Connecting TeV to VBF

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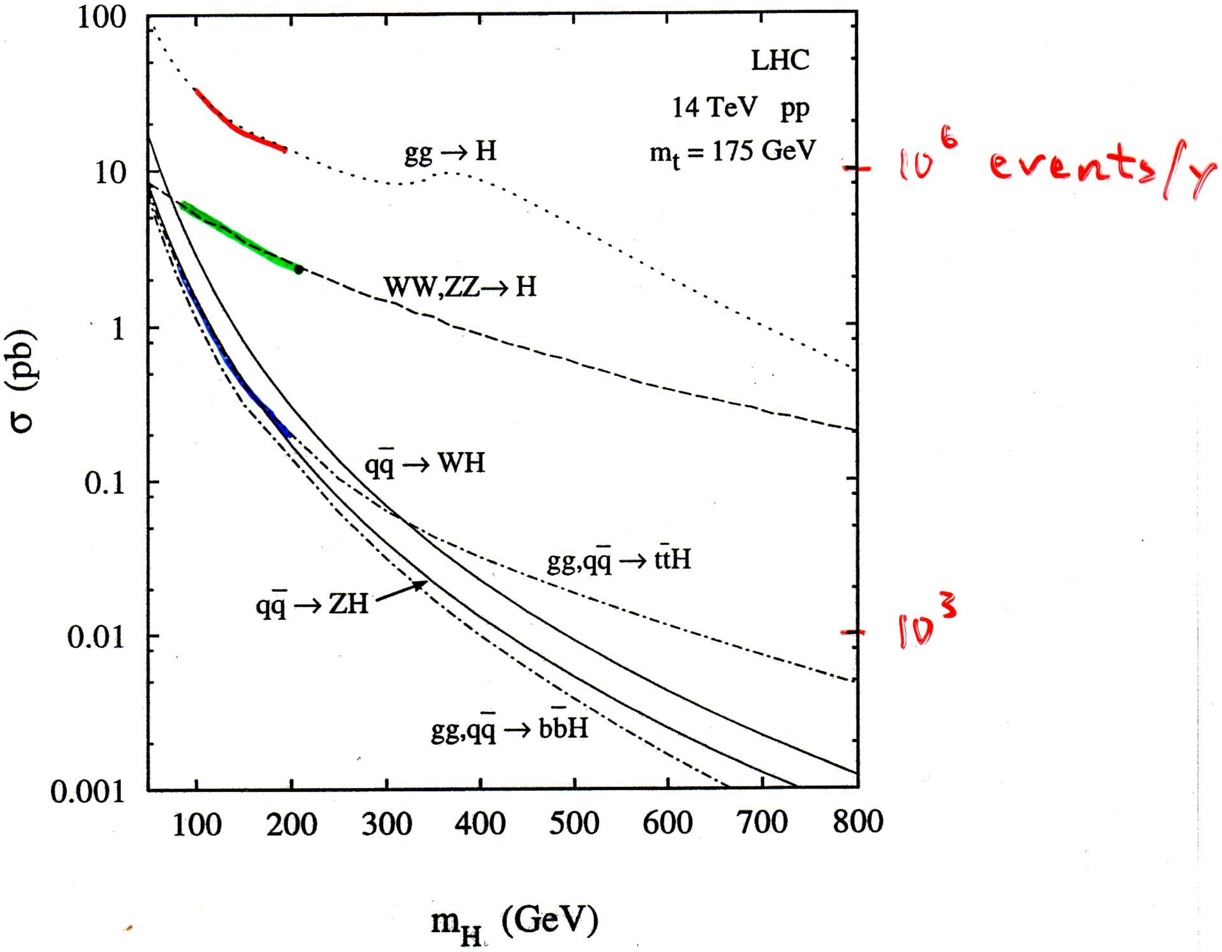
LHC: Higgs production via VBF

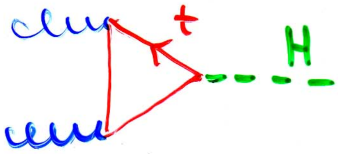
- Central jet veto
  → Wjj studies at the Tevatron
- $H \to \tau\tau$
  → $Z \to \tau\tau$ at the Tevatron
- Forward tagging jets

LHC cross sections



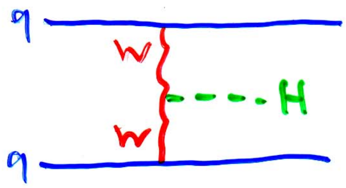
Dominant production processes

gluon fusion



10–30 pb

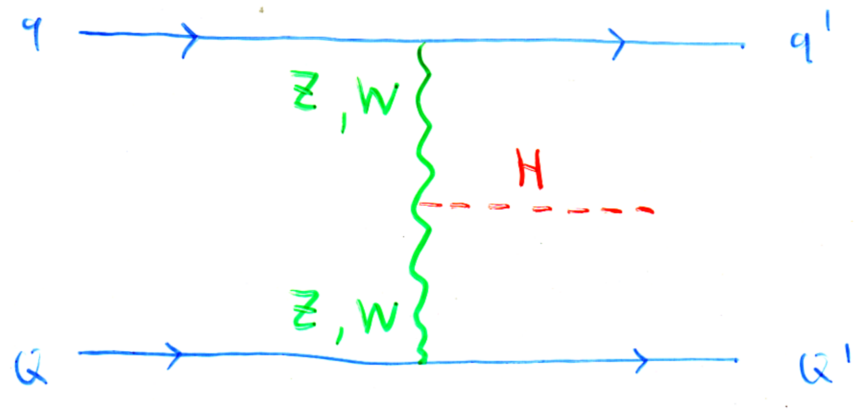
weak boson fusion



3–5 pb

$t\bar{t}$H production — 0.2–2 pb

Exploit weak boson fusion (WBF)



Characteristics:

- 2 forward tagging jets (q', Q')
  $(p_{Tj} > 20 \text{ GeV}, |\eta| < 5)$

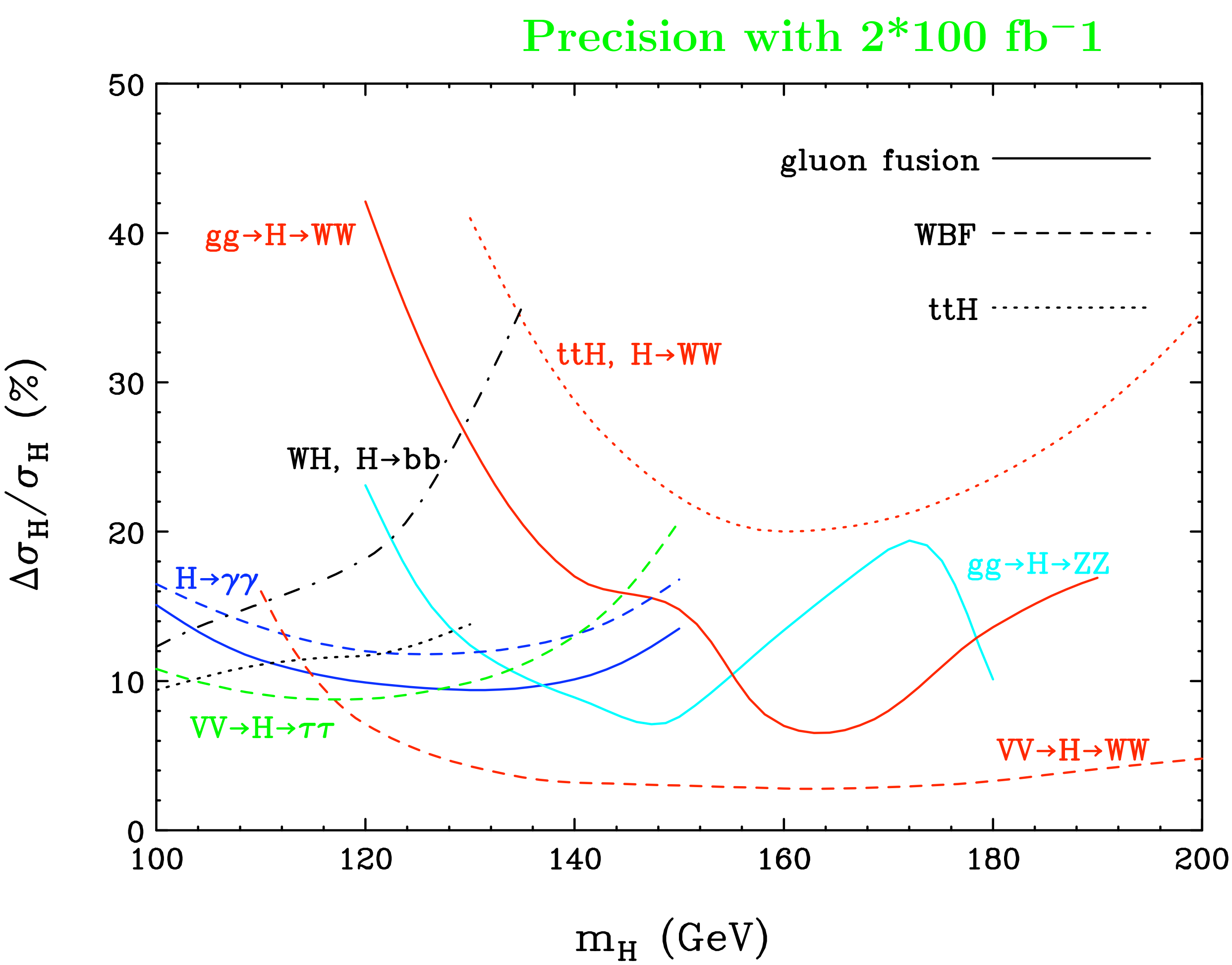
- Observe Higgs decay products between tagging jets

- Little gluon radiation due to W, Z exchange (no color exchange)
  (central jet veto, $p_T > 20$ GeV)

- small NLO corrections $(K \approx 1.1)$

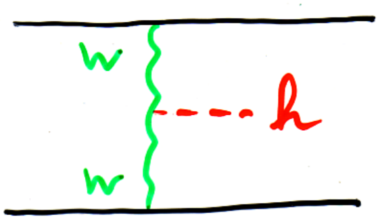
important for coupling measurements:

VBF provides for some of the most accurate measurements

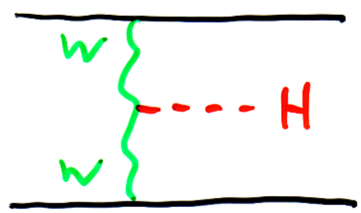


- **VBF is only place to measure tau couplings at LHC**
- **VBF production cross section is needed to measure HVV couplings**

little change in $B(h \to \tau\tau)$, $B(h \to bb)$



$\sim \sin^2(\alpha-\beta)$



$\sim \cos^2(\alpha-\beta)$

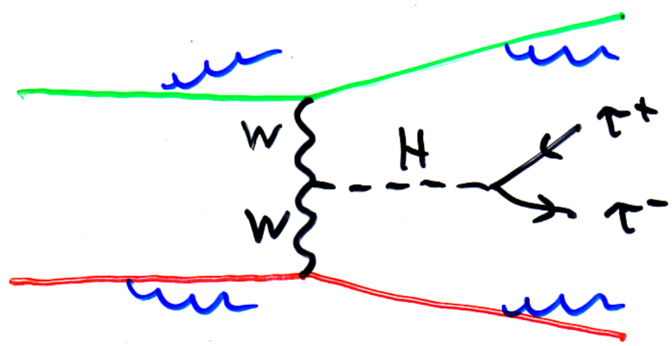
Depending on m_A:

$\sin^2(\alpha-\beta) \gtrsim \frac{1}{2}$ see $h \to \tau\tau$ in VBF

see $H \to \tau\tau$ in VBF

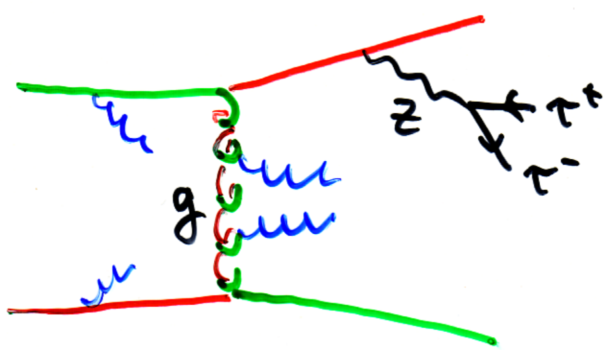
Gluon emission in WBF events

Color singlet exchange in t-channel
⇔ "synchrotron" radiation between initial and final quark direction



⇒ central jets suppressed

Major backgrounds: t-channel color exch.



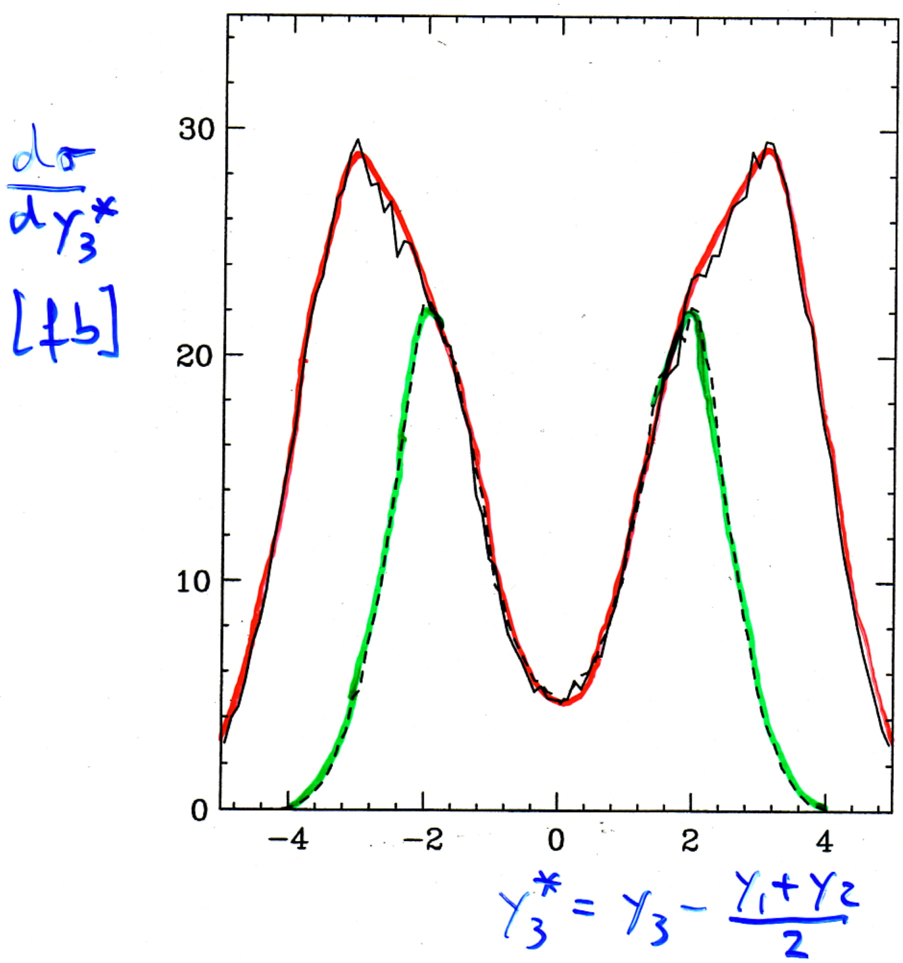
deflection of color charge by ~ 180°
⇒ central gluon emission

WBF Higgs signal for $m_H = 120$ GeV

$p_{T1} > p_{T2} > p_{T3} > 20$ GeV

Rapidity of third jet with respect to 2 leading tagging jets

$|y_1 - y_2| > 4$



NLO parton MC

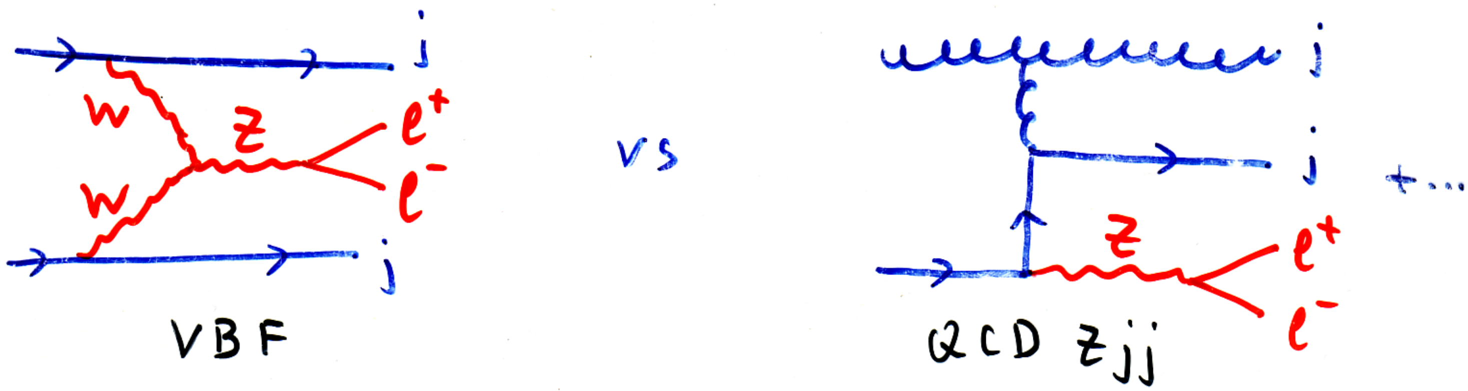
13% of events have 3 jet with $p_T > 20$ GeV

6.3% of events have this jet in $y_1 < y_3 < y_2$

⇒ characteristic radiation pattern for color singlet exchange

Good lab for studying t-channel color singlet vs color octet exchange is

Zjj production at LHC



⇒ study events with

- 2 central leptons, $m_{\ell\ell} = m_Z \pm 10$ GeV
- 2 tagging jets in opposite hemispheres
  $p_{Tj} > 40$ GeV, $|\eta_j| < 5$, $|\eta_{j_1} - \eta_{j_2}| > 4.4$

⇒ $B \cdot \sigma_{signal} \approx 90$ fb

$B \cdot \sigma_{QCD\ bkgd} \approx 630$ fb

Consider emission of third (soft) parton

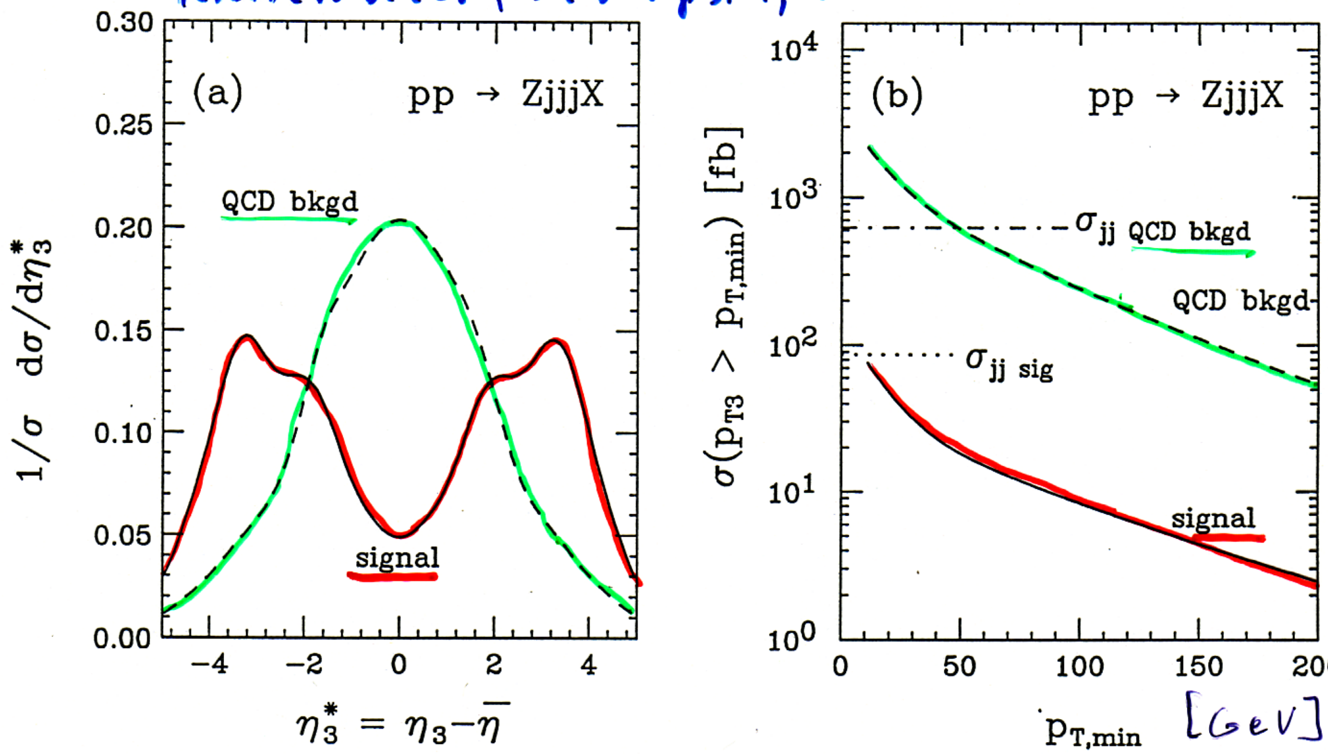
signal: central emission suppressed (rapidity gap)

$\sigma_{3j} \approx \sigma_{2j,\text{incl.}}$ for $E_{Tj} \approx 8$ GeV

QCD bkgd: central emission dominates

$\sigma_{3j} \approx \sigma_{2j,\text{incl.}}$ for $E_{Tj} \approx 50$ GeV

Rainwater, Szalapski, Z.



Wjj and Zjj event rates at Tevatron

$p_{Tj} > 20$ GeV $\not{p}_T, p_{T\ell} > 20$ GeV

$|\eta_j| < 3$ $|\eta_e| < 1.5$

tagging jets = 2 highest p_T jets

$|\eta_1 - \eta_2| > 2$

LO cross sections, decay to $\ell = e, \mu$

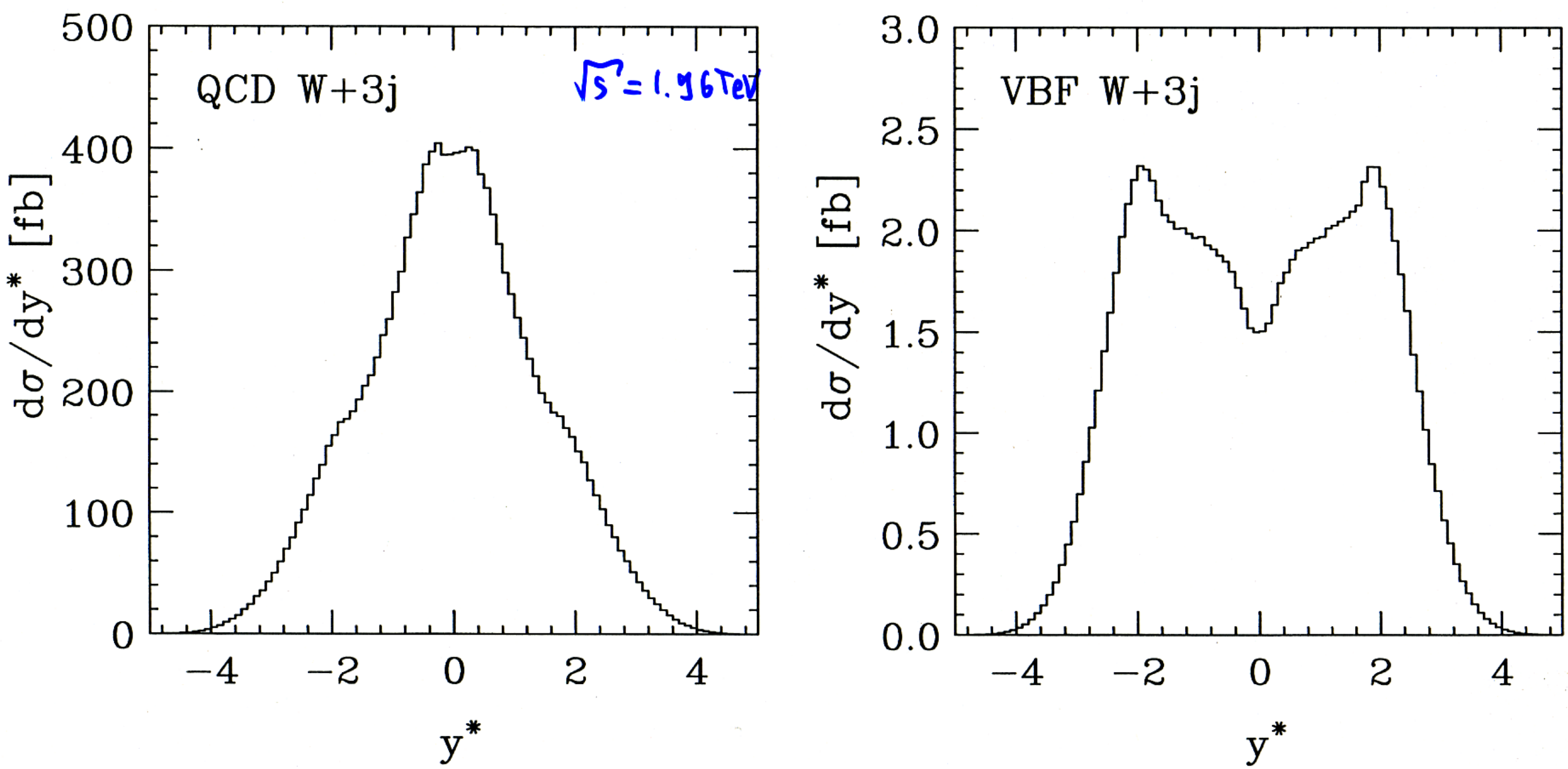
	Wjj	Zjj
QCD	8.5 pb	0.7 pb
VBF	80 fb	5 fb

$\Rightarrow$ concentrate on QCD Wjj sample

Rapidity distribution of 3rd (softest) jet (LO ME,

$p_T^{tag} > 30$ GeV $p_{T3} > 15$ GeV

$\Delta\eta_{tag} = |\eta_1 - \eta_2| > 2$



$$y^* = y_3 - \frac{y_1 + y_2}{2}$$

Expected (LO) cross sections for 2,3 jets in $W^\pm$ production; $B(W \to e\nu, \mu\nu)$ included

$p_{Tj} > 15$ GeV, $|\eta_j| < 3$

	W+2j	W+3j	σ_3/σ_2
$\lvert\eta_1-\eta_2\rvert > 2$	15 pb	3 pb	19%
$p_T^{tag} > 30$ GeV			
$\mu_R = m_W$	3.2 pb	1.4 pb	44%
$\mu_R = p_{Tj}$	4.2 pb	2.6 pb	62%
$\lvert\eta_1-\eta_2\rvert > 3$	0.8 pb	0.37 pb	47%

- No NLO calculation for W+3j available
  → substantial scale dependence
- 3 jet fraction is large
  → fixed order perturbation theory insufficient

More reliable predictions from parton shower programs?

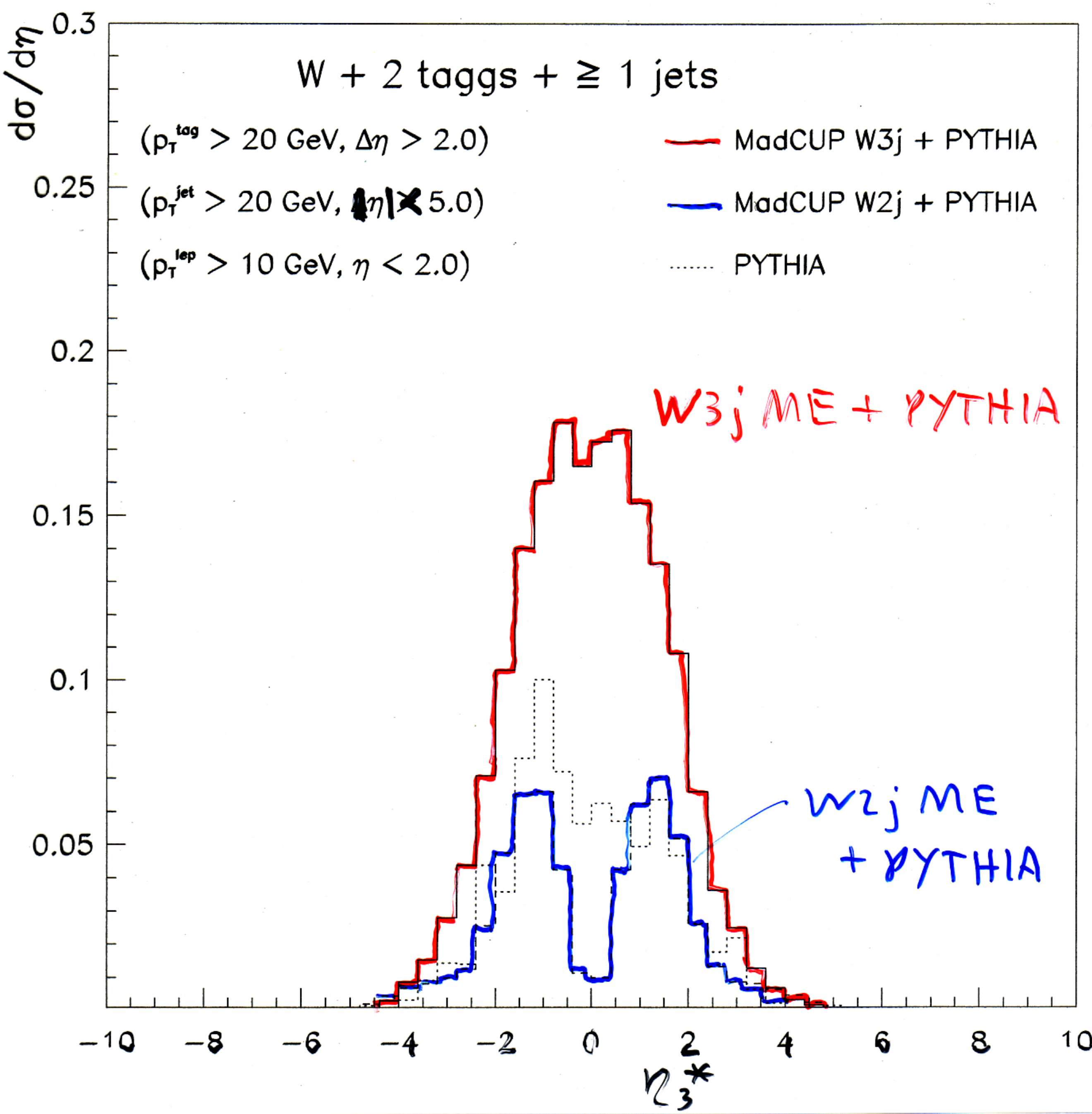
Study by E. Richter-Was

QCD Wjj events @ Tevatron, $W \to \mu\nu$

$B\sigma(\Delta\eta_{tag} > 2, \geq 2 jets) \approx 8 pb$

$B\sigma($ " $, \geq 3 jets) \approx 1.3 pb$

for $p_{Tj} > 20$ GeV



$\eta_3^* = \eta_3 - \frac{\eta_1 + \eta_2}{2}$

$p_{T1} > p_{T2} > p_{T3}$

....

Get answers from $W + \gtrsim 2$ jet data

$p_{Tj_1}, p_{Tj_2} \gtrsim 30$ GeV $\qquad |\eta_{j_1} - \eta_{j_2}| > 2 \ldots 3$

p_{Tj_3} as soft as possible

- Fraction of events r_{2+n} with $n = 1, 2, 3 \ldots$ additional jets of $p_T > p_{Tmin}$
- p_{Tmin} dependence of r_{2+n}
- rapidity distribution of extra jets $\frac{d\sigma}{d\eta_3^*}$

By how much can a central jet veto reduce the Wjj background?

i.e. please tell us your jet detection efficiencies .... or provide uncorrected r_{2+n}

$H \to \tau\tau$ at LHC

VBF $H \to \tau\tau$ signal is small (order 1 fb) due to small detection efficiencies

- $B(\tau\tau \to \ell^+\nu\bar{\nu}\,\ell^-\nu\bar{\nu}) = 12\%$

  leptons are fairly soft ⇒ importance of low $p_{T\ell}$ trigger thresholds

- $(\tau \to \text{hadrons}\ \nu_\tau) \times (\tau \to \ell\nu\bar{\nu})$

  $p_{T\ell} > 20$ GeV for single lepton trigger
  $p_T(\tau\,\text{jet}) > 40$ GeV for QCD jet rejection

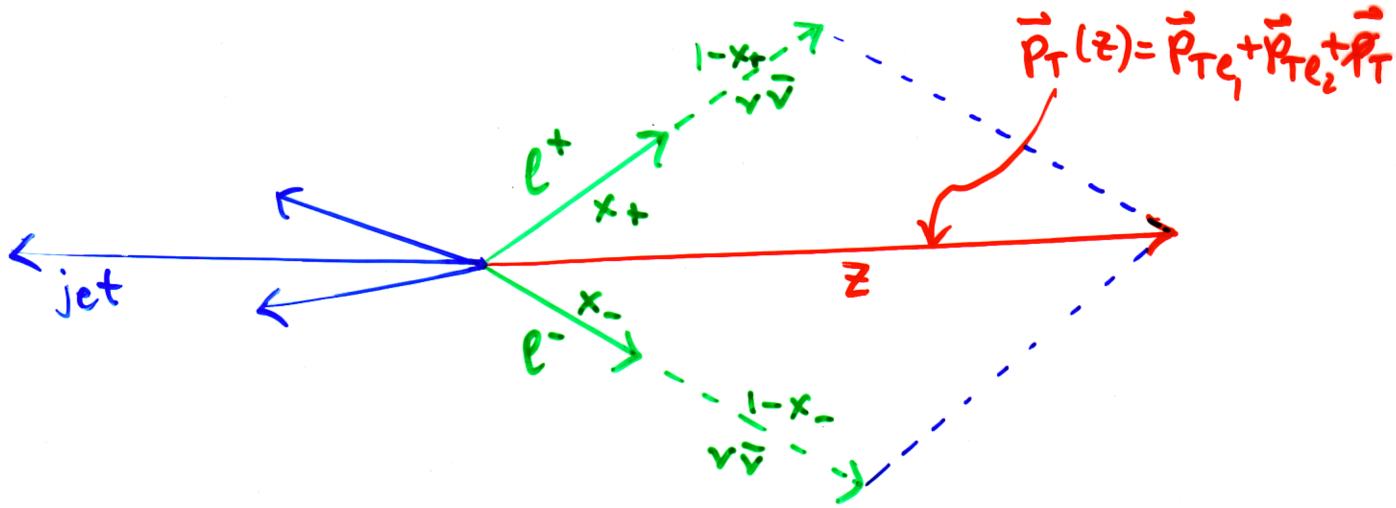
LHC studies of 90's (Clavalli et al.) were optimized for heavy $H/A \to \tau\tau$

different optimization for $m_h = 120$ GeV

$Z \to \tau\tau$ is ideal proxy for $h \to \tau\tau$

Substantial Tevatron experience already

$\tau\tau$ mass reconstruction from transverse momentum parallelogram



$$p_{\tau^\pm} = p_{\ell^\pm}/x_\pm \implies m^2_{\tau\tau} = m^2_{\ell^+\ell^-}/x_+x_-$$

need sizable $p_T(Z)$ for non-degenerate parallelogram

Compare LHC: $\langle p_{TH} \rangle_{VBF} \approx$ order 100 GeV

- use Z+jet events to study $Z \to \tau\tau$ mass reconstruction
- measure mass resolution
- extrapolate to $H \to \tau\tau$ at LHC

Forward tagging jets

VBF tagging jets at LHC are quark jets which typically have

$$2 < |\eta_{tag}| < 4$$

$$20\ \text{GeV} < p_T^{tag} \lesssim 100\ \text{GeV}$$

Study such jets at Tevatron

- performance of jet algorithms in forward region
- internal structure of such jets, i.e. energy flow and jet shape
- influence of underlying event
- pile up
- ...

Goal: optimize tagging efficiency at LHC