Measurement of normalised differential $pp \to t\bar{t}$ production cross sections at 7 TeV with the CMS detector

– LHC Physics Discussions @ DESY –

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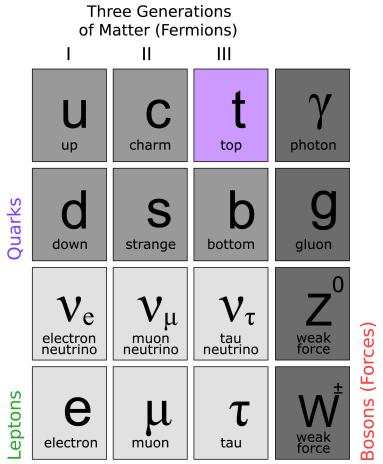
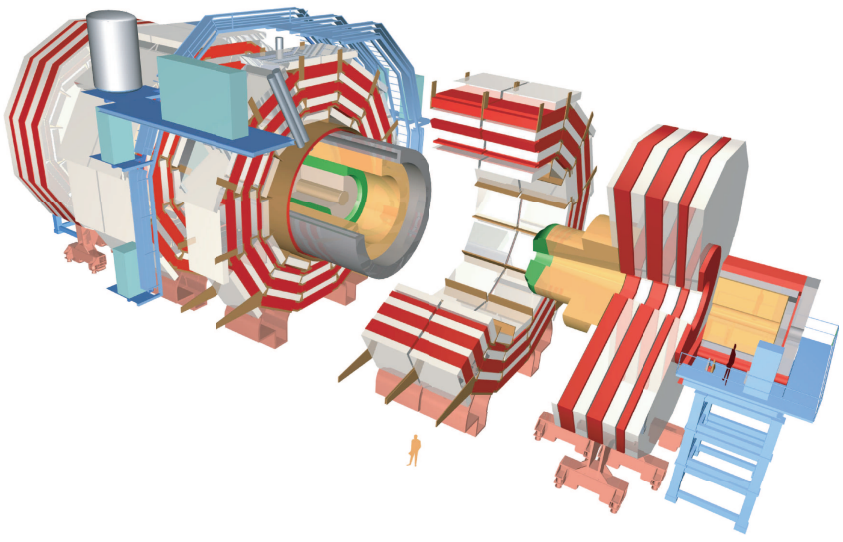
Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

Bundesministerium
für Bildung
und Forschung

Overview

- The Measurement
- Event Selection
- $t\bar{t}$ Reconstruction
- Unfolding
- Uncertainties
- Results





The measurement

Normalised differential $t\bar{t}$ production rates:

$$\frac{1}{d\sigma_{t\bar{t}}} \cdot \frac{d\sigma_{t\bar{t}}}{dX}$$

with X:

- lepton: $p_T(\ell)$, $\eta(\ell)$
- lepton pair: $p_T(\ell^+\ell^-)$, $\eta(\ell^+\ell^-)$, $M(\ell^+\ell^-)$
- top quark: $p_T(t)$, $y(t)$
- top quark pair: $p_T(t\bar{t})$, $y(t\bar{t})$, $M(t\bar{t})$

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In the **dilepton** and **lepton + jets** channel:

- in the 'visible' phase space
- corrected for detector effects
- corrected back to parton level

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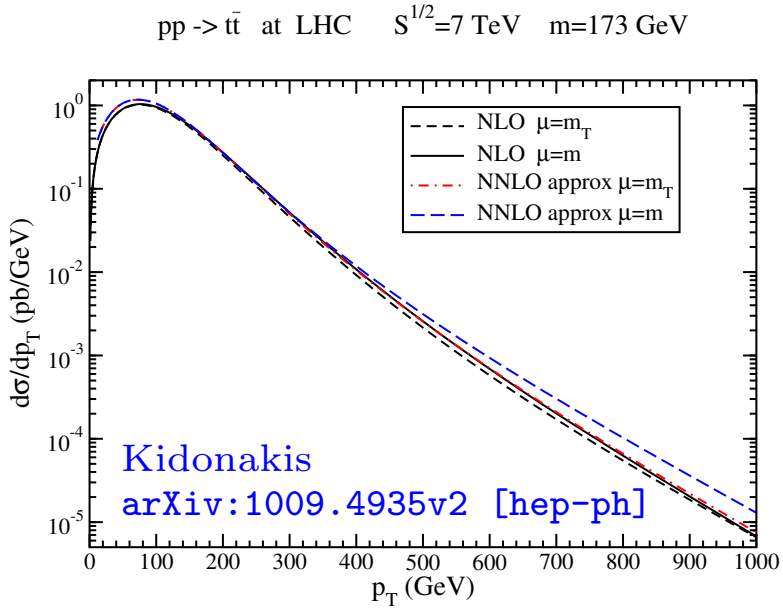
$\rightarrow$ **test pQCD at 7 TeV**

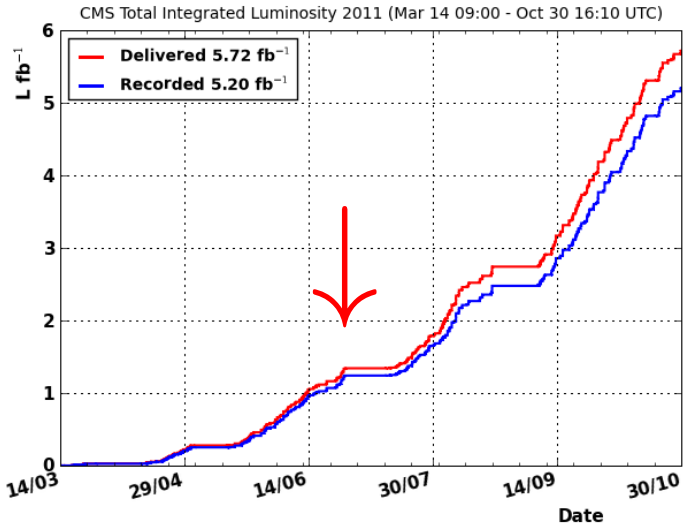


Dataset & Triggers

2011

$\int \mathcal{L} dt = \mathbf{1.14\ fb^{-1}}$ of
pp collisions at 7 TeV

Note:
$\sigma_{t\bar{t}} \approx 164$ pb $\rightarrow$ 187 000 $t\bar{t}$ pairs!



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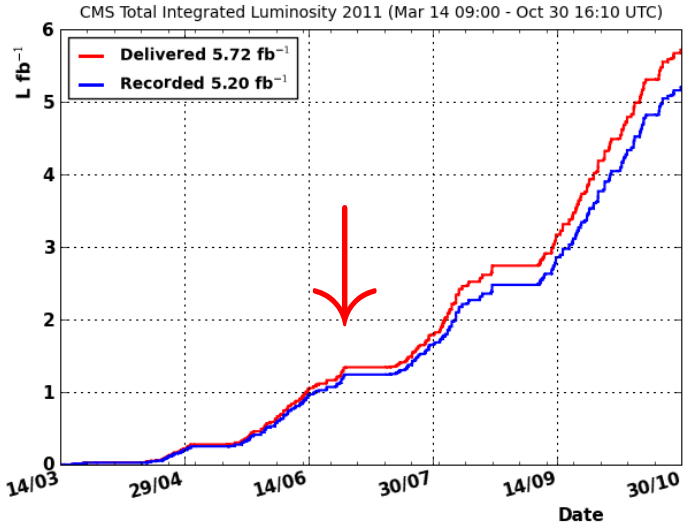
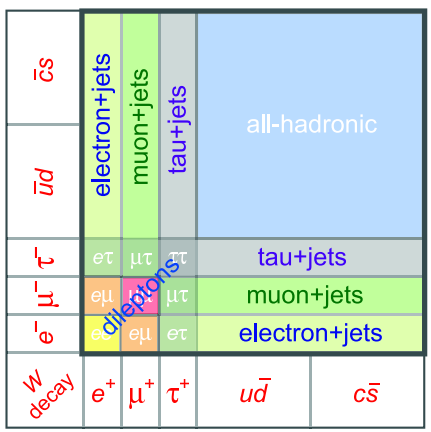


$\mathrm{Br}(t \rightarrow bW) \approx 100\%$
$\mathrm{Br}(W \rightarrow \ell\nu_\ell) \approx 1/3^{rd}$
$\mathrm{Br}(W \rightarrow q\bar{q}') \approx 2/3^{rd}$



Channel	Trigger
μ+jets	`IsoMu17`
e+jets	`Ele25_TriJet30`
$\mu^+\mu^-$	`DoubleMu7`, `Mu13_Mu7`
$e^\pm\mu^\mp$	`Ele17_Ele8`
e^+e^-	`Ele17_Mu8`, `Mu17_Ele8`

Event Selection

Lepton + jets channel

- **exactly 1 lepton**
  (e+jets, μ+jets)
  - muon
    $p_T > 20$ GeV/c, $|\eta| < 2.1$,
    $I^{rel}_{0.4} < 0.125$, $\Delta R_{j\mu} > 0.3$
  - electron
    $E_T > 30$ GeV/c, $|\eta| < 2.5$,
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- **≥ 4 jets**
  anti-k_T with R = 0.5,
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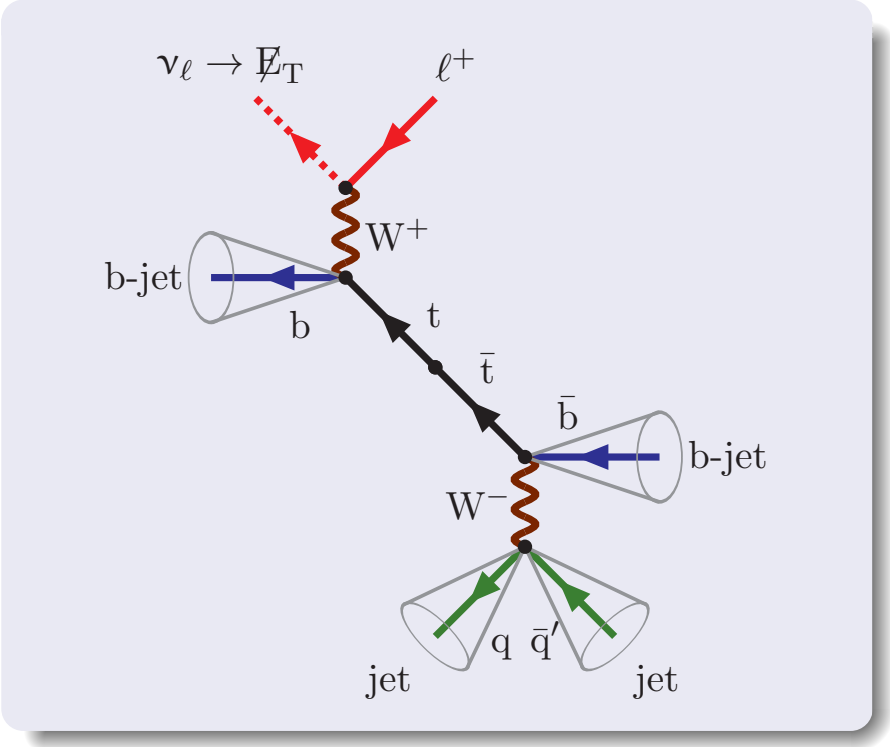
- **≥ 2 b-tagged jets**
  secondary vertex algorithm
  ϵ: 62%, mis-tag: 1.4%



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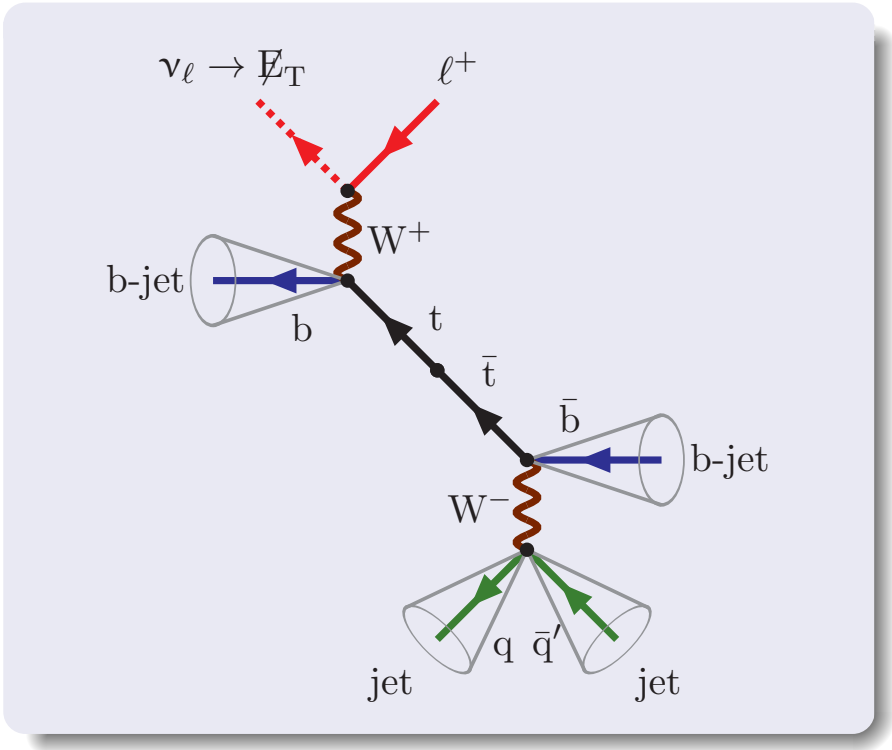

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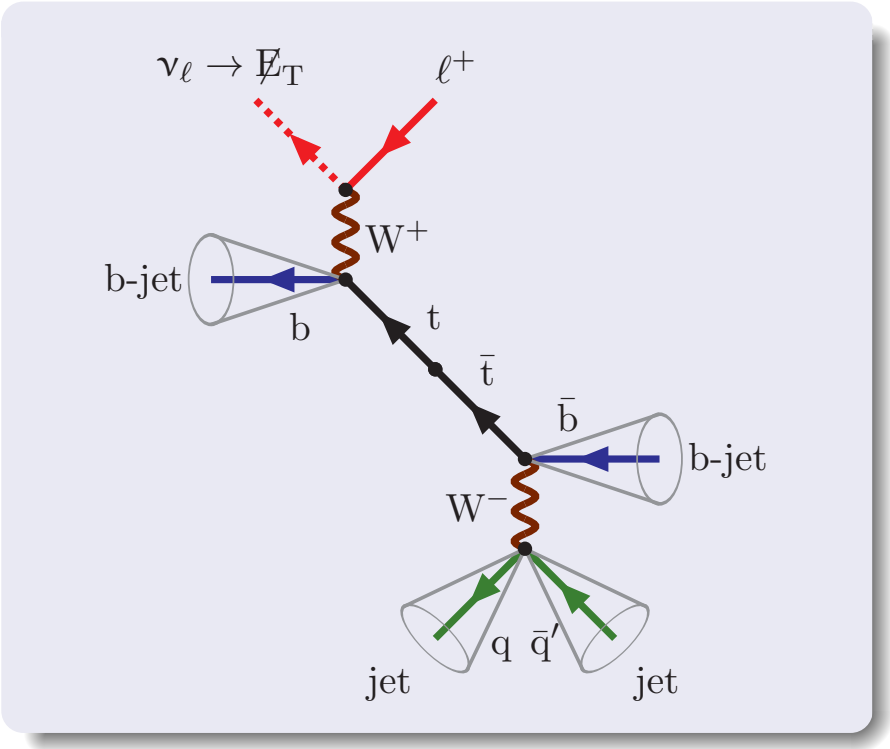

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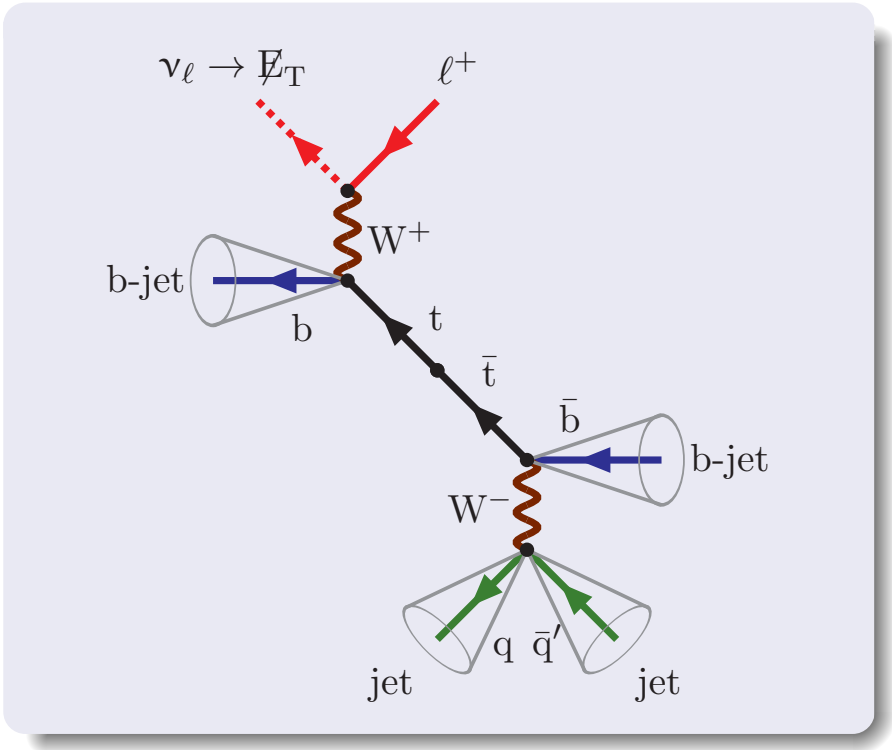
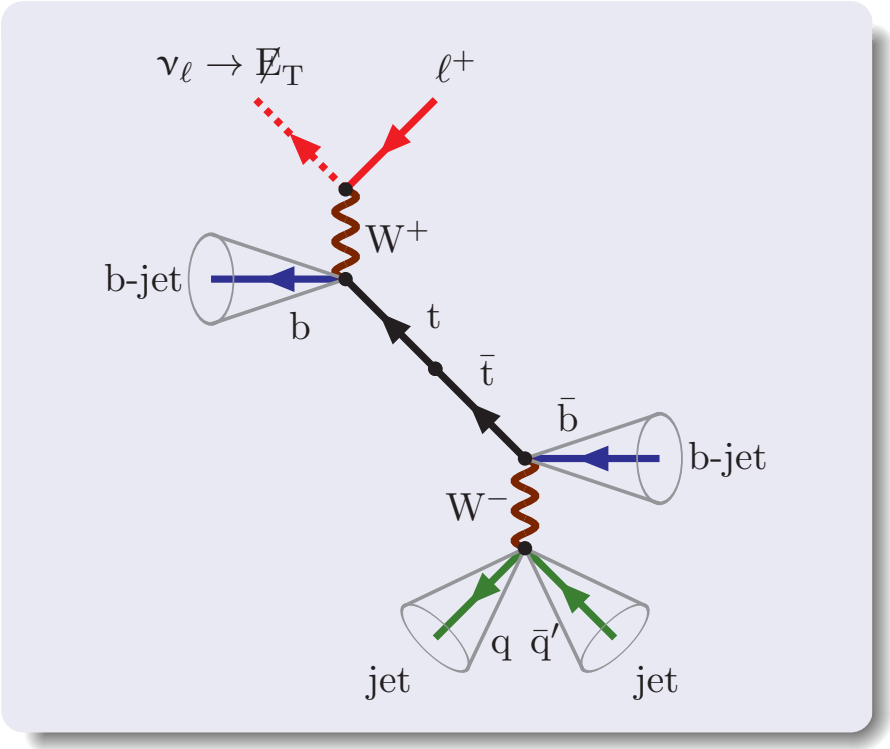


Event reconstruction

Lepton + jets channel

Kinematic fit (KinFit):

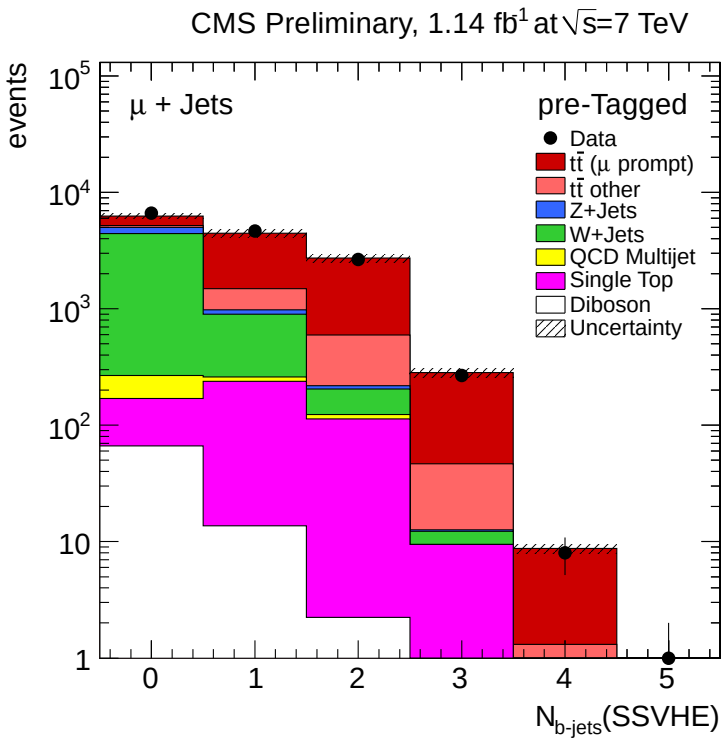
- 5 leading jets
- b-tagged jets → b-quarks
- ν_ℓ: E_T^{miss} with $p_z = 0$ initially
- vary 4-vectors of jets, ℓ and ν within their resolutions to satisfy:
  - $m_t = m_{\bar{t}}$
  - $M_W = 80.4\ GeV/c^2$
- permutation with minimum χ^2 is taken



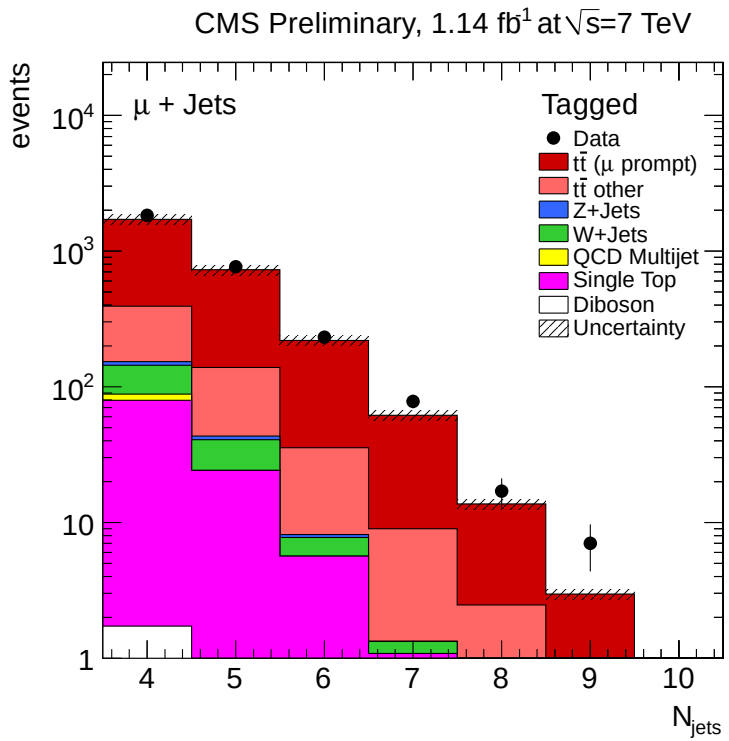
Event Yields

μ + jets channel

b-tag multiplicity



jet multiplicity



μ + jets: 2 657 evts
e + jets: 1 797 evts

} of which 93% $t\bar{t}$ (7% single t, W+ jets)

Event Selection

Dilepton channel

- **2 oppositely charged ℓ's** (e^+e^-, $\mu^+\mu^-$, $e^\pm\mu^\mp$)
  - muon
    $p_T > 20$ GeV/c, $|\eta| < 2.4$,
    $E^{rel}_{0.3} < 0.20$
  - electron
    $E_T > 20$ GeV/c, $|\eta| < 2.4$,
    $I^{rel}_{0.3} < 0.17$
  - QCD veto
    $M_{\ell\ell} > 12$ GeV/c^2

- **≥ 2 jets**
  anti-k_T with $R = 0.5$,
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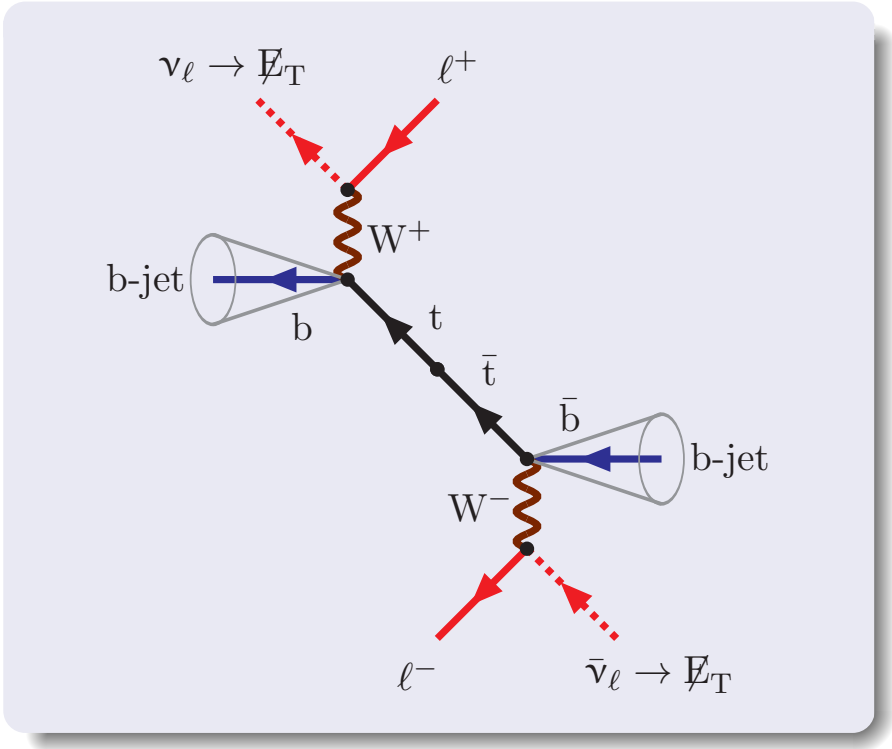
- **≥ 1 b-tagged jet**
  track counting algorithm
  ϵ: 80%, mis-tag: 10%



- **e^+e^-, $\mu^+\mu^-$ channel:**
  $E_T^{miss} > 30$ GeV
  Z veto: $76 < M_{\ell\ell} < 106$

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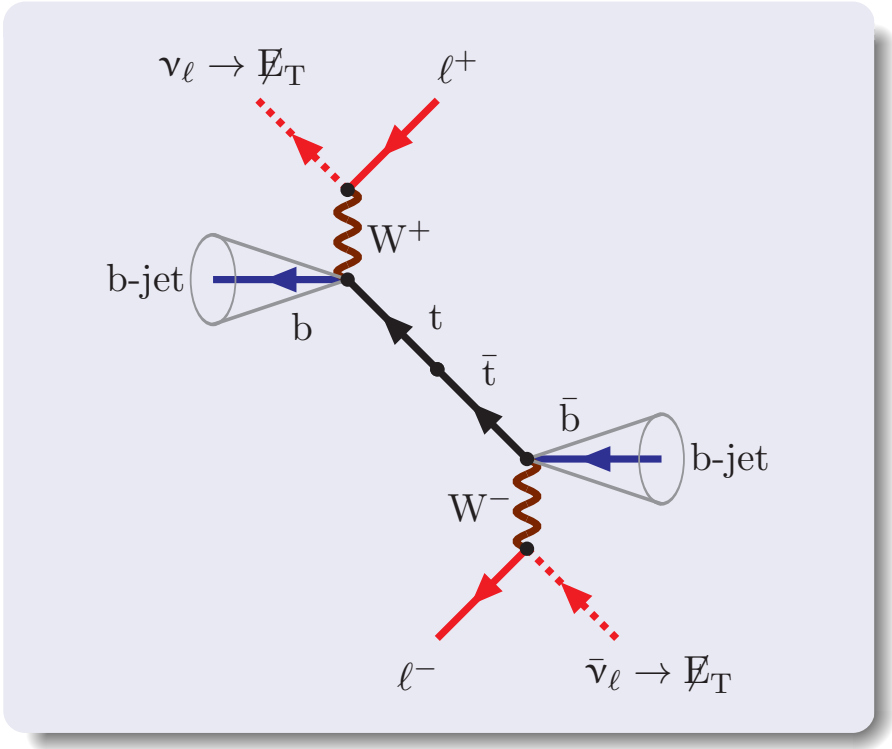

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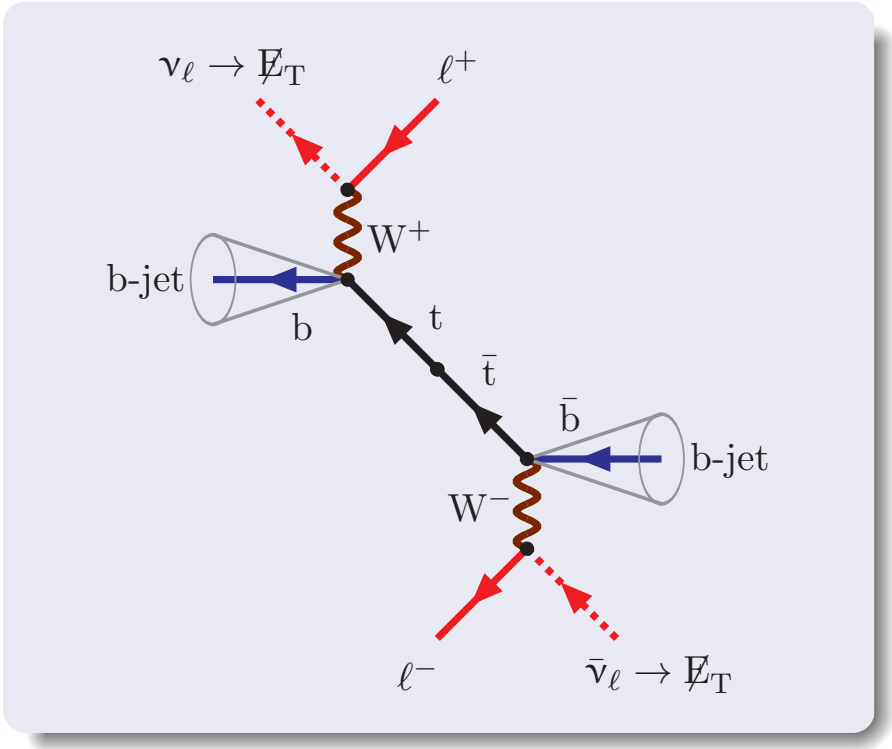

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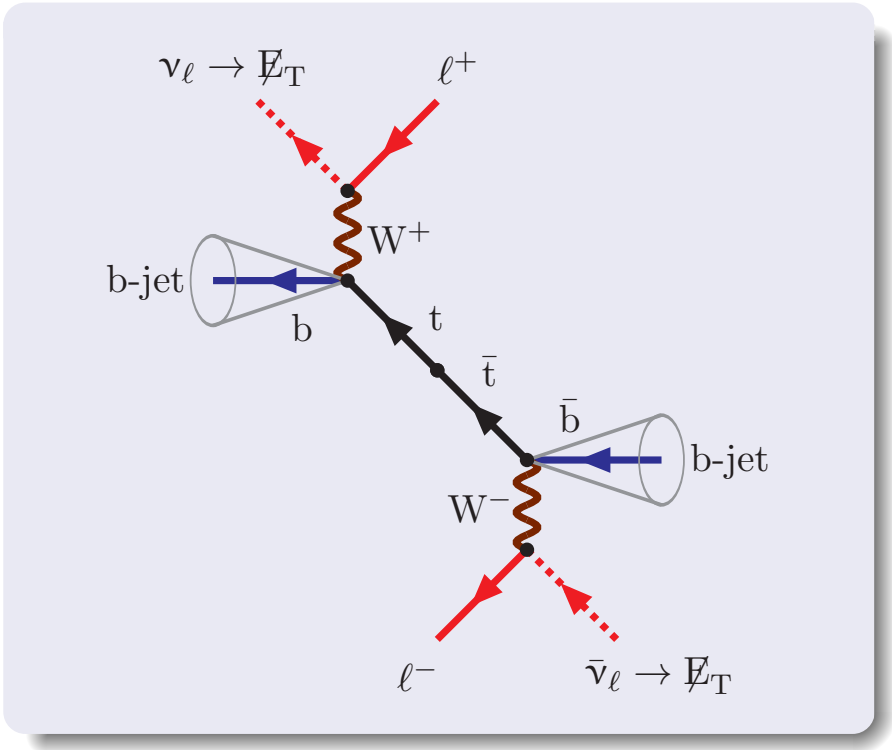

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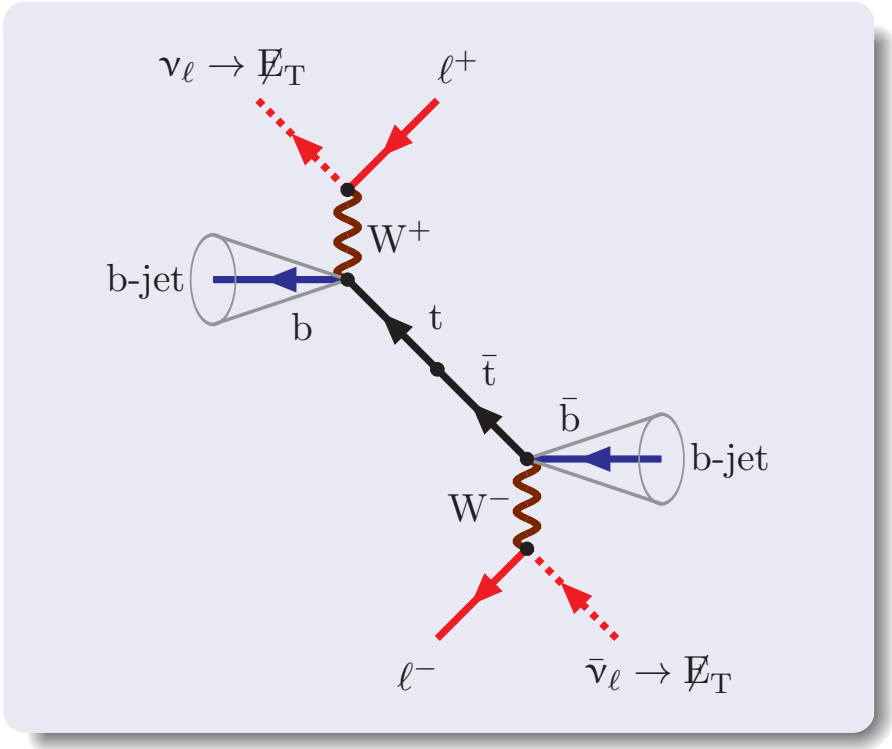

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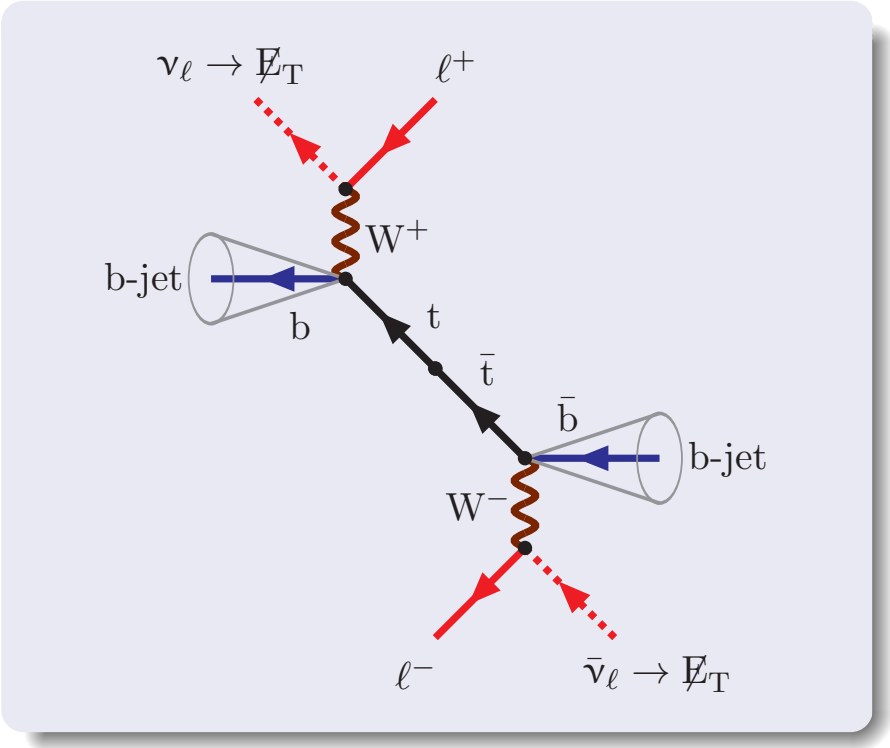
Event reconstruction

Dilepton channel

Kinematic reconstruction:

- system is underconstrained due to the 2 ν's
- take 2 b-jets (or leading jets), 2 leptons, and E_T^{miss}
- constraints:
  - $M_W = 80.4\ GeV/c^2$
  - $p_{x,y}(\nu_1) + p_{x,y}(\nu_2) = E_T^{miss}$
  - $m_t = m_{\bar{t}} =$ fixed

  with m_t varied in steps of 1 GeV between 100–300 GeV
- reconstructed E_ν comparing best to MC spectrum taken



- **For $d\sigma/dM_{t\bar{t}}$ only:**
  4-vector sum of 2 leading jets, 2 leptons, and E_T^{miss}

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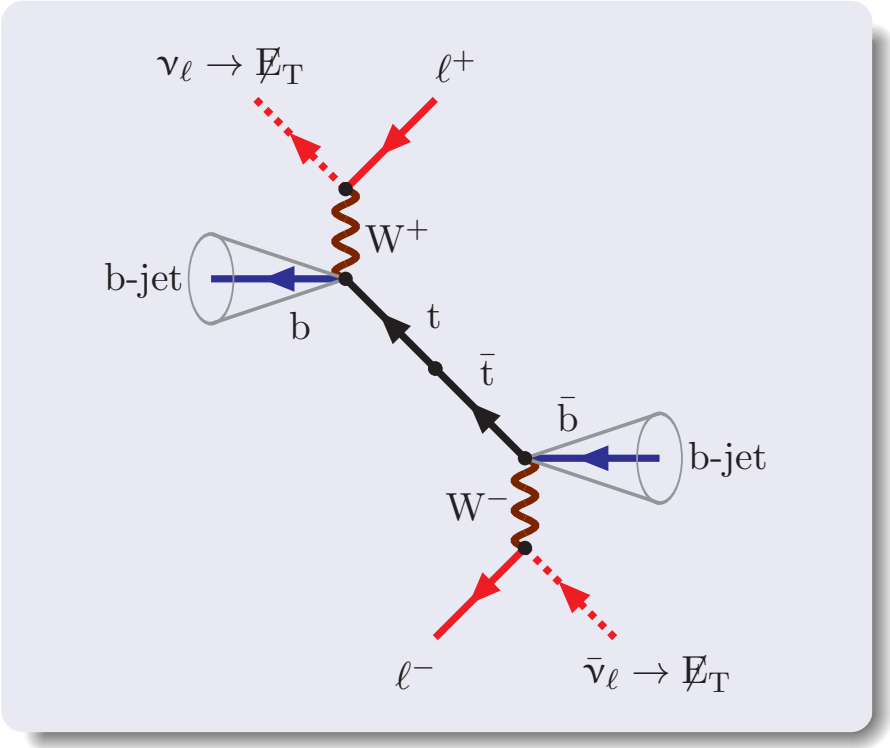

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Event Yields

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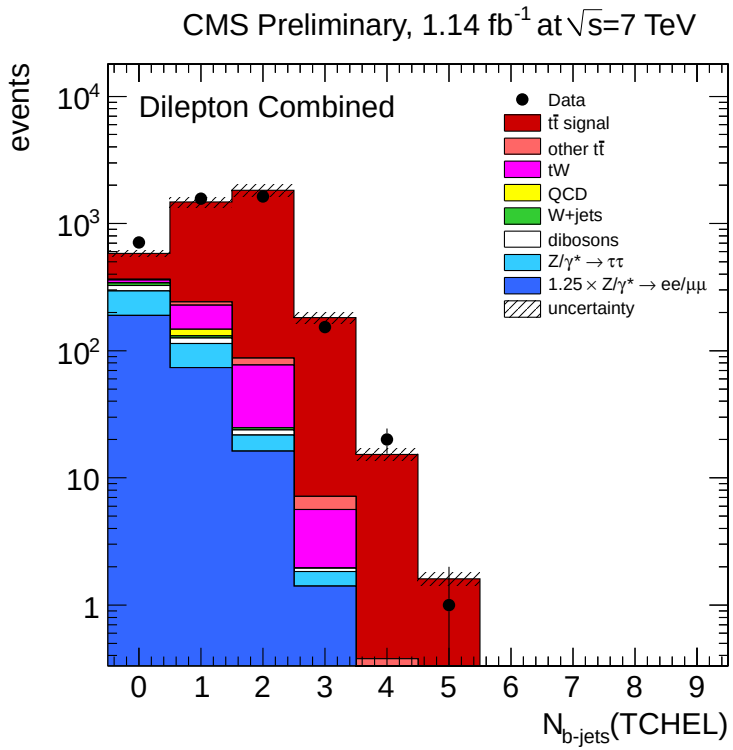
b-tag multiplicity



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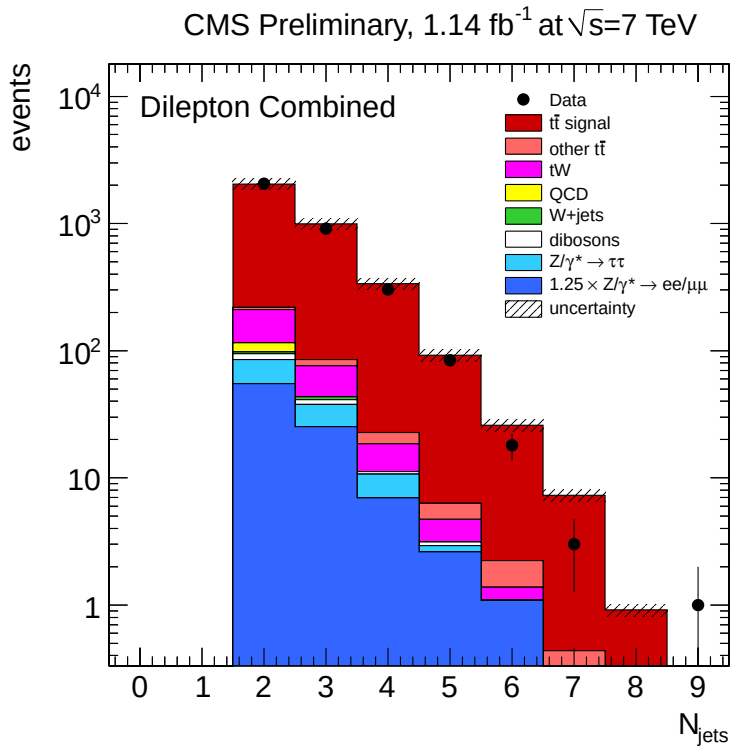
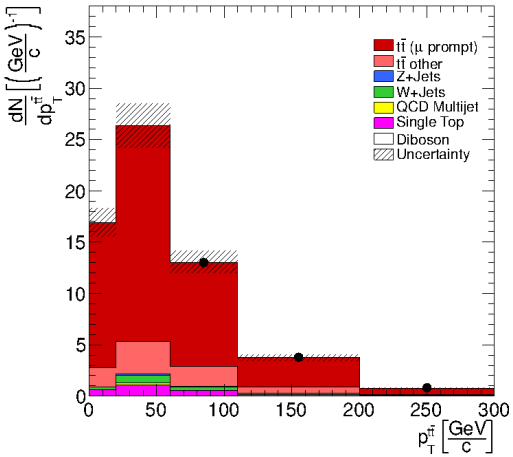


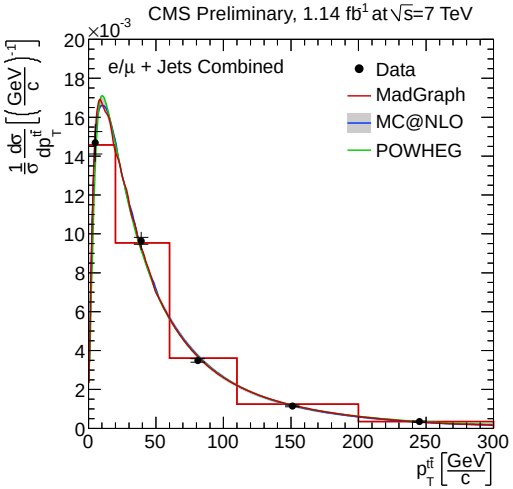
$\mu^+\mu^-$	612 evts	} of which 90–93% $t\bar{t}$ (rest: single t, DY)
$e^\pm\mu^\mp$	1 764 evts	
e^+e^-	597 evts	

Normalized Cross Sections

Unfolding



$$\frac{1}{\sigma}\frac{d\sigma^i}{dX} = \frac{1}{\sigma}\frac{N^i_{Data} - N^i_{BG}}{\Delta^i_X\ \epsilon^i\ \mathcal{L}_{int}}$$



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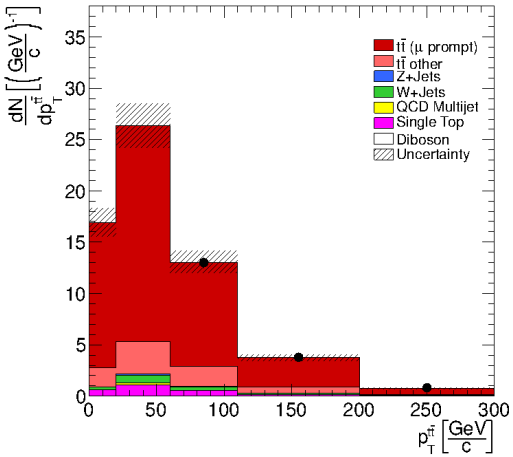

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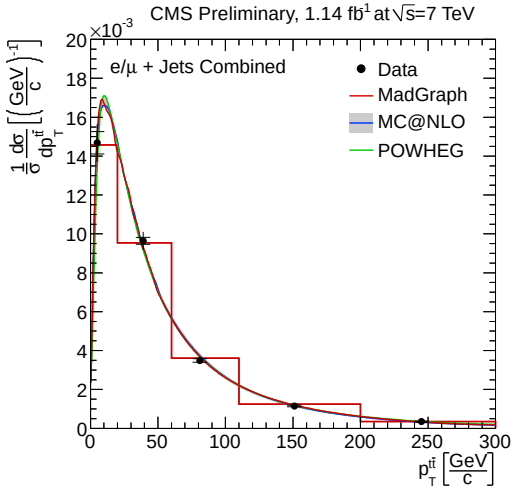
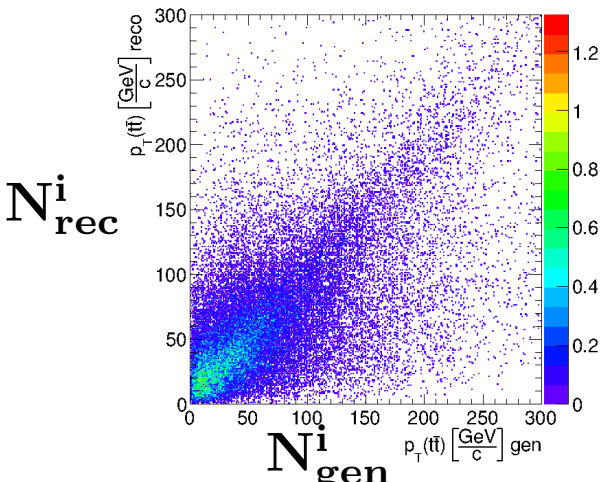


$$\epsilon^i = \frac{N^i_{rec}}{N^i_{gen}}$$



- Normalised to unity
- Restricted to visible phase space
  - quarks $p_T > 30$, $|\eta| < 2.4$
  - lepton $p_T > 30$, $|\eta| < 2.1$ (l+jets)
    lepton $p_T > 20$, $|\eta| < 2.4$ (dilepton)
- Corrected back to parton level (MC)
- Corrected for detector effects
  - Bin-by-bin corrections
    purity, stability limited to $\geq 50\%$
  - SVD unfolding for $d\sigma/dM_{t\bar{t}}$ in the dilepton channel only

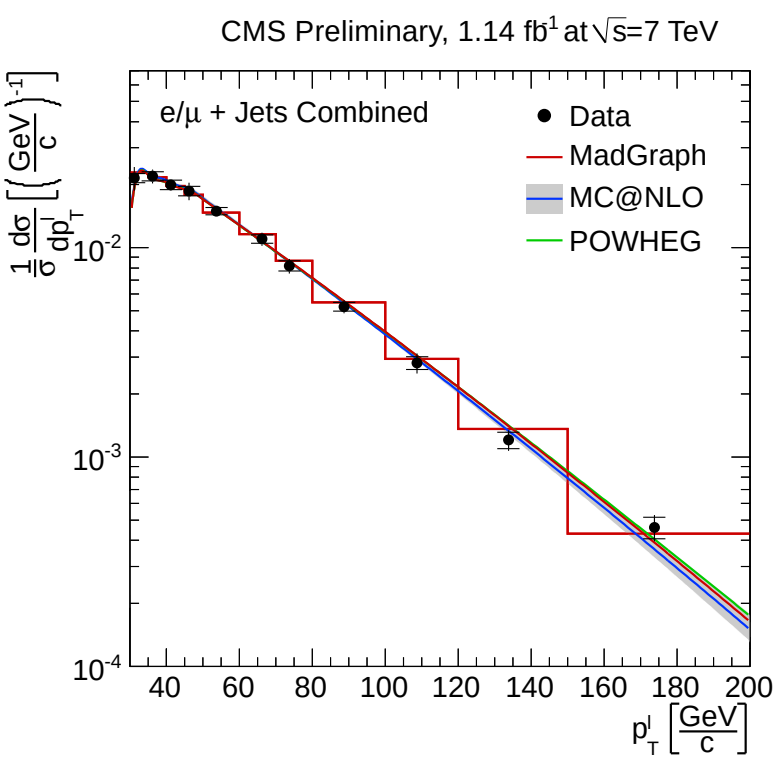
Systematic uncertainties

Typical values per bin

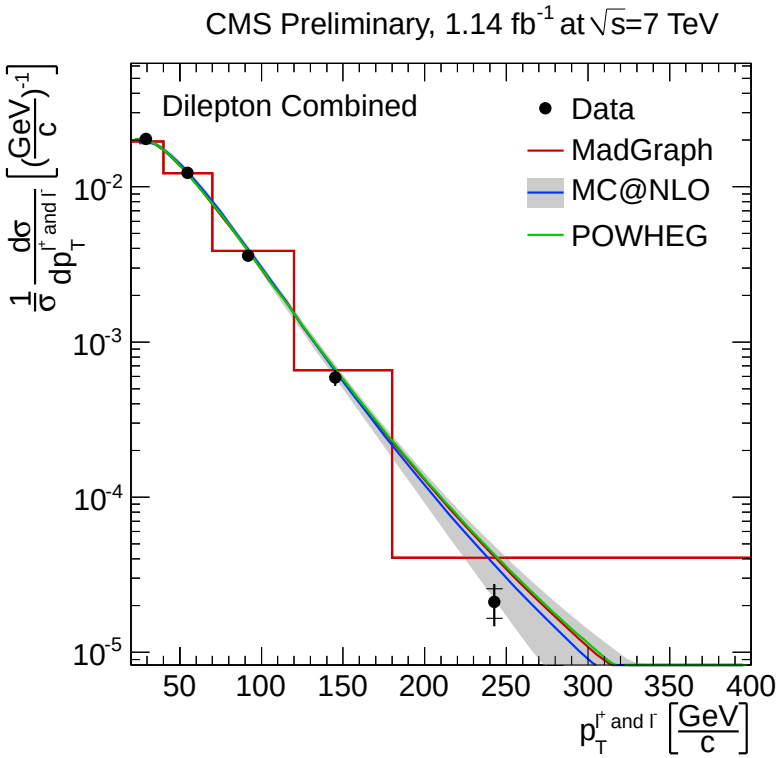
Source	**Method**	**l+jets** (in %)	**dilepton** (in %)
Background	vary with 30–50%	0.5	3.0
Trigger & lepton eff.	p_T, η dependent	0.5	2
Jet Energy Scale	p_T, η dependent	0.5	1.0
Jet Energy Resolution	p_T, η dependent	1.0	<1.0
Pile-up	vary $\pm$0.6 PU evts	<1.0	<1.0
b-tagging	p_T, η dependent	1–4	1.7
Kinematic reconstruction	p_T, η dependent	–	1–4
Q^2, matching scale	vary factor 0.5–2	3.5	1.2
Hadronisation	Pythia vs Herwig	2–4	2–10
Top Quark Mass	172.5 ± 0.9	0.5	0.5
PDF	PDF4LHC	0.5	0.5

Transverse momentum of the lepton

lepton+jets channel

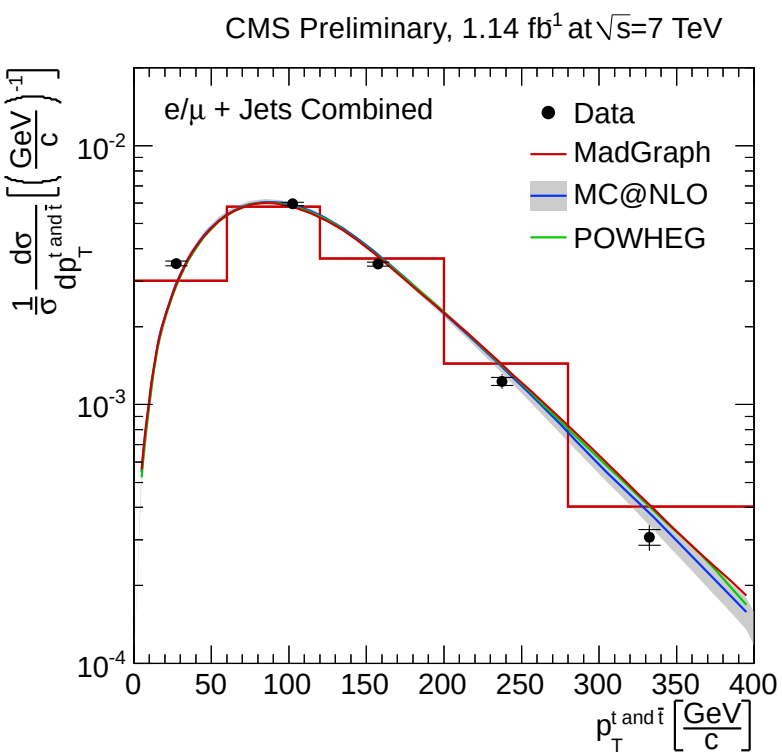


dilepton channel

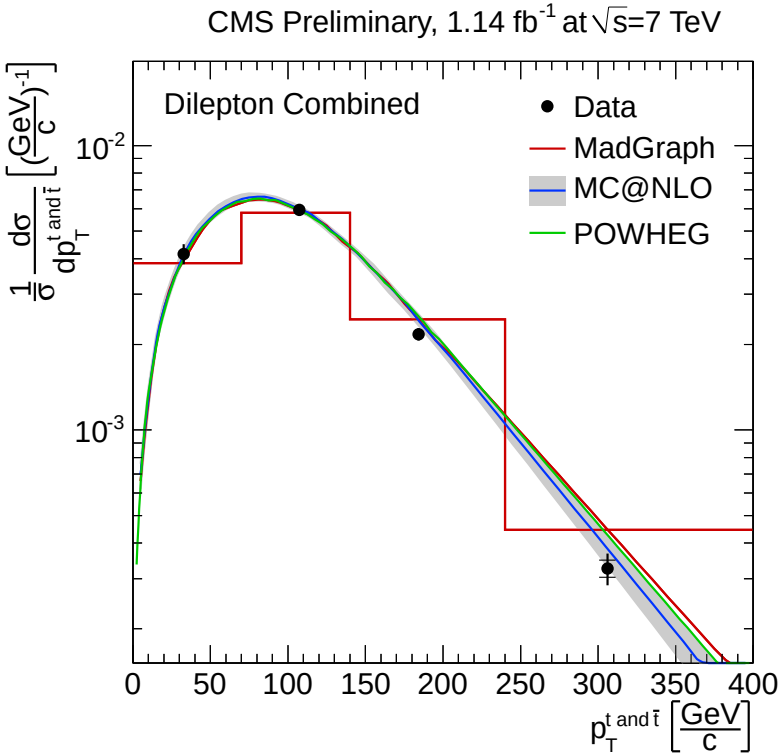


Transverse momentum of the top quark

lepton+jets channel

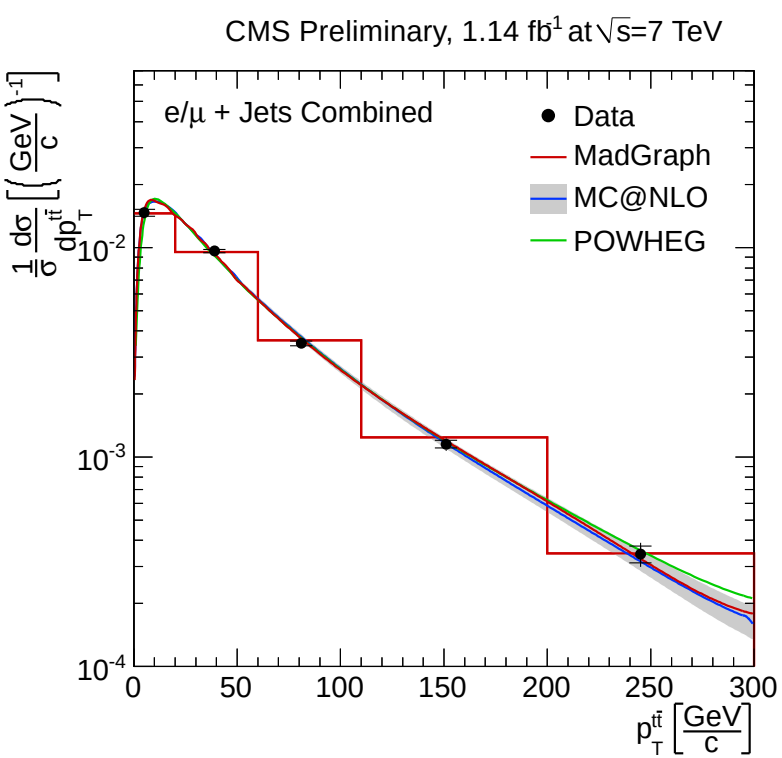


dilepton channel

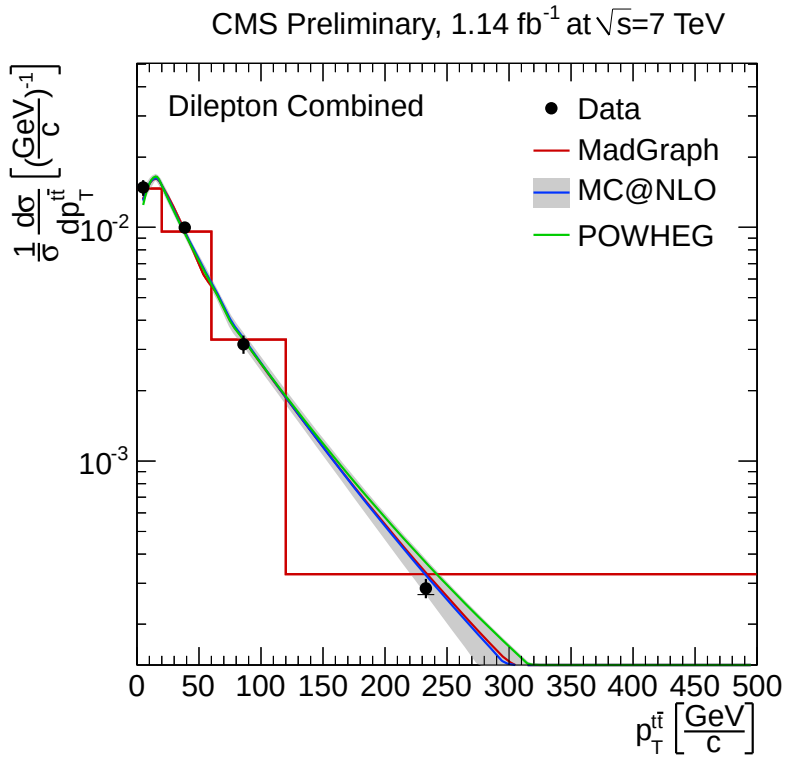


Transverse momentum of the top quark pair

lepton+jets channel

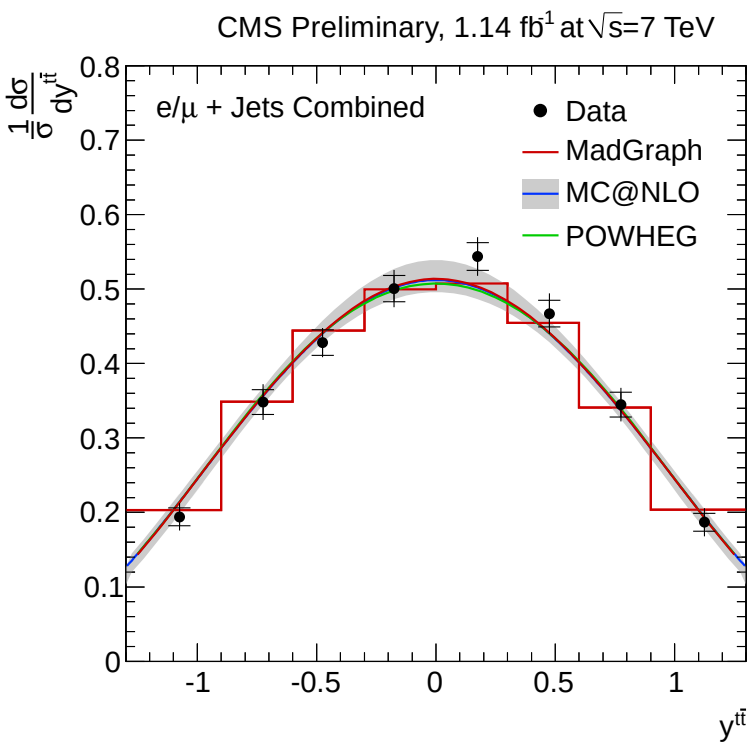


dilepton channel

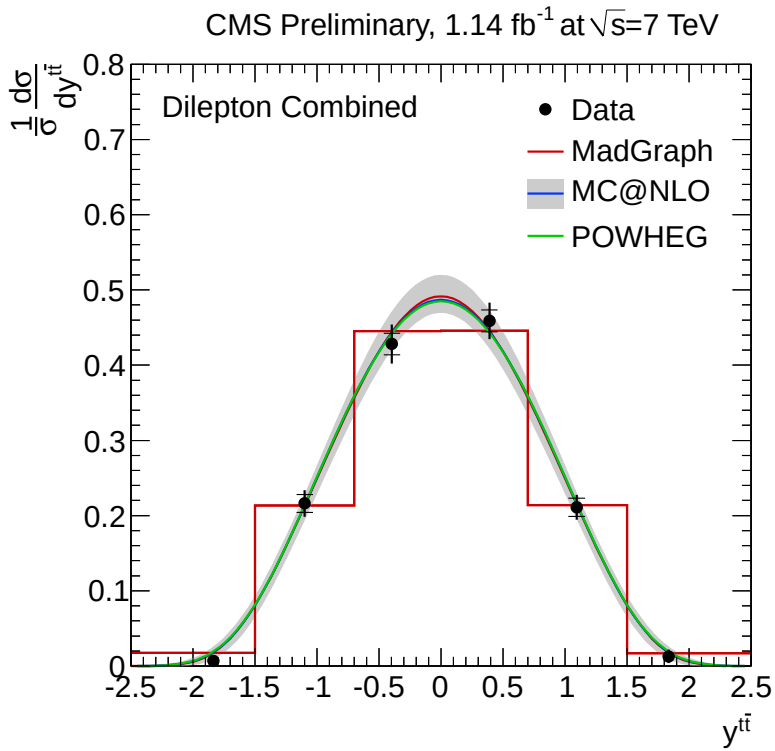


Rapidity of the top quark pair

lepton+jets channel

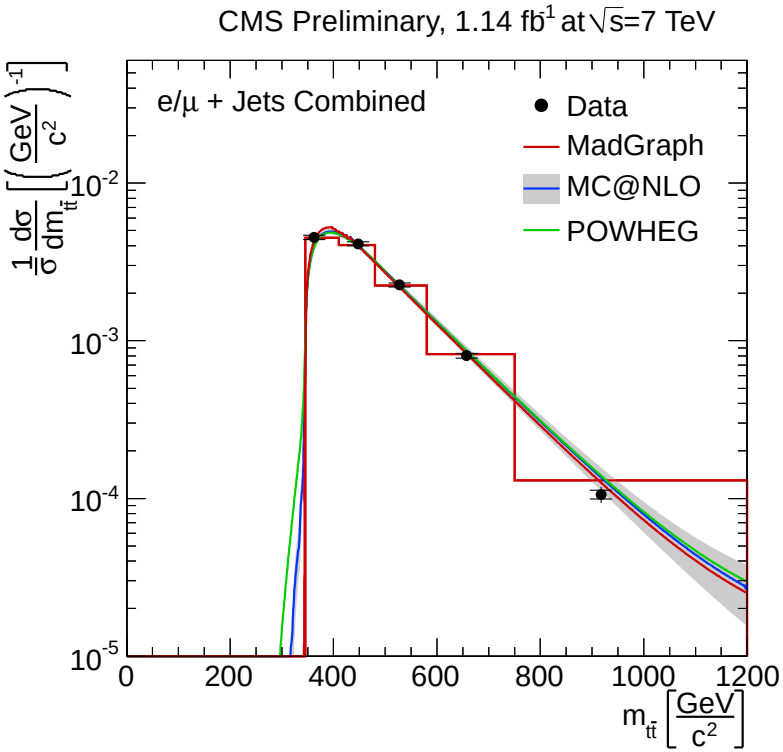


dilepton channel

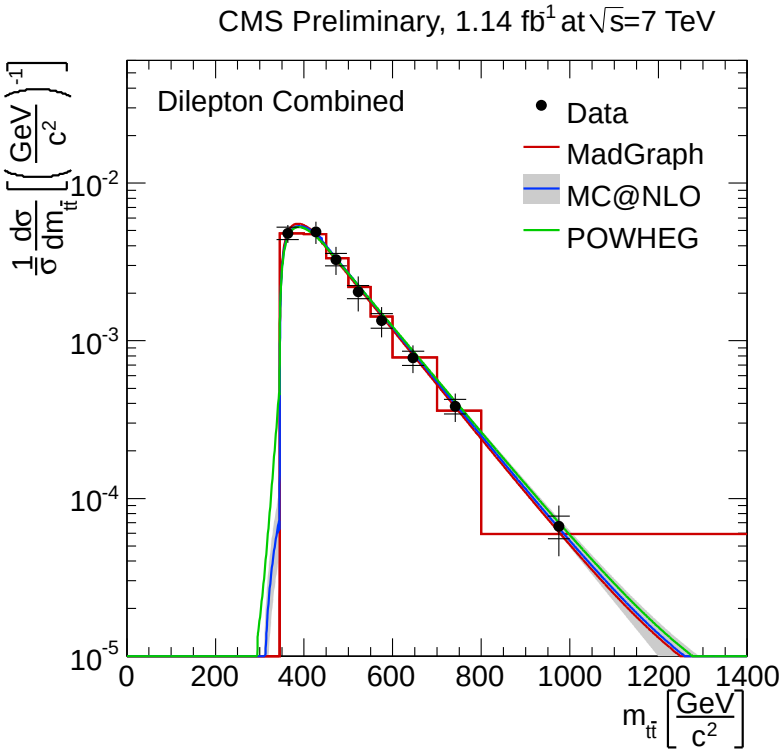


Invariant mass of the top quark pair

lepton+jets channel



dilepton channel



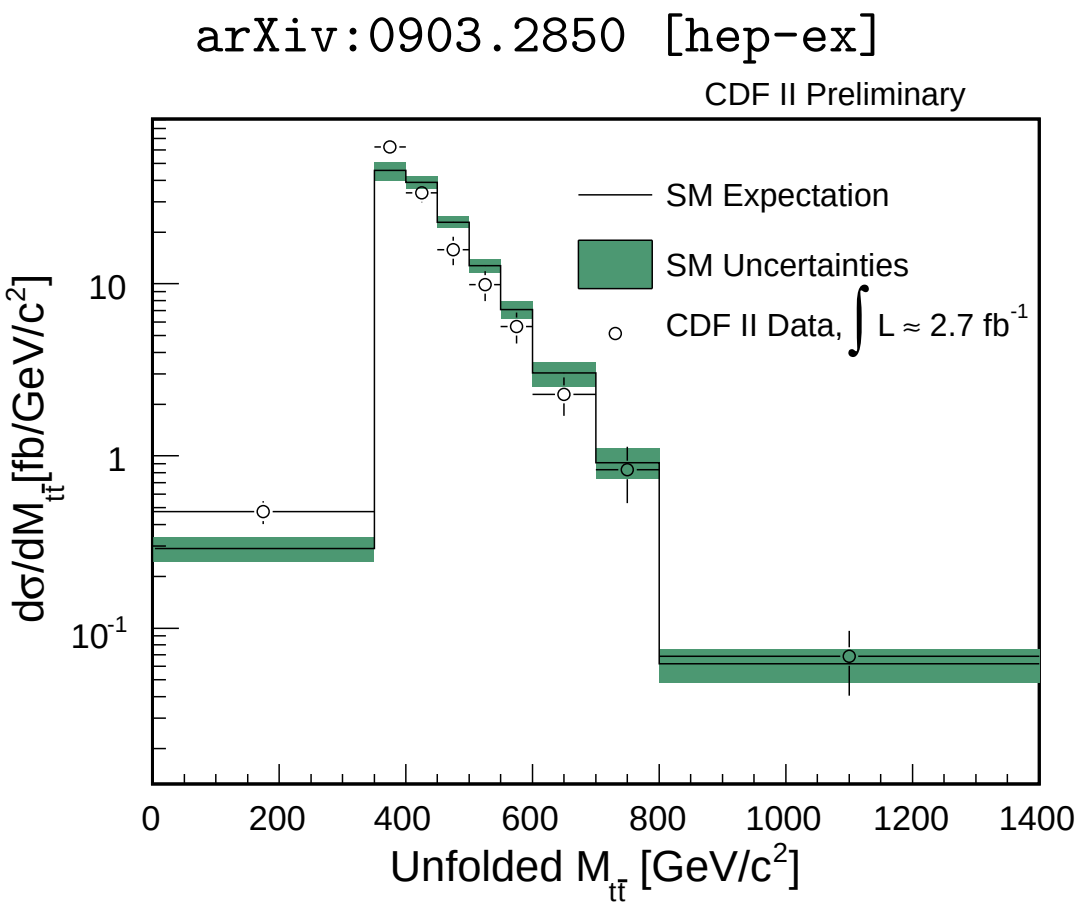
Summary

- A large sample of $t\bar{t}$ pairs has been collected in 2011
- First CMS measurement of differential $t\bar{t}$ cross sections
- Good agreement observed between data and various predictions
- Nice collaboration between DESY and UHH groups

For more details: http://cdsweb.cern.ch/record/1422425

Tevatron results

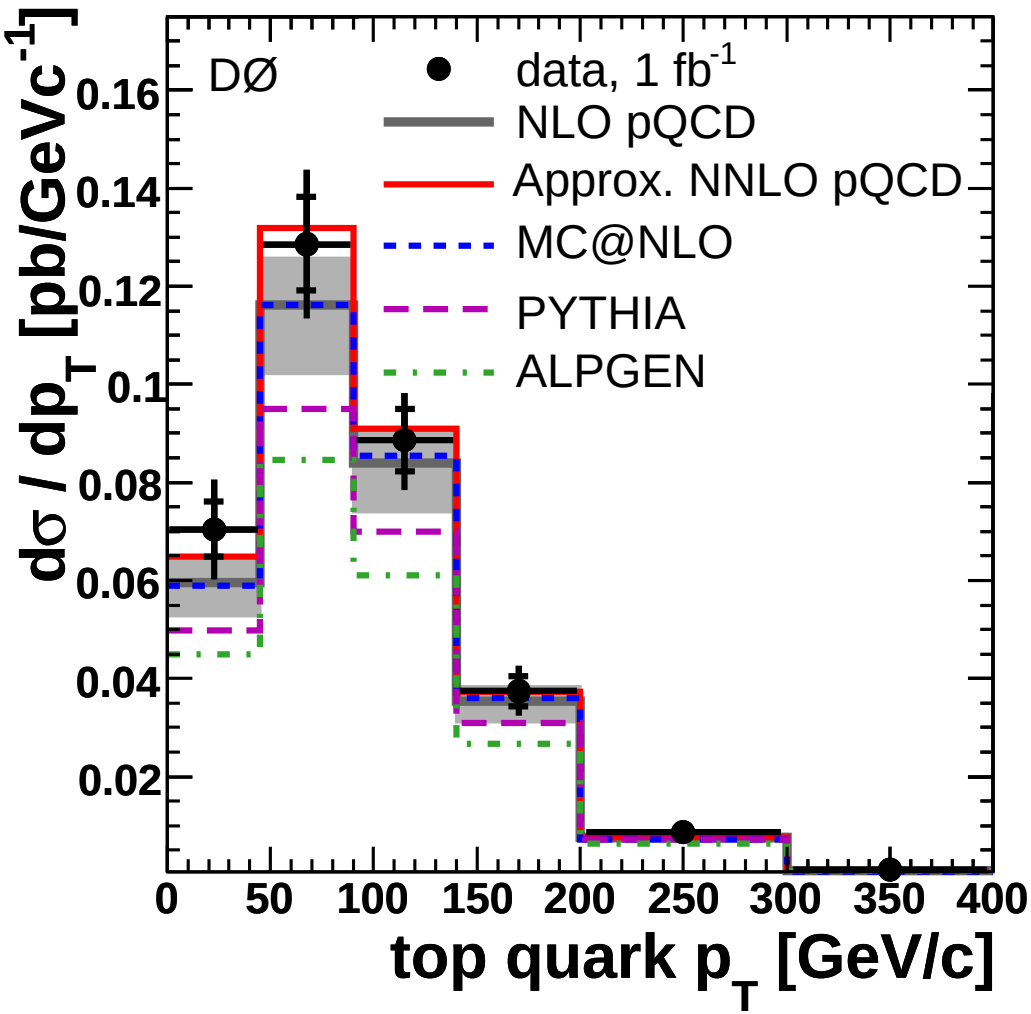
CDF



Tevatron results

DØ

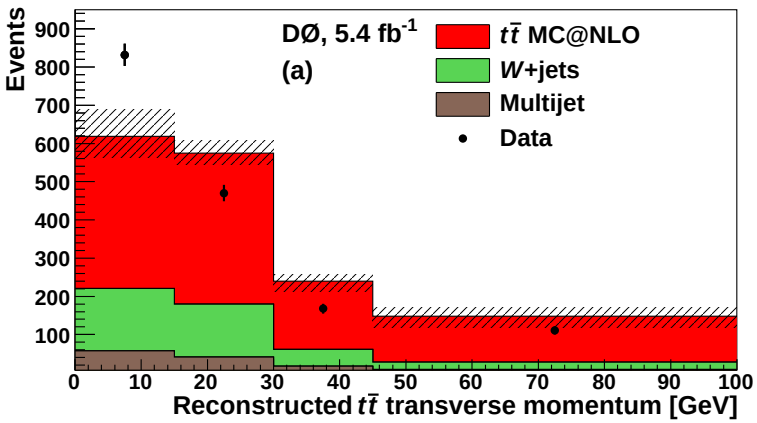
arXiv:1001.1900 [hep-ex]

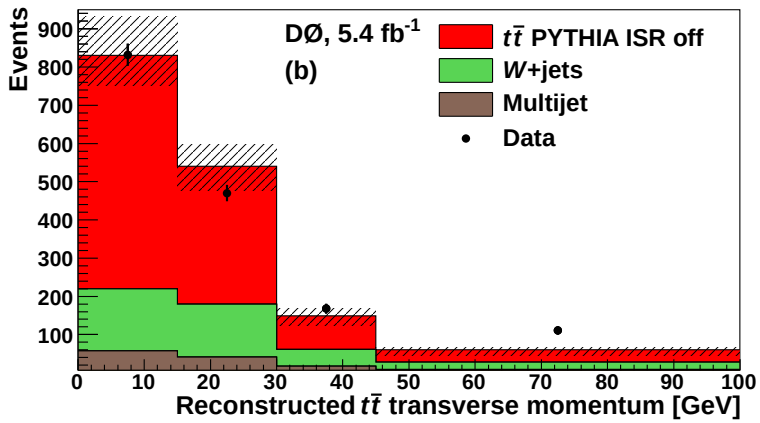


Tevatron results

DØ

arXiv:1107.4995 [hep-ex]





Among leading systematic uncertainties for A_{fb} measurement!