Object definition and performance at CMS

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for the CMS collaboration

DESY

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Outline

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2. Leptons
    - Muons and electrons
    - Taus
3. Jets
4. B-tagging
5. Mising transverse energy
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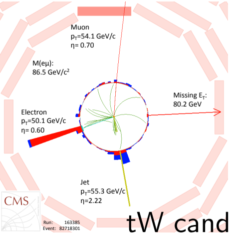
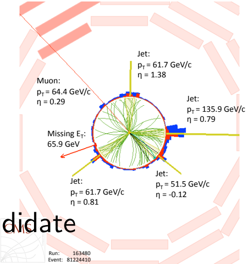
7. Documentation



tW candidate

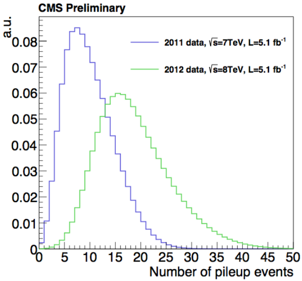


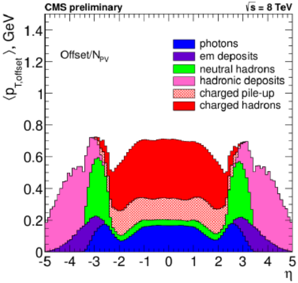
$t\bar{t}$ candidate

Introduction

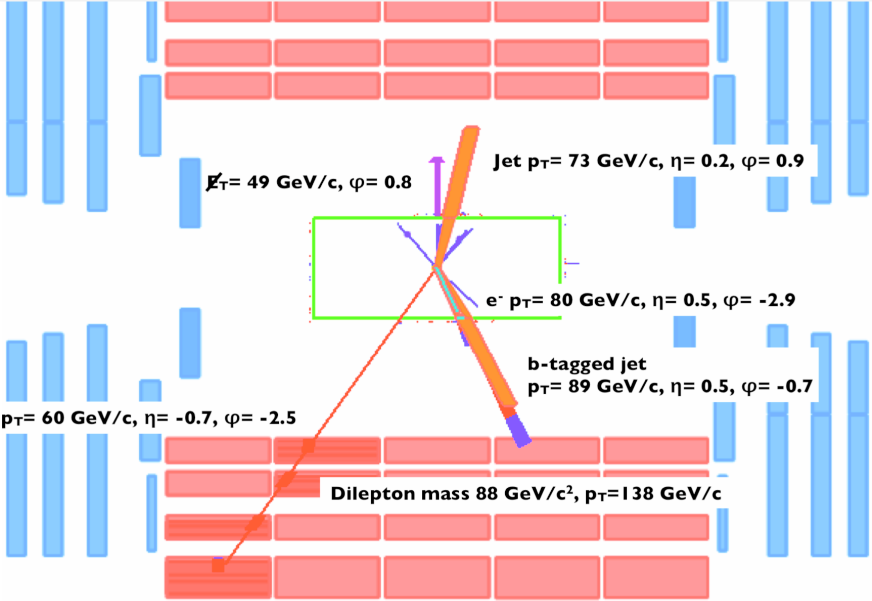
- All physics objects are essential for top physics: leptons, (b)-jets, MET

  Describe energy scale, efficiency, fake rates
- Top analyses rely on reconstruction of objects using all subdetectors
- Results shown from 7 TeV and 8 TeV data
- Large increase of PU, about 30% increase in PU in 2012 Run A compared to end of 2011 data-taking
  - Pile-up corrections for jets and missing energy
  - Impact on isolation

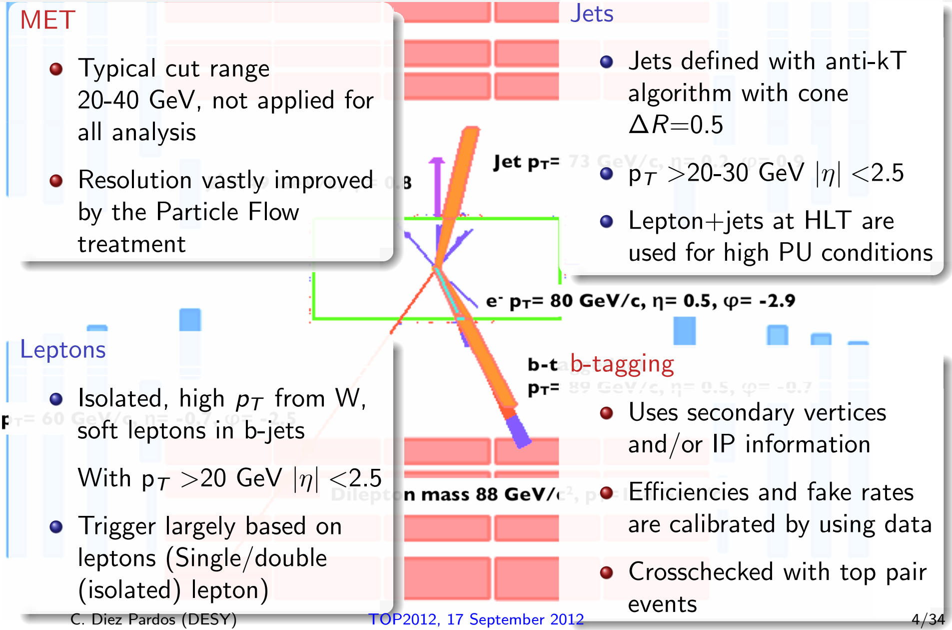




Top quarks


Jet p_T= 73 GeV/c, η= 0.2, φ= 0.9
$\not{E}_T$= 49 GeV/c, φ= 0.8
e^- p_T= 80 GeV/c, η= 0.5, φ= -2.9
b-tagged jet
p_T= 89 GeV/c, η= 0.5, φ= -0.7
p_T= 60 GeV/c, η= -0.7, φ= -2.5
Dilepton mass 88 GeV/c^2, p_T=138 GeV/c

Top quarks



MET

- Typical cut range 20-40 GeV, not applied for all analysis
- Resolution vastly improved by the Particle Flow treatment

Jets

- Jets defined with anti-kT algorithm with cone ΔR=0.5
- p_T >20-30 GeV $|\eta|$ <2.5
- Lepton+jets at HLT are used for high PU conditions

Leptons

- Isolated, high p_T from W, soft leptons in b-jets

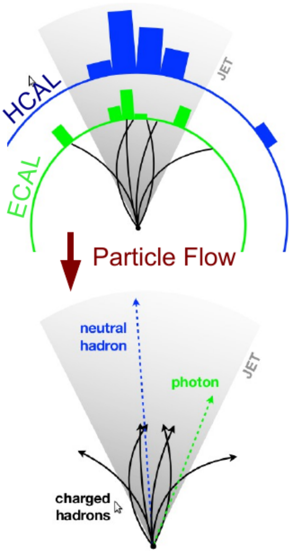
  With p_T >20 GeV $|\eta|$ <2.5
- Trigger largely based on leptons (Single/double (isolated) lepton)

b-tagging

- Uses secondary vertices and/or IP information
- Efficiencies and fake rates are calibrated by using data
- Crosschecked with top pair events

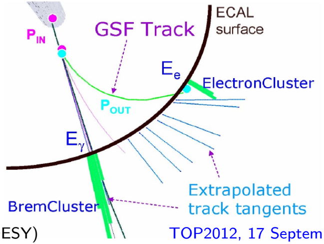
Particle Flow Algorithm

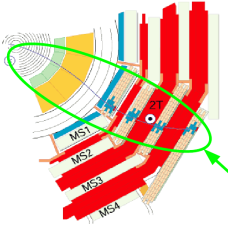
- PF combines information from all-subdetectors prior to jet clustering, MET calculation etc. to reconstruct particles (hadrons, photons, mu/e)
- From these particles composite objects (Jets, taus, MET) are reconstructed
- Big improvement in energy resolution and tau identification
- Contribution from different detector components accessible
- Widely used in top analysis



Leptons: muons and electrons

- Impact on top: efficiency, QCD estimate & modeling
- Trigger largely based on leptons
- Excellent ID capabilities
  - ◇ Use redundancy of sub-detectors for muons
  - ◇ Shower shapes, H/E, conversion vetoes for electrons
- Generally speaking, muons have fewer fakes than electrons, which leads to a smaller QCD fraction
- Charge mis-identification: μ (p $<$ 1 TeV) sub-percent level, electrons at percent level

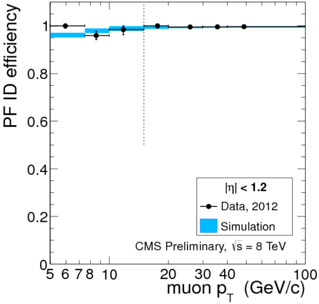


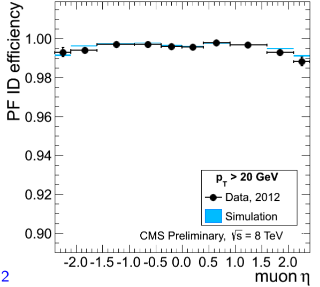


Muon reconstruction efficiency

Combine different algorithms to reach a robust and efficient μ reconstruction, using information from silicon tracking and muon systems

- Measure lepton identification efficiencies with the Tag and Probe method
- Select pairs from Z resonances (covering same kinematic phase space as muons from top decays)
  - Tag lepton: Strict selection requirements
  - Probe lepton: Relaxed selection, not bias
- Subtract combinatorial background with simultaneous fit for the probes passing and failing the selection requirements

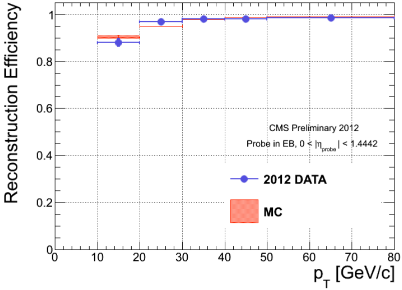




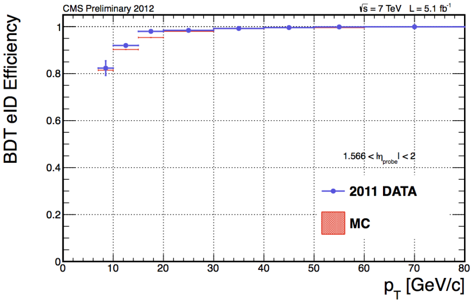
Electron reconstruction efficiency

- Electron reconstruction: combination of tracker and calorimeter information
- Efficiency also measured with T&P method
- Good description data/MC, very high efficiency reco/Id

8 TeV



7 TeV



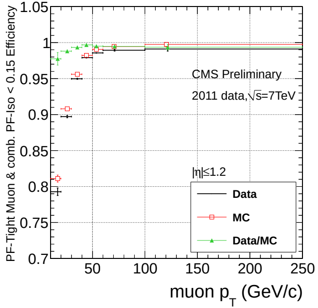
In the analysis MC yields corrected with SF(data/MC)$\sim$1

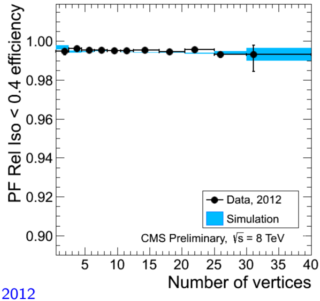
Isolation efficiency

- Using particle-based isolation.
- Cut on relative isolation in a cone with typically $\Delta R = 0.3$ $\text{relIso} = \frac{p_{CH}+p_{NH}+p_{\gamma}}{p_T}$.
- Isolation requirements also included in lepton triggers.

- Pile up contribution:
  - ◇ Negligible for charged hadrons (vertexing)
  - ◇ Developed methods to correct for neutral particle candidates: Use global average energy density (ρ)

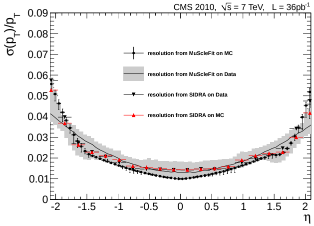
SF data/MC applied to analysis $\sim$1.



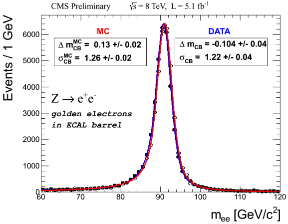


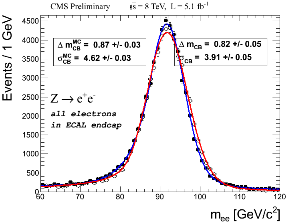
Lepton momentum scale and resolution

- Muons
  - Measurement dominated by silicon tracker for $p_T < 200$ GeV.
  - Low and medium ranges ([0-100] GeV) with di-μ resonances: resolution <1–2 % barrel, <6% endcap



- Electrons
  - From di-electron resonances: resolution <1–2% barrel, <4% endcap

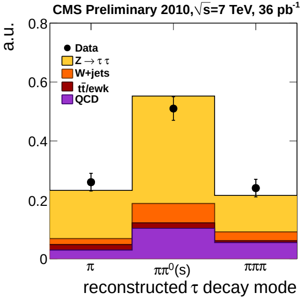




Muon p_T resolution for top is 1-2%, ECAL resolution 1% for top

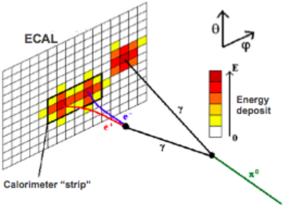
Taus

- 2/3 decays hadronically (into one or three charged mesons, predominantly π, a ν and potentially additional neutral π.)



Impact on top (τ+jets, dilepton channel with τ decays): efficiency, qcd/fake estimate, modeling

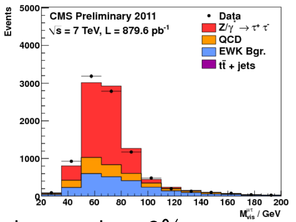
Challenge: reject hadronic jets (larger production rate) faking tau candidates



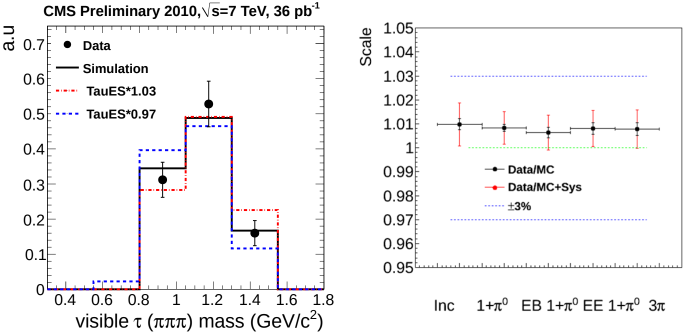
- Using hadrons plus strip algorithm (takes into account the broadening in ϕ of calorimeter signatures due to early showering photons.)
- Candidates are required to satisfy isolation based identification using charged hadrons and photons within cone around the τ candidate

Taus: Efficiency, energy scale

- Efficiency measured using tag and probe on $Z \to \tau\tau \to \mu\tau_{had}$, estimated $\sim$45%

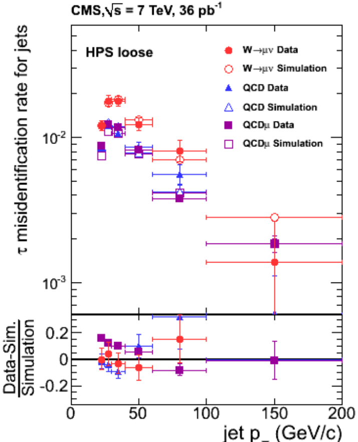


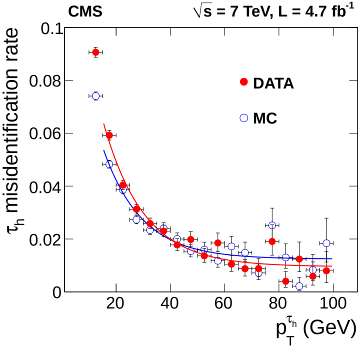
- Energy scale $\sim$1, with measured uncertainty better than 3%



Taus: Miss-identification rate

- Major sources of jets that can fake hadronic taus: QCD, W+jets
- Discrimination against electrons using MVA with efficiency <2% (estimated with $Z \to ee$)
- Discrimination against muons with efficiency $< 0.2\%$
- Charged Misid. Rate 1%-2%



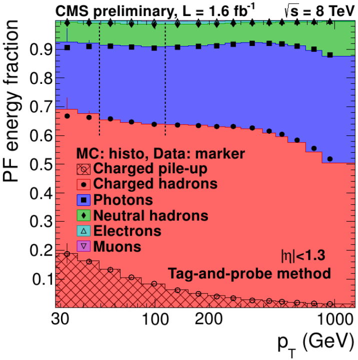


Jets in CMS

PFJets, reconstructed with anti-kT algorithm (Cone 0.5)

Well calibrated jets are important for any analysis

- Factorized approach for jet calibration in CMS
  1. Offset corrections for pile-up and electronic noise
  2. Corrections for detector calibration and reconstruction efficiencies from MC
  3. relative residual corrections for η dependence (data based)
  4. residual corrections to absolute p_T (data based)

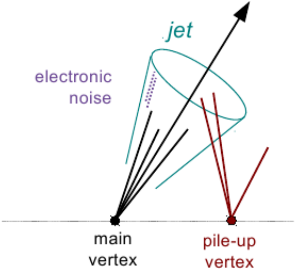


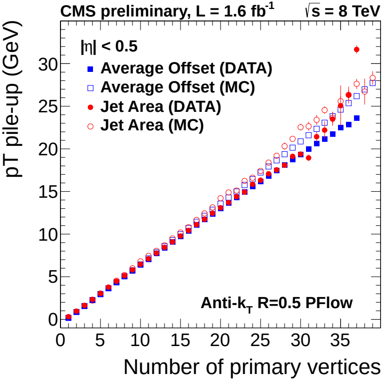
Impact on mass measurement, cross-section, on total syst. uncertainty

JES uncertainty <2% for most of the p_T range, JER about 10%

Pile Up Corrections

- ◇ Pile Up: Corrections based on two methods, Average Offset correction and Jet Area Correction



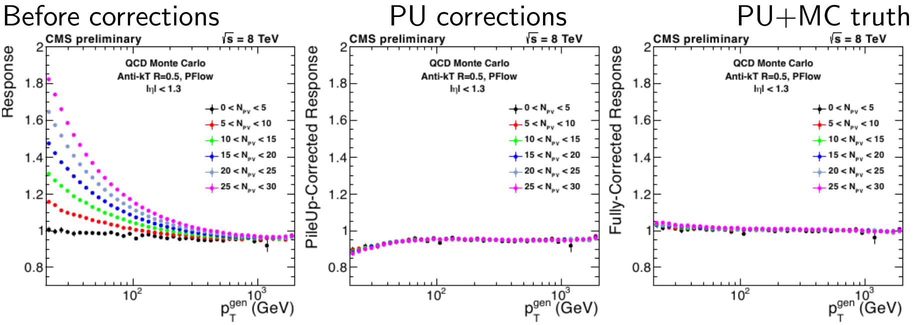


The pile-up dependence on N_{PV} is very linear for data, while MC requires a small quadratic correction.

Jet Energy Corrections for detector effects

- ◇ η and p$_T$ corrections derived from QCD MC sample
- ◇ Reconstructed jet p_T corrected to generator jet ($\frac{p_T^{reco}}{p_T^{gen}}$)

Before corrections | PU corrections | PU+MC truth

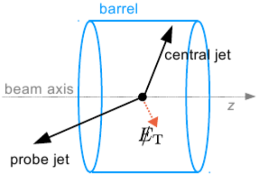


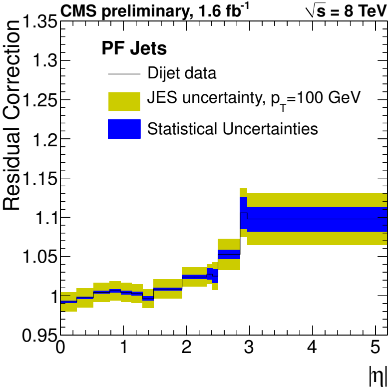
Closure test at unity over whole kinematic range

Residual Jet Energy Corrections

◇ Data-driven corrections for η dependence:

  - Derived from dijet balance
  - Make the jet response flat vs eta. Essentially, the uniformity in pseudorapidity is achieved by correcting a jet in arbitrary η relative to a jet in the central region ($|\eta|$ <1.3)

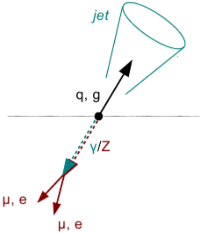




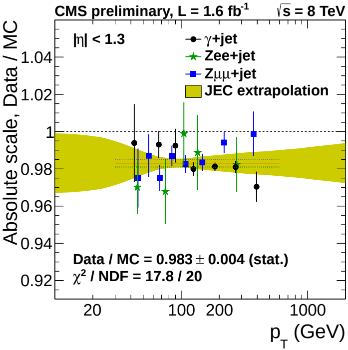
- Detector modeling accurate: η-dependent residuals for all jets types below 2.5% at $|\eta| < 2.4$
- Slightly larger residual in end caps outside tracker coverage.

Residual Jet Energy Corrections

- Absolute JEC scale determined with three topologies: $Z\mu\mu$+jet, Zee+jet, and γ+jet

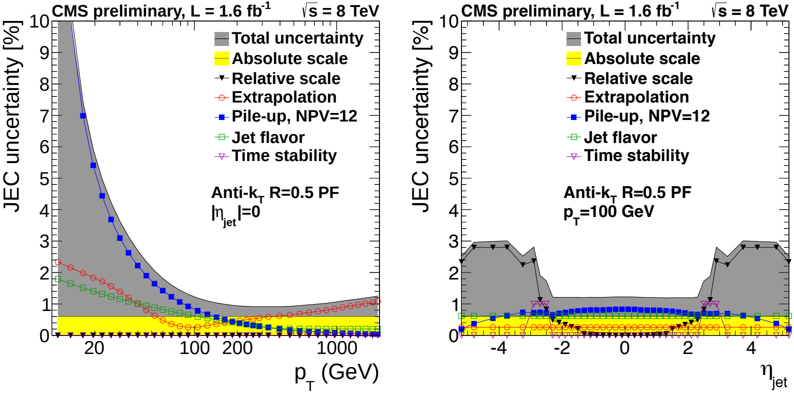


  - Make the jet response flat vs p_T
  - The residual correction required for absolute scale is of the order of 1.5%
  - No significant p_T dependence



JEC uncertainties

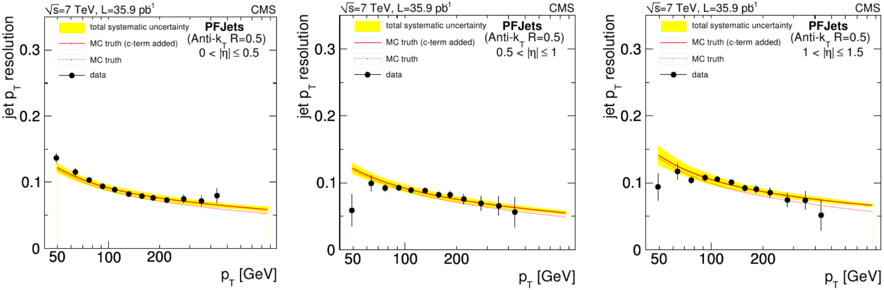
- Uncertainties comparable to 2010, 2011.
- Pile-up uncertainties increasing due to higher average pile-up.



- The contribution of different uncertainty sources depends on p_T and η
- Total uncertainty of the jet energy scale is close to 1% for $|\eta| < 2.4$

Jet Resolution Measurement

- Dijet Asymmetry method $(\frac{p_{T,1}-p_{T,2}}{p_{T,1}+p_{T,2}})$
- Balance method on γ+jets $(\frac{p_{T,jet}}{p_{T,\gamma}})$



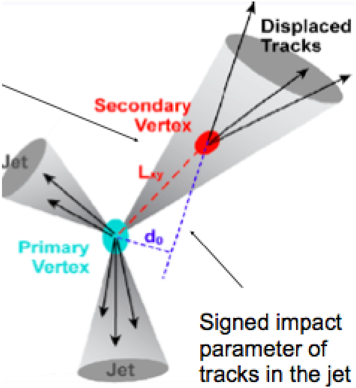
JER factor varies between 15% to 10% with increasing p_T

b-tagging

- Fundamental to identify jets from hadronization of heavy flavour quarks
- Main feature to identify b-jets from the light-flavour jets: large lifetime ($\sim$1.5 ps) and decay length (1.8mm)

  Different algorithms used

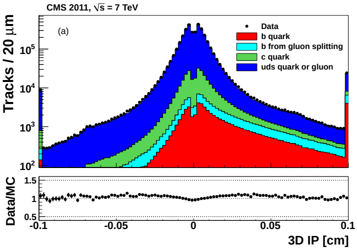
  - Based on track impact parameter significance
  - Secondary vertex
- Impact on top: amount and uncertainty of light flavour background for all tagged analysis

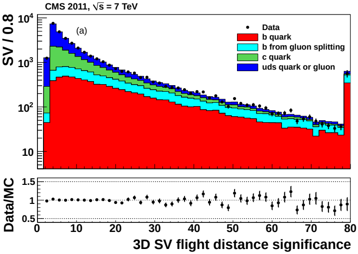


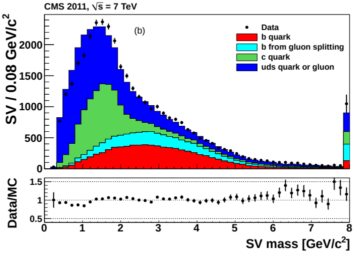
Signed impact parameter of tracks in the jet

b-tagging identification

1. Using impact parameter calculated in 3D
2. Presence of secondary vertex and kinematic variables associated to it (flight distance and direction, properties of the system of associated tracks - multiplicity, energy, mass)



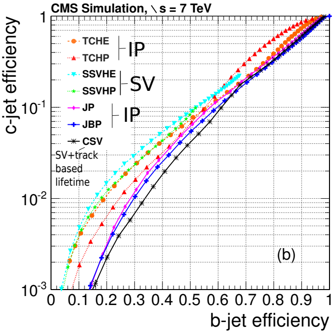




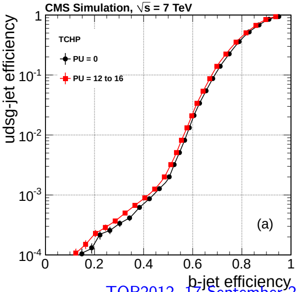
Selected tracks in a sample firing a jet trigger with p_T >60 GeV

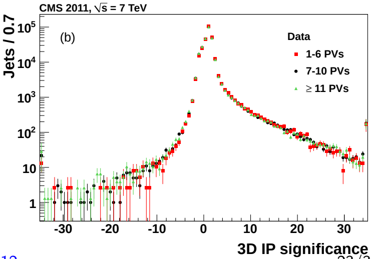
b-tagging performance

- Performance of the different algorithms: c-jet efficiencies vs b-jet efficiency
- Usage in top analysis:
  - first ∼ fb^{-1} 2011 data: Track counting
  - Full 2011 data and 2012: Combined SV



◇ Impact on running conditions: Alignment, increased track densities due to pile-up





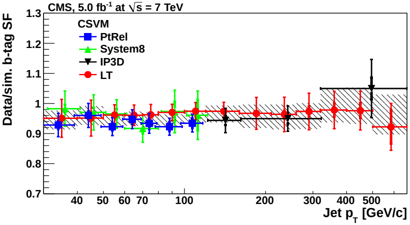
b-tagging Efficiency

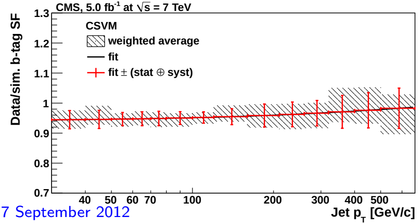
- Several methods using multijets events
- Dijets with a muon jet - using the kinematic properties of muon jets (p_T^{rel}, IP): They rely on fitting the variabes with simulated spectra for the b signal and c+light background
- Lifetime tagger with muon jet and inclusive jet sample

◇ Individual results combined for the optimal measurement of data/MC SF for 30< p_T <670 GeV.

◇ Combination based on a weighted mean of the scale factors in each jet p_T bin

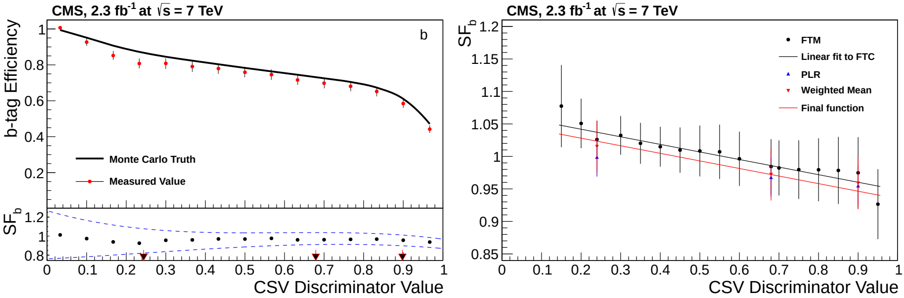
◇ Top analyses apply those SF to correct MC yields





b-tagging Efficiency

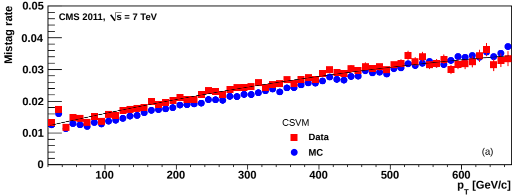
- Various methods using $t\bar{t}$ events in the lepton+jets and dilepton channels, provide inclusive results
- Suited for measurements other than the cross section
- Event selection follows the selection for $t\bar{t}$ cross section measurements (without b-tagging requirements)

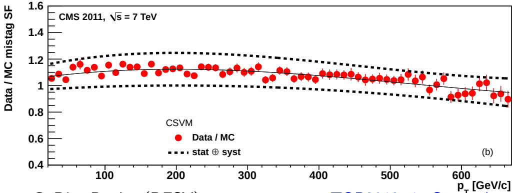


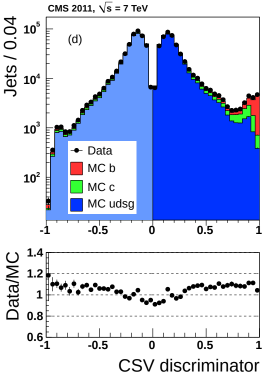
$t\bar{t}$ selection

b-tagging Mis-tag rate

- Use tracks with negative impact parameter or secondary vertices with negative decay length to measure the negative tag rate
- Evaluate for different jet triggers and use average







Missing Transverse Energy

- Events are reconstructed with the Particle Flow technique: MET computed as the negative vectorial sum of all particles candidates, corrected for JES
- Impact on top: QCD estimate & modeling, mass measurement

Challenging variable

Easy to obtain fake MET due to large shower fluctuations

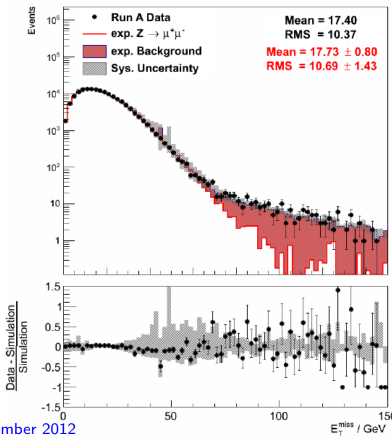
Non linear calorimeter response

Instrumental noise, poorly instrumented area

Use Z→ $\mu\mu$ to study MET resolution

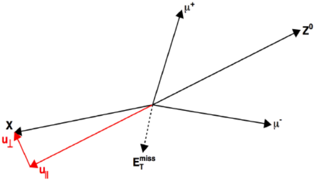
- Clean final state, small background contributions
- No intrinsic MET, only resolution effects

7 TeV



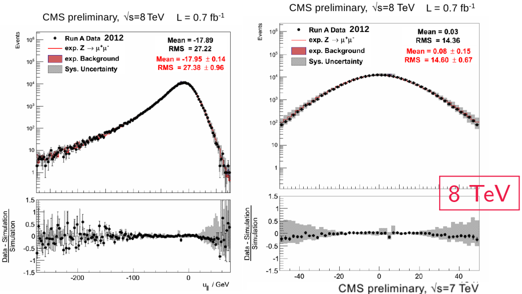
MET Scale and resolution

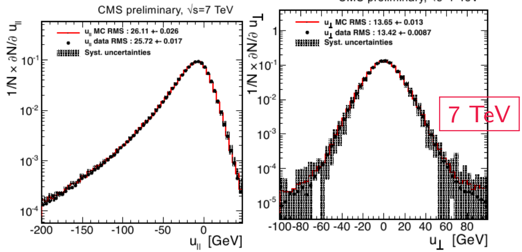
$$u_{recoil} + q_T^Z + E_T^{miss} = 0$$



- The mean of the distribution of $u_\parallel / q_T$ is a measure response
- The RMS widths of $u_\parallel - q_T$ and $u_\perp$ are used to measure resolution

MET distributions agree well between data and simulation



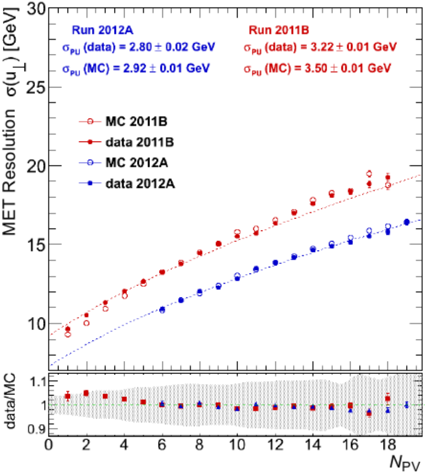


Missing Energy Resolution

- MET resolution for different N_{PV} is fitted with:

$$\sigma_{tot} = \sqrt{c^2 + \frac{N_{PV}}{0.7} \cdot \sigma_{PU}}$$

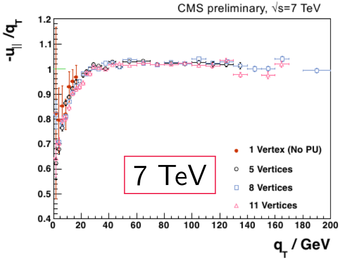
  - c: average resolution without PU
  - σ_{PU} degradation in resolution caused by PU
- Good agreement data-simulation
- Improved resolution in 2012
- PU introduces an additional smearing of $\sim$3 GeV

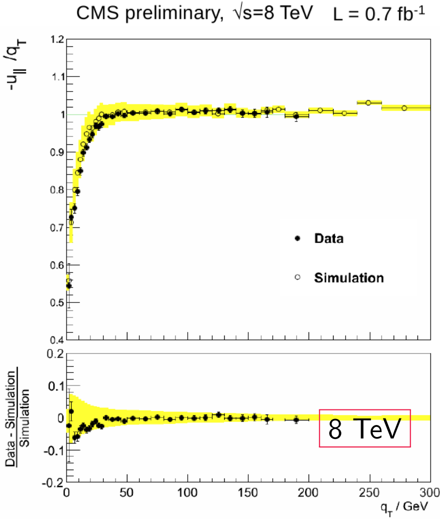


Missing Energy Response

- corrected MET
  - jet corrections are applied
  - MET is recalculated

- MET response in $Z \to \mu\mu$ is close to unity
  - Independent of PU multiplicity of the event





Summary

- Great performance of the object identification both at 7 and 8 TeV for precision measurement of top quark properties
- The agreement between data-simulation is remarkable
- CMS is performing well in this scenario, adapting to the increasing luminosity
    - PU dependent correction
    - customize isolation
- So far, top analyses show no significant dependence on the changing conditions.
- All CMS public results available from: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

Documentation

- Muons: CMS MUO-10-004
- Electrons: CMS-PAS-EGM-10-004, CMS-PAS-EGM-10-001
- Taus: CMS-PAS-TAU-11-001
- Jets: CMS DP-12-012, 2011 JINST 6 P11002
- b-tagging: CMS PAS-BTV-11-003, PAS-BTV-11-004
- MET: CMS DP-12-003, CMS DP-12-013

BACK UP

Trigger efficiency