Identification of jets, taus and missing transverse energy at CMS

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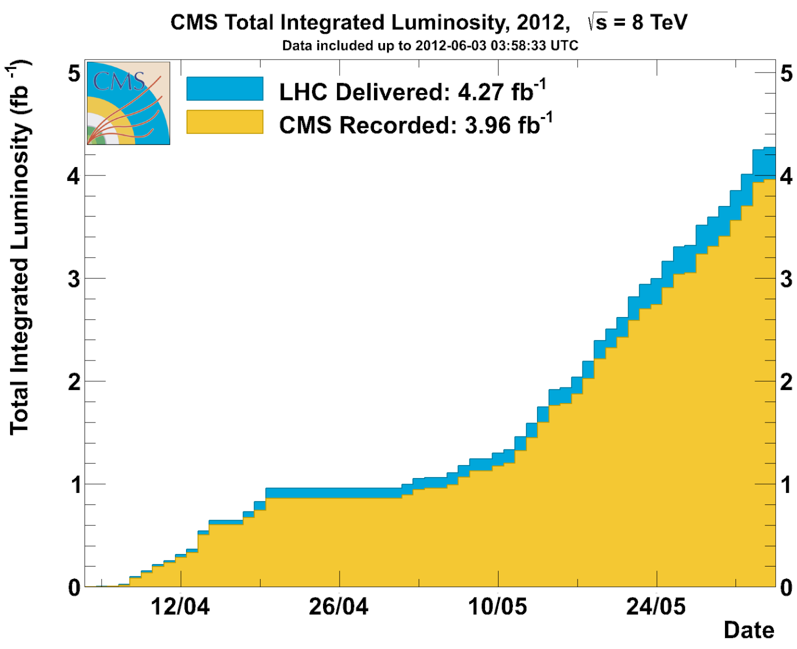
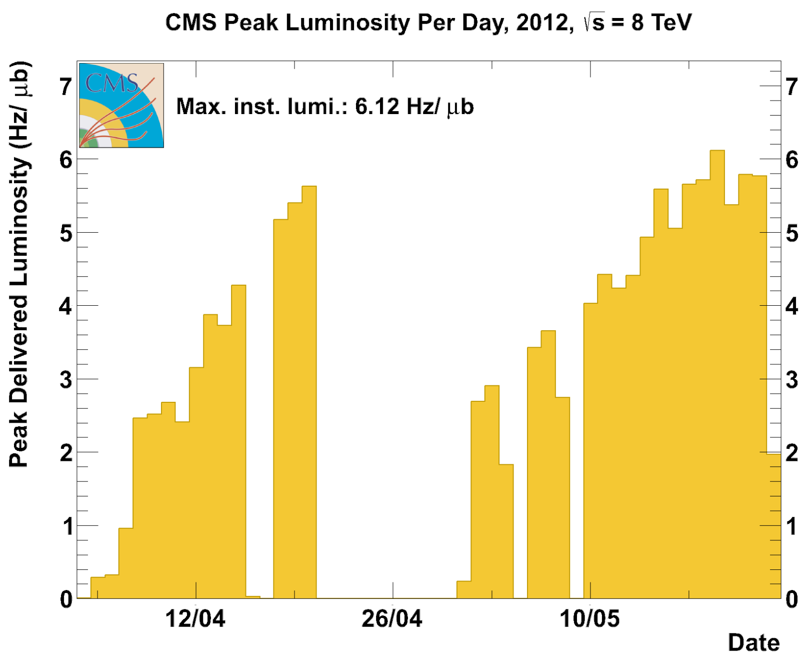
On behalf of the CMS collaboration

LHC Performance

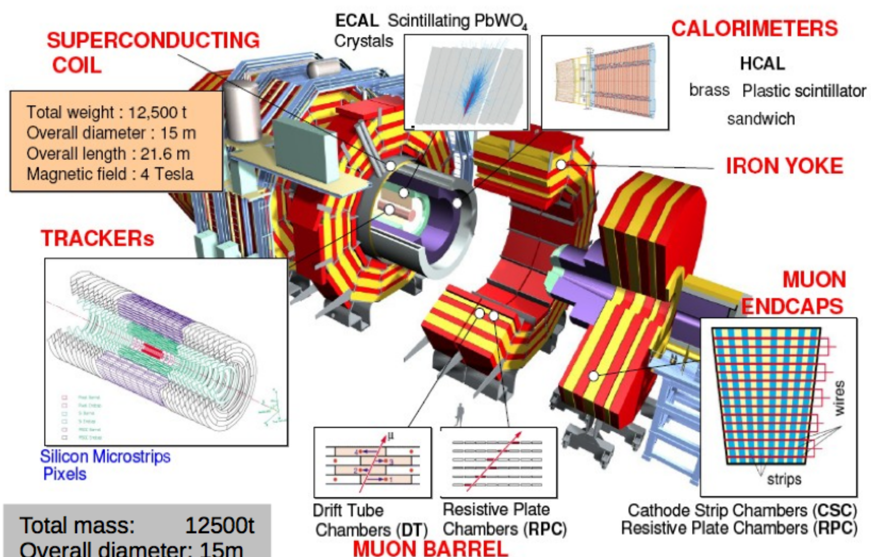
Data available: >5/fb @ 7 TeV
and ~ 4/fb @ 8 TeV

Peak Inst. Lumi > 6 Hz/μb

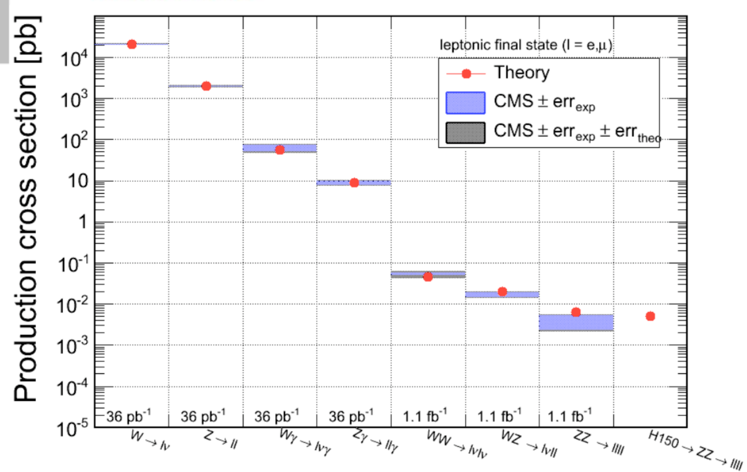




CMS Performance

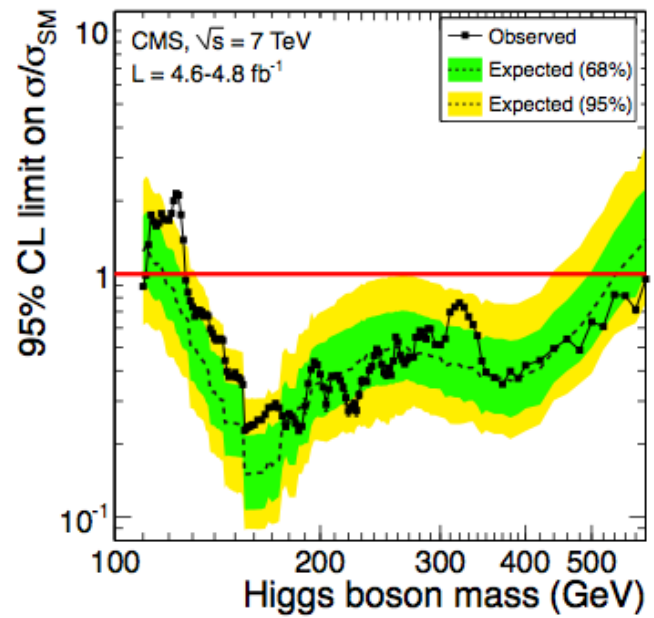


Total mass:	12500t
Overall diameter:	15m
Overall length:	22m
Magnetic Field:	3.8T



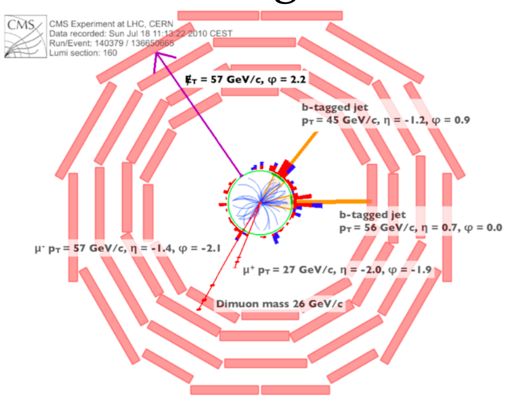
Excellent performance

- Each sub-detector > 98% operational
- Rediscovered the SM
- Great results on Higgs/SUSY/Exotica searches

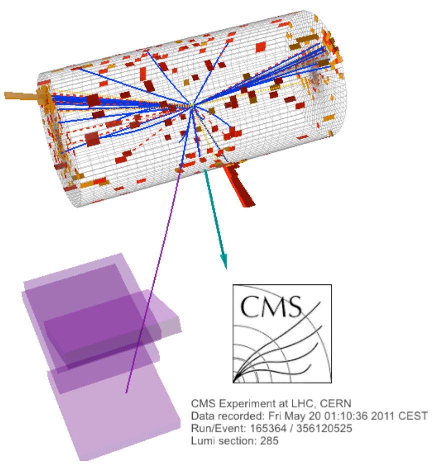


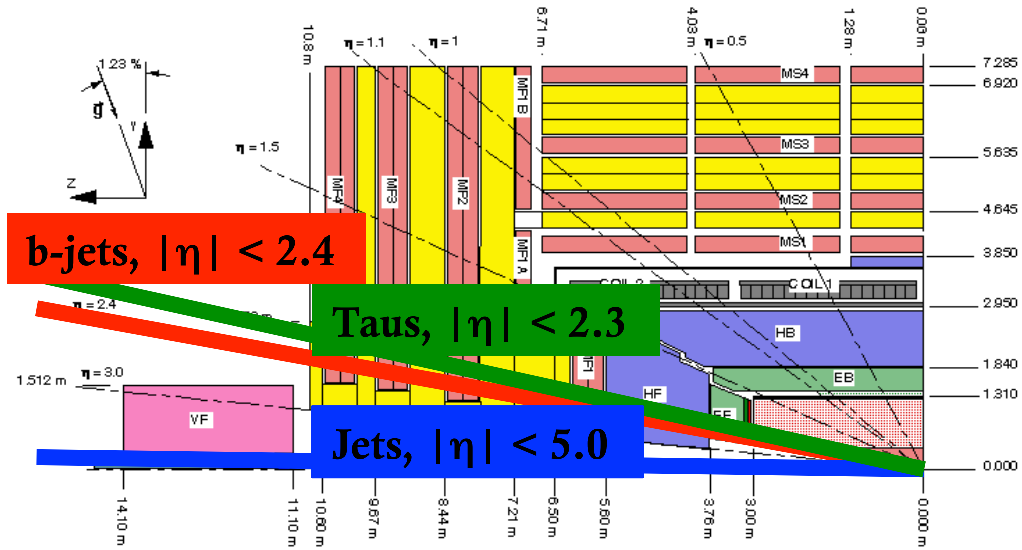
Physics Objects

Candidate event with 2 muons, 2 bjets, and missing transverse energy



Candidate event with muon, tau, 2 jets



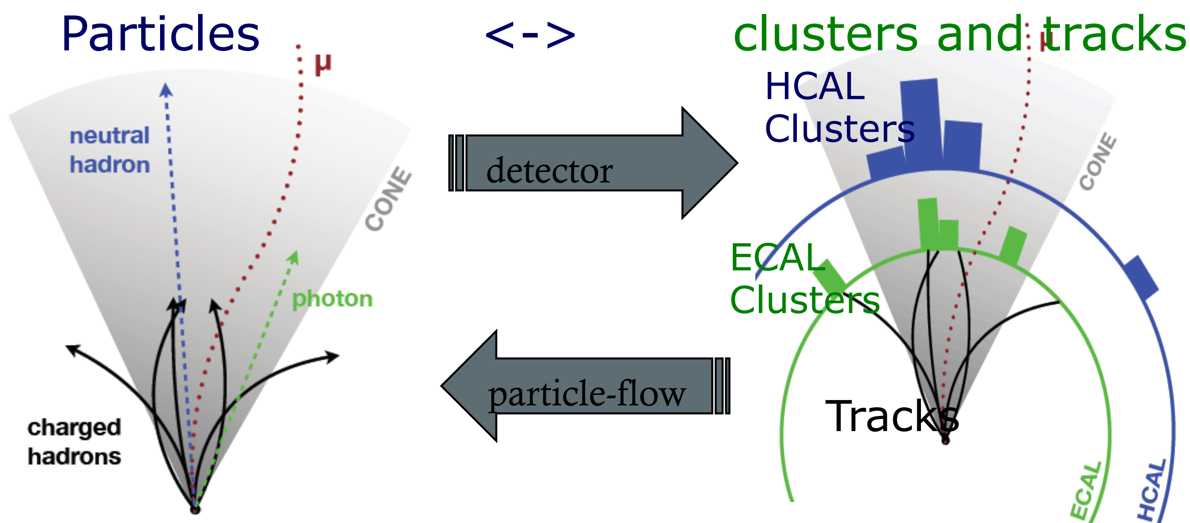


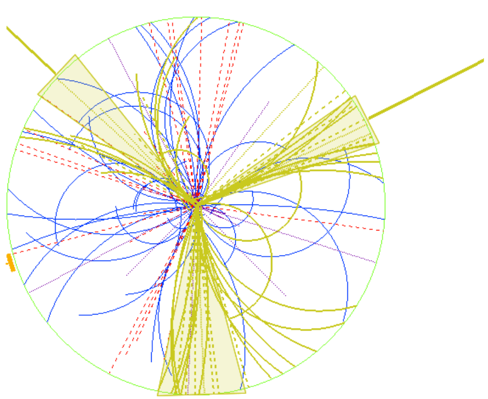
Physics Objects :

- Jets
- B-jets
- Taus
- Missing transverse energy

Particle Flow

- Combine information from all sub-detectors to reconstruct sea of particles
  - Hadrons
  - Photons
  - Muons/electrons

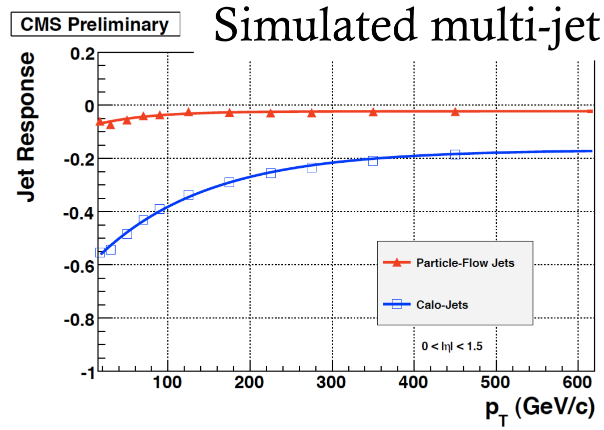


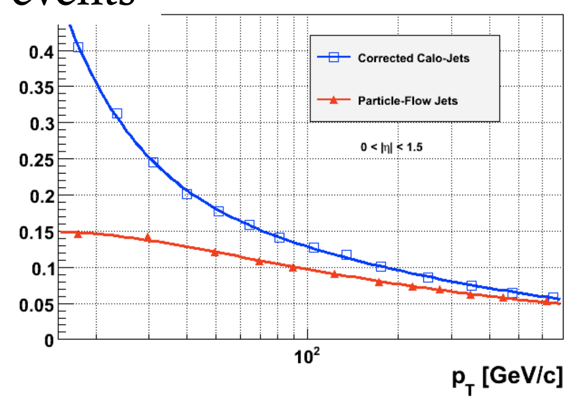


Create composite objects

Jets, taus, missing ET

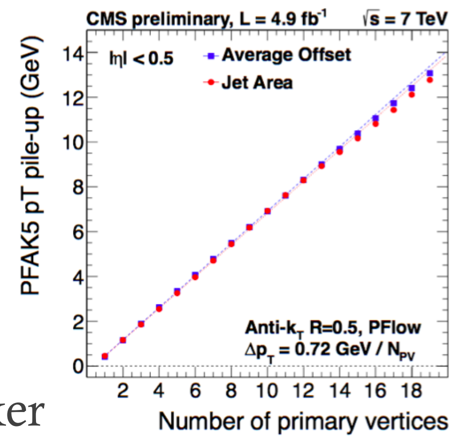
Simulated multi-jet events

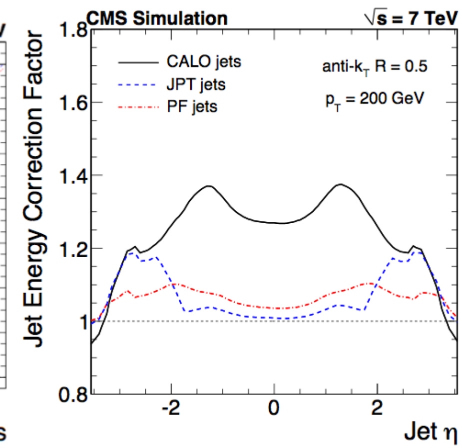


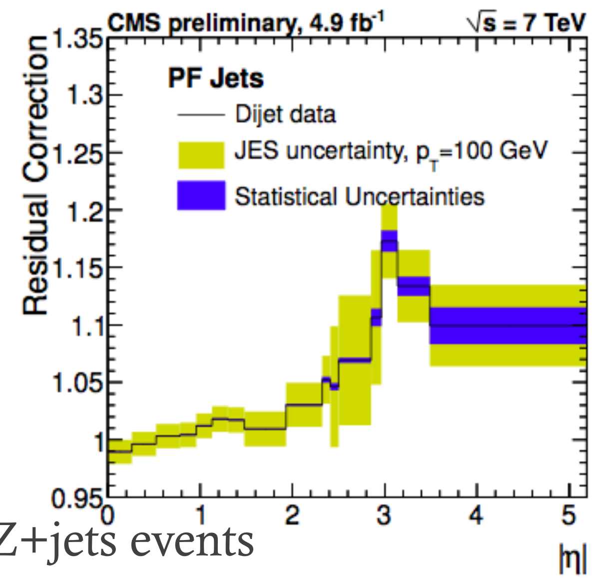


Jets Energy Corrections

- JEC are applied to correct for
  - Energy deposition from pileup
    - Both Offset vs N_{pv} and FastJet area/median corrections supported
    - Corrections are linear up to N_{pv}~20 and little η dependence within tracker
  - Dependence on η and absolute scale
    - Derived from multijet MC truth information
    - Closure checks within 0.5% for p_T>30 GeV
    - Flavor dependence within +1/-3%
  - Residual corrections for data
    - Relative η-dependent corrections derived from dijet events. Corrections within 5% for |η| < 2.5
    - Absolute scale at |η|<1.3 derived from γ+jets and Z+jets events

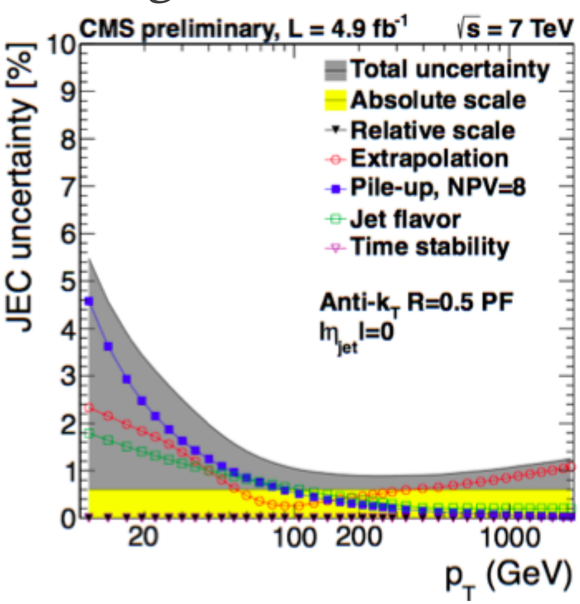


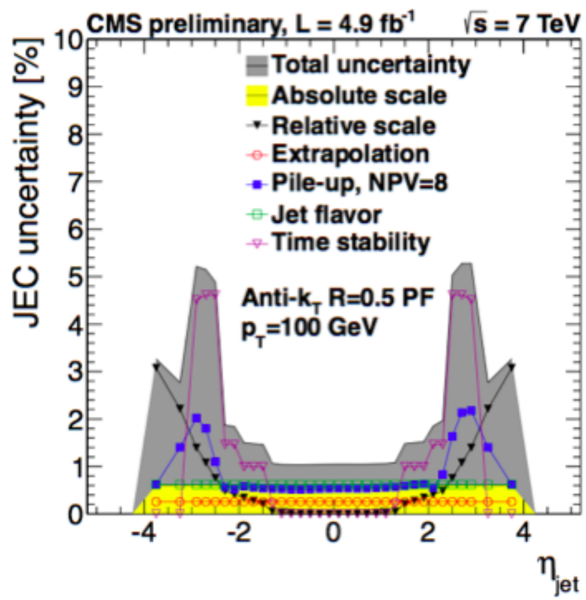


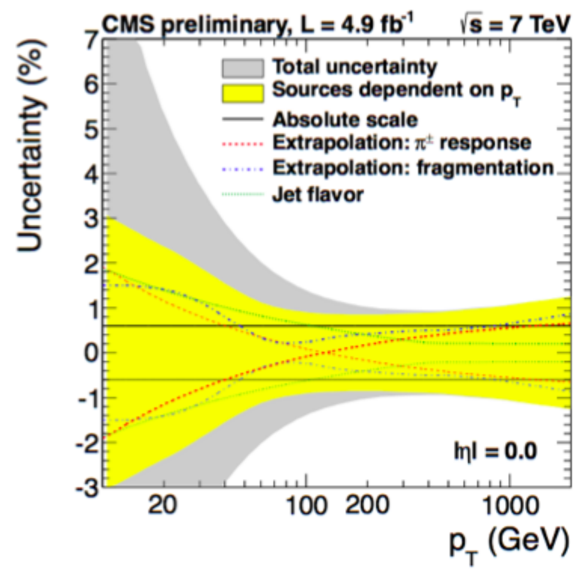


JEC Uncertainties

- Detailed accounting the sources of uncertainties
  - Main sources for |η| < 1.3 are pileup, jet flavor, extrapolation depending on the p_T range
  - Main source for 2.5 <|η| < 3 are time dependence and out of time pileup
  - Total uncertainty is the sum of uncertainties from all sources
- Effect of uncertainties is reduced by taking into account the positive/negative variation of the correlated sources







Jet p_T Resolution

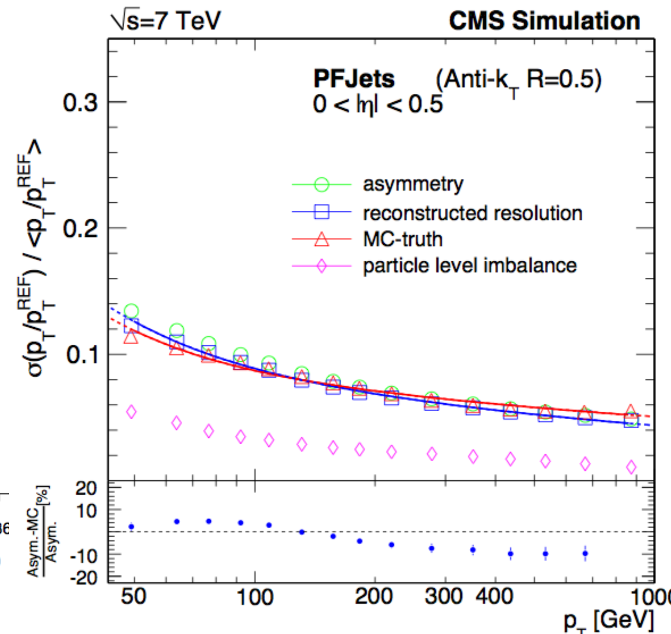
- Resolution is measured with two methods
  - Asymmetry method on dijet events

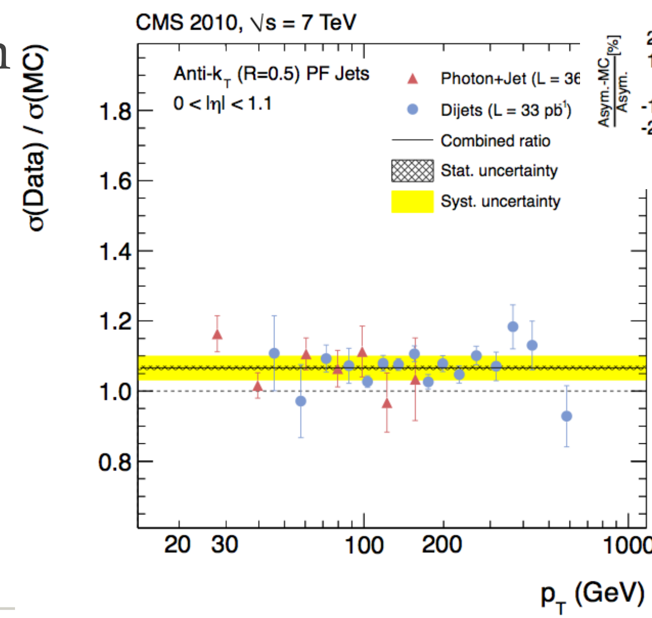
$$A = \frac{p_T^1 - p_T^2}{p_T^1 + p_T^2}, \qquad \frac{\sigma(p_T)}{p_T} = \sqrt{2}A$$

  - Balancing method on γ+jet events

$$\sigma\left(\frac{p_T^{jet}}{p_T^{\gamma}}\right) = \sigma\left(\frac{p_T^{jet}}{p_T^{Genjet}}\right) \oplus \sigma\left(\frac{p_T^{Genjet}}{p_T^{\gamma}}\right)$$

- Correct for biases from
  - Particle level imbalance in dijet method
  - Gen jet-γ imbalance in γ+jet method
  - Soft-radiation correction in both methods

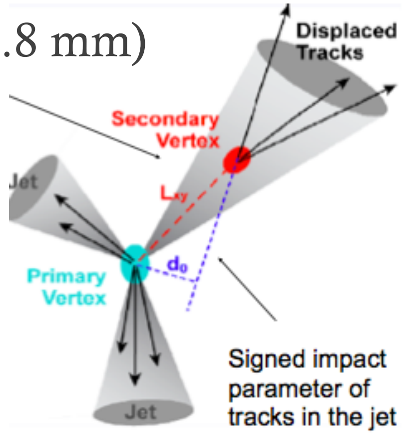




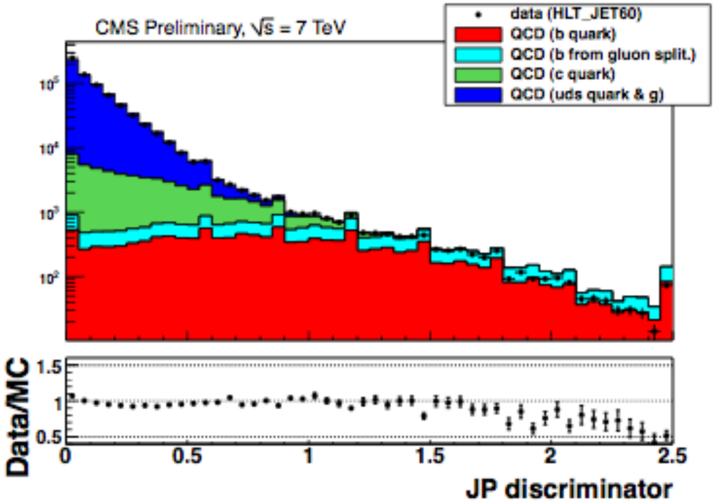
- The resolution in data is ~5-15% broader than in MC depending on the η region
- Jet pT in MC is smeared to match that in data

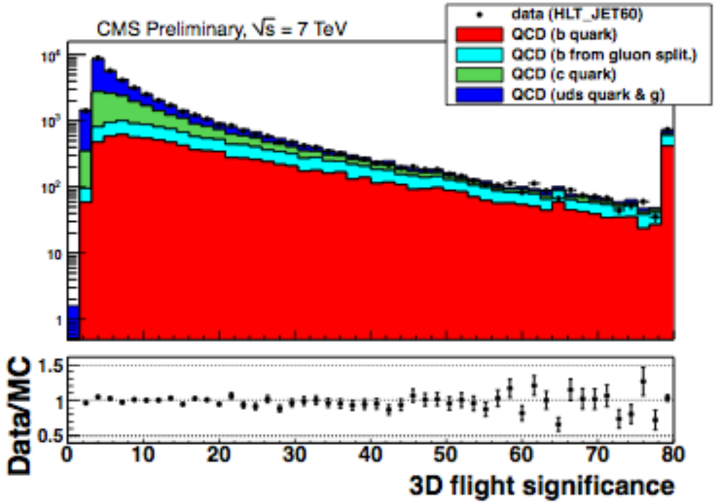
b-Tagging

- Important to identify jets from hadronization of heavy flavor quarks
  - Large lifetime (~1.5 ps) and corresponding decay length (1.8 mm)
  - High mass of 5.2 GeV and decay multiplicity
  - High p_T of decay products relative to the b-flight direction



- Taggers based on track impact parameter significance and/or secondary vertex
  - Excellent alignment and tracking performance

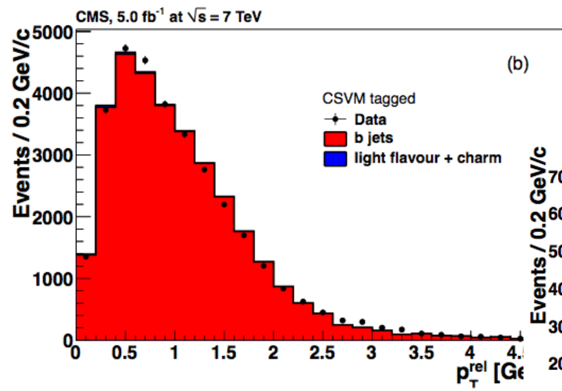




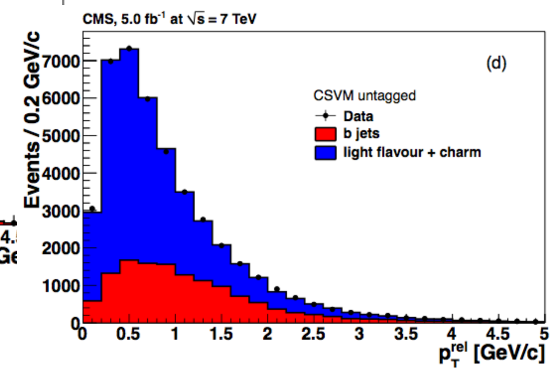
b-Tagging Efficiency

Multiple methods are used to measure b-tagging efficiency in multijet events

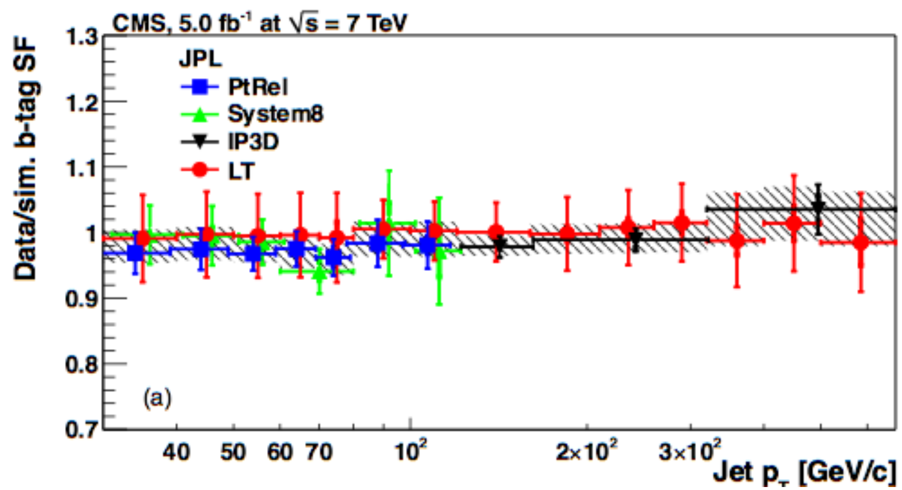
- Using relative p_T or 3D impact parameter of muons in jets to discriminate b-jets from light or c-jets
- Using lifetime tagger method on both muon-jet and inclusive jet sample



$$\varepsilon_b^{tag} = \frac{f_b^{tag} \cdot N_{data}^{tag}}{f_b^{tag} \cdot N_{data}^{tag} + f_b^{untag} \cdot N_{data}^{untag}}$$



Different measurements are combined based on weighted mean of the scale factors for jets with 30 GeV < p_T < 670 GeV

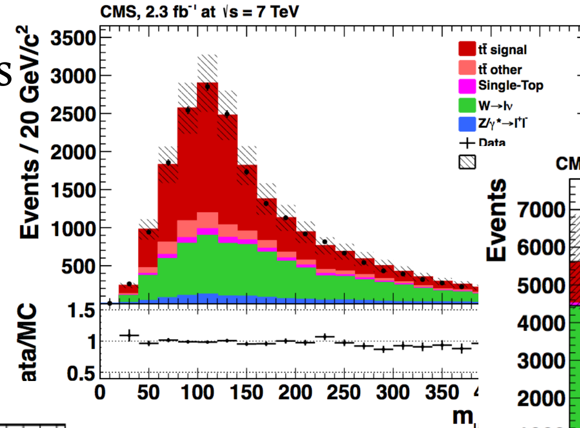


b-Tagging Efficiency

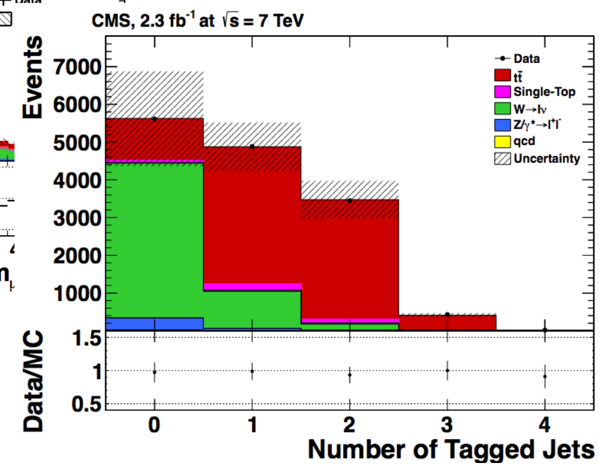
Multiple methods are used to measure b-tagging efficiency in ttbar events

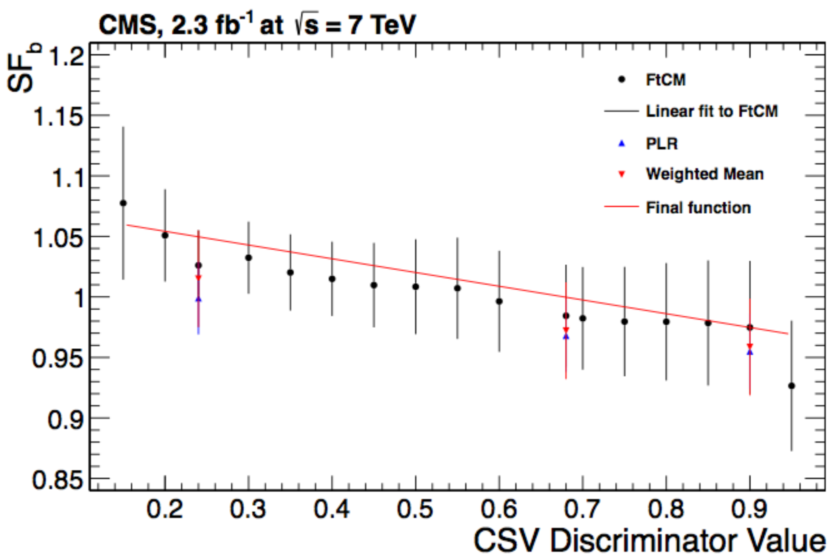
lepton+jets and dilepton+jets decays

- b-enriched jet sample
- *Flavor tag consistency method*
- *PL ratio*
- Flavor tag matching method



$$\hat{\Delta}_b^{enr} = \Delta_b^{enr} - F \times \Delta_b^{depl}$$

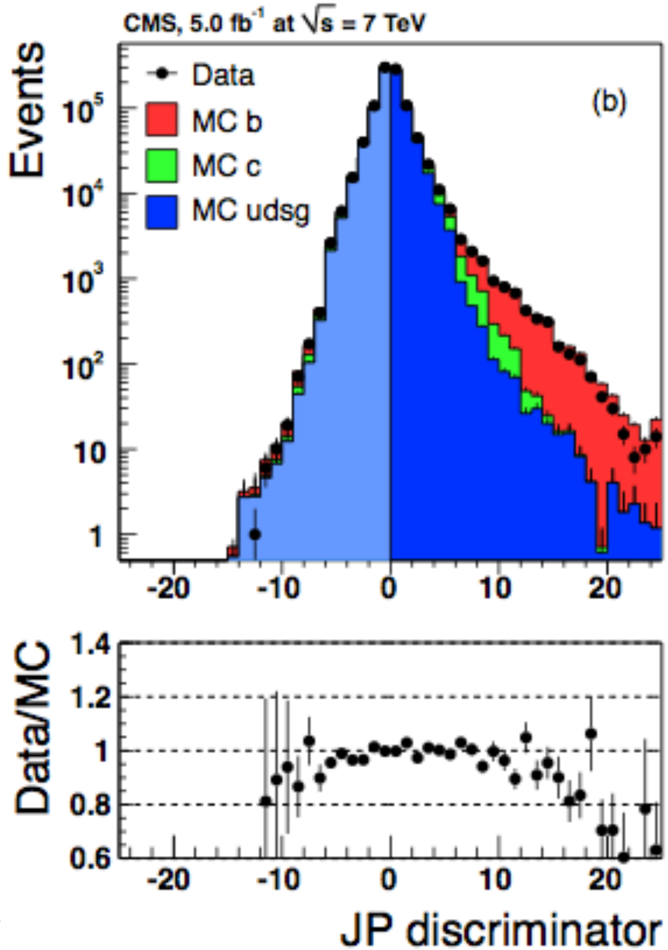




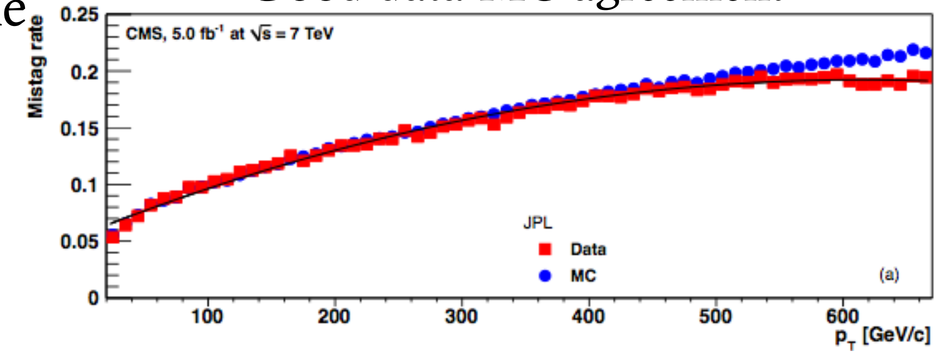
- Combined scale factor is derived as a weighted mean of scale factors from two best measurements from two samples yielding ~4% uncertainty
- Scale factor as function of discriminator value is available for MVA methods

Mis-tagging Efficiency

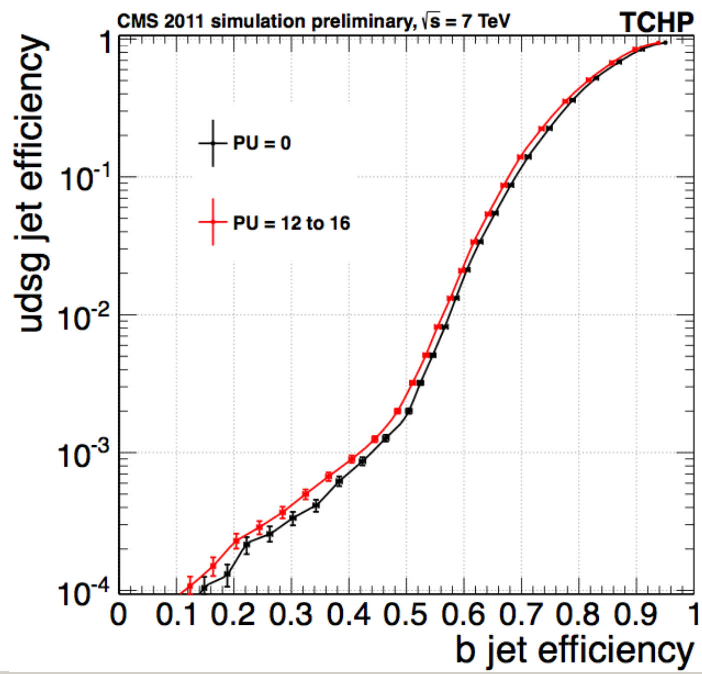
Negative taggers are used to measure the misidentification rate from data



Good data-MC agreement



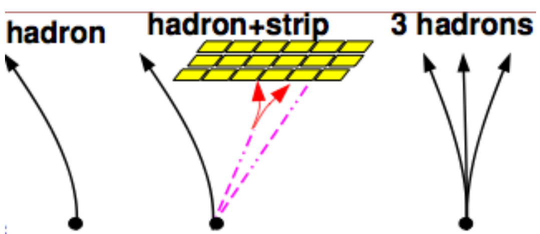
The effect from high pileup is concentrated on high purity region

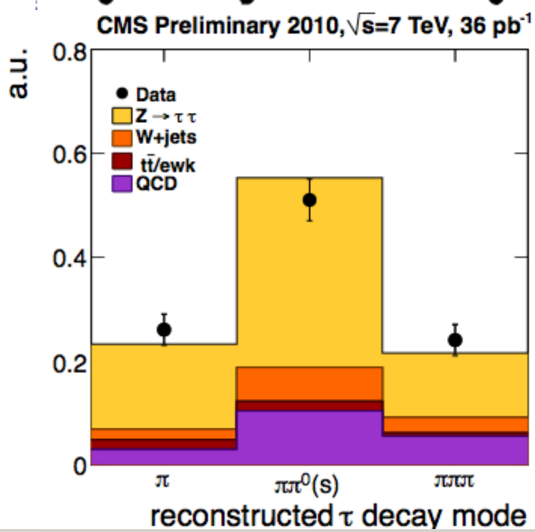


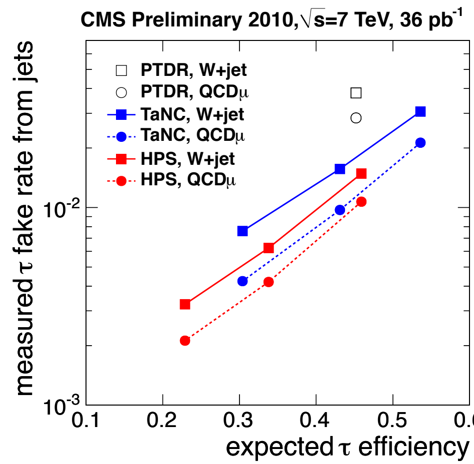
Taus

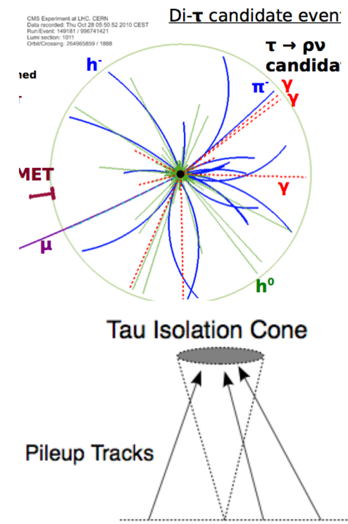
- Using Hadrons Plus Strips algorithm

Decay Mode	Resonance	Mass, MeV/c^2	Branching ratio, %
$\tau \to h^- \nu_\tau$			11.6%
$\tau \to h^- \pi^0 \nu_\tau$	ρ	770	26.0%
$\tau \to h^- \pi^0 \pi^0 \nu_\tau$	a1	1200	10.8%
$\tau \to h^- h^+ h^- \nu_\tau$	a1	1200	9.8%
$\tau \to h^- h^+ h^- \pi^0 \nu_\tau$			4.6%
Total			63.1%
Other hadronic decays			1.7%





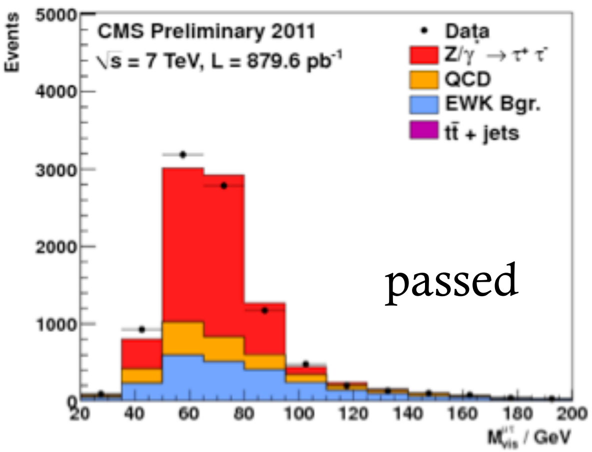


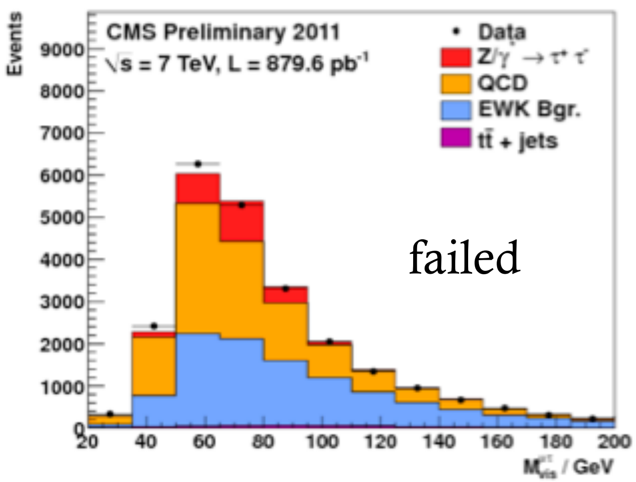


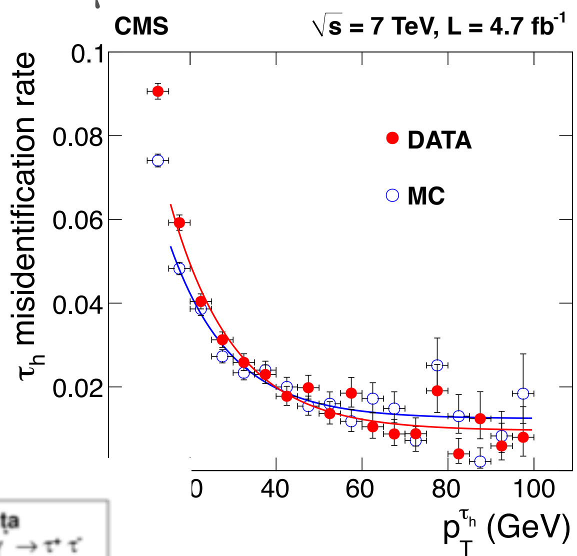
- Isolation based identification using charged hadrons and photons within cone around the tau candidate
  - Corrected for PU activity with no/small dependence of efficiency vs N_{pu}
- Discrimination against muons with efficiency < 0.2%
- Discrimination against electrons using MVA with efficiency <2%

Id. Efficiency and Energy Scale

Using Tag&Probe on $Z \to \tau\tau \to \tau\mu$ events in data for eff. measurement with precision of 6%

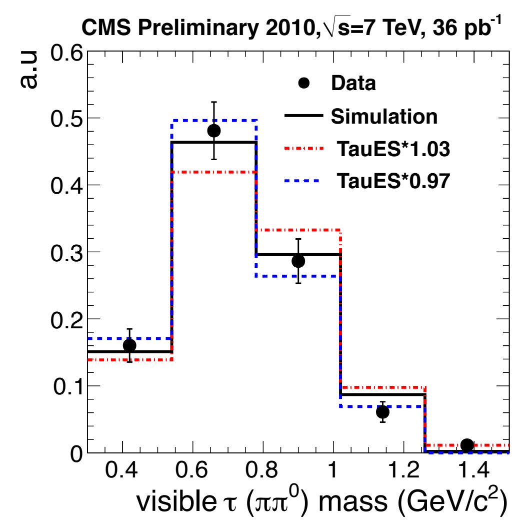






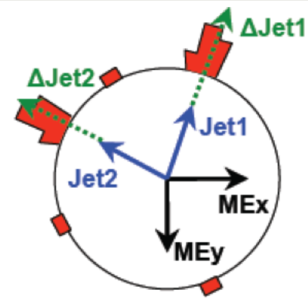
Jet misidentification rate measured in W+jets and multijet events

Tau energy scale is within 3% -- very small effect from PU

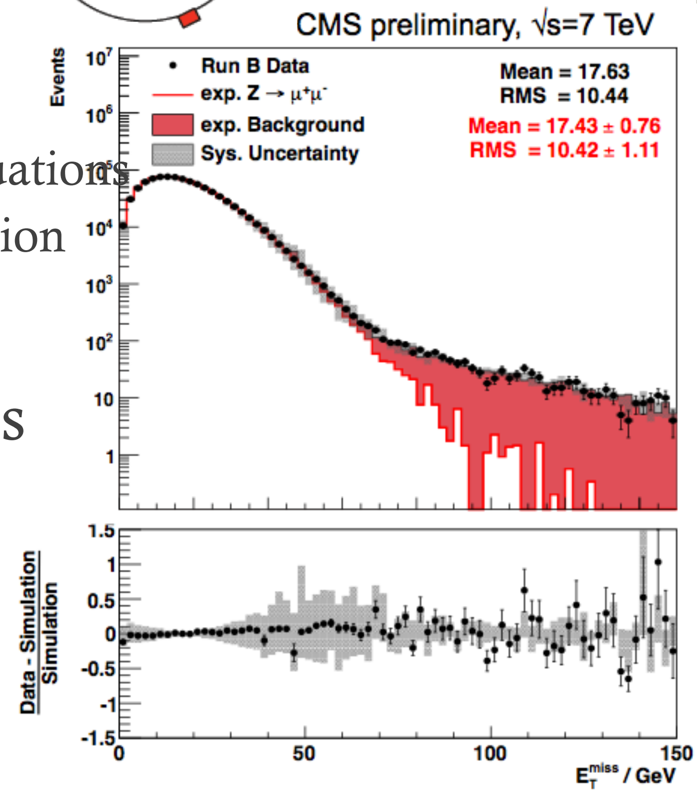


Missing Transverse Energy

- Very important variable for analysis
  - Detect invisible particles
  - One of the most promising signatures of new physics



- Challenging variable
  - Easy to obtain fake MET due large shower fluctuations
  - Non-linear calorimeter response, non-compensation
  - Instrumental noise, poorly instrumented area

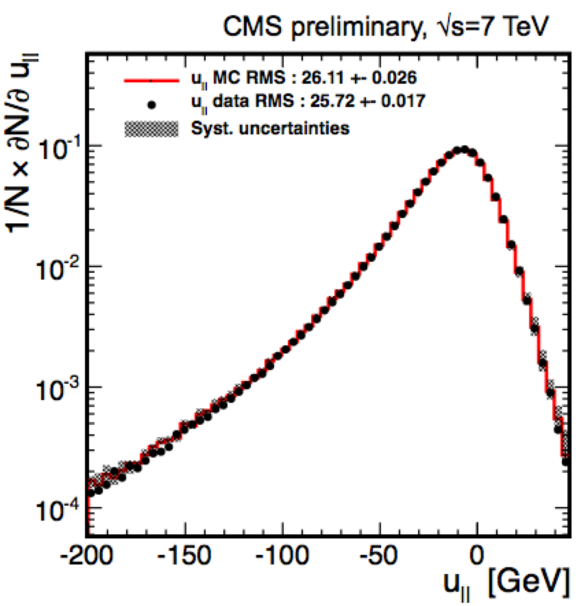


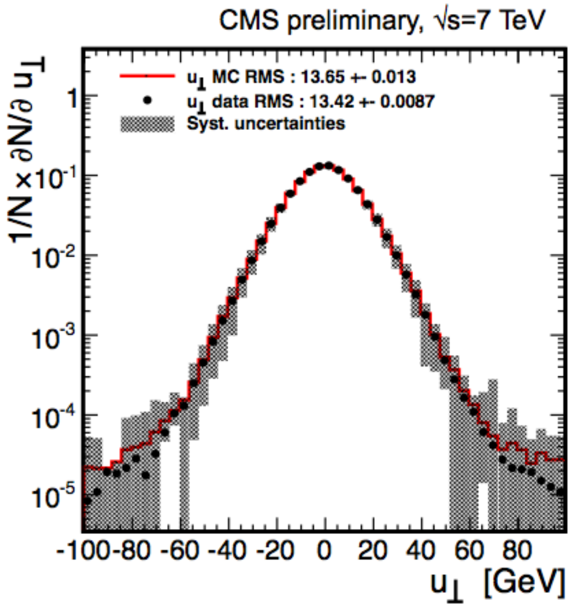
- Compute MET using all PF-candidates in event
  - Corrections on jet energy are taken into account

- Using clean final state of $Z \rightarrow \mu\mu$ to study the resolution effects

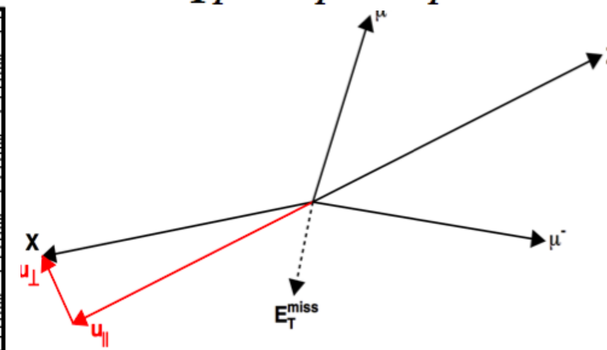
MET Response and Resolution

- In well measured event u_T would balance Z boson momentum
- Mean of distribution u_{ll}/q_T is a measure of MET response
- RMS of $-u_{ll}$-qT and $u_{\perp}$ are measures of MET resolution





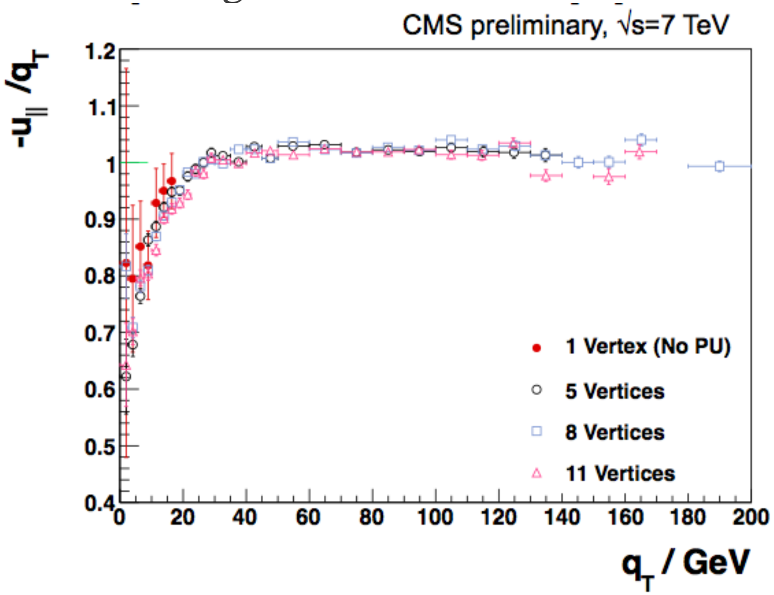
$$\vec{q}_T + \vec{u}_T + \vec{\not{E}}_T = 0$$

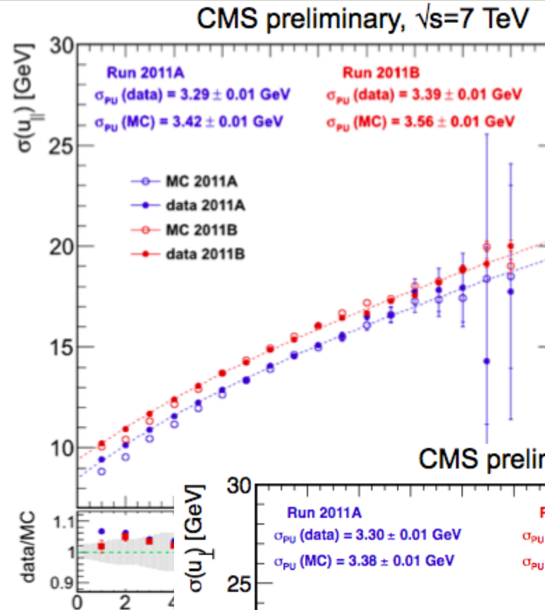


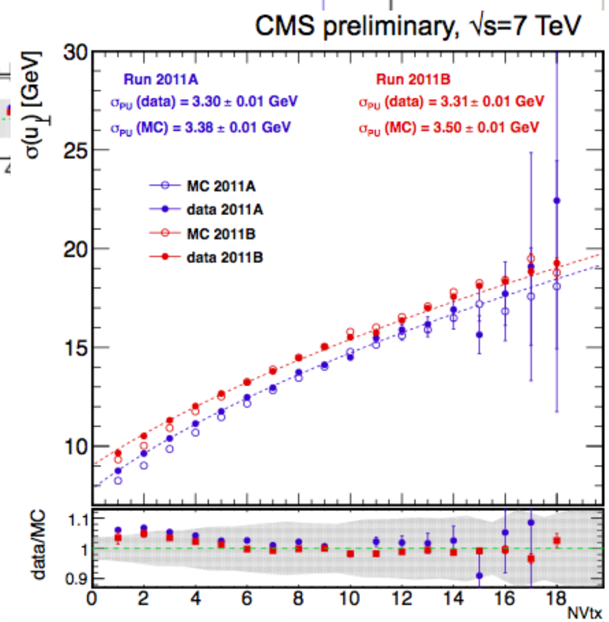
- Parallel and perpendicular recoil components agree well in data and MC

MET Response and Resolution

- Met response in Z→μμ events is close to unity
  - Independent of PU multiplicity in the event
- Met resolution vs N_{pu} in Z→μμ events
  - Worsened resolution in events with high PU
  - Good agreement between data and MC simulation





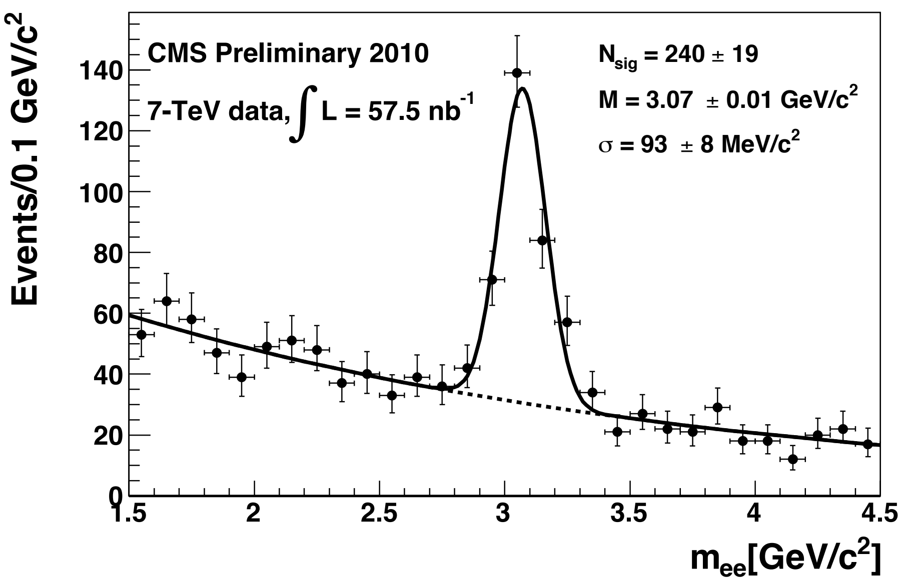


Conclusion

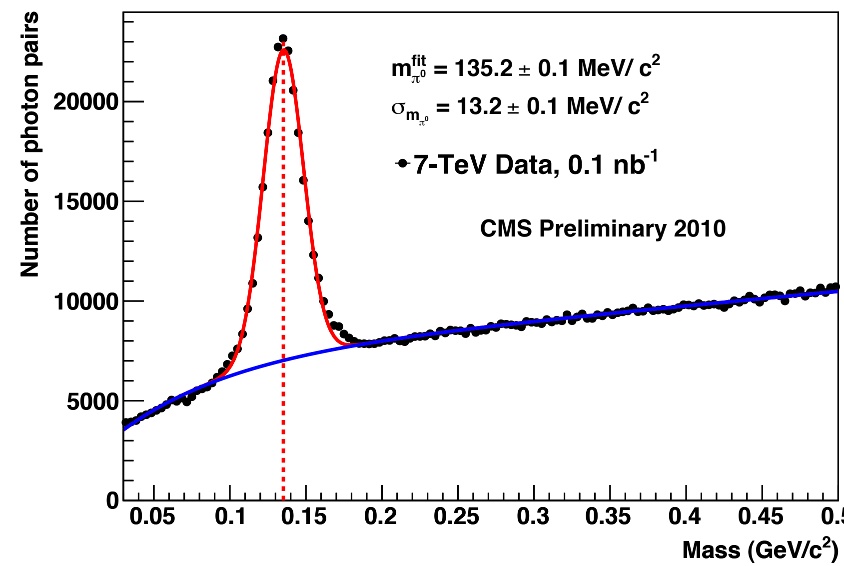
- The identification of the jets, b jets, taus and missing transverse energy is well understood at CMS
  - The identification/misidentification efficiencies, energy scale/resolution are determined *in-situ*
  - Performance in MC simulation agrees well with data observation
  - Further developments for high-PU conditions are ongoing to fully capitalize on the CMS capabilities
- Great performance of the object identification offers unique opportunity to explore a tremendous physics program at CMS

BACKUP

PF commissioning

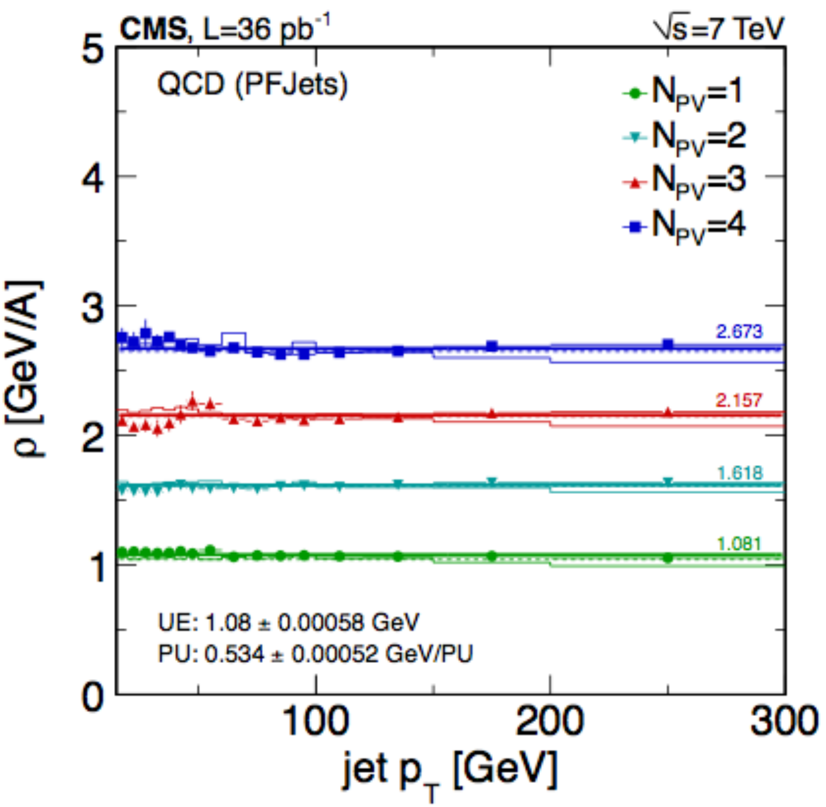


Particle flow commissioning with electrons and muons from J/Psi mass peak

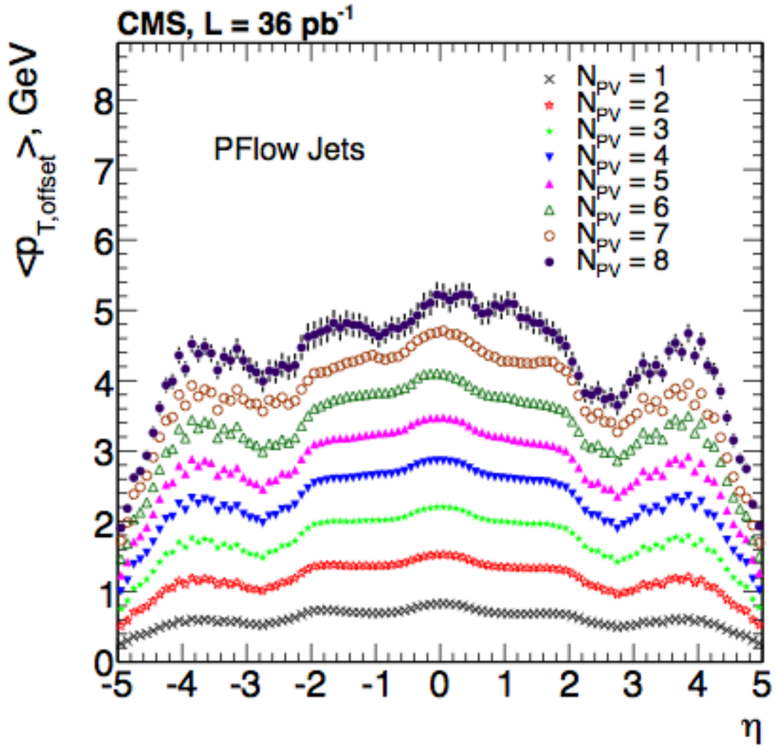


Particle flow commissioning with π^0 events

Jet energy calibration

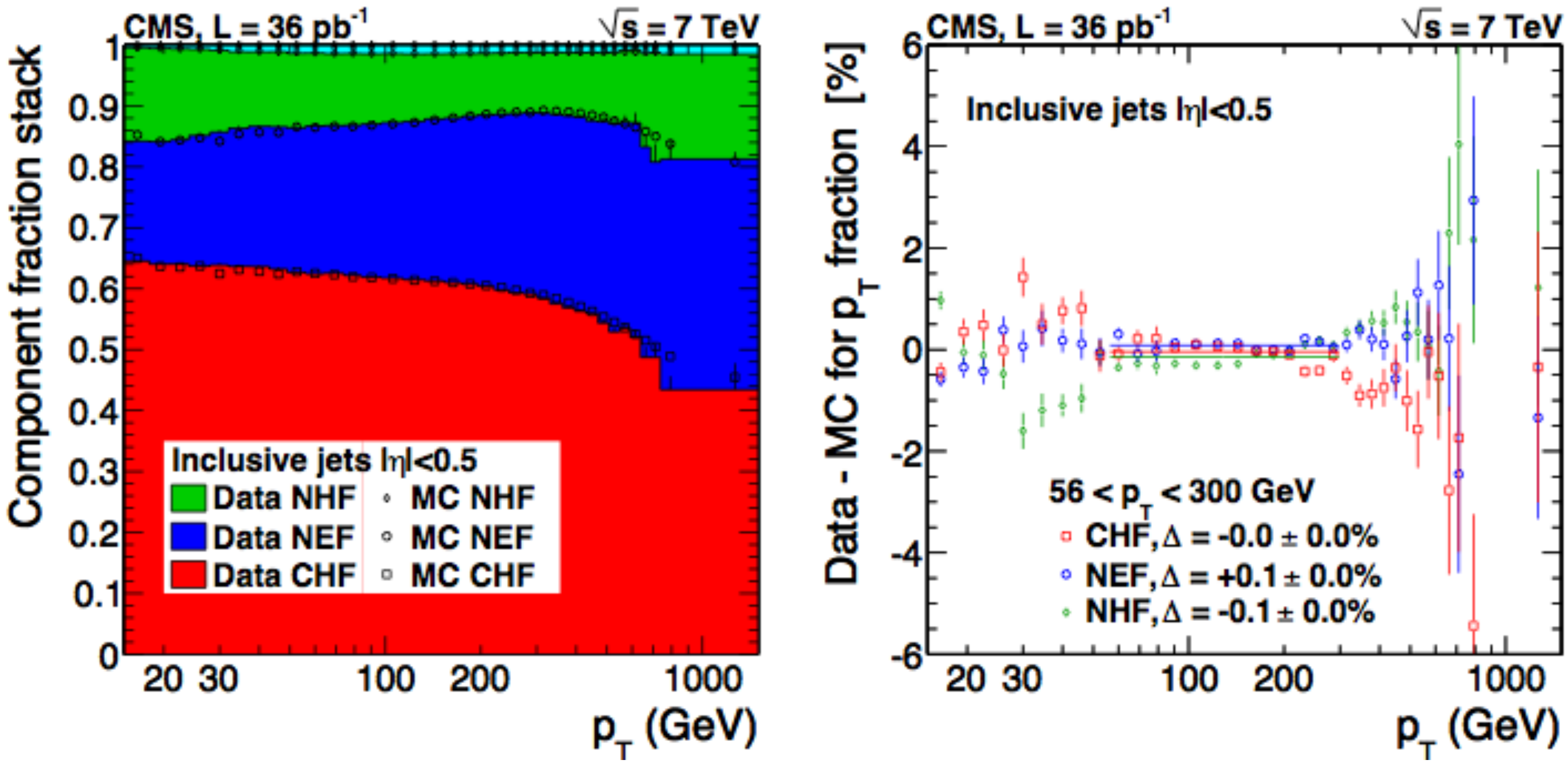


PU and underlying event PF p_T-density



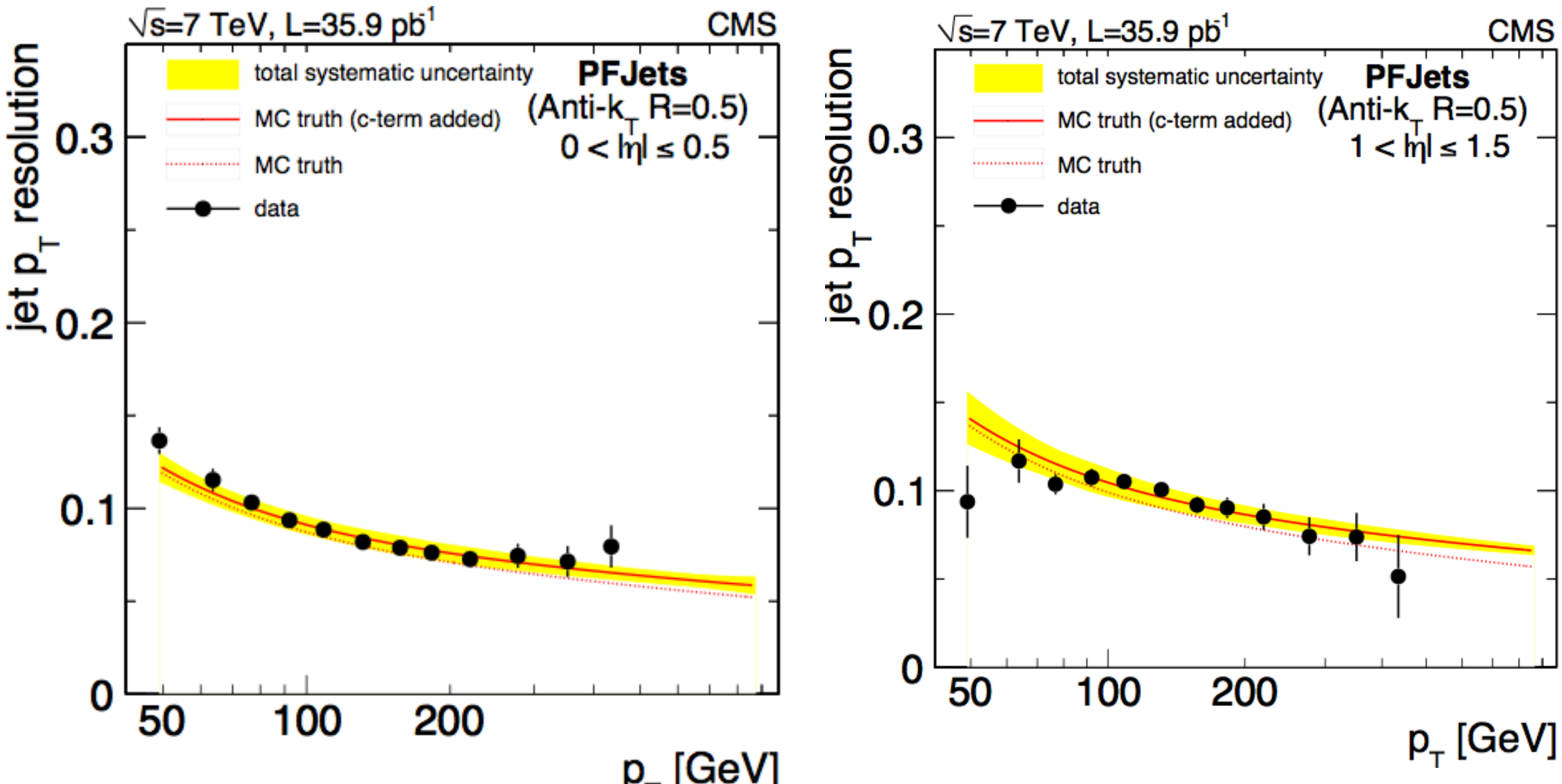
Average offset in p_T measured in minimum bias events

PF jet composition



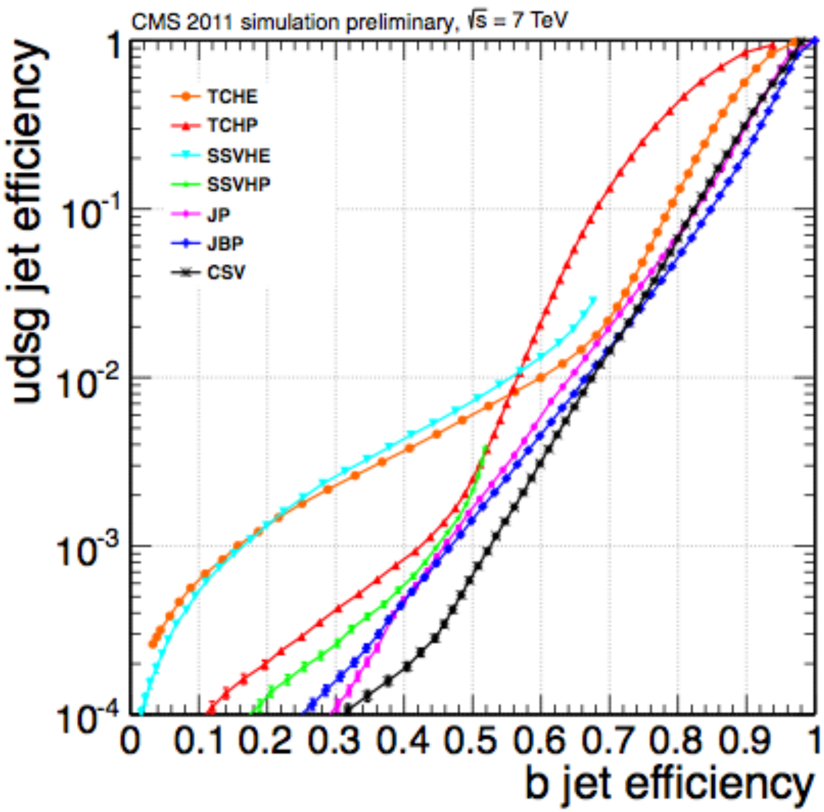
- Major part of energy is carried by charged hadrons (~65%) and photons
- Good agreement between data and MC simulation

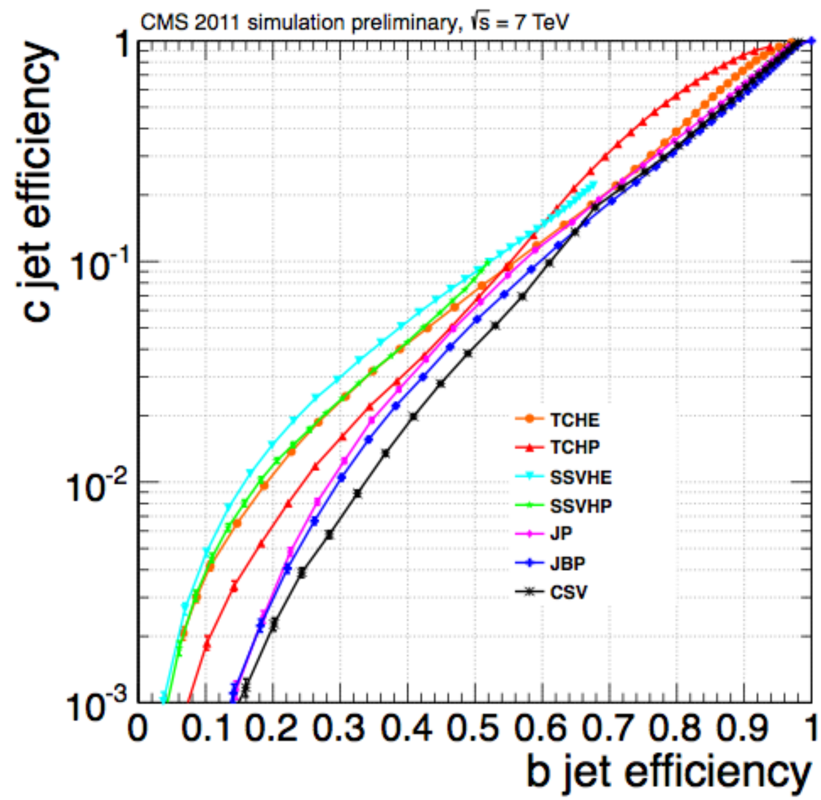
Jet p_T resolution



- Bias corrected data measurement, compared to the generator level MC pT resolution before and after correction for the discrepancy between data and simulation

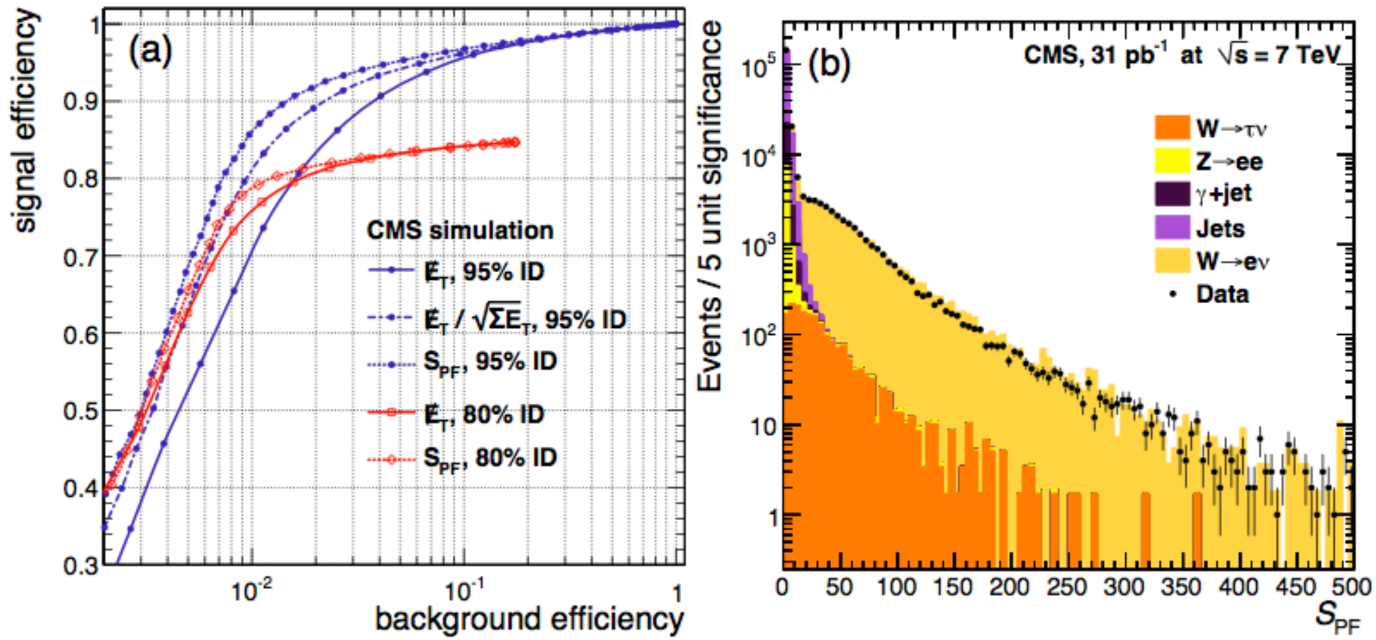
b-tagging performance





- Performance of different taggers
- Jet probability definition $$P_{jet} = \Pi \cdot \sum_{i=0}^{N-1} \frac{(-\ln \Pi)^i}{i!} \quad \text{with} \quad \Pi = \prod_{i=1}^{N} \max(P_i, 0.005)$$

MET significance



- MET significance is introduced obtained from event by event likelihood that MET is consistent with zero given reconstructed content of the event and measurement resolution
  - Insensitive to PU
  - Significantly improves rejection of backgrounds with low MET for the same signal efficiency e.g. W events