Top physics at hadron colliders

Luca Lista

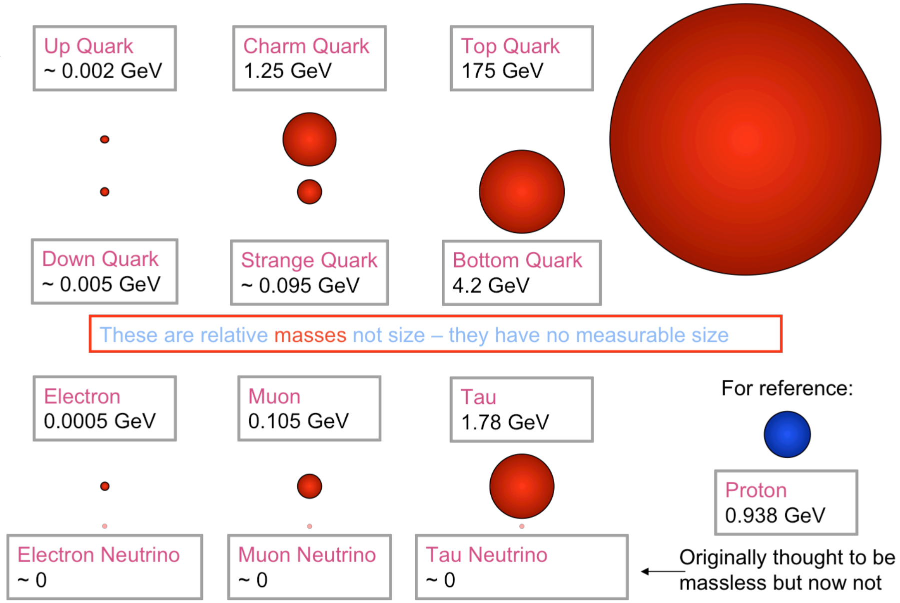
INFN

Outline

- Top quark properties
- Top quark production
- Top pair production
- Top quark decays
- Top mass measurement
- Single-top measurements
- Search for new physics with top

Top: the heaviest quark

- Top is by far the heaviest quark, and the heaviest particle ever observed
  - As heavy as a Au atom!
- Top mass is close to the Electroweak scale
- Unlike all other quarks, it's heavier than W, so it can decay into a real W: t→Wq
- Decay time faster than typical hadronization time
  - Top decays before it can hadronize, so it's a unique opportunity to study "bare" quark properties



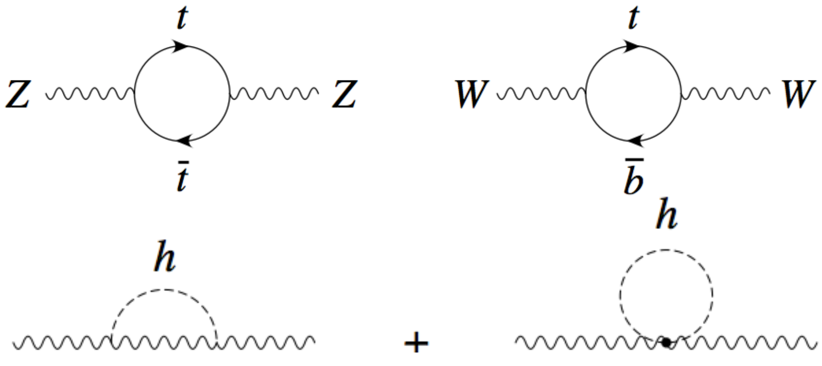
Top history timeline

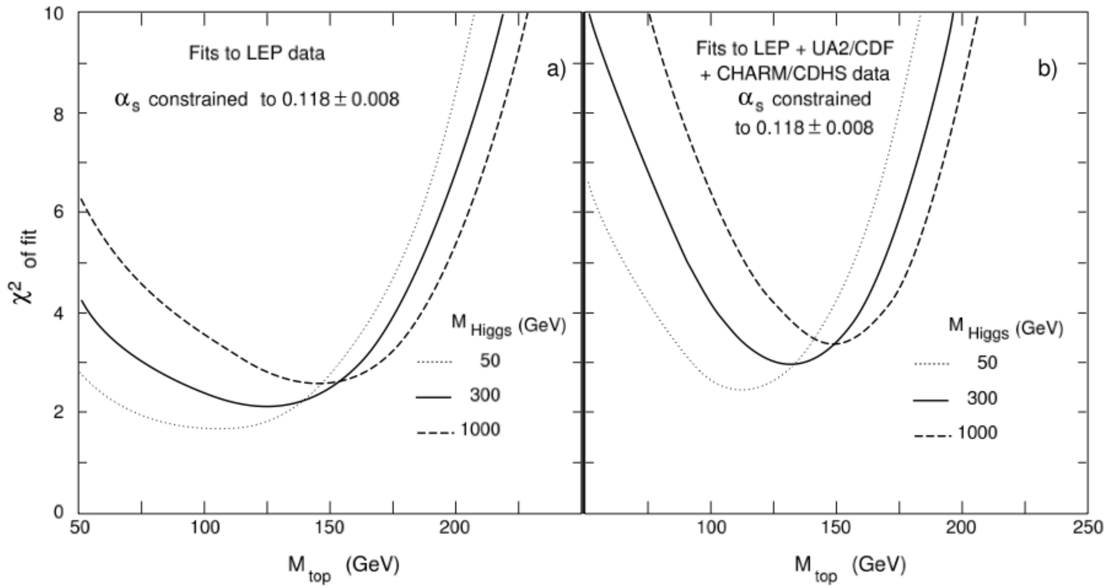
- 1977 – b-quark discovered at FNAL, top quark hypothesizes as weak isospin partner and 6th quark to complete the three SM generations
- Direct search in e^+e^- colliders, increasing limits on the top mass
- ~1990– indirect estimate of quark mass from precision EWK measurements (LEP)
- 1995 – discovered at FNAL by CDF and D0 in direct top-pair production

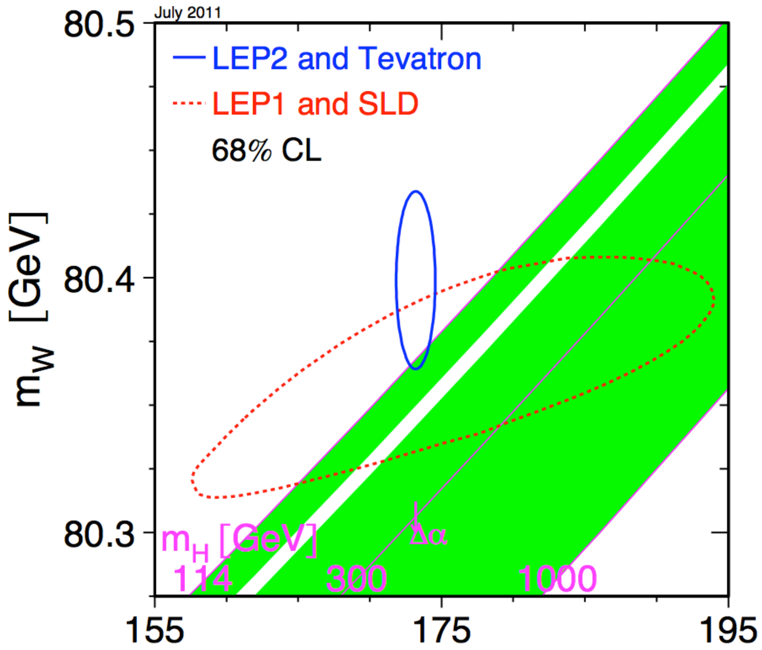
Year	Collider	Particles	References	Limit on m_t
1979-84	PETRA (DESY)	e^+e^-	[45]-[58]	> 23.3 GeV/c^2
1987-90	TRISTAN (KEK)	e^+e^-	[59]-[63]	> 30.2 GeV/c^2
1989-90	SLC (SLAC), LEP (CERN)	e^+e^-	[64]-[67]	> 45.8 GeV/c^2
1984	Sp$\bar{\text{p}}$S (CERN)	$p\bar{p}$	[70]	> 45.0 GeV/c^2
1990	Sp$\bar{\text{p}}$S (CERN)	$p\bar{p}$	[71, 72]	> 69 GeV/c^2
1991	TEVATRON (FNAL)	$p\bar{p}$	[73]-[75]	> 77 GeV/c^2
1992	TEVATRON (FNAL)	$p\bar{p}$	[76, 77]	> 91 GeV/c^2
1994	TEVATRON (FNAL)	$p\bar{p}$	[79, 80]	> 131 GeV/c^2
1995	TEVATRON (FNAL)	$p\bar{p}$	[37]	$= 174 \pm 10^{+13}_{-12}$ GeV/c^2
			[38]	$= 199^{+19}_{-21} \pm 22$ GeV/c^2

Indirect top quark evidence

- Precision measurements of the Elecroweak parameters, mainly from LEP, allowed to measure virtual corrections with sufficient precision to put constraints on the top-quark mass
  – $\Delta r \sim m_t^2, \ln(m_H)$



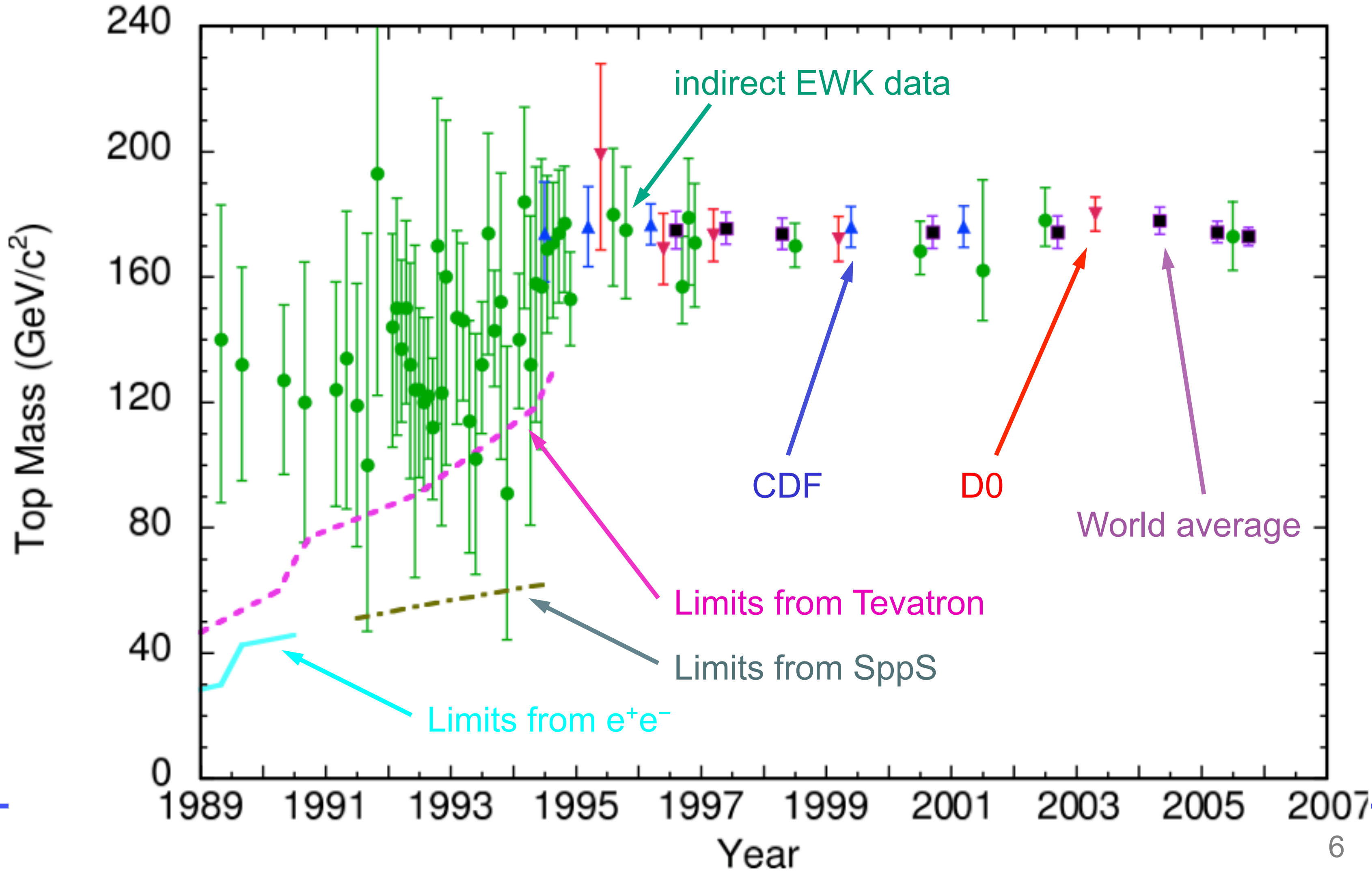




1 GeV change on $m_t \Rightarrow$ ~10 GeV change on m_H

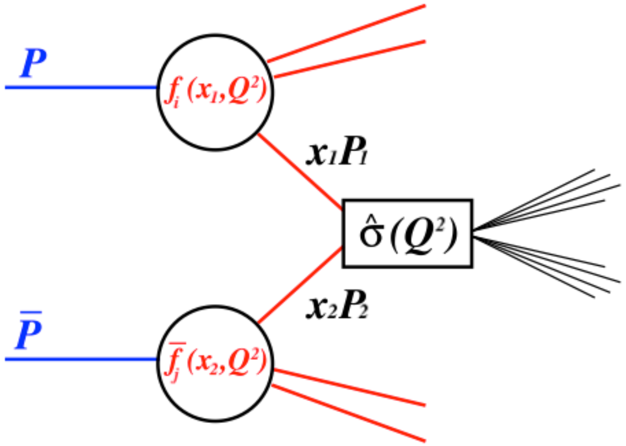
Top mass history

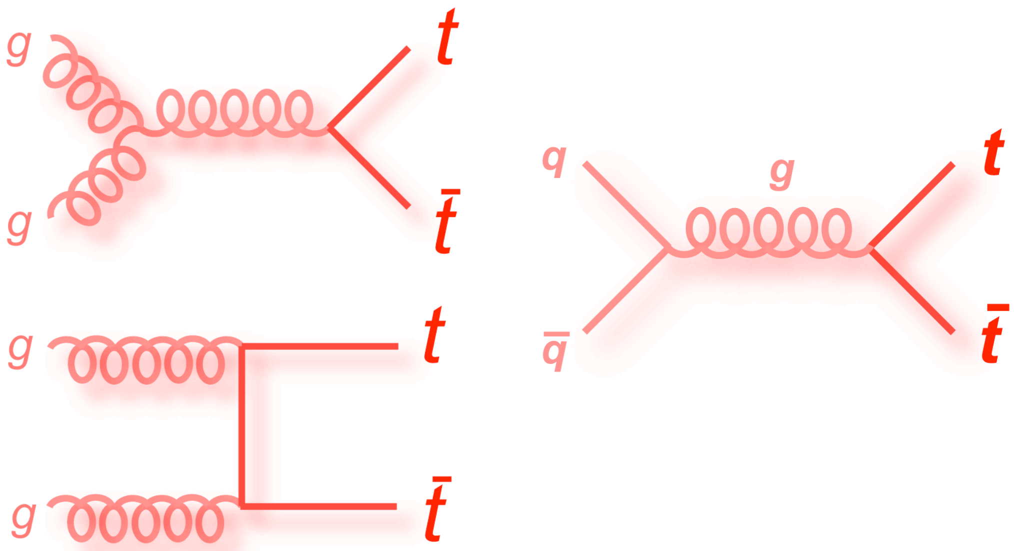
- Limits or estimate vs time



Top quark production

Top quark pair production

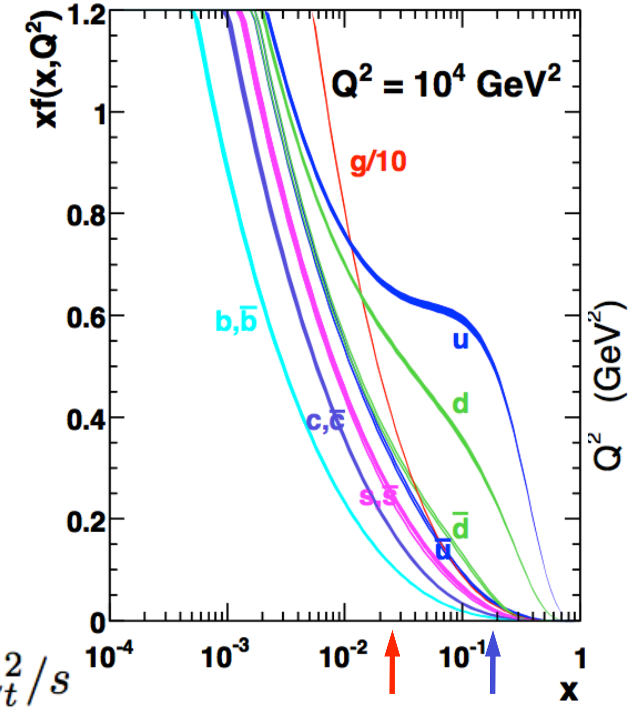


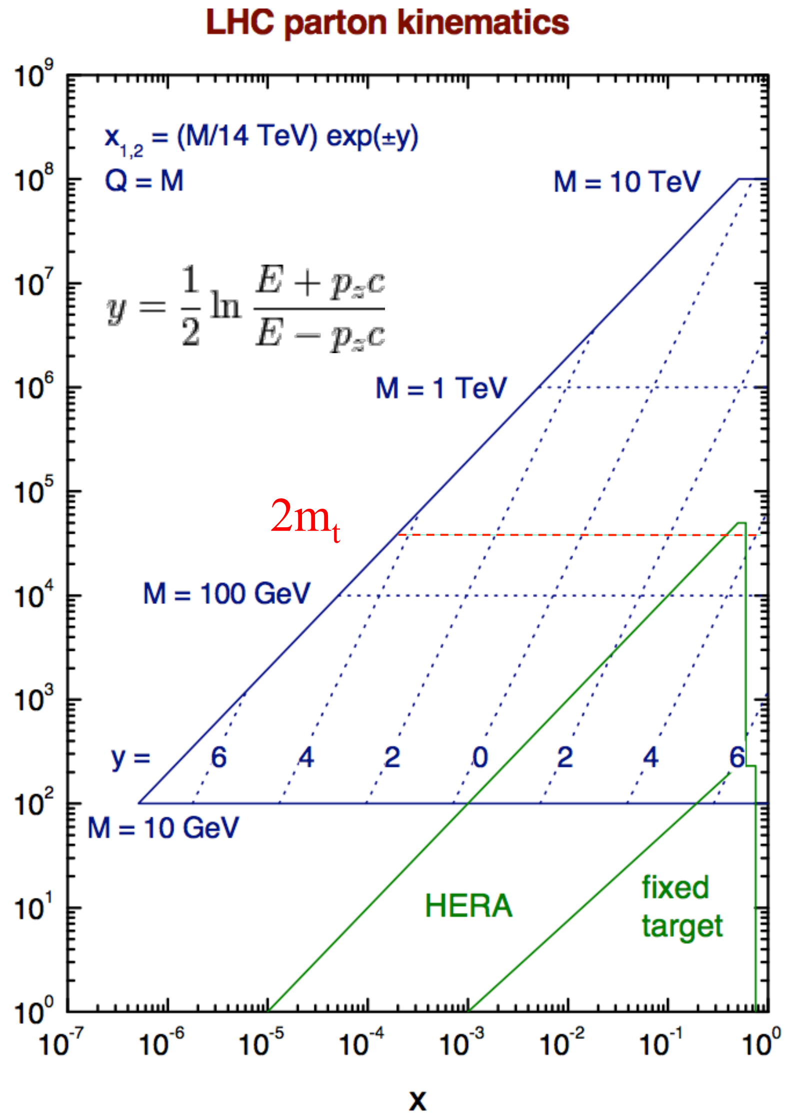


$$\sigma^{t\bar{t}}(\sqrt{s}, m_t) \quad = \sum_{i,j=q,\bar{q},g} \int dx_i\, dx_j\, f_i(x_i,\mu^2) \cdot \bar{f}_j(x_j,\mu^2) \cdot \hat{\sigma}^{ij\to t\bar{t}}\,(\rho, m_t^2, \alpha_s(\mu^2), \mu^2)$$

LHC kinematics

- Smaller x implies larger gluon contribution





$$y = \frac{1}{2}\ln\frac{E + p_z c}{E - p_z c}$$

$$\hat{s} = x_i \cdot x_j \cdot s$$

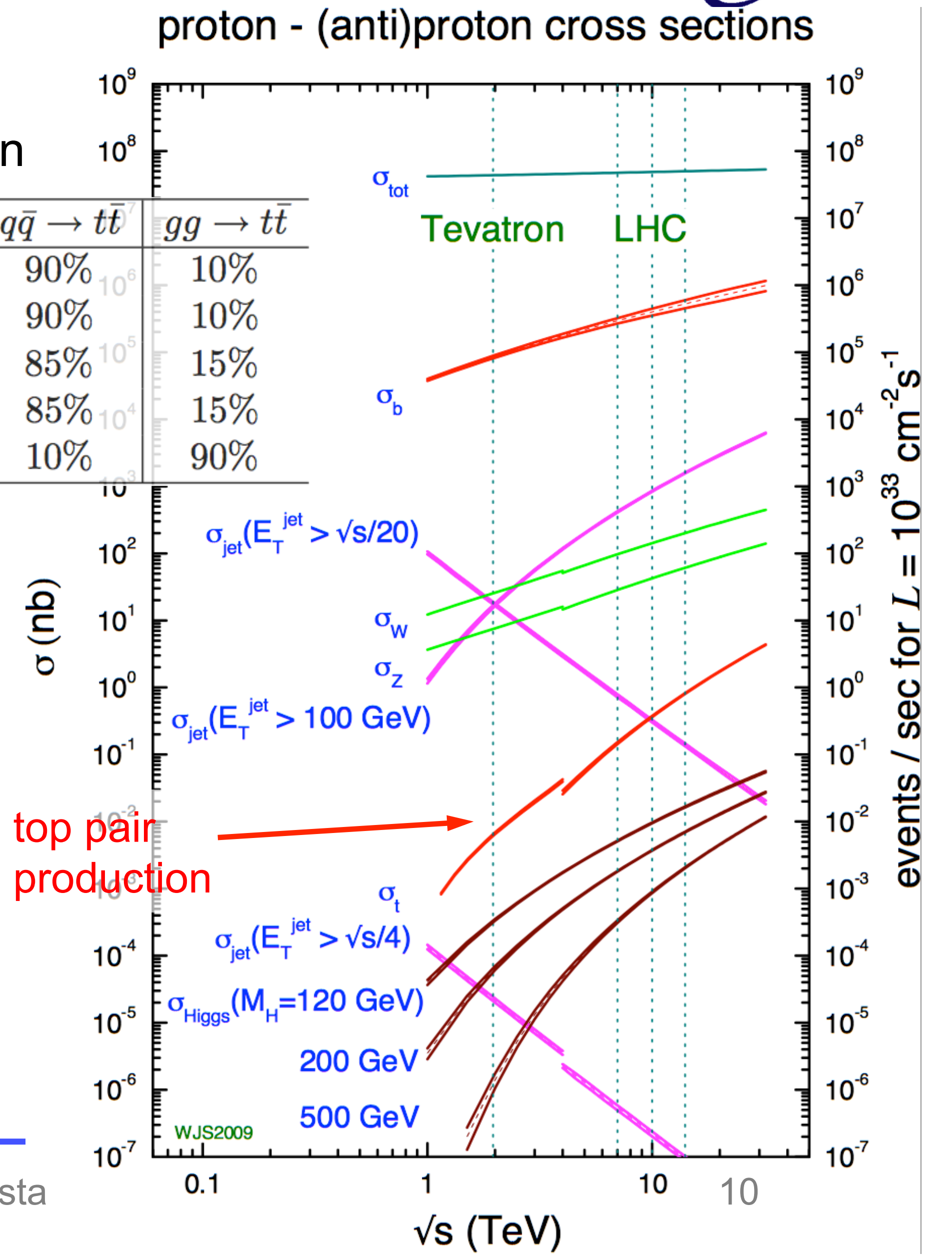
$$x_i \cdot x_j = \hat{s}/s \geq 4m_t^2/s$$

$$x \approx \frac{2m_t}{\sqrt{s}} \begin{cases} \sim 0.19 \text{ at Tevatron} \\ \sim 0.025 \text{ at LHC (14 TeV)} \end{cases}$$

Tevatron vs LHC

- Gluon fusion dominates at LHC, while $q\bar{q}$ annihilation dominates at Tevatron

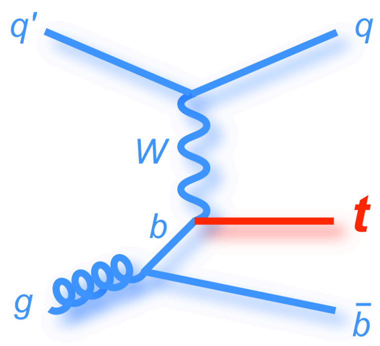
	$\sigma_{\rm NLO}$ (pb)		$q\bar{q} \to t\bar{t}$	$gg \to t\bar{t}$
TEVATRON ($\sqrt{s} = 1.8$ TeV, $p\bar{p}$)	$5.19 \pm 13\%$	[106]	90%	10%
	$5.24 \pm 6\%$	[108]	90%	10%
TEVATRON ($\sqrt{s} = 1.96$ TeV, $p\bar{p}$)	$6.70 \pm 13\%$	[106]	85%	15%
	$6.77 \pm 9\%$	[108]	85%	15%
LHC ($\sqrt{s} = 14$ TeV, pp)	$833 \pm 15\%$	[105]	10%	90%

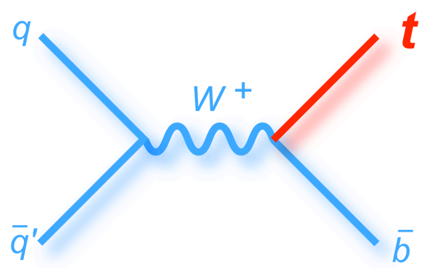


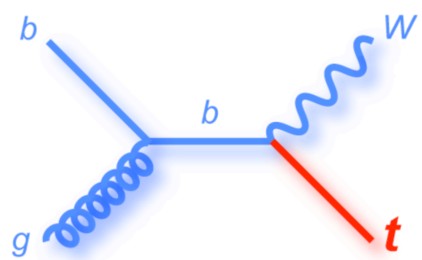
- Expectation:
  - Tevatron: 10 $t\bar{t}$/day, LHC: 1 $t\bar{t}$/s
  - Single-top: 4/day vs 0.5/s
- LHC is effectively a top factory

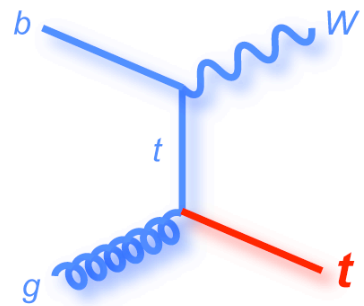
Single-top production

- Single top quark production is possible via the mediation of a W
- Three possible processes: t, s channels, tW







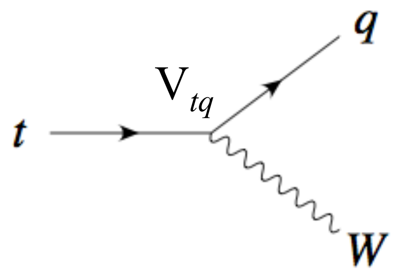


Cross sections(pb) (top mass =173)	***s-channel*** Phys. Rev. D 81, 054028 (2010), N. Kidonakis	***tW channel*** Phys. Rev. D 82, 054018 (2010), N. Kidonakis	***t channel*** Phys. Rev. D 83, 091503(R) (2011) N. Kidonakis
LHC: *pp* @7 TeV	4.59	15.6	63.2
Tevatron *pp* @1.96 TeV	1.04	0.22 (arxiv.org/pdf/0909.0037)	2.08
LHC *pp* @14 TeV	11.9	83.6	243

Top quark decay

Top quark decays

- Main top decay: $t \to Wb$ ($|V_{tb}| \sim 1$)

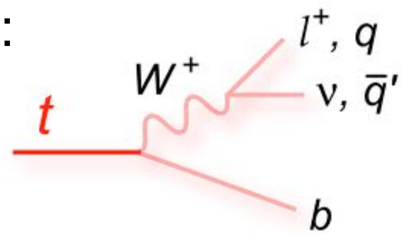


$$\Gamma_t = \frac{G_F m_t^3}{8\pi\sqrt{2}}\left(1-\frac{M_W^2}{m_t^2}\right)^2\left(1+2\frac{M_W^2}{m_t^2}\right)\left[1-\frac{2\alpha_s}{3\pi}\left(\frac{2\pi^2}{3}-\frac{5}{2}\right)\right]$$

- Top lifetime is ~ 0.5×10^{-24}s, smaller than typical hadronization time ($1/\Lambda_{QCD} \sim 3\times10^{-24}$s)
  - Top decays too quickly to produce top hadrons, so no top spectroscopy is possible

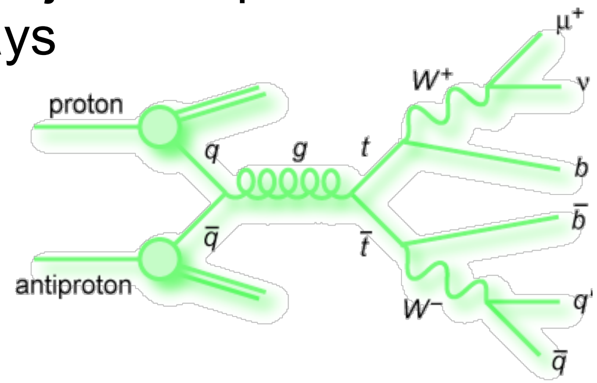
Final states in top events

- The signature of top events is dictated by the decay mode of the W boson in t→Wb
- Possible decay modes:
  - Dileptons (e, μ): ~5%
  - Leptons + jets: ~30%
  - All hadronic: ~45%

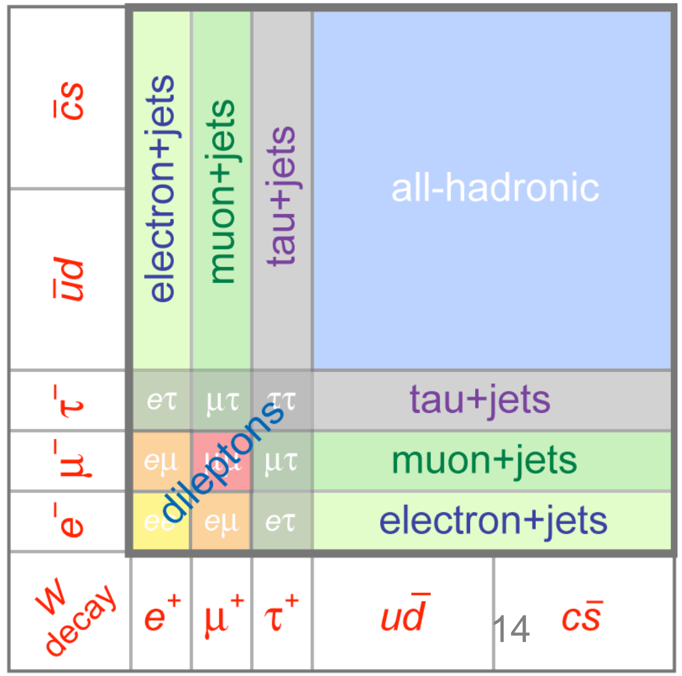


W^+ DECAY MODES	Fraction (Γ_i/Γ)
$\ell^+\nu$	(10.80 ± 0.09) %
$e^+\nu$	(10.75 ± 0.13) %
$\mu^+\nu$	(10.57 ± 0.15) %
$\tau^+\nu$	(11.25 ± 0.20) %
hadrons	(67.60 ± 0.27) %

- Two b-jets at leas are present in the event
- Neutrinos are present when the W decays leptonically
- Non-b jets are present in W hadronic decays



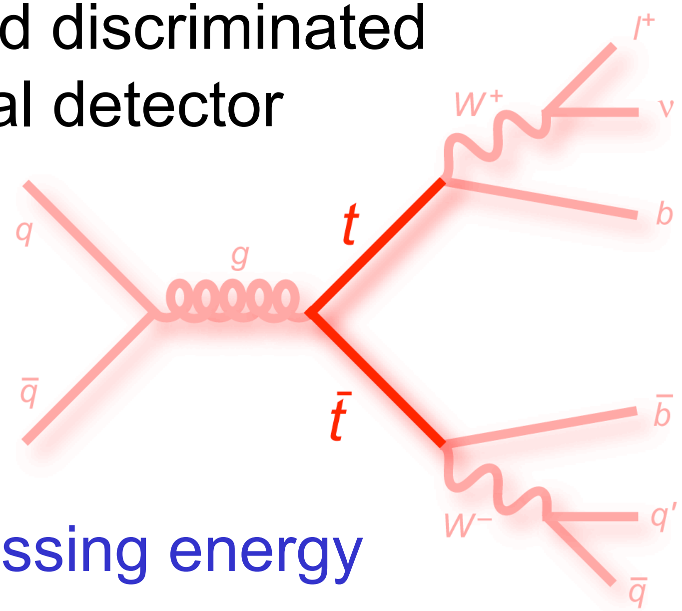
Top Pair Decay Channels



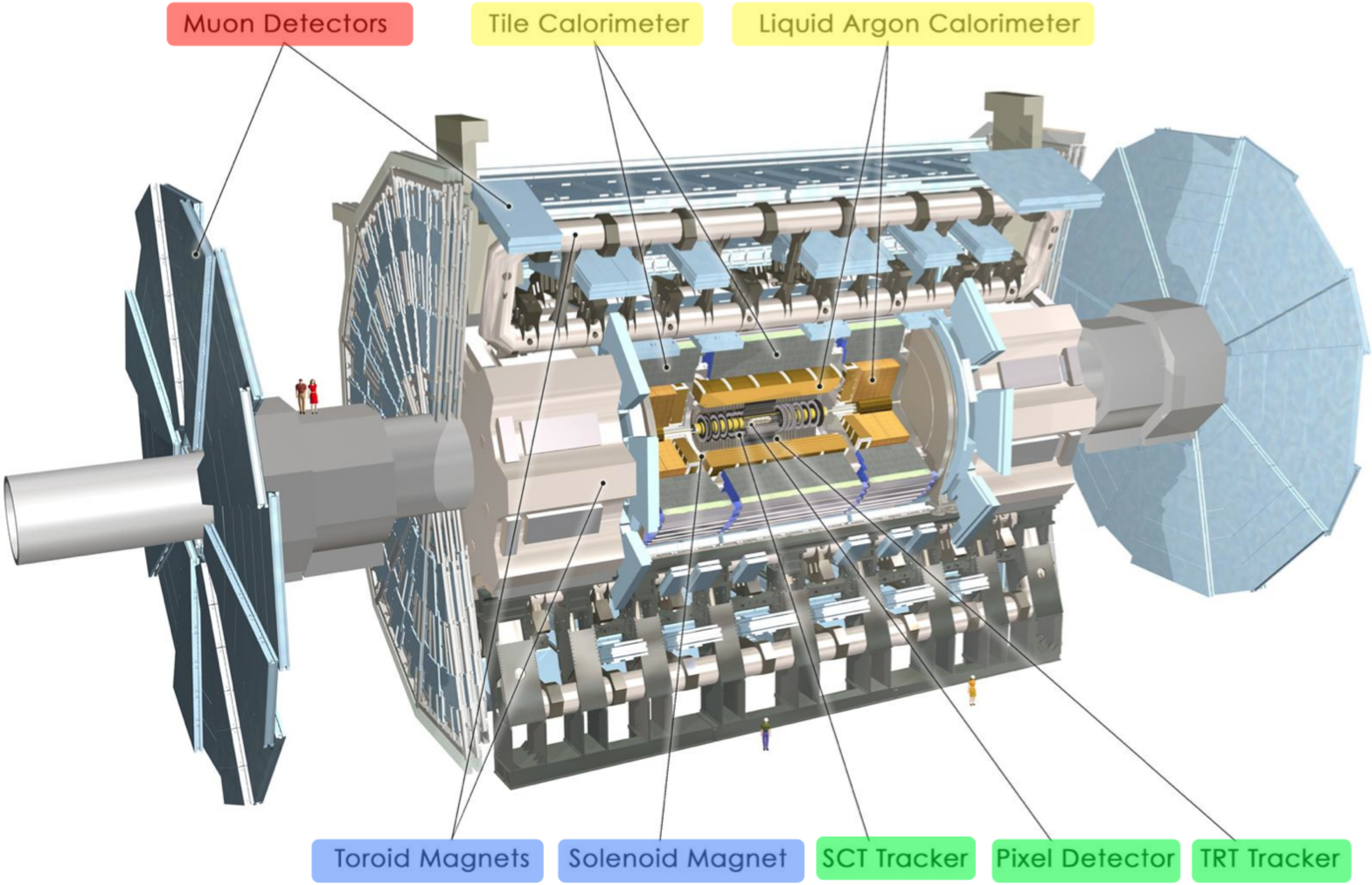
Top quark identification and reconstruction

Experimental physics ‘objects’

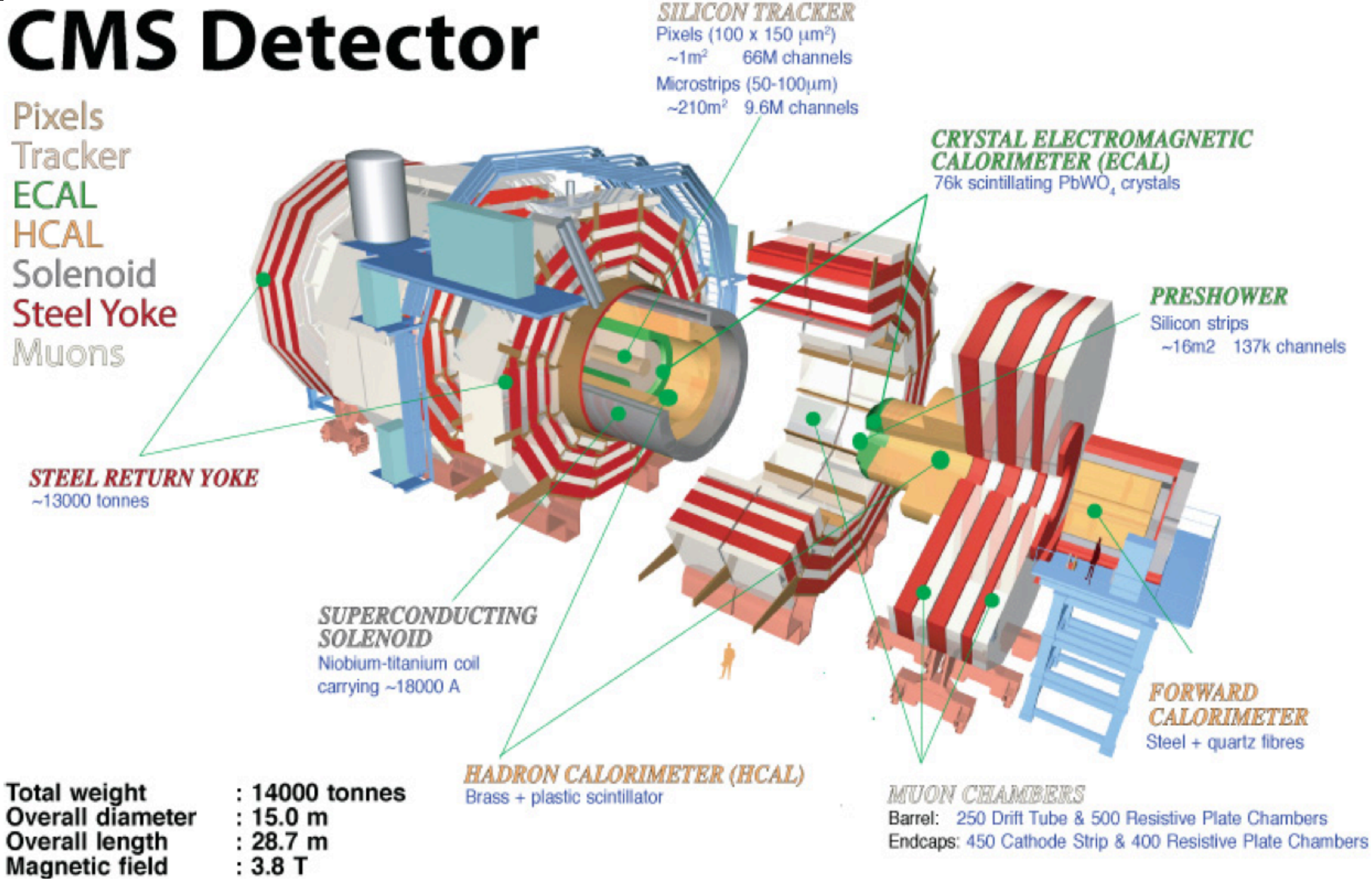
- Top events can be recognized and discriminated from the background using several detector information
- Lepton identification
- Hadronic jet reconstruction
- Identification of b-jets (b tagging)
- Reconstruction of neutrinos as missing energy
  - in the transverse plane only at hadron colliders
- Further background reduction can be achieved using kinematic variables, depending on the specific channel



LHC experiments: ATLAS

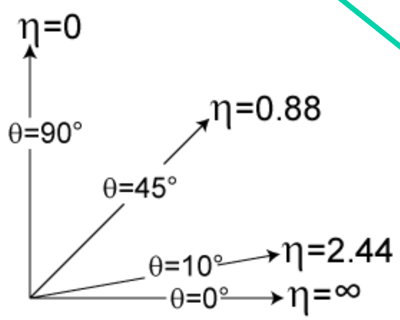


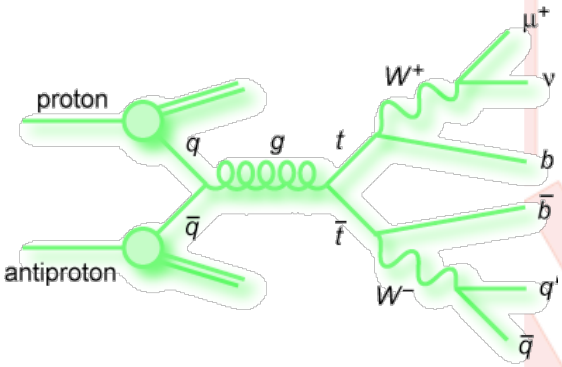
LHC experiments: CMS

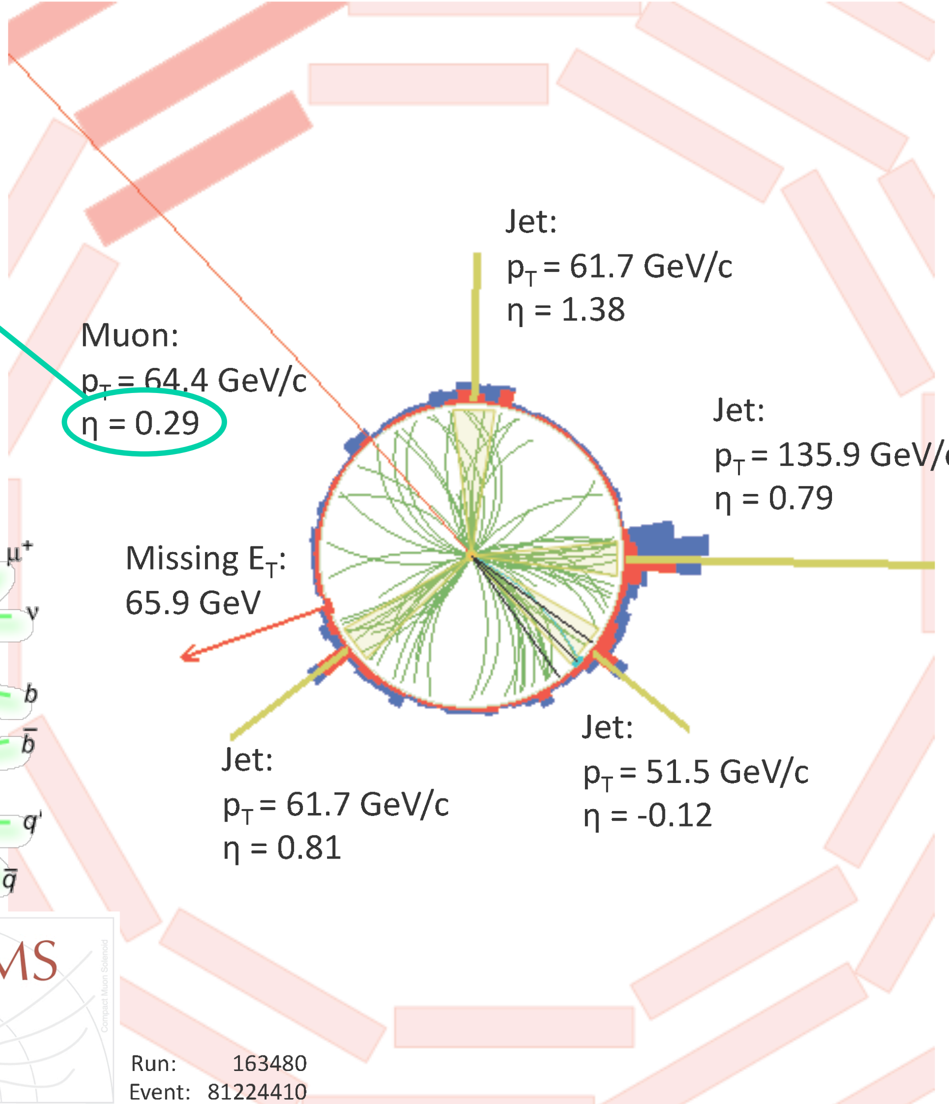


A top-antitop candidate event

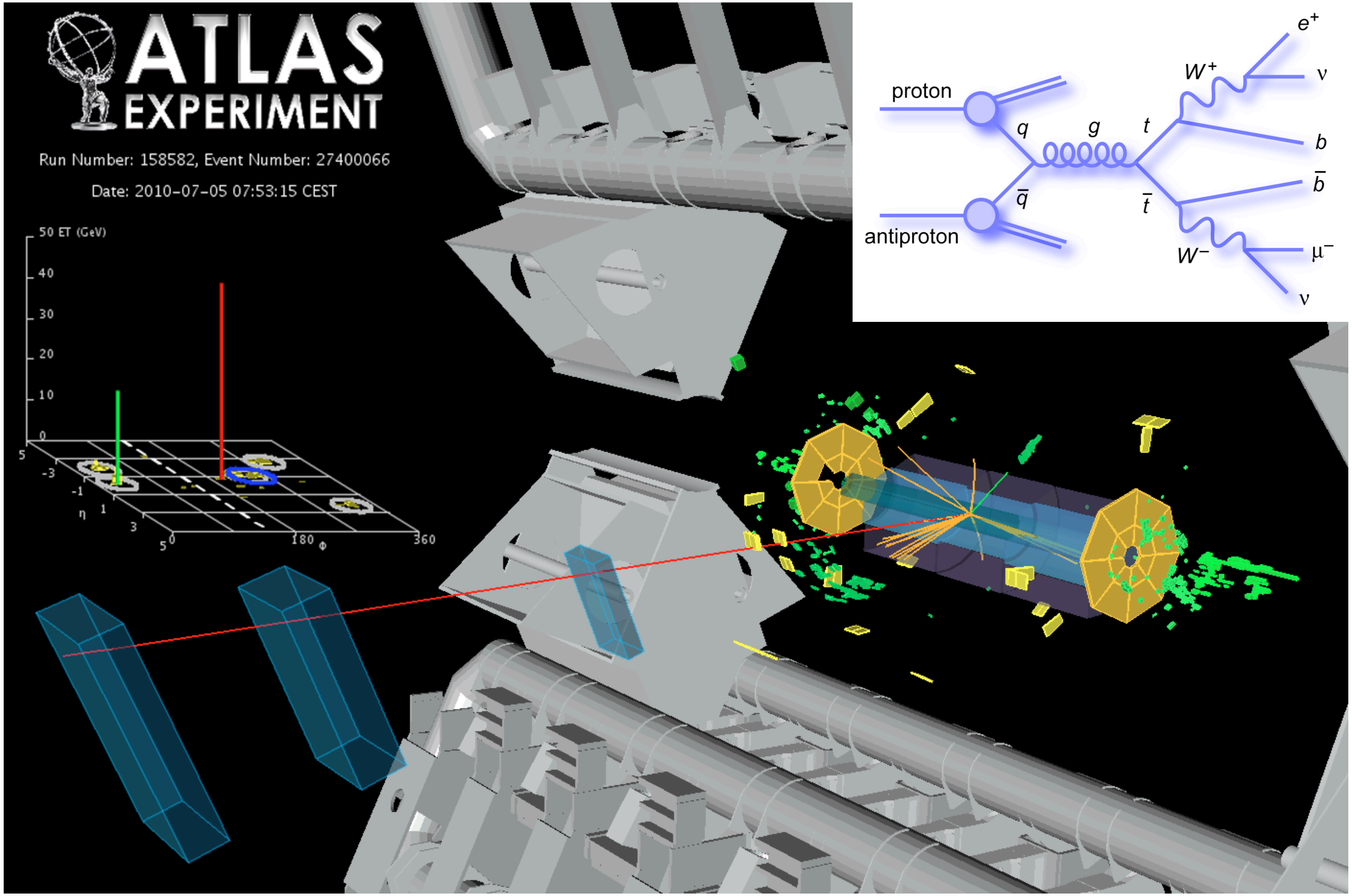
$$\eta = -\ln\left[\tan\left(\frac{\theta}{2}\right)\right],$$





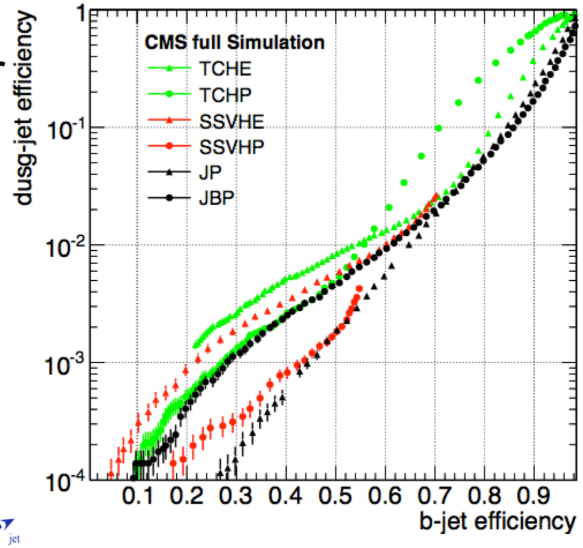


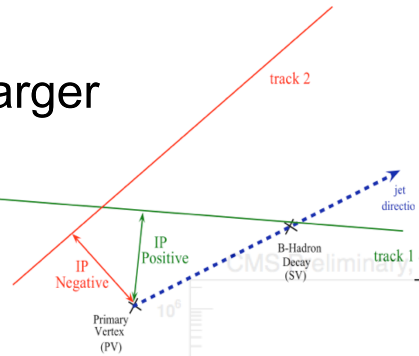
One more candidate (eμ+2 jets)

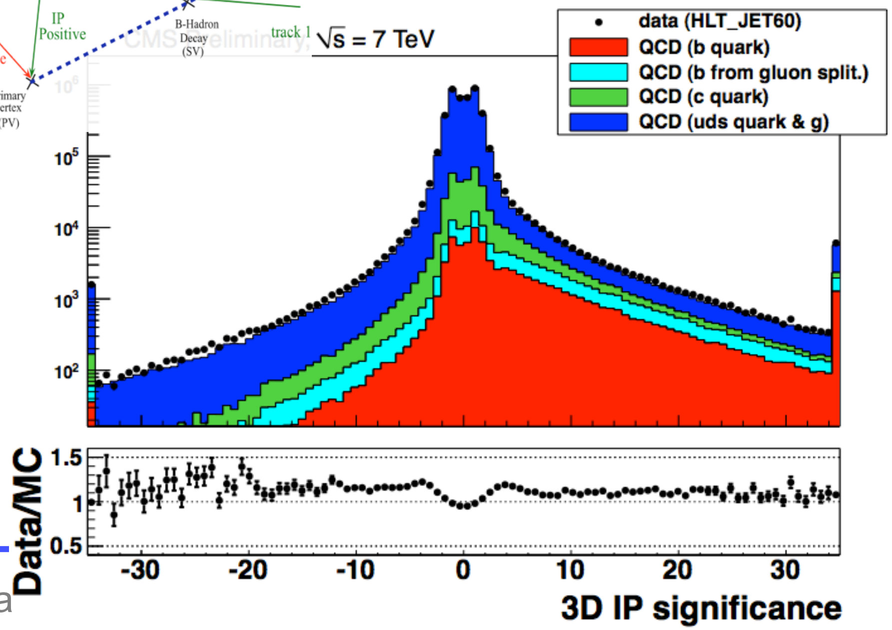


Identifying the b jet: “tagging”

- Different algorithms are used to determine whether a jet is produced from a b-quark fragmentation
- b mesons/barions have long lifetimes
  - τ~1.5ps, cτ ~ 450μm, l~1.8mm at p=20 GeV/c
  - Impact parameter reconstruction can detect long-lived tracks
- Semileptonic branching ratio is larger than non-b jets
  - ~11%, ~20% including cascade decays
- Harder b frabmentation
  - Some difference in kinematics
  - Larger p_T of tracks w.r.t. the jet direction
- Different information can be combined into a single tagger algorithm







$t\bar{t}$ cross section

$t\bar{t}$ cross section measurement

- Typical event selection for lepton + jets

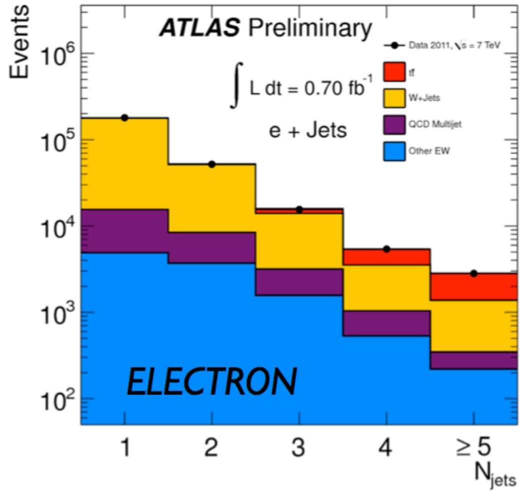
ATLAS	Electron	Muon
Trigger	$p_T > 20$ GeV	$p_T > 18$ GeV
Jets	Anti-Kt 0.4, $p_T > 20$ GeV, $\lvert\eta\rvert < 2.5$, ΔR(jet, electron) < 0.2	
Electron	$E_T > 25$ GeV, $\lvert\eta\rvert < 2.5$, E_T (cone 0.2) < 3.5 GeV	
Muon	$p_T > 20$ GeV, $\lvert\eta\rvert<2.1$, E_T (cone 0.3) < 4 GeV & P_T (cone 0.3) < 4 GeV, ΔR(muon,jet (p_T>20 GeV)) < 0.4	
Missing E_T	> 35 GeV	> 25 GeV
$m_T(W_{lep})$	> 25 GeV	$E_T + m_T(W_{lep})$> 60 GeV

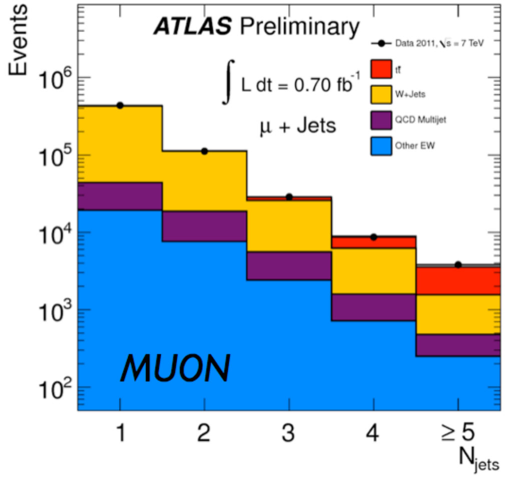
CMS	Electron	Muon
Trigger	$p_T > 22$ GeV	$p_T > 15$ GeV
Jets	Anti-Kt 0.5, $p_T > 30$ GeV, $\lvert\eta\rvert < 2.4$ ΔR(jet, muon || electron) < 0.3	
Electron	$E_T > 30$ GeV, $\lvert\eta\rvert < 2.5$ I_{rel}(cone 0.3) < 0.1	
Muon	$p_T > 20$ GeV, $\lvert\eta\rvert<2.1$, I_{rel} (cone 0.3) < 0.05	
Missing E_T	no cut on missing E_T as is used in the likelihood	

$$m_T(W) = \sqrt{2p_T^l p_T^\nu(1 - \cos(\phi^l - \phi\nu))}$$

$$I_{rel} = (I_{charged} + I_{neutral} + I_{photon})/p_T$$

l+jet: jet multiplicity (untagged)



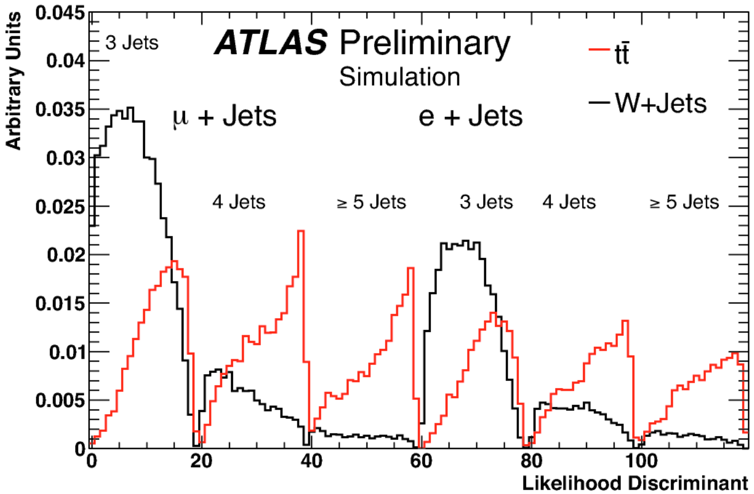


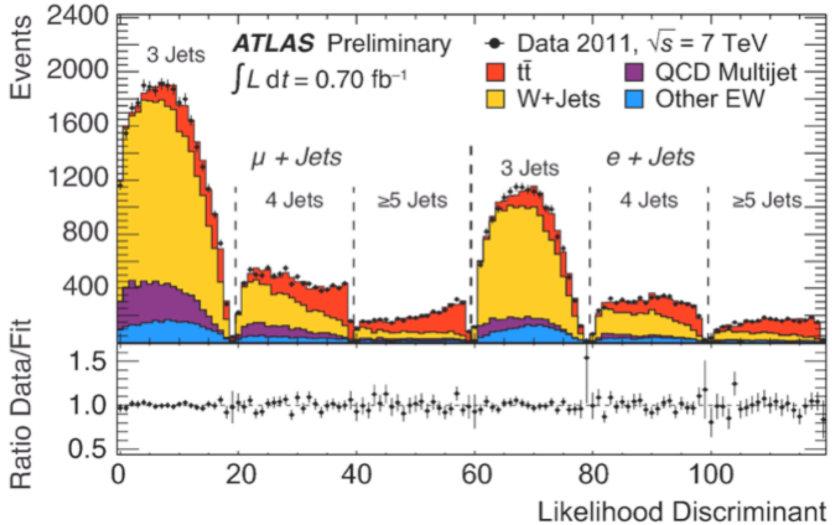
Likelihood discriminator based on four discriminating variables

ATLAS-CONF-2011-121

$$\sigma_{t\bar{t}} = 179.0^{+7.0}_{-6.0}(stat + syst) \pm 6.6(lumi)pb$$

Likelihood discriminant based on kinematical quantities

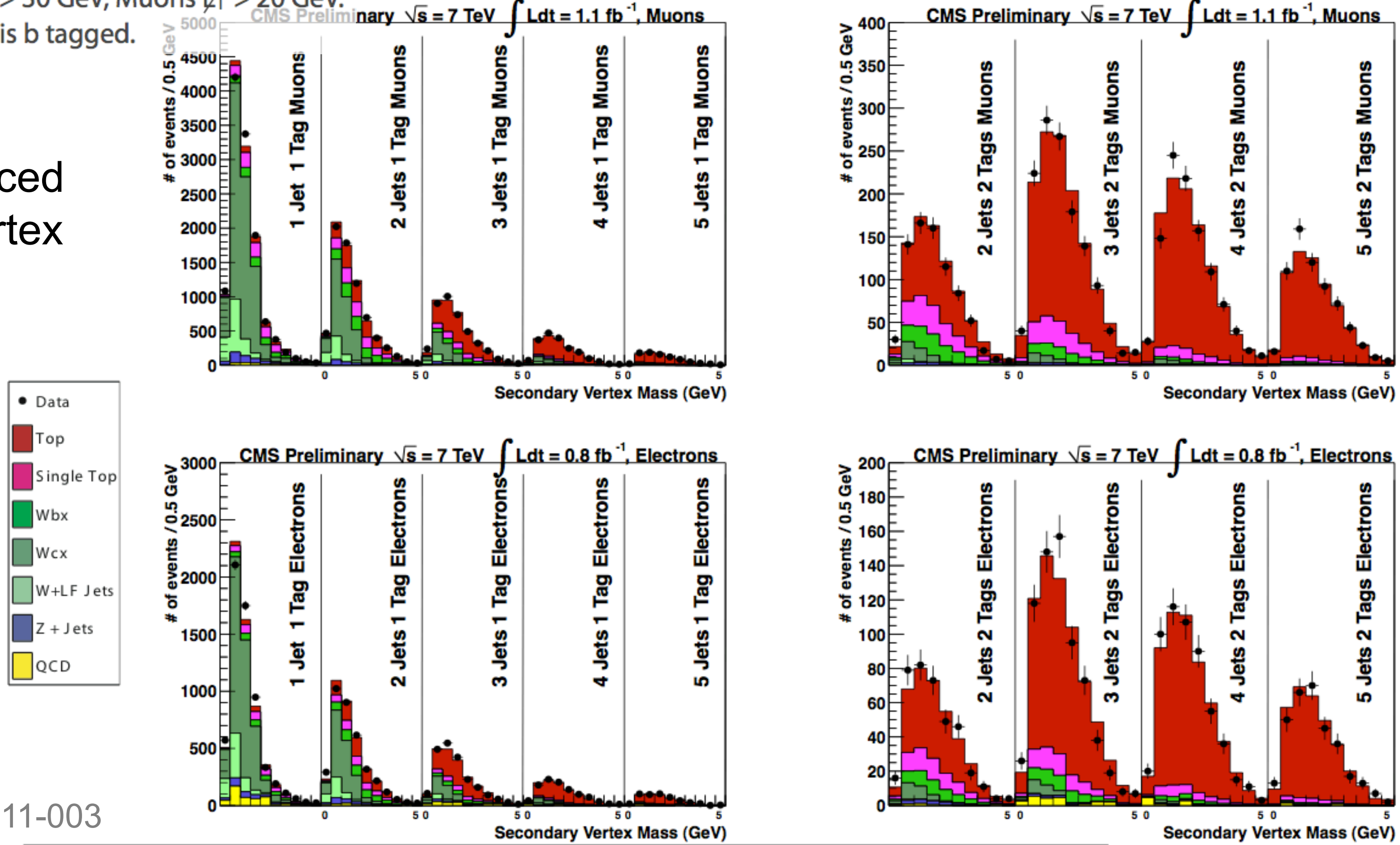




Lepton + jets with b-tag

Lepton p_T: Electron $p_T > 45$ GeV, Muons $p_T > 35$ GeV.
Missing E_T: Electrons $\not{E}_T > 30$ GeV, Muons $\not{E}_T > 20$ GeV.
At least one selected jet is b tagged.

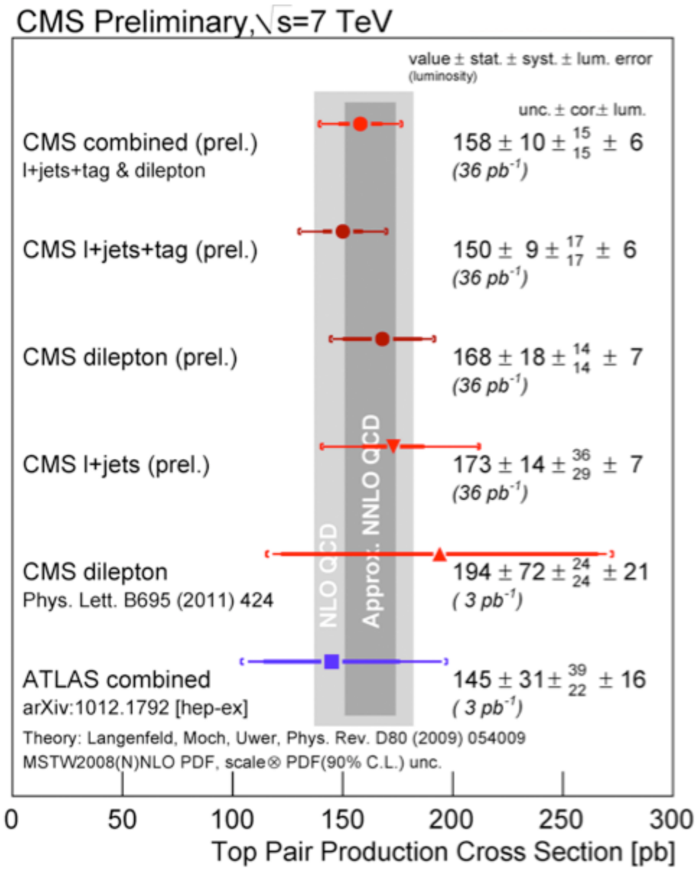
b-tag = displaced secondary vertex



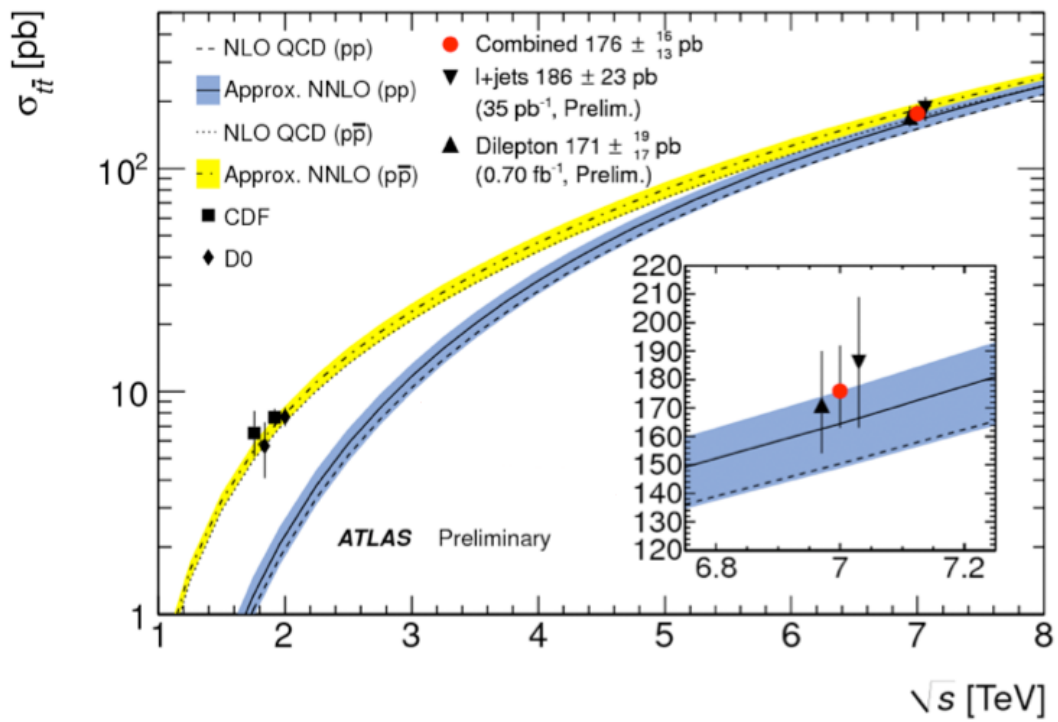
CMS PAS TOP-11-003

$$\sigma_{t\bar{t}} = 164.4 \pm 2.8(stat.) \pm 11.9(syst.) \pm 7.4(lum.)pb$$

Cross section summary (2010…)



2010 data (no 2011 combination available yet!)



Top mass measurement

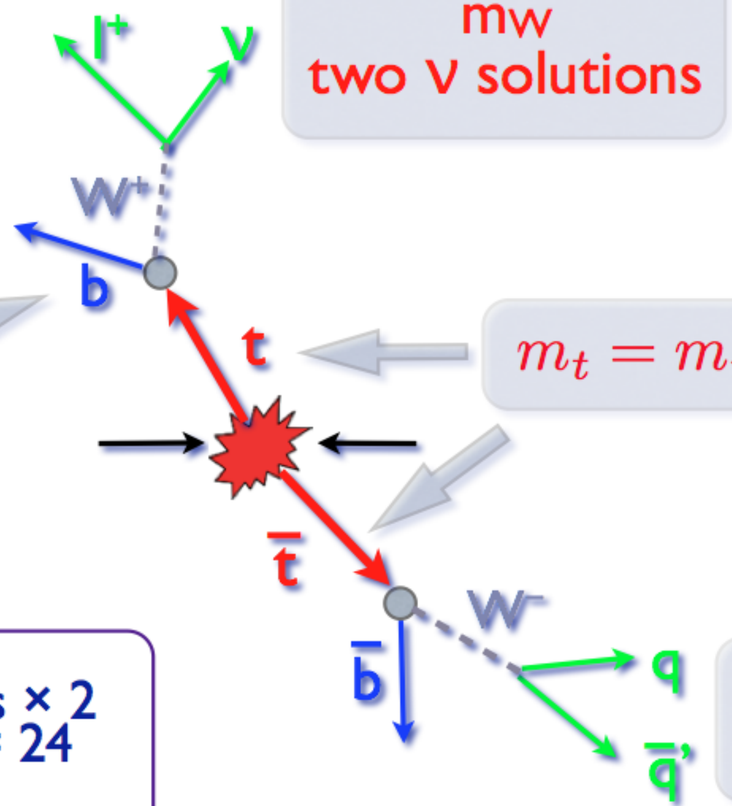
Top event reconstruction (l+jets)

Over constrained kinematic (-2)

- 18 variables
- 17 measured quantities
- 3 constraints

Invariant mass
mw
two ν solutions

b-tag



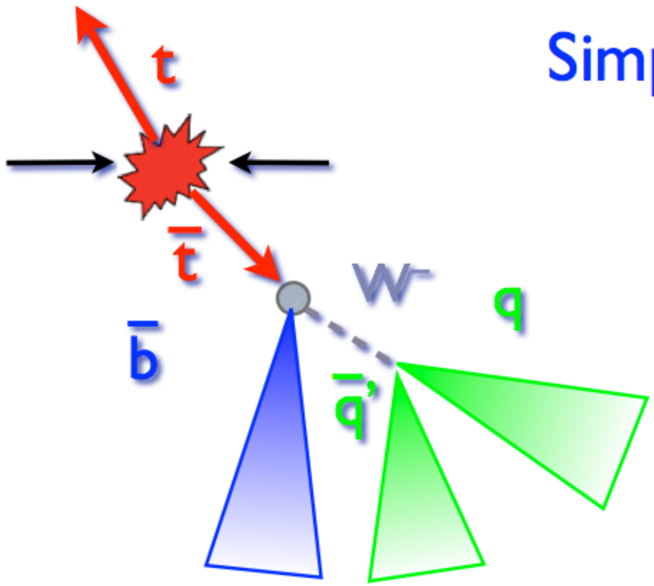
$m_t = m_{\bar{t}}$

Invariant mass
mw

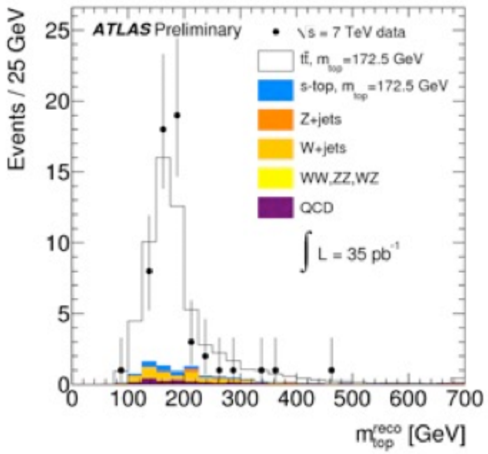
- 12 jet configurations × 2 neutrino solutions = 24
- b-tag: 12 permutation
- 2 b-tags: 4 permutations

More permutations in all-hadronic mode
Two neutrinos in dileptonic mode

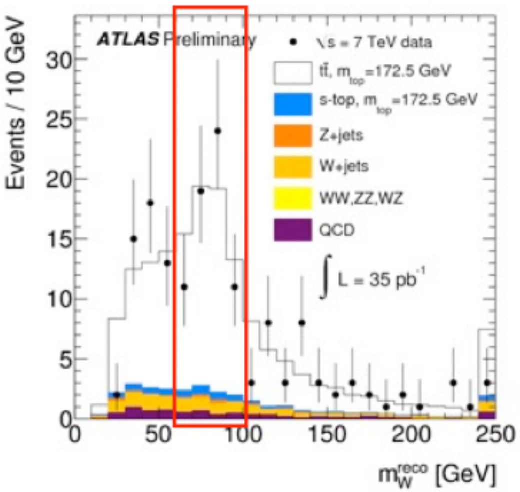
Reconstruct the top mass



Simple reconstruction - hadronic top



- take three highest p_T jets to build top mass



- W mass window cut: $60<m_W<100$ GeV

45%(36%) of correctly reconstructed W(top)

- if 1 b-tag in triplet take two jets with no b-tag to build W mass
- if 2 b-tags in triplet drop the event
- if no b-tag take two jets with min ΔR

ATLAS-CONF-2011-033

Constrained fit for m_t

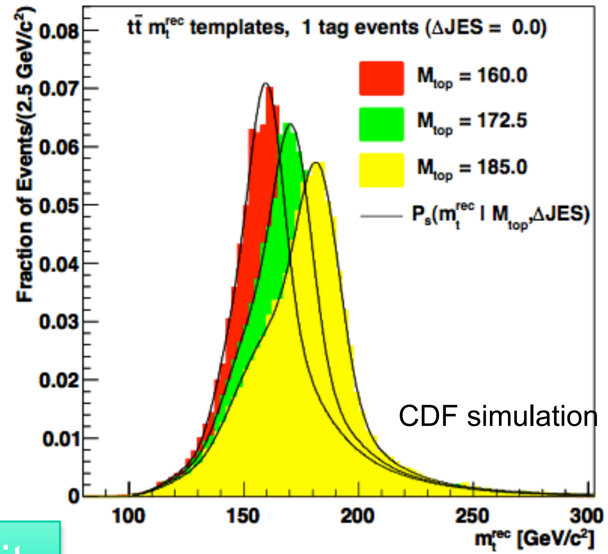
- Mass resolution improves if kinematical constraints are applied
- Chi-squared minimization problem
  - Gaussian approximation for Breit-Wigner shapes

$$\chi^2 = \frac{(m_{jj} - M_W)^2}{\Gamma_W^2} + \frac{(m_{\ell\nu} - M_W)^2}{\Gamma_W^2} + \frac{(m_{jjb} - m_t^{rec})^2}{\Gamma_t^2} + \frac{(m_{\ell\nu b} - m_t^{rec})^2}{\Gamma_t^2}$$
$$+ \sum_{i=\ell,4jets} \frac{(p_T^{i,fit} - p_T^{i,meas})^2}{\sigma_i^2} + \sum_{j=x,y} \frac{(p_j^{UE,fit} - p_j^{UE,meas})^2}{\sigma_{UE^2}}$$

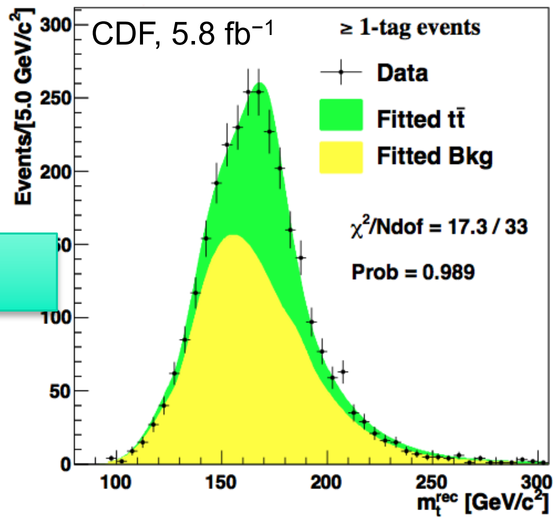
Template method

CDF Conf. Note 10456

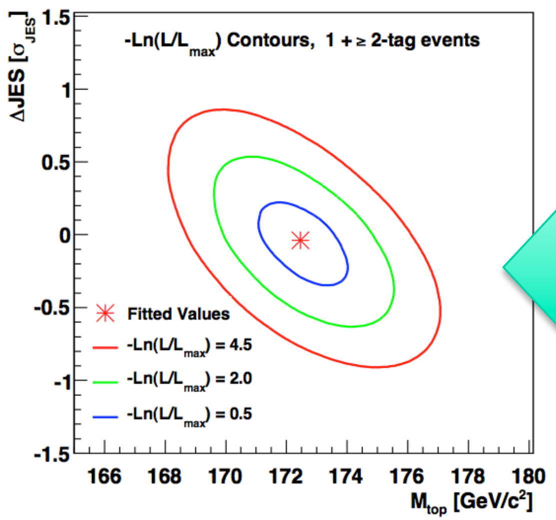
1. Generate m_t-dependent observable (e.g.: reconstructed top mass)
2. Generate template distributions at different m_t (Monte Carlo)
3. Fit the templates to data and determine m_t

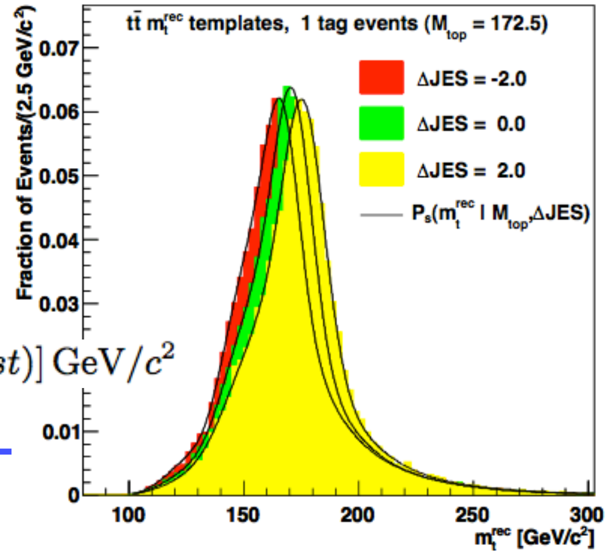


Fit



CDF Run II Preliminary (5.8 fb⁻¹)





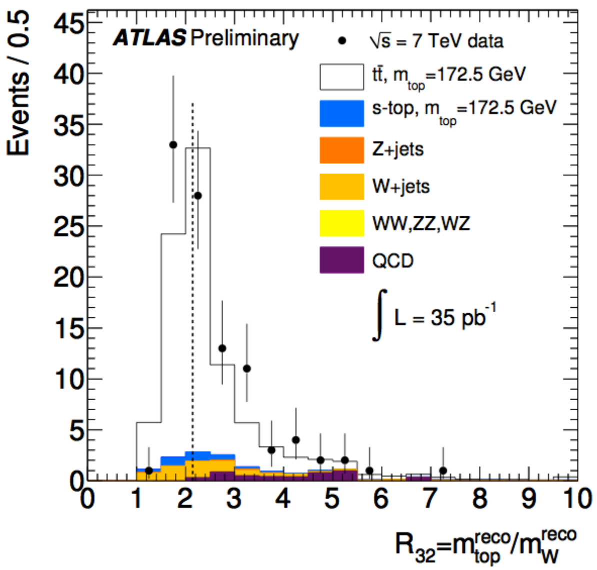
Simultaneous determination of Jet Energy Scale and m_t from the same sample improves overall resolution

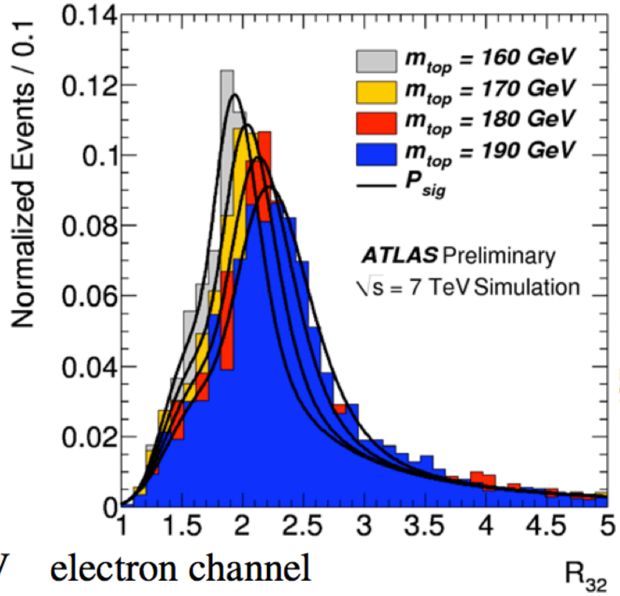
$$M_{top} = [172.5 \ \pm 1.4\,(stat) \ \pm 1.4\,(syst)]\ \mathrm{GeV}/c^2$$

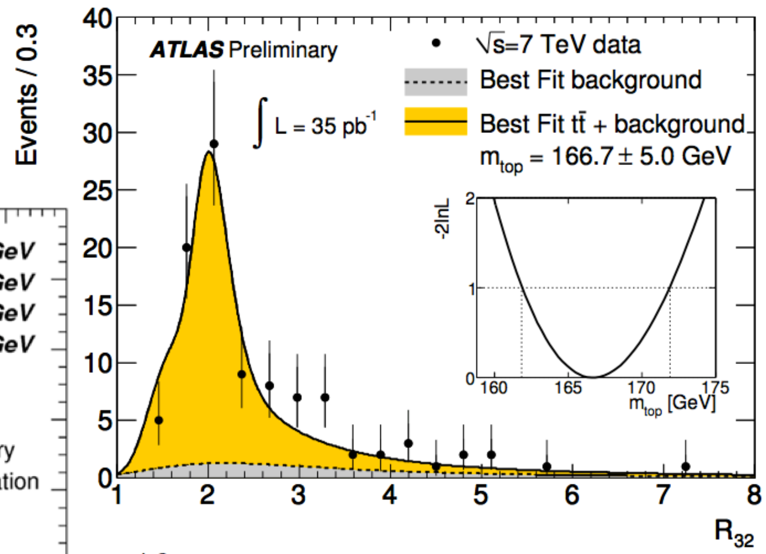
Template method: ATLAS

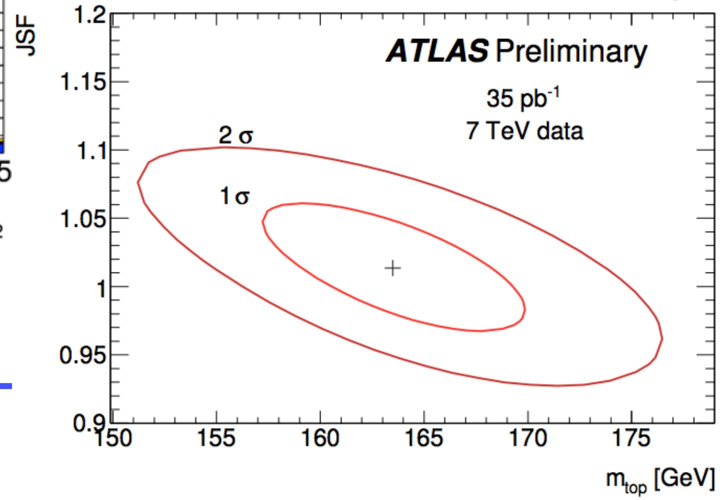
- Similar method, different discriminating variable to reduce systematic uncertainties

$$R_{32} \equiv \frac{m_{\mathrm{top}}^{\mathrm{reco}}}{m_{\mathrm{W}}^{\mathrm{reco}}}$$









$$m_{\mathrm{top}} = (168.3 \pm 6.2 \pm 4.3)\ \mathrm{GeV} \quad \text{electron channel}$$
$$m_{\mathrm{top}} = (163.5 \pm 6.7 \pm 4.6)\ \mathrm{GeV} \quad \text{muon channel}$$
$$m_{\mathrm{top}} = (166.1 \pm 4.6 \pm 4.4)\ \mathrm{GeV} \quad \text{combined}$$

Matrix element method

1. Compute the event probability density as:

$$P_{\rm evt}(x_{\rm evt}; m_{\rm t}, k_{\rm jes}) = f_{\rm t\bar{t}} P_{\rm t\bar{t}}(x_{\rm evt}; m_{\rm t}, k_{\rm jes}) + (1 - f_{\rm t\bar{t}}) P_{\rm bkg}(x_{\rm evt}; m_{\rm t}, k_{\rm jes})$$

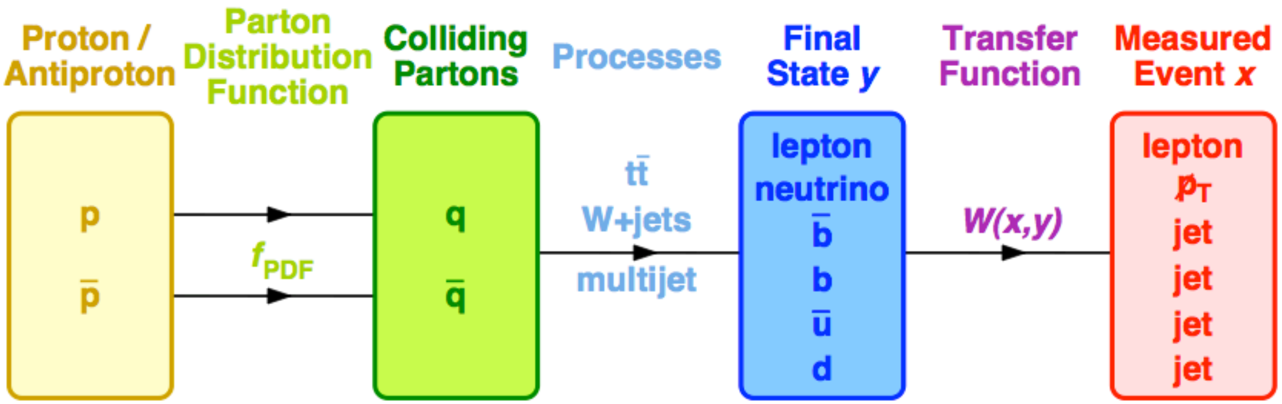
where:

$$P_{\rm t\bar{t}}(x; m_{\rm t}, k_{\rm jes}) = \frac{1}{\sigma_{\rm t}(m_{\rm t})} \int \sum_{\rm flav.} \frac{{\rm d}\sigma(y; m_{\rm t})}{{\rm d}y} f_1(q_1) f_2(q_2) W(x, y; k_{\rm jes}) {\rm d}q_1 {\rm d}q_2 {\rm d}y$$

2. Determine sample likelihood

$$\mathcal{L} = \prod_{\rm evt} P_{\rm evt}(x_{\rm evt}; m_{\rm t}, k_{\rm jes})$$

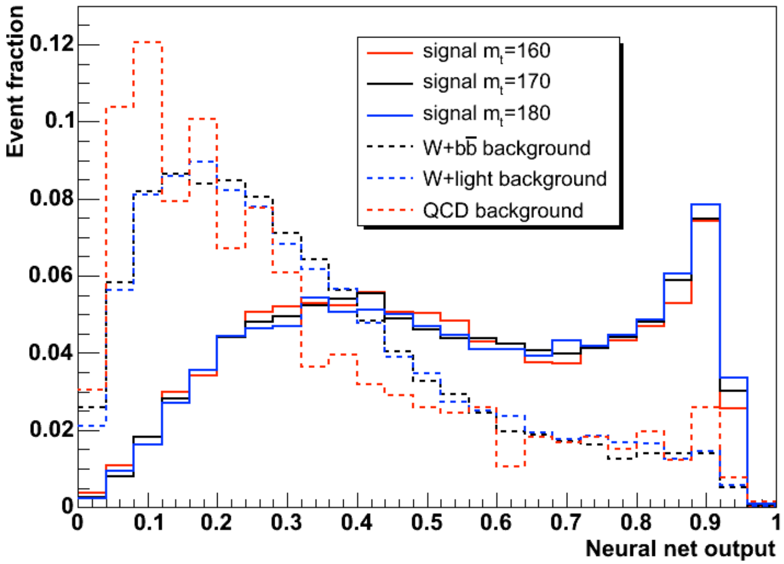
3. Fit m_t, k_{jes}

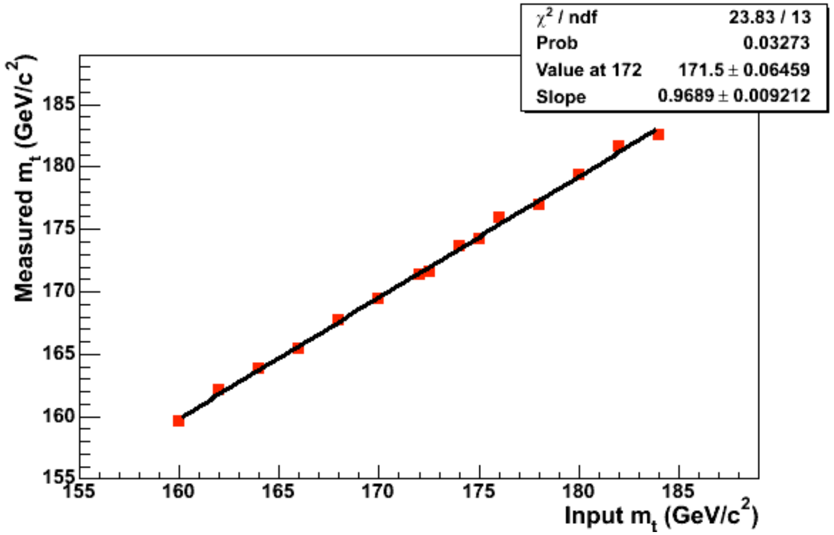


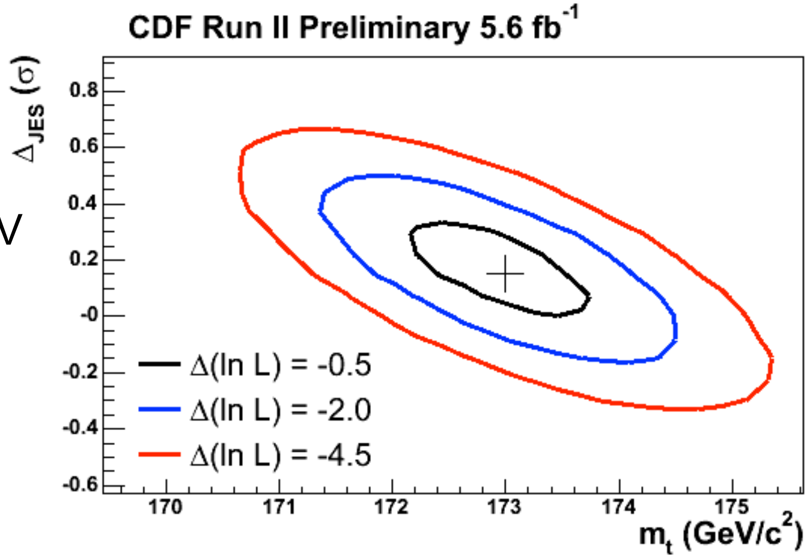
Application in CDF

CDF/PHYS/TOP/PUBLIC/10191

- Signal and background classified using a neural network discriminator







m_t = 173.0 ± 0.7 (stat.) ± 0.6 (JES) ± 0.9 (syst.) GeV
= 173.0 ± 1.2 (total) GeV

Ideogram method

- Some similarities with Matrix Element method: per-event probability, overall data sample likelihood
- Top mass per event extracted from a kinematic constrained fit
- Resolution and m_t shape included in the model
- Probability of wrong assignment taken into account

probability that a solution has the correct jet-parton assignment

wrong jet-parton assignment

$$P_{t\bar{t}}(x_{\mathrm{mass}}|m_t) = \sum_{i}^{24} \boxed{w_i} \left(f_{cp} \cdot \int_{m_{min}}^{m_{max}} dm' \boxed{G(m'|m_i,\sigma_i)} \boxed{BW(m'|m_t,\Gamma_t)} + (1 - f_{cp}) \boxed{WP(m_i|m_t)} \right)$$

weight of each permutation based on b-tagging information and fit χ^2

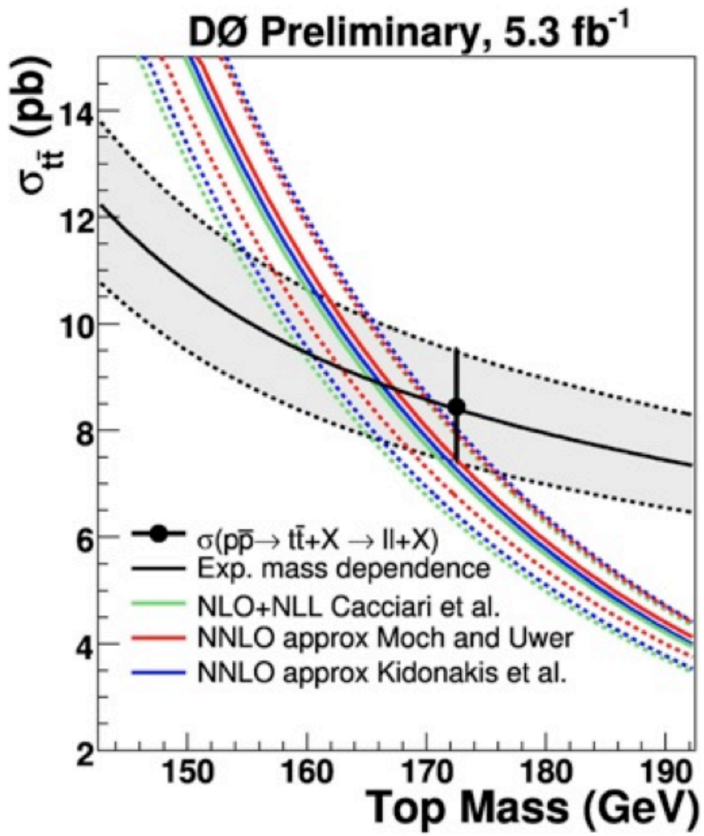
Gaussian mass resolution function

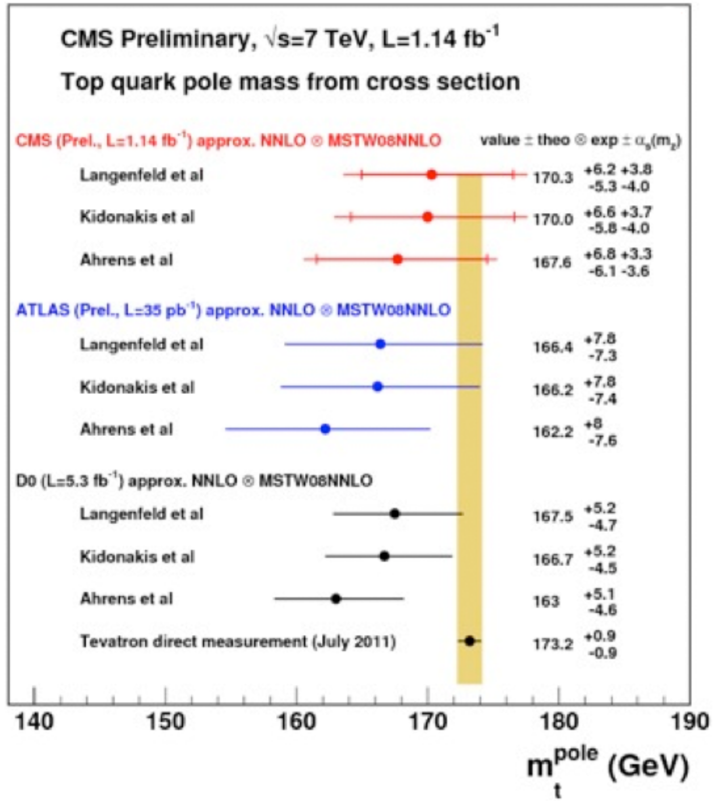
top quark Breit-Wigner lineshape

PD for wrong permutations from MC

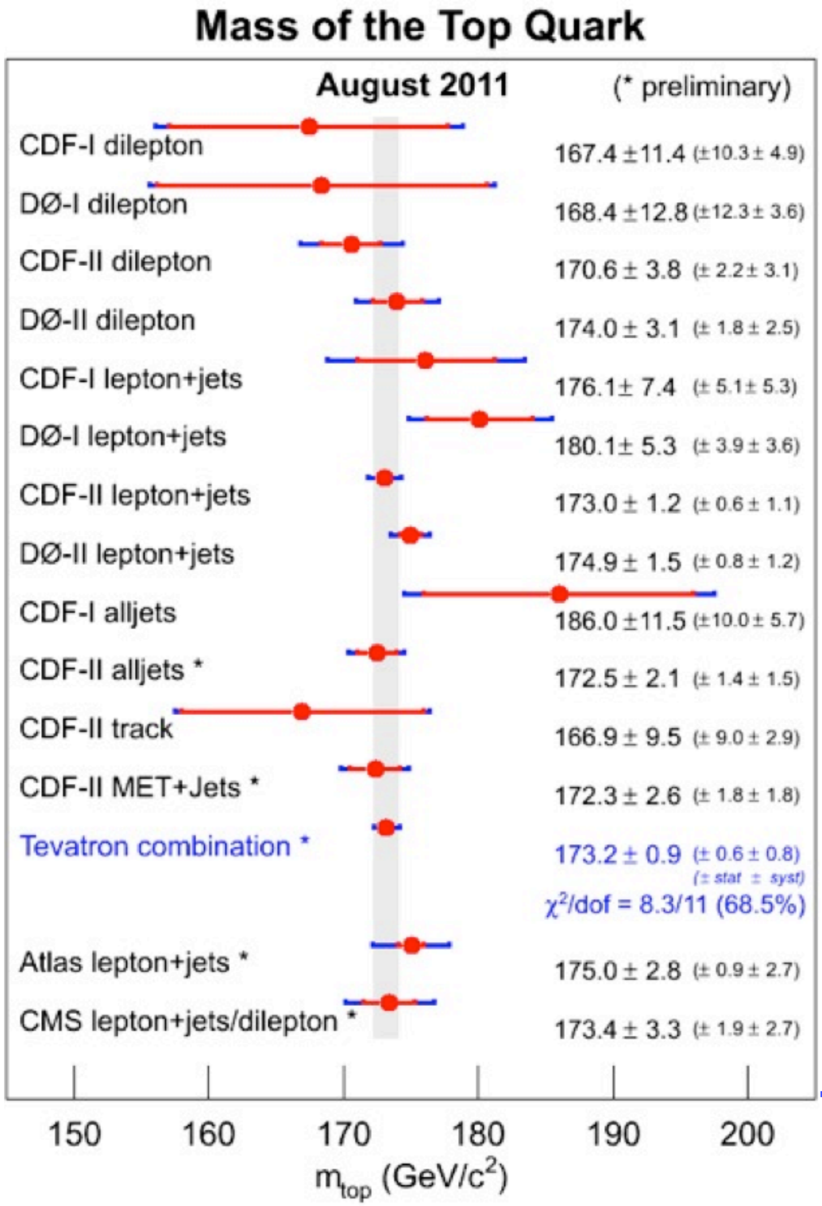
Mass from cross section

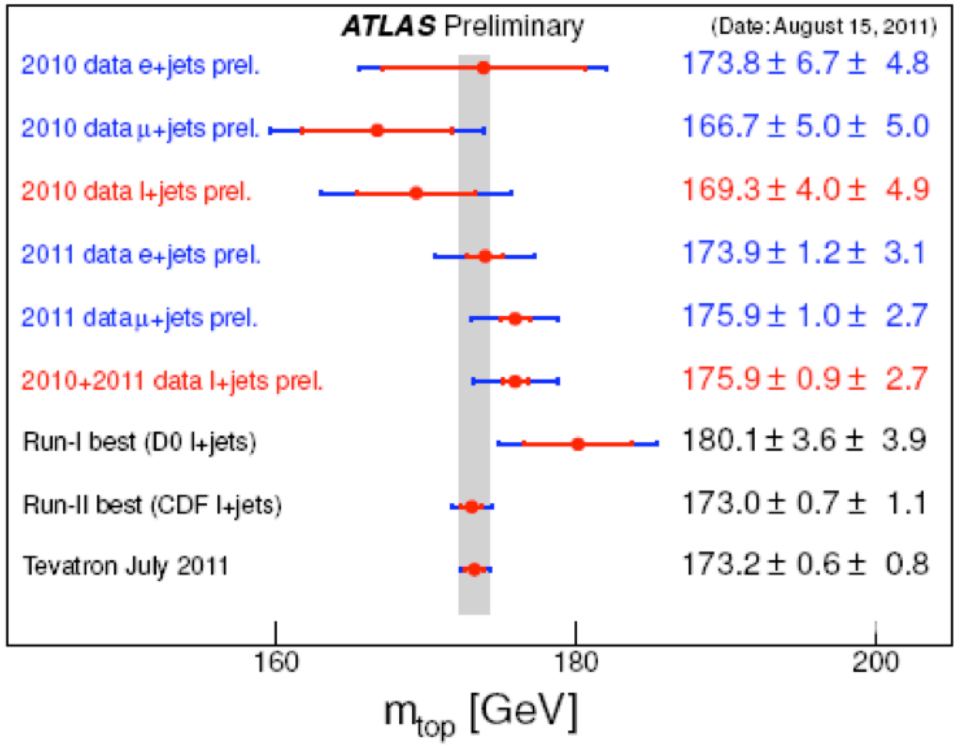
- Renormalization scheme subtlety: pole mass or $\overline{MS}$ mass…
- The smallest uncertainty in σ does not imply smallest uncertainty on m_t





Summary of m_t measurements

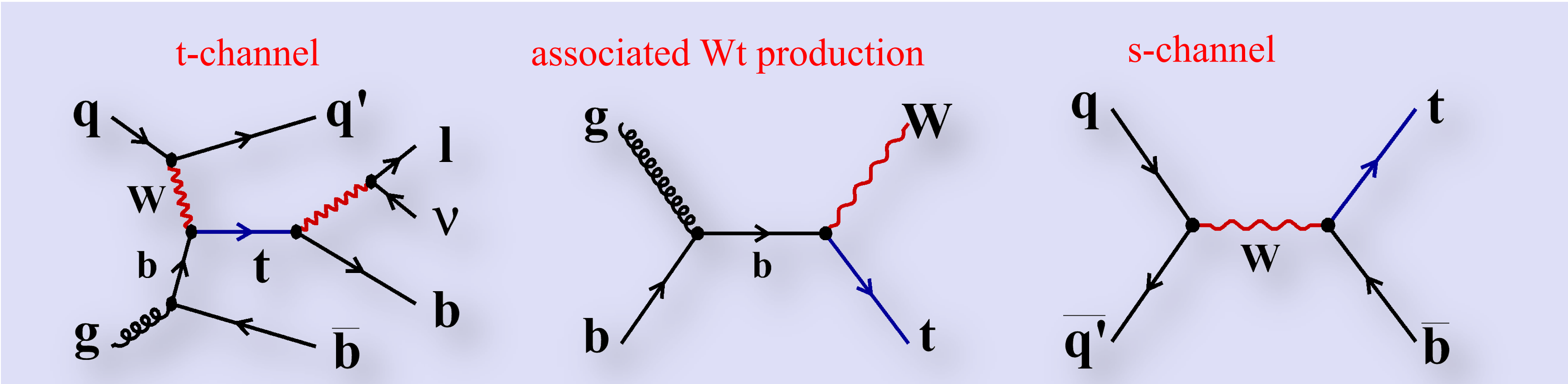




- Tevatron precision still dominates

Single top

Single top production



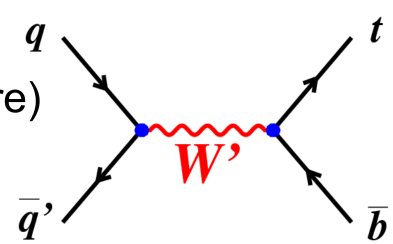
Cross sections(pb) (top mass =173)	***s-channel*** Phys. Rev. D 81, 054028 (2010), N. Kidonakis	***tW channel*** Phys. Rev. D 82, 054018 (2010), N. Kidonakis	***t channel*** Phys. Rev. D 83, 091503(R) (2011) N. Kidonakis
LHC: *pp* @7 TeV	4.59	15.6	63.2
Tevatron *pp* @1.96 TeV	1.04	0.22 (arxiv.org/pdf/0909.0037)	2.08
LHC *pp* @14 TeV	11.9	83.6	243

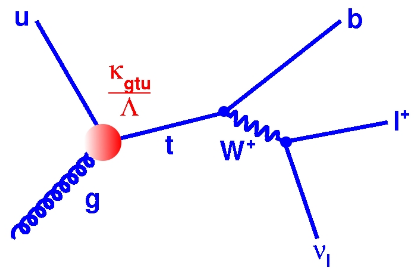
Interest in single-top

1. Test of the SM prediction.
   - Does it exist? ✔
   - Establish different channels separately
   - Cross section ∝ $|V_{tb}|^2$
     Test unitarity of the CKM matrix, .e.g.
     Hints for existence of a 4th generation ?
   - Test of b-quark PDF

$$V_{ub}^2 + V_{cb}^2 + V_{tb}^2 \stackrel{?}{=} 1$$

2. Search for non-SM phenomena
   - Search W' or H$^+$ (Wt or s-chan. signature)
   - Search for FCNC, e.g. ug → t
   - …

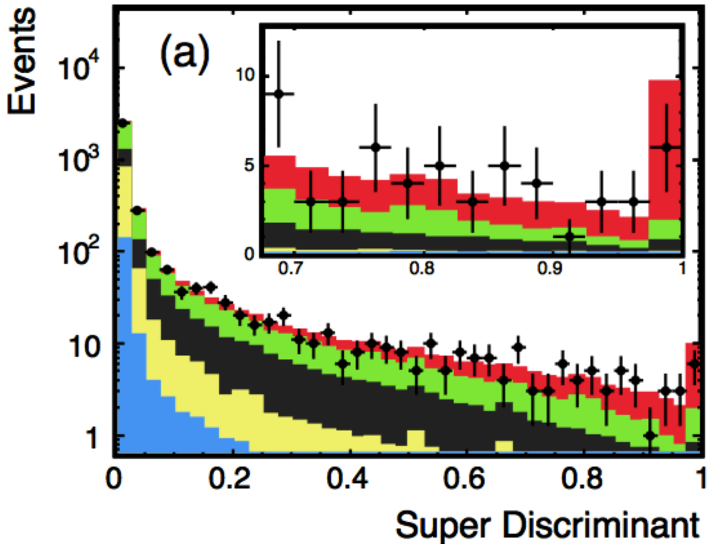




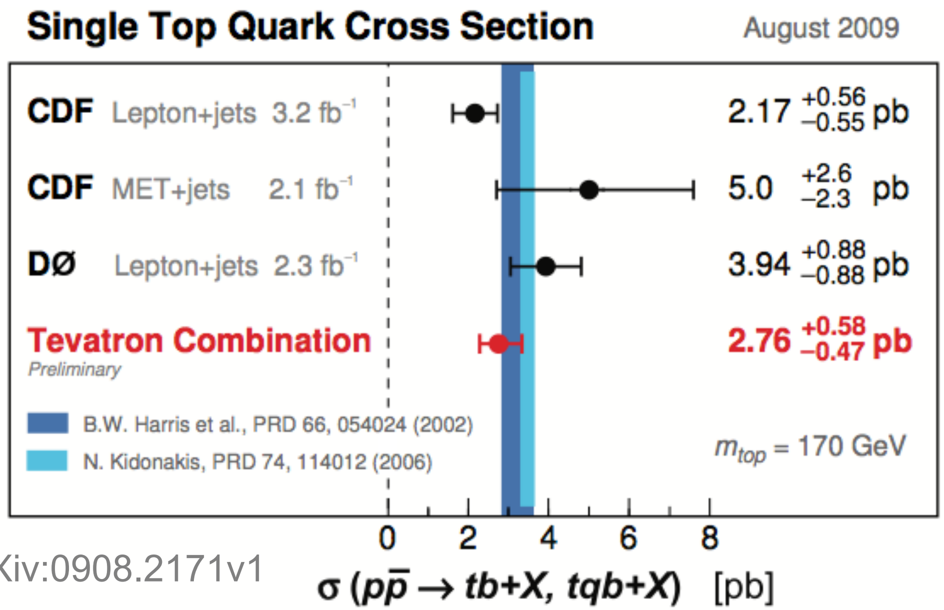
3. Single top as an experimental benchmark
   - Object identification: lepton fake rates, QCD background estimates, b-quark jet identification, …
   - Redo measurements of top properties in different environment, for example, m_t, W polarization in top decay, …

Single top at Tevatron

- Sum of s and t channel cross sections measured
- Hard to assess experimental significance, analysis heavily relying on multivariate techniques



PRL 103 092002



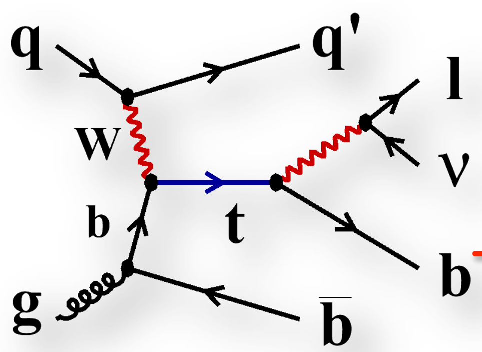
arXiv:0908.2171v1

Claim: 5.9 standard deviations significance, $|V_{tb}| = 0.91 \pm 0.11(\text{exp.}) \pm 0.07(\text{th.})$

t-channel single top at LHC

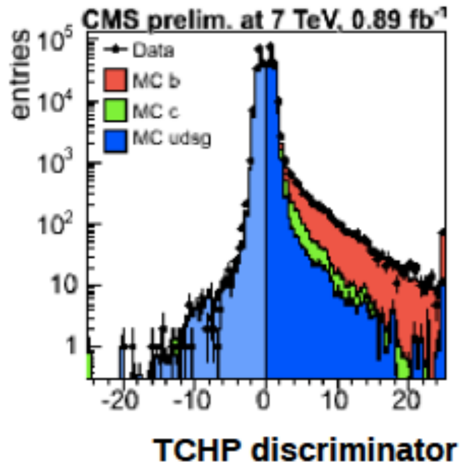
- Largest cross section of single-top processes
- Improved S/B ratio (≈10%) compared to Tevatron (≈7%)

E.g.: CMS selection



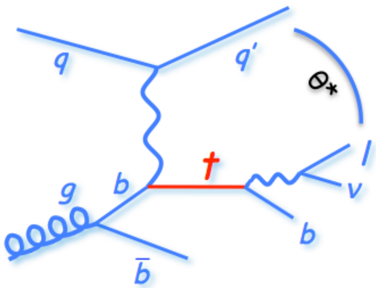
- Select only events with leptonic W decays, to suppress QCD-multijets background.
- Some acceptance due to W →τν decays.

- Data sets defined by single lepton (e / μ) or lepton + jet triggers
- Charged lepton selection (electron / muon):
  - p_T (μ) > 20 GeV, E_T(e) > 30 GeV
  - |η(e)| < 2.5, |η(μ)| < 2.1
  - Relative isolation
- Jet selection
  - 2 jets, b tagging/veto
- QCD multijet veto
  - M_T(W) > 50 GeV



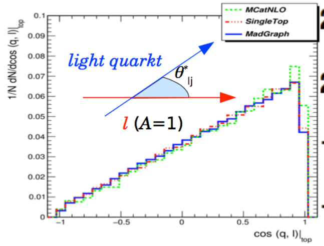
Background estimate from data

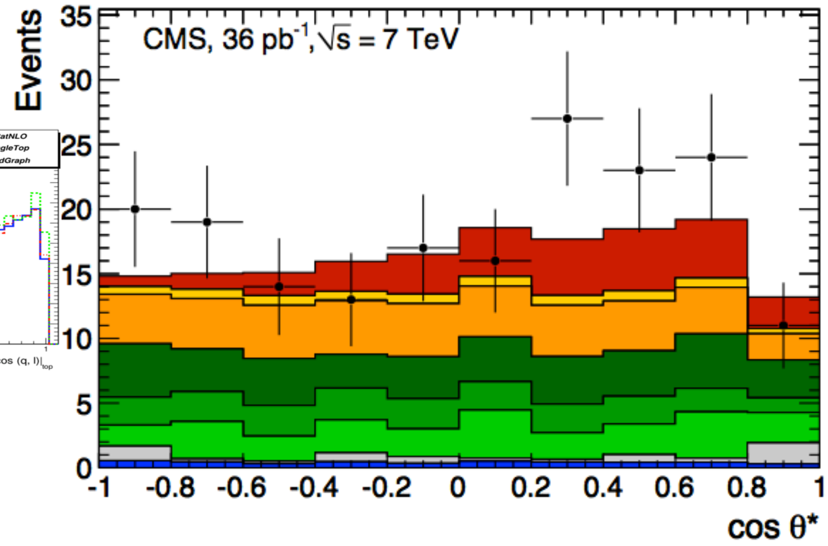
CMS: fit M_T (W)

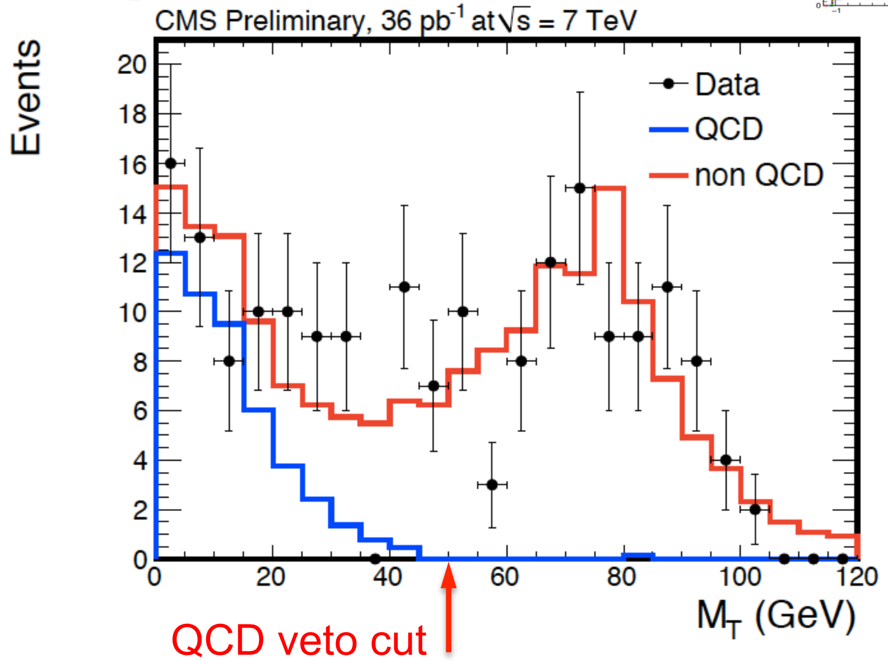


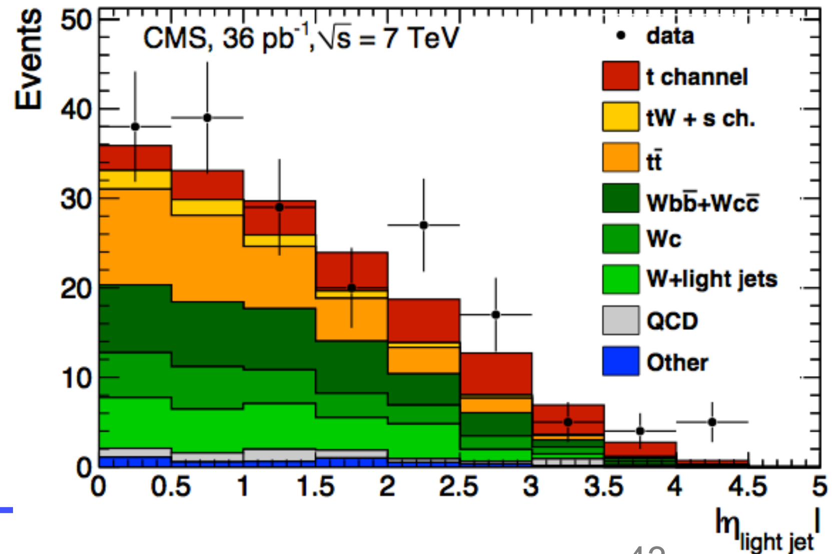
$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta^*} = \frac{1}{2}(1+\cos\theta^*)$$

100% left (right) polarization of t($\bar{t}$)







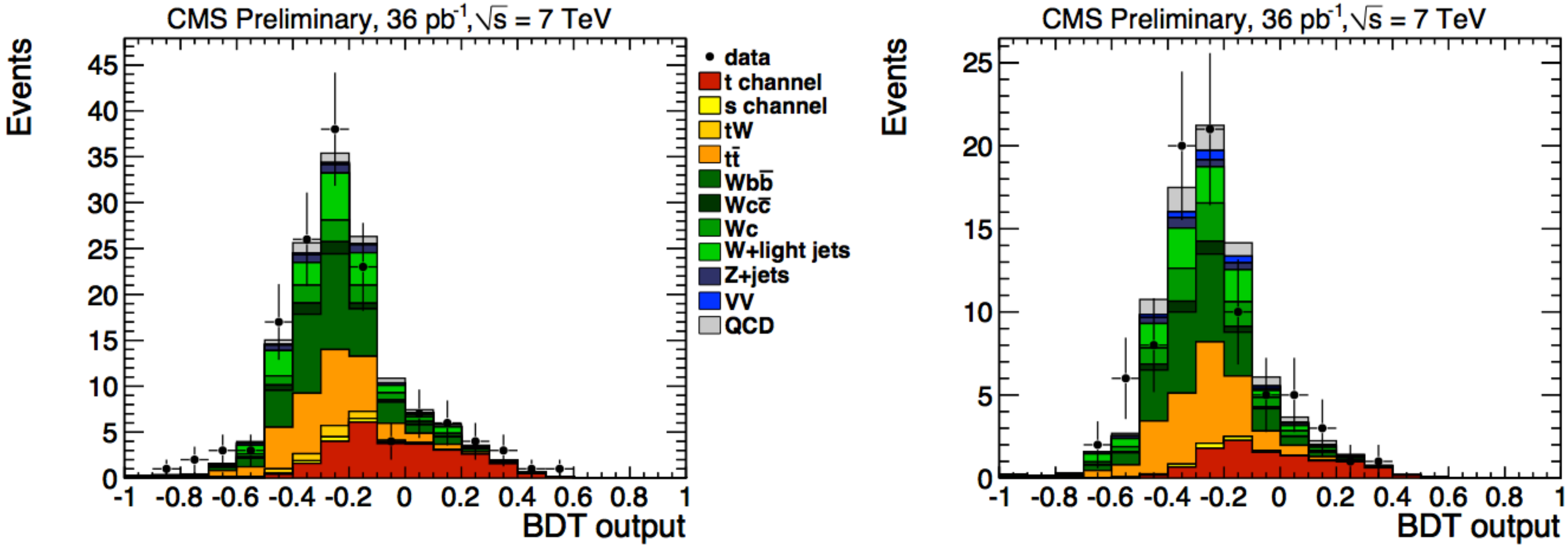


$$F(M_T) = N_{sig-like} \cdot S(M_T) + N_{qcd} \cdot B(M_T)$$

Signal extraction

Phys. Rev. Lett. 107 (2011) 091802
ATLAS-CONF-2011-101

- Complementary approaches adopted:
  - 2D maximum likelihood method ($\cos\theta^*$, $|\eta_{lq}|$)
  - Multivariate analysis (Boosted Decision Trees)



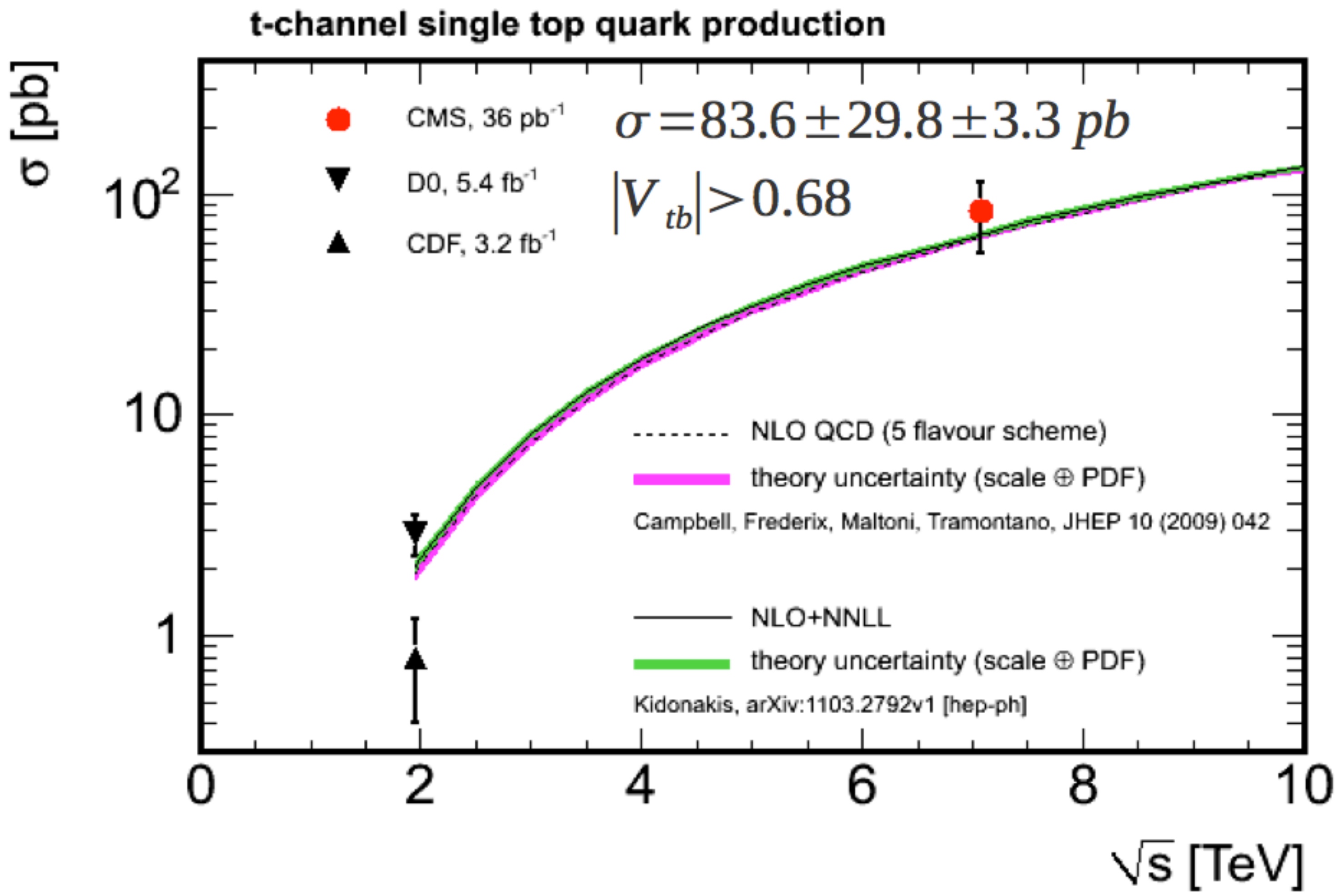
$$\sigma = 83.6 \pm 29.8(stat. + syst.) \pm 3.3(lumi.)\ \text{pb}$$

CMS (36pb^{-1})

$$|V_{tb}| = \sqrt{\frac{\sigma^{exp}}{\sigma^{th}}} = 1.16 \pm 0.22(exp) \pm 0.02(th)$$

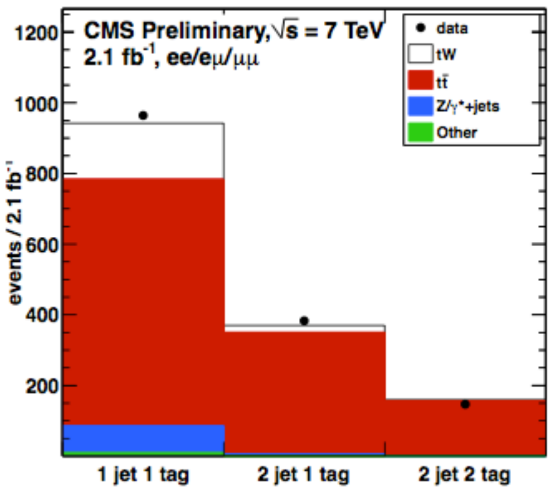
ATLAS (0.7fb^{-1}) : $\sigma_t = 90^{+32}_{-22}$ pb

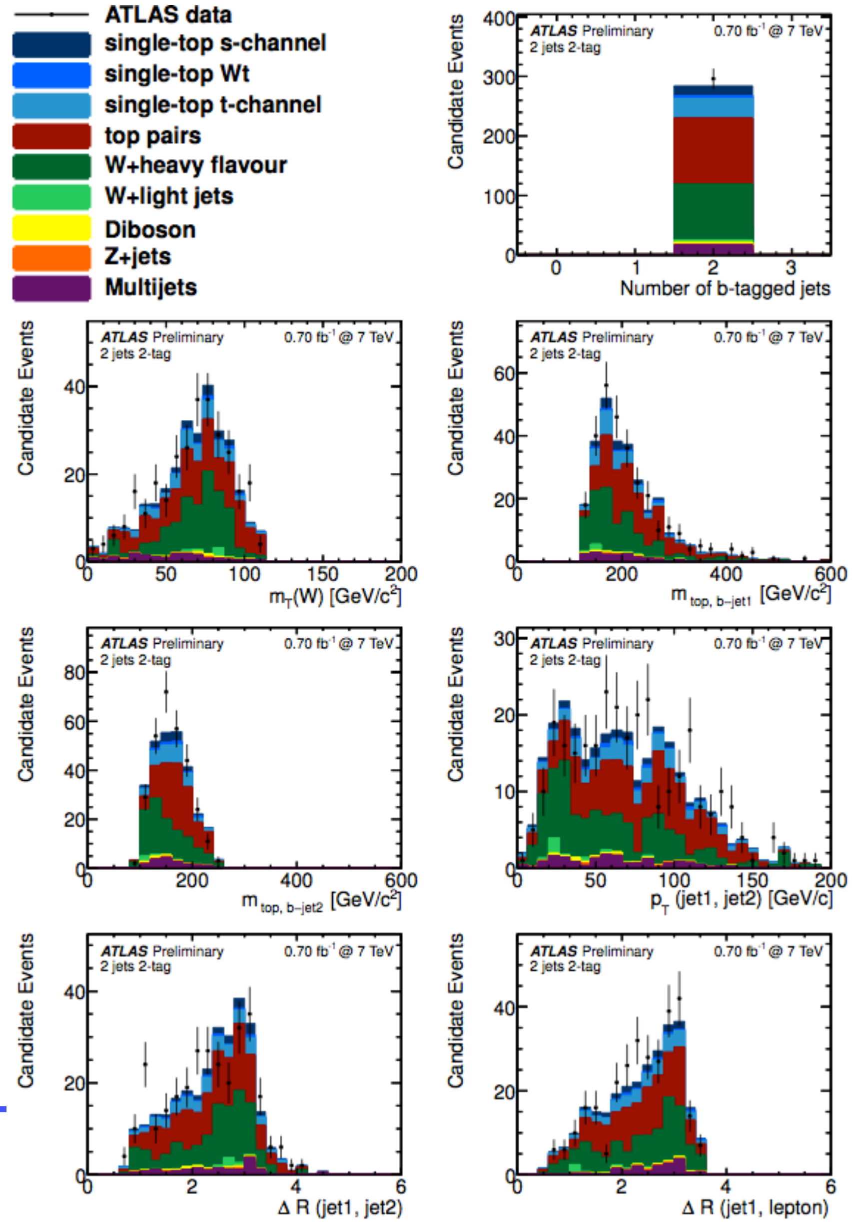
Tevatron vs LHC



More single top channels

- tW measurement by CMS (CMS PAS TOP-11-022, 2.1fb^{-1})
  - $\sigma_{tW} = 22^{+9}_{-7}$pb (2.7σ signif.)
  - SM: σ_{tW} = 15.6pb
- s-channel: limit presented by ATLAS (ATLAS-CONF-2011-027, 35pb^{-1}, cut-based):
  - $\sigma_{s\text{-ch.}}$ < 26.5pb (95% CL)
  - But in SM $\sigma_{s\text{-ch.}}$ = 4.6pb!

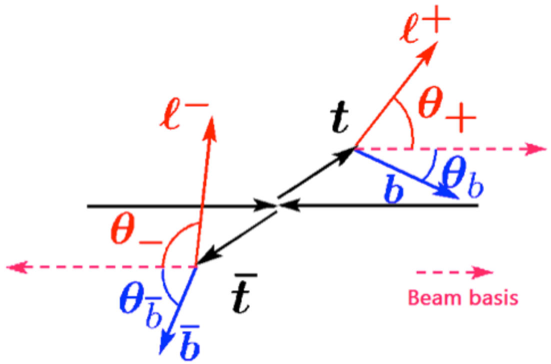




More top properties

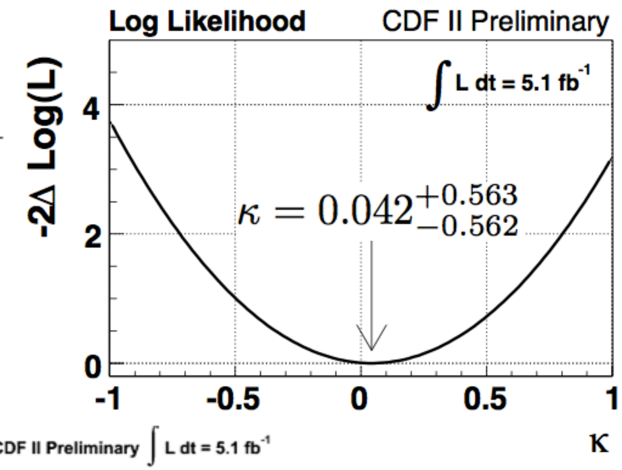
Spin correlation at CDF

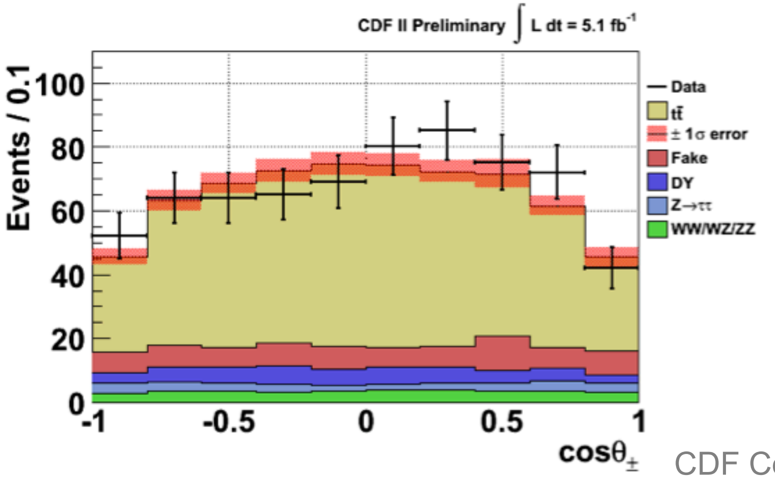
- top and anti-top are produced with their spins correlated and decay as bare quarks before losing their spin polarizations

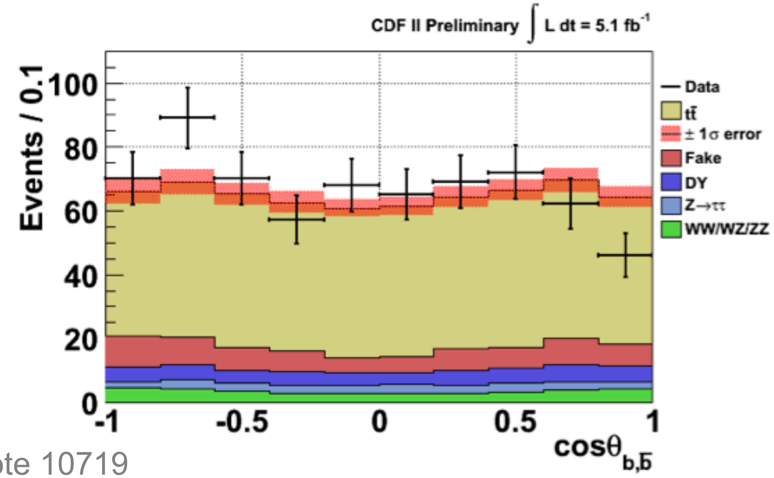


$$\frac{1}{\sigma}\frac{d^2\sigma}{d\cos\theta_+ d\cos\theta_-} = \frac{1+\kappa\cos\theta_+\cos\theta_-}{4}$$

SM prediction: κ ~ 0.8
No conclusive result (κ = 0?)





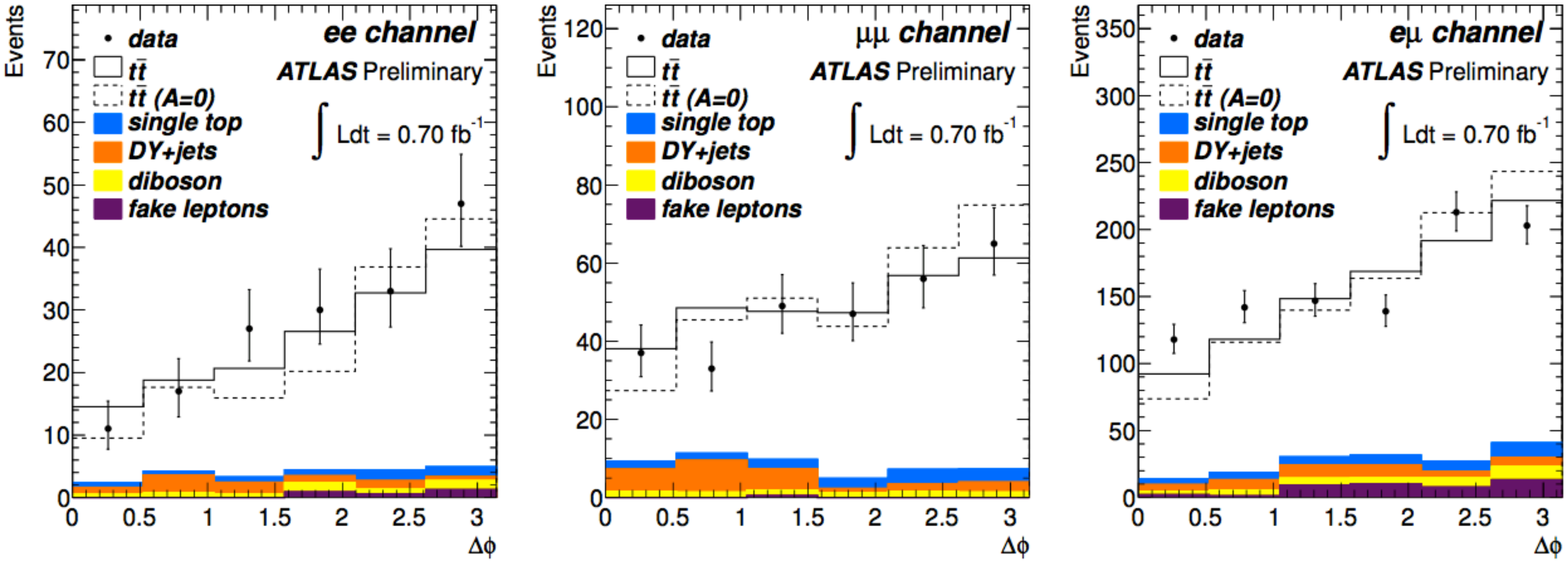


CDF Conf. Note 10719

Top pair spin correlation

- Top pairs produced mainly via gluon fusion (LHC) or quark-antiquark annihilation (Tevatron)
- V-A structure of top decay

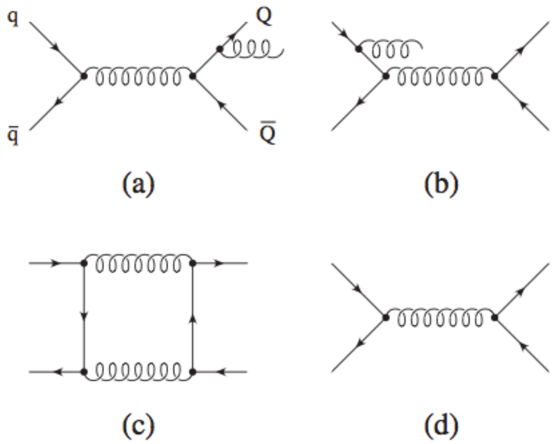
$$A = \frac{N_{like} - N_{unlike}}{N_{like} + N_{unlike}} = \frac{N(\uparrow\uparrow) + N(\downarrow\downarrow) - N(\uparrow\downarrow) - N(\downarrow\uparrow)}{N(\uparrow\uparrow) + N(\downarrow\downarrow) + N(\uparrow\downarrow) + N(\downarrow\uparrow)}$$



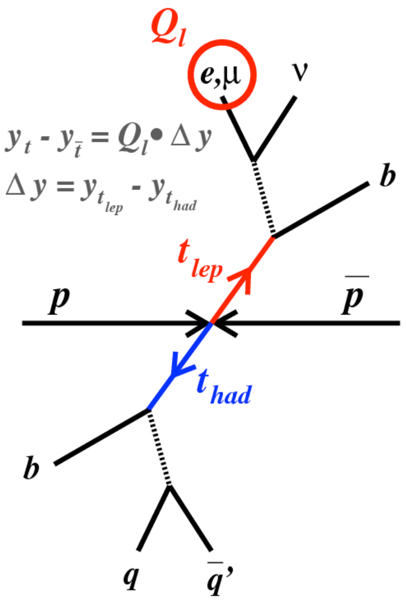
ATLAS-CONF-2011-117

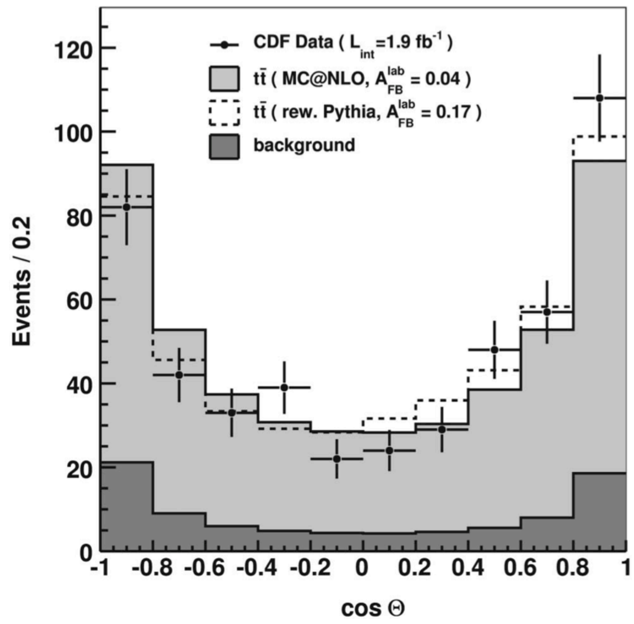
$f_{SM} = A/A_{SM} = 1.06 \pm 0.21(\text{stat.})^{+40}_{-27}(\text{syst.})$

Charge asymmetry

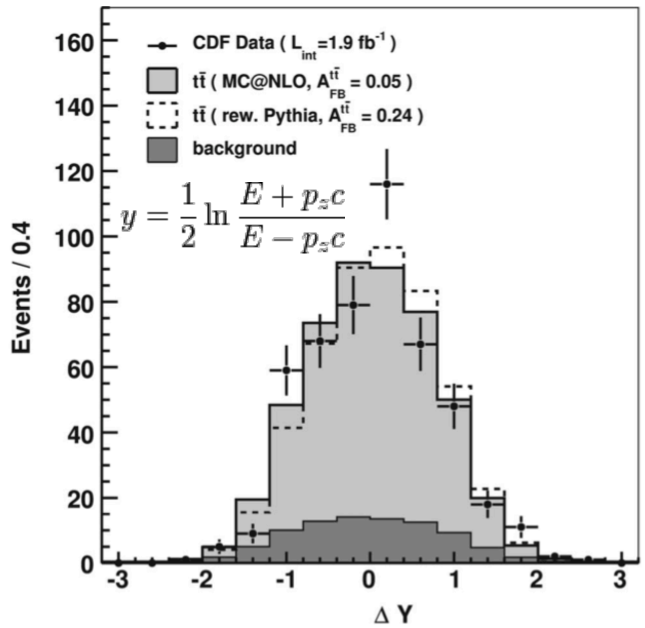


- Small FB asymmetry predicted by theory
- Could be larger with new particles
- Note: different initial state in Tevatron and LHC!





$$A_{\mathrm{FB}}^{p\bar{p}} = \frac{N(\cos\theta > 0) - N(\cos\theta < 0)}{N(\cos\theta > 0) + N(\cos\theta < 0)}$$



$$A_{\mathrm{FB}}^{t\bar{t}} = \frac{N(\Delta Y > 0) - N(\Delta Y < 0)}{N(\Delta Y > 0) + N(\Delta Y < 0)}$$

A_{FB} = 0.24 ± 0.13 (stat.) ± 0.04 (syst.); A_{FB}(theo)=0.050± 0.015

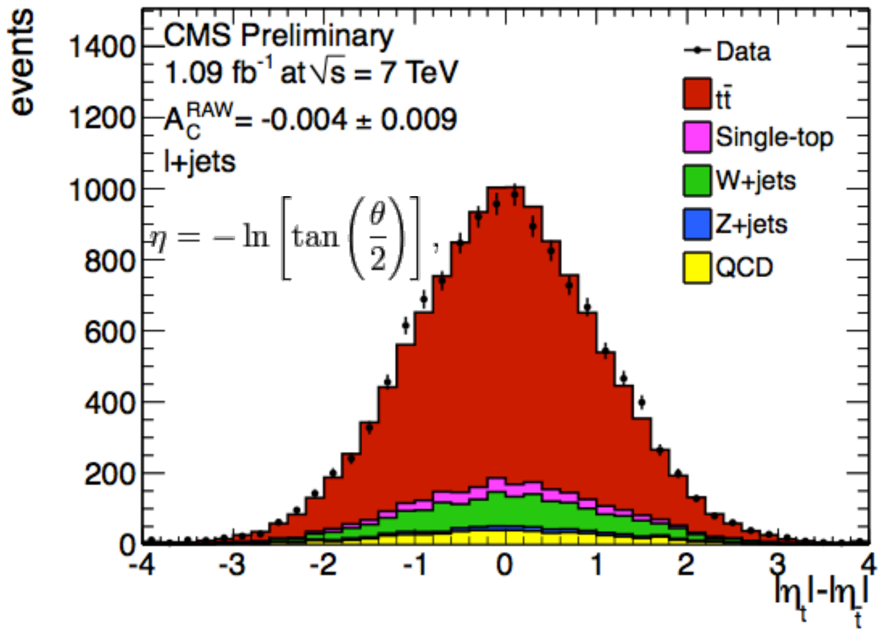
PRL 101 202001

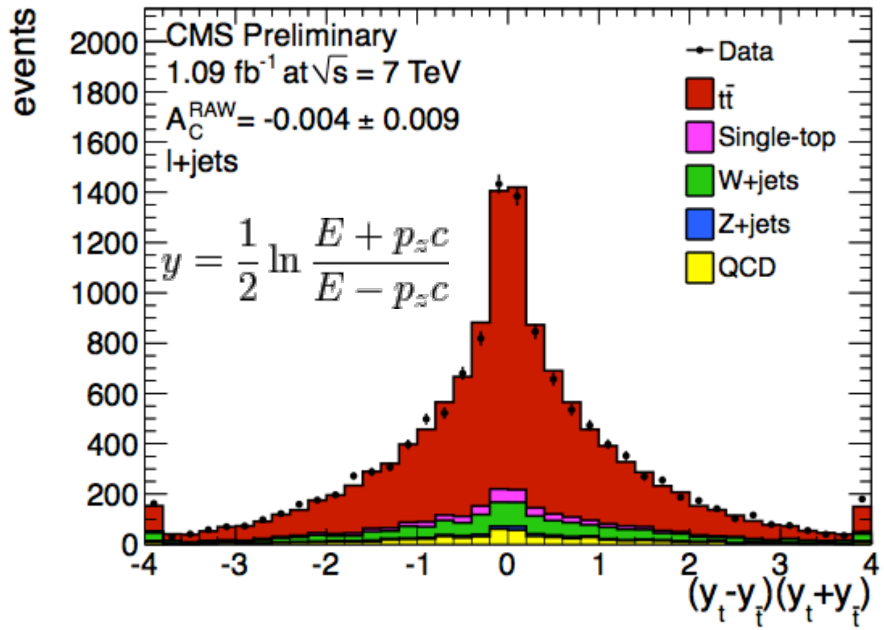
Charge asymmetry at LHC

CMS PAS TOP-11-014

- LHC has a symmetric initial state
- Charge asymmetry measured at Tevatron turns into an angular asymmetry

$$A_C = \frac{N^+ - N^-}{N^+ + N^-}$$





$$A_C^{\eta} = -0.016 \pm 0.030\ (\text{stat.})^{+0.010}_{-0.019}(\text{syst.})$$

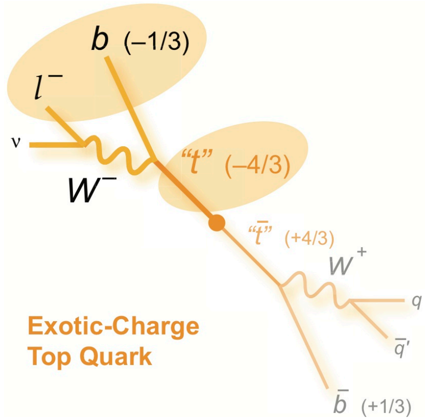
$$A_C^{\eta}(theo.) = 0.013 \pm 0.001$$

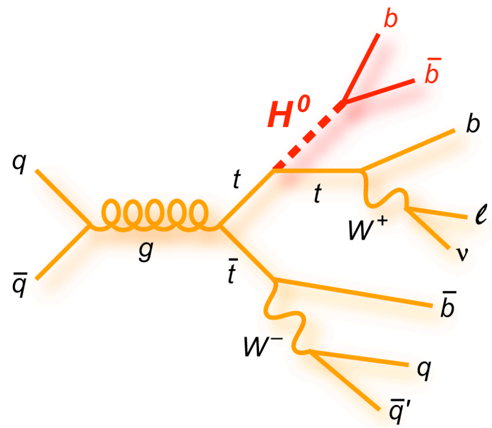
$$A_C^{y} = -0.013 \pm 0.026\ (\text{stat.})^{+0.026}_{-0.021}(\text{syst.})$$

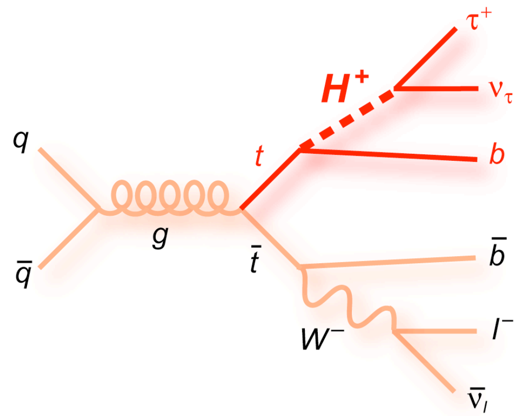
$$A_C^{y}(theo.) = 0.011 \pm 0.001$$

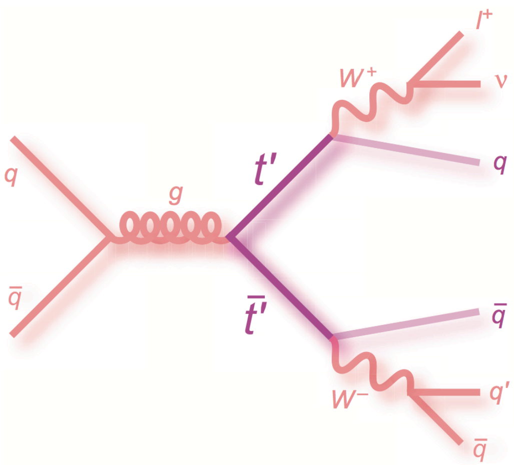
New physics in top processes

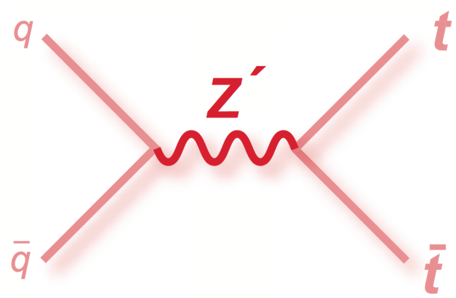
- Top processes are suitable to study exotic physics

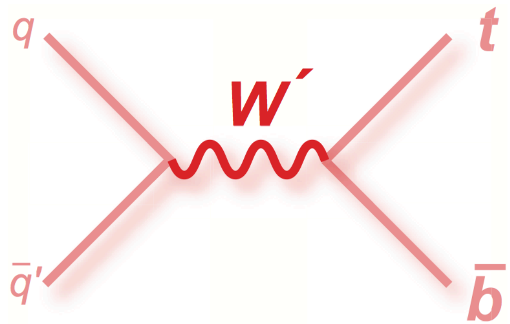






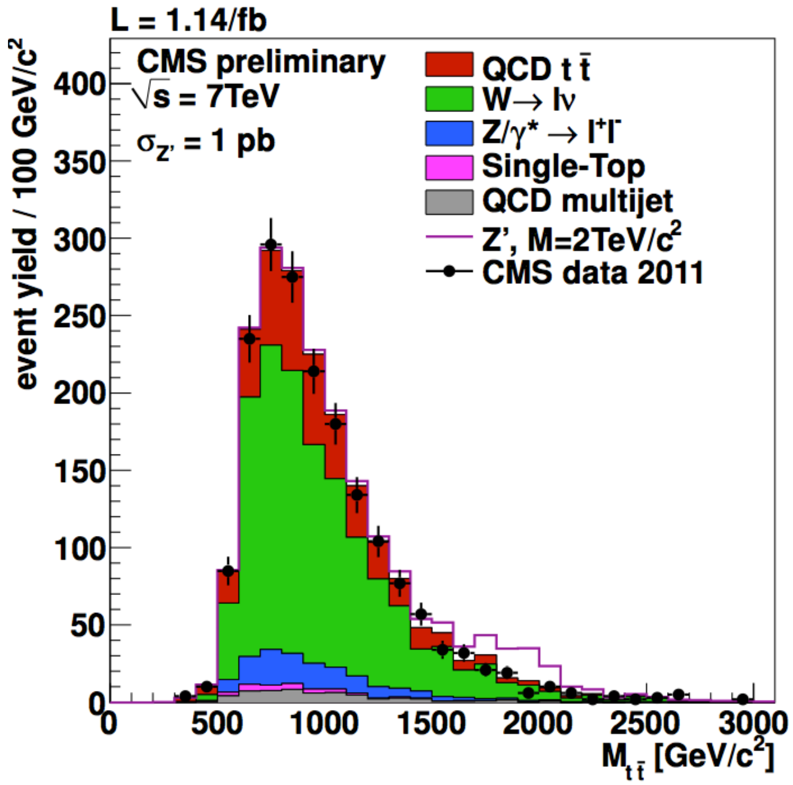


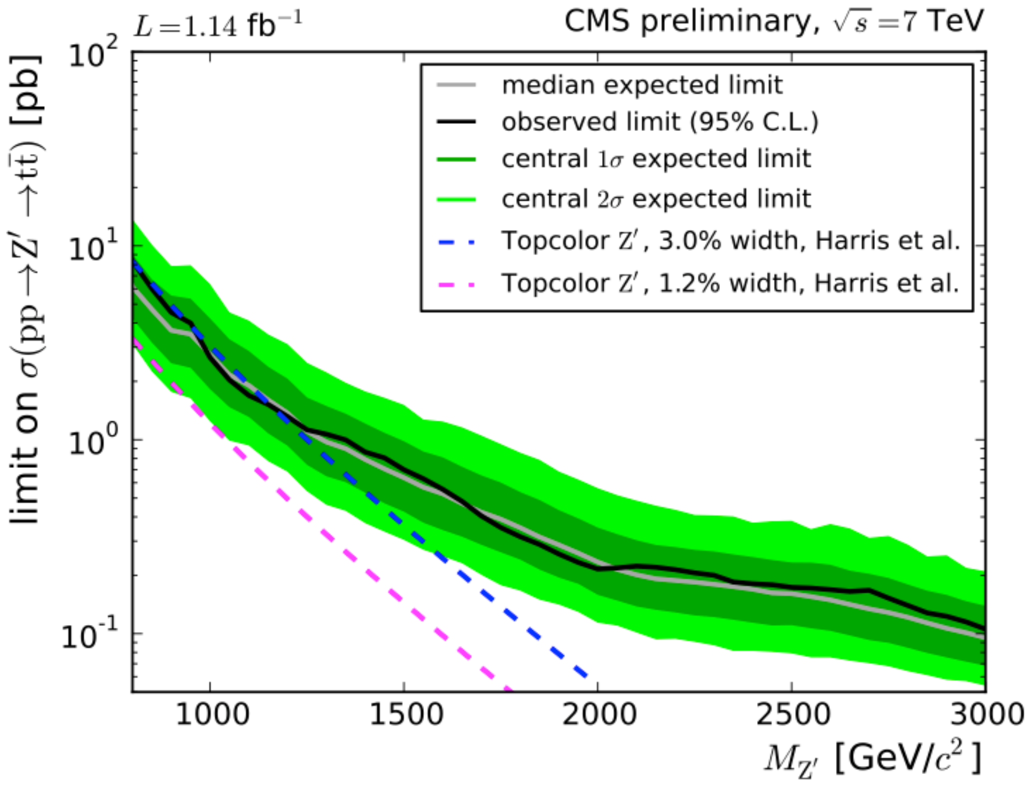




Search for tt resonances

- CMS measured the tt^{bar} invariant mass spectrum in (μvb)(qqb) decays

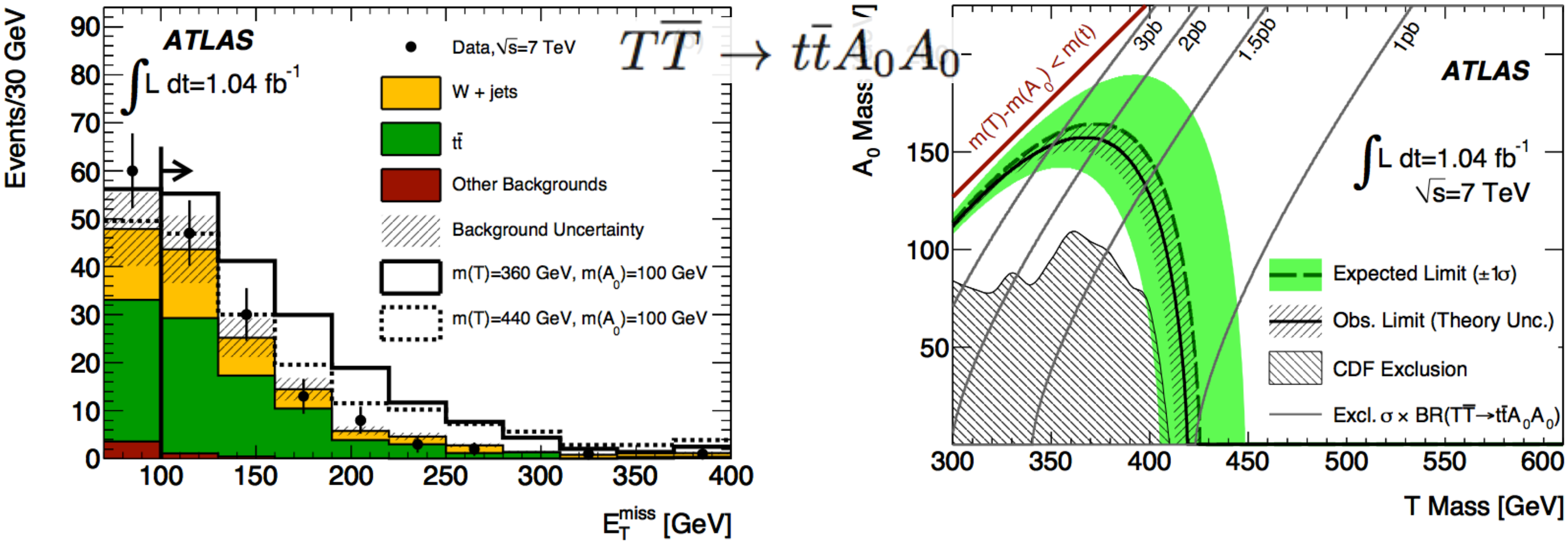




CMS PAS EXO-11-055

Search for new particles

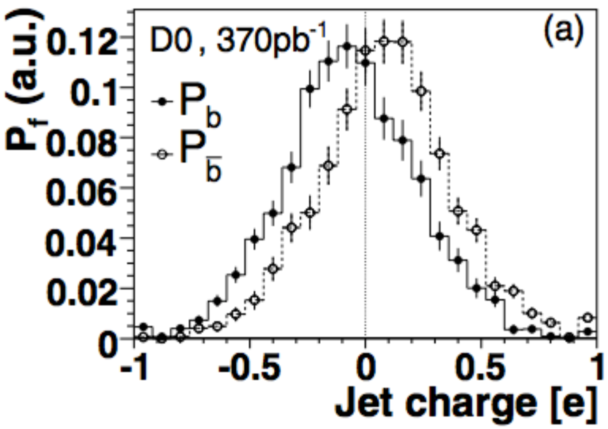
- ATLAS:
  - Search for New Phenomena in ttbar Events with Large Missing Transverse Momentum in Proton-Proton Collisions at sqrt(s) = 7 TeV with the ATLAS Detector

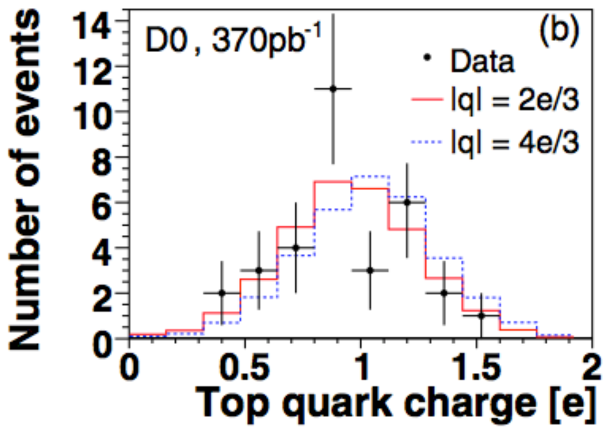


arXiv:1109.4725

Top quark charge

- Some models predict an exotic $-^{4}/_{3}$ particle, the true SM top (q= $+^{2}/_{3}$) quark being heavier and undetected
- b flavour has to be identified (b or bbar), Jet charge or lepton tag

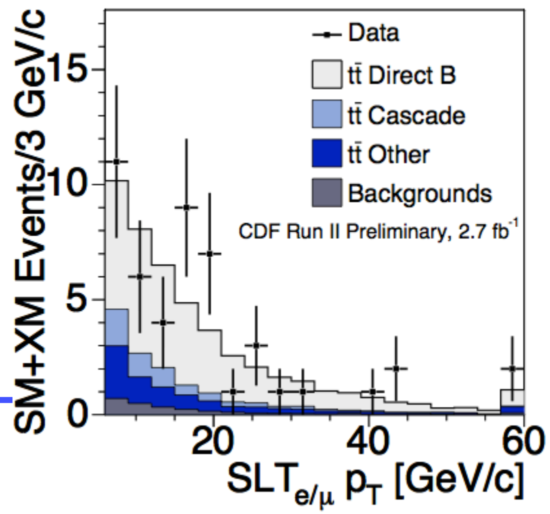


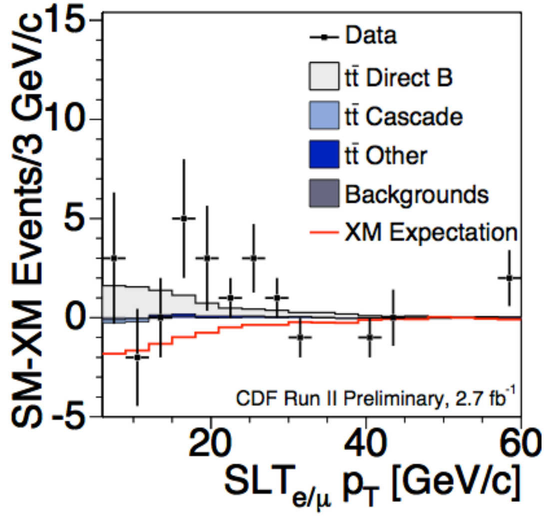


$$Q_1 = |q_\ell + q_{b_\ell}|$$
$$Q_2 = |-q_\ell + q_{b_h}|$$
$$q_{\text{jet}} = (\textstyle\sum_i q_i p_{T_i}^{0.6})/(\sum_i p_{T_i}^{0.6})$$
$$p_T > 0.5 \text{ GeV}$$

Phys. Rev. Lett. 98, 041801 (2007), Conf. Note 9939, …

Experimental data disfavor exotic $-^{4}/_{3}$ quark





References

- S. Willenbrock, the Standard Model and the top quark, hep-ph/0211067
- A. Quadt, Top quark Physics at hadron colliders, Eur. Phys. J. C 48 (2006) 835-1000
- F. Deliot, D. Glenzinski, Top Quark Physics at the Tevatron, arXiv:1010.1202