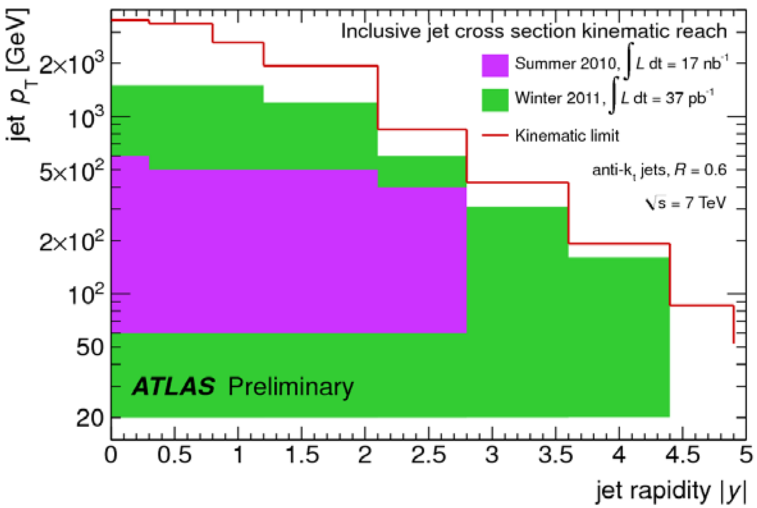
Results on QCD jet and photon production in ATLAS

Lydia Roos (LPNHE Paris)
on behalf of the ATLAS Collaboration

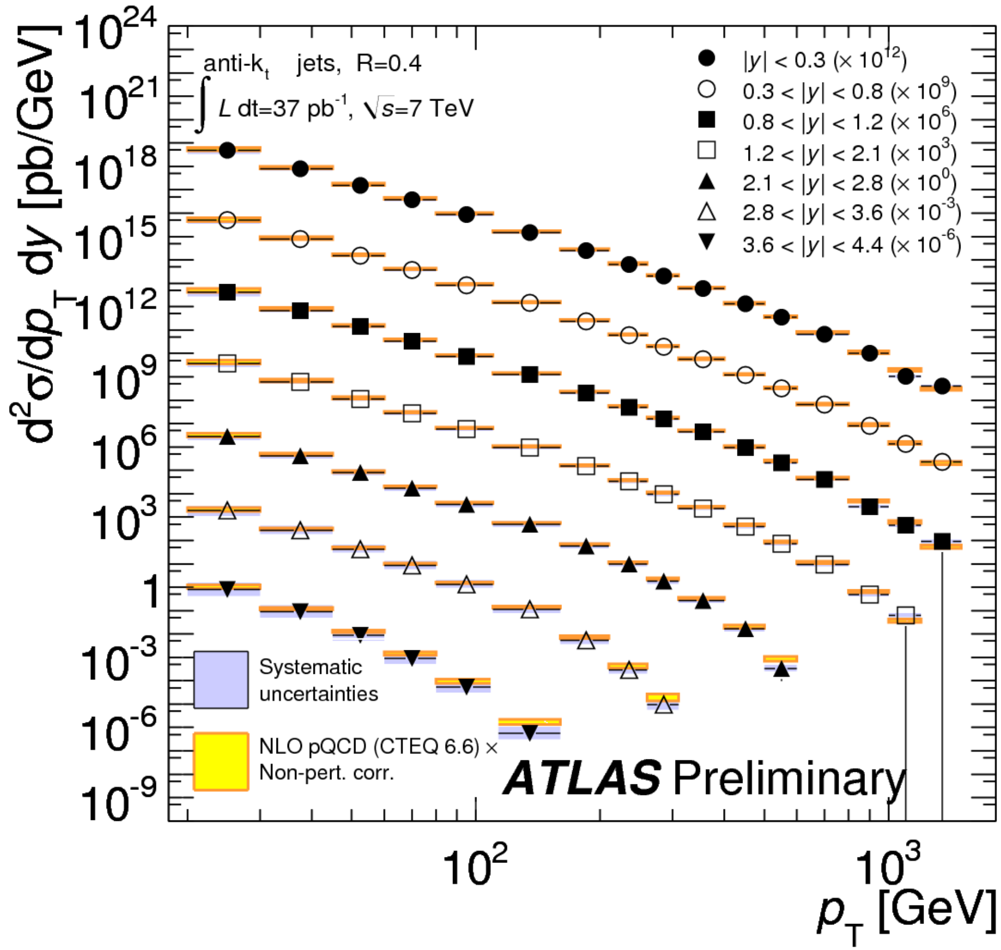
Rencontres de Blois, Particle Physics and Cosmology

Château Royal de Blois May 29-June 3, 2011

Inclusive Jet Production



Test in an extended kinematic region :
- NLO pQCD
- parton distribution functions

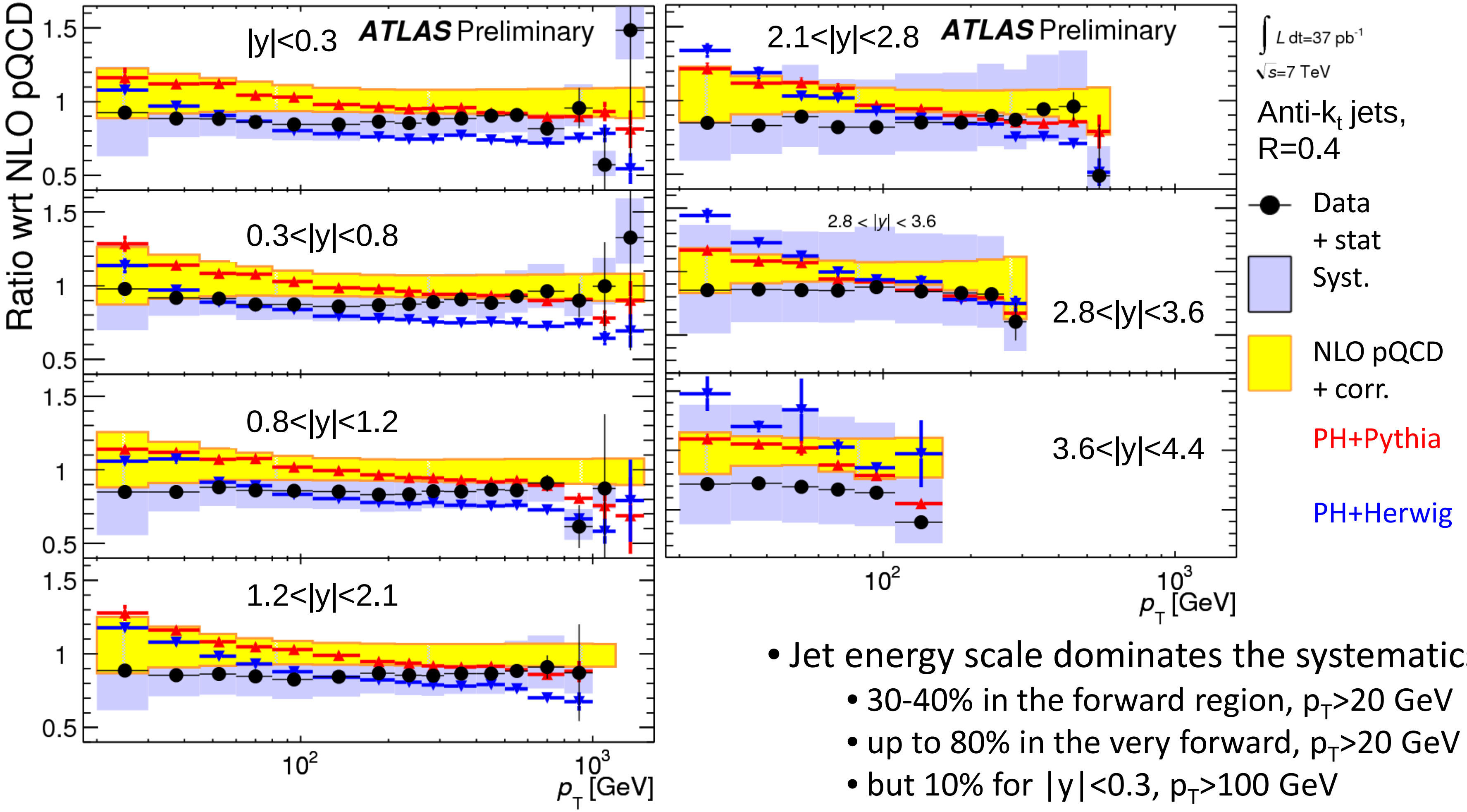


Anti-k_t jets, R=0.4 or 0.6, in:
- $|y|<4.4$
- 20 GeV < p_T < 1.5 TeV

Integrated luminosity: 37.3±1.2 pb^{-1}

Theoretical predictions:
- NLOJet++ with CTEQ6.6 PDFs
- correction for non-perturbative effects using Pythia

Comparison with PowHeg

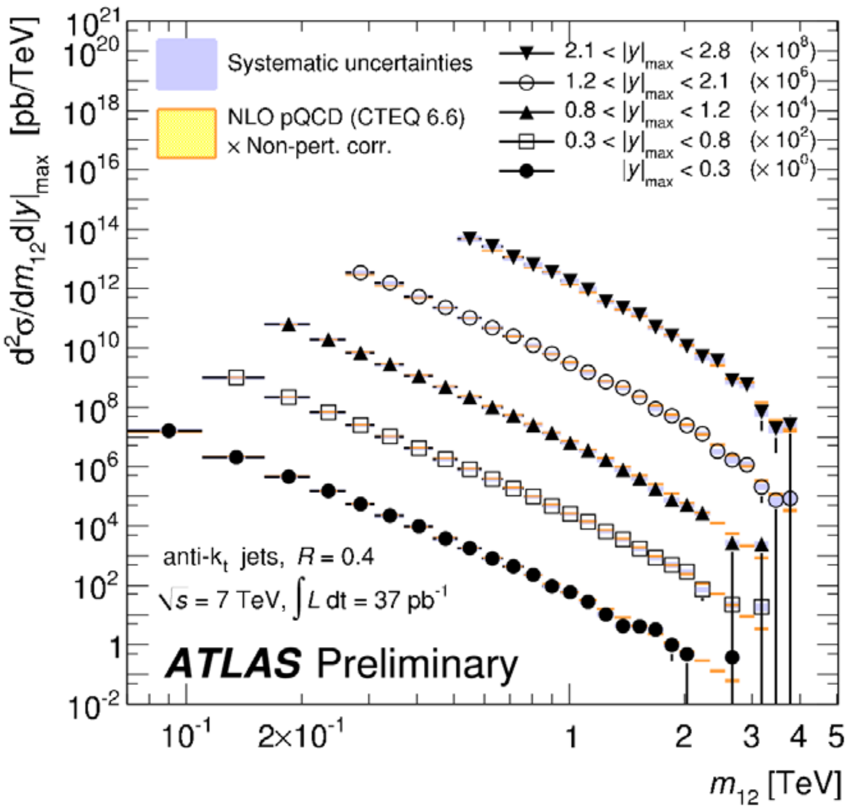


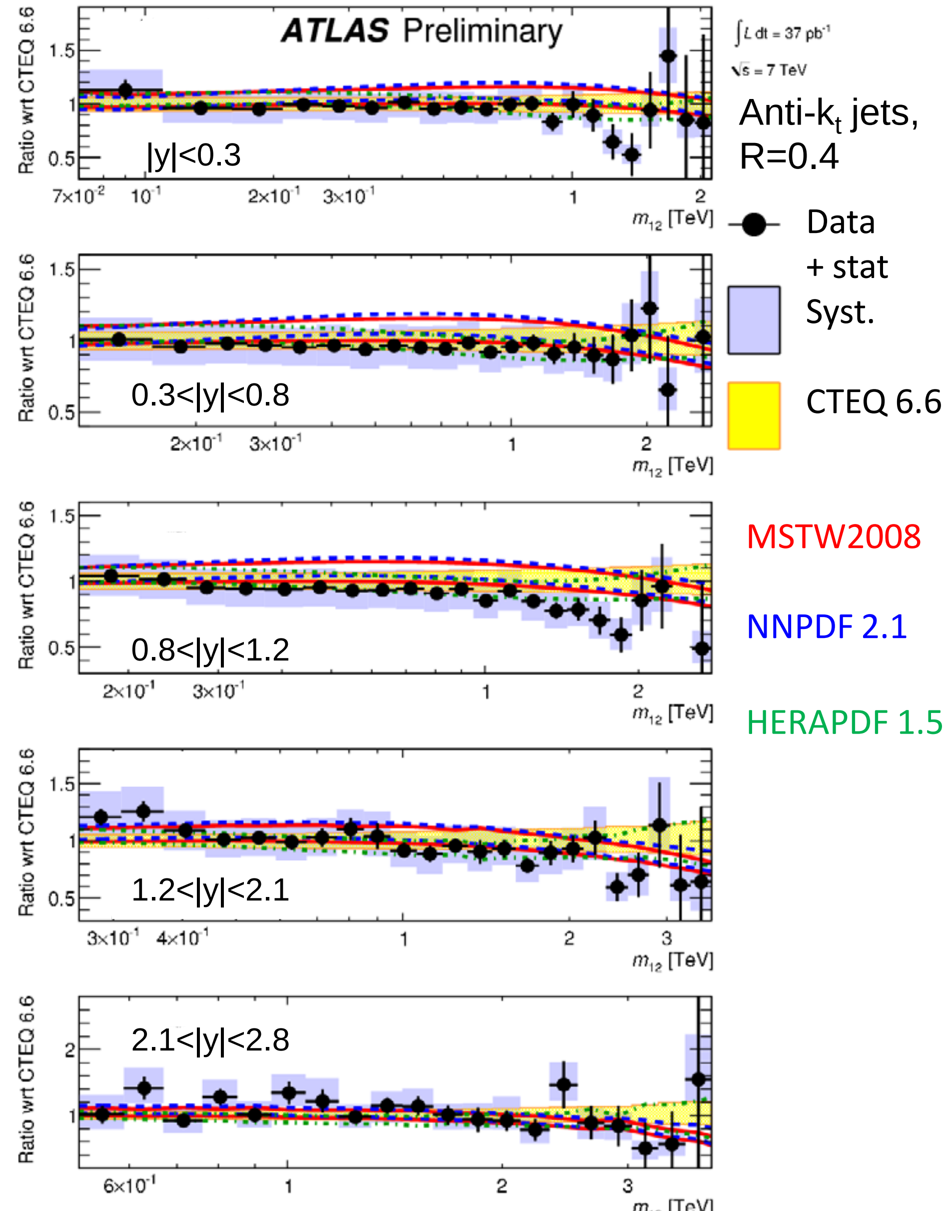
- Jet energy scale dominates the systematics:
  - 30-40% in the forward region, p_T>20 GeV
  - up to 80% in the very forward, p_T>20 GeV
  - but 10% for |y|<0.3, p_T>100 GeV
- others: unfolding (20%), luminosity (3.4%)

- Significant difference between PowHeg+Pythia and PowHeg+Herwig
- Agree with data and NLO pQCD within uncertainties

Di-jet production

Two-jet events with:
- p_{T1}>30 GeV, p_{T2}>20 GeV
- |ymax| = max(|y_1|,|y_2|): from 0 to 2.8
- m_{12} from 60 GeV to 4.1 TeV!





Best agreement with HERAPDF1.5, CTEQ6.6

Jet mass & substructure

NEW

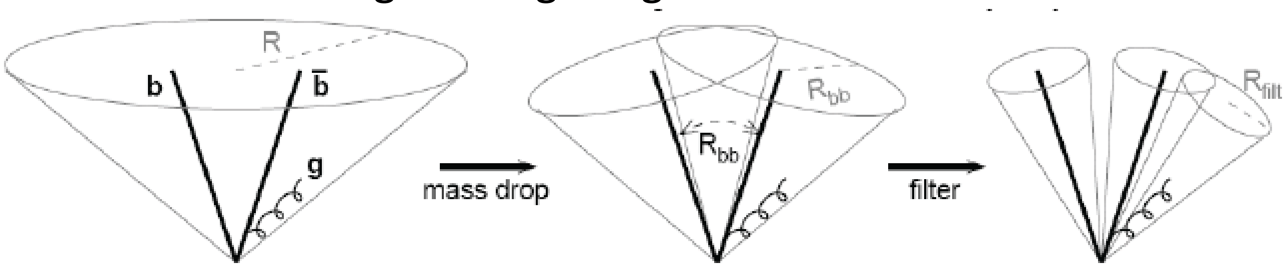
At LHC, decay products of highly boosted heavy particles might be clustered in one single jet
→ study of the jet substructure to discriminate from QCD background
- boosted W or top
- $H \to bb$ searches
- SUSY

Ideas tested on MC, need to be validated on data

Sample:
- 2010 data, N(primary vertex)=1

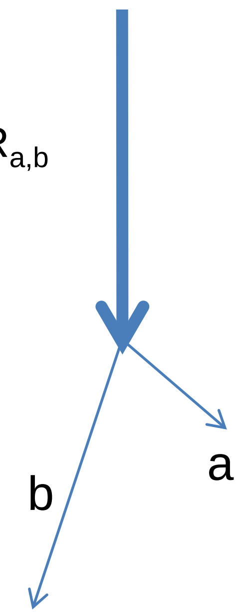
→ integrated lumi: 8 pb^{-1}
- large area, central, boosted jets: p_T>300 GeV, $|y|<2$
  - Cambridge-Aachen R=1.2
  - Anti-k_T R=1

Jet splitting and filtering:
- undo the last CA step
- search for symmetric splittings with large mass drop
- recluster filtering out large angle radiation.



k_T splitting scale d_{12}:

$$\sqrt{d_{12}} = \min(p_{Ta}, p_{Tb}) \times \delta R_{a,b}$$



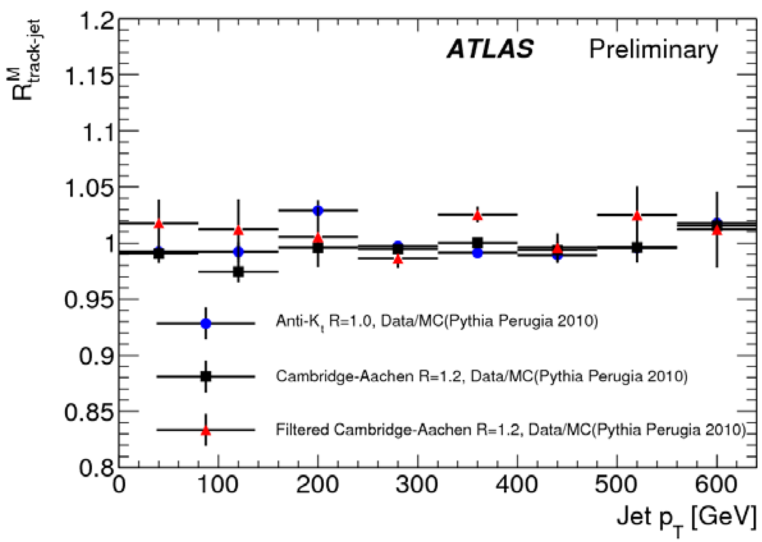
Jet mass & substructure

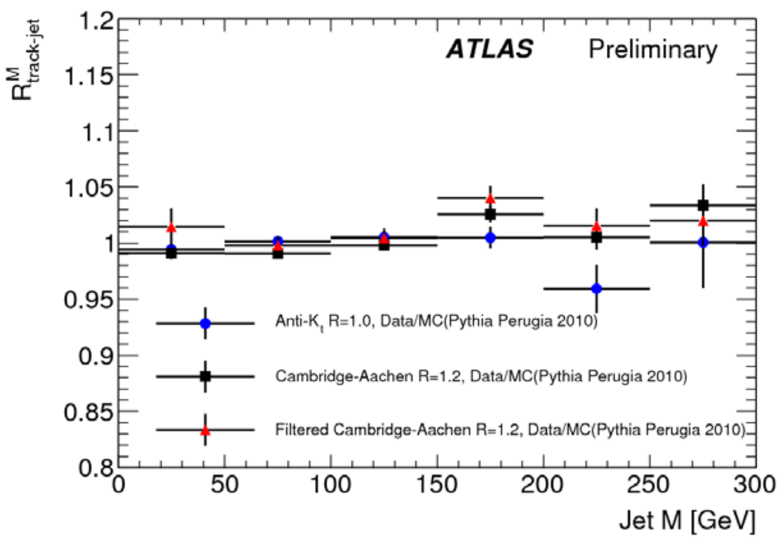
Specific study of jet calibration uncertainties is needed:

- Much larger jets than in the standard ATLAS jet analyses
- Check the uncertainty on the jet energy scale and mass scale

→ compare calorimeter jets with their corresponding track jets in MC and data

$$R^{M}_{trk\text{-}jet} = (M^{jet}/M^{trk\text{-}jet})^{data} / (M^{jet}/M^{trk\text{-}jet})^{MC}$$



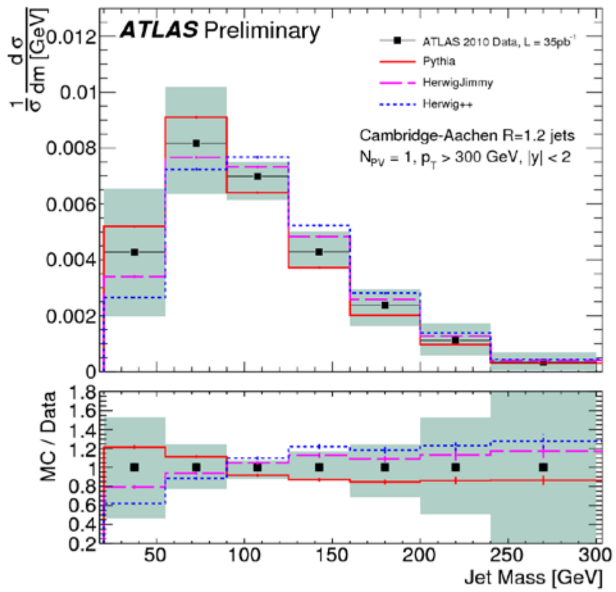


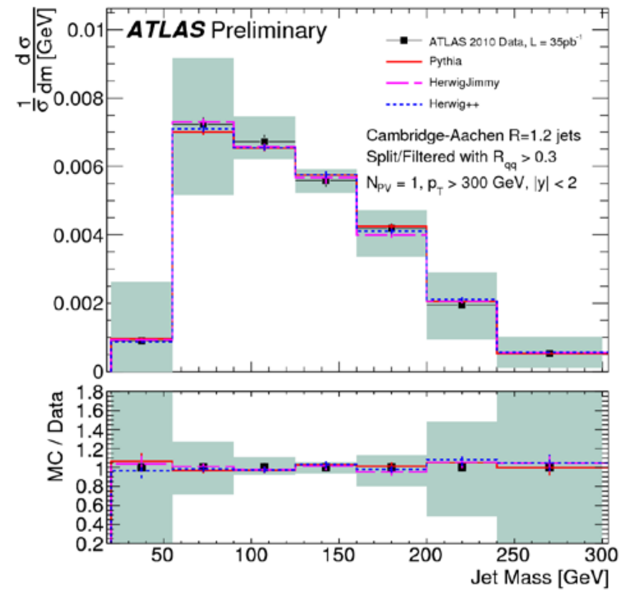
Final uncertainties:

Jet Algorithm	JES	JMS	JER	JMR
anti-$k_\perp$ $R = 1.0$	5%	7%	20%	30%
Cambridge-Aachen $R = 1.2$	5%	6%	20%	30%
Cambridge-Aachen Filtered $R = 1.2$	6%	7%	20%	30%

	Scale	Resolution
d_{12}	15%	30%

Jet mass & substructure

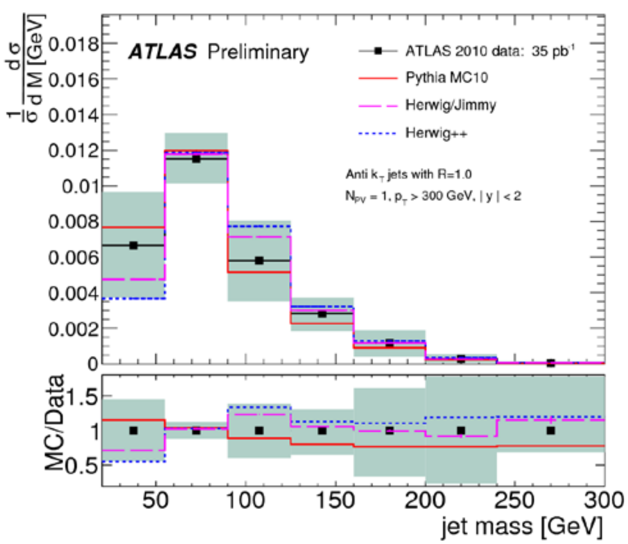


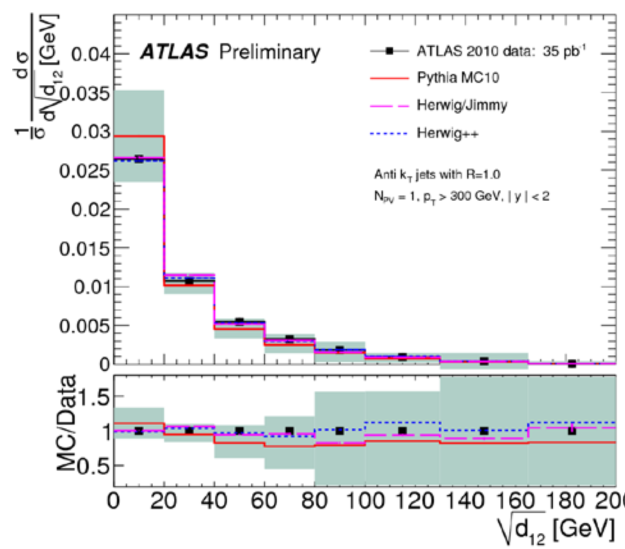


Cambridge Aachen jets before & after Splitting/filtering

Good agreement between MC and data

Herwig++ CA jet mass slightly harder

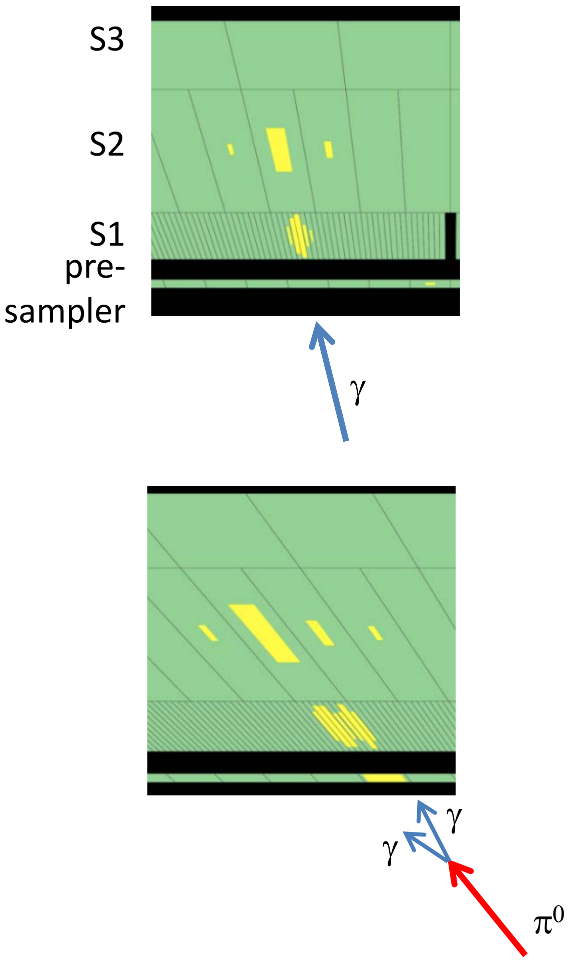




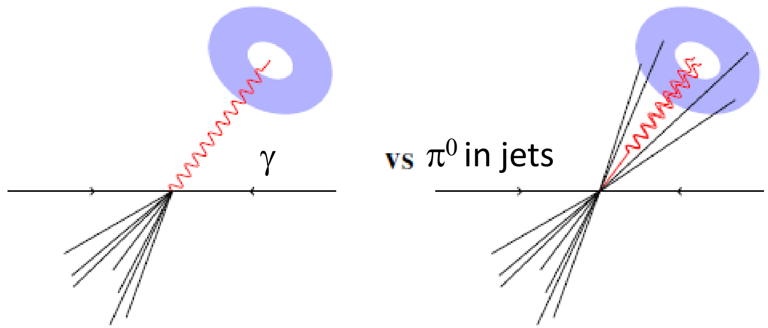
Anti-k_T jets

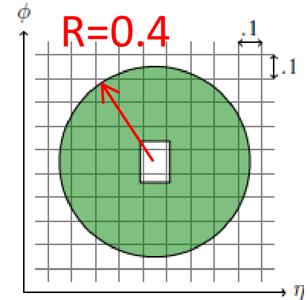
Photons

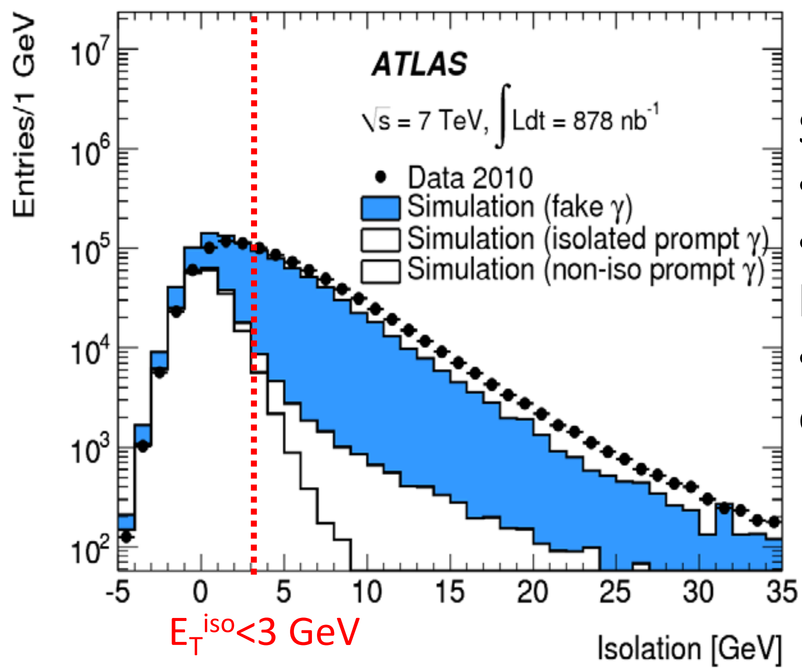
Photon identification



Photon isolation







Sum energies in R<0.4:

- exclude 5x7 cells
- correct for out-of-core leakage
- subtract ambient energy density

Inclusive Photon Production

Two measurements:

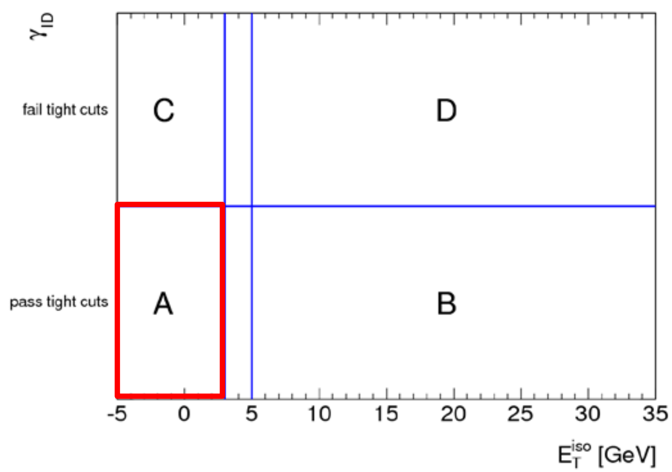
- $L=0.88\ pb^{-1}$: 15-100 GeV, $|\eta|<1.37$, $1.52<|\eta|<1.81$
- $L=34.6\pm1.2\ pb^{-1}$: 45-400 GeV, $|\eta|<1.37$, $1.52<|\eta|<2.37$

Theoretical prediction:
JetPhox with CTEQ6.6 PDFs

Goal: extract photon yield in region A (tight & isolated)

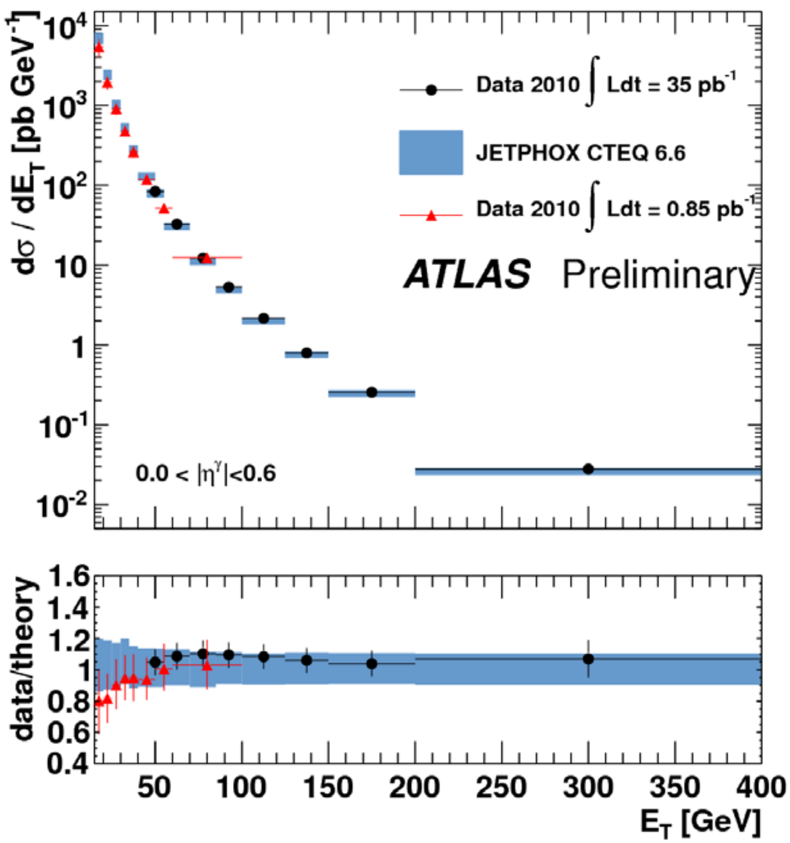
Background subtraction in signal enriched region :

- Reverse some ID cuts (minimize correlation with E_T^{iso})
- $E_T^{iso}>5$ GeV



to first approximation: $N_A^{sig}=N_A - N_B \times (N_C/N_D)$

Good agreement above 35 GeV



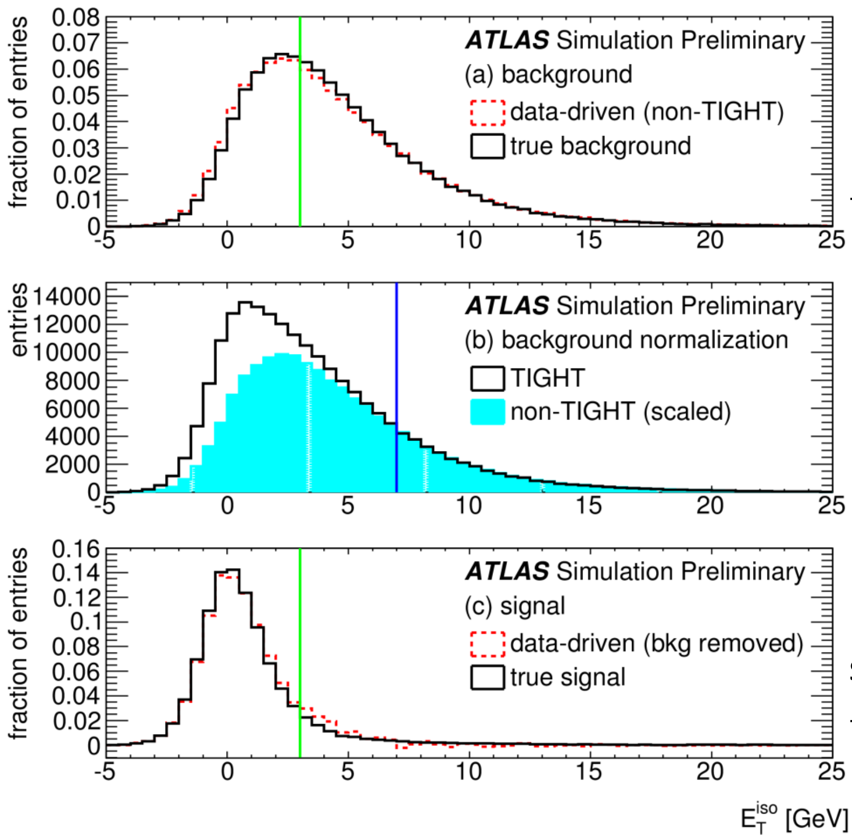
Di-photon Production

VERY NEW

Analysis on L=37.2±1.3 pb^{-1}
- E_T^{γ}>16 GeV
- |η|<1.37, 1.52<|η|<2.37
- $\Delta R_{\gamma\gamma}$>0.4

Goal: Extract the di-photon yield in the region with two tight & isolated candidate photons

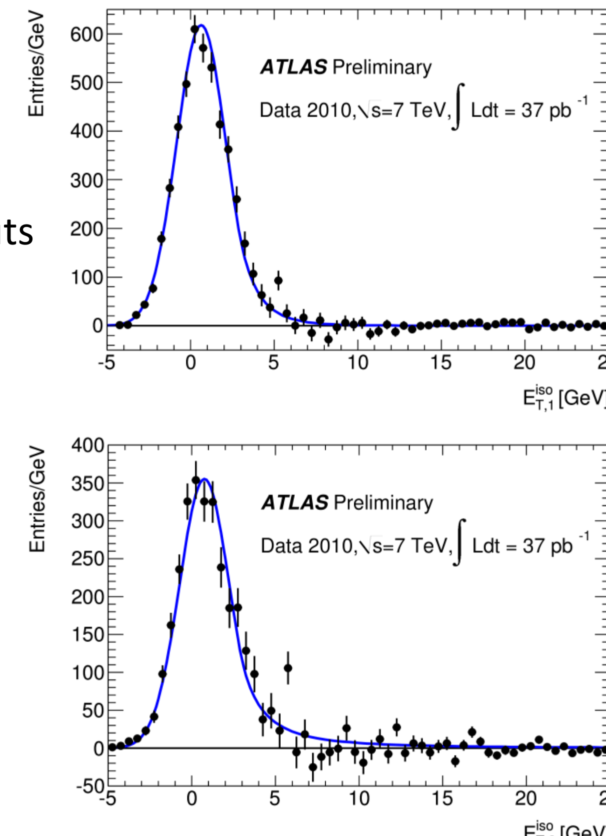
Extract the signal and fake photon isolation distributions from data



reverse some ID cuts → fake

normalize to E_T^{iso}>7 GeV

subtraction → signal

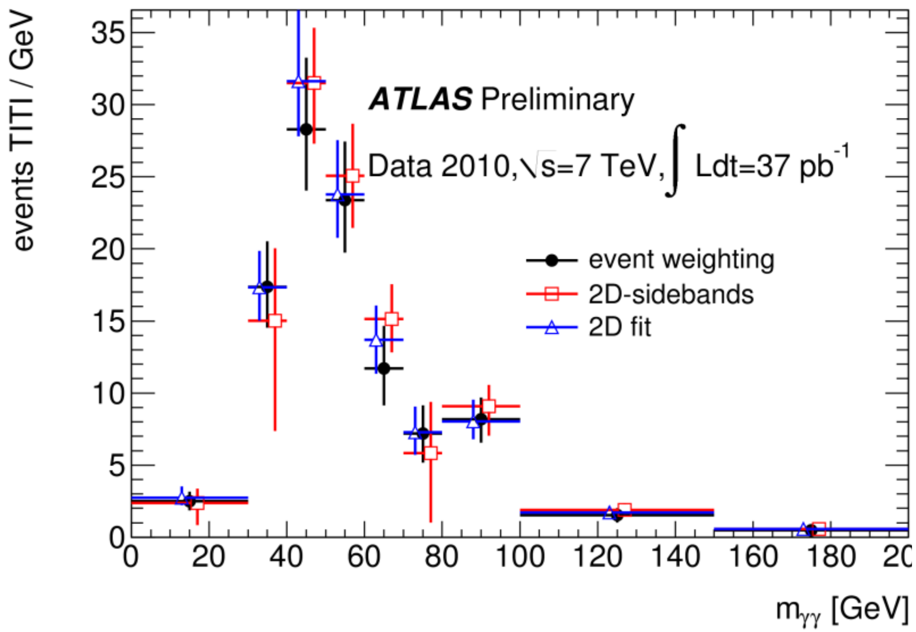


Excellent agreement with electrons from W & Z decays + e-to-γ MC corrections

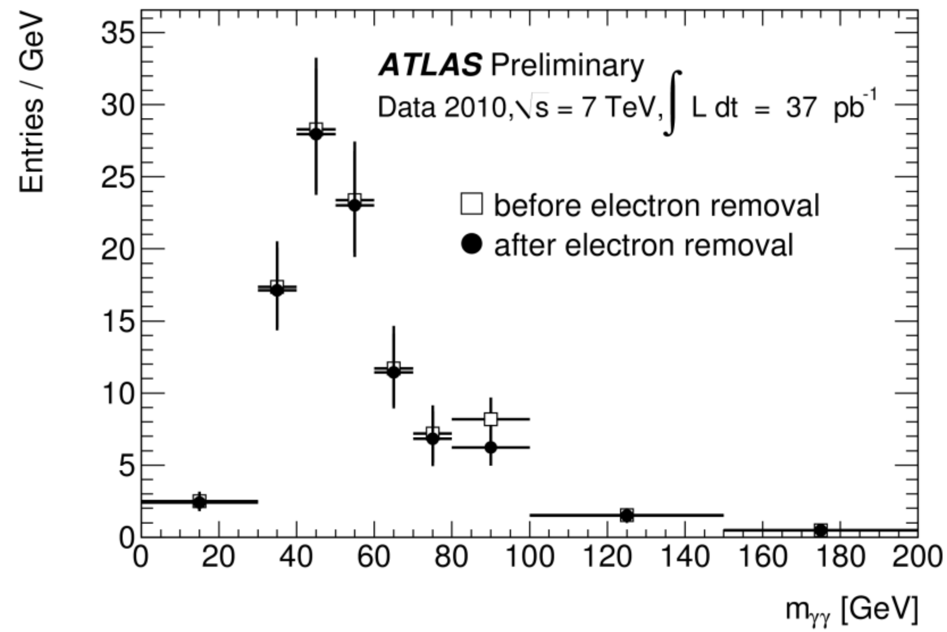
Di-photon Production

Subtract γ-jet and jet-jet background using isolation efficiency matrix method from Tevatron

Alternative methods are:
- an extended 2x ABCD method
- a fit to the 2D isolation transverse energy distribution of the two candidates



Excellent agreement between the 3 methods

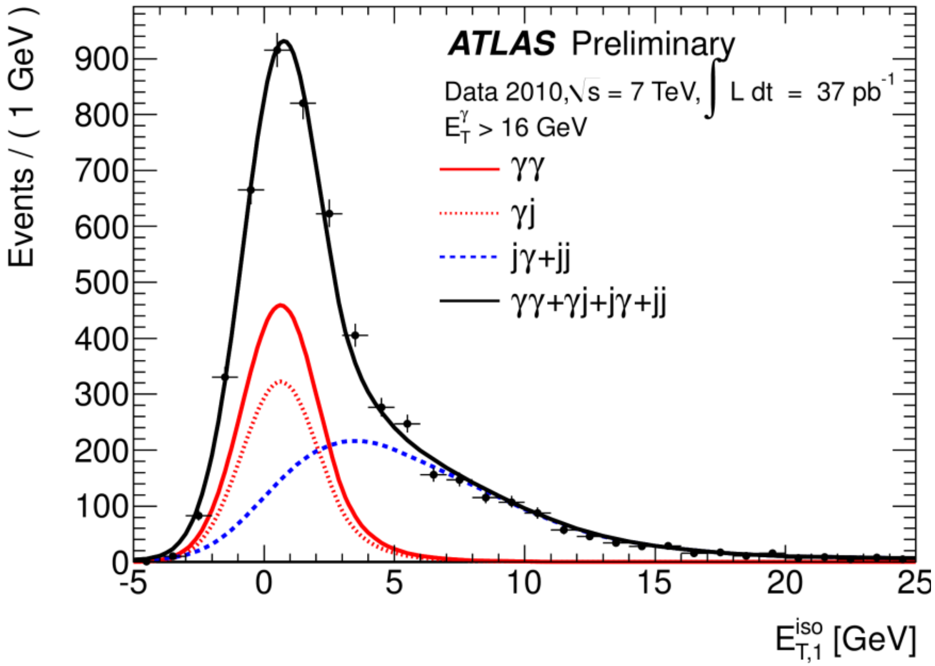


ee and eγ background subtraction

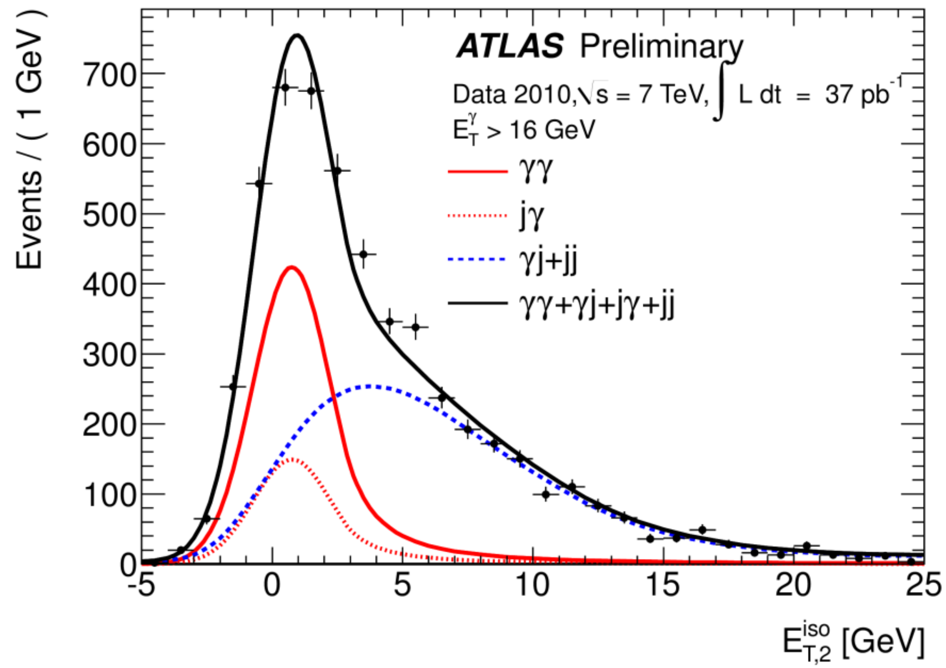
Di-photon Production

Projections of the 2D isolation fit result

Leading p_T candidate photon



Subleading p_T candidate photon

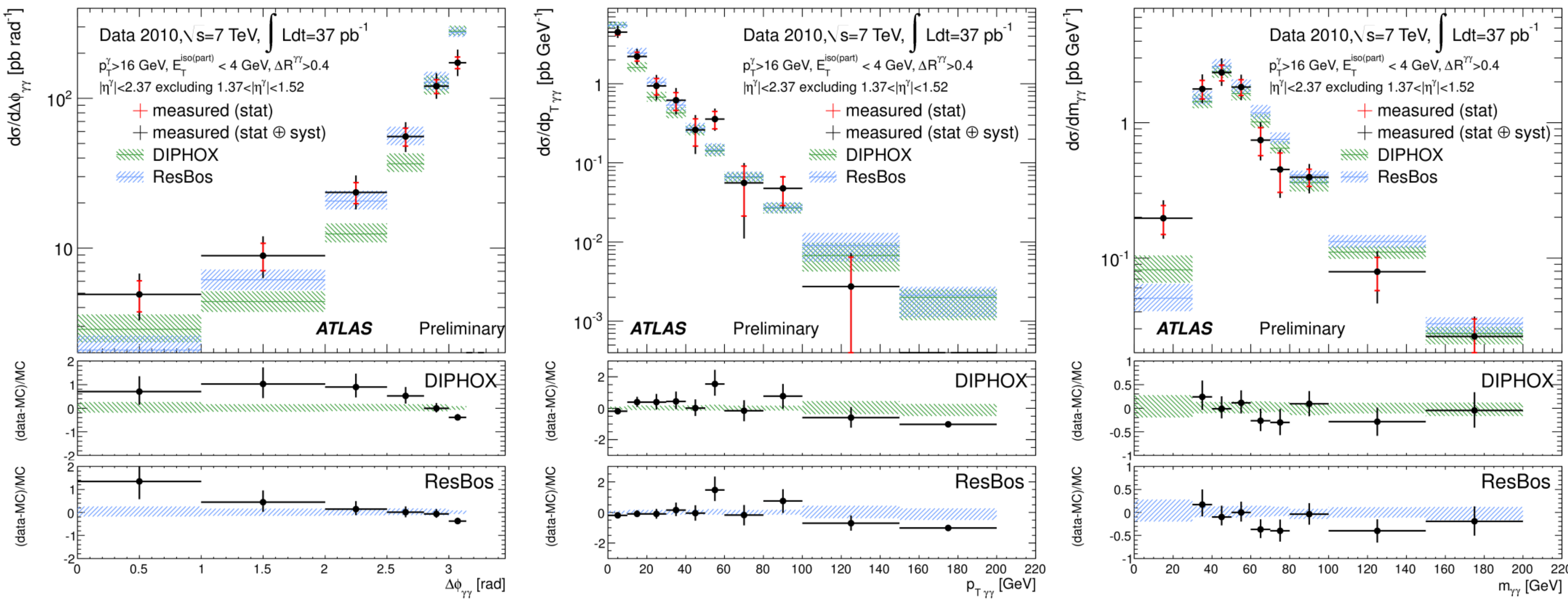


Clear di-photon signal in isolation distributions

Di-photon Production

Differential cross-sections as function of observables of the two-photon system

Azimuthal angle between 2γ | Transverse momentum | Invariant mass



- clear discrepancy observed for $\Delta\phi_{\gamma\gamma}$
- good agreement for $p_{T\gamma\gamma}$ and $m_{\gamma\gamma}$
- discrepancy at low $m_{\gamma\gamma}$ can be related to low $\Delta\phi_{\gamma\gamma}$ region

Summary

Only a few jet and photon ATLAS studies presented here:

- Inclusive jet and di-jet cross-sections:
  - Good agreement with NLO calculation
  - start to probe PDFs, NLO generators

- **First measurement of jet mass and jet substructure!**
  - Validation of LO MC predictions

- Inclusive photon production cross-section up to 400 GeV
  - Very good agreement with NLO calculation except at low transverse energy

- **First measurement of di-photon differential cross-section!**
  - Significant discrepancies with NLO generators observed in the distribution of the azimuthal angle between the two photons

More…

Papers and conference notes

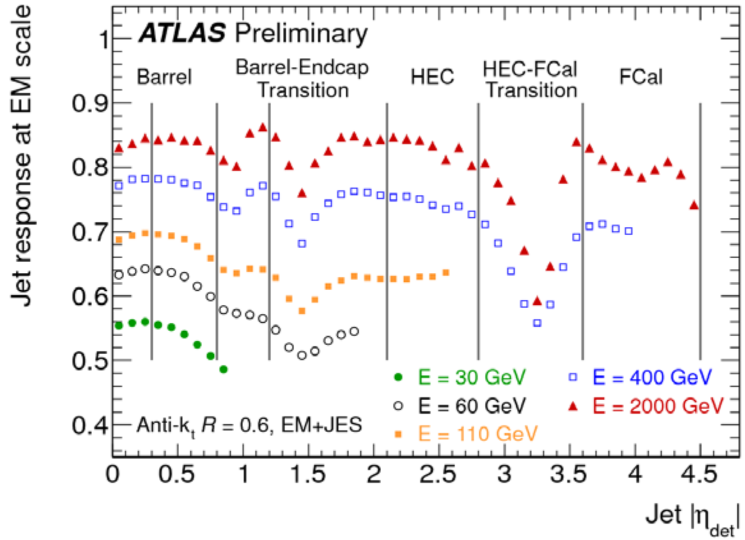
All results presented in these slides can be found on http://cdsweb.cern.ch/

- Inclusive jet and di-jet cross-section
  - ATLAS-CONF-2011-47
- Jet mass and substructure
  - ATLAS-CONF-2011-73
- Inclusive photon cross-section
  - Phys. Rev. D 83 (2011) 052005
  - ATLAS-CONF-2011-58
- Di-photon cross-section: coming soon

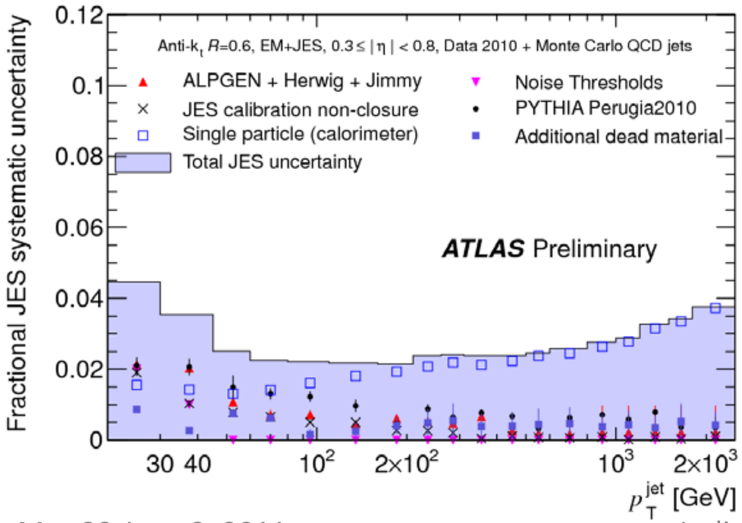
Jet calibration

Standard ATLAS jets: anti-kT, R=0.4 or 0.6, energy measured at the EM scale

Jet Energy Scale estimation:
- correct for pile-up
- set jet origin to primary vertex
- correct energy by reco vs truth in MC

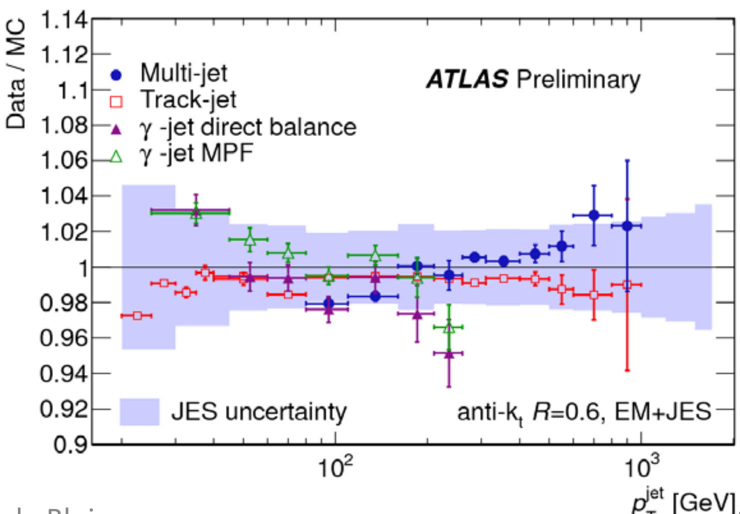


JES uncertainty estimation in |η|<0.8:
- single particle response from E/p and beam tests
- non-closure due to average over jet components & non-zero jet mass
- MC: noise & material, event modelling

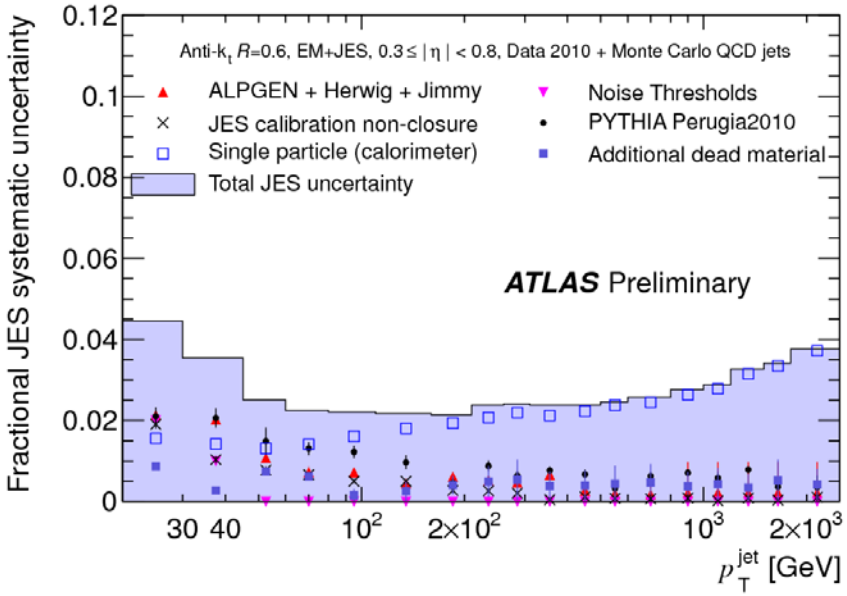


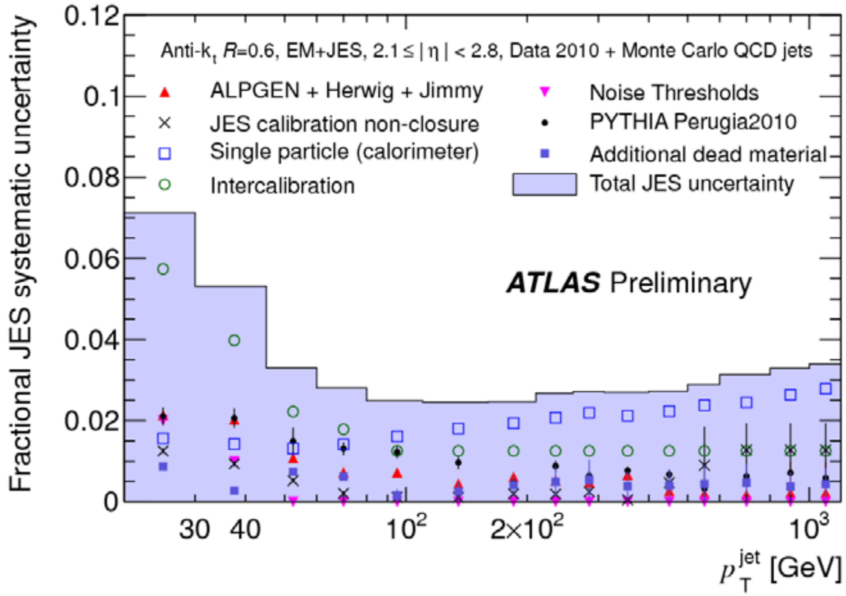
Extrapolation to higher η via di-jet balance

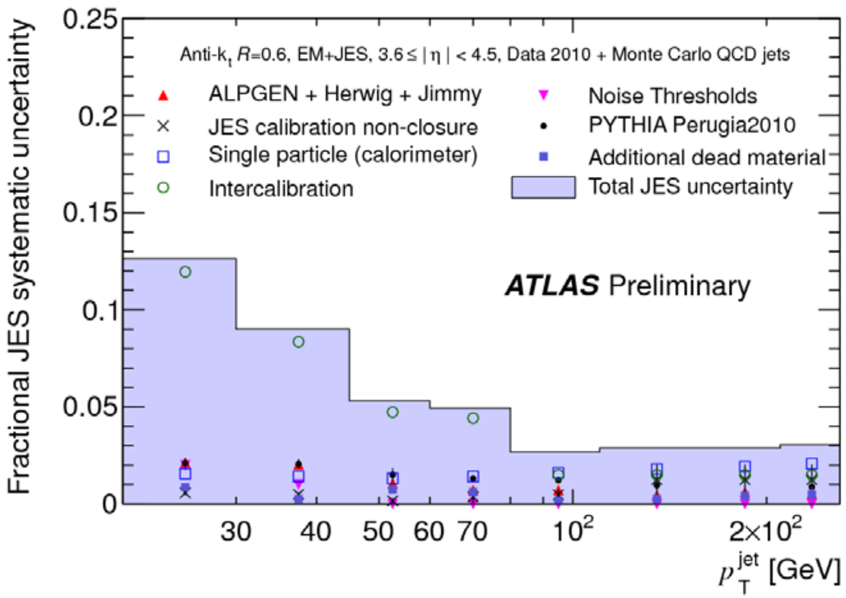
Validation by in-situ measurements



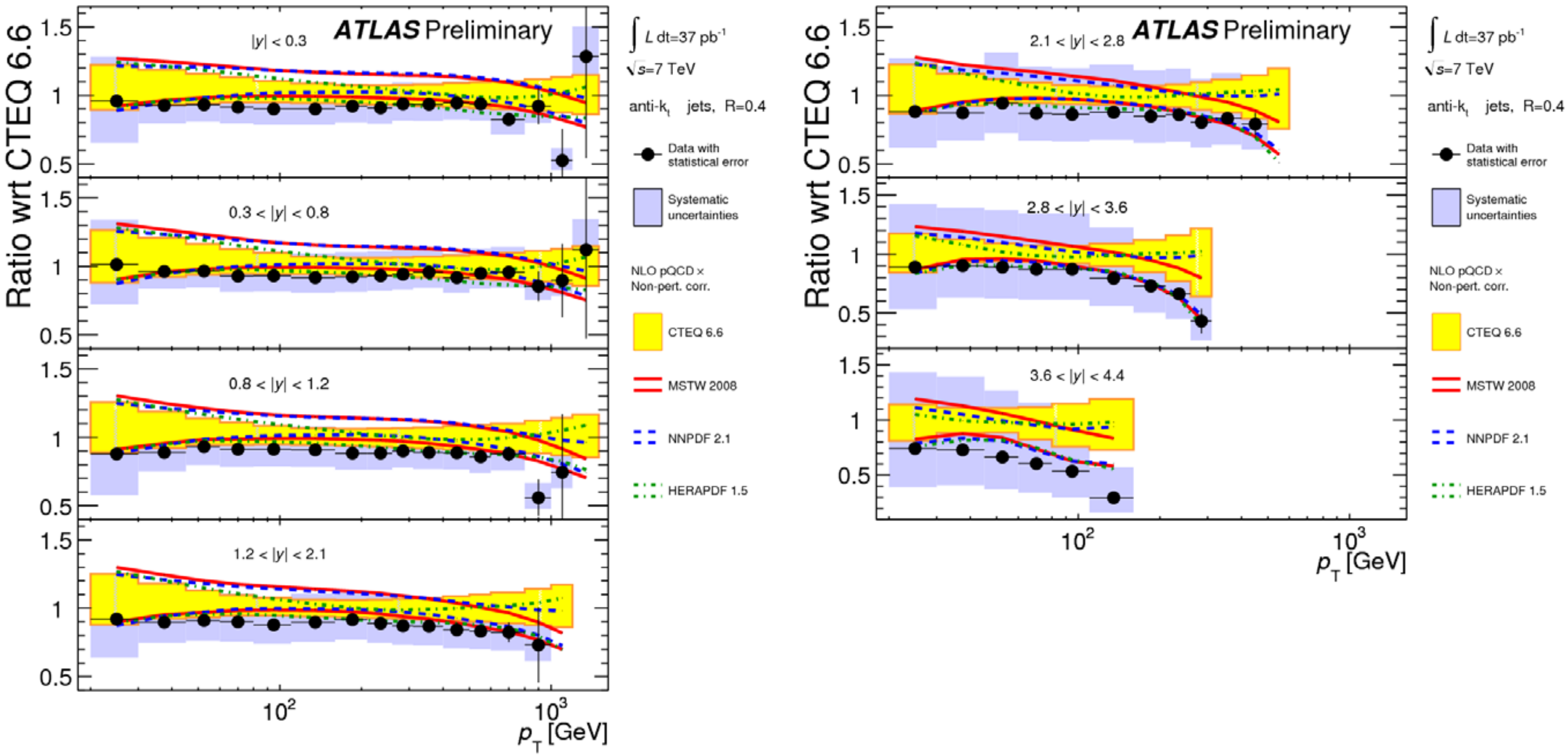
JES uncertainty



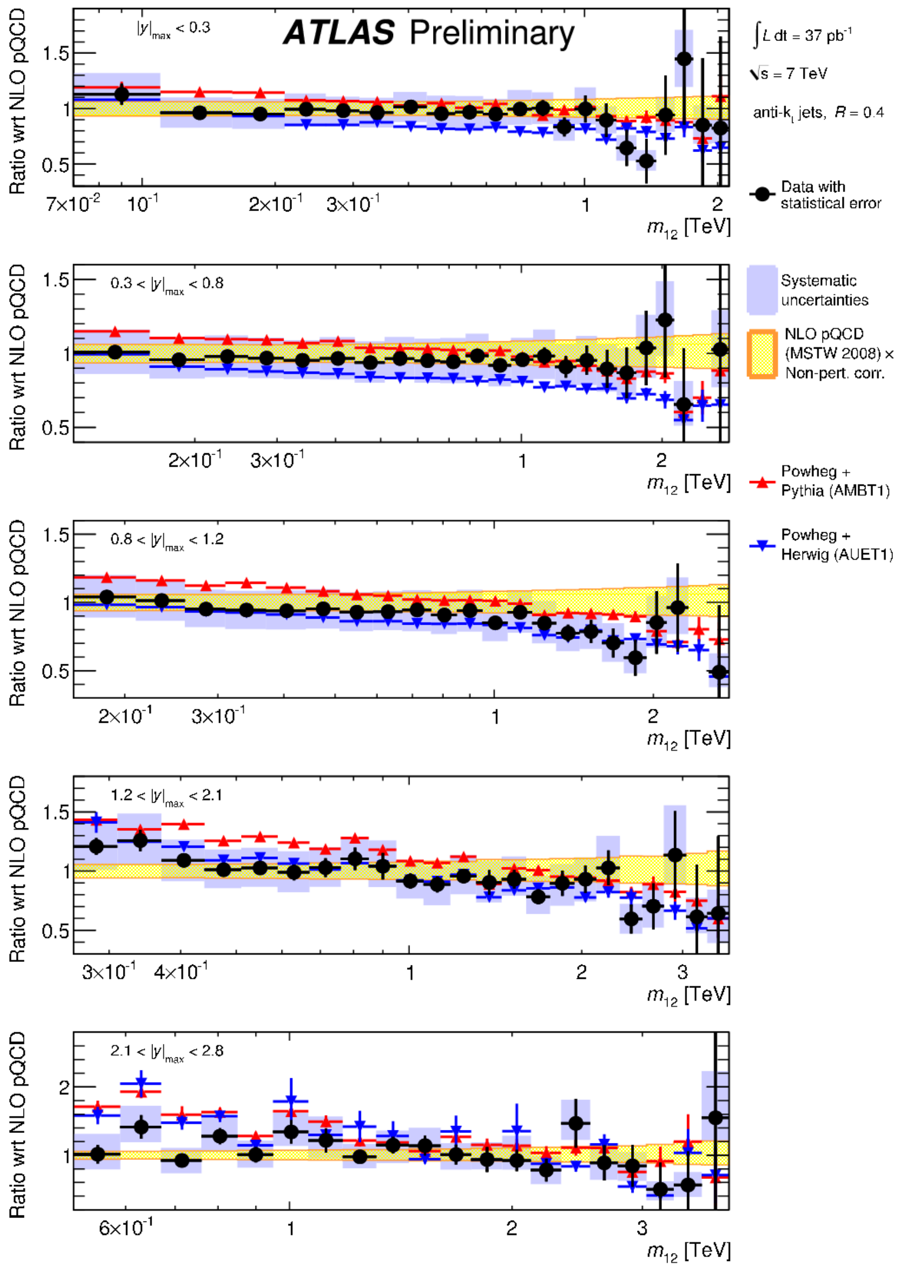




Inclusive jet production

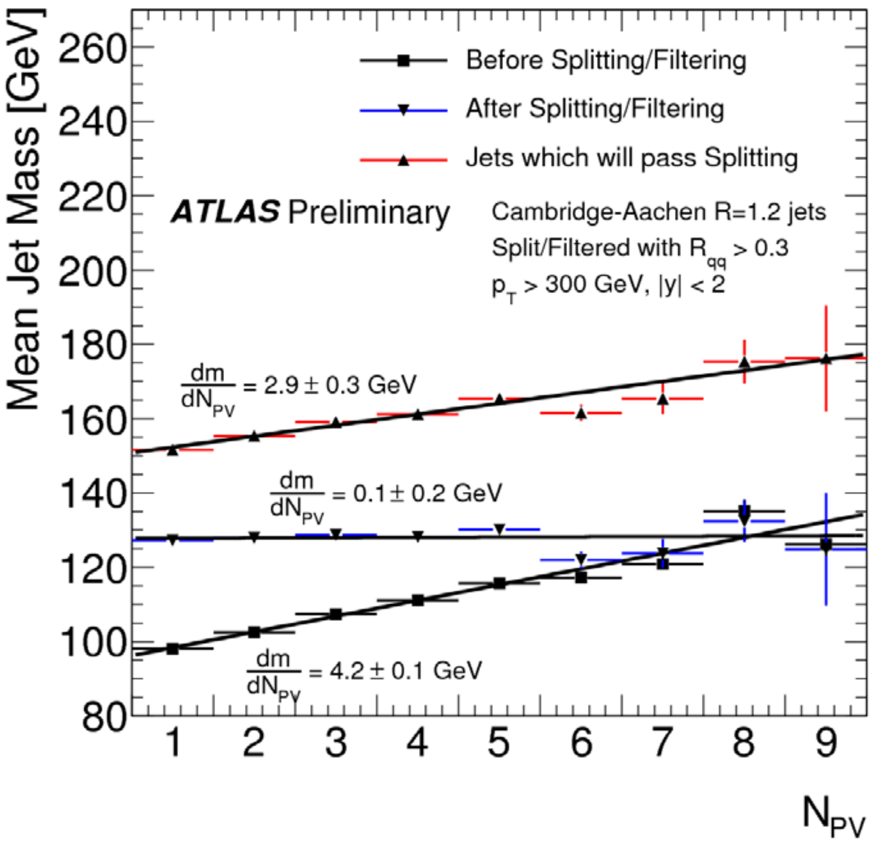


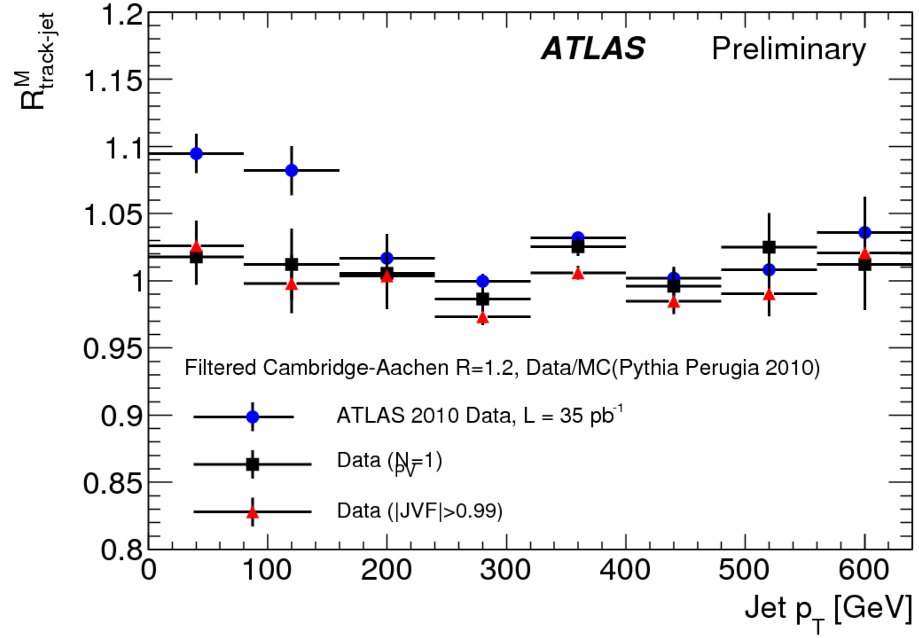
Di-jets

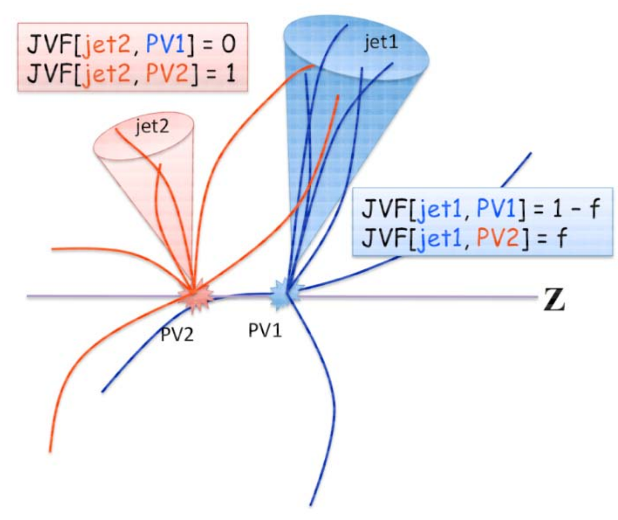


ATLAS Preliminary
$\int L\,dt$ = 37 pb^{-1}
$\sqrt{s}$ = 7 TeV
anti-k_t jets, R = 0.4
Data with statistical error
Systematic uncertainties
NLO pQCD (MSTW 2008) × Non-pert. corr.
Powheg + Pythia (AMBT1)
Powheg + Herwig (AUET1)
$|y|_{max}$ < 0.3
0.3 < $|y|_{max}$ < 0.8
0.8 < $|y|_{max}$ < 1.2
1.2 < $|y|_{max}$ < 2.1
2.1 < $|y|_{max}$ < 2.8
Ratio wrt NLO pQCD
m_{12} [TeV]

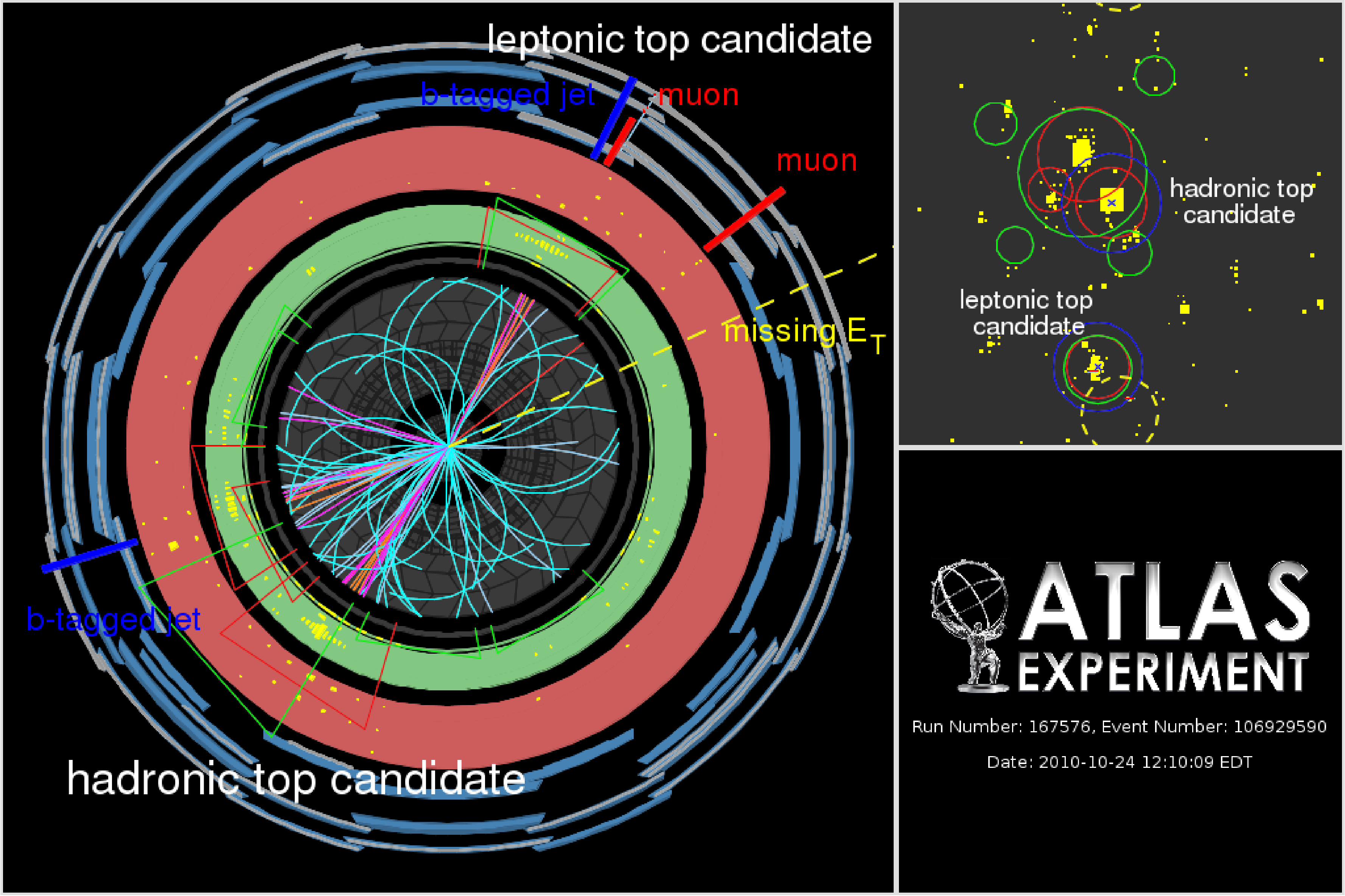
Jet mass & substructure







Jet mass & substructure

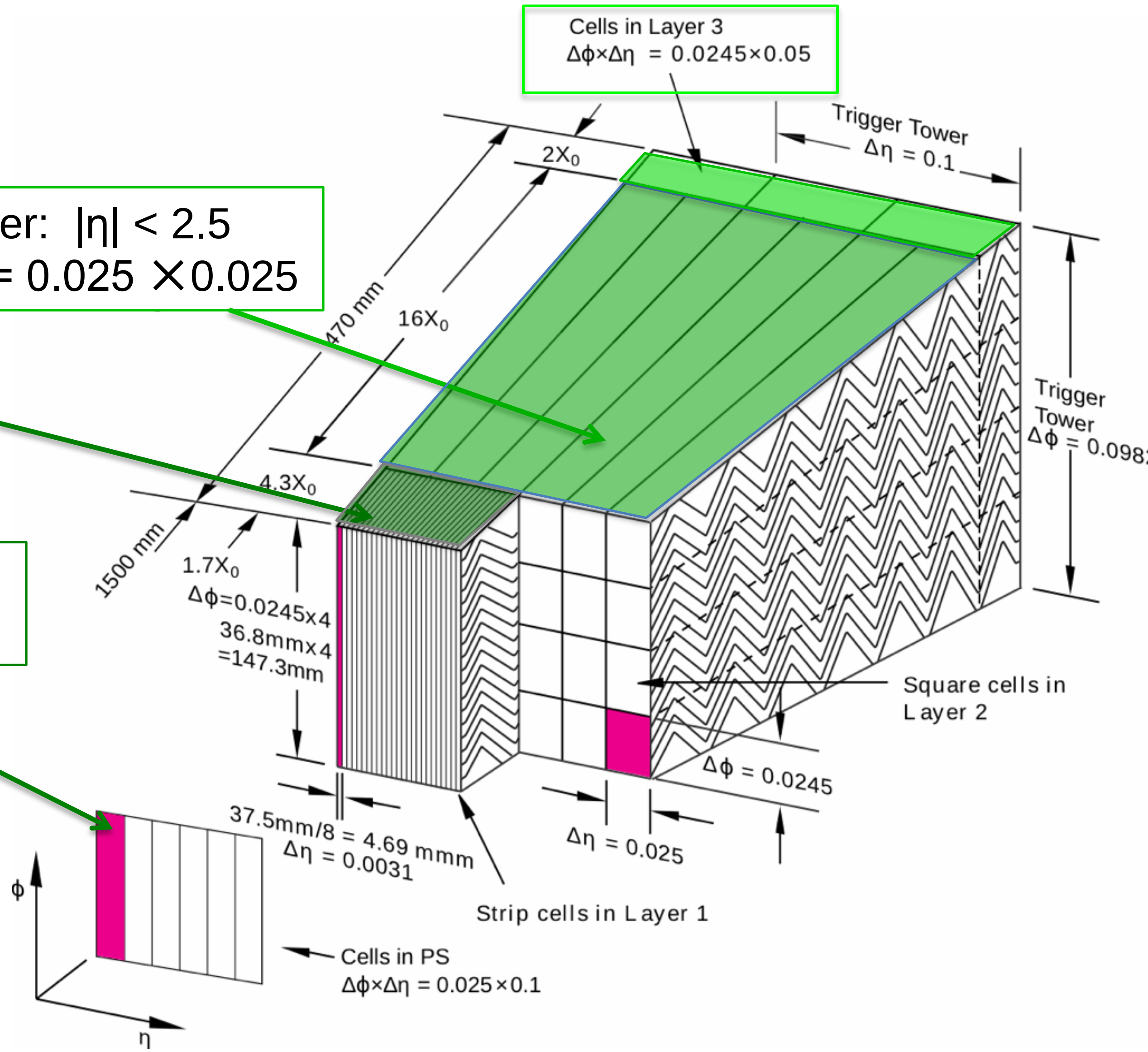


EM Calorimeter

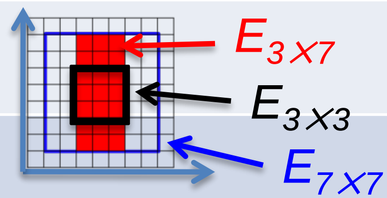
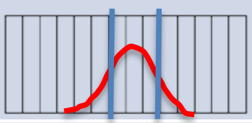
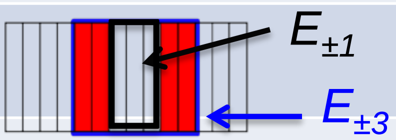
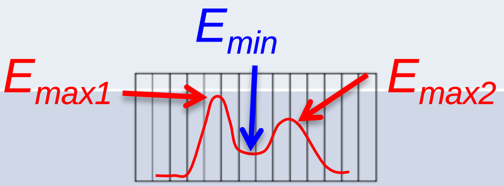
Middle layer: |η| < 2.5
$\Delta\eta \times \Delta\Phi = 0.025 \times 0.025$

Strip layer: |η| < 2.5
$\Delta\eta \times \Delta\Phi = 0.003 \times 0.1$

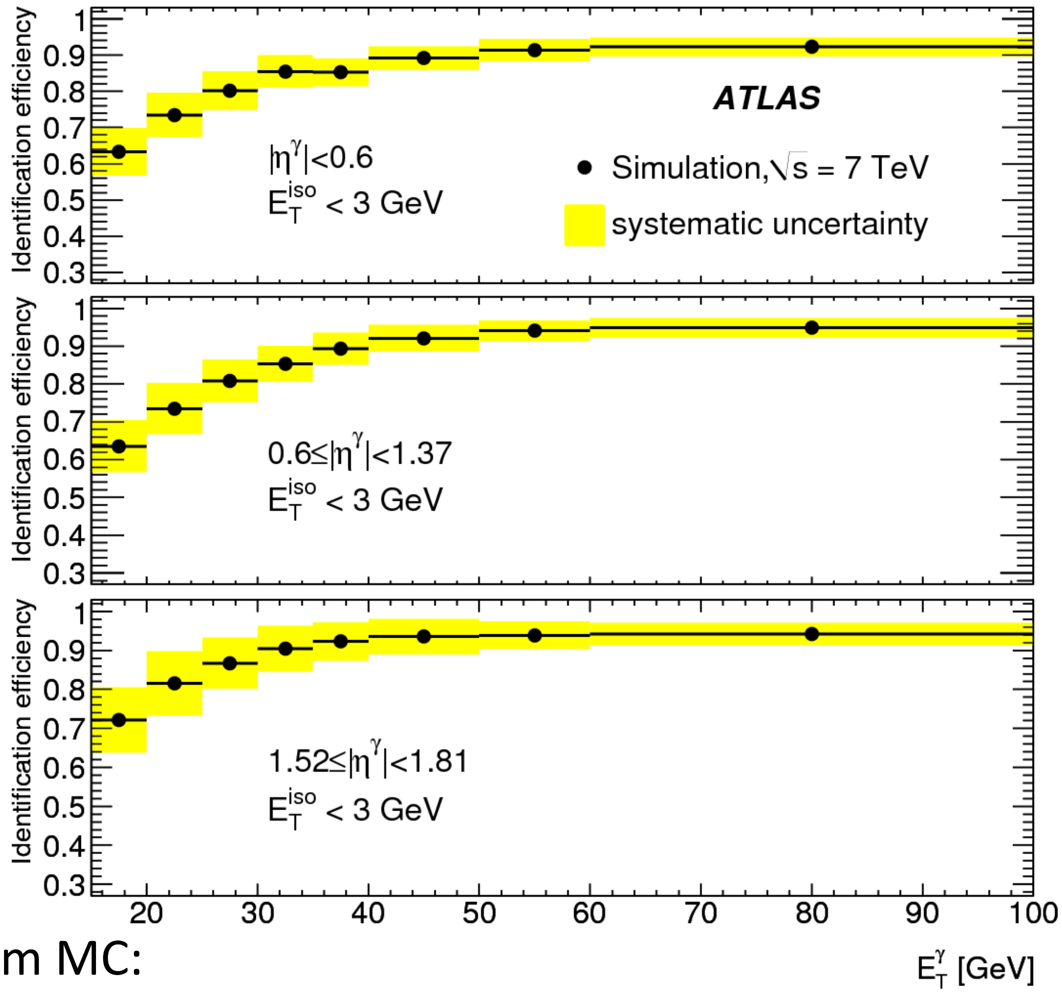
Pre-sampler: |η| < 1.8
$\Delta\eta \times \Delta\Phi = 0.025 \times 0.1$



Photon identification variables

	variable	Definition	description
	R_{had1}	$R_{\text{had}_1} = \frac{E_T^{\text{had}_1}}{E_T}$	Hadronic leakage
Middle Layer	R_η	$R_\eta = \frac{E^{S2}_{3\times7}}{E^{S2}_{7\times7}}$	
Middle Layer	R_Φ	$R_\phi = \frac{E^{S2}_{3\times3}}{E^{S2}_{3\times7}}$	
Middle Layer	ω_2	$\omega_2 = \sqrt{\frac{\sum E_i\eta_i^2}{\sum E_i} - \left(\frac{\sum E_i\eta_i}{\sum E_i}\right)^2}$	Shower width in middle layer
Strip Layer	ω_{s3}	$\omega_{s\,3} = \sqrt{\frac{\sum E_i(i-i_{\max})^2}{\sum E_i}}$	 Shower width in 3 strips around the hottest strip
Strip Layer	$\omega_{s\ tot}$	$\omega_{s\,\text{tot}} = \sqrt{\frac{\sum E_i(i-i_{\max})^2}{\sum E_i}}$	Shower width in all strips
Strip Layer	F_{side}	$F_{\text{side}} = \frac{E(\pm3)-E(\pm1)}{E(\pm1)}$	
Strip Layer	ΔE	$\Delta E = E^{S1}_{2^{\text{nd}}\max} - E^{S1}_{\min}$	
Strip Layer	E_{ratio}	$E_{\text{ratio}} = \frac{E^{S1}_{1^{\text{st}}\max} - E^{S1}_{2^{\text{nd}}\max}}{E^{S1}_{1^{\text{st}}\max} + E^{S1}_{2^{\text{nd}}\max}}$	

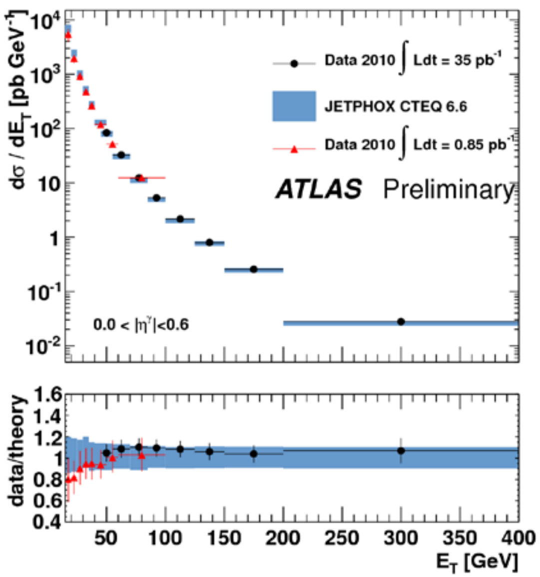
Photons

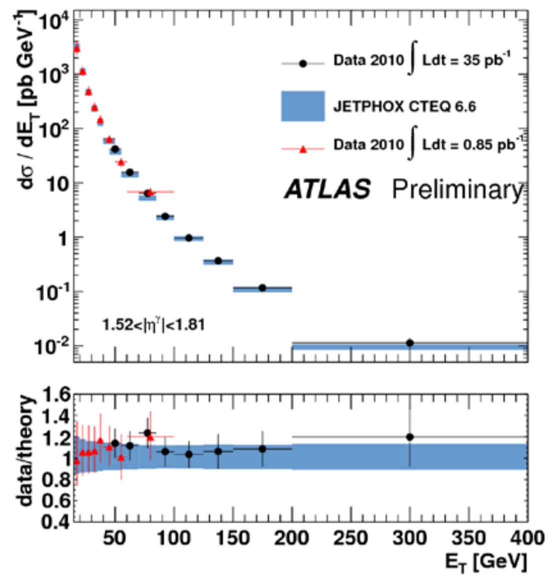


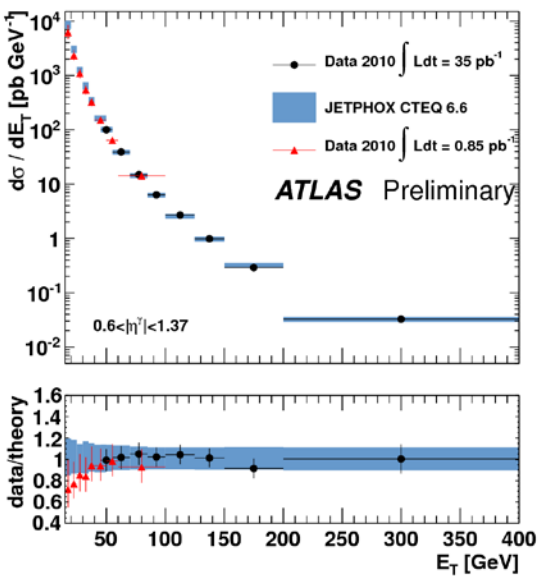
Efficiencies from MC:

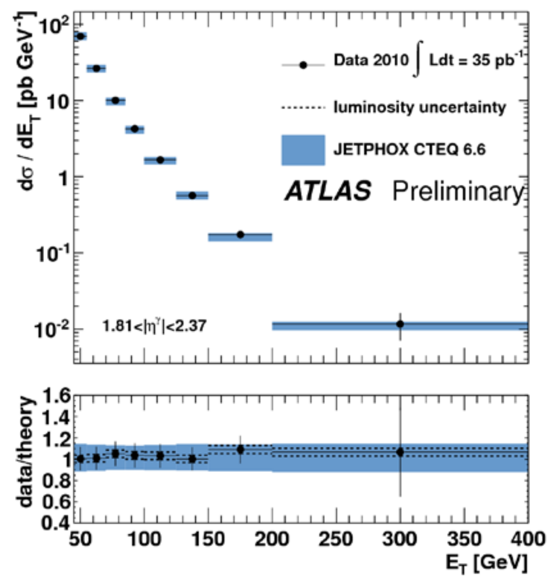
- shift shower shapes to match data
- unconverted and converted separately
- checked on $W\rightarrow e\nu$

Inclusive photons





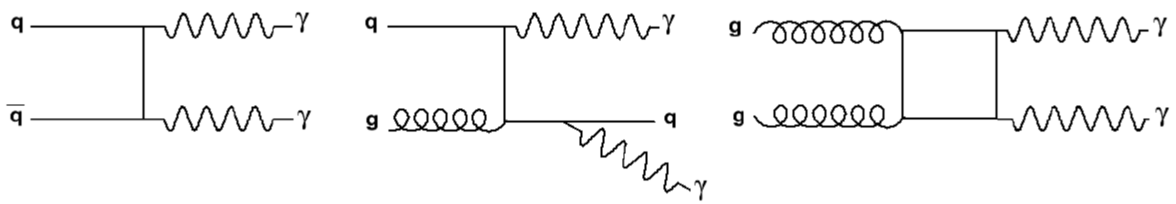




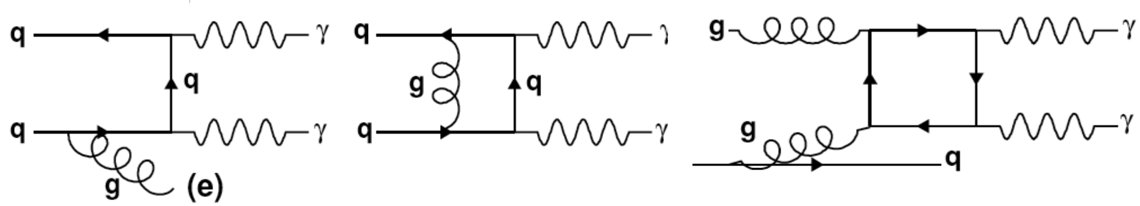
Di-photon Production

Leading-Order:

born *brem* *box*



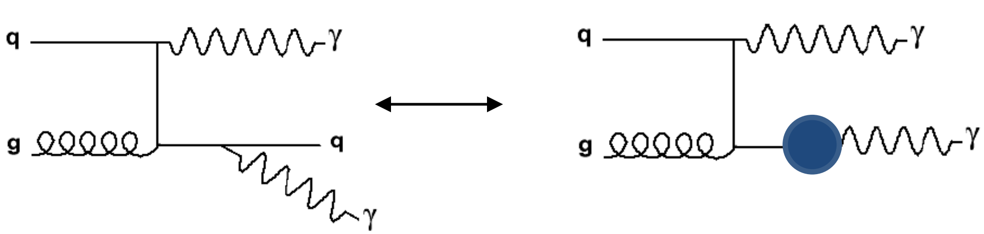
NLO corrections: in ResBos and Diphox



NLL resummation: resummation of divergences arising at small $P_{T\gamma\gamma}$ due to initial-state soft gluon emission

In ResBos
but not in DiPhox

Fragmentation contribution: provides a complete treatment of the collinear part of brem



In DiPhox (NLO 1 and 2-photon fragmentation)
but not in ResBos (LO 1-photon fragmentation only)

Di-photons: matrix method

Event-by-event: S_{XY} = 0 or 1, W_{ab} is a weight for each category $\gamma\gamma$, γj,jγ ,or jj

2[nd] highest p_T γ Passes or Fails isolation

Event weights

$$\begin{pmatrix} S_{PP} \\ S_{PF} \\ S_{FP} \\ S_{FF} \end{pmatrix} = \begin{pmatrix} \epsilon_1\epsilon_2 & \epsilon_1 f_2 & f_1\epsilon_2 & f_1 f_2 \\ \epsilon_1(1-\epsilon_2) & \epsilon_1(1-f_2) & f_1(1-\epsilon_2) & f_1(1-f_2) \\ (1-\epsilon_1)\epsilon_2 & (1-\epsilon_1)f_2 & (1-f_1)\epsilon_2 & (1-f_1)f_2 \\ (1-\epsilon_1)(1-\epsilon_2) & (1-\epsilon_1)(1-f_2) & (1-f_1)(1-\epsilon_2) & (1-f_1)(1-f_2) \end{pmatrix} \begin{pmatrix} W_{\gamma\gamma} \\ W_{\gamma j} \\ W_{j\gamma} \\ W_{jj} \end{pmatrix}$$

highest p_T γ Passes or Fails isolation

$\gamma\gamma$ yield in signal $E_{T1,2}^{iso}$<3 GeV region:

$N\gamma\gamma = \sum W_{\gamma\gamma}\varepsilon_1\varepsilon_2$

To be taken into account:

- ε_1, ε_2 depend on η, f_1, f_2 on η and p_T
- correlations between the two candidates