Study of Top-Antitop Production with the ATLAS Detector at the LHC

Max-Planck-Institut
für Physik
(Werner-Heisenberg-Institut)

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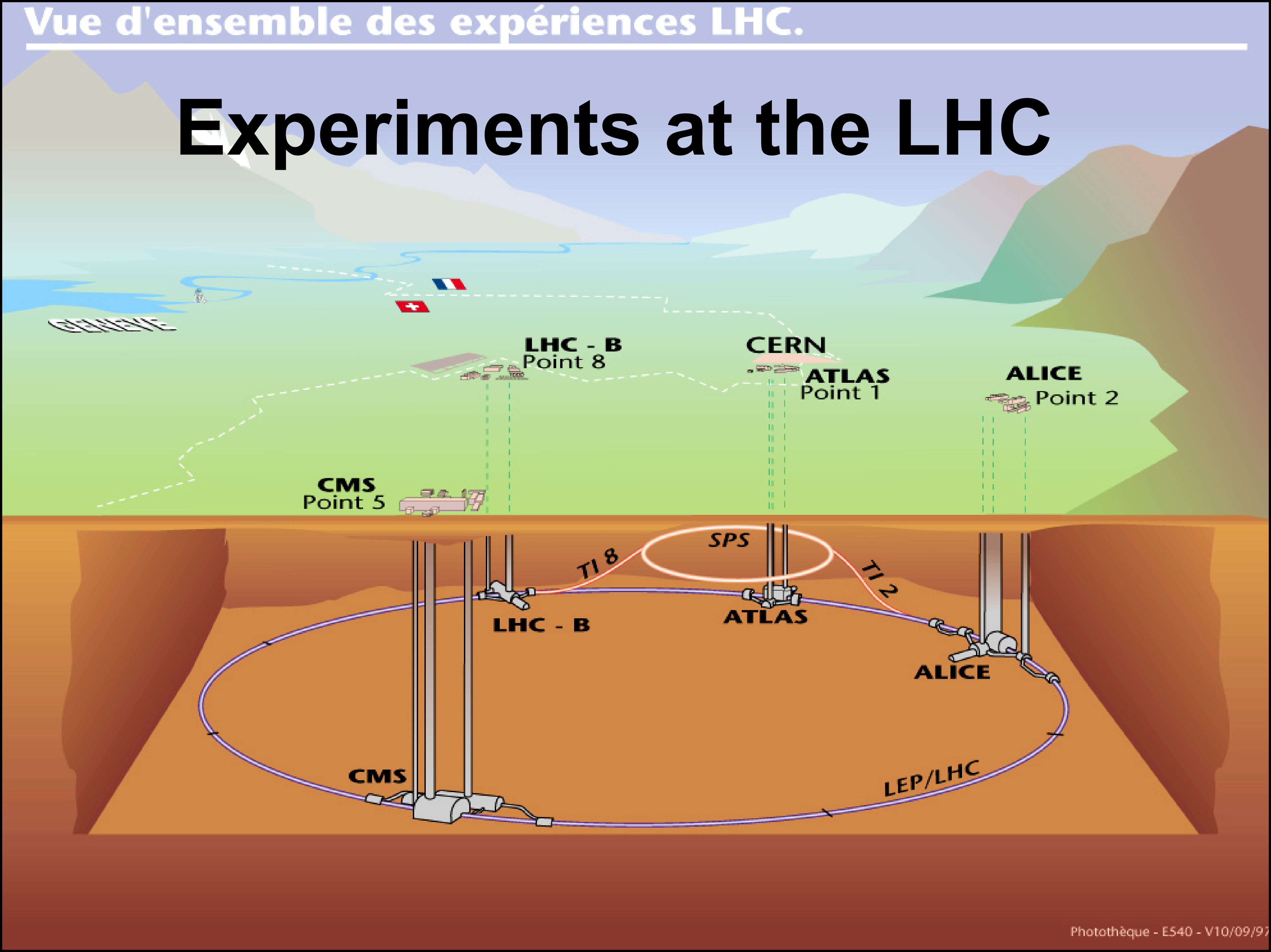
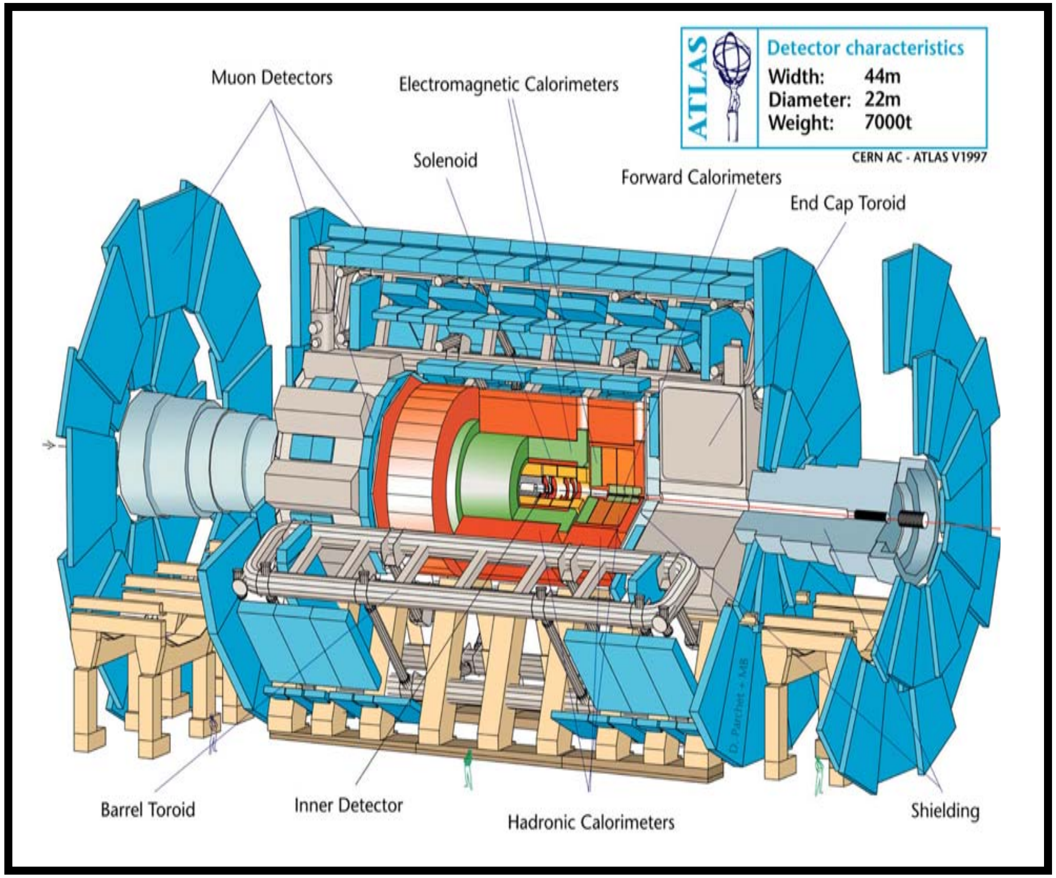
The Large Hadron Collider
E_{CM} = 14 TeV
L = $10^{34}cm^{-2}s^{-1}$

Experiments at the LHC



The ATLAS Detector

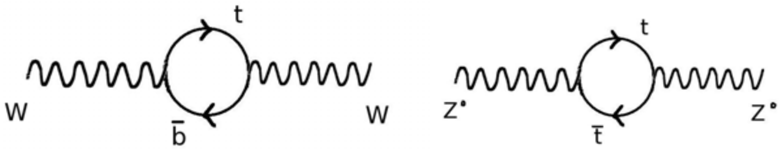
- Inner Detector surrounded by superconducting solenoid magnet.
  - **Pixel detector, semiconductor tracker, transition radiation tracker.**
  - **Momentum and vertex measurements, electron, tau and heavy-flavor ID.**



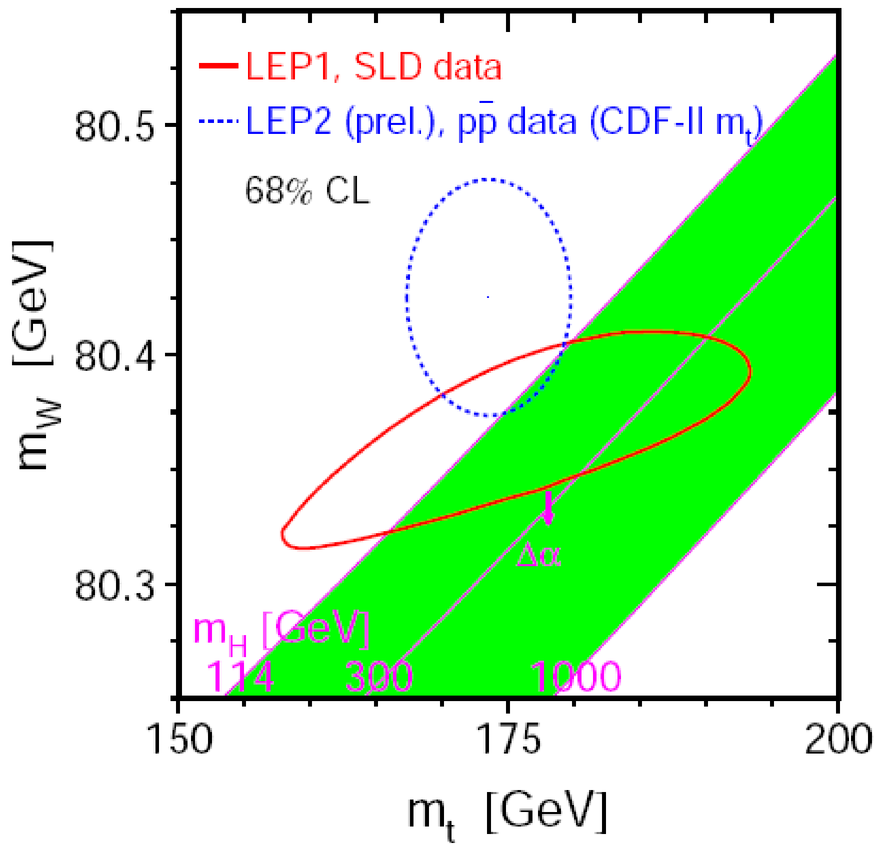
- **Lead / liquid argon electromagnetic sampling calorimeter.**
  - **Electron, photon ID and measurements.**
- **Hadronic calorimeter.**
  - **Scintillator-tile barrel calorimeter.**
  - **Copper / liquid argon hadronic end-cap calorimeter.**
  - **Tungsten / liquid argon forward calorimeter.**
  - **Measurements of jet properties.**
- **Air-core toroid magnet**
  - **Instrumented with muon chambers.**
- **Muon spectrometer.**
  - **Measurement of muon momentum.**

Why Study the Top Quark?

- Measurement of top-antitop production cross section provides a test of QCD.
- Accurate measurement of m_t is valuable as input to precision electroweak analyses.



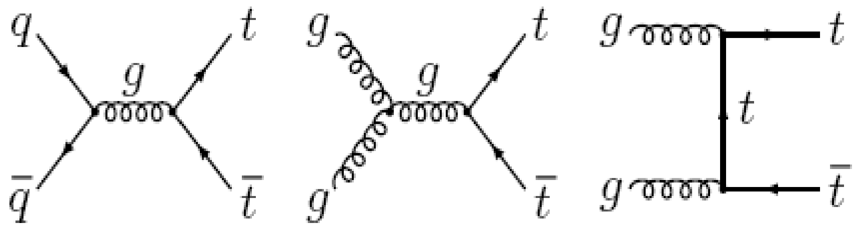
- A precision measurement of m_t and m_W can be used to constrain the Higgs mass.
- Top pair production will provide a significant background to future measurements.
  - It is important to measure the production rate precisely.



LEP, Tevatron, SLD: m_W = 80.392 ± 0.029

Tevatron: m_t = 171.4 ± 2.1 GeV

Top Quark Physics

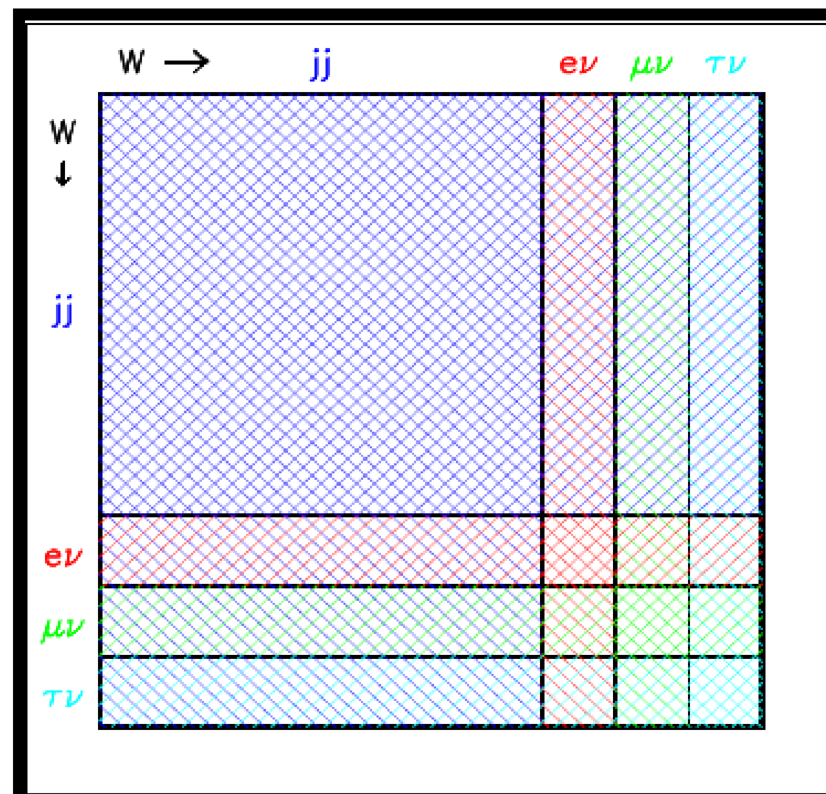


LHC:

10% quark-antiquark annihilation

90% gluon fusion

- $\Gamma(t \rightarrow Wb) \sim 100\%$
- **Hadronic channel:**
- $tt \rightarrow Wb\ Wb \rightarrow jjb\ jjb$
- $\Gamma = 44.4\%$
- **Semileptonic channel:**
- $tt \rightarrow Wb\ Wb \rightarrow l\nu b\ jjb$
- $\Gamma = 50.7\%$
- **Dileptonic channel:**
- $tt \rightarrow Wb\ Wb \rightarrow l\nu b\ l\nu b$
- $\Gamma = 4.9\%$



Samples

- **Semileptonic ttbar events are signal.**
- **Dileptonic ttbar events are background.**
  - csc11.005200, σ=461 pb, L=1072 pb^{-1}
  - NLO event generator MC@NLO / Herwig
  - Detector simulation performed using Athena 11.0.42

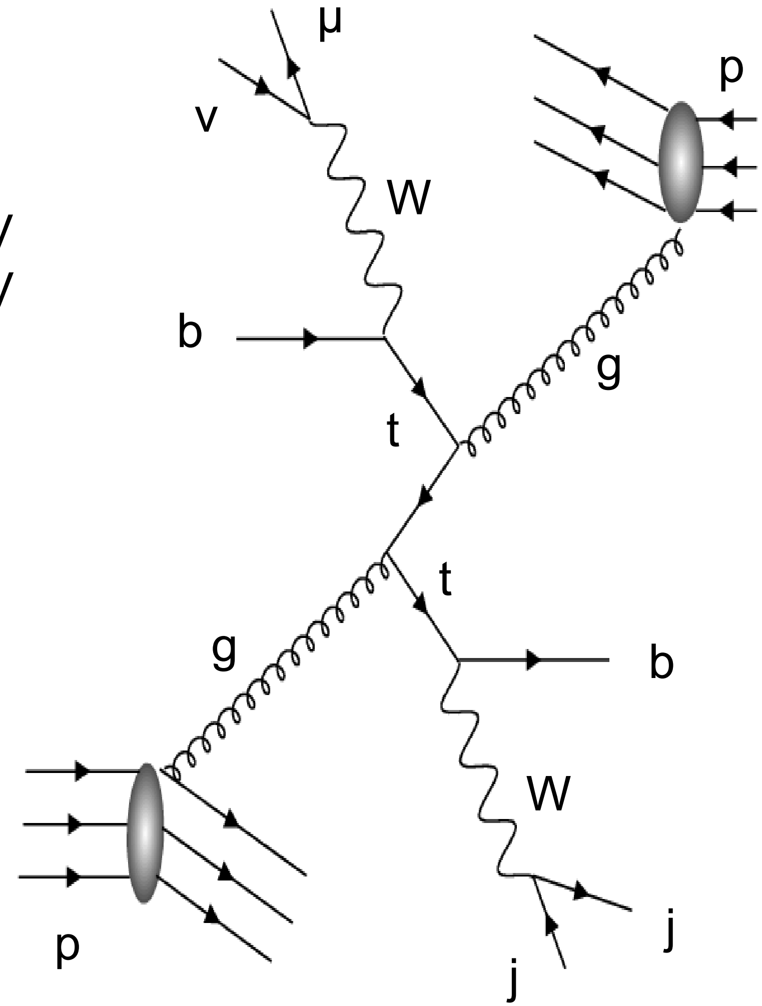
- **Hadronic ttbar events are background.**
  - csc11.005204, σ=369 pb, L=105 pb^{-1}
  - NLO event generator MC@NLO / Herwig
  - Detector simulation performed using Athena 11.0.42

- **Inclusive W+N jets events are main physics background.**
  - rome.003017, σ=1200 pb, L=136 pb^{-1}
  - LO event generator Alpgen
  - Generated using Athena 10.0.2
  - Reconstructed using Athena 11.0.42

Selection Cuts

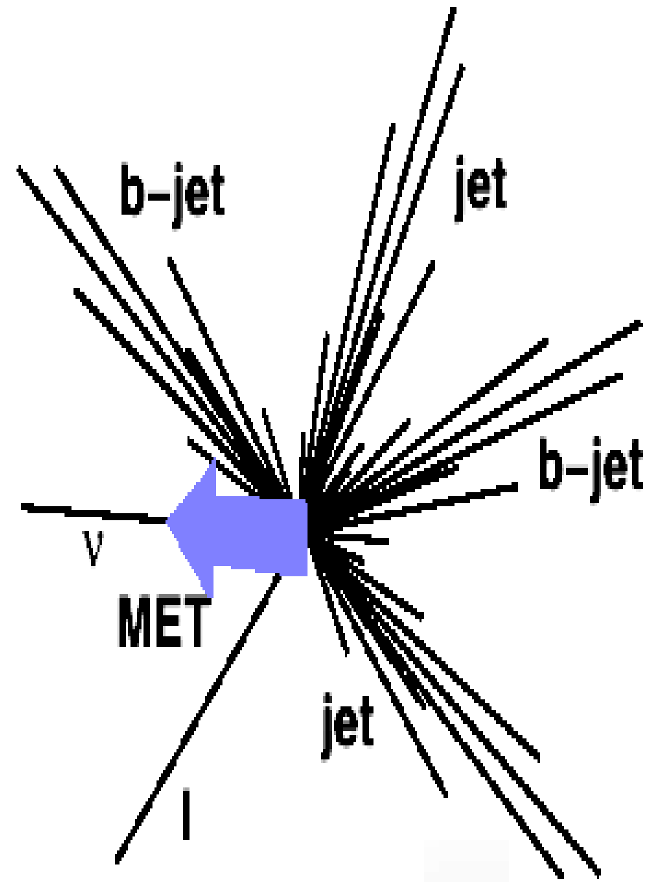
• Considered events in the semileptonic ttbar channel where the lepton is an electron or a muon. $\Gamma = 29.9\%$

- Each event was required to have:
  - Exactly one isolated, high-p_T electron or muon.
    - For e "isolated" meant $E_{\Delta R=0.45} < 6$ GeV
    - For μ "isolated" meant $E_{\Delta R=0.20} < 1$ GeV
    - $p_T(l) > 20$ GeV, $|\eta| < 2.5$
    - (isEM == 0) for electrons
  - At least four jets.
    - Jets are reconstructed using k_T algorithm with D = 0.4.
    - $|\eta| < 2.5$
    - $p_T(j_1) > 40$ GeV, $p_T(j_2) > 40$ GeV
    - $p_T(j_3) > 20$ GeV, $p_T(j_4) > 20$GeV
  - Missing $E_T > 20$ GeV
- No b-tagging was required.



Event Reconstruction

- For each event:
  - Consider all jets with $p_T > 20$ GeV.
    - Create all possible 3-jet combinations.
    - Select that 3-jet combination with maximum p_T to represent the reconstructed hadronic top quark.
  - Consider the 3 jets used to reconstruct top quark.
    - Form the 3 possible 2-jet combinations.
    - Take the 2-jet combination with the maximal p_T to represent the reconstructed hadronic W boson.



Hadronic Top and W Boson Mass

Mass of Hadronic Top

m_t^{fit} = 168.3 ± 0.8 GeV

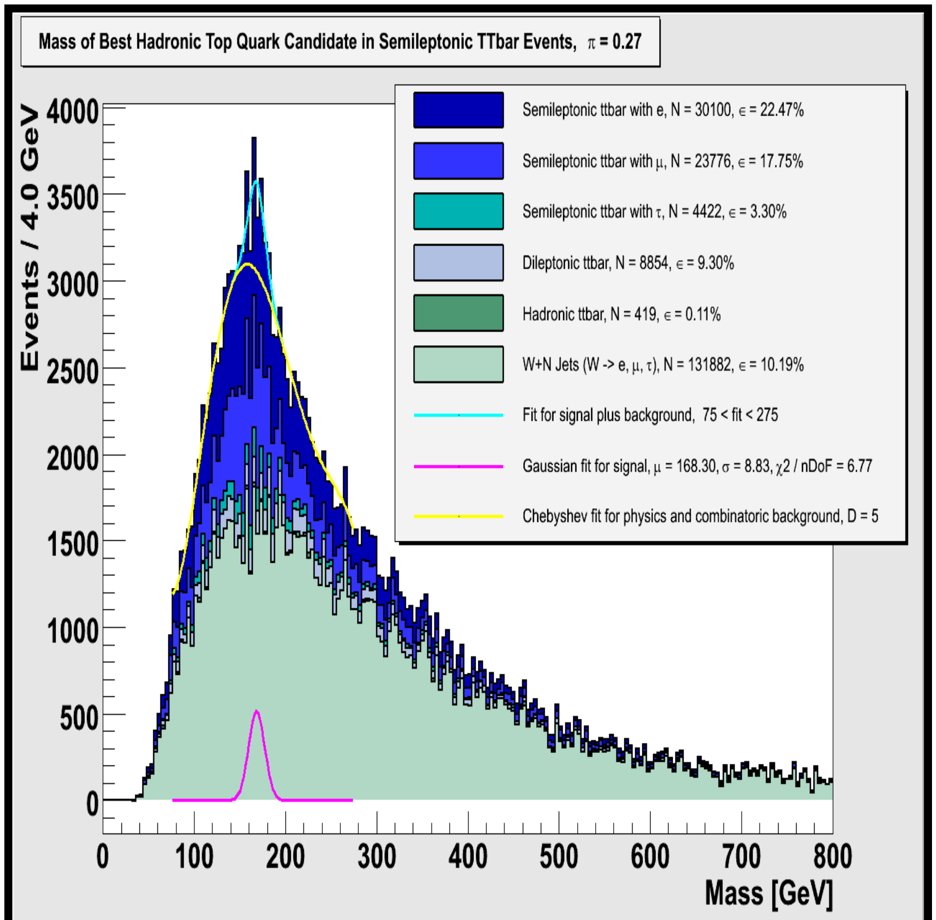
$m_t^{Tevatron}$ = 171.4 ± 2.1 GeV

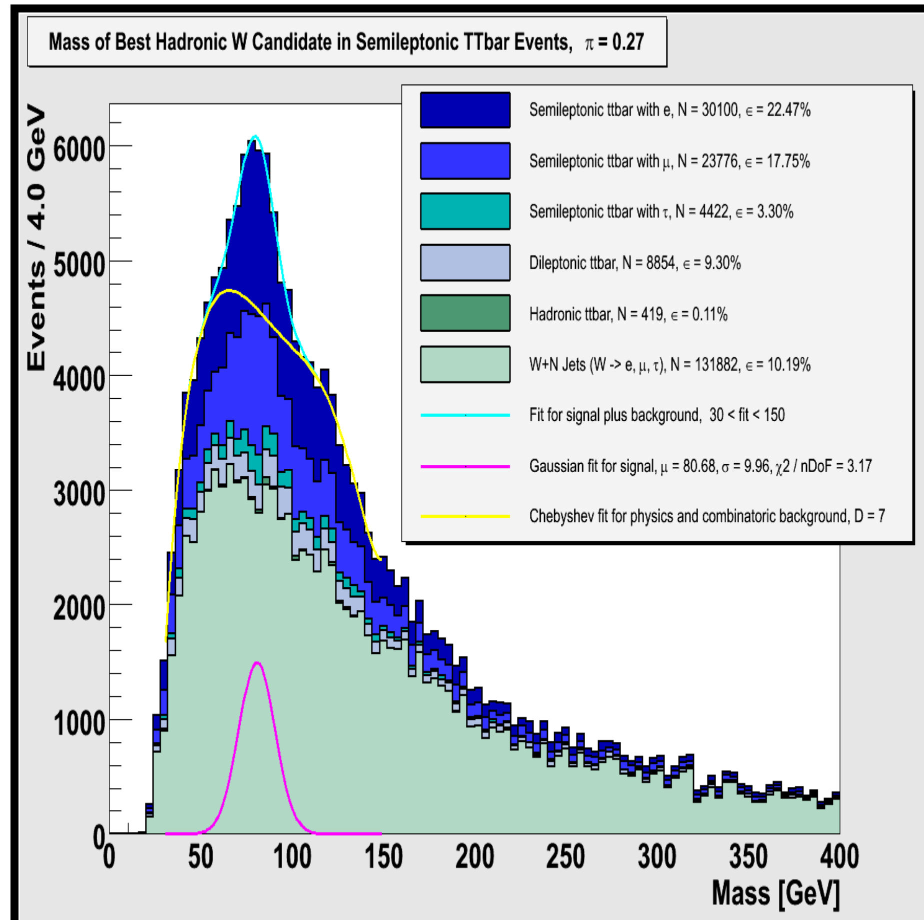
m_t^{MC} = 175.0 GeV

Mass of W Boson

m_W^{fit} = 80.7 ± 0.5 GeV

m_W^{LEP} = 80.39 ± 0.03 GeV

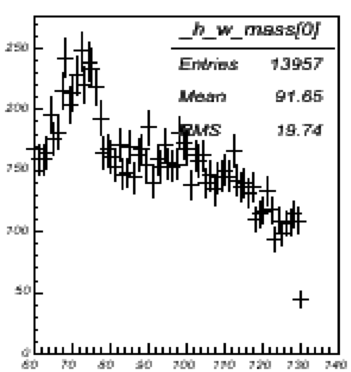




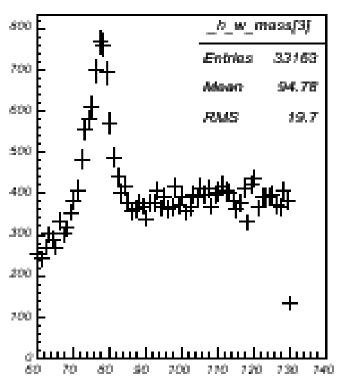
Optimization of k_T Jet Algorithm

- **A successive combination algorithm such as k_T recursively combines objects (particles, calorimeter cells, towers, clusters) with "nearby" momenta into jets.**
  - **"Nearby" is defined in η-φ space: $\Delta R = \sqrt{((\Delta\eta)^2 + (\Delta\varphi)^2)}$**
- **Two objects will be merged into one jet if $\Delta R < D^2$.**
  - **The parameter D must be chosen properly for the process in question.**
  - **If D is too small, objects which should be combined into a jet may be excluded.**
  - **If D is too large, objects which should not be merged into a single jet may be merged.**

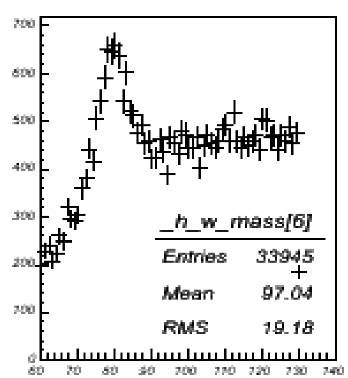
- **Invariant Mass Distribution of Hadronic W Boson**
  - **Jet reconstruction algorithm was run on Monte Carlo truth after hadronization.**
  - **No detector simulation was performed.**



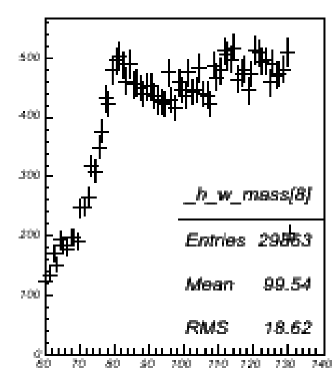
D = 0.1



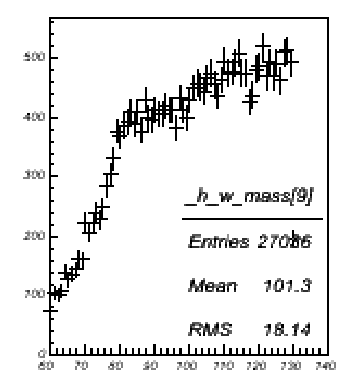
D = 0.4



D = 0.7



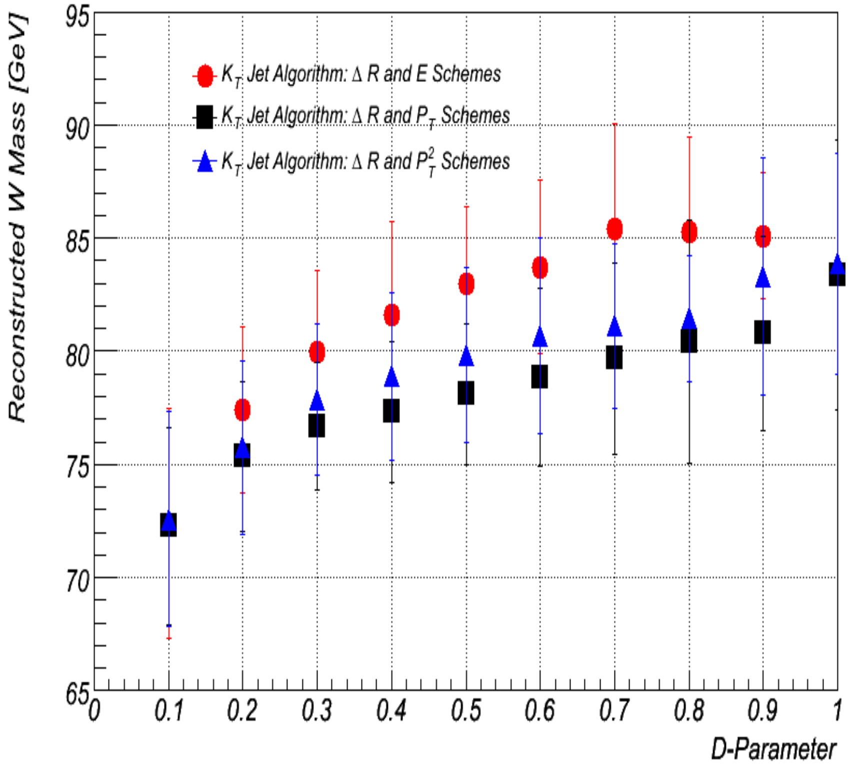
D = 0.9



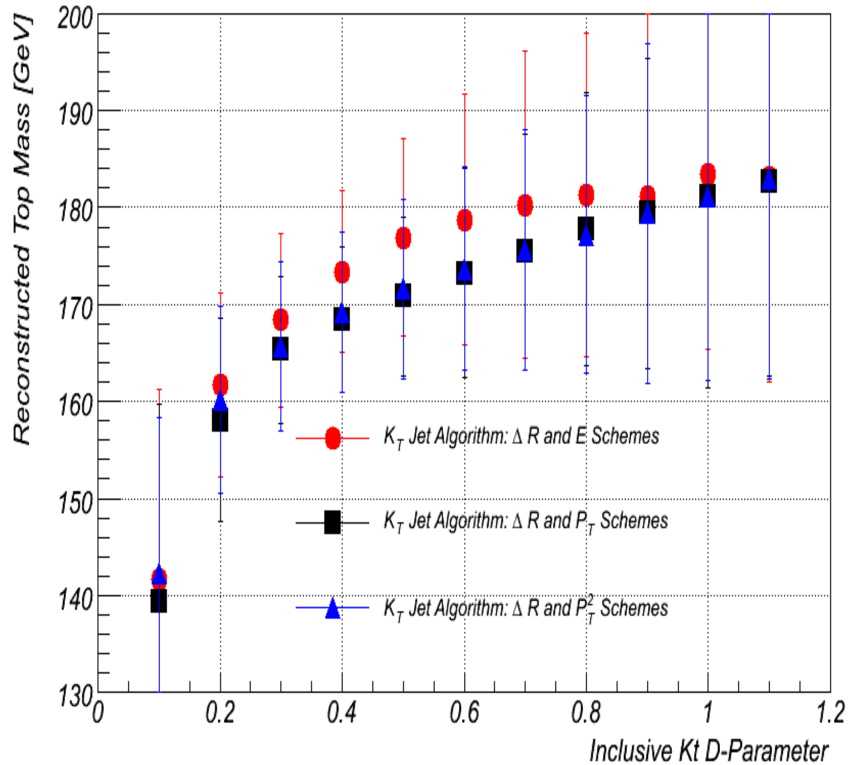
D = 1.0

Optimization of kT Jet Algorithm

- **Jet reconstruction algorithm was run on Monte Carlo truth after hadronization.**
- **No detector simulation was performed.**
- **D = 0.4 is "reasonable".**



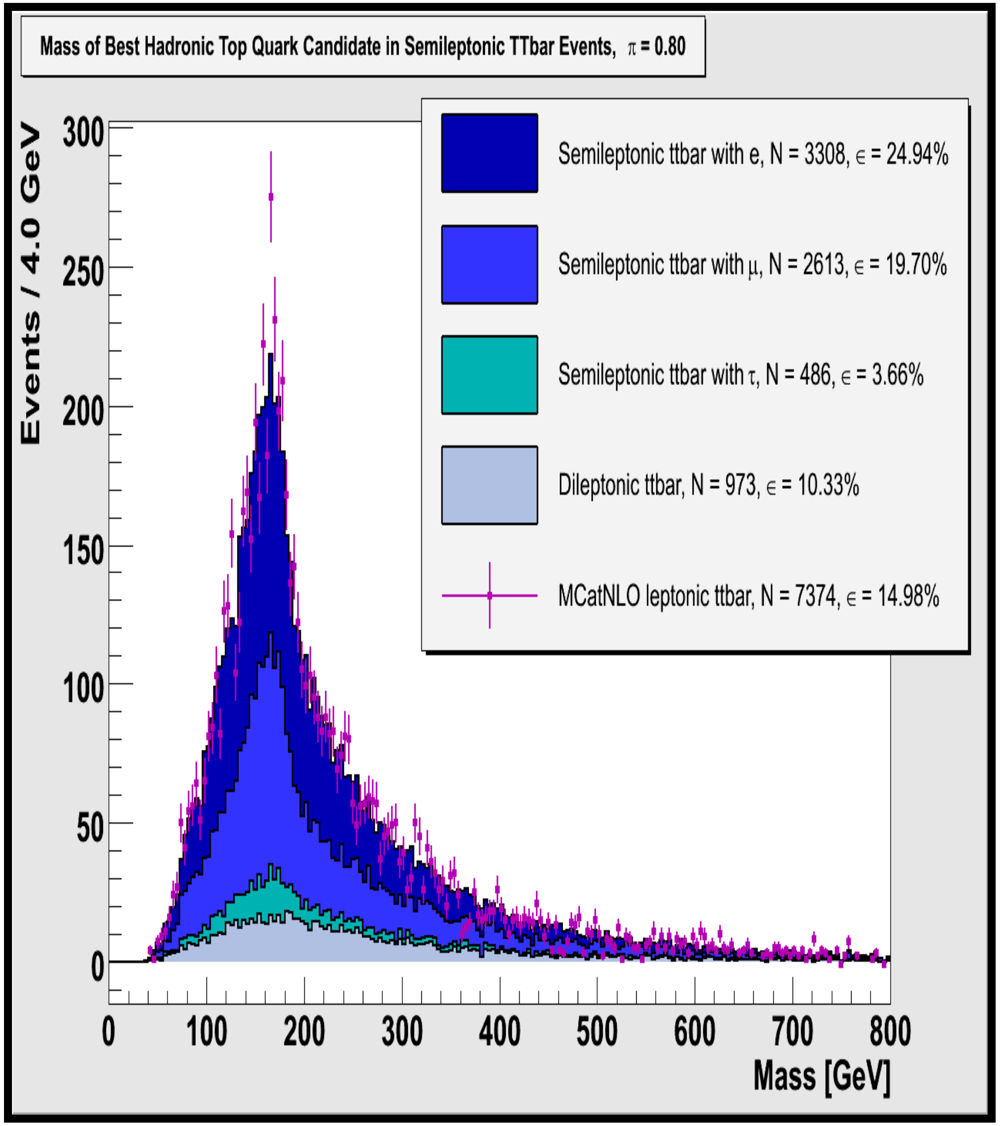
W Mass as function of D Parameter



Top Mass as function of D Parameter

Monte Carlo Cross Section Studies

- Used 10% of ttbar signal sample as "data".
- Used remaining 90% of sample as Monte Carlo.
  - L_{MC} = 971 pb^{-1}
  - L_{data} = 106 pb^{-1}
- Only ttbar background was considered.
- Consistency check:
  - ε_{data} = 0.1498 ± 0.0014
  - ε_{MC} = 0.1499 ± 0.0005
- For Monte Carlo:
  - ε_e = 24.94 %, ε_μ = 19.70 %
  - ε_τ = 3.66 %, ε_{ll} = 10.33 %



Monte Carlo Cross Section Studies

- $\sigma_{data} = N^{data} / L_{data}\, \varepsilon_e^{MC}$
- For semileptonic ttbar events with electron or muon:
  - σ_{data} = 248 ± 3 *(stat)* pb
- Consistency check:
  - Known from Monte Carlo: σ_{MC} = 248 pb
- L_{data} = 100 pb^{-1} gives statistical precision of 1%.
  - Statistics will not be an issue at the LHC.

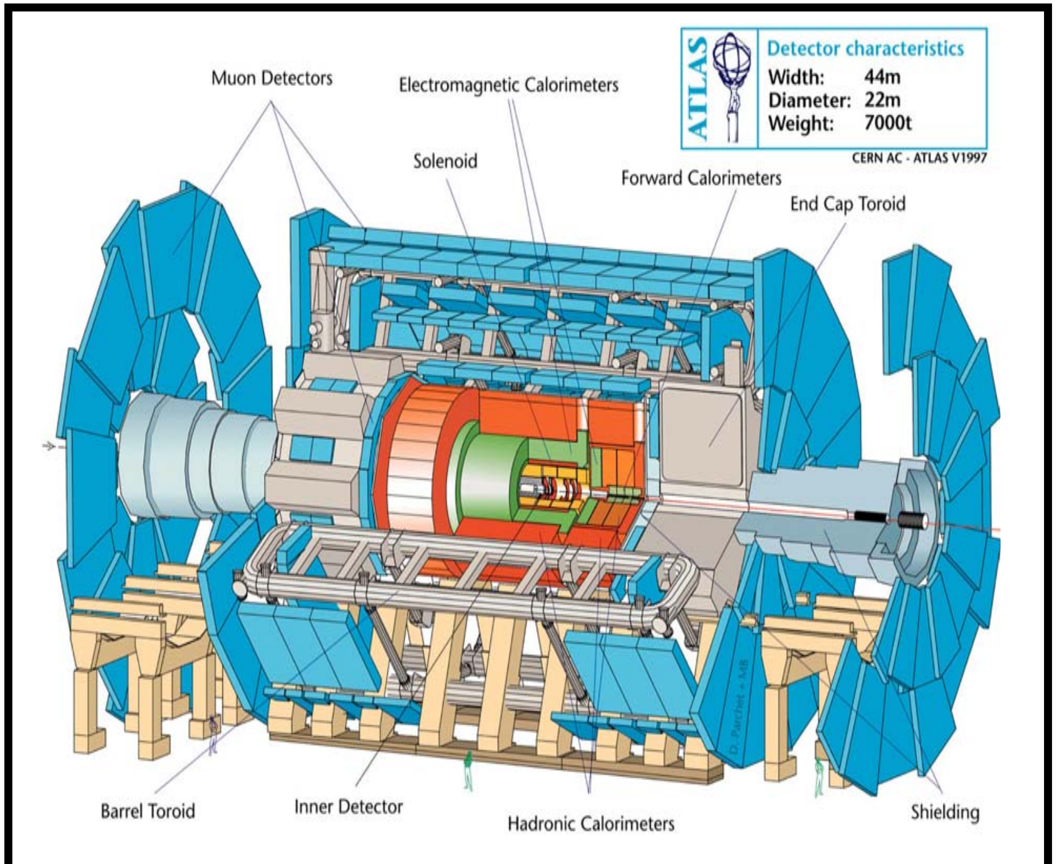
Summary

- Studies were performed in semileptonic channel with electron or muon.
- Jet reconstruction was performed using k_T algorithm with D = 0.4.
- Efficiencies:
  - **For semileptonic signal:**
    - **ε_e = 22.5 %, ε_μ = 17.8 %**
  - **For semileptonic background with tau lepton:**
    - **ε_τ = 3.3 %,**
  - **For dileptonic and hadronic ttbar background:**
    - **ε_{ll} = 9.3 %, ε_{jj} = 0.1 %**
  - **For W+N jets background:**
    - **$\varepsilon_{W+Njets}$ = 10.2 %**
- Purity is π = 0.27
- No adjustment has yet been made for jet energy scale.
- No estimate of systematic errors on top mass or cross section has yet been performed.

Backup Slides

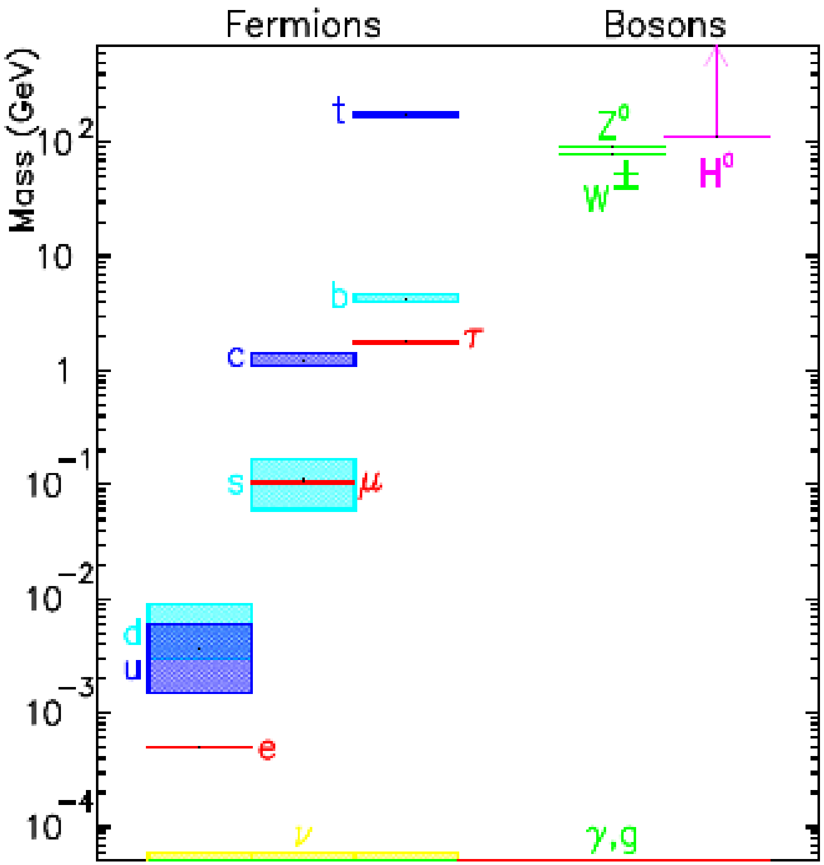
Goals of the ATLAS Experiment

- Operate at $L = 10^{34}\ cm^{-2}s^{-1}$
  - Provide as many different types of event signatures as possible.



- Investigate mechanism of mass generation.
  - Detect and measure properties of Higgs boson.
- Search for evidence of Supersymmetry.
- Probe the nature of matter-antimatter asymmetry and CP violation.
- Investigate nature of dark matter and dark energy.
- Perform precision measurements of top quark properties.

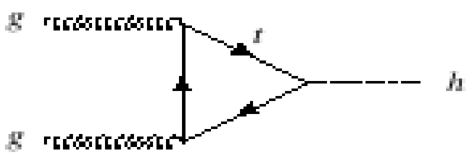
Why Study the Top Quark?



Dhiman Chakraborty

Mass hierarchy of the elementary particles.

- Top is the heaviest known fundamental fermion.
  - Top will couple more strongly to the Higgs boson.



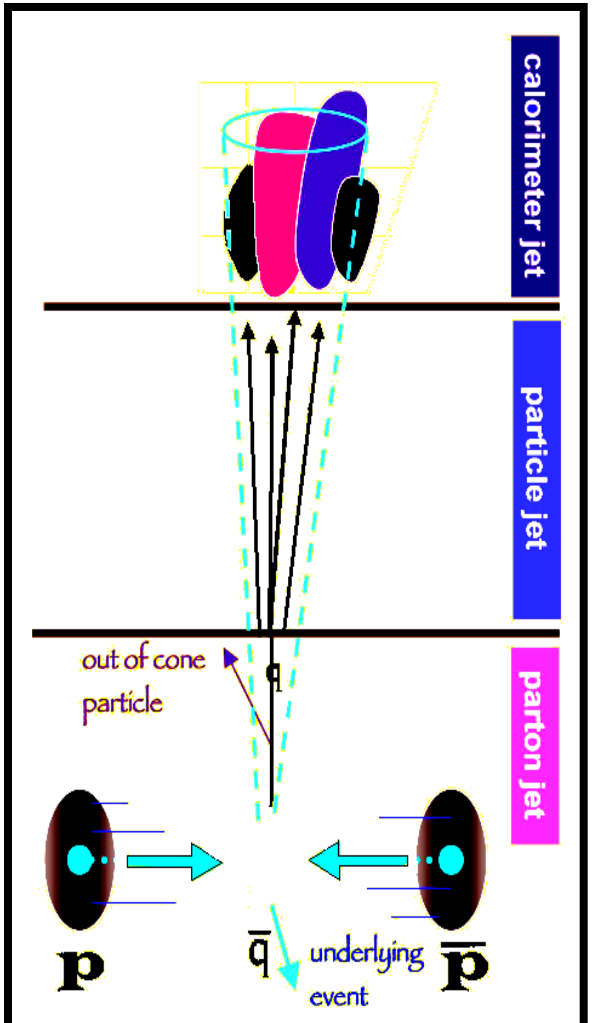
  - Top provides logical point of departure for studies of the nature of fermion mass generation.

isEM: Quality Control for Electrons

- The isEM flag is designed to identify electrons and reject jets.
- Represents result of combinations of cuts imposed on quantities reconstructed within:
  - Electromagnetic and hadronic calorimeters:
    - Very little hadronic leakage (1^{st} bit).
    - Energy deposit in electromagnetic calorimeter is narrow in width (2^{nd} bit).
    - Energy deposit in electromagnetic calorimeter has one narrow maximum, no substructure (3^{rd} bit).
  - Inner detector:
    - At least nine precision hits from pixel detector and semiconductor tracker; small transverse impact parameter.
    - η and φ of track are extrapolated to calorimeter cluster; extrapolated and measured values are required to match.
    - Energy measured in electromagnetic calorimeter is required to match momentum measured in inner detector.
- Requiring isEM==0 demands that each electron candidate pass all of above cuts before being accepted.

Hadronic Calibration

- Hard scattering → partons → hadrons → calorimeter cluster → reconstructed jet
- Jet energy calibration must correct for:
  - Break up of nuclei and nuclear excitation.
  - Escaping energy (neutrinos).
  - Cracks and gaps in calorimeter; dead material.
  - Energy deposited in front of and beyond the calorimeter.
  - Energy deposited outside the jet cone.
  - Energy deposited by underlying event; pile-up.
- Corrections will depend upon jet algorithm used, jet cone size and jet p_T.
  - Weight proportional to energy is derived for each calorimeter cell.
  - Corrections for invisible and escaped energy, losses due to cracks and dead material will be performed upon clusters of calorimeter cells.
  - Calibrated clusters will be used as input for jet reconstruction algorithms.
  - Corrections for energy deposited outside the jet cone due to noise, jet size cuts and parton radiation will be performed at the jet level.



Successive Combination vs. Cone Algorithm

- Successive combination algorithm recursively groups particles with "nearby" momenta into larger sets of particles. "Nearby" is defined in (E_T, η, φ) space. Initial sets contain one particle each; final sets are the jets.
- Never assigns a single particle to more than one jet.
- Merging jets is not an issue: the algorithm performs this automatically.
- Geometry of jet boundaries can be complicated. Does not yield regular shapes in η-φ plane.
- Jet cross sections are likely to exhibit smaller higher-order and hadronization corrections.
- S. Ellis, D. Soper, CERN-TH.6860/93

- Cone algorithm defines jet as set of particles whose angular momentum vectors lie within a cone centered on the jet axis.
- Jet cones can overlap such that one particle is contained in more than one jet.
- Merging jets is an issue.
- Cone jets always have smooth, well defined boundaries.
- Jet cross sections may have larger higher-order perturbative corrections.

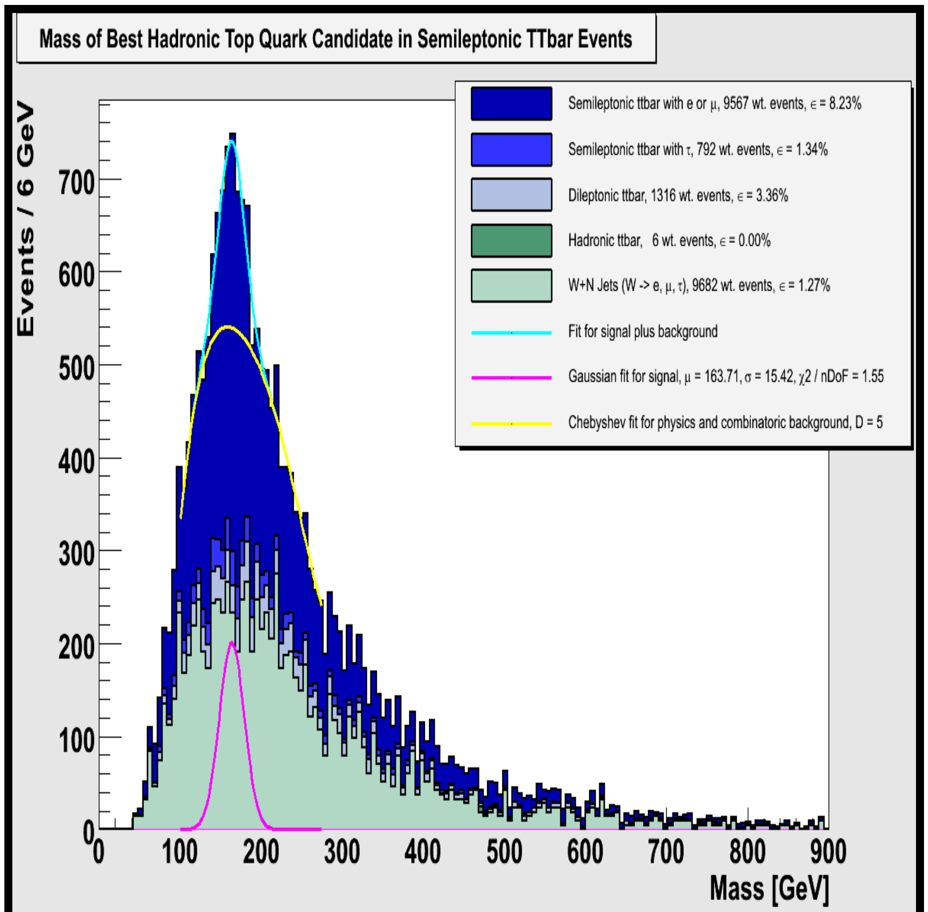
- Parameters can be adjusted such that the inclusive jet cross section resulting from application of successive combination algorithm is essentially identical to inclusive jet cross section obtained by applying cone algorithm.

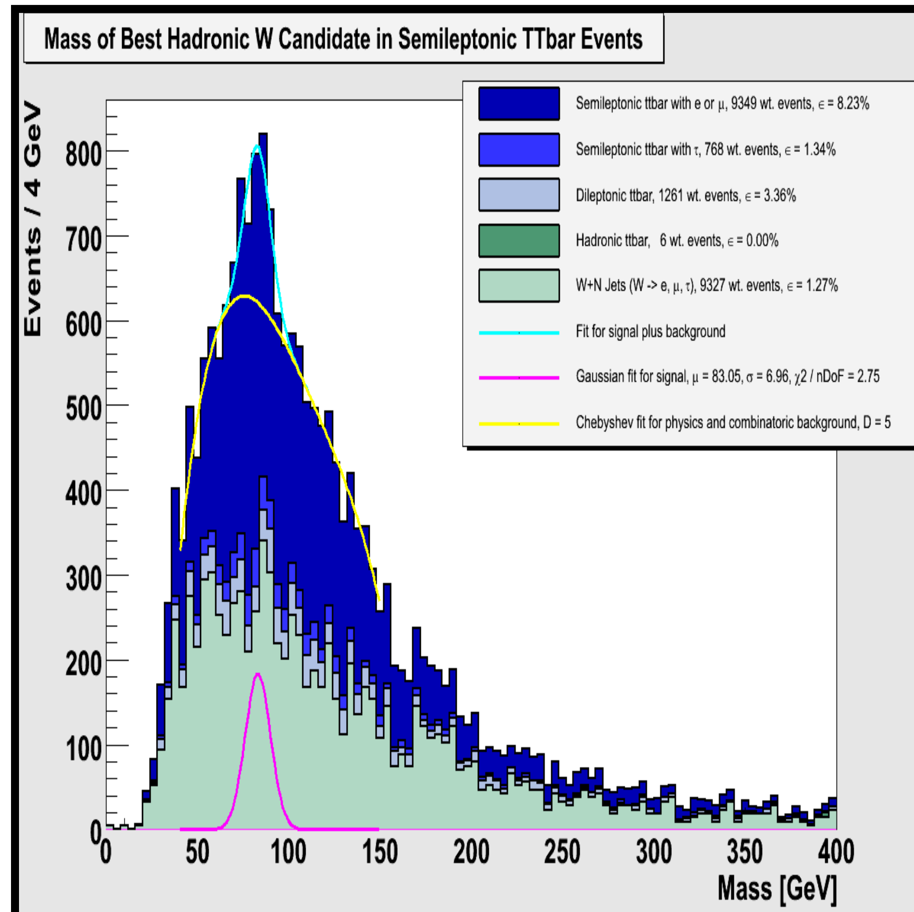
Fit to Top Mass, W Mass

- Jets were reconstructed using Cone4 jet algorithm.

$m_t^{fit} = 163.7 \pm 1.5$ GeV
$m_t^{PDG} = 174.2 \pm 3.3$ GeV

$m_W^{fit} = 83.05 \pm 1.14$ GeV
$m_W^{PDG} = 80.40 \pm 0.03$ GeV





Cross Section Estimate

- Number of initial events in each channel was known from Monte Carlo.
- Number of final events in each channel after selection cuts was obtained from Monte Carlo.
- Efficiency was computed for each channel:
  - $\varepsilon^{MC} = N_f^{MC} / N_i^{MC}$
- Fraction of events in each channel was calculated using Monte Carlo:
  - $F_e^{MC} = N_f^{MC}(e) / N_f^{MC}$
- Fraction of final events per decay channel and efficiency obtained from Monte Carlo were assumed to be valid for "data".
  - $N_f^{data}(e) = F_e^{MC} N_f^{data}$, $N_f^{data}(\mu) = F_\mu^{MC} N_f^{data}$
- $\delta N_e = \sqrt{N_e}$, $\delta\sigma_e = \delta N_e / L^{data}\varepsilon_e$, $\delta\sigma = \sqrt{(\delta\sigma_e^2 + \delta\sigma_\mu^2)}$
- $\delta_\varepsilon = \sqrt{(\varepsilon (1 - \varepsilon) / N_i)}$