Trilinear γWW Couplings at a γγ – collider at ILC

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Introduction

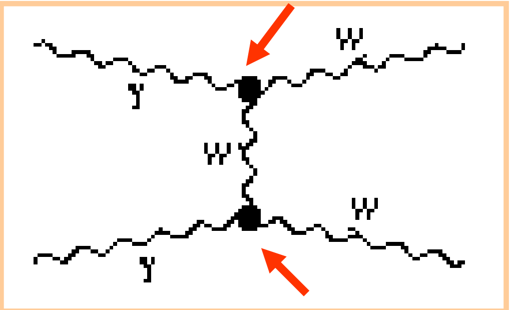
$$\gamma\gamma \rightarrow W^+W^- \rightarrow q\bar{q}q\bar{q} \qquad \sqrt{S_{ee}} = 500GeV$$

Dominating diagram for $\gamma\gamma \rightarrow W^+W^-$

Two initial states

$$J_Z = 0, \left(h_\gamma, h_\gamma = \pm 1, \pm 1\right)$$

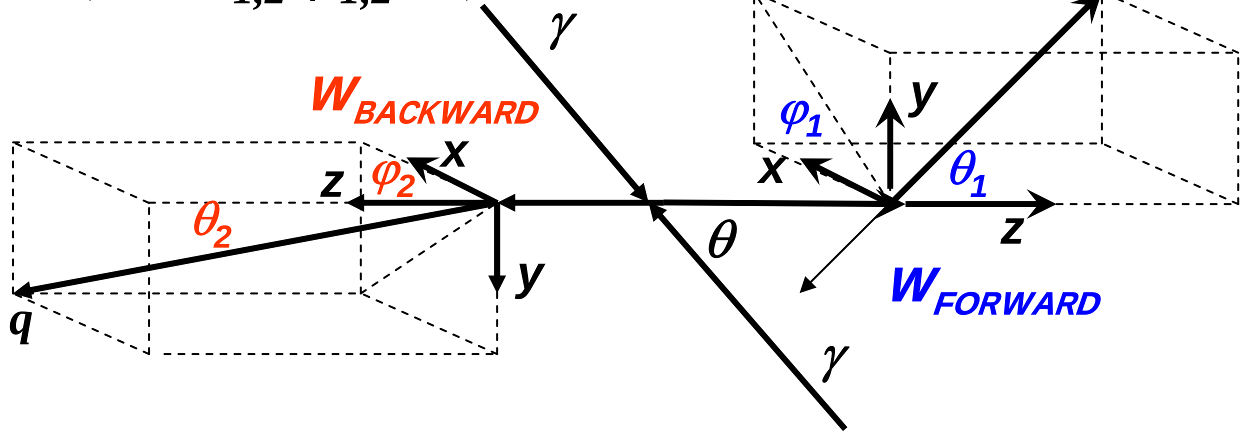
$$J_Z = 2, \left(h_\gamma, h_\gamma = \pm 1, \mp 1\right)$$



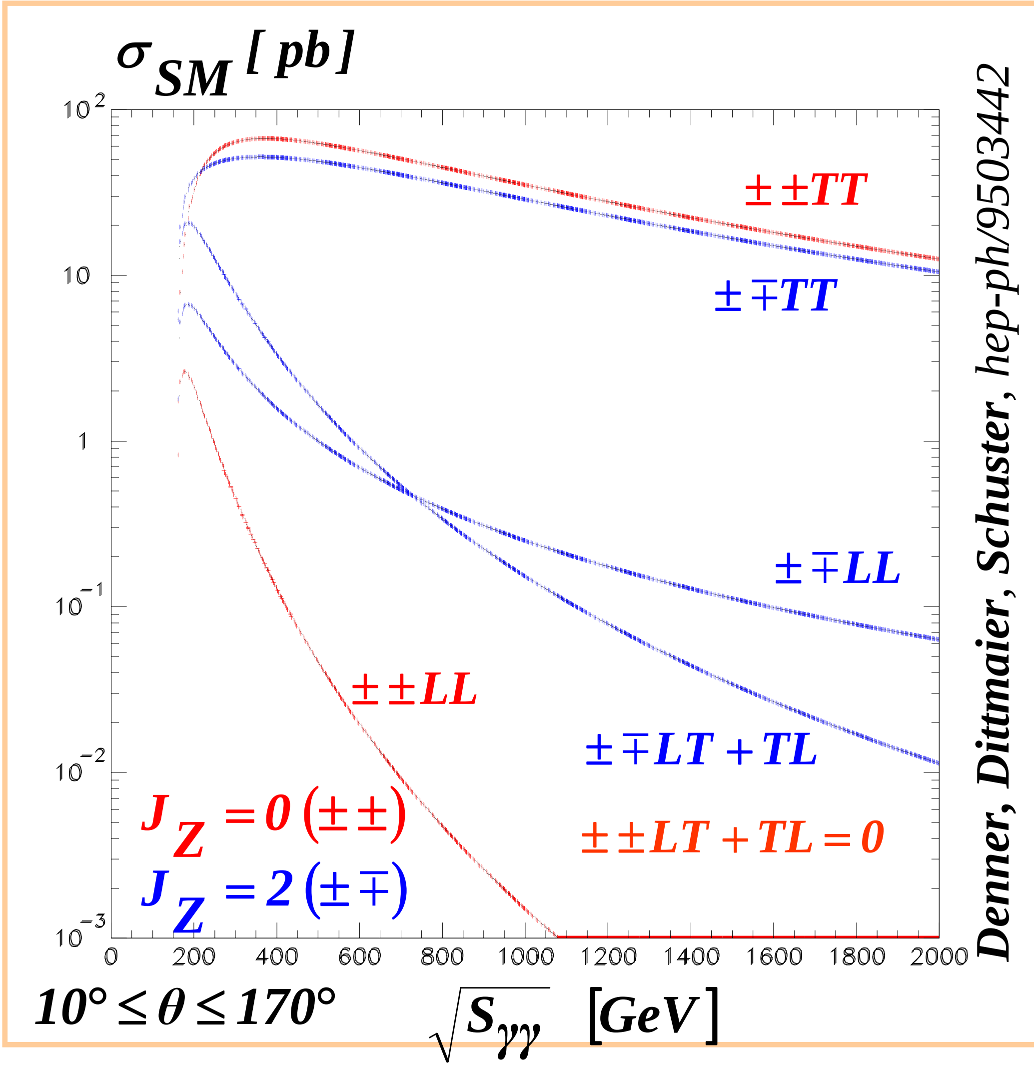
$TGCs: \ \kappa_\gamma, \lambda_\gamma \ (in\ SM\ 1,0)$

Ambiguities in 4-jet events:

$(\cos\theta_{1,2}, \varphi_{1,2}) \leftrightarrow (-\cos\theta_{1,2}, \varphi_{1,2}+\pi)$



Total Cross-Section vs. CMS



notation

$(TT) \rightarrow W_T W_T$

$(TL) \rightarrow W_L W_T$

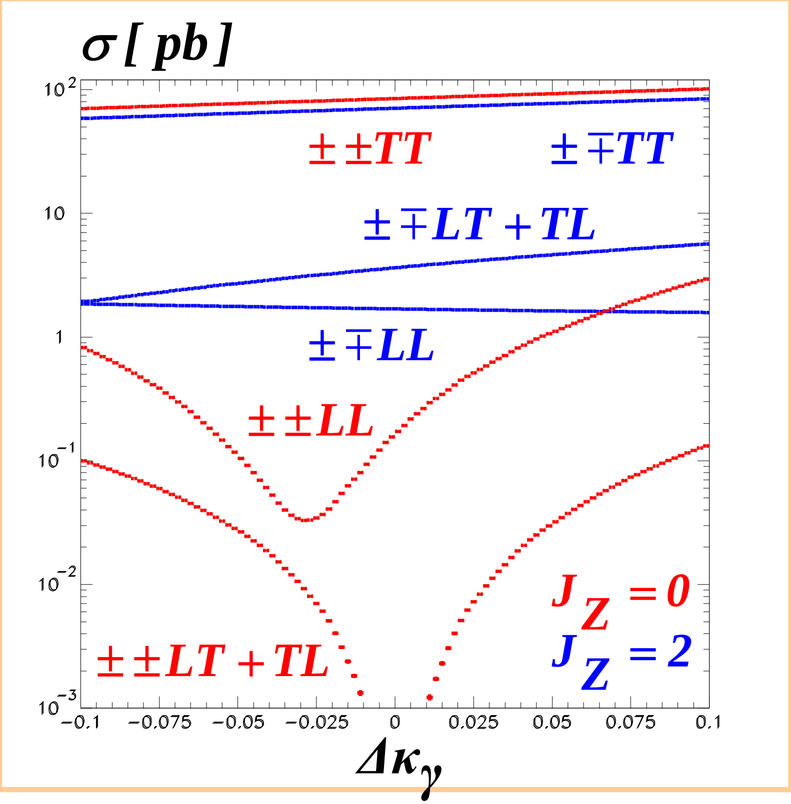
$(LL) \rightarrow W_L W_L$

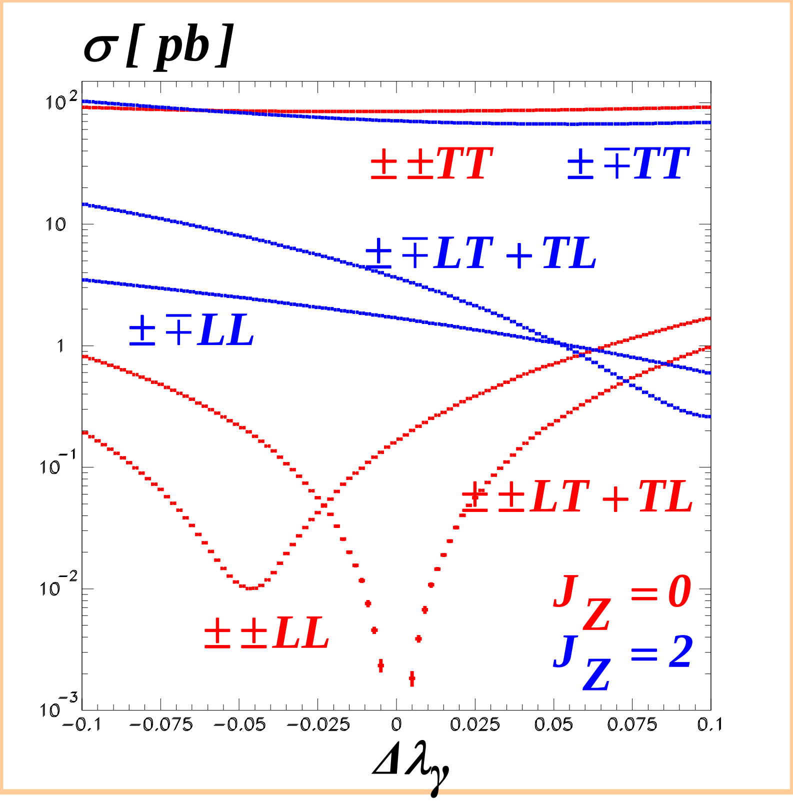
$L =$ **longitudinal W**

$T =$ **transversal W**

Total Cross-Section (κ_γ, λ_γ) - Whizard

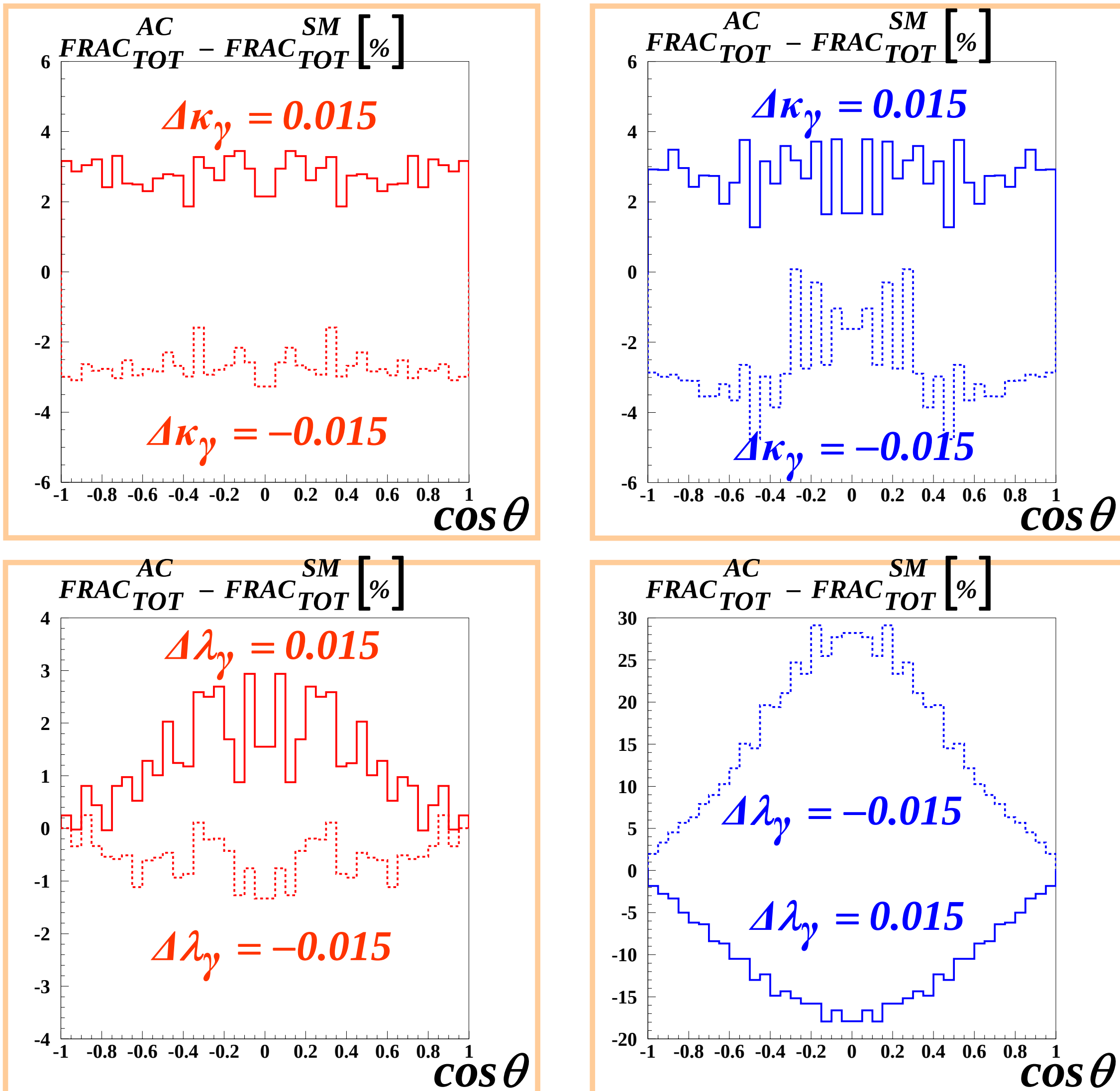
On-shell Ws at cme = 400 GeV, 100% polarized beams





Diff. Cross-Section (κ_γ, λ_γ) - Whizard

Relative deviations of diff. cross-section from the SM in presence of anomalous couplings



$J_Z = 0$

$J_Z = 2$

W_LW_L masked by dominating W_TW_T fraction

Analysis

- Signal ($\gamma\gamma \rightarrow WW$) and (background, pile-up) samples at detector level WHIZARD – W. Kilian & CIRCE2 – T. Ohl (Telnov's spectra) (variable energy spectra, 85% polarized e^- and 100% γ beams)

  - **pileup** : low-energy $\gamma\gamma \rightarrow qq$ (1.8 ev/BX)

  - **background** : $\gamma\gamma \rightarrow qq \rightarrow$ 4 jets (O'Mega)

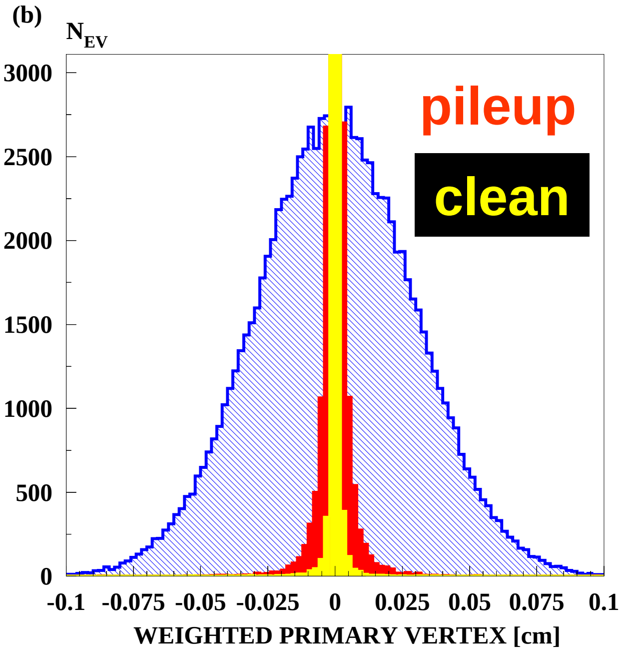
  $J_Z=2 \rightarrow \sigma(QCD) \sim (1+ i\alpha_s/\pi)$, $J_Z=0 \rightarrow \sigma(QCD) \sim (1+j\alpha_s/\pi)$ $i[O(1)] < j$

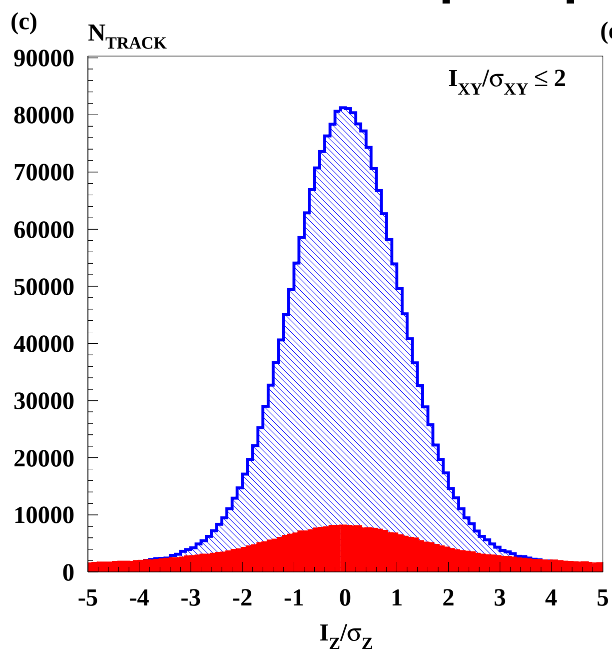
  (for $J_Z=0$ + QCD contribution $O(\alpha^2)$) via $\gamma\gamma \rightarrow qqgg$ and $\gamma\gamma \rightarrow qq(g\rightarrow)qq$) (MadGraph)

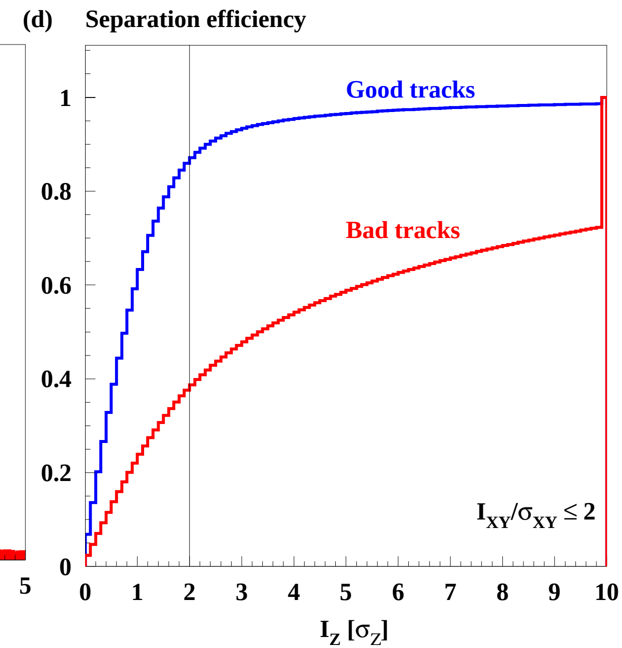
- Response of a detector simulated with SIMDET V4
- Ws are reconstructed from hadronic final states
- Estimated errors of measurement of κ_γ and λ_γ parameters, obtained by fit (binned Likelihood)

Pileup rejection

track selection via impact parameter $I\ (xy, z)$







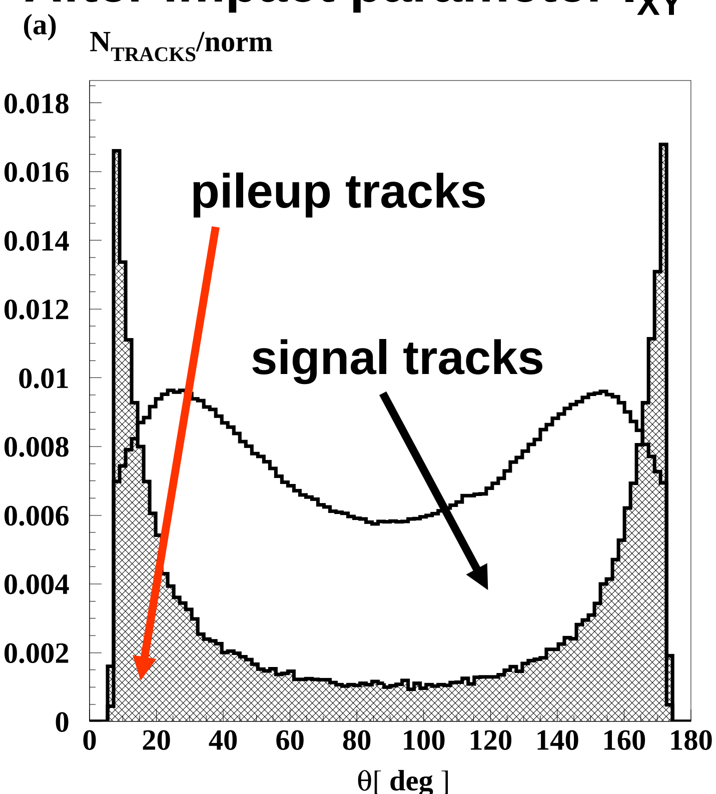
Reconstructed PV of an event as the momentum weighted average impact parameter I_Z of all tracks, using the information from VTX

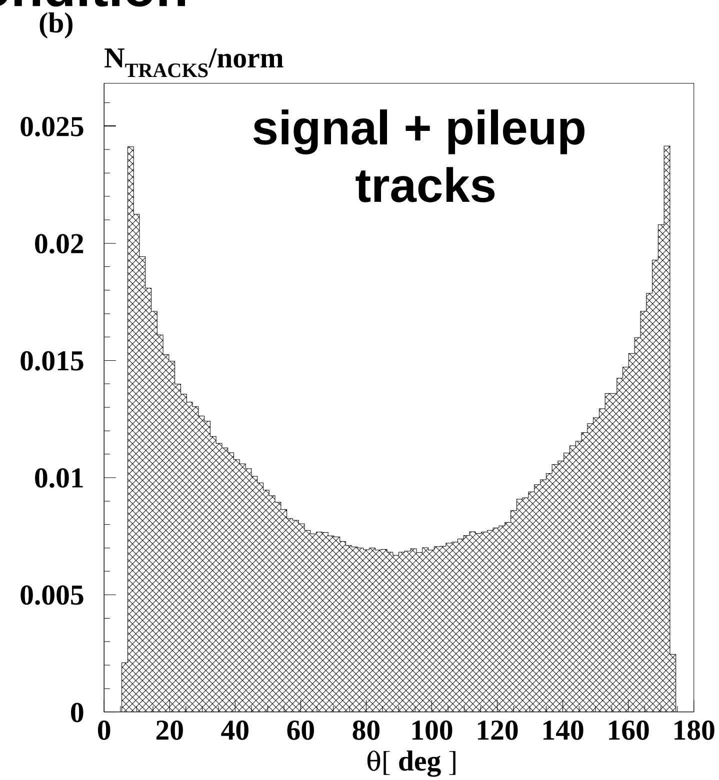
Reconstructed I_Z of each good/bad track normalized to its error

Separation efficiency

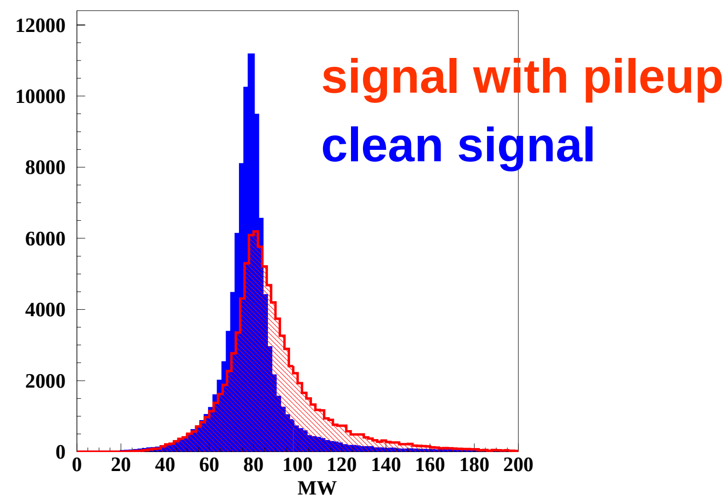
- All neutral accepted
- neutral + tracks with $\theta > 7^o$

After impact parameter $I_{XY} < 2\sigma_{XY}$ condition



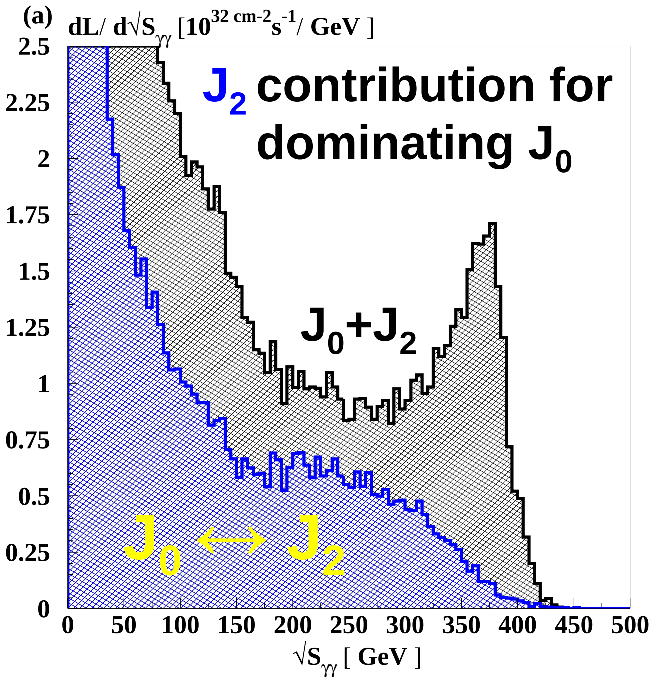


- All neutral accepted
- neutral + tracks with $\theta > 7^{o}$



$\gamma\gamma \to qq \to$ 4jets Background

- used luminosity spectra (with mixed J_Z=0 and J_Z=2 states $\to \sigma^{mix}$)



Born Level $\sigma_2 >> \sigma_0$

J_Z=2: σ_2

J_Z=0: $\sigma_0 \sim \sigma_2 \cdot (m^2/s) \to$ suppression

NLO corrections $k_2^{QCD} < k_0^{QCD}$

J_Z=2: $k_2^{QCD} \sim (1+i\alpha_s/\pi)$

J_Z=0: $k_0^{QCD} \sim (1+j\alpha_s/\pi)$ $i < j$

$$j \sim 1 + aF + \ldots + bF^4$$

$$F \sim \frac{\alpha_s}{\pi} \log^2 \frac{s}{m_q^2}$$

1-loop non-Sudakov form factor

Corrections to the Born Level σ

J_Z=2: $\gamma\gamma \to qq$ (O'Mega) + QCD (4-5%) parton shower well described by Lund model ($q \to qg$ soft gluons); J_0 ($\to$ 0) and $J_2 \to$ dominates in σ^{mix}

J_Z=0: $\gamma\gamma \to qq$ (O'Mega) $\sigma_0^{Born} << \sigma_2^{Born} \to J_2$ dominates in σ^{mix} but…

O'Mega $\sigma_0^{Born} \to 0$ due to the (m^2/s) suppression

Correction to $\sigma_{\gamma\gamma \to qq}$ in the $J_Z = 0$ state

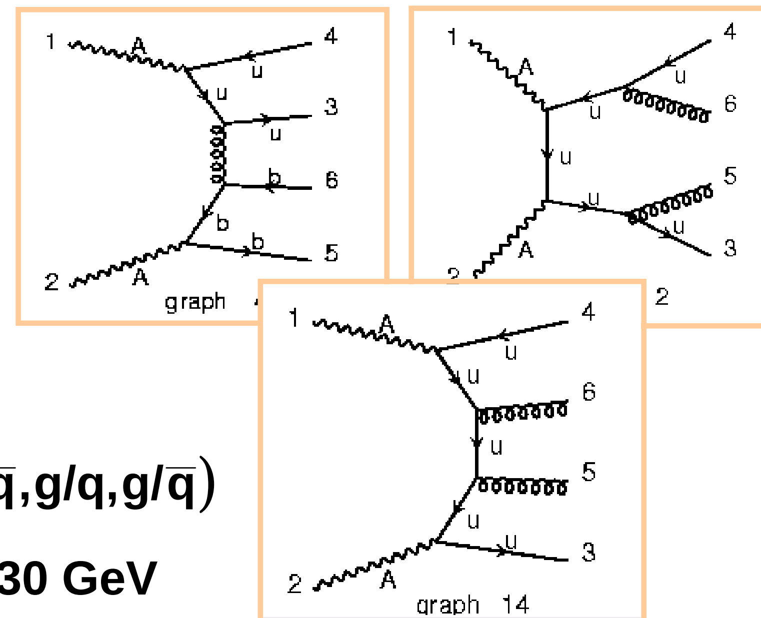
$\sigma_0^{QCD} \to 0$ (m^2/s) suppression canceled by double-logarithms (two-loop)

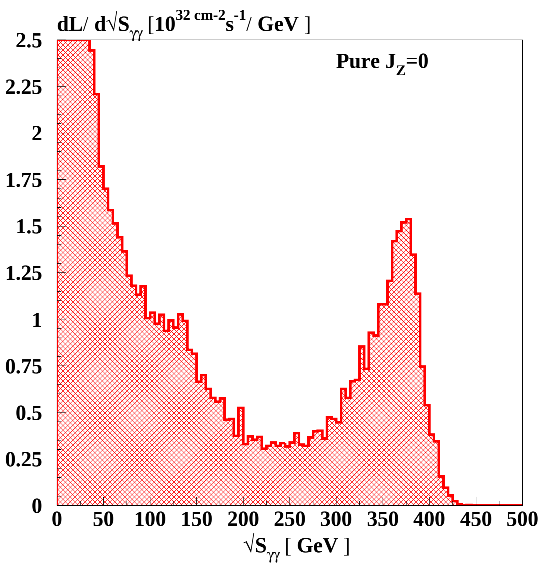
QCD corrections to the Born Level σ in $J_Z = 0 > \sigma_2^{QCD}$

Pure J_Z=0 (whole spectrum):

MadGraph → $\gamma\gamma \to qqgg + qq(g \to qq)$

(O'Mega does not calc. QCD)





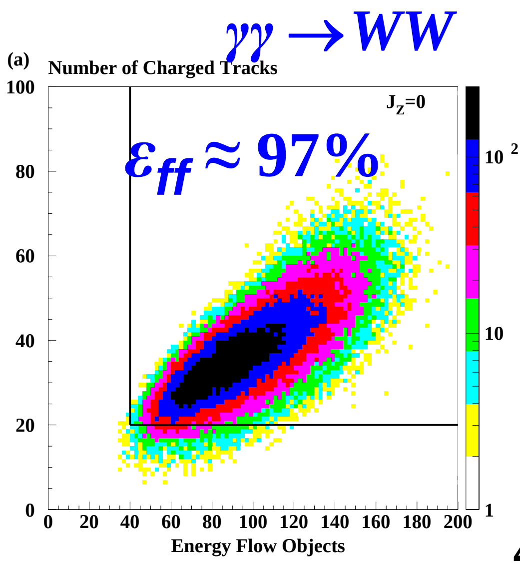
$$(p_i + p_j)^2 > ys, (i, j = q, \overline{q}, g/q, g/\overline{q})$$

M_{INV}(3,5,6,9,10,12) > 30 GeV

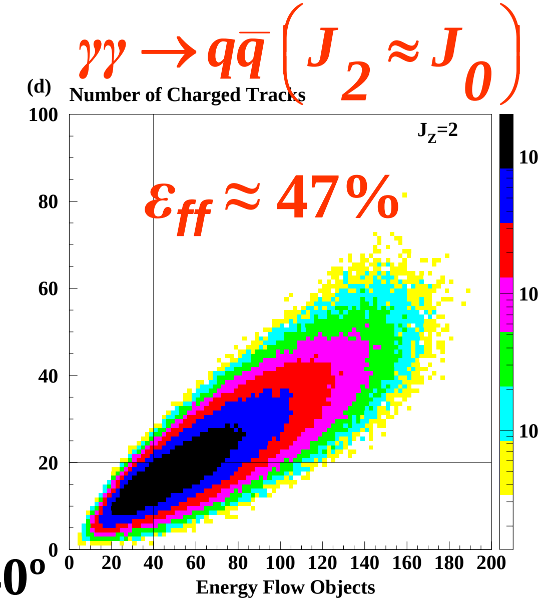
M_{INV}(3,5,6,9,10,12) > 30 GeV

… and added to $\gamma\gamma \to qq$ (O'Mega) with J_Z=0

Selection



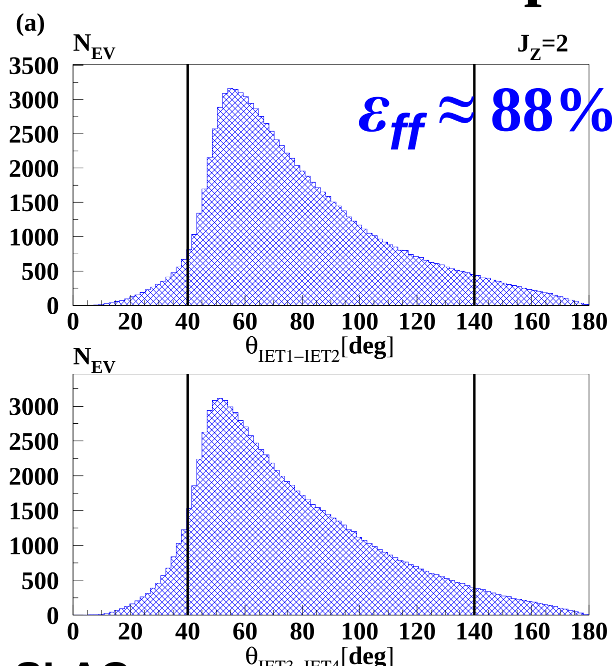
Accepted events:
NENFLO > 40,
NCT > 20

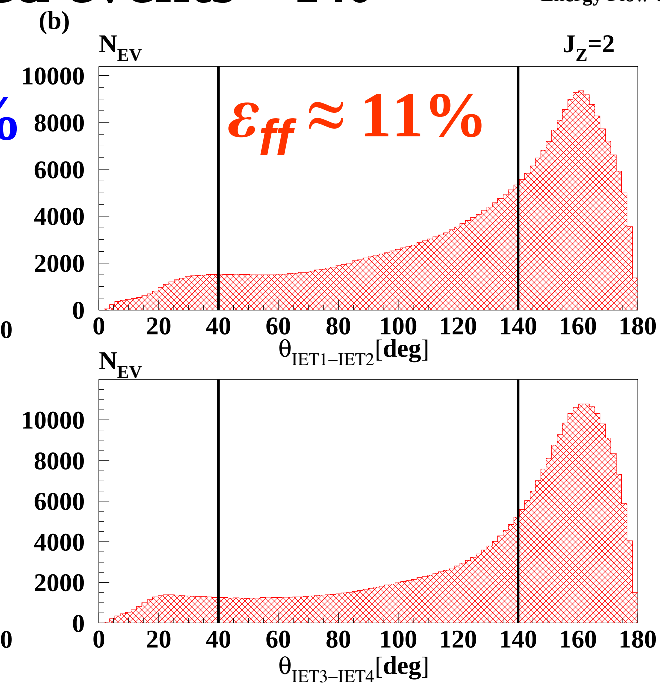


40^o < accepted events < 140^o

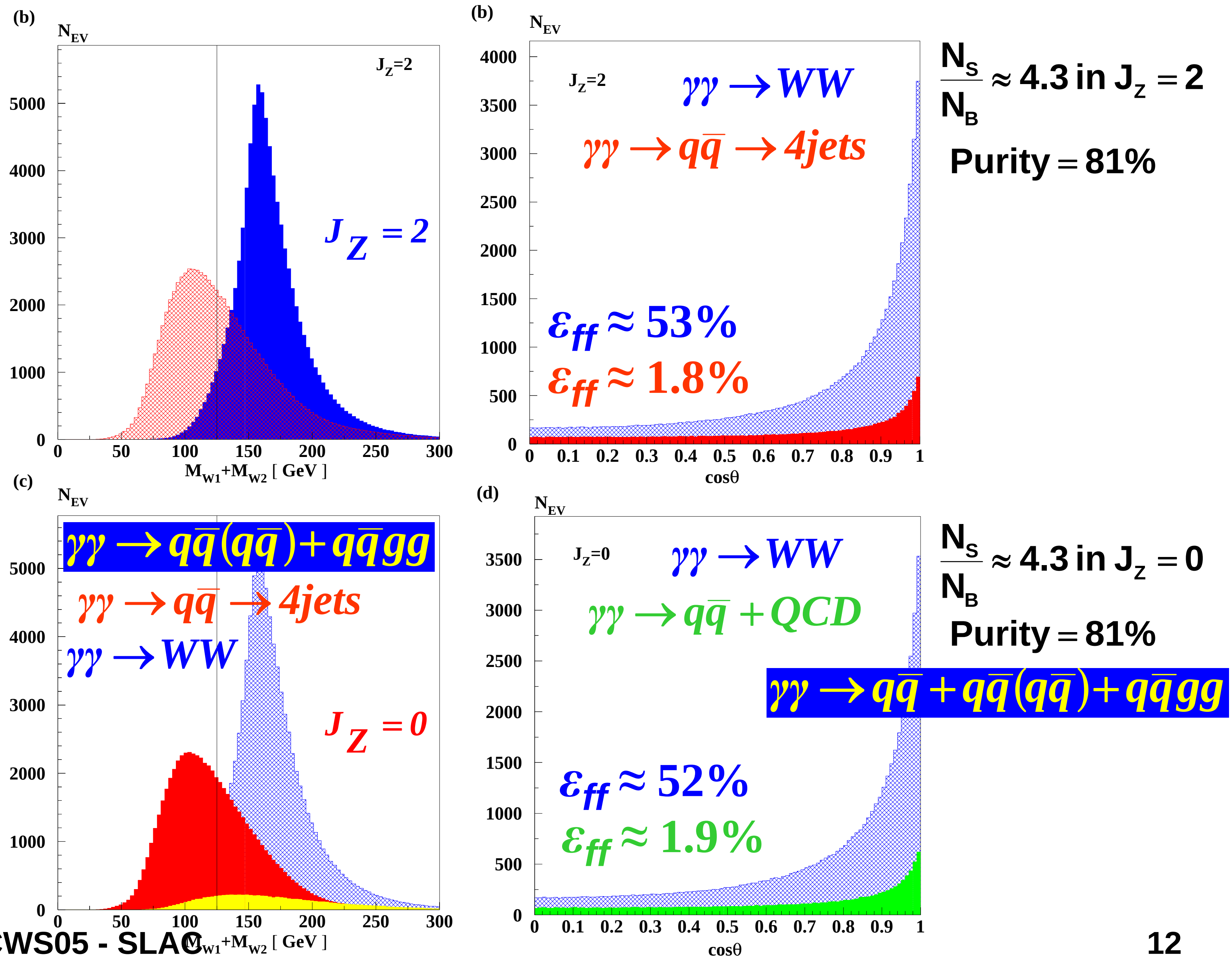
W_F cosθ > 0
W_B cosθ < 0

J1,J2 → W_F
J3,J4 → W_B



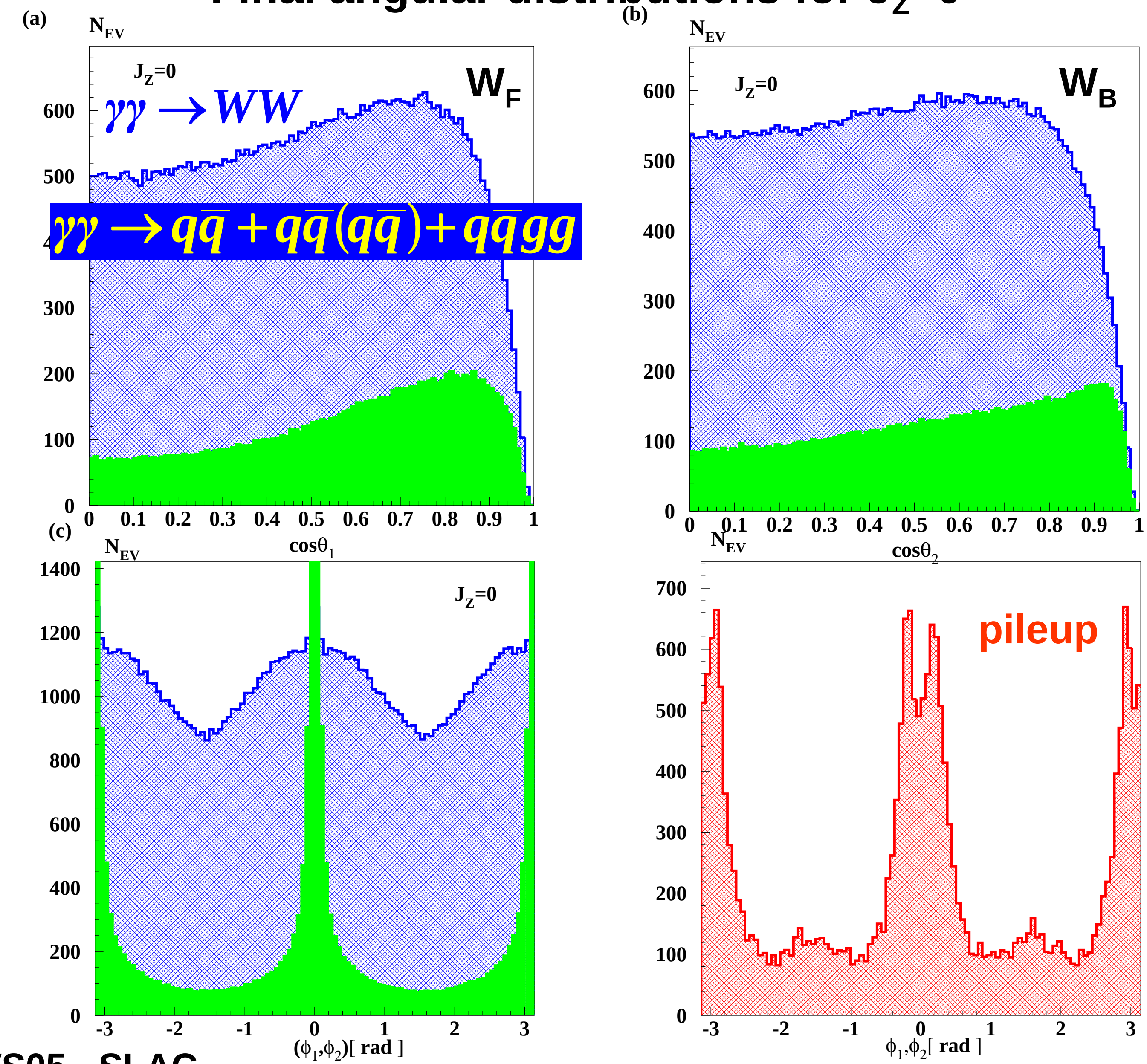


$(MW_1+MW_2) > 125$ GeV
$+ 60$ GeV $< MW_1, MW_2 < 100$ GeV



Final angular distributions for J_Z=0

similar distributions for J_Z=2



Events made of pileup tracks only

Monte Carlo Fit

Each event described with 5 kinematical variables (sensitive to TGC) :

- W production angle, $\cos\theta$ of W boson
- W polar decay angles, $\cos\theta_{1,2}$ (sensitive to the different W helicity states)
- azimuthal decay angles, $\varphi_{1,2}$ (sensitive to the interference between different W helicity states)

Matrix element calculations (O'Mega) $\rightarrow$ weights to reweight SM events ($\Delta\kappa_\gamma=0$, $\Delta\lambda_\gamma=0$) as functions of anomalous TGC by

Weight/event:

$$R(\Delta\kappa_\gamma,\Delta\lambda_\gamma) = 1 + A\cdot\Delta\kappa_\gamma + B\cdot(\Delta\kappa_\gamma)^2 + C\cdot\Delta\lambda_\gamma + D\cdot(\Delta\lambda_\gamma)^2 + E\cdot\Delta\kappa_\gamma\,\Delta\lambda_\gamma$$

+ 6-th dimension $\rightarrow$ cme

$$L=\{-\sum_{ijklmn} N^{DATA}_{ijklmn}\log\left(N^{MC}_{ijklmn}\right)+\sum_{ijklmn} N^{MC}_{ijklmn}\}+\frac{(n-1)^2}{\Delta L^2}$$

$N^D=N^{SM}$ - data sample (SM), N^{MC} - Monte Carlo sample $[N^{SM}\cdot R(\Delta\kappa_\gamma,\Delta\lambda_\gamma)]$,

ΔL – error on luminosity measurement

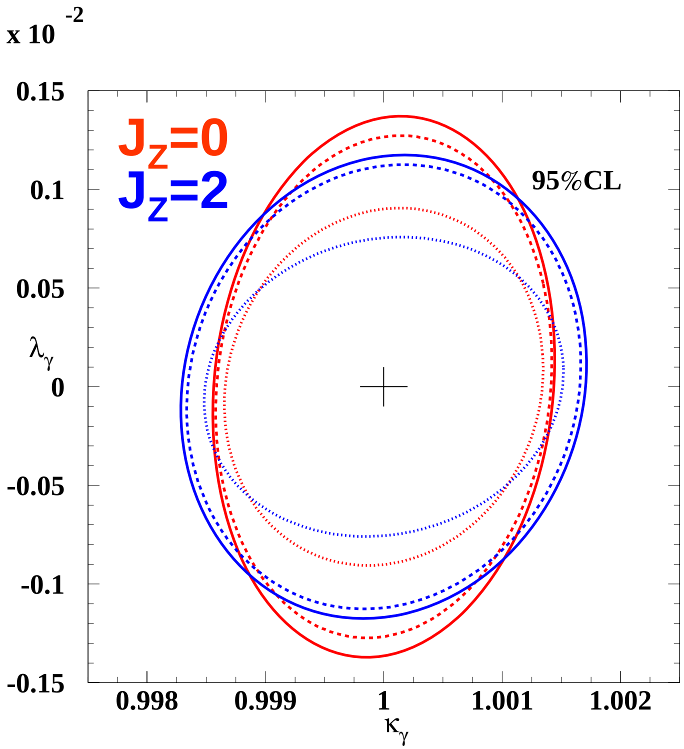
Error Estimations

Estimated errors for κ_γ and λ_γ - two-parameter + *n* 6D fit

6D FIT	$J_z = 0$		
	without pileup / with pileup / + background		
ΔL	1%	0.1%	accurate
$\Delta\kappa_\gamma \cdot 10^{-4}$	19.9 / 26.9 / 27.8	5.5 / 5.8 / 5.9	2.6 / 3.0 / 3.1
$\Delta\lambda_\gamma \cdot 10^{-4}$	3.7 / 5.4 / 5.7	3.7 / 5.2 / 5.6	3.7 / 5.2 / 5.6

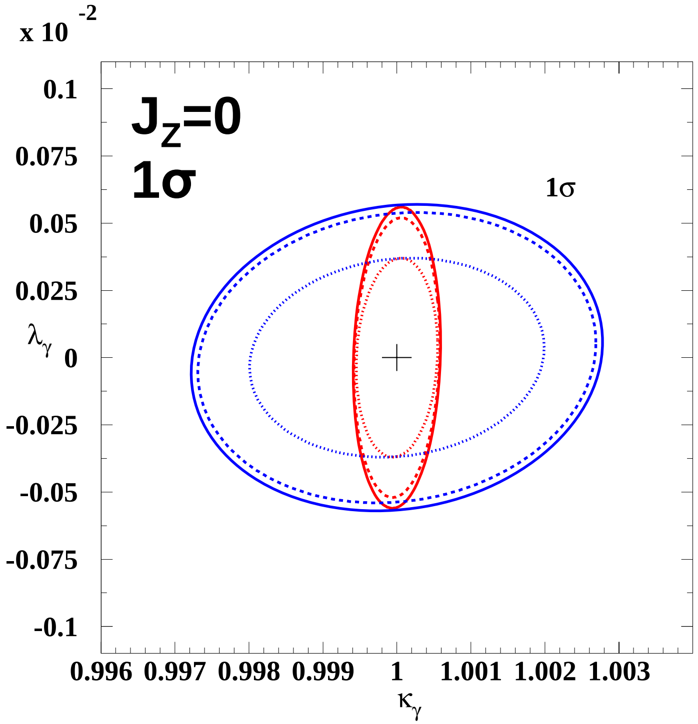
6D FIT	$J_z = 2$		
	without pileup / with pileup / + background		
ΔL	1%	0.1%	accurate
$\Delta\kappa_\gamma \cdot 10^{-4}$	29.9 / 37.4 / 37.8	6.2 / 6.8 / 7.0	3.7 / 4.6 / 4.8
$\Delta\lambda_\gamma \cdot 10^{-4}$	3.1 / 4.6 / 4.8	3.1 / 4.6 / 4.8	3.1 / 4.6 / 4.8

2-dimensional contour plots



ΔL = 0.1%

95% CL



ΔL = 0.1%

ΔL = 1%

400 GeV % 800 GeV

Estimated errors for κ_γ and λ_γ - two-parameter + *n* (5D fit)

(generator level, fixed beam energy)

5D FIT	$J_z = 0$			$J_z = 2$		
	400 GeV / 800 GeV (110 fb^{-1})			400 GeV / 800 GeV (110 fb^{-1})		
ΔL	1%	0.1%	accurate	1%	0.1%	accurate
$\Delta\kappa_\gamma \cdot 10^{-4}$	14.4/7.2	5.4 / 4.5	2.6 / 2.4	20.1/8.1	6.2/4.6	3.8/2.6
$\Delta\lambda_\gamma \cdot 10^{-4}$	3.0 / 1.3	3.0 / 1.3	3.0 / 1.3	1.6/0.63	1.6/0.58	1.6/0.56

γe - $\gamma\gamma$ - e^+e^- comparison

500 GeV	γe $\int L\Delta t \approx 160/230\ fb^{-1}$	$\gamma\gamma$ $\int L\Delta t \approx 1000\ fb^{-1}$	e+e- $\int L\Delta t = 500\ fb^{-1}$
ΔL	0.1%	0.1% (1%)	-
$\Delta\kappa_\gamma \cdot 10^{-4}$	10.0 / 11.0	7.0 / 5.9 (28)	3.6[1]
$\Delta\lambda_\gamma \cdot 10^{-4}$	4.9 / 6.7	4.8 / 5.6 (5.7)	11.0[1]

1000GeV	e+e-(800) $\int L\Delta t = 1000\ fb^{-1}$	$\gamma\gamma$ $\int L\Delta t \approx 1000\ fb^{-1}$
ΔL	-	(0.1%) / (1%)
$\Delta\kappa_\gamma \cdot 10^{-4}$	2.1[1]	5.2 / 13.9
$\Delta\lambda_\gamma \cdot 10^{-4}$	3.3[1]	1.7 / 2.5

γe: Real / Paras.

$\gamma\gamma$:JZ=2 / JZ=0

[1] generator level e- & e+ pol.

Scaled for bkg., spectrum, pileup

Systematic Errors

✓ **Polarization influence on κ_γ and λ_γ**

Data sample - 1% changed polarization J_Z=2/J_Z=0 in the sample with $P_{0,2}$ = + 0.90 J_Z=0/J_Z=2
(realized increasing N_{ev} with J_Z= 2,0 for 10% → increase of N_{ev} corresponds to the $P_{0,2}$ = + 0.89)

fit (with MC): J_Z=0 (ΔL= 1%) → κ_γ,λ_γ shifted < 1σ
J_Z=2 (ΔL= 0.1%) → κ_γ shifted < 3σ, λ_γ shifted < 1σ

✓ **Effect of the background**

Data sample

Estimated background per bin is changed for both modes, fit (with MC): (ΔL= 0.1%)

J_Z=2 → for κ_γ shifted by 1σ → bck. at level of < 0.8%, for λ_γ < 4%

J_Z=0 → for κ_γ shifted by 1σ → bck. at level of < 1.1%, for λ_γ < 0.6%

(ΔL= 1%) for κ_γ shifted by 1σ → bck. at level of ~ 15%, for λ_γ < 0.6%

Conclusions

- Pileup rejection is difficult (still has a large contribution – decrease: to enlarge 'b')
- Good signal / background separation
- Information on $\Delta\kappa_\gamma$ in the cross-section (via n)
- Information on $\Delta\lambda_\gamma$ in the shape of the distributions
- Statistical error estimations $\Delta\kappa_\gamma$, $\Delta\lambda_\gamma \sim 10^{-4}$
- Systematic errors $\rightarrow$ background