qqH and qqZ

Dan Green

Fermilab

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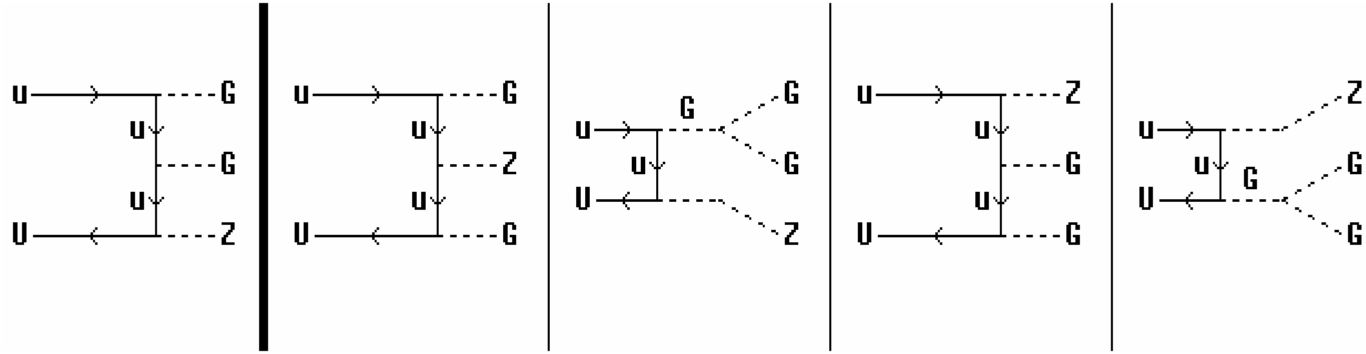
qqZ as VBF "Standard Candle"

- There are the same Feynman diagrams for VBF of both Z and H due to WWZ and WWH couplings.
- Using leptonic W decays, the H->W +W -> l+l+v+v signal appears in the dilepton + jets trigger stream as does the Z -> l + l decay.
- The Z decays will be seen prior to "finding the H". Therefore, use them to set cuts and to define the normalization.

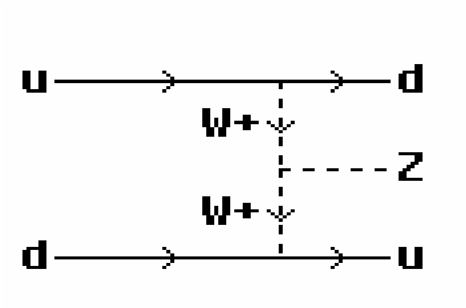
ggZ Feynman Diagrams

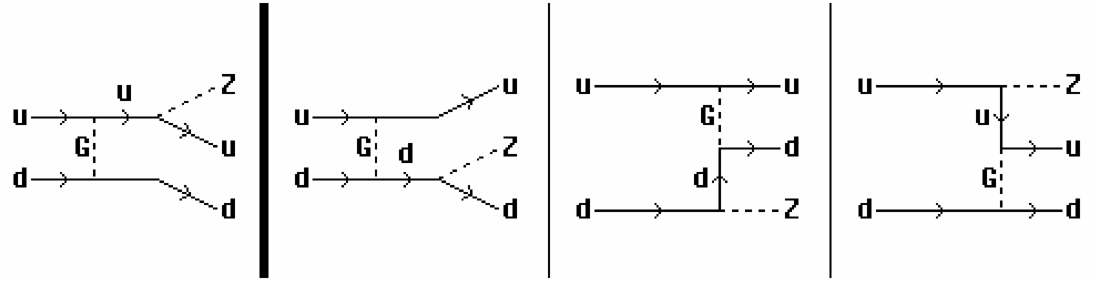


	COMPHEP	Ellis et al.
Z (D-Y)	39 nb	22
Z + g (D-Y+ISR)	17	7
Z + g + g (ISR,split)	3.6	2.8

Check NLO against simple DY LO in COMPHEP. Get "reasonable" agreement.

qqZ Feynman Diagrams

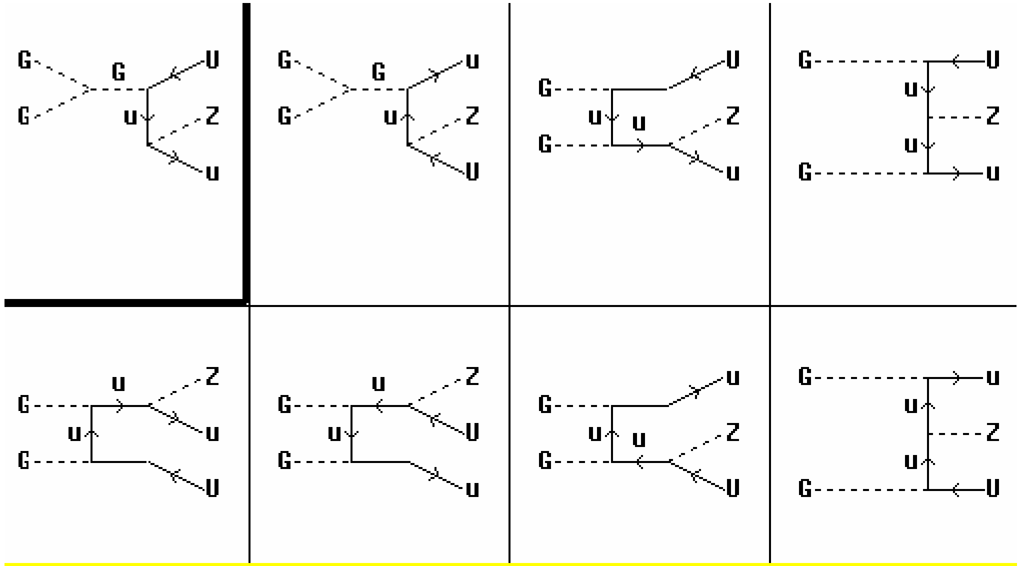




VBF production of qqZ arises from valence u and d emission of W’s. The cross section is ~ 13.4 pb. There is a QCD production of qqZ which is due to strong u + d scattering with Z ISR or FSR. The cross section is 340 pb, ~ 25 times larger than VBF production of Z. The ggZ cross section is 209 times larger.

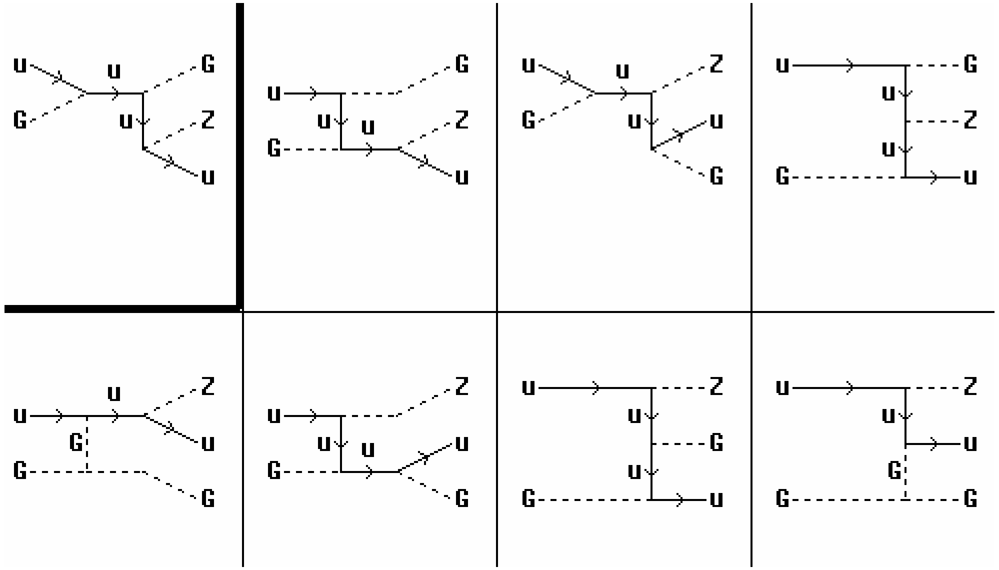
A light H has a cross section ~ 5 pb, BR to WW ~ 1/3. Therefore the dilepton cross section for H is ~ 75 fb. The dilepton Z cross section (e + u only) is 965 fb. Therefore, if we can isolate VBF production of Z we have a “calibration” which comes earlier than the H search.

(qqZ)gg Diagrams



The qqZ final state can also be created in a g + g interaction, with a substantial cross section. A priori it is difficult to say which process will be the biggest background when rejection factors of ~ 1000 are required.

(gqZ) Diagrams



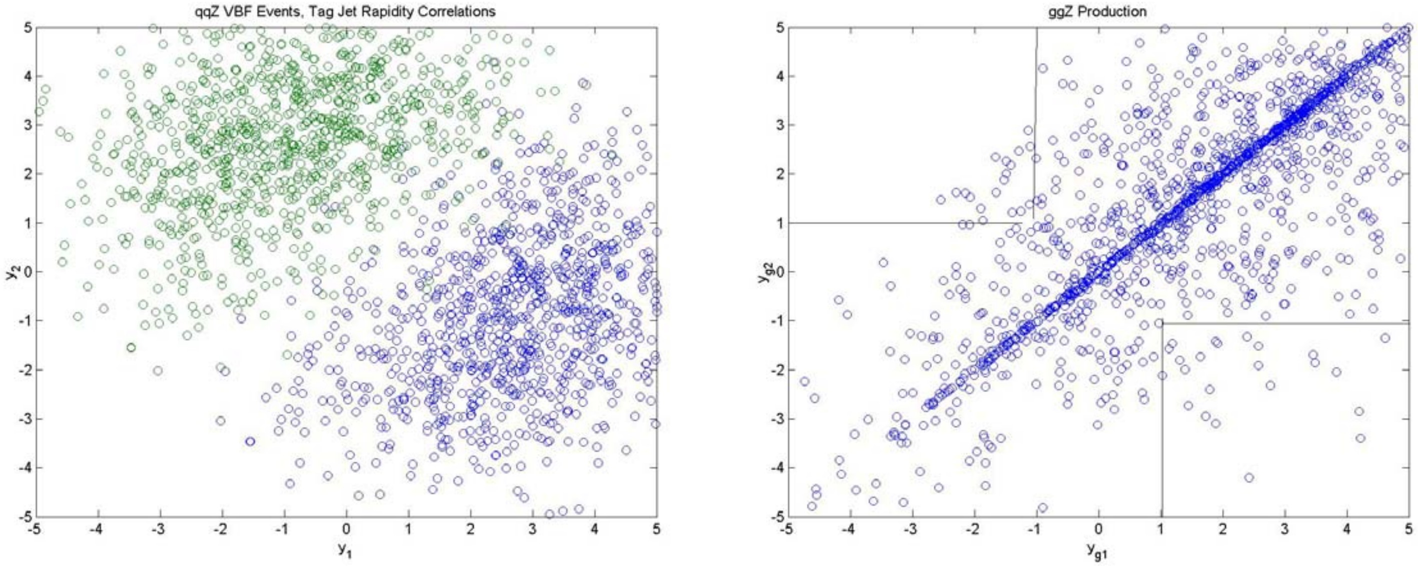
The largest uncut cross section comes from q + g production of Z + q + g. it is ~ 1400 times larger than the (qqZ) VBF cross section.

(qqZ) Cut Studies

Table 1
Cross Sections for VBF and
Background Processes in Zjj Production

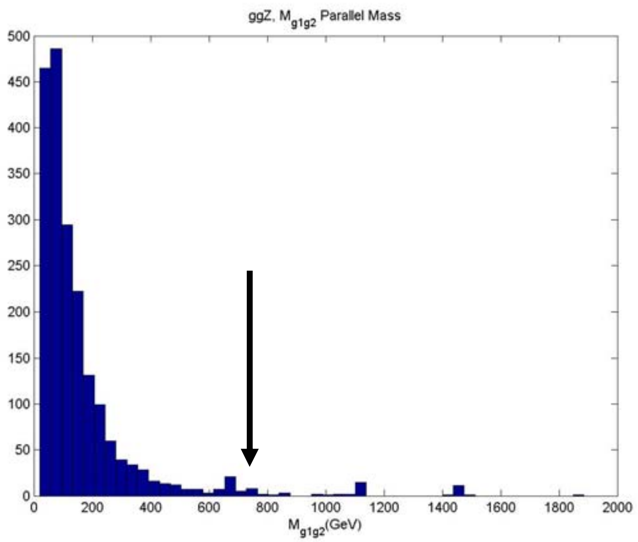
Cut	ggZ (pb)	$(gqZ)_{gq}$	$(qqZ)_{QCD}$	$(qqZ)_{gg}$	$(qqZ)_{VBF}$
none	3000	20,000	340	1700	13.4
y_1=(-5,-1) & y_2=(1,5)	101	860	150	190	10.2
M_{12} > 750 GeV	2.3	4.3	27.0	0.88	5.8
y_1-y_Z>1.5 & y_Z-y_2>1.5	0.45	2.8	1.85	0.41	2.9
P_{TZ} > 80	0.15	1.3	0.91	0.20	2.4
Other cuts? M_{1Z},M_{2Z} Harder on angular ordering?		606, 403	612, 544 GeV		668, 643 GeV

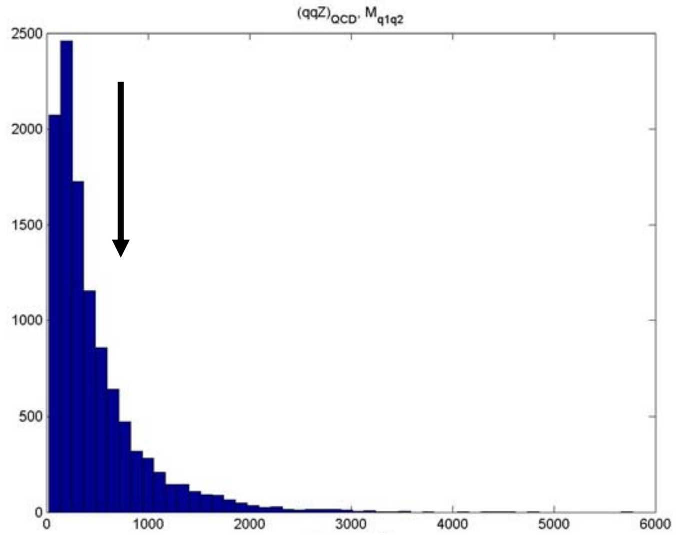
ggZ Removal – Tag Jet y



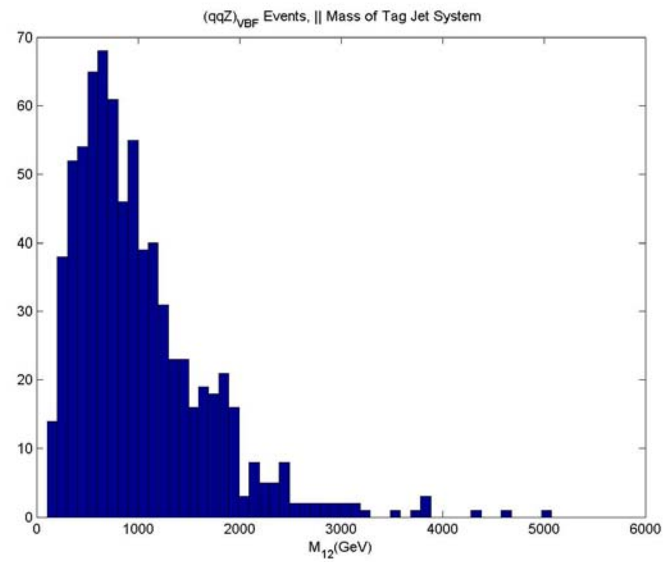
The VBF events have real tag jets. The ggZ events have 2 ISR gluons or a ISR gluon splitting acting as tag jets. Asking 1 in F hemisphere (-5,-1) and 1 in B is a strong cut (1, 5). Note the splitting y1 ~ y2 correlation.

ggZ Removal - II

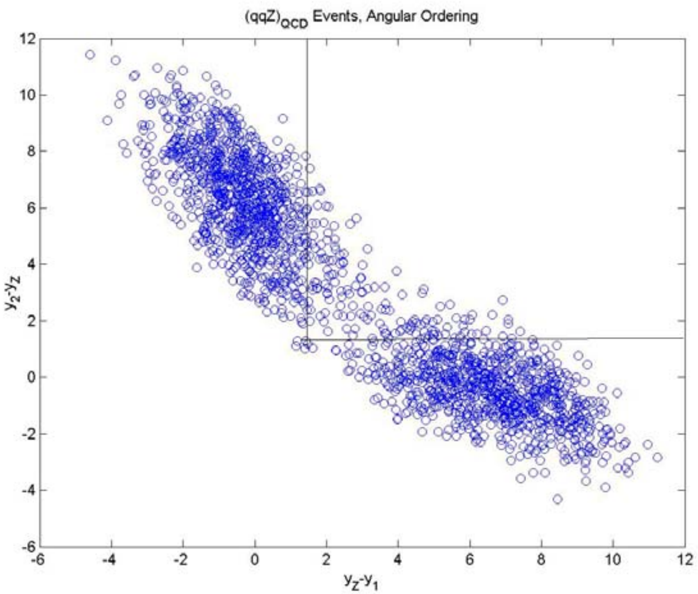


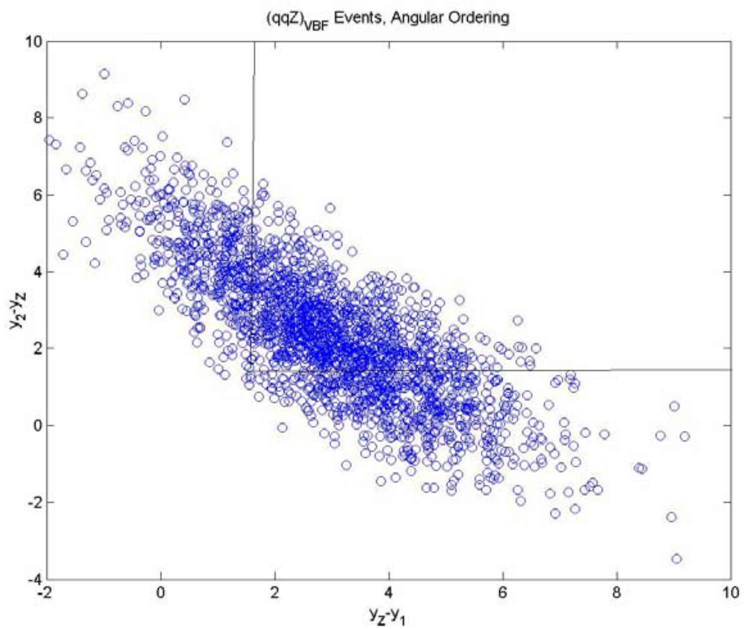


The mass of the tag jets is a strong cut for ggZ, gqZ and $(qqZ)_{QCD}$ backgrounds. Mean mass is 162 GeV for ggZ, 474 GeV for QCD and 1021 GeV for VBF.



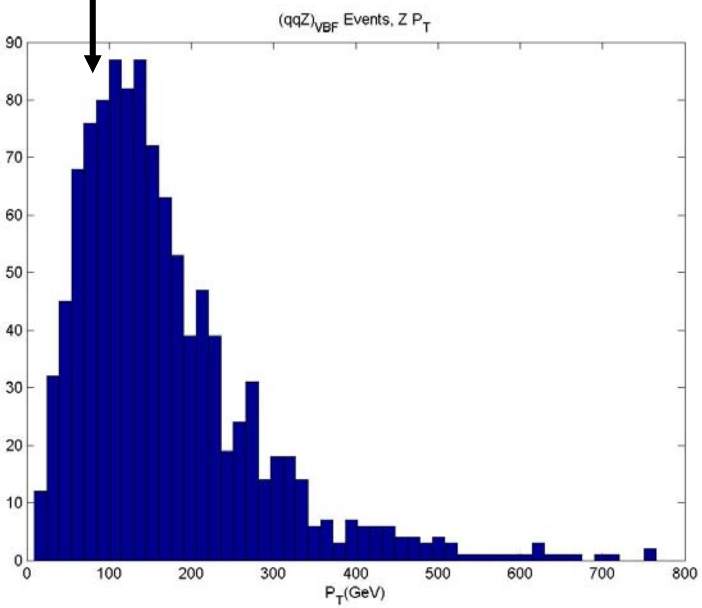
$(qqZ)_{QCD}$ Removal - I

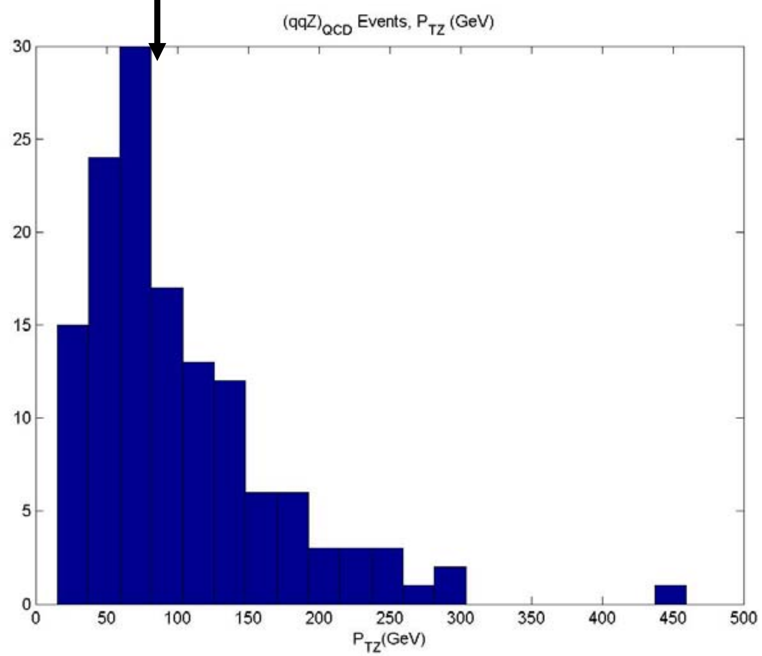




Largest remaining background is $(qqZ)_{QCD}$. The QCD events have Z radiated as ISR or FSR in u + d scattering with t channel g exchange. Requiring the Z to be "central" and well separated from the "tag" jets removes much of this background.

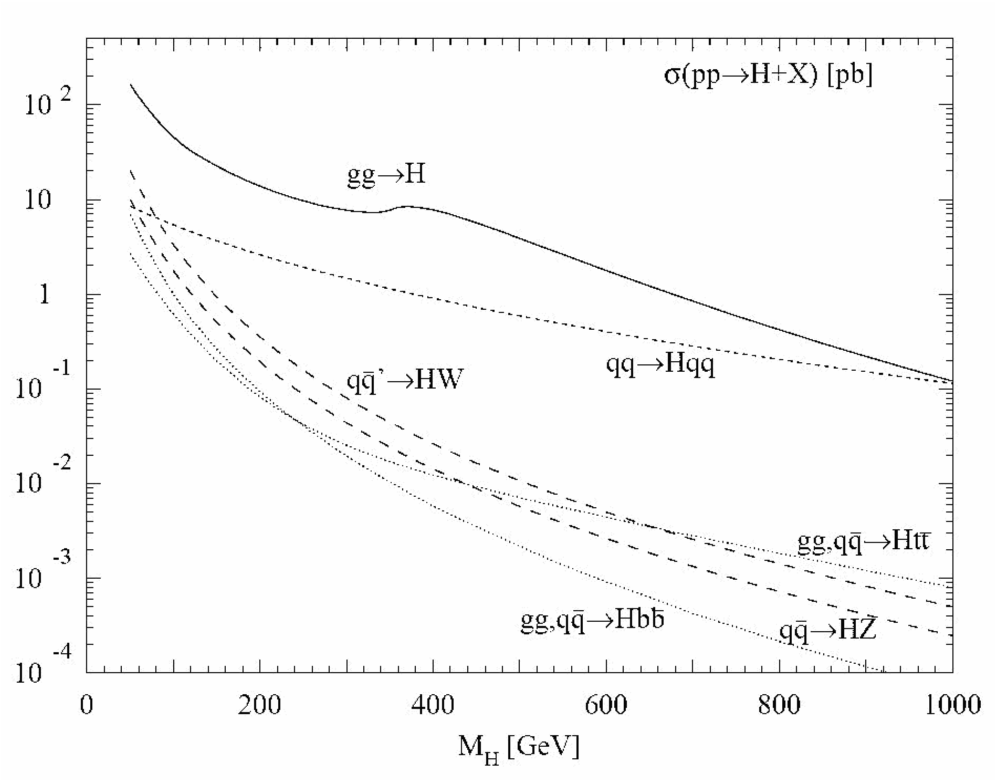
$(qqZ)_{QCD}$ Removal - II





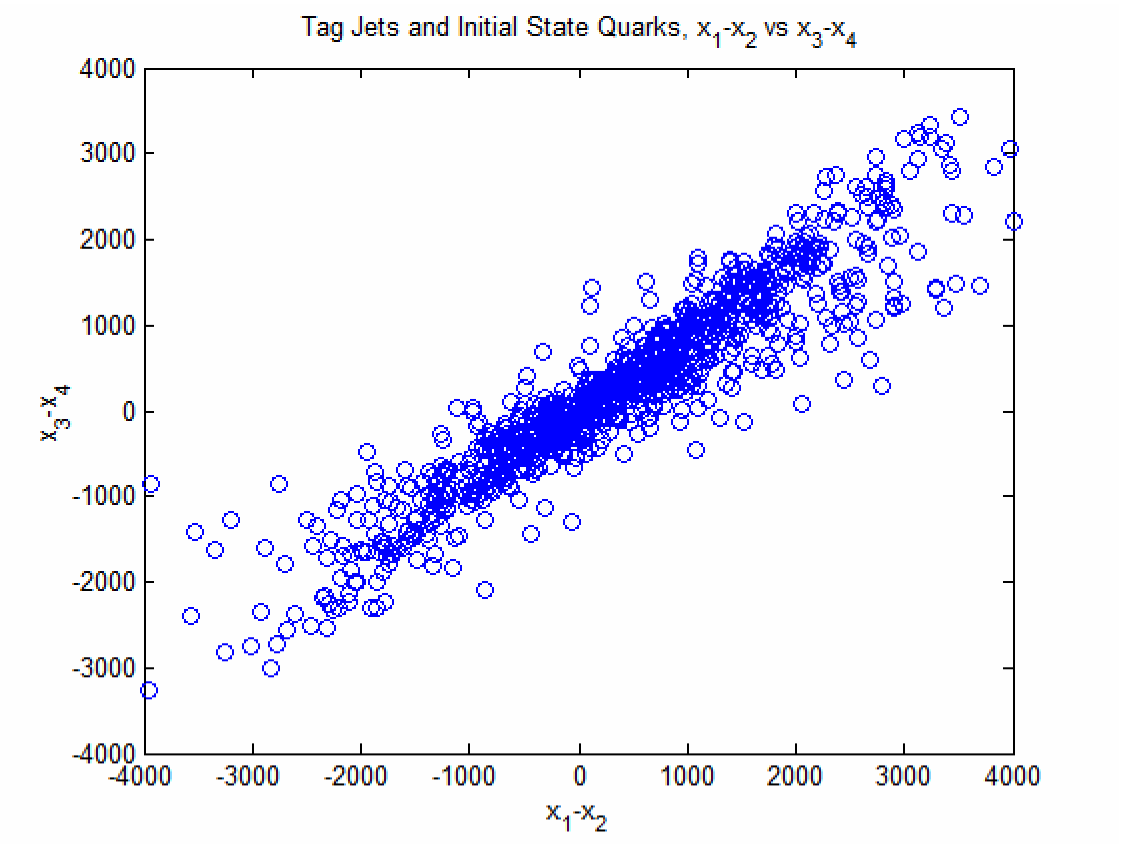
Radiated Z are low PT with respect to the VBF produced Z. <PTZ> = 102 GeV for QCD, 168 GeV for VBF. After this cut, VBF has a cross section ~ the sum of all backgrounds, or a S/B of ~ 1. There are additional cuts available, such as the mass of the tag jet and the Z.

(qqH) Production



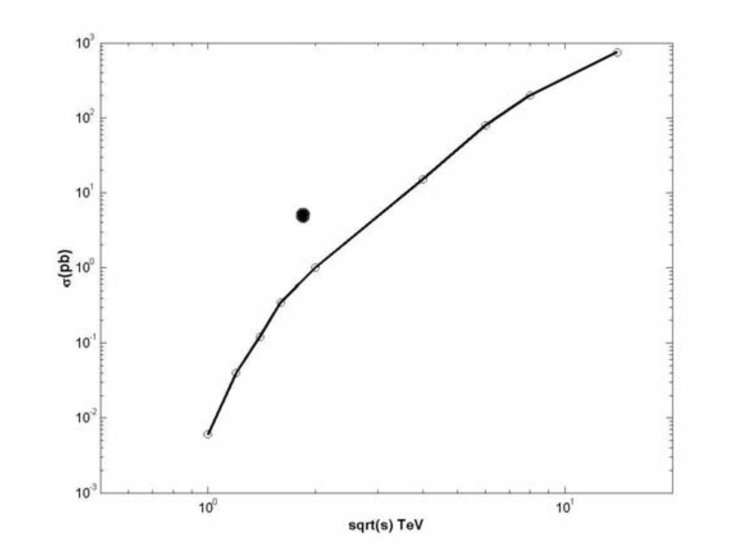
(qqH) is always > 1/10 of the gluon fusion cross section. In addition the tag jet remnants allow for a large reduction of the backgrounds. The H ->WW final state gives a cross section isolating the HWW coupling.

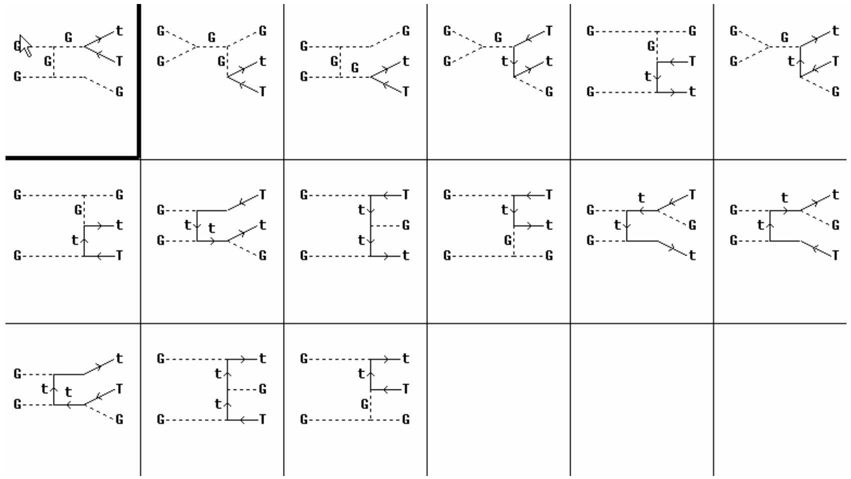
Tag Jets and Initial State



The tag jets indicate the initial state C.M. motion because the radiated W are fairly low x.

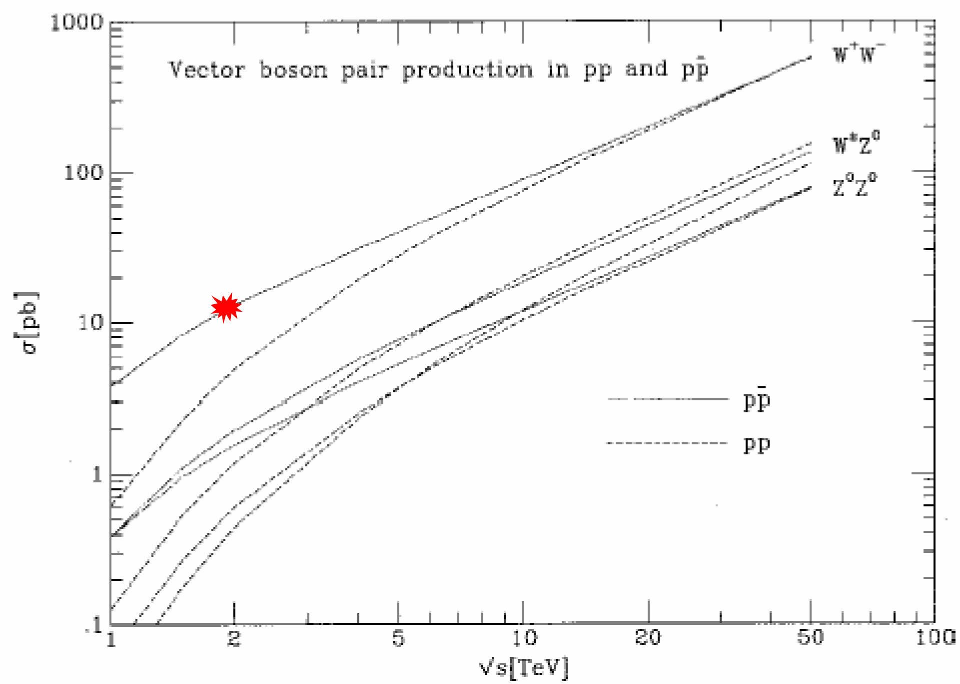
jtt Background





Background due totop pair production and decay into WWjj. Top cross section well measured at the Tevatron. Extrapolate to LHC energy. Another possible background is WWj, adding a radiated gluon – ISR or FSR which better mimics a tag jet than the b from top decay..

WW Cross Section Measured at CDF

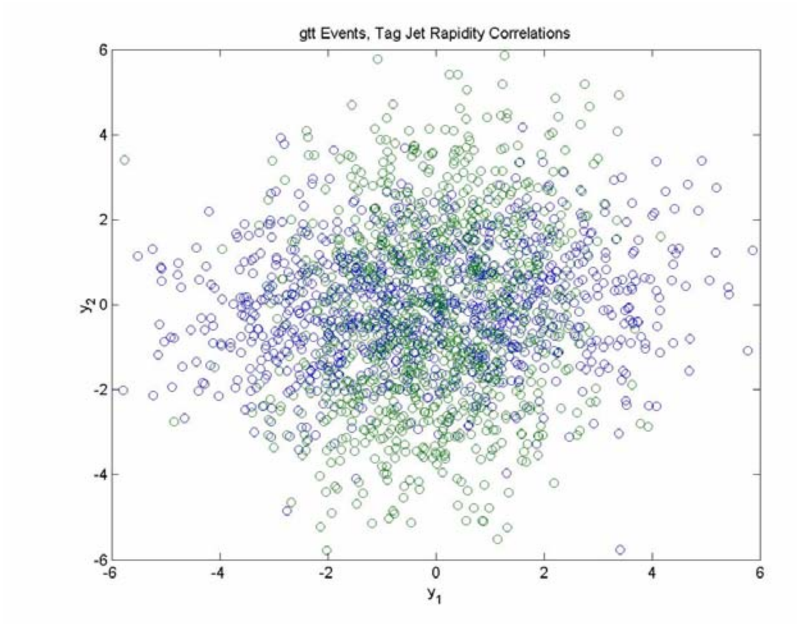


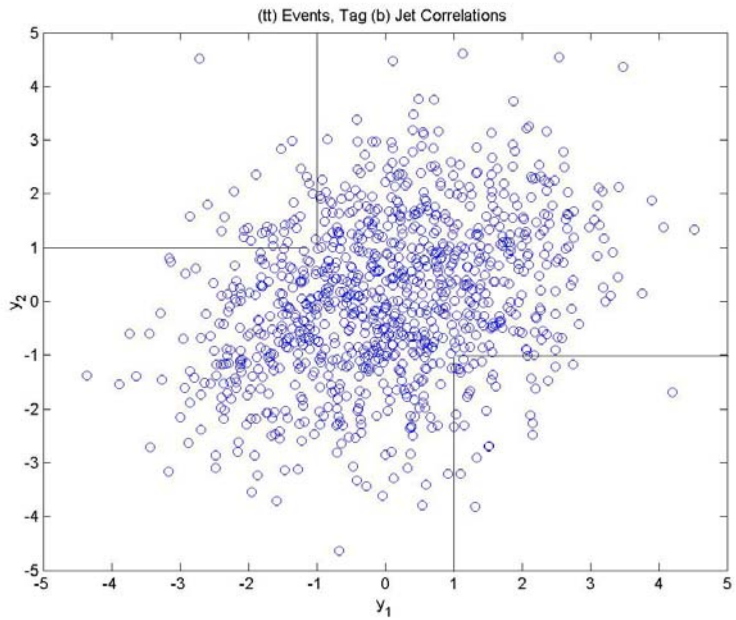
Extrapolate to LHC energy and add 2 radiated gluons to simulate WWjj background. COMPHEP gives D-Y cross section of 72 pb, WWg of 64 pb and WWgg of 40 pb. Approximate agreement with full WW calculation.

COMPHEP Cut Study

Cut	tt	gtt	qqH
none	1320 pb	3700 pb	3 pb
y_1=(5,1)& y_2=(1,5)	87 $\langle M_{12} \rangle$ = 315 GeV	480 $\langle M_{12} \rangle$ = 306 GeV	2.4 $\langle M_{12} \rangle$ =1181 GeV
M_{12} > 750 GeV	2.0	27 $\langle P_{Tb2} \rangle$ = 100 GeV	1.7
Jet Veto, 20 GeV	2.0 <Ml1>=107 GeV <Ml2>=99 GeV	0.75 <Ml1>=113 GeV <Ml2>=365 GeV	1.7 <Ml1>=277 GeV <Ml2>=278 GeV
Both l-tag masses > 150 GeV	~ 0.0	~ 0.0	1.5
$\langle M_H - P_{TH} \rangle$	660 GeV	370 GeV	181 GeV

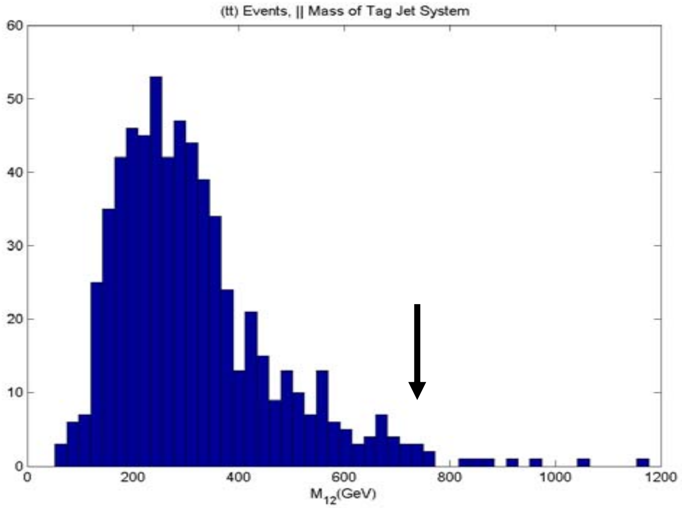
Tag Jet Cuts, (tt), (ttg)

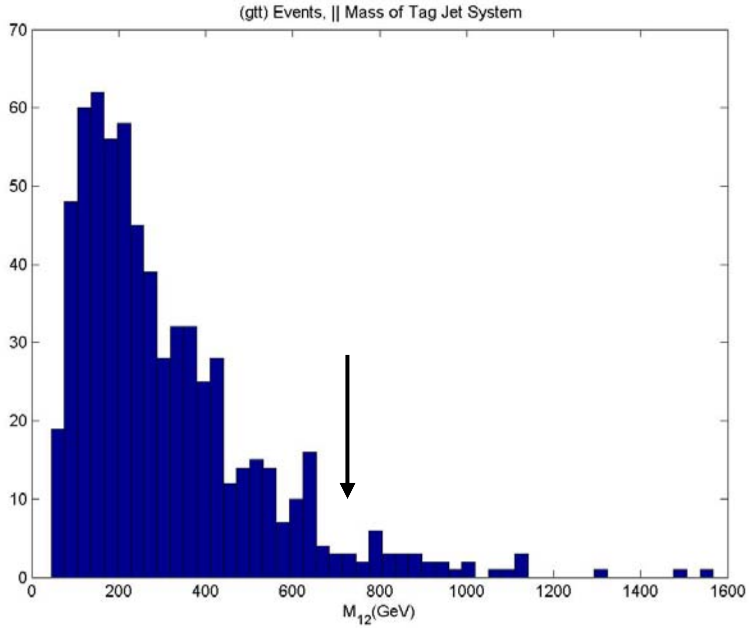




Same cuts as in (qqZ) study. The gtt events are most efficient to pass the cut.

Tag Jet Mass Cut, (tt), (gtt)

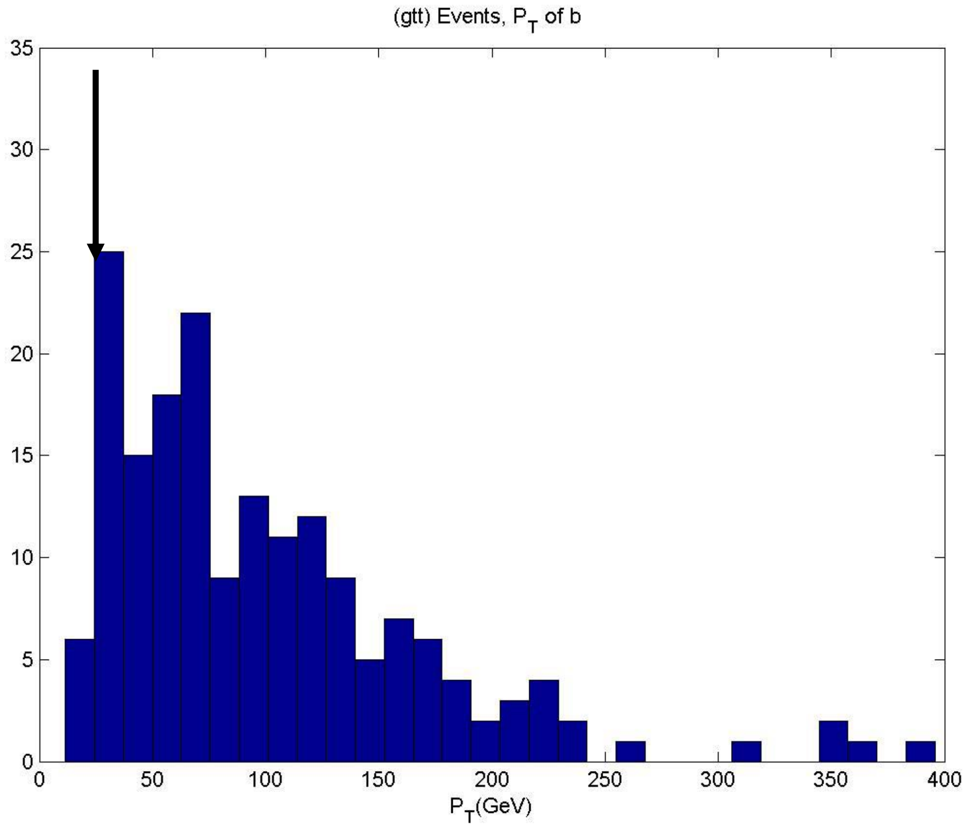




$$M_{tag}^2 = (|\vec{P}_{tag1}| + |\vec{P}_{tag2}|)^2 - (\vec{P}_{tag1} + \vec{P}_{tag2})_{\|}^2$$

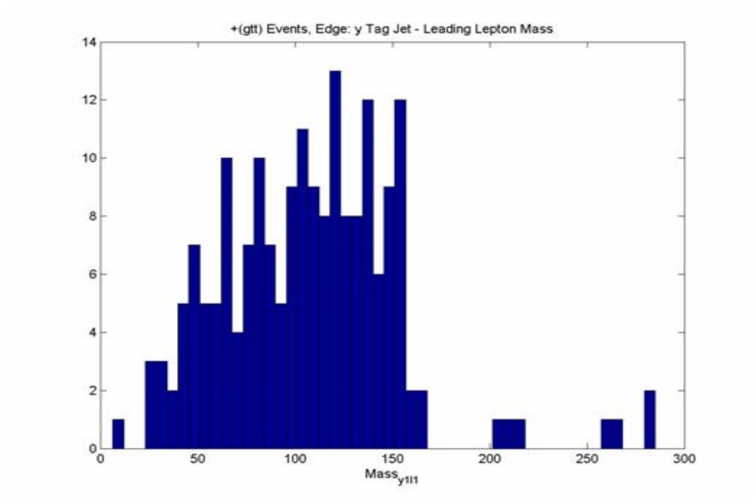
Cut on tag jet "parallel mass". Cut is at the same point as imposed for (qqZ). At this level the signal cross section is ~ that for tt, but the gtt is still > 10x larger than the signal.

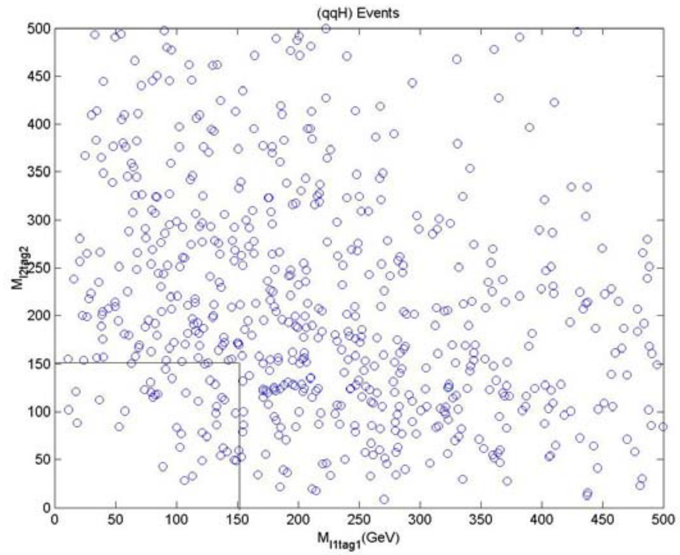
(gtt) Events – Jet Veto



Extra jet – g is assumed to be 1 tag jet, and one b is the other tag jet. Extra b jet is available for veto imposition. Assume 20 GeV jet can be well resolved from "fake" jets due to pileup.

Lepton-Tag Jet Mass





The angular ordering of the tag jets and the lepton pair and the cut on transverse momentum of the lepton pair do not greatly improve the signal/background. Presumably the lepton pair is not that well connected to the H. Therefore to reduce the backgrounds and make S/B > 1, rely on the mass of the tag jet and lepton nearest in angle. There is a kinematic edge from t -> W + b -> l + v for both (tt) – 2 edges - and (gtt) – 1 edge - backgrounds.

Higgs Momentum

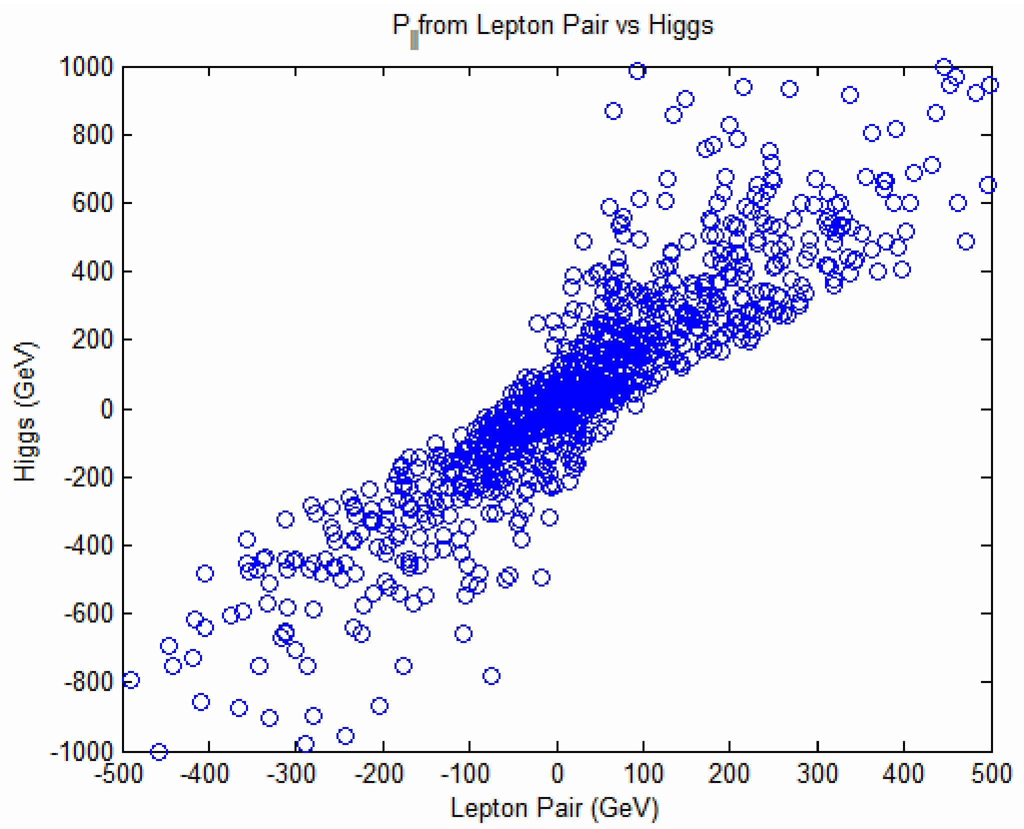


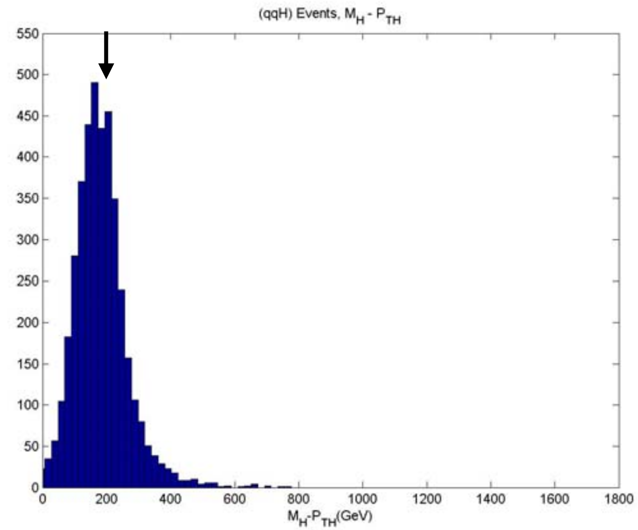
Figure 6: Correlation in the qqH process of the longitudinal momentum of the lepton pair and the Higgs. Decays H -> W + W -> l + v + l + v are modeled assuming isotropy.

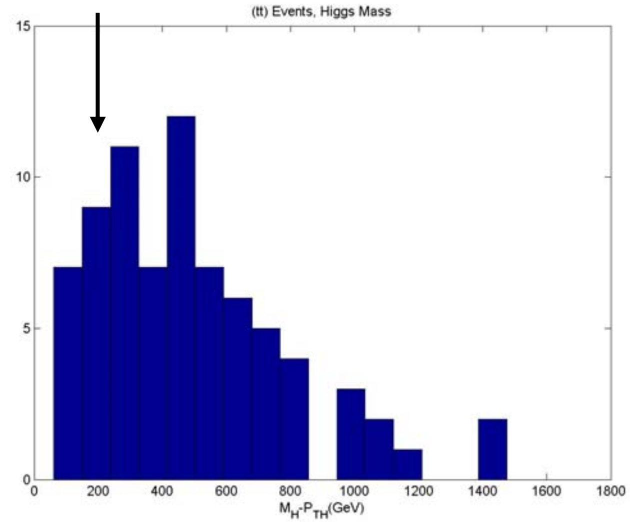
Higgs "Mass"

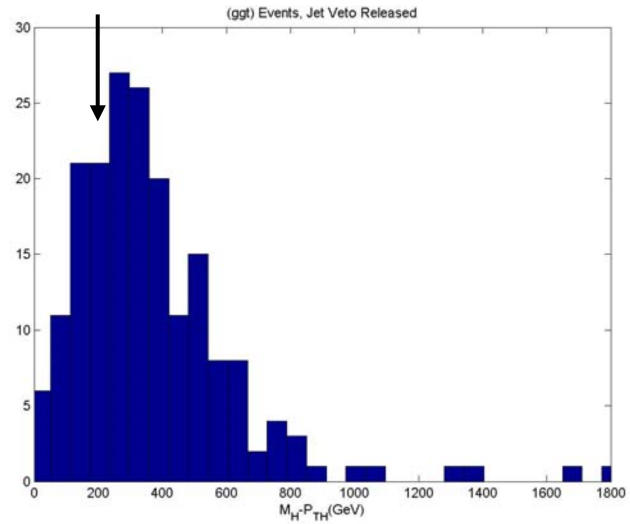
$$E_H = 2(E_{\ell 1} + E_{\ell 2}) + \not{E}_T$$
$$(\vec{P}_H)_T = -(\vec{P}_{tag1} + \vec{P}_{tag2})_T$$
$$(\vec{P}_H)_{\parallel} = 2(\vec{P}_{\ell 1} + \vec{P}_{\ell 2})_{\parallel}$$
$$M_H^2 = E_H^2 - |\vec{P}_H|_T^2 - |\vec{P}_H|_{\parallel}^2$$
$$M_H - (\vec{P}_H)_T$$

Tag jets determine the H transverse momentum (zero initial state). Leptons approximately give the H longitudinal momentum. Define a variable which scales with H mass and which is ~ always positive.

Higgs Mass, (qqH) and (tt), (gtt)







Masses for (tt) and (gtt) are with lepton-tag mass cuts released. Shape differs and this need not be a "counting experiment" as there is a resonant bump. Higgs of 180 GeV assumed here.

WWjj Backgrounds

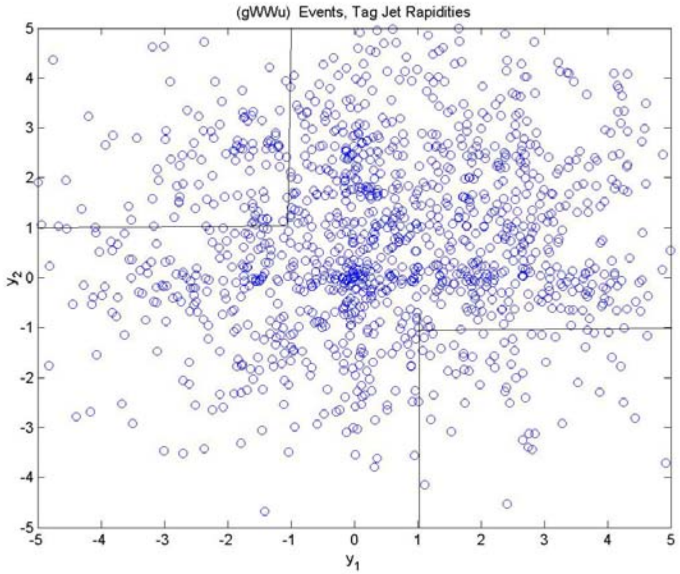
WWgg cross section in D-Y is 40 pb but < 0.04 pb with tag jet y cuts

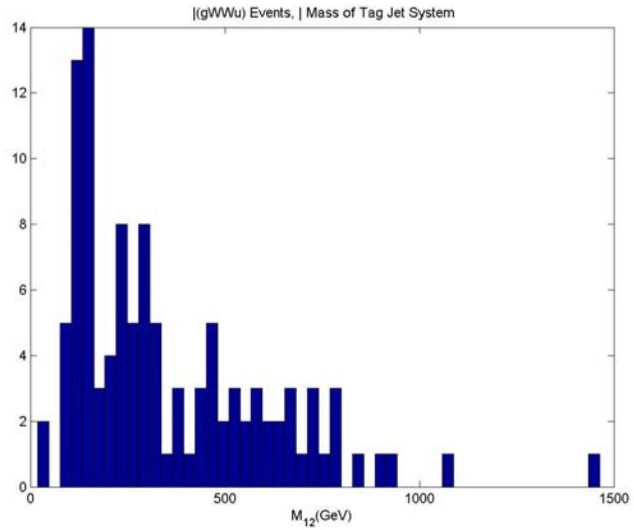
WWgq production is 120 pb which reduces to 01.8 pb with the tag jet y cuts

WWqq cross section is only 2.0 pb and can be ignored.

All cross sections after tag jet y cuts are far below the tt and gtt backgrounds.

gWWq Background





For example in gWWq production the cross section is ~ 120 pb. The tag jet rapidity cuts reduce this to ~ 2 pb and the tag jet mass cut (mean 357 GeV) reduces it again down to 0.4 pb.

Conclusions

- The (qqZ) process allows LHC experiments to define a VBF “standard candle”. However, there are serious backgrounds that must be overcome.

- The (qqH) process also has large backgrounds. Several of the cuts used to reduce them are the same as used in (qqZ) extraction. The other cuts (jet veto, lepton-tag mass) arise from specific backgrounds (tt, gtt) that must be reduced.