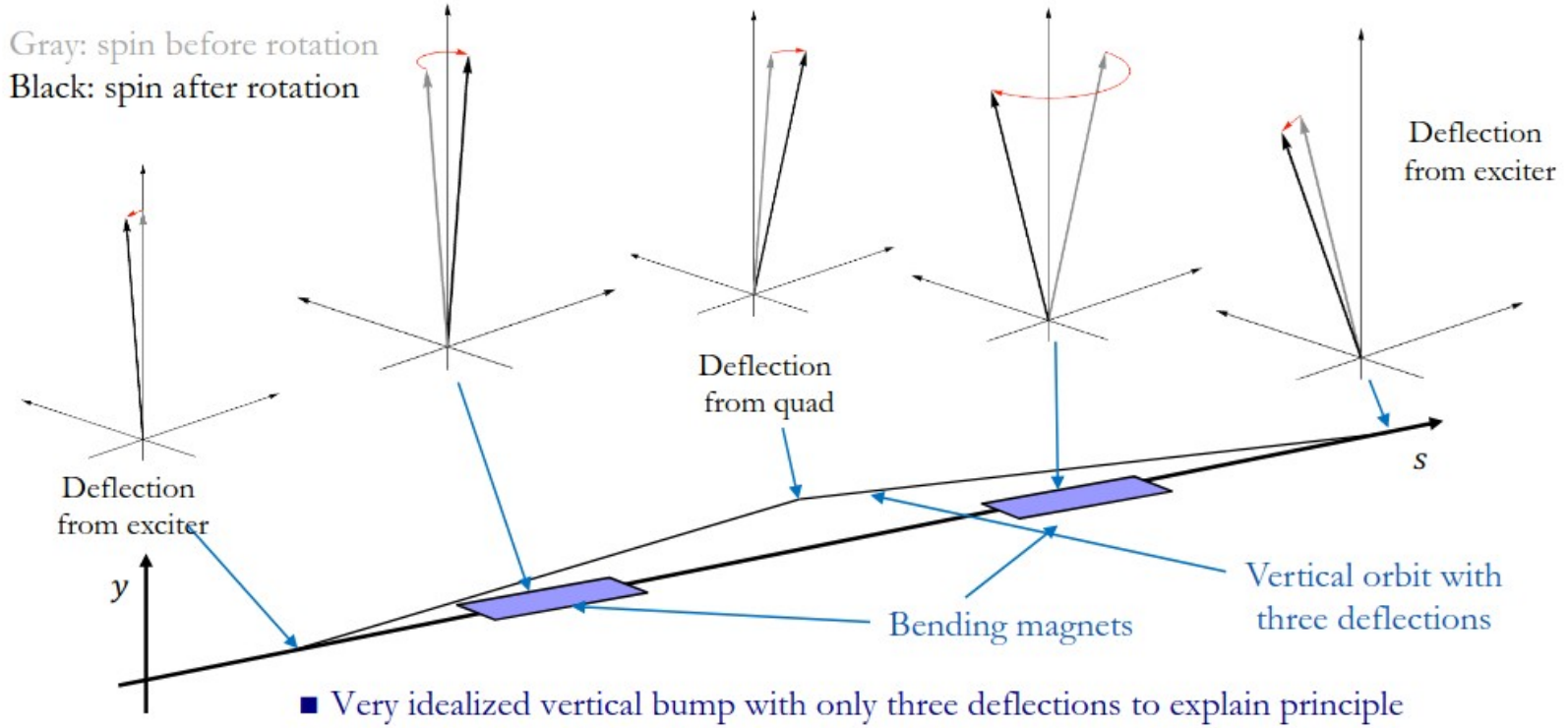
- Goal: achieve spin rotation with local and non-propagating closed-orbit bump
  - Requires n x 180° phase advance between 2 RF-kickers for closed orbit bump



Courtesy: C. Carli

RF-Kicker Location

- Goal: achieve spin rotation with local and non-propagating closed-orbit bump
  - Requires n x 180° phase advance between 2 RF-kickers for closed orbit bump
  - Requires dipoles in-between to have a non-zero spin deflection → installed in regular arc structure



Courtesy: C. Carli