Top Quark Mass Reconstruction from High Pt Jets at LHC

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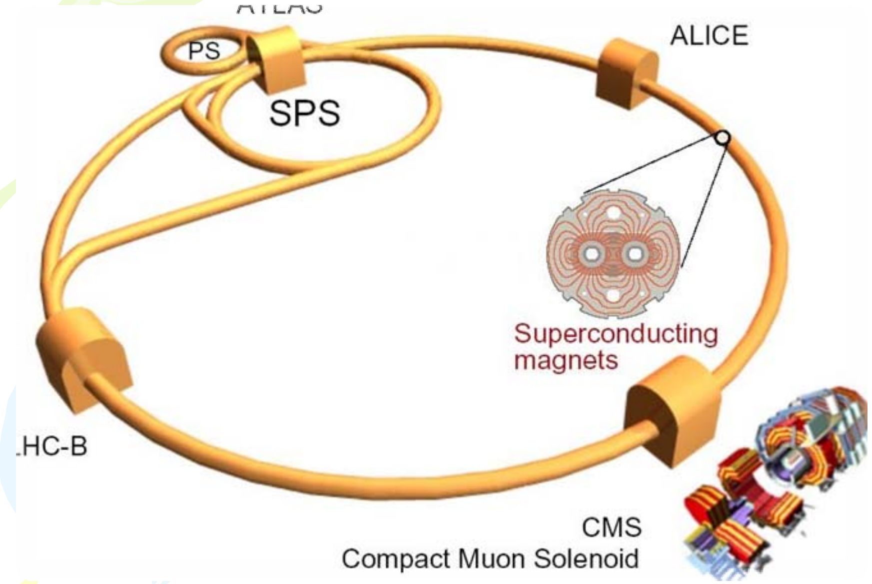
Signaling the Arrival of the LHC Era, ICTP, Italy

Outlines

- Motivations of Top Physics
- Topology of Lepton + Jets
- High Pt top basic idea
- Method for jets selection
- Top quark mass reconstruction from jets
- Jets clustering in detector
- Clusters invariant masses M^{top}_{clus}
- Underlying Event (UE_{clus}) estimation and subtraction
- Systematics
- Summary

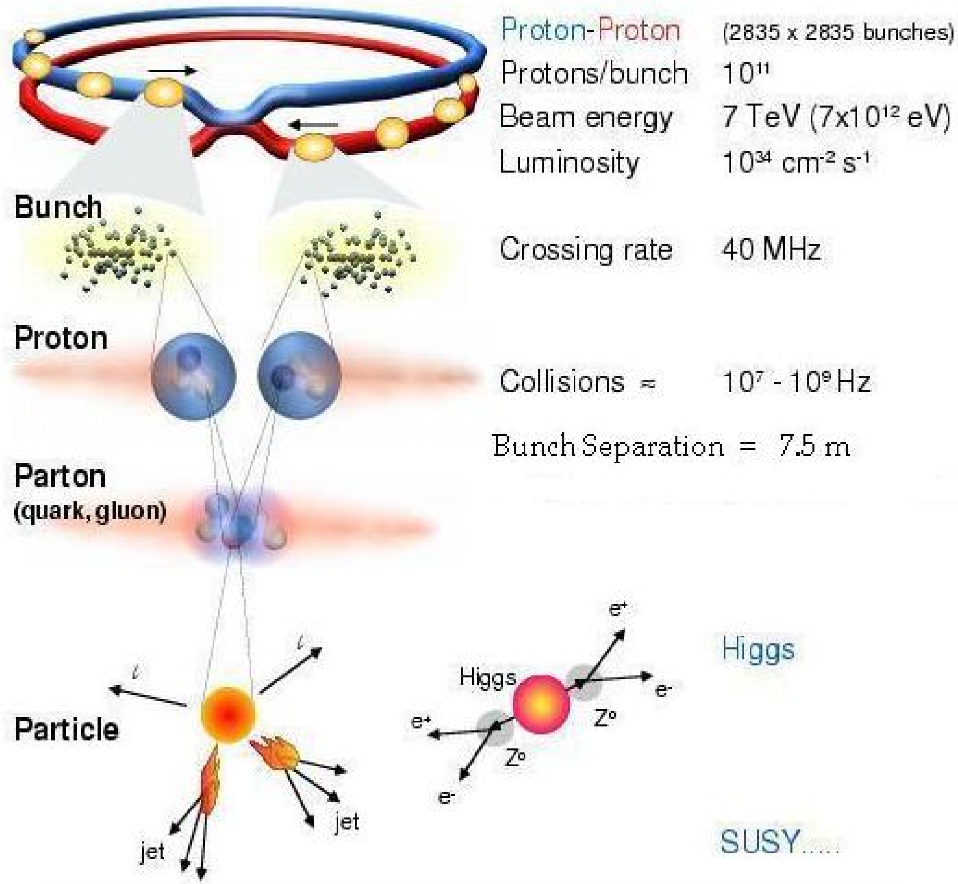
Large Hadron Collider (LHC)



$$L = \frac{\gamma f k_b N_P^{\ 2}}{4\pi\varepsilon_n \beta^*} F = 10^{34} cm^{-2} s^{-1}$$

Integrated luminosity=10fb^{-1}

Collisions at LHC

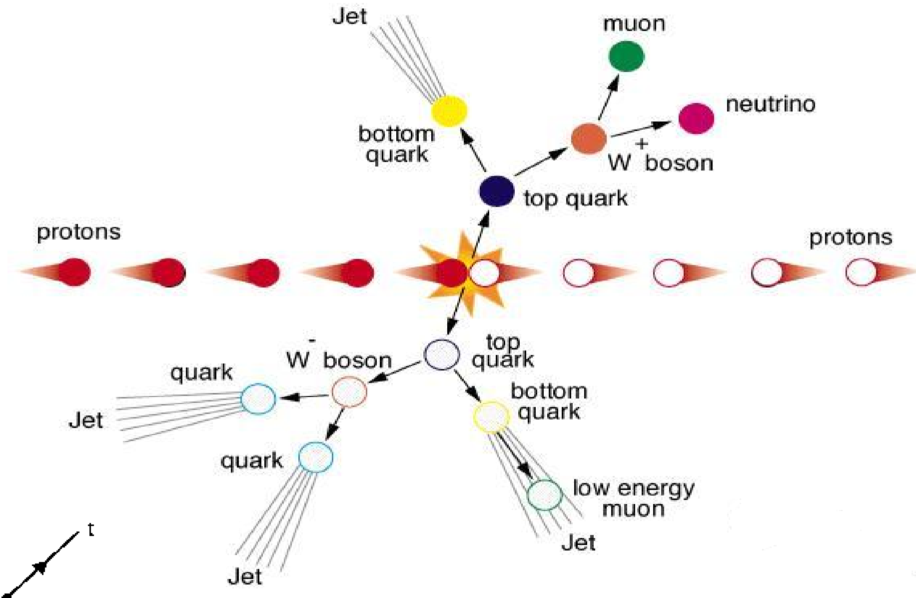


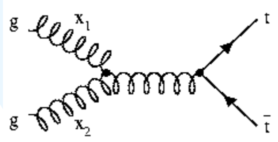
Selection of 1 in 10,000,000,000,000

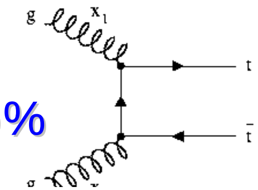
Top Quark Properties, Production and Decay

Striking Features of top quark

- ✓ Heaviest particle (spin ½, charge 2/3)
- ✓ Origin of mass, EWSB, Higgs
- ✓ Short life time ($\tau_{top} = 1/\Gamma_{top}$, $\tau_{had} = 1/\Lambda_{QCD}$)
- ✓ No bound state
- ✓ Yukawa coupling-unity

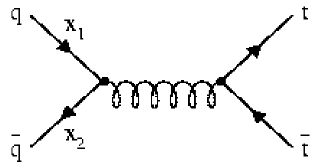


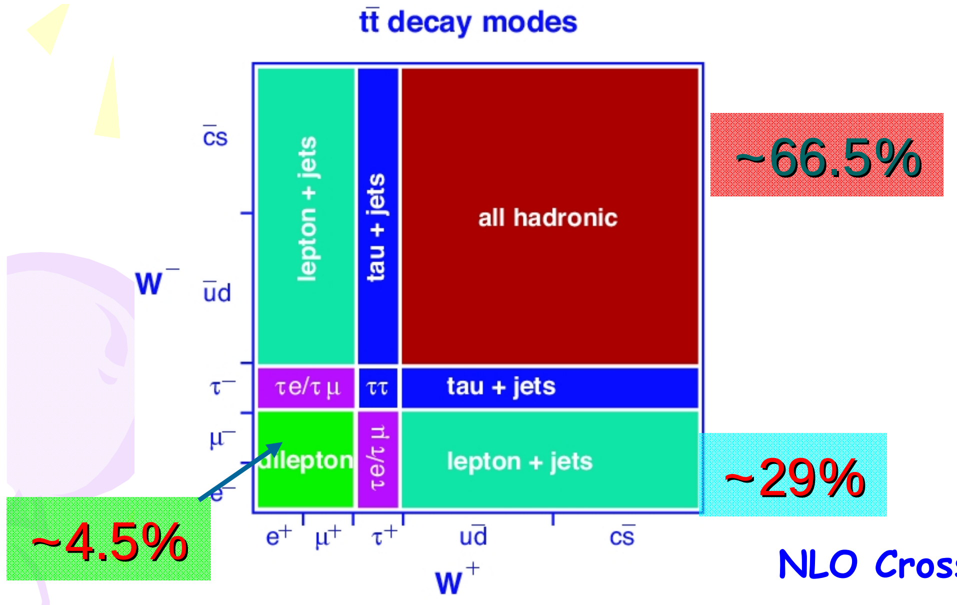




90%

10%



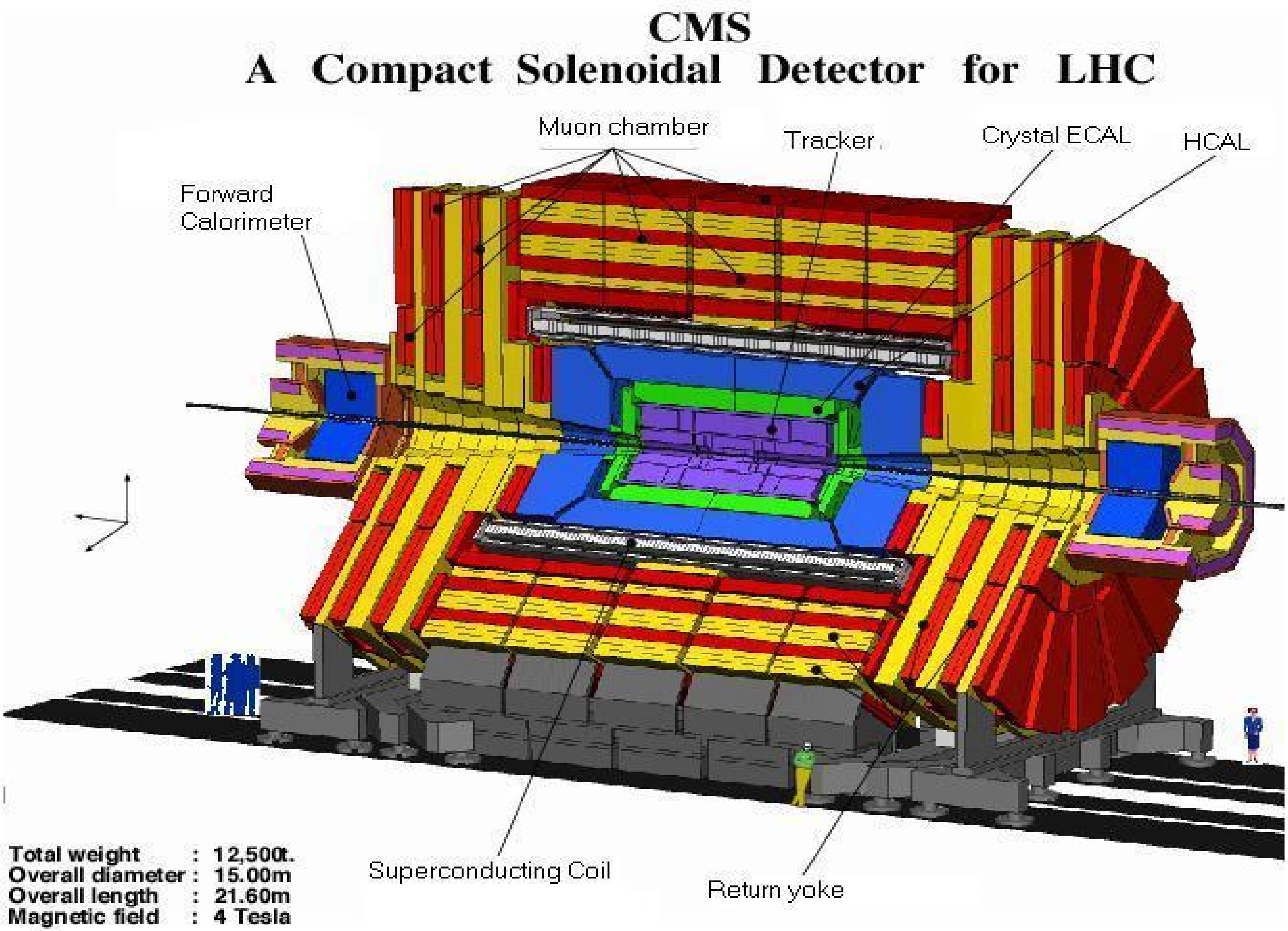


☞ need to reconstruct and identify

- electrons, muons
- missing E_T (neutrinos)
- b-jets
- light jets (u,d,c,s)

NLO Cross-section for tt~ production at LHC is σ(tt)~830pb

Compact Muon Solenoid Detector (CMS)



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 in larger cone around the top quark direction of flight and then correlation with the real top mass.
- ✓ Top quark needs to have a larger : **Pt > 200 GeV**.

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

Event Selection at Partonic Level

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

- $P_t^{top} > 200$ 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

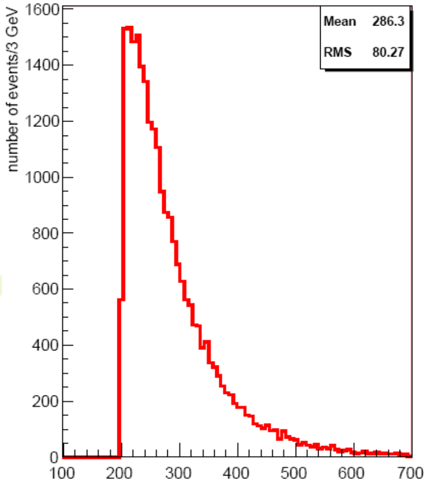
185 Top mass point = 20K events

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

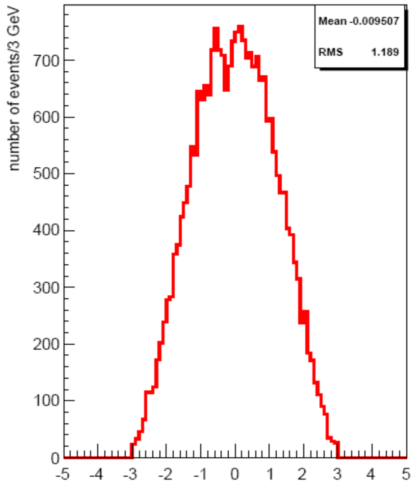
Pile-up events are included

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

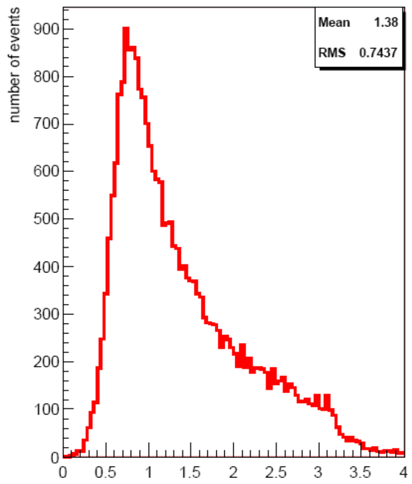
Distributions at Vertex Level



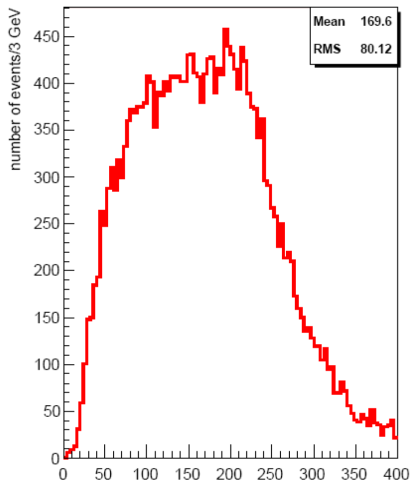
P_t^{top}



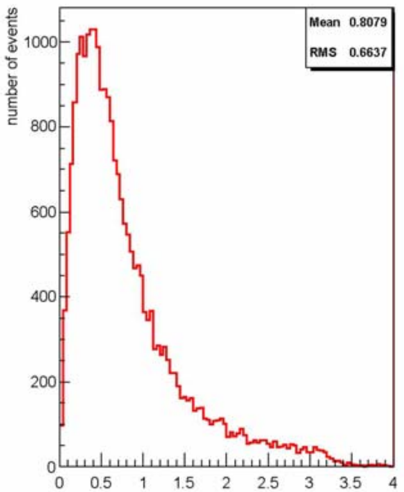
MC η^{top}



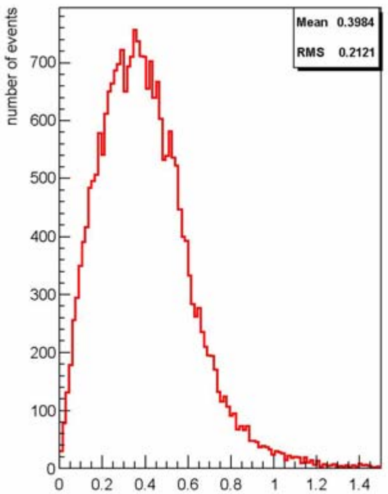
ΔR(q,qbar)



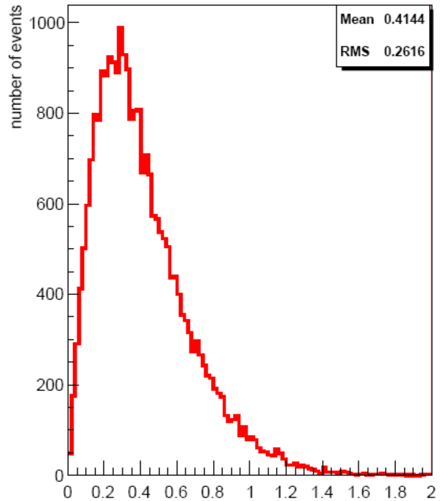
P_t^W



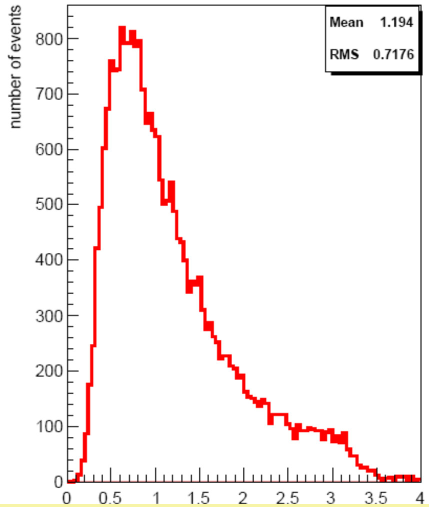
ΔR(top,b-par)



ΔR(top,W)

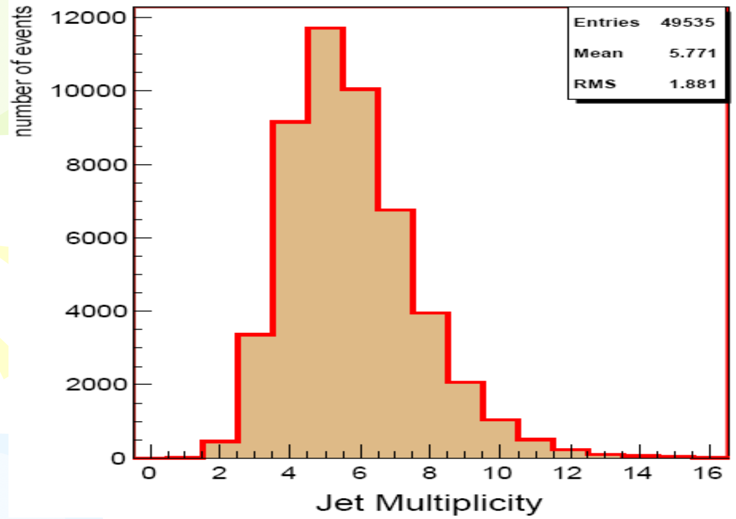


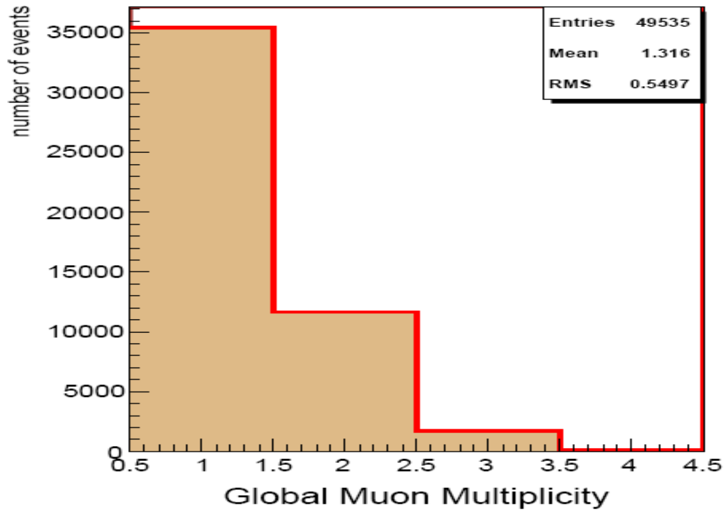
ΔR(top, min W-quarks)



ΔR(top, max W-quarks)

Reconstruction Techniques

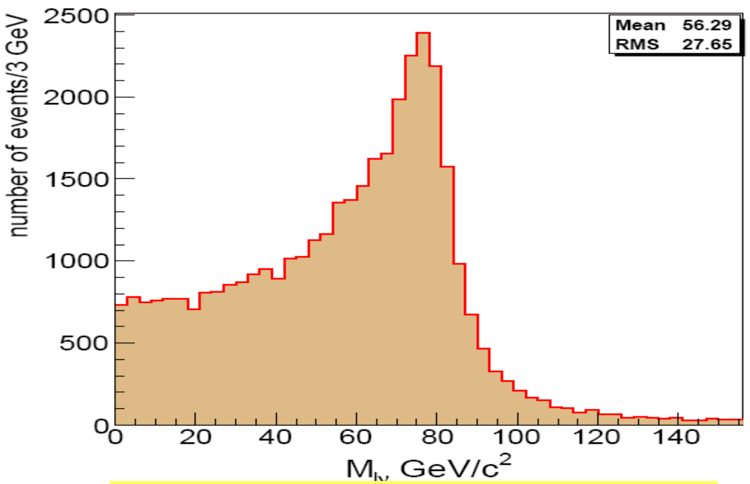




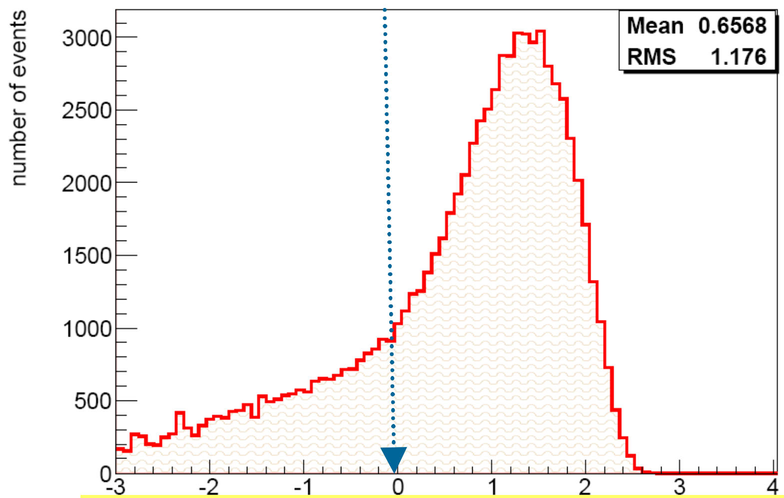
- ❑ MET-> Missing Transverse Energy
- ❑ MET > 30 GeV
- ❑ At least 1 iso. muon, P_t>20 GeV, $|\eta|$<2.0

combined b-tag disc. < 1.0

(60% b-tag efficiency)



leptonic W reco mass



combined b-tag discriminator

Leading jets and muons P_t Spectrum

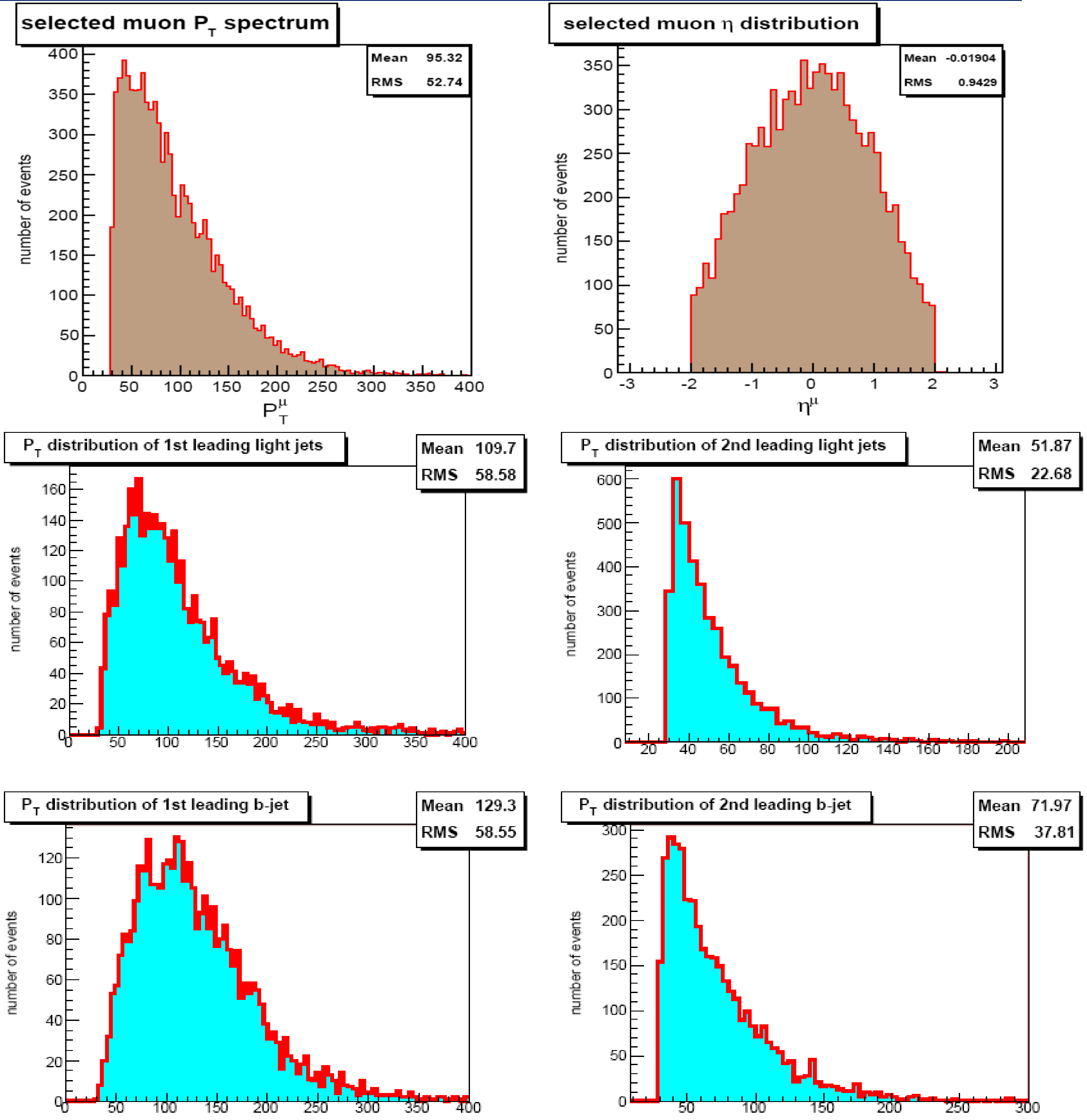
Muon Isolation Criteria

Pt > 30 GeV

$\Sigma Pt_{trks}/Pt_{\mu}) < 5\%$
(ΔR=0.01-0.2)
Efficiency > 92%

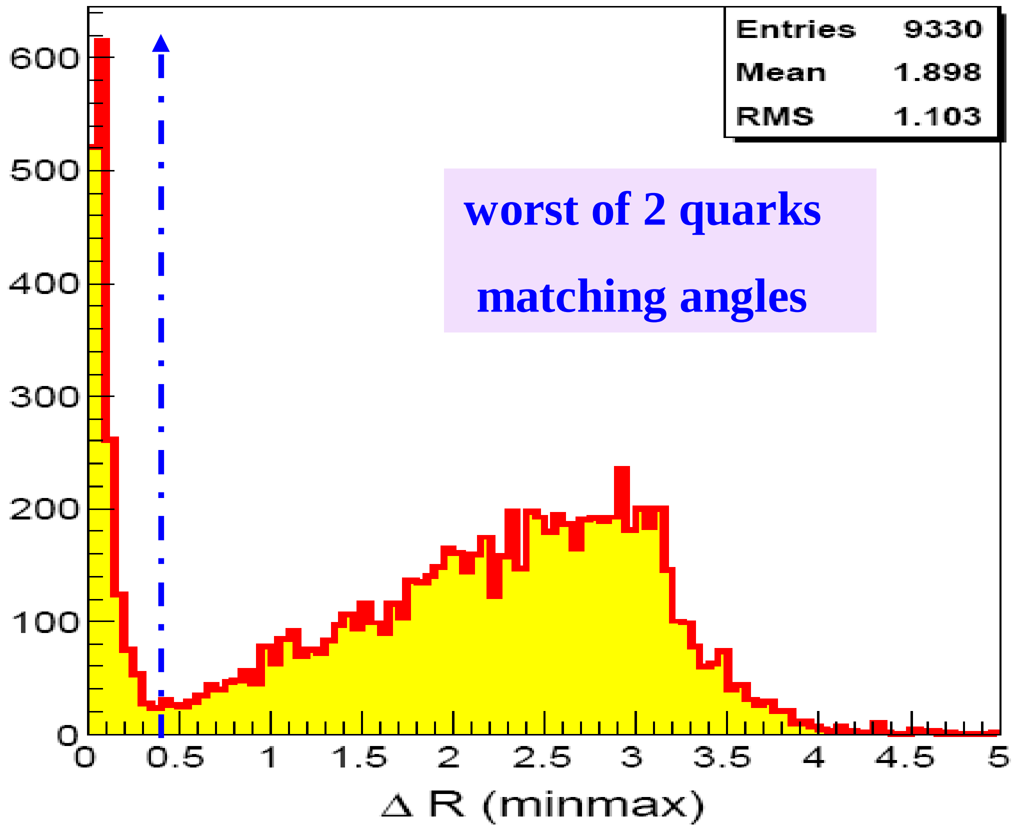
Leading light jets P_t
P_t^{jets} > 20 GeV

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



Identifications of correct jets (Jet-Parton Matching)

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



Correctly matched if ΔR < 0.4

(J1,j2), (q1, q2)

****

(J1,q1), (j1,q2)

(j2, q1), (j2,q2)

ΔR(j1,q1)

ΔR(j1,q2)

ΔR(j2,q1)

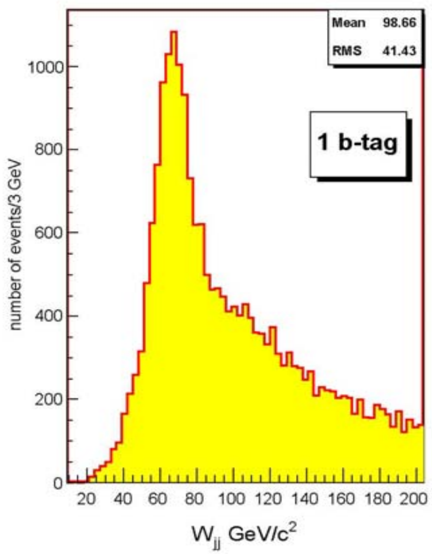
ΔR(j2,q2)

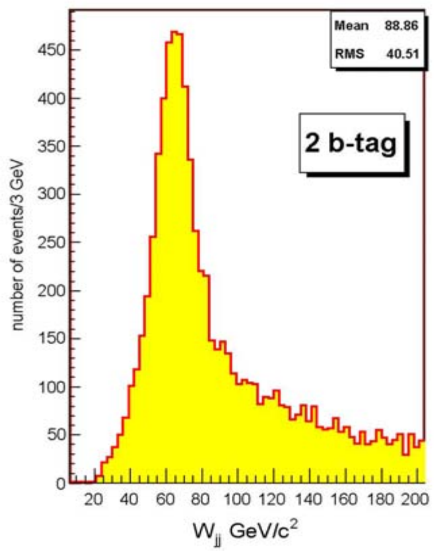
I1=Max (ΔR(j1,q1),ΔR(j1,q2))

I2=Max (ΔR(j2,q1),ΔR(j2,q2))

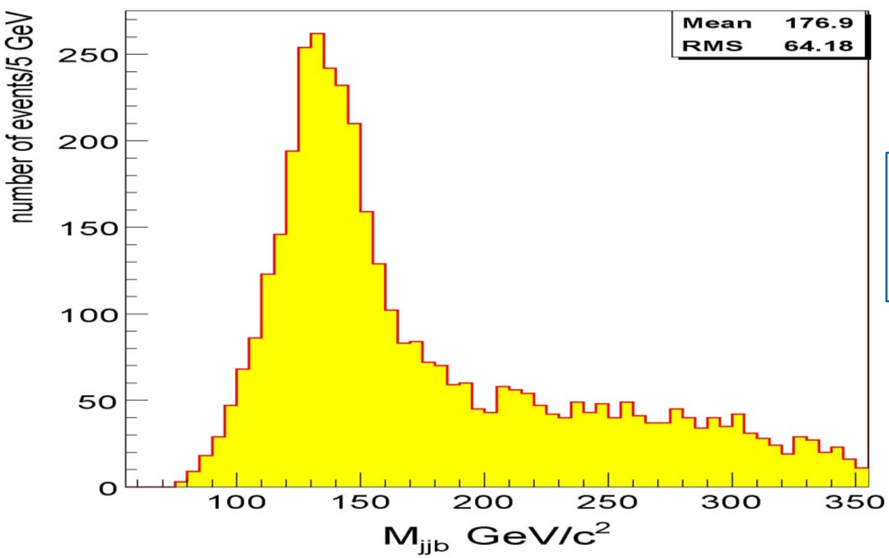
Min(I1, I2)<0.4

Top Quark Selection: Leading jets Topology





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



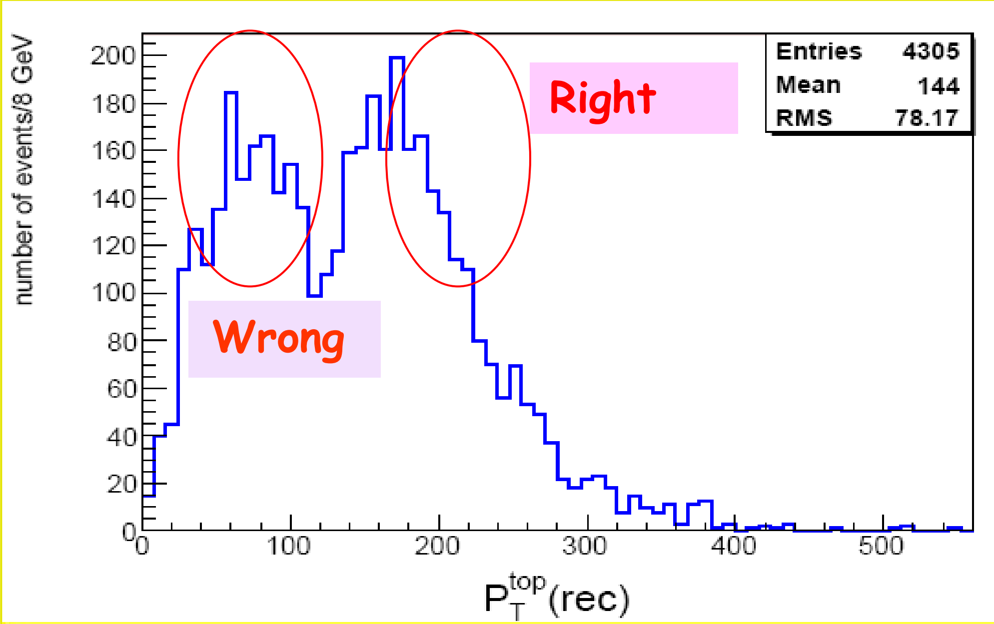
Kinematical cuts	Selection efficiency %	No. of events
Before selection	100	49535
no of iso. muons	93.6	46370
≥ 1 iso muon P_t > 30 GeV	92.7	45920
≥ 1 reco light jets P_t > 20 GeV	91.1	45117
≥ 2 reco light jets $\|\eta\| < 2.5$	73.6	36484
≥ 1 b-jet P_t > 20 GeV	55.6	27543
≥ 2 b-jets $\|\eta\| < 2.5$	18.6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

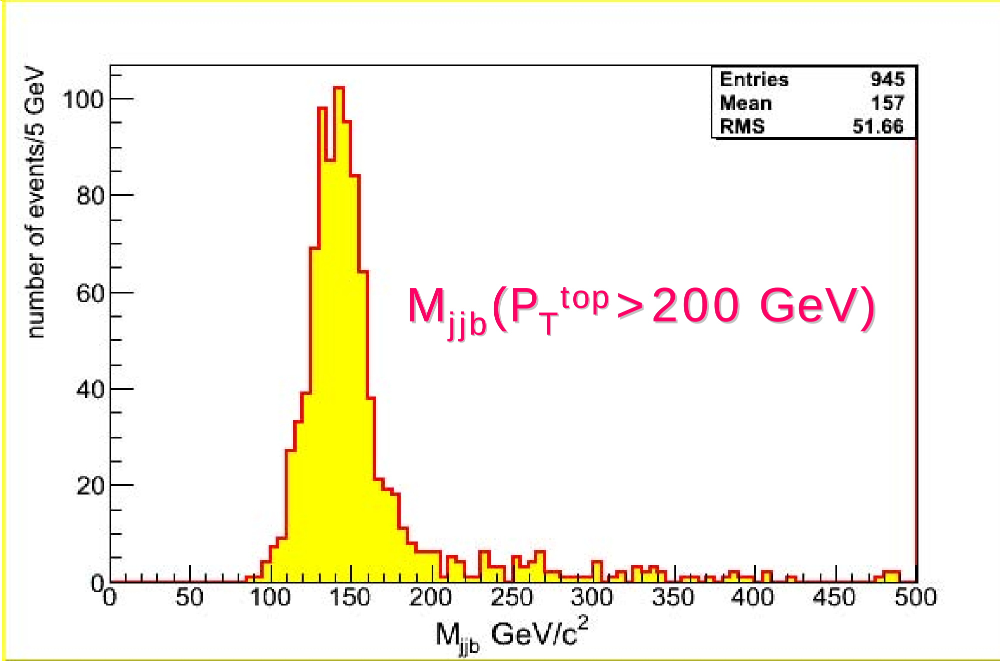
m_W^{nom} = 65.24 (gaussian fitted correctly jet-parton matching)

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

Top Quark Selection: 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, because at preselection level we demand high Pt jets





Calorimetric Clusters Reconstruction Method

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

$$m^2_{clusters}(\Delta R) = (E^2 - P^2) = \left(\sum_{i=0.7}^{n\Delta R} E_i\right)^2 - \left(\sum_{i=0.7}^{n\Delta R} \overline{P}_i\right)^2$$

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

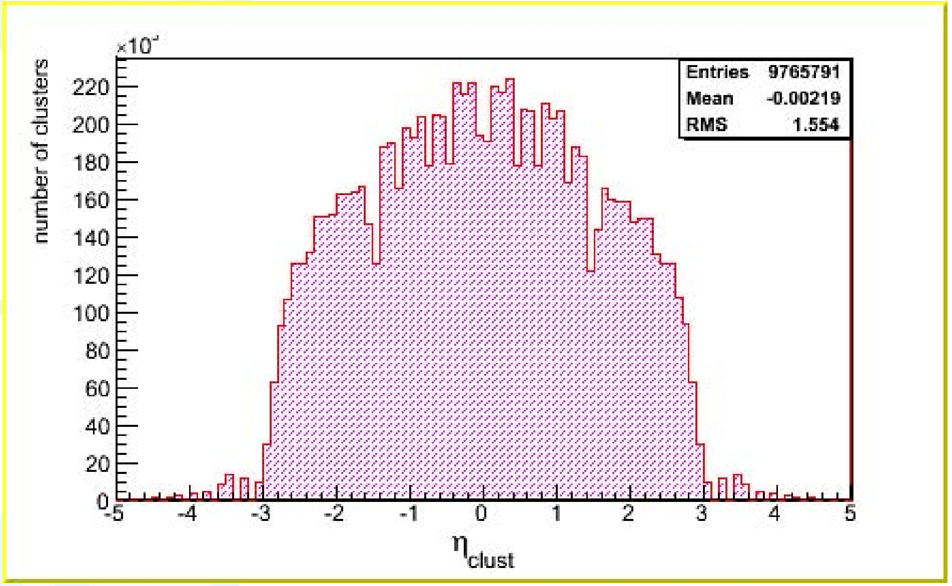
Known: E,η, φ about clusters

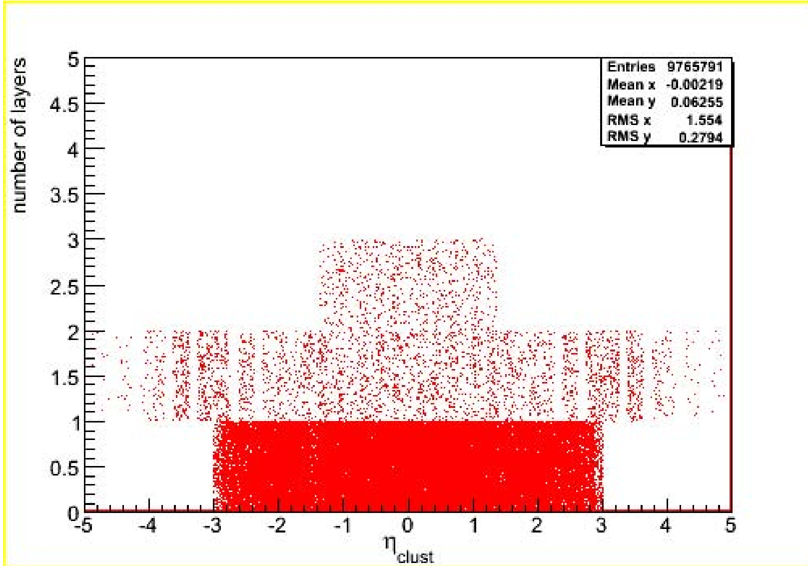
Assumptions: considering particles to be mass-less

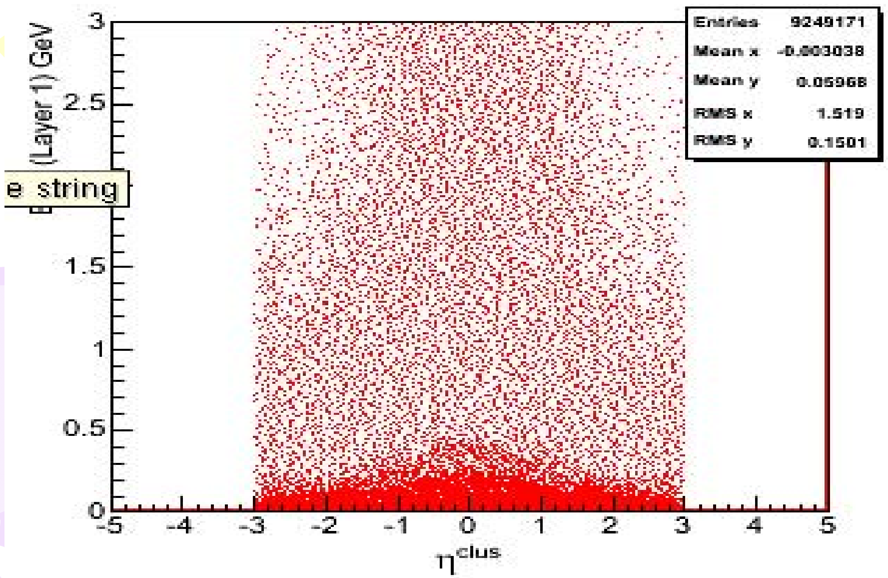
$$m \approx 0 \Rightarrow E^2 \equiv P^2$$
$$P_x = E \sin\vartheta \cos\varphi$$
$$P_y = E \sin\vartheta \sin\varphi$$
$$P_z = E \cos\vartheta$$

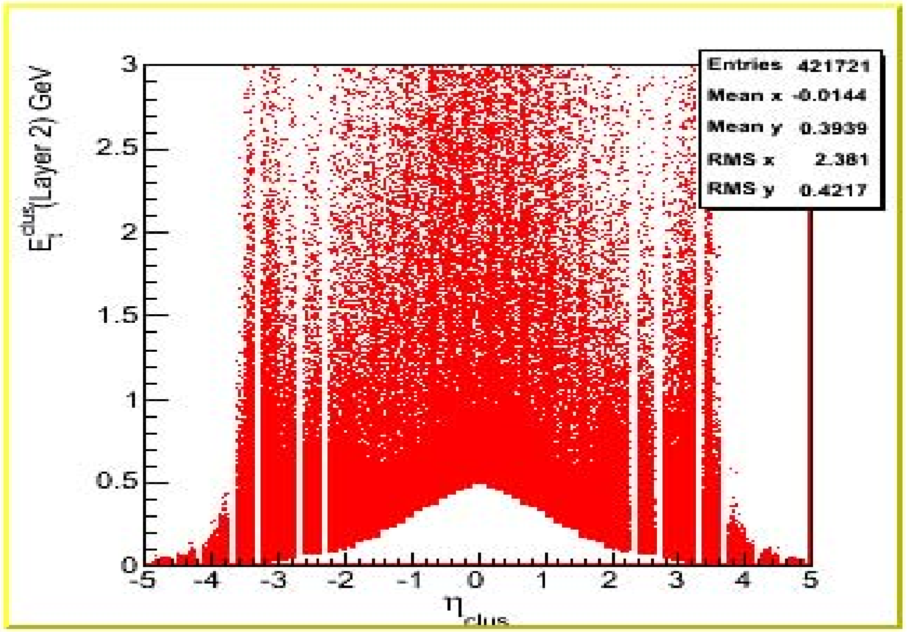
Reco clusters pseudo-rapidy

Calorimeters identifications

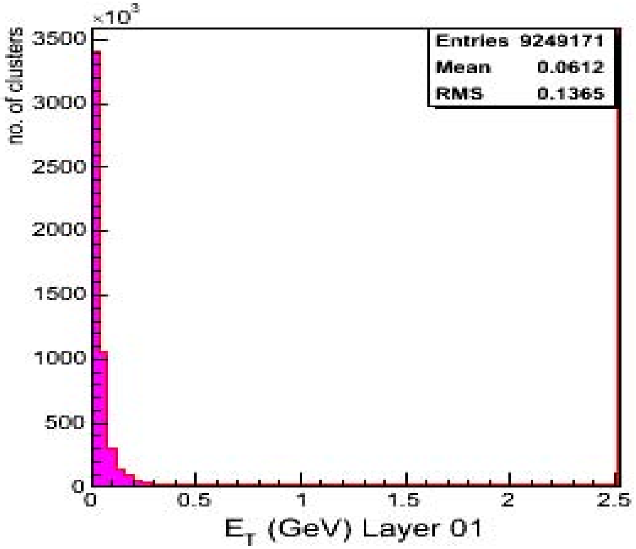


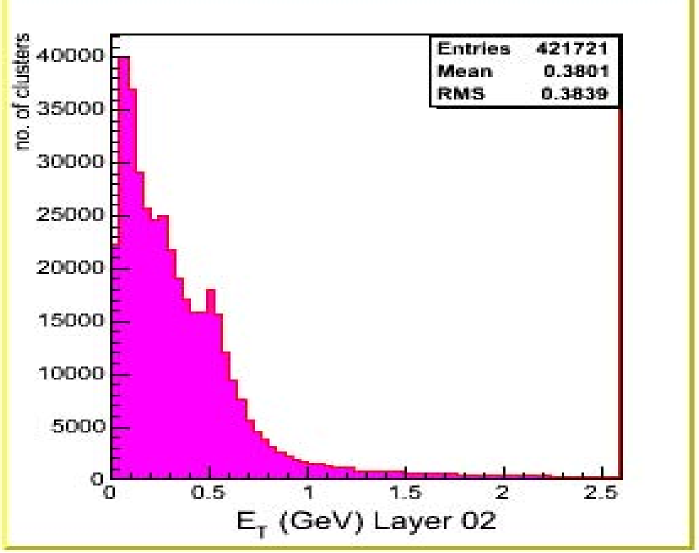


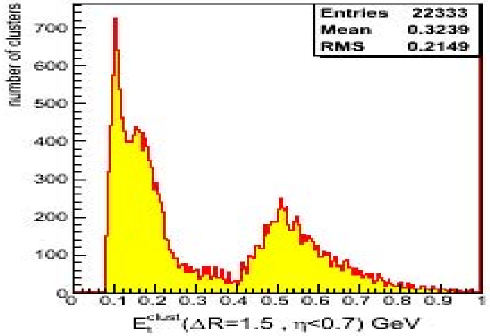


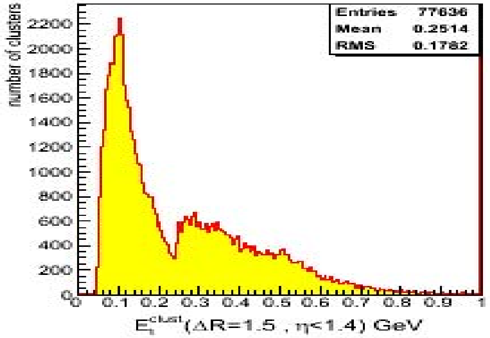


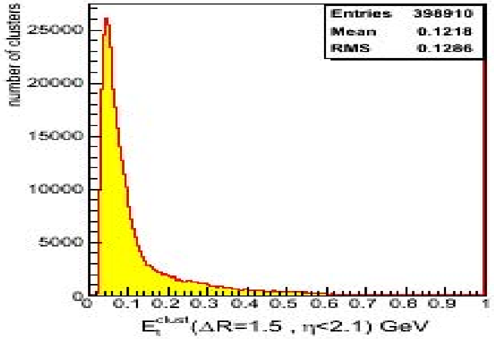
Clusters Transverse Energy Deposition

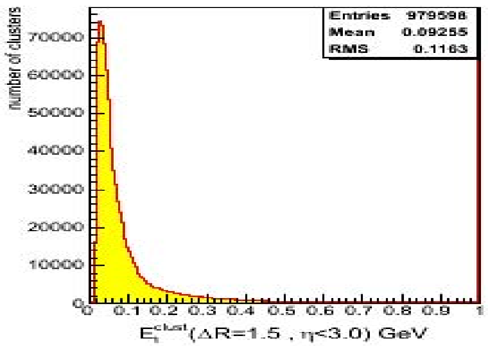


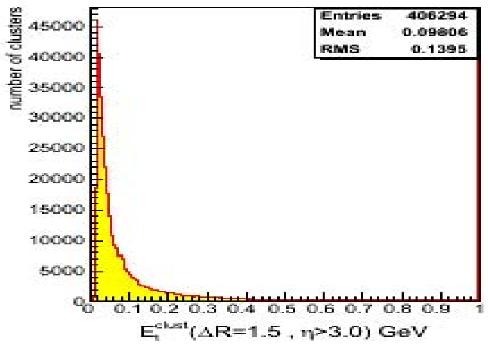


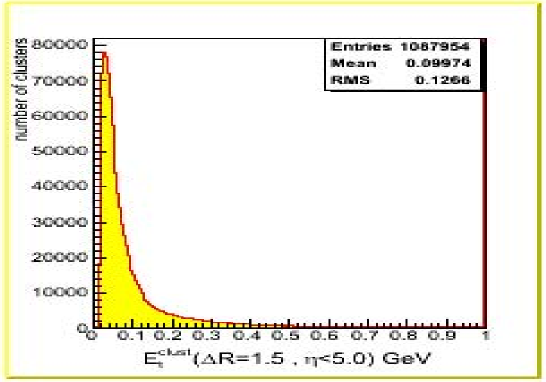




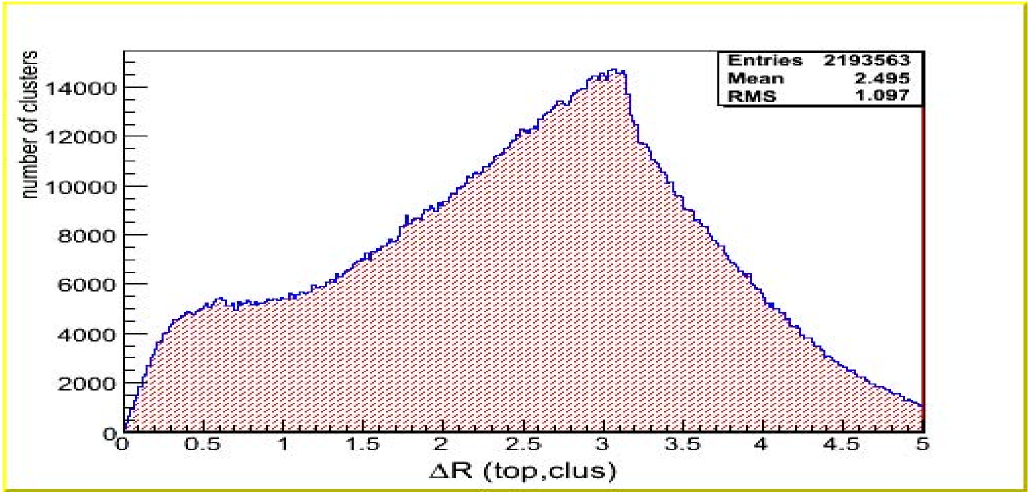


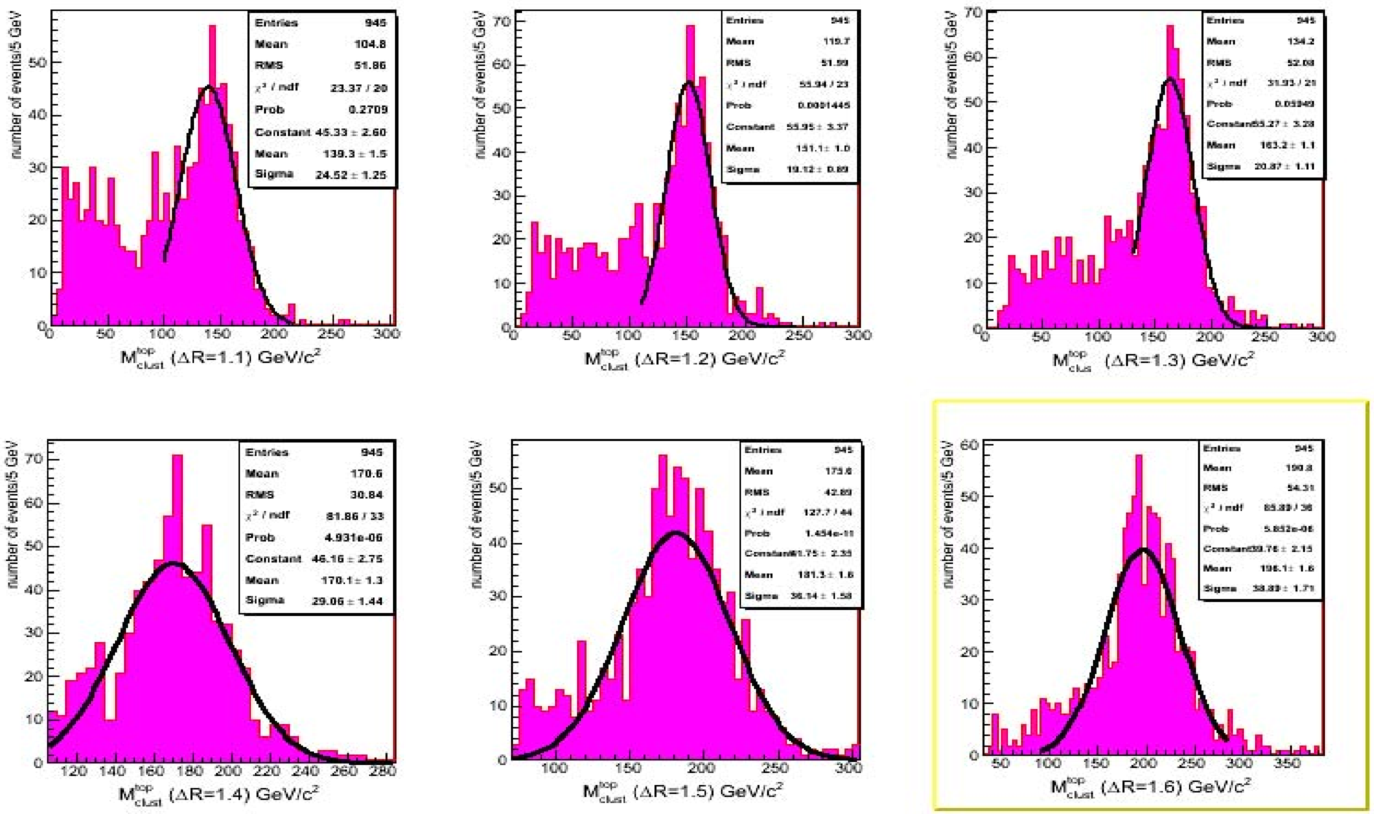






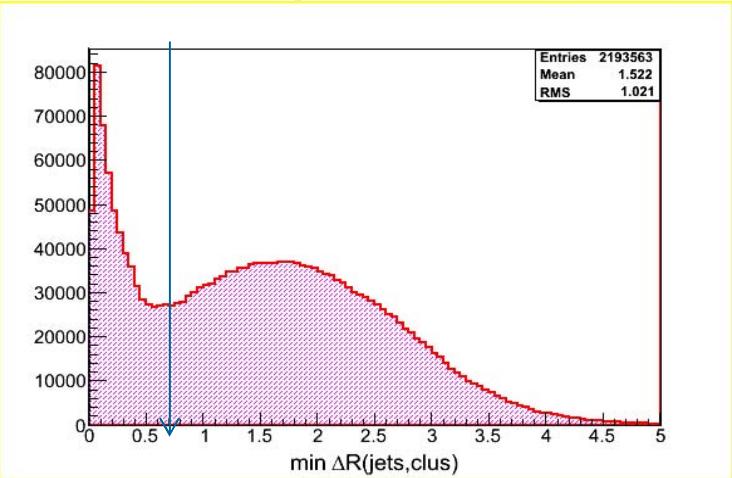
• All clusters opening angle w.r.t reco. Top quark flight direction.





Underlying Event Estimation Method

- It is not only minimum bias even!
- 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)



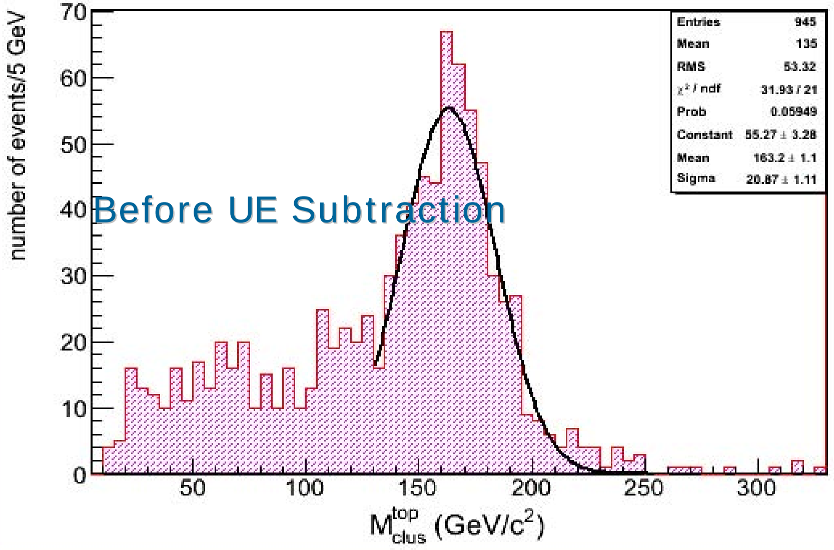
Electromagnetic Calorimeter

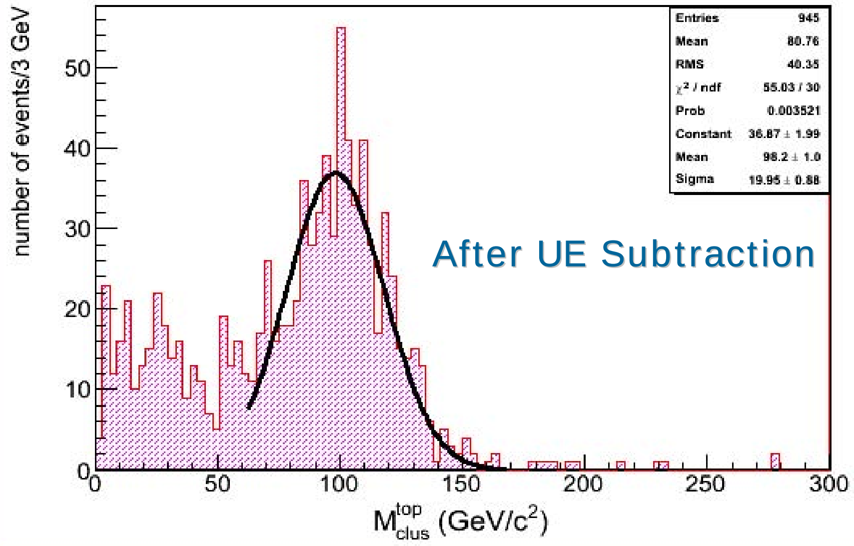
Jet Isolation	$\langle E_t \rangle$ / cluster (MeV) < no of clusters > / high P_t event					
	$\lvert\eta\rvert < 0.7$	$\lvert\eta\rvert < 1.4$	$\lvert\eta\rvert < 2.1$	$\lvert\eta\rvert < 3.0$	$\lvert\eta\rvert > 3.0$	$\lvert\eta\rvert < 5.0$
ΔR = 0.7	626.89 38	509.19 88	445.77 134	363.00 229	236.77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

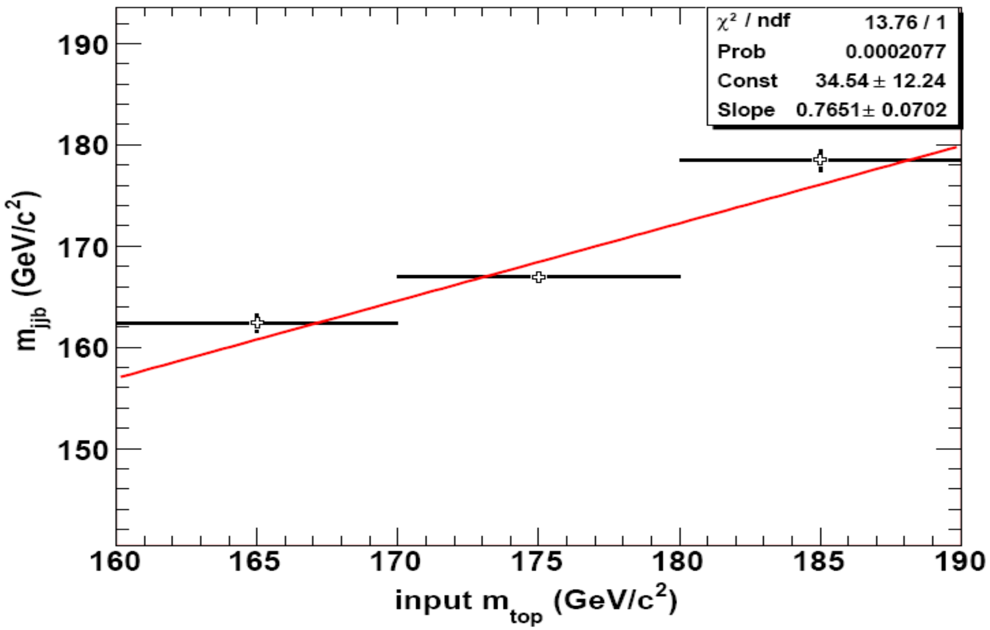
Hadronic Calorimeter

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

Top mass M_{clus}^{top} and UE_{clus} subtraction







With 50,000 events which corresponds to 7.2 fb^{-1}, one can expect a statistical uncertainty about dm=1-1.5 GeV on top mass.

Summary of Expected Systematic

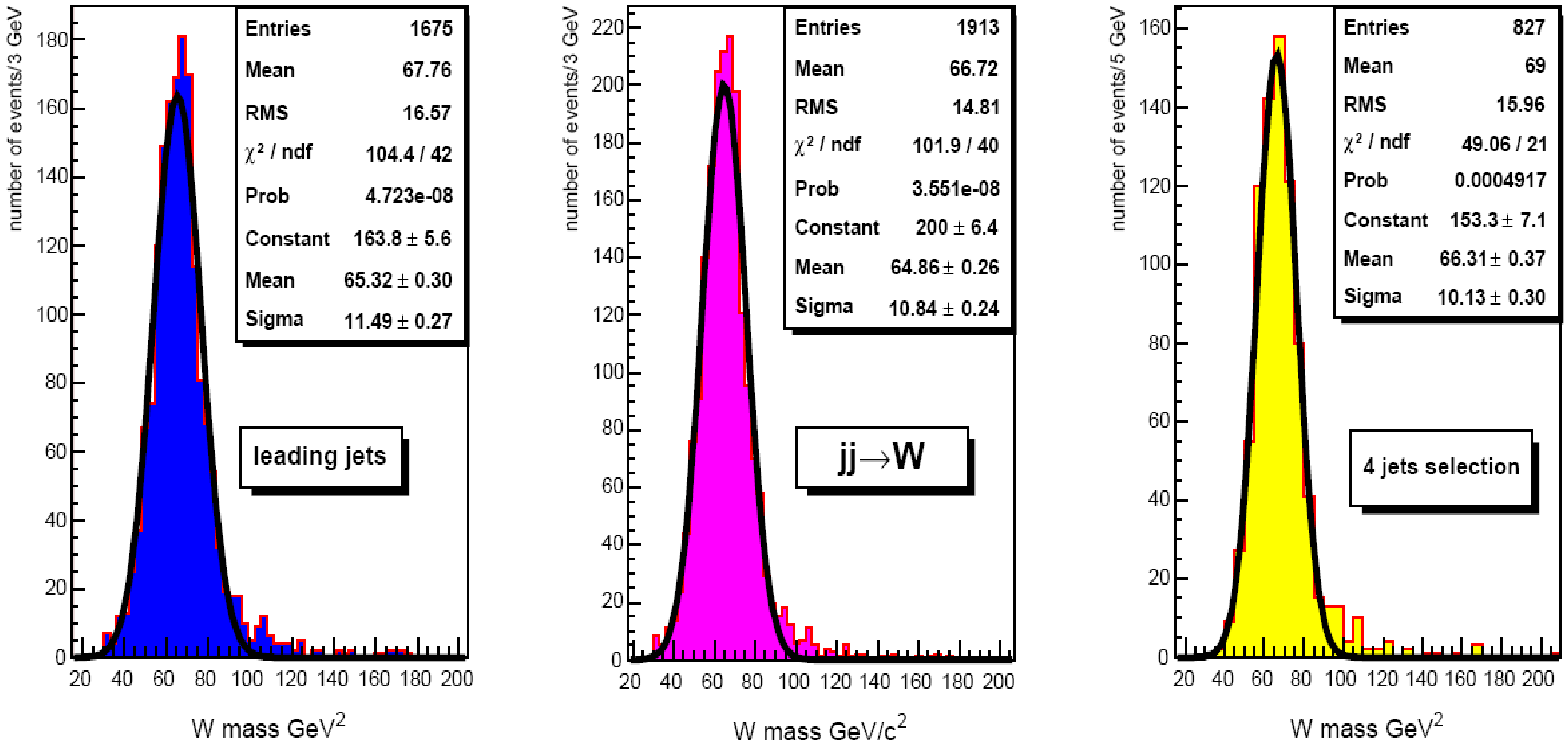
Source Of uncertainity	$\Delta m_{top}(GeV/c^2)$
Re-calibration	0.9
Electronic noise	1.2
ISR on/off	0.14
FSR on/off	0.07
B-quark fragmentation	0.3
UE estimate (+-10%)	1.34
Cluster mis calibration:+-1(5)%	0.7(1.3)
Calorimeter: e/h=1.25 (1.63)	0.8(0.3)

Summary

- A new method for Underlying event (UE) is developed
- An alternate method for top mass reconstruction in CMS is presented, strongly depends on Calorimeters.
- Analysis based ($P_t^{top} > 200$ GeV) with Full and Fast Simulation of CMS detector is performed.
- Statistical error 1-1.5 GeV on top mass is determined.

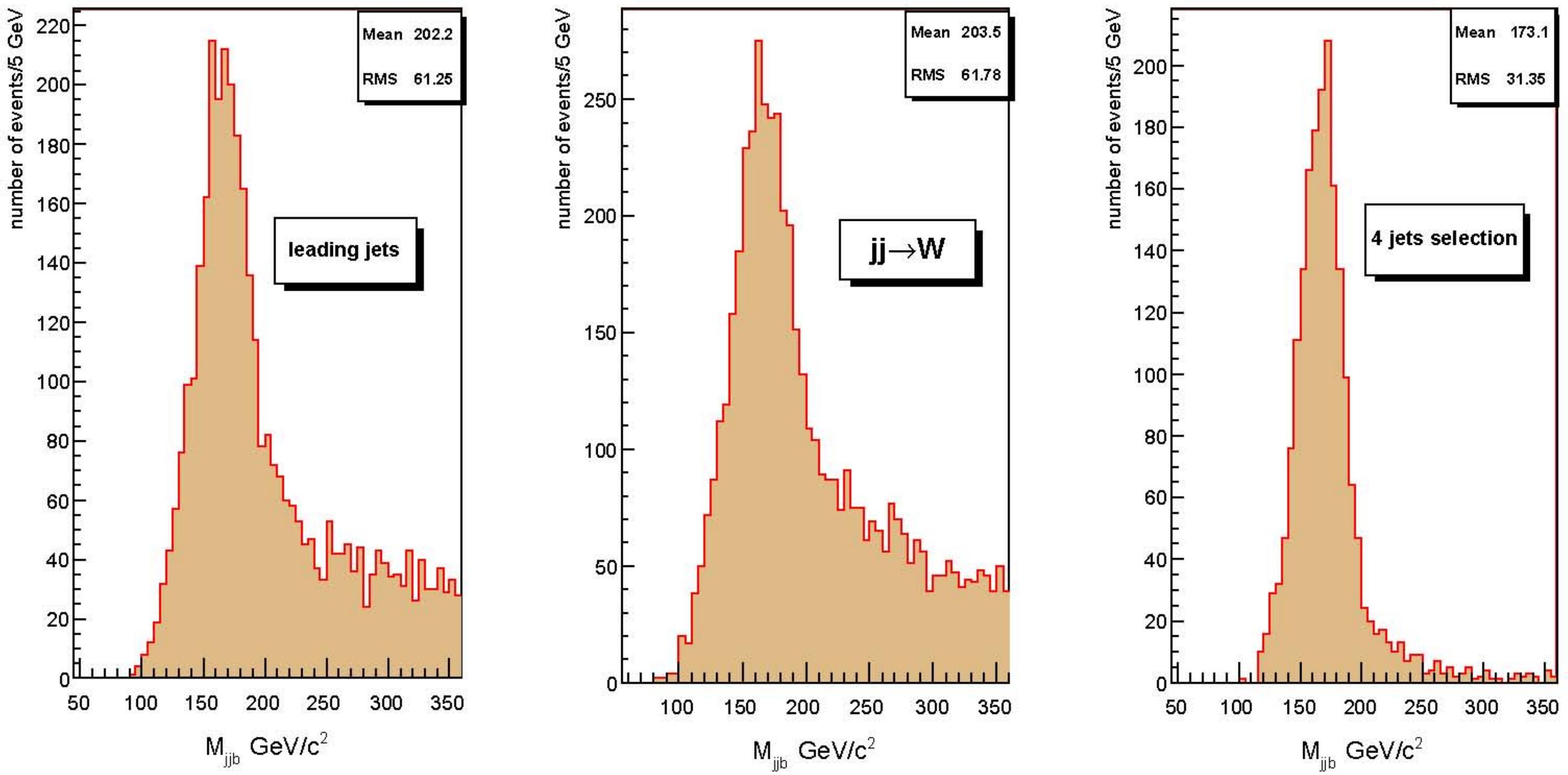
BACKUP SLIDES

Nominal mass—fitted mass ~ 65 GeV



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

Calibrated Top Quark mass M_{jjb}



- Peaks are shifted towards the nominal Top mass

Introducing three Approaches for jets Selection

Three approaches to select events

+ jet combination (for top 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

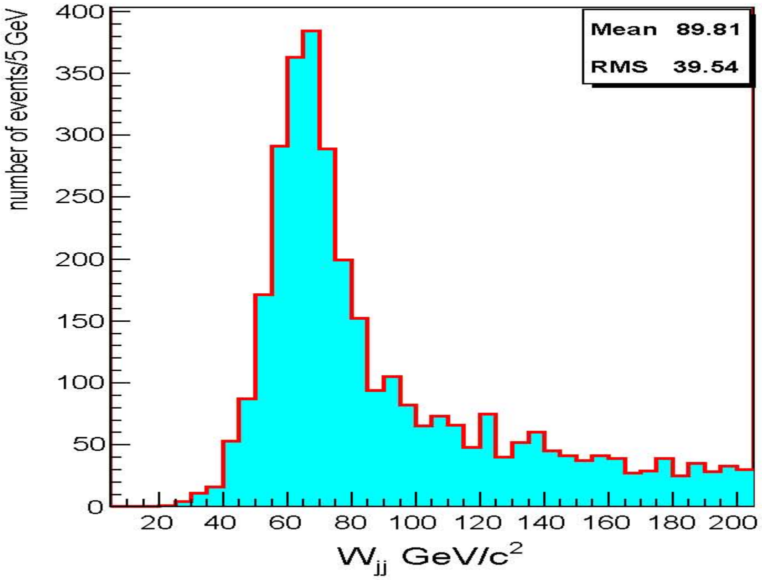
Top Quark Selection: Four jets Topology

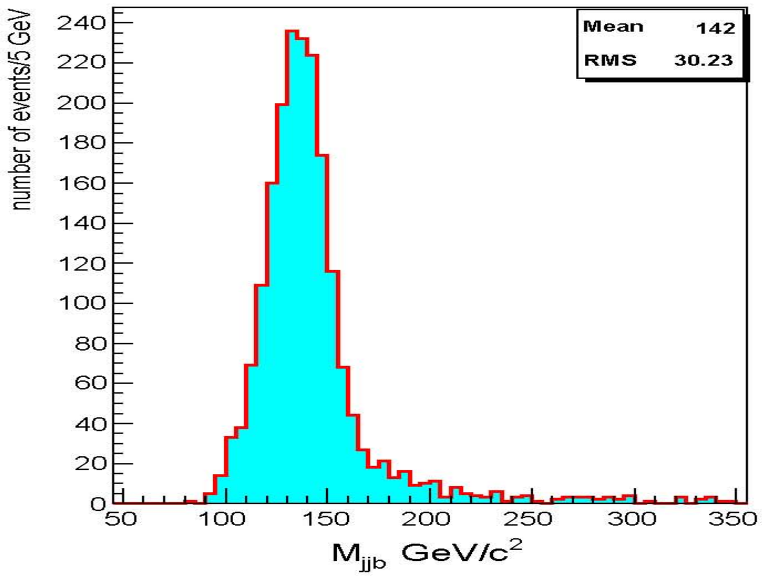
Hadronic top selection

- 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

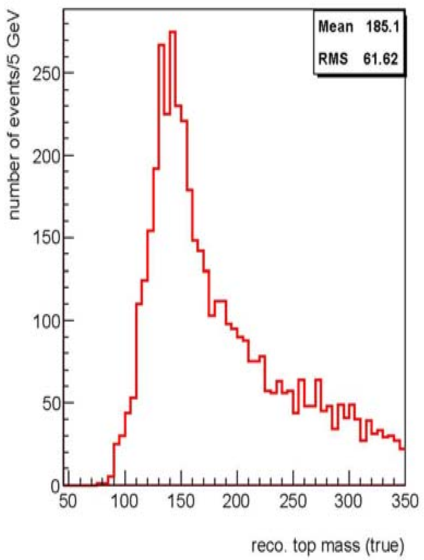
Kinematical cuts	Selection efficiency %	No. of events
Before selection	100	49535
no of iso muons	93.6	46370
≥ 1 iso muon P_t > 30 GeV	92.7	45916
≥ 1 reco light jets P_t > 20 GeV	92.7	45915
Exectly 4 jets $\|\eta\|$ < 2.5	21.3	10551
Exectly 2 light jets	8.0	3941
Exectly 2 b-jets	8.0	3941
$\|m_{jj} - m_W\|$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

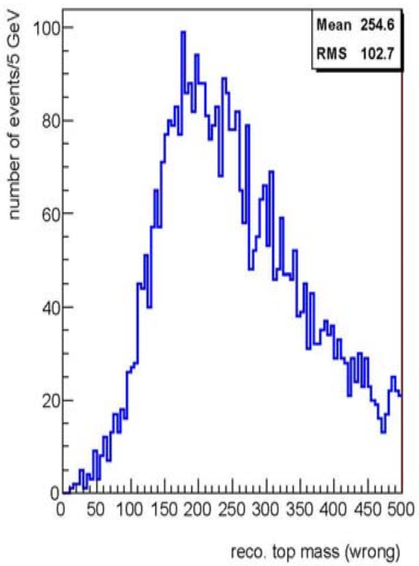
1 quark matched = 20.98%
2 quarks matched = 43.26%





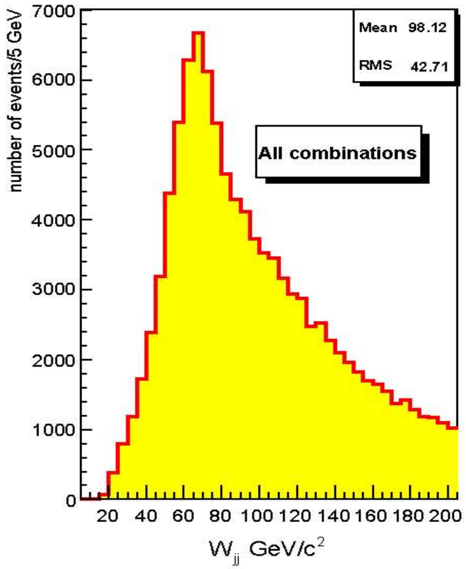
Top Quark Selection: j+j → W

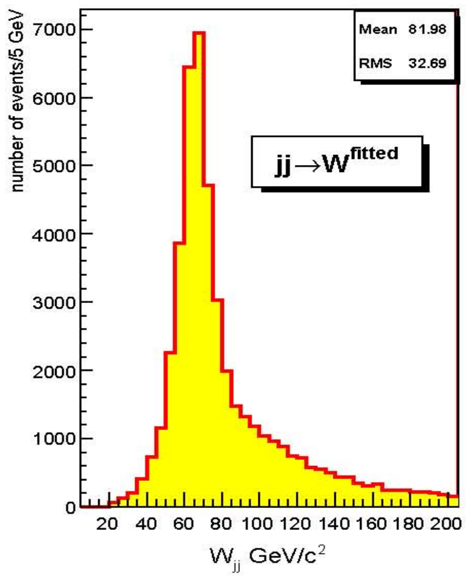


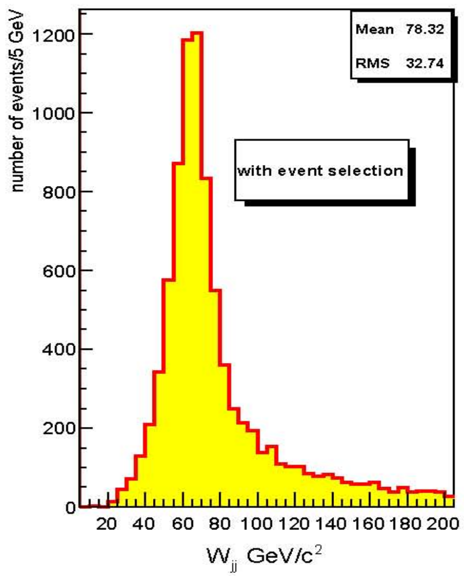


Kinematical cuts	Selection efficiency %	No. of events
Before selection	100	49535
no of iso muons, P_t > 30 GeV, $\|\eta\| < 2.0$	92.7	45920
2 jj →W, P_t > 20 GeV, $\|\eta\| < 2.5$	73.6	36484
≥ 2 b-jets P_t > 20 GeV, $\|\eta\| < 2.5$	18.6	9214
$\|m_{jj} - m_W\| < 20$ GeV	11.9	5917

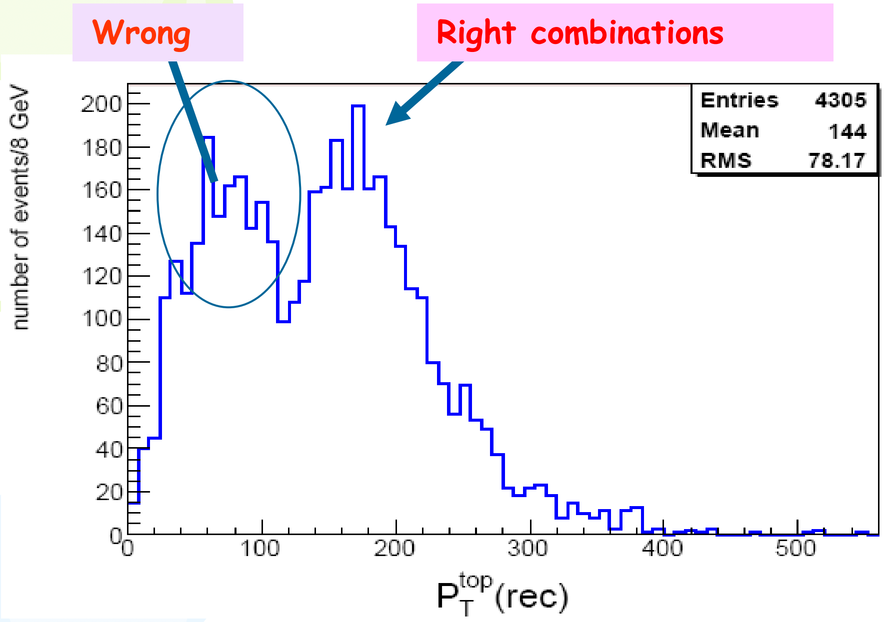
1 quark matched = 20.76%
2 quarks matched = 40.6%

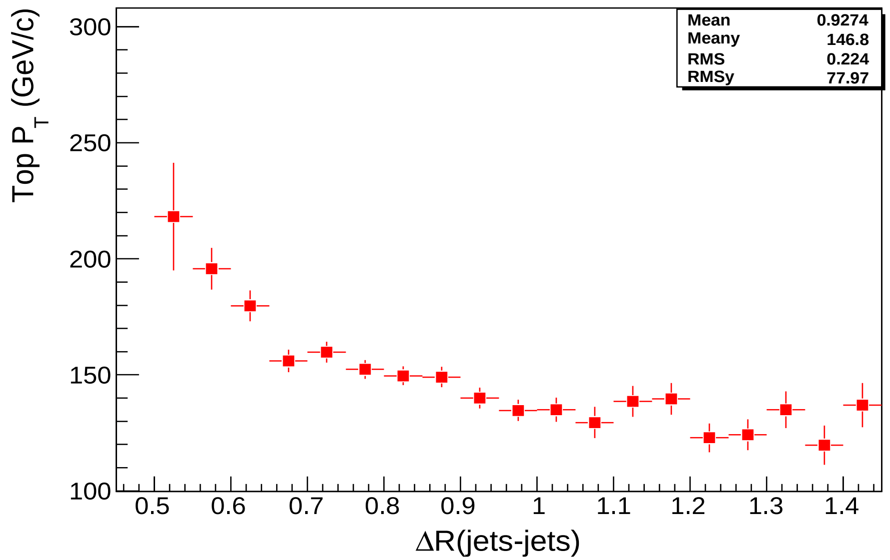


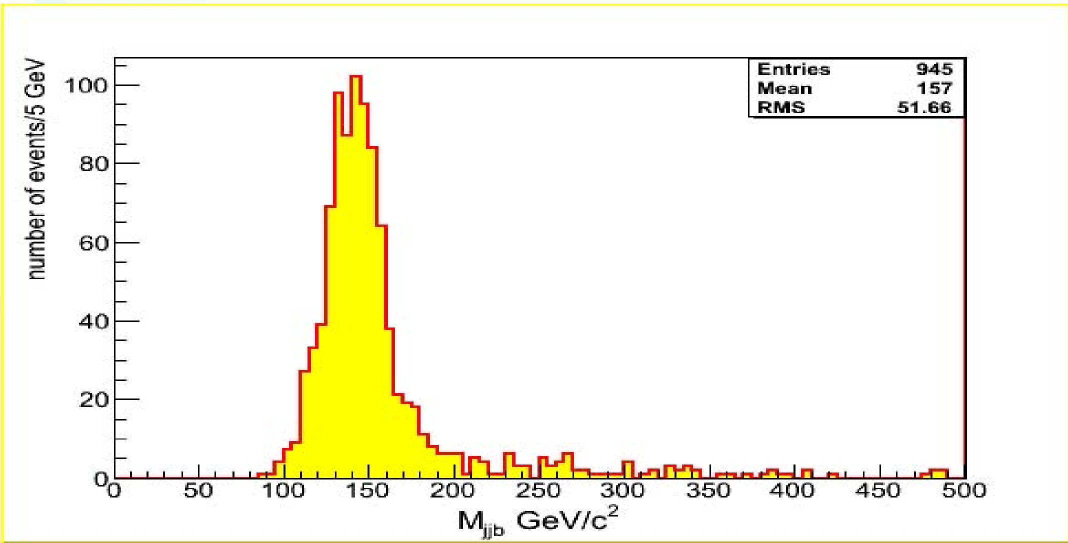


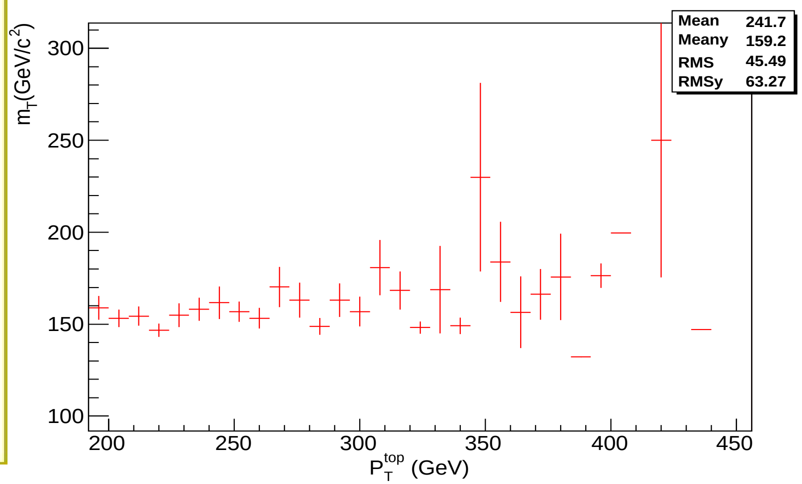


Leading jet Approach: Pt Dependence









Comments on M_{jjb}

- Study based on shape of distributions for top direction determination
- Explored 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