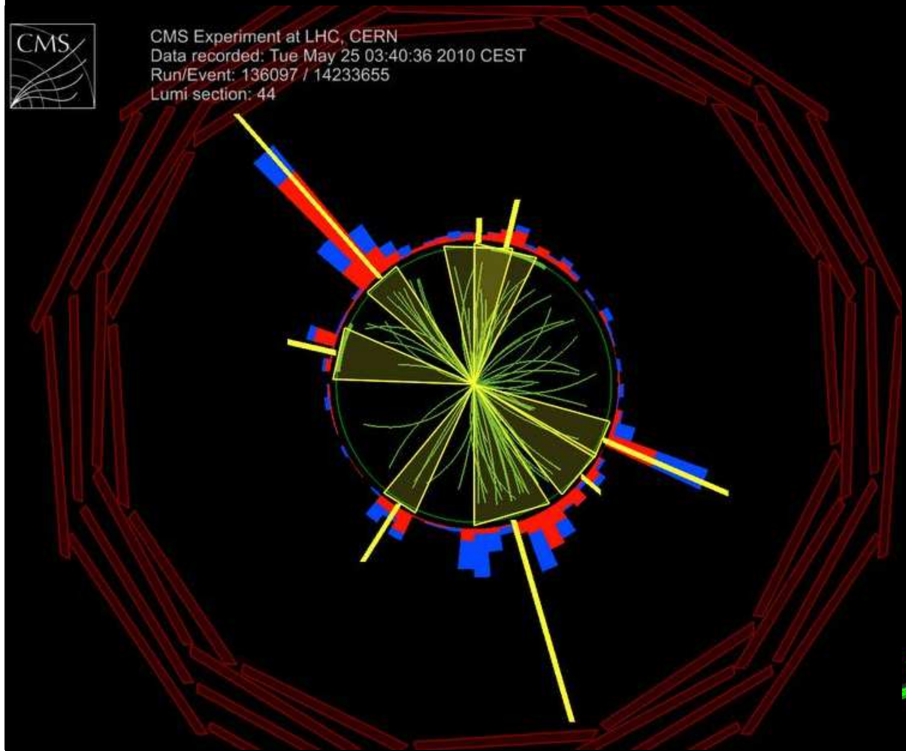
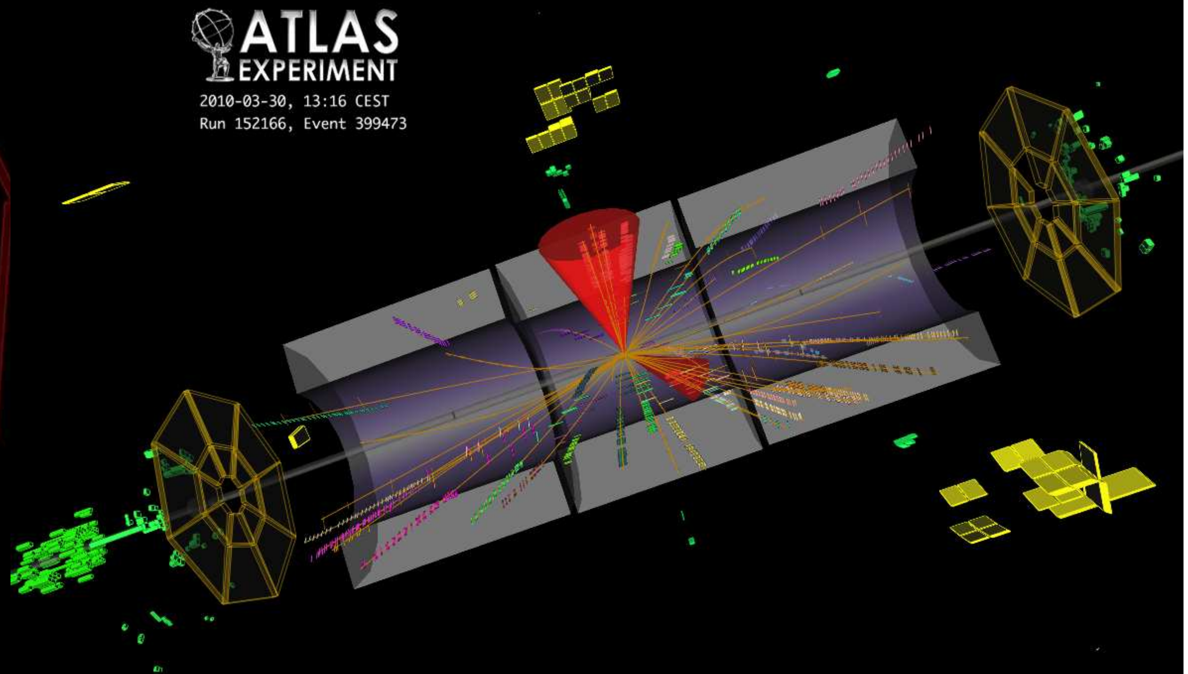
LHC 2010 - Jets and Relevance for VBF

Higgs Hunting - Orsay

30.07.2010





Jana Schaarschmidt (TU Dresden)

for the ATLAS and CMS Collaborations

Outline

I. ATLAS & CMS

II. Vector Boson Fusion and Prospects

III. Jet and MET Performance

IV. Inclusive Jet Cross Section

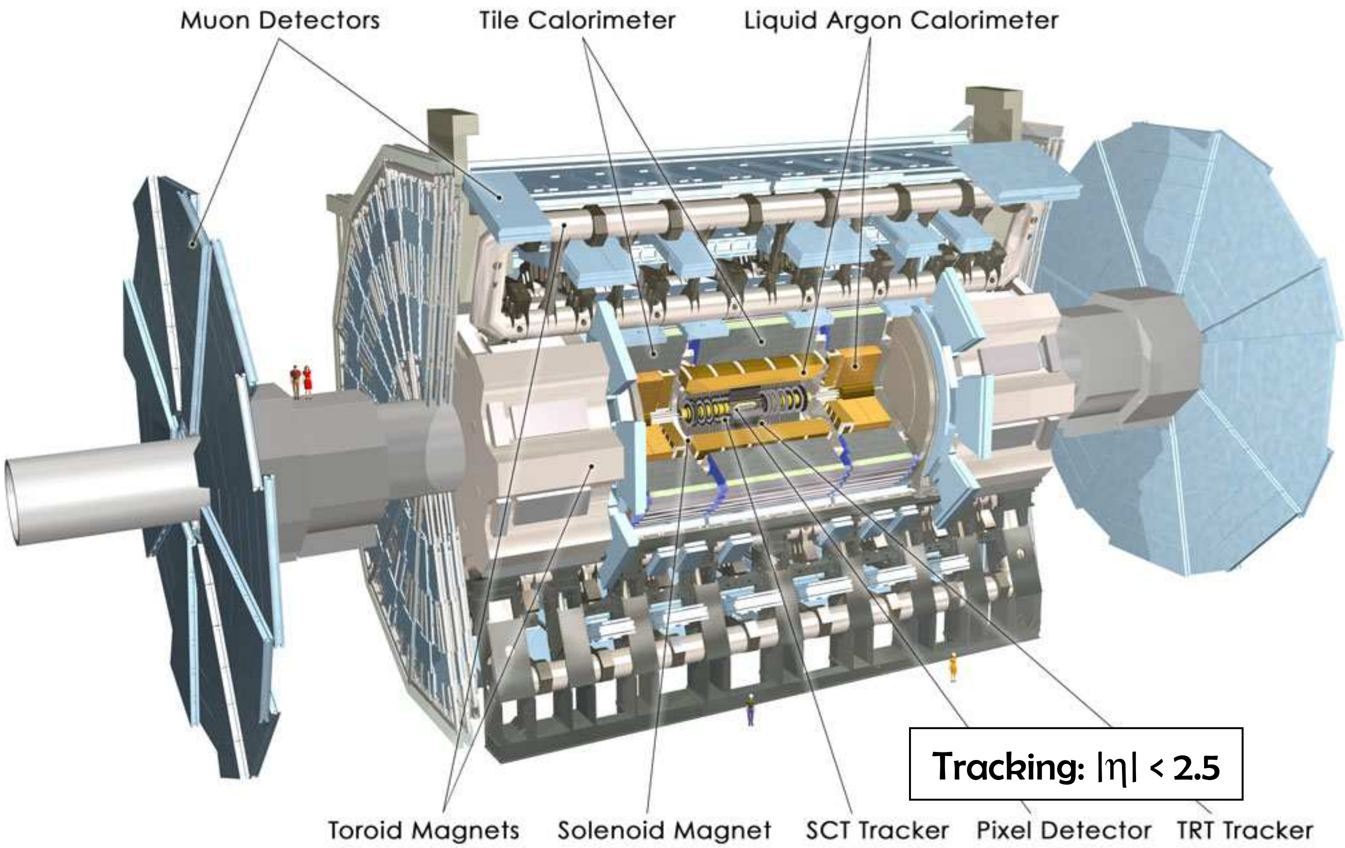
A list of references can be found in the back-up.

I. The ATLAS Detector

Calorimeters:

- **Non-compensating:**
  Response to hadrons lower than to EM objects, correct for e/γ, but jet energy underestimated
- Dead Material before and between calos

⇨ **Need jet energy correction by calibration**



Components:

LAr	EM Barrel	$\|\eta\| < 1.5$
LAr	(EM & had) end-caps	$1.5 < \|\eta\| < 3.2$
LAr	(EM & had) Forward calo	$3.2 < \|\eta\| < 4.9$
Scintil-lator	(had) Tile Barrel	$\|\eta\| < 0.7$
Scintil-lator	(had) Tile Ext. Barrel	$0.8 < \|\eta\| < 1.7$

Resolutions:

EM:

$$\sigma / E = 10\% / \sqrt{E\,[\mathrm{GeV}]} \oplus 0.7\,\% \oplus \frac{0.3\ \mathrm{GeV}}{E}$$

Hadronic:

$$\sigma / E = 50\% / \sqrt{E\,[\mathrm{GeV}]} \oplus 1.7\,\% \oplus \frac{3\ \mathrm{GeV}}{E}$$

I. The CMS Detector

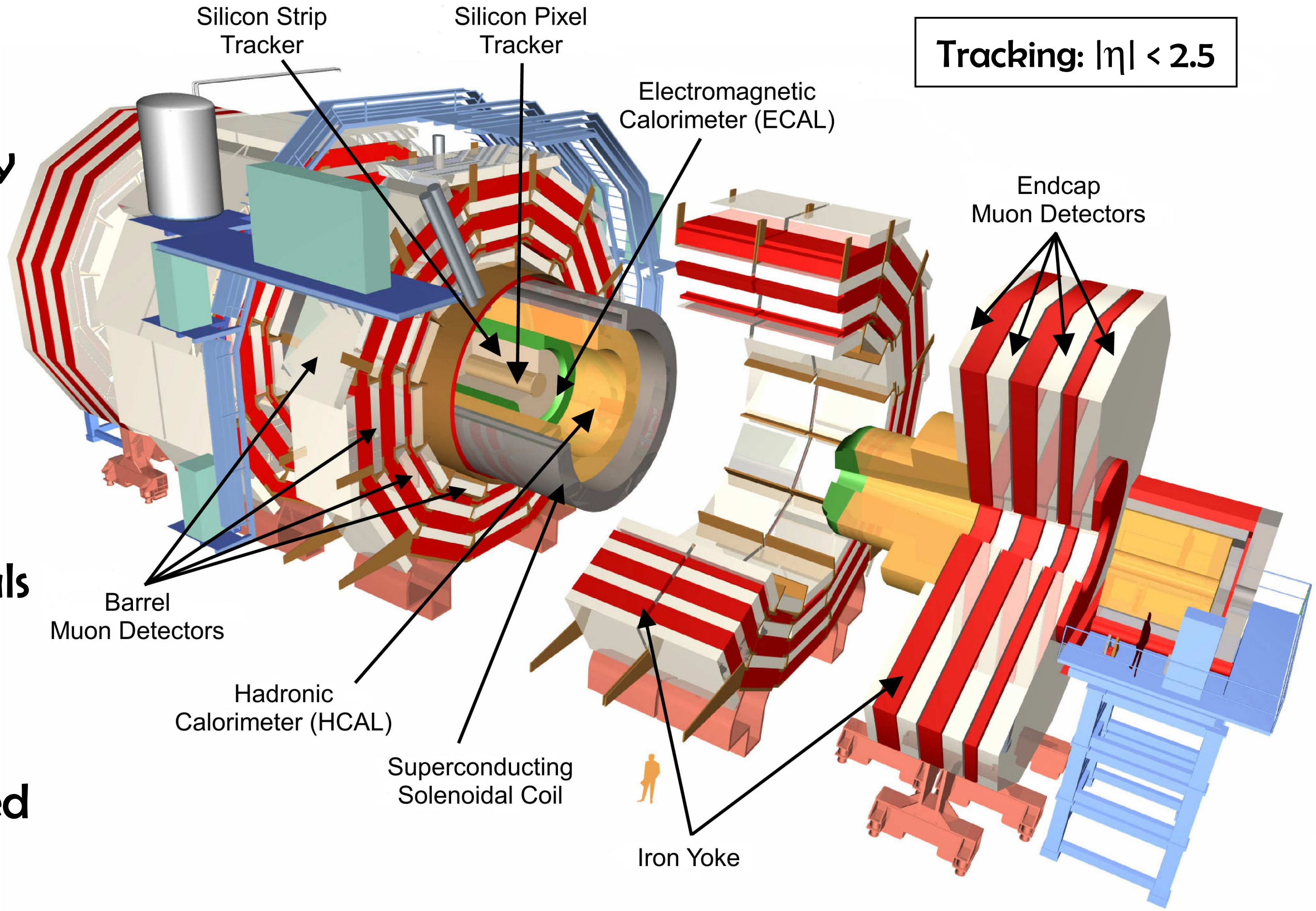
Calorimeters:

- Calibration of hadronic energy deposits required due to non-linear and non-compensating response

Components:

- ECAL: Lead-tungstate crystals
- HCAL: Brass absorber and plastic tile scintillators
- HF: Iron/quartz-fibre based Cherenkov detector

Tracking: $|\eta| < 2.5$



ECAL Barrel + End-caps	$|\eta| < 3.0$
Central HCAL	$|\eta| < 3.0$
Forward HCAL	$3.0 < |\eta| < 5.0$

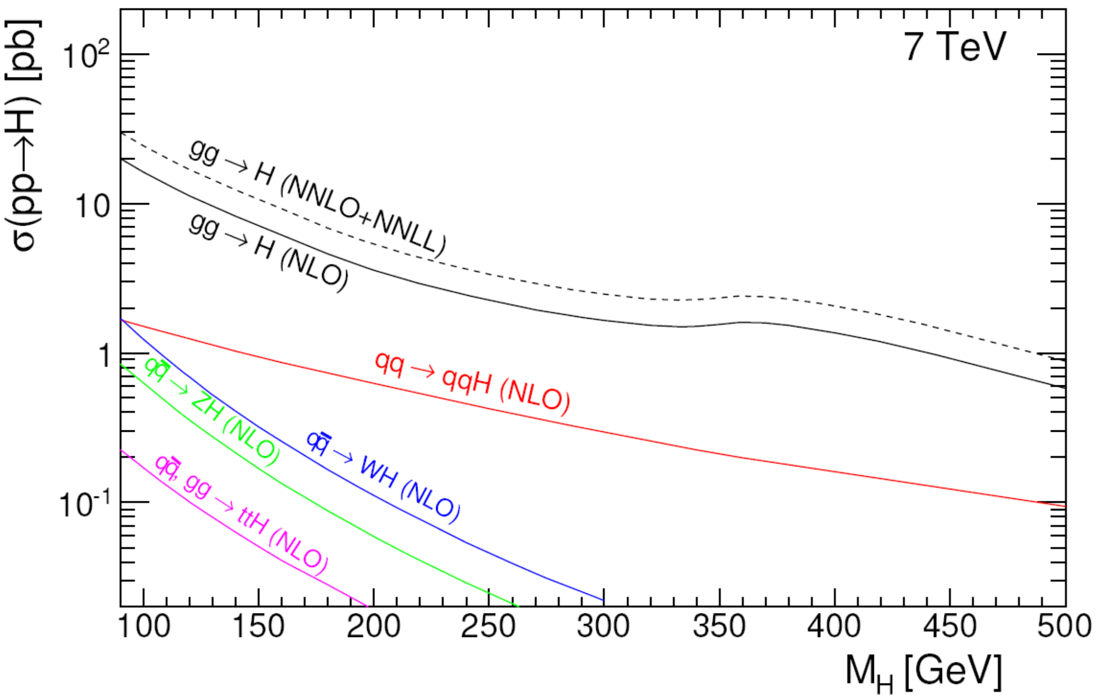
Resolutions:

EM: $\sigma / E = 3\ \% / \sqrt{E\ [\mathrm{GeV}]}$

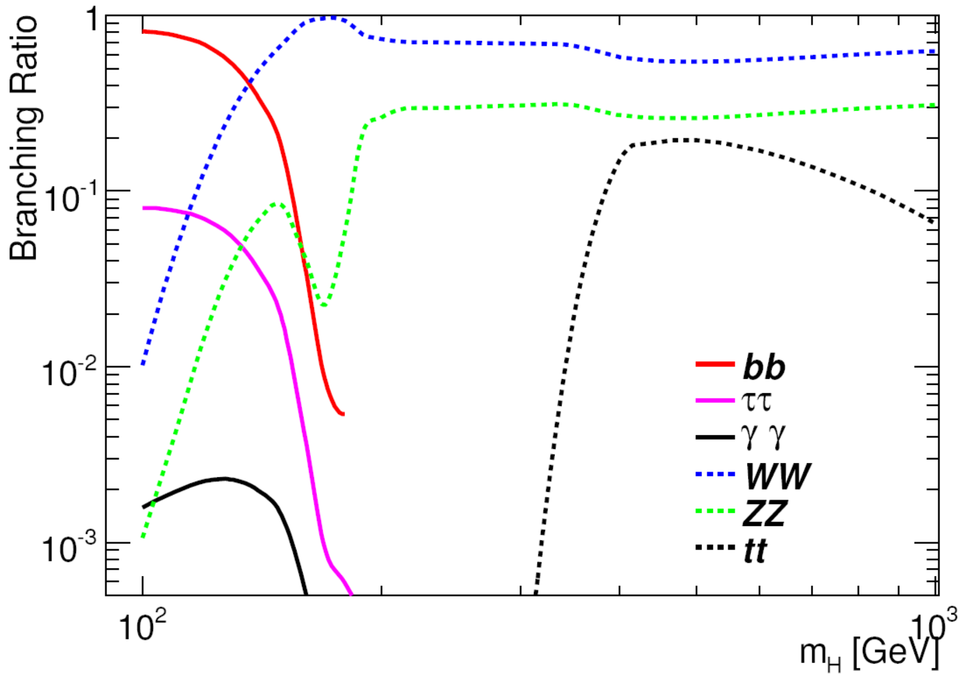
Had: $\sigma / E = 100\ \% / \sqrt{E\ [\mathrm{GeV}]}$

II. SM Higgs Boson Production

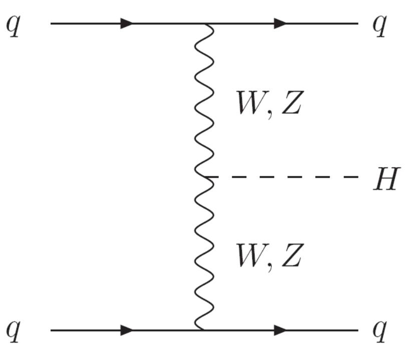
Cross sections



Branching ratios



Vector Boson Fusion (VBF):

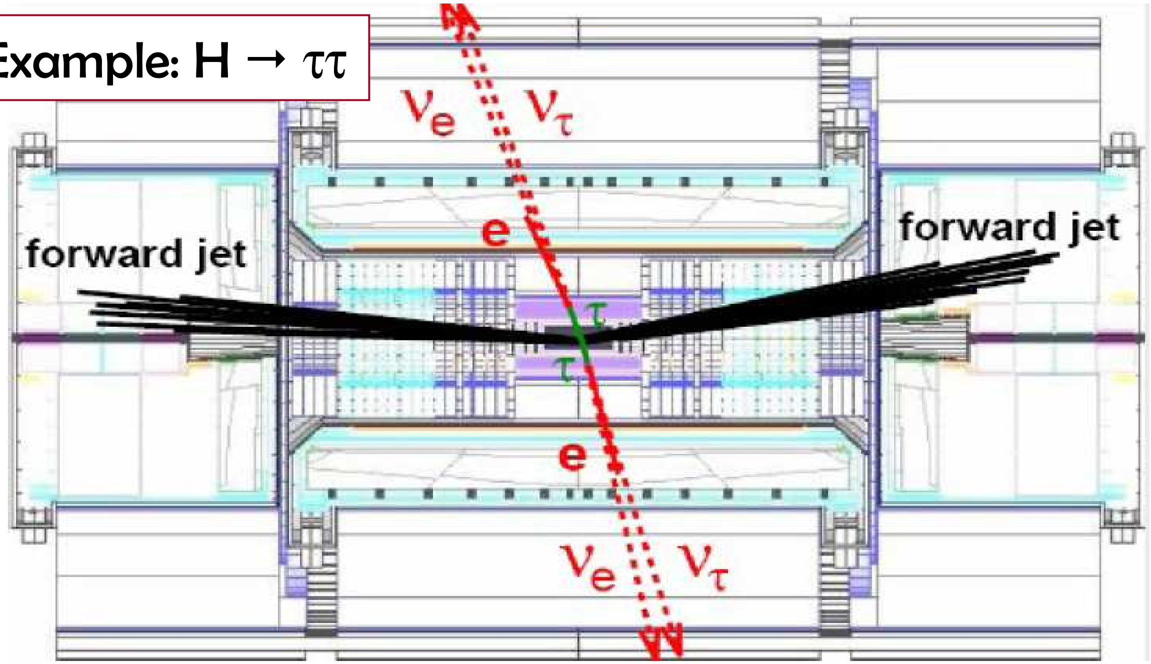


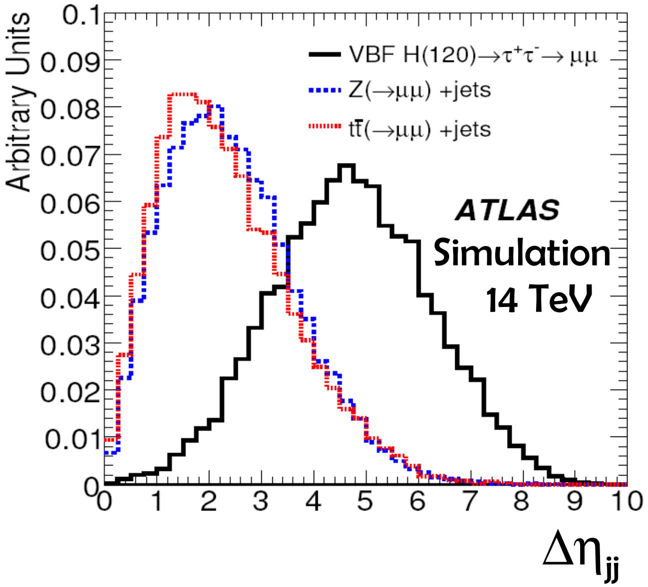
- 2nd largest cross section after gluon fusion (10 times below ggH)
- Provides special topology used to suppress (QCD) backgrounds
- Studied in ττ (115-145 GeV), WW (≥ 140 GeV) and γγ (110-140 GeV) final states

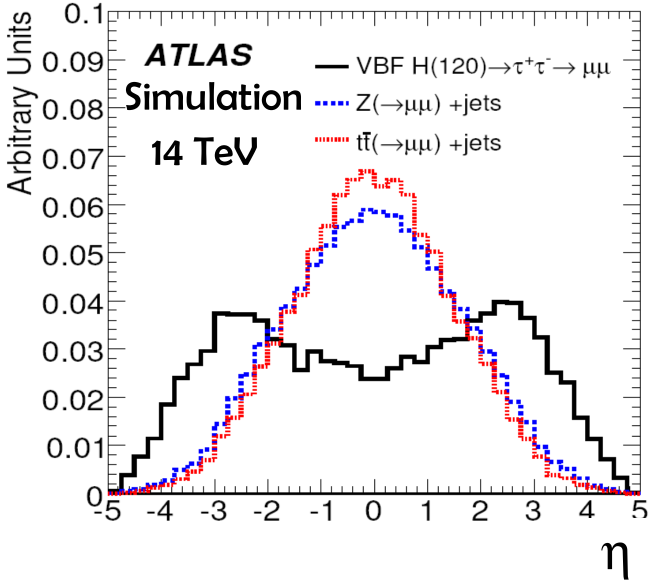
General signal signature:

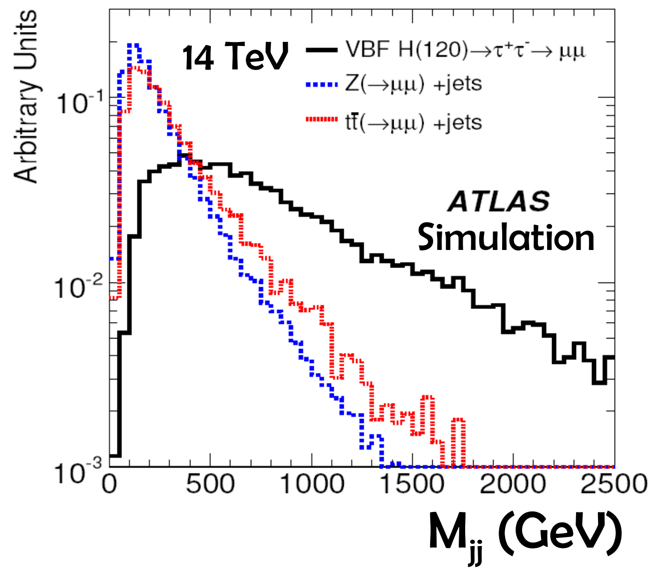
- Two jets in opposite direction (‚tagging jets') with large η gap
- Higgs boson decay products in central region
- No color flow between quarks
  ⇨ Central Jet Veto (CJV)
- Large invariant dijet mass

Example: $H \rightarrow \tau\tau$









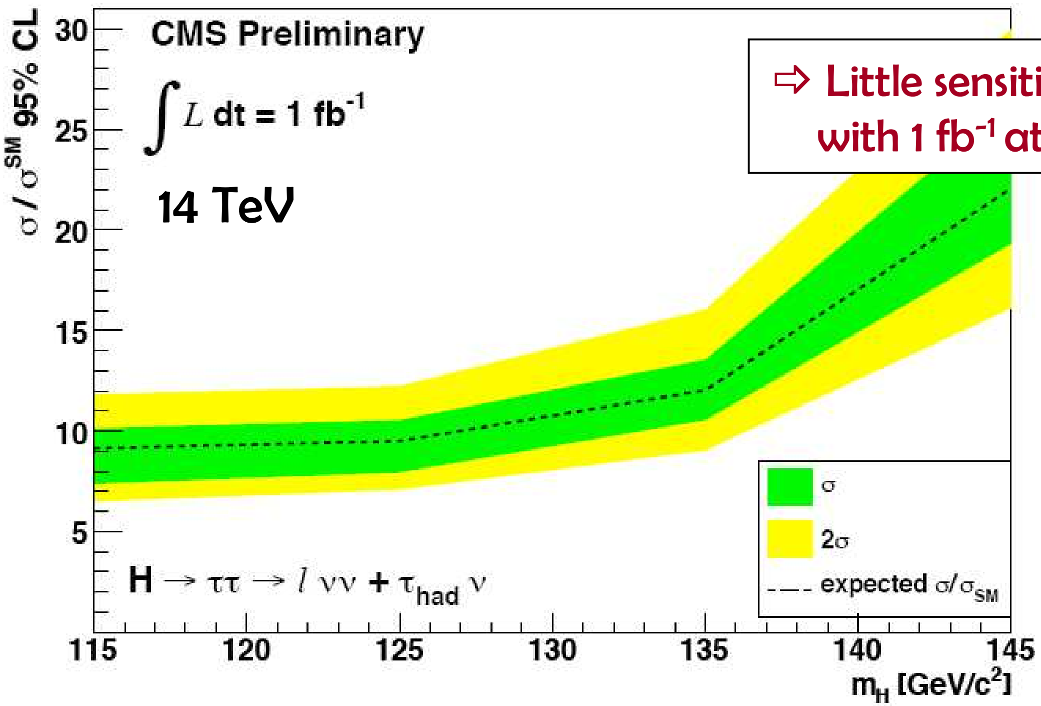
II. Prospects for VBF $H \to \tau\tau$

Challenges:

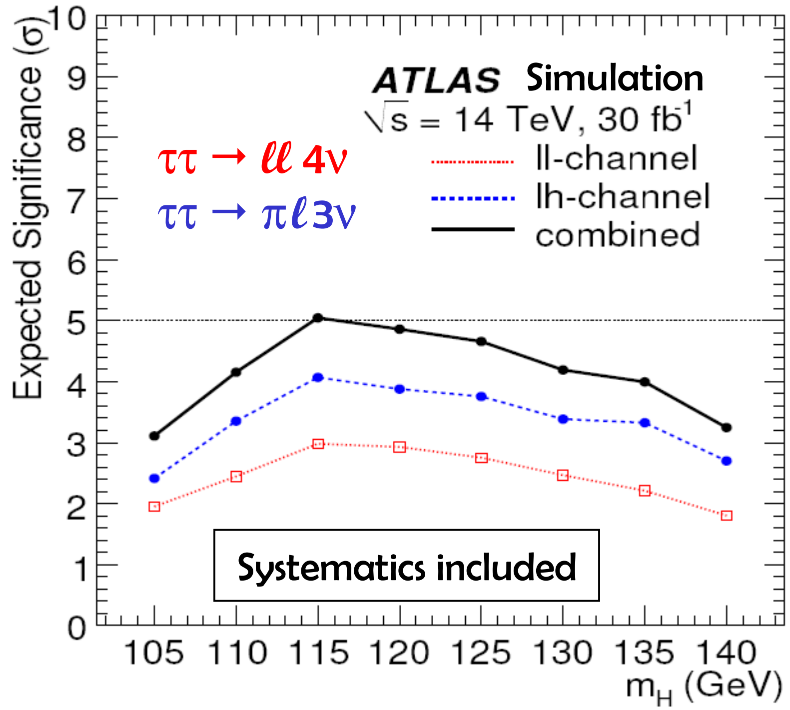
- MET resolution crucial:
  - Higgs mass reconstruction
  - Discriminant variable
- Influence by pile-up:
  - CJV
  - Higgs mass resolution
  - tau ID

Dominant systematic uncertainties:

	Expected uncertainty ($\approx$ 10 fb^{-1})		Impact on signal efficiency
CMS	JES $\Delta E/E$ = 7 %	all jets	$\pm$ 10 %
ATLAS	JES $\Delta E/E$ = 7 % (15 %)	central (forward) jets	+16 % / - 20 %
	Jet resol. $\sigma(E) = 0.45\ (0.63)\ \sqrt{E}$		$\pm$ 1 %
ATLAS & CMS	Tagging and CJV efficiency		each $\pm$ 2 %



⇨ Little sensitivity with 1 fb^{-1} at 7 TeV



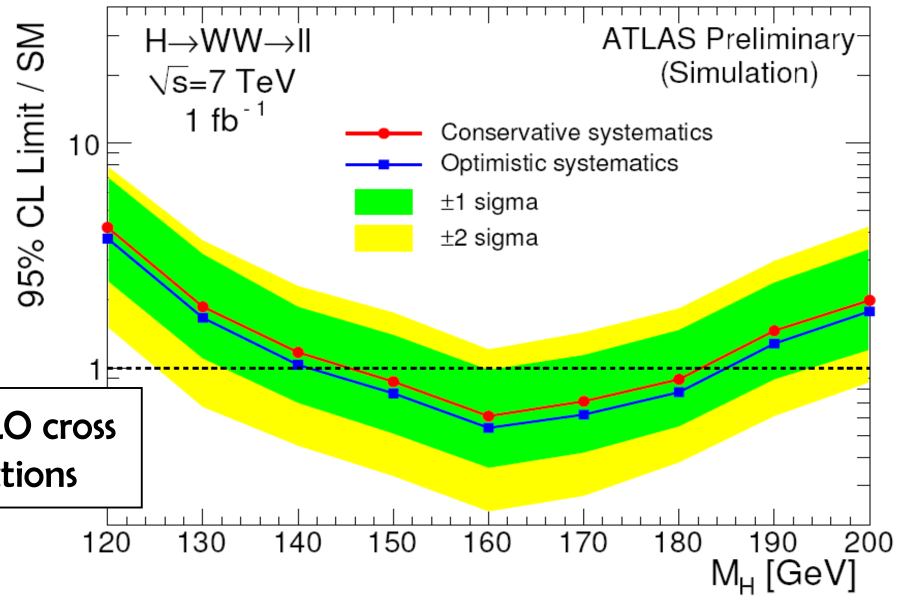
Systematics included

II. Prospects for H → WW (VBF and Gluon Fusion)

- ee/μμ/eμ + MET final states considered
- Impact of jet uncertainties on backgrounds:
  - ATLAS (H+2j study @ 10 TeV) up to 15 %
  - CMS (14 TeV study) overall 10 %
- Dominant backgrounds: WW, ttbar, W/Z
- CMS: 0 jet strategy ⇨ ggH dominant
- ATLAS: 0/1/2 jet bins
  ⇨ VBF relevant in 2 jet analysis

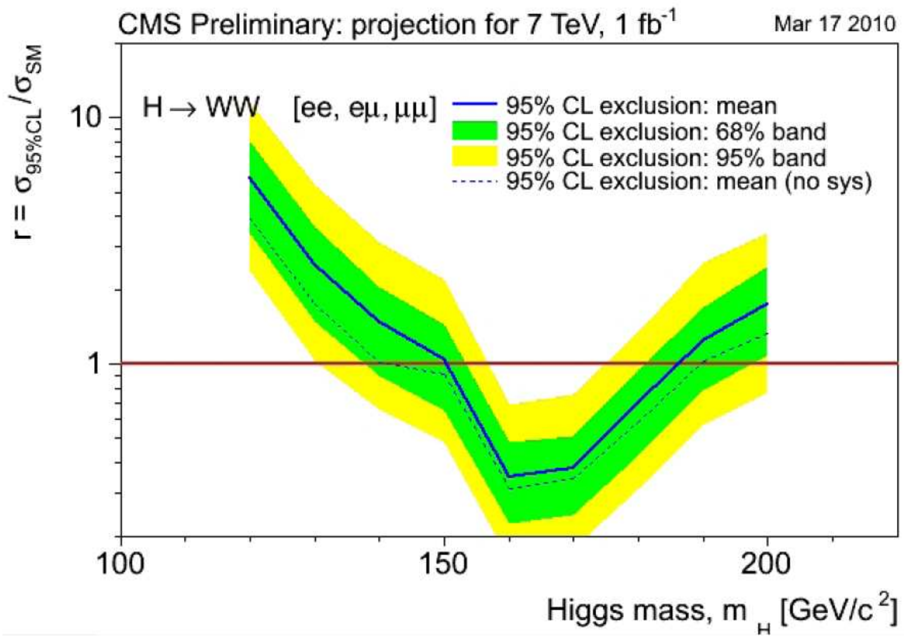
Prospects for 2011:

ATLAS



NLO cross sections

CMS



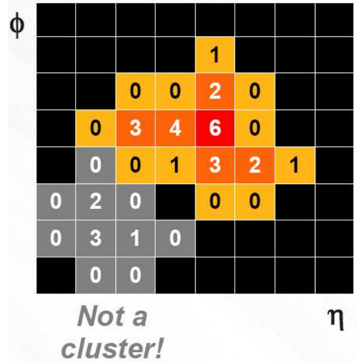
- Sensitivity to SM Higgs starts with 250 pb^{-1}
- Discovery of m_H=160 GeV with 5 fb^{-1} (full systematics)
- NNLO+NNLL signal cross sections
- Exclusion (1 fb^{-1}) : 150 GeV < m_H < 185 GeV

⇨ Hope to confirm and improve Tevatron limits with 1 fb^{-1}

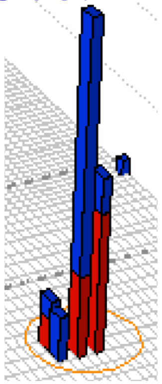
III. Jet Reconstruction

- ATLAS: Topological clusters as inputs to the anti-k_t algorithm with R = 0.6 or R=0.4

TopoCluster:
- Seeded by calorimeter cells with energy deposit E_{cell} > 4 * noise
+ Neighbouring cells with E_{cell} > 2 * noise iteratively added
+ All nearest neighbours around cluster to accumulate shower tail



- CMS: Three types of jets

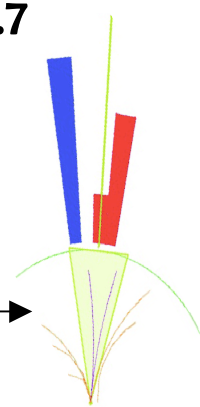


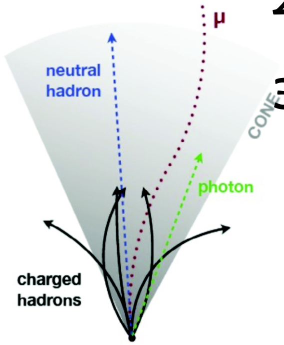
1) Calorimeter jets (Calo)

Calorimeter towers as inputs to the anti-k_t jet finder with R=0.5 or R=0.7

Calo Tower:
- Built from HCAL cells + corresponding ECAL crystals
- For |η| > 3.0 each tower corresponds to one HCAL cell

2) Jet plus Track jets (JPT): Calo towers replaced by tracks if matched





3) Particle Flow Jets (PF)

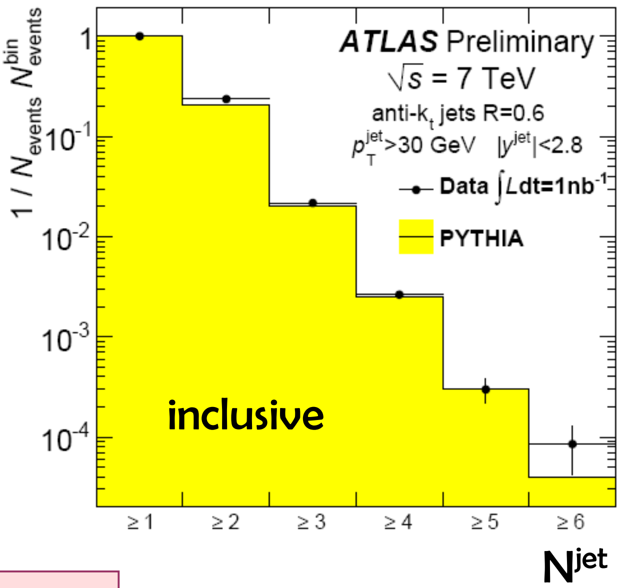
Coherent combination of all subdetectors for reconstruction and ID of all particles. Jets are computed out of these calibrated particles

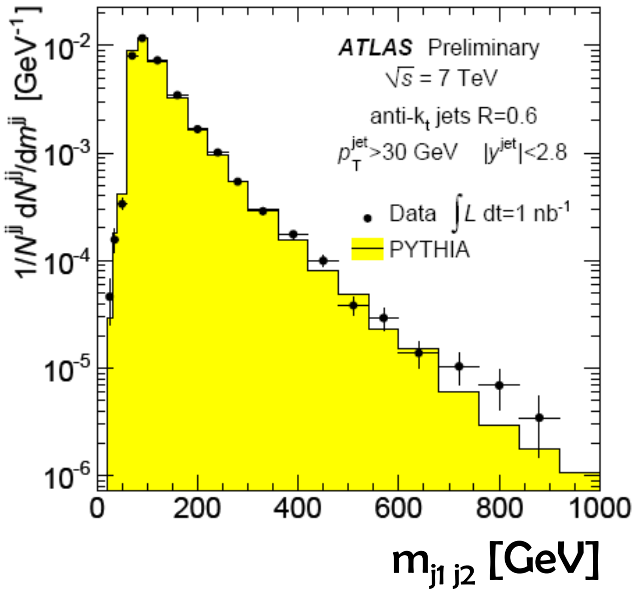
- Track Jets (ATLAS and CMS) Reconstructed from tracks alone, independent from calos

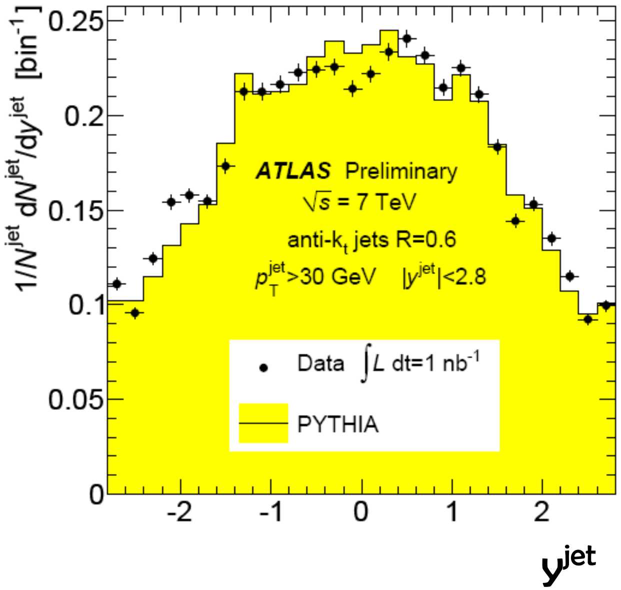
III. Kinematic Distributions

ATLAS

1 nb^{-1}

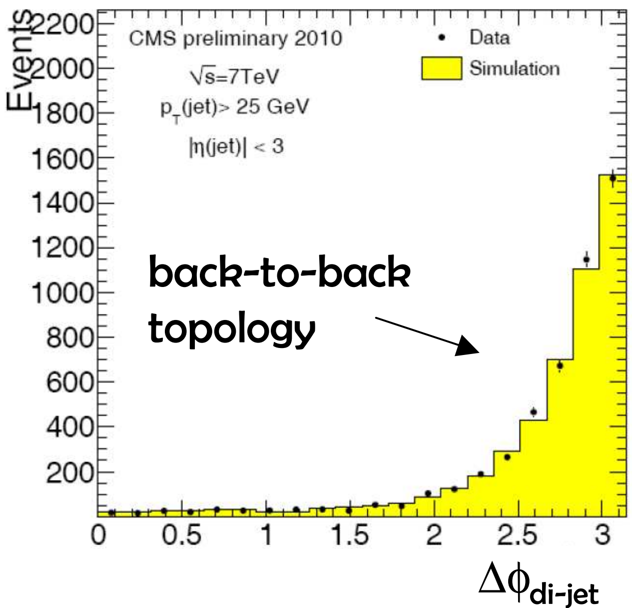


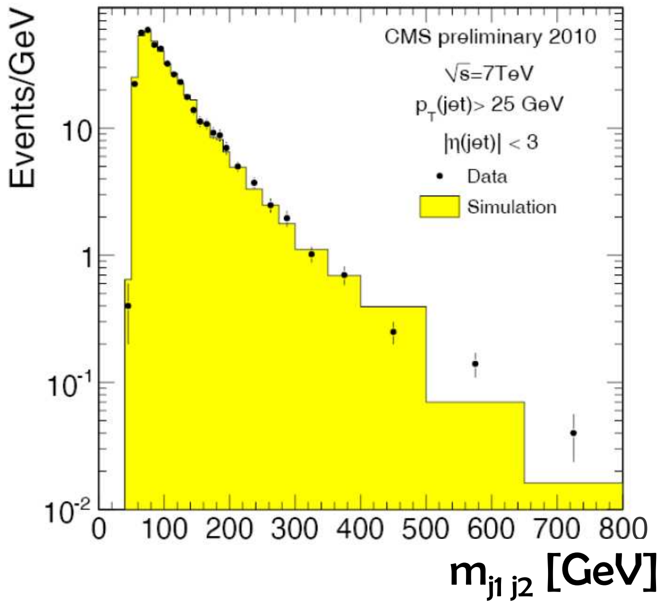


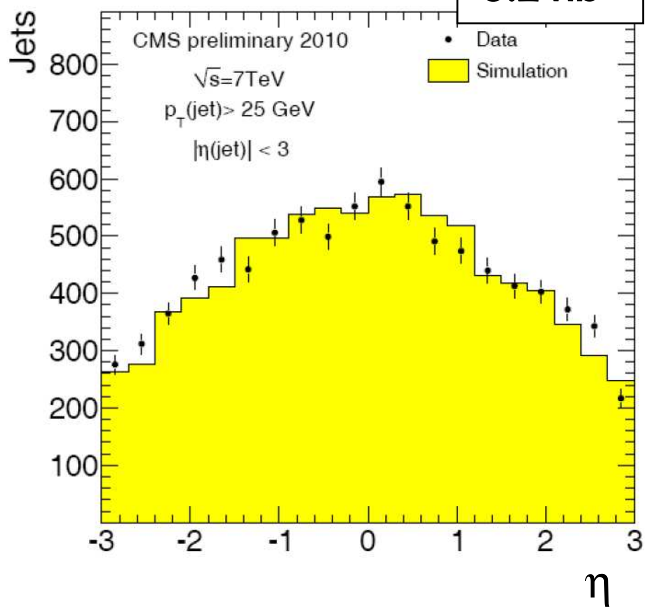


CMS (Calorimeter jets only)

0.2 nb^{-1}

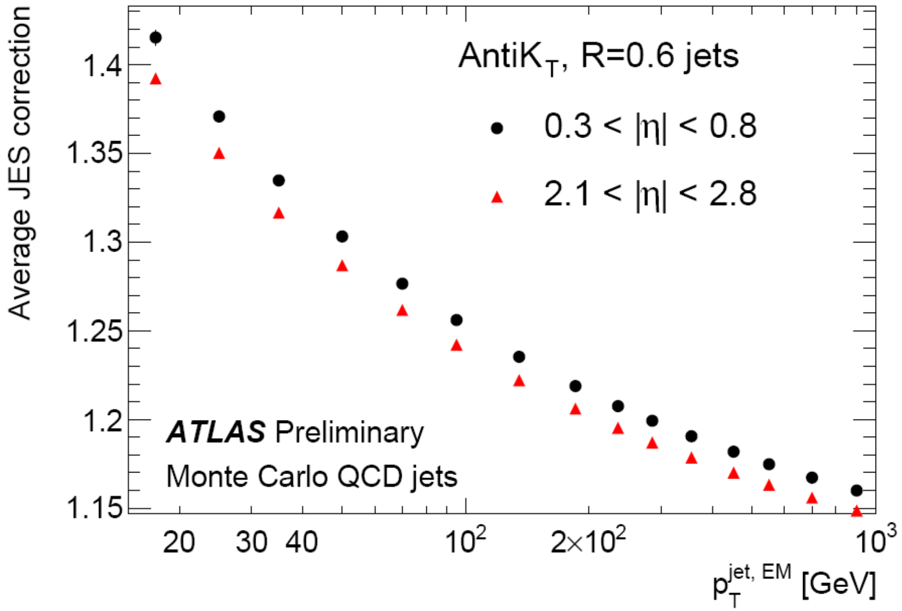




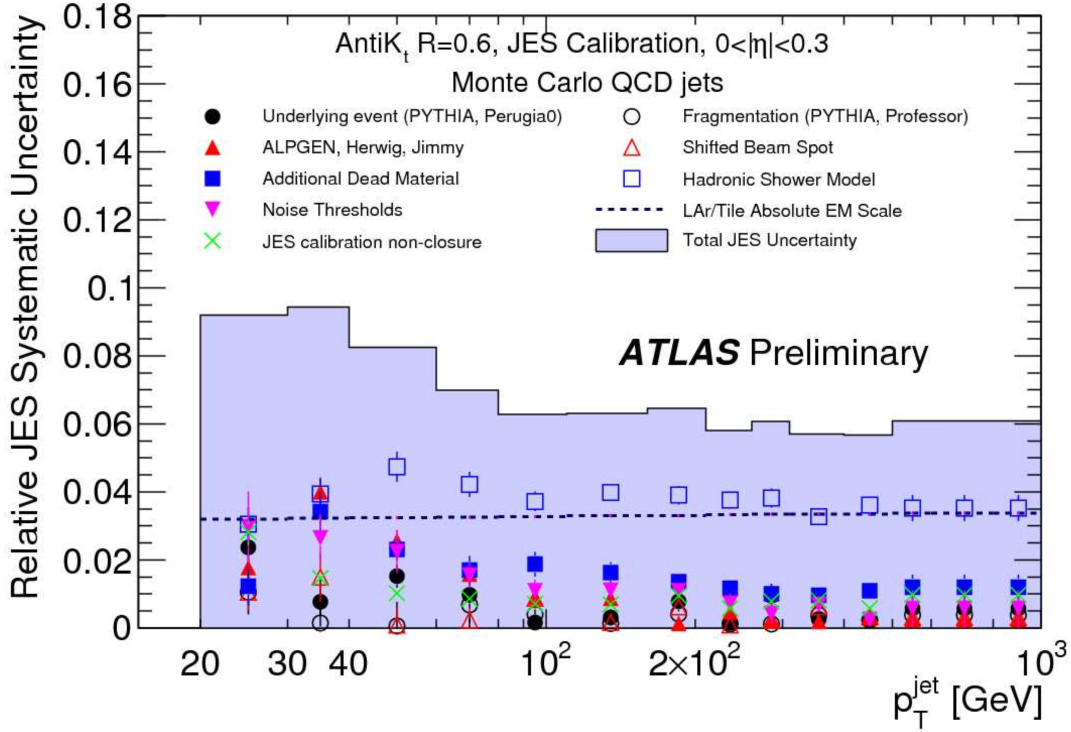


III. Jet Energy Scale (JES) and Uncertainty - ATLAS

Calibration factors C (p_T,η) from MC:



JES uncertainty for central jets obtained from MC:



Dominant contributions:

- Detector geometry
- Noise description
- Hadronic shower model

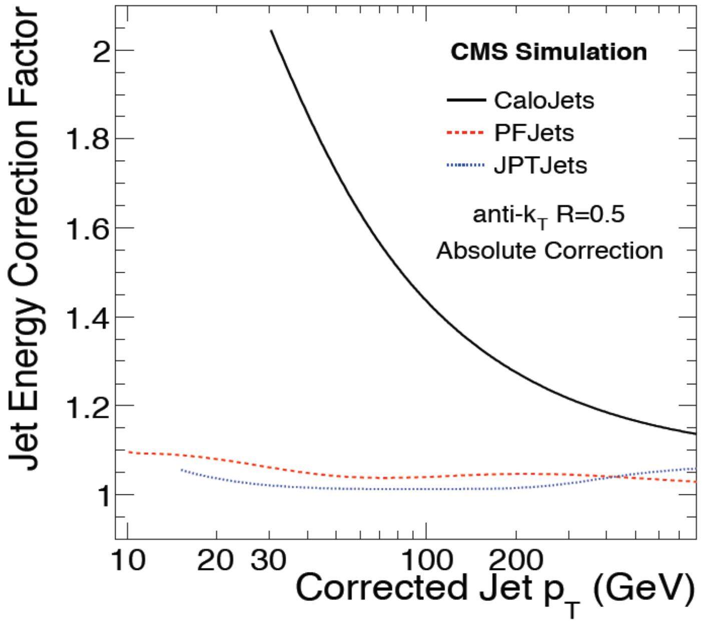
+ Additional 2 % from pile-up

- Cross checked by single particle response
- JES uncertainty for forward jets not yet evaluated

Summary for anti-kt jets R=0.6:

η region	Maximum relative JES Uncertainty	
	$p_T^{jet} > 20$ GeV	$p_T^{jet} > 60$ GeV
$0 < \|\eta\| < 0.3$	9.4%	6.9%
$0.3 < \|\eta\| < 0.8$	9.4%	6.8%
$0.8 < \|\eta\| < 1.2$	9.3%	7.0%
$1.2 < \|\eta\| < 2.1$	9.5%	6.9%
$2.1 < \|\eta\| < 2.8$	10%	7.6%

III. JES and Uncertainty - CMS



JES correction depends on jet type

⇨ JES uncertainty depends on jet type

Conservative estimates:
- Calo jets: 10 %
- JPT and PF jets: 5%

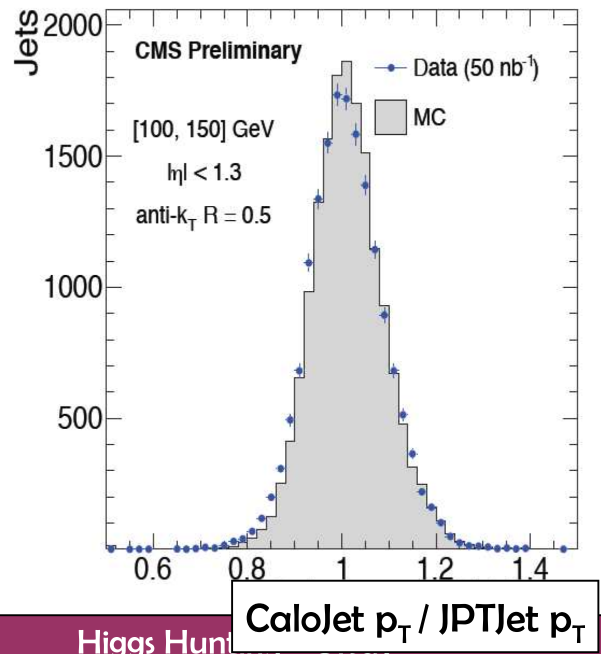
} + 2 % · |η|

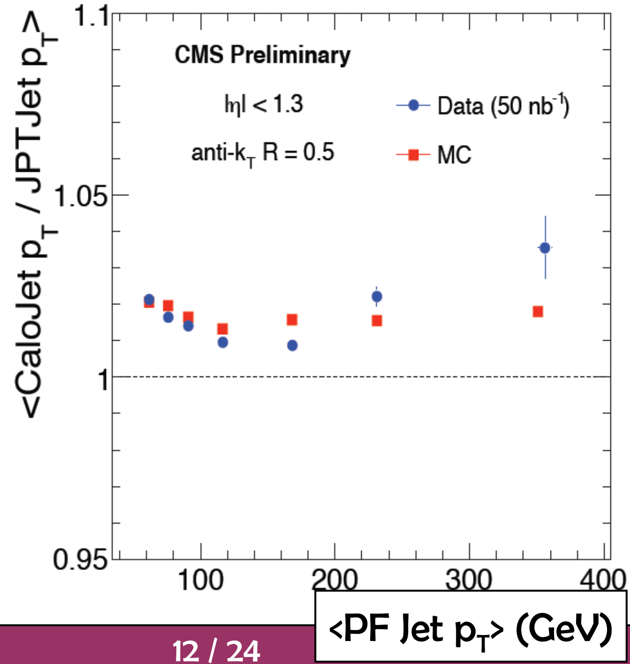
From single particle responses, eg. PF jets:
- EM scale: 1-2 %
- low pT: JES uncertainty of charged hadrons < 1 %
  JES uncertainty of neutral hadrons 3-5 %

50 nb^{-1}

Cross checks between jet types to evaluate JES uncertainty:

- Matching of calo, JPT and PF jets in $\Delta R < 0.25$
- Relative response: p_T^{type1}/p_T^{type2} (after calibration)
- Mean values of responses of data and MC agree well





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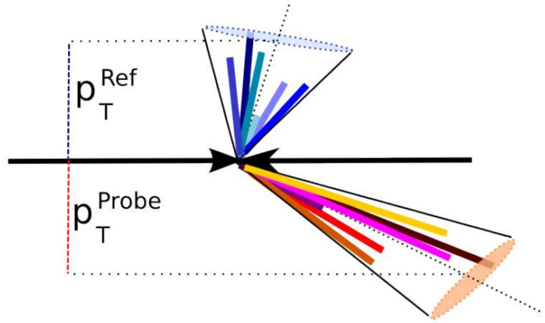
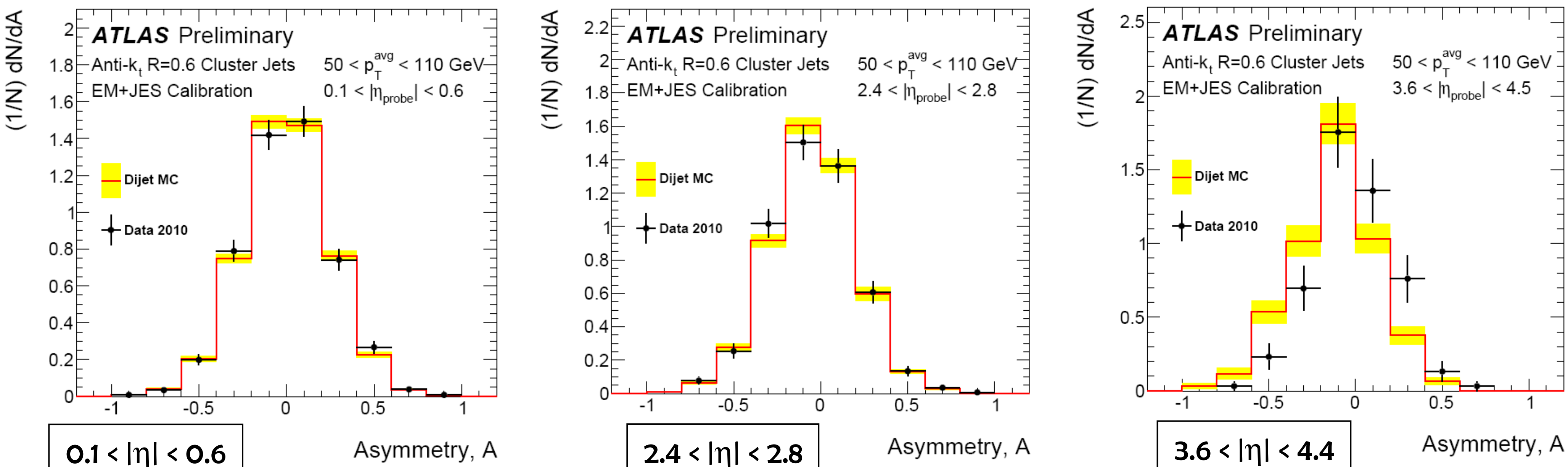
Eta Inter-calibration with dijet p_T balance

- Before: Calibration factors $C(p_T,\eta)$ derived from MC
- Now: Use central calorimeter as reference region and quantify calorimeter response by the p_T balance between central (reference) jet and a forward (probe) jet



- Asymmetry of dijet system: $$\mathcal{A} = \frac{p_T^{probe} - p_T^{ref}}{p_T^{avg}}$$ $p_T^{avg} = ½ * (p_T^{j1}+p_T^{j2})$

- Selection: MinBias or L1_J5 trigger, 2 jets with $p_T^{avg} > 20$ GeV, $\Delta\Phi > 2.6$ and $p_T^{j3} < 0.25\ p_T^{avg}$



0.1 < |η| < 0.6

2.4 < |η| < 2.8

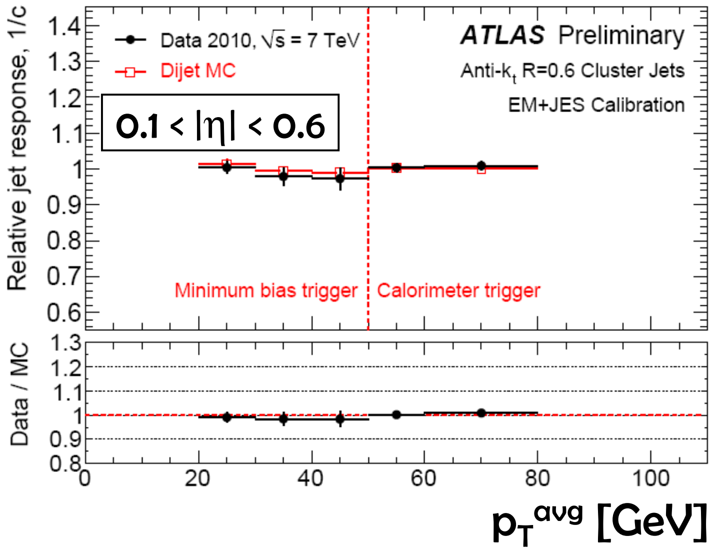
3.6 < |η| < 4.4

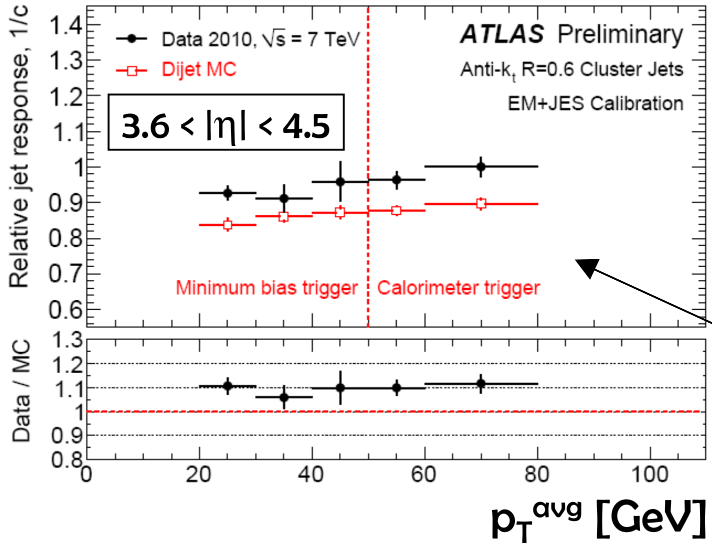
17 nb^{-1}

Eta Inter-calibration - Results

Mean value of asymmetry in each (p_T,η) bin used to calculate 1/c

$$\frac{p_T^{\mathrm{probe}}}{p_T^{\mathrm{ref}}} = \frac{2+\mathcal{A}}{2-\mathcal{A}} = 1/c$$

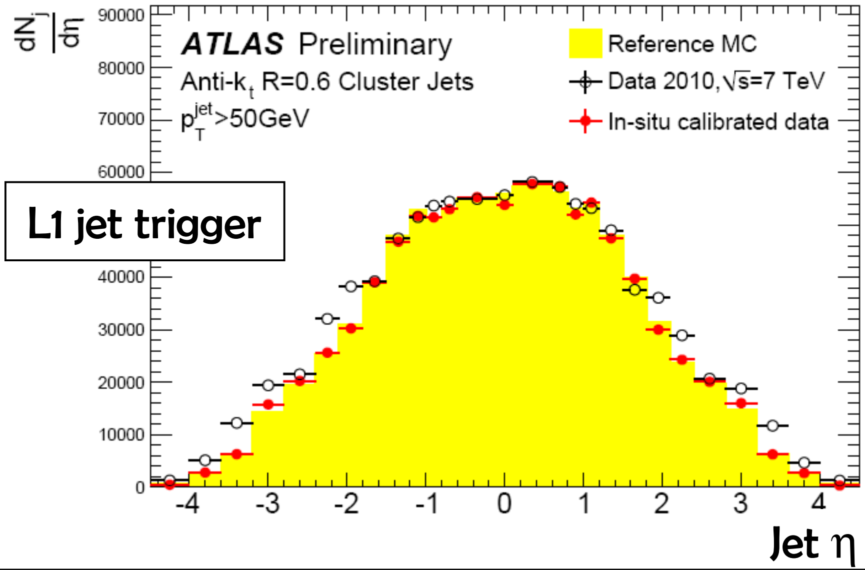




MC and data agree to

- 2 % in |η| < 1.8
- 5 % in 1.8 < |η| < 2.8
- 10 % in |η| > 2.8

Larger discrepancies in forward regions



Re-calibration of data:

- First MC based C(p_T,η) applied, then data re-calibrated using factors c obtained insitu
- Excess of foward jets in data compared to MC is improved with eta inter-calibration

⇦ After re-calibration, data and MC match.

73 nb^{-1}

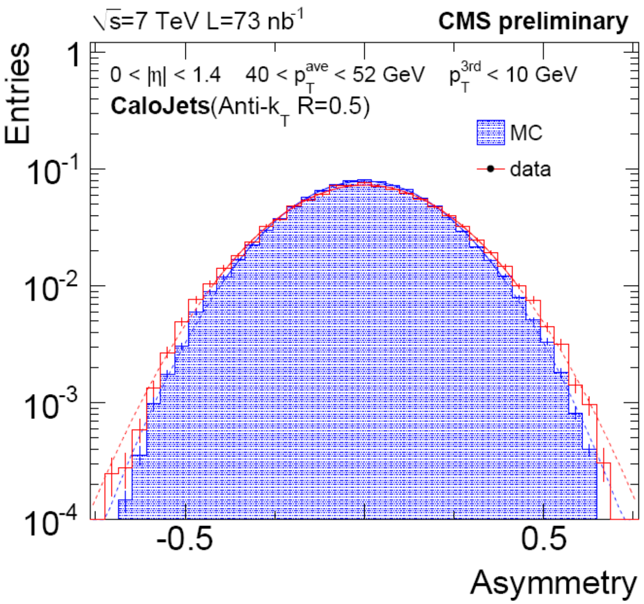
Jet resolution from dijet asymmetry

This method was also applied in ATLAS

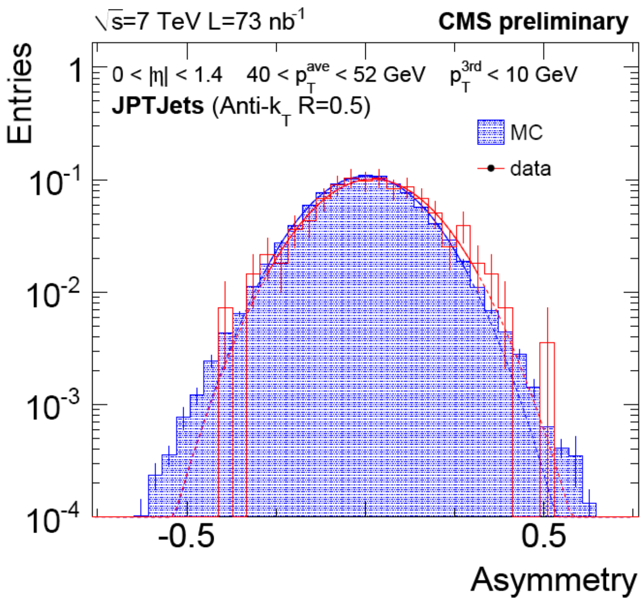
- Event selection:
  - Trigger: MinBias, dijet p_T average 15 GeV and 30 GeV
  - Dijets: $\Delta\Phi > 2.7$, $|\eta| < 1.4$, veto on third jet with $p_T < p_T^{j3,max}$

- Asymmetry: $$A = \frac{p_T^{\text{jet1}} - p_T^{\text{jet2}}}{p_T^{\text{jet1}} + p_T^{\text{jet2}}}$$ For $p_T^{jet1} \approx p_T^{jet2}$: $$\frac{\sigma(p_T)}{p_T} = \sqrt{2}\sigma_A$$

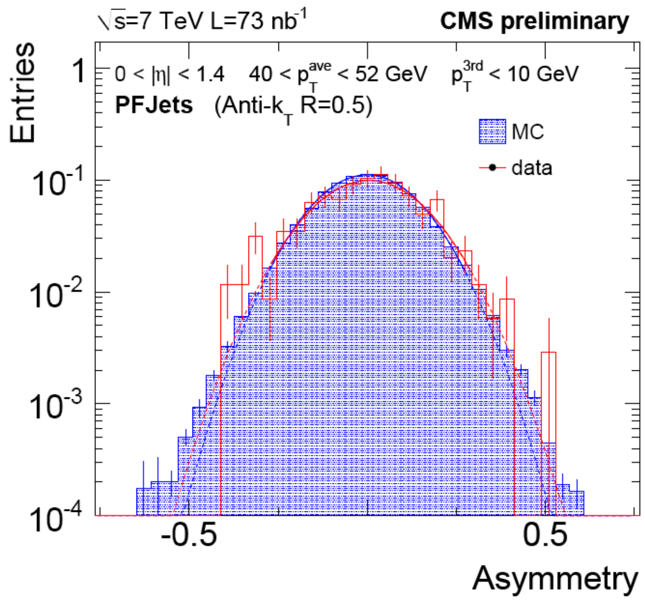
Calo jets:



JPT jets:

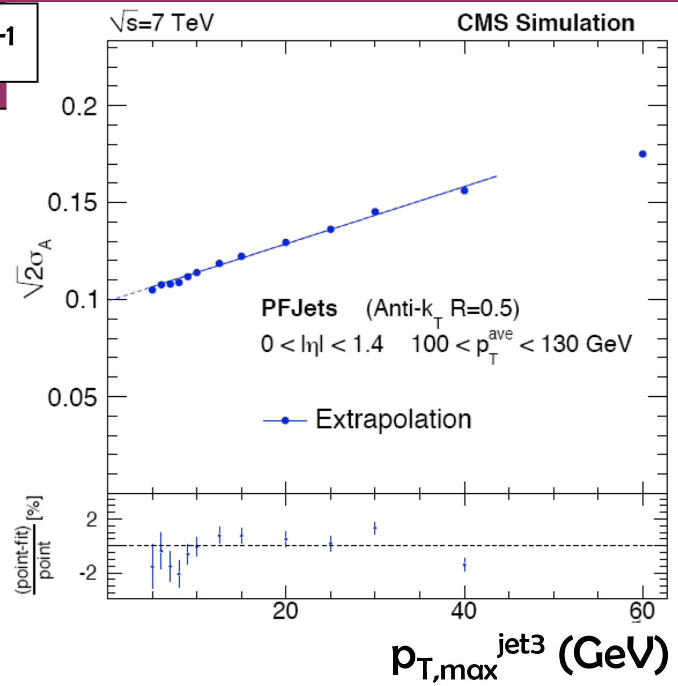


PF jets:



- Underlying event and out of cone particles by showering broaden p_T resolution already at truth level ⇨ (Small) correction necesarry.

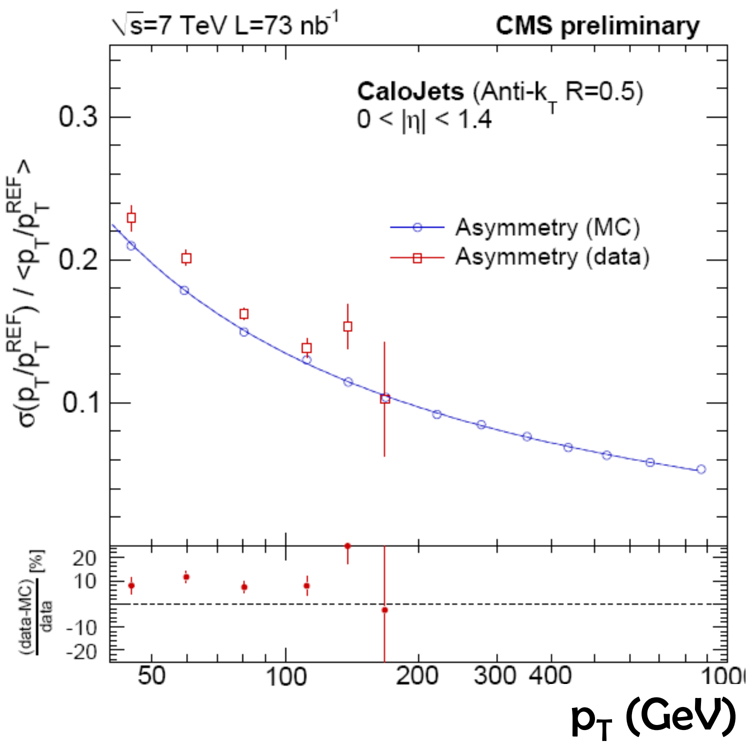
73 nb^{-1}

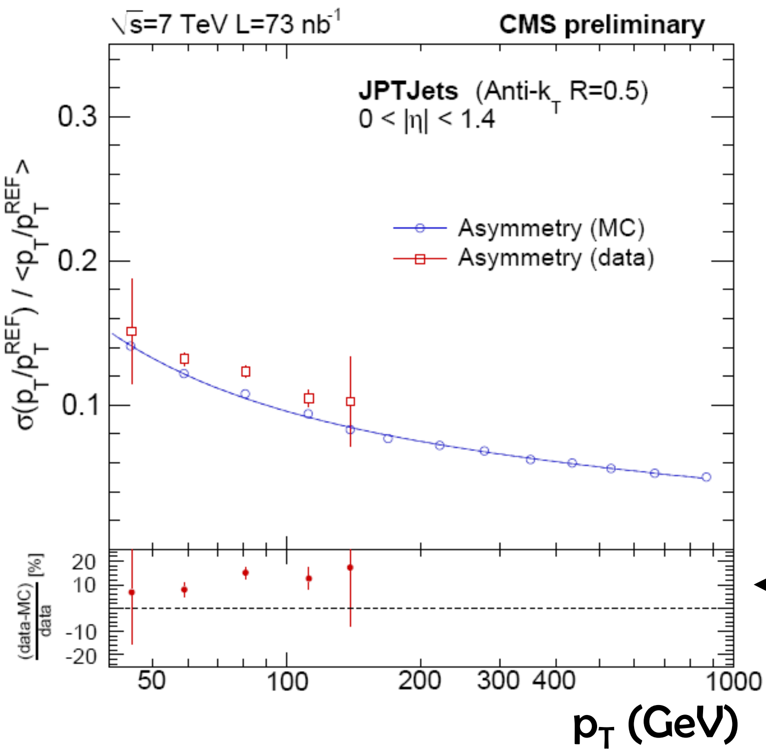


Jet resolution from dijet asymmetry

- Jet p_T resolution over-estimated due to additional soft radiations spoiling the p_T balance
- Jets not reconstructed below p_T threshold, instead extrapolation to $p_T^{jet3} \rightarrow 0$ GeV

Results:





- Use of tracking info improves p_T resolution
- Jet resolution for PF jets very similar to JPT jets

Uncertainties within 10 %

III. Forward Jet Performance in Min Bias Events - ATLAS

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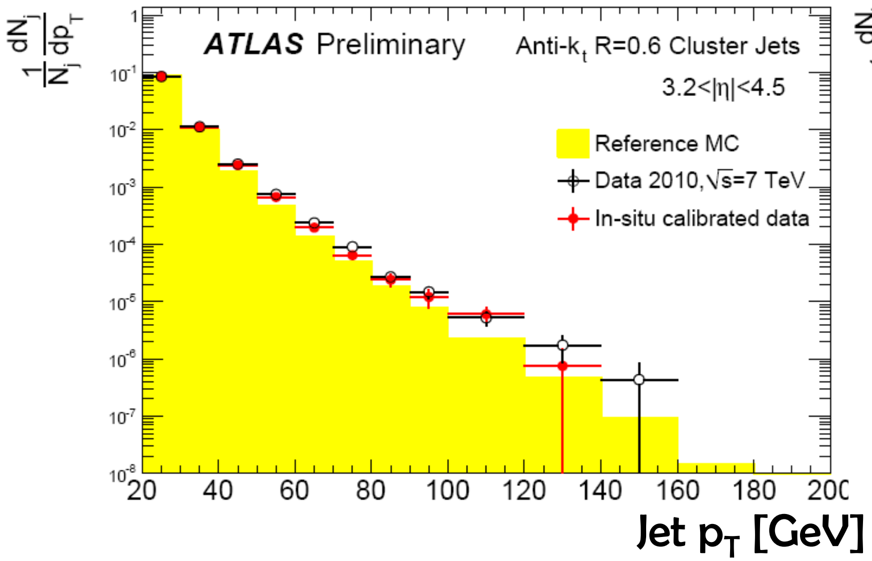
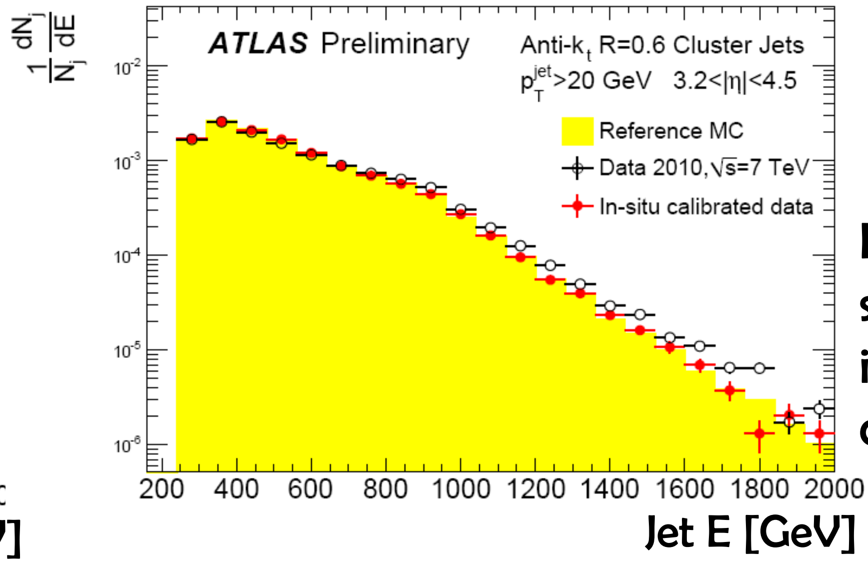


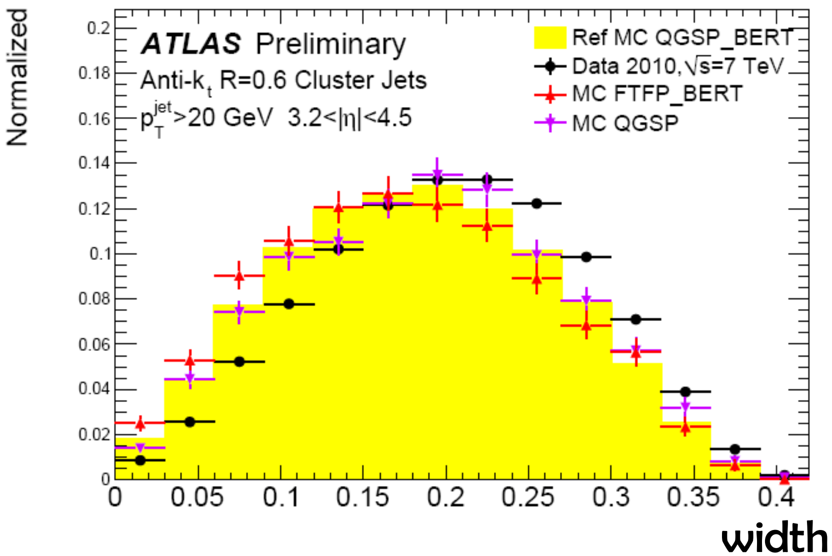


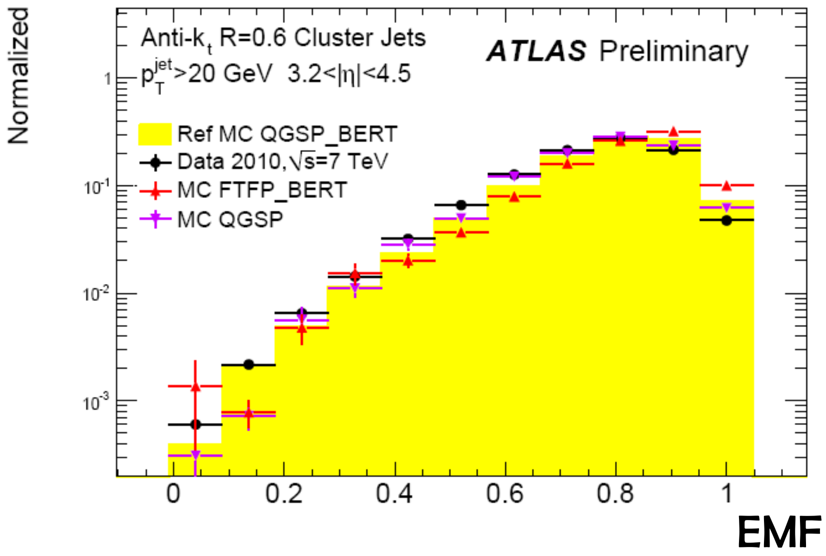
Discrepancies smaller with η inter-calibration applied.

|η| > 3.2

Jet width $w = (\Sigma_i R^i * E_T^i) / \Sigma E_t^i$
with distance R of cluster i to jet center:

Fraction of energy deposited in EM layers:



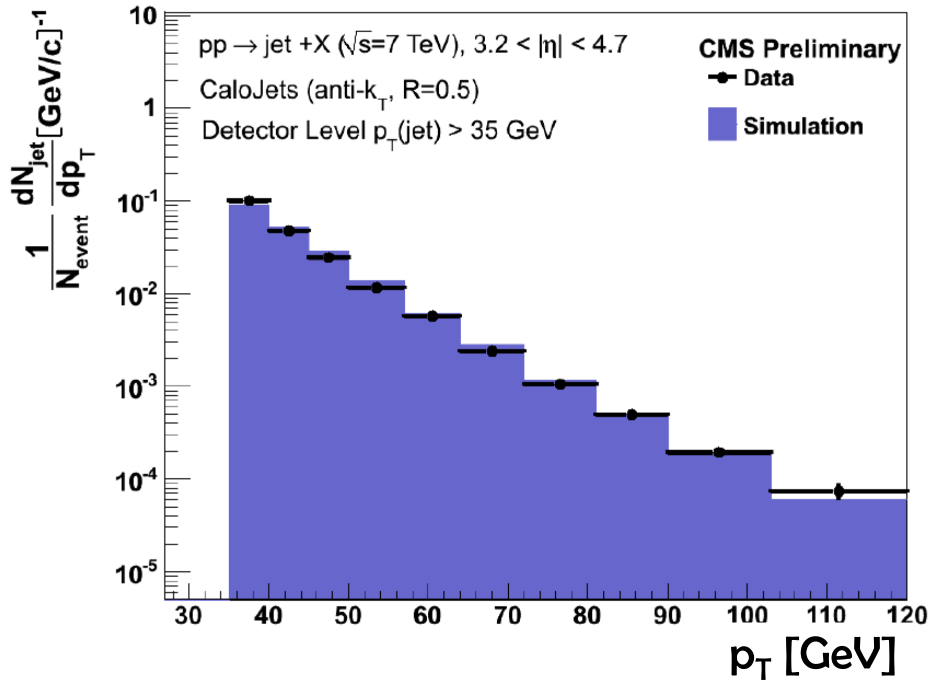


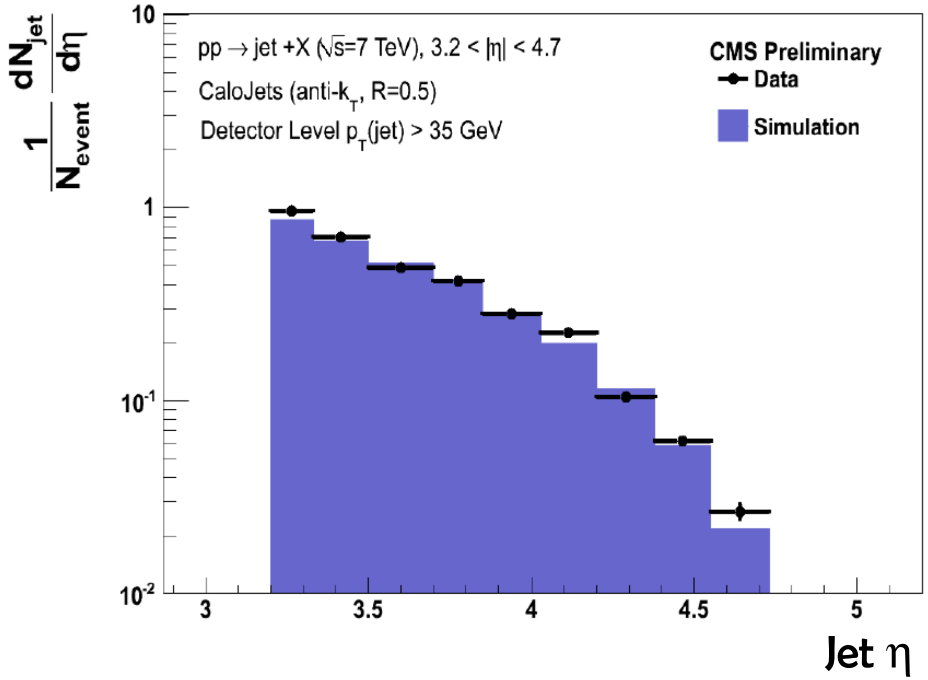
Comparisons to different shower models. Details:

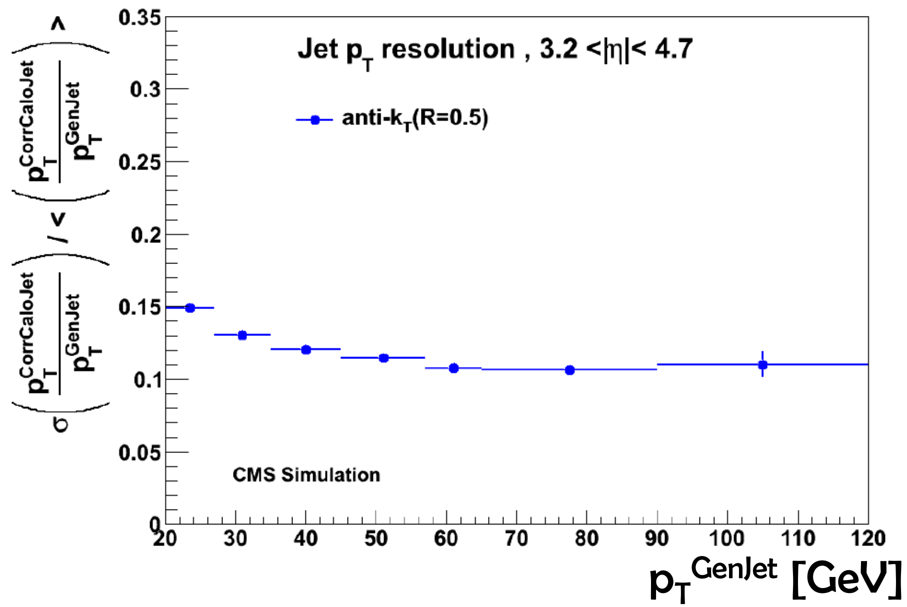
CERN-LCGAPP-2010-02

35 GeV < p_T < 120 GeV
3.2 < |η| < 4.7

10 nb^{-1}







- Calorimeter jets only
- JES calibration from MC only
- No systematics, no unfolding

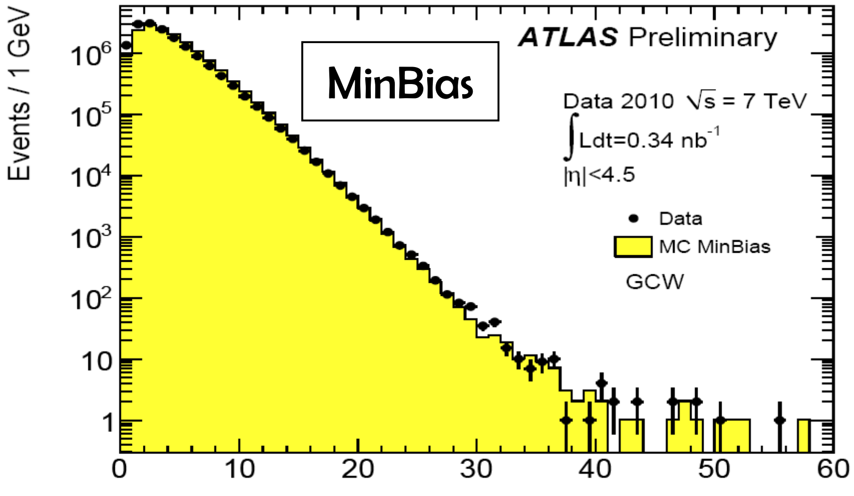
⇨ Reasonable MC description

Jet p_T resolution estimated from MC:
15 % for p_T = 20 GeV
12 % for p_T > 100 GeV

$$\not{E}_{x,y}^{\rm Final} = \not{E}_{x,y}^{\rm calo} + \not{E}_{T}^{\rm muon} + \not{E}_{x,y}^{\rm cryo}$$

0.3 nb^{-1} MinBias
14.3 nb^{-1} L1Calo

GCW calibrated MET:

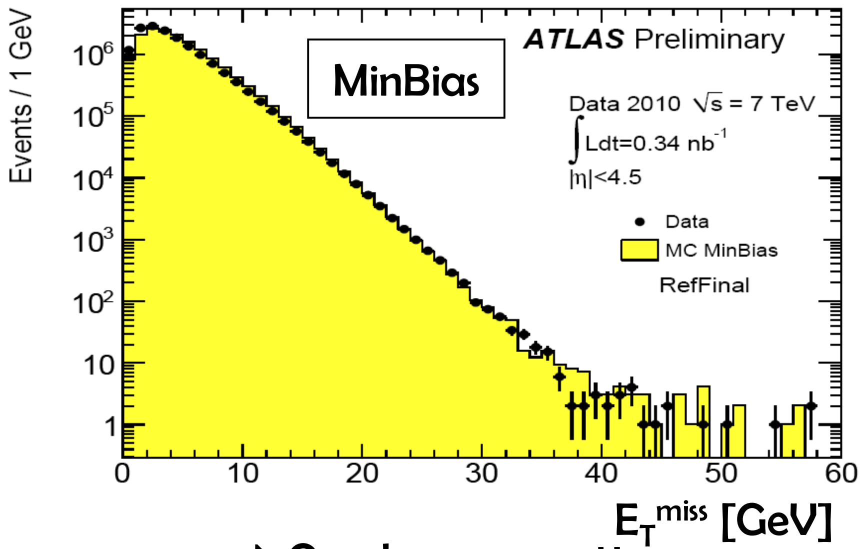


- MET Calibration:
  - GCW: Global cell energy weighting
  - LCW: Local cluster energy weighting
  - ReFined: Association to reconstructed objects
- MET resolution measured in MinBias data:

$\sigma_{EM} = 0.41\ \sqrt{\Sigma E_T}$ $\sigma_{GCW} = 0.39\ \sqrt{\Sigma E_T}$

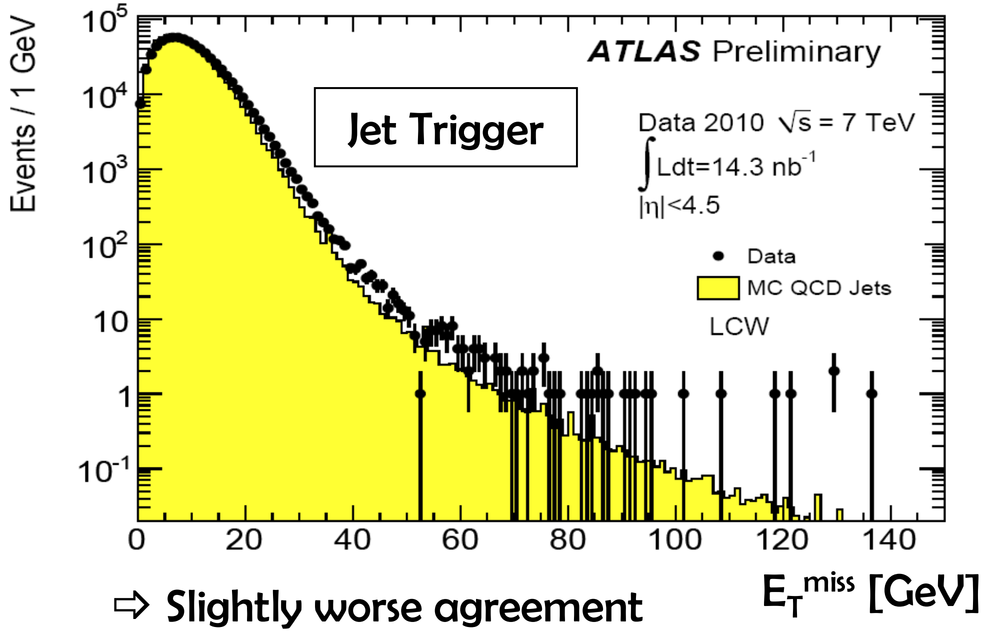
$\sigma_{LCW} = 0.37\ \sqrt{\Sigma E_T} \approx \sigma_{refined}$

LCW calibrated & refined MET:



⇨ Good agreement!

At least one jet with $p_T^{EM} > 20$ GeV:

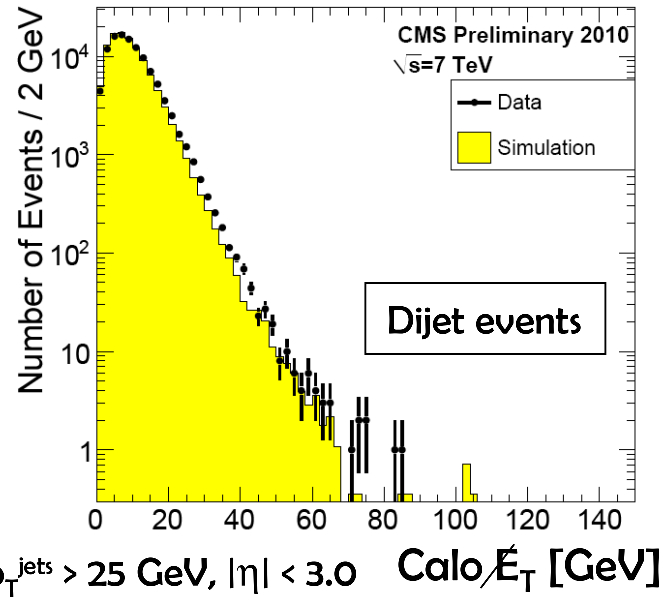


⇨ Slightly worse agreement

III. MET Performance - CMS

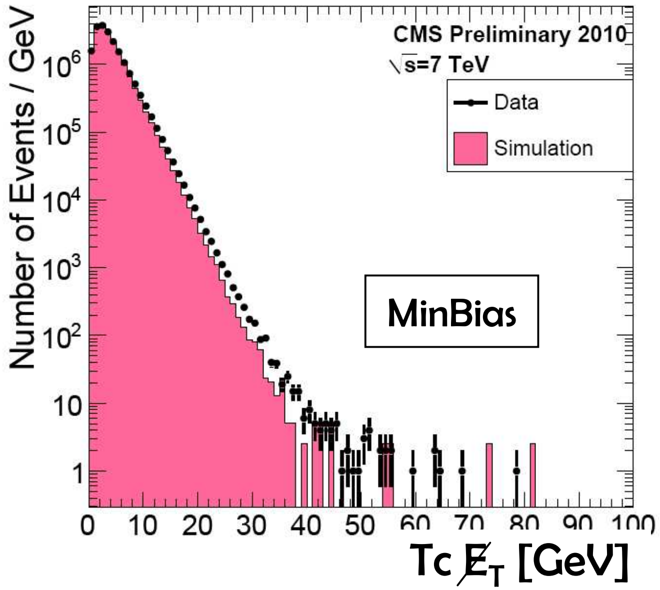
12 nb^{-1}

Calo based MET

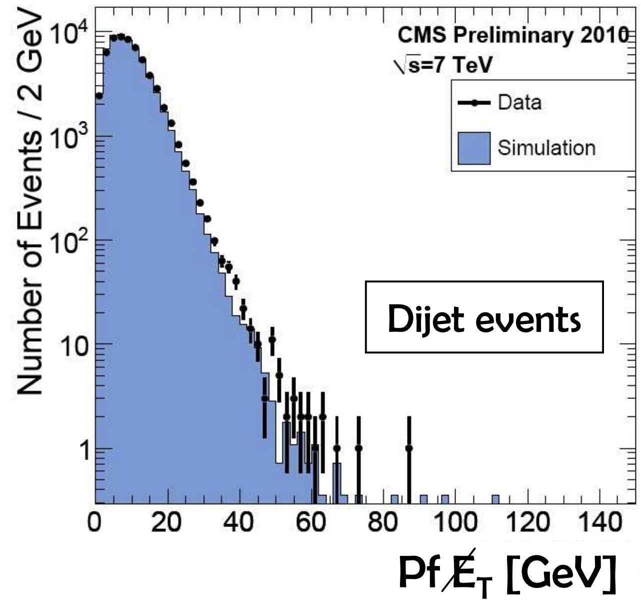


p_T^{jets} > 25 GeV, |η| < 3.0

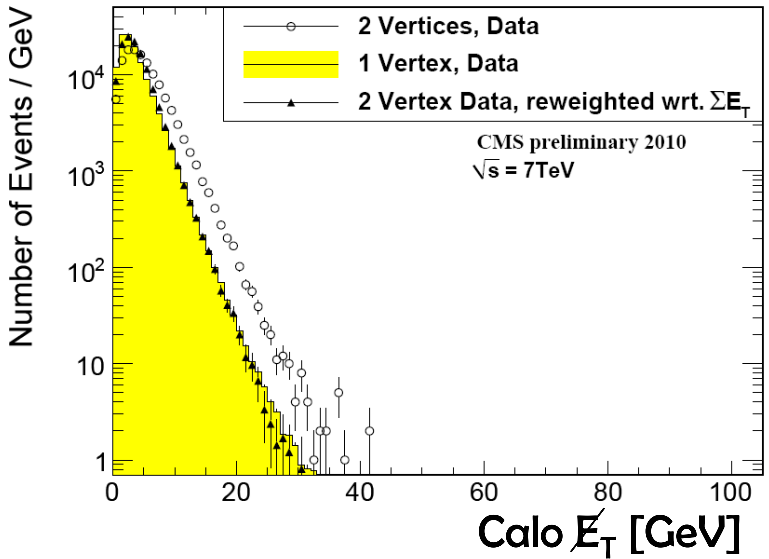
Track corrected MET



Particle Flow MET



MET Calo with Pile-Up:



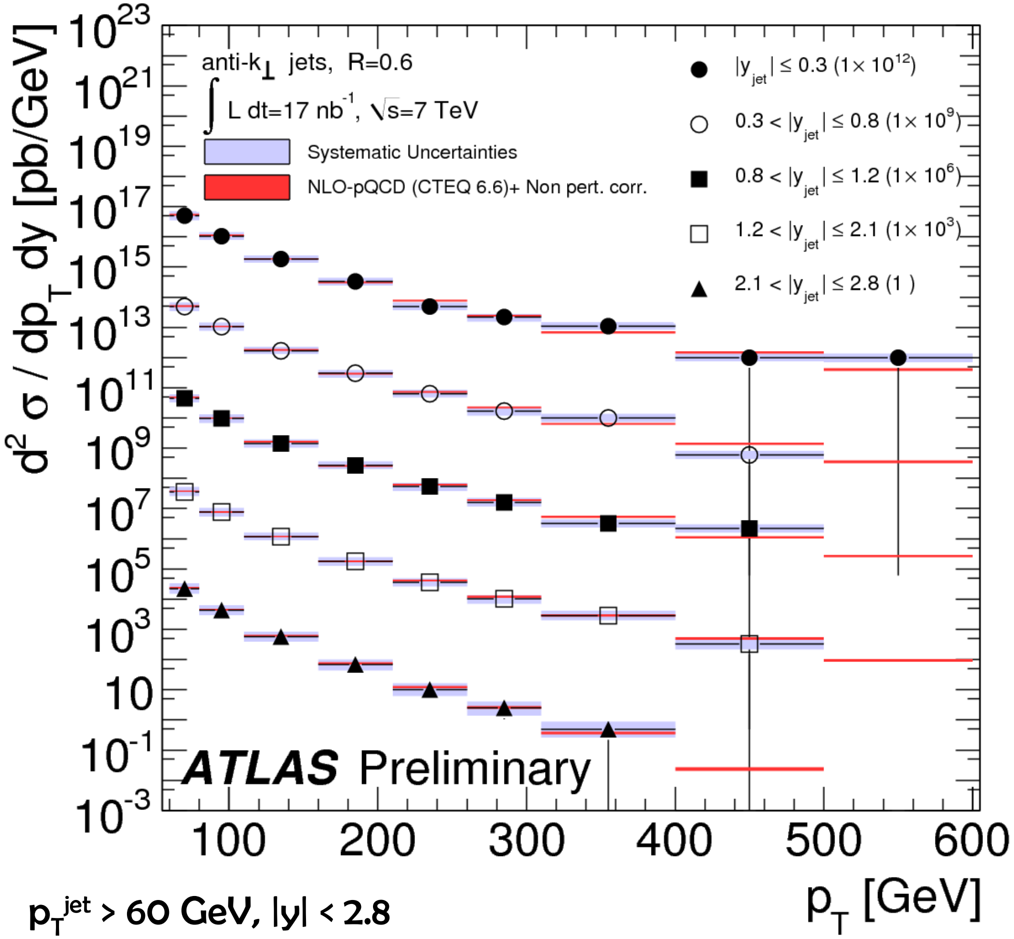
- Cleaning cuts applied to reject anomalous signals and beam induced backgrounds
- MET better described in Dijet than in MinBias data
- MET resolution comparison among three algorithms
  Same calibration determined in-situ from γ+jets events
  ⇨ Pf MET best resolution, before TcMET and CaloMET
- Fraction of pile-up events: 1 %
  Higher ΣE_T and MET expected

IV. Inclusive Jet Cross Section - ATLAS

anti-k_t R=0.6

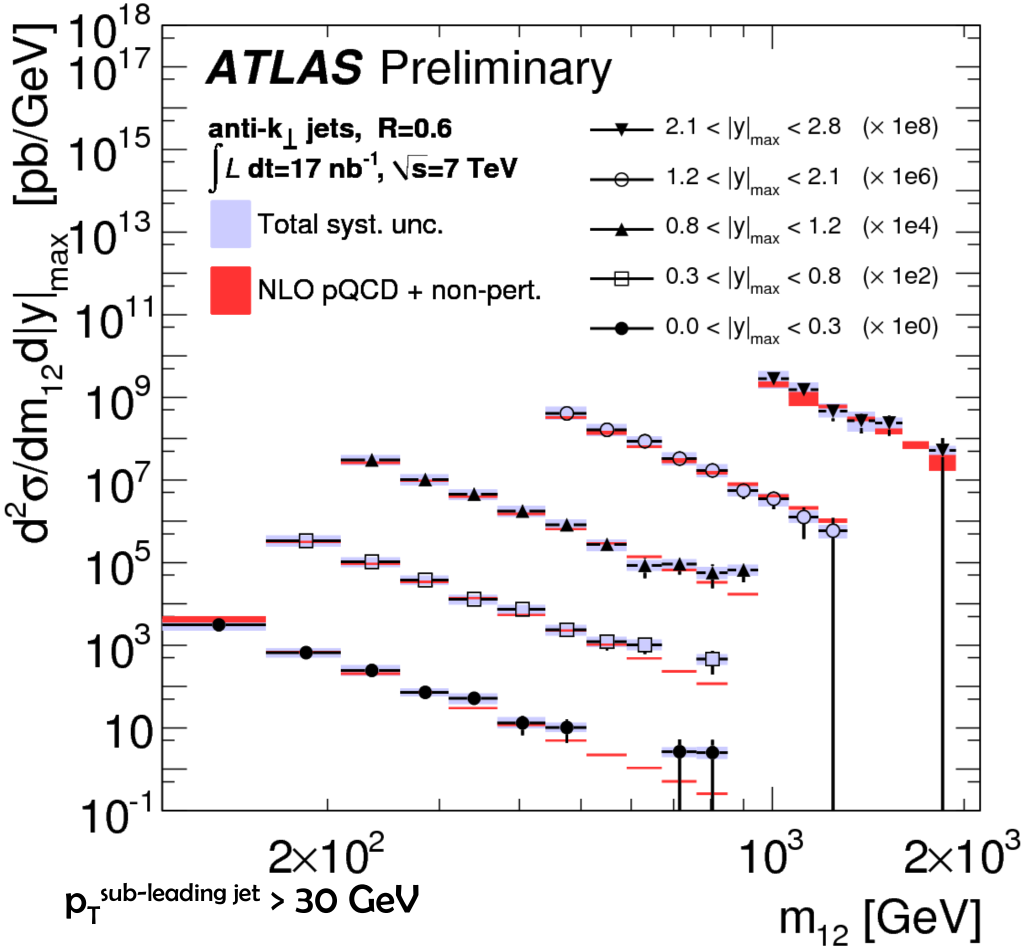
17 nb^{-1}

Jet cross section in p_T:



p_T^{jet} > 60 GeV, |y| < 2.8

Dijet mass cross section:



$p_T^{sub\text{-}leading\ jet}$ > 30 GeV

- Systematics: JES, jet resolution, pile-up
- 11 % luminosity uncertainty (not included)
- Theory uncertainty: Renormalization & factorisation scales, PDFs, α_s and effects from soft QCD modelling

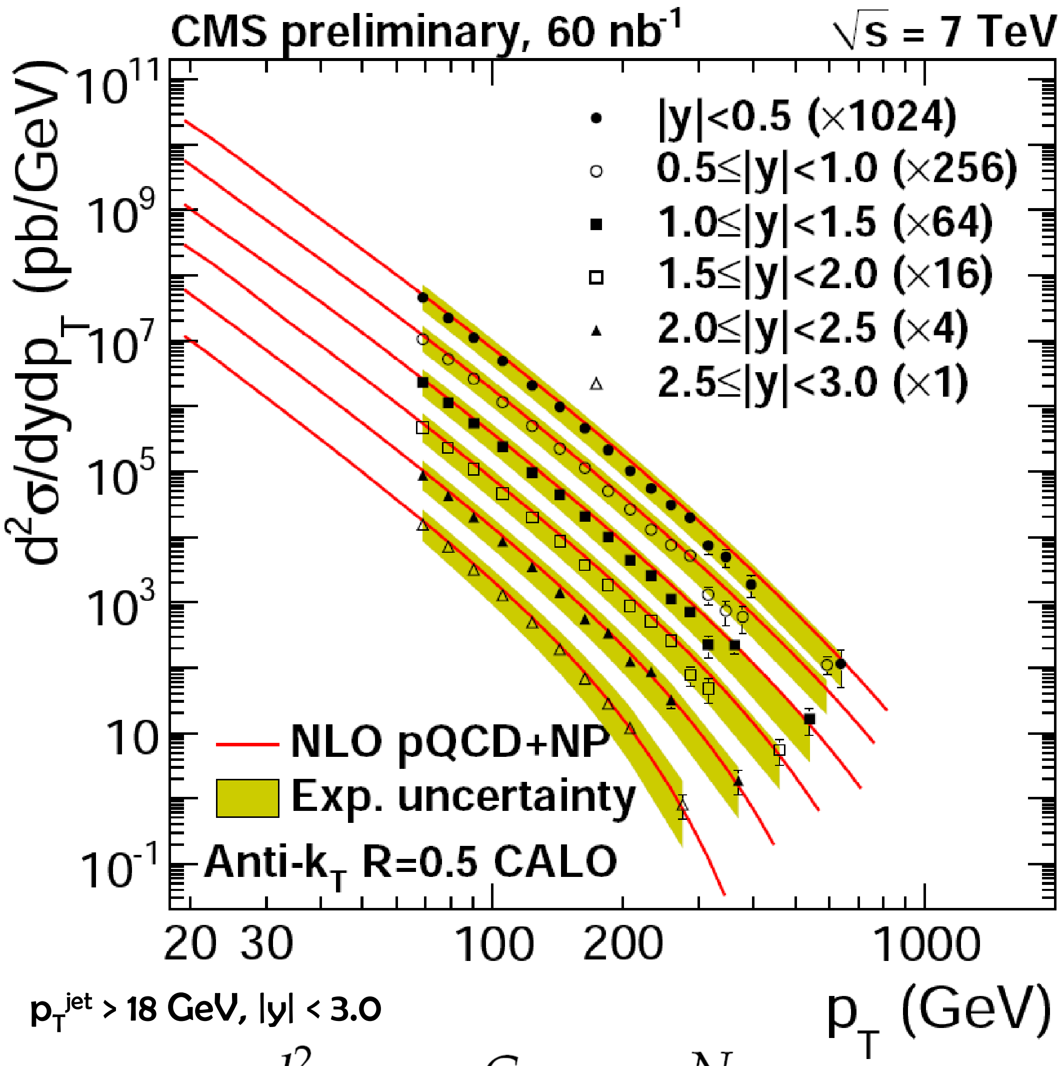
Bin-by-bin data correction:
Correction factor from ratio of MC truth to simulation applied to data in each bin

⇨ Corrections < 20 %

anti-k_t R=0.5

60 nb^{-1}

Jet cross section in p_T, calo jets:



p_T^{jet} > 18 GeV, |y| < 3.0

$$\frac{d^2\sigma}{dp_T dy} = \frac{C_{res}}{\mathcal{L}\cdot\epsilon} \cdot \frac{N_{jets}}{\Delta p_T \cdot \Delta y}$$

ε efficiency (≈ 100 %)

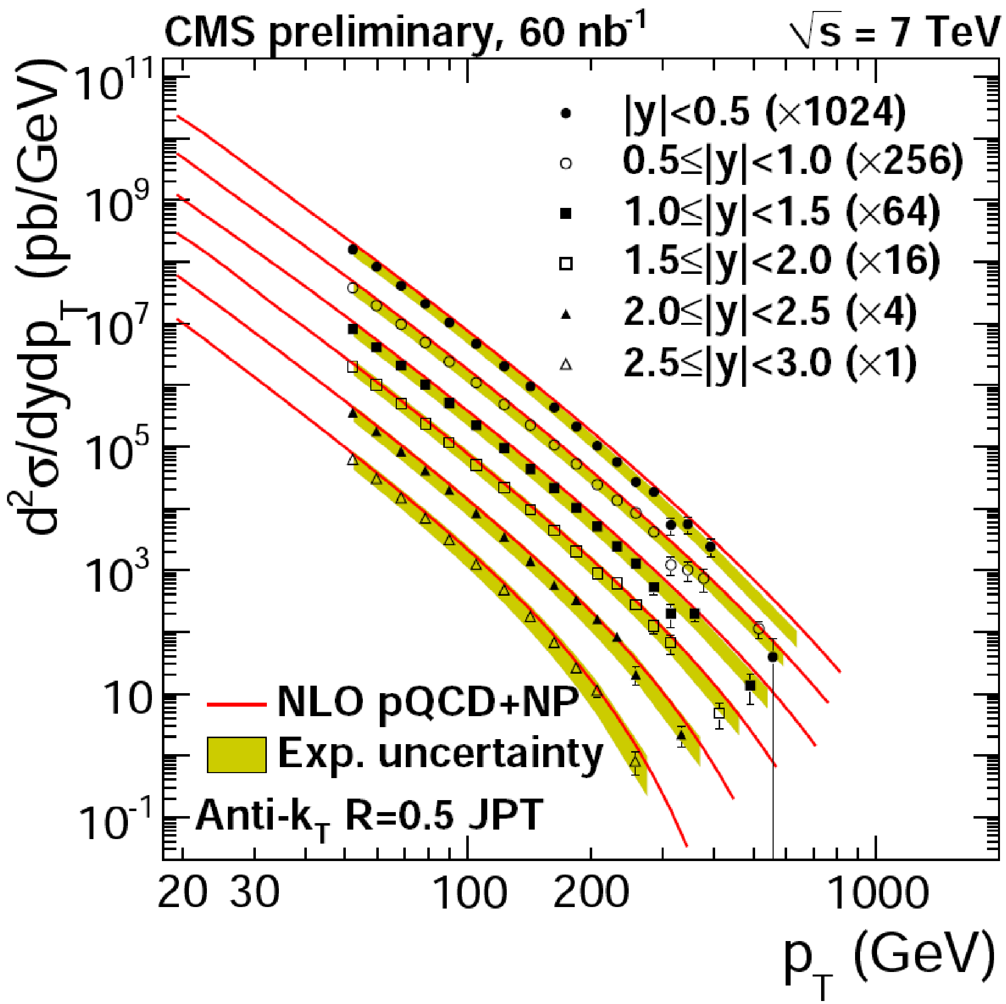
- **JES correction** from MC, in addition y dependent relative calibration correction in-situ from dijets
- **Systematics:**
  - JES uncertainty: 10 % for calo jets
  - 10 % jet resolution uncertainty
  - 11 % luminosity uncertainty
- **Bin-by-bin migration correction:** ansatz for truth pT spectrum $f(p_T)$ smear $f(p_T)$ to data ⇨ $F(p_T)$ ⇨ unsmearing correction $C_{res} = f(p_T) / F(p_T)$
- **Theory uncertainties:**
  - soft QCD modelling
  - PDFs
  - renormalization & factorization scales

IV. Inclusive Jet Cross Section - CMS

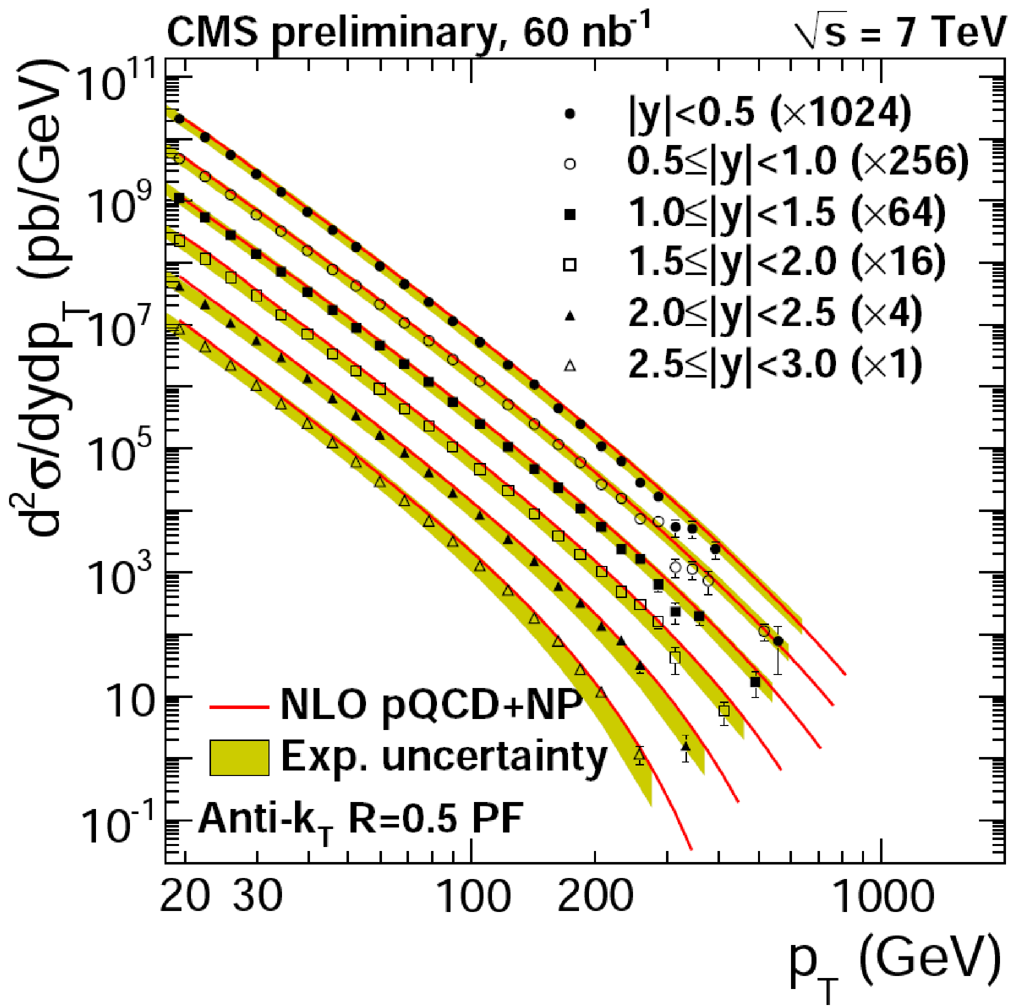
anti-k_t R=0.5

60 nb^{-1}

Jet cross section in p_T, JPT jets:

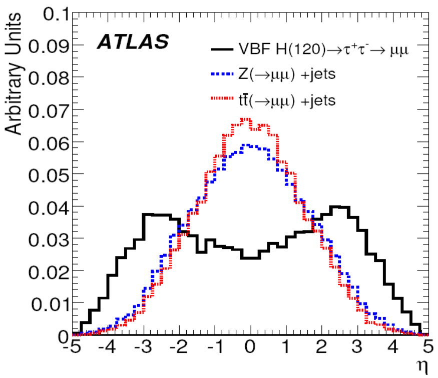


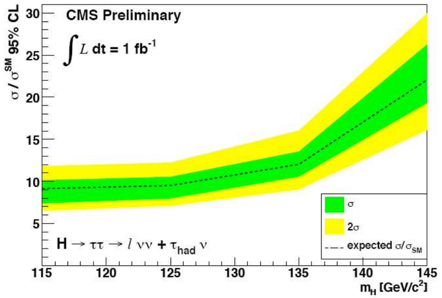
Jet cross section in p_T, PF jets:

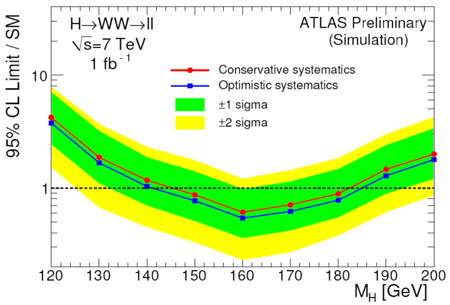


JES uncertainty: 5 % for JPT and PF jets

Conclusions and Outlook







- Jet/MET reconstruction and control of uncertainties crucial for upcoming Higgs searches
- Energy calibration of jets and MET based on MC and/or in-situ
- JES uncertainty: ATLAS: 7-10 % (central jets)
  CMS: 10 % (calo jets), 5 % (JPT and PF jets) + 2% $|\eta|$

Prospects:

- Further performance checks, understanding of small discrepancies between data and MC, testing of other MC tunes
- With 1 pb^{-1}: Expect $W \rightarrow \tau\nu$ and $Z \rightarrow \tau\tau$ events ⇨ Study real taus
  Approaching ttbar production with 1 pb^{-1}
  Jet calibration with Z/W events
- With 250 pb^{-1}: Sensitivity to exclusion of SM $H \rightarrow WW$ begins
- With 1 fb^{-1}: Improve exclusion limits, Background studies to various SM and MSSM Higgs analyses

Back-Up

References

First Data Performances:

ATLAS:

- Jet production cross section (ATL-CONF-2010-049)
- Jets and input to calibration (ATL-CONF-2010-052)
- Eta inter-calibration and forward jets (ATL-CONF-2010-053)
- In-situ jet efficiency and resolution (ATL-CONF-2010-054)
- Single particle reponse and JES (ATL-CONF-2010-050)
- JES and JES uncertainty (ATL-CONF-2010-056)
- MET Performance (ATL-CONF-2010-055)
- Energetic jets at 7 TeV (ATL-CONF-2010-043)
- Jet cleaning cuts (ATL-CONF-2010-038)

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/RESULTS/summer2010.html

CMS:

- Inclusive jet cross section (CMS-PAS-QCD-10-011)
- Jet performance (CMS-PAS-JME-10-003)
- Forward jet performance (CMS-DPS-2010-026)
- Single particle response (CMS-PAS-JME-10-008)
- MET performance (CMS-PAS-JME-10-004)
- Tau reconstruction (CMS-PAS-PFT-10-004)
- Jet cleaning cuts (CMS-PAS-JME-09-008)

Sensitivity Studies:

- ATLAS CERN-OPEN-2008-20
- 10 TeV $H \to WW$ Atlas (ATL-PHYS-PUB-2010-006)
- $H \to WW$ CMS (CMS-PAS-HIG-07-001)
- CMS TDR Vol II (CERN/LHCC 2007-021)
- 7 TeV Sensitivity ATLAS (ATL-PHYS-PUB-2010-009)
- 7 TeV Sensitivity CMS (CERN-CMS-NOTE-2010-008)
- CMS $H \to \tau\tau$ with 1 fb^{-1} (CMS-PAS-HIG-08-008)

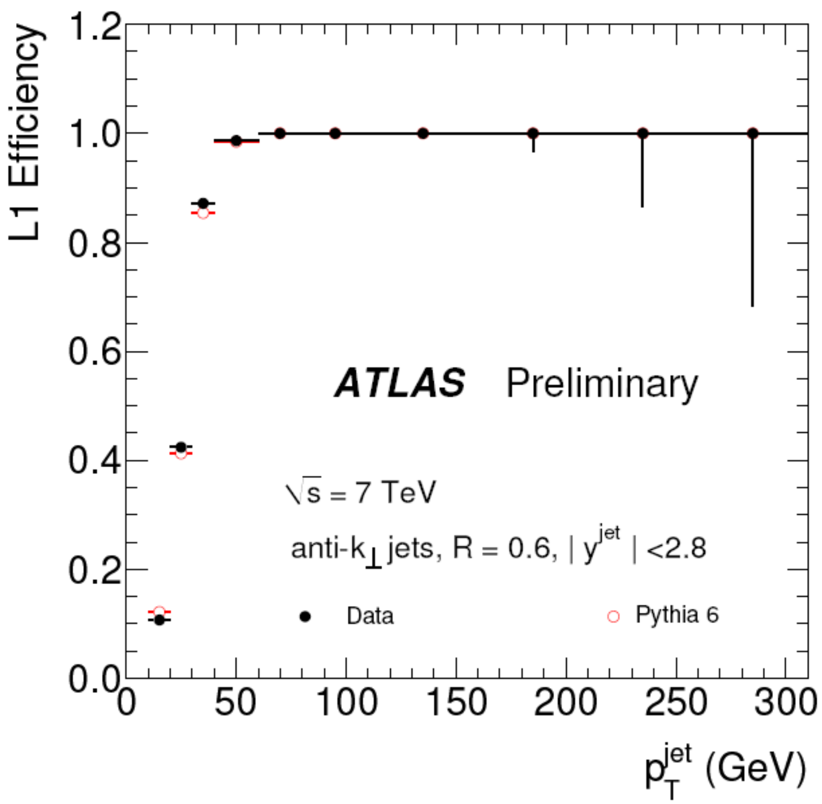
Misc:

- Cacciari, Salam: anti-k_t jet algorithm (arXiv:0802.1189)
- ATLAS Topocluster algorithm (ATL-LARG-PUB-2008-002)

Trigger & Event Selection

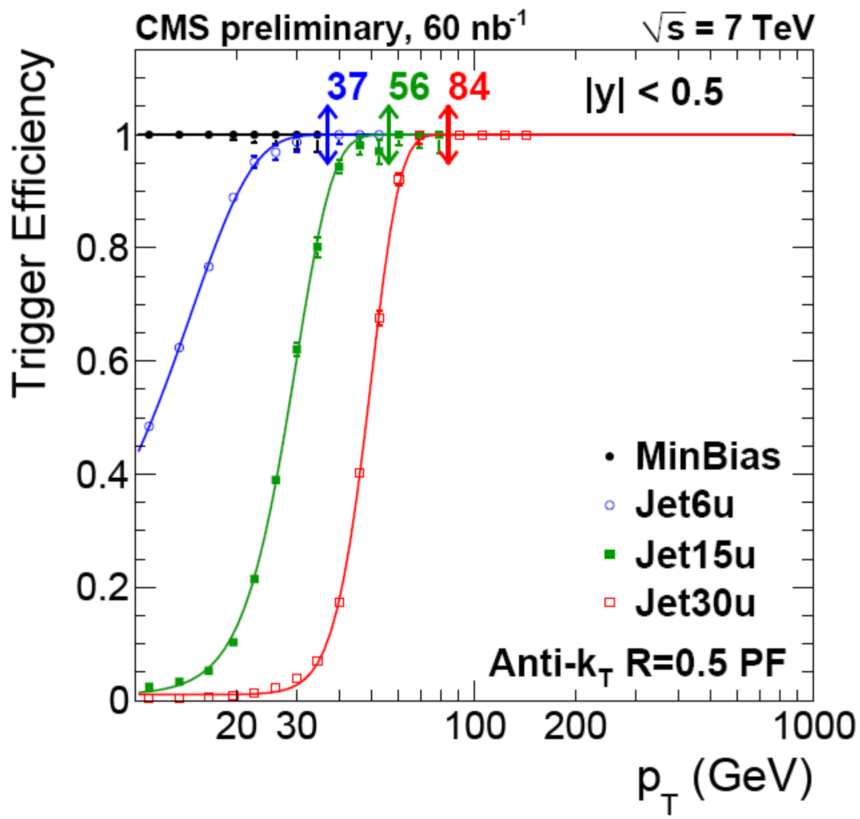
ATLAS

- Minimum Bias events triggered by MBTS and/or signal from BPTX
- QCD events triggered by L1 jet trigger L1_J5 (jet with 5 GeV, unprescaled)
- Primary vertex with at least 5 tracks



CMS

- Minimum Bias triggered by Beam Scintillator Counter in coincidence with BPTX
- QCD triggered by high level jet triggers with different thresholds and prescales
- Veto on beam-halo events
- Primary vertex with at least 4 or 5 tracks



Jet and MET Cleaning (ATLAS & CMS)

- **Detector level:** Only high quality data flagged as valuable for physics analysis (‚good runs‘) with stable beam condition
- **Object level:**
  - Certain fraction of energy deposit distributed among certain number of channels to reject spurious (sporadic) signals
  - Jet timing within small difference to average event time, to suppress non-collision backgrounds: Cosmics, beam-gas, beam-halo, cavern background.
- **Details:** ATL-CONF-2010-038, CMS-PAS-JME-09-008