Precision measurement of Triple Gauge Couplings at future e^+e^- colliders

13th Annual Meeting of the Helmholtz Alliance "Physics at the Terascale"

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HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

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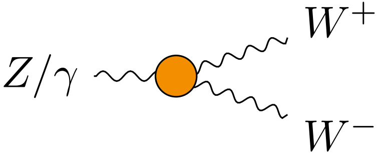
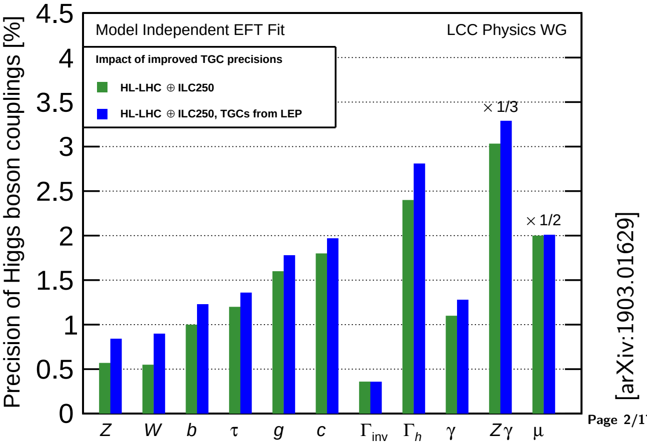
DESY.

Charged Triple Gauge Couplings (TGCs)



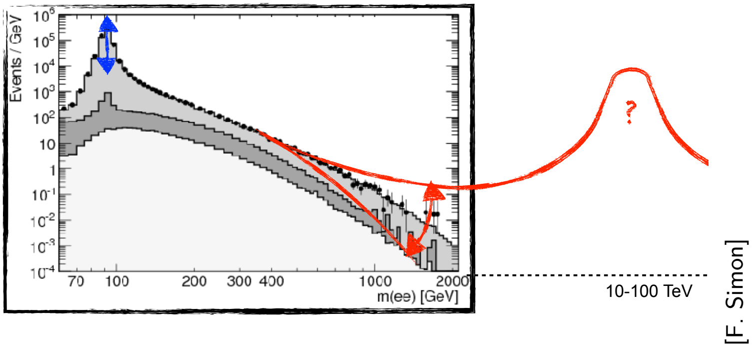
$\longrightarrow$ LEP: $\sim 10^{-2} - 10^{-1}$ precision



Relevance today:

- Gauge boson BSM?
- Higgs coupling fit!

Effective Field Theory (EFT)



Here: High-M BSM

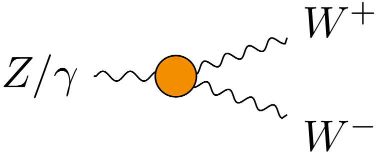
$\Longrightarrow$ **Effective Field Theory**

$$\mathcal{L}_{\text{dim-6}} = \sum_i \frac{f_i^{(\text{dim-6})}}{\Lambda^2} \mathcal{O}_i^{(\text{dim-6})} \Longrightarrow \text{To measure: } c_i = \frac{f_i^{(\text{dim-6})}}{\Lambda^2}$$

TGCs in SM-EFT

$$\mathcal{L}_{\text{dim-6}} = \sum_i \frac{f_i^{\text{(dim-6)}}}{\Lambda^2} \mathcal{O}_i^{\text{(dim-6)}} \implies \text{To measure: } c_i = \frac{f_i^{\text{(dim-6)}}}{\Lambda^2}$$

$$\mathcal{L}^{\text{TGC}}_{dim-6} = i g_1 \frac{f_{B\Psi}}{\Lambda^2} \left(D^L_\mu \Psi\right)^\dagger B^{\mu\nu} \left(D^L_\nu \Psi\right) + i g_2 \frac{f_{W\Psi}}{\Lambda^2} \left(D^L_\mu \Psi\right)^\dagger \tau^a W^{a,\mu\nu} \left(D^L_\nu \Psi\right)$$
$$+ g_2 \frac{f_W}{6\Lambda^2} \epsilon^{abc} W^{a,\mu}_\nu W^{b,\nu}_\rho W^{c,\rho}_\mu$$



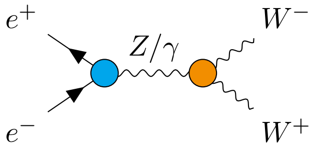
$$g_1^Z = 1 + f_{B\Psi} \frac{m_Z^2}{\Lambda^2}$$

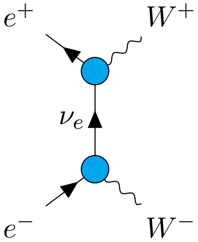
$$\kappa_\gamma = 1 + \left(f_{B\Psi} + f_{W\Psi}\right) \frac{m_W^2}{\Lambda^2}$$

$$\lambda_\gamma = \frac{3 m_W^2 g_2^2}{\Lambda^2} f_W$$

$$\implies \text{Deviations: } \Delta\{g_1^Z, \kappa_\gamma, \lambda_\gamma\} \sim \{c_i \cdot m_{W/Z}^2\}$$

Extracting TGCs





Key process: WW production
s-channel: **TGCs** $\{g_1^Z, \kappa_\gamma, \lambda_\gamma\}$

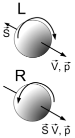
$$\text{Idea: Minimize } \chi^2 = \sum_{\text{bins}} \left(\frac{\sigma_{\text{meas}} - \sigma_{\text{pred}}(\textbf{TGCs})}{\Delta\sigma_{\text{meas}}} \right)^2$$

However: s- and t-channel **highly chirality dependent**...

Beam polarisation

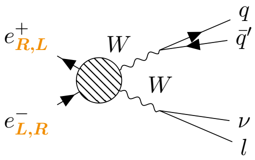
$\hat{=}$ $x\%$ particles fixed helicity, $(100-x)\%$ random helicity

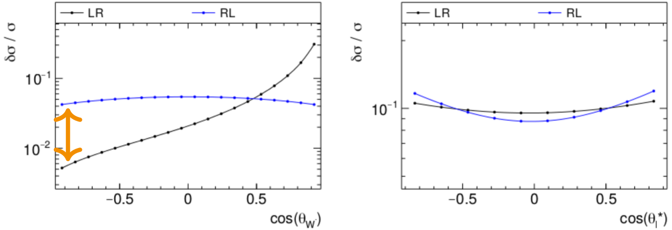
For $m \sim 0$:



- 1 polarised beam $\longrightarrow$ 2 datasets: L enhanced / R enh.
- 2 polarised beam $\longrightarrow$ 4 datasets: LR / RL / LL / RR enh.

σ chirality dependent! (SM: $U(1) \times SU(2)_L \times SU(3)$)



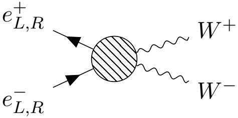


[R. Karl]

@ e^+e^- collider: high-precision $\sigma_{WW}^{LR/RL}$

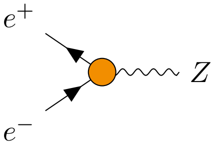
$\Longrightarrow$ **Beam polarisation measurement from WW pair production!**

Combined measurement



- Triple Gauge Couplings
- Beam polarisations

Other SM parameters?



$\Longrightarrow$ A_e, ...

Here **generalized**: 1 total cross-sec. $\sigma^{\text{tot}}_{\text{process}}$ & 1 asymmetry $A_{ij,\text{process}}$ per process

Extract

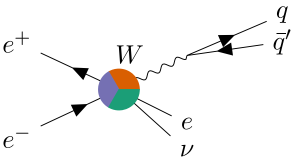
$$\{g_1^Z, \kappa_\gamma, \lambda_\gamma, \textbf{beam polarisations}, \sigma^{\text{tot}}_{\text{process}}, A_{ij,\text{process}}\}$$

in parallel from measurement!

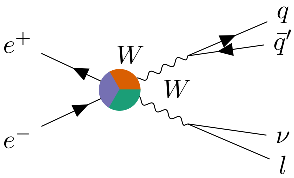
Considered processes

Fit parameters: $\{g_1^Z, \kappa_\gamma, \lambda_\gamma$, beam polarisations, $\sigma^{\text{tot}}_{\text{process}}, A_{ij,\text{process}}\}$

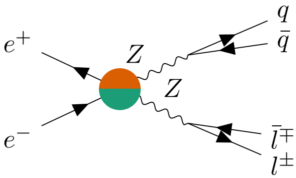
Processes:



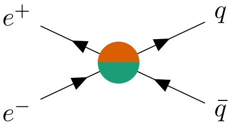
2000 3D-Bins $\times 2(W^\pm)$



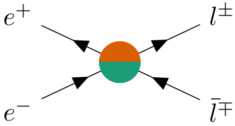
2000 3D-Bins



2000 3D-Bins



20 1D-Bins



20 1D-Bins

Combined fit setup

$$\text{Minimize } \chi^2 = \sum_{\text{processes,bins}} \left(\frac{\sigma_{\text{meas}} - \sigma_{\text{pred}}(\textbf{parameters})}{\Delta\sigma_{\text{meas}}} \right)^2$$

$$\{g_1^Z, \kappa_\gamma, \lambda_\gamma, \textbf{beam polarisations}, \sigma_{\text{process}}^{\text{tot}}, A_{ij,\text{process}}\}$$

Input:

- “Collider”: Energy, luminosity, polarisations
- “Measurement”: σ_{meas} $\forall$processes, bins
- Theory: σ_{pred} $\forall$processes, bins
  & **parameter-dependence**

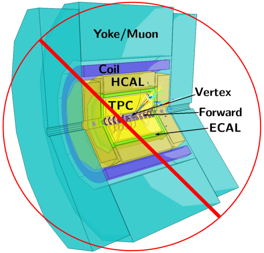
Output:

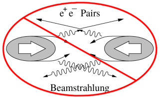
- **Parameter uncertainties / sensitivities**

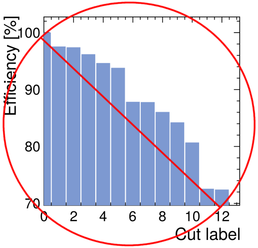
So far:

- Only 250 GeV
- Generator level
- "Analysis": $\epsilon = 60\%$, $\pi = 80\%$ $\forall$bins, processes (motivated by WW full sim. study)

DISCLAIMER





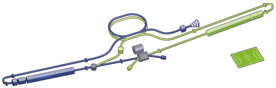


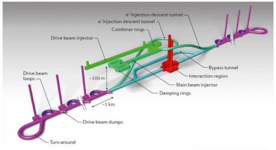
Not considered:

- ISR / Beam spectrum for 4f
- Detector & full analysis (all channels)
- **Systematic Unc.** $(\Delta\epsilon, \Delta L, ...)$
  Except:
  - Polarisation
  - Theory uncert. (partially)

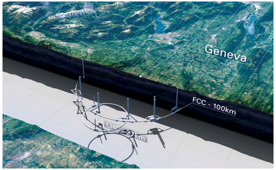
  as fit parameters

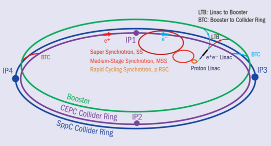
Lepton collider options





Linear





Circular

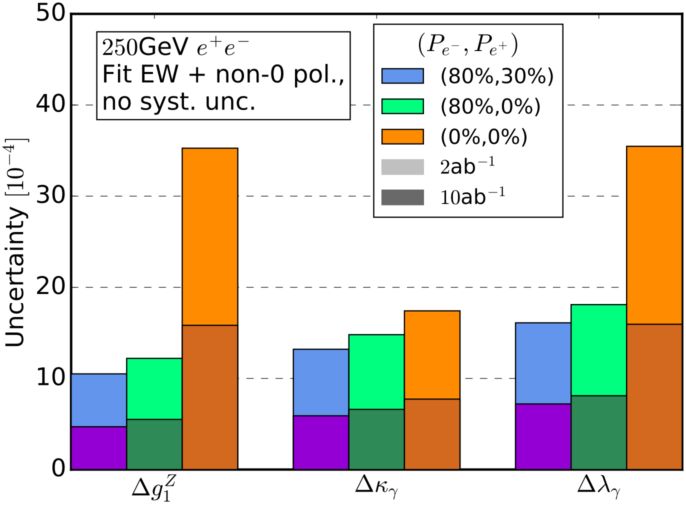
Typical: $L \sim 2\,\text{ab}^{-1}$, e^- (& e^+) polarised

Typical: $L \sim 10\,\text{ab}^{-1}$, e^- & e^+ unpolarised

$\Longrightarrow$ **6 scenarios**:

- **Luminosity:** $2\,\text{ab}^{-1}$ / $10\,\text{ab}^{-1}$
- **Polarised beams:**
  - $e^-\&e^+$: $45\%(-+)$, $45\%(+-)$, $5\%(--)$, $5\%(++)$
  - e^- : $80\%(-0)$, $20\%(+0)$
  - None : $100\%(00)$

Combined fit results



- g_1^Z, λ_γ:
  $10\,\text{fb}^{-1}$ **unpol.** $\approx 2\,\text{fb}^{-1}$ **pol.**
- κ_γ:
  $10\,\text{fb}^{-1}$ **unpol.** $\ll 2\,\text{fb}^{-1}$ **pol.**

* $(0\%, 0\%)$ case may benefit from more distributions

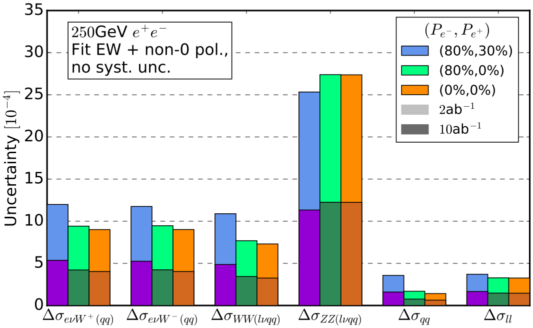
Combined fit results

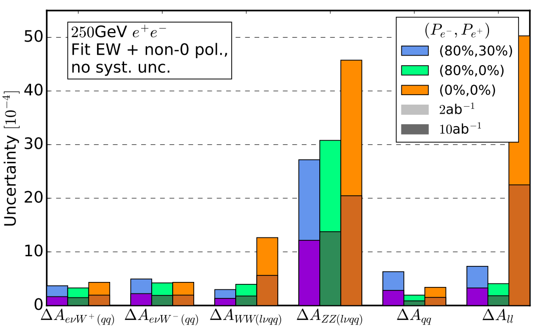
$\Delta\mathcal{P}/\mathcal{P} \sim 10^{-3} - 10^{-4}$ [Appendix]

$$\sigma^{\text{tot}}_{\text{process}} = \sum_{LR,RL,\ldots} \sigma_{ij,\text{process}}$$

$$A_{ij,\text{process}} = (\sigma_{ij} - \sigma_{ji}) \,/\, (\sigma_{ij} + \sigma_{ji})$$

(Definition process-dependent)





Overall similar sensitivities.

However: 0-polarisations fixed!

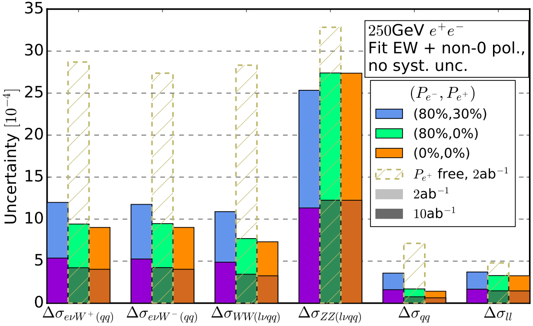
If $0 \neq 0$?

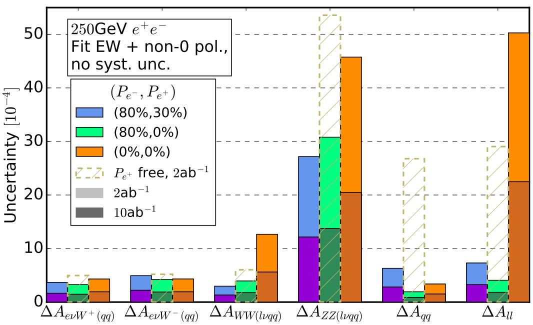
Reminder: Only fitting **non-0 polarisations**

$\longrightarrow$ Less fit parameters $\Longrightarrow$ Physical??

> Circular: Maybe... (Sokolov-Ternov)

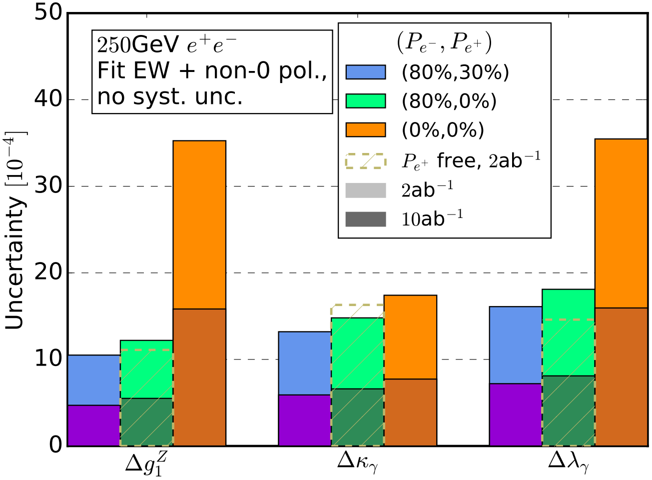
> **Linear: Need to measure!**





$\Longrightarrow$ **If $0 = 0$ not guaranteed, large uncertainties!**

If $0 \neq 0$?



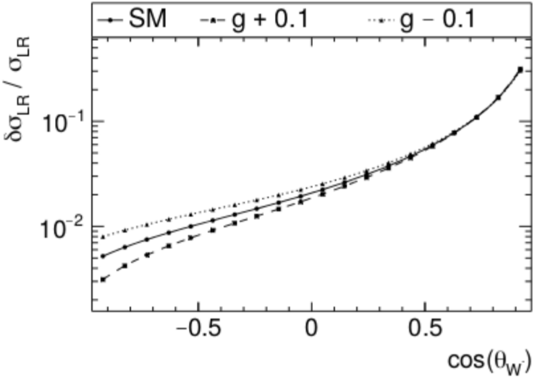
> **No significant effect** on **TGCs**

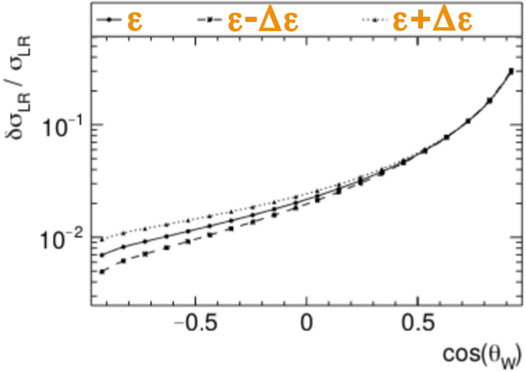
But:

Syst. unc. not considered!

Adding systematics...

Ongoing study



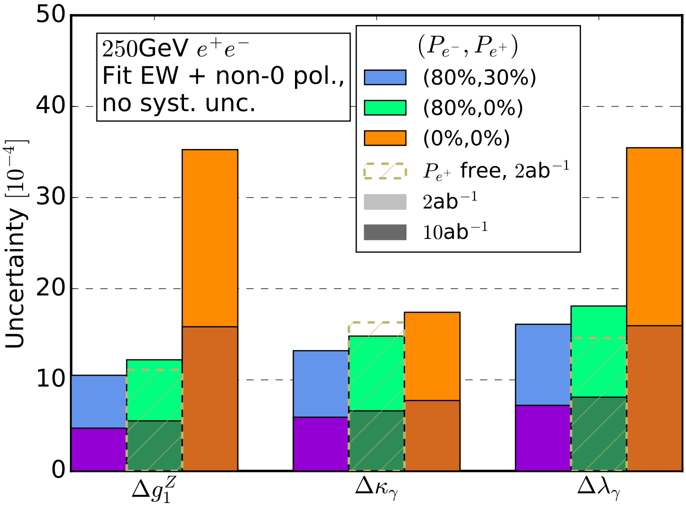


(schematic)

> **No polarisation:** Deviations ambiguous

> **2 (4) *correlated* polarisation settings:** ϵ effect **in all**, **TGC** effect enhanced **in 1 (2)**

TGCs & the future of HEP



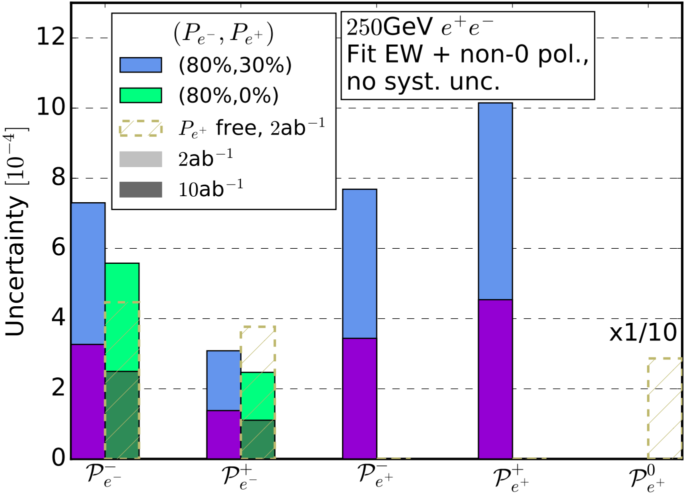
- Studied here:

  TGCs
  +
  EW cross sections / theory unc.
  +
  polarisation

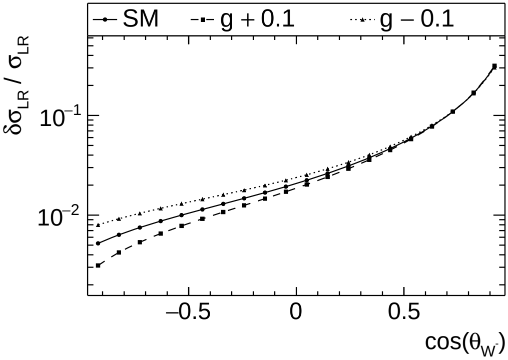
- Significant improvement with **beam polarisation** (w/o detector effects, ...!)

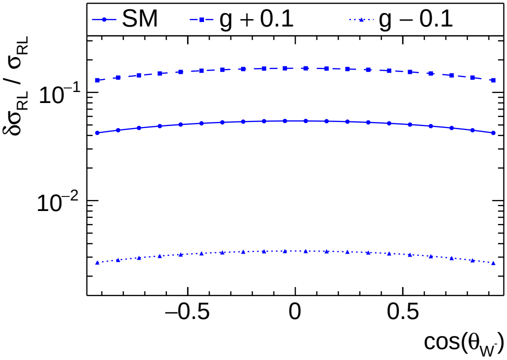
BACKUP

Combined fit: polarisation



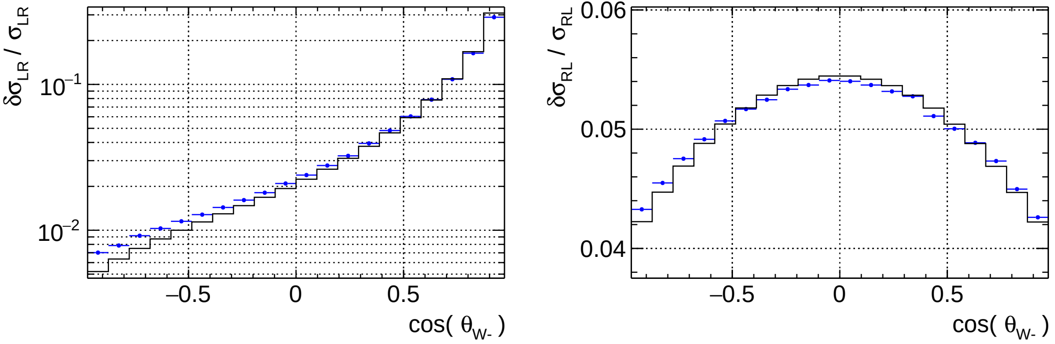
$WW \to \mu\nu qq$ g_1^Z-dependence [R. Karl]





$WW \to \mu\nu qq$ check cross section vs. full MC check [R. Karl]

Comparing matrix element differential distributions with MC distributions (incl. ISR & Beamstrahlung):



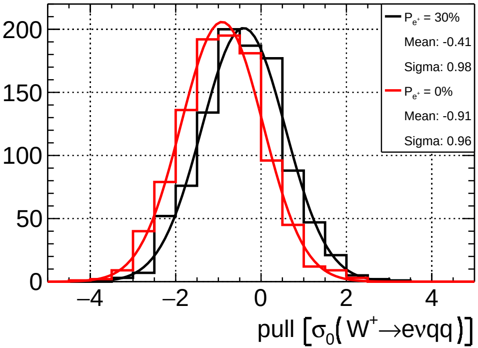
Polarimeter effect on polarisation [R. Karl]

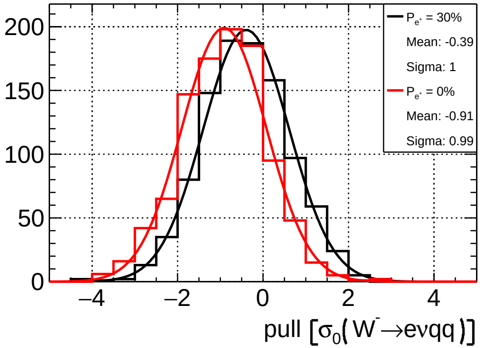
	Without Constraint					With Constraint				
E[GeV]	500	350	250	500	250	500	350	250	500	250
$\mathcal{L}$[1/fb]	500	200	500	3500	1500	500	200	500	3500	1500
$\Delta P^{-}_{e^-}/P$	2.1	3.3	1.7	0.8	0.95	1.2	1.3	1.1	0.69	0.79
$\Delta P^{+}_{e^-}/P$	0.45	0.83	0.45	0.17	0.26	0.44	0.78	0.44	0.17	0.26
$\Delta P^{-}_{e^+}/P$	2	3.2	1.5	0.75	0.87	1.5	2	1.3	0.71	0.81
$\Delta P^{+}_{e^+}/P$	3.6	5.4	2.6	1.3	1.5	1.9	2	1.7	1.1	1.2

Table 8.4: *The final precision of the polarization* $[10^{-3}]$ *after each run of the H-20 scenario as shown in fig. 8.11. The red colored values exceed the* 0.25% *polarimeter precision, while the blue colored values can improve the precision to be better than the polarimeter precision due to the soft constraint.*

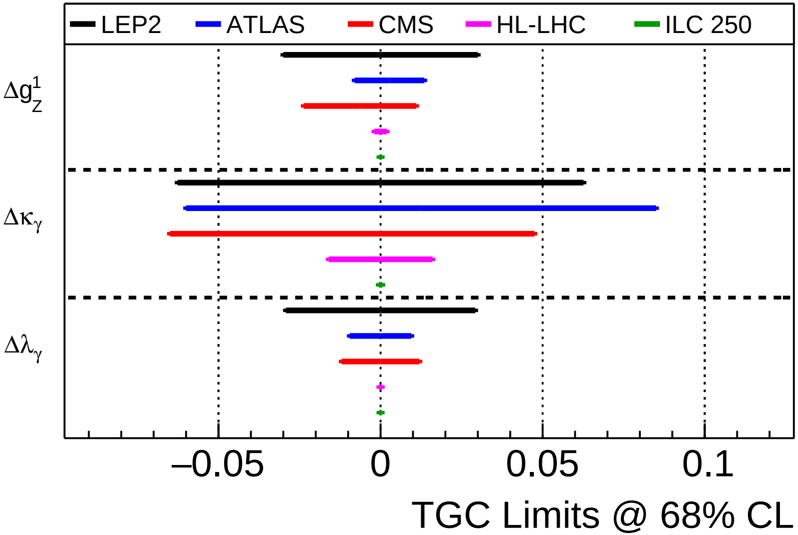
Polarimeter induced bias [R. Karl]

What if polarimeter measures $\mathcal{P}$ off by 1σ?





Single parameter fit sensitivity comparison [arXiv:1903.01629]



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