Hard QCD measurements from ATLAS.

Oct 2010

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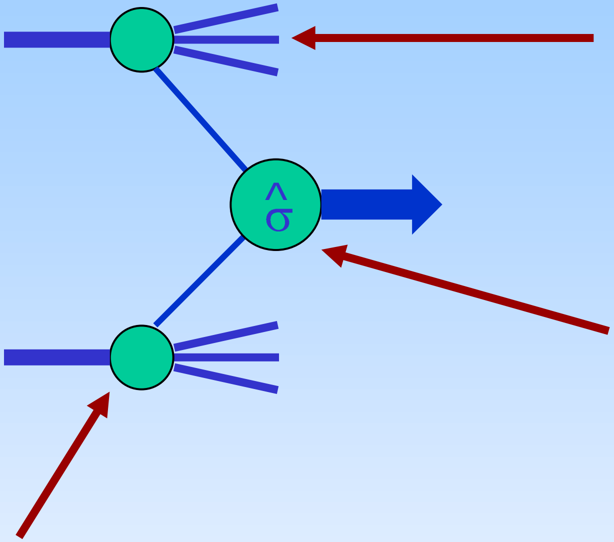
for ATLAS.

- High *pt* inclusive jet and dijet production
- Azimuthal de-correlation
- Multijet production
- Rapidity Gaps

Precision pQCD at LHC



tuned event simulation (parton showers + UE) MCs, interfaced with LO or NLO hard scattering MEs

LO, NLO, NNLO, … supplemented by re-summed N^nLL improvements, EW corrections, …

parton distribution functions

the QCD **factorization theorem** for hard-scattering (short-distance) inclusive processes

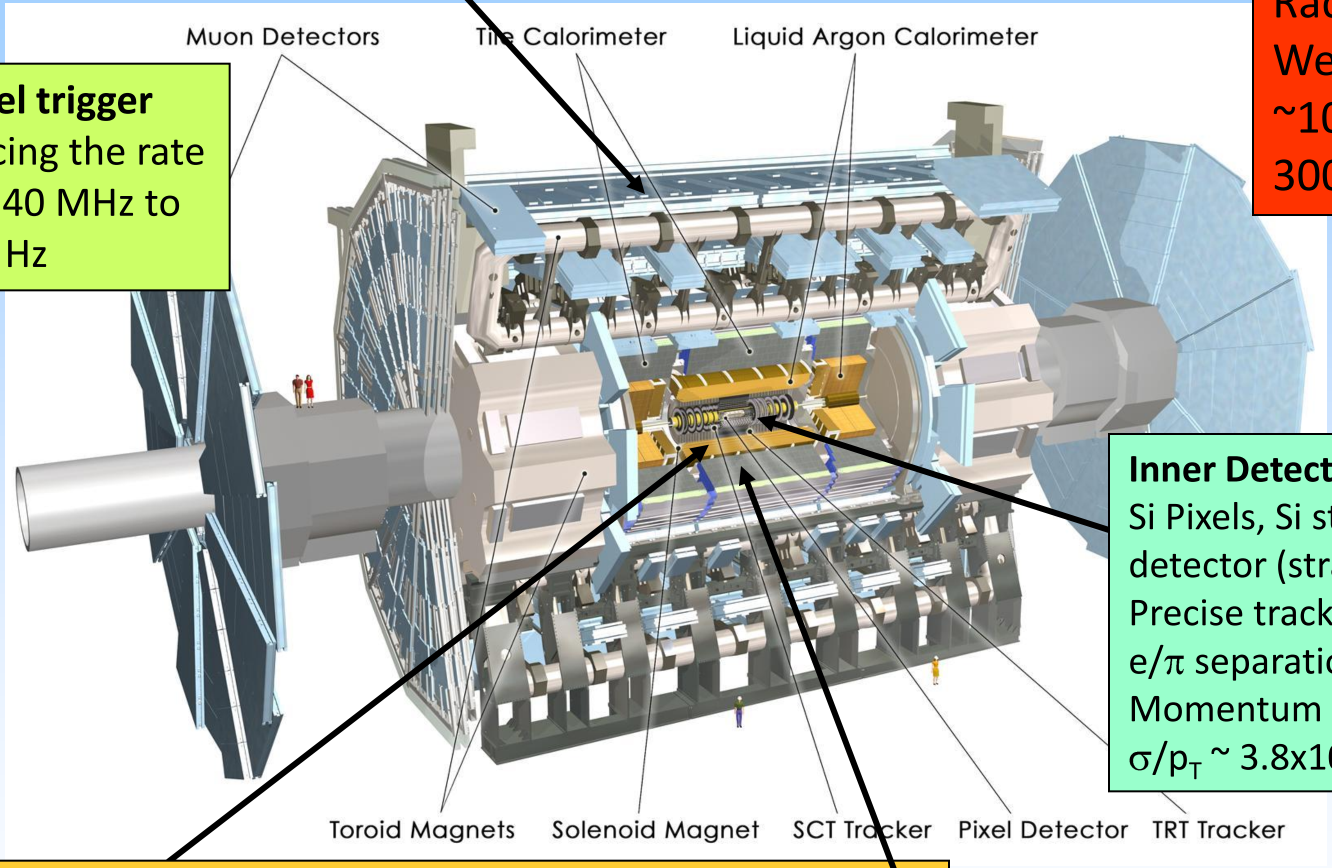
$$\sigma_X = \sum_{a,b} \int_0^1 dx_1 dx_2\, f_a(x_1, \mu_F^2)\, f_b(x_2, \mu_F^2) \times \hat{\sigma}_{ab\to X}\left(x_1, x_2, \{p_i^\mu\}; \alpha_S(\mu_R^2), \alpha(\mu_R^2), \frac{Q^2}{\mu_R^2}, \frac{Q^2}{\mu_F^2}\right)$$

Detector operation and performance

Muon Spectrometer ($|\eta|<2.7$): air-core toroids with gas-based muon chambers
Muon trigger and measurement with momentum resolution < 10% up to E_μ ~ 1 TeV

Length : ~ 46 m
Radius : ~ 12 m
Weight : ~ 7000 tons
~10^8 electronic channels
3000 km of cables

3-level trigger
reducing the rate from 40 MHz to ~200 Hz



Inner Detector ($|\eta|<2.5$, B=2T):
Si Pixels, Si strips, Transition Radiation detector (straws)
Precise tracking and vertexing,
e/π separation
Momentum resolution:
$\sigma/p_T \sim 3.8\times10^{-4}\, p_T\,(\mathrm{GeV}) \oplus 0.015$

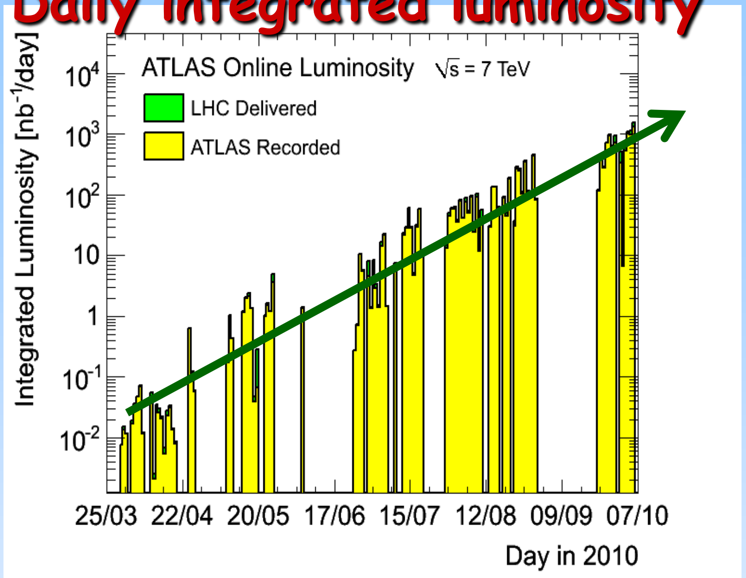
EM calorimeter: Pb-LAr Accordion
e/γ trigger, identification and measurement
E-resolution: $\sigma/E \sim 10\%/\sqrt{E}$

HAD calorimetry ($|\eta|<5$): segmentation, hermeticity
Fe/scintillator Tiles (central), Cu/W-LAr (fwd)
Trigger and measurement of jets and missing E_T
E-resolution: $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$

Detector Operation

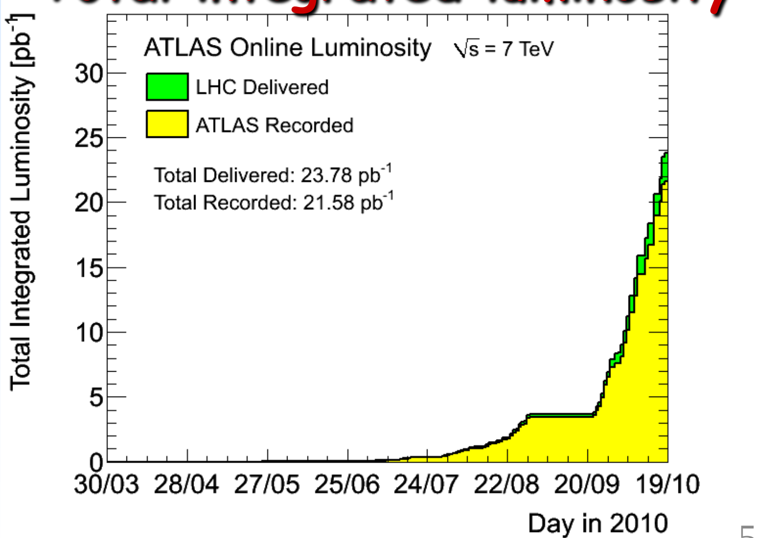
Peak luminosity began at ~E27 on March 30 and is now ~E32/cm2/s.
Luminosities known to 11% from van der Meer scans, where one beam swept through the other to determine size.
Present limitation from knowledge of beam current.

Daily integrated luminosity



Increase in luminosity is almost exponential.
ATLAS records about 91% of the delivered luminosity.
Sub-systems are operational a good fraction of time.

Total integrated luminosity



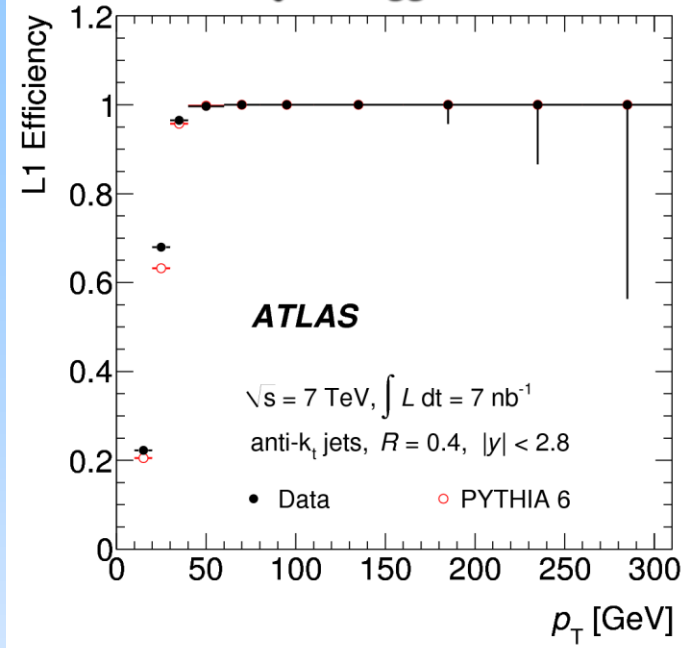
Inner Tracking Detectors			Calorimeters				Muon Detectors			
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	TGC	CSC
96.7	97.5	100	93.8	98.8	99.0	99.7	98.6	98.5	98.6	98.5

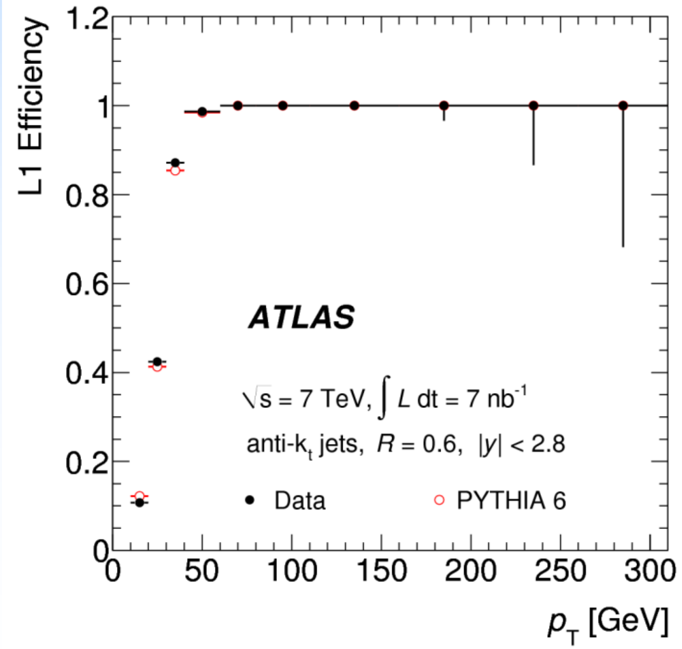
Luminosity weighted relative detector uptime and good quality data delivery during 2010 stable beams at √s=7 TeV between March 30th and August 30th (in %)

Jet Trigger Efficiency

Turn-on curves for L1 jet trigger efficiencies

- Calorimeter based triggers are very efficient and robust
  - The jet trigger efficiency evaluated against MBTS trigger
  - The MBTS trigger efficiency evaluated on randomly triggered data sample
- For the first measurements the triggers were unprescaled.
- Trigger efficiency above 99% for jets with Pt > 60GeV.





Understanding JES

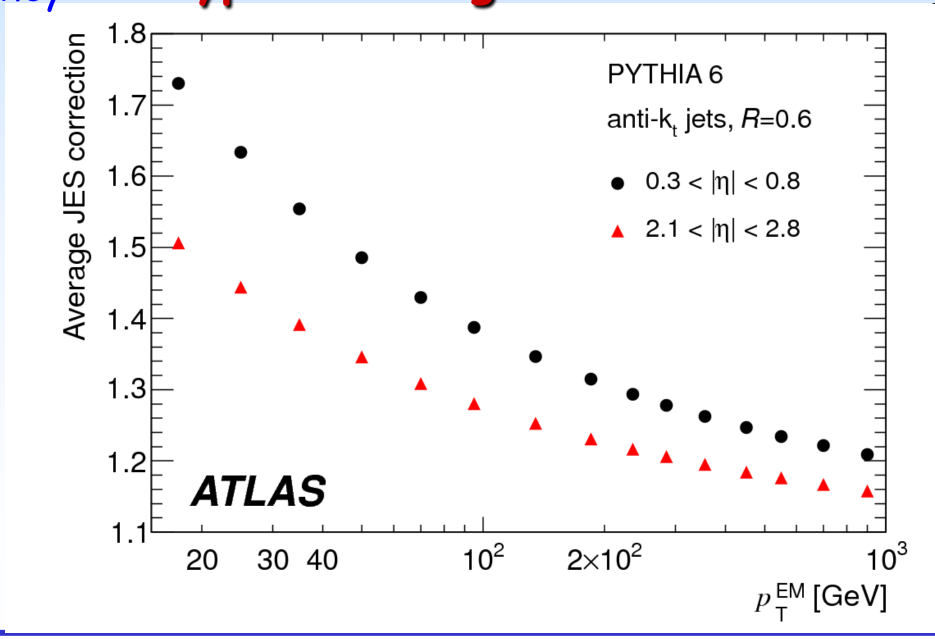
Jet Energy Scale

CERN-PH-EP-2010-034
submitted to EPJC

- **JES is crucial for QCD measurements**
- Current Strategy
  - Electromagnetic (EM) scale from test beam measurements (electrons & muons)
  - Correction for
    - Difference in hadronic/electromagnetic response
    - Losses in material in front of Calorimeter
    - Leakage from back of the calorimeter
    - Magnetic field
    - Cluster and jet algorithmic inefficiency

  are all dealt with by simulation, which in turn was tuned on the (test beam) data

Typical average JES correction



Jet Energy Scale Uncertainty

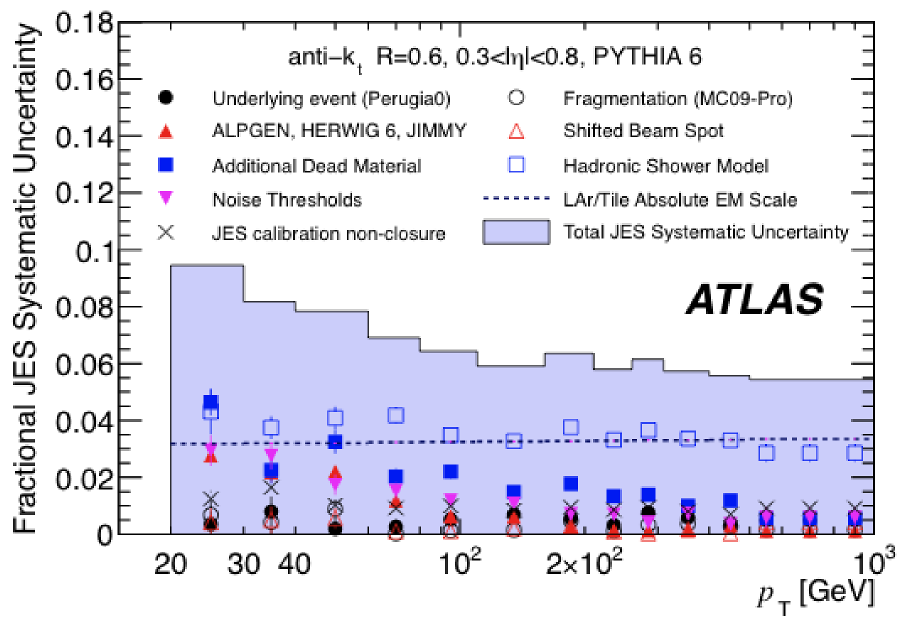
- Dominant systematic in ~all measurements involving jets or missing energy.

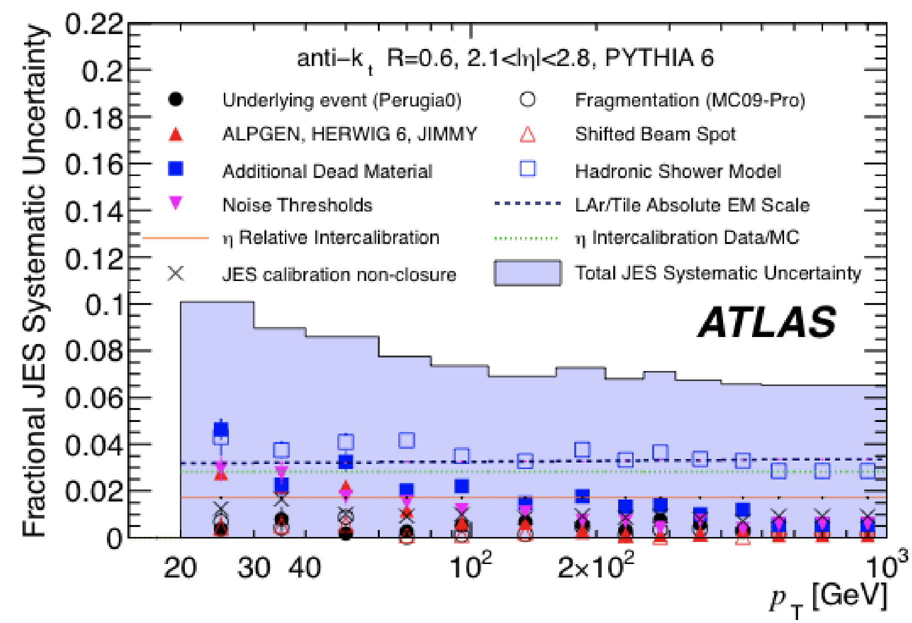
- Uncertainties from
  - Translating test beam EM scale to in situ (3-4%)
  - Material knowledge/simulation ~2%
  - Noise <3%
  - Beam spot position <1%
  - "closure test" <2%
  - Hadronic (GEANT) shower model ~4%
  - SoftQCD modeling <4%
  - Pile up: variable. (<1% for cross section measurement)

- JES uncertainty has been derived up to |eta|<4.5
  - |eta|<2.8 used in the following analysis
  - In the barrel the JES uncertainty verified with isolated hadrons
  - dijet balance is used to transport the uncertainty from barrel to end-cap

- **Current JES uncertainty (6-9)%** depending on pt range.
- Ultimate – 1%

Jet Energy Scale Uncertainty





CERN-PH-EP-2010-034
To be submitted to EPJC

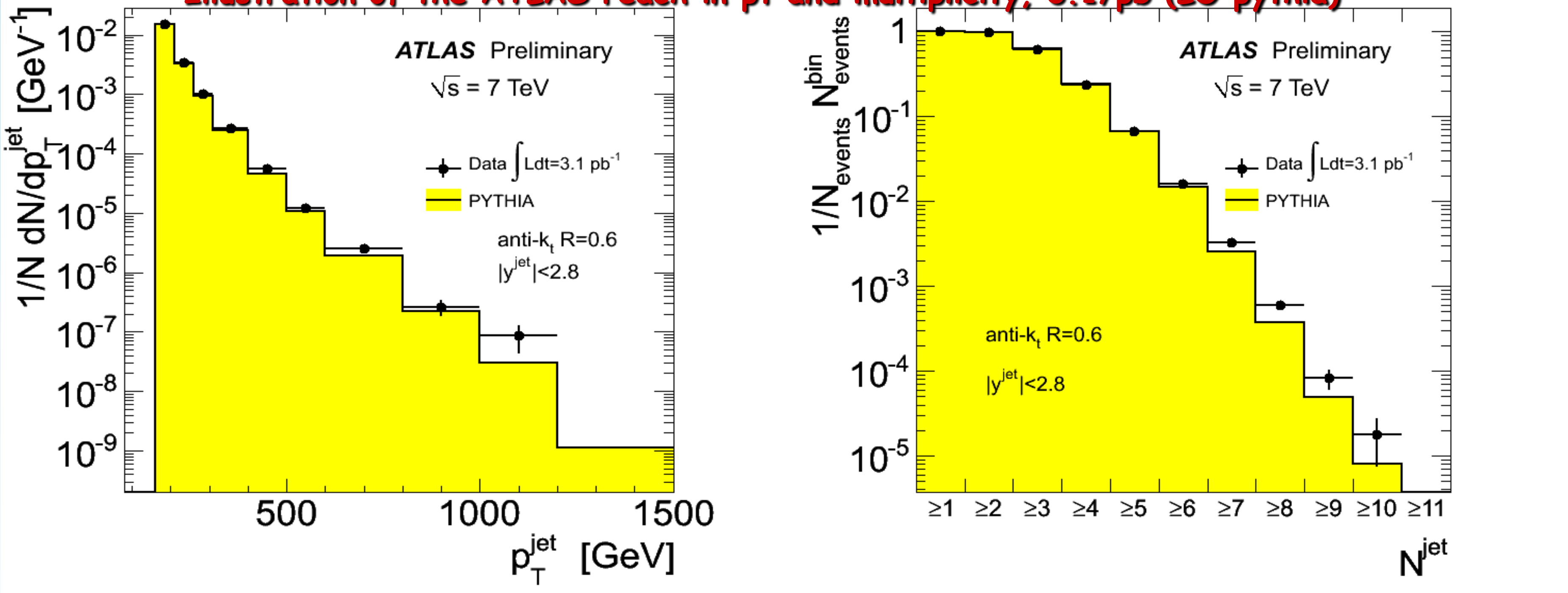
- < 9% everywhere. ~6% for high pt
- **~40% error on jet cross section**
- Checked with extensive single-particle studies in collision data, with dijet balance, and soon by photon-jet balance

Inclusive jet production

Jet physics in ATLAS

- Requiring one jet with *pt* > 60 GeV, |*eta*| < 2.8
  - Trigger more than 99% efficient

Illustration of the ATLAS reach in pt and multiplicity, 3.1/pb (LO pythia)



- o Jet distributions well described over 5 orders of magnitude.
  - o LO MC on the plots, better agreement with NLO simulations
  - o Uncertainty is 30-40%, dominated by Jet Energy Scale
- o ***Accessing high energy and jet multiplicity regions.***

Inclusive Jet Production

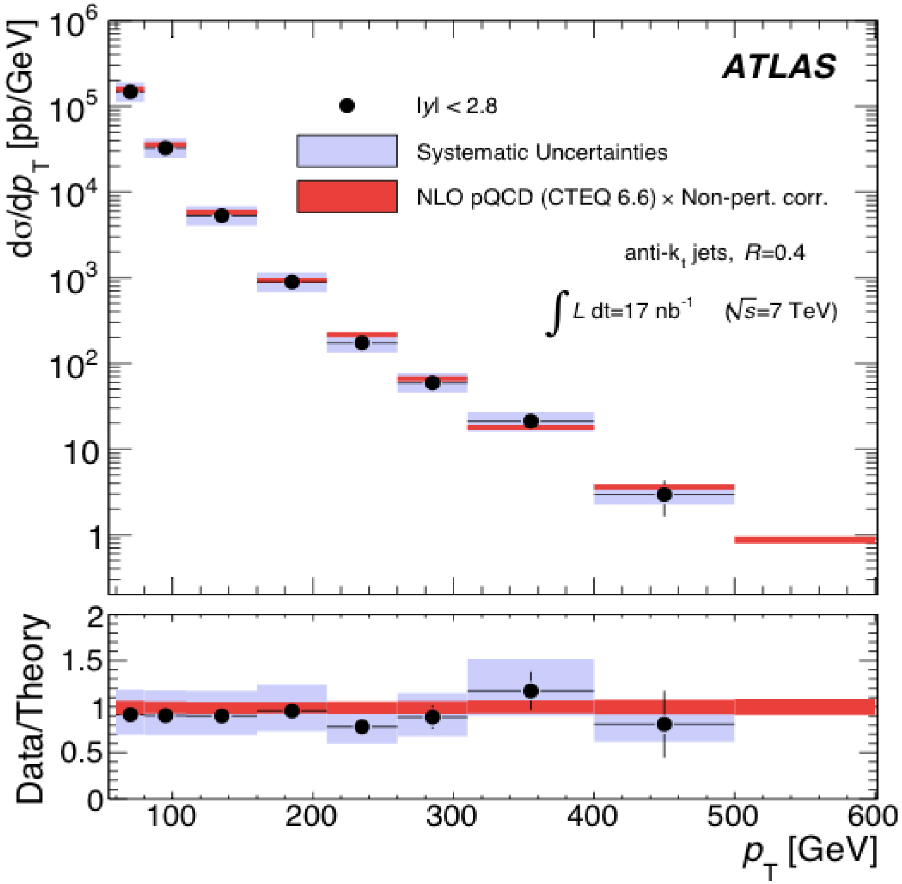
Traditional channel for studying hard scattering

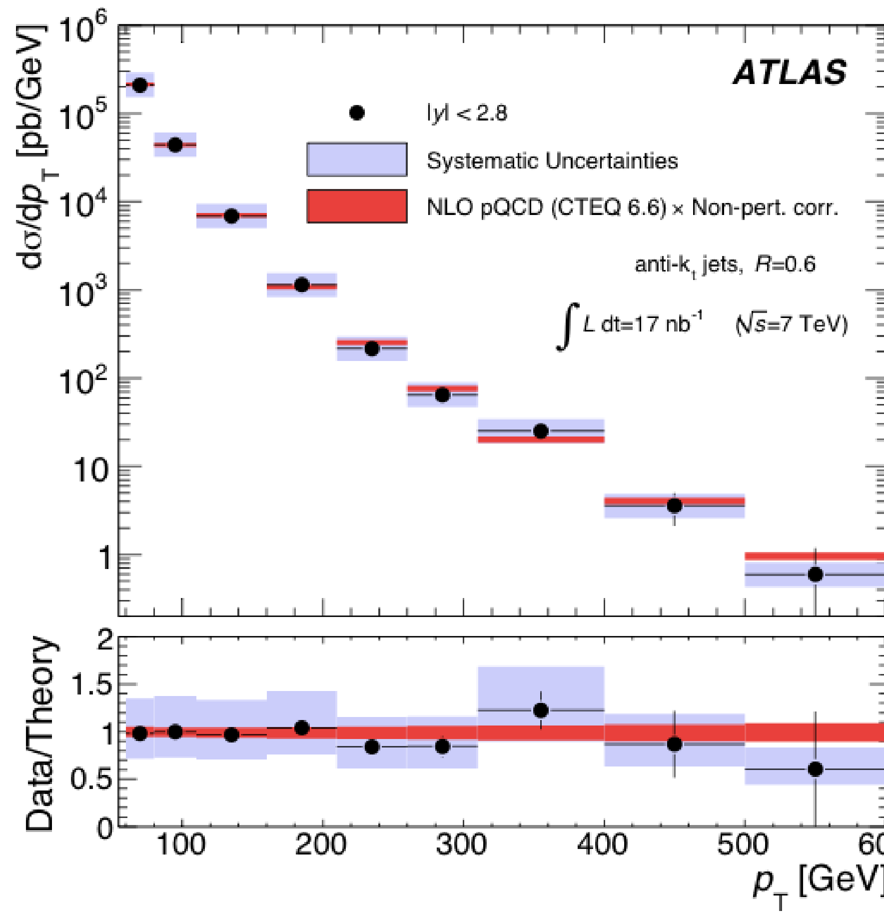
- Believed to be well described by pQCD with the PDF for the proton
  - Application of these tools to a new *Q*2 regime

- First 17/nb data sample
  - **Currently >1000 times more data is available**

- Define jets with anti-*kt* jet algorithm
  - A clustering algorithm
  - Stable under infra-red and collinear radiation
  - Leads to regular jet shapes ("cone-like")
  - Use jet resolution parameter *R*=0.6 and *R*=0.4

Inclusive Jet Cross Sections





- Inclusive single jet cross section measured to *pt* of 550 GeV

-**Excellent agreement with NLO prediction over 5 orders of magnitude** for different sensitivities to soft QCD corrections (R parameter).

- The dominant systematic uncertainty for the data is the JES

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submitted to EPJC

Inclusive Jet double-differential cross sections

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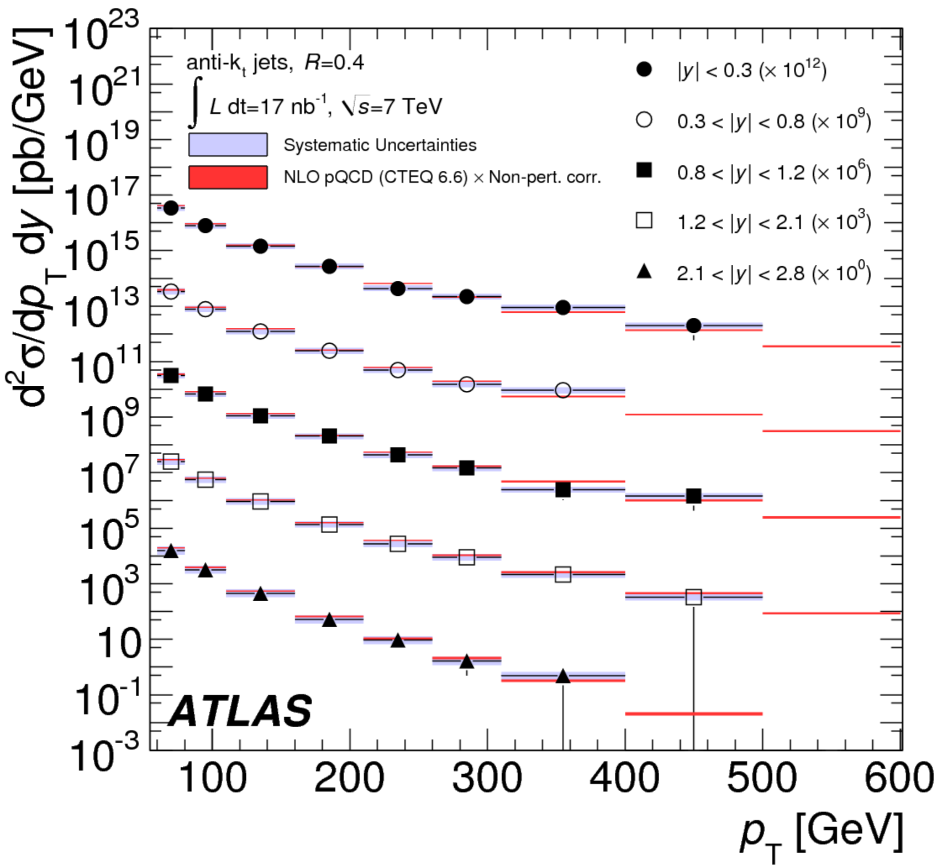
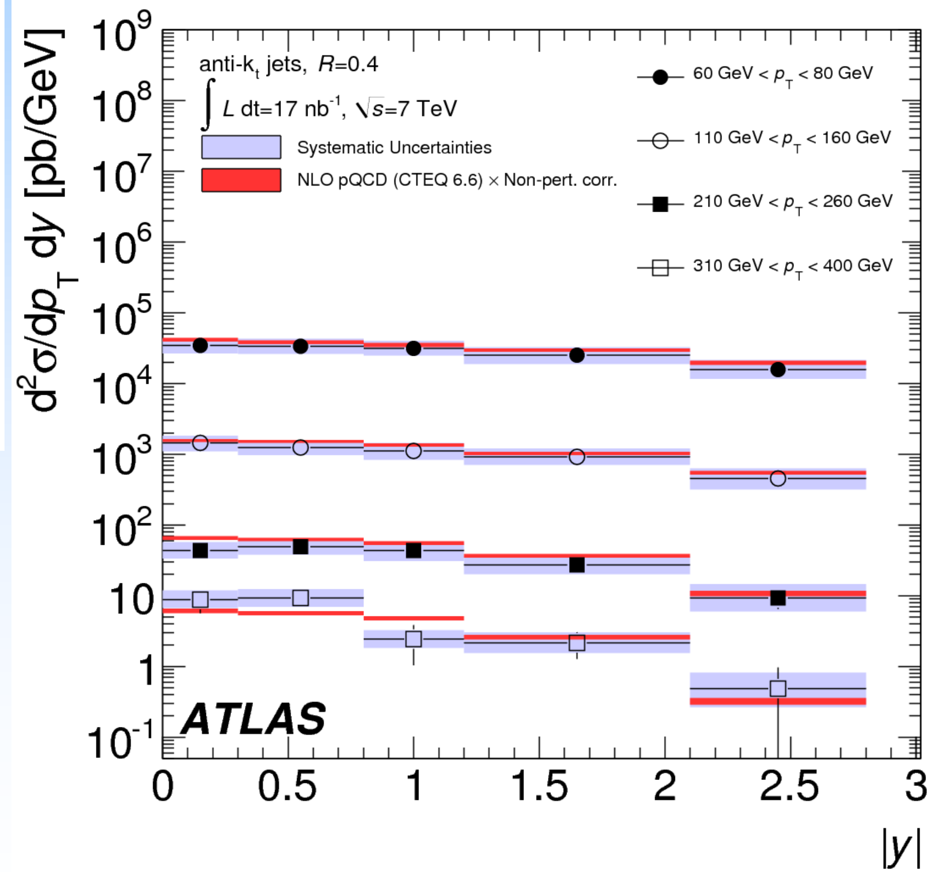




-Excellent agreement with NLO predictions
for different slices in rapidity
(regions with different calorimeters)

Dijet production

Dijet Production

Another classic observable for studying hard scattering

- Well described by pQCD with the PDF for the proton
    - Application of these tools to a new *Q2* regime

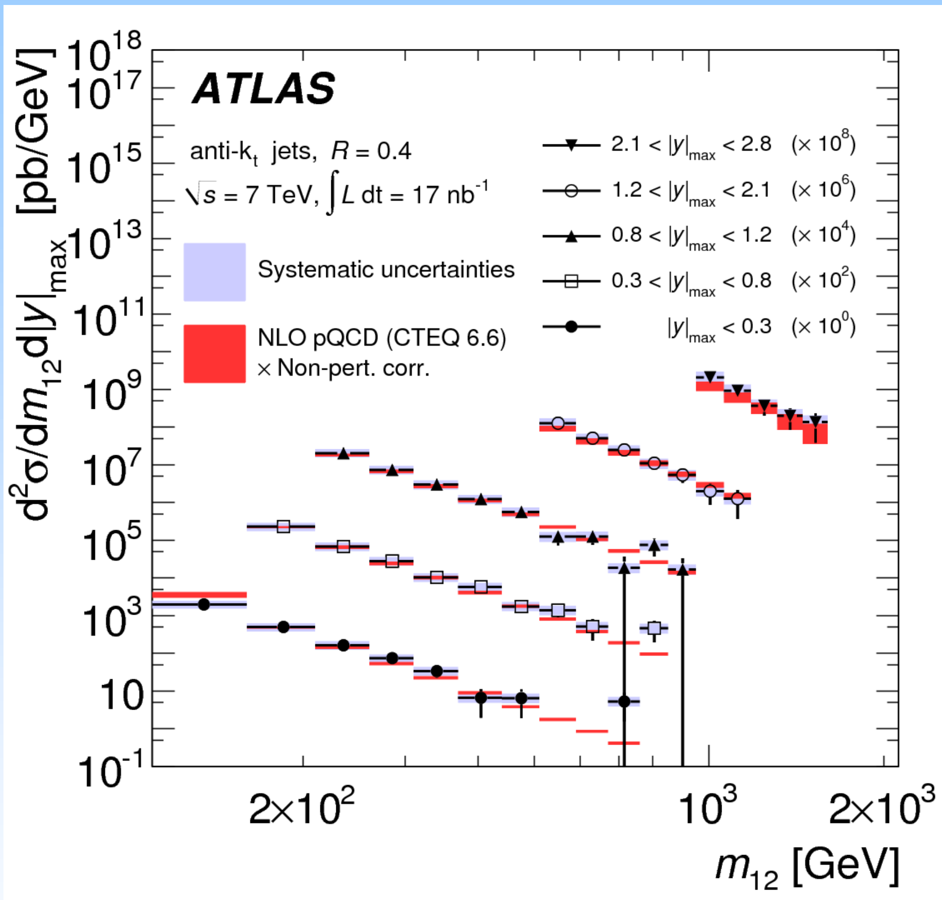
-Sensitive to new-physics effects

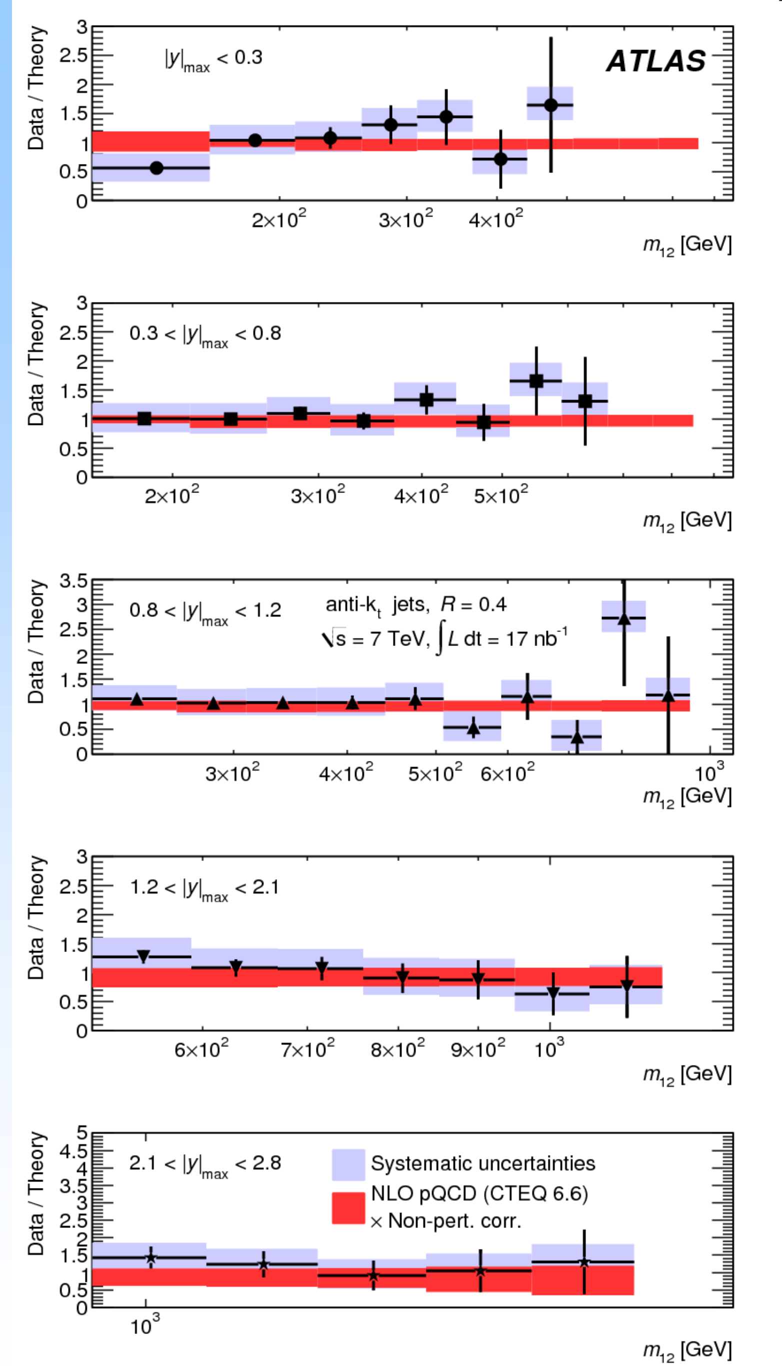
    - contact terms in interaction
    - Resonances decaying to two jets

- Required one jet with *pt* > 60 GeV, |*eta*| < 2.8
- and a second jet with *pt* > 30 GeV and |*eta*| < 2.8
    - Trigger more than 99% efficient
    - First 17/nb data sample
        - **Currently 1000 times more data is available**

-Same anti-*kt* jet algorithm

Inclusive dijet double-differential cross sections



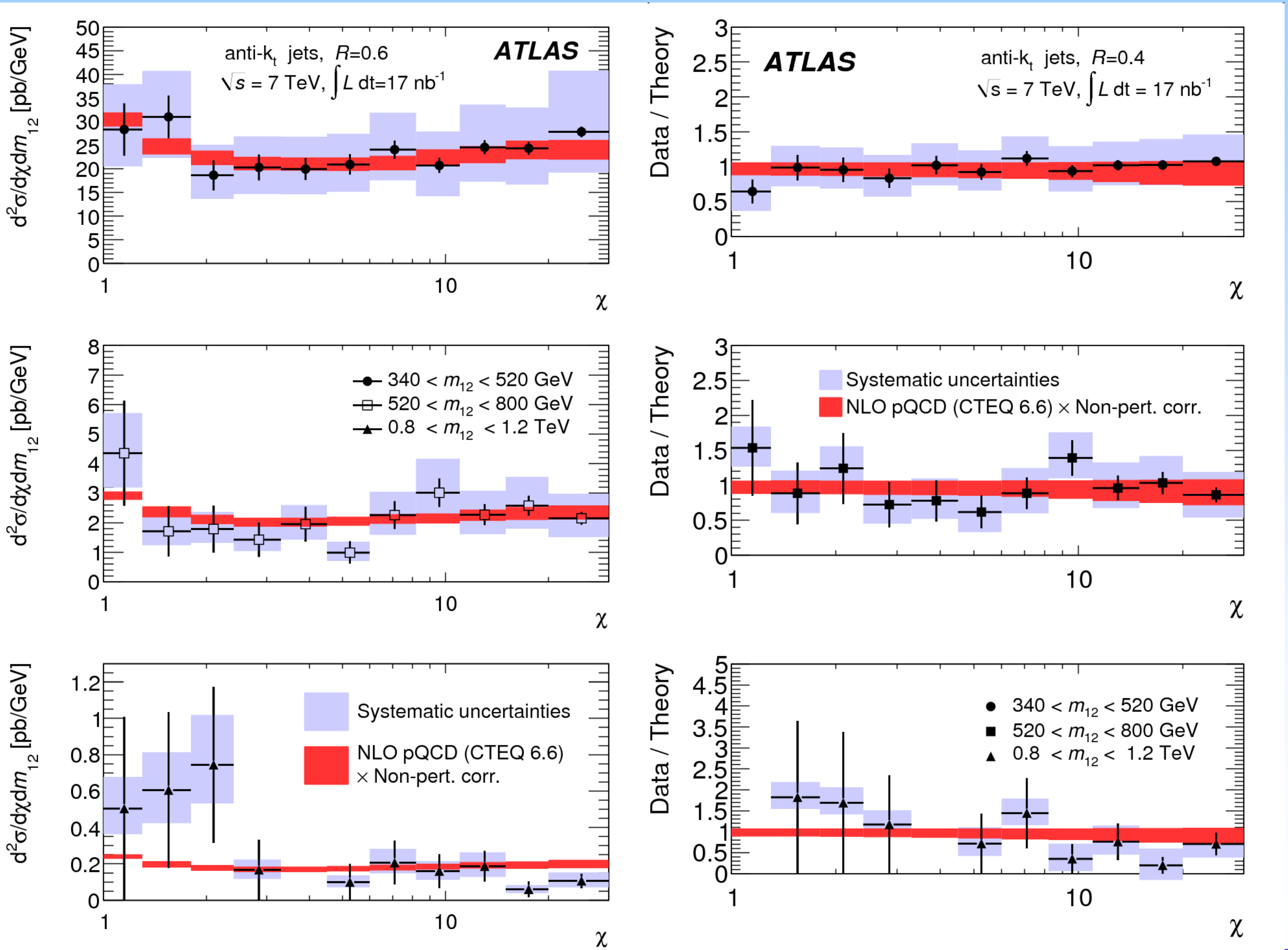


- Inclusive dijet cross section measured to **M ~ 2 TeV**

- Excellent agreement with NLO predictions

Inclusive dijet double-differential cross sections as function of chi, (exp|y1-y2|)

CERN-PH-EP-2010-034
submitted to EPJC



-Good agreement of data and prediction in angular variable chi

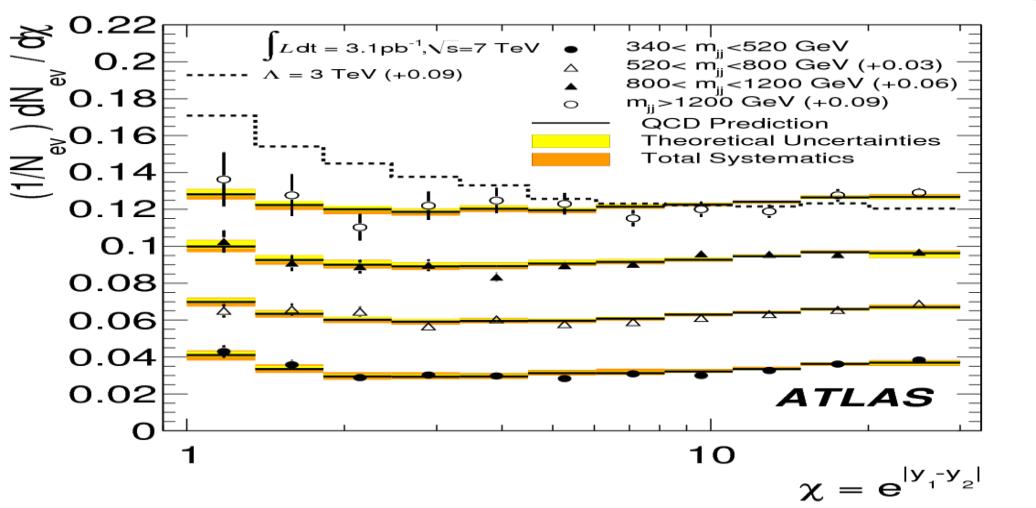
-Also excellent angular resolution

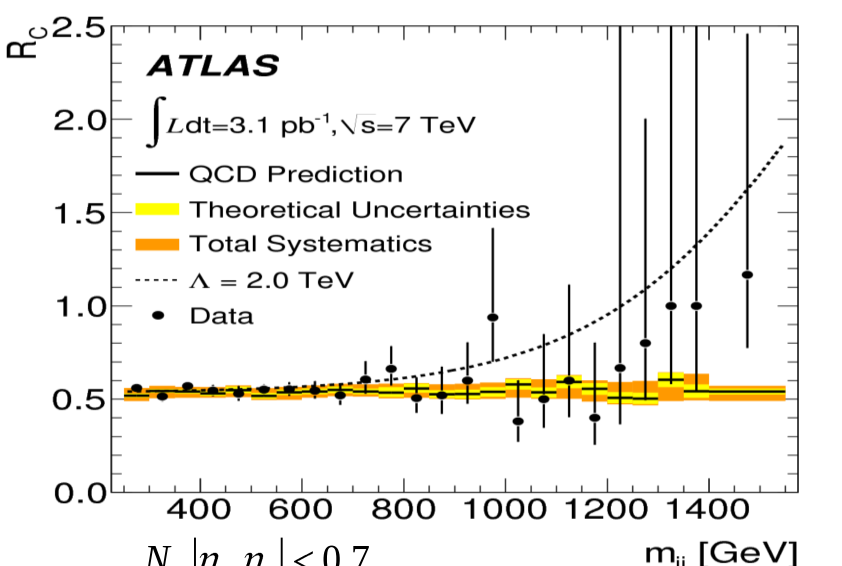
- both above make a ground for strong exclusion of contact interactions

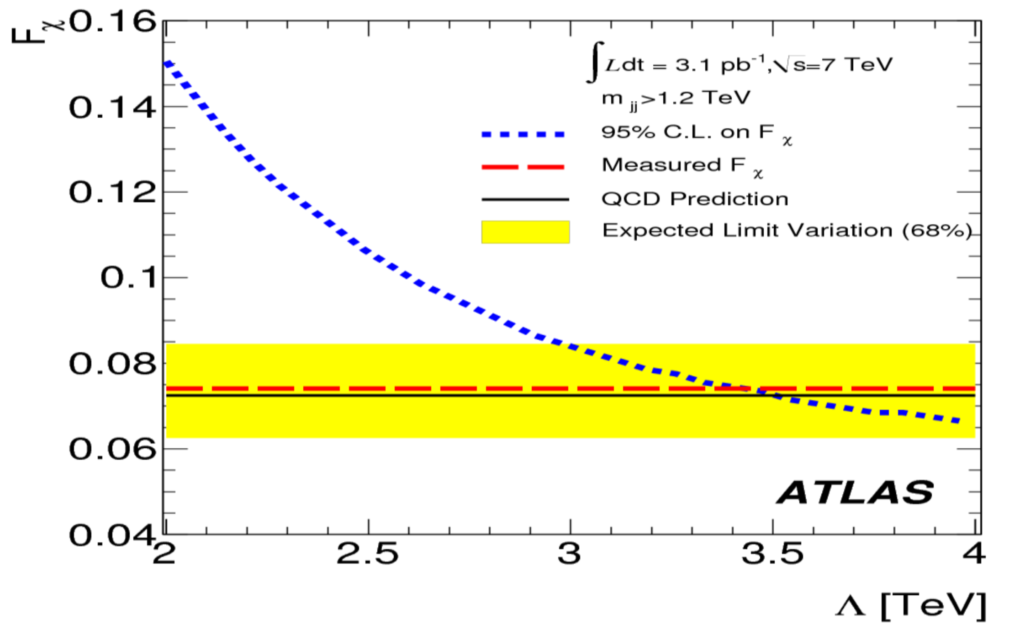
Search for Quark Contact Interactions in Dijet Angular Distributions

CERN-PH-EP-2010-033
submitted to PLB

$\Lambda_q > 3.4$ TeV (95% CL)







$$R_C = \frac{N\ \ |\eta_1, \eta_2| < 0.7}{N\ \ 0.7 < |\eta_1, \eta_2| < 1.3}$$

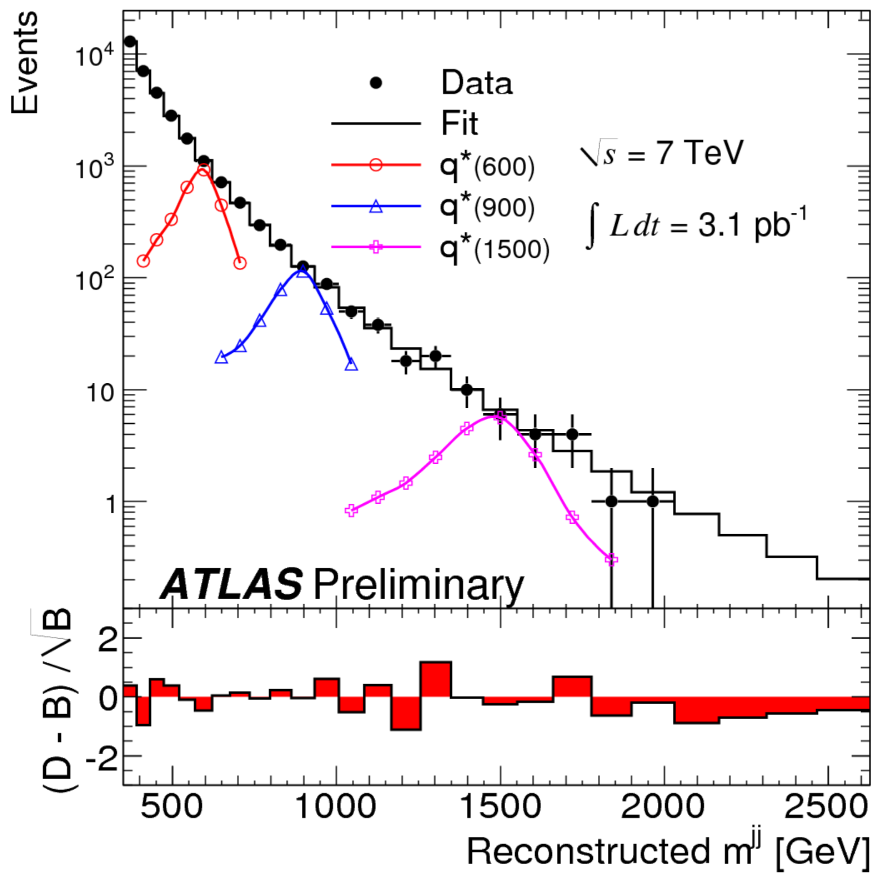
Search for New Particles in Two-Jet Final States

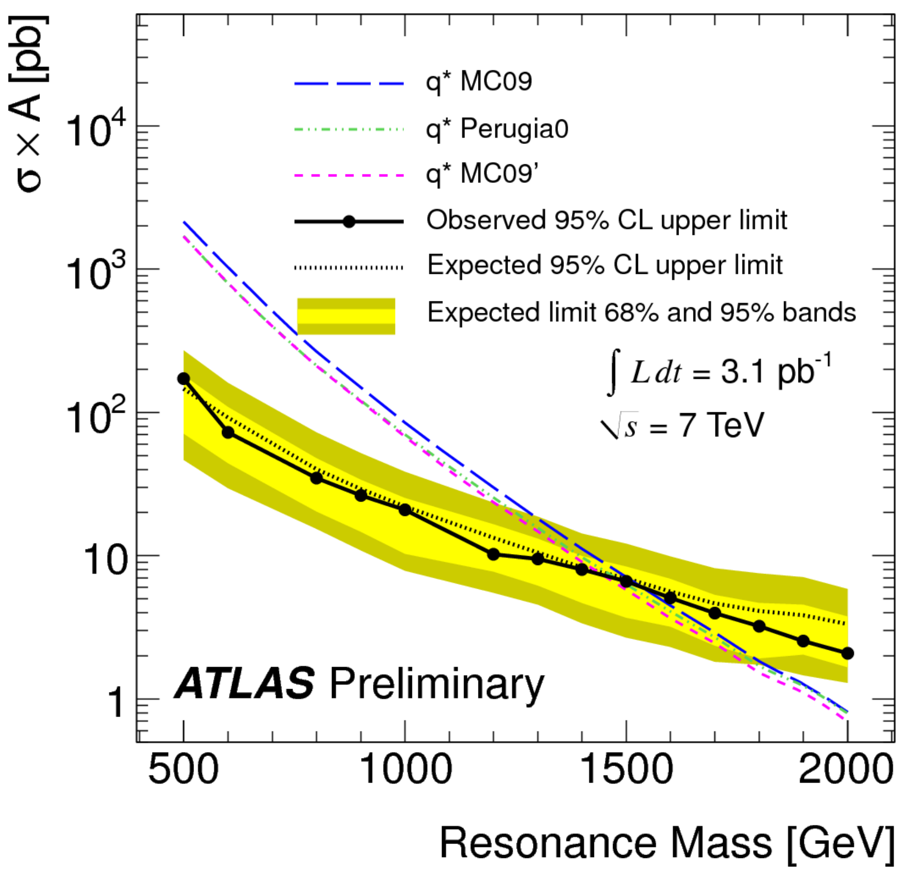
315/nb published in 10.1103/PhysRevLett.105.161801

3.1/pb: *ATLAS-CONF-2010-093*

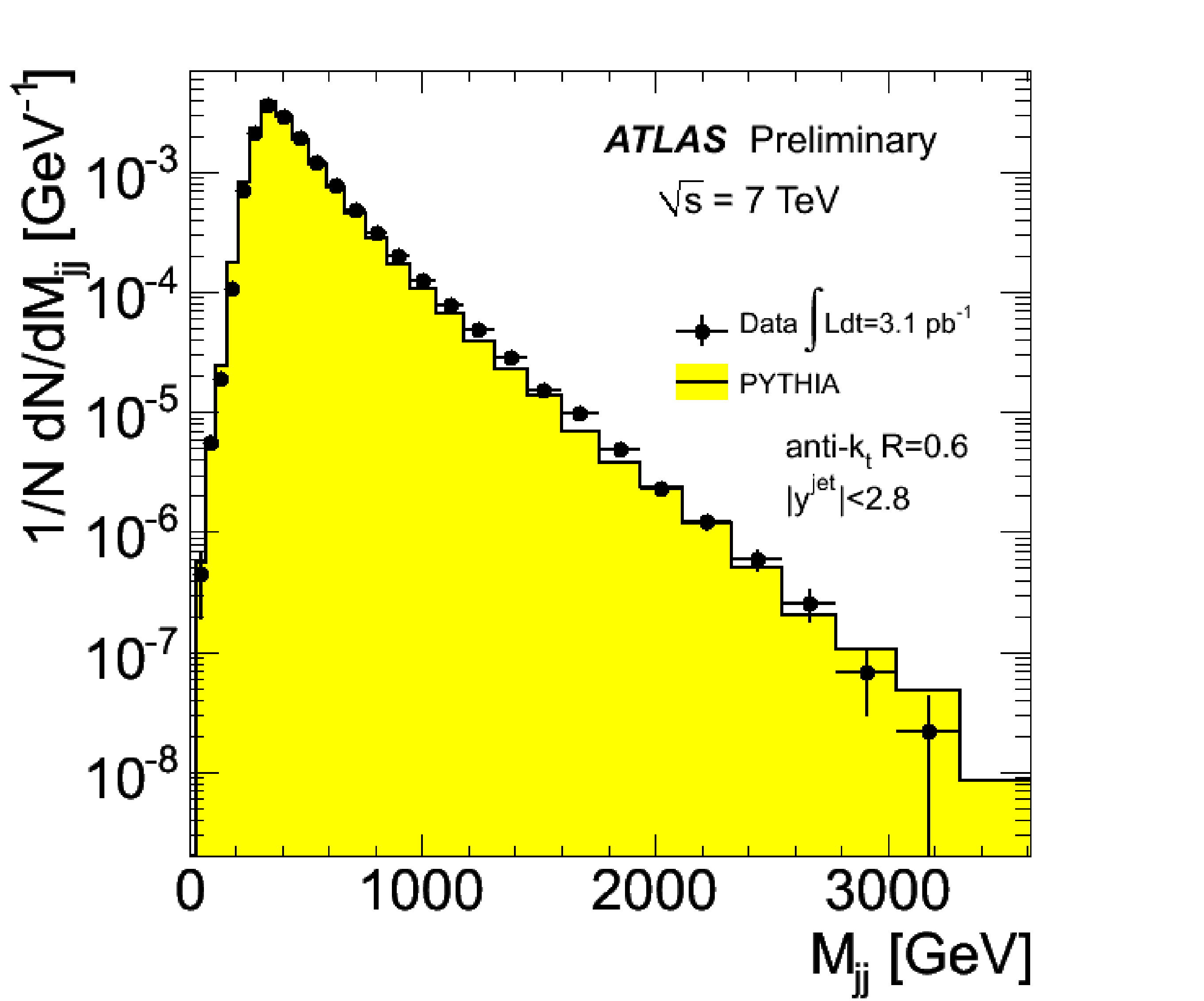
3.1/pb

m(q*)>1.53 TeV (95% CL)

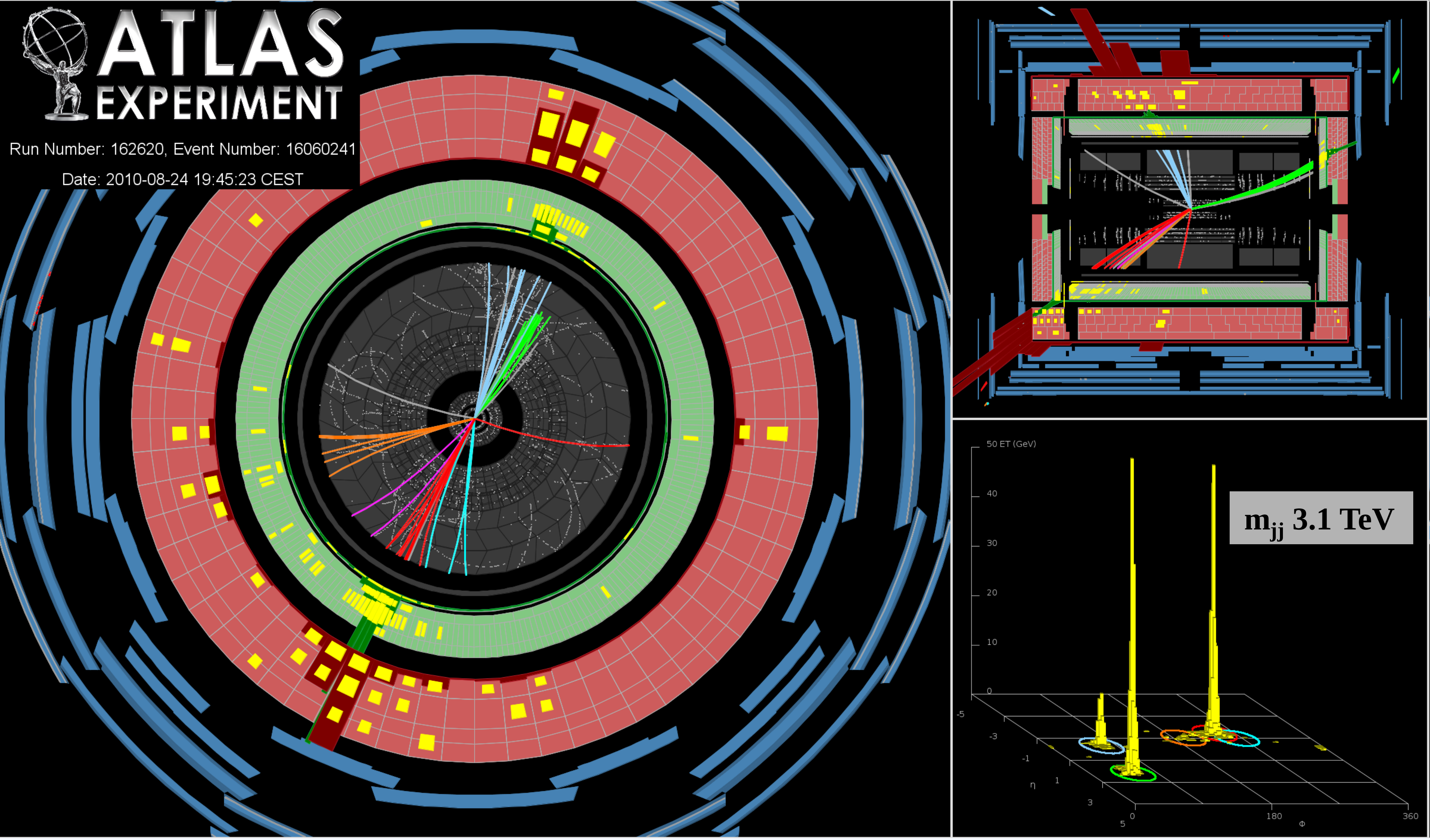




The data is coming fast



Current mass reach with 3.1/pb
- Full analysis still in progress

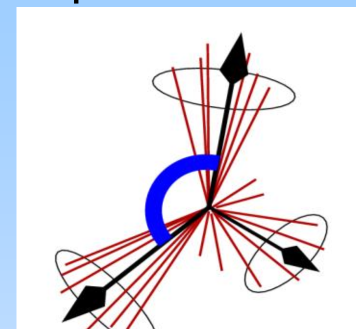


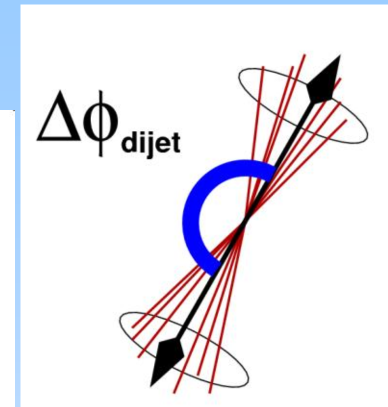
...and new events always coming in!

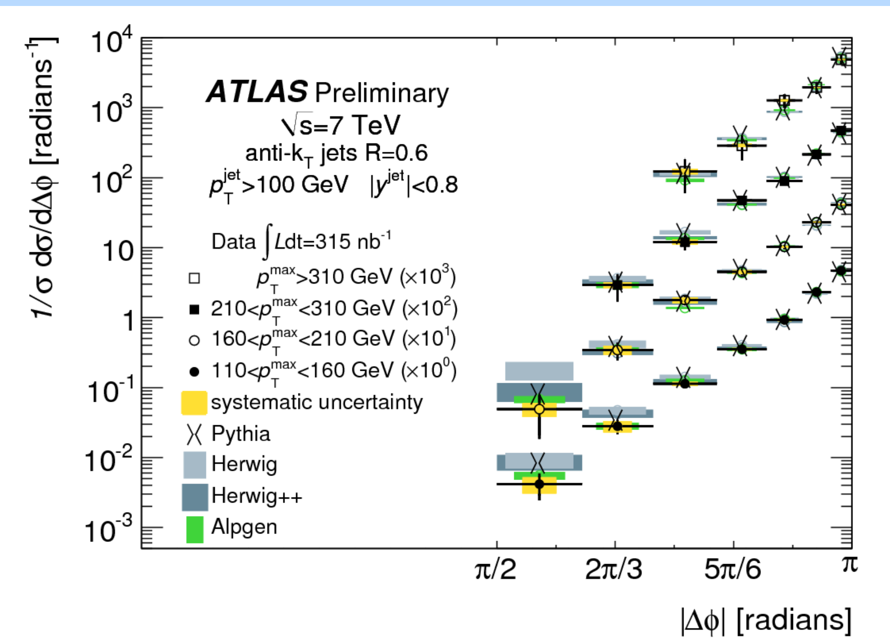
Multijet production

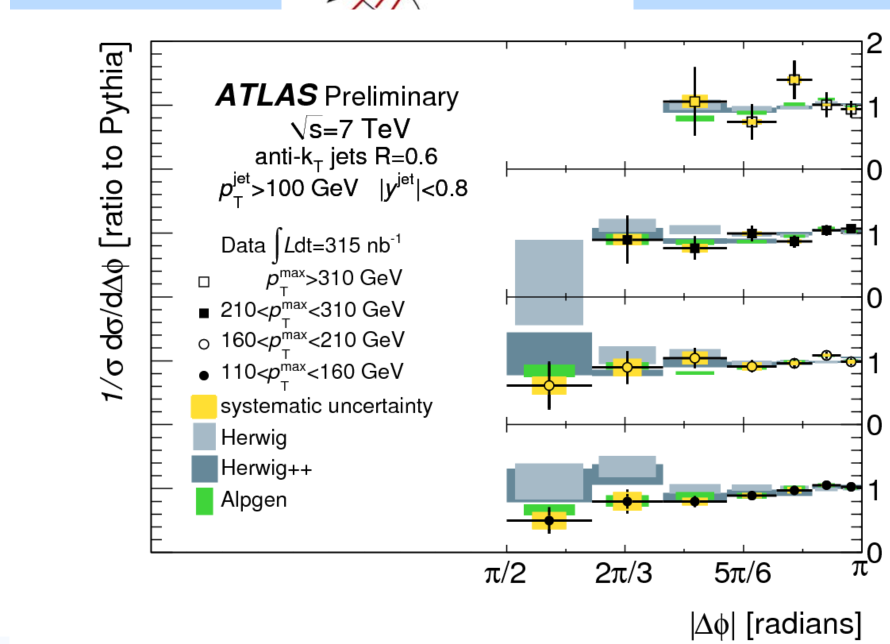
Azimuthal Decorrelations in Dijet Events

- Inclusive dijet events are not back-to-back in ϕ
- Additional jets in final state
- How large is the effect?
- Does MC describe it properly?









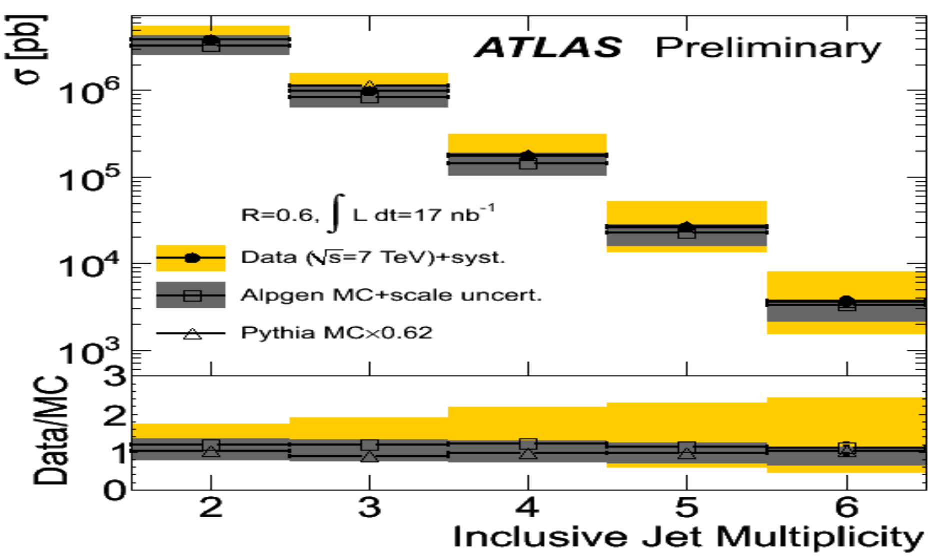
Alpgen works well over 3 orders of magnitude
- Also NLO pQCD (NLOJET++) (not shown)
- Data is well described by the appropriate models

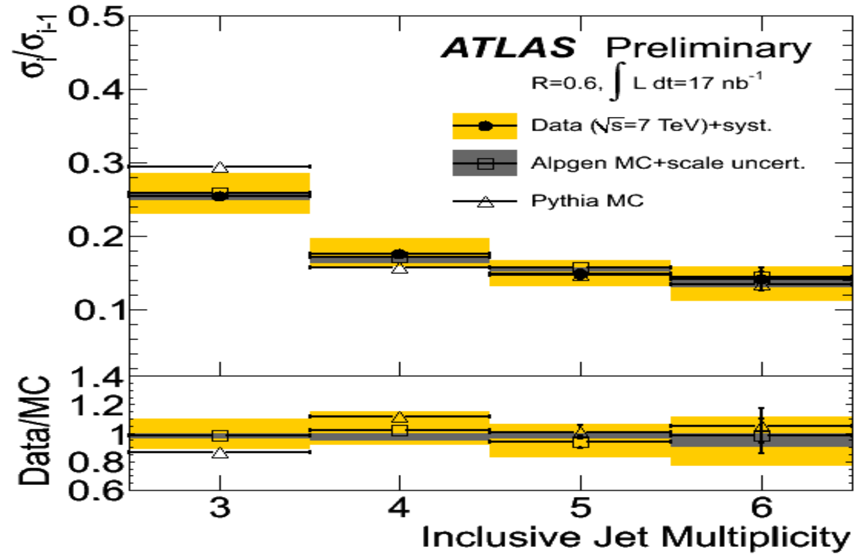
ATLAS-CONF-2010-084

Multijet production

ATLAS-CONF-2010-084

- Can we count and characterize the additional jets?
  - Essential to understand for new-particle searches
  - Prediction requires higher order QCD corrections
- Count jets with *pt* > 30 GeV, |*y*| < 2.8
  - Jet energy scale (JES) crucial because of steeply falling *pt* spectrum
  - Correct for detector smearing effects
  - Corrections depend on proximity of jets (overlap)
  - MC dependent (additional systematic)
- Plot ratio of cross sections for successive multiplicities
  - Many systematic errors cancel
  - Uncertainties significantly reduced





Multijet production

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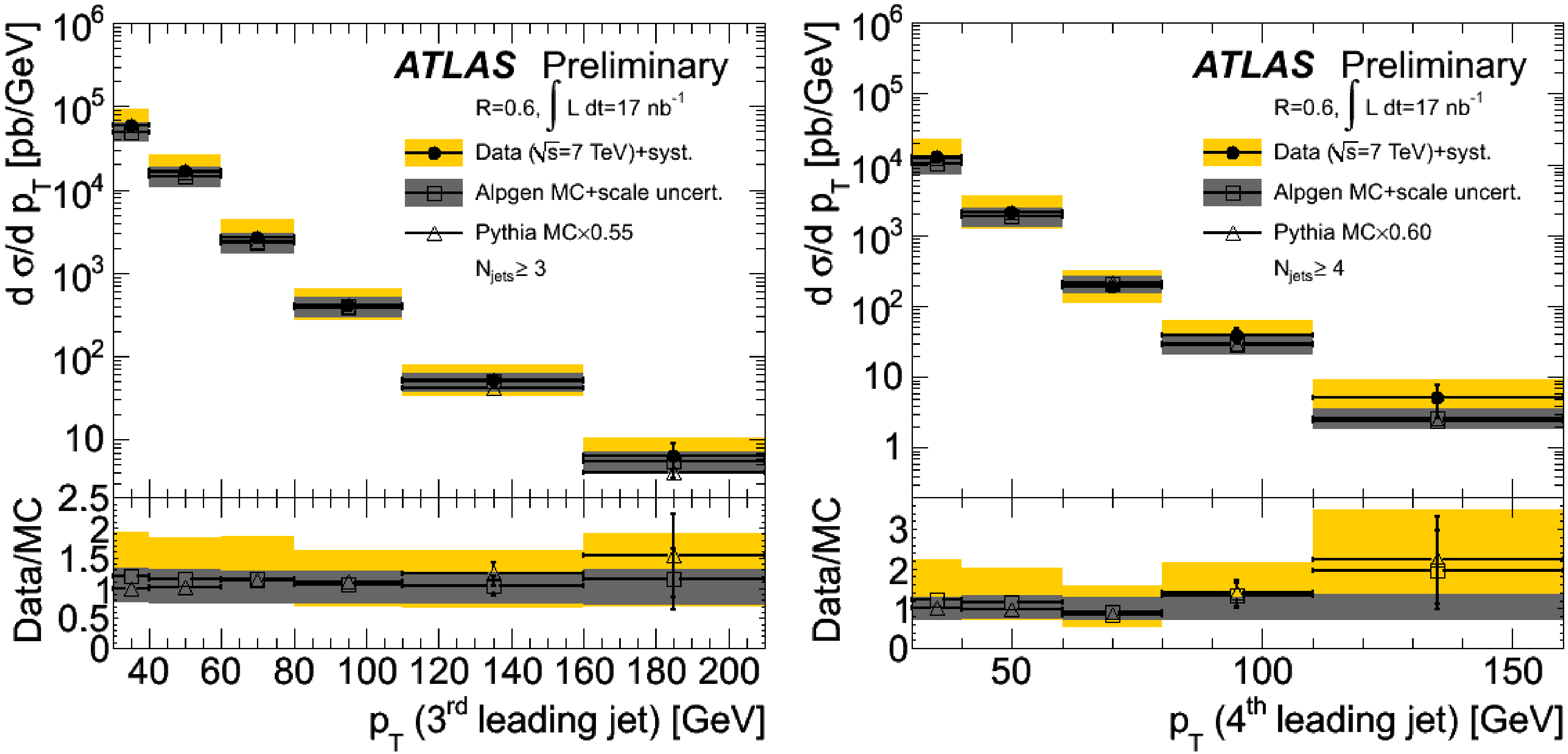
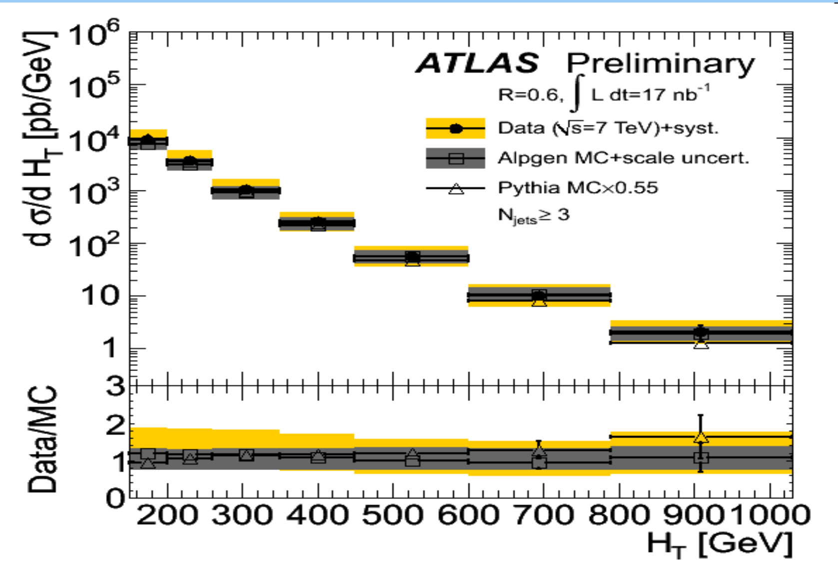
- Do we understand the *pt* spectrum of the extra jets?
  - Pythia spectrum renormalized to data for each jet multiplicity
  - Results in reasonable agreement with Alpgen

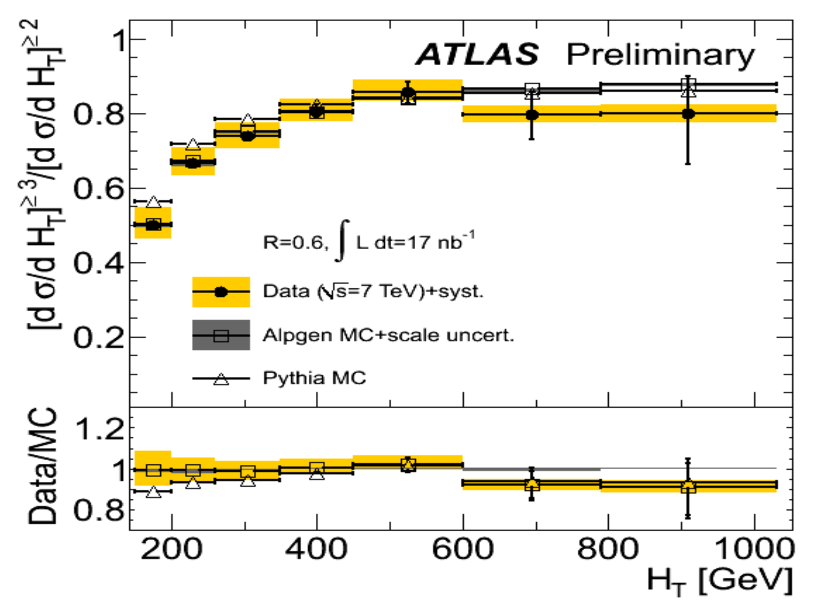


Multijet production

- Many new-particle searches use the *Ht* variable to characterize the level of high-*pt* activity in an event
    - Scalar sum of jet *pt* values
    - Overall spectrum well described (top)
    - Ratio for successive multiplicities reduces uncertainties to ~10% level

- Quantitative aspects of multijet final states very well described by Alpgen MC model
    - Comparisons with higher statistics in the future
    - Many checks already at 10% level





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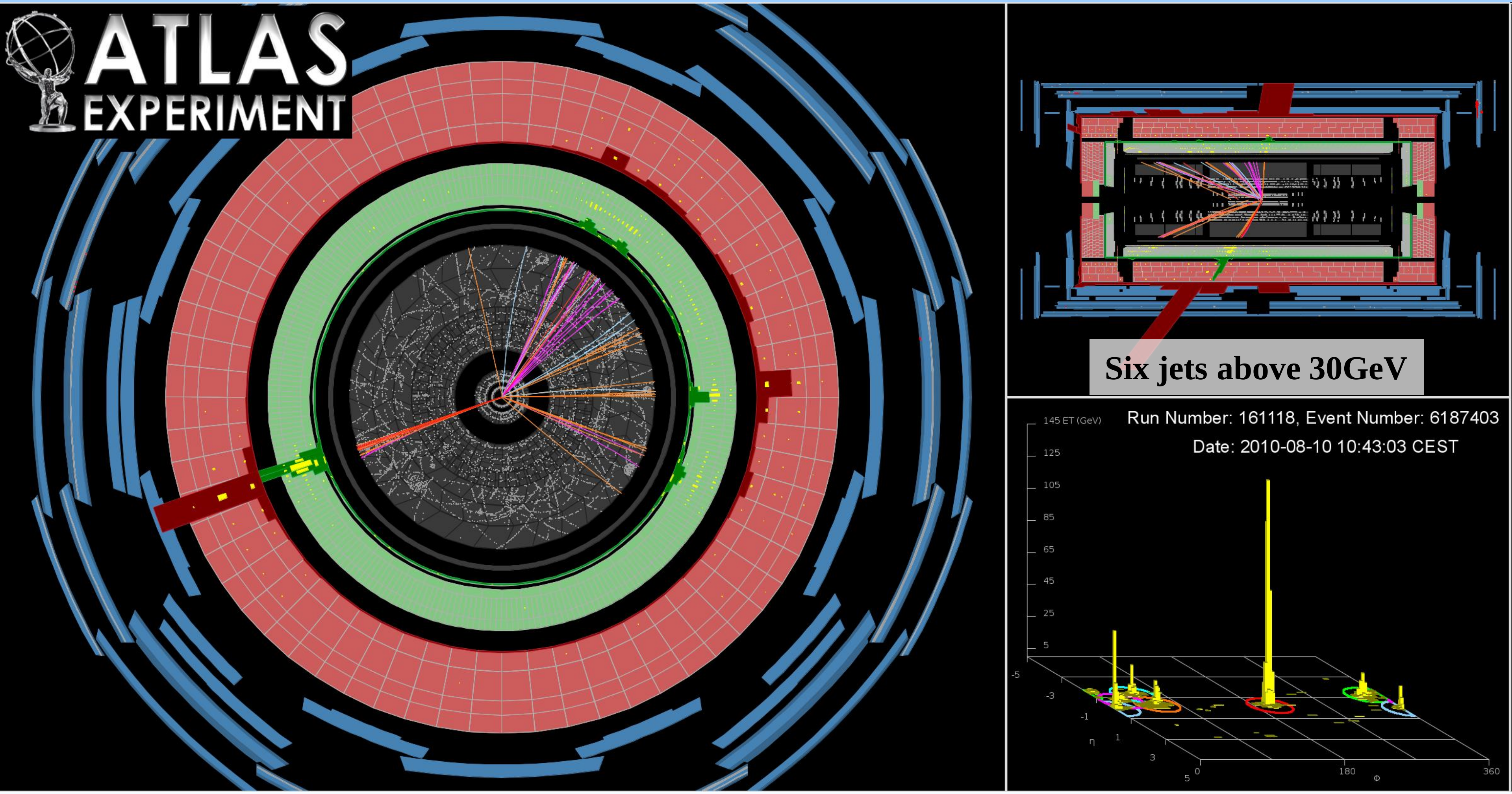
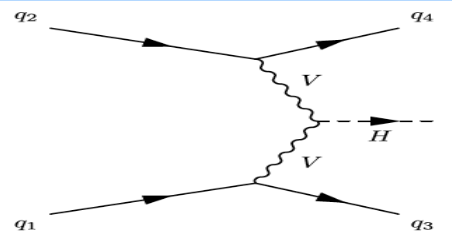

ATLAS
EXPERIMENT
Six jets above 30GeV
Run Number: 161118, Event Number: 6187403
Date: 2010-08-10 10:43:03 CEST
145 ET (GeV)
η
Φ

Rapidity Gap Studies

Rapidity Gap Studies

ATLAS-CONF-2010-085

- Level of activity in rapidity gap between leading jets is important at LHC
    - Vector boson fusion production of the Higgs expected to yield two forward jets with "quiet" color-free central region except for the Higgs



    - How well do we understand the rapidity gap activity for QCD events (the background)?

- CDF, D0, ZEUS, H1 observe a special class of QCD events with very little activity in the gap
    - Very low multiplicity or *Et* in gap (*Et* < 2 GeV)
    - Interpreted as color-singlet exchange
    - ~1% of events for collisions (CDF/D0)
    - ~10% of photo produced dijet events for collisions (H1/ZEUS)

- Work is in progress to understand the activity in the gap

Measurement of dijet production with a jet veto

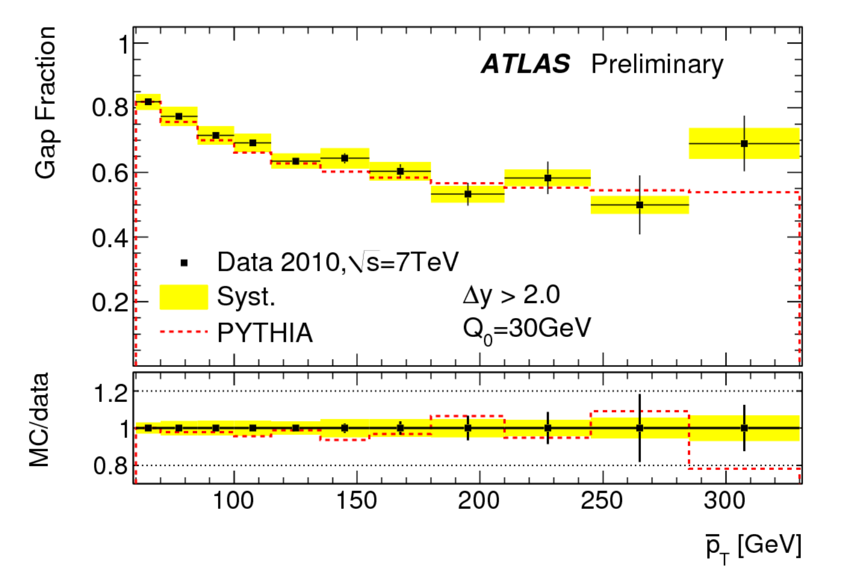
ATLAS-CONF-2010-085

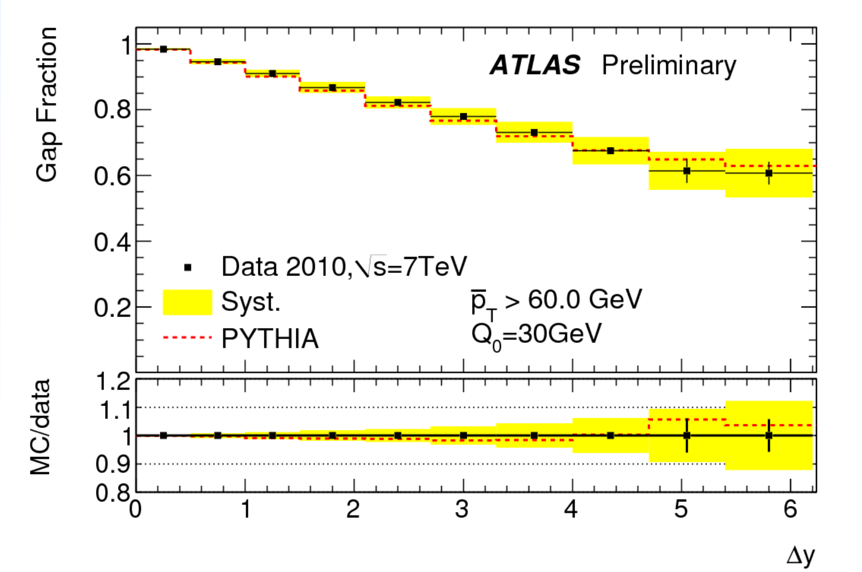
Probability of no jet with *pt* > 30 GeV in the gap, vs <*pt*> of boundary jets and vs Δy between boundary jets, where boundary are the two highest *pt* jets

Data is in good agreement with LO MC predictions of Pythia 6 for no jets in the gap with *pt* > 30 GeV

Plans to

- increase statistics
- explore lower *pt* threshold for vetoing jets in gap
- need to be at level of few GeV to see color-singlet exchange
- Compare with other predictions for gap activity
- extend Δy range of the gap





Summary-1

- **ATLAS and the LHC are performing very well**
  - the LHC does very well with almost daily improvements and records
  - detector is fully operational
  - data-taking efficiency above 90%

- **Uncertainties on Jet energy scale are understood**
  - (6-9)% depending on the pt range for $|y|<2.8$
  - Feasible fast improvement

- **Detailed studies of the soft QCD environment and MC tuning are well underway**
  - (see talk of Chiara)

Summary-2

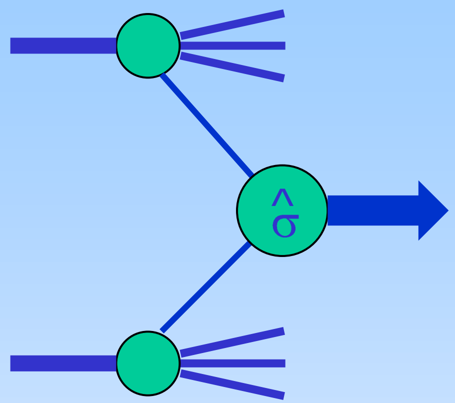
- **Jet cross sections measured, agree with NLO QCD**
  - preparing the ground for top rediscovery
  - preparing the ground for the BSM searches with QCD backgrounds

- **W & Z cross sections and asymmetries measured**
  - (see talk of Jose for more details)

- **New physics searches exploiting the understanding of QCD (through precise simulation) and of the detectors.**
  - improved limits on excited quarks and contact interactions (talk of Evgeny)

Back-up slides

Precision pQCD at LHC



- Hard processes are rather well described by QCD
    - Quantitative descriptions for Q2 scales above ~ 10 GeV2
    - Decades of earlier work have taught us how to make useful predictions and what questions to ask of the data
- Extend measurements into a new Q2 range
    - Gain confidence in the predictions and our ability to confront them with data
- Hard scattering is the domain of new physics
    - Essential that we understand the standard model processes if we are to be able to identify new physics

First Collisions – Nov 2009

Detector Status

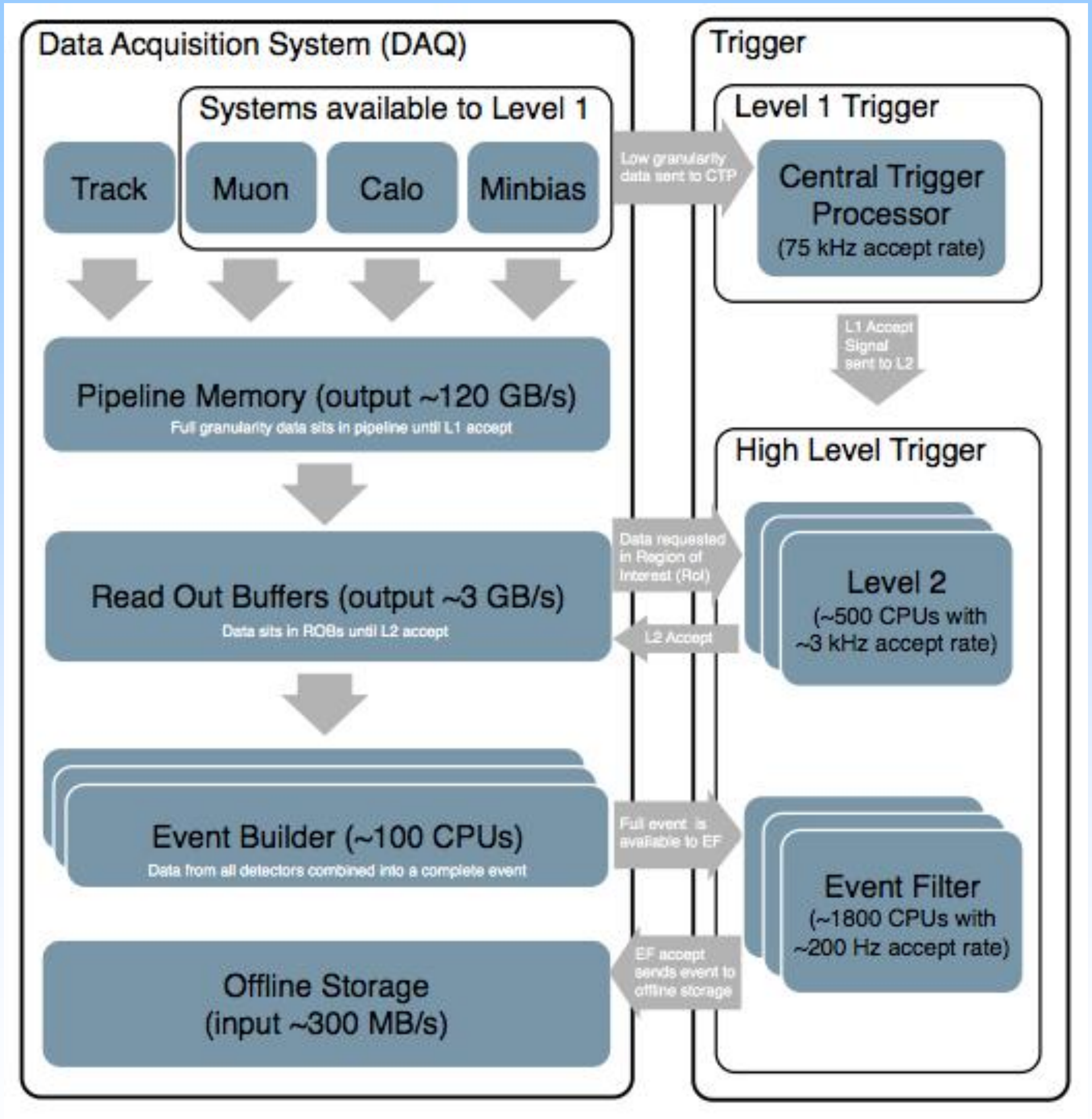
Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	80 M	97.3%
SCT Silicon Strips	6.3 M	99.2%
TRT Transition Radiation Tracker	350 k	97.1%
LAr EM Calorimeter	170 k	98.1%
Tile calorimeter	9800	96.9%
Hadronic endcap LAr calorimeter	5600	99.9%
Forward LAr calorimeter	3500	100%
LVL1 Calo trigger	7160	99.9%
LVL1 Muon RPC trigger	370 k	99.5%
LVL1 Muon TGC trigger	320 k	100%
MDT Muon Drift Tubes	350 k	99.7%
CSC Cathode Strip Chambers	31 k	98.5%
RPC Barrel Muon Chambers	370 k	97.0%
TGC Endcap Muon Chambers	320 k	98.6%

Inner tracking

Calorimeters

Muon detectors

38

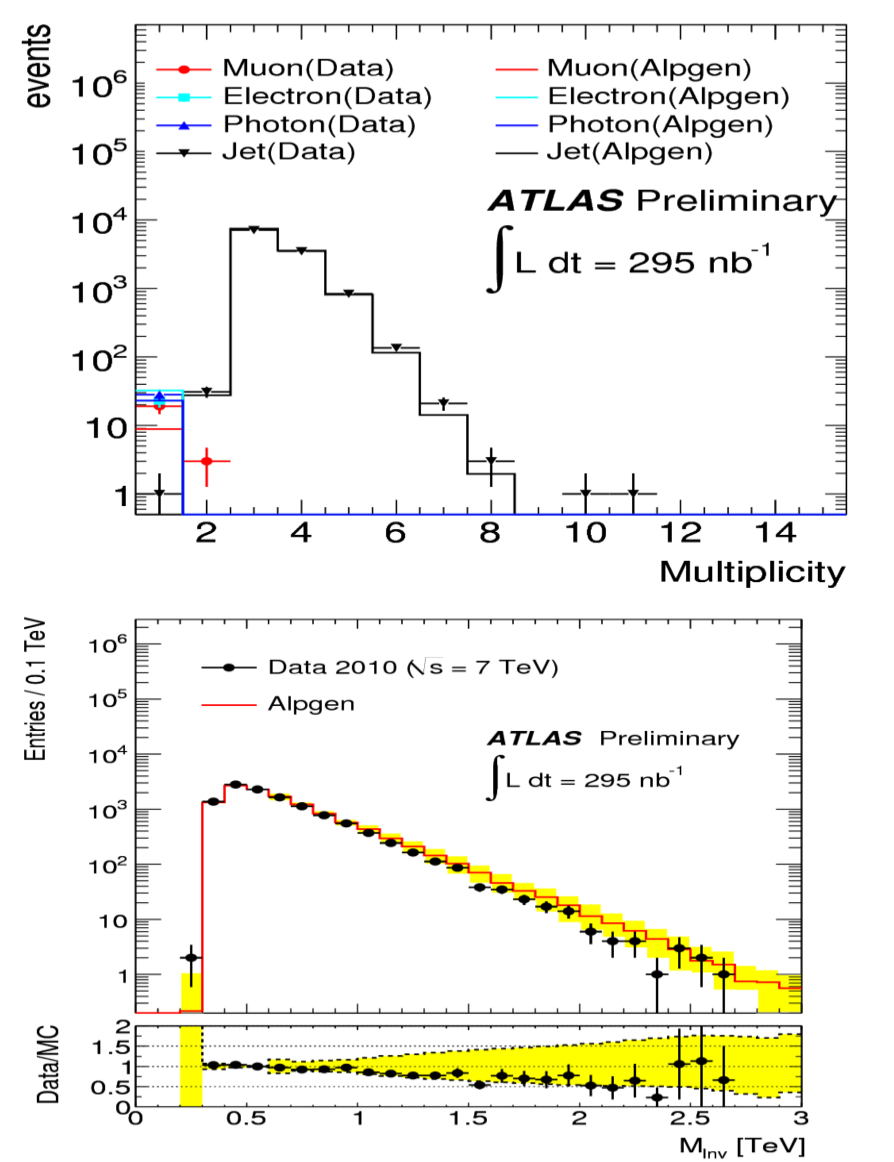


Data Acquisition System (DAQ)
Systems available to Level 1
Track
Muon
Calo
Minbias
Pipeline Memory (output ~120 GB/s)
Full granularity data sits in pipeline until L1 accept
Read Out Buffers (output ~3 GB/s)
Data sits in ROBs until L2 accept
Event Builder (~100 CPUs)
Data from all detectors combined into a complete event
Offline Storage
(input ~300 MB/s)
Low granularity data sent to CTP
Data requested in Region of Interest (RoI)
L2 Accept
Full event is available to EF
EF accept sends event to offline storage
Trigger
Level 1 Trigger
Central Trigger Processor
(75 kHz accept rate)
L1 Accept Signal sent to L2
High Level Trigger
Level 2
(~500 CPUs with ~3 kHz accept rate)
Event Filter
(~1800 CPUs with ~200 Hz accept rate)

Search for new physics in multi-body final states

- One may attempt to look for new particles in multijet final state

- An upper limit of 0.34 nb, at the 95% confidence level, is determined for the production cross section times acceptance of new physics models that result in final states with at least three particles and an invariant mass above 800 GeV and with pt > 700GeV



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