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Status of top pair cross section combination

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FSP 101 ATLAS

PHYSICS AT THE TERA SCALE
Helmholtz-Alliance

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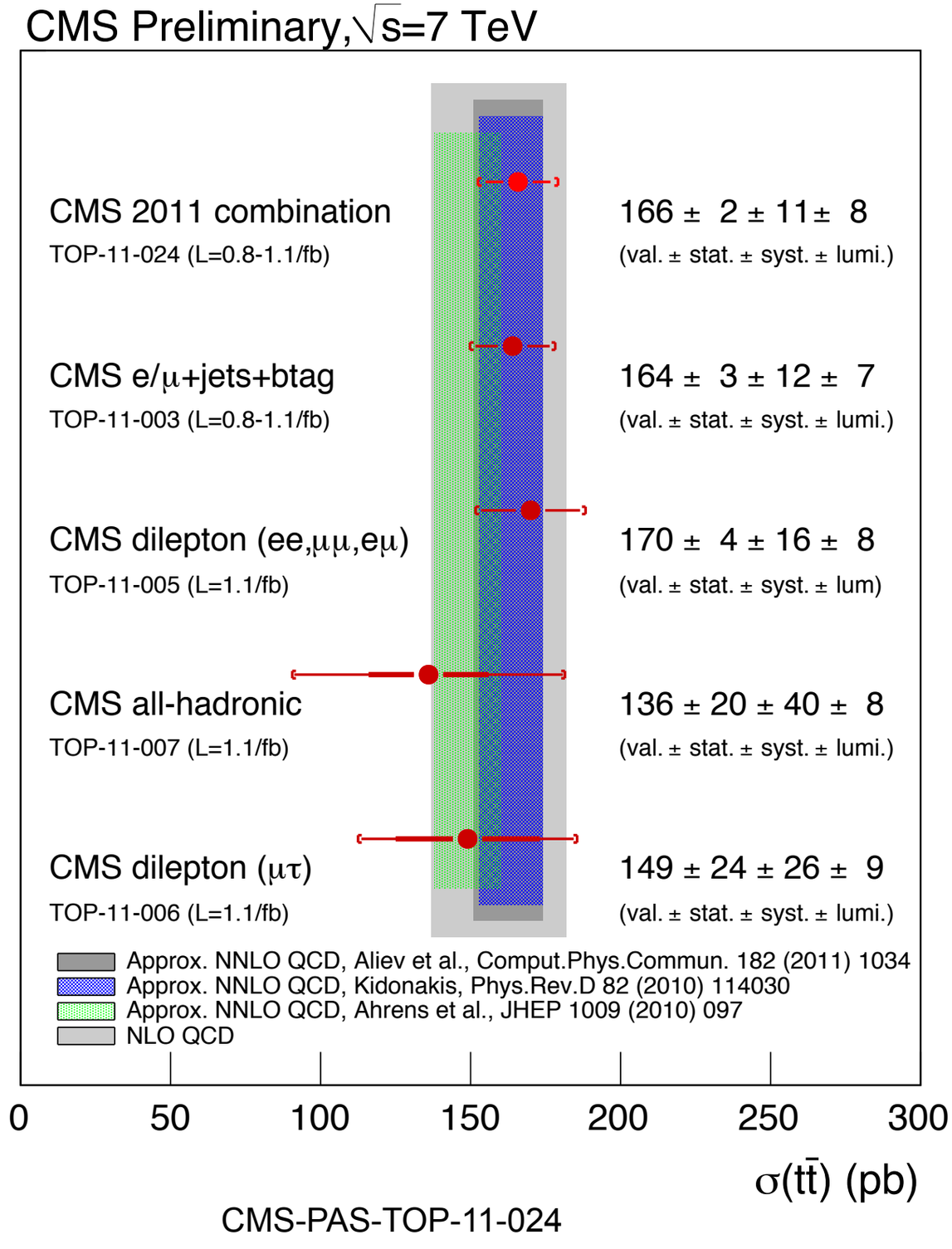
Disclaimer

- This talk does not discuss potential combination using the latest results because the strategy has nit been discussed yet between CMS and ATLAS
- New results became public recently
- When are we ready for the final 7 TeV cross section combination?

CMS combination

- up to 1.1/fb
- 4 channels
- relative uncertainty 8%
- dominated by l+jets - 8.6% uncertainty



CMS combination method

- Techniques in individual channels
  - l+jets: binned profile likelihood fit
  - dilepton and μ+τ: cut and count
  - all hadronic: unbinned maximum likelihood fit to reconstructed m_{top}
- Combination: fitter used in l+jets extended to include other channels
  - channels using counting methods are modeled by histograms with one bin
  - results of unbinned LH fit are parameterized to be represented as a single bin in combined likelihood
  - not straightforward to extend to include ATLAS measurements
- BLUE method used as a cross check
  - results agree very well
    - central value differs by 0.7%
    - relative uncertainty is the same

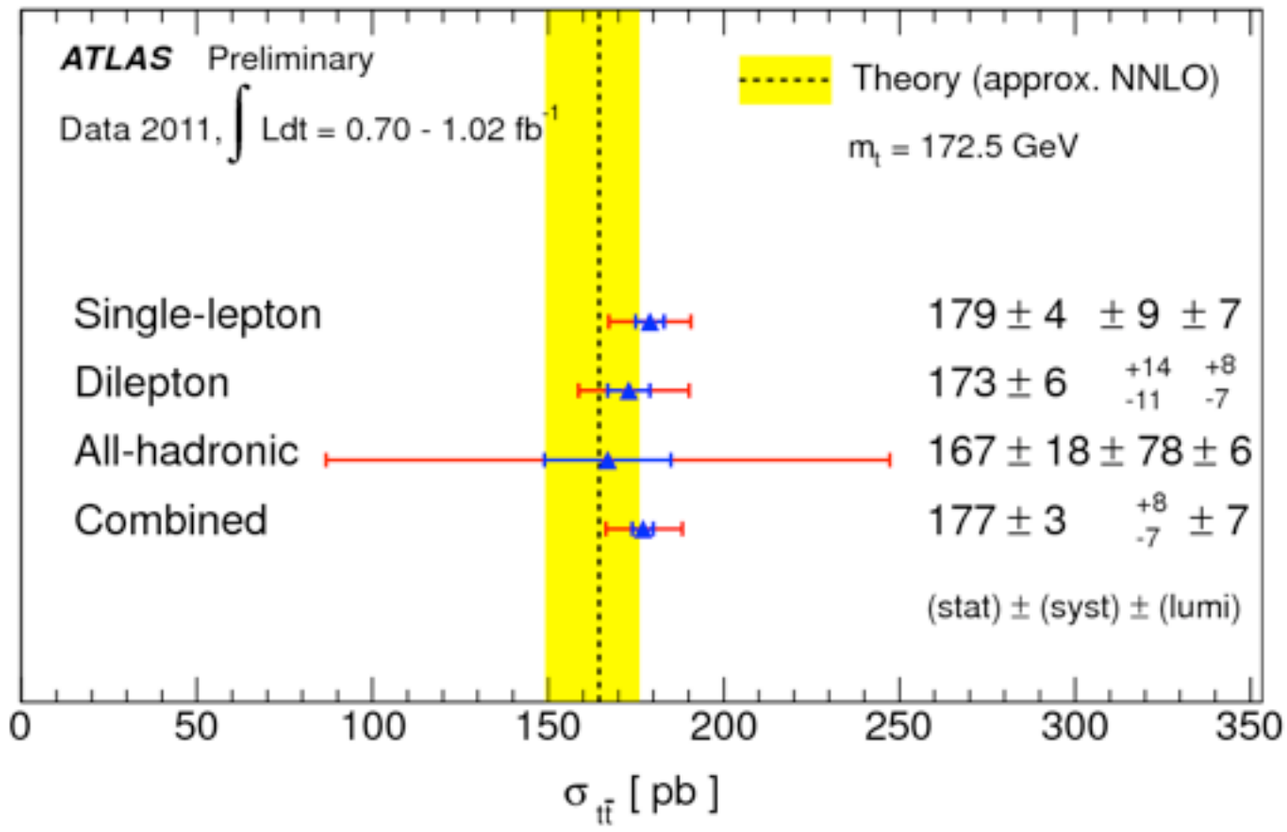
CMS systematics

systematic source	single lepton	ee	$\mu\mu$	$e\mu$	$\mu\tau$	hadronic
JES	poly	1.9	1.7	1.9	4.4	14.3
b-tag (single)	poly					
b-tag (hadronic)						15.7
b-tag ($\mu\tau$)					5.5	
b-tag (dilepton)		5.0	5.0	5.0		
Pileup	2.6	5.0	5.0	5.0	3.1	0.6
$t\bar{t}$ Q^2	2.8	2.4	2.4	1.8	2.0	10.3
luminosity	4.5	4.5	4.5	4.5	6.0	6.0
Lepton efficiency (single)	3.4					
Lepton efficiency ($\mu\tau$)					2.1	
Lepton efficiency (dilepton)		3.0	1.6	2.3		
W leptonic branching ratio		1.7	1.7	1.7	1.7	
Top quark mass		2.6	2.6	1.5	1.6	5.3
JetMet model		3.2	3.2	0.4	1.0	
ME-PS matching	2.0				1.0	5.2
W+jets Q^2 (single)	poly					
PDF (single)	3.4					
Lepton model (dilepton)		4.0	4.0	4.0		
Decay model (dilepton)		2.0	2.0	2.0		
fake rate ($\mu\tau$)					13.0	
τ jet mis-ID ($\mu\tau$)					7.3	
tau and hadron decay model ($\mu\tau$)					2.0	
MC bkgd ($\mu\tau$)					1.6	
MC tune (hadronic)						8.1
trigger (hadronic)						4.5
bkgd (hadronic)						12.2

- Uncertainties for individual channels on the signal
- Breakdown of uncertainties on the combined cross section is not available in the public note

ATLAS combination

ATLAS-CONF-2012-024



- up to 1.1/fb
- 3 final channels
  - 4th channel was available (l+tau) but not included into combination due to overlap with l+jets
- relative uncertainty - 6.2%
- dominated by l+jets - 6.7%

Atlas combination method

- driven by the techniques used in individual measurements
  - l+jets (2 channels): uses binned profile likelihood fit
  - dilepton (3 channels) - cut and count in individual channels combined using nuisance parameter technique
  - all hadronic (1 channel) - binned likelihood fit to χ^2 distribution
- 6 channel combination is implemented as a product of individual likelihoods
  - constraints on common systematics enter only once
- approximating for l+jets channel
  - single lepton LH function is approximated by a multivariate Gaussian with covariance given by the Hessian matrix from MINUIT HESSE algorithm

$$L_{l+\text{jets}}(\vec{\theta}) = G(\hat{\vec{\theta}}\,|\,\vec{\theta}, V) = \frac{1}{(2\pi)^{k/2}|V|^{1/2}} \exp\left(-\frac{1}{2}(\hat{\vec{\theta}} - \vec{\theta})^T V^{-1} (\hat{\vec{\theta}} - \vec{\theta})\right)$$

$$V_{ij}^{-1} = -\frac{\partial^2}{\partial\theta_i \partial\theta_j} \log L(\vec{\theta}) \,\Big|\, \hat{\vec{\theta}} \qquad \vec{\theta} = (\sigma_{t\bar{t}}, \vec{\alpha})$$

ATLAS combined likelihood

$$L_{\text{comb}}(\sigma_{t\bar{t}}, \mathcal{L}, \vec{\alpha}) = L_{l+\text{jets}}(\sigma_{t\bar{t}}, \mathcal{L}, \vec{\alpha}) \prod_{i \in \{ee,\mu\mu,e\mu\}} \text{Pois}(N_i^{\text{obs}} | N_{i,\text{tot}}^{\text{exp}}(\vec{\alpha}))$$
$$\times \prod_{k \in \text{all-had bins}} \text{Pois}(n_k \,|\, s_k(\vec{\alpha}) + b_k(\vec{\alpha})) \prod_{j \notin \text{l+jets sys}} \text{Gaus}(0|\alpha_j, 1)\,.$$

- 89 parameters total
- 26 shared between l+jets and dilepton LH
- 12 common to all three channels

BLUE combination

- much simpler
- more approximations
  - symmetrized uncertainties
- excellent agreement with LH method

Uncertainty source	Uncertainty (pb)
Signal modeling uncertainties	
Event generator	+3.8 / −3.4
Parton shower modeling	+2.0 / −1.9
Initial-state and final-state radiation	± 1.2
Parton distribution function	+2.9 / −2.7
Detector modeling	
Muon identification	+3.3 / −3.1
Electron identification	+2.9 / −2.7
Jet energy scale	+2.4 / −2.3
Jet efficiency	± 0.8
Missing transverse momentum	± 0.9
Background from data	
Fake lepton estimate	+1.4 / −1.3
Shape of single-lepton QCD template	+0.6 / −0.5
Background from Monte Carlo	
Shape of single-lepton W + jets template	+0.7 / −0.6
All others	+2.6 / −2.5

LHC combination

- Performing combination of all individual channels from two experiments using likelihood technique is very complicated
  - unless common technique (HistFactory)
- Strategy: combine combined likelihoods from CMS and ATLAS
  - perform LHC combination using ATLAS and CMS machinery independently
    - ATLAS - same machinery as for ATLAS internal combination (J. Lewis)
    - CMS - new framework developed by J. Ott
  - compare the results
  - even simplified approach requires significant code development to include properly systematics and correlations
  - not enough progress recently

LHC combination issues

- A set of systematic uncertainties is quite different between ATLAS and CMS
- Much finer split of systematic components in ATLAS
- Often hard to get an idea of correlations
- Need to come up with mapping of uncertainties
- Obvious problems:
  - JES uncertainty - what fraction comes from MC modeling (should be correlated) and what from the detector?
  - Luminosity - what fraction of total uncertainty is correlated between two experiments?

An attempt to map uncertainties

Category	ATLAS systematics	CMS systematics	correlation
Statistical			0
Detector simulation			
	muon, electron identification	lepton efficiency, lepton selection	0
	JES, bJES, jeteff, MET	Jet and MET model	0 ??
	JES pileup	pileup	0
	btag-allHad	b-tagging	0
	trigger muon, electron, allHad	trigger allHad	0
Signal model			
	Generator		
	Parton shower	ME-PS matching	1
	ISR FSR	tt Q2	1
	PDF	PDF	1
		MC tune	
		W branching	
		τ and hadron decay model	
Background from data			0
	QCD shape		
	fake background		
	multijet background		
	Z pt model		
	DY normalization		
		τ fake rate	
		τ jet mis-ID	
Background from MC			
	theoretical cross-sections	cross sections of MC backgrounds	1
	W shape	W+jets Q2	1
	Monte Carlo statistics		
	Luminosity	Luminosity	???
		Top mass	
		Lepton decay model	

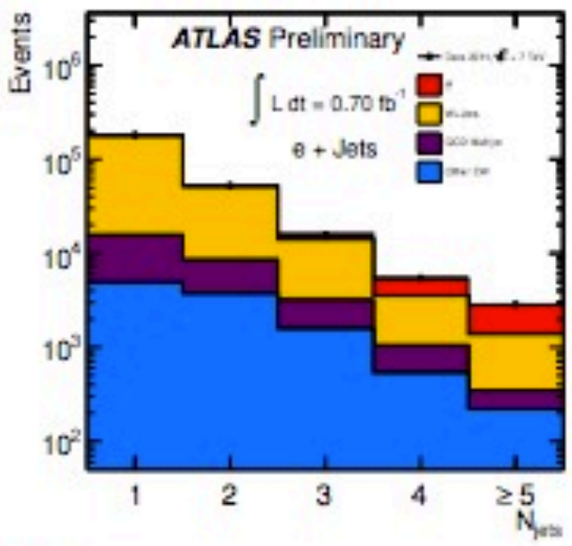
?

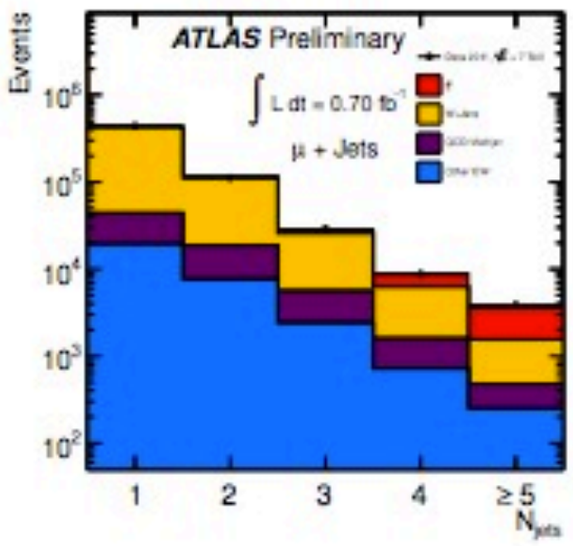
Conclusions and outlook

- Selected strategy to combine combined likelihoods from CMS and ATLAS involves significant code development
- Although mathematically more precise it still requires a lot of assumptions and approximations
- Shall we consider BLUE as a simpler alternative?
  - used by both experiments as a cross check and showed good agreement with the likelihood approach
  - same technique is used for mass and single top cross sections
  - can follow split of systematics and correlations assumed for other combinations where possible
  - breakdown of uncertainties for BLUE
    - available in ATLAS public document
    - available from CMS contact (J.Ott), extracted from CMS combination using standard procedure

Backup

ATLAS: l+jets





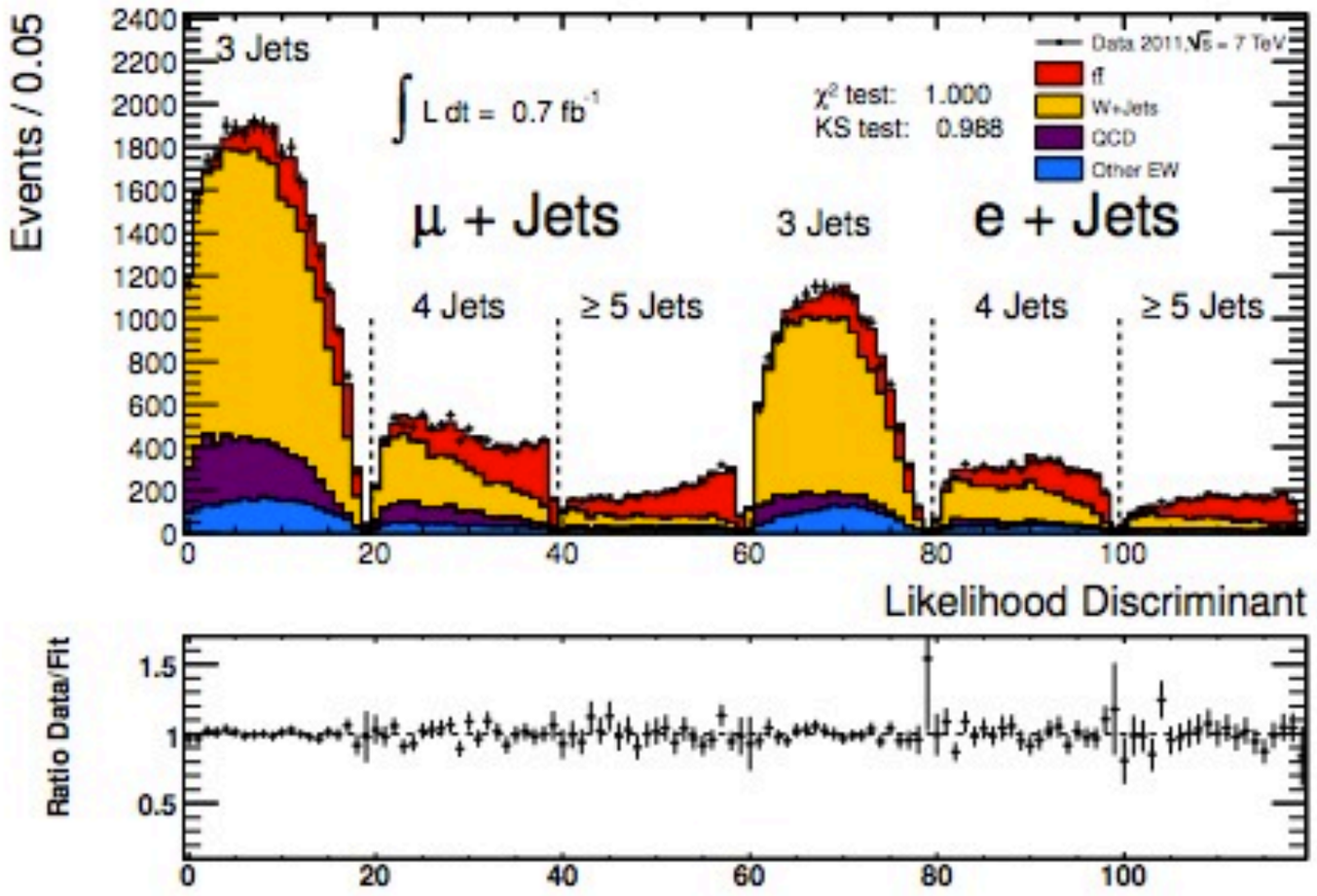


Figure 17: Result of combined fit to data in the exclusive three-jet bin, the exclusive four-jet bin and the inclusive five-jet bin.

The 2011 l+jets analysis

- Multivariate likelihood fits
- No b-tagging requirement
- Interpolation of systematics based on templates

30 nuisance parameters describing systematic uncertainties

15 parameters for background normalization

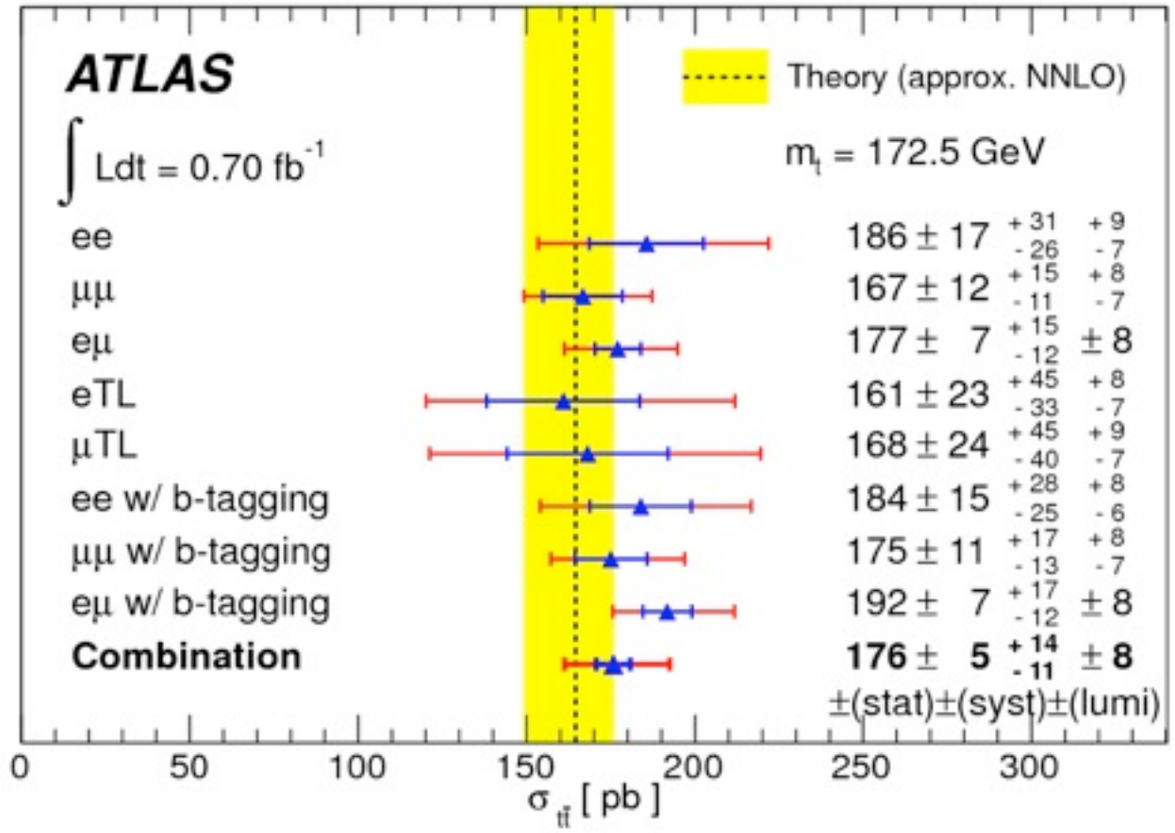
1 parameter of interest

Full likelihood for l+jets is very "gaussian" looking

- eg. in asymptotic regime

ATLAS dilepton channel

- Cut and count in 3 pretag samples
- Combination does not include l+track channels due to overlap with l+jets



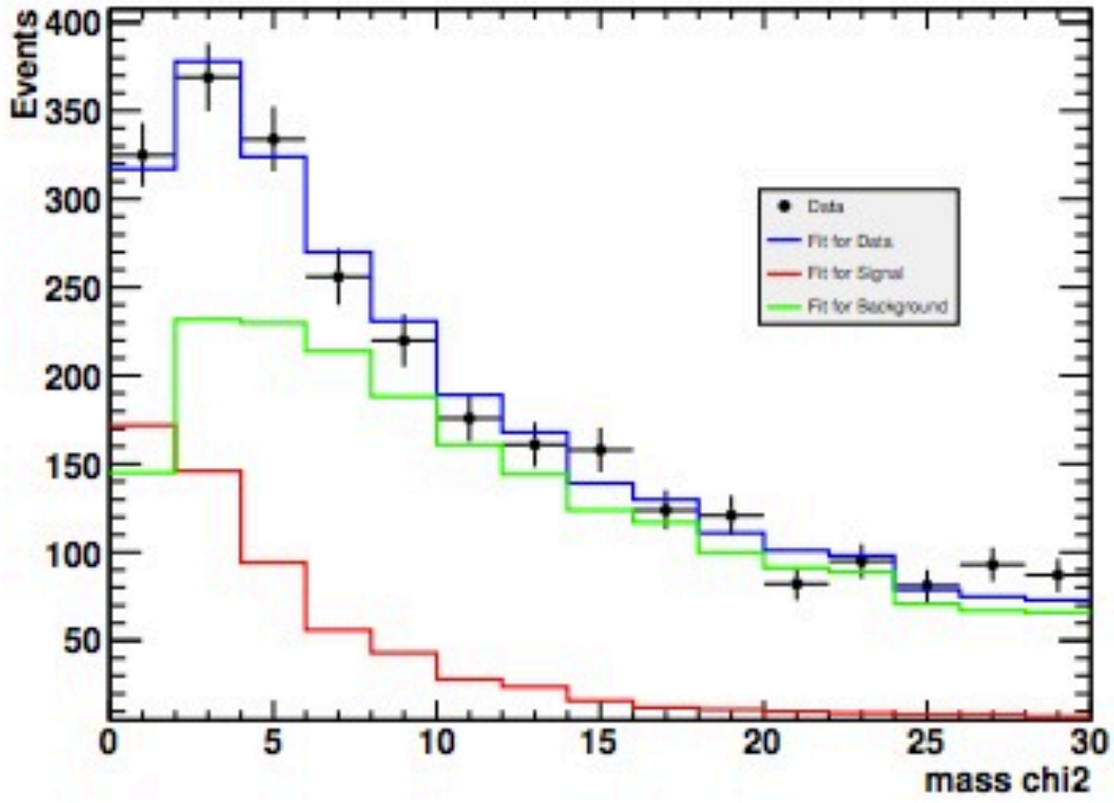
Uncertainties $\Delta\sigma/\sigma$[%]	ee	$\mu\mu$	$e\mu$	eTL	μTL	Combined
Data statistics	±8.1	±6.1	±3.9	±14.1	±14.2	±2.9
Luminosity	+4.4/-3.8	+4.4/-3.9	±4.2	+5.1/-4.2	+5.4/-4.4	±4.3
MC statistics	±1.6	±1.2	±0.8	±5.5	±4.6	+0.7/-0.6
Lepton uncertainties	+6.2/-5.4	+2.9/-1.3	±3.1	±4.1	+1.8/-1.6	+2.6/-2.2
Track leptons	—	—	—	±4.4	±1.9	+0.3/-0.2
Jet/$E_{\mathrm{T}}^{\mathrm{miss}}$ uncertainties	+5.7/-5.7	+6.4/-3.5	+4.7/-3.2	+14.8/-6.4	±13.1	+4.4/-3.4
b-tagging uncertainties	+1.2/-1.0	±0.7	—	—	—	+0.4/-0.0
Z/γ^*+ jets evaluation	±0.4	+0.5/-0.0	—	±6.2	+2.4/-2.7	+0.3/-0.2
Fake lepton evaluation	±3.3	1.5/-1.3	±3.0	±13.7	±15.1	±1.7
Generator	+12/-11	+4.5/-4.3	+4.8/-4.5	+14/-11	+14/-13	+5.1/-4.9
All syst.(except lumi.)	+16.4/-14.4	+8.8/-6.4	+8.2/-6.8	+27.9/-20.7	+26.5/-23.7	+8.0/-6.5
Stat. + syst.	+18.9/-16.9	+11.6/-9.5	+10.1/-8.8	+31.8/-25.2	+30.7/-27.8	+9.6/-8.2

ATLAS all-hadronic channel

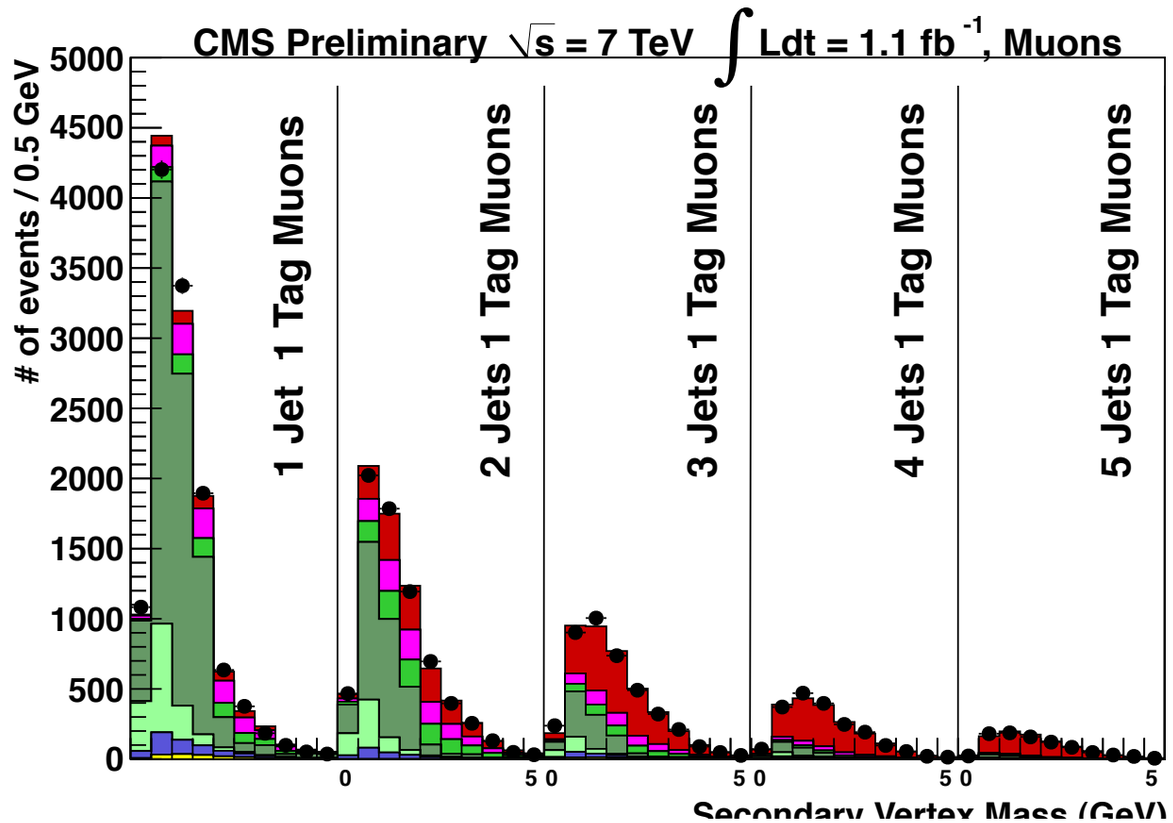
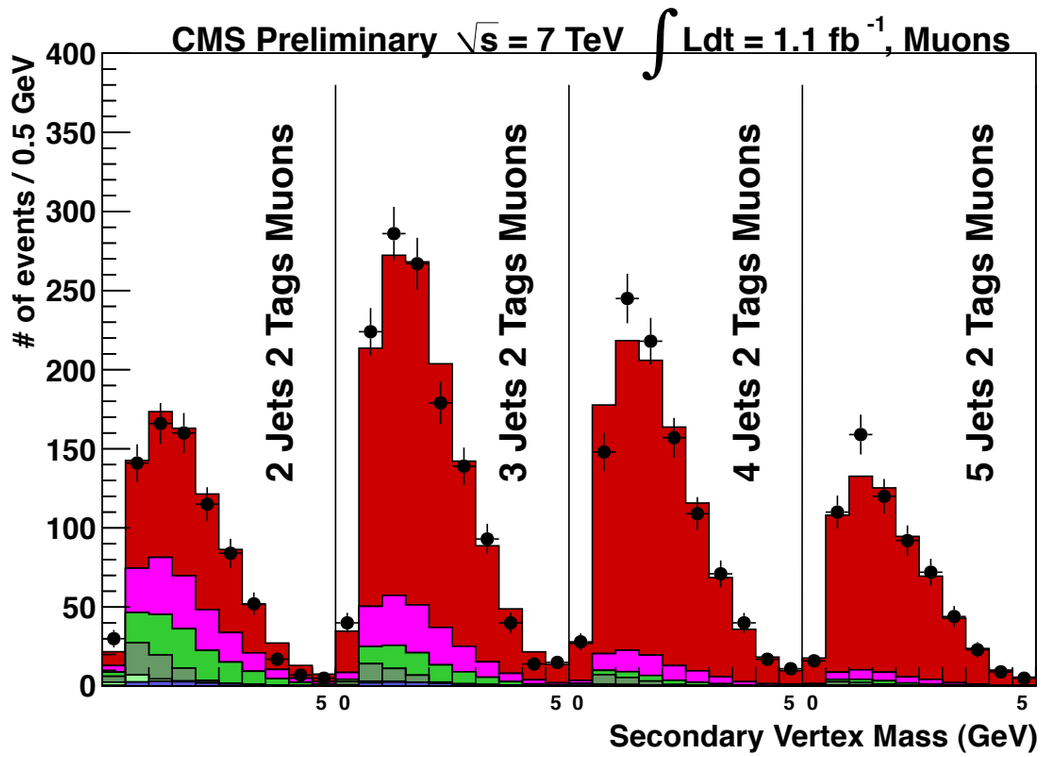
Likelihood fit of templates based on ttbar mass fit

- 2011 data with 1.02 fb^{-1}
- Single channel with a 2 b-jet requirement
- Data-driven QCD estimation based on "Event Mixing"
- Cross Section is extracted using a likelihood fit for the signal fraction in data
- Systematics measured using shifted templates, and errors added in quadrature

$$\chi^2 = \frac{\left(M_{j_1,j_2} - M_w\right)^2}{\sigma_w^2} + \frac{\left(M_{j_1,j_2,b_1} - M_t\right)^2}{\sigma_t^2} + \frac{\left(M_{j_3,j_4} - M_w\right)^2}{\sigma_w^2} + \frac{\left(M_{j_3,j_4,b_2} - M_t\right)^2}{\sigma_t^2}$$



$$\sigma(pp \to t\bar{t}) = 167 \pm 18\ (\text{stat.}) \pm 78\ (\text{syst.}) \pm 6\ (\text{lum.})\ \text{pb}$$

CMS l+jets channel

- Fit to secondary mass distribution in
  - njets = 1,2,3,4 and ≥5
  - nbtag = 1,2
- Profile likelihood fit