Prospects for QCD Physics at the Large Hadron Collider

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Overview

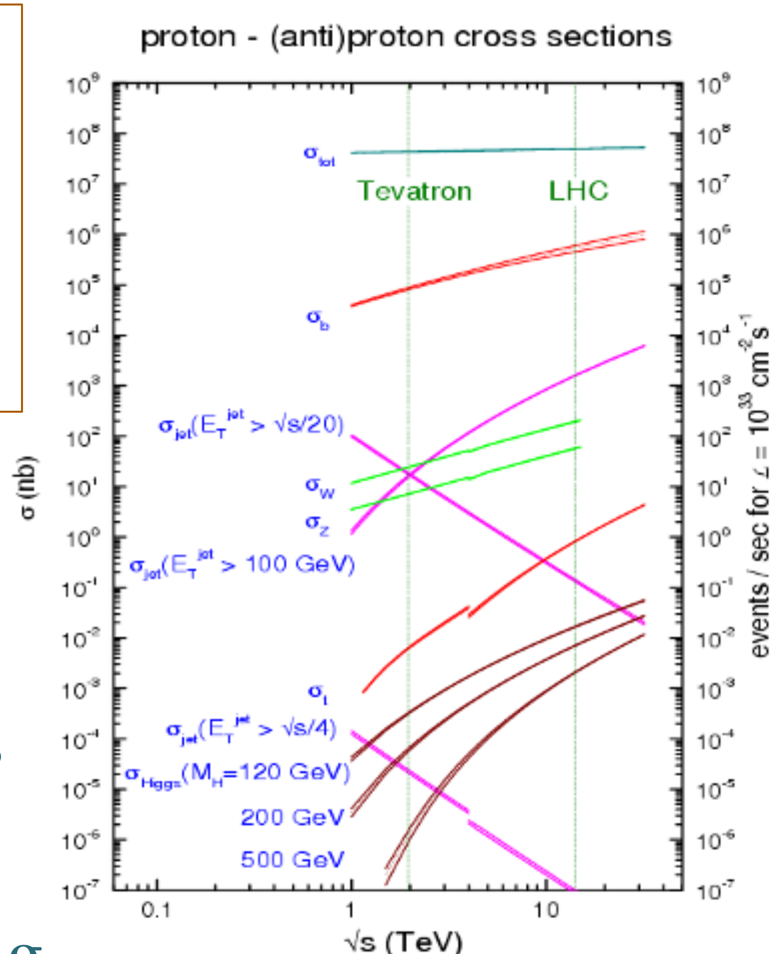
- Overview of the LHC and the ATLAS and CMS experiments
- Physics of strong interactions
  - Underlying event studies
  - Minimum bias measurements
  - Jet production physics
    - Inclusive jet cross-section
    - Measurement of dijet mass and angle
- Conclusions

The Large Hadron Collider

Low Luminosity: $L \approx 10^{33}\ cm^{-2}\ s^{-1}$
$\mathcal{L} \approx 10 fb^{-1}$/year

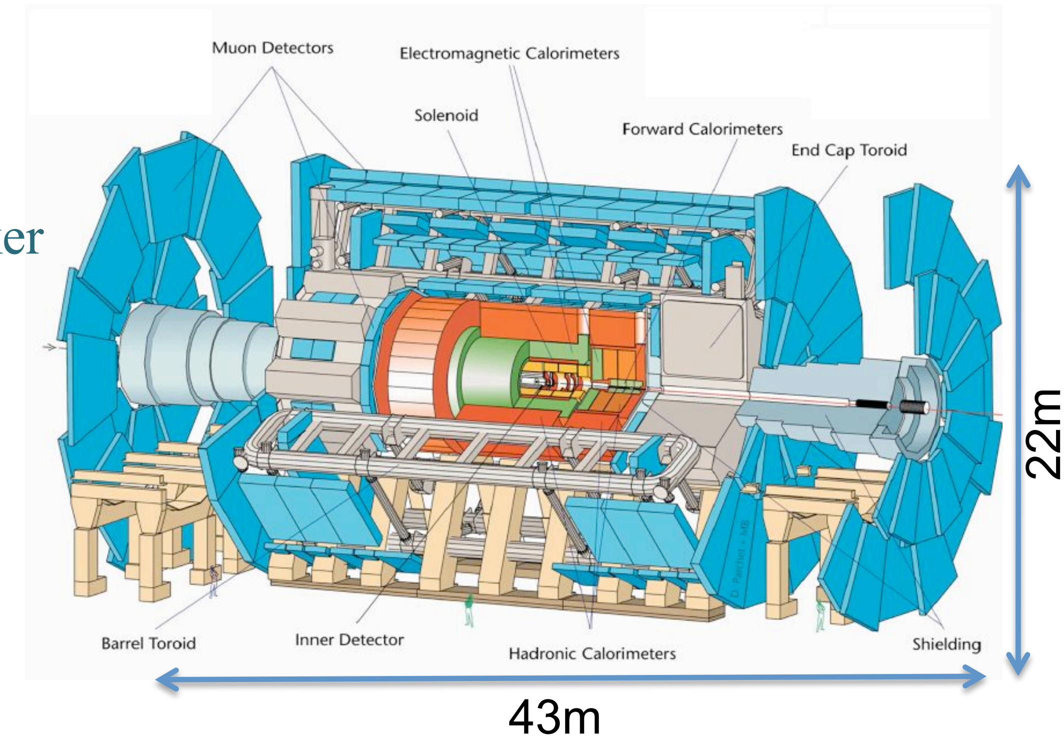
High Luminosity: $L \approx 10^{34}\ cm^{-2}\ s^{-1}$
$\mathcal{L} \approx 100 fb^{-1}$/year

- QCD physics at the LHC
  - Large cross-sections
  - One of the first physics results
  - Sensitive to new physics
  - Is the background to everything



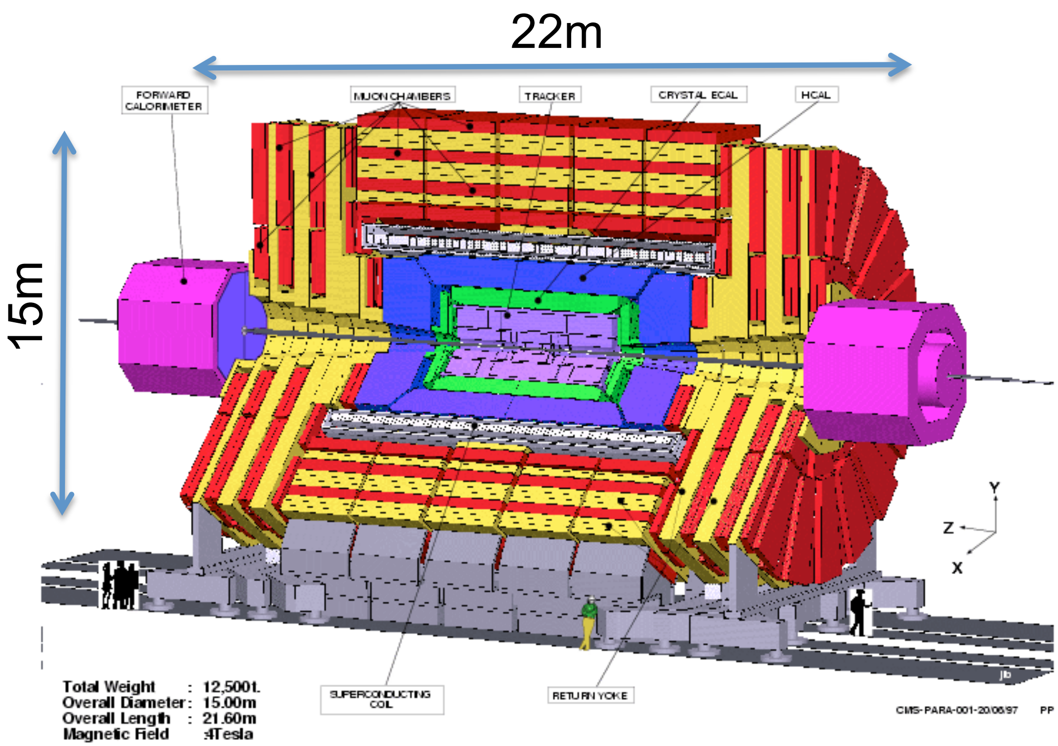
The ATLAS Detector

- Coverage up to $|\eta| = 5$
- Inner Detector ($|\eta| < 2.5$):
  - Silcon pixel and strip detectors and Transition Radiation Tracker
  - 2T Solenoid field
- Calorimeters ($|\eta| < 5.0$):
  - High granularity liquid argon calorimeter
  - Scintillating Tile hadronic calorimeter
- Muon Spectrometer ($|\eta| < 2.7$):
  - 80 μm resolution in drift tubes
  - 4T Toroid field
- Forward Cherenkov and zero-degree calorimeter partial coverage $|\eta| > 5.0$



Lepton energy scale ~ 0.02%
Jet energy scale ~ 1%
Absolute luminosity < 5%

The CMS Detector



Lepton energy scale ~ 0.05%
Jet energy scale ~ 1-2%
Absolute luminosity < 5%

Coverage up to $|\eta| = 5$

Inner Detector ($|\eta| < 2.5$):

- Silcon pixel and strip detectors
- 4T Solenoid field

Calorimeters ($|\eta| < 5.0$)

- Lead tungstate crystal EM calorimeter
- Brass/Scintillator tile hadronic calorimeter

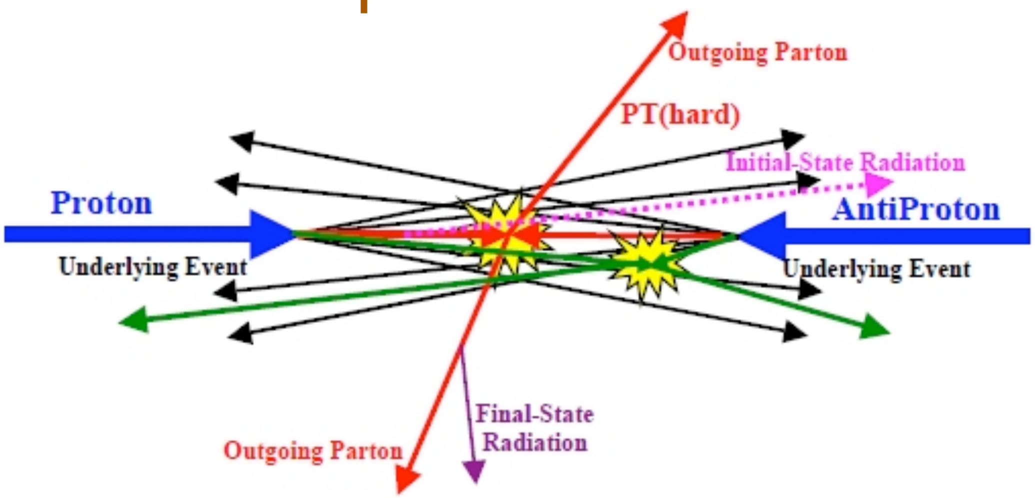
Muon Spectrometer ($|\eta| < 2.4$)

- Gas chambers in iron return yoke

Forward zero-degree calorimeter partial coverage $|\eta| > 5.0$

Underlying Event Studies

Underlying Event: Everything in the event except the hard scatter



This includes initial and final state radiation, remnant interactions and hadronization

Minimum bias events are generally only the soft-part of the underlying event

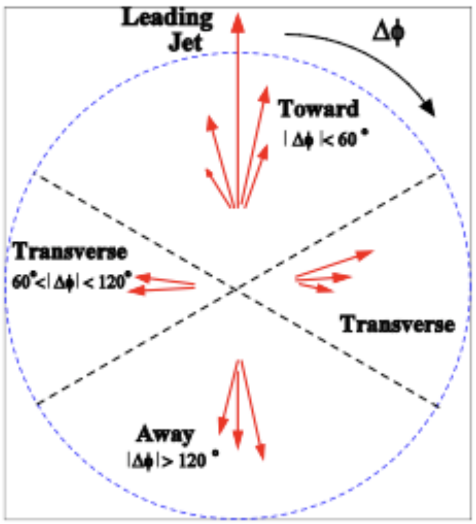
Modeling of underlying events is…

- Important for high P_t physics
- Necessary ingredient for understanding jet and lepton isolation, energy flow, jet tagging

Measuring Underlying Events

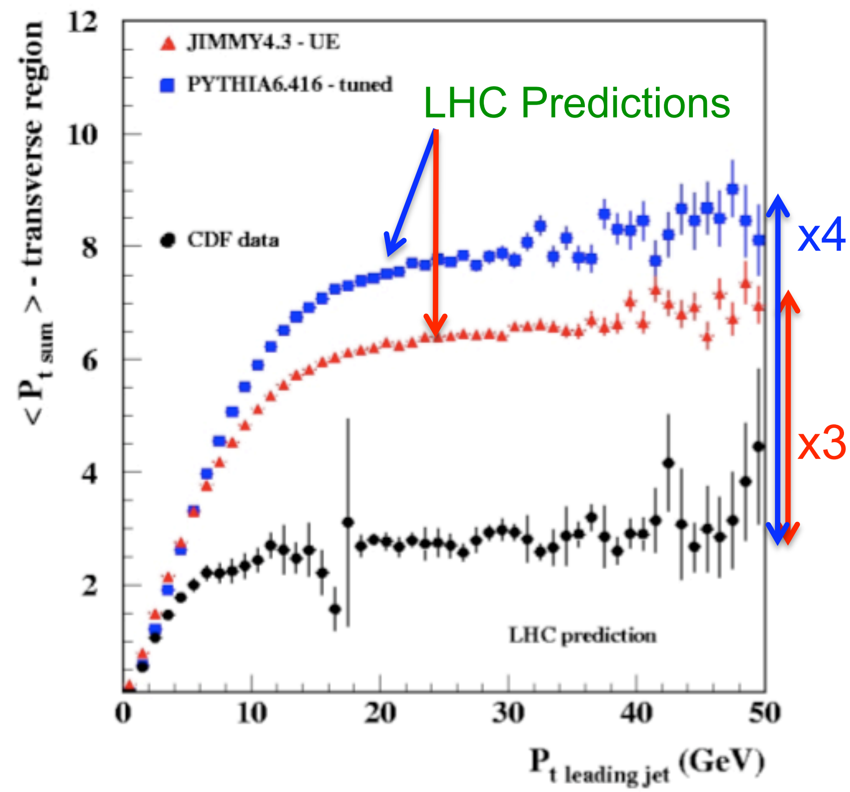
Measure in transverse region

- Number of charge particles
- Average scalar P_t sum



Developed in CDF Run I

Moraes et al EPJ C50, 435 (2007)



Different underlying event tunings need to reproduce the particle density as well as the average scalar P_t sum

Measurement of Minimum Bias

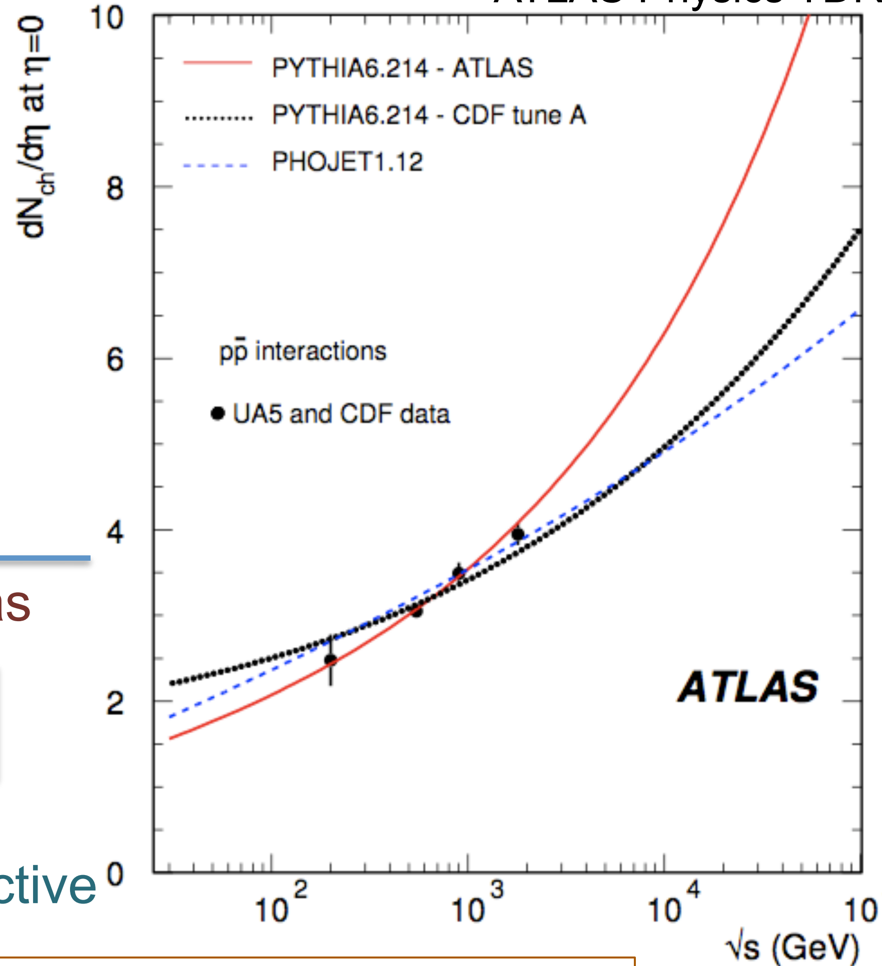
- Minimum bias interactions are a major background to all physics processes
  - ~ 2 interactions per beam crossing (low luminosity)
  - ~18 interaction per beam crossing (high luminosity)

A common definition of minbias

$$\sigma_{tot} = \sigma_{elas} + \sigma_{sd} + \sigma_{dd} + \sigma_{nd}$$

elastic, single diffractive, double diffractive, non-diffractive

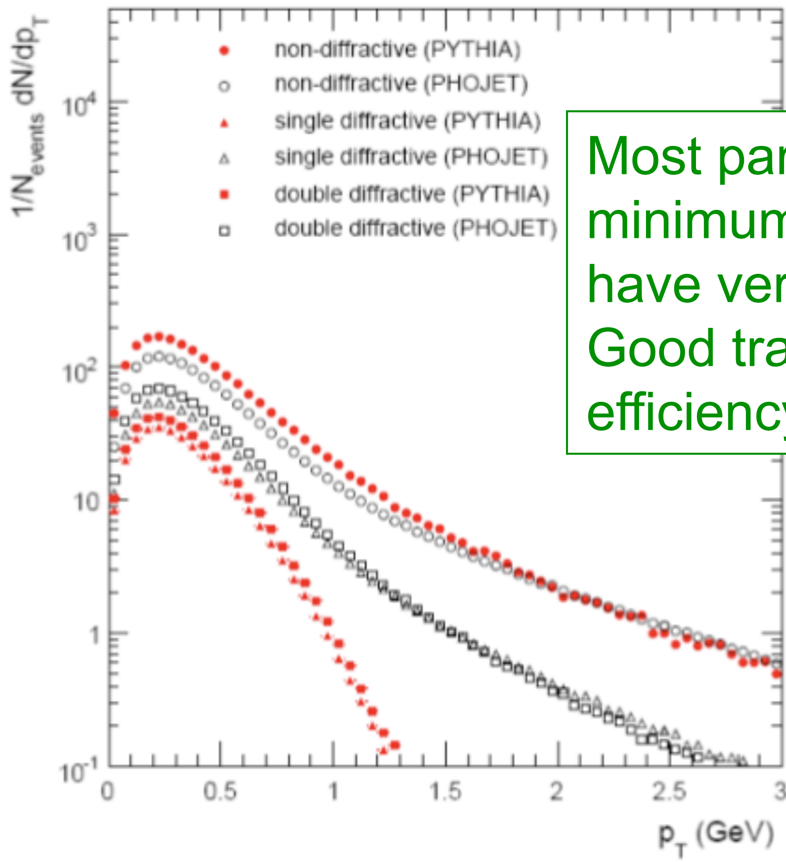
ATLAS Physics TDR



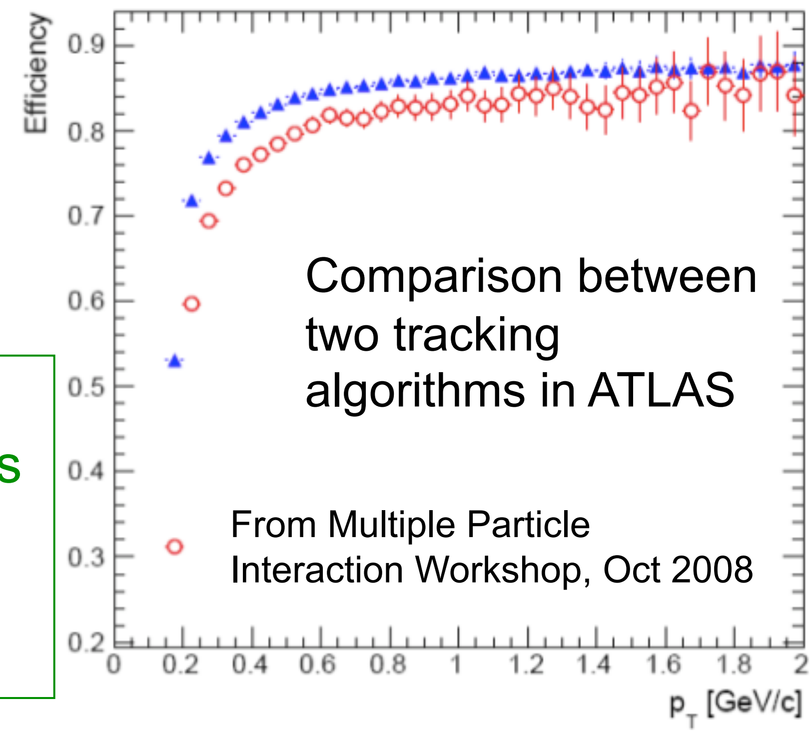
Important measurement for first data

ATLAS Minimum Bias Analysis

- Analysis goal is to measure number of charged particles per unit of η and P_t



Most particles in minimum bias events have very low P_t. Good tracking efficiency is critical

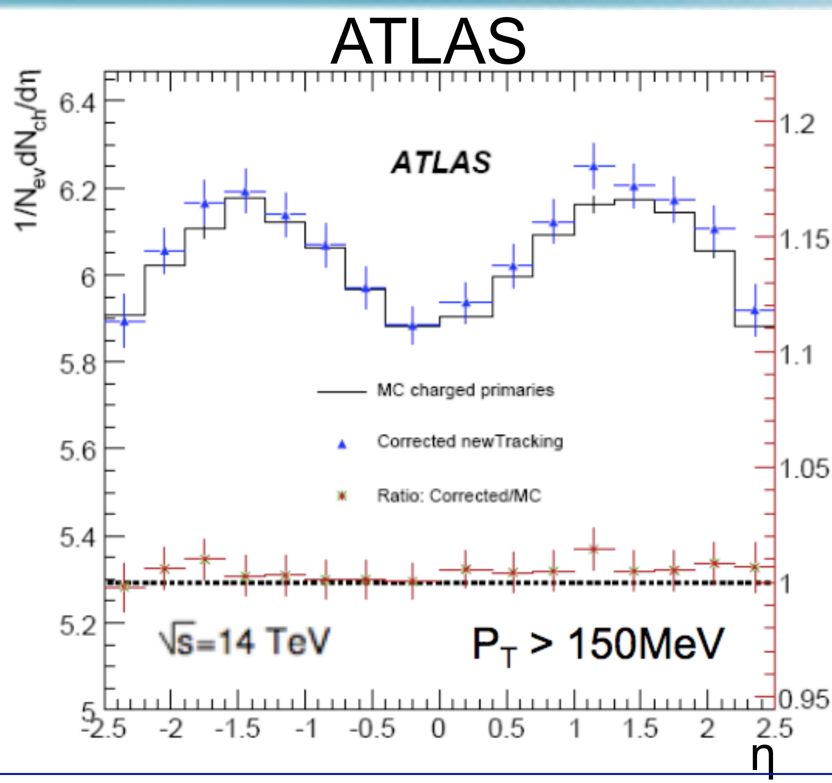


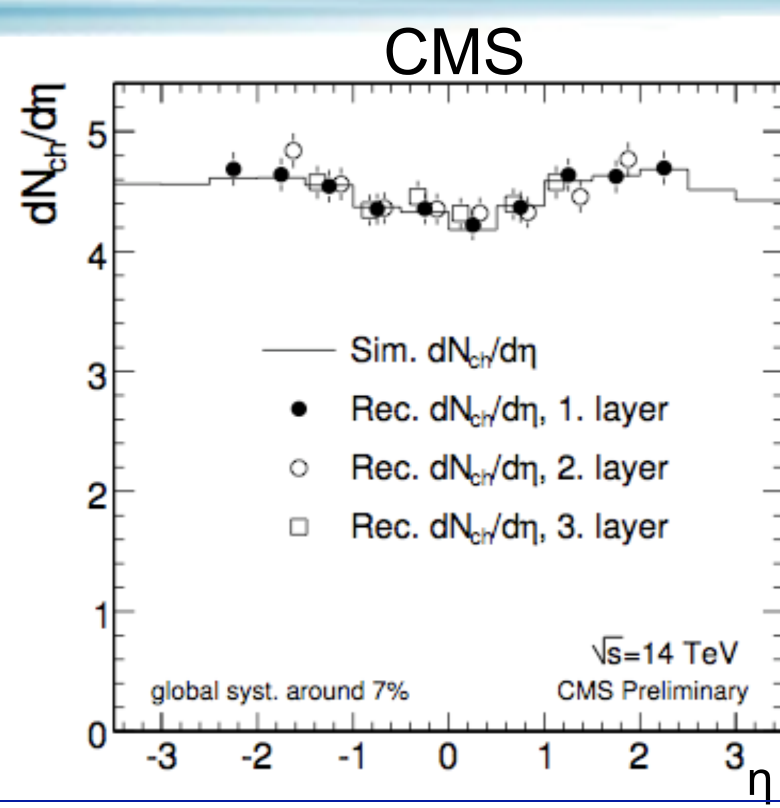
Analysis selects reconstructed tracks with P_t > 150 MeV

Apply selection cuts to reduce fake tracks and tracks from secondary particles

ATLAS http://arxiv.org/abs/0901.0512

An ATLAS and CMS Comparison





From Multiple Particle Interaction Workshop, Oct 2008

Total systematic uncertainties: 8%
Uses a tracking-based method
Dominant uncertainties from inner detector misalignment and diffractive cross-sections

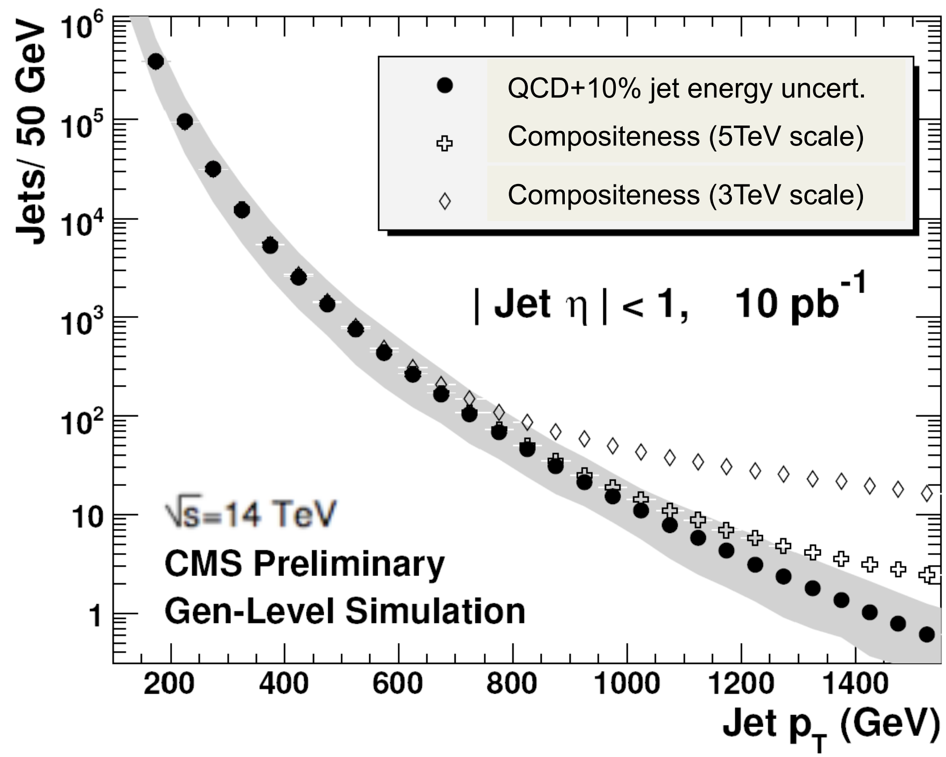
Total systematic uncertainties: <10%
Uses a hit counting method
Dominant uncertainties from vertex bias and the hit number to charge particle conversion functions

Jet Production Physics

Inclusive jet cross-section measurement…

1. Tests perturbative QCD in new energy regime
2. Sensitive to new physics
   – Will discuss sensitivity to compositeness, Z' and q* models
3. Tons of statistics and fast
4. Can be one of the first physics measurements for ATLAS and CMS

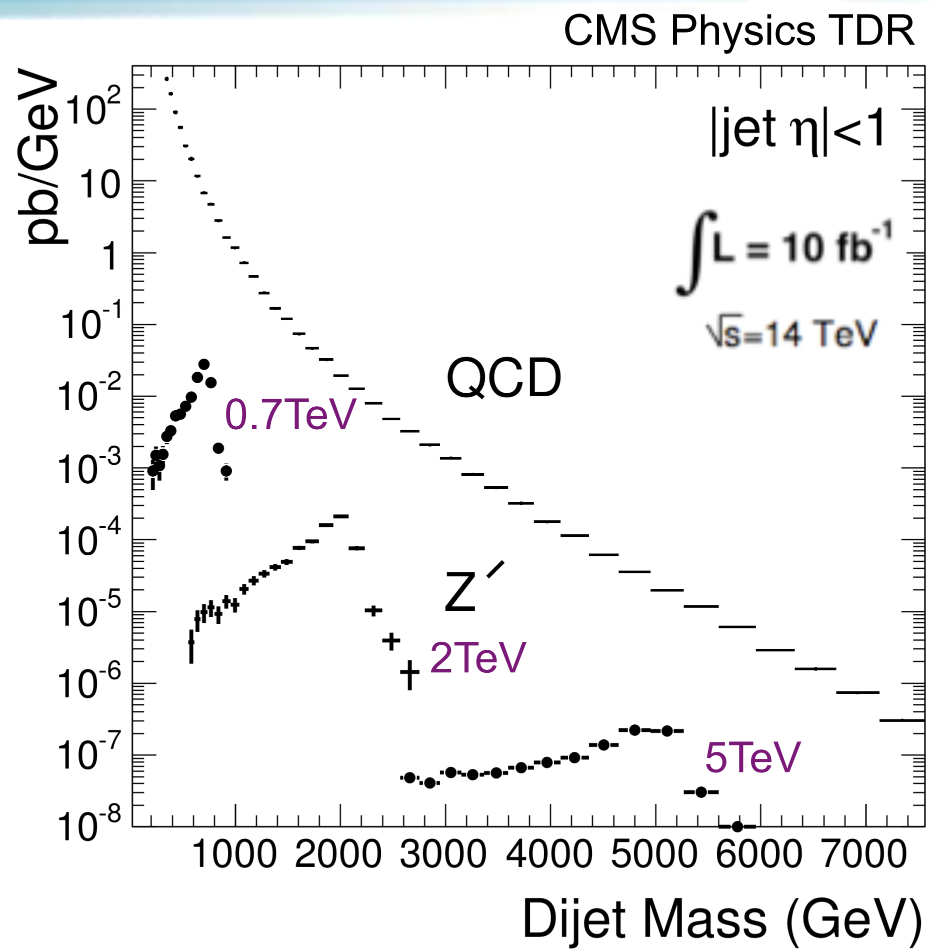
QCD08, 7-12 July, 2008, hep-ex 0807.4961



CDF/D0 measurements up to jet P_t of 700 GeV

Dijet Mass Spectrum

- Dijet mass is also sensitive to new physics like Z' models with masses 0.7, 2 and 5TeV shown here



Dijet Mass Definition

$$m = \sqrt{(E_1 + E_2)^2 - (\vec{P}_1 + \vec{P}_2)^2}$$

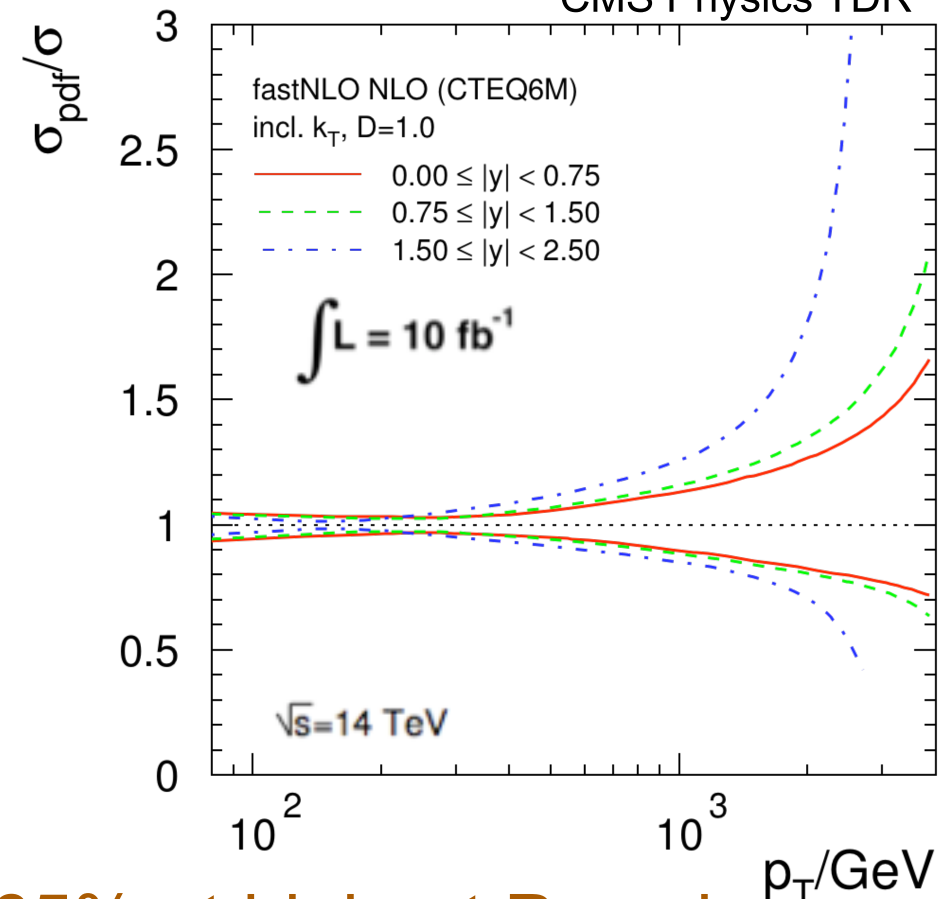
Current CDF/D0 dijet mass measurements up to 1400 GeV

Limits on Z' mass (using dijet mass spectrum): 320GeV<m<740GeV

Theoretical Systematic Uncertainties

- Parton distribution functions uncertainties is the major uncertainty for the inclusive jet cross-section and dijet mass measurements
  - Especially at high P_t and large dijet mass

CMS Physics TDR

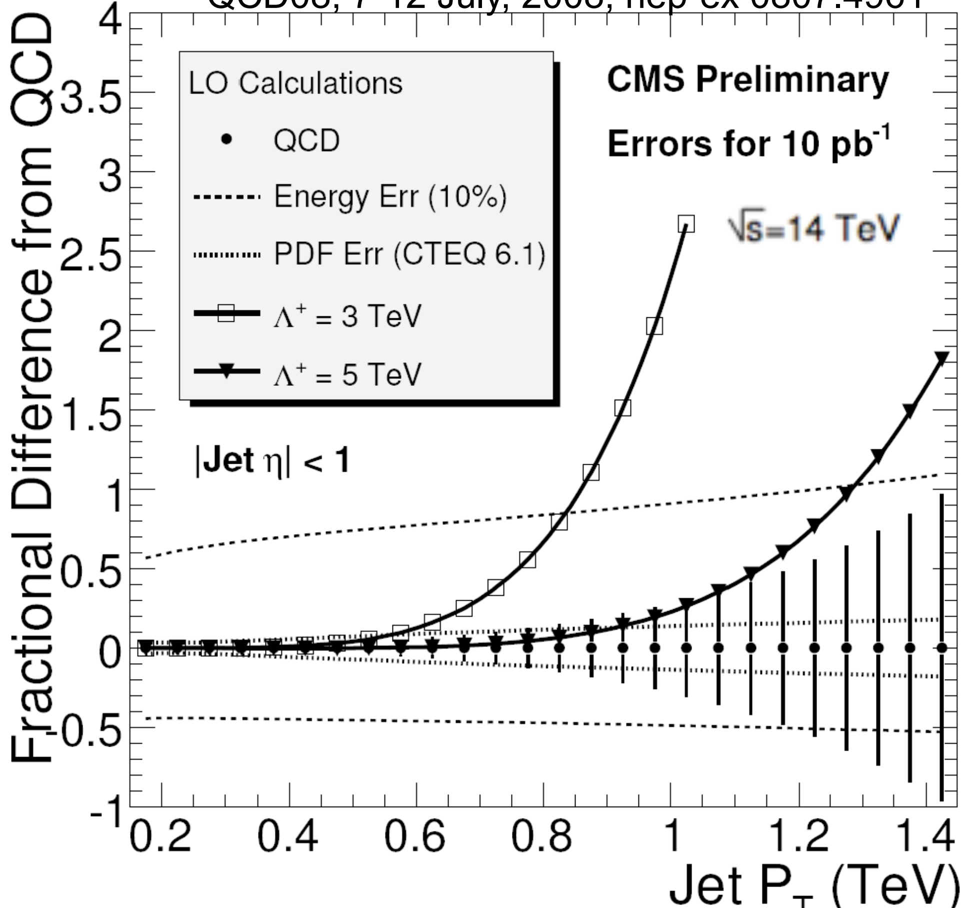


For PDF uncertainties: ~65% at highest P_t and ~20% at the largest dijet masses

Experimental Systematic Uncertainties

- Small uncertainties in absolute jet energy scale result in large effects on the inclusive jet cross-section and dijet mass
- Even with large uncertainty on energy scale expected for early data and only $10pb^{-1}$ are still sensitive to compositeness models

QCD08, 7-12 July, 2008, hep-ex 0807.4961



CDF/D0 analysis excludes Λ<2.7 TeV (quark-quark interactions)

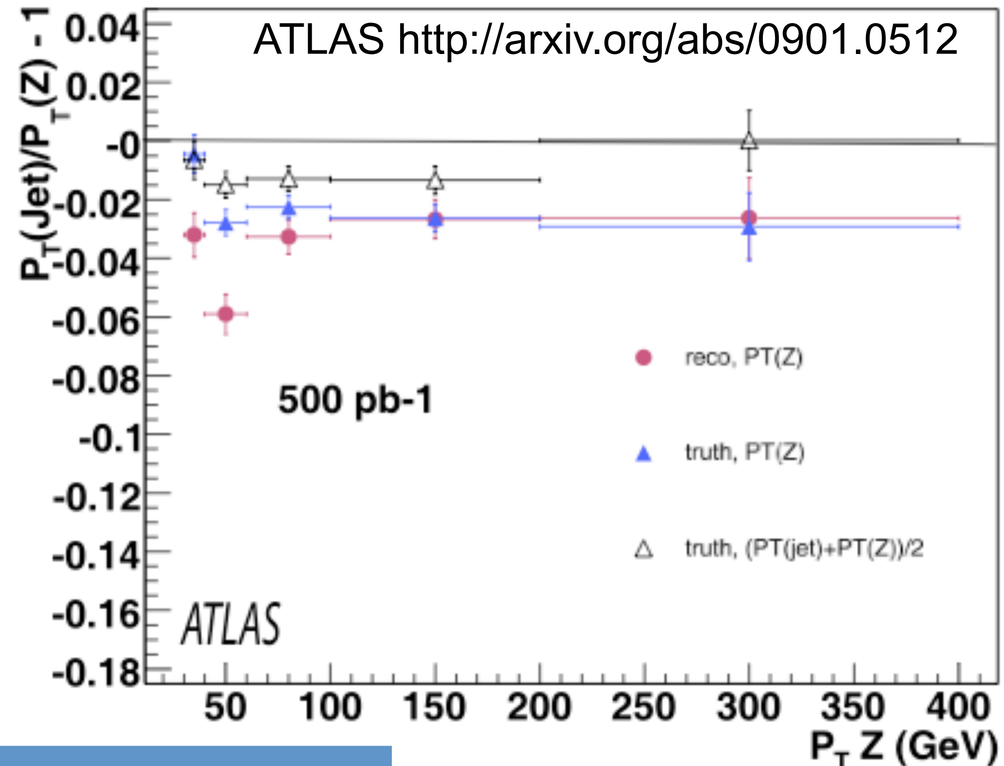
Λ is the compositeness scale ($\Lambda \rightarrow \infty$ no compositeness)

Establishing Jet Energy Scale

Need to establish good absolute jet energy scale uncertainty over a large range of jet P_t

~5-10% in first running

~1-2% long term



In-situ Measurement Process	Jet P_t Range
Z+Jets balancing	10 GeV < P_t < 100-200 GeV
γ+Jets balancing	100-200 GeV < P_t < 500 GeV
Multijet balancing	P_t > 500 GeV

Use in-situ processes to test energy scale over full P_t range

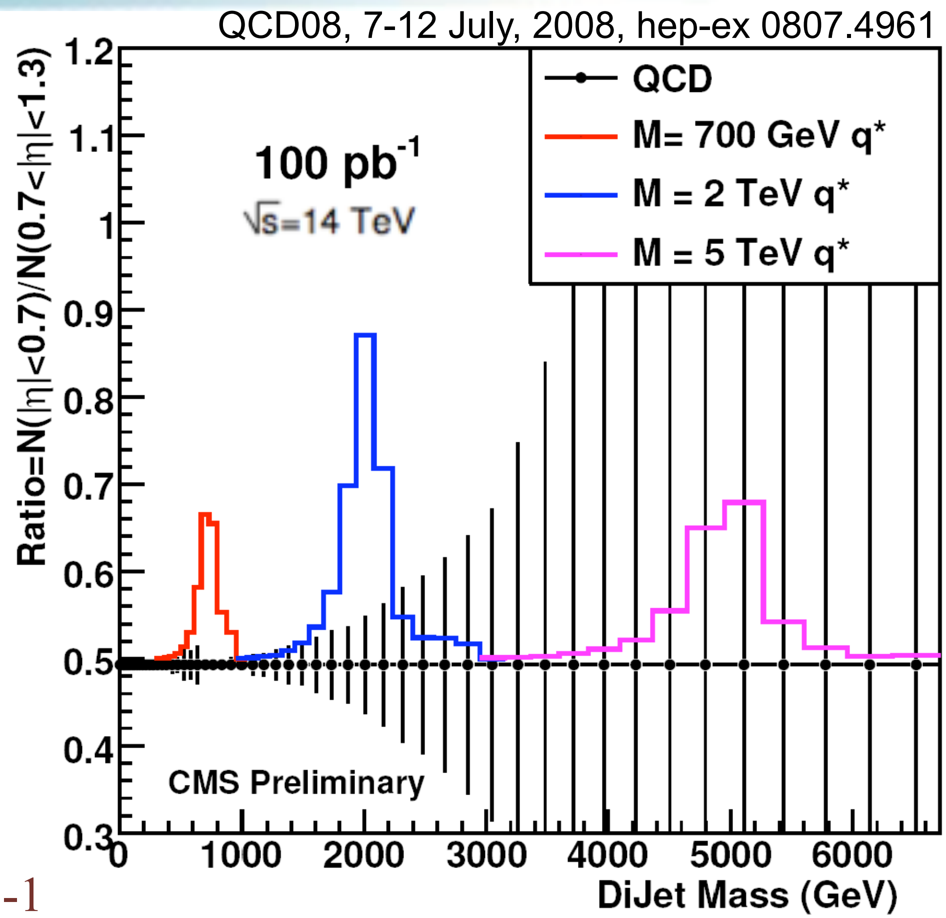
Searches with Dijet Ratio

- Measure dijet ratio to test for new physics (q* models shown here)
  - Absolute jet energy scale uncertainties cancel with the ratio

$$\text{Dijet Ratio: } R = \frac{N(|\eta| < 0.5)}{N(0.5 < |\eta| < 1)}$$

Expect to be sensitive to q* masses of 2.5 TeV with $100pb^{-1}$

CDF/D0 analysis excludes q* mass < 0.87 TeV



Vertical bars are statistical uncertainties

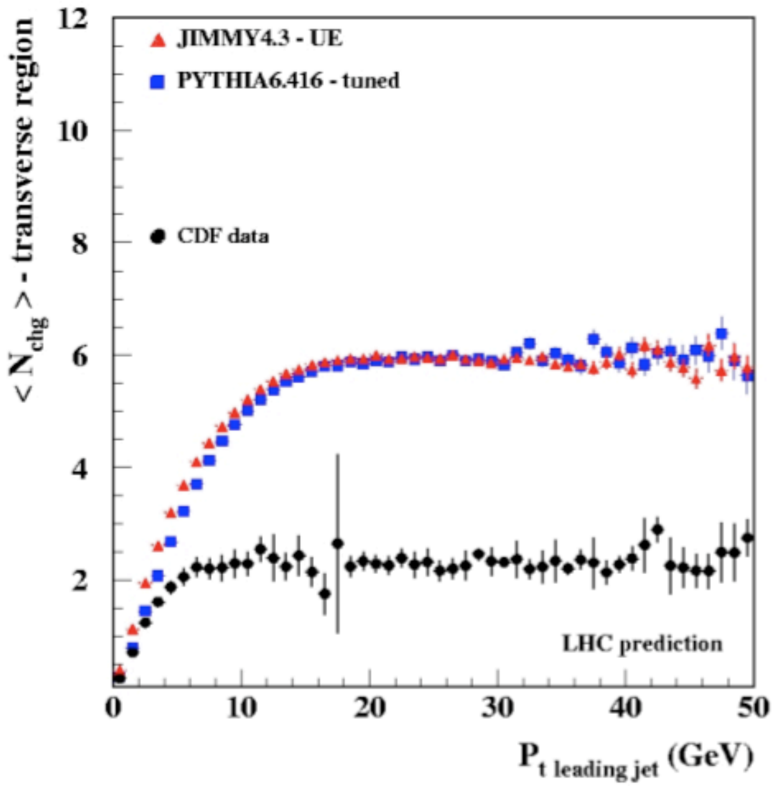
Conclusions

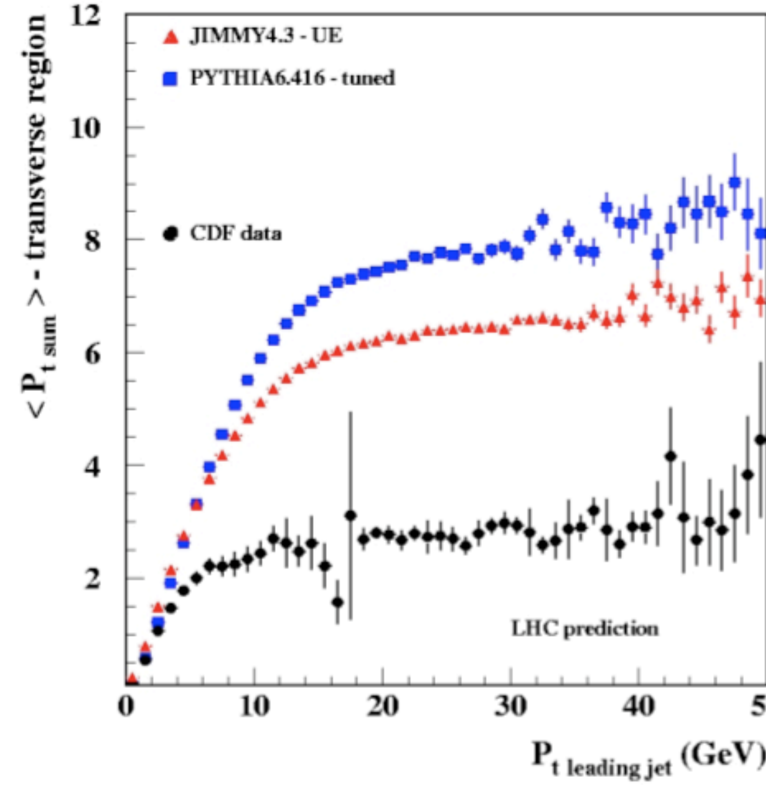
- QCD physics are important measurements especially for first data
- First data measurements should focus on
  - Underlying events: Important for generator tuning as well as understanding the systematic corrections to other physics processes
  - Minimum bias events: These events are the background to everything else. Important effect even at low luminosities
  - Jet Physics: Inclusive jet cross-section and dijet mass spectrum are very high statistics processes and are sensitive to new physics models. Important first data measurement in an energy regime never before explore

Backup Slides

Measuring Underlying Events

These two tunings produce the same particle density but Pythia tuning generates harder particles (for √s = 14TeV)





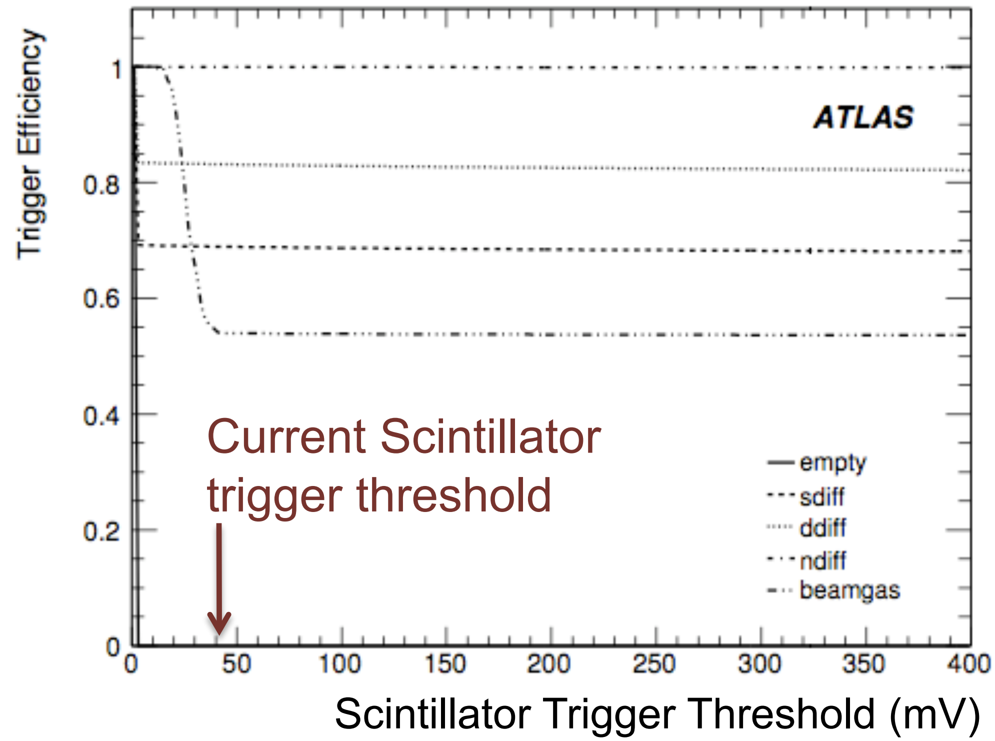
Moraes et al EPJ C50, 435 (2007)

First LHC data critical for generator tuning

A Low Luminosity Trigger

- For first low luminosity running a random trigger is inefficient for selecting a good minbias sample
- On ATLAS have designed for this purpose special scintillators ($2.12<|\eta|<3.85$)
- Form trigger either from special scintillators, random triggers or inner detector tracks

ATLAS http://arxiv.org/abs/0901.0512

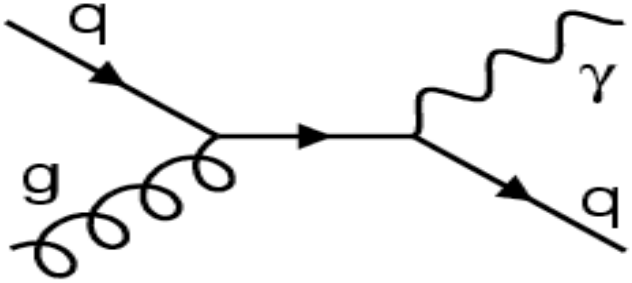


Analysis selects reconstructed tracks with P_t > 150 MeV

Used to measure the number of primary charge particles per unit of η and per unit of P_t

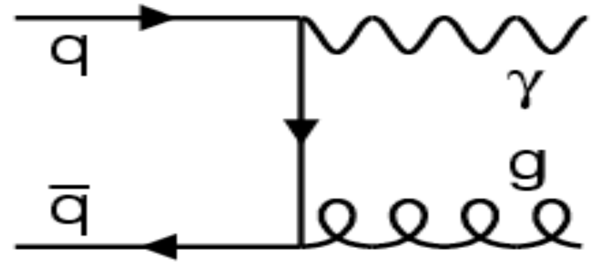
Inclusive Photon Production

qg→γq Compton Process



Dominate process at LHC

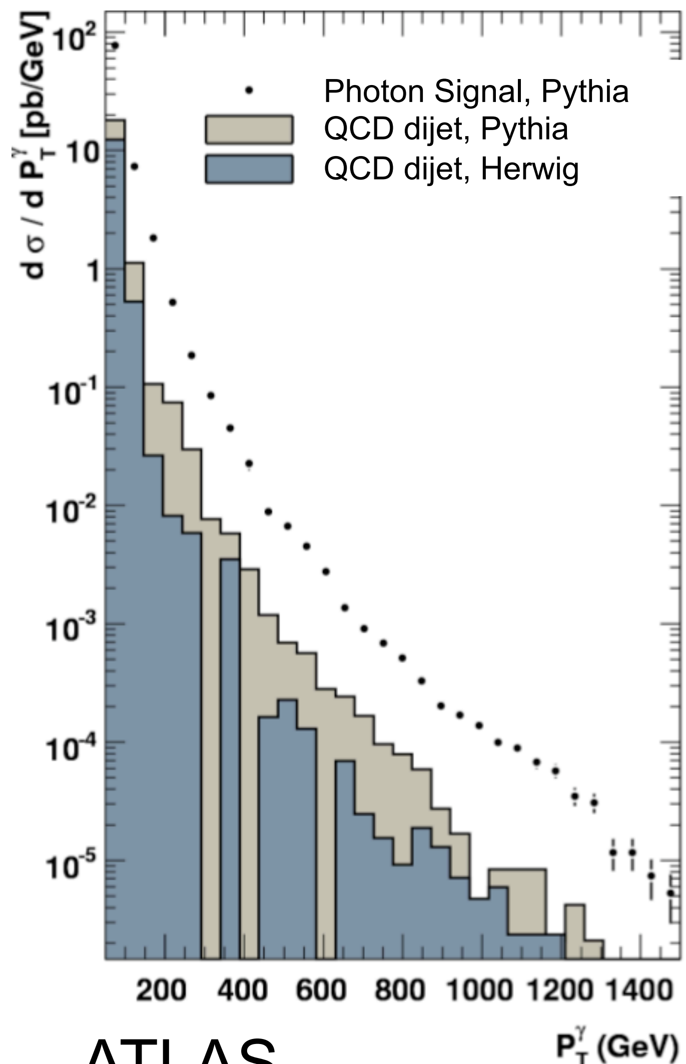
qq→γg annihilation graph



- Used to study underlying parton dynamics: Compton process is sensitive to the gluon distribution in the proton, $f_g(x)$
  - Requires a good knowledge of α_s
- Understanding the QCD photon production is a prerequisite for Higgs→γγ searches

Inclusive Photon Production

- High statistic process
- ATLAS and CMS both have high calorimeter granularity and $|\eta| < 2.5$
  - Necessary for good background rejection
- Main backgrounds due to QCD dijet where one jet fakes a photon and jets with π_0
  - Can be reduced by require photon candidates to be isolated



ATLAS

Measurement of Jet Multiplicity

- Multi-jet production is critical to many physics studies (ttbar production, SUSY searches, Higgs→ttbar or bbar)
  - QCD multi-jet events are backgrounds to all these processes
- The 2-jet to 3-jet cross-section ratio can be used to measure α_s

ATLAS Physics TDR