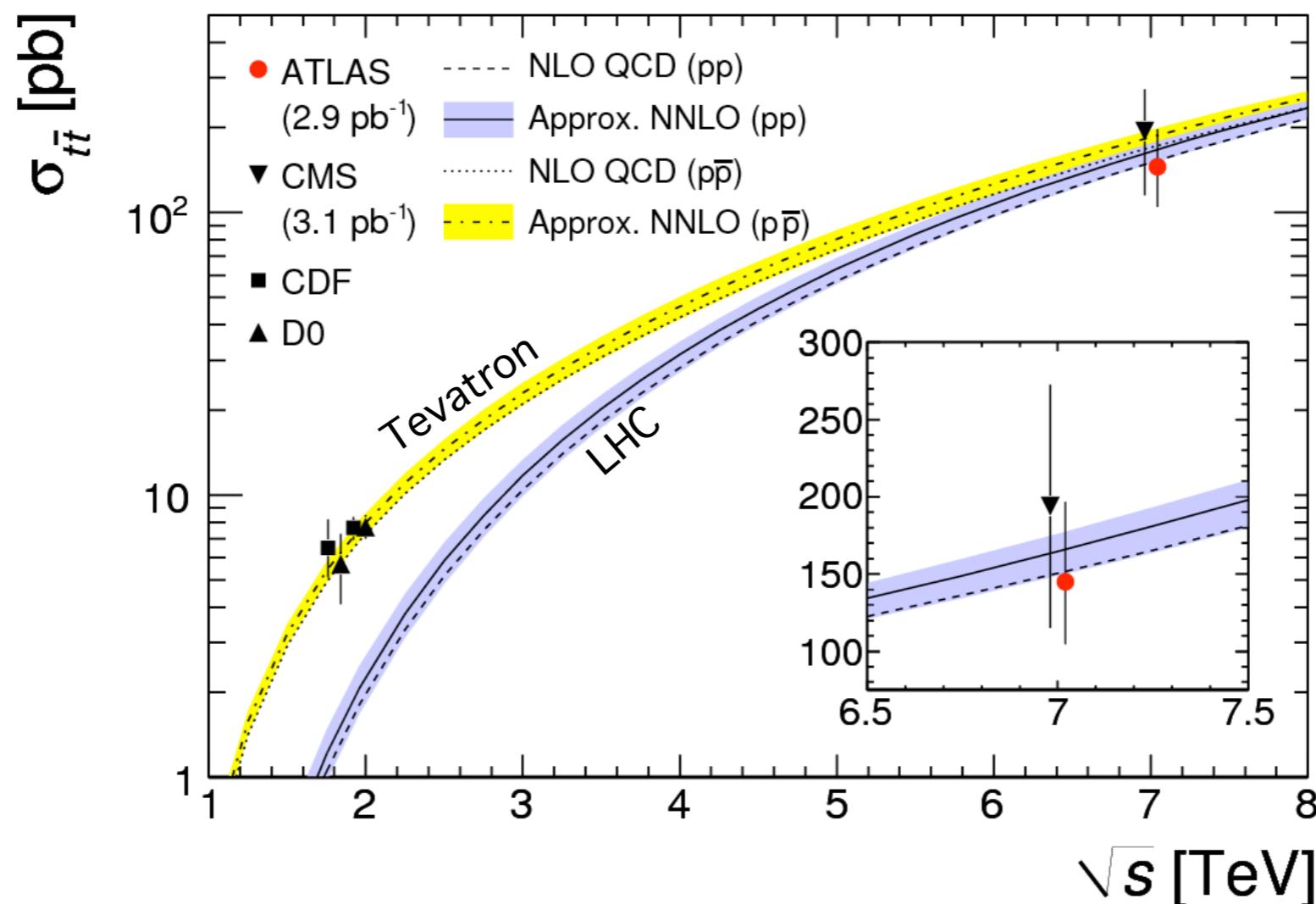


# multivariate top-pair cross-section measurement in semi-leptonic channel

first top precision measurements from the **ATLAS** experiment

autumn 2010



Clemens Lange (DESY)

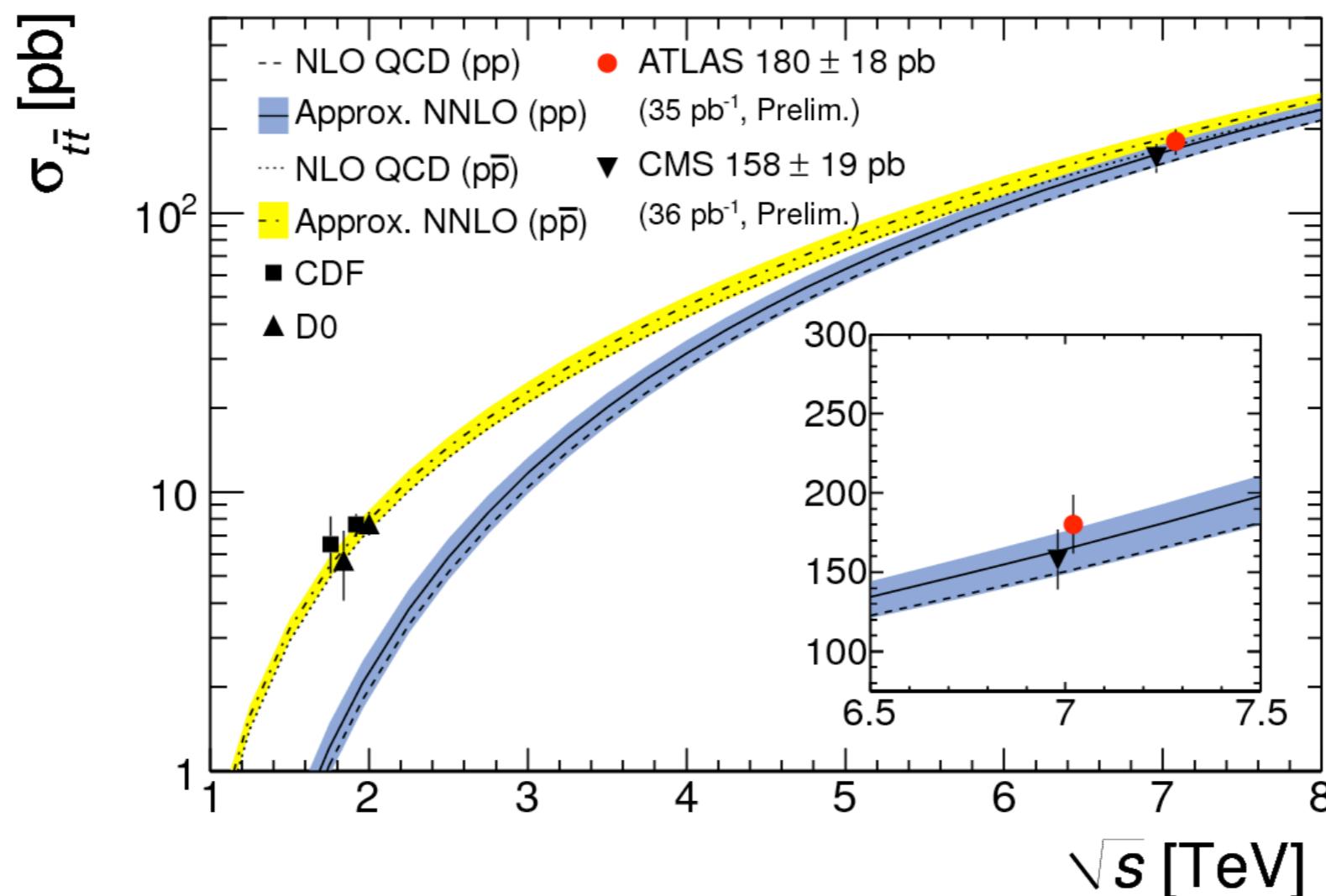
Alliance Workshop on Top Quark Physics  
Wuppertal  
7<sup>th</sup> April 2011



# multivariate top-pair cross-section measurement in semi-leptonic channel

first top precision measurements from the **ATLAS** experiment

winter 2011



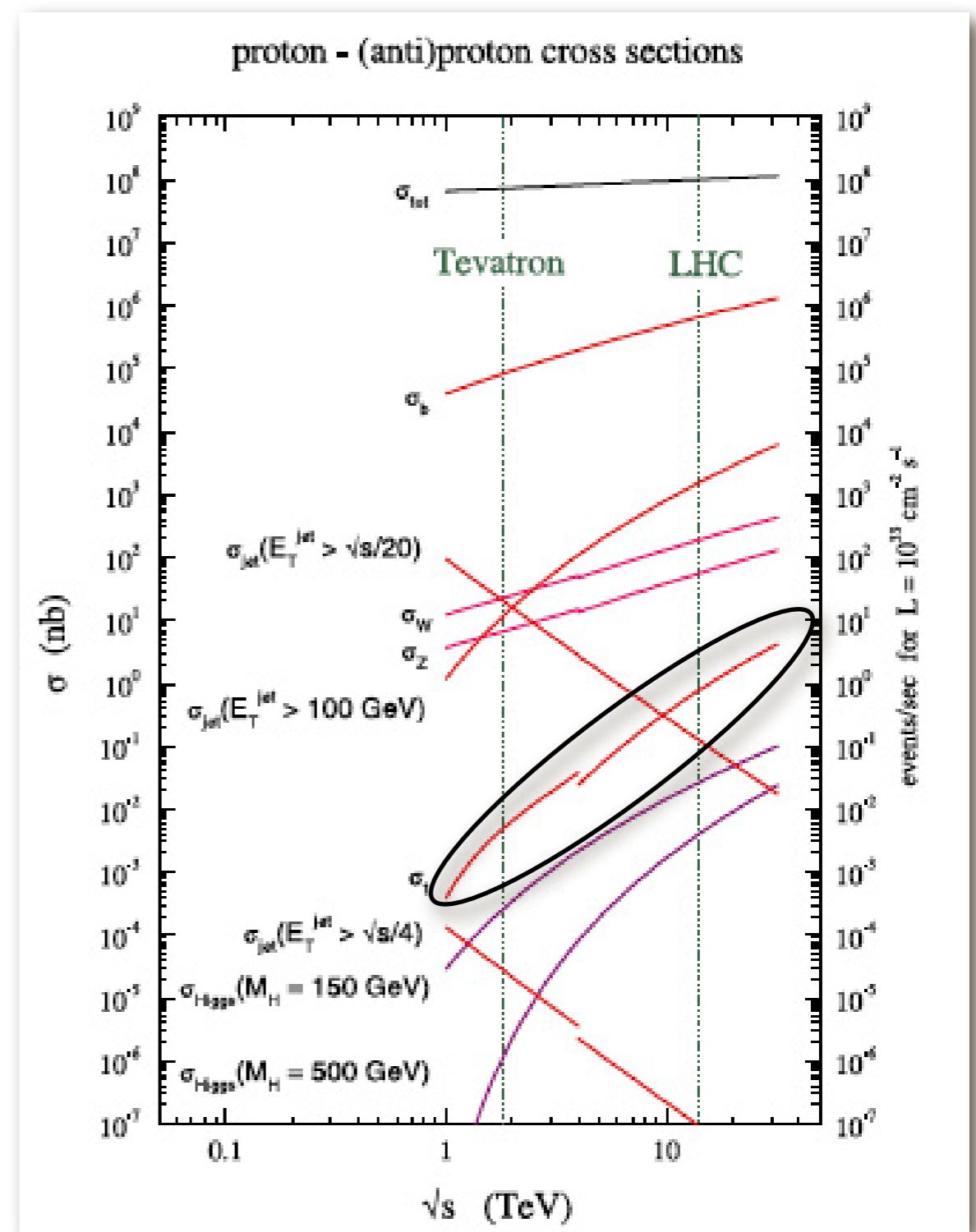
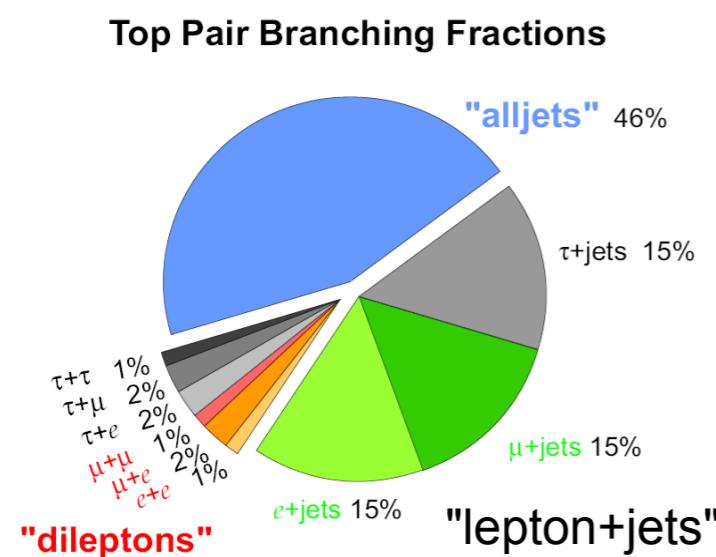
Clemens Lange (DESY)

Alliance Workshop on Top Quark Physics  
Wuppertal  
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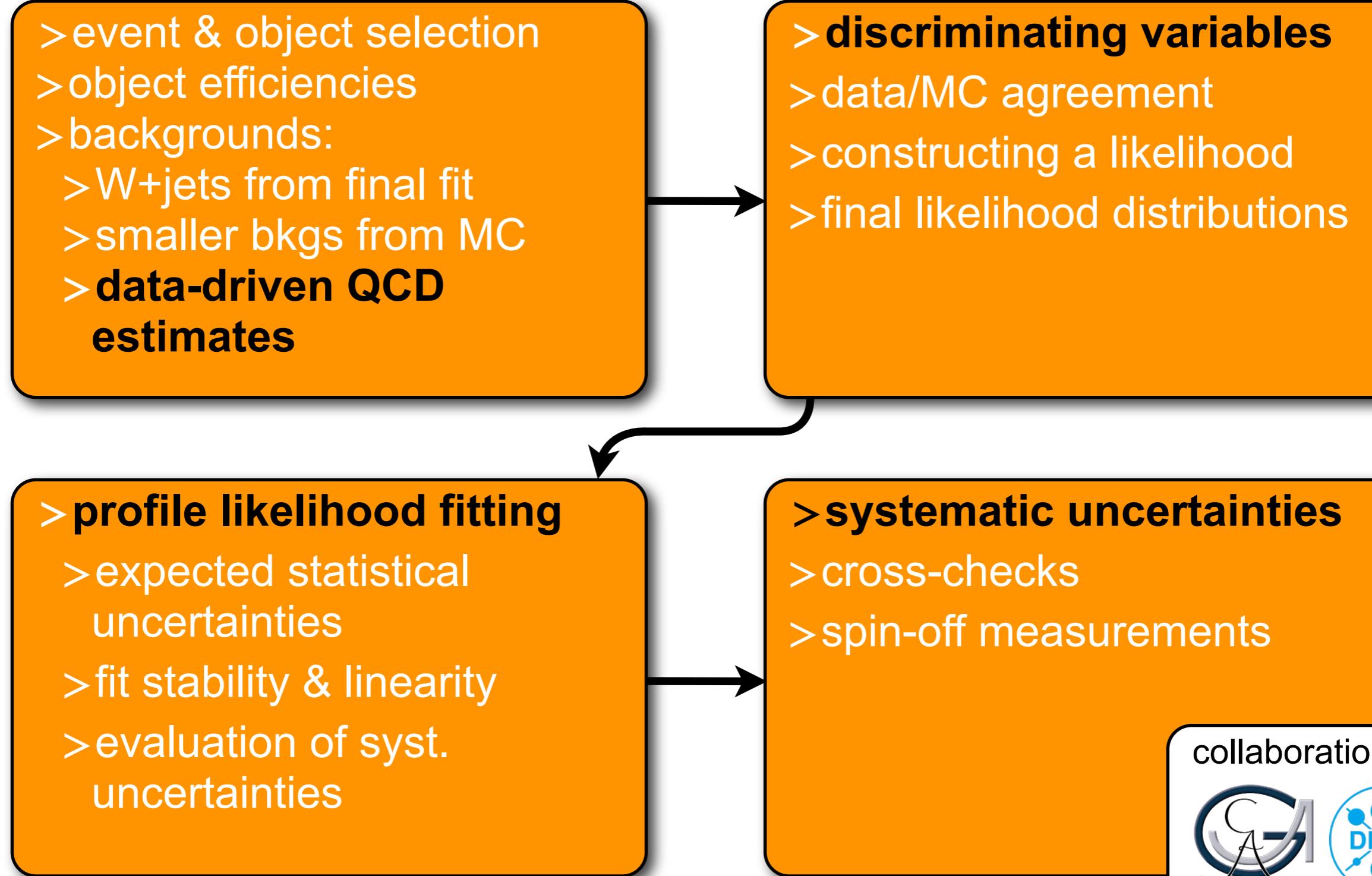


# top cross-section precision measurement

- production cross-section important test of theory
- new standard candle for high-p<sub>T</sub> physics
- strategy:
  - combine a few sensitive variables into a likelihood discriminant
  - measure xsec using profile likelihood technique
- semi-leptonic channel balances signal and background ( $\ell = e, \mu$ )



# building blocks of analysis



see ATLAS-CONF-2011-035

# Monte Carlo samples

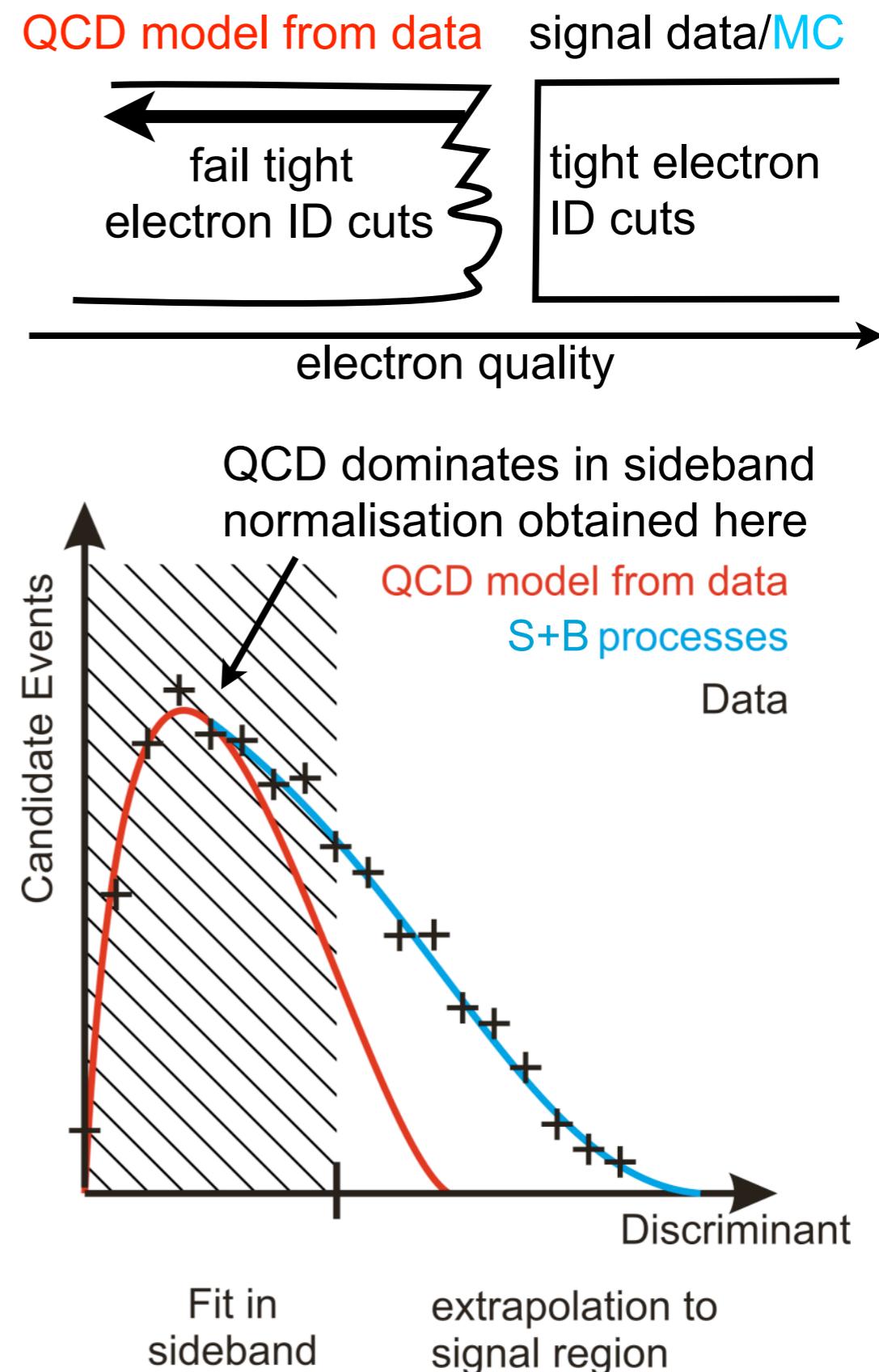
- MC@NLO used for ttbar and single top events (CTEQ66,  $m_t = 172.5 \text{ GeV}$ )
- ttbar normalised to HATHOR prediction at approx. NNLO (Moch & Uwer, Beneke et al.), central value:

$$\sigma_{t\bar{t}} = 164.6^{+11.4}_{-15.7} \text{ pb}$$

- uncertainty given as linear sum of pdf and scale uncertainty
- W+jets and Z+jets events generated by Alpgen+Herwig+Jimmy (CTEQ6L1), normalised to NNLO prediction by MCFM
- double counting of W+jets and W+heavy flavour events removed based on an angular scheme
- diboson background using Herwig (MRST2007 LO\*), normalised to NNLO
- QCD background taken from data
  - well understood in theory, but in this study instrumental effect
  - MC production limited by computing power

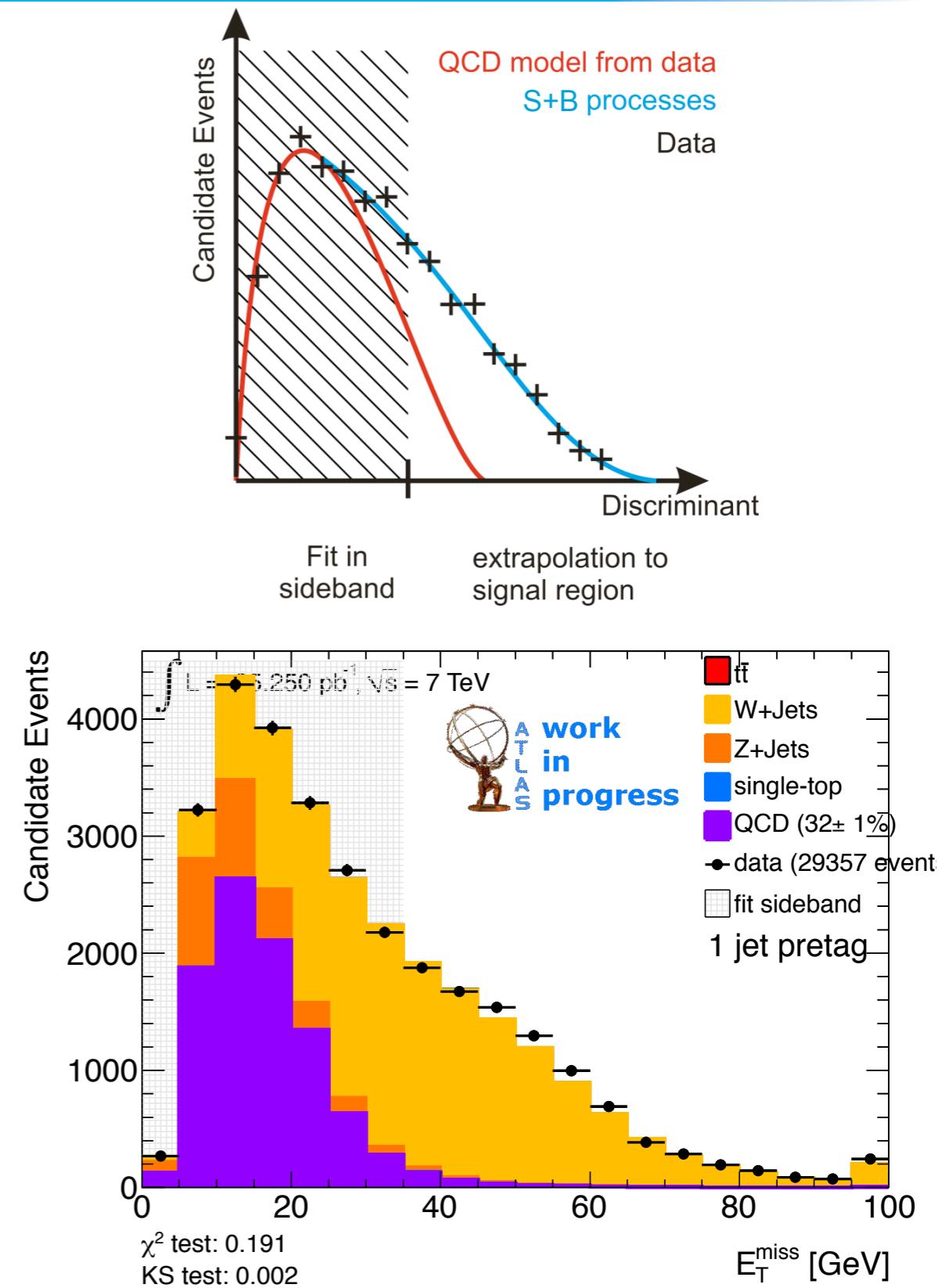
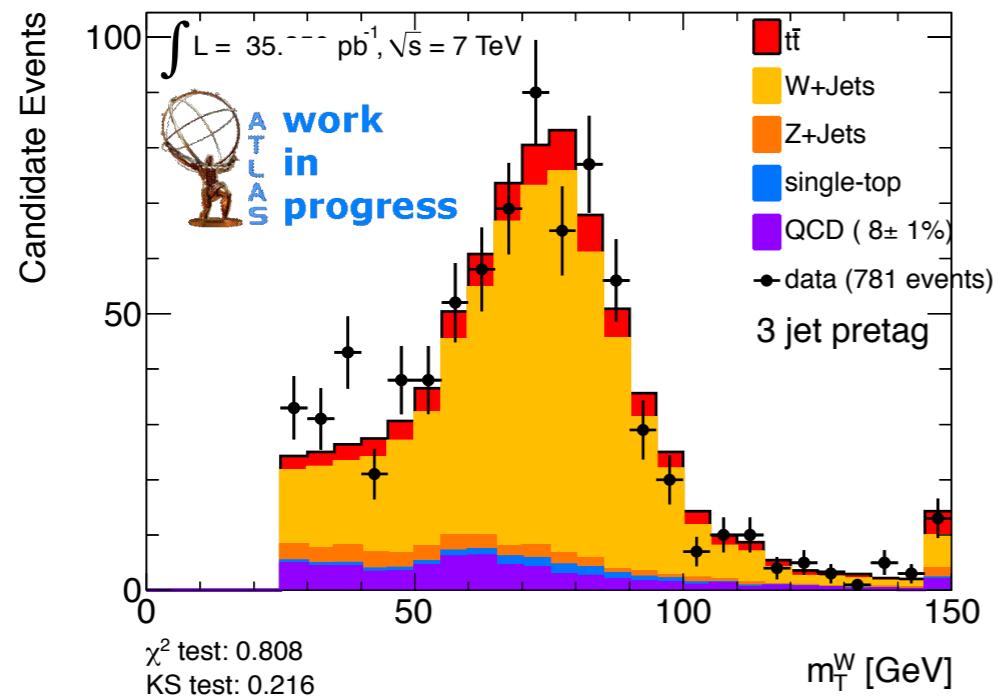
# modelling QCD from data

- > need to find region where QCD dominates while staying as close as possible to signal selection
- > select sample orthogonal to standard top selection by inverting cut on electron particle ID selection  
→ **anti-electron sample - provides full QCD model**
- > find distribution that is sensitive to lepton fakes → **missing transverse energy** (QCD here mostly instrumental background)
- > shape of QCD background taken from data, but model provides no cross-section → **determine amount of QCD background from fit**



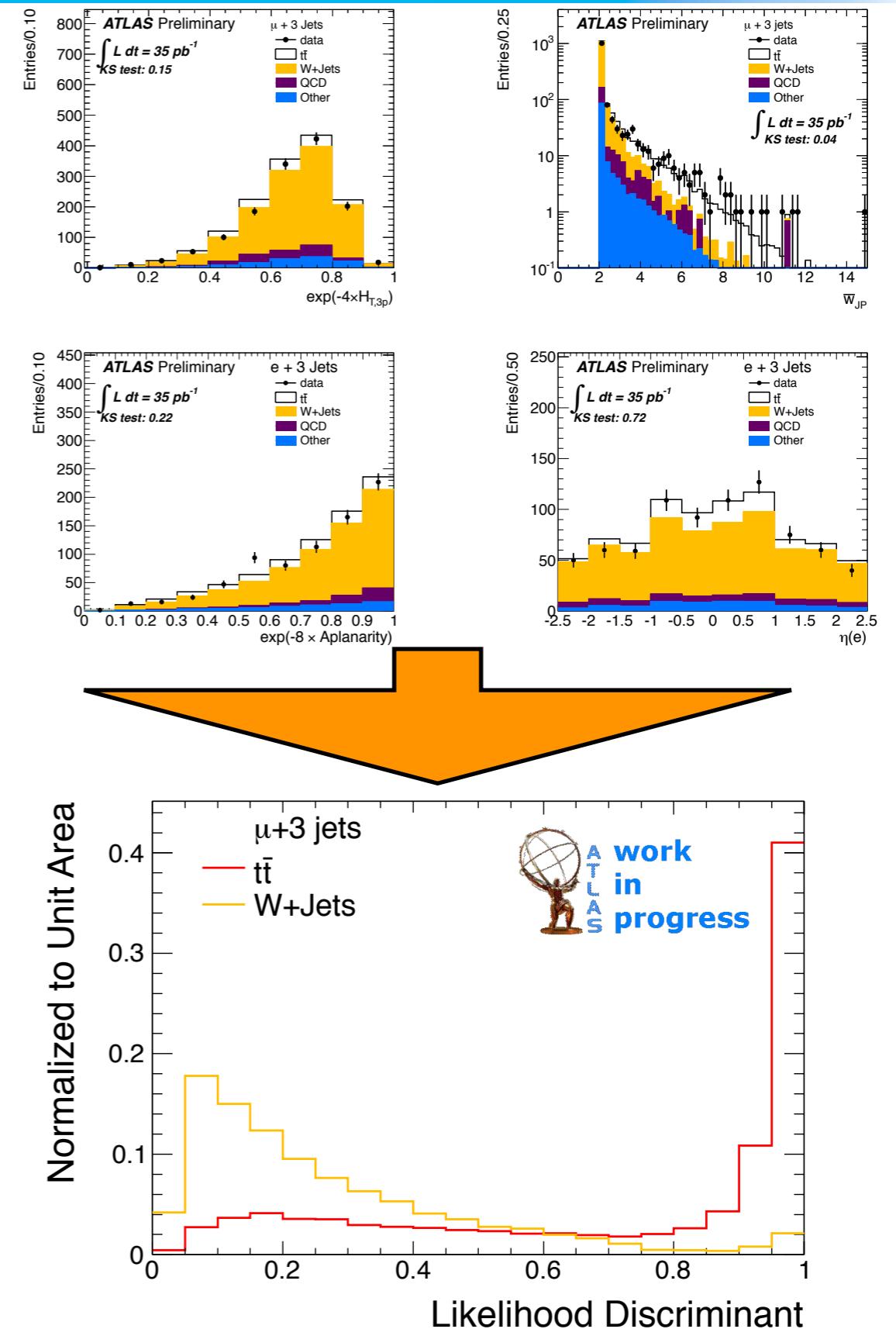
# anti-electron model

- if we can fit in sideband we can perform another fit ( $W+jets$  background) in the signal region later
- top selection applies MET cut of 35 GeV → **use 0-35 GeV sideband for fit and extrapolate**
- all processes taken from MC and scaled to SM expectation
- **several distributions well modelled**



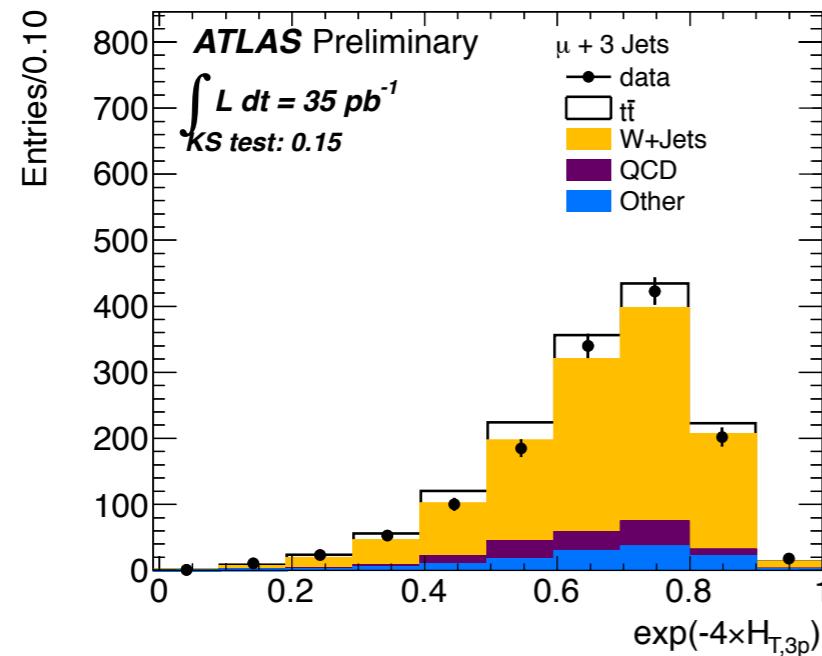
# cross-section measurement input & fitter

- combine sensitive variables into one likelihood discriminant
- 6 analysis channels:
  - 3 (constrain W+jets), 4 and 5+ jet bins
  - each for electron and muon channel
- Gaussian constraints applied to processes according to their uncertainties
- fit all channels simultaneously
  - top signal treated as 100% correlated
- statistical uncertainty:
  - sum of all template contributions in a bin gets Gaussian constraint corresponding to template statistical uncertainty
  - one parameter for each bin

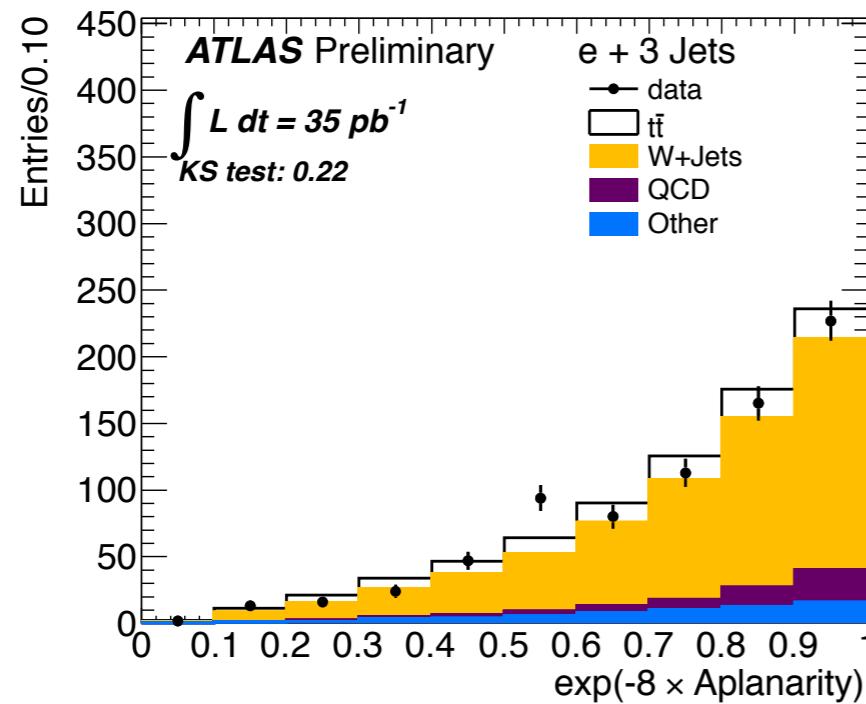


# input distributions in detail

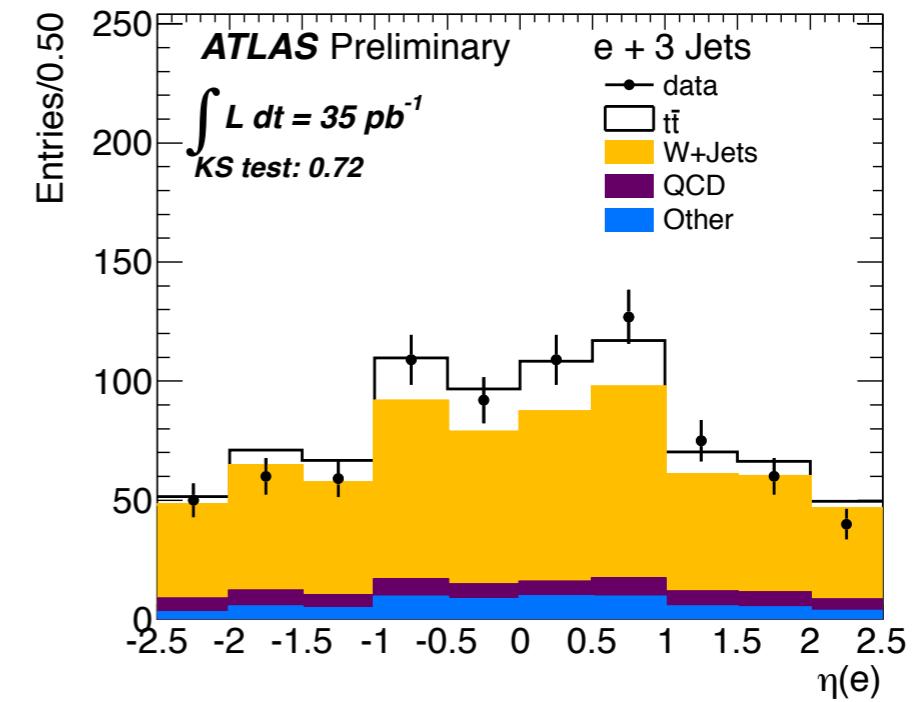
$$H_{T,3p} = \frac{\sum_{i=3}^{N_{\text{jets}}} |p_{T,i}^2|}{\sum_{j=1}^{N_{\text{objects}}} |p_{z,j}|}$$



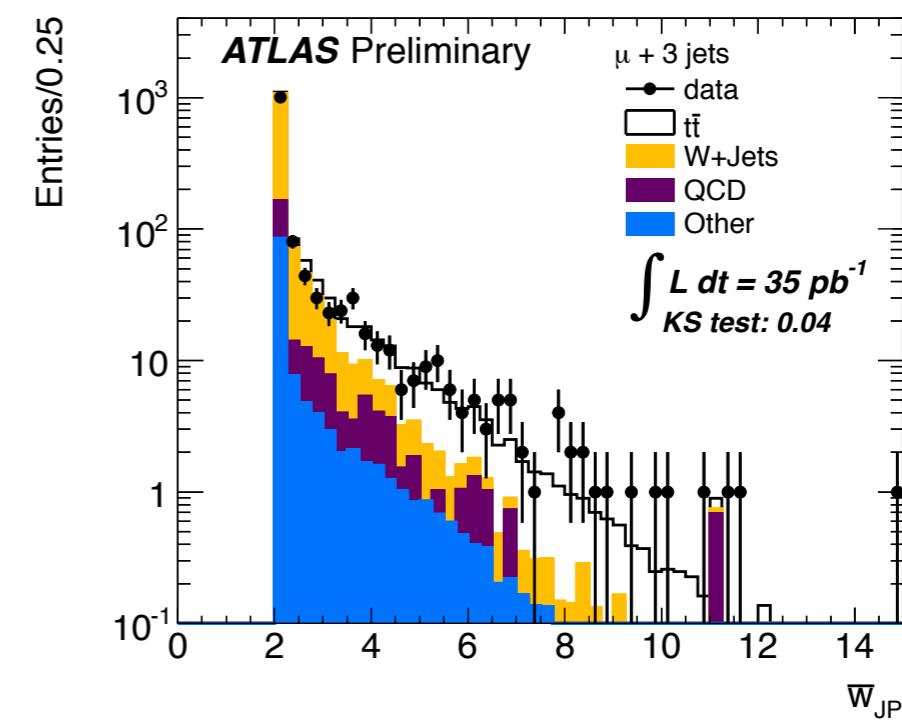
aplanarity



lepton  $n$

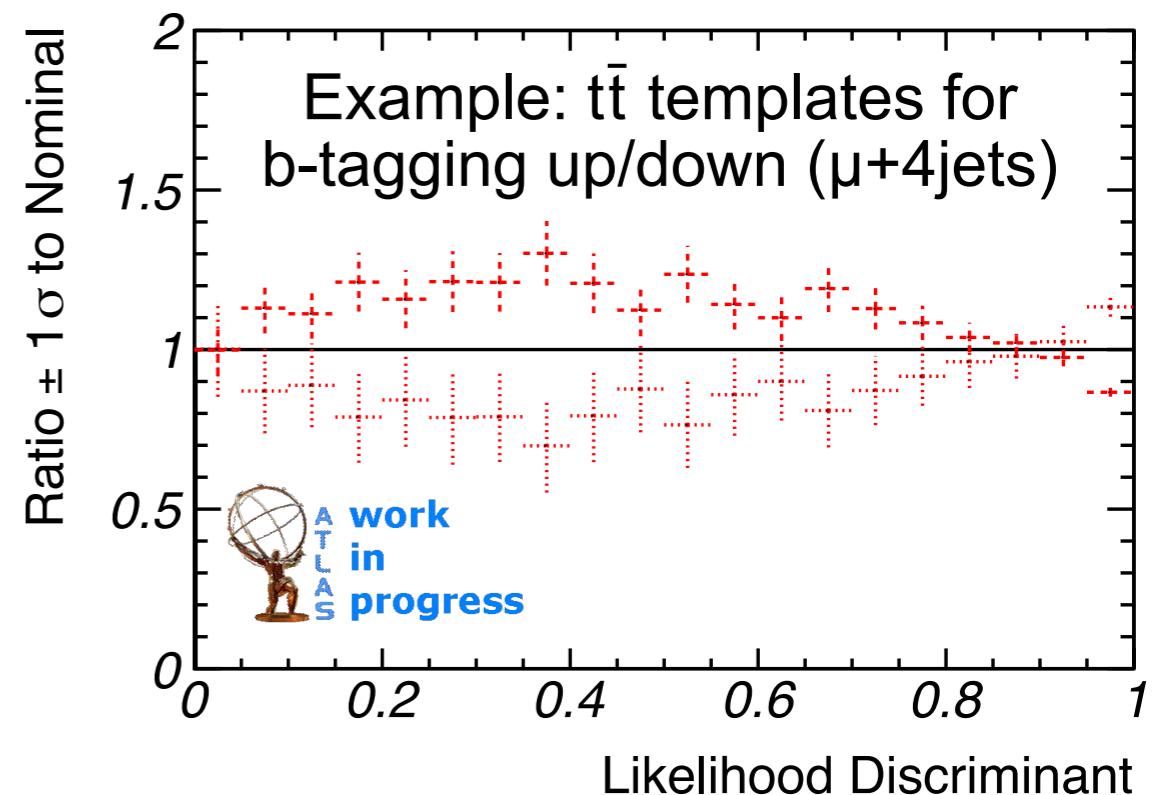
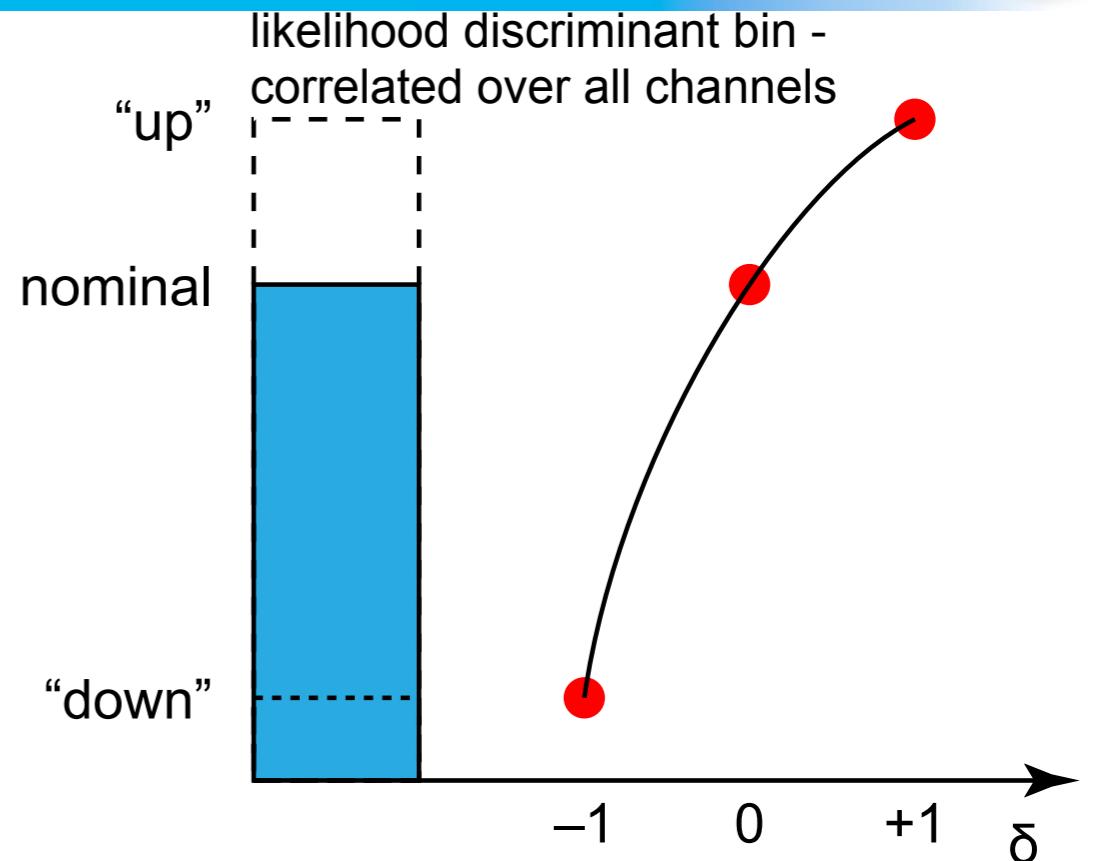


mean tag weight of two jets with highest weight



# nuisance parameters

- systematic uncertainties considered as nuisance parameters  $\delta_i$ 
  - „up“ and „down“ templates in addition to nominal for each  $\pm 1\sigma$  variation
- each nuisance parameter assumed to be Gaussian with mean 0
  - vertical morphing of templates → continuous parameters  $\delta_i$
  - quadratic interpolation for  $|\delta_i| < 1$  (Lagrange polynomials), linear extrapolation beyond
- systematics enter as parameters in the minimisation process
- let data adjust size of corresponding systematic uncertainty
- fit error of one corresponds to variation given for the input uncertainty



# summary of systematic uncertainties

dominant systematics:

➤ W+jets heavy flavour content

- extrapolation of HF fraction from lower jet bins to signal region

➤ b-tagging calibration

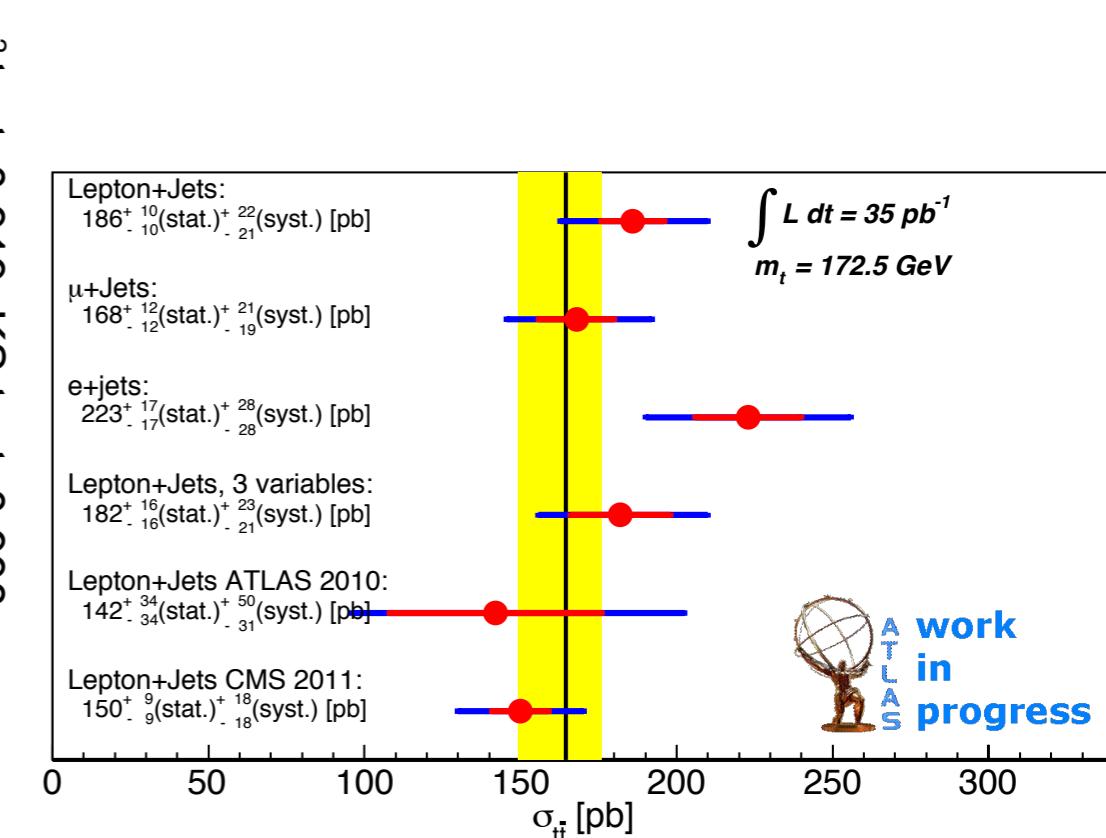
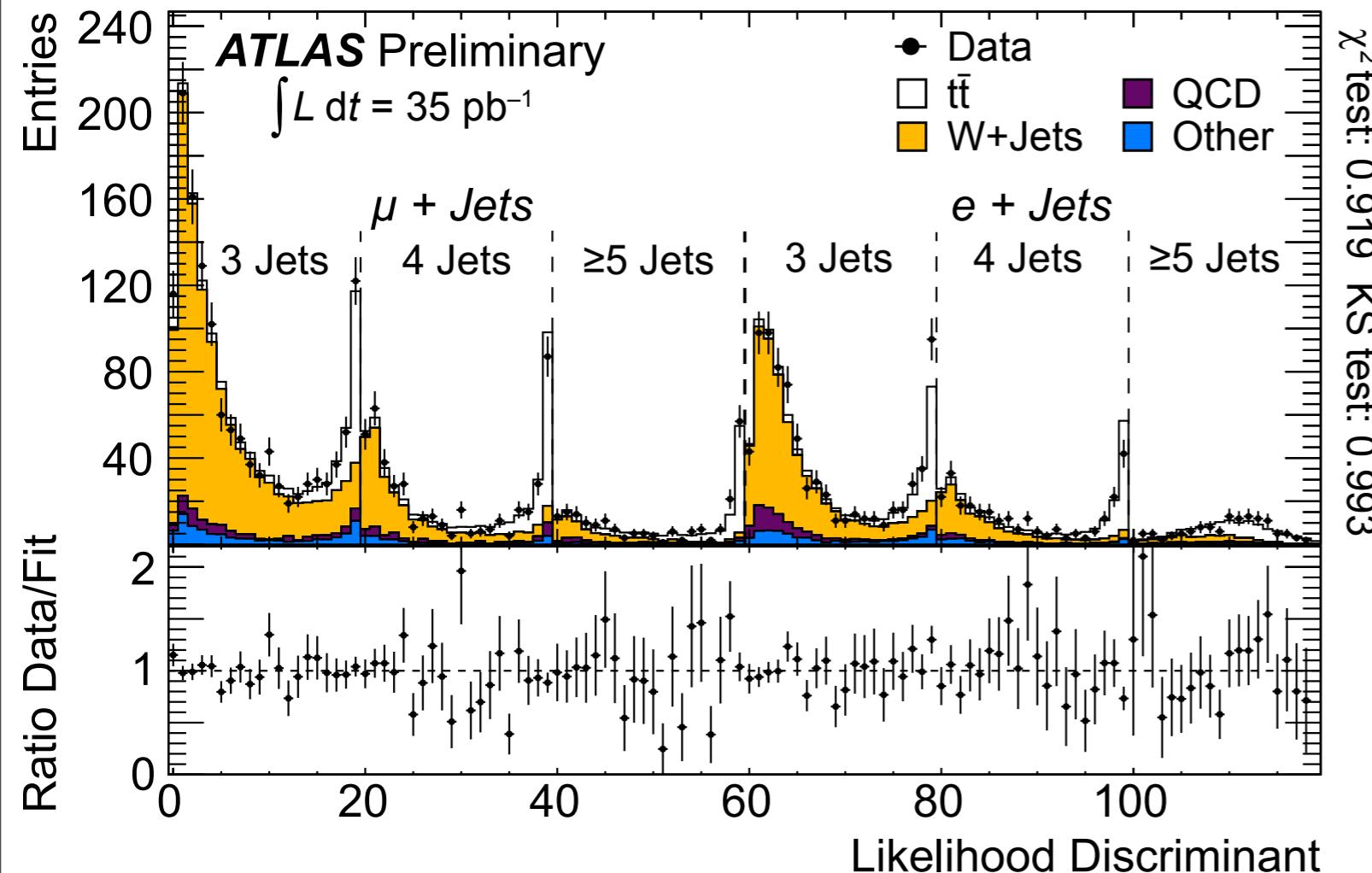
➤ ISR/FSR

- no recipe for MC@NLO available
- use AcerMC and vary parameters

Statistical Error (%)	+5.3	-5.2
<b>Object selection (%)</b>		
Jet energy scale	+3.8	-2.8
Jet reconstruction efficiency	+4.2	-4.2
Jet energy resolution	+0.8	-0.2
Electron scale factor	+1.2	-0.8
Muon scale factor	+0.5	-0.6
Electron smearing	+0.3	-0.2
Muon smearing	+0.6	-0.4
<b>Background modeling (%)</b>		
Wjets HF content	+7.2	-6.3
Wjets shape	+1.5	-1.5
QCD shape	+1.0	-1.0
<b>t̄t signal modeling (%)</b>		
ISR/FSR	+4.0	-4.0
NLO generator	+0.5	-0.7
Hadronisation	+0.0	-0.6
PDF	+1.7	-1.7
<b>Others (%)</b>		
b-tagging calibration	+7.5	-6.3
Simulation of pile-up	+1.5	-0.6
Templates statistics	+1.6	-1.5
<b>Total Systematic (%)</b>	<b>+11.5</b>	<b>-10.5</b>



# results



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

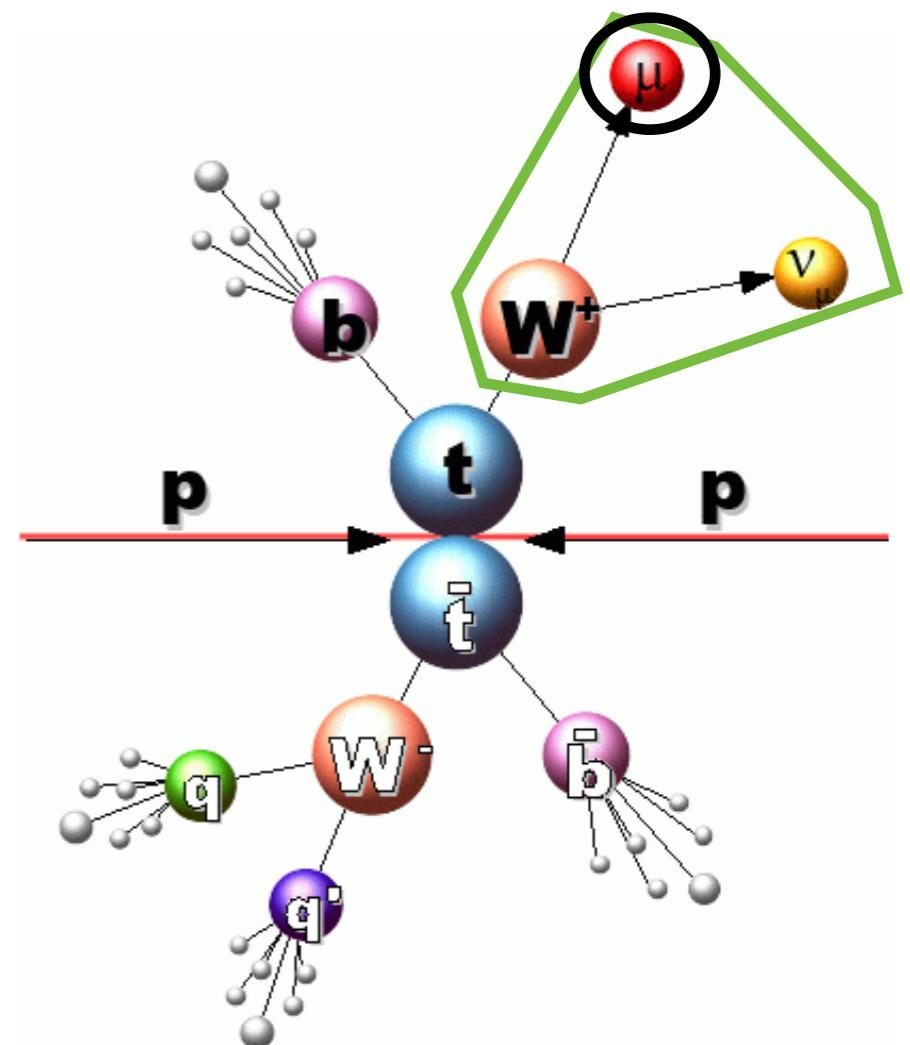
most precise measurement of  $\sigma_{t\bar{t}}$  @ 7 TeV @ ATLAS

# backup



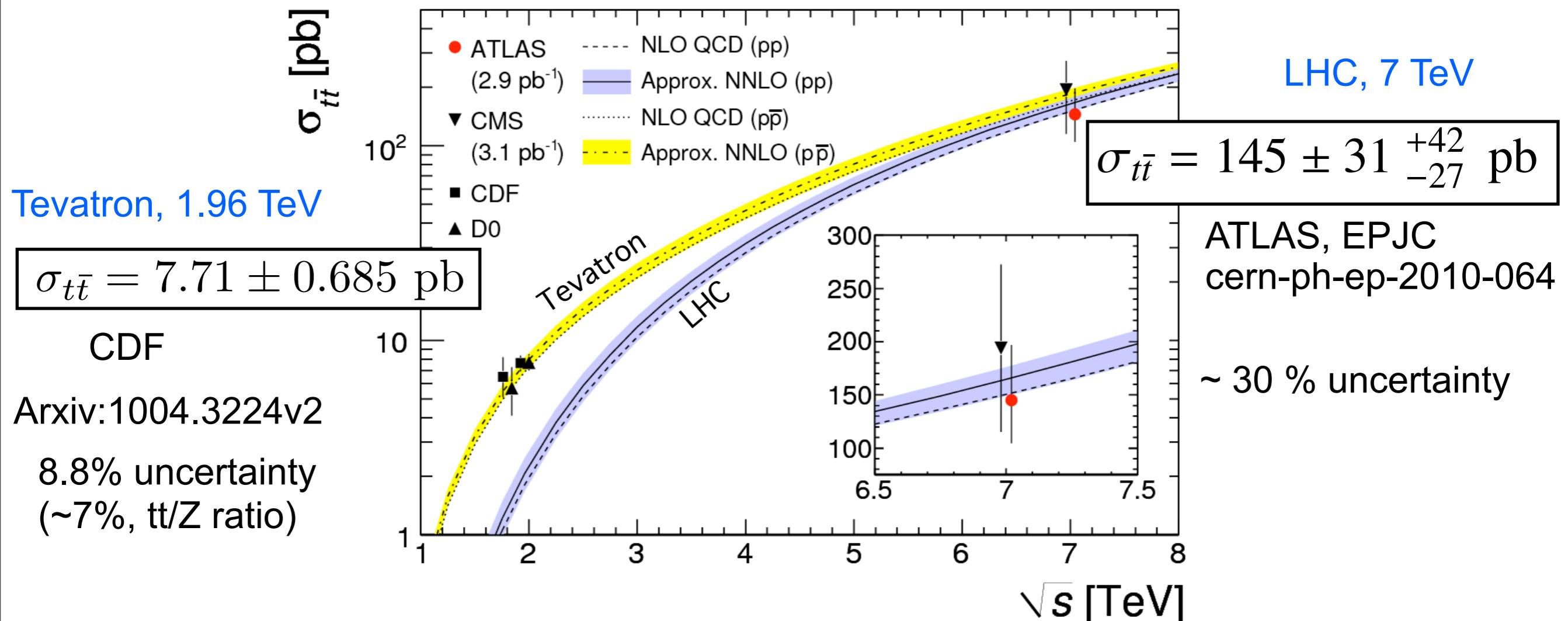
# data-driven QCD background estimation

- QCD contributes only due to mis-identified leptons (electron fake rate of order  $10^{-3}$ - $10^{-4}$ )
- QCD MC production limited by computing power
- mostly instrumental background, difficult to model → **take from data**
- my work: **QCD estimation in electron channel**
- muon channel uses matrix method
- fake electrons mostly collimated jets, photon conversions



# Where do we stand?

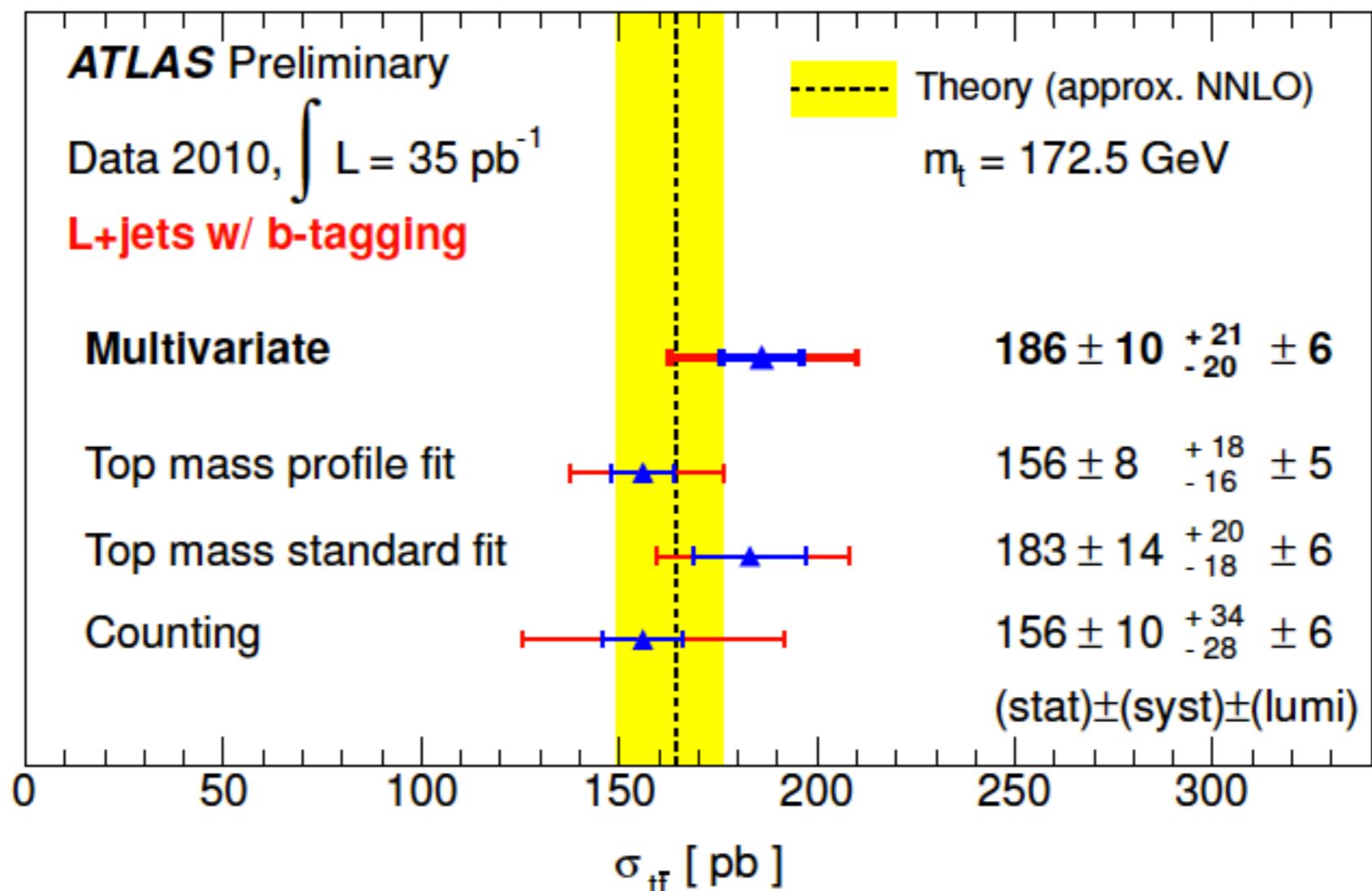
Summer 2010



# full fit result table

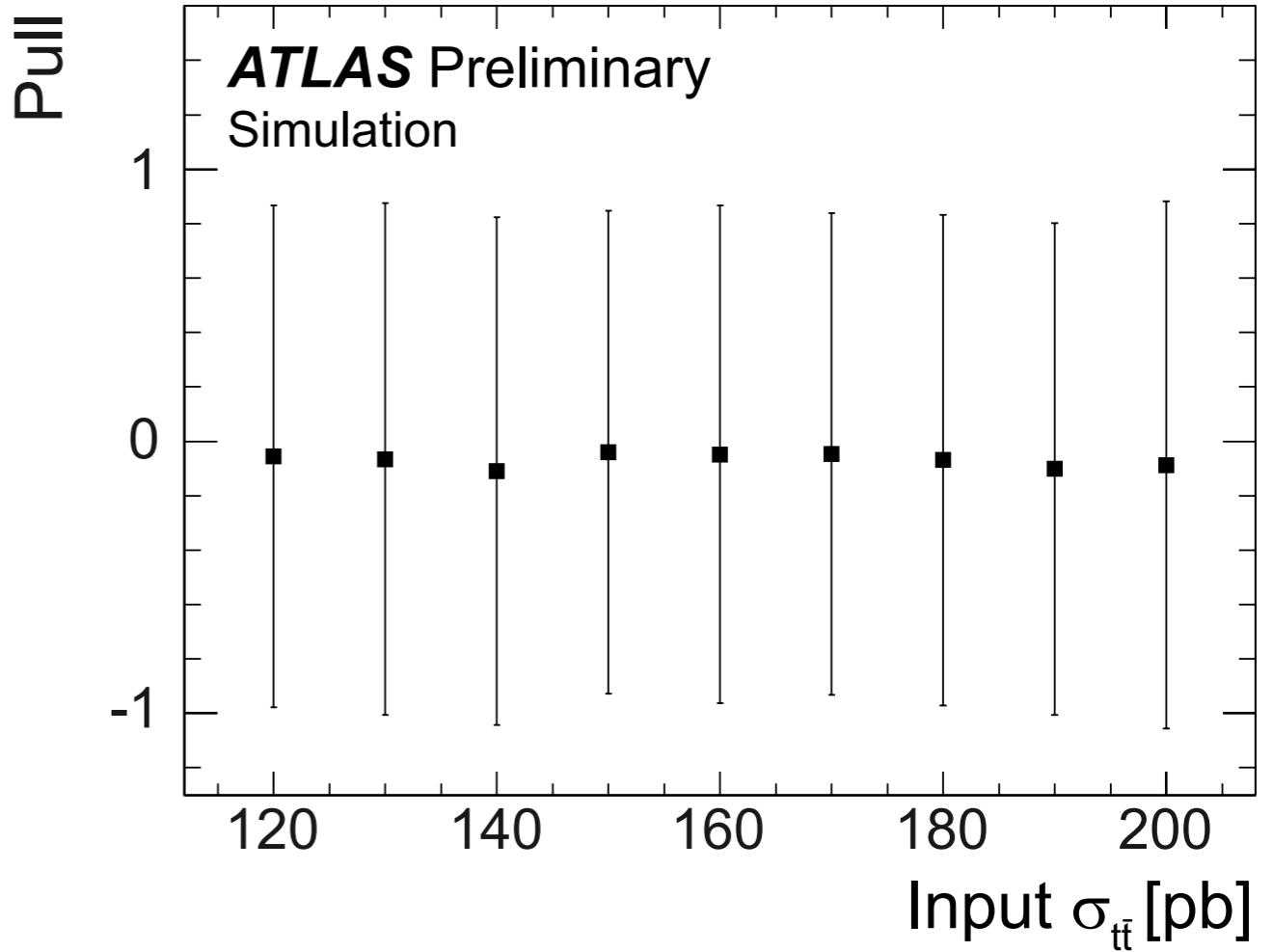
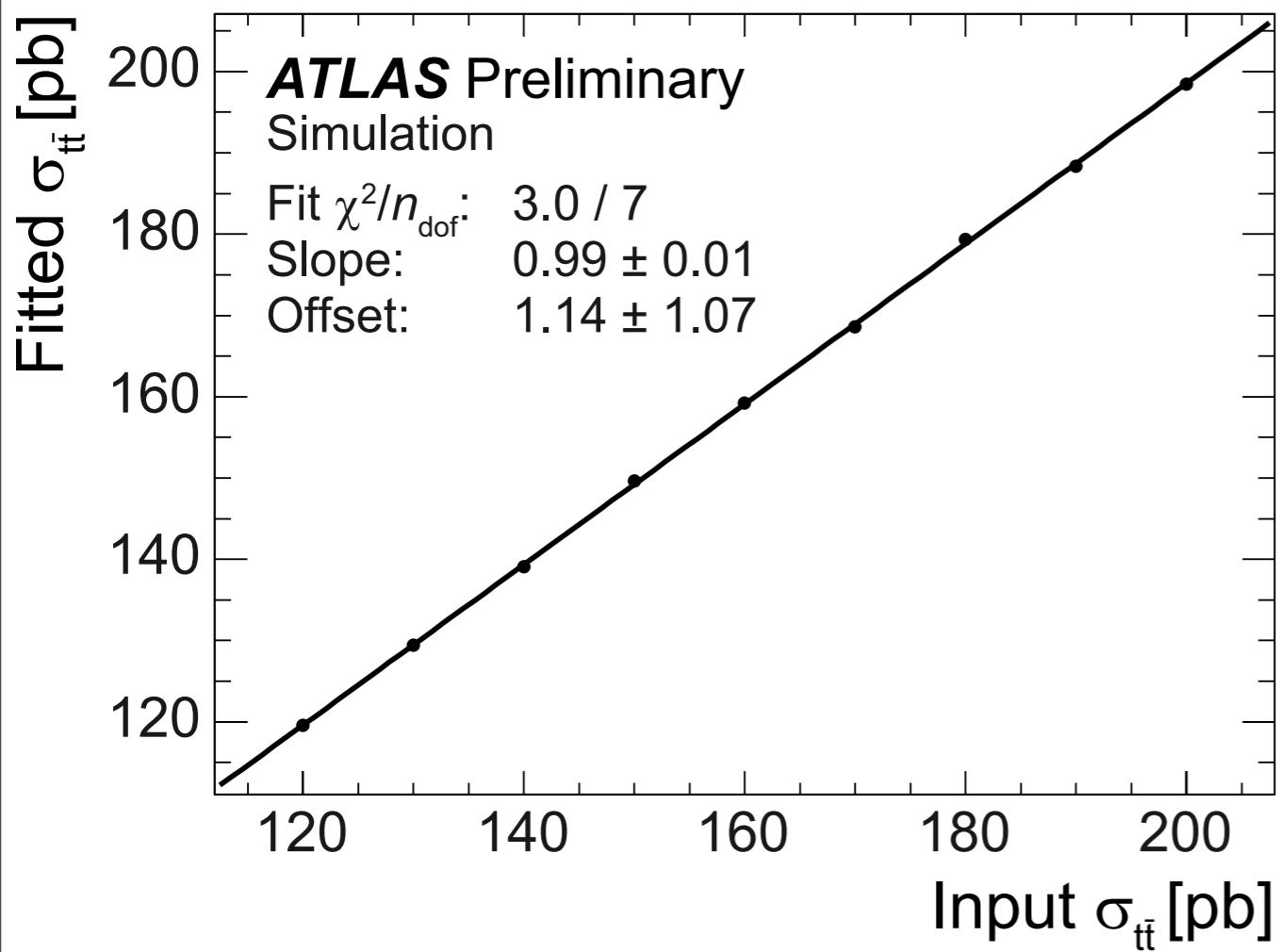
Parameter	Value	Error	Error Up	Error Down
$\beta(t\bar{t})$	1.125	0.125	0.132	-0.120
$\beta(W+jets)$ in $\mu+3$ Jets	1.078	0.115	0.111	-0.114
$\beta(W+jets)$ in $\mu+4$ Jets	1.089	0.147	0.145	-0.145
$\beta(W+jets)$ in $\mu+5$ Jets	1.101	0.269	0.277	-0.258
$\beta(W+jets)$ in $e+3$ Jets	1.040	0.142	0.139	-0.137
$\beta(W+jets)$ in $e+4$ Jets	1.200	0.265	0.276	-0.238
$\beta(W+jets)$ in $e+5$ Jets	0.949	0.335	0.343	-0.323
$\beta(Z+jets)$	1.071	0.310	0.307	-0.310
$\beta(\text{single } t)$	1.013	0.105	0.105	-0.105
$\beta(\text{diboson})$	1.000	0.060	0.060	-0.060
$\beta(\text{QCD})$ in $\mu+3$ Jets	0.506	0.409	0.411	-0.412
$\beta(\text{QCD})$ in $\mu+4$ Jets	0.928	0.466	0.467	-0.467
$\beta(\text{QCD})$ in $\mu+5$ Jets	0.738	0.445	0.446	-0.445
$\beta(\text{QCD})$ in $e+3$ Jets	1.029	0.483	0.485	-0.486
$\beta(\text{QCD})$ in $e+4$ Jets	0.992	0.495	0.496	-0.496
$\beta(\text{QCD})$ in $e+5$ Jets	0.969	0.492	0.492	-0.493
$\delta(b\text{-tagging WP1})$	-0.229	0.562	0.564	-0.544
$\delta(b\text{-tagging WP2})$	0.545	0.603	0.566	-0.618
$\delta(\text{mistags WP1})$	0.041	0.656	0.663	-0.637
$\delta(\text{mistags WP2})$	0.143	0.586	0.583	-0.571
$\delta(\text{JES})$	-0.521	0.403	0.419	-0.347
$\delta(\text{Jet Efficiency})$	-0.083	0.817	0.806	-0.826
$\delta(\text{JER})$	0.914	0.628	0.618	-0.633
$\delta(\text{MC Generator (POWHEG+Herwig)})$	-0.214	0.563	0.572	-0.549
$\delta(\text{Hadronization (POWHEG+Pythia)})$	-0.035	0.711	0.708	-0.710
$\delta(Wb\bar{b}/c\bar{c} \text{ Fraction})$	-0.009	0.642	0.635	-0.651
$\delta(Wc \text{ Fraction})$	-0.111	0.929	0.927	-0.927
$\delta(\text{Pileup})$	-0.221	0.582	0.594	-0.572
$\delta(\mu \text{ SFs})$	-0.215	0.867	0.874	-0.762
$\delta(e \text{ SFs})$	0.341	0.874	0.828	-0.891
$\delta(\mu \text{ Smearing})$	-0.372	0.757	0.754	-0.734
$\delta(e \text{ Resolution})$	-0.053	1.022	0.970	-0.972

# cross-check results comparison



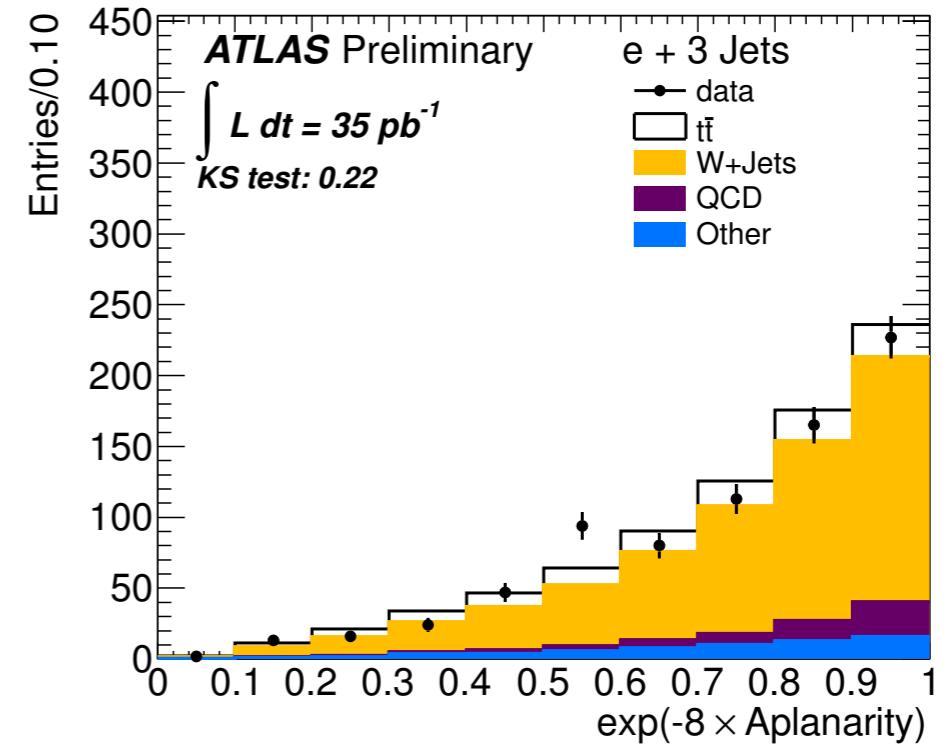
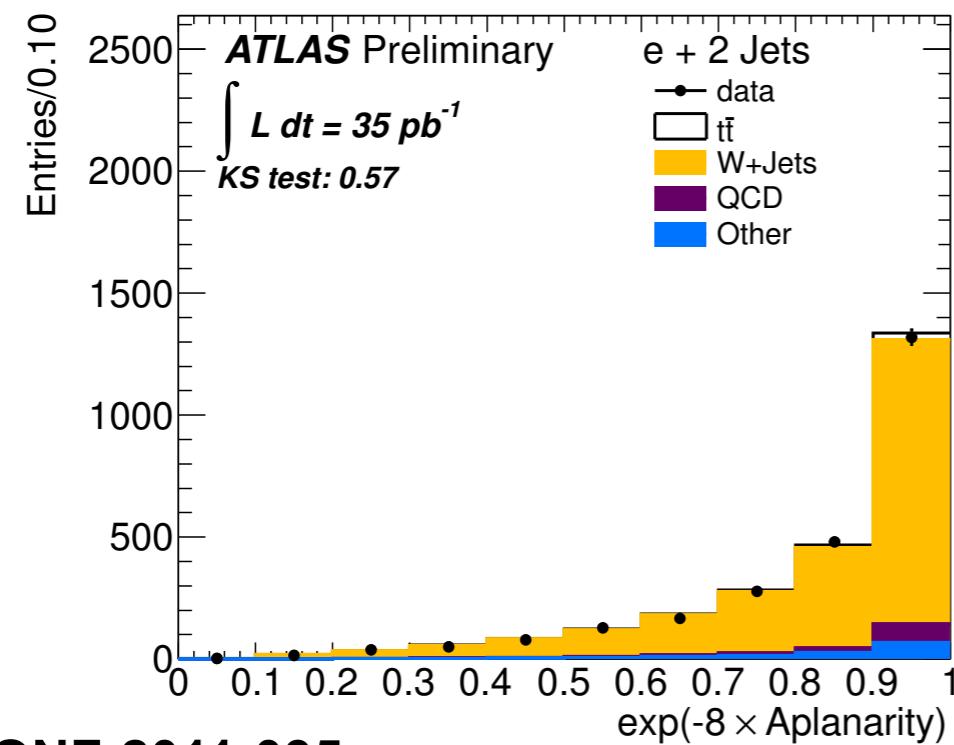
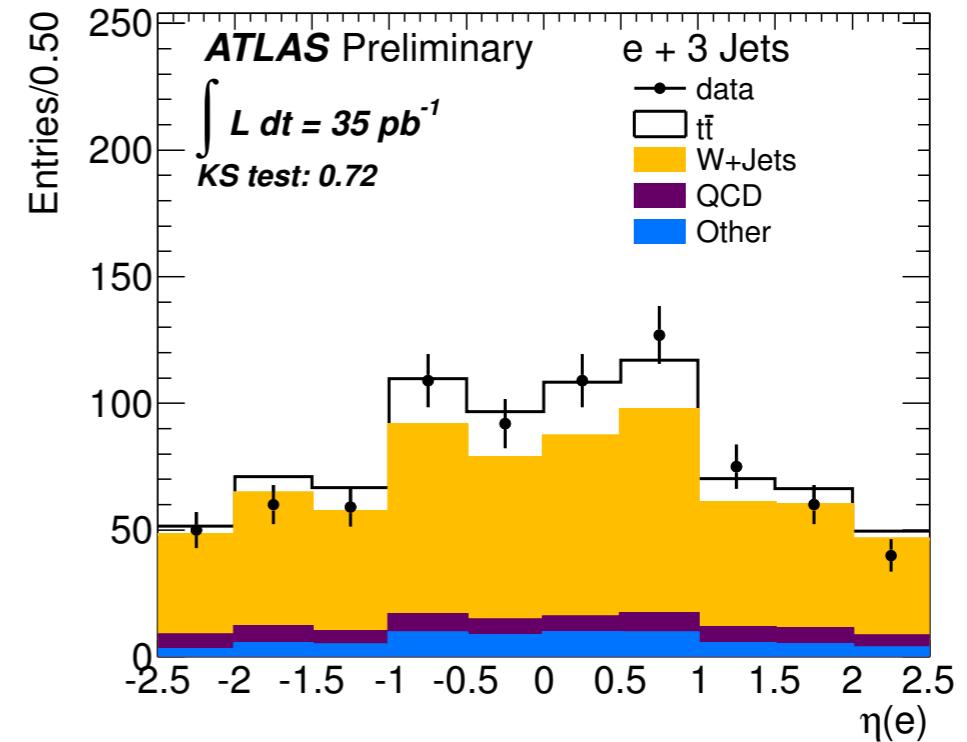
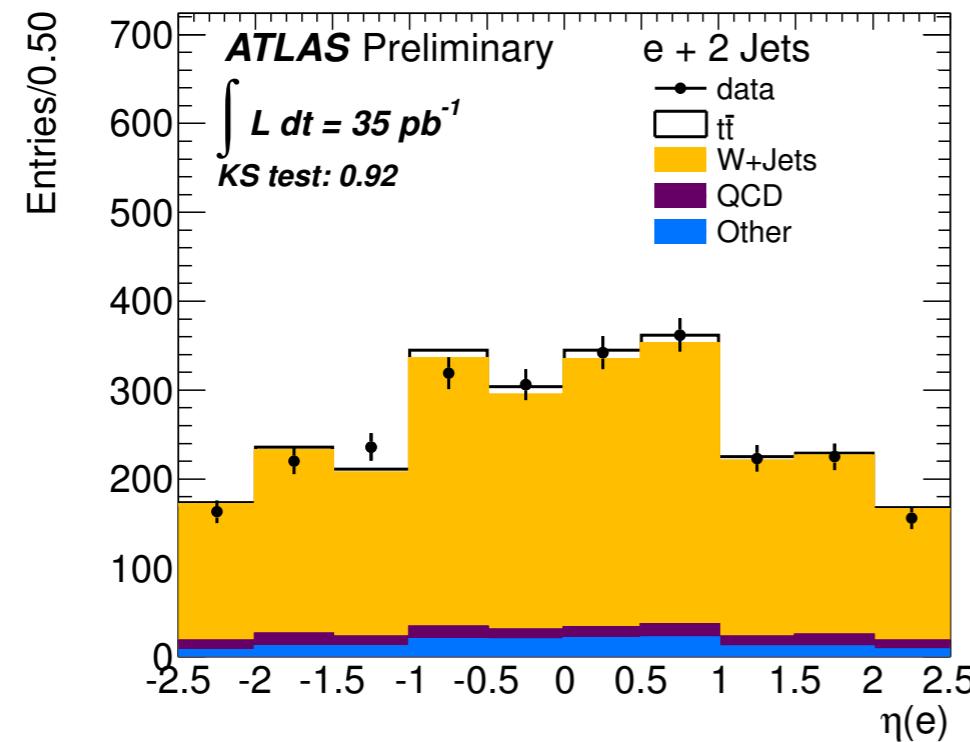
ATLAS-CONF-2011-035

# linearity of fit & pulls



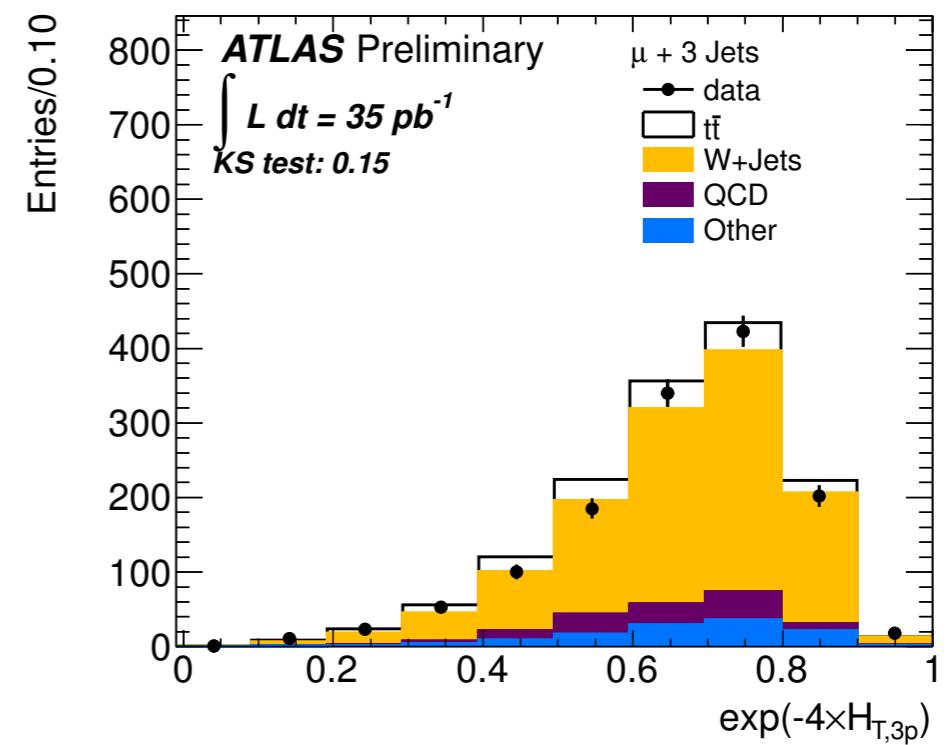
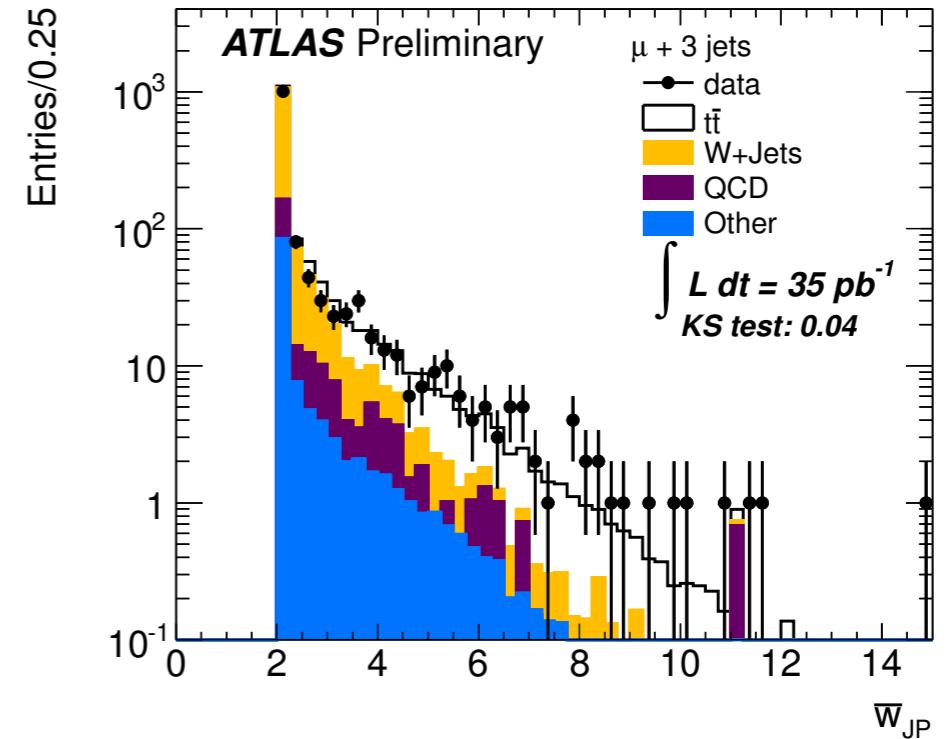
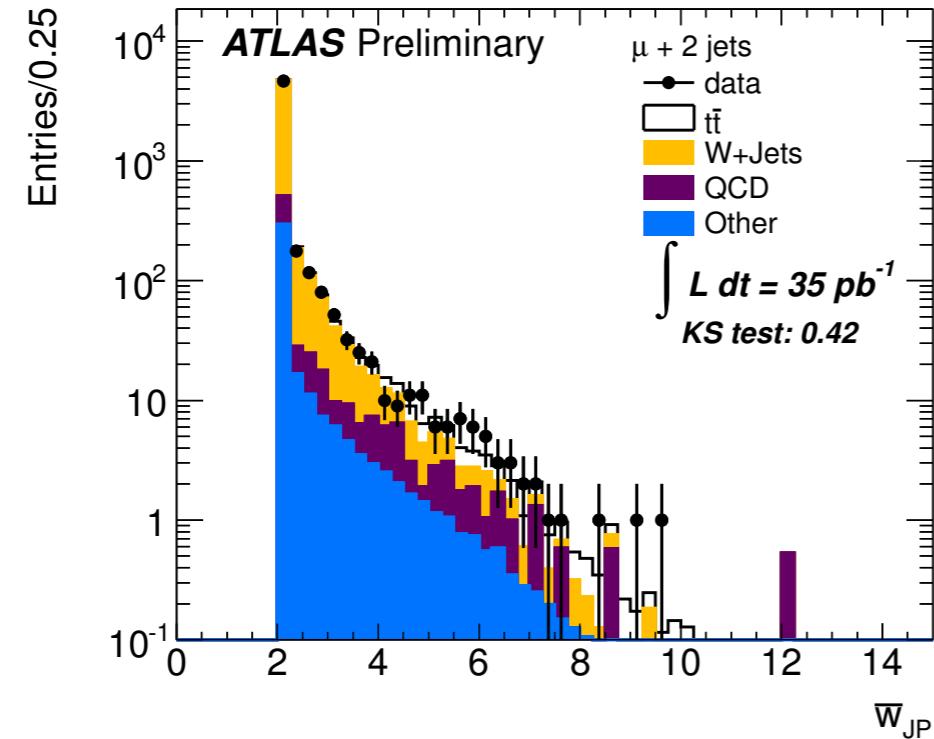
ATLAS-CONF-2011-035

# input distributions (1)

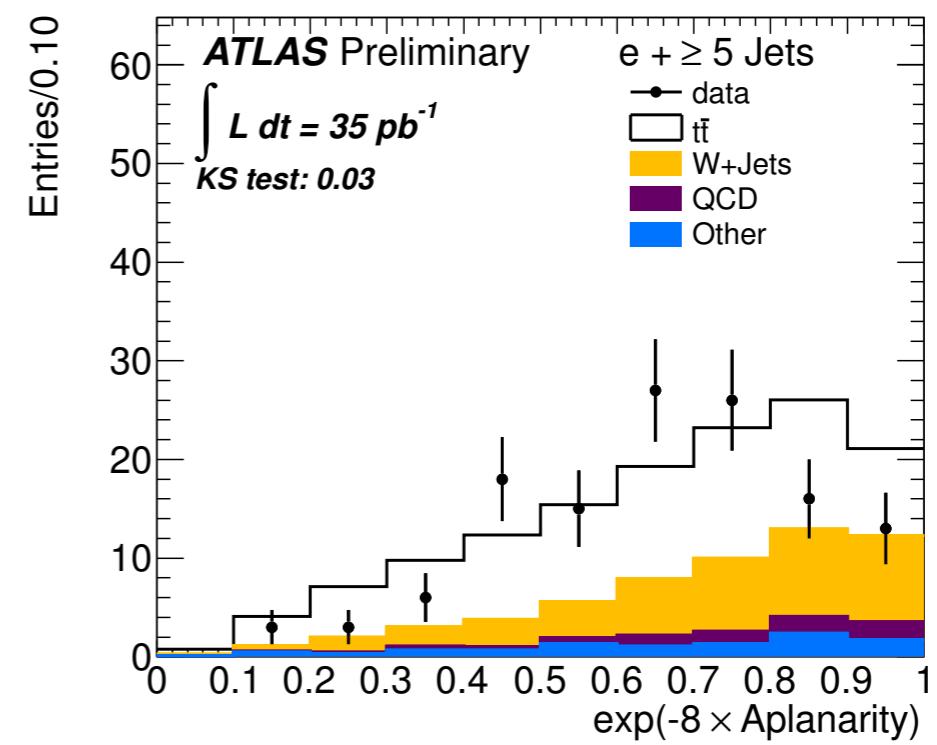
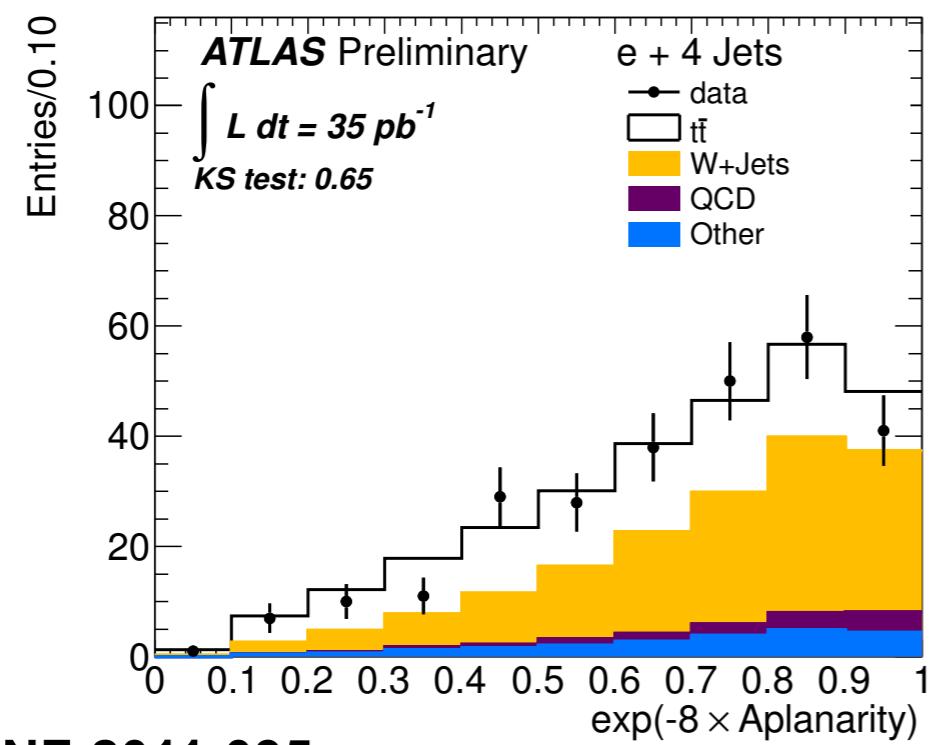
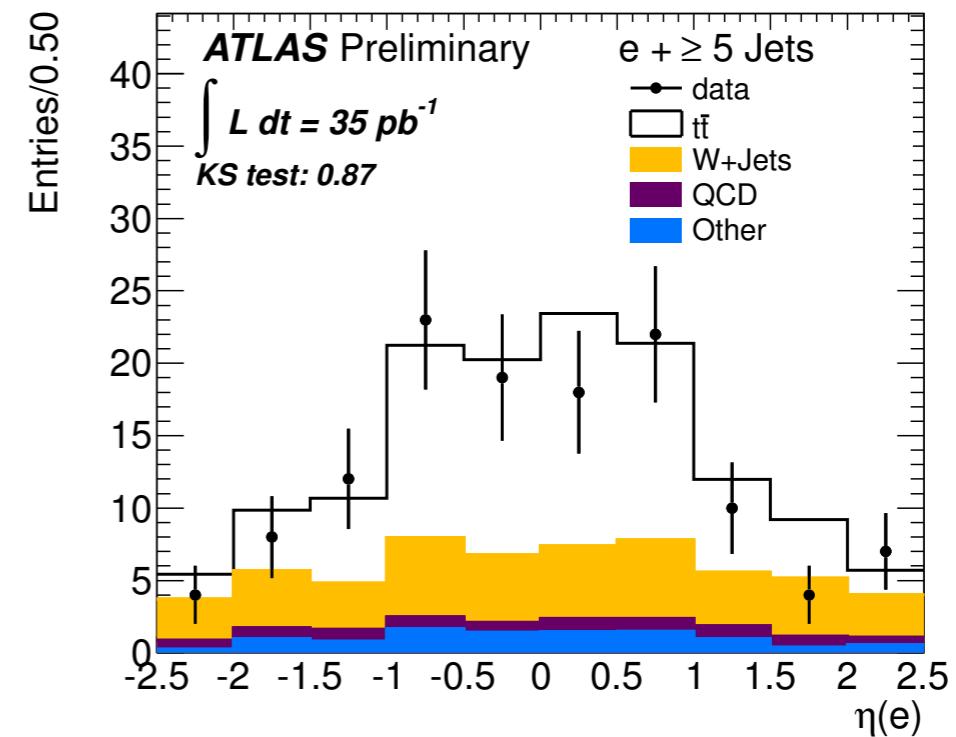
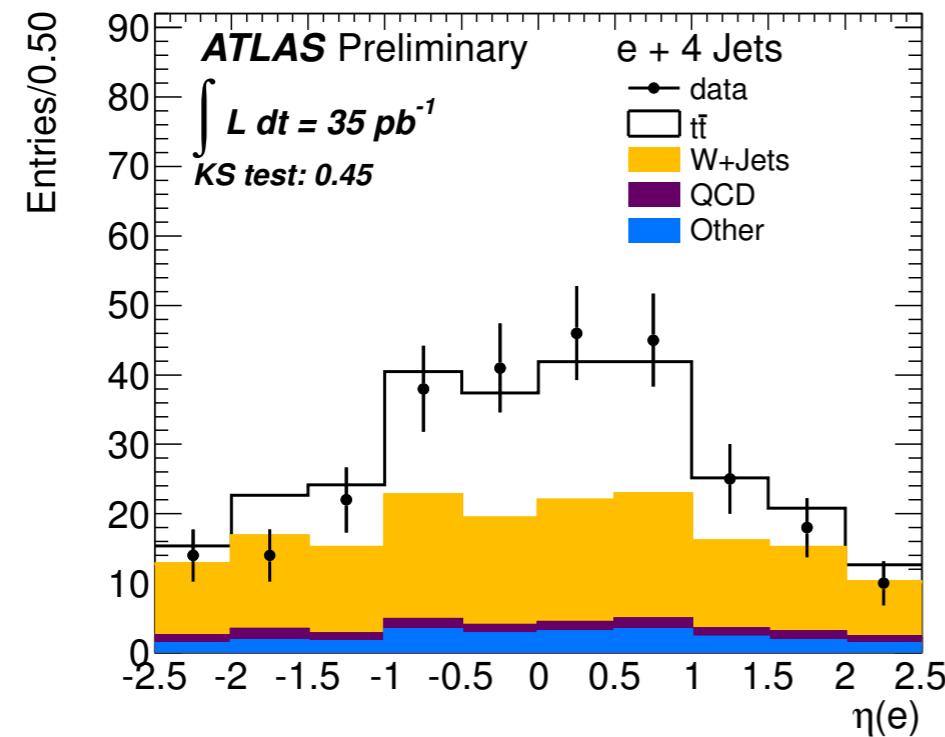


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# input distributions (2)

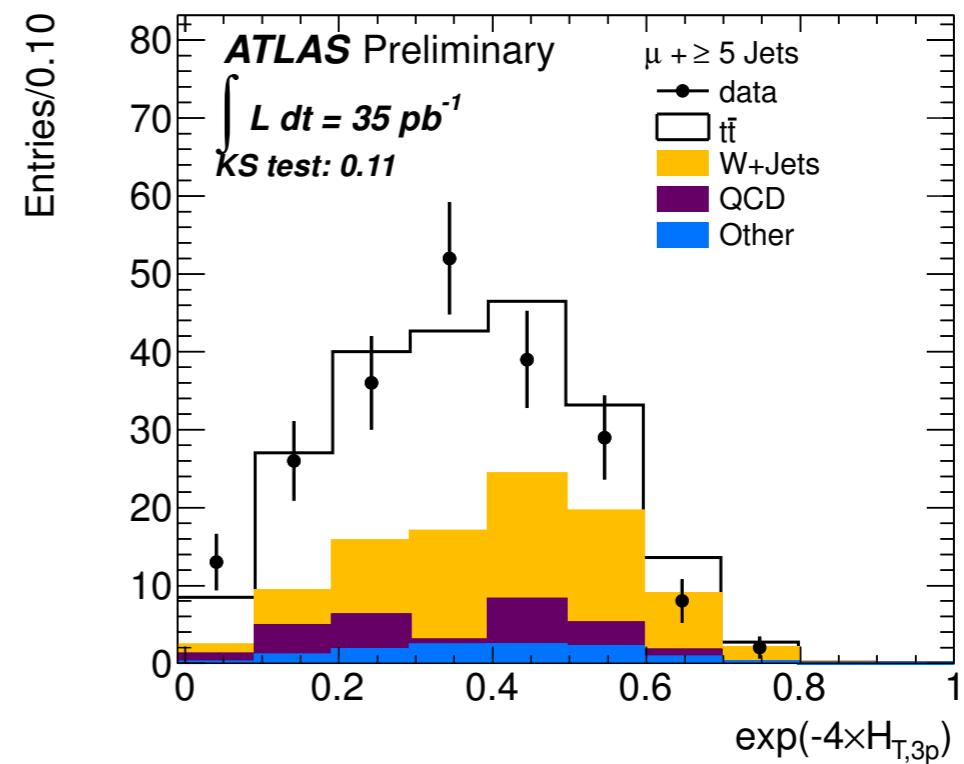
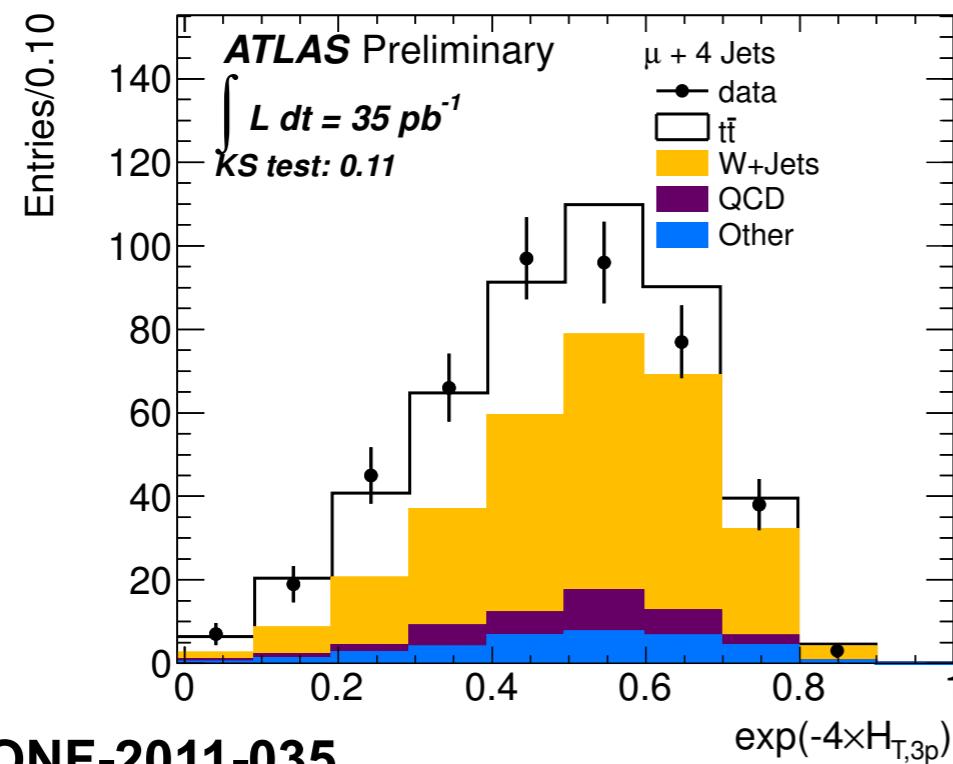
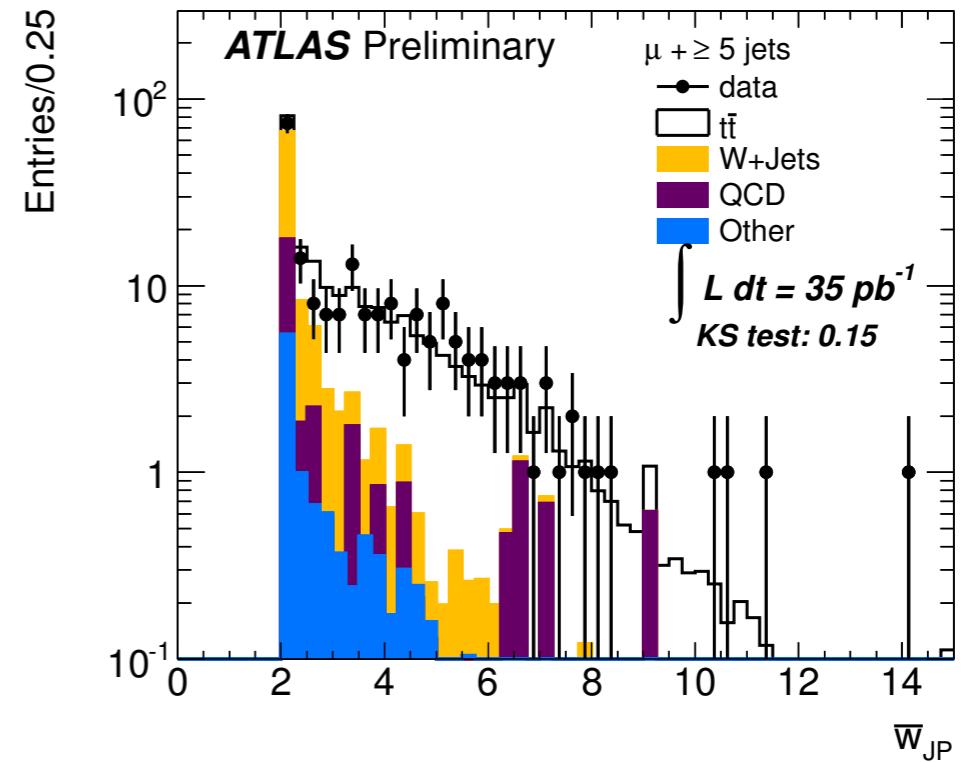
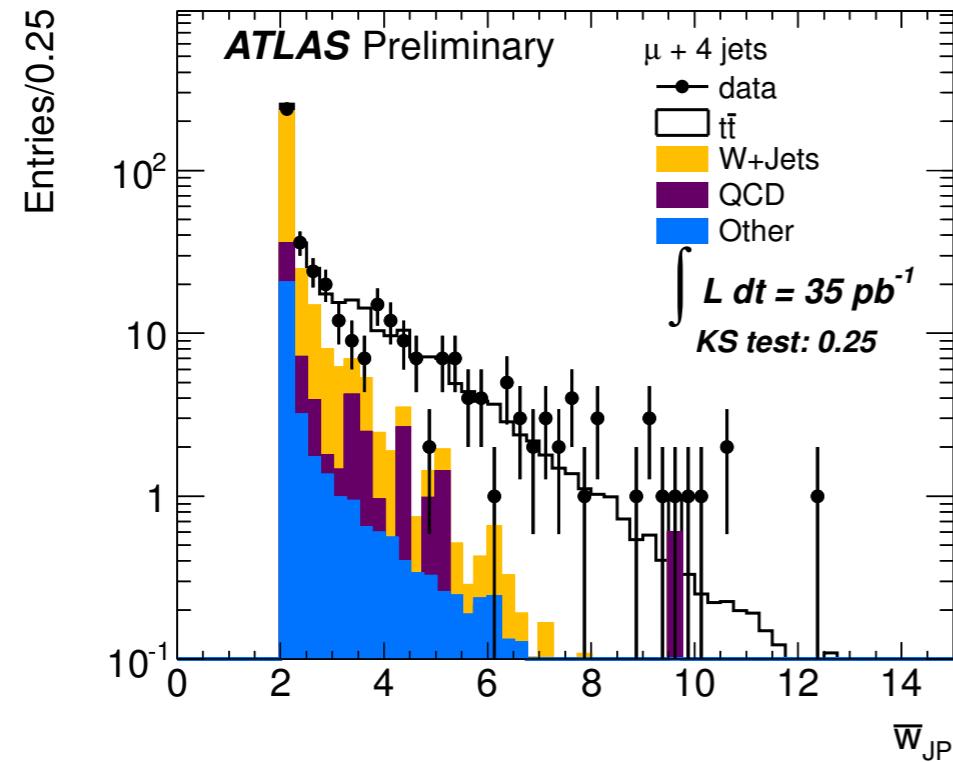


# input distributions (3)



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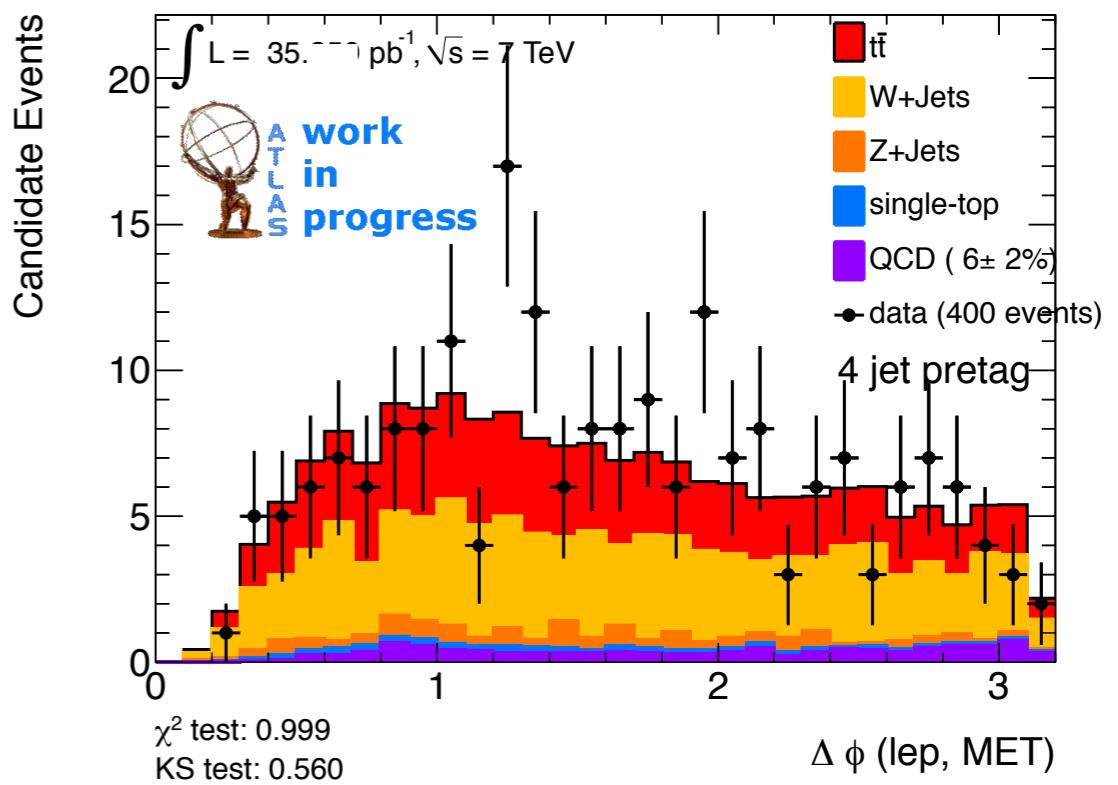
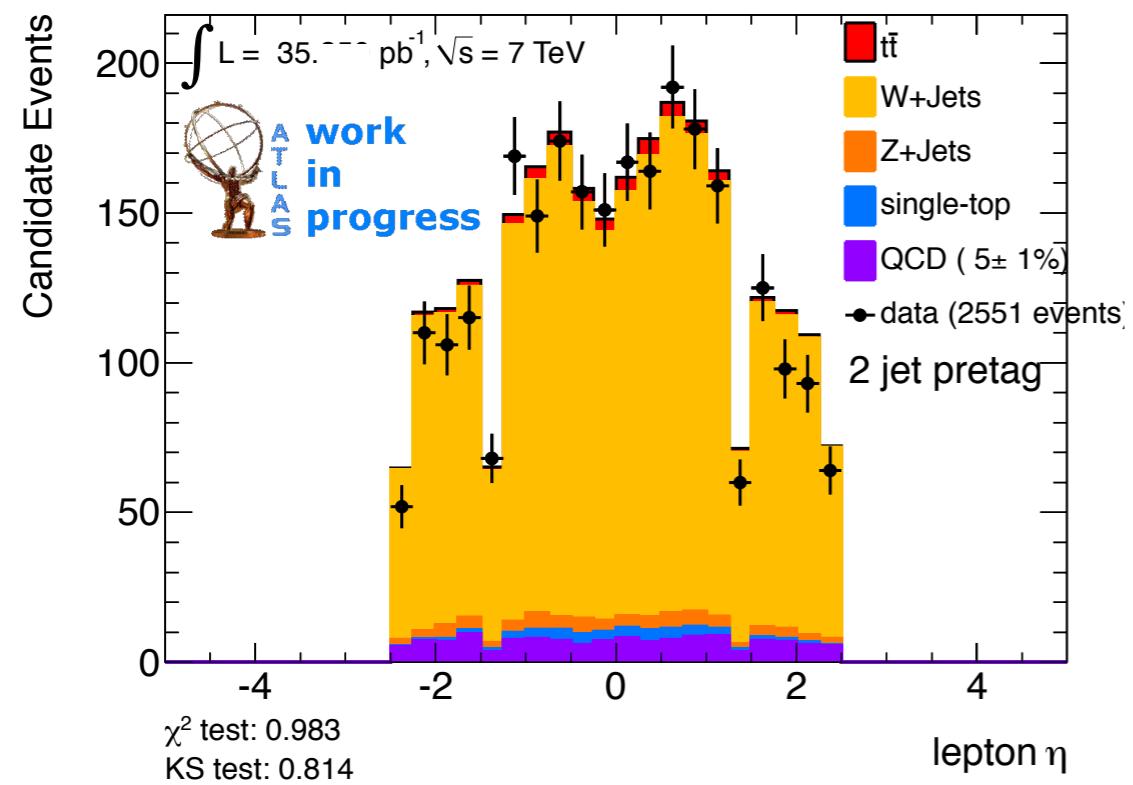
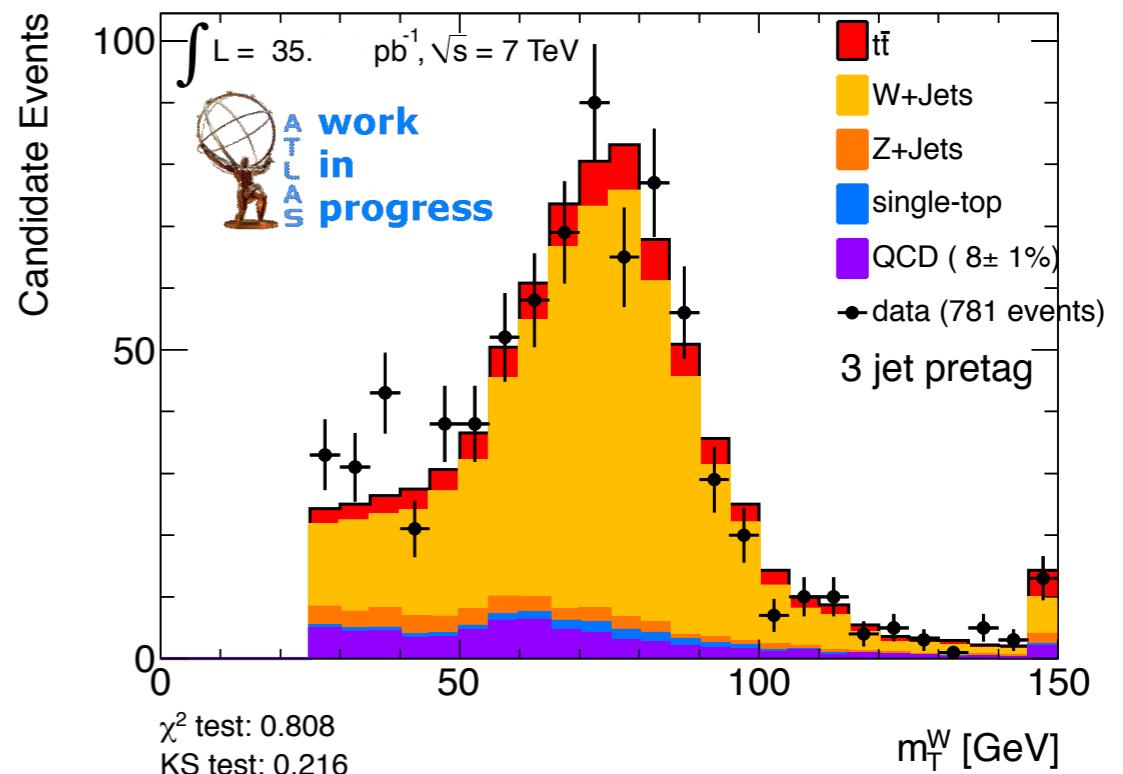
# input distributions (4)



ATLAS-CONF-2011-035

# anti-electron model control plots

- good agreement with data!
- alternative model used for systematics
- model also works in muon channel



# fitter cross-checks

- $\pm 1\sigma$  template variations may be envelopes
- what if real shape inside heavily fluctuates (e.g. jet energy scale)
- evaluate this effect in pseudo-experiments using several functions
- result: deviation covered by systematic uncertainty ✓
- cross-check uncertainty absorption ability of fitter
- run pseudo experiments with one systematic uncertainty fixed to  $-1\sigma$
- injected  $\delta$  is returned (with small shift due to Gaussian constraint), xsec value not affected ✓

