Yale University

Top Physics and W Mass Prospects at LHC in 2011/2012

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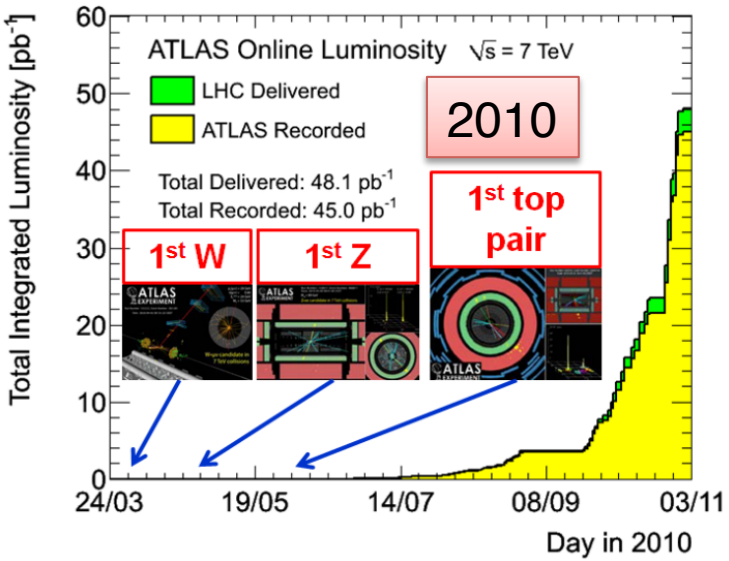
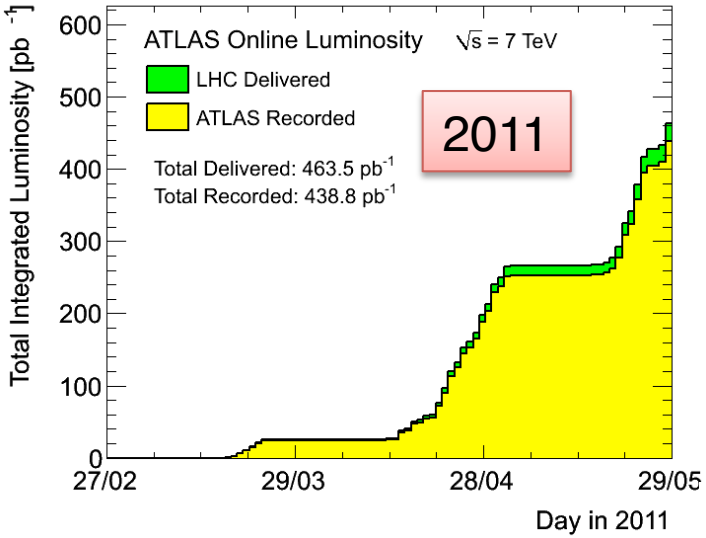
Disclaimer

- Supposed to be a talk on “prospects”
- However, most prospects are done on 10 TeV or 14 TeV and are therefore obsolete for 2011/2012 data
- I will give an overview over the status of top physics and the W mass measurement and I will try to extrapolate using MC studies

ATLAS Data Taking (Similar for CMS)

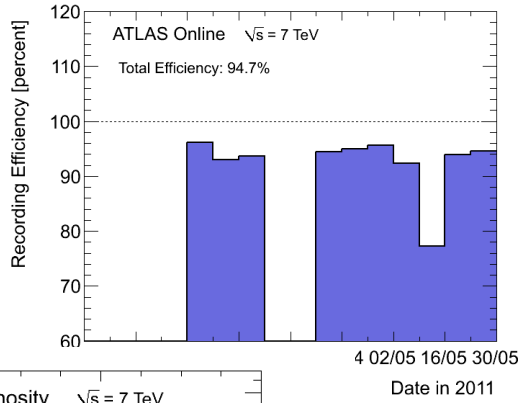




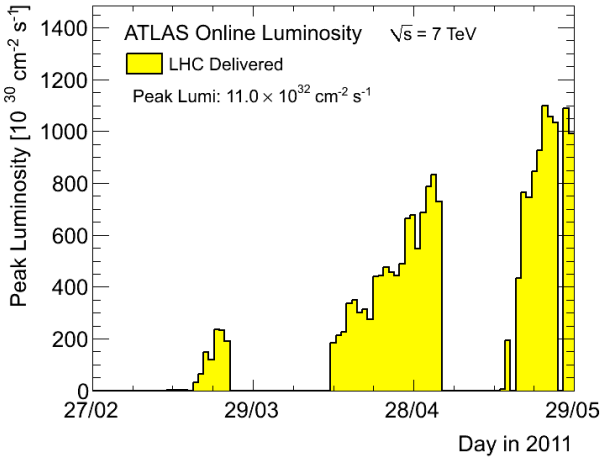
Total as of this morning: 512 pb^{-1}

Inner Tracking Detectors			Calorimeters				Muon Detectors				Magnets	
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
99.5	99.4	100	87.5	92.4	94.5	100	100	99.0	99.9	99.8	96.8	95.1

Luminosity weighted relative detector uptime and good quality data delivery during 2011 stable beams in pp collisions at √s=7 TeV between March 13th and May 3rd (in %). The inefficiencies in the LAr calorimeter will partially be recovered in the future. The magnets were operational for a 3-day period at the start of the data taking.



- New record: 1.26 10^{33} cm^{-2}s^{-1} (yesterday)
- 20-40 pb^{-1} per day (43 pb^{-1} yesterday)
- 1042 bunches colliding in machine (yesterday)
- Stored energy: close to 100 MJ
- Luminosity uncertainty: 3.4% (2010), 4.5% (2011)



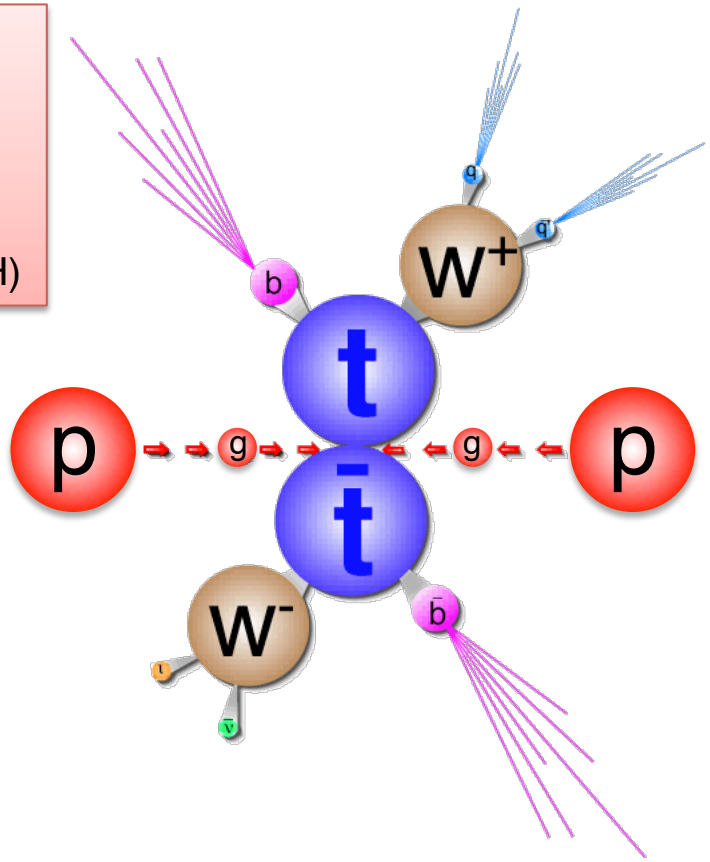
Top Physics at the LHC

Production
- cross section
- kinematics
- resonant production
- production mechanism (gg, qq)
- new particles (Z', W', t', stop, LH)

Boosted top quarks

ttbar system
- spin correlation
- charge asymmetry
- CPT

Detector calibration
- jet energy scale
- b- and c-tagging efficiency



Top quark decay
- anomalous couplings
- rare decays, FCNC
- branching ratios
- CKM $|V_{tb}|$ and $|V_{ts}|$
- new particles (e.g. H^+)

Top mass, width, charge, coupling (ttbar+γ), lifetime

W helicity

EW single top quark production

All accessible in 2011/2012

Top Quark Results – ATLAS and CMS

- 280 nb^{-1}
  - First event display (ATLAS-CONF-2010-063)
  - Background distributions (ATLAS-CONF-2010-087)
- 3 pb^{-1}
  - Top quark pair cross section (arXiv:1012.1792)
- Production cross section (35 pb^{-1})
  - Single lepton pre-tag (ATLAS-CONF-2011-023)
  - Single lepton b-tag (ATLAS-CONF-2011-035)
  - Dilepton(ATLAS-CONF-2011-034)
  - Combination (ATLAS-CONF-2011-040)
  - All-hadronic (ATLAS-CONF-2011-066)
  - Single top (ATLAS-CONF-2011-027)
- Properties (35 pb^{-1})
  - Mass (ATLAS-CONF-2011-033)
  - Mass from cross section (ATLAS-CONF-2011-054)
  - W helicity (ATLAS-CONF-2011-037)
- Search for new physics (35 pb^{-1})
  - tt + anomalous MET (ATLAS-CONF-2011-036)
  - tt resonances (ATLAS-CONF-2011-070)
  - FCNC (ATLAS-CONF-2011-061)

- 78 nb^{-1}
  - First event display (CMS-PAS-TOP-10-004)
- 3 pb^{-1}
  - Top quark pair cross section (arXiv:1010.5994)
- Production cross section (35 pb^{-1})
  - Combination (CMS-PAS-TOP-11-001)
  - Single top (CMS-PAS-TOP-10-008)
- Properties (35 pb^{-1})
  - Mass (CMS-PAS-TOP-10-006)
  - Charge asymmetry (CMS-PAS-TOP-10-010)
- Search for new physics (35 pb^{-1})
  - tt resonances (CMS-PAS-TOP-10-007)
  - Charged Higgs (CMS-PAS-HIG-11-002)

Will show example results with full 2010 data set (~35 pb^{-1}) from ATLAS or CMS typically performance is comparable

http://cds.cern.ch/

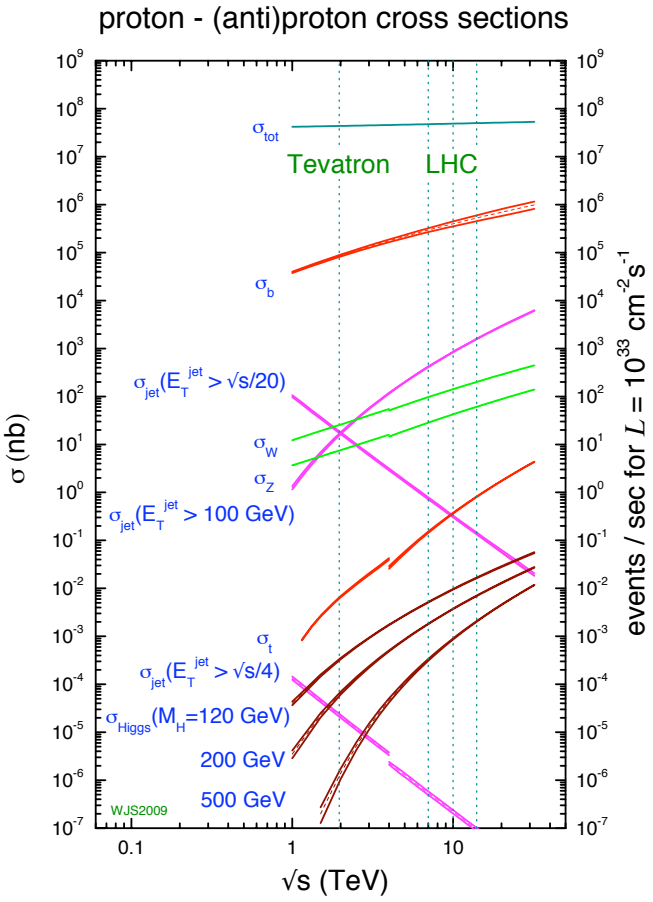
Top Prospects – ATLAS and CMS

- Top potential for 2011/2012 (ATL-PHYS-PUB-2011-004)
- Top mass (ATL-PHYS-PUB-2010-004)
- tt resonances (ATL-PHYS-PUB-2010-008)
- Single top (ATL-PHYS-PUB-2010-003)
- Single top (ATL-PHYS-PUB-2009-001)
- arXiv:0901.0512v4 (Expected Performance)

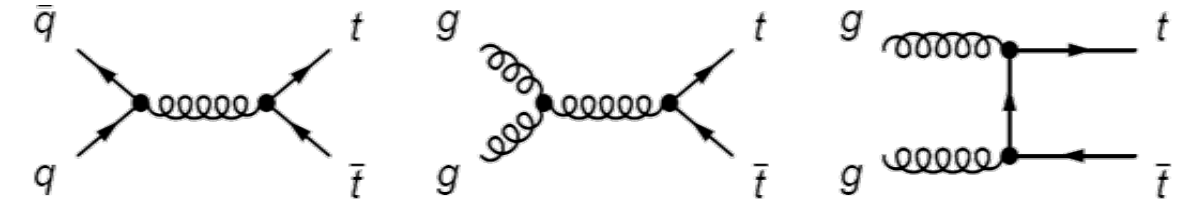
- JES using tt (CMS-PAS-TOP-07-004)
- R and efficiency in tt (CMS-PAS-TOP-09-001)
- R in tt (CMS-PAS-TOP-09-007)
- tt resonances (CMS-PAS-TOP-09-009)
- Single top (CMS-PAS-TOP-09-005)

http://cds.cern.ch/

The LHC is a Top Factory (already now)



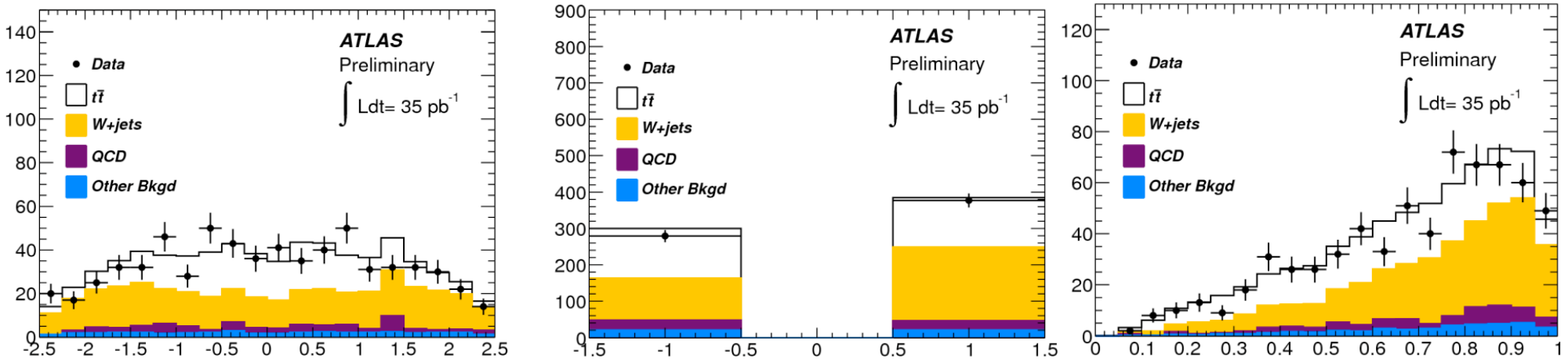
- $\sigma_{ttbar}^{NNLO}(\sqrt{s}=7\ TeV) \sim 165\ pb = 20\ \sigma_{ttbar}\ (Tevatron)$
- 3 fb^{-1} @ 7 Tev (expected by end of 2011)
  - 500 k ttbar produced (~6 times the Tevatron statistics)
  - 30 k selected b-tagged lepton+jets events (e and μ)
  - 7 k selected dilepton events (e and μ)



Dominant at Tevatron Dominant at LHC

σ_{tt} Single Lepton (no b-tagging)

- Likelihood based on three uncorrelated discriminating variables



- Binned maximum likelihood to 4 channels (3-jets,≥4-jets; e,μ)

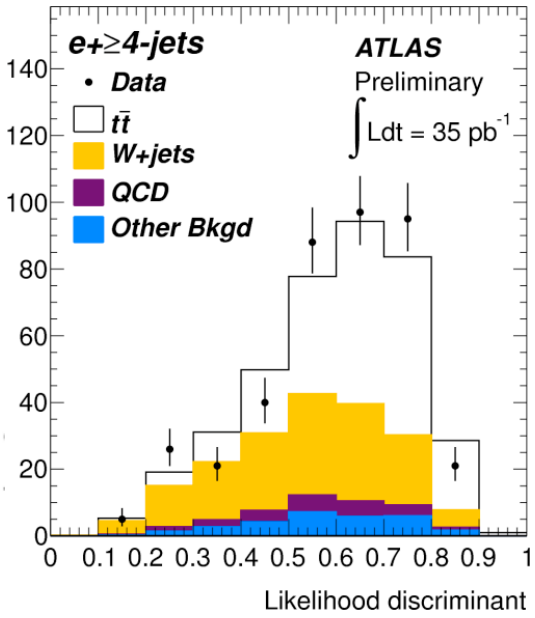
Syst. source	Rel. unc. %
Jet en. scale & Reconstruction	-6.1 / +5.7
ISR/FSR	-2.1 / +6.1
QCD norm.	3.9
QCD shape	3.4
Parton shower & hadronisation	3.3
Total syst.	**-10.2 / +11.6**

Independent of b-tagging

Avoids related b-tagging systematics at the price of a worse S/B

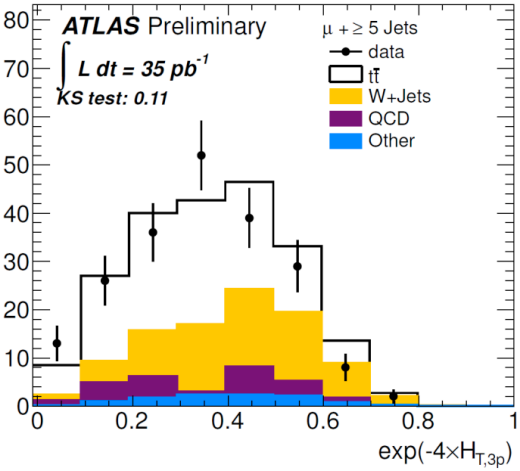
Relative uncertainty ~15%

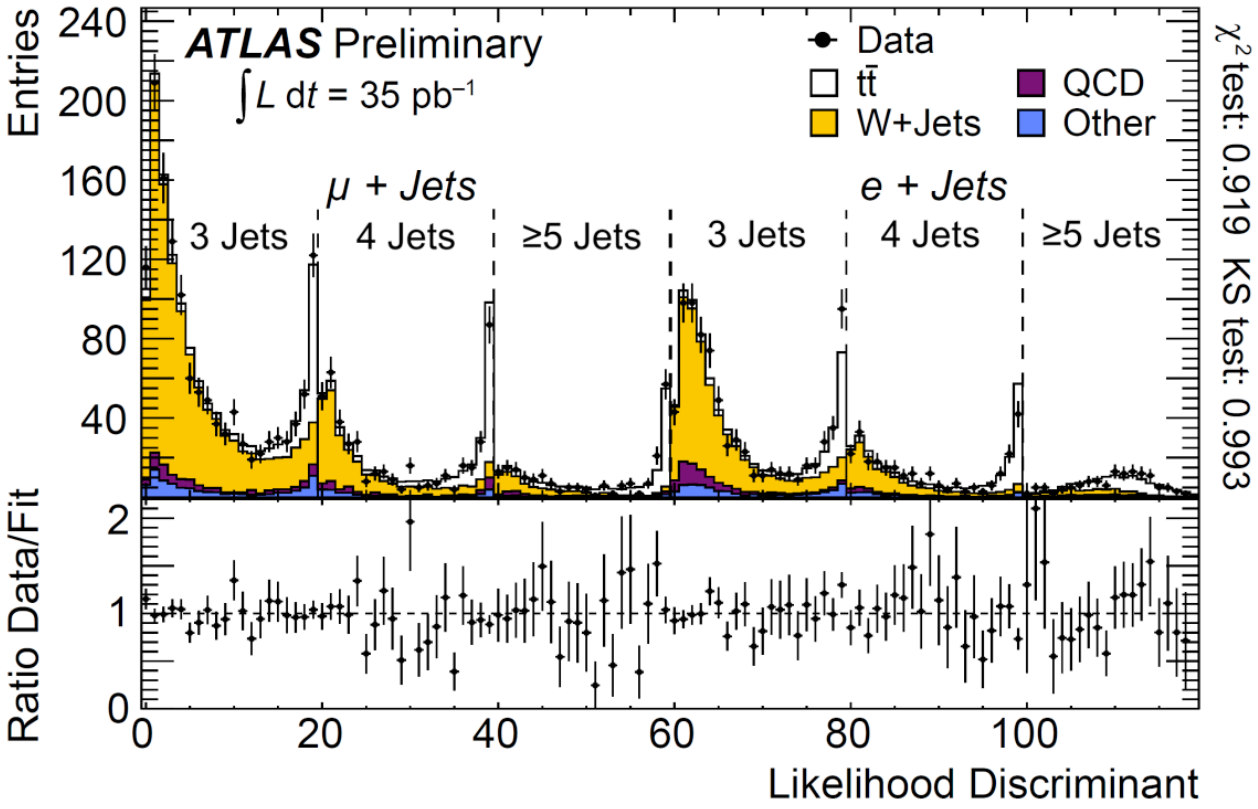
σ_{tt} = 171 ± 17(stat) $^{+20}_{-17}$(syst) ± 6(lumi) pb



σ_{tt} Single Lepton (with b-tagging)

- Multivariate method
- Input variables: lepton η, aplanarity, $H_{T,3p}$, b-tag weight
- Profile likelihood with nuisance parameters





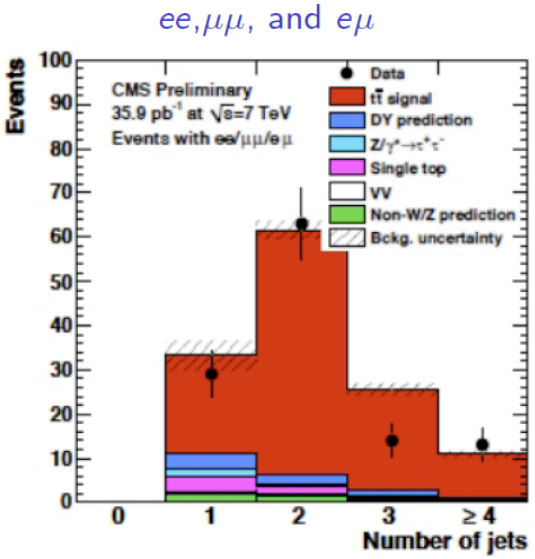
Main systematics:
- W+jet HF content (7%)
- B-tagging (7%)

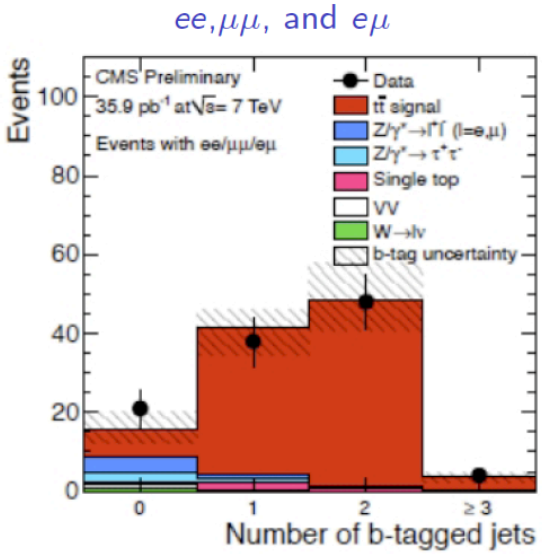
Relative uncertainty ~13%

$$\sigma_{tt} = 186 \pm 10(\text{stat})\ ^{+21}_{-20}(\text{syst}) \pm 6(\text{lumi})\ \text{pb}$$

σ_{tt} Dilepton Channel

- Event counting with dedicated data-driven techniques for the estimation of background





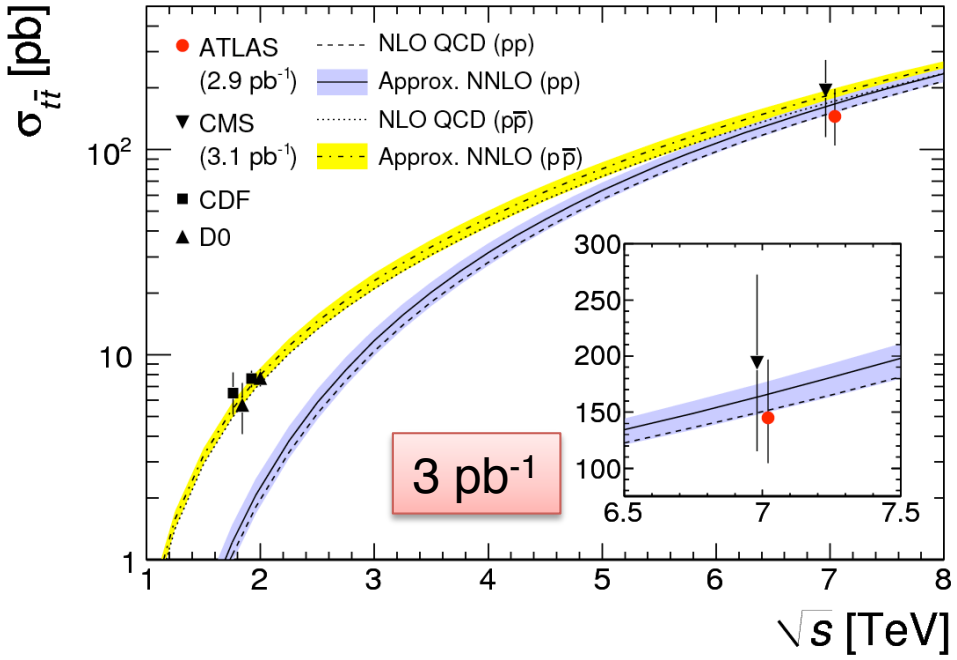
Main systematics:
- JES (4%)
- B-tagging (5%)

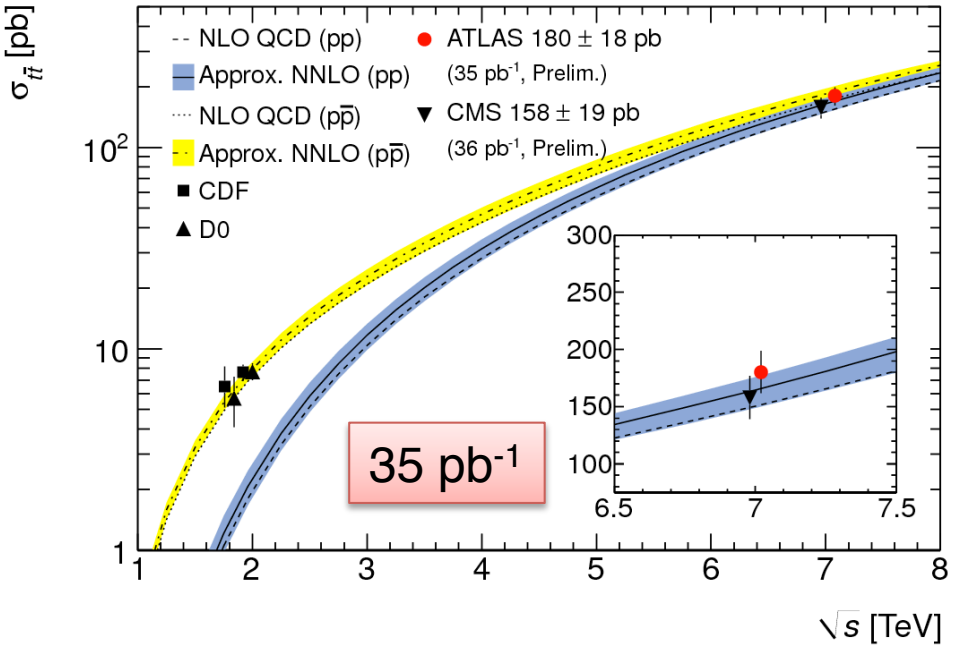
Relative uncertainty ~14%

Soon systematics limited

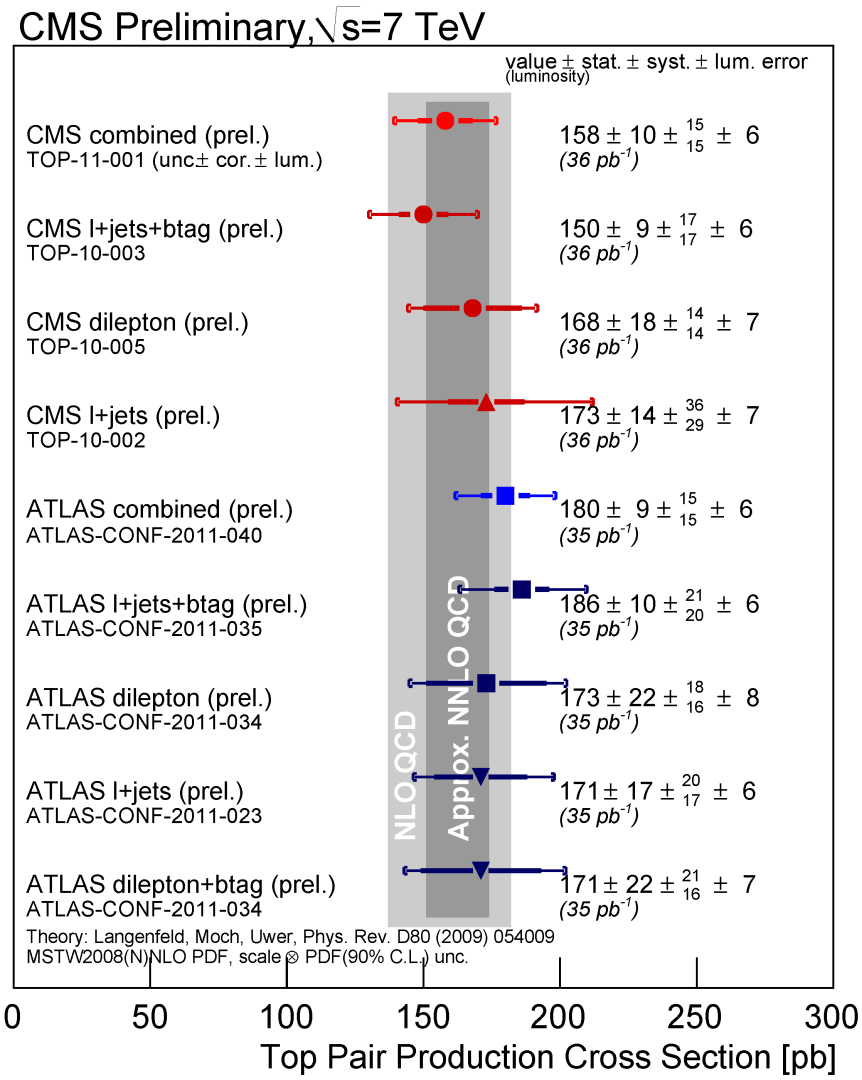
$$\sigma_{t\bar{t}} = 168 \pm 18\,(\text{stat.}) \pm 14\,(\text{syst.}) \pm 7\,(\text{lumi.})\ \text{pb}$$

tt Cross Section Combination





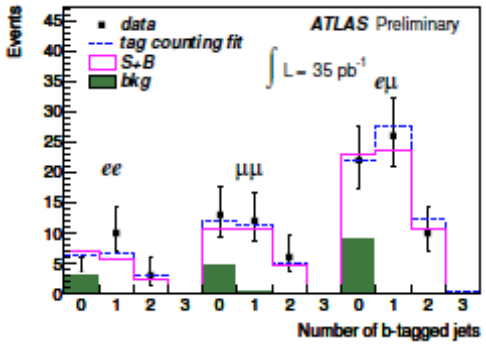
- Combined lepton+jets and dilepton from joint fit
  - Accounts for all (anti)-correlated systematic uncertainties
  - Reached 10% relative uncertainty
  - Already systematics limted
  - But systematics will improve with more statistics

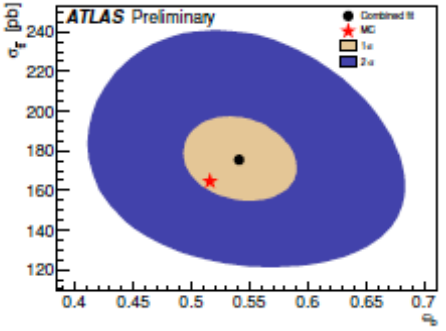


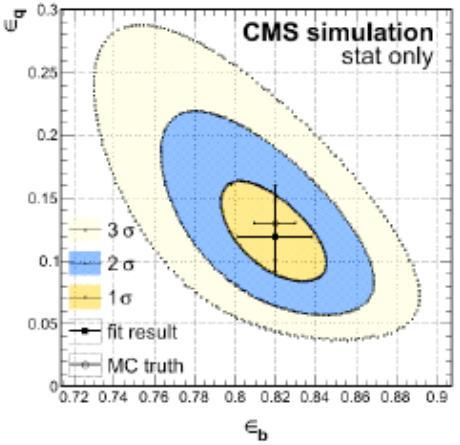
Prospects for tt Cross Section

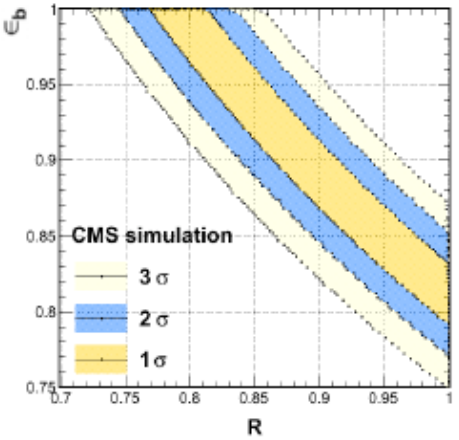
- Already now systematics limited, ideas to reduce systematics
  - Use kinematic discriminants insensitive to JES
  - Measure b-tagging efficiency together with cross section
  - Measure light and b-jet JES in hadronic top decays, 1% uncertainties possible
  - Measure tt+jets to constrain ISR/FSR uncertainties
- Differential tt cross sections benefit from increased statistics
- Possible 8 TeV collisions in 2012 would allow for new cross section measurement
  - Cross section increase by 40%
  - No big change in S/B

$$< N_n >= \sum_{i,jk} \Big\{ [\sigma_{t\bar{t}} \cdot BR \cdot A_{t\bar{t}} \cdot L \cdot F^{t\bar{t}}_{ijk} + N_{\text{Z+jets}} F^{\text{Z+jets}}_{ijk} + N_{\text{other}} \cdot F^{\text{other}}_{ijk}] \times \sum_{i'+j'+k'=n} C^{i'}_{i} \epsilon_b^{i'} (1-\epsilon_b)^{i-i'} \cdot C^{j'}_{j} \epsilon_c^{j'} (1-\epsilon_c)^{j-j'} \cdot C^{k'}_{k} \epsilon_l^{k'} (1-\epsilon_l)^{k-k'} \Big\}.$$





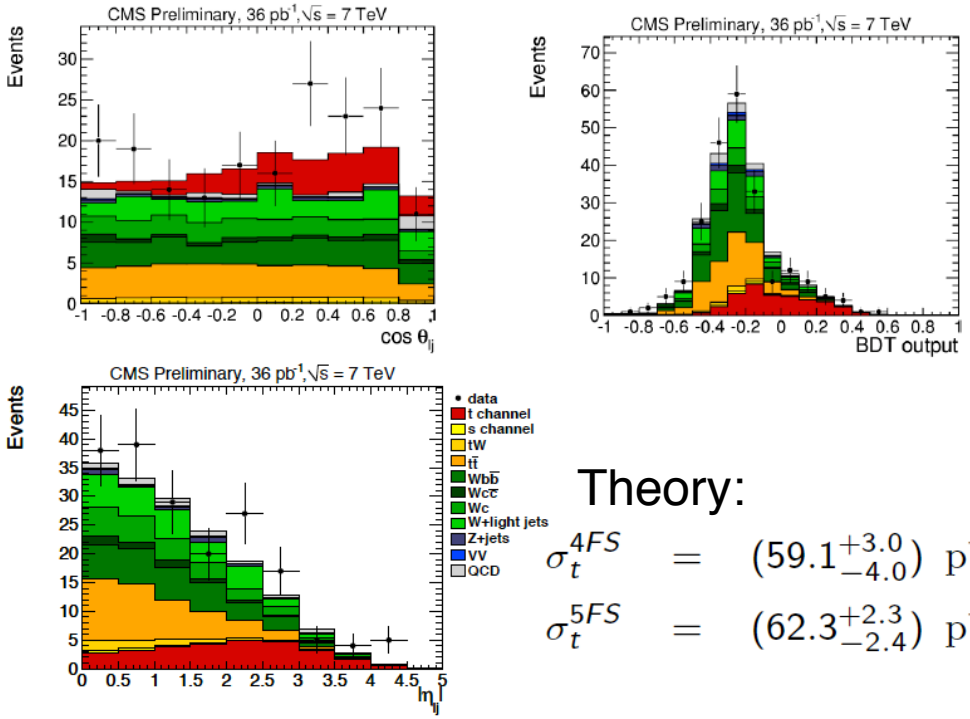




Single Top Quark Cross Section

- 2D template fit and a multivariate technique (BDT)

Combined: e+jets & μ+jets



Theory:

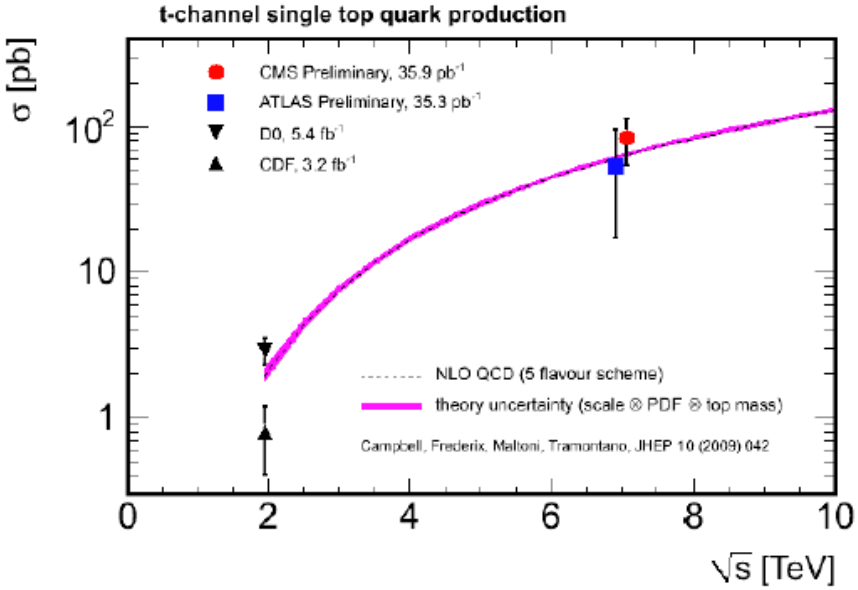
$$\sigma_t^{4FS} = (59.1^{+3.0}_{-4.0})\ \text{pb}$$

$$\sigma_t^{5FS} = (62.3^{+2.3}_{-2.4})\ \text{pb}$$

Combination of both analyses:

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

σ_{Wt} < 158 pb at 95%



> 3σ significance for t-channel

Limited by:
- statistics
- B-tagging
- JES

Relative uncertainty <40%

Prospects for Single Top

Process	Cross-section (pb)
top-antitop pair	164.6
single-top t-channel	66.2
single-top Wt-channel	14.6
single-top s-channel	4.3

Channel	$\mathscr{A} \times$ BR	$N_t(\int \mathscr{L} = 1\ \mathrm{fb}^{-1})$	$N_t(\int \mathscr{L} = 5\ \mathrm{fb}^{-1})$	S/B
t-ch (CB)	0.47%	310	1550	0.67
t-ch (MVA)	0.22%	150	750	1.13
Wt-ch (CB)	1.32%	190	950	0.08
Wt-ch (MVA)	0.33%	50	250	0.30
s-ch (CB)	0.23%	10	50	0.05
s-ch (MVA)	0.13%	6	30	0.10

Process	$\int \mathscr{L} = 1\ \mathrm{fb}^{-1}$	$\int \mathscr{L} = 5\ \mathrm{fb}^{-1}$
t-ch (CB)	38% (9%)	17% (4.2%)
t-ch (MVA)	32% (10%)	13% (4.8%)
Wt (CB)	100% (25%)	52% (11%)
Wt (MVA)	68% (30%)	32% (13%)

Cut Based (CB), Multivariate (MVA)
Numbers in brackets are statistical errors only

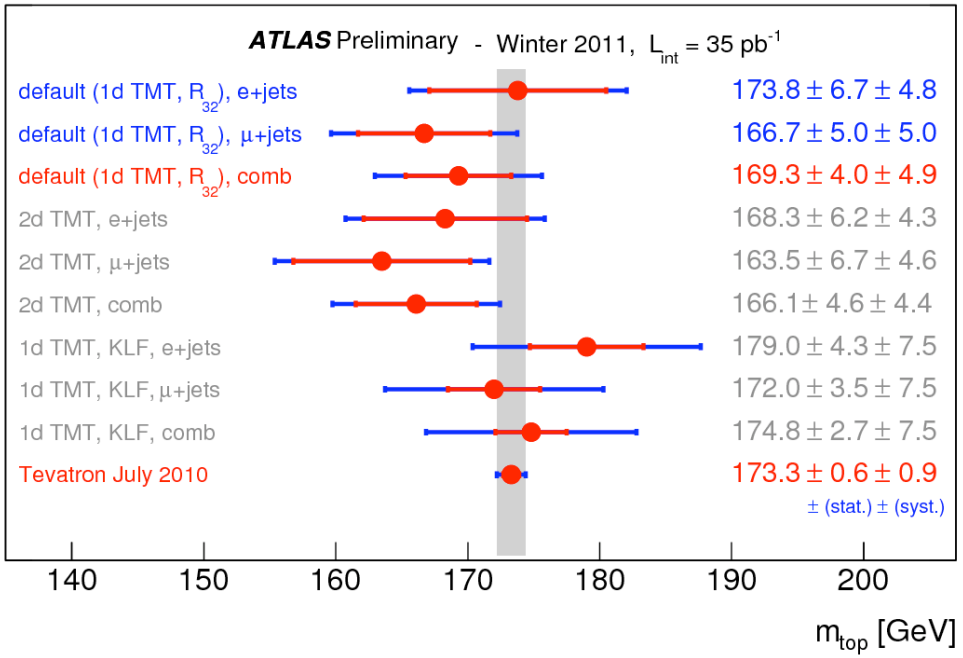
- Prediction of systematic uncertainties can only be approximate
  - Assume same uncertainties for 1 fb^{-1}
  - Assume improved JES, b-tag calibration, QCD estimates by factor 2 for 5 fb^{-1} (ISR/FSR, modeling etc. unchanged)

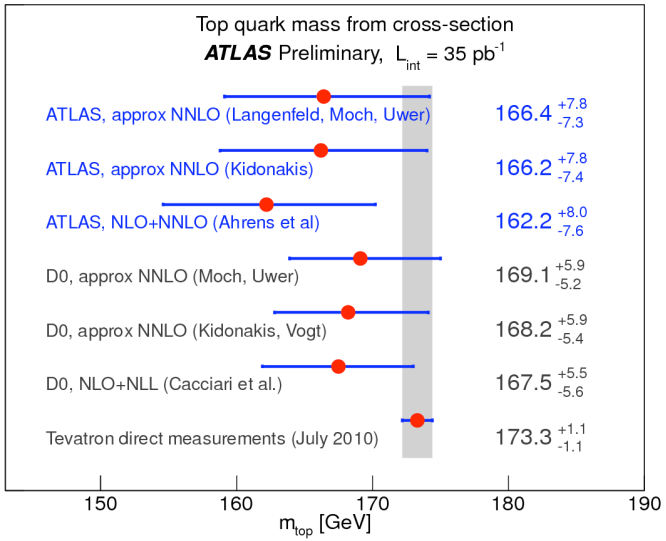
Prospects for Single Top

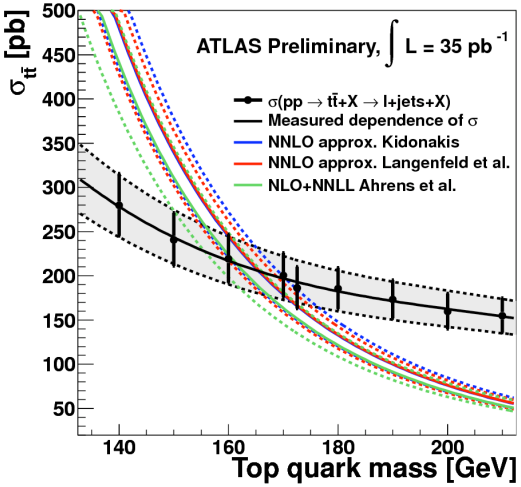
- Wt channel out of reach for Tevatron
- t-channel vs. Wt-channel cross section with 5 fb^{-1} sensitive to:
  - Anomalous couplings
  - 4th generation quarks
  - FCNC
  - Charged Higgs boson
  - Etc
- With smaller uncertainties than at the Tevatron
- S-channel remains difficult (10 expected events/fb^{-1} with S/B ~ 5-10%) – more interesting in 2012 or beyond
- 8 TeV collisions
  - increase the single-top cross-section by 20, 30 and 40% for s-, t- and Wt-channels respectively
  - Improved S/B

Prospects for Top Mass & Charge

- Limited by JES uncertainty already below 1fb^{-1}
- Study estimators built on
  - using the pT of the lepton
  - using track jets
  - using a partial reconstruction of the final state involving J/ψ

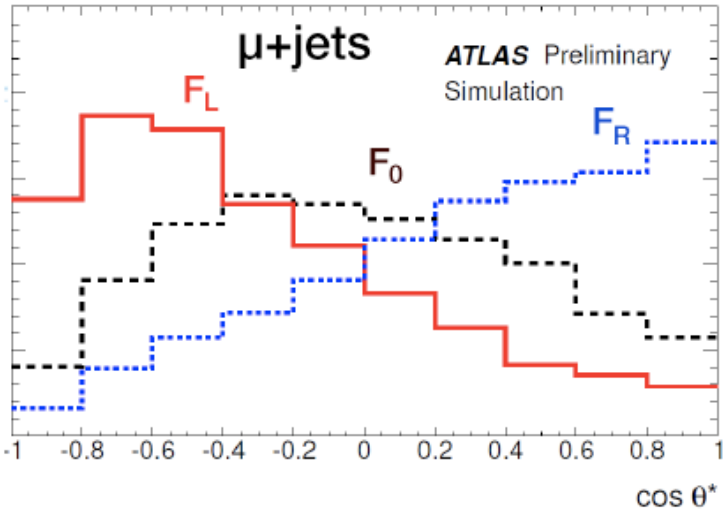






- Exotic top charge of 4/3 e can be excluded by more than 5σ with the data already taken (work in progress)

Prospects for W Helicity

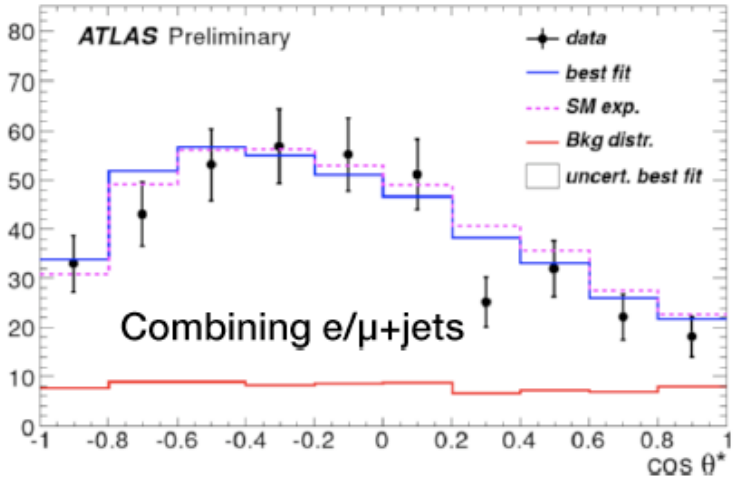


- SM predict helicity fractions of W from top
  - F_L=0.301, F_0=0.698, F_R=4.1 10^{-4}
  - Set limits on new physics
- Benefit from larger luminosity

	Template method	Asymmetry method
F_L	0.41 ± 0.12	0.36 ± 0.10
F_0	0.59 ± 0.12	0.65 ± 0.15
F_R	Fixed 0	-0.01 ± 0.07

35 pb^{-1}, 2010

35 pb^{-1}, 2010



Prospects:

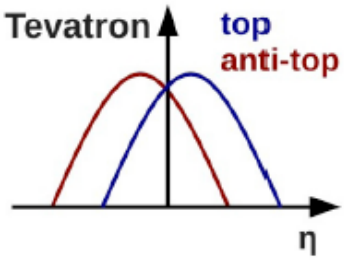
Quantity	Stat. ($\int \mathscr{L} = 1$ fb^{-1})	Stat. ($\int \mathscr{L} = 5$ fb^{-1})	Syst.
e+jets channel:			
f_L	0.03	0.01	0.03
f_0	0.06	0.03	0.02
f_R	0.03	0.01	0.02
μ+jets channel:			
f_L	0.03	0.01	0.03
f_0	0.05	0.02	0.02
f_R	0.03	0.01	0.02

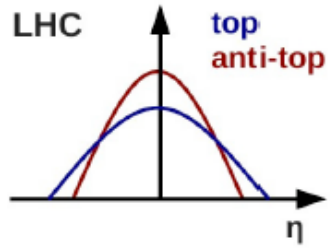
Prospects for tt Spin Correlations

- Systematics dominated by
  - PDFs
  - Factorization
  - b-fragmentation
- They do not change with an increased amount of data
- Statistics improvement are relevant for 5 fb^{-1}

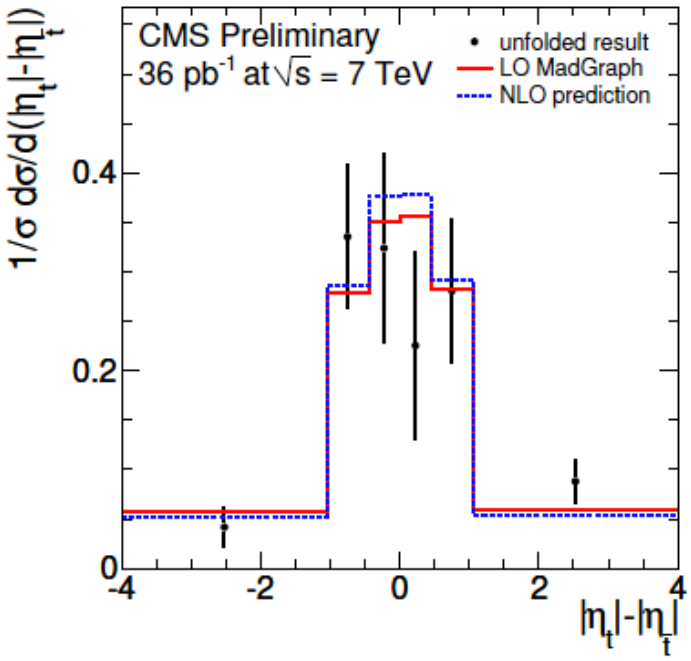
Quantity	Stat. ($\int \mathscr{L} = 1$ fb^{-1})	($\int \mathscr{L} = 5$ fb^{-1})	Syst.
e+jets channel:			
A	0.27	0.12	0.18
A_D	0.17	0.08	0.09
μ+jets channel:			
A	0.22	0.10	0.18
A_D	0.14	0.06	0.09

Charge Asymmetry



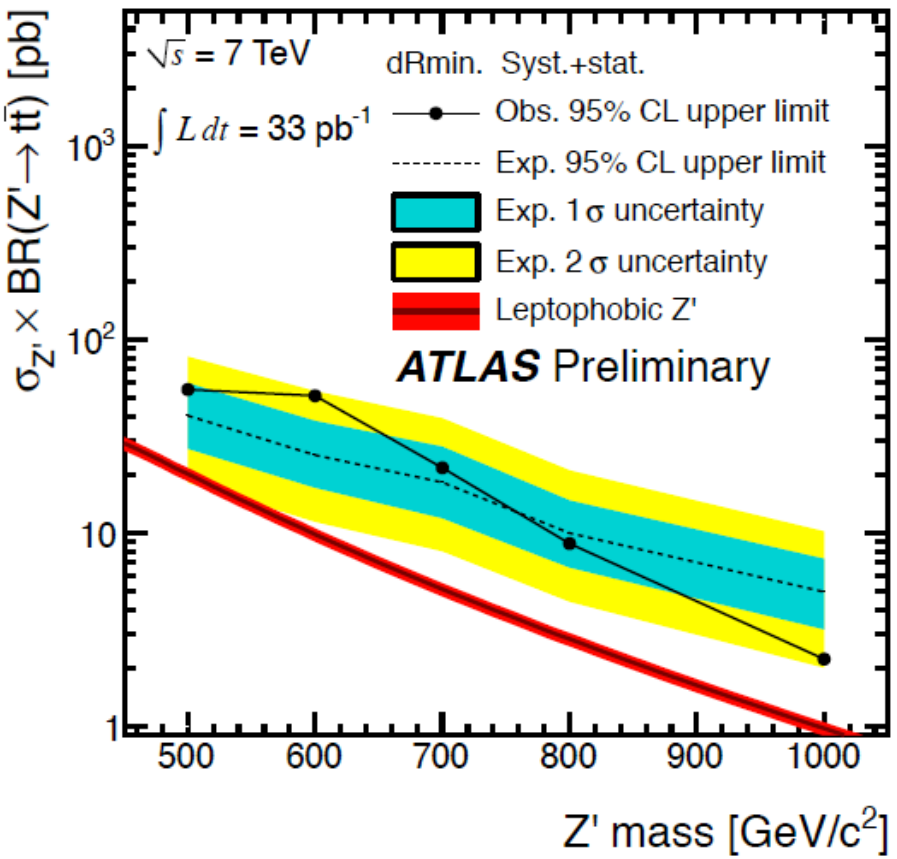


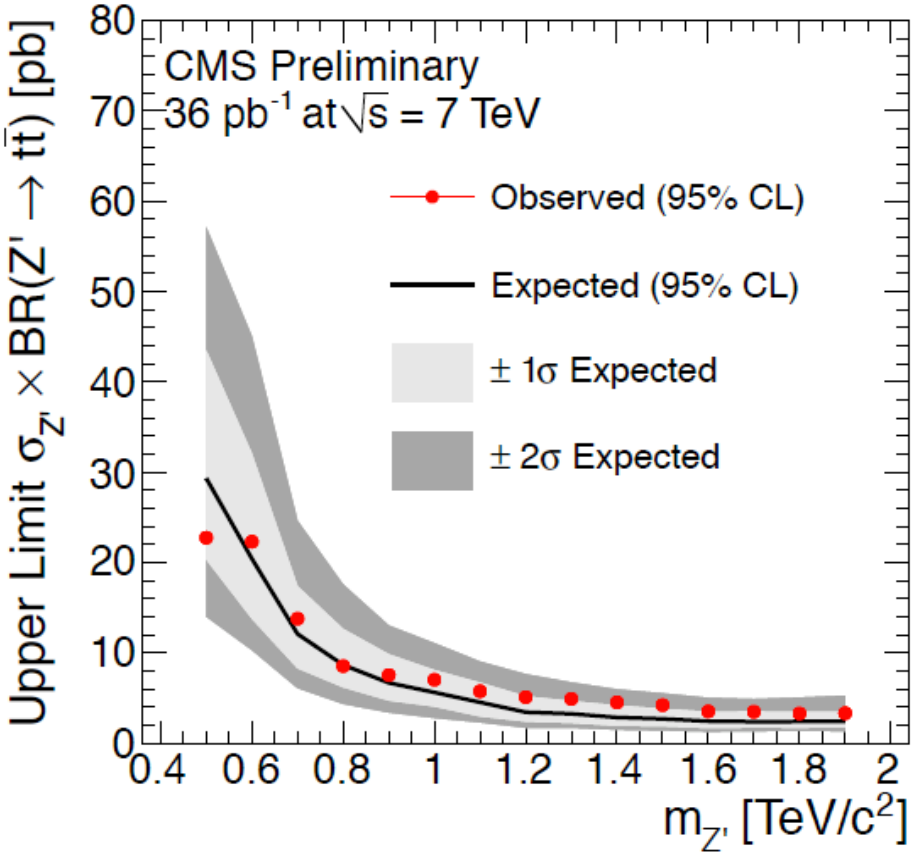
- At the Tevatron: deviation > 3σ from SM predicted A_{FB} ~5%
- At the LHC: Initial state symmetric (pp collider!)
  - charge asymmetry visible in
- Expected asymmetry is small A_C = 0.0130(11) [Ferrario, Rodrigo, et. al.]
  - Increased by BSM like a Z', W' or axigluon
- L = 1 fb^{-1} necessary to compete with Tevatron



$$A_C = 0.060 \pm 0.134\,(\text{stat.}) \pm 0.026\,(\text{syst.})$$

tt Resonances





- Expect 95% CL of ~1 pb (or better) for Z' of 1 TeV with 5 fb^{-1}

FCNC

Table 2: Present experimental limits on the branching fractions of the FCNC top quark decay channels.

	LEP	HERA	Tevatron
$Br(t \to q\gamma)$	2.4% [30–34]	0.64% ($tu\gamma$) [35]	3.2% [36]
$Br(t \to qZ)$	7.8% [30–34]	49% (tuZ) [37]	3.2% [38]
$Br(t \to qg)$	17% [39]	13% [37,40,41]	2.0×10^{-4} (tug), 3.9×10^{-3} (tcg) [42]

Limits with 35 pb^{-1} (2010):

$$BR(t \to qZ) < 17\% \text{ at } 95\% \text{ confidence level (CL).}$$

$$\sigma_{qg \to t} \times \mathrm{BR}(t \to bW) < 17.3 \text{ pb.}$$

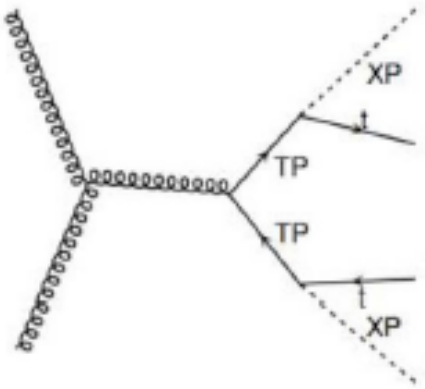
Prospects (2011/2012):

Quantity	Limit ($\int \mathscr{L} = 1$ fb^{-1})	($\int \mathscr{L} = 5$ fb^{-1})
$BR(\bar{t}t \to bWq\gamma)$	$1.5 \cdot 10^{-3}$	$6.8 \cdot 10^{-4}$
$BR(\bar{t}t \to bWqZ)$	$6.3 \cdot 10^{-3}$	$2.8 \cdot 10^{-3}$
$BR(\bar{t}t \to bWqg)$	$2.7 \cdot 10^{-2}$	$1.2 \cdot 10^{-2}$

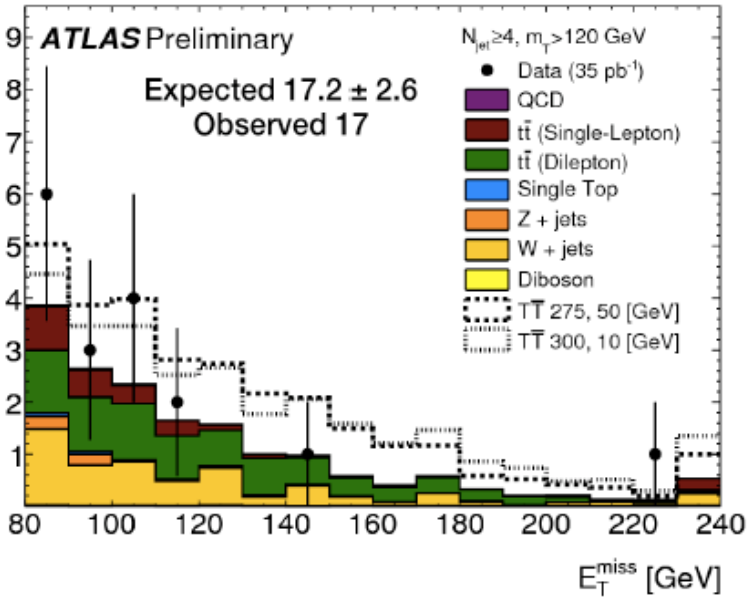
- Limits with 5 fb^{-1} are expected to be better than Tevatron

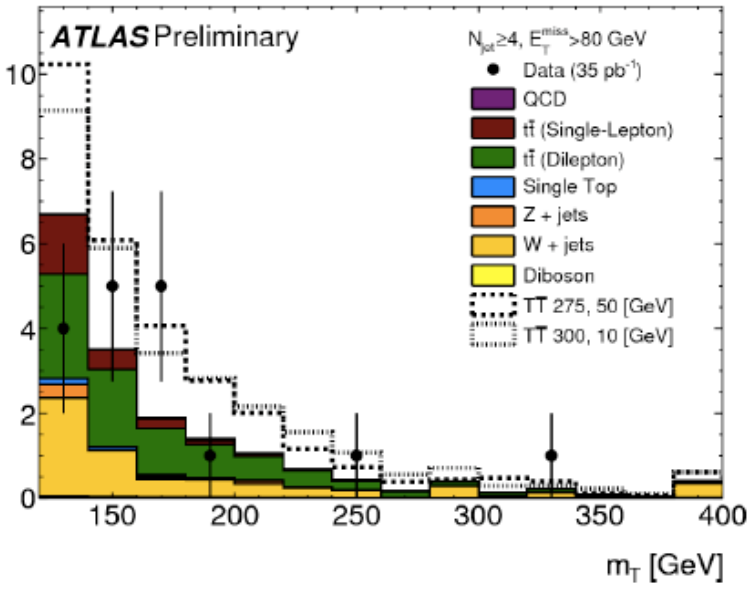
tt+MET

- Search for anomalous MET in tt events
- Benchmark: TT pair, T→t+dark matter particle
- Signal region: high MET, high W mT
- Exclude m(T)<275 (300)GeV for m(XP)<50 (10)GeV
- Soon competitive with Tevatron
- Reach full interesting mass region m(T)~600 GeV end of 2012
- Also sensitive to 3rd gen LQ, stop production etc.

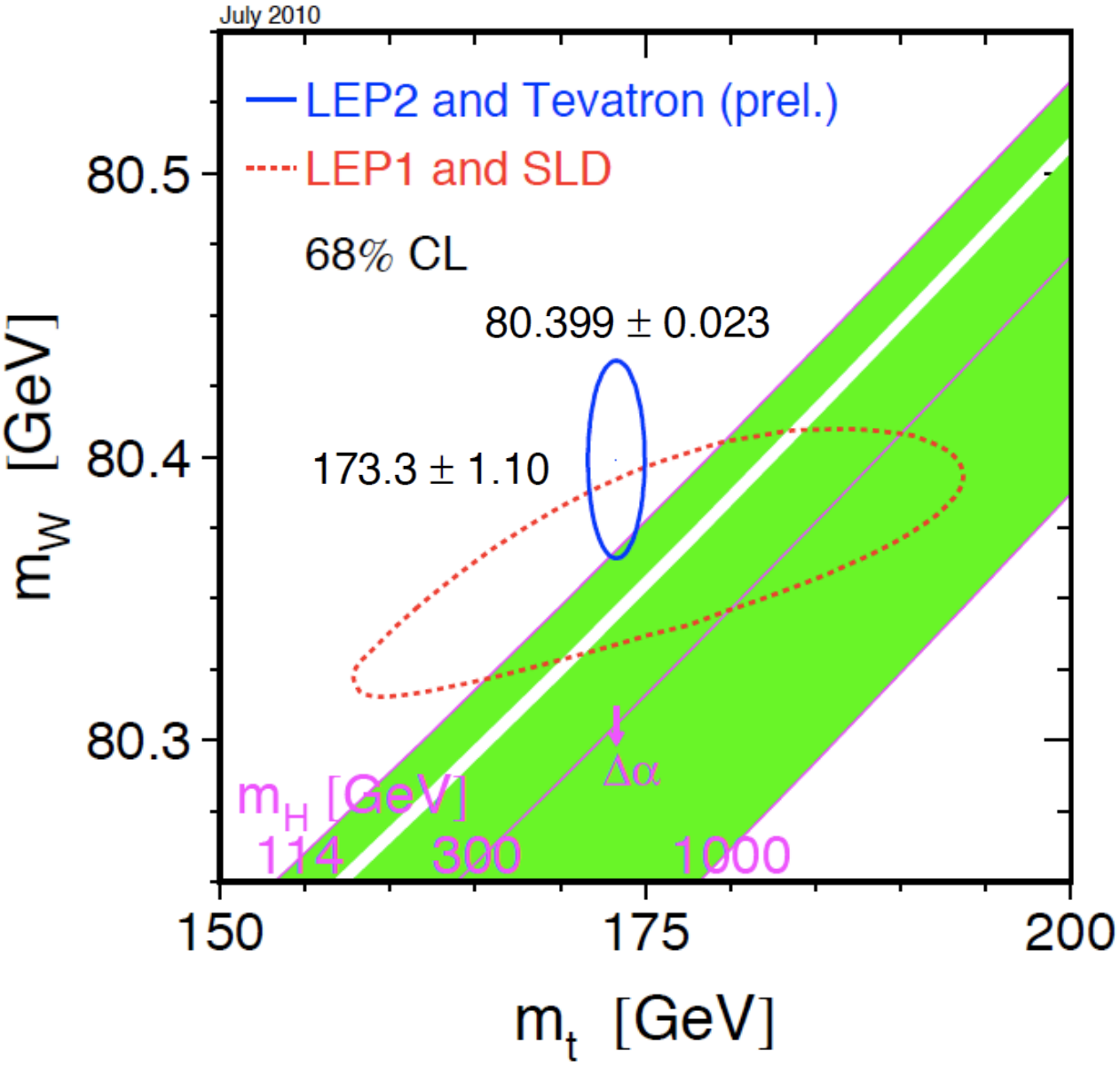


Alwall, Feng, Kumar *et al.* (2010)
Berger, Cao (2009)





W Mass Measurement – Motivation

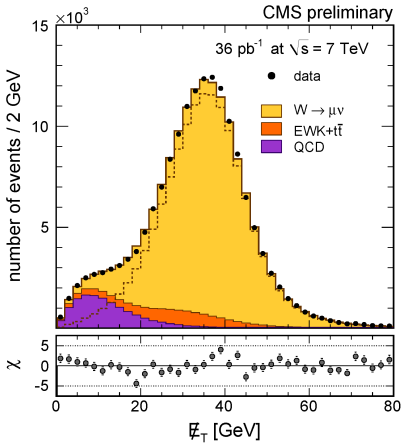


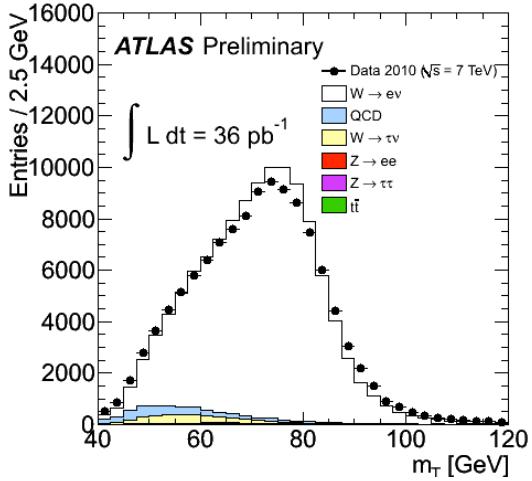
mW Measurement – LHC Prospects

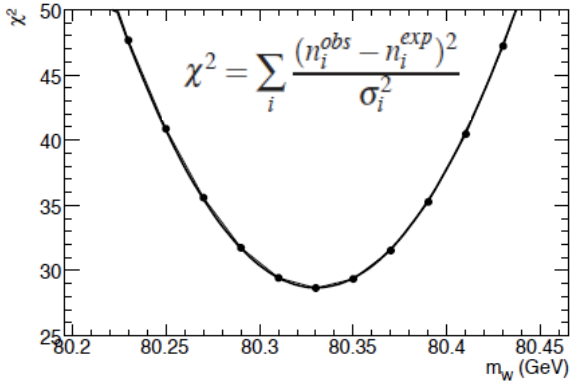
- arXiv:0805.2093v2: Re-evaluation of the LHC potential for the measurement of mW (14 TeV)
- 10^7 W events per lepton channel (e, μ) in 5 fb^{-1}
- 2 MeV statistical uncertainty
- Measurement systematics limited
  - energy scale, resolution, efficiency
  - Theoretical inputs: W boson kinematical distributions (rapidity, transverse momentum)
    - proton structure function uncertainties and higher orders QCD effects
  - QED effects (photon radiation)
  - Background, pile-up
- Systematic uncertainties can be strongly constrained with Z measurements (factor of ten less statistics)
  - lineshape, $d\sigma_Z/dm$ (robustly predicted)
    - Detector resolution and absolute scale
  - differential cross-section $d^2\sigma_Z/dydp_T$ absorbs the strong interaction uncertainties

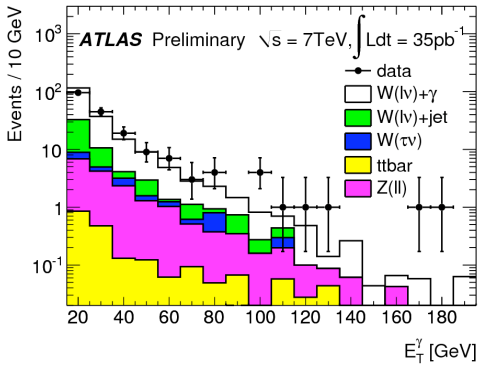
Towards mW Measurement

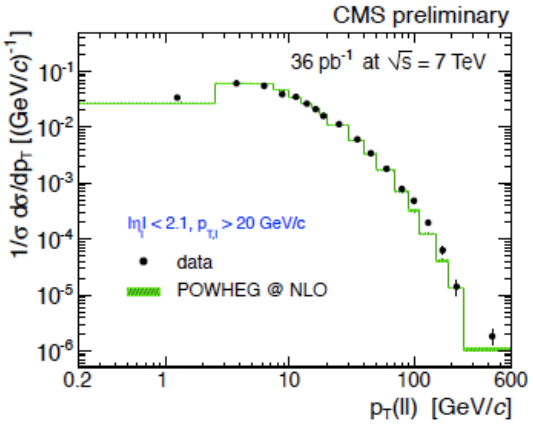
- QCD background estimate from low MET
- Compare m_T with templates
- m_W from χ^2 test
- First measurements:
  - Zγ, Wγ (arXiv: 1105.2758, ATLAS-CONF-2011-013)
  - $d\sigma_Z/dy$, $d\sigma_Z/dp_T$ (CMS-PAS-EWK-10-010)
  - W charge asymmetry (arXiv:1103.2929, arXiv:1103.3470)

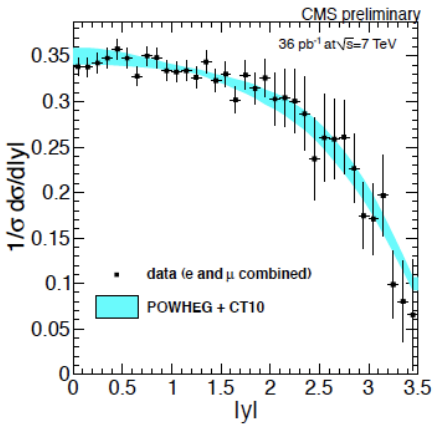












10 fb^{-1} @ 14 TeV

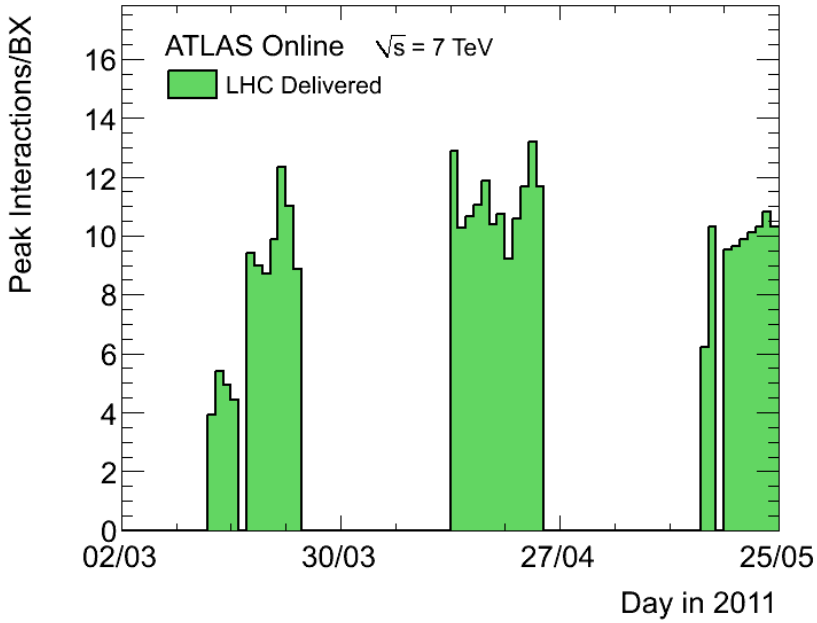
- Systematics ~scales with Z statistics
- Can be further improved with higher statistics
- Main assumptions in Table
  - QED simulation tools providing the same level of accuracy as @ LEP, already satisfactory (PHOTOS, HORACE, ...)
  - Light flavor symmetry in PDF's
  - Heavy flavor input from Wc, Zb (EWK-10-015), Zc

Source	Effect	$\partial m_W/\partial_{rel}\alpha$ (MeV/%)	$\delta_{rel}\alpha$ (%)	δm_W (MeV)
Prod. Model	W width	1.2	0.4	0.5
	y^W distribution	–	–	1
	p_T^W distribution	–	–	3
	QED radiation	–	–	<1 (*)
Lepton measurement	Scale & lin.	800	0.005	4
	Resolution	1	1.0	1
	Efficiency	–	–	4.5 (e) ; <1 (μ)
Recoil measurement	Scale	–	–	–
	Resolution	–	–	–
Backgrounds	$W \to \tau\nu$	0.15	2.5	2.0
	$Z \to \ell(\ell)$	0.08	2.8	0.3
	$Z \to \tau\tau$	0.03	4.5	0.1
	Jet events	0.05	10	0.5
Pile-up and U.E				<1 (e); ~ 0(μ)
Beam crossing angle				<0.1
Total (p_T^l)				~7 (e); 6 (μ)

Source	Effect	$\partial m_W/\partial_{rel}\alpha$ (MeV/%)	$\delta_{rel}\alpha$ (%)	δm_W (MeV)
Prod. Model	W width	3.2	0.4	1.3
	y^W distribution	–	–	1
	p_T^W distribution	–	–	1
	QED radiation	–	–	<1 (*)
Lepton measurement	Scale & lin.	800	0.005	4
	Resolution	1	1.0	1
	Efficiency	–	–	4.5 (e) ; <1 (μ)
Recoil measurement	Scale	-200	–	–
	Resolution	-25	–	–
	Combined	–	–	5 (**)
Backgrounds	$W \to \tau\nu$	0.11	2.5	1.5
	$Z \to \ell(\ell)$	-0.01	2.8	0.2
	$Z \to \tau\tau$	0.01	4.5	0.1
	Jet events	0.04	10	0.4
Pile-up and U.E				<1 (e); ~ 0(μ)
Beam crossing angle				<0.1
Total (m_T^W)				~8 (e); 7(μ)

LHC and Detector Outlook

- Great LHC and detector performance
  - Plan to reach 5 x 10^{33} in next weeks/months
  - 20 events pile-up
    - 12 already now
  - 25 ns bunch spacing planned before end of year
  - >500 pb^{-1} recorded in 2011
  - 3-5 fb^{-1} by end of 2011



- Important: pile-up
  - Impact on JES, MET, lepton isolation, b-tagging

Physics Summary and Outlook

- The era of LHC top physics has started
  - First measurements of top quark pair production with 3 pb^{-1}, then 35 pb^{-1} (2010)
  - ATLAS and CMS measurements and theory agree well
  - First 2011 top results shown at PLHC next week
  - Systematic uncertainties already start to dominate total uncertainties
- 2011 is the year of precision top measurements at the LHC
  - Expect 6-10 times top Tevatron statistics in 2011
  - In-situ calibration techniques to reduce systematics
  - Advanced analysis techniques
  - Cross section, single top t-channel observation, sensitivity to Wt single top mechanism
  - top mass, charge and other properties, such as spin correlations, the W-helicity and the search for resonances, gain from the full luminosity of 2011
  - Further properties, e.g., CTP tests, V_{ts}, tt+photon production cross-section or qqbar vs gg production might only be measurable within 2012 or beyond
- Improved W mass measurement expected by the end of 2012: ≤10 MeV

Backup

Extrapolated tt Numbers

Assuming σ_{tt} = 164.6 pb (HATHOR)

Channel	$\mathscr{A} \times$ BR	$N_{t\bar{t}}(\int \mathscr{L} = 1\ \mathrm{fb}^{-1})$	$N_{t\bar{t}}(\int \mathscr{L} = 5\ \mathrm{fb}^{-1})$	S/B
$t\bar{t} \rightarrow e$+*jets*	3.10%	5.1k	25.5k	2.0
$t\bar{t} \rightarrow \mu$+jets	3.20%	5.3k	26.3k	4.6
$t\bar{t} \rightarrow ee$	0.24%	0.4k	2.0k	1.9
$t\bar{t} \rightarrow \mu\mu$	0.38%	0.6k	3.1k	2.0
$t\bar{t} \rightarrow e\mu$	0.81%	1.3k	6.6k	4.0

- After kinematic selection
- Requiring ≥1 b-tag in l+jets channel