

Dilepton ttH



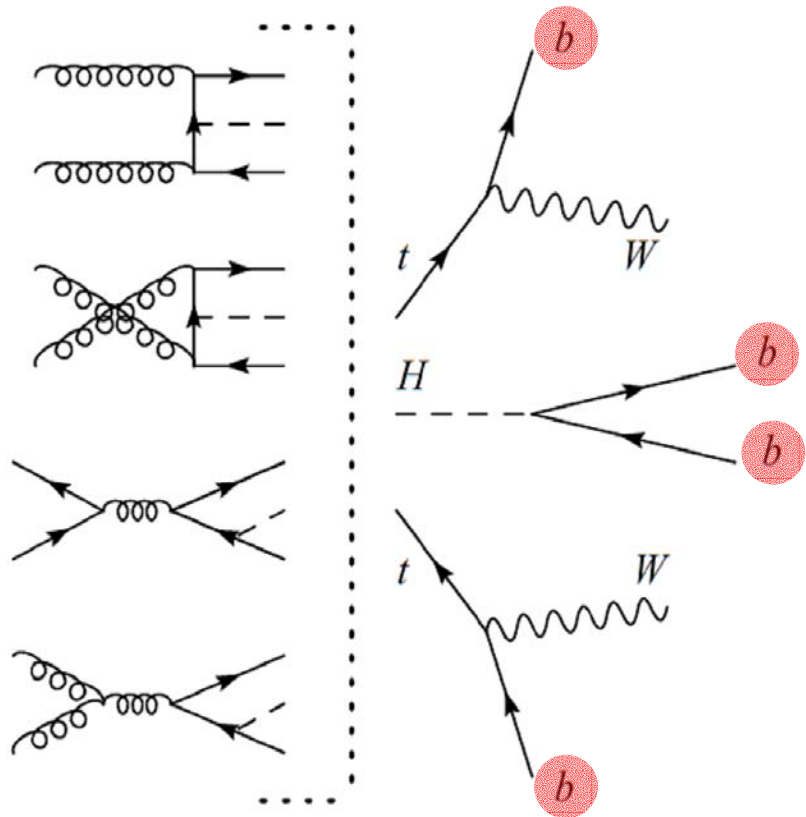
Joe Incandela
with Chris Hill, Sue Ann Koay

$$\begin{bmatrix} u \\ c \\ s \end{bmatrix} \begin{bmatrix} c \\ s \\ b \end{bmatrix}$$

February, 2006

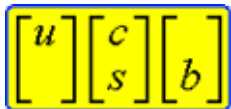
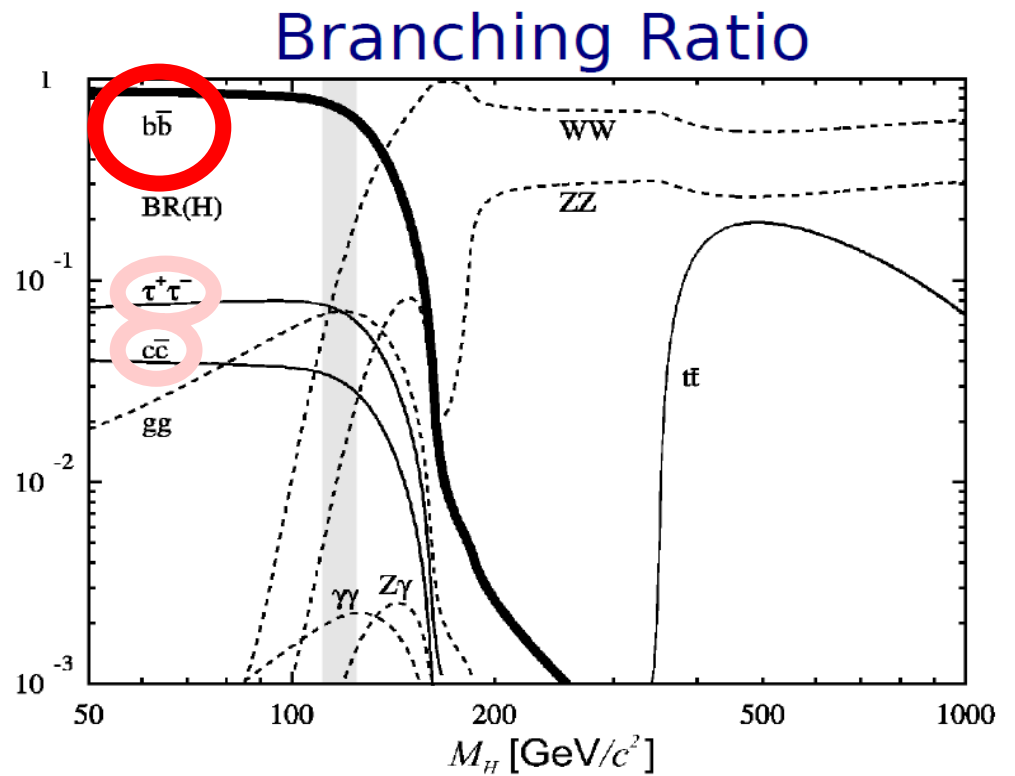
For the CMS ttH group
[CERN, Karlsruhe, Perugia, UCSB]

Focus on light **H** in conjunction with **t \bar{t}**



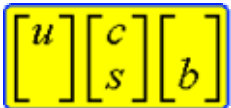
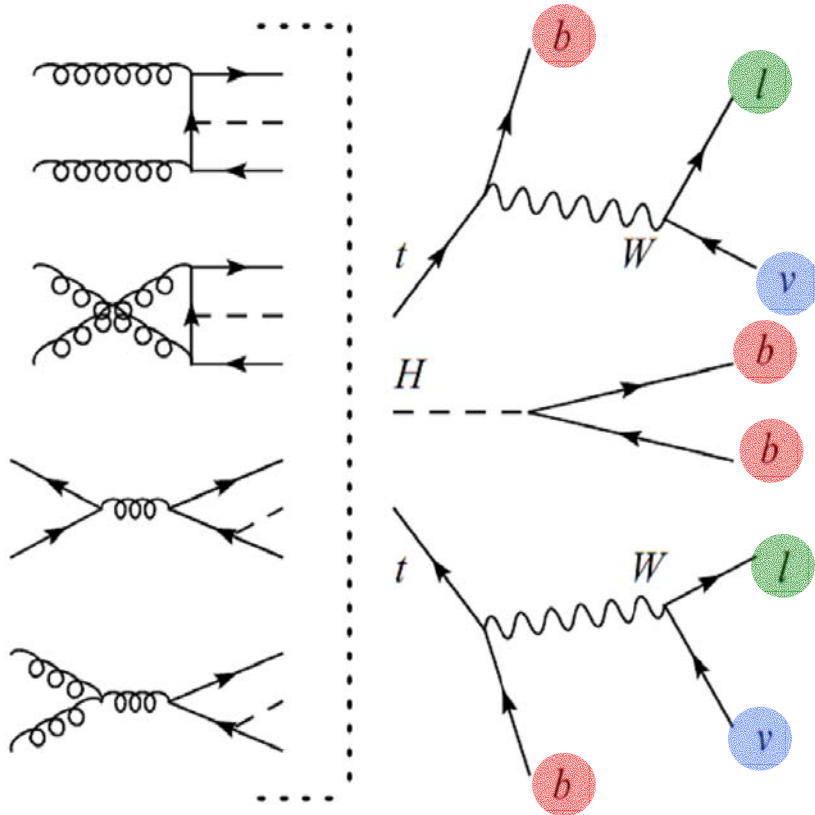
Production Modes

Decay Mode

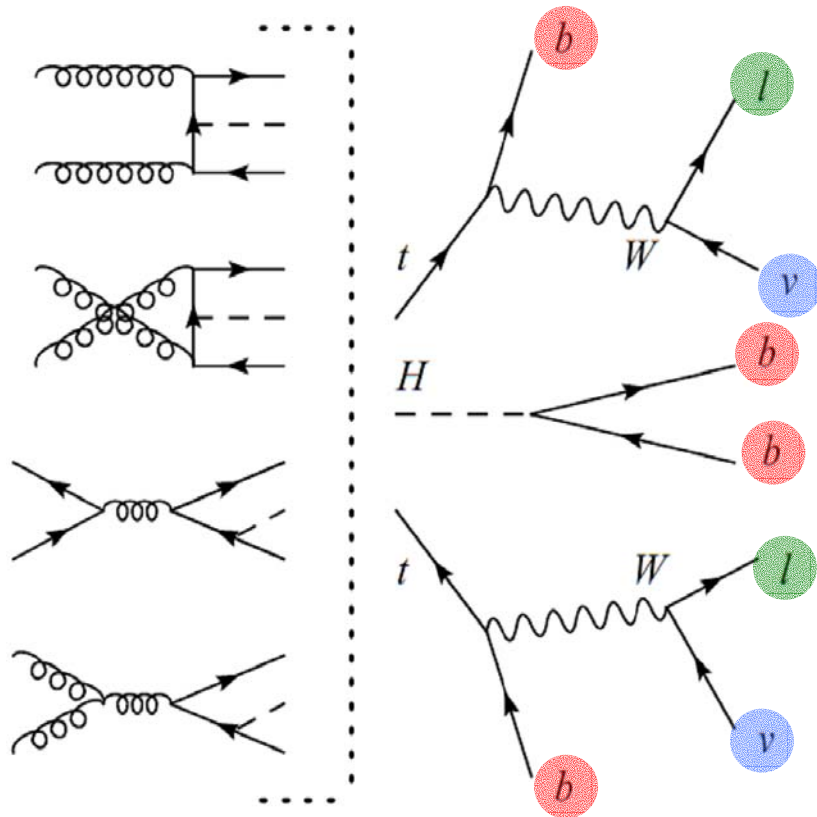


$2 \times (W \rightarrow l \nu) : \underline{\text{dilepton channel}}$

e, μ

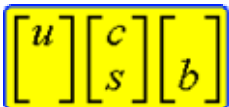


$2 \times (W \rightarrow l \nu) : \text{dilepton channel}$

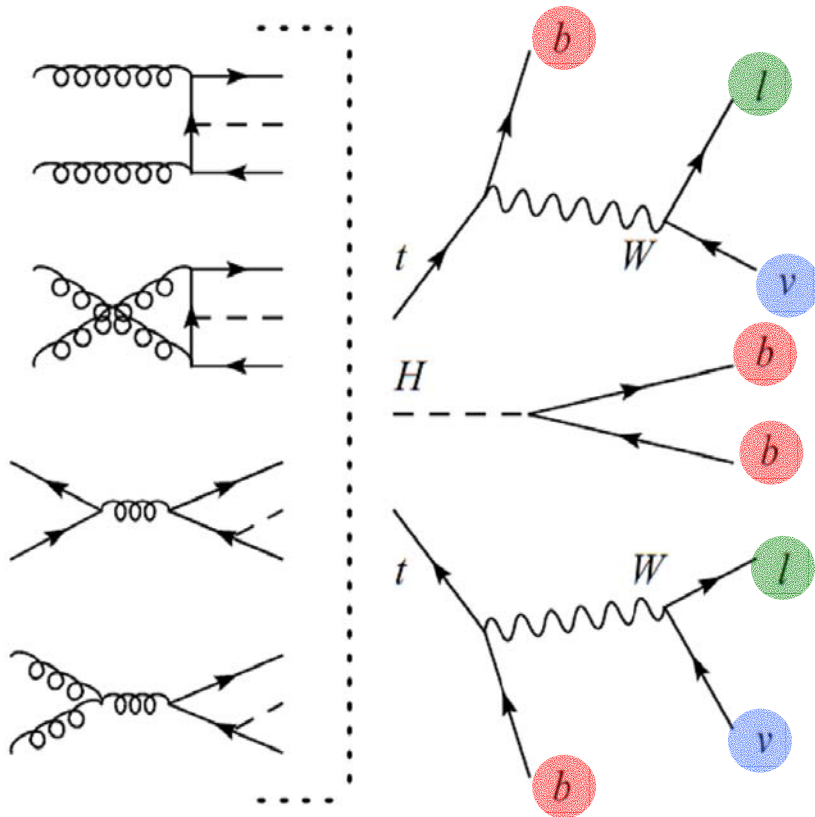


Distinct signature:

- 4 b-jets
- 2 oppositely charged leptons
- Missing energy



$2 \times (W \rightarrow l \nu) : \text{dilepton channel}$

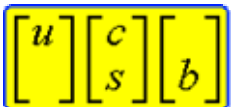


Distinct signature:

- 4 b-jets
- 2 oppositely charged leptons
- Missing energy

But...

- Which two b's come from H?
- Necessary to reconstruct $t\bar{t}$?



- Recent work $t\bar{t}H$

- Studied $t\bar{t}H$ channel in the context of the Tevatron
[Hill, Incandela, Stuart, *Phys. Rev. Lett.* **86**, 2001]
- Methods that don't require $t\bar{t}$ reconstruction

- Some recent $t\bar{t}$ studies in CDF

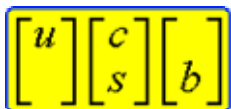
- $t\bar{t}$ -dilepton studies
[Hill, Incandela, Mills, *Phys. Rev. Lett.* **93**, 2004]
- $t\bar{t}$ + jets production
[Affolder, Incandela, Lamb in collaboration With S. Mrenna]
- Top mass, and b tagging in $t\bar{t}$ lepton + jets
[Hill, Incandela, Lamb, *Phys. Rev. D* **71**, 2005]



Tools

Selection

Improvements



Tools

Selection

Improvements

- CMS Software

(Root, CMKIN, OSCAR, ORCA, ExRootAnalysis, CRAB, GRID tools)

- Datasets (self-generated, FNAL, GRID)

- Selection algorithms

We had lots of help from many people at FNAL, CERN, ...

Thanks!



Tools

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Improvements

- CMS Software
(Root, CMKIN, OSCAR, ORCA, ExRootAnalysis, CRAB, GRID tools)
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Stood on shoulders of many at FNAL, CERN, ...

Thanks!

-
- Basic selection strategy established
 - S/\sqrt{B} (Relatively Good – since dileptons are ‘clean’)
 - How to extract Higgs...



Tools

Monte-Carlo

HERWIG
PYTHIA
...

interfaces
with

CMKIN 4.3.1

Full detector simulation

OSCAR 3.6.5

Digitization +
Reconstruction

ORCA 8.7.4

Package up relevant
reconstructed objects

ExRootAnalysis
(customized)

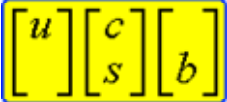
Our Analysis Code

HEPEVT
n-tuple

(Detector)
Hits

Digi
(digitized
output)

ROOT
TTree



Tools

Signal

- $M_H = 115 \text{ GeV},$
 $120 \text{ GeV},$
...
- Running full
production
cycle on the
GRID

CMKIN 4.3.1

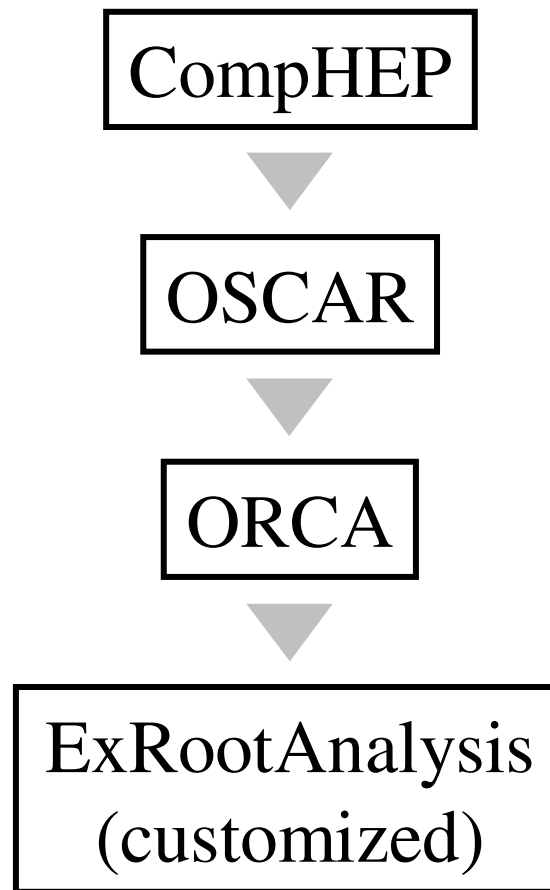
OSCAR 3.6.5

ORCA 8.7.4

ExRootAnalysis
(customized)



Tools



Background

- Using available samples



Tools

Background	Cross-section [fb]	Number of events
$t\bar{t}jj$	507,800	1,336,453
$t\bar{t}b\bar{b}$	3,300	395,669
$t\bar{t}Z$	650	113,811
$t\bar{t}$	770,000	975,216

(CompHEP + PYTHIA) (NLO)

PYTHIA (LO, for comparison)



✓ Tools

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→ CompHEP + PYTHIA (NLO)

PYTHIA (LO, for comparison) ←





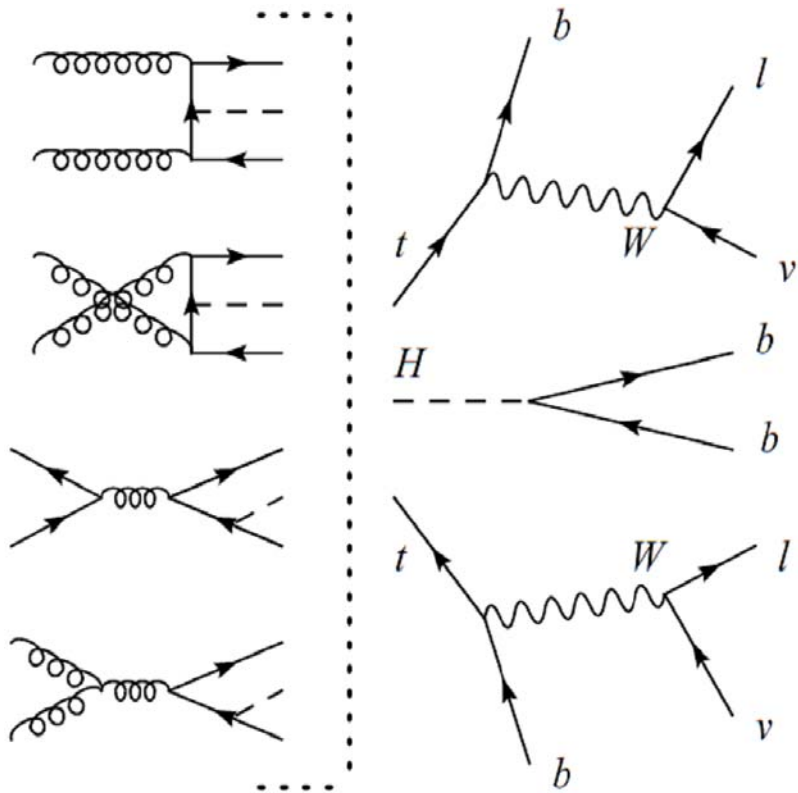
Tools

Selection



✓ Tools

Selection

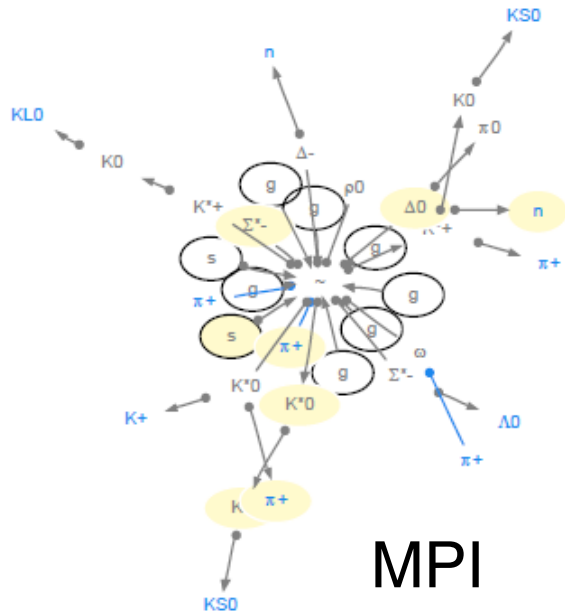


$\begin{bmatrix} u \\ c \\ s \end{bmatrix} \begin{bmatrix} c \\ s \\ b \end{bmatrix}$

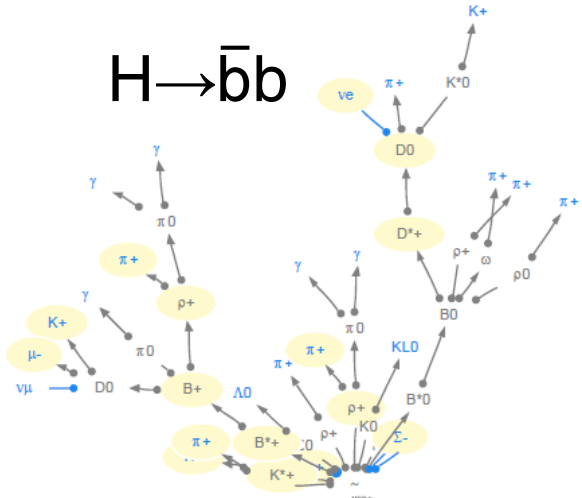
J. Incandela, b/τ workshop CERN, Feb. 10, 2006

Slide 16

$E_T > 3 \text{ GeV}$

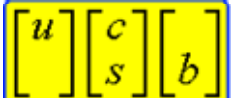
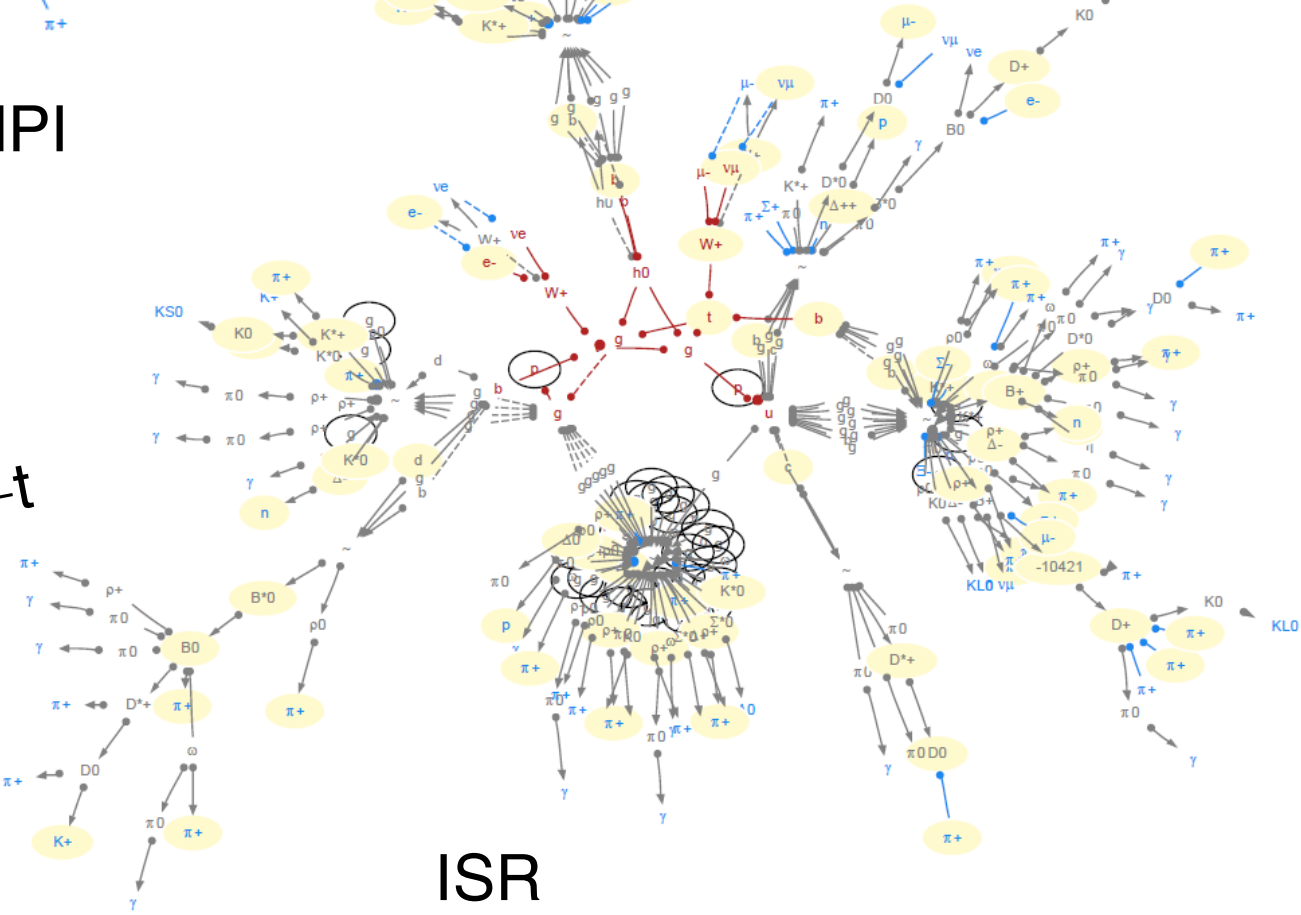


$H \rightarrow \bar{b}b$



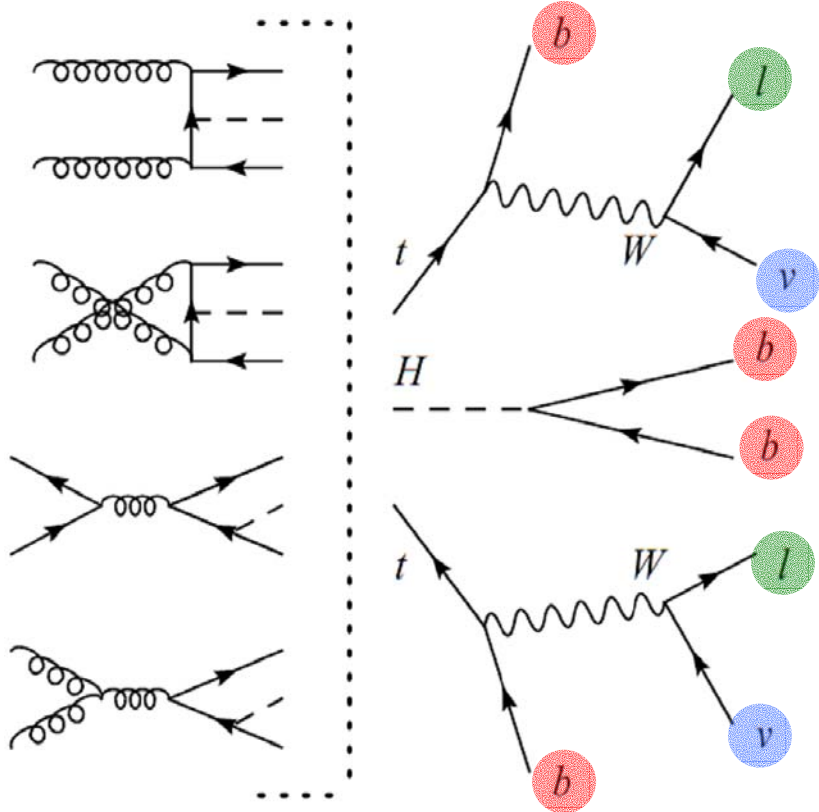
$\bar{t} \rightarrow W^- \bar{b}$

$W^+ b \leftarrow t$



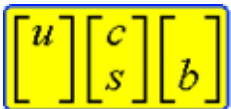
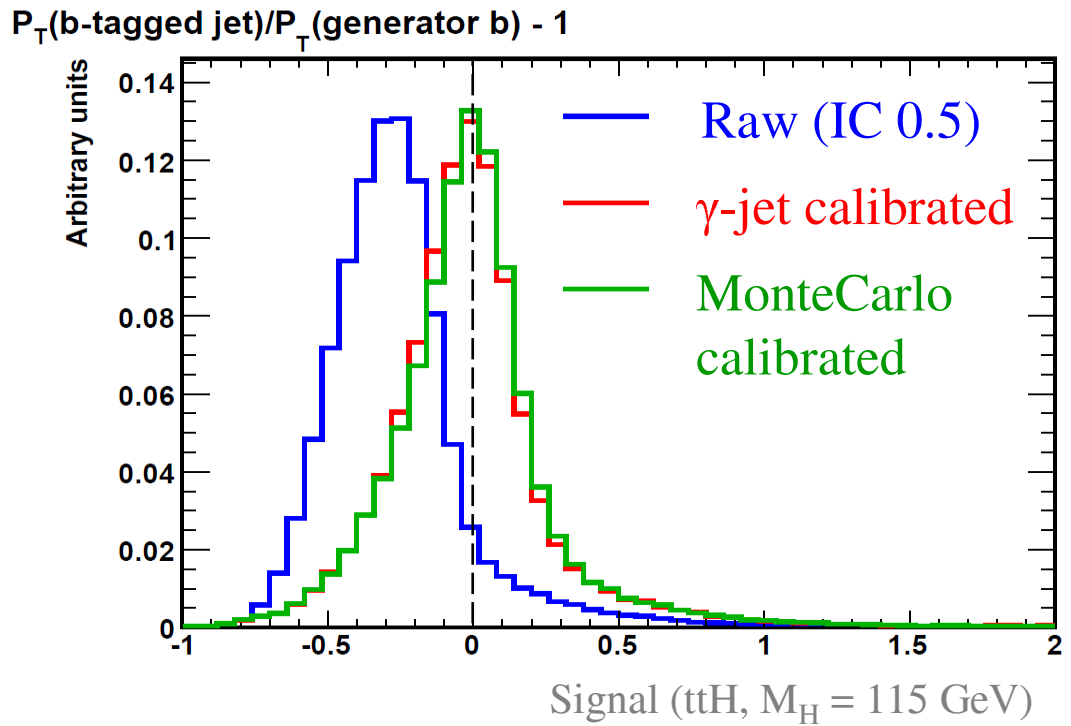
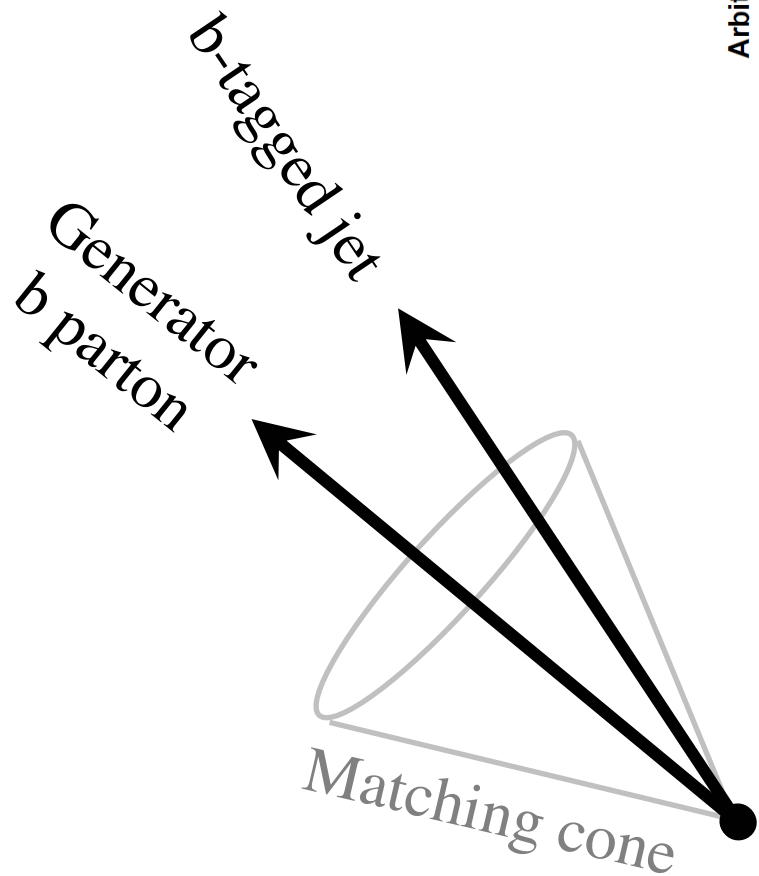
Event selection criteria:

- ≥ 4 jets
 - ≥ 3 b-tagged
- Missing transverse energy ≥ 40 GeV
- 2 oppositely charged, “good” leptons



✓ Tools

Selection



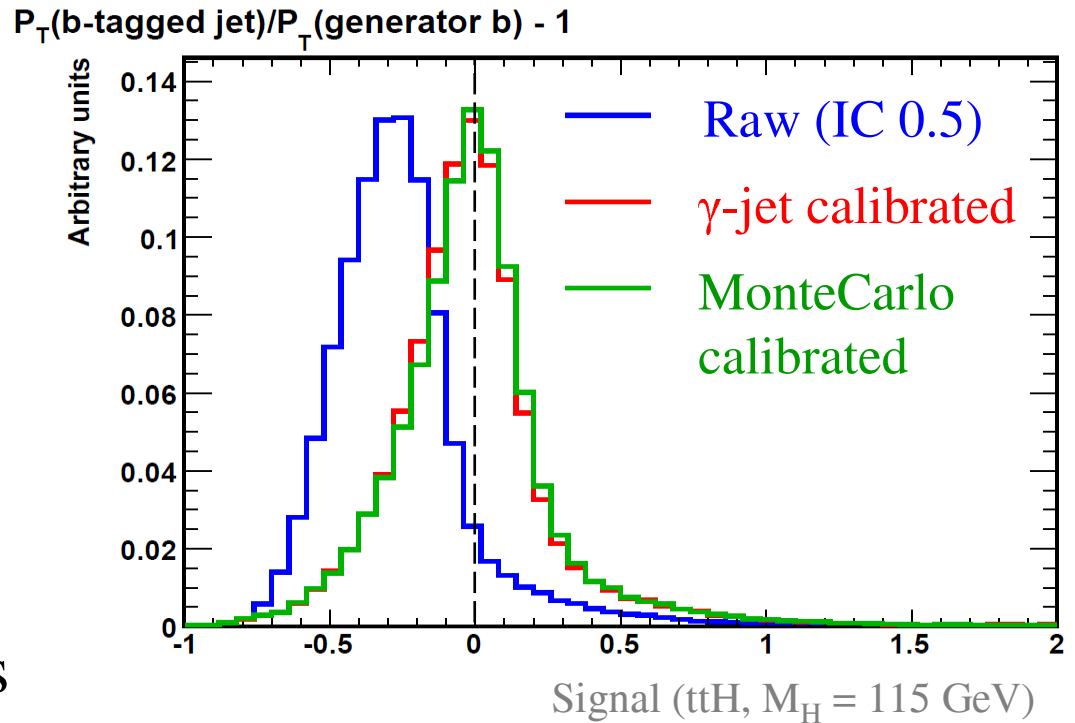


Tools

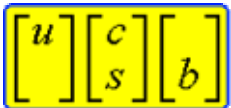
Selection

Jets

- $E_T > 20$
- $|\eta| < 2.5$
- Use MC calibrated jets
- Remove electrons that match within $R < 0.4$



← $R \equiv \sqrt{(\Delta\eta^2 + \Delta\phi^2)}$



Missing E_T

Calorimeter tower measurements



$$\cancel{E}_T(ecal + hcal)$$

$$- \sum [E_T(calib) - E_T(raw)]$$

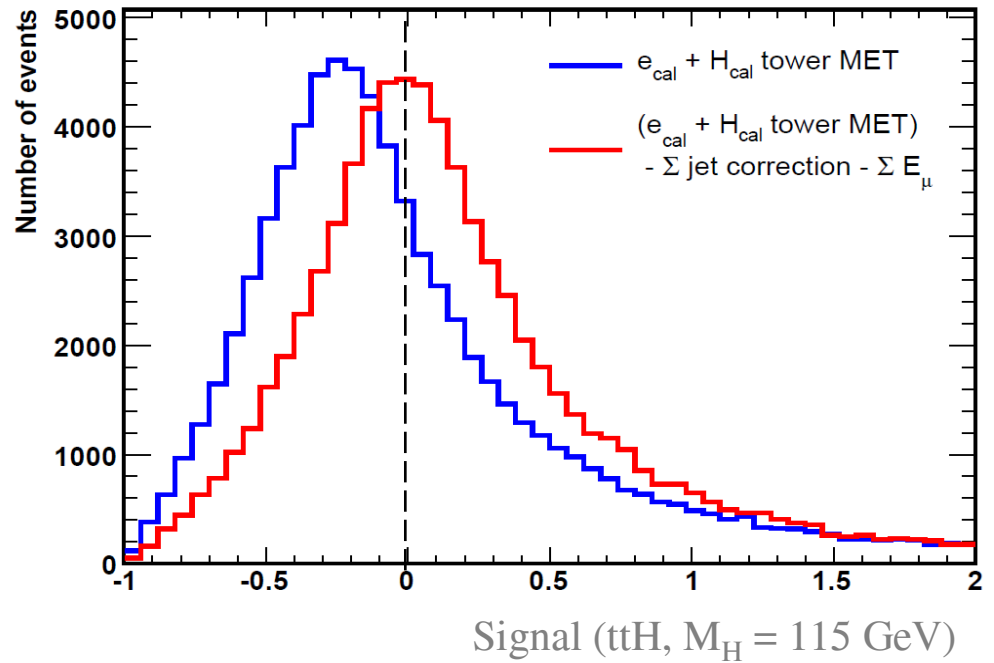
← Jet corrections

$$- \sum p_T(\mu)$$

← Muon momenta

$$\begin{bmatrix} u \\ c \\ s \\ b \end{bmatrix}$$

MET(reconstructed) / MET(generator ν) - 1



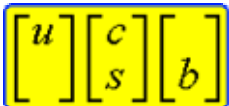
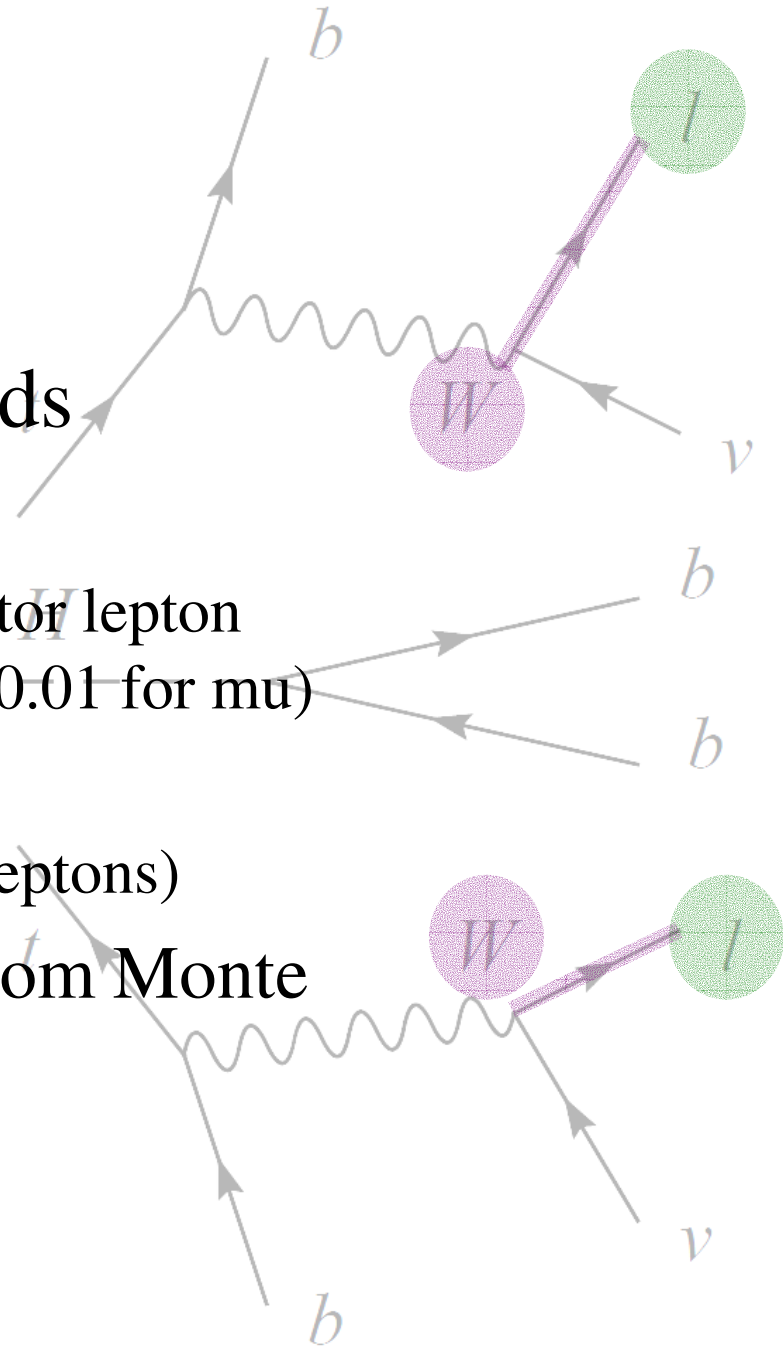


Tools

Selection

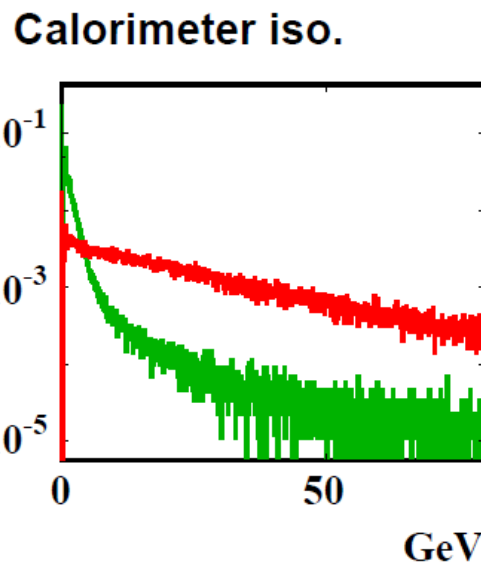
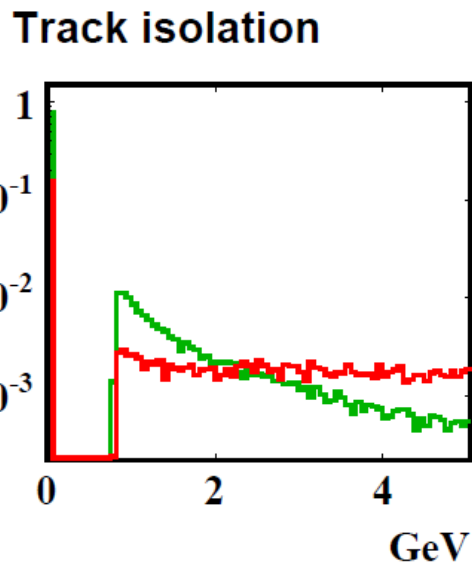
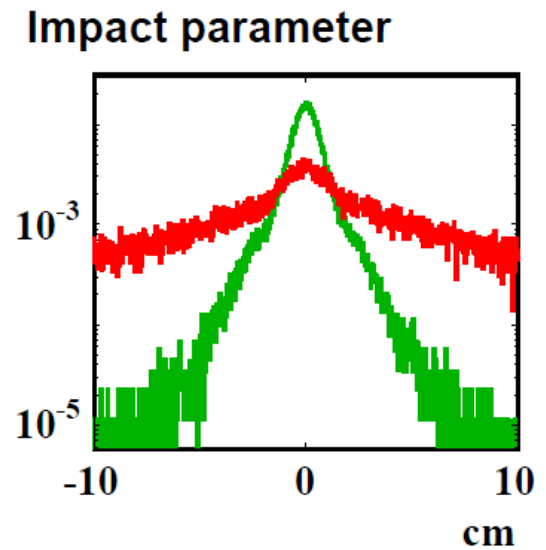
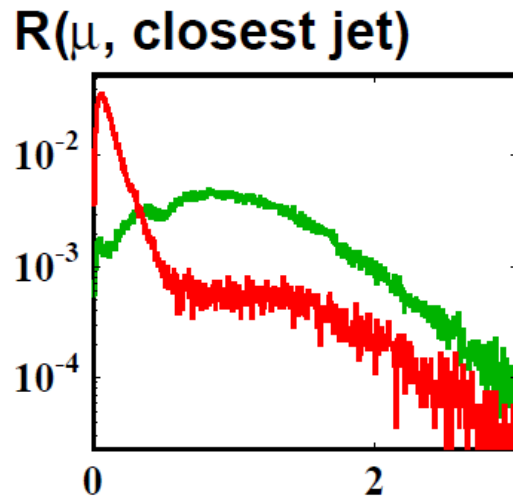
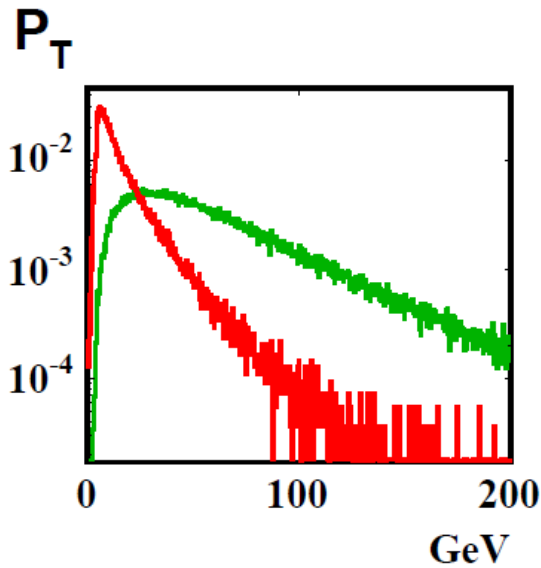
Leptons

- Use ttH group's likelihoods
- Categorize leptons as
 - “**Good**”: Matched to generator lepton from W ($R < 0.1$ for e, $R < 0.01$ for mu)
 - “**Bad**” (Fake): All others
(non-leptons, non-isolated leptons)
- Probability distributions from Monte Carlo “truth”



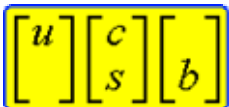
✓ Tools

Selection

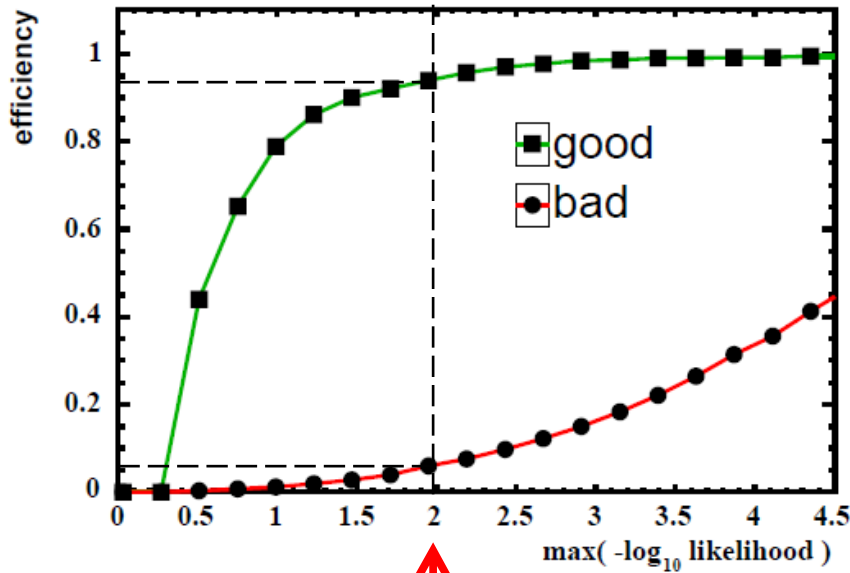


Discriminators for Muons

— Good
— Bad

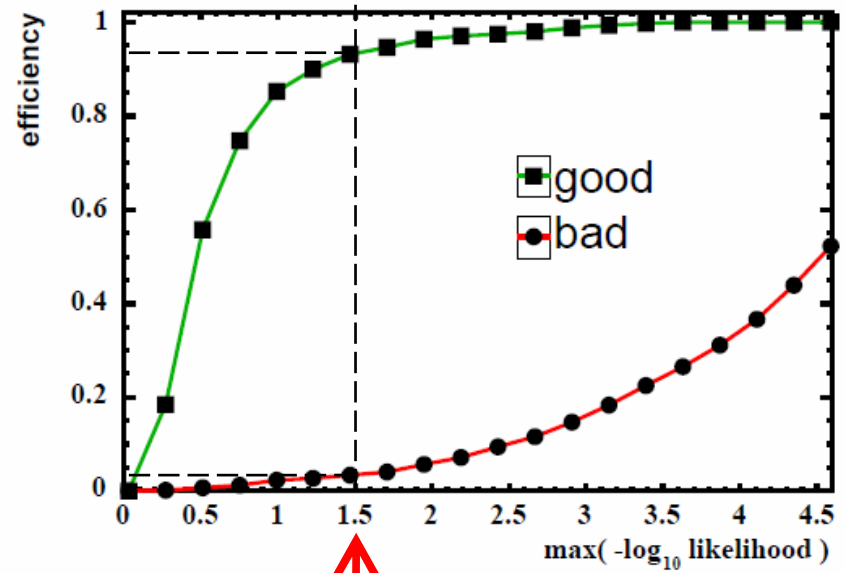


Electron selection efficiencies

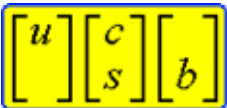


Cut: $2 \max(-\log_{10} \text{e-likelihood})$
 Efficiency: ~95% good
 ~5% bad

Muon selection efficiencies



Cut: $1.5 \max(-\log_{10} \mu\text{-likelihood})$
 Efficiency: ~95% good
 ~3% bad



✓ Tools

Selection

	Cross-section [†] (fb)	(Elimination) Strategy
$t\bar{t}H$ ‡	747	!
$t\bar{t}jj$	507,800	b-tags
$t\bar{t}b\bar{b}$	3,300	(irreducible)
$t\bar{t}Z$	650	b-tags, reconstruct Z mass (?)

} Background

[†] Next-Leading-Order (CompHEP) calculation

[‡] For Higgs mass $M_H = 115$ GeV





Tools

Selection

Fraction of selected $t\bar{t}b\bar{b}$ events that we expect to be dilepton:

$$\epsilon_{lb\bar{b}\bar{b}\bar{b}} / (\epsilon_{lud\bar{b}\bar{b}\bar{b}} + \epsilon_{lcs\bar{b}\bar{b}\bar{b}} + \epsilon_{b\bar{b}\bar{b}q\bar{q}q}) \approx 0.57$$

Based on ID efficiencies, event composition,
careful treatment of combinations...

Fraction of selected events that are dilepton

$t\bar{t}H$	0.55
$t\bar{t}jj$	0.58
$t\bar{t}b\bar{b}$	0.60
$t\bar{t}Z$	0.39





Tools

Selection

$C_{N,k}$ \equiv Binomial coefficient

“back-of-envelope” cross-check

E_q \equiv b-tagging efficiency for q -jets

E_j \equiv efficiency for mis-identifying jets as leptons

$$BR_{W \rightarrow l\nu} \approx 2/9$$

$$BR_{W \rightarrow cs} \approx 3/9$$

$$BR_{W \rightarrow ud} \approx 3/9$$

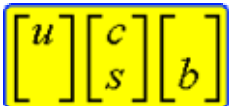
E_{bbbbll} \equiv $t\bar{t}b\bar{b} \rightarrow bW\bar{b}Wb\bar{b} \rightarrow llb\bar{b}b\bar{b}$ selection efficiency

$$= BR_{W \rightarrow l\nu}^2 (\varepsilon_b^4 + C_{3,1} \varepsilon_b^3)$$

$$E_{bbbbllud} = C_{1,1} BR_{W \rightarrow l\nu} BR_{W \rightarrow ud} (\varepsilon_b^4 + C_{3,1} \varepsilon_b^3) C_{1,1} \varepsilon_j$$

$$\varepsilon_{bbbbllcs} = C_{1,1} BR_{W \rightarrow l\nu} BR_{W \rightarrow cs} [(\varepsilon_b^4 + C_{3,1} \varepsilon_b^3) C_{1,1} \varepsilon_j + (C_{3,1} \varepsilon_b^3 \varepsilon_c + C_{2,2} \varepsilon_b^2 \varepsilon_c) \varepsilon_j]$$

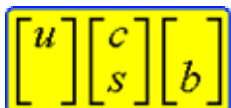
$$\varepsilon_{bbbbllqqq} = \dots$$



✓ Tools Selection

	Total	Selected	Efficiency (%)
$t\bar{t}H$	125,534	895	0.71
$t\bar{t}jj$	1,336,453	1,105	0.083
$t\bar{t}b\bar{b}$	395,669	2,751	0.70
$t\bar{t}Z$	113,811	384	0.34
$t\bar{t}^\dagger$	975,216	110	0.011

† PYTHIA inclusive $t\bar{t}$ for comparison





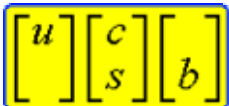
Tools

Selection

Estimated Yields (# events) @ 60 fb⁻¹

Signal (M_H = 120 GeV)

$$\bullet \underbrace{\sigma_{ttH}}_{747 \text{ fb}} \times \underbrace{\varepsilon_{ttH}}_{0.0071} \times \underbrace{\int L dt}_{60 \text{ fb}^{-1}} \approx 318$$



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CompHEP Backgrounds

• t \bar{t} jj	507,800 [fb] × 0.00083 × 60	≈	25,288
• t \bar{t} b \bar{b}	3,300 × 0.0070 × 60	≈	1,386
• t \bar{t} Z	650 × 0.0034 × 60	≈	132
			<hr/>
			26,807



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$$\mathbf{S/B} \approx \mathbf{0.012}$$

$$\mathbf{S/\sqrt{B}} \approx \mathbf{1.9}$$



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PYTHIA Background

$$\bullet t\bar{t} \quad 770,000 \times 0.00011 \times 60 \approx 5,082$$

5,082

S/B ≈ 0.063

S/√B ≈ 4.5



✓ Tools

✓ Selection

Estimated Yields (# events) @ 60 fb⁻¹

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✓ Tools

✓ Selection

Improvements

Estimated Yields (# events) @ 60 fb⁻¹

Signal (M_H = 120 GeV)

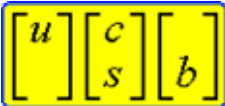
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CompHEP Backgrounds

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• ttbb:	3,300 × 0.0070 × 60	≈	1,386
• ttZ:	650 × 0.0034 × 60	≈	132
			<hr/>
			26,807

S/B ≈ 0.012
S/√B ≈ 1.9

Want
≥ 5





Tools



Selection

Improvements

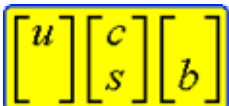
- Discrimination with/out $t\bar{t}$ reconstruction

$\nu\nu + jj \Rightarrow$ lose constraints, many combinations

- hard to use top mass to isolate Higgs.

Try to exploit kinematics of the b jets alone

- General approach showed promise at Tevatron
- Expect to be less successful at LHC due to frequency of harder ISR/FSR
- Currently
 - optimizing discriminant values (lepton id, b tagging)
 - Identifying new event variables to separate S and B
 - » Applying fitting methods (later... neural net)

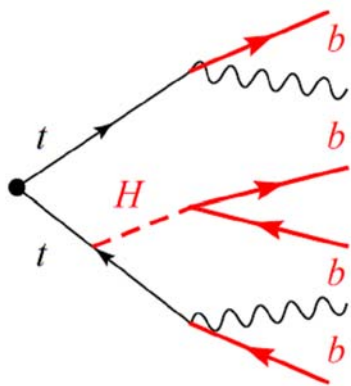


✓ Tools

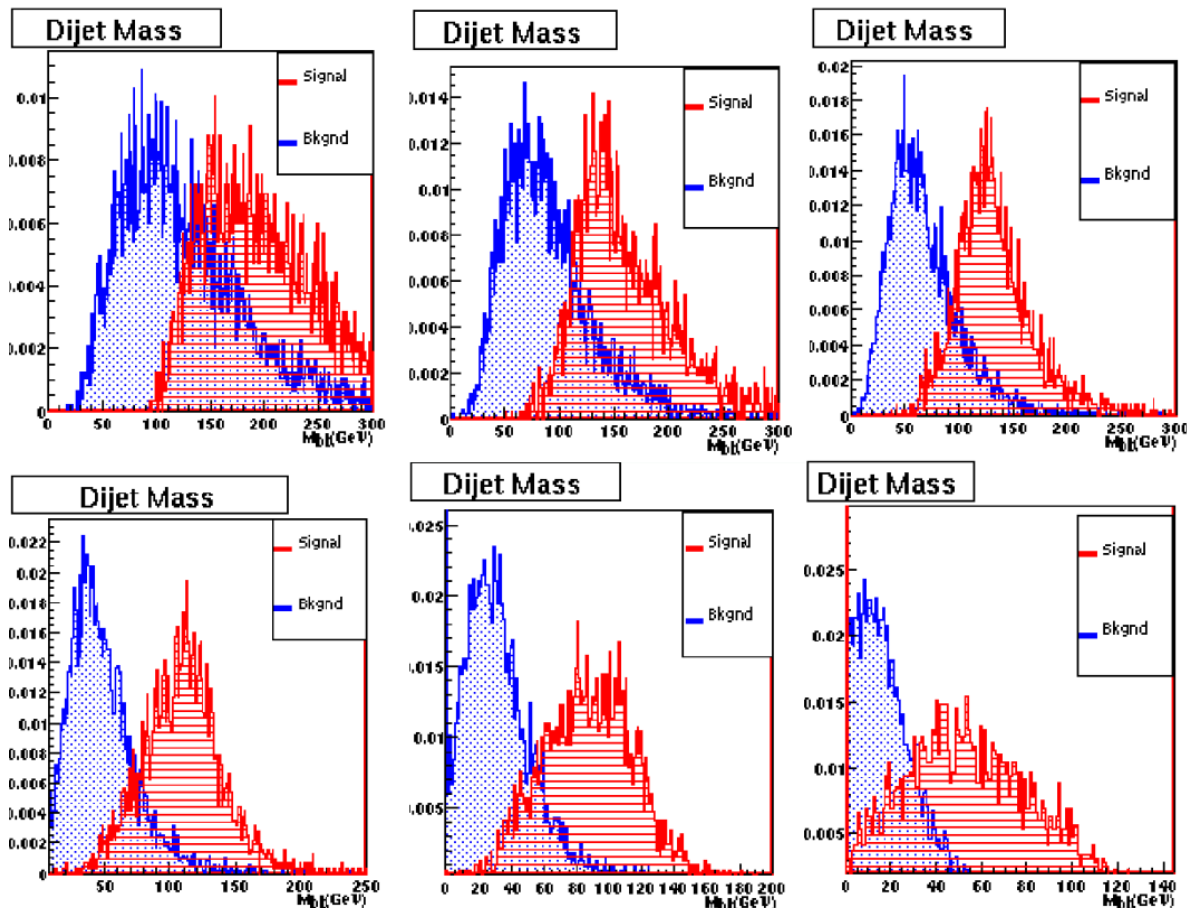
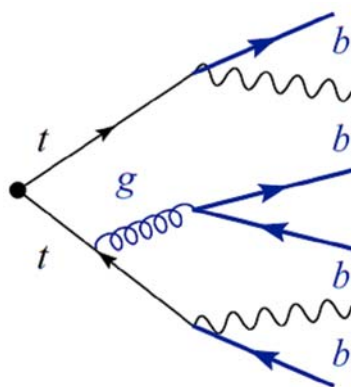
✓ Selection

Improvements

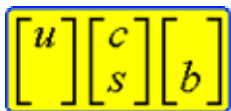
Tevatron Example: 6 ordered mass pairs for each event and plotted for **signal** and **backgrounds**



$$M(g \rightarrow bb) < M(H \rightarrow bb)$$



[Higgs Workshop, FNAL (May 5, 2001) — Incandela]

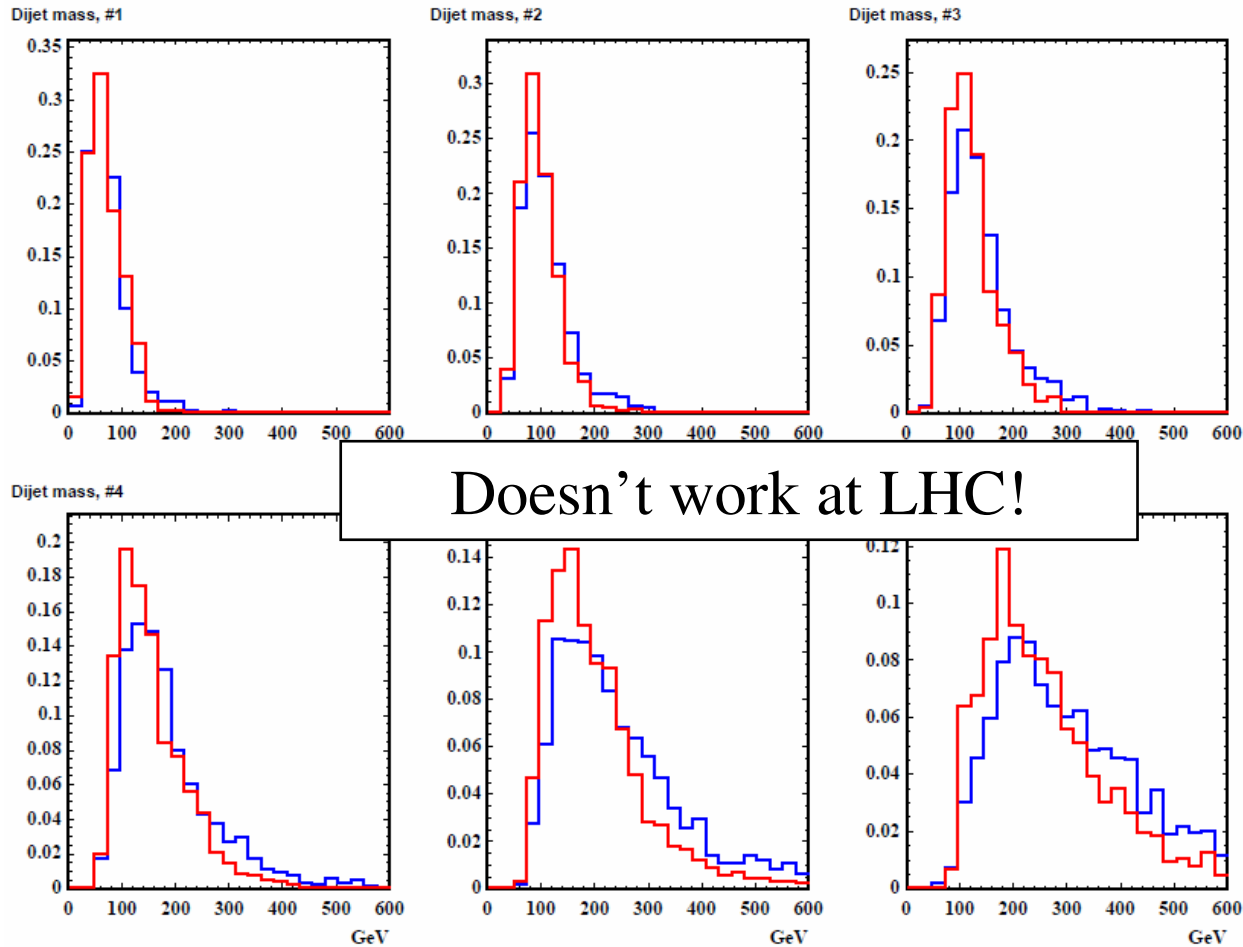


✓ Tools

✓ Selection

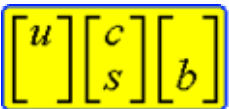
Improvements

~90%
@ LHC

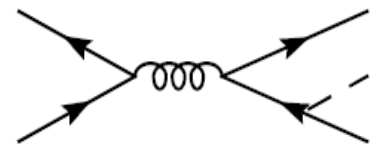
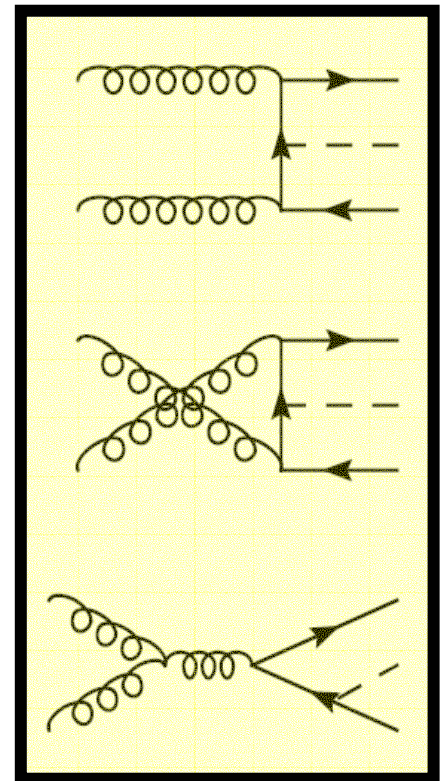


Doesn't work at LHC!

— $t\bar{t}H$
 — $t\bar{t}jj + t\bar{t}b\bar{b} + t\bar{t}Z$ (CompHEP)



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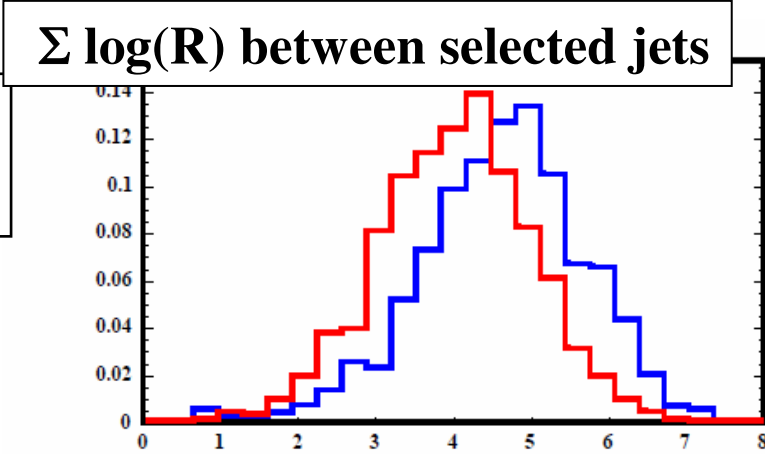
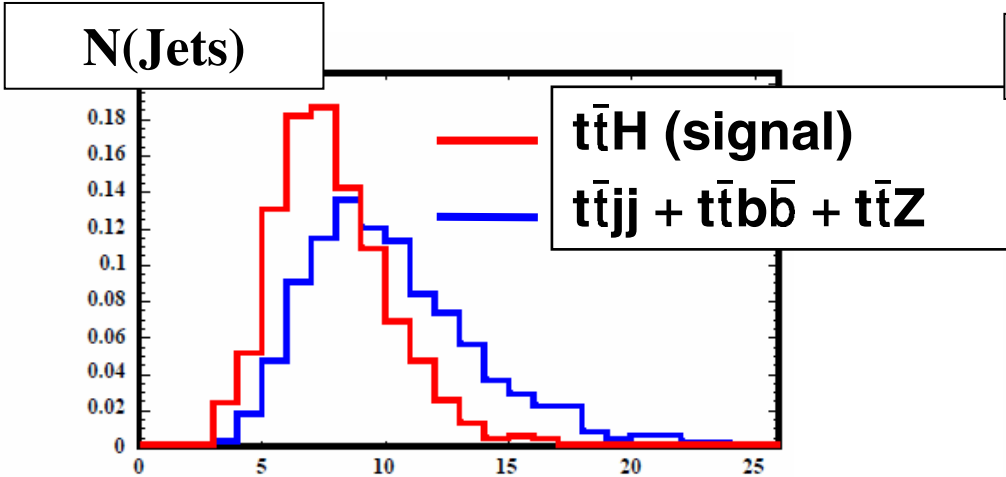


✓ Tools

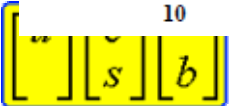
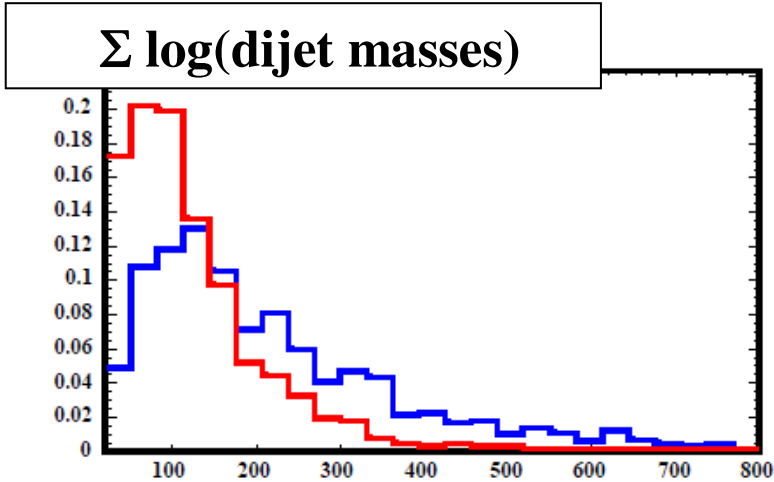
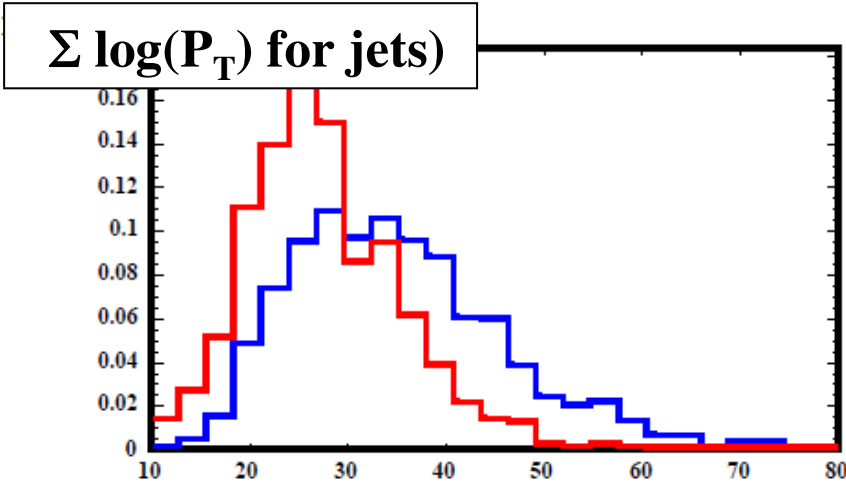
✓ Selection

Improvements

Working on S,B fitting



Prospective discriminators (vs. CompHEP background)

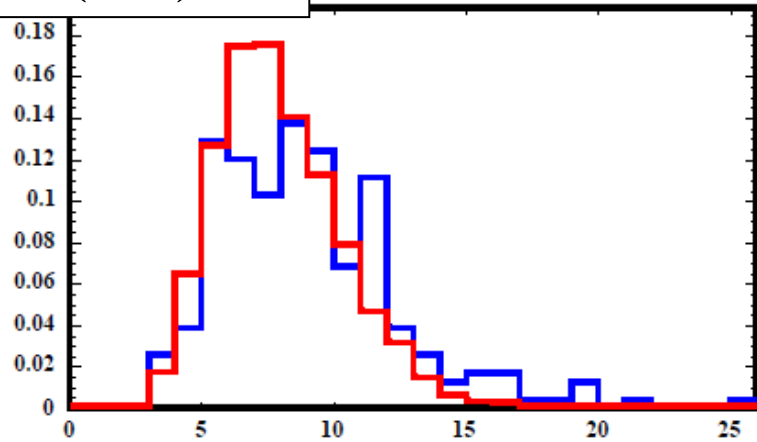


✓ Tools

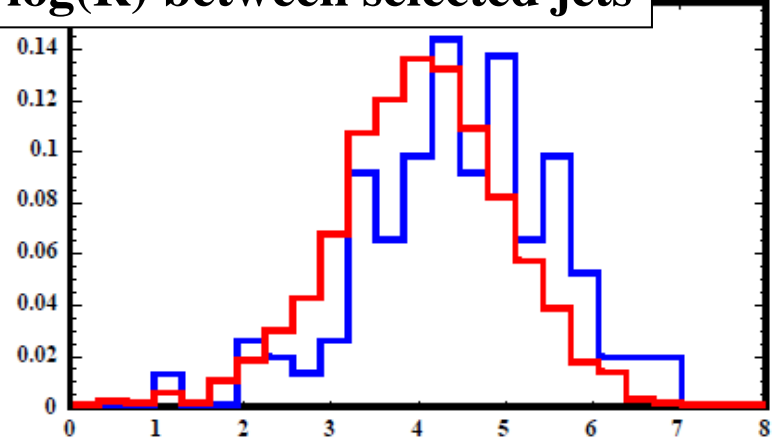
✓ Selection

Improvements

N(Jets)

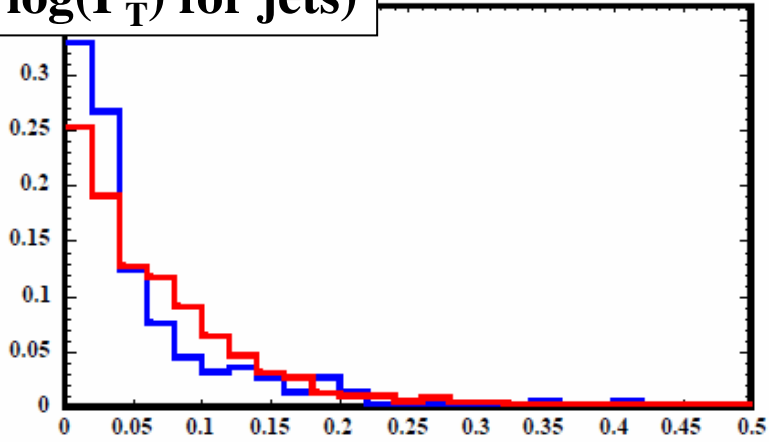


$\Sigma \log(R)$ between selected jets

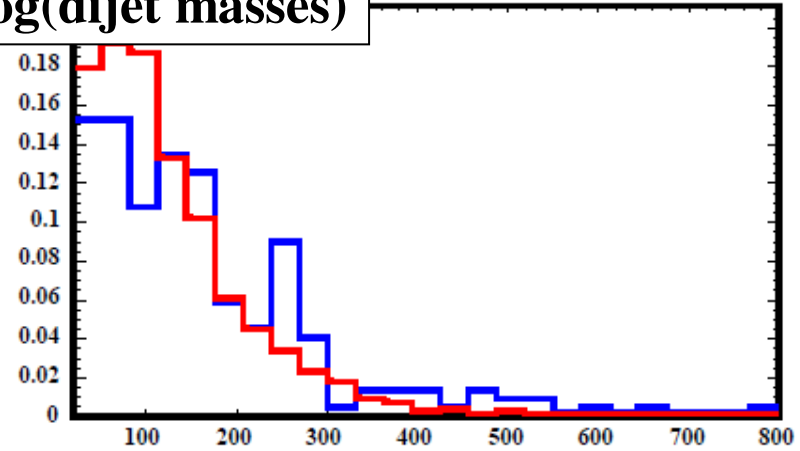


Prospective discriminators (vs. PYTHIA background)

$\Sigma \log(P_T)$ for jets



$\Sigma \log(\text{dijet masses})$





Tools



Selection



Improvement



M_H

- **Summary**

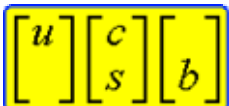
- **Basic tools mostly in hand**

- Will refine lepton id and b-tagging
- Improved jet corrections, if available etc.

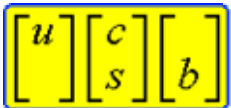
- **Decent S/\sqrt{B}**

- May improve with aforementioned optimizations
- As it is, could give confirmation of a signal seen in other channels for large $\int L dt$

- **Continue to study kinematics for further improvements**



More Information



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Slide 41

✓ Tools

Selection

Percent of events with...	$t\bar{t}jj$	$t\bar{t}$
≥ 3 b-tags	3.8	1.8
...and ≥ 2 “hard” [†] gluons	3.7	1.3
[†] $P_T > 15$ GeV, $ \eta < 3$		
Actual selection efficiency (%)	0.083	0.011
Yield at 60 fb^{-1}	25,288	5,082

Fraction of selected events that are dilepton	In MC	0.58	0.39
	back-of-envelope estimate	0.57	

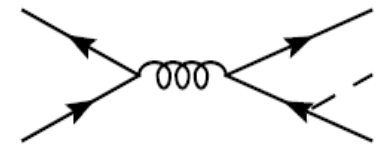
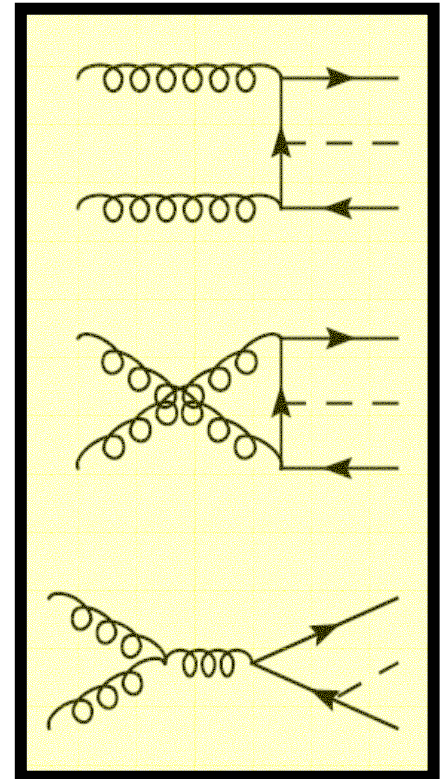
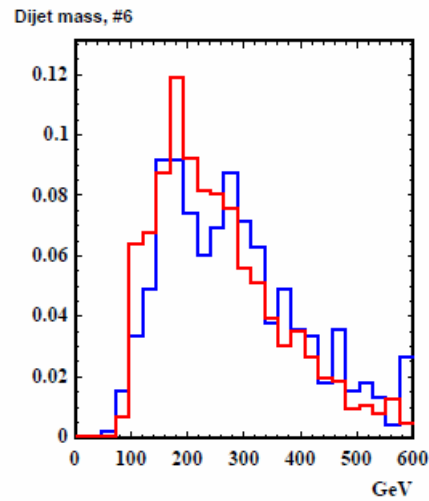
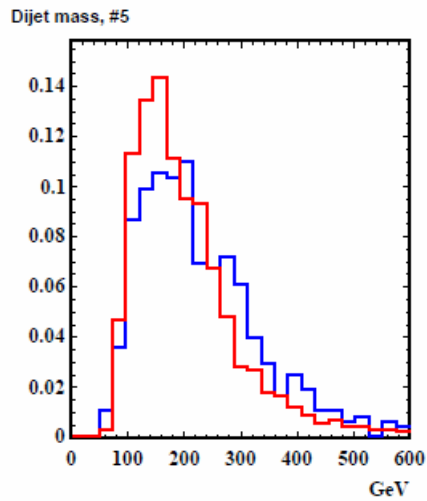
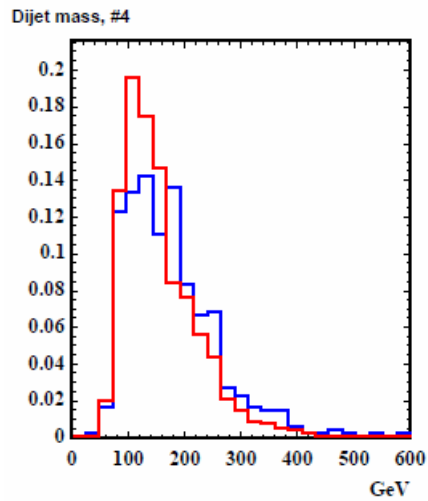
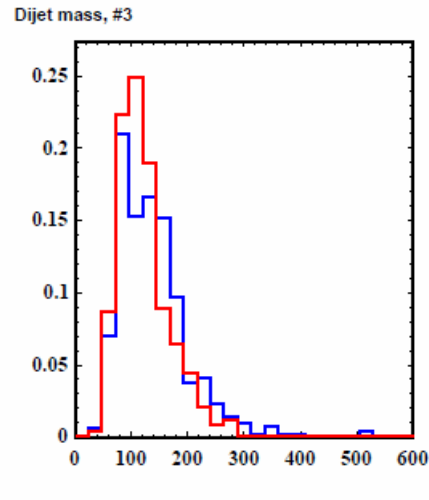
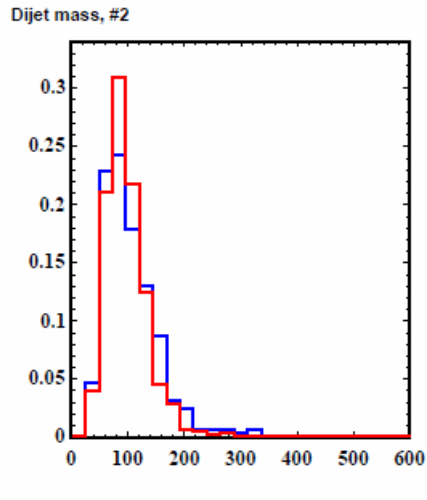
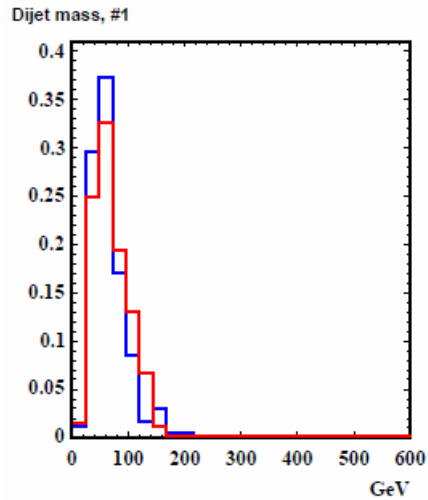


✓ Tools

✓ Selection

Improvements

~90%
@ LHC



— $t\bar{t}H$ (Signal)

$\left[\begin{matrix} u \\ c \\ s \\ b \end{matrix} \right]$ $t\bar{t}$ leptonic (PYTHIA Background)

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