Measuring Gauge Boson Couplings with CMS

Alexander Oh, CERN-EP

on behalf of the CMS collaboration

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V2.1

Outline

- Introduction
- Gauge Couplings
- Measurements & Methods
- Sensitivity to anomalous couplings
- Summary

Introduction

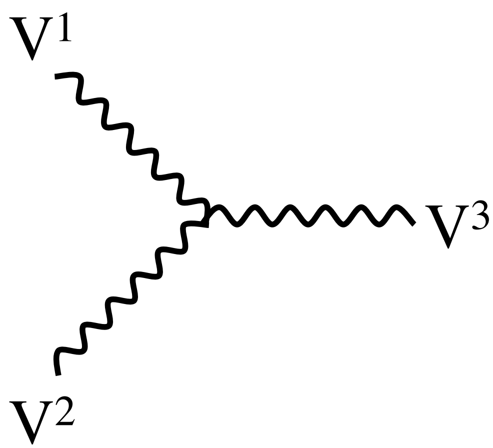
- The SM is based on gauge-invariance.
  - The non-Abelian gauge group structure predicts specifically the couplings between electroweak gauge bosons.

- Testing the gauge boson self couplings (GC) tests a fundamental aspect of the SM.

- Deviations will hint to Physics not described within the SM, changes to the SM could involve:
  - Extra fermions
  - extension of gauge group
  - Strong interactions of gauge bosons

- Complements direct searches for new physics.

Introduction

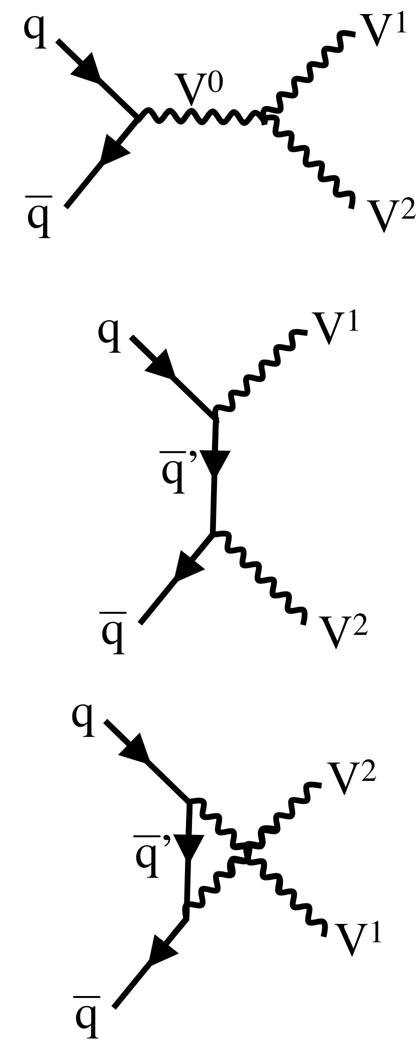


- Triple Gauge Boson (W,Z,γ) Couplings
  - Charged couplings
    - Allowed in the Standard Model
    - WWZ, WWγ
  - Neutral couplings
    - Forbidden in the Standard Model
    - ZZZ , ZZγ , Z$\gamma\gamma$

Introduction

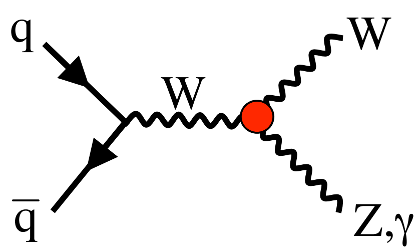
- Production Processes at the LHC
  - Leading order Feynman diagrams:
  - Only s-channel has three boson vertex
  - Anomalous couplings tend to manifest in:
    - Cross section enhancement
    - Enhancement at high p_T of $V^{1,2}$.
    - Production angle.

  - closer look at the parametrisation of the anomalous three boson vertex:



Triple Gauge Couplings

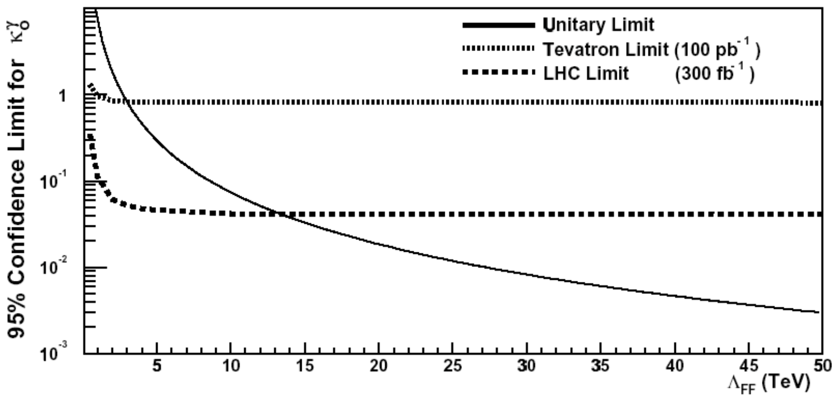
$\kappa_{\gamma,Z}$	1	Dim4, $\propto \sqrt{s}$
$\lambda_{\gamma,Z}$	0	Dim6, $\propto s$
g_1^Z	1	Dim4, $\propto \sqrt{s}$



h_1	dim6 , $\propto s^{3/2}$	!CP
h_2	dim8 , $\propto s^{5/2}$	!CP
h_3	dim6 , $\propto s^{3/2}$	CP
h_4	dim8 , $\propto s^{5/2}$	CP
f_4	dim6 , $\propto s^{3/2}$	!CP
f_5	dim6 , $\propto s^{3/2}$	CP

- Non-abelian $SU(2)_L xU(1)_Y$ gives WWZ and WWγ vertices.
  - Most general Langrangian gives 14 free parameters => effective Langrangian.
  - Requiring C, P conservation and EM Gauge invariance leaves 5 parameters.
- ZZZ, ZZγ and Z$\gamma\gamma$ vertices are forbidden in the SM.
  - Higher order corrections $\approx 10^{-4}$
  - The vertex is described by 12 parameters requiring Lorentz + EM gauge invariance, Bose symmetry.

Form Factors



from CERN 2000-004

$$A = \frac{A_0}{\left(1 + \frac{\hat{s}}{\Lambda_{FF}^2}\right)^n}$$

- Non-zero anomalous couplings violate unitarity => need for Form Factors (FF) to safeguard high energy limit.
- Choice of FF arbitrary
  - Anything that guards unitarity.
  - Common is the dipole FF.
  - $n > n_{Coupling}$ sufficient
  - Derived limits on A_0 are dependent on FF if integrated over s.
  - Fixing s allows measuring Λ_{FF}.

Experimental Methods

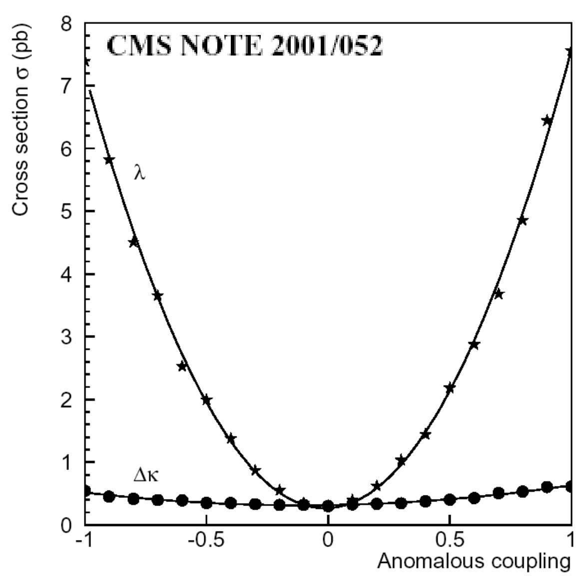
- Sensitivity to anomalous TGC
  - Total cross-section
  - enhanced p_T distribution at high di-boson masses
  - Angular distribution

- Charged Coupling Signatures
  - $W\gamma \Rightarrow l\gamma\nu$
  - $WZ \Rightarrow lll\nu$
- Neutral Coupling Signatures
  - $Z\gamma \Rightarrow ll\gamma$

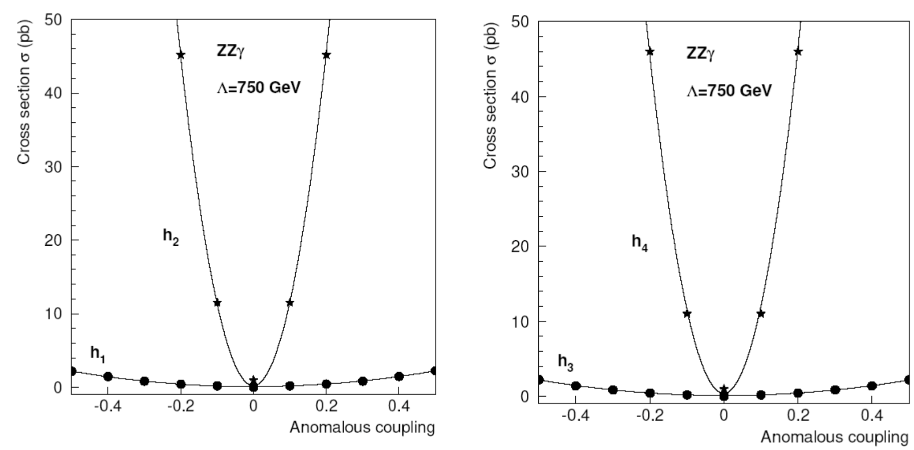
Sensitivity to Anomalous Couplings

- Total cross-section dependence ($|\eta| < 2.5$, $\sqrt{s} = 14$ TeV)
  - $\sigma_{tot} \propto$ (anomalous coupling)^2 dependence (linear in the Lagrangian)

Baur et al. generator including α_s.



charged couplings



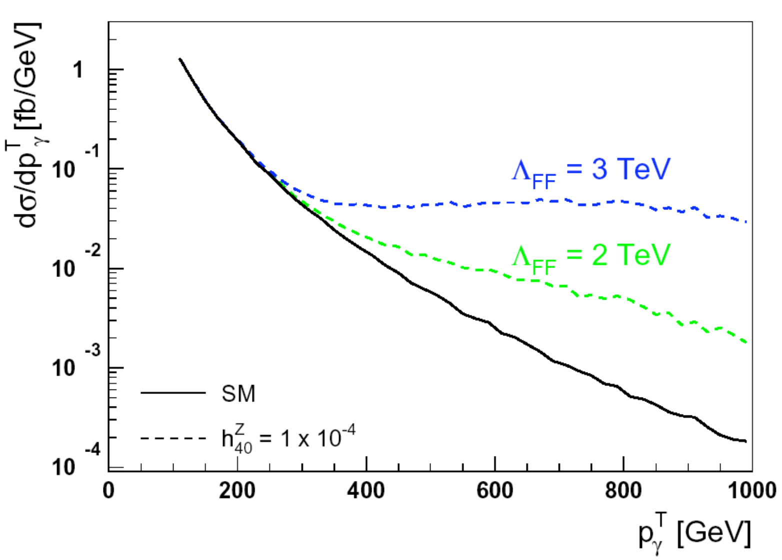
CMS NOTE 2000/017

neutral couplings

Sensitivity to Anomalous Couplings

Baur et al. generator including α_s.

- p_T distribution
  - Enhancement for high di-boson masses.
  - Notice dependence on Λ_{FF} scale.



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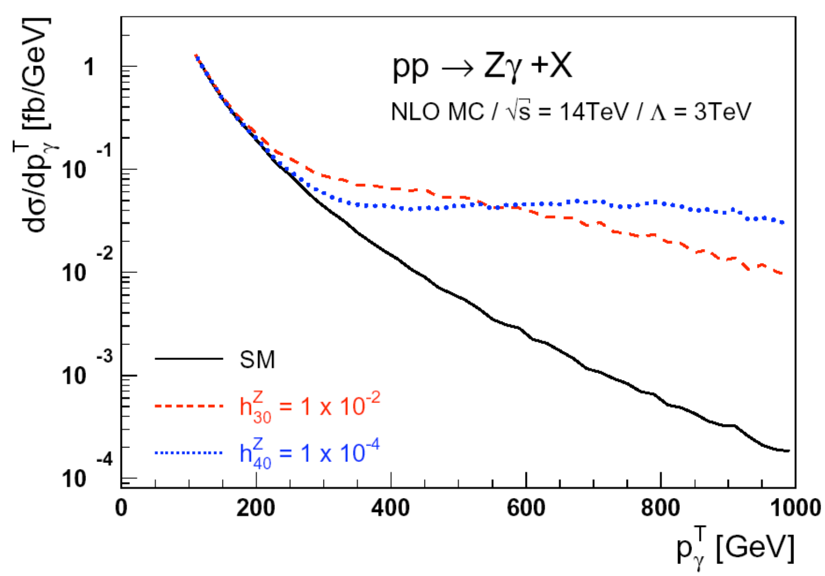
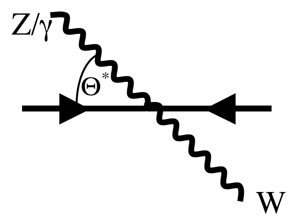


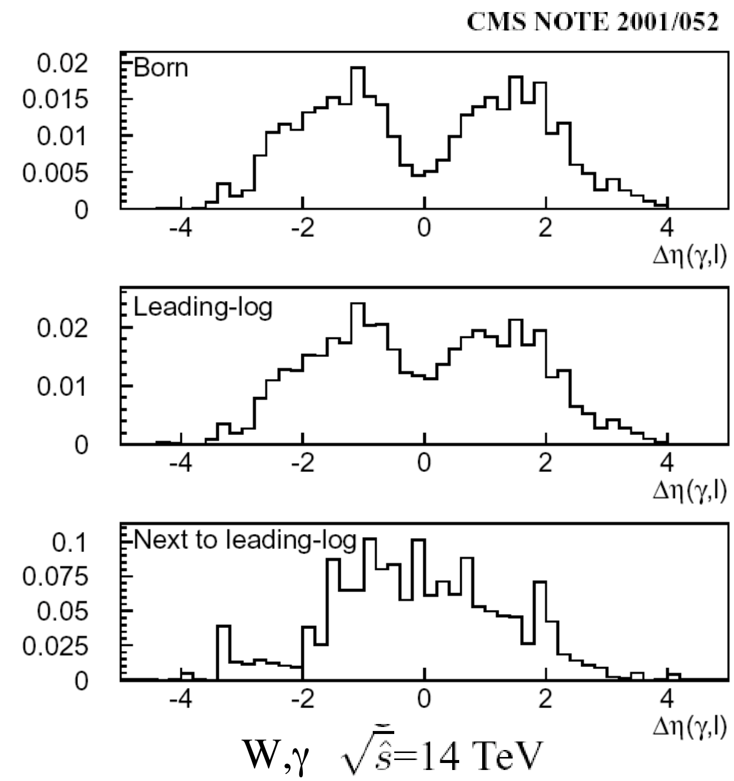
neutral couplings

Sensitivity to Anomalous Couplings

Baur et al. generator (BHO) including α_s.

- angular distribution
  - W, Z/γ: interference at Born level gives "radiation zero" at $\cos\left(\Theta^*\right) \approx -0.1(Z), -0.3(\gamma)$
  - The observable rapidity difference $\Delta\eta$ of lepton and Z/γ shows a dip.
  - NLO and anomalous contributions tend to "wash out" the interference.





Experimental Methods

Event selection

- Select only leptonic channels (e,μ) to avoid QCD background.
- Require
  - High p_T lepton (second l: Z, missing E_T: W)
  - isolated photon
- Additional jet veto minimizes NLO effects

Pseudorapidity Photon/Lepton	$\vert\eta_{\gamma/\ell}\vert < 2.4$
Transverse Energy Photon	$P_{T,\gamma} > 100\,\mathrm{GeV}$
Transverse Energy Lepton	$P_{T,\ell} > 25\,\mathrm{GeV}$
Photon-Lepton Separation	$\Delta R_{\ell\gamma} > 0.7$
Missing Energy	$\not{E}_T > 50\,\mathrm{GeV}$
Wγ Cluster Transverse Mass	$M_{TC}^{W\gamma} > 90\,\mathrm{GeV/c^2}$
Zγ Three-body Mass	$M_{\ell\ell\gamma} > 100\,\mathrm{GeV/c^2}$

- CMS studies:
  - at L=1fb^{-1}, 10fb^{-1}, 100fb^{-1}
  - fast simulation (CMSJET)
  - Wγ, Zγ
  - Extraction of FF dependent limits on anomalous couplings

charged TGC

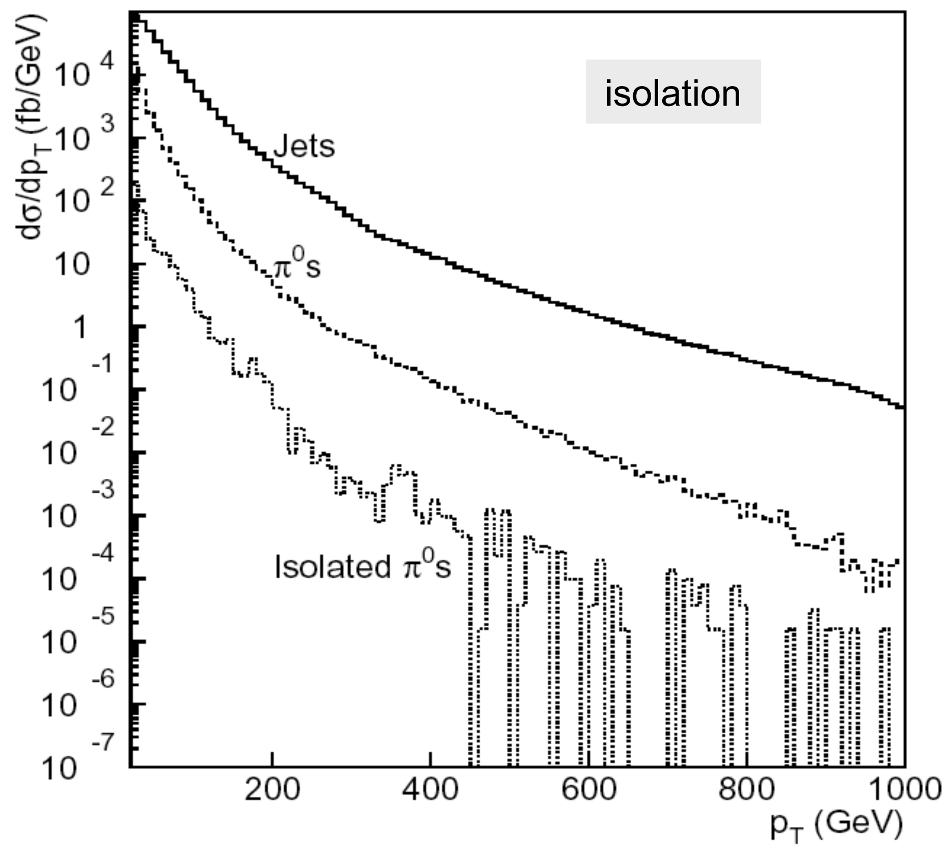
- Strategy Wγ
  - background
    - W+jets
    - Radiative W
    - bbγ
    - ttγ
  - rejected by
    - isolation cut
    - transverse mass cut
    - $p_T(\nu)$ cut
    - 2nd jet veto

Background	$\sigma_{backgrd}/\sigma_{signal}$
W + jet	500
Radiative W	10000
$b\bar{b}\gamma$	42
$t\bar{t}\gamma$	0.20
$Z\gamma$	0.04
$W(\tau\nu)\gamma$	0.05

CMS NOTE 2001/056

charged TGCs

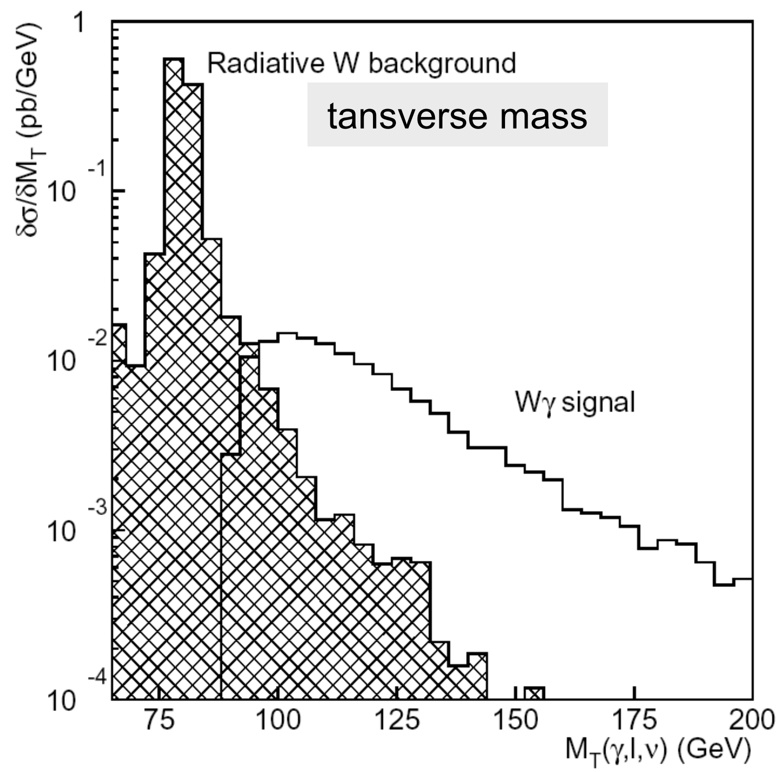
- Backgrounds of $W\gamma$ rejected by:
  - discrete isolation of photon
    - no tracks with $p_T > 2$GeV within $\Delta R=0.25$
    - rejects W + jets
    - loss 5%, rejection factor 7



CMS NOTE 2001/056

charged TGCs

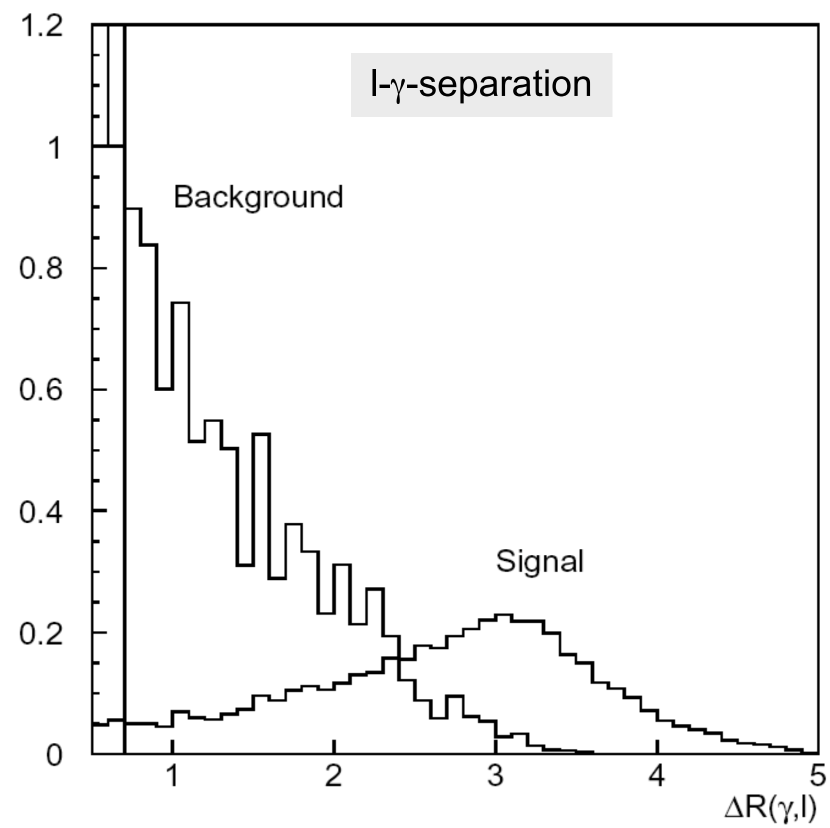
- Backgrounds of Wγ rejected by:
  - transverse mass cut & coliniarity of lepton and photon
    - reduces radiative W events
    - cut on transverse mass > 100GeV
    - cut on separation $\Delta R(\gamma,l) > 0.7$



CMS NOTE 2001/056

charged TGCs

- Backgrounds of $W\gamma$ rejected by:
  - cut on $p_T(\nu)$
    - require $p_T(\nu) > 50$GeV
    - reduces $bb\gamma$ background

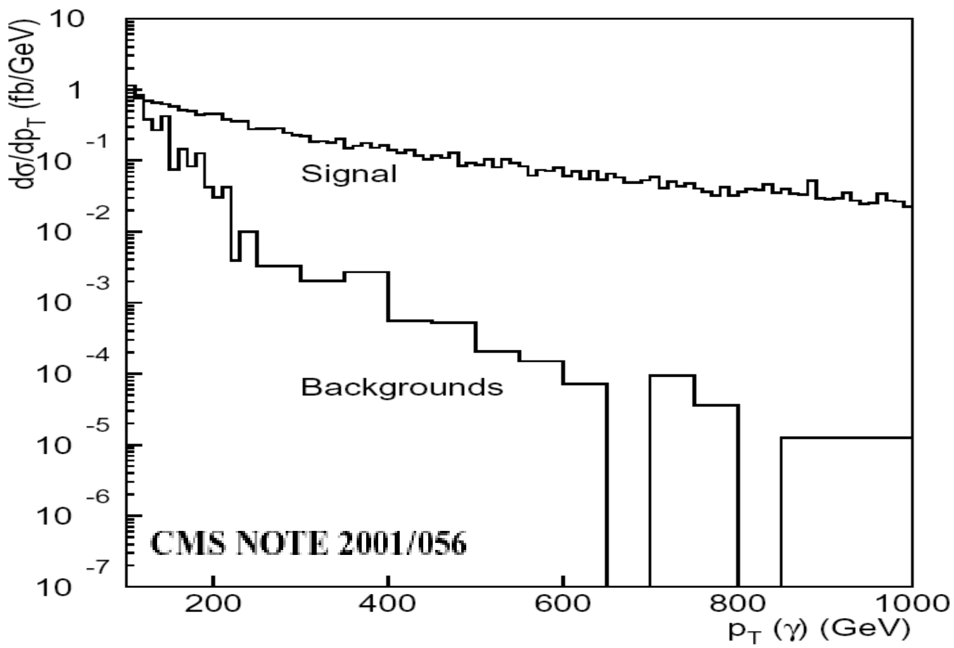


CMS NOTE 2001/056

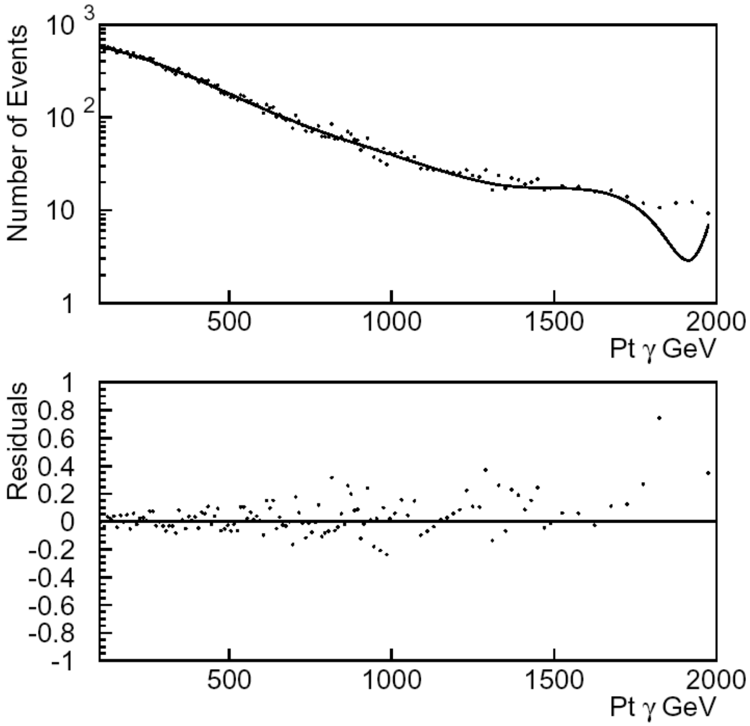
charged TGC

- After all cuts

Cut	Signal %	Background %		
		W+jet/Rad.W	$t\bar{t}\gamma$	$bb\gamma$
$P_t(\gamma)$	67±0.49	0.06±0.008	72±5.33	84±0.22
$P_t(\ell)$	84±0.52	62±0.25	5±1.02	0.2±0.001
$M_T(\gamma,\ell,\nu)$	85±0.52	19±0.14	87±4.2	0.3±0.0115
$\Delta R(\gamma,\ell)$	95±0.55	94±0.3	95±4.4	94±0.23
$P_t(\nu)$	86±0.53	60±0.25	43±2.9	28±0.124
2nd jet	89±0.54	42±0.2	0+0.2	34±0.14
All Cuts	55±0.42	0.33±0.018	0+0.2	0.006±0.0019



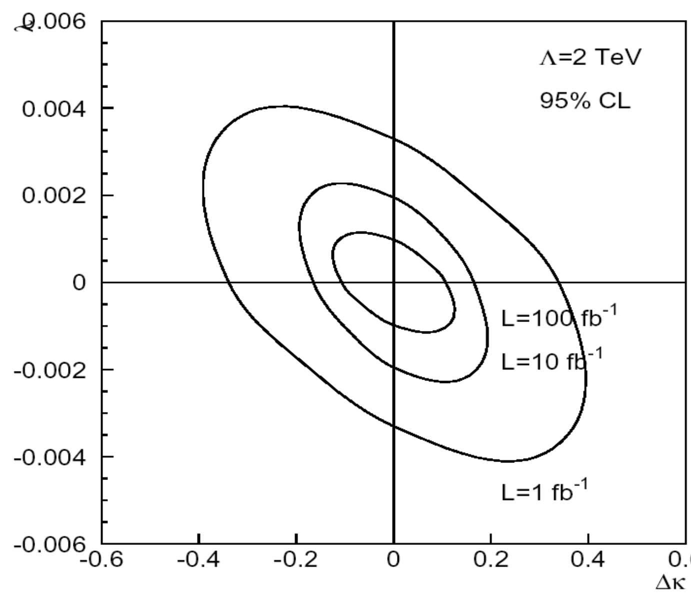
charged TGC



- Strategy $W\gamma$
  - Binned log likelihood fit to $p_T(\gamma)$ distribution.
  - Use parametrised p_T spectrum ($\Delta\kappa$, λ) from BHO NLO generator.

Luminosity (fb^{-1})	CMS Predictions		TeV2000 Predictions	
	$\Delta\kappa$	λ	$\Delta\kappa$	λ
1	$\pm$ 0.34	$\pm$ 0.0034	$\pm$ 0.4	$\pm$ 0.12
10	$\pm$ 0.17	$\pm$ 0.0019	$\pm$ 0.2	$\pm$ 0.06
100	$\pm$ 0.10	$\pm$ 0.0009	-	-

Λ_{FF}=2TeV



CMS NOTE 2001/056

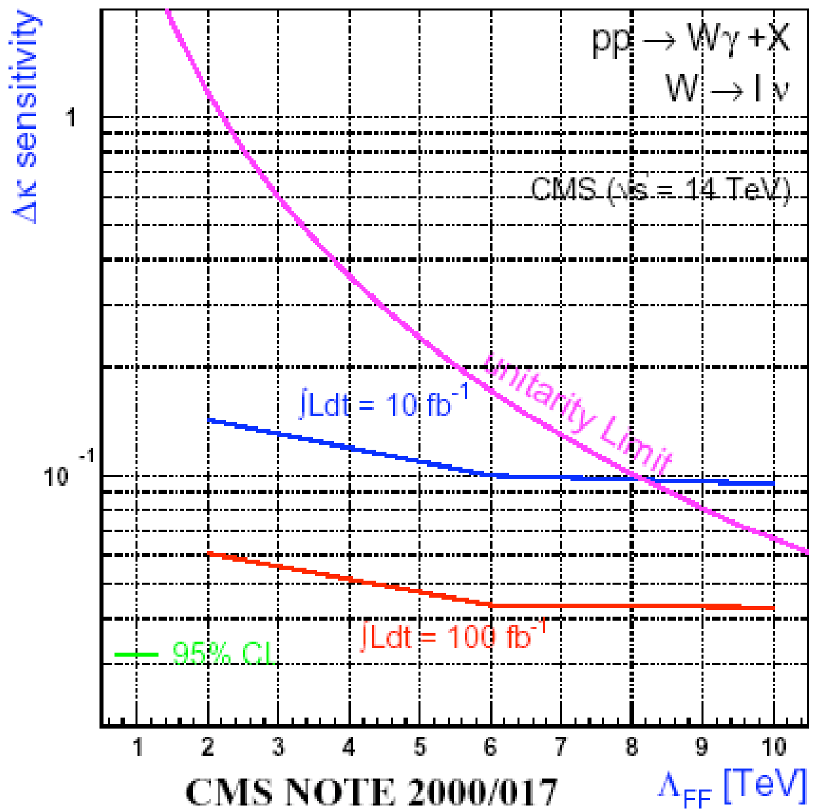
LEP2 combined:

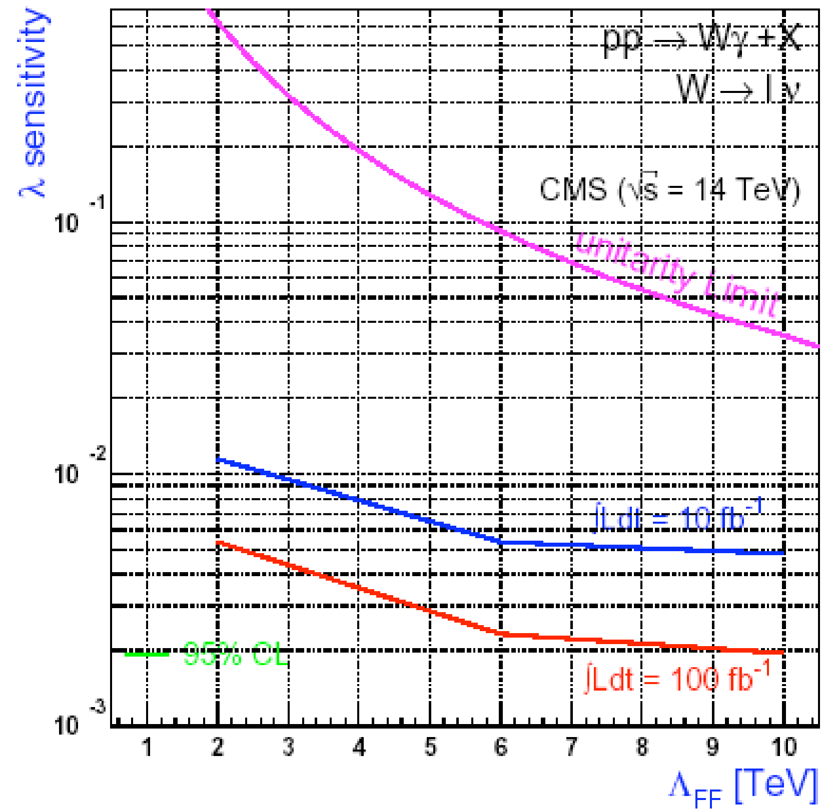
Parameter	68% C.L.	95% C.L.
g_1^Z	$0.991^{+0.022}_{-0.021}$	[0.949, 1.034]
κ_γ	$0.984^{+0.042}_{-0.047}$	[0.895, 1.069]
λ_γ	$-0.016^{+0.021}_{-0.023}$	[−0.059, 0.026]

Limits with $L=100fb^{-1}$ improve by two orders of magnitude for λ_γ.

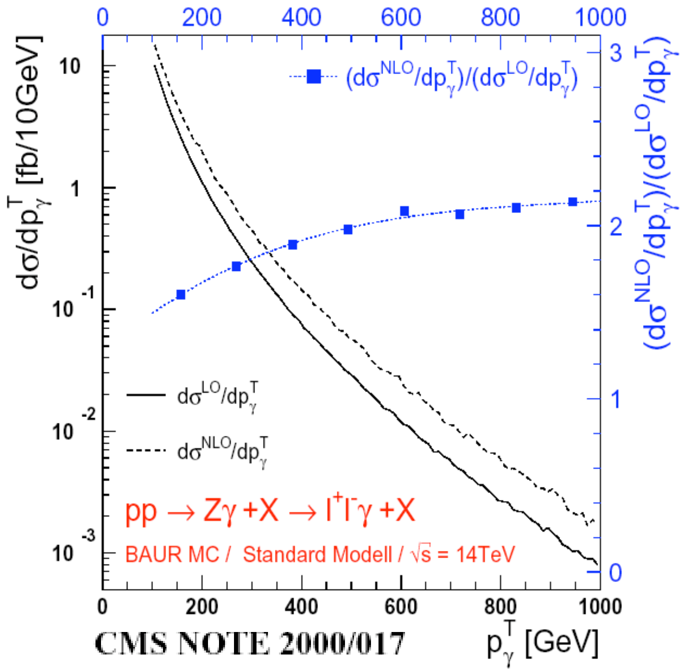
charged TGC

- Λ_{FF} dependence





neutral TGC

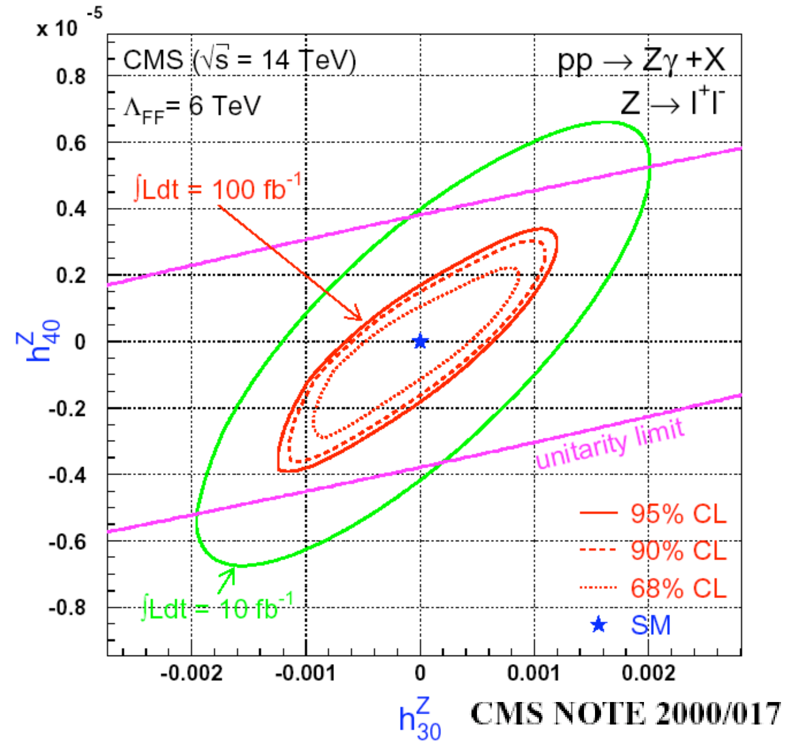


LEP2 combined:

h_3^Z	$[-0.20, \quad +0.07]$
h_4^Z	$[-0.05, \quad +0.12]$

Limits with L=100fb^{-1} improve by 3(5) orders of magnitude for h_3(h_4).

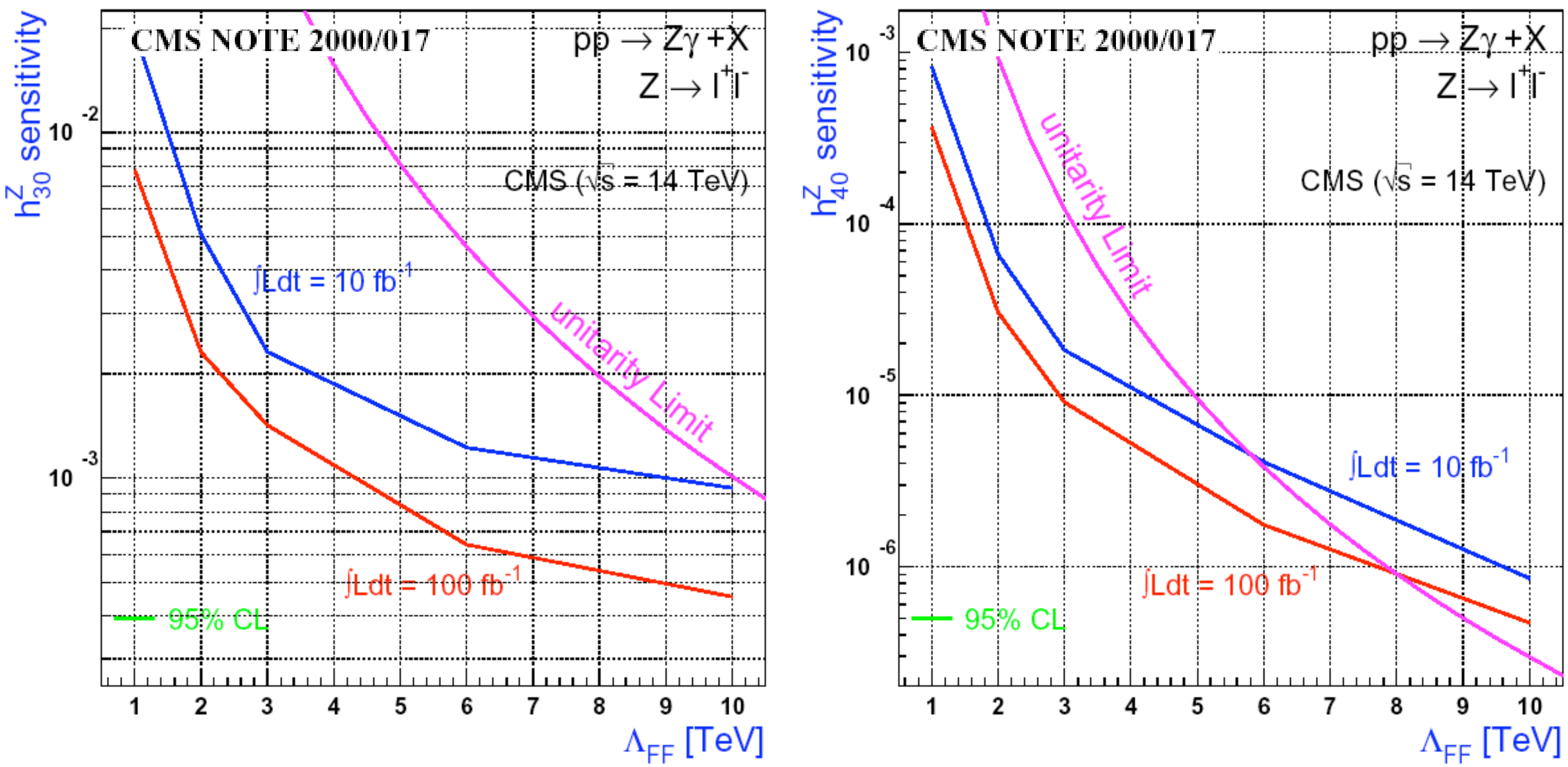
- Zγ channel
  - binned log likelihood fit to $p_T(\gamma)$ distribution.
  - NLO taken into account



$$-6.5 \cdot 10^{-4} < h_{30}^Z < 6.4 \cdot 10^{-4}$$
$$-1.8 \cdot 10^{-6} < h_{40}^Z < 1.7 \cdot 10^{-6}$$

neutral TGC

- Λ_{FF} dependence



CMS NOTE 2000/017

Summary

- LHC provides with its high $\sqrt{s}$ a good place to look for anomalous couplings.
- Expected to improve the limits significantly for coupling with $\propto s^n$, $n \geq 1$.
  - 1(2) order of magnitude for $\Delta\kappa$ (λ).
  - 3(5) orders of magnitude for h_3 (h_4).
- Upcoming studies:
  - WZ channel, refined $Z\gamma$, $W\gamma$ analysis.
  - using improved simulation models of CMS.
  - better NLO MC generators.