Measuring the top-quark Forward-Backward Asymmetry at the LHC

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Research Examination
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Outline

- **Background:** The $t\bar{t}$ Forward-Backward Asymmetry, the LHC, and CMS
- **Analysis Scheme:** Event Selection and Reconstruction
- **Theory:** Cross Section and Signal Modeling; Fit Procedure
- **Results:** Sensitivity Tests and Fits to 2012 Single Muon Data
- **Next Steps:** Future Goals

The Standard Model of Particle Physics

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- Electromagnetic, Weak and Strong Nuclear Interactions
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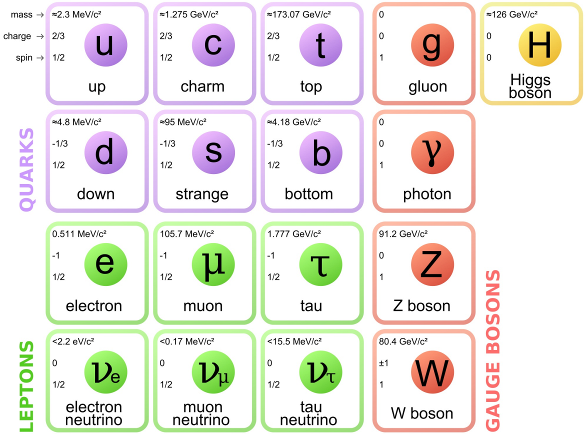
- Successful at making predictions ever since
  - $W^{\pm}$ and Z bosons (1983)
  - top quark t (1995)
  - tau neutrino ν_τ (2000)
  - Higgs boson H (2012)

Contains 61 Total Particles



Beyond the Standard Model

- Still has shortcomings
- Many theoretical extensions
- Experiments test these theories or look for new physics
- Our analysis seeks to explain an anomalous measurement from 2011 that may be an indicator of new physics

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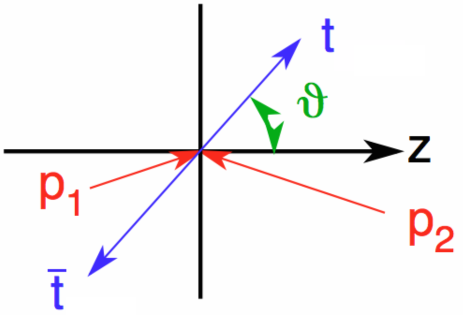

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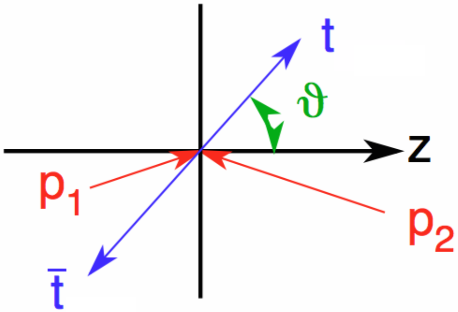
- Can be calculated using perturbative QCD
- Predicted from SM: $A_{\mathrm{FB}} \approx 10\%$



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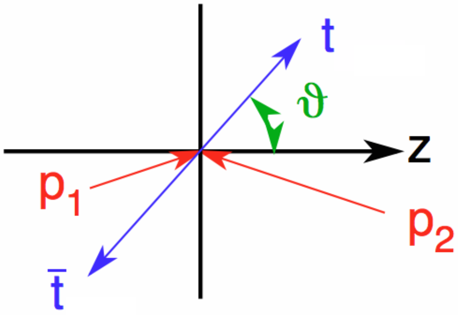
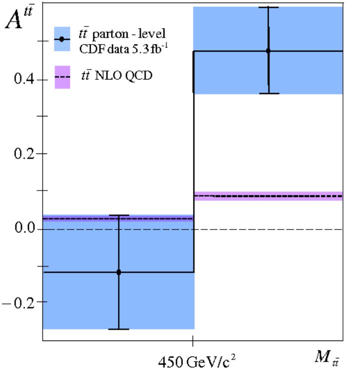
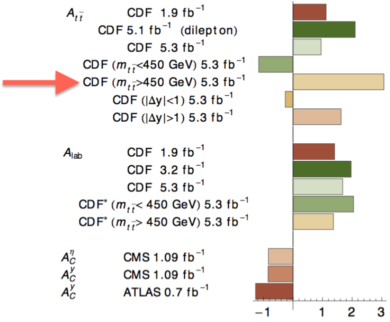


A_{FB} Predictions and Measurements



Plot: CDF Collaboration, *Evidence for a Mass Dependent Forward-Backward Asymmetry in Top Quark Pair Production*, **arXiv:1101.0034 [hep-ex]**

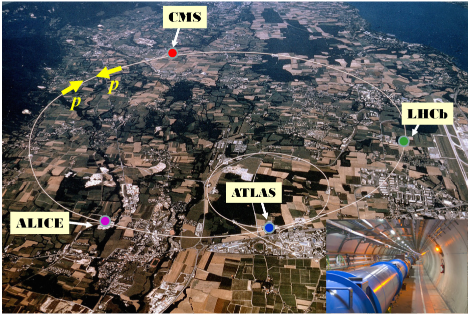


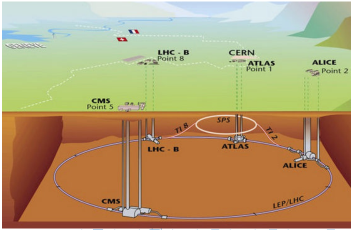
Plot: J. Kuhn and G. Rodrigo, *Charge asymmetries of top quarks at hadron colliders revisited*, **arXiv:1109.6830 [hep-ph]**

Analysis at the LHC

The Large Hadron Collider

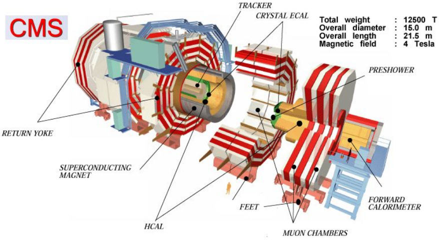
- Largest and highest energy particle collider in the world
- Built by CERN just outside of Geneva
- 10,000 scientists and engineers from more than 100 countries
- 7 experiments, 4 main detectors
- 27km in circumference
- 175m below ground

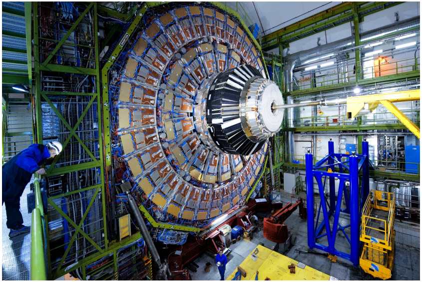


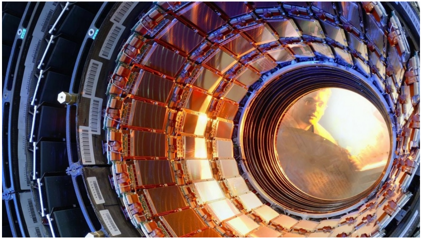


The CMS Experiment

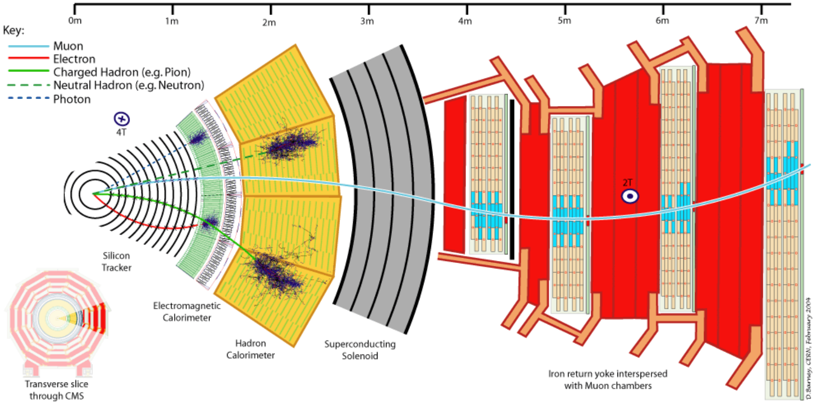
- General purpose detector
- More than 3,000 scientists, engineers, technicians, and students
- 172 institutes, 40 countries



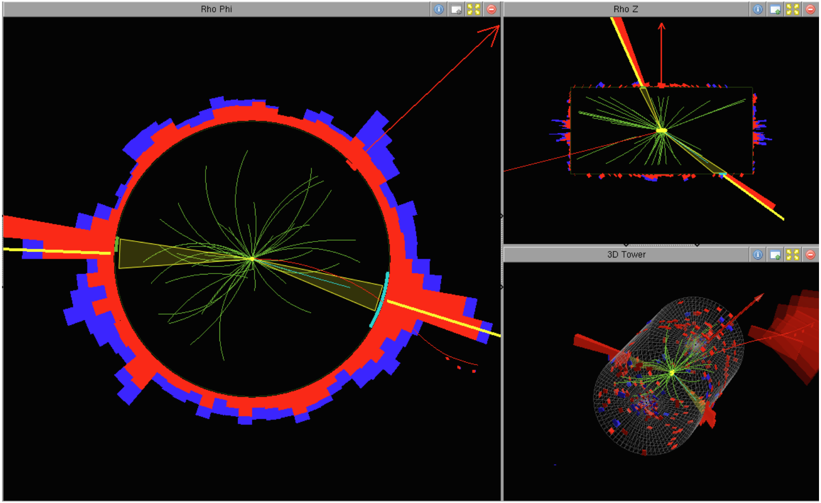




Particle Behavior in the CMS Detector



Physics Objects

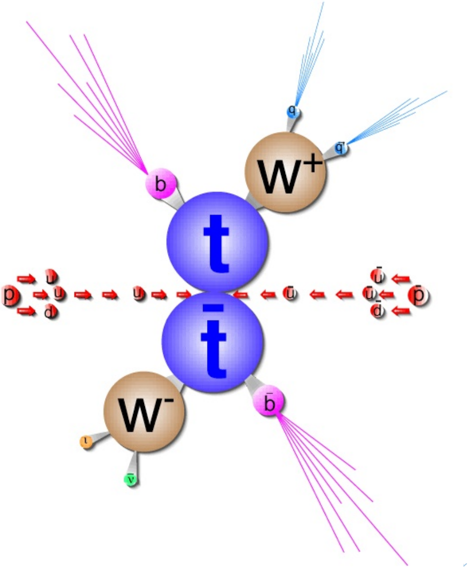


Plot: CMS "Fireworks" Event Display Tool

Our Analysis

What do Our Signal Events Look Like?

- Semileptonic $t\bar{t}$ is best laboratory
    - Gives charge info
    - High cross section
    - Efficient selection



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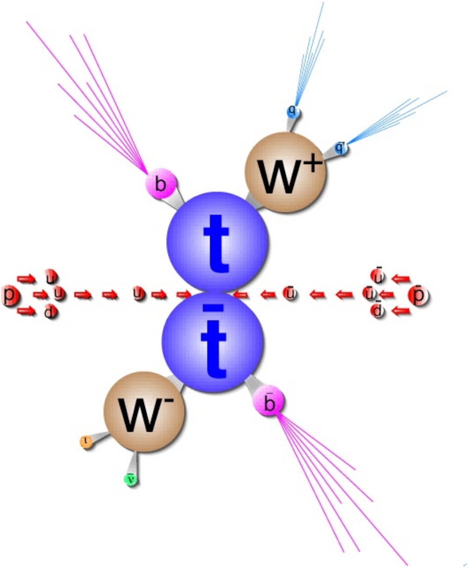

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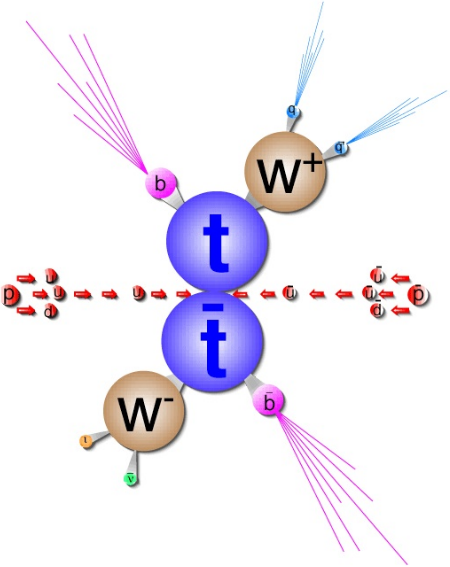

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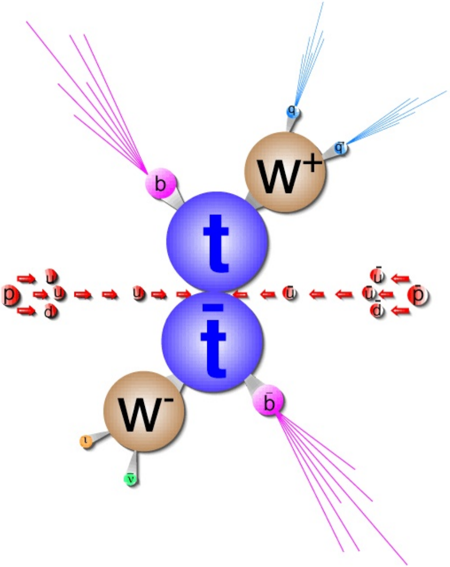
        - Lepton is reconstructed
        - Neutrino is MET



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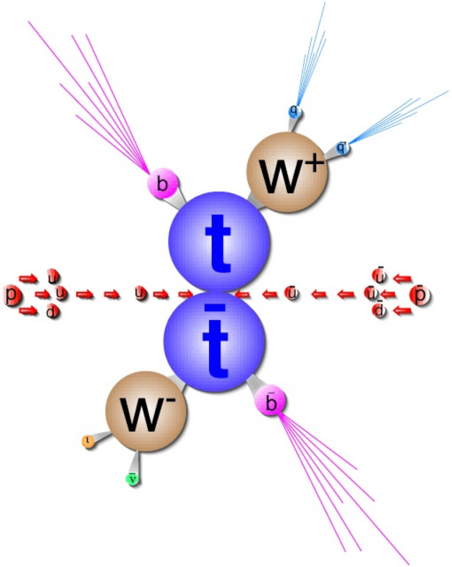

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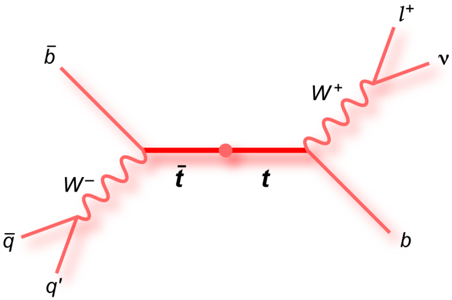
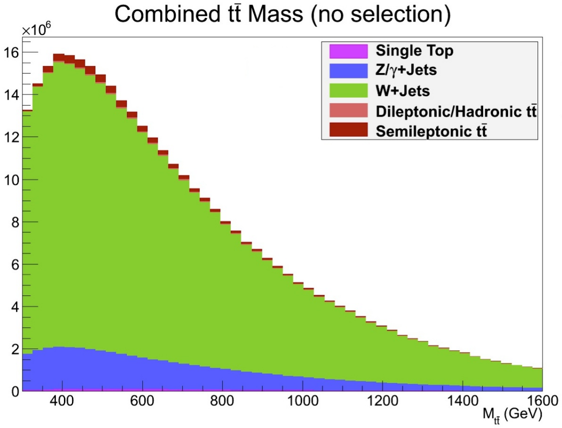
  - Both b quarks become jets
  - One W decays to a lepton and a neutrino
    - Lepton is reconstructed
    - Neutrino is MET
  - One W decays to two quarks
    - Each quark becomes a jet
- Result: one lepton, four jets, some MET



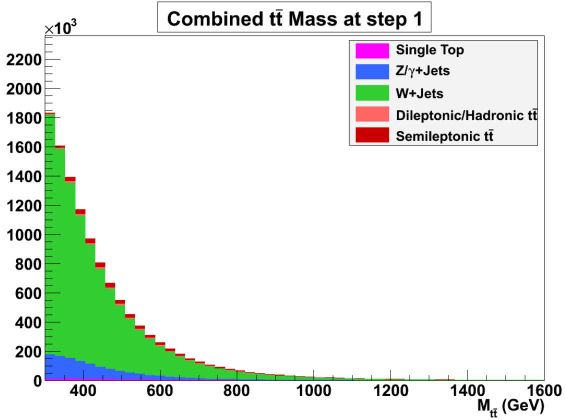
Event Selection

- Pre-selection



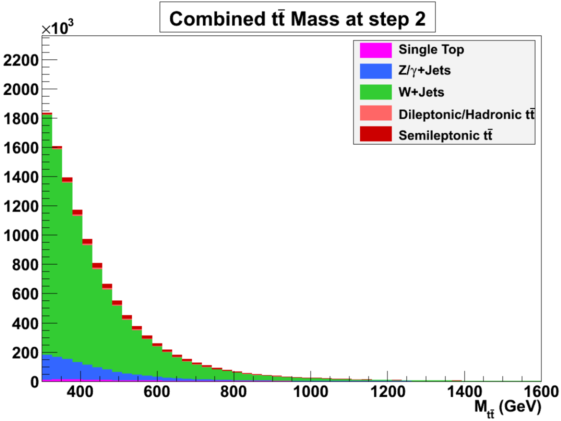
Event Selection

- Pre-selection
- Lepton
    - Kinematic Cuts
    - Exactly one final state lepton



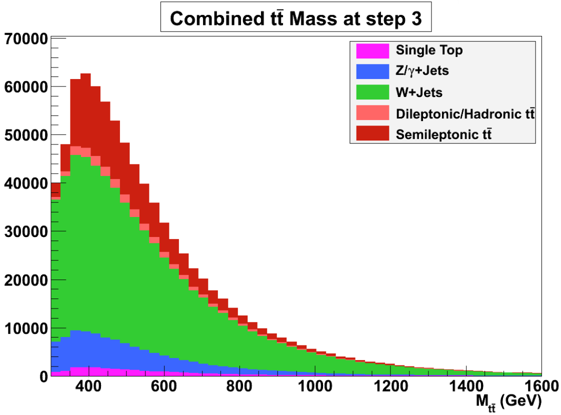
Event Selection

- Pre-selection
- Lepton
  - Kinematic Cuts
  - Exactly one final state lepton
- Neutrino
  - Require non-zero MET



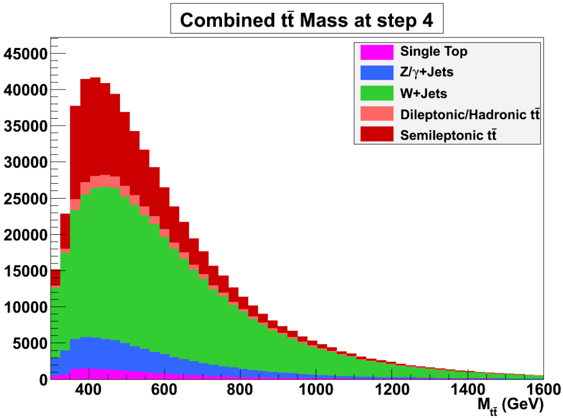
Event Selection

- Pre-selection
- Lepton
  - Kinematic Cuts
  - Exactly one final state lepton
- Neutrino
  - Require non-zero MET
- Jets
  - Kinematic Cuts



Event Selection

- Pre-selection
- Lepton
  - Kinematic Cuts
  - Exactly one final state lepton
- Neutrino
  - Require non-zero MET
- Jets
  - Kinematic Cuts
  - 4 “hard” jets



Event Selection

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- Lepton
  - Kinematic Cuts
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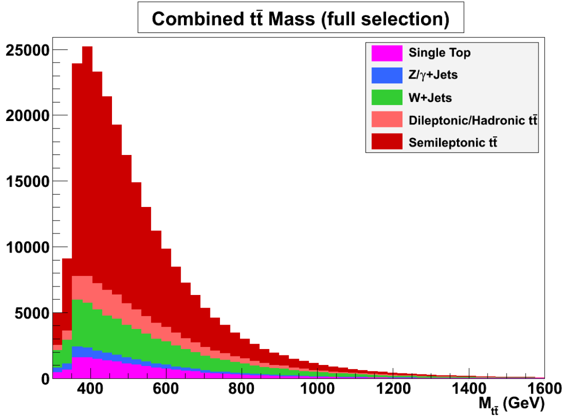
  - 4 "hard" jets
  - Two b-jets



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- Lepton
  - Kinematic Cuts
  - Exactly one final state lepton
- Neutrino
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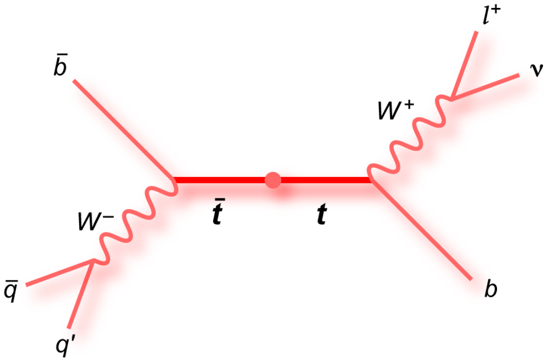
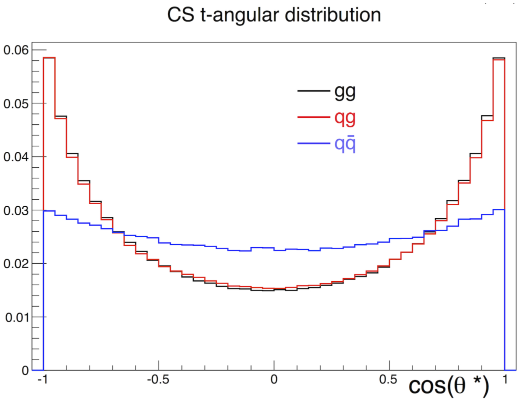
- Jets
  - Kinematic Cuts
  - 4 “hard” jets
  - Two b-jets
- This gives us our lepton, MET, and four jets



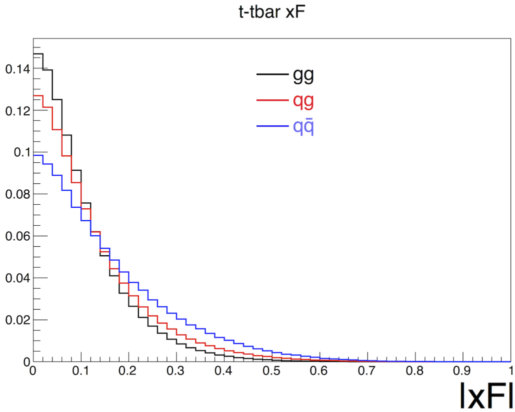
Physical Observables

- Production angle $\cos\theta_{cs}$ or c_*
  - Main observable: exhibits asymmetry
  - Discrimination between gluon-gluon ("gg") and quark-antiquark ("$q\bar{q}$") events
- Boost amount $|x_F|$
- Pairwise invariant mass $M_{t\bar{t}}$ or M



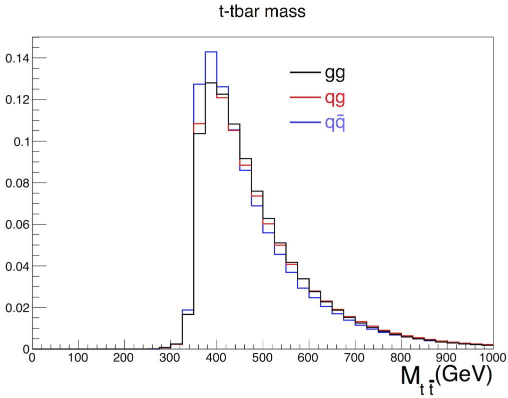
Physical Observables

- Production angle $\cos\theta_{cs}$ or c_*
- Boost amount $|x_F|$
  - Analogous to momentum of $t\bar{t}$ pair
  - Further discrimination between gg and $q\bar{q}$ events
- Pairwise invariant mass $M_{t\bar{t}}$ or M



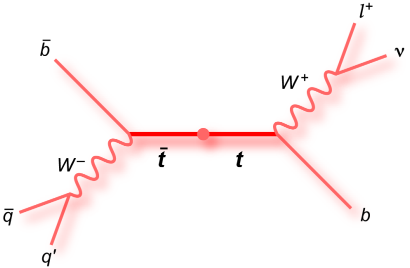
Physical Observables

- Production angle $\cos\theta_{cs}$ or c_*
- Boost amount $|x_F|$
- Pairwise invariant mass $M_{t\bar{t}}$ or M
    - CDF result: A_{FB} is $M_{t\bar{t}}$-dependent
    - Eventually analysis should be done separately in bins of $M_{t\bar{t}}$



Event Reconstruction Using a Kinematic Fit

- How can we calculate observables using the lepton, jets, and MET?
- Need to reconstruct both top quarks in the event



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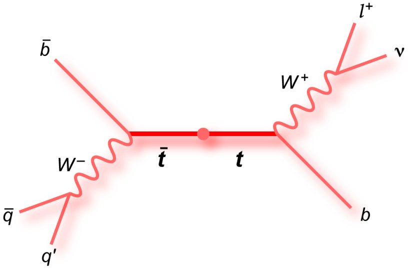
- See which jet assignment gives best values for invariant masses



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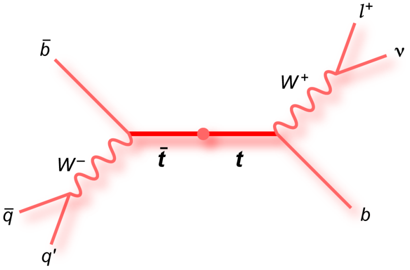
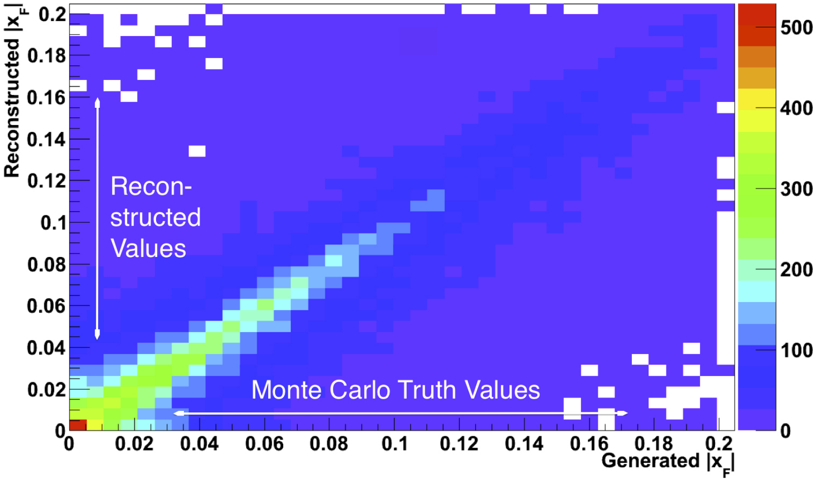
- Actual fit is more complex:
  - -Take into account CSV values
  - -Require btags in place
  - -Momentum scaling factors
  - -Neutrino longitudinal momentum
- **Kinematic fit is a major contribution from our analysis**



Kinematic Fit Performance



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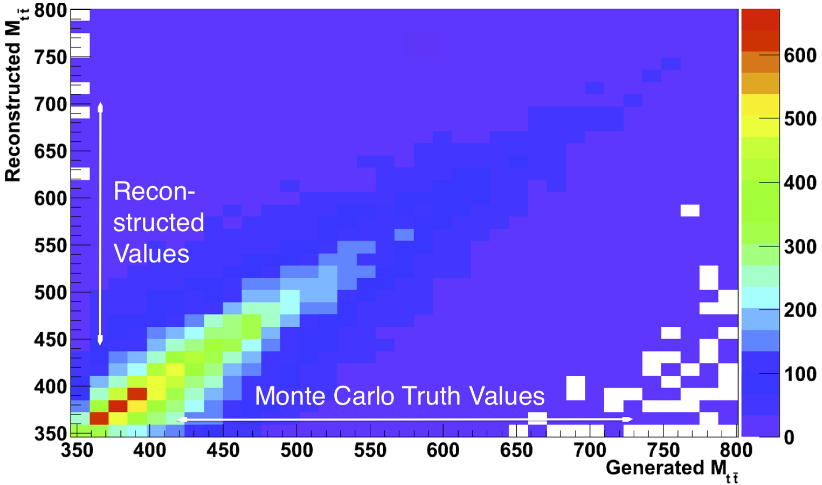

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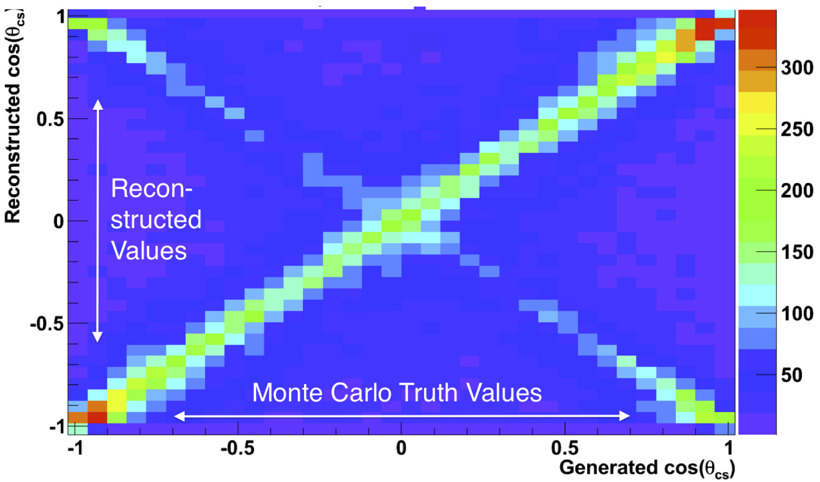
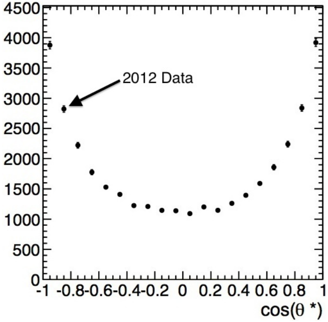


How to Measure A_{FB}

Differential Cross Section

Total differential cross section:

$$\frac{d^3\sigma}{dx_{\mathrm{F}}\,dM dc_*} \propto \frac{d\sigma}{dc_*}(q\bar{q};M^2) + \frac{d\sigma}{dc_*}(gg;M^2) + \frac{d^3\sigma}{dx_{\mathrm{F}}\,dM dc_*}(background)$$



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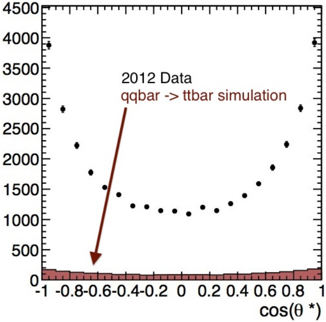
For each subprocess:

$$\frac{d\sigma}{dc_*}(q\bar{q}; M^2) \propto F_{q\bar{q}s}(M^2, \beta, c_*^2)$$



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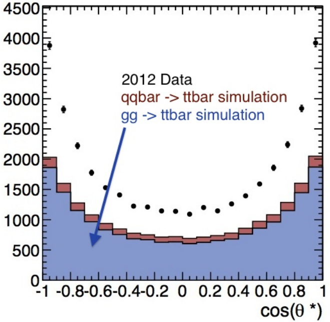

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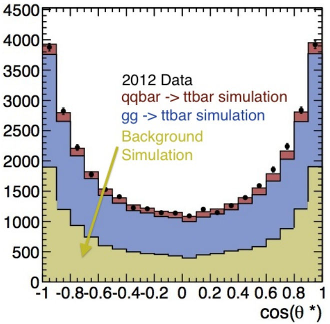

Modeling the Asymmetry

Describe asymmetry by adding generalized antisymmetric part to the tree-level $q\bar{q}$ cross section:

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Where $A_{\mathrm{FB}}^{(1)}$ describes full A_{FB} to linear first order (very good approximation of many models)

Antisymmetric Event Reweighting

New $q\bar{q}$ cross section:

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Means the antisymmetric distribution with $A_{\mathrm{FB}}^{(1)}$ factored out can be built from the symmetric one by convolving with a form factor (or multiplying by an event weight) w_{a}:

$$w_{\mathrm{a}}(M^2, c_*) = \frac{F_{q\bar{q}a}(M^2, \beta)}{F_{q\bar{q}s}(M^2, \beta, c_*^2)} c_*$$

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Therefore no special Monte Carlo simulation required to describe effect!

Modeling the Differential Cross Section

Use four 3D histograms f_{bk}, f_{gg}, f_{qs}, and f_{qa} to model the differential cross sections:

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This template-based construction is a novel method for measuring generator-level $\mathbf{A_{FB}}$

Fitting Recap

- Simulate $q\bar{q} \to t\bar{t}$, $gg \to t\bar{t}$, and background processes
  - Model asymmetry in $q\bar{q} \to t\bar{t}$ cross section
  - Reweight simulated $q\bar{q} \to t\bar{t}$ events
- Select and Reconstruct Monte Carlo and data events in the same way
- Build template histogram from Monte Carlo for each term in cross section
- Float relative template normalizations in a fit to data
- Extract R_{bk}, $R_{q\bar{q}}$, and $A_{\mathrm{FB}}^{(1)}$

Testing Sensitivity with Pseudodata

- Can use 3D templates to generate Monte Carlo "data" samples
  - Choose inputted R_{bk}, $R_{q\bar{q}}$, and $A_{\mathrm{FB}}^{(1)}$
  - Build and sample probability distribution

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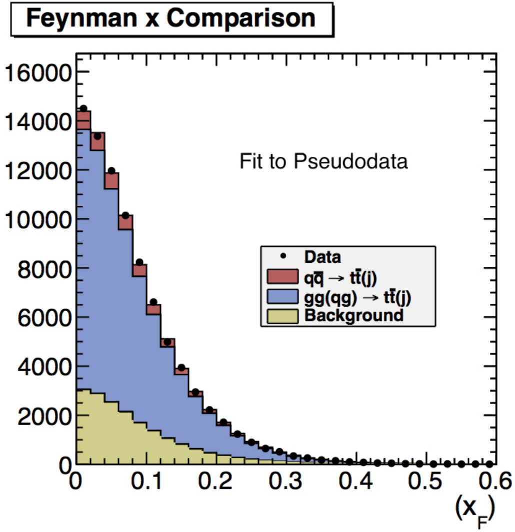
- Fit to 50 different samples of 85,000 "pseudodata" events (87,575 events in 2012 data)

Pseudoexperiment Results



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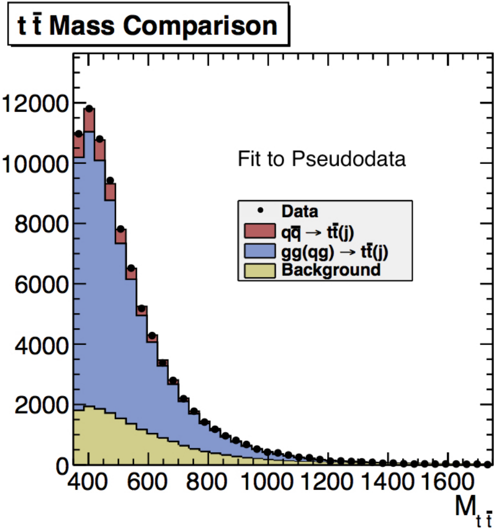

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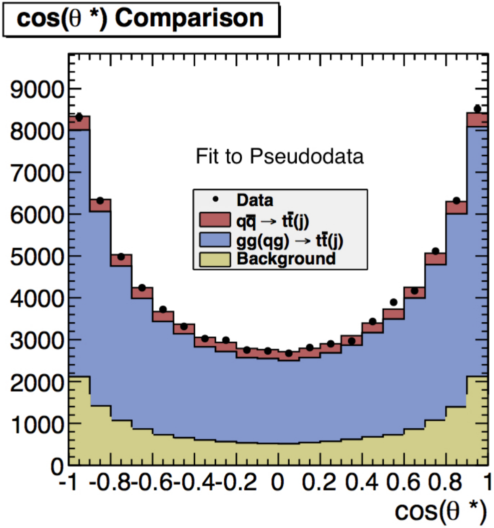
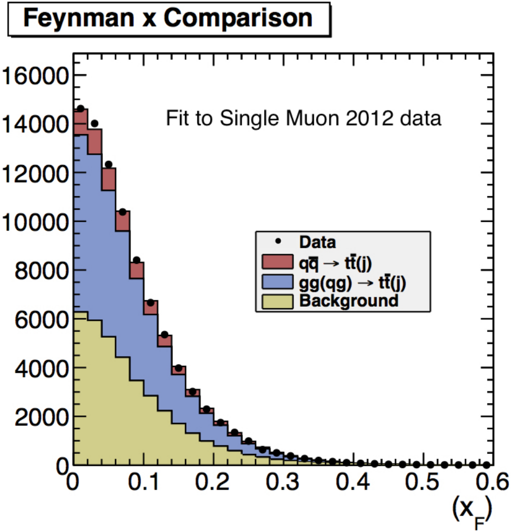


Conclusions from Pseudoexperiments

- Able to get out what we put in
- Uncertainties small
- No overall worrying pull from fitting procedure
- In other words, the method works

Fitting Real Data



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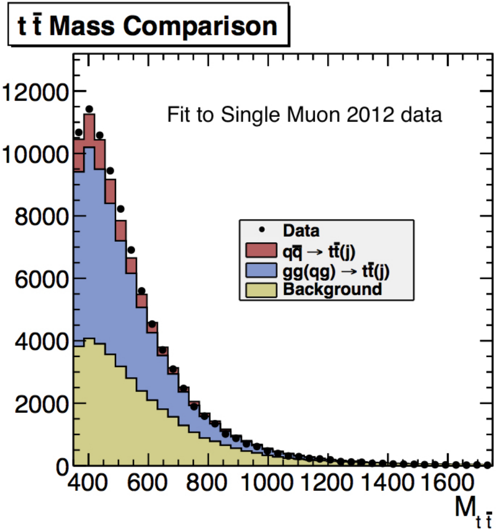

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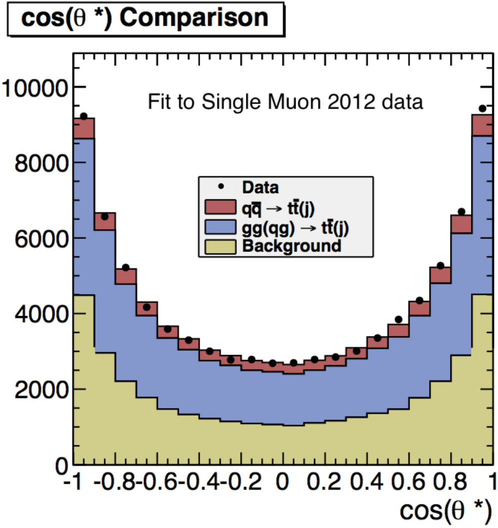

Preliminary Conclusions

- Developed analysis method sensitive to A_{FB}
- Preliminary Measurement: $\mathbf{A_{FB} = (8 \pm 6)\%}$
- Compare to
  - Latest CDF Combination measurement[1]: $A_{\mathrm{FB}} = (9 \pm 3)\%$
  - Most Recent D0 Measurement[2]: $A_{\mathrm{FB}} = (9 \pm 4)\%$
  - NLO Standard Model prediction[3]: $A_{\mathrm{FB}} = (8.8 \pm 0.6)\%$

[1] CDF Collaboration, CDF Conf. Note 11035 (2013)

[2] D0 Collaboration, *Forward-backward asymmetry in top quark-antiquark production*, Phys. Rev. D **84**, 112005 (2012)

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- **This analysis will be the first measurement of generator-level $\mathbf{A_{FB}}$ at the LHC**

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Next Steps

- Finish muonic analysis
- Simple Extensions
    - Events with high-η jets
    - electron+jets channel
- Longer-term goals
    - Application in boosted regime with merged jets
    - Application as general high-mass $t\bar{t}$ resonance search/characterization tool

Summary

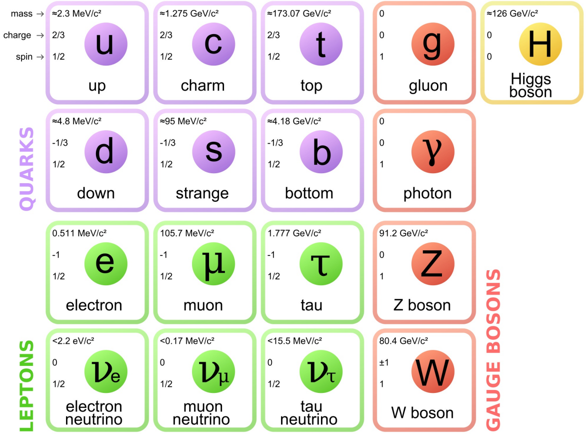
Things I've learned in the past year

- Physics
  - How the LHC and the CMS detector work
  - How data analysis in the CMS collaboration is done
- About the $t\bar{t}$ charge and forward-backward asymmetries
  - Theories
  - Experiments
- Research Practices
  - How to select events in a particular analysis channel
  - How to reconstruct systems with mass constraints and several final-state particles
  - How to write complicated fitting codes
  - Working with grid and cluster computing systems

Backup

Contains 61 Total Particles

- 48 fermions
  - Matter
  - 18 quarks
  - 6 leptons
  - antiparticles
- 12 gauge bosons
  - Force carriers
  - photon
  - 3 weak mediators
  - 8 gluons
- Higgs boson

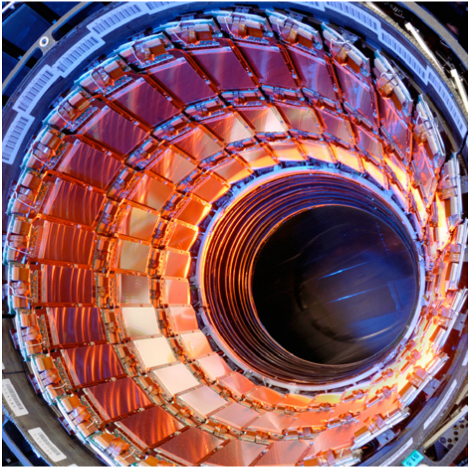


Beyond the Standard Model

- Still has shortcomings
  - Missing Gravitational Interaction
  - No Dark Matter or Dark Energy
  - Matter/Antimatter Asymmetry
  - Hierarchy Problem
  - Assumes massless neutrinos with no oscillations
- Many theoretical extensions
  - Supersymmetry
  - Neutrino Theories
  - "Grand Unified Theory"
- Experiments test these theories or look for new physics
- Our analysis seeks to explain an anomalous measurement from 2011 that may be an indicator of new physics

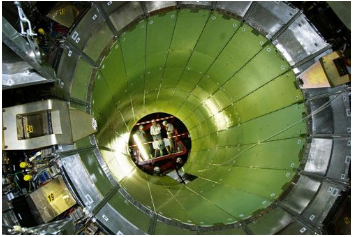
Parts of the Detector

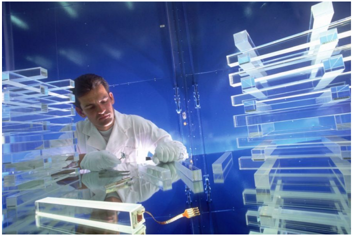
- Tracker
  - Silicon
  - Pixels
  - Microstrips
- Electromagnetic Calorimeter (ECAL)
- Hadronic Calorimeter (HCAL)
- Magnet
- Muon Systems and Return Yoke



Parts of the Detector

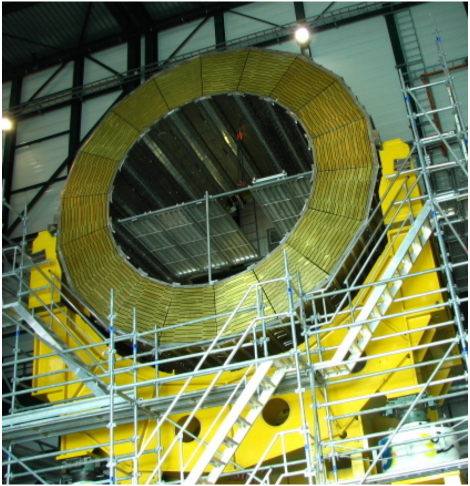
- Tracker
- Electromagnetic Calorimeter (ECAL)
  - Lead Tungstate
  - Crystal Scintillators
  - Electrons and photons interact
- Hadronic Calorimeter (HCAL)
- Magnet
- Muon Systems and Return Yoke





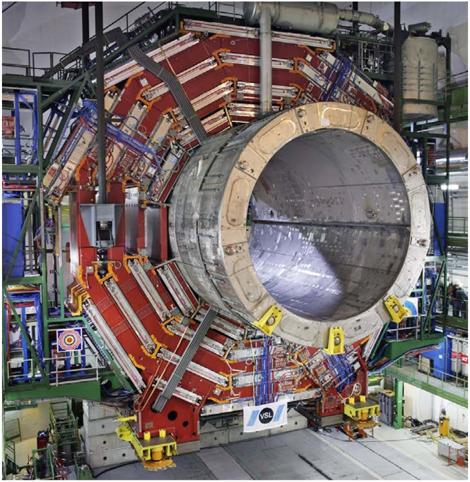
Parts of the Detector

- Tracker
- Electromagnetic Calorimeter (ECAL)
- Hadronic Calorimeter (HCAL)
  - Brass, steel, plastic
  - Plastic Scintillators
  - Hadrons interact
- Magnet
- Muon Systems and Return Yoke



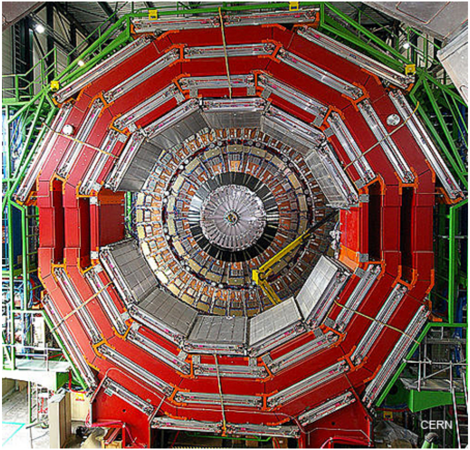
Parts of the Detector

- Tracker
- Electromagnetic Calorimeter (ECAL)
- Hadronic Calorimeter (HCAL)
- Magnet
  - Niobium-Titanium
  - Superconducting Solenoid
  - 4T magnetic field
- Muon Systems and Return Yoke



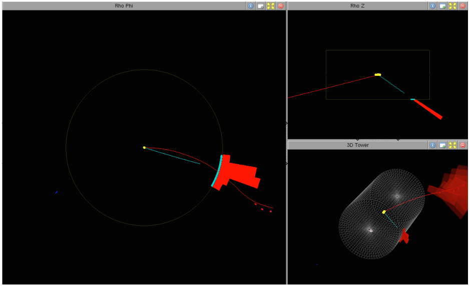
Parts of the Detector

- Tracker
- Electromagnetic Calorimeter (ECAL)
- Hadronic Calorimeter (HCAL)
- Magnet
- Muon Systems and Return Yoke
  - Drift Tubes
  - Cathode Strip Chambers
  - Resistive Plate Chambers
  - All work on same principle
  - Iron Return Yoke



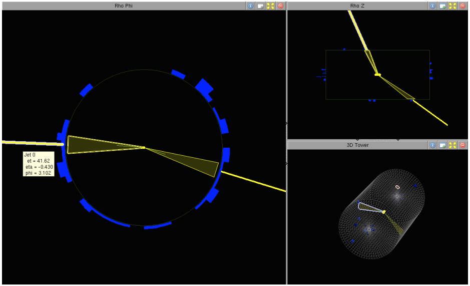
Physics Objects at Hadron Colliders

- Leptons (Electrons and Muons)
  - Easy to track, especially muons
  - Electrons deposit energy in ECAL
- Jets (Hadronic Objects)
- Photons



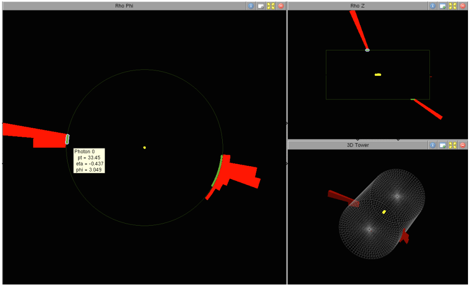
Physics Objects at Hadron Colliders

- Leptons (Electrons and Muons)
- Jets (Hadronic Objects)
    - Clusters of tracks
    - Deposits in HCAL
    - Many algorithms for collecting tracks into jets
- Photons



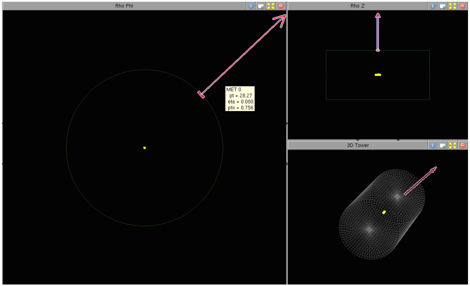
Physics Objects at Hadron Colliders

- Leptons (Electrons and Muons)
- Jets (Hadronic Objects)
- Photons
    - No charge
    - Just deposits in ECAL



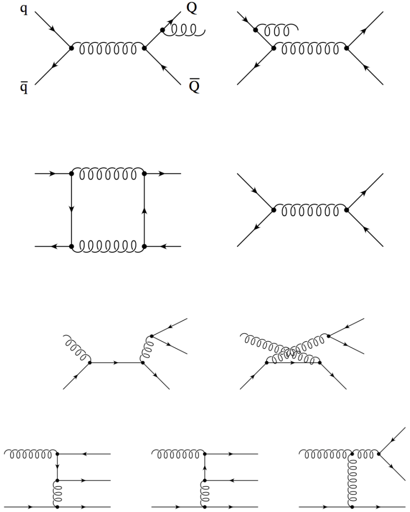
Physics Objects at Hadron Colliders

- Leptons (Electrons and Muons)
- Jets (Hadronic Objects)
- Photons
- Missing Transverse Energy (MET)
    - From a neutrino
    - Undetectable
    - Reconstructed using conservation of momentum



The $t\bar{t}$ Charge Asymmetry

- Perturbative QCD calculations
- Pair-produced $t\bar{t}$ should have an intrinsic differential charge asymmetry $\hat{A}(\cos\theta)$
  - See different amount of top- and antitop-quarks at a given angle
  - Due to interference of different production processes
- Can be reframed as a forward-backward asymmetry A_{FB}



Differential Cross Section

Total differential cross section:

$$\frac{d^3\sigma}{dx_{\mathrm{F}}\, dM dc_*} = \frac{2M}{s\sqrt{x_{\mathrm{F}}^2 + 4M^2/s}} \left\{ \frac{d\sigma}{dc_*}(q\bar{q}; M^2)\left[D_q(x_1)D_{\bar{q}}(x_2) + D_q(x_2)D_{\bar{q}}(x_1)\right] + \frac{d\sigma}{dc_*}(gg; M^2) D_g(x_1) D_g(x_2) \right\} + \frac{d^3\sigma}{dx_{\mathrm{F}}\, dM dc_*}(background)$$

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For each subprocess:

$$\frac{d\sigma}{dc_*}(q\bar{q}; M^2) = \frac{\pi\alpha_s^2}{9M^2}\beta\left[1 + \beta^2 c_*^2 + (1 - \beta^2)\right]$$

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$$\frac{d\sigma}{dc_*}(gg;M^2) = \frac{\pi\alpha_s^2}{48M^2}\beta\left[\frac{16}{1-\beta^2c_*^2} - 9\right]\left\{\frac{1+\beta^2c_*^2}{2} + (1-\beta^2) - \frac{(1-\beta^2)^2}{1-\beta^2c_*^2}\right\}$$

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Modeling the Asymmetry

Describe asymmetry by adding generalized antisymmetric part to the $q\bar{q}$ cross section:

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$$\Downarrow$$

$$\frac{d\sigma}{dc_*}(q\bar{q}; M^2) = R\frac{\pi\alpha_s^2}{9M^2}\beta\Big\{1 + \beta^2 c_*^2 + \left(1 - \beta^2\right) + 2\left[1 + \frac{1}{3}\beta^2 + (1 - \beta^2)\right] A_{\mathrm{FB}}^{(1)} c_*\Big\}$$

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Where $A_{\mathrm{FB}}^{(1)}$ describes A_{FB} to linear first order (very good approximation of many models)

Antisymmetric Event Reweighting

New $q\bar{q}$ cross section:

$$\frac{d\sigma}{dc_*}(q\bar{q};M^2) = R\frac{\pi\alpha_s^2}{9M^2}\beta\Big\{1+\beta^2c_*^2+(1-\beta^2) + A_{\mathrm{FB}}^{(1)}2\left[1+\frac{1}{3}\beta^2+(1-\beta^2)\right]c_*\Big\}$$

Means the antisymmetric distribution with $A_{\mathrm{FB}}^{(1)}$ factored out can be built from the symmetric one by convolving with a form factor (or multiplying by an event weight) w_{a}:

$$w_{\mathrm{a}}(M^2,c_*) = 2\frac{1+\frac{1}{3}\beta^2+(1-\beta^2)}{1+\beta^2c_*^2+(1-\beta^2)}c_*$$

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Therefore no special Monte Carlo simulation required to describe effect!

Modeling the Differential Cross Section

- The actual fitting function used is much more complicated
- The analysis is split by lepton charge
  - Provides discrimination over background
  - Takes advantage of CP symmetry to double number of $q\bar{q}$ events
- Also split by jet multiplicity (use 4- and 5-jet events)
  - A_{FB} is different for events with four jets or five jets
- Includes some nuisance parameters
  - ξ accounts for mismodeling of c_* dependence in differential cross section
  - δ accounts for possible longitudinal gluon polarization

Modeling the Differential Cross Section

Actually, the fitting function is:

$$f(x_r, M_r, c_r, Q, N) = R^N_{\mathrm{bk}} f_{\mathrm{bk}}(x_r, M_r, c_r, Q, N) + \left(1 - R^N_{\mathrm{bk}}\right)\left[\left(1 - R^N_{q\bar{q}}\right) f_{gg}(x_r, M_r, c_r, Q, N)\right.$$
$$+ \frac{R^N_{q\bar{q}}}{1 + \xi^N F^N_\xi + \delta^N F^N_\delta}\left\{ f_{\mathrm{qs}}(x_r, M_r, c_r, Q, N) + \xi^N f_{\mathrm{qs}\xi}(x_r, M_r, c_r, Q, N) + \delta^N f_{\mathrm{qs}\delta}(x_r, M_r, c_r, Q, N)\right.$$
$$\left.\left. + A^{(1)}_{\mathrm{FB}}(N)\left[f_{\mathrm{qa}}(x_r, M_r, c_r, Q, N) + \xi^N f_{\mathrm{qa}\xi}(x_r, M_r, c_r, Q, N) + \delta^N f_{\mathrm{qa}\delta}(x_r, M_r, c_r, Q, N)\right]\right\}\right]$$

where we normalize the distributions as:

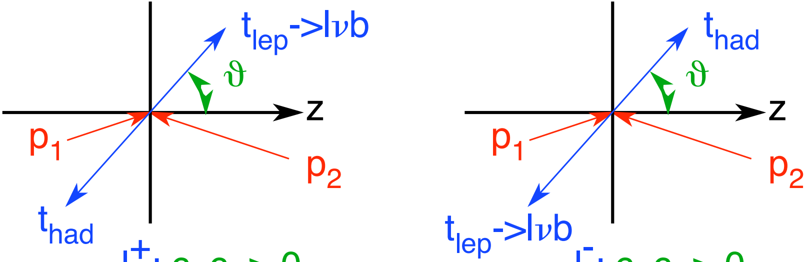
$$\sum_Q \int dx_{\mathrm{r}}\, dM_{\mathrm{r}}\, dc_{\mathrm{r}}\, f_{\mathrm{bk}}(x_{\mathrm{r}}, M_{\mathrm{r}}, c_{\mathrm{r}}, Q, N) = 1 \qquad \sum_Q \int dx_{\mathrm{r}}\, dM_{\mathrm{r}}\, dc_{\mathrm{r}}\, f_{gg}(x_{\mathrm{r}}, M_{\mathrm{r}}, c_{\mathrm{r}}, Q, N) = 1$$

$$\sum_Q \int dx_{\mathrm{r}}\, dM_{\mathrm{r}}\, dc_{\mathrm{r}}\, f_{\mathrm{qs}}(x_{\mathrm{r}}, M_{\mathrm{r}}, c_{\mathrm{r}}, Q, N) = 1$$

and the constant parameters F are:

$$F^N_\xi = \sum_Q \int dx_{\mathrm{r}}\, dM_{\mathrm{r}}\, dc_{\mathrm{r}}\, f_{\mathrm{qs}\xi}(x_{\mathrm{r}}, M_{\mathrm{r}}, c_{\mathrm{r}}, Q, N) \qquad F^N_\delta = \sum_Q \int dx_{\mathrm{r}}\, dM_{\mathrm{r}}\, dc_{\mathrm{r}}\, f_{\mathrm{qs}\delta}(x_{\mathrm{r}}, M_{\mathrm{r}}, c_{\mathrm{r}}, Q, N)$$

Exploiting CP Invariance



l^+: $c_r, c_* > 0$

l^-: $c_r, c_* < 0$

l^-: $c_r, c_* > 0$

l^+: $c_r, c_* < 0$

Kinematic Cuts

- Leptons
  - Muon POG "Tight" requirements
  - "Global" Muons
  - p_T >26 GeV, $|\eta|$ <2.1
  - $PFiso/p_T$ <0.12
  - Veto: any "loose" or "tight" muon or electron
- Jets
  - p_T >20 GeV, $|\eta|$ <2.5
  - Exactly 4 or 5 jets
  - 4 hardest jets: p_T >45, 35, 20, 20 GeV
  - Fifth jet allowed with p_T >20 GeV
  - Two btags: each with CSVdisc $>$ 0.679

Event Reconstruction Using a Kinematic Fit

$$\chi^2 = -2 \sum_{i=\ell,\mathrm{h}} \ln \left\{ \frac{C}{(q_t^2[i] - m_t^2)^2 + m_t^2\Gamma_t^2} \cdot \frac{(m_t^2 - q_W^2[i])^2(2m_t^2 + q_W^2[i])}{(q_W^2[i] - m_W^2)^2 + m_W^2\Gamma_W^2} \right\}$$
$$+ \sum_{j=1}^{5} \frac{(\lambda_j - 1)^2}{\sigma_j^2} - 2\ln\left\{g_b(d_{b\ell})g_b(d_{bh})g_q(d_{h1})g_q(d_{h2})\right\}$$

Event Reconstruction Using a Kinematic Fit

-Take into account CSV values

-Require btags in place

-Momentum scaling factors

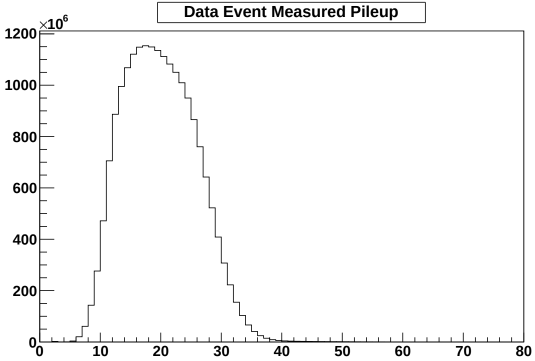
-Neutrino longitudinal momentum

$$\chi^2 = -2 \sum_{i=\ell,\mathrm{h}} \ln \left\{ \frac{C}{(q_t^2[i] - m_t^2)^2 + m_t^2 \Gamma_t^2} \cdot \frac{(m_t^2 - q_W^2[i])^2 (2m_t^2 + q_W^2[i])}{(q_W^2[i] - m_W^2)^2 + m_W^2 \Gamma_W^2} \right\} + \sum_{j=1}^{5} \frac{(\lambda_j - 1)^2}{\sigma_j^2} - 2 \ln \left\{ g_b(d_{b\ell}) g_b(d_{bh}) g_q(d_{h1}) g_q(d_{h2}) \right\}$$

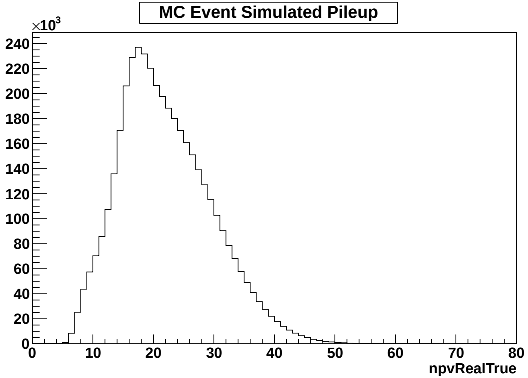
Corrections to Simulated Samples

- Data and simulation differ in several known ways
- Apply corrections (usually scalefactors) to account for differences
- Jets
  - Jet energy corrections
  - Jet energy smearing
- Pileup reweighting
- top p_T reweighting
- Leptons
  - Tracking effeciency
  - Trigger efficiency
  - ID efficiency
  - Isolation efficiency

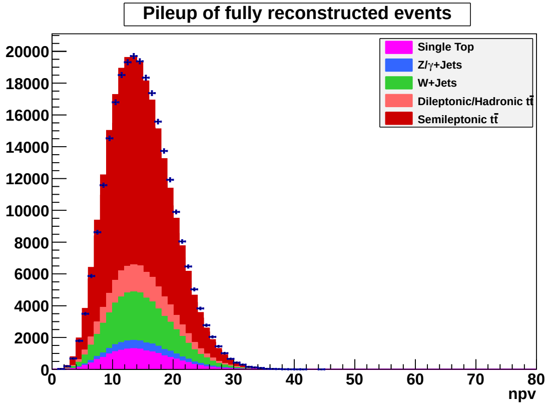
Pileup Reweighting



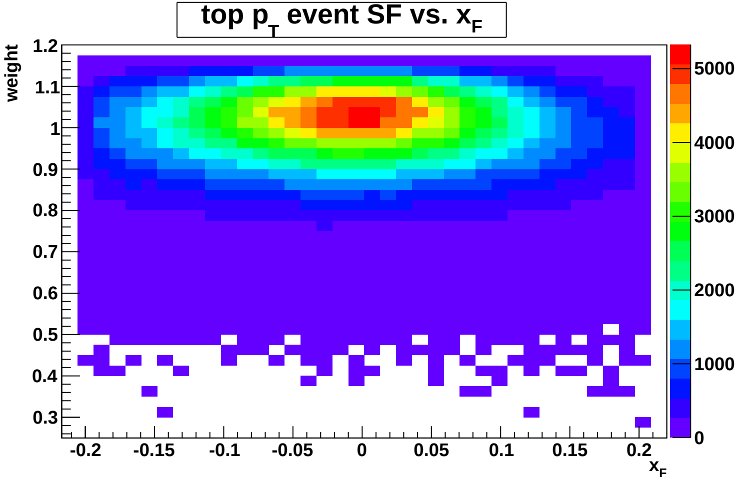
Pileup Reweighting



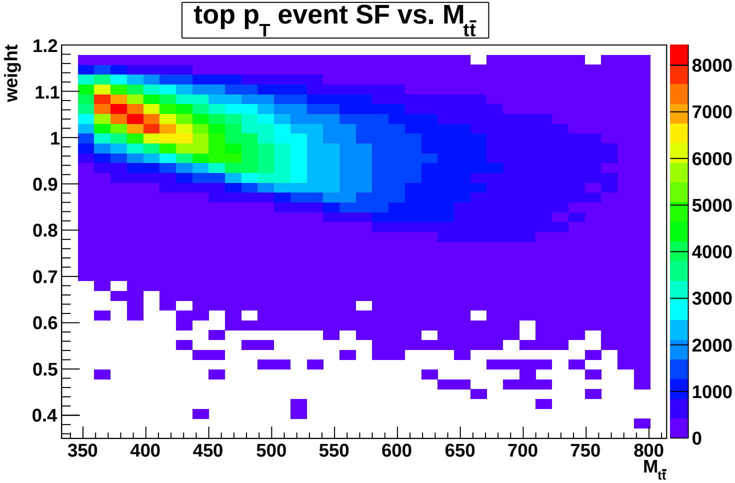
Pileup Reweighting



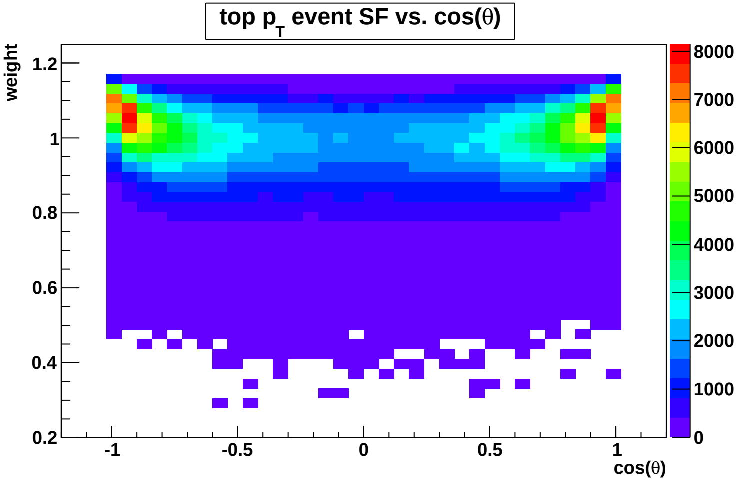
top p_T Reweighting



top p_T Reweighting



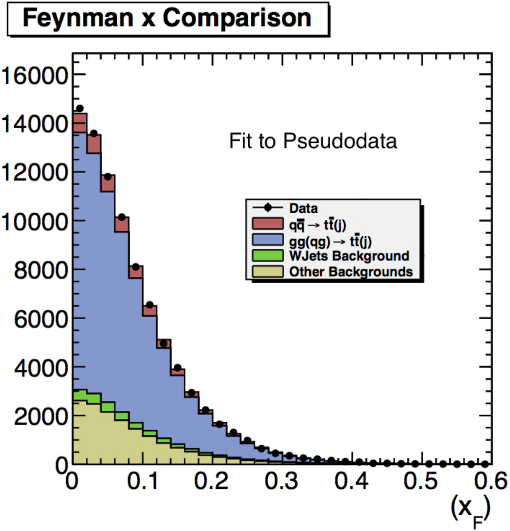
top p_T Reweighting



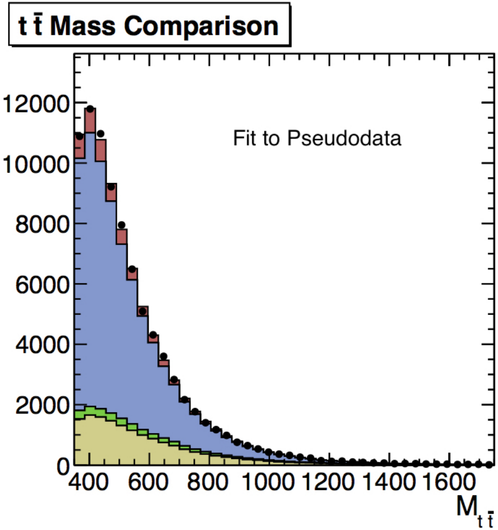
Pseudoexperiment Results

Parameter	Input	Fit (bk float)	Fit (bk fixed)	Fit (bk,WJets fixed)
R_{bk}	0.171	0.191±0.006	0.171	0.171
R_{WJets}	0.037	0.042±0.003	0.049±0.003	0.037
$R_{q\bar{q}}$	0.078	0.088±0.005	0.089±0.005	0.088±0.004
$A_{FB}^{(1)}$	0.036	0.050±0.060	0.045±0.071	0.059±0.055
R_{bk}^4	0.193	0.212±0.005	0.193	0.193
R_{bk}^5	0.140	0.126±0.009	0.140	0.140
R_{WJets}^4	0.043	0.047±0.005	0.052±0.004	0.043
R_{WJets}^5	0.028	0.023±0.004	0.020±0.005	0.028
$R_{q\bar{q}}^4$	0.092	0.094±0.006	0.092±0.007	0.093±0.008
$R_{q\bar{q}}^5$	0.060	0.059±0.007	0.061±0.007	0.059±0.005
$A_{FB}^{(1)}(4)$	0.090	0.048±0.089	0.035±0.119	0.041±0.083
$A_{FB}^{(1)}(5)$	-0.070	0.058±0.125	0.054±0.130	0.036±0.137

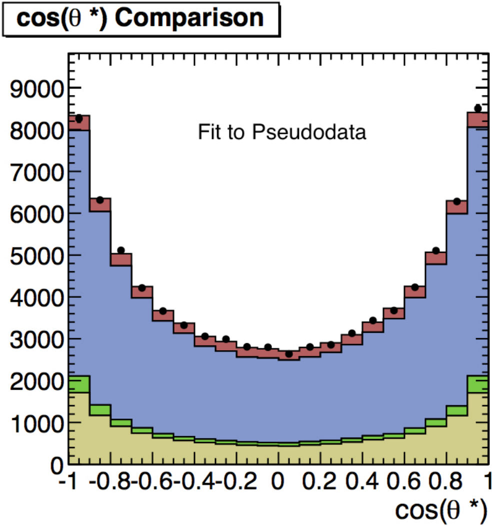
Pseudoexperiment Results



Pseudoexperiment Results



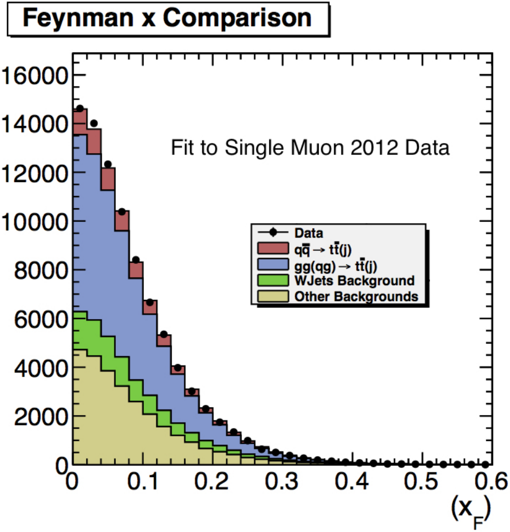
Pseudoexperiment Results



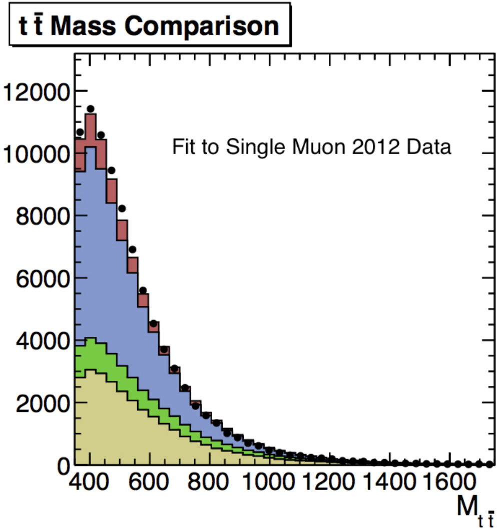
Fitting Data

Parameter	Fit (bk float)	Fit (bk fixed)	Fit (bk,WJets fixed)
R_{bk}	0.293±0.006	0.171	0.171
R_{WJets}	0.107±0.004	0.151±0.004	0.037
$R_{q\bar{q}}$	0.120±0.007	0.119±0.007	0.120±0.006
$A_{FB}^{(1)}$	0.080±0.059	0.068±0.053	0.032±0.045
R_{bk}^4	0.313±0.009	0.193	0.193
R_{bk}^5	0.311±0.009	0.140	0.140
R_{WJets}^4	0.127±0.006	0.169±0.005	0.043
R_{WJets}^5	0.101±0.006	0.151±0.006	0.028
$R_{q\bar{q}}^4$	0.161±0.012	0.147±0.010	0.137±0.008
$R_{q\bar{q}}^5$	0.110±0.011	0.106±0.009	0.101±0.007
$A_{FB}^{(1)}(4)$	0.059±0.069	0.053±0.066	0.025±0.058
$A_{FB}^{(1)}(5)$	0.115±0.094	0.096±0.082	0.052±0.072

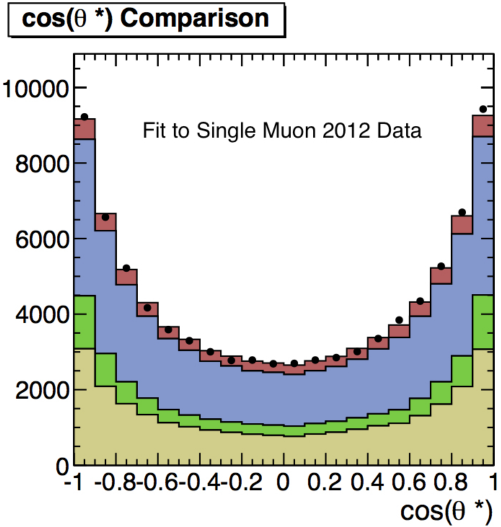
Fitting Data



Fitting Data



Fitting Data



Background Smoothing

- Simulated background distribution has lowest statistics
- Histograms suffer from overpeaking and underpopulation
- (Even have some zero-valued bins)
- Correct these problems by applying smoothing
  - Software package is called "TemplateBuilder"
  - Developed for use in the Higgs Group
- Background is smoothed in four steps:
  - Filling
  - Smoothing (adaptive Gaussian kernel)
  - Reweighting
  - Renormalization
- Changes are $<1\%$ effects along each 1D axis
- Every bin is populated with a nonzero value
- Overpeaking and underpopulation reduced
- No loss in accuracy in precision in pseudoexperiments

QCD Background Modeling

- QCD multijet background is very difficult to simulate
  - Extremely high cross section
  - Extremely low selection efficiency
- Contribution to cross section is determined using a data-driven method
- In a lepton isolation sideband ($0.13 < PF_iso/p_T < 0.20$)
  - Reversing isolation cut enhances amount of QCD
  - Subtract all simulation off of data
  - QCD shape remains
- Float QCD shape in fit
- Contribution completely negligible in muon+jets channel

Linear Approximation of A_{FB}