First QCD results in ATLAS

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Accelerating Science
Accélérateur de science
CERN
Square GALILEO GALILEI
UNIVERSE OF PARTICLES exhibition
IL FUTURO È UN BUCO

Jets in the LHC era

At the Large Hadron Collider (LHC), jet production is the dominant high transverse-momentum (p_T) process.

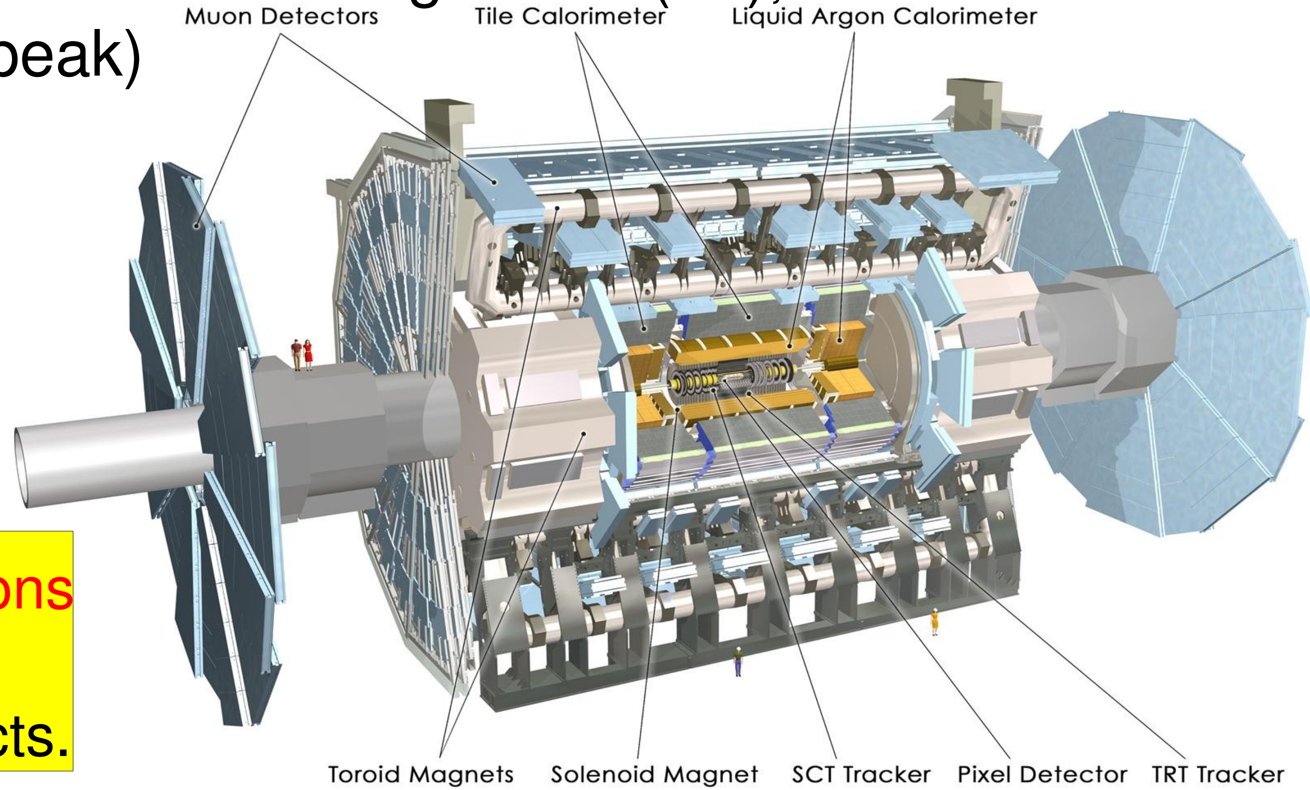
It gives the first glimpse of physics at the TeV scale.

Jet cross sections and properties are key observables in high-energy particle physics.
Measured in $\mathbf{e^+e^-}$, **ep** , $\mathbf{p\bar{p}}$, and **pp** colliders,
and in $\boldsymbol{\gamma}$**p** and $\boldsymbol{\gamma\gamma}$ collisions.

- Measurements of the strong coupling constant.
- Information about the structure of the proton and photon.
- Tools for understanding the strong interaction
- Tools for searching for physics beyond the Standard Model.

ATLAS Detector overview

Magnetic field: one solenoid surrounding the ID (2T), one toroid (muon spectrometer - 4T peak)

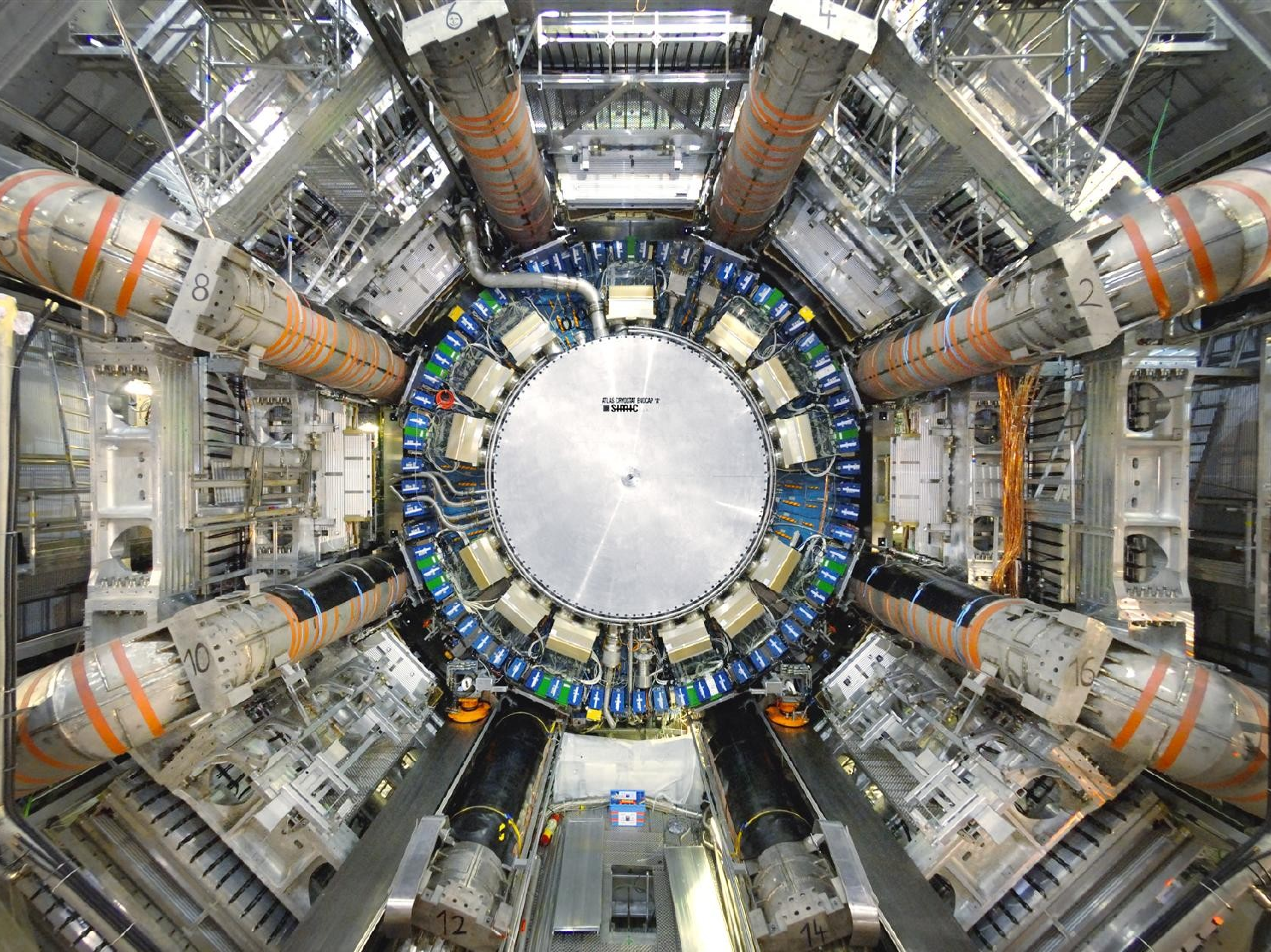


ID made up of three different detectors (Pixel, SCT, TRT):
High resolution tracking in $|\eta| < 2.5$

EM calorimeter - two sections covering up to $|\eta| \approx 3.2$.
High resolution on e/γ objects.

HAD calorimeter - 3 sections covering up to $|\eta| \approx 5$
Good containment, good resolution for jet measurement

Muon system (4 different technologies) covering up to $|\eta| = 2.7$
High precision muon momentum measurement (also standalone)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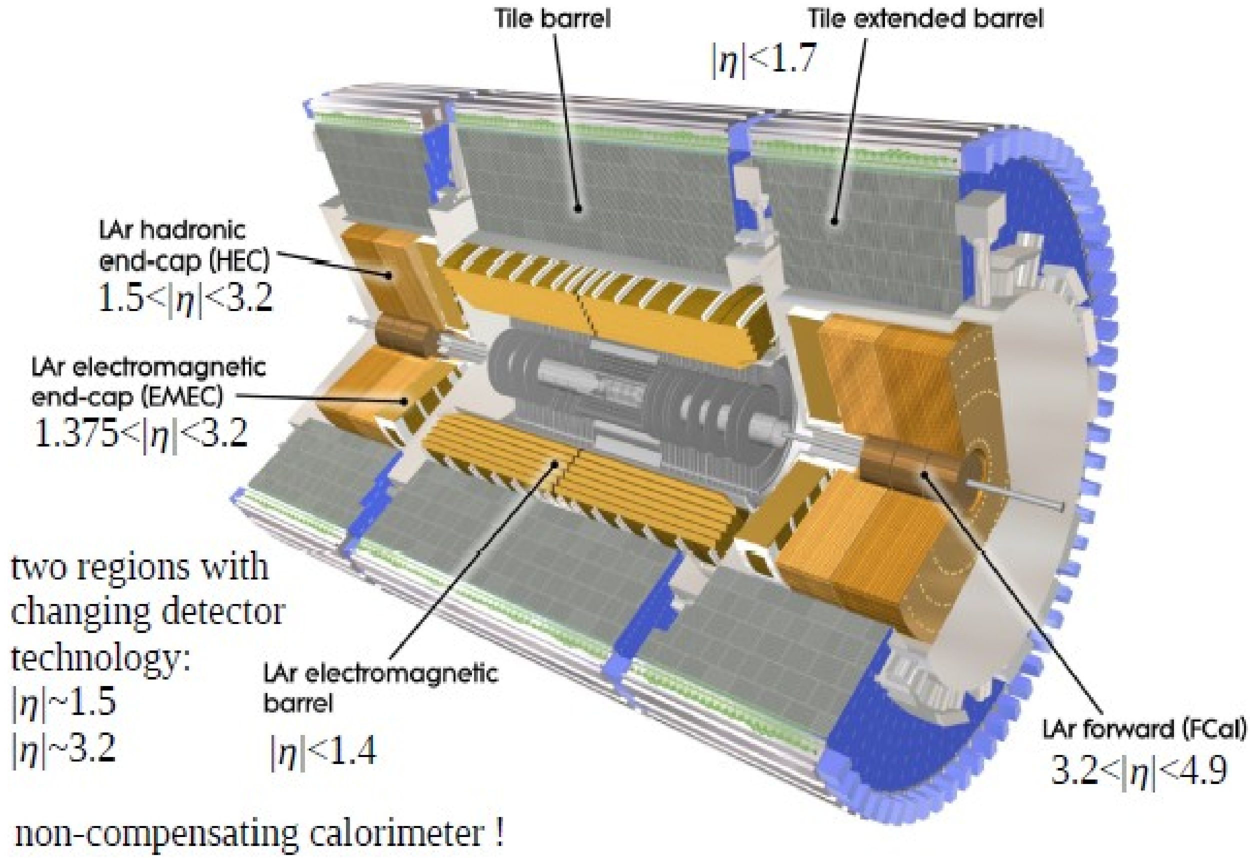
ATLAS Calorimeter System

EM LAr: $|\eta| < 3$ - Pb/LAr calorimeter, high resolution for e/γ objects. e/h ~1.7

Central hadronic calorimeter (TileCal): $|\eta| < 1.7$: Fe(82%), scintillator (18%) - e/h = 1.36

End Cap Hadronic Calorimeter (HEC): $1.7 < |\eta| < 3.2$ - Cu/LAr



Forward calorimeter: $3 < |\eta| < 4.9$. First layer EM (Cu/LAr), the two remaining layers HAD.

Highly hermetical ($|\eta| < 5$), non compensating calorimeters.

Data Sample

In this talk:

Performance

Trigger Efficiency

E/P calorimeter studies

Jet Calibration

Jet Resolution

Properties

Jet Shapes

Trackjet and fragmentation

$\Delta\varphi$ Decorrelation

Cross Sections

Inclusive jet cross section

Di-Jet cross section

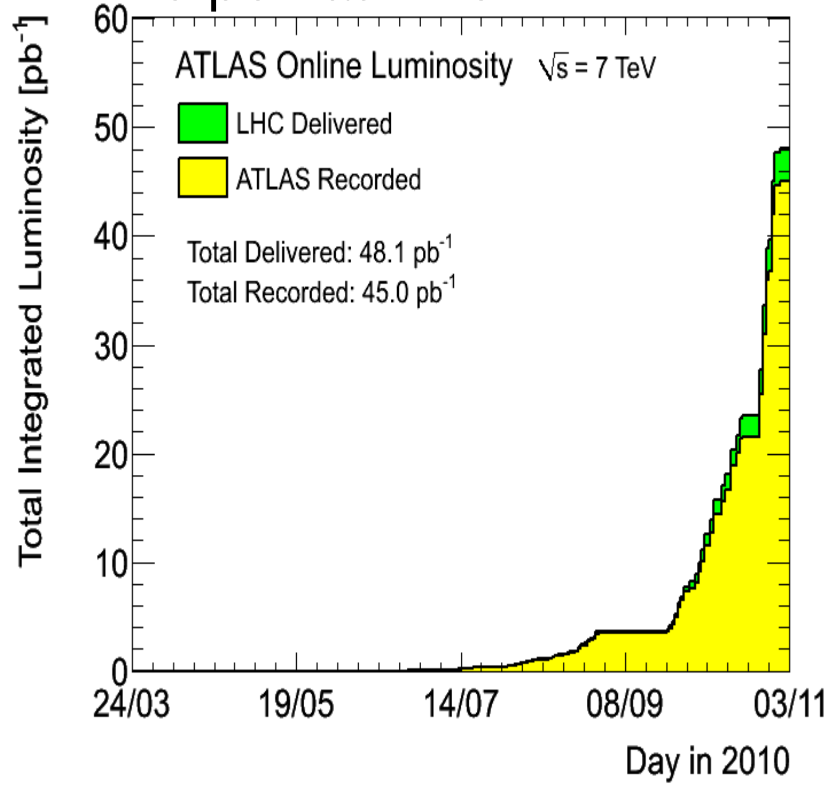
MultiJet cross section

BSM: exclusions

Exclusions: DijetMass

Exclusions: Angular

Dataset recoded by ATLAS in 2010: ~40 pb^{-1} at 7 TeV



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MultiJet cross section

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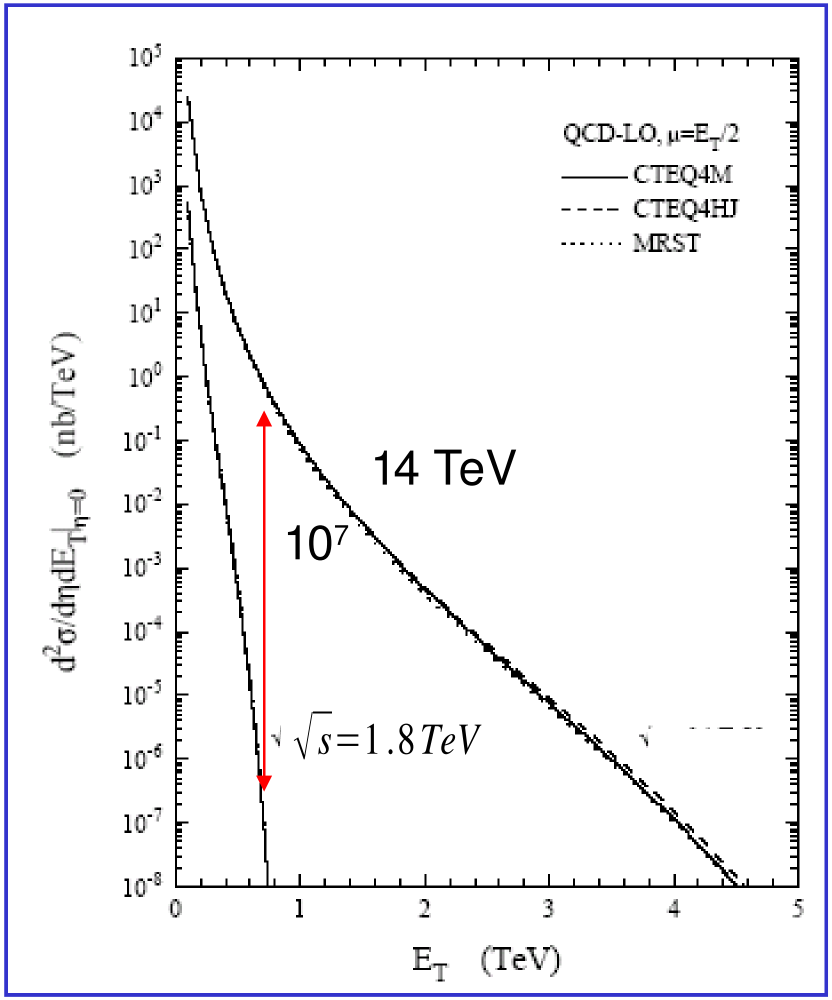


Trigger

MBTS: Minimum Bias Trigger Scintillators

(scintillators that detect activity in the forward region of the detector)

- In coincidence of the beam pick-up signal
- Inclusive Trigger
- **No significant bias introduced to the jet measurement**

Level 1 Jet Trigger:

E_T in calorimeter elements

Element granularity:

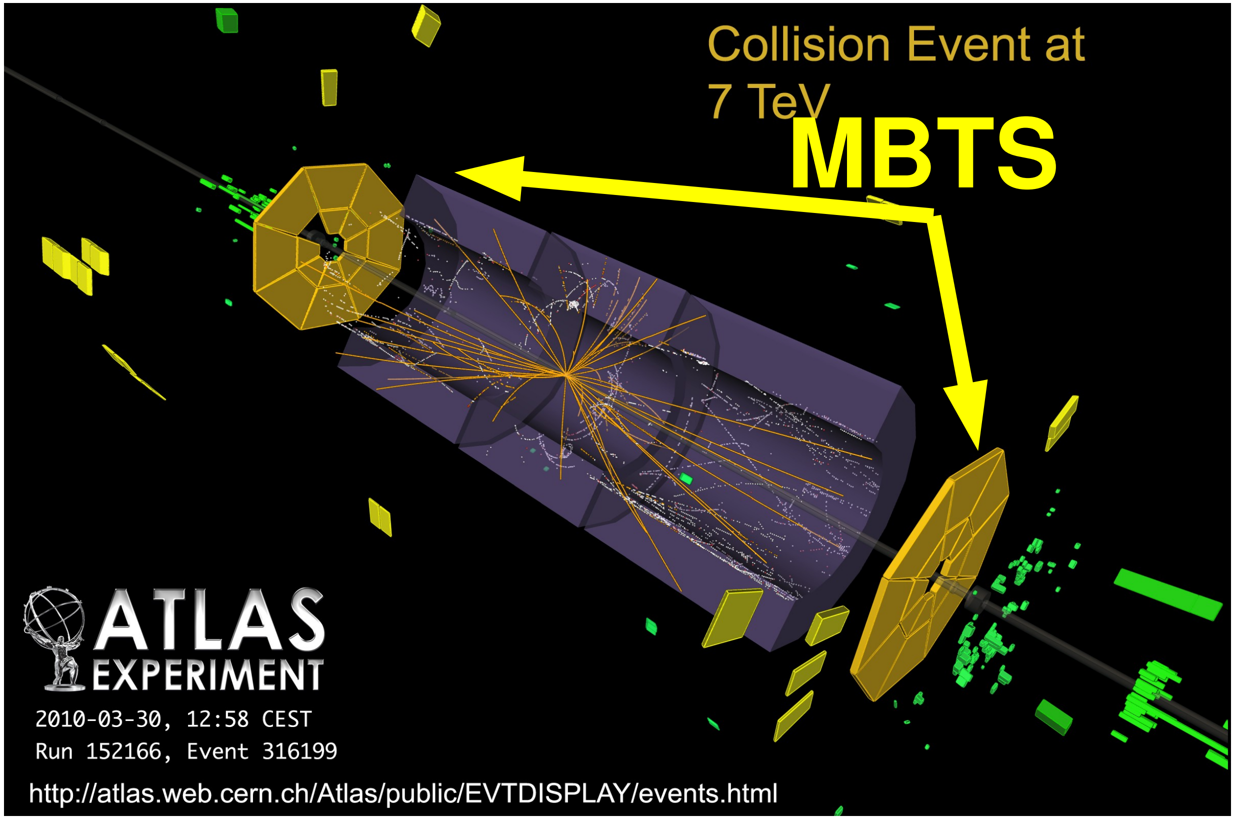
$\Delta\varphi \times \Delta\eta$- 0.2 x 0.2

Jet finding:

sliding window

with steps of one element

E_T is computed in a window of configurable size.



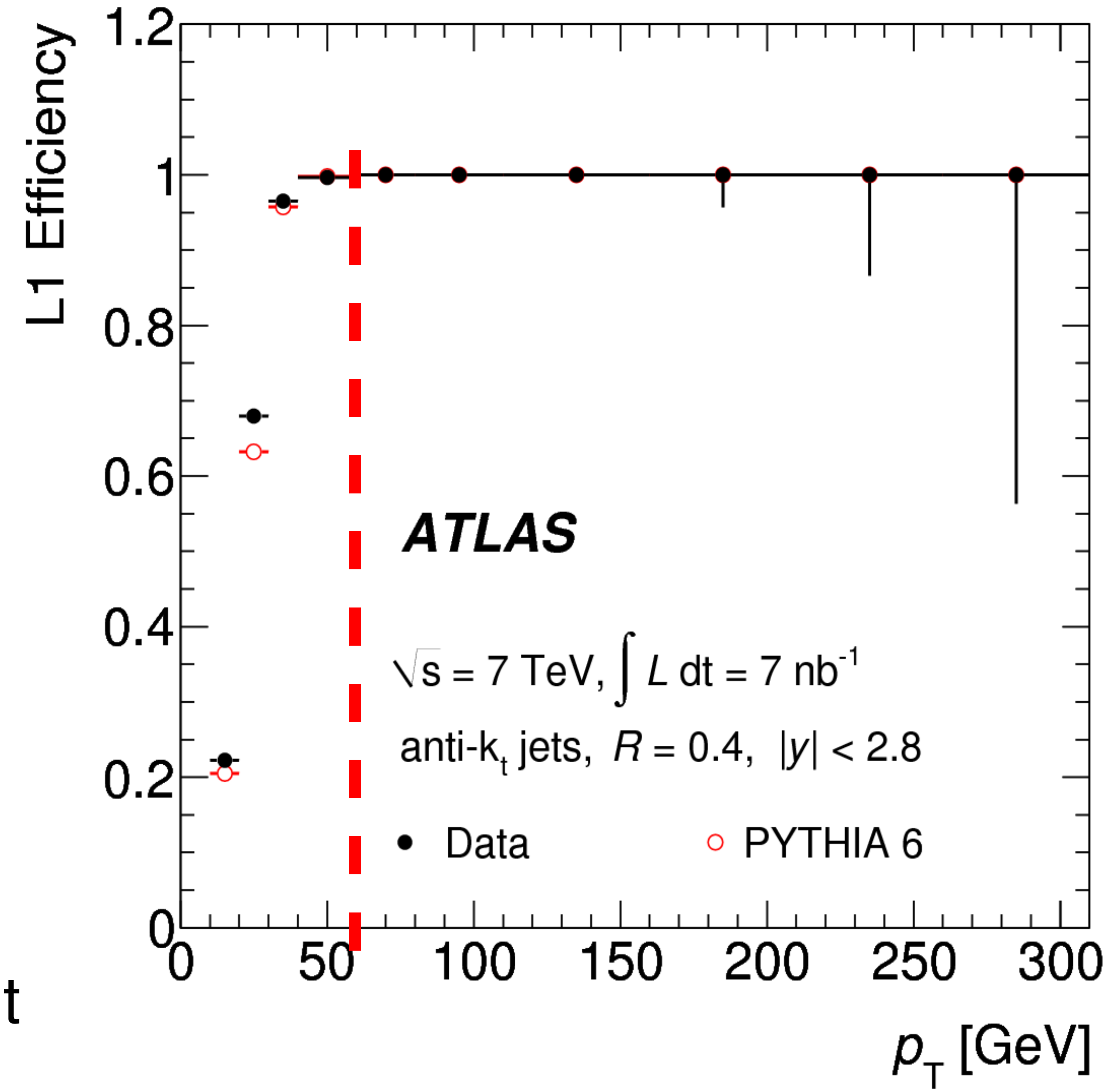
Jet Trigger Efficiencies

MBTS inefficiency:Negligible from randomly triggered events

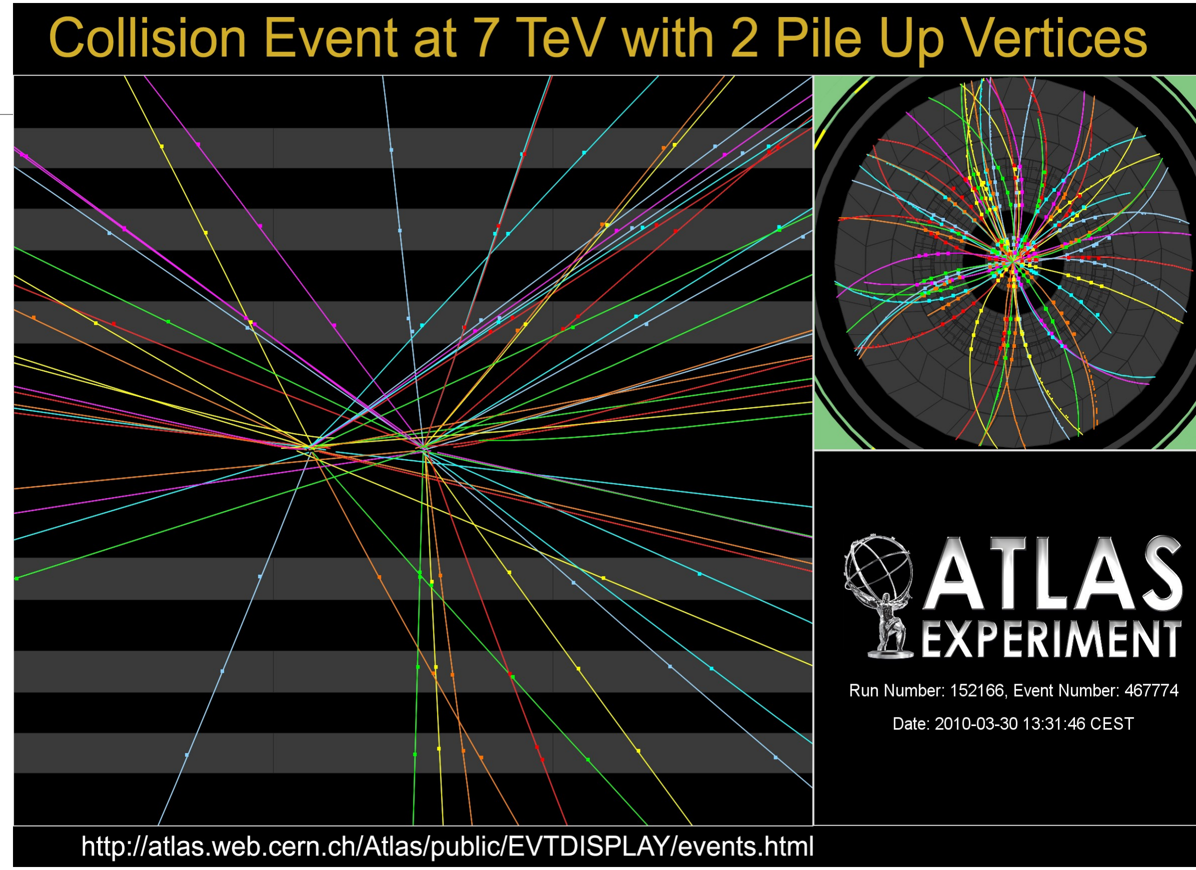
L1 Jet Trigger
Inclusive jet efficiency:
Measured with respect to the **MBTS** trigger.

The efficiency is for jets with pT > 60 GeV and |y| < 2.8 is above 99%.

Similar studies done for different jet algorithm sizes and different regions in rapidity.



Event Selection



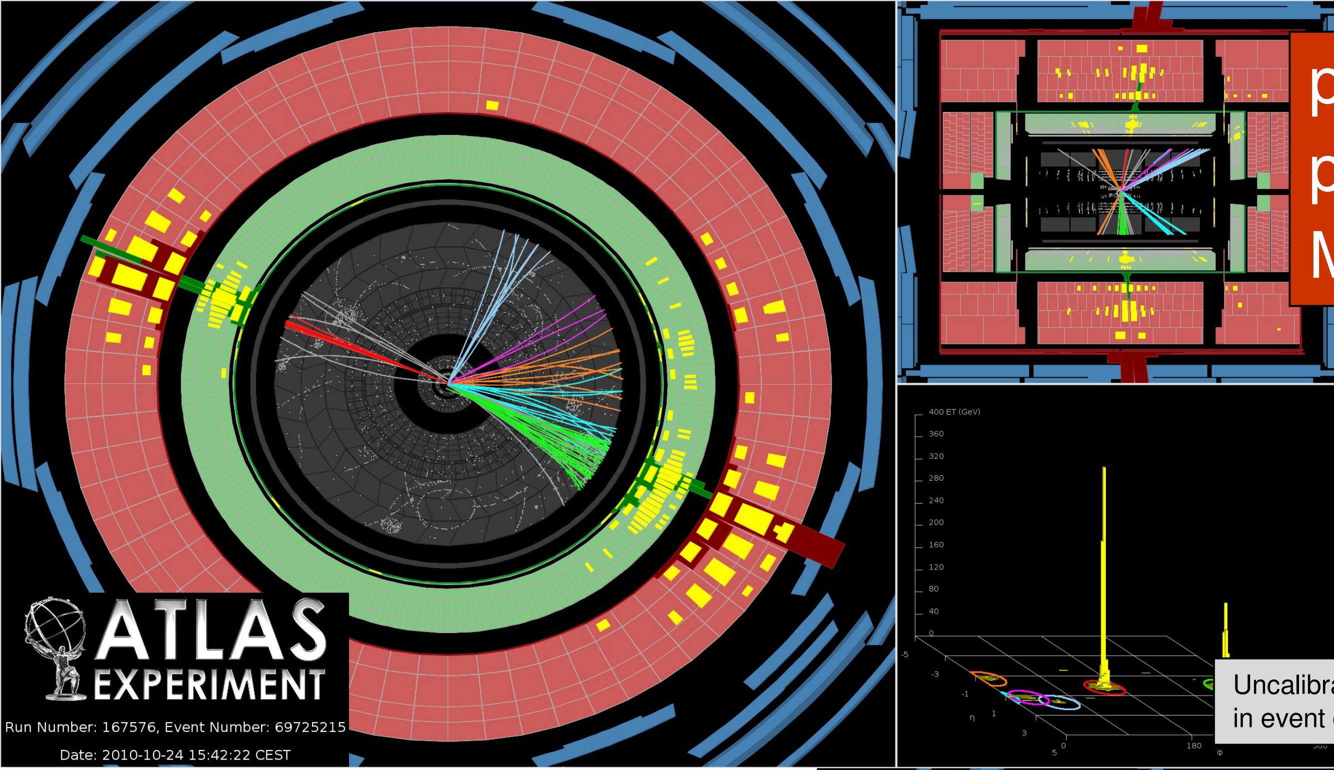
Data Quality (DQ) used
to select the periods with the nominal performance of the detector

Primary vertex (PV) selection:
PV from center of ATLAS detector

MBTS Trigger and timing requirements: depending on the detector and accelerator conditions of the different analyses presented here.

Effectively no bkg due to cosmic ray shower and beam related bkg left.

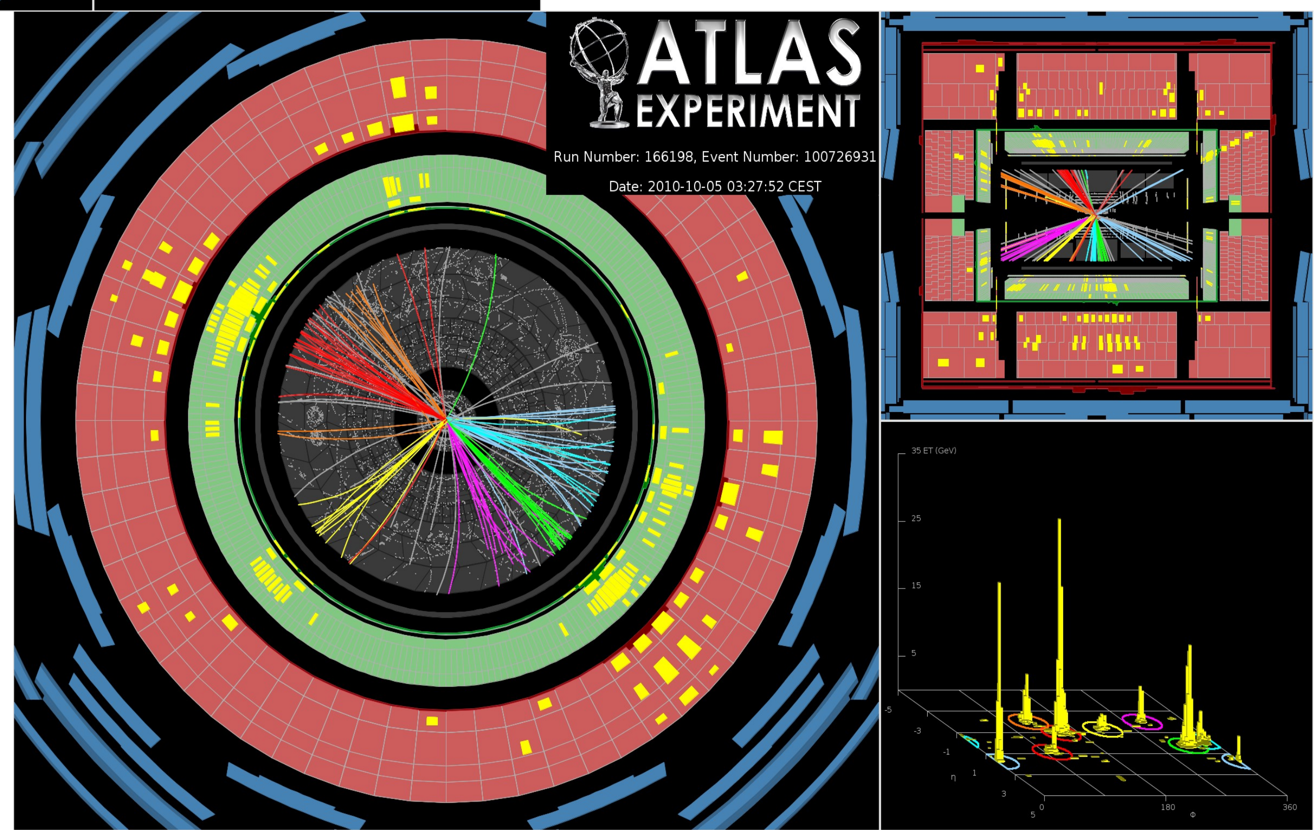
Negligible impact from pileup in data sample reported in these slides.



p_T (j_1) ~ 1.3 TeV
p_T (j_2) ~ 1.2 TeV
M (jj) ~ 2.6 TeV

Uncalibrated E in event display

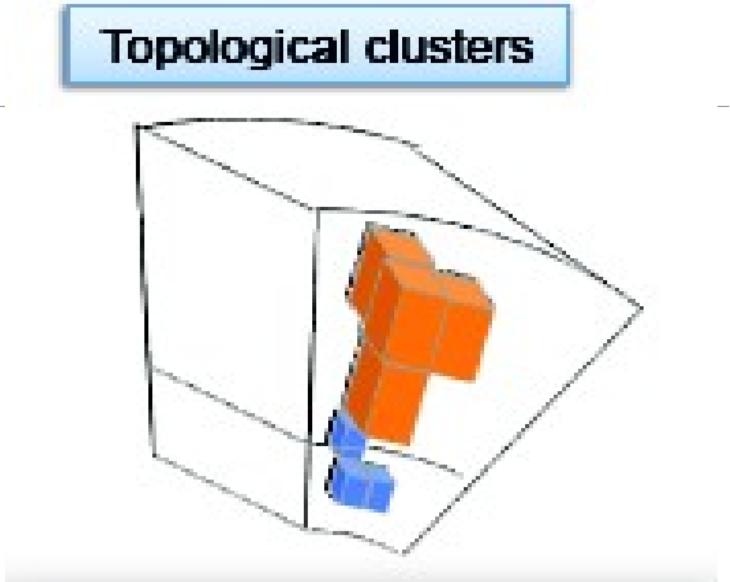
Event with high jet multiplicity



First QCD results in ATLAS

Jet reconstruction and performance

Jet Reconstruction



Inputs:

3D Clusters:

find local cell energy maxima and cluster neighboring cells

Pro: noise suppression

Projective Towers:

All the cells in $\Delta\varphi$ x $\Delta\eta$- 0.1 x 0.1

Pro: Stable under extreme conditions (useful to validate the clusters)

Jet Algorithm:

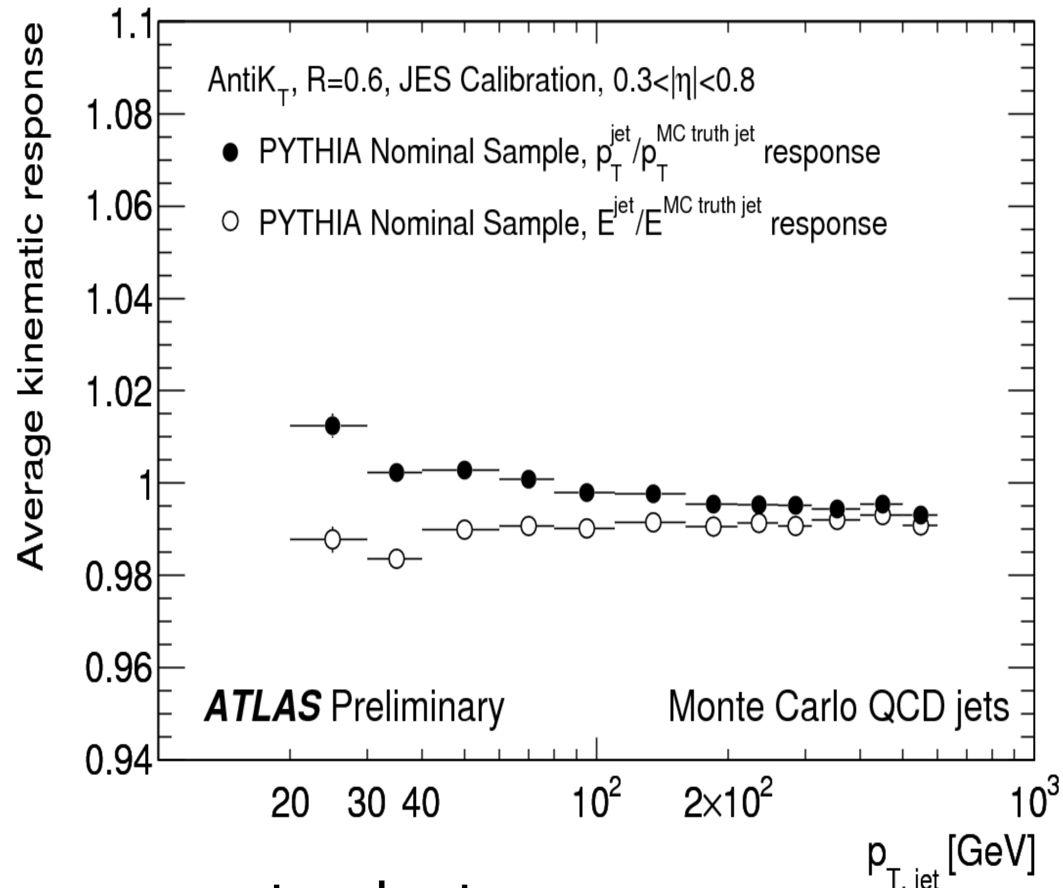
The Anti-K_T (infrared safe) algorithm has been taken as the default jet algorithm.

$$d_{ij} = \min(k_{ti}^{2p}, k_{tj}^{2p})\Delta R_{ij}^2/R^2$$

The Anti-K_T is a sequential recombination jet algorithms with p= -1, (Kt, p=1) which behaves like an idealized cone algorithm.

Calorimetric calibration

Electromagnetic (EM) scale:
Baseline cluster calibration, established using test beam with e and μ in the calorimeters.
Good estimate of the energy deposited by γ and e.
60-70% estimate of the energy deposited for hadrons and jets



Hadronic Calibration. Why?:
In the ATLAS Calorimeters,
- Response to hadrons lower than response to electrons.
- Energy losses in inactive regions of the detector.

Hadronic Jet Calibration driven by MC description.

Correction factor: $p_T^{Calibrated} = C(p_T^{EM},\eta)\ \ p_T^{EM}$

Checks on the EM scale simulation

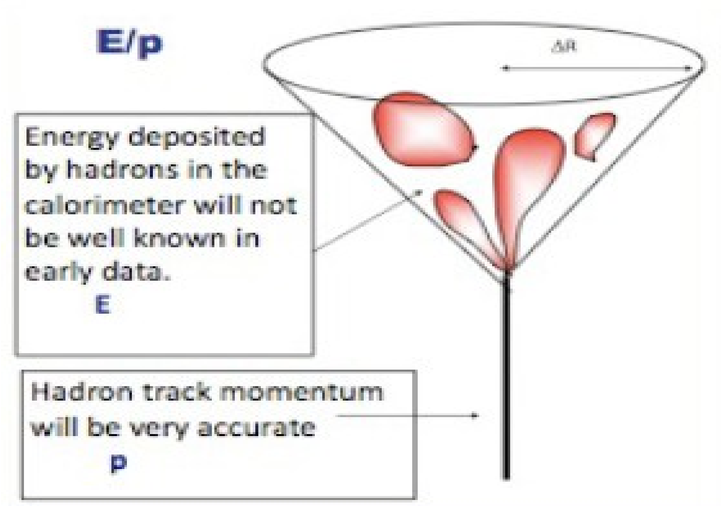
The simulation has been validated using test-beam and collision data.

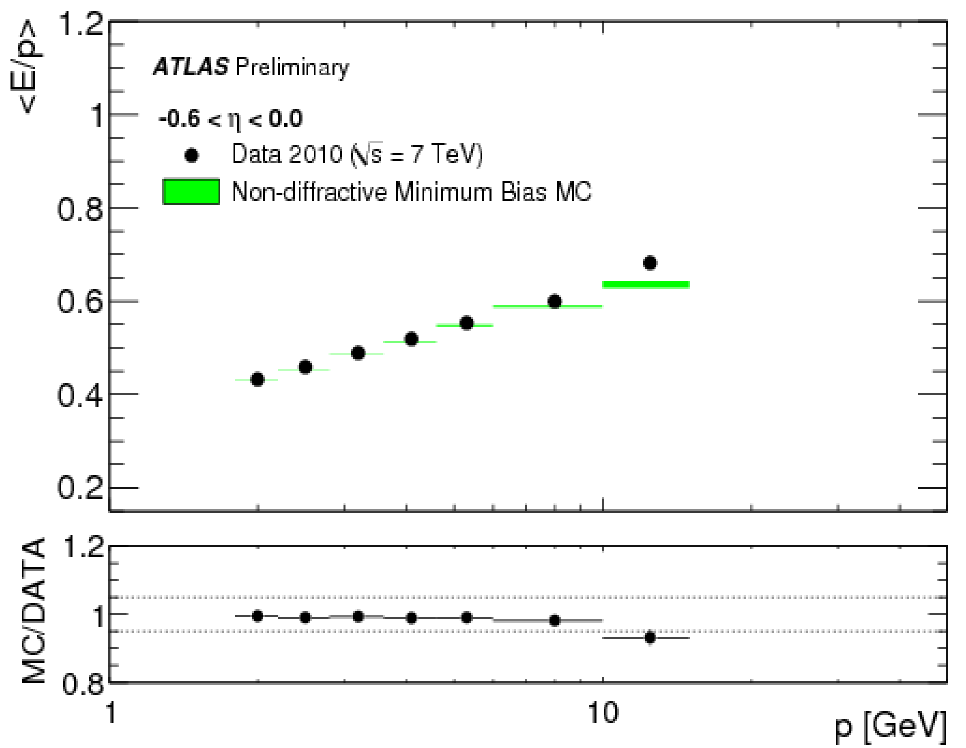
Checks on Collisions data:

- Select isolated tracks;
- Collect the energy in the calorimeter around the track;
- Compare to MC.

<E/P> measured in

- $|\eta| < 2.3$
- 500 MeV < p < 10 GeV



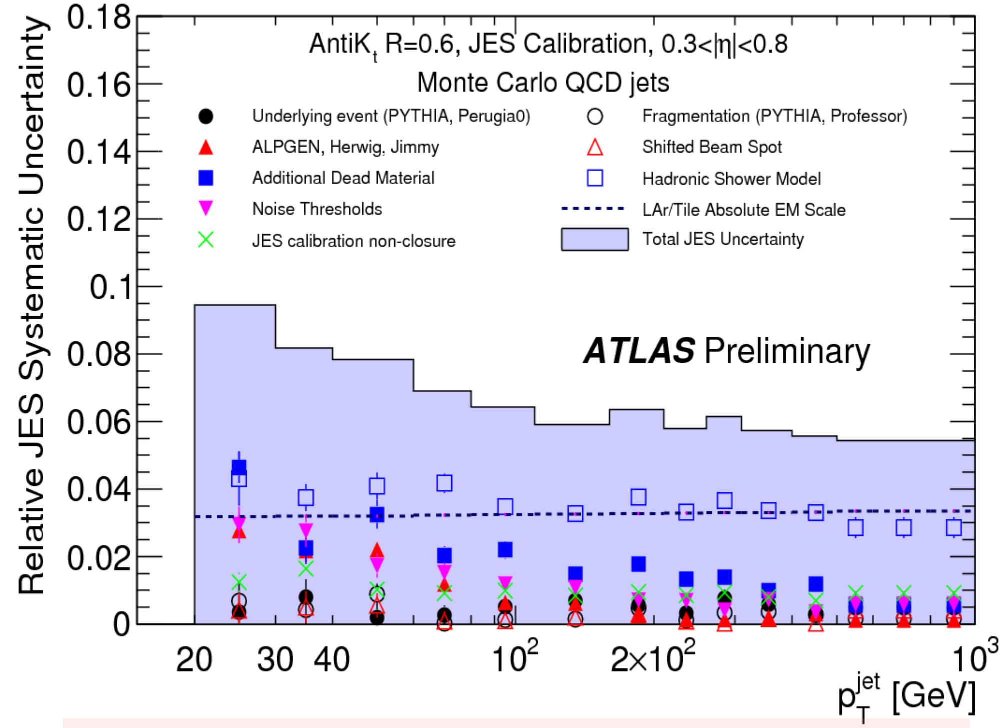


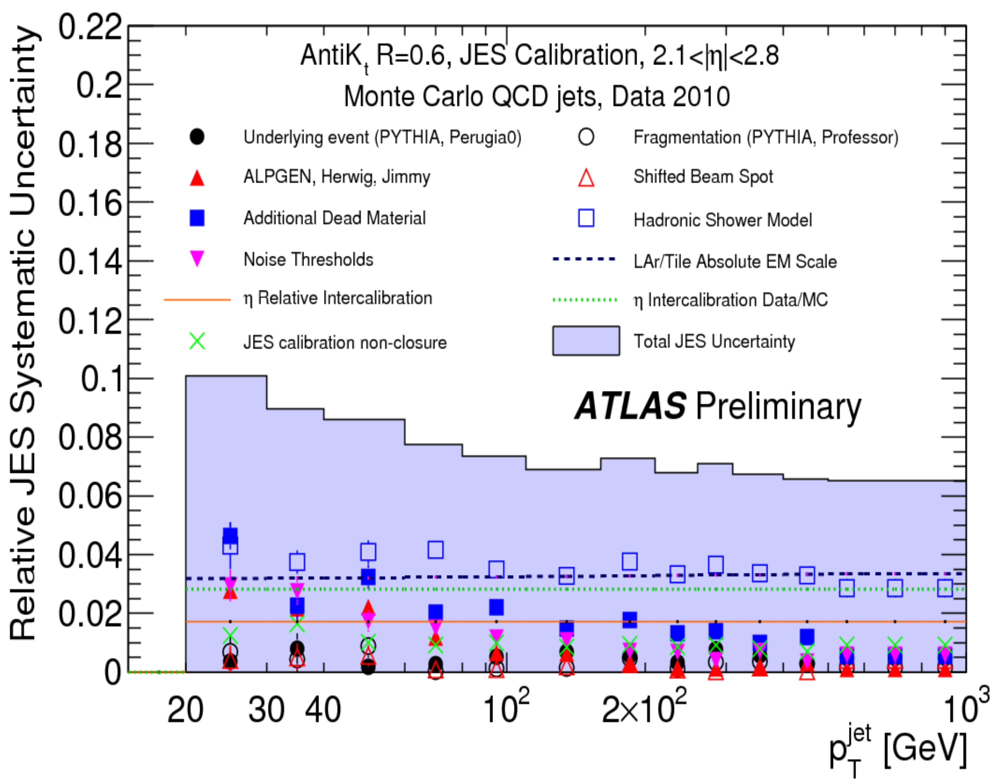
The calorimeter response to isolated hadrons shows agreement between Data and MC at the 5% level for most of the calorimeter.

Jet Energy Scale Uncertainty

Stability of the MC response.

Variations driven by test beam and collision data





Dominant:

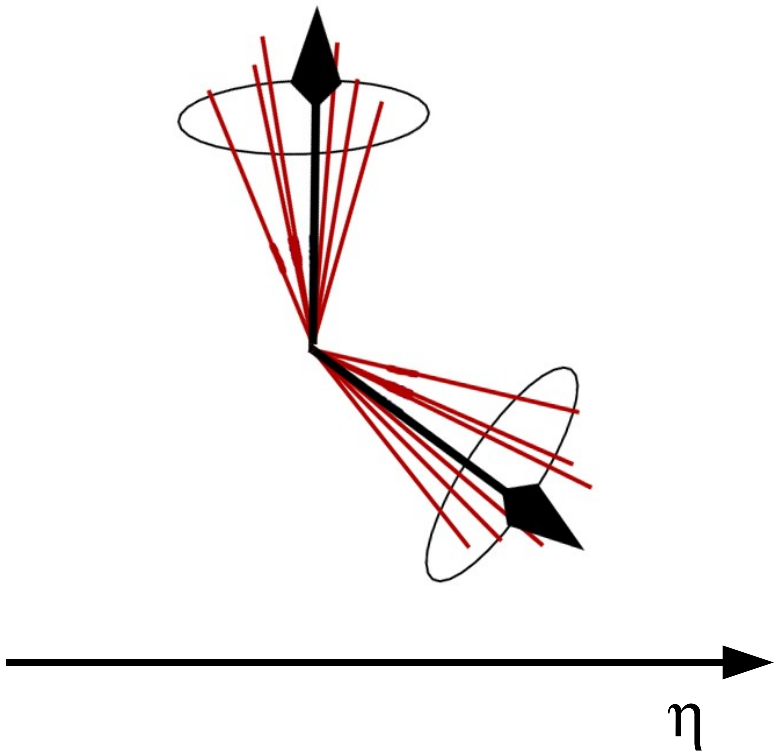
Hadronic showers model
Tile/LAr EM Scale
Noise description
Dead Material
η intercalibration

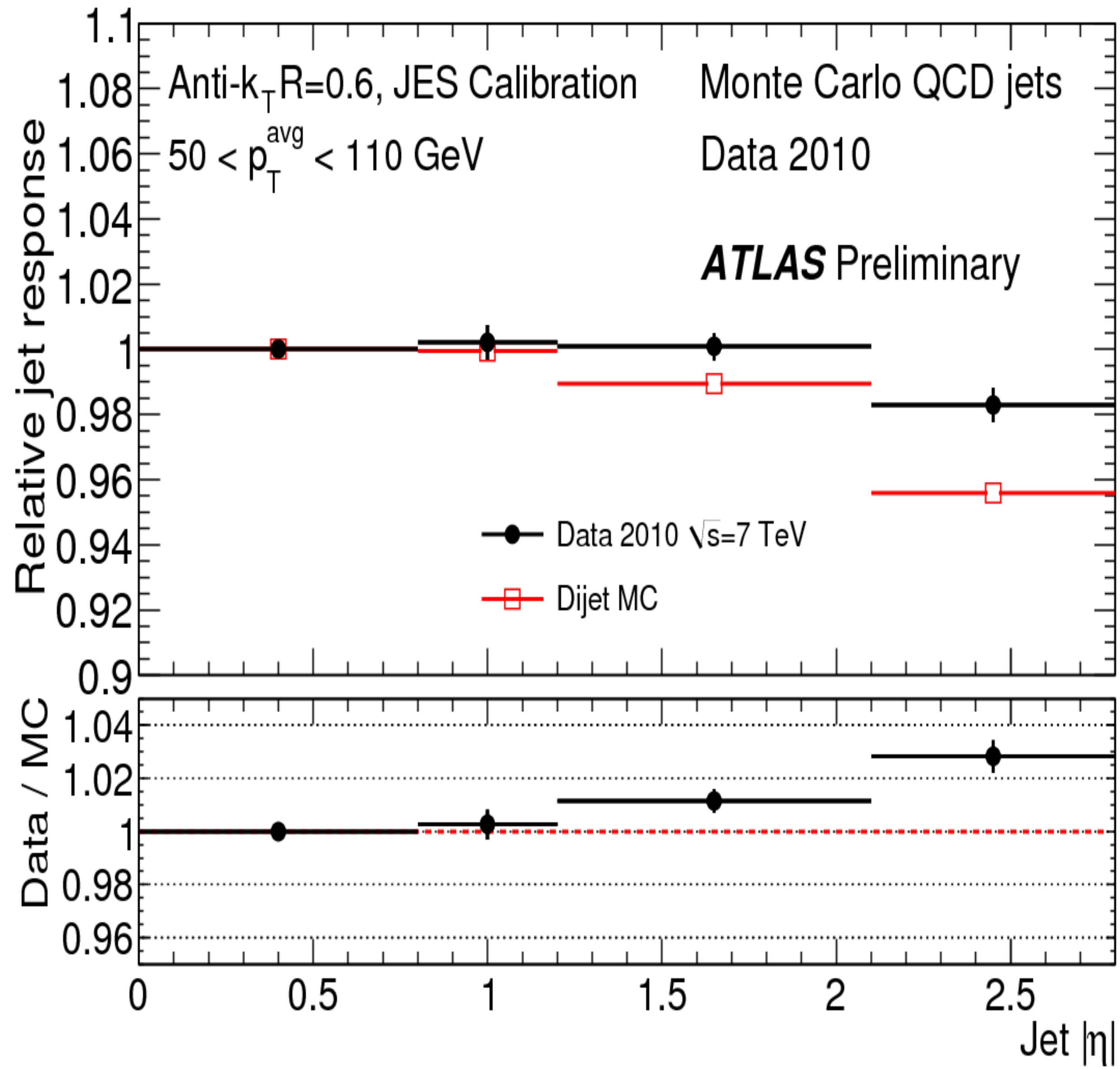
Smaller:

Hadronization
Underlying Event
Parton Shower
Pileup

Jet Calibration VS. η

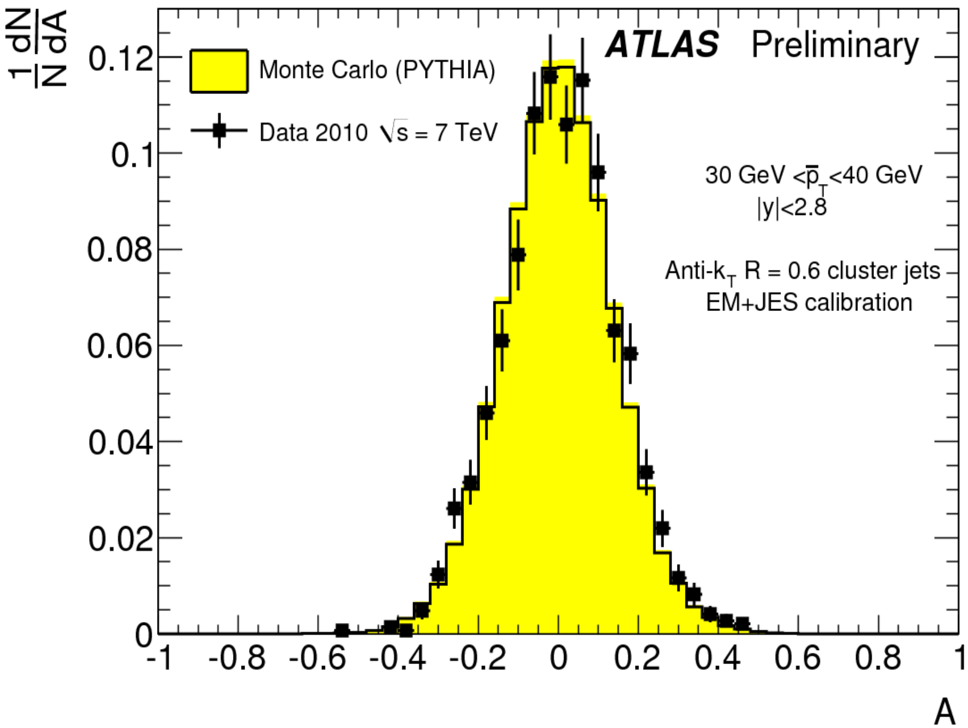
Reference region





Small (~2%) deviation at high pseudorapidity

Jet Resolution



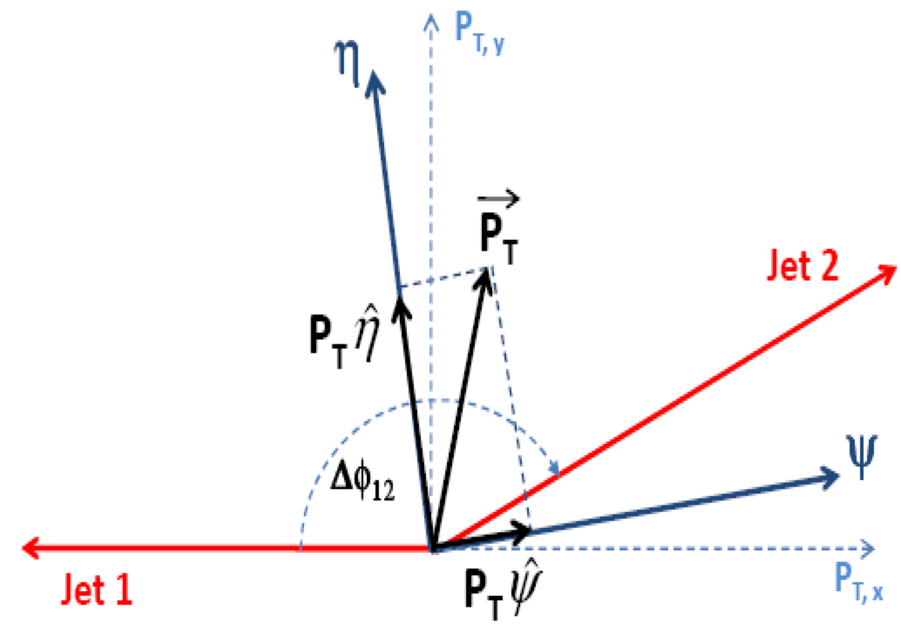
Di-jet Events

$\Delta\varphi$>2.8 and p_T[3rd jet]<10 GeV

A=(p_T[1]-p_T[2]) / <p_T>

$\sigma(p_T)/p_T=\sqrt{2}\,\sigma_A$

Estimate of the unbalance due to soft radiation.



Particle Level: $\sigma_\psi \sim \sigma_\eta \neq 0$ Radiation

Detector Level:

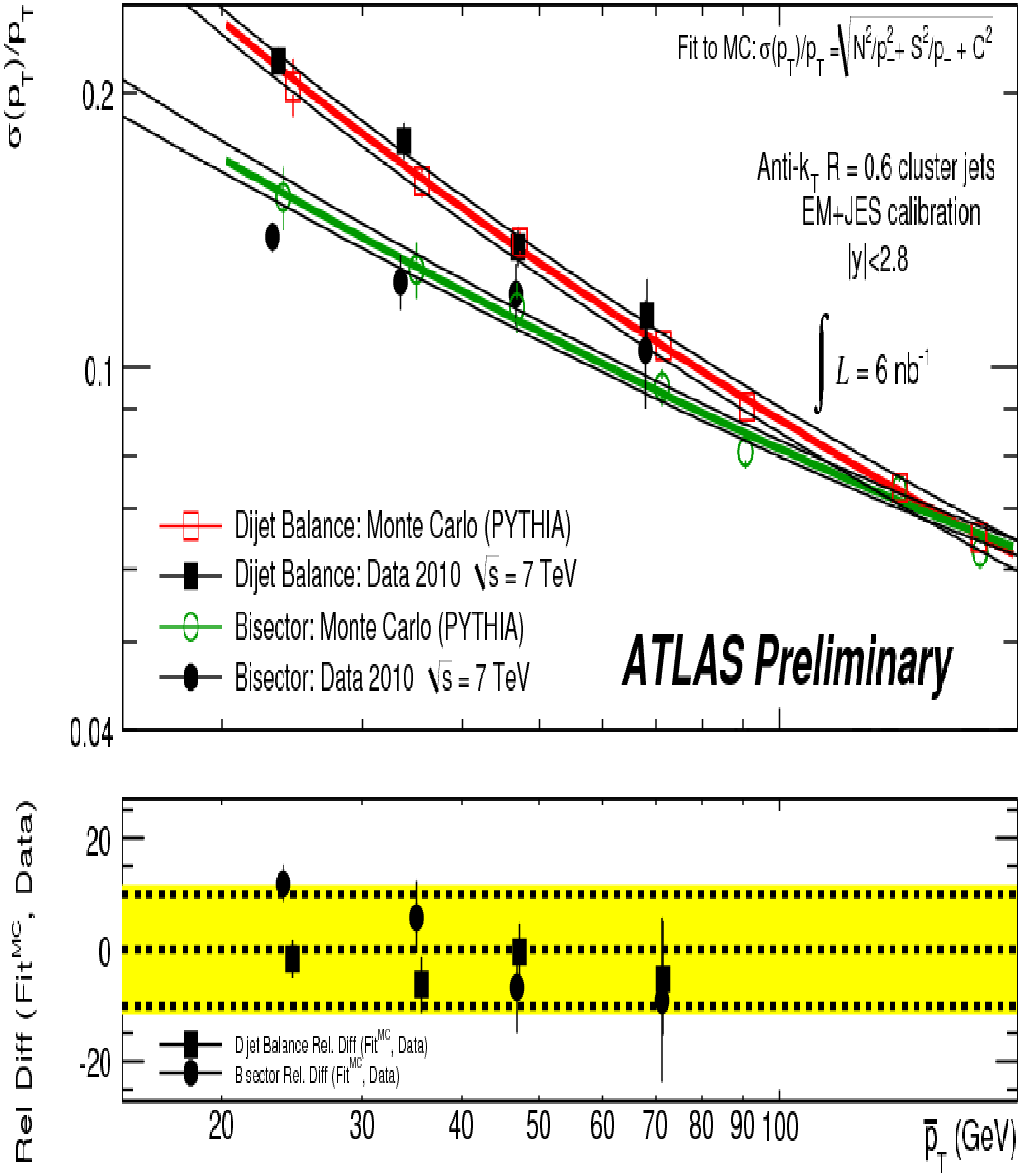
$$\sigma(p_T)/p_T = \frac{\sqrt{(\sigma_\psi^2-\sigma_\eta^2)}}{\sqrt{2}<p_T>|\cos(\Delta\varphi_{12})|}$$

Jet Resolution

Main goal of the methods: Check if the simulation does agree with data.

Differences in the methods due to unbalances (even at particle level)
Data and Simulation found to be in agreement.

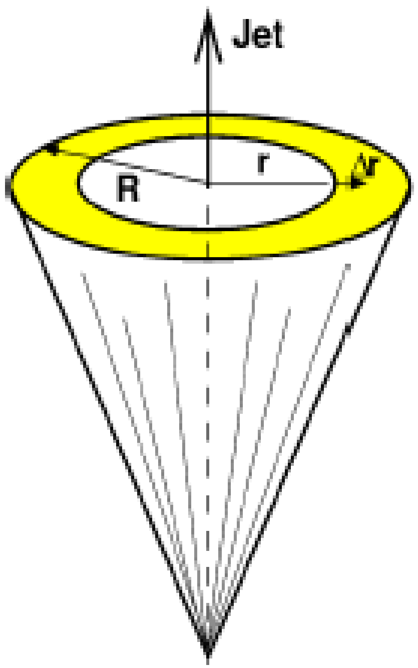
The Monte Carlo simulation describes the jet energy resolution measured from data within 14 % for jets with p_T>20 GeV and |y| < 2.8.

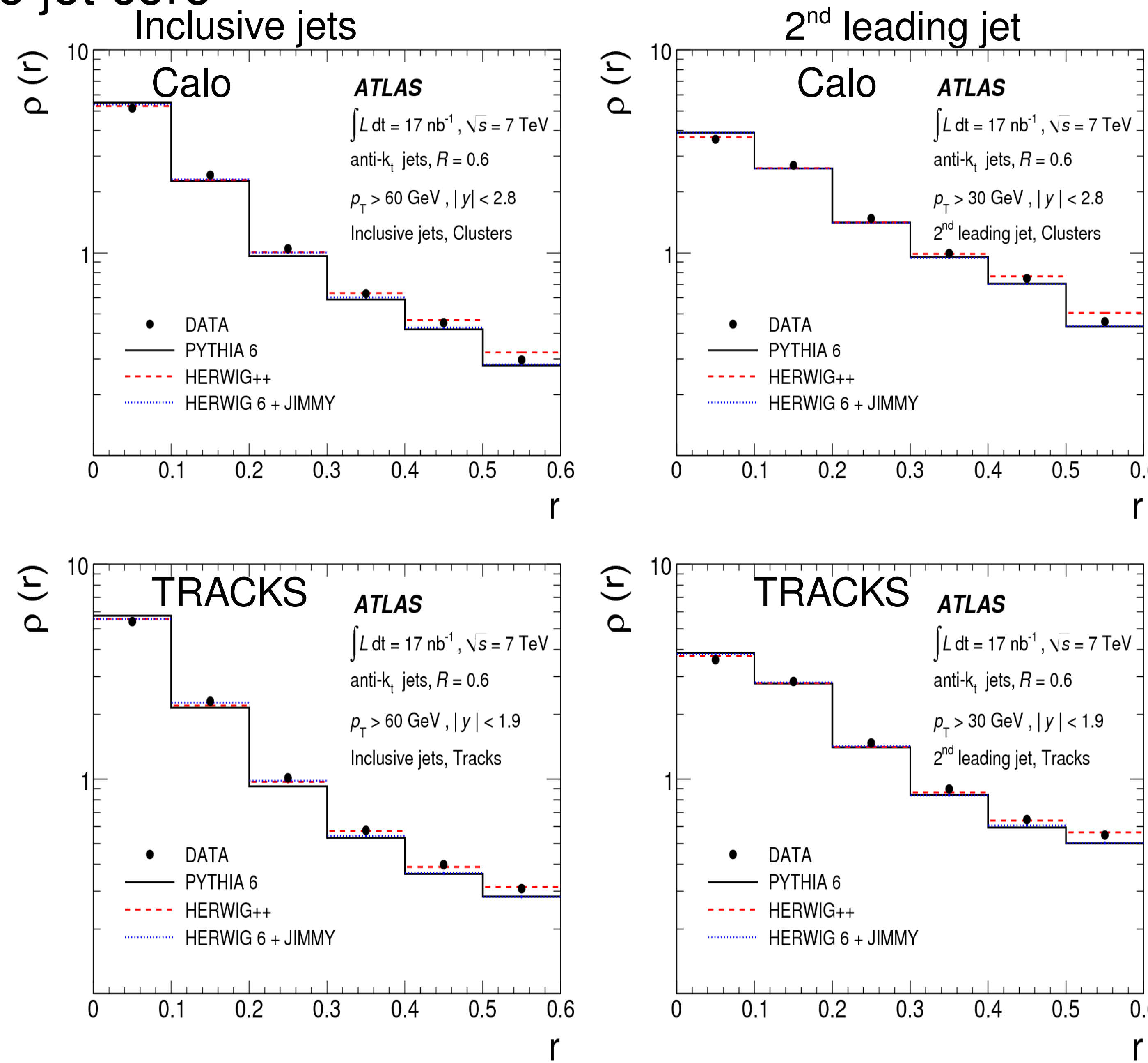


From the constituents to the topologies

Jet Shapes

Energy flow around the jet core

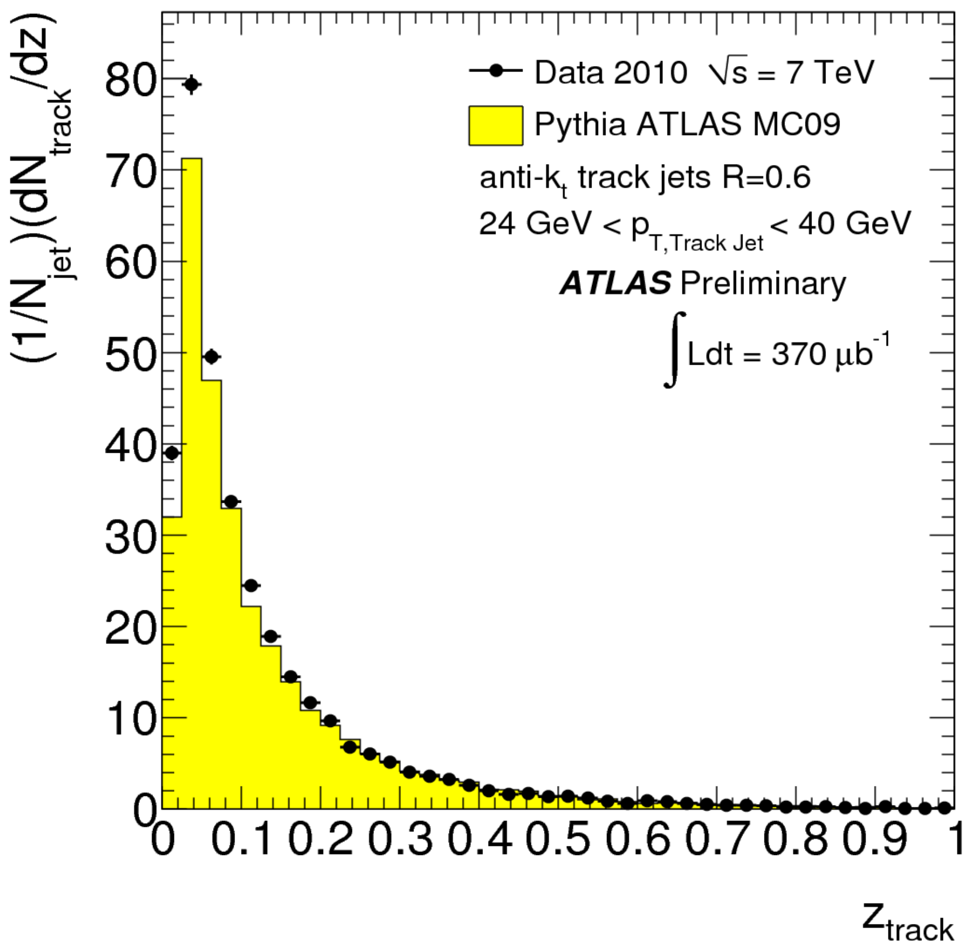


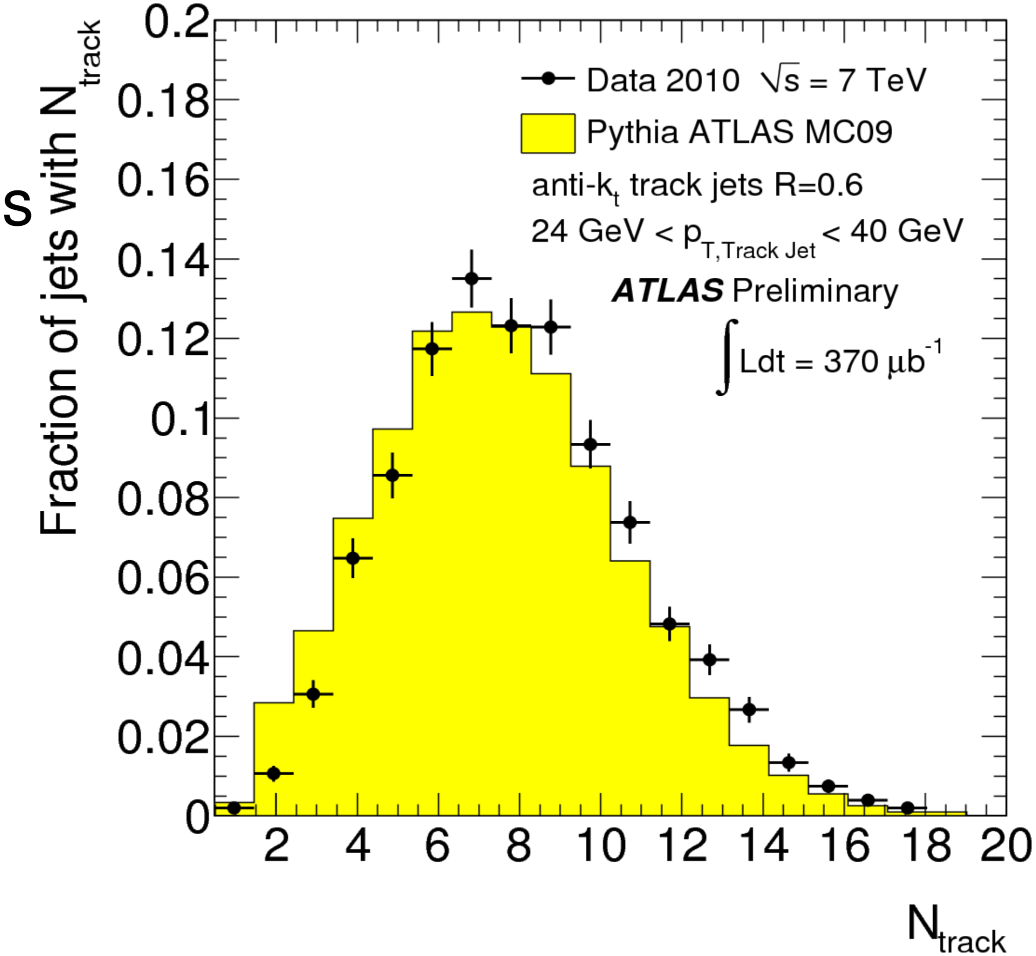


The distribution of energy within the jets is reasonably well simulated.

Tracks in jets: Fragmentation

The tracks are a useful input to the jet clustering to study the jet fragmentation in charged particles and to improve the fragmentation models used in the MC simulations

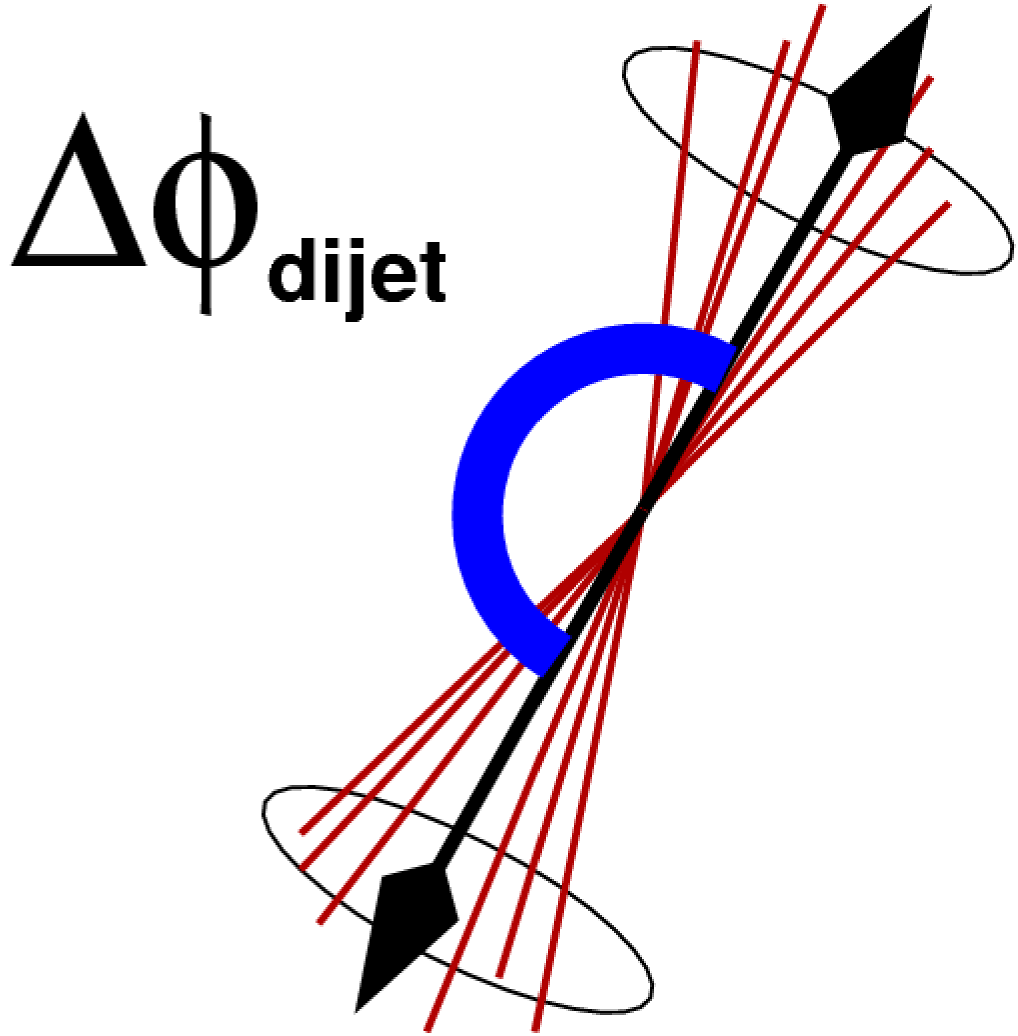




$Z_{track} = p_T^{track} / p_T^{Jet}$

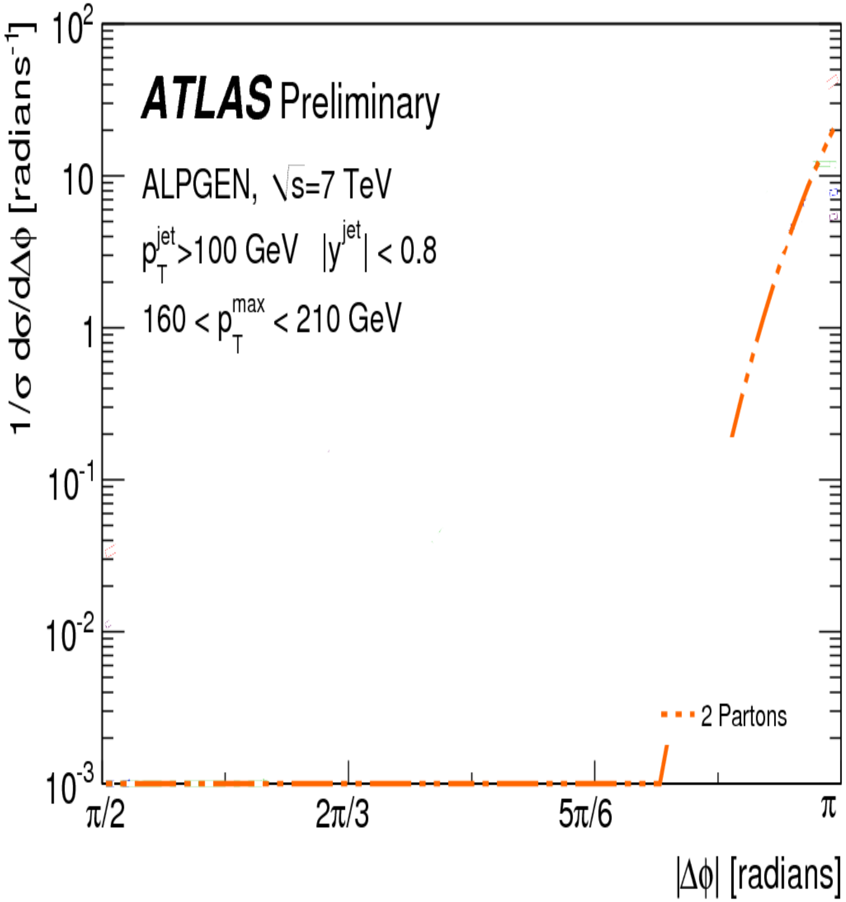
is the relative p_T contribution to the jet.

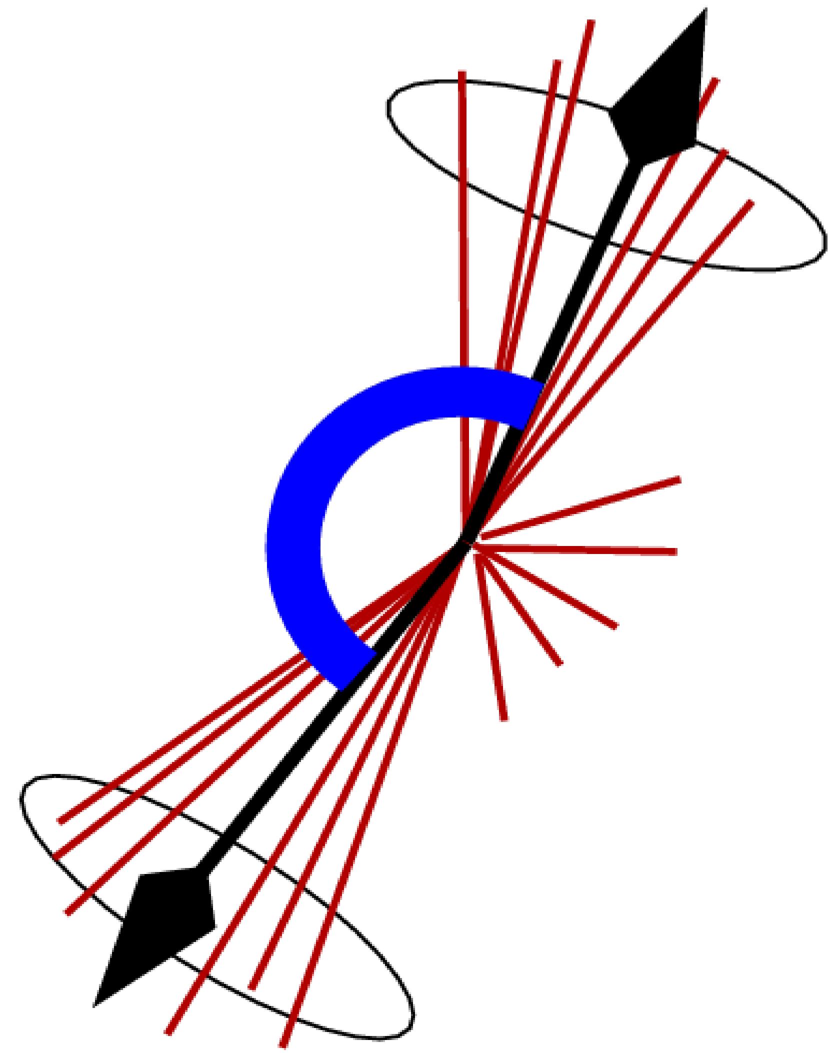
Azimuthal decorrelation



Dijet production at leading order (LO) results in two jets with equal p_T and correlated azimuthal angles **$\Delta\varphi=\pi$.**

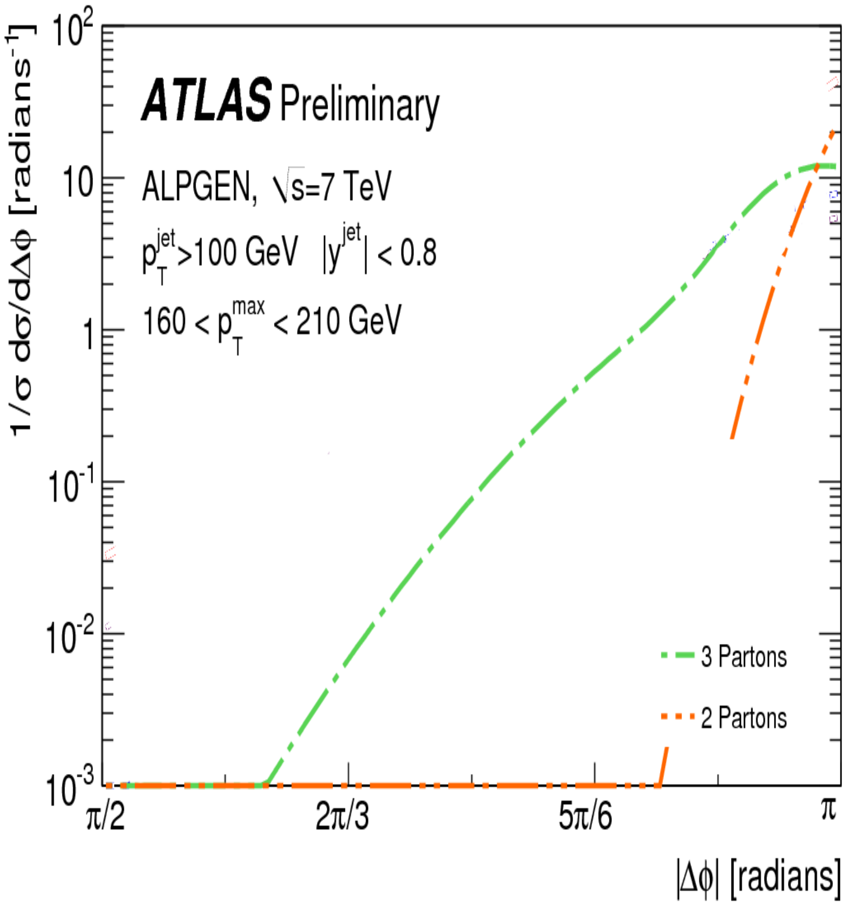
Azimuthal decorrelation

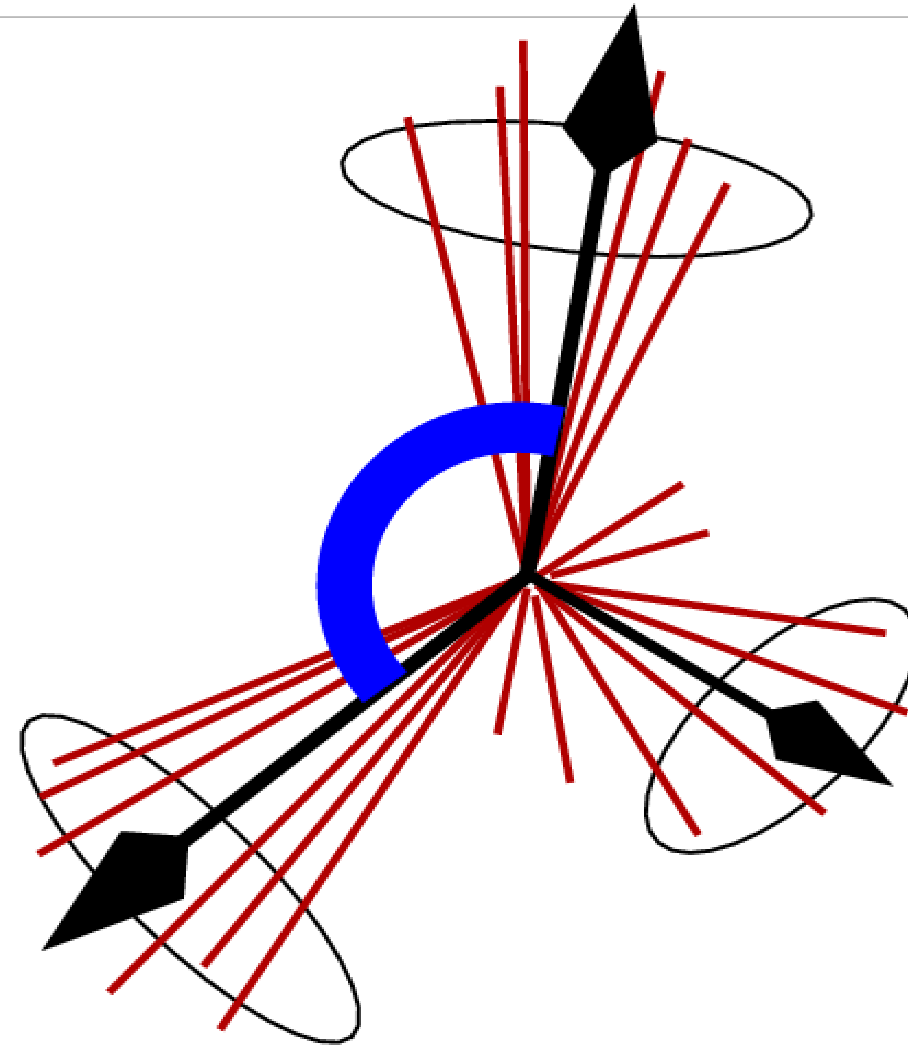




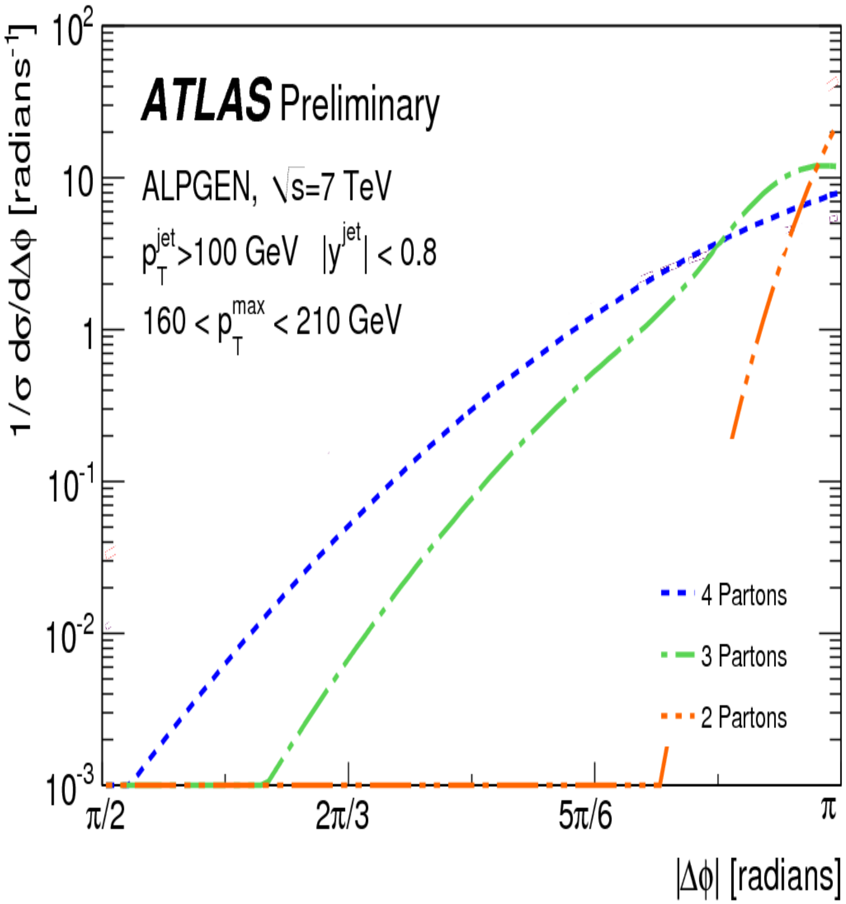
Soft radiation in dijet events starts to produce a decorrelation in $\Delta\varphi$.

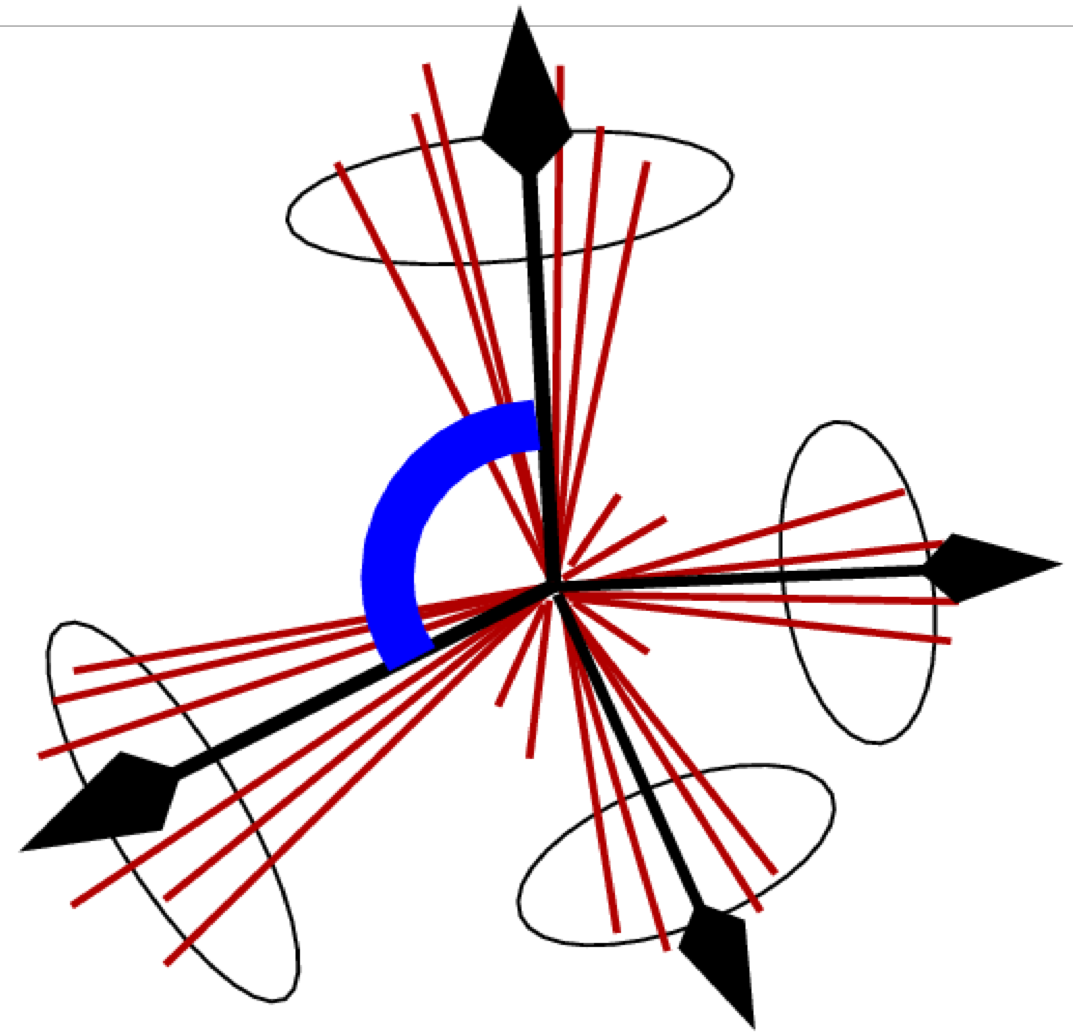
Azimuthal decorrelation



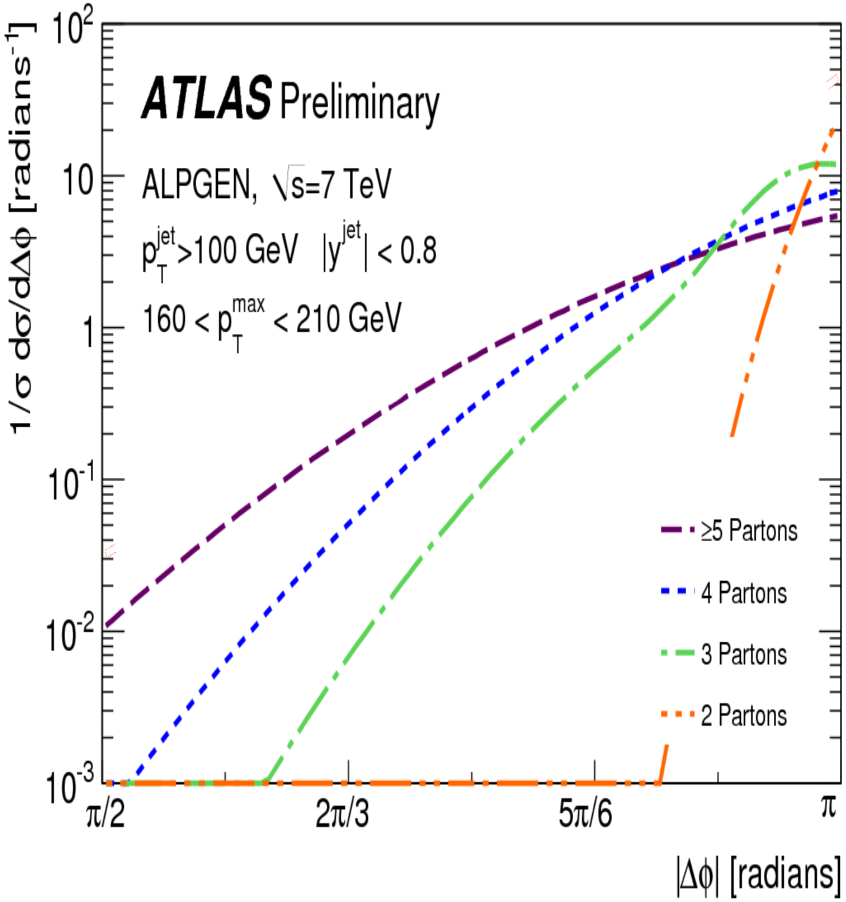


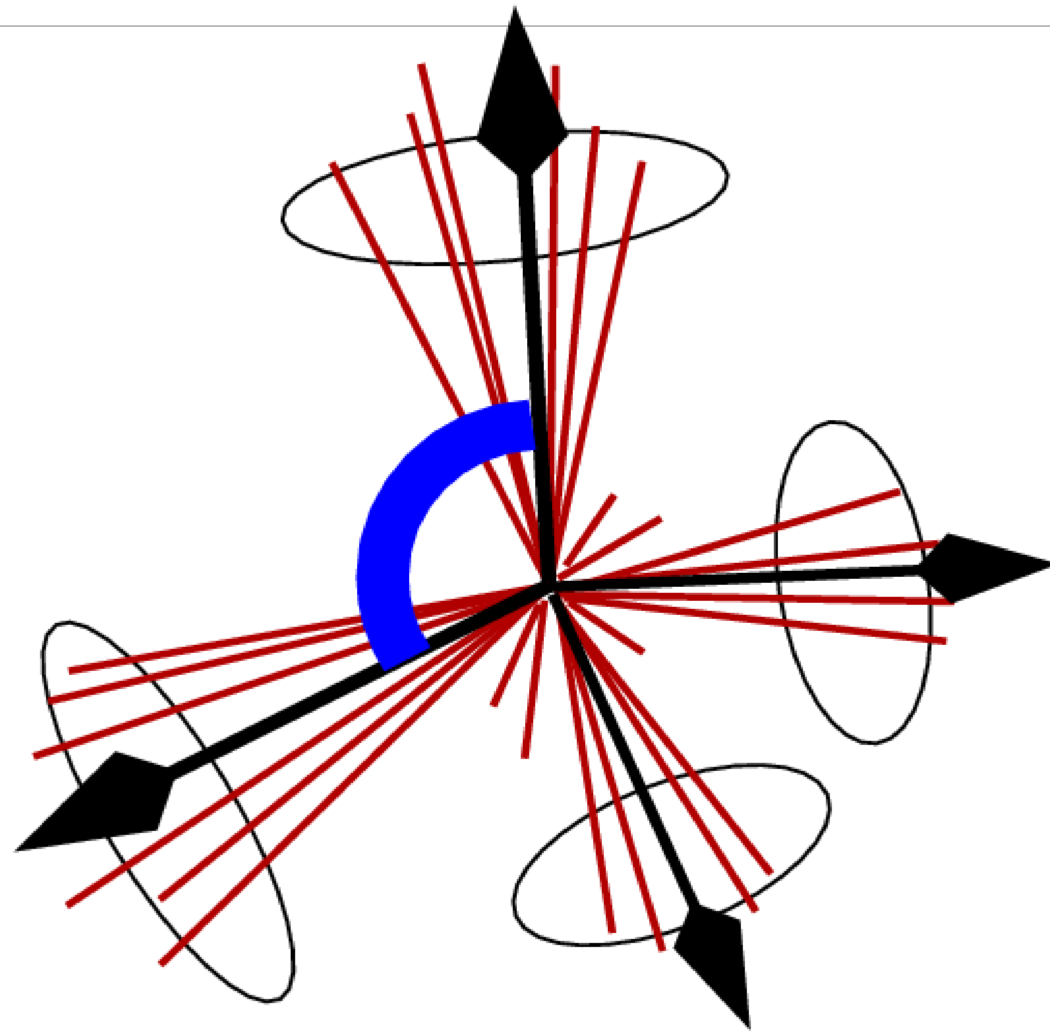
Azimuthal decorrelation



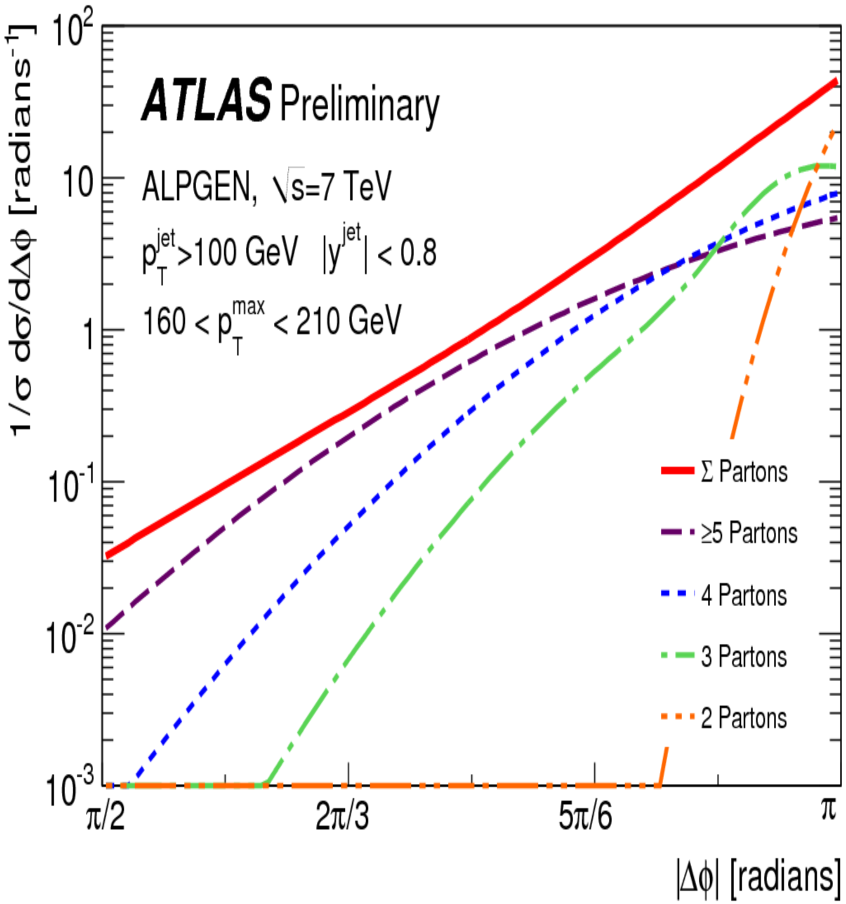


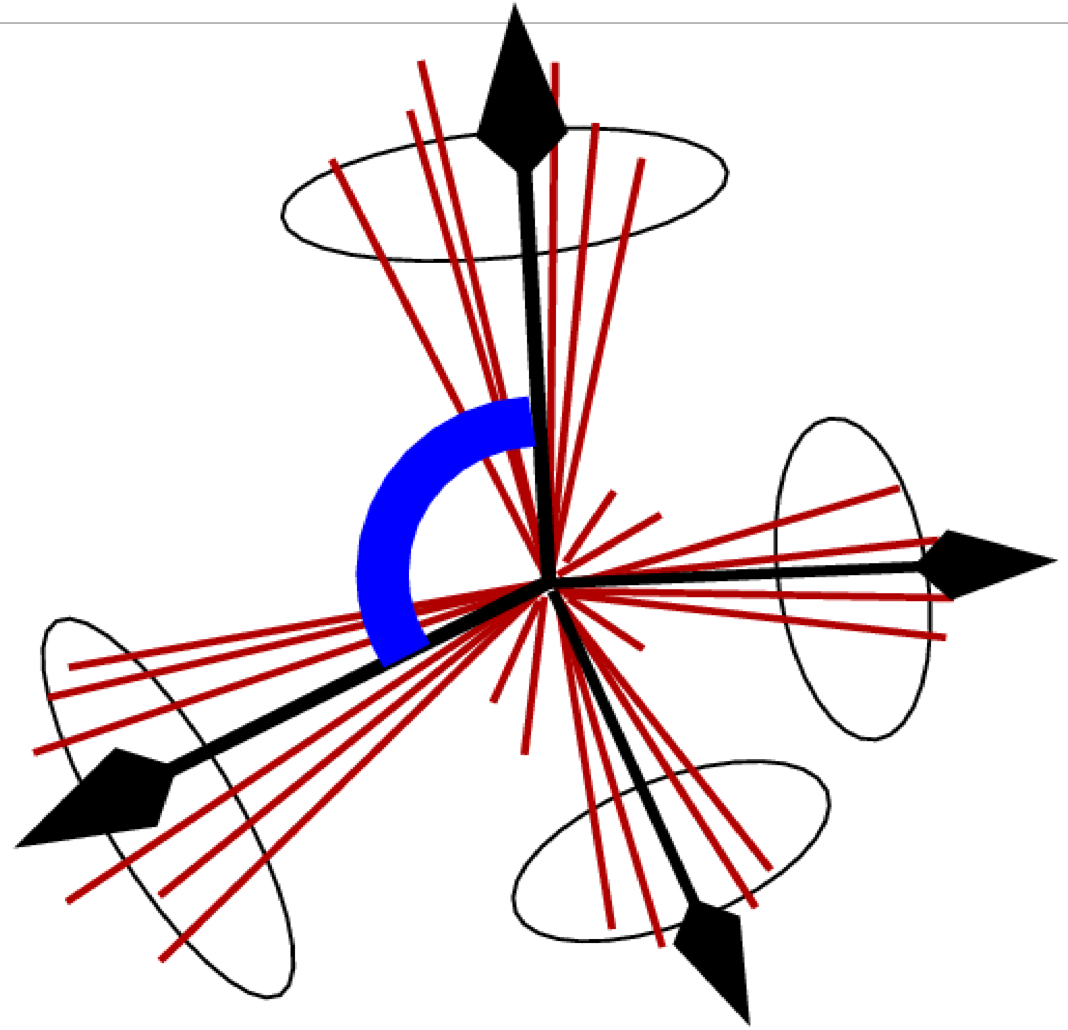
Azimuthal decorrelation





Azimuthal decorrelation

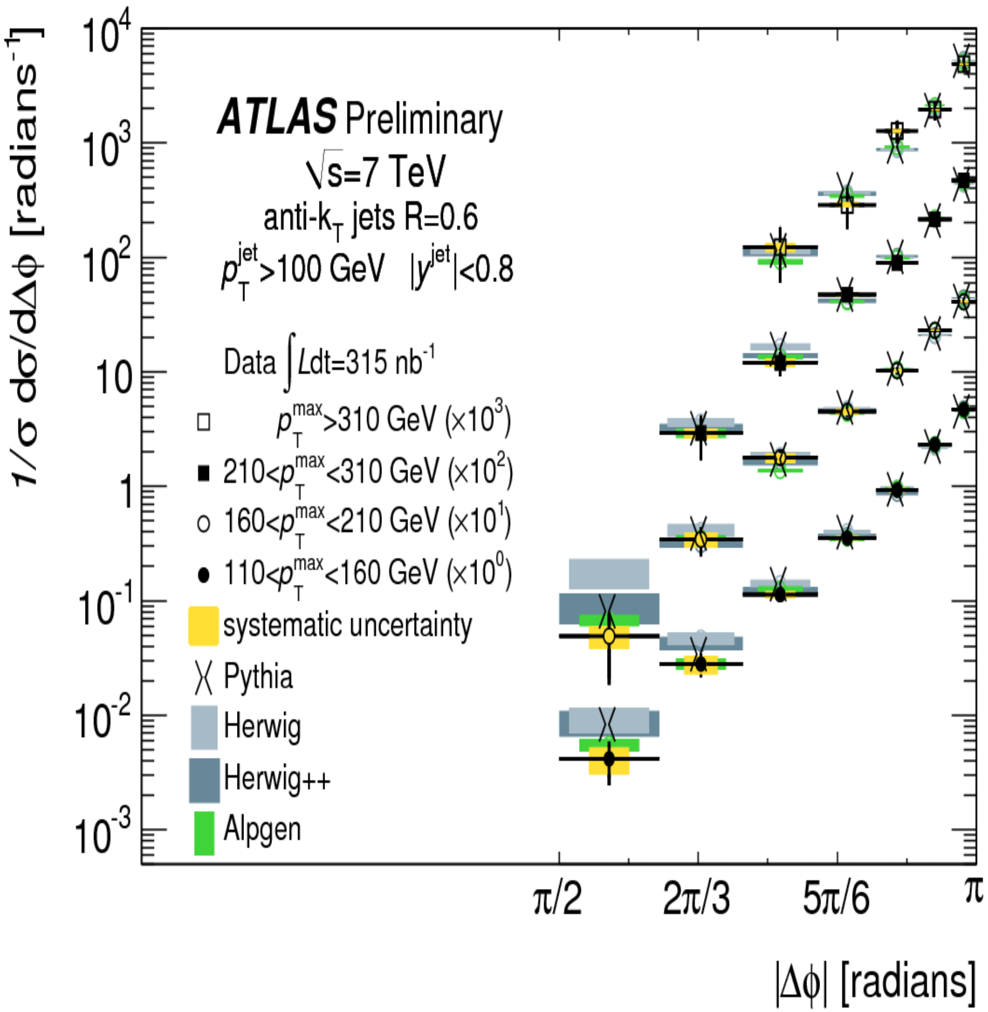


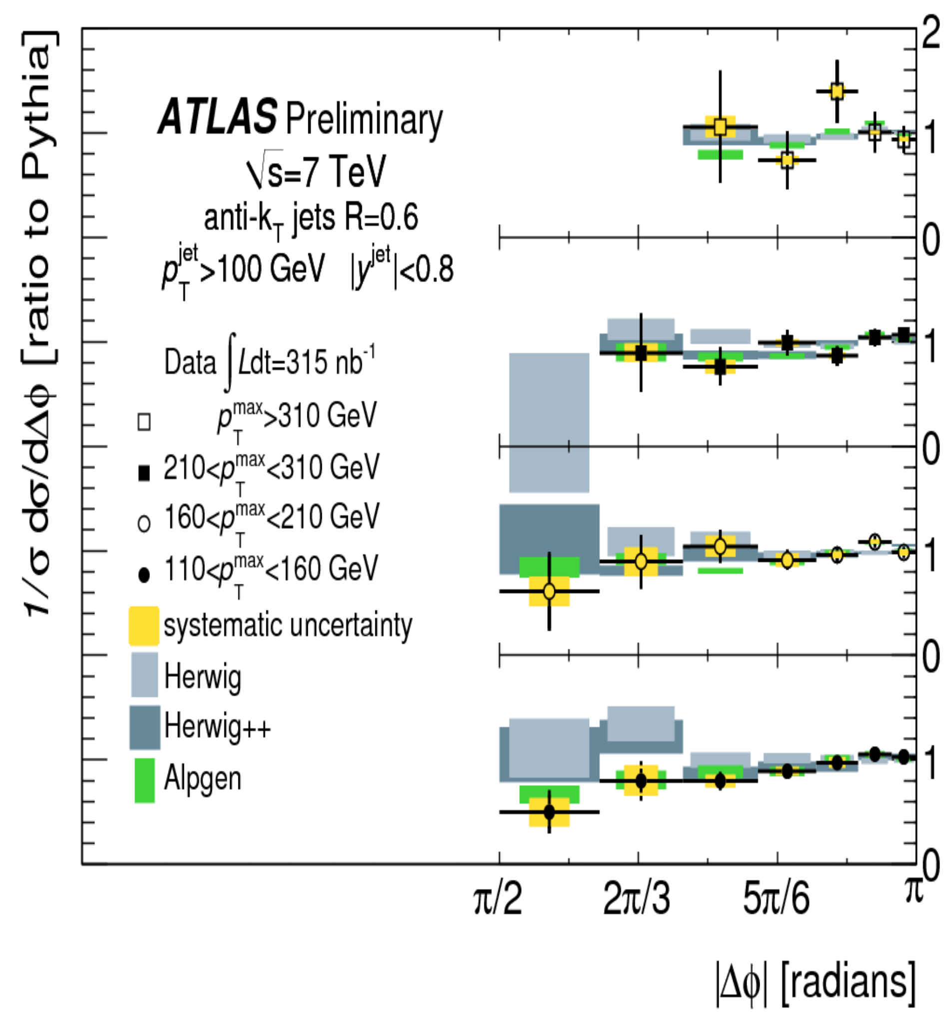


The azimuthal decorrelation Δφ is a test higher-order perturbative QCD (pQCD) calculations without requiring the reconstruction of additional jets and a way to examine the transition between soft and hard QCD processes with a single observable.

Azimuthal decorrelation

Alpgen shows the best agreement with data.
(Emission of extra patrons driven by the matrix element calculation)





Similar agreement for the NLO calculation (NLOJET++)

Cross Sections

Cross Section:
Inclusive Single Jet

Measurements of inclusive cross-sections are important verifications of perturbative QCD and probes of new physics (e.g. quark compositeness, etc.).

Cross Sections:
Inclusive single-jet double-differ. cross-sections as a function of p_T and y

$$d^2\sigma/dP_{T,jet}\, d|y|$$

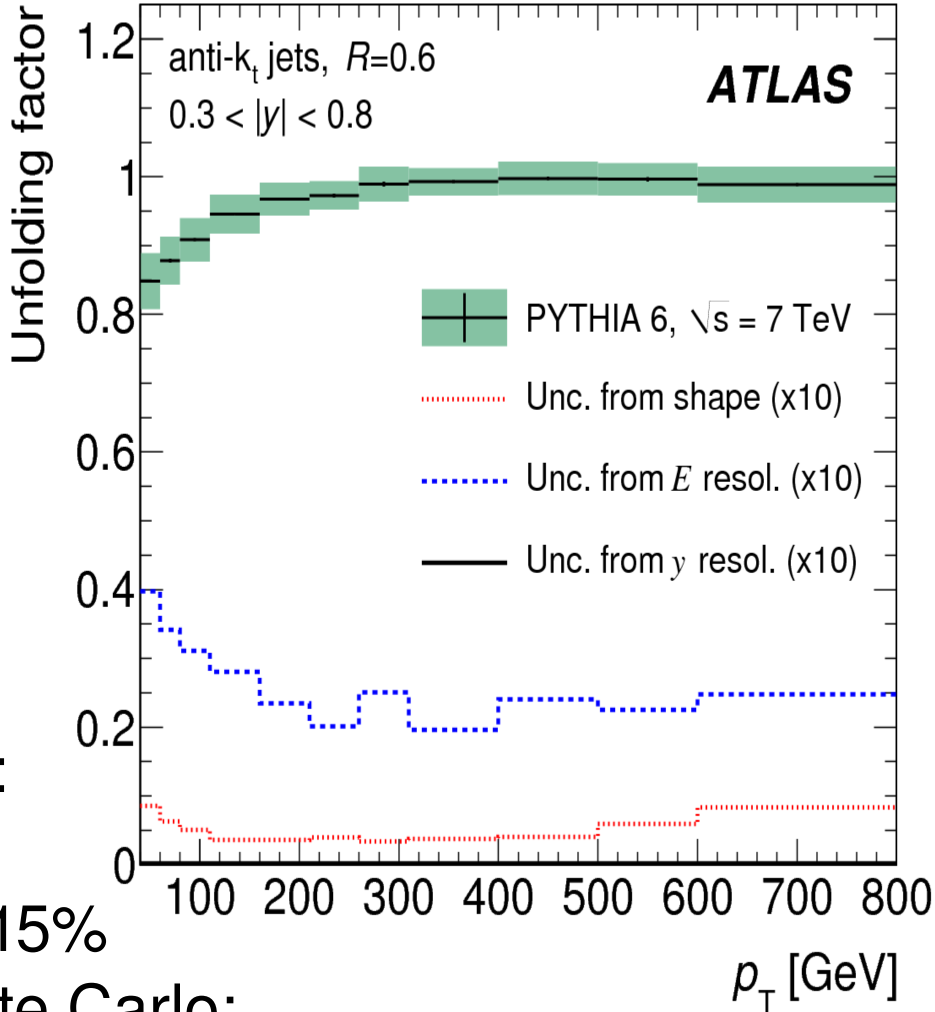
Transverse momentum: **$p_T > 60$ GeV** **Rapidity: $|y| < 2.8$**

Jet Algorithm: Anti-K_T jets with R=0.4 and R=0.6

Integrated Luminosity: 17 nb^{-1}

The cross section is corrected by the detector effects

Cross Section: Inclusive Single Jet



Bin-by-bin detector unfolding is used to correct for all detector effects.

Main contributions:

- Jet energy resolution fluctuations
- Detector efficiencies
- Jet Cleaning cuts

Pythia MC09 to derive correction factors:

Systematic uncertainties derived by:

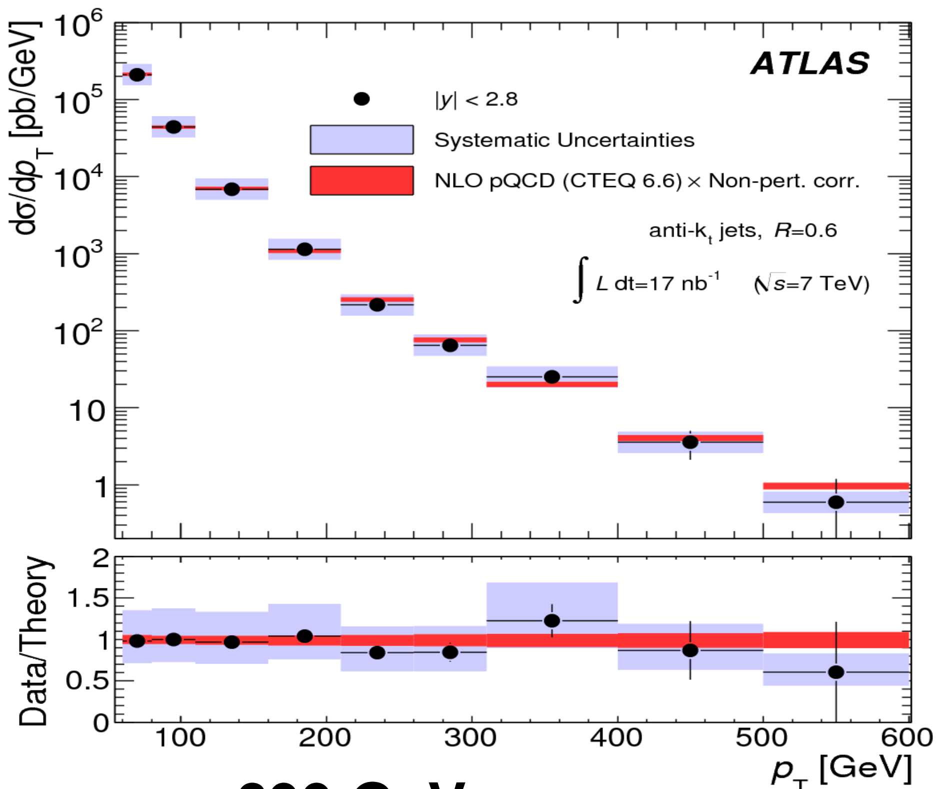
- Worsening the jet energy resolution by 15%
- Altering the cross-section shape in Monte Carlo:

< 3% over the full p_T range

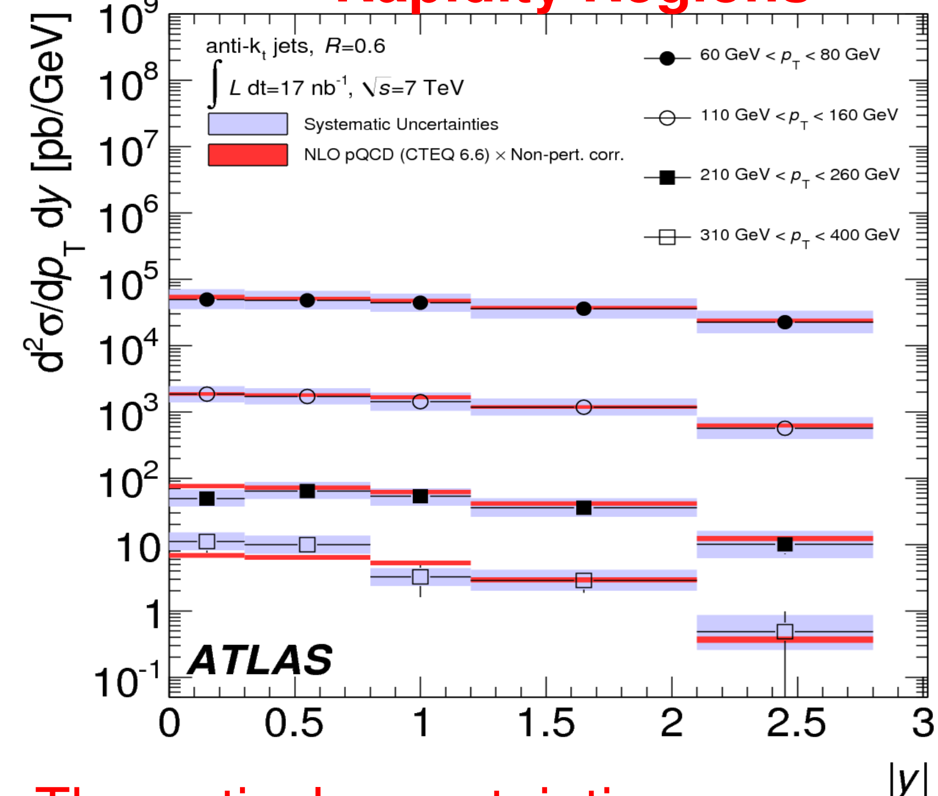
This is motivated by the demonstrated good modeling of trigger efficiencies, p_T spectrum shape, and energy flow around jet core in the Monte Carlo

Cross Section: Inclusive Single Jet

R=0.6



Rapidity Regions



$P_{T,jet}$ max~ 600 GeV

Data and theory are consistent

Uncertainty in data larger than in theory.

Dominated by jet energy scale.

Theoretical uncertainties:

Renormalization scale

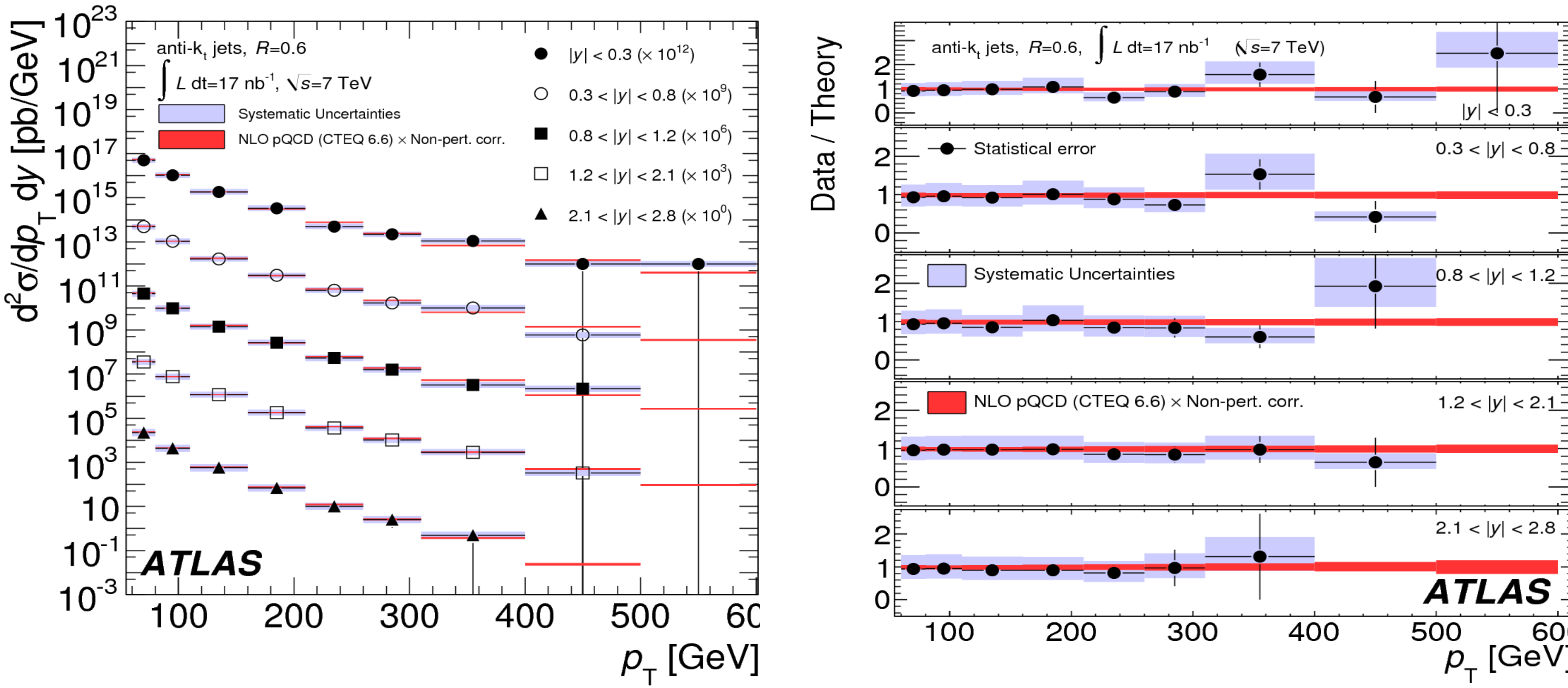
Factorization scale

PDF α_s

Fragmentation and Underlying event

Cross Section: Inclusive Single Jet

R=0.6



The p_T spectrum in data and theory are consistent in all rapidity regions

Cross Section: Di-Jets

Cross Sections:

Di-jet cross-sections as a function of di-jet mass and angle.

$$d^2\sigma/dM_{1,2}\, d|y|_{max}$$

$M_{1,2}$ is invariant mass of first two leading jets with $P_{T,1} > 60$ GeV and $P_{T,2} > 30$ GeV

$|y|_{max} = \max(|y|_1, |y|_2)$ with y_1 and y_2 rapidity of two leading jets

$$d^2\sigma/dM_{1,2}\, d\chi$$

$\chi = \exp(|y1-y2|) \sim (1+\cos\theta^*)/(1-\cos\theta^*)$

(Restricted to $y^* = 0.5\,|y_1-y_2| < 0.5\log(30)$ and $y_{boost} = 0.5\,|y_1+y_2| < 1.1$)

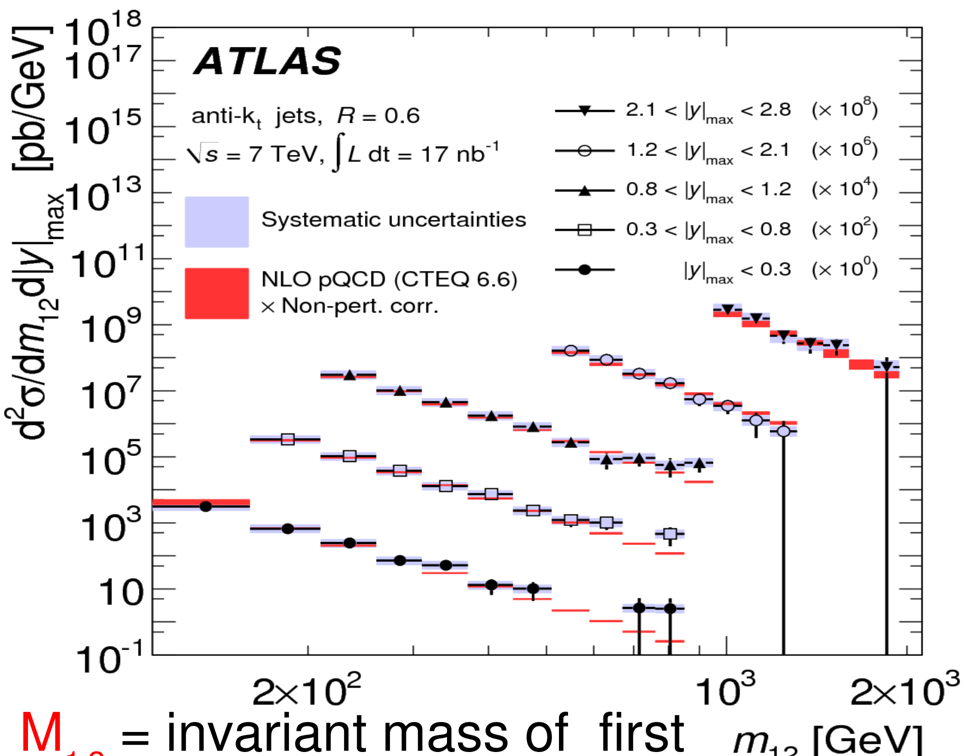
Jet Algorithm: Anti-K_T jets with R=0.4 and R=0.6

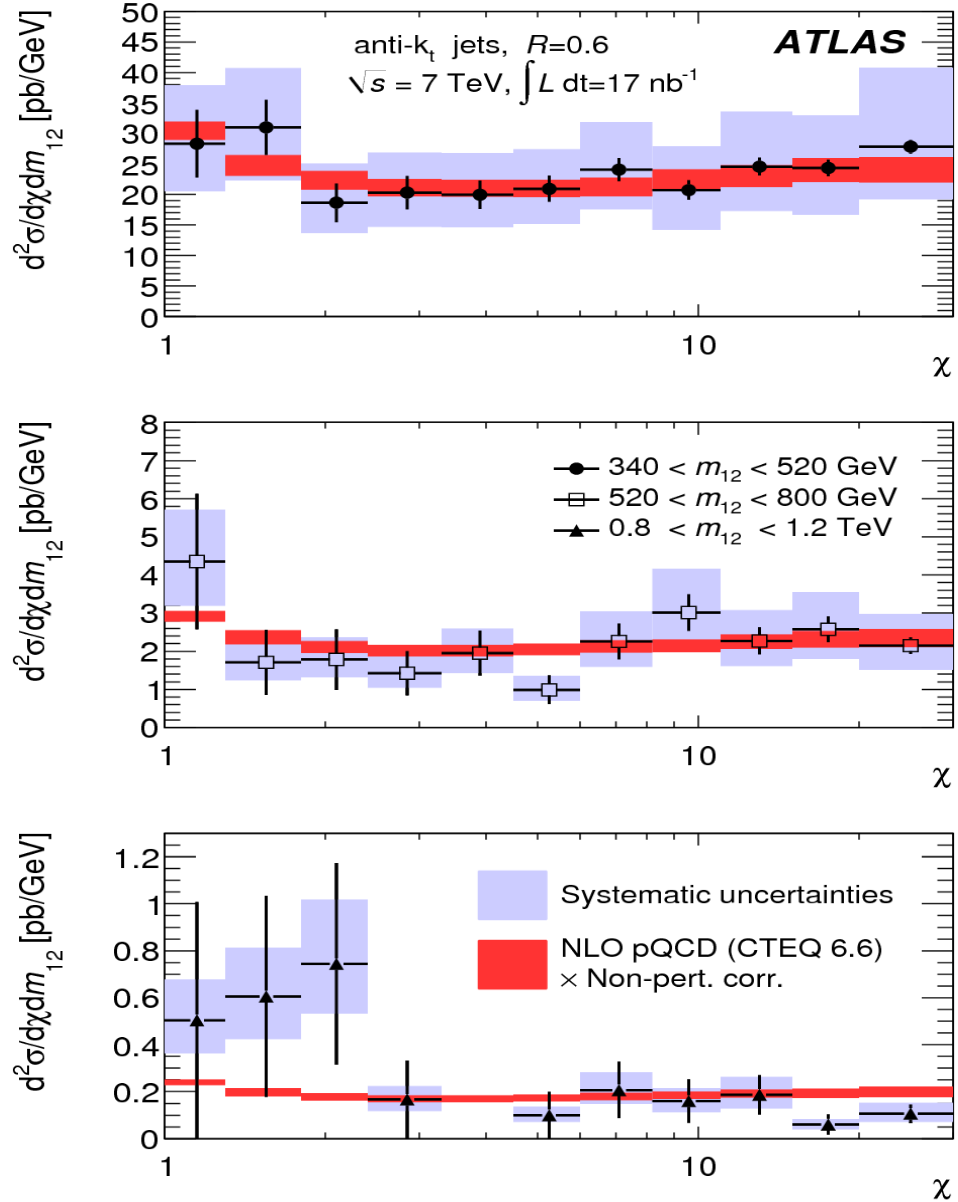
Integrated Luminosity: 17 nb^{-1}

The cross section is corrected by the detector effects

Cross Section: Di-Jets

R=0.6





$M_{1,2}$ = invariant mass of first two leading jets with $P_{T,1} > 60$ GeV and $P_{T,2} > 30$ GeV

$|y|_{max} = \max(|y|_1, |y|_2)$

χ = $\exp(|y1-y2|)$

$\sim (1+\cos\theta^*)/(1-\cos\theta^*)$, where θ^* angle in cm system

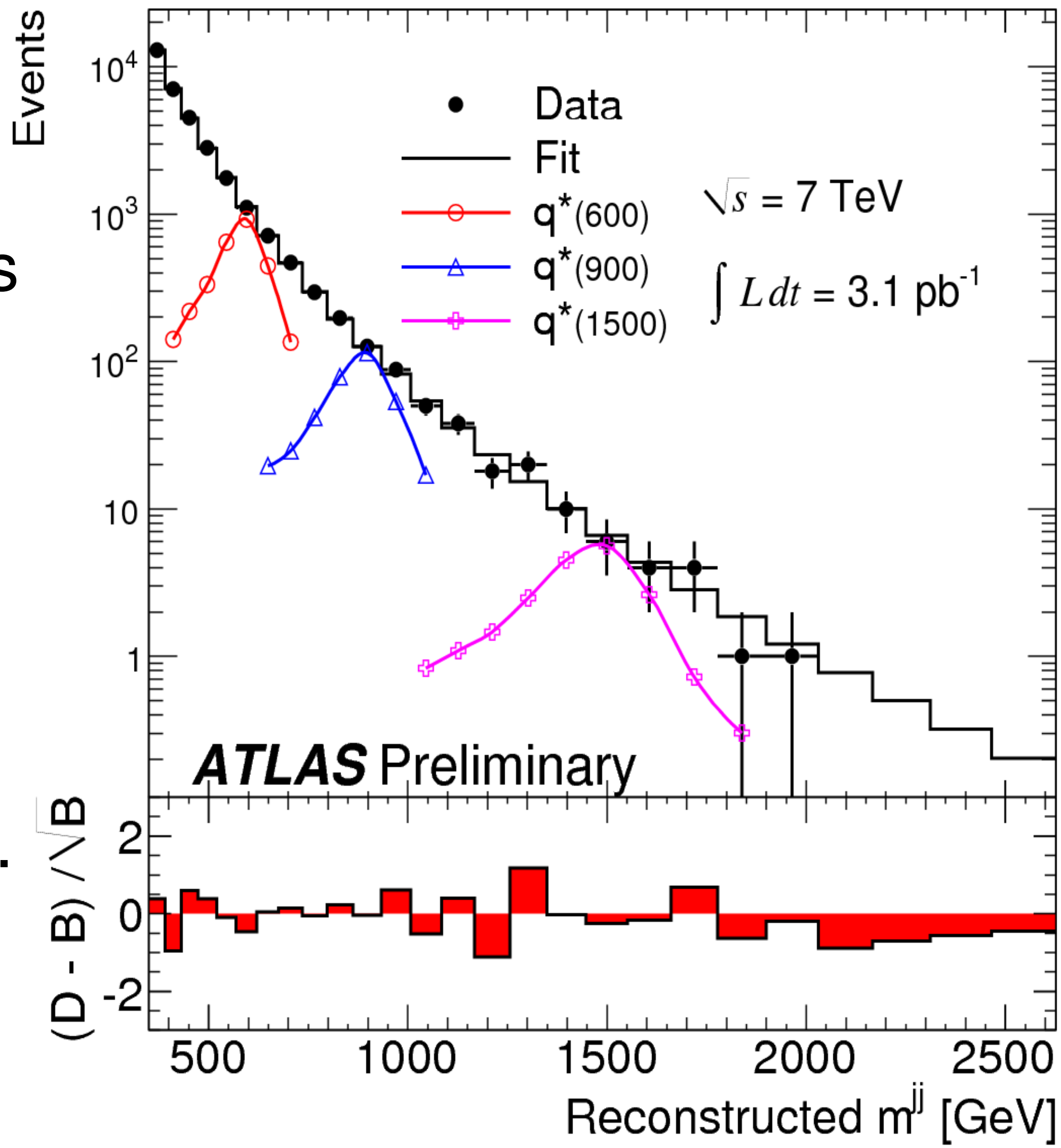
Di-jet masses up to ~ 2 TeV !

Exclusions: Di-jet Mass

By using the di-jet measurements,
a first limit on new physics can be studied.

Search for bumps in the di-jet spectrum.

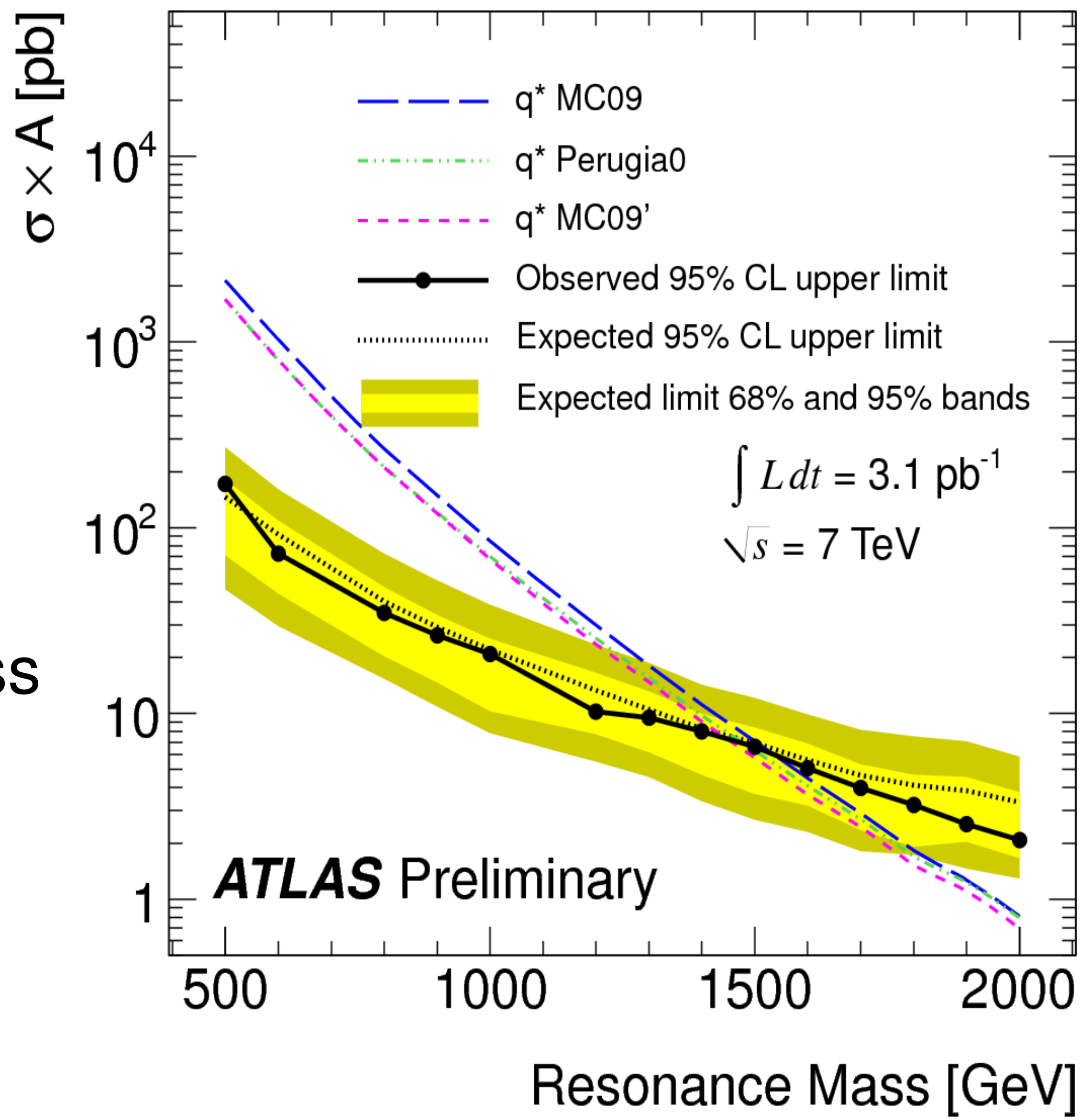
The fluctuation are not statistically significant.



Exclusions: Di-jet Mass

Assuming a narrow di-jet spinorial resonance, the di-jet mass measurement can be used to exclude a certain cross section for the production of a resonance at a certain mass

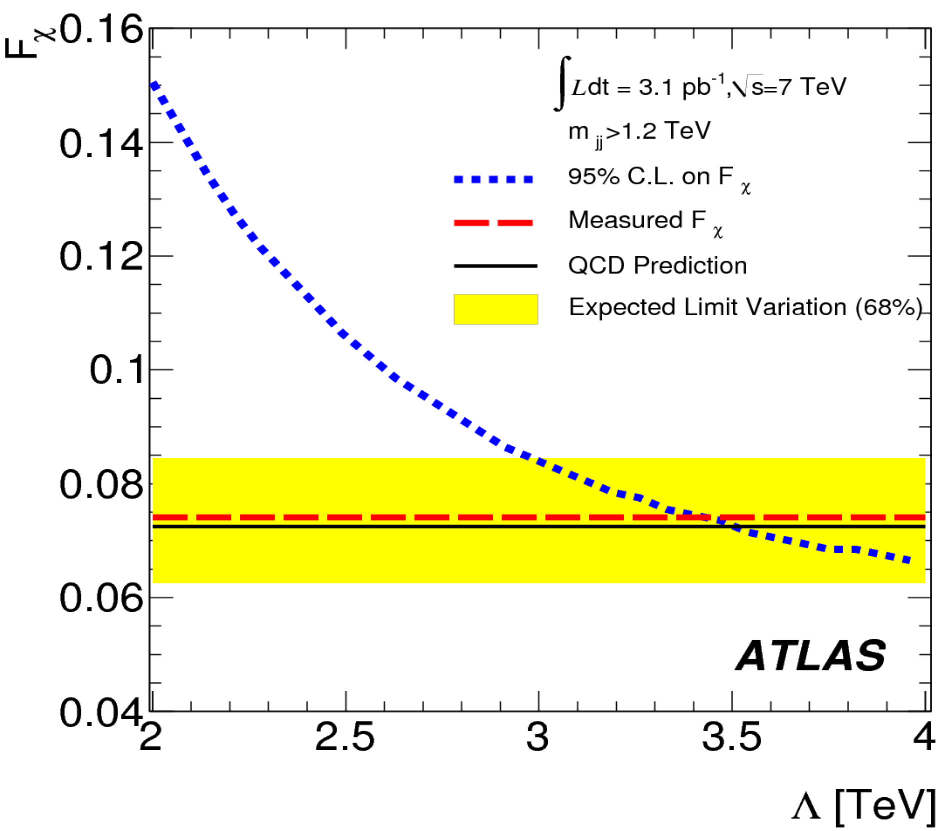
This result can be used to exclude regions in the plane masses/couplings for effective theories.

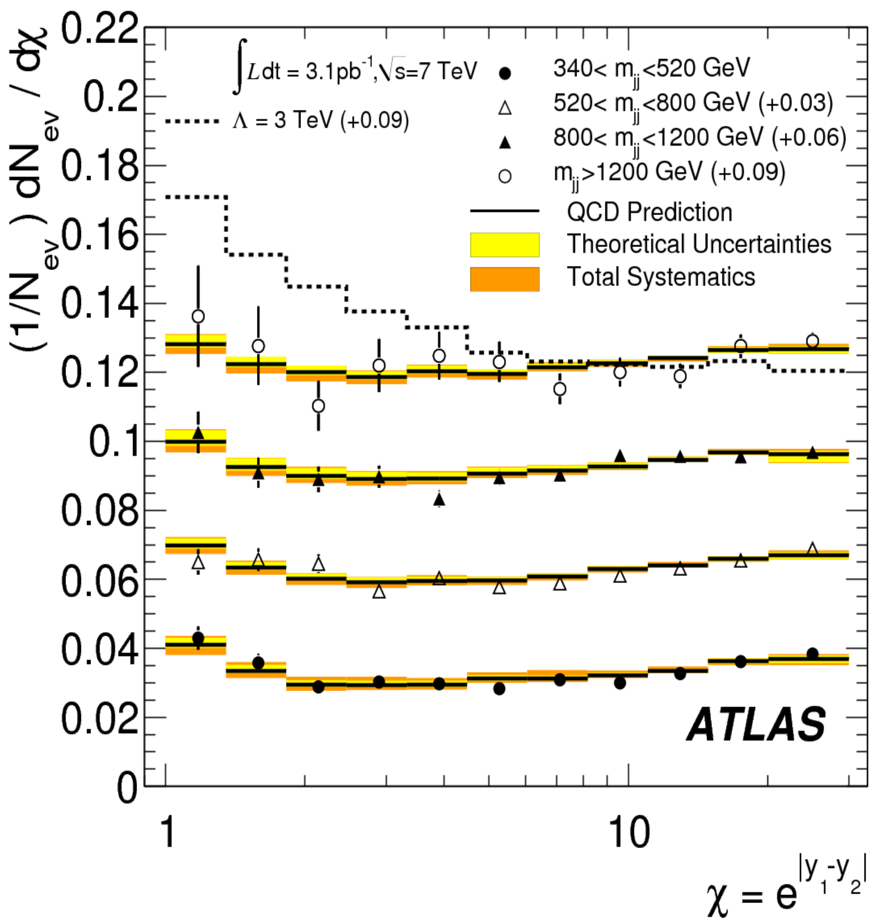


Exclusions: Di-jet Angles

Even the angular distribution for jets have an important role to constrain models of new physics:

i.e. contact interaction





Λ <3.4 TeV excluded (95% CL.)

Tevatron: 2.8 TeV (0.7 fb^{-1})

Cross Section: Multi-Jets

A first step toward the measurement of complex QCD final states

- Important as a measurement in itself
  (i.e. to extract the strong coupling constant)
- Fundamental to start the controls for the QCD background for
  searches.

Cross Sections:

Multi-Jet cross section:

- Multi Jet rates
- p_T spectrum for the 1st, 2nd, 3rd, 4th jet (ordered in p_T)
- H_T distribution for different multiplicity

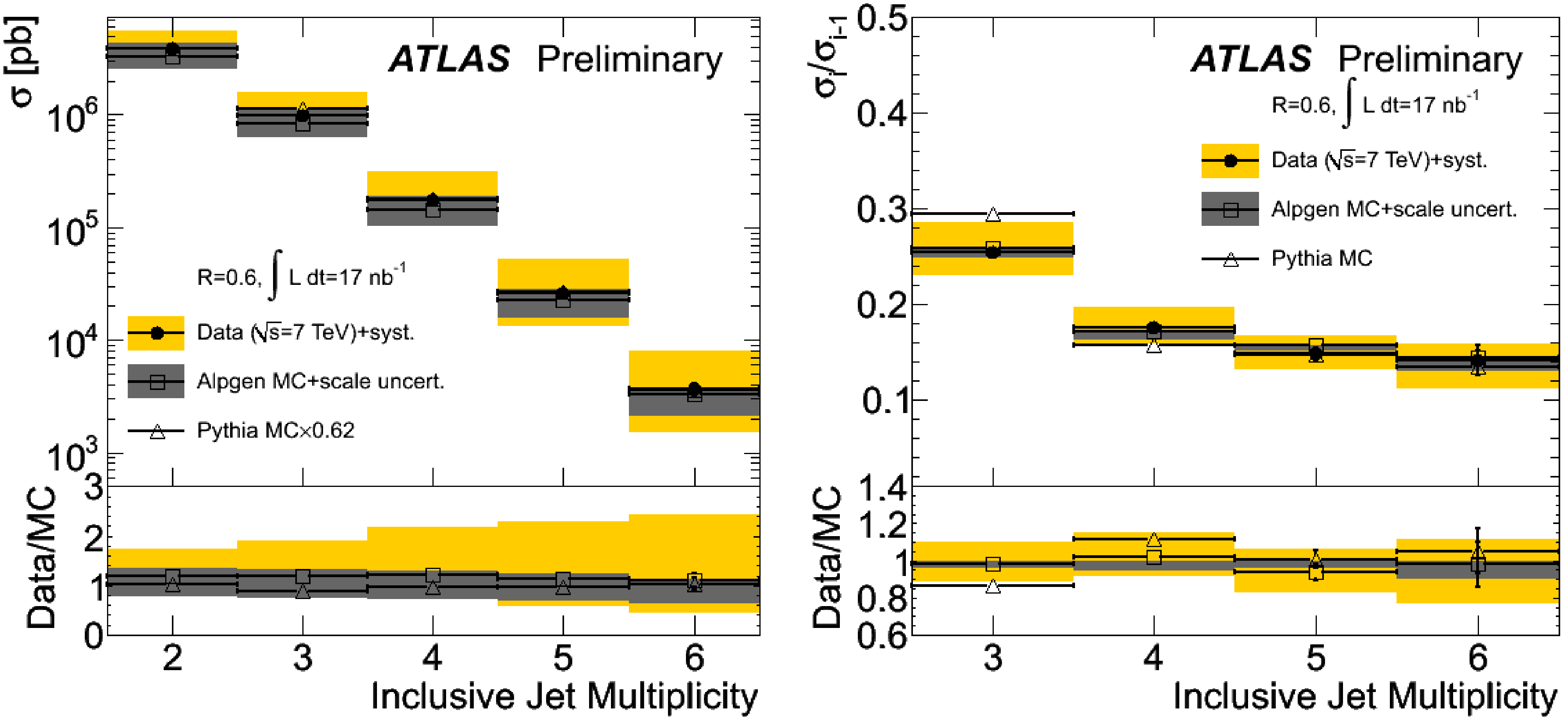
Cuts: leading jets: p_T > 60 GeV, subleading jets p_T> 30 GeV

Jet Algorithm: Anti-K_T jets with R=0.6

Integrated Luminosity: 17 nb^{-1}

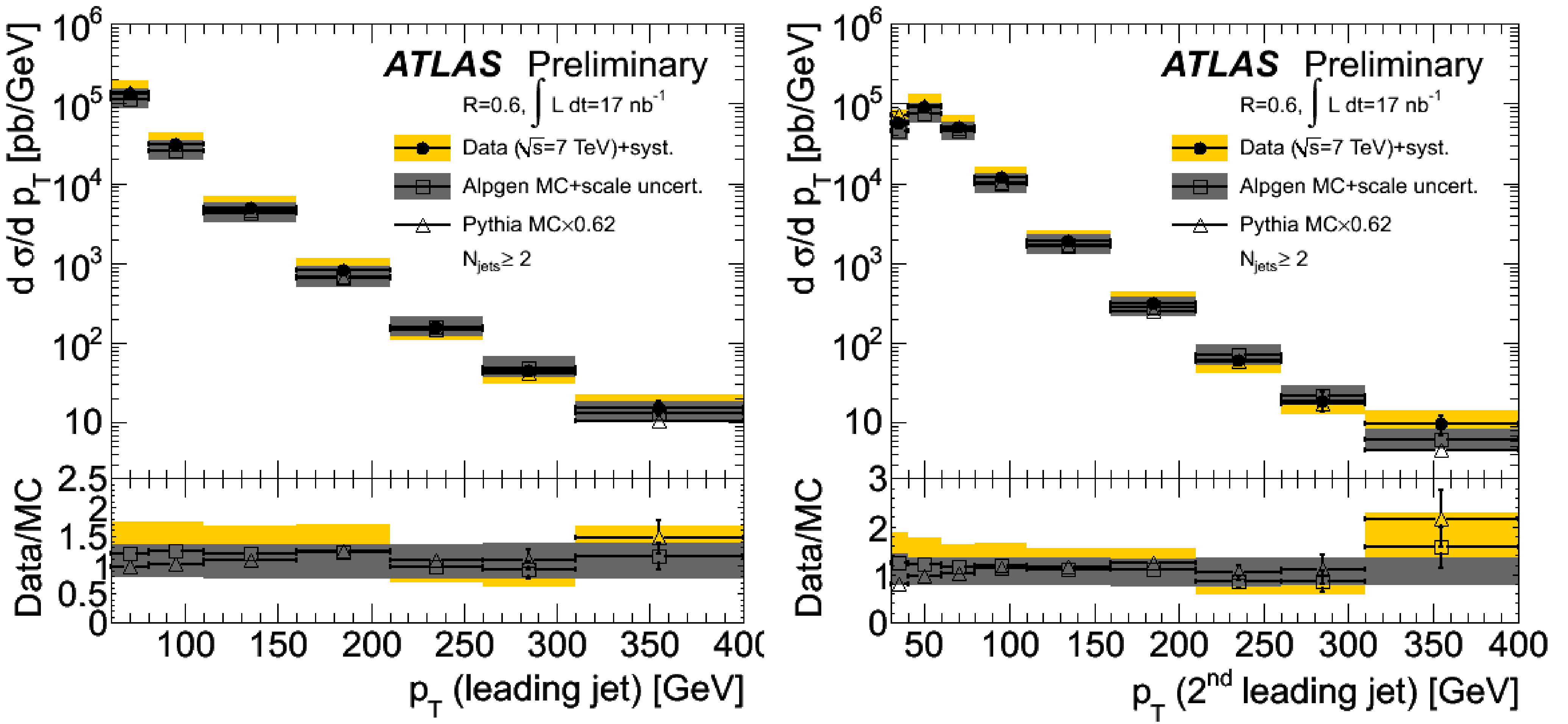
The cross section is corrected by the detector effects

Cross Section: Multi-Jets

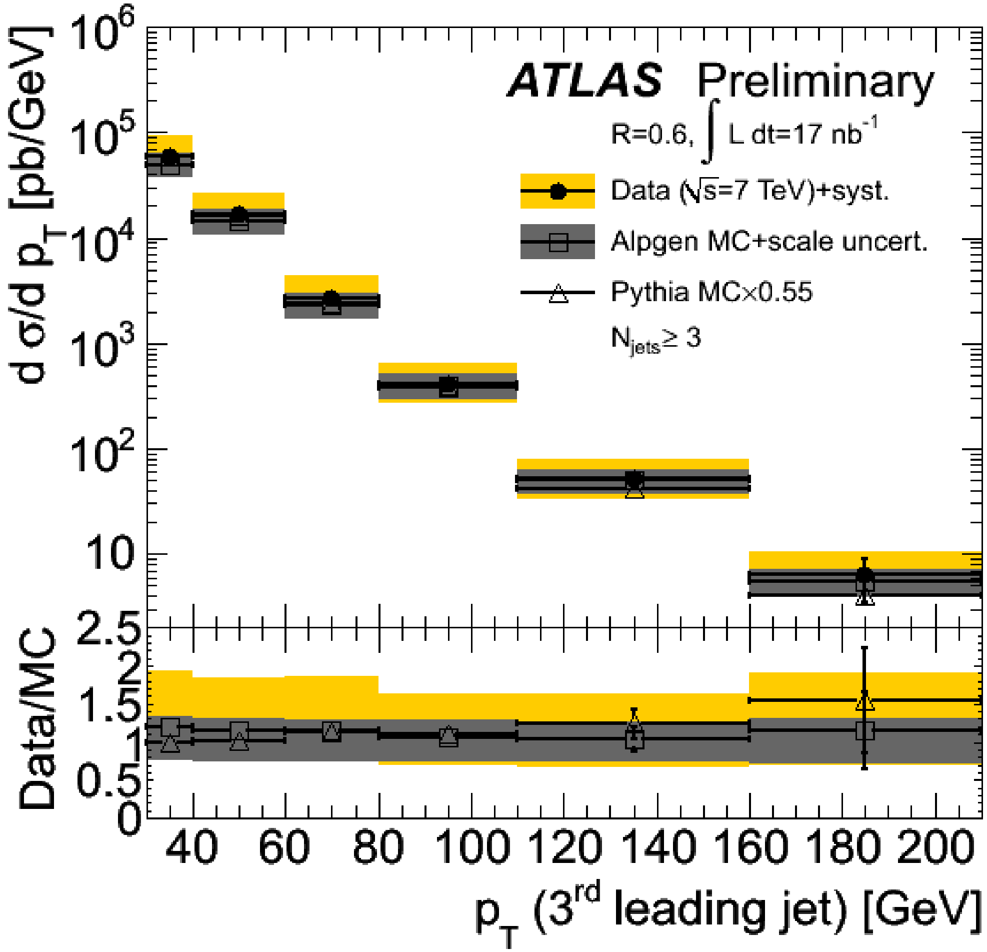


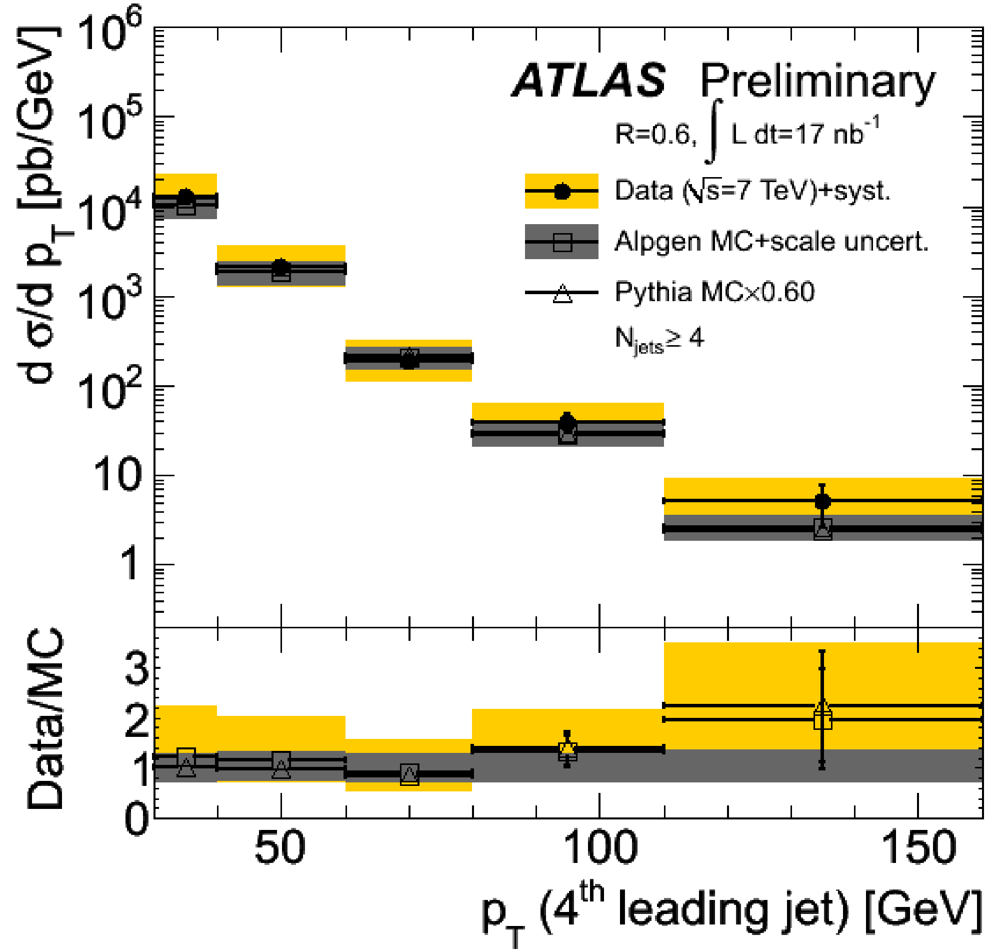
Alpgen describes better the data.
Pythia has a factor 0.62

Cross Section: Multi-Jets



Cross Section: Multi-Jets

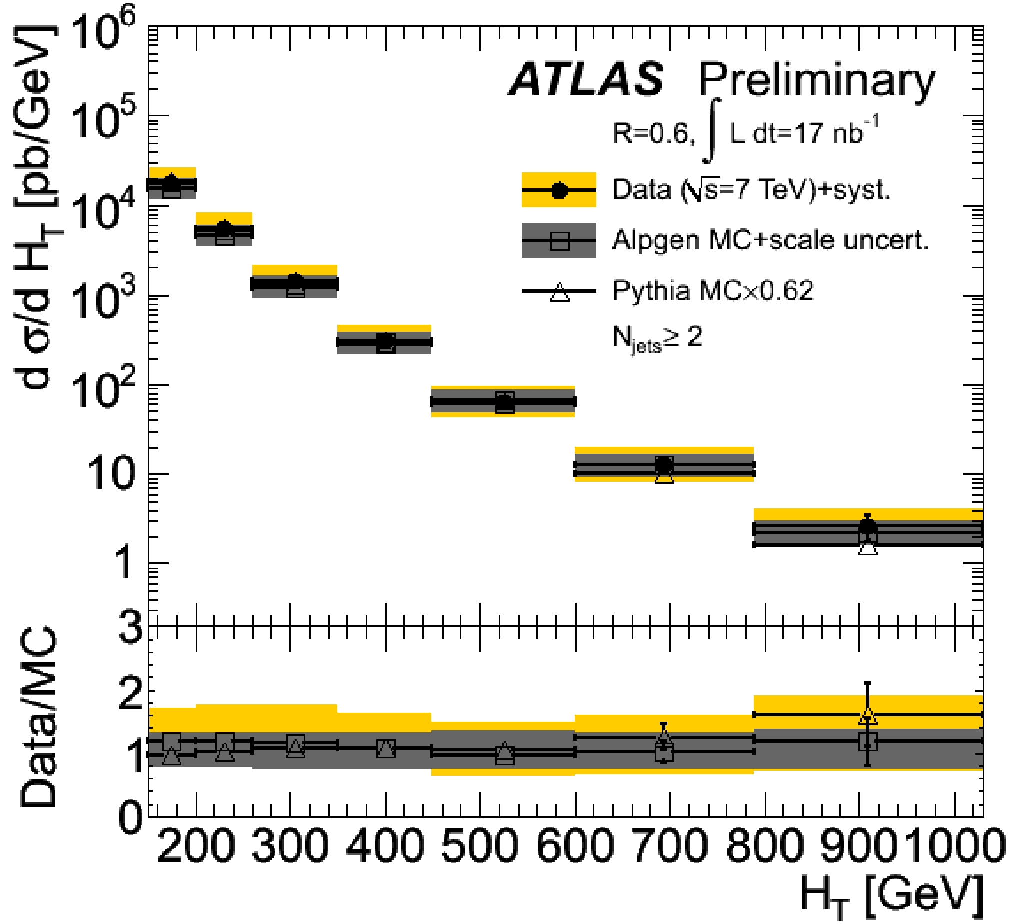




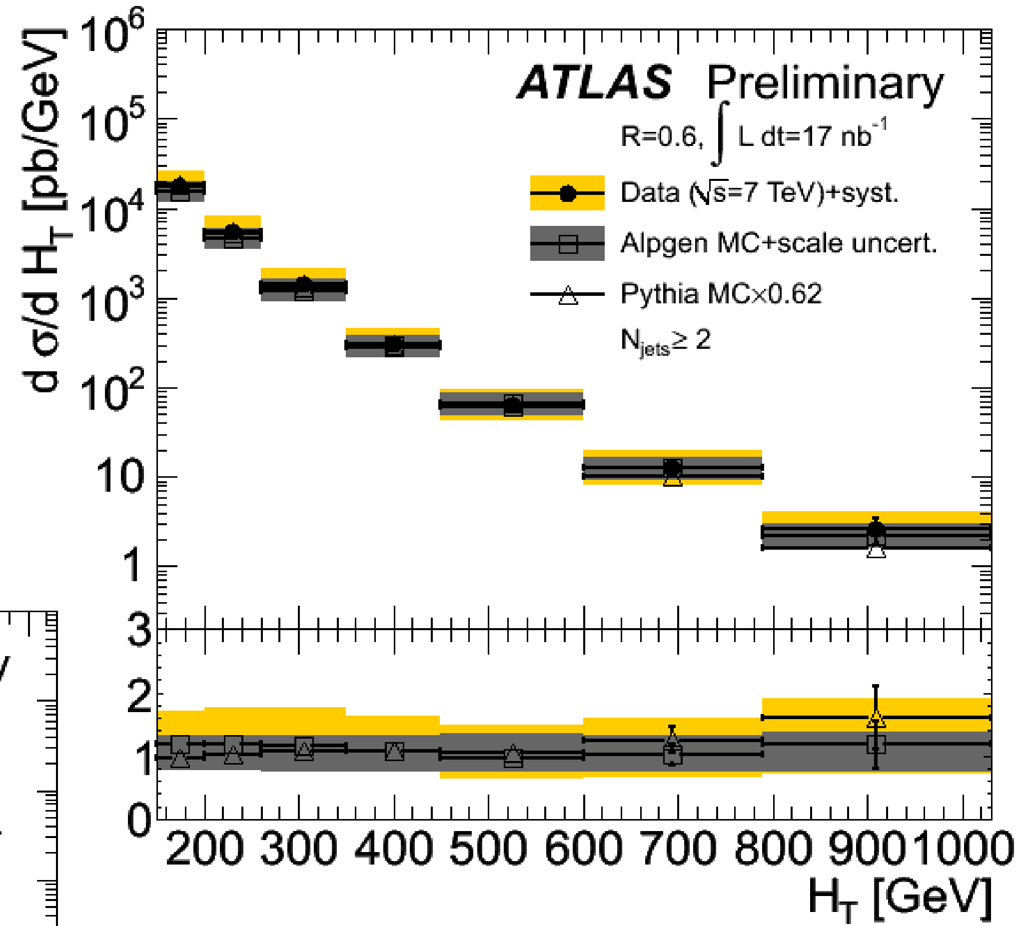
Cross Section: Multi-Jets

$H_T = \Sigma p_T$ of selected jets

Inclusive variable to describe the events.

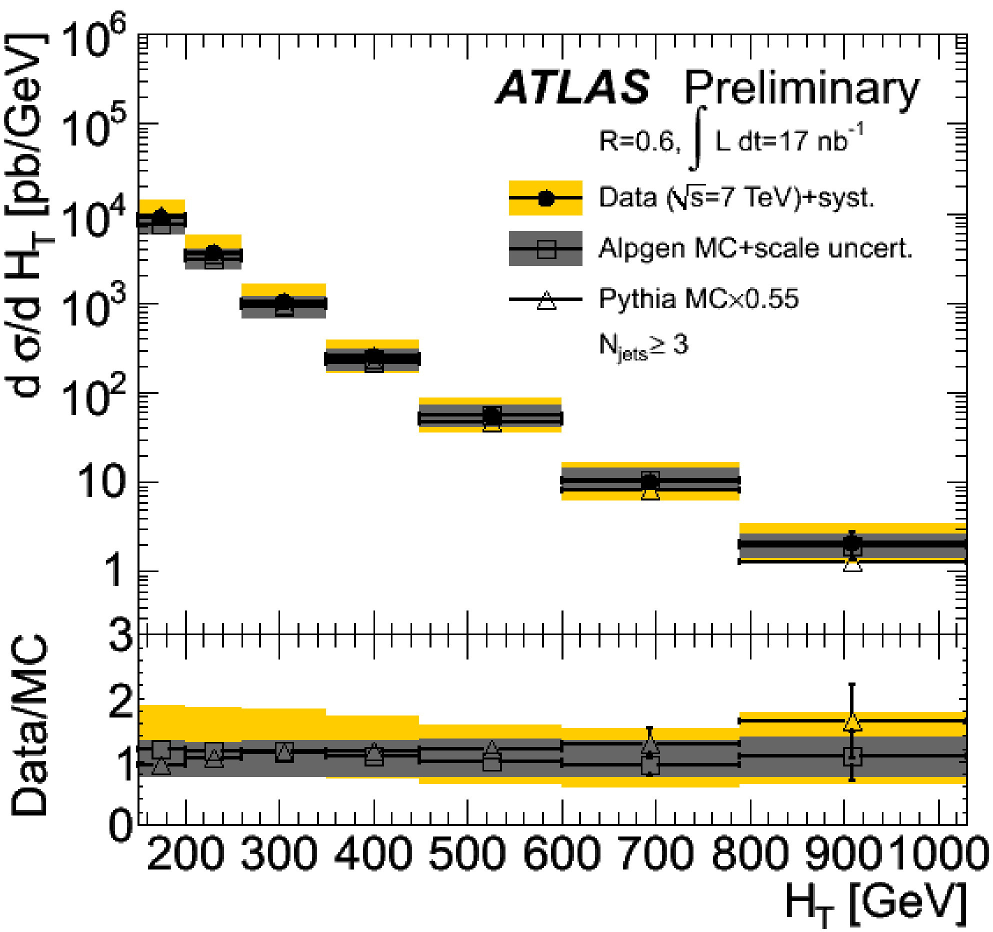


Cross Section: Multi-Jets



$H_T = \Sigma p_T$ of selected jets

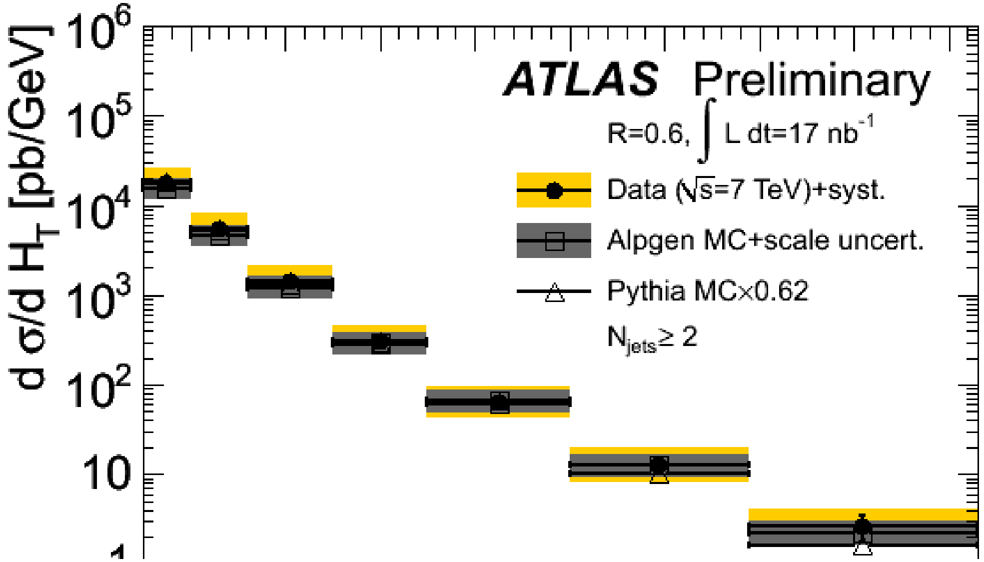
Inclusive variable to describe the events.

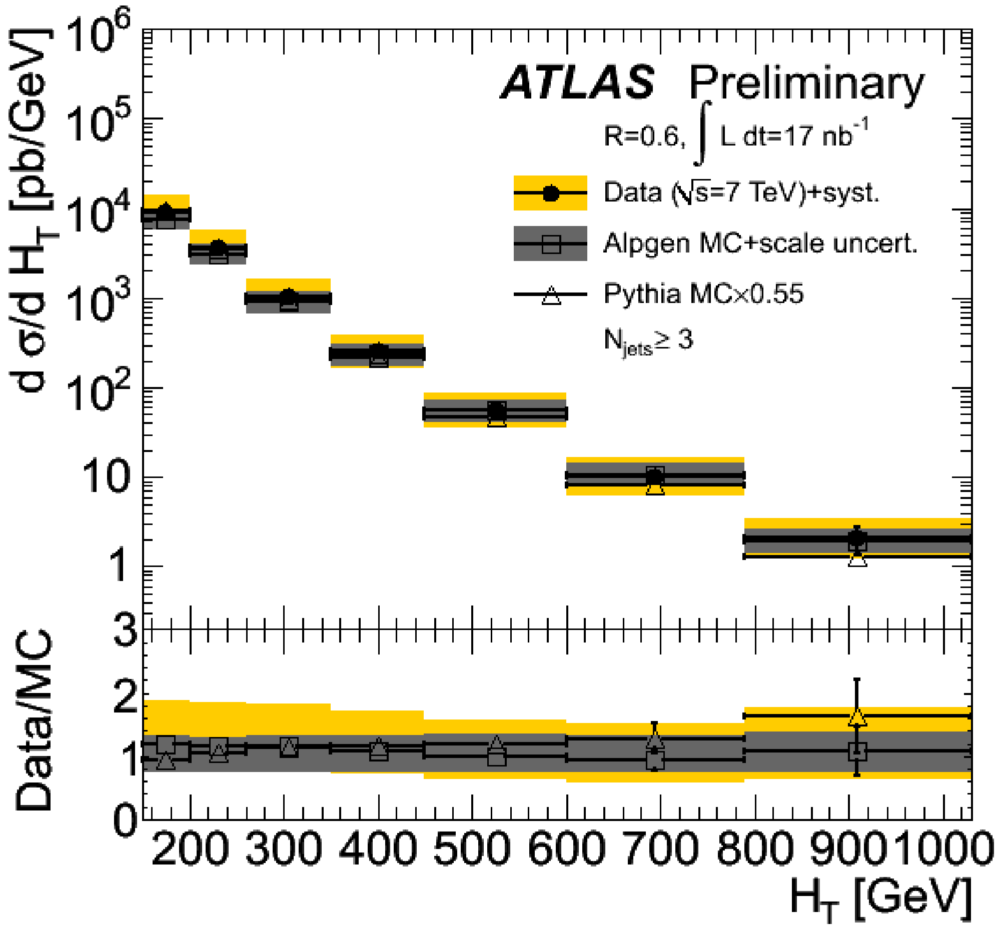


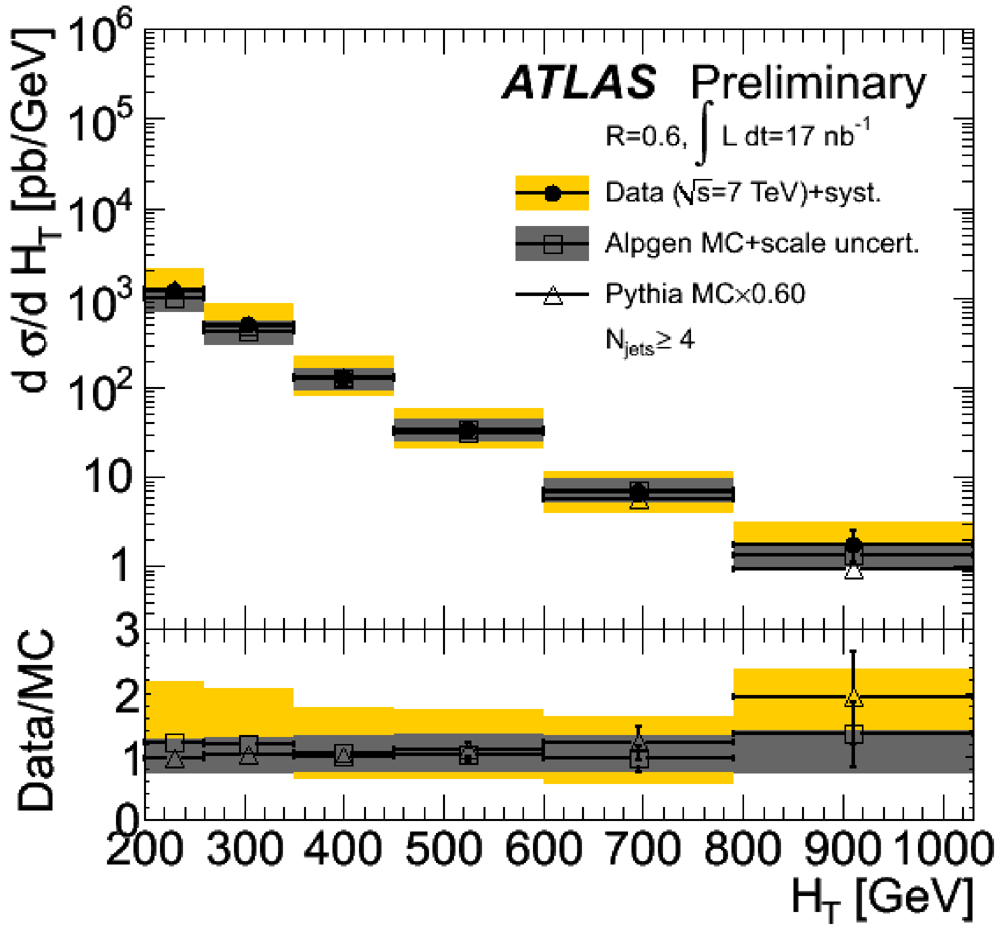
Cross Section: Multi-Jets

***$H_T = \Sigma p_T$* of selected jets**

Inclusive variable to describe the events.





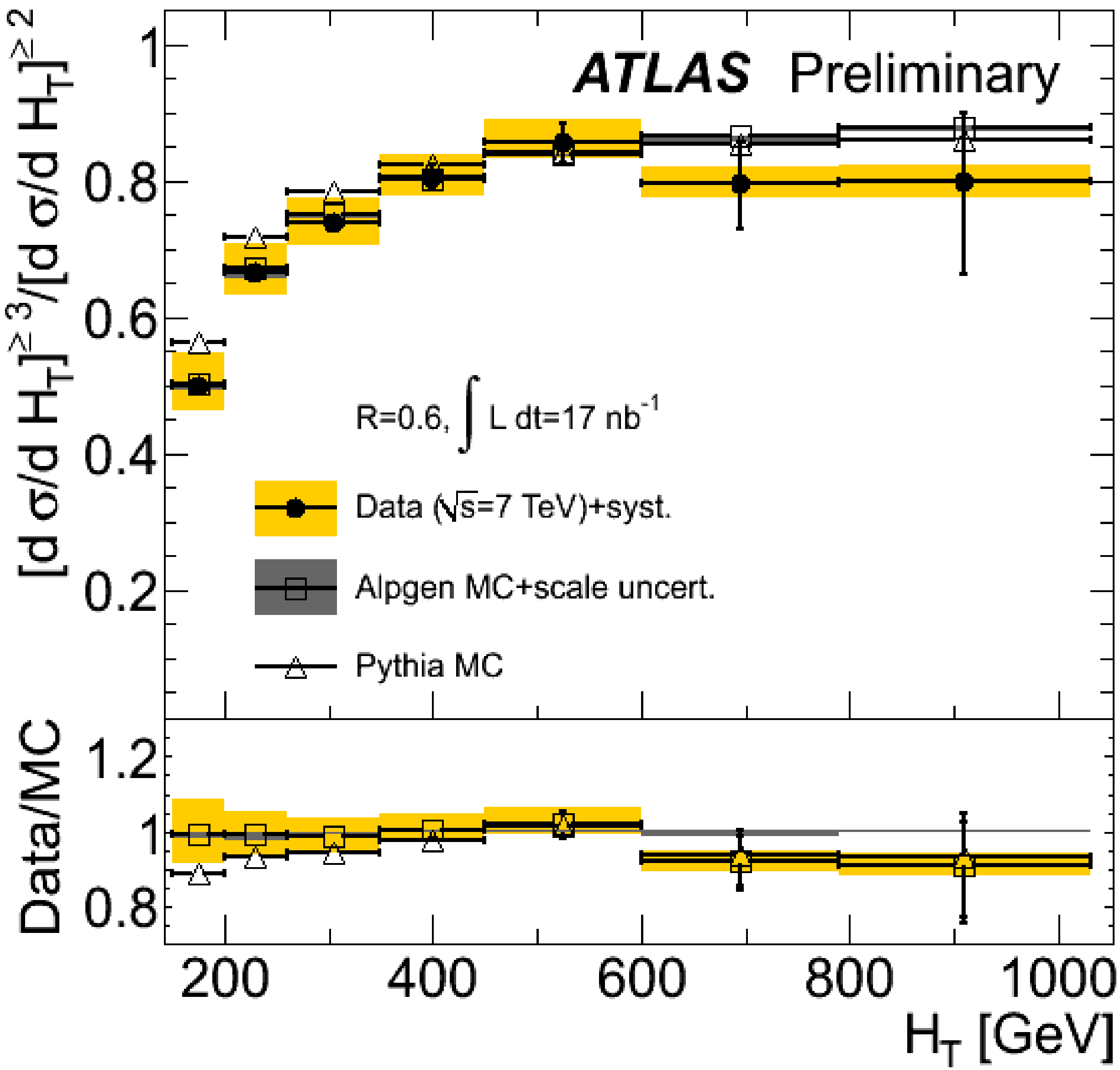


Cross Section: Multi-Jets

By making the ratio, part of the systematics cancel out.

Useful as an input for the strong coupling constant evaluation

(rough indication of the scaling violation).



Heavy Ions:
A first glance

Heavy Ions: A first glance

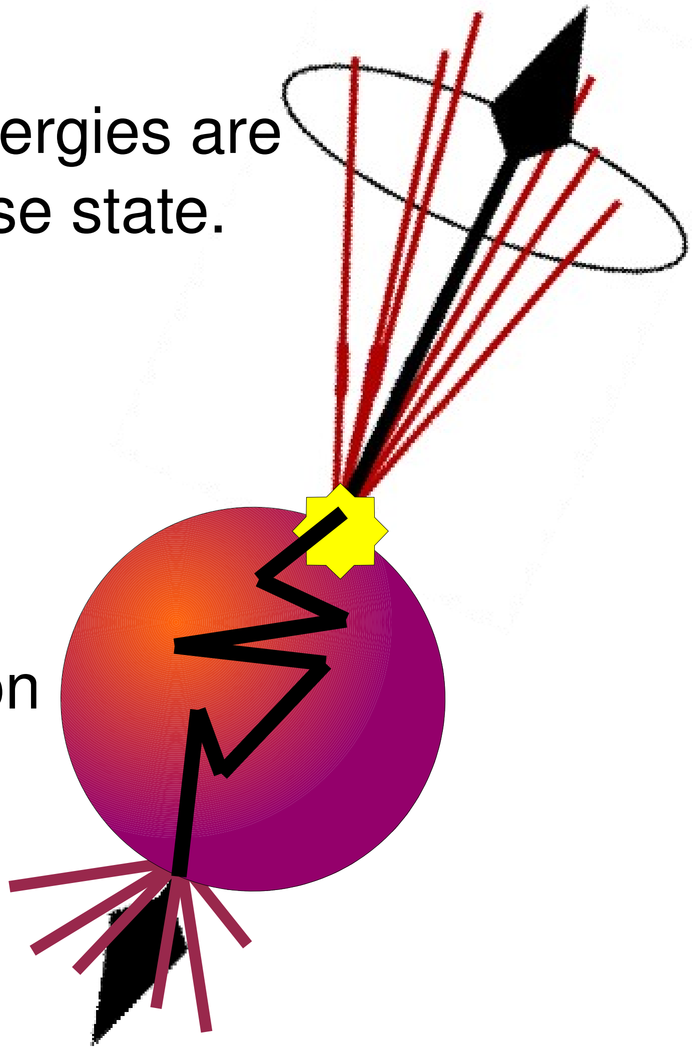
Motivation

Collisions of heavy ions at ultra-relativistic energies are expected to produce an evanescent hot, dense state.

High energy gluons and quarks are expected to transfer the energy to the medium.

-> Jet Quenching (idea from Bjorken)

Highly unbalanced di-jet when one jet is produced at the periphery of the collision



Status and Data with Lead-Lead

LHC started the Heavy Ions Program at the beginning of November 2010.

$\sqrt{s_{NN}}$=2.76 TeV, Luminosity=17 μb^{-1}

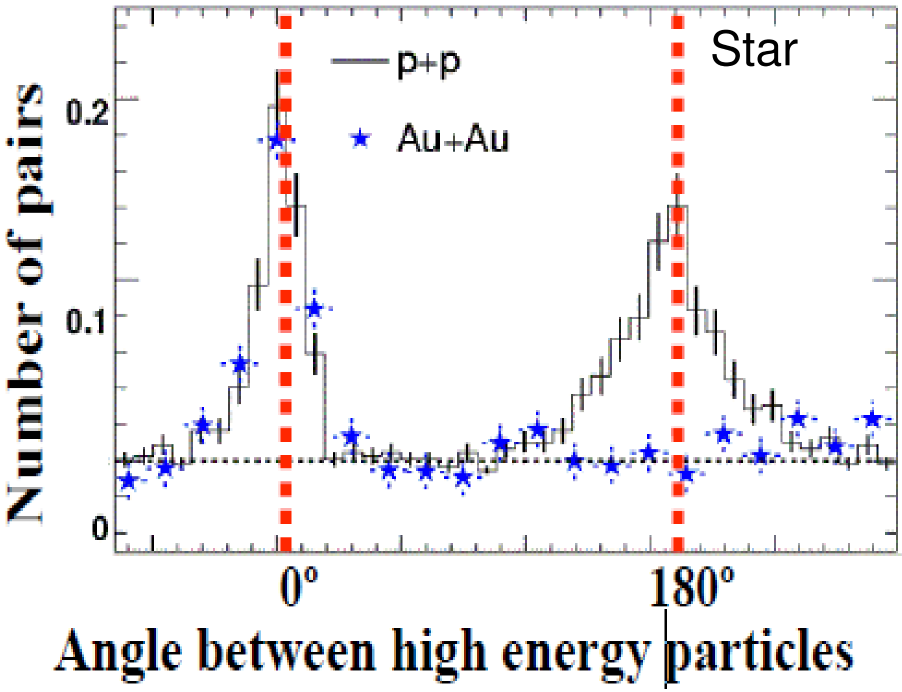
~ 1600 events with jets with p_T > 100 GeV

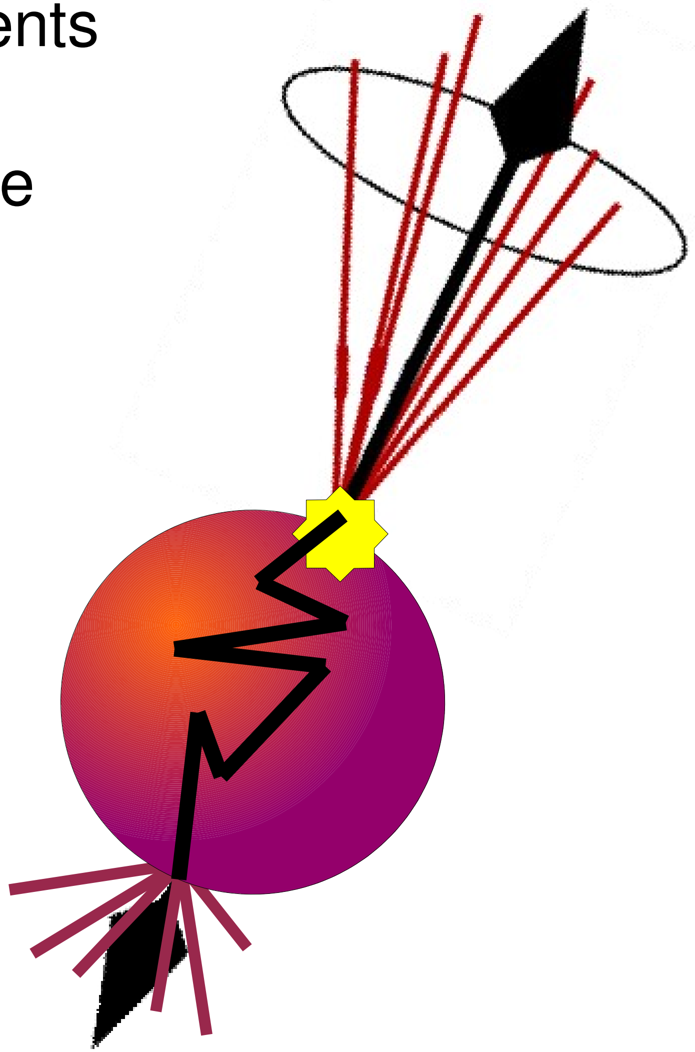
Triggered with MBTS

Heavy Ions: A first glance

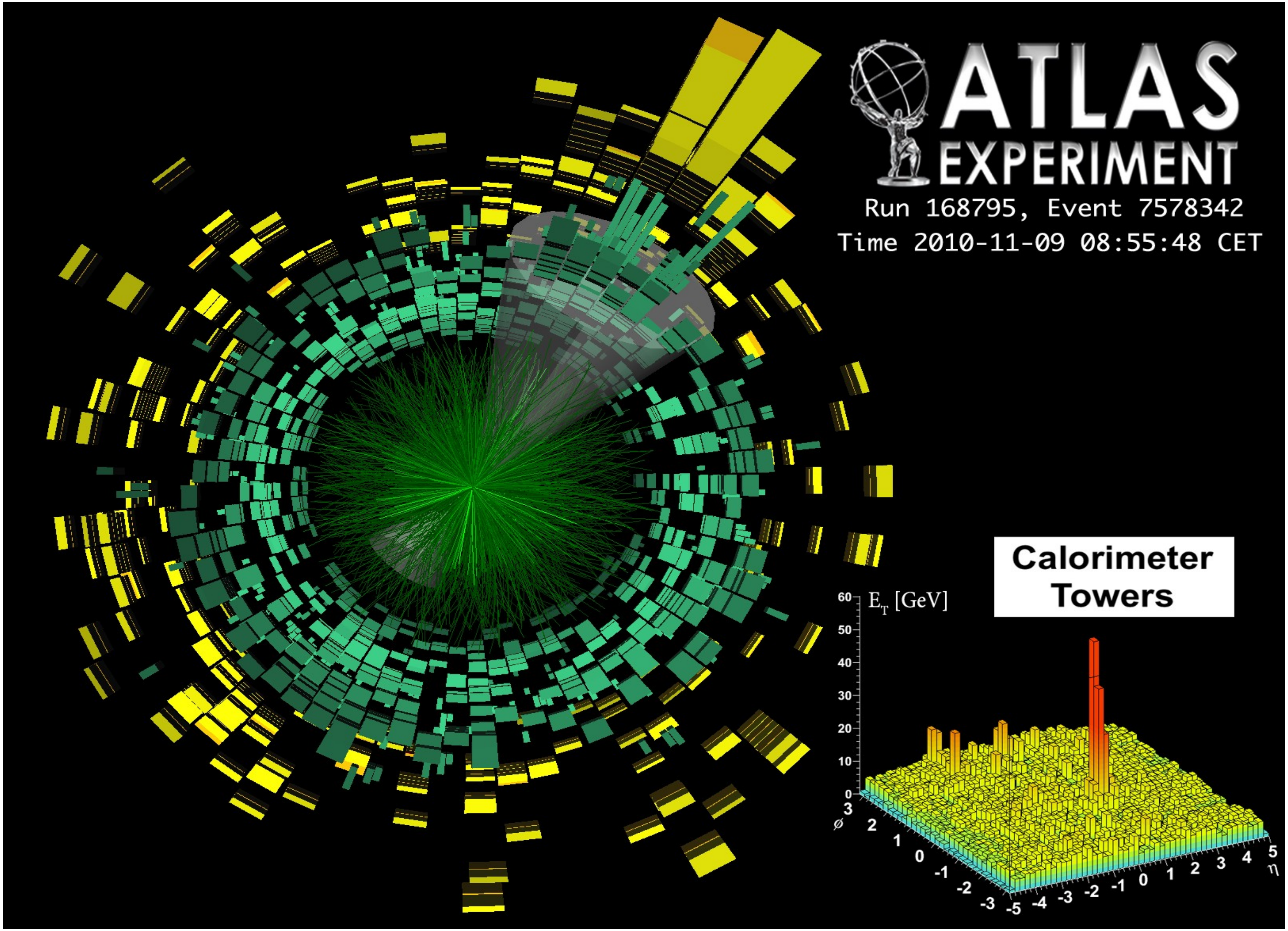
Indication for this effect in the RHIC experiments (i.e. STAR)
Studies done looking at the suppression in the particle production (i.e. charged tracks).
This is an hard way to study jets.

Track-jets (?): a natural asymmetry due to different fragmentation.



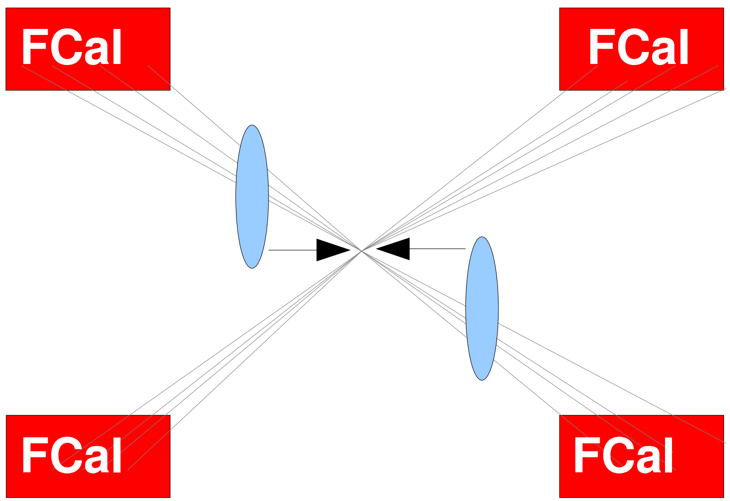


Heavy Ions: A first glance

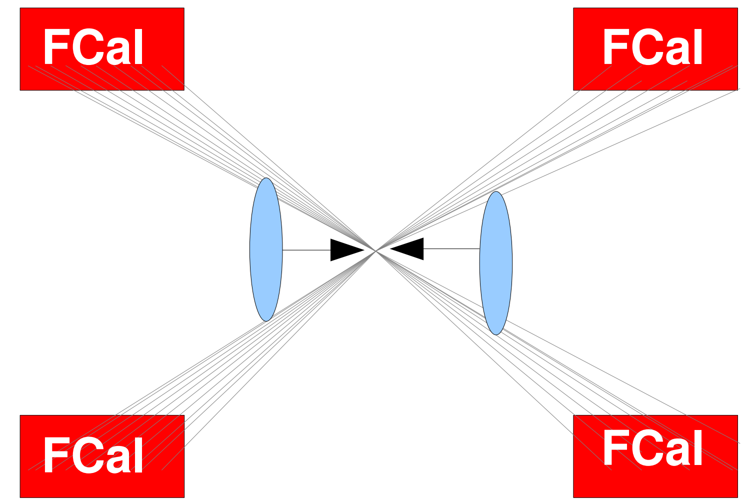


Heavy Ions: A first glance

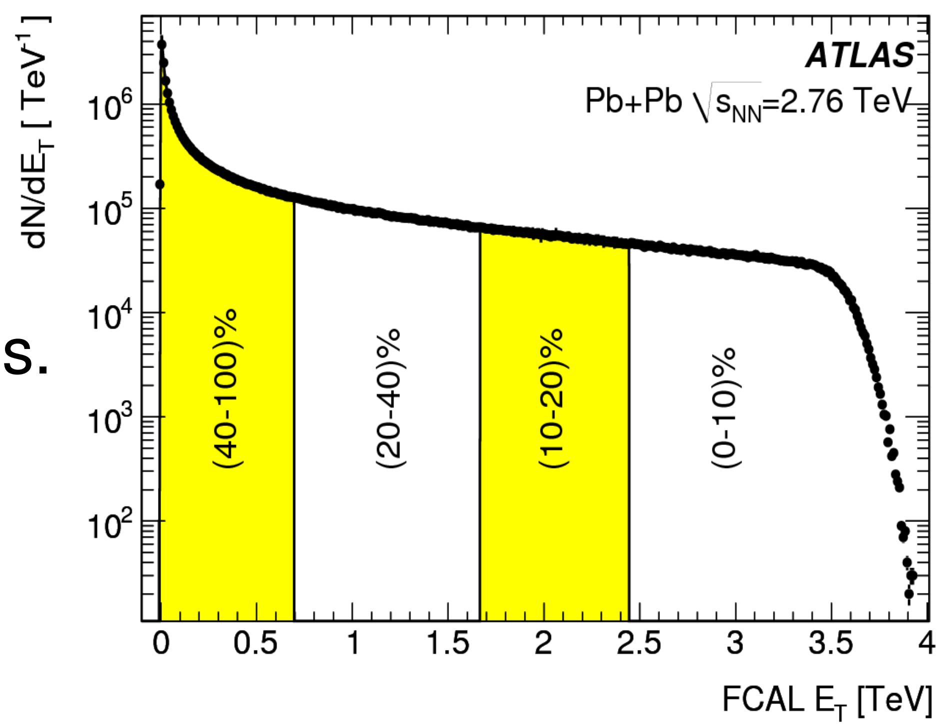
Peripheral Collisions



Central Collisions



Head-on collisions (Central collision) produce more final state activities.
=> The final state activity is used to separate central and peripheral collisions.
To avoid biases, the events are divided in centrality bins according to the FCal E_T measurement.

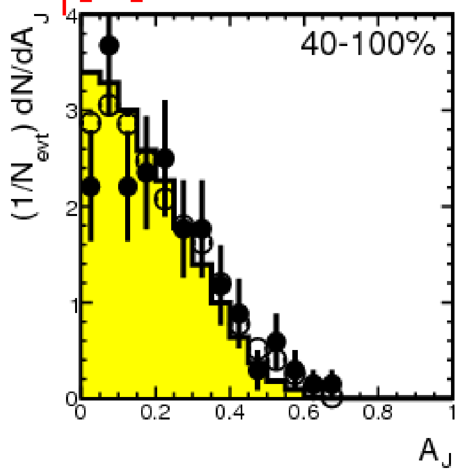


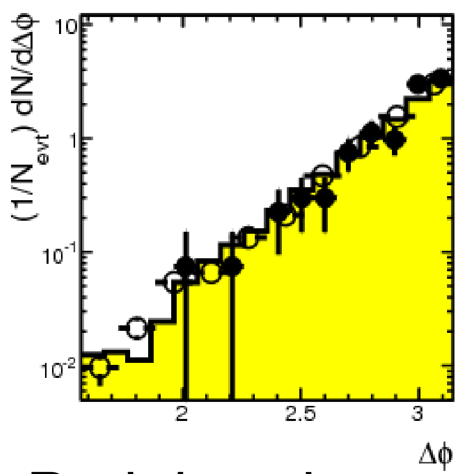
Heavy Ions: A first glance

$A_j = (E_T[1]-E_T[2]) \;/\; (E_T[1]+E_T[2])$ Big A = Big unbalalance

Event Selection: back-to back configuration $\Delta\varphi > \pi/2$

$E_T[1] > 100$ GeV; $E_T[2] > 25$ GeV $|y| < 2.8$





Peripheral → Central

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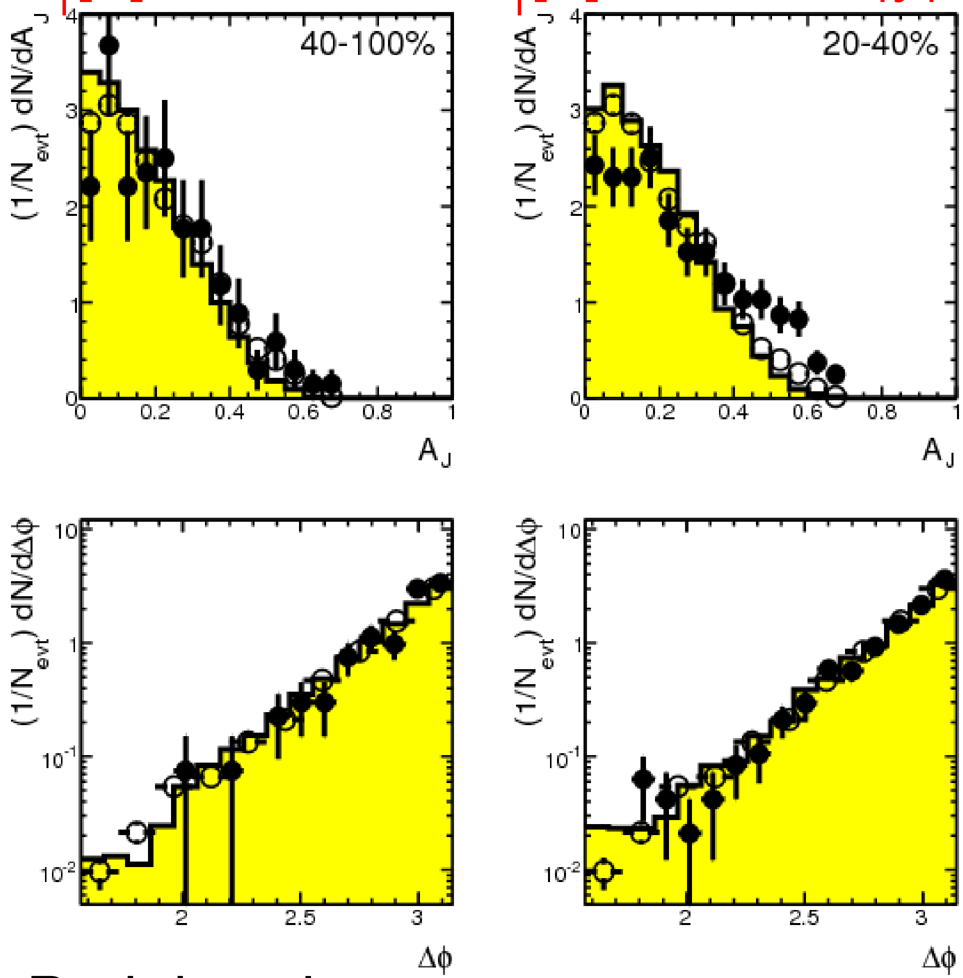

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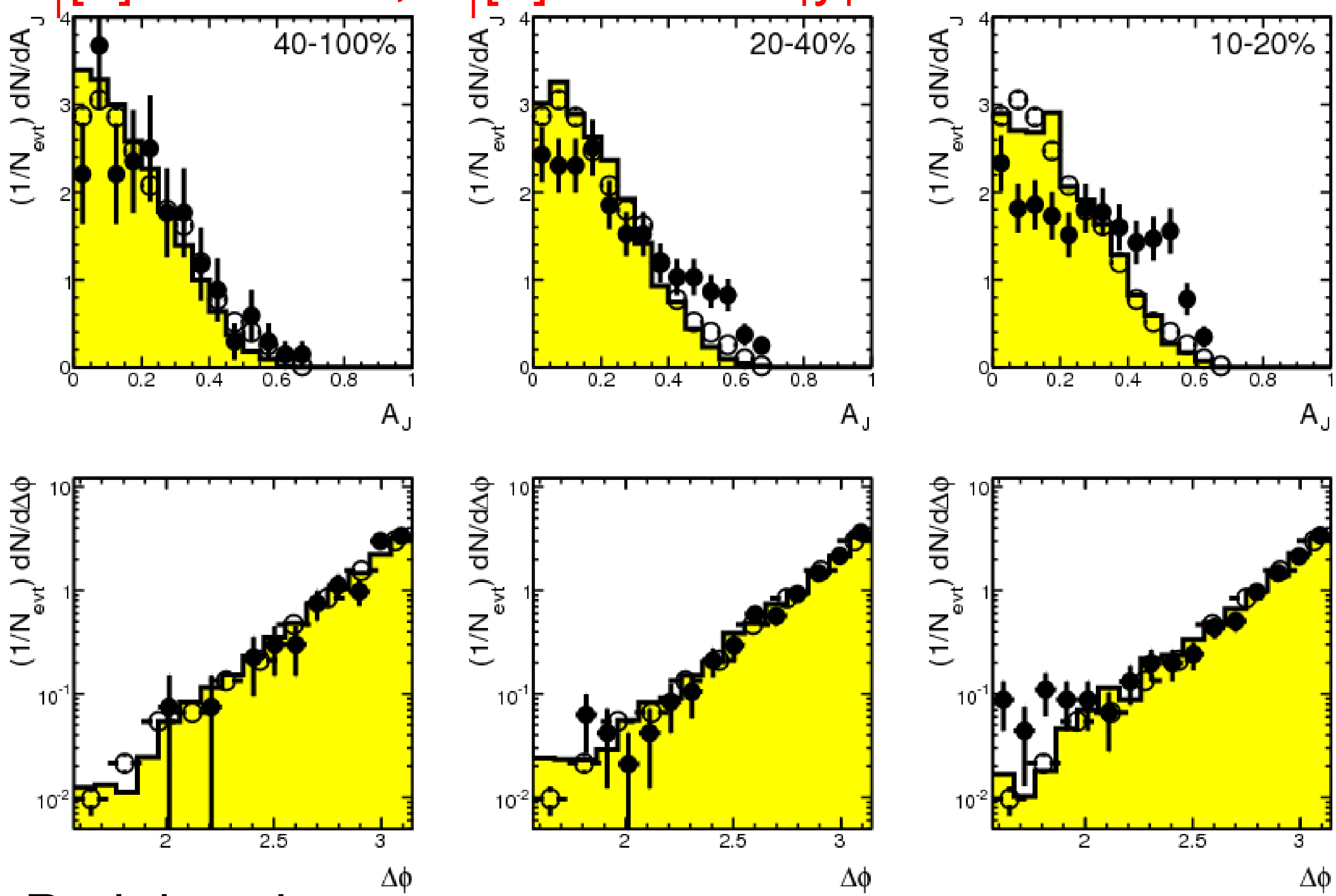

Peripheral → Central

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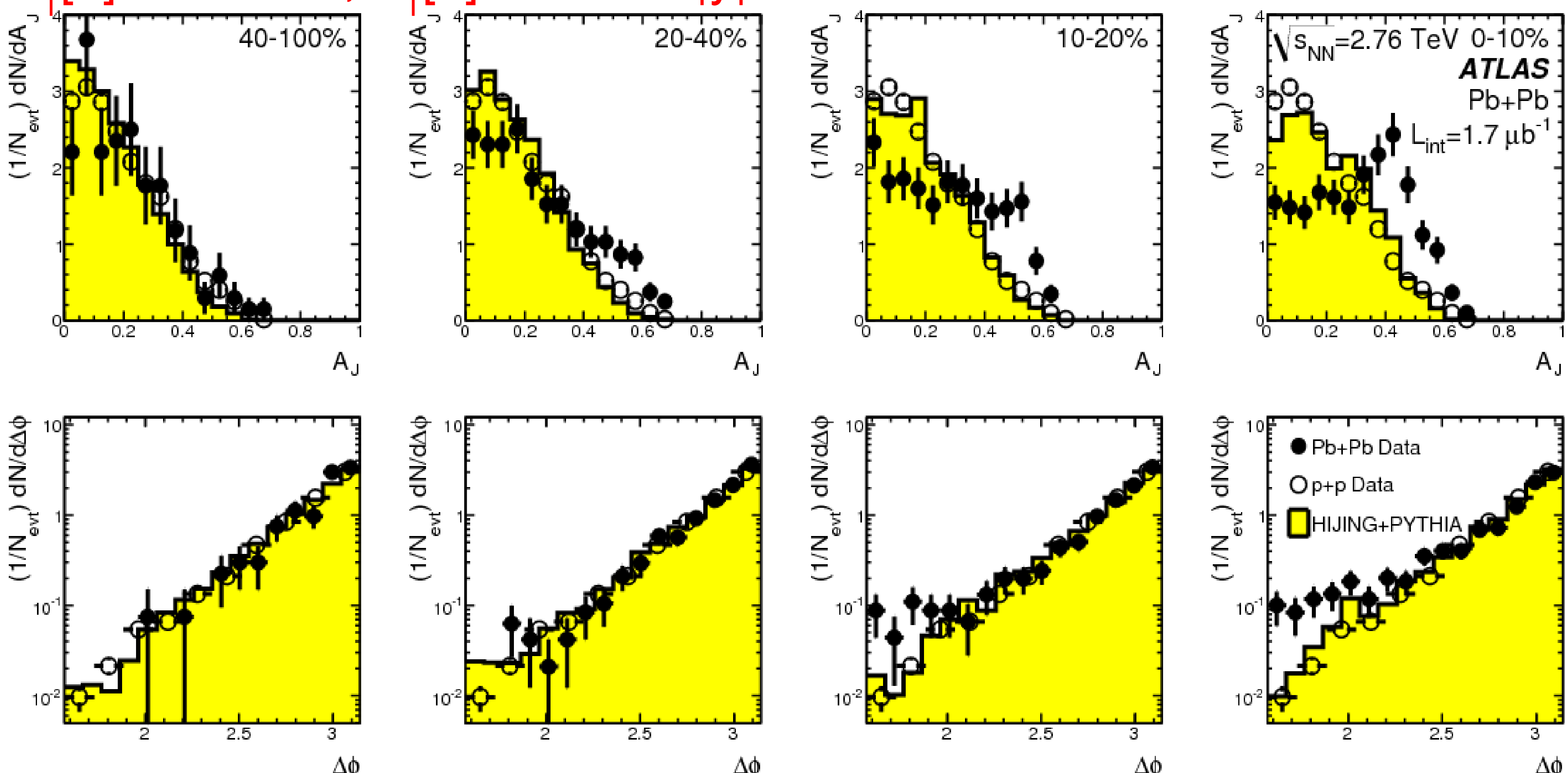
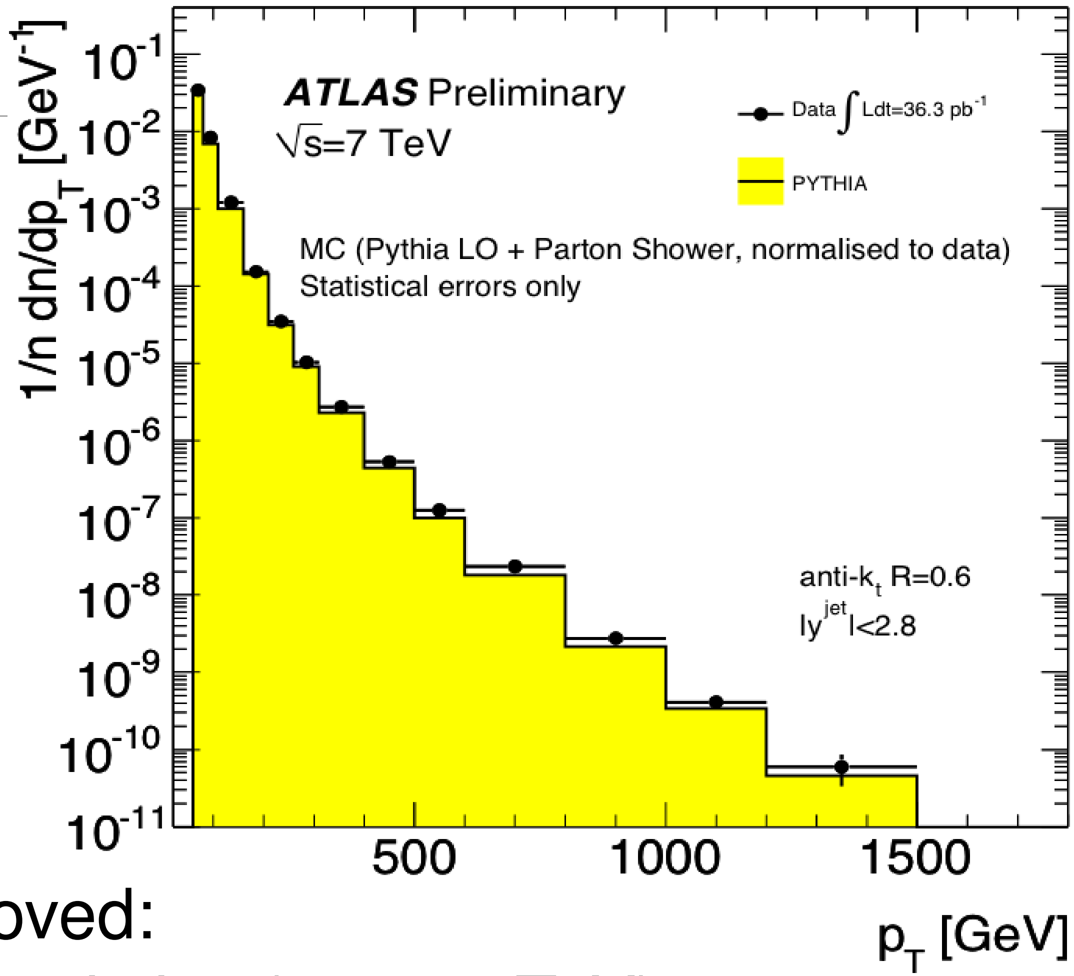


Peripheral → Central

Conclusions



Exciting period for the QCD analyses at LHC

A rich program of measurements begun with the LHC collisions.

Most of the analysis will be improved:

By using the complete 2010 statistics (p_T~1.5 TeV)

By a deeper understanding of the detector (smaller systematics)

LHC Plans for 2011: 200 days of proton-proton (~ 1-2 fb^{-1})

And surprises may happens – Stay tuned.