

How beam polarisation changes EW measurements at 250GeV

IDT-WG3-Phys Open Meeting

Jakob Beyer, Jenny List

17.11.2022

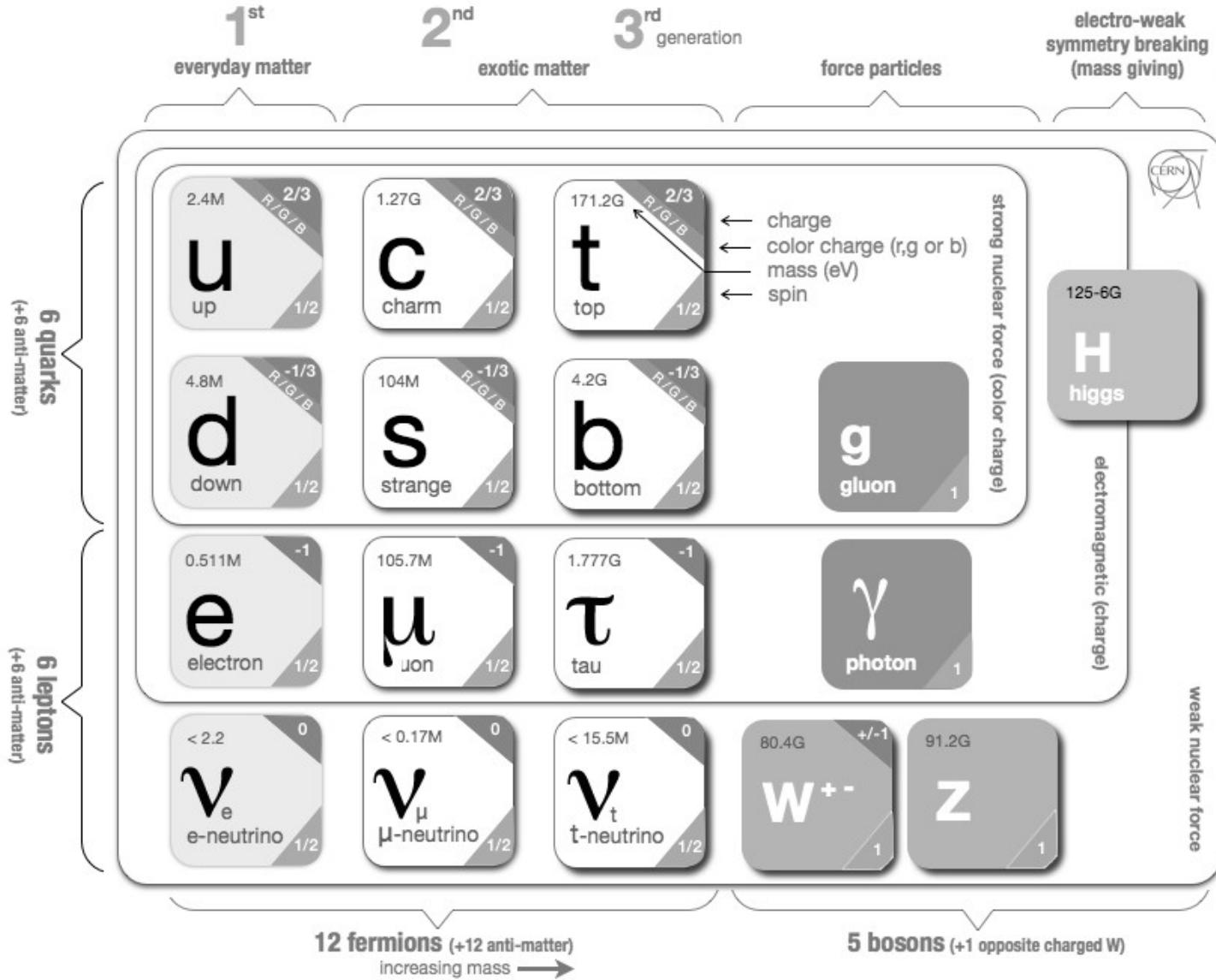
HELMHOLTZ



CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE



We have a Standard Model working for most experiments ...



High precision predictions

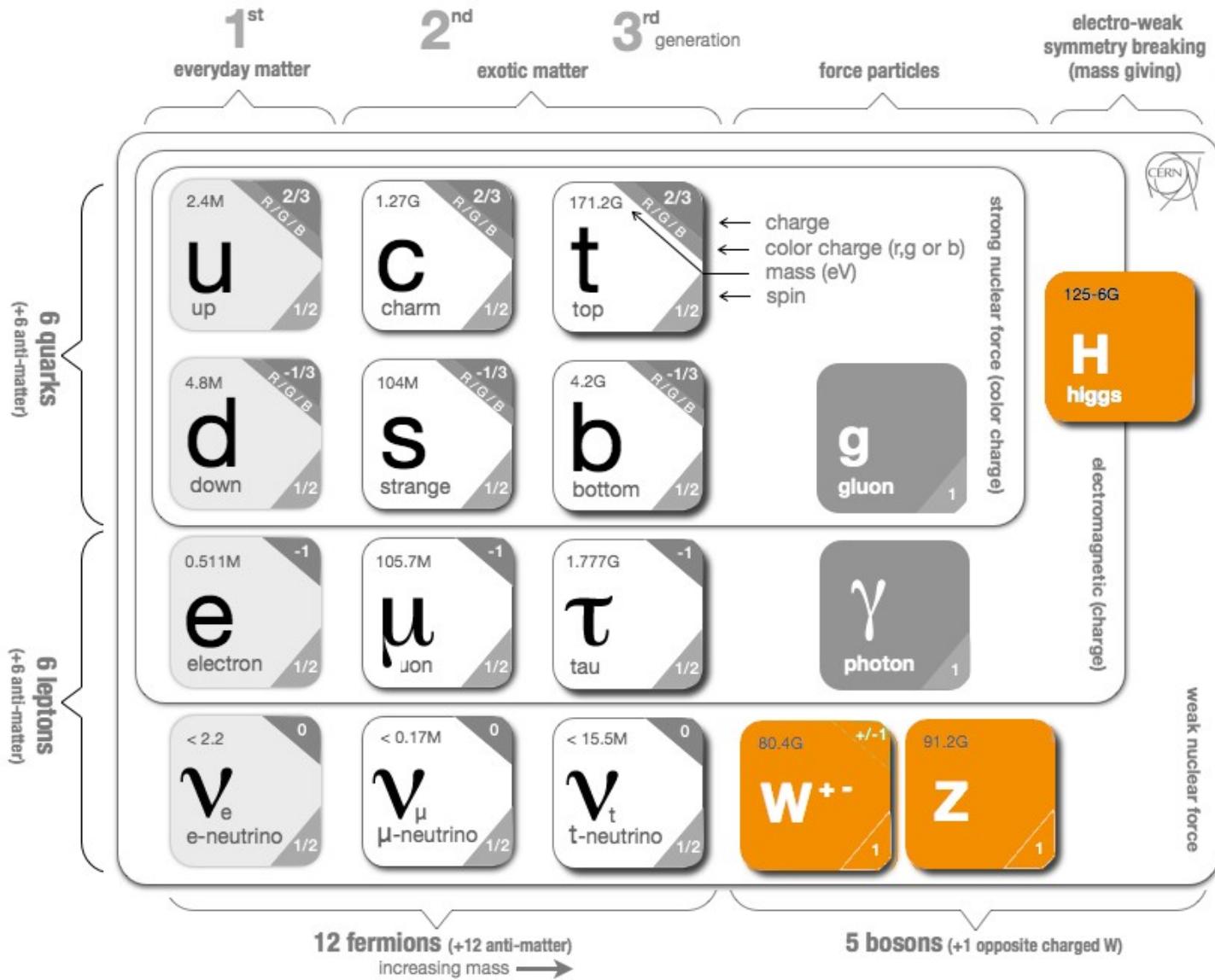
- From low-energy experiments
- To high-energy collisions

2012: Higgs-Observation

→ all predicted SM particles observed

[David Galbraith, Carsten Burgard]

... yet leaving many questions open



Origin of mass and coupling values?

Particle description of dark matter?

...

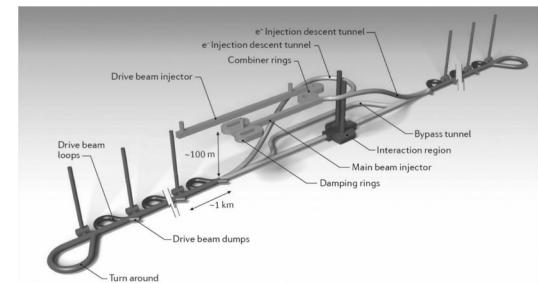
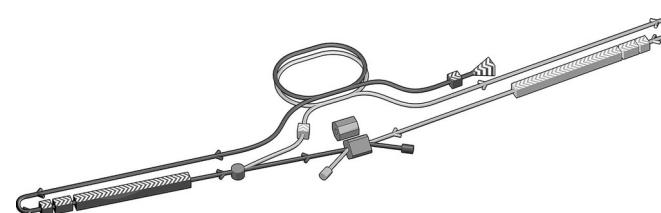
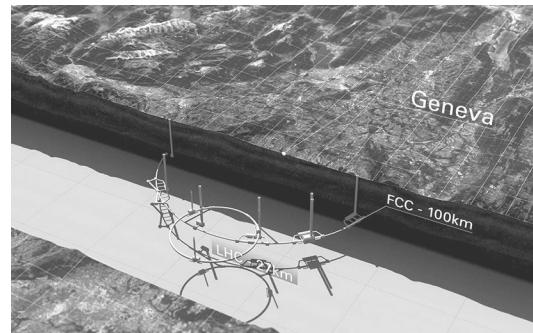
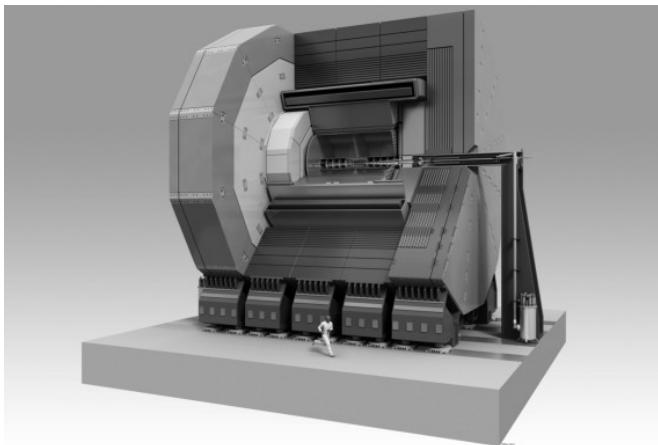
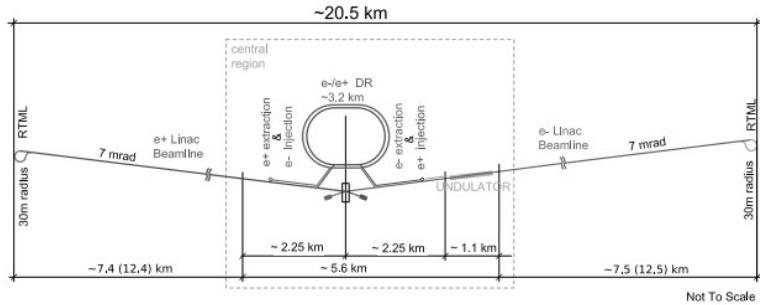
Future colliders to check “newest” sector:

Higgs /
Electroweak Symmetry Breaking
in e^+e^- collisions

What determines electroweak precision ...

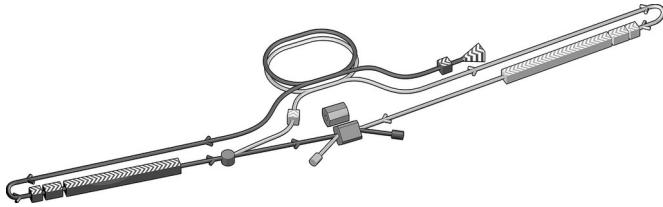
... in the event reconstruction process?

... when choosing between collider options?

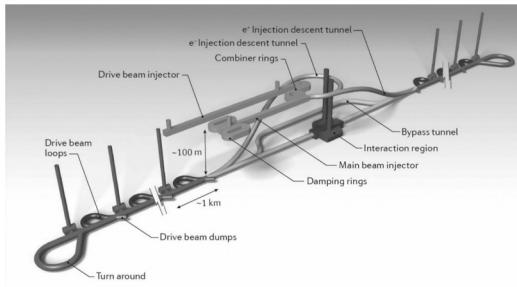


Linear for high-E, circular for “low”-E

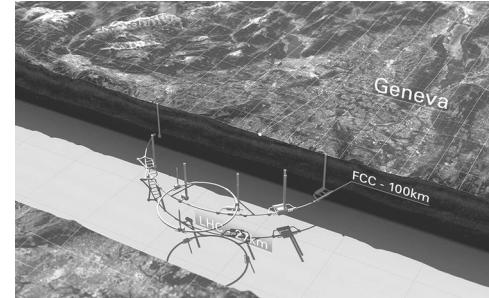
ILC



CLIC



FCC-ee

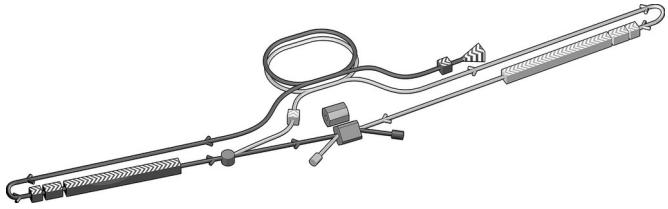


CEPC

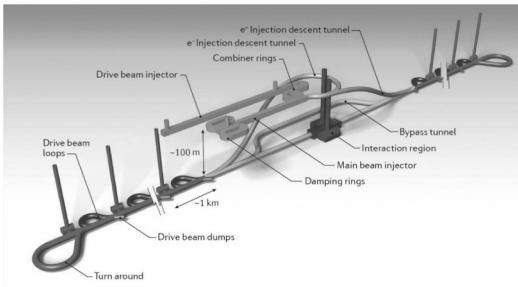


Linear for high-E, circular for “low”-E

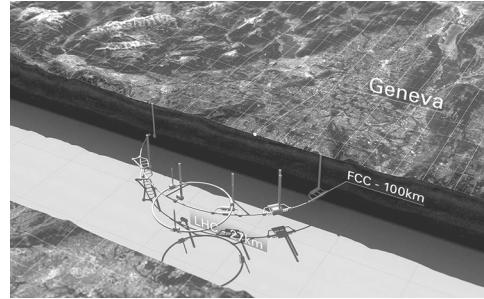
ILC



CLIC



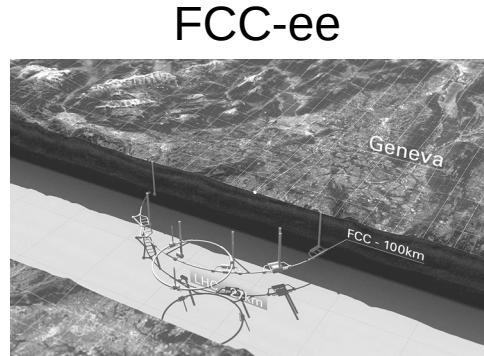
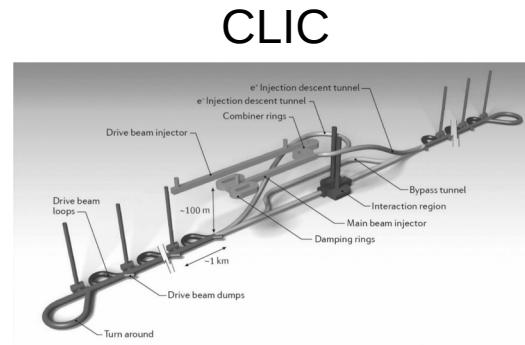
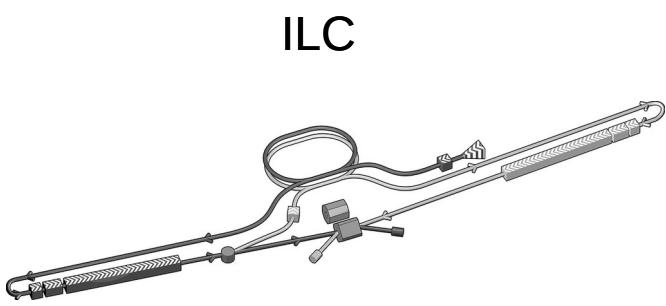
FCC-ee



CEPC



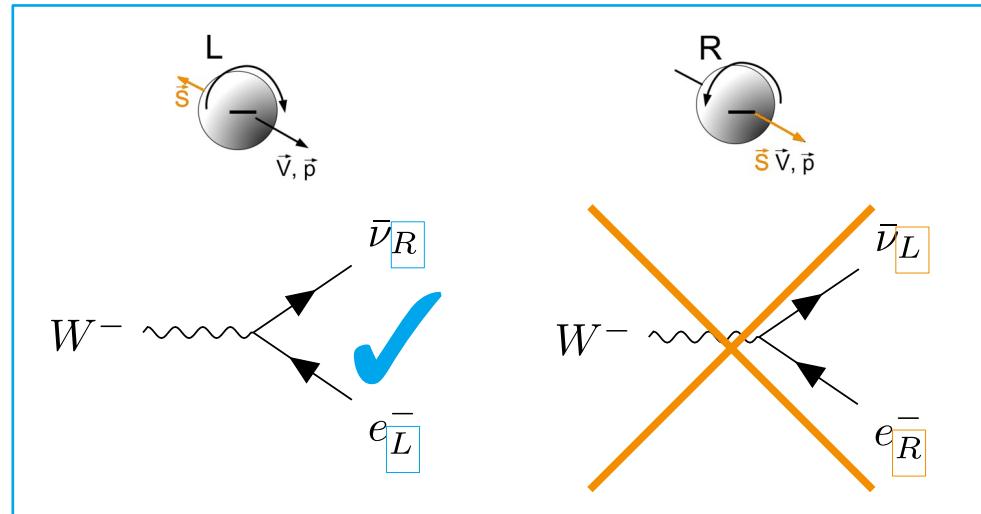
Only linear provides longitudinal beam polarisation...



e⁻ & e⁺ polarised

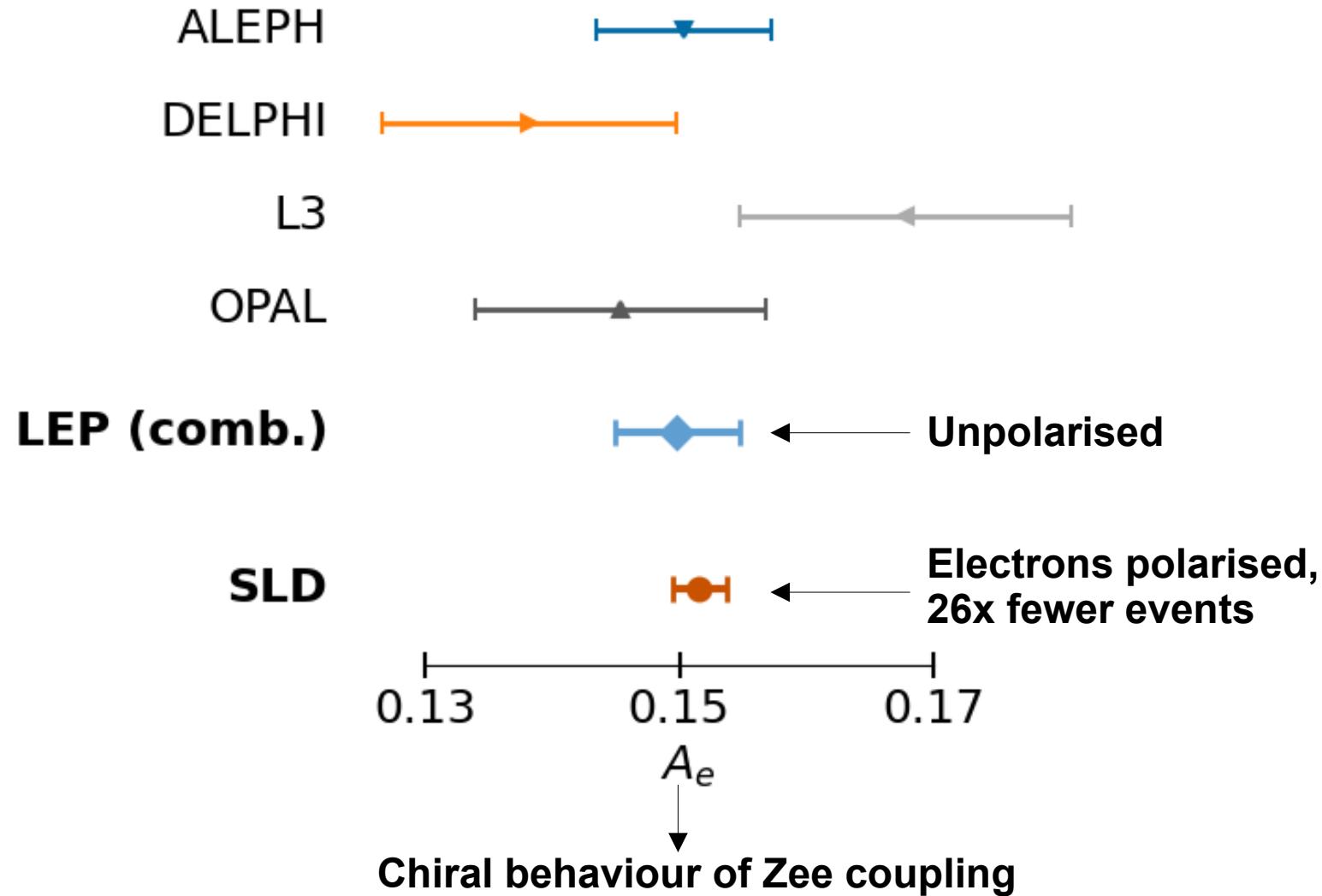
e⁻ polarised

both beams unpolarised

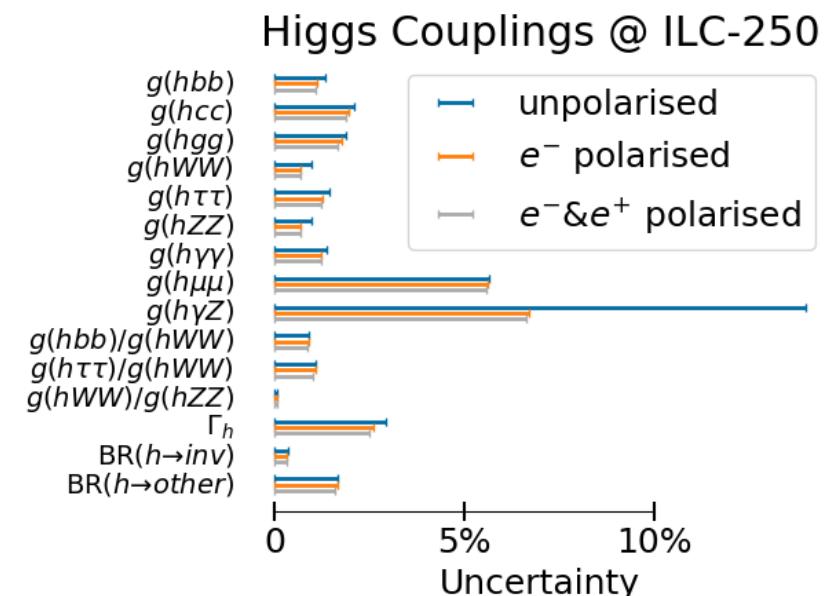
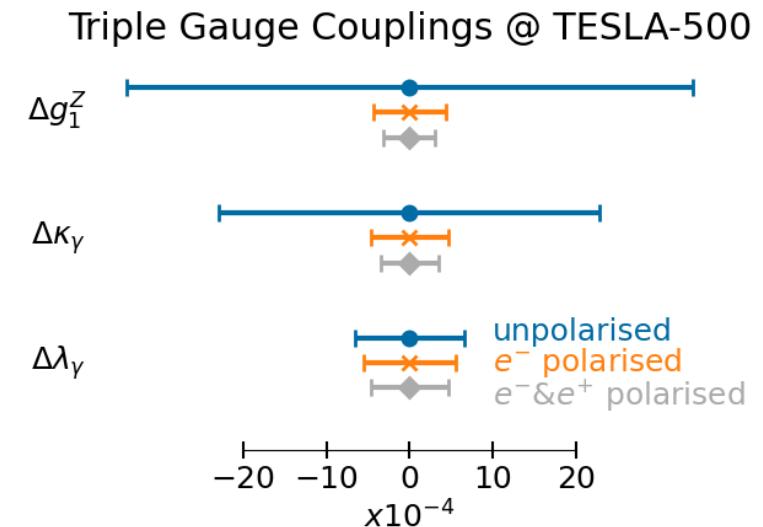
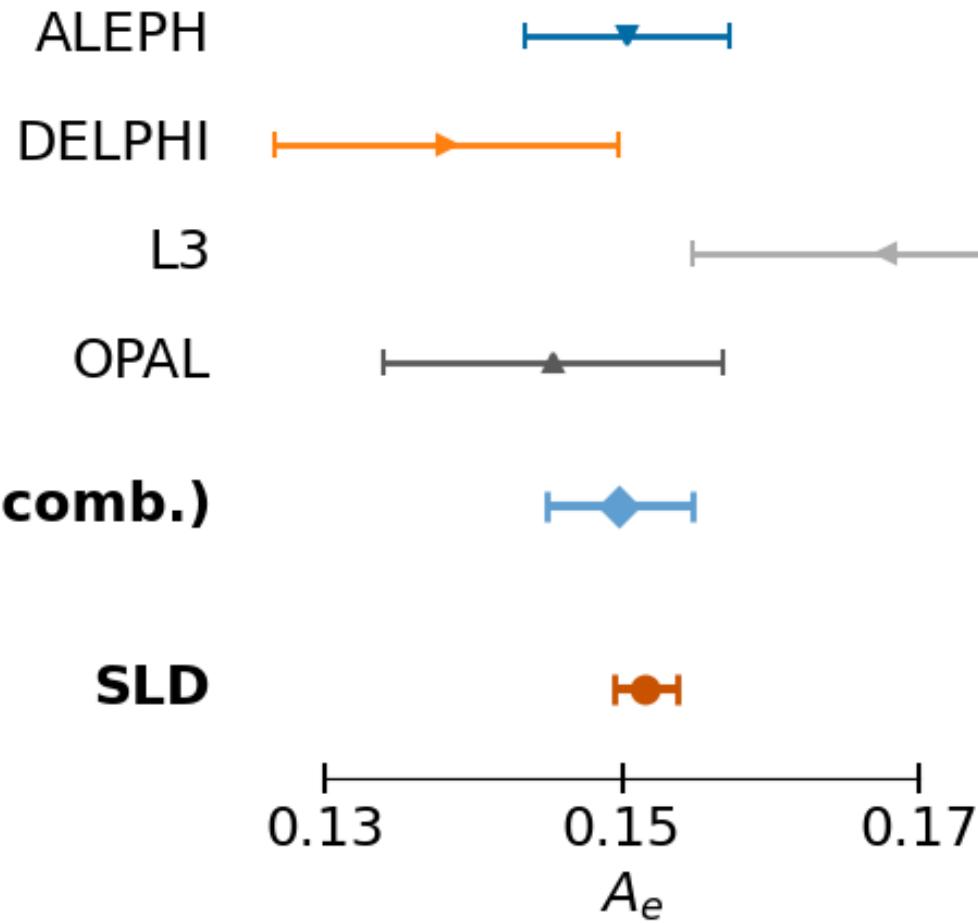


... which provides direct access to chiral behavior through flips of polaris. sign

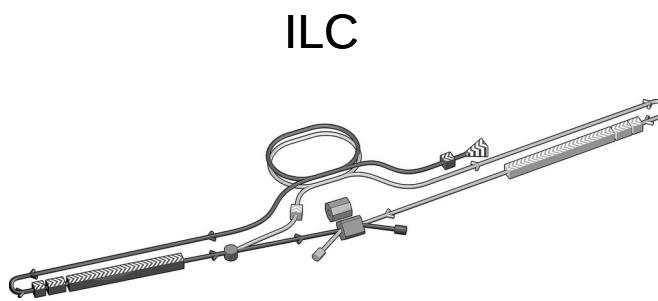
We know polarisation makes a qualitative difference



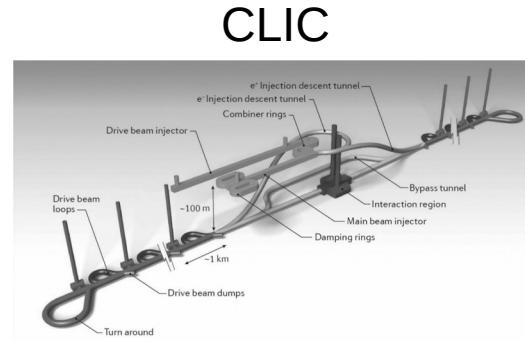
We know polarisation makes a qualitative difference



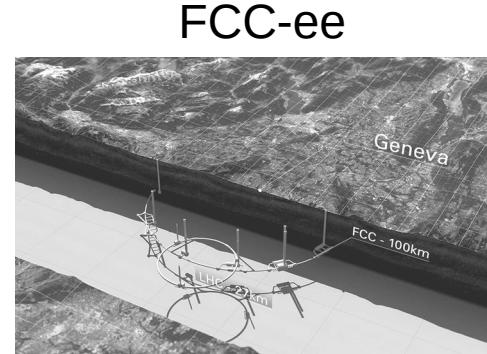
Study tests impact on EW meas. with generic 250GeV collider



ILC



CLIC



FCC-ee



CEPC

e^- & e^+ polarised

Realistic e^- pol.: 80% or 0%
Realistic e^+ pol.: 30% or 0%

e^- polarised

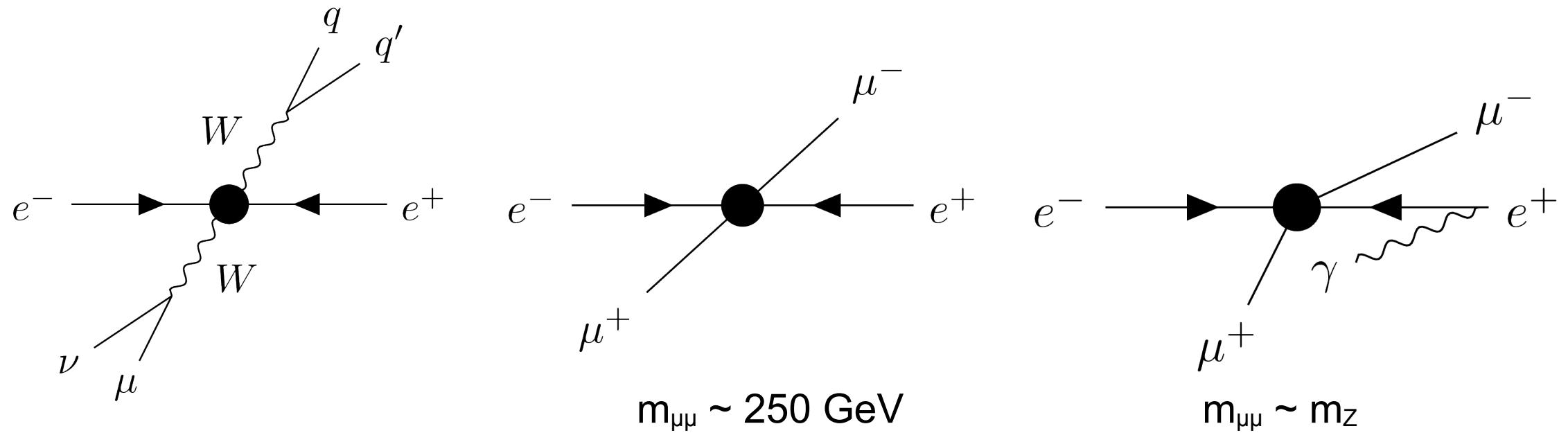
4 pol. scenarios:

(80,30), (80/0,30/0)

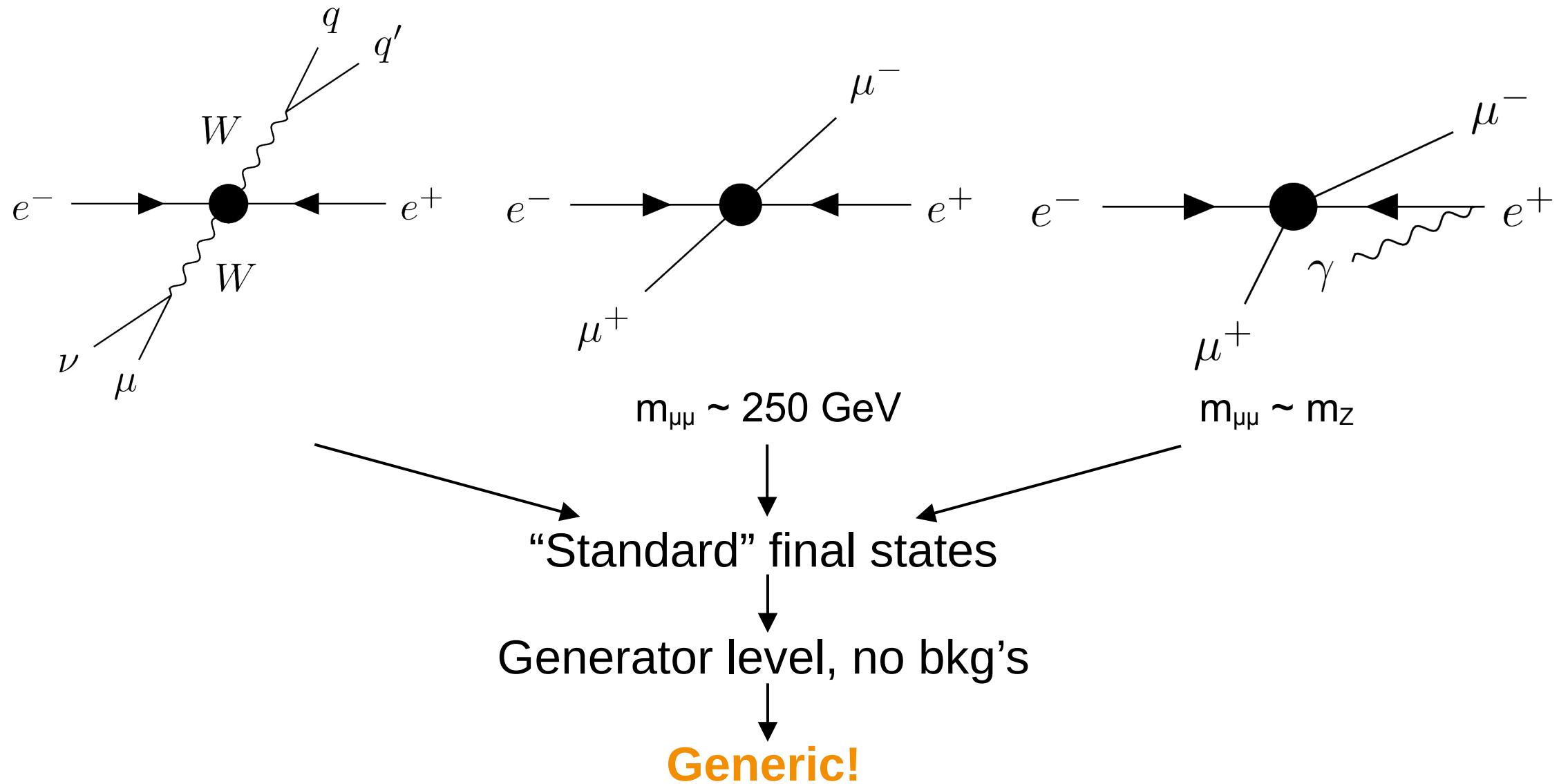
(80,0)

(0,0)

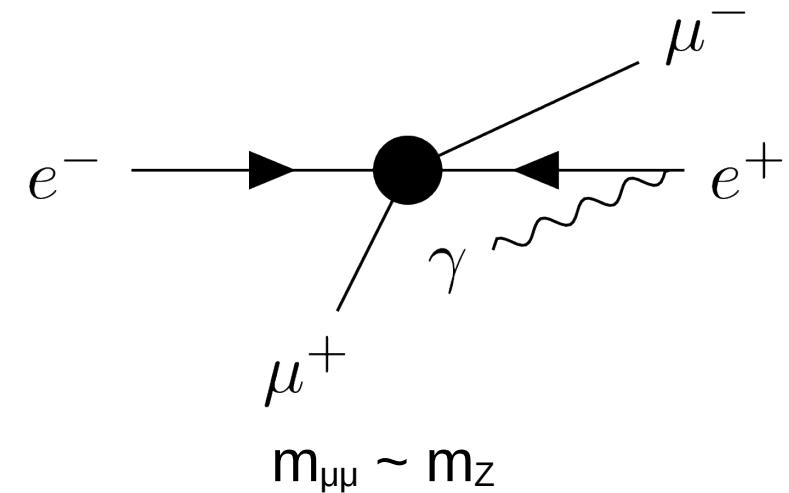
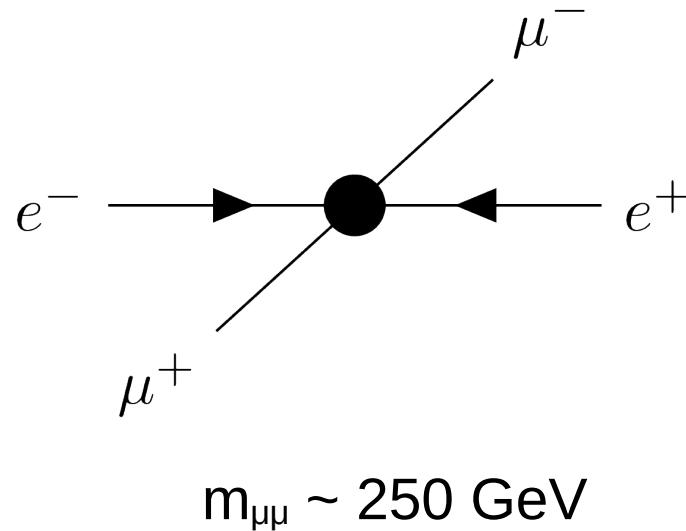
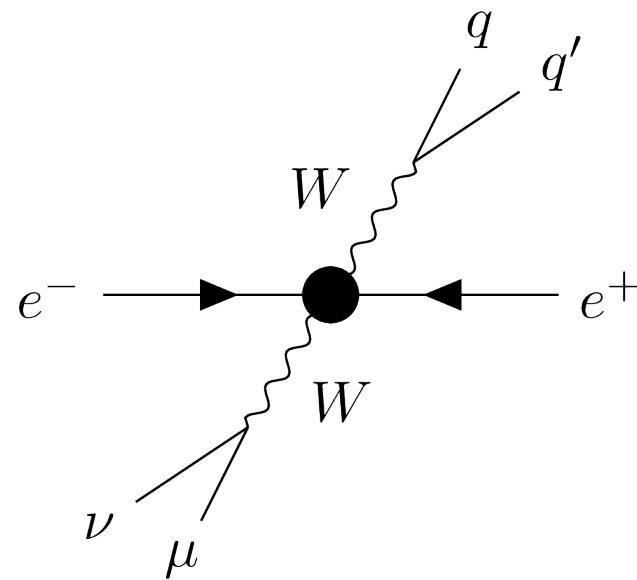
Simultaneous fit of processes uses differential distributions



Simultaneous fit of processes uses differential distributions



Simultaneous fit extracts physical and systematic parameters



Triple Gauge Couplings
#: 3

$\mu\mu$ parameters @ 250GeV
#: 6, 3 unpolarised

$\mu\mu$ parameters @ m_Z
#: 6, 3 unpolarised

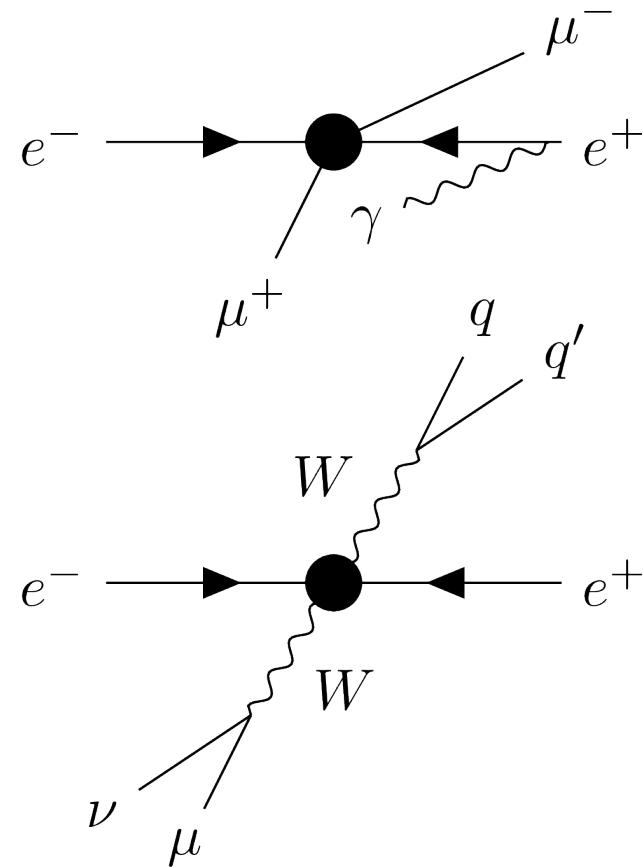
Total cross section
#: 1

Common systematics (#)

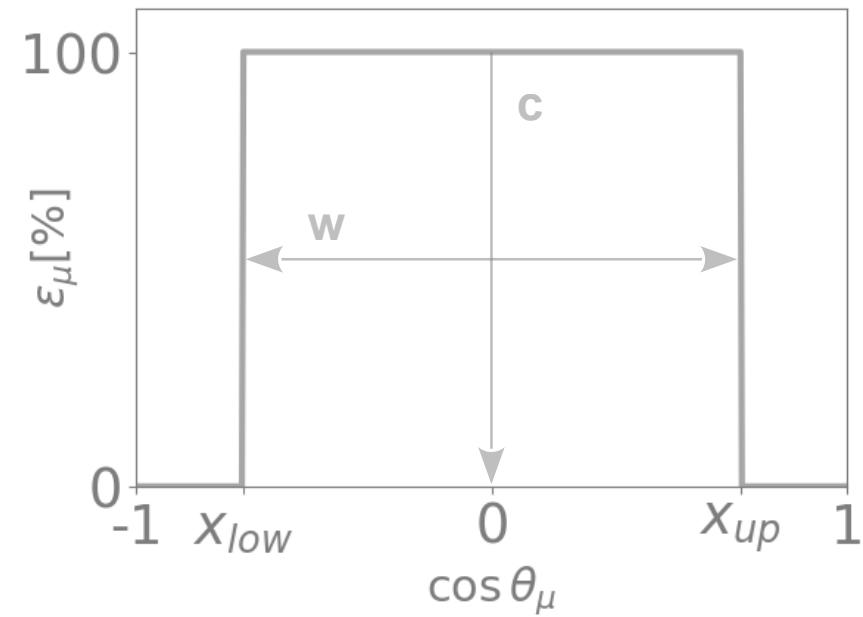
- Luminosity (1)
- Polarisations (2-6)
- μ acceptance (2)

Beam polarisation improves EW measurements ...

... by direct access to chiral observables

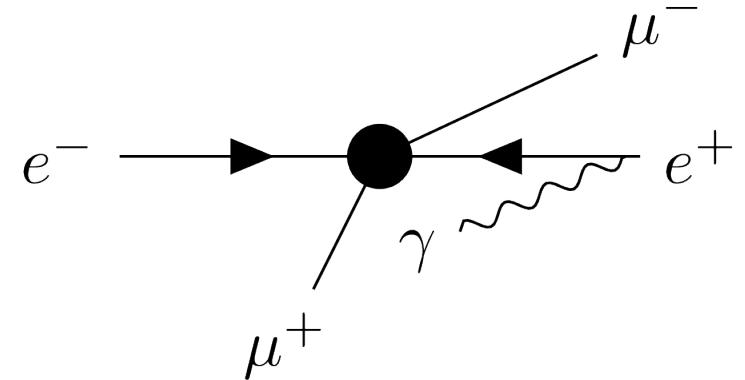
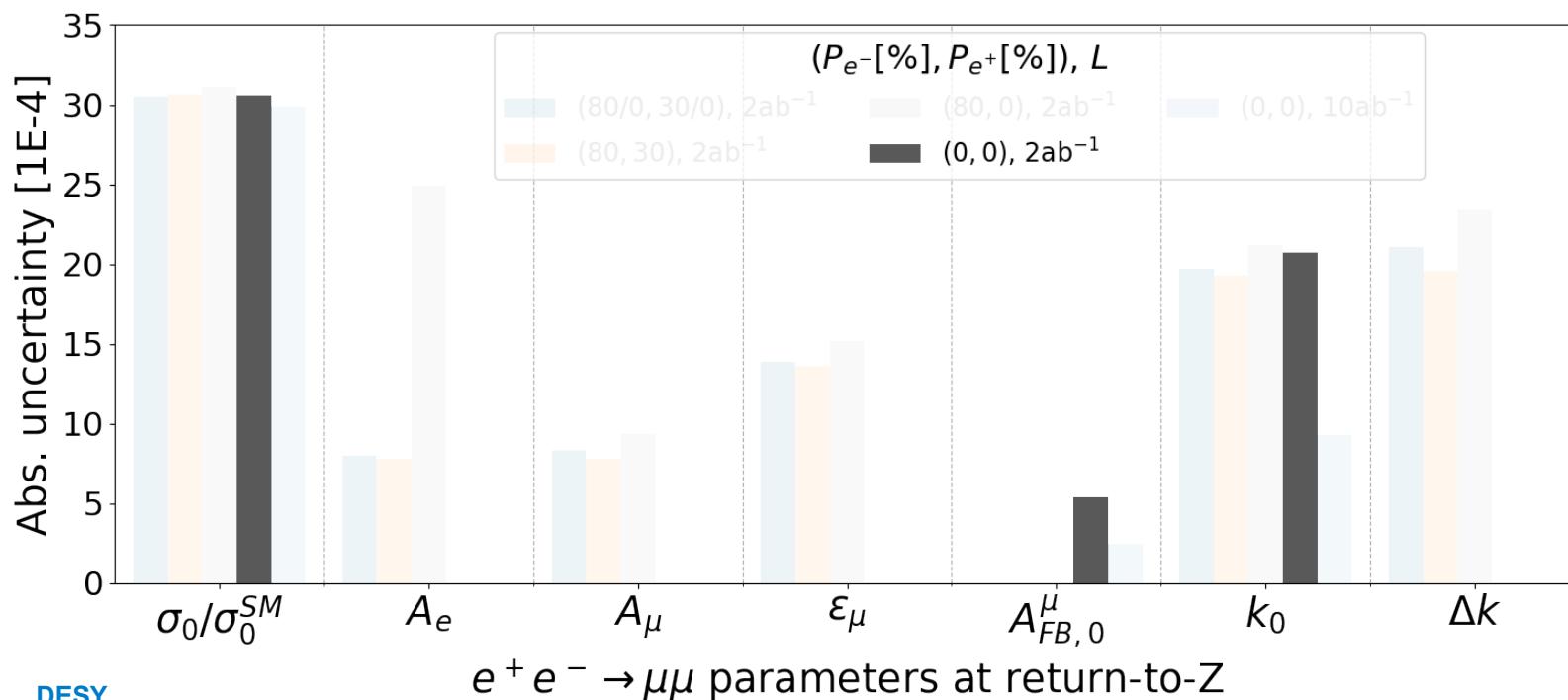


... by minimizing systematic uncertainties



Beam polarisation brings access to chiral observables

$$\frac{d\sigma_{\text{unpol}}^f}{d\cos\theta} = \frac{1}{4} \frac{3}{8} \sigma_0^f \left[(1 + \cos^2\theta) + \frac{8}{3} A_{FB}^f \cos\theta + \frac{k_0}{2} (1 - 3\cos^2\theta) \right]$$



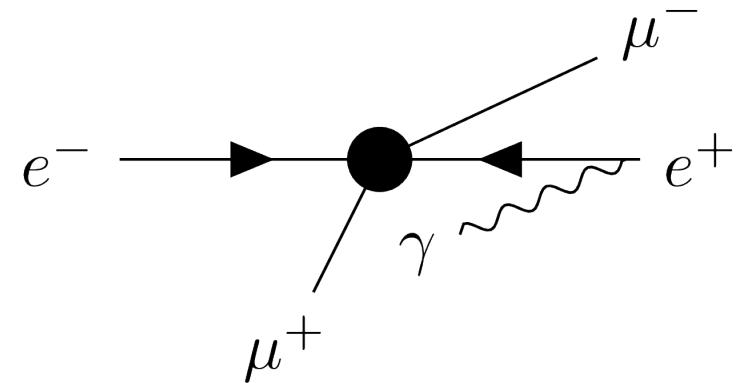
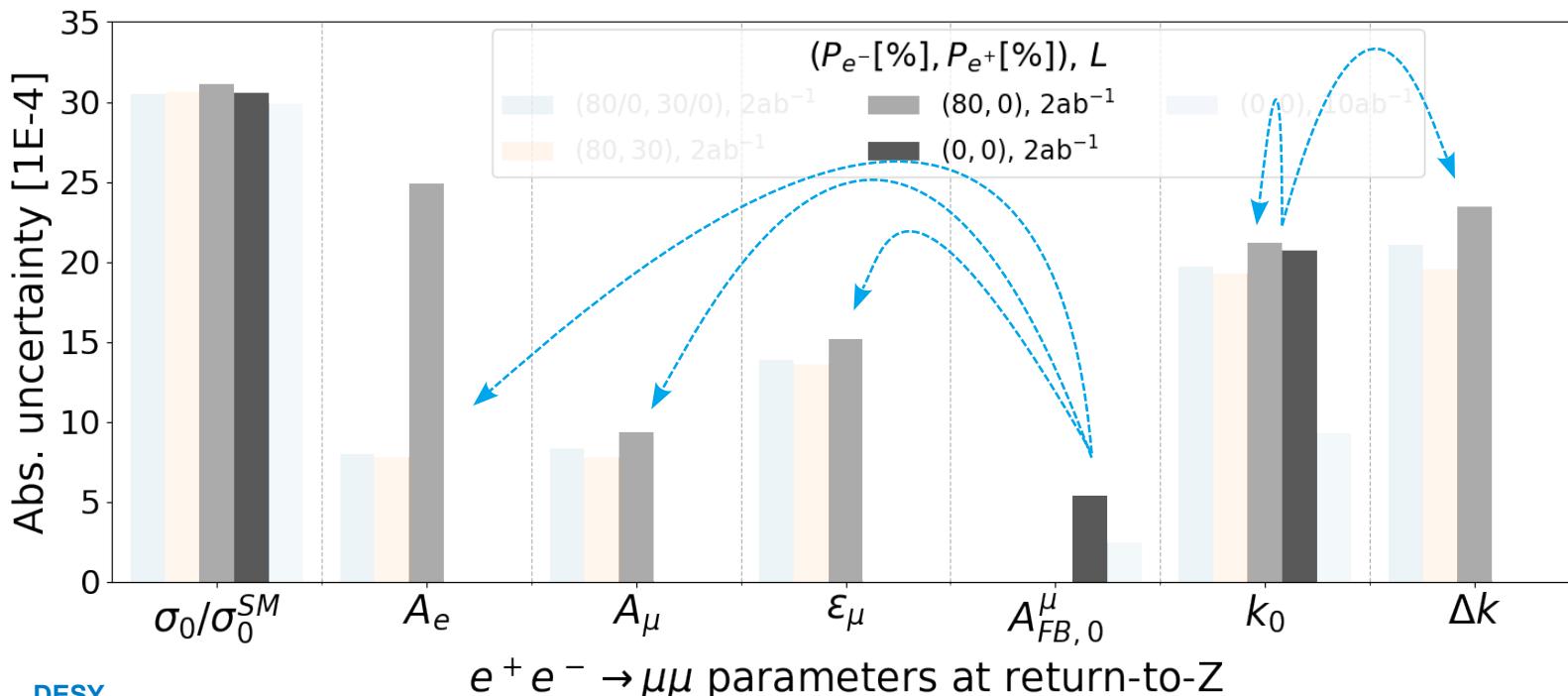
Beam polarisation brings access to chiral observables

$$\frac{d\sigma_{\text{unpol}}^f}{d\cos\theta} = \frac{1}{4} \frac{3}{8} \sigma_0^f \left[(1 + \cos^2\theta) + \frac{8}{3} A_{FB}^f \cos\theta + \frac{k_0}{2} (1 - 3\cos^2\theta) \right]$$

↗

$$\frac{d\sigma_{LR}^f}{d\cos\theta} = \frac{3}{8} \sigma_0^f \frac{1 + A_e}{2} \left[\left(1 + \frac{k_0 + \Delta k}{2}\right) + (\epsilon_f + 2A_f) \cos\theta + \left(1 - 3\frac{k_0 + \Delta k}{2}\right) \cos^2\theta \right]$$

$$\frac{d\sigma_{RL}^f}{d\cos\theta} = \frac{3}{8} \sigma_0^f \frac{1 - A_e}{2} \left[\left(1 + \frac{k_0 - \Delta k}{2}\right) + (\epsilon_f - 2A_f) \cos\theta + \left(1 - 3\frac{k_0 - \Delta k}{2}\right) \cos^2\theta \right]$$

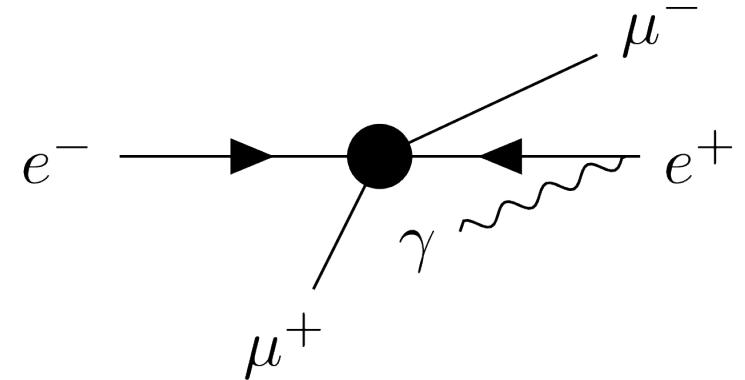
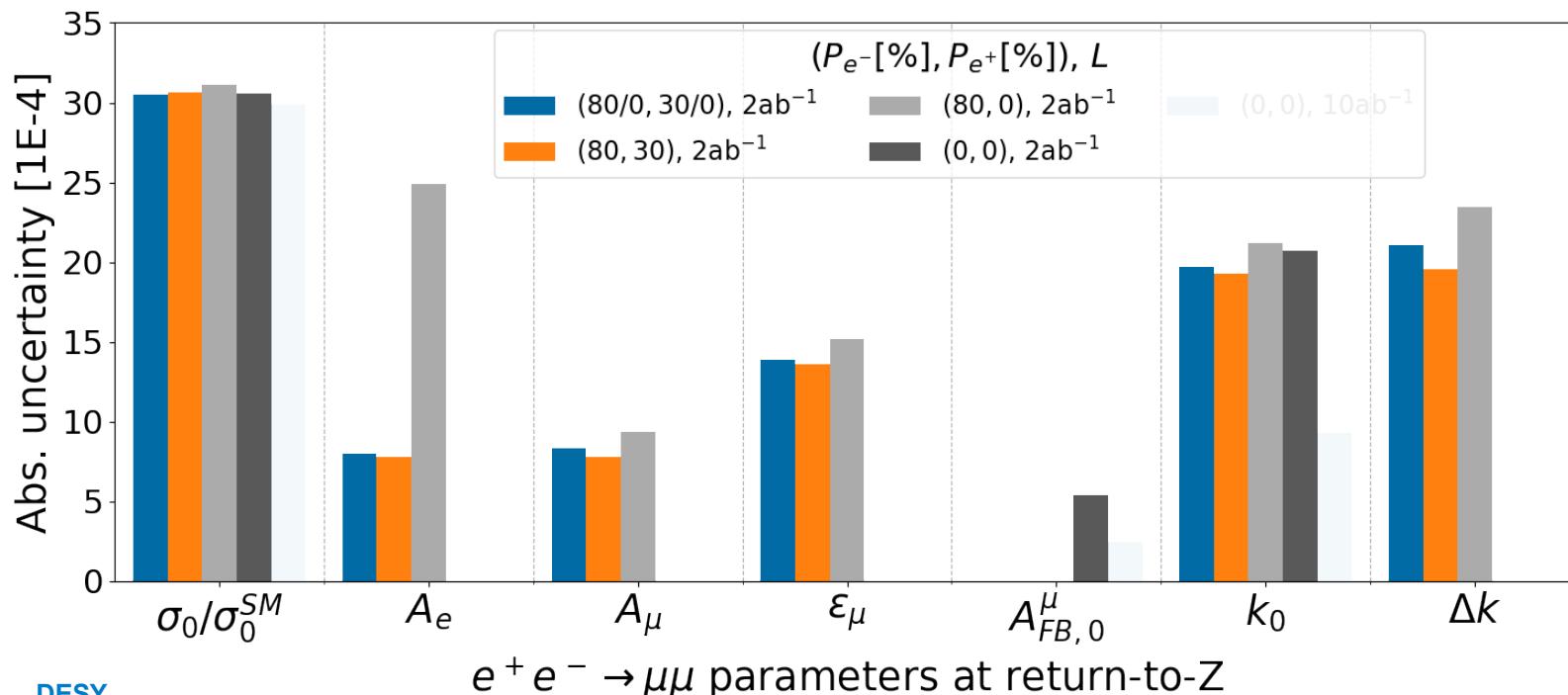


Beam polarisation brings access to chiral observables

$$\frac{d\sigma_{\text{unpol}}^f}{d\cos\theta} = \frac{1}{4} \frac{3}{8} \sigma_0^f \left[(1 + \cos^2\theta) + \frac{8}{3} A_{FB}^f \cos\theta + \frac{k_0}{2} (1 - 3\cos^2\theta) \right]$$

$$\frac{d\sigma_{LR}^f}{d\cos\theta} = \frac{3}{8} \sigma_0^f \frac{1 + A_e}{2} \left[\left(1 + \frac{k_0 + \Delta k}{2}\right) + (\epsilon_f + 2A_f) \cos\theta + \left(1 - 3\frac{k_0 + \Delta k}{2}\right) \cos^2\theta \right]$$

$$\frac{d\sigma_{RL}^f}{d\cos\theta} = \frac{3}{8} \sigma_0^f \frac{1 - A_e}{2} \left[\left(1 + \frac{k_0 - \Delta k}{2}\right) + (\epsilon_f - 2A_f) \cos\theta + \left(1 - 3\frac{k_0 - \Delta k}{2}\right) \cos^2\theta \right]$$

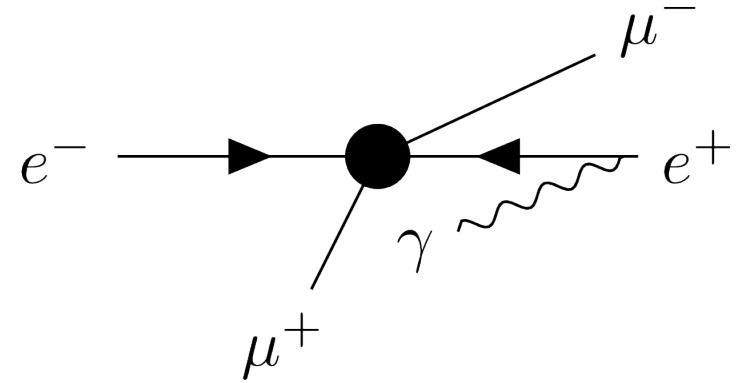
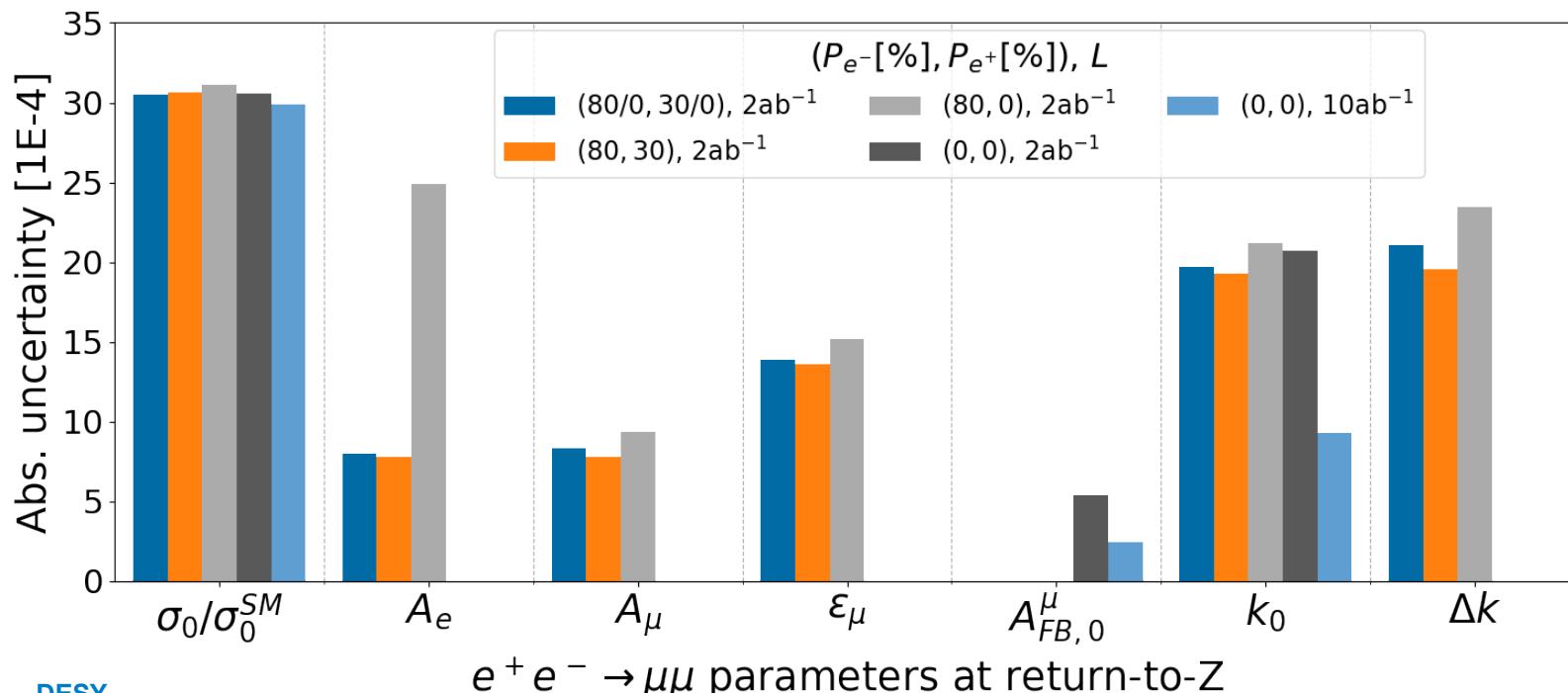


Beam polarisation brings access to chiral observables

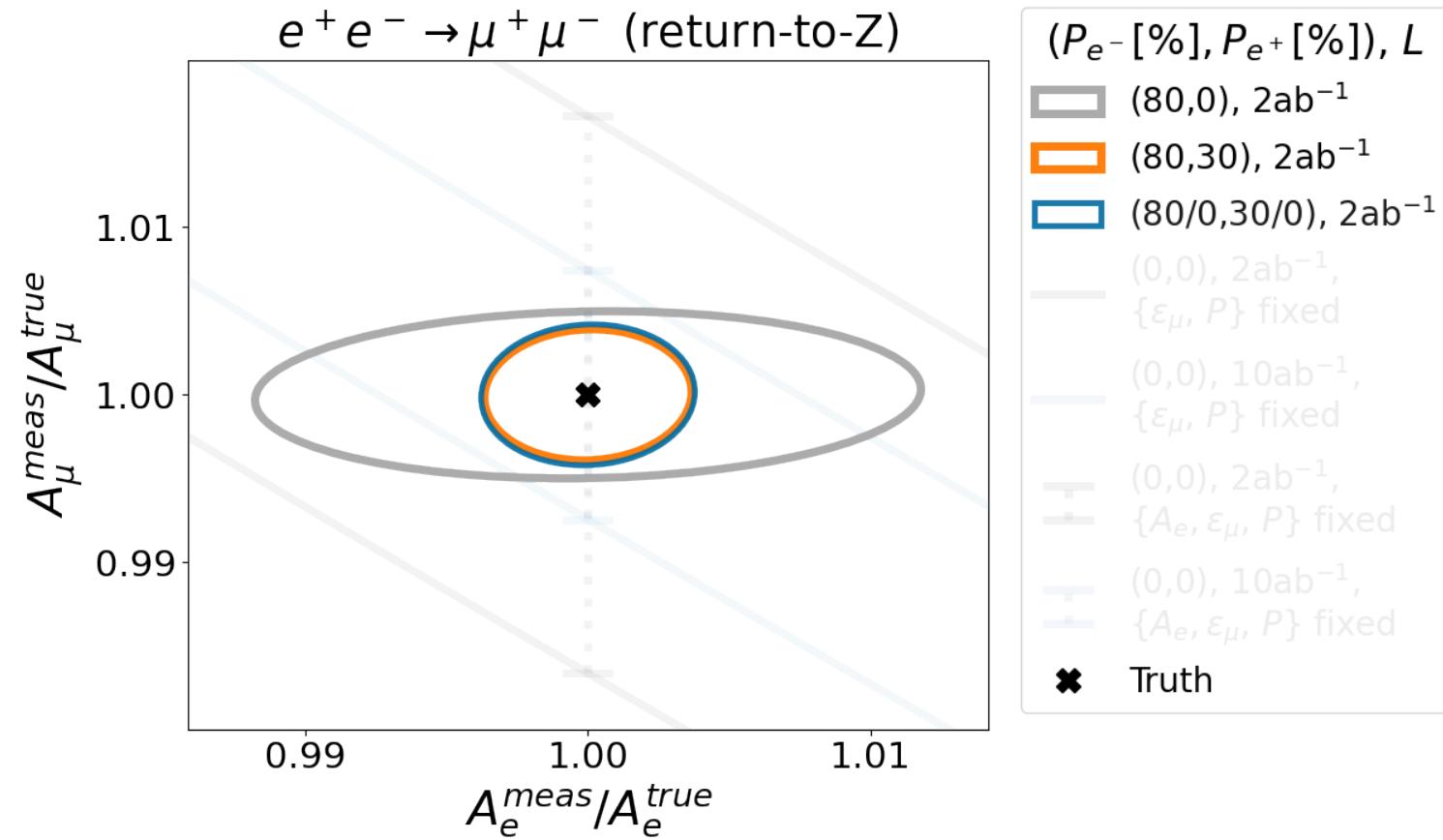
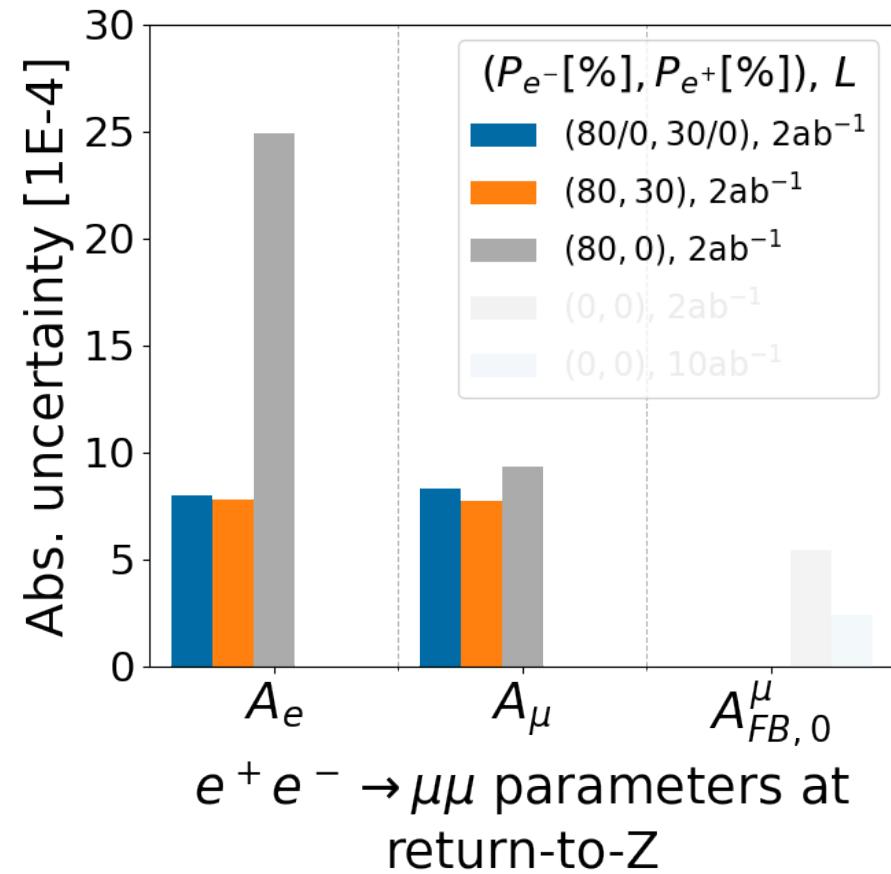
$$\frac{d\sigma_{\text{unpol}}^f}{d\cos\theta} = \frac{1}{4} \frac{3}{8} \sigma_0^f \left[(1 + \cos^2\theta) + \frac{8}{3} A_{FB}^f \cos\theta + \frac{k_0}{2} (1 - 3\cos^2\theta) \right]$$

$$\frac{d\sigma_{LR}^f}{d\cos\theta} = \frac{3}{8} \sigma_0^f \frac{1 + A_e}{2} \left[\left(1 + \frac{k_0 + \Delta k}{2}\right) + (\epsilon_f + 2A_f) \cos\theta + \left(1 - 3\frac{k_0 + \Delta k}{2}\right) \cos^2\theta \right]$$

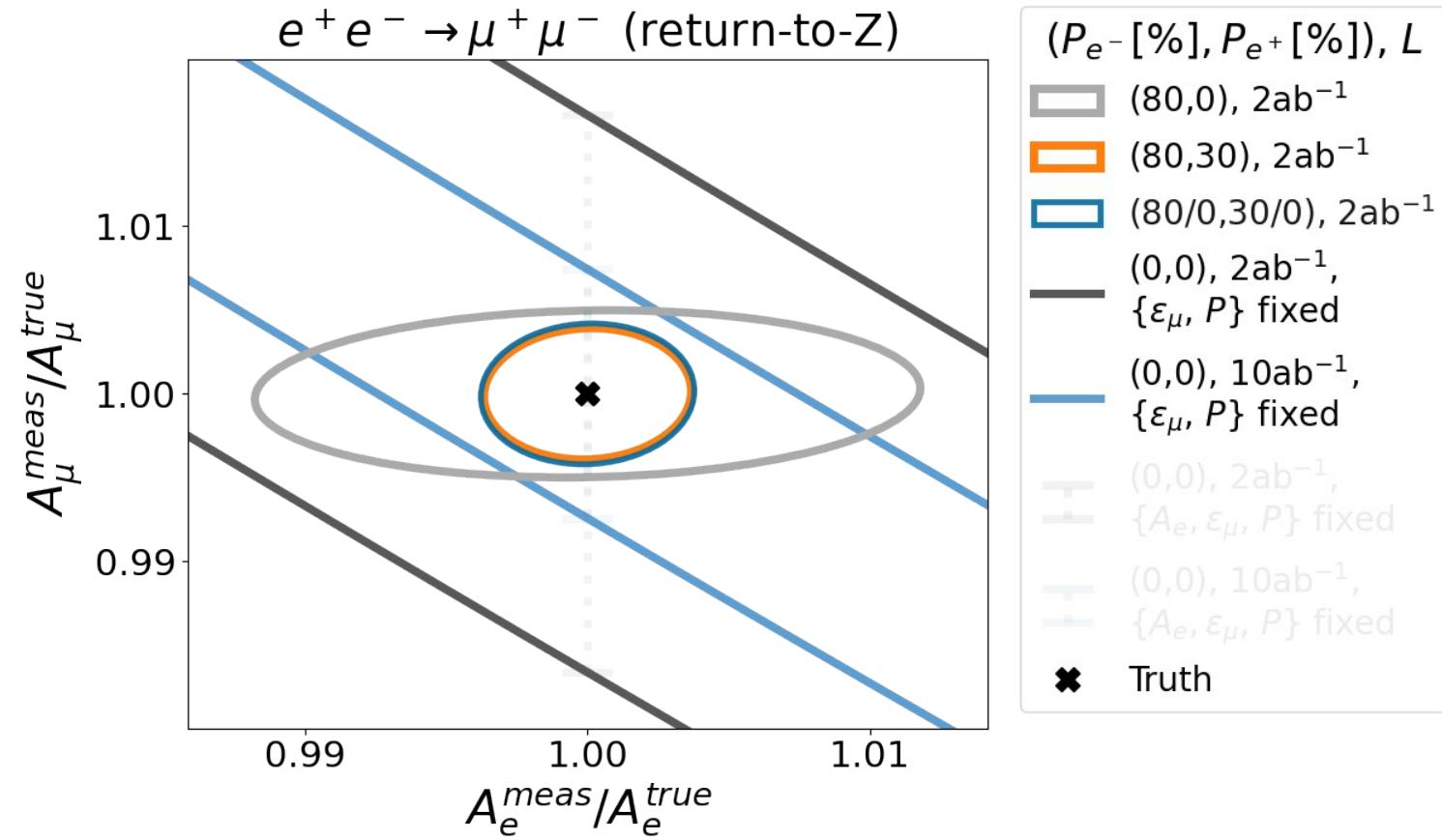
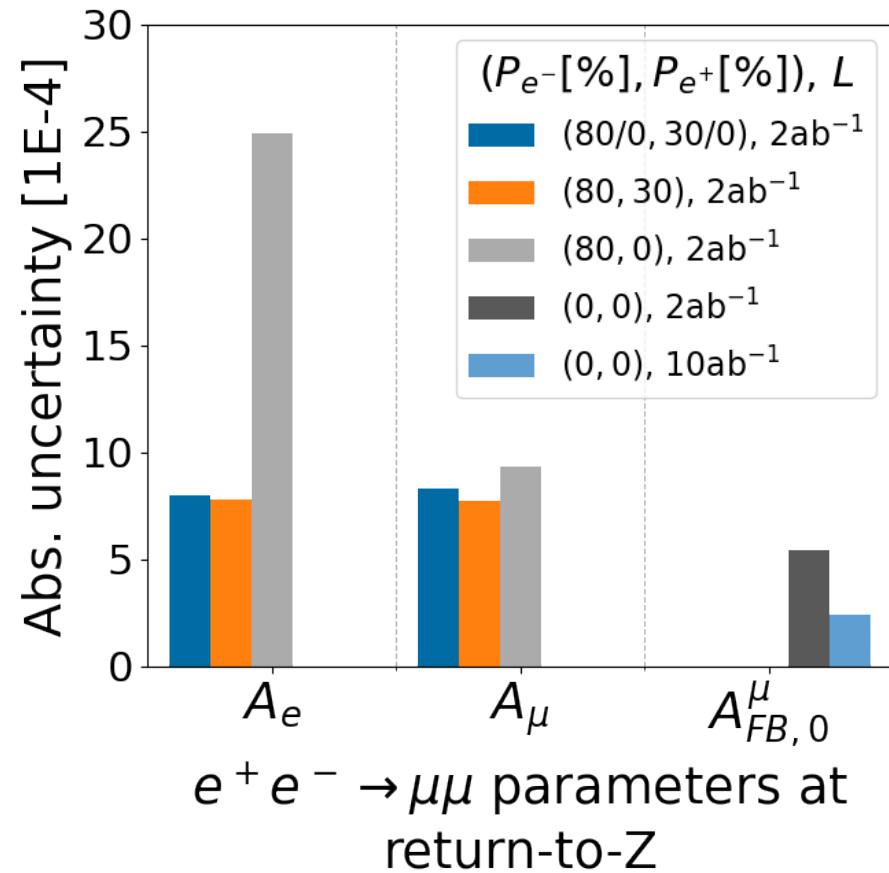
$$\frac{d\sigma_{RL}^f}{d\cos\theta} = \frac{3}{8} \sigma_0^f \frac{1 - A_e}{2} \left[\left(1 + \frac{k_0 - \Delta k}{2}\right) + (\epsilon_f - 2A_f) \cos\theta + \left(1 - 3\frac{k_0 - \Delta k}{2}\right) \cos^2\theta \right]$$



Beam polarisation removes assumptions & brings precision

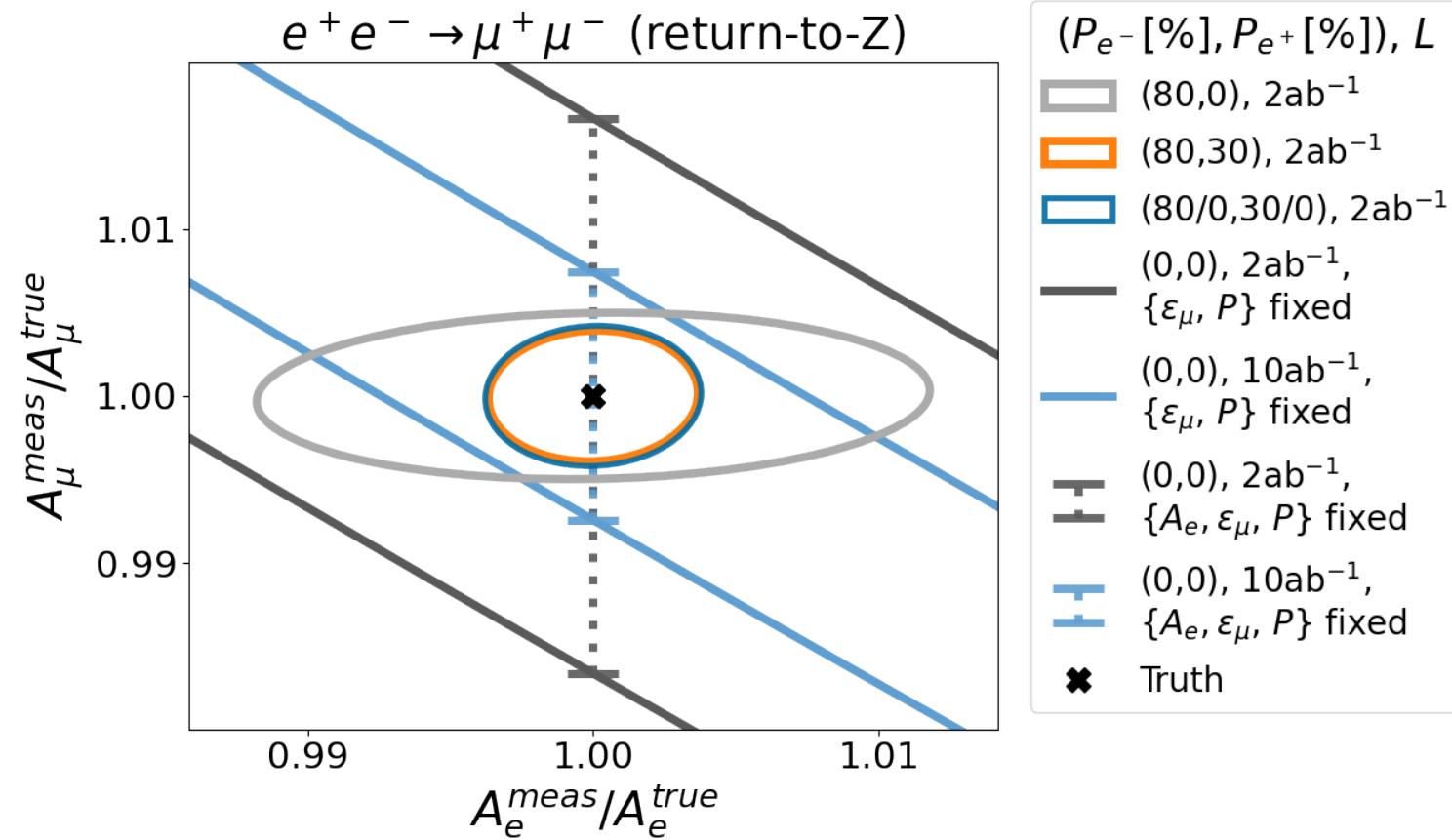
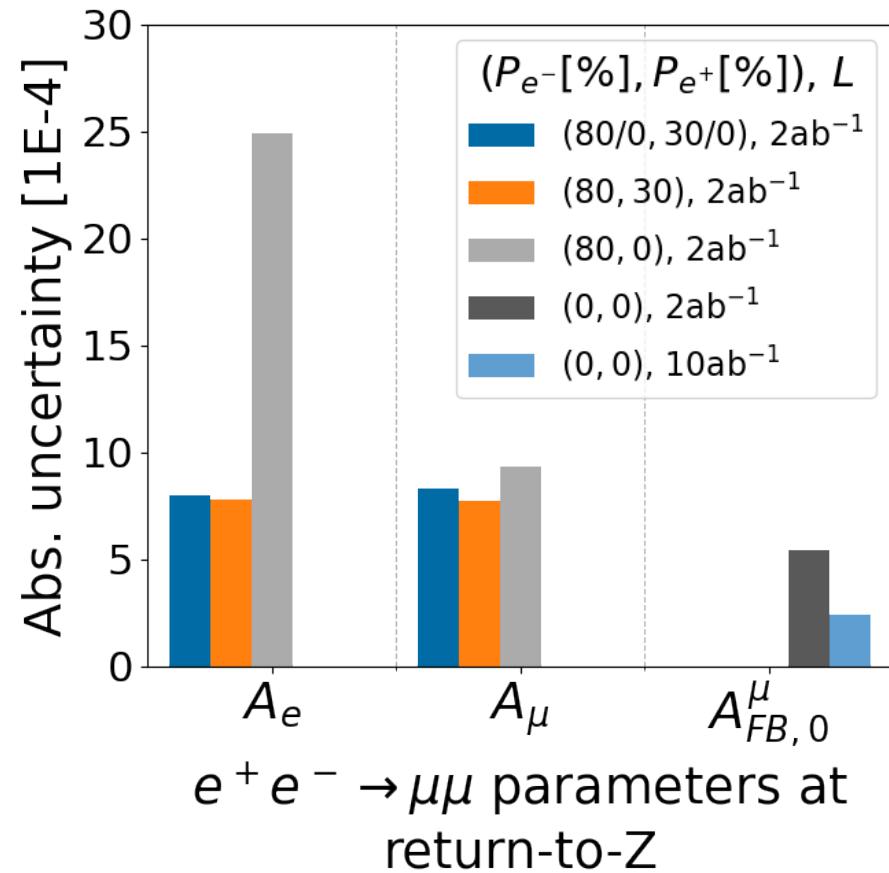


Beam polarisation removes assumptions & brings precision



$$A_{FB,0}^\mu = \frac{3}{8} \left(\epsilon_\mu + 2A_\mu \frac{\mathcal{P}_{\text{eff}} + A_e}{1 + \mathcal{P}_{\text{eff}} A_e} \right)$$

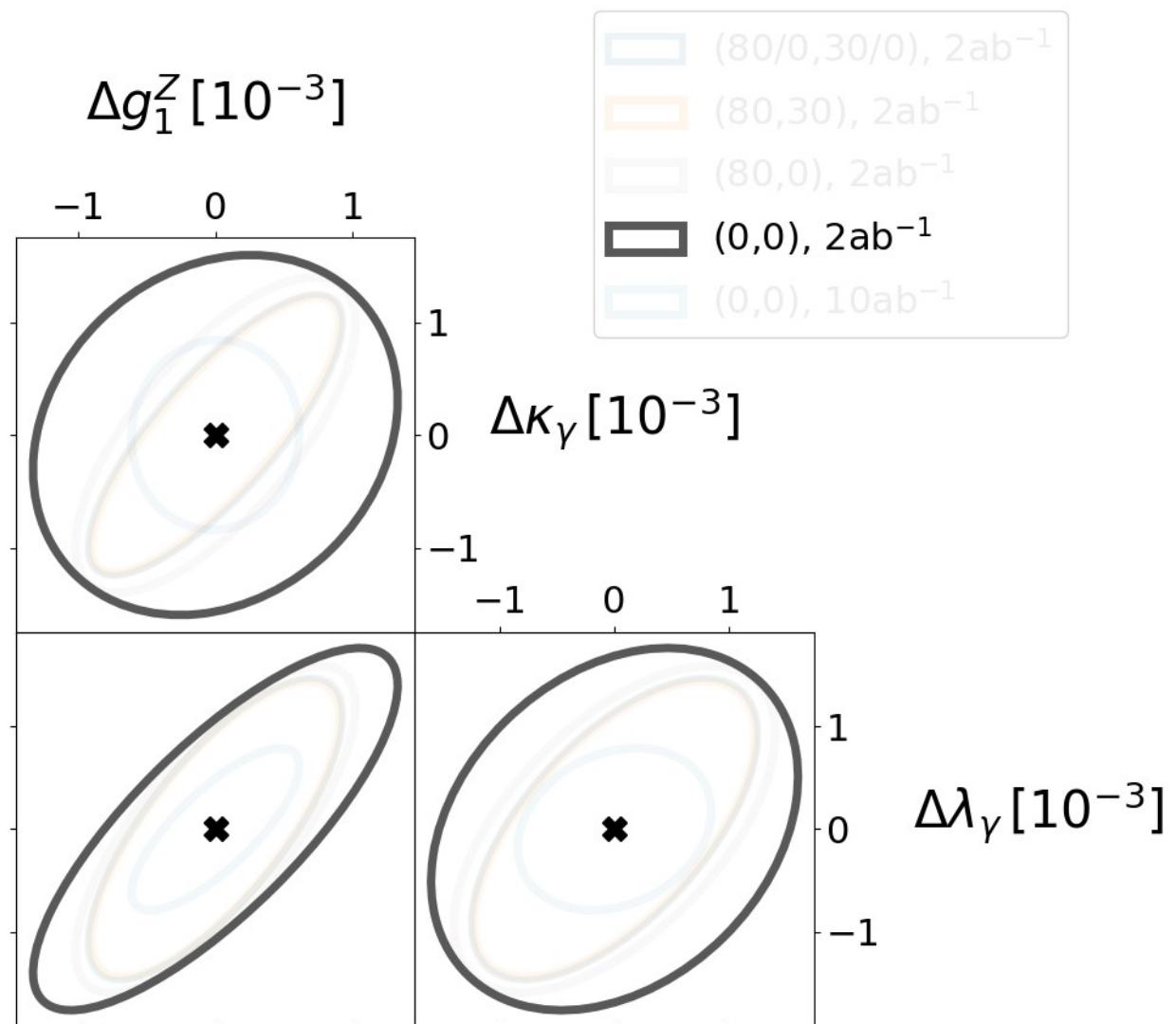
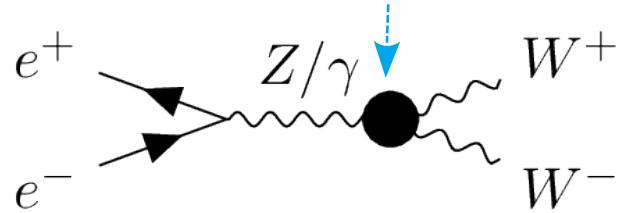
Beam polarisation removes assumptions & brings precision



$$A_{FB,0}^\mu = \frac{3}{8} \left(\epsilon_\mu + 2A_\mu \frac{\mathcal{P}_{\text{eff}} + A_e}{1 + \mathcal{P}_{\text{eff}} A_e} \right)$$

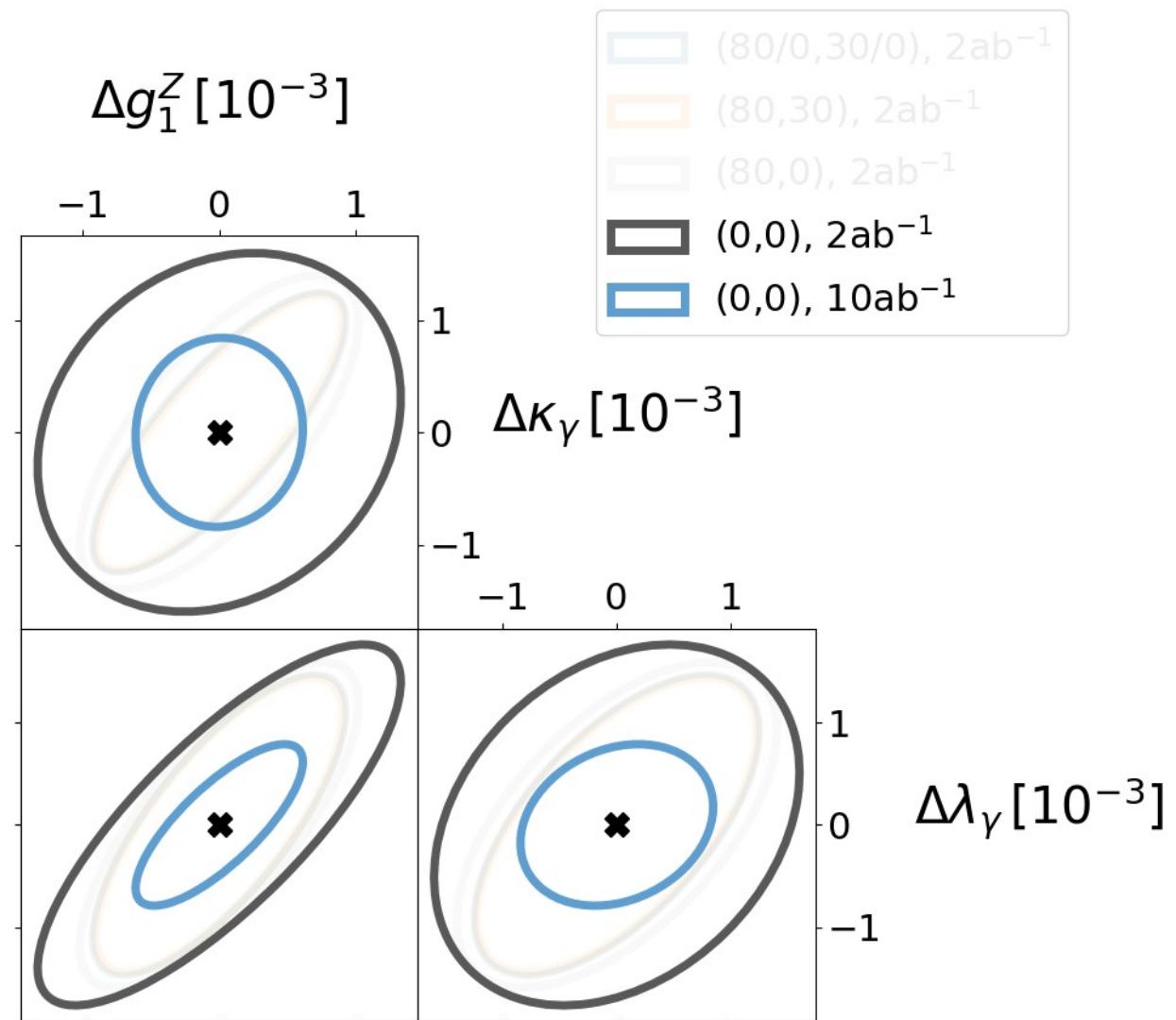
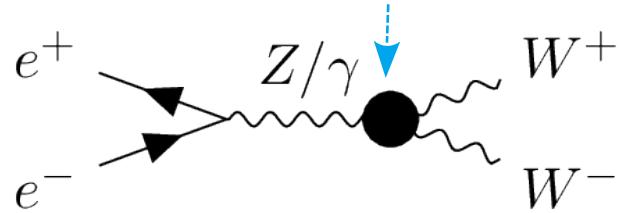
Chiral asymmetry measurement for TGC limits

Triple Gauge Couplings: $g_1^Z, \kappa_y, \lambda_y$



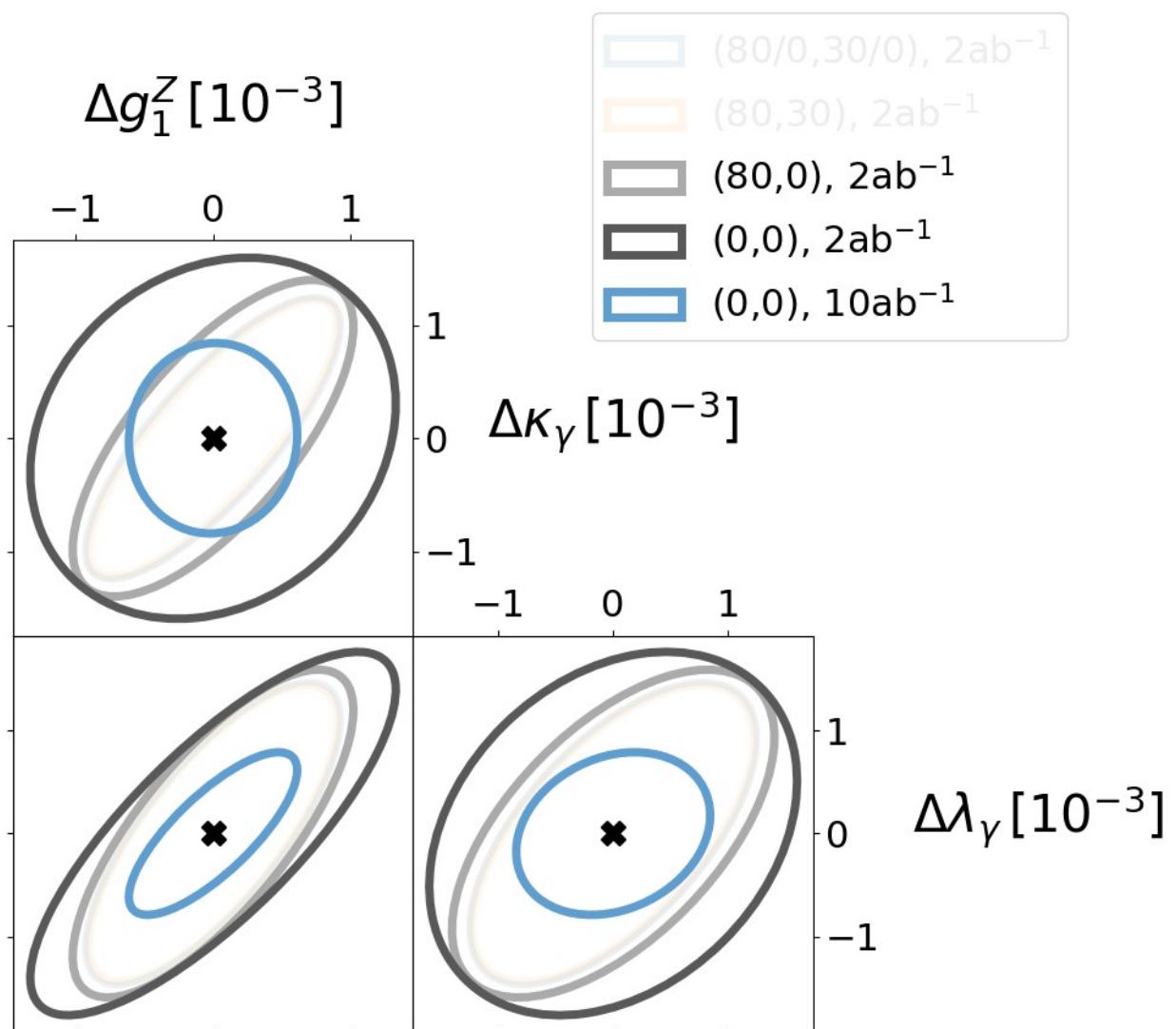
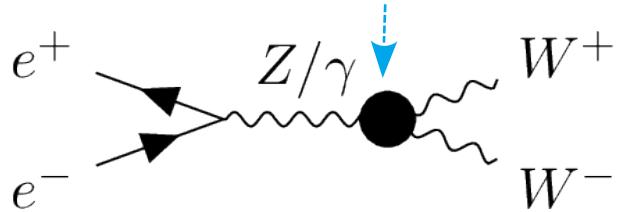
Chiral asymmetry measurement for TGC limits

Triple Gauge Couplings: $g_1^Z, \kappa_y, \lambda_y$



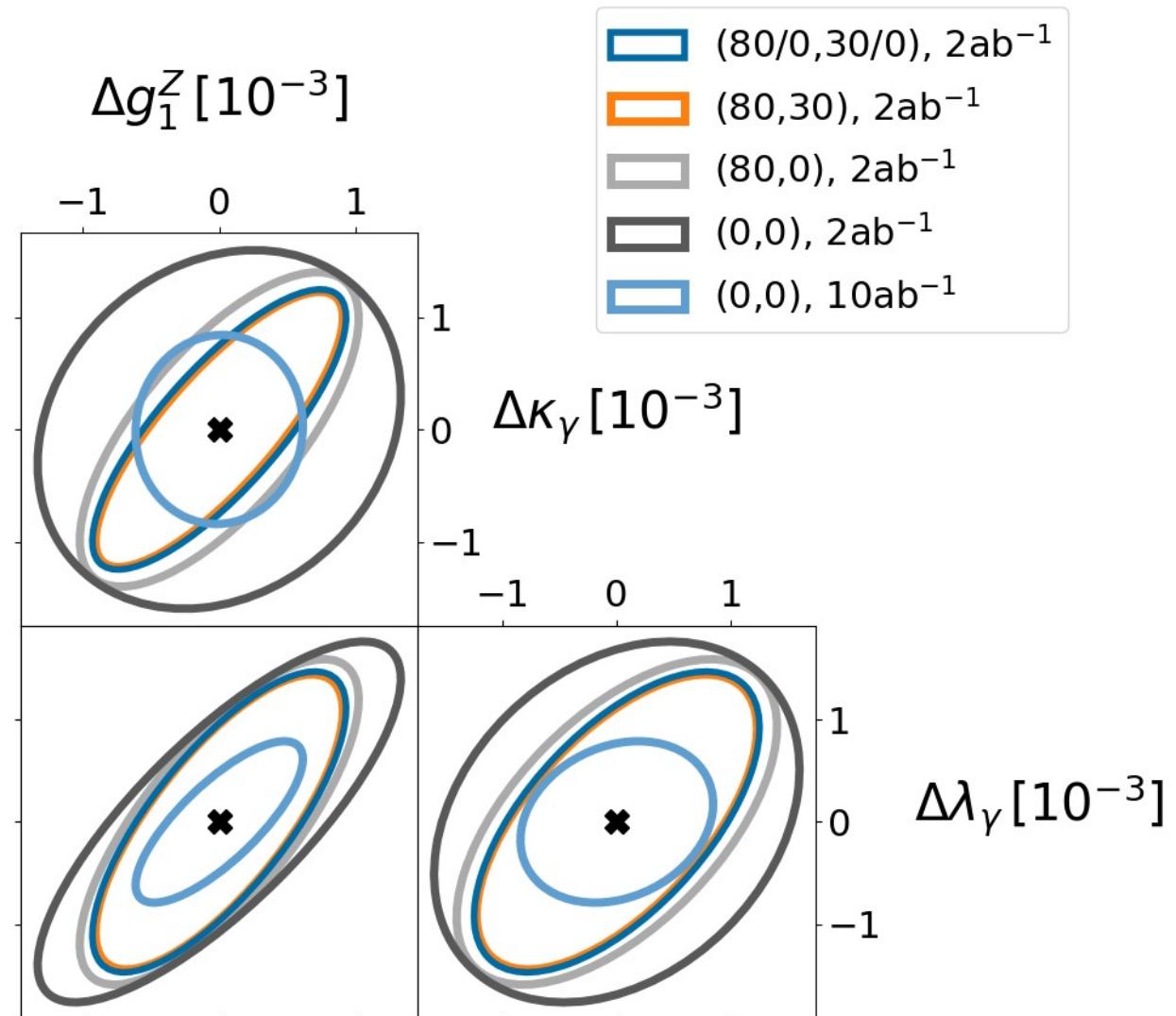
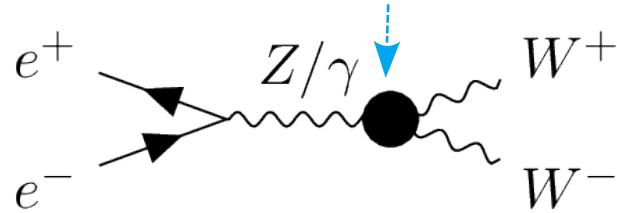
Chiral asymmetry measurement for TGC limits

Triple Gauge Couplings: $g_1^Z, \kappa_y, \lambda_y$



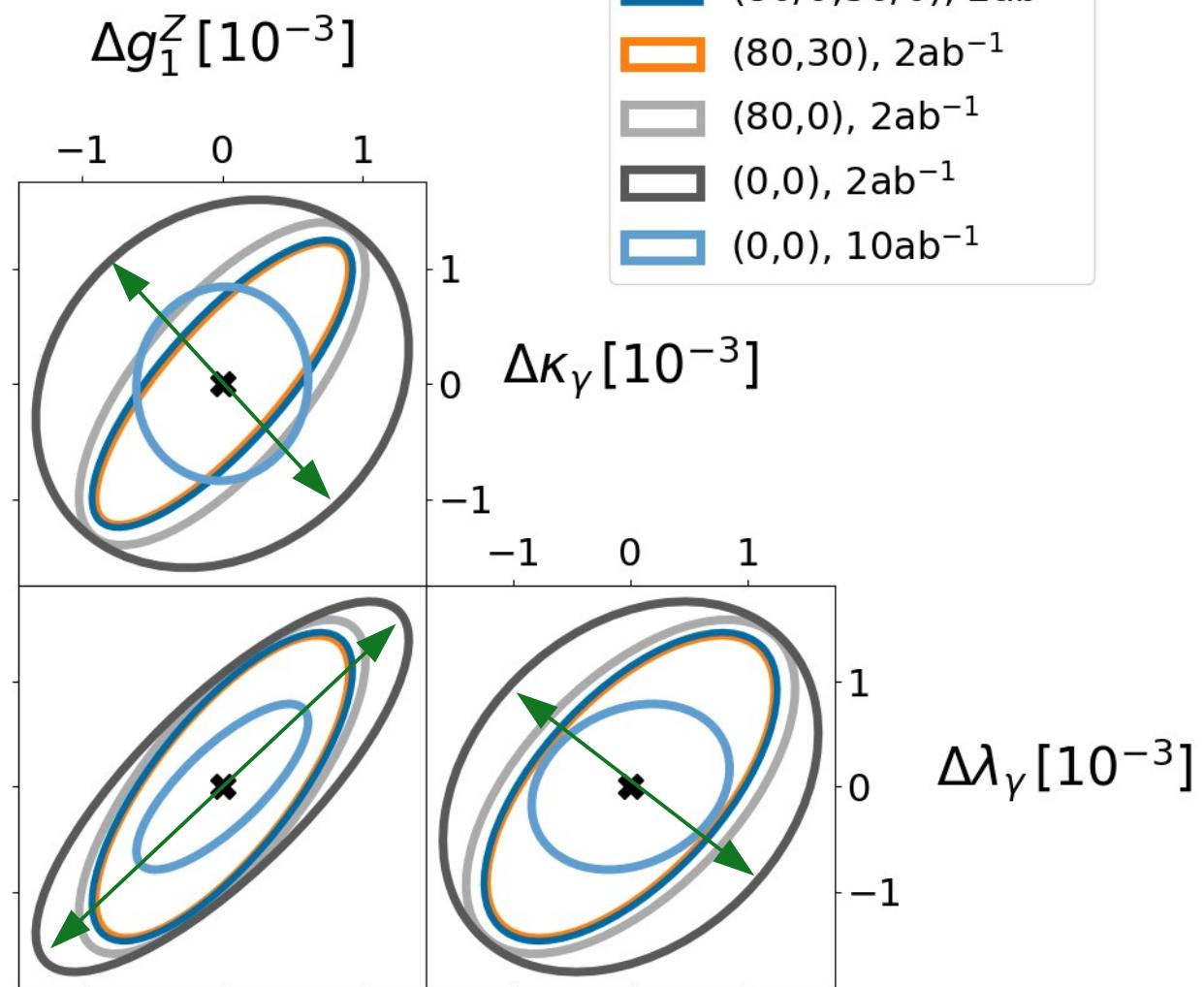
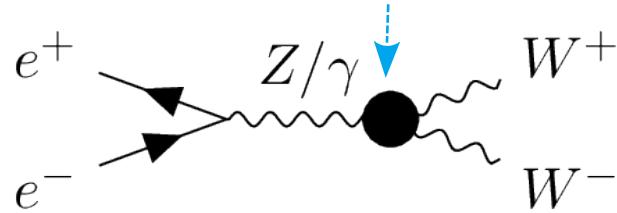
Chiral asymmetry measurement for TGC limits

Triple Gauge Couplings: $g_1^Z, \kappa_y, \lambda_y$



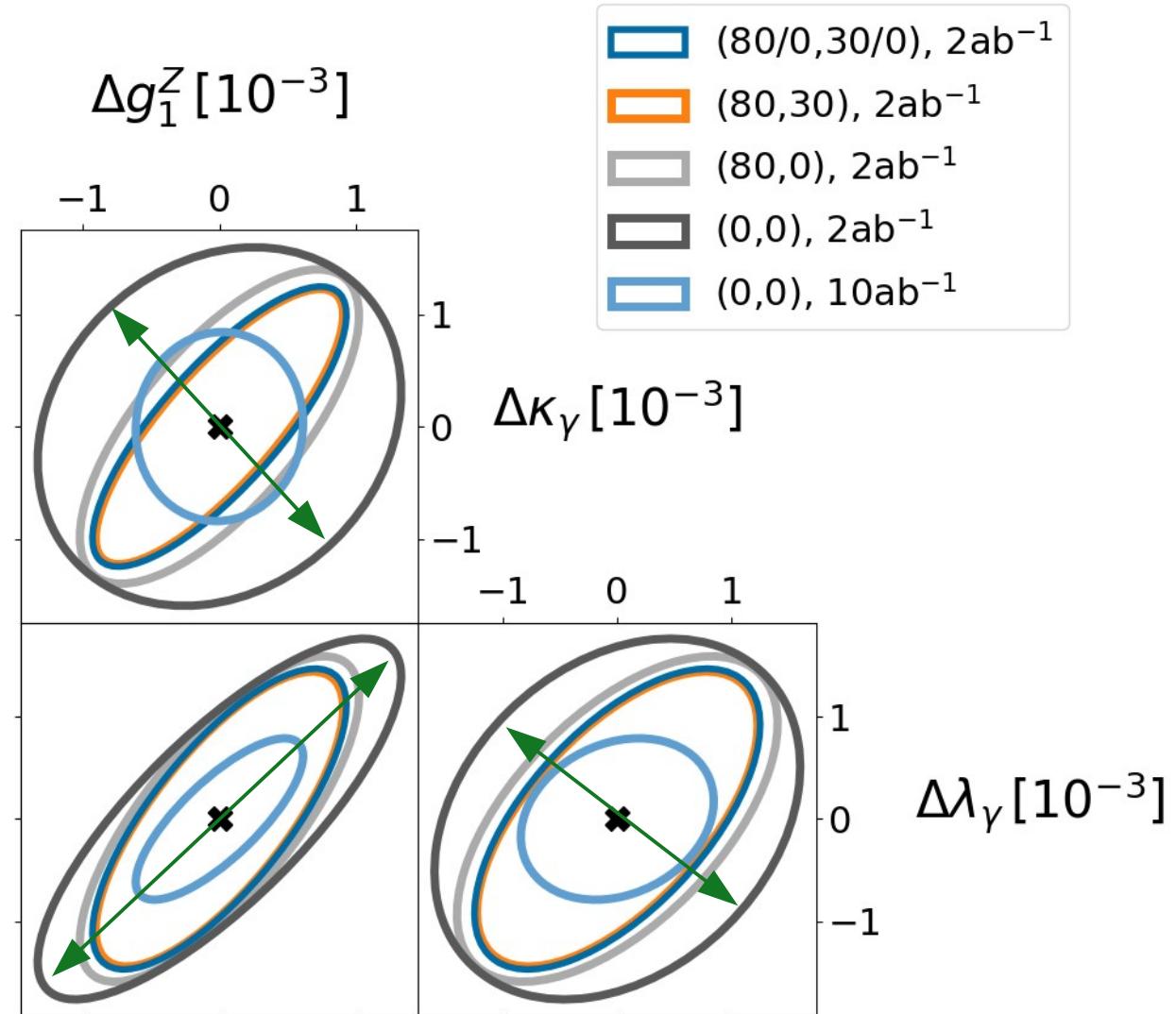
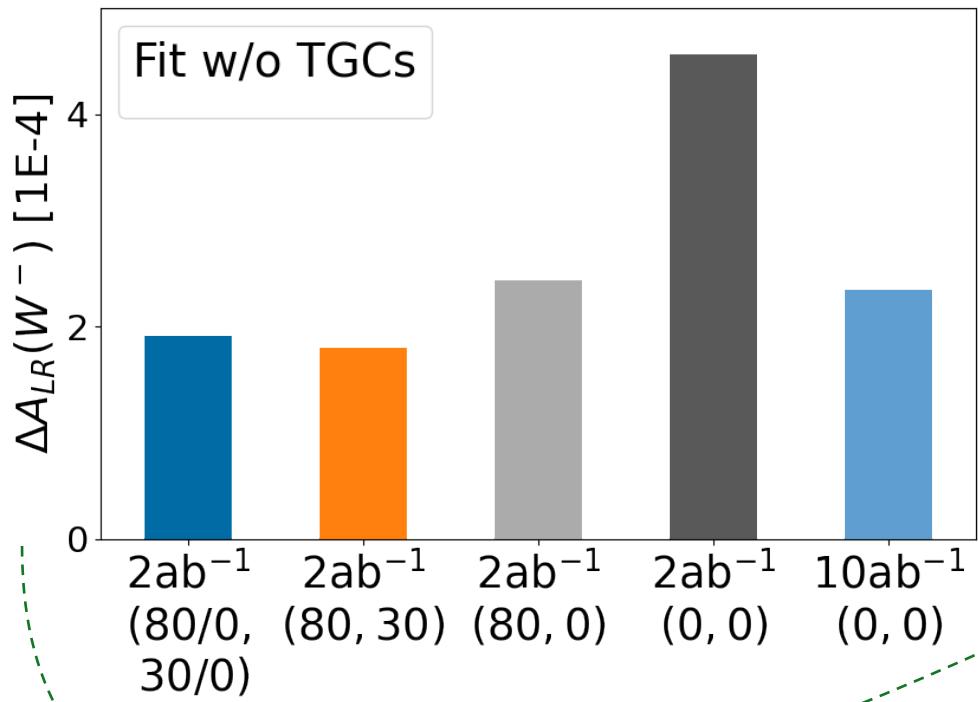
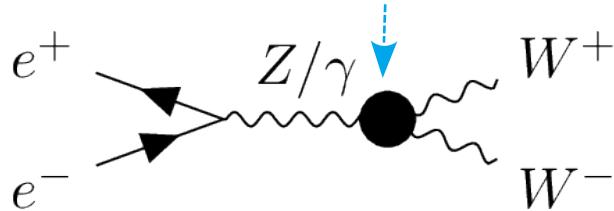
Chiral asymmetry measurement for TGC limits

Triple Gauge Couplings: $g_1^Z, \kappa_y, \lambda_y$

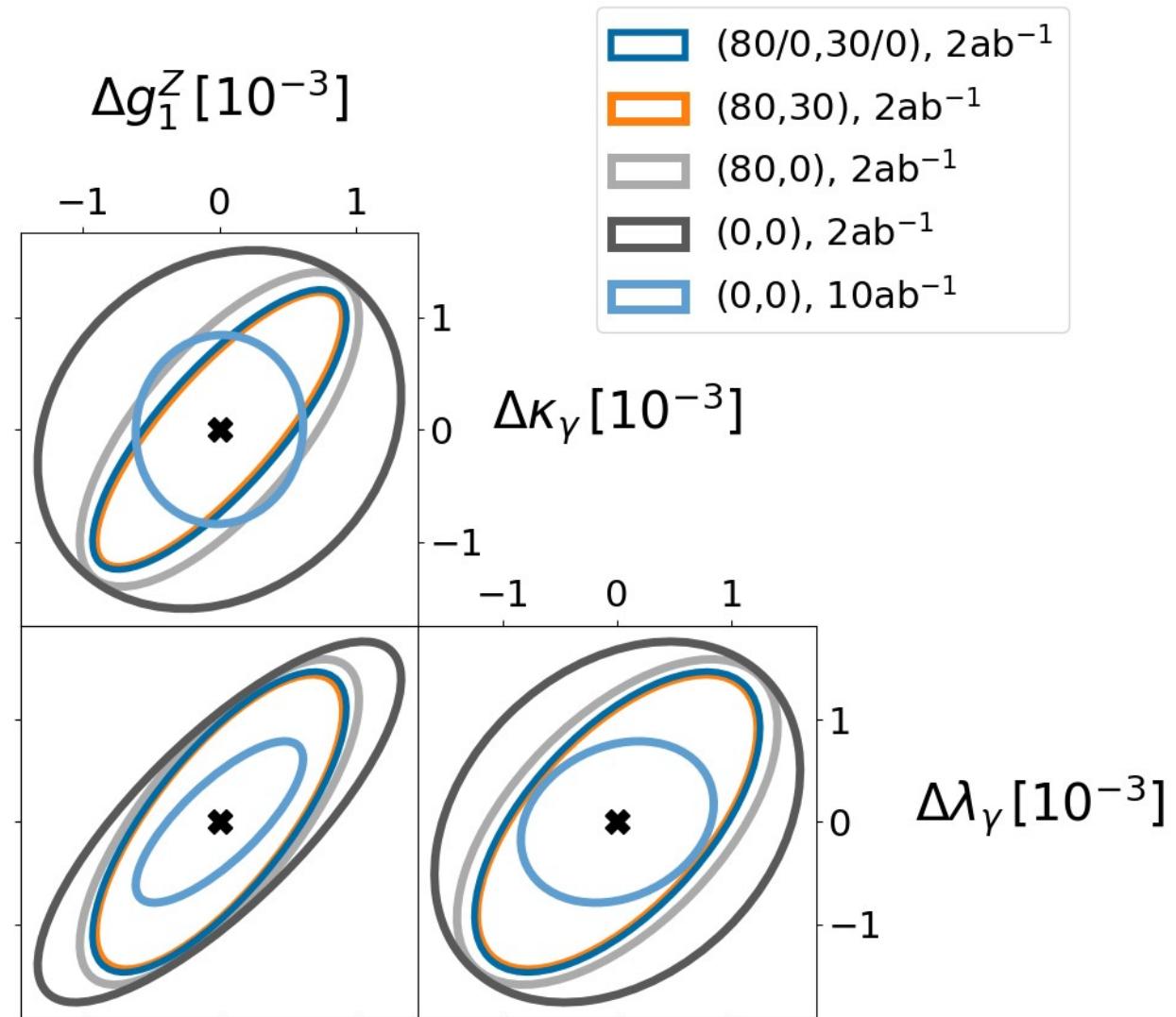
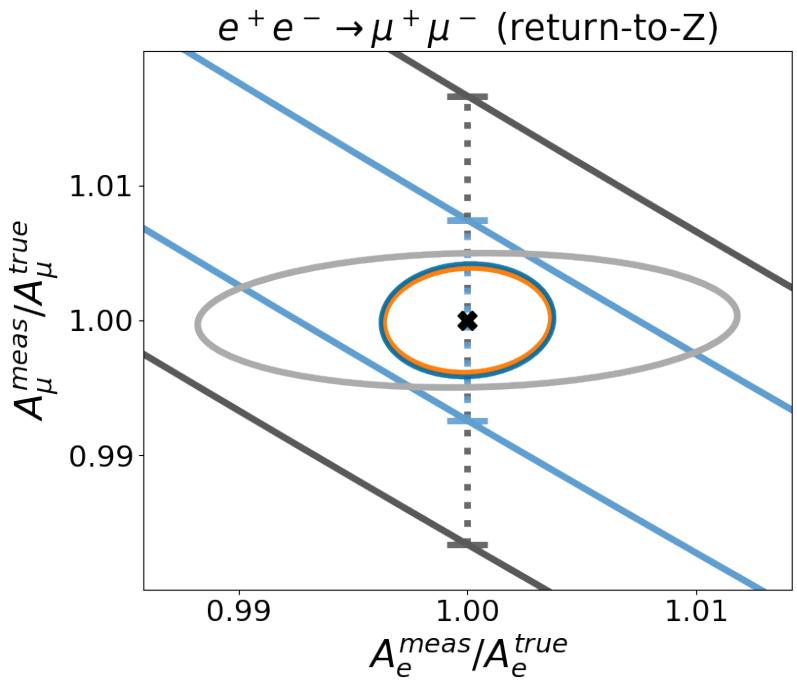


Chiral asymmetry measurement for TGC limits

Triple Gauge Couplings: $g_1^Z, \kappa_y, \lambda_y$

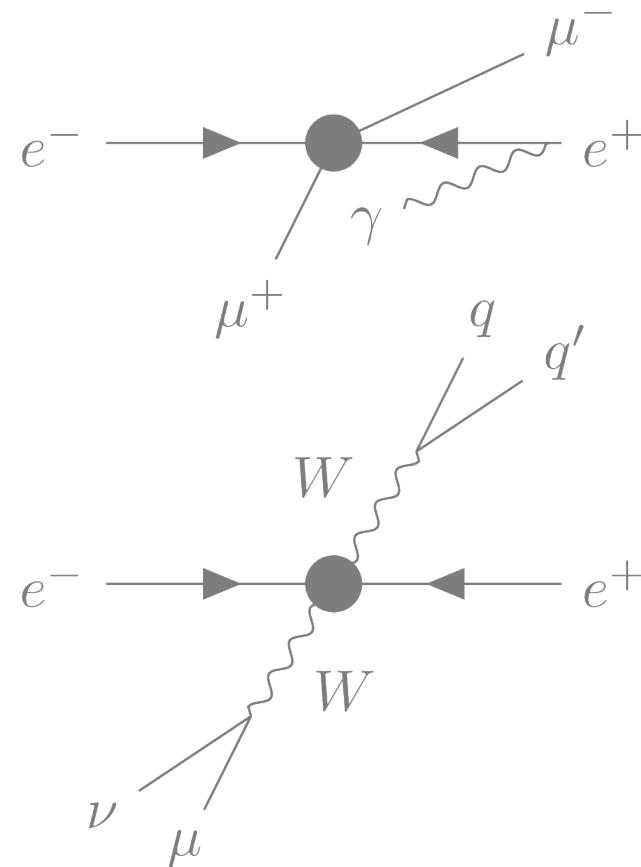


Beam polarisation brings assumption-free precision

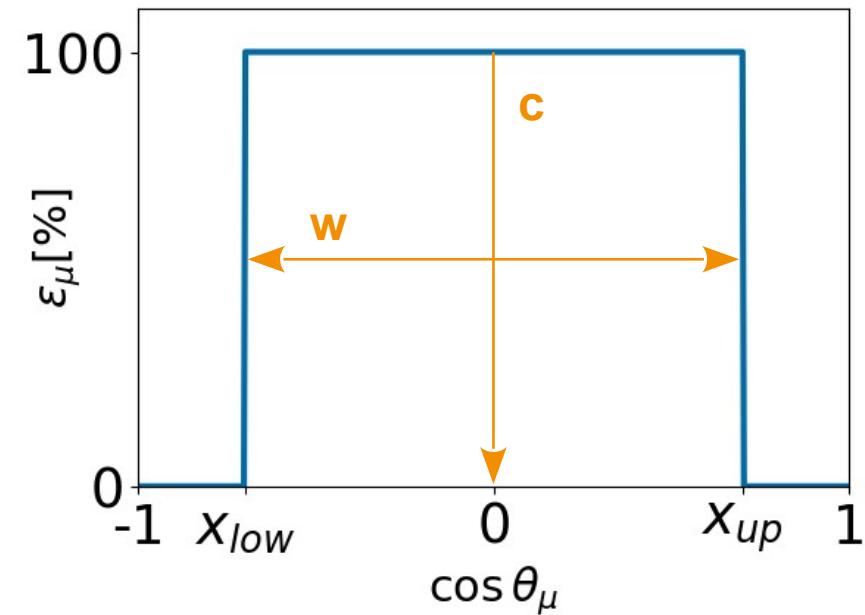


Beam polarisation improves EW measurements ...

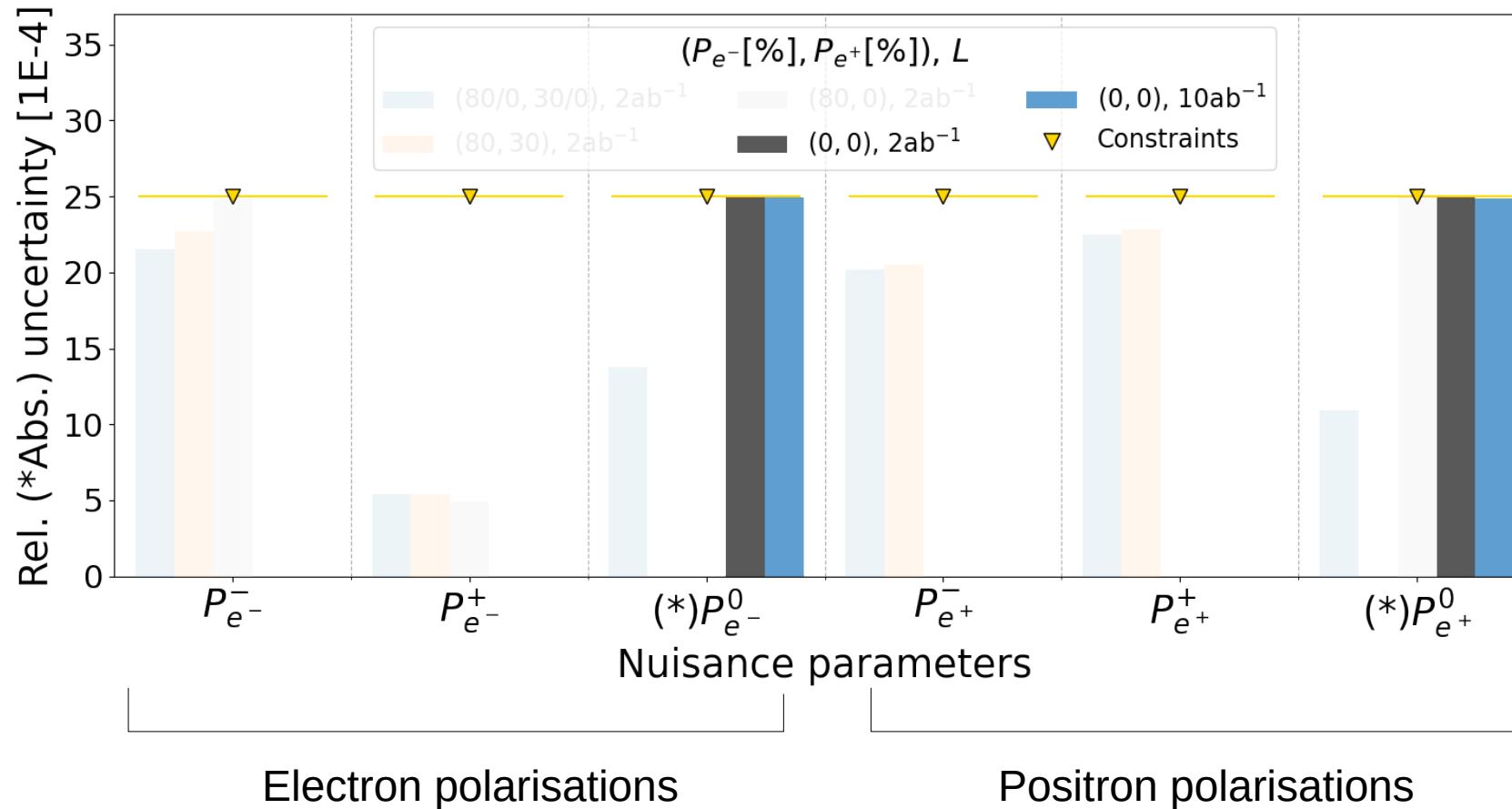
... by direct access to chiral observables



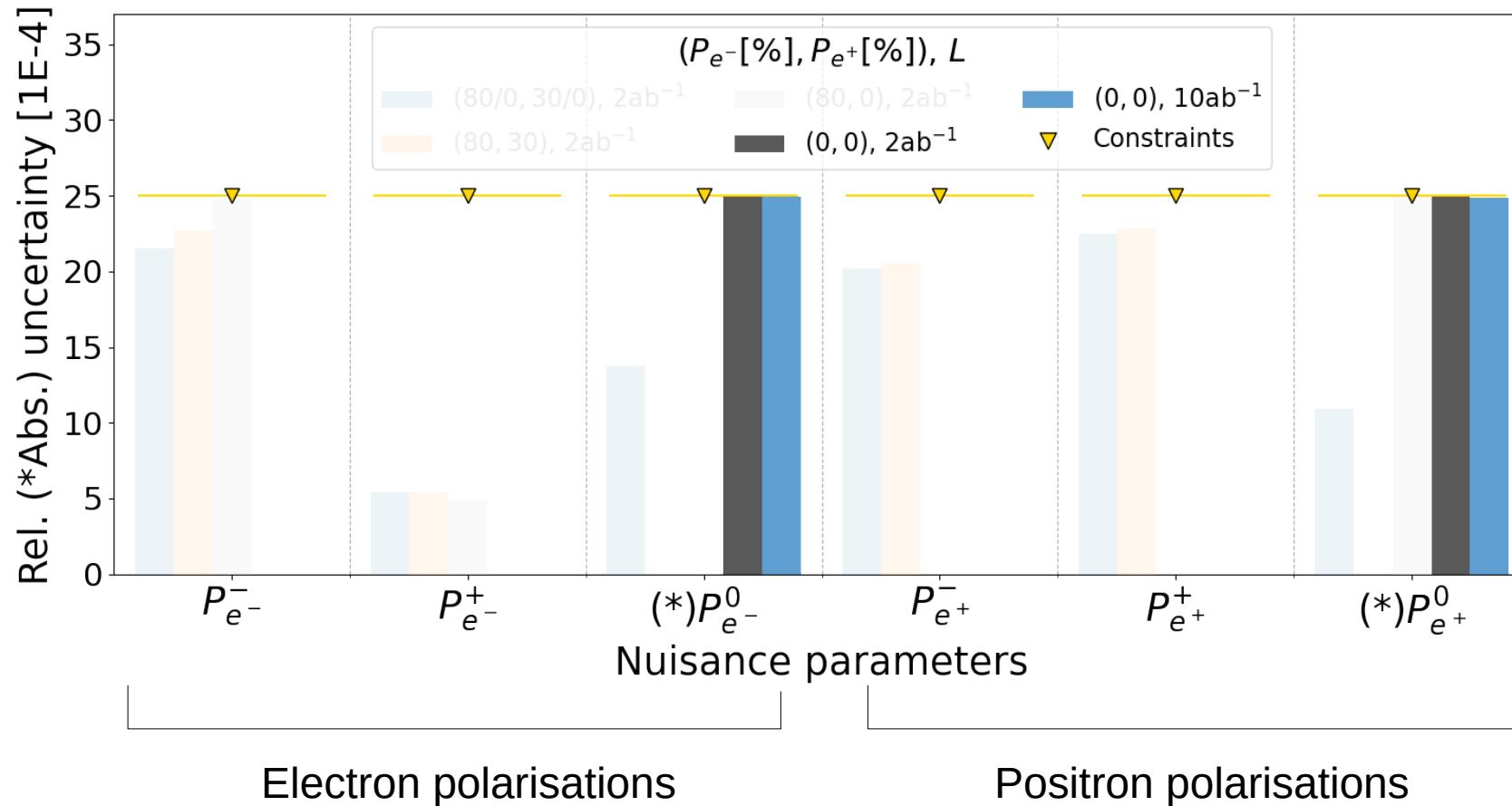
... by minimizing systematic uncertainties



Polarisation for polarisations sake (mostly from WW)



Polarisation for polarisations sake (mostly from WW)



Assume N_{LR} and N_{RL} measured from diff. cross-section

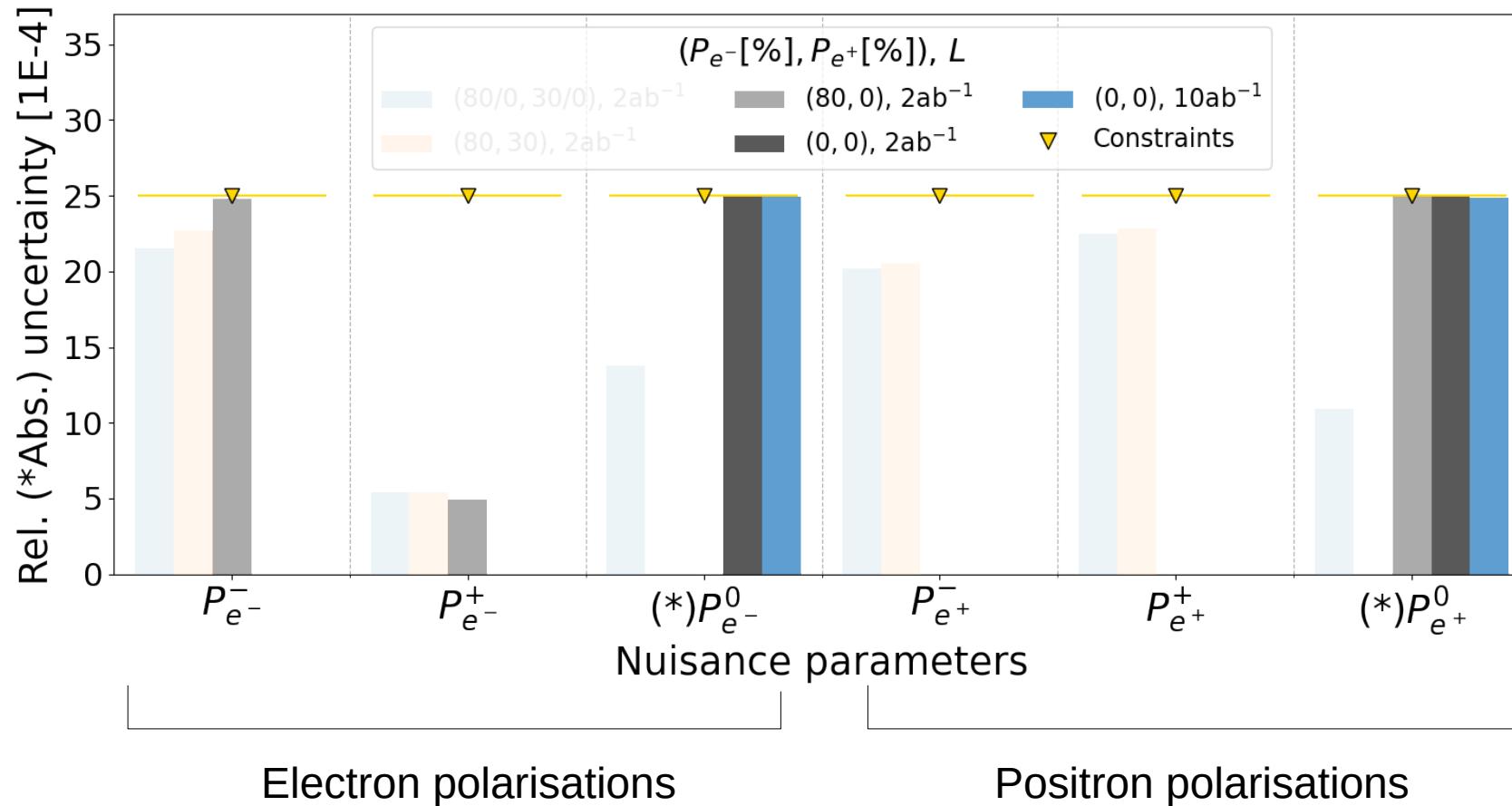
1 dataset

→ $1 \times 2 = 2$ measurement points

3 free parameters

- Norm
- 2 Polarisations

Polarisation for polarisations sake (mostly from WW)



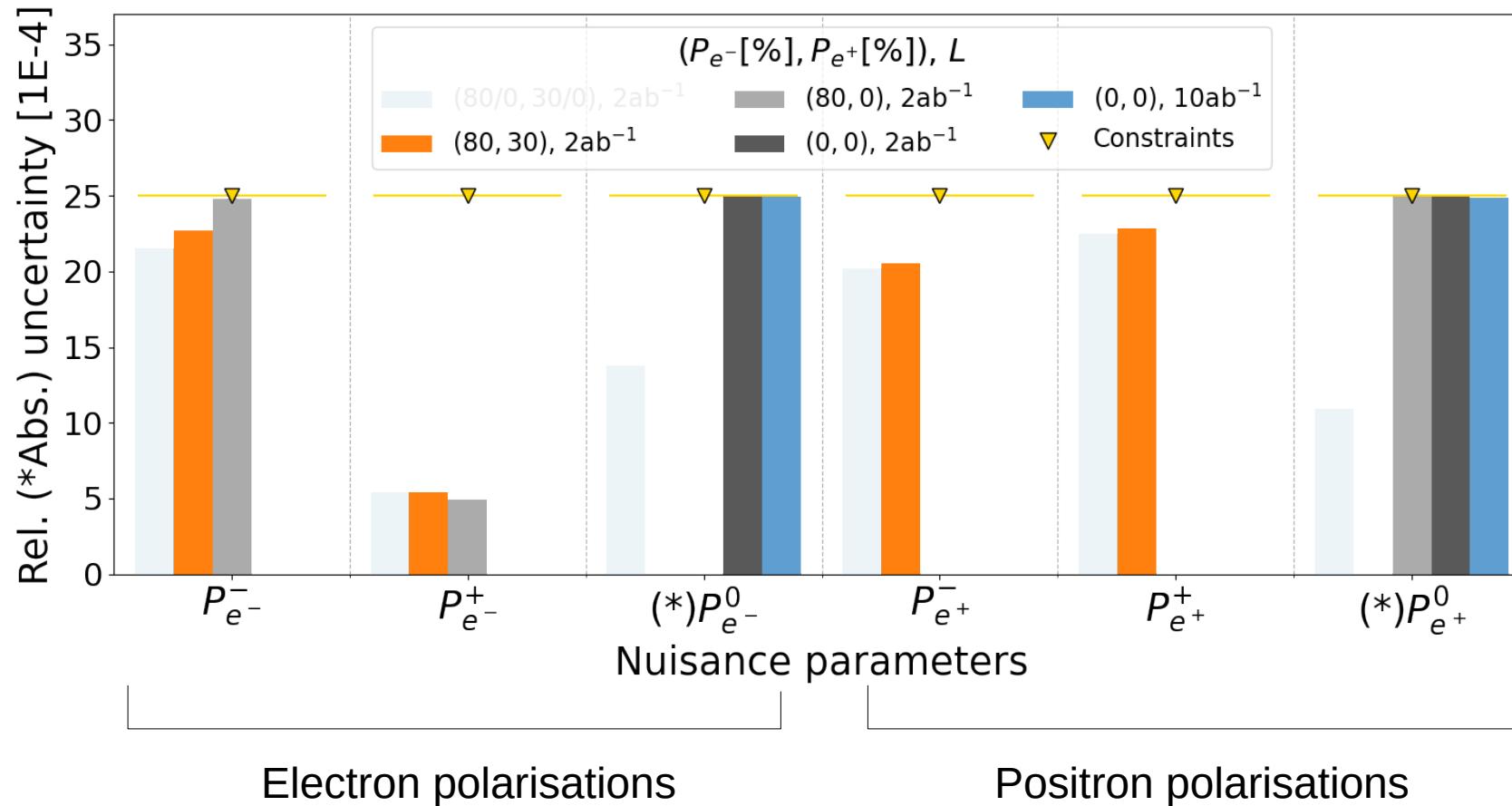
Assume N_{LR} and N_{RL} measured from diff. cross-section

2 datasets
→ **2x2=4** measurement points

4 free parameters

- Norm
- **3** Polarisations

Polarisation for polarisations sake (mostly from WW)



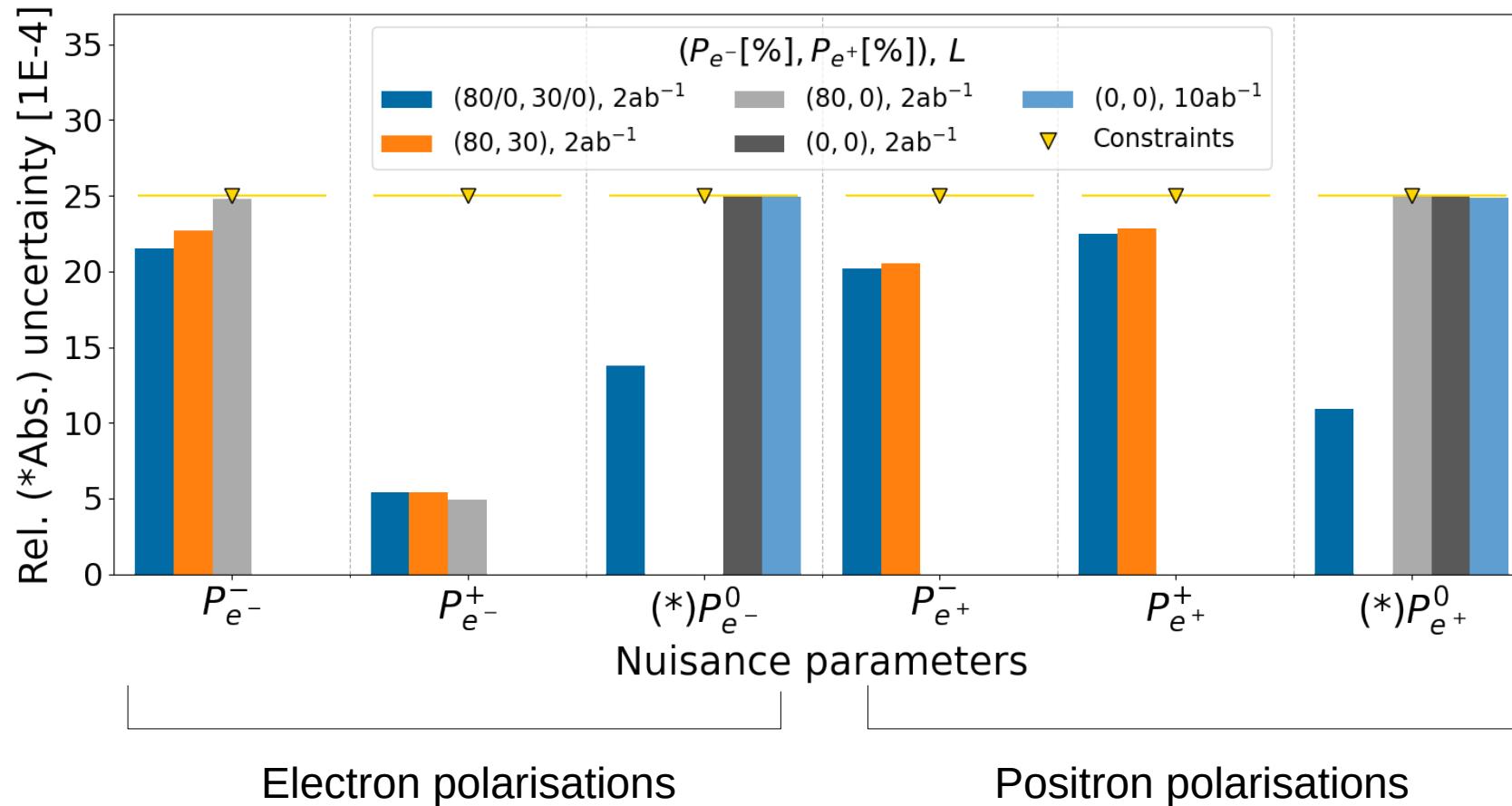
Assume N_{LR} and N_{RL} measured from diff. cross-section

4 datasets
→ **4x2=8** measurement points

5 free parameters

- Norm
- **4** Polarisations

Polarisation for polarisations sake (mostly from WW)



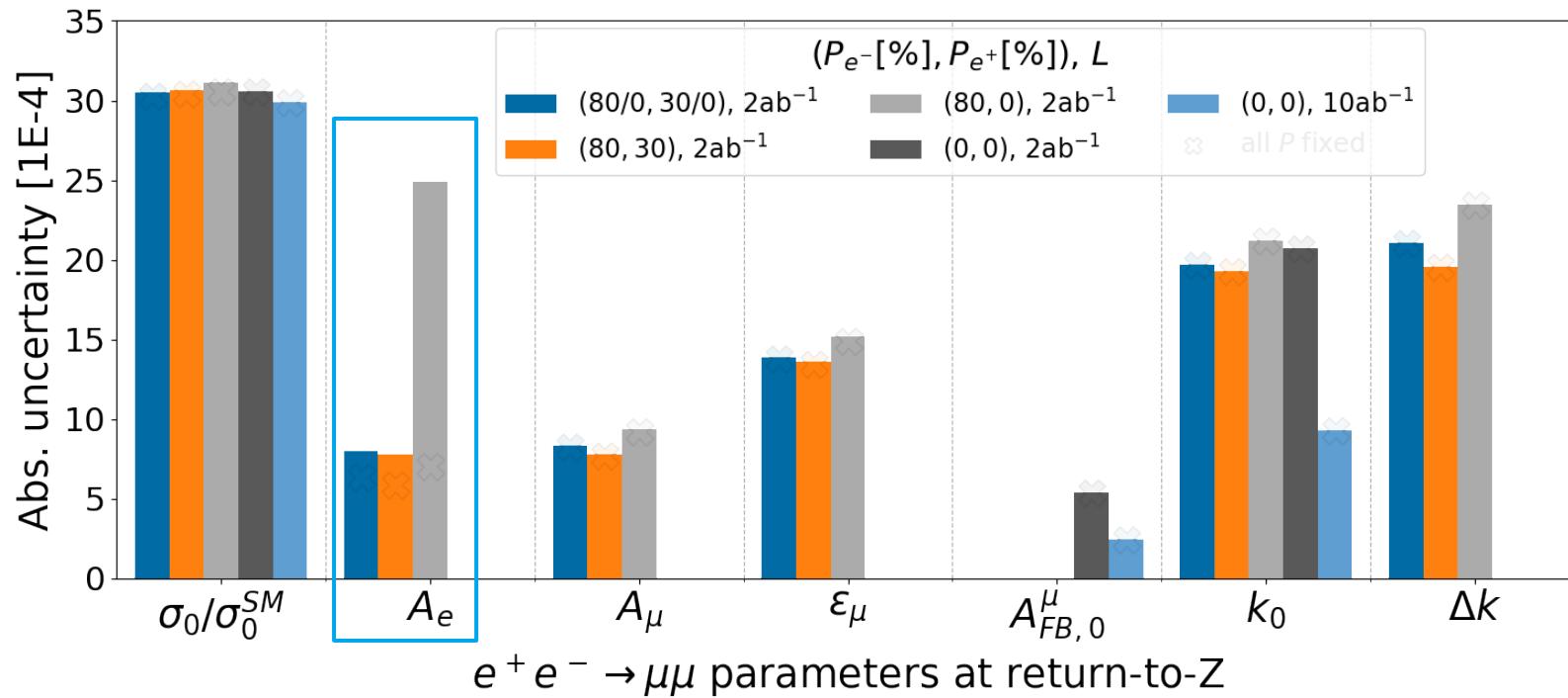
Assume N_{LR} and N_{RL} measured from diff. cross-section

9 datasets
→ **9x2=18** measurement points

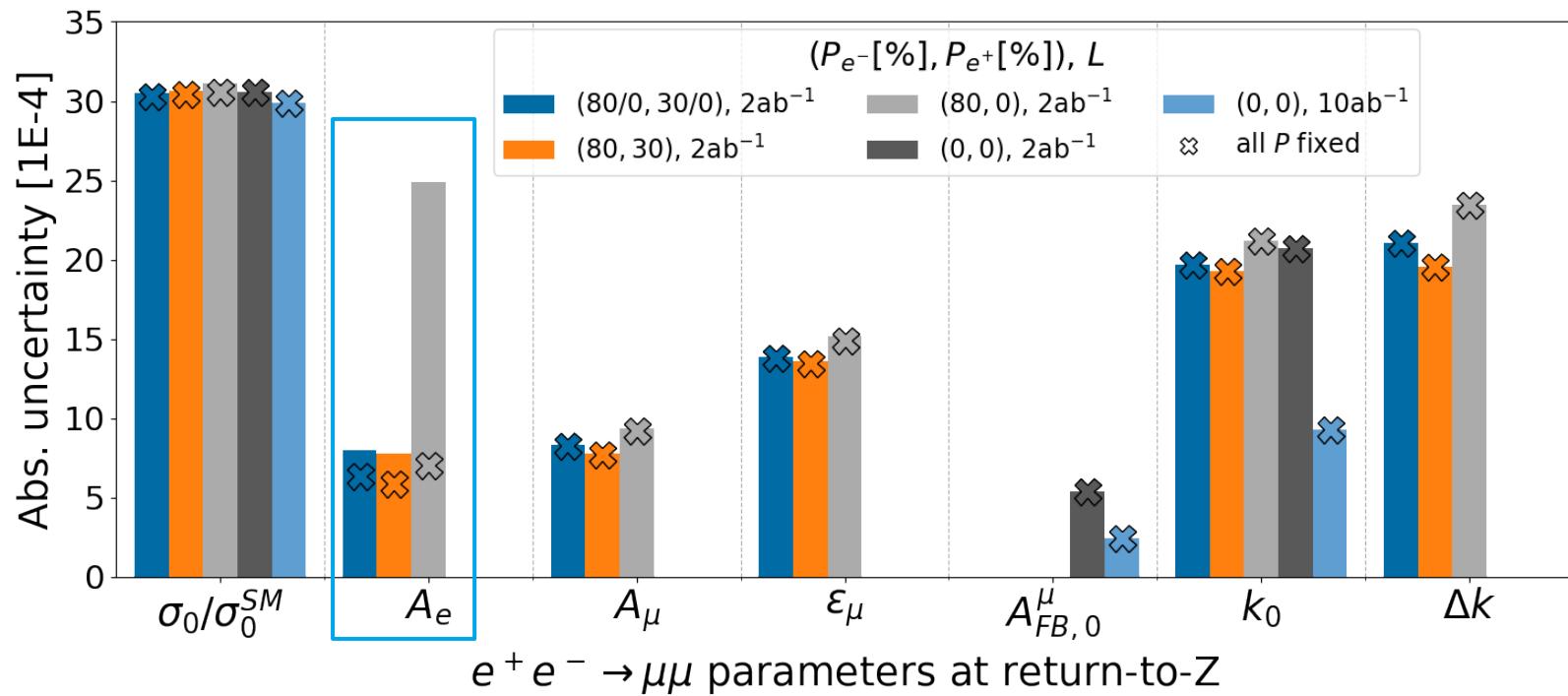
7 free parameters

- Norm
- **6** Polarisations

Positron polarisation decouples physics and systematics



Positron polarisation decouples physics and systematics



Reminder: (80,0)

Assume N_{LR} and N_{RL} measured from diff. cross-section

2 datasets

→ $2 \times 2 = 4$ measurement points

4 free parameters

- Norm
- 3 Polarisations

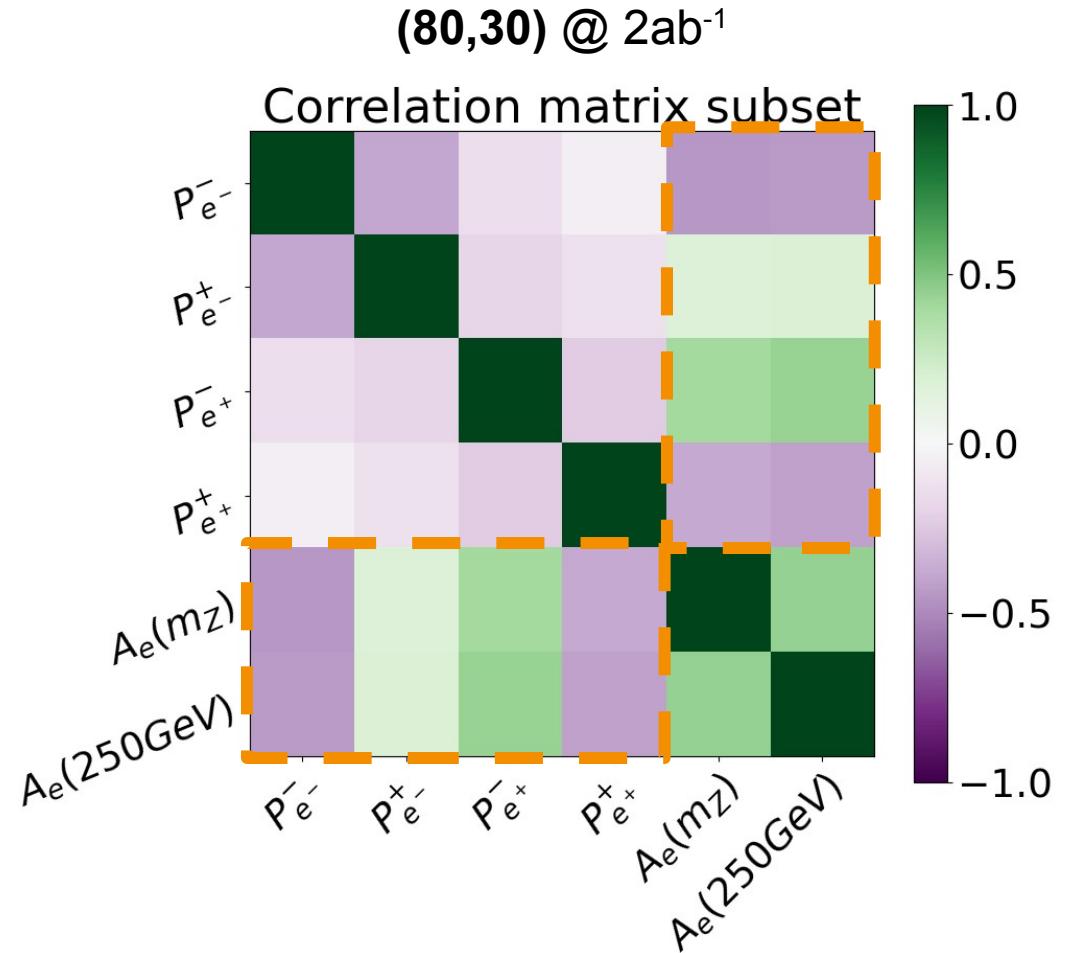
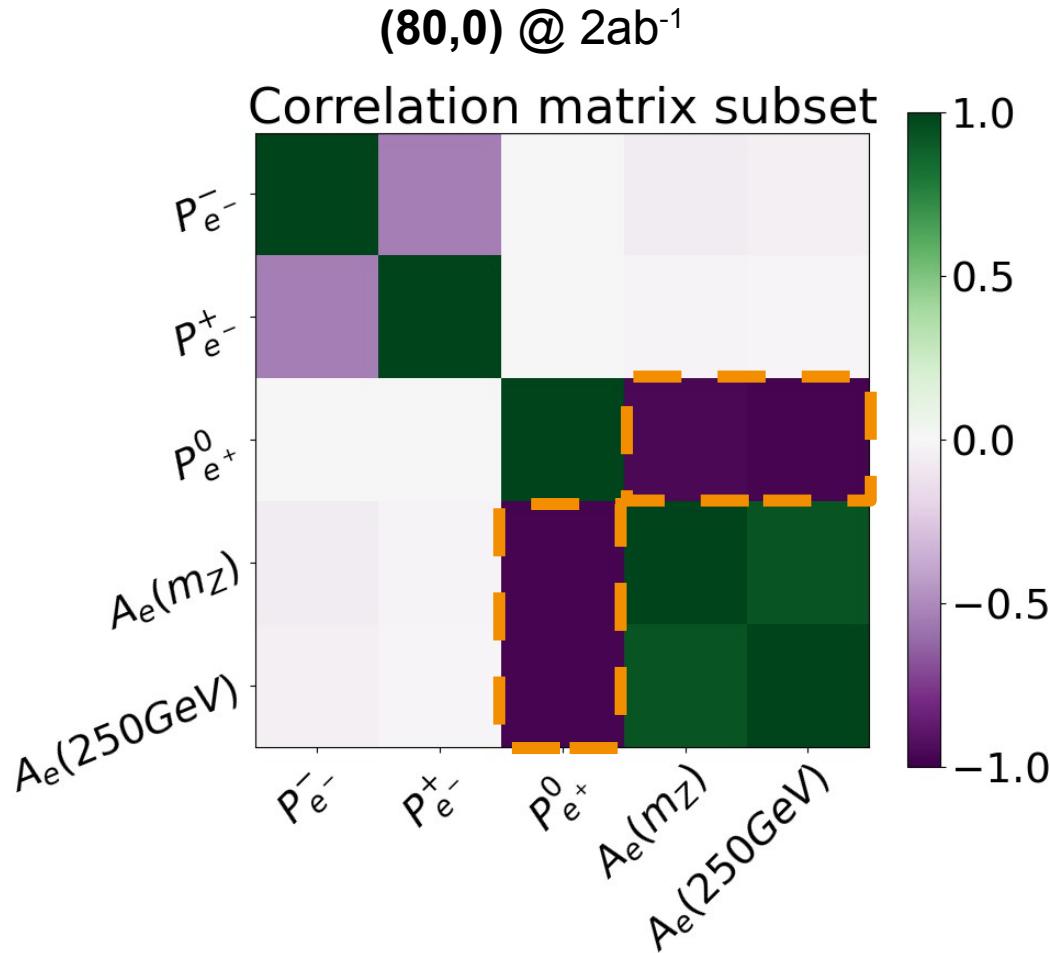
Now for $\mu\mu$:

+ LR-Asymmetry A_e



Enters in solution for P_{e^+}

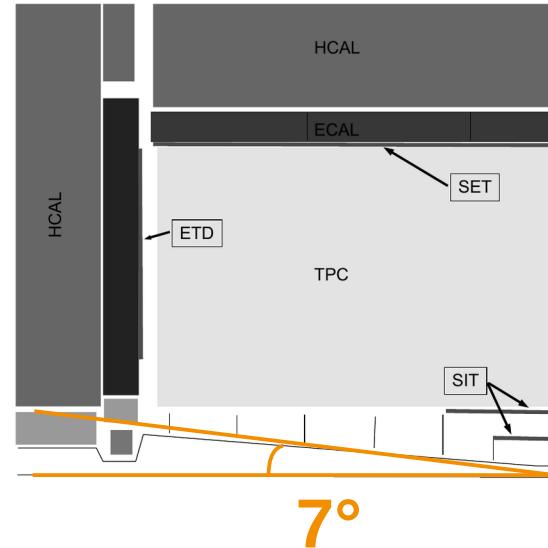
Positron polarisation decouples physics and systematics



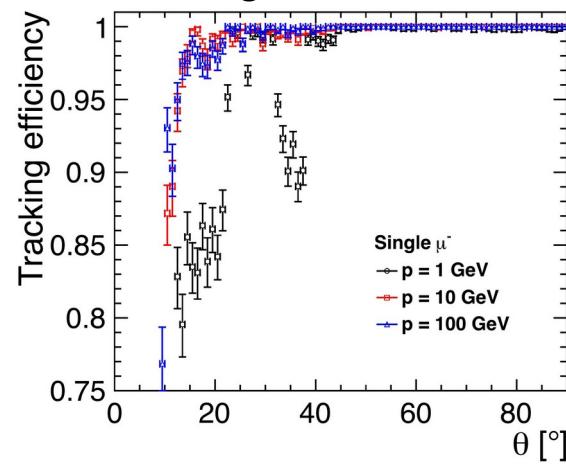
Problem-free polarisation & A_{LR} measurements
only with positron polarisation

Testing the impact on other systematics with simplified model

ILD tracking down to:

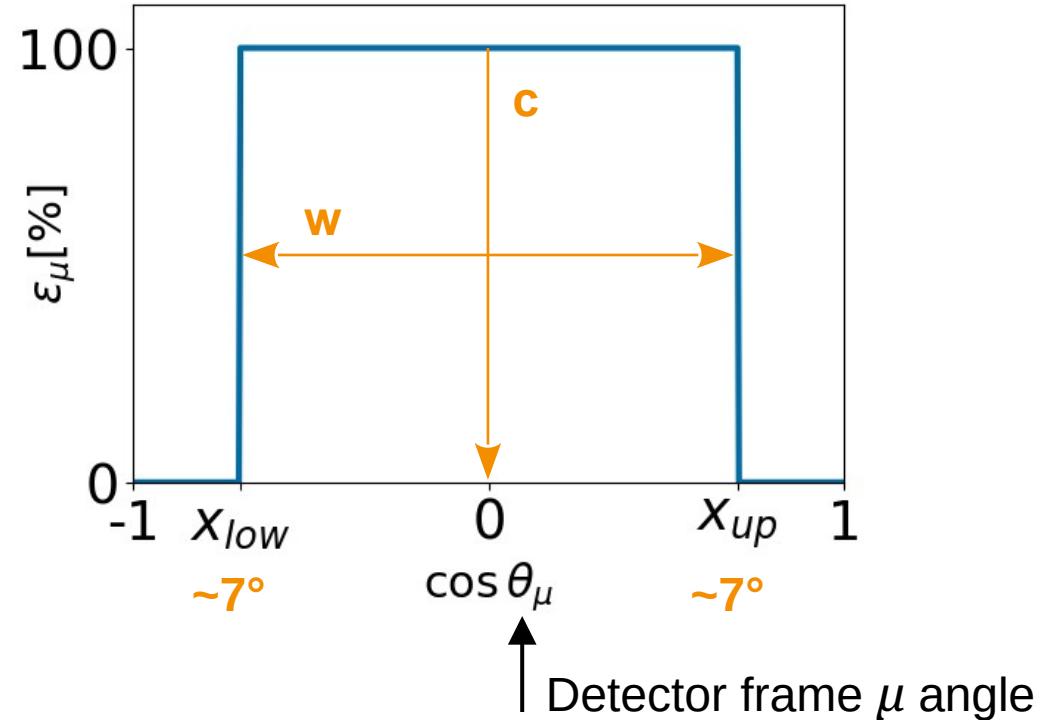


SiD tracking box-like:



Box-like μ acceptance down to 7°

→ 2 Parameters: Δc , Δw

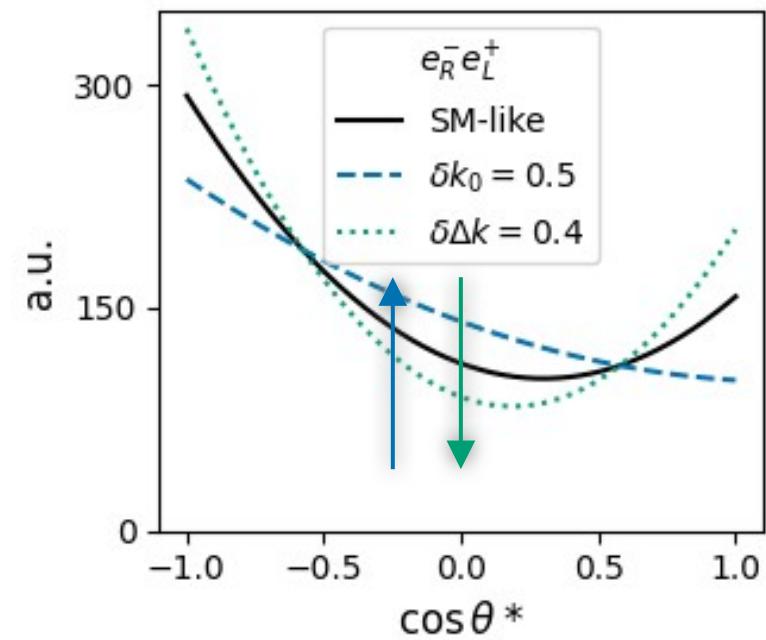
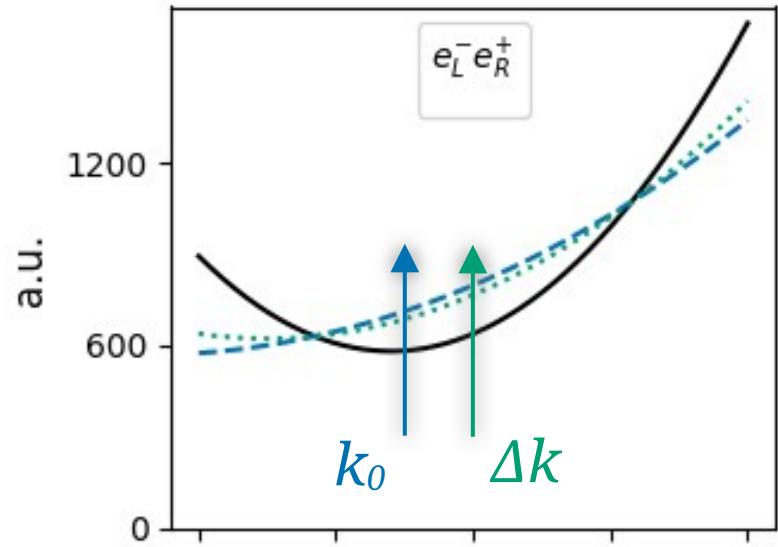


Polarisation for systematic-free measurements

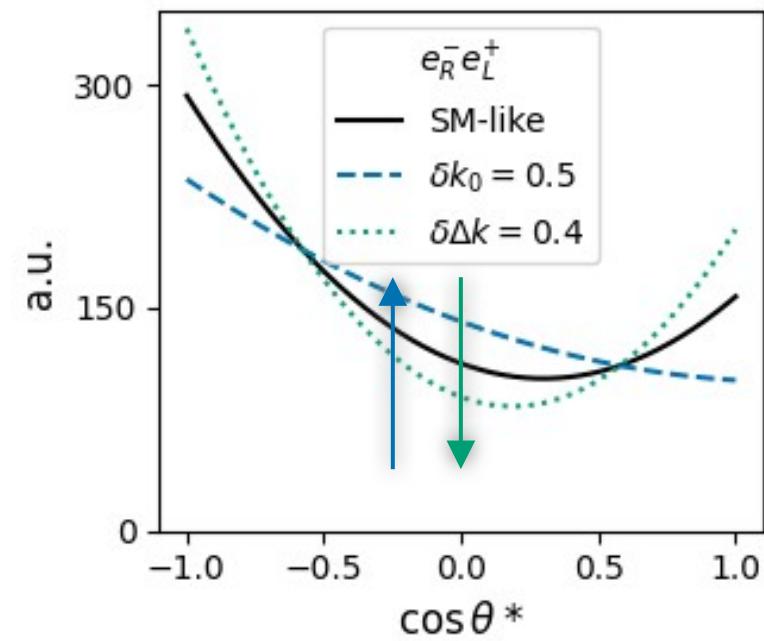
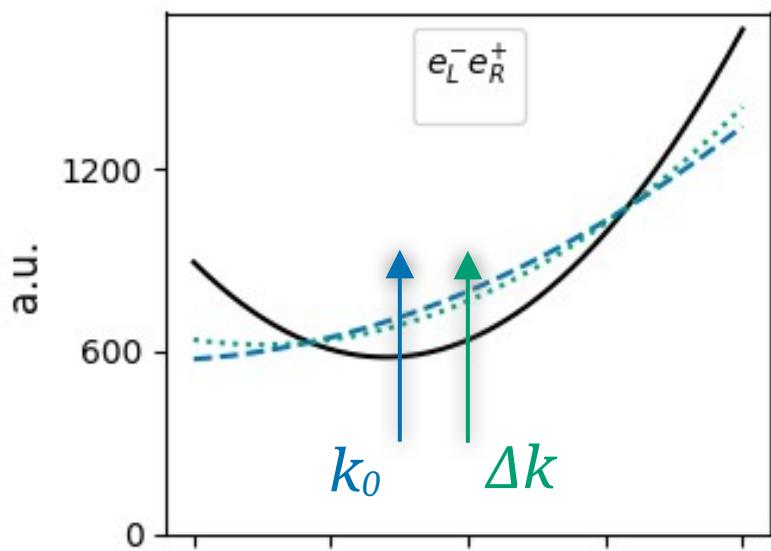
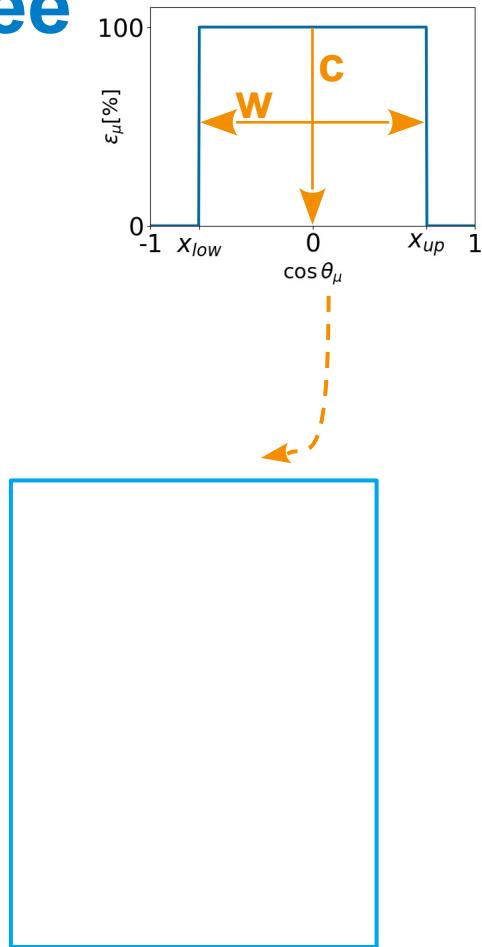


$$\frac{d\sigma_{LR}^f}{d\cos\theta} = \frac{3}{8}\sigma_0^f \frac{1+A_e}{2} \left[\left(1 + \frac{\mathbf{k}_0 + \Delta\mathbf{k}}{2}\right) + (\epsilon_f + 2A_f) \cos\theta + \left(1 - 3\frac{\mathbf{k}_0 + \Delta\mathbf{k}}{2}\right) \cos^2\theta \right]$$

$$\frac{d\sigma_{RL}^f}{d\cos\theta} = \frac{3}{8}\sigma_0^f \frac{1-A_e}{2} \left[\left(1 + \frac{\mathbf{k}_0 - \Delta\mathbf{k}}{2}\right) + (\epsilon_f - 2A_f) \cos\theta + \left(1 - 3\frac{\mathbf{k}_0 - \Delta\mathbf{k}}{2}\right) \cos^2\theta \right]$$



Polarisation for systematic-free measurements



Systematic only affects chirality-independent observable!

Electroweak precision at future e^+e^- colliders will benefit from polarised beams ...

... through direct insight into chiral behaviour

... through precise polarisation measurements

... through observables free of systematics

