based on
0807.5087
0801.4235

Unusual signatures of spin-1 resonances

keywords: Z-prime, Z-star
W-prime, W-star

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γ, $W^{\pm}$, Z …

… till now:

abelian U(1)′ extension → Z′

$$\mathcal{L}_{Z'} = \bar{\psi}\gamma^{\mu}\left(g_V + g_A\gamma^5\right)\psi \cdot Z'_{\mu}$$

or adjoint representation of SU(2)′ extension → Z′, W′

$$\mathcal{L}_{W'} = \bar{\psi}\gamma^{\mu}\left(g_V + g_A\gamma^5\right)\vec{\tau}\,\psi \cdot \vec{W}'_{\mu}$$

Canonical signature of spin-1 resonance

Table 3.10. Angular distributions for the decay products of spin-1 and spin-2 resonances, considering only even terms in $\cos\theta^*$.

Channel	d-functions	Normalised density for $\cos\theta^*$
$q\bar{q} \to G^* \to f\bar{f}$	$\lvert d^2_{1,1}\rvert^2 + \lvert d^2_{1,-1}\rvert^2$	$P_q = \frac{5}{8}(1 - 3\cos^2\theta^* + 4\cos^4\theta^*)$
$gg \to G^* \to f\bar{f}$	$\lvert d^2_{2,1}\rvert^2 + \lvert d^2_{2,-1}\rvert^2$	$P_g = \frac{5}{8}(1 - \cos^4\theta^*)$
$q\bar{q} \to \gamma^*/Z^0/Z' \to f\bar{f}$	$\lvert d^1_{1,1}\rvert^2 + \lvert d^1_{1,-1}\rvert^2$	$P_1 = \frac{3}{8}(1 + \cos^2\theta^*)$

3.3.6. Discriminating between different spin hypotheses

The fractions of generated events arising from these processes are denoted by ϵ_q, ϵ_g, and ϵ_1, respectively, with $\epsilon_q + \epsilon_g + \epsilon_1 = 1$. Then the form of the probability density $P(\cos\theta^*)$ is

$$P(\cos\theta^*) = \epsilon_q P_q + \epsilon_g P_g + \epsilon_1 P_1. \quad (3.24)$$

is not complete !

What about bosons in fundamental reps. of $SU(2)_L$

SU(3) extensions, extra spatial dimentions…

MC and G. Dvali, in preparation

i.e. with the internal quantum numbers identical to the SM Higgs doublet. Due to their quantum numbers, to the leading order such bosons can only have anomalous chiral interactions with the SM fermions,

$$\mathcal{L}_{Z^*W^*} = \frac{g_u}{\Lambda}\left(\bar{u}_L\ \bar{d}_L\right)\sigma^{\mu\nu} u_R \cdot \left[\partial_\mu \begin{pmatrix} Z_\nu^* \\ W_\nu^{*-} \end{pmatrix} - \partial_\nu \begin{pmatrix} Z_\mu^* \\ W_\mu^{*-} \end{pmatrix}\right] + \frac{g_d}{\Lambda}\left(\bar{u}_L\ \bar{d}_L\right)\sigma^{\mu\nu} d_R \cdot \left[\partial_\mu \begin{pmatrix} -W_\nu^{*+} \\ \bar{Z}_\nu^* \end{pmatrix} - \partial_\nu \begin{pmatrix} -W_\mu^{*+} \\ \bar{Z}_\mu^* \end{pmatrix}\right] + \text{h.c.}$$

Technicolor

techni-pions, techni-rhos, techni-omegas …

What else?

π^0 $I^G(J^{PC}) = 1^-(0^{-+})$

Mass $m = 134.9766 \pm 0.0006$ MeV (S = 1.1)
$m_{\pi^\pm} - m_{\pi^0} = 4.5936 \pm 0.0005$ MeV
Mean life $\tau = (8.4 \pm 0.6) \times 10^{-17}$ s (S = 3.0)
$c\tau = 25.1$ nm

$$\bar{q}\gamma^\mu q \cdot V_\mu$$

$$\bar{q}\gamma^\mu\gamma^5 q \cdot A_\mu$$

$\rho(770)$ [j] $I^G(J^{PC}) = 1^+(1^{--})$

Mass $m = 775.49 \pm 0.34$ MeV
Full width $\Gamma = 149.1 \pm 0.8$ MeV
$\Gamma_{ee} = 7.04 \pm 0.06$ keV

$a_1(1260)$ [m] $I^G(J^{PC}) = 1^-(1^{++})$

Mass $m = 1230 \pm 40$ MeV [n]
Full width $\Gamma = 250$ to 600 MeV

$\omega(782)$ $I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 782.65 \pm 0.12$ MeV (S = 1.9)
Full width $\Gamma = 8.49 \pm 0.08$ MeV
$\Gamma_{ee} = 0.60 \pm 0.02$ keV

$f_1(1285)$ $I^G(J^{PC}) = 0^+(1^{++})$

Mass $m = 1281.8 \pm 0.6$ MeV (S = 1.6)
Full width $\Gamma = 24.3 \pm 1.1$ MeV (S = 1.4)

$h_1(1170)$ $I^G(J^{PC}) = 0^-(1^{+-})$

Mass $m = 1170 \pm 20$ MeV
Full width $\Gamma = 360 \pm 40$ MeV

$b_1(1235)$ $I^G(J^{PC}) = 1^+(1^{+-})$

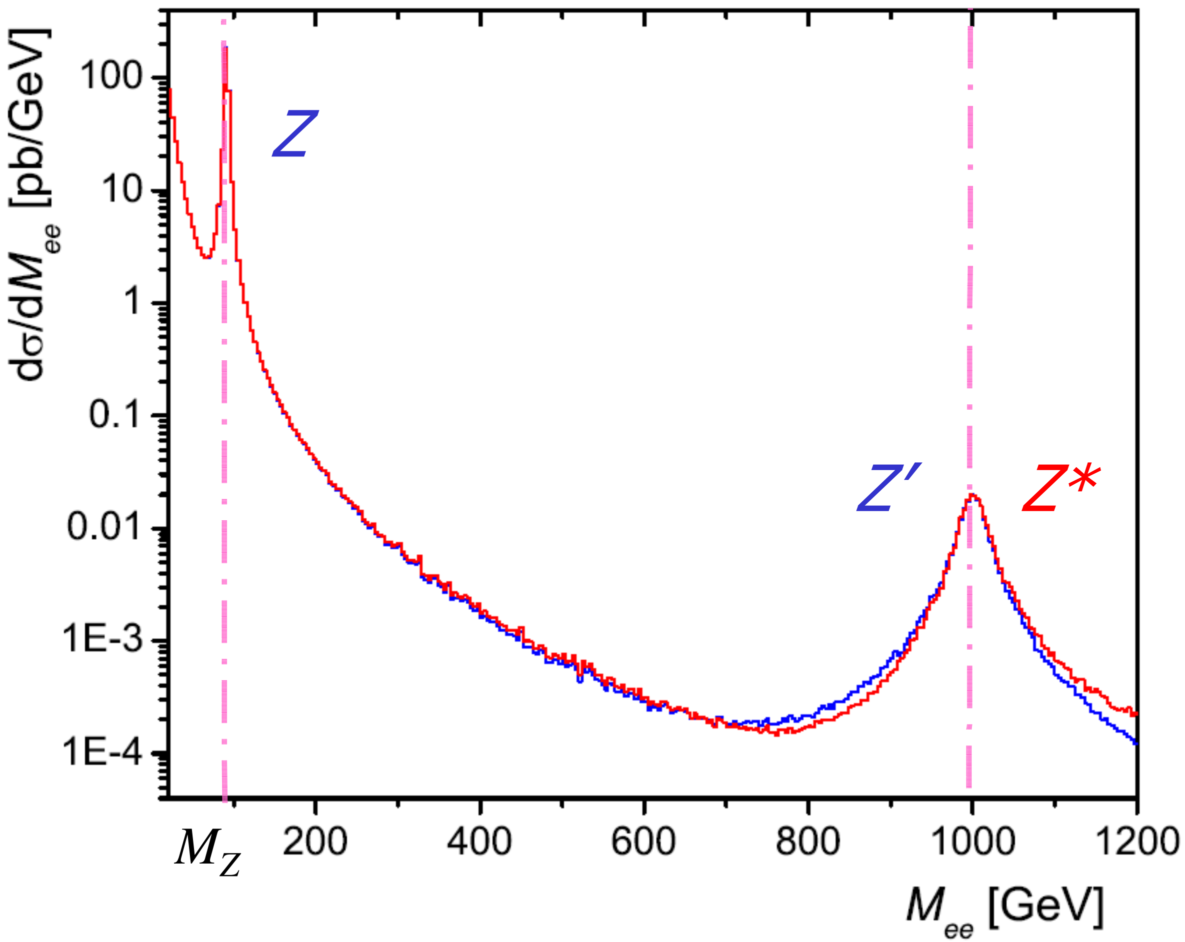
Mass $m = 1229.5 \pm 3.2$ MeV (S = 1.6)
Full width $\Gamma = 142 \pm 9$ MeV (S = 1.2)

$$\bar{q}\sigma^{\mu\nu}\gamma^5 q \cdot \left(\partial_\mu A_\nu^* - \partial_\nu A_\mu^*\right)$$

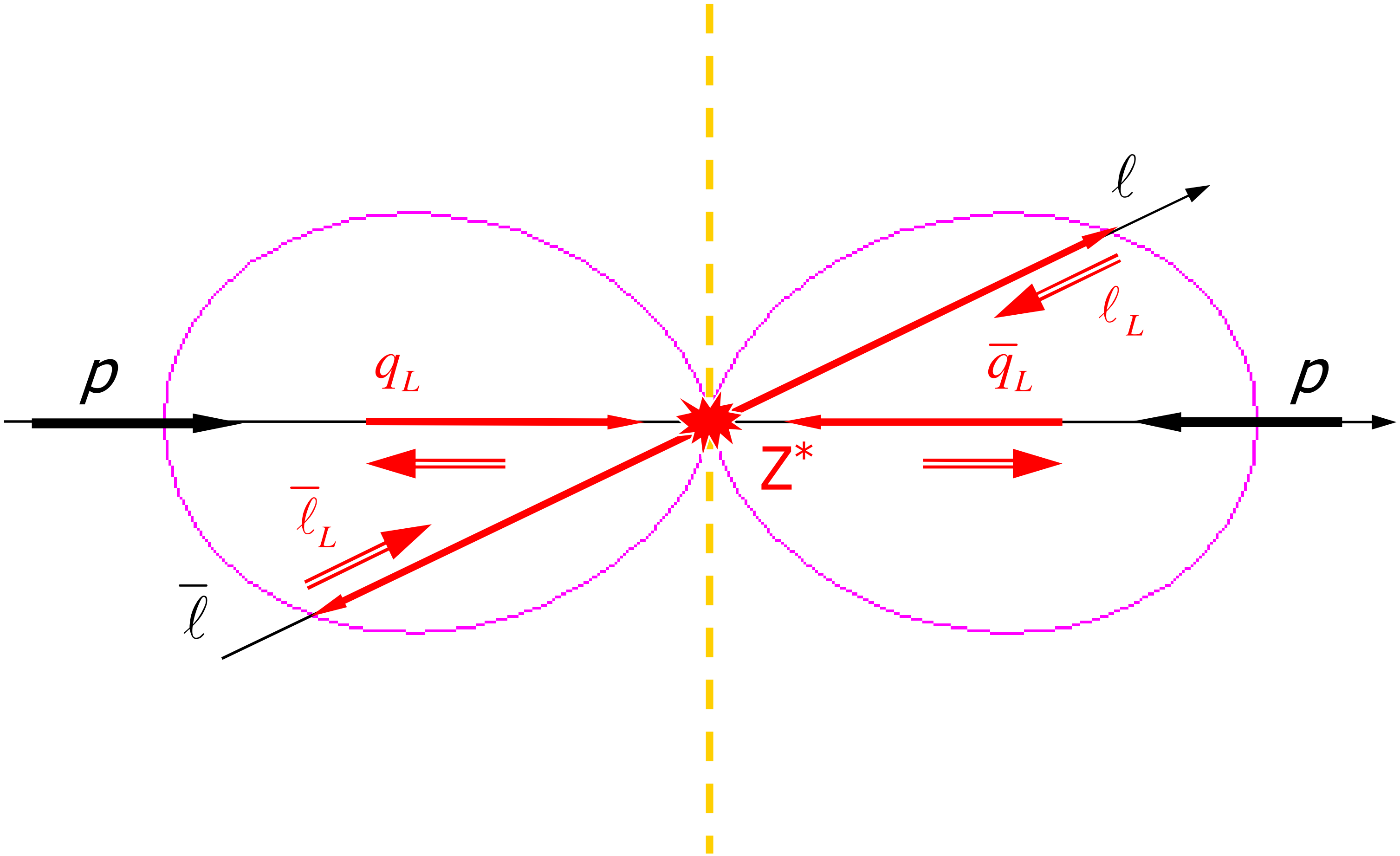
? ? ?

Invariant dilepton mass distributions

Several models predict high mass resonances that could decay into dileptons (Z′, G, TC, KK, …)



Angular distribution of Z*



$$\left|d^1_{00}\right|^2 \propto \cos^2\theta$$

Spin-1 and graviton angular distributions

Table 3.10. Angular distributions for the decay products of spin-1 and spin-2 resonances, considering only even terms in $\cos\theta^*$.

Channel	d-functions	Normalised density for $\cos\theta^*$
$q\bar{q} \to G^* \to f\bar{f}$	$\lvert d^2_{1,1}\rvert^2 + \lvert d^2_{1,-1}\rvert^2$	$P_q = \frac{5}{8}(1 - 3\cos^2\theta^* + 4\cos^4\theta^*)$
$gg \to G^* \to f\bar{f}$	$\lvert d^2_{2,1}\rvert^2 + \lvert d^2_{2,-1}\rvert^2$	$P_g = \frac{5}{8}(1 - \cos^4\theta^*)$
$q\bar{q} \to \gamma^*/Z^0/Z' \to f\bar{f}$	$\lvert d^1_{1,1}\rvert^2 + \lvert d^1_{1,-1}\rvert^2$	$P_1 = \frac{3}{8}(1 + \cos^2\theta^*)$

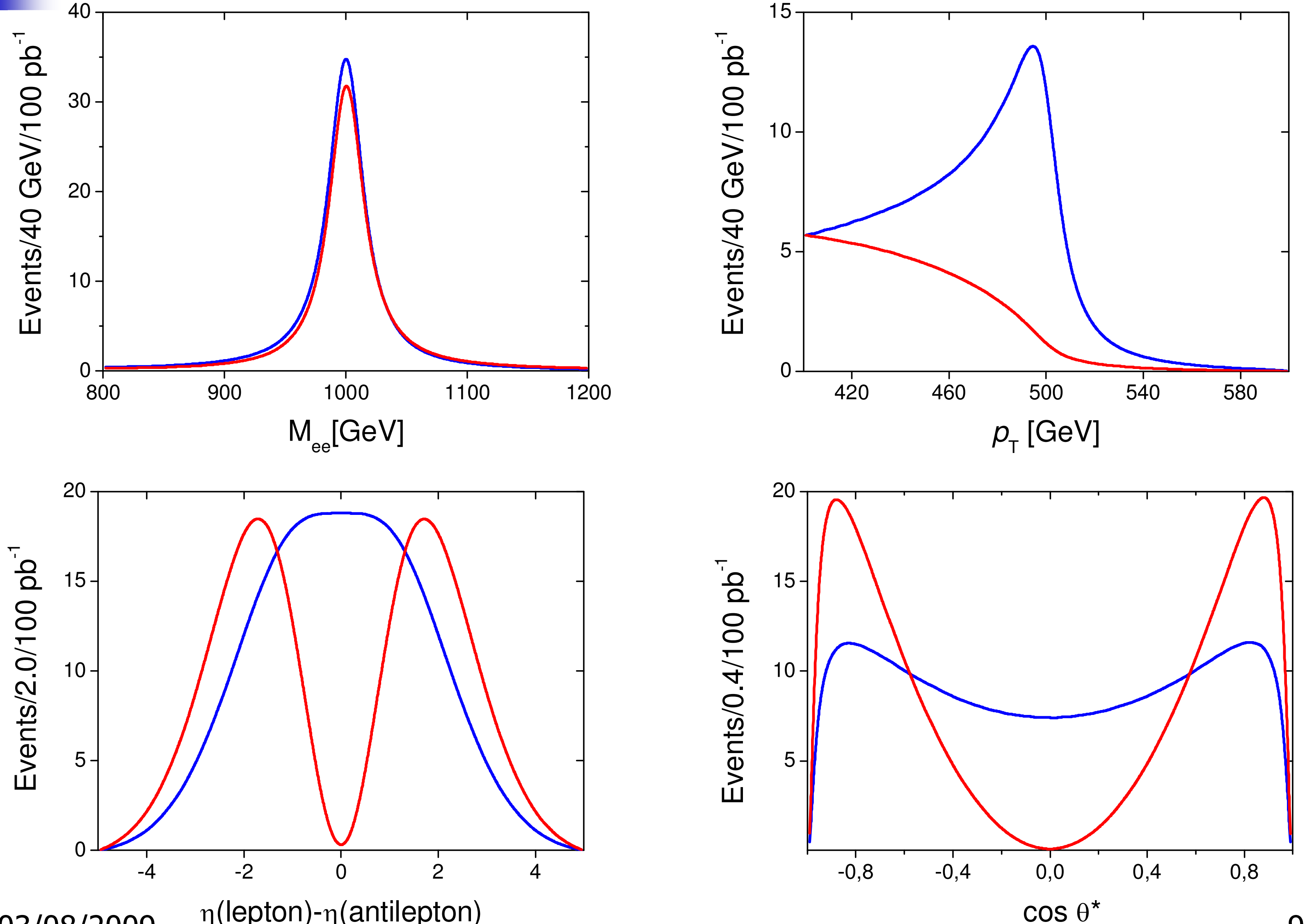
$$P_1^* = \frac{3}{2}\cos^2\theta^*$$

3.3.6. Discriminating between different spin hypotheses

The fractions of generated events arising from these processes are denoted by ϵ_q, ϵ_g, and ϵ_1, respectively, with $\epsilon_q + \epsilon_g + \epsilon_1 = 1$. Then the form of the probability density $P(\cos\theta^*)$ is

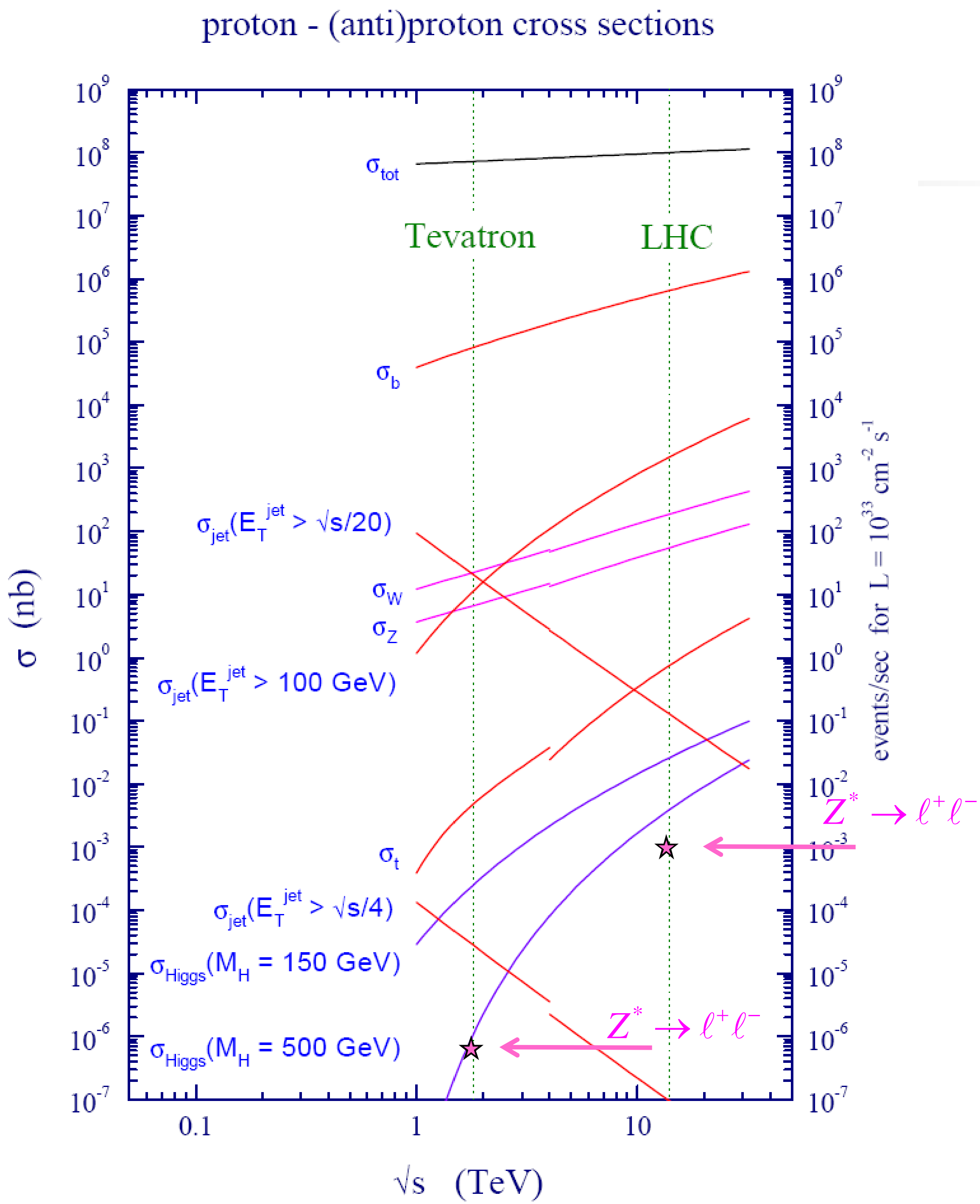
$$P(\cos\theta^*) = \epsilon_q P_q + \epsilon_g P_g + \epsilon_1 P_1. + \varepsilon_1^* P_1^* \qquad (3.24)$$

Comparison between Z′ and Z* for $M_{Z'} = M_{Z*} = 1\ \text{TeV},\ L = 100\ \text{pb}^{-1}$ @ 10 TeV



Conclusions

- There are intense searches for excited fermions, but not for excited bosons at electroweak scale.
- In contrast to the gauge bosons the excited bosons have anomalous chiral couplings to matter. This leads to a distinctive signature of their production at the hadron colliders.
- The clearest channel for their discovery by the early LHC data should be the dilepton one.



proton - (anti)proton cross sections
σ (nb)
events/sec for L = 10^33 cm^-2 s^-1
√s (TeV)
Tevatron
LHC
σ_tot
σ_b
σ_jet(E_T^jet > √s/20)
σ_W
σ_Z
σ_jet(E_T^jet > 100 GeV)
σ_t
σ_jet(E_T^jet > √s/4)
σ_Higgs(M_H = 150 GeV)
σ_Higgs(M_H = 500 GeV)
Z* → ℓ+ℓ−
Z* → ℓ+ℓ−

Excited particles (compositeness)

$$\mathcal{L}_{\psi^*} = \frac{g}{\Lambda}\,\bar{\psi}^*\sigma^{\mu\nu}\psi\;\cdot\left(\partial_\mu Z_\nu - \partial_\nu Z_\mu\right)$$

Searches for excited fermions ψ^* have been fulfilled at all powerful colliders, such as LEP, HERA and Tevatron. They are also included in experimental program at the LHC.

ψ^* why not Z^* **?**

$$\mathcal{L}_{Z^*} = \frac{g}{\Lambda}\,\bar{\psi}\sigma^{\mu\nu}\psi\;\cdot\left(\partial_\mu Z^*_\nu - \partial_\nu Z^*_\mu\right)$$

*Z^* has **different** interactions than Z'* **!**

$$\mathcal{L}_{Z'} = \bar{\psi}\gamma^\mu\left(g_V - g_A\gamma^5\right)\psi\;\cdot Z'_\mu$$

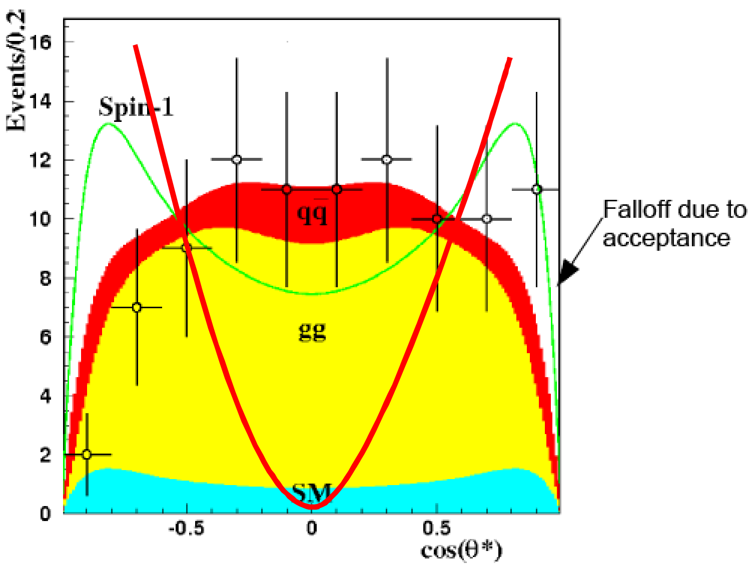
Dilepton resonances

Measurements after discovery

- **Distinguish between models via:**
  - $\sigma \cdot \Gamma_{ee}$
  - **Forward-backward asymmetry**
- **Measure spin**
- **Measure couplings**

But these will take more time...

1.5 TeV Kaluza-Klein RS graviton:

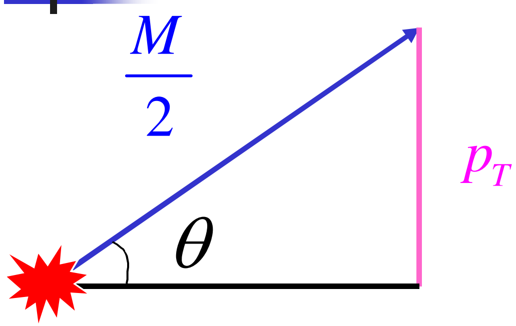


[Allanach 00]

Spin measurement via decay angle distribution

~50-100 events needed to distinguish spin-2 RS graviton from spin-1 Z'

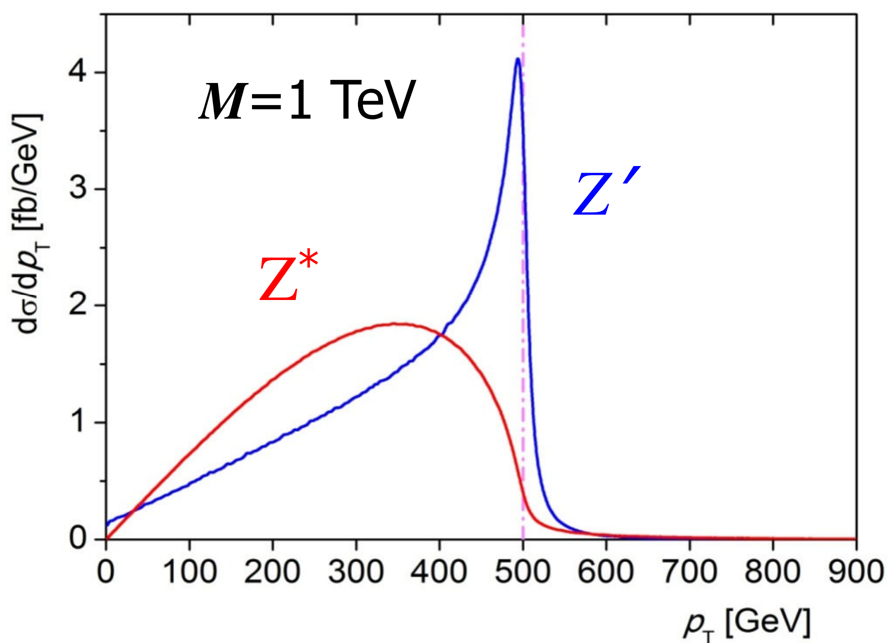
Jacobian factor for $\cos\theta \to p_T$



$$p_L = \frac{M}{2}\cos\theta$$

$$\cos\theta = \sqrt{1 - \frac{4p_T^2}{M^2}};$$

$$\frac{\mathrm{d}\cos\theta}{\mathrm{d}p_T^2} = -\frac{2}{M^2\cos\theta}:$$



$$\frac{\mathrm{d}\sigma}{\mathrm{d}p_T^2} = \left|\frac{\mathrm{d}\cos\theta}{\mathrm{d}p_T^2}\right| \cdot \frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta} = \frac{2}{M^2\cos\theta} \cdot \frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta}$$

"The divergence at $\theta = \pi/2$ which is the upper endpoint $p_T \approx M/2$ of the p_T distribution stem from the Jacobian factor and is known as a *Jacobian peak* ; it is characteristic of **all** two-body decays …"

w r o n g ! V. Barger "Collider physics"