Standard Model process contributions to

$VV \to \tau\tau + X$

at the LHC

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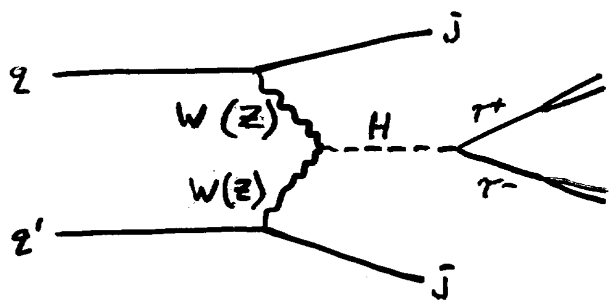
- first analysis
- components: SM H
  "2" Z poles
  W + jets
  $b\bar{b}$ + jets
- EW v. QCD characteristics
- reconstructed $M_{\tau\tau}$ spectra
- challenges and some final thoughts

$qq \, VV \to qqH \to \tau^+\tau^- jj$

- parton-level Monte Carlo simulation at tree level
- includes τ helicity correlations for proper decays
- $\tau^\pm \to h^\pm \not{p}$, $\tau^\mp \to \ell^\mp \not{p}$ mode only (easiest)
- only 2 Feynman graphs to consider:



with H decay simply a branching fraction

- factorization scale for CTEQ4L

$$\mu_f = \min(p_{T_j})$$

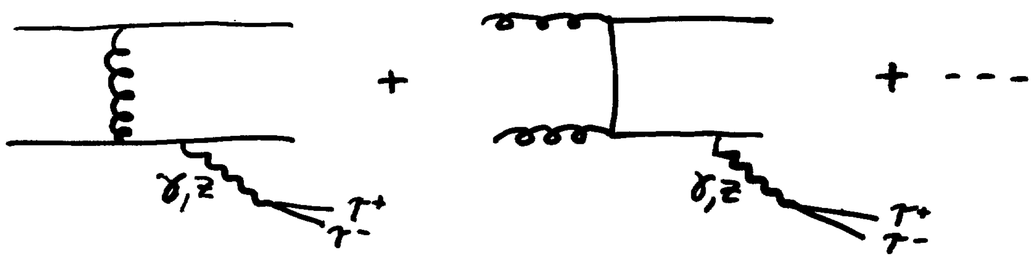
$$\rightarrow \mu_f = 2\times\mu_f \text{ or } \tfrac{1}{2}\times\mu_f \Rightarrow \pm 10\% \text{ variation}$$

- $\epsilon_\tau(\tau \to h\nu_\tau) = 0.26$ (ATLAS)

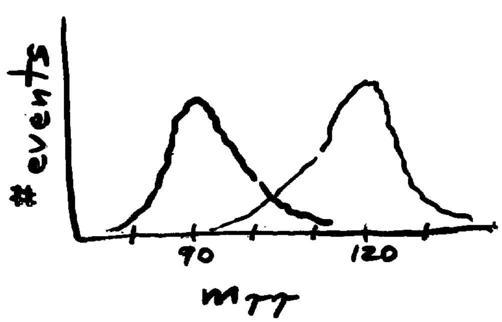
QCD "Zjj" irreducible background

→ real emission corrections to Drell-Yan

- including γ, Z interference effects
- dominated by t-channel gluon exchange



- factorization scale $\mu_f = \min(p_{T_j})$ (factor 1.5 uncerty)
- $\alpha_s^n = \prod_{i=1}^{n} \alpha_s(p_{T_i})$ (all partons)



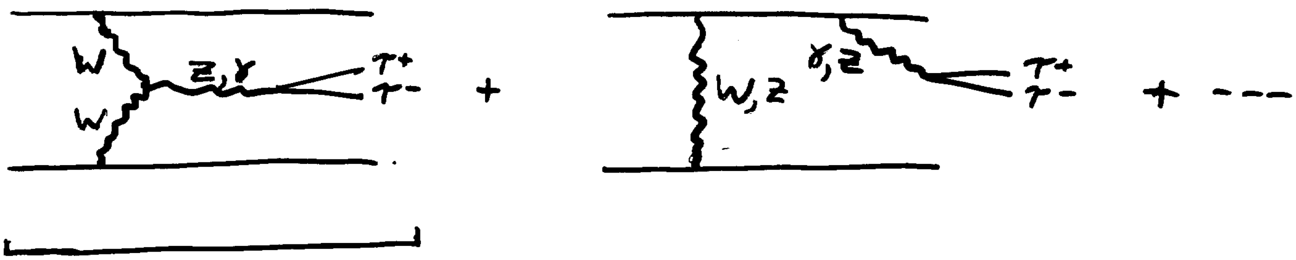
significant overlap for $m_H \lesssim 120$ GeV

- τ polarization done explicitly by helicity amplitudes

EW "Zjj" irreducible background

→ t-channel EW boson exchange (NC + CC)

→ momentum and color structure identical to signal for $VV \to \tau^+\tau^-$ ⇒ can't ignore!!



this survives

- factorization scale same as signal uncertainty $\lesssim 15\%$

- τ polarization approximated

Reducible (QCD) backgrounds

→ anything that can mimic the signal profile of

1. hard, isolated lepton
2. $\not{p}_T$
3. hard, narrow jet

→ $Wj + jj$, $W \to \mu, e$ and j fakes hadronic τ

→ $b\bar{b} + jj$, $b \to \mu, e$ and b or j fakes τ

$$\text{misident} \left\{ \begin{array}{l} \epsilon_\tau(b \to h + \nu) < 0.0015 \\ \epsilon_\tau(q,g \to h + \not{p}) = \frac{1}{400} \end{array} \right\} \text{(ATLAS)}$$

① $Wj + jj$

has suppression $\frac{1}{400}$

random assignment of partons to be fake τ

scales μ_f, μ_r follow QCD Zjj bkg

② $b\bar{b}+jj$ lots of $b\bar{b}$ @ LHC!

$gg \to b\bar{b}gg$
$gq \to b\bar{b}gq$
$qq' \to b\bar{b}qq'$

b mass included for exact $\mathcal{O}(\alpha_s^4)$ matrix elements, including all crossings

- $\mu_R = \min(p_{T_{partons}})$ <u>before</u> b decay

$$\alpha_s^n = \prod_{i=1}^{n} \alpha_s(p_{T_i}) \quad \text{again}$$

1. $b \to \ell \nu c$ ($B = .395$) via 3-body phase space
   ↓ needed for ℓ isolation cuts ↙

   $E_T < 5$ GeV for $\Delta R < 0.6$

   - no parton shower included, so we adjust by overall factor to match ATLAS result (factor of 100 reduction from ℓ isolation cut)

2. misident as τ via either narrow q/g jet or other b
   probab. $\frac{1}{400}$ prob. .0015

Detector resolution

- p_{T_j} distributions steeply falling for bkgds!
- especially important for $b\bar{b}jj$ (p_{T_c})

1. hadronic $\dfrac{\Delta E}{E} = \dfrac{5.2}{E} \oplus \dfrac{0.16}{\sqrt{E}} \oplus .009$ (ATLAS)

2. charged leptons $\dfrac{\Delta E}{E} = 2\%$

3. $\not{p}_T$ $\sigma(\not{p}_x, \not{p}_y) = 0.46\sqrt{\sum E_{T_{had}}}$ (each component)

   $\downarrow$

   added linearly to $\sum \vec{p}_\nu$

Basic cuts

1. see stuff

   $p_{T_j} > 40, 20$ GeV $\qquad |\eta_j| < 5.0$

   $|\eta_\tau| < 2.5$

   $\Delta R_{jj, j\tau, \tau\tau} > 0.7$

2. central τ pair + jets in opp. hemispheres

   $\eta_{j,min} + .7 < \eta_{\tau_{1,2}} < \eta_{j,max} - .7$

   $\eta_{j_1} \cdot \eta_{j_2} < 0$

3. forward tagging

   $\Delta\eta_{tags} \geq 4.4$

$B\sigma$ (fb):	Hjj	QCD Zjj	EW Zjj
1.	132		
2.	77		
3.	58	1670	90

↳ ~$\frac{1}{4}$ of inclusive

$H \to \tau^+\tau^-$: reconstruction

$\tau \to \ell + \not{p}$ 35%

$\tau \to (\pi, \rho, a_1) + \not{p}$ 65%

IF one assumes

- collinear decay products (satisfied by $p_{T\ell}, p_{Th}$)
- $\tau^+\tau^-$ not back-to-back (satisfied by large $p_{T H,V,b\bar{b}}$)

THEN can solve system of 2 eq^s, 2 unknowns

2 unknowns: E_{τ^+}, E_{τ^-} (or z_+, z_-)

2 measurements: $\not{p}_{Tx}, \not{p}_{Ty}$

solve $\vec{\not{p}} = E_{\nu_1} \cdot \vec{u}_1 + E_{\nu_2} \cdot \vec{u}_2$

$$m_{\tau\tau} = 2\,(E_1 + E_{\nu_1})(E_2 + E_{\nu_2})(1 - \cos\theta)$$

1. decay probability to (π, ρ, a_1) known as a fn of z
   chirality correlations! [Hagiwara, Martin, Zeppenfeld]
2. z generated randomly

Advanced cuts

1. τ ID

   branching ratios, efficiencies, counting

   plus $p_{T_\ell} > 20$ GeV and $p_{T_h} > 40$ GeV

2. mass bin → ± 10 GeV (plus physicality cuts $\cos\theta_{\tau\tau} > -0.9$, $x_\tau > 0$)

3. m_{jj} and $m_T(\ell, \not{p}_T)$

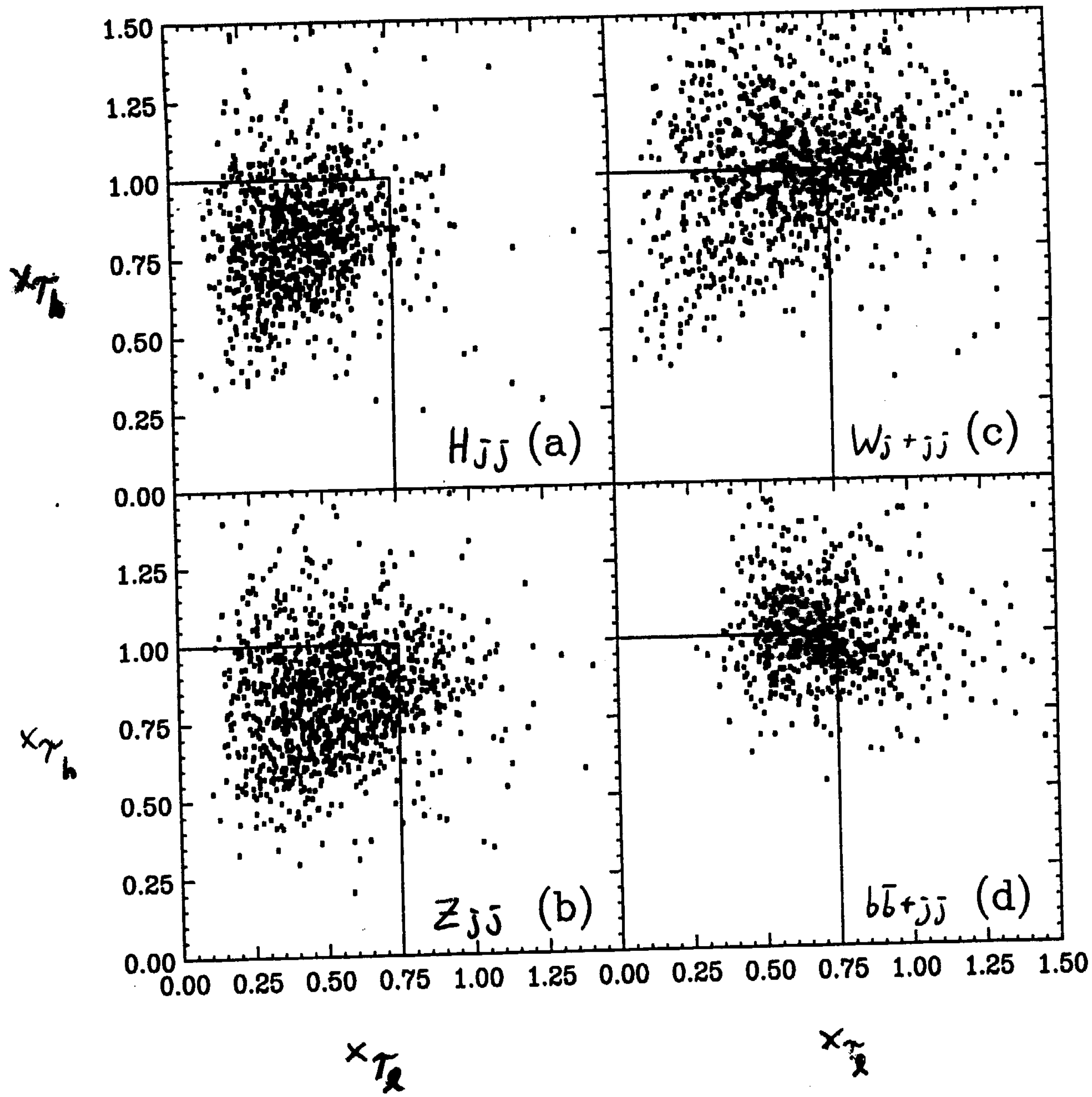
   $m_{jj} > 1$ TeV

   $m_T(\ell, \not{p}_T) < 30$ GeV (W Jacobian peak)

4. x_τ

   $x_{\tau_\ell} < 0.75$

   $x_{\tau_h} < 1.0$



Hjj (a)
Wj + jj (c)
Zjj (b)
bb̄ + jj (d)
x τh
x τℓ

TABLE I. Signal and background cross sections $B\sigma$ (fb) for $m_H = 120$ GeVHjj events in pp collisions at $\sqrt{s} = 14$ TeV.

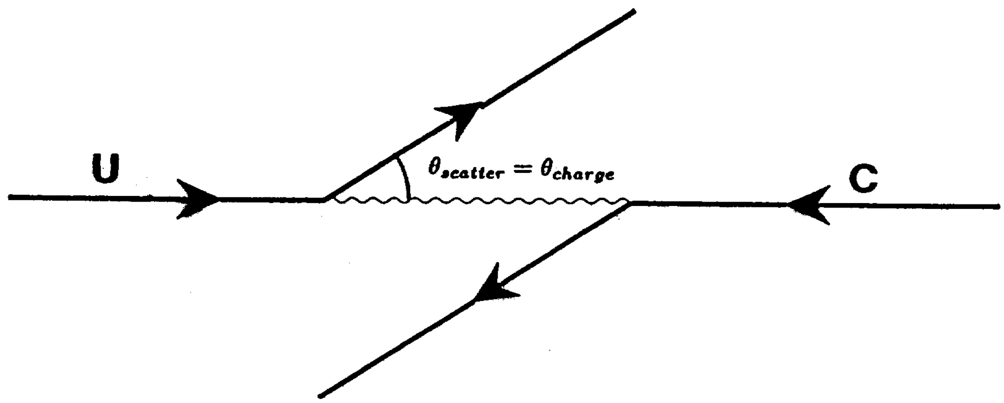
	Hjj	QCD Zjj	EW Zjj	$Wj + jj$	$b\bar{b} + jj$	S/B
forward tagging	57.6	1670	90			
+ τ identification	1.79	20.0	1.44	26.4	7.6	1/30
+ $110 < m_{\tau\tau} < 130$GeV	1.18	0.95	0.07	1.77	0.6	1/3
+ $m_{jj} > 1$ TeV, $m_T(\ell, \not{p}_T) < 30$ GeV	0.62	0.17	0.04	0.11	0.15	1.3/1
+ $x_{\tau_l} < 0.75$, $x_{\tau_h} < 1.0$	0.49	0.14	0.03	0.02	0.05	2/1

I.

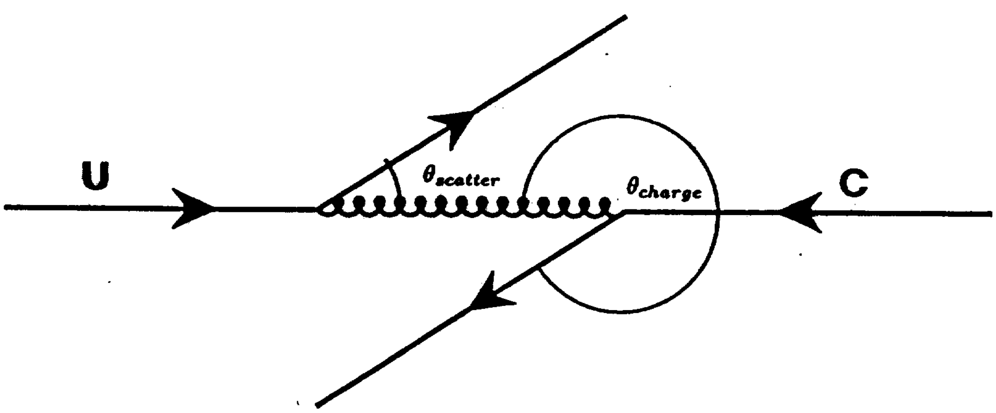
How to separate signal and background

Bjorken: exploit color structure

EW signal is color singlet exchange



QCD bkgd is color octet exchange

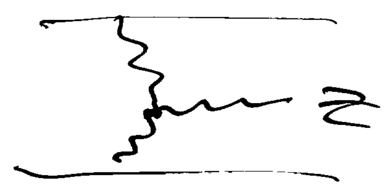


(Stelzer & Fletcher, 1993)

Gluon Radiation ($pp \to ZjjjX$) Patterns

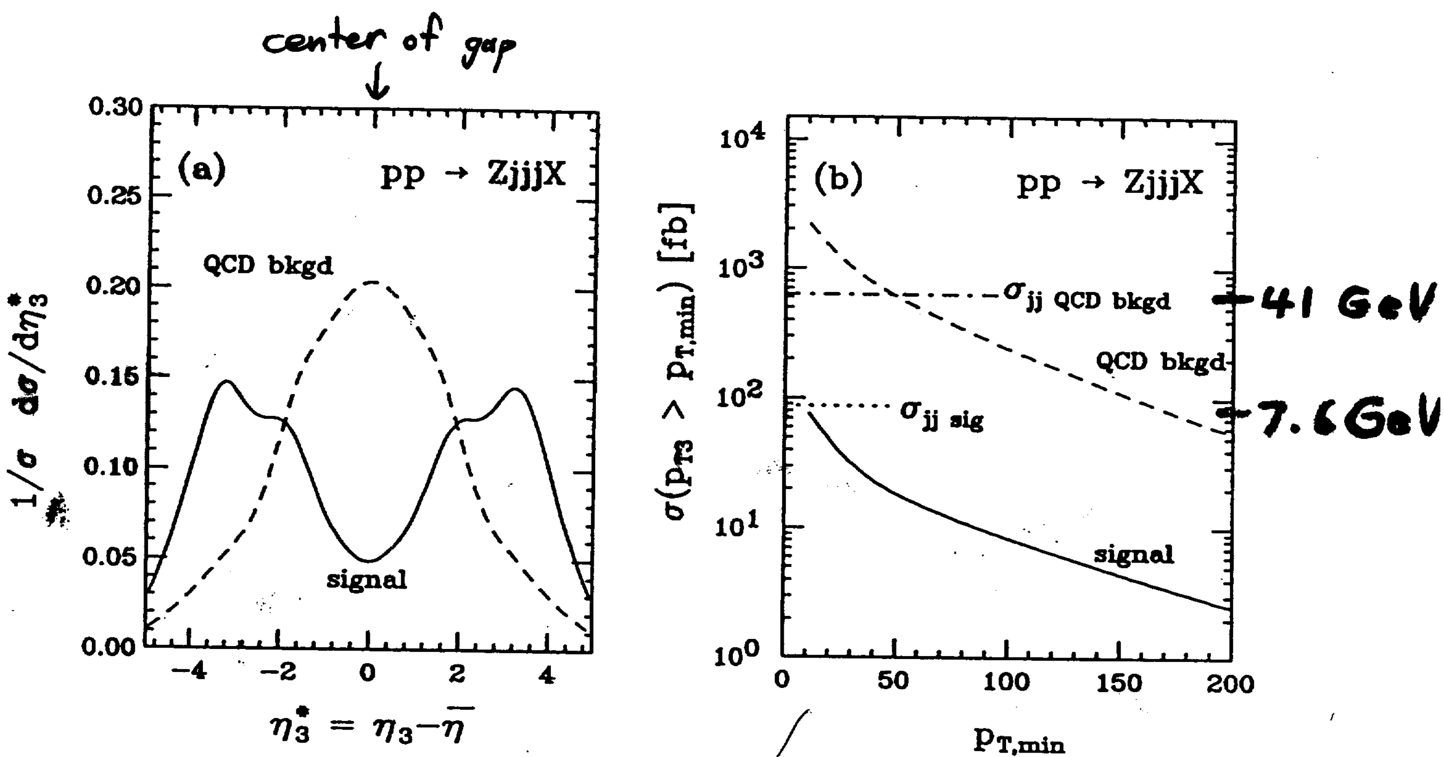
The gluon can be radiated off all available legs.

Define tags: 2 most energetic jets
opposite hemispheres
$p_T > 40$ GeV



Use shifted rapidity:

$$\eta_3^* = \eta_3 - (\eta_{\text{tag }1} + \eta_{\text{tag }2})/2$$



saturation nonphysical!
must reinterpret
or regulate

Truncated Shower Approximation (TSA)

- don't reinterpret soft jets, simply regulate:

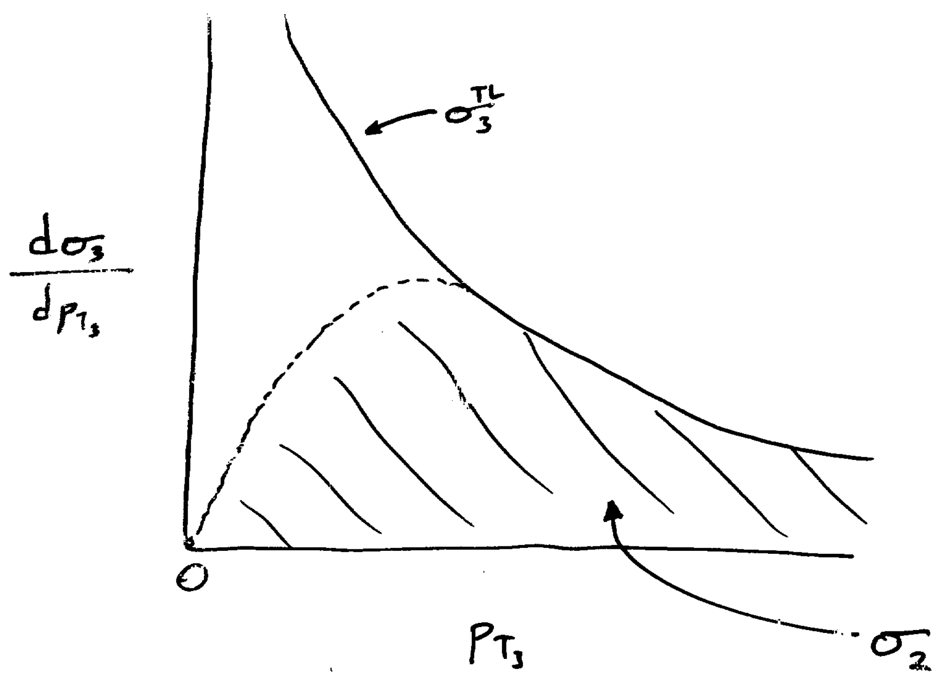
  assume σ_2 is INCLUSIVE cross section

  multiply MC σ by factor → min-p_T parton

$$d\sigma_3^{TSA} = d\sigma_3^{TL}\left[1 - e^{-p_{T_3}^2/p_{TSA}^2}\right]$$

subject to the matching condition

$$\sigma_2 = \int_0^\infty \frac{d\sigma_3^{TSA}}{dp_{T_3}}\, dp_{T_3}$$



- veto regulated events w/ $p_{T_3} > p_T^{veto}$
- produces very similar results to exponentiation

$H \to \tau^+ \tau^-$ results

survival probability (minijet veto) after all cuts: ($p_T^{veto} = 20$ GeV)

Hjj	.71
QCD Zjj	.14
EW Zjj	.48
$Wj + jj$	.15
$b\bar{b} + jj$	.15

events in 30 fb^{-1} after cuts + veto: ($m_H = 120$ GeV)

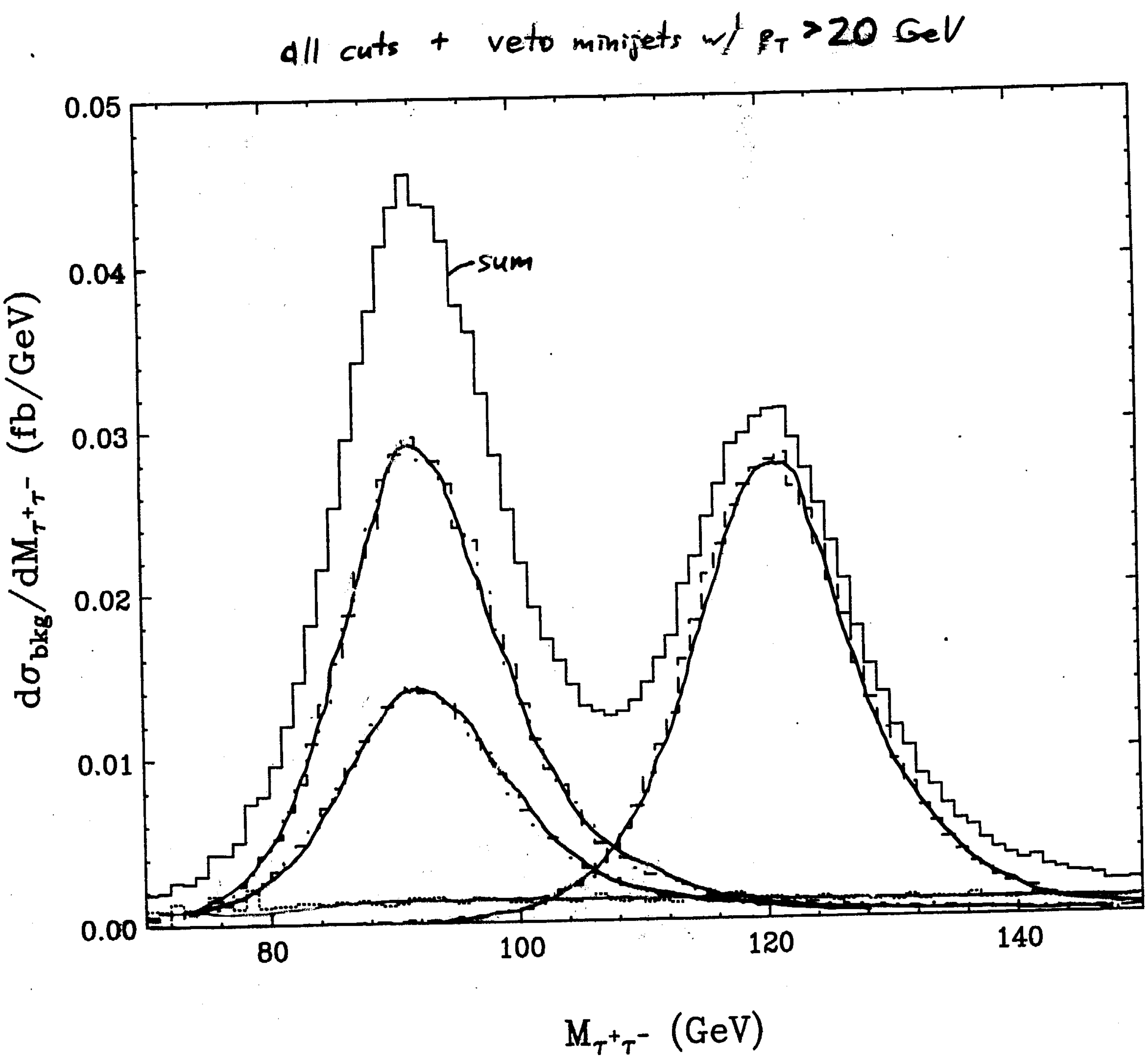
Hjj	13.6	
QCD Zjj	1.5	3.5 (sum of 1.5, 1.0, 0.3, 0.7)
EW Zjj	1.0	
$Wj + jj$	0.3	
$b\bar{b} + jj$	0.7	

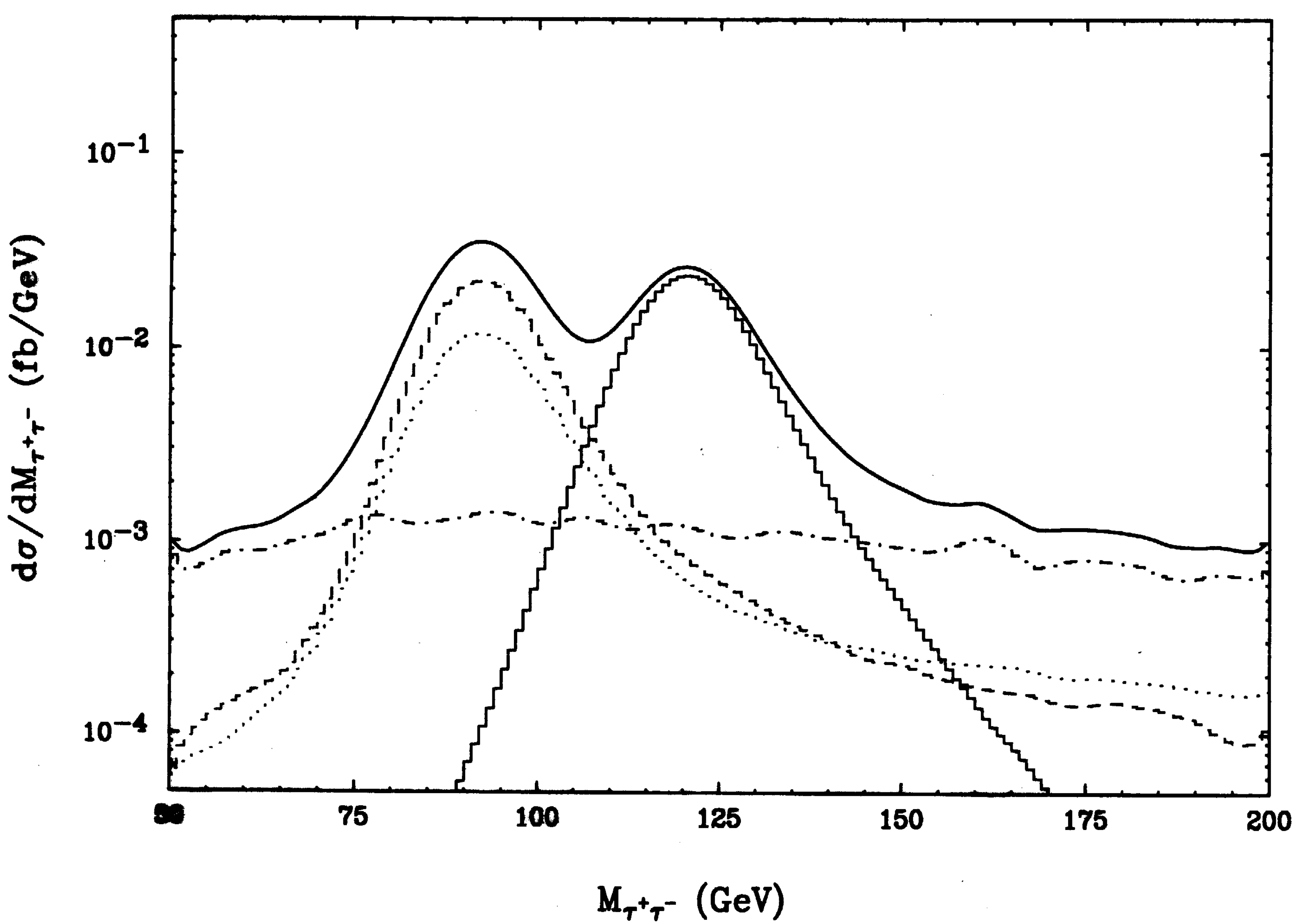
→ not as good as $H \to \gamma\gamma$ (~ 3x $\int \mathcal{L} dt$ required), but still better than via gluon-fusion H production!

TABLE II. Number of expected events for the signal and backgrounds, for 30 fb^{-1} integrated luminosity and full cuts times survival probability, but for a range of Higgs boson masses.

m_H(GeV)	Hjj	QCD Zjj	EW Zjj	$Wj+jj$	$b\bar{b}jj$	σ_{Gauss}
110	11.1	2.1	1.4	0.1	0.3	4.1
120	10.4	0.6	0.5	0.1	0.2	5.2
130	8.6	0.3	0.3	0.1	0.2	5.0
140	5.8	0.2	0.2	0.1	0.2	3.9
150	3.0	0.1	0.2	0.1	0.2	2.3

II.


all cuts + veto minijets w/ p_T >20 GeV
sum
0.05
0.04
0.03
0.02
0.01
0.00
$d\sigma_{bkg}/dM_{\tau^+\tau^-}$ (fb/GeV)
80
100
120
140
$M_{\tau^+\tau^-}$ (GeV)



dσ/dM$_{\tau^+\tau^-}$ (fb/GeV)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
50
75
100
125
150
175
200
M$_{\tau^+\tau^-}$ (GeV)

Summary

- $VV \to H \to \tau^+\tau^-$ w/ (30 fb^{-1}) data quite feasible
  - → could be first direct measurement of a $Hf\bar{f}$ coupling!
- crucial issues:
  - take advantage of information in tagging jets
  - careful analysis of lepton isolation ($b\bar{b}jj$)
  - study/calibration of minijet veto tool
    - ↓ Zjj production
    - ↓ allows low luminosity measurement
- further study:
  - change to tagging jet trigger? (allows looser cuts on τ?)
  - detailed ATLAS study
    - → our assumptions + requirements are somewhat different