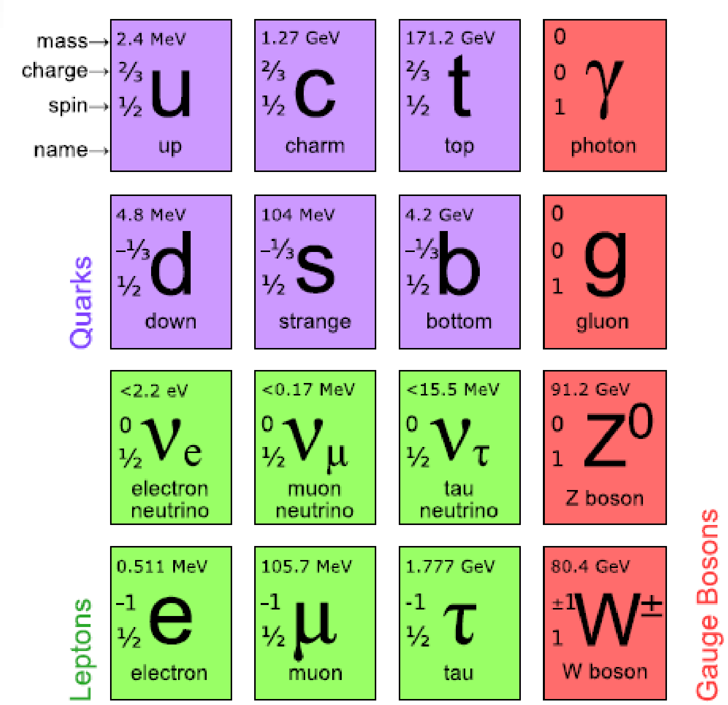
Top Quark Introduction

The last quark discovered. Precision SM measurements predict its existence and its mass.
In particular the asymmetry backward-forward of b-jets produced in e+e- annihilation at the Z resonance can be easily explained assuming that the b quark is in an SU(2) doublet with the top quark
Precision electroweak fits constrained the mass: 178^{+8+17}_{-8-20} GeV

The top discovery dates 1995 by the two experiments at the Tevatron Collider.

We are now in the era of precision top measurements

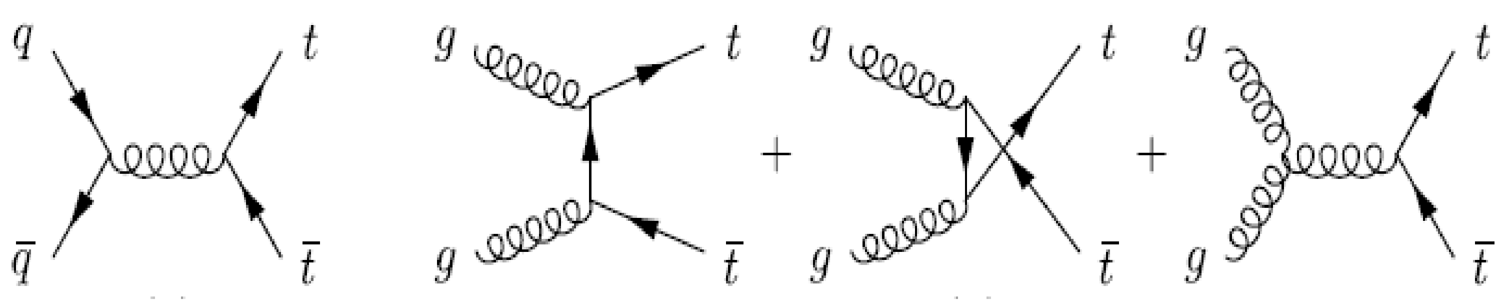


Top Quark Cross Sections

$$\sigma(pp \to t\bar{t} + X) = \sum_{i,j} \int dx_i dx_j \times F_i(x_i,\mu) F_i(x_j,\mu) \hat{\sigma}_{ij}(x_i, x_j, m_{top}^2, \mu^2)$$

$m_{top}/2 < \mu < 2m_{top}$ since the mass is so large the calculation can be performed with the perturbative QCD

At LO the diagrams that contribute are



LHC: 80% gluon fusion 20% $q\bar{q}$

Tevatron: 85% $q\bar{q}$ 15% gluon fusion

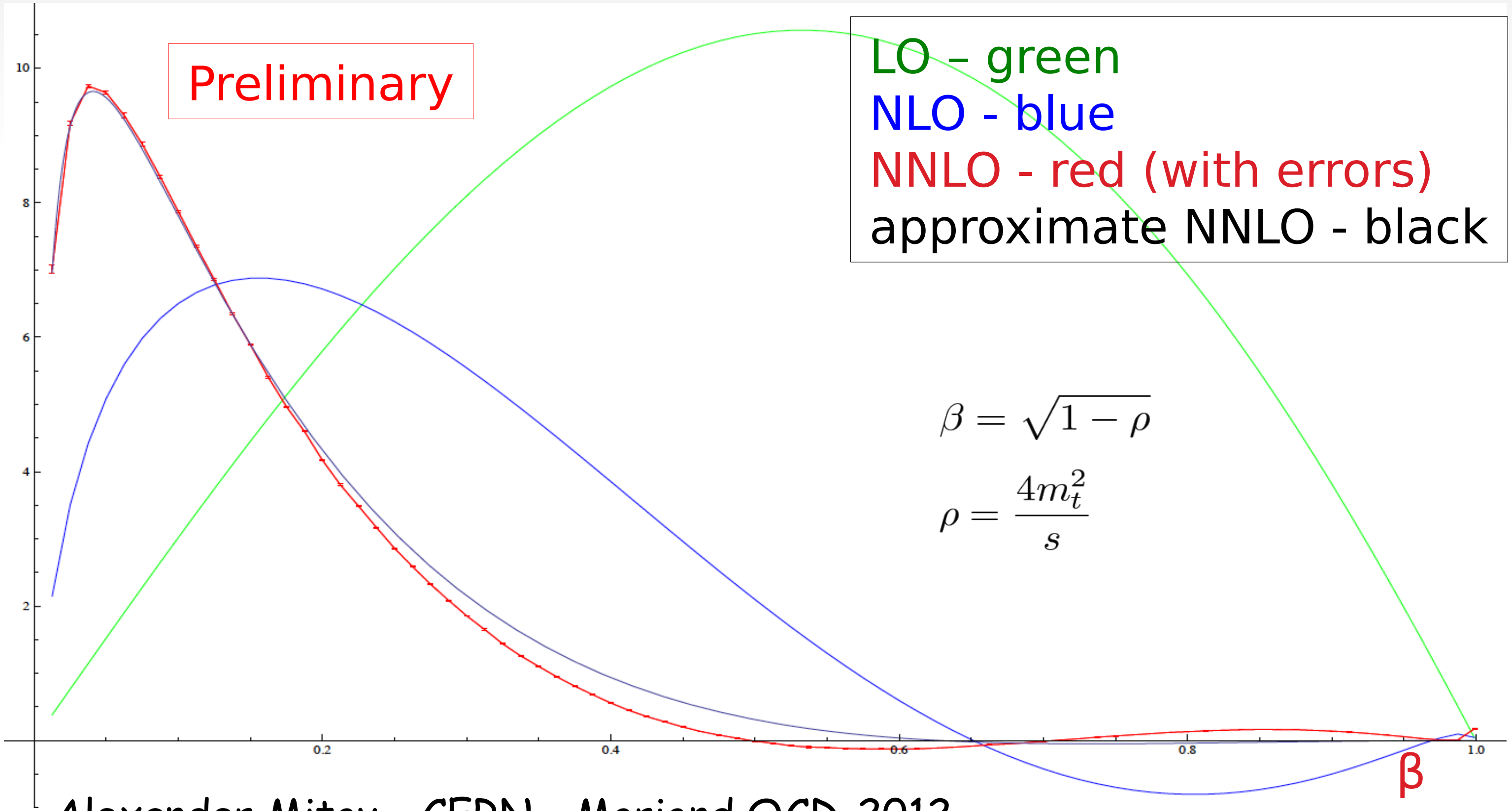
NLO calculations available.

Top Quark Cross Sections high order

NLO calculations are important: ~50%

Since not everything is in agreement with the theoretical expectations theoreticians are calculating also the NNLO corrections

$$\hat{\sigma}_{q\bar{q}\to t\bar{t}}(\beta) = \frac{\alpha_S^4(m_t)}{m_t^2}\left\{\mathrm{LO} + \mathrm{NLO} + \mathrm{NNLO}\right\}$$



$$\beta = \sqrt{1-\rho}$$

$$\rho = \frac{4m_t^2}{s}$$

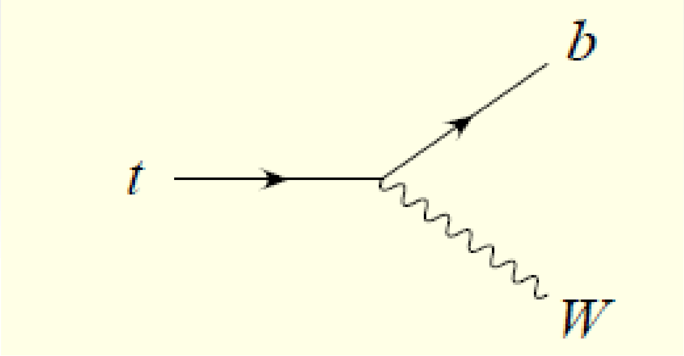
Alexander Mitov – CERN - Moriond QCD-2012

Top Quark Decay

Quark top decay before it can form a bound state

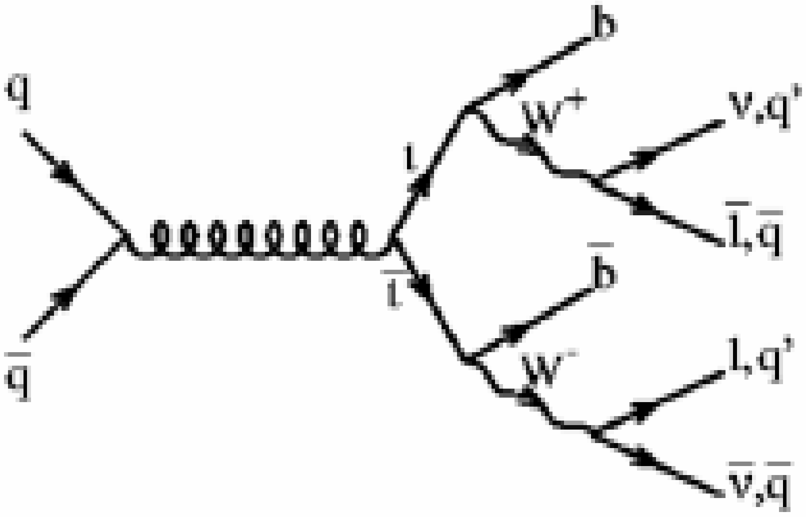
$\tau_t \simeq 10^{-25}$ sec   compare to $\tau_{\rm QCD} \simeq 10^{-24}$ sec

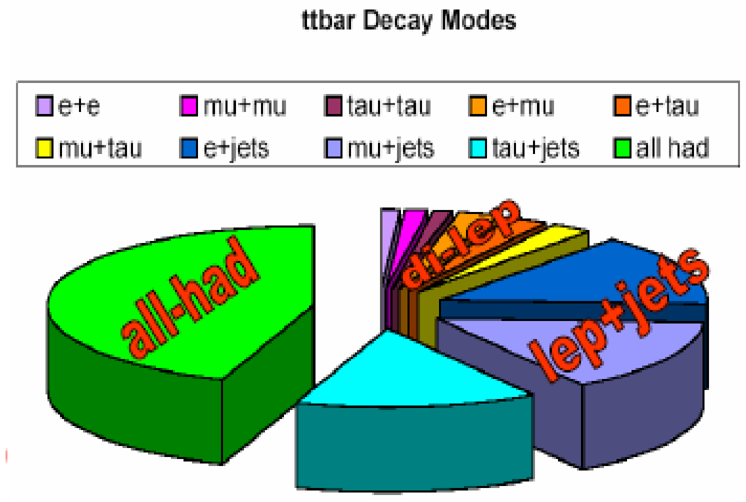
It decays predominantly



$$t \rightarrow bW^+ \begin{cases} W^+ \rightarrow l^+\nu_l \\ W^+ \rightarrow q\bar{q}' \end{cases}$$

The event is





Cross Section Definition

In order to measure the top-anti-top cross section we need:

$$\sigma_{tt} = \frac{N_{Data} - N_{Background}}{Acc\int Ldt}$$

N_{Data} = number of events identified

$N_{Background}$ = number of events of background that passes the selections

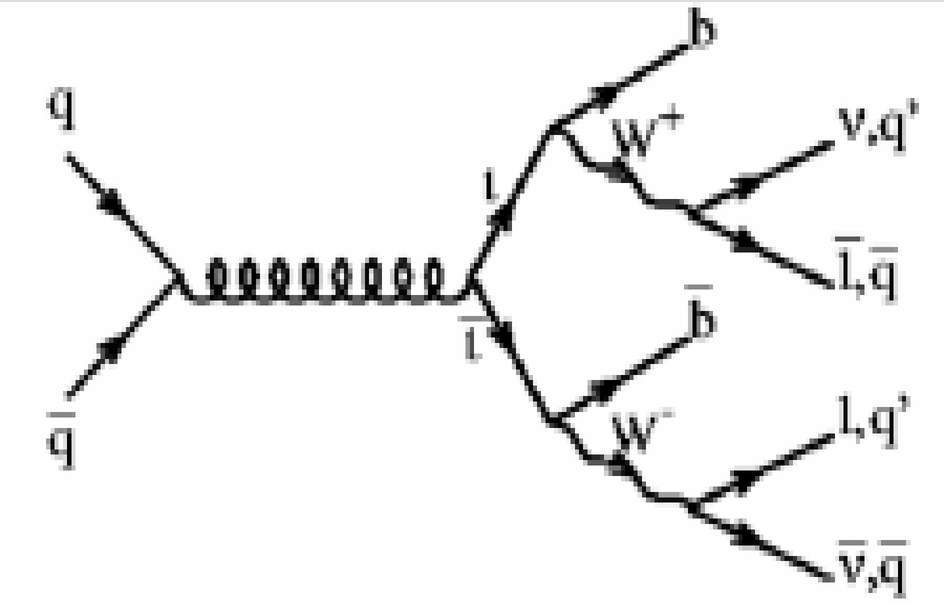
Acc = acceptance

$\int Ldt$ = integrated luminosity

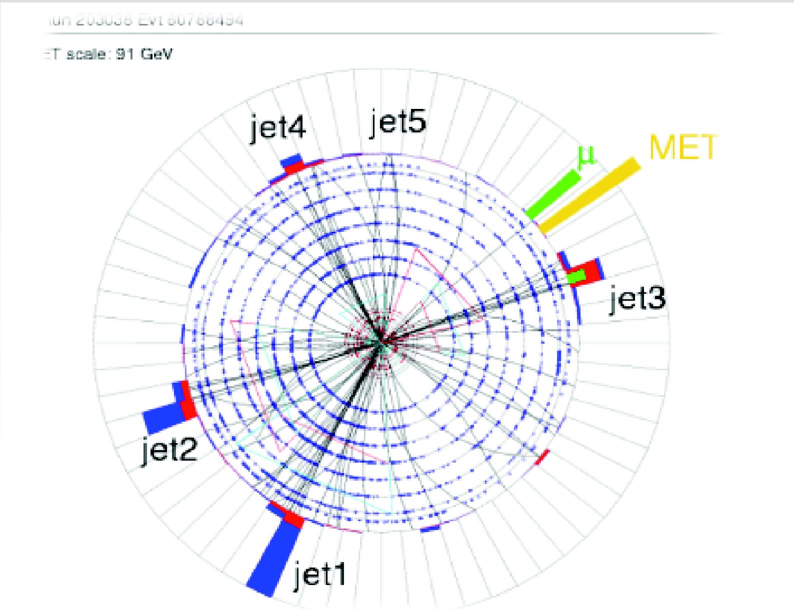
These numbers have to be evaluated for each selection

Top Quark Reconstruction

Theory



Detector



Events classified depending on the W decay:

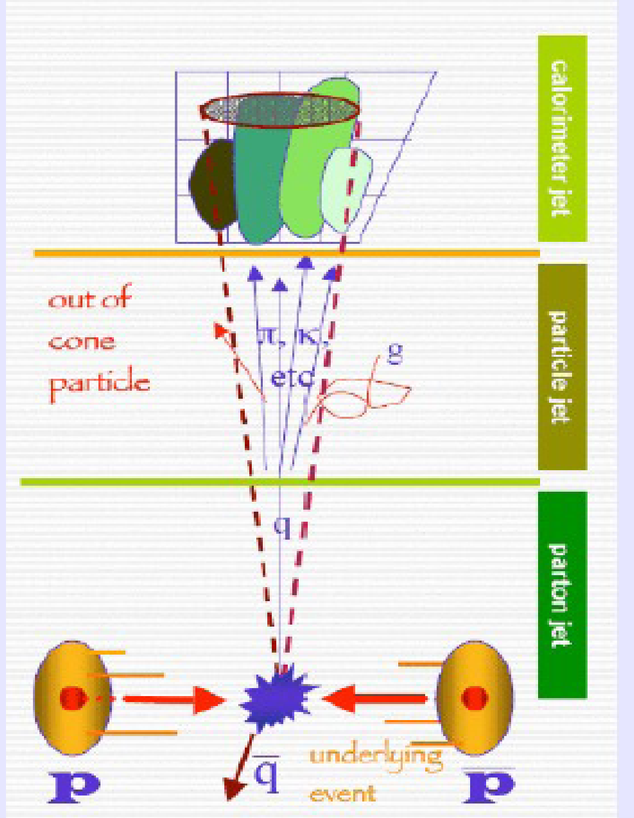
- Di-lepton: low yield, low background, well defined leptonic signature, neutrinos → MET
- Lepton+jets: higher yield, moderate background, lepton signature + MET + jets
- All hadronic: highest yield, huge background, only jets

Top Quark Events Reconstruction: Common tools

Final states always with jets and b-quark in jets.

1. Reconstruct jets
2. Use b-tag algorithm to determine if the jet is originated by a b-quark

1.



Use cone algorithm

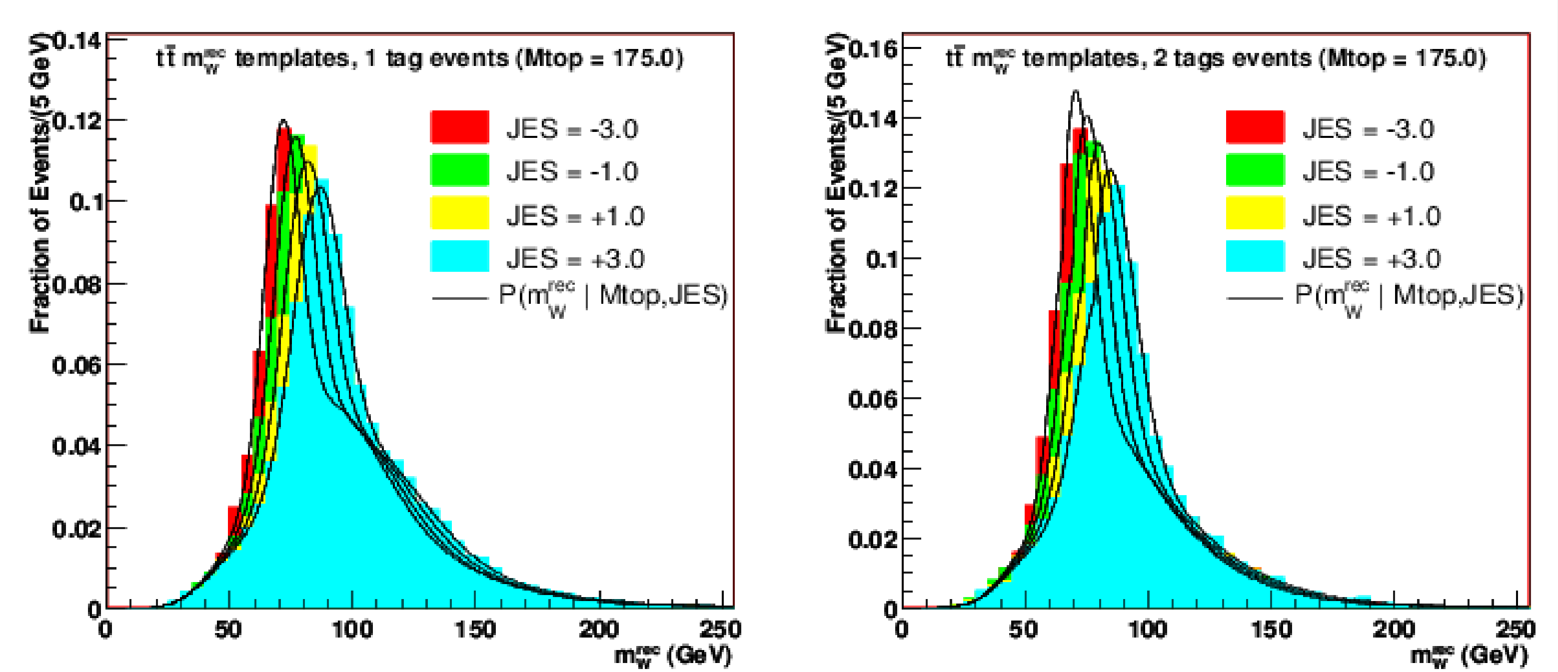
Jet Energy Scale (JES) is one of the major source of uncertainty (see discussion on jet reconstruction)

Top analysis now use a new method to determine the energy scale: the "in situ" calibration.

Common Tools: "In situ" Energy Calibration

In the decay channels where both Ws decay in hadrons it is possible to leave the JES as free parameter and fit the W mass.

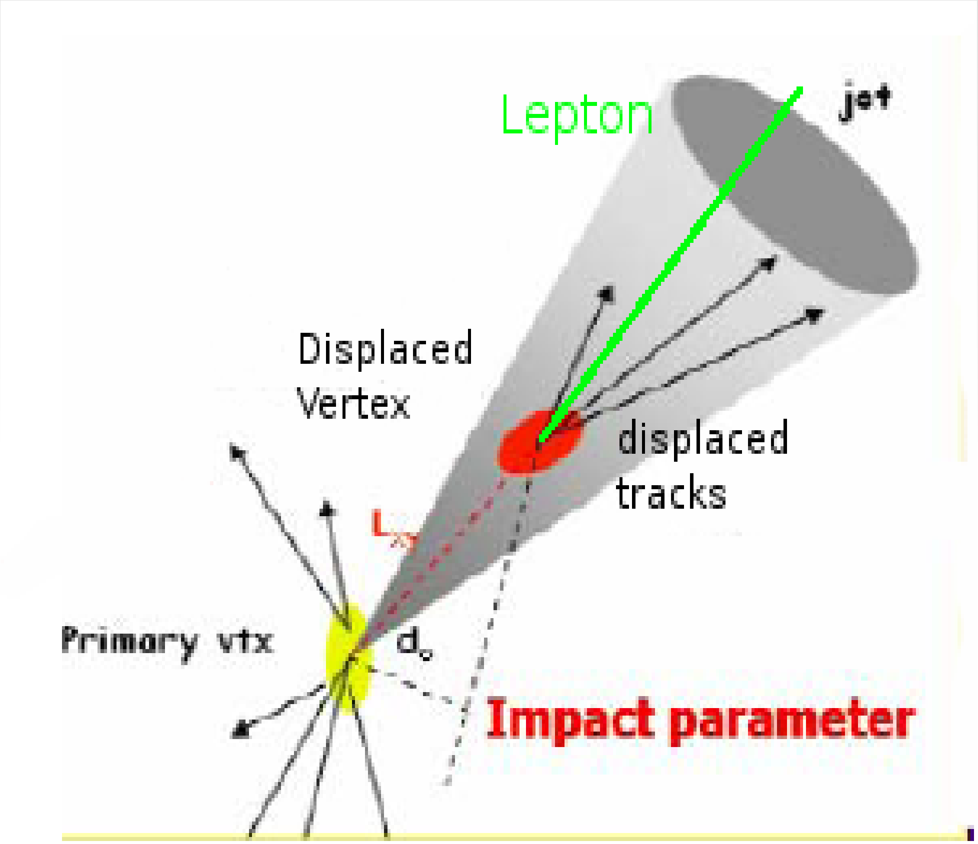
Templates with different JES are produced and the W mass is fitted



$$\chi^2 = \frac{\left(M_{jj}^{a} - M_W^{rec}\right)^2}{\Gamma_W} + \frac{\left(M_{jj}^{b} - M_W^{rec}\right)^2}{\Gamma_W}$$

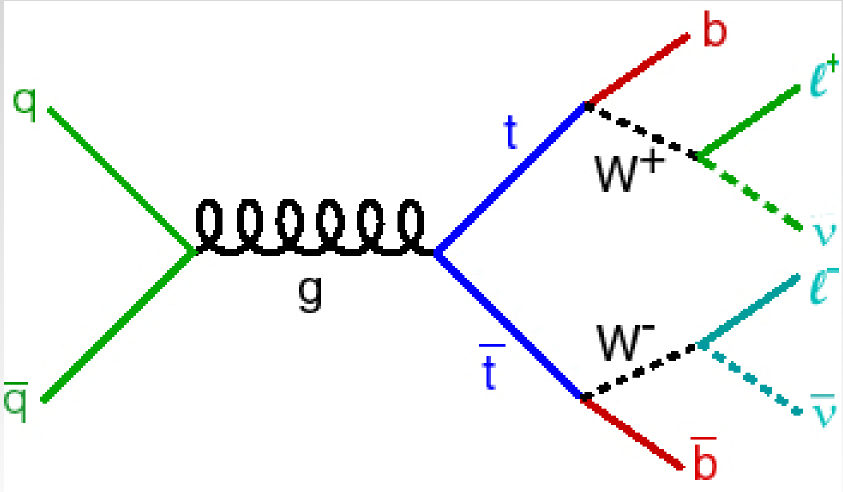
Top Quark Reconstruction:Common tools

2. Use b-tag algorithm to determine if the jet is originated by a b-quark



- Select tracks with high impact parameter respect to primary vertex
- Request at least 2 tracks
- Fit the tracks to identify a secondary vertex
- Cut on decay lenght L_{xy} to be compatible with the distance traveled by a b-hadron

Top Quark Decay Selections

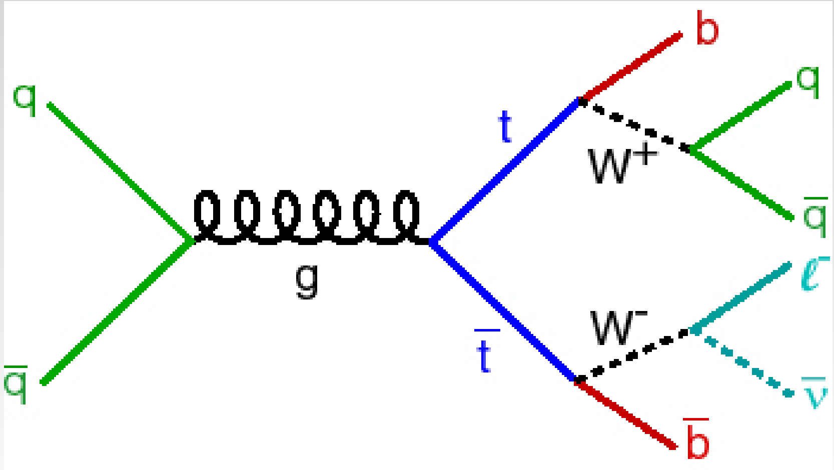


Requirements:

- two high P_T opposite charge isolated leptons
- at least 2 high E_T jets
- at least one vertex b-tag
- Significant MET

Major Backgrounds

- Process with 2 leptons in the final state: Drell-Yan Z/γ^*, WW,WZ,ZZ
- QCD: fake leptons



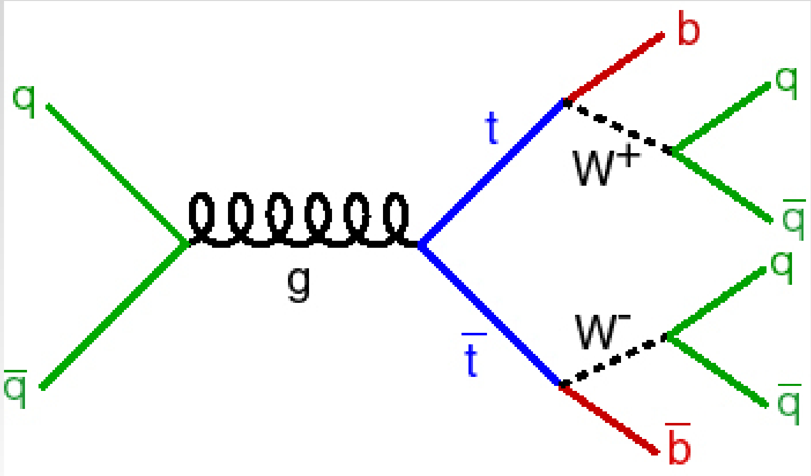
Requirements:

- one high P_T isolated leptons
- at least 4 high E_T jets
- at least one b-tag
- Significant MET

Major Background

- Process with 1 lepton + jets in the final state: W+jets
- Other contributions from non-W

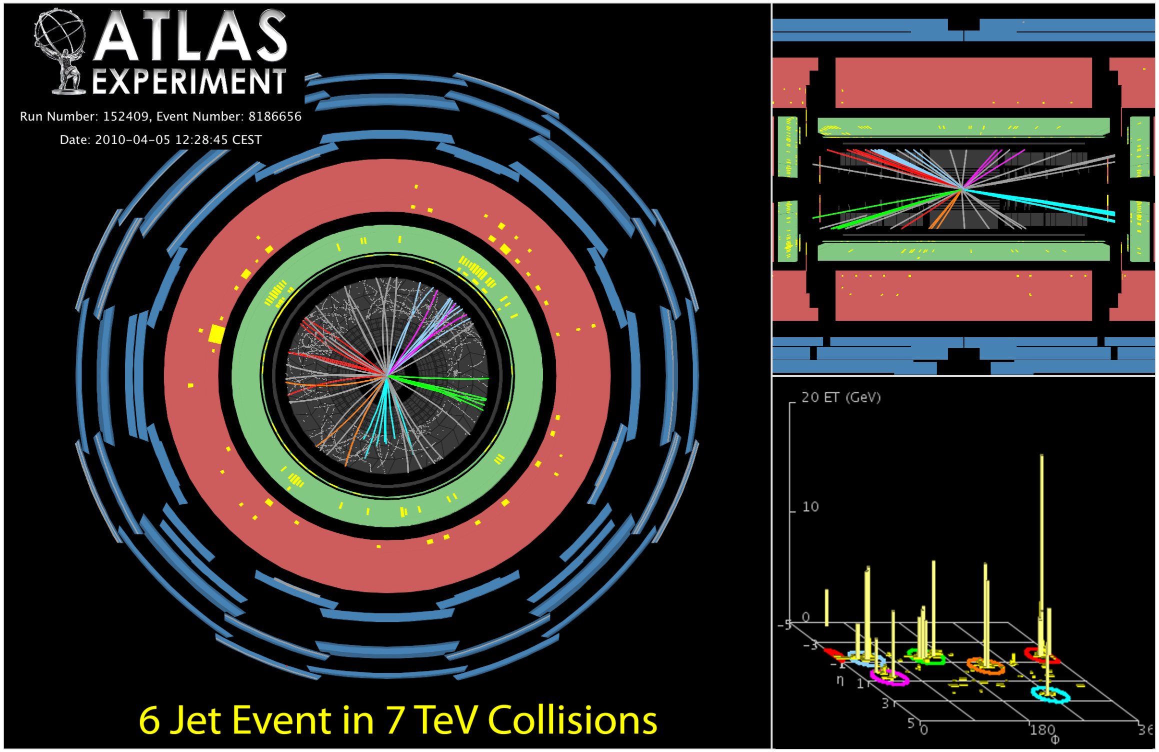
Top Quark Decay Selections



Requirements:

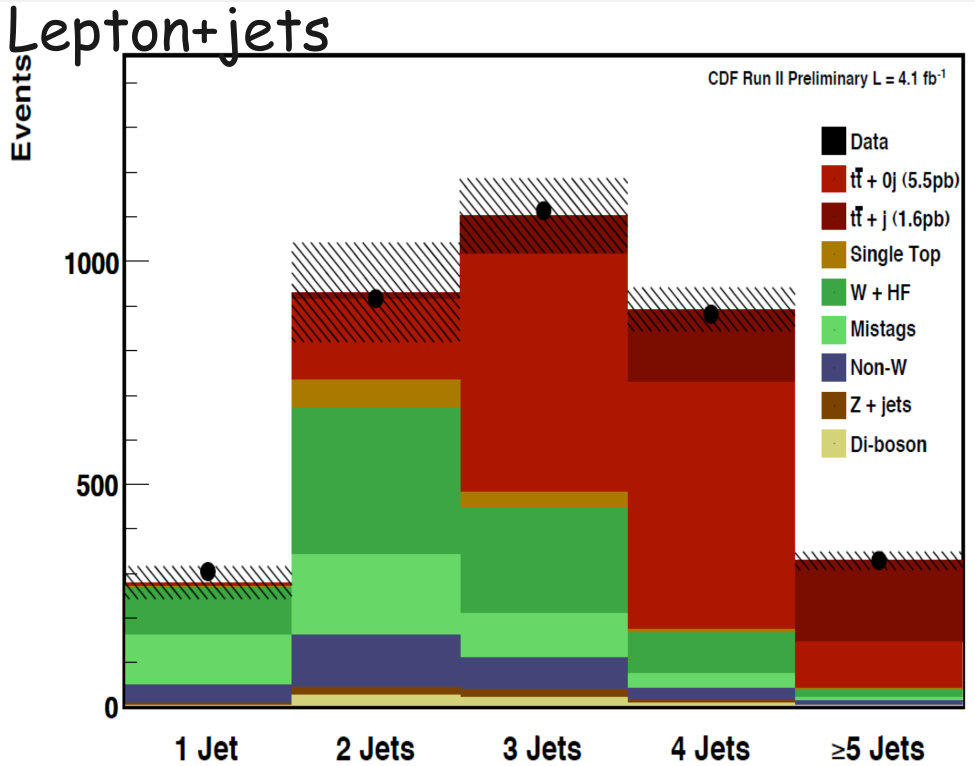
- at least 6 high E_T jets
- at least one b-tag
- Small MET
- No leptons

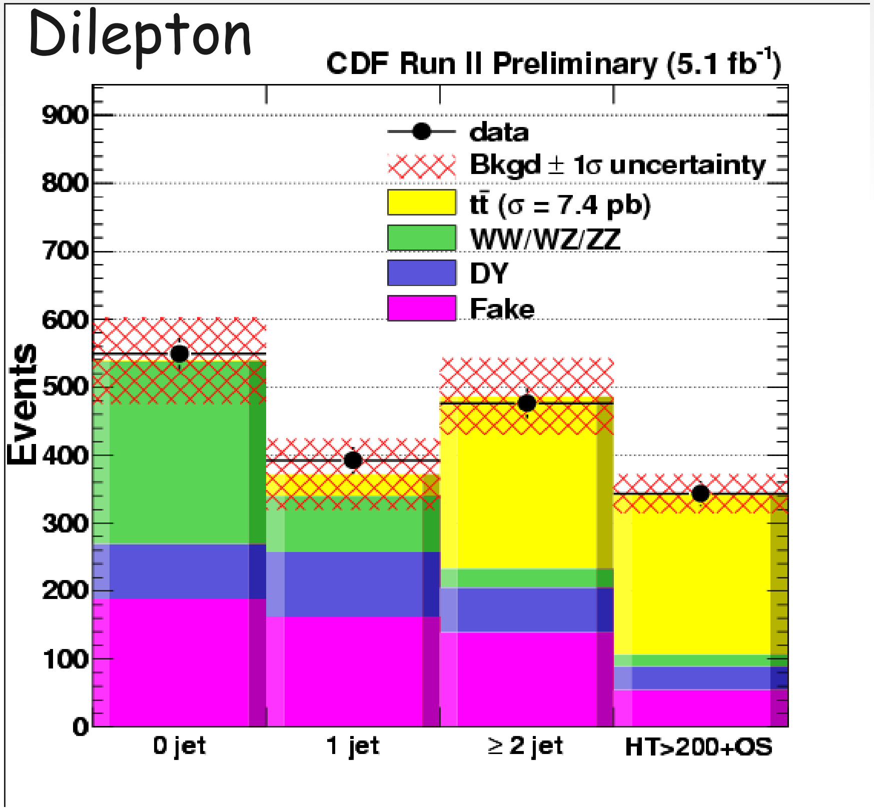
Dominant Background: QCD multi-jets



Top Quark Event count

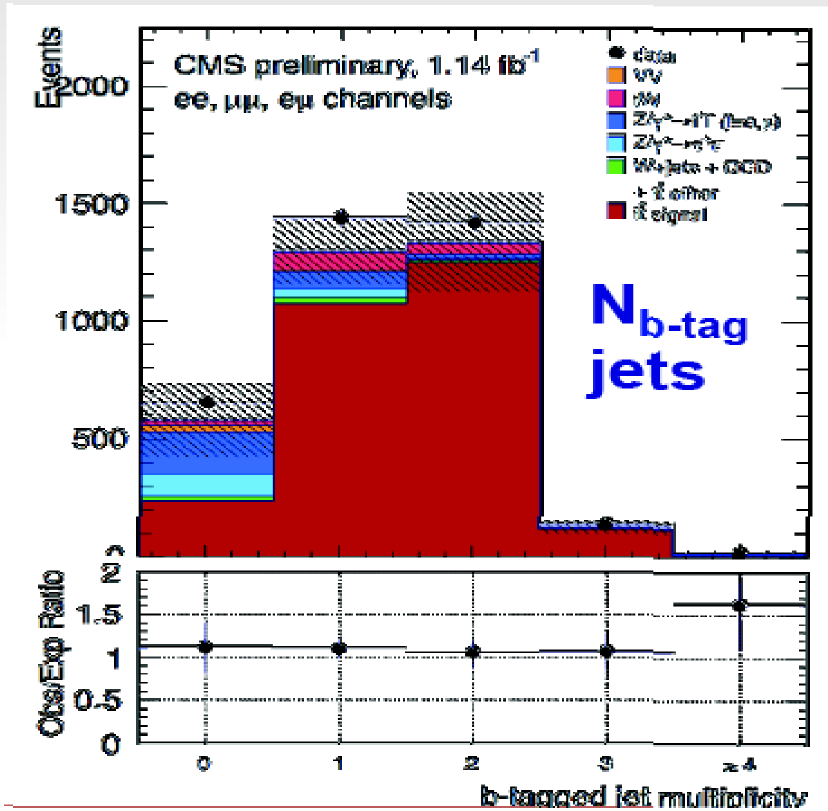
In order to count the number of top-anti-top event candidates the number of events is plotted versus the n umber of jets per event. In each bin the contribution of signal and background is different.

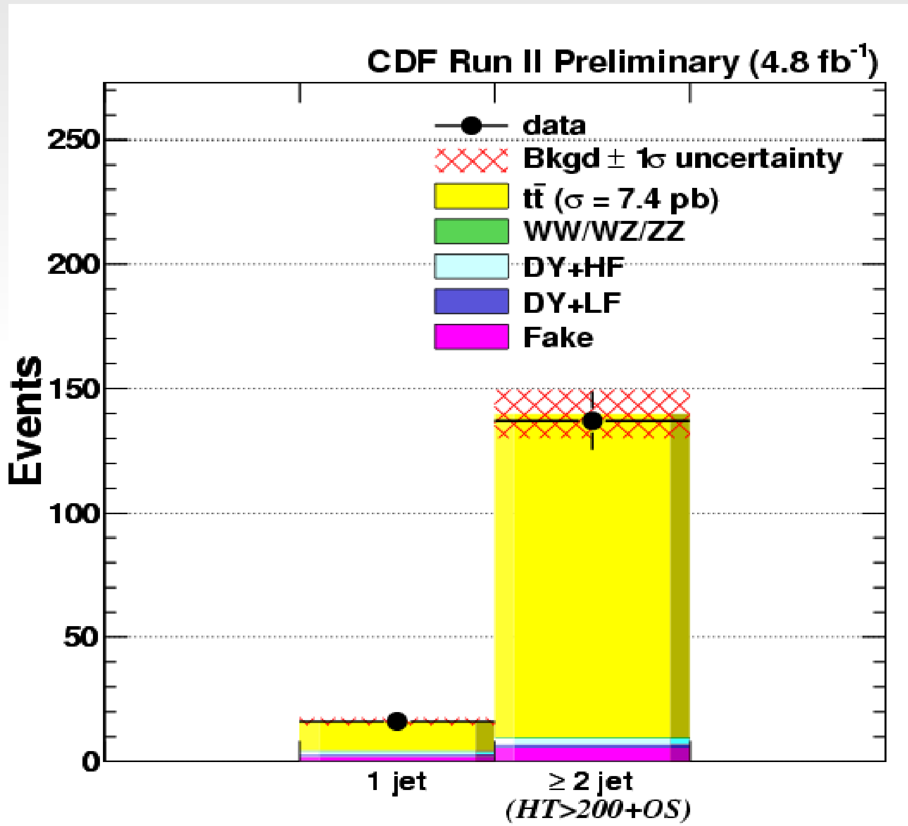




Top Quark Event count - 2

In order to increase the purity of the sample the number of b-tagged jets are counted or at least 2 b-jets are required.

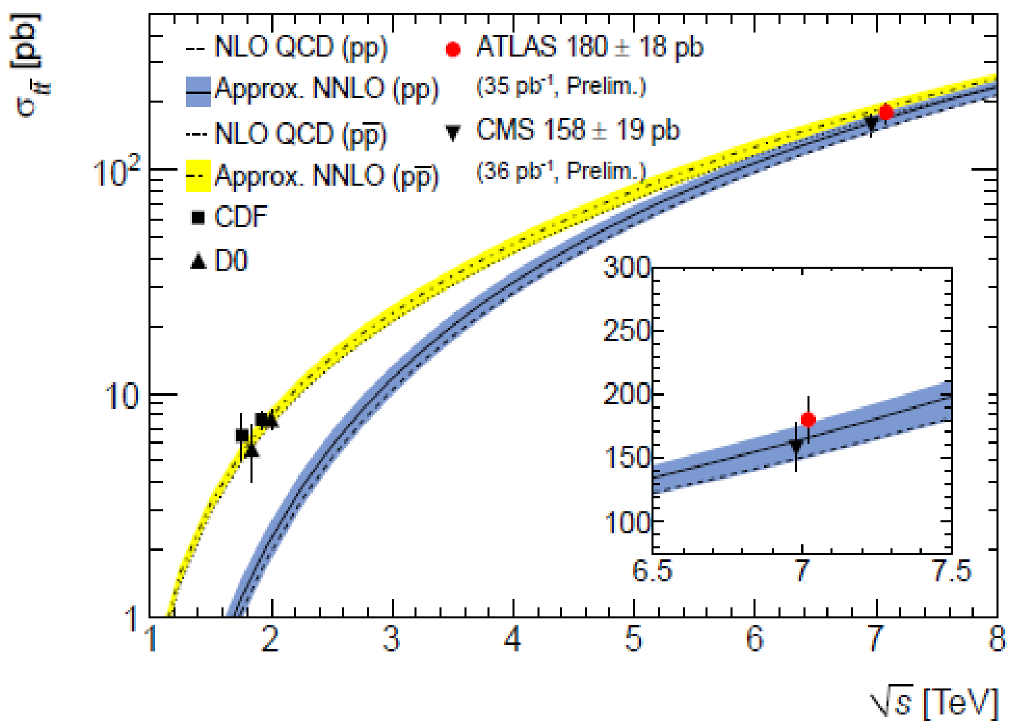




Top Quark Croiss Section

$$\sigma_{tt} = \frac{N_{Data} - N_{Background}}{Acc \int L dt}$$

Inserting the number of signal and background events in the formula and knowing luminosity and efficiency on signal we have the cross section

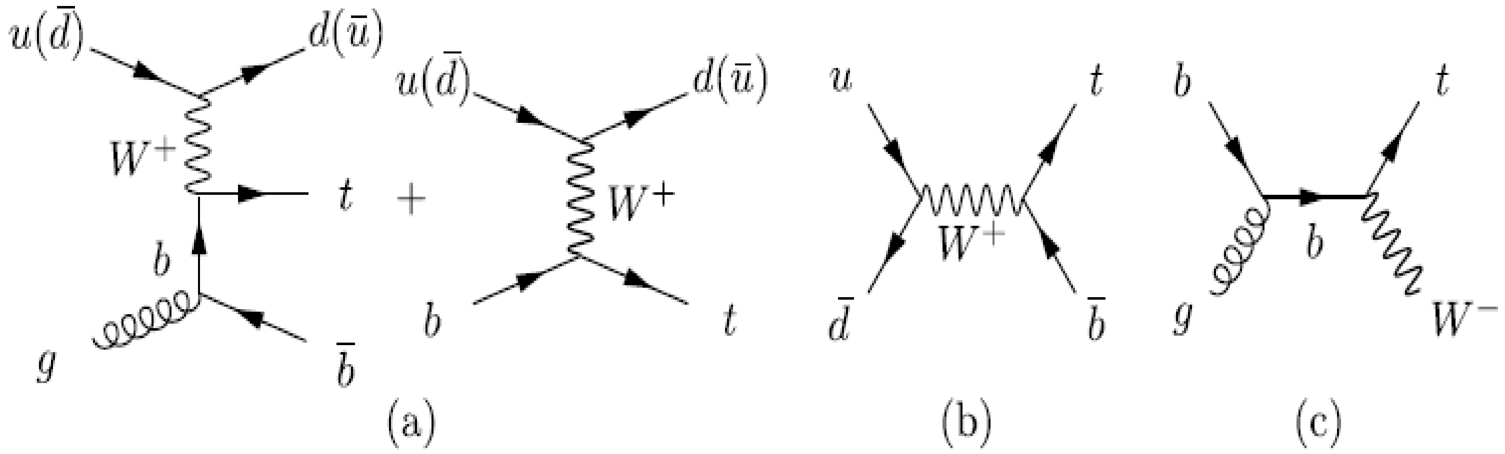


Good agreement with the expectations

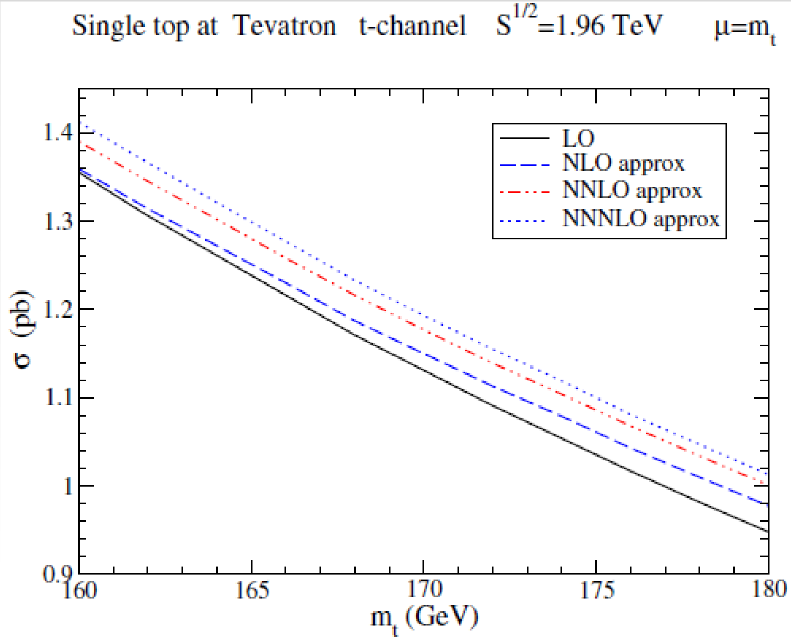
Single Top Quark

Top can be produced also via electroweak interaction involving a vertex Wtb. There are three different production models depending on the Q^2 of the W:

1. t-channel: a virtual W-boson interact with b-quark (sea quark) (a)
2. s-channel: a virtual W boson $q^2 > (m_{top} + m_b)^2$ is produced by the fusion of 2 quark of SU(2) isospin doublet (b)
3. W-associated production: top quark is produced with a real W-boson starting from a sea b-quark and gluon (c)



Single Top Quark Expected Cross Section

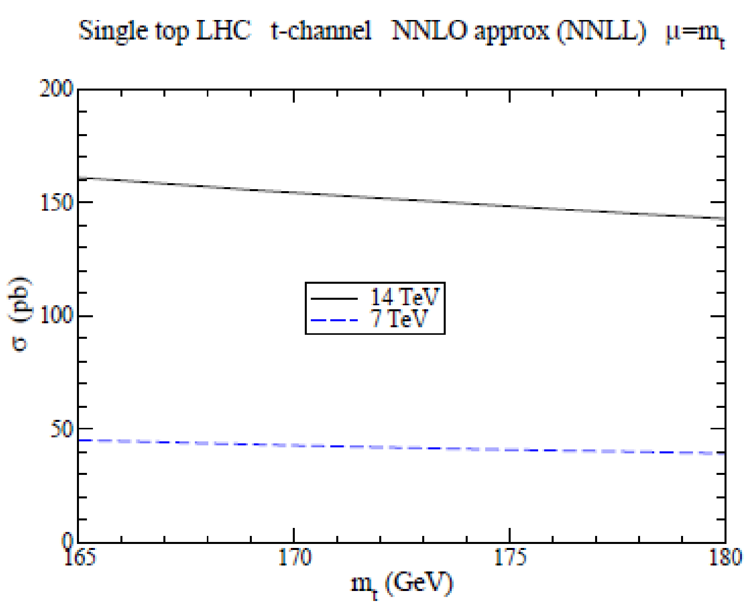


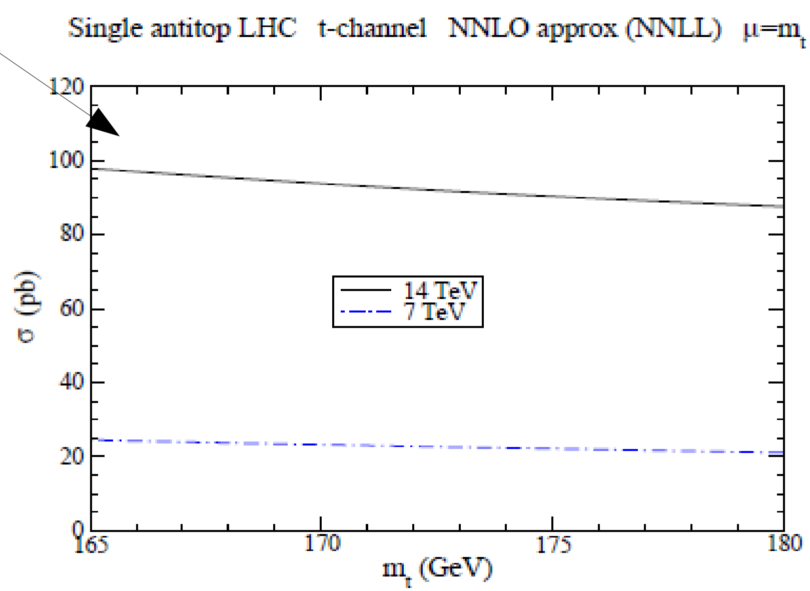
Single top cross section t-channel

Dominate at Tevatron and LHC

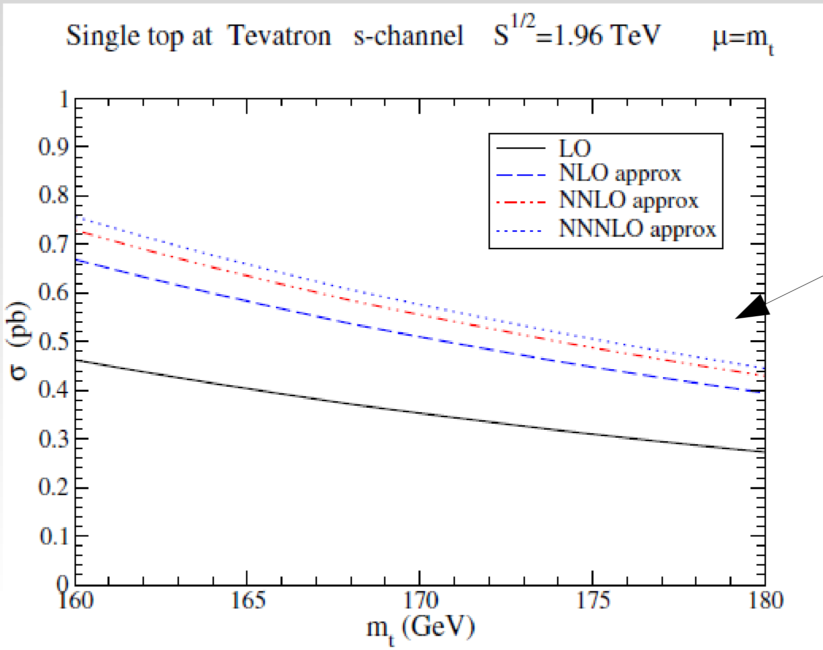
PRD74,114012,(2006)

LHC





Single Top Quark Expected Cross Section

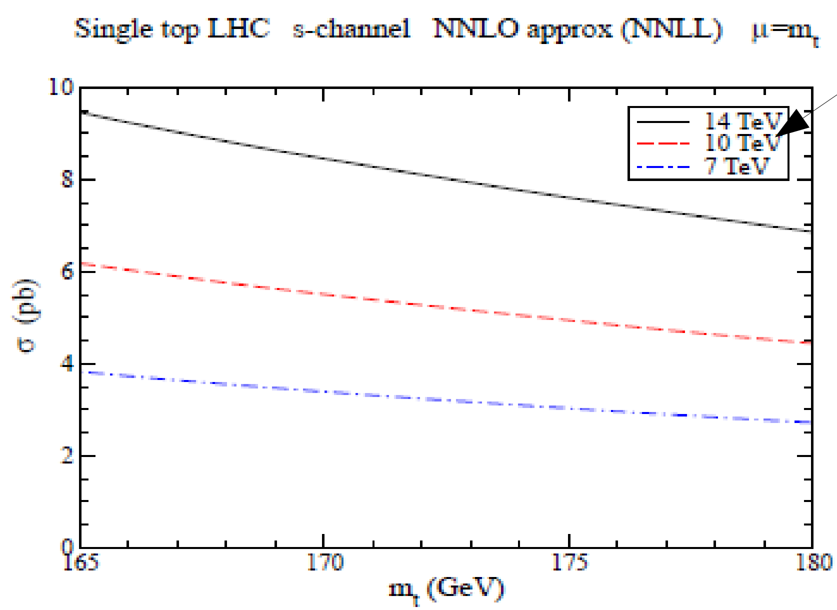


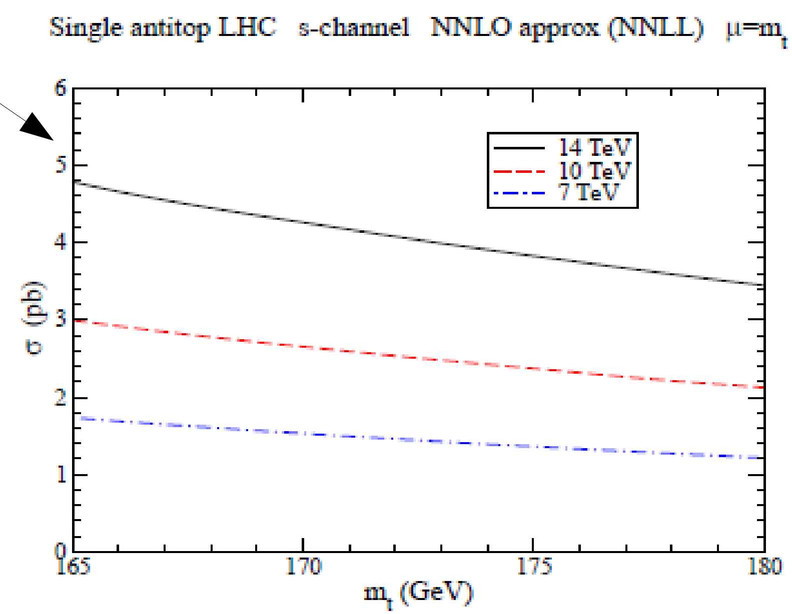
Single top cross section s-channel

Tevatron

PRD74,114012,(2006)

LHC

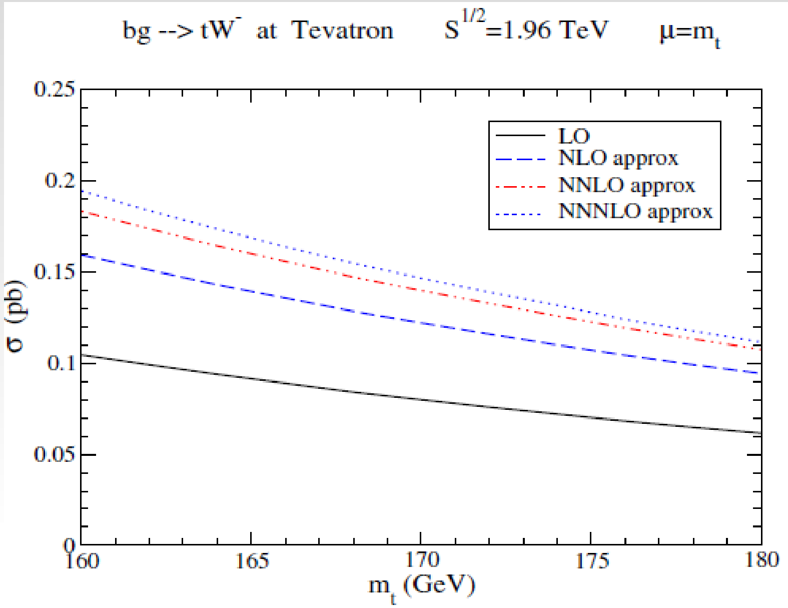


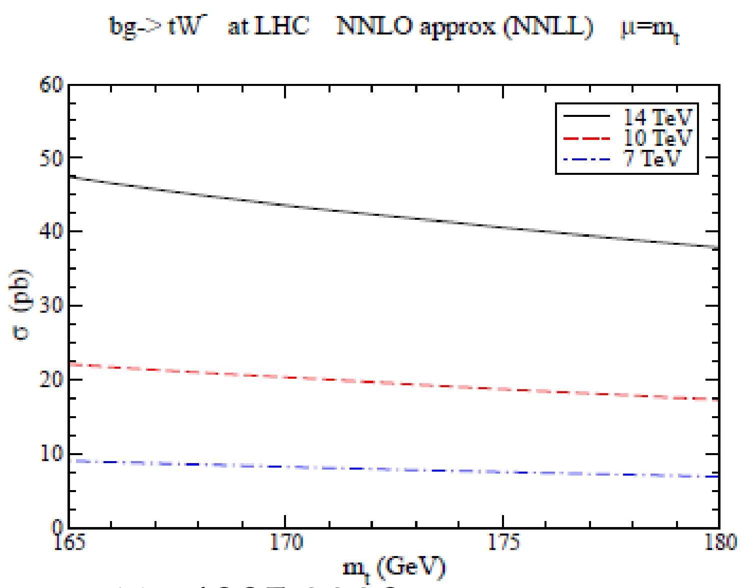


arXiv:1005.3330

Single Top Quark Expected Cross Section

PRD74,114012,(2006)





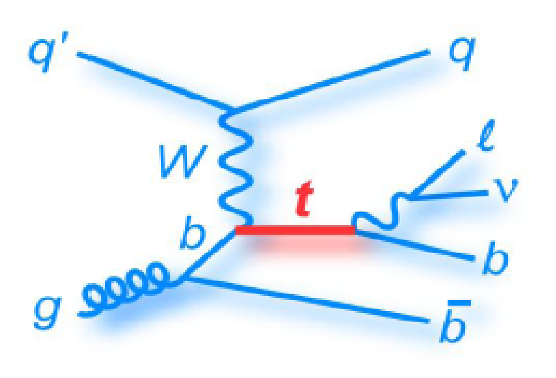
arXiv:1005.3330

Single top cross section:

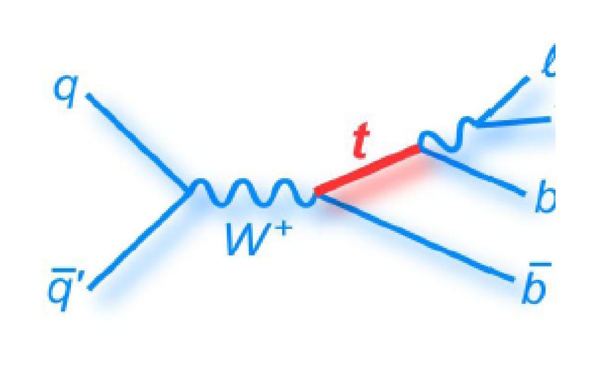
Wt associated production

Not enough sensitivity at Tevatron

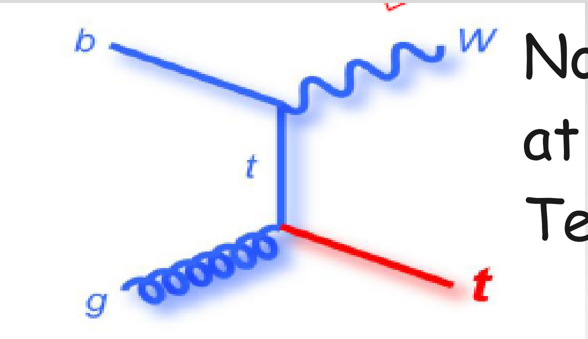
Single Top Quark Event Signature



t-channel production



s-channel production



Associated Wt production

Not at Tevatron

Requirements:

- one high P_T isolated lepton
- at least 2 high E_T jets
- at least one vertex b-tag
- large MET

Major Backgrounds

- W-boson+jets
- top-anti-top
- QCD: multijets

Requirements:

- 2 high P_T isolated lepton
- at least one b-jets
- large MET

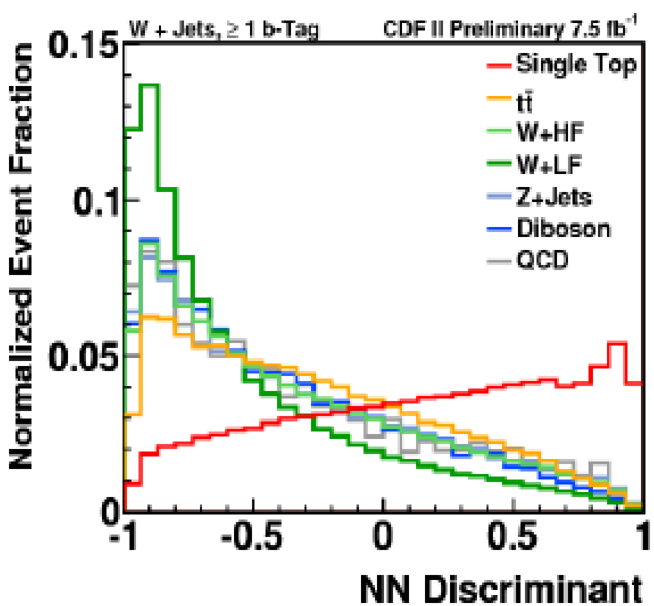
Major Backgrounds

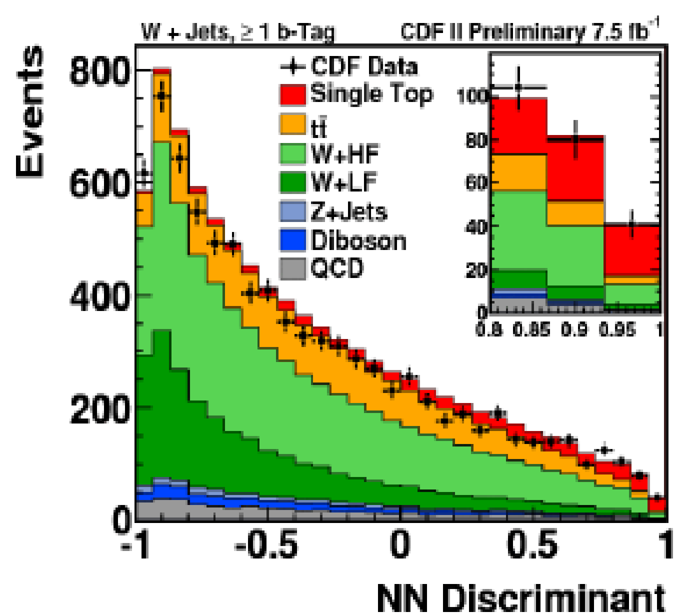
- top-anti-top
- Z-boson+jets

Single Top Quark Signal Extraction Tevatron

Use multivariate analysis techniques:

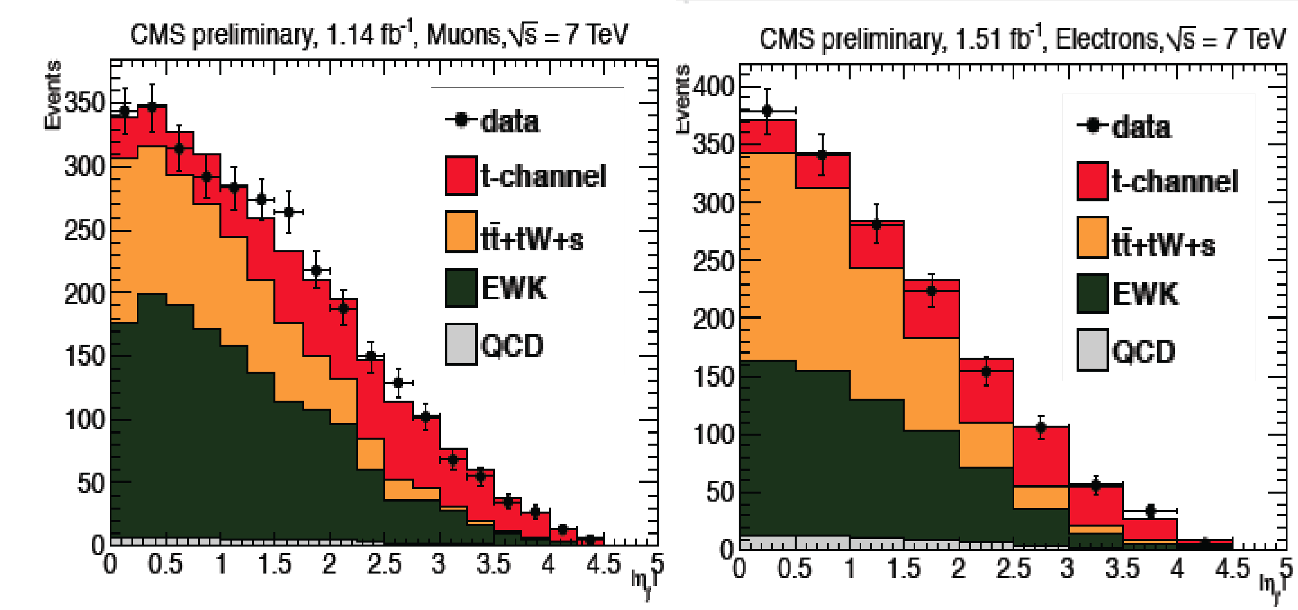
- parametrize the signal distributions using Monte Carlo
- use a combination of Monte Carlo and data to have the background distributions.
- "train" a Neural Network or any other method to distinguish signal from background.
- apply the "method" to data





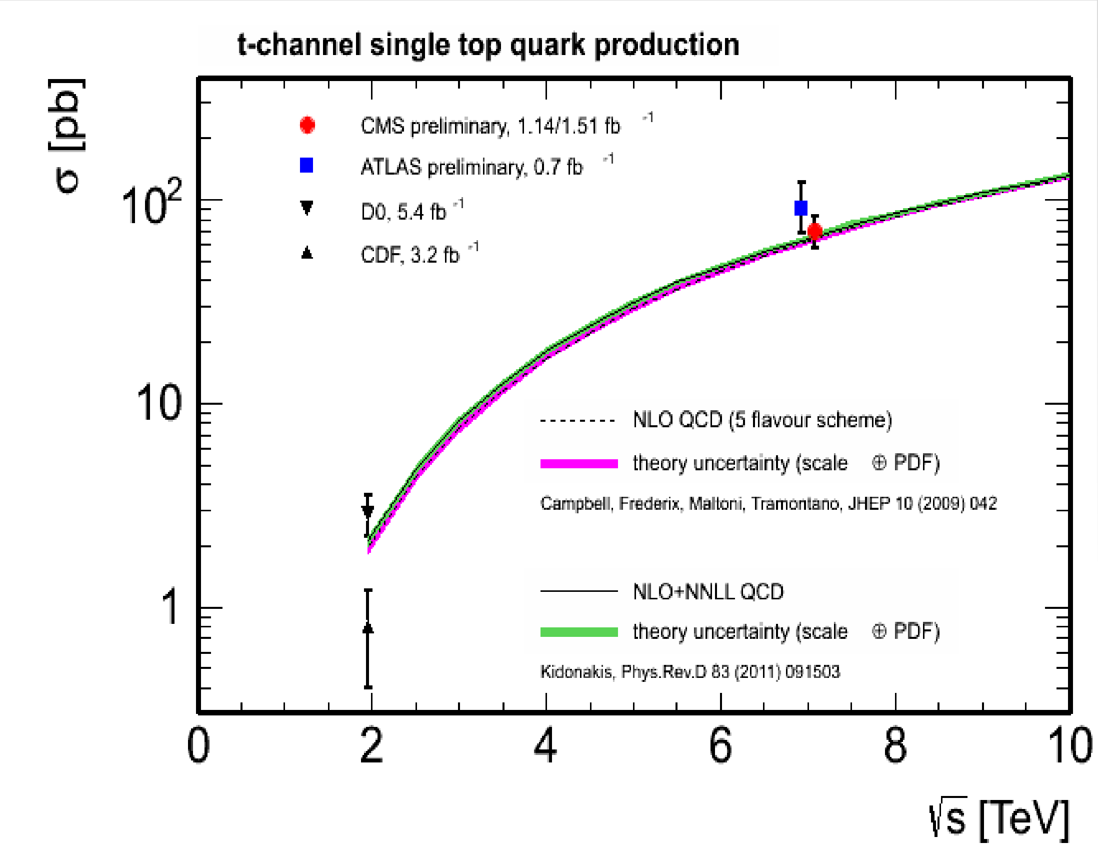
Single Top Quark Signal Extraction LHC

Use multivariate analysis techniques and cut based analysis since the number of expected events is much higher.



fit to the distribution of the pseudorapidity of the light (untagged) jet

Single Top Quark Cross Section Results



Wt production: there are limits on the cross section from Atlas and CMS

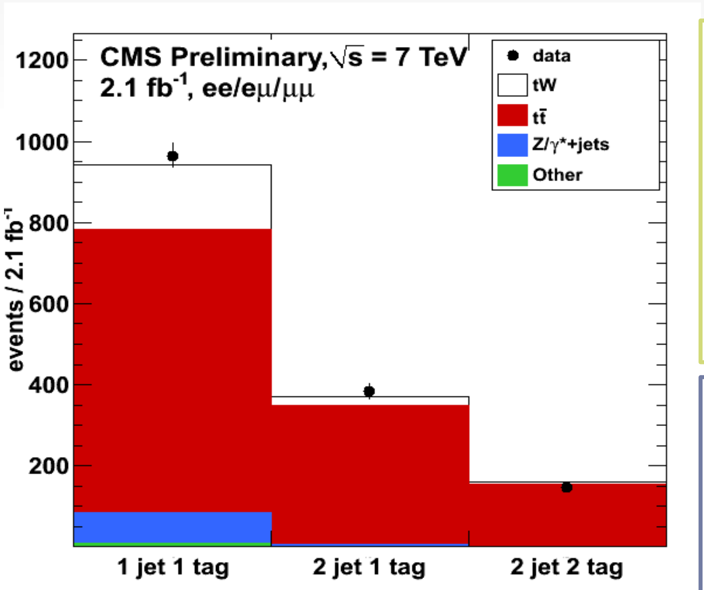
Wtop Associate Production

ee, ***eμ*** and ***μμ*** final states (with no extra leptons)

Jet selection: exactly 1 jet (ATLAS/CMS), b-tagged (CMS)

MET: significant

Anti Z+jets: Remove events in the Z mass window 81 < mll < 101 GeV



ATLAS:

Observed significance of 1.2σ

With a value of the cross-section:

$\sigma tW = 14 +5.3-5.1(\text{stat.}) +9.7-9.4(\text{syst.})$ pb

CMS:

Observed (expected) significance of

2.7σ ($1.8\pm0.9\sigma$)

Measured value of the cross-section:

$\sigma tW = 22 +9-7$ (stat+sys) pb

Top Quark Properties