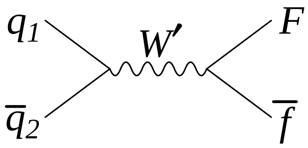
Tev4LHC workshop

SEARCHING FOR W' BOSONS AT HADRON COLLIDERS



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September 17, 2004

Based on:

Z.S., Phys. Rev. D 66, 075011 (2002) [hep-ph/0207290]

Z.S., QCD Moriond 2003 [hep-ph/0306266]

Z.S., in production

Lots of room for further study.

W' bosons appear in many models

Working definition: A W' boson is any particle that mediates a flavor-changing charged vector or axial-vector current.

Left-right symmetric models: Broken SU(2)$_L \times$ SU(2)$_R$

- Generic mixing of W_L–W_R

  R. N. Mohapatra, J. Pati, A. Salam, G. Senjanovic, . . .

- Orbifold-breaking — suppressed mixing, enhanced couplings

  Y. Mimura, S. Nandi, . . .

- Supersymmetric L–R models

  M. Cvetic, J. Pati, . . .

Models with additional left-handed W'

- Little Higgs: SU(5)/SO(5), SU(6)/SP(6), SU(N)/SU(N–1), . . .

  T. Gregoire, N. Arkani-Hamed, S. Chang, H. C. Cheng, A. Cohen, I. Low, D. E. Kaplan, E. Katz, O. C. Kong, A. Nelson, M. Schmaltz, W. Skiba, D. Smith, J. Terning, J. Wacker, . . .

- Topcolor — topflavor, leptophobic topflavor seesaw, generic mixing

  H. Georgi, H. J. He, E. Jenkins, X. Li, E. Ma, E. Malkawi, D. Muller, S. Nandi, E. Simmons, T. Tait, C. P. Yuan, . . .

- Extra dimensions: Kaluza-Klein modes of the W

  A. Datta, P. O'Donnell, T. Huang, Z. Lin, X. Zhang, . . .

- Non-commuting extended technicolor

  R. Chivukula, E. Simmons, J. Terning, . . .

+ 1000's more

Fully differential NLO W' cross section

Z.S., PRD 66, 075011 (2002) [hep-ph/0207290].

Calculated widths and 2-to-2 cross section for arbitrary couplings:

$$\mathcal{L}=\frac{1}{\sqrt{2}}\overline{f}_i\gamma_\mu\left(g_R e^{i\omega}\cos\zeta\, V^R_{f_if_j}P_R+g_L\sin\zeta\, V^L_{f_if_j}P_L\right)W' f_j+\mathrm{H.c.}$$

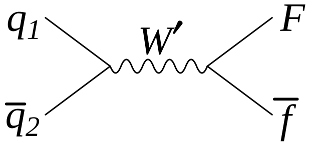
Proved factorization of couplings through NLO in width:

$$\frac{\Gamma(W')}{\Gamma_{SM}}=|gV'_{f_if_j}|^2\equiv|g_L\sin\zeta\, V^L_{f_if_j}|^2+|g_R\cos\zeta\, V^R_{f_if_j}|^2$$

$$\Gamma_{\mathrm{NLO}}(W'\to\nu\bar{\ell}) = \frac{g^2}{16\pi}|V'_{\nu\ell}|^2\frac{M_{W'}}{3} \quad (\text{if left}-\text{handed})$$

$$\Gamma_{\mathrm{NLO}}(W'\to q\bar{q}') = \frac{g^2}{16\pi}|V'_{qq'}|^2 M_{W'}(1+\alpha_s/\pi)$$

$$\Gamma_{\mathrm{NLO}}(W'\to t\bar{q}') = \frac{g^2\beta^2}{16\pi M_{W'}}|V'_{tq'}|^2(M^2_{W'}+m_t^2/2)[1+\alpha_s/\pi F(\beta)]$$



The fully differential LO cross section including width effects is

$$\sigma_0=\int q_1\otimes\bar{q}_2\otimes\frac{1}{2\hat{s}}\frac{2N_c}{3}\frac{R_t t(t-m^2)+R_u u(u-m^2)}{(\hat{s}-M^2_{W'})^2+M^2_{W'}\Gamma^2_{W'}}d\mathrm{PS}_2$$

$$R_{t/u} = (|V_i|^2+|A_i|^2)(|V_f|^2+|A_f|^2)\pm 4\mathrm{Re}(V_iA_i^\star)\mathrm{Re}(V_fA_f^\star)$$

$$|V|^2+|A|^2 = \frac{|g_R\cos\zeta V^R_{f_if_j}|^2+|g_L\sin\zeta V^L_{f_if_j}|^2}{4}$$

$$2\mathrm{Re}(V_iA_i^\star) = \frac{|g_R\cos\zeta V^R_{f_if_j}|^2-|g_L\sin\zeta V^L_{f_if_j}|^2}{4}$$

If $W'\equiv W'_L$, W'_R, or small mixing: $|V|=|A|$

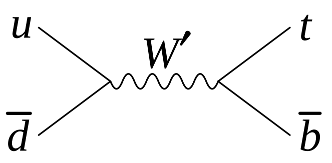
$\Rightarrow R_u=0;\ R_t=\frac{g^4|V'_i|^2|V'_f|^2}{8}$

$\Rightarrow \sigma_{\mathrm{NLO}}=\sigma^{\mathrm{SM}}_{\mathrm{NLO}}$ up to overall factor: $(g'/g_{\mathrm{SM}})^4$

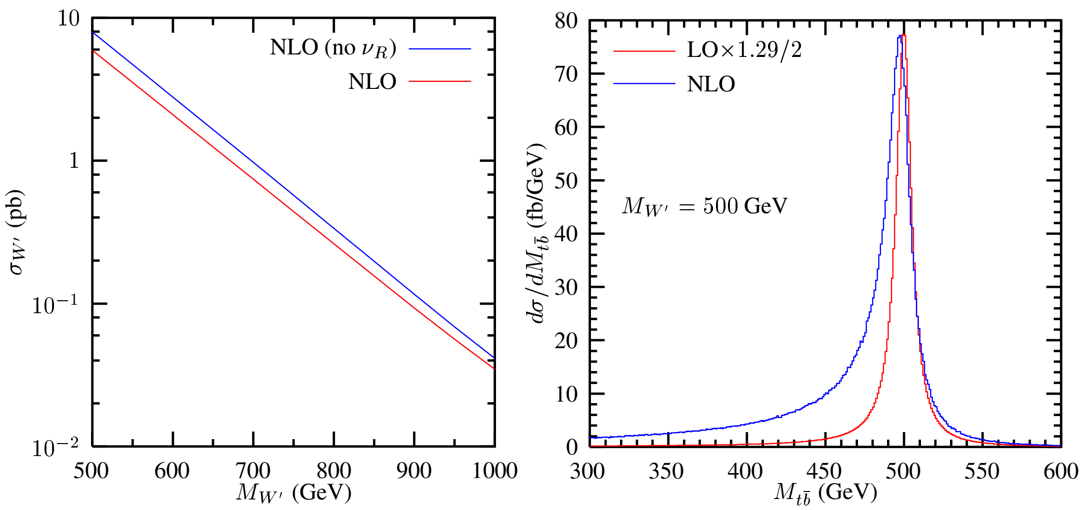
A model independent search for W'

Z.S., PRD 66, 075011 (2002) [hep-ph/0207290].

The single-top-quark cross section is the same whether you have a W'_L, W'_R, or small mixing. Thus this is a great channel for model-independent searches.



$p\bar{p} \to W' \to t\bar{b}$ production at the Tevatron



CDF just set a bound of $M_{W'} > 536(566)$ GeV. PRL 90, 081802 (03)

Previous limit for W'_R was ~ 400 GeV $\qquad (g' = g_{\mathrm{SM}})$,
CDF limit is ~ 786 GeV for $W'_L \to \ell\nu$.

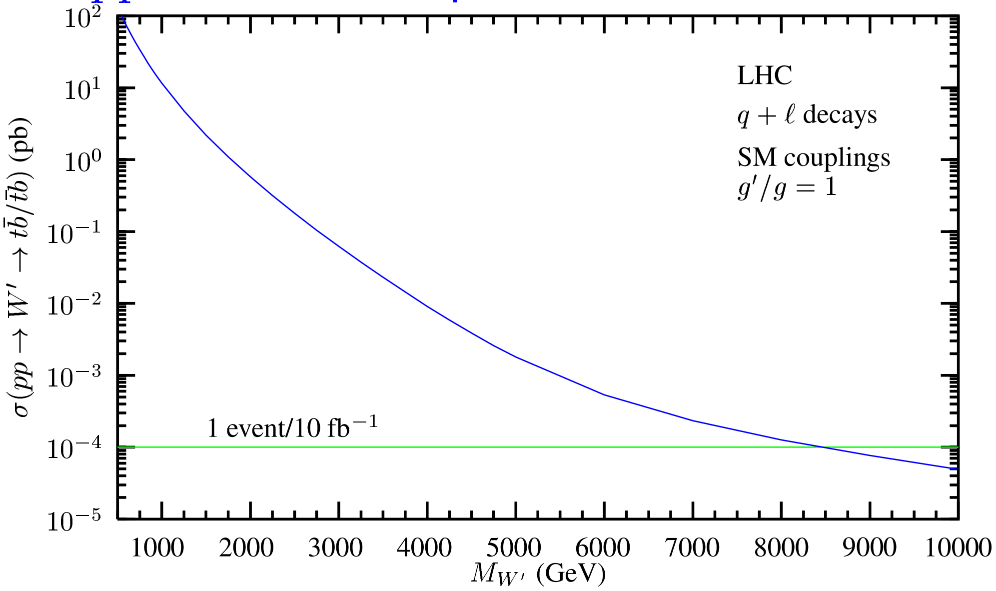
The mass reach should extend to 800–900 GeV in Run IIA.

If a W' is found we can use angular correlations of decay products to determine whether it looks like a W'_L, W'_R, or mixed state.

The search for W' at the LHC

Z.S., QCD Moriond 2003 [hep-ph/0306266].

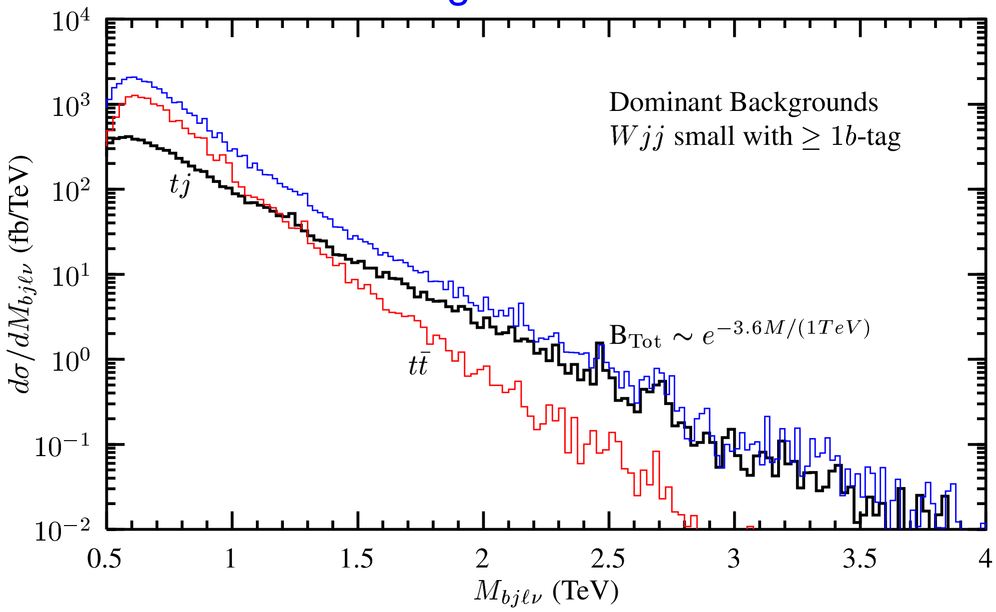
$pp \to W' \to t\bar{b}$ production at the LHC



About 50, 10 TeV W's are produced in 100 fb^{-1} of data.

Can we find them?

Dominant backgrounds at the LHC



Total Background includes: $t\bar{t}$, t-channel single-top, $Wjj, Wcj, Wb\bar{b}, Wc\bar{c}, WZ, Wt$, & s-channel single-top.

Simulation details

Method

Signal (S) and backgrounds (B) used PYTHIA, except for high-mass backgrounds which use a ME calculation fit to differential NLO.

Note: PYTHIA/HERWIG alone fail by 2 orders of magnitude simulating single-top and Wjj for our cuts. Generally difficult to generate high-mass backgrounds.

Used SHW detector simulation updated to match ATLAS.

Cuts

Demand at least 2 jets (w/ $\geq 1b$-tag), a lepton (e/μ), and $\not{E}_T$

$E_{Tj_1} > \max[200 \text{ GeV}, \min(10\% M_{W'}, 500 \text{ GeV})]$	$\lvert\eta_{j_1}\rvert < 2.5$
$E_{Tj_2} > \min(10\% M_{W'}, 150 \text{ GeV})$	$\lvert\eta_{j_2}\rvert < 2.5$
$E_{T\ell} > 30 \text{ GeV}$	$\lvert\eta_\ell\rvert < 2.5$
$\not{E}_T > 50 \text{ GeV}$	

k_T-jets $R=1$ (this is like a cone of 0.7)

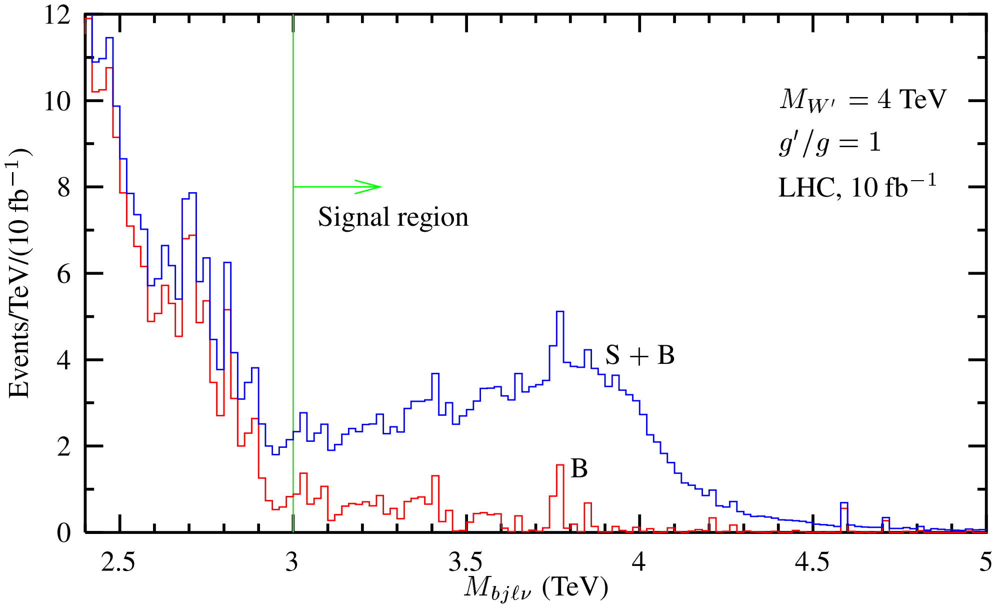
$100 \text{ GeV} < M_{j_2\ell\nu} < 450 \text{ GeV}$ (reduces Wjj, but can be ignored)

Finally reconstruct $M_{bj\ell\nu}$, and place cut just below target mass (up to 3 TeV).

Aside: Triggered on lepton, but a high-E_T jet trigger might have been better.

What does the signal look like?

Signal+Background vs. Background for $M_{W'} = 4$ TeV

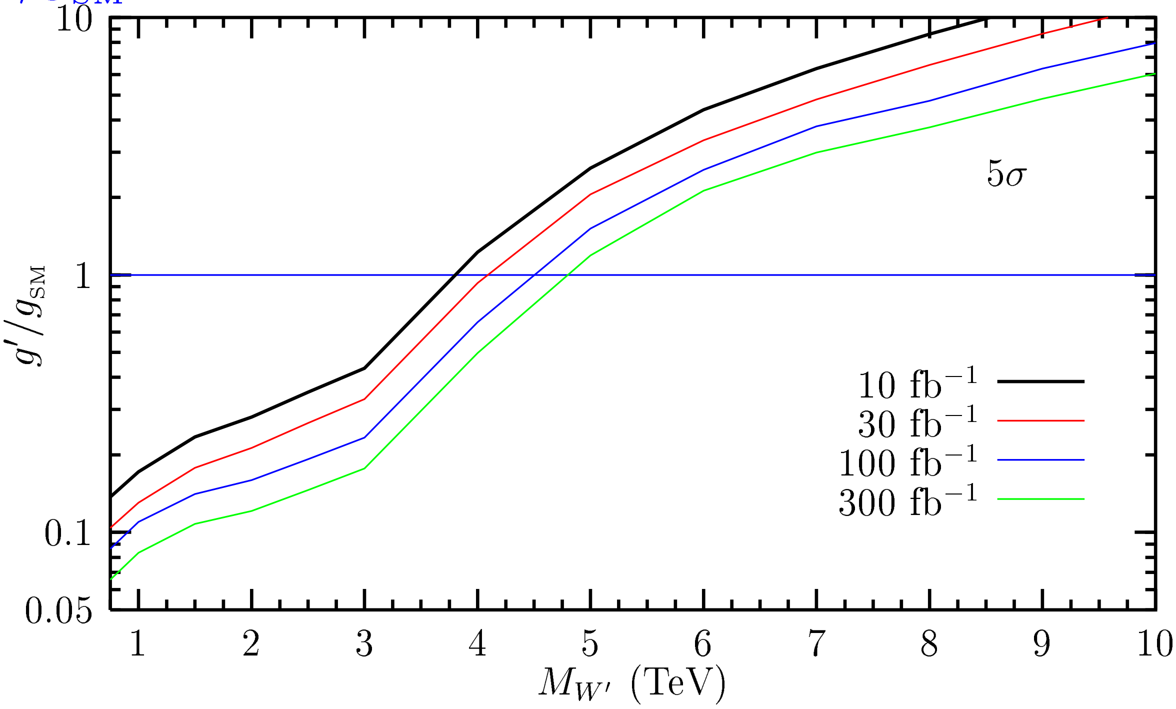


For a W' with SM-like couplings, we expect ~ 4 events per low-luminosity year over a background of less than 1 event.

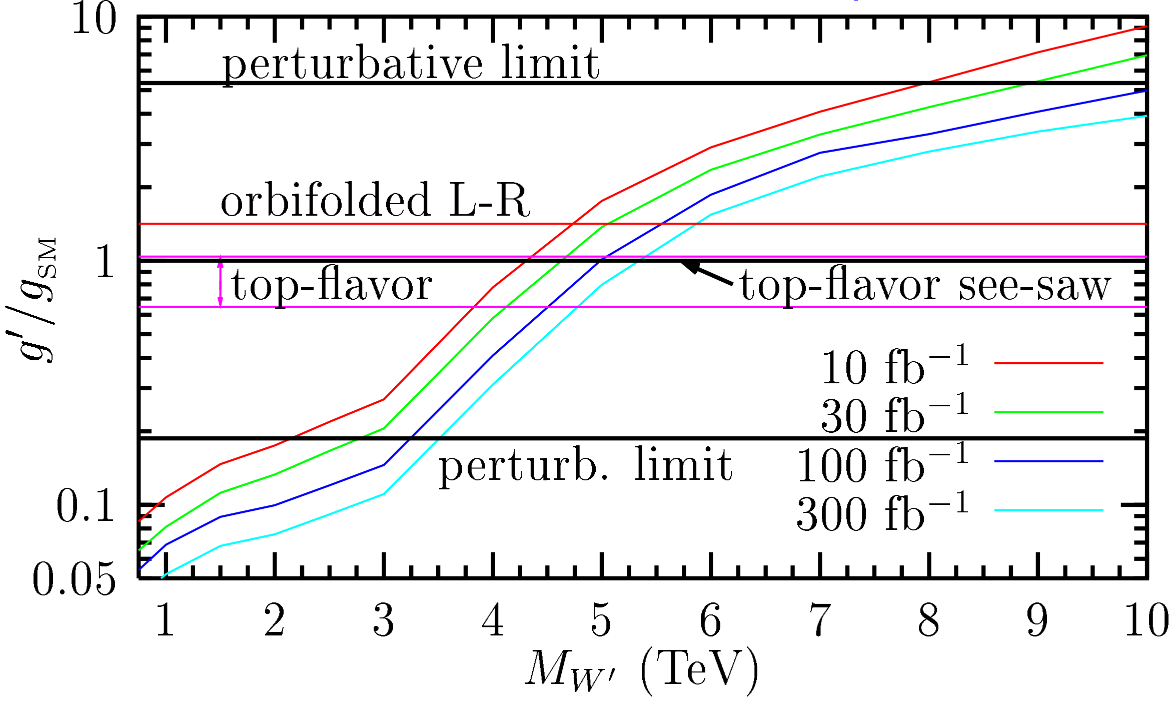
5σ discovery or 95% exclusion at the LHC

(using a Tevatron-like analysis)

W's can be discovered between 3.7–4.7 TeV for SM-like ($g'/g_{\rm SM} \sim 1$) couplings.

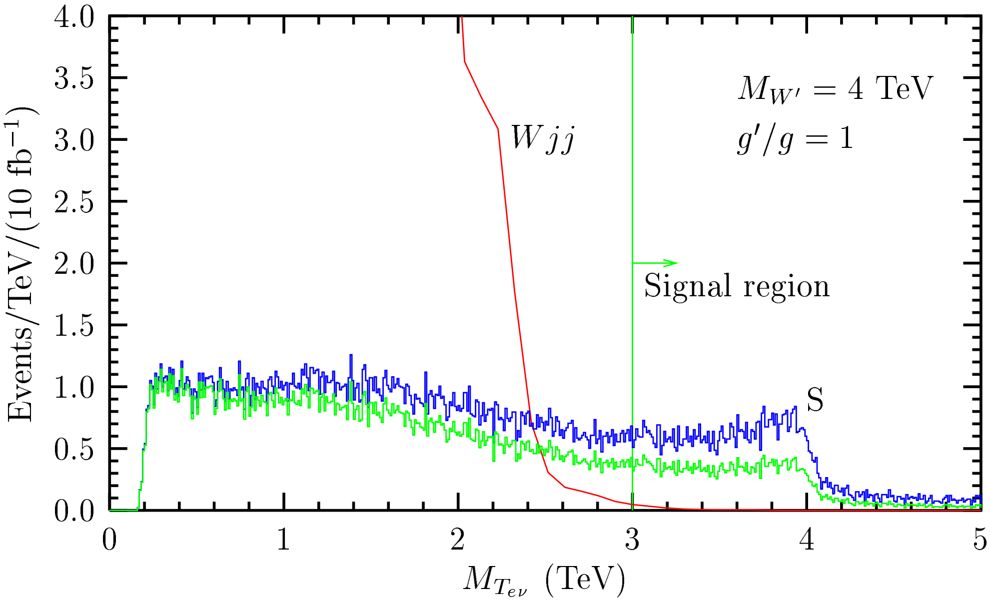


SM-like W's can be excluded at 95% C.L. up to 5.5 TeV!



What does $W' \to e\nu$ look like?

Signal vs. Wjj background for $M_{W'} = 4$ TeV



For a W' with SM-like couplings, we expect < 1 event per low-luminosity year.

This is less than $1/4$ the signal of the Wbj final state, and does not give a mass peak.

Only the Wjj background is shown. There are many other large backgrounds.

Can we improve on this?

Questions for W' physics and more

- A large fraction of non-supersymmetric models will be strongly constrained by the search for W' bosons in the single-top-quark channel. All models are now simple to compare. Z.S., PRD 66, 075011 (2002) [hep-ph/0207290].
  - Reach: Tevatron ~900 GeV, LHC ~750 GeV–5.5 TeV.
    Z.S., PRD 66, 075011 (2002); and hep-ph/0306266.
  - Factor of 2 improvements in the LHC cross section reach are attainable, but not fully studied. Are there other ideas?
  - Is there a better analysis for the Tevatron?
- The lepton final state will be very hard to observe at LHC. Can we get around this?
- More NLO calculations may be necessary to get kinematic distributions at the LHC. What backgrounds are missing?

The following applies to both W' and Z' measurements.

- What is the tagging rate for > 1 TeV b-jets?
  For the W' study, I assumed only the ~200 GeV b from the top decay could be tagged. What about the recoil b?
- What is the E resolution and tagging rate for > 1 TeV μ?
  This effects $W' \to \mu\nu$ and $Z' \to \mu^+\mu^-$. Do the muons bend enough? Do material interactions hide them?
- What is the E resolution and tagging rate for > 1 TeV e?
  They shower 100+ GeV photons. How well do you separate e–γ, or even e–jet? Using a jet-shape variable $\Rightarrow \epsilon_e$?

There will be a broadly defined “Z-prime” workshop on Nov. 16 at Northwestern. W' issues will be addressed there too.