Experimental Tests of the Standard Model (3)

- Measurements of the Weinberg angle
- $W^{\pm}$ and Z^0 discovery
- Precision measurements of the Z^0
- Precision measurements of the W
- **Discovery/measurements of the top**
- Discovery of the Higgs

CP violation

- Well before the clear evidence of the quarks and the discovery of the J/ψ meson, an experiment found a small **violation of the CP invariance** in the weak interaction of the neutral kaons.

- In a small percentage, K^0_2 are seen to decay into two pions (experiment made by Christenson, Cronin, Fitch, Turlay (1964))

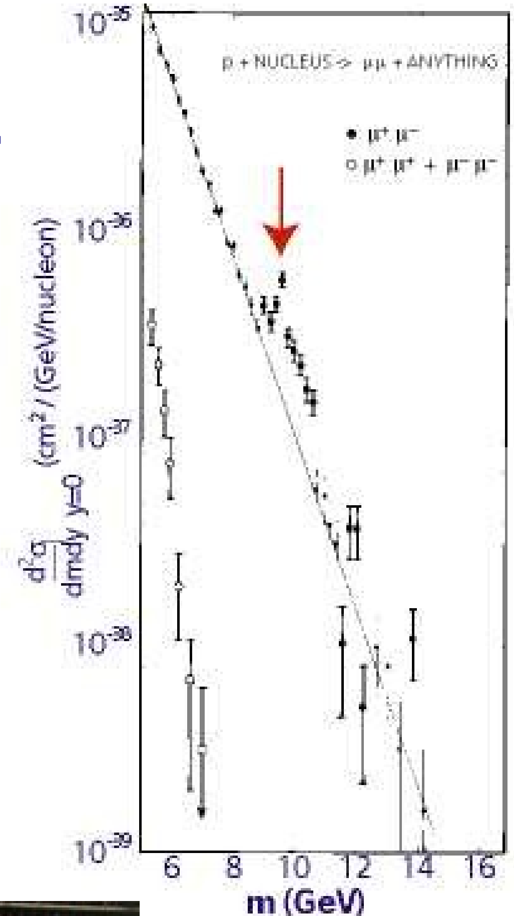
- In 1973 Kobayashi and Maskawa noted that the presence of the CP invariance in the weak interactions implies, in the context of the quark model of the hadrons, the presence of a **complex phase** in the matrix representing the transition probabilities.

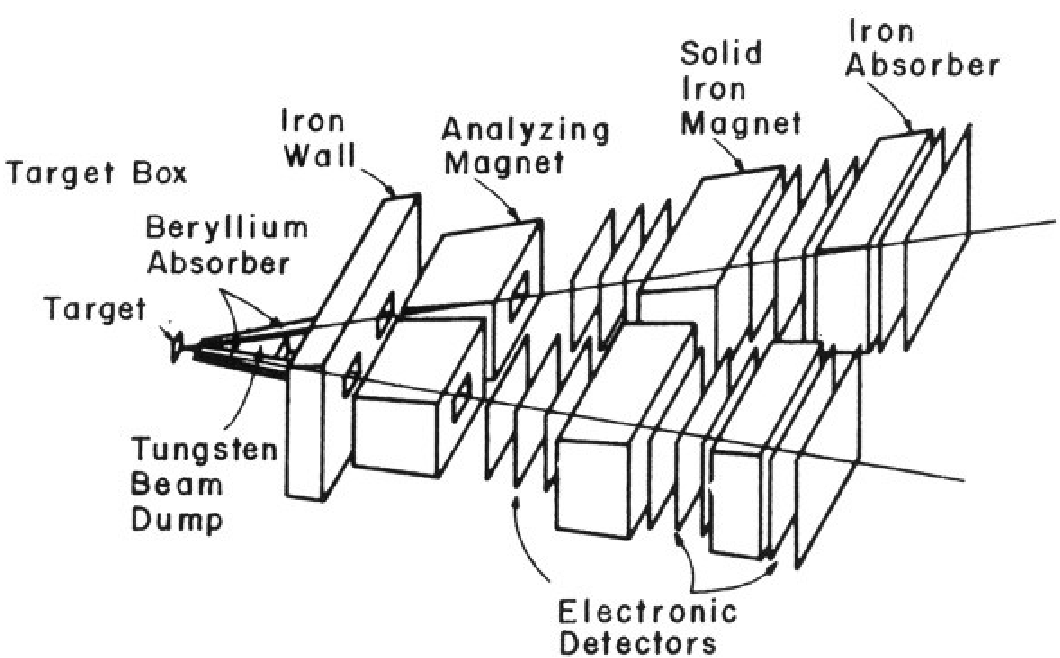
  - With 4 quarks, the matrix is 2x2 and the unitarity request implies $(n-1)^2 = 1$ free parameter: θ_c (Cabibbo angle)
  - The number of complex phases in a unitary matrix is **(n-1)(n-2)/2**, therefore **the minimum number of quark generation to have CP violation is 3.**

- The K.M. speculation becomes more credible after the discovery of the charm.
- The following discovery of the tau lepton (Perl et al., 1975) makes more strong the hypothesis of the three quarks generation, and the hunt of the *b* quark starts.

b quark discovery

- Lederman *et al.* 1977: 400 GeV protons from the Fermilab synchrotron collide against a berillium target, final states with muons in the two magnetic spectrometers are analyzed.
- The experiment finds a bump of events with an invariant mass of about 9 - 10 GeV, they were recognized as three distinct resonances: Υ(1S,2S,3S).
- The properties of the new quark are studied also in the *e*+*e*- collider confirming the charge (-1/3, PLUTO/DASP), the increase of *R*, and the weak isospin (PETRA, 1983)





3 generations: theoretical motivations

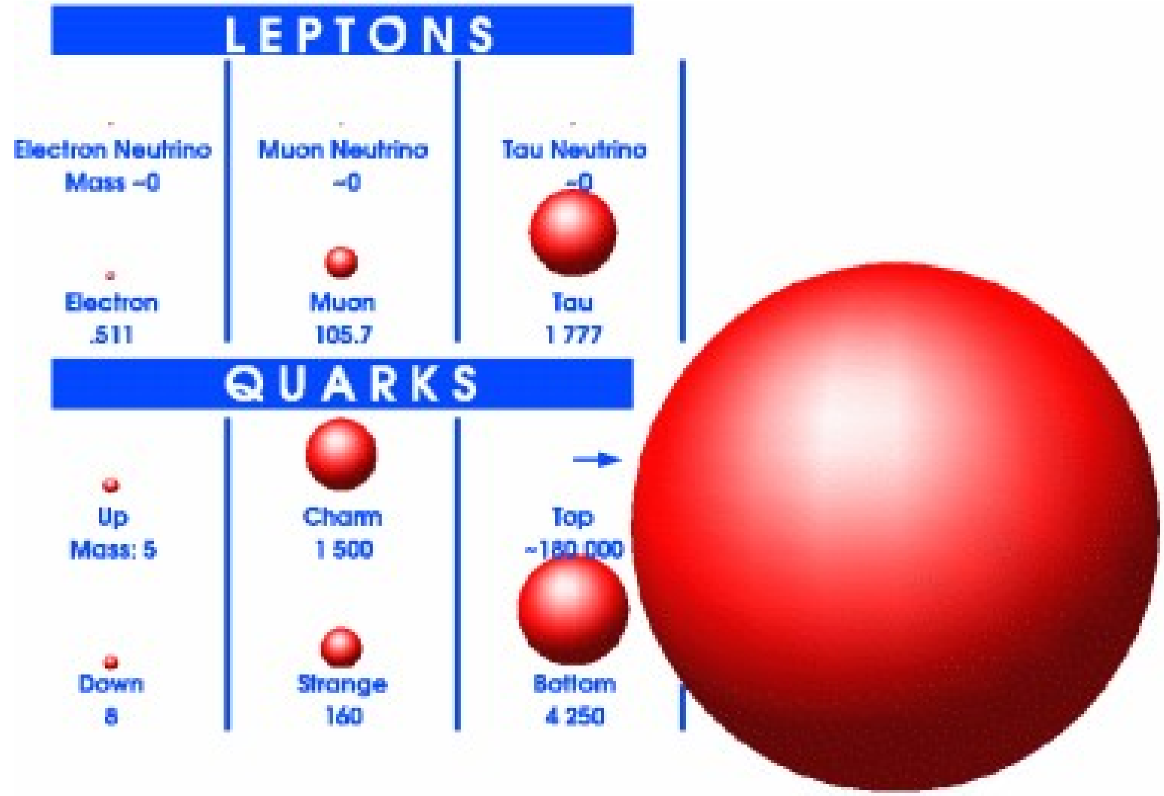
- At this point there are many experimental reasons to search for the top quark completing the third quarks family and explain the CP violation in a natural manner.

  From the theoretical side there are even more suggestions for the top existence:

  1) Cancellation of the *triangular anomalies*
  2) Weak isospin of the *b*-quark
  3) Non-existence of the FCNC of the neutral *B*
  4) Frequency of the neutral *B* oscillations
  5) Width of the *W* boson

Phenomenology of the top quark

- Decay mechanisms:
  - **Standard decay**
  - FCNC decays ($t \rightarrow Bq$ with $B = g, \gamma, Z, H$ and $q = u, c$)
- Production mechanisms at the hadronic colliders
  - **Pair production**
  - Electroweak single-top production ($q\bar{q}' \rightarrow t\,\bar{b},\ qb \rightarrow t\,q'$)

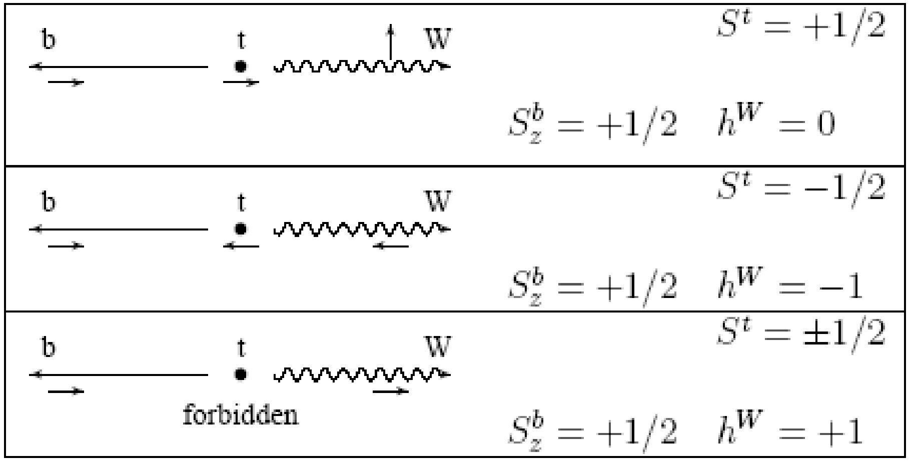


top decays

- The "standard" decays of the top always include a *W* boson and a *b* or *s* or *d* quark

$$V_{tb} = 0.9990 \pm 0.0004 \;\Rightarrow\; BR(b) \approx 1$$
$$V_{ts} = 0.044 \pm 0.010 \;\Rightarrow\; BR(s) \approx 0.2\%$$
$$V_{td} = 0.011 \pm 0.009 \;\Rightarrow\; BR(d) \approx 0.01\%$$

  - From the values of $|V_{tb}|$ and $|V_{ts}|$ follows that $t \rightarrow Wb$ is dominant
    - B($t \rightarrow Ws$): 0.2% only
  - The helicity conservation prevents the decay into *W* with $h = +1$
  - The decay is "semi-weak" because the top mass is huge and the width depends on the third power of the top mass $\rightarrow \tau = 10^{-25}$ s



$$\Gamma = \frac{G_F m_t^3}{8\sqrt{2}\pi}\left(1 - \frac{M_W^2}{m_t^2}\right)^2\left(1 + 2\frac{M_W^2}{m_t^2}\right)$$
$$\approx 175\,\mathrm{MeV}\left(\frac{m_t}{M_W}\right)^3$$

Implications of Γ(top) = 1.5 GeV

- The big value of Γ works as a cut-off for the QCD dynamics, which is connected to the Λ = 150-200 MeV
  - The angular distribution of the top decays follows the predictions of a ½ spin particle, because QCD has no time to modify the decay of a "free particle".
  - To be compared with the *b*-quarks decay, which happens inside the mesons ($\tau_B >> 1/\Lambda$), it is isotropic (does not depend on the *b* spin)
  - <u>The top quark is produced and decays as a free particle, QCD has no time to work</u>
  - This implies the possibility:
    - to measure the spin of the top directly from the angular distributions of the decay product
    - to measure the dynamics of the decays and verify if it is governed by the V-A interaction

There are no *T* mesons

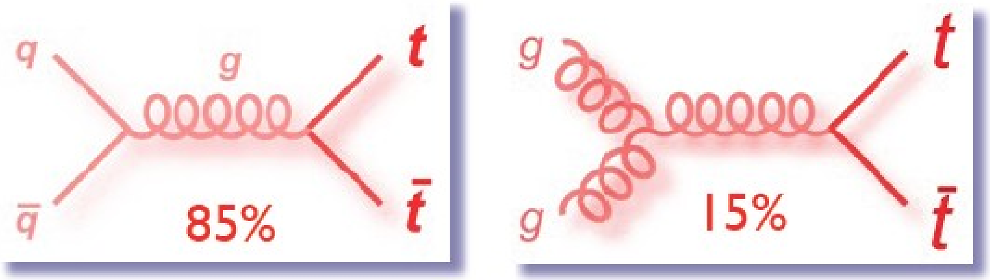
- For the tt toponium: $\Gamma(tt) = 2\Gamma(t) = 3$ GeV while the foreseen splitting between the states 1S and 2S is 1.2 GeV → there is no time for the building of the resonances

- At Tevatron and LHC it is possible to study the characteristics of the top spin, at a linear collider one will observe the cross section increasing with s without any spike.

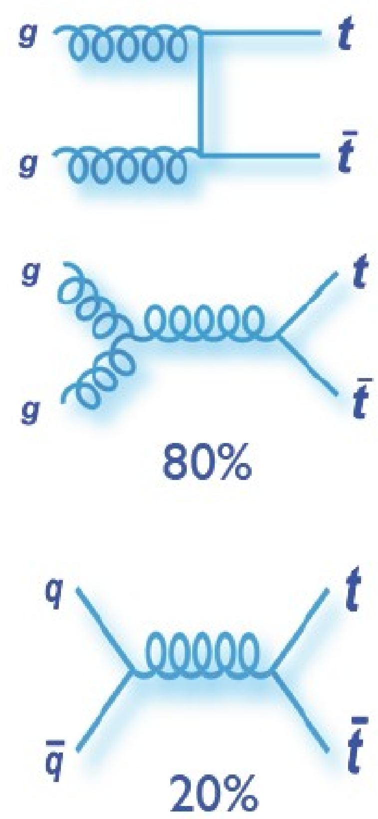
Top quark pair production

Main mechanism: pair production via strong interaction

Tevatron



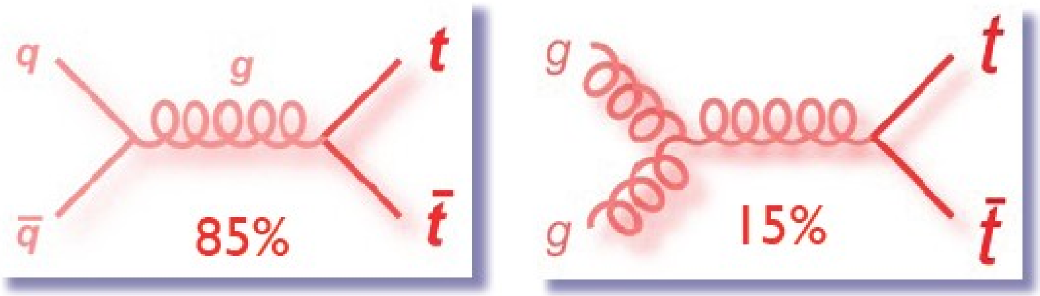
LHC



Top quark pair production

Main mechanism: pair production via strong interaction

Tevatron



- Full next-to-next-to-leading-order (NNLO) accuracy in the strong coupling constant α_s, including the resummation of next-to-next-to-leading logarithmic (NNLL) soft gluon terms

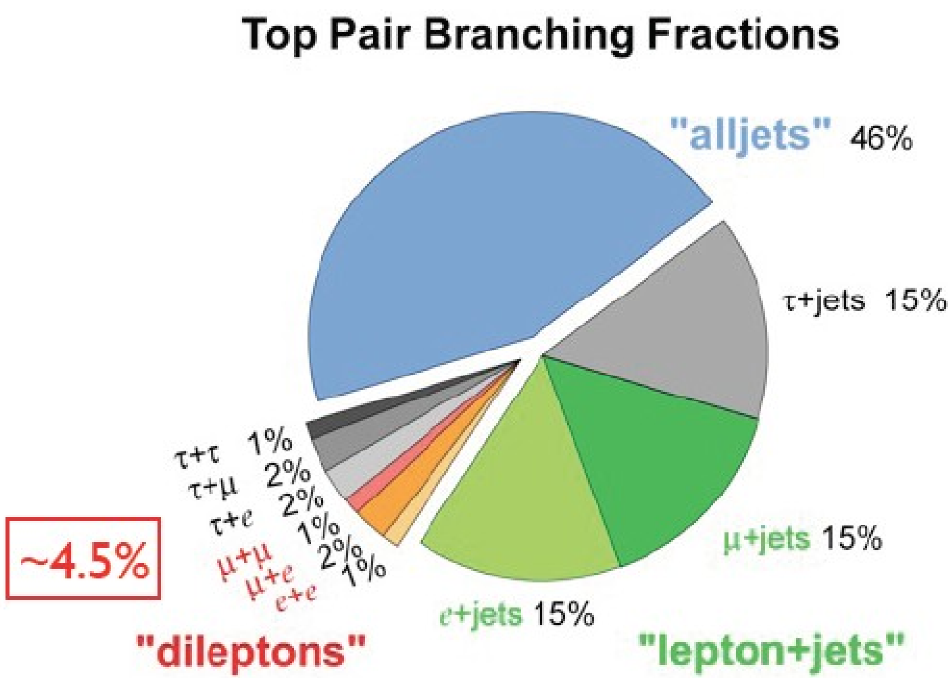
m_t = 172.5 GeV, MSTW2008NNLO PDF

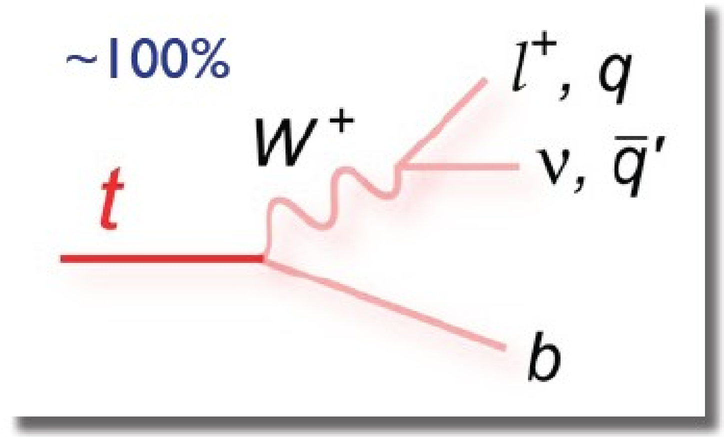
$\sqrt{s}$ (TeV)	2	7
$\sigma_{t\bar{t}}$ (pb)	7.35	177.3

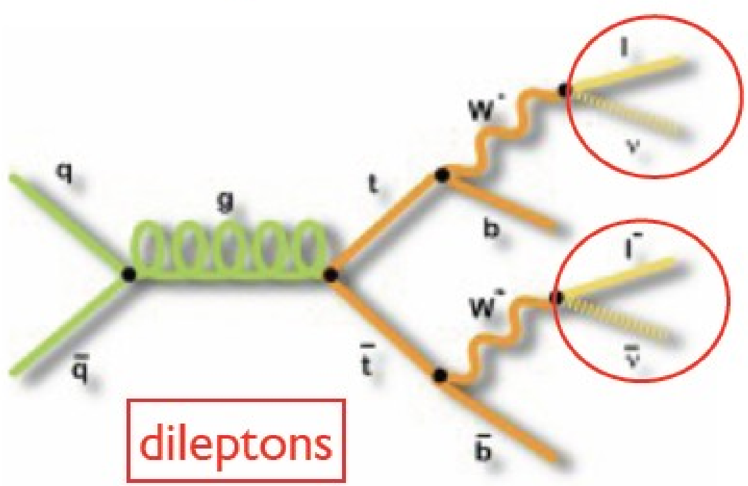
- Uncertainty from scale variation and PDF
- ~4% uncertainty for Tevatron

LHC: ATLAS full 7 TeV sample ~29,000 l+jets events
Tevatron: D0 full sample ~2,700 l+jets events

Top quark decay

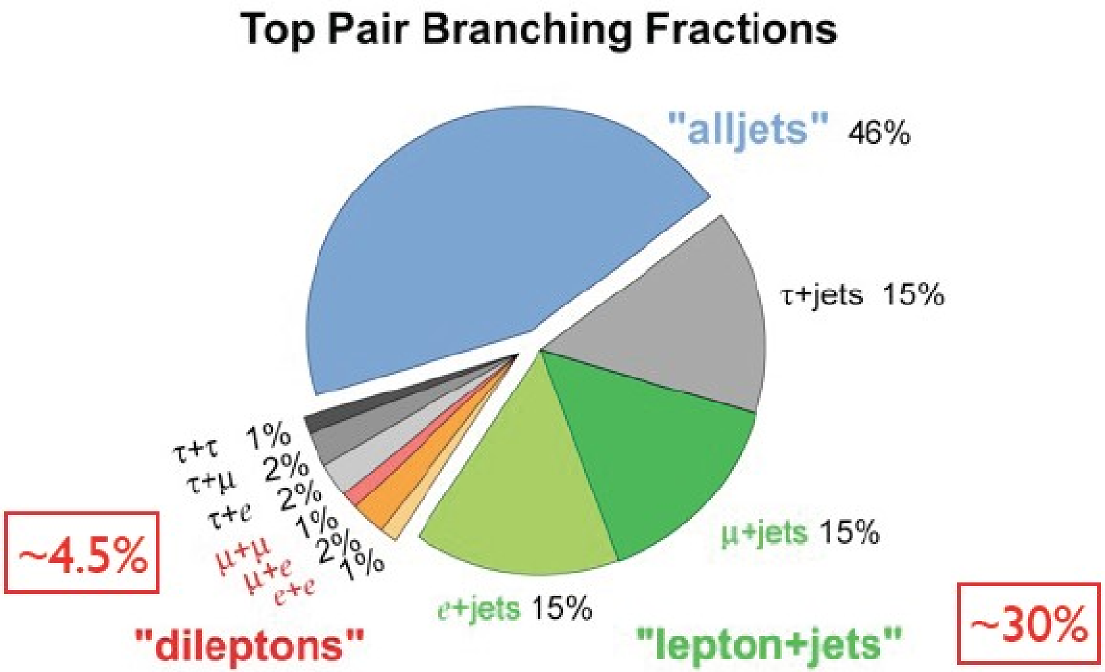


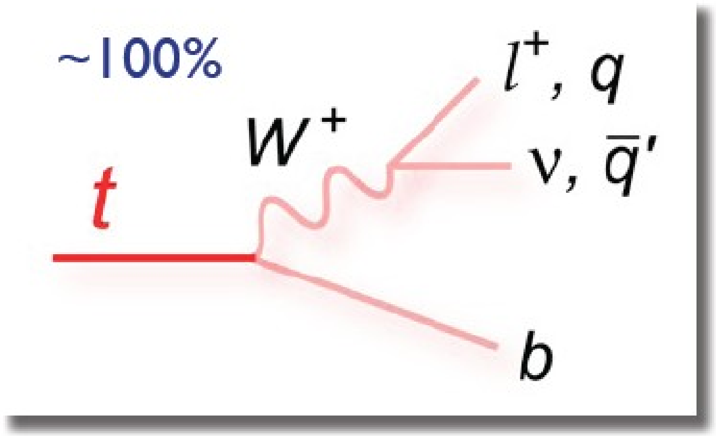


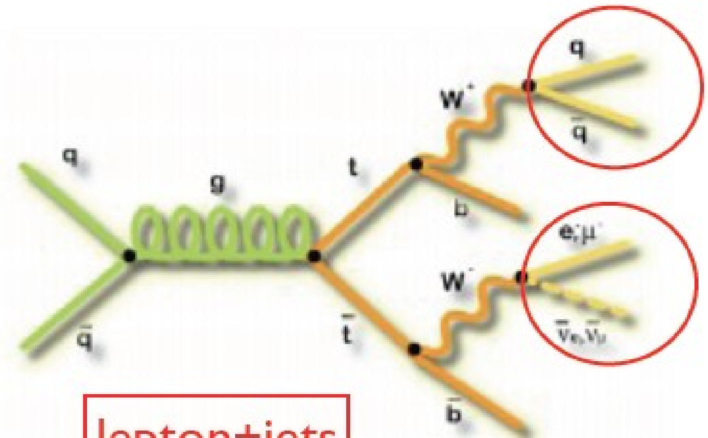


- Small rate
- Small backgrounds

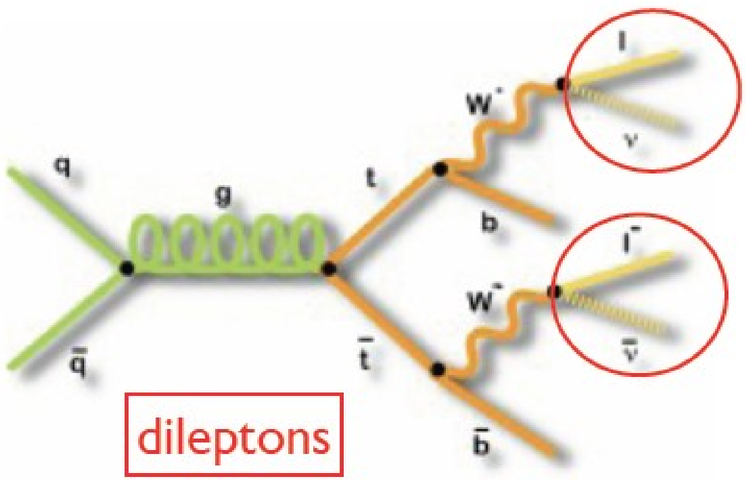
Top quark decay







lepton+jets



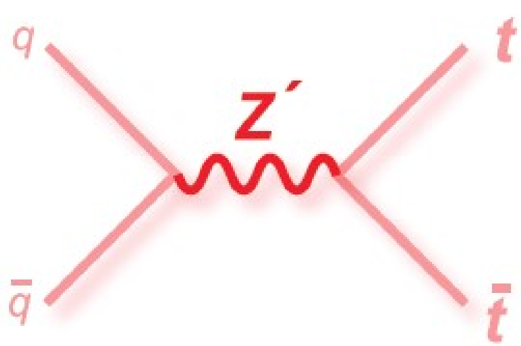
dileptons

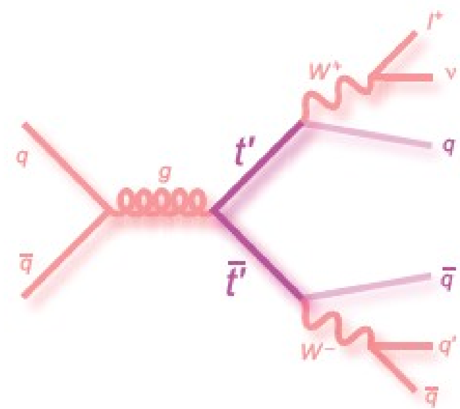
- "Golden channel"
  - good rate
  - manageable backgrounds

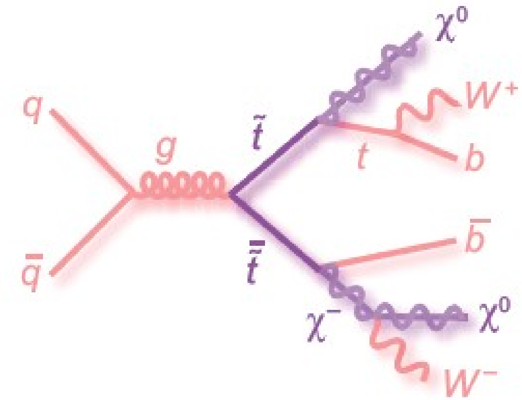
Motivations

- First step in understanding selected $t\bar{t}$ sample
- Test of theoretical QCD calculations

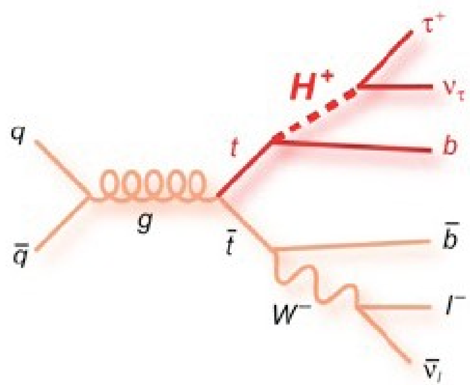
New physics in top quark production







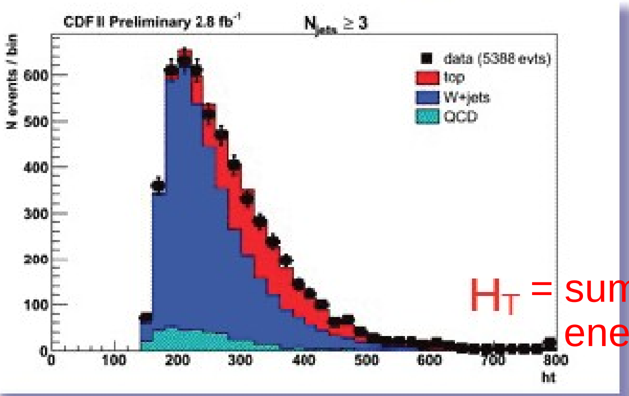
... and decay



- New physics can change
  - overall production rate
  - rate in different channels
- Precision measurements of cross section are important in different decay channels

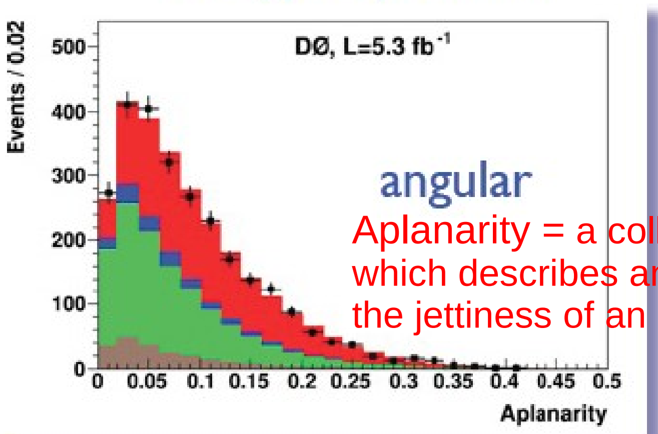
Finding top quark decay: kinematics

- exploit differences between kinematic properties of signal and background
- select discriminating variables



H_T = summed transverse energy over all particles

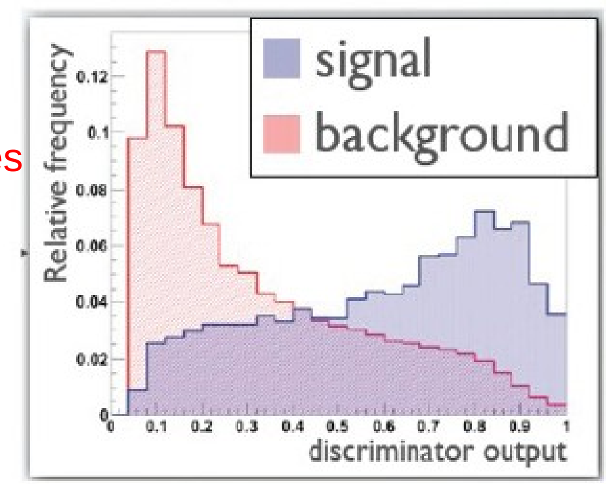
energy-dependent



angular

Aplanarity = a collective variable which describes and quantifies the jettiness of an event

- build a discriminant from these variables
  - likelihood
  - neural network
  - boosted decision trees

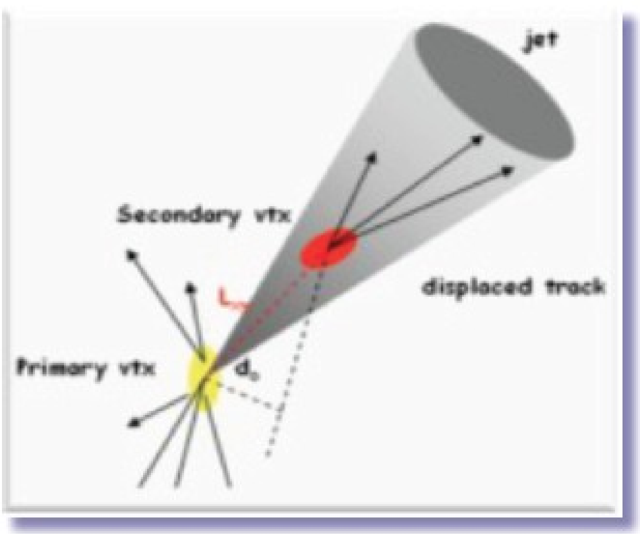


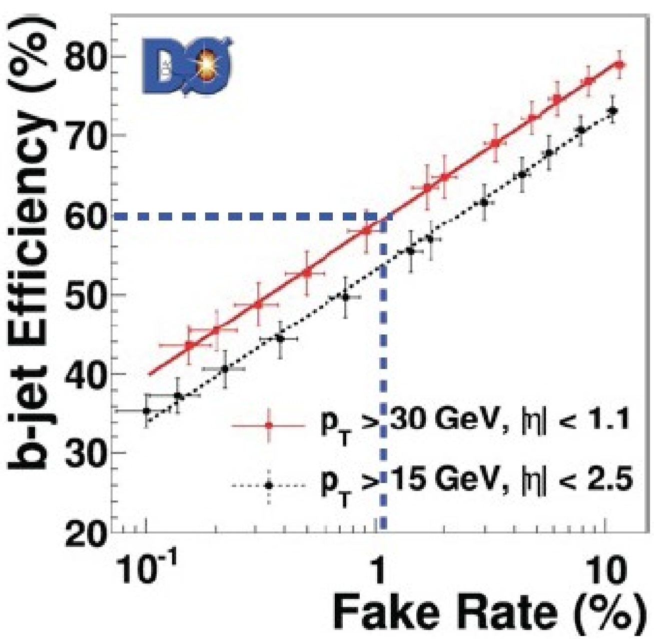
- extract cross section from a binned likelihood fit to data

Finding top quark decay: b-tagging

- Powerful tool to suppress backgrounds to top
- Utilizes
  - long live time of B-hadrons
- Use as
  - cut on b-tagging algorithm output
  - continuous variable

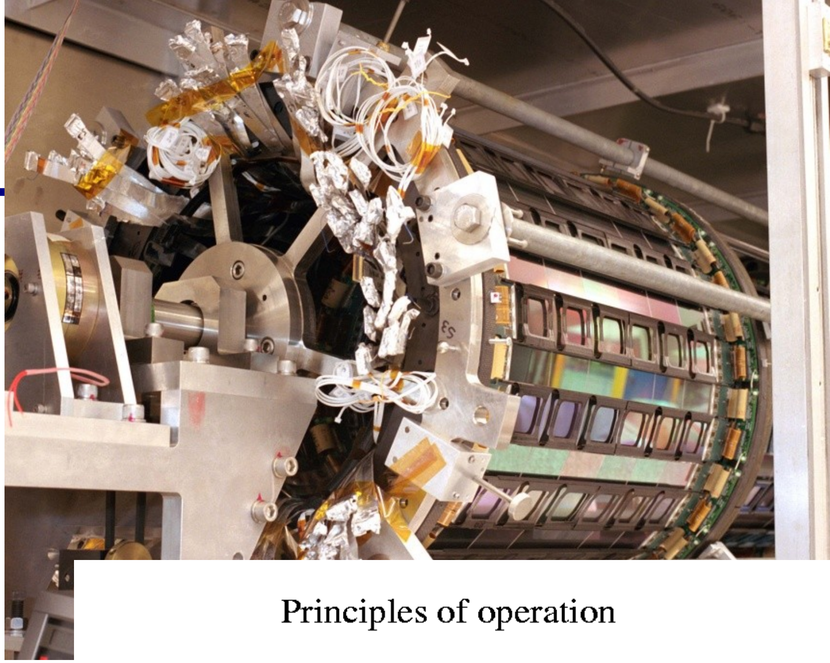
- Secondary Vertex tagger (SVX)
  - reconstructs secondary vertex
  - $L_{2D}/\sigma > 7.5$
- Neural Network tagger
  - combines properties of displaced tracks and secondary vertex
  - 7 variables total



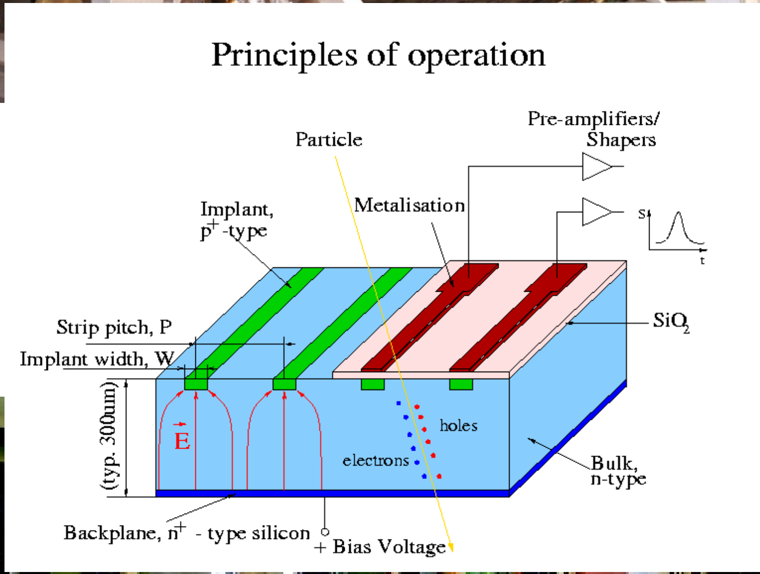


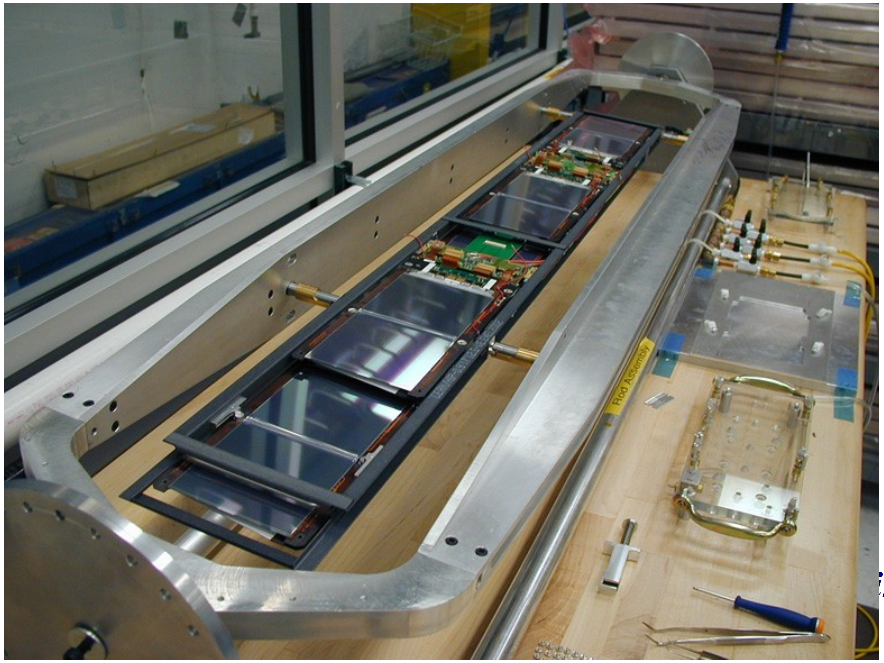
NIM, A620, 400 (2010)

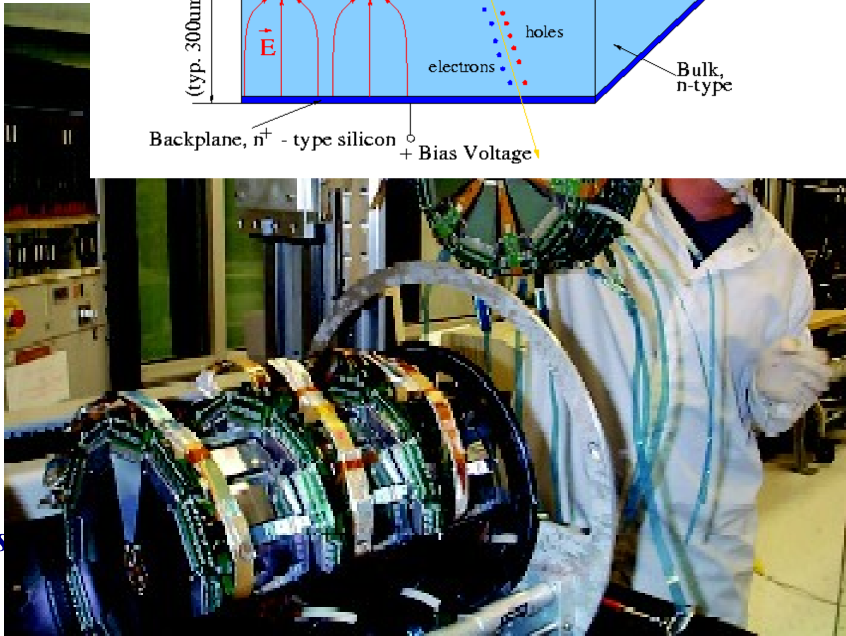
Silicon Detectors



- Almost all detectors at the hadron colliders have microvertex detectors (CDF from1992, D0 from 2002)
- Various concentric cylinders, built of “modules” - silicon layers, 300 μm depth , with strips at a distance of 50-60 μm and with a positive bias of 100-200 V, charge (20000 electrons) is collected
- The silicon is a *pn* junction inversely polarized → depleted of free charge → all the charge produced by ionization is collected with low noise
- The detector permits high precision in the position measurement of the charged particles passing the silicon layers → a tracking of high precision is obtained → B tagging!

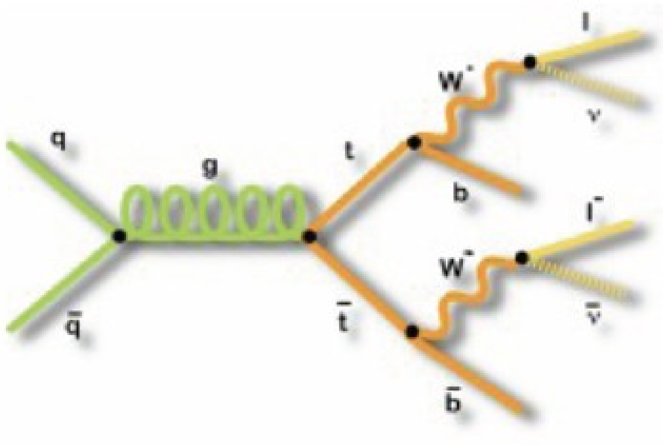






Dilepton channel

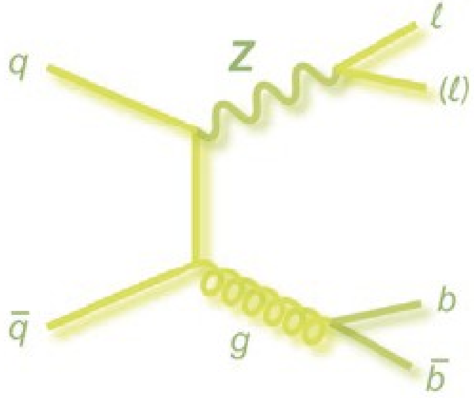
- **Signature**
  - two high p_T isolated leptons
  - large missing transverse momentum
  - $\geq$ 2 b-jets

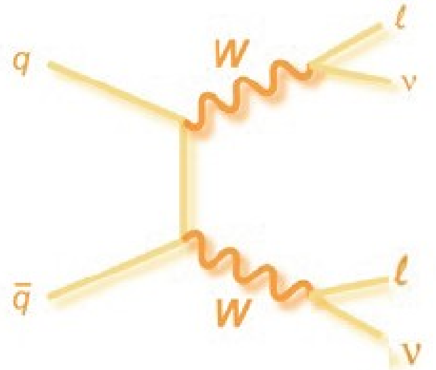


S/B

topo	1 b-tag
3:1	15:1

- **Backgrounds**





- Statistically limited at the Tevatron for a very long time
- Low backgrounds motivate the methods

Dilepton channel

- cut and count with and w/o b-tagging
  - 576 dilepton candidate events for pretag
  - 246 dilepton candidate events for b-tagged

systematic uncertainties

Source	pretag (%)	b-tag (%)
signal acceptance pretag	4.8	4.8
b-tagging		5.0
total acceptance	4.8	6.9
background model	7.1	2.1
Total	8.6	7.2

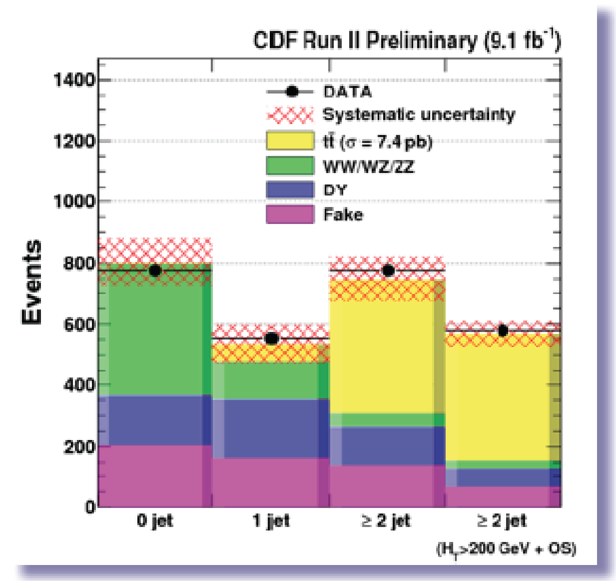
- luminosity uncertainty 6.1%

m_t = 172.5 GeV

$$\sigma_{t\bar{t}}^{tag} = 7.09 \pm 0.49(\text{stat}) \pm 0.52(\text{syst}) \pm 0.43(\text{lumi})\ \text{pb}$$

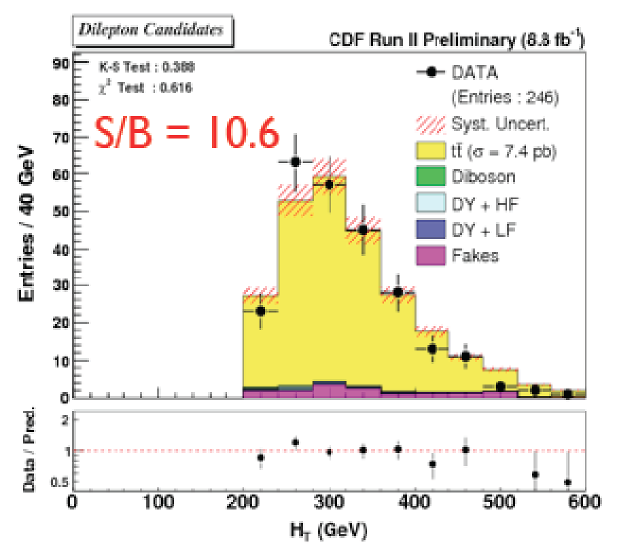
b-tag measurement has better precision: 9.4%

Phys.Rev.D88:091103, 2013



9.1 fb^{-1}

S/B = 2.6



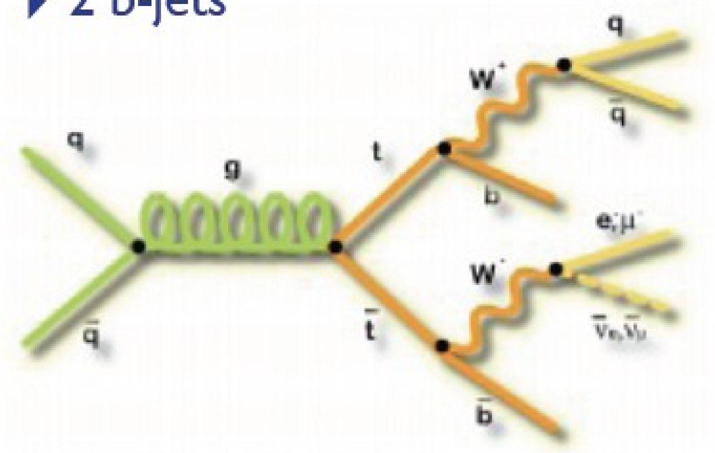
8.8 fb^{-1}

lepton + jets channel

Provides the most precise measurements

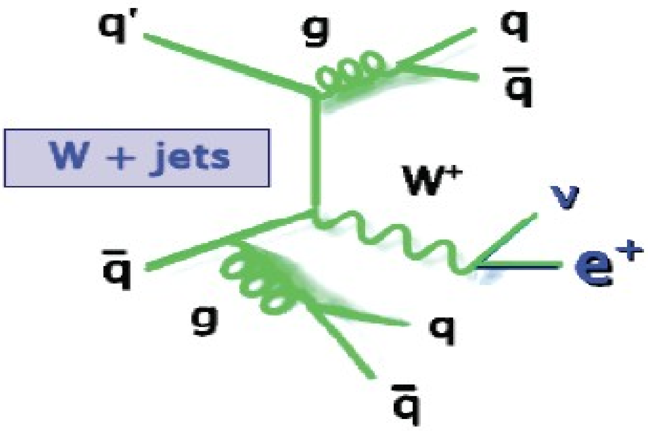
Signature

- one high p_T isolated lepton
- large missing transverse momentum
- $\geq$ 4 jets
- 2 b-jets

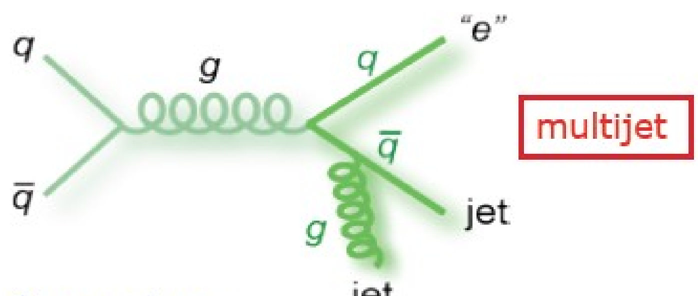


S/B (4 jets)	
topo	1 b-tag
2:3	4:1

Backgrounds



- based on MC simulation

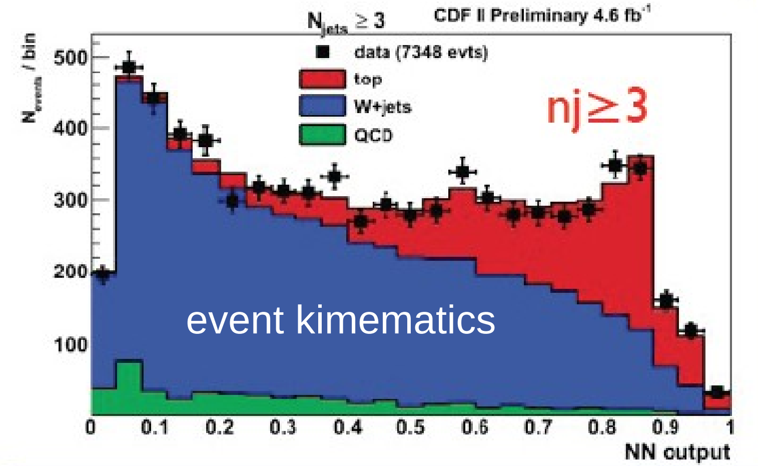


- from data

lepton + jets channel

- analysis targets luminosity uncertainty
- two methods
  - b-tag counting
  - event kinematics
- measure Z cross section
  - use same triggers
  - same data set
- compute the ratio of $t\bar{t}$ to Z cross section taking into account correlations
- trade luminosity uncertainty for Z cross section theoretical uncertainty

PRL 105:012001,2010   4.6 fb^{-1}



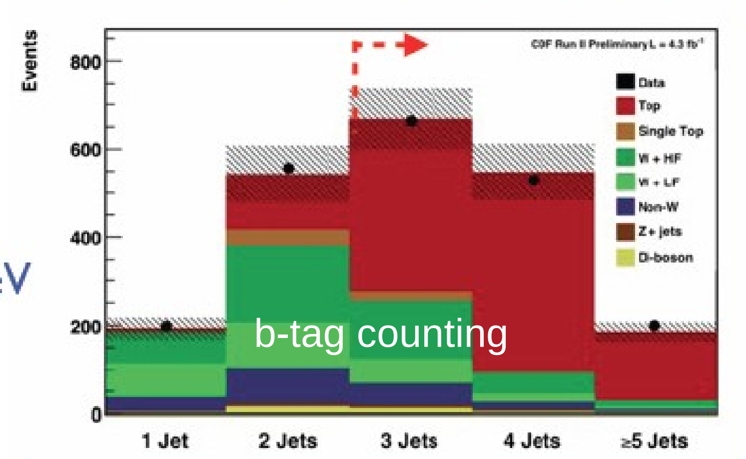
$\sigma_{t\bar{t}}$ = 7.82±0.38(stat)±0.37(syst)±0.15(th) pb

- combine using BLUE
- statistical correlation 32%

$\sigma_{t\bar{t}}$ = 7.70 ± 0.52 (total) pb m_t = 172.5 GeV

Total Uncertainty: 7%

$$\sigma_{t\bar{t}}^{\exp} = \left(\frac{\sigma_{t\bar{t}}}{\sigma_{Z/\gamma^* \to ll}}\right)_{\exp} \times \sigma_{Z/\gamma^* \to ll}^{theory}$$

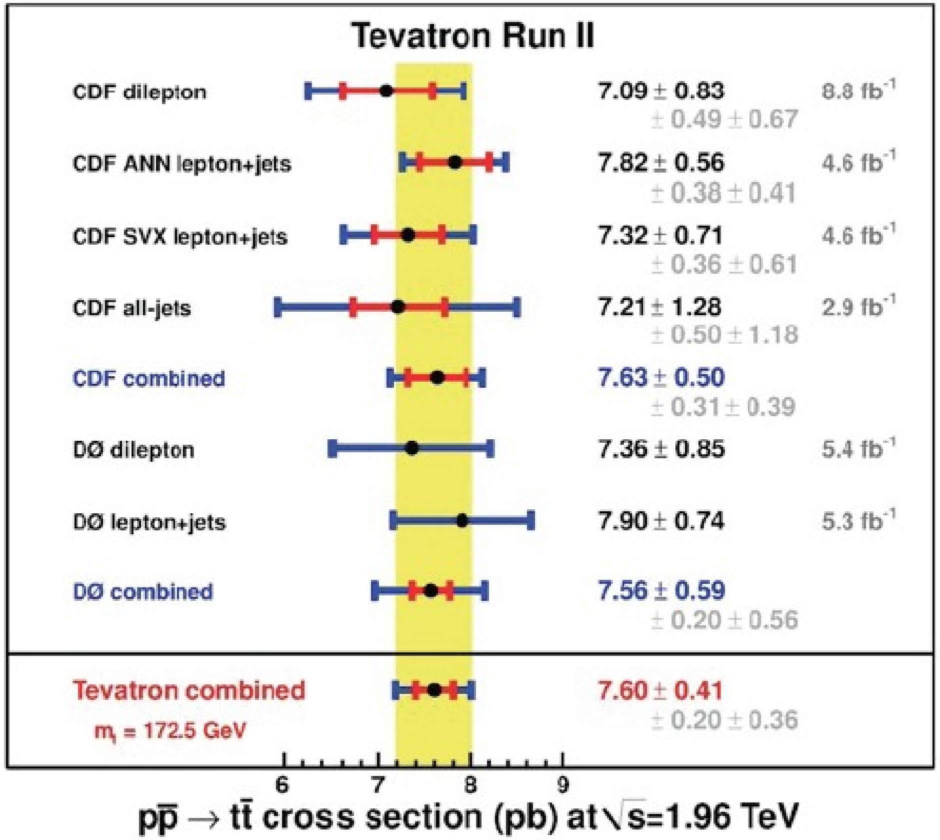


$\sigma_{t\bar{t}}$ = 7.32±0.36(stat)±0.59(syst)±0.14(th) pb

TEVATRON combination

PRD 89, 072001 (2014)

- Combination of combined CDF and D0 measurements
- measurements up to 8.8 fb^{-1}
  - lepton+jets channel measurements use half of the full data set
- BLUE method



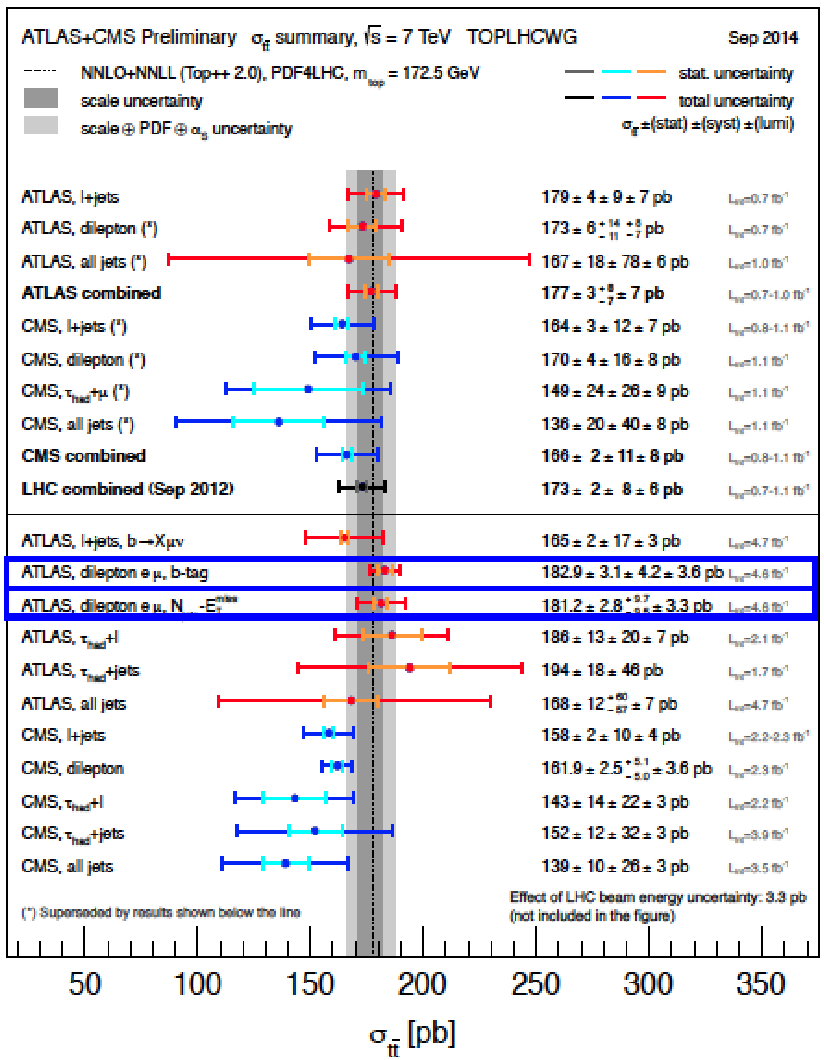
$$\sigma_{t\bar{t}} = 7.60 \pm 0.20(\mathrm{stat}) \pm 0.29(\mathrm{syst}) \pm 0.21(\mathrm{lumi})$$

$$\sigma_{t\bar{t}} = 7.60 \pm 0.41(\mathrm{total})$$ m_t = 172.5 GeV

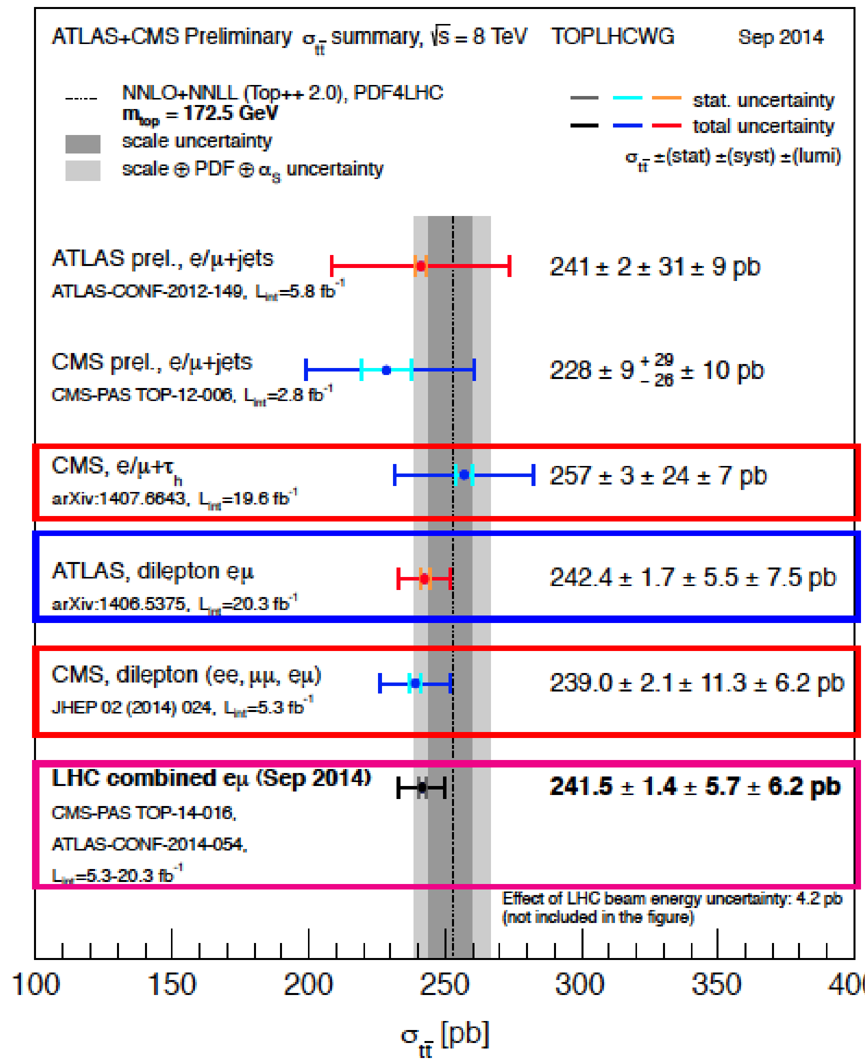
weight: 60% CDF, 40% D0
probability - 92%, correlation - 17%

Tevatron combination: 5.4% precision

LHC results

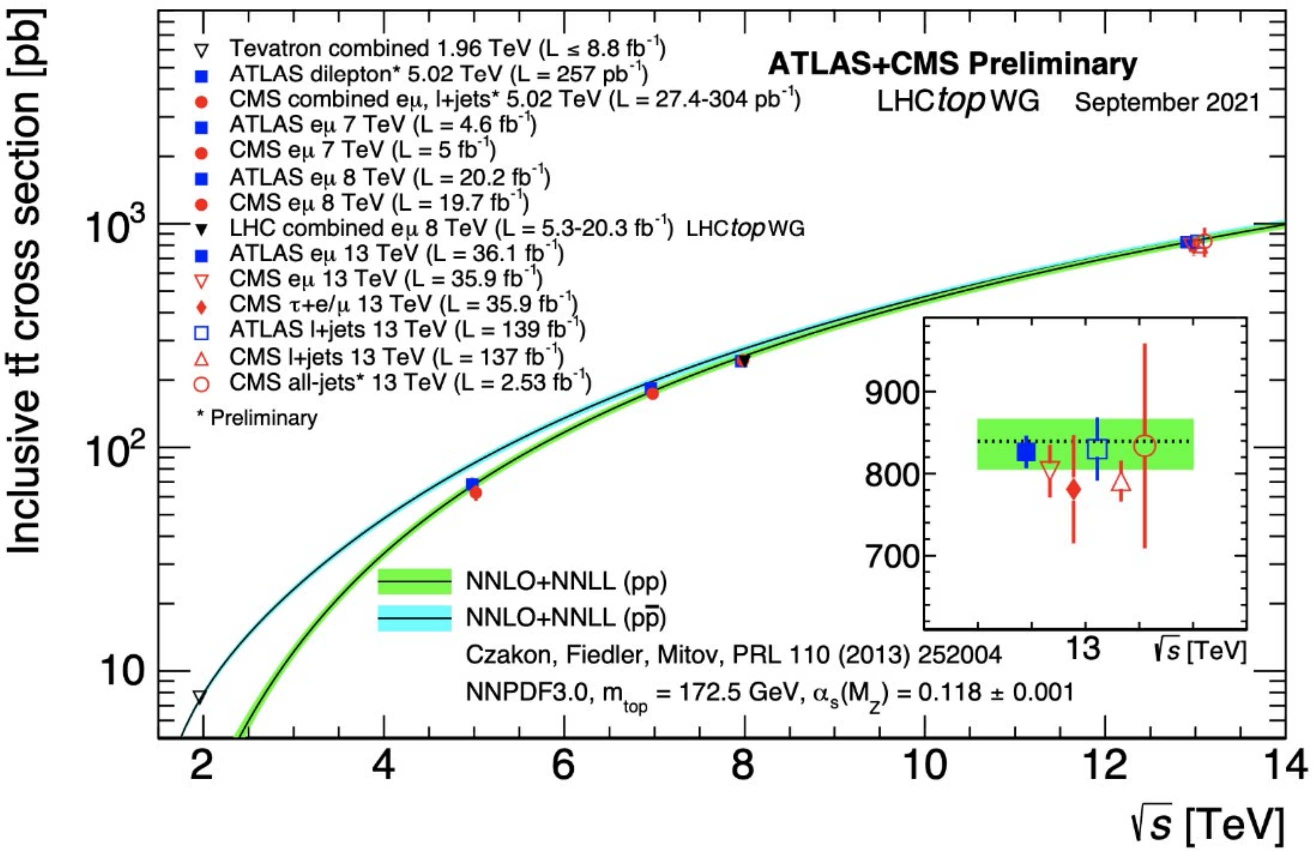


ATLAS+CMS Preliminary $\sigma_{t\bar{t}}$ summary, $\sqrt{s}$ = 7 TeV TOPLHCWG Sep 2014
NNLO+NNLL (Top++ 2.0), PDF4LHC, m_{top} = 172.5 GeV
scale uncertainty
scale ⊕ PDF ⊕ α_s uncertainty
stat. uncertainty
total uncertainty
$\sigma_{t\bar{t}}$ ±(stat) ±(syst) ±(lumi)
ATLAS, l+jets 179 ± 4 ± 9 ± 7 pb
ATLAS, dilepton (*) 173 ± 6 $^{+14}_{-11}$ $^{+8}_{-7}$ pb
ATLAS, all jets (*) 167 ± 18 ± 78 ± 6 pb
ATLAS combined 177 ± 3 $^{+8}_{-7}$ ± 7 pb
CMS, l+jets (*) 164 ± 3 ± 12 ± 7 pb
CMS, dilepton (*) 170 ± 4 ± 16 ± 8 pb
CMS, τ_{had}+μ (*) 149 ± 24 ± 26 ± 9 pb
CMS, all jets (*) 136 ± 20 ± 40 ± 8 pb
CMS combined 166 ± 2 ± 11 ± 8 pb
LHC combined (Sep 2012) 173 ± 2 ± 8 ± 6 pb
ATLAS, l+jets, b→Xμν 165 ± 2 ± 17 ± 3 pb
ATLAS, dilepton eμ, b-tag 182.9 ± 3.1 ± 4.2 ± 3.6 pb
ATLAS, dilepton eμ, N_{jets}-E_T^{miss} 181.2 ± 2.8 $^{+9.7}_{-9.5}$ ± 3.3 pb
ATLAS, τ_{had}+l 186 ± 13 ± 20 ± 7 pb
ATLAS, τ_{had}+jets 194 ± 18 ± 46 pb
ATLAS, all jets 168 ± 12 $^{+60}_{-57}$ ± 7 pb
CMS, l+jets 158 ± 2 ± 10 ± 4 pb
CMS, dilepton 161.9 ± 2.5 $^{+5.1}_{-5.0}$ ± 3.6 pb
CMS, τ_{had}+l 143 ± 14 ± 22 ± 3 pb
CMS, τ_{had}+jets 152 ± 12 ± 32 ± 3 pb
CMS, all jets 139 ± 10 ± 26 ± 3 pb
(*) Superseded by results shown below the line
Effect of LHC beam energy uncertainty: 3.3 pb (not included in the figure)
50 100 150 200 250 300 350
$\sigma_{t\bar{t}}$ [pb]

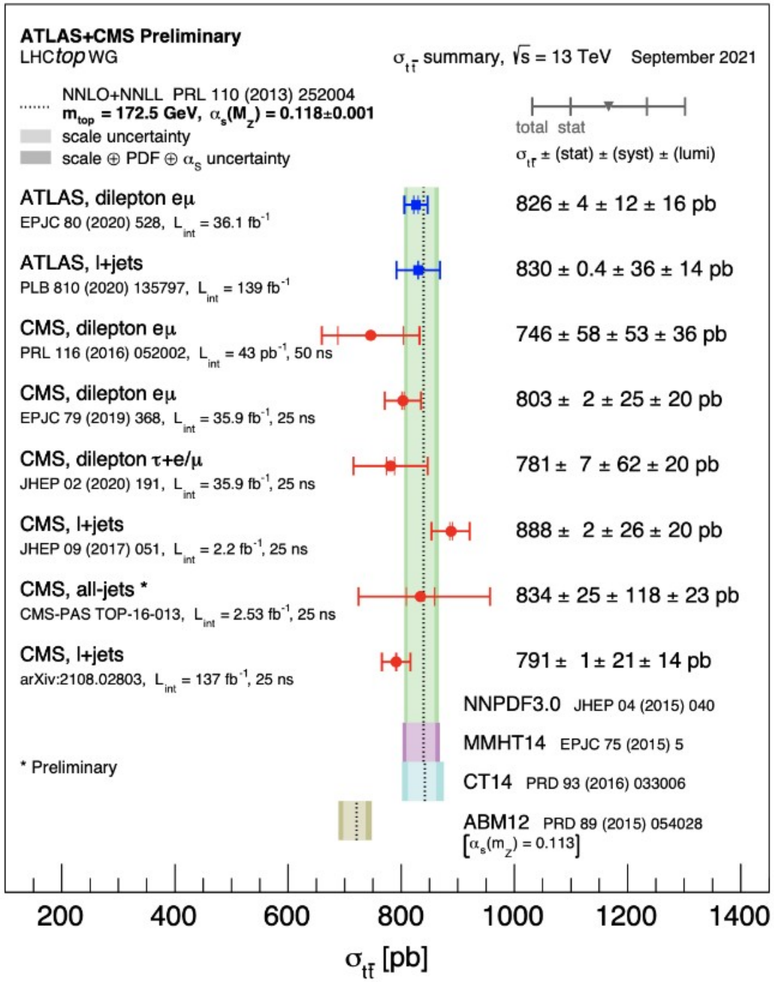


ATLAS+CMS Preliminary $\sigma_{t\bar{t}}$ summary, $\sqrt{s}$ = 8 TeV TOPLHCWG Sep 2014
NNLO+NNLL (Top++ 2.0), PDF4LHC
m_{top} = 172.5 GeV
scale uncertainty
scale ⊕ PDF ⊕ α_s uncertainty
stat. uncertainty
total uncertainty
$\sigma_{t\bar{t}}$ ±(stat) ±(syst) ±(lumi)
ATLAS prel., e/μ+jets
ATLAS-CONF-2012-149, L_{int}=5.8 fb^{-1}
241 ± 2 ± 31 ± 9 pb
CMS prel., e/μ+jets
CMS-PAS TOP-12-006, L_{int}=2.8 fb^{-1}
228 ± 9 $^{+29}_{-26}$ ± 10 pb
CMS, e/μ+τ_h
arXiv:1407.6643, L_{int}=19.6 fb^{-1}
257 ± 3 ± 24 ± 7 pb
ATLAS, dilepton eμ
arXiv:1406.5375, L_{int}=20.3 fb^{-1}
242.4 ± 1.7 ± 5.5 ± 7.5 pb
CMS, dilepton (ee, μμ, eμ)
JHEP 02 (2014) 024, L_{int}=5.3 fb^{-1}
239.0 ± 2.1 ± 11.3 ± 6.2 pb
LHC combined eμ (Sep 2014)
CMS-PAS TOP-14-016,
ATLAS-CONF-2014-054,
L_{int}=5.3-20.3 fb^{-1}
241.5 ± 1.4 ± 5.7 ± 6.2 pb
Effect of LHC beam energy uncertainty: 4.2 pb (not included in the figure)
100 150 200 250 300 350 400
$\sigma_{t\bar{t}}$ [pb]

LHC results

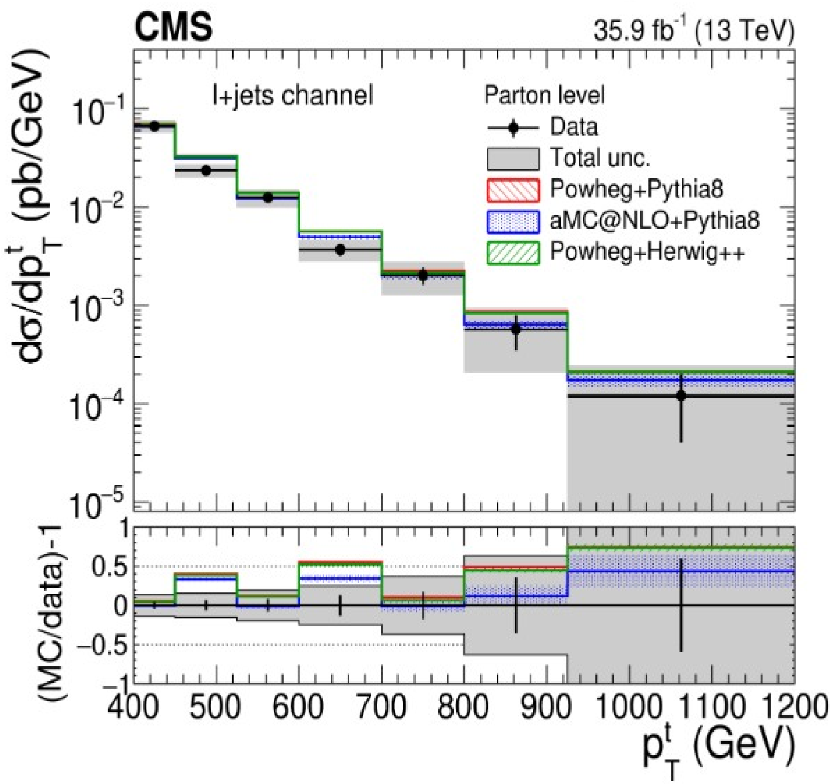


Inclusive tt̄ cross section [pb]
Tevatron combined 1.96 TeV (L ≤ 8.8 fb^{-1})
ATLAS dilepton* 5.02 TeV (L = 257 pb^{-1})
CMS combined eμ, l+jets* 5.02 TeV (L = 27.4-304 pb^{-1})
ATLAS eμ 7 TeV (L = 4.6 fb^{-1})
CMS eμ 7 TeV (L = 5 fb^{-1})
ATLAS eμ 8 TeV (L = 20.2 fb^{-1})
CMS eμ 8 TeV (L = 19.7 fb^{-1})
LHC combined eμ 8 TeV (L = 5.3-20.3 fb^{-1}) LHCtopWG
ATLAS eμ 13 TeV (L = 36.1 fb^{-1})
CMS eμ 13 TeV (L = 35.9 fb^{-1})
CMS τ+e/μ 13 TeV (L = 35.9 fb^{-1})
ATLAS l+jets 13 TeV (L = 139 fb^{-1})
CMS l+jets 13 TeV (L = 137 fb^{-1})
CMS all-jets* 13 TeV (L = 2.53 fb^{-1})
* Preliminary
ATLAS+CMS Preliminary
LHCtopWG
September 2021
NNLO+NNLL (pp)
NNLO+NNLL (pp̄)
Czakon, Fiedler, Mitov, PRL 110 (2013) 252004
NNPDF3.0, m_{top} = 172.5 GeV, $\alpha_s(M_Z)$ = 0.118 ± 0.001
$\sqrt{s}$ [TeV]

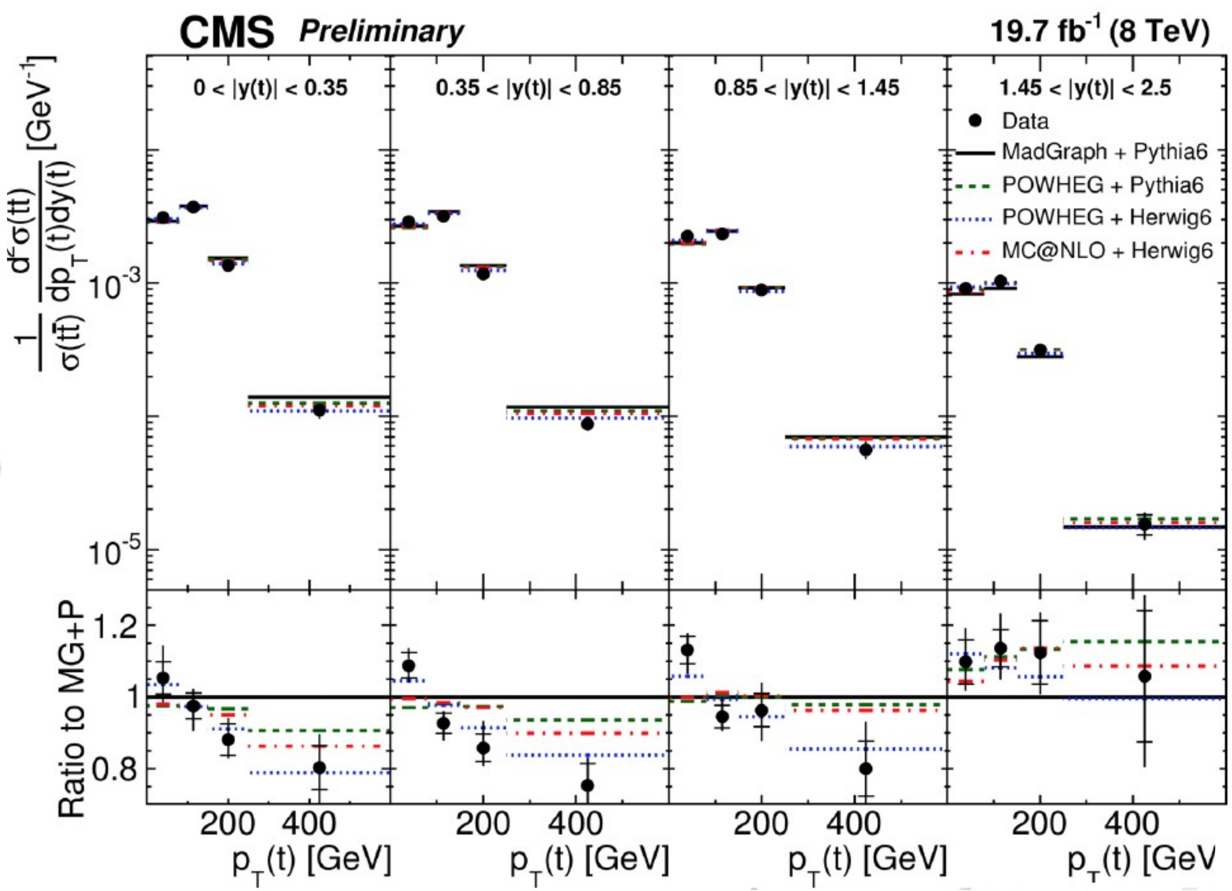


ATLAS+CMS Preliminary
LHCtopWG
$\sigma_{t\bar{t}}$ summary, $\sqrt{s}$ = 13 TeV September 2021
NNLO+NNLL PRL 110 (2013) 252004
m_{top} = 172.5 GeV, $\alpha_s(M_Z)$ = 0.118±0.001
scale uncertainty
scale ⊕ PDF ⊕ α_s uncertainty
total stat
$\sigma_{t\bar{t}}$ ± (stat) ± (syst) ± (lumi)
ATLAS, dilepton eμ
EPJC 80 (2020) 528, L_{int} = 36.1 fb^{-1}
826 ± 4 ± 12 ± 16 pb
ATLAS, l+jets
PLB 810 (2020) 135797, L_{int} = 139 fb^{-1}
830 ± 0.4 ± 36 ± 14 pb
CMS, dilepton eμ
PRL 116 (2016) 052002, L_{int} = 43 pb^{-1}, 50 ns
746 ± 58 ± 53 ± 36 pb
CMS, dilepton eμ
EPJC 79 (2019) 368, L_{int} = 35.9 fb^{-1}, 25 ns
803 ± 2 ± 25 ± 20 pb
CMS, dilepton τ+e/μ
JHEP 02 (2020) 191, L_{int} = 35.9 fb^{-1}, 25 ns
781 ± 7 ± 62 ± 20 pb
CMS, l+jets
JHEP 09 (2017) 051, L_{int} = 2.2 fb^{-1}, 25 ns
888 ± 2 ± 26 ± 20 pb
CMS, all-jets *
CMS-PAS TOP-16-013, L_{int} = 2.53 fb^{-1}, 25 ns
834 ± 25 ± 118 ± 23 pb
CMS, l+jets
arXiv:2108.02803, L_{int} = 137 fb^{-1}, 25 ns
791 ± 1 ± 21 ± 14 pb
NNPDF3.0 JHEP 04 (2015) 040
MMHT14 EPJC 75 (2015) 5
CT14 PRD 93 (2016) 033006
ABM12 PRD 89 (2015) 054028
[$\alpha_s(m_Z)$ = 0.113]
* Preliminary
$\sigma_{t\bar{t}}$ [pb]

LHC results



Differential cross sections



Double Differential cross sections

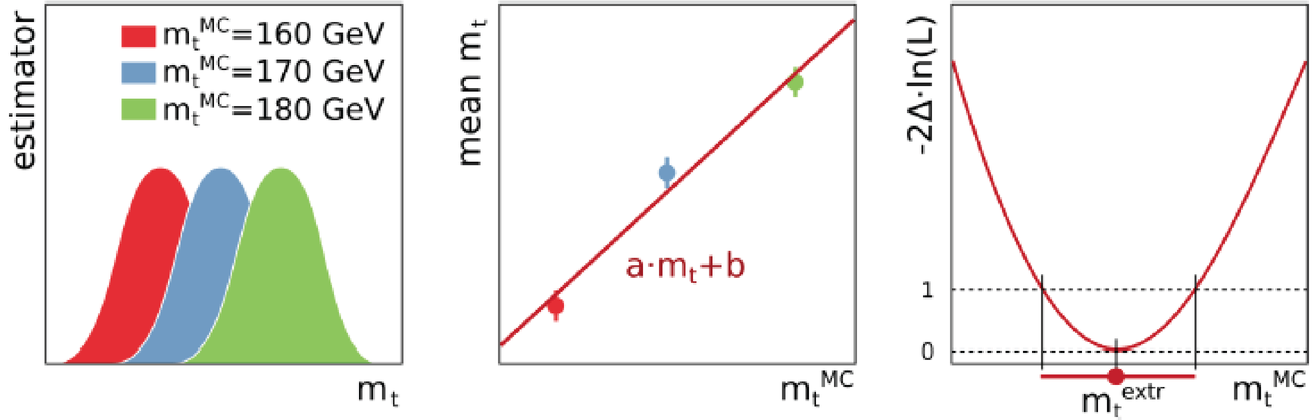
Mass measurement

Standard Reconstruction

- Reconstruct invariant mass distributions from final state objects:
  - Leptons, jets, and missing transverse momentum
- Measured mass corresponds to definition used in MC
- All presented measurements on m_t^{MC}
  - Relation between theoretical well defined top-quark mass and m_t^{MC} to be determined

Measurement Method

- Build estimator for m_t (e.g. inv. mass of decay products)
- Parametrize estimator as function of m_t^{MC} (and possible other parameters)
- Possible per event combination of multiple estimators
- Ideogram method, CMS all-jets and l+jets
- Template method, all other measurements
- Perform maximum likelihood fit to data



Mass measurement

Datasets

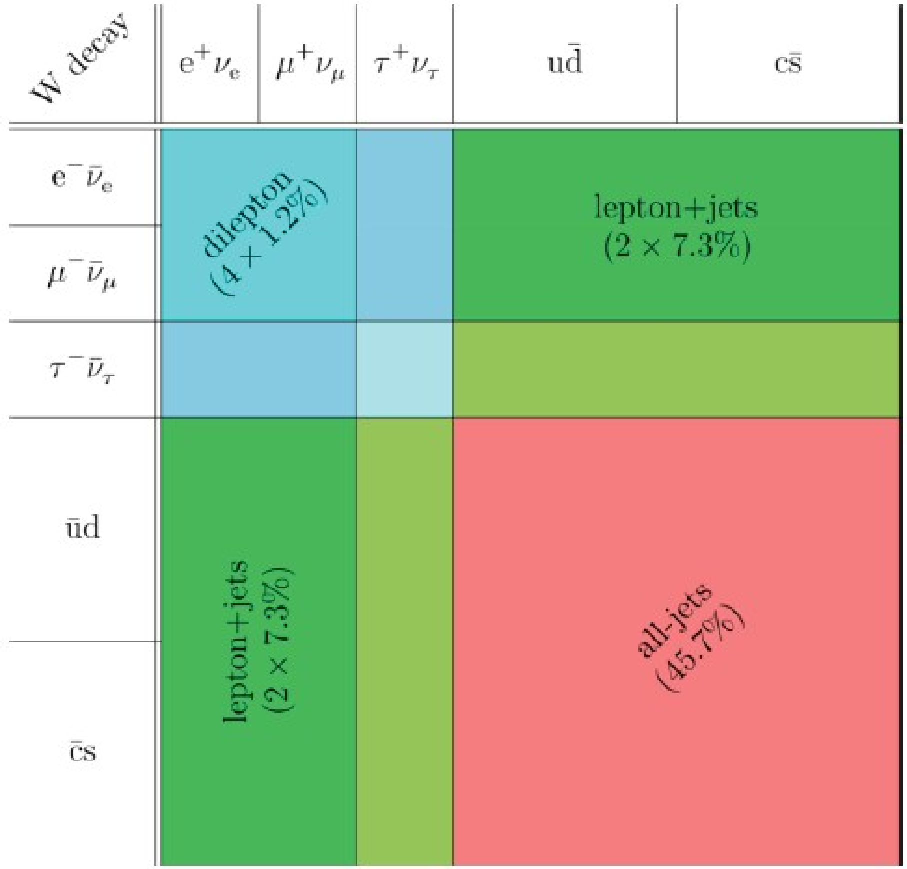
- 7 TeV analyses based on 3.5 - 5.0 fb^{-1} from 2011
- 8 TeV analyses based on 18.2 - 19.7 fb^{-1} from 2012
- Produced number of top-quark pair events:
    - 2011: 800k, 2012: 5M, each number per experiment
- Cornerstones of measurements are understanding and minimizing impact of systematic uncertainties

Mass measurement

Overview of Measurements

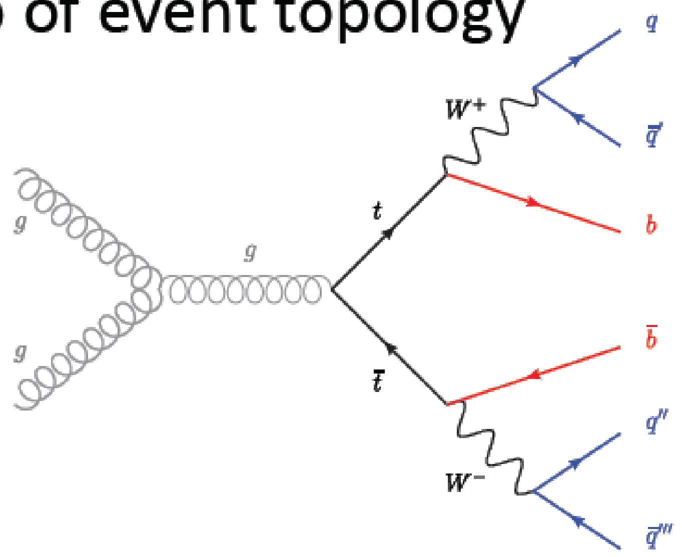
- Alljets channel:
  - ATLAS @ 7 TeV
  - CMS @ 7 & 8 TeV
- Lepton+Jets channel:
  - ATLAS @ 7 TeV
  - CMS @ 7 & 8 TeV
- Dilepton channel:
  - ATLAS @ 7 TeV
  - CMS @ 7 & 8 TeV

- No measurements in final states with τ



All-Jets Channel

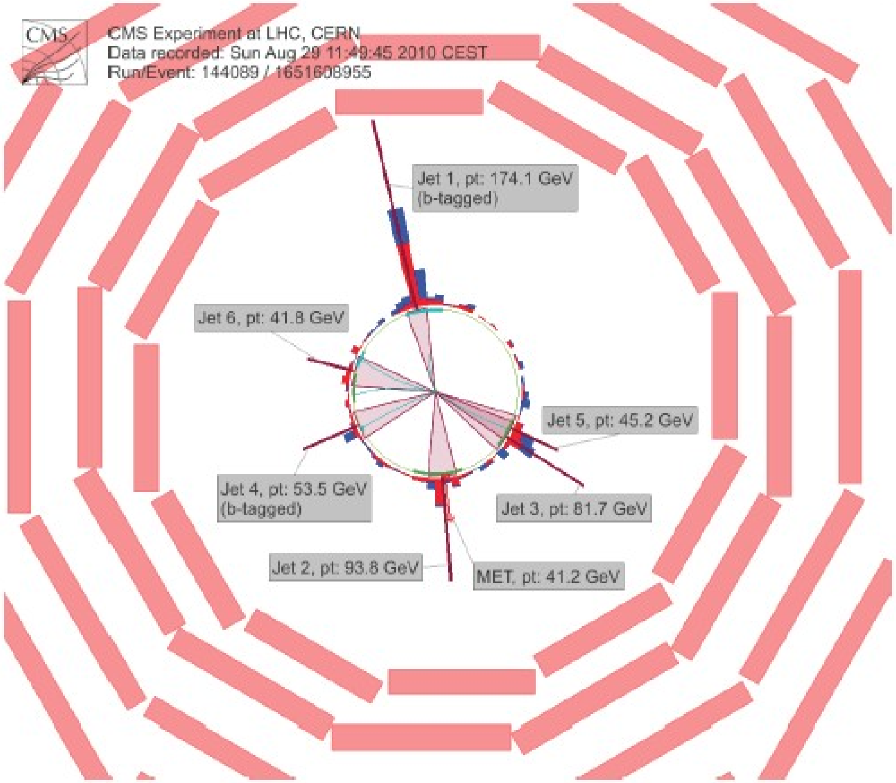
- Largest branching ratio (46%)
- 2 bottom quarks and 4 lighter quarks in the final state
  - Require 6 jets with 2 b tags (as clean as possible)
- Largest and worst predictable background (multijets)
  - Fully data-driven background prediction needed
- Background reduction with help of event topology
  - Kinematic Fit

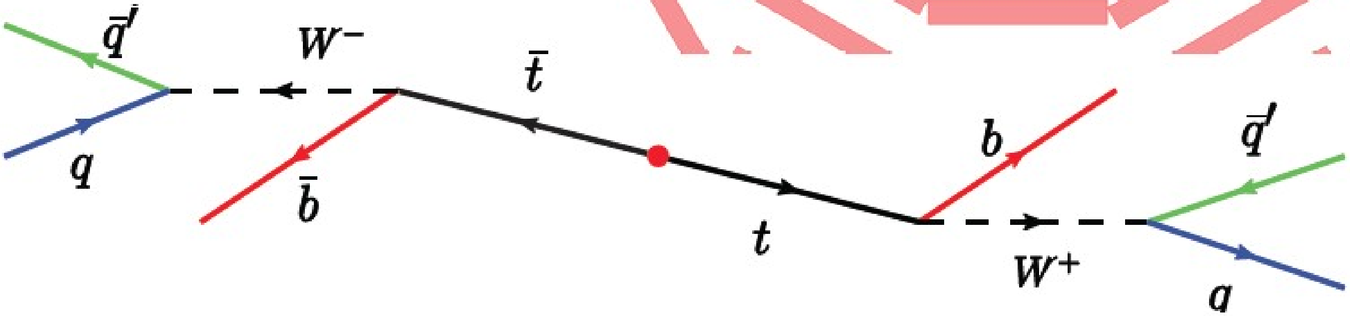


Mass measurement

Kinematic Fit

- Selected objects:
  - 4 untagged jets
  - 2 b-tagged jets

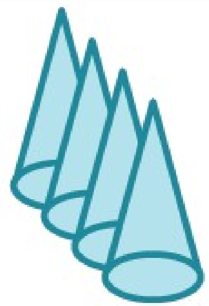


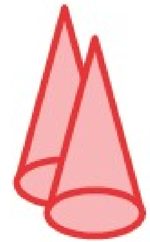


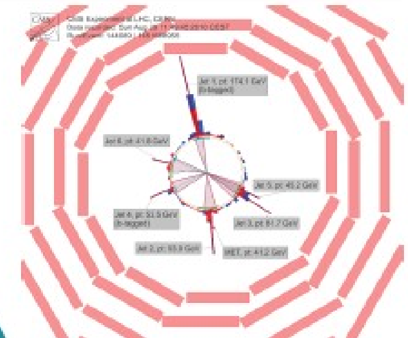
Mass measurement

Kinematic Fit

- Selected objects:
  - 4 untagged jets
  - 2 b-tagged jets



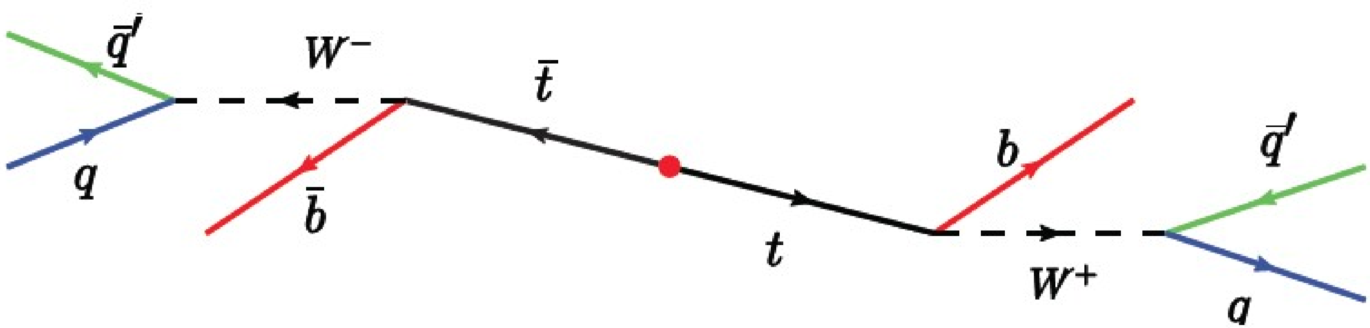




- Constraints:
  - 2x $m_{jj} = m_W$

= W boson &

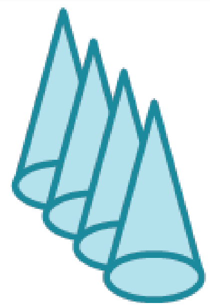
= W boson

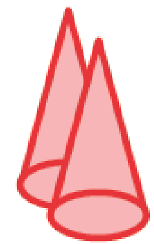


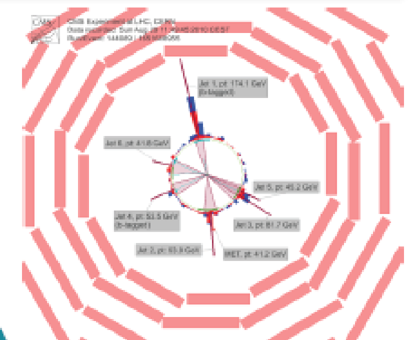
Mass measurement

Kinematic Fit

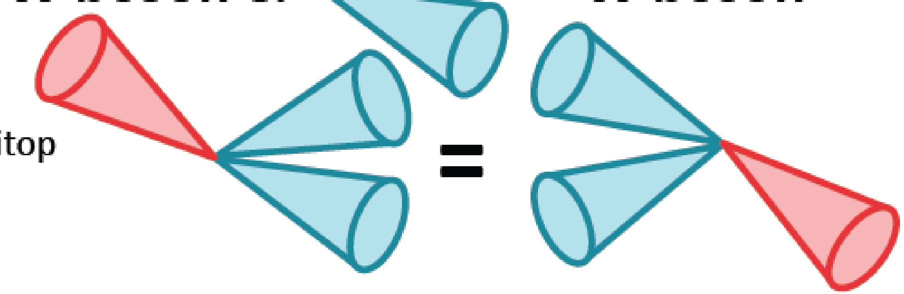
- Selected objects:
  - 4 untagged jets
  - 2 b-tagged jets

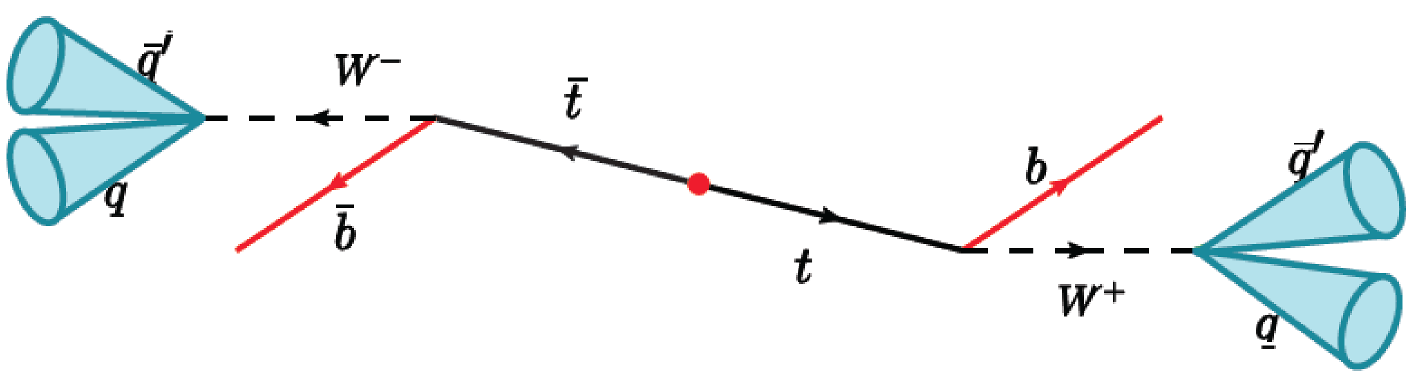






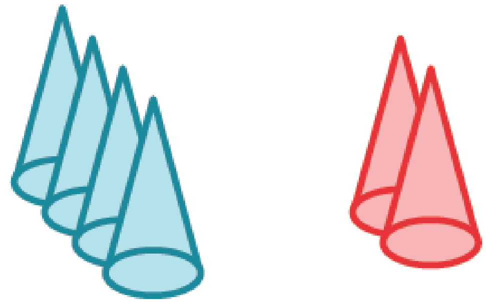
- Constraints:
  - $2x\ m_{jj} = m_W$
  - $m_{top} = m_{jjb,1} = m_{jjb,2} = m_{antitop}$

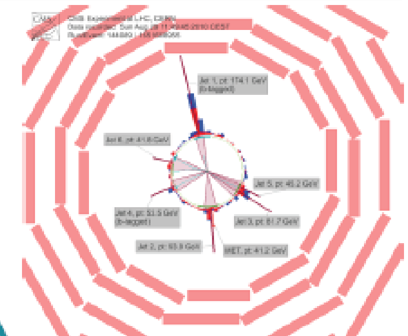




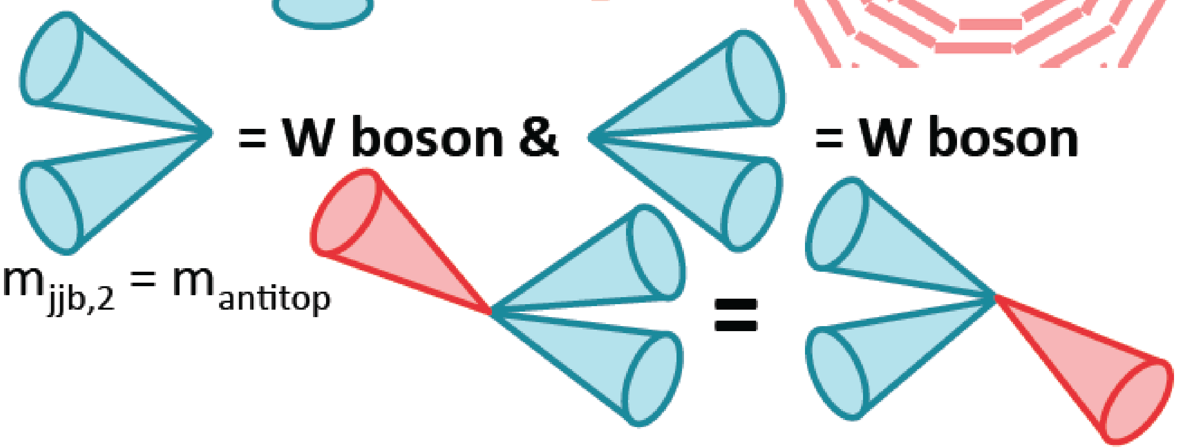
Kinematic Fit

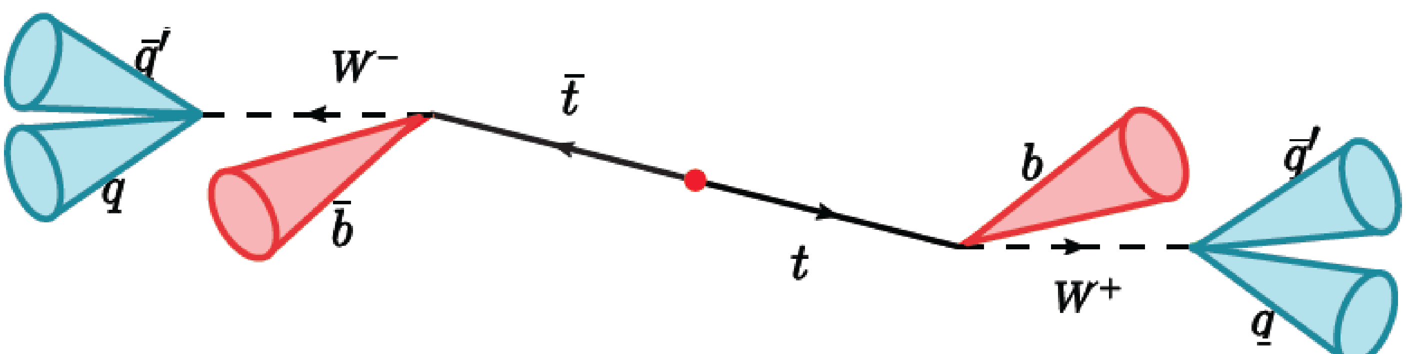
- Selected objects:
  - 4 untagged jets
  - 2 b-tagged jets





- Constraints:
  - 2x $m_{jj} = m_W$
  - $m_{top} = m_{jjb,1} = m_{jjb,2} = m_{antitop}$

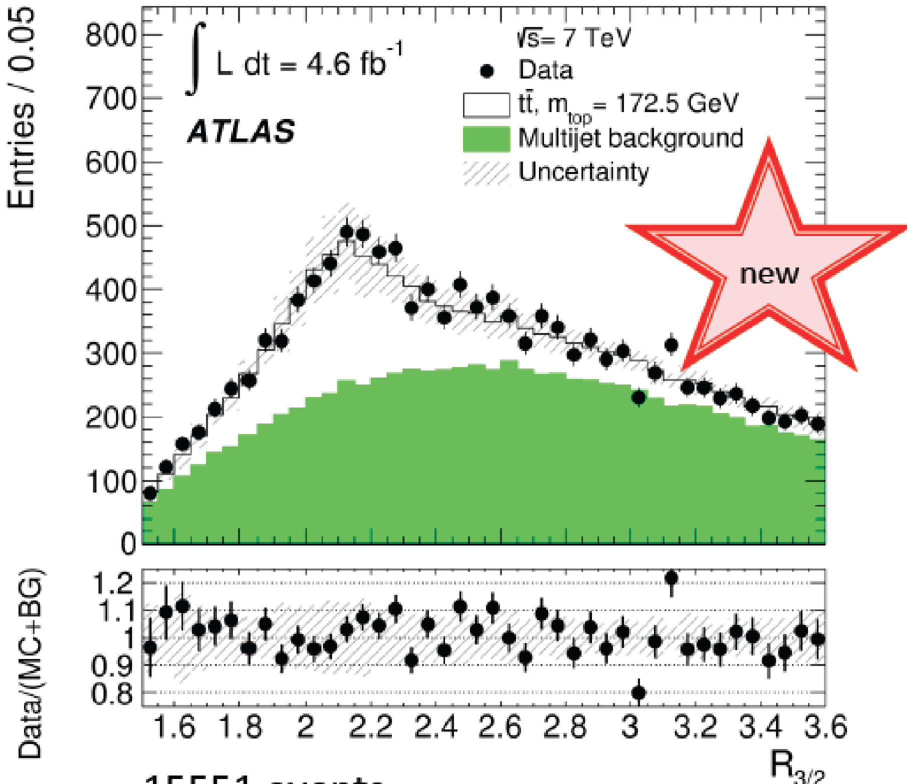




All-Jets Top-Quark Mass @ ATLAS 7 TeV

- Kinematic fit for jet-parton assignment
- Background: ABCD method
- Reduce JES uncertainty:
  - $R_{3/2} = m_{jjj} / m_{jj}$

arXiv:1409.0832
Submitted to: EPJC



15551 events

m_t = 175.1 ± 1.9 GeV (1.06%)

bJES: 0.62
Had: 0.50

Source	Unc. [GeV]
JES+PU	0.52
bJES+Had	0.80
Detector modelling	0.17
Signal modelling	0.51
Background	0.35
Method	0.42
Syst.	1.22
Stat.	1.40
Total	1.86

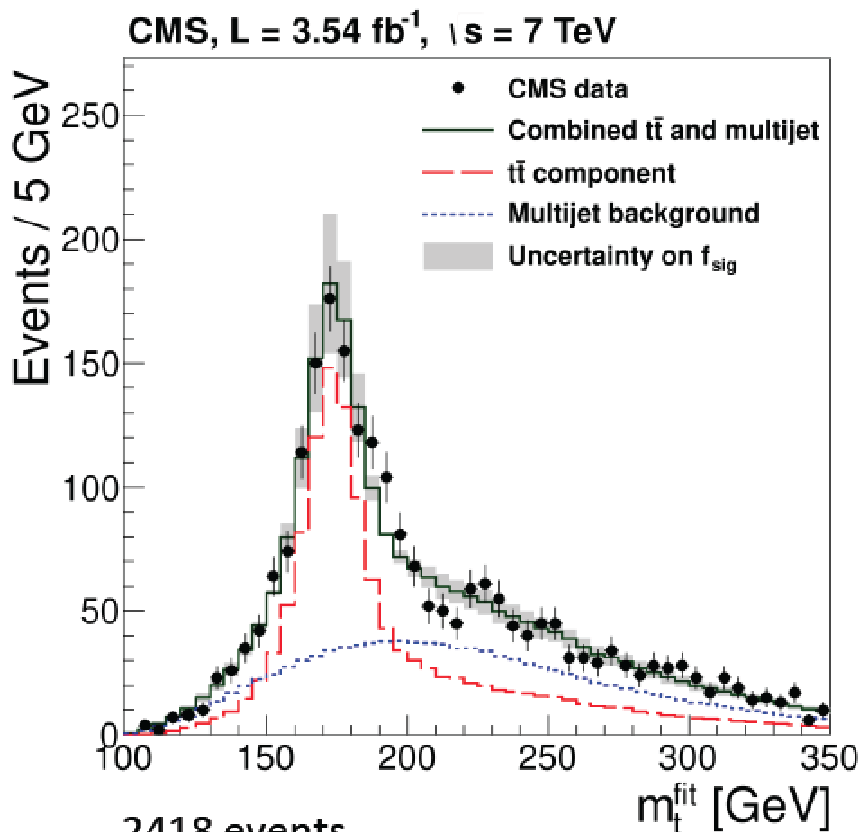
Mass measurement

All-Jets Top-Quark Mass @ CMS 7 TeV

- Kinematic fit
- Background: event mixing
- Tighter selection than ATLAS
  - Less events
  - Narrower peak

Source	Unc. [GeV]
JES+PU	0.97
bJES+Had	0.49
Detector modelling	0.29
Signal modelling	0.46
Background	0.13
Method	0.13
Syst.	1.23
Stat.	0.69
Total	1.41

EPJC74 (2014) 2758



2418 events

$m_t = 173.49 \pm 1.41$ GeV (0.81%)

Mass measurement

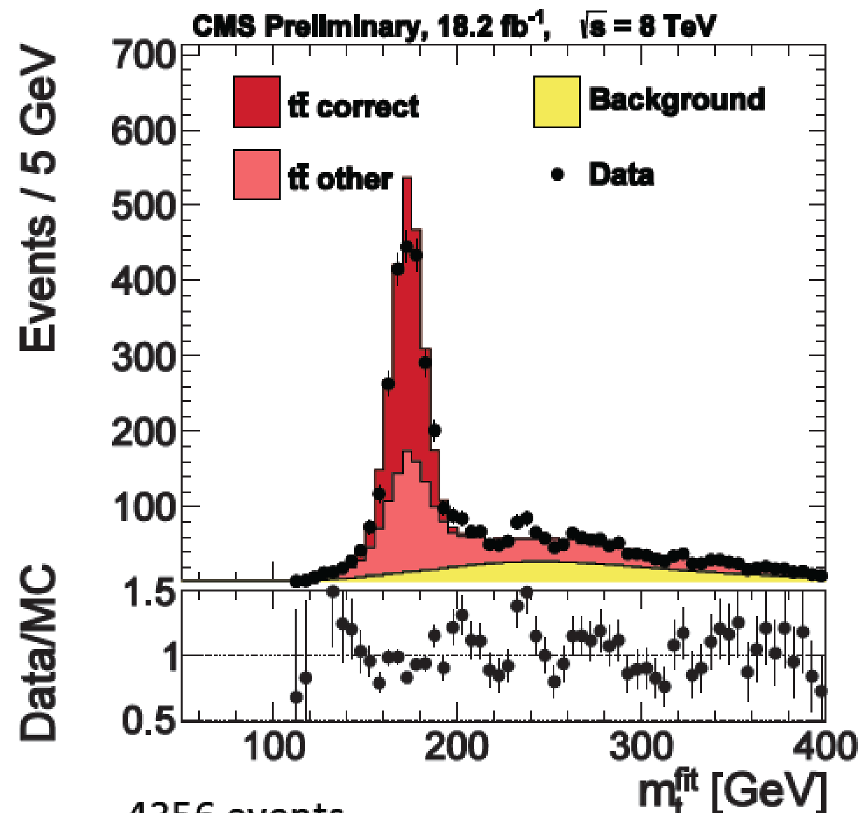
All-Jets Top-Quark Mass @ CMS 8 TeV

- Improved reconstruction
- Switch to 2D fit with JES scale factor (JSF)
- Fit signal and correct permutation fractions

JES+PU: 0.42
JSF: 0.24

Source	Unc. [GeV]
JES+PU+JSF	0.48
bJES+Had	0.39
Detector modelling	0.21
Signal modelling	0.52
Background	0.22
Method	0.06
Syst.	0.86
Stat. (m_t only)	0.27
Total	0.90

CMS-PAS-TOP-14-002

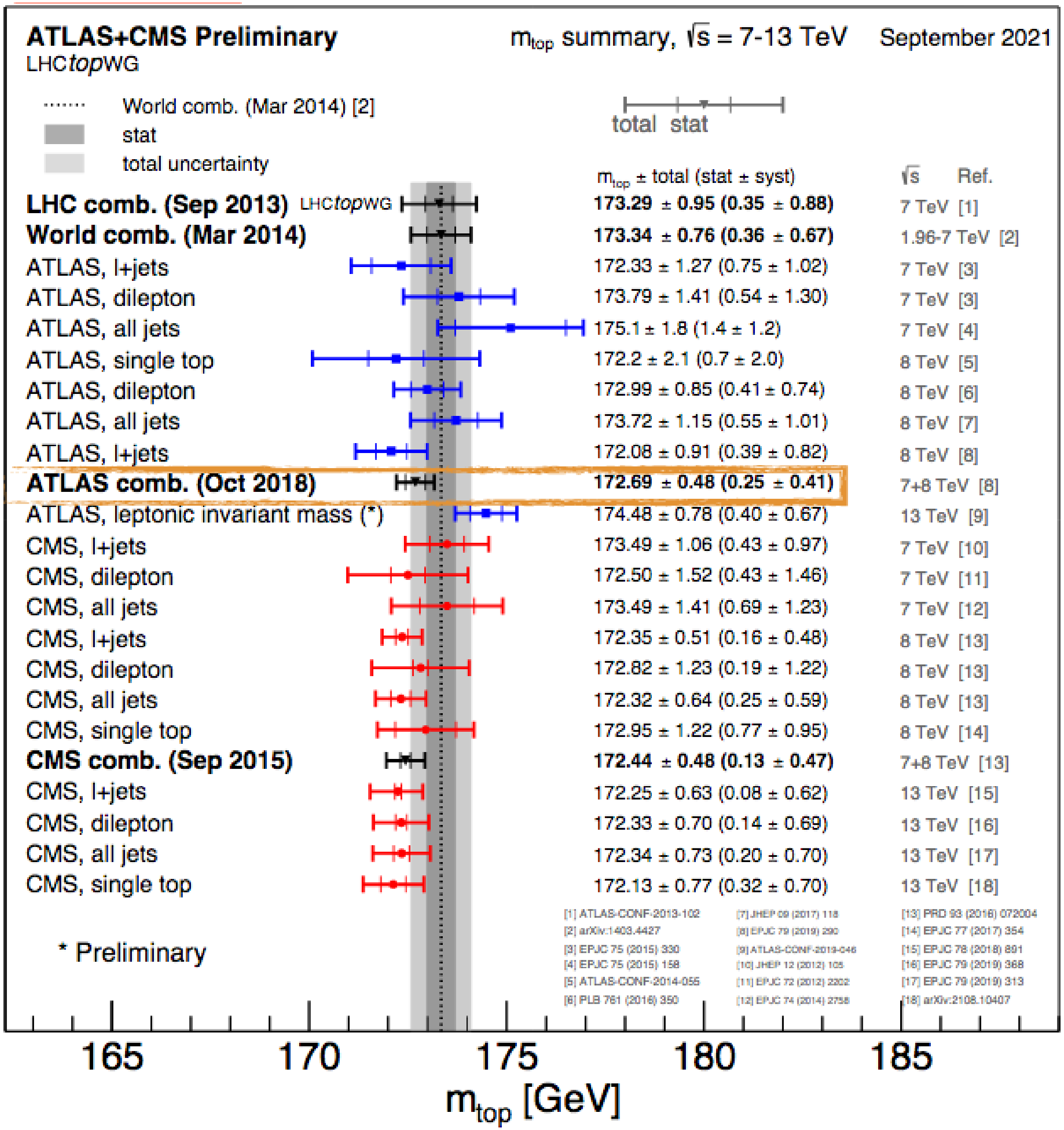


4356 events

$m_t = 172.08 \pm 0.90$ GeV (0.53%)

JSF = 1.007 ± 0.011

Mass measurement



Further material

- **Ideogram method for mass determination**: V.M. Abazov et al. (D0 Collaboration), *Measurement of the top quark mass in the lepton+jets channel using the IdeogramMethod*, hep-ex/0702018.pdf
- **Template method for mass determination**: T. Aaltonen et al. (CDF Collaboration), *Top quark mass measurement using the template method at CDF*, arXiv: 1105.0192v3