KK excitations of W/Z gauge bosons

M. Escalier, LPNHE Paris, ATLAS Experiment

On behalf of the ATLAS collaboration

References/thanks:

- G. Azuelos, G. Polesello (KK of Z/γ)
- M. Prata, (PhD work), G. Polesello KK of W
- To those i forgot

ADVANCED STUDIES INSTITUTE
PHYSICS AT LHC (LHC-Praha-2003)
Prague, July 6 - July 12, 2003

XD: the models

$$\Phi(x_\mu, y) = \sum_{k=-\infty}^{+\infty} e^{\frac{iky}{R_c}} \Phi^{(k)}(x_\mu) \longrightarrow m_n^2 = m_0^2 + n^2 M_C^2$$

- ADD large XD (~mm) R_c>>1 TeV^{-1}
- Small XD (TeV^{-1}) (Antoniadis)
- Randal Sandrum

Detection of KK excitations of gauge bosons

direct observation of KK of SM gauge bosons

- gluon→qq, most abundant $\Gamma \sim \alpha_s$
  →difficult to detect over jet-jet QCD background
- γ, Z G. Azuelos and G. Polesello – proceedings of the Workshop "Physics at TeV colliders", Les Houches, May 2001 – hep-ph/0204031, ATL-COM-PHYS-2003-004
- W G. Polesello, M. Prata

Results within the ATLAS experiment

Model

- At least 2 larges XD (R_c>>TeV^{-1}) where only gravity propagates
- 1 small XD (~TeV^{-1}) where SM can propagate (compactified on S1/Z2)
- Fermions confined on 3-brane
  - W: at same orbifold point →simplification $g^e(n)=g^q(n)=g(n)$
  - Z, γ: Same or opposite (M1, M2)
- Higgs field can propagate into bulk
- Excitations of boson couple to fermions on the 3-brane

$$g_{XD} = g_{SM} \times \sqrt{2}$$

→KK excitations of gauge bosons

Constraints

EW precise measurement →minimum KK=4 TeV

Rizzo and Wells, Phys. Rev. D61 2000 016007

$$m_n^2 = m_0^2 + (nM_c)^2$$

M_c>>m_0→m_n~nM_c gauge bosons are degenerated in mass

KK implementation

γ/Z (G. Azuelos and G. Polesello)

W (G. Polesello, M. Prata)

Z

qq→ll ME from T. Rizo Phys. Rev. D61 2000 055005

M1: q, l in same brane

M2: q, l at opposite fixed points

Int SM γ/Z - KK ~

$$\frac{1}{M_c^2}\sum_{n=1}^{\infty}\frac{1}{n^2}$$ M1

$$\frac{1}{M_c^2}\sum_{n=1}^{\infty}(-1)^n\frac{1}{n^2} = -\frac{1}{2}\frac{1}{M_c^2}\sum_{n=1}^{\infty}\frac{1}{n^2}$$ M2

W

$u_i\bar{d}_j \to e^+\nu$ channels

$$\begin{cases} q\bar{q} \to W^{(1)} \to l^{\pm}\nu \\ q\bar{q} \to W^{(1)} \to jet\ jet \end{cases}$$

- $$\frac{d\sigma}{d\cos\theta} = \frac{\pi\alpha^2\hat{s}}{48\sin^2\theta_W}|V_{ij}|^2|\mathcal{M}|^2(1+\cos\theta)^2$$

$$\mathcal{M} = \underbrace{\frac{g^q g^e}{\hat{s}-M_W^2+i\Gamma_W M_W}}_{\text{fundamental}} + \underbrace{\sum_{n=1}^{\infty}\frac{g^q(n)g^e(n)}{\hat{s}-M_n^2+i\Gamma_n M_n}}_{\text{KK}}$$

- width $$\Gamma_n \sim \frac{\Gamma_W}{m_W}\left(\frac{g^e(n)^2}{3}+g^q(n)^2\right)$$

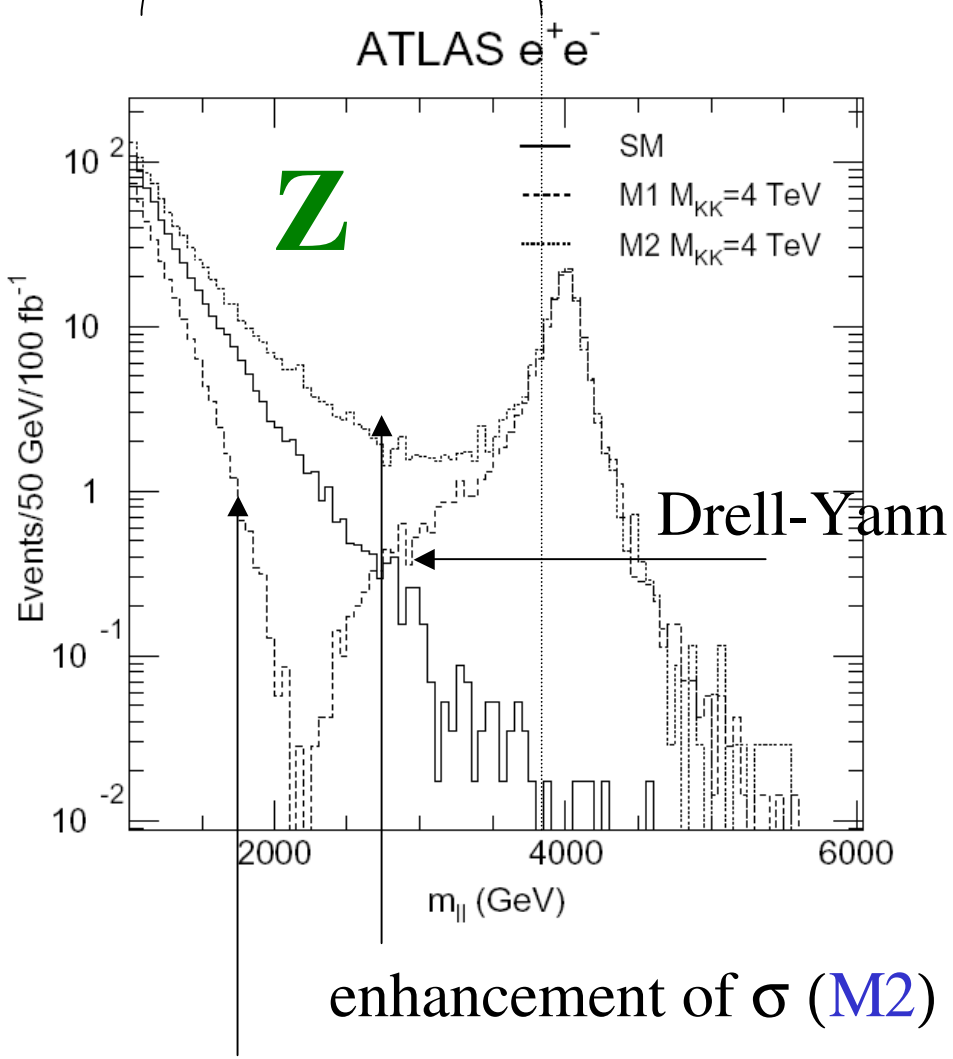
Inv. mass distrib.

$$\frac{\Gamma_{W^{(1)}}}{M_{W^{(1)}}} \sim 7\%$$

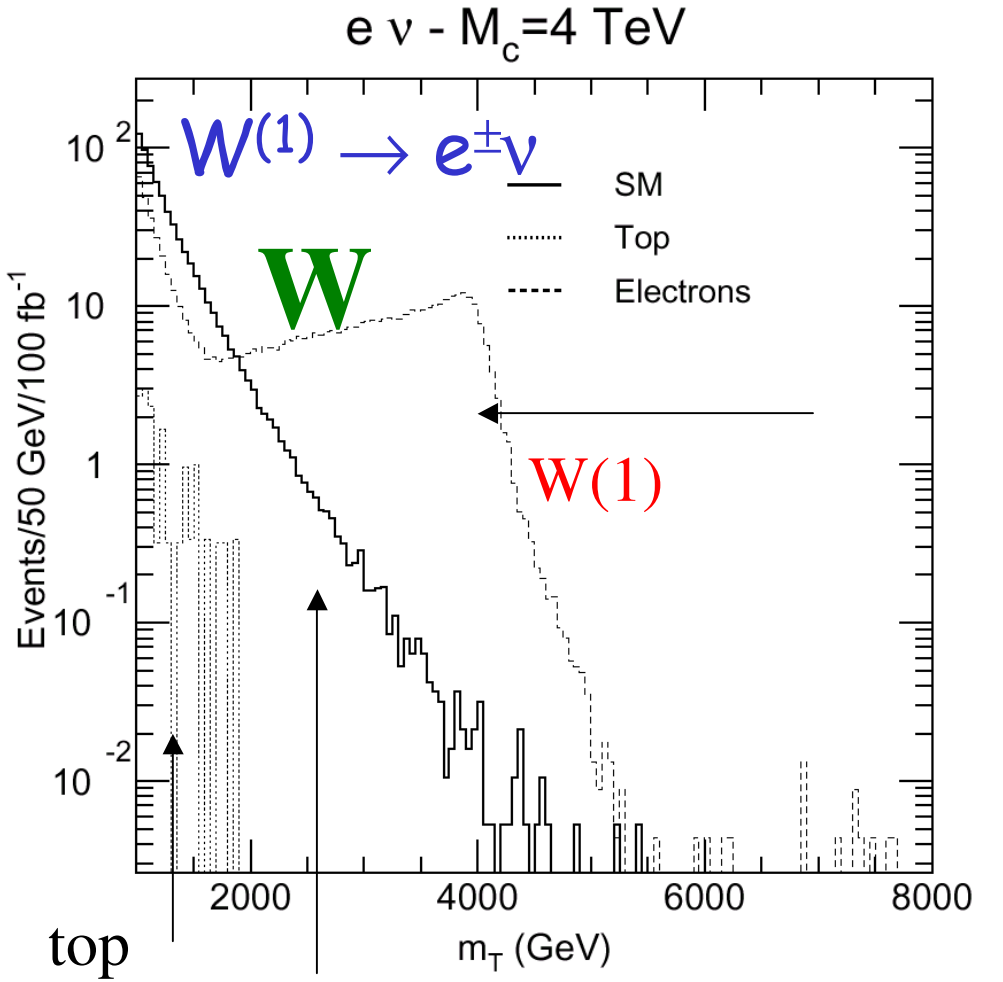
$$\frac{\sigma(p_T^{\mu})}{p_T^{\mu}} \sim 20\% \qquad (p_T^{\mu} \sim 2TeV)$$

$$\frac{\sigma(p_T^{e})}{p_T^{e}} \sim 0.7\% \qquad (p_T^{e} \sim 2TeV)$$

Off-peak region



no new physics→500 events survive cuts



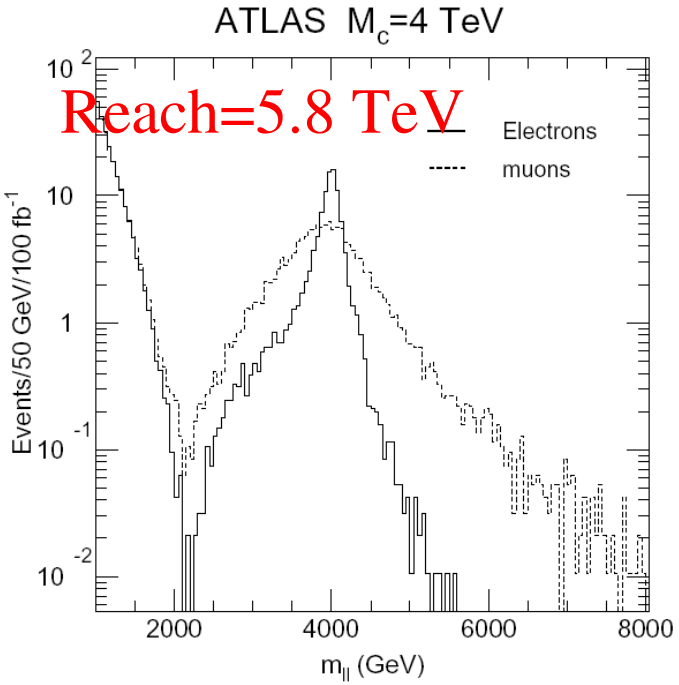
$$m_T = \sqrt{2p_T^l p_T^{\nu}\,(1-\cos\Delta\Phi)}$$

Observation of a peak

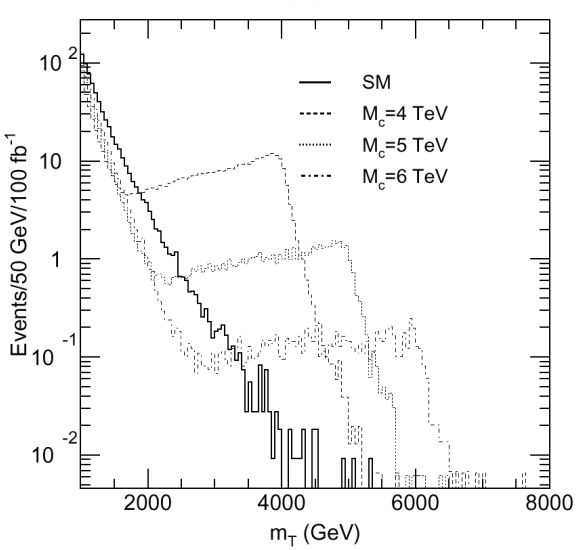
- m_{l+l-}>100 GeV P_T^l>20 GeV $|\eta|$<2.5
- events >10 in peak S/√B>5

Z

M_c(GeV)	Cut (GeV)	$N_{ev}(e)$	$N_{ev}(\mu)$	Background (e)	Background (μ)
4000	3000	172	156	1.45	1.8
5000	4000	23	20	0.15	0.22
5500	4000	9	8	0.15	0.22
6000	4500	3.3	2.8	0.05	0.1
7000	5000	0.45	0.38	0.015	0.05
8000	6000	0.042	0.052	0.0015	0.012



- isol. l^{+-} w/ P_T>200 GeV E_T^{miss} >200 GeV
- $m_T^{l\nu}$>1 TeV events>10 S/√B>5



W

M_c [GeV]	Cut [GeV]	N_{ev} (e)	Bg (e)	N_{ev} (μ)	Bg (μ)	N_{ev} (e) + N_{ev} (μ)	S/√B
4000	3000	204	1.43	171	3.12	375	175
5000	4000	26	0.13	20	0.78	46	49
6000	4000	6.1	0.13	4.5	0.78	10.6	11.0
7000	5000	0.8	0.009	0.5	0.26	1.3	2.5
8000	6000	0.1	0.001	0.1	0.07	0.2	0.6

Reach=6 TeV (High Lumi)

➔second resonance ($W^{(2)}$> 8 TeV) is not observable

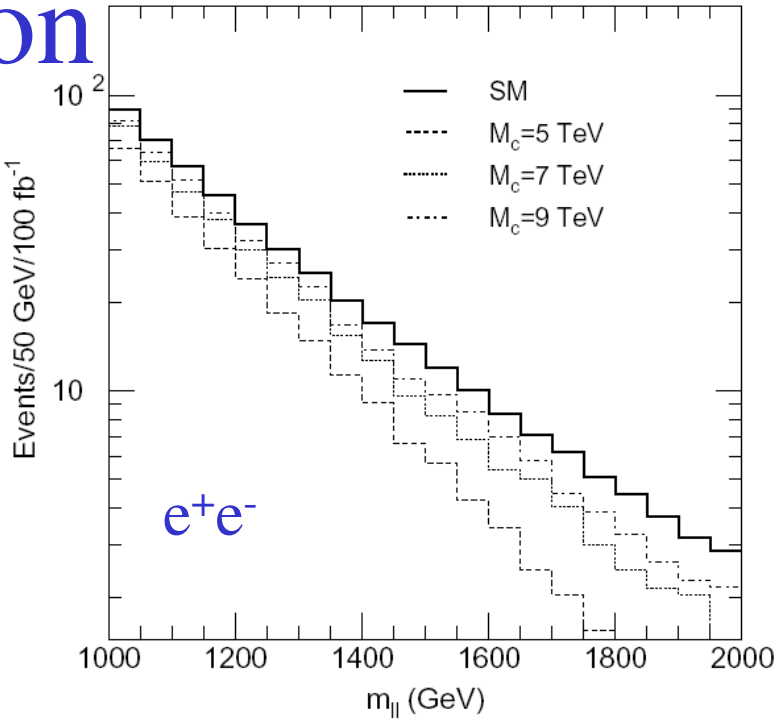
Off resonance region

$$\frac{|N_{ev}(M_c) - N_{ev}(SM)|}{\sqrt{N_{ev}(SM)}}$$

Z

8 TeV 100 fb^{-1}

10.5 TeV 300 fb^{-1}



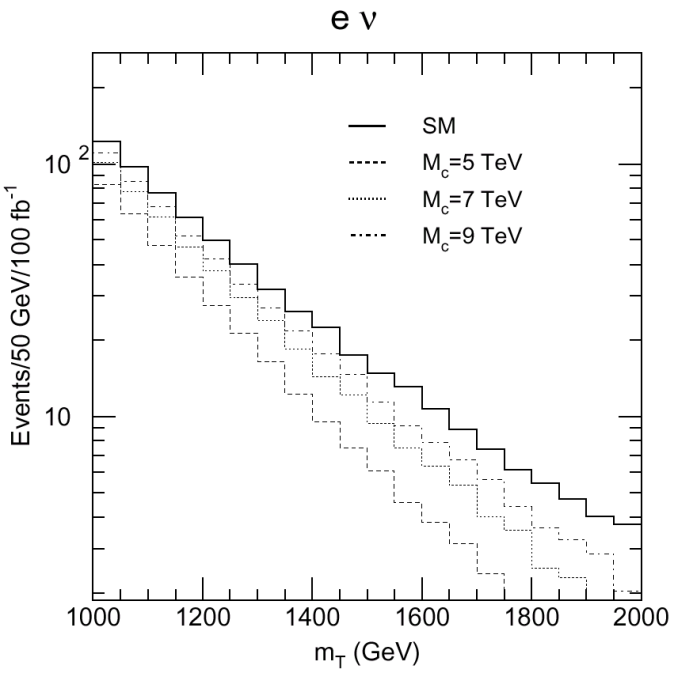
Mc(GeV)	$N_{ev}(\ell)$
SM	483
4000	210
5000	295
5500	324
6000	349
7000	381
8000	405
8500	413
9000	419
10000	432
11000	443
12000	450

Off-resonance sensitivity to interference effects variation events for m_T in [1000-2000 GeV]=f(M_c)

M_c [GeV]	N_{ev} (e)	N_{ev} (μ)	N_{ev} (l)	$\frac{\lvert N_{ev}(l)-N_{ev}(SM)\rvert}{\sqrt{N_{ev}(SM)}}$	$\frac{N_{ev}(l)}{N_{ev}(SM)}$
SM	625	615	1240		
4000	298	307	605	18.0	0.49
5000	351	350	701	15.3	0.57
6000	419	415	834	11.5	0.67
7000	467	463	930	8.8	0.75
8000	507	501	1008	6.6	0.81
9000	529	521	1050	5.4	0.85
10000	552	542	1094	4.1	0.88
11000	561	552	1113	3.6	0.90
12000	572	564	1136	3.0	0.92

W

5σ for M_c=9 TeV

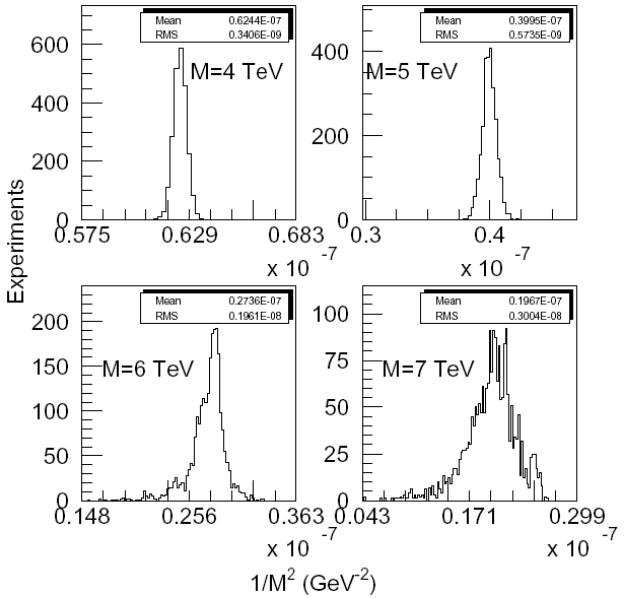


Optimal reach (e^-e^+)

Likelihood fit $-2\ ln\ \mathcal{L} = \sum_i \left[2(N_i^{th} - N_i^{obs}) + 2N_i^{obs} ln\left(\frac{N_i^{obs}}{N_i^{th}}\right)\right] = \chi^2$

with x_1^i, x_2^i, cos θ^i $\begin{cases} \frac{2P_L^{l^+l^-}}{\sqrt{s}} = x_1 - x_2 \\ m_{l^+l^-}^2 = x_1 x_2 s \end{cases}$

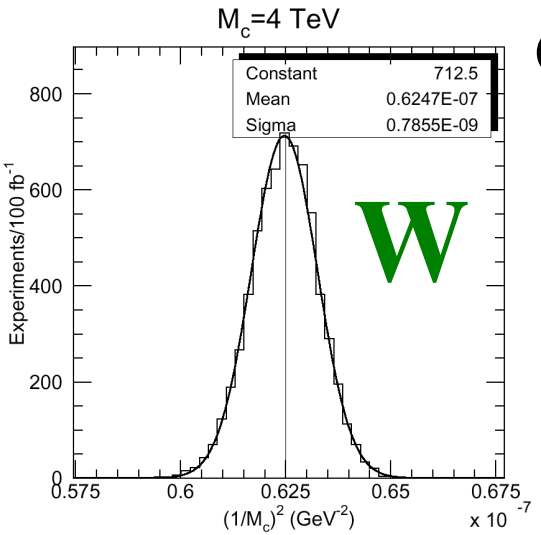
Z



Average estimate value (~2500 experiments)

Mc(GeV)	M_{lik}(GeV)	RMS
4000.	4001.96	10.91
5000.	5003.16	35.91
5500.	5502.19	77.24
6000.	6045.22	216.61
7000.	7129.48	544.35

9.5 TeV (100 fb^{-1}), 11 TeV (200 fb^{-1}), 12 TeV (300 fb^{-1})
Assume sensitivity μ~e
➔13.5 TeV for 300 fb^{-1}(both species)



W

6000 MC exp. (100 fb^{-1} each)
Th. histo. gen.
in M_c=[300 GeV;15 TeV]

12000 MC with SM pp→eν

M_c [GeV]	M_{fit} [GeV]	σ [GeV]	σ/M_{fit} %
4000	4001	25	0.6
5000	5008	73	1.5
6000	5997	121	2.0
7000	6984	285	4.1
8000	7923	519	6.6

95% CL computed
11,3 TeV (for 100 fb^{-1})

Systematic uncertainties

Detector-related uncertainties

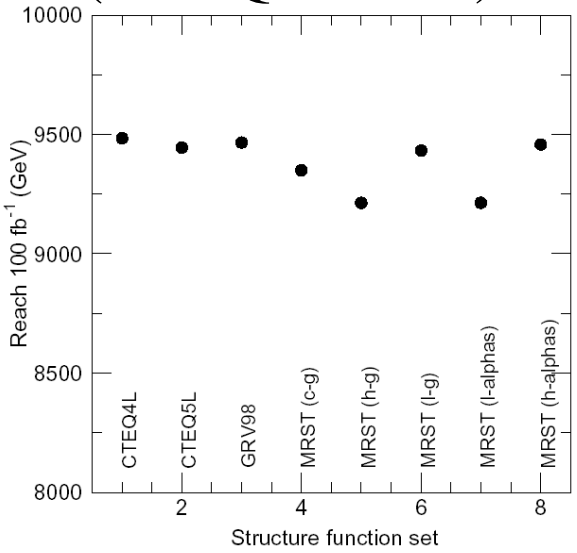
- Lepton energy and momentum scale
- Energy and momentum resolution
- Detector response to the recoil fragments
- Effect of the lepton identification cuts

EW higher order corrections

Large NLO corrections (K factor~1.35)

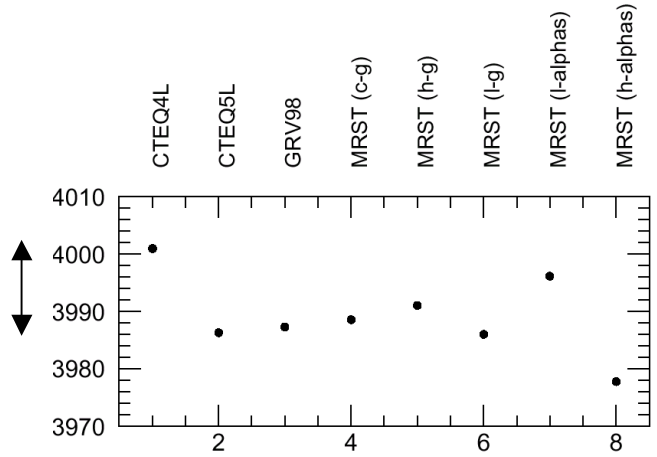
pdfs uncertainties (CTEQ4L used)

Z

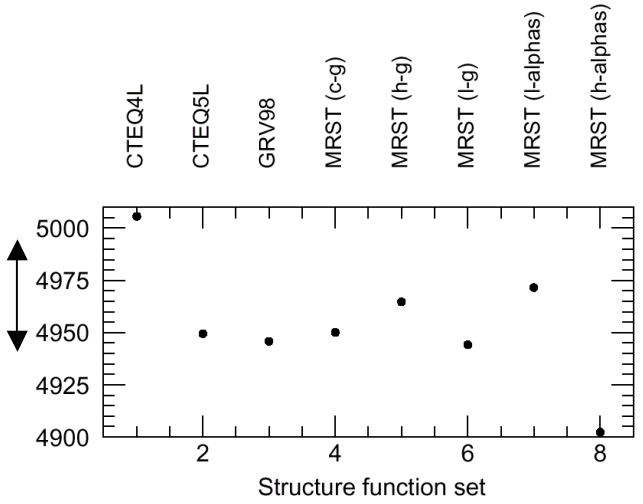


W

25 GeV



100 GeV

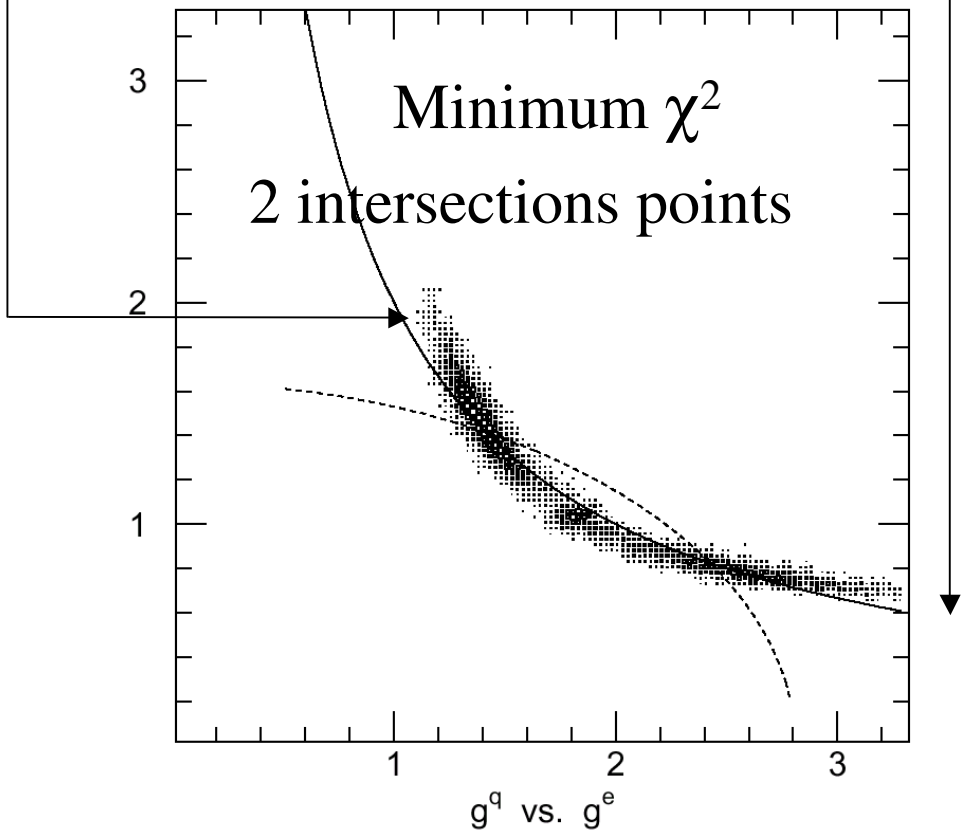


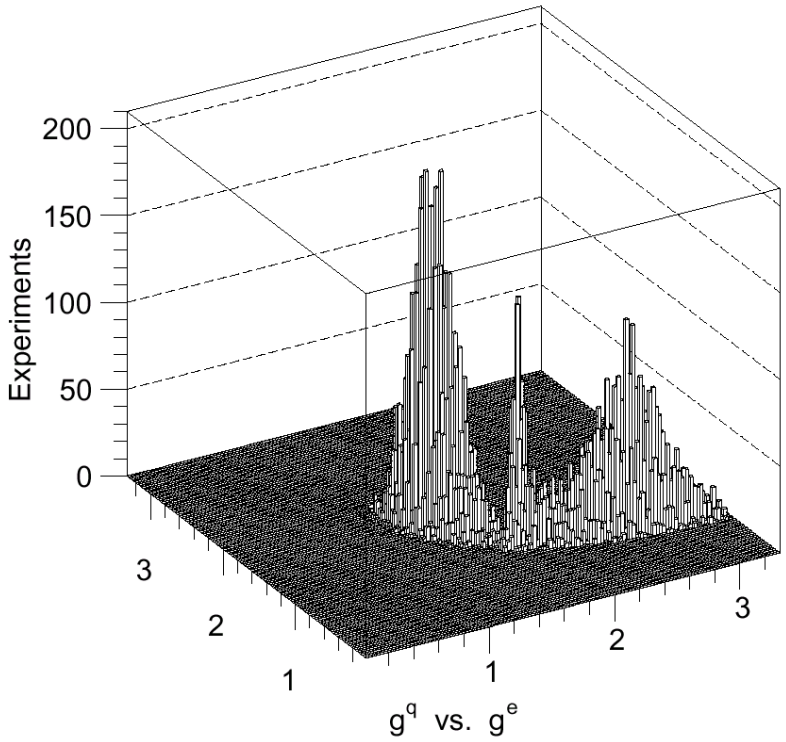
uncertainty ~same order as statistical error

Measurement of $W^{(1)}$ coupling

$$\sigma BR \sim [g^e(n) g^q(n)]^2$$
$$\Gamma \sim a g^e(n)^2 + b g^q(n)^2$$

Solve this system





One solution if not enough statistics

choice of the good solution: look at decay $W^{(1)} \rightarrow t \bar{b}$, involves only g^q

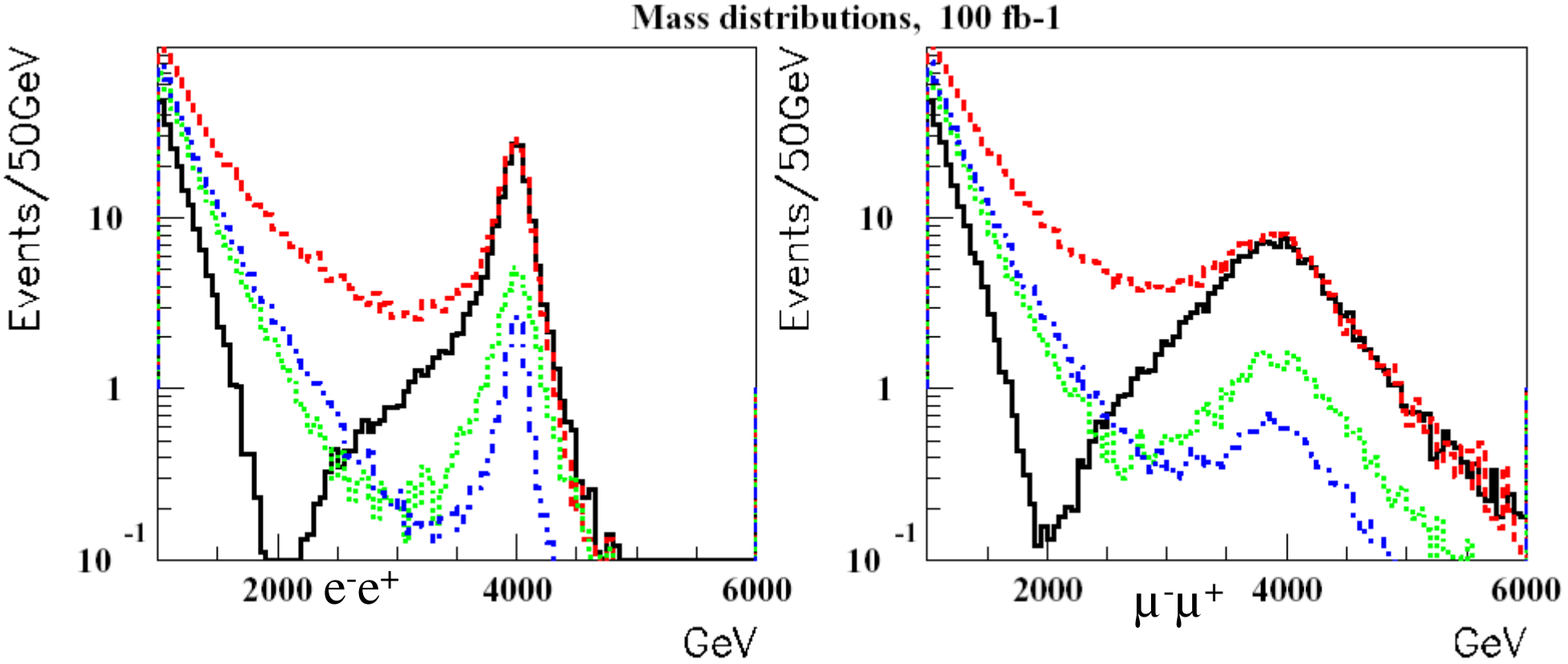
Distinction from others models

Angular distributions

- Z/γ M1
- Z/γ M2
- Z'
- G*+SM Drell-Yan resonance

Z

process	$\sigma \times BR(Z^* \to e^+e^-)$ (fb)
$Z^{(1)}/\gamma^{(1)}$	4.05
$Z^{(1)}/\gamma^{(1)}$-M2	11.75
Z'	4.65
$qq \to G^*$	0.20
$gg \to G^*$	0.13
$qq \to e^+e^-$	4.83

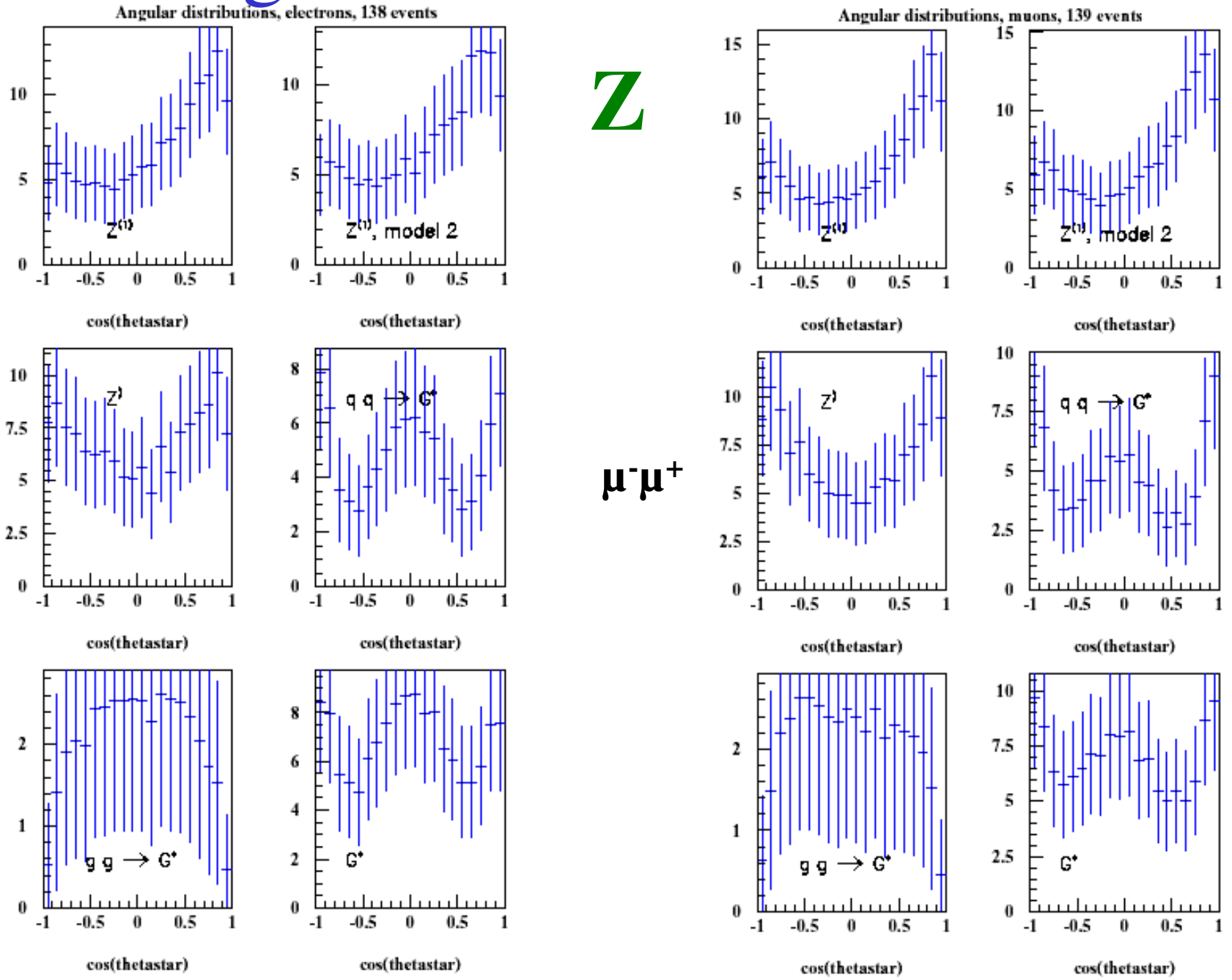


Angular distributions

Z

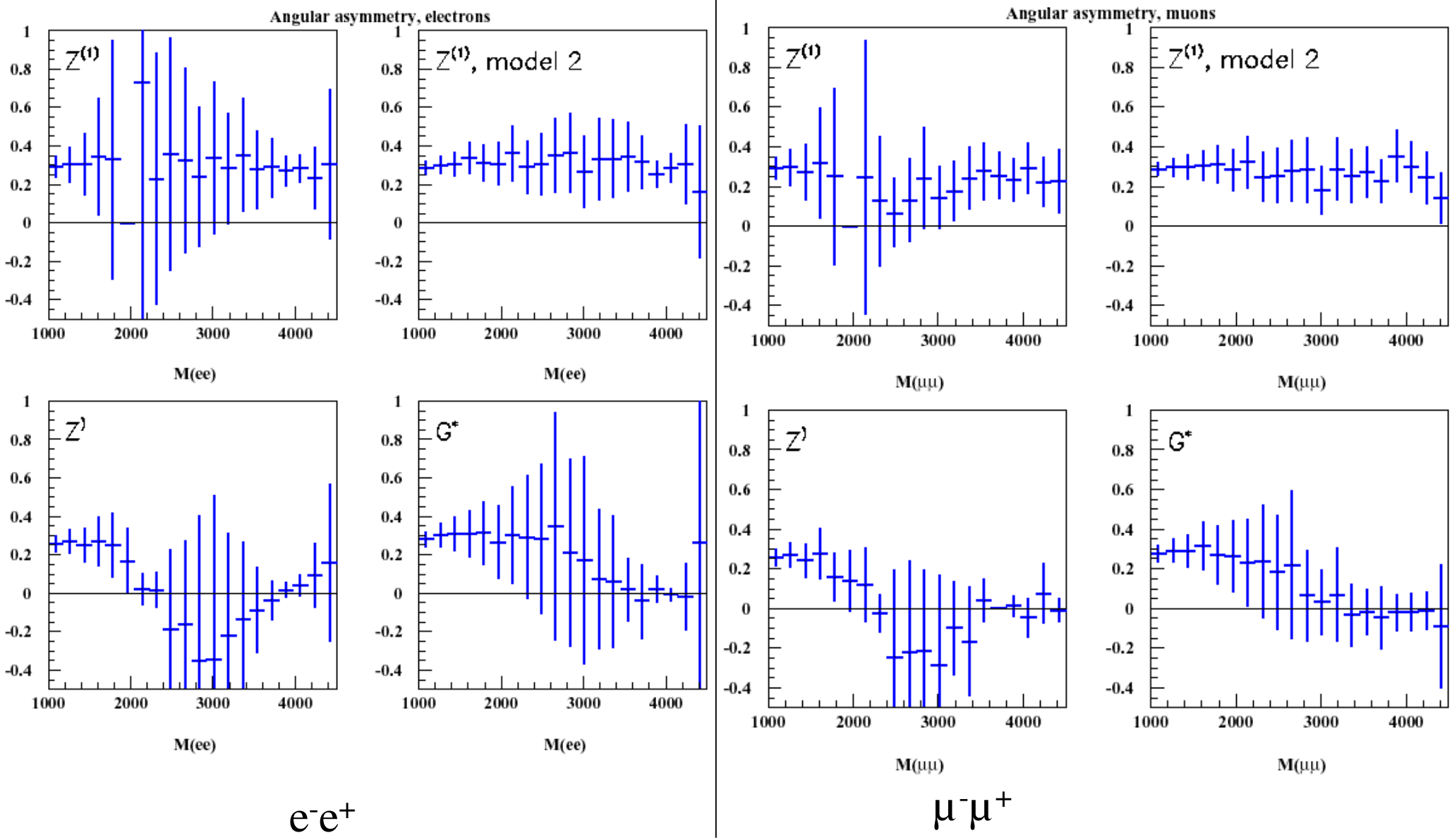
e^-e^+

$\mu^-\mu^+$



Forward/backward distributions

Z



W

Heavy gauge bosons from others models, eg Little Higgs

- KK reference model

Equally spaced KK resonances

- Toy « sequential model » with a single W'

Region of interference

loss in σ: ~ 2 for KK model

~ $\pi^2/6$ for sequential model

Statistics doesn't allow the discrimination

Conclusion

Z

Resonance reach 5.8 TeV
Off-peak region: 13.5 TeV (300 fb^{-1})
Angular distribution→FB asymmetry
Can reject from others models

W

Resonance reach M_c<6 TeV
Off-peak region: Mc=9 TeV (100 fb^{-1})
No rejection from others models