INSTITUTE FOR THEORETICAL PHYSICS, HEIDELBERG UNIVERSITY

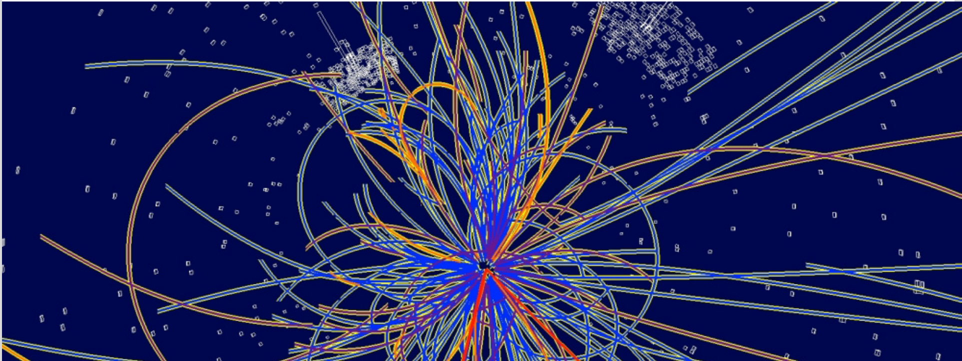
WZ+jet, Wγ+jet with anomalous couplings

What can the ILC learn from the LHC?

work with F. Campanario, M. Spannowsky, D. Zeppenfeld

Christoph Englert | 20.03.2010

ALCP '11, EUGENE



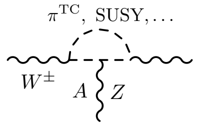
Why anomalous couplings?

We still do not have a test of the Fermi-scale and beyond! But we may expect . . .

$$\mathcal{L} = \mathcal{L}_{\text{SM w/o Higgs}} + \mathcal{L}_{[SU(2)\times U(1)/U(1)]} + \frac{1}{\Lambda_{UV}^2}\mathcal{L}^{(6)} + \dots$$

Try to measure $\mathcal{L}$ in model-independent way: bottom-up phenomenology of $\mathcal{L}^{(n)}$

Focus on the SM extended by operators modifying the *WWV* gauge vertices



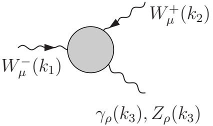
$$\left\langle J_A^{\mu}(p) J_A^{\nu}(-p)\right\rangle = (p^2 g^{\mu\nu} - p^{\mu}p^{\nu})\left(\frac{F_\pi^2}{p^2} + \sum_n \frac{F_n^2}{p^2 - m_n^2}\right)$$

['t Hooft '74], [Witten '79]

$$\mathcal{L}_{WW\gamma} = -ie\big[W^{\dagger}_{\mu\nu}W^{\mu}A^{\nu} - W^{\dagger}_{\mu}A_{\nu}W^{\mu\nu} + \kappa_\gamma(Q^2) W^{\dagger}_{\mu}W_{\nu}F^{\mu\nu} + \frac{\lambda_\gamma(Q^2)}{m_W^2} W^{\dagger}_{\lambda\mu}W^{\mu}_{\nu}F^{\nu\lambda}\big]$$

$$\mathcal{L}_{WWZ} = -ie\cot\theta_w\,\big[g_1^Z(Q^2)\left(W^{\dagger}_{\mu\nu}W^{\mu}A^{\nu} - W^{\dagger}_{\mu}A_{\nu}W^{\mu\nu}\right) + \kappa_Z(Q^2) W^{\dagger}_{\mu}W_{\nu}Z^{\mu\nu} + \frac{\lambda_Z(Q^2)}{m_W^2} W^{\dagger}_{\lambda\mu}W^{\mu}_{\nu}Z^{\nu\lambda}\big]$$

[Hagiwara, Peccei, Zeppenfeld, Hikasa '87]



modified production cross section,
shape-deviations from the SM for large Q^2

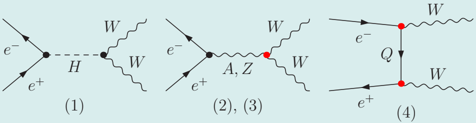
LHC vs ILC: $\sqrt{s}$ vs $\Delta\sigma$

How can we measure and constrain anomalous parameters?

indirect measurement via $e^+e^- \to W^+W^- + X$ at LEP & ILC

[ALEPH, DELPHI, L3, OPAL, arXiv:hep-ex/0612034]

1. cross section is highly sensitive to gauge cancellations



$$[1](s) - 2m_e\big([3]_L(s) + [3]_R(s)\big) = 0$$
$$[3]_R(s) + [3]_L(s) - [4]_L(t) = 0$$
$$[2](s) - [3]_R(s) = 0$$

2. clean handle on final state particles' helicities, polarized beams & $e^{\pm}\gamma$ option
3. systematics under excellent control, straightforward comparison of data against Monte Carlo, e.g. RACOONWW *[Denner, Dittmaier, Roth, Wackeroth '01, '02]*

Parameter	68% C.L.	95% C.L.
g_1^Z	$0.991^{+0.022}_{-0.021}$	[0.949, 1.034]
κ_γ	$0.984^{+0.042}_{-0.047}$	[0.895, 1.069]
λ_γ	$-0.016^{+0.021}_{-0.023}$	[−0.059, 0.026]

[hep-ex/0612034]

coupling	error $\times 10^{-4}$	
	$\sqrt{s} = 500\,\mathrm{GeV}$	$\sqrt{s} = 800\,\mathrm{GeV}$
Δg_1^Z	15.5	12.6
$\Delta\kappa_\gamma$	3.3	1.9
λ_γ	5.9	3.3
$\Delta\kappa_Z$	3.2	1.9
λ_Z	6.7	3.0

$\sigma(\lambda_\gamma = 0.035)/\sigma^{\mathrm{SM}} \simeq 1.11$

[Menges, LC-PHSM-2001-022]

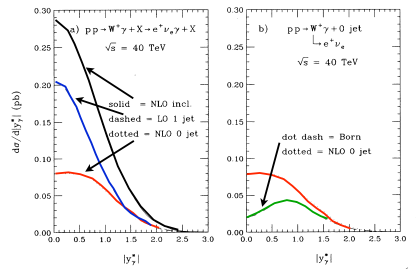
LHC vs ILC: $\sqrt{s}$ vs $\Delta\sigma$

How can we measure and constrain anomalous parameters?

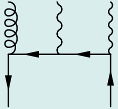
direct measurement via $p\bar{p}$, $pp \to W^{\pm}\gamma + X$ at Tevatron & LHC

[D0, arXiv:0907.4952], [CDF, arXiv:0912.4500]

1. radiation zeros: Destructive interference for $q\bar{Q} \to gW\gamma$ in the SM for $y^{\star}_{\gamma} \approx 0$

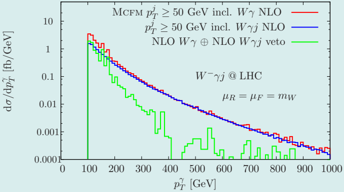


[Baur, Han, Ohnemus '93]



$$\sim \log^2 \frac{p^2_{T,\gamma}}{m^2_W}$$

$\Rightarrow$ impose jet veto to enhance sensitivity!?



σ^{had} are highly dynamical quantities: $\sigma^{W\gamma}/\sigma^{W\gamma+\text{jet}} = \mathcal{O}(1)$ @ LHC

... NNLO / resummed log contributions will significantly affect the jet veto performance.

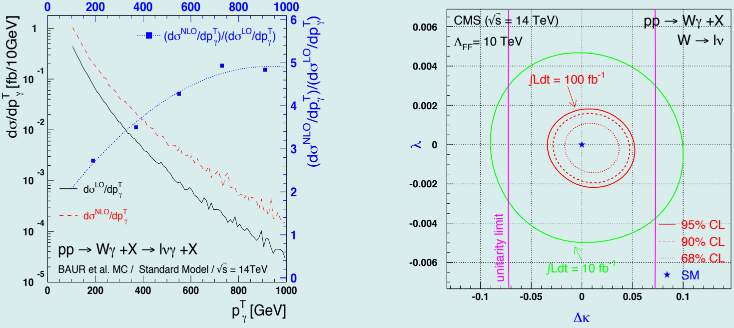
LHC vs ILC: $\sqrt{s}$ vs $\Delta\sigma$

How can we measure and constrain anomalous parameters?

direct measurement via $p\bar{p}$, $pp \to W^{\pm}\gamma + X$ at Tevatron & LHC

[Müller et al. '00]

2 shape deviations



$\sigma^{\rm had}$ is a highly dynamical quantity: $\sigma^{W\gamma}/\sigma^{W\gamma+\rm jet} = \mathcal{O}(1)$ @ LHC

... NNLO / leading log contributions will significantly affect the jet veto performance at the LHC.

Status of charged anomalous *WWV* couplings

	Λ (TeV)	λ_Z	Δg_1^Z	$\Delta\kappa_\gamma$
Expected	1.5	(-0.05,0.07)	(-0.09,0.17)	(-0.23,0.31)
Observed	1.5	(-0.16,0.16)	(-0.24,0.34)	(-0.63,0.72)
Expected	2.0	(-0.05,0.06)	(-0.08,0.15)	(-0.20,0.27)
Observed	2.0	(-0.14,0.15)	(-0.22,0.30)	(-0.57,0.65)

[CDF, arXiv:0912.4500]

Parameter	Minimum	68% C.L.	95% C.L.
$\Delta\kappa_\gamma$	0.07	$[-0.13, 0.23]$	$[-0.29, 0.38]$
Δg_1^Z	0.05	$[-0.01, 0.11]$	$[-0.07, 0.16]$
λ	0.00	$[-0.04, 0.05]$	$[-0.08, 0.08]$

[D0, arXiv:0907.4952]

Parameter	68% C.L.	95% C.L.
g_1^{Z}	$0.991^{+0.022}_{-0.021}$	$[0.949, \quad 1.034]$
κ_γ	$0.984^{+0.042}_{-0.047}$	$[0.895, \quad 1.069]$
λ_γ	$-0.016^{+0.021}_{-0.023}$	$[-0.059, \quad 0.026]$

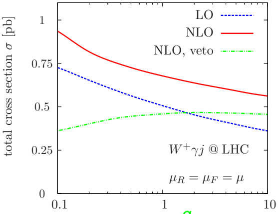
[ALEPH, DELPHI, L3, OPAL, arXiv:hep-ex/0612034]

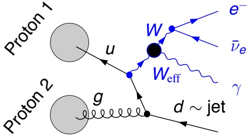
Turning the vetoed contribution into an additional measurement

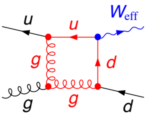
[Campanario, CE, Spannowsky '10], [Campanario, CE, Spannowsky, Zeppenfeld, '09]

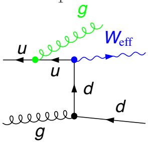
- $pp \to W(\gamma Z) + jet + X$ is large: new partonic channels enter the game!

  Can we use of it instead of excluding it?
  If yes we could constrain TGC from inclusive measurements ← perturbative QCD
- Improved perturbative precision is mandatory!









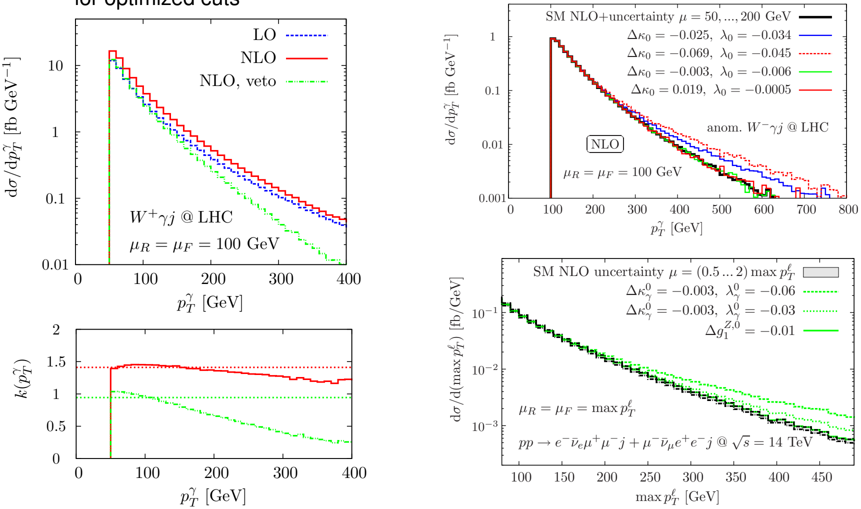
Numerical calculation, implementation and checks

- Catani-Seymour dipole subtraction
- semi-automized FORTRAN code set up
- cross & gauge checks
- optimization, cache systems
- redundant calculations, . . .

Turning the vetoed contribution into an additional measurement

[Campanario, CE, Spannowsky '10], [Campanario, CE, Spannowsky, Zeppenfeld, '09]

- differential QCD correction necessary to reach quantitative results from $\mathrm{d}\sigma/\mathrm{d}p_T^\gamma$ for optimized cuts



Is this of any help?

- W+jets background negligible to first approximation

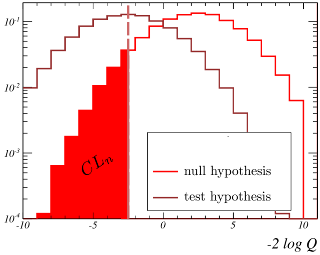
$$\text{jet fakes } \gamma \ll 10^{-5} \text{ for large } p_T^\gamma \geq 100 \text{ GeV}$$

[Escalier et al. , ATL-PHYS-PUB-2005-018]

- binned log-likelihood analysis, “simple hypothesis test” à la LEPHWG

[Barate et al. ’03]

- include perturbative shape uncertainty of the SM hypothesis as a nuisance parameter and compute confidence levels *[CE, Spannowsky, in progress]*



$\underline{\kappa_\gamma = 0, \lambda_\gamma = 0.035}$ $\sigma = 3 : 25\ \text{fb}^{-1}$

$\sigma = 5 : 50\ \text{fb}^{-1}$

Summary

- LEP's legacy implies a serious challenge for TGC searches at the LHC, Tevatron (direct) bounds are comparable
- LHC's energy bump will allow us to further constrain TGCs, however limits will be set by intrinsic uncertainties and our understanding of QCD
  (jet energy scales, perturbative uncertainty, . . .)
- one jet-inclusive contribution has a residual dependence on anomalous couplings we can use
- sensitivity at a new level is predominantly ILC business