matthew schwartz, johns hopkins

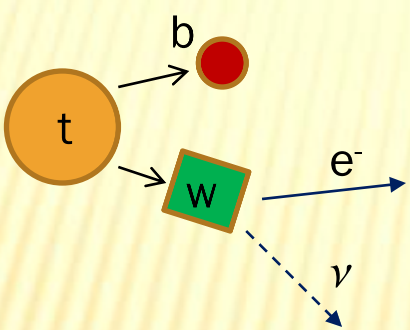
TOP-TAGGING

INTRODUCTION TO TOP PHYSICS

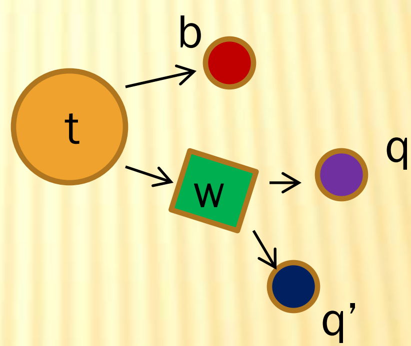
- The top quark is the **heaviest** known particle

$$m_t = 172.6 \pm 2.4 \text{ GeV}$$

- Top decays to a **b** and a **W**



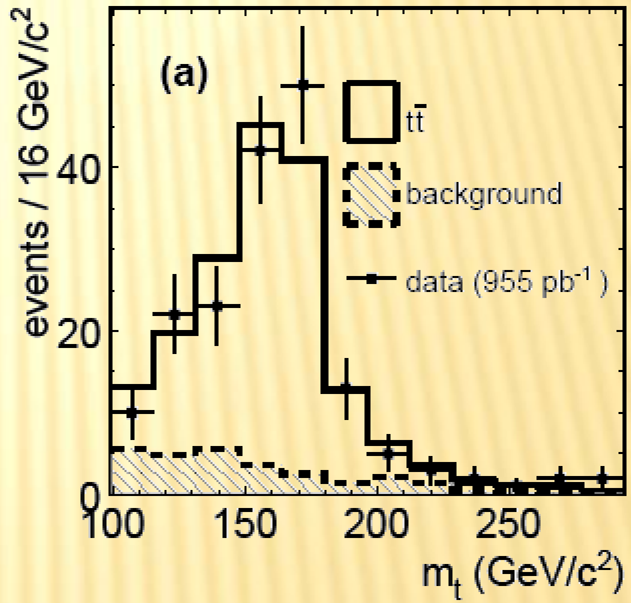
semi-leptonic



hadronic

TOPS AT THE TEVATRON

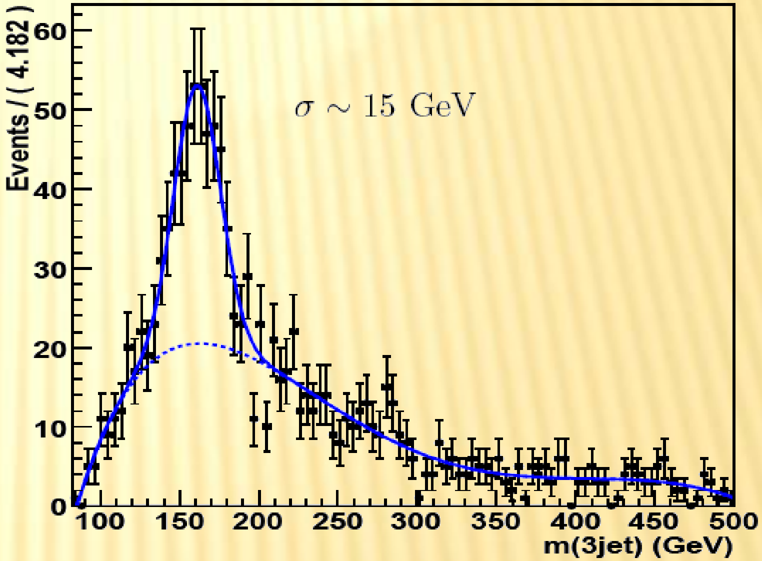
- We have already produced 10,000 tt pairs at the Tevatron
- What do we know about the top?
  - mass: ~1%
  - charge: not -4/3 to ~95%
  - decay modes
    - Wb > 80%
    - Zc,Zγ < 10%
  - (V - A) coupling ~12%
  - evidence for single top (3σ)
- What don't we know?
  - spin
  - width
  - Yukawa coupling
  - non-Wb decay modes



TOPS AT THE LHC

- cross section is 850 pb at the LHC (vs 8 pb at the Tevatron)
- LHC will produce 1 million ttbar pairs/ fb^{-1}

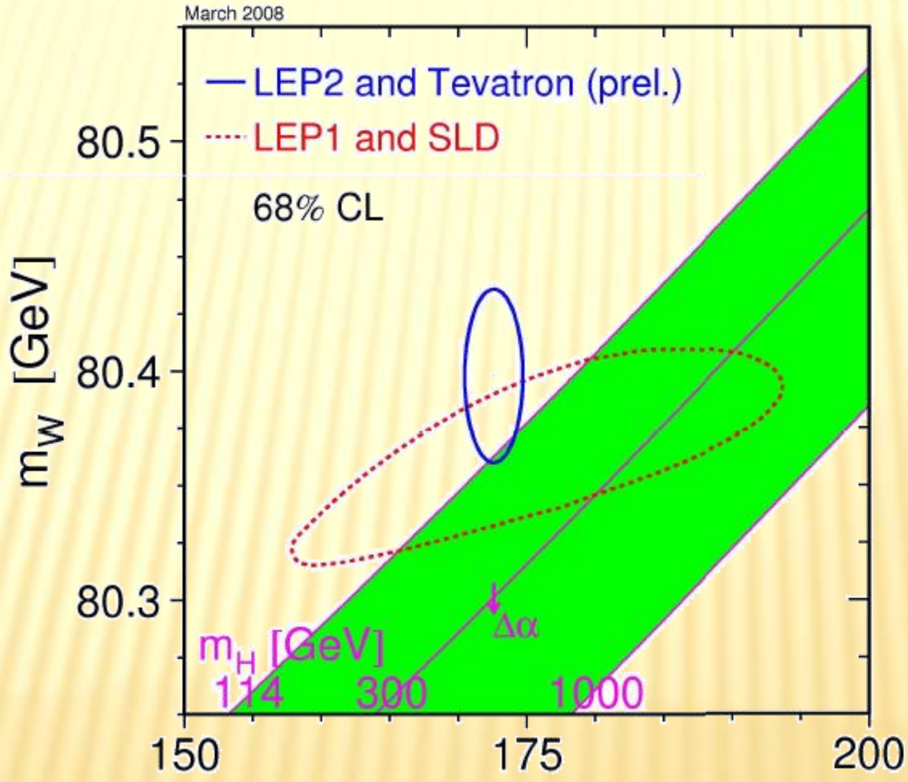
Hubaut, hep-ex/0605029



- Allows precision top physics.
- With 10 fb^{-1} :
  - 0.5% accuracy on mass
  - 2% accuracy on V-A couplings
  - 4% accuracy on spin
  - Yukawa coupling – depends on Higgs mass
    - 20% accuracy with 30 fb^{-1} if $m_H \sim 200$ GeV,
  - Flavor-Changing Neutral Currents (eg. $t \rightarrow cZ$):
    - BR< 5×10^{-4}

TOPS

- The top contribution to precision electroweak studies give the best indication of new physics so far



TOPS

•Top couples **strongly** to the Higgs

$$\lambda_t = \sqrt{2}\frac{m_t}{v} = 0.99$$

•The top usually couples strongly to new physics too

- Stops in **supersymemtry**
- Kaluza-Klein (KK) modes in **extra dimensions**
- Top primes/Z primes in **Little Higgs** models
- KK gluons in **Randall-Sundrum** models

New Physics Searches

Top Decays

•$t \rightarrow H^+ b$,

•FCNCs

- strong indirect constraints from **B-physics**
- window open for t_R decays

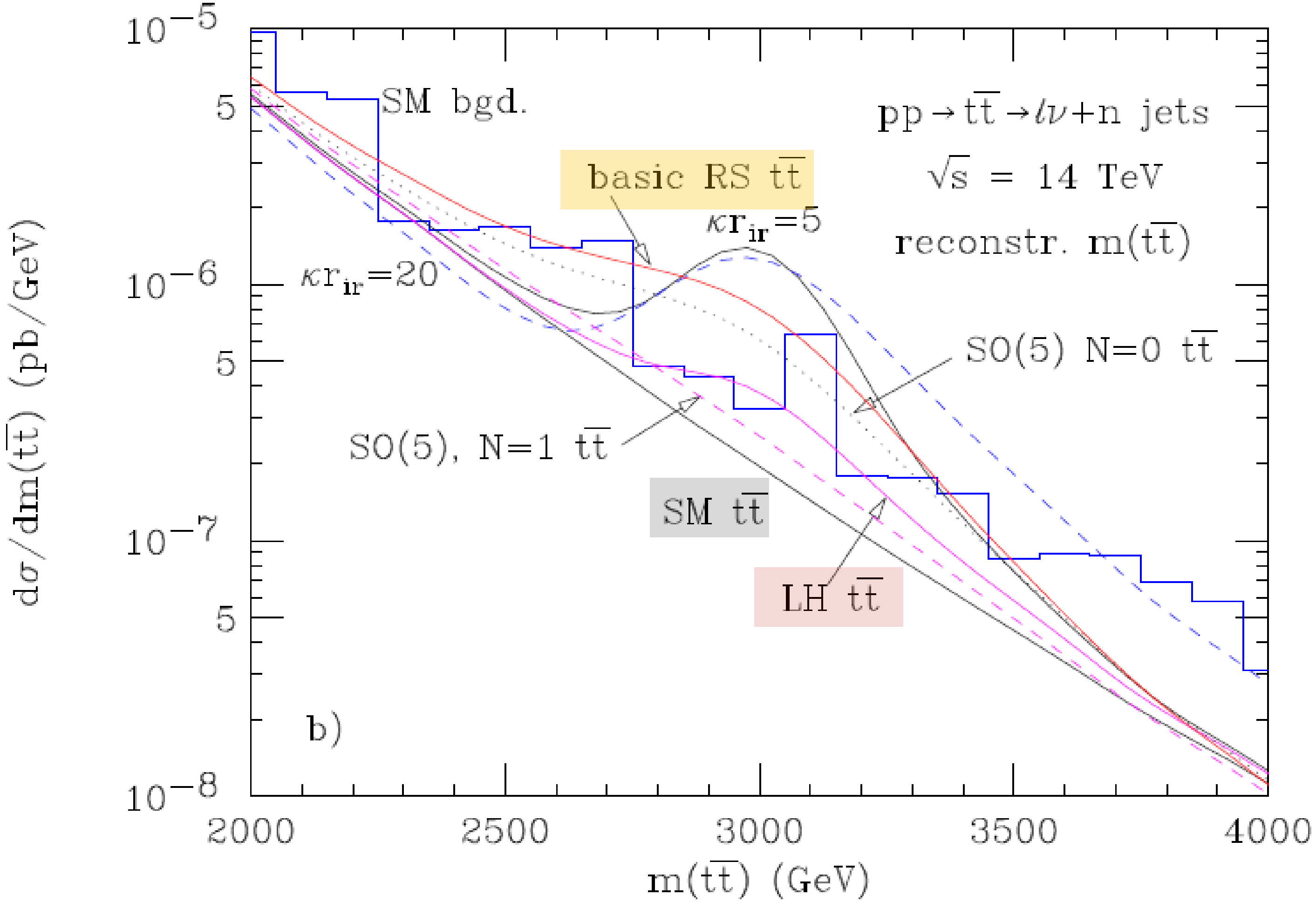
Top Production

- tt **resonances**
- top-partner pair production

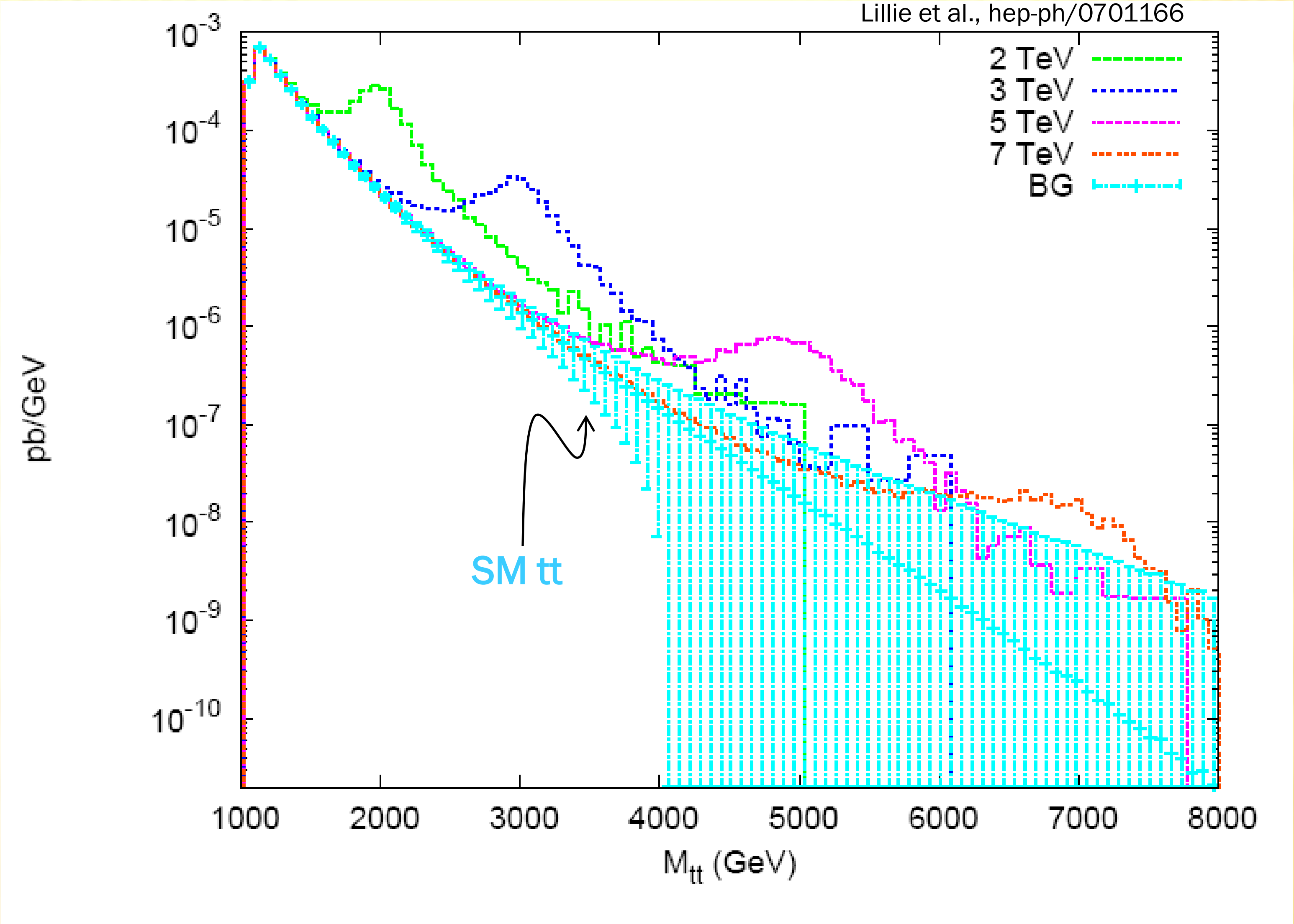
$pp \rightarrow t't' \rightarrow t\, t + \not{E}_T$

TT RESONANCES

Baur and Orr, arXiv:08031160

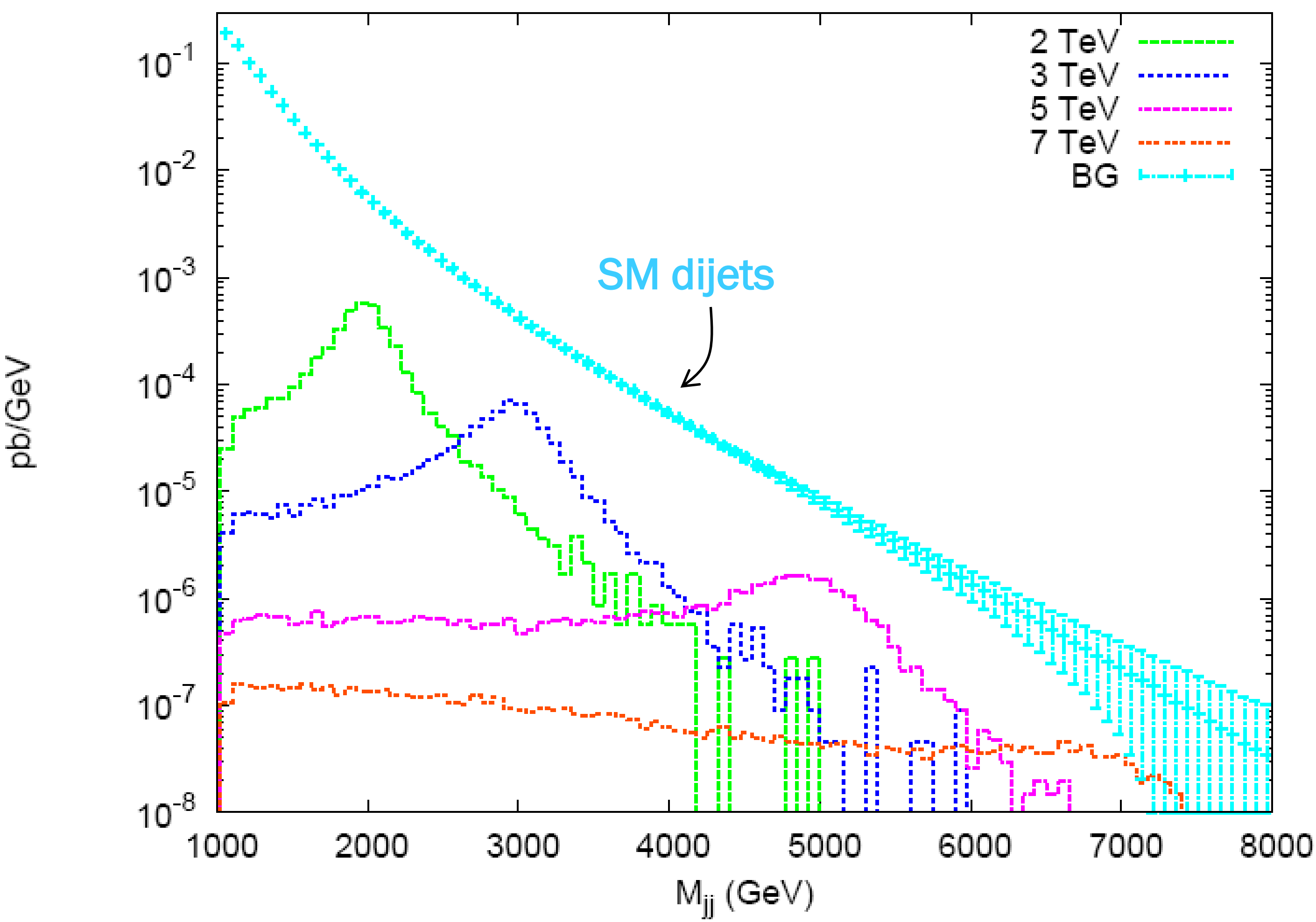


KK GLUONS

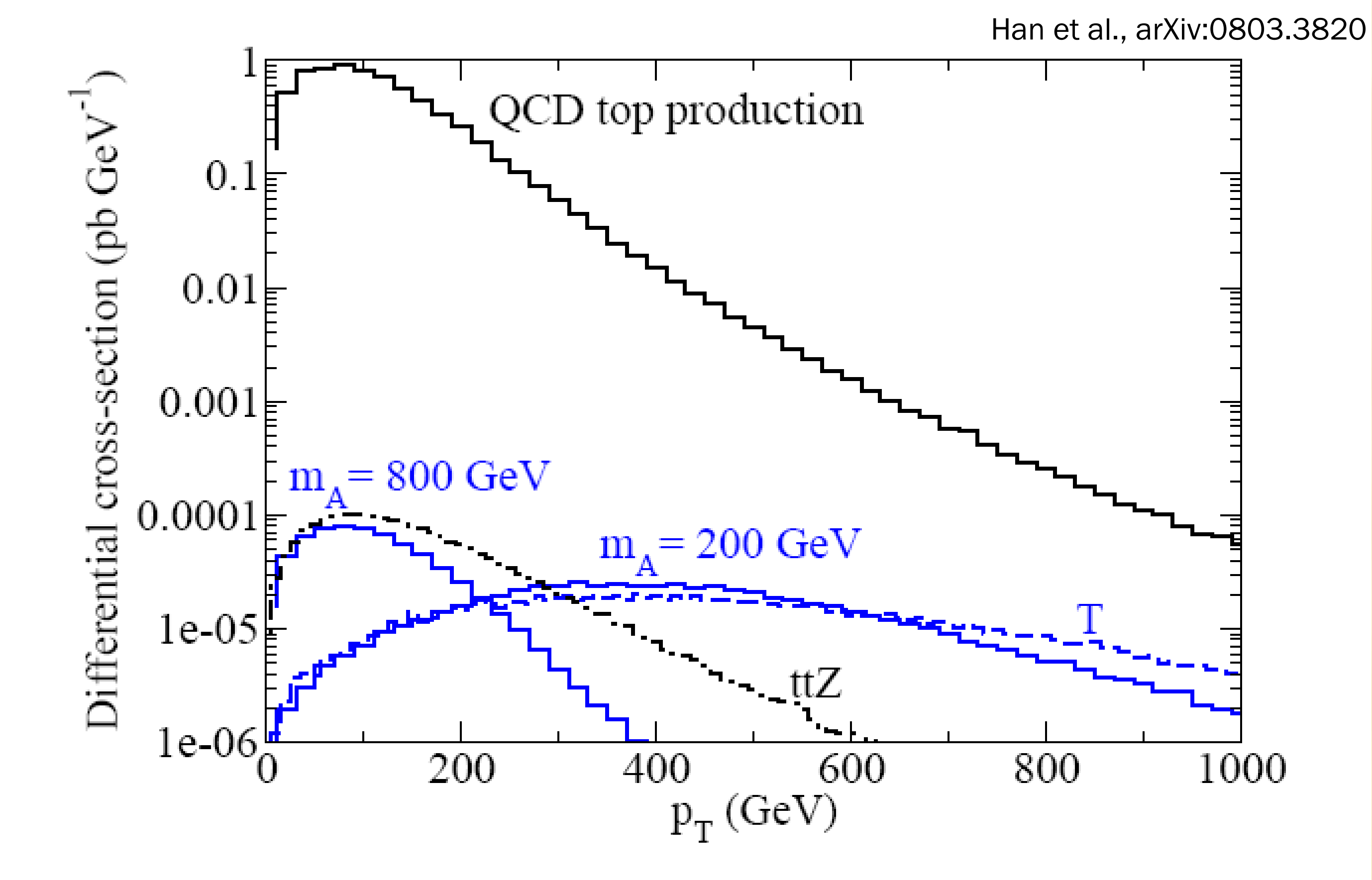

Lillie et al., hep-ph/0701166
pb/GeV
M_{tt} (GeV)
2 TeV
3 TeV
5 TeV
7 TeV
BG
SM tt
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
10^-10
1000
2000
3000
4000
5000
6000
7000
8000

BACKGROUND IS HUGE

Lillie et al., hep-ph/0701166



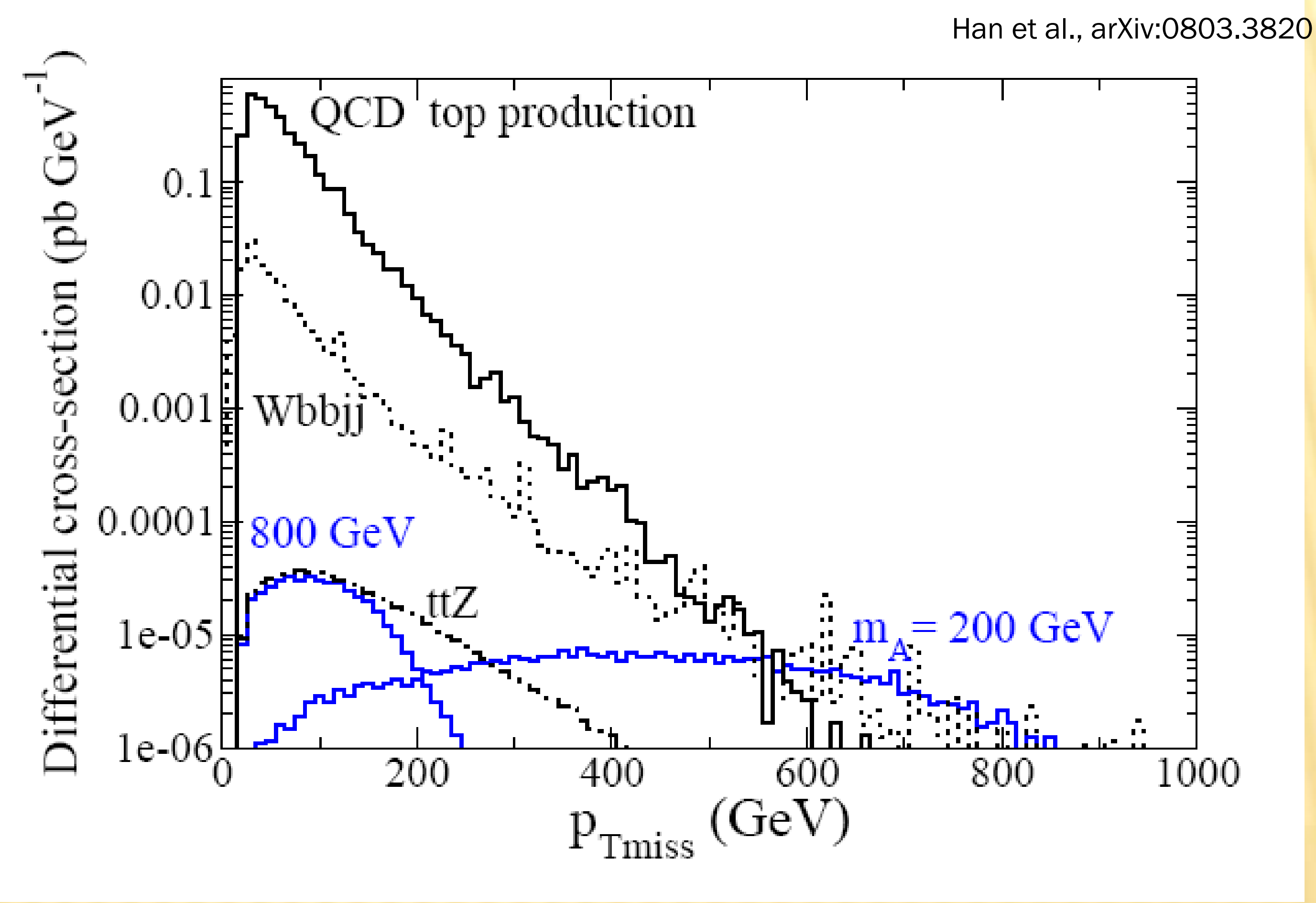
TOPS + $\not{E}_T$



$$pp \to T\bar{T}\ X \to tA^0\ \bar{t}A^0\ X \to t\bar{t} + \not{E}_T + X$$

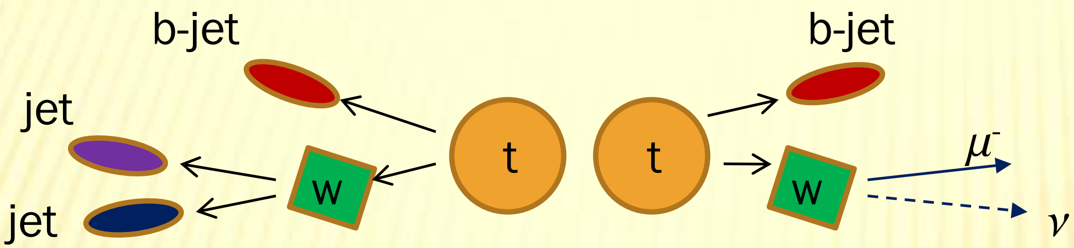
TOPS + $\not{E}_T$

Even with missing energy cut, QCD background is huge



FINDING TOPS

Standard Procedure is look for tt in lepton+jets channel:



= 2 b-jets + 2 jets + μ + E_T

- Backgrounds are
  - Wbb + jets
  - W+ jets
  - t + jets

- Difficult to use electrons – at high p_T not isolated
- Branching ratio with one muon is 10% -- lose a lot of signal
- Branching ratio to two muons = 1% -- lose most of signal

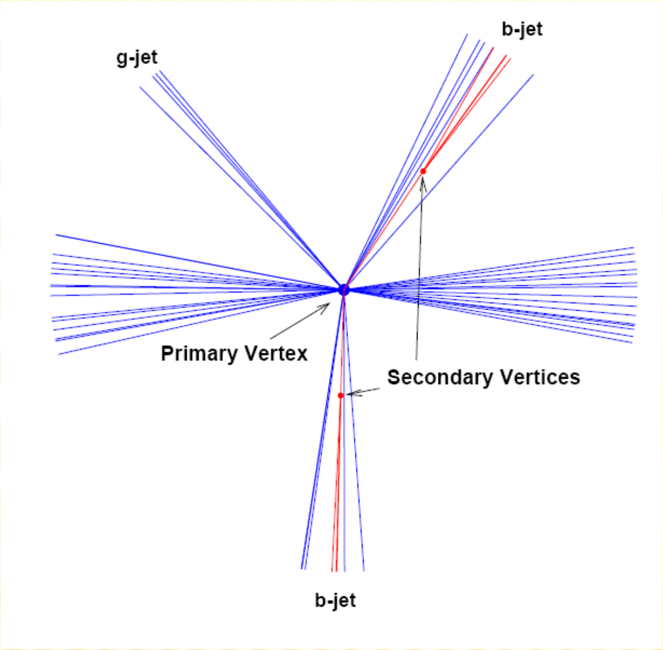
- Require 1 or 2 b-tags
  - b-tagging efficiency degrades at high p_T

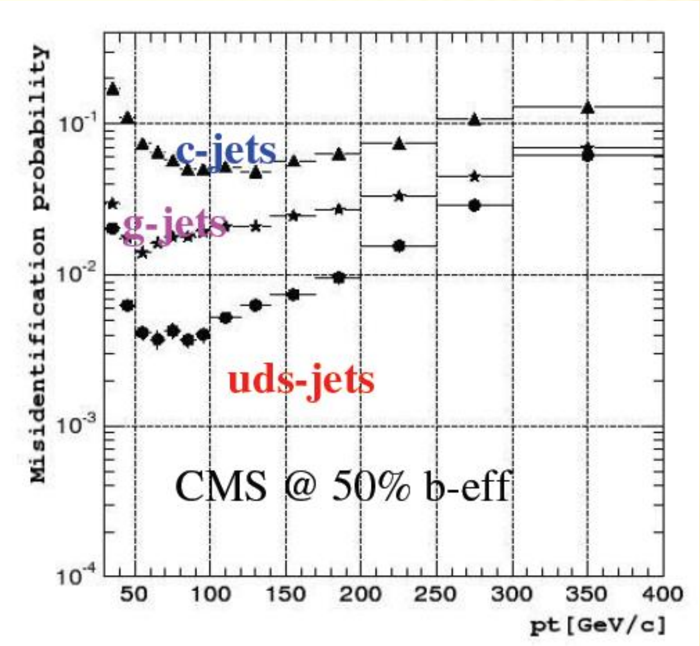
- At high p_T, jets on hadronic side are not isolated

B-TAGGING

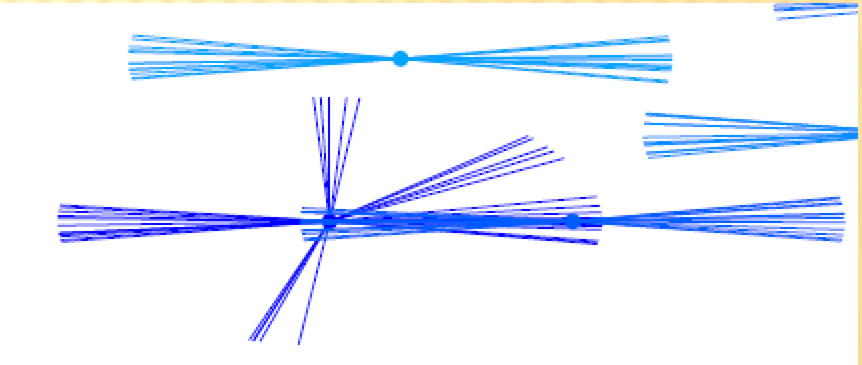
Taken from A. Rizzi

b-tagging efficiency degrades at high p_T



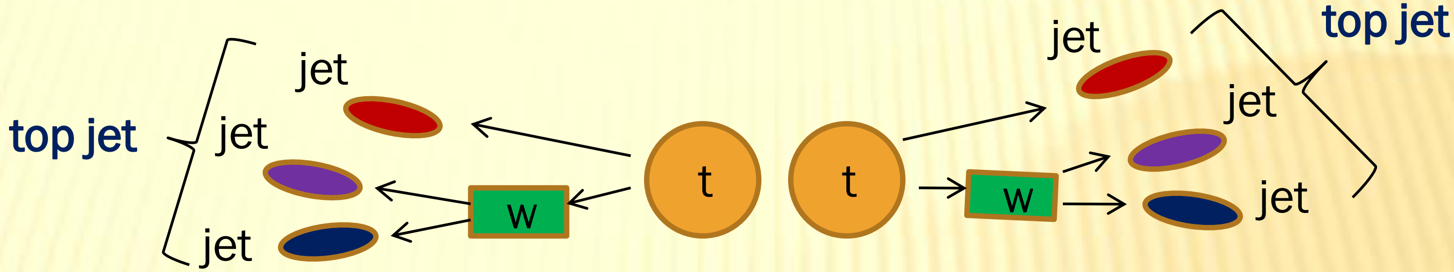


and high luminosity:



ALL-HADRONIC TT

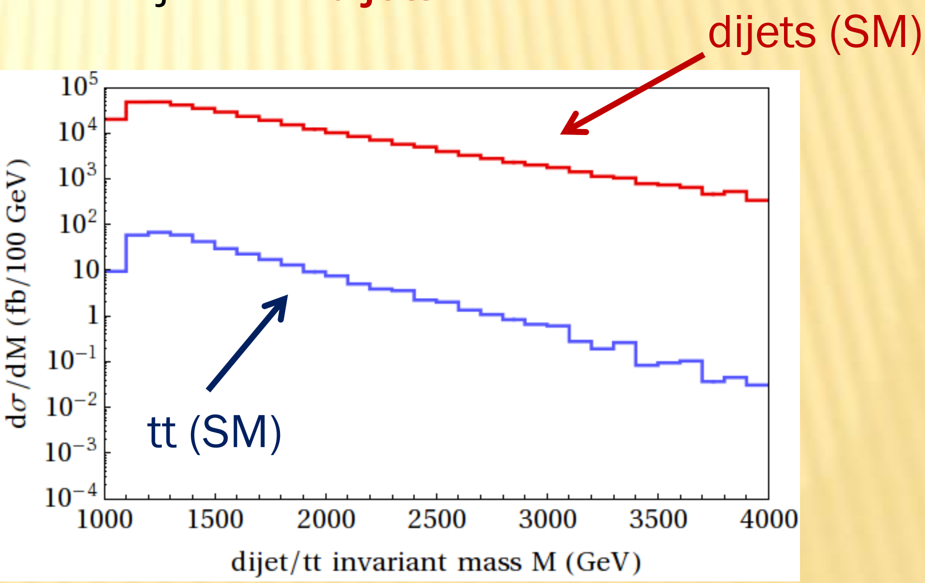
Can we tag the **all-hadronic** tt events at **high p_T**?



tt events look just like **dijets**!

D. Kaplan, K. Rehermann, MDS, and B. Tweedie
arXiv:0806.0848

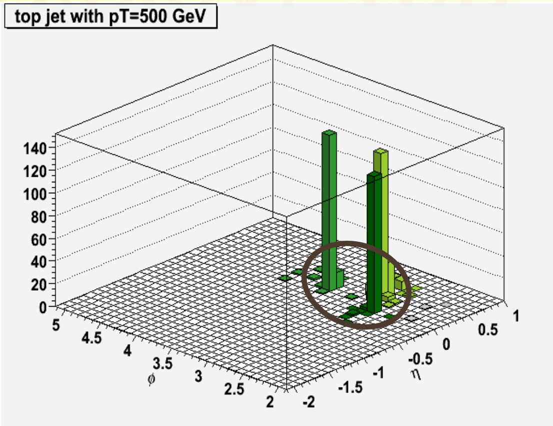
1. Look for **subjets**
2. Cut on **top mass**
3. Cut on **W mass**
4. Cut on **helicity angle**

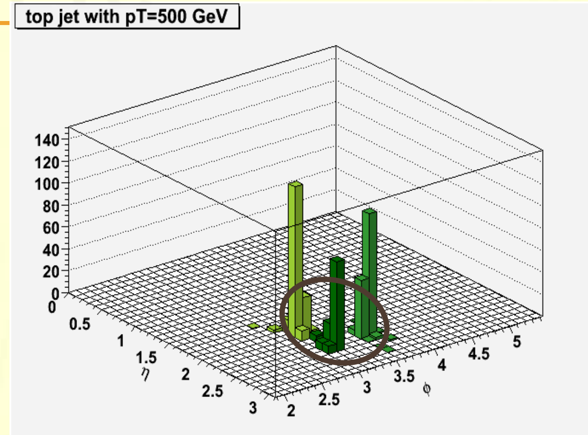


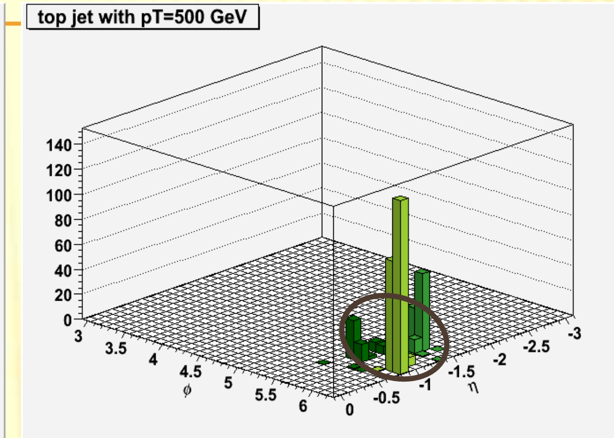
We can beat the background with no b-tagging!

TYPICAL TOP JETS

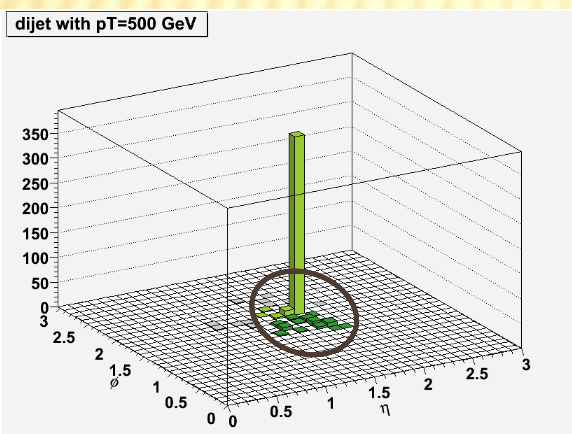
$p_T > 500$ GeV

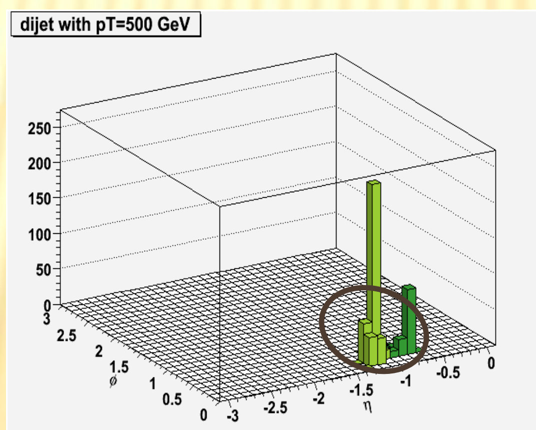


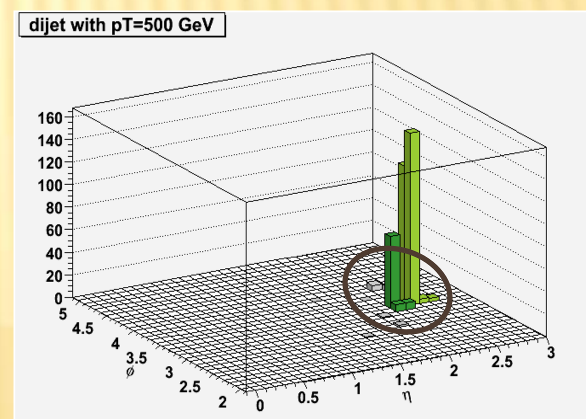




TYPICAL DIJETS

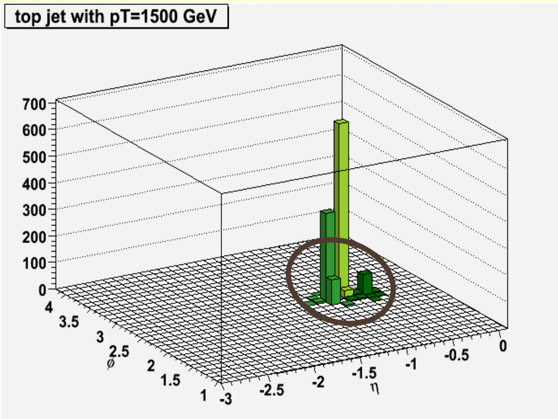


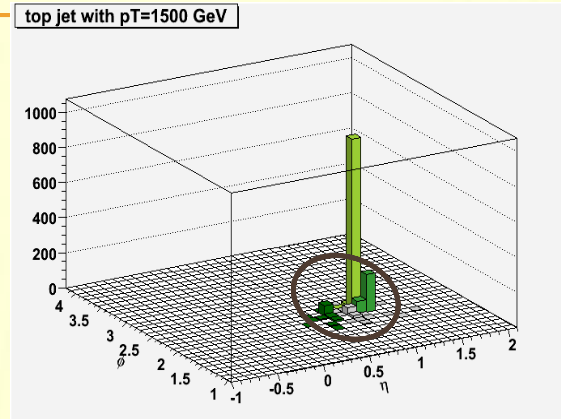


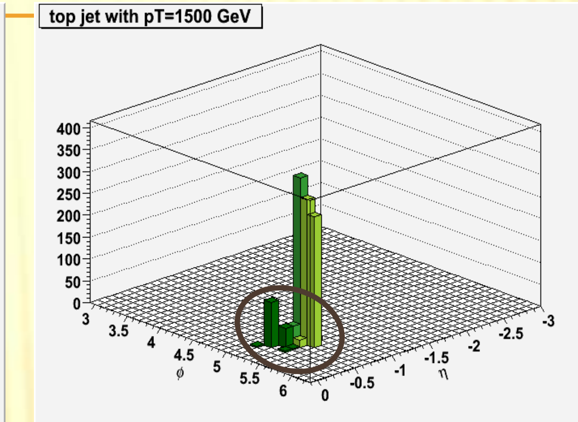


TYPICAL TOP JETS

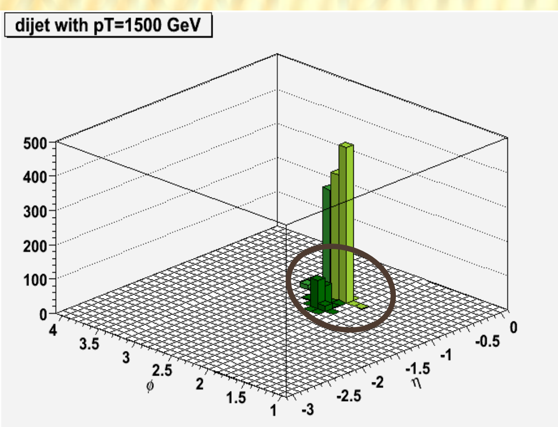
$p_T > 1500$ GeV

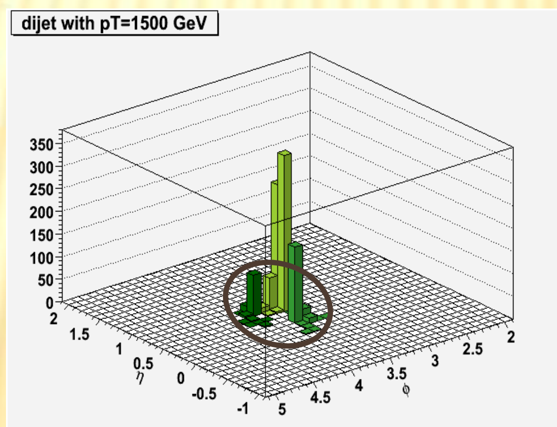


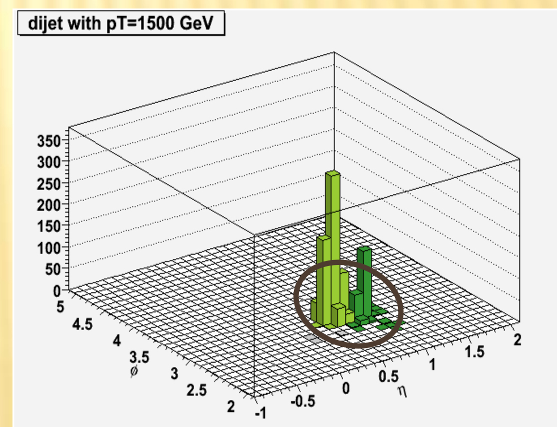




TYPICAL DIJETS

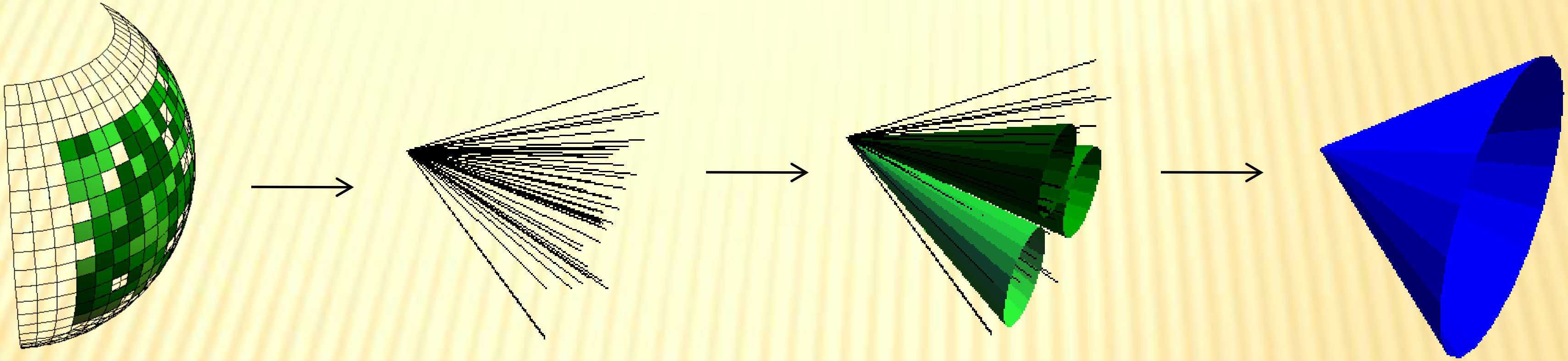




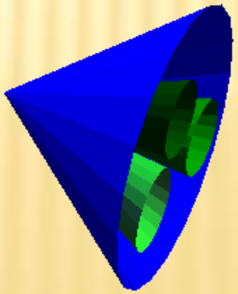


SUBJET DECOMPOSITION

1. Find **fat jets** first
   - We use **Cambridge-Aachen** algorithm – purely **geometric**
   - **Fat jet** size R = 0.4-0.8



2. **Reverse** clustering steps
   - **Ignore soft "particles"**: $\frac{p_T^{(\text{particle})}}{p_T^{(\text{jet})}} > \delta_p \sim 0.05 - 0.1$
   - Demand **minimal separation**: $|\Delta\eta| + |\Delta\phi| > \delta_r \sim 0.2$
   - Tops should have **3** (or 4) **subjets**

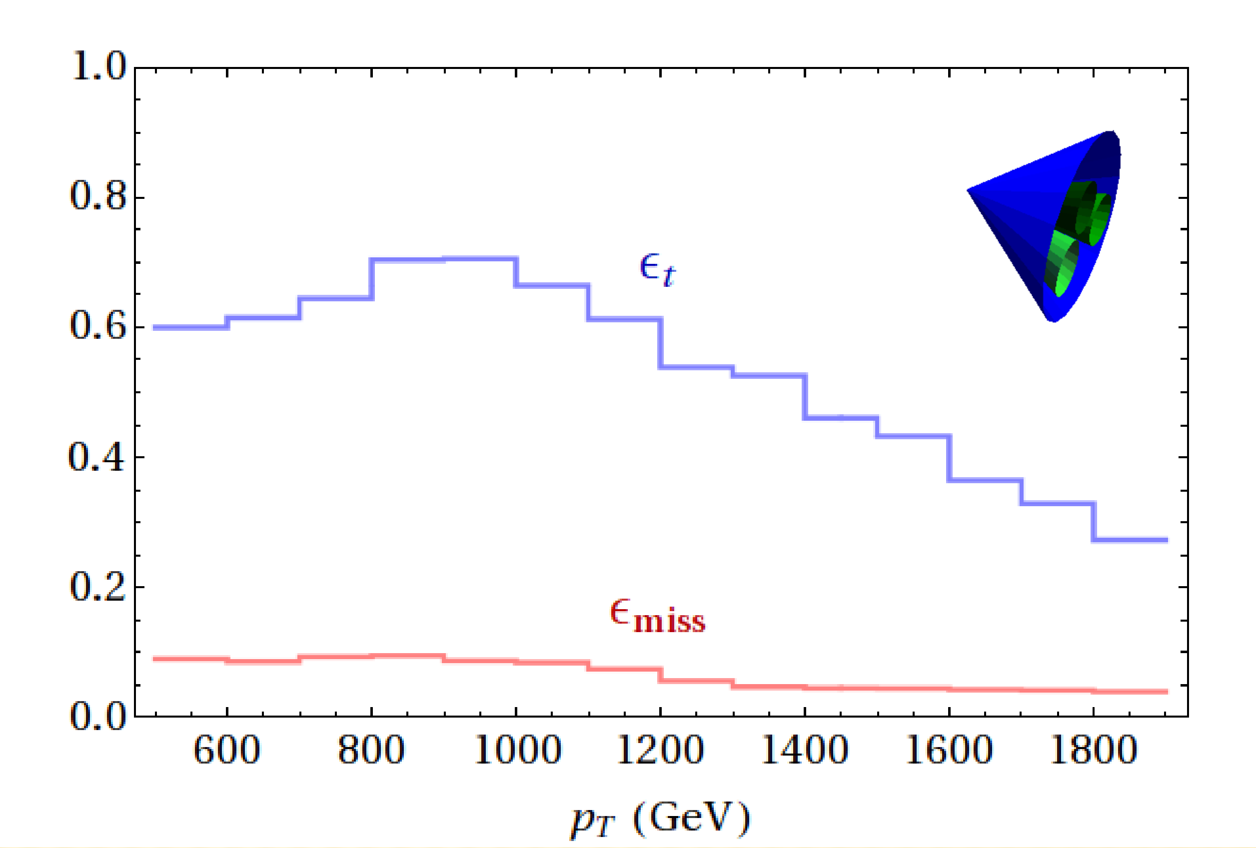


EFFICIENCY

- **Fat jet** with 3 or 4 **hard** (δ_p), **separated** (δ_r) **subjets**

keep 60% of tops

reject 90% of jets



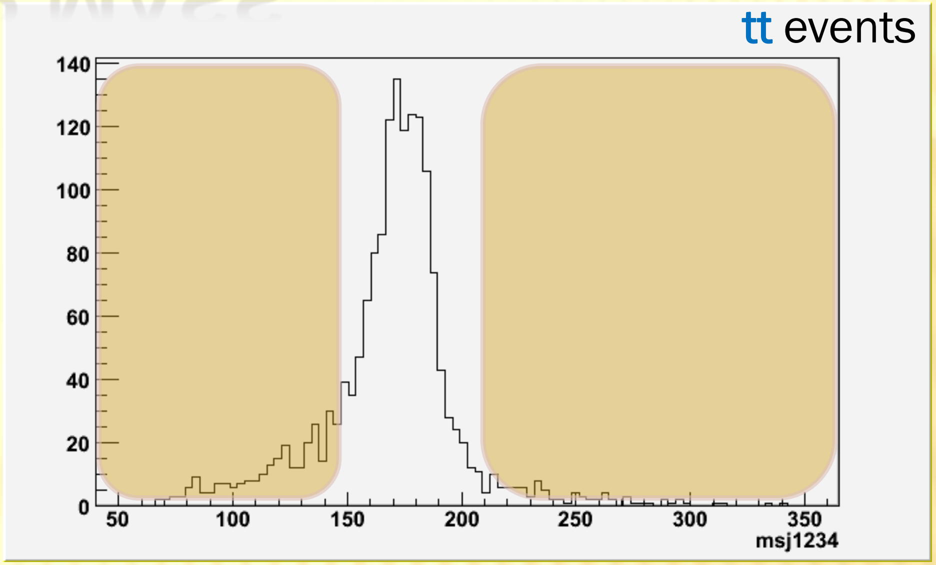
CUT AROUND TOP MASS

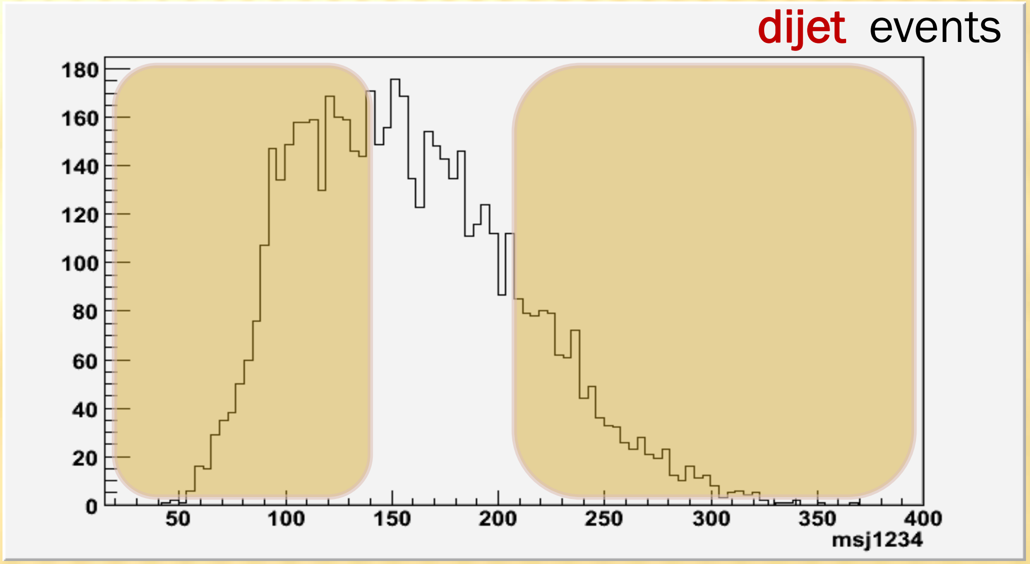
p_T > 700 GeV

- After subjet requirement
- Cut on fat jet mass around M_t

145 GeV< M_j < 205 GeV

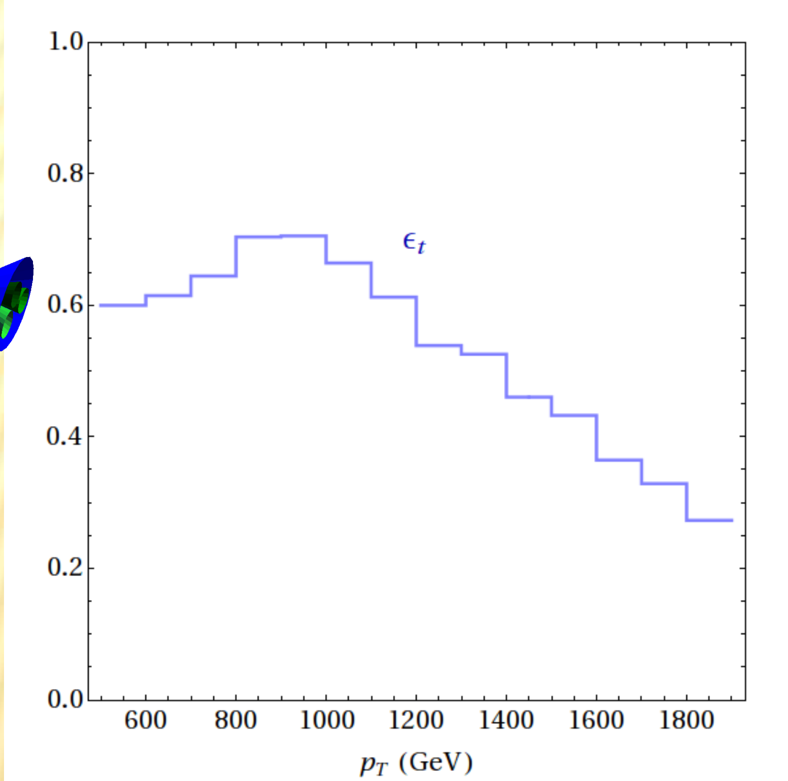
(for M_t = 175 GeV)

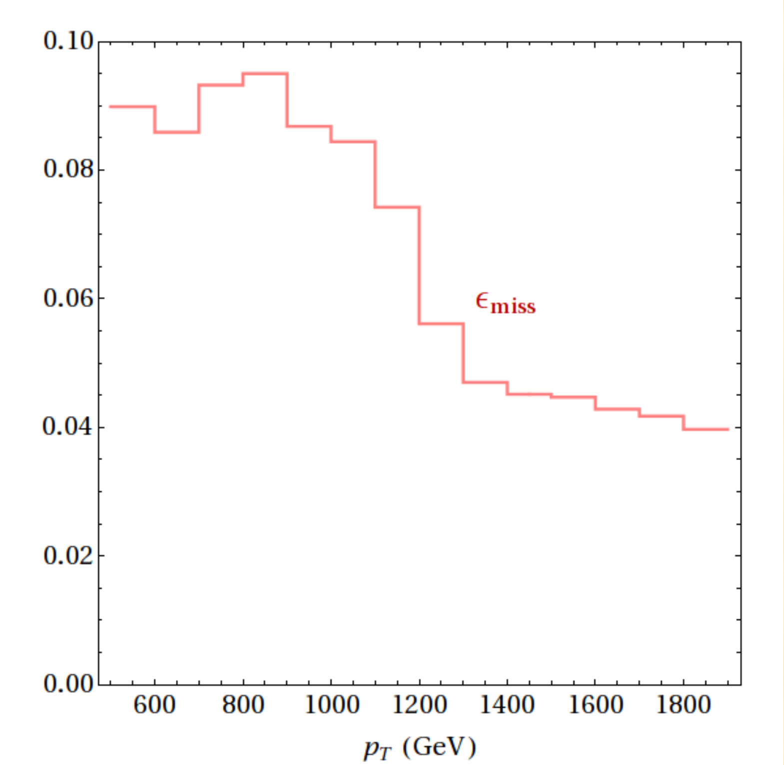




EFFICIENCIES

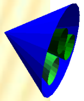
subjet cut only



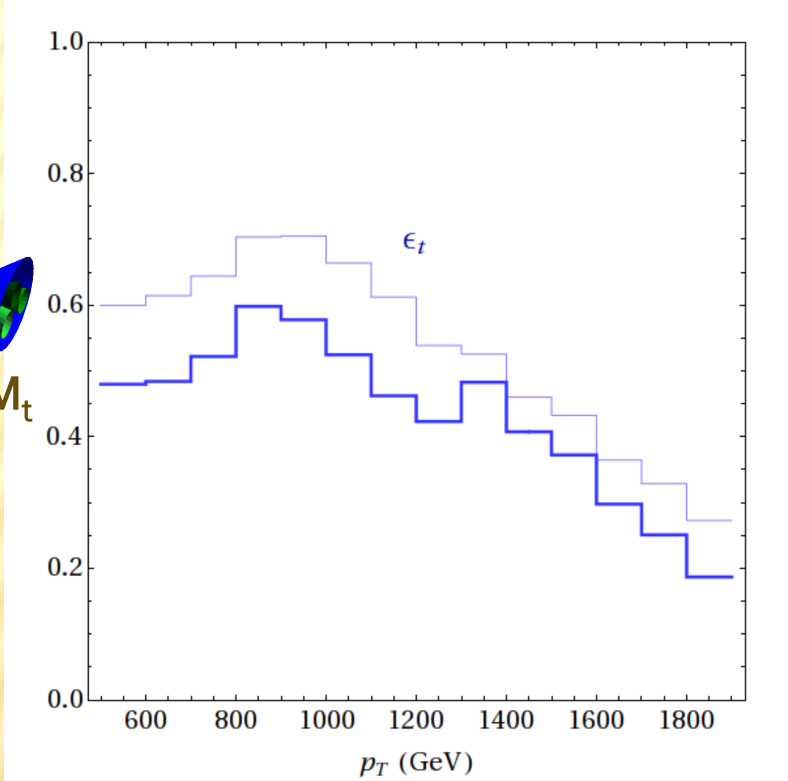


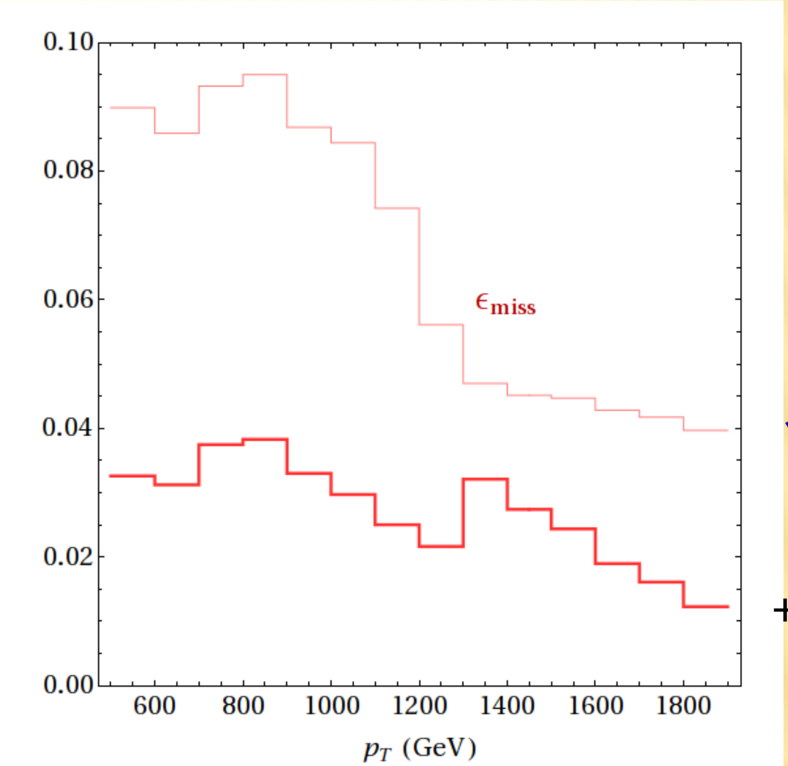
EFFICIENCIES

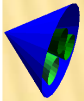
subjet + M_t cuts



+ M_t







+ M_t

CUT AROUND W MASS

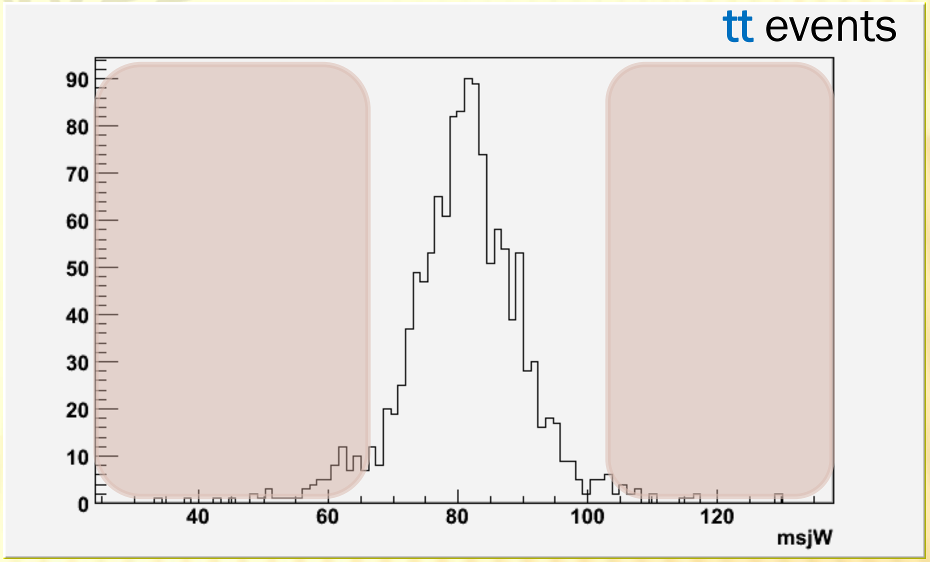
p_T > 700 GeV

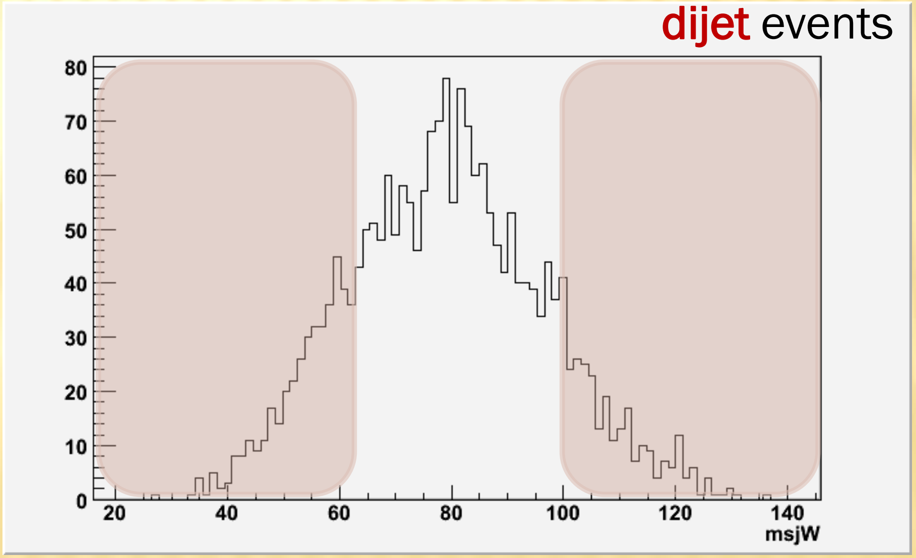
- After **subjet** requirement
- After M_t cut
- **One pair** of jets
  should have mass M_W

65 GeV< M_{12} < 105 GeV

(M_W = 80 GeV)

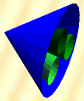
M_{12} ≡ pair whose mass is closest to M_W



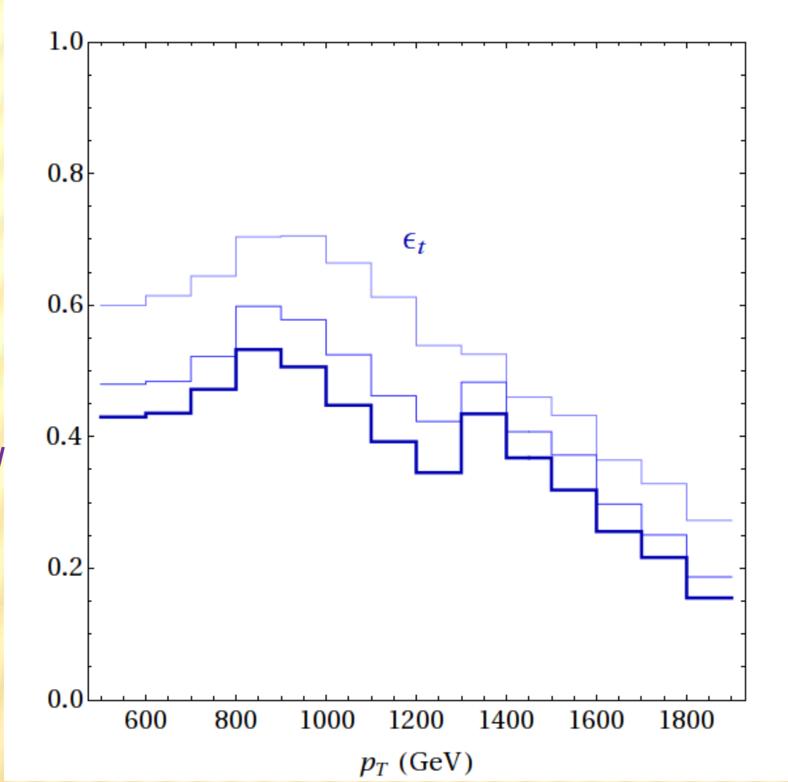


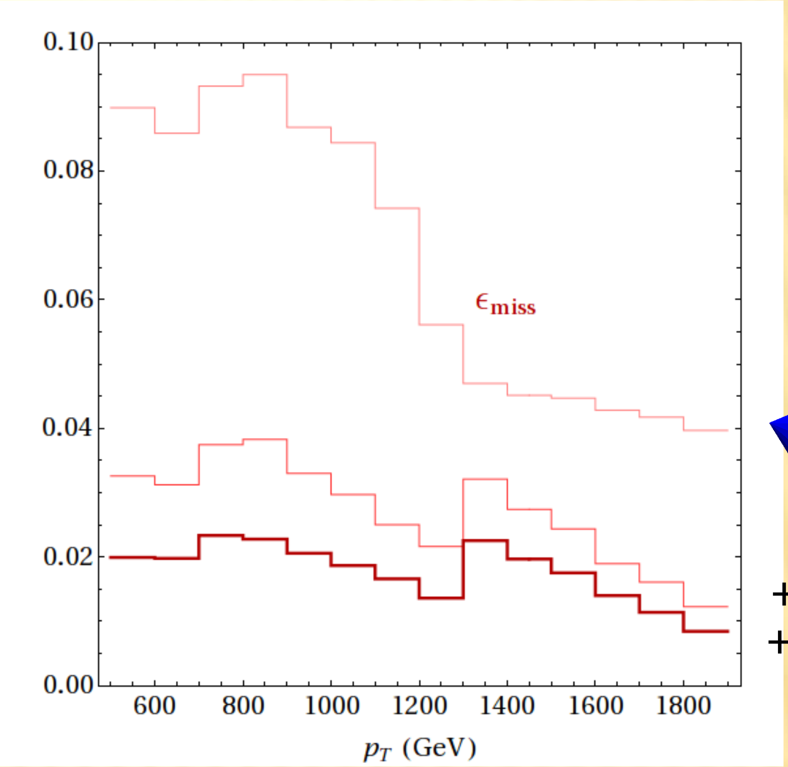
EFFICIENCIES

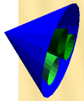
subjet + M_t + M_W cuts



+M_t
+M_W



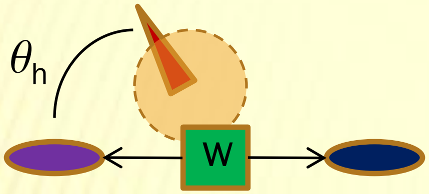




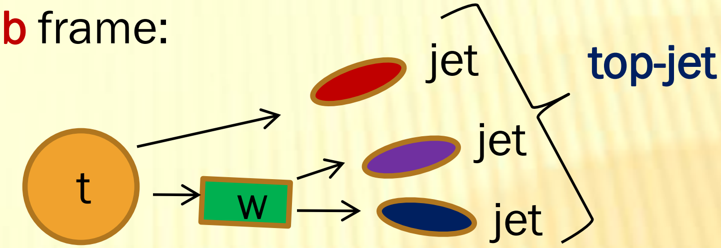
+M_t
+M_W

HELICITY ANGLE

W frame:

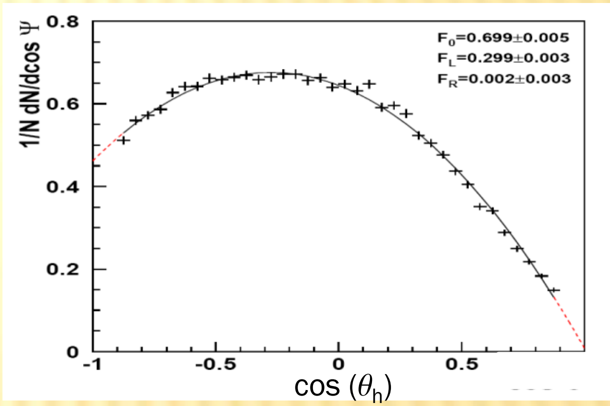


lab frame:



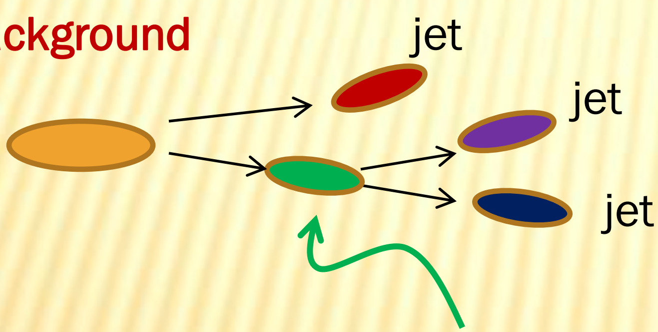
- W decays basically isotropically
- can be used to measure W helicity

Hubaut :hep-ex/0605029



LHC simulation

Background



- Intermediate off-shell massless parton
- Helicity angle strongly peaked
- divergent in perturbation theory (soft divergence)

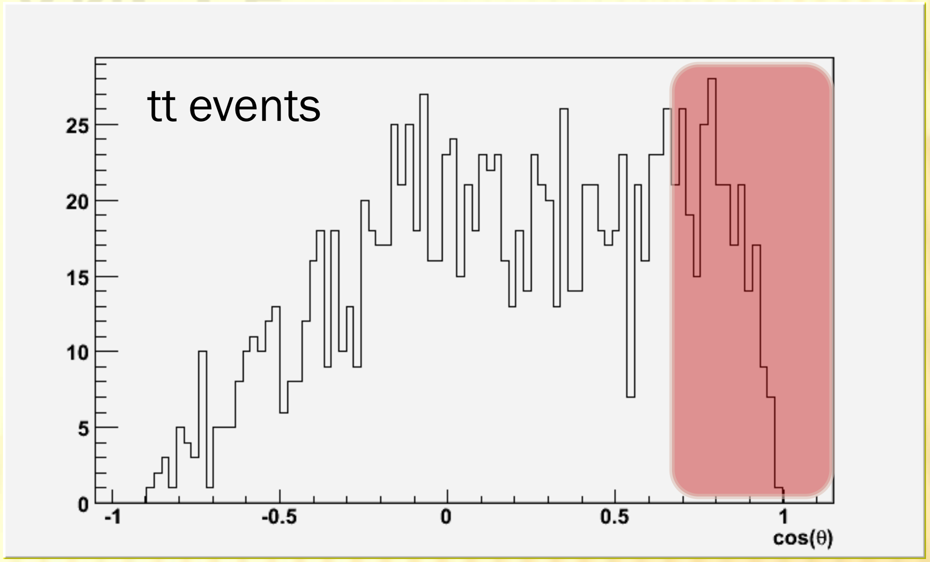
$$\frac{d\sigma}{dM_{12}\,d\cos\theta_h} = \frac{2 - \frac{M_{12}^2}{M_{123}^2} - \frac{2M_{123}^2}{M_{12}^2}}{1-\cos(\theta_h)} + \cdots$$

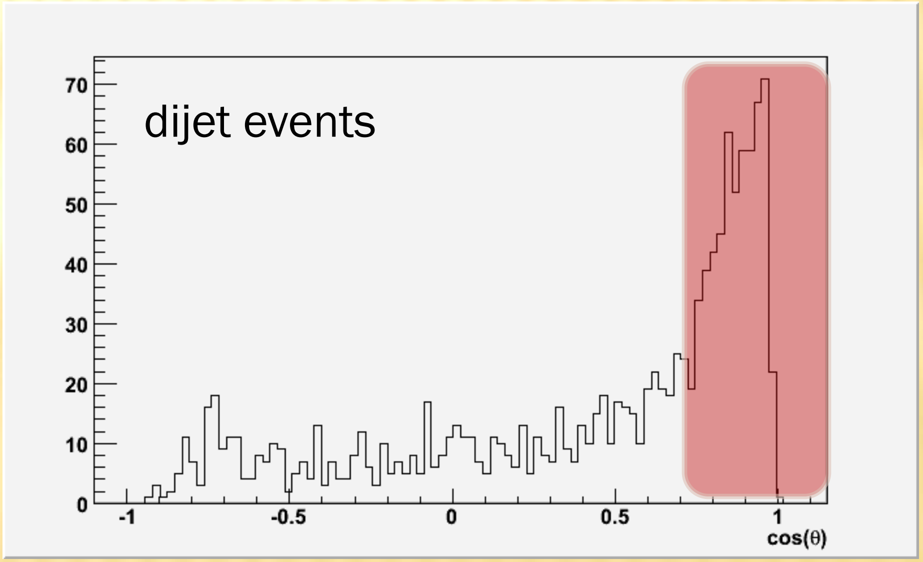
CUT ON HELICITY ANGLE

p_T > 700 GeV

- After subjet requirement
- After M_t cut
- After M_W cut
- Exclude small $\cos(\theta_h)$

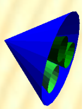
$\cos(\theta_h) < 0.7$



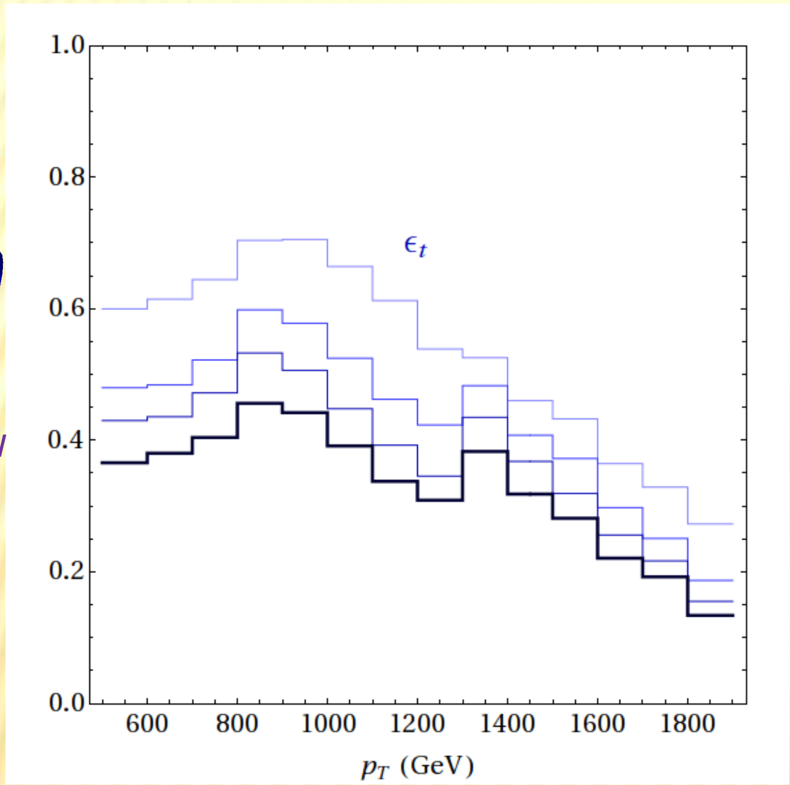


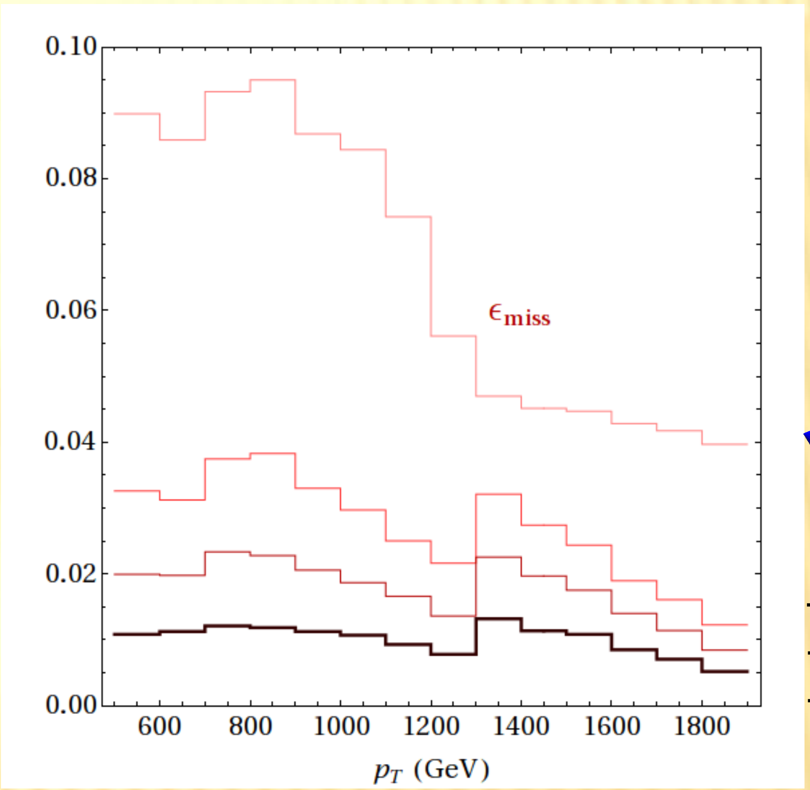
EFFICIENCIES

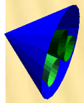
subjet + M_t + M_W + θ_h cuts



+M_t
+M_W
+θ_h







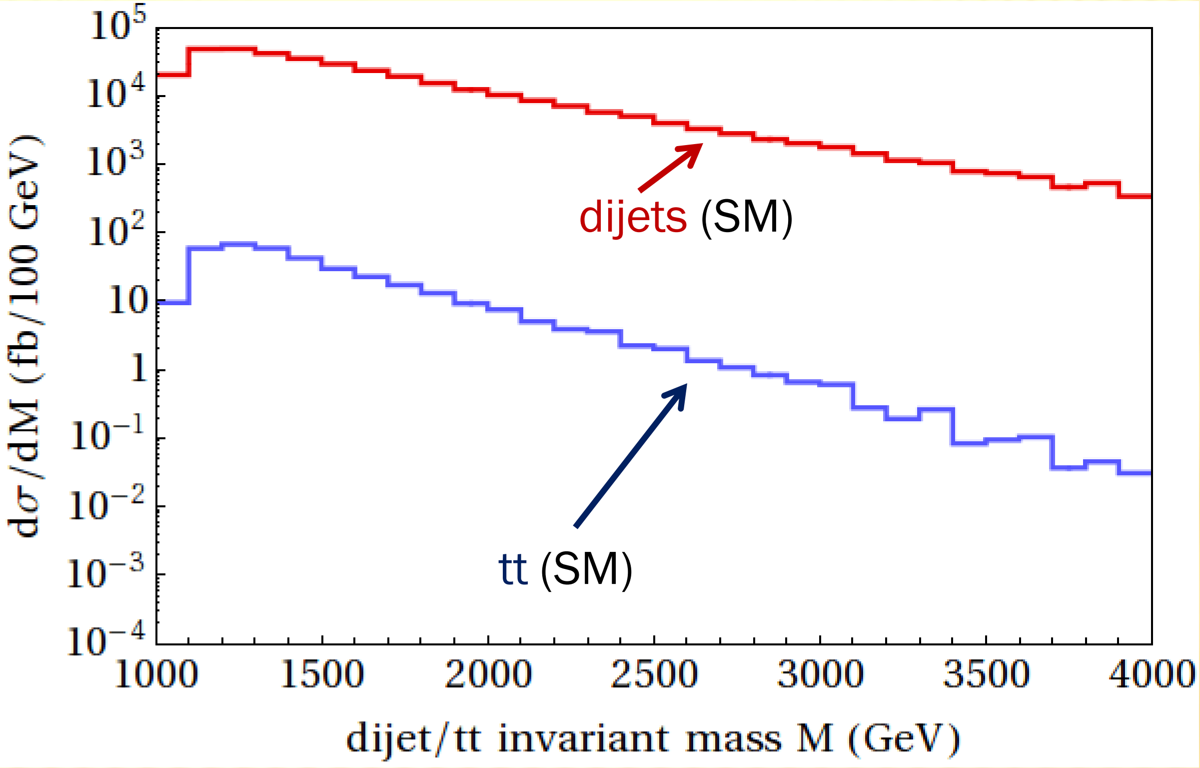
+M_t
+M_W
+θ_h

For p_T>1000 GeV

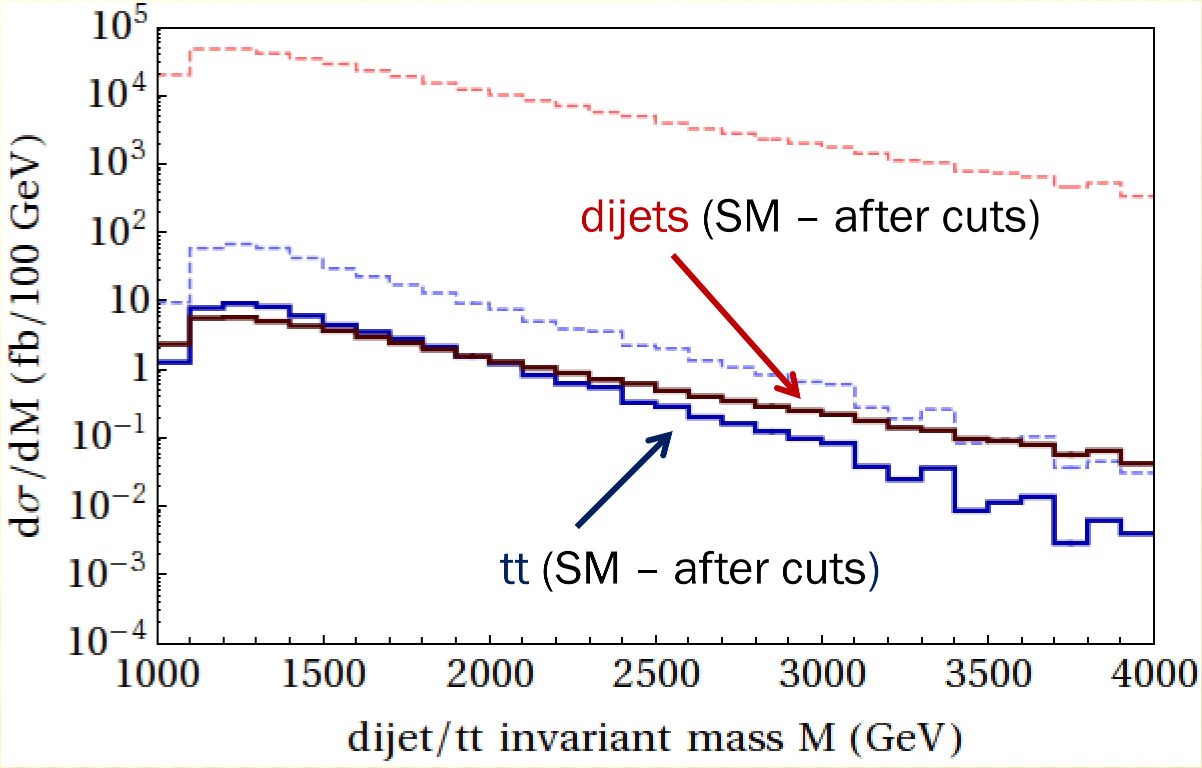
- Keep **40% tops**
- Reject **99% of light jets**

} numbers get squared for **dijet** events

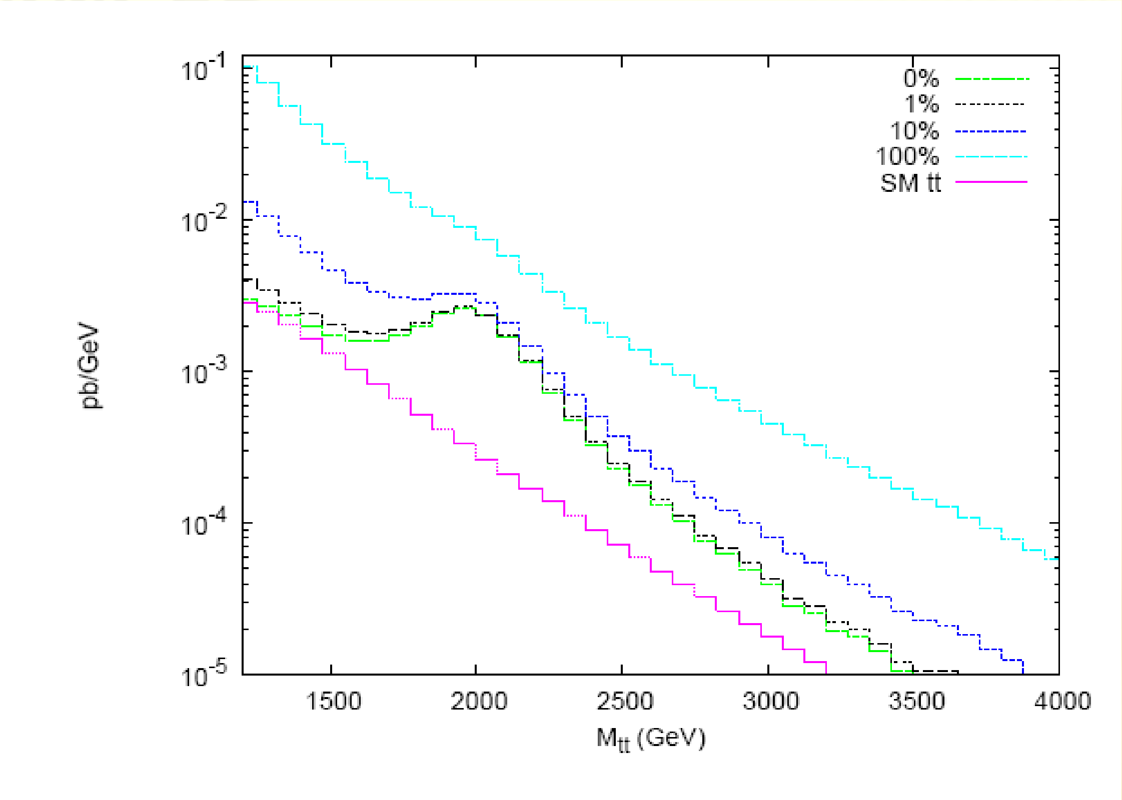
DIJET CROSS SECTION



DIJET CROSS SECTION



RESONANCES



•Lillie et al, hep-ph/0701166, p.10

“extraction of signal will require a background **rejection** of about a factor of **10**”

•We have a **rejection** factor of **10,000!**

IMPROVEMENTS

- Use b-tagging
  - efficiency degrades at high p_T
  - top jets can be used to calibrate b-tagging!

- Finer resolution on particles
  - we used segmentation of hadronic calorimiter: $\Delta\eta \sim \Delta\phi \sim 0.1$
  - EM calorimiter: $\Delta\eta \sim \Delta\phi \sim 0.02$
  - tracking information – even higher resolution

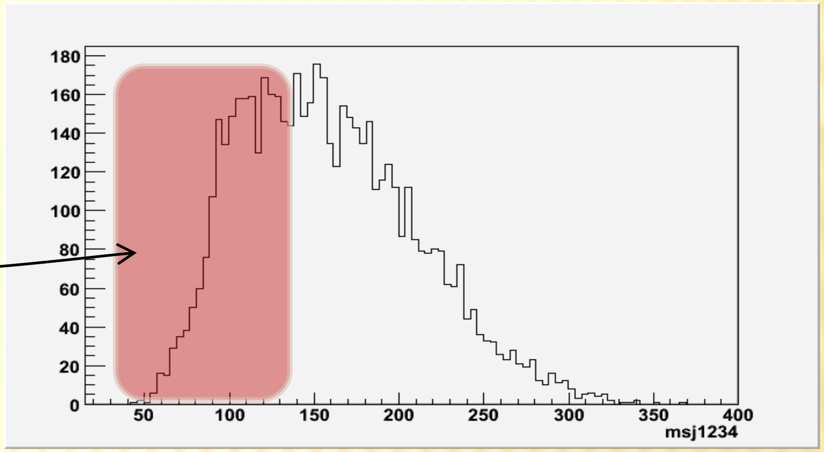
- More sophisticated observables
  - event shapes
  - fragmentation functions

  } • MC dependent
  • may be calculable using field theory

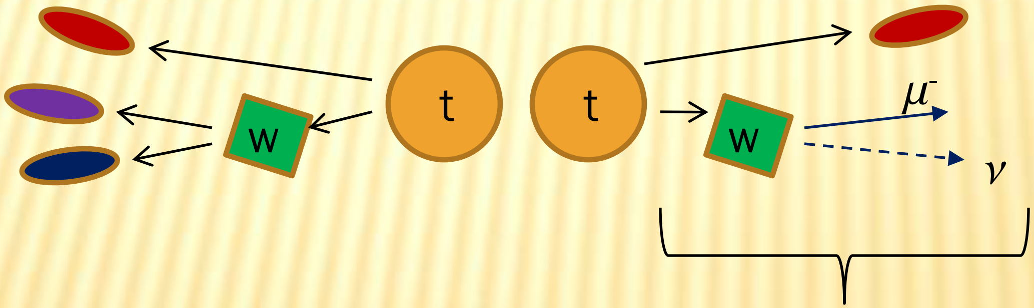
- Cuts can be optimized
  - for particular new physics searches
  - including proper detector simulation
  - using decision trees/neural networks

HOW TO TEST

- Background (e.g. dijets)
  - Tevatron has plenty of dijets
  - Use sideband analysis at LHC
  - Calibrate the Monte-Carlo



- Signal (tt)
  - Use lepton+jets events



CONCLUSIONS

Top-tagging
at high p_T is extremely efficient

Boosted hadronic tops
can be included with *confidence*
in standard model and new physics studies
at the LHC