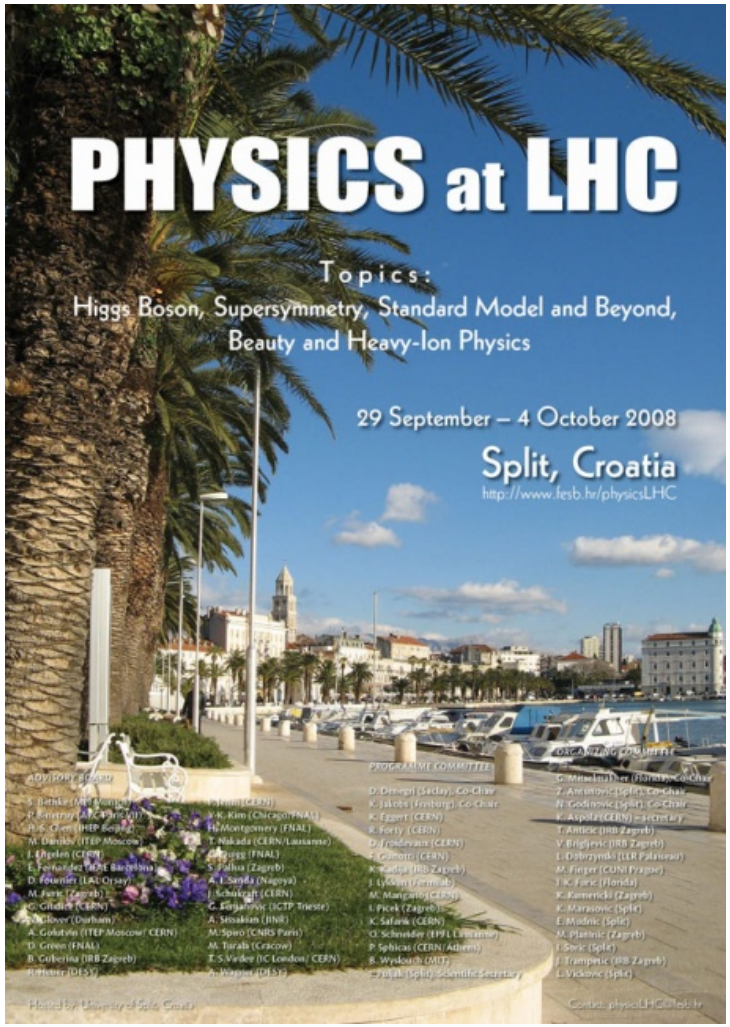
QCD and Top Quark Physics at the LHC



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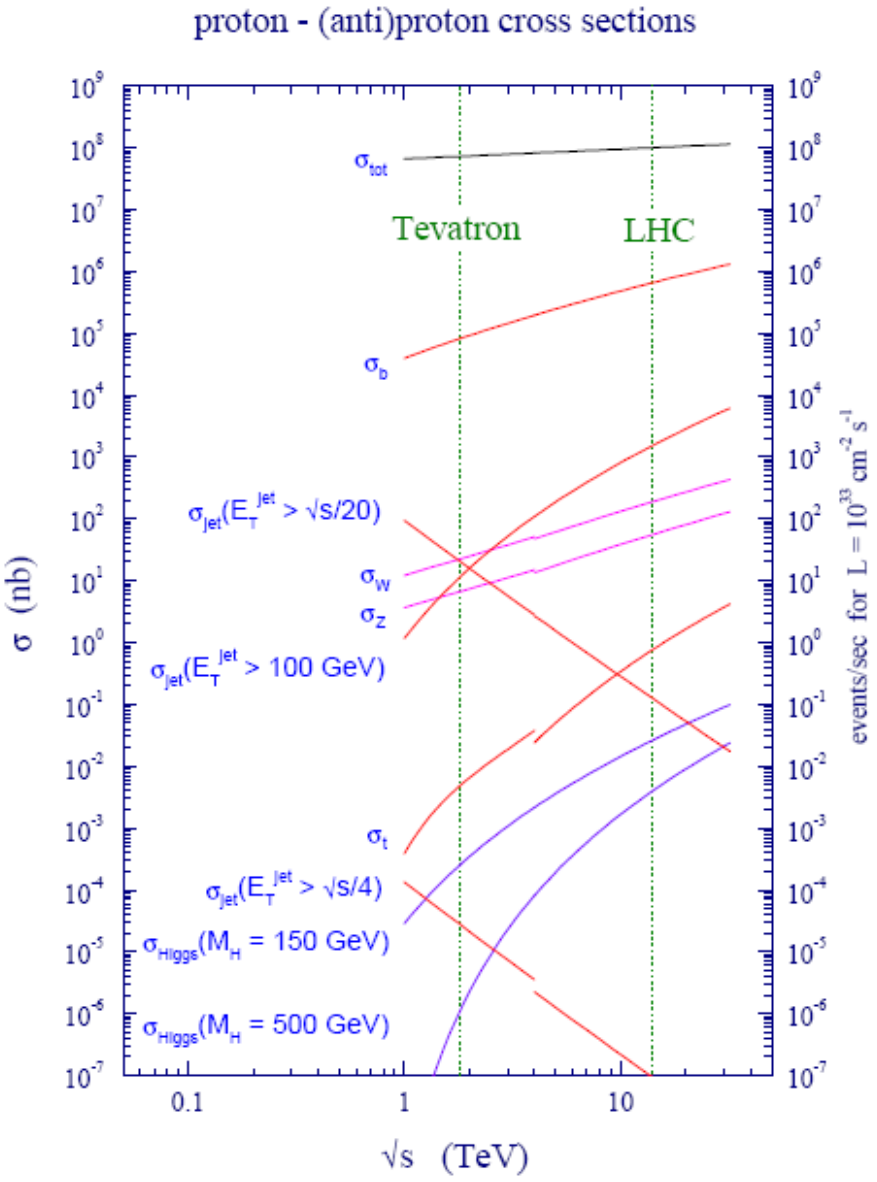
On behalf of the CMS and ATLAS Collaborations

Physics at the LHC 2008, Split

01 October 2008

Introduction

- **LHC opens new regime in rates and phase space**
  - ❑ **QCD: large phase space for gluon emission (low-x); very high Pt jet production**
  - ❑ **Top: cross section factor 100 enhanced wrt Tevatron**
- **With the first LHC data:**
  - ❑ **rediscover standard model at LHC energies**
  - ❑ **Can not claim new physics if SM is not understood**
  - ❑ **QCD and Top are backgrounds to many new physics processes**
- **Focus here on early measurements (10-100 pb-1)**

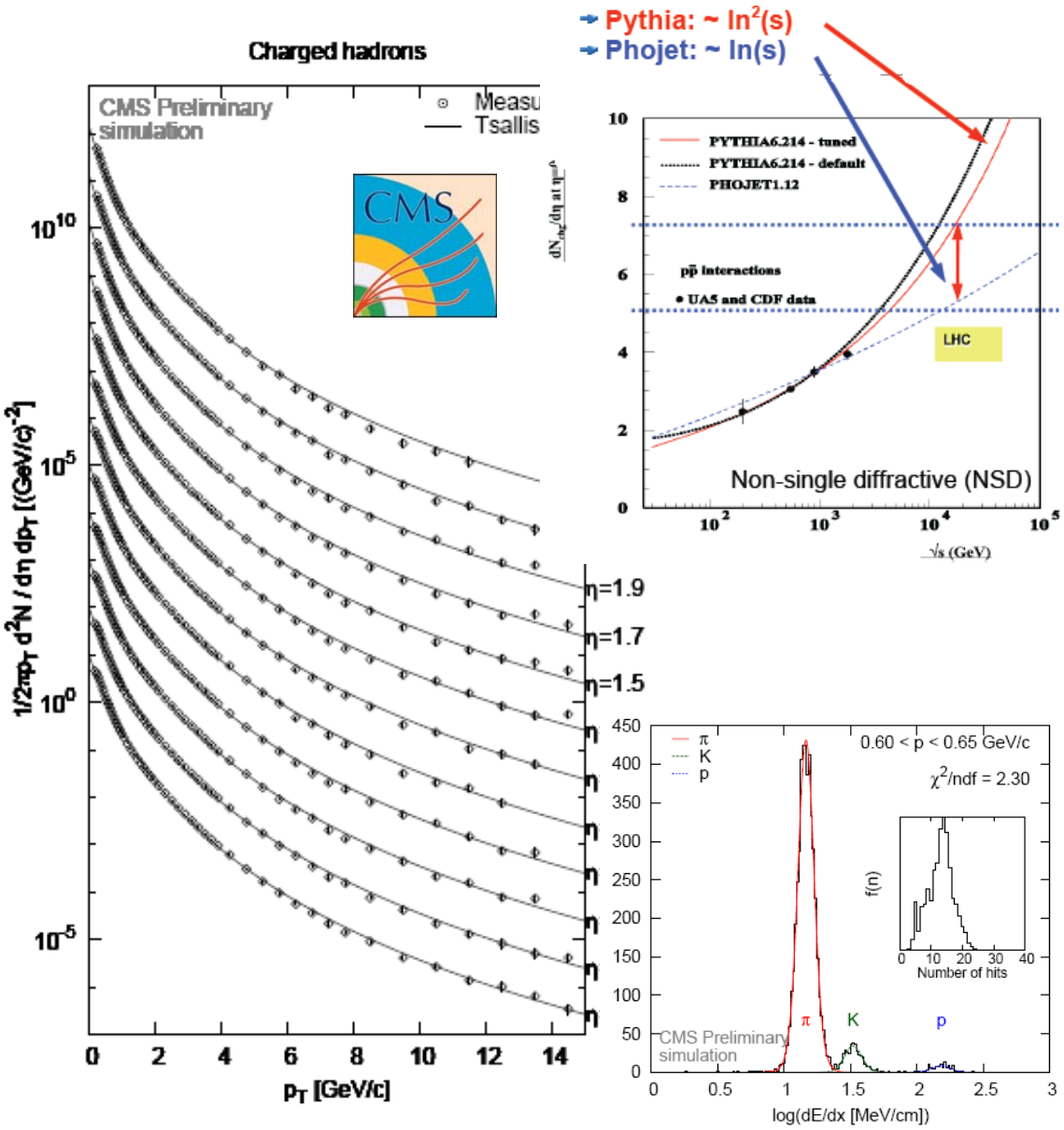


Campbell, Huston, Stirling, Rept.Prog.Phys.70:89,2007

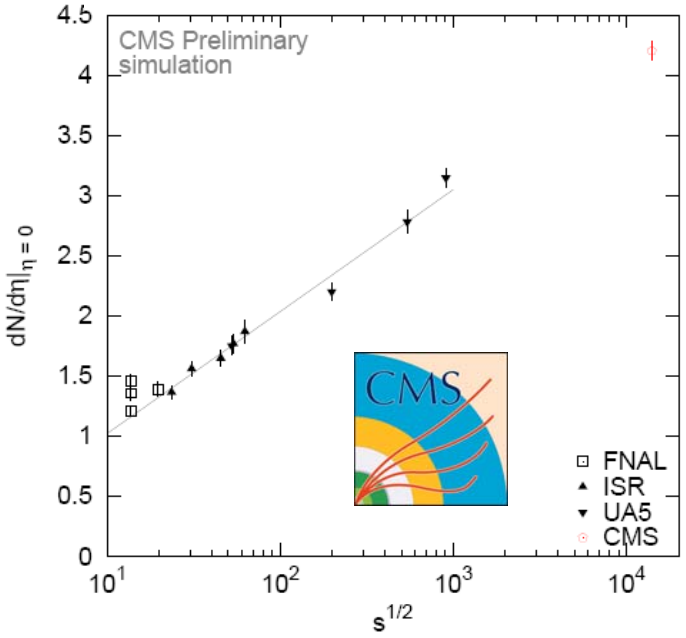
Charged hadron multiplicity

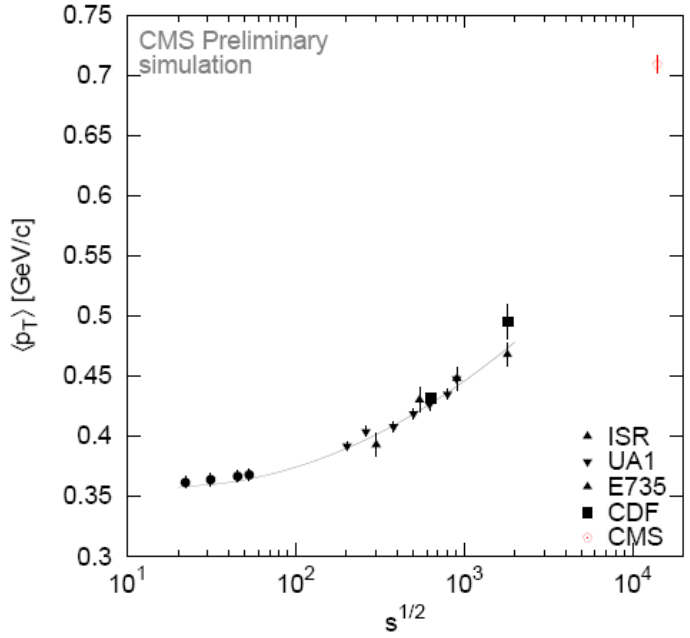
- **Motivation:**
  - One of the first possible analyses!
  - Large uncertainty in model predictions for LHC!

- **Technique:**
  - Tracks from pixel hit triplet seeding
  - Tracking down to pt>75 MeV! (avoid large extrapol to pt=0!)
  - K/pi/p separation using dE/dx in tracker possible
  - 1.9M events (1Hz @ 1 Month)
  - Corrected distributions



Charged Hadron Multiplicity (cont.)





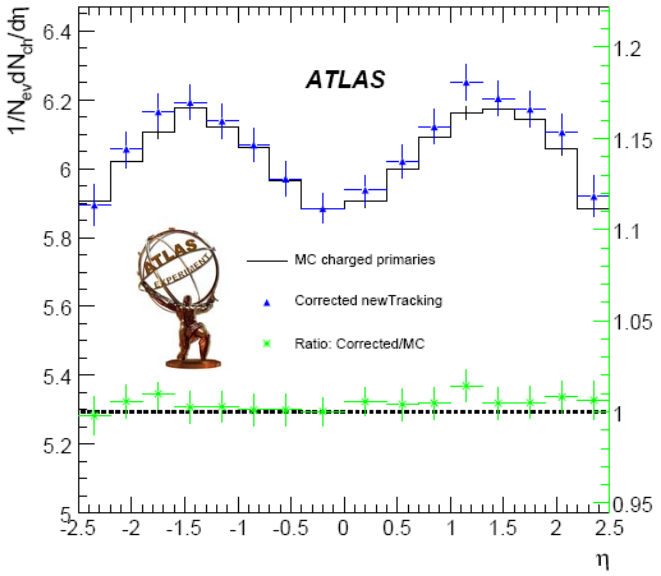
$dN/d\eta_{\eta=0} \sim 4.2$
$\langle pT \rangle \sim 0.7$ GeV/c
syst ~ 8%

Trigger efficiency:

Single Diffractive	**~60%**
Double Diffractive	**~70%**
Not Diffractive	**~99%**

- **CMS study vs sqrt(s):**

- **ATLAS study (for NSD events)**
  - ❑ **Largest exp. Syst.: misalignment**

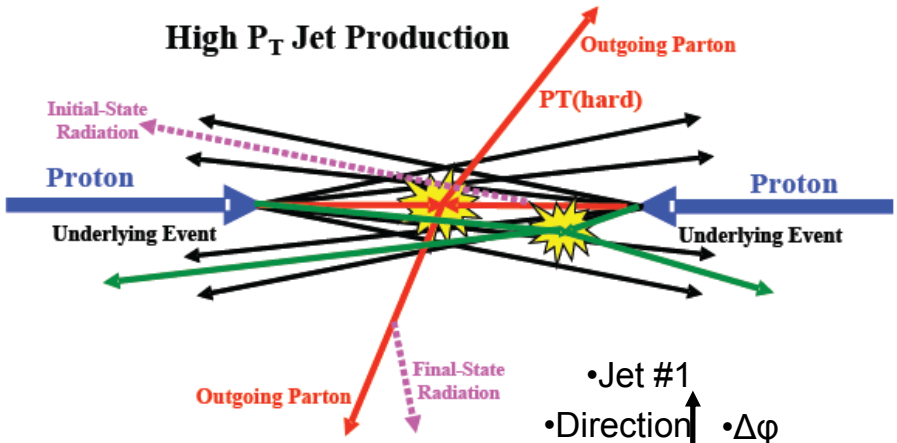


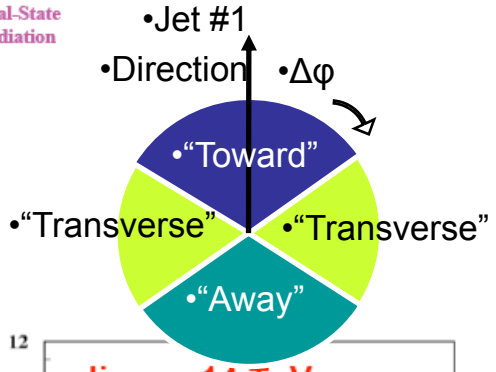
Summary of systematic uncertainties

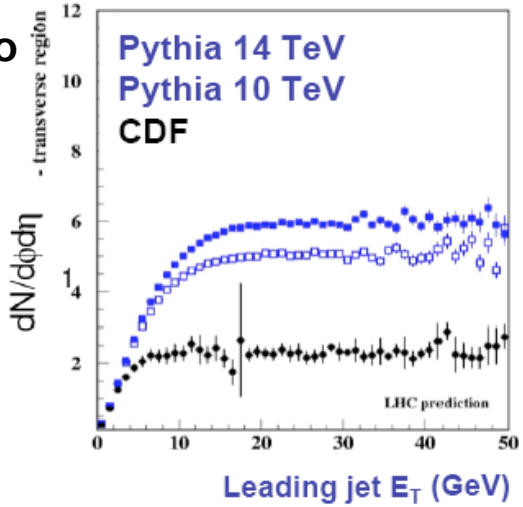
Track selection cuts	2%
Mis-estimate of secondaries	1.5%
Vertex reconstruction	0.1%
Mis-alignment	6%
Beam-gas & pile-up	1%
Particle composition	2%
Diffractive cross-sections	4%
Total:	**8%**

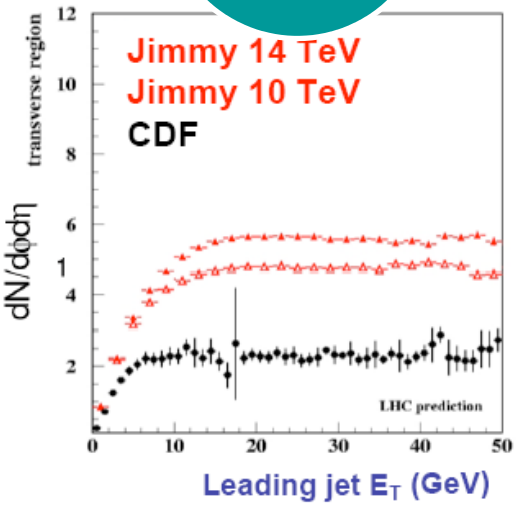
Underlying Event

- **Underlying event is everything BUT the hard scatter**
  - ISR+FSR, beam remnants, multiple parton interactions (MPI)
- **Motivation:**
  - Understanding of MPI @ 14 TeV
  - Tuning of MC models
- **Measurement possibility:**
  - Charged particle mult. / mom. density in region transverse to leading jet (c.f. R.Field)
- **Expectation:**
  - Activity ~2 times higher than Tevatron







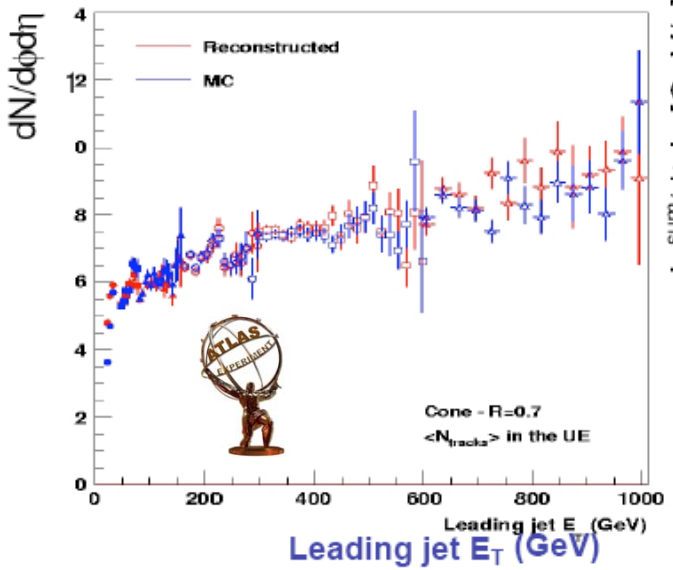


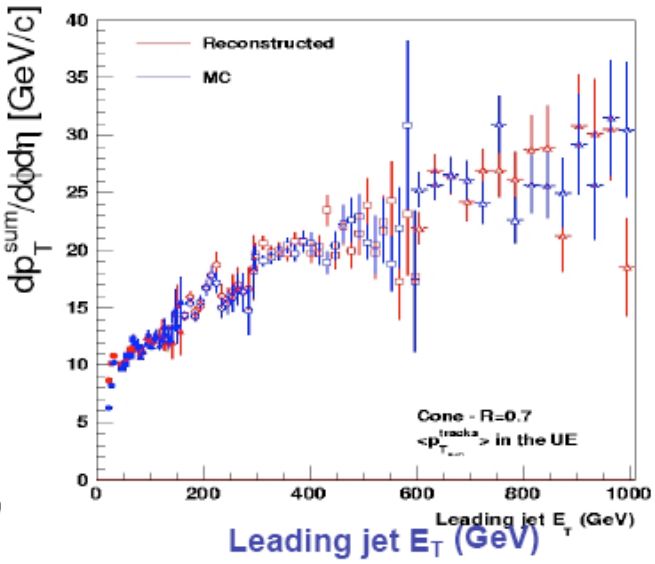
Underlying Event (cont.)

- **ATLAS study:**
  - Up to 1 TeV in ~60 pb-1

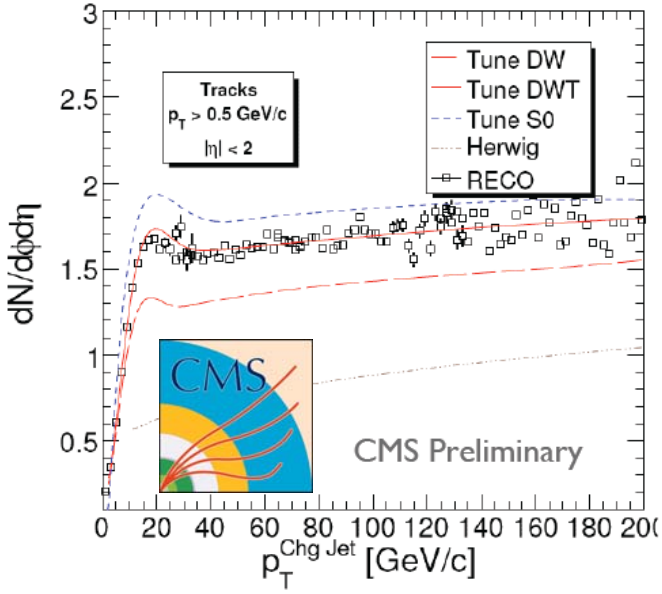
$N_{jets} > 1$,
$|\eta_{jet}| < 2.5$,
$E_T^{jet} > 10$ GeV,

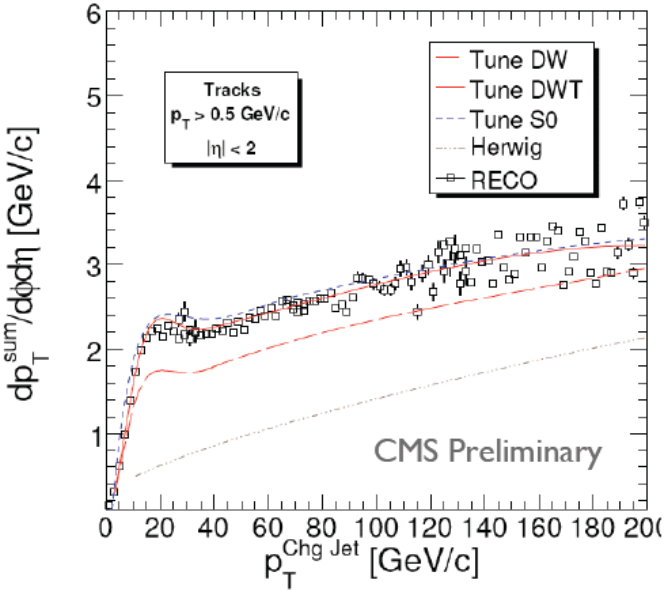
$|\eta_{track}| < 2.5$,
$p_T^{track} > 1.0$ GeV/c





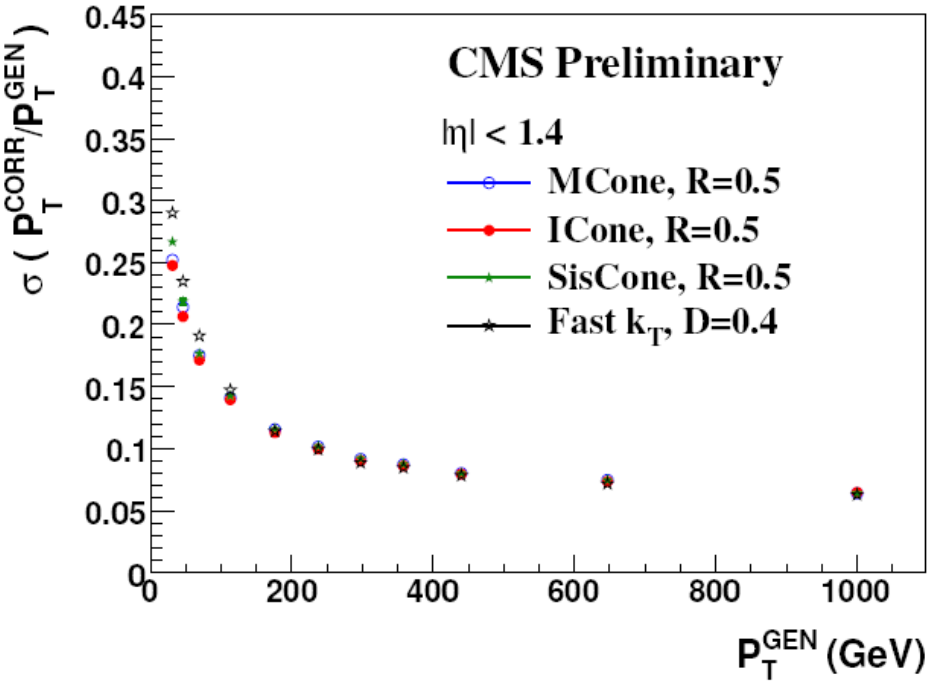
- **CMS Study:**
  - Transverse region (10pb-1)
  - Event by event correction
  - High sensitivity to different tunes



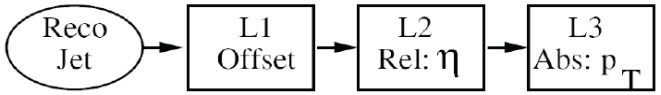


Jet Reconstruction and Calibration

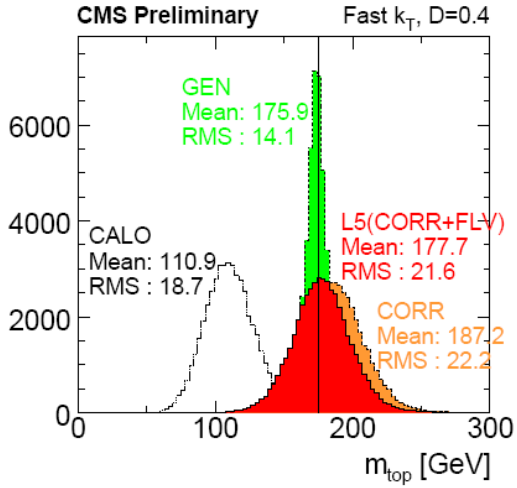
- **Jet algoritms used:**
  - SISCone, Kt, Iterative cone (various R,D values)
- **Input:**
  - Calorimeter towers
  - (tracks and particle flow)



- **Jet Energy Calibration:**
  - **CMS: factorized multi-level correction**
    1. Offset correction (pileup, noise,thres.)
    2. Rel. response correction in eta (dijets)
    3. Abs. correction to particle level (Z/gamma + jet, ttbar)

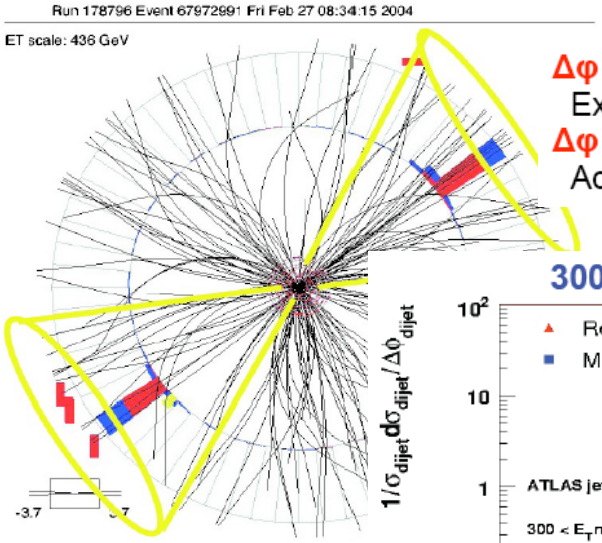


  - **ATLAS: local hadron calibration**
    - Calibrate clusters to particle scale (before jet algo.)
    - Make jets out of calibrated clusters
  - **Optional: parton corrections**
    - Flavour, underlying event, parton level



Dijet Azimuthal Decorrelations

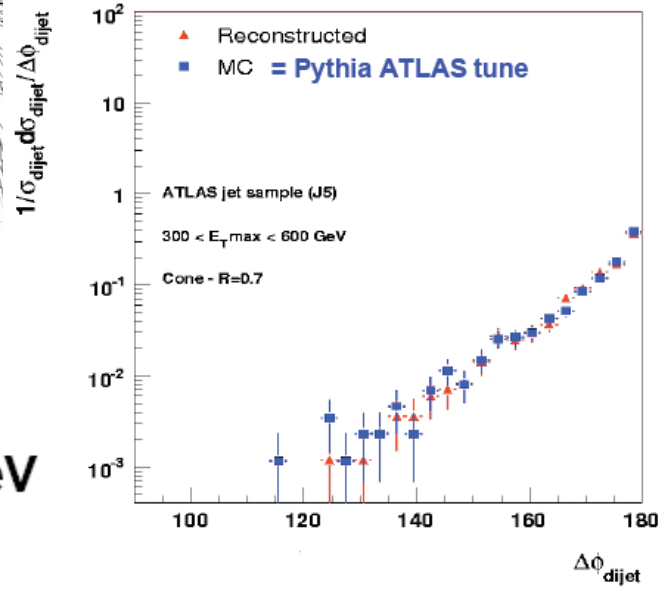
- **Distance in phi between leading and 2nd jet in "dijet" events sensitive to gluon radiation effects**
- **Tuning of MC models (FSR, higher order diagrams)**
- **ATLAS comparison between generated and reconstructed distributions:**



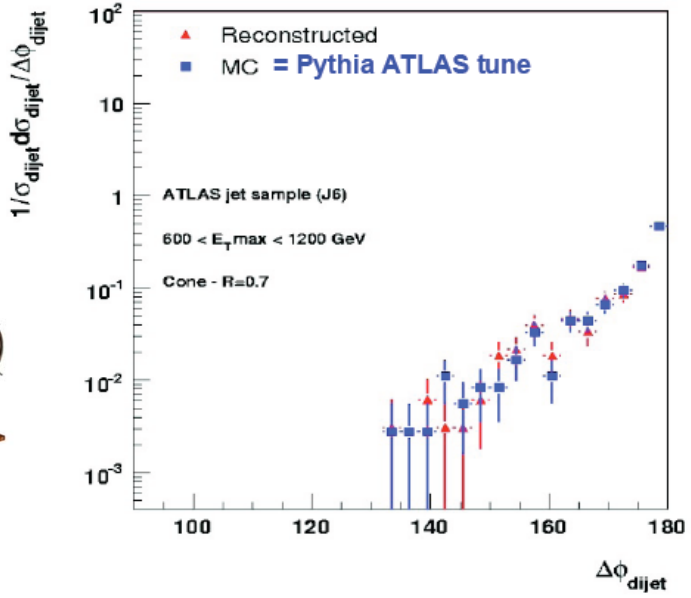
Δφ dijet = π →
Exactly two jets, no further radiation
Δφ dijet small deviations from π →
Additional soft radiation outside the jets

Δφ dijet as small as 2π/3 →
One additional high-pT jet
Δφ dijet small – no limit →
Multiple additional hard jets in the event

300 < ET MAX < 600 GeV



600 < ET MAX < 1200 GeV



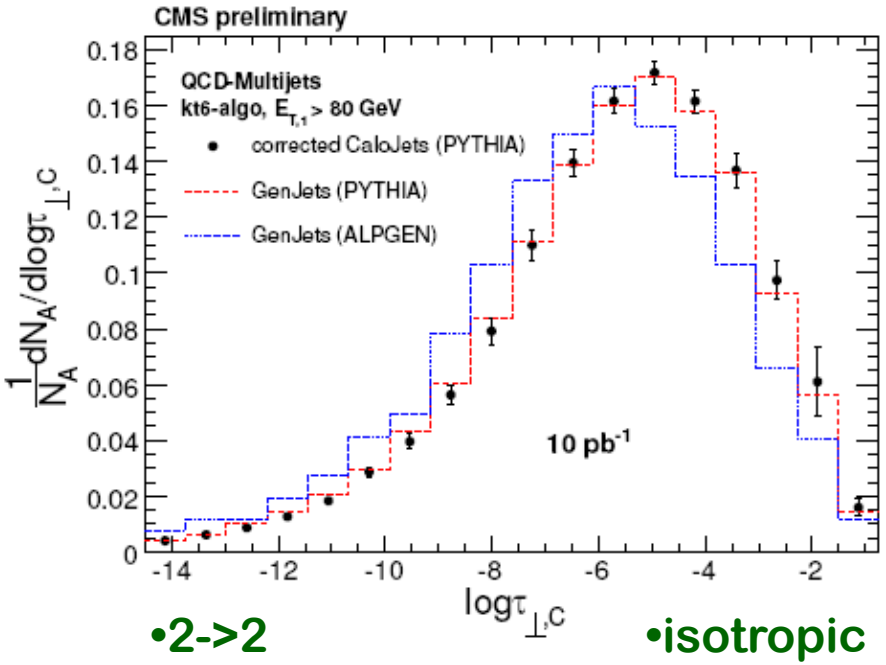
R=0.7
$|\eta_{jet}| < 0.5$
$ET_{jet\ \#2} > 80$ GeV

Event Shapes

- **Normalized event shapes robust against JES uncertainties**
  - ❑ **Suitable for early data analysis (central region)**
- **Collinear and infrared safe observables**
- **Study multijet production, compare with MC models**

Central transverse thrust

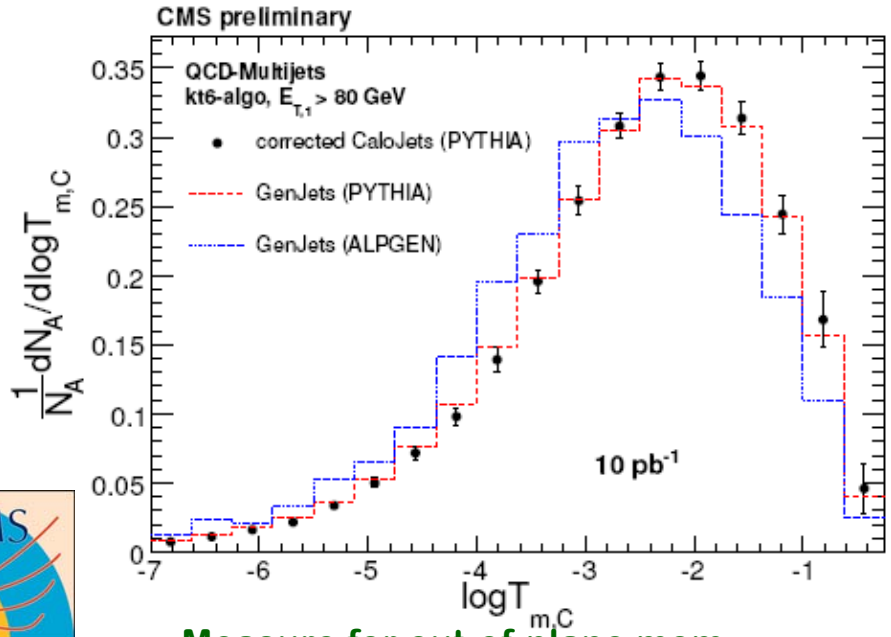
$$T_{\perp,C} \equiv \max_{\vec{n}_T} \frac{\sum_{i\in C} |\vec{p}_{\perp,i} \cdot \vec{n}_T|}{\sum_{i\in C} p_{\perp,i}}$$



•2->2 •isotropic

Central thrust minor

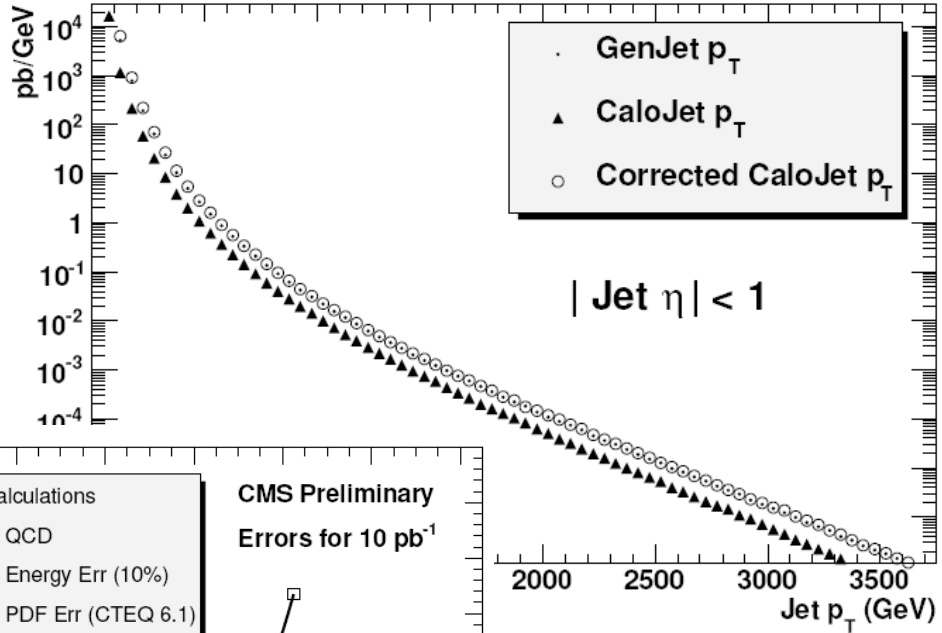
$$T_{m,C} \equiv \frac{\sum_{i\in C} |p_{x,i}|}{\sum_{i\in C} p_{\perp,i}} = \frac{\sum_{i\in C} |(\vec{p} \times \vec{n}_B) \times \vec{n}_{T,C}|}{\sum_{i\in C} p_{\perp,i}}$$

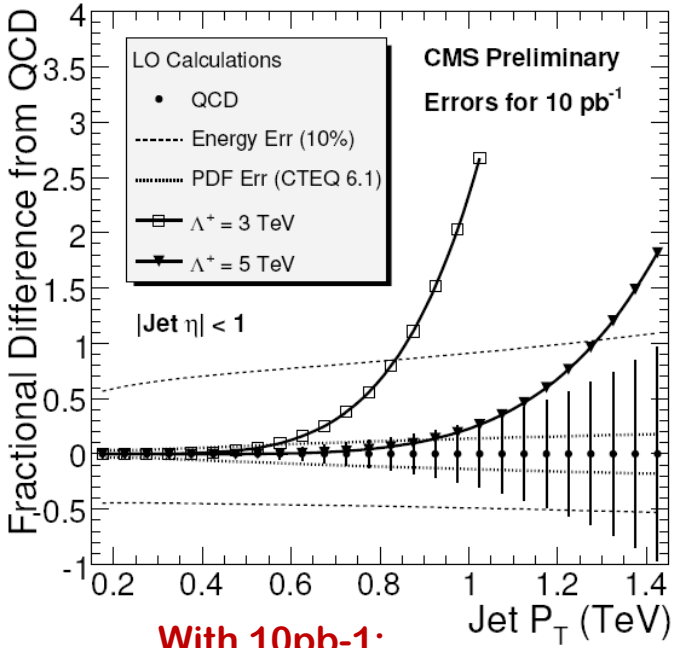


•Measure for out-of-plane mom.

Inclusive Jet Cross Section

- **Motivation**
  - Early measurement
  - Test pQCD in a new regime
  - Constraints on PDFs and alpha-s
  - Sensitivity to new physics (contact interactions)
- **Theoretical issues**
  - Scale uncertainties (higher orders)
  - PDF uncertainties
- **Experimental issues**
  - Energy scale and its error
  - Resolutions from data
  - Underlying event
  - Jet counting (lumi, trigger and reco efficiencies)

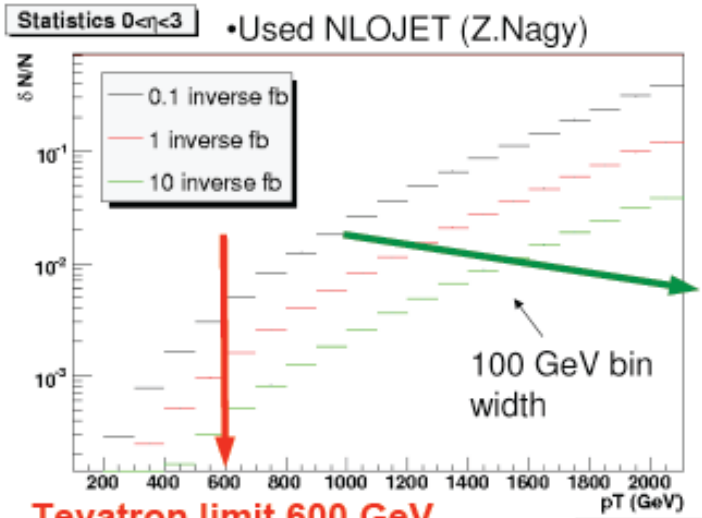




With 10pb-1:
Can probe contact interactions up to 3 TeV
(main uncertainty: JES)

Inclusive Jet Cross Section: Errors

Evaluation of jet cross section uncertainties by ATLAS



Tevatron limit 600 GeV

Statistics:

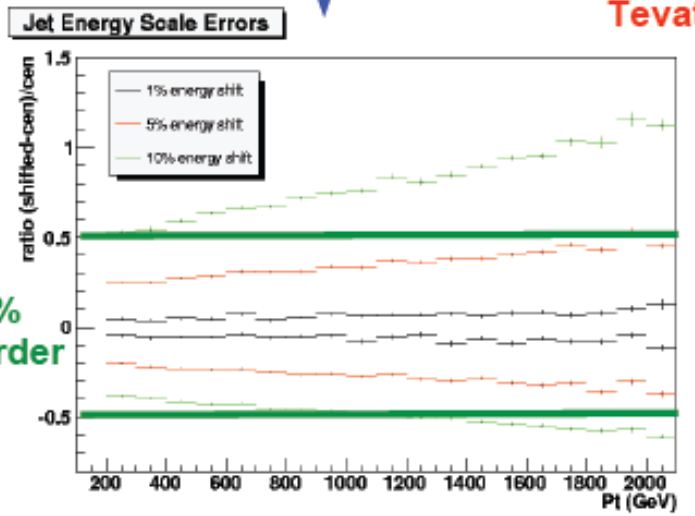
Estimated as √N/N from NLO cross section

- 10 / fb
- 1 / fb
- 0.1 / fb

100/pb LHC: 2% at 1 TeV
30% at 2 TeV

Jet Energy Scale

- 10% shift
- 5% shift
- 1% shift

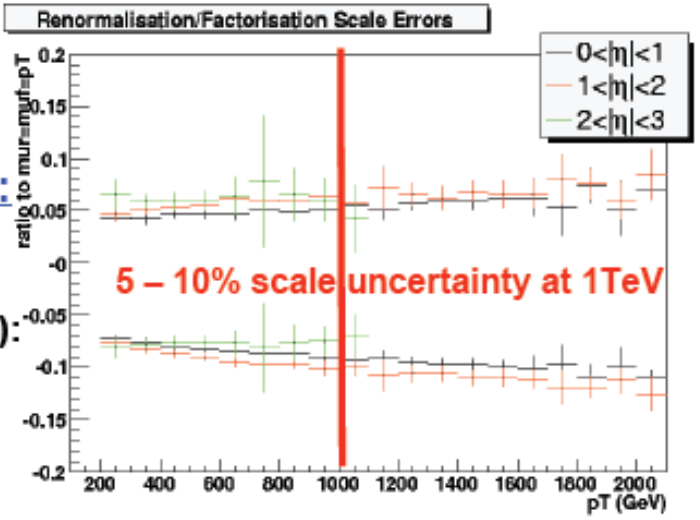


50% border

Scale Uncertainty:

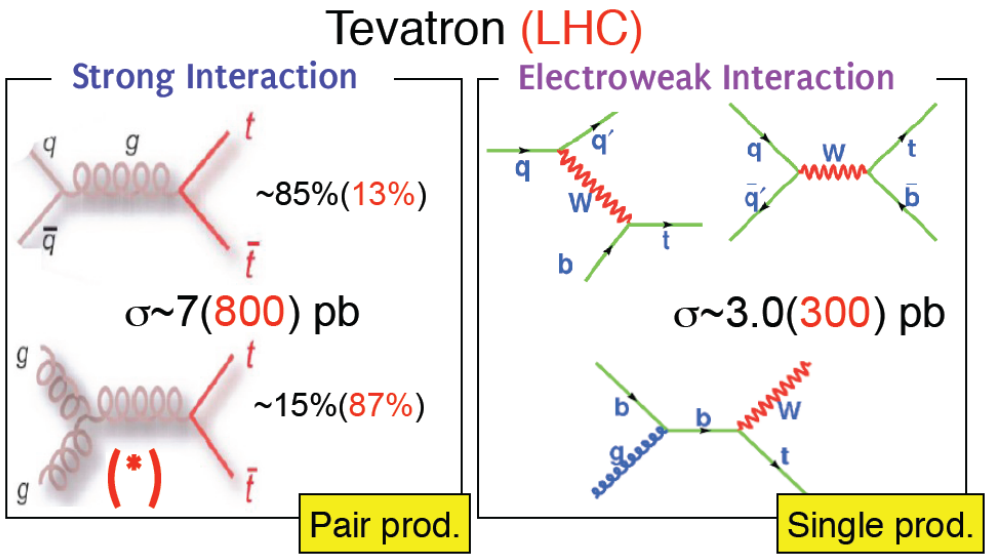
By varying $\mu_r = \mu_f$ from pT/2 to 2 pT (in pseudorapidities):

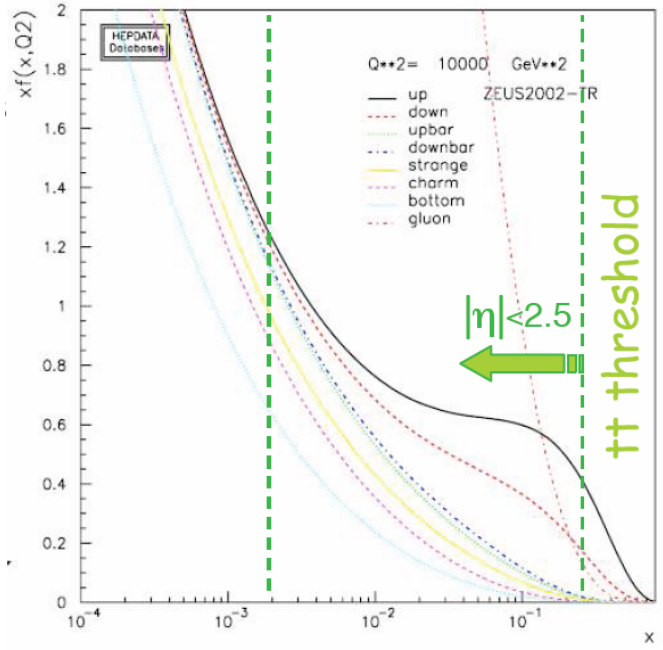
- 2 < |η| < 3
- 1 < |η| < 2
- 0 < |η| < 1



Top Quark Physics

- **LHC will be "top factory"**
  - 8M ttbar events per year (10fb-1 @ 14 TeV)
- **Production dominantly gluon induced**
- **At 10 TeV, ttbar cross section drops by ~50%, e.g arXiv:0804.2800:**
  - NLO+NLL, CTEQ6.5, mtop=171 GeV:
  - Sigma (14 TeV) = 908 +/- 83 (sc.) +/- 30 (pdf) pb
  - Sigma (10 TeV) = 414 +/- 40 (sc.) +/- 20 (pdf) pb

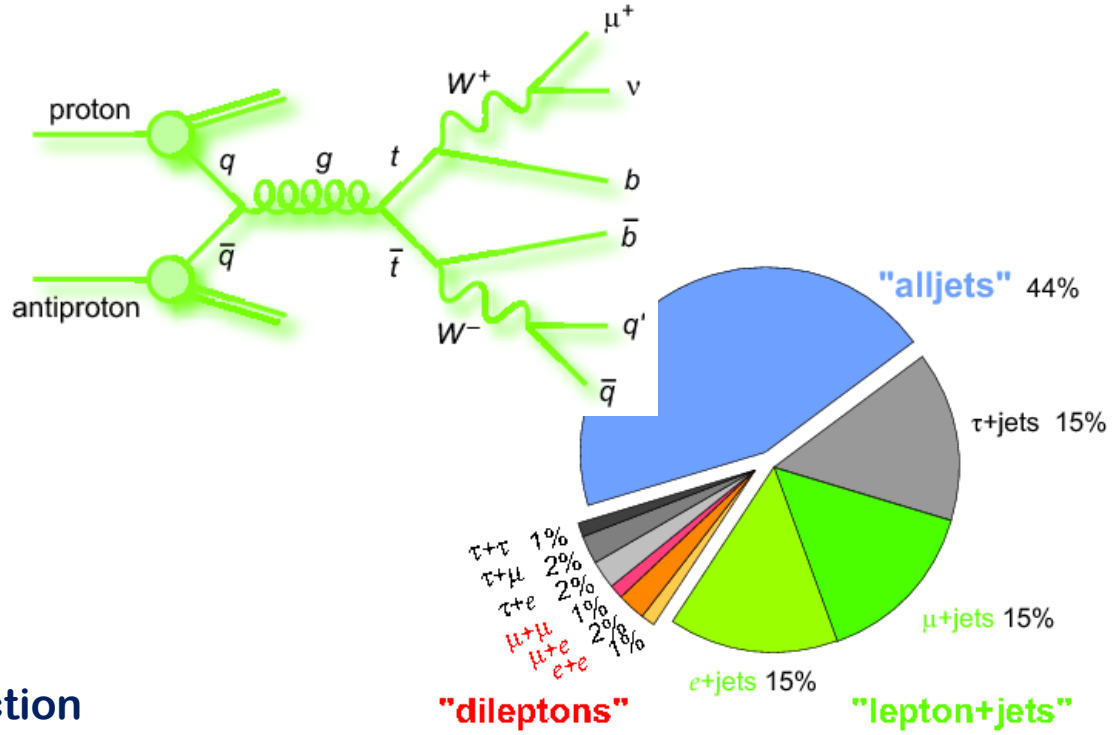




Top Quark Physics (cont.)

- **In the beginning, focus on channels with leptonic W decay(s)**
  - ❑ **Dilepton channel**
    - o Two leptons, >=2 jets, MET
  - ❑ **Lepton+jets channel**
    - o One lepton, >=4 jets, MET
  - ❑ **"Easier" w.r.t. trigger, QCD background**

- **Top Physics Program**
  - ❑ **"Rediscovery" and cross section at LHC energies**
  - ❑ **Differential cross sections, validate MC (background for searches)**
  - ❑ **Ttbar resonances**
  - ❑ **Properites (mass, spin, charge..)**
  - ❑ **Single top**

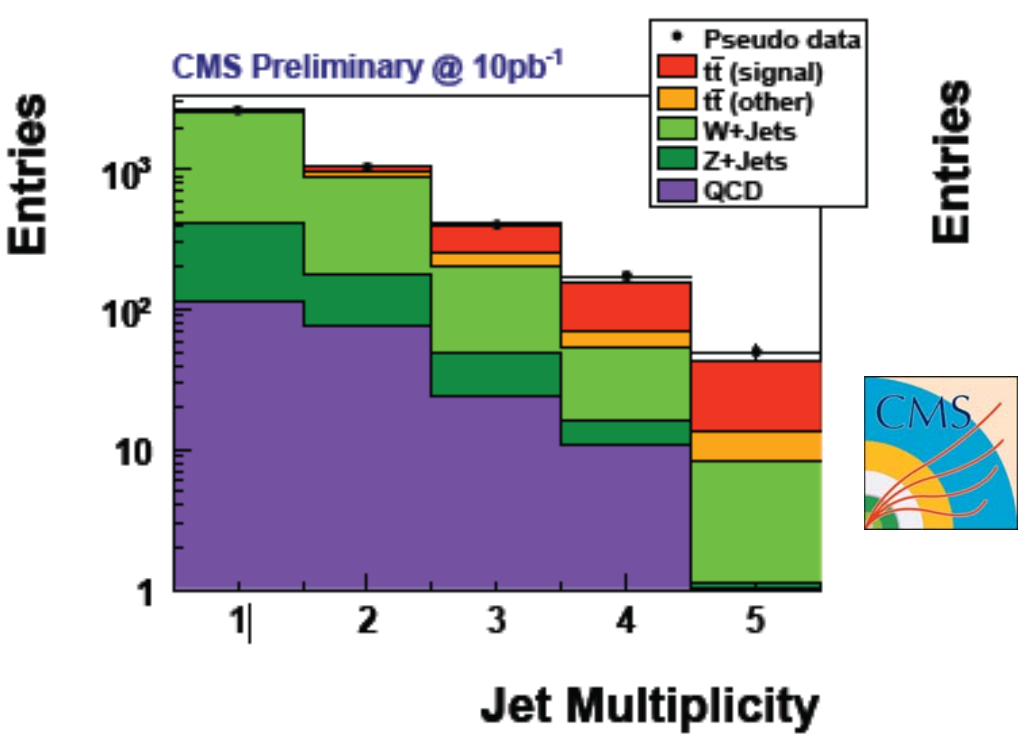


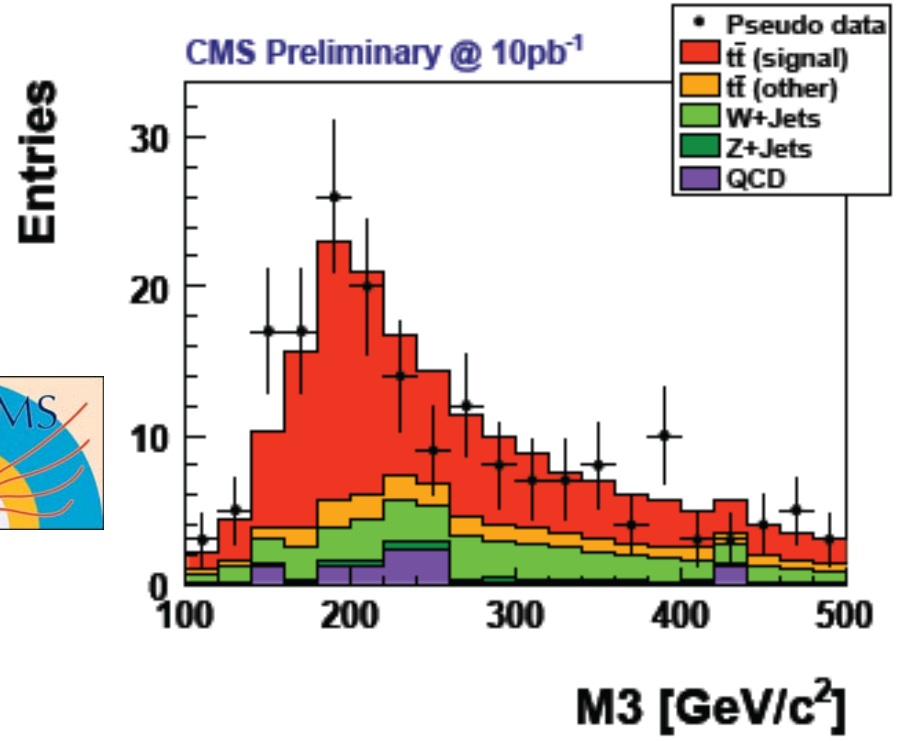
- **Ttbar events as commissioning tool**
  - ❑ **Understanding of most physics objects required (leptons, jets, MET, b-tagging)**
  - ❑ **Use to constrain JES and b-tag efficiency**

Rediscovery: Muon+Jets

- **Simple and robust event selection**
  - ❑ One tightly isolated muon, Pt>30 GeV
  - ❑ At least 4 jets, Et>65,40,40,40 GeV
- **No b-tagging, no MET**
- **For 10pb-1: expect 128 / 90 signal / background events**

Inv. Mass of 3 jets with highest vec.sum. Pt

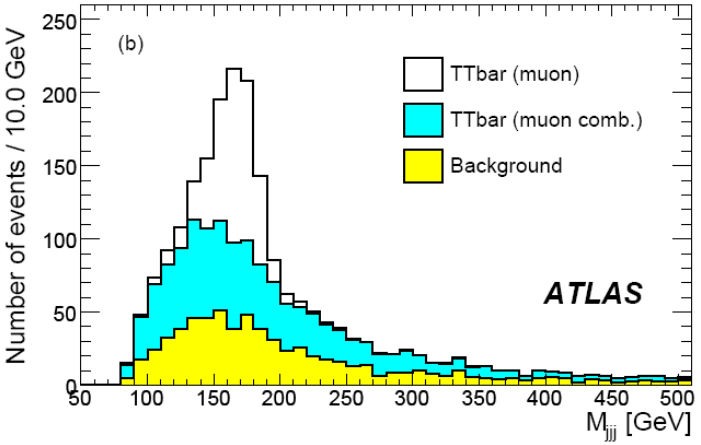




Lepton+Jets

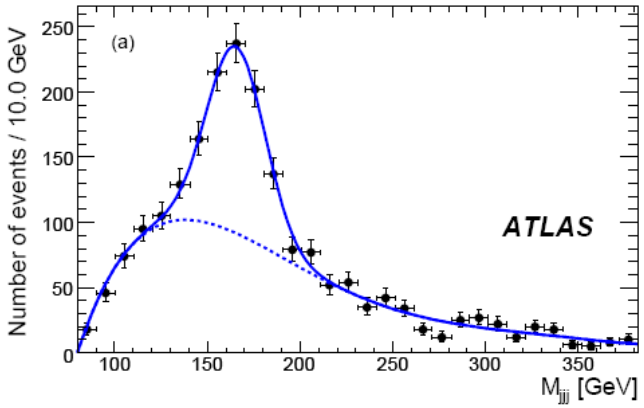
- **ATLAS event selection for 100pb-1**
  - One lepton (e or mu) with Pt>20 GeV
  - MET > 20 GeV
  - >=4 jets with Et>40,40,40,20 GeV
  - W-mass constraint
- **Optionally**
  - Mtop window
  - B-tagging

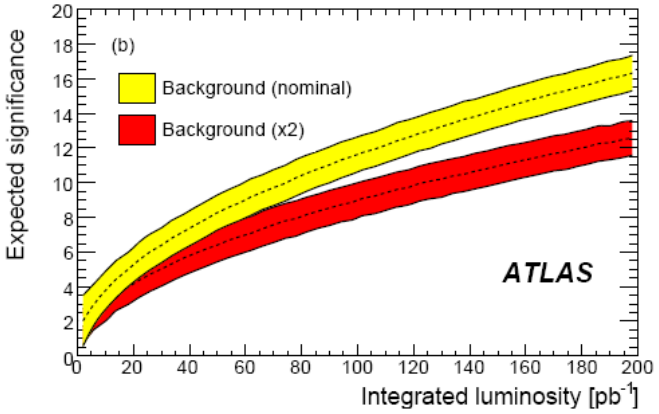
QCD not included …
"comparable to W+jets"



Muon analysis						
Sample	default	W const.	m_t win	W const. + $\|\eta\| < 1$	W const. + 1 b-tag	W const. + 2 b-tag
Signal	3274	1606	755	386	403	280
Background	1497	495	143	84	42	14
S/B	2.2	3.2	5.3	4.6	9.6	20.1

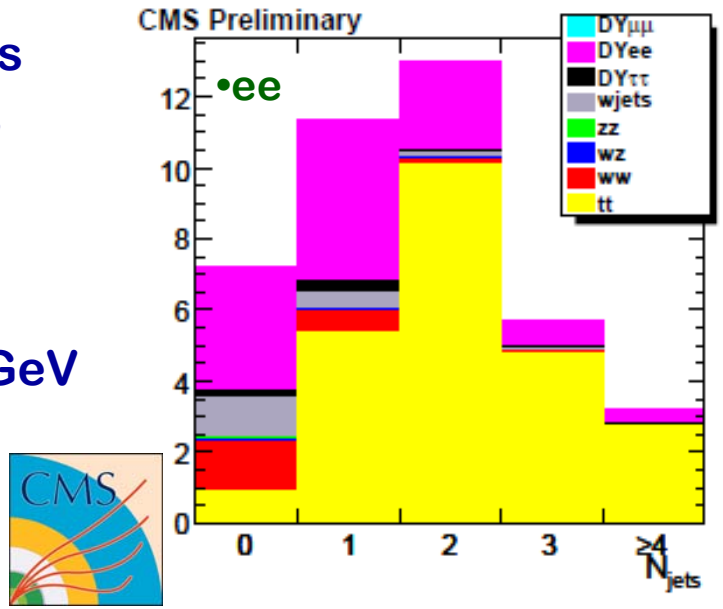
- **Cross section extraction from fit to mass distribution**

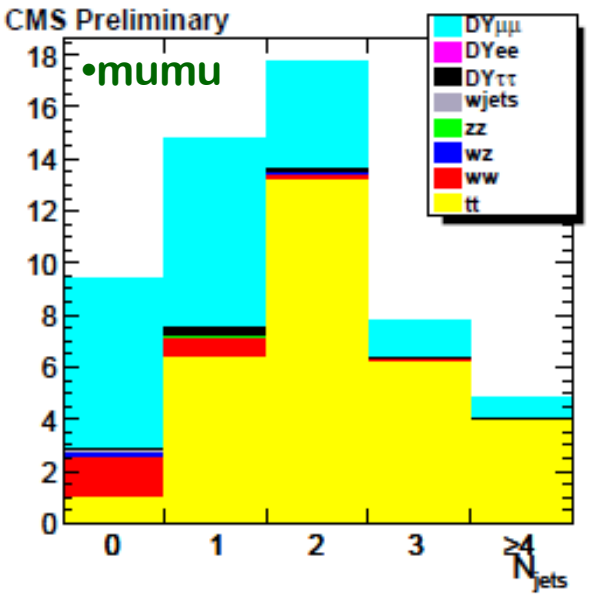




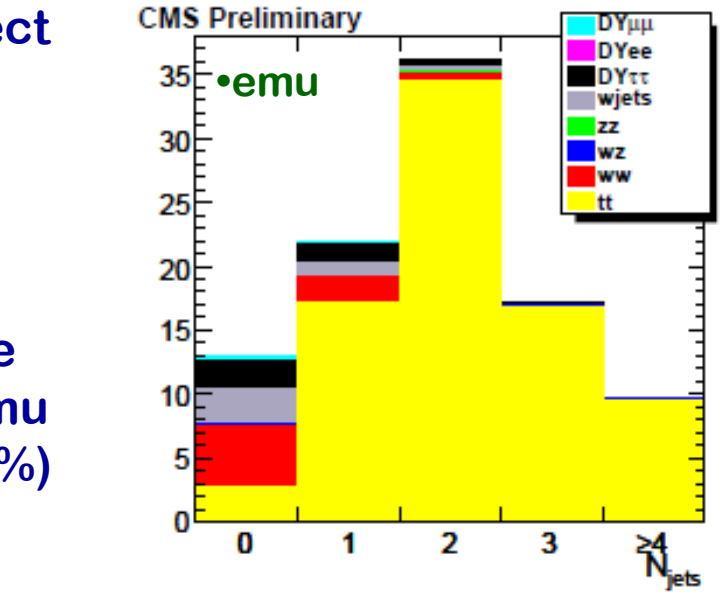
Dilepton channel

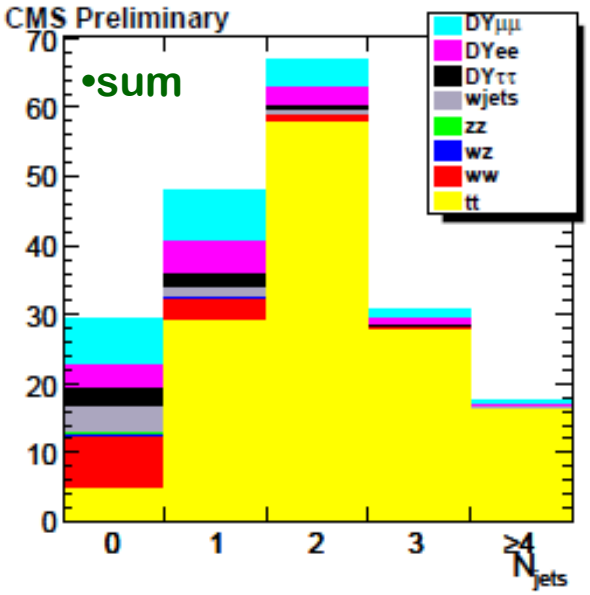
- 2 isolated leptons (ee,mumu, emu), Pt>20 GeV
  - ❑ DY veto
- MET>20/30 GeV
- >=2 jets, Et> 30 GeV
- DY veto





- For 10pb-1, expect 10% stat error combined

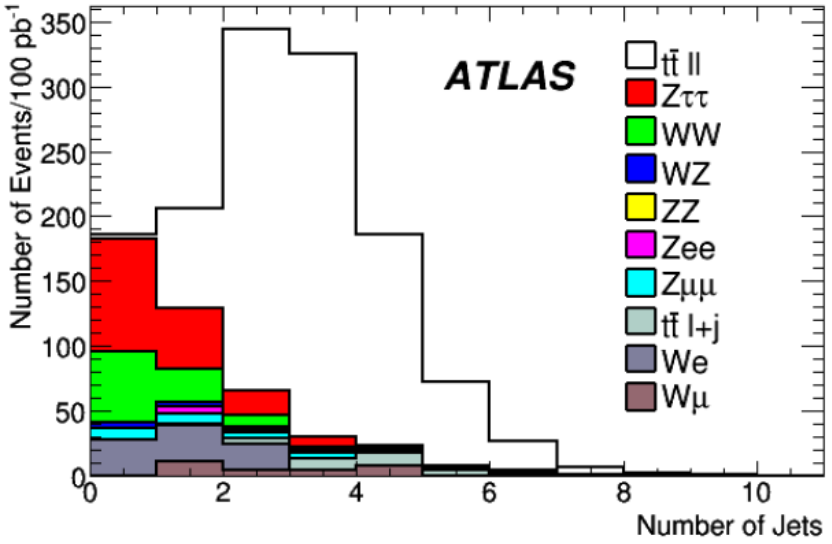




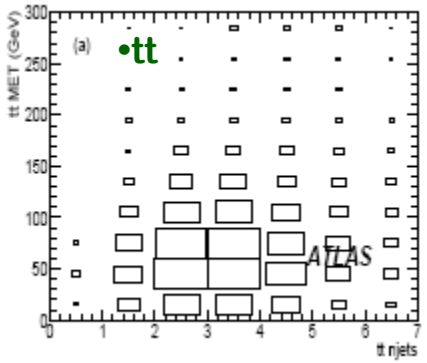
- If MET, cannot be controlled, do emu only (stat err. 13%)

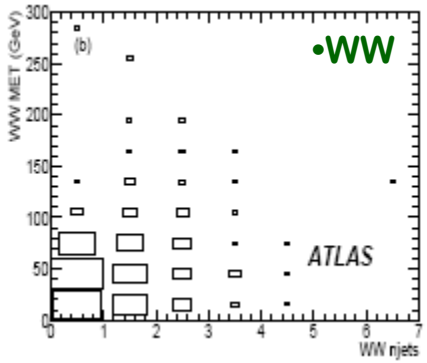
Dilepton cross section

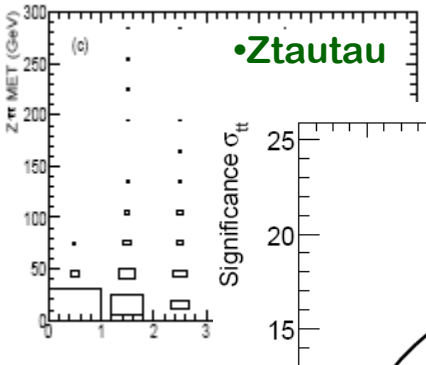
- **Event selection:**
  - 2 leptons, pt> 20 GeV
  - Jets with Et> 20 GeV
  - MET>30 GeV, DY veto

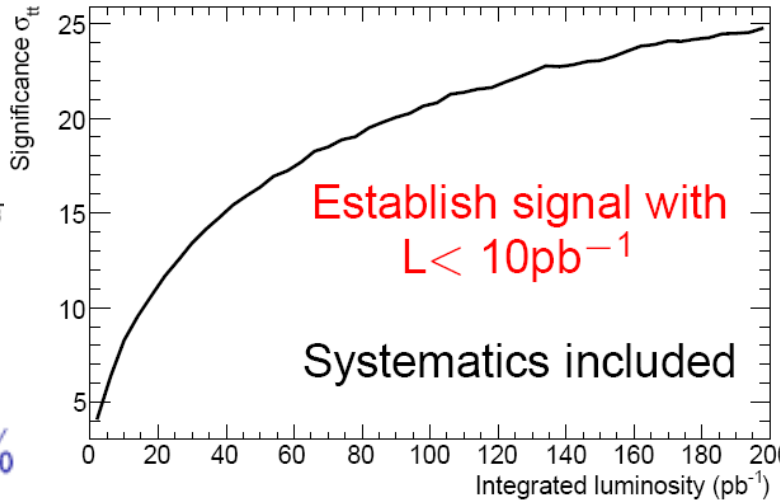


- **Cross section measurement**
  - Fit MET vs Njets templates for signal and background







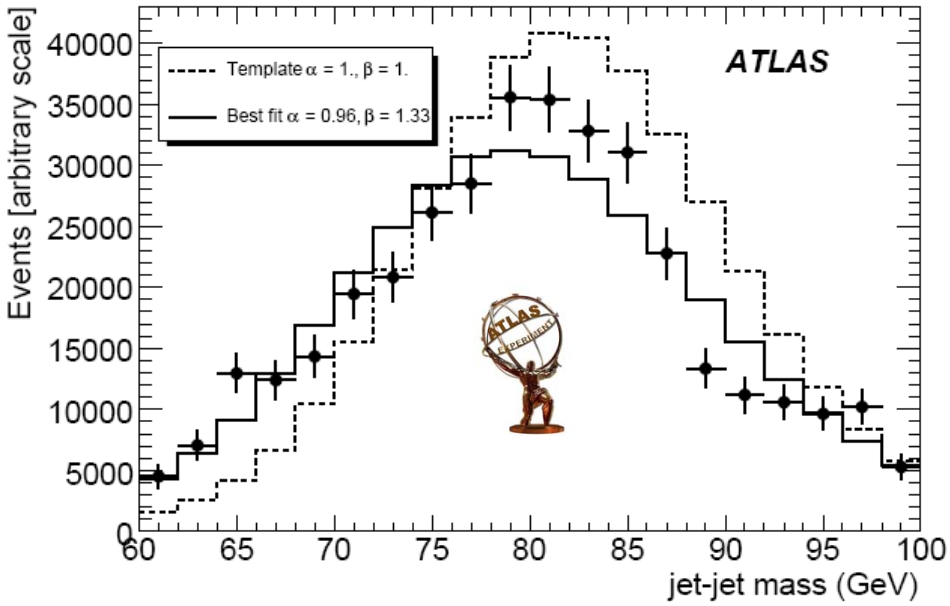


- Expected precision for 100pb-1 (incl. syst.):

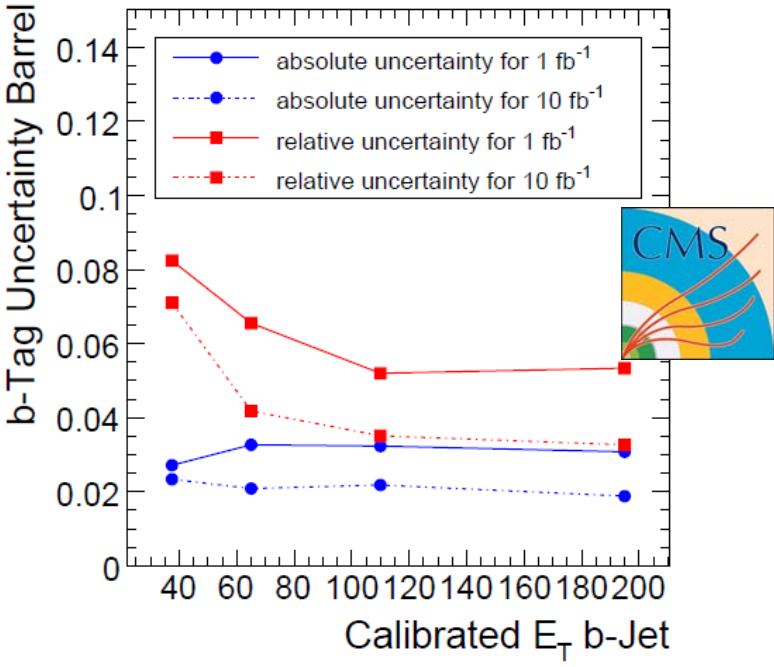
$$\Delta\sigma/\sigma = (4(\text{stat}) \pm 4(\text{sys}) \pm 2(\text{pdf}) \pm 5(\text{lumi}))\%$$

Top as Calibration tool

- **Light Jet Energy Scale (ATLAS)**
  - Semileptonic events
  - 2 b-tagged jets
- **Apply template fits to inv mass of 2 light jets**
  - JES to 2% in 50pb-1 (0.5% syst.)
  - 1% with 1fb-1 possible



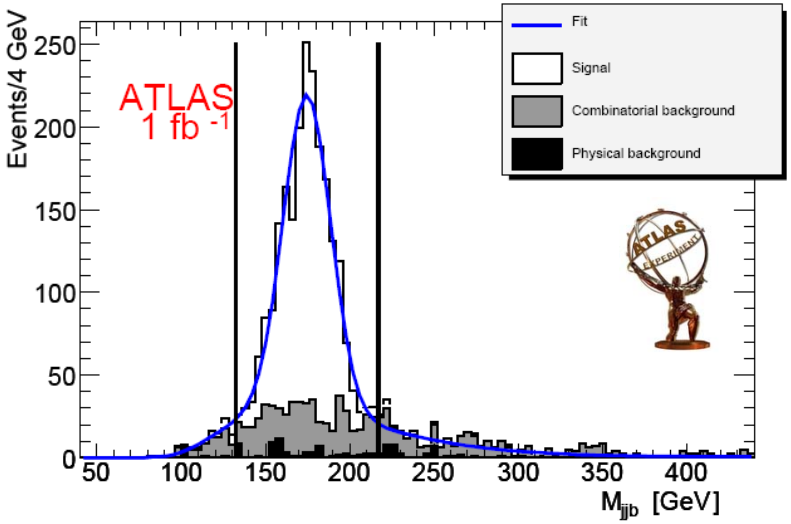
- **B-tagging efficiency (CMS)**
  - Selection of high-purity dilepton ttbar events
  - Purity of b-content in selected sample: 44%
  - Rel. uncertainty on btag eff.
    - 1 fb^{-1}: 6%
    - 10 fb^{-1}: 4%



Top Mass

Various channels+methods studied by both experiments, here only two examples
See talk by Lucia Di Ciaccio for details

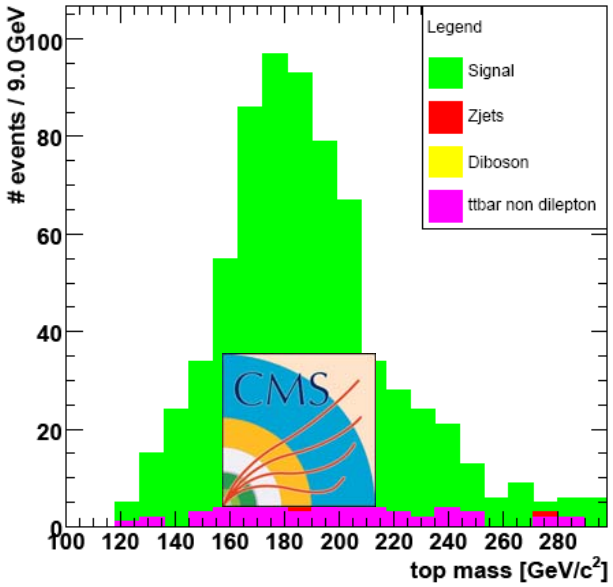
- **ATLAS lepton+jets, 1fb-1**
  - Semileptonic event selection
  - 2 b-tags
  - Geometric reconstruction:
  - W candidate from min dR(jet,jet)
  - Top candidate min dR (W,b-jet)



$$m_t = 174.6 \pm 0.5(\text{stat}) \pm 0.7/\%(\text{b-JES}) \pm 0.2/\%(\text{JES}) \pm 0.4(\text{ISR/FSR}) \pm 0.1(\text{b fragmentation}) \text{ GeV}$$

  - 1…3.5 GeV, dep. On b-JES precision

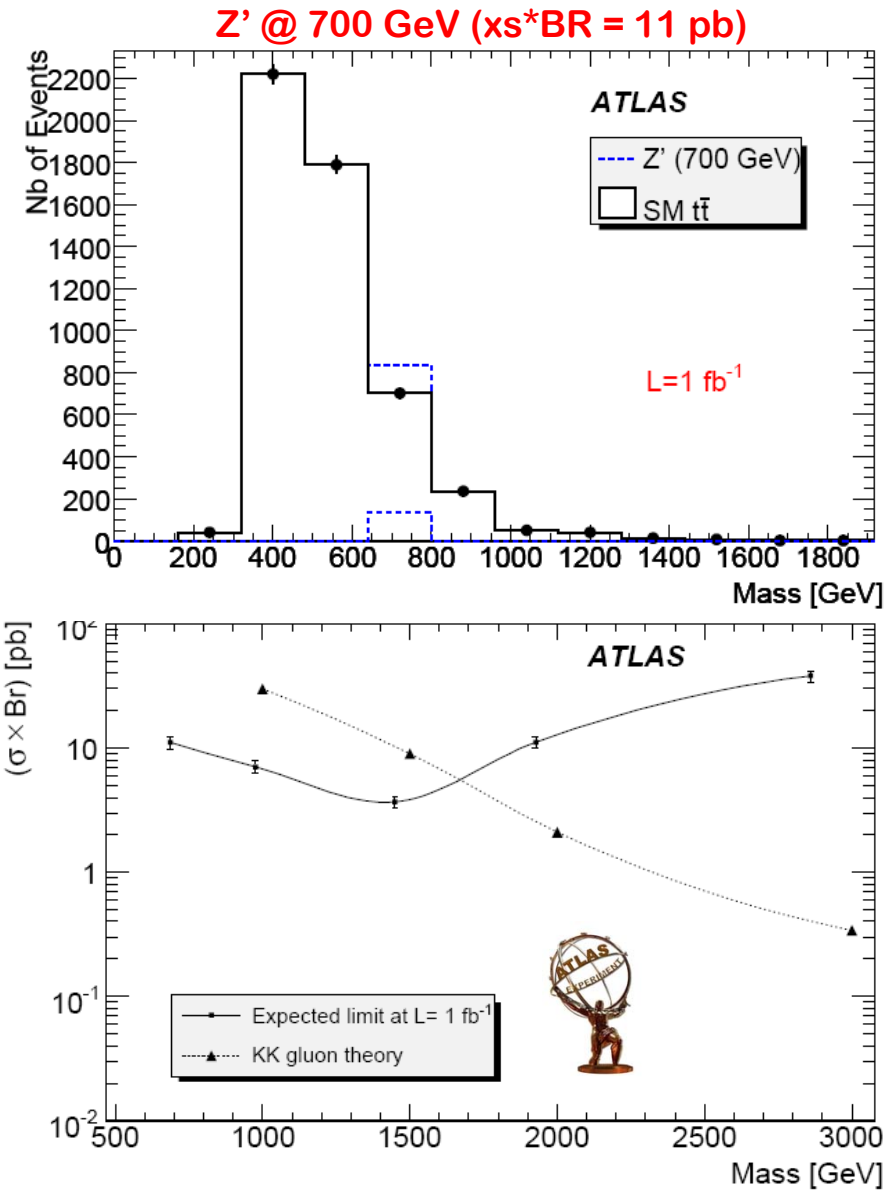
- **CMS dilepton channel**
  - Experimental error dominated by jet energy scale, known to
    - 15% at 1 fb^{-1}: $\Delta m \sim 4.2$ GeV
    - 10…3.0% for 1…10 fb^{-1} $\Delta m \sim 2.9$ GeV
    - 1.5% longer term: $\Delta m \sim 1.0$ GeV



Δm_t = 1.5 (0.5) (stat.) +/- 2.9 (1.1) (syst.) GeV @ 1 (10) fb^{-1}

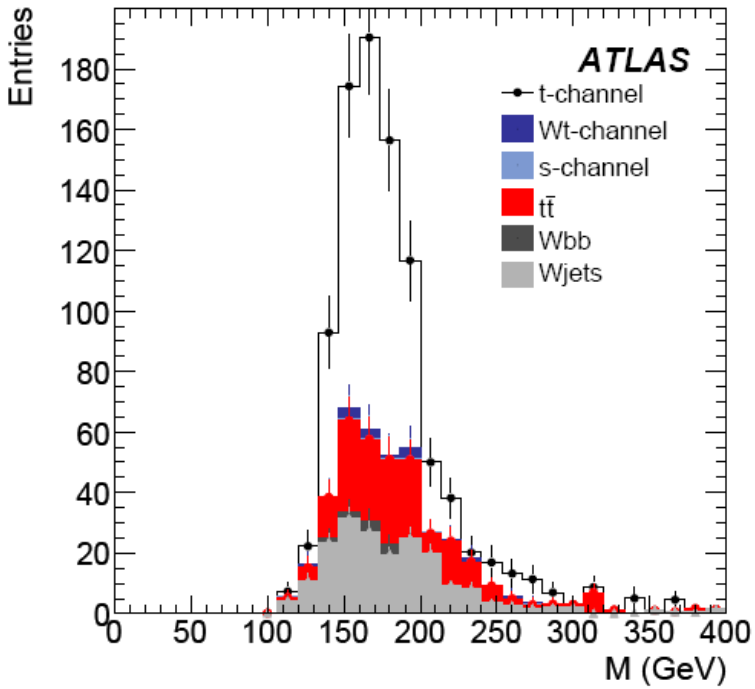
Ttbar resonances

- **Motivation**
  - High potential to discover new physics by searching for new resonances / gauge bosons in pp->X->ttbar (large Yukawa coupling)
  - Manifest in M(ttbar) distribution (shape distort., peak)
- **Experimental issues at high M(ttbar)**
  - Top decay products closeby (boost): breakdown of isolation, jet merging
  - Breakdown of b-tagging
  - Efforts ongoing …
- **ATLAS Study:**
  - Standard M(ttbar) reco in lepton+jets
  - KK gluon resonances can be excluded with 1fb-1 up to 1.5 TeV

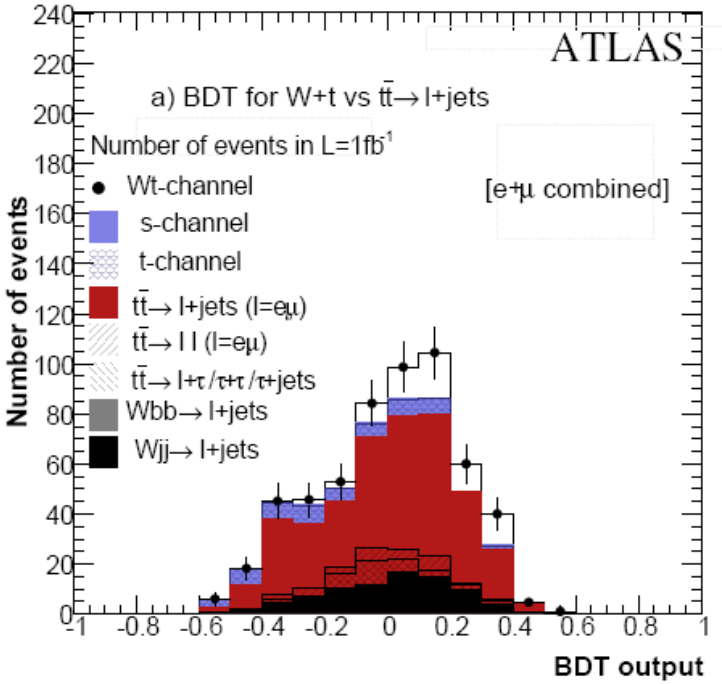


Single Top (cont.)

•t-channel: mtop



•Wt-channel: BDT output



- **ATLAS: new studies of all single top channels using various methods**

	method	S/B	$\mathcal{L}$	xsec precision
t-chan	cuts	0.37	1fb^{-1}	$\pm 5\% \pm 45\%$
t-chan	BDT	1.3	1fb^{-1}	$\pm 6\% \pm 22\%$
Wt	BDT	0.35	10fb^{-1}	$\pm 20\%$
s-chan	likelihood	0.19	30fb^{-1}	3σ evidence

$|V_{tb}|$: $\pm 11\%(\text{stat+sys}) \pm 4\%(\text{theor})$

Conclusions

- **Rich program for early QCD and Top Quark Physics at LHC**

- **QCD: probe of strong interactions in new regime**
  - ❑ **Low Pt QCD:**
    - o MC model tuning with early data
    - o Measurement of multiple partonic interactions
  - ❑ **High Pt QCD:**
    - o Confront data with pQCD calculations at very high Q^2
    - o Input to PDF/alpha-s determinations
    - o New physics at very high Pt
- **Top Quark Physics:**
  - ❑ **Rediscovery possible already at low luminosities**
  - ❑ **Measurements of x.s., mass and other properties**
  - ❑ **Window to new physics (ttbar resonances)**

- **Crucial to understand SM backgrounds before any new physics signal can be claimed!**