PHYSICS AT THE TERA SCALE
Helmholtz Alliance

FSP 101 ATLAS

Bundesministerium für Bildung und Forschung

Jet Production Cross-Section in pp Collisions with ATLAS

- Motivation
- Measurement
- Analysing the 2010 sample

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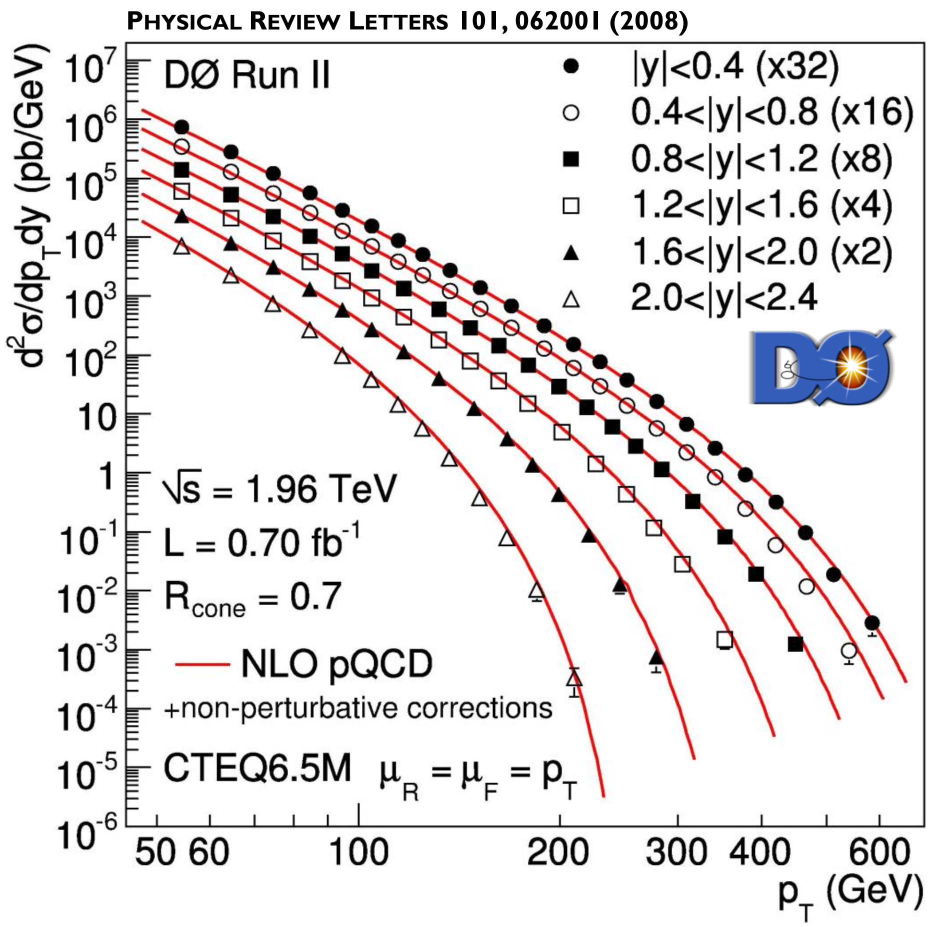
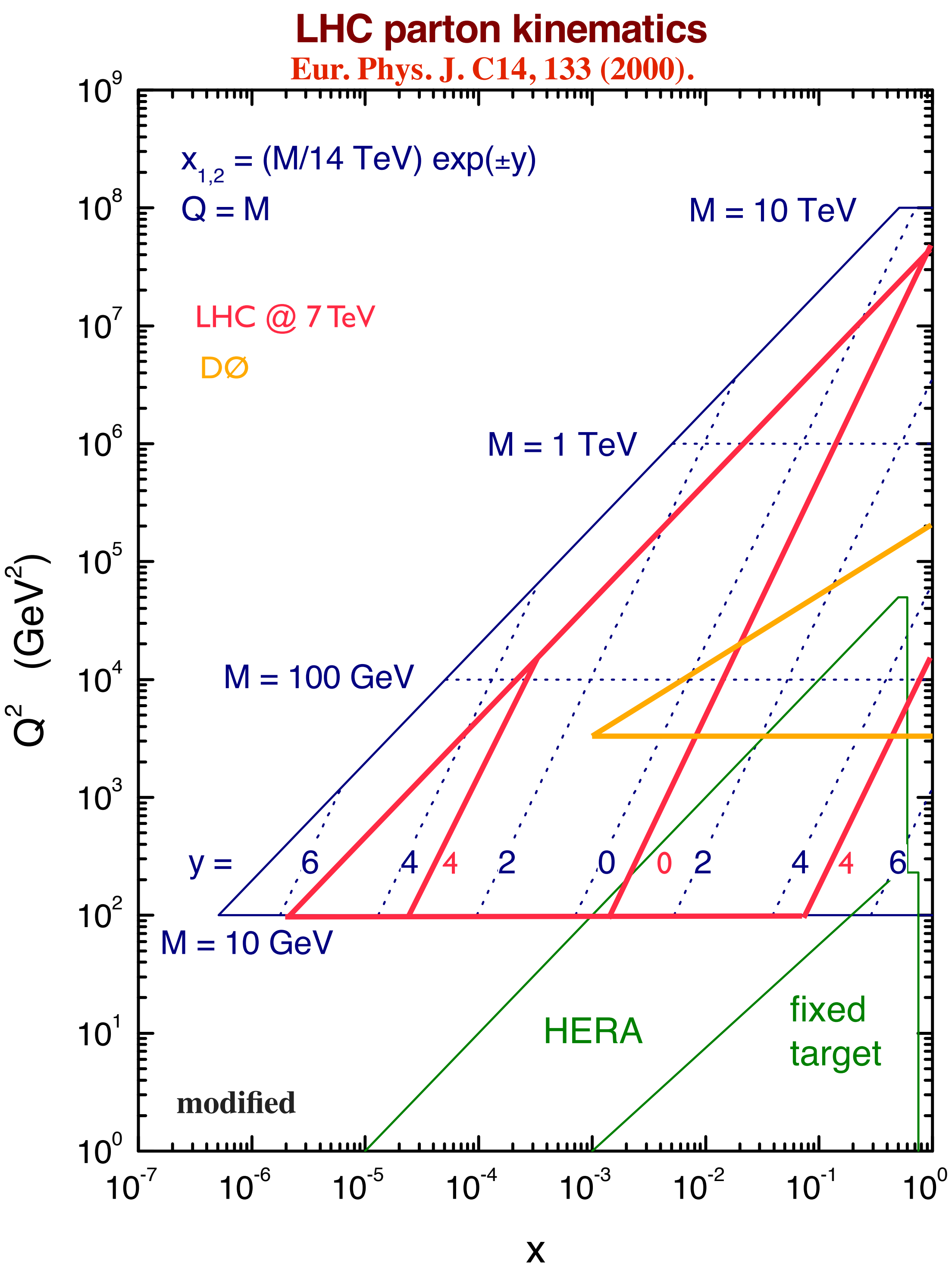
- Jet production most basic QCD process
- Large cross-section offers early physics measurement with access
  - to α_s
  - to PDFs
  - to new physics (e.g. excited quarks)

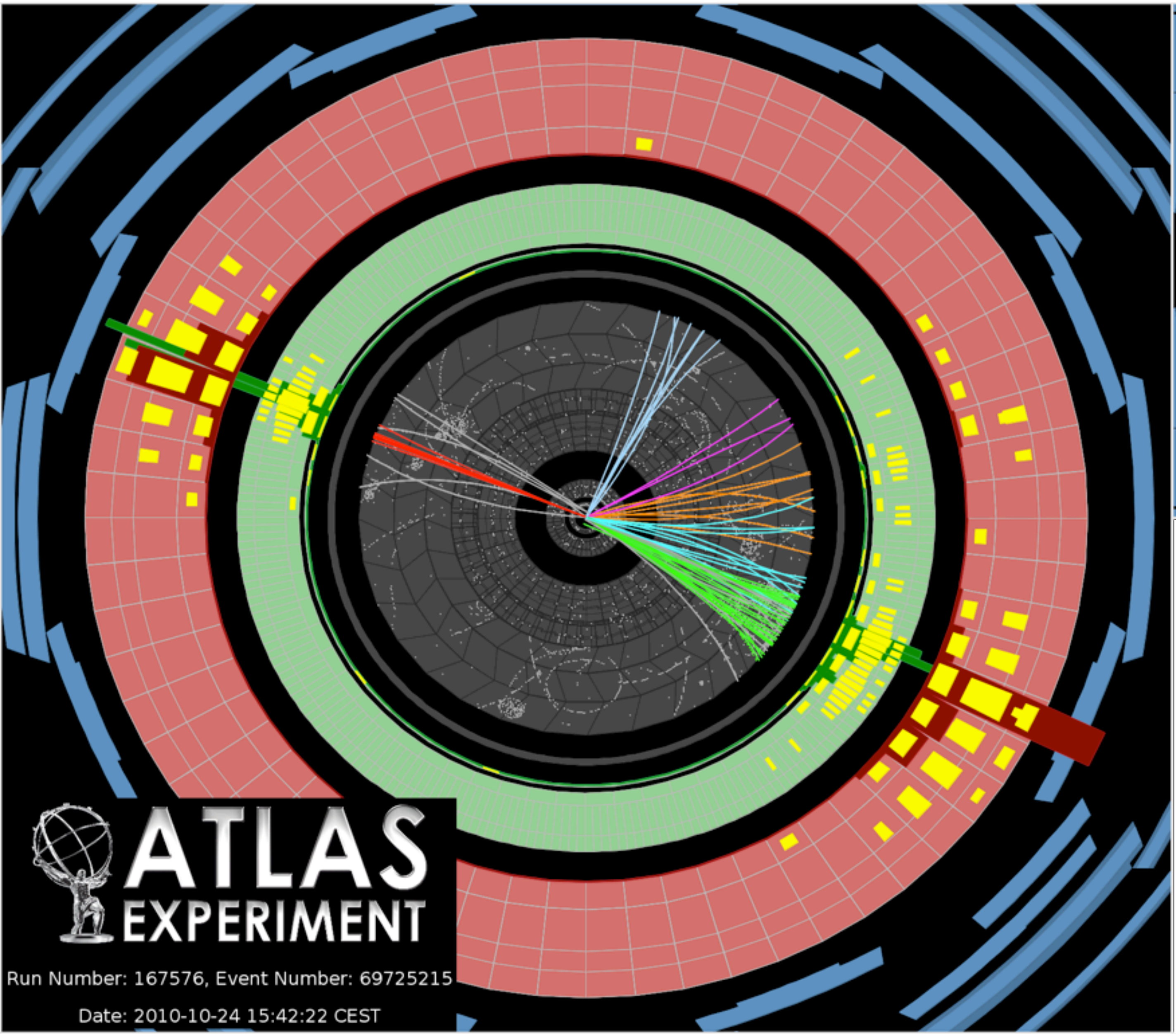
(Phys.Rev.Lett. 105:161801,2010.)

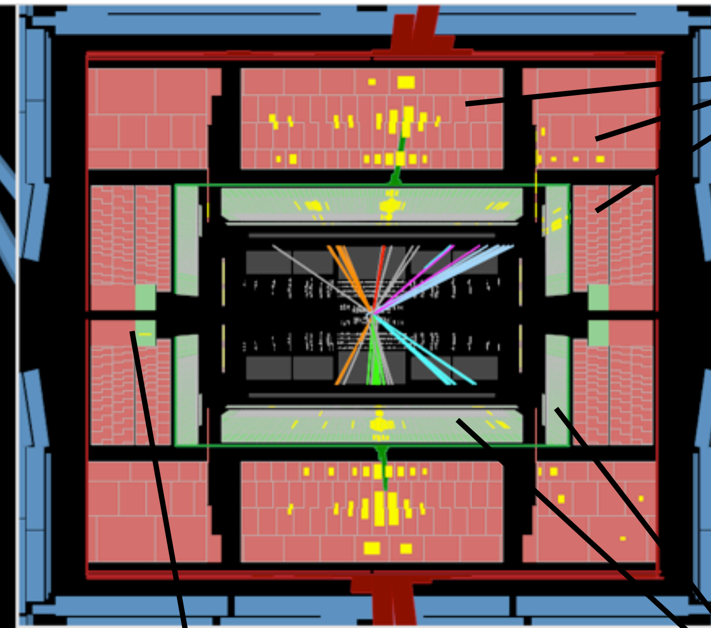
- Test of pQCD in a new kinematic regime





a diJet event in ATLAS





Hadronic barrel/ extended barrel/ endcap

$(\Delta\eta, \Delta\phi) =$
$(0.1,\ 0.1)$

$|\eta| < 1.0$ tile barrel

$0.8 < |\eta| < 1.7$ tile ext. barrel

$1.5 < |\eta| < 3.2$ LAr endcap

LAr forward

3 modules:
1 optimised for EM.
2 optimised for had.

$3.1 < |\eta| < 4.9$

LAr EM barrel/ endcap

3 (2) layers,
middle layer:

$(\Delta\eta, \Delta\phi) =$
$(0.025,\ 0.025)$

$|\eta| < 1.47$

$1.4 < |\eta| < 3.2$

- Highly granular calorimeter
- Especially fine longitudinal segmentation
- 3 layers each in EM and hadronic calorimeters allow to define very localised calibration schemes

Observable definition

$$\frac{d^2\sigma}{dp_T dy}$$

- probes pQCD at smallest scales
  sensitive to: α_s , PDFs

$$\frac{d^2\sigma}{dm_{jj} dy_{max}}$$

- is in addition sensitive to resonances $|y|_{max} = \max\{|y_1|, |y_2|\}$
  (excited quarks, large extra dimensions,..)

2 major challenges with Jets

- Jet finding
  - anti-kt, R=0.4/0.6
- Jet calibration

- jet finding via Anti-kt algorithm
  - clustering algorithm
  - infrared & collinear safe def.

$$\begin{aligned} d_{ij} &= \min(k_{T,i}^{-2}, k_{T,j}^{-2})\frac{\Delta_{ij}^2}{R^2} \\ d_{iB} &= k_{T,i}^{-2} \end{aligned}$$

- find smallest moment
- if it is a d_{ij}
  - cluster two items
- if its a d_{iB}: its a jet
  - remove it from your list

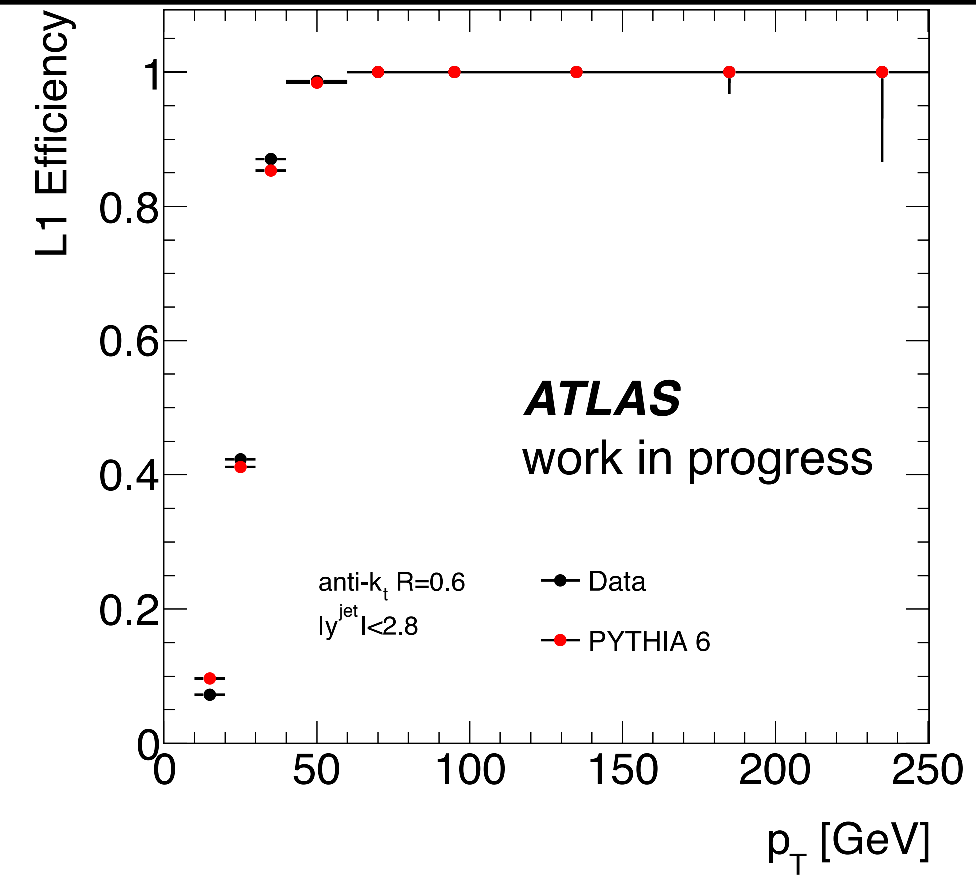
Cross section measurement

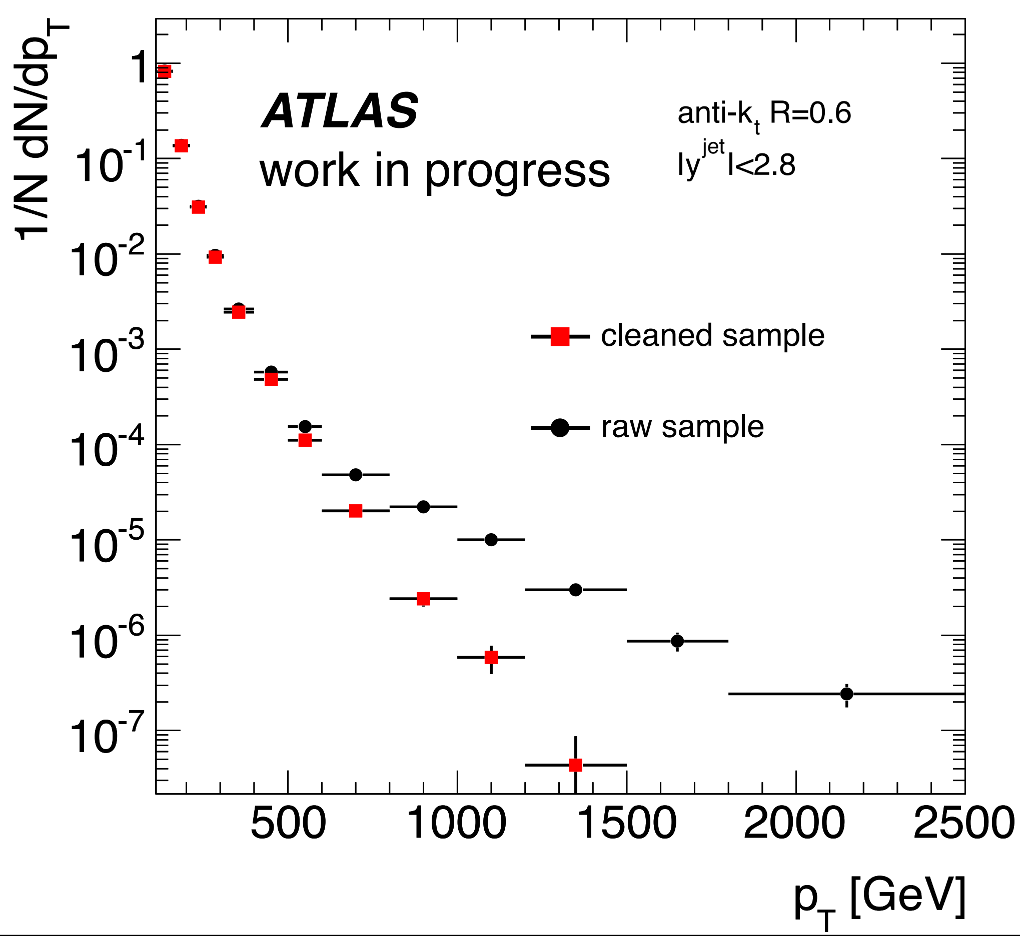
Event selection

- Events recorded by fully efficient jet trigger
  (above offline pt cut)

- Event selection based on detector status
  (HV on, Trigger configured, etc..)

- Jet quality selection removes
  - jets from non collision background
  - badly measured jets
  - calorimeter noise bursts





Jet energy scale calibration

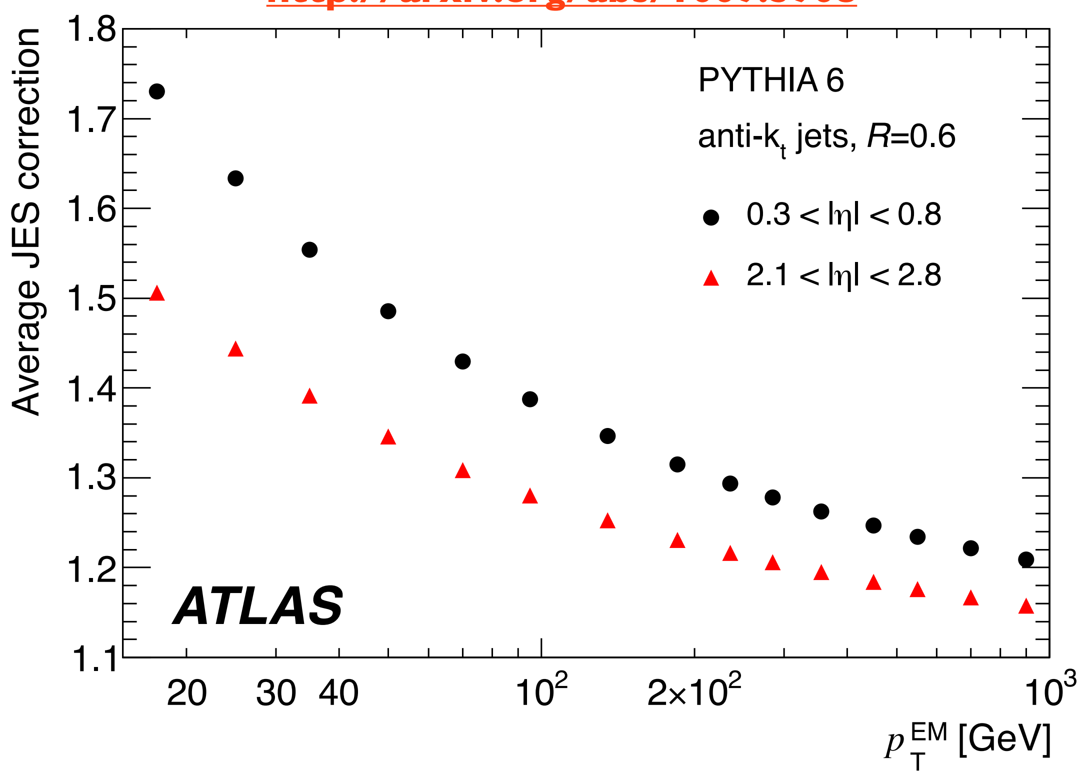
- Calorimeter response different between e.m. and hadronic shower

- Calibration needs to correct for
  - non compensating hadronic calorimeter
  - non linearity

- Calibration used so far: simple MC based calibration constants
  - cell weighting schemes will not only correct the scale, but also improve the resolution use information from longitudinal intersections

- MC based calibration is a function: $\text{JES}(p_T, \eta)$

http://arxiv.org/abs/1009.5908



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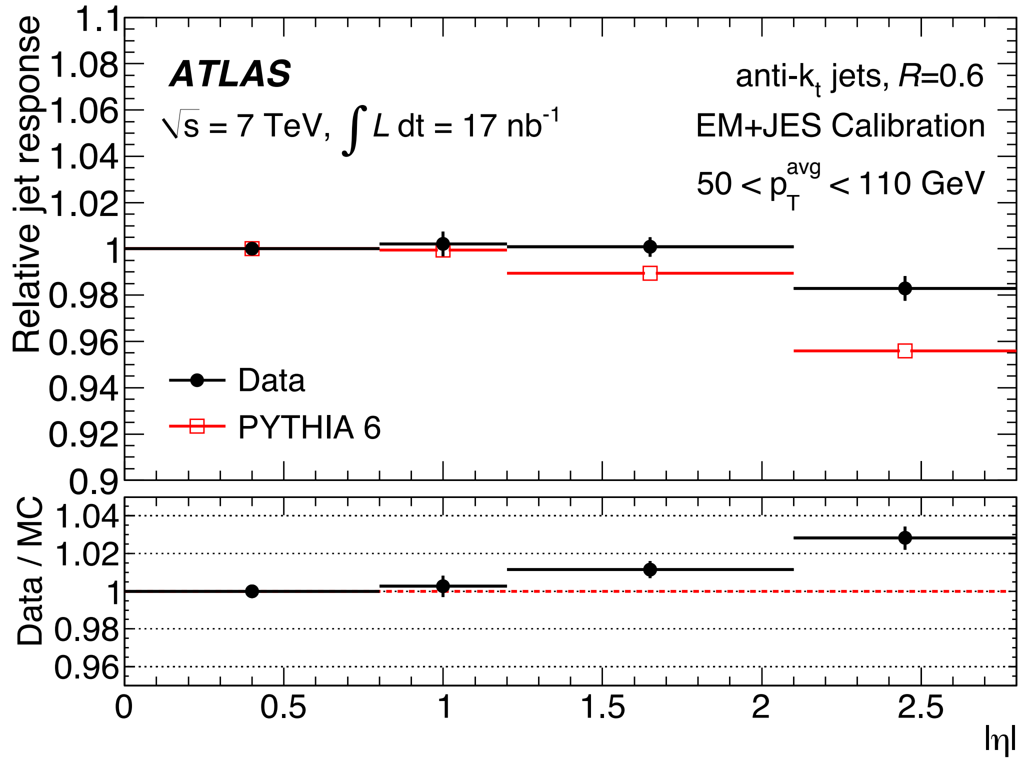
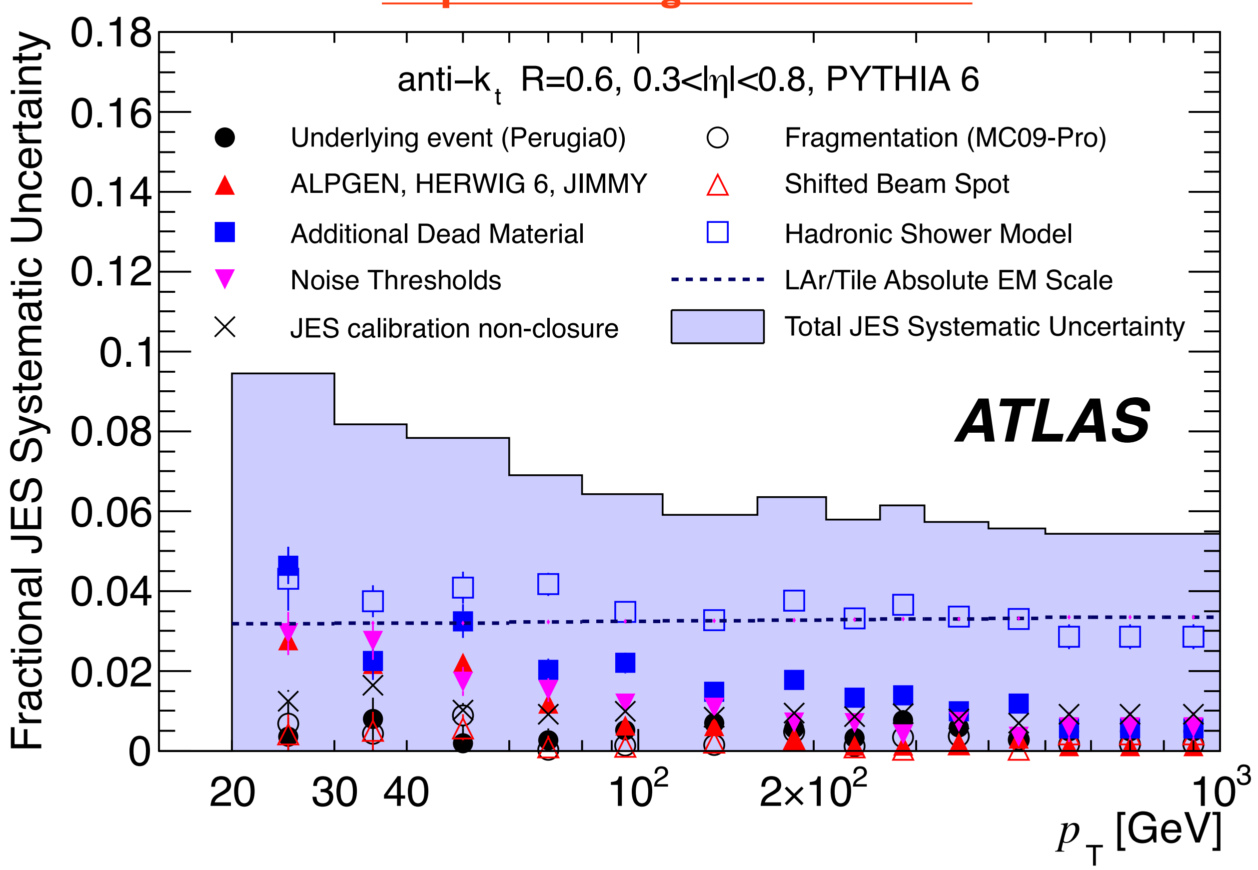


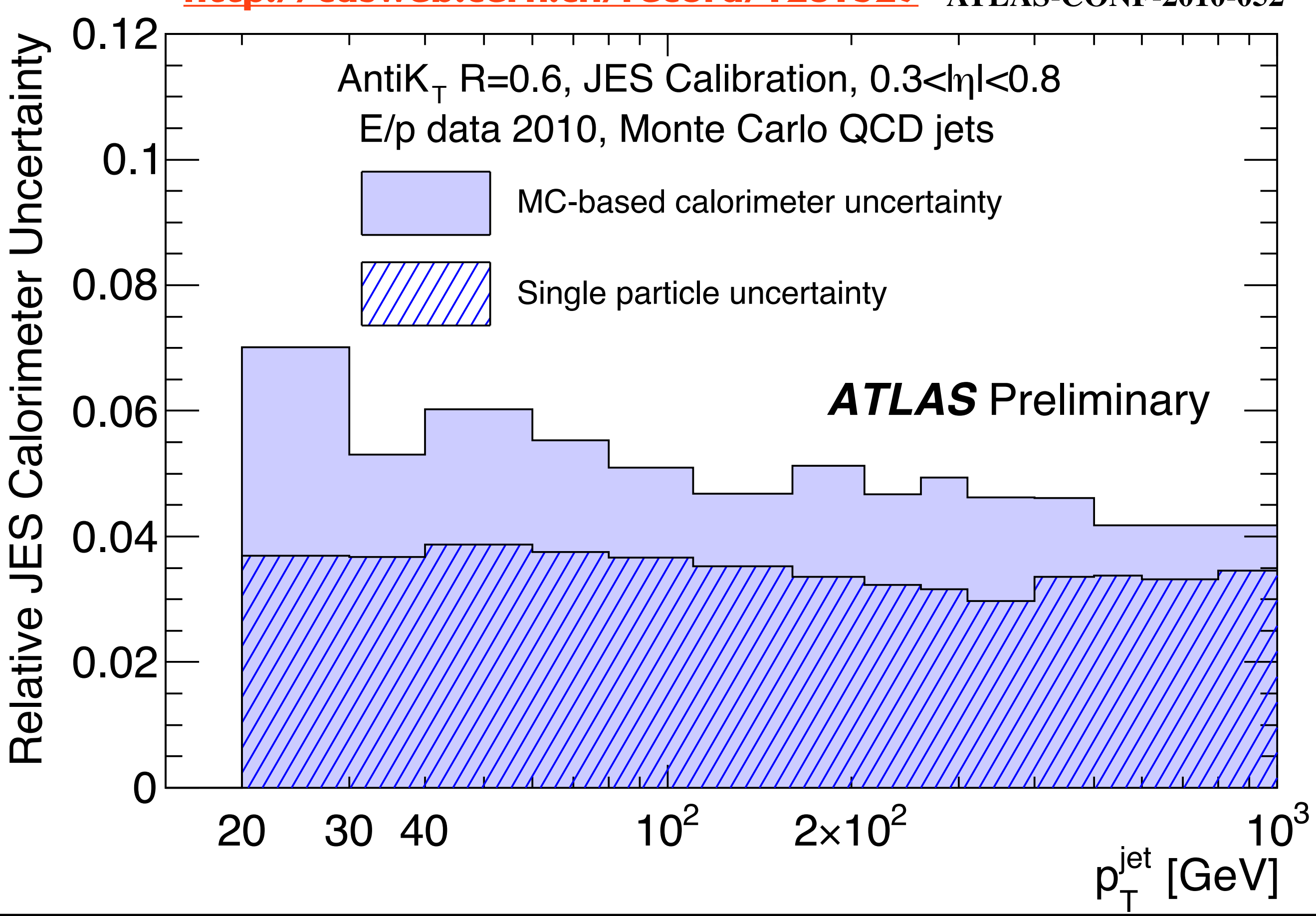
Jet energy scale uncertainty

- Jet energy scale by far the largest systematic uncertainty
  - steeply falling spectrum amplifies the impact
- ~7 % for $p_T > 60$ GeV
- Robust MC based estimate
- Cross checked with single particle response
- In-situ methods will help
- Ultimate goal: ~1%

http://arxiv.org/abs/1009.5908

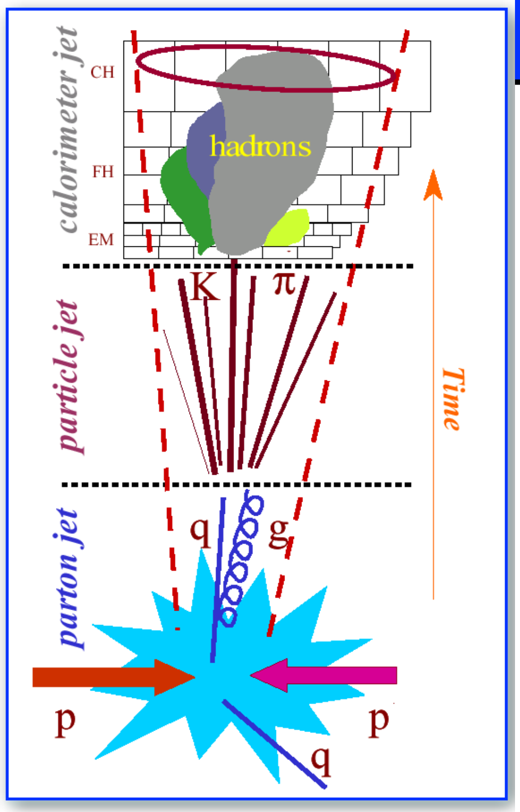


http://cdsweb.cern.ch/record/1281329 ATLAS-CONF-2010-052



Unfolding

- Correct calorimeter jets back to particle level
- Correction factor $c(p_T, y) = \frac{\sigma_{MC}^{truth}}{\sigma_{MC}^{reco}}$
- Corrects also for inefficiencies



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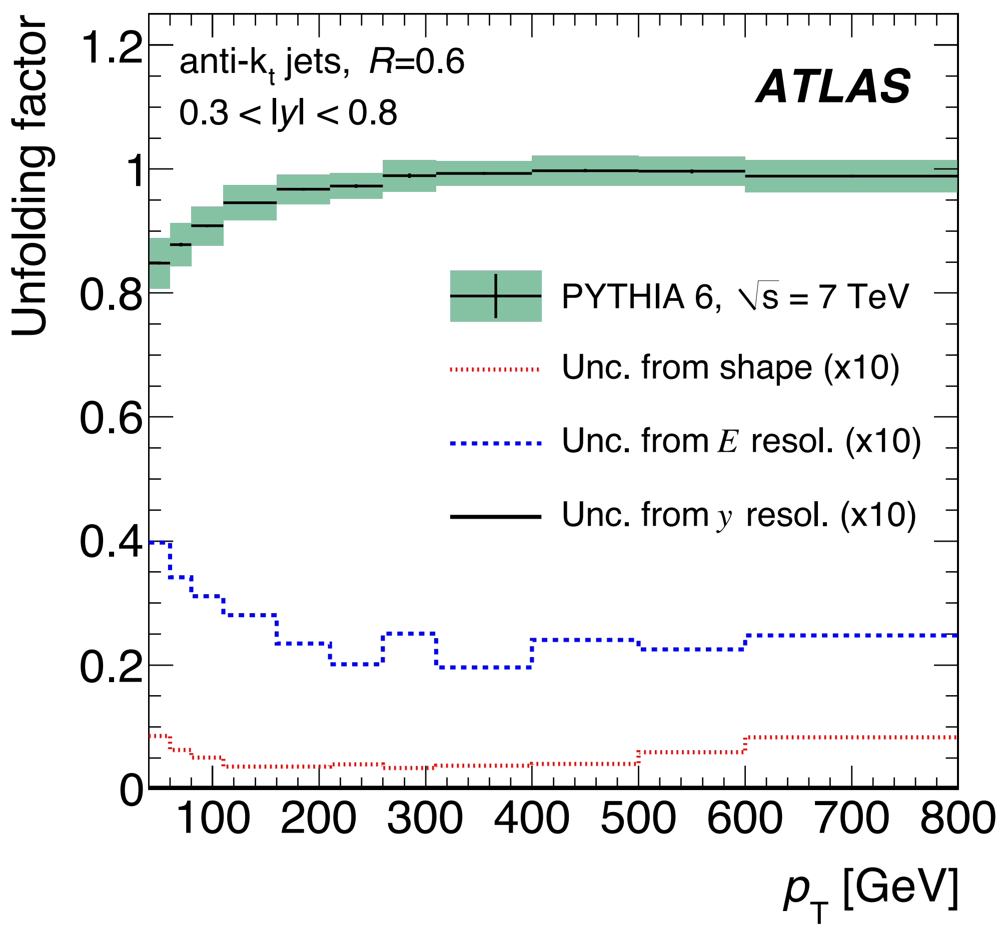


- Bin-by-bin method reasonable choice because
  - pt dependence well described by MC
  - MC describes data in a quite detailed way (see good description of jet shapes)

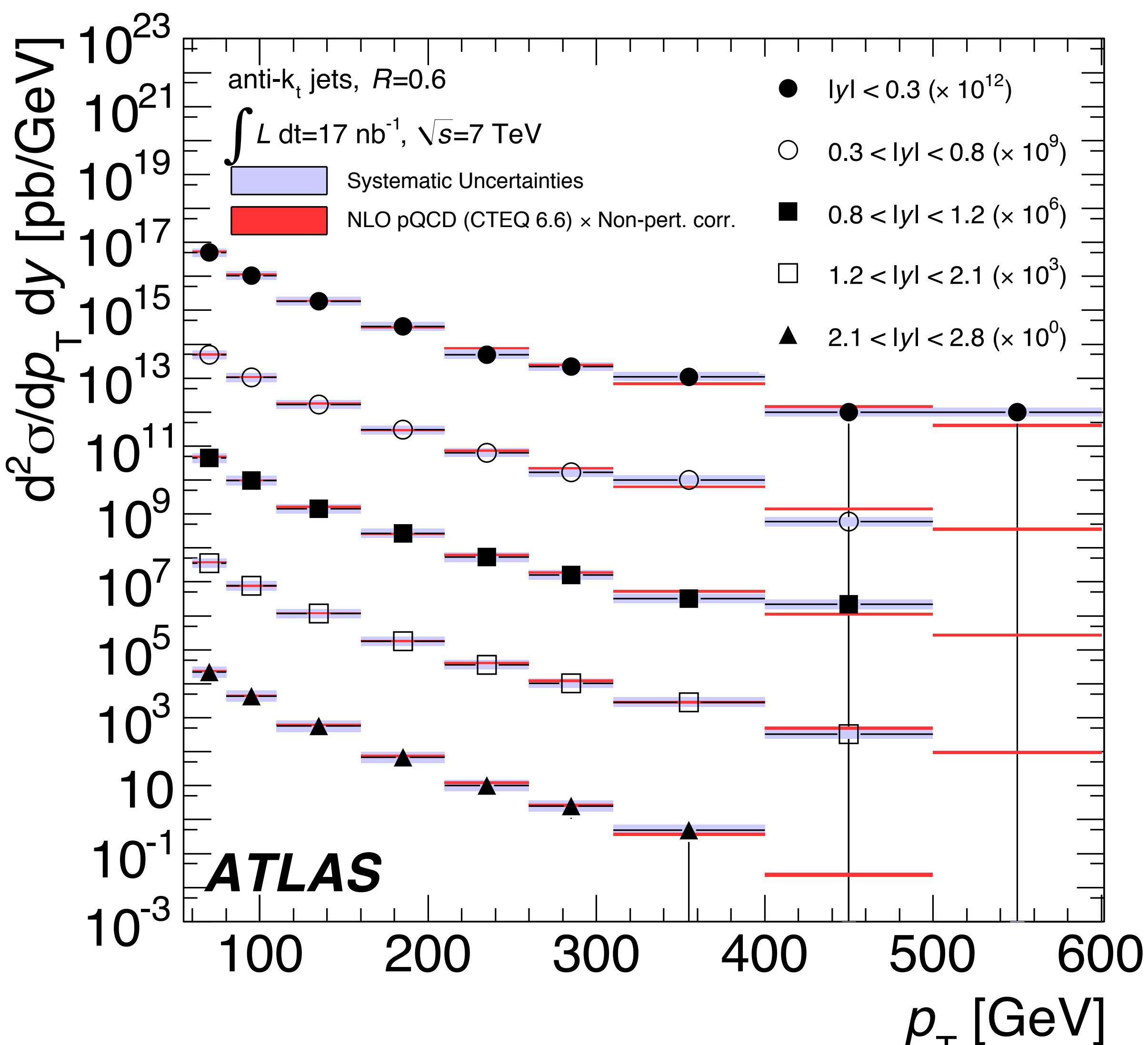
- Uncertainties from:
  - resolution worsening (migrations)
  - expected p_T shape (bias)

Results

- Measurement for R=0.4 and R=0.6 with ICHEP sample $\int \mathcal{L}dt = 17\text{nb}^{-1}$
  - basically no pile up $\mathcal{L}_{peak} < 10^{30}\frac{1}{cm^2 s}$

accepted by EPJC

- Comparing unfolded measurement to NLO prediction
  - calculated with NLOJet++ with CTEQ6.6 + non pert. corrections
- Systematics ~40% (mainly JES)
  - 11% luminosity uncertainty not included



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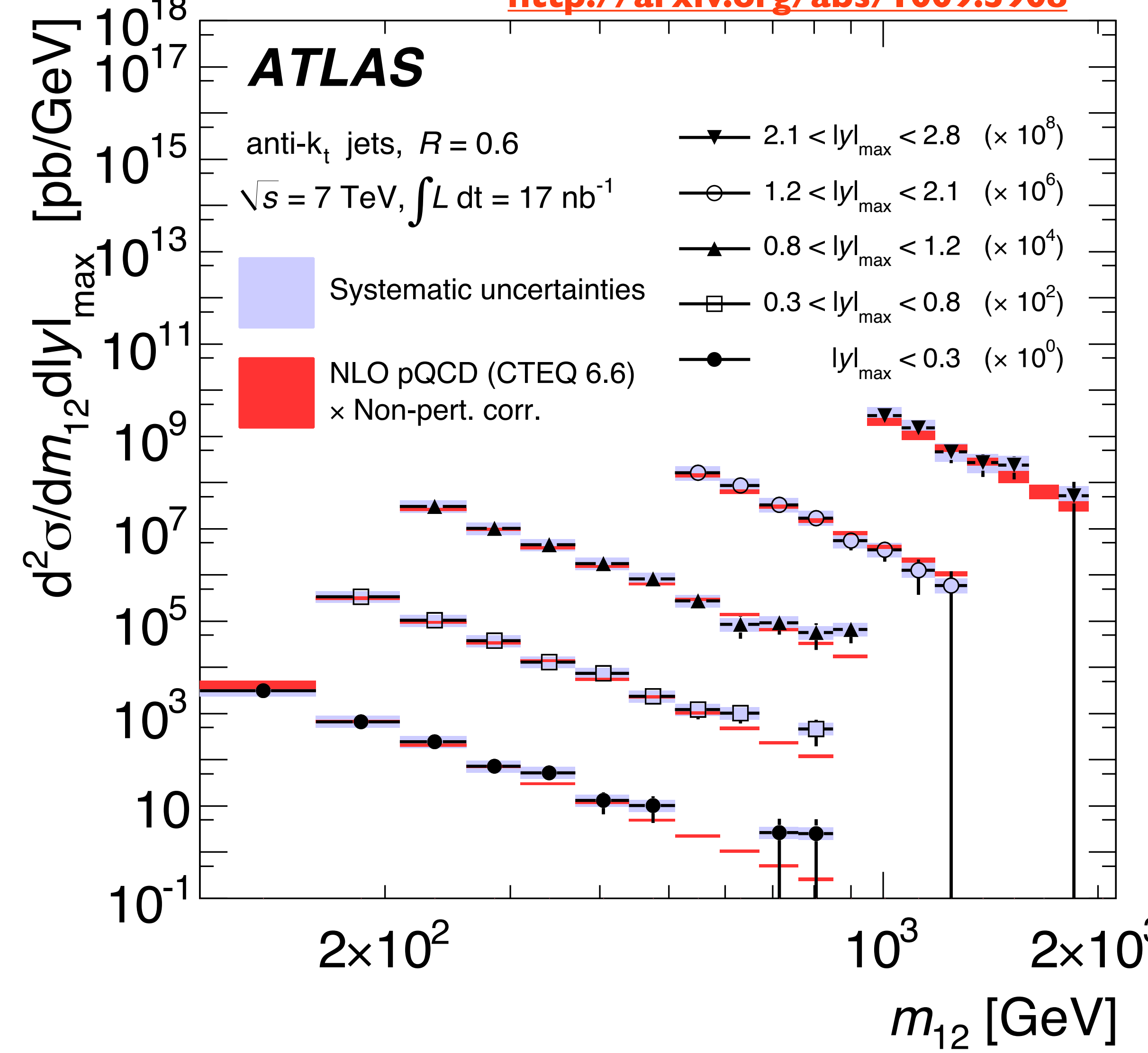
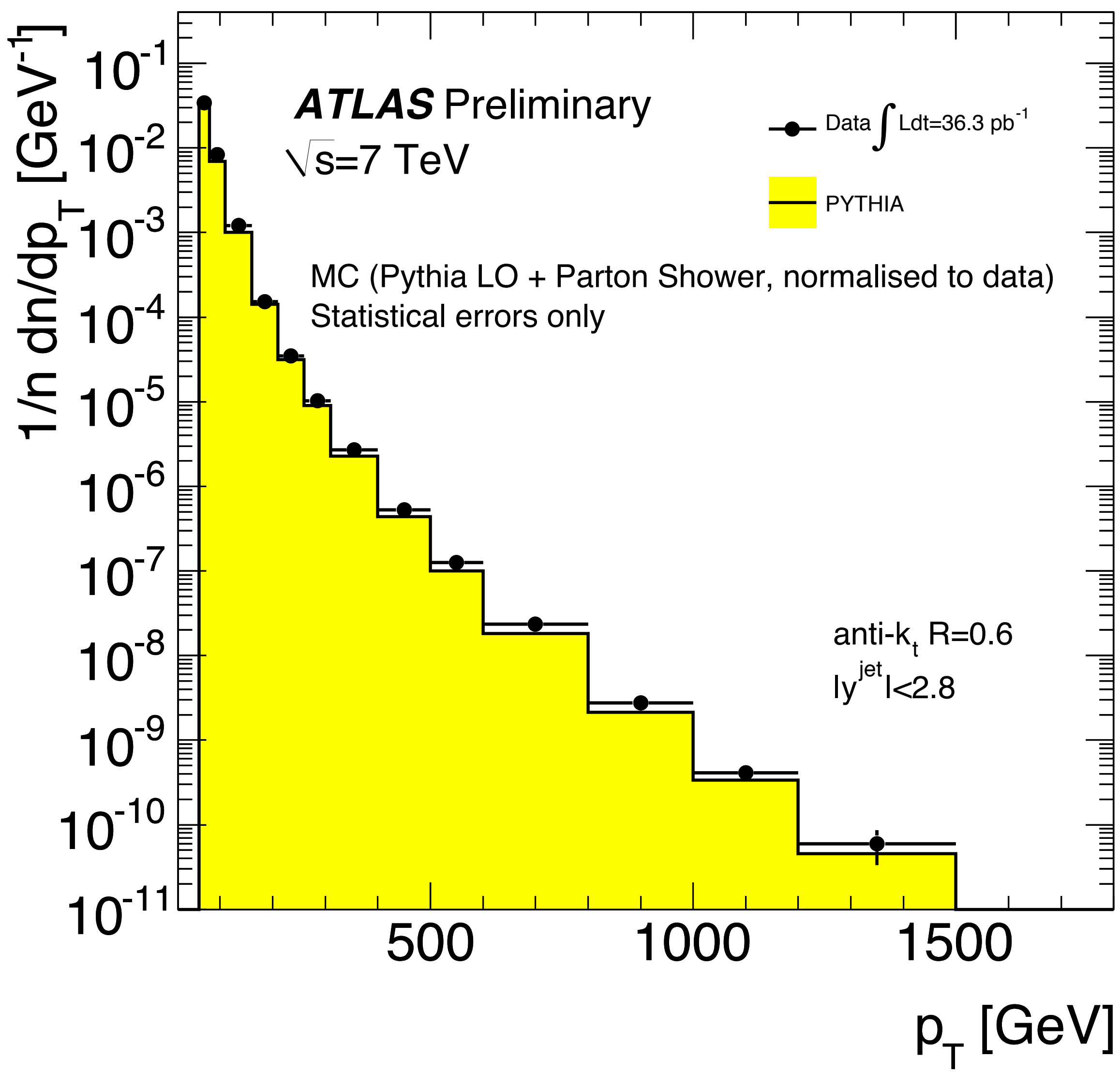
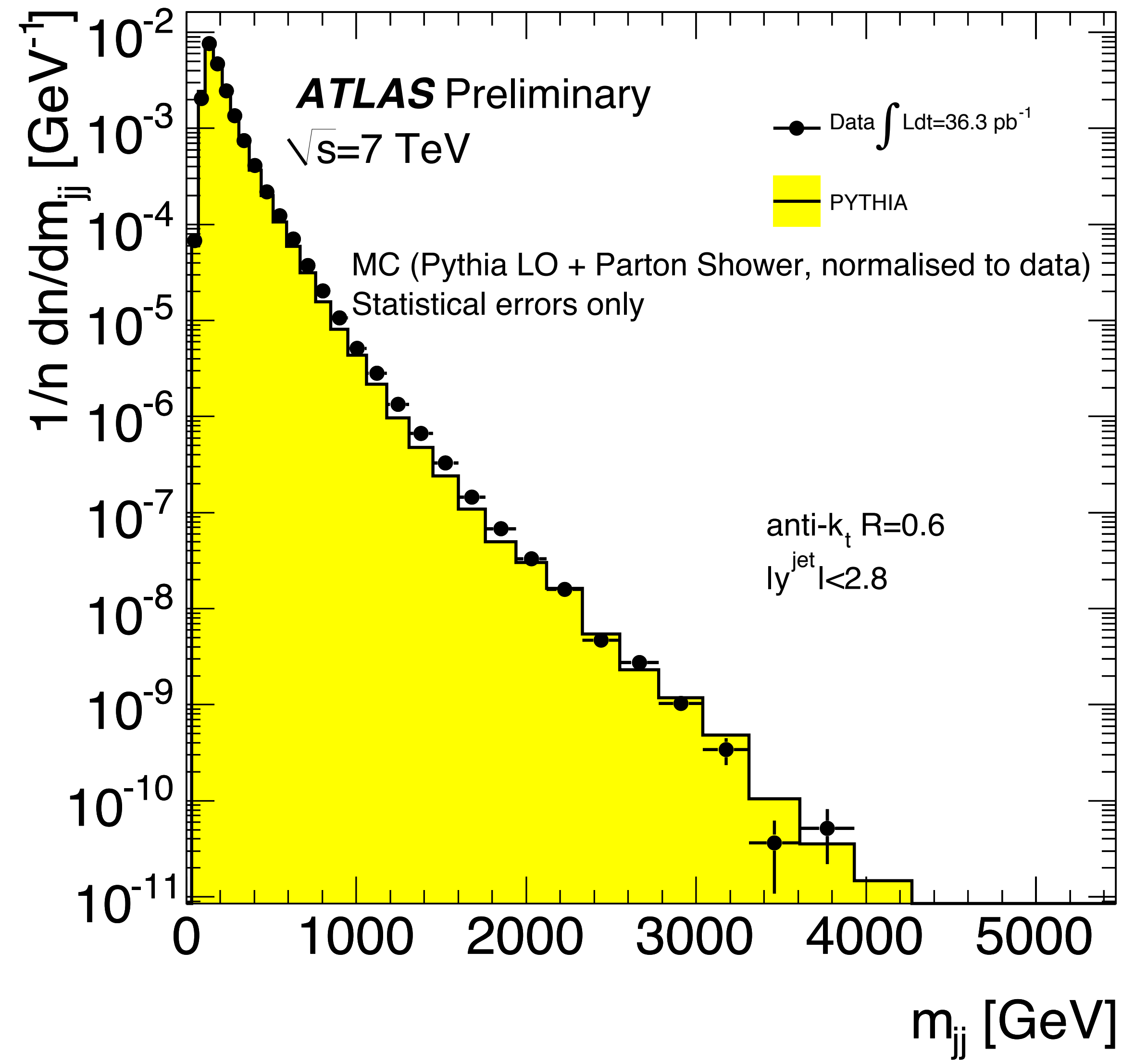


Analysing the 2010 sample..

Extensions

- Paper out with $\int \mathcal{L}dt = 17\mathrm{nb}^{-1}$, the full 2010 sample contains $\int \mathcal{L}dt = 36pb^{-1}$

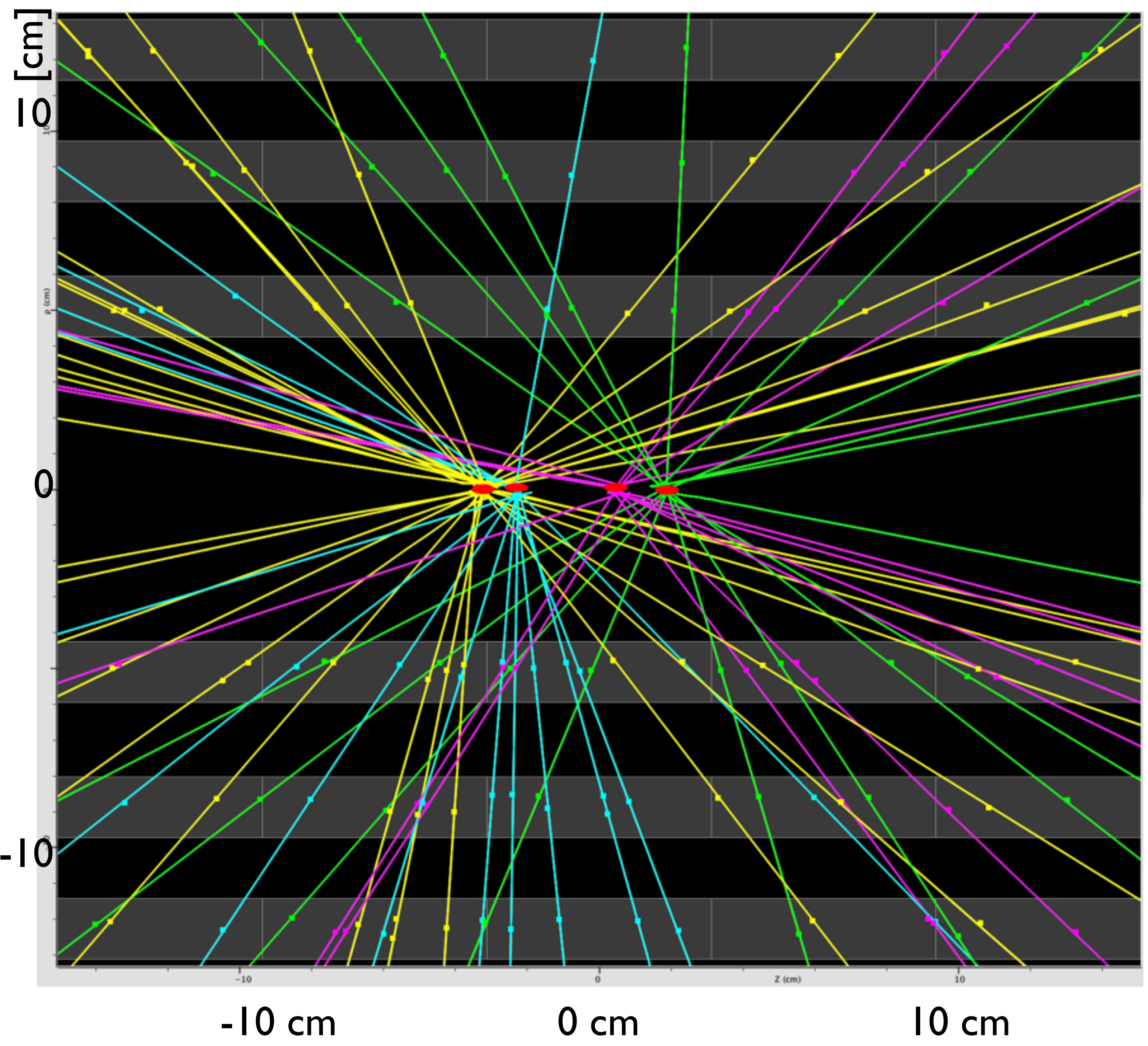




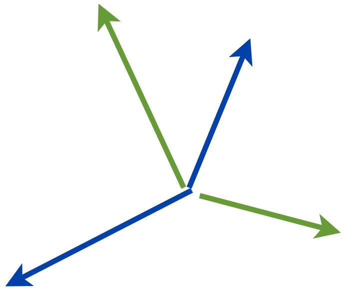
- Two major extensions could be thought of
  - towards higher |y|
    probes low x gluon PDF
  - towards lower p_T
- Improve JES uncertainty to gain sensitivity

Pile up for diJet observables

- Most of 2010 data came in a high luminosity environment
  - latest data: $< N_{PV} > \approx 2.5$ pre ICHEP $< N_{PV} > \approx 1.05$;



- Jet calibration will depend on the pile up environment
- diJet observables might suffer from mis-reconstruction



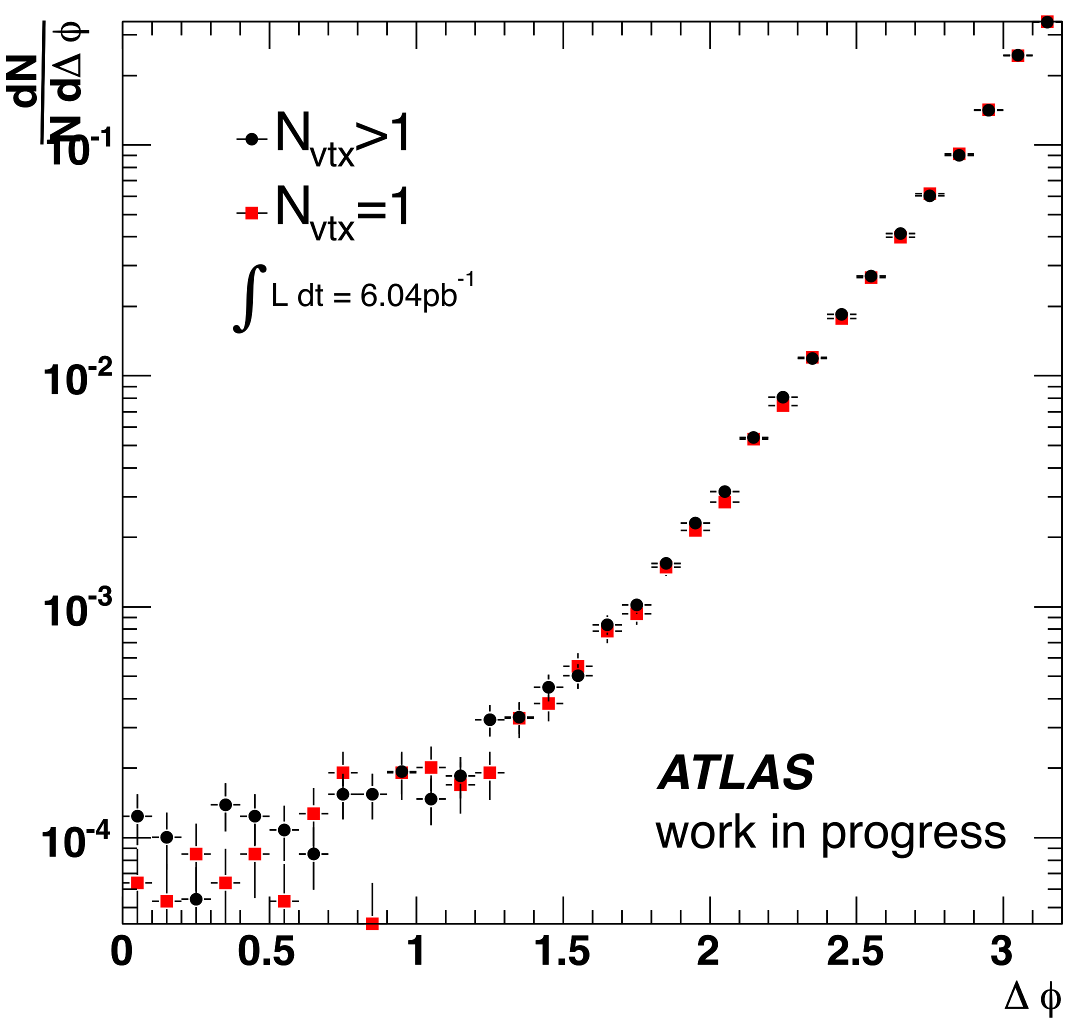
- diJet reconstruction takes the two hardest jets
- How often do we pick the wrong combination?

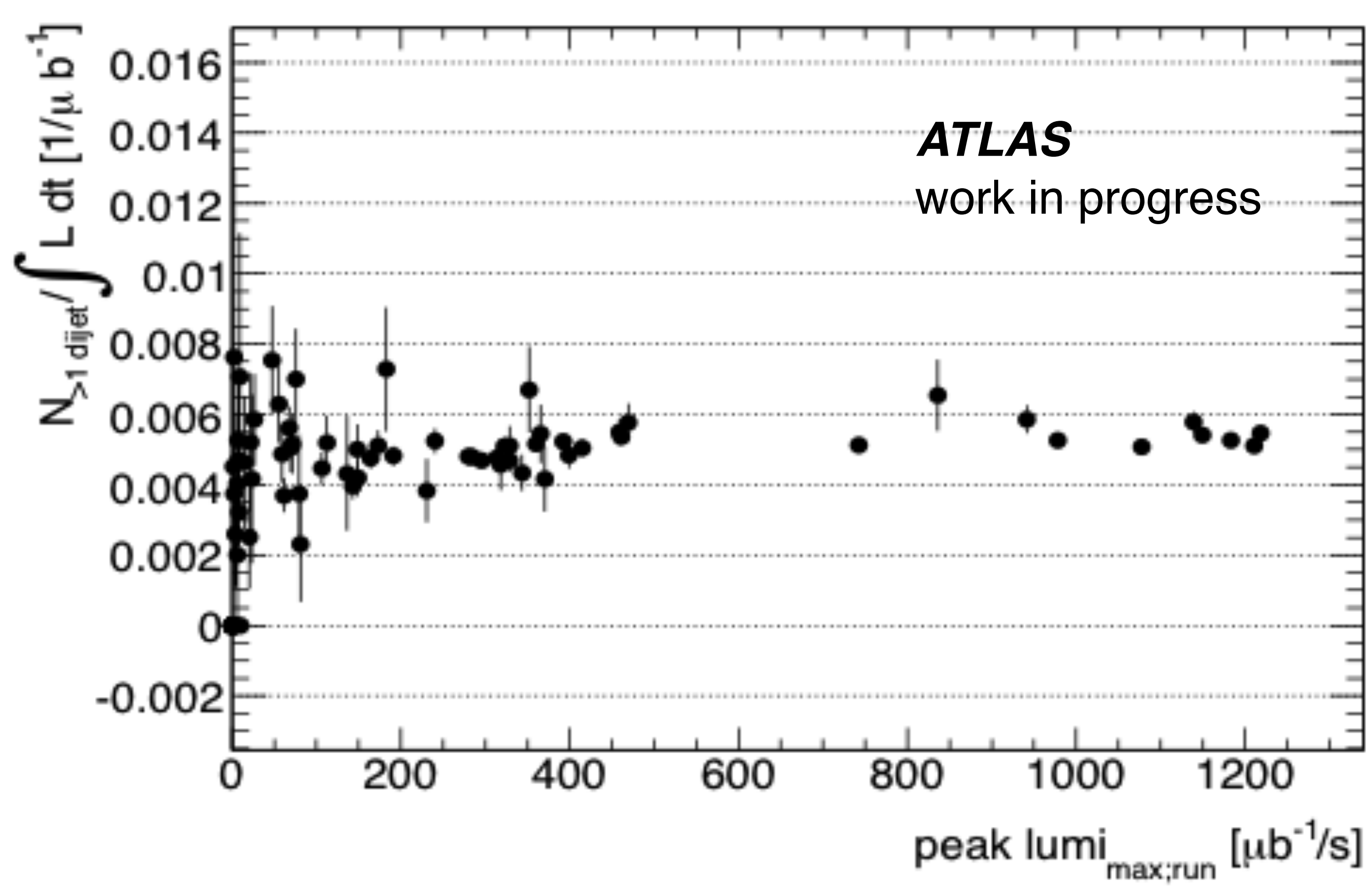
one 4-jet event ?
two 2-jet events?

Pile up for diJet observables

- How large are these effects?

- Two distributions containing information about this:
  - number of events with > 1 diJet candidates (how hard is pile up)
  - $\Delta\phi$ between the two selected jets (how often are events mis-reconstructed)





Trigger combination

- High cross-section → Jet trigger prescaled early and heavy

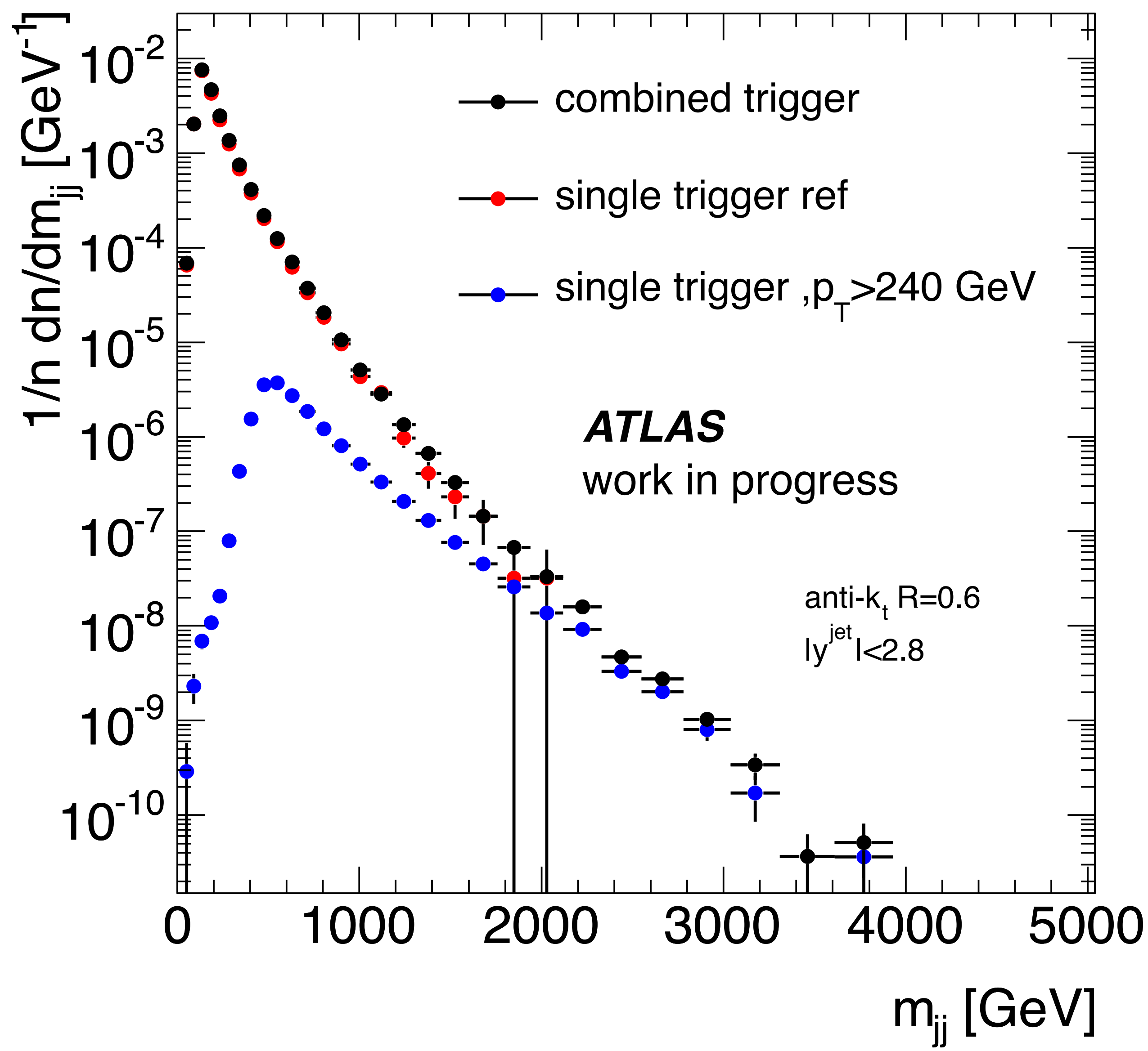
- Combination of different triggers non trivial for diJet observables
  - trigger is not a direct function of the measured observable

- One possible approach:
  - cut on p_T
  - evaluate unbiased m_{jj}^{thresh}

- at LO: $M_{jj}^2 = 2p_{T,1}p_{T,2} * (\mathrm{Cosh}(\Delta\eta) + 1)$
  - highly non linear at large rapidities

- Second approach:
  - measure the diJet mass in bins of p_T^{lead}, use one

$$\frac{d\sigma}{dm_{jj}} = \int dp_T^{lead} \frac{d^2\sigma}{dm_{jj}dp_T^{lead}}$$



by construction the optimal way to combine

Summary

- Presented measurement of inclusive Jet production and diJet production
  - using $\int \mathcal{L}dt = 17\mathrm{nb}^{-1}$ of data
- Understanding of the calorimeter response to jets makes fast progress
- A first jet energy scale is set-up based on MC with various data crosschecks
  - its uncertainty is the robust result of detailed studies of various effects
- Jet energy scale uncertainty will benefit from in-situ methods

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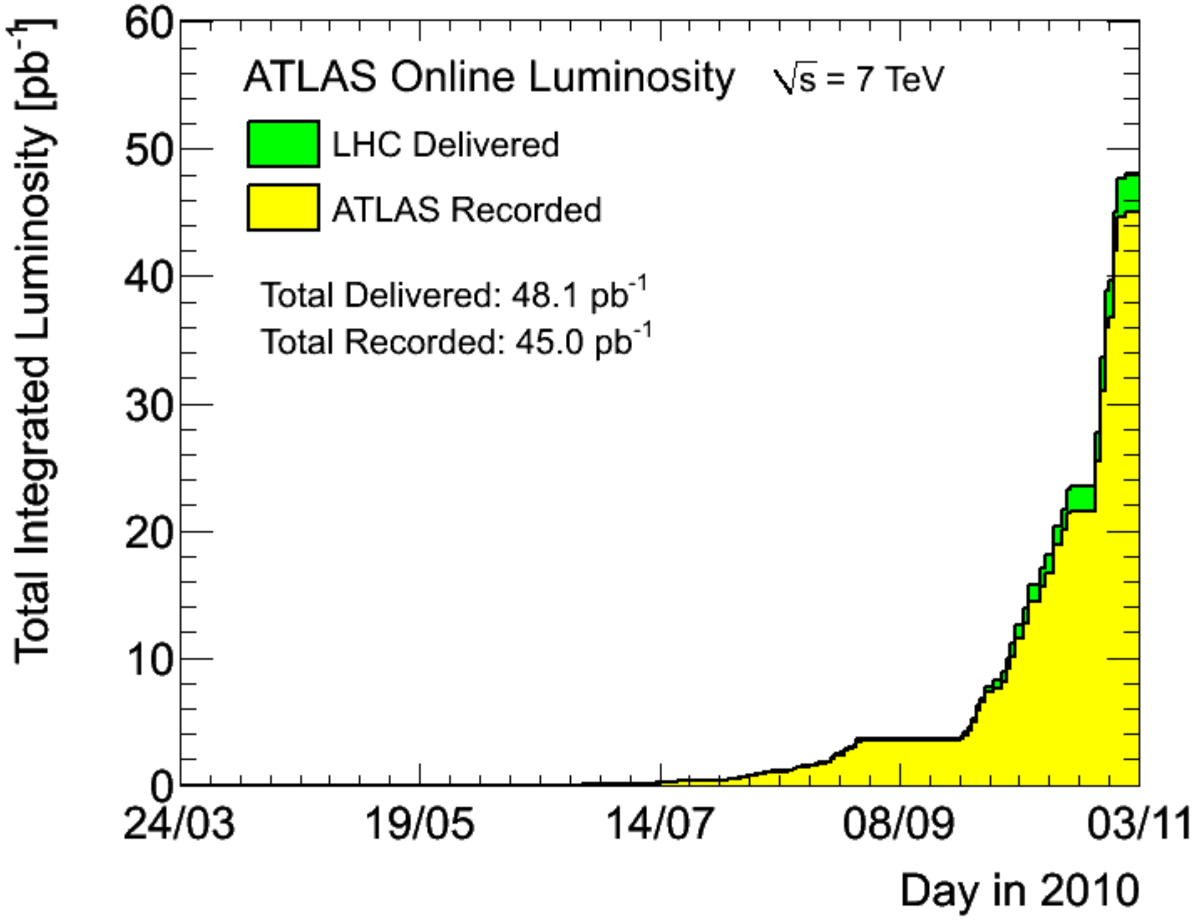
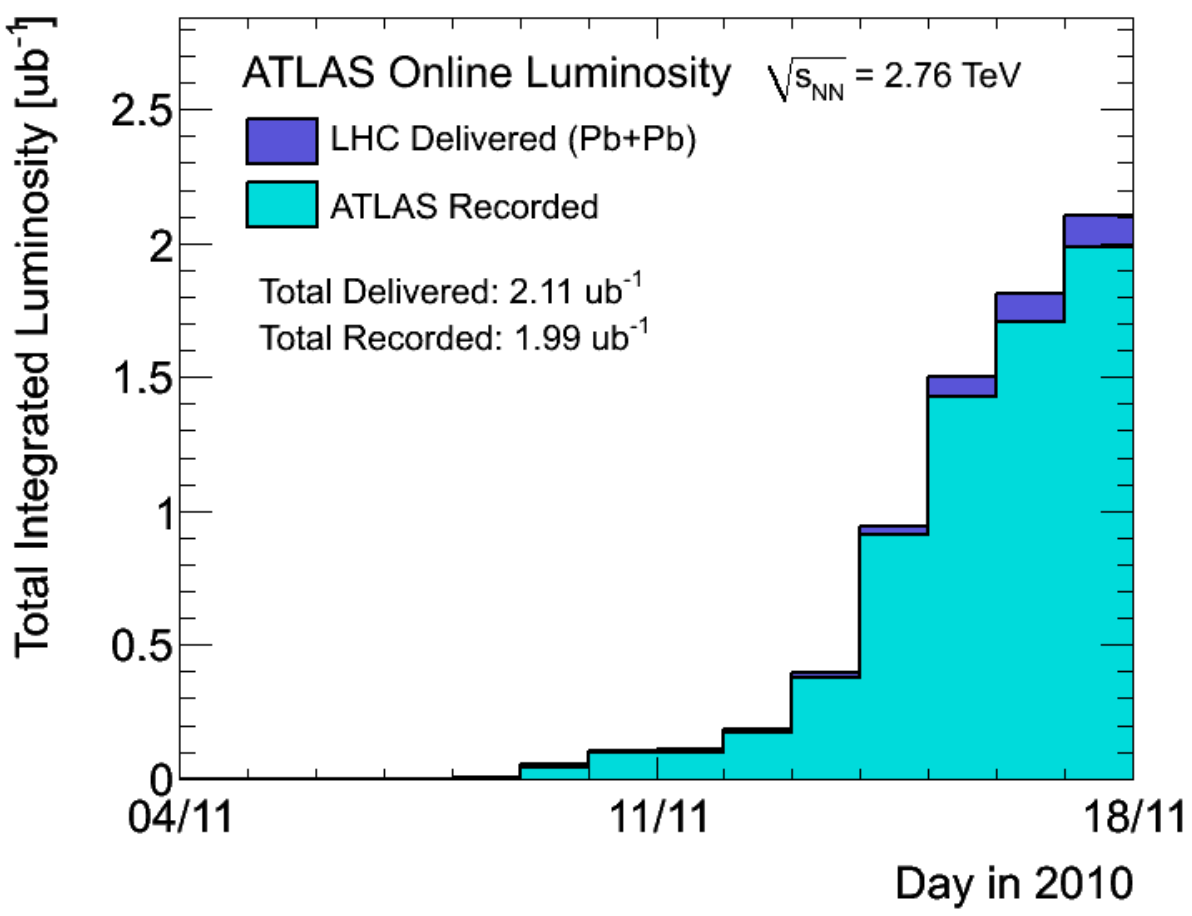
- ~2000 times more data on tape
  - ..just waiting to be analysed
- Lot of work is ongoing to control effects like multiple interactions, calorimeter response in bunch trains etc..
- Great prospects for QCD @ LHC..

BACKUP

Data taking summery





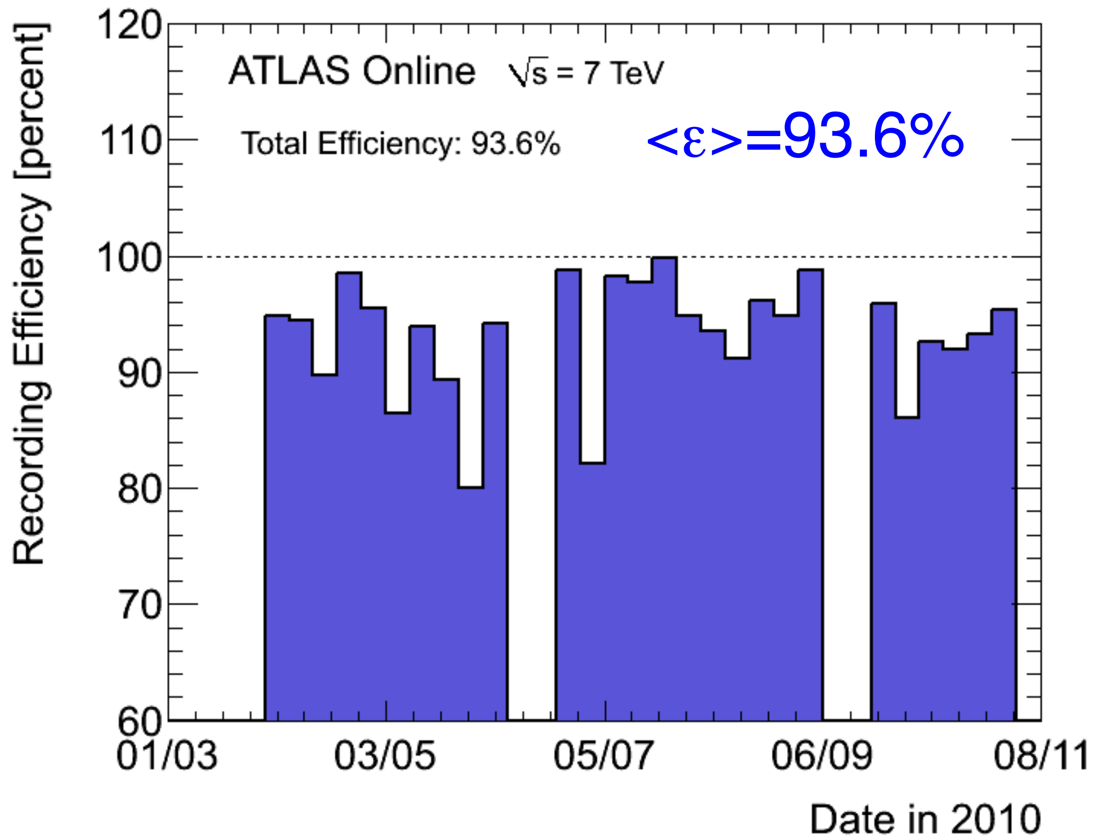
Data quality

Inner Tracking Detectors			Calorimeters				Muon Detectors			
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	CSC	TGC
99.0	99.9	100	90.5	96.6	97.8	94.3	99.9	99.8	96.2	99.8

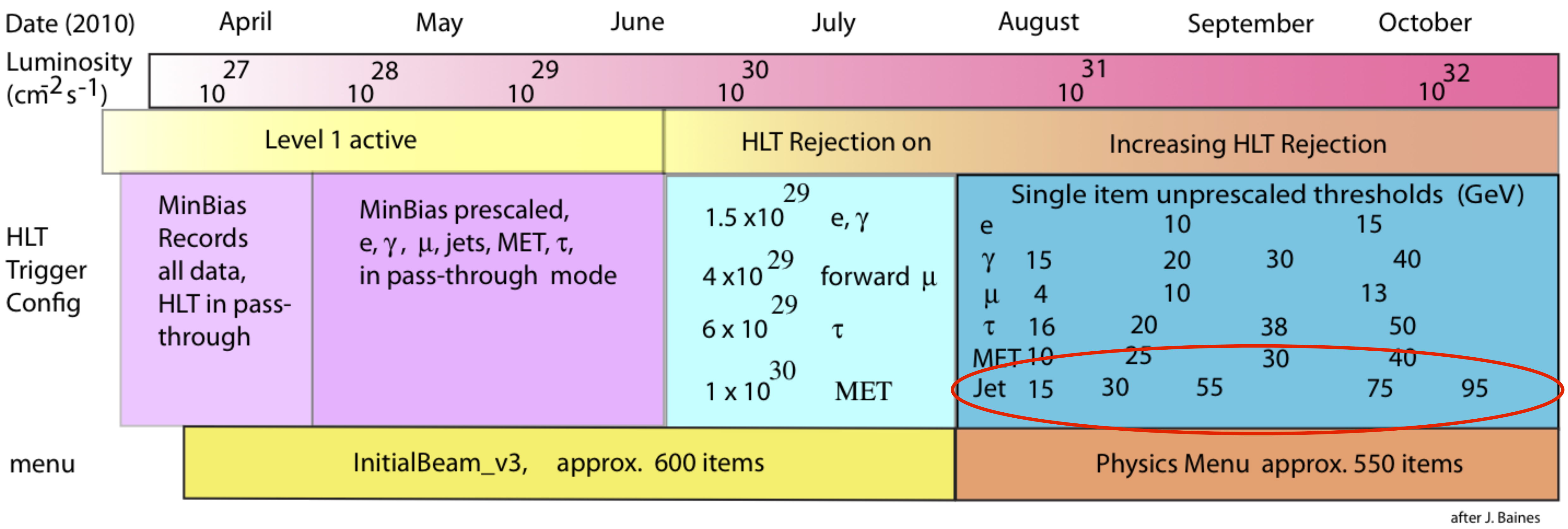
Luminosity weighted relative detector uptime and good quality data delivery during 2010 stable beams at √s=7 TeV between March 30th and October 31st (in %). The inefficiencies in the calorimeters will largely be recovered in a future data reprocessing.

- Fraction of good quality data for the 45 pb^{-1} of pp data recorded
  - Problems in different subdetectors not correlated in time. With first-pass processing, ~40pb^{-1} for μ, 36 pb^{-1} for e or E_T^{miss} analyses
- LAr: HV trips and noise bursts
  - Will be partially recovered with reprocessing
- Tile: Incorrect bad channel masking for one fill
  - Will be fully recovered by reprocessing
- CSC: 6/16 problematic chambers on one side for three days
  - Chambers were recovered after an access.

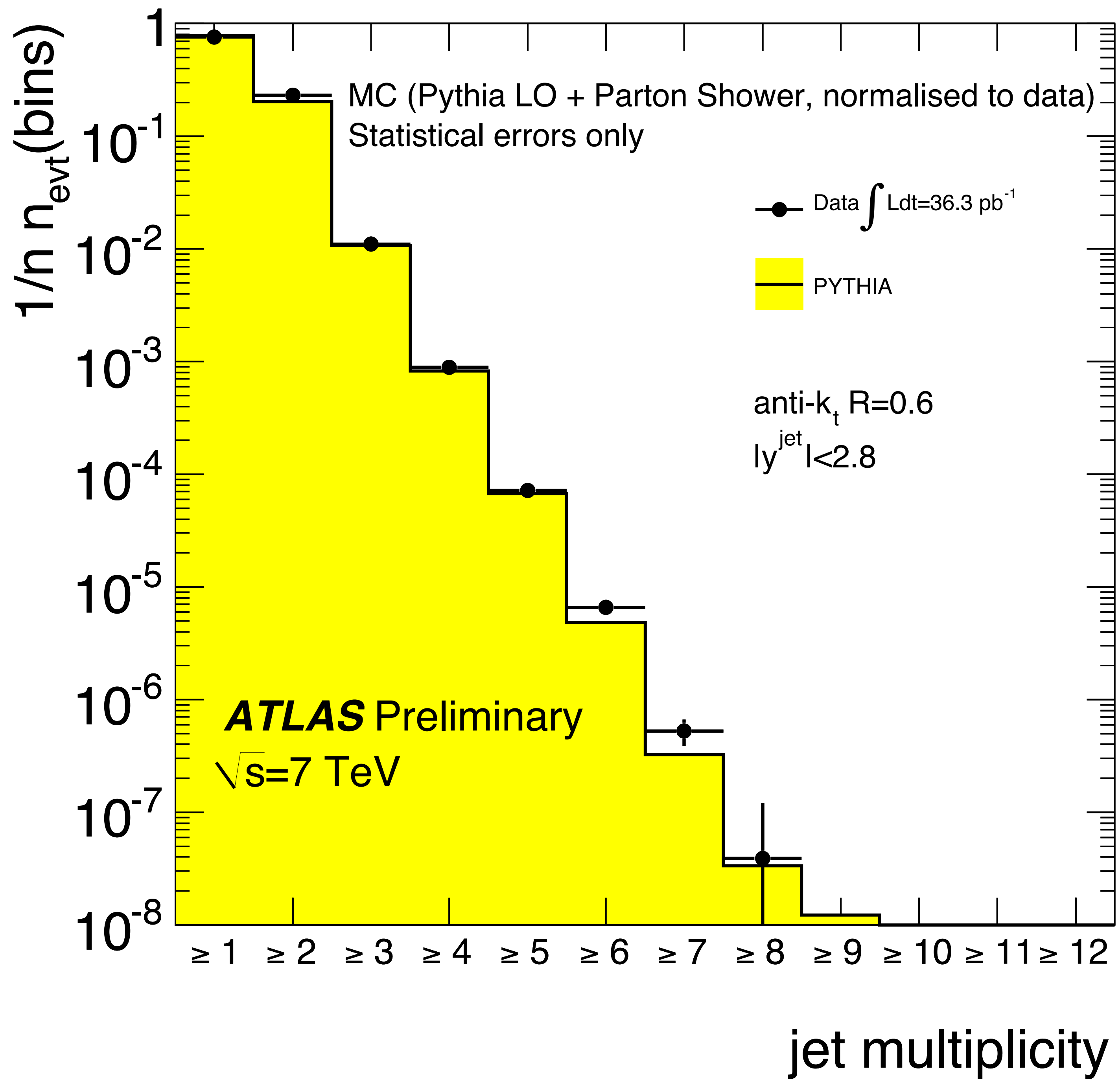
17 Nov 2010 Pippa Wells, ATLAS



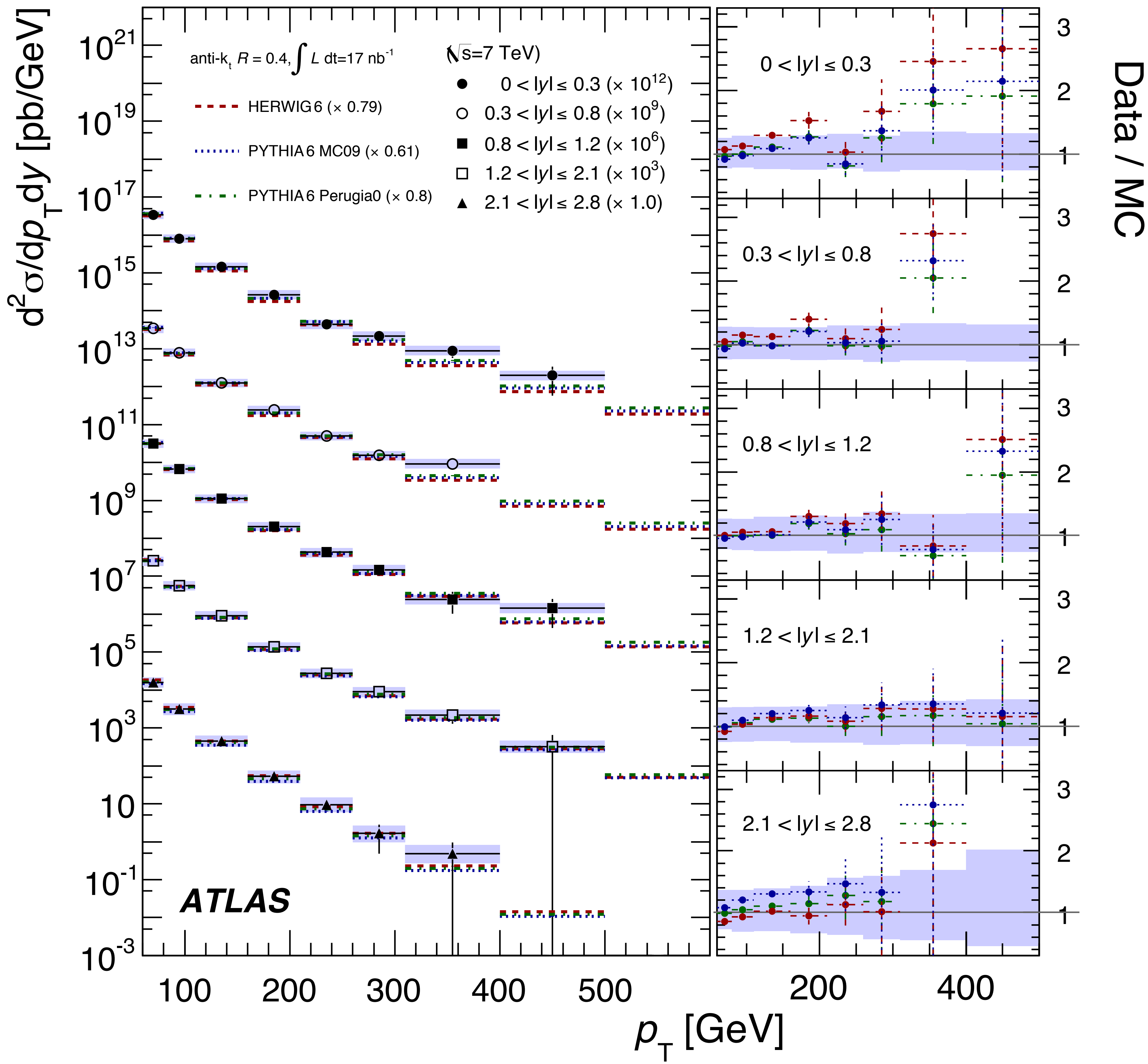
Data taking summery



- observing high multiplicity events

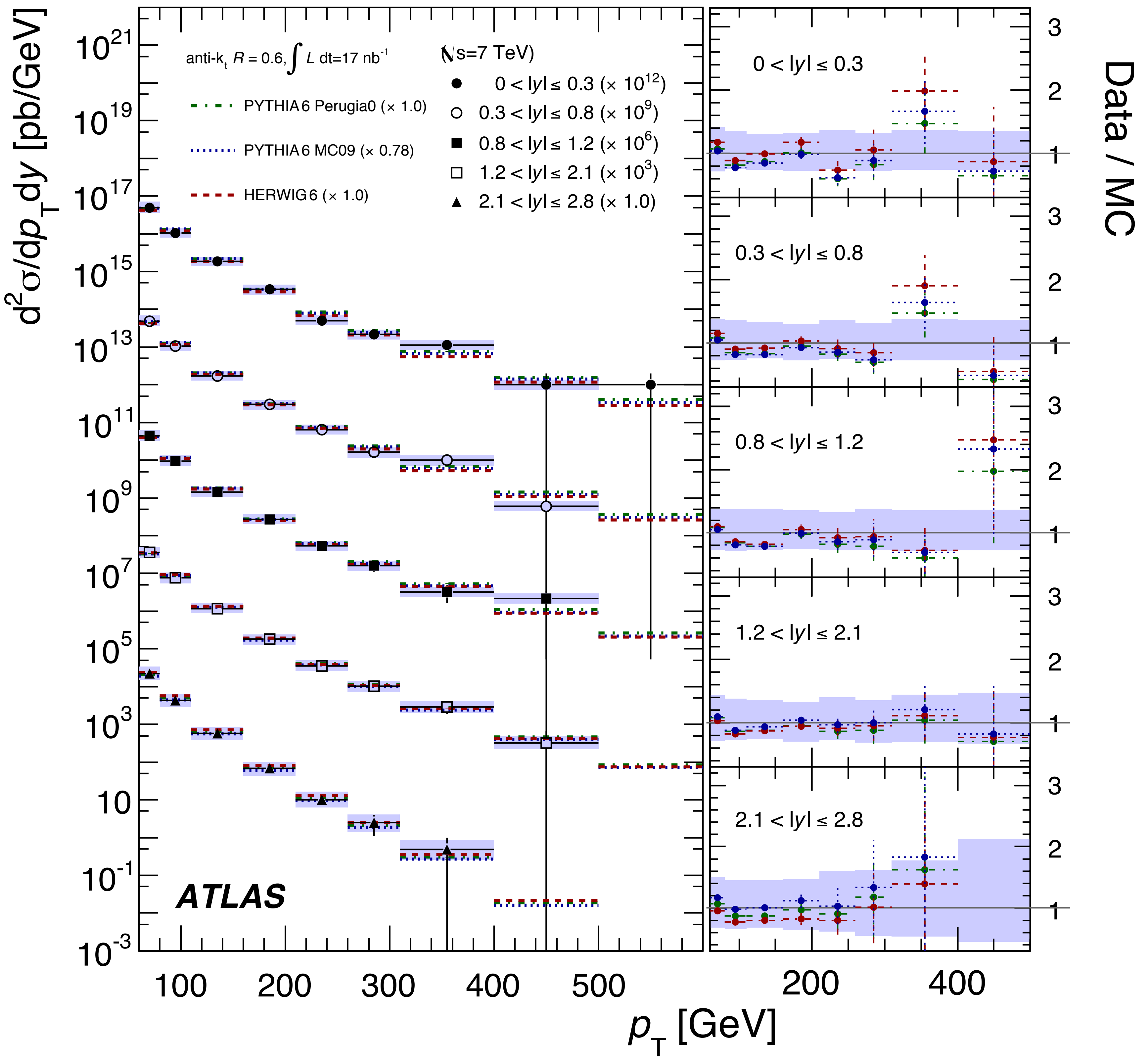


results R=0.4



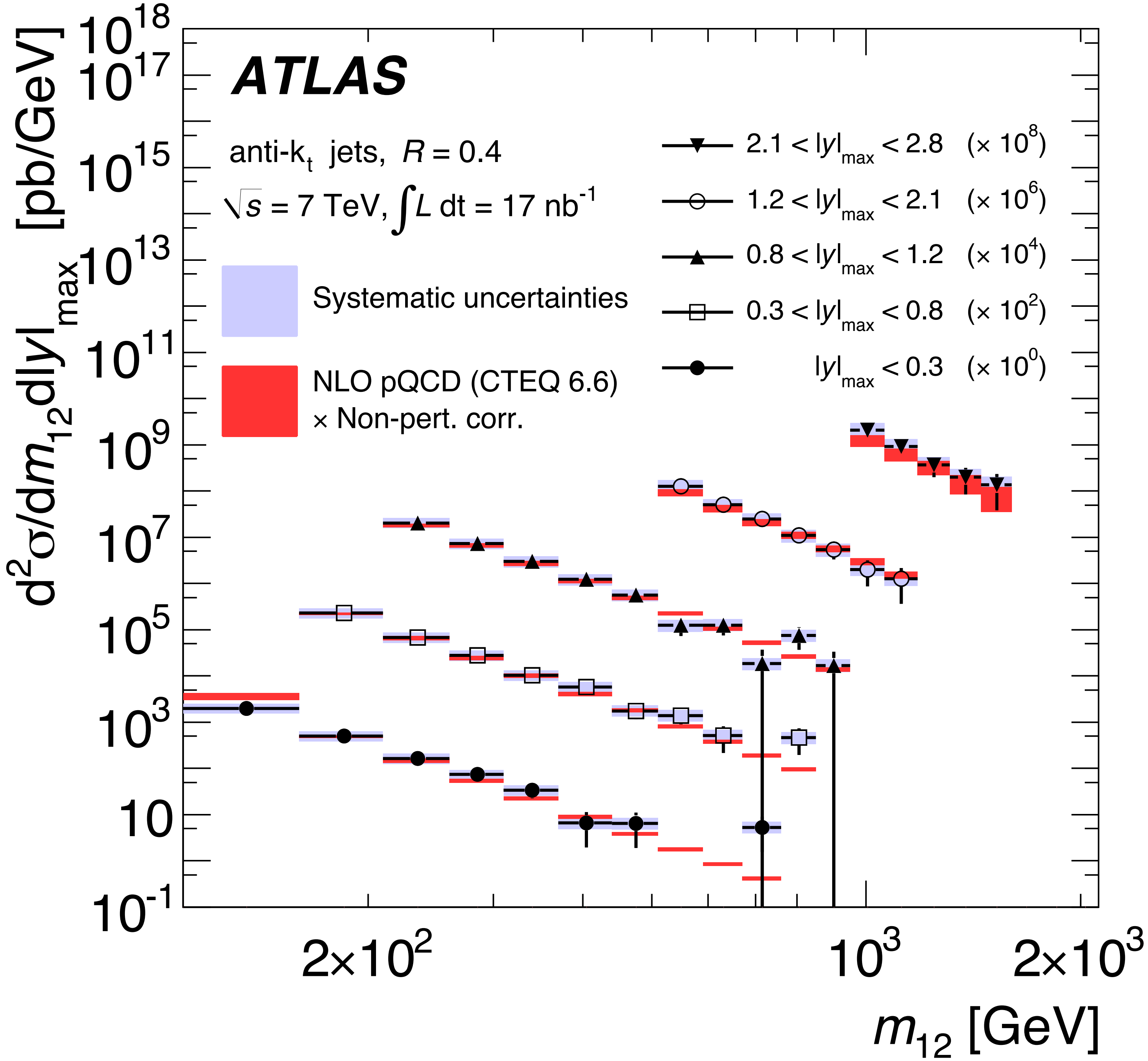
anti-k$_t$ R = 0.4, $\int L$ dt=17 nb^{-1}
$\sqrt{s}$=7 TeV)
HERWIG6 (× 0.79)
PYTHIA6 MC09 (× 0.61)
PYTHIA6 Perugia0 (× 0.8)
0 < |y| ≤ 0.3 (× 10^{12})
0.3 < |y| ≤ 0.8 (× 10^{9})
0.8 < |y| ≤ 1.2 (× 10^{6})
1.2 < |y| ≤ 2.1 (× 10^{3})
2.1 < |y| ≤ 2.8 (× 1.0)
ATLAS
$d^2\sigma/dp_T dy$ [pb/GeV]
p_T [GeV]
Data / MC
0 < |y| ≤ 0.3
0.3 < |y| ≤ 0.8
0.8 < |y| ≤ 1.2
1.2 < |y| ≤ 2.1
2.1 < |y| ≤ 2.8

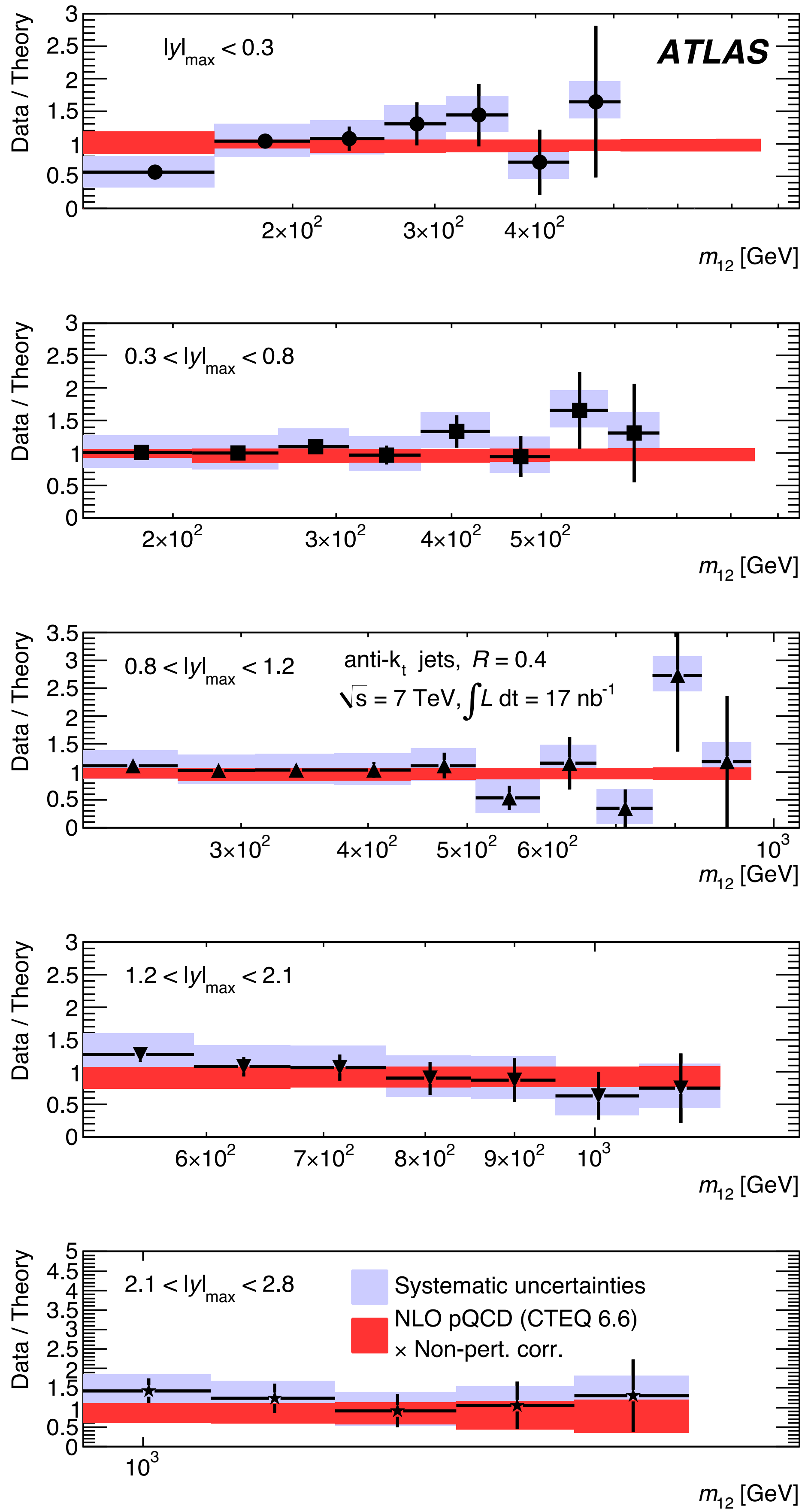
results R=0.6



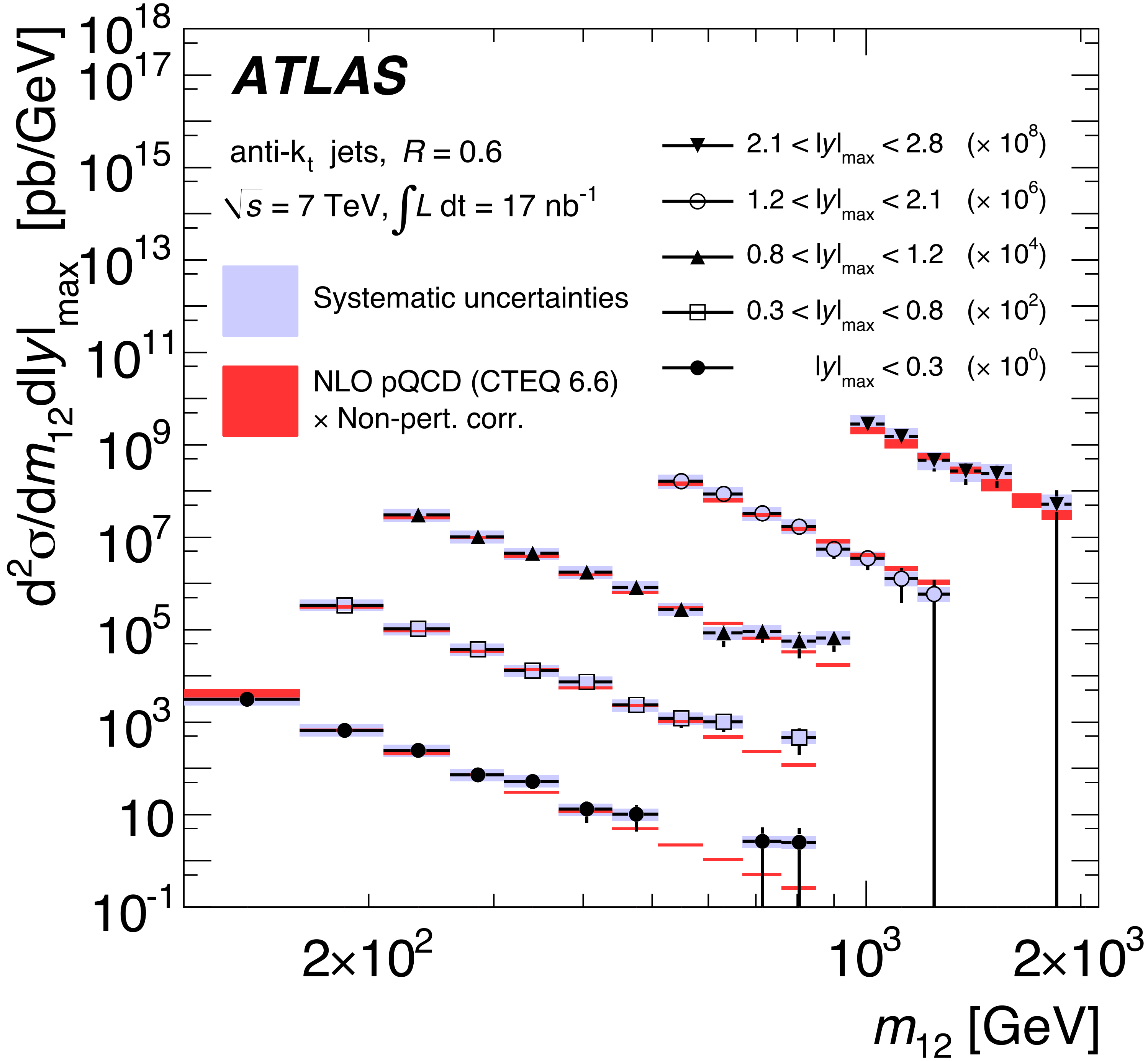
anti-k$_t$ R = 0.6, ∫ L dt=17 nb^{-1}
√s=7 TeV)
PYTHIA6 Perugia0 (× 1.0)
PYTHIA6 MC09 (× 0.78)
HERWIG6 (× 1.0)
0 < |y| ≤ 0.3 (× 10^{12})
0.3 < |y| ≤ 0.8 (× 10^{9})
0.8 < |y| ≤ 1.2 (× 10^{6})
1.2 < |y| ≤ 2.1 (× 10^{3})
2.1 < |y| ≤ 2.8 (× 1.0)
ATLAS
d^{2}σ/dp$_T$dy [pb/GeV]
p$_T$ [GeV]
Data / MC
0 < |y| ≤ 0.3
0.3 < |y| ≤ 0.8
0.8 < |y| ≤ 1.2
1.2 < |y| ≤ 2.1
2.1 < |y| ≤ 2.8

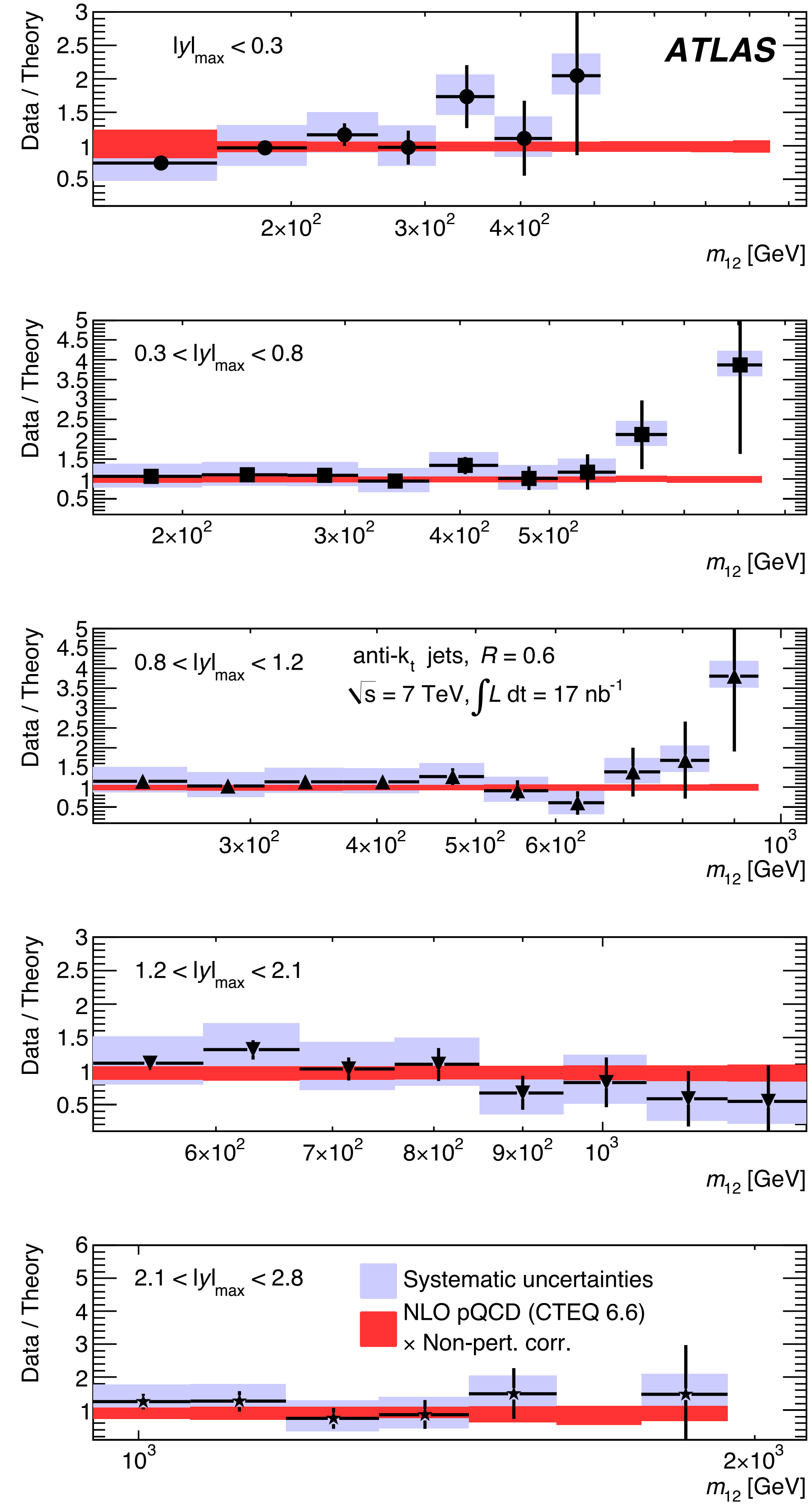
results R=0.4


ATLAS
anti-k_t jets, $R = 0.4$
$\sqrt{s}$ = 7 TeV, $\int L\, dt$ = 17 nb^{-1}
Systematic uncertainties
NLO pQCD (CTEQ 6.6) × Non-pert. corr.
$2.1 < |y|_{max} < 2.8$ ($\times 10^8$)
$1.2 < |y|_{max} < 2.1$ ($\times 10^6$)
$0.8 < |y|_{max} < 1.2$ ($\times 10^4$)
$0.3 < |y|_{max} < 0.8$ ($\times 10^2$)
$|y|_{max} < 0.3$ ($\times 10^0$)
$d^2\sigma/dm_{12}d|y|_{max}$ [pb/GeV]
m_{12} [GeV]

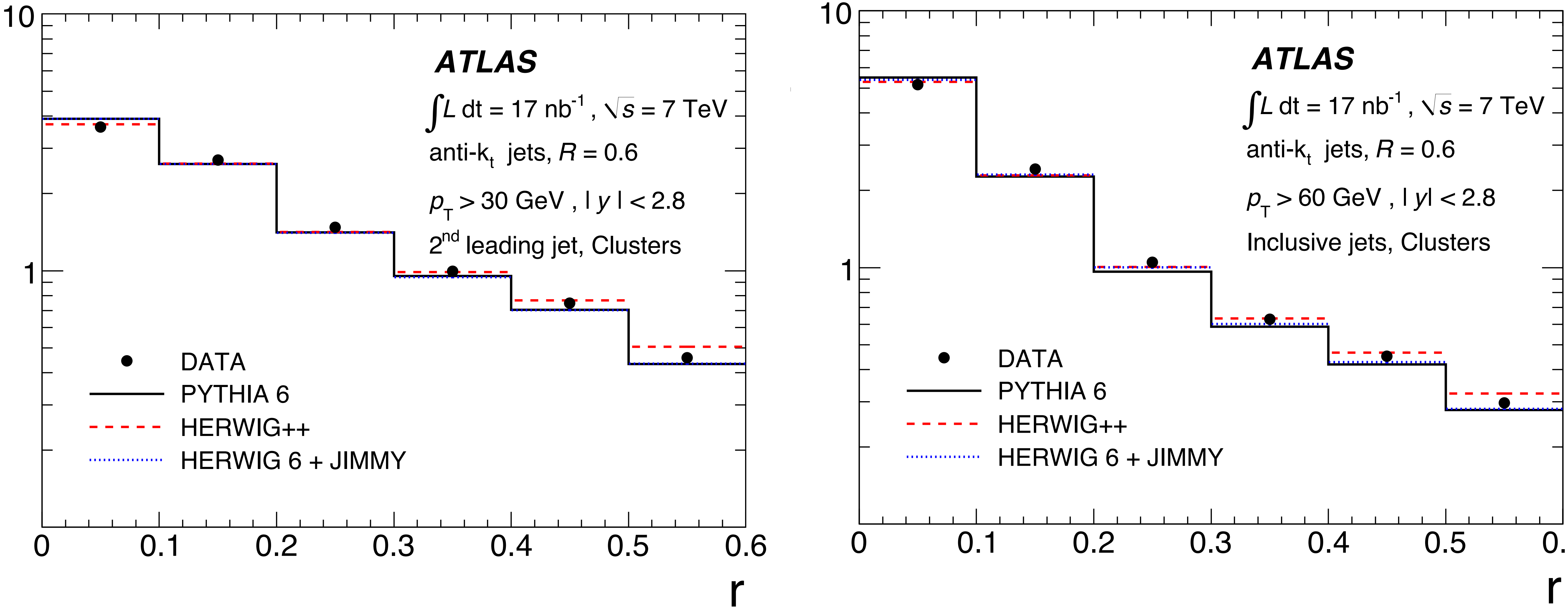

ATLAS
$|y|_{max} < 0.3$
$0.3 < |y|_{max} < 0.8$
$0.8 < |y|_{max} < 1.2$
anti-k_t jets, $R = 0.4$
$\sqrt{s}$ = 7 TeV, $\int L\, dt$ = 17 nb^{-1}
$1.2 < |y|_{max} < 2.1$
$2.1 < |y|_{max} < 2.8$
Systematic uncertainties
NLO pQCD (CTEQ 6.6) × Non-pert. corr.
Data / Theory
m_{12} [GeV]

results R=0.6

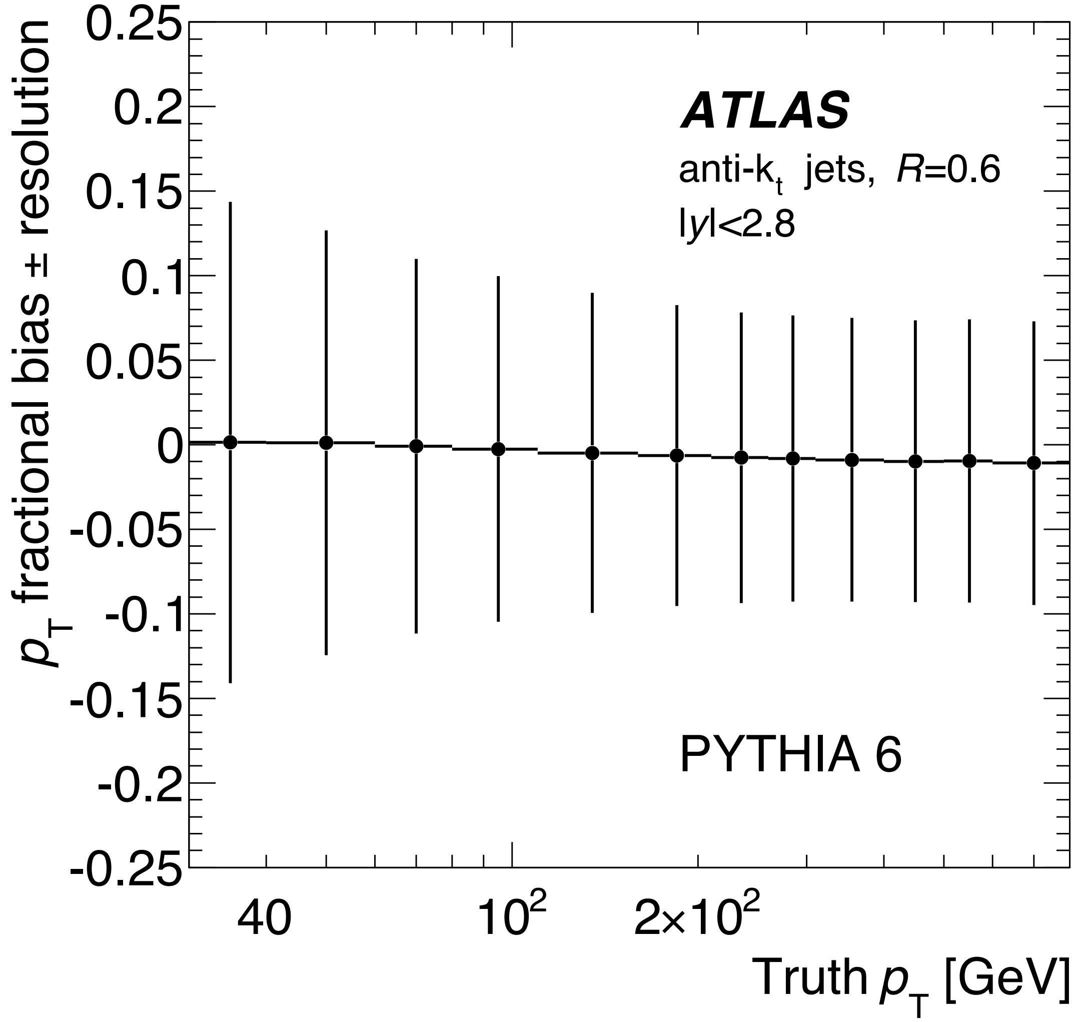

ATLAS
anti-k_t jets, $R = 0.6$
$\sqrt{s}$ = 7 TeV, $\int L\,dt$ = 17 nb^{-1}
Systematic uncertainties
NLO pQCD (CTEQ 6.6)
× Non-pert. corr.
$2.1 < |y|_{max} < 2.8$ (× 10^8)
$1.2 < |y|_{max} < 2.1$ (× 10^6)
$0.8 < |y|_{max} < 1.2$ (× 10^4)
$0.3 < |y|_{max} < 0.8$ (× 10^2)
$|y|_{max} < 0.3$ (× 10^0)
$d^2\sigma/dm_{12}d|y|_{max}$ [pb/GeV]
m_{12} [GeV]

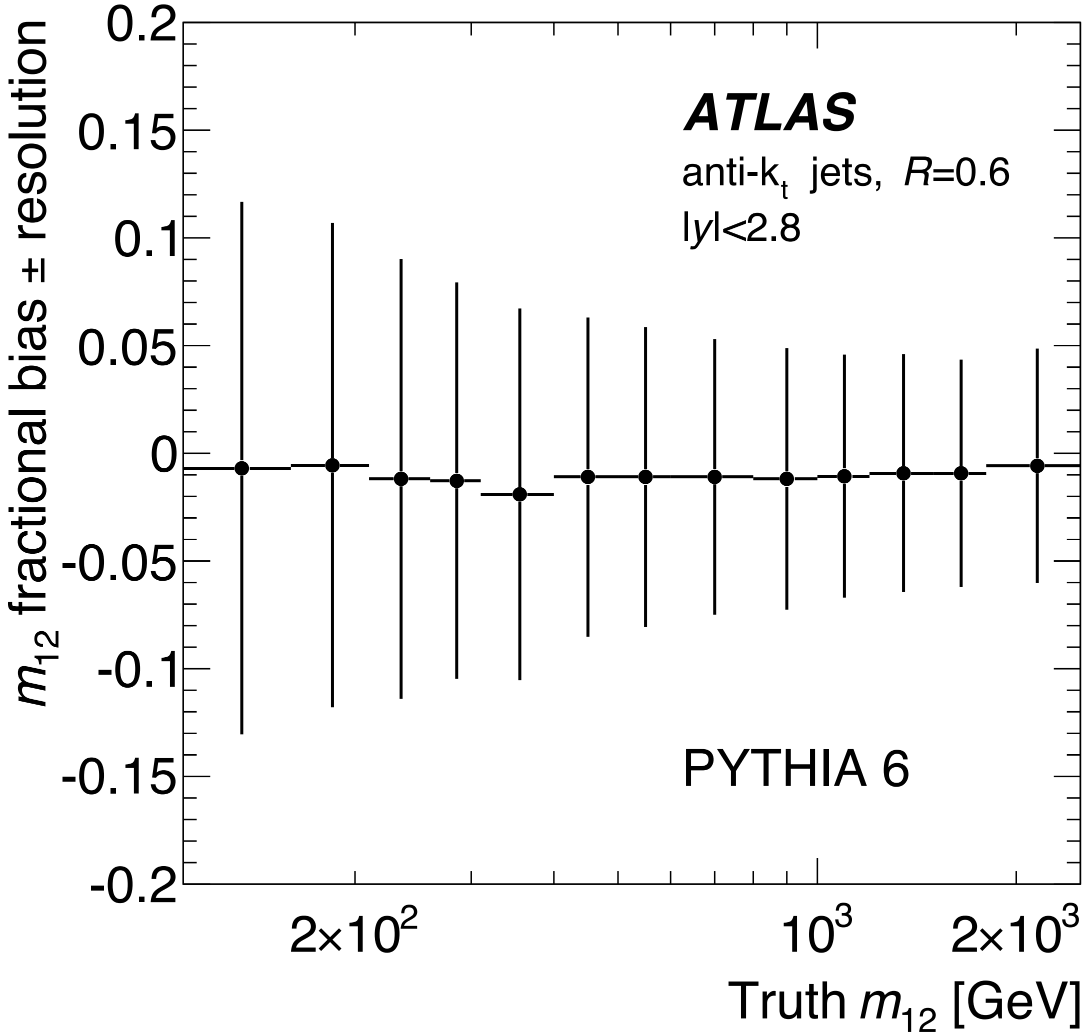

ATLAS
Data / Theory
$|y|_{max} < 0.3$
$0.3 < |y|_{max} < 0.8$
$0.8 < |y|_{max} < 1.2$
anti-k_t jets, $R = 0.6$
$\sqrt{s}$ = 7 TeV, $\int L\,dt$ = 17 nb^{-1}
$1.2 < |y|_{max} < 2.1$
$2.1 < |y|_{max} < 2.8$
Systematic uncertainties
NLO pQCD (CTEQ 6.6)
× Non-pert. corr.
m_{12} [GeV]

jet shapes

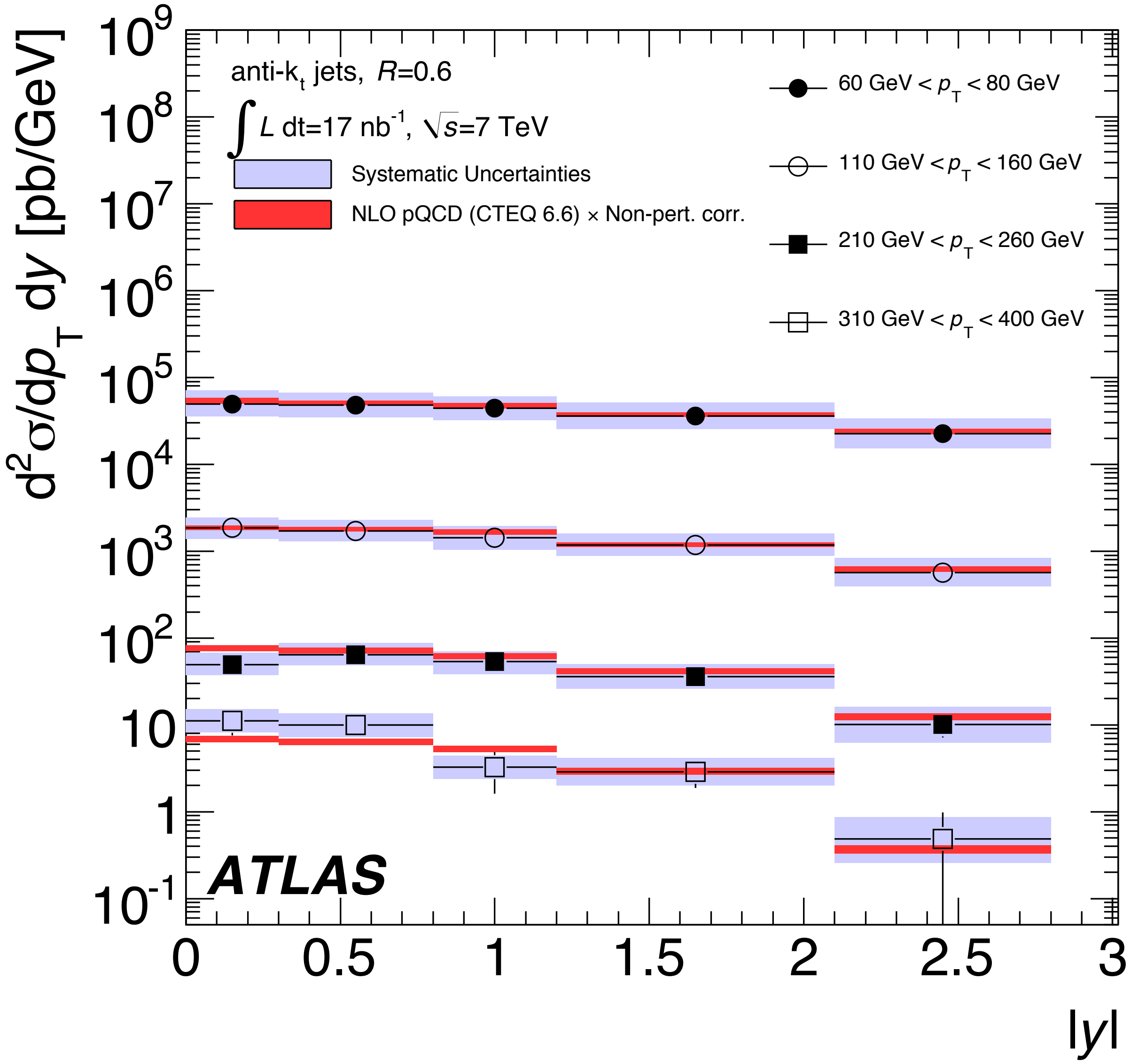

ATLAS
∫L dt = 17 nb-1 , √s = 7 TeV
anti-kt jets, R = 0.6
pT > 30 GeV , | y | < 2.8
2nd leading jet, Clusters
DATA
PYTHIA 6
HERWIG++
HERWIG 6 + JIMMY
r
ATLAS
∫L dt = 17 nb-1 , √s = 7 TeV
anti-kt jets, R = 0.6
pT > 60 GeV , | y| < 2.8
Inclusive jets, Clusters
DATA
PYTHIA 6
HERWIG++
HERWIG 6 + JIMMY
r

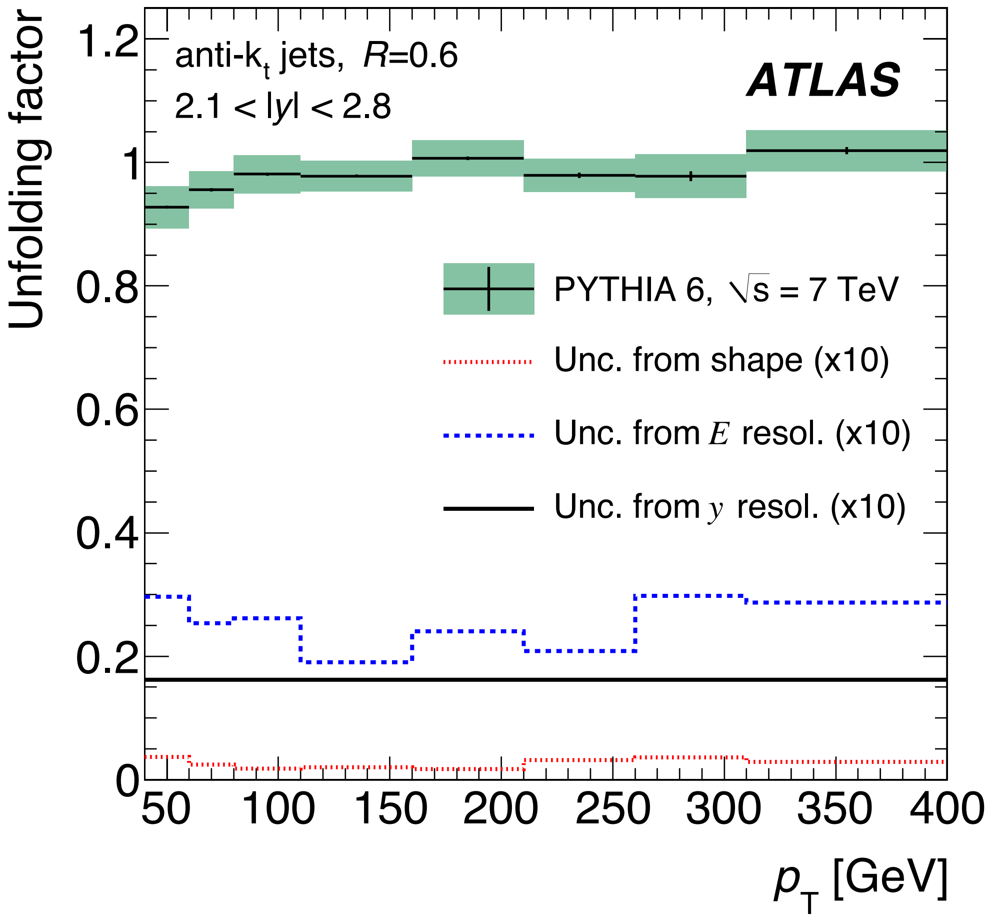
- resolution of observables main input to binning
- resolution available from dijet balance and E/p studies
- detector simulation agrees well



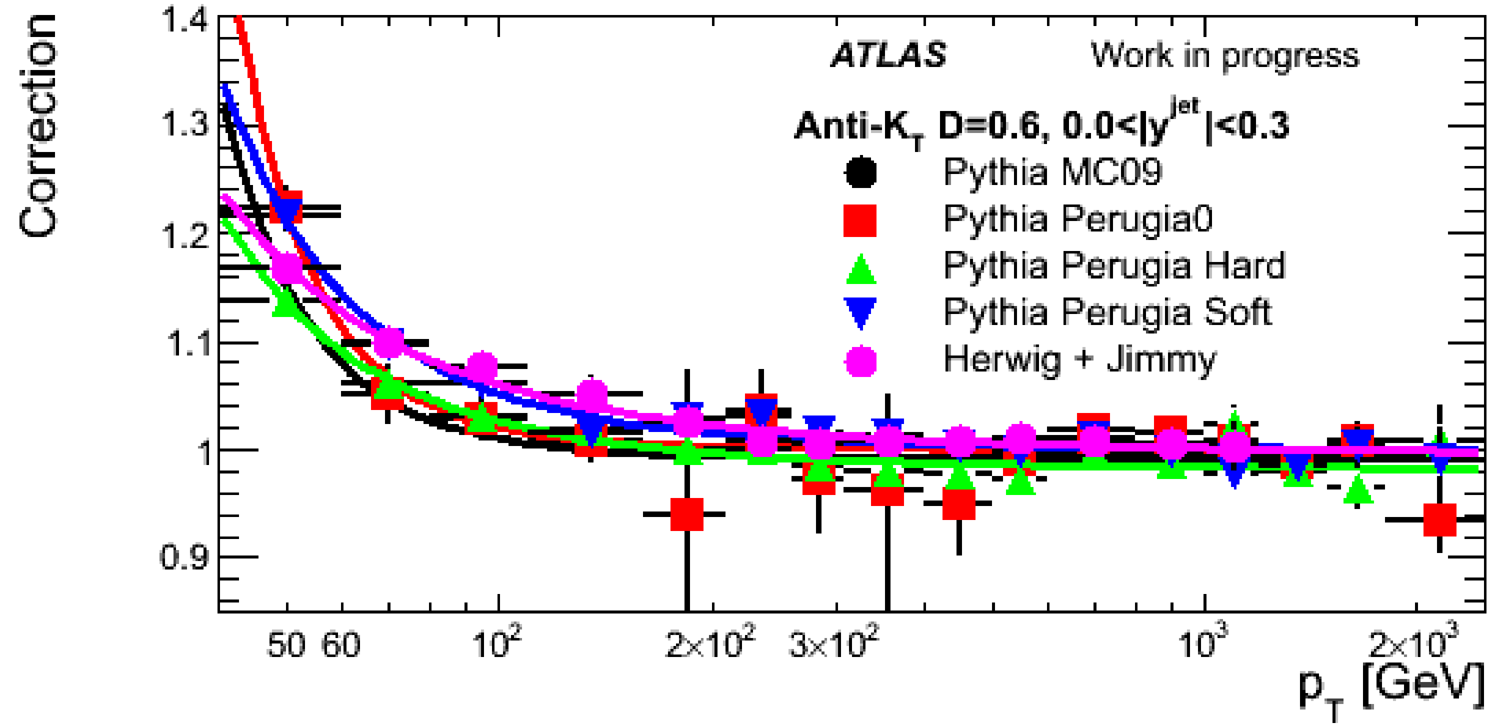


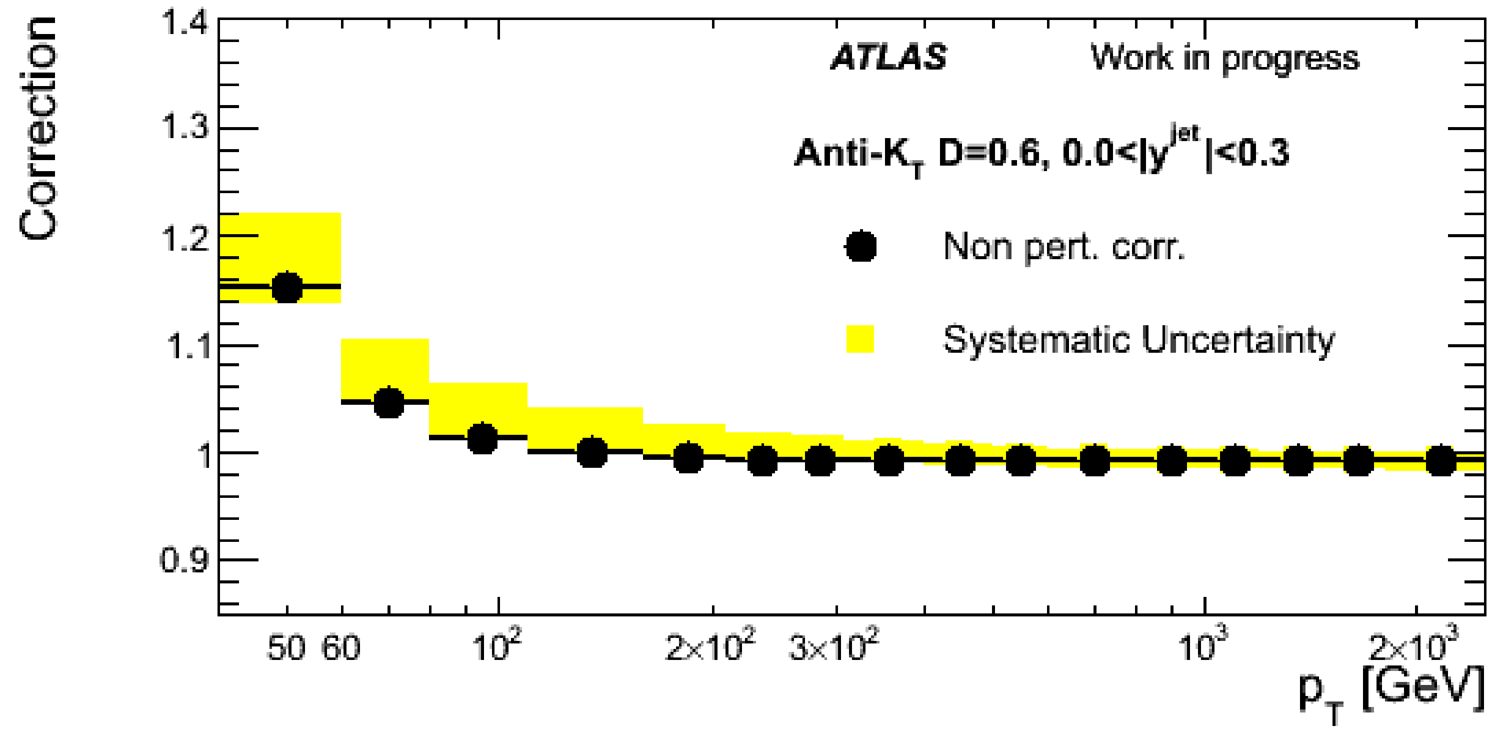
- y resolution gains significance in the forward direction since cross-section dependence on y is increasing





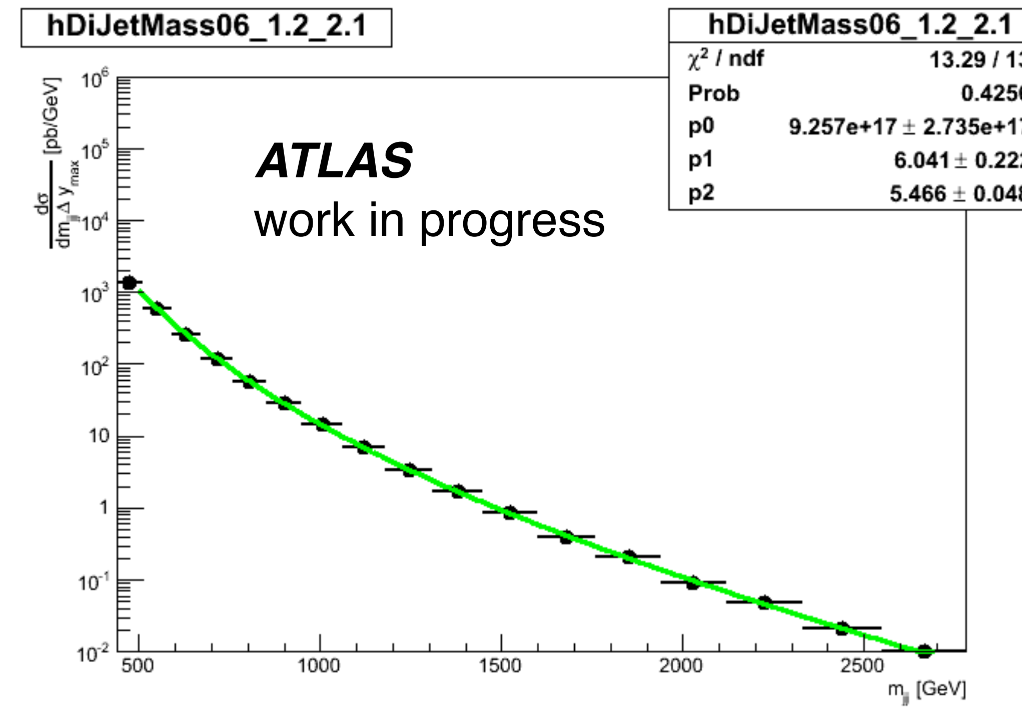
non pert. corrections





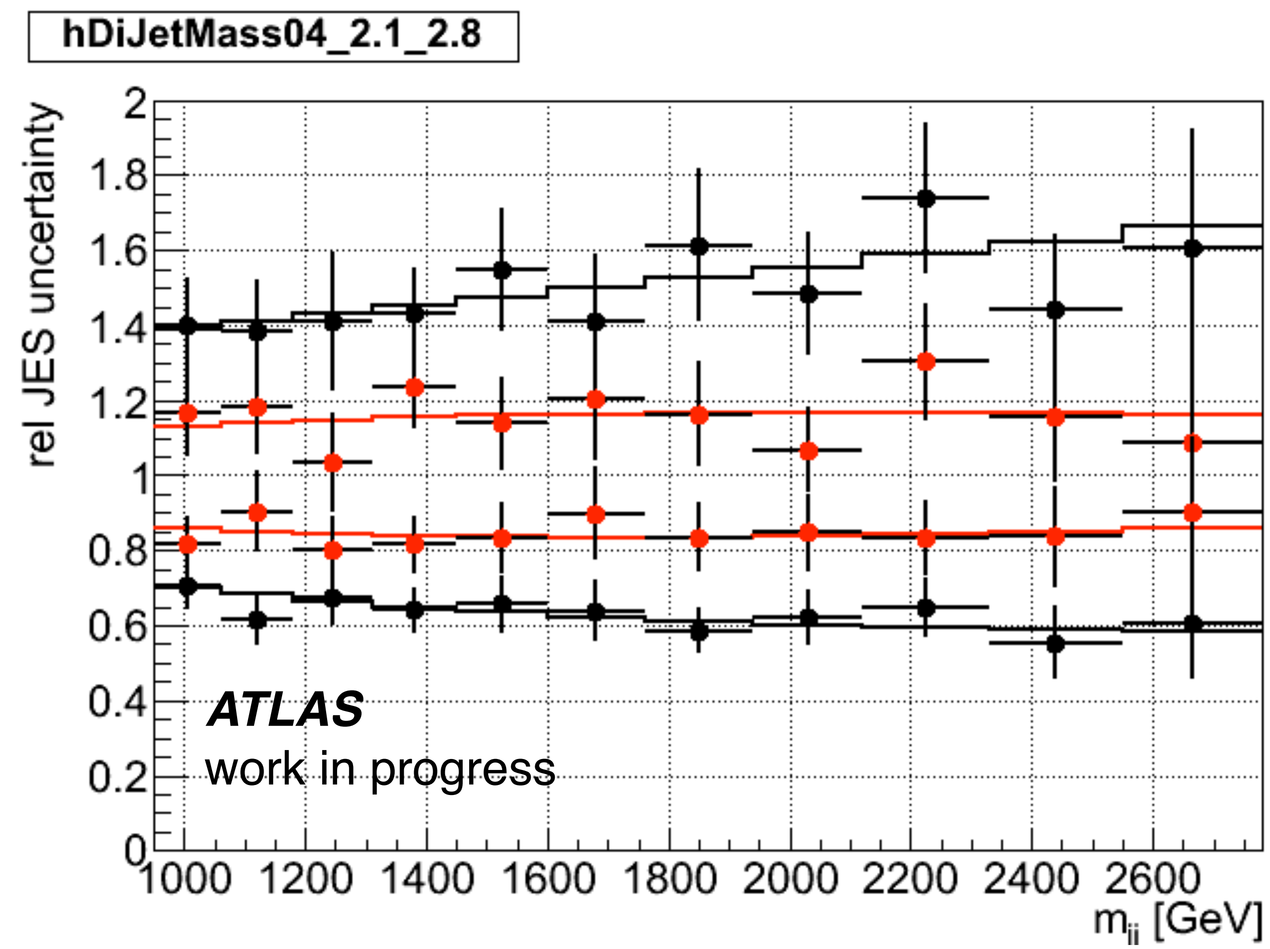
Jet energy scale uncertainty

- JES uncertainty is evaluated using MC
  - allows stable evaluation even at the kinematic boundary
  - is justified by good MC vs data agreement



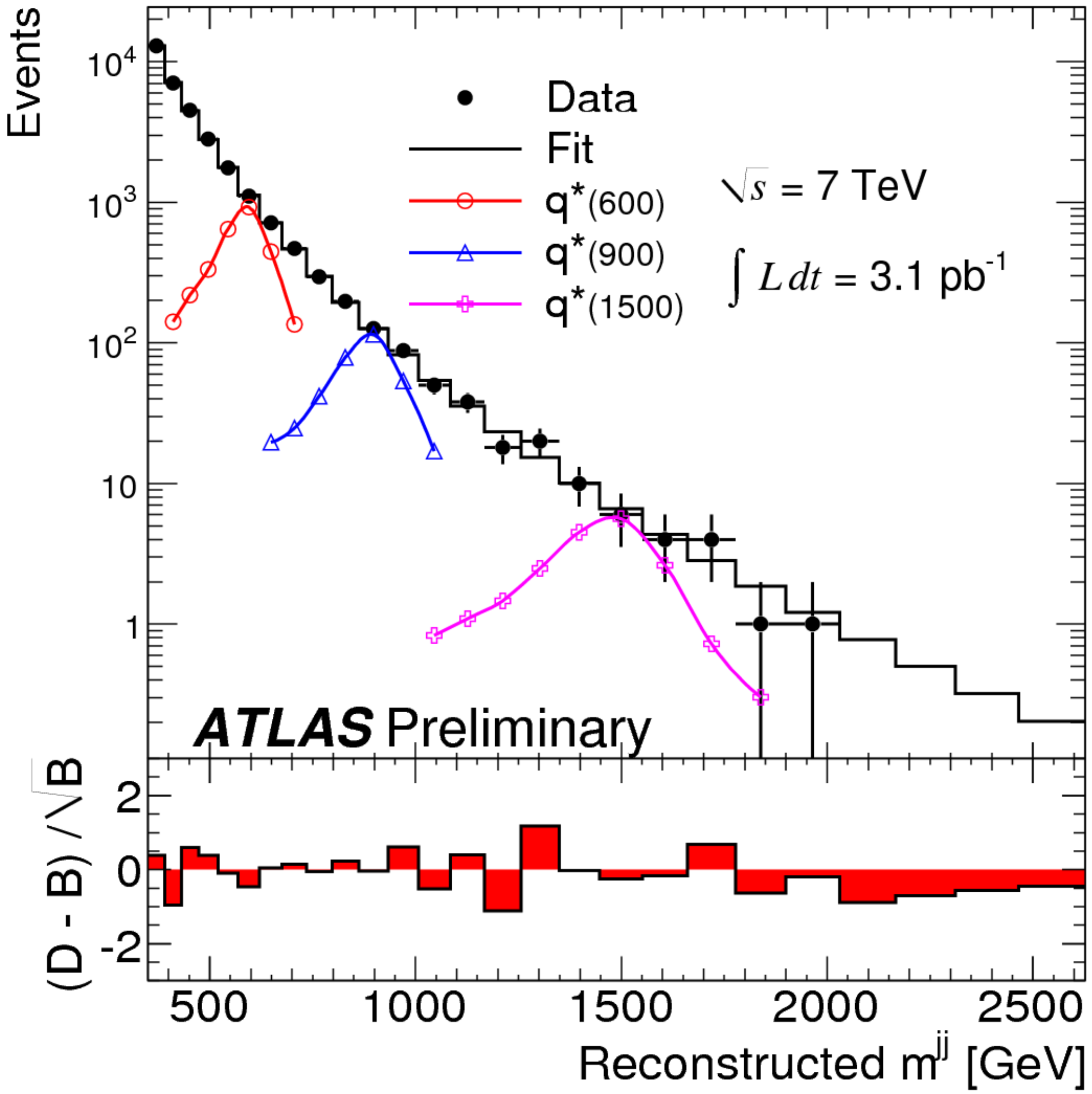
- spectra are fitted to smooth the uncertainty

- $$\frac{d\sigma}{dm_{jj}} = p_0 \frac{(1 - m_{jj}/\sqrt{s})^{p_1}}{m_{jj}^{p_2}}$$

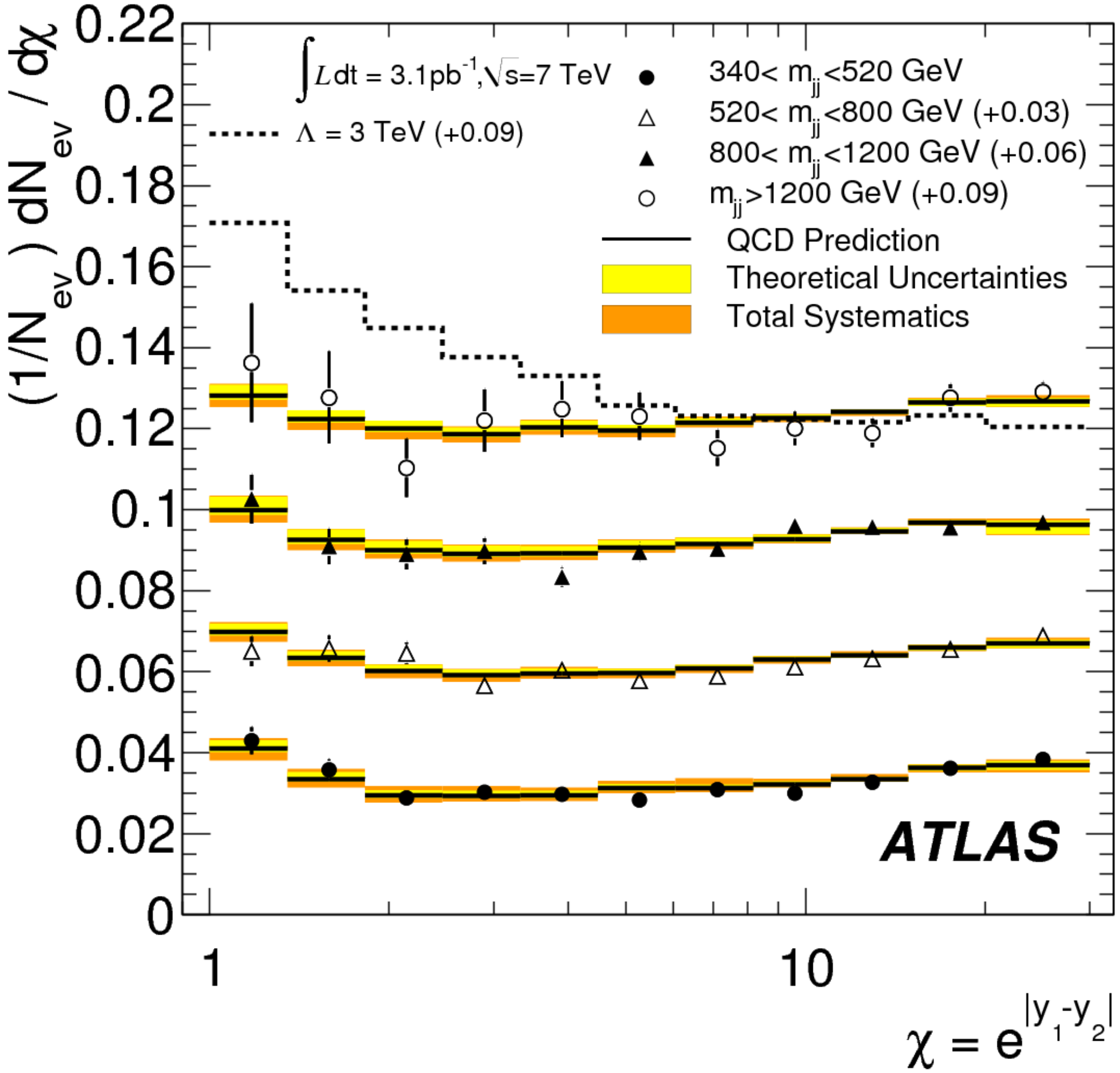


New physics searches with jets

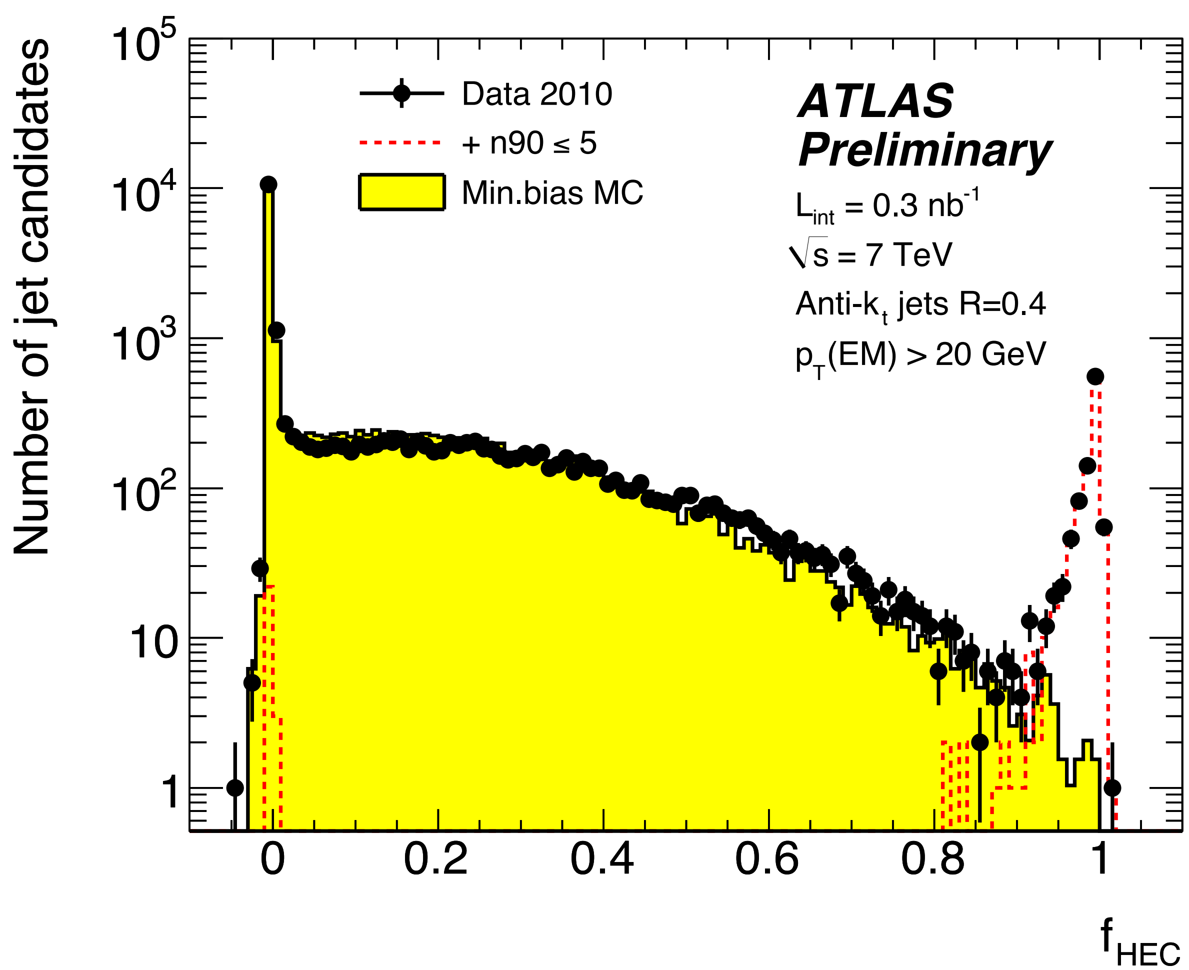
0.50 < m(q*) < 1.53 TeV @ 95% CL

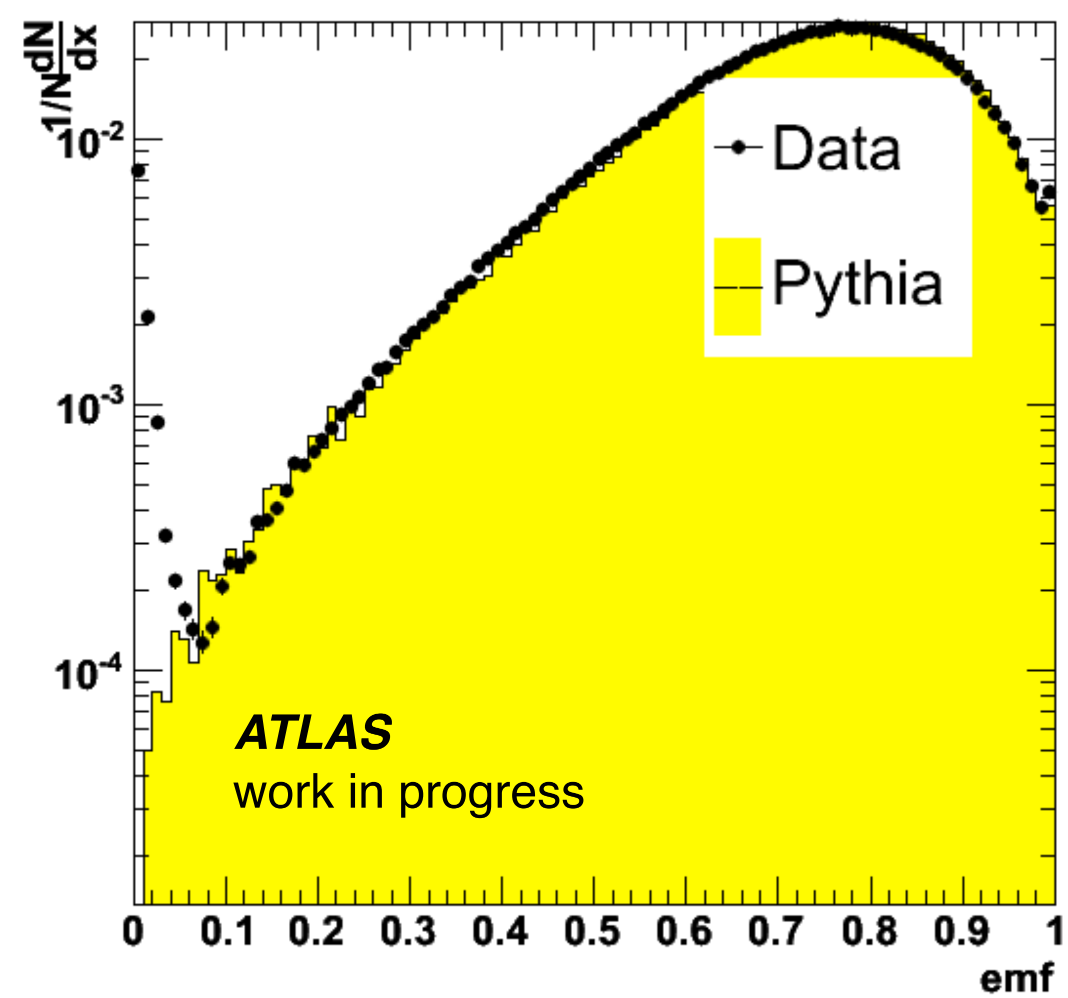


Quark contact interactions with scale Λ < 3.4 TeV @ 95% CL



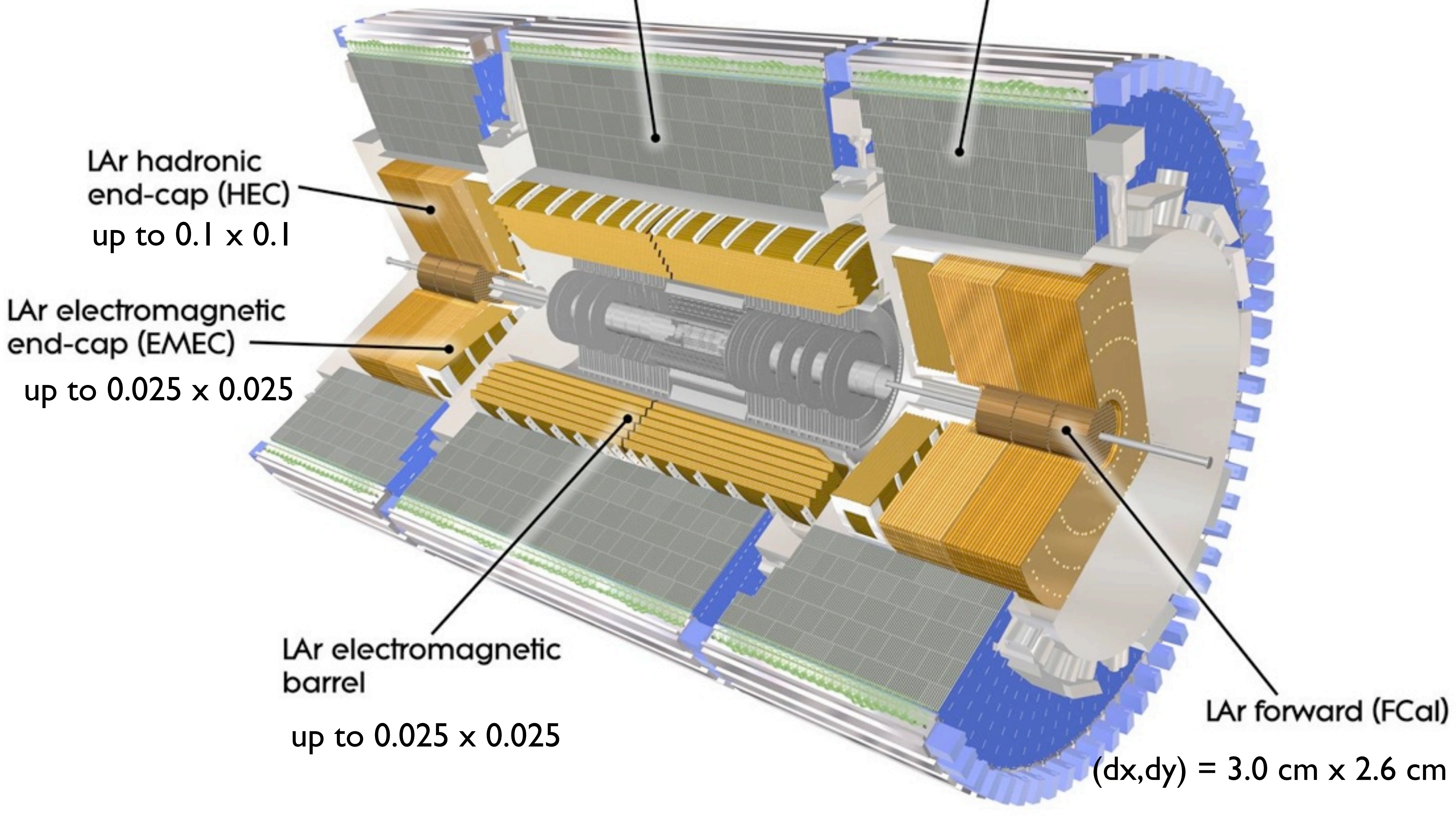
- |y|_max <2.5
- y* < 2.6


Number of jet candidates
Data 2010
+ n90 ≤ 5
Min.bias MC
ATLAS
Preliminary
L_int = 0.3 nb^-1
√s = 7 TeV
Anti-k_t jets R=0.4
p_T(EM) > 20 GeV
f_HEC


1/N dN/dx
Data
Pythia
ATLAS
work in progress
emf

ATLAS calorimetry

granularity in
$\Delta\eta \times \Delta\phi$



ATLAS calorimetry

Table 1.3: Main parameters of the calorimeter system.

	Barrel		**End-cap**	
EM calorimeter				
Number of layers and $\|\eta\|$ coverage				
Presampler	1	$\|\eta\| < 1.52$	1	$1.5 < \|\eta\| < 1.8$
Calorimeter	3	$\|\eta\| < 1.35$	2	$1.375 < \|\eta\| < 1.5$
	2	$1.35 < \|\eta\| < 1.475$	3	$1.5 < \|\eta\| < 2.5$
			2	$2.5 < \|\eta\| < 3.2$
Granularity $\Delta\eta \times \Delta\phi$ versus $\|\eta\|$				
Presampler	0.025×0.1	$\|\eta\| < 1.52$	0.025×0.1	$1.5 < \|\eta\| < 1.8$
Calorimeter 1st layer	$0.025/8 \times 0.1$	$\|\eta\| < 1.40$	0.050×0.1	$1.375 < \|\eta\| < 1.425$
	0.025×0.025	$1.40 < \|\eta\| < 1.475$	0.025×0.1	$1.425 < \|\eta\| < 1.5$
			$0.025/8 \times 0.1$	$1.5 < \|\eta\| < 1.8$
			$0.025/6 \times 0.1$	$1.8 < \|\eta\| < 2.0$
			$0.025/4 \times 0.1$	$2.0 < \|\eta\| < 2.4$
			0.025×0.1	$2.4 < \|\eta\| < 2.5$
			0.1×0.1	$2.5 < \|\eta\| < 3.2$
Calorimeter 2nd layer	0.025×0.025	$\|\eta\| < 1.40$	0.050×0.025	$1.375 < \|\eta\| < 1.425$
	0.075×0.025	$1.40 < \|\eta\| < 1.475$	0.025×0.025	$1.425 < \|\eta\| < 2.5$
			0.1×0.1	$2.5 < \|\eta\| < 3.2$
Calorimeter 3rd layer	0.050×0.025	$\|\eta\| < 1.35$	0.050×0.025	$1.5 < \|\eta\| < 2.5$
Number of readout channels				
Presampler	7808		1536 (both sides)	
Calorimeter	101760		62208 (both sides)	
LAr hadronic end-cap				
$\|\eta\|$ coverage			$1.5 < \|\eta\| < 3.2$	
Number of layers			4	
Granularity $\Delta\eta \times \Delta\phi$			0.1×0.1	$1.5 < \|\eta\| < 2.5$
			0.2×0.2	$2.5 < \|\eta\| < 3.2$
Readout channels			5632 (both sides)	
LAr forward calorimeter				
$\|\eta\|$ coverage			$3.1 < \|\eta\| < 4.9$	
Number of layers			3	
Granularity $\Delta x \times \Delta y$ (cm)			FCal1: 3.0×2.6	$3.15 < \|\eta\| < 4.30$
			FCal1: $\sim$ four times finer	$3.10 < \|\eta\| < 3.15$,
				$4.30 < \|\eta\| < 4.83$
			FCal2: 3.3×4.2	$3.24 < \|\eta\| < 4.50$
			FCal2: $\sim$ four times finer	$3.20 < \|\eta\| < 3.24$,
				$4.50 < \|\eta\| < 4.81$
			FCal3: 5.4×4.7	$3.32 < \|\eta\| < 4.60$
			FCal3: $\sim$ four times finer	$3.29 < \|\eta\| < 3.32$,
				$4.60 < \|\eta\| < 4.75$
Readout channels			3524 (both sides)	
Scintillator tile calorimeter				
	Barrel		Extended barrel	
$\|\eta\|$ coverage	$\|\eta\| < 1.0$		$0.8 < \|\eta\| < 1.7$	
Number of layers	3		3	
Granularity $\Delta\eta \times \Delta\phi$	0.1×0.1		0.1×0.1	
Last layer	0.2×0.1		0.2×0.1	
Readout channels	5760		4092 (both sides)	