High Energy Physics Seminar
University of Pennsylvania

Towards an Understanding of Electroweak Symmetry Breaking

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January 24, 2008

Standard model

- What we know
- Six quarks, six leptons
  - including 3 neutrinos with small or zero masses
- The pattern of fermions replicate itself 3 times
- Electromagnetic force: Photon
- Weak force: W+, W-, Z
  - Unify into one elegant theory: electroweak

- Photon and gluon appear to be massless
- W and Z bosons are quite heavy
  - $M_W \sim 80$ GeV
  - $M_Z \sim 90$ GeV
- Fermions have a variety of different masses

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Electroweak symmetry is broken

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Higgs mechanism

- How do we incorporate masses into the standard model without breaking the theory?

- Simplest mechanism:
  - Create a field that spans over the whole universe
  - W and Z bosons acquire masses through degrees of freedom of the field
  - Fermions acquire masses interacting with the Higgs field

- This mechanism requires a new particle: Higgs boson

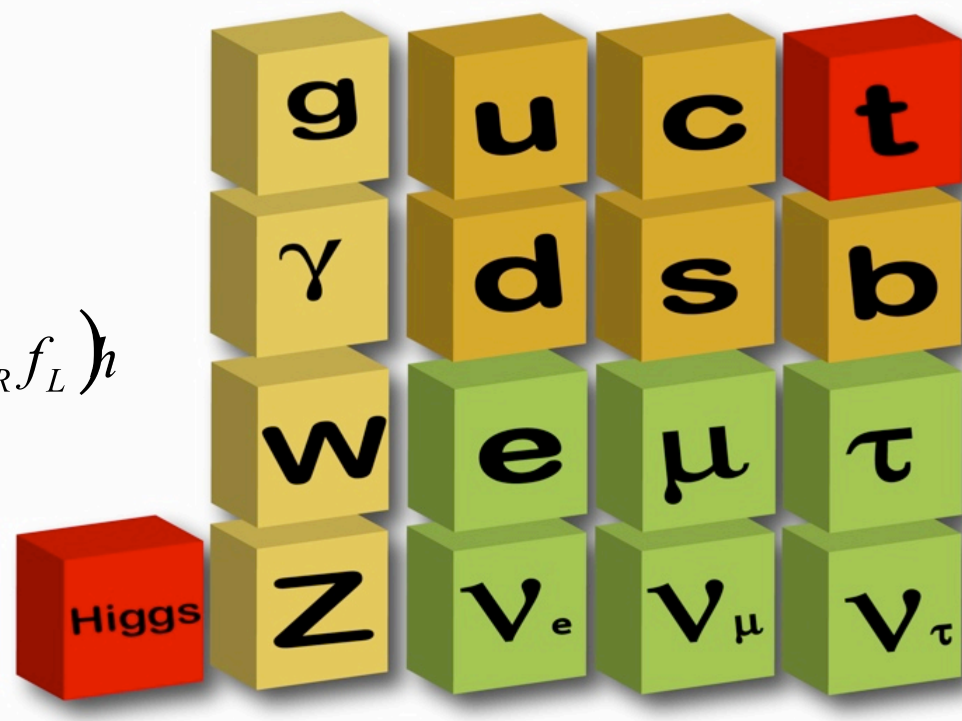
- Finding the Higgs boson would confirm our theory of mass

Higgs boson and top quark

- Top quark being so heavy is the only fermion with significant coupling to the Higgs boson

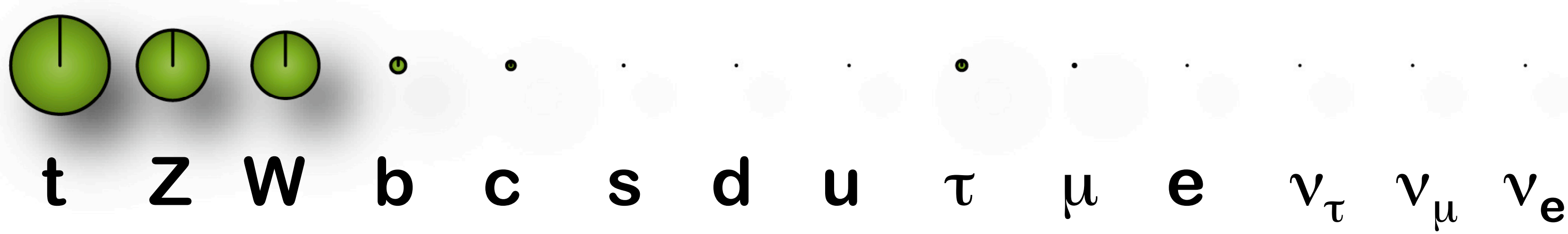
$$L = -\frac{m_f}{v}\bar{f}fh = -\frac{m_f}{v}\left(\bar{f}_L f_R + \bar{f}_R f_L\right)h$$

v = 256 GeV, m_t = 175 GeV



- Top-Higgs couplings plays a special role ?

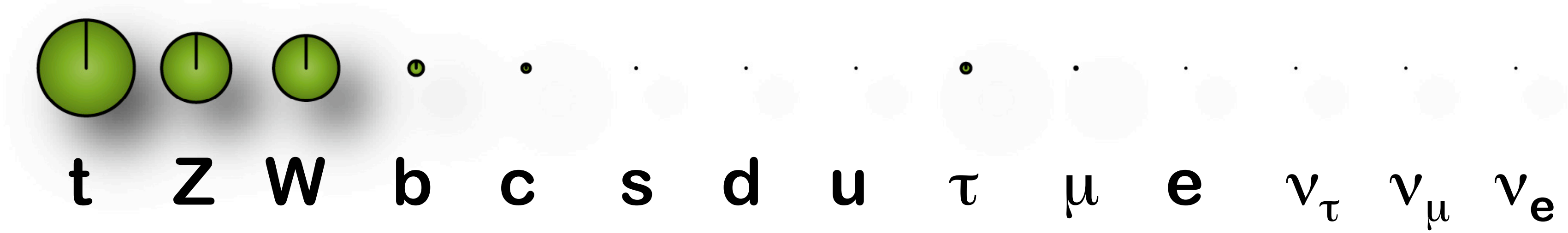
Particle Masses



The top quark

- Is top special ?
  - Top is the only fundamental fermion with a mass at the electroweak scale
  - New physics may be discovered either in its production or its decay
  - Top quark mass plays a special role in the standard model and beyond entering in loop corrections to most observables

Particle Masses

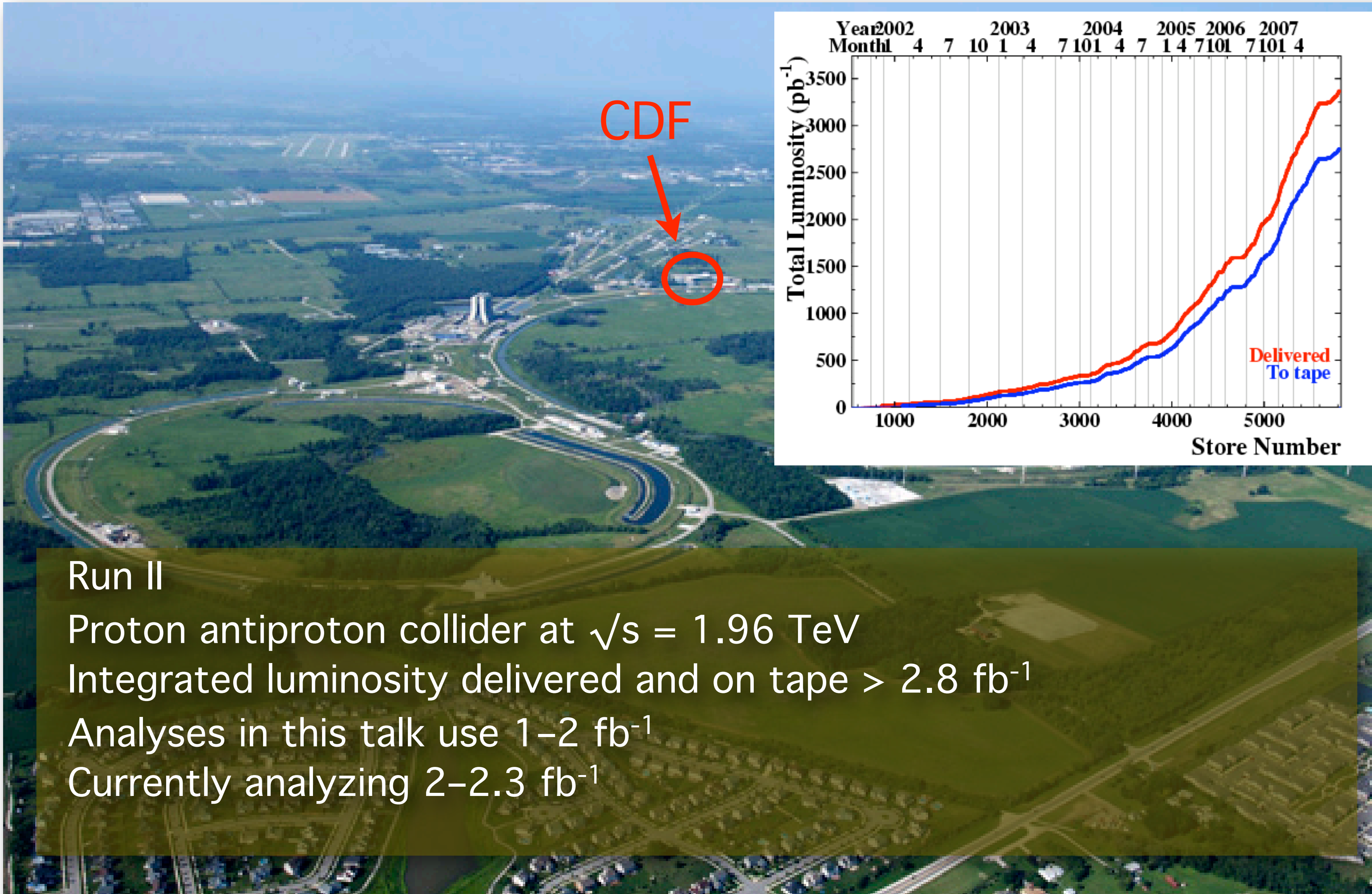


In this talk

- Top quark mass: Constraining the Higgs boson mass
- Top couplings: Is there something new at the electroweak scale?
- Top electroweak production: Towards finding the Higgs boson
- Challenges and experimental techniques in hadron colliders

Fermilab

Fermilab



Run II

Proton antiproton collider at $\sqrt{s}$ = 1.96 TeV

Integrated luminosity delivered and on tape > 2.8 fb^{-1}

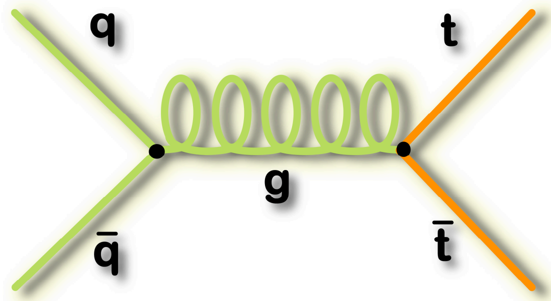
Analyses in this talk use 1–2 fb^{-1}

Currently analyzing 2–2.3 fb^{-1}

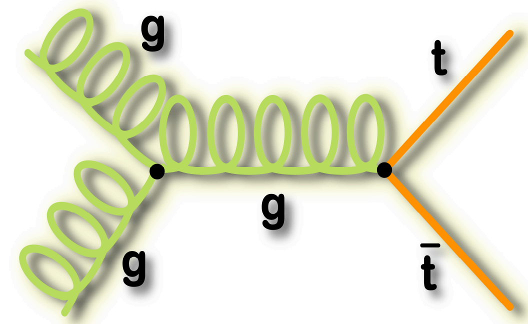
Top production

- Mainly produced via strong interactions: ttbar
- Process discovered in 1995

$\sigma_{t\bar{t}} = 6.7$ pb



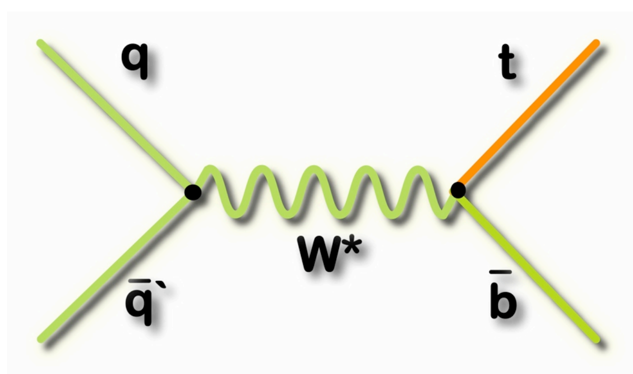
85%



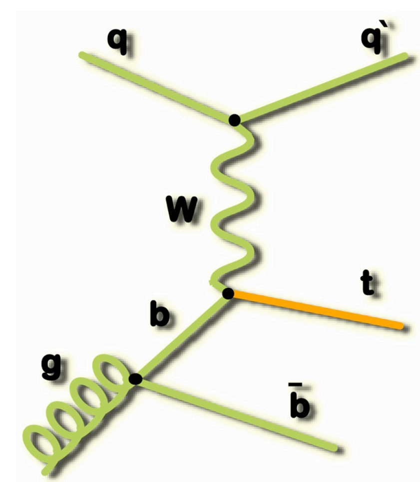
15%

- But also via electroweak: single top
- Evidence of this process found in 2006

$\sigma_{s\text{-channel}} = 0.9$ pb

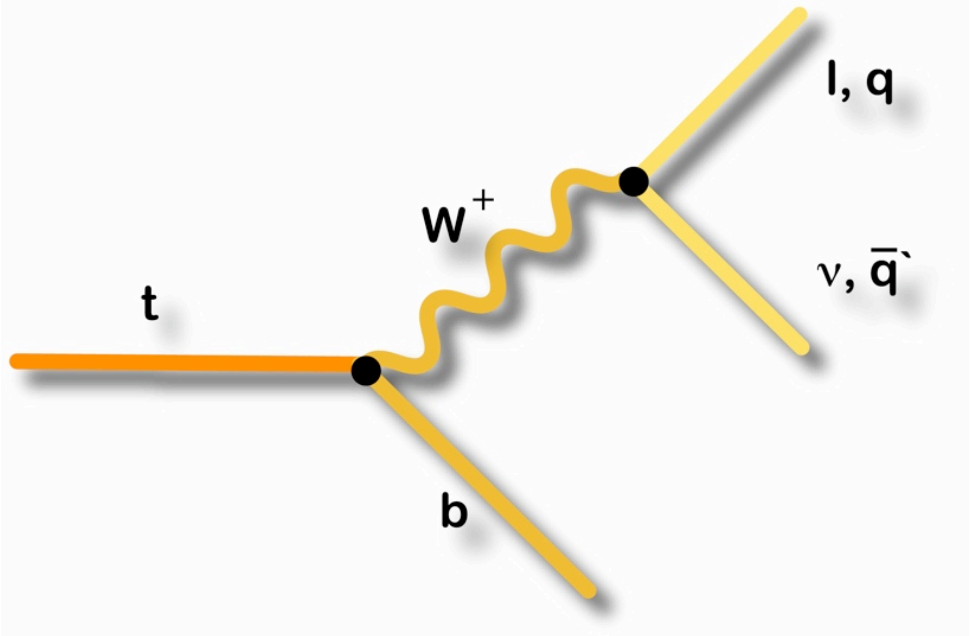


$\sigma_{t\text{-channel}} = 2.0$ pb



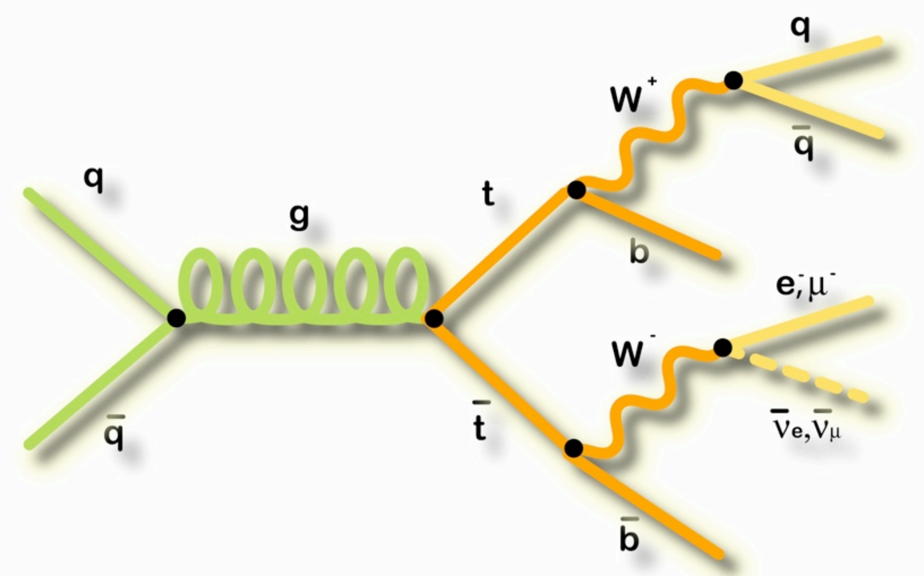
Top decay

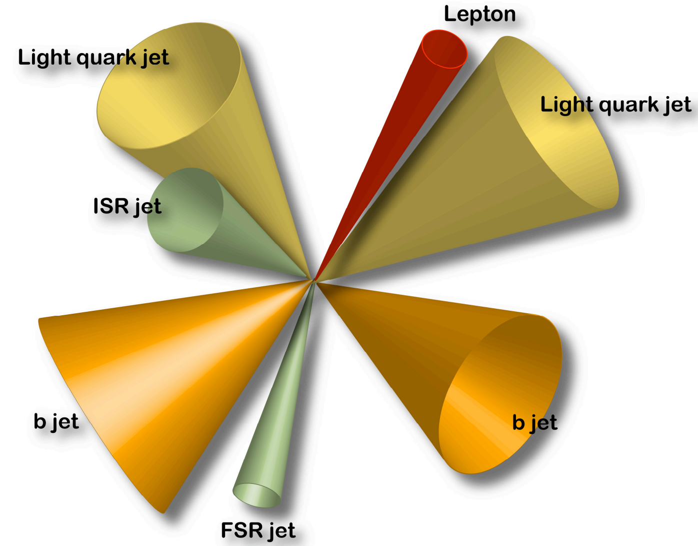
- Top decays via electroweak interactions
- Due to large mass $m_t > m_W + m_b$ and assuming unitarity: $BR(t \Rightarrow Wb) \sim 100\%$
- Top decays before hadronizing $\Gamma \sim 1.4$ GeV $\gg \Lambda_{QCD}$

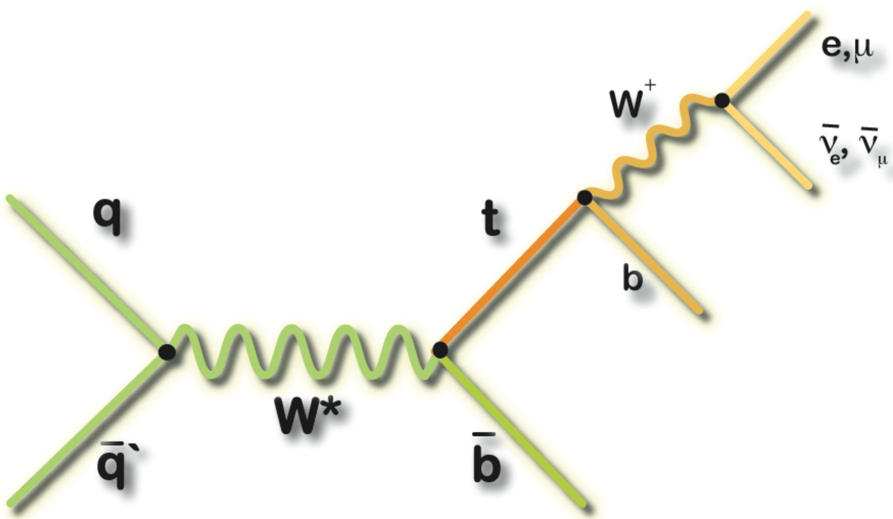


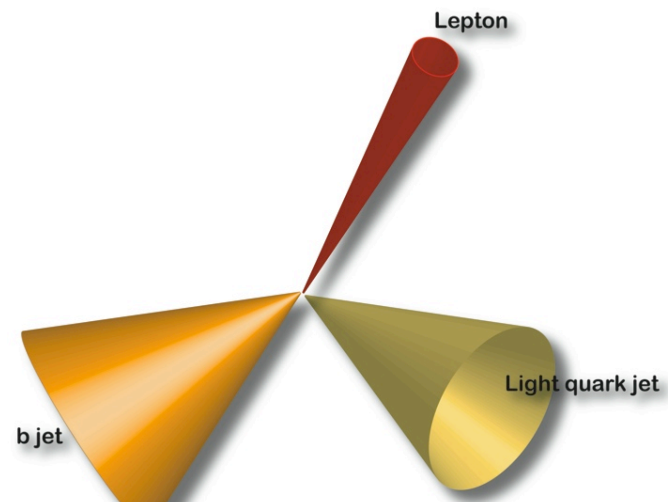
- Hadronic decay swamped by multijet (QCD) background
- Require an electron or muon in the event

Top in real life



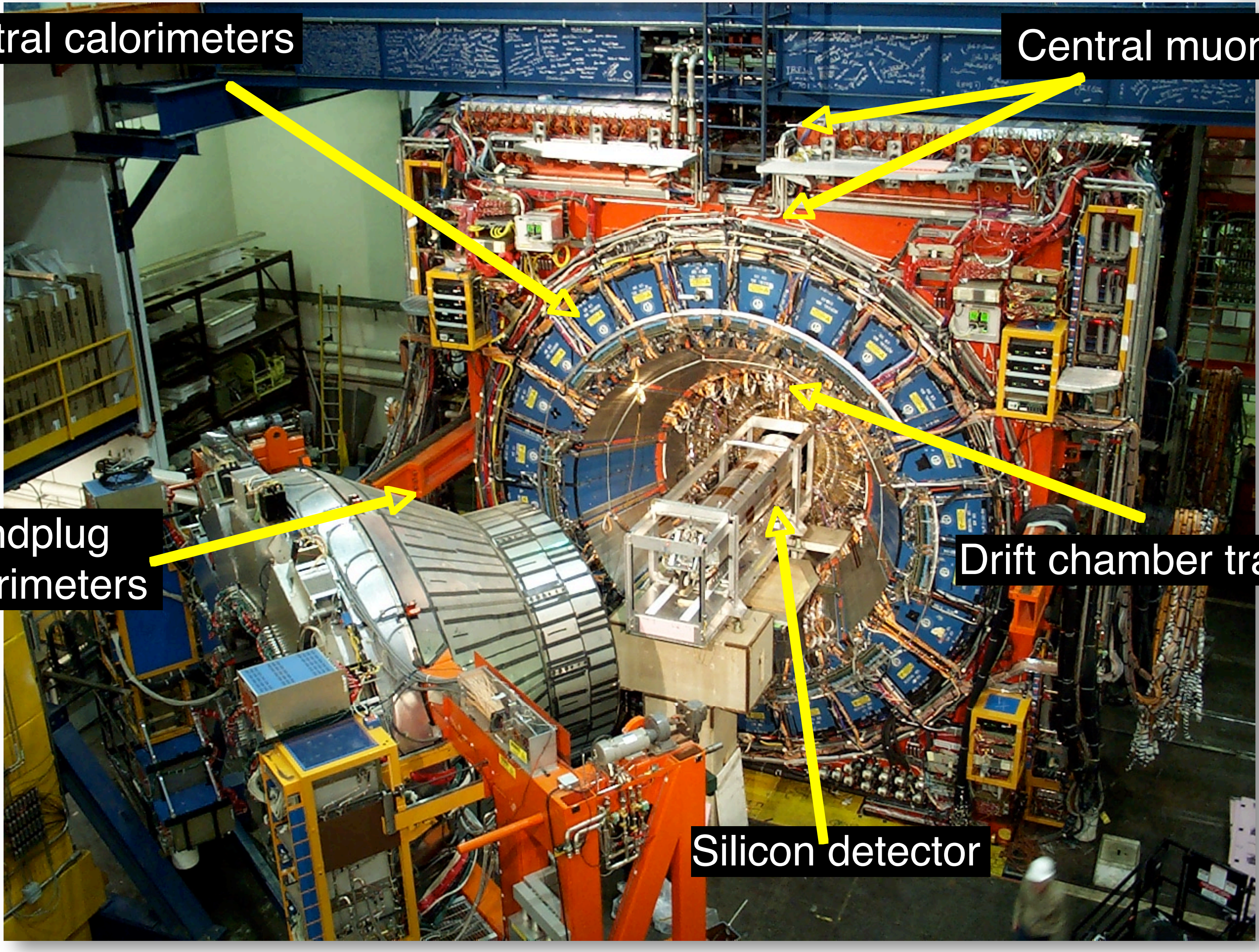




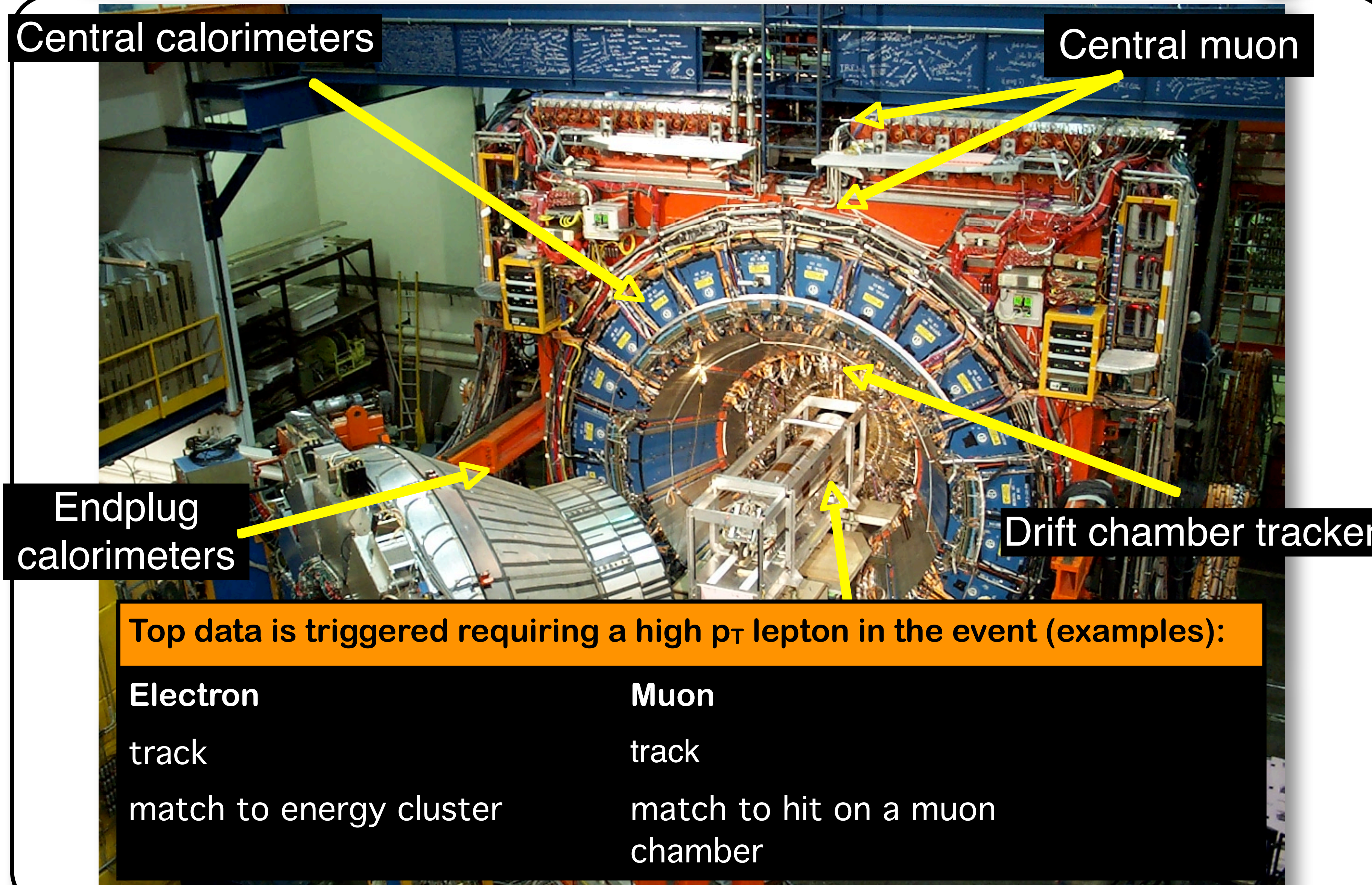


similar for t-channel

CDF


Central calorimeters
Central muon
Endplug
calorimeters
Drift chamber tracker
Silicon detector

CDF

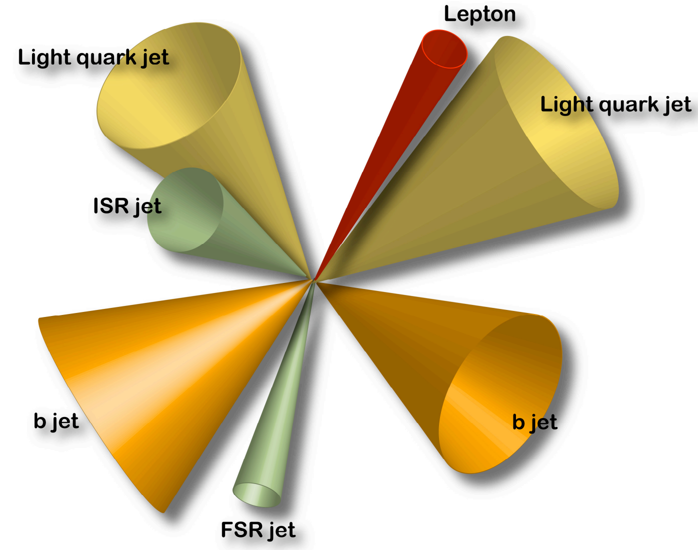


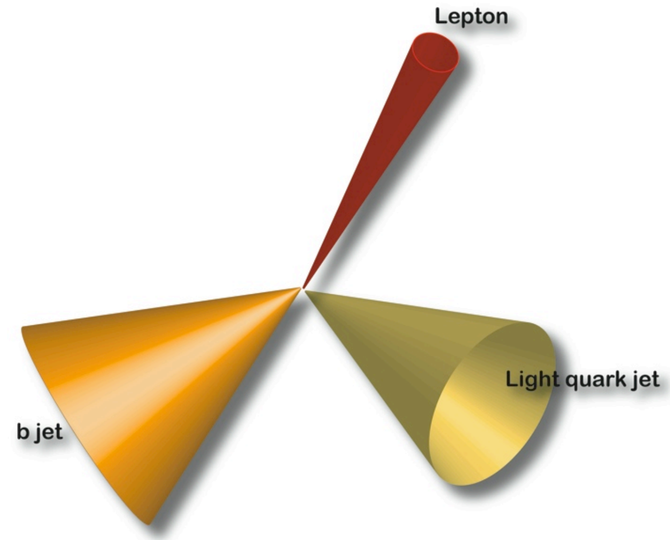
Top data is triggered requiring a high p_T lepton in the event (examples):

Electron	Muon
track	track
match to energy cluster	match to hit on a muon chamber

Top in real life

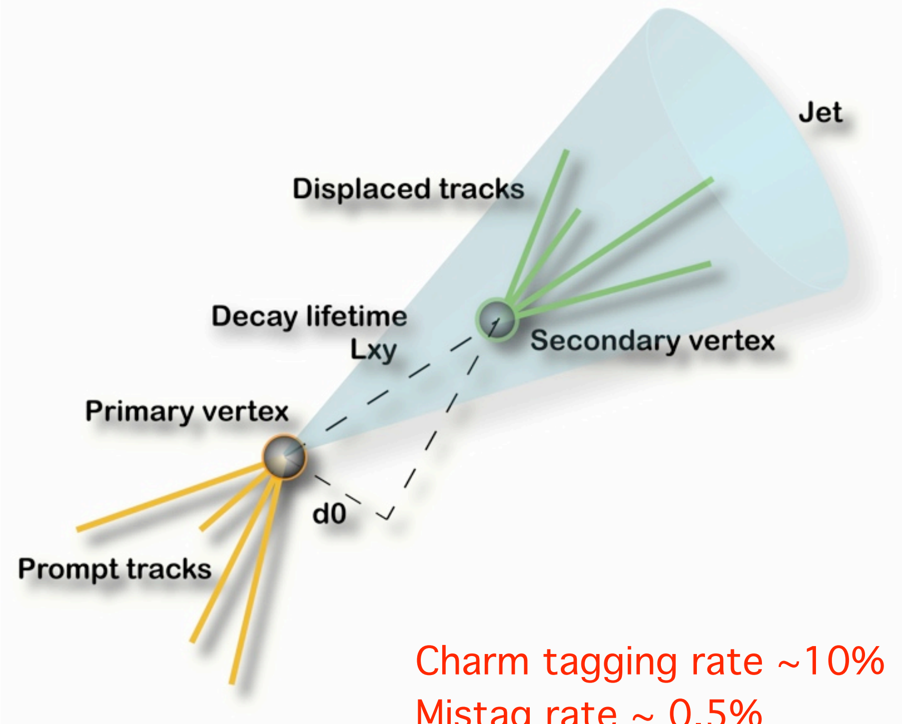
- Require an electron or muon:
  - E_T>20 GeV
  - $|\eta_{electron}|$<2.0, $|\eta_{muon}|$<1.0
- Missing transverse energy (MET)
  - MET > 25 GeV
- Jets
  - ttbar 4 or more jets with E_T>20 GeV, $|\eta|$<2.0
  - single top 2 jets with E_T>20 GeV, $|\eta|$<2.8
- At least one b-tagged jet



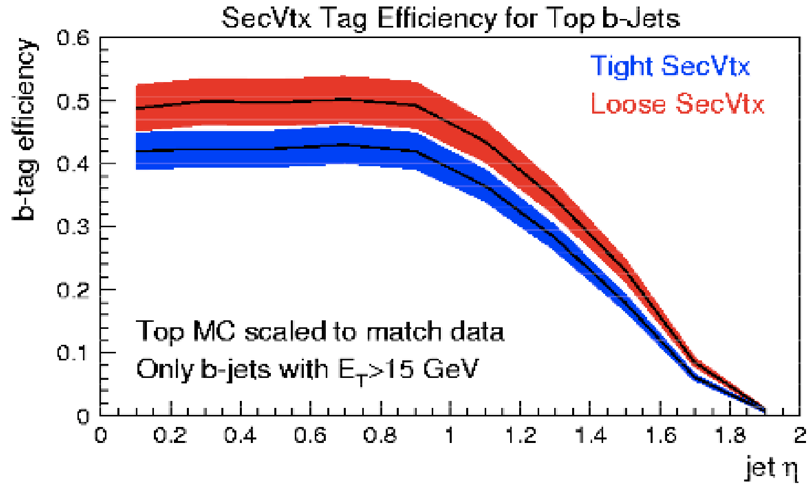


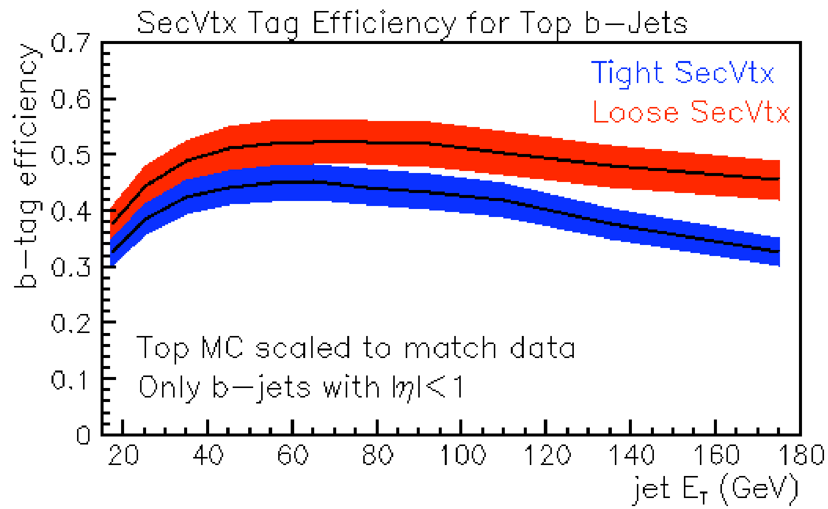
b-tagging

- Identify b-jets by exploiting the long lifetime of B hadrons and the large track multiplicity of their decay



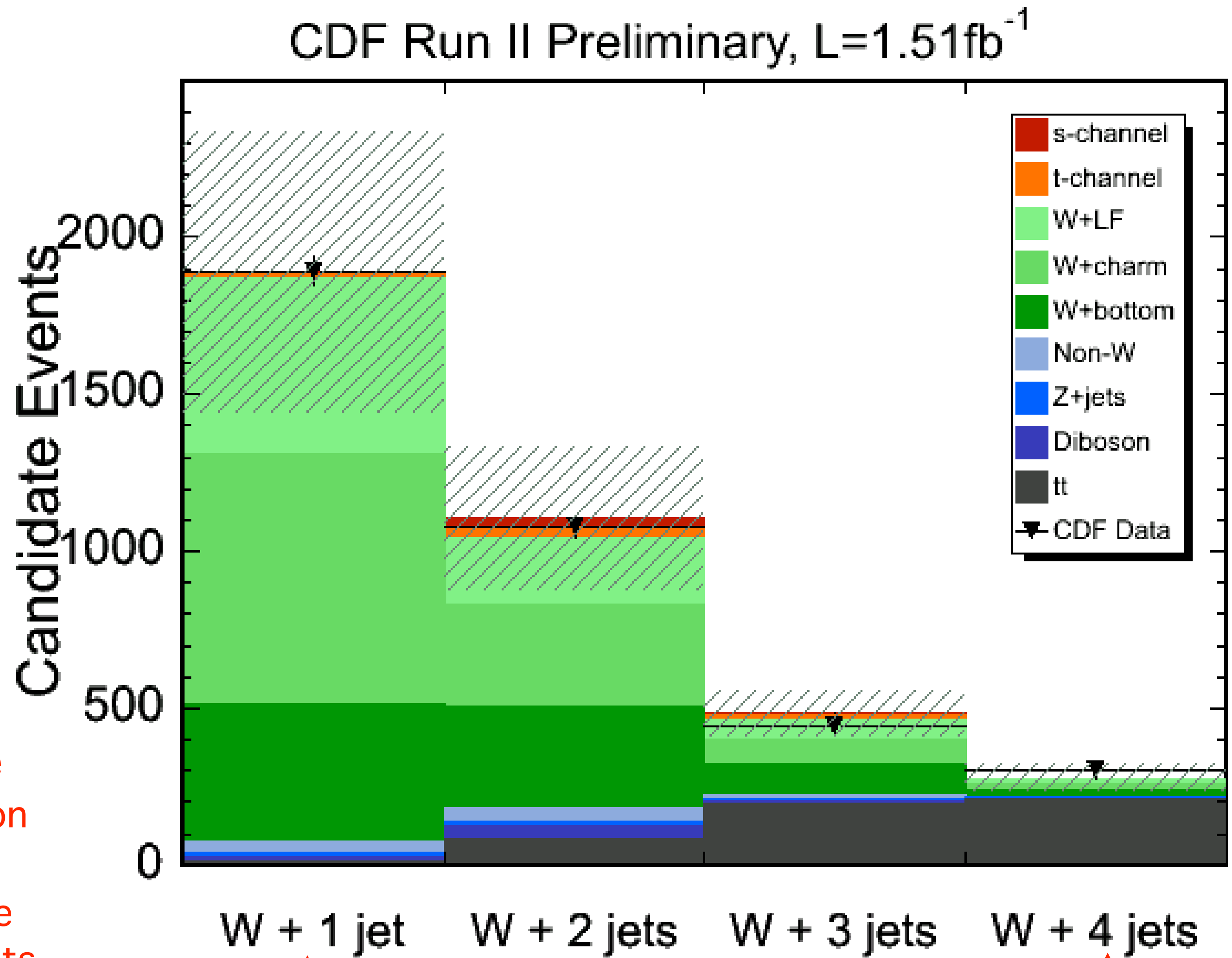
Charm tagging rate ~10%
Mistag rate ~ 0.5%





- Reduces background contamination processes with no b-quark content

Top in real life



After single top selection with one or more b-tagged jets

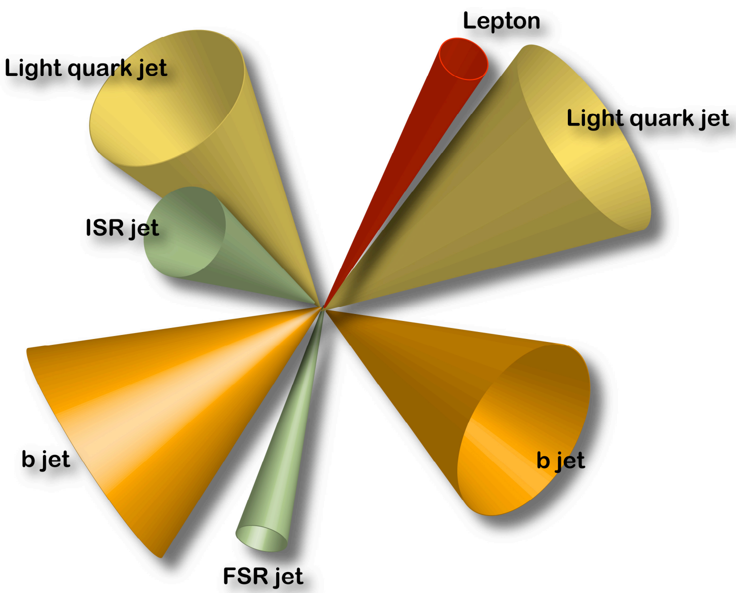
Used to calibrate backgrounds

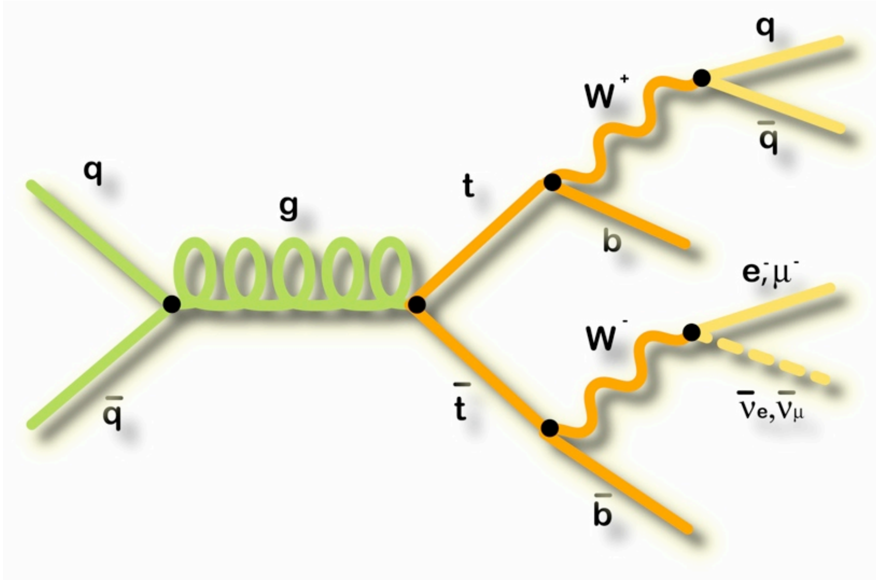
Single-top (Higgs)

Top properties: mass, couplings

Top physics challenges

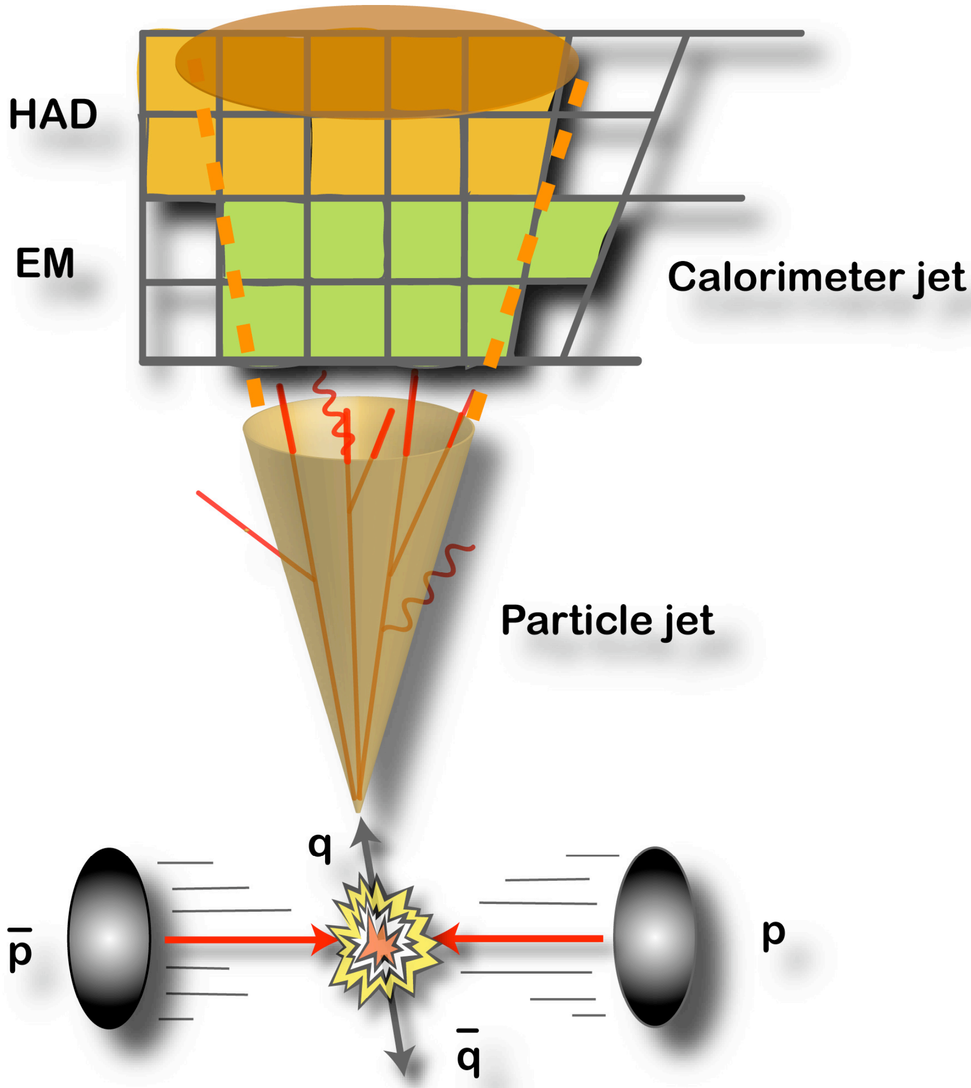
- In general, measurements of top quark properties need to reconstruct top quark 4-vectors
  - Neutrino escapes detection (in analysis technique)
  - Different ways to assign jets to partons (jet permutations)
- Background events degrade measurement resolution and/or hide signal (later in single top)
- Monte carlo modeling limitations (systematic uncertainties)
- Reconstructing quark energies from jet energies (jet energy scale)





Jet energy scale

- Determine the energy of the quarks
- Correct for effects such as hadronization, calorimeter non-linearity and non-compensation, multiple-interactions, underlying event, algorithm shortfalls, etc.
- Correction: derived from data and Monte Carlo events
- Uncertainty: differences between data and Monte Carlo jet energies



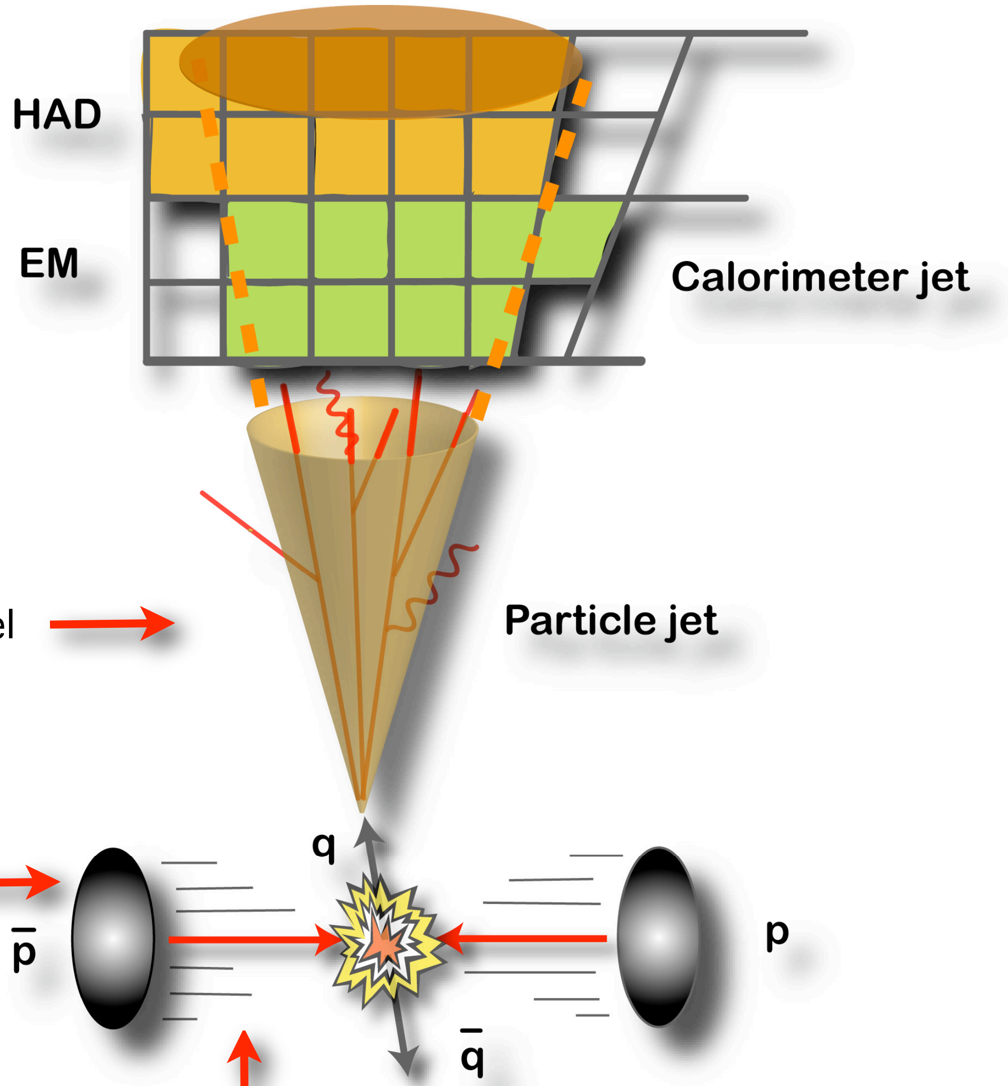
Jet energy scale

- Tune the simulation

Calorimeter response in simulation tuned to data using E/p from data from single track trigger, test beam, etc.

Pythia and Herwig for hadronization model

Underlying event with Pythia Tune A, Jimmy for Herwig



Multiple interactions: Pythia or vertex reweighting

Jet energy scale

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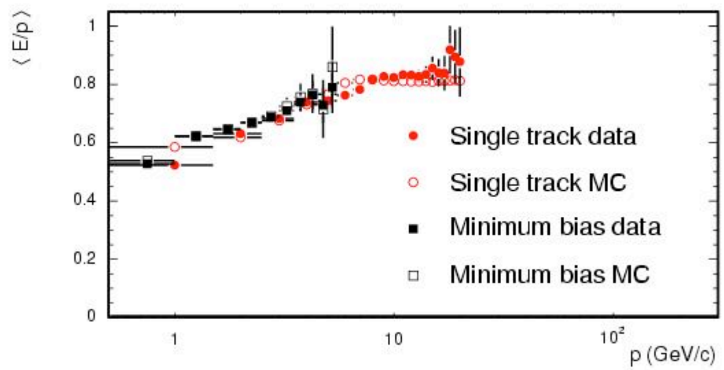
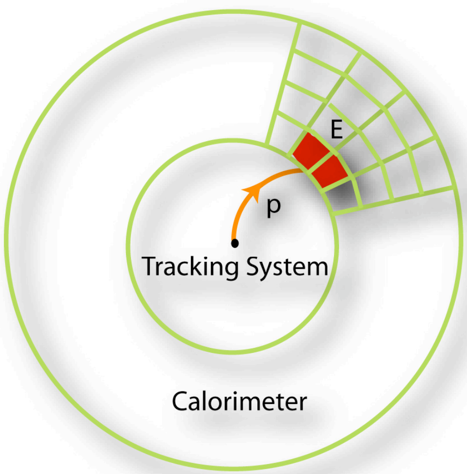
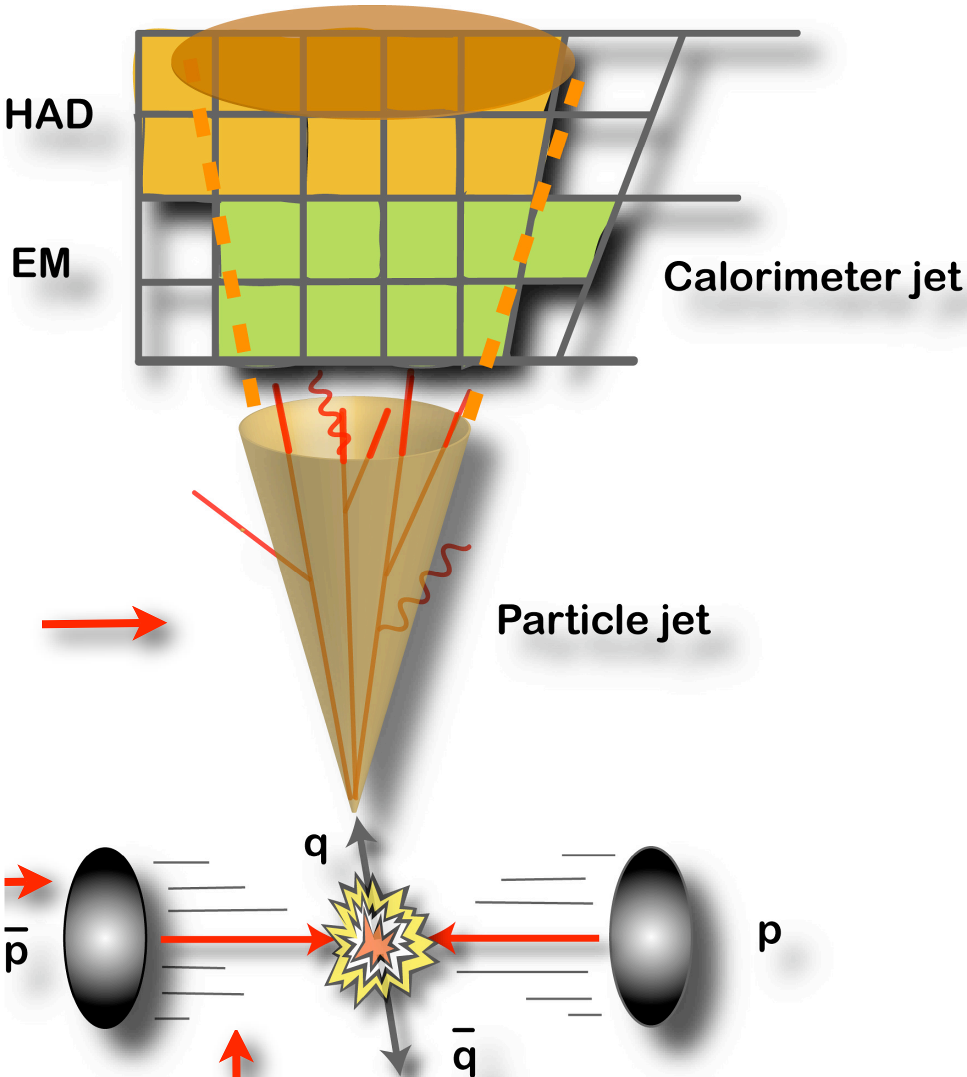
Calorimeter response in simulation tuned to data using E/p from data from single track trigger, test beam, etc.



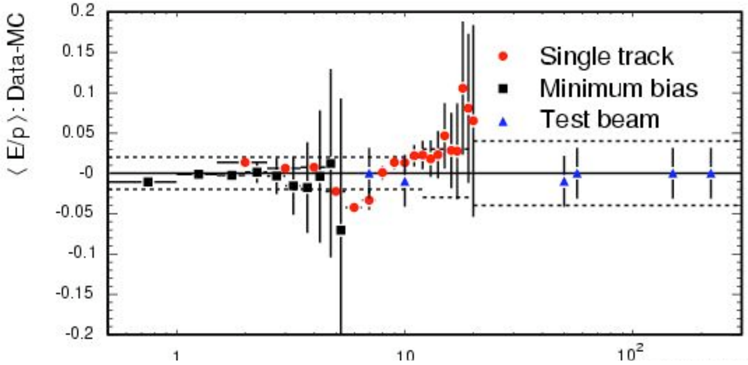


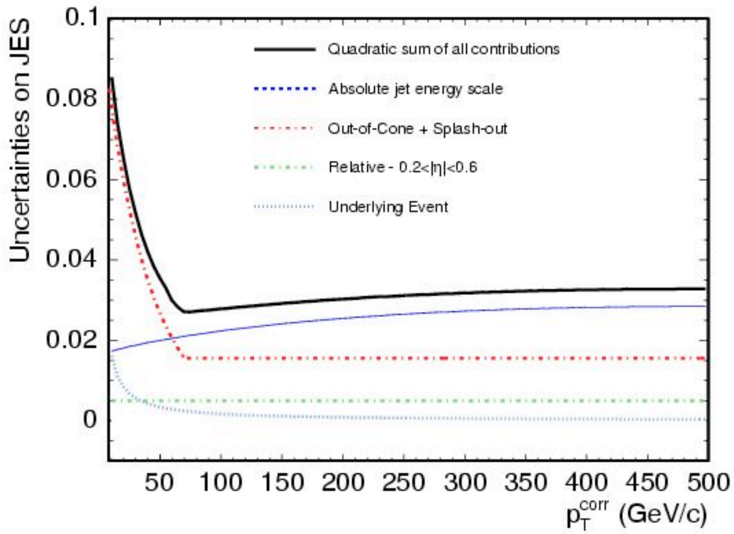


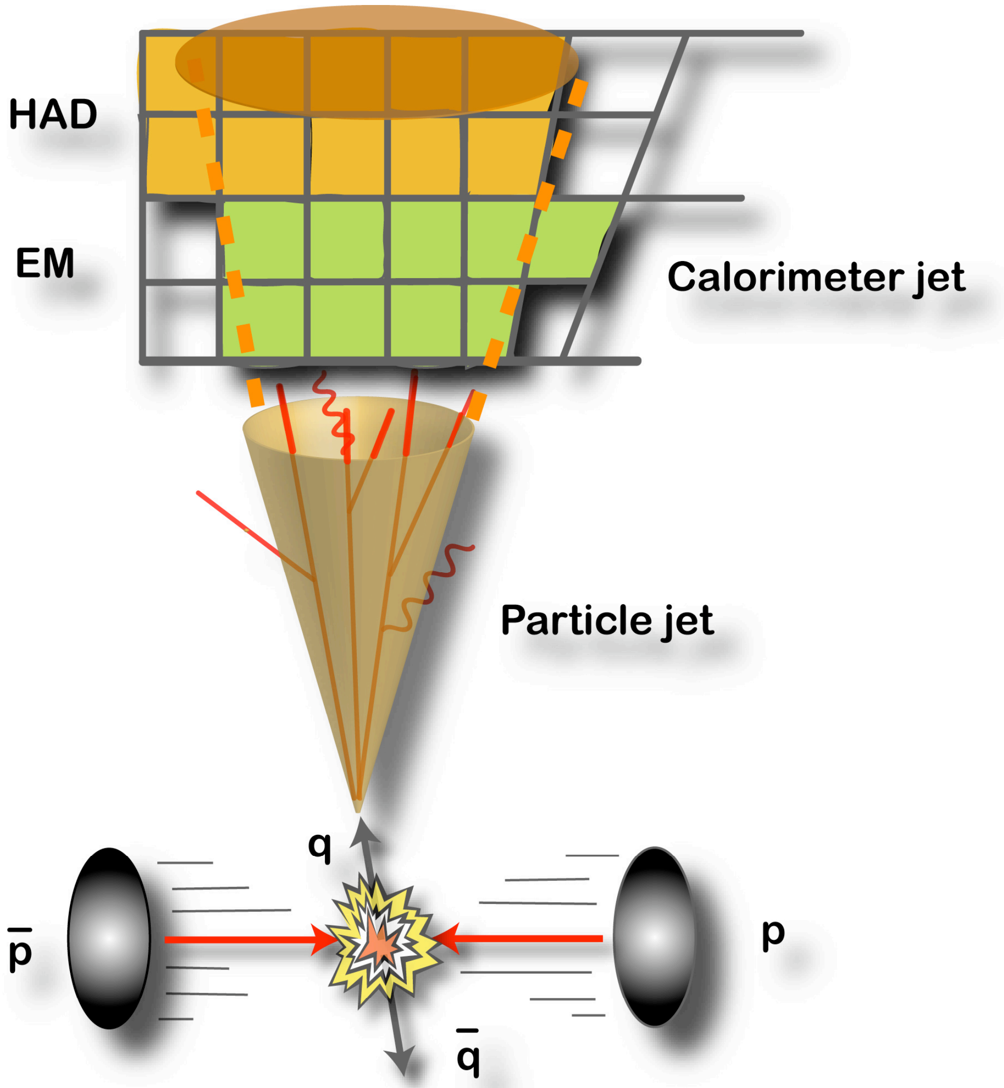
Multiple interactions: Pythia or vertex reweighting

Jet energy scale

- Evaluate uncertainties: data – Monte Carlo



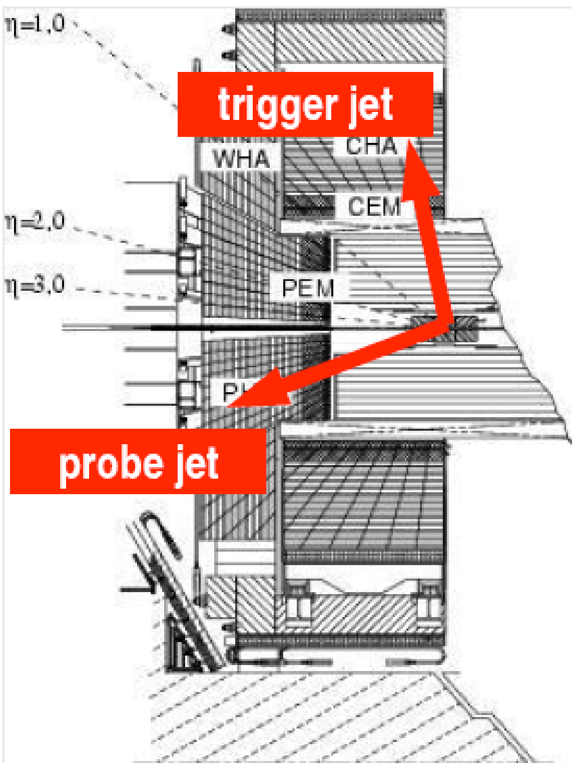


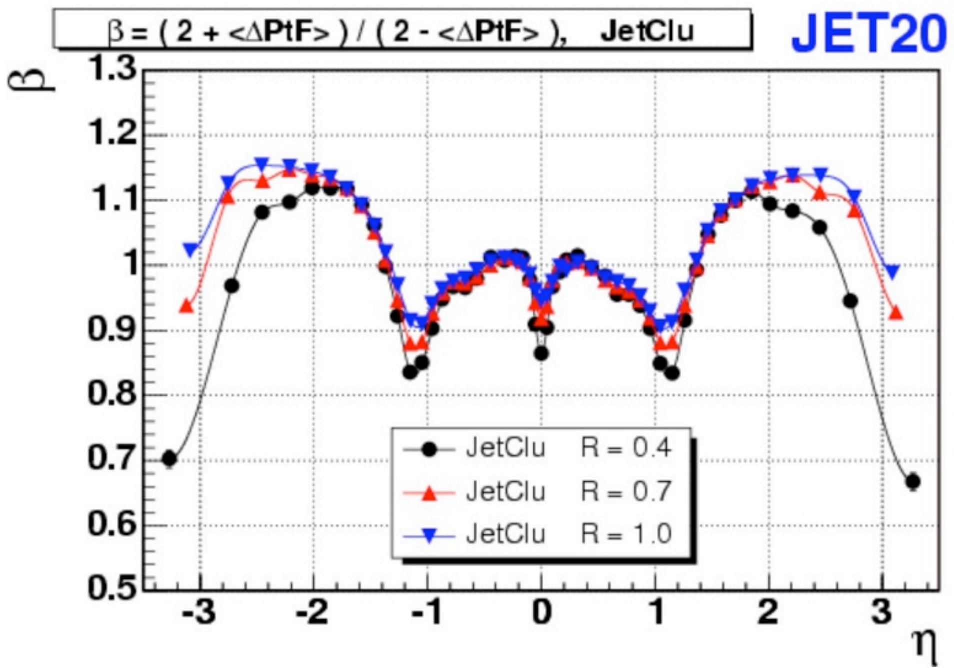


Largest systematic in top mass measurements

Jet energy scale

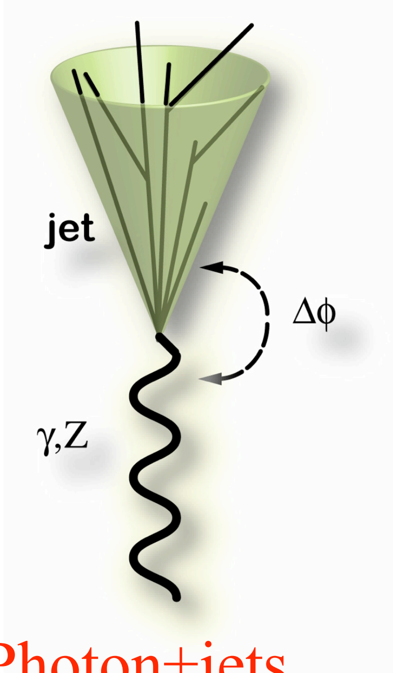
- Dijet events: use to correct for differences in the calorimeters and non-instrumented regions (method used in UA1)
- Trigger jet selected in well measured region (central) and above trigger E_T threshold
- Study momentum balance with probe jet



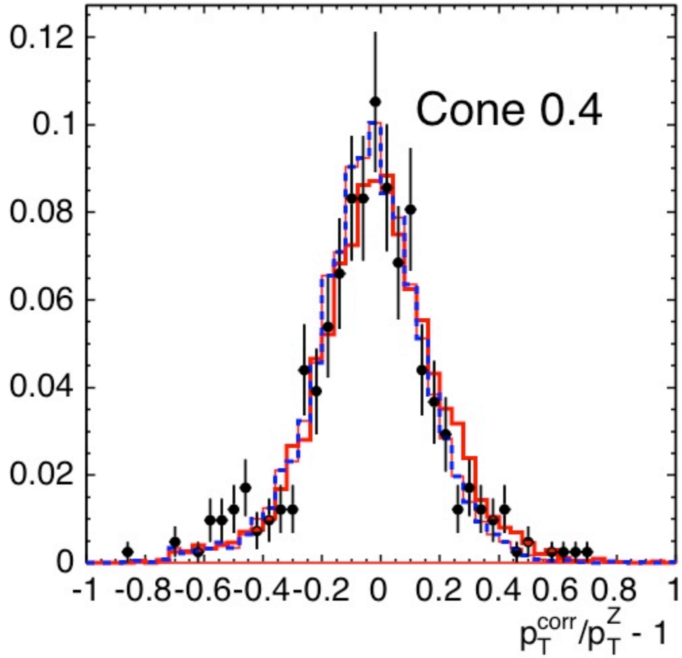


Jet energy scale

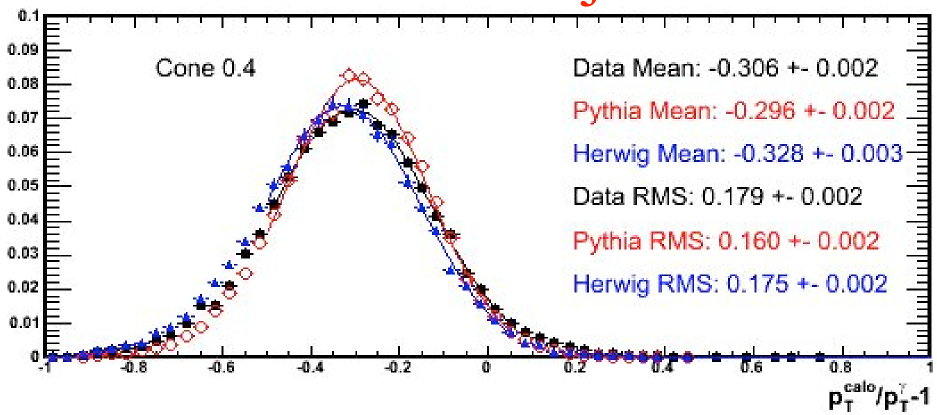
- Photon+jets and Z+jets: used to evaluate differences between data and Monte Carlo (systematic uncertainties)
- EM calorimeter scale well known
- Events with back-to-back jet to Z/photon



Z+jets



Photon+jets



Precision measurement of the top quark mass

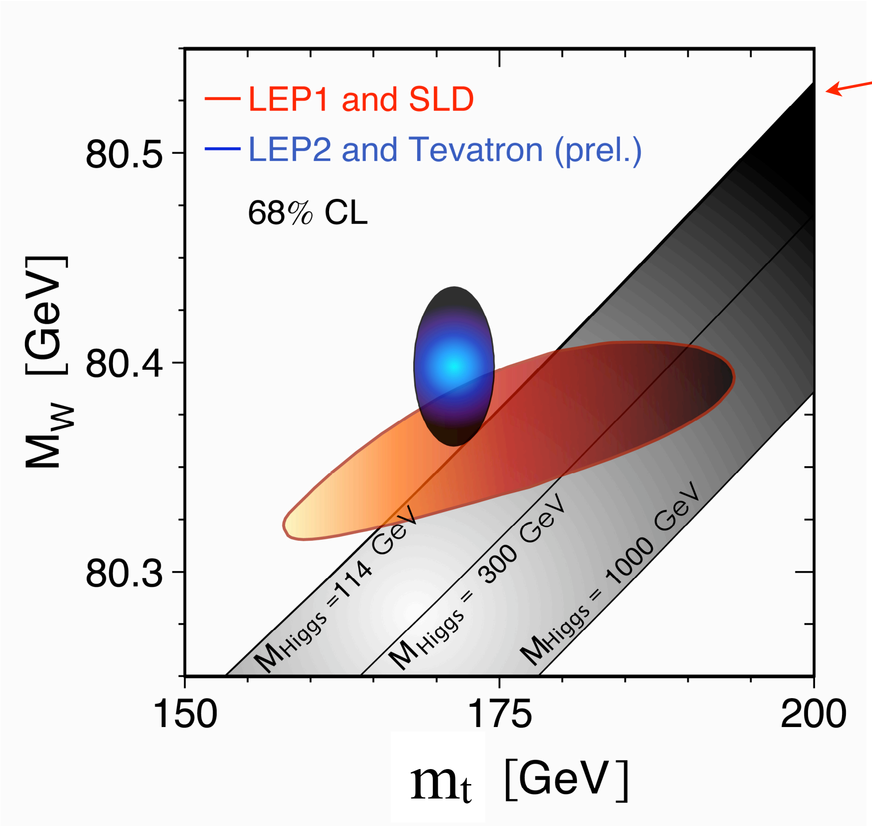
PhD students : Brian Mohr (UCLA, 2007), Adam Gibson (Berkeley, 2006)

+ PhD students: Daryl Hare (Rutgers, 2008), Jacob Linacre (Oxford, 2008)
+ Postdoc: Sasha Golossanov (Fermilab)

Top quark mass

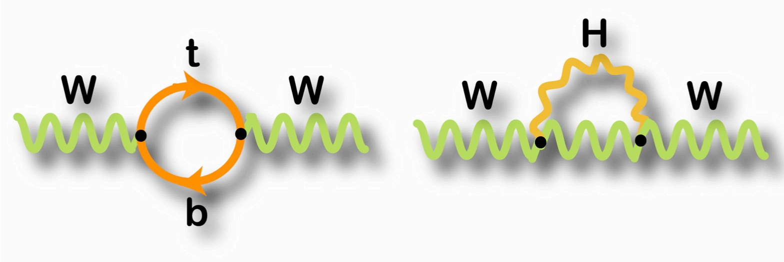
- A precise top quark mass measurement allows for prediction of the mass of the Higgs boson

- Top quark mass and Higgs mass are related to standard model observables and parameters through loop diagrams



$$M_W^2(1 - M_W^2/M_Z^2) = A^2/(1 - \Delta r)$$

$$A = 37.2802 GeV$$



$$\Delta r \approx a + b m_t^2 + c ln(M_H^2/M_W^2)$$

- Constraint on Higgs can point to physics beyond the standard model

Matrix element technique

- Matrix element technique was created to address the challenges of top quark physics (Similar to the methods suggested by R. H. Dalitz and G. R. Goldstein, Phys. Rev. D 45, 1531 (1992), K. Kondo, J. Phys. Soc. Jpn. 60, 836 (1991), K. Kondo, J. Phys. Soc. Jpn. 57, 4126 (1998); m_t measurement in the dilepton channel by DØ – PRD 60 52001 (1999) and idea by Berends et al. for W^+W^- production. And based on DØ Run I mt and W helicity measurments V. M. Abazov et al., Nature 429, 02589 (2004), Phys. Lett. B 617, 375 (2005))

- Calculate probability densities by convoluting the differential cross-sections with the experimental resolutions and parton distribution functions and by integrating over all the possible parton quantities y that lead to the observed quantities x

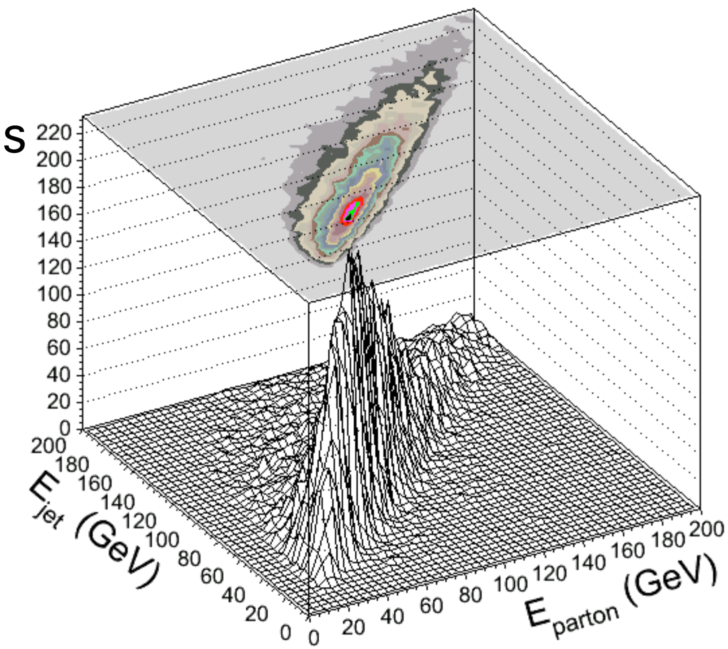
$$\bar{P}(x) = \frac{1}{\sigma} \int d^n \overbrace{\sigma(y)}^{\text{Differential cross section}} \underbrace{dq_1 dq_2 f(q_1) f(q_2)}_{\text{Parton distribution functions}} \overbrace{W(x,y)}^{\text{Experimental resolutions}}$$

Experimental resolutions

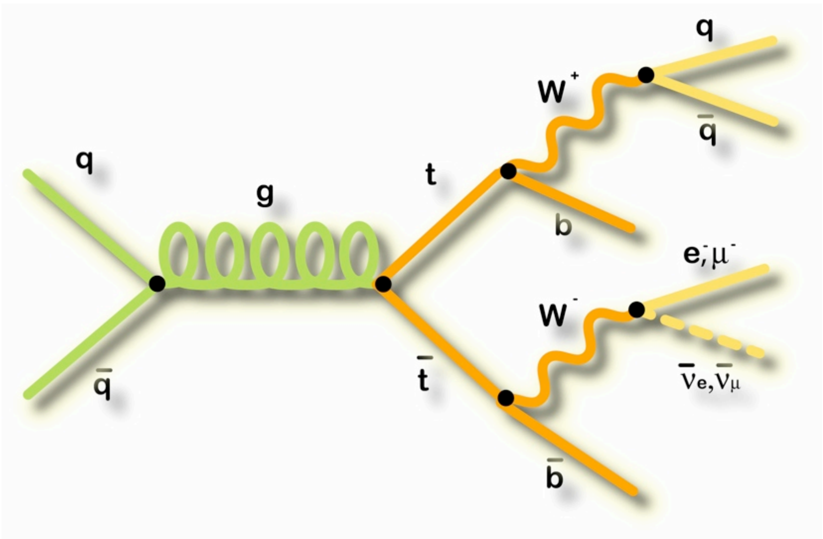
- Experimental resolutions are considered well measured (lepton energies, angles) or parametrized from the Monte Carlo (jet energies)

$$W(x,y) = \delta^3(p^y_{lepton} - p^x_{lepton}) \prod_{j=1}^{4} W_{jet}(E^x_j, E^y_j) \prod_{1=1}^{4} \delta^2(\Omega^y_i - \Omega^x_i)$$

- W_{jet} models transition of parton to jet
  - b and light jet flavor parameterizations
  - uses two Gaussian functions, one to account for the peak and the other to fit the asymmetric tails



Top mass measurement



Constrain the invariant mass of the non-b-tagged jets to be 80.4 GeV/c^2 (W mass from LEP measurements known very precisely) to measure the jet energy scale in-situ

$$P_{t\bar{t}}(x; m_t, JES) = \frac{1}{\sigma_{t\bar{t}}(m_t)} \int \underline{d\rho dm_1^2 dM_1^2 dm_2^2 dM_2^2} \sum_{perm,\nu} |M_{t\bar{t}}(m_t)|^2 \frac{f(q_1)f(q_2)}{|q_1||q_2|} \phi_6 W_{jet}(JESx, y)$$

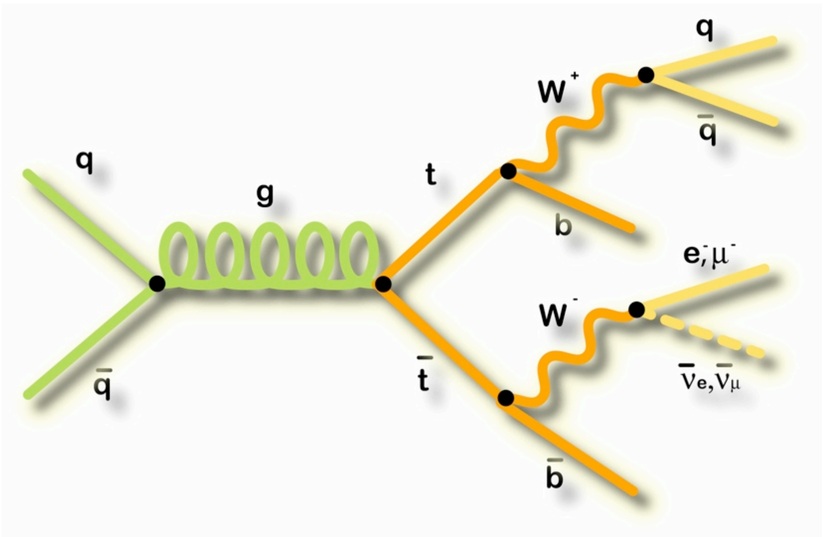
lepton and jets 4-vectors

5 integrals: choose M_{top}, m_W and jet energy of one of the jets from the W, because $|M_{tt}|^2$ is almost negligible, except near the peaks of the four BW within $|M_{tt}|$

LO matrix element

Six-body phase space

Top mass measurement



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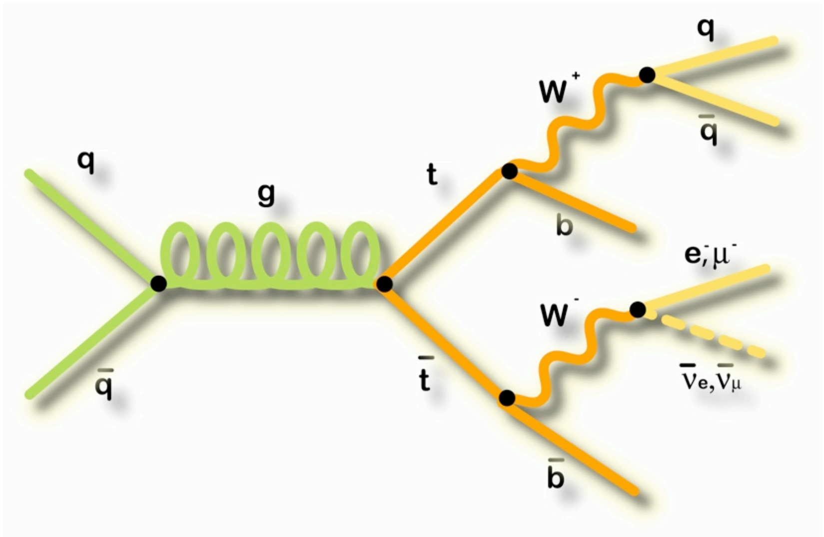

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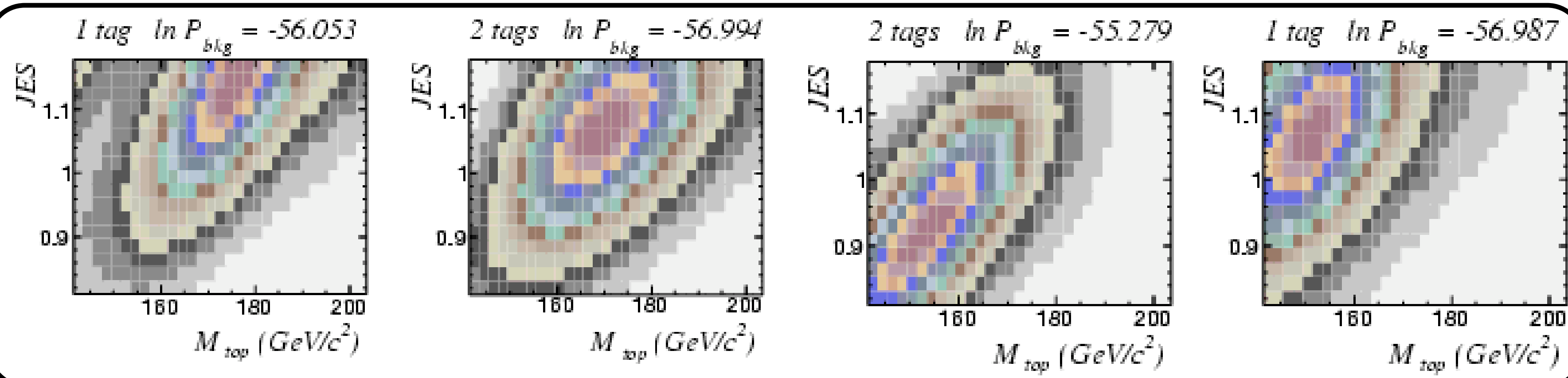

Top mass measurement

- We optimize the use of statistics by using much of the individual kinematical information in the event
  - well measured events contribute more information than poorly measured events
  - all neutrino p_Z allowed are included
  - the right jet permutation is always considered (along with the others)
  - background contamination is separated from signal

$$P_{t\bar{t}}(x;m_t,JES) = \frac{1}{\sigma_{t\bar{t}}(m_t)} \int \underline{d\rho dm_1^2 dM_1^2 dm_2^2 dM_2^2} \sum_{perm,\nu} |M_{t\bar{t}}(m_t)|^2 \frac{f(q_1)f(q_2)}{|q_1||q_2|} \phi_6 W_{jet}(JESx,y)$$

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LO matrix element

Six-body phase space

Measuring top mass

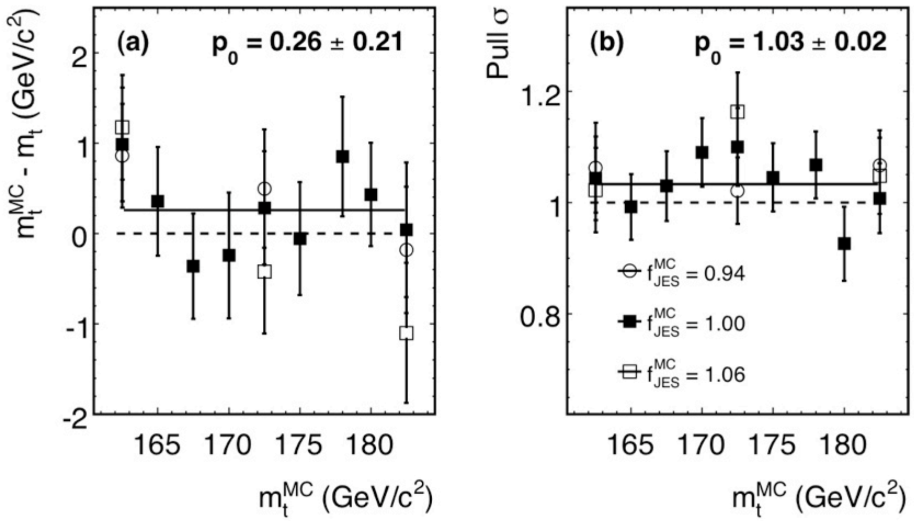
- Calculate a probability density for a background hypothesis using a matrix element from the VECBOS MC generator subroutine

- Likelihood used to simultaneously fit m_t, JES, and signal fraction, C_s

$$L(C_s, m_t, JES) \propto \prod_{i=1}^{Nevents} [C_s P_{t\bar{t},i}(m_t, JES) + (1 - C_s) P_{W+jets,i}(JES)]$$

- Test method using Monte Carlo events

	Events in 955 pb^{-1}
tt (σ_{tt}=8.0pb)	145.1 ± 16.5
W+jets	14.5 ± 5.1
non-W	5.2 ± 2.6
EWK	2.2 ± 0.5
Data	167



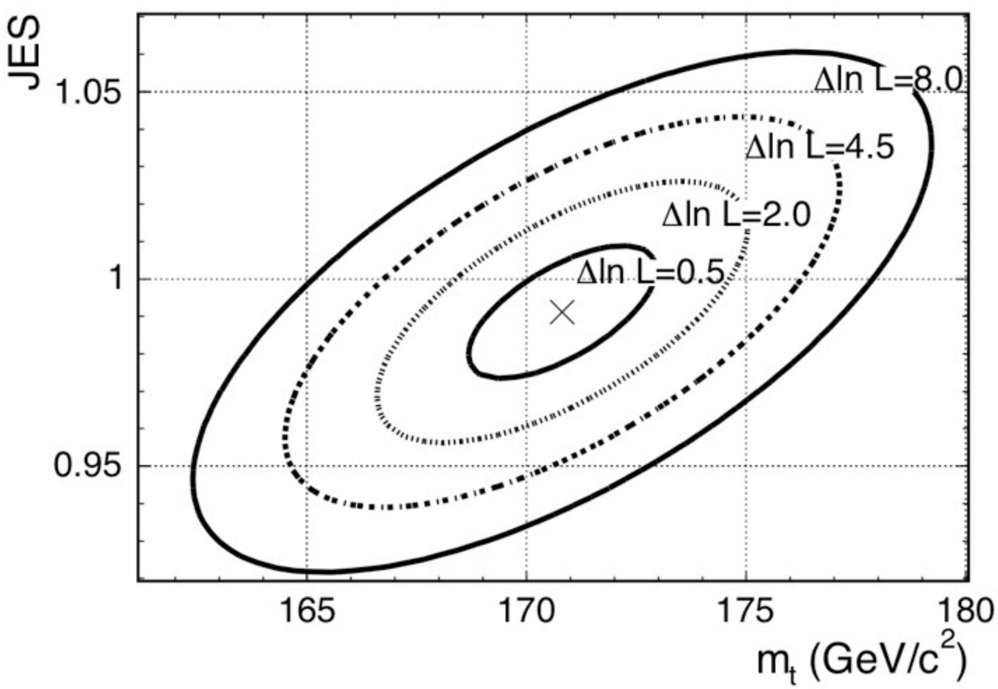
Top quark mass result

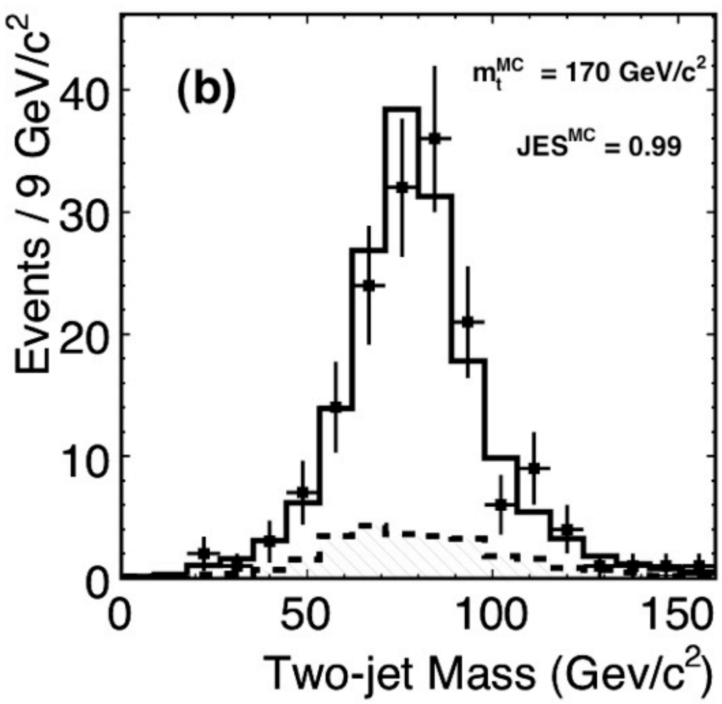
- With 955 pb^{-1} we measure

$$m_t = 170.9 \pm 1.6(stat) \pm 1.4(JES) \pm 1.4(sys) GeV/c^2$$

- and JES = 0.99 ± 0.02(stat)

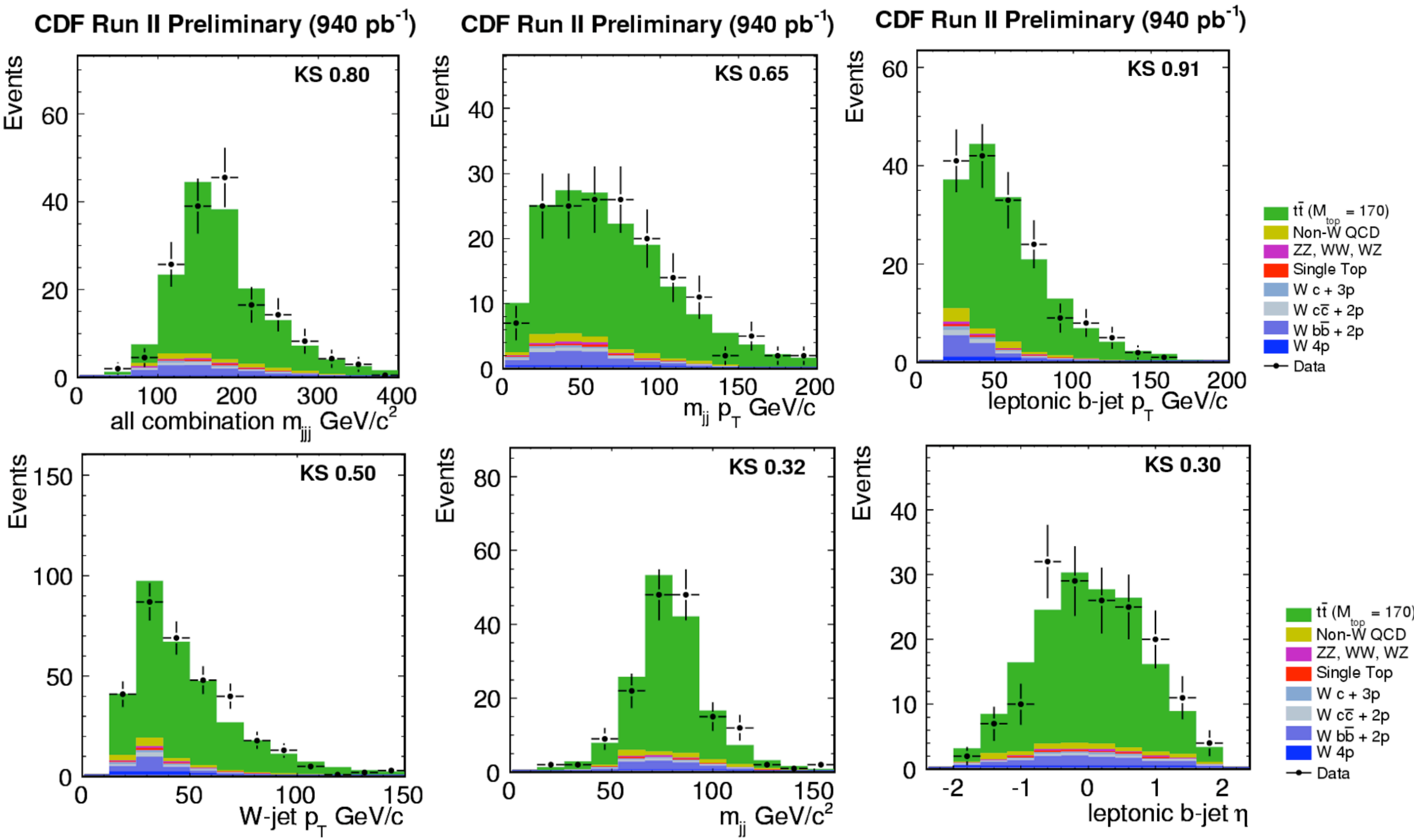
PRL 99, 182002 (2007)





Data and Monte Carlo

- Some example plots using the most probable configuration



Systematic uncertainties

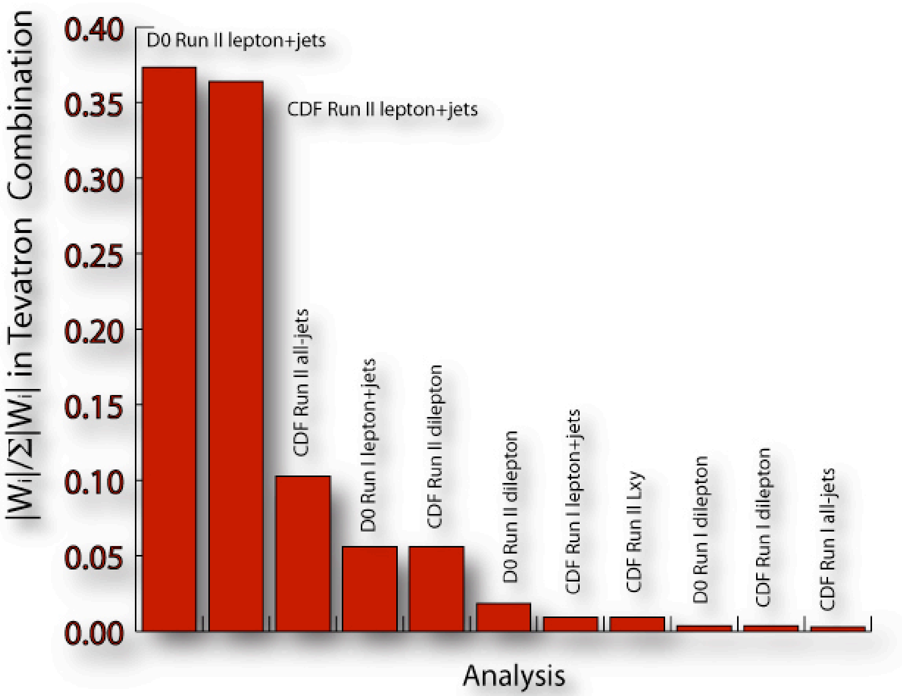
- Measurements are now systematically limited
- Some of them are limited by the number of events in Monte Carlo samples
- The lack of experimental understanding of radiation and b-JES are the main uncertainties

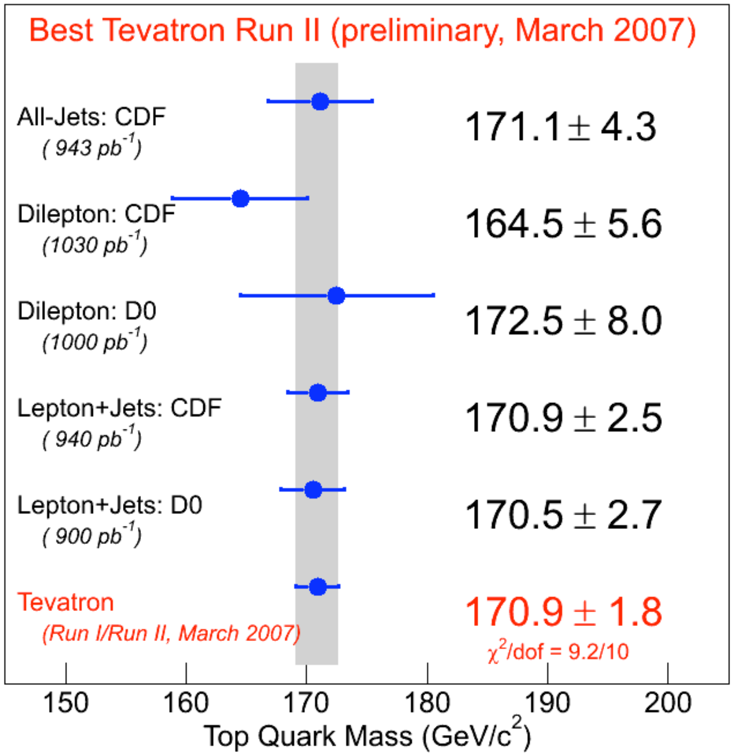
Systematic uncertainties (GeV/c^2)	
JES residual	0.42
Initial state radiation	0.72
Final state radiation	0.76
Generator	0.19
Background	0.21
PDFs	0.12
b-JES	0.60
b-tagging	0.31
Monte Carlo statistics	0.04
Lepton p_T	0.22
Multiple interactions	0.05
Total	1.36

Top mass combination

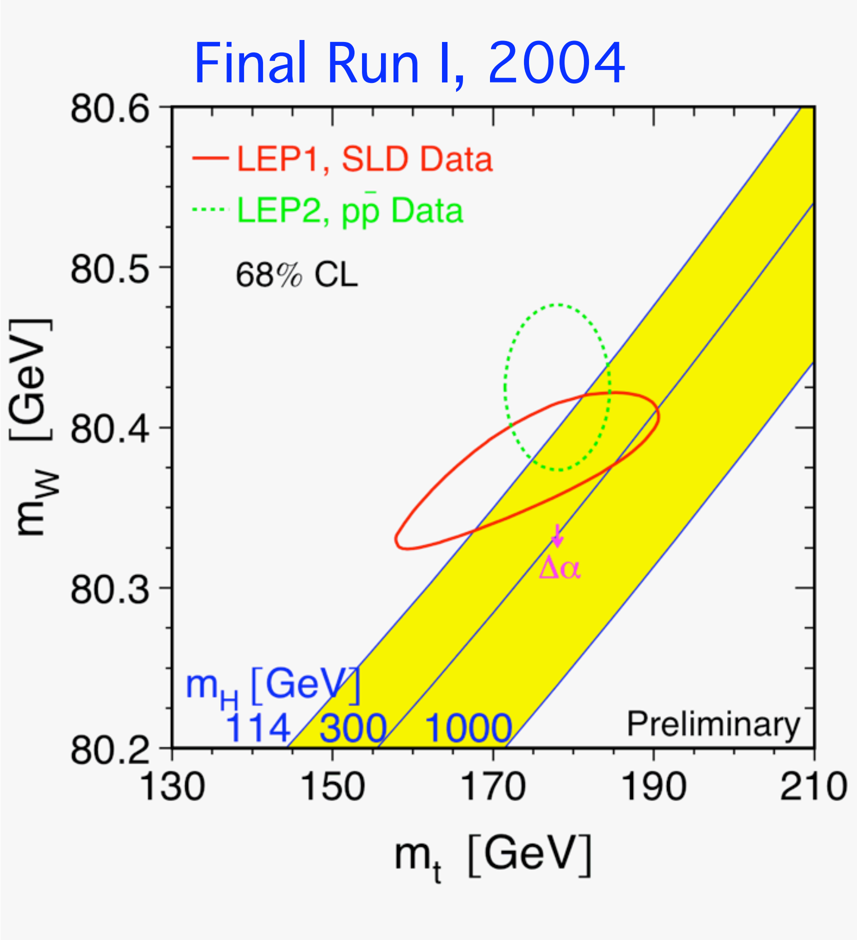
- The latest Tevatron combination includes this result (winter 2007)

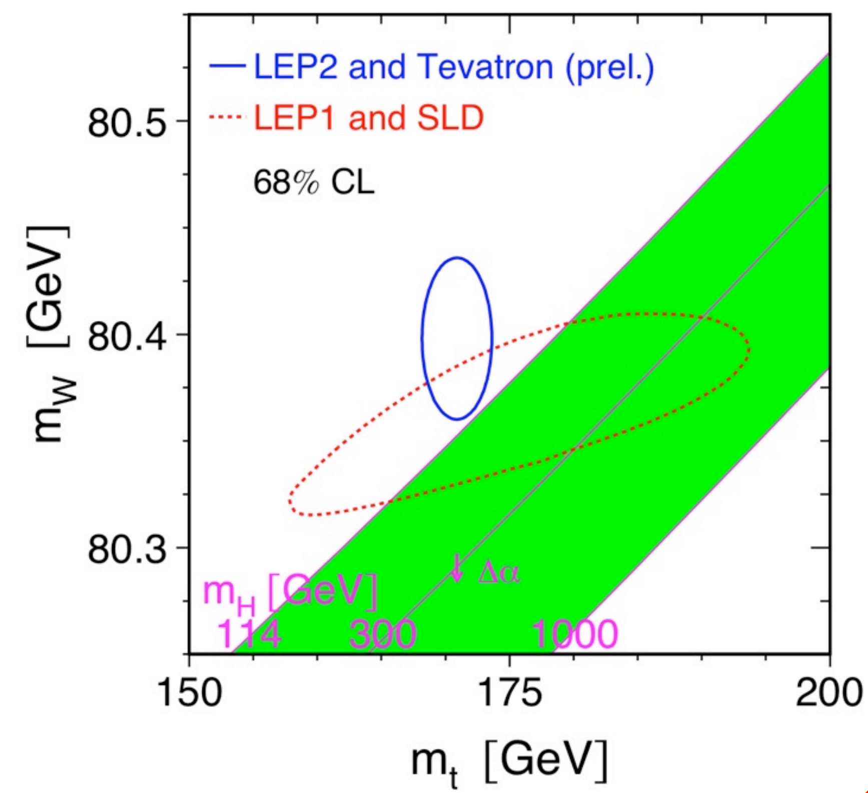
$$m_t = 170.9 \pm 1.8 GeV/c^2$$





- Top quark mass hints at a low Higgs mass

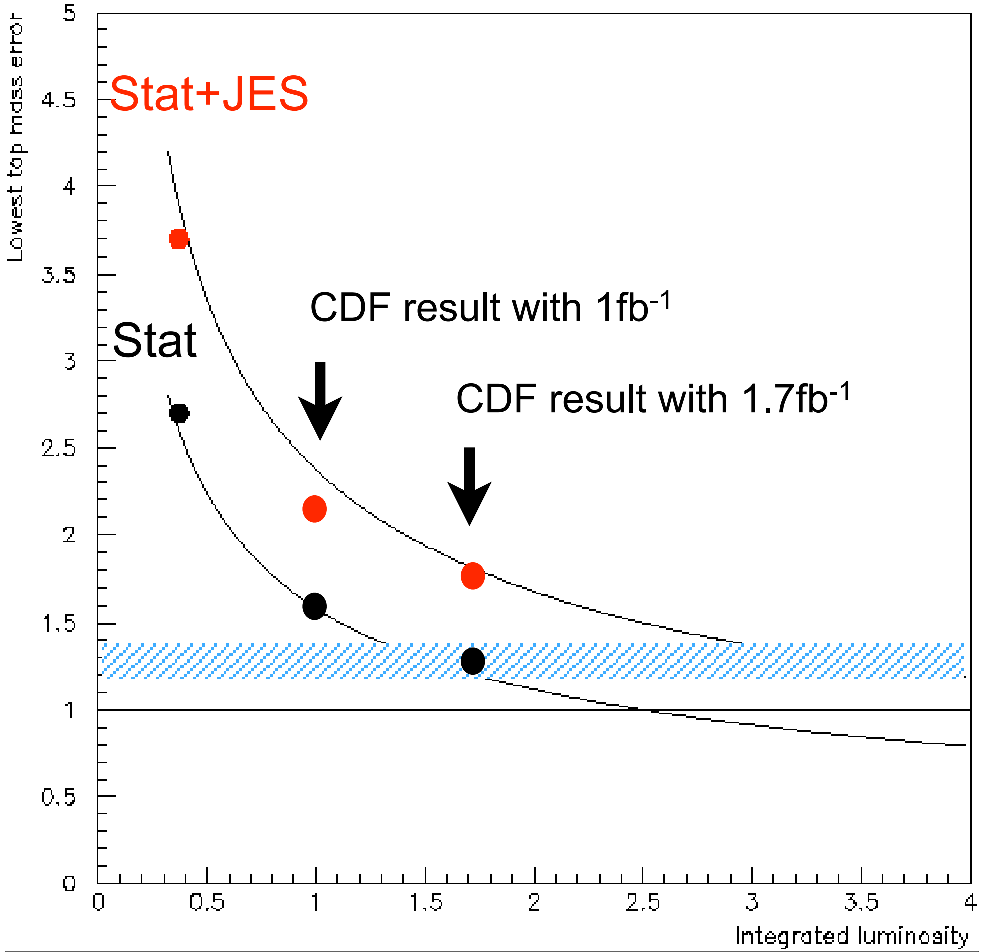




Top quark mass future

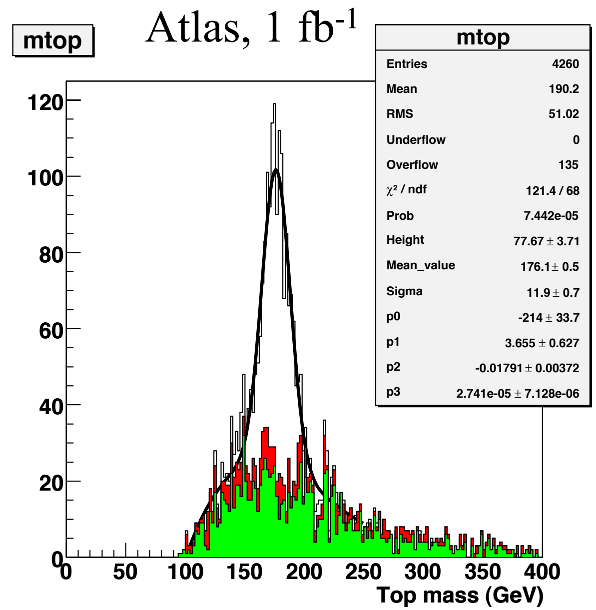
- With 4 fb^{-1} the stat+JES lepton +jets uncertainty will be ~1GeV/c^2
- The systematic uncertainty is harder to predict
- New improvements from other top reconstruction channels using in-situ JES technique
- Very possible that by the end of Run II we will have measurements in other channels approaching 1.5 GeV /c^2 by D0 and CDF
- Tevatron-only top mass uncertainty most likely will reach 1 GeV/c^2

m_t uncertainties in lepton+jets channel



Top mass at the LHC

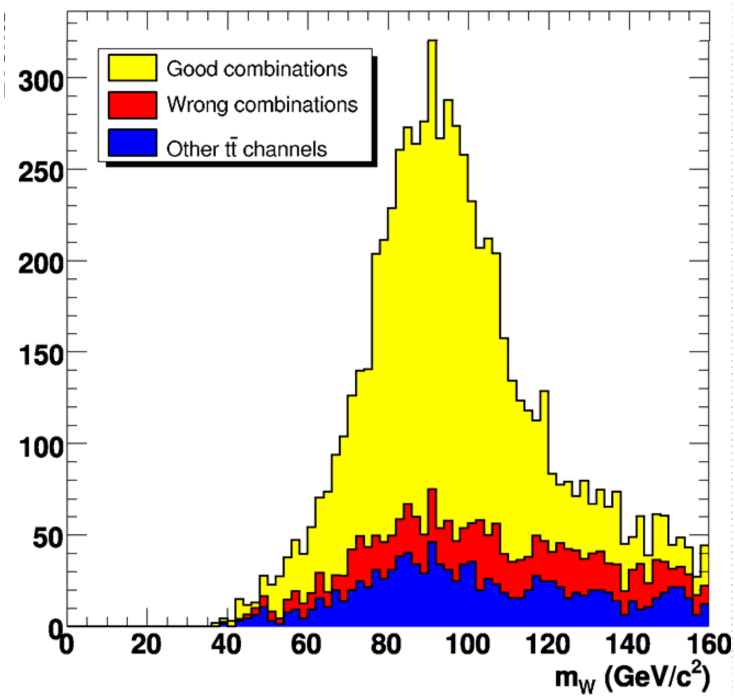
- Top factory:
  - σ_{ttbar} LHC ~ 160 σ_{ttbar} Tevatron
  - σ_{W+jets} LHC ~ 6 σ_{W+jets} Tevatron
  - S/B ~1 at Tevatron => S/B ~20 at LHC

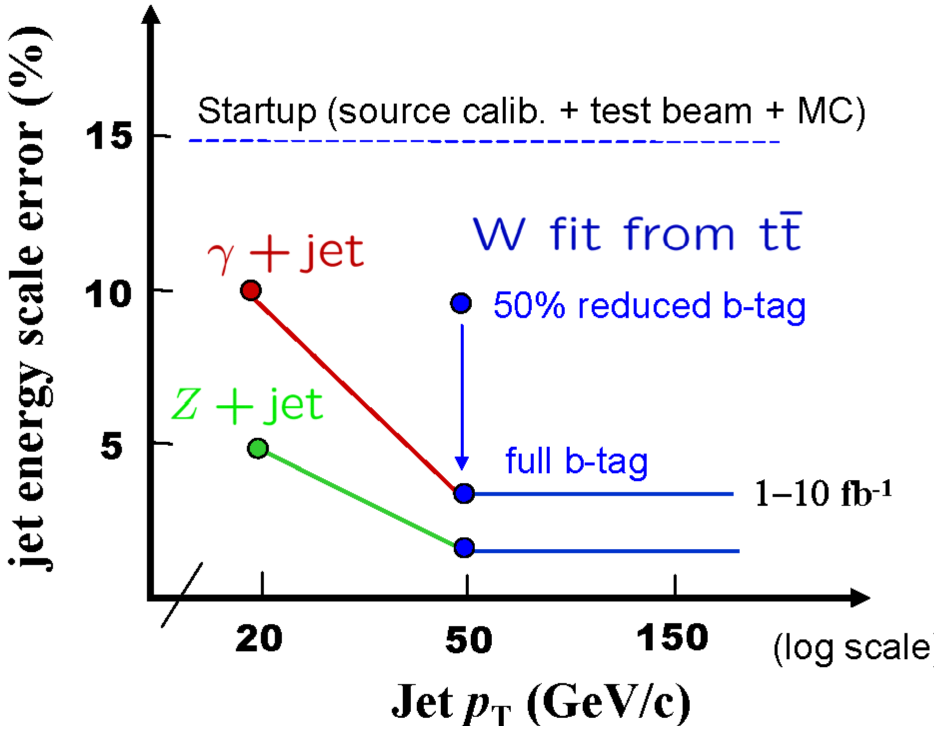


- Expected number of events in l+jets channel:
  - 130/fb^{-1}(Tevatron) → 20,000/fb^{-1} at LHC
- More radiation and more pile up
- Precision on m_t is estimated to be 1 GeV/c^2
- But by using the huge statistics to measure the mass in many different regions it should be possible to gain control of the systematic uncertainties and reduce the uncertainty even further
  - jet angles, b-jets with soft muons tagged, different number of interactions

Top mass at the LHC

- Tevatron uses W mass from LEP to reduce the uncertainties in m_t and calibrate JES
- LHC can use the Tevatron precise measurement of m_t (and LEP W mass) to calibrate JES
  - Can calibrate light JES and b-JES and b-tagging algorithms
  - Requires b-tagging ?



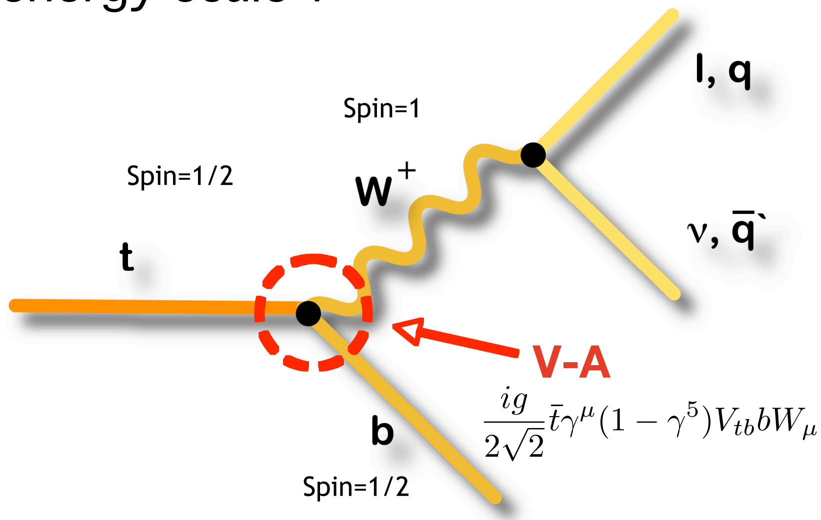


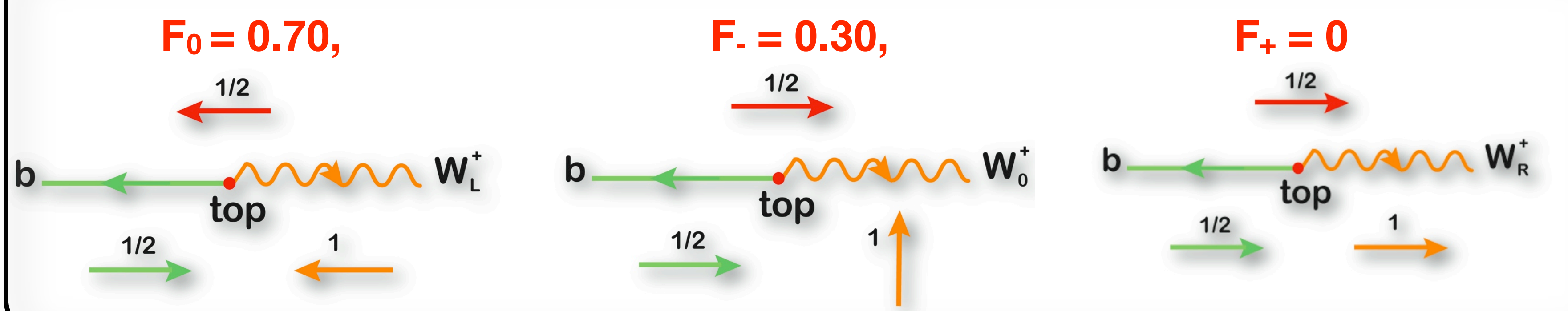
Measurement of the top couplings

Postdocs: Mousumi Datta, Ricardo Eusebi (Fermilab)

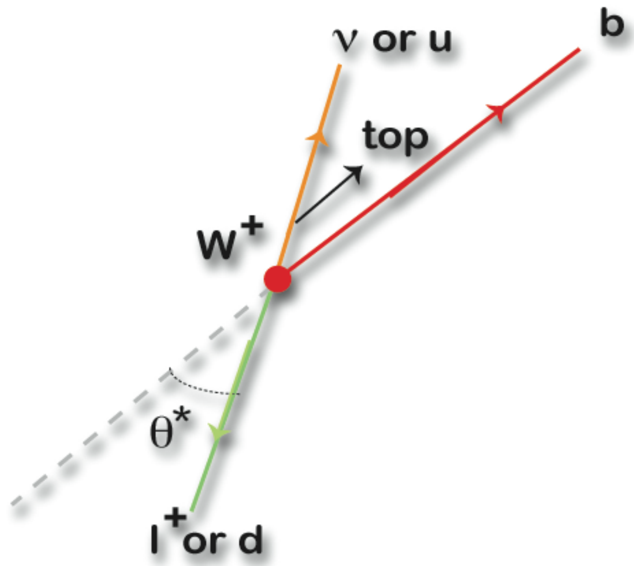
Top couplings

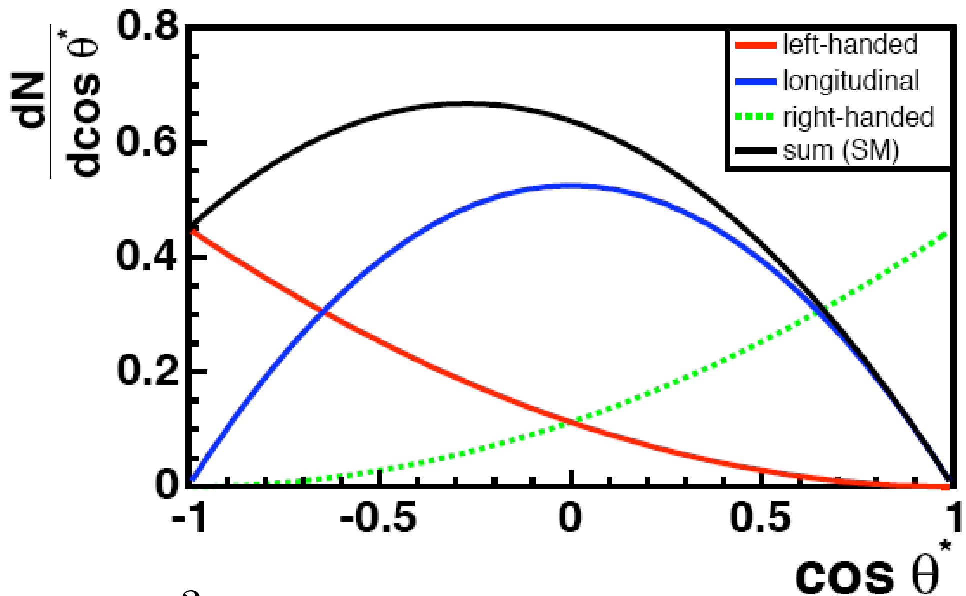
- Are there new interactions at a higher energy scale ?
- Important to directly measure the top couplings
- The V-A character of the decay determines the W boson helicity fractions :





Extracting top couplings





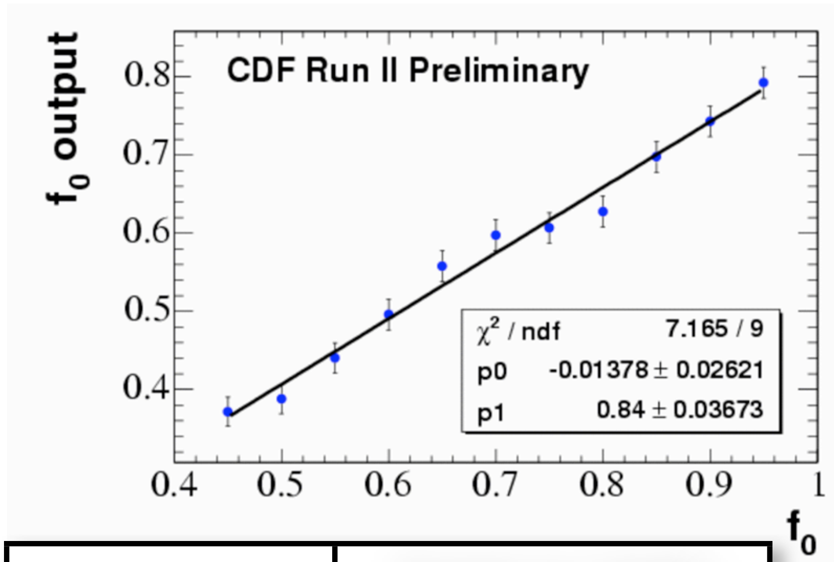
$$w(cos\theta^*) = f_+\frac{3}{8}(1-cos\theta^*)^2 + f_0\frac{3}{4}(1-cos^2\theta^*) + (1-f_0-f_+)(1+cos\theta^*)^2$$

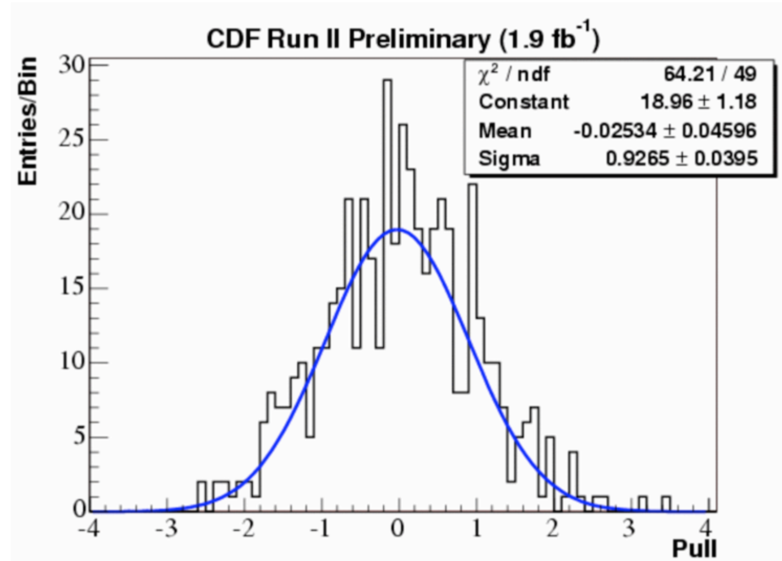
$$P_{t\bar{t}}(x;f_0) = \frac{1}{\sigma_{t\bar{t}}(m_t)}\int d\rho dm_1^2 dM_1^2 dm_2^2 dM_2^2 \sum_{perm,\nu} |M_{t\bar{t}}(f_0)|^2 \frac{f(q_1)f(q_2)}{|q_1||q_2|}\phi_6 W_{jet}(x,y)$$

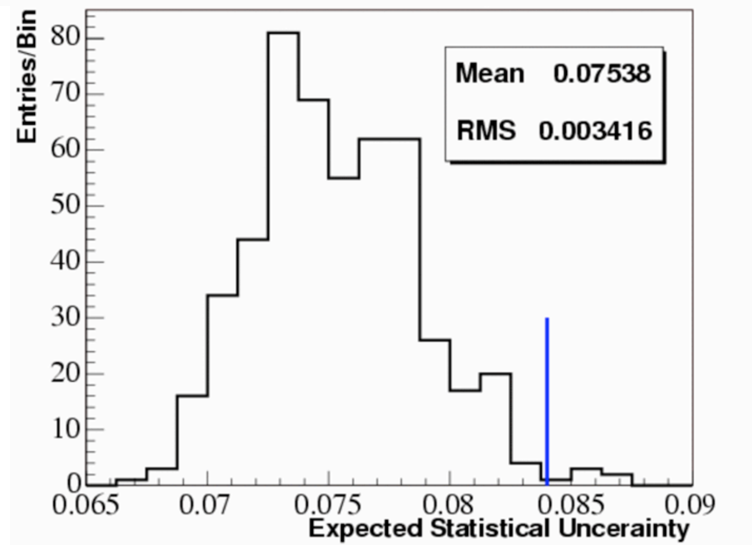
- Same technique as top mass but parametrizing the matrix element as a function f_0 assuming $f_+=0$ and using $m_t=175$ GeV/c^2

Measurement of f_0

- Use simulation to understand biases and estimate the expected uncertainties







	Events in 1.9 fb^{-1}
tt (σ_{tt}=8.2pb)	417.3 ± 56.8
W+jets	46.4 ± 16.0
non-W	17.8 ± 16.2
EWK	11.0 ± 6.7
Data	468

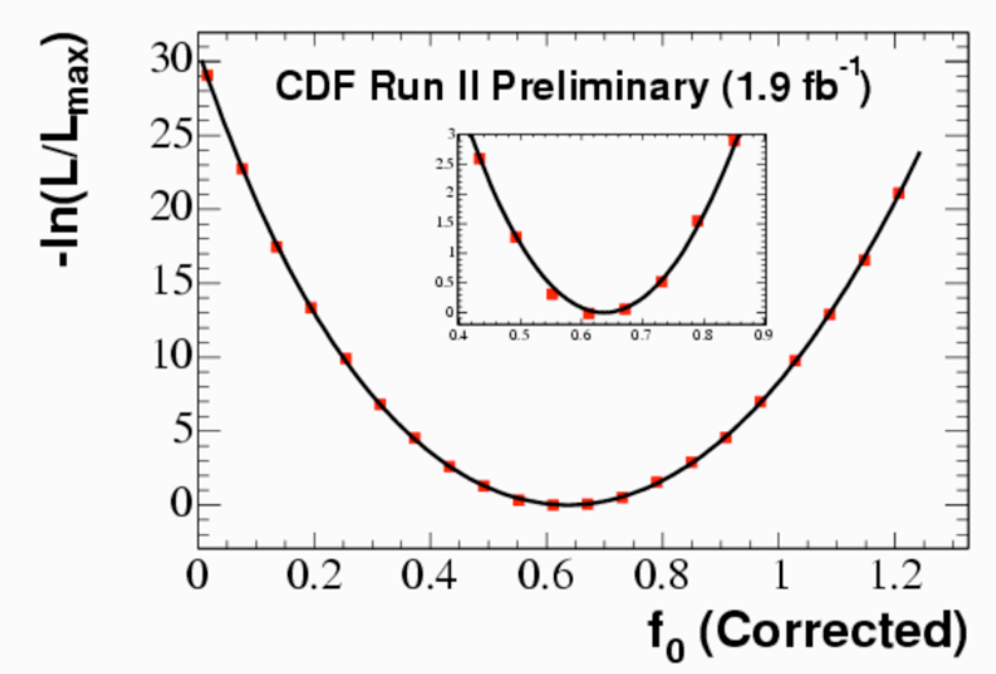
Use 4 or more jets

Measurement of f_0

- Using 1.9 fb^{-1} and assuming $f_+=0$ for m_t=175 GeV/c^2 we measure

$$f_0 = 0.637 \pm 0.084(stat) \pm 0.069(sys)$$

- Consistent with standard model expectations



Systematic uncertainties (GeV/c^2)	
JES	0.019
Initial state radiation	0.026
Final state radiation	0.020
Generator	0.050
Background	0.009
PDFs	0.023
b-tagging	0.002
Method	0.012
Total	0.069

Next: perform analysis in 2D f_0 and f_+ (model independent)

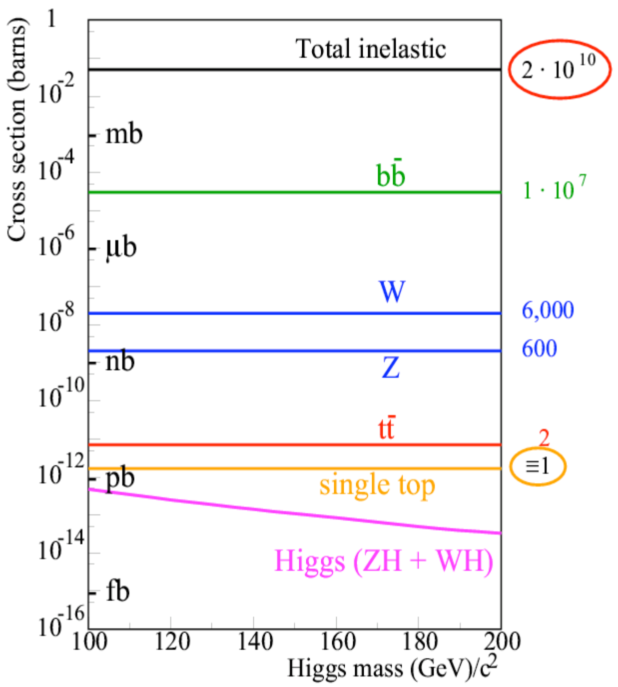
Electroweak single top production

PhD students: Peter Dong (UCLA, 2008)

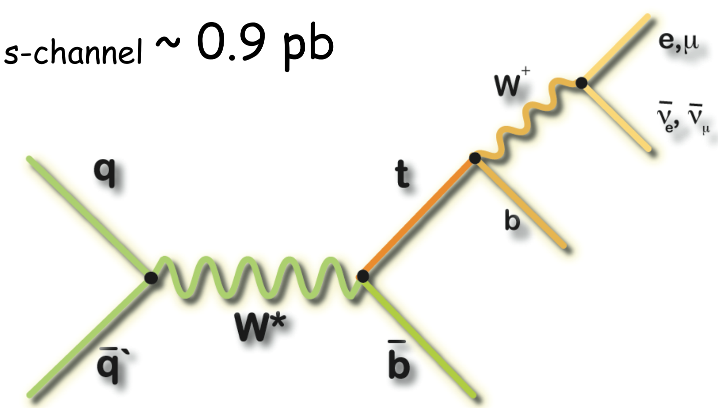
Postdoc: Bernd Stelzer (UCLA)

Single top

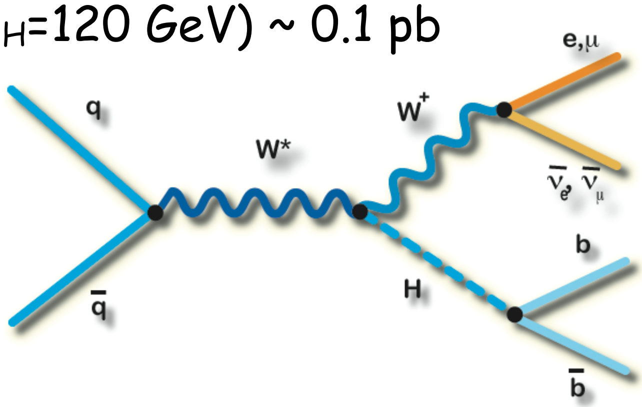
- Predicted by the standard model but only evidence by D0 in Dec. 2006
- Same signature than WH production:
  - Single top irreducible background
  - Testing ground for experimental techniques such as triggers, selection, multivariate analyses, b-tagging, jet resolution algorithms



$\sigma_{\text{s-channel}} \sim 0.9$ pb



σ_{WH} (m_H=120 GeV) ~ 0.1 pb



Single top

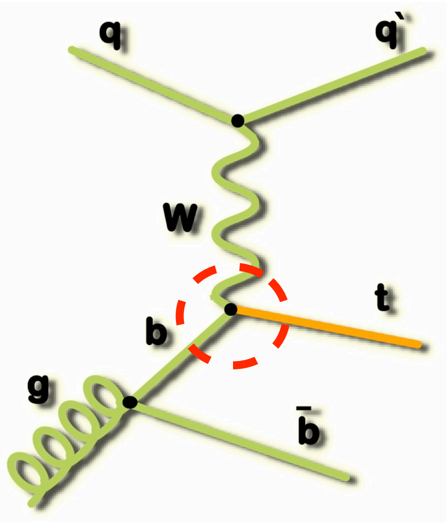
- It allows for the only direct measurement of $|V_{tb}|$ without assuming 3 generations of CKM matrix unitarity

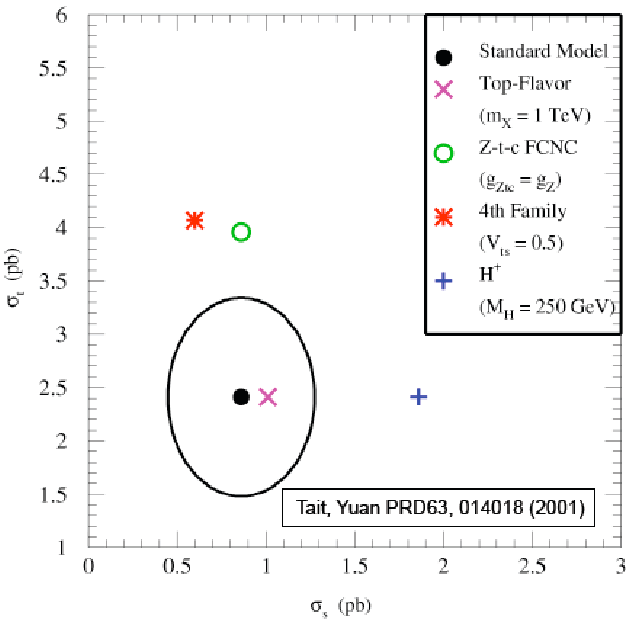
$$\sigma_{singletop} \propto |V_{tb}|^2$$

- Tests the V-A structure of EWK interaction. Production rate proportional to V-A coupling

$$\frac{ig}{2\sqrt{2}}\bar{t}\gamma^{\mu}(1-\gamma^5)V_{tb}bW_{\mu}$$

- New physics can be inferred by comparing different production modes





Single top challenge

- Backgrounds!
- Reduce backgrounds: good b-tagging, multivariate techniques

Number of Events / 1.51 fb^{-1}	Single Top	Background	S/B
$W(l\nu)$ + 2 jets	136	28300	~1/210
$W(l\nu)$ + 2 jets + b-tag	61	1042	~1/17

- Model all backgrounds: validate data and Monte Carlo
- Normalize backgrounds: estimate the amount of expected background in the sample

Backgrounds

- W+HF jets (Wbb/Wcc/Wc) ~60%
  - ALPGEN + PYTHIA
  - W+jets normalization from data and heavy flavor fractions from ALPGEN
- Mistags (W+ light flavor jets) ~20%
  - Falsely tagged light quark or gluons
  - ALPGEN + PYTHIA
  - Mistag probability parameterization obtained from inclusive jet data
- Top/EWK (WW/WZ/Z,ttbar) ~15%
  - PYTHIA
  - MC normalized to theoretical cross-section
- Non-W (QCD) 5% (about the same size as the signal!)
  - Multijets events with semileptonic b-decays or mismeasured jets
  - Anti-electron data sample
  - Fit low MET data and extrapolate into signal region

Main background: W+HF

- The W+jets contribution is not known a priori, due to large corrections to the calculable cross section at high order

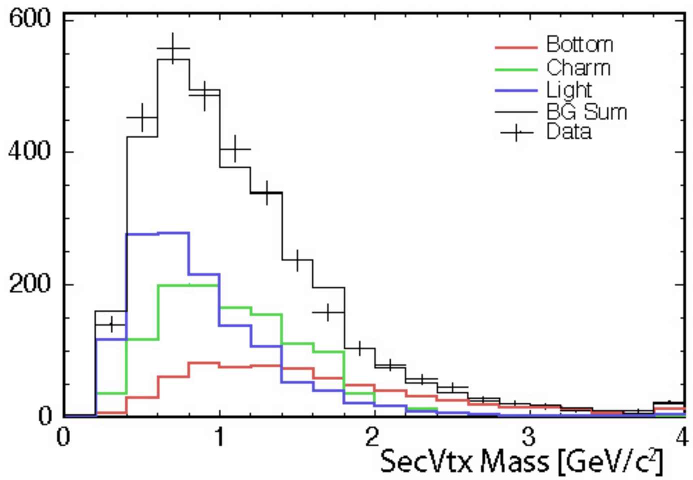
HF fraction from ALPGEN+PYTHIA

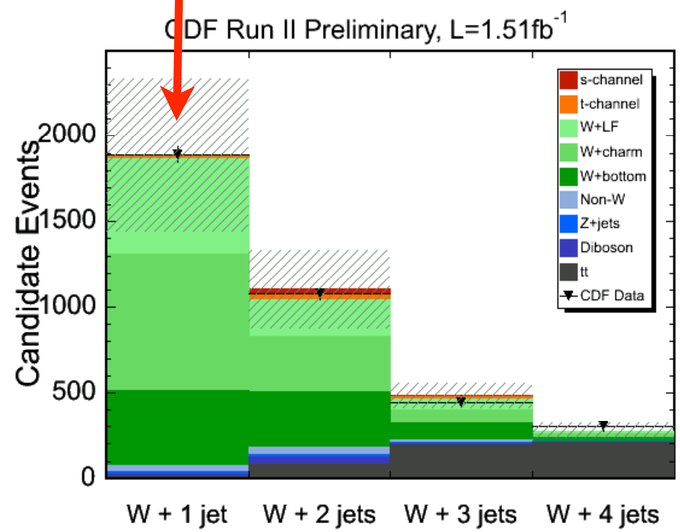
b-tagging efficiency from data

Calibrate the HF fractions by comparing W+1jet data with ALPGEN jet MC

Correct for non W+jets events

$$N^{data}_{Wb\bar{b}} = \left(\frac{N_{Wb\bar{b}}}{N_{W+jets}}\right)^{MC} \epsilon_{b-tag} K_{HF} N^{data}_{W+jets}$$



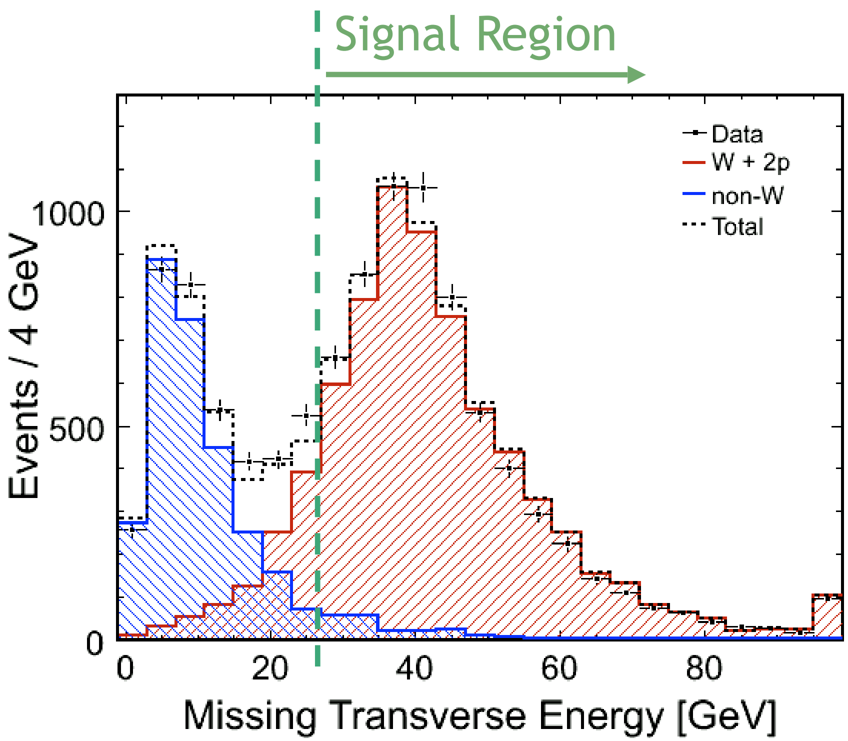


Note: similar for W+charm background

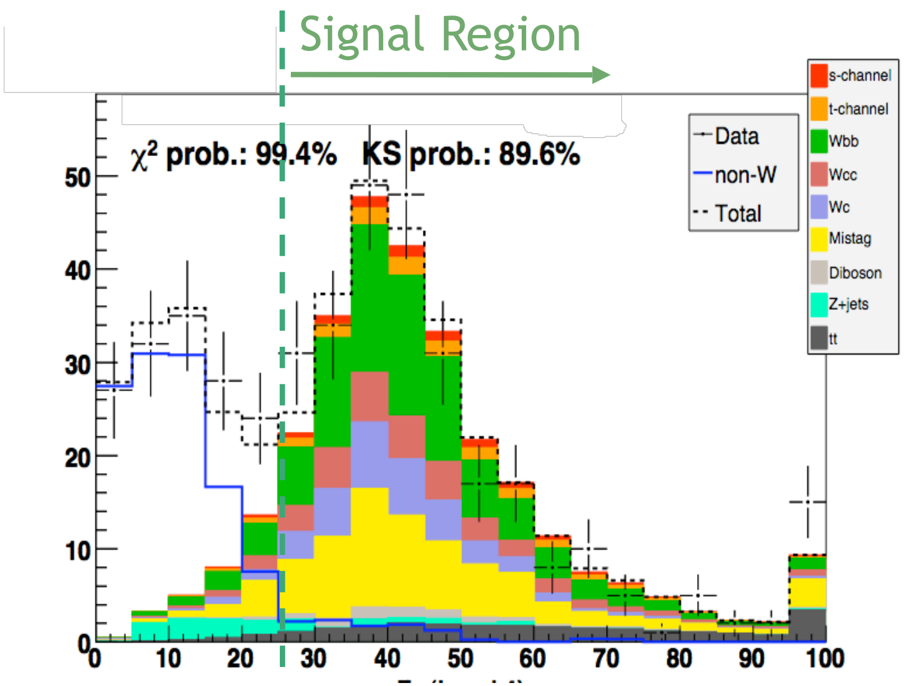
Non-W background

- Need to model background with data
- Model with anti-electron sample where at least one of the ID electron selection fails
- Obtain normalization fitting the missing E_T distribution

Before b-tagging:

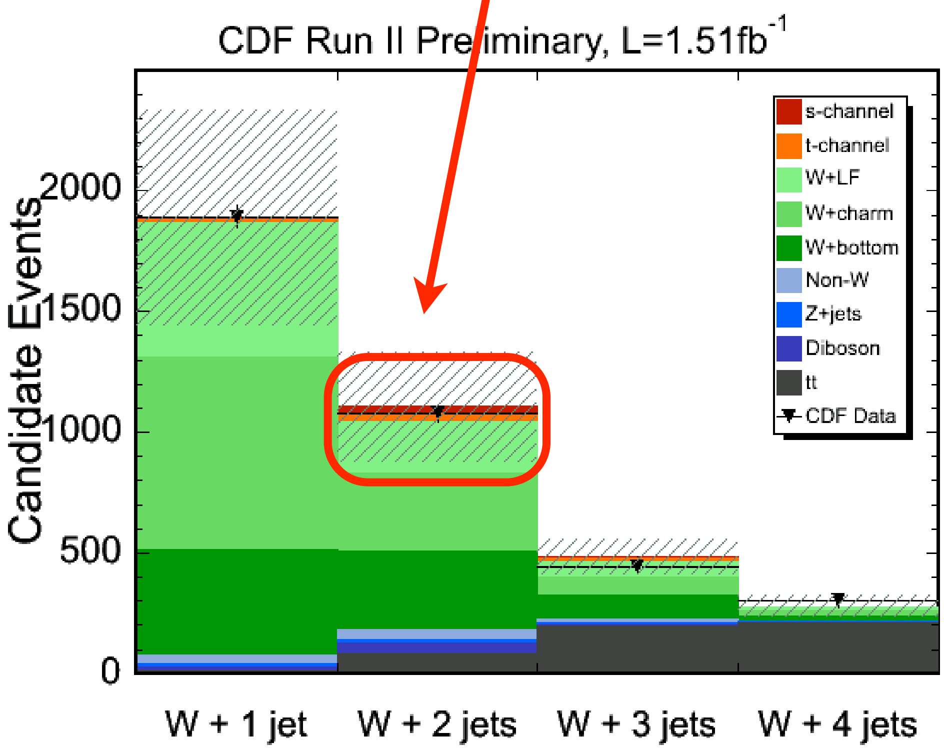


After b-tagging:



Estimate of the background

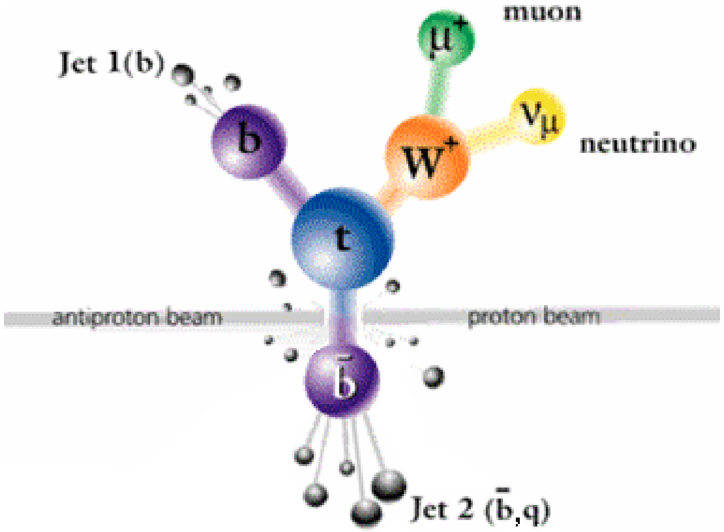
- Although we expect ~60 single top events, we expect ~1000 background events
- The uncertainty on the background is about 3 times the size f the single top and hidden behind background



CDF Run II Preliminary, L=1.51 fb^{-1}
Predicted Event Yield in W+2 jets

s-channel	23.9 ± 6.1
t-channel	37.0 ± 5.4
Single top	60.9 ± 11.5
tt	85.3 ± 17.8
Diboson	40.7 ± 4.0
Z + jets	13.8 ± 2.0
W + bottom	319.6 ± 112.3
W + charm	324.2 ± 115.8
W + light	214.6 ± 27.3
Non-*W*	44.5 ± 17.8
Total background	1042.8 ± 218.2
Total prediction	1103.7 ± 230.9
Observed	1078

Extracting single top



- Similar idea to tt analysis: only 4-body phase space
- Calculate many probability densities using matrix elements from the MADEVENT subroutines

$$P(x) = \frac{1}{\sigma}\int \underline{d\rho_{j1} d\rho_{j2} dp_z^{\nu}} \sum_{perm} |M|^2 \frac{f(q_1)f(q_2)}{|q_1||q_2|}\phi_4 W_{jet}(x,y)$$

3 integrals: we choose those quantities measured the least precisely

4-body phase space

Signal: s-channel t-channel
Backgrounds: Wbb Wcc Wcj

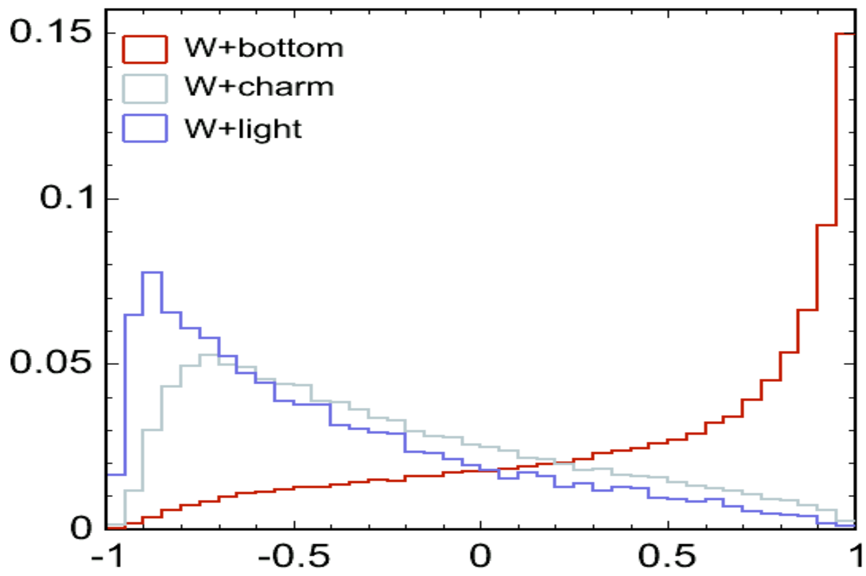
Discriminant

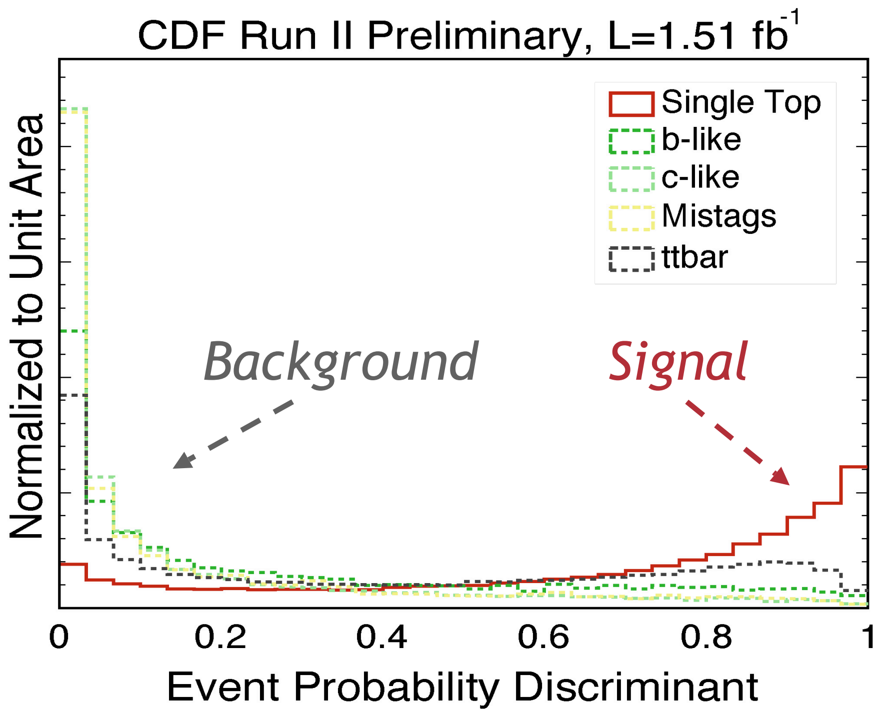
- Define ratio of probability density hypotheses as event probability discriminant (EPD):

$$EPD = \frac{b \cdot P_{singletop}}{b \cdot P_{singletop} + b \cdot P_{Wb\bar{b}} + (1-b) \cdot P_{Wc\bar{c}} + (1-b) \cdot P_{Wcj}}$$

b = Neural Network b-tagger output

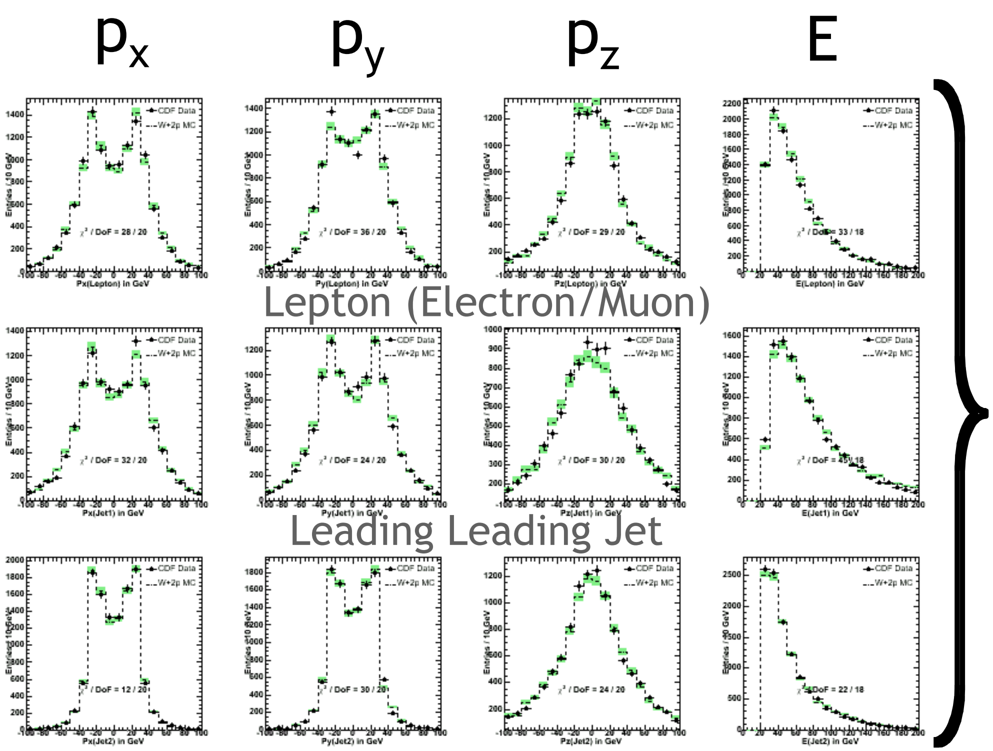
Separate tagged b-jets from charm/light jets using a NN trained with tracking information:

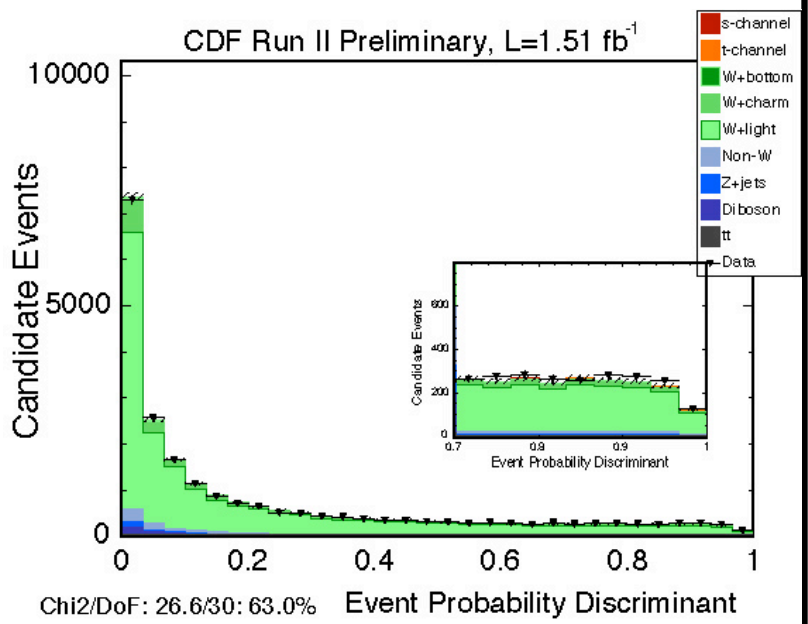




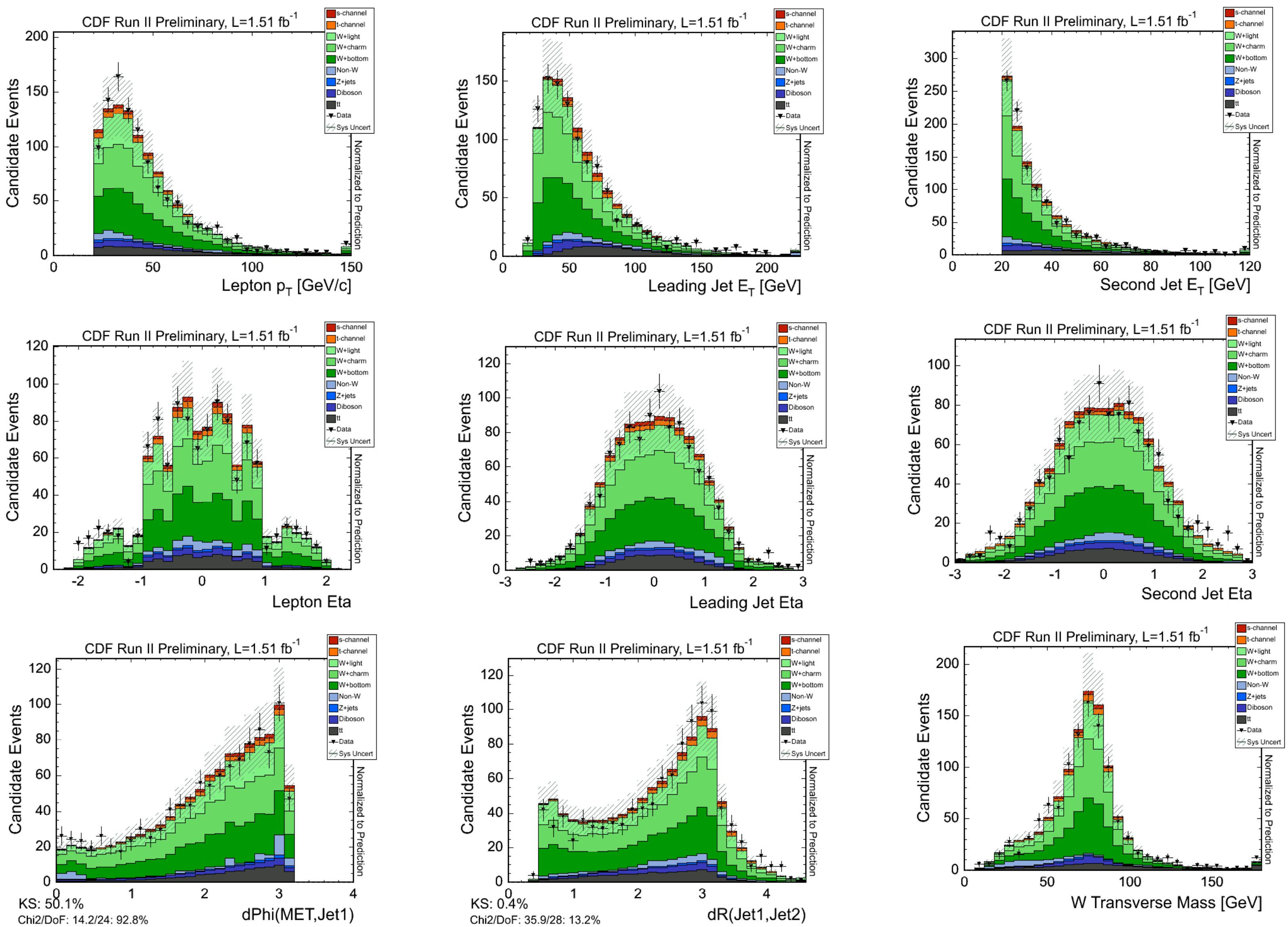
Cross-checks

- Multivariate techniques require validating input and EPD templates in various data control samples
  - W+2 jets data (veto b-jets, selection orthogonal to the candidate sample)
  - Similar kinematics, with very little contribution from top (<0.5%)





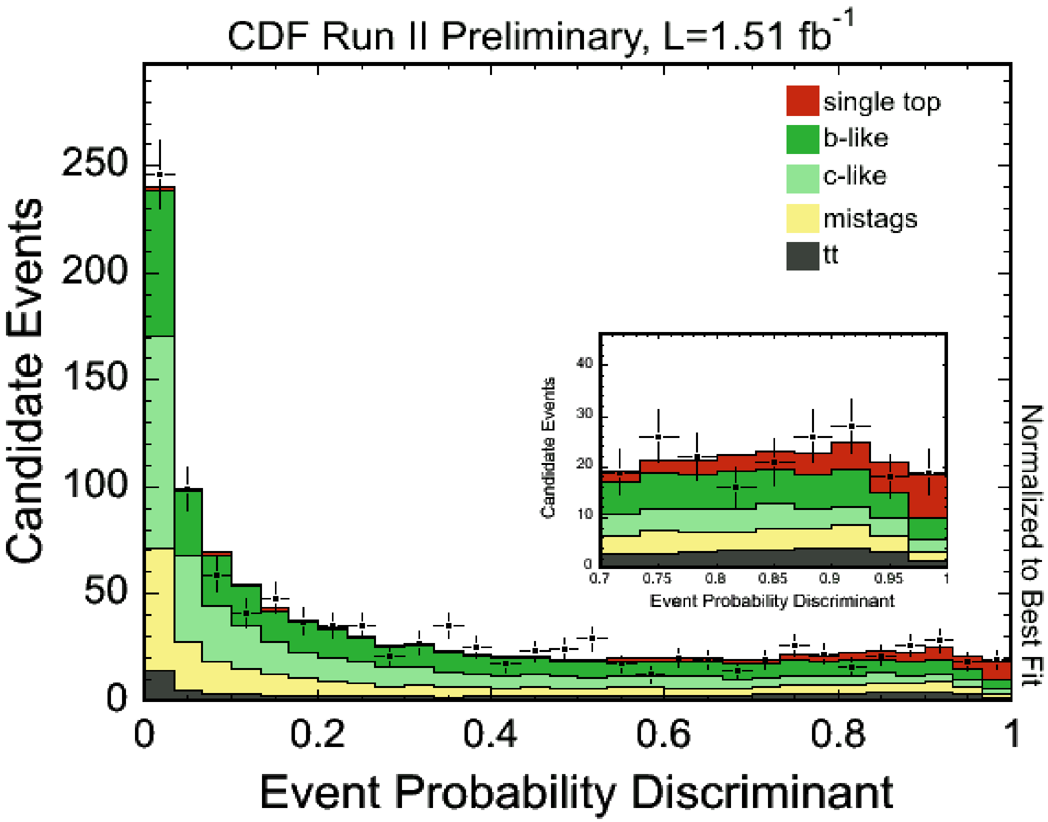
MC modeling checks

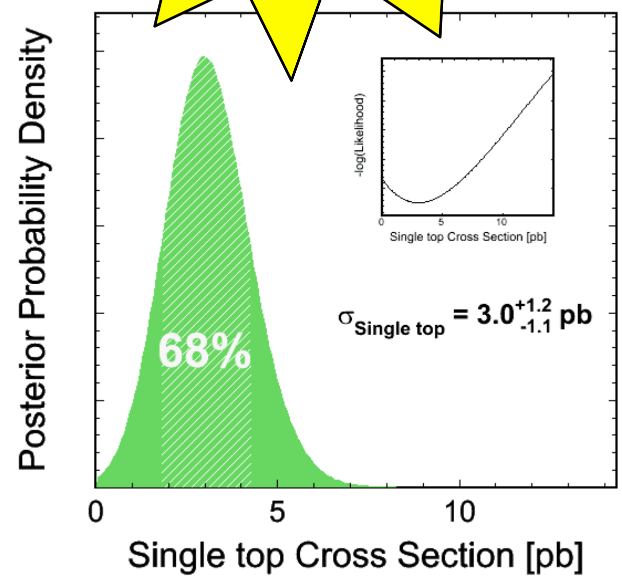


- Using 1.5 fb^{-1} we measure

$$\sigma_{singletop} = 3.0^{+1.2}_{-1.1} pb$$

3.1 σ Evidence





Median p-value = 0.13% (3.0σ)

Observed p-value = 0.09% (3.1σ)

(new) Single top & Higgs

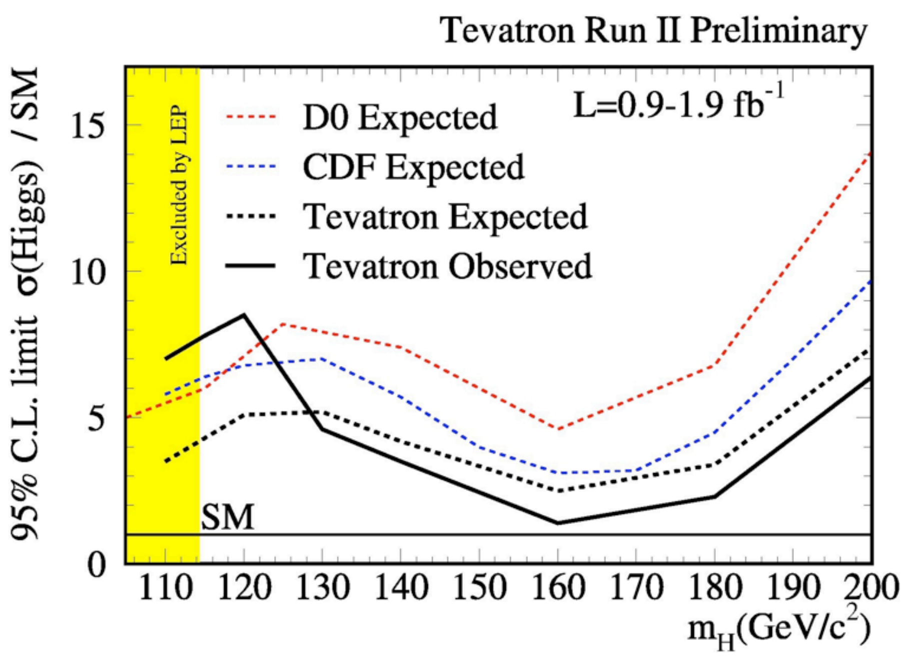
PhD students: Peter Dong (UCLA), Barbara Alvarez, Bruno Casal (Cantabria)

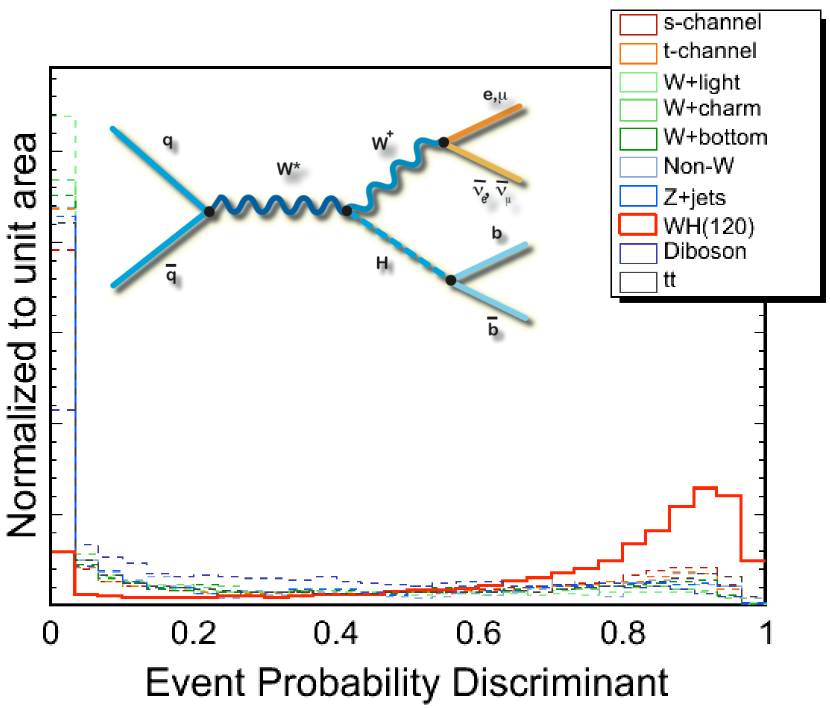
Postdocs: Bernd Stelzer (UCLA), Craig Group, Enrique Palencia (Fermilab)

Search for Higgs boson

- Technique and improvements in single top are now implemented in Higgs searches

$$EPD = \frac{b \cdot P_{WH}}{b \cdot P_{WH} + b \cdot P_{st} + b \cdot P_{Wbb} + b \cdot P_{tt} + (1-b) \cdot P_{Wcc} + (1-b) \cdot P_{Wcj}}$$



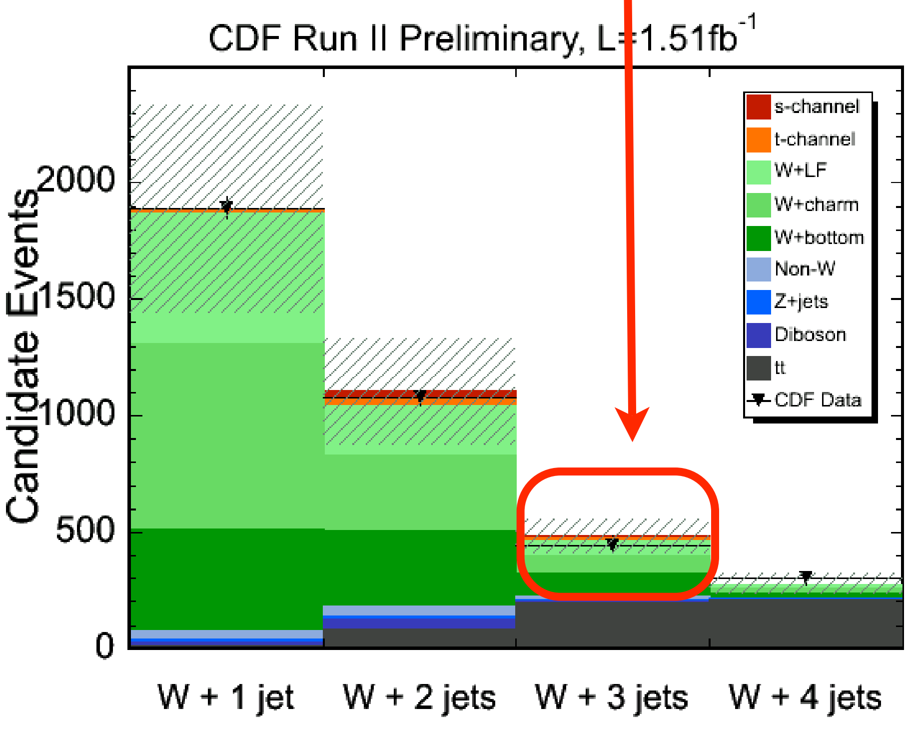


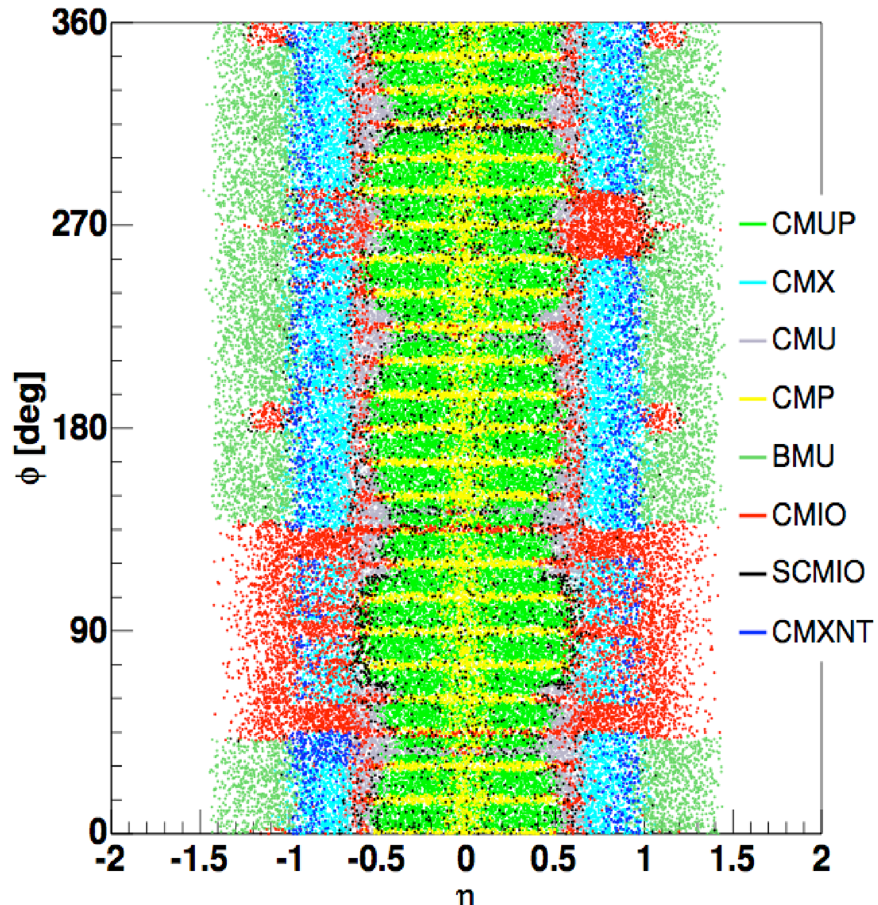
4 improvements

- Maximizing sensitivity

Increased acceptance by35% including a non-lepton trigger (MET +jets) All new muons but CMPU, CMX

Added the 3-jet bin: greater ttbar contamination





New EPD with more probability densities in the 2 and 3 jets bins: ttbar and W+light

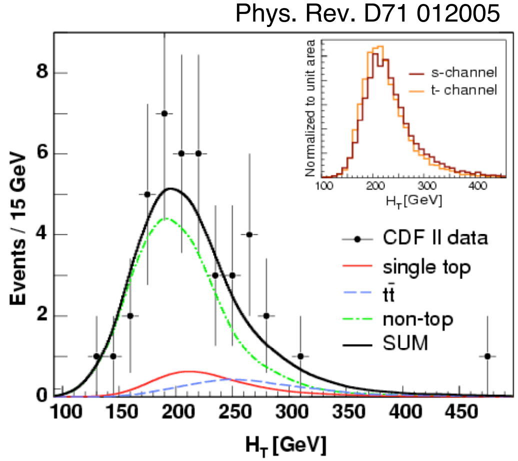
More information in jet transfer functions (larger cone size, η) and added gluon jets

4 improvements

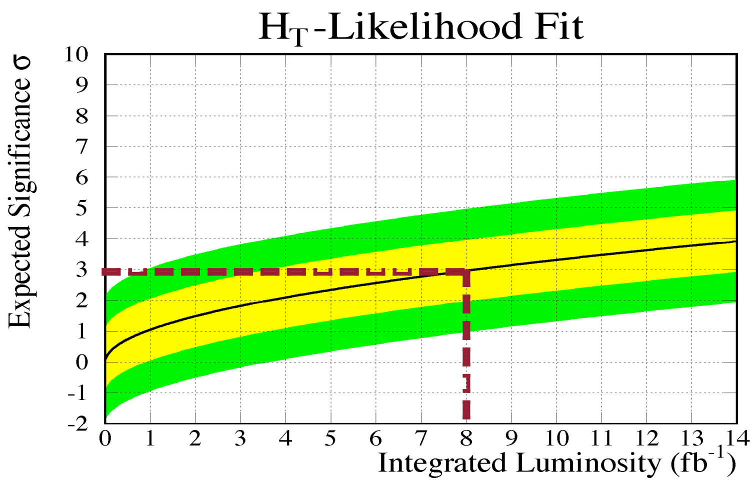
- Using the single top analysis as a benchmark:
- + matrix element improvements: 9.2% gain, mostly ttbar matrix element and new transfer functions
- + new muons from MET+jets trigger: 8% gain
- + two- and three-jet bin combined: 3.5% gain

History and future

2004: Simple analysis while refining Monte Carlo samples and analysis tools



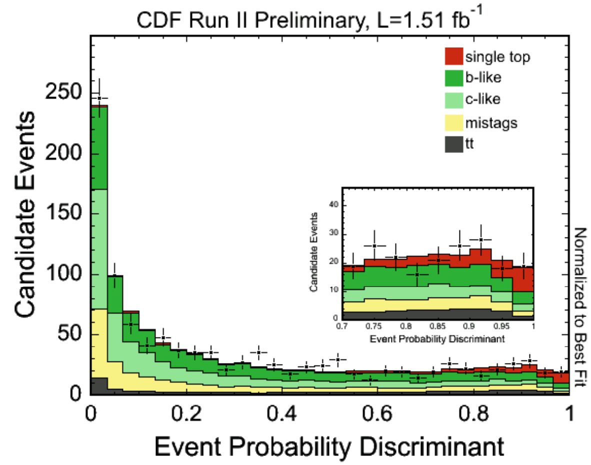
First Tevatron Run II result using 162 pb^{-1}
$\sigma_{single\ top}$ **< 17.5 pb at 95 % C.L.**



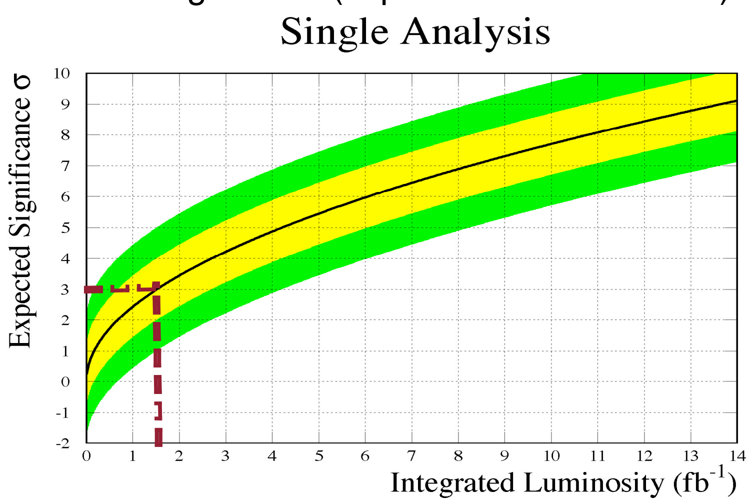
2 Years

- *Development of powerful analysis techniques (Matrix Element, NN, Likelihood Discriminant)*
- *NN Jet-Flavor Separator to purify sample*
- *Refined background estimates and modeling*
- *Increase acceptance (forward electrons)*
- *10x more data*

2006: Established sophisticated analyses
Check robustness in data control samples

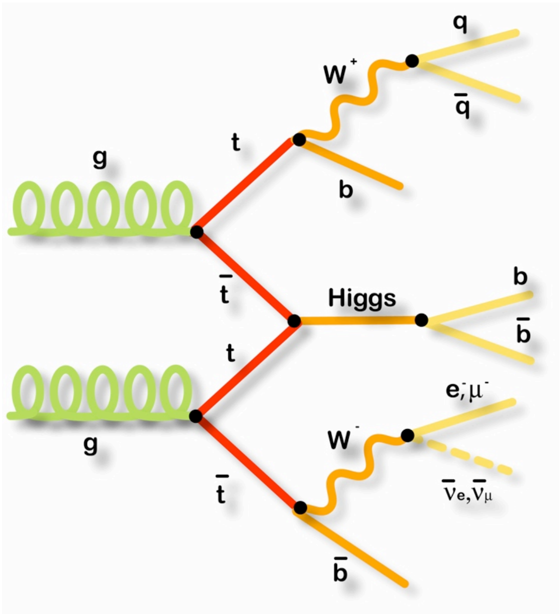


2007: Evidence for single top quark production using 1.5 fb^{-1} (expected and observed!)



Higgs at the LHC

- For a Higgs mass < 135 GeV
  - Tevatron may find H→bb
  - LHC should discover H→γγ, H→ZZ
  - Complementary results would help to confirm if it is the Higgs boson
- LHC will also have access to ttH with H→bb
  - Important to measure Yukawa coupling
  - Enhanced in MSSM by 10–20% compared to standard model
  - Very challenging channel!
  - One lepton: tracking, alignment, trigger
  - Many jets: calorimeter EM and HAD calibration, JES
  - Missing transverse energy
  - b-jets: good (very good) b-tagging
    - ttbar events will enable understanding of these tools, **eg. R=BR(t→Wb) / BR(t→Wq)**
  - Multivariate techniques to separate signal and background



Summary

- Top quarks offer a way to learn about the Higgs boson and explore the electroweak scale
  - Precise measurements of m_t at the Tevatron will reach 1 GeV/c^2
  - Couplings begin to be systematically limited
  - Single top in the horizon
  - Searches for Higgs boson at the Tevatron are rapidly improving
- Top quark physics is experimentally challenging and rich
  - It is at the core of hadron collider physics
  - Produced many experimental techniques for high p_T physics
    - Triggers, jet energy scale, b-tagging, etc.
    - Multivariate techniques
    - Shape and rate of backgrounds
  - It will play a main role in calibrating and understanding the LHC experiments
- These are the most exciting years!

Likelihood fit

$$\mathcal{L}(\beta_1, \ldots, \beta_5; \delta_1, \ldots, \delta_{10}) = \underbrace{\prod_{k=1}^{B} \frac{e^{-\mu_k} \cdot \mu_k^{n_k}}{n_k!}}_{Poisson\ term} \cdot \underbrace{\prod_{j=2}^{5} G(\beta_j | 1, \Delta_j)}_{Gauss\ constraints} \cdot \underbrace{\prod_{i=1}^{10} G(\delta_i, 0, 1)}_{Systematics}$$

- Systematic uncertainties can affect rate and template shapes
  - Rate systematics give fit templates freedom to move vertically only
  - Shape systematics allow events to ‘slide horizontally’ (from bin to bin)