How to Measure Top Quark Mass with CMS Detector ???

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Outlines

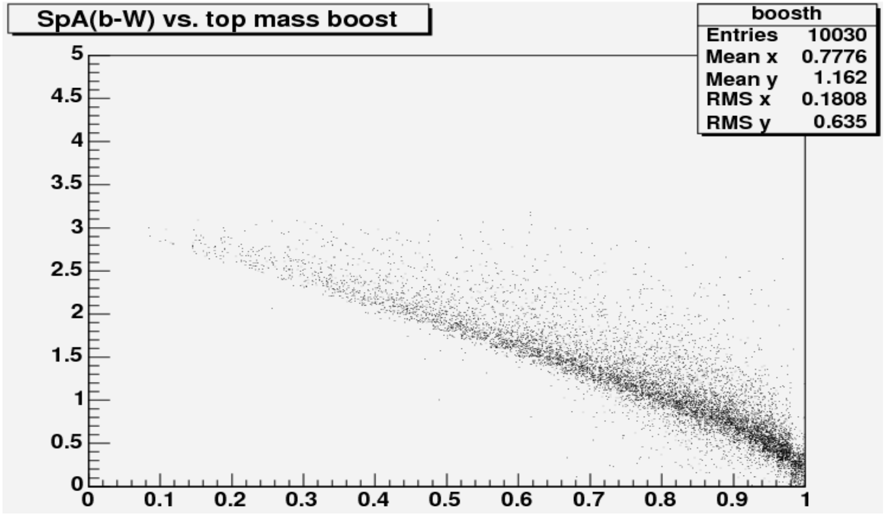
- High Pt top basic idea
- Methods for jets selection
- Top quark mass reconstruction from jets
- Jets clustering and clusters method for M^{top}_{clus}
- Underlying Event (UE_{clus}) estimation and subtraction
- Systematics errors
- Summary

Boosted Top Quark Analysis

- Highly boosted top quarks : Decay back-to-back
- Higher top boost : Small opening angle of W-boson and b-quark
- High Pt top quarks : Large probability of jets overlaping in space.
- Invariant mass of the objects (jets/clusters) in larger cone around the top quark flight direction : Correlation with the real top quark mass.
- Top quark needs to have a larger boost : **Pt > 200 GeV**.

WHY --?

- Reduces the combinatorial background.
- The systematic effects due to jet energy calibration and gluon effects
- Potential to reduce the systematic errors



Kinematical variables

- Invariant mass $m^2 = p^\mu p_\mu = E^2 - \vec{p}^{\,2}$
- Transverse momentum $p_T^{\,2} = p_x^{\,2} + p_y^{\,2}$
- Transverse mass $m_T^{\,2} = m^2 + p_T^{\,2} = E^2 - p_z^{\,2}$
- Transverse energy $E_T = E \sin \vartheta$
- Pseudo-rapidity $\eta = -\ln\left(\tan\frac{\vartheta}{2}\right)$
- Rapidity $y = \frac{1}{2}\ln\left(\frac{E+p_z}{E-p_z}\right) = \ln\left(\frac{E+p_z}{m_T}\right)$
- Jet cone radius $\Delta R = \sqrt{\Delta\eta^2 + \Delta\varphi^2}$
- Missing Transverse Energy E_T^{miss}

Event Simulation: Tools and Methods

1. Event generation (PYTHIA, TOPREX, CMKIN)
2. Simulation of the interaction of the generated particles with the detector (OSCAR, FAMOS, CMSSW : GEANT4)
3. Simulation of digitized phase (FAMOS, CMSSW, ORCA)
   - Level-1 trigger (100 KHz)
   - High Level Trigger (100 Hz)
4. Local and global event reconstruction (FAMOS, CMSSW, ORCA)
5. Physics Analysis tools (PAW,ROOT)

Even Selection at Partonic Level

$$t\bar{t} \rightarrow bW^{+}bW^{-} \rightarrow b\bar{b}q\bar{q}\mu\nu_{\mu}$$

- $P_t^{top} > 200$ GeV, $|\eta| < 3.0$
- $P_t^{anti\text{-}top} > 200$ GeV, $|\eta| < 3.0$
- $P_t^{\mu} > 30$ GeV, $|\eta| < 2.0$
- $P_t^{q} > 20$ GeV, $|\eta| < 2.5$

Fast simulation based samples

165 Top mass point = 20K events

175 Top mass point = 50K events

185 Top mass point = 20K events

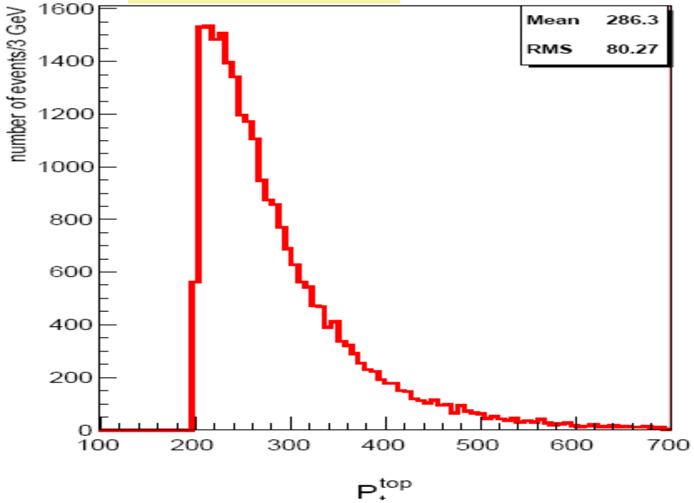
Pile-up events are included

Cross-section approximately 1% of the total tT cross-section

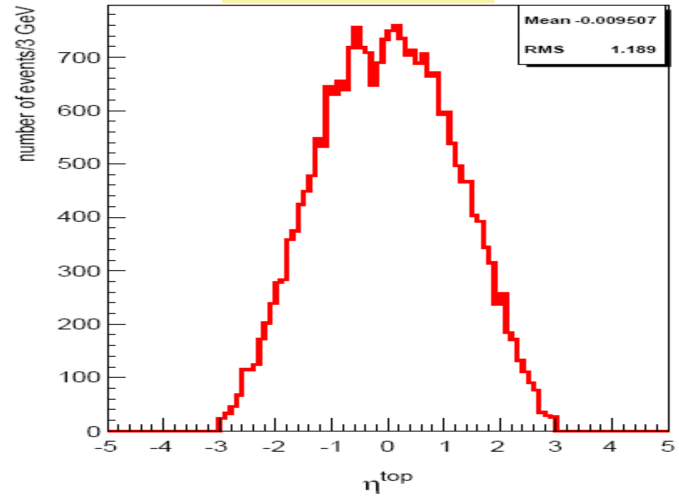
	No. of events With pile-up	Int . luminosity fb^{-1}	X-section pb
$t\bar{t} \rightarrow bW^{+}bW^{-} \rightarrow bq\bar{q}bl\nu(l=\mu)$	49535	7.23	6.85

Distributions at Decay Vertex (1)

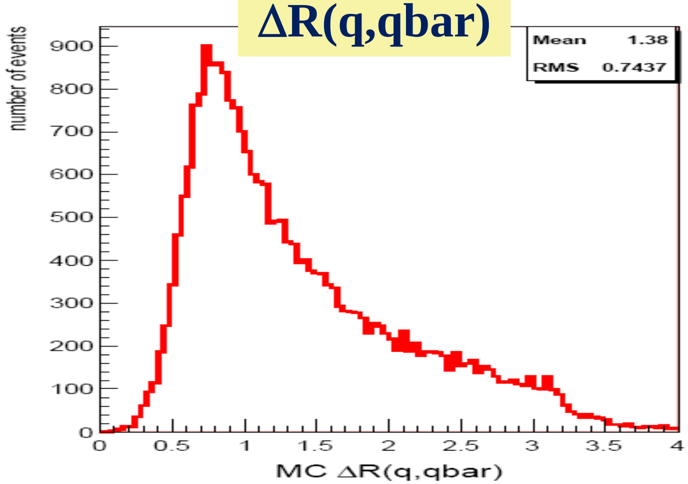
P_t^{top}



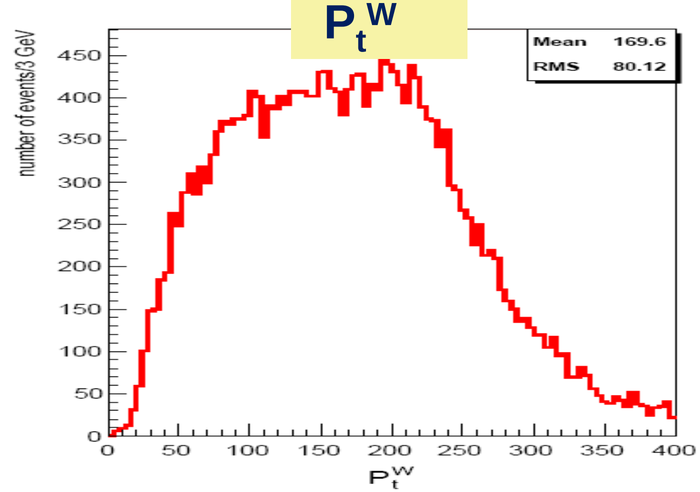
MC η^{top}



$\Delta R(q,qbar)$

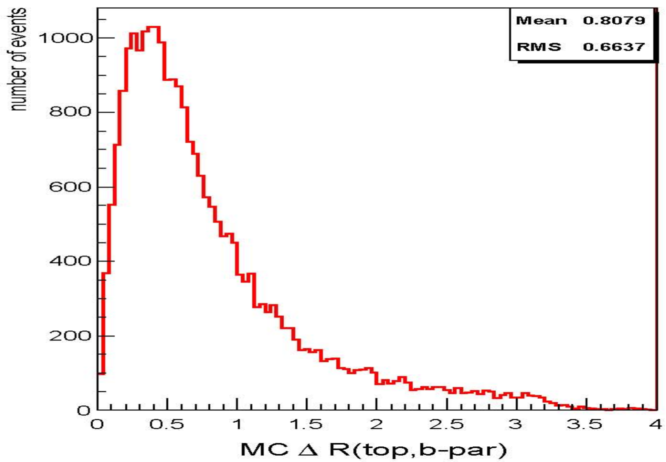


P_t^W

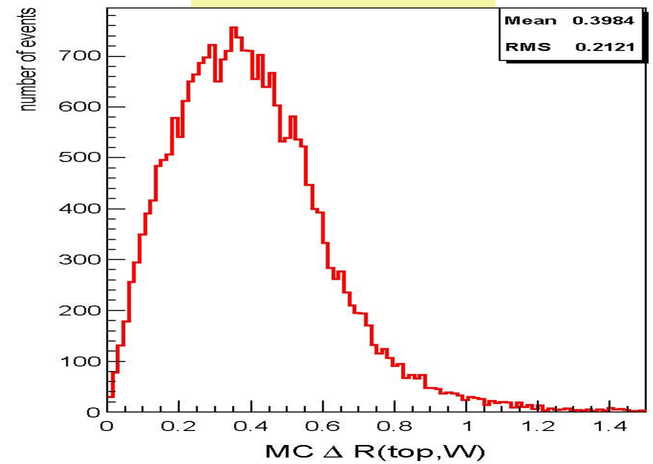


Distributions at Decay Vertex (2)

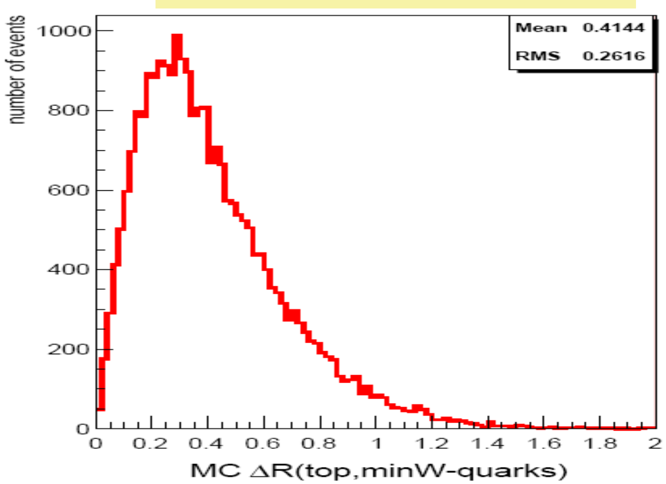
ΔR(top,b-par)



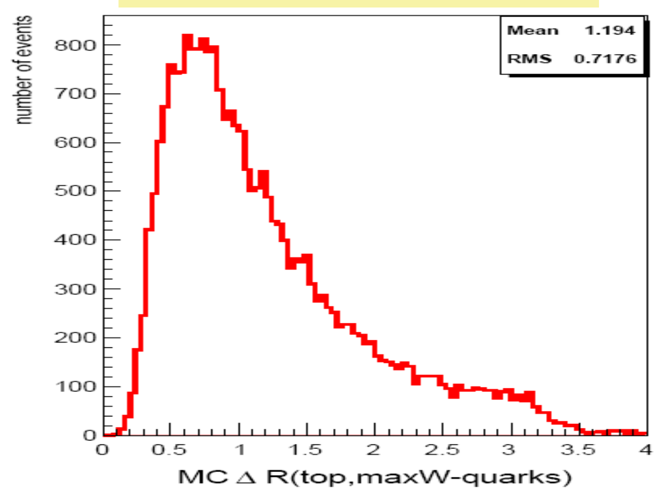
ΔR(top,W)



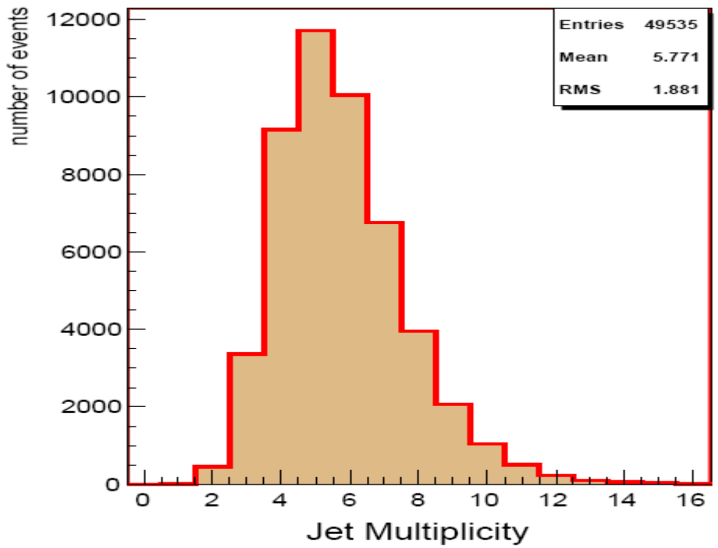
ΔR(top, min W-quarks)

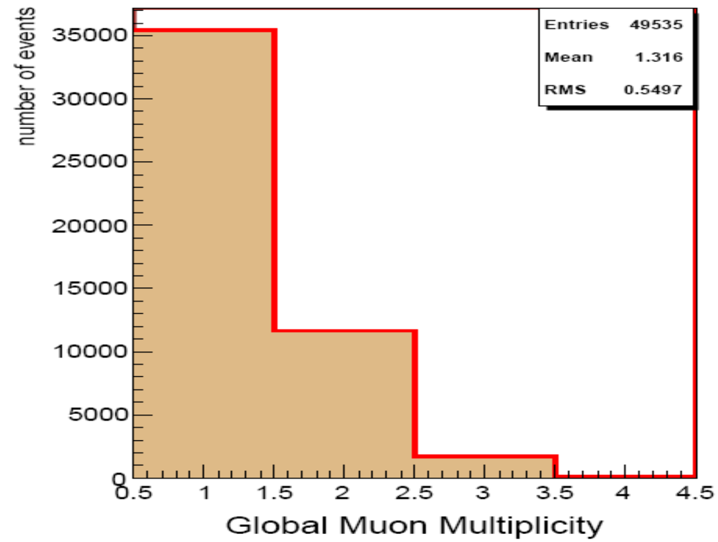


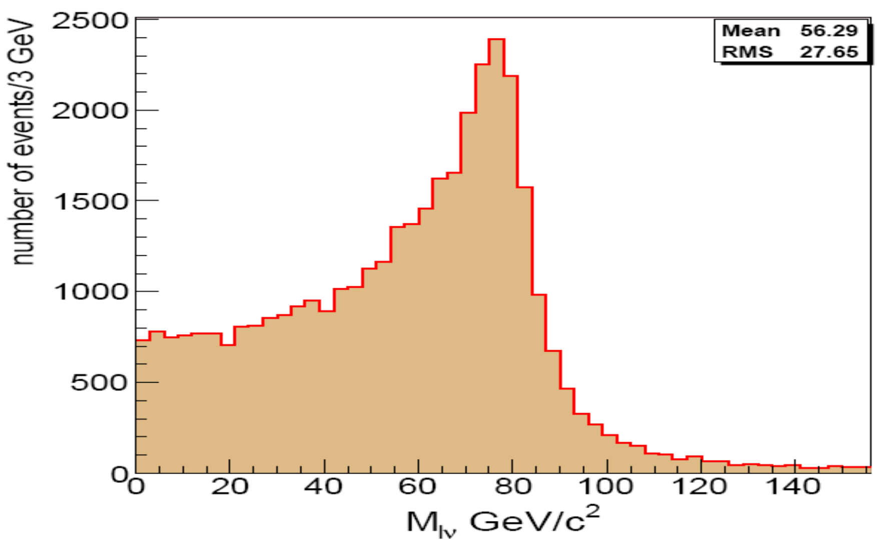
ΔR(top, max W-quarks)



Reconstruction







- ❑ MET-> Missing Transverse Energy
- ❑ MET > 30 GeV
- ❑ At least 1 iso. muon, P_t>20 GeV, $|\eta|$<2.0

leptonic W reco mass

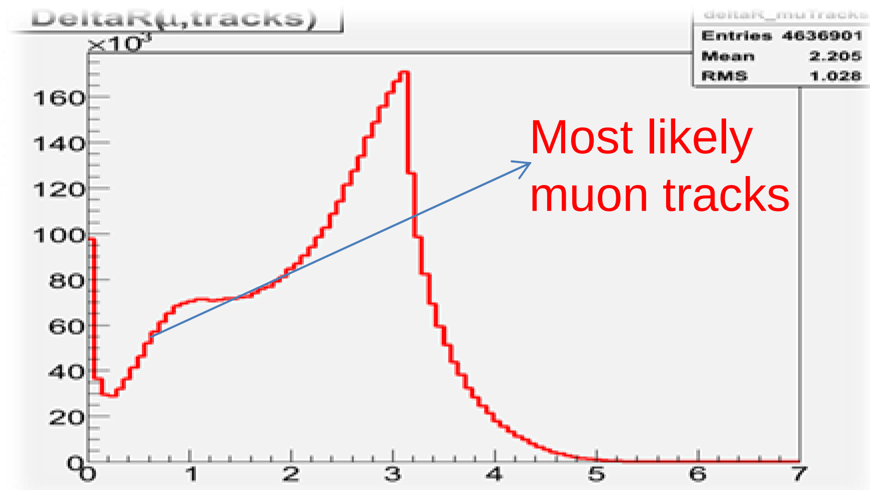
Muon reconstruction and isolation

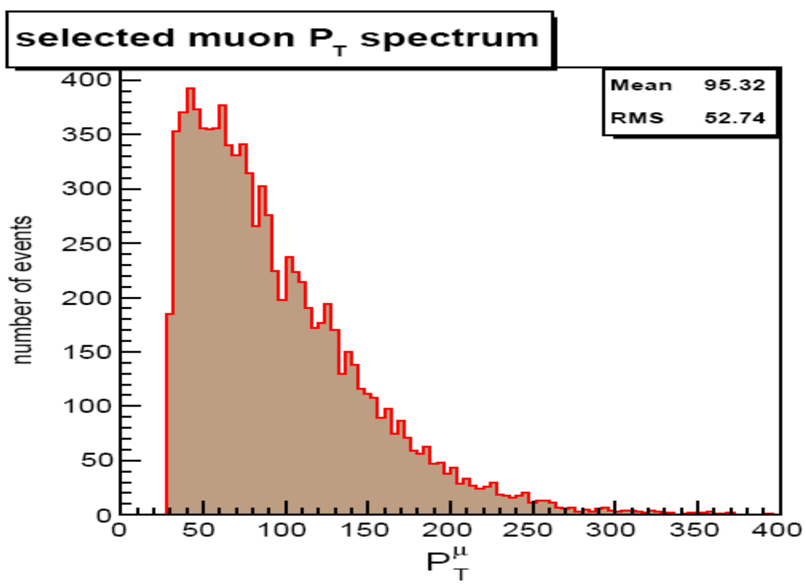
Isolation Criteria

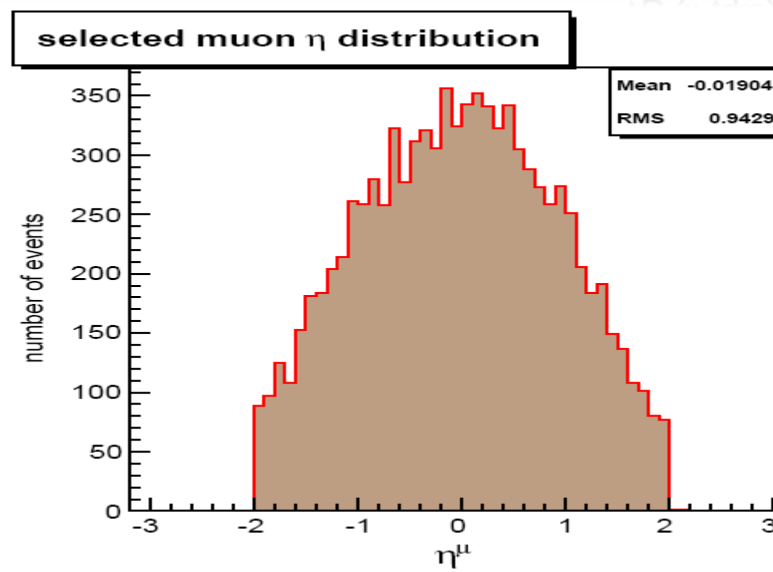
$\Sigma Pt_{trks}/Pt_{\mu}) < 5\%$

$(\Delta R = 0.01 - 0.2)$

Efficiency > 92%





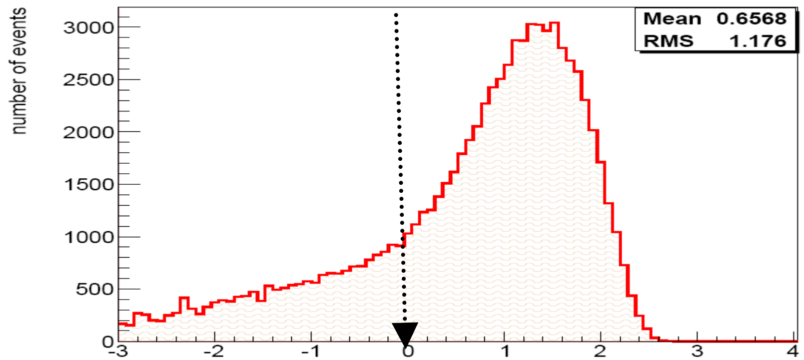


Jets Reconstruction and Identification

combined b-tag discriminator

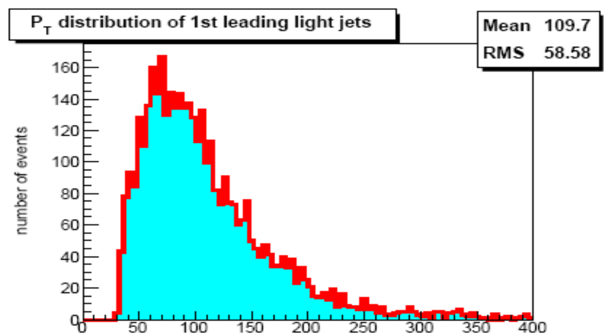
combined b-tag disc. > 0

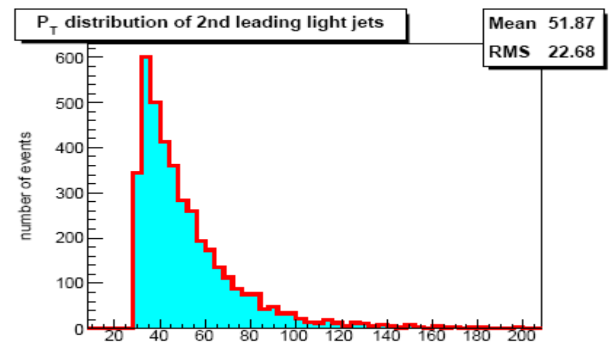
(60% b-tag efficiency based on the secondary vertex, a vertiex which is displaced from the primary vertex.



Leading light jets P_t

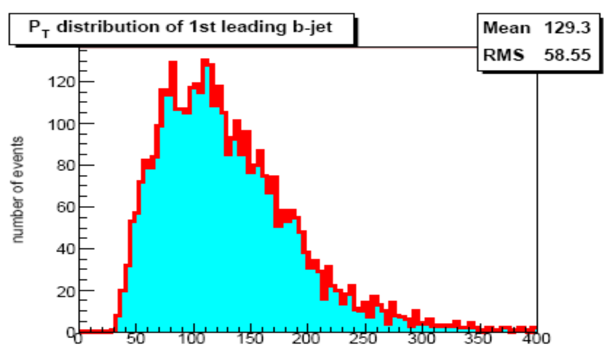
$P_t^{jets} > 20$ GeV

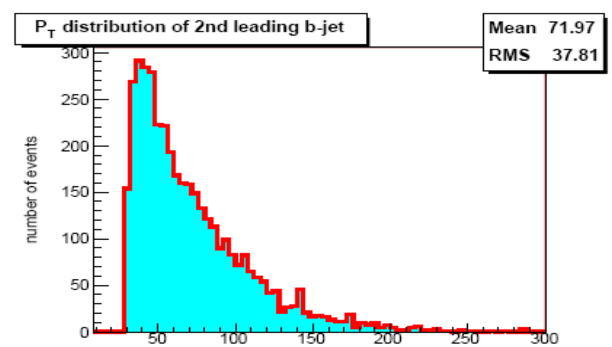




Leading b-jets P_t

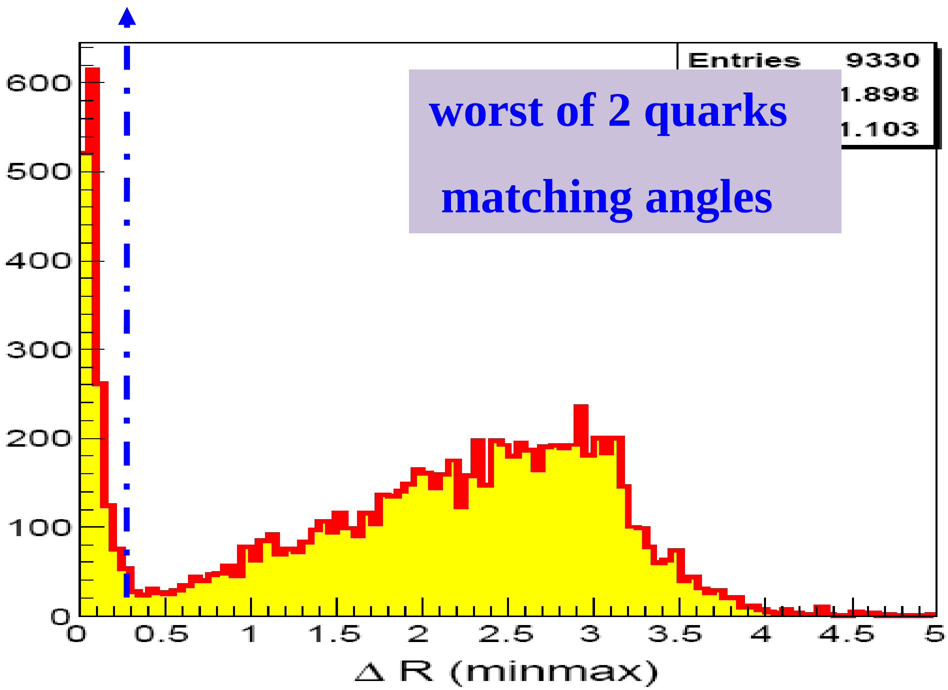
$P_t^{b\text{-}jets} > 20$ GeV





Jet-Parton Matching

- 2 light jets corresponds to 2 quarks from W boson
- Four possible jet combinations
- Take best combination which gives correctly matching



Correctly matched if ΔR < 0.4

(J1,j2), (q1, q2)

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(J1,q1), (j1,q2)

(j2, q1), (j2,q2)

ΔR(j1,q1)

ΔR(j1,q2)

ΔR(j2,q1)

ΔR(j2,q2)

I1=Max (ΔR(j1,q1),ΔR(j1,q2))

I2=Max (ΔR(j2,q1),ΔR(j2,q2))

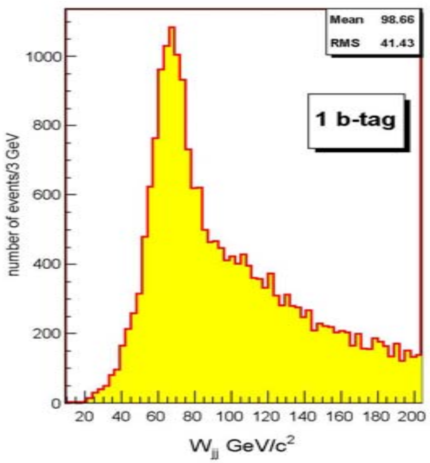
Min(I1, I2)<0.4

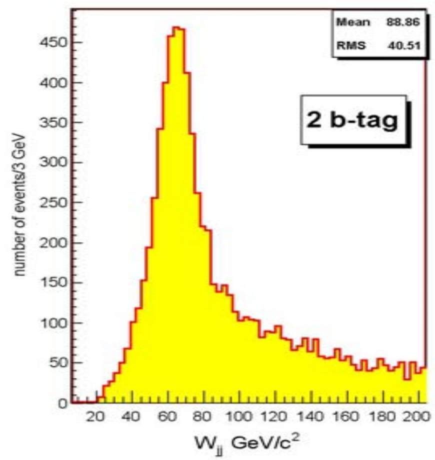
Various Approaches for Jets Selection

Steps to measure top quark direction

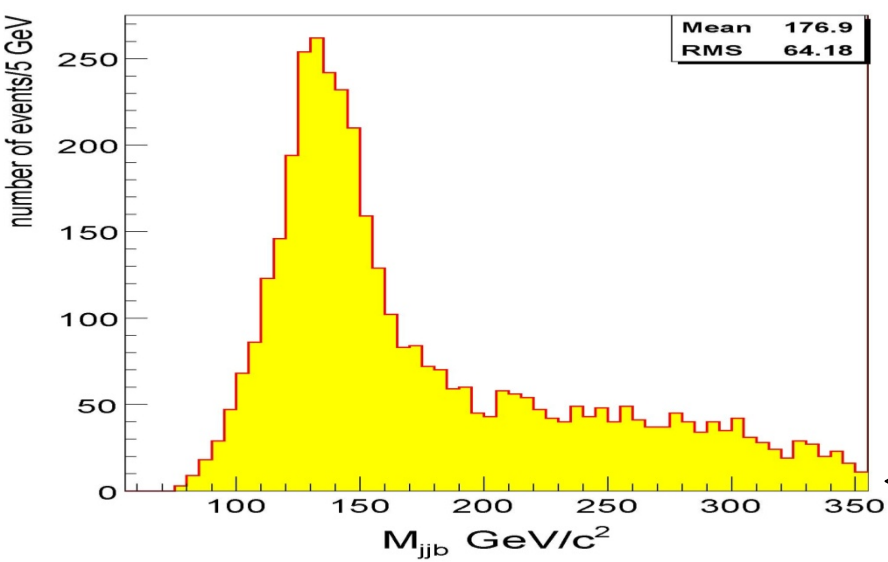
- Leading jets > = 2 b-tagged jets, > = 2 non b-tagged jets
- Exactly 4 jets, =2 b-tagged jets, = 2 non b-tagged jets
- > 2 leading b-jets, 2 light jets with m_{jj} closest to W mass

Top Quark Selection: Leading Jets Topology





1 quark matched = 42.7%
2 quarks matched = 18.17%



Kinematical cuts	Selection efficiency %	No. of events
Before selection	100	49535
no of iso. muons	93.6	46370
$\geq$ 1 iso muon P_t > 30 GeV	92.7	45920
$\geq$ 1 reco light jets P_t > 20 GeV	91.1	45117
$\geq$ 2 reco light jets $\|\eta\|$ < 2.5	73.6	36484
$\geq$ 1 b-jet P_t > 20 GeV	55.6	27543
$\geq$ 2 b-jets $\|\eta\|$ < 2.5	18.6	9214
$\|m_{jj} - m_W^{nom}\|$ < 20 GeV	8.5	4235

m_W^{nom} = 65.24 (gaussian fitted correctly jet-parton matching)

b-jet with biggest angle wr.t muon called Hadronic b-jets

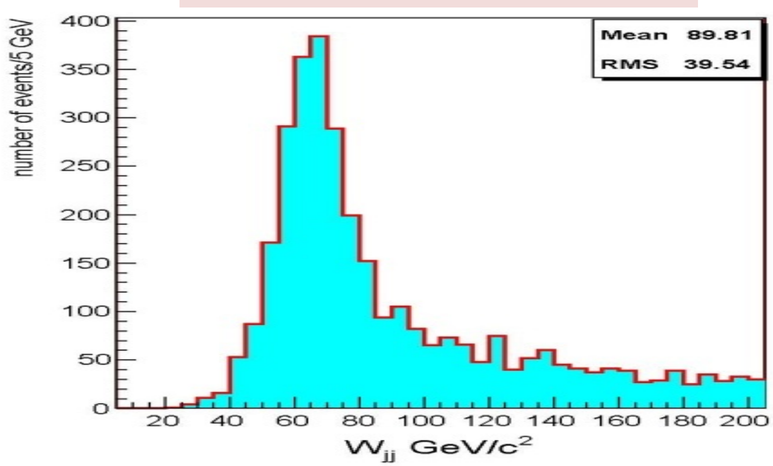
Top Quark Selection: Four Jets Topology

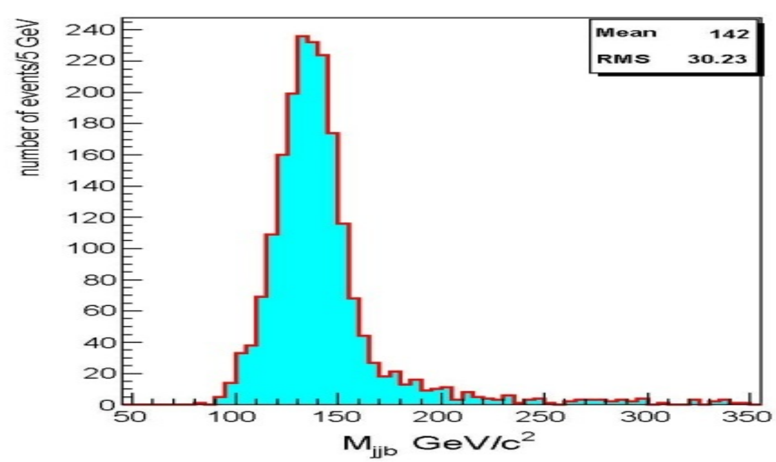
Hadronic top selection

- **Four highest Pt jets selection**
- **b-jets identification with b-tagging**
- **Two light jets invariant mass reconstruction**
- **Hadronic b-jet requires**
  - **for away from isolated muon with maximum distance 0.4**
  - **or closests to light jets**

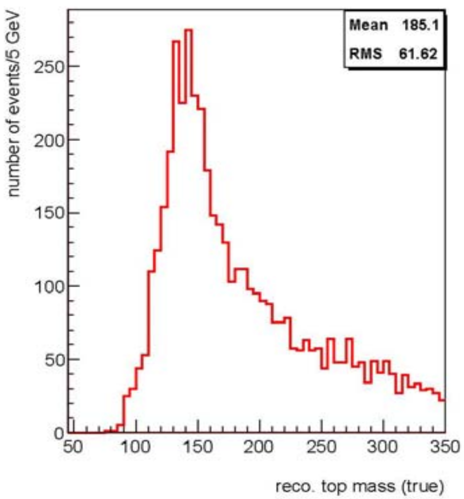
Kinematical cuts	Selection efficiency %	No. of events
Before selection	100	49535
no of iso muons	93.6	46370
≥ 1 iso muon P_t > 30 GeV	92.7	45916
≥ 1 reco light jets P_t > 20 GeV	92.7	45915
Exectly 4 jets $\|\eta\|$ < 2.5	21.3	10551
Exectly 2 light jets	8.0	3941
Exectly 2 b-jets	8.0	3941
$\|m_{jj} - m_W\|$ < 20 GeV	3.9	1937

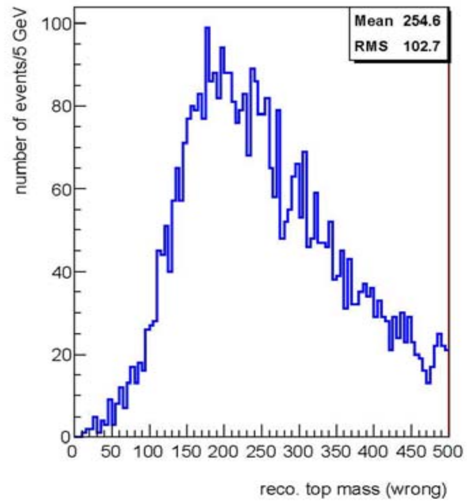
1 quark matched = 20.98%
2 quarks matched = 43.26%





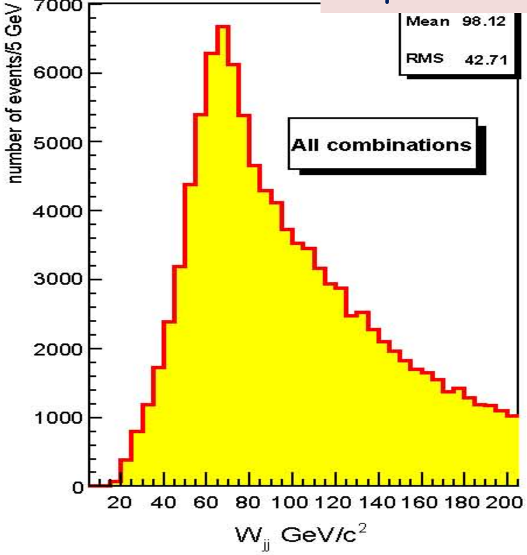
Top Quark Selection: $\vec{JJ} \rightarrow W$

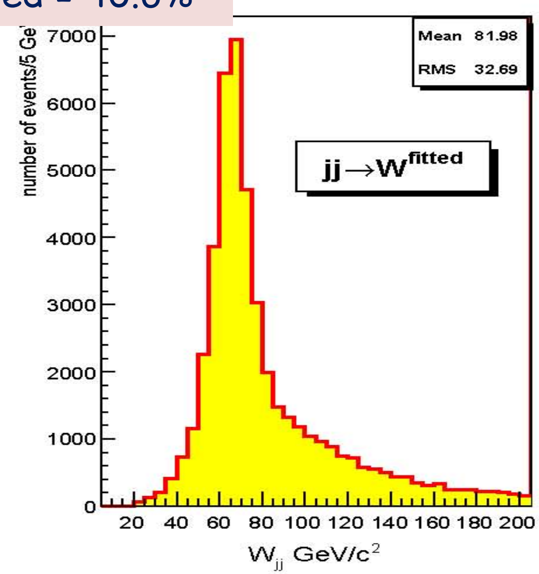


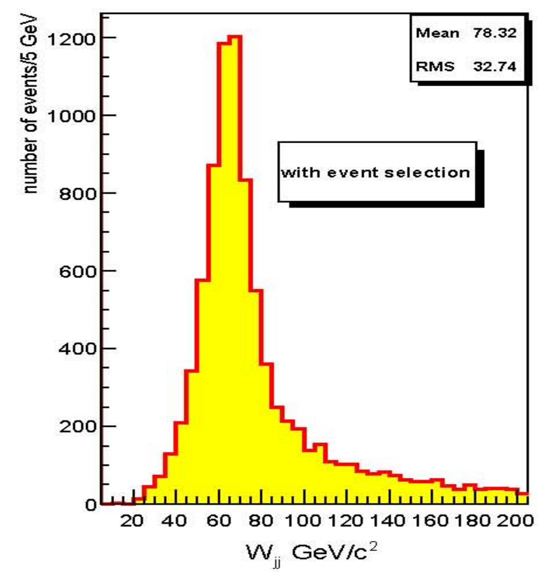


Kinematical cuts	Selection efficiency %	No. of events
Before selection	100	49535
no of iso muons, P_t > 30 GeV, $\|\eta\| < 2.0$	92.7	45920
2 jj → W, P_t > 20 GeV, $\|\eta\| < 2.5$	73.6	36484
≥ 2 b-jets P_t > 20 GeV, $\|\eta\| < 2.5$	18.6	9214
$\|m_{jj} - m_W\| < 20$ GeV	11.9	5917

1 quark matched = 20.76%
2 quarks matched = 40.6%

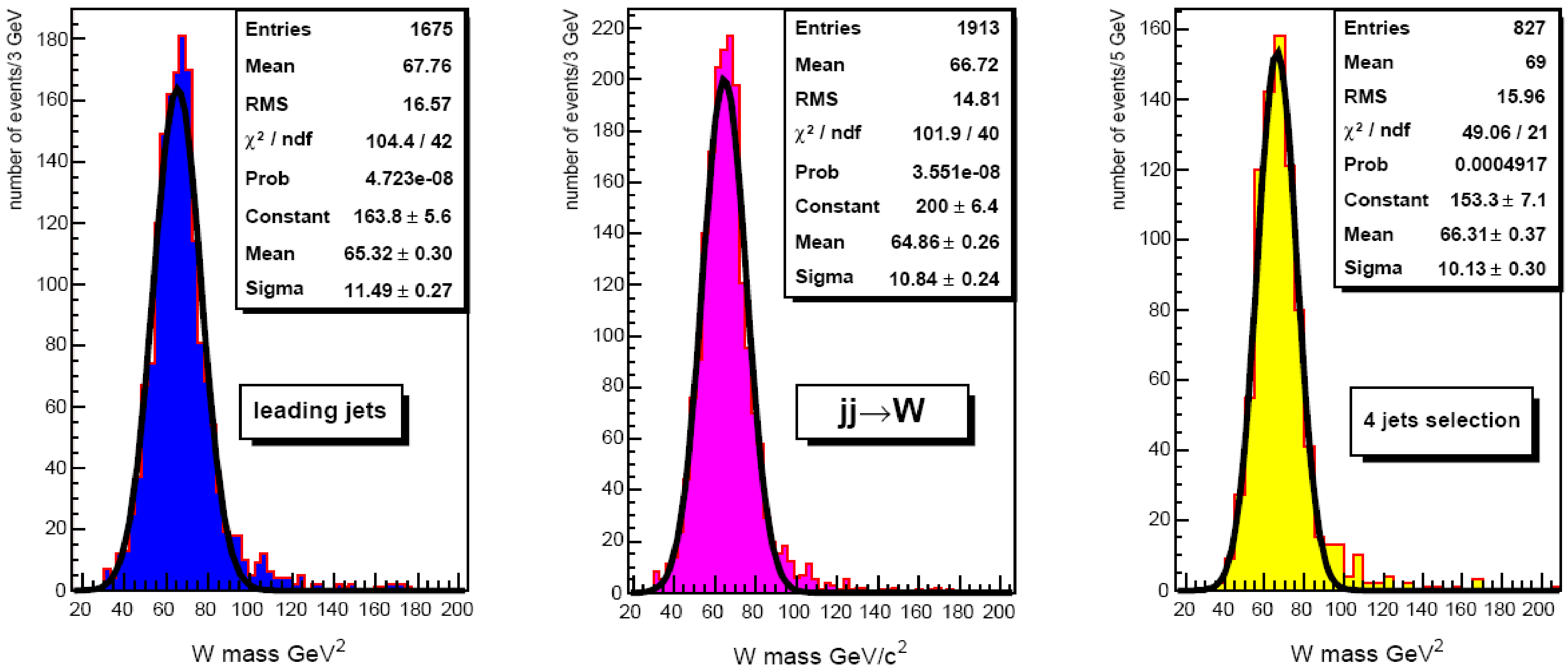






W Mass from Three Approaches

Nominal mass—fitted mass ~ 65 GeV



Same $m_W^{nominal}$ used in all selections (JPM)

Comments on M_{jjb}

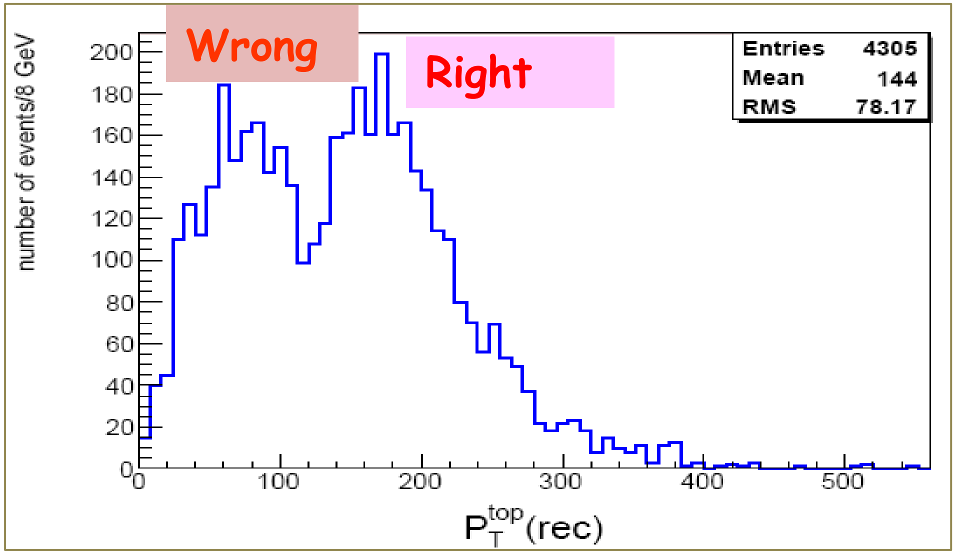
❖ Study based on shape of distributions for top direction determination.

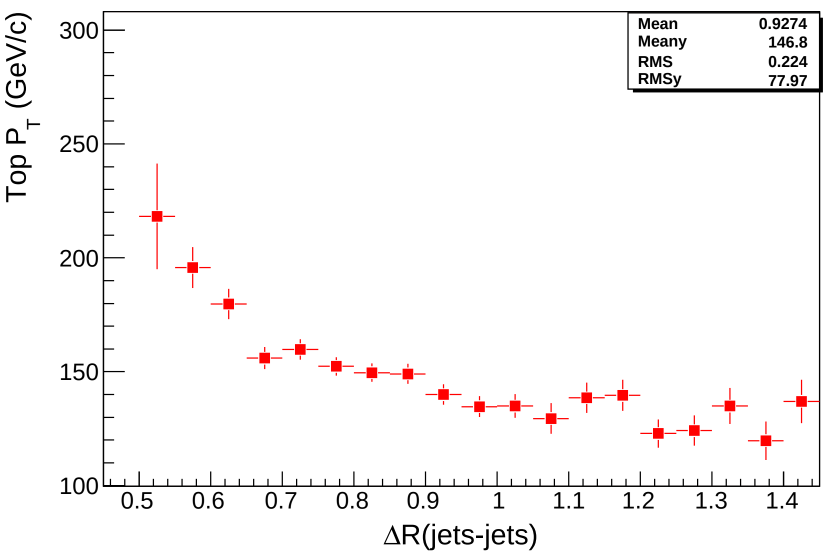
❖ Expalored three types of selection criteria for hadronic top mass reconstruction

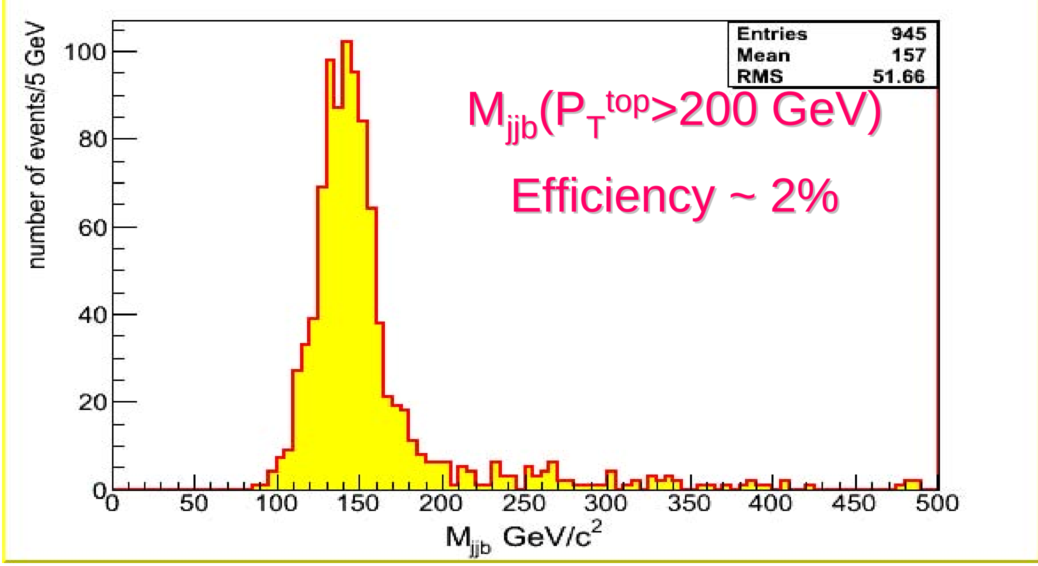
- Four jets selection results low efficiency with higher W purity
- Jets with invariant mass close to W have higher efficiency with intermediate purity of W
- Leading jets selection gives sharp and narrow dist. shape with less long tail behaviour and reasonable selection efficiency

Top Quark Selection: Leading Jets Topology

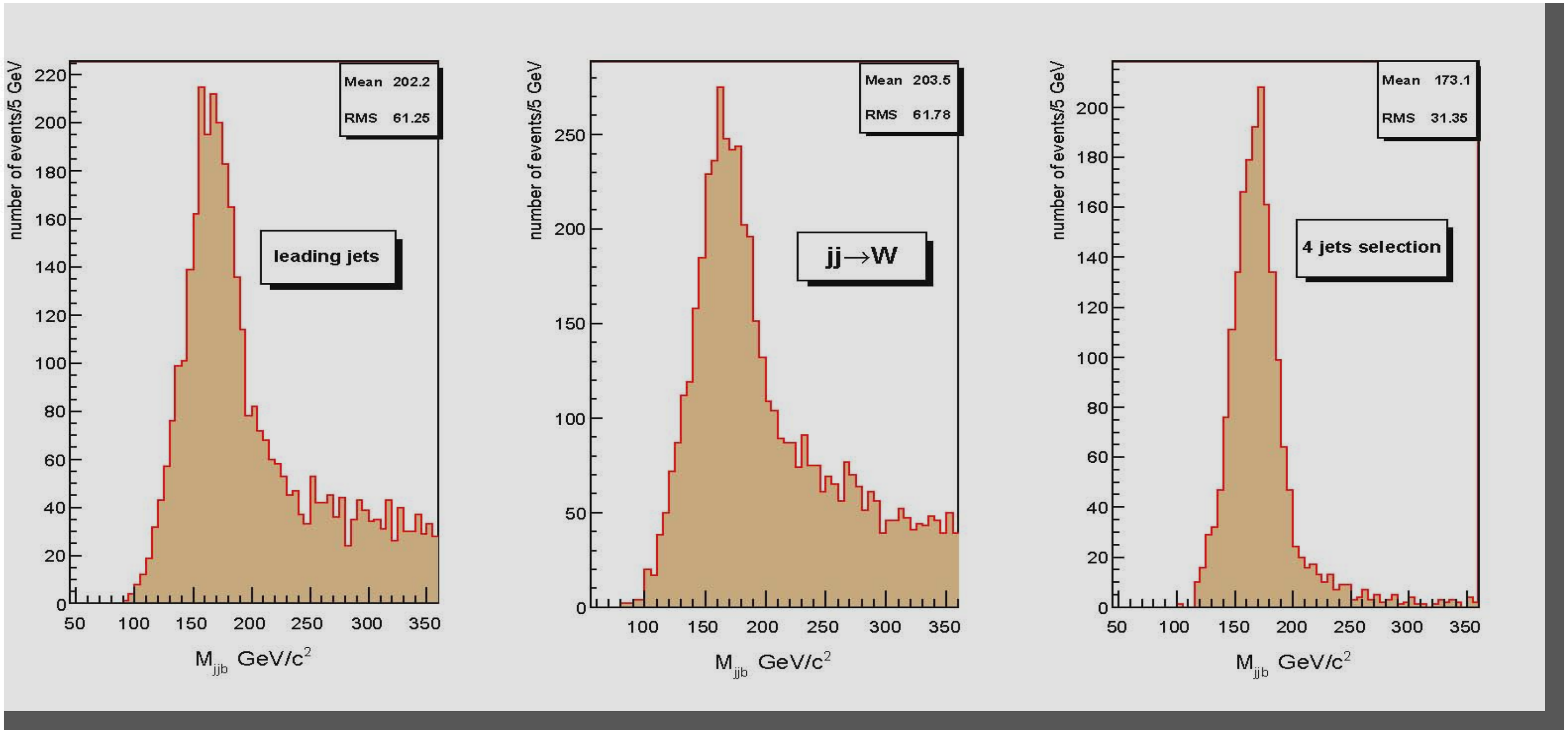
- ❖ First peak from the wrong jet combination
  - • Exchanging the leptonic b-jet into hadronic b-jet
  - • One of the 4 leading jets could be coming from the gluon radiation
  - • Soft QCD events
- ❖ Second peak corresponds to the correct combinations
  - • At preselection level we demand high Pt jets







Calibrated Top Quark Mass



Peaks are shifted towards the nominal Top mass

Calo Clusters Reco Method

Invariant mass of all calorimeters clusters in $\Delta\eta \times \Delta\varphi$ around top direction

Calorimetric Clusters Reconstruction Method

$$m^2_{clusters}(\Delta R) = (E^2 - P^2) = (\sum_{i=0.7} E_i)^2 - (\sum_{i=0.7} P_i)^2$$

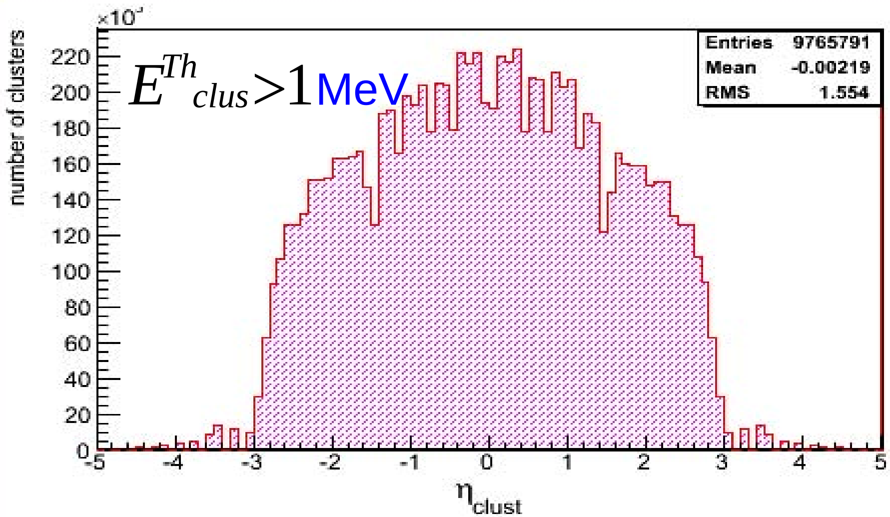
- ✓ E_i represents total energy of the ith cluster
- ✓nDR runs over all clusters within selected cone size
- ✓P_i its 3-momenta vector

Known: E,η, φ about clusters

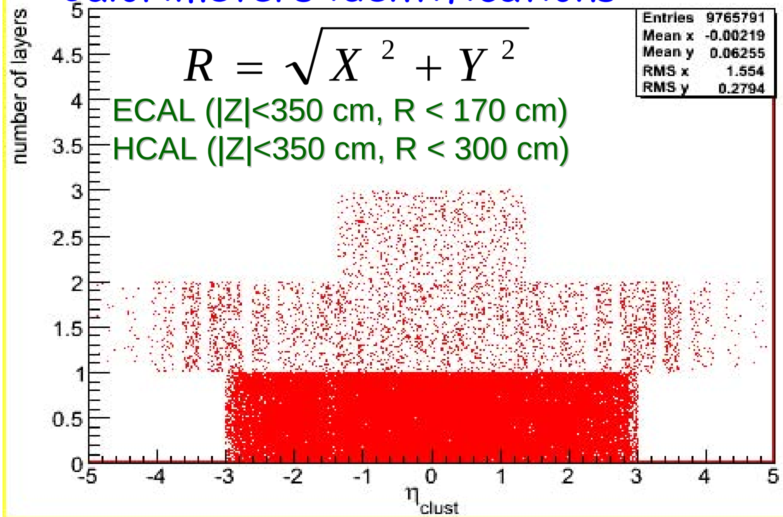
Assumptions: considering particles to be mass-less

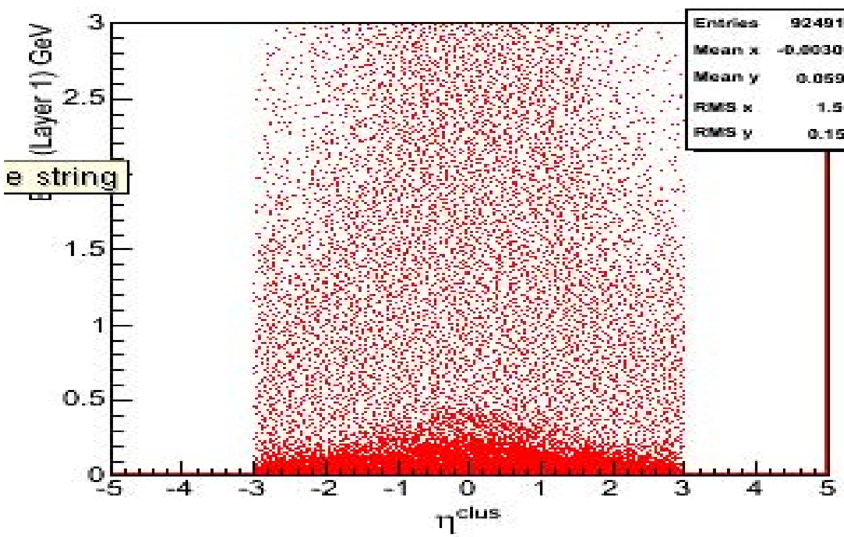
$$m \approx 0 \Rightarrow E^2 \equiv P^2$$
$$P_x = E \sin\vartheta \cos\varphi$$
$$P_y = E \sin\vartheta \sin\varphi$$
$$P_z = E \cos\vartheta$$

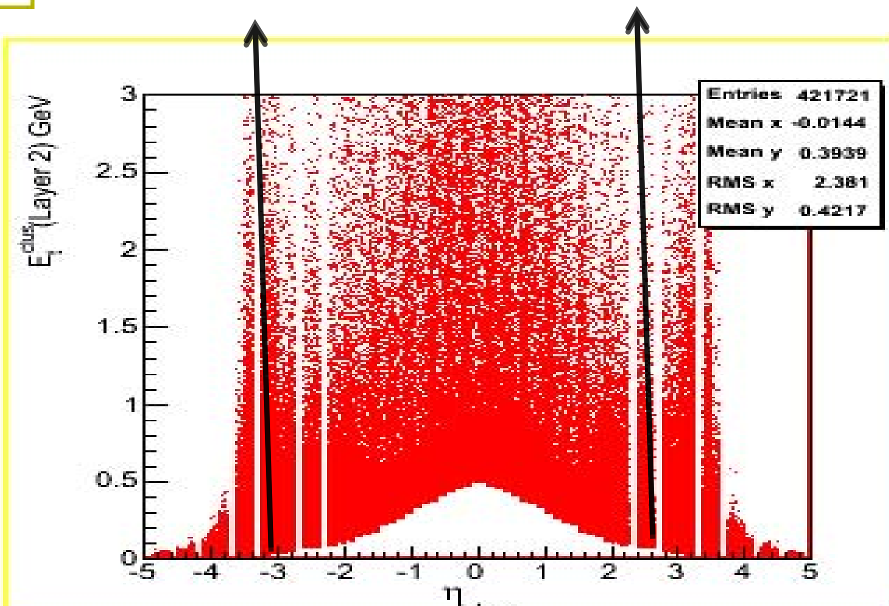
Reco clusters pseudo-rapidy



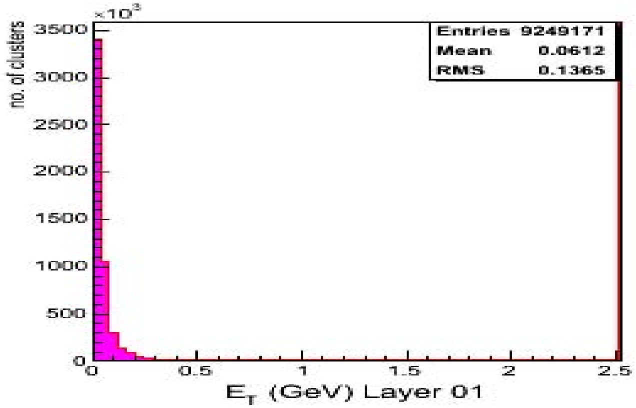
Calorimeters identifications

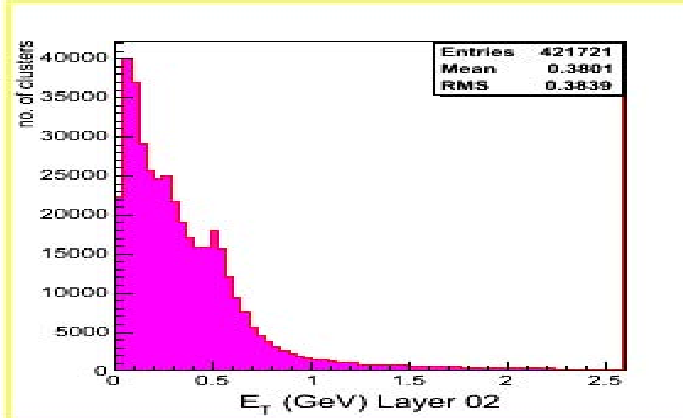


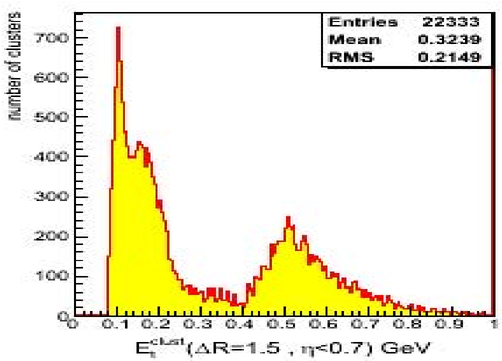


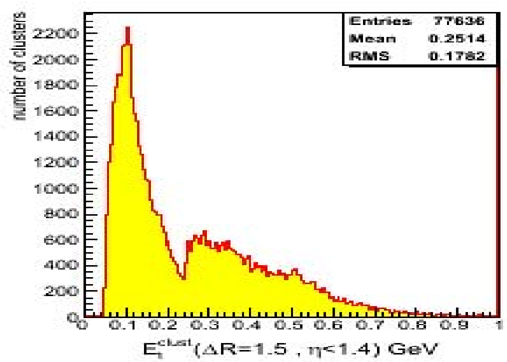


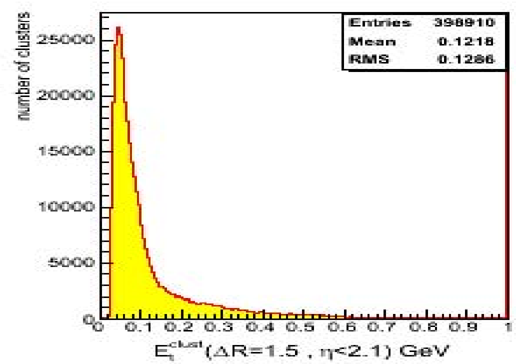
E_T^{clus} Deposition

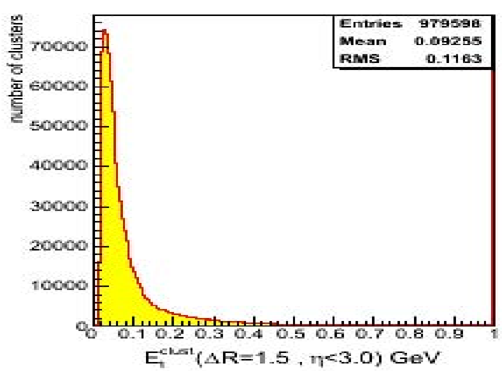


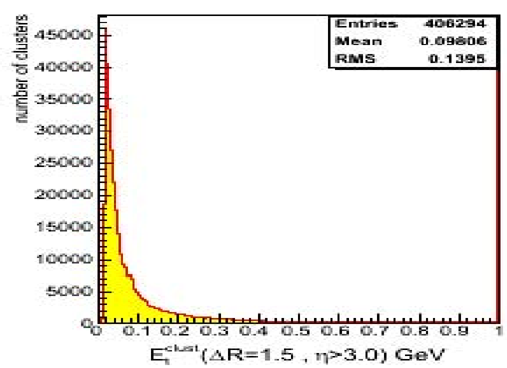


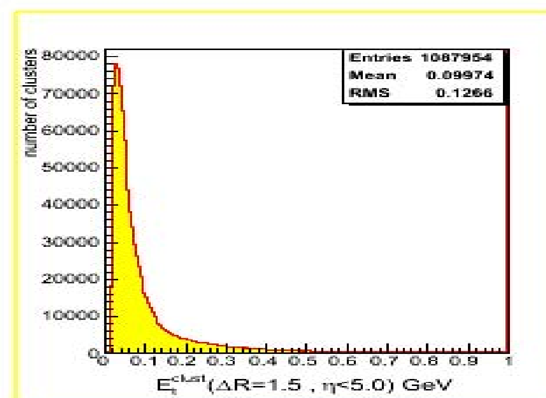












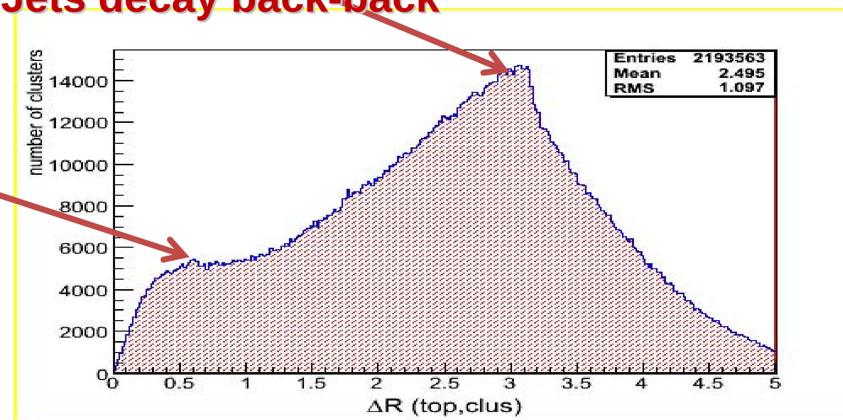
M_{top}^{clus} Determination

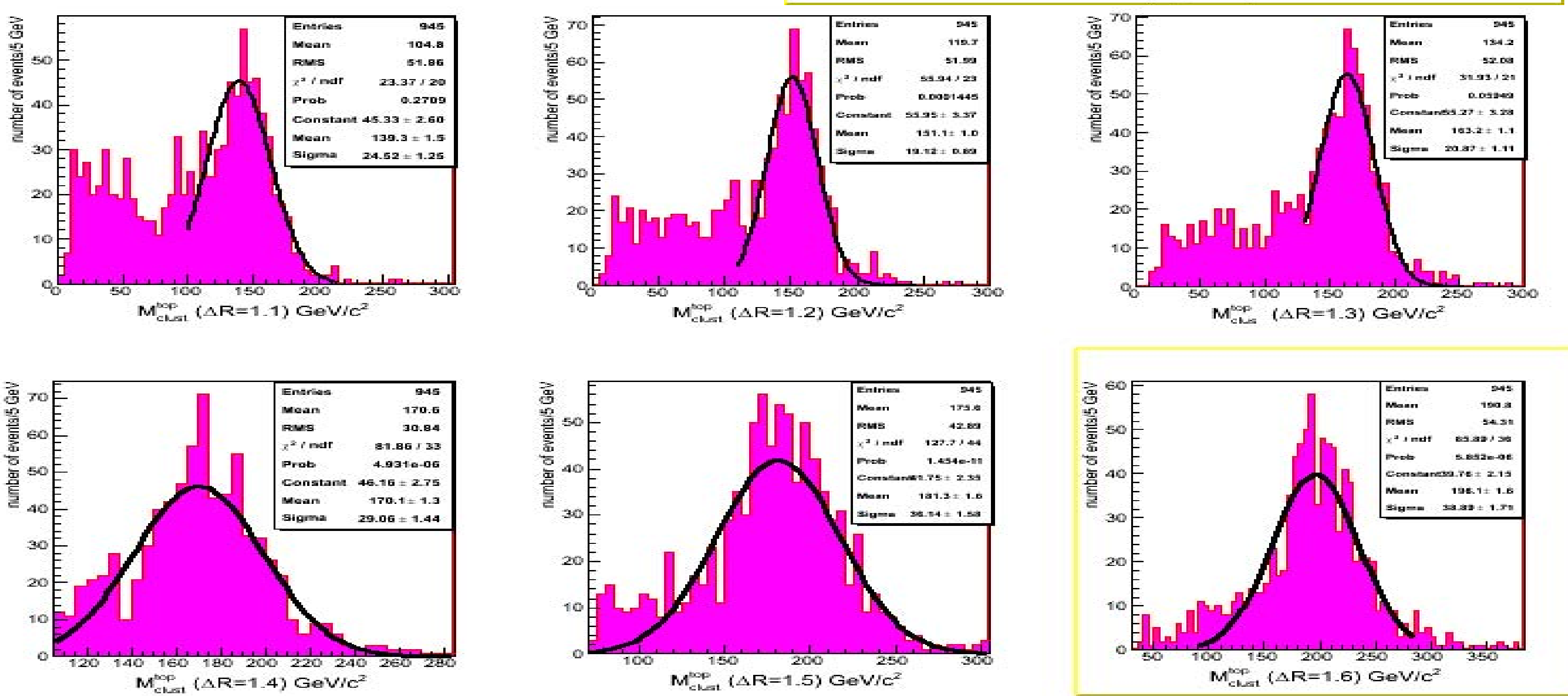
Reduce intrinsic complexities of effects due to energy leakage outside a narrow cone

Reduce system errors arising due to jet calibration

Clusters lie close to the top quark flight direction

Jets decay back-back

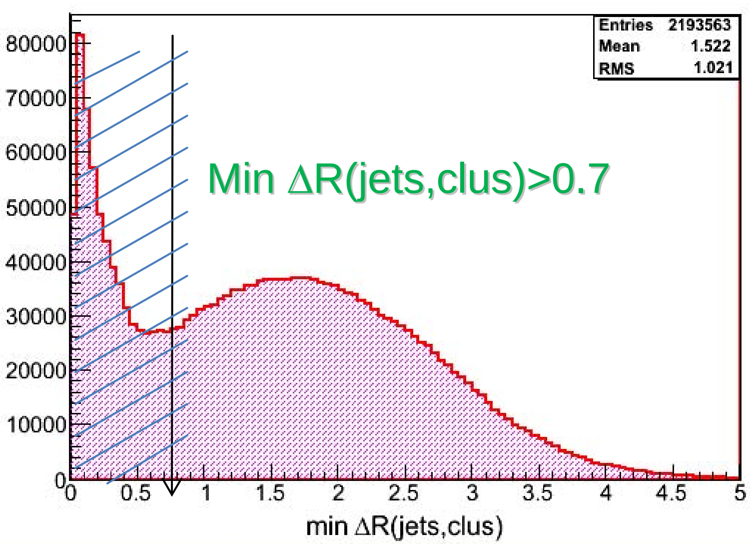




UE Estimation Method

- It is not only minimum bias event
- The underlying event is everything except the two outgoing hard scattered jets
- In a hard scattering process, the underlying event has a hard component (initial+final state radiation and particles from the outgoing hard scattered partons) and a soft component (beam-beam remnants)

Jet Isolation variable



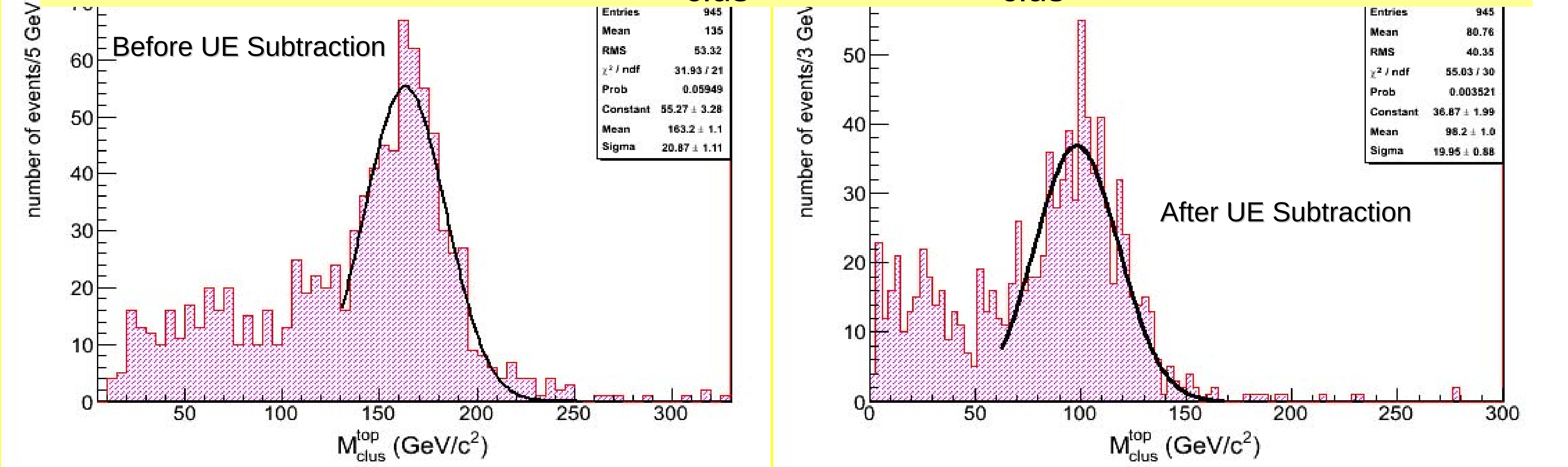
Hadronic Calorimeter

Jet Isolation	$\langle E_t \rangle$ / < no of clusters > / high P_t event					
	$\lvert\eta\rvert < 0.7$	$\lvert\eta\rvert < 1.4$	$\lvert\eta\rvert < 2.1$	$\lvert\eta\rvert < 3.0$	$\lvert\eta\rvert > 3.0$	$\lvert\eta\rvert < 5.0$
$\Delta R = 0.7$	626.89 38	509.19 88	445.77 134	363.00 229	236.77 182	326.78 352
$\Delta R = 0.8$	623.07 33	503.17 80	439.69 125	356.43 218	236.76 181	321.39 33
$\Delta R = 0.9$	618.47 29	496.66 73	433.11 116	349.36 180	236.69 330	315.67 208
$\Delta R = 1.1$	614.85 22	485.24 22	420.82 22	335.58 22	236.35 22	304.62 22
$\Delta R = 1.5$	599.83 8	459.49 28	394.11 56	306.64 136	237.03 169	283.05 53

Electromagnetic Calorimeter

Jet Isolation	$\langle E_t \rangle$ / cluster (MeV) / < no of clusters > / high P_t event					
	$\lvert\eta\rvert < 0.7$	$\lvert\eta\rvert < 1.4$	$\lvert\eta\rvert < 2.1$	$\lvert\eta\rvert < 3.0$	$\lvert\eta\rvert > 2.5$	$\lvert\eta\rvert < 5.0$
$\Delta R = 0.7$	201.24 76	173.59 81	102.26 708	102.26 708	53.99 309	78.73 1383
$\Delta R = 0.8$	199.50 66	172.54 66	100.71 66	100.71 66	53.99 66	77.43 66
$\Delta R = 0.9$	198.50 57	171.20 146	99.28 630	99.28 630	54.01 303	76.23 1285
$\Delta R = 1.1$	197.46 41	168.08 112	96.26 546	96.26 546	54.17 295	73.79 1175
$\Delta R = 1.5$	192.99 16	164.27 55	91.25 372	69.88 922	54.77 268	69.88 922

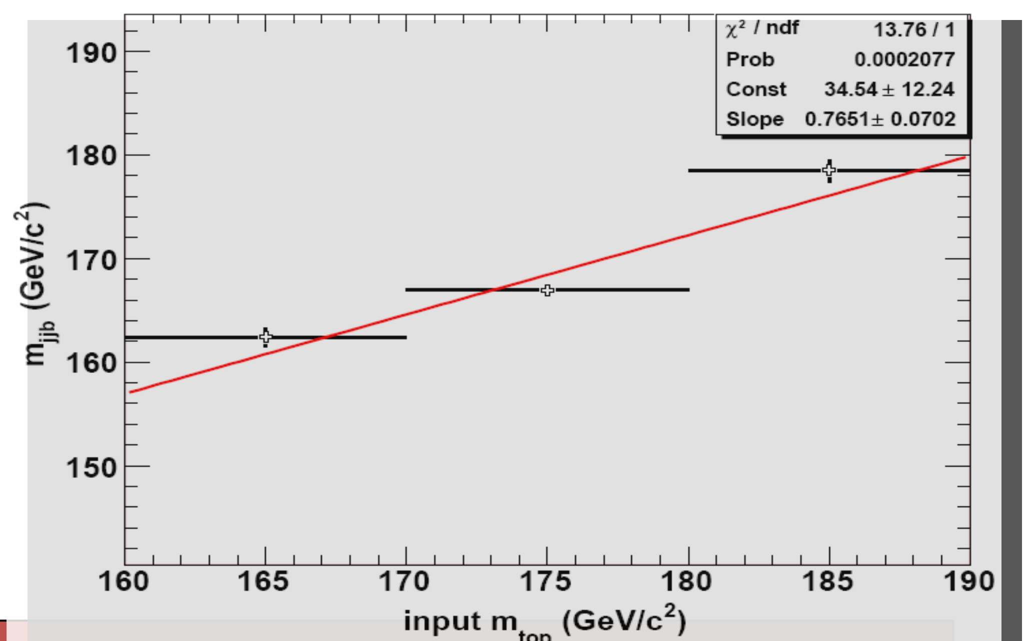
Top Quark Mass M_{clus}^{top} and UE_{clus} Subtraction



<UE_ecal>= 93 MeV

<UE_hcal>= 342 MeV

A correlation with a slop about 0.7866 is observed, which implies that error of **0.9 GeV** in the mean of peak translates to an statistical uncertainity of **0.9/0.786 = 1.1456 GeV/c** in $\mathbf{M_{jjb}}$ and **1.1 --- 1.6 GeV/c** in $\mathbf{M_{clus}^{top}}$



50K events corresponds to 7.2 fb^{-1}, statistical uncertainty about δm=1-1.5 GeV on top mass.

Systematic

Source of uncertainty	$\Delta m_{top}(GeV/c^2)$
Re-calibration	0.9
Electronic noise	1.2
ISR on/off	0.14
FSR on/off	0.07
B-quark fragmentation	0.3
UE estimate (+-10%)	1.34
Cluster mis calibration:+-1(5)%	0.7(1.3)
Calorimeter: e/h=1.25 (1.63)	0.8(0.3)

Summary

- An alternate method for top mass reconstruction in CMS is presented, which strongly depends on CMS Calorimeters.
- A new method for Underlying Event (UE) estimation, subtraction and calibration is developed.
- This analysis is performed with both Full and Fast Simulations techniques.
- Statistical error on top mass M_{jjb}(1-1.5 GeV) and 1.1 -- 1.6 GeV/c in M_{clus}^{top} is estimated.