Detector-level studies of electroweak processes at future e+e- colliders — and their interface to global interpretations

ECFA
European Committee for Future Accelerators

ECFA workshops on e+e- Higgs/EW/Top factory

Jenny List
WWdiff mini-workshop
25 June 2024

DESY.

Outline

of this talk

- Introduction: what’s the problem?
- Previous studies and what we learned from them
- Ongoing studies
- What we should discuss and find a solution for together

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The central question for this talk:

How can we define the interface between

- experimental / detector-level projections
    - including projected systematic uncertainties
- and global fitting, e.g. in SMEFT?

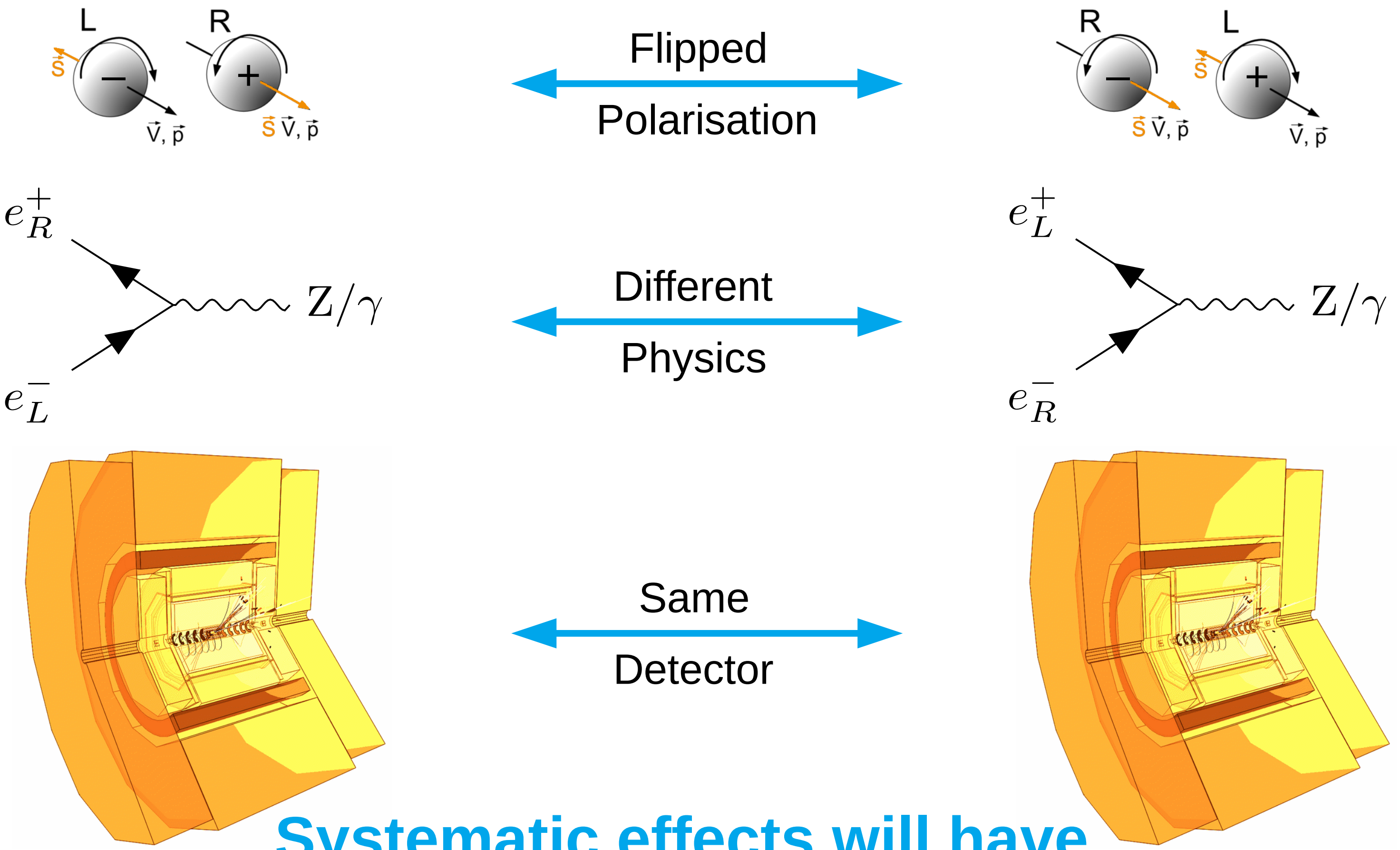
Introduction

Why do we need to discuss this?

- Up to now, detector-level projections - also many measurements eg at LEP - are presented in terms of pseudo-observables:
    - eg for ee->Z->ff: A_{LR}, A_{FB}, …
    - or for WW: g_1, κ, λ , …
- Advantages:
    - limited set of parameters extracted from measured (eg angular) distributions at detector-level,
        - i.e. **compare “data” to detector-level MC for different values of the parameters**
        - extract parameters from fit of detector-level prediction (as function of parameters) to “data”
    - straight-forward inclusion of systematic uncertainties (determined independently)
    - **crucial: minimisation of impact of systematic effects by joint extraction of nuisance parameters together with the physics parameters**

Importance of treating detector systematics in combined interpretation

Illustration J.Beyer, EPS-HEP 2021 https://indico.desy.de/event/28202/contributions/105243



Systematic effects will have uniquely global signatures if included in combined fit!

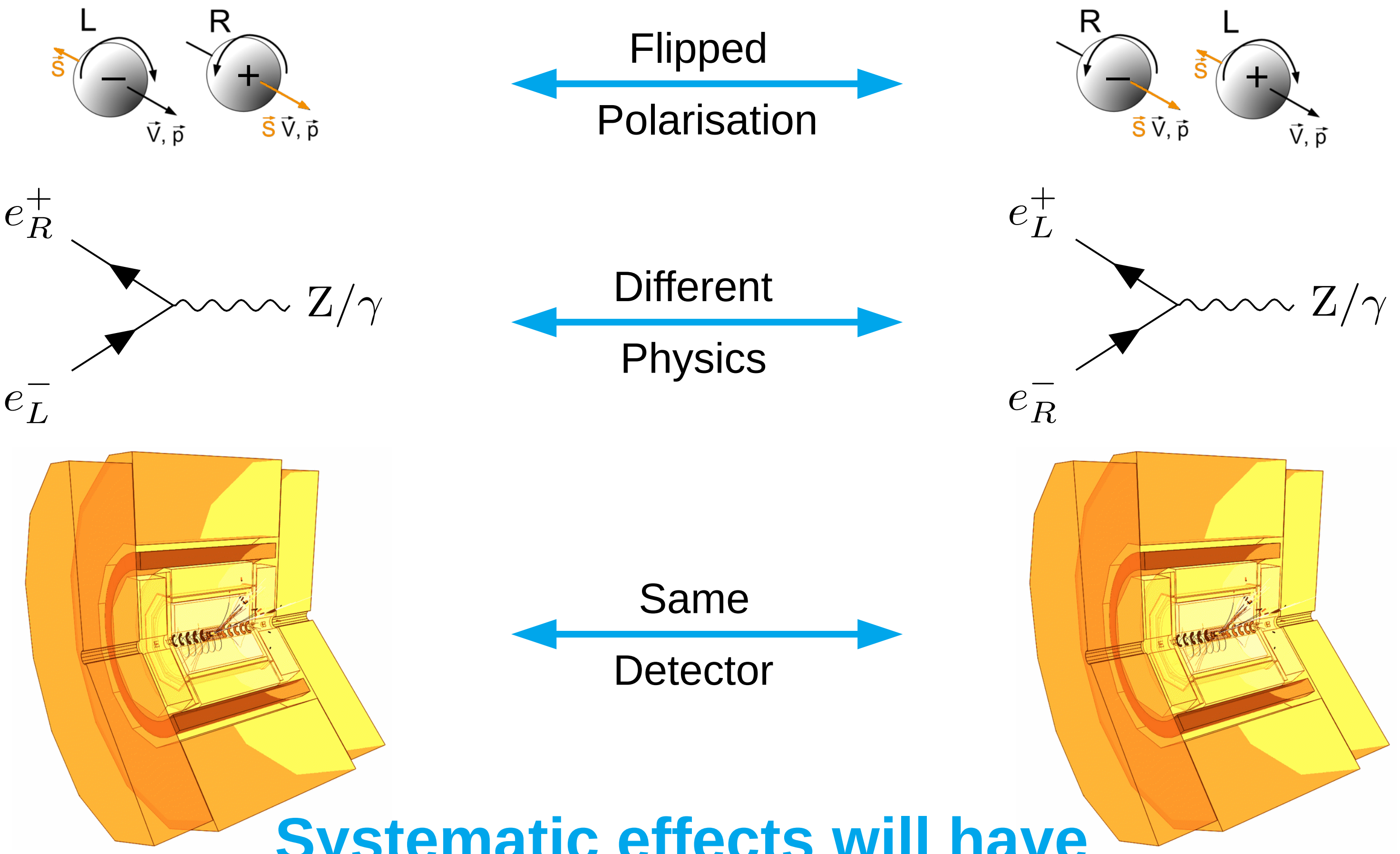
Importance of treating detector systematics in combined interpretation

Illustration J.Beyer, EPS-HEP 2021 https://indico.desy.de/event/28202/contributions/105243

Combination of data sets with different beam polarisations

—taken “quasi-concurrently” with fast (few Hz) helicity flipping —

can strongly reduce the impact of systematic effects in a combined fit



Systematic effects will have uniquely global signatures if included in combined fit!

So what's the problem?

Can't we stick with the previously used scheme?

- **in a global fit, eg in SMEFT, "everything depends on everything"**
- eg:
  - WW is not the only process with sensitivity to cTGCs
  - WW also depends on other SMEFT operators
- therefore
  - **a 3x3 covariance matrix of g_1, κ, λ as result of detector-level study is not sufficient**
- on the other hand
  - directly interpreting detector-level MC in SMEFT would require propagation of expected modifications to detector-level, for all to be included measurements **=> unrealistic complexity?**
- thus need
  - **some intermediate level, at which detector effects have been minimized / eliminated — but still sufficient information is preserved to combine with other measurements in global fit**

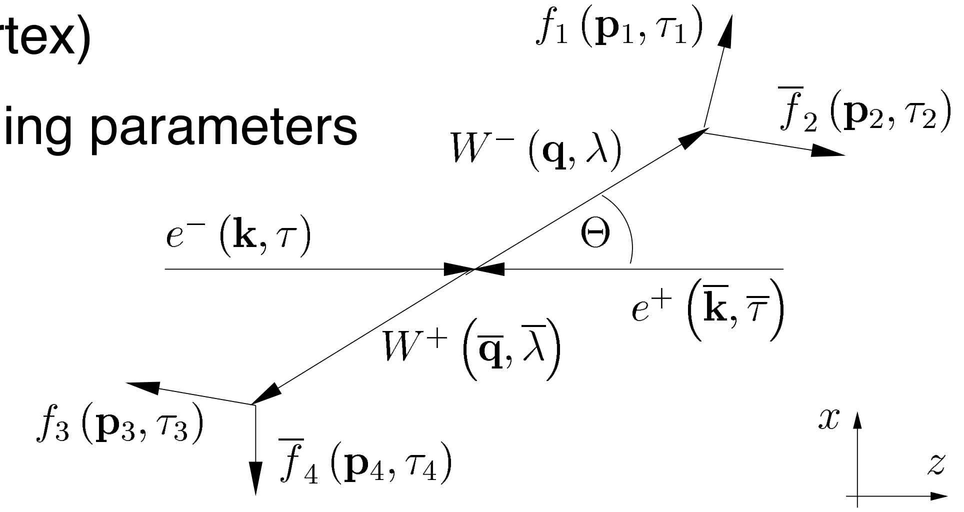
Previous studies

Early Theory-Level Studies

for TESLA :)

[Eur.Phys.J.C 27 (2003) 375-397](#)
& [Eur.Phys.J.C 32 (2003) 17-27](#)

- Theory-level study (Markus Diehl et al 2003!)
  - optimal observables
  - most general set of CP conserving and CP violating triple-gauge boson couplings (28 real parameters!)
  - can all be disentangled and constrained at a centre-of-mass energy of 500 GeV with polarised beams (incl. transverse polarisation for some of the CPV couplings)
- no detector, no systematics
- but more general than Dim6-SMEFT (in ZWW / yWW vertex)
- fun fact: fortran77 implementation of OOs for all 28 coupling parameters exists and happily compiles & runs
  => true code longelivity !!! ;)

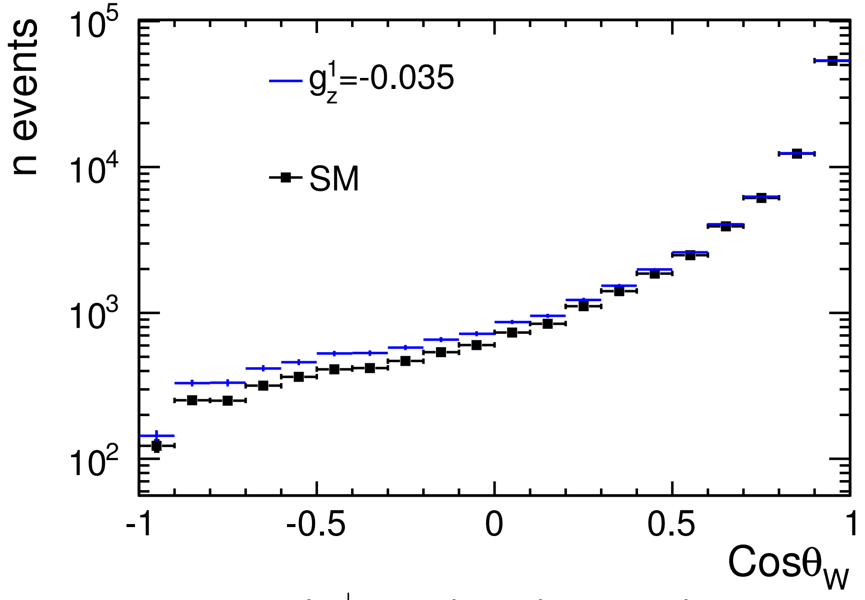


Detector-level Simulations

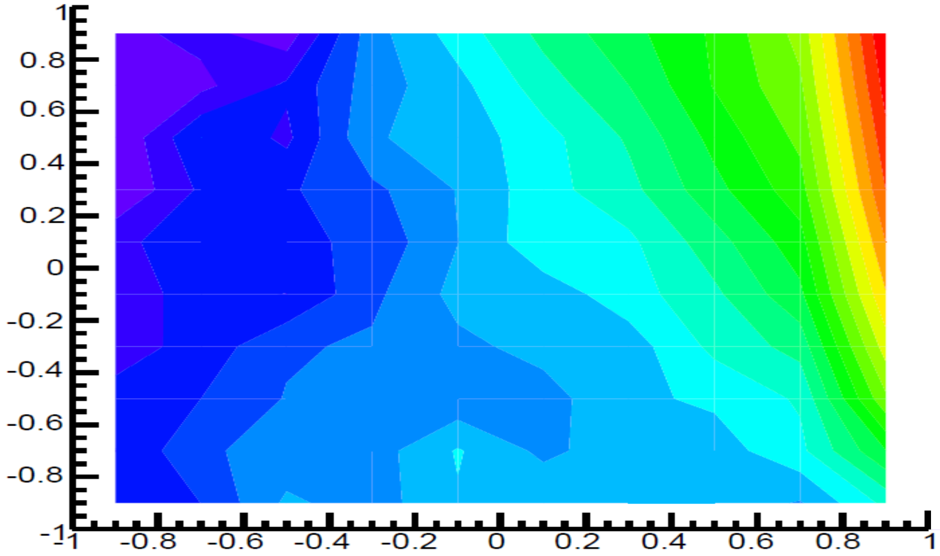
ILD & SiD for ILC TDR (Marchesini, Rosca, Barklow ~2011 ff)

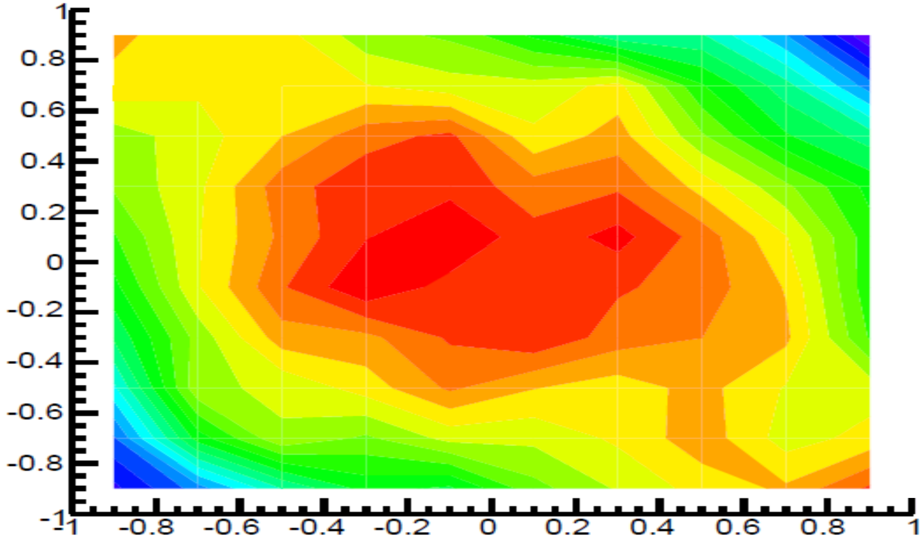
PhD Thesis I. Marchesini

- 500 GeV and 1 TeV
- joint extraction of 3 TGCs (LEP parametrisation) and beam poalrisations => model impact of all parameters on detector-level
- restricted to WW -> munuqq and WW->enuqq
- 3 TGCs and their covariance matrix passed on to global interpretations, e.g. SMEFT fits



$P(e^+, e^-) = (+1, -1)$ cos θ_{decay} vs $cos\theta_W$ $P(e^+, e^-) = (-1, +1)$



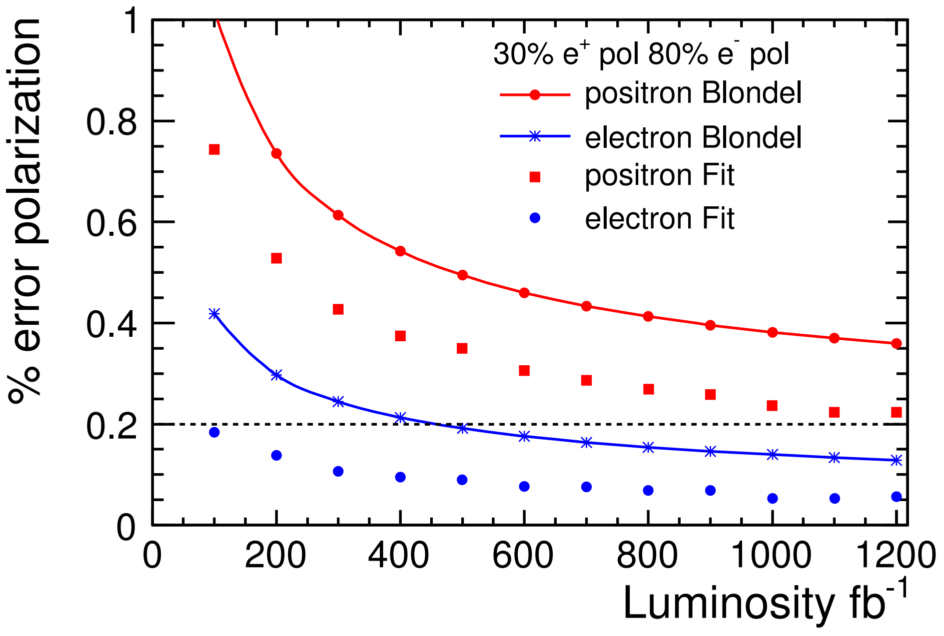


Some Results

ILD & SiD for ILC TDR

PhD Thesis I. Marchesini

- Polarisation from TGC fit much better than total cross-sections aka “modified Blondel scheme”
- small fraction of like-sign data eg 5…10% sufficient to reach 0.1% on polarisations
- LEP TGCs to few 10^{-4} with $1ab^{-1}$ at 500 GeV



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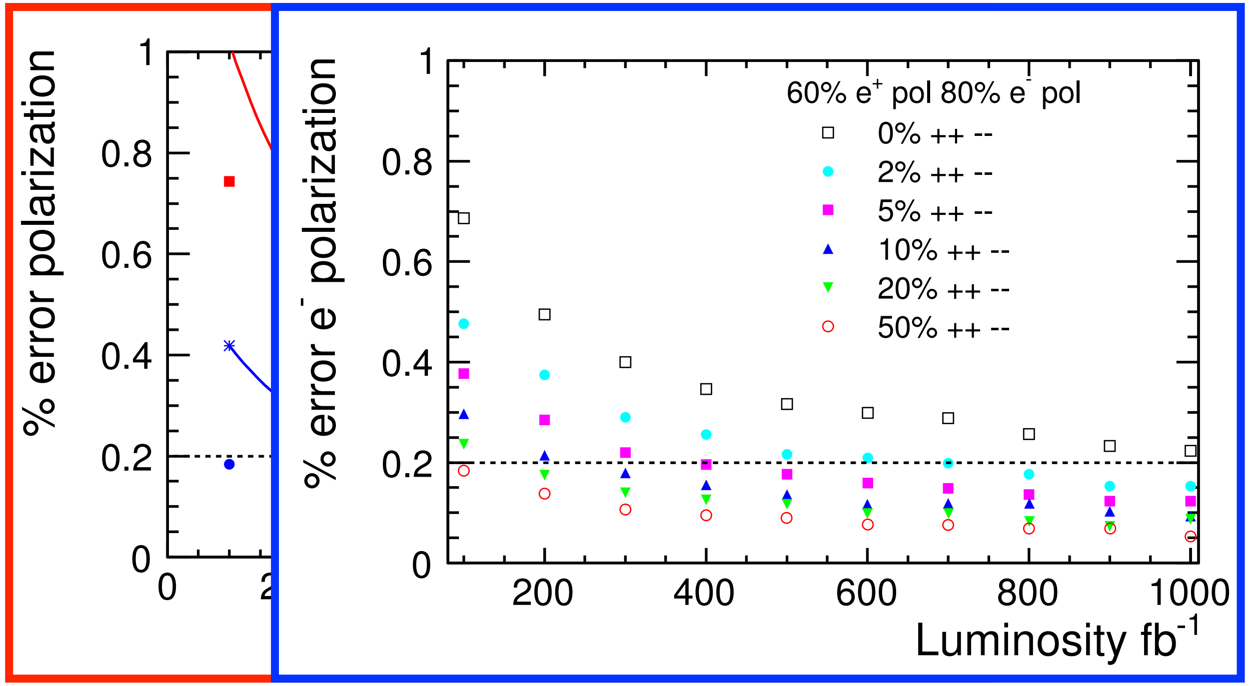

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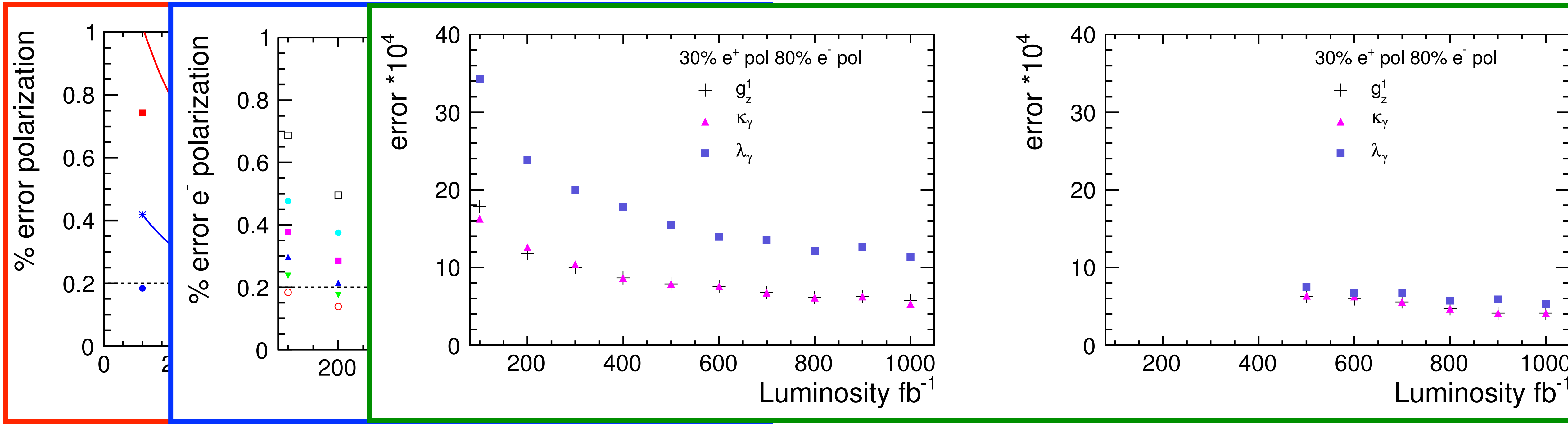

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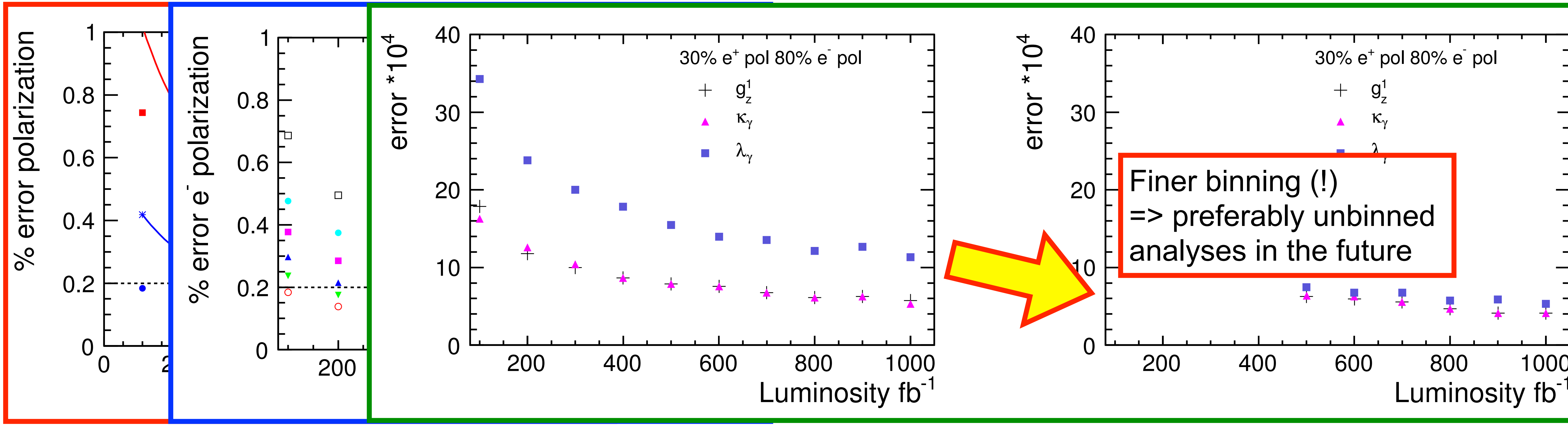
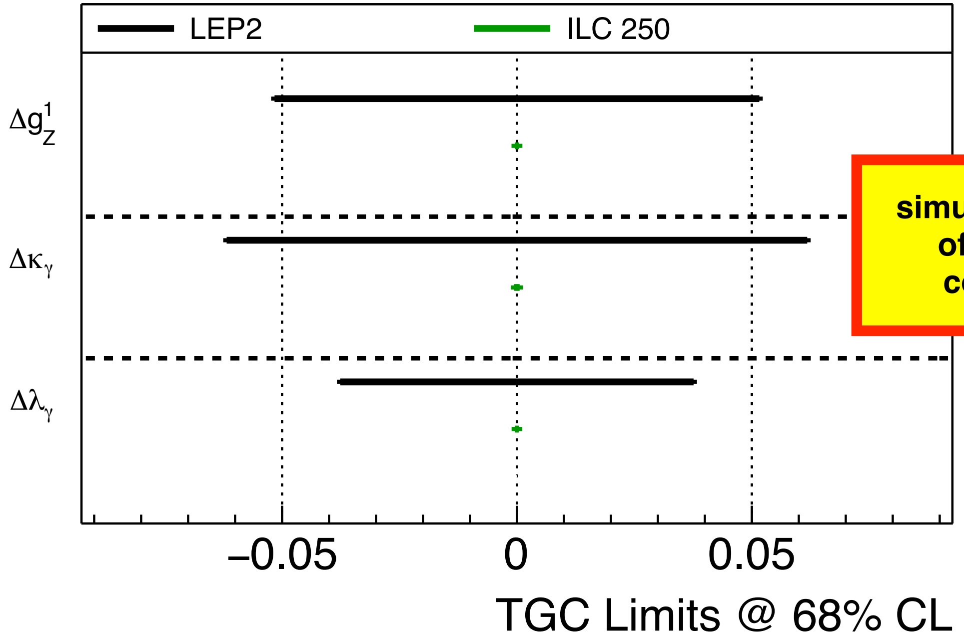


More recently

including 250 GeV (~2017-2018)

PhD Thesis R. Karl

- Extrapolation of 500 GeV / 1 TeV detector-level studies to 250 GeV
- And first look into "single-W" contribution to evqq final-state (detector effects parametrized, but systematics included)
  => single-W important contribution to TGC precicision
  => must be fully included in the future!



simultaneous fit of all three couplings

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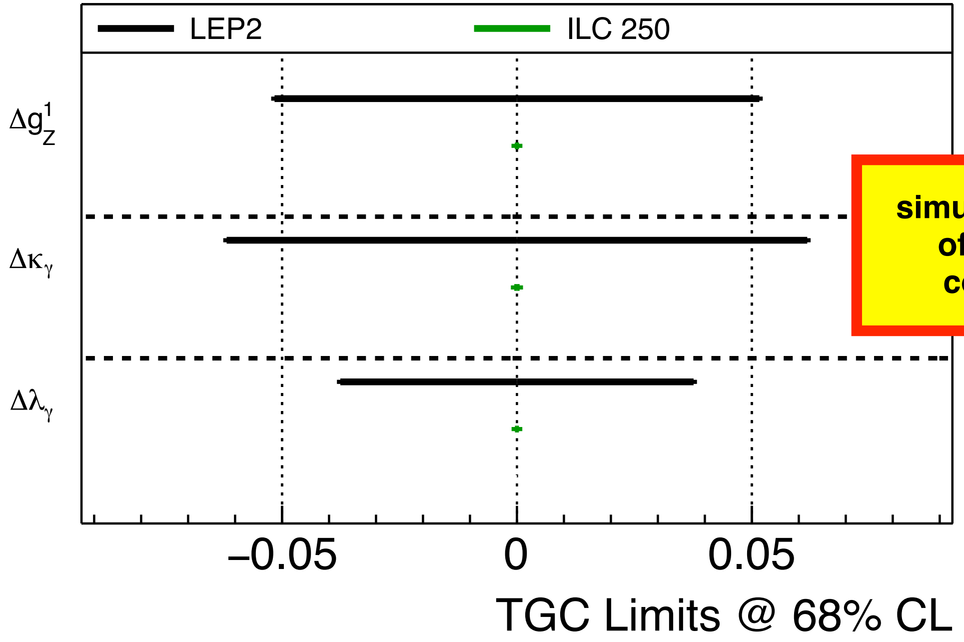

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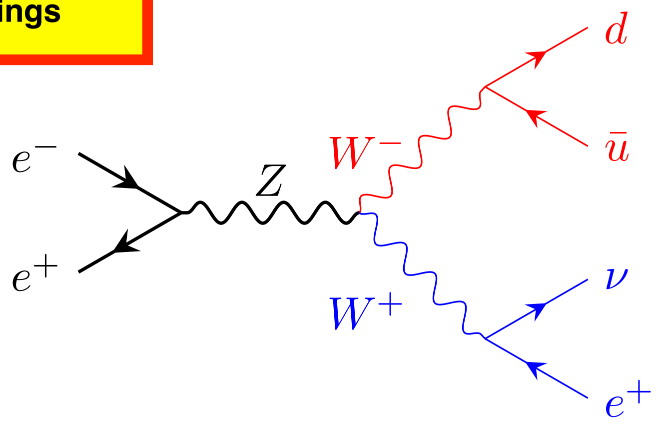

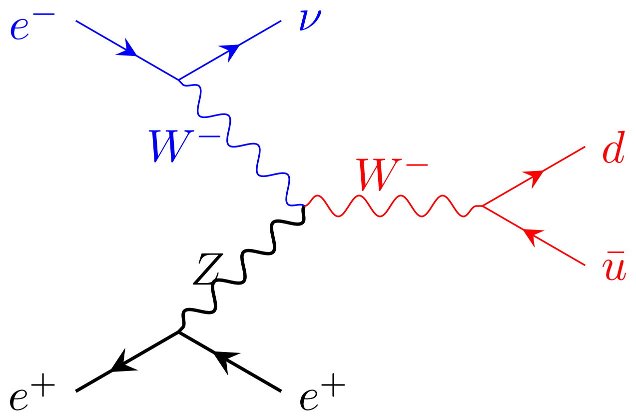

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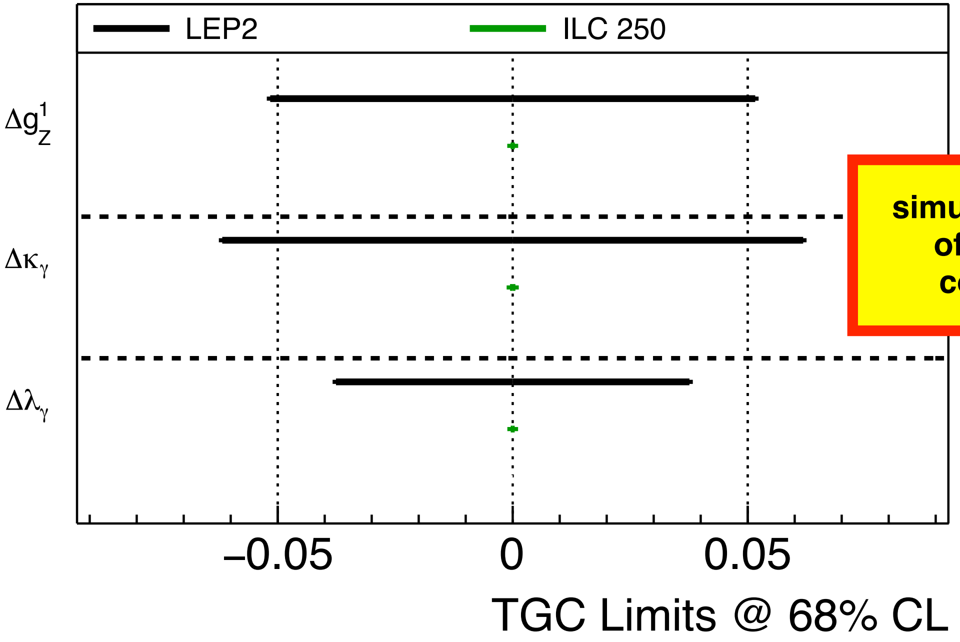

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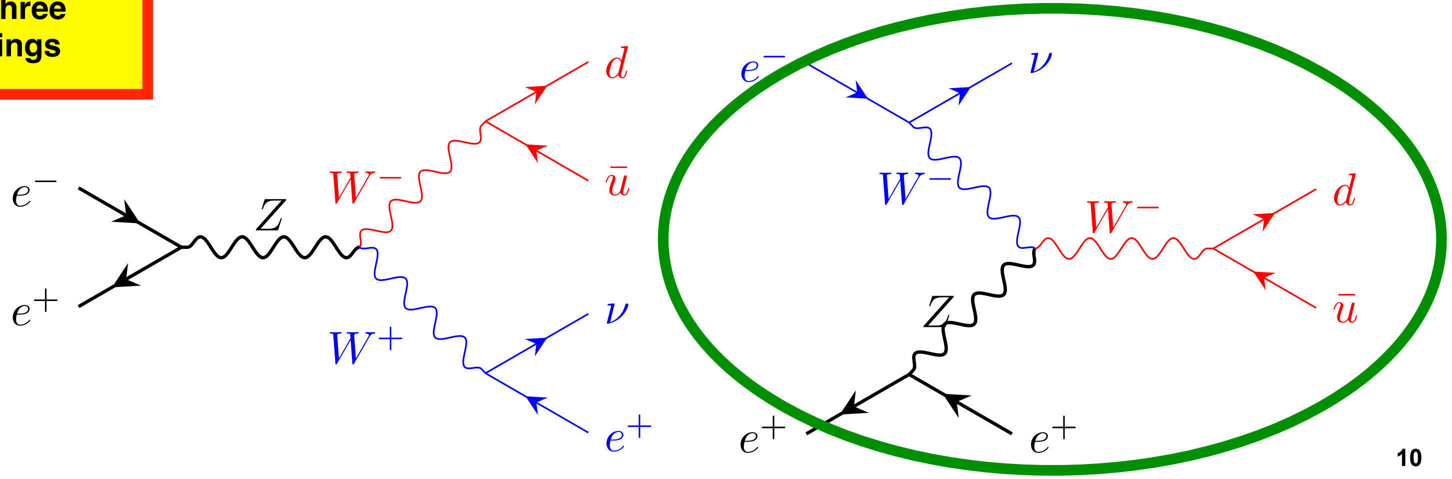

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TGC	E_{CMS}[GeV]	$e^+e^- \to \mu\nu q\bar{q}$	$e^+e^- \to e\nu q\bar{q}$	**comb.**
Δg $[10^{-4}]$	250	45.8	15.8	13.9
	500	8.46	4.14	3.52
$\Delta\kappa$ $[10^{-4}]$	250	54.9	19	16.5
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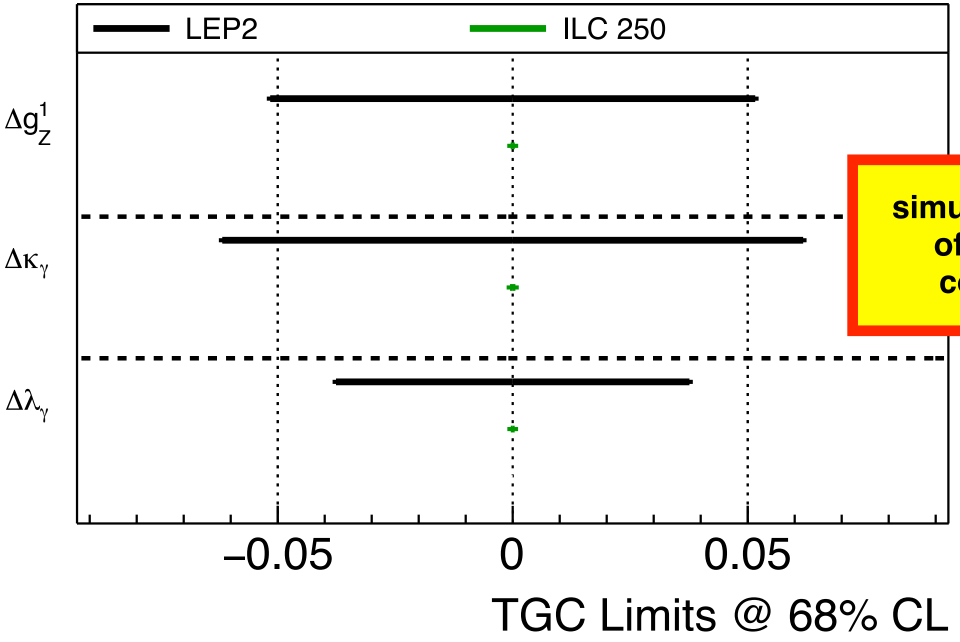
$\Delta\lambda$ $[10^{-4}]$	250	68.6	22.5	21.6
	500	15.6	6.14	5.77



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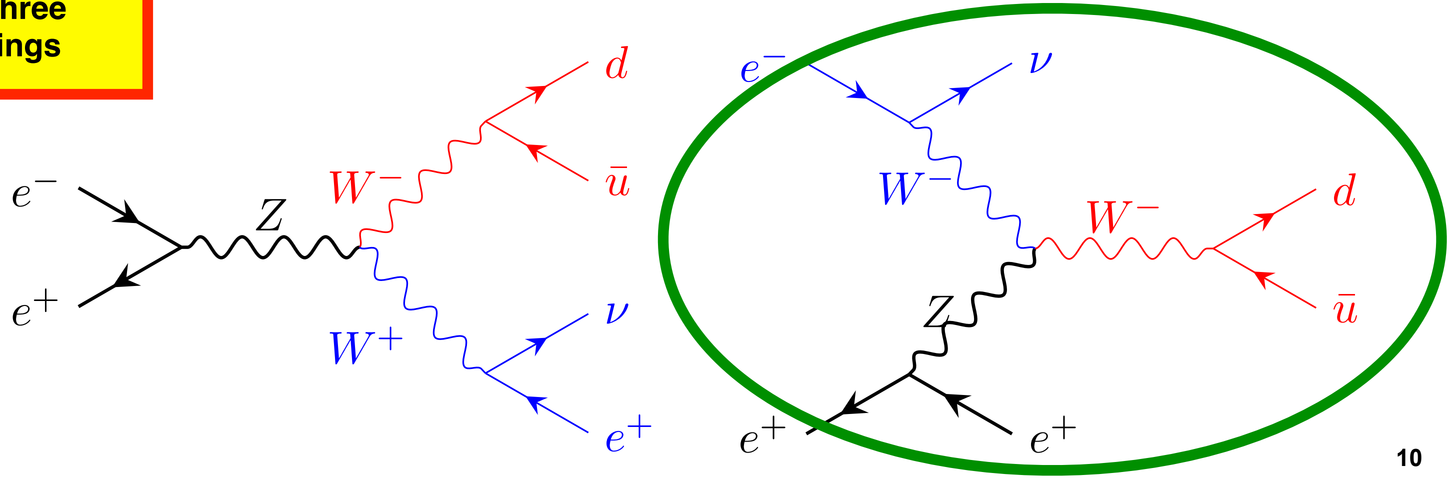

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+single-W

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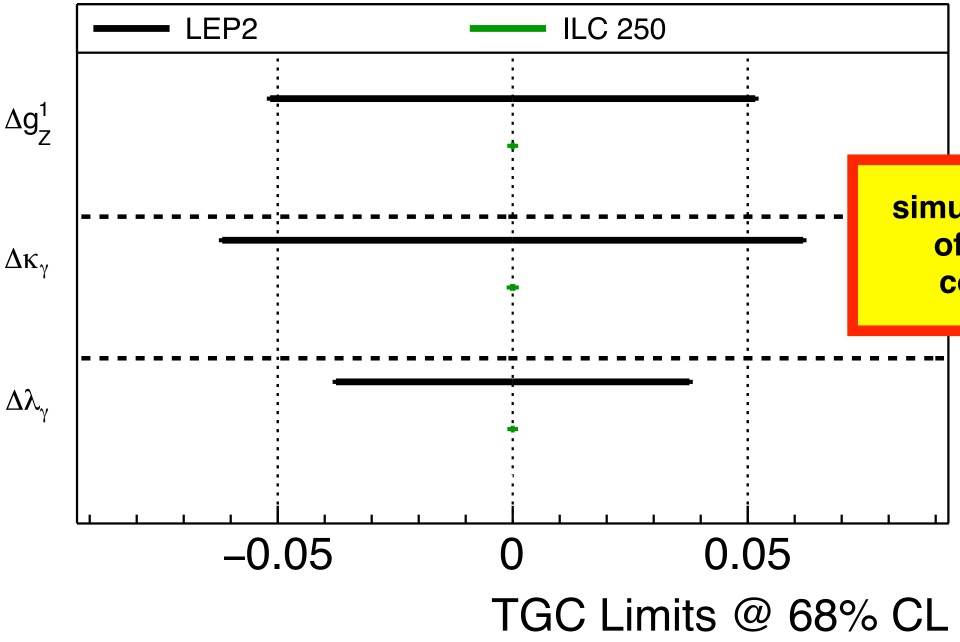

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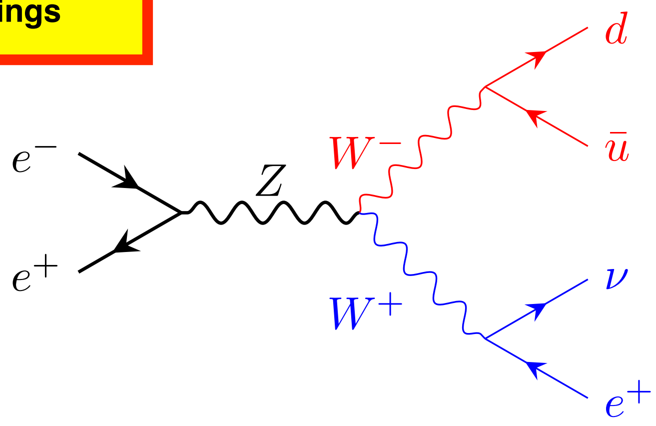
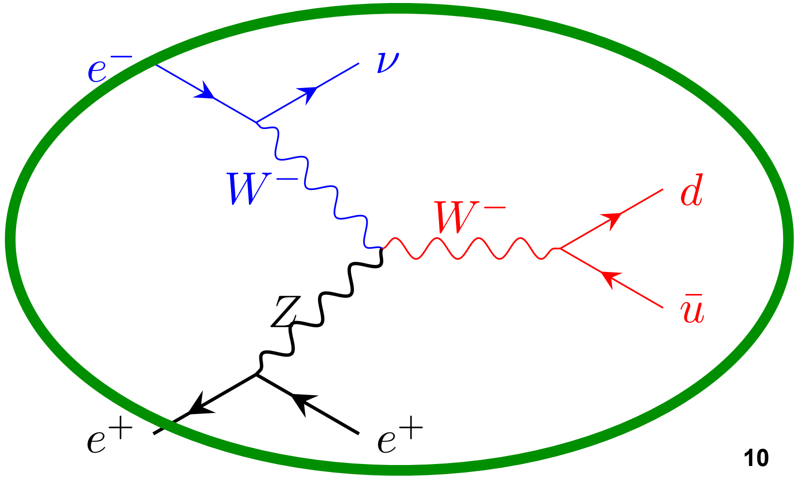


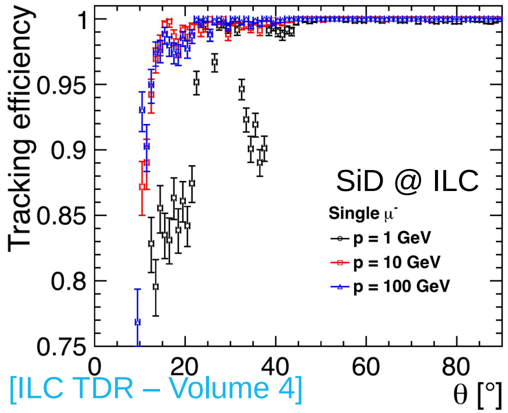


Even more recently

PhD Thesis J. Beyer

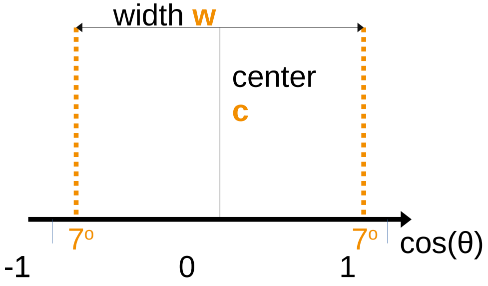
4f and 2f final state combination with detector effects eg acceptance

- detector acceptance in forward region was a leading systematic in ee->$\mu\mu$ at LEP
- future colliders aims for much higher precision
  => can we eliminate this source of uncertainty by extracting the acceptance directly together with physics parameters?
- **detailed study of ability to reduce impact systematics by combined fits to differential cross sections of 2f and 4f processes including many nuisance parameters at 250 GeV using LEP parametrisation**



[ILC TDR – Volume 4]

Simplified picture:
Event passes if all μ's inside box



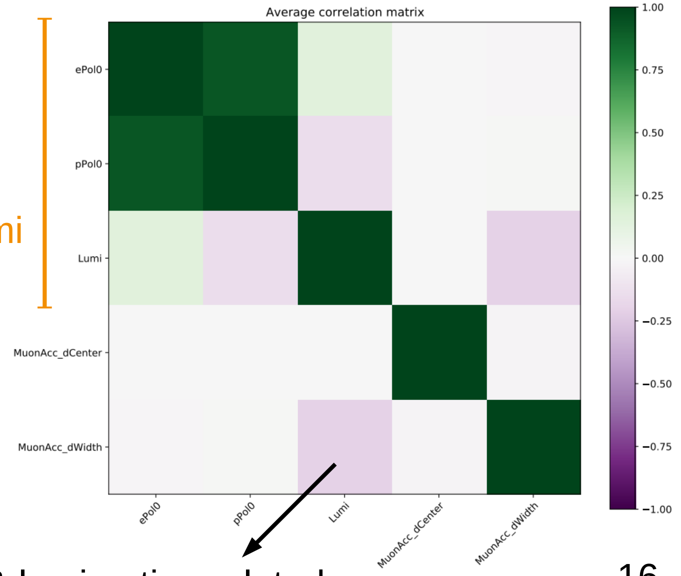
Fit parameters: Δc, Δw

Example:
2ab^{-1} unpolarised

Free parameters:

Polarisations & Lumi
(w/ constraints)

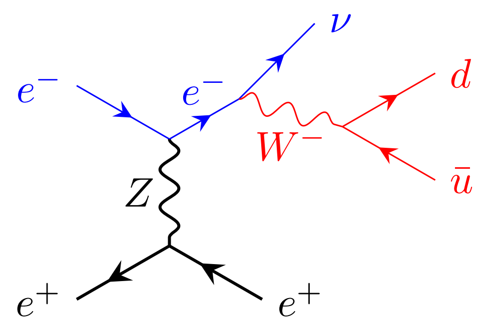
μ acceptance parameters



accept. width & lumi anticorrelated

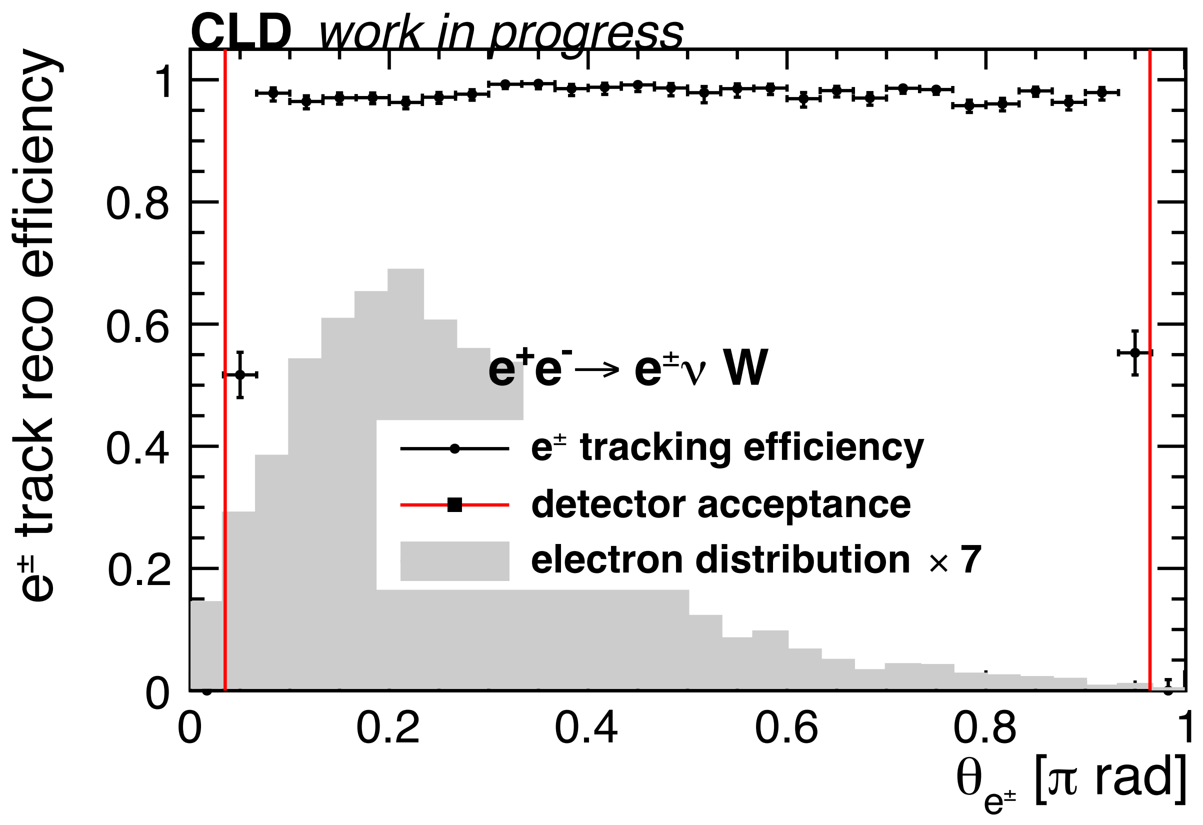
16

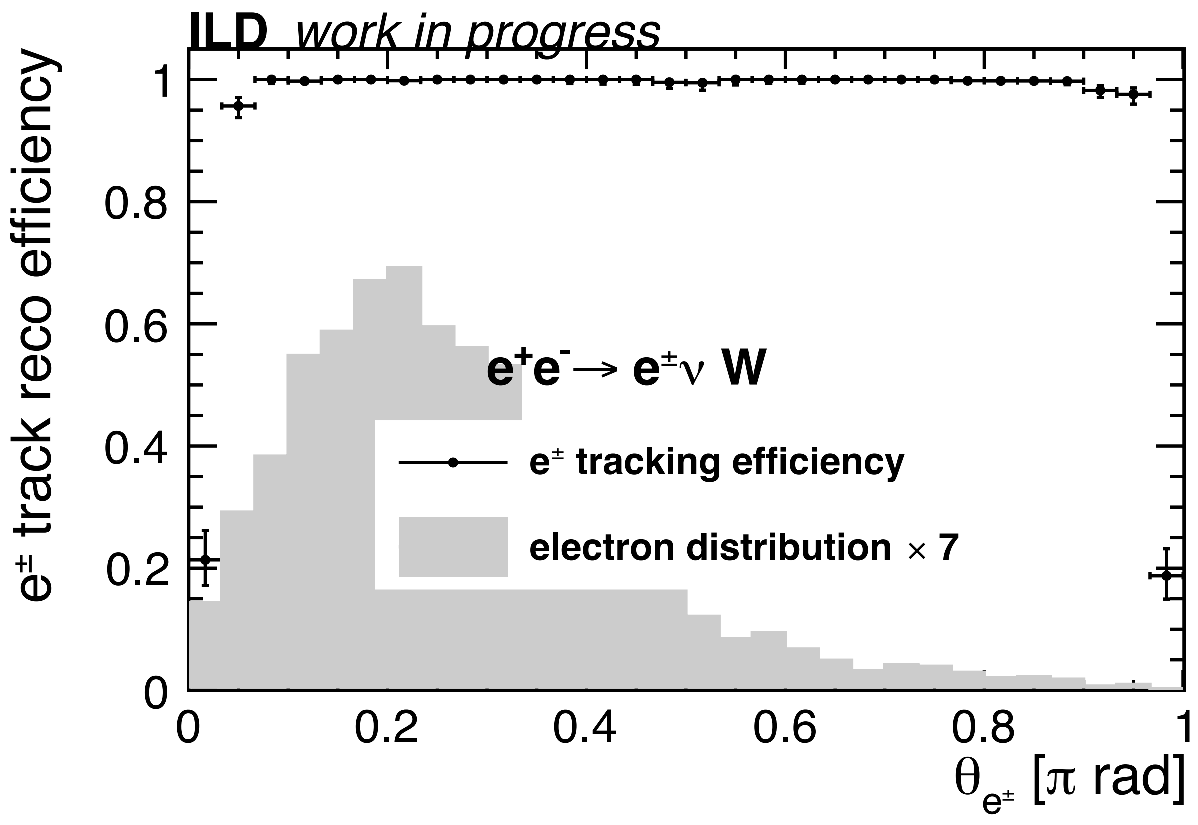
First Steps - WORK IN PROGRESS -



The enuqq channel - WW and singleW - tracking efficiency (Leonhard Reichenbach)

- **vs polar angle** for electron/positron (on eLpR sample, i.e. singleW dominated)





Wanted

Basic requirements

A general scheme which

- is physics-wise consistent - all relevant parameter <-> observable relations contained
- allows to constrain nuisance parameters in addition to physics parameters
    - can be added in SMEFT?
    - Global (L, P etc) easy?
    - Differential like acceptance ????
- can use the full experimental information without “exploding” the complexity (#parameters, #inputs)
    - Optimal observables for nuisance parameters?
    - Predictions of variations on detector level ?
- **Your idea here!**