(Compton) Polarimetry at ILC

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With major help from Jenny List (DESY) and material from her colleagues

Polarimetry at ILC

LCC Phys WG arXiv:1801.02840, List @ALCW 2015, R. Karl PhD thesis (10.3204/PUBDB-2019-03013)

Mostly interest in knowledge of longitudinal polarization at IP

- Ultimately can be extracted from the collected data at IP from known helicity dependence of SM cross-sections
- Can exploit Total/Differential/Angular cross-sections

Still independent measurement of beams polarization is welcome → Compton polarimeters

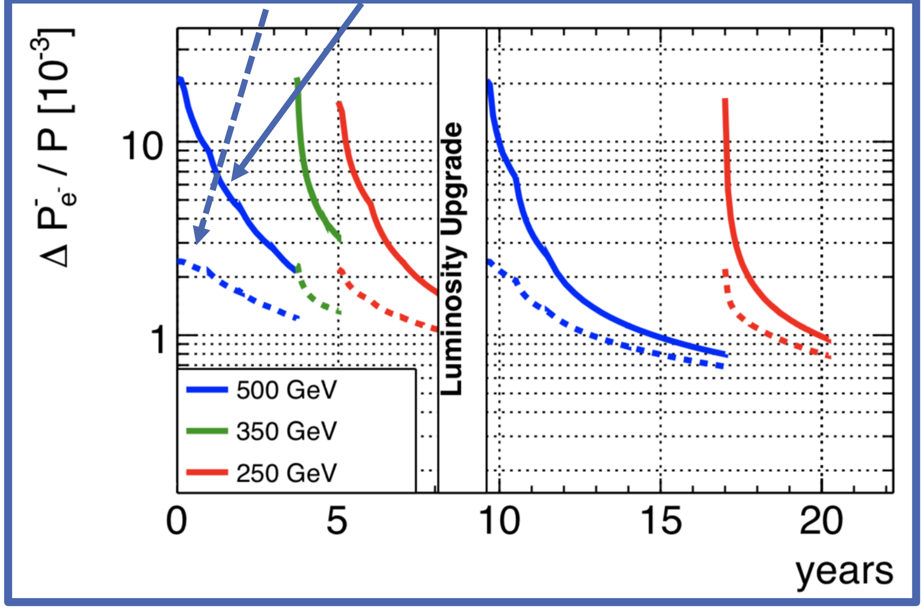
- Improves determination of longitudinal polarization for physics
- Major operational/quality aspects
  - Spot anything bad immediately
  - Polarisation reversal accuracy
  - Machine optimization

Not obvious !

- Intrinsic systematics
- Beam transport
- Beam-beam effects at IP
- Lumi-weighting…

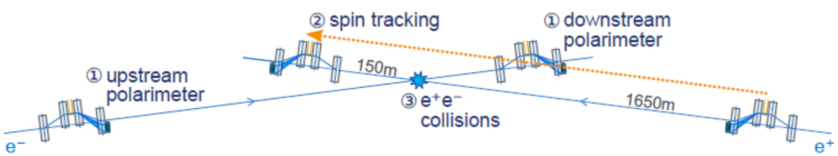
$$\langle P_z \rangle_{IP} = \frac{\int P_z(t)\mathcal{L}(t)dt}{\int \mathcal{L}(t)dt}$$

Beam polarisation determination with total x-section w/ and w/o polarimeter constraint



Current strategy

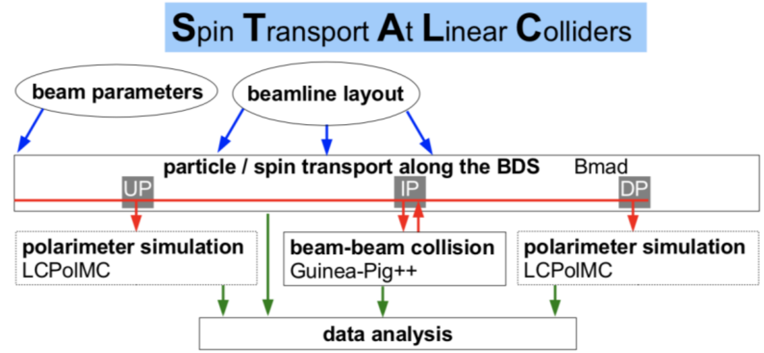
Goal for ILC polarimetry: per mille level precision by combining



① Compton polarimeter measurements upstream and downstream of the e^+e^- interaction point

② Spin tracking to relate these measurements to the polarization at the e^+e^- interaction point

③ Long-term average determined from e^+e^- collision data as absolute scale calibration



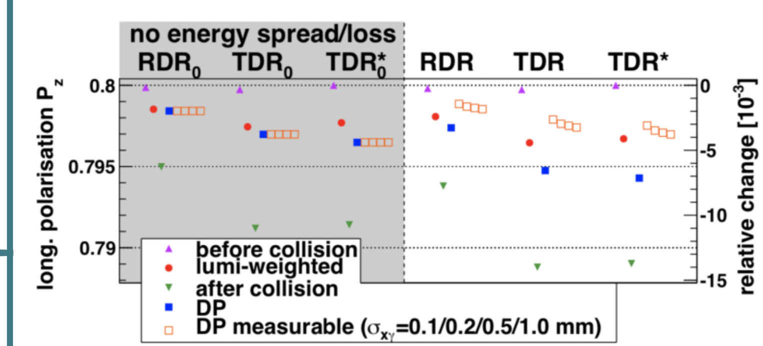
Contribution	$\delta\mathcal{P}_z/\mathcal{P}_z$ $[10^{-3}]$
Beam and polarisation alignment at polarimeters (assuming $\Delta\vartheta_{\text{bunch}} = 50\,\mu\text{rad}$, $\Delta\vartheta_{\text{pol}} = 25\,\text{mrad}$)	0.72
Random misalignments ($10\,\mu\text{m}/\mu\text{rad}$) with beam orbit correction	0.35
Variation in beam parameters (10 % in the emittances)	0.03
Longitudinal precession in detector magnets	0.01
Bunch rotation to compensate the beam crossing angle	< 0.01
Emission of synchrotron radiation	0.005
Total	0.80

Table 10: Contributions to the uncertainty of the spin transport from the upstream to the downstream polarimeter for a beam energy of 250 GeV in the absence of collisions.

Relate Up/down-stream measurements to

- Calibrate spin tracking w/o collisions at IP
  - Beam angular alignments and spin rotators alignment crucial

- Calibrate beam-beam effects w/ collisions at IP
  - collision parameters
  - Luminosity
  - Spent beam sampling



Bartels et al., JINST 7 P01019 (2012), Boogert JINST 4 P10015 (2009), List @ALCW 2015,
Beckmann et al 2014 JINST 9 P07003

TDR error budget

	$\delta\mathcal{P}/\mathcal{P}$	
source of uncertainty	SLC	ILC goals
laser polarisation	0.1%	0.1%
detector alignment	0.4%	0.15 – 0.2%
detector linearity	0.2%	0.1%
electronic noise and beam jitter	0.2%	0.05%
Total	0.5%	0.25%

Improvements related to

- Alignment precision (validated in testbeam)
- Detector non-linearity (in situ-calibration technique validated)
- DAQ hardware (validated in testbeam)
- Beam jitter (related to ILC luminosity goals)

Laser polarization at same level as SLC but still requires careful control

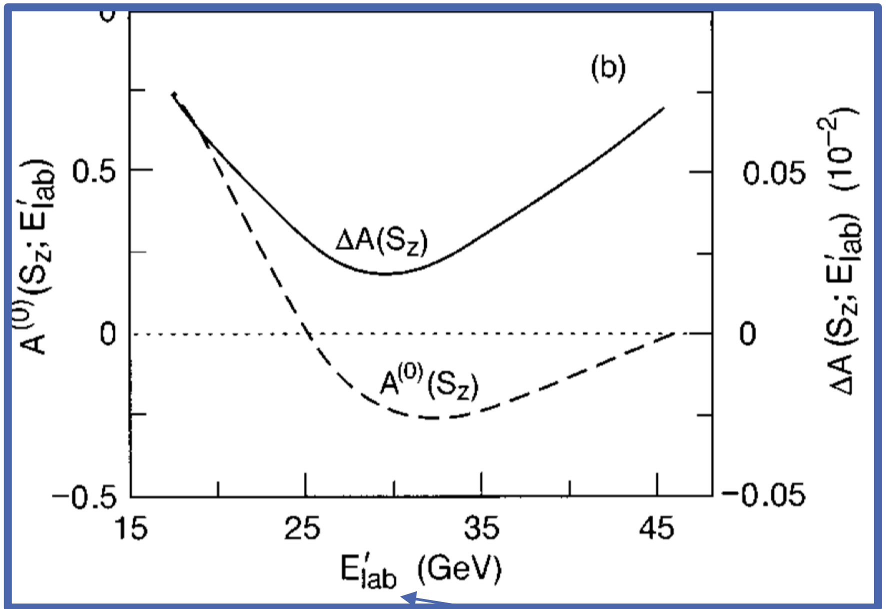
Vormvald et al., JINST 11 P01014 (2016), Bartels et al., JINST 7 P01019 (2012)

Involved processes $e\gamma \rightarrow e\gamma$, $e\gamma \rightarrow eee$, $e\gamma \rightarrow e\gamma\gamma$

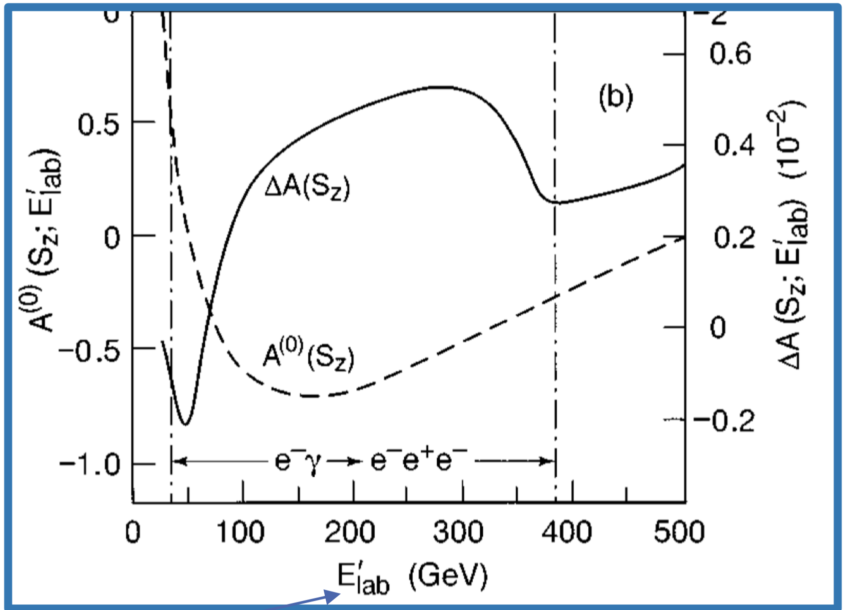
QED corrections

$$\frac{d\sigma}{dE'}(E') \cong \frac{d\sigma_0}{dE'}(1+\delta)\left[1+\mathcal{P}_z\mathcal{P}_{C,las}(A+\Delta A)\right]$$

QED corrections<0.1% @ 45 GeV



QED corrections about 0.5% @ 500 GeV



Scattered electron energy

Not included (yet) in polarimeter Monte-Carlo

TDR design of polarimeters

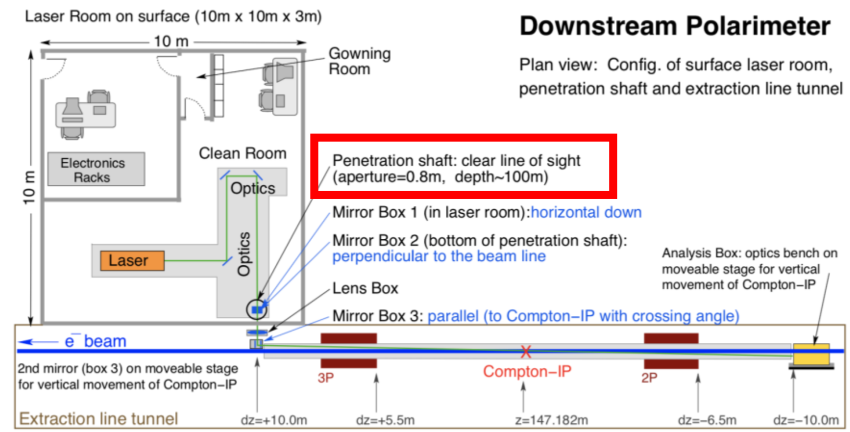
Bartels et al., JINST 7 P01019 (2012), Boogert JINST 4 P10015 (2009), List @ALCW 2015

TDR's design need to be adapted to actual location

- Radiation hardness
- Beam transport
- Beam pointing stabilization issues

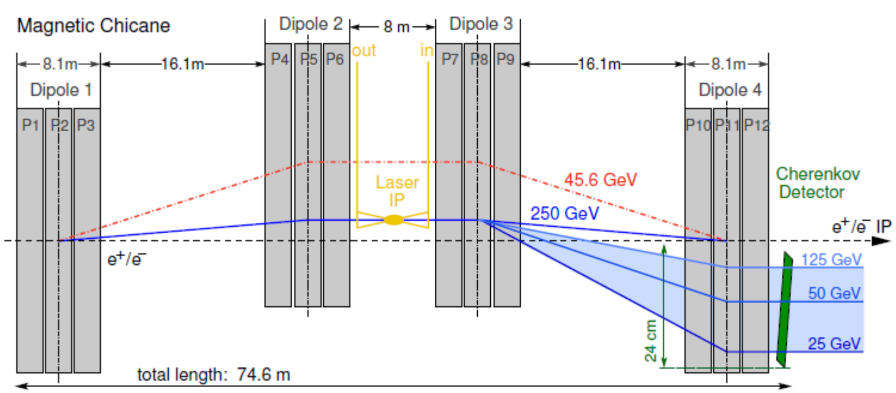
Chicanes

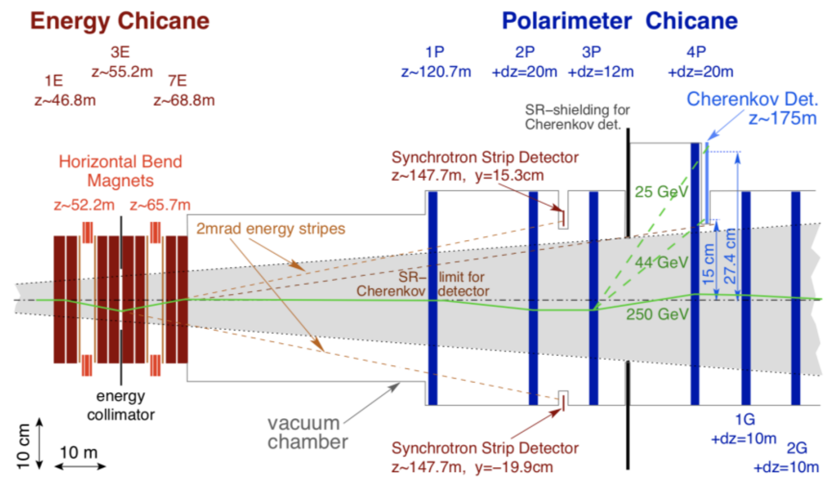
- Fixed detector acceptance
- Moving e-/laser beam IP
- upstream@1800m: 30µJ/laser pulse
- downstream@150m: 100mJ/pulse @ 5Hz



downstream

upstream





Recent proposal about lasers

Took note that laser technology has evolved

- Upstream: industrial robust and compact systems, every bunch can be measured
- Downstream: may require work on robustness ?

Possibly to insert those in service tunnels

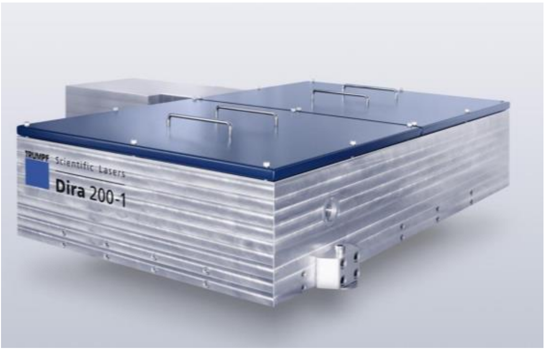
- Would require further investigations

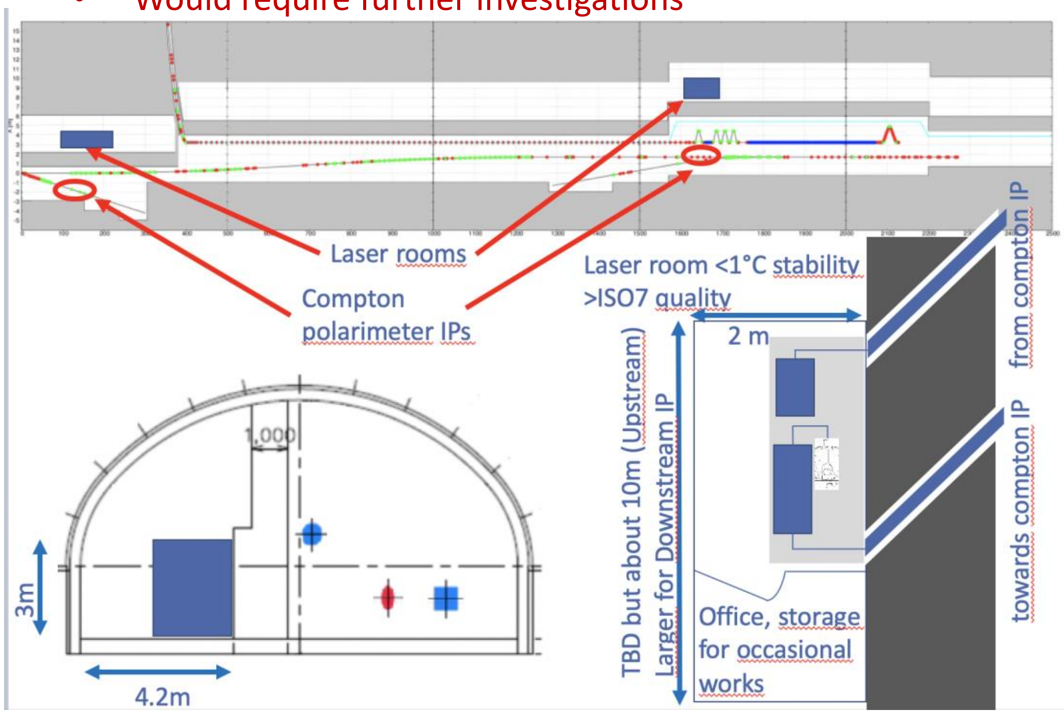
Laser specifications

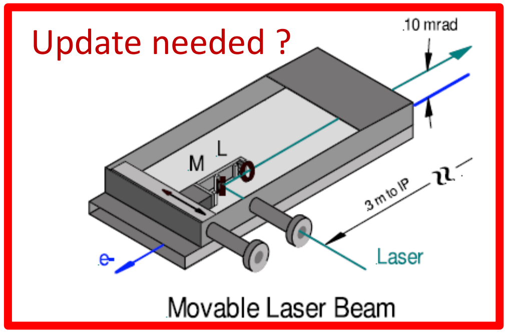
	TANGOR	TANGOR HP
Average power	> 50 W	> 100 W
Pulse energy	> 300 µJ	> 500 µJ
Pulse duration	< 500 fs to 10 ps	
Repetition rate	Single shot to 40 MHz	
Wavelength	1030 nm	
Beam quality	Beam M² < 1.3	
Spatial mode	TEM₀₀	
Dimensions	68 cm x 48 cm x 16 cm	

Applications

www.amplitude-laser.com

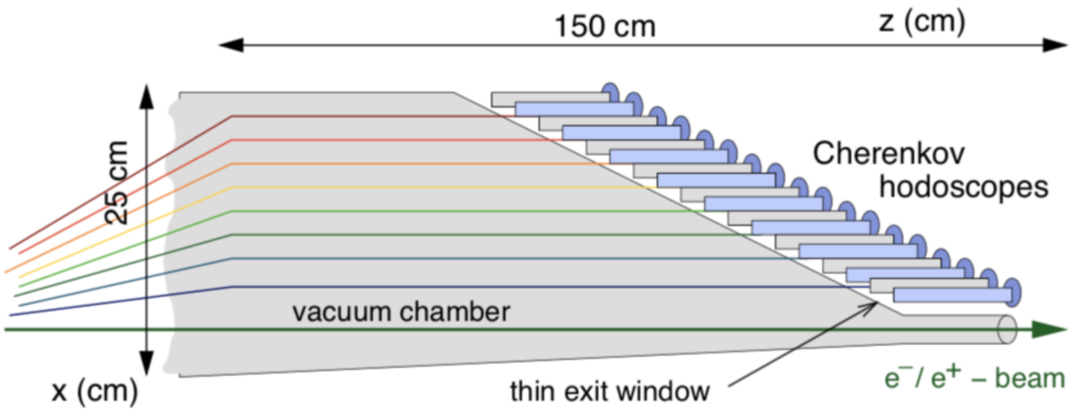


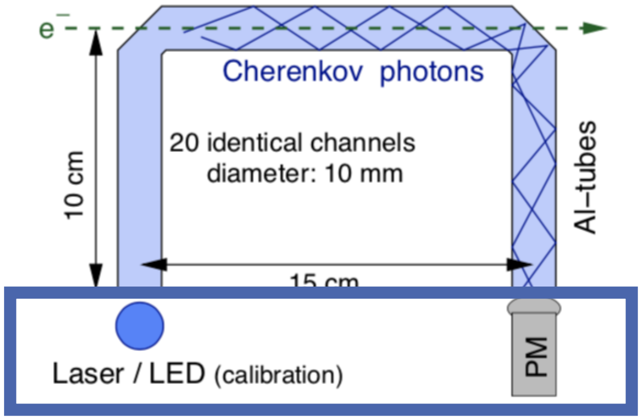


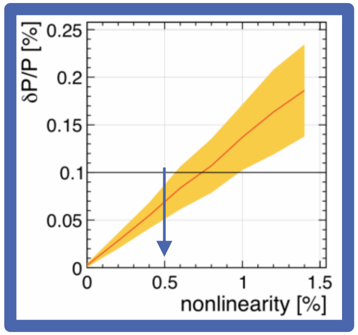


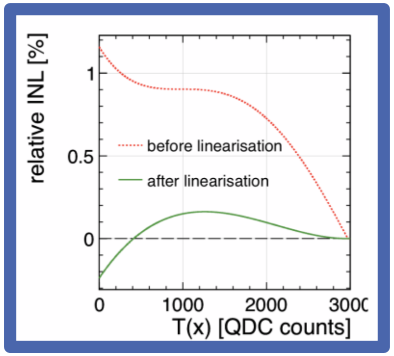
Detector

Vormwald et al., JINST 11 P01014 (2016), List et al., JINST 10 P05014 (2015)

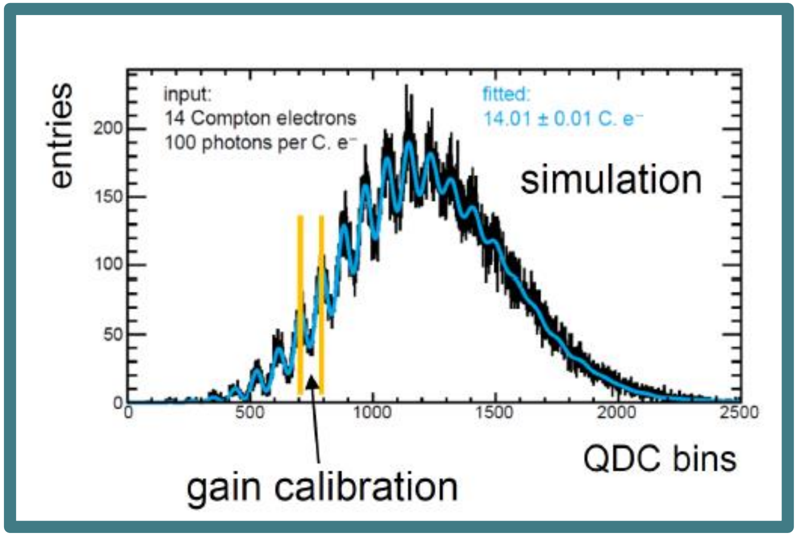








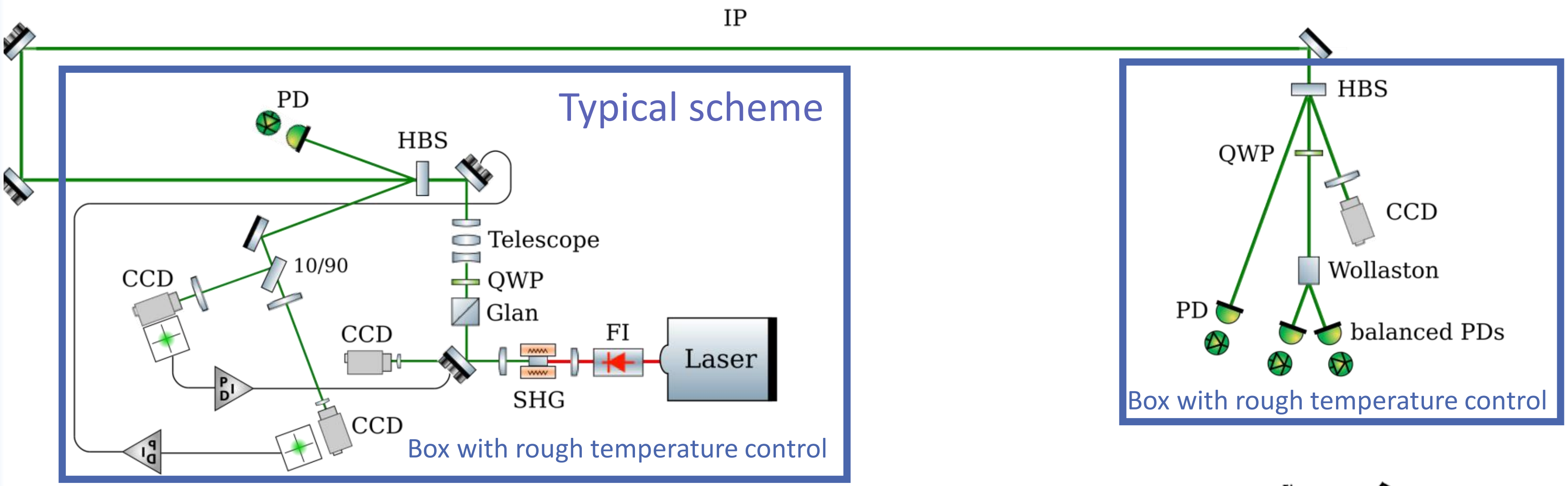
In-situ calibration principle validated

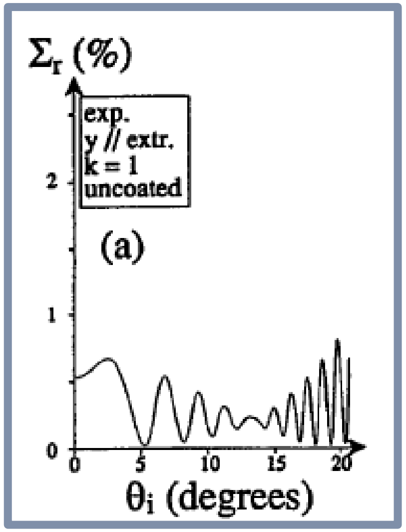


Alternative using Quartz crystals studied:
→ data-driven gain calibration possible
→ Option for the upstream polarimeter

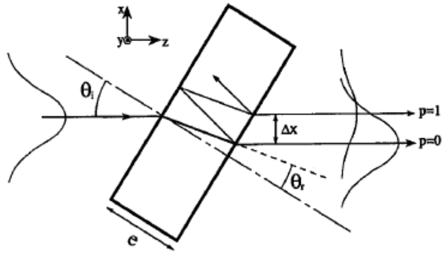
Laser polarization shaping and control

Poirson et al. Applied Optics 34 6806 (1995), Brisson JINST 5 P06006 (2010), Zomer HDR (2003), Jacquet HDR (2009), Baudrand PhD thesis (2007)





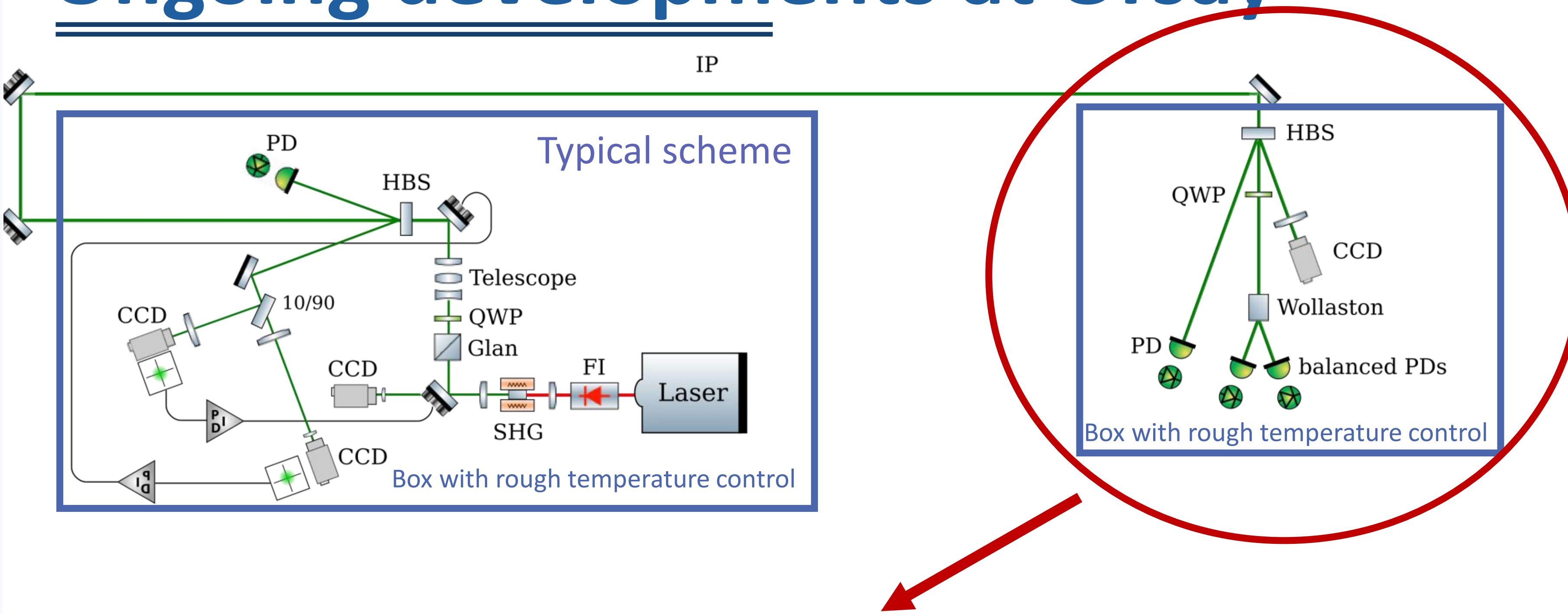
$$|n_e - n_o| e = k\lambda + \frac{\lambda}{4}(1 + \varepsilon).$$



Per-mille polarization control is not easy !

- Control optical birefringence of all optical elements
  - Mechanical stress, Temperature, Rouhgness defects, Thickness defects
- Internal reflections and interferences in waveplates
- Detailed model used succesfully at HERA
- What about laser-induced thermal effects at tens of Watts ?

Ongoing developments at Orsay



Avoid DC measurements by investigating a lock-in detection:

- ~50kHz elasto-optic modulators
- Balanced, lock-in, photo-detection

Slowly starting activity

- SuperKEKB upgrade
- French ANR proposal submitted

ILC-dedicated studies needed?

→ Manpower + hardware needs

Poirson et al. Applied Optics 34 6806 (1995), Brisson JINST 5 P06006 (2010), Zomer HDR (2003), Jacquet HDR (2009), Baudrand PhD thesis (2007)

Conclusion

A lot of work made by DESY group (J. List) on nearly all aspects related to polarimetry

- Extraction with e+e- data
- Compton polarimeter design and integration
- Very detailed simulations
- Detectors, including very low systematics validated

Few points to complement maybe ?

- Laser systems re-design in view of modern technologies and actual location
- Laser polarization control and monitoring (model update, experimental setup validation)
- Downstream polarimeter may benefit from a design review (once ILC gets build)
- Overall review and update of implementation ?

Exploit ’synergies’ with other projects

- LUXE project at DESY
- SuperKEKB upgrade proposal (contribution by IJCLab)