Standard Model Physics in ATLAS

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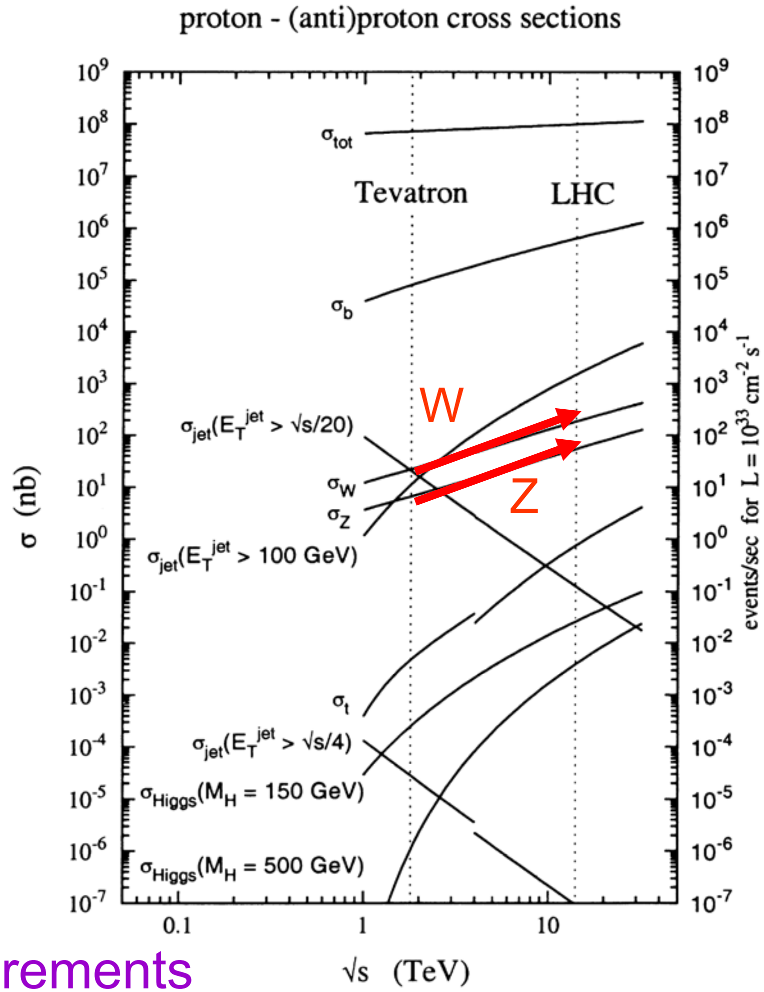
On behalf of the ATLAS collaboration

LHC numbers

Typical Standard Model processes

Process	σ (nb)	Events ($\int \mathcal{L} dt$ = 100 pb^{-1})
Min bias	10^8	$\sim 10^{13}$
bb	$5 \cdot 10^5$	$\sim 10^{12}$
Inclusive jets $p_T > 200$ GeV	100	$\sim 10^7$
$W \to e\nu, \mu\nu$	15	$\sim 10^6$
$Z \to ee, \mu\mu$	1.5	$\sim 10^5$
tt	0.8	$\sim 10^4$



LHC is a W, Z, top factory

→ Small statistical errors in precision measurements

→ can search for rare processes

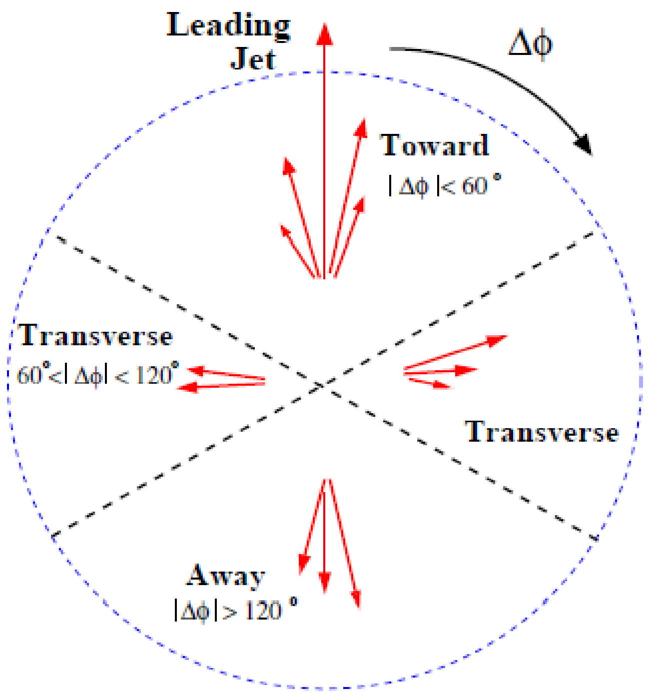
→ large samples for studies of systematic effects

Overview

- Can't cover everything, so
  - Just focus on few topics
  - Emphasis on first measurements
- Will cover
  - Underlying event
  - $Z \rightarrow \mu\mu$ cross-sections
  - Constraints on PDF's using W's
  - Gauge boson pair production
  - Jet cross section measurement
  - Top mass and cross section
- Will not cover
  - EW precision measurement e.g. $\sin^2\Theta_W$, W mass and width
  - Top precision physics e.g. polarisation, single top production etc (➔ talk by E. Chabert)
  - B-physics
  - Standard Model Higgs Searches
- Good understanding needed as this is the background for searches for New Physics (➔ talk by H.P. Beck)

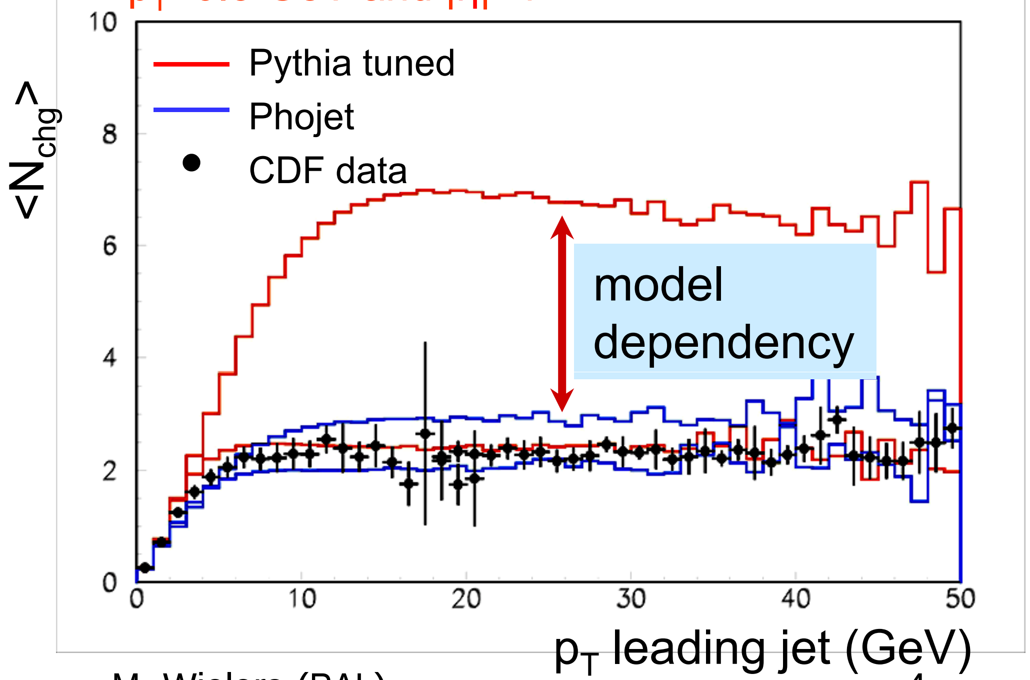
Measurement of Underlying Event

- Modelling of underlying event necessary tool for high p_T physics
  - Important ingredient for jet and lepton isolation, energy flow, jet tagging, etc
- Underlying event uncertain at LHC, depends on
  - multiple interactions, PDFs, gluon radiation
- Look at tracks in transverse region w.r.t. jet activity



Nº charged particles in transverse region:

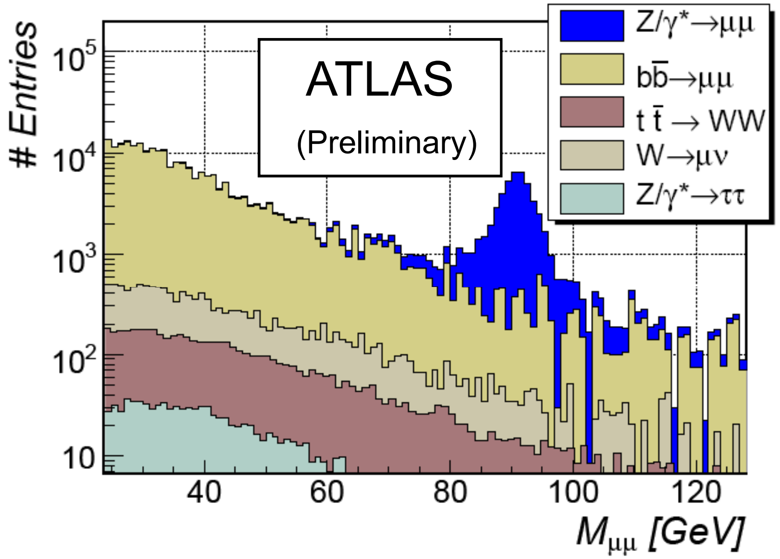
p_T>0.5 GeV and |η|<1



W and Z production

- LHC is W/Z factory
  - $\sigma(W \to \ell\nu) \sim 15nb$ ➔ $\sim 10^6$ events in $\int \mathcal{L}\, dt = 100\ pb^{-1}$
  - $\sigma(Z \to \ell\ell) \sim 1.5nb$ ➔ $\sim 10^5$ events in $\int \mathcal{L}\, dt = 100\ pb^{-1}$
- First physics measurements
  - Measurement of W/Z inclusive cross section as well as W/Z+jet
  - Constraining PDF's
  - Measurement of gauge boson pair production
  - Measurement of triple gauge couplings
- Useful to understand detector and performance
  - In situ calibration of EM calorimeter using $Z \to ee$
  - Momentum scale from $Z \to \mu\mu$, $Z \to ee$
  - Alignment via $Z \to \mu\mu$
  - Extraction of trigger and offline lepton identification efficiencies from Z decays (➔ see talk by V. Perez-Reale)
  - Luminosity measurement

Z→μμ cross section



- Background Processes
  - $b\bar{b} \to \mu\mu + X$
  - $W + jets \to \mu\upsilon + jets$
  - $t\bar{t} \to Wb + Wb \to \mu\upsilon + jet + \mu\upsilon + jet$
  - $Z \to \tau\tau \to \mu\upsilon + \mu\upsilon$
  - Background Uncertainty < 0.002
- Selection
  - Two reconstructed opposite charged isolated muons in $|\eta|<2.5$
  - $p_{T1}>15$ GeV, $p_{T2}>25$ GeV
  - $|91.2 \text{ GeV} - M_{\mu\mu}|<30$ GeV
- Experimental systematics from
  - Efficiency extraction, momentum scale, misalignment, magnetic field knowledge, collision point uncertainty, underlying events, (pileup)
- Theoretical uncertainties arising from
  - PDF choice, initial state radiation, p_T effects (LO to NLO)
- Plus 10% uncertainty from luminosity measurement
- Expected Precision for $\int \mathcal{L}\, dt = 100 \text{ pb}^{-1}$

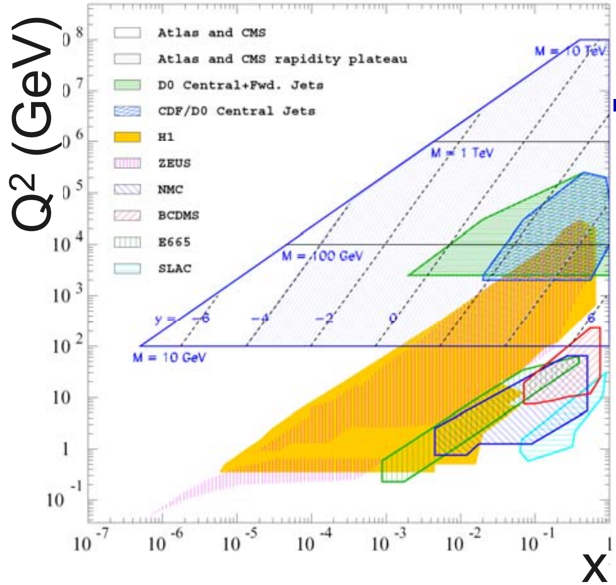
$$\frac{\Delta\sigma}{\sigma}(pp \to Z/\gamma^* + X \to \mu\mu) = 0.004\,(\text{stat}) \pm 0.008\,(\text{ex.sys}) \pm 0.02(\text{th.sys}) \pm 0.1(\text{lumi})$$

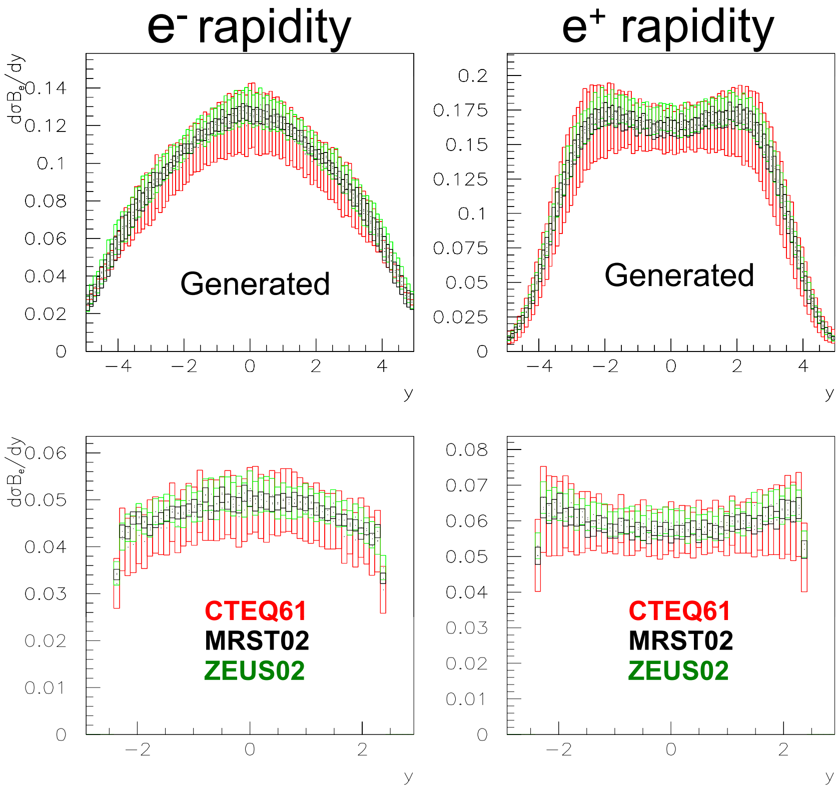
Constrain PDF using W→ℓν

- Production
  - Main (LO) contribution
    $$u\bar{d} \rightarrow W^{+} \qquad d\bar{u} \rightarrow W^{-}$$
  - Dominant sea-sea parton interactions at low x
  - At $Q^2 = M_W^2$ dominated by $g \rightarrow q\bar{q}$
  - Low x gluon has large uncertainty
- Studying W and Z production can increase our knowledge of gluon SF

➔ PDF error sensitive to W→eν rapidity distribution

  - Exp. uncertainty (dominated by systematics) sufficiently small to distinguish between different PDF sets
  - PDF uncertainties only slightly degraded after detector simulation and selection cuts



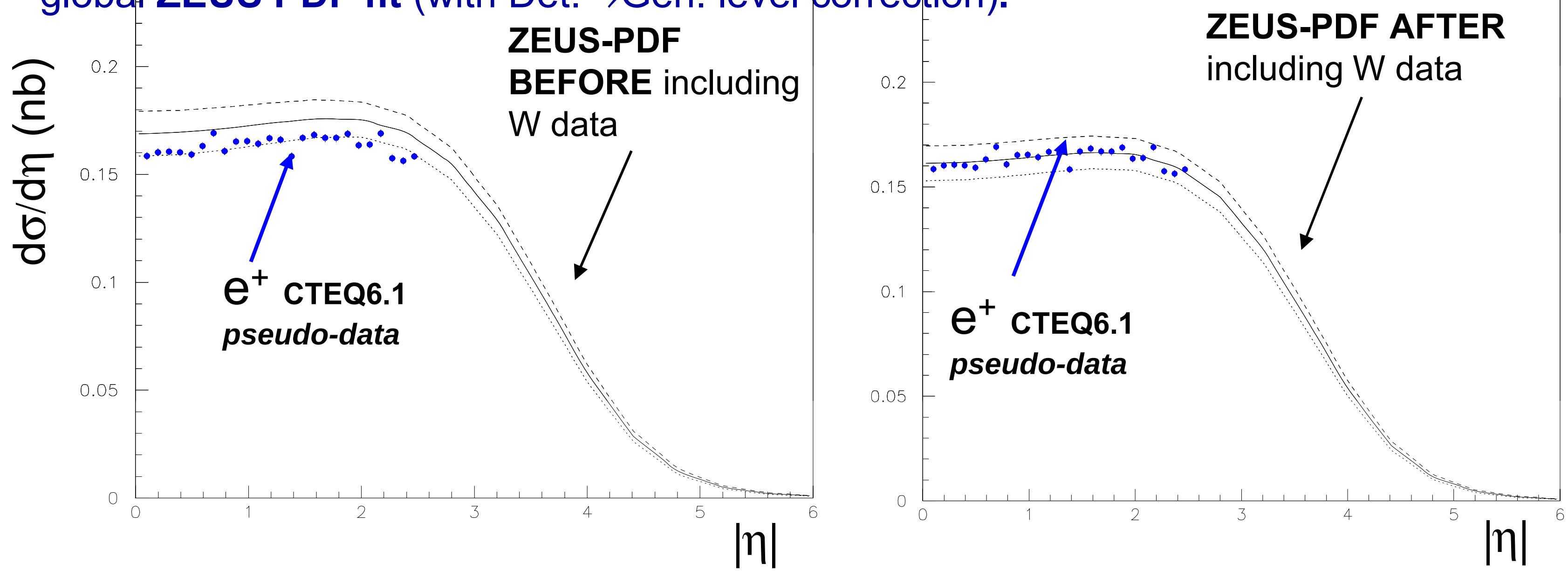


PDF constraining potential of ATLAS

Include ATLAS W Rapidity "pseudo-data" in global PDF Fits

Simulate real experimental conditions:

Generate 1M "data" sample with **CTEQ6.1 PDF** through ATLFAST detector simulation and then include this *pseudo-data* (with imposed 4% error to simulate exp uncertainties) in the global **ZEUS PDF fit** (with Det.→Gen. level correction).



low-x gluon distribution determined by shape parameter λ, $xg(x) \sim x^{-\lambda}$:

BEFORE λ = -0.199 ± 0.046

AFTER λ = -0.186 ± 0.027

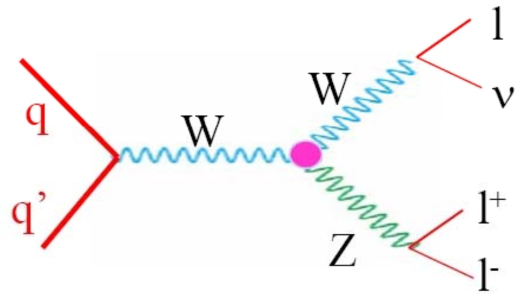
} 41% error reduction (after ~ $\int \mathcal{L}dt$ = 100 pb^{-1})

Normalisation free → independent of luminosity

Di-boson production

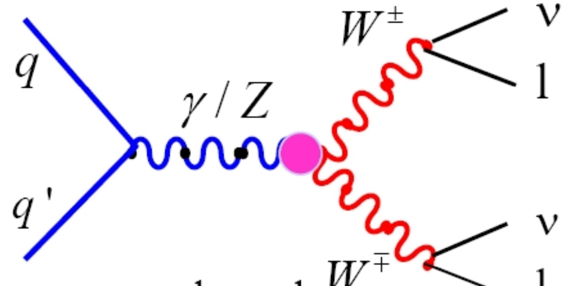
- Probes non abelian SU(2)xU(1) structure of SM
- Trilinear gauge boson couplings measured directly from ZW, WW, ZZ cross section
- Compare to SM predictions for
  - Cross section
  - Boson p_T($V=W, Z, \gamma$)
  - Production angle
- These variables sensitive to modification to TGC structure from BSM effects
- Di-boson production for $\int \mathcal{L}dt = 1\ fb^{-1}$

Channel	# events	bkgs	S/√B
ZW	75.7	ZZ→4ℓ, Z+jet, Zγ, DY	30.1
WW	358.7	DY, Z+jet, $t\bar{t}$, ZW, Zγ, ZZ, W+jet	18.9
ZZ	13	Nearly bkg free, Zγ, $t\bar{t}$, Zbb	0 bkg events



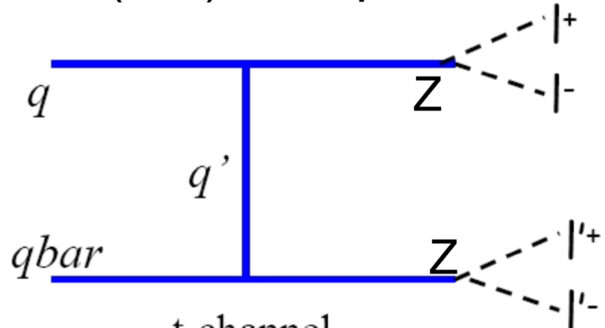
s-channel

σ(SM)=58 pb



s-channel

σ(SM)=128 pb



t-channel

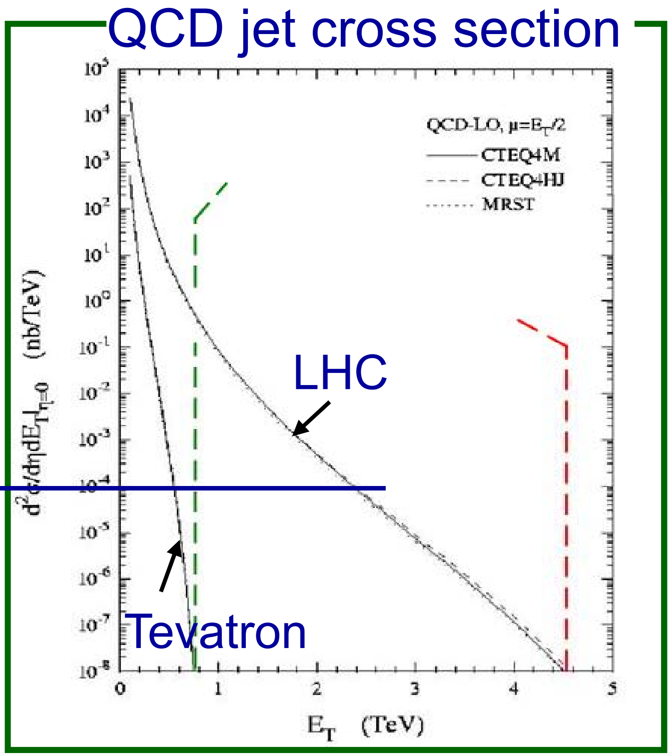
σ(SM)=17 pb

s-channel suppressed by $O(10^{-4})$

Measurements with jets

➔Will jump immediately into new territory!

10 events
with 100 pb^{-1}



- Inclusive jet spectra provide
  - Study of high-p_T tails of cross-section sensitive to New Physics (e.g. quark compositeness)
  - Test of QCD (running of α_s)
  - di-jet cross section and properties (E_T,η_1,η_2) constrain parton distribution function
- Good understanding of errors needed!

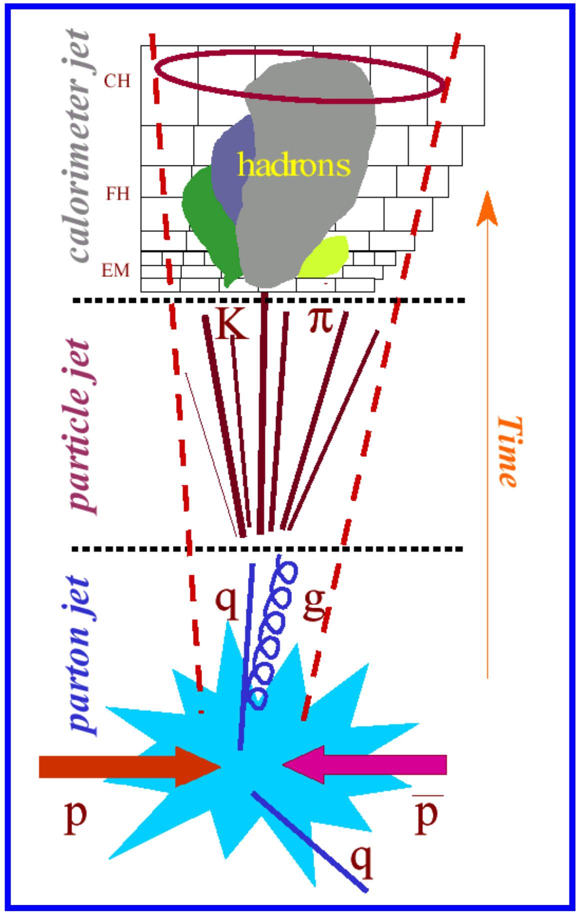
Jet Reconstruction

General task: Transform calorimeter response into four-vectors representing the properties of a jet/parton

Experimental factors
- Dead material in front of calo
- Non-sensitive regions
- Detector inefficiencies
- Non-compensation
- Longitudinal leakage
- Lateral shower size
- Read-out granularity
- Non-linearities
- Electronics noise
- Pile-up noise
- Magnetic field effects

Physics related factors
- Initial state radiation
- Final state radiation
- Fragmentation (flavour dependence)
- Underlying event
- Minimum bias pile-up

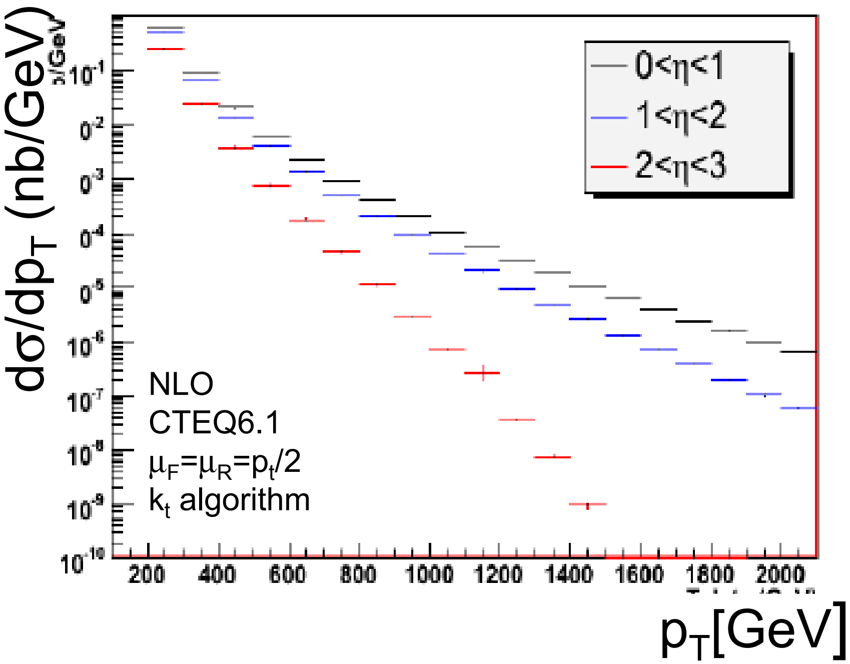
Effects due to jet finding algorithm
- Efficiency
- Jet size
- Treatment of nearby jets
- Jet direction calculation
- Jet corrections
- …



Inclusive jet cross section

- Cross section measurement
  - Test of QCD
  - High p_T region sensitive to new physics
- Statistical Errors
  - Naïve Error Estimation $\Delta N = \sqrt{N}$
  - 1% error at $p_T \approx$ 1TeV with $\int \mathcal{L} dt =$ 1 fb^{-1} in $|\eta| < 3$
  - For $3.2 < |\eta| < 5$ error up to 10%
- Experimental Errors
  - Luminosity measurement
  - Jet Energy Scale
  - Jet Resolution, UE, trigger efficiency
  - …

Jet p_T spectra for different η



Jet cross section

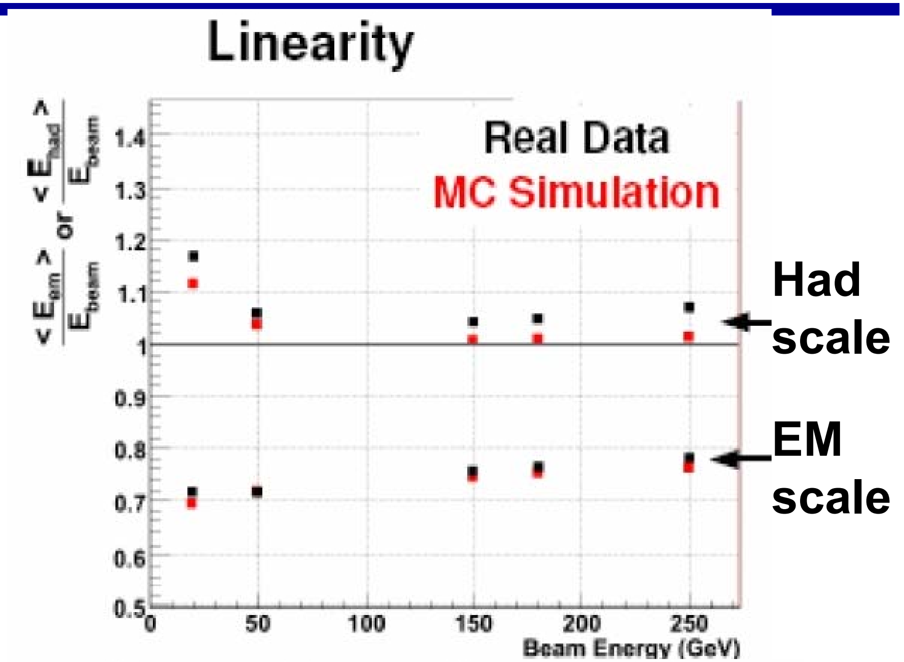
Jet Energy Scale:

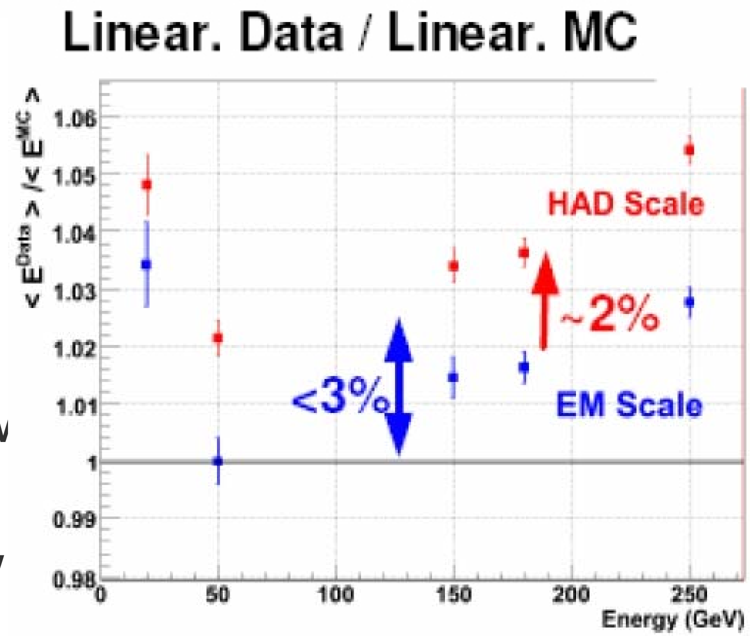
Uncertainty	Error on σ
1%	10%
5%	30%
10%	70%

- If known to 1-2%, experimental errors not dominant
- First estimate of uncert. at start-up from pion test beam data
  - At EM scale: ~3% diff between data and MC
  - At had scale: 4-5%

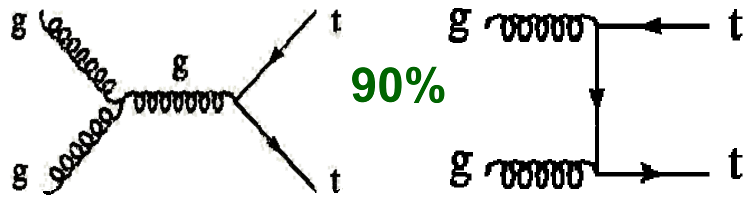
Theoretical Error

- scale uncertainties (Factorisation μ_F, Renormalisation μ_R)
  - ~ 10% uncert. at 1TeV, less below
- PDF uncertainties
  - ~ 15% uncert. at 1TeV, less below

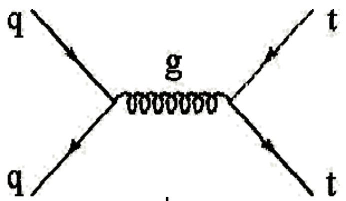




Top Production and Decay at LHC



90%



10%

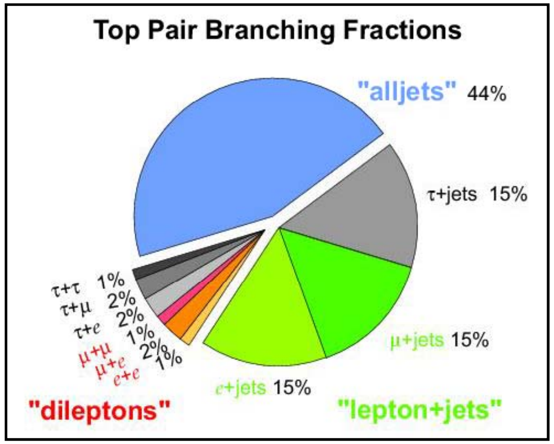
BR (t→Wb) ~ 100 %

W→eν, μν, **qq**

tt̄ final states (LHC, ∫ℒdt = 100pb^{-1})

- Full hadronic **(37 K)** : 6 jets
- Semileptonic **(25 K)** : ℓ + ν + 4jets, ℓ=e,μ
- Dileptonic **(4 K)** : 2ℓ + 2ν + 2jets

- σ_{tt}(LHC) ~ 830 ± 100 pb
- For comparison:
  - Cross section LHC: 100 x Tevatron
  - Background LHC: 10 x Tevatron

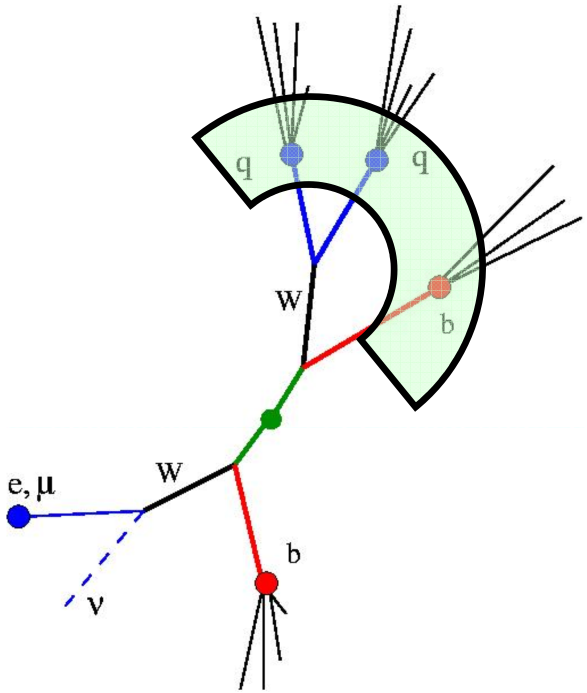


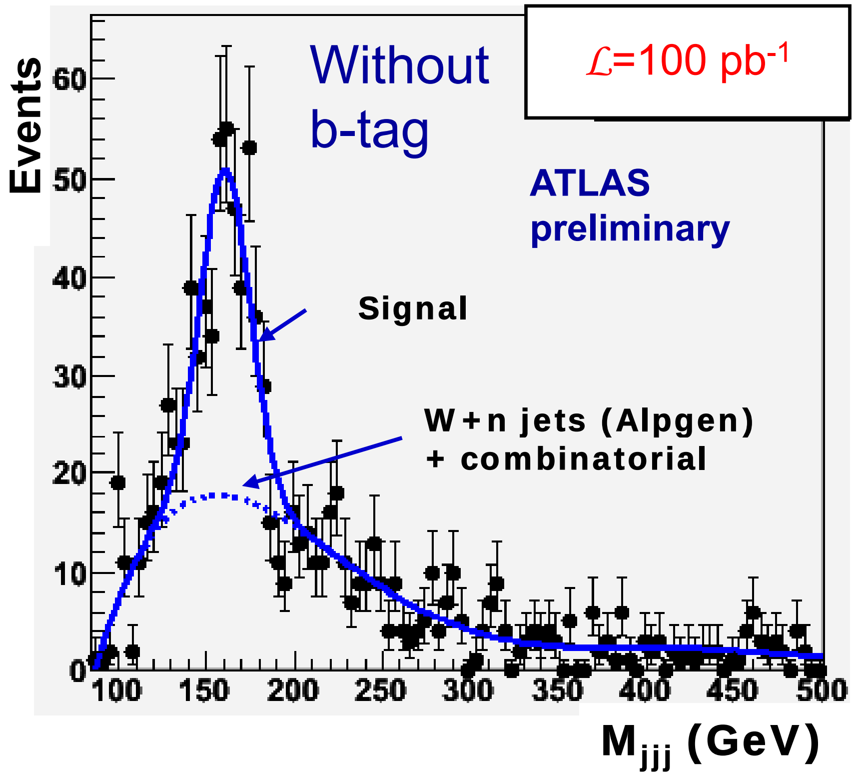
Golden channel

(early physics, precision meas.)

Early Top mass measurement

- Event selection:
  - no b-tag yet on day-1 (might not be well understood)
  - Isolated lepton : p_T> 20 GeV
  - missing E_T > 20 GeV
  - 4 jets p_T> 40 GeV
  - 3 jets with highest $\sum p_T$





Early Top measurements

- Top mass with $\int \mathcal{L}dt = 30\ pb^{-1}$:
  - δm_{top} ~ 3.2 GeV
  - Sys. error dominant: FSR, b-jet energy scale ➔ those 30 pb^{-1} must be well understood (ie actually need more data)
- Top cross section
  - σ_{tt} measured with ~20% precision
- Excellent samples for
  - Commission b-tagging
  - Jet energy scale calibration using $W \rightarrow jj$ from $t \rightarrow bW$

Conclusions

- As soon as collisions at 14 TeV happen, interesting SM physics available in recorded data
- First SM physics studies
  - Underlying event and min. bias production
  - W, Z (+jet) production:
    - understand detector performance (calib/alignment, eff extraction)
    - Improve knowledge of PDFs
  - Di-boson production: probe gauge coupling
  - Jet cross-section
  - Photon cross sections
  - Measure top mass and cross section
    - also useful for hadronic calibration and b-tagging
- Focus here was on first measurements, many more topics studied
  - EW precision measurement e.g. $\sin^2\Theta_W$, W mass and width
  - Top precision physics e.g. polarisation, single top production etc
  - Standard Model Higgs Searches
- Very good understanding of SM processes needed for searches for New Physics