CDF Single Top Group

FNAL, February 23, 2007

DØ single top analysis details

- Overview of analysis: strategy
- Event yields: background normalization
- Heavy flavor fraction
- Systematic errors
- Discriminant distributions

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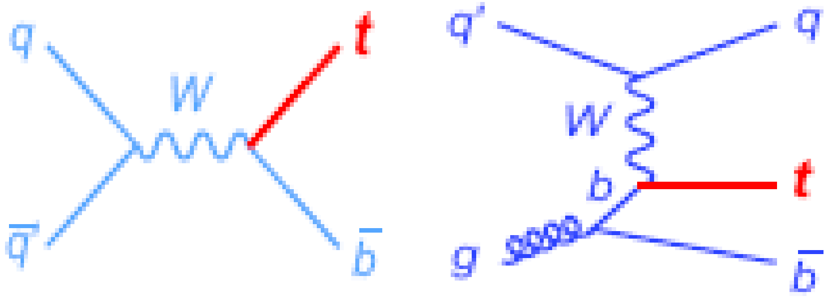
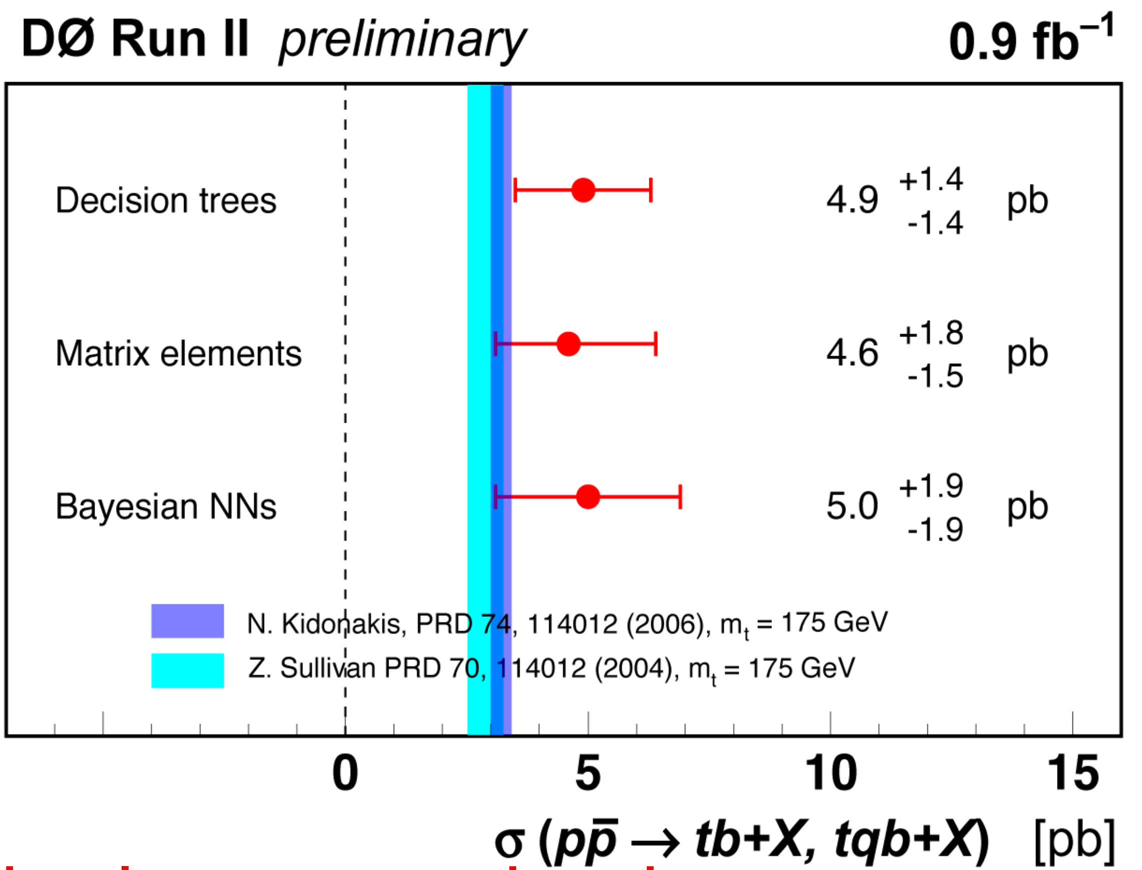
for the DØ Single Top Group

DØ single top result





- SM production:
  σ(tb) = 0.9±0.1pb
  σ(tqb)=2.0±0.3pb
- Window to new physics
- Measure $|V_{tb}|$

First evidence for single top production:

3.4 std. dev. from background-only hypothesis

- Consistent with SM

Technical webpage with plots for talks and more:
http://www-d0.fnal.gov/Run2Physics/top/public/fall06/singletop/

Signal modeling

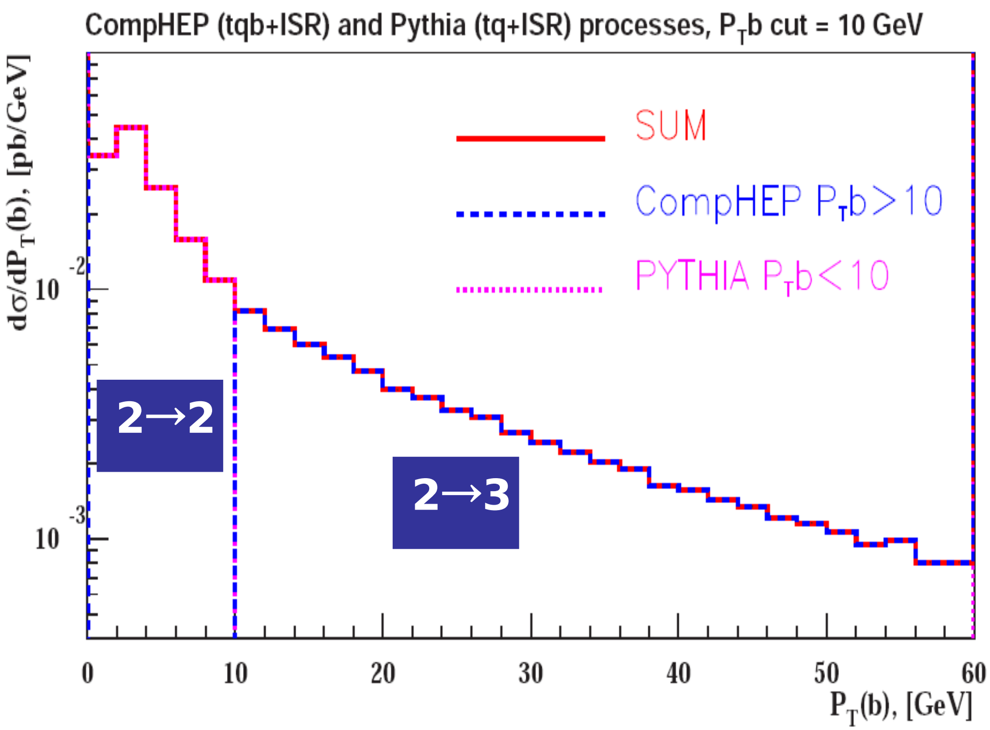
Have to get the t-channel right:
Avoid double counting when different diagrams produce same final states in different kinematic regions
Use ZTOP as NLO benchmark http://home.fnal.gov/~zack/ZTOP

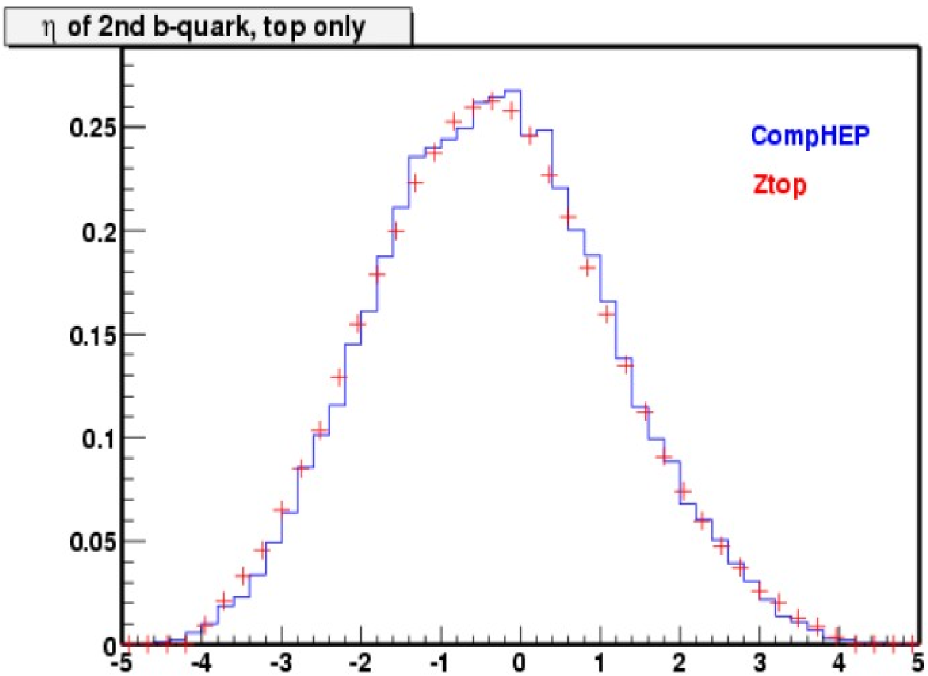
- DØ: “Effective” NLO CompHEP (Phys. Atom. Nucl. 69, 1317-1329, 2006)

Match 2→2 and 2→3 processes using b p_T for cross over, normalize to NLO

Resulting distributions agree well with ZTOP & MCFM

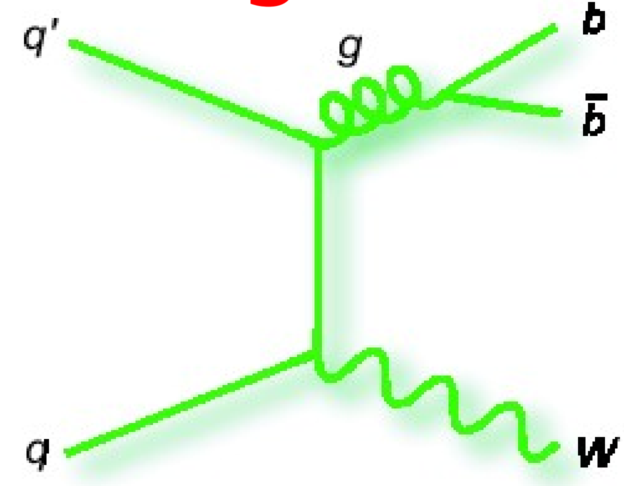
- Recently available: MC@NLO, MCFM, Alpgen 2, C.-P. Yuan et al.

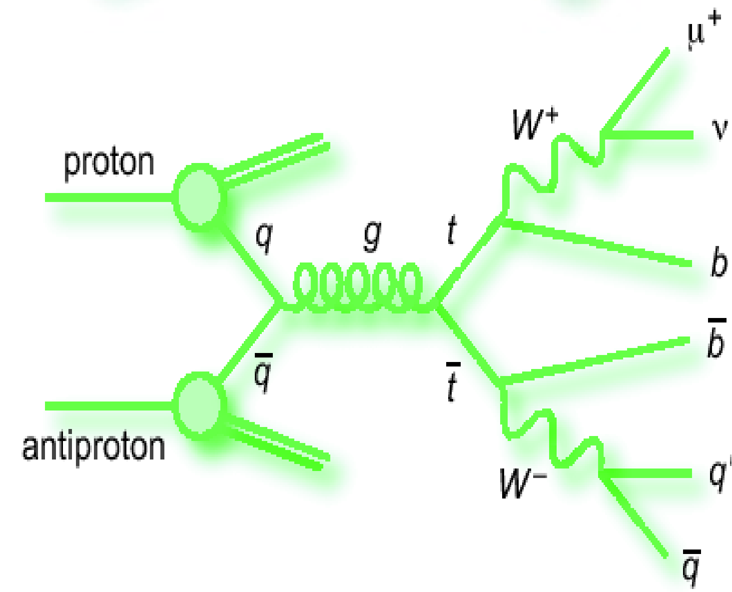




Background modeling

- W+jets: ~o(1000) pb
  - Distributions from Alpgen 2
  - Normalization from data
    - How much W+jets?
  - Heavy flavor fractions from data
    - How much Wbb+Wcc in W+jets?
- Top pairs: 6.8 ± 1.2 pb (Kidonakis)
  - Topologies: dilepton and ℓ+jets
  - Use Alpgen 2 with MLM matching
  - Normalize to NNLO σ
- Multijet events (misidentified lepton)
  - From selected data with reversed lepton isolation requirement

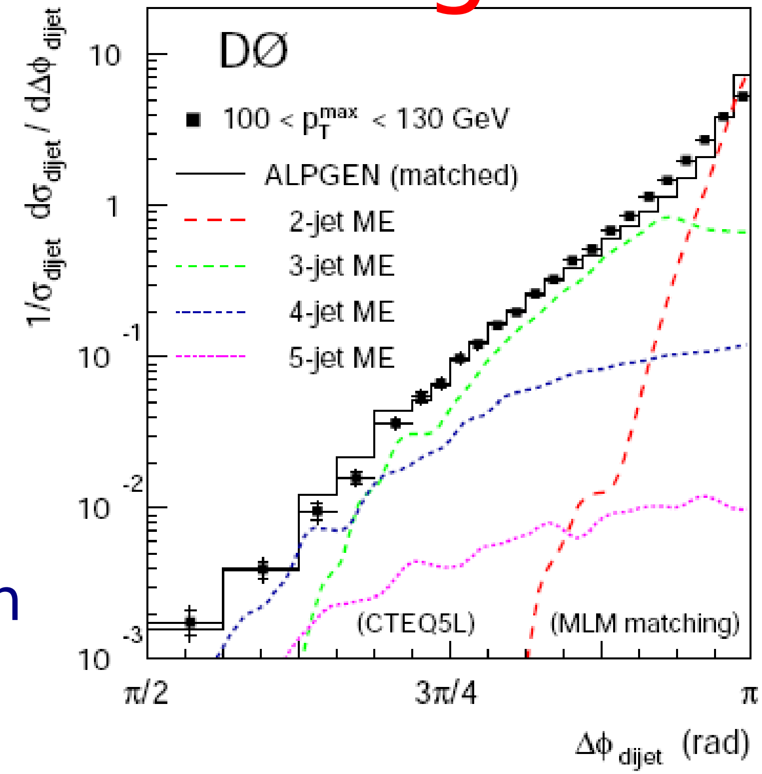




- No model for diboson and Z+jets: too small!
  - Will be included in W+jets via data norm.

Alpgen 2 with MLM matching

- Alpgen 2.05+Pythia for W+jets and tt, with CTEQ6L1
- New feature: jet-parton matching à la MLM
  - Fills each jet parton multiplicity bin with Alpgen jets, not radiative Pythia jets as before: avoids double counting
  - MLM clustering: p_T>8GeV, ΔR>0.4
- More cumbersome for generation: deal with tens of files when before there were two
- Wcj is included in the W+lp generation
  - Massless c quarks
  - At the parton level, ~7% of the total W+lp
  - Gets normalized to data before tagging
- Many, many problems found along the way, in both Alpgen and our generation
  - Painful to correct: reprocessing, skimming, ...



Alpgen samples used:

W+(0,1,2,3,4,5incl)lp

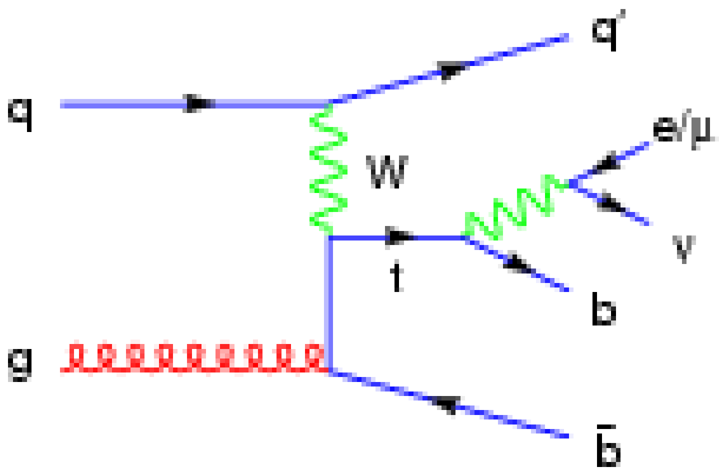
Wbb+(0,1,2,3incl)lp

Wcc+(0,1,2,3incl)lp

tt+(0,1,2incl)lp

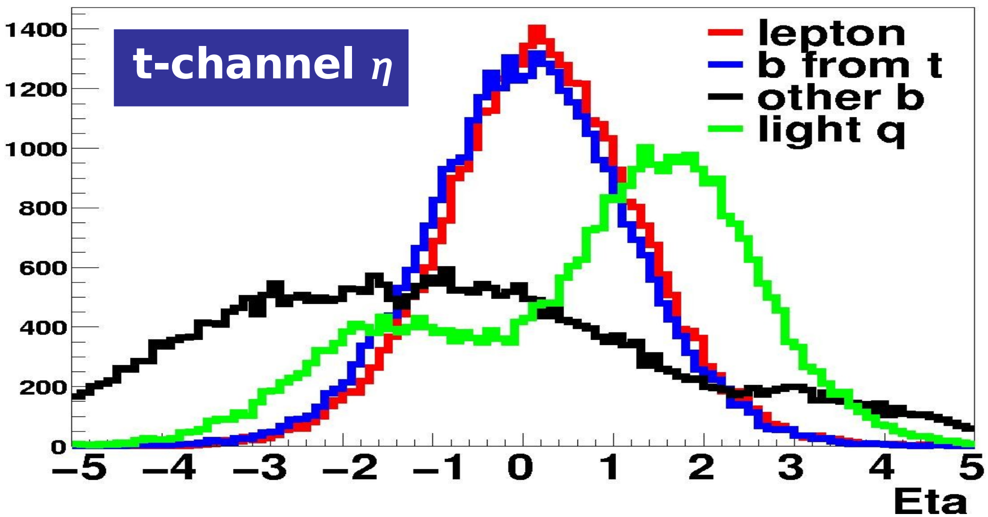
(lp = light partons)

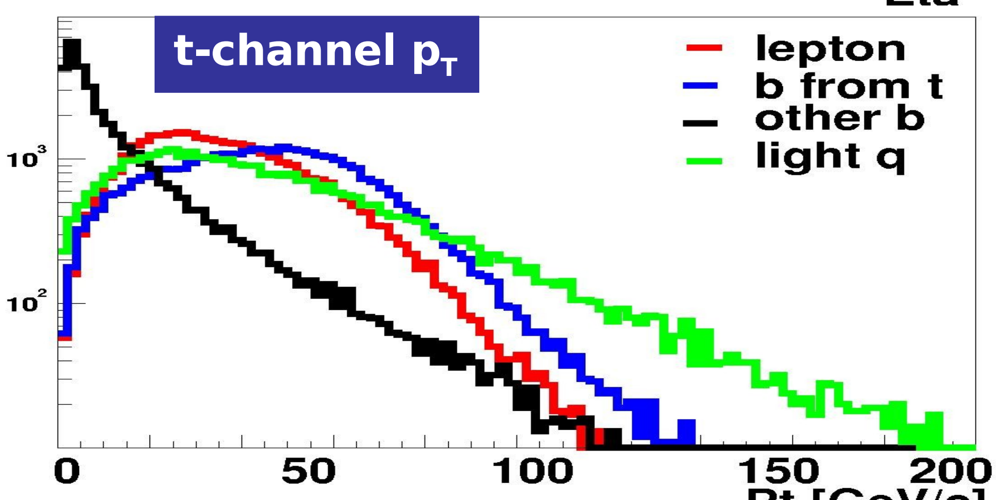
Signal selection



Signature:

- One high p_T isolated lepton (from W)
- MET (ν from W)
- One b-quark jet (from top)
- A light flavor jet and/or another b-jet



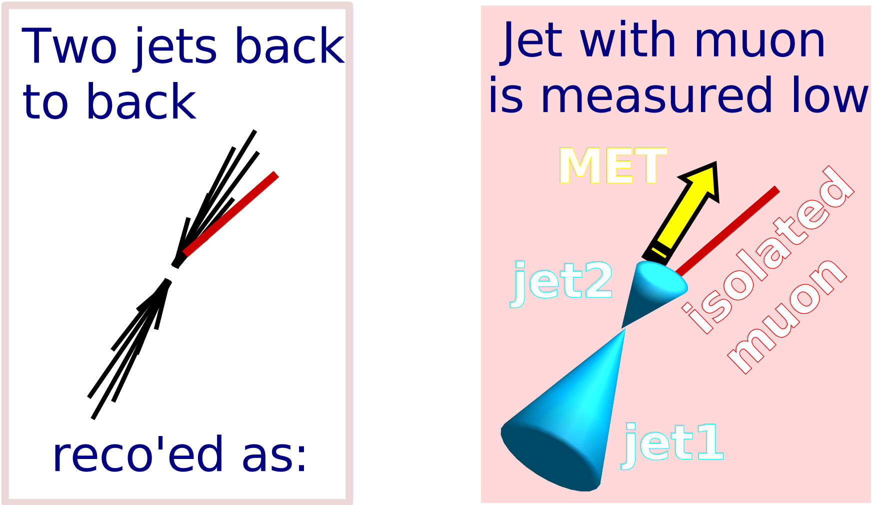


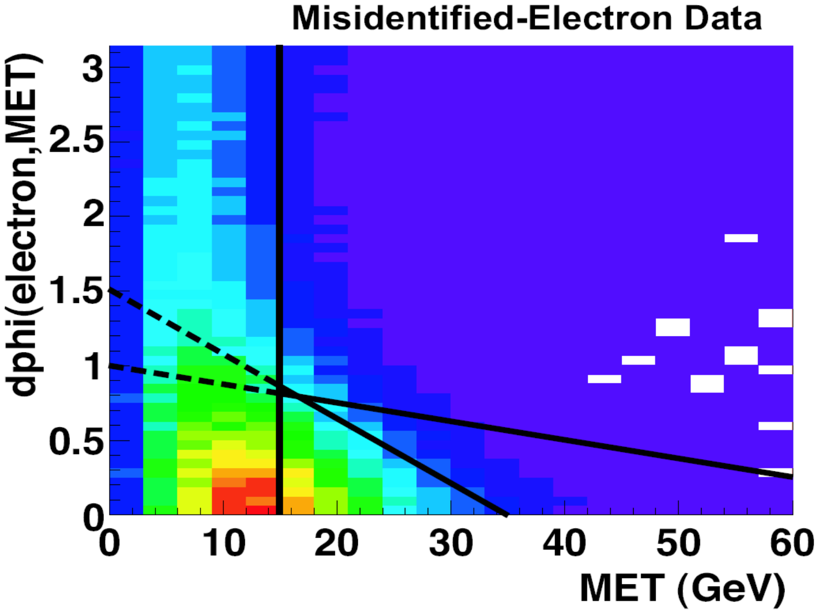
Event selection:

- Only one tight (no loose) lepton:
  - e: p_T >15 GeV and $|\eta^{det}|<1.1$
  - μ: p_T >18 GeV and $|\eta^{det}|<2.0$
- MET > 15 GeV
- 2-4 jets: p_T >15 GeV and $|\eta^{det}|<3.4$
  - Leading jet: p_T>25GeV ; $|\eta^{det}|<2.5$
  - Second leading jet: p_T >20 GeV
- One or two b-tagged jets

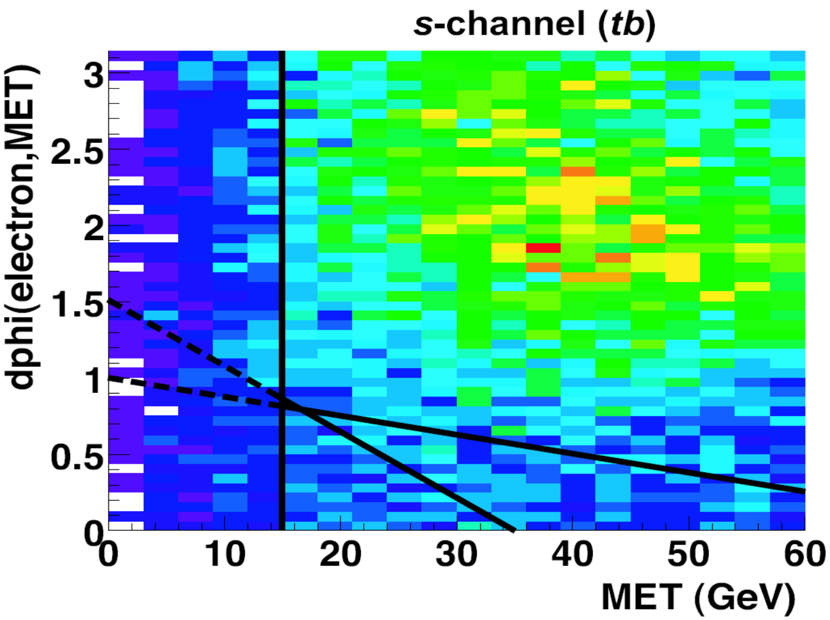
Cleaning up the data

- We use the $\Delta\phi(\ell,\text{MET})$ vs. MET plane to clean up pathological backgrounds like badly mismeasured muons or jets or noise in the calorimeter





- Used for e, μ and jets
- Our simulation does not reproduce these effects, so we remove them
- These cuts also allow to reduce QCD in the low $m_T(W)$ without having to cut directly on $m_T(W)$



"Matrix method" normalization

- Normalize the QCD and W+jets yields to data before tagging
- Similar to CDF's MET vs ISO method (4 sector method)
- Split data samples according loose and tight lepton isolation:

$$N^{loose} = N^{loose}_{fake} + N^{loose}_{real}$$

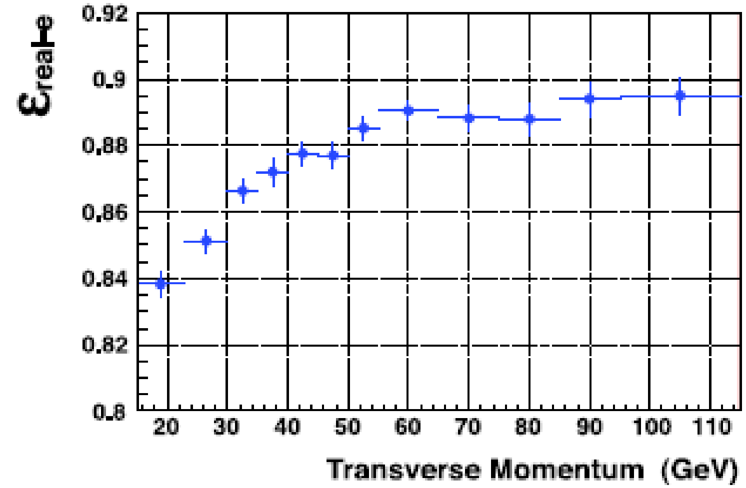
$$N^{tight} = \varepsilon_{fake} N^{loose}_{fake} + \varepsilon_{real} N^{loose}_{real}$$

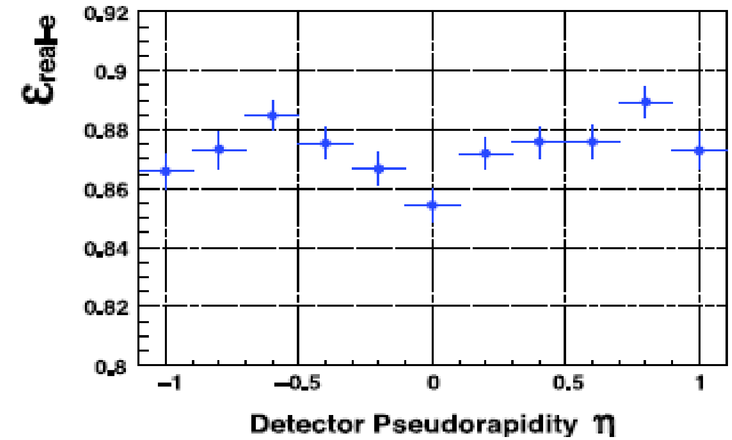
Obtain: N^{loose}_{real} and N^{loose}_{fake}

- Need probability for a fake QCD lepton to pass isolation ($\varepsilon_{\text{fake}}$) and the probability for a real lepton to pass isolation ($\varepsilon_{\text{real}}$)
- $\varepsilon_{\text{real}}$ is determined in $Z \to \ell\ell$ data where one lepton is "tagged" as tight and the other (the "probe") is used to measure the probability to pass the tight isolation cut
- $\varepsilon_{\text{fake}}$ is determined in our data sample: in the low MET (MET<10 GeV) region, dominated by multijet events, as the ratio of tight over loose events

Isolation efficiencies

- ε_{real} for electrons parametrized in p_T and η
- ε_{real} for muons parametrized in p_T and N_{jets}
- ε_{fake} for electrons is parametrized as a function of the trigger version and N_{jets} (saw no dependence on p_T or η)
- ε_{fake} for muons is parametrized in η (weak dependence on p_T)

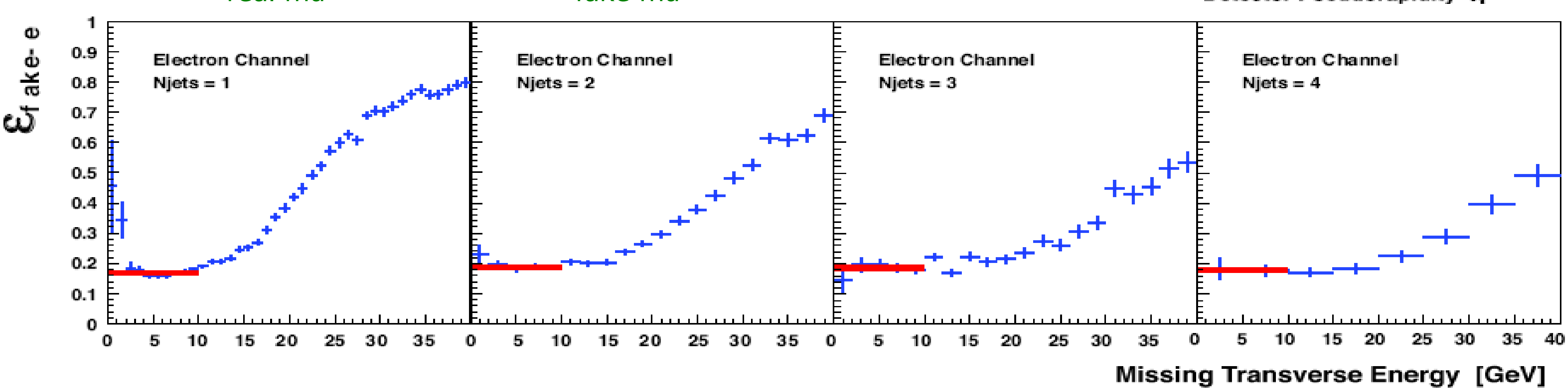




Averages for the 2jet bin:

$\varepsilon_{real\text{-}e} = 87\%$; $\varepsilon_{fake\text{-}e} \sim 19\%$

$\varepsilon_{real\text{-}mu} = 99\%$; $\varepsilon_{fake\text{-}mu} = 36\%$

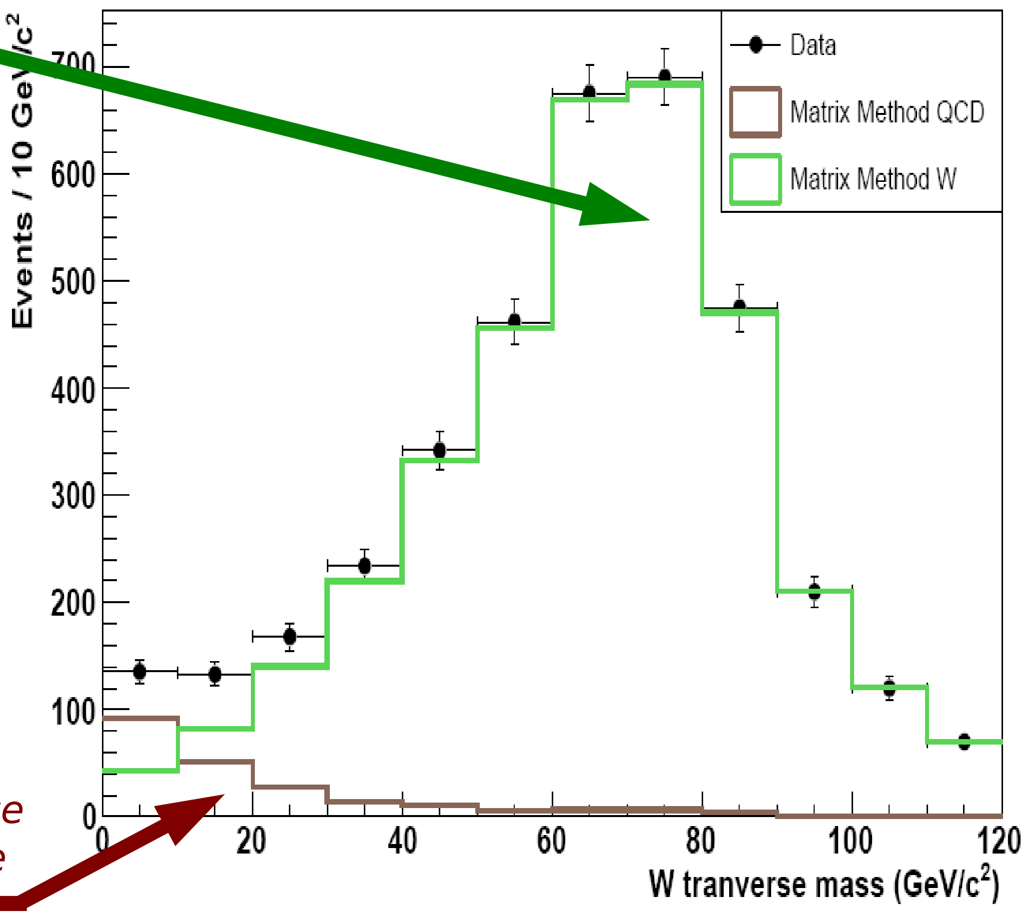


Matrix method continued

- We normalize the W+jets samples to the real-ℓ yield found in data, after correcting for the presence of tt events, and obtain the W+jets yield: (here Y=Acc*L*σ_{Alpgen})

$$\varepsilon_{real} N_{real}^{loose} = MM_{SF}[\alpha Y(Wjj) + \alpha Y(Wb\bar{b}) + Y(Wc\bar{c})] + Y(t\bar{t})$$

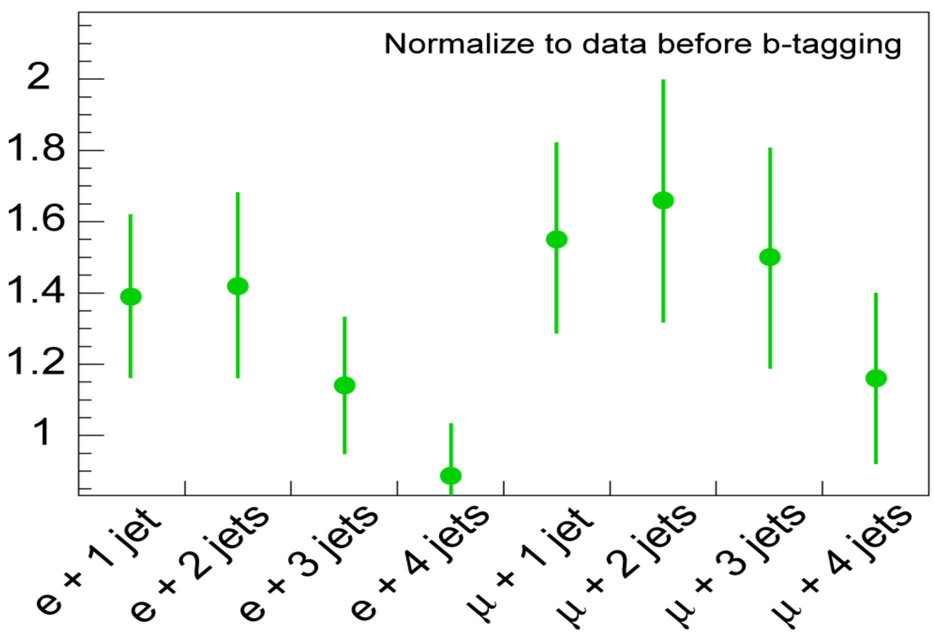
- Y(Wjj)+Y(Wbb)+Y(Wcc) are the Alpgen yields: Y=Acc*L*σ
- α is the HF factor (later)
- The MM_{SF} comes around 1.4 (different for each jet bin and e or mu channel)
- Numbers are very similar if done for 2+3+4 jets together
- Scale the QCD yield from orthogonal sample to: $\varepsilon_{fake} N_{fake}^{loose}$



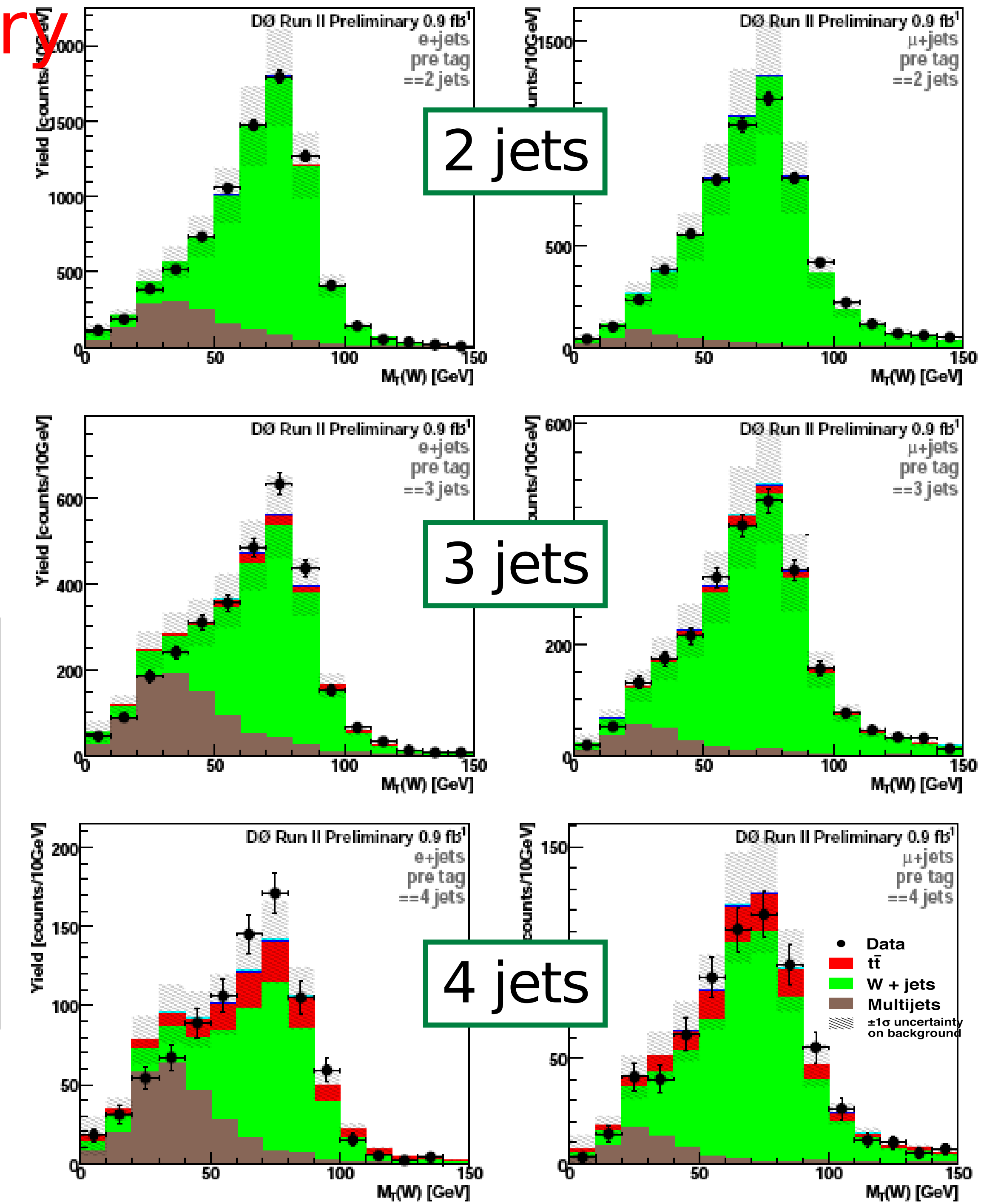
W+jets and multijet normalization summary

- Each jet bin normalized separately
- MM_{SF} ~1.4 for W+jets

W+jets normalization factors



Electrons | Muons



Single Top Group

Heavy flavor fraction: the problem

- We know the NLO cross section changes wrt LO values for Wbb and Wcc, and also for Wjj
- Since we usually normalize all W+jets to data, the problem is not so much the absolute σ(Wbb) or σ(Wjj), but the fraction of Wbb (and Wcc) in W+jets: the HF ratio
- Our Alpgen samples have LO σ values and massive b's, and they are matched (generated with no parton cut on b pT)
- MCFM gives NLO with massless b's and requires a b pT cut
- In the past, Alpgen was not matched and we could use MCFM with the same Alpgen parton cuts (away from m_b) and got a NLO value for both Wbb and Wjj, and ensured the HF fraction was that NLO ratio.

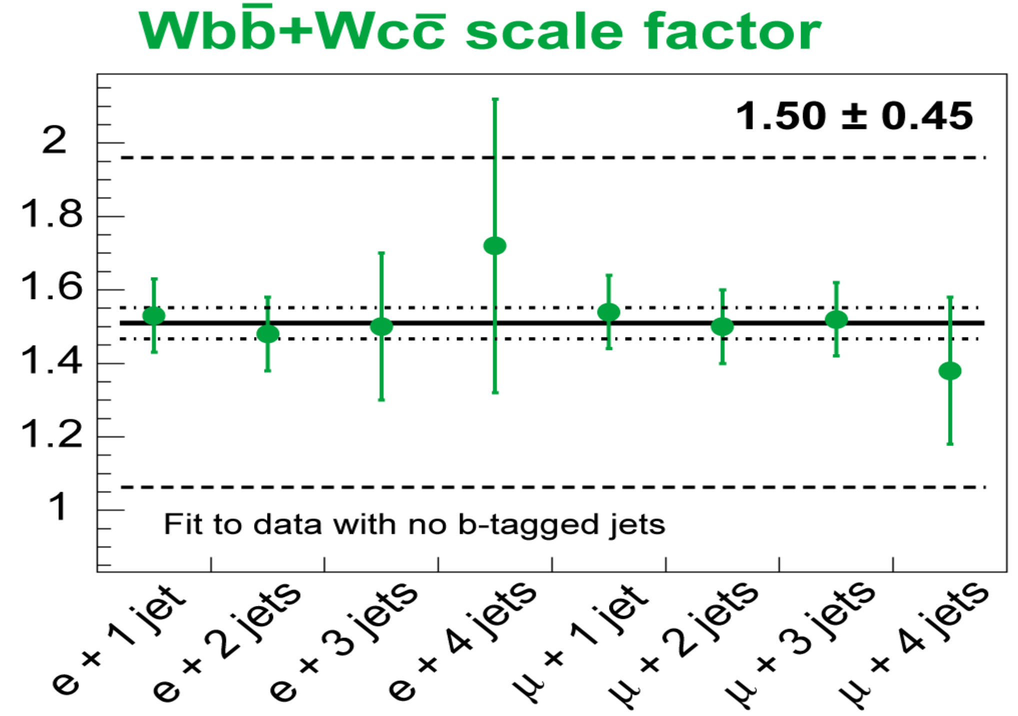
MCFM NLO/LO k-factors
- massless b's
- Wcc included in Wjj

Jet pT	Wbb k-factor	Wjj k-factor	HF factor
4	1.88	1.20	1.57
6	1.74	1.23	1.41
8	1.64	1.22	1.35
10	1.58	1.23	1.28

- But now Alpgen is matched and cannot be compared to MCFM at LO, so what NLO σ should we use?

Use the data!

- Similar approach to CDF, but instead of using a generic multijet data, we use our own selected sample:
  The **0-tag sample** (where the tagger finds zero b-tagged jets)
- Easy extrapolation to 2,3,4 jets with 1 or 2 tags (signal region)
- Check that the signal region also requires something similar
- We apply a constant 1.5±0.45 factor to Wbb+Wcc
- Assign 30% uncertainty for differences in event kinematics and assumption Wbb and Wcc are equal

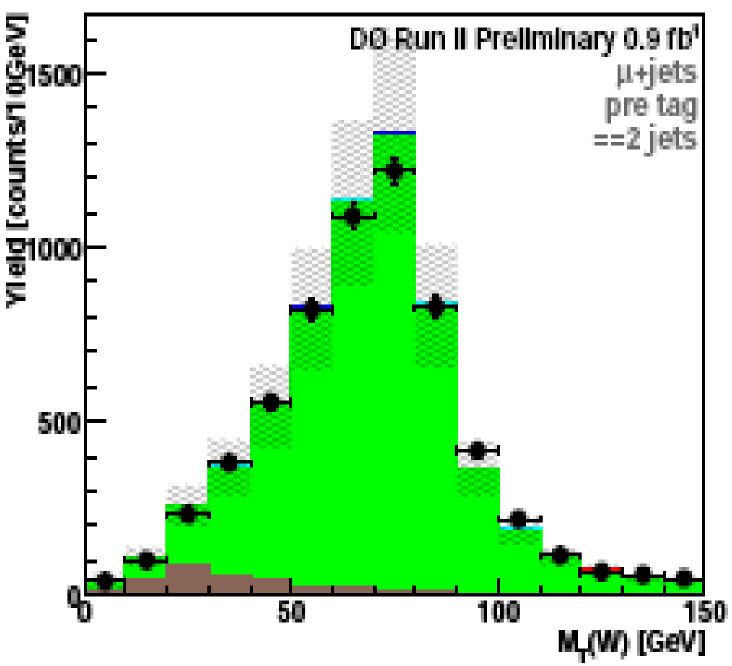


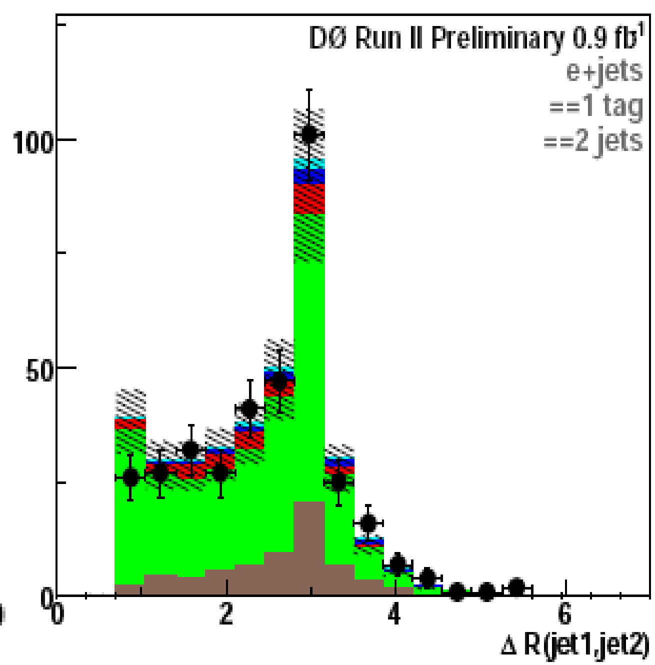
Scale Factor α to Match Heavy Flavor Fraction to Data

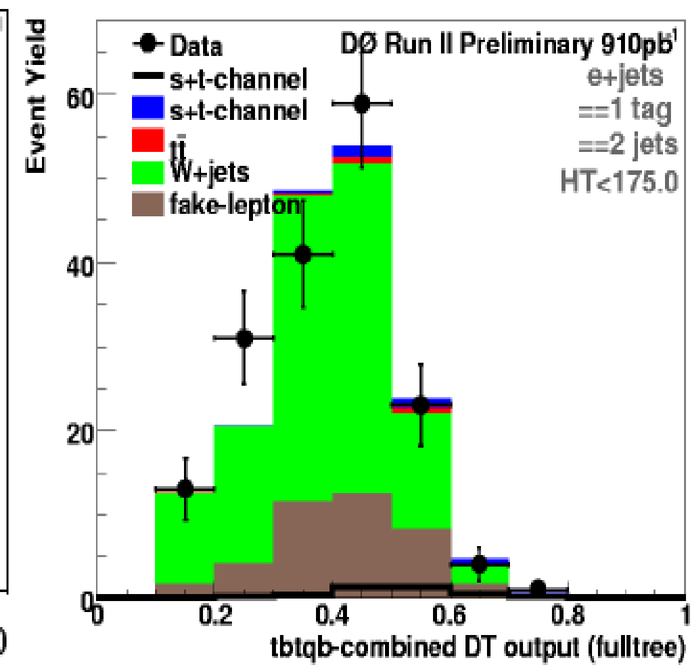
	1 jet	2 jets	3 jets	4 jets
Electron Channel				
0 tags	1.53 ± 0.10	1.48 ± 0.10	1.50 ± 0.20	1.72 ± 0.40
1 tag	1.29 ± 0.10	1.58 ± 0.10	1.40 ± 0.20	0.69 ± 0.60
2 tags	—	1.71 ± 0.40	2.92 ± 1.20	-2.91 ± 3.50
Muon Channel				
0 tags	1.54 ± 0.10	1.50 ± 0.10	1.52 ± 0.10	1.38 ± 0.20
1 tag	1.11 ± 0.10	1.52 ± 0.10	1.32 ± 0.20	1.86 ± 0.50
2 tags	—	1.40 ± 0.40	2.46 ± 0.90	3.78 ± 2.80

What about shapes?

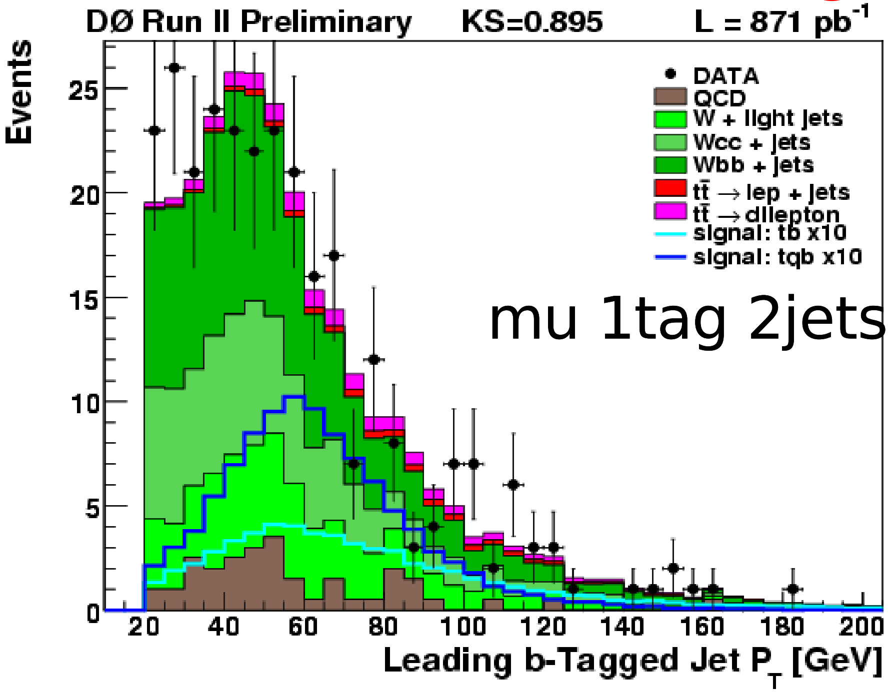
- NLO shapes for Wbb are different from Alpgen (LO)
- Specially at low b-jet p_T (<25GeV) and m_{bb} (<25GeV & >80GeV)
  - Until we have a data-based method to extract Wbb or a pT dependent k-factor from MC, we are stuck with a constant
  - Let the data judge. We have found overall good agreement in all kinds of distributions inside our acceptance before and after tagging: angular correlations, pTs, background cross check samples, discriminant outputs...

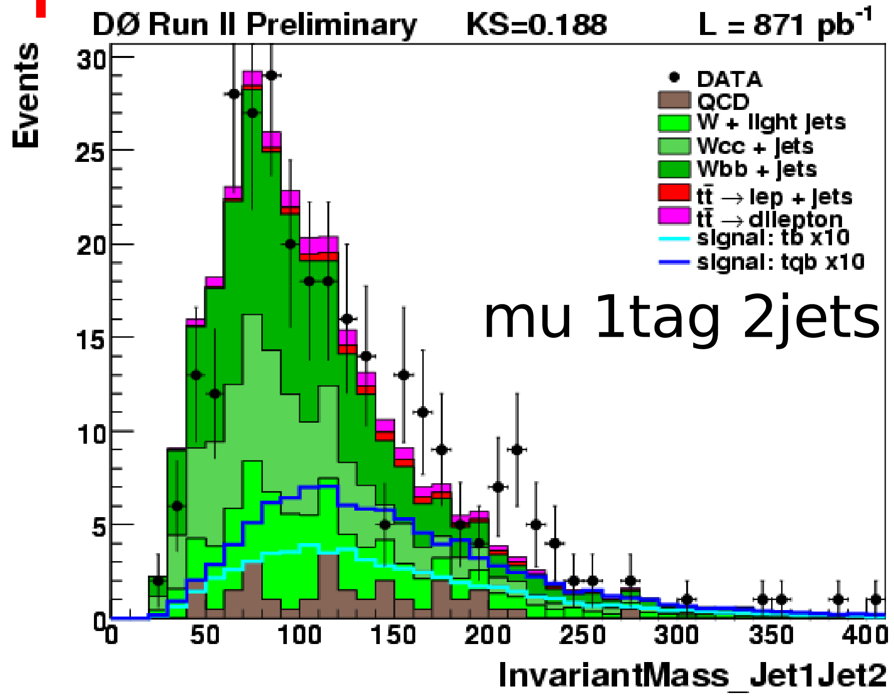


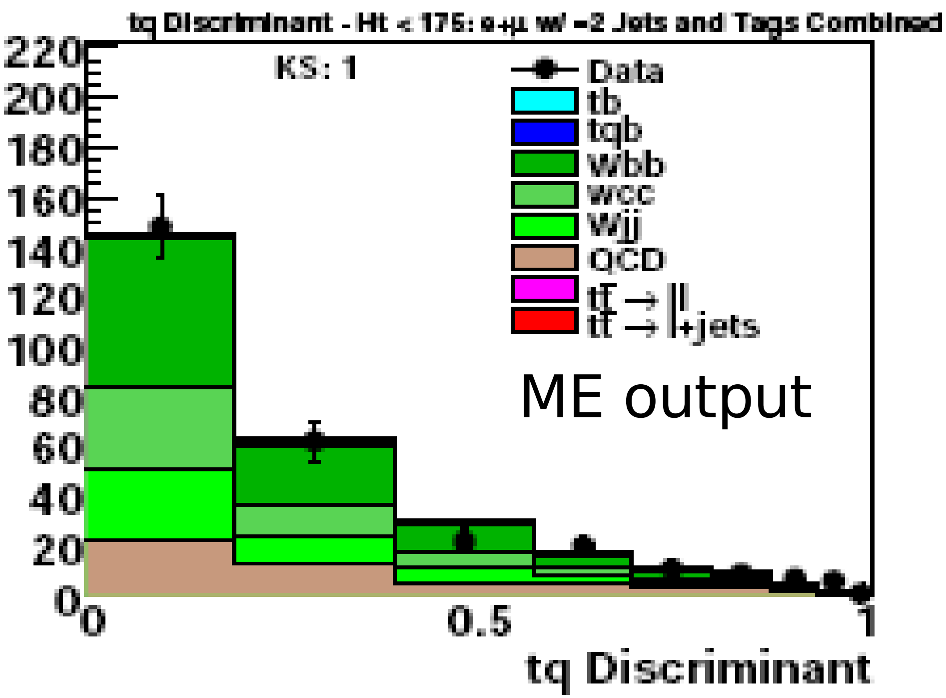


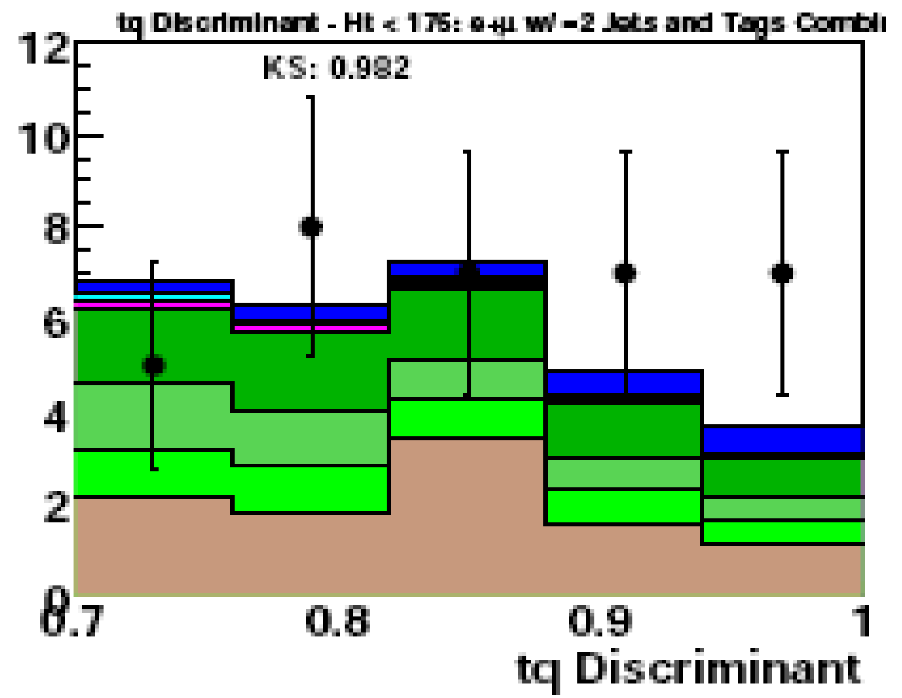


More shapes


DØ Run II Preliminary
KS=0.895
L = 871 pb^{-1}
Events
DATA
QCD
W + light jets
Wcc + jets
Wbb + jets
$t\bar{t} \rightarrow$ lep + jets
$t\bar{t} \rightarrow$ dilepton
signal: tb x10
signal: tqb x10
mu 1tag 2jets
Leading b-Tagged Jet P_T [GeV]

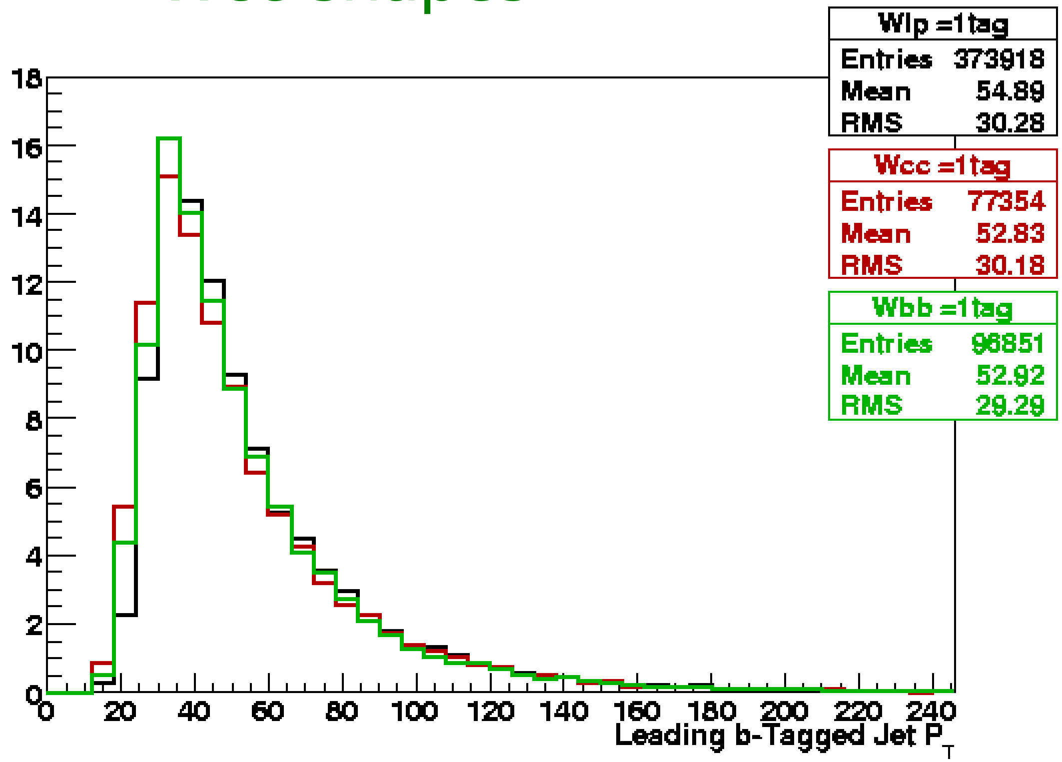

DØ Run II Preliminary
KS=0.188
L = 871 pb^{-1}
Events
DATA
QCD
W + light jets
Wcc + jets
Wbb + jets
$t\bar{t} \rightarrow$ lep + jets
$t\bar{t} \rightarrow$ dilepton
signal: tb x10
signal: tqb x10
mu 1tag 2jets
InvariantMass_Jet1Jet2

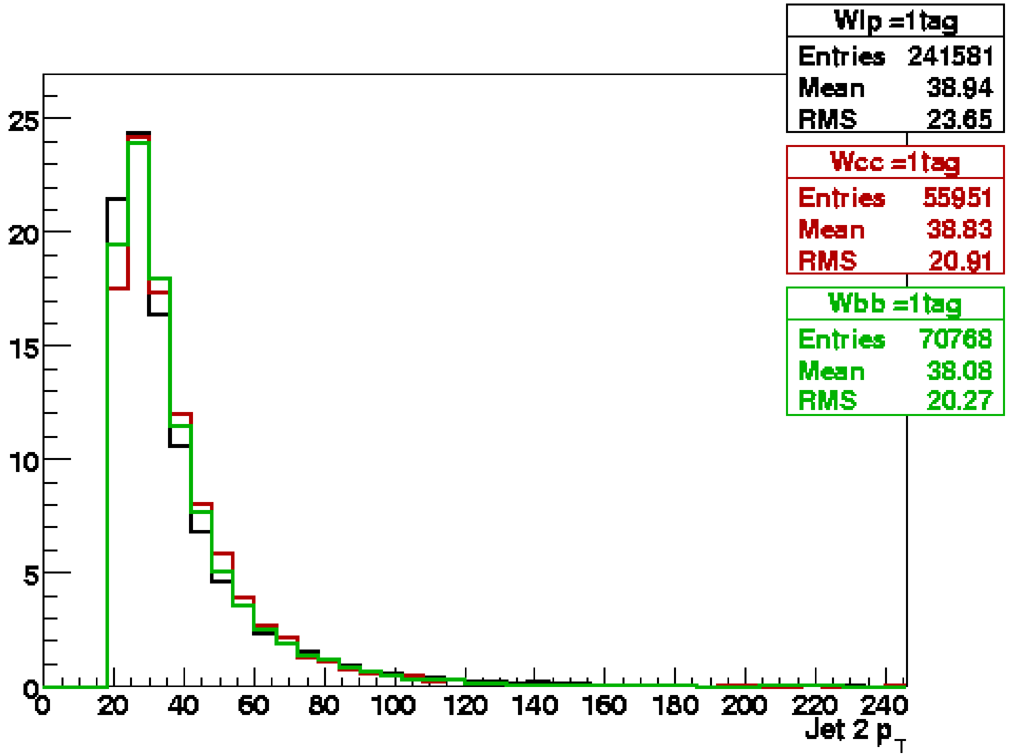

tq Discriminant - Ht < 175: e+μ w/ =2 Jets and Tags Combined
KS: 1
Data
tb
tqb
Wbb
wcc
Wjj
QCD
$t\bar{t} \rightarrow ll$
$t\bar{t} \rightarrow l$+jets
ME output
tq Discriminant


KS: 0.982
tq Discriminant

Wbb/Wcc shape difference

- Can you assume that Wbb and Wcc fractions separately can be described by the Wbb+Wcc fraction?
  - We changed the Wbb/Wcc ratio by ±10% and re-calculated the single top cross section:
  - More Wbb, less Wcc: σ(tb+tqb)=4.85±1.4pb
  - Less Wbb, more Wcc: σ(tb+tqb)=4.98±1.5pb
  - Weak dependence based on similarity between Wbb and Wcc shapes





Error on the HF fraction

- How come a 30% error on HF fraction doesn't destroy all sensitivity?
  - This (still) is a statistics limited analysis: 1.2pb out of 1.4pb error comes from stats alone
  - The 30% error (1.5±0.45) covers shape differences in the NLO distributions and between Wbb and Wcc
  - After tagging, the uncertainty on the total W+jets yield is reduced from 30% because:

    a) Not the entire sample is Wbb+Wcc, the uncertainty on the sum is smaller than 30%

    b) The anti-correlation between Wjj and Wbb+Wcc due to the normalization before tagging further reduces the uncertainty
  - This uncertainty is still the largest flat systematic in the end

Yield table

Source	Event Yields in 0.9 fb^{-1} Data Electron+muon, 1tag+2tags combined 2 jets	3 jets	4 jets
tb	16 ± 3	8 ± 2	2 ± 1
tqb	20 ± 4	12 ± 3	4 ± 1
$t\bar{t} \rightarrow ll$	39 ± 9	32 ± 7	11 ± 3
$t\bar{t} \rightarrow l$+jets	20 ± 5	103 ± 25	143 ± 33
$W+b\bar{b}$	261 ± 55	120 ± 24	35 ± 7
$W+c\bar{c}$	151 ± 31	85 ± 17	23 ± 5
$W+jj$	119 ± 25	43 ± 9	12 ± 2
Multijets	95 ± 19	77 ± 15	29 ± 6
Total background	686 ± 41	460 ± 39	253 ± 38
Data	697	455	246

- This table, and its errors, are NOT used in the σ determination
- The Wbb, Wcc, Wjj and QCD contributions have a ~20% error for orientation purposes only
- The total error (on W+jets+QCD) takes into account the anti-correlations imposed by the normalization to data

Systematics

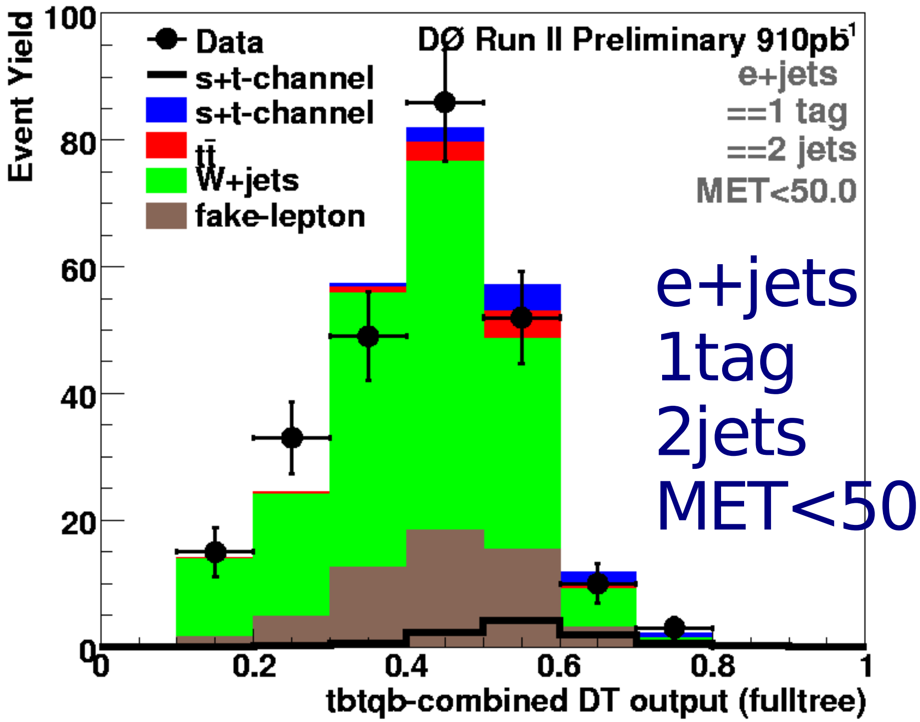
$t\bar{t}$ cross section	18%	Primary vertex	3%
Luminosity	6%	Electron reco * ID	2%
Electron trigger	3%	Electron trackmatch & likelihood	5%
Muon trigger	6%	Muon reco * ID	7%
Jet energy scale	wide range	Muon trackmatch & isolation	2%
Jet efficiency	2%	$\varepsilon_{\mathrm{real}-e}$	2%
Jet fragmentation	5–7%	$\varepsilon_{\mathrm{real}-\mu}$	2%
Heavy flavor fraction	30%	$\varepsilon_{\mathrm{fake}-e}$	3–40%
Tag-rate functions	2–16%	$\varepsilon_{\mathrm{fake}-\mu}$	2–15%

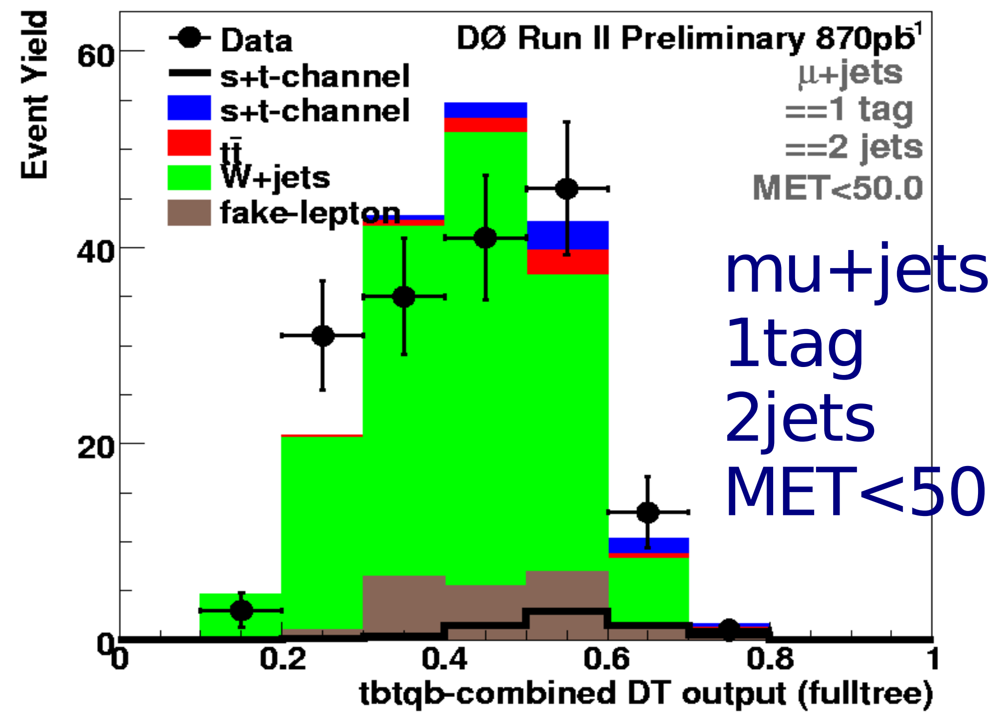
- We handle the correlations imposed by the MM by treating W+jets + QCD as one source
- The 30% relative error on Wbb+Wcc becomes ~20% because of the anticorrelation between Wjj and Wbb+Wcc

QCD modeling

- The orthogonal sample we use to derive our QCD model has the following problems:
  - Assumes no real lepton contamination (ε_{real}~1)
  - Kinematic dependence of ε_{fake} biases the sample (e.g. if ε_{fake} depends strongly on the lepton p_T or η)
  - Low statistics after b-tagging
- The uncertainty on the QCD yield (~20%) comes from the Matrix Method, and is actually applied to the sum of W+jets+QCD
- It includes the errors on the determination of ε_{real} and ε_{fake} and the error from the HF (dominant)

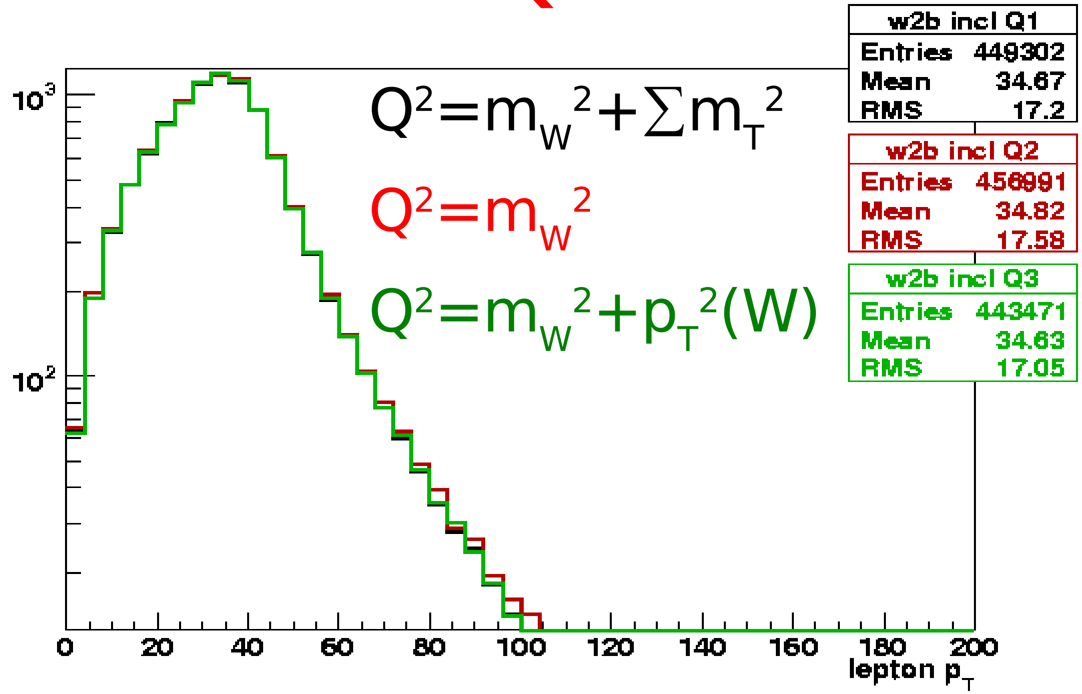
DT output for QCD sample



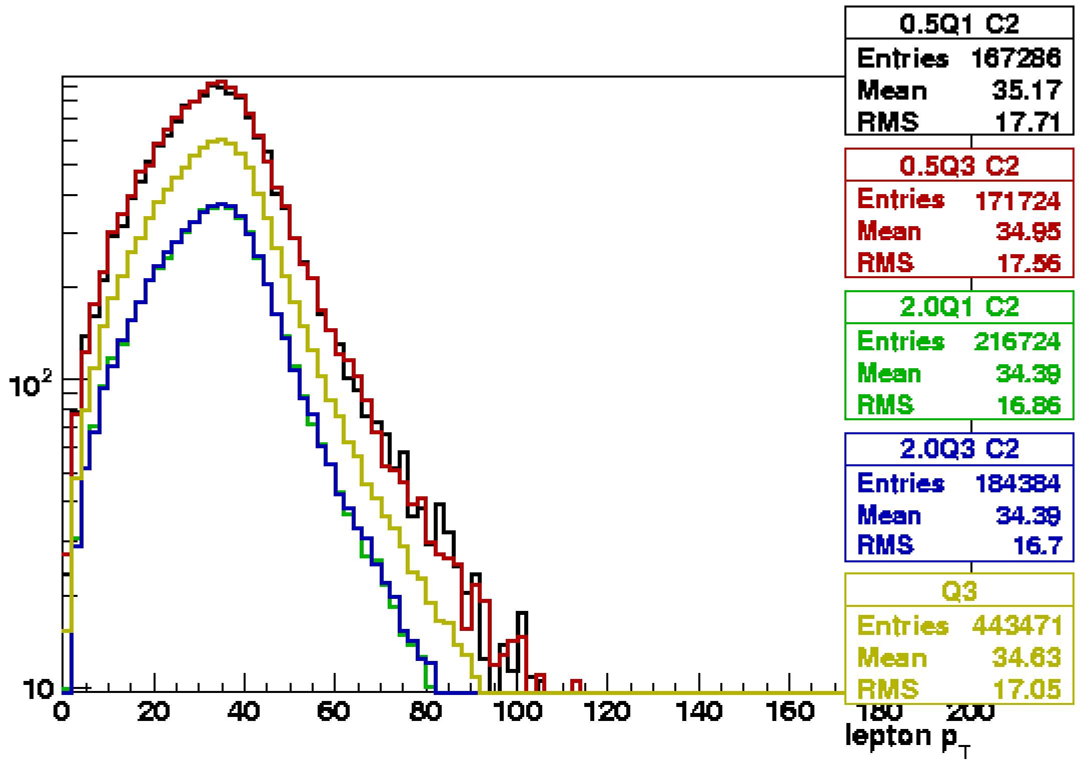


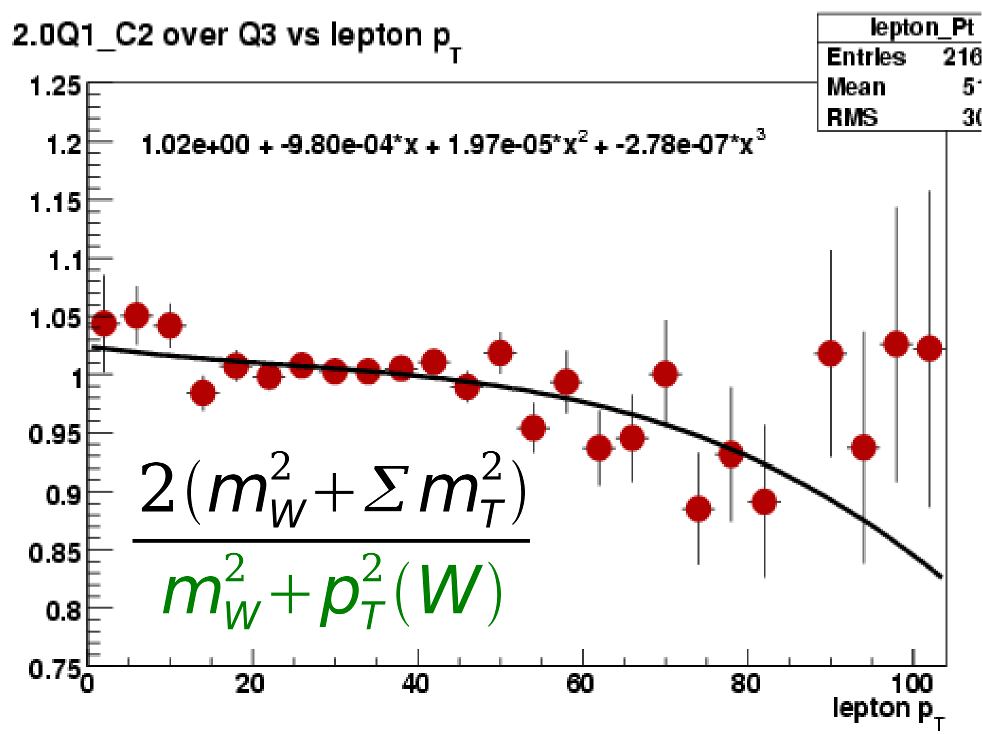
- Few total events with MET < 25 GeV: hard to get a pure QCD sample with high statistics
- Trees are not trained against QCD
- QCD appears spread out in discriminant output
- It's a small component of the total background!

Q^2 effect on shapes



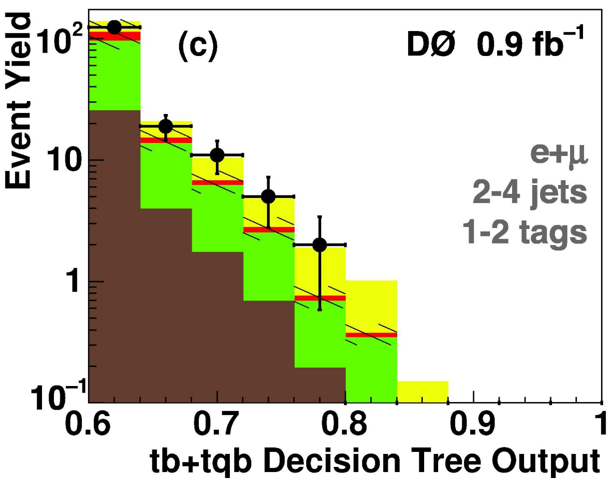
- W+jets uses: $Q^2=m_W^2+p_T^2(W)$
- tt uses: $Q^2=m_t^2+\sum p_T^2(\text{jets})$
- For Wbb, changed Q^2 and the factorisation scale to 0.5 and 2.0 x renormalization scale
- Shapes stay similar

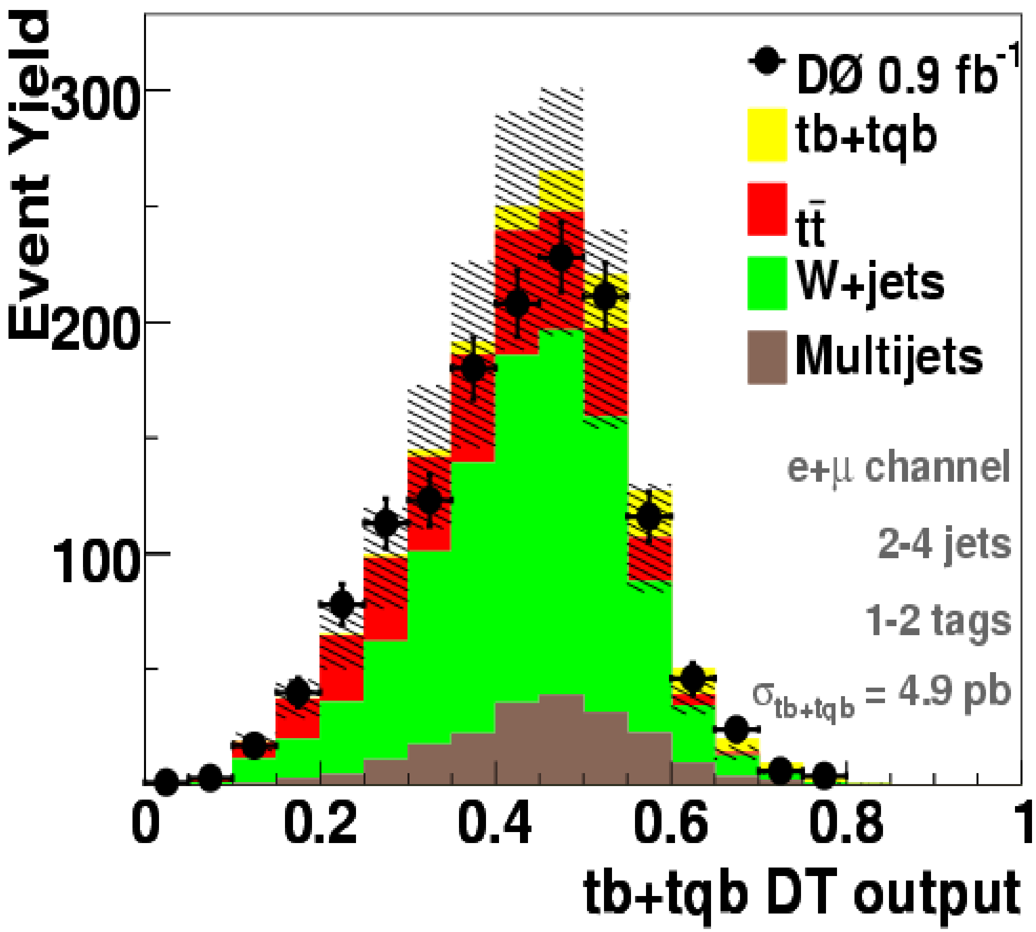


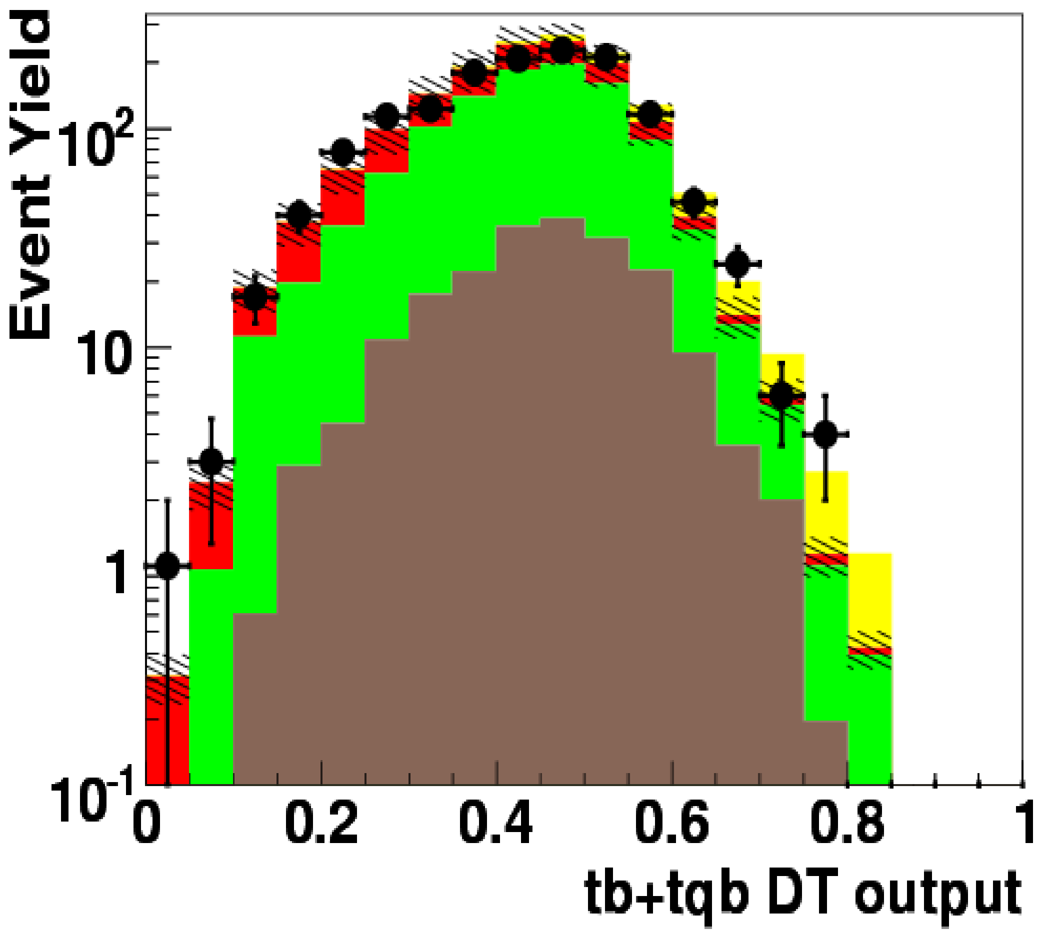


Combined DT ouptut

- Full combined DT output: this plot is not used in the analysis
- The measurement comes from 12 different plots

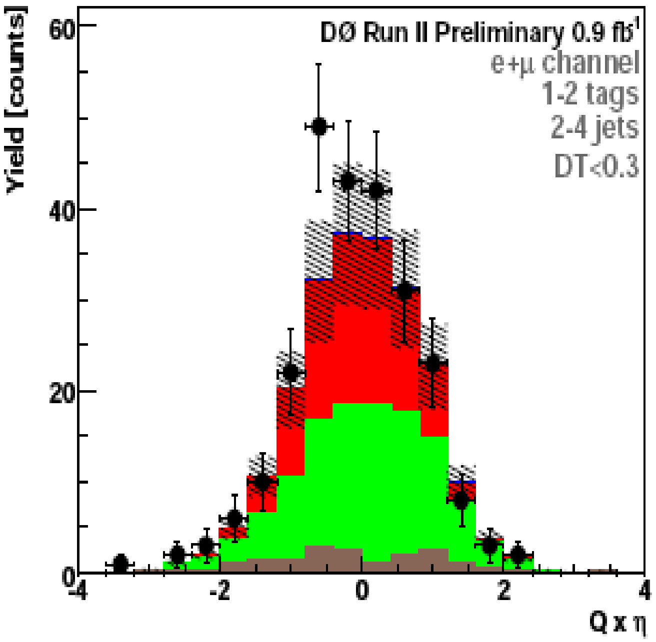




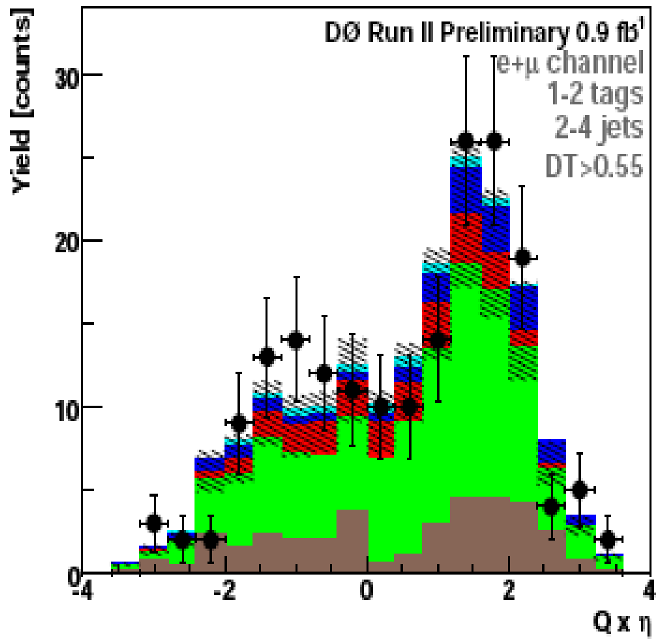


Qxeta plots

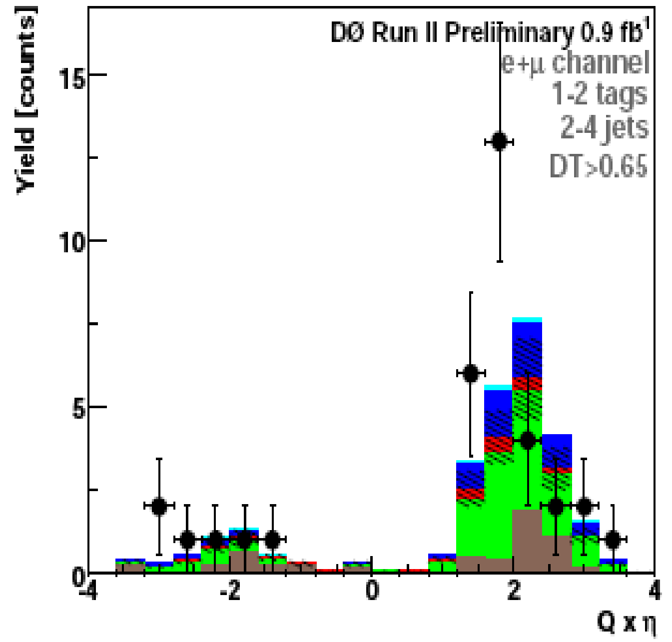
DT < 0.3



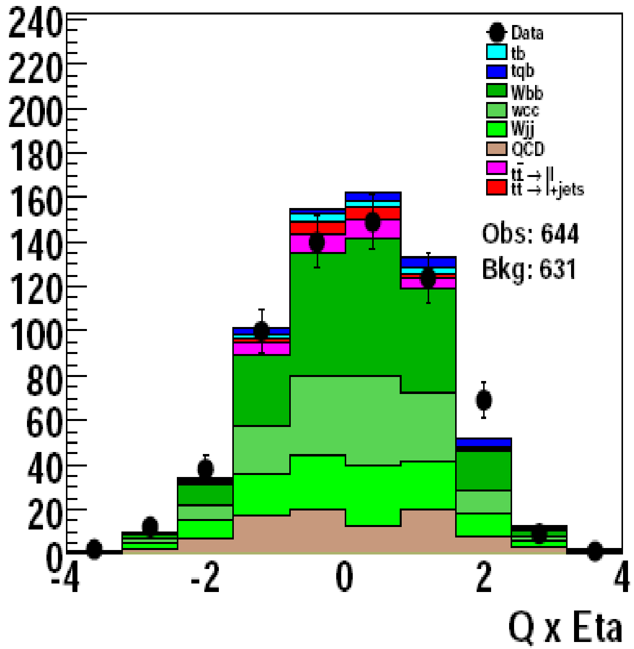
DT > 0.55



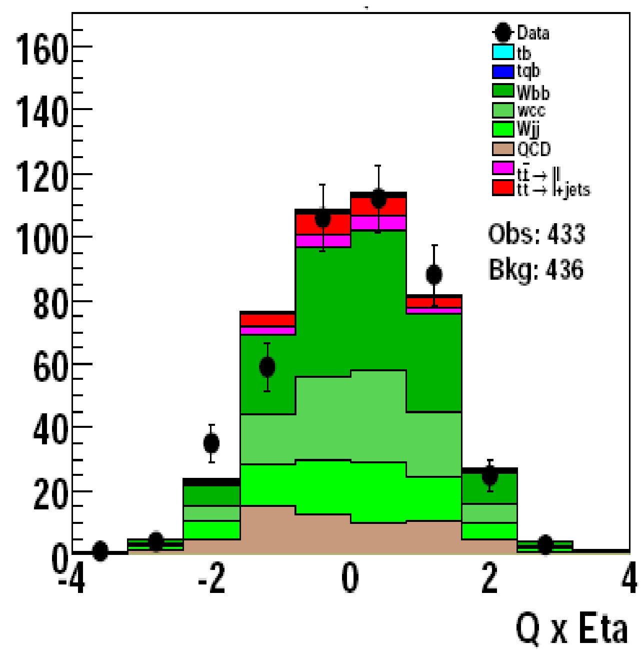
DT > 0.65



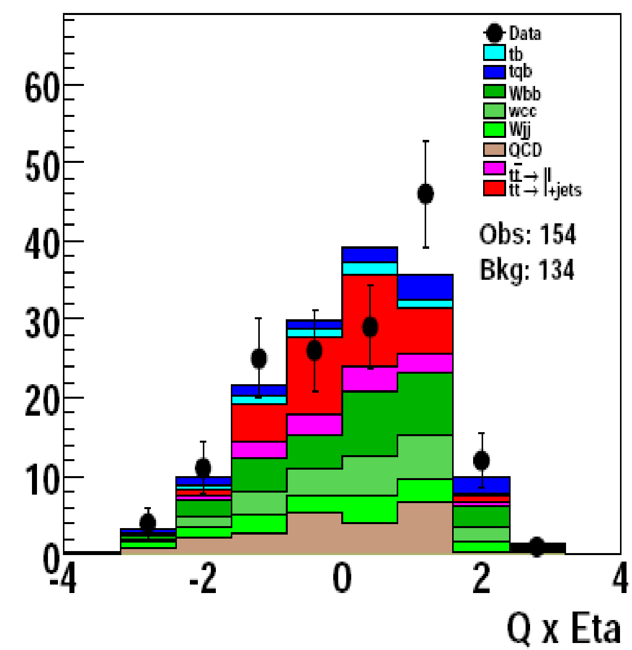
ME > 0



ME < 0.40



ME > 0.70



Overconstraining the bkg?

- Test if the background uncertainty is mostly set in the low DT region and thus an excess in the high DT region can only come from signal, as the bkg there is tightly constrained
  - Measure only with DT>0.6: σ(s+t)=$4.89^{+2.5}_{-2.1}$pb