Systematics in charged Higgs boson searches in CMS

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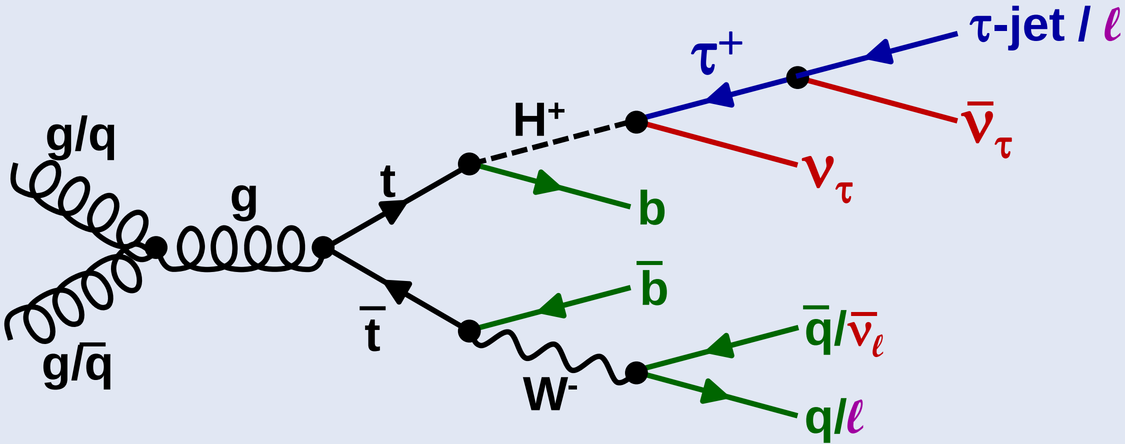
Uppsala, Sweden**

Sources of systematic uncertainties affecting charged Higgs boson searches

- Cross-section
- Luminosity measurement
- Lepton systematics
  - e/mu reconstruction
  - e/mu ID efficiency
  - e/mu fake rate
- Hadr. tau decay systematics
  - tau-jet energy scale
  - tau ID efficiency
  - tau fake-rate
- Jet/MET energy scale
- b-tagging
  - b-tag efficiency
  - b-mistag



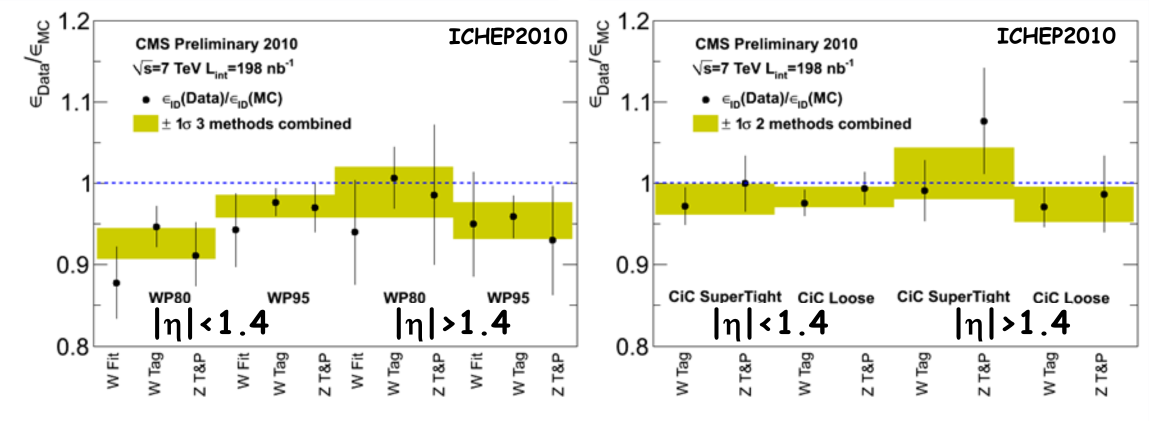
Charged Higgs boson searches are at the top of the food chain: need to consume the whole systematics "menu"!

The most important backgrounds will be measured from data to minimize the influence of the systematic uncertainties

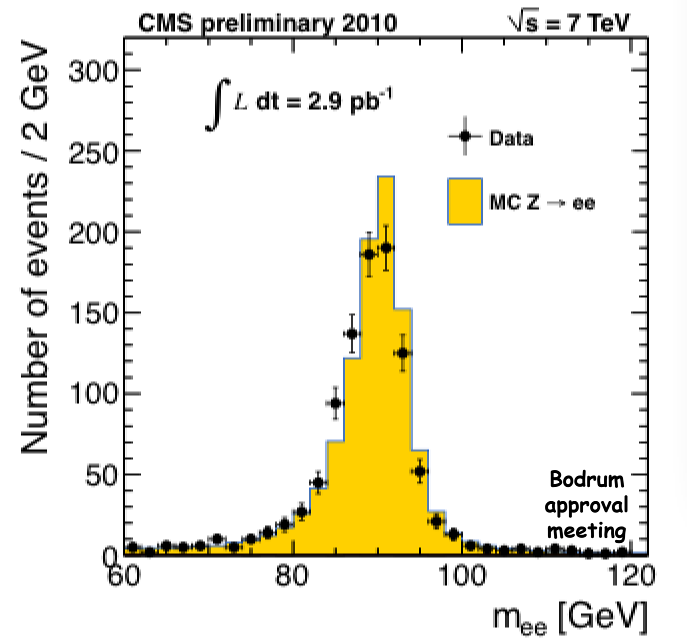
Electron identification systematics

ICHEP, $\int L=198\ \mathrm{nb}^{-1}$
CMS PAS EWK-10-002

- W and Z selections are used to measure electron ID efficiency for high p_T electrons
- Z→ee selection:
  - Tag: identified (isolated) electron
  - Probe: 1 em. calorimeter supercluster
  - Mass window $60 < M_{ee} < 120\ \mathrm{GeV}/c^2$
- From the Z→ee analysis one can estimate ~3 % for electron reconstruction and identification uncertainty



Electron selection efficiency ratio between data and MC for cut-based (left) and category-based (right) approach

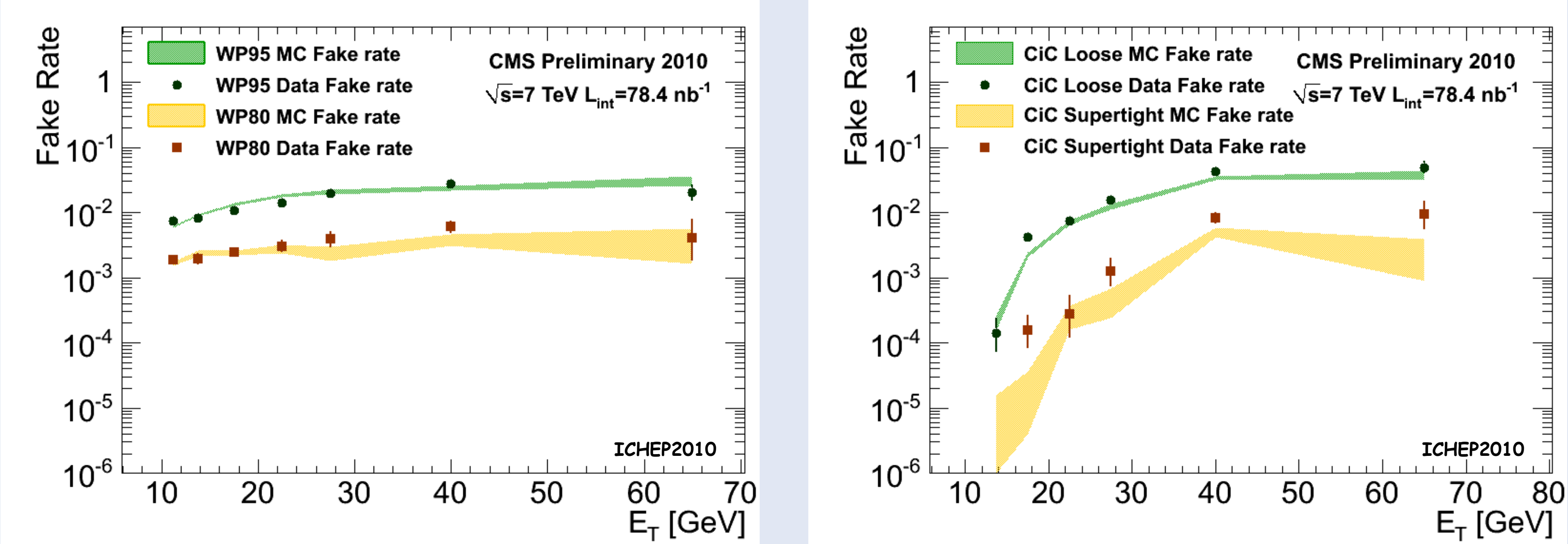


Invariant Z mass from Z→ee

Electron fake rate systematics

ICHEP, $\int L = 78\ \mathrm{nb}^{-1}$

- Event selection:
  - Single jet trigger with raw jet E_T>15 GeV
  - Require small MET in the event
  - Reconstruct electrons outside the jet that was triggered

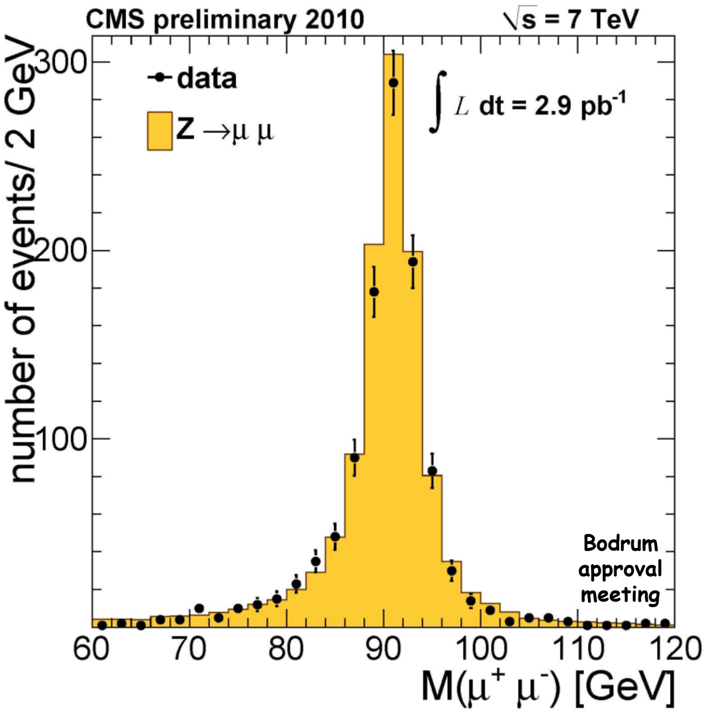


Electron fake rate per reconstructed electron as a function of E_T in data and MC for cut-based (left) and category-based (right) approach

Muon identification systematics

CMS PAS EWK-10-002
CMS PAS MUO-10-002

- Muon reconstruction and identification are studied with inclusive muons with $p_T > 15$ GeV/c
  - Evaluate matching of inner track with muon clusters
  - Evaluate matching of muon track with inner track
  - Evaluate identification cuts from MC
  - Results agree within a statistical uncertainty of 2.5-3 %
- Z mass peak in $Z \rightarrow \mu\mu$ decay:
  - Select two oppositely charged muons with $p_T > 20$ GeV/c
  - Require tight quality cuts from one muon (tag) and looser from the other (probe)
  - Require $60 < M_{\mu\mu} < 120$ GeV/c^2
- From the $Z \rightarrow \mu\mu$ analysis one can estimate ~3 % for the uncertainty of muon reconstruction and identification efficiency

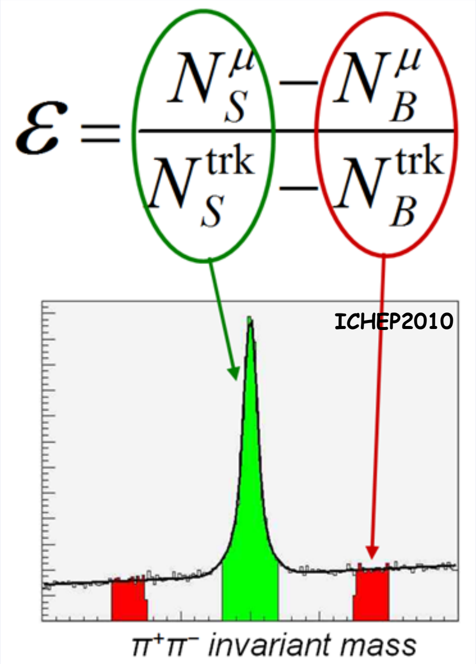


Invariant Z mass from $Z \rightarrow \mu\mu$

Muon fake rate systematics

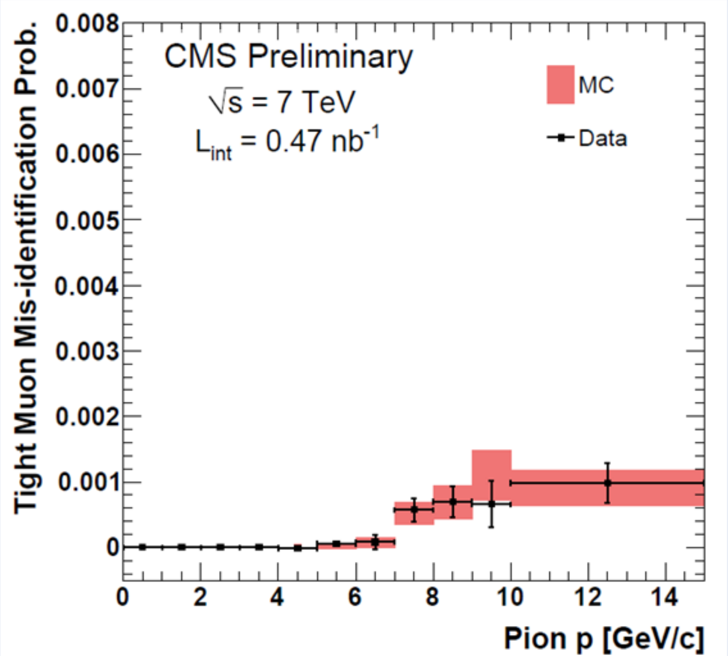
CMS PAS MUO-10-002
$\int L=0.47\ \mathrm{nb}^{-1}$

- Select π/K/p tracks from identified K_S, ϕ, and Λ resonances (MinBias trigger)
- Measure the probability for π/K/p → μ fake rate
  - Decay in flight and punch-through probability
  - Require tracker track to match with muon track; good track quality
- Data ($\varepsilon=1.0\pm0.2 \times 10^{-4}$) agrees well with MC ($\varepsilon=1.0\pm0.2 \times 10^{-4}$)



$$\mathcal{E}=\frac{N_S^{\mu}-N_B^{\mu}}{N_S^{\mathrm{trk}}-N_B^{\mathrm{trk}}}$$

Definition of the fake rate with sideband subtraction

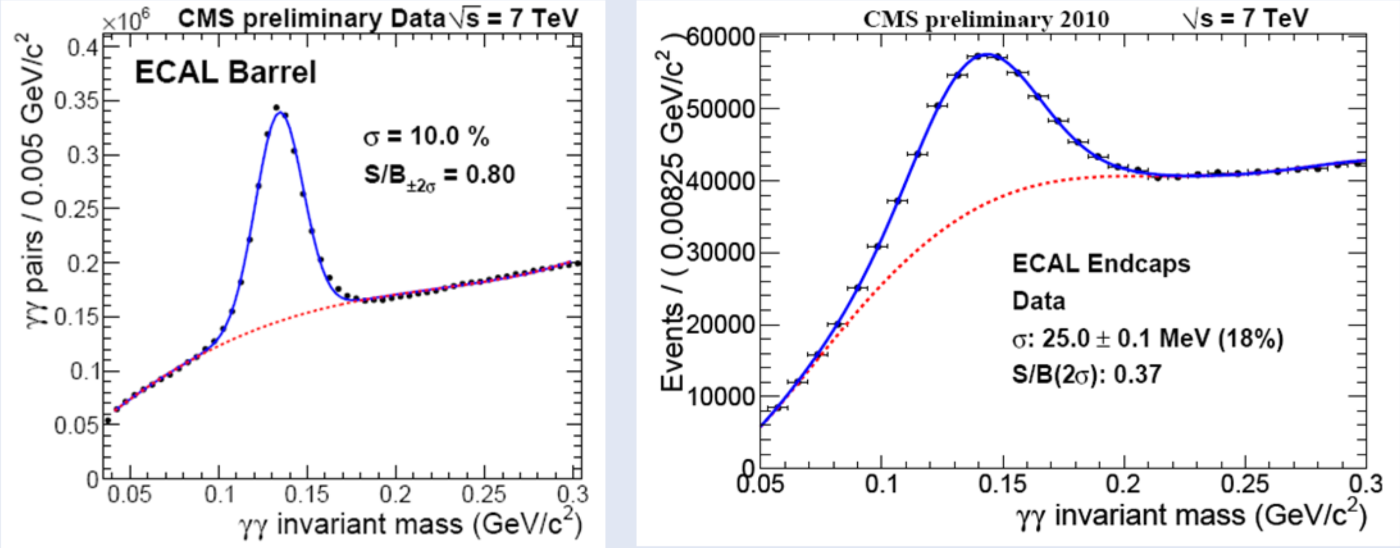


π→μ fake rate after background subtraction from sidebands

Electromagnetic energy scale

CMS PAS EGM-10-003
$\int L = 123\ \mathrm{nb}^{-1}$

- The energy scale is evaluated from π^0 and η decays
  - Absolute energy scale obtained from test-beam results
- Systematic uncertainty estimated from comparing the mass of π^0 and η obtained from data against MC
  - Evaluated separately for the barrel ($|\eta|<1.4$) and endcap ($|\eta|>1.4$) parts
  - Pseudorapidity cut: barrel 0.5 % / endcap 1.3 %
  - E_T cut variation: barrel 0.6 % / endcap 1.7 %
  - Energy corrections: barrel 0.4 % / endcap 0.5 %
  - Combined: barrel 0.9 % / endcap 2.2 %

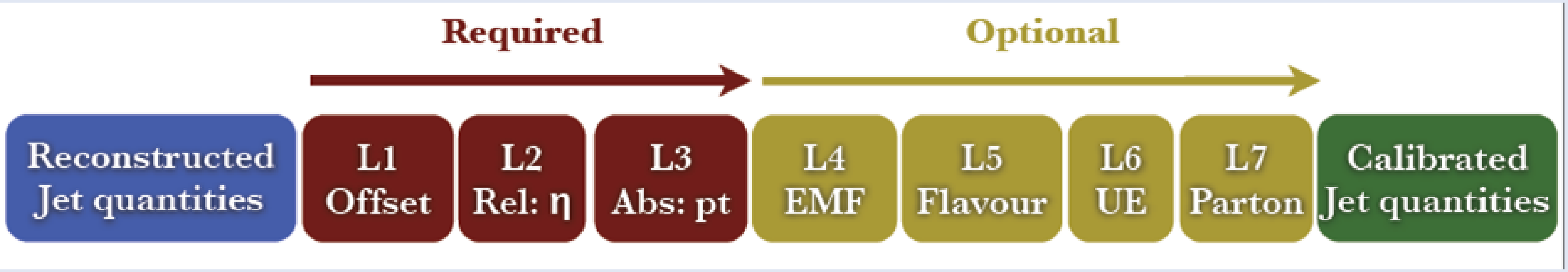


The reconstructed $m(\pi^0)$ from the data for $|\eta|<1.4$ (left) and $|\eta|>1.4$ (right)

Jet energy scale

CMS PAS JME-10-003
$\int L = 73\ \mathrm{nb}^{-1}$

- Three jet algorithms used (calorimeter jets, Jet-Plus-Track (JPT), and Particle-Flow (PF) jets)
  - all based on the anti-k_T clustering algorithm; typical cone size is 0.5
- Factorized jet energy scale approach used:



Required

Optional

Reconstructed Jet quantities

L1 Offset

L2 Rel: η

L3 Abs: pt

L4 EMF

L5 Flavour

L6 UE

L7 Parton

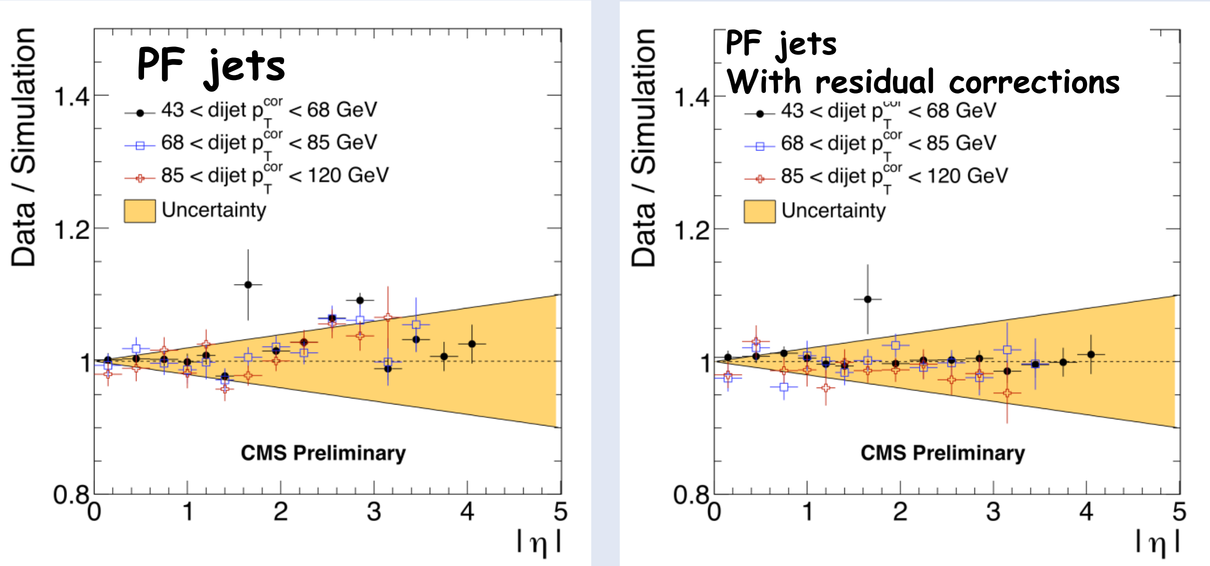
Calibrated Jet quantities

- Incremental improvements; allows for clear identification and understanding of systematics
- Two correction methods available:
  - MC-truth based (p_T^{reco} / p_T^{gen})
  - In-situ (di-jet p_T balance method)
  - Currently the majority of CMS physics analyses use MC-truth based approach
  - In-situ subcorrections will replace MC-truth based subcorrections one by one once they become available

Jet energy scale (II)

CMS PAS JME-10-003
$\int L = 73\ \mathrm{nb}^{-1}$

- Data vs. MC agreement can be improved by applying residual corrections
- Current CMS physics analyses use as jet energy scale uncertainty
  - 10 % + 2 % x $|\eta|$ for calorimeter jets (obtained from MC)
  - 5 % + 2 % x $|\eta|$ for JPT and PF jets (obtained from MC)
- Absolute scale will be obtained from γ+jet events once enough data is available; first look indicates that the taken uncertainty is quite conservative

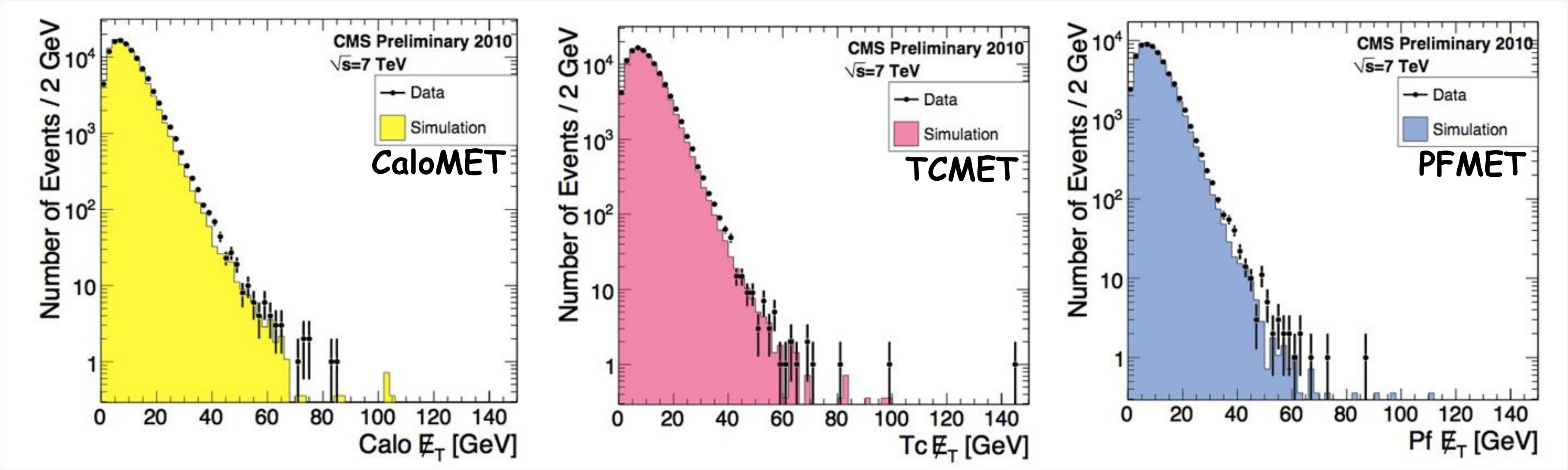


Data vs. MC ratio of relative calorimeter response for MC-truth corrected PF jets. Residual corrections have been applied in the right plot.

Missing E_T scale

CMS PAS JME-10-004
$\int L = 11.7 nb^{-1}$

- Event selection:
  - Inclusive di-jets (p_T>25 GeV/c and $|\eta|$<3)
- Three MET algorithms evaluated
  - Calorimeter jet based type II corrected MET (CaloMET)
  - Track-corrected MET (TCMET)
  - Particle Flow MET (PFMET)
- Conservative estimate of systematic uncertainty ~10 %

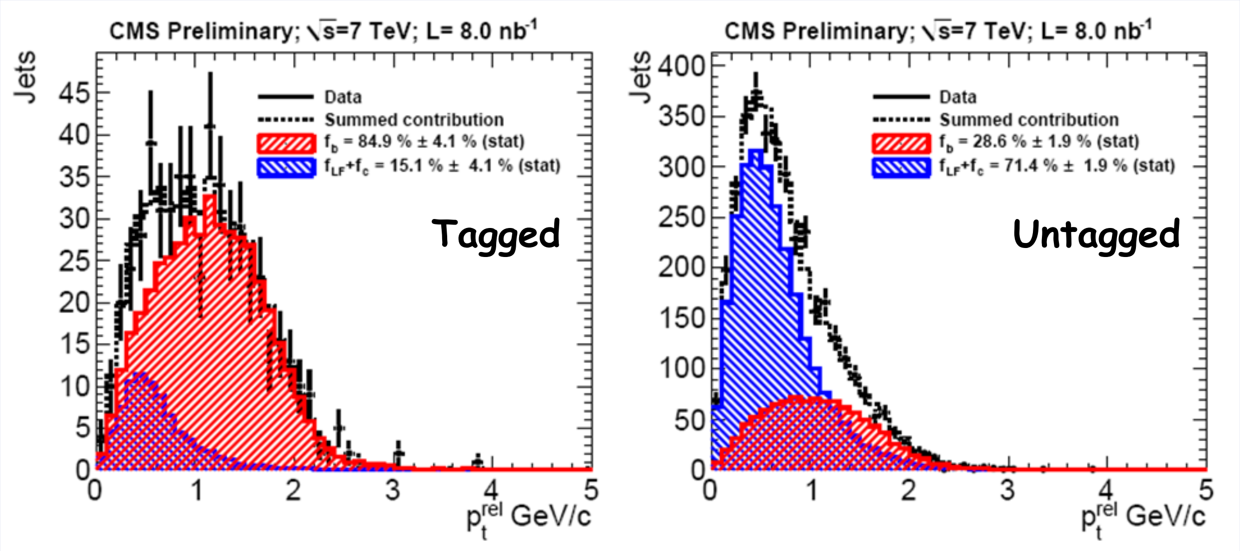


MET distributions for data and MC for calorimeter MET (left), track-corrected MET (middle), and particle flow MET (right)

b-tagging efficiency systematics

CMS PAS BTV-10-001
$\int L = 8\ \mathrm{nb}^{-1}$

- Event selection for b-tagging efficiency measurement:
  - Require jet $p_T > 30$ GeV/c
  - Require one muon ($p_T > 5$ GeV/c) in the event
  - b-tagging algorithm: impact parameter or secondary vertex based
  - Require matching of the muon to good tracks in b-jet
- Efficiency measurement method:
  - Construct templates based on muon p_T^{rel} for b-jets and for light+charm jets
  - Apply maximum likelihood fit to events that have passed/not passed the b-tag to obtain fraction of b-jets and non-b-jets
  - Calculate efficiency from the fractions
- Systematic uncertainty of 19 % obtained for most b-tagging working points



Fit of the muon p_T^{rel} distributions to b- and udsc-templates for events that pass (left) or fail (right) the b-tagging algorithm TCHPM

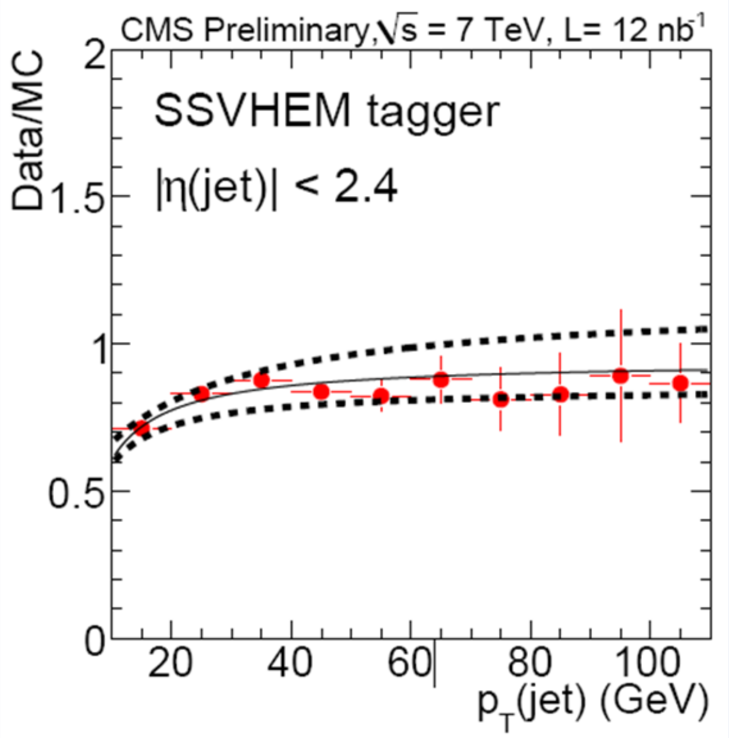
b-mistag systematics

CMS PAS BTV-10-001
$\int L=12\ \mathrm{nb}^{-1}$

- The b-mistag rate is evaluated from tracks with negative impact parameter or from secondary vertices with negative decay lengths

  $\varepsilon^{\text{mistag}} = \varepsilon^{\text{neg. tags}} * \varepsilon^{\text{MC mistag}} / \varepsilon^{\text{MC neg. tags}}$

- Sources of systematic uncertainty for $\varepsilon^{\text{MC mistag}} / \varepsilon^{\text{MC neg. tags}}$:
  - b- and c-fractions: ±20 % (rel.)
  - gluon fraction (PDF): ±20 % (rel.)
  - Long lived K^0_S and Λ decays: ±10-20 % (rel.)
  - Photon conversions and nuclear interactions: ±5 % (rel.)
  - Mismeasured tracks: ±50 % (rel.)
  - Sign flip: 0.5-2 % (abs.)
- Systematic uncertainty for mistagging found to be: 3 % / 6-12 % / 40-60 % for operating point of 10 % / 1 % / 0.1 % of light flavors passing the b-tag

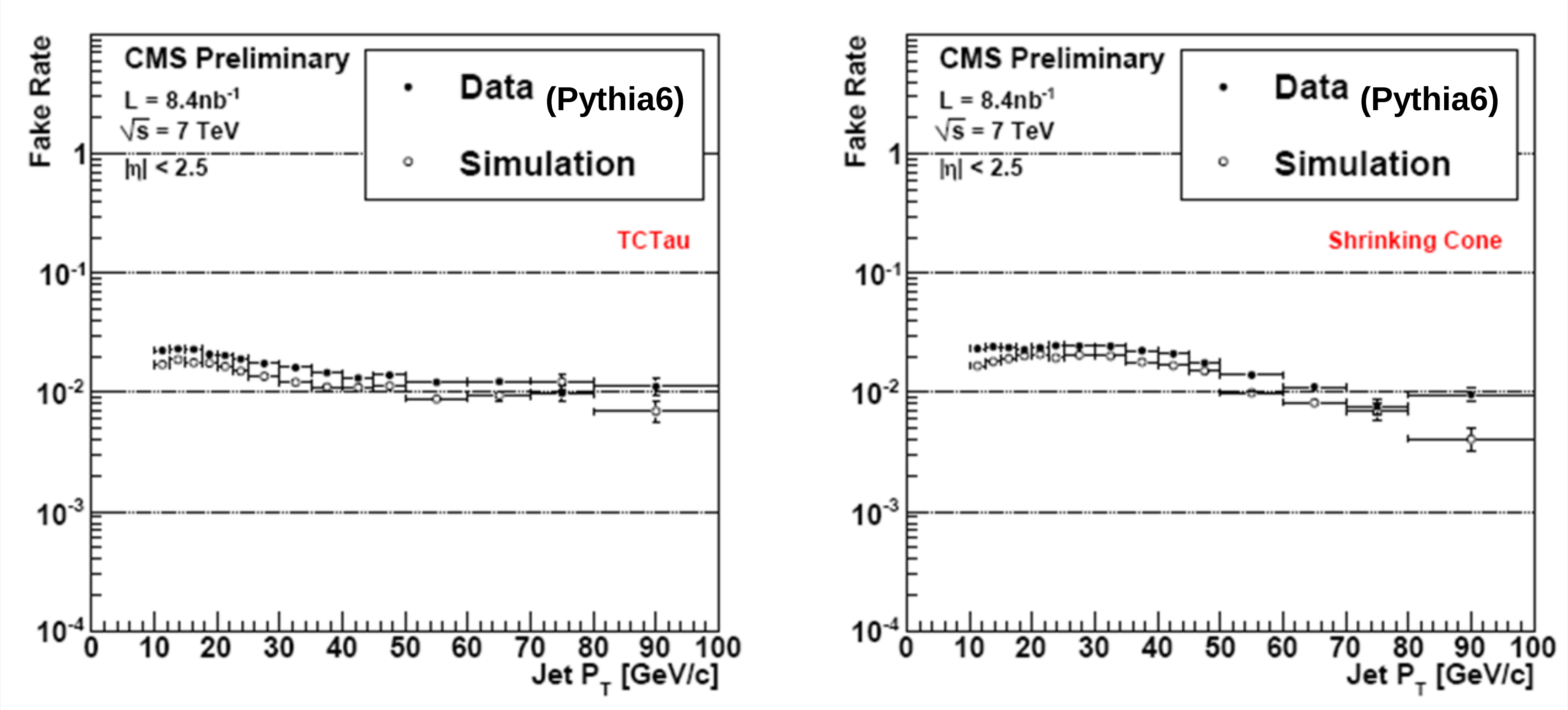


Mistag rate comparison between data and MC for secondary vertex based b-tagging

Systematics on tau jets

CMS PAS PFT-10-004
$\int L = 8.4\ \mathrm{nb}^{-1}$

- No study published so far quotes systematics for tau jets
- Based on the jet→tau fake rate study, 20-40 % disagreement found between MC and data
  - Not a problem, since the fake rate will be measured from the data

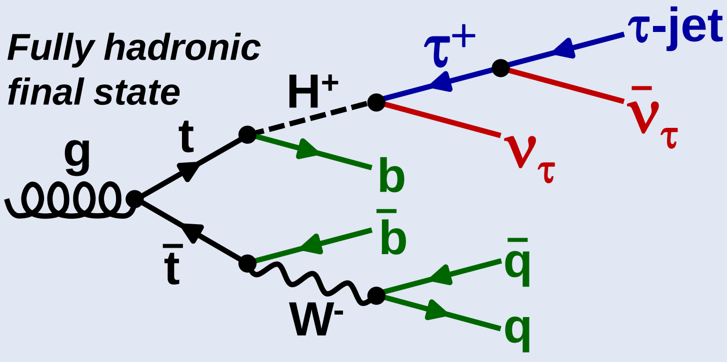


Probability of a quark/gluon jet to pass the tau candidate selection criteria of the TCTau (left) and shrinking cone Particle Flow (right) algorithms

QCD multi-jet background measurement for the fully hadronic final state

Planned/work in progress

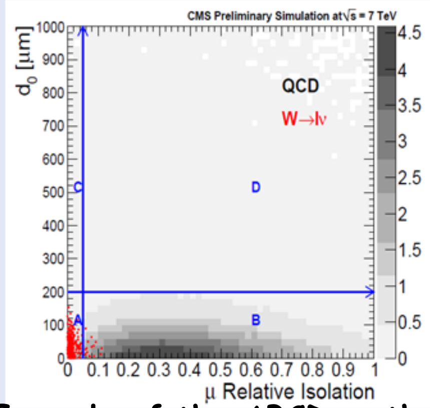
- Measurement strategy:
  - Require Tau20Trk15 + MET20 trigger
    - QCD multi-jets still dominate after this requirement
  - Take as offline tau jet the jet that matches with the HLT object
  - Apply jet→τ fake rate
    - Obtained from single jets
  - Apply rest of event selection and correct for bias from ttbar / W+jets events (bias evaluated with MC)
- See Alexandros' talk for more details



QCD multi-jet background measurement for the τ-jet + lepton final state

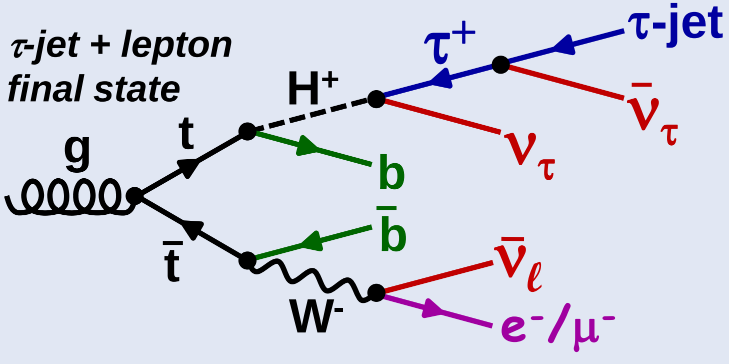
CMS PAS TOP-10-004
$\int L = 78\ \mathrm{nb}^{-1}$

- Data-driven methods that can be used independently:
  - The ABCD method
    - Exploits two uncorrelated variables (e.g. μ isolation and d_0) to evaluate number of background in the signal area ($N_A/N_B = N_C/N_D$)

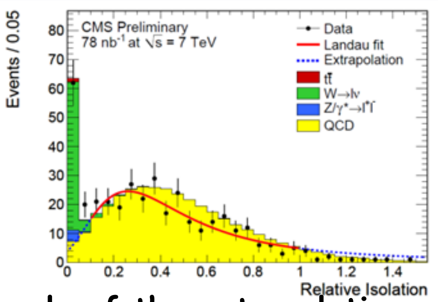


Example of the ABCD method

τ-jet + lepton final state

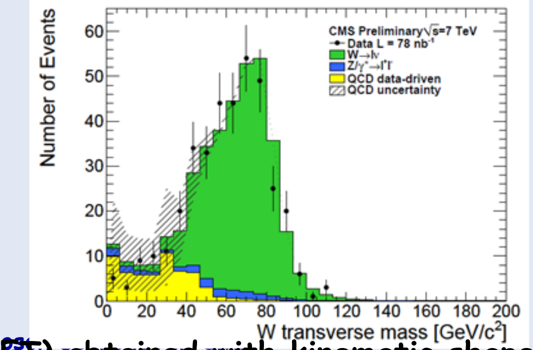


  - Extrapolation method
    - Obtain shape of variable (e.g. μ isolation) and extrapolate it to signal area



Example of the extrapolation method

  - Kinematic shape modelling method
    - Obtain the shape with the extrapolation method and the normalization from the ABCD method

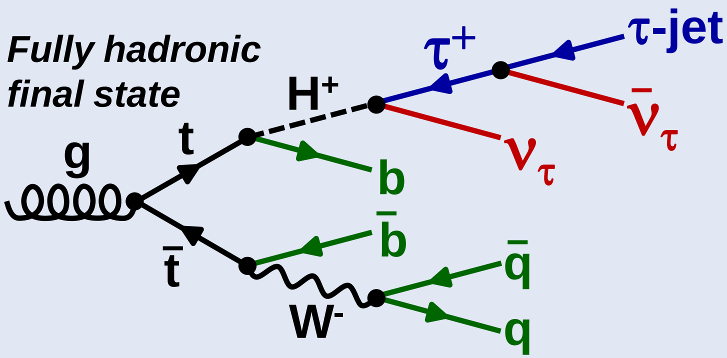


$M_T(\mu,\mathrm{MET})$ obtained with kinematic shape modelling

Electroweak backgrounds measurement: fully hadronic final state

Planned/work in progress

- The hadronic ttbar and W+jets backgrounds can be measured from data with the μ+jet events by replacing the reconstructed muon with a simulated τ jet (embedding)
  - Such approach removes the jet energy scale uncertainty from the systematics

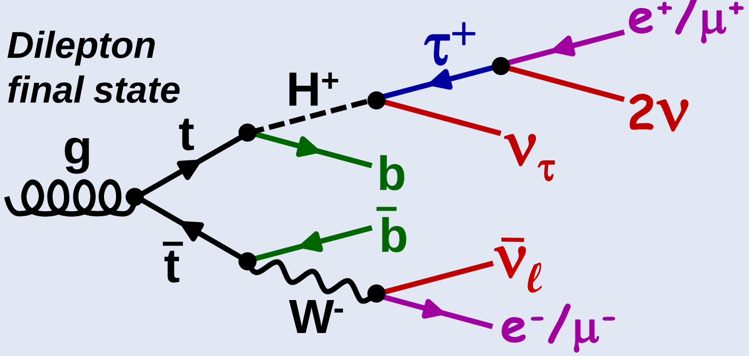


- Event selection:
  - require one isolated muon
  - require veto on other muons and isolated electrons
  - apply cut on MET
  - require at least 3 hadronic jets
- No mass requirements → no need to separate the ttbar and W+jets events

$Z/\gamma^* \rightarrow ee$ or $\mu\mu$ background measurement for the di-lepton final state

- Measurement strategy:
  - Use standard dilepton event selection, but require that the invariant mass is within 15 GeV/c^2 of the Z mass
  - Obtain from MC the ratio of Z/γ^* events outside and inside the Z mass window
  - Apply correction for non-Z/γ^* events within the Z mass window

CMS PAS TOP-10-004
$\int L = 78\ \mathrm{nb}^{-1}$



- Obtained number of Z/γ^* outside the Z mass window:

$$N_{\mathrm{out}}^{ee,\mathrm{data}} = \underline{R^{ee}_{\mathrm{out/in}}} \left(N_{\mathrm{in}}^{ee,\mathrm{data}} - \underline{0.5 N_{\mathrm{in}}^{e\mu,\mathrm{data}} k_{ee}} \right), \quad k_{ee} = \sqrt{\frac{N_{\mathrm{in}}^{ee,\mathrm{loose}}}{N_{\mathrm{in}}^{\mu\mu,\mathrm{loose}}}},$$

Ratio of Z/γ^* events outside and inside the Z mass window

Term for taking into account non- Z/γ^* events inside the Z mass window

- *A conservative estimate of the systematic uncertainty of this method is 50 %*
  - Detector calibration effects and change of R when selections are tightened

Summary

• Cross-section uncertainties		
– ttbar cross-section	16 %	
– W/Z + jets cross-sections	100 %	estimate
– QCD multi-jet cross-sections	100 %	estimate
• Luminosity measurement	11 %	EWK-10-004
• Underlying event	10 %	QCD-10-010
• Electrons		
– reconstruction and identification efficiency	~3 %	ICHEP, 198 nb^{-1}
– fake rate	~5 %	ICHEP, 78 nb^{-1}
• Muons		
– reconstruction and identification efficiency	~3 %	EWK-10-002, 198 nb^{-1}
– fake rate	negligible	MUO-10-002, 0.47 nb^{-1}
• Electromagnetic calorimeter energy scale	0.9/2.2 %	EGM-10-003, 123 nb^{-1}
• Jet energy scale	5-10 %	JME-10-003, 73 nb^{-1}
• Missing E_T	~10 %	JME-10-004, 11.7 nb^{-1}
• tau-jets energy scale	n.a.	to be determined
• tau-jet reconstruction and identification efficiency	~10 %	estimate
• jet→tau fake-rate	20-40 %	PFT-10-004, 8.4 nb^{-1}
• b-tagging		
– b-tagging efficiency	19 %	BTV-10-001, 8 nb^{-1}
– b-mistag rate	3-60 %	BTV-10-001, 12 nb^{-1}

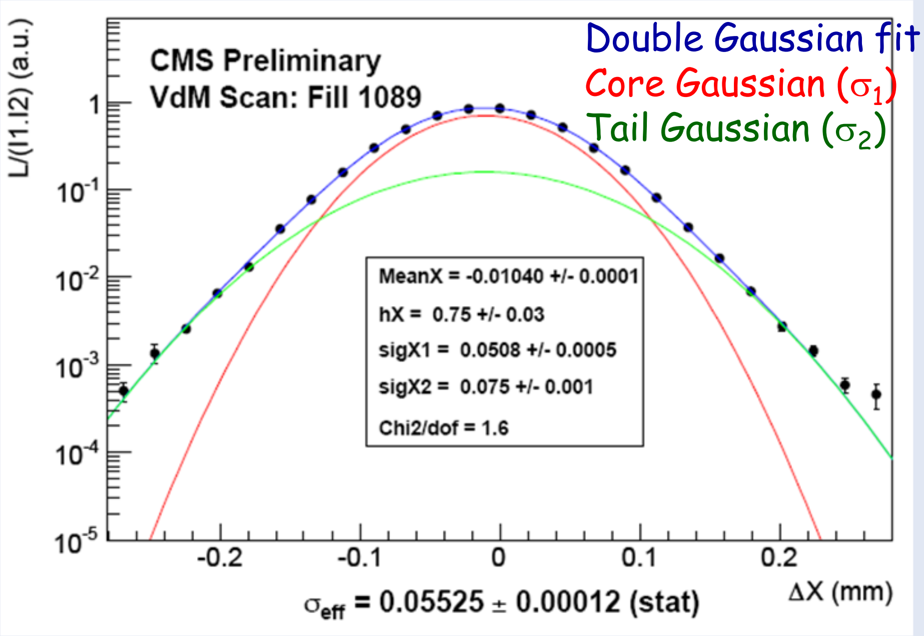
- Work ongoing on background measurements from data

BACKUP SLIDES

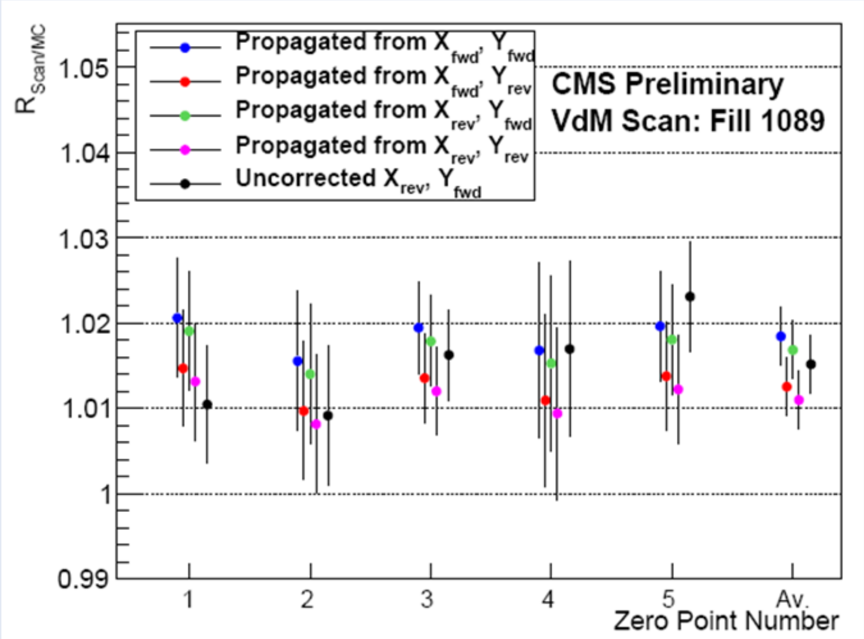
Luminosity measurement systematics

CMS PAS EWK-10-004

- The size and shape of the interaction region are measured by recording the relative interaction rate as a function of the transverse beam separations (S. Van der Meer scans).
- The beam intensities are measured with Fast Beam Current transformers (measure current in each 25 ns bunch)



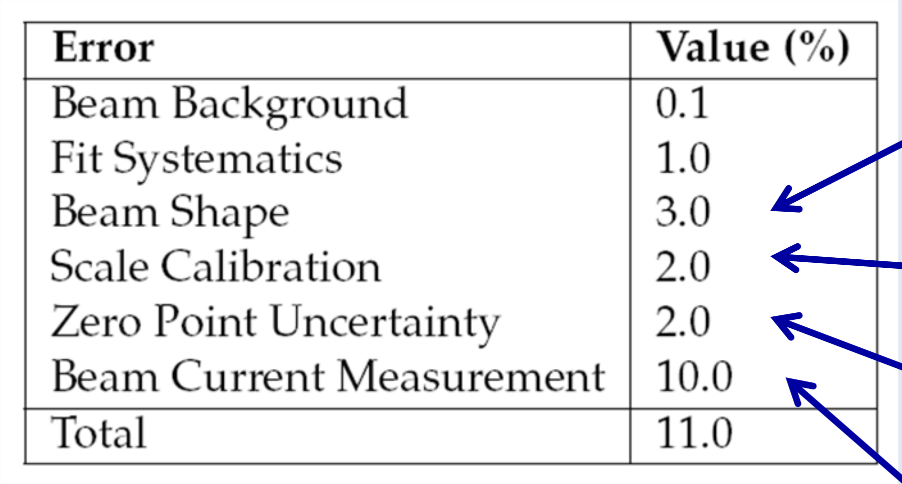
Van der Meer scan results in x direction



Calibration relative to MC normalization at five central zero points (i.e. points where the beam offsets were set to zero)

Luminosity measurement systematics (2)

CMS PAS EWK-10-004



Error	Value (%)
Beam Background	0.1
Fit Systematics	1.0
Beam Shape	3.0
Scale Calibration	2.0
Zero Point Uncertainty	2.0
Beam Current Measurement	10.0
Total	11.0

Systematic errors on the 2010 CMS calibration scan measurements using the Van der Meer method.

Double gaussian might not describe accurately the actual beam shape. Estimated by replacing the double Gaussian fit with a spline fit.

Inaccuracy of methods to determine the beam offsets

Variation of the beam size (emittance growth) during the scans

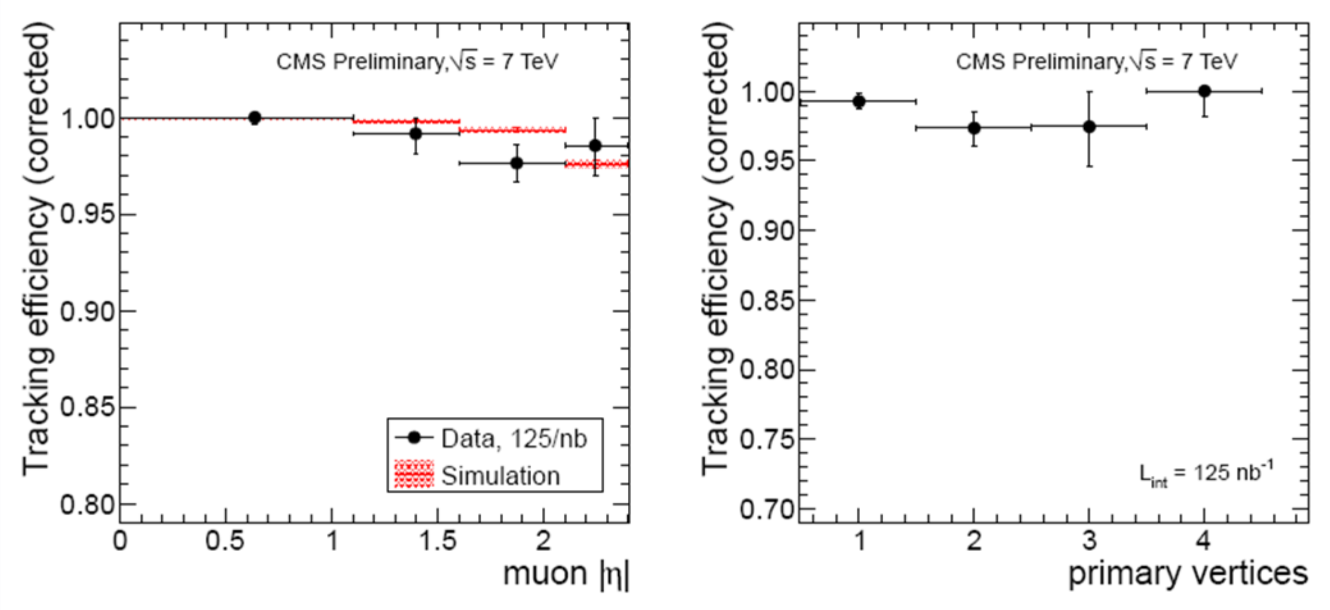
RMS error of 5.0 % per beam; conservatively assumed to be non-correlated.

- Systematics on the beam current measurement are assumed to decrease as the LHC beam currents increase
- Additional scans and better understanding of the error sources is expected to decrease other sources of systematics

Tracking efficiency systematics of isolated muons

CMS PAS TRK-10-002
$\int L = 125\ \mathrm{nb}^{-1}$

- Tag and probe with isolated muons from J/ψ events
  - Tag muons: global muons passing HLT_Mu3
  - Probe muons: muons reconstructed from muon chambers only
  - Match condition: $\Delta\eta < 0.2$ and $\Delta R < 0.5$
- Tracking efficiency defined as: true tracking eff. x matching eff.
- Comparison between data and MC yields 1-2 % as systematic uncertainty



Corrected tracking efficiency as a function of η (left) and as a function of the number of reconstructed primary vertices (right)

Tracking efficiency systematics of non-isolated muons

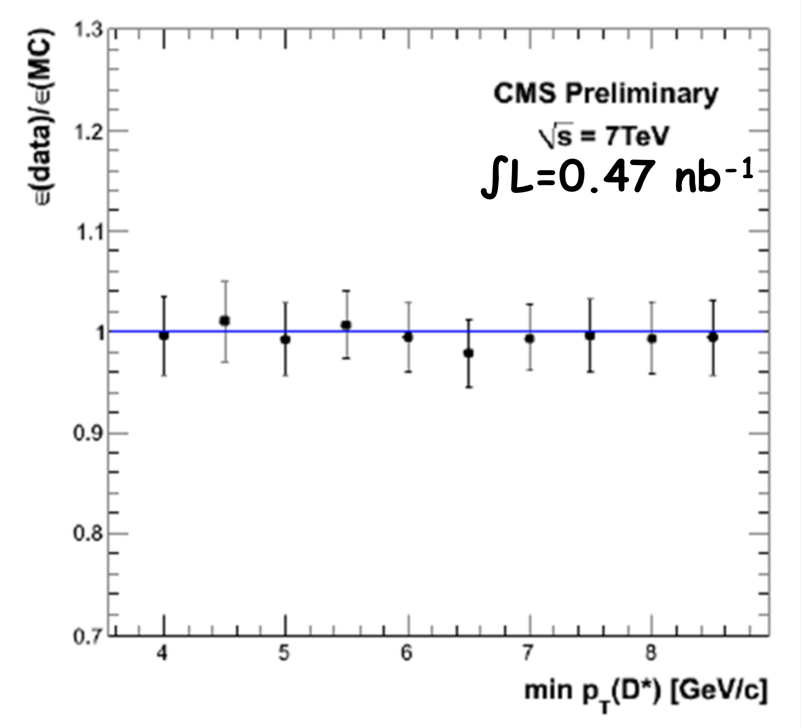
CMS PAS TRK-10-002
$\int L=9\ \text{nb}^{-1}$

- Selection method (choose b- or c-jets with muons):
  - MinBias trigger
  - Require a good quality muon recoed in the muon stations, $p_T > 5$ GeV/c
  - Require at least two PF jets with $E_T > 10$ GeV/c
    - Require one jet to be within $\Delta R < 0.4$ of the muon
    - Require the other jet to pass b-tagging and to be separated $\Delta R > 1.5$ of the muon
- The muon is matched to a good quality track from the tracker
- Tracking efficiency is calculated from passing/failing the muon matching
- Tracking eficiency is corrected for the presence of light quarks and gluons
- Systematic uncertainty estimated with pseudo-experiments as 5.3 %
  - Tracking efficiency of muons from b or c decays assumed to be equal
  - Systematics for muons from light flavored jets estimated to be slightly lower

Tracking efficiency systematics of charged pions

CMS PAS TRK-10-002
$\int L=0.47\ \mathrm{nb}^{-1}$

- Measurement is based on comparing the production rate of $D^0 \rightarrow K^-\pi^+\pi^-\pi^+$ and $D^0 \rightarrow K^-\pi^+$ decays in the $D^{*+} \rightarrow D^0\pi^+$ chain
  - $\varepsilon_{data}/\varepsilon_{MC} = \mathrm{sqrt}(R/R_{PDG})$, where $R = N_{K3\pi}/ N_{K\pi} * \varepsilon_{K\pi} / \varepsilon_{K3\pi}$
- Event selection:
  - Select tracks with $p_T > 300$ MeV/c compatible with the primary vertex
  - Find 4/2 tracks that form a secondary vertex with positive decay length; find also the track of the "slow pion" from the D^{*+} decay
  - Reconstruct D^0 and D^{*+} masses
  - Require $|M(D^0) - M(D^{*+})| < 159$ MeV/c^2
  - Require $M(K^-\pi^+\pi^-\pi^+)$ ($M(K^-\pi^+)$) to agree within 10 (25) MeV/c^2 of the PDG value
- Tracking efficiency systematics evaluated by varying the br. fraction and efficiency uncertainty of the 6 subdecay modes
- Obtained uncertainty: 1.4 % (includes 0.5 % from template shapes)



The ratio of tracking eff. in data and MC as a function of the minimum pT of the D* candidate