Top-quark physics with early LHC data

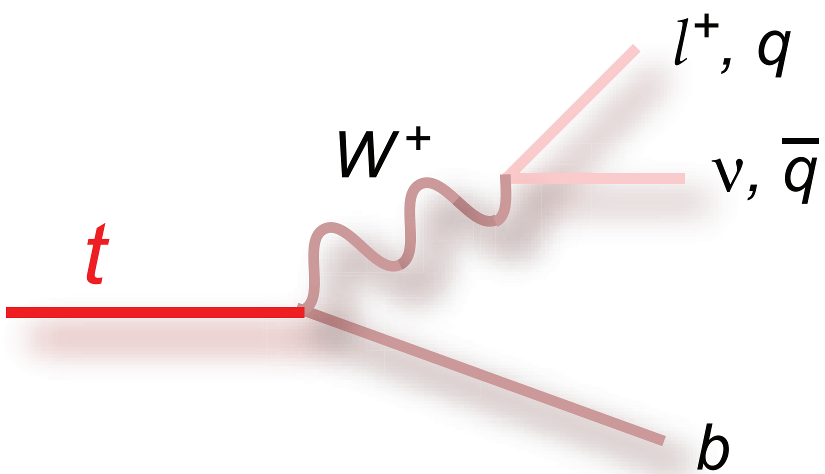
T. Barillari Seminar: Physics at the Large Hadron Collider München, 14 July 2009

- Introduction
- $t\bar{t}$ pair production
- Dilepton, lepton+jets and all-jets events
- Event selection
- $t\bar{t}$ reconstruction methods
- Results
- Conclusions

Introduction

- The top quark differs from the other quarks, it is the heaviest known elementary particle

- It can decay in $t \rightarrow Wq$ $(q = d, s, b)$,
- The Ws and Wd final states expected to be suppressed relative to the Wb by the square of the CKM matrix elements V_{ts} and V_{td}
  - $0.9990 < V_{tb} < 0.9993$
- Main top decay: $t \rightarrow Wb$ $(> 99.8\%)$

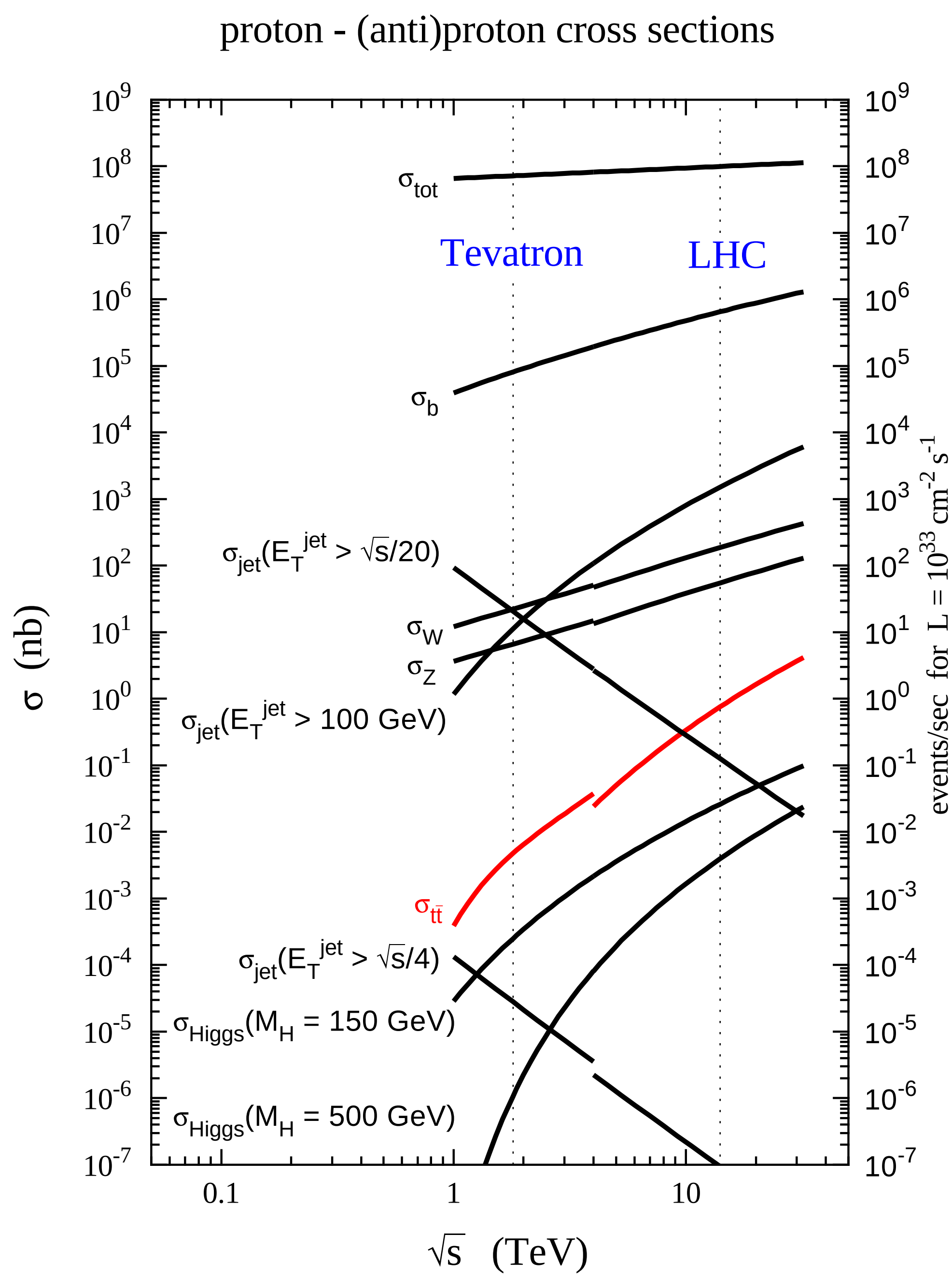


Top production at hadron colliders

- With a $m_t = 180\,\mathrm{GeV}$ the predicted decay width is $\Gamma \approx 1.56\,\mathrm{GeV}$, and its lifetime $\tau = \Gamma^{-1} \approx 5\mathrm{x}10^{-25}\,\mathrm{s}$
  - The top quark decays before it can interact via QCD
- The final states for the leading $t\bar{t}$-production process can be divided in three main classes:
  - Dilepton:
    $t\bar{t} \rightarrow W^{+}bW^{-}\bar{b} \rightarrow \bar{l}\nu_l b l^{'}\overline{\nu_{l'}}\bar{b}$ (10.3%)
  - Lepton+jets:
    $t\bar{t} \rightarrow W^{+}bW^{-}\bar{b} \rightarrow q\bar{q}^{'}bl\overline{\nu_l}\bar{b} + \bar{l}\nu_l bq\bar{q}^{'}\bar{b}$ (43.5%),
  - All-jets:
    $t\bar{t} \rightarrow W^{+}bW^{-}\bar{b} \rightarrow q\bar{q}^{'}bq^{''}\bar{q}^{'''}\bar{b}$ (46.2%),

$t\bar{t}$ production: total cross section

- The top quark has been observed only at Tevatron
  - ▷ $p\bar{p}$: $\sqrt{s} = 1.8\,\text{TeV}_{\text{RunI}}$, and $1.96\,\text{TeV}_{\text{RunII}}$
- LHC will be a top factory
- Total cross section for $t\bar{t}$-production is about a factor of 100 larger at LHC than at Tevatron
- $\sigma_{t\bar{t}}(1.80\,\text{TeV}) = 5\,\text{pb}$
- $\sigma_{t\bar{t}}(1.96\,\text{TeV}) = 7\,\text{pb}$
- $\sigma_{t\bar{t}}(14.0\,\text{TeV}) = 800\,\text{pb}$

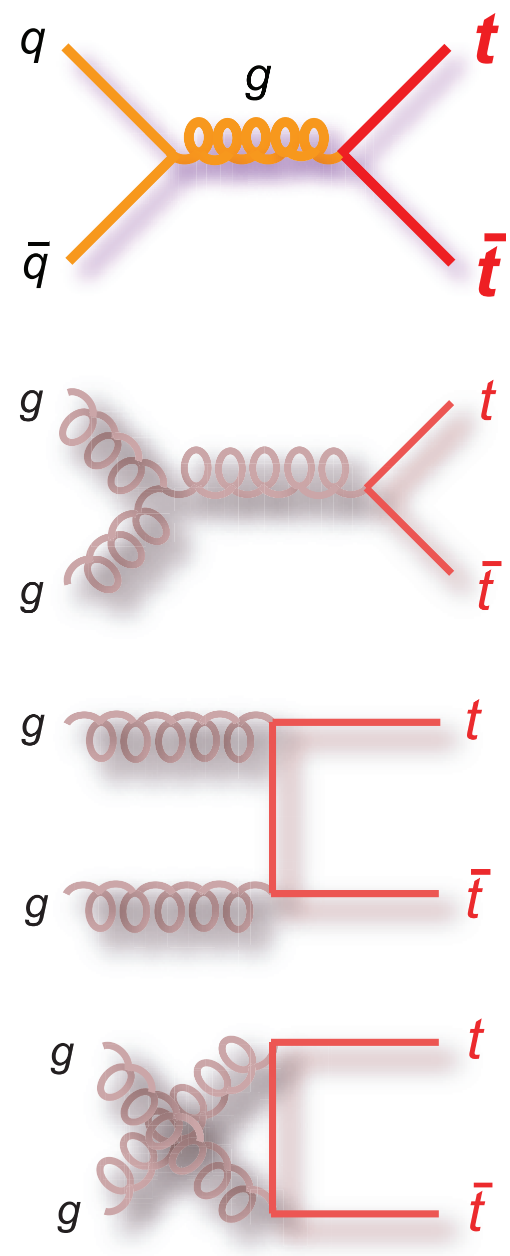


W.J. Stirling, 1998

$t\bar{t}$ *production at Tevatron and LHC*

- $q\bar{q}$ annihilation

$\sqrt{s}$	$\sigma_{q\bar{q}\to t\bar{t}}/\sigma_{t\bar{t}}$
1.8TeV	90%
1.96TeV	85%
14TeV	5%



- Gluon fusion

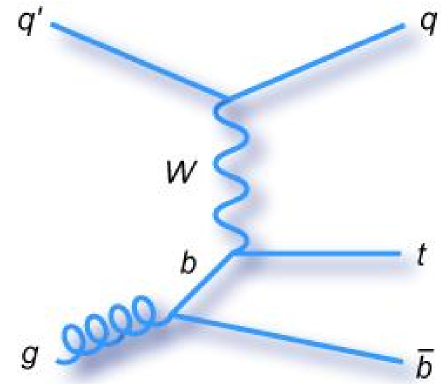
$\sqrt{s}$	$\sigma_{gg\to t\bar{t}}/\sigma_{t\bar{t}}$
1.8TeV	10%
1.96TeV	15%
14TeV	95%

- At LHC the $gg \to t\bar{t}$ dominates over the $q\bar{q} \to t\bar{t}$

- Large total cross-section for single top production (40%)

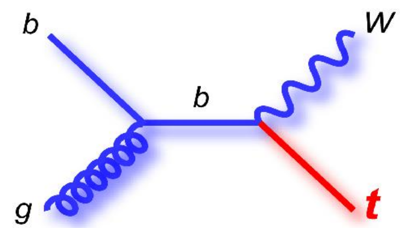
- W-boson and gluon fusion. It includes the t-channel contribution or Wg

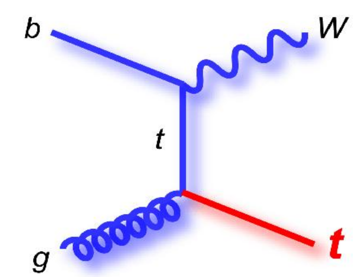
$\sqrt{s}$	$\sigma_{\mathrm{EWt}}/\sigma_{\mathrm{single\ t}}$
1.8TeV	60%
1.96TeV	65%
14TeV	77%



- Associated production of top quark and W-boson, Wt

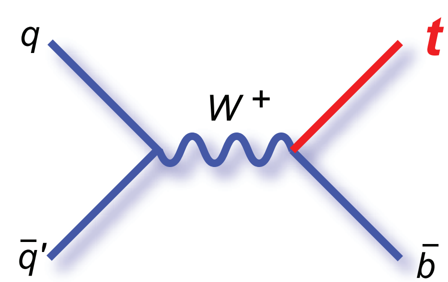
$\sqrt{s}$	$\sigma_{\mathrm{EWt}}/\sigma_{\mathrm{single\ t}}$
1.8TeV	5%
1.96TeV	5%
14TeV	20%



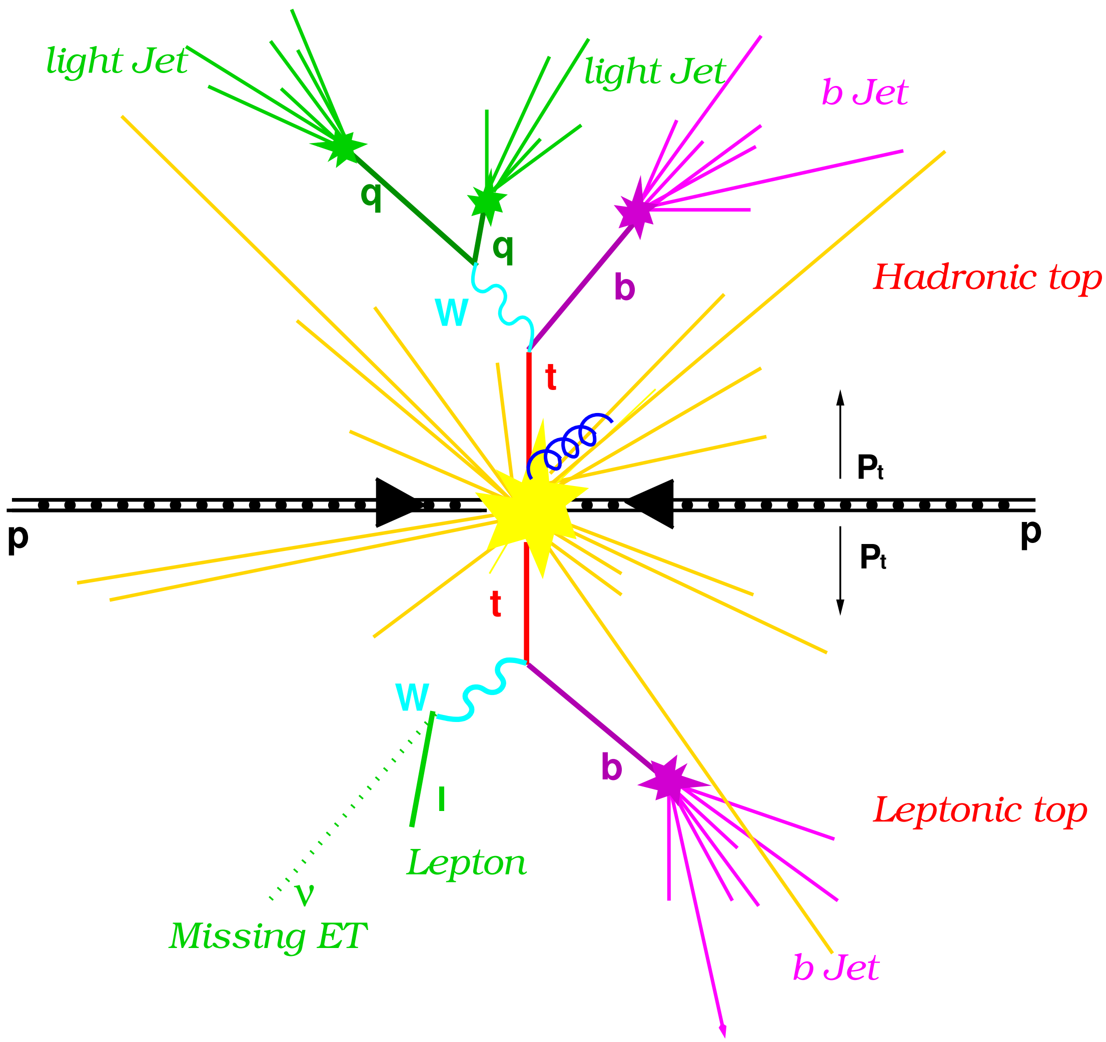


- s-channel production

$\sqrt{s}$	$\sigma_{\mathrm{EWs}}/\sigma_{\mathrm{single\ t}}$
1.8TeV	35%
1.96TeV	30%
14TeV	3%



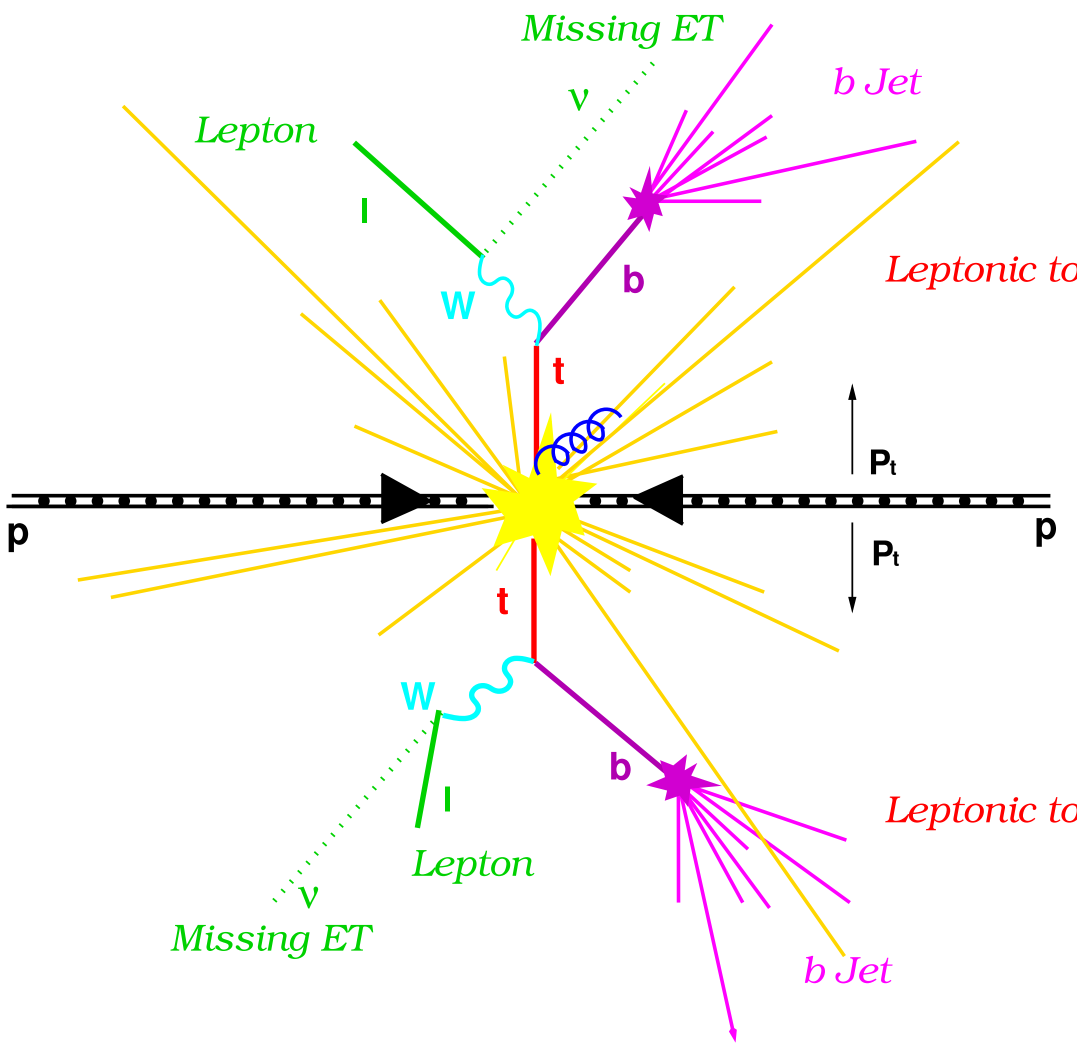
Experimental challenges



- $t\bar{t}$ events provide:
  - Jets with a wide spectrum of $p_\perp$
  - b-jets
  - Lepton(s)
  - Missing ET
  - ... etc., etc.
- The whole detector capability at work

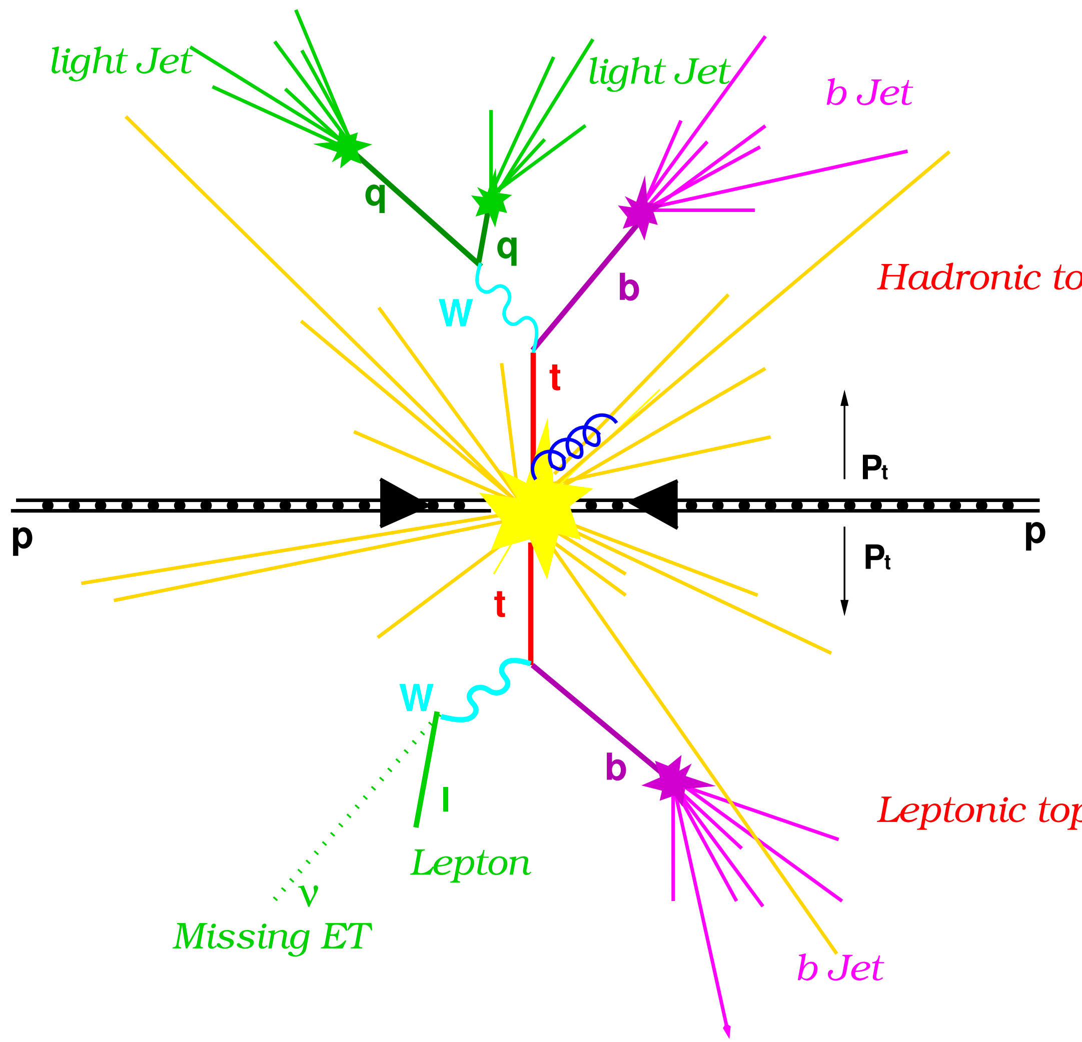
Dilepton events: $t\bar{t} \rightarrow WWb\bar{b} \rightarrow (l\nu)(l\nu)b\bar{b}$

- It represents about $1/9$ of all $t\bar{t}$ events
- Both Ws decay into a lepton-neutrino pair
- The event has two charged leptons, two neutrinos and two b-jets
  - A clean sample of top quark can be achieved by requiring two high $p_\perp$ leptons and the presence of $\not{E}_\perp$
- Important to tag the b-jets:
  - Reduces the background
- Top reconstruction limited by the two escaping neutrinos



Golden plated event $t\bar{t} \rightarrow WWb\bar{b} \rightarrow (l\nu)(jj)b\bar{b}$

- The "lepton+jets" is the golden channel: one W decays leptonically (e, μ) and the other W decays hadronically
  - Clean trigger from the isolated lepton
- The reconstruction starts with the W mass:
  - JES using the W
- Important to tag the b-jets:
  - Reduces the background
  - Clean top quark samples
- Main background comes from W + Jets events
- S/B $\approx$ 10



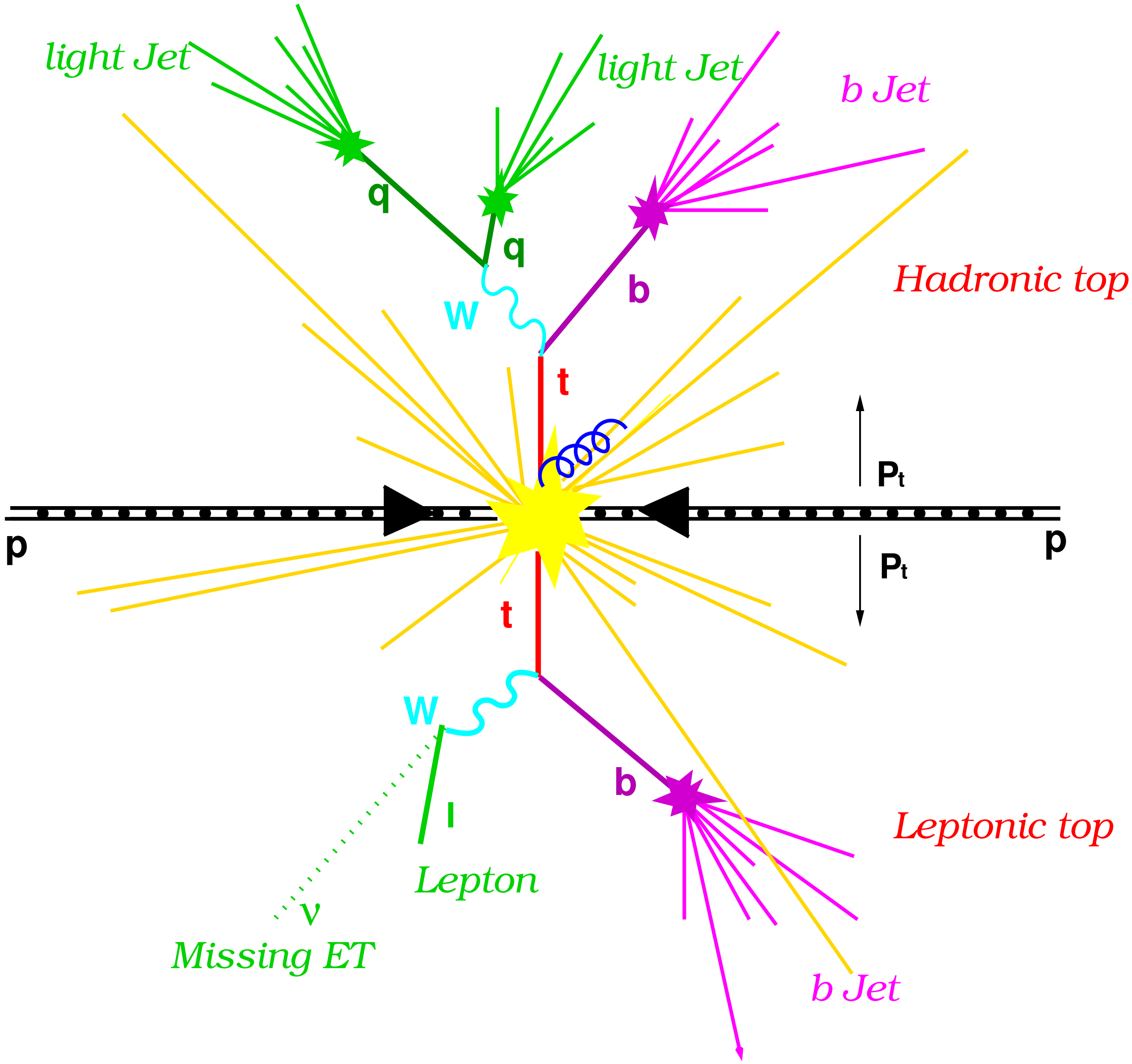
All-jets events: $t\bar{t} \rightarrow WWb\bar{b} \rightarrow (jj)(jj)b\bar{b}$

- The all-jets channel is the most copious $t\bar{t}$ final state, $4/9$ of all $t\bar{t}$ events. Here both Ws decay hadronically
- The signal is overwhelmed by the background coming from QCD multijets production
- Use trigger to reduce background
  - The ATLAS multijet-trigger
- The reconstruction starts with the W mass:
  - JES using the W
- Important to tag the b-jets:
  - Reduces the background
  - Clean top quark samples
- S/B $\approx 10^{-4}$ without btagging

Lepton+jets event selection

- Typical ATLAS event selection for Lepton+jets $t\bar{t}$ events:
  - 3 jets with $p_\perp > 40$ GeV
  - 1 jet with $p_\perp > 20$ GeV
  - $|\eta| < 2.5$
  - Exactly one isolated electron or muon with:
  - $p_\perp > 20$ GeV, $|\eta| < 2.5$
  - Muons reconstructed with STACO; electrons with eGamma
  - MET > 20 GeV
  - b-tag used on one or two jets to decrease the combinatorial background (no b-tag with early data)
- Use different methods to reconstruct the top mass
- With early data in ATLAS one can use e.g. Maximum "$P_\perp$ method", to combine the triplet of Cone4 or AntiKt4 jets with max $P_\perp$ to obtain the top mass, no b-tag involved
- Similarly in CMS, with early data one can combine Cone5 jets (3 out of the 4 selected) that give the highest summed $E_\perp$ to reconstruct the hadronic top mass.

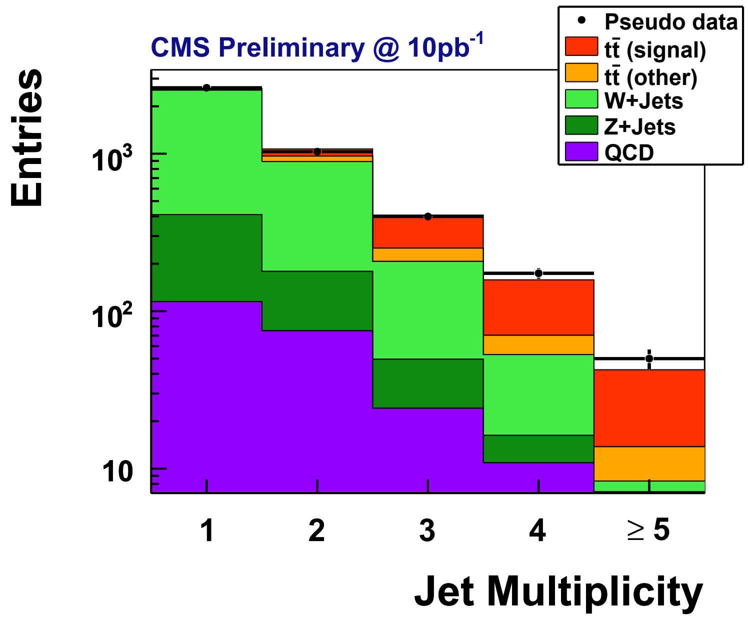
Lepton + jets event

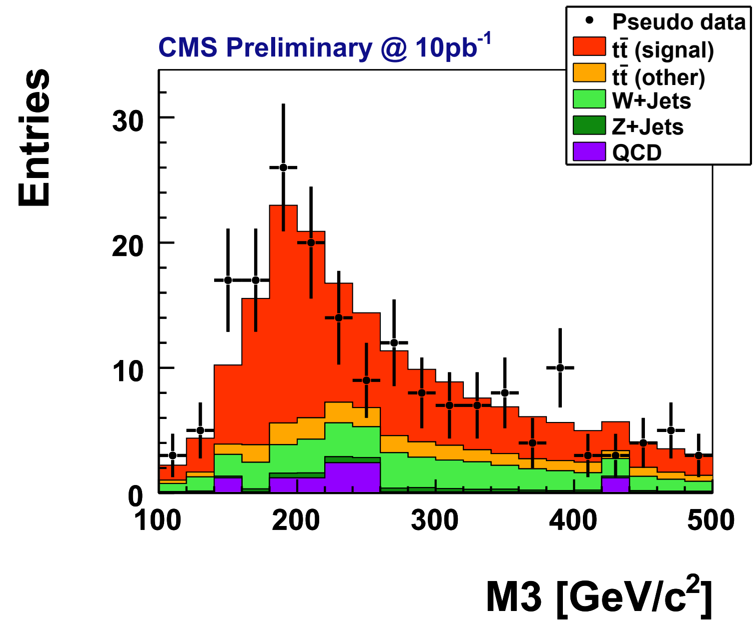


Top mass with 10 pb^{-1} of CMS data

- Basic event selection:
  - 1 isolated μ with $p_\perp > 30\,\mathrm{GeV}$ and $|\eta| < 2.1$
  - Events with two leptons are rejected to reduce contamination from dilepton $t\bar{t}$ events
  - At least 4 jets with $|\eta| < 2.4$, no b-tag jet used in the analysis
  - Used Cone5 jets
  - One jets has $E_\perp > 65\,\mathrm{GeV}$, the other 3 jets have $E_\perp > 40\,\mathrm{GeV}$
  - To improve the S/B, it is required that the muon has a $E_{iso}^{calo} < 1\,\mathrm{GeV}$ and a $dR_{min} > 0.3$, distance to the next closest jet
- With this event selection 128 signal events are expected with the early $10\,\mathrm{pb}^{-1}$ CMS data, with a selection efficiency of 10%. together with 25 other $t\bar{t}$ final state events, 45 (7) W+jets (Z+jets) events, and 11 QCD background events.

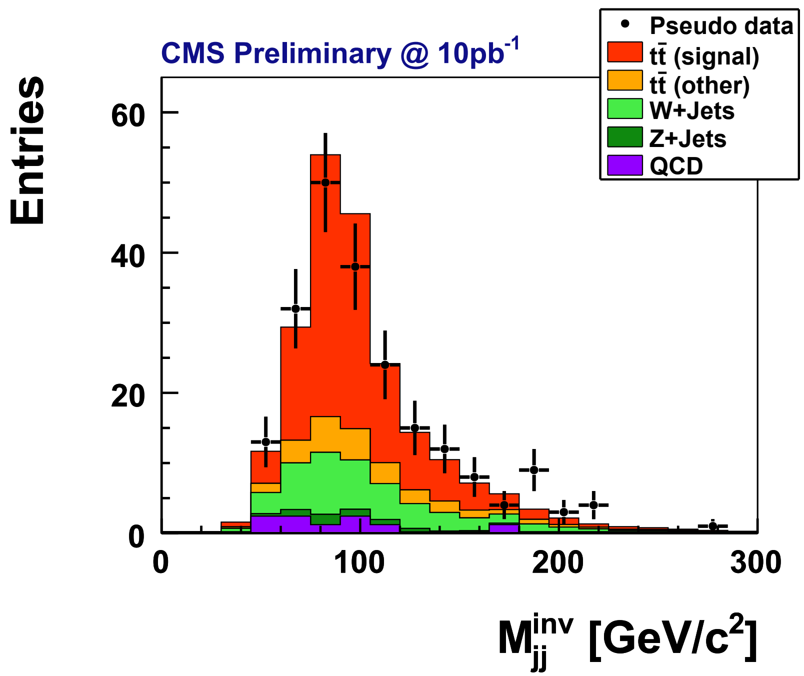
Top mass with first 10 pb^{-1} of CMS data

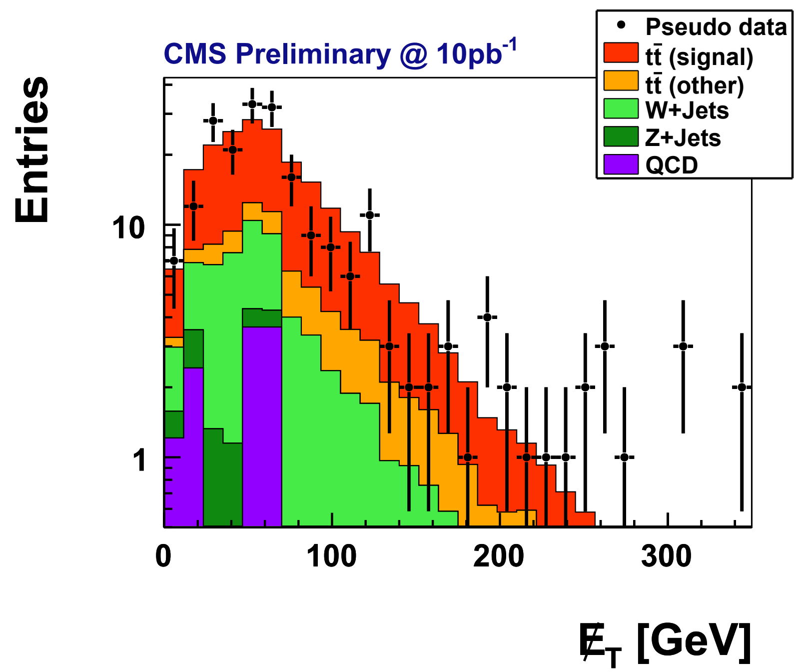




- Jet multiplicity distribution for events passing the final selection (left plot), and invariant mass of the 3 jets with the highest vectorially summed $E_\perp$ (right plot)

W mass with first 10 pb^{-1} of CMS data

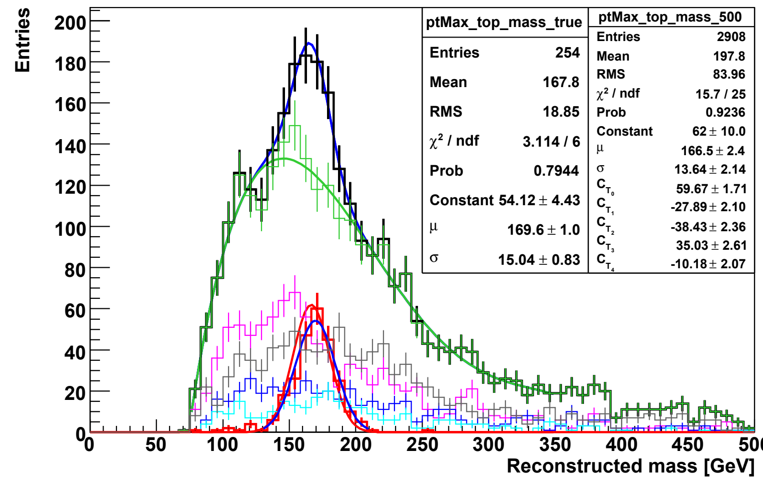




- Invariant mass of two jets which best correspond to the nominal value of M_W (right plot). Missing transverse energy for the events passing the event selection (left plot)

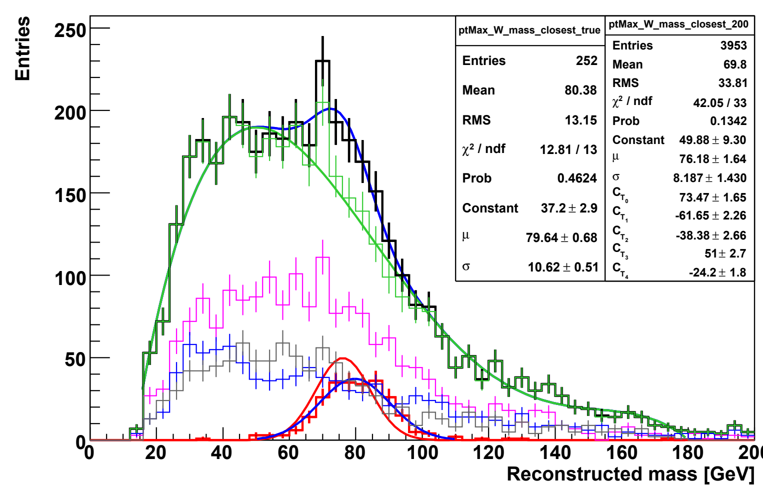
Top mass with the Maximum $p_\perp$ method

- Top mass with $145\,\mathrm{pb}^{-1}$ at $\sqrt{s} = 10\,\mathrm{TeV}$ of ATLAS data (E. Rauter PhD today)
- Top reconstruction
  - Take jet triplet maximasing $p_\perp$ as top candidate
  - Method chooses the correct combination in 25% of the cases
  - Left upper plot shows the top reconstructed in the electron channel



background: combinatorial, QCD,top-mass dependent, remaining physics bkg

- W reconstruction
  - Boost to the top CMS system and take the closest two jets in the triplet as W candidate



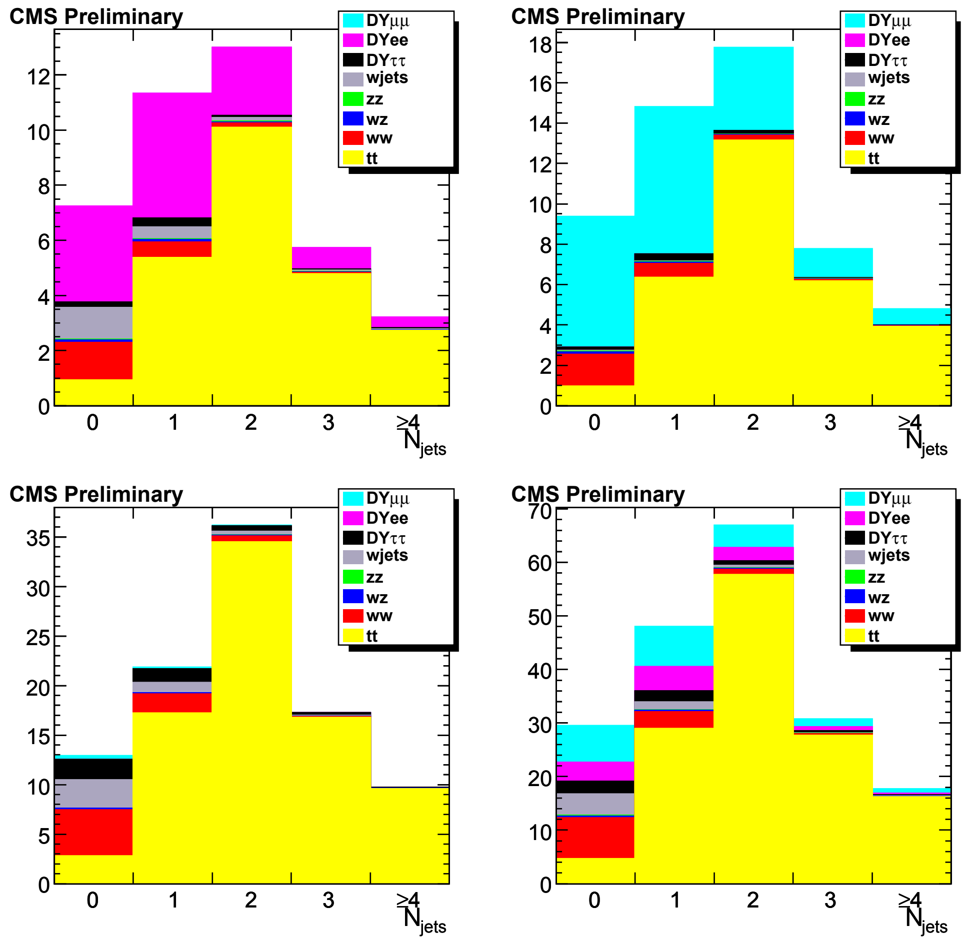
- Bkgd here is, inclusive $Z \to ll$, and $W \to l\nu$ + jets, diboson events, QCD, all hadronic and single top events

Top mass Maximum $p_\perp$ method (Emanuel's results)

- simulated data with an integrated luminosity of 145 pb^{-1}, the top quark mass was reconstructed in the leptons plus jets decay channel using local hadron calibrated Kt4 jets resulting in a top mass e.g. in the electron channel
  - before in-situ calibration:
    $$m_t^{electron} = 166.55 \pm (2.38)_{stat} \, (^{+9.58}_{-9.10})_{syst} \text{ GeV}$$
  - after in-situ calibration:
    $$m_t^{electron} = 167.22 \pm (2.36)_{stat} \, (^{+3.9}_{-2.49})_{syst} \text{ GeV}$$
- compatible with input top mass value of 172.5 GeV.
- before the application of the in-situ calibration, the dominant errors are the light jet energy scale and the combinatorial background
- after application of the in-situ calibration, only the latter remains dominant
- with samples of higher statistics the combinatorial background is expected to decrease and the fitting procedure is expected to become more stable

Dilepton events in $10\,\mathrm{pb}^{-1}$ of CMS data

- Top-quark pair production in pp collisions at $\sqrt{s} = 14\,\mathrm{TeV}$ with two leptons in the final state (μ or e)



- Expected number of dilepton events as function of jet multiplicity in ee events (top left), $\mu\mu$ (top right), $\mathrm{e}\mu$ events (bottom left), all channels combined (bottom right)

Dilepton results with $10\,\mathrm{pb}^{-1}$ *of CMS data*

- Clear observation of the signal expected in the sample with 2 or more jets, with $\mathsf{S/N} \approx 2/1$ in all channel combined and a $\mathsf{S/N} \approx 25/1$ in the $\mathsf{e}\mu$ channel
- With first data the top pair production cross-section is expected to be measured with a stat. uncertainty of 9% (13%) using the all dilepton channel ($\mathsf{e}\mu$ channel) and with comparable syst. uncertainty
- Many improvements of understanding the systematics effects will come with with the first data

Conclusions

- A lot of work has been done and good results has been achived to study $t\bar{t}$ events with the first LHC data by ATLAS and CMS
- We have seen that with a basic but robust event selection, ATLAS and CMS can both have a first measurement of the mass of the top and the mass of the W in e.g. lepton+jet channel and with e.g. $10\,\mathrm{pb}{-}1$ of CMS data
- We will be able to control better the statistics and the syestematics uncertanties, once we will understand better the performance of our detectors
- A better understanding of the detectors (JES, QCD background, ...), will allow us to e.g explore the all-jet $t\bar{t}$ channel, the single top channel, probe for potential new physics