General searches for new particles at the LHC

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ANL Jamboree, Jan 2010

Introduction

- **Searches of high-mass resonances will be a primary task at ATLAS**
- **Many models, many final-state topologies (good topic for many talks)**
- **From the point of view of final-state signatures, they fall into 3 categories:**

(1) All decay products of a particle “X” are observable and spatially well separated

- Any 2-body decays or cascade decays with masses < 1 TeV
- Examples: $G \to \gamma\gamma$, $h \to W^+W^-$ etc

(2) Decay products are not directly observable

- Examples: decays involving neutrino or any other unobservable state

(3) Decay products partially or completely overlap

- Cascade decays of TeV-scale particles (large Lorentz boost)

Introduction

- **A general search program was developed for cases (1-2) to look at distinctive signatures when decay product can be resolved as separate objects**
  - Covers processes with missing pT
  - See also detailed discussion at the jet+X meeting (November 2009)

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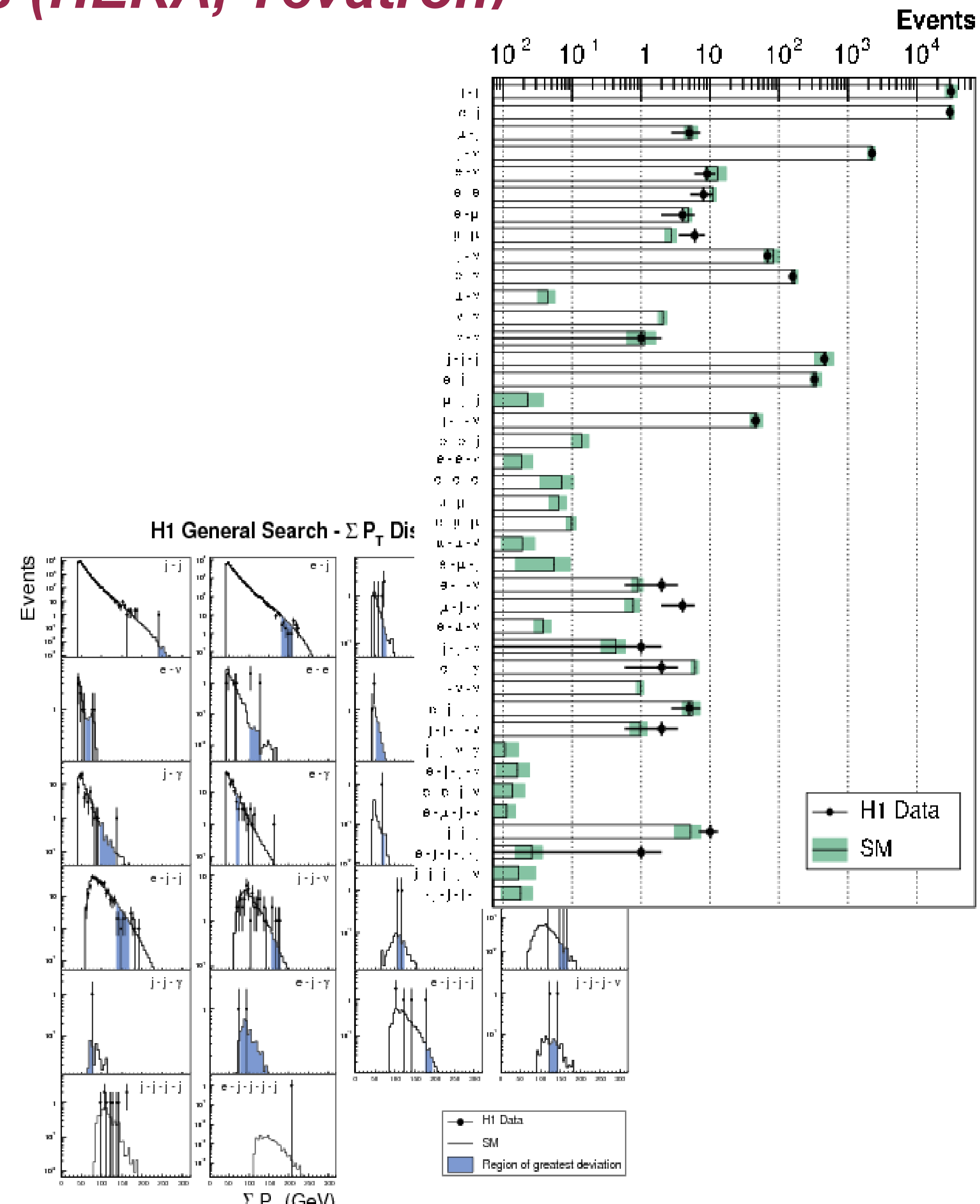
- **As a general tool, it's designed to:**
  - generate statistical summaries with decay signatures
  - alert a searcher
  - identify most interesting channels and put them under scrutiny
  - identify reflections (overlap) from other channels

Previous studies (HERA, Tevatron)

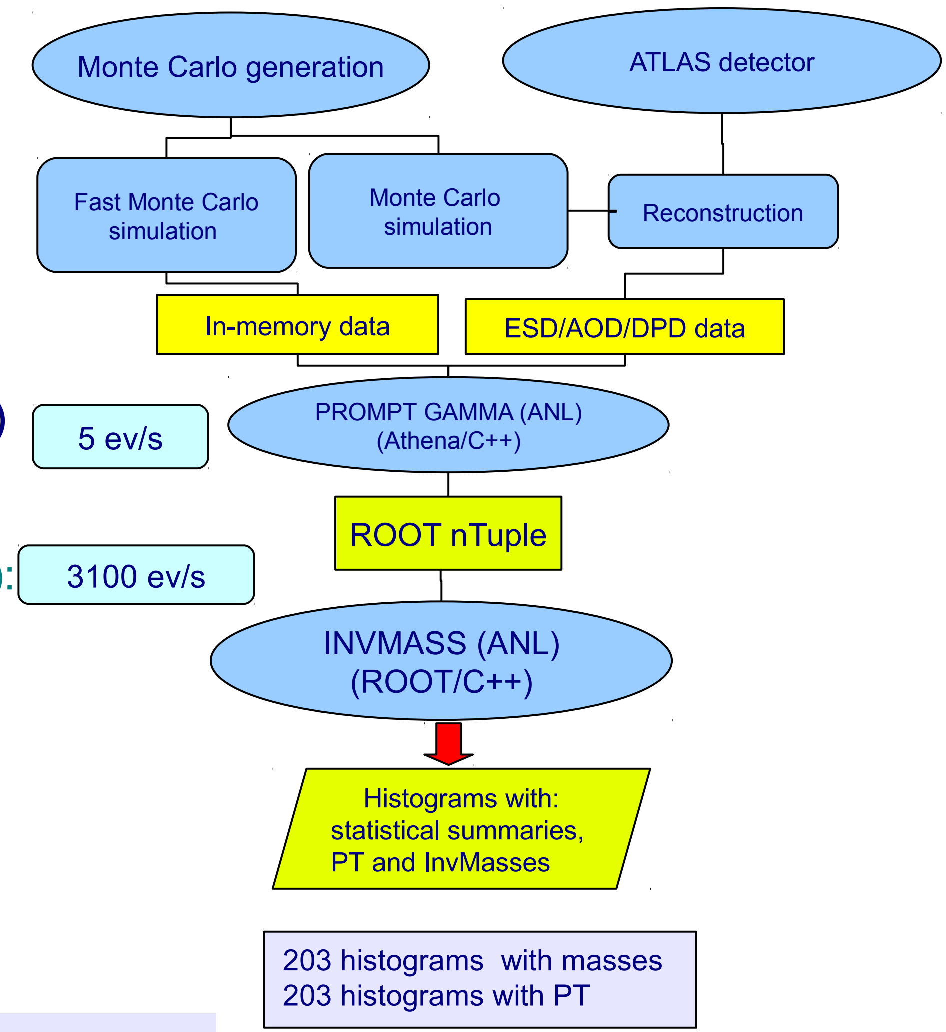
- **H1 Collaboration at HERA**
  - search for deviations from the SM in ep
  - broke events into classes and analyzed:
    - ✓ Invariant mass
    - ✓ Transverse momenta
    - ✓ Event distribution
- **Tevatron at FermiLab**
  - Several programs (Bump Hunter,Sleuth)



- **Neither search found new physics**
  - No significant variation from SM
  - Some discrepancies with D0 and CDF data are attributed to difficulties in simulation of SM processes

InvMass: In Brief

- **Input: AOD/DPDs**
- **Process with PromptGamma package**
  - Ntuples with up to 6 particle types
- **Process Ntuples with InvMass package**
  - Output: Histograms of all possible unique combinations of input particle types
    - ✓ Invariant mass (M) or transverse mass
    - ✓ pT of all combinations
- **All can be done using AtlFast simulation** (in-memory data, no AOD/DPD creation)



Example: For 6 particles (jet,gamma,mu,missET,e,tau):
- ✓ 21 combinations for 2 decays
- ✓ 56 combinations for 3 decays
- ✓ 126 combinations for 4 decays

Total: 203 histograms with M
203 histograms with pT

General searches cannot handle by a human –
need a computer program

InvMass: Architecture

- **Compartmentalized:**
  - Class InvMass to create and fill histograms
  - Host program with loop to access individual events in .root file(s)
- **Generic code in Class InvMass**
  - Works with for any number of particle types, and any variety
  - Any-body decays (2,3,4,...)
- **Configuration file (text file) allows for changes without recompiling**
- **Input configuration file:**
  - Which particle types to use
  - How many combinations to search for
  - Pt cuts
  - Rapidity cut
  - Overlap removal
  - Histogram details (bins, range)
  - Input File(s)
  - Output file name

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InvMass: More to Come

- **Working prototype is ready**
- **Tested using PYTHIA:**
  - signal (realistic MC) & background (AtlFast)
- **Available at ANL Analysis support center SVN:**
  - http://atlaswww.hep.anl.gov/asc/WebSVN/
  - Will be moved to the group common ATLAS common area
- **Realistic MC simulation can be done for filtered events**

Limitation:

- InvMass is not suited when decay products are so close that they are unresolved (for example, are all inside a single jet)

- Example: cascade decays of TeV-scale particles. See next.

Searches for TeV-scale particles with cascade decays

- **Many models predict heavy-mass resonances decaying to WW, tt, etc..**

  Examples:

  - Z' with the SM coupling (ttbar, qq, W+W-)
  - Gravitons to ttbar, γγ
  - Kaluza-Klein gluon excitations: B.Lillie (ANL), L.Randall, L.T.Wang JHEP 09 (2007) 74

- **For a cascade decays, decay products will be highly boosted**

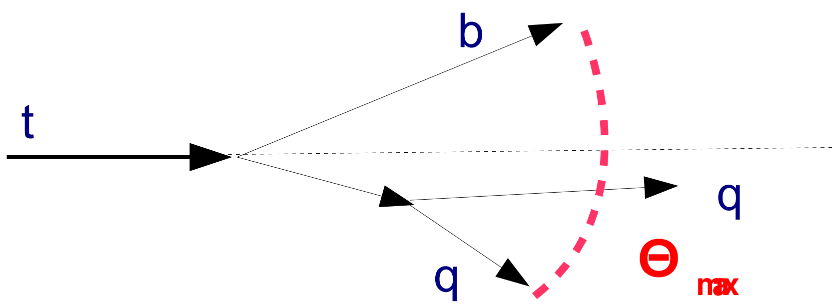
  $X \to t\bar{t} \to W^+b\ W^-b \to 4\ q\ 2\ b$ or $X \to W^+\ W^- \to 4\ q$

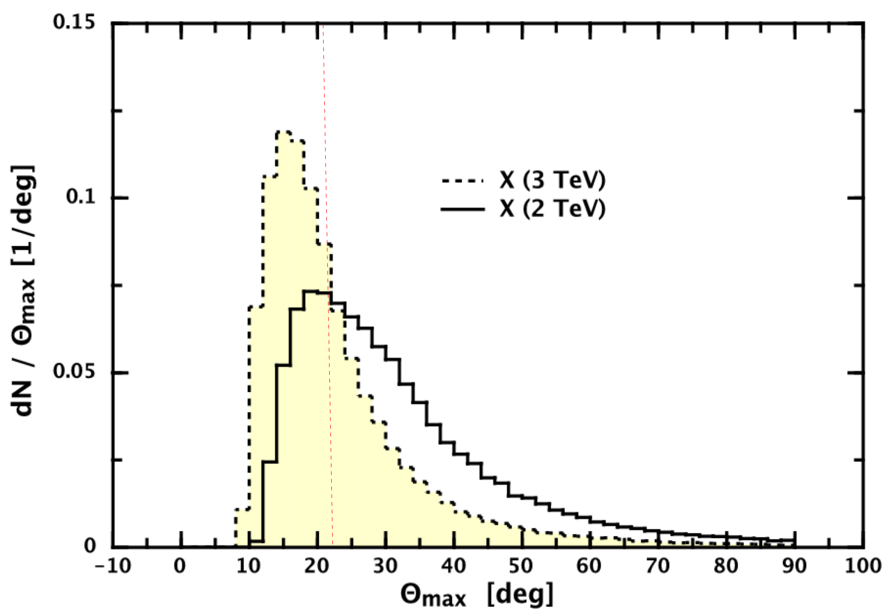
- **Will be detected as jets, where jet substructure may reflect the underlying production mechanism which will (hopefully) be distinct from QCD jets**

  - Use this feature to deal with QCD background

Kinematic consideration

- Assume the reaction: X → t$\bar{t}$ → W+b W-b → 4 q 2 b
- Look at maximum angle between all final decay products (quarks) and the original top-quark direction
- Use a simple Monte Carlo consisting of a decays in HCM system and Lorentz boost to the laboratory frame





For anti-kT algorithm with D=0.4, 2 jets cannot be resolved if angular separation is smaller than 21 deg

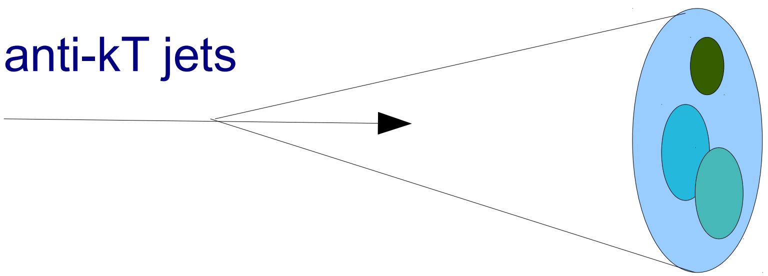
(31 deg for D=0.6)

→ Significant fraction of events with decay products from one of the top quarks inside a single "mono" jet

Looking at jet shapes

- Jet shapes can help to reduce contribution from QCD jets
- Suggested in several recent articles
  - For ttbar: B.Lillie (ANL), L.Randall, L.T.Wang JHEP 09 (2007) 7
- For other channels:
- J. M. Butterworth, J. R. Ellis, A. R. Raklev, JHEP 05 (2007) 033.
- J. M. Butterworth, et al., Preprint CERN-PH-TH/2009-073, hep-ph/0906.0728, 2009.

anti-kT jets



Goal:
Extend the study of the channel X-> ttbar
by considering jet shapes for background rejection

Jet selection
- Use anti-kT jet algorithm with D=0.4
- Consider 1st and 2nd leading in pT jet
- pT(jet)>500 GeV

Jet shapes
- Jet mass (only 2 leading in pT)
- Jet width (weighted in R ~ $\sum$ dR pT)
- Jet eccentricity (ECC ~ 1 – v_X / v_Y)
  - ECC = 0 for circular jets, =1 for elongated
- kT flip parameters: y12flip and y23flip

Correlations between jet shape variables

	mass	width	ECC	yflip12	yflip23
mass	1	0.88 (0.78)	0.32 (-0.10)	0.13 (-0.10)	0.24 (-0.11)
width	0.88 (0.78)	1	0.32 (-0.10)	0.87 (0.78)	0.30 (0.31)
ECC	0.32 (-0.10)	0.32 (-0.10)	1	0.05 (0.06)	0.05 (0.07)
yflip12	0.13 (-0.10)	0.87 (0.78)	0.05 (0.06)	1	0.90 (0.97)
yflip23	0.24 (-0.11)	0.30 (0.31)	0.05 (0.07)	0.90 (0.97)	1

Pearson's correlation coefficients (p) for jet shape variables using PYTHIA model for inclusive pp production (pT(jet)>500 GeV):

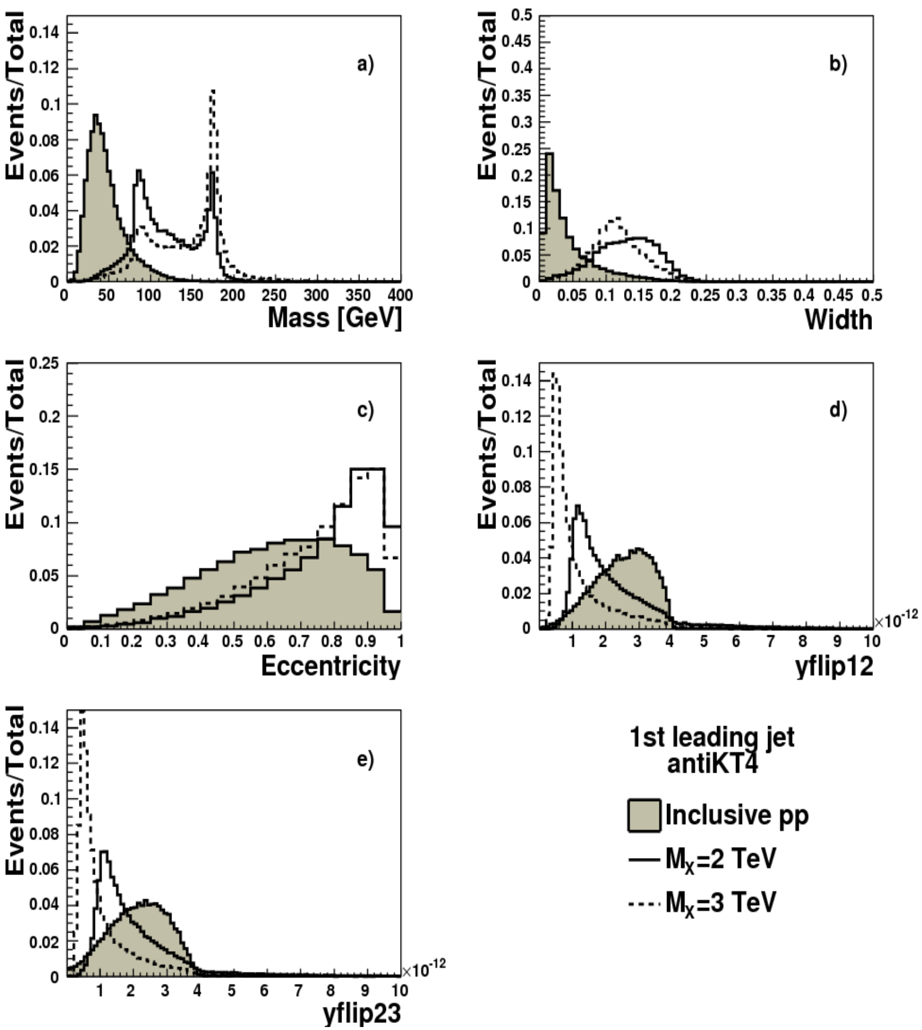
p= -1 - full anti-correlations
p= 1 - correlations
p= 0 – no correlations

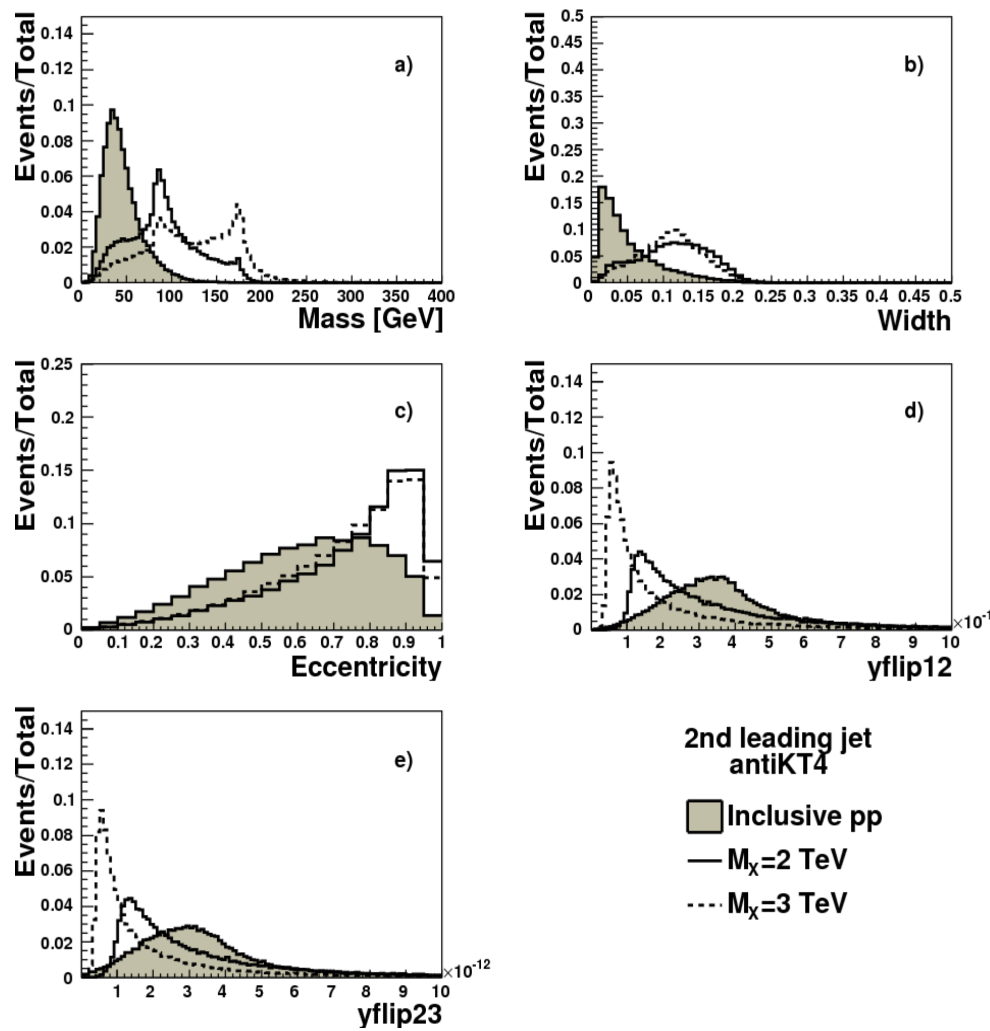
(Parentheses show the channel Z' -> ttbar)

- Strong correlation between anti-kT flip parameters (yflip12 and yflip23)
- Other variables weakly correlated (like EEC)

(discussed in ANL-HEP-PR-10-2, S.C., J.Proudfoot)

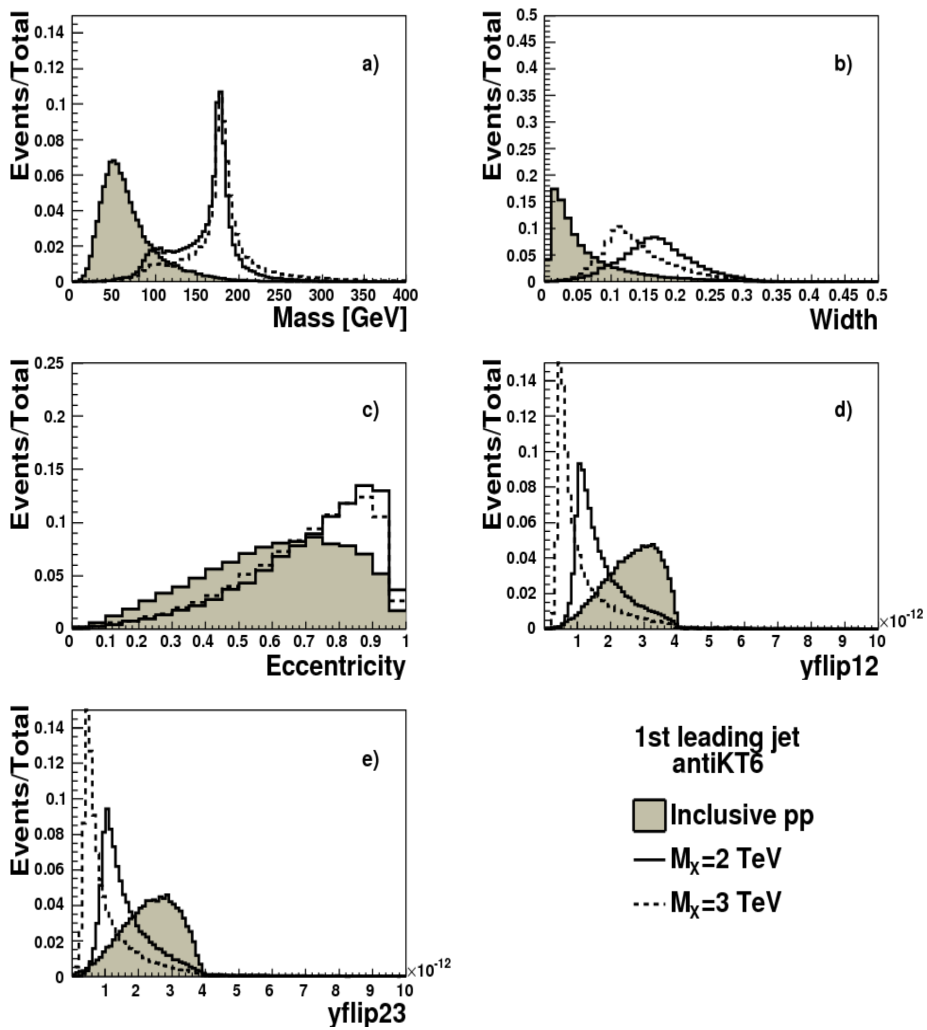
Characteristics of 1st and 2nd leading antiKT4 jets

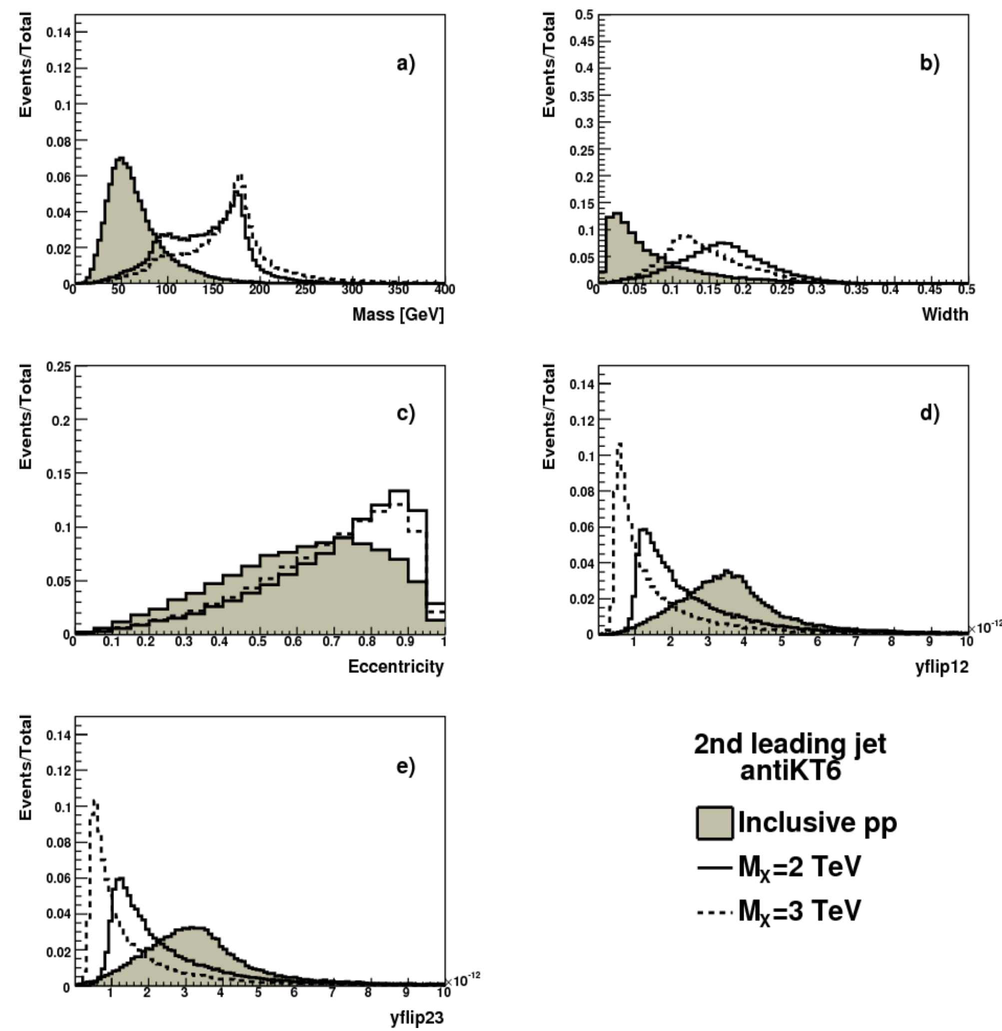




(discussed in ANL-HEP-PR-10-2, S.C., J.Proudfoot)

Characteristics of 1st and 2nd leading antiKT6 jets

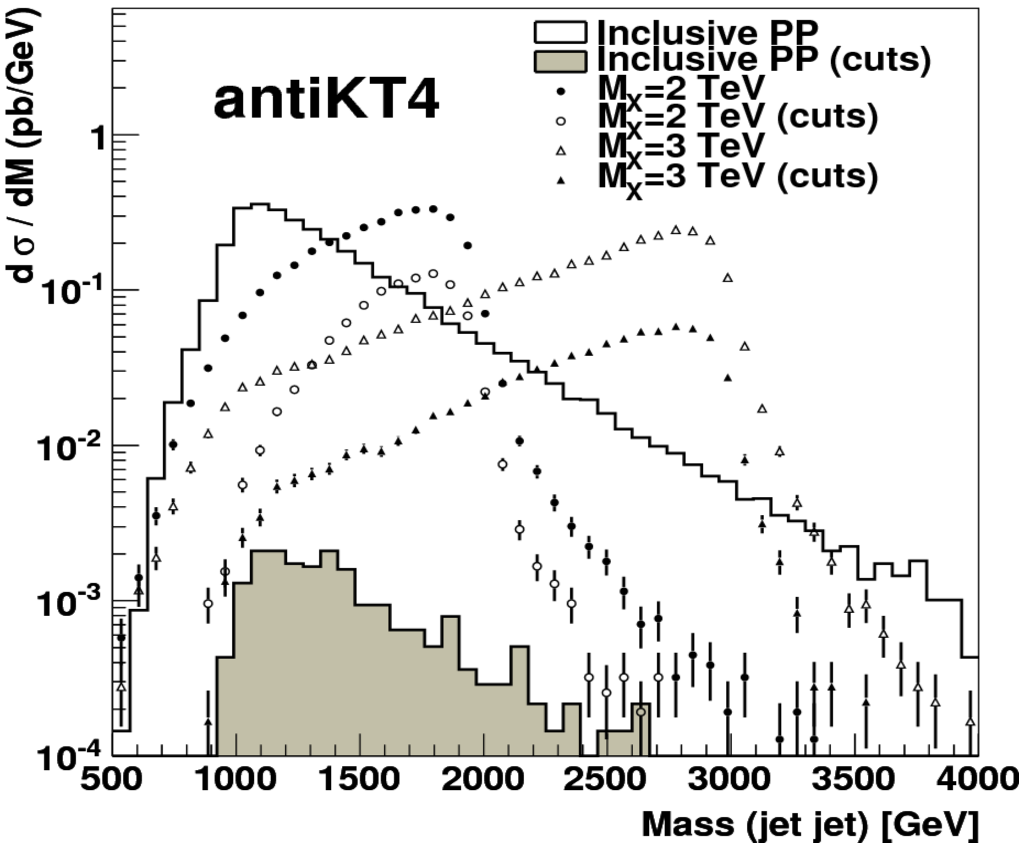




Preferred algorithm: Jet masses exhibit large peaks near the mass of the t quark

Selection cuts and rejection factors

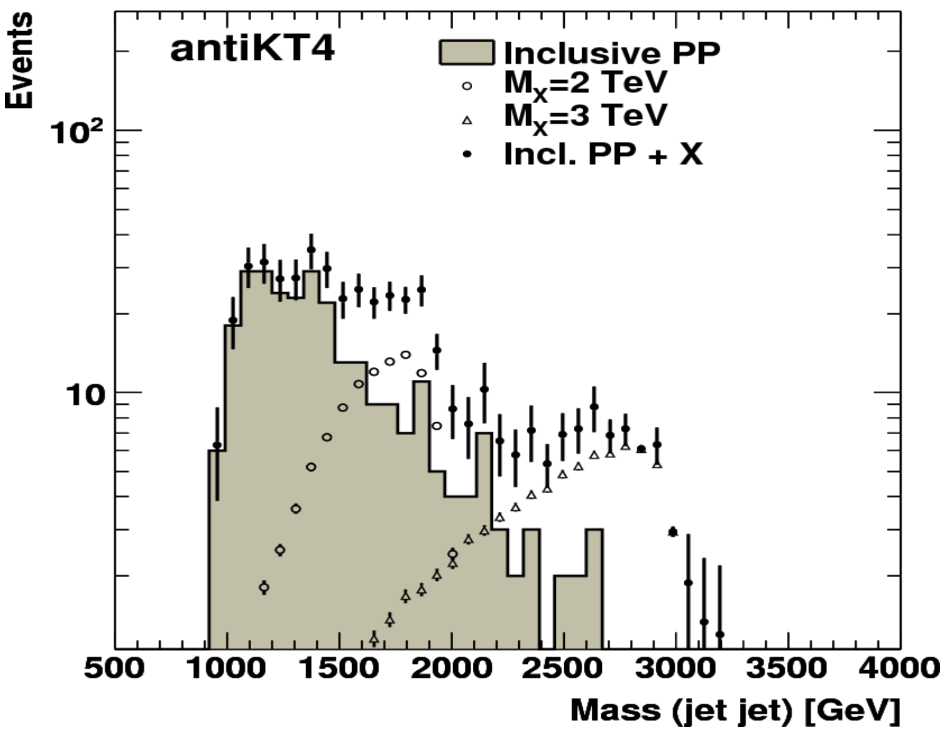
- **Goal: Reject QCD background using the jet shapes**
- **Accept events with at least one jet at pT>500 GeV:**
  - Mass(jet)>70 GeV
  - Jet width > 0.07 (for both)
  - ECC > 0.75
  - yflip12, yflip23 < 2 * 10^{-12}

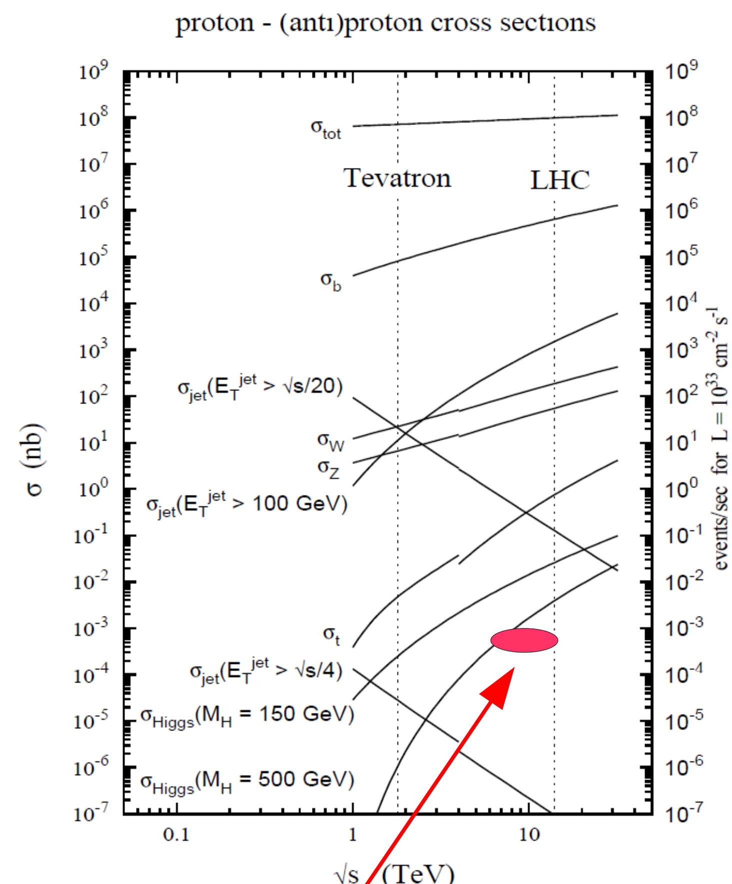


- Rejection factor ~120 for QCD jets
- ~ 3-4 for 2-3 TeV particles
- Significantly better than expected when no jet shapes are used
  - ~10 rejection was required for observation of KK gluon excitation

6-sigma discovery level

Expectations for 200 pb^{-1} & 10 TeV





2-3 pb cross section for ~6 sigma discovery using 200 pb^{-1}

~ factor 10 smaller than for the Higgs production (150 GeV)

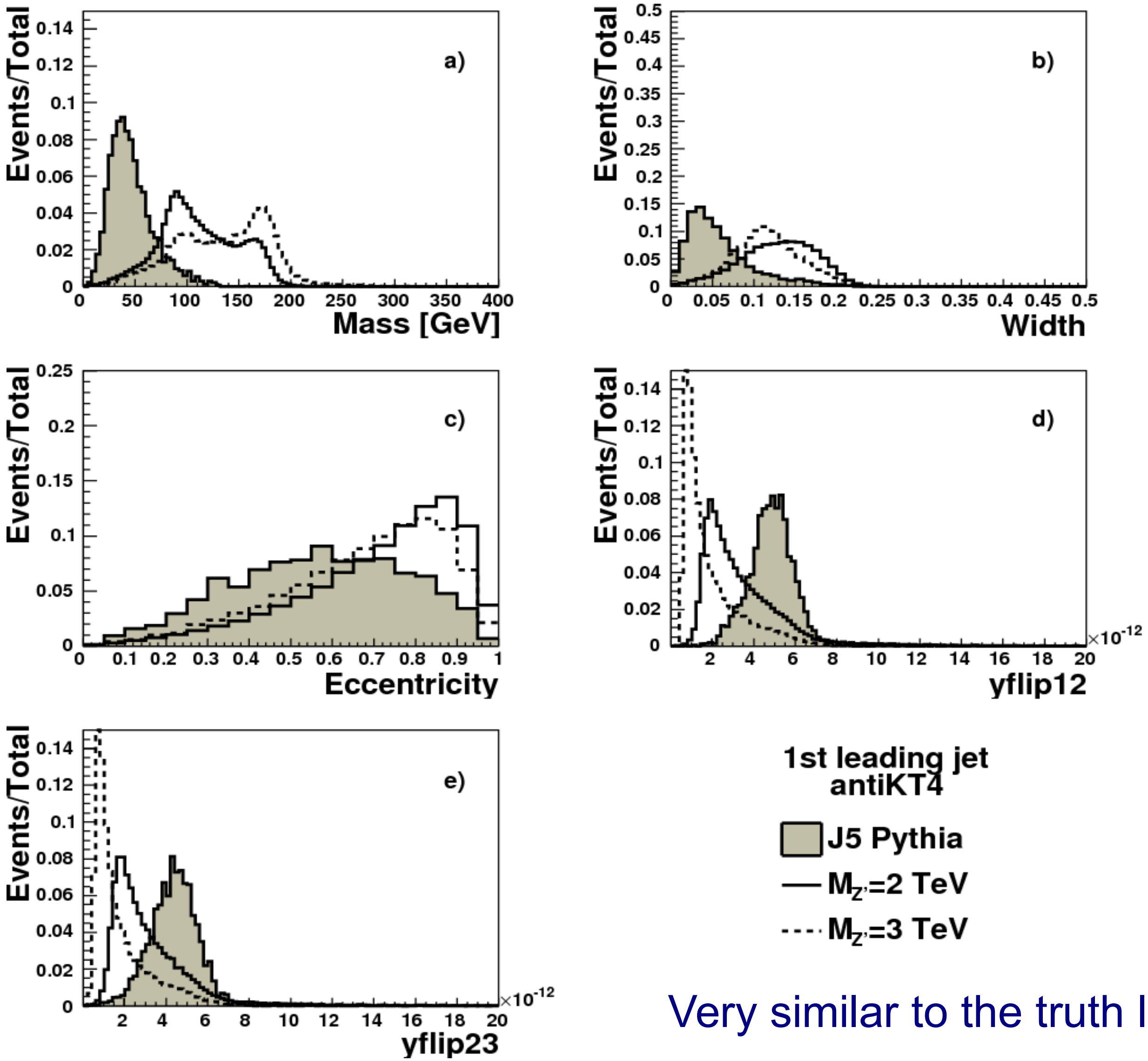
→ same discovery level as for 10 fb^{-1} without jet shapes!

M.Beneke and others. hep-ph/0003033

Full detector simulation

- **Model “X” particle using Z'**
- **Signal events**
  - mc08.105609.Pythia_Zprime_tt2000.recon.AOD.e393_s462_s520_r635
  - mc08.105597.Pythia_Zprime_tt3000.recon.AOD.e435_s462_s520_r808
- **QCD background**
  - mc08.105015.J6_pythia_jetjet.recon.AOD.e344_s479_s520_r809
  - mc08.105014.J5_pythia_jetjet.merge.AOD.e344_a84_t53

Characteristics of 1st leading antiKT4 jets

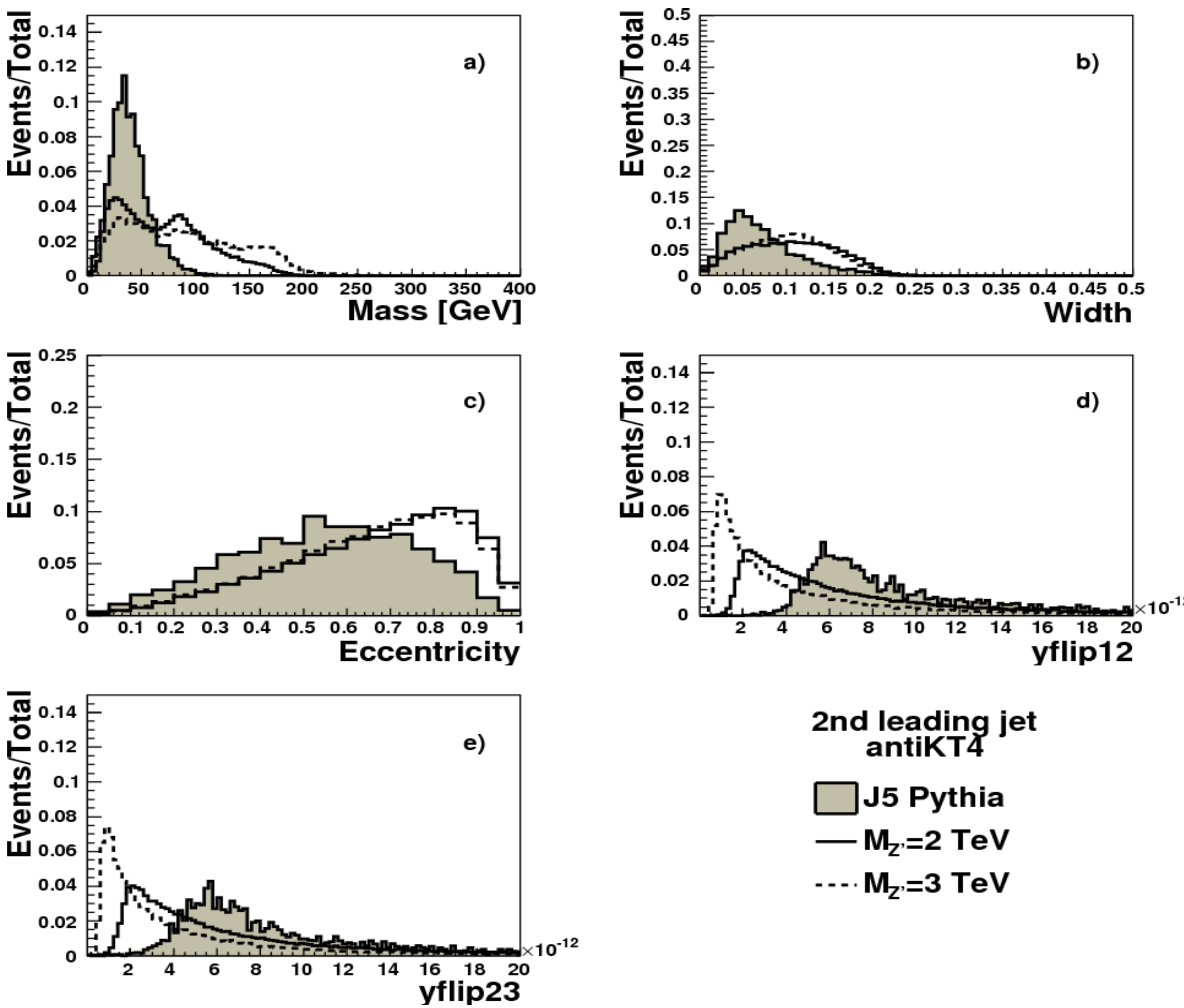


pT>500 GeV

<pT>~900 GeV

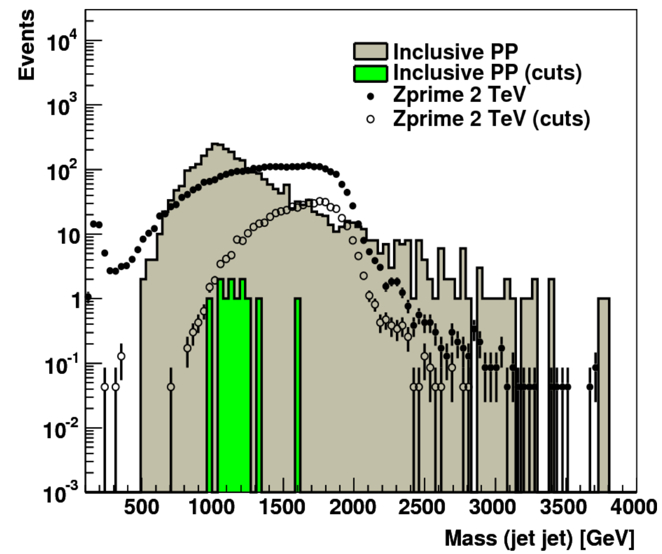
Very similar to the truth level, but broader

Characteristics of 2nd leading antiKT4 jets



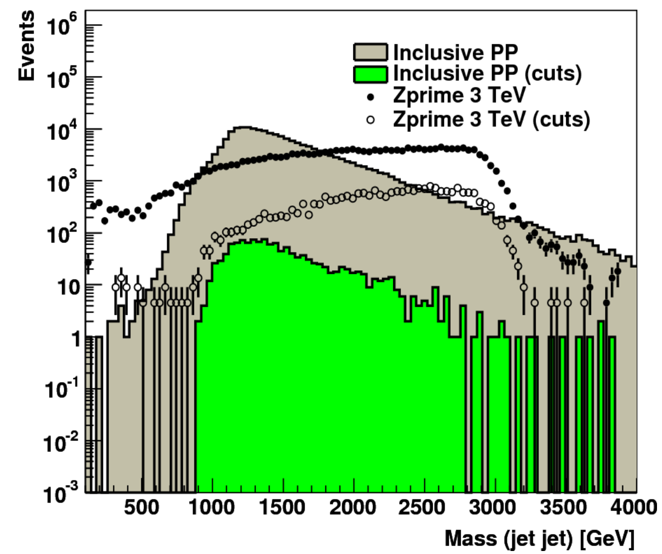
QCD background rejection

- **Acceptance cuts (same as for the truth level)**
  - yflip12, yflip23 < 2 * 10^{-12}
  - Leading jet PT>500 GeV
  - Jet mass>60 GeV
  - Jet width > 0.1 (>0.05 for second) and
  - Circularity>0.7

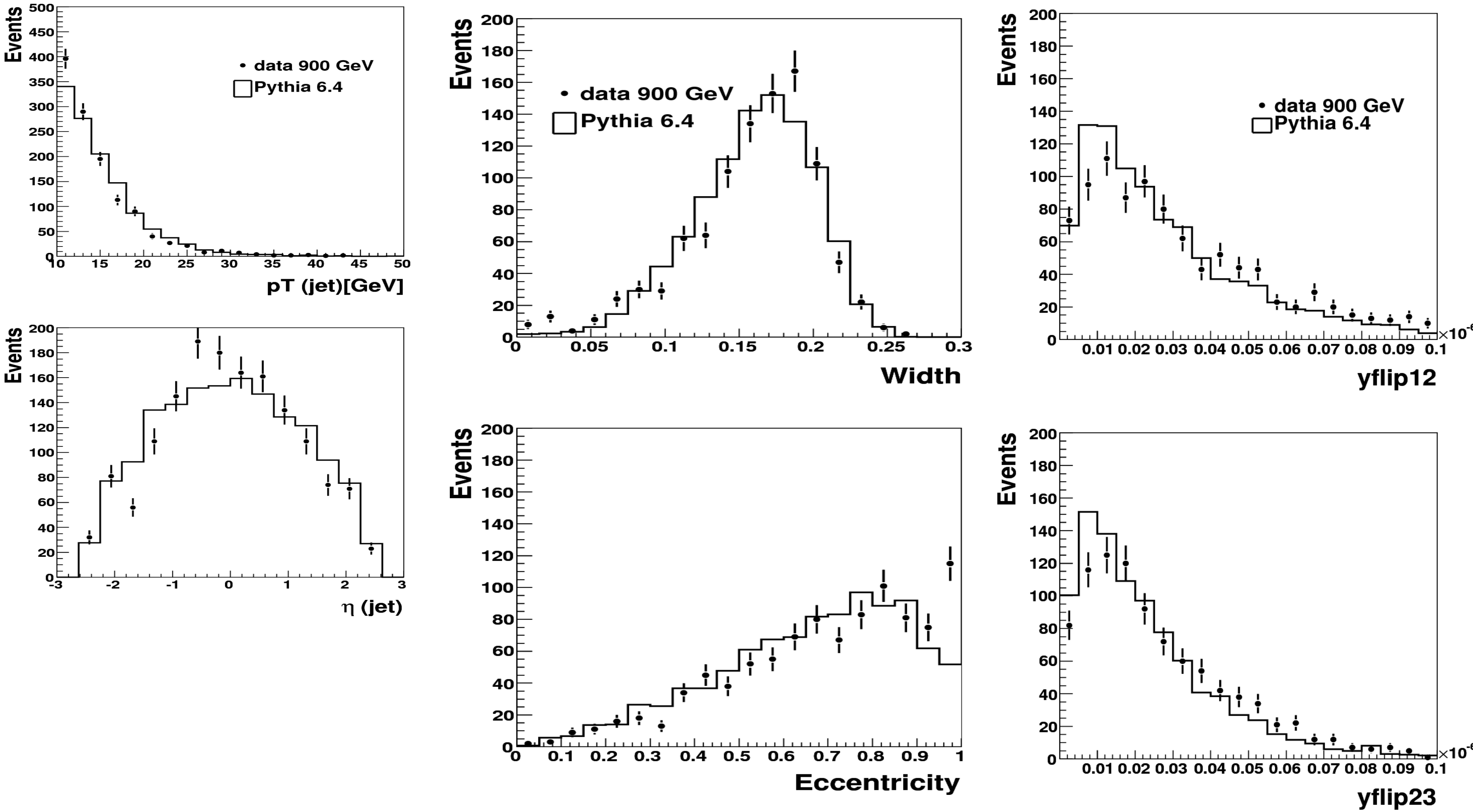


- **Rejection for QCD events**
  factor ~120-200 under 2 and 3 TeV mass

- **Rejection of ZPrime events factor: ~3**
  - Similar conclusion as for the truth level



First look at jet shapes using 900 GeV MinBias data



Reasonable agreement,
signs of discrepancies for large eccentricity and y-flip distributions?

Summary

- **Model-independent searches for new particles are under way**
- **Studies cover:**
  - channels with well-separated objects (InvMass program)
    - 2-body and cascade decays (<1 TeV particles)
  - channels with complete/partial overlap of decay products
    - TeV-scale particles with N-body decays
- **Jet shapes are very attractive for searches of TeV-mass particles:**
  - **Rejection factors:**
    - >100-200 for QCD jets
    - ~3 for the signal events
- **~ few pb cross section for ~6 sigma discovery in X→ ttbar →6q using 10 TeV & 200 pb^{-1}**

Similar to the expectations for 10 fb^{-1} using only dijet invariant masses

M.Beneke and others
hep-ph/0003033