ANOMALOUS COUPLINGS AT W-W-GAMMA VERTEX IN γp COLLISION

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1. Beyond the SM and New Physics

Although there is no confirmed experimental evidence from colliders against the Standard Model it is known that there are many unsatisfactory aspects which can be organized as follows:

- Problem of flavour

How many flavours are there ?, What is the origin of three families of leptons and quarks?, what explains flavour mixing and CP violation? (observed baryon assymetry needs new sources of CP violation)

- Problem of mass

Do particle masses really originate from a Higgs boson? , if so where is the Higgs boson?, are there neutrino masses?

Future strategy:

It is widely believed that

- the SM is the starting point to answer the above problems and **physics beyond the SM** should be considered,
- deviations from the SM predictions should be a signal leading to **new physics**,
- to search for the **new physics** one should move into the regimes beyond the energy scales available today , $E \approx O(TeV)$.

2. Anomalous Couplings at Triple Gauge Boson Vertex (TGV) and Low Energy Constraints

In the absence of a specific model of new physics effective lagrangian techniques are extremely useful.

An effective lagrangian parametrizes the low energy effects of the new physics to be found at higher energies.

In general an effective lagrangian is organized in powers of $1/\Lambda$ where Λ is the energy scale of new physics.

Low energy effects of the new physics beyond the SM can be written as follows:

$$L_{eff} = L_{SM} + \sum_{n=1}^{\infty} \frac{1}{\Lambda^n} (\ldots)_{(n)}$$

Following description of Λ may be useful for better understanding (E : available energy)

if	$E \ll \Lambda$	effective theory, contact interactions
if	$E \gg \Lambda$	new physics, new particles
if	$E \approx \Lambda$	strongly depends on model
if	$\Lambda \rightarrow \infty$	SM is recovered

- At present experiments, **couplings of fermions to vector bosons** (ffW, ffZ) can be measured with $O(10^{-3})$ (or better) accuracy that is a confirmation of a gauge boson nature of W and Z. (*http:/pdg.lbl.gov*)
- But non-abelian **self couplings of** W, Z and γ are poorly measured with $O(10^{-1})$.
- If sufficient accuracy is reached such measurement can be used to probe **new physics** in the bosonic sector.

For our discussion, CP conserving $W\ W\ \gamma$ vertex in momentum space can be expressed as follows

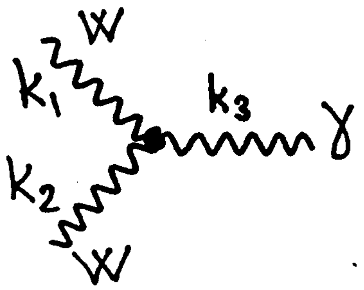
$$ig_{WW\gamma}\Gamma_{\mu\nu\rho}(k_1,k_2,k_3) =$$

$$ig_{WW\gamma}\Bigg[g_{\mu\nu}(k_1 - k_2 - \frac{\lambda}{M_W{}^2}\{(k_2.k_3)k_1 - (k_1.k_3)k_2\})_\rho$$

$$+ g_{\nu\rho}(k_2 - \kappa\, k_3 - \frac{\lambda}{M_W{}^2}\{(k_1.k_3)k_2 - (k_1.k_2)k_3\})_\mu$$

$$+ g_{\rho\mu}(\kappa\, k_3 - k_1 + \frac{\lambda}{M_W{}^2}\{(k_2.k_3)k_1 - (k_1.k_2)k_3\})_\nu$$

$$\frac{\lambda}{M_W{}^2}(k_{2\mu}k_{3\nu}k_{1\rho} - k_{3\mu}k_{1\nu}k_{2\rho})\Bigg]$$



$\Delta\kappa = \kappa - 1$, λ are anomalous coupling parameters (actually form factors) and they are related to

$$\mu_W = \frac{e}{2M_W}(1 + \kappa + \lambda) \qquad \text{magnetic dipol M.}$$

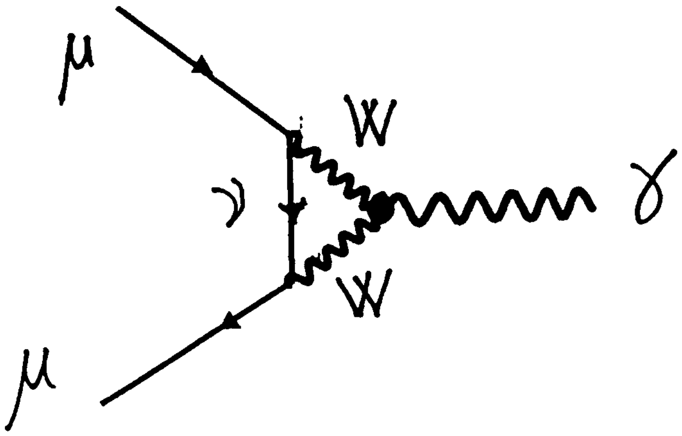
$$Q_W = -\frac{e}{M_W{}^2}(\kappa - \lambda) \qquad \text{electric quadrupole M.}$$

When $\Delta\kappa = 0$ and $\lambda = 0$ the SM result is obtained.

Low energy constraints :

From anomalous magnetic moment of the muon (one loop constraint) $\Delta\kappa$ and λ are expected to be at most $O({M_W}^2/\Lambda^2)$.

For $\Lambda \approx 1\ TeV$ they are expected $O(10^{-2})$ or less . One of the diagrams which contributes to the anomalous magnetic moment of the muon is shown



Linac-Ring type ep collider: LC+HERA-p

After basic e^-e^+ (LC) collider is constructed γe, $\gamma\gamma$, ep and γp modes should be discussed and may work as complementary to basic collider.

Linear collider design at DESY is the only one that can be converted into an ep collider. According to present project at DESY linear electron beam (250 or 500 GeV) is allowed to collide 820 GeV protons in the HERA ring.

- Estimations show that luminosity of this linac-ring type ep collider can reach $\approx 10^{31}\,cm^{-2}s^{-1}$ with improved proton parameters.

γp collider mode is an additional advantage of linac-ring type ep collider where real gamma beam can be obtained by Compton backscattering of laser photons off linear electron beam.

- The luminosity of the γp mode is almost the same as that of ep collider, because $\sigma_p >> \sigma_\gamma$ where σ_p and σ_γ are transverse sizes of proton and photon bunches at collision point.

Most of the photons are produced at high energy region in the case of Compton backscattering.

- Therefore, cross sections are about one order of magnitude larger than corresponding *ep* machines for photoproduction processes.
- Another advantage of the linac-ring type γp collider is high polarization of gamma beam.

For our calculation in this work we have used the following collider parameters:

$$\sqrt{s_{ep}} = 1.28\,\text{TeV} \qquad \sqrt{s_{\gamma p}}^{\,\max} = 1.16\,\text{TeV}$$

$$L_{\text{int}} = 200\, pb^{-1} \;\; (\text{for } \gamma p \text{ and } ep)$$

3. Cross Sections and p_T Distribution

Signal process: For the signal we are considering a quark jet and on-shell W with leptonic decay mode:

$$\gamma p \to W^{\pm} + j \to \ell + p_T^{miss} + j$$

$$\ell = e, \mu$$

and related Feynman diagrams are given in **Fig.1**. In this mode charged lepton and the quark jet are in general well separated and the signal is in principle free of background of the SM.

In **Table I** integrated total **cross section** times branching ratio **BR**$(W \to \mu\nu)$ and corresponding **number of events** are shown for various values of κ and λ. The cross sections obtained using Weizsacker-Williams approximation (**WWA**) are also shown on the same table.

Number of events has been calculated using

$$N = \sigma(\gamma p \to W + j) BR(W \to \mu\nu) A L_{\text{int}}$$

where **muon acceptance** A=65% is taken.

$\boxed{\gamma\, p \rightarrow W\, j}$

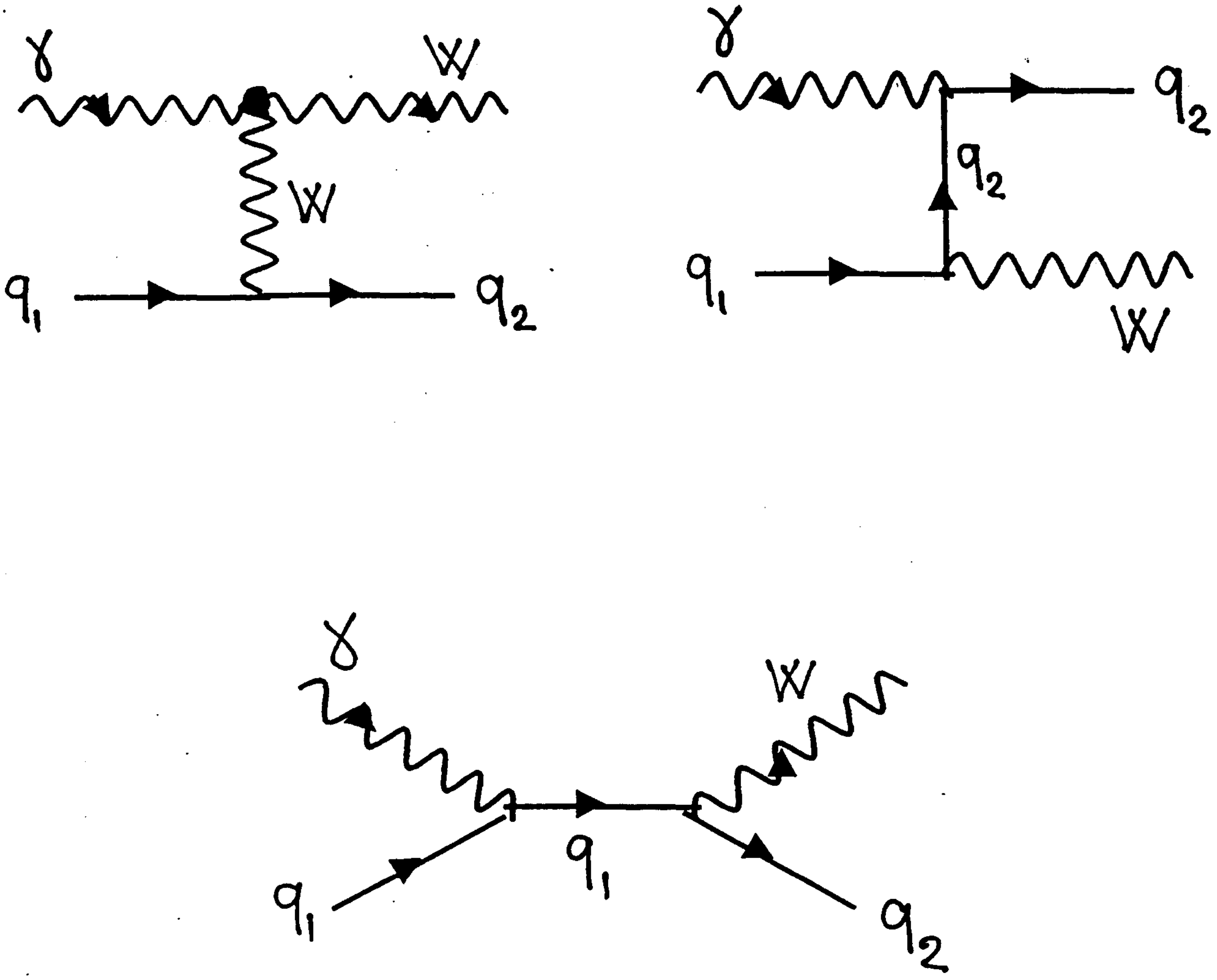


Fig. 1

Table I.
Integrated total cross section times branching ratio $\sigma(\gamma p \to Wj) \times BR(W \to \mu\nu)$ in pb and corresponding number of events (in parentheses). $L_{\text{int}} = 200\ pb^{-1}$, $\sqrt{s} = 1.28$ TeV.

$\Delta\kappa$	λ	Backscattered Photons	WWA
1	0	13.8 (1780)	1.3 (170)
1	1	25.1 (3262)	1.9 (246)
1	2	59.0 (7670)	3.7 (480)
0	0	9.7 (1262)	0.9 (120)
2	0	23.4 (3042)	2.1 (274)

From **Table I** :

$\Delta\kappa = 1$ changes cross sections 30-70%

$\Delta\lambda = 1$ changes cross sections 80%

Transverse momentum distribution:
p_T spectrum $BR(W \to \mu\nu)d\sigma/dp_T$ of the quark jet is shown in **Fig. 2** for several κ and λ in the case of Compton backscattered photons.

Similar distribution is given in **Fig. 3** for **WWA** case that covers major contribution from ep collision.

From **Fig.2** and **Fig.3 :**

- Cross sections at large p_T is quite sensitive to anomalous couplings.
- Curves become more separable as $\hat{s}$ gets large.
- Cross sections with **real gamma** beam are one order of magnitude larger than the case **WWA.**
- As λ increases the cross section grows more rapidly when compared with κ dependence at high p_T region p_T>100 GeV.

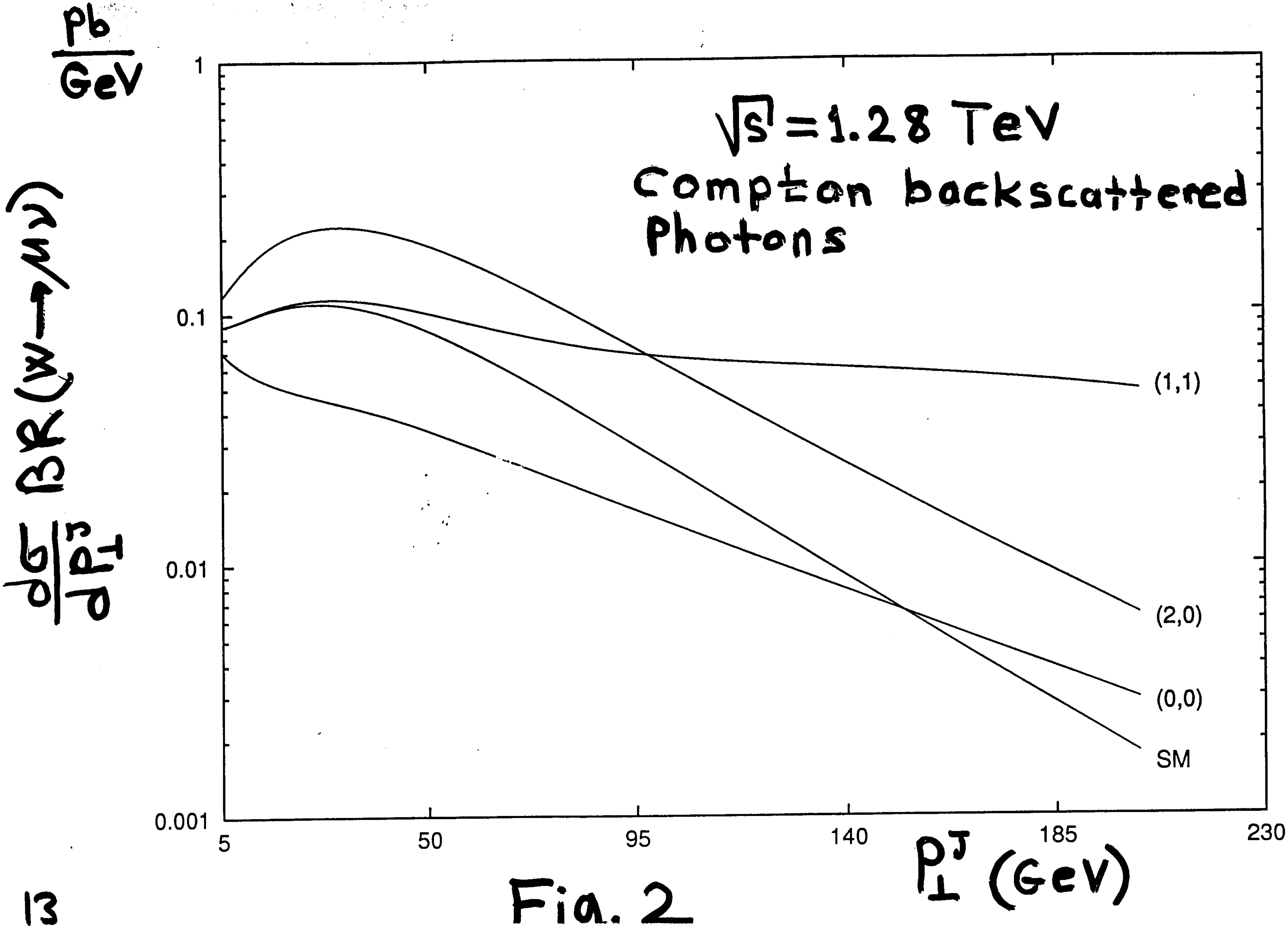

pb/GeV
$\frac{d\sigma}{dp_\perp^J} BR(W\to\mu\nu)$
1
0.1
0.01
0.001
$\sqrt{s} = 1.28$ TeV
Compton backscattered Photons
(1,1)
(2,0)
(0,0)
SM
5
50
95
140
185
230
$p_\perp^J$ (GeV)

Fig. 2

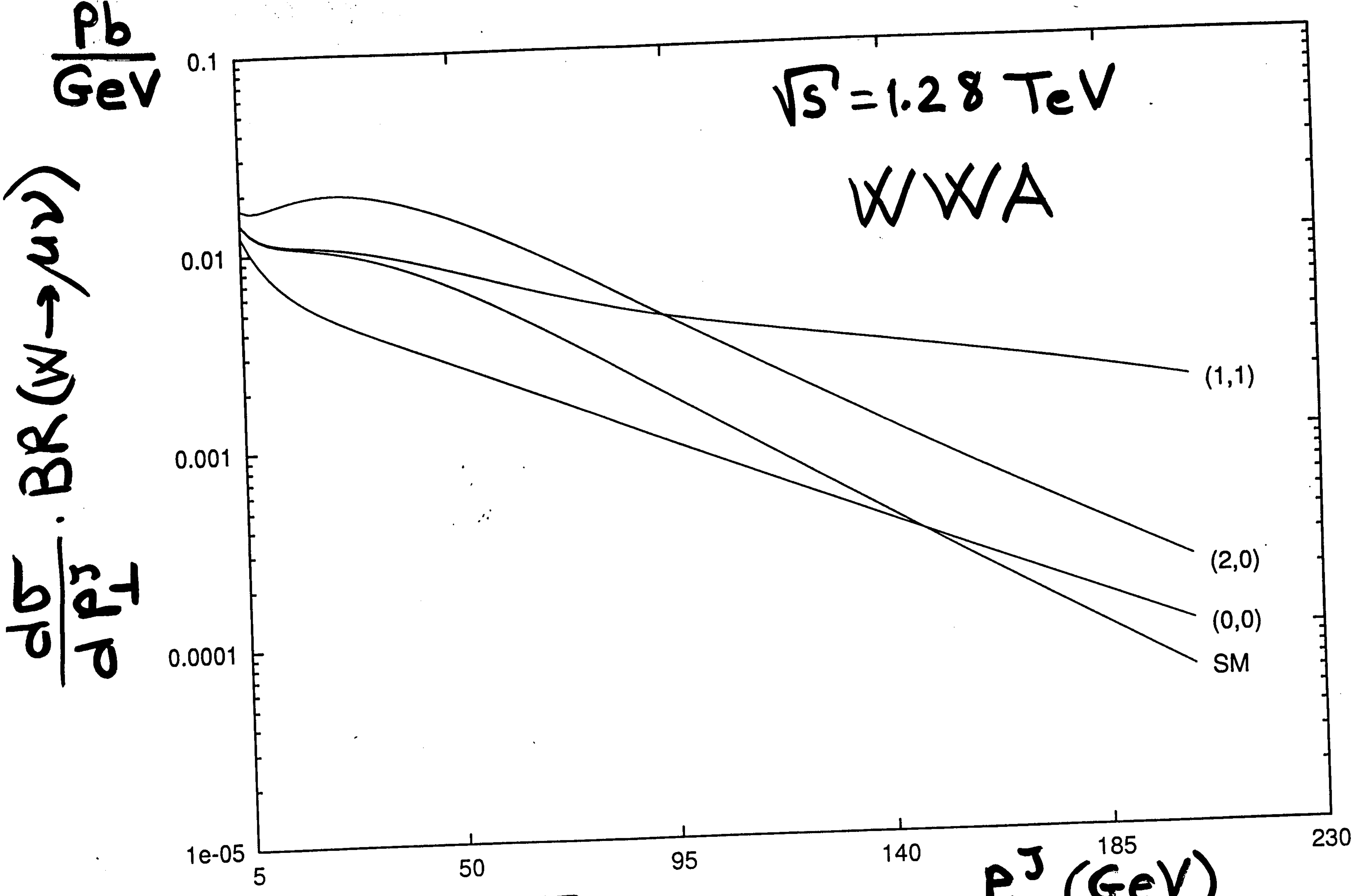

$\frac{pb}{GeV}$
$\frac{d\sigma}{dP_\perp^J} \cdot BR(W \to \mu\nu)$
0.1
0.01
0.001
0.0001
1e-05
5
50
95
140
185
230
$P_\perp^J$ (GeV)
$\sqrt{s} = 1.28$ TeV
WWA
(1,1)
(2,0)
(0,0)
SM

Fig 2

4. Sensitivity to Anomalous Couplings

A set of values of $\Delta\kappa$ and λ which give rise to cross sections deviated from the SM at a certain confidence level can be calculated using simple χ^2- criterion

$$\chi^2 = \sum_i \left(\frac{X_i - Y_i}{\Delta_i^{\exp}} \right)^2$$

$$X_i = \int_{V^i}^{V^{i+1}} \left(\frac{d\sigma^{SM}}{dV} \right)_i dV$$

$$Y_i = \int_{V^i}^{V^{i+1}} \left(\frac{d\sigma^{NEW}}{dV} \right)_i dV$$

$$\Delta_i^{\exp} = X_i \sqrt{\delta_{syst}^{\ 2} + \delta_{stat}^{\ 2}}\,, \qquad \delta_{syst} \approx 0.02$$

$$dV = dp_T$$

where summation is over p_T bins. In each bin we considered at least ten events.

Table II.
Sensitivity of **LC+HERAp** based γp collider to anomalous couplings using **Compton backscattered photons.** $L_{\text{int}} = 200\, pb^{-1}$.

	$\Delta\kappa$ 68% C.L	λ 68% C.L
Without syst. Error	-0.019, 0.019	-0.075, 0.075
With 0.02 syst. error	-0.022, 0.022	-0.078, 0.078
	$\Delta\kappa$ 95% C.L.	λ 95% C.L.
Without syst. Error	-0.038, 0.037	-0.11, 0.11
With 0.02 syst. error	-0.044, 0.042	-0.11, 0.11

Table III.
Sensitivity of **LC+HERAp** collider to anomalous couplings using **WWA**. $L_{\text{int}} = 200\ pb^{-1}$.

	$\Delta\kappa$ 68% C.L	λ 68% C.L
Without syst. Error	-0.068, 0.066	-0.28, 0.28
With 0.02 syst. error	-0.069, 0.067	-0.28, 0.28
	$\Delta\kappa$ 95% C.L.	λ 95% C.L.
Without syst. Error	-0.14, 0.13	-0.39, 0.39
With 0.02 syst. error	-0.14, 0.13	-0.39, 0.39

5. Conclusion

Order of magnitudes of sensitivities are compared in **Table IV** for present and future colliders.

Table IV.
Comparison of sensitivities of various present and future colliders.

Colliders		**Sensitivities (95%C.L.)** (Order of magnitude)	
		$\Delta\kappa$	λ
Present Colliders	LEP2	10^{-1}	10^{-1}
	TEVATRON	10^{-1}	10^{-1}
Projected Future Colliders	LHC	10^{-2}	10^{-3}
	LC	$10^{-3}-10^{-4}$	$10^{-3}-10^{-4}$
Possible Future Colliders	LC+HERAp (WWA)	10^{-1}	10^{-1}
	LC+HERAp Based γp	10^{-2}	10^{-1}

A few comments on the possible future status of the LC+HERAp based γp collider within the study of anomalous $W W \gamma$ couplings may be as follows:

- LHC and LC will greatly improve the precision to various anomalous gauge boson self couplings.

- γp mode of LC+HERA-p probes $\Delta\kappa$ and λ with better sensitivity than present colliders and comparable with LHC in the case of $\Delta\kappa$ but worse than linear $e^{-}e^{+}$ collider.

- **The advantage** of the process $\gamma p \to Wj$ is to probe the $WW\gamma$ couplings independently of WWZ effects.

- After the possible energy and luminosity improvement, linac-ring type γp colliders will give complementary information to LHC and LC.