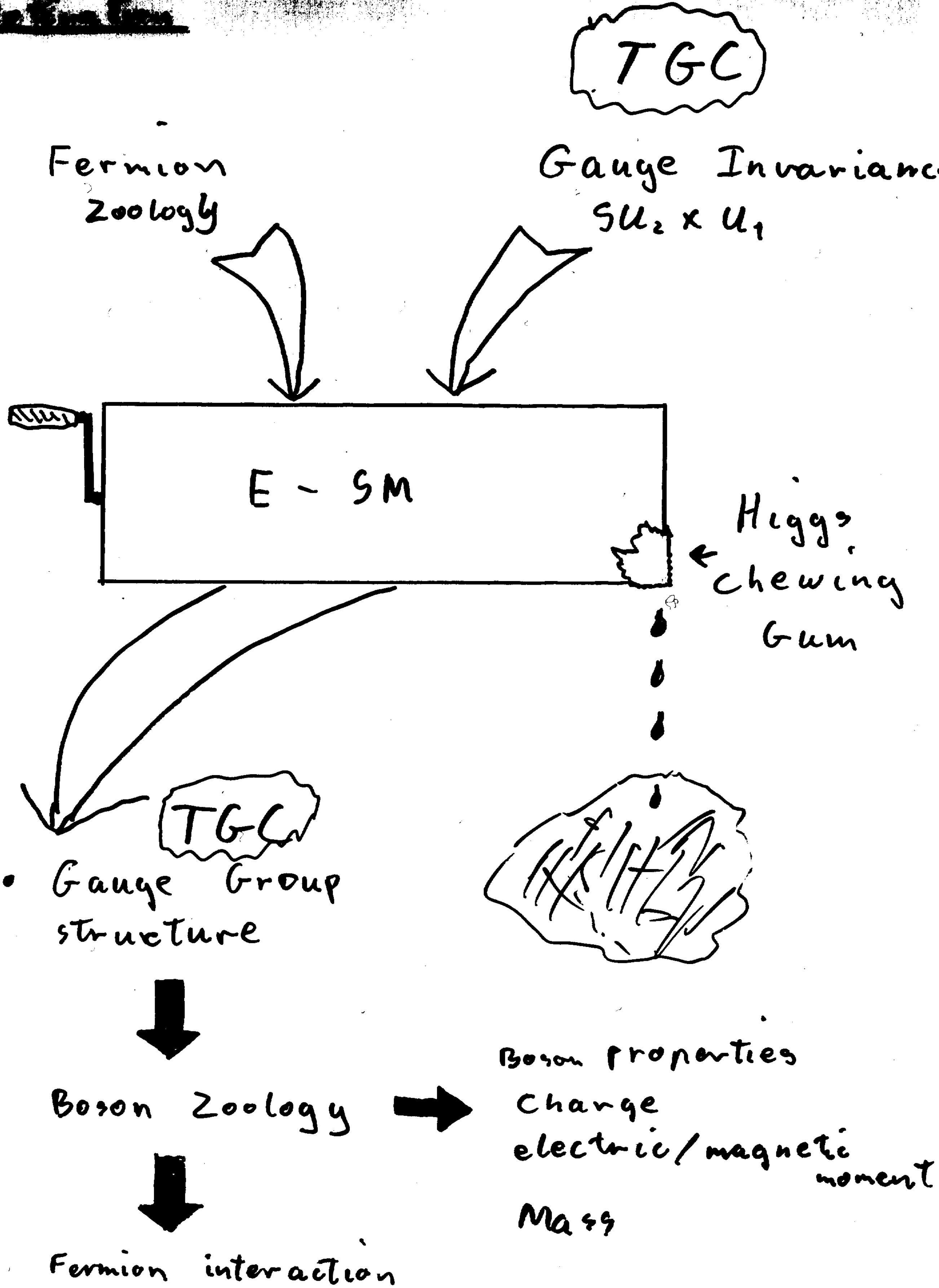
Triple Gauge-boson Couplings in Boson pair production

Jørgen Beck Hansen
CERN/ATLAS

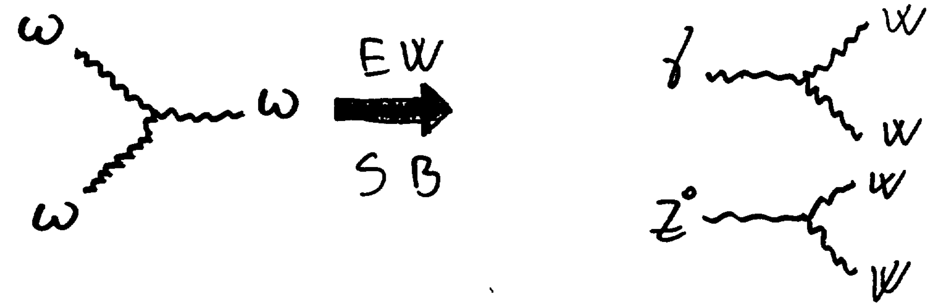
LHC Physics Workshop
CERN 22/1-1999

Outline:

- Introduction
  - Why → What → How
- Present status
  - TeVAtron
- At LHC / ATLAS


TGC
Fermion Zoology
Gauge Invarianc
$SU_2 \times U_1$
E - SM
Higgs chewing Gum
TGC
Gauge Group structure
Boson Zoology
Fermion interaction
Boson properties
Charge
electric/magnetic moment
Mass

The starting point for the TGCs is the non-Abelian structure of SM



Therefore:

- The TGCs are tightly connected with symmetry breaking
- The couplings of the γWW and Z^0WW vertices reflect the full gauge group structure
- Connected to W properties

$$Q_W = e g_1^\gamma \qquad \text{(charge)}$$

$$\mu_W = \frac{e}{2m_W}(g_1^\gamma + \kappa_\gamma + \lambda_\gamma) \qquad \text{(Magn. dip.)}$$

$$q_W = -\frac{e}{m_W^2}(\kappa_\gamma - \lambda_\gamma) \qquad \text{(Elec. quad.)}$$

➡ Test SM with γWW and Z^0WW

- One step further (pessimistic scenario....)

  TGCs also probe for New Physics

- In this context additional non-SM contributions has the magnitude

$$|TGC| \sim \left(\frac{M_W}{\Lambda_{NP}}\right)^2$$

- But: In order to have a completely model independent description we need 7 TGCs per vertex → 14 TGCs !
  Allows a determination of the structure of NP !

- Restricting us to C, P and em. gauge invariant TGCs :

$$\underbrace{g_1^Z, \kappa_\gamma, \kappa_Z}_{=1 \text{ in SM}} \quad \text{and} \quad \underbrace{\lambda_\gamma, \lambda_Z}_{=0 \text{ in SM}}$$

- What can we expect ?

$$\Lambda_{NP} = 1 \text{ TeV} \Rightarrow \text{TGCs} \sim \mathcal{O}(10^{-2})$$

- Radiative corrections : $\mathcal{O}(10^{-3})$
- SUGRA - Gut MSSM : $\mathcal{O}(10^{-3})$
- Unconstrained MSSM : $\mathcal{O}(10^{-2})$

Characteristics of TGCs

- Main sensitivity lie in the angular distribution of the boson production angles ➡
- But: different TGCs contribute to different boson helicity states
  - → Decay angular information enhance sensitivity to individual TGCs
  - → Advantage for clean e^+e^- machines
- Since the Lagrangian is linear in the TGCs we have

$$\frac{d\sigma}{d\Omega} = \underset{\text{SM}}{\underset{|||}{a_0}} + a_1 \cdot TGC + a_2 \cdot (TGC)^2$$

at most quadratic dependence!

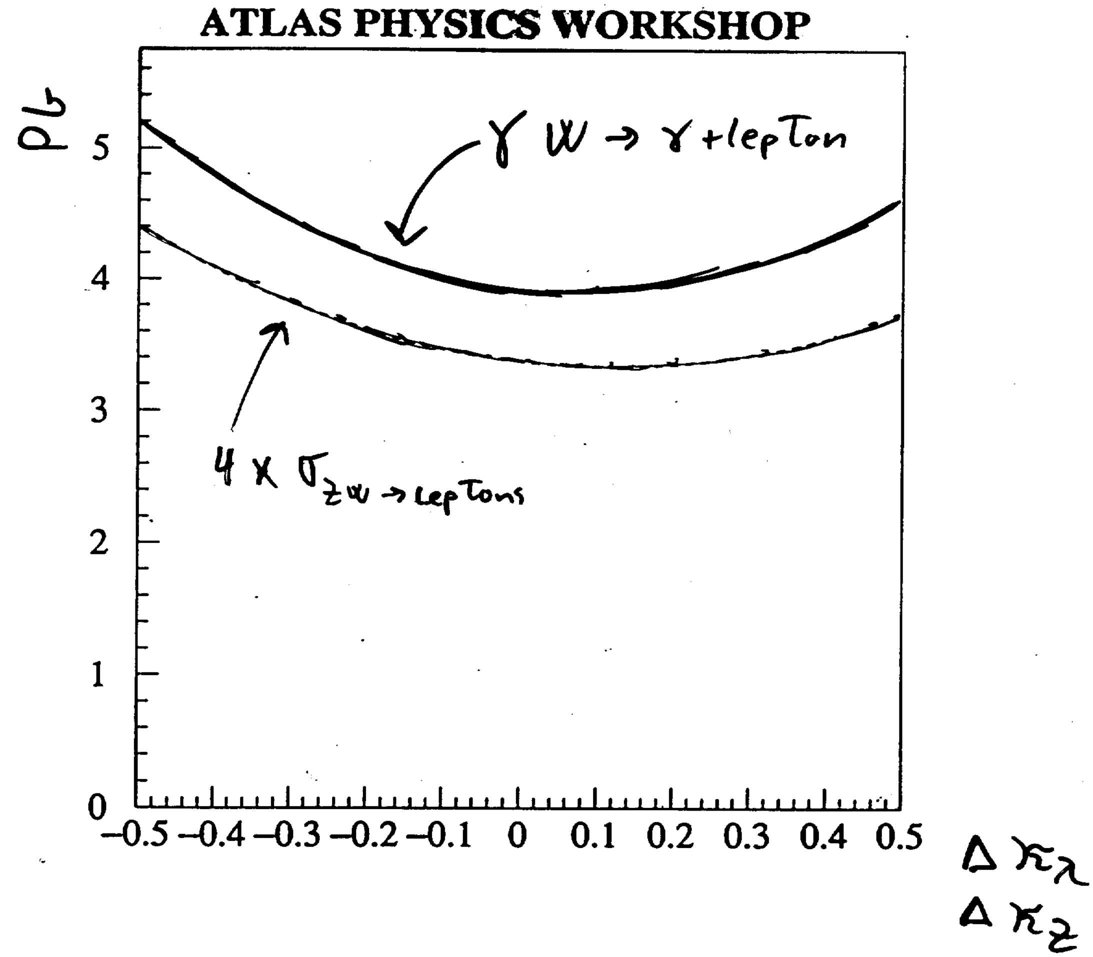
- Generally we have that

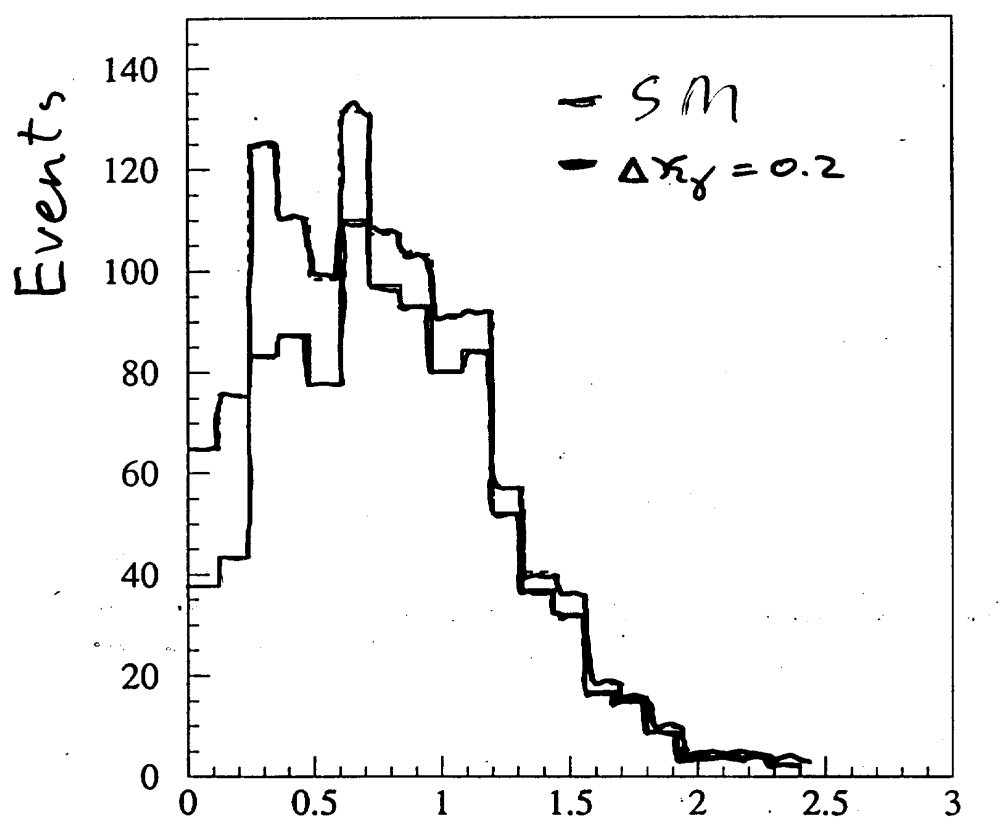
$$\sigma \propto +(TGC)^2 \quad \text{(Increasing)}$$

- Sensitivity increases strongly with energy

$$\frac{a_1 \cdot TGC + a_2 \cdot (TGC)^2}{a_0} \propto S$$

→ Favor Hadron machines with their high energy ("p_T counting")





$$|y| = \frac{1}{2}\left|\ln \frac{1+\cos\theta}{1-\cos\theta}\right|$$

θ: angle between γ and beam in Wγ-system

TGCs from Tevatron

- At hadron colliders we have distinguisable final states

$$W\gamma, \quad WZ$$

along with WW

- Provide independent constrains on γWW and ZWW couplings

- Important difference for hadron machines: The TGCs are introduced as form factors with scale Λ

$$TGC \rightarrow \frac{TGC}{(1+s/\Lambda^2)^2}$$

→ Higher Λ improve limits. Usually $\Lambda \sim \sqrt{s}$

- At CDF/DØ all 3 final states are studied

  - $W\gamma \rightarrow \binom{e}{\mu}\nu\gamma$

    TGCs extracted via binned likelihood fit to E_T of γ.

  - $WW \rightarrow \ell\nu\ell\nu$

    Binned likelihood fit to E_T (e) and P_T (μ)

  - $WW/WZ \rightarrow \ell\nu jj/\ell\ell jj$ (high backg.)

    Binned likelihood fit to P_T lepton system

Present ⊕

DØ : Fermilab-Pub-97/136-E

FIGURES

$\Delta\kappa_Z = 1$

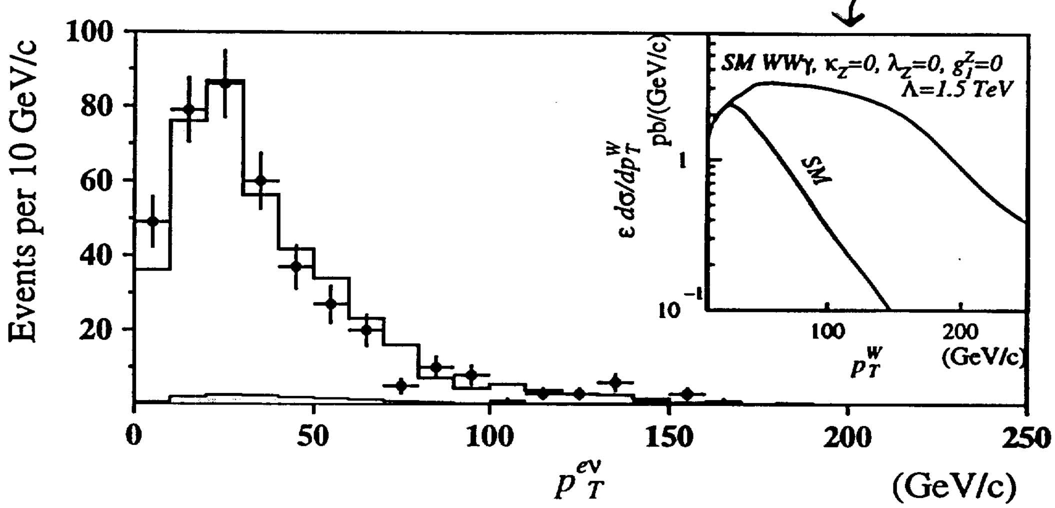
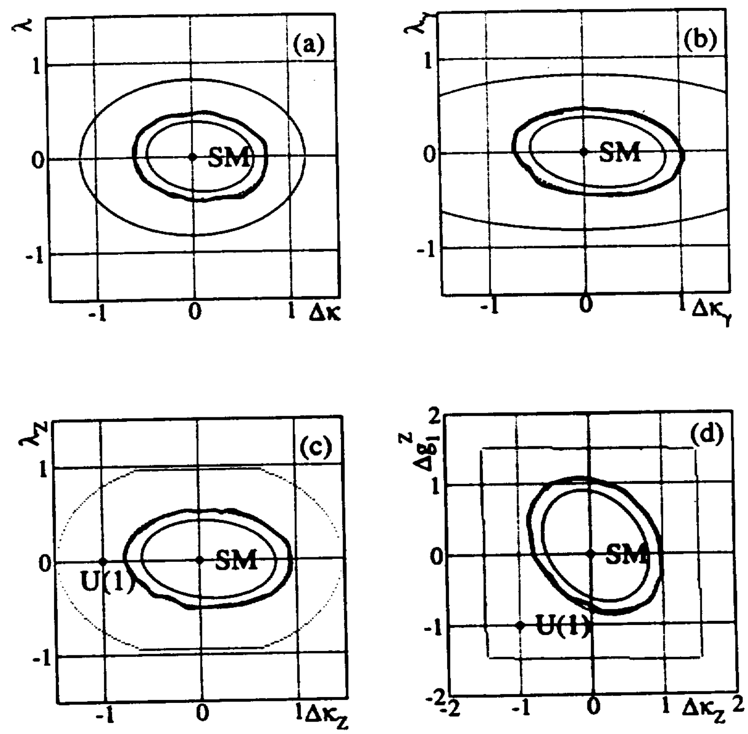


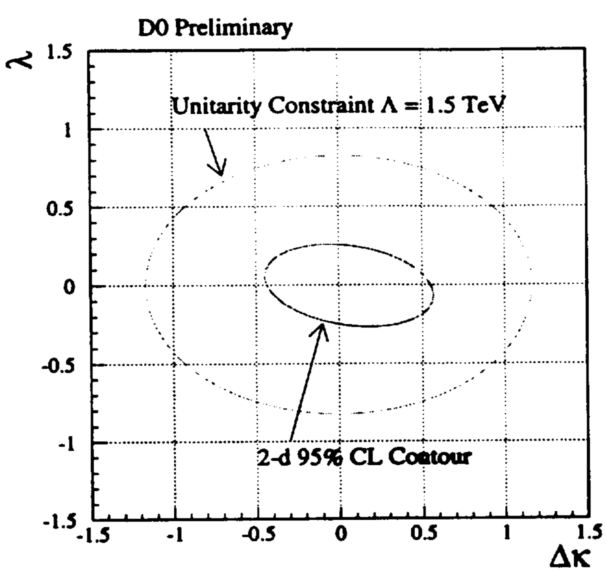
FIG. 1. p_T distributions of the $e\nu$ system for the 1993–1995 data set. The points with error bars represent the data. The solid histogram is the total background estimate plus the SM Monte Carlo predictions of WW and WZ production (shown as shaded histogram). The inset shows the predicted $d\sigma/dp_T^W$, folded with the detection efficiencies, for SM $WW\gamma$ and WWZ couplings (lower curve), and for SM $WW\gamma$ and the indicated anomalous WWZ couplings (upper curve).

DØ



(a)
λ
SM
Δκ
(b)
λ_γ
SM
$\Delta\kappa_\gamma$
(c)
λ_Z
SM
U(1)
$\Delta\kappa_Z$
(d)
Δg_1^Z
SM
U(1)
$\Delta\kappa_Z$

— 95%



D0 Preliminary
λ
Unitarity Constraint Λ = 1.5 TeV
2-d 95% CL Contour
Δκ

- Combined fits to all analyses gives

$$-0.93 < \Delta\kappa_\gamma < 0.94$$

$$-0.31 < \lambda_\gamma < 0.29 \qquad 95\%\ CL$$

$$-0.33 < \Delta\kappa = (\Delta\kappa_\gamma = \Delta\kappa_Z) < 0.45 \qquad \Lambda = 2\ TeV$$

$$-0.20 < \lambda (= \lambda_\gamma = \lambda_Z) < 0.20 \qquad \text{run } 1$$

To conclude

After so many years with SM we can still not constrain the Gauge group structure !

- Imidiate future perspectives :

Ultimate limits from

LEP : ~ 3 lower

Tevatron : ~ 3 lower

→ 4–5 times lower

→ $O(0.07)$ when LHC starts

- scaling to $10\ fb^{-1}$ @ 14 TeV should give ~ 10 times lower !

An ATLAS study of the Potential limits @ LHC

- Follows the line from the previous study (TP: 1994):
  - Leptonic final states for γW and WZ
  - Limits derived from high P_T event counting
  - AT $\sqrt{s} = 14$ TeV and $\int \mathcal{L} dt = 100\ fb^{-1}$:

γW $\quad |\Delta\kappa_\gamma| < 0.07$

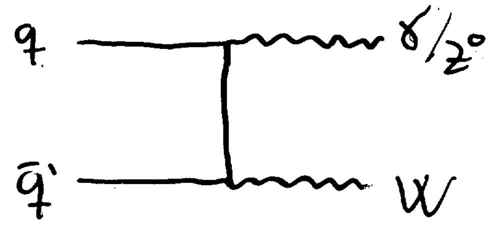
$\quad\quad\; |\lambda_\gamma| < 0.0025$

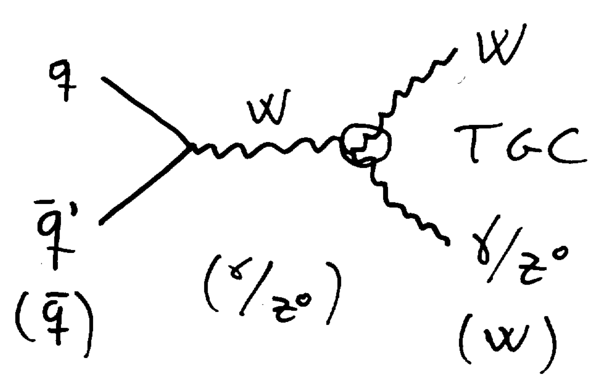
$\Lambda = 10$ TeV

ZW $\quad |\Delta\kappa_Z| < 0.13$

$\quad\quad\; |\lambda_Z| < 0.006$

- In hadron machines the dominant Gauge boson pair production processes are





- Considering lepton final states only the dominant physics background is (as usual)

$$pp \to t\bar{t} \to \text{lepton(s)} + X$$
$$pp \to b\bar{b} \to \text{lepton(s)} + X$$

$$pp \to \gamma b \to \gamma + \text{lepton} + X \quad (\gamma W)$$
$$pp \to \gamma Z \to \gamma + \text{lepton(s)} + X \quad (\gamma W)$$

(not included yet: $ZQ\bar{Q}$, ZQ + fake id combinatorics)

- Selection based on <u>Isolated</u> lepton / photon id + event quantities

γW	ZW
<u>One</u> lepton with $E_T > 40$ GeV	<u>Three</u> leptons with $E_T > 10$ GeV and <u>at least</u> one valid $l\bar{l}$ flavour comb.
No $l\bar{l}$ pair with	<u>At least</u> one $l\bar{l}$ pair with
$-15 < M_{l\bar{l}} - M_Z < 15$	$-20 < M_{l\bar{l}} - m_Z < 20$
$E_T^{\gamma} > 100$ GeV	$\mathrm{Max}(E_T^{l}, E_T^{\bar{l}}) > 25$ GeV
$M_T^{l\nu} > 35$ GeV	$\min(E_T^{l}, E_T^{\bar{l}}) > 15$ GeV
Extra leptons: $E_T < 10$ GeV	$E_T^{lw} > 10$ GeV
Jet energy veto $E_T^{\text{2nd jet}} < 20$ GeV	$M_T^{l\nu} > 35$ GeV

- More sophisticated selection forseen (eg. anti-b tag) but present selection is compatible with previous study and Tevatron

- Resulting event sample

γW : P = 94 % (caution)

Number of events/Year (Low) ~ 1000

ZW : ε = 34 % P = 84 % (caution)

Number of events/Year (low) ~ 1500

Extracting TGCs

- The TGCs are extracted individually for γW and ZW using unbinned maximum likelihood fit to the distribution of

γW : P_T^γ

ZW : P_T^Z

- The likelihood for each event is evaluated from a MC distribution generated with Baur + Zeppenfeld γW and ZW processes, which have been implemented into PYthia/ATLfast

- The advantage of this method is
  - To the extent that MC will describe reality -

  that it automatically include detector and background effects.

↓

Equivalent to Tevatron

- Results ($\Lambda = 14$ TeV)

$0.063 <$	$\Delta\kappa_\gamma$	< 0.060		
$0.005 <$	λ_γ	< 0.007		95% CL
$0.087 <$	$\Delta\kappa_Z$	< 0.129		
$0.013 <$	λ_Z	< 0.028		

- <u>NOTE:</u> SNapshot of ongoing studies!

  Plan: Combine γW and ZW

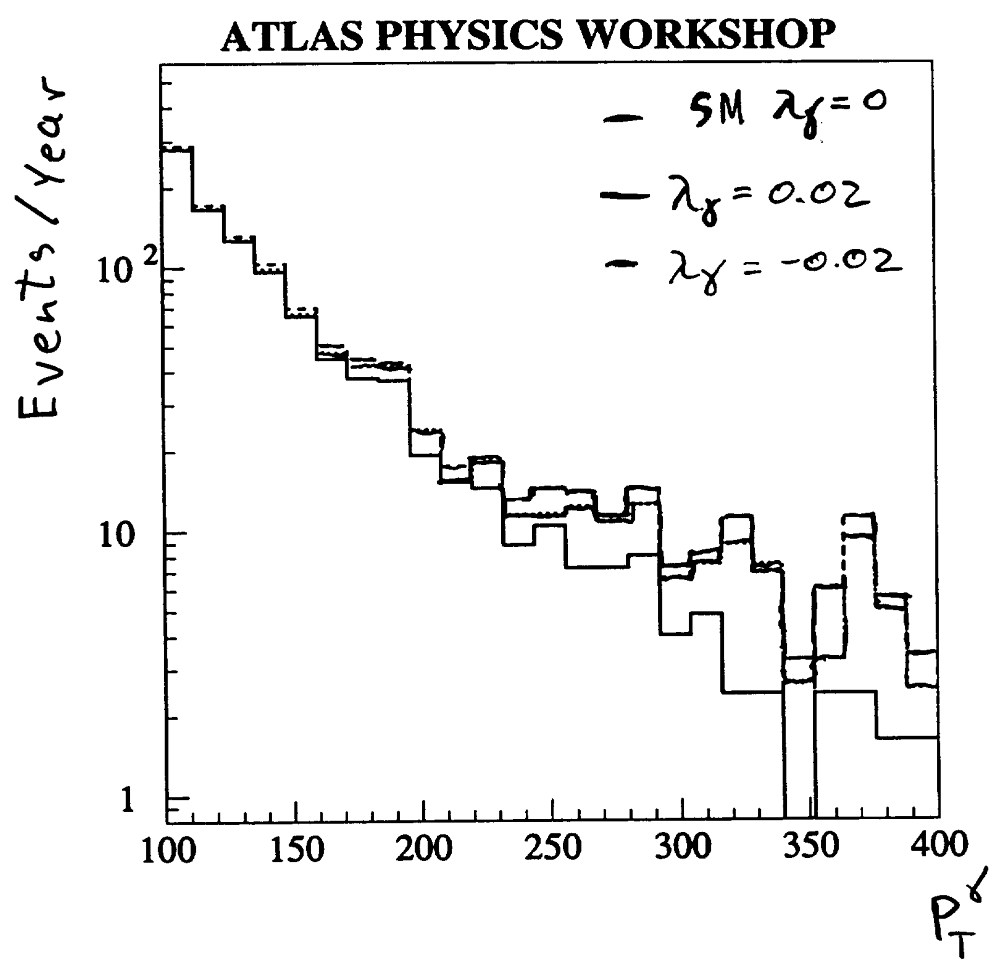
  Include angular information

  Look into WW channel

  High statistics background study

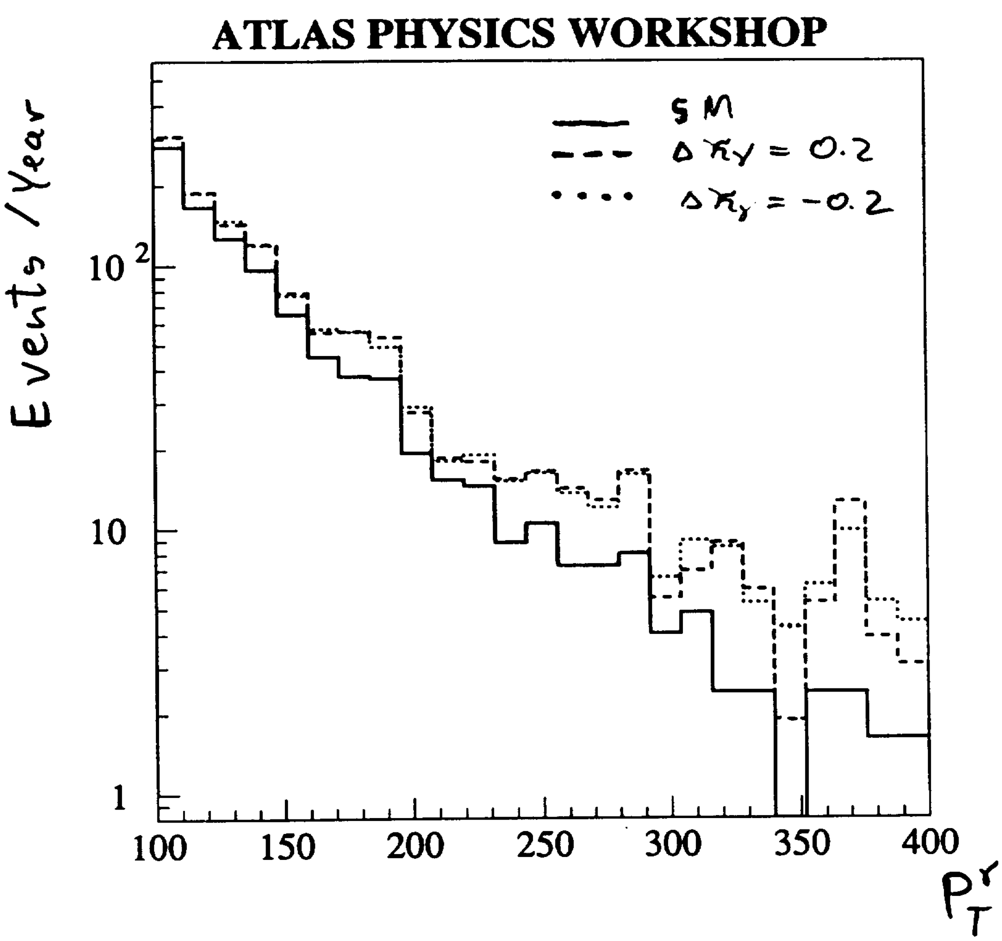
LHC (5)

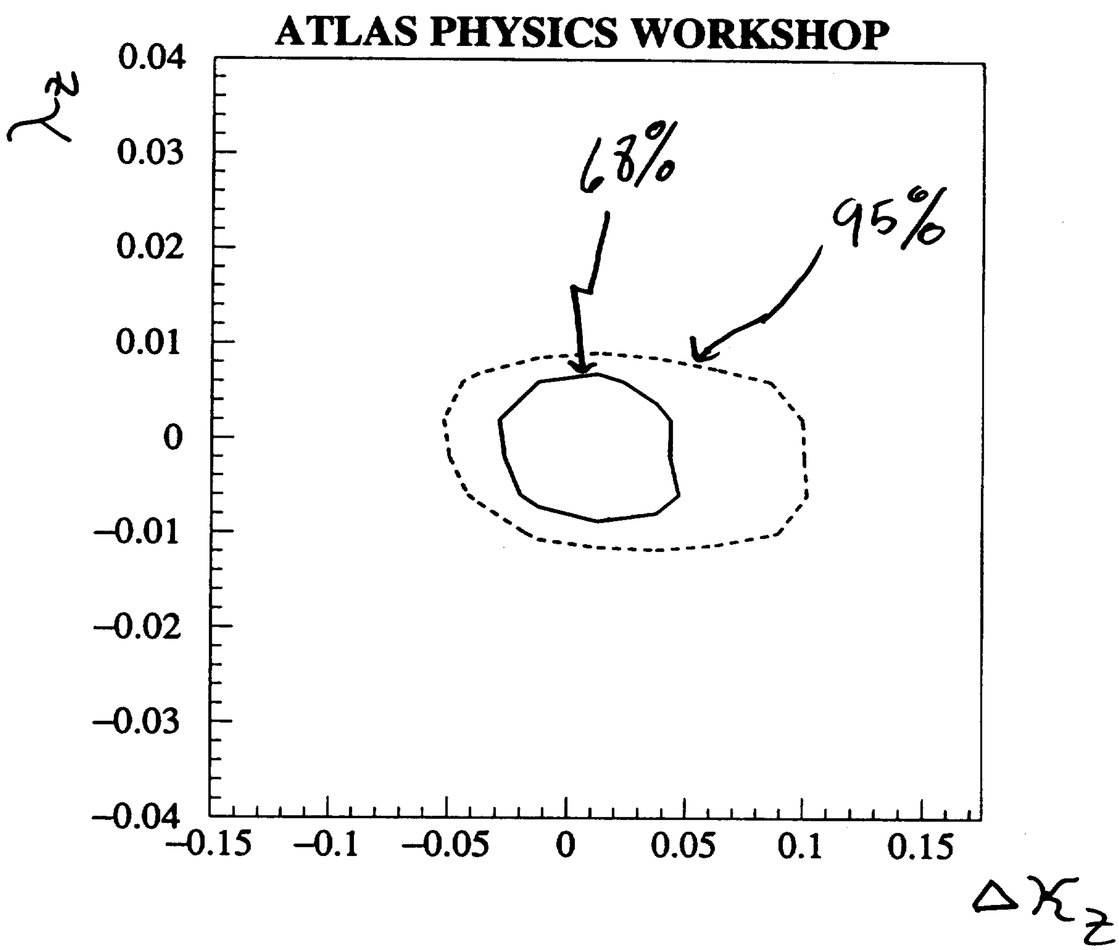
γ W

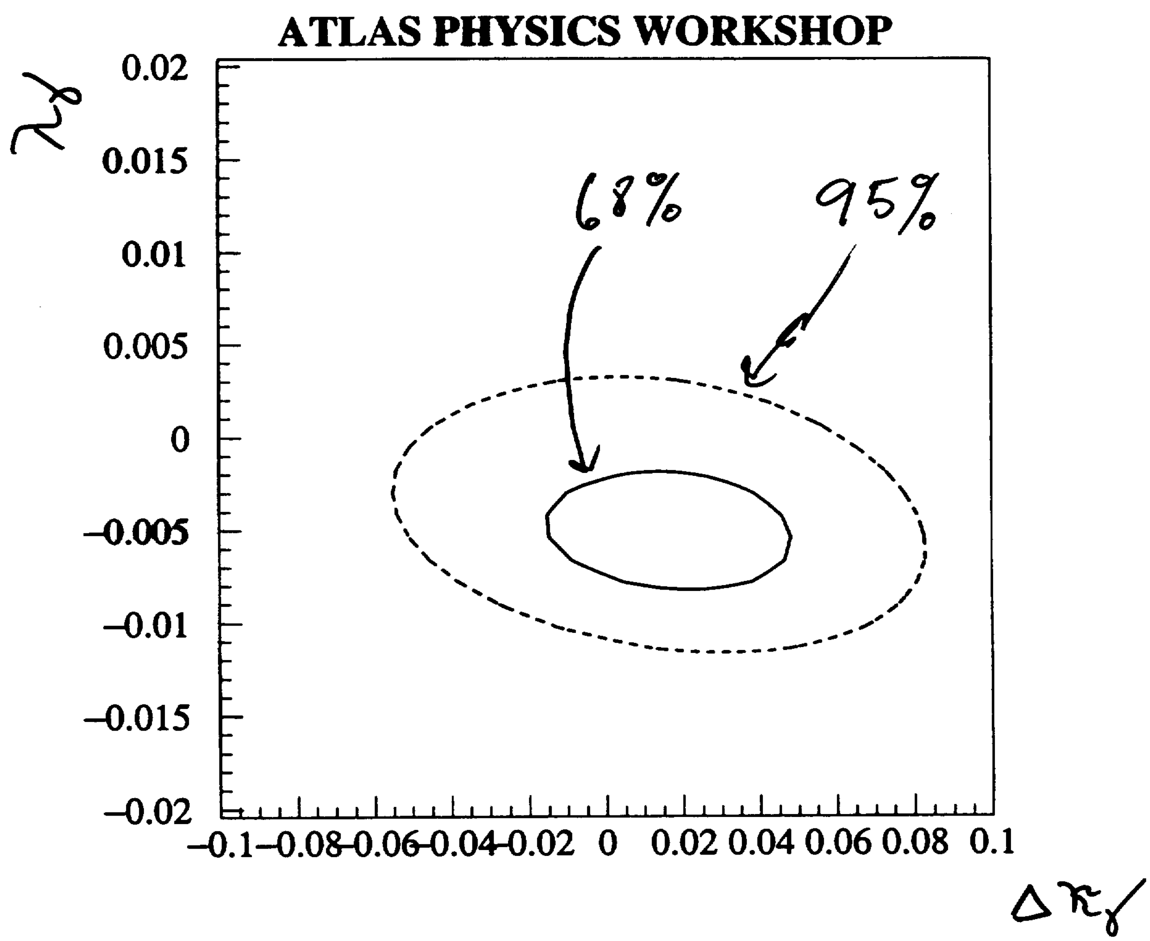


- Similarity of opposite sign come from quadratic behaviour of total cross-section

γ W


ATLAS PHYSICS WORKSHOP
SM
Δκγ = 0.2
Δκγ = -0.2
Events / Year
10 ²
10
1
100
150
200
250
300
350
400
PTγ


ATLAS PHYSICS WORKSHOP
68%
95%
0.04
0.03
0.02
0.01
0
−0.01
−0.02
−0.03
−0.04
−0.15
−0.1
−0.05
0
0.05
0.1
0.15


ATLAS PHYSICS WORKSHOP
λ_γ
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
68%
95%
−0.1 −0.08 −0.06 −0.04 −0.02 0 0.02 0.04 0.06 0.08 0.1
$\Delta\kappa_\gamma$

Conclusion

- The study of boson pair production provides a Unique determination of the SM Gauge group structure
- LHC will provide the ideal situation for a precision equal or better than radiative corrections !
- Already the first year @ LHC will improve limits with almost an order of magnitude