QCD backgrounds in charged Higgs searches

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for the CMS Collaboration

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- Summary

Introduction

- QCD Multi-Jet production is:
  - of great importance in **$H^{\pm}$ searches** as it constitutes significant background
    - $\Rightarrow$Need Event Selection that **suppresses** QCD background
  - challenging to predict due to **large** & **poorly known** cross-section.

- Suppression of **QCD backgrounds** not enough due to**:**
  - **fake Tau-jets** and..
  - **fake-MET**, resulting primarily from **jet resolution effects**

  which can allow QCD Events to pass the Signal Event selection.

$\Rightarrow$Must control both **Fake Tau-jet Rates** and **MET tails.** To do this need:

- Data-driven methods to **estimate QCD background** in **signal region**

τ-Jet ID algorithms

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- Commissioning of the algorithms for RECO and ID of **τ-Jets @ 7TeV :**
  - **Efficiencies** using MC
  - **Fake-Rates** using MC & Data
- Algorithms studied:
  - **Simple algos** (cone-based) : **TCTau** , **PF Shrinking Cone**
  - **Complex algos** (constituent-analysing) : **TaNC** , **HPS**
- **TCTau:** a cut-based τ-Jet algorithm that uses Tracker to correct Energy + direction from Calo.
- **PF Shrinking Cone:** uses a **signal cone** that shrinks as a function of jet E_T **($\Delta R_{signal} = 5.0/E_T^{PF\text{-}Jet}$)**
- **TaNC:** A **multivariate** Tau-ID algorithm based on **Neural Networks (NN)**
- **HPS:** Based on charged hadrons and neutral EM objects (photons) & aims for optimised π^0 reconstruction

τ-Jet ID algorithms Efficiencies

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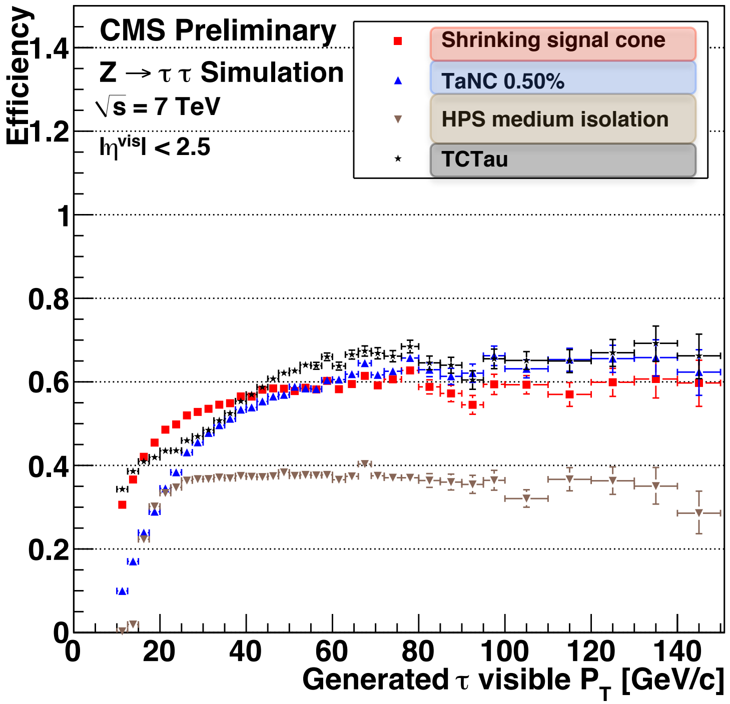
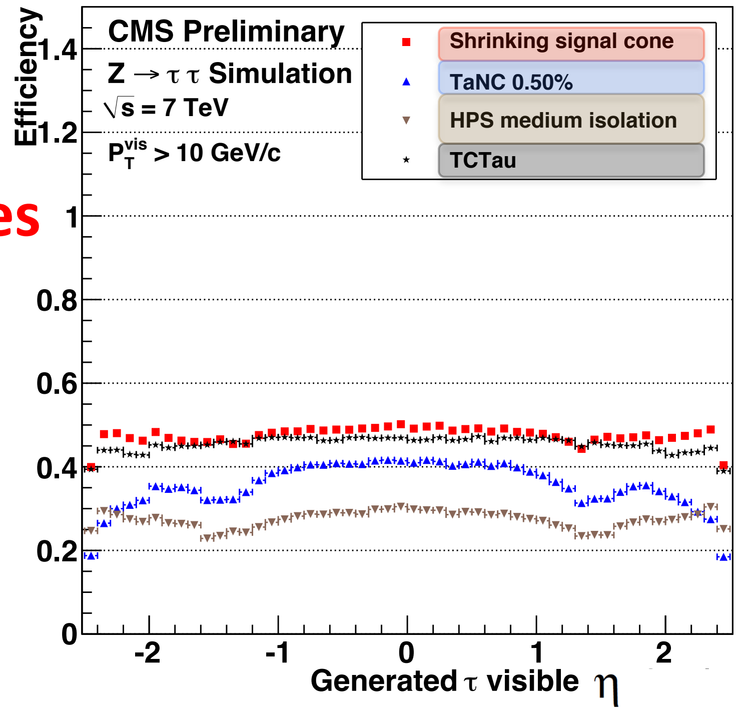
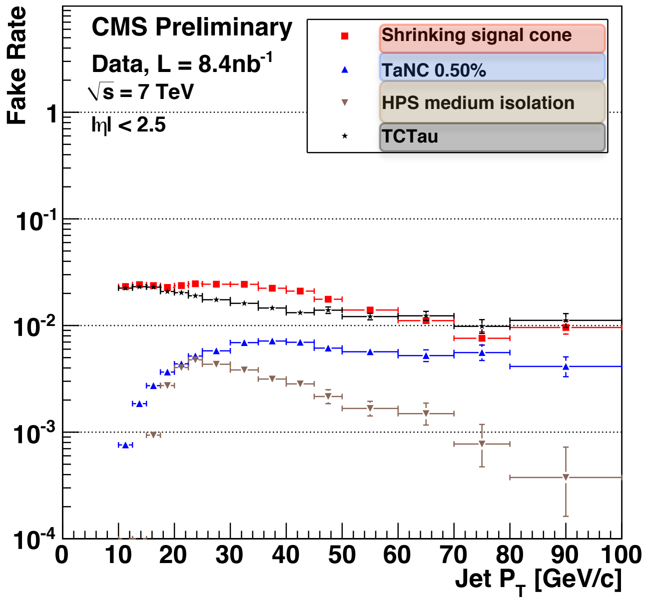


MC Efficiencies @ 7TeV



- **Efficiency** determined from τ-leptons (decaying hadronically) selected at **GEN Level:**
  - using a sample of simulated $Z \rightarrow \tau^+\tau^-$ events
- **strong p_T dependence**
  - Fast rise at **low p_T**, reach plateau **at hight p_T** (for both “classes” of algos)
- **flat in η** (efficiency slightly higher for **central jets)**
- Efficiency of all algorithms to be **investigated with data** and **compared** with all physics analyses (**~100 pb^{-1}**)

τ-Jet ID algorithms
Fake-Rates



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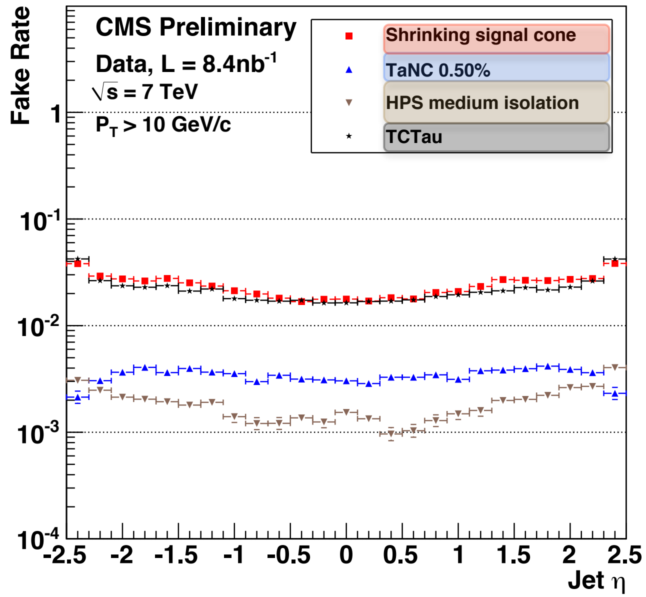
Fake-Rates

Data @ 7TeV

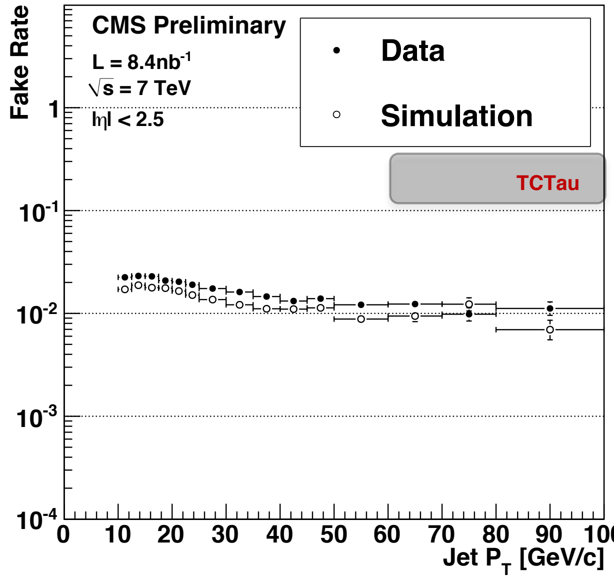
- **QCD Multi–Jet** data
- parametrized with **jet p_T** and **η**.
- **Probability** a jet "**fakes**" **τ-jet**:

$$(\mathrm{P}_{\mathrm{fake-rate}})_{\mathrm{bin}} = \left(\frac{\mathrm{N_{jets}\ passed}\ \tau-\mathrm{ID}}{\mathrm{N_{jets}}}\right)_{\mathrm{bin}}$$



- Fake-Rates are have **strong p_T dependence** & are **flat in jet η** :
  - The **PF Shrinking Cone** & **TCTau** have **better** performance at **high p_T**
  - The **HPS** & **TaNC** rise steeply at **low p_T**. **HPS** falls sharply at **high p_T**
- The Fake-Rate & Efficiency of **complex algos** depend on working–point. "Medium tight selection criteria":
  - **HPS** **≈0.2% Fake-Rate** for ≈27% efficiency
  - **TaNC** **≈0.3% Fake-Rate** for ≈36% efficiency
- **Simple algos** have very similar Fake-Rates & Efficiencies: **≈2.0% Fake-Rate** for ≈45% efficiency

τ-Jet ID algorithms Fake-Rates



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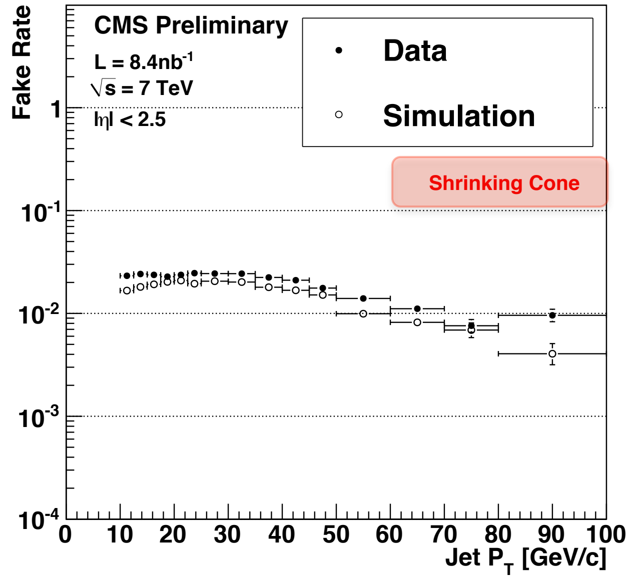
Fake-Rates

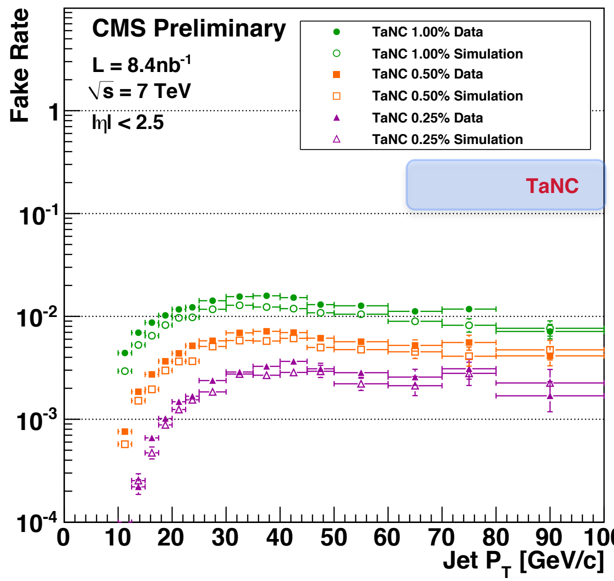
MC Vs Data @ 7TeV

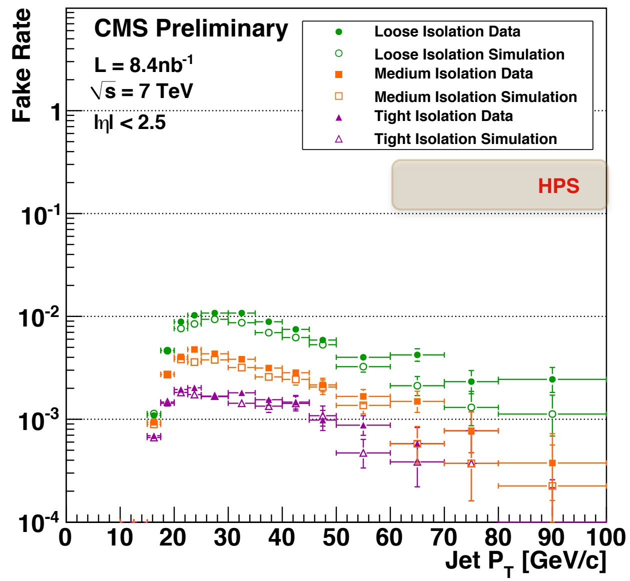
● ■ ▲ = Data @ 8.4 nb^{-1}

○ □ △ = Simulation PYTHIA 8.135



- MC predictions systematically **underestimate** the fake-rates
- Preliminary studies suggest **"modelling of hadronisation processes in the MC generator"** might be the reason.
- **Under investigation** to what extent different **PYTHIA tunes** affect the MC **Fake-Rates**.

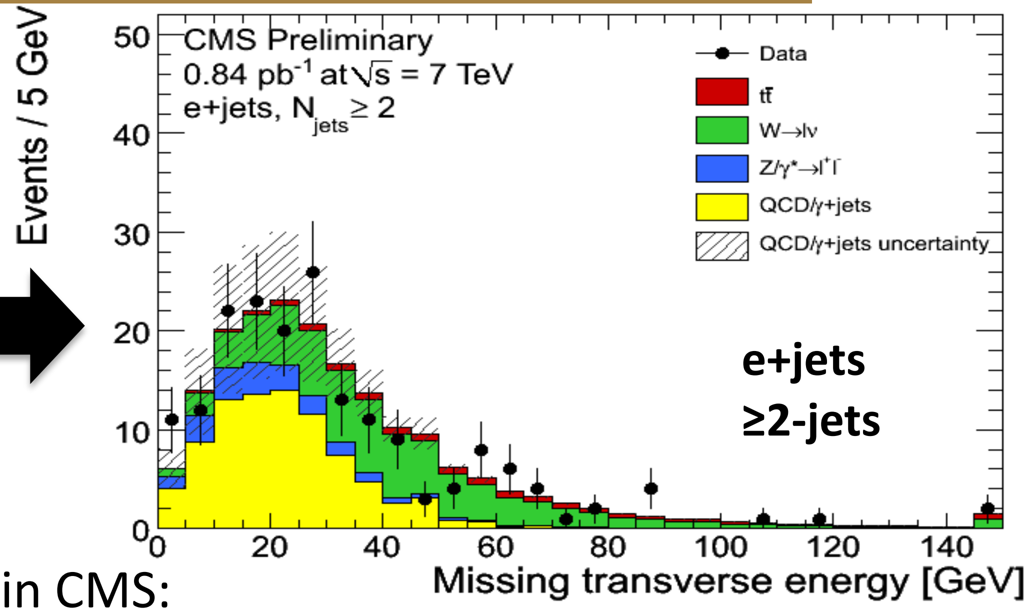




Data-driven methods for estimating QCD Multi-Jet background

- **Generic QCD bkgs** significant in TTbar:
  - Jets faking e⁻ in **e+jets final state**
  - muons in hadronic jets from heavy flavours in **μ+jets final state**

- Expect similar contributions for **lepton +jets** **final state in H± searches**
  - lepton + **≥2 jets** starting point



Data-driven methods investigated so far in CMS:

- **TTbar “lepton+jets”** studies (can be used in **H±** by replacing lepton with the tau-Jet)
  - **Fake-Rate Application**
  - Extrapolation methods using **Relative Isolation**
  - Fits to discriminating variables using a **Template Fitting** method
- **SUSY** studies
  - Extrapolation methods using **kinematical variable α_T**

Fake-Rate Application: $t\bar{t}$ "lepton+jets" channel

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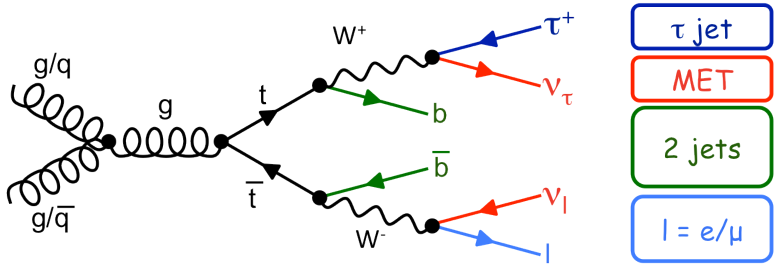
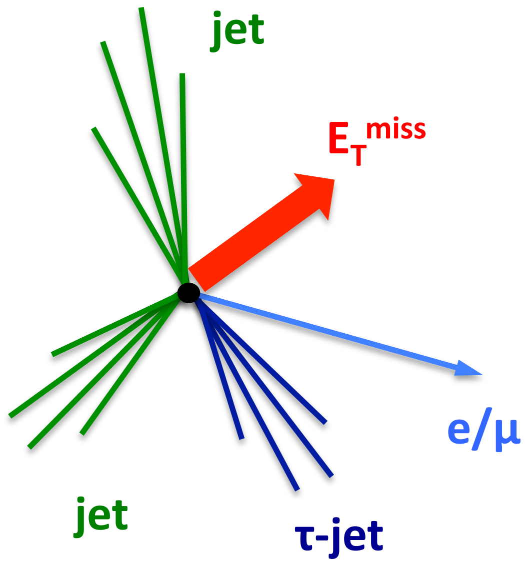
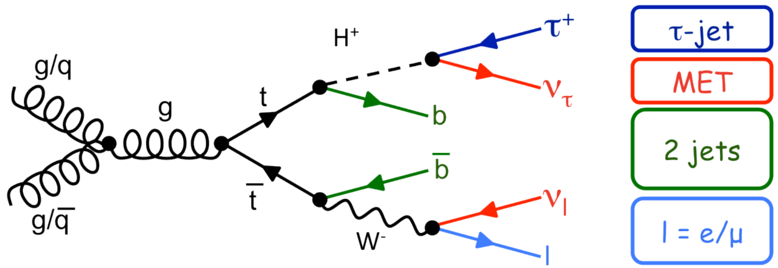
- Recent TTar studies have investigated strategies to estimate backgrounds due to:
  - QCD, W+Jets, TTbar with W→ l ν , W→q q
- **Fake-Rates** have been used to estimate **Multi-Jet Backgrounds** for **TTbar "lepton +jets"** Events: $t\bar{t} \rightarrow (l\nu)\,(\tau\nu_\tau)\,b\bar{b} \quad , \quad (l = e/\mu)$





- This channel is of particular interest for **H± searches**:



  - if $\mathbf{m_{H\pm} < m_t}$ exists, expect **anomalous** τ-lepton production due to $t\bar{t} \rightarrow W^{\mp}\bar{b}H^{\pm}b$

⇒Same strategies can be used for **H± Searches** in the **"lepton+jets" final state**

Fake-Rate Application: $t\bar{t}$ "lepton+jets" channel

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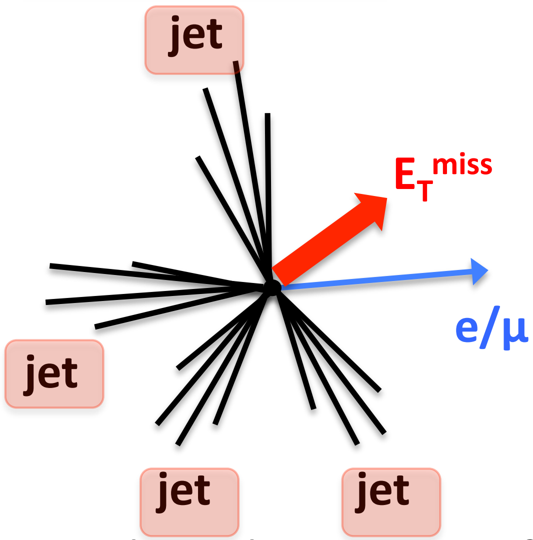
- Estimated the number of expected Events in **Multi-Jet** and **γ+Jets** samples.
- The **QCD Multi-Jets** and **γ+jets** samples were **normalised** to: $\int \mathcal{L}\,\mathrm{dt} = 100\,\mathrm{pb}^{-1}$
- Method used:

1. Calculate **τ-Jet Fake-Rate** & parametrise with **jet p_T**: $\left(\mathrm{p}^{\mathrm{fake}}\right)_{\mathrm{bin}} = \left(\frac{\mathrm{N}_{\mathrm{jets}}^{\tau-\mathrm{ID}}}{\mathrm{N}_{\mathrm{jets}}}\right)_{\mathrm{bin}}$
2. Apply **Fake-Rate** to each jet in Event & sum up to get an **Event Weight**



$$\mathrm{N}_{\mathrm{fake}}^{\mathrm{Evts}} = \sum_{\mathrm{j}}^{\mathrm{All\,Evts}} \mathrm{p}_{\mathrm{j}}^{\mathrm{fake}}$$

$$\mathrm{p}_{\mathrm{j}}^{\mathrm{fake}} = \sum_{\mathrm{i}}^{\mathrm{All\,jets}} \mathrm{p}_{\mathrm{i}}\left(\mathrm{p}_{\mathrm{T}}, \eta\right)_{\mathrm{j}}$$

3. Number Bkg Events is found by **summing** all **Weighted Events**
4. **Compare to** Number of Events expected from MC

Fake-Rate Application: $t\bar{t}$ ”lepton+jets” channel

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- The **QCD Multi-Jets sample** was divided to 3 sub-sets (**correlated**)
  - Ldg Jets, Next-To-Ldg Jets, Back-To-Back Jets ($\Delta\phi > 2.4$)

Sample	Method	τ-fakes	
	1- or 3-prongs	”data”	MC
QCD Multi-Jets	”all” Jets	542 ± 9	
QCD Multi-Jets	Ldg-Jets	639 ± 10	
QCD Multi-Jets	”Next-To-Ldg Jets	498 ± 9	438 ± 20
QCD Multi-Jets	”Back-To-Back Jets	577 ± 10	
γ+Jets	”all” Jets	523 ± 8	

Main Features:

- **Average** of the two samples used is 20% away from MC - underestimate
- Method **strongly depended** on the **sample composition** & **jet-selection :**
  - **QCD sub-sets** have up to **25% discrepancies** (“**Ldg**” – “**Next-to-Ldg**” Jets)
    - Indicative of biases introduced by the various methods

Relative Isolation: $t\bar{t}$ "lepton+jets" channel

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- **Relative Isolation** quantifies the degree of isolation of a lepton:

$$\mathrm{isol}^{\mu/e}_{\mathrm{Rel}} = \frac{\sum^{\Delta R^{cone}<0.3} p_T^{trk} + \sum^{\Delta R^{cone}<0.3} E_T^{ECAL} + \sum^{\Delta R^{cone}<0.3} E_T^{HCAL}}{p_T^{\mu/e}}$$

- **Non-isolated** (**large** isolation values) leptons come mostly from **QCD generic jets**
- Whereas, μ/e candidates from W-decays are:
  - **isolated** from other Event activity (**small** isolation values)
  - consistent with originating from the I.P. (**small** impact parameter d_0)

⇒The **signal region** is characterised by **small** values of **Relative Isolation** ($\mathrm{isol}_{\mathrm{Rel}}$)

- To estimate the QCD contributions in the **signal region**, one can:
  - define a **control region** (**large** $\mathrm{isol}_{\mathrm{Re}}$values), dominated by **QCD Multi-Jet Events**
  - Fit $\mathrm{isol}_{\mathrm{Rel}}$ to a function in the **contol region** and **extrapolate** in the **signal region**

    e.g. $\mathbf{0.1 \leq isol_{Rel} \leq 1.0}$ and $\mathbf{0.0 \leq isol_{Rel} \leq 0.1}$

  - Get estimate of number of **QCD Multi-Jet Events** in **signal region**

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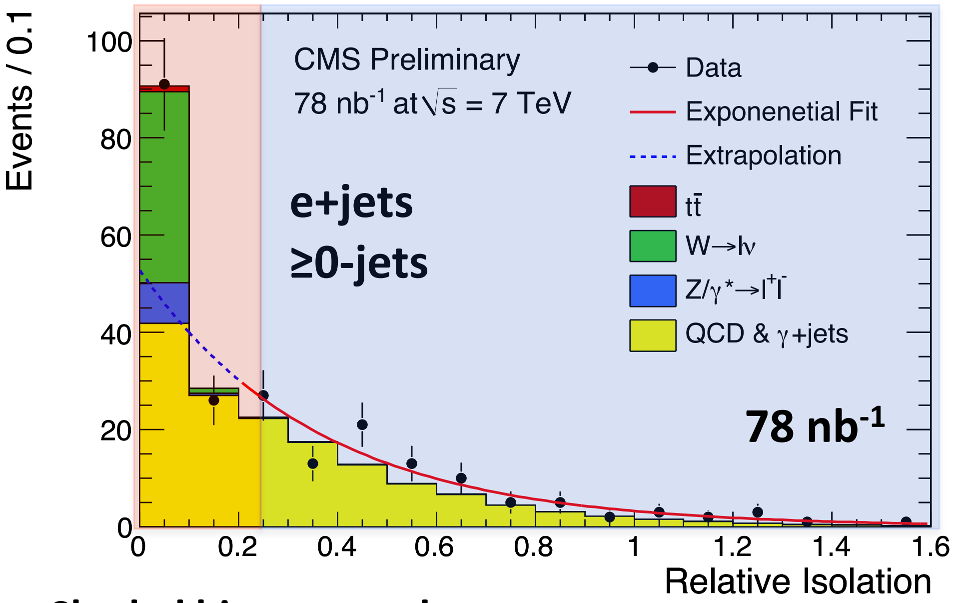

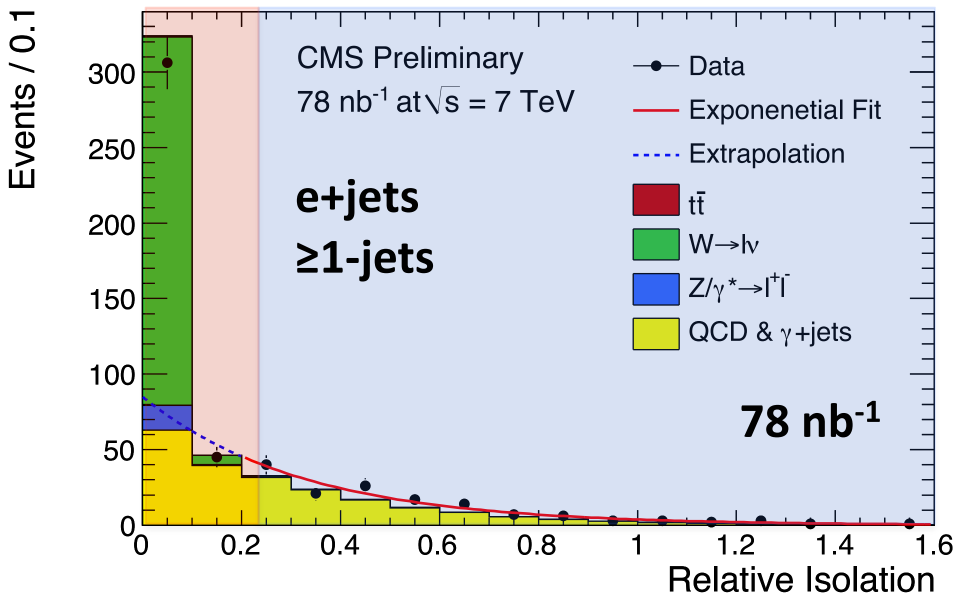

- **Shaded histograms denote:**
  - Expected Signal & Bkg contributions, Normalized to 78 nb^{-1}
- **QCD composition:**
  - electrons from b/c-decays in jets and…
  - electrons originating from γ-conversions in Si Tracker
- **Exponential Function Fit**
- **50%** uncertainty assigned to predicted QCD Events
- Good agreement with MC (~10% discrepancies)

extrapolate | fit

signal region | control region

isol_{rel} extrapolation method (e + jets)	$\geq$ 0-jet	$\geq$ 1-jet
Averaged $N^{est.}_{QCD}$	70 ± 35	44 ± 22
Prediction N^{MC}_{QCD}	63 ± 7	42 ± 6

Relative Isolation: $t\bar{t}$ "lepton+jets" channel

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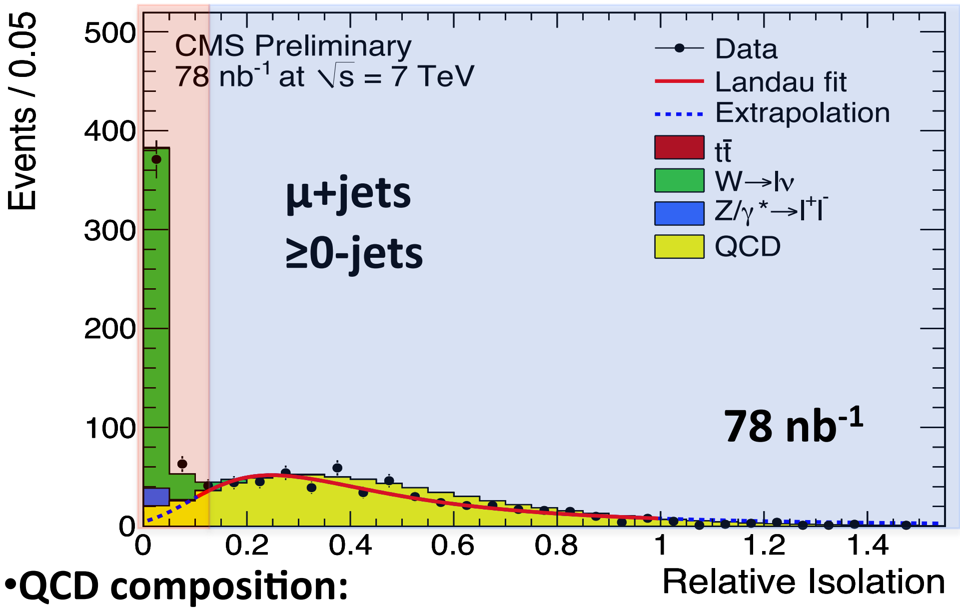

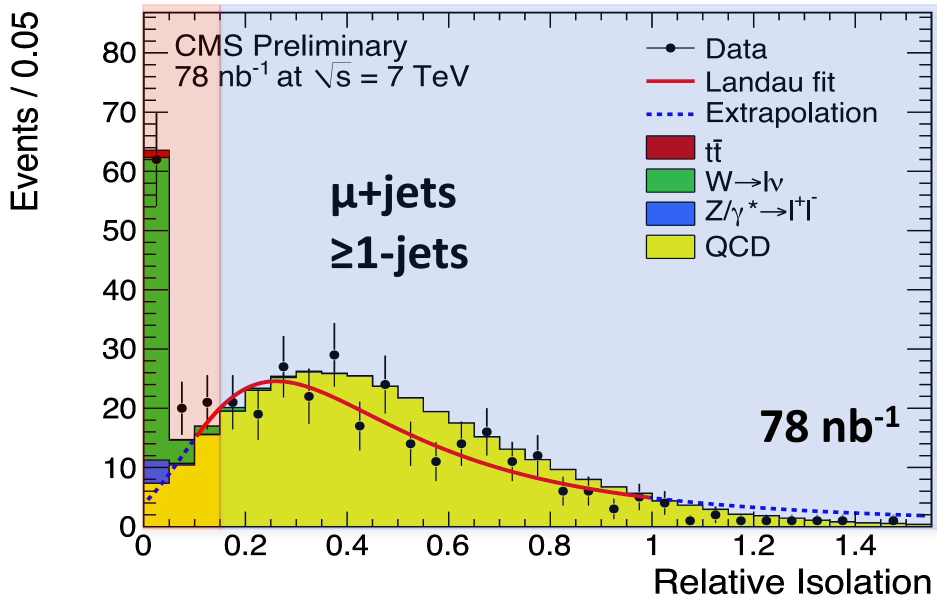

extrapolate | fit

signal region | control region

- **QCD composition:**
  - muons from b/c-decays in jets
  - decays-in-flight of hadrons
  - hadronic showers reaching muon systems
- **Landau Fit** (QCD background composition different)
- **50%** uncertainty assigned to predicted QCD Events
- Poor agreement with MC for ≥ 0-jets (~300%)
- Better agreement with MC for ≥ 1-jets (~15%)

$isol_{rel}$ extrapolation method (μ + jets)		
	$\geq$ 0-jet	$\geq$ 1-jet
Averaged $N^{est.}_{QCD}$	7 ± 4	6 ± 3
Prediction N^{MC}_{QCD}	21 ± 2	7 ± 2

Template Fit: $t\bar{t}$ "lepton+jets" channel

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- Use discriminating **Kinematical Variables** to separate **QCD Multi-Jet** from **signal Events**
  - Missing Transverse Energy ($\not\!\!E_{\mathrm{T}}$)
  - Scalar Sum of E_T^{miss} and the lepton transverse Energy: $\mathrm{H_T^{lep} = E_T^{miss} + E_T^{lep}}$
- Construct **QCD shapes** from Events with **near-miss e^-** and **large EM Fraction jets**:
  - "**Background Electrons Template**": Any e-candidate **failing** any of 3 quality cuts:
    - $isol_{Rel} < 0.1$,
    - electron-ID
    - $d_0 < 200$ µm (wrt average beam spot)
  - "**Jet-Electrons Template**":
    - No e-candidate passed Event Selection
    - 1 Jet with E > 30 GeV , $|\eta| < 2.5$, **EMFraction > 0.9**
    - Use these Jets **as electrons**
- According to simulation, both selections yield a **QCD purity** approx. 99%
- **QCD Model used for estimation**: Normalised mean of the **two templates** (**bkg-e** + **jet-e**)

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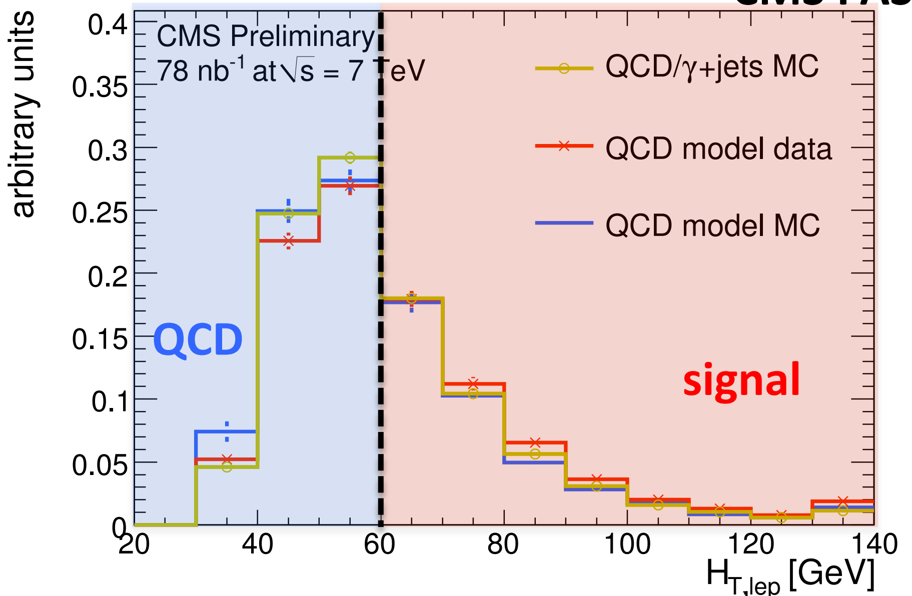
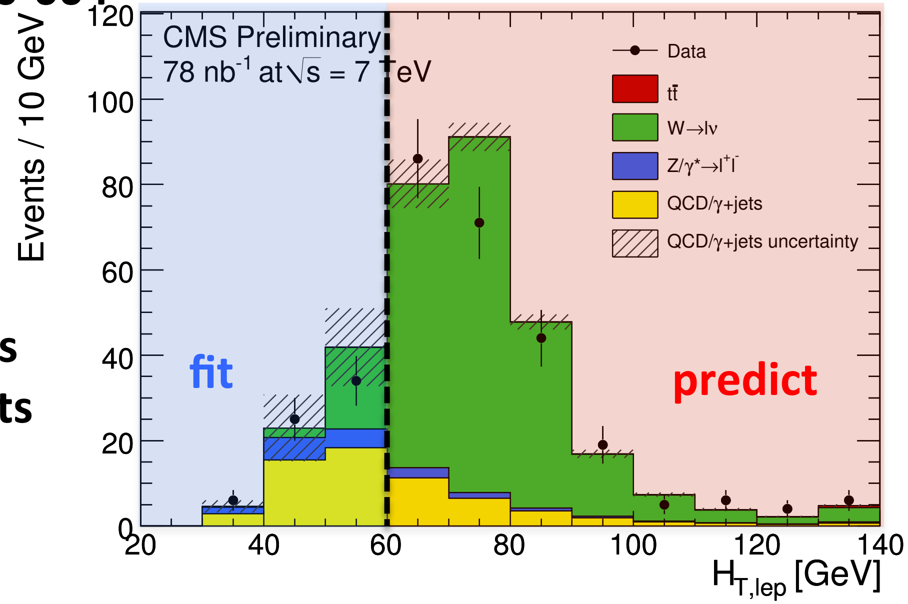


e+jets
≥0-jets



- **Model Bias**: Shift to larger values of H_T^{lep} for QCD model data
- **Template Fit Method:**
  - Divide **model distributions** to QCD region and signal region
  - Fit in QCD region ($0 \le H_T^{lep} \le 60$) & extrapolate in signal region
- $N_{QCD}^{est.}$ is the integral of the **QCD template** in the signal region
- **For ≥0-jets: 50%** away from MC predictions
- **For ≥1-jets: 16%** away from MC predictions

Template Fit method ($\geq$ 0-jet)		
Variable	$N_{QCD}^{est.}$	N_{QCD}^{MC}
$\not{E}_T > 25$ GeV	19 ± 7	12.2 ± 0.2
$H_T^{lep} > 60$ GeV	39 ± 11	26.0 ± 0.3

Template Fit method ($\geq$ 1-jet)		
Variable	$N_{QCD}^{est.}$	N_{QCD}^{MC}
$\not{E}_T > 30$ GeV	8 ± 5	5.3 ± 0.1
$H_T^{lep} > 70$ GeV	10 ± 4	12.4 ± 0.2

Kinematical Variable α_T: SUSY Searches

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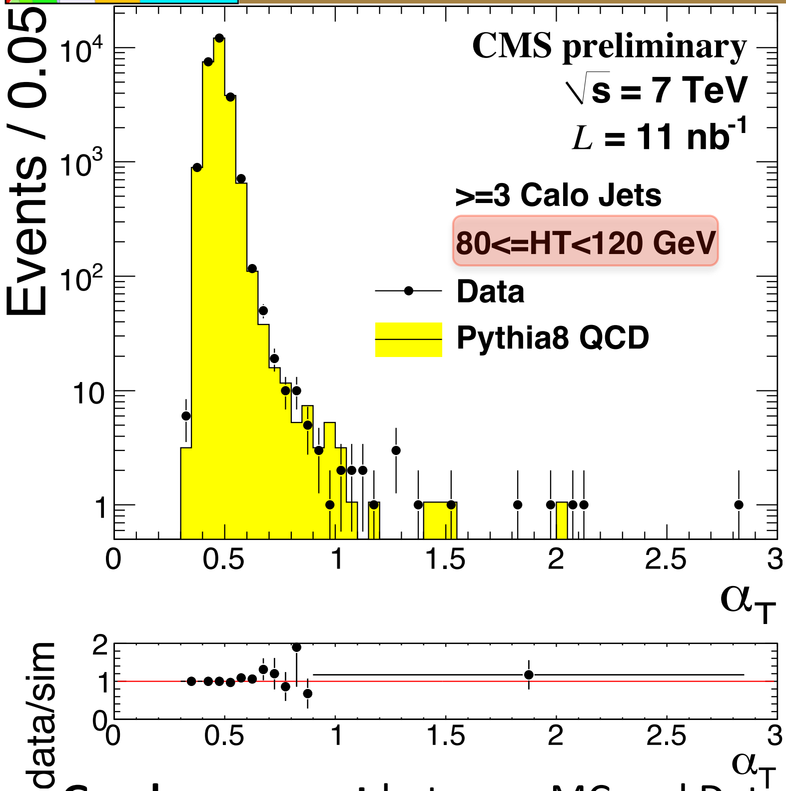
- The kinematical variable **α_T** characterises the **p_T imbalance** of an event.
- Like MET, can be a **powerful discriminator** against **QCD background.**
- For **multi-jets Events** (**N-jets system**), group the jets into **2 pseudo-jets** and define:
  - Total Transverse Energy: $H_T = \sum_i^{jets} p_{T_i}$
  - Difference in pseudo-jets H_T: $\Delta H_T = p_T^{pseudo-jet1} - p_T^{pseudo-jet2}$
  - Missing H_T : $MHT = \left|\sum_i^{jets} -\vec{p}_{T_i}\right|$ ("Hadronic" MET)
    - → MHT is dependent on jet thresholds
- The **unique configuration** of the **2 pseudo-jets** is the one that **minimises ΔH_T**.
- For an **N-jets system** the variable α_T is: $\alpha_T = \frac{1}{2}\frac{H_T - \Delta H_T}{\sqrt{H_T^2 - (MHT)^2}}$
- For **a perfectly balanced** multi-jet event with no real MET: $\alpha_T \to 0.5$
  - **QCD Events** largely confined in the region: $\alpha_T \leq 0.5$
- **SUSY & $H^\pm$ searches:** extend to well above 0.5 (effect **increases** with $m_{H\pm}$)

Kinematical Variable α_T: SUSY Searches



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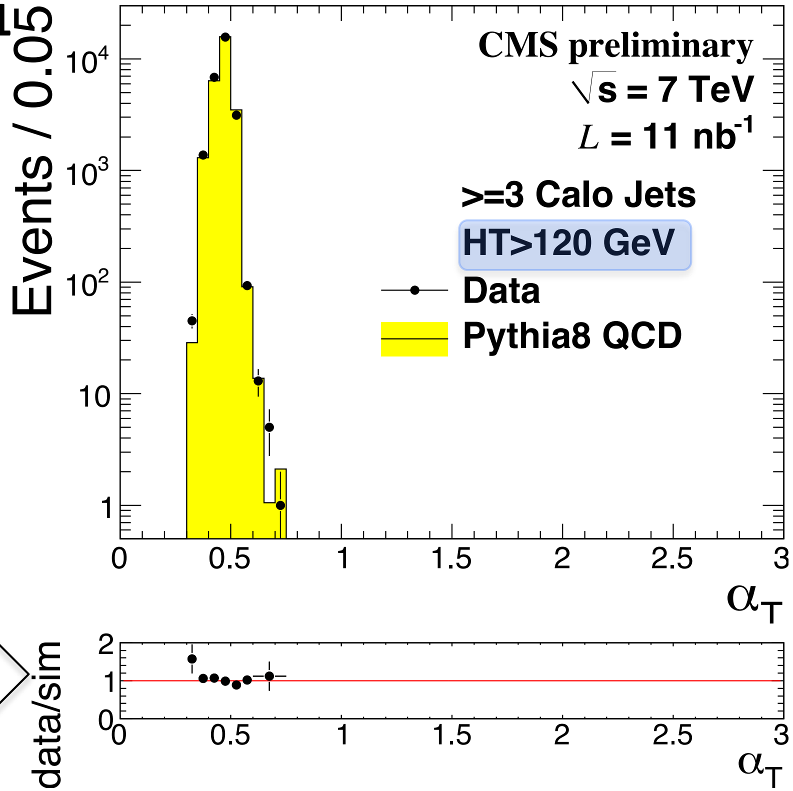
MC Vs Data

- **Data:** 12 nb^{-1} sample
- **Trigger:**
  - ≥ 1 jet
  - p_T > 15 GeV



Data/MC

- **Good agreement** between MC and Data.
- **Most QCD Events** have $\alpha_T \leq 0.5$.
- **Significant tail** for slice $80 \leq H_T \leq 120$ GeV with $\alpha_T > 0.5$ (both MC and Data)
- **α_T tail** of QCD Events reduced dramatically by increasing H_T in Event:
  - Jet resolution effects become **less significant** $\Longrightarrow$ balance of pseudo-jets **“easier”**
- **For H± fully hadronic final state we require:** H_T > 110 GeV

Kinematical Variable α_T: SUSY Searches

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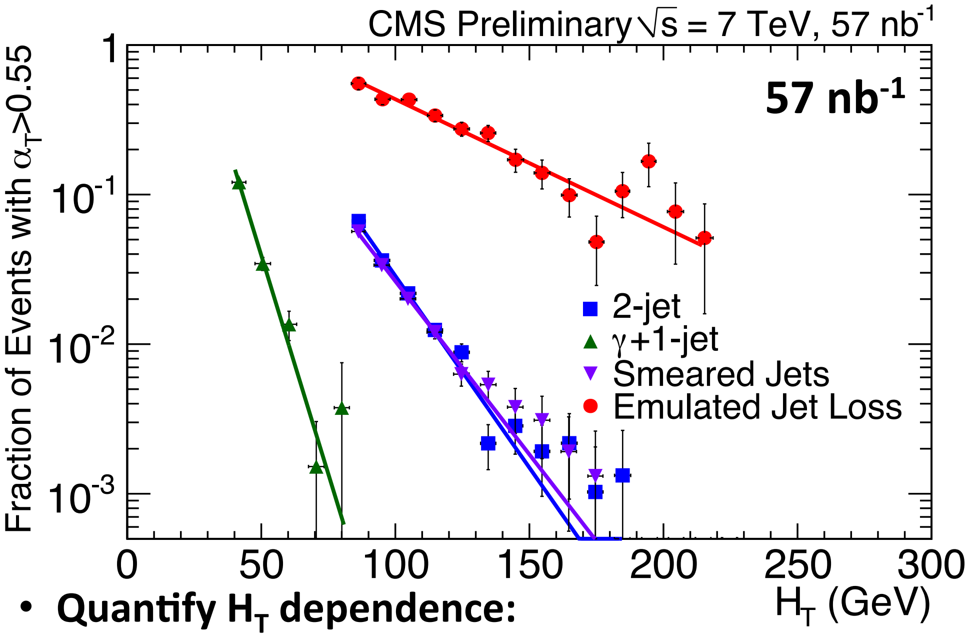

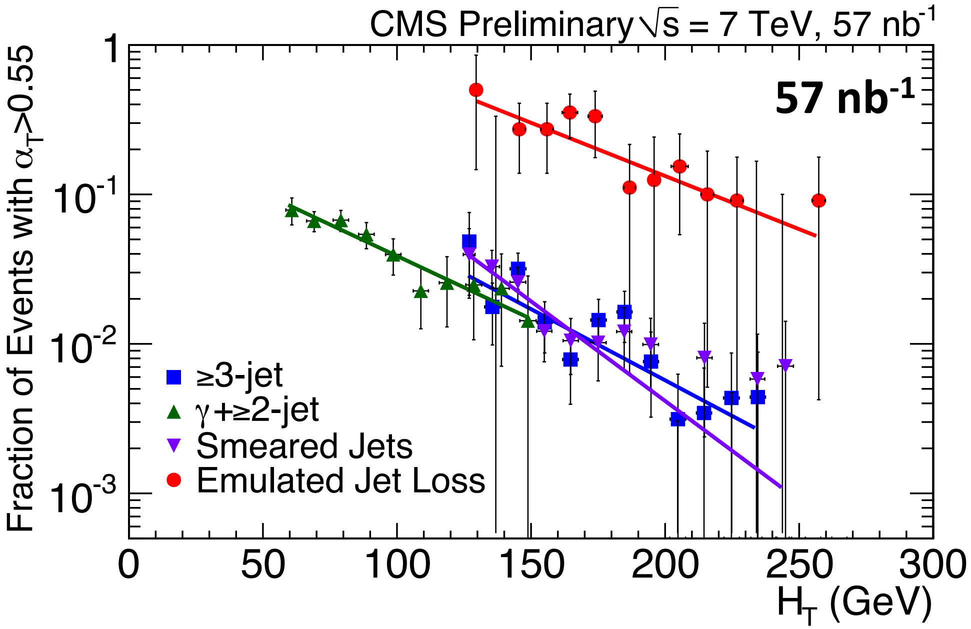

- **Quantify H_T dependence:**
  - Compute fraction of Events that pass the $\alpha_{\rm T} \geq 0.55$ cut **as a function of H_T**
- ~**Exponential decrease** of surviving events with **increasing H_T** observed (for both **2-jet and ≥ 3-jets**)
- **Same behaviour even if:**
  - **A photon is treated as a jet**
  - **Jet energies are smeared**
  - **A jet is randomly removed from Event**

⇒ Rejection power of α_T gets better with increasing H_T, even with mis-measurement biases

Kinematical Variable α_T: SUSY Searches

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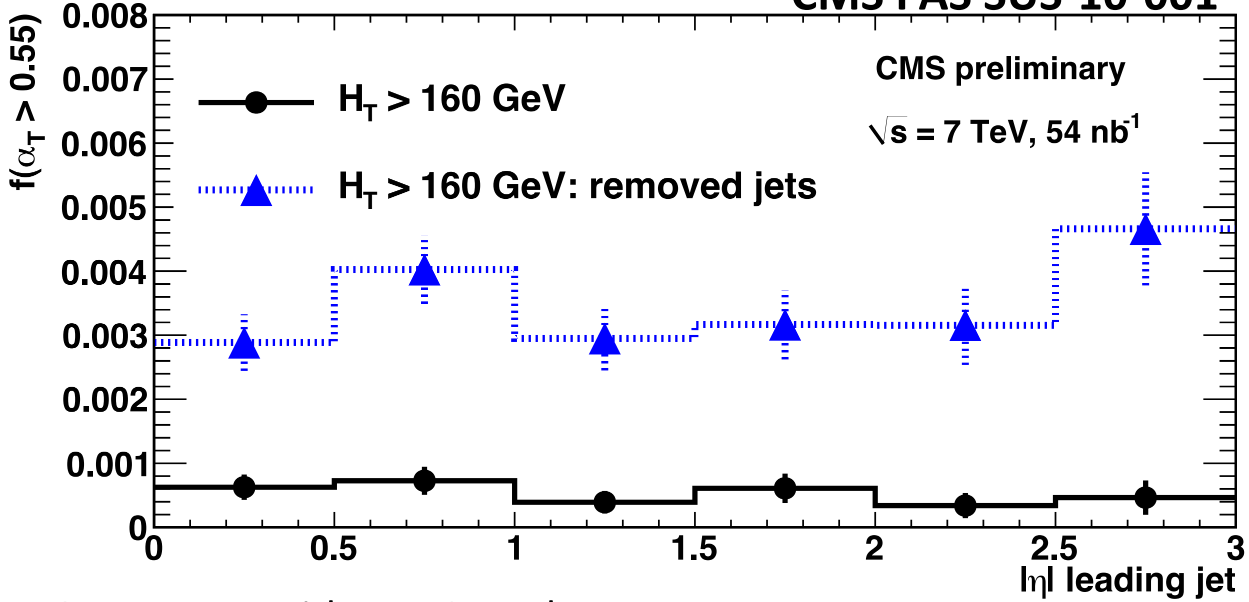


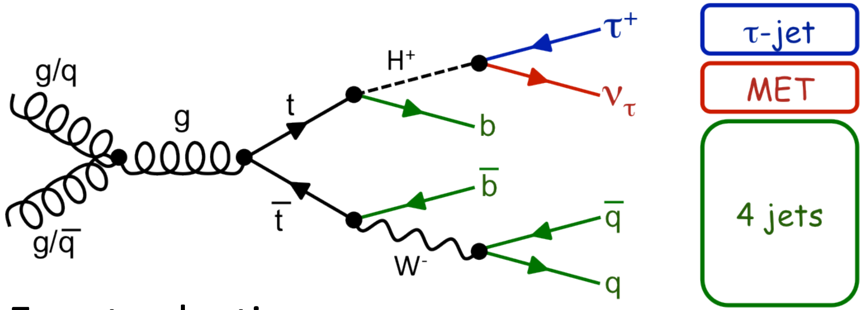
Fraction of Events passing the **α_T > 0.55** cut, as a function of Leading Jet |η|

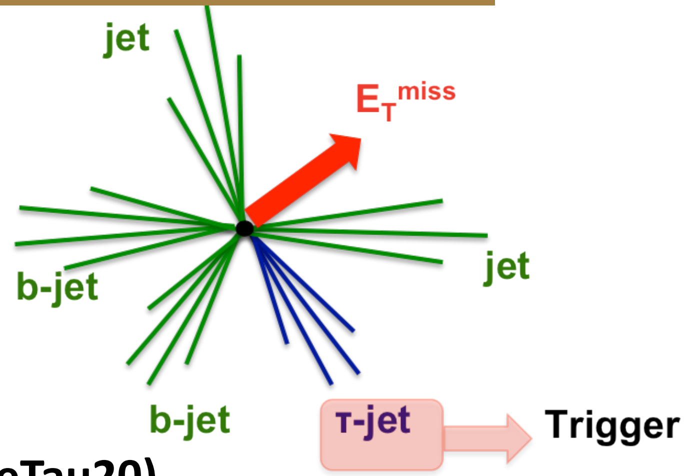
- QCD Events with $\alpha_T > 0.55$ show:
  - **no dependence** on the **Leading Jet |η|**
  - Simulating **large lost MET (**by randomly removing a jet from the Event) has **no effect**
- **SUSY** Events expected to be **more central** than QCD Events.
- **Estimate QCD background** by use of signal-depleted control sample at **high |η|**
- **Extrapolate QCD background** in the SUSY **signal region** (low |η|)

- Under investigation whether the **same method** can be used for **$H^\pm$ searches**

Fake-Rate Application: $H^{\pm}$ searches (fully hadronic)

$$t\bar{t} \rightarrow W^{\mp} b H^{\pm} b \rightarrow (q\bar{q}')\,(\tau\nu_\tau)\,bb$$





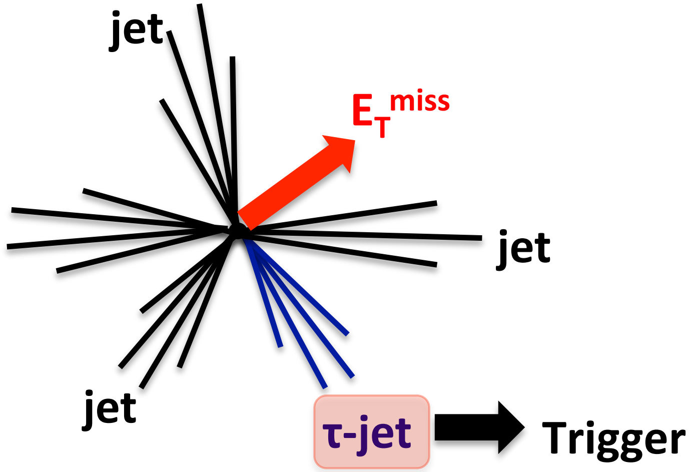
Event selection:

- **HLT_IsoTau20_Trk15 + HLT_MET20 (seeded by L1SingleTau20)**
- **1 τ-jet which must match HLT Tau object** (E_T > 40 GeV , p_T^{LdgTrk} > 20 GeV/c , |η| < 2.4)
- **$N_{jets} \geq 3$** (E_T > 30 GeV , |η| < 2.4)
- **E_T^{miss} > 60 GeV**
- **Other possible cuts:** 1 (or two) b-tagged jets, hadronic top reconstruction, M_T reco of $H^{\pm}$

- Plans for **Tau-Jet Fake-Rates** measurement using data:
  - Use **Single Jet Trigger**
  - Select **Multi-Jet Events** (≥3 jets with E_T > 30 GeV and |η| < 2.4)
  - Apply the tau-ID to jets that pass the **HLT_IsoTau20_Trk15** trigger: $p^{fake} = \left(\frac{N_{jets}^{\tau-ID}}{N_{jets}^{HLT\ \tau-ID}} \right)$

- Measurement strategy for **QCD Multi-Jets:**
  - **Fake-Rate Application** to estimate Number of QCD Events in signal region
- **Event selection:**
  - **HLT_IsoTau20_Trk15 + HLT_MET20 (seeded by L1SingleTau20)**
  - Get **QCD dominated** sample (**TTbar** & **W+jets** assumed negligible)
- **Apply Fake-Rate** to offline tau (matched to **HLT τ-Jet)** to get **Event Weight**
- Apply a **QCD-efficiency factor (ε_{QCD})** as determined by data

  (fraction of QCD events that survives all selection cuts **apart** from tau-ID)
- Number of surviving events gives **Number of estimated QCD Events in signal region**
- **Systematic Uncertainties** expected for this method:
  - **Purity** of QCD sample **- Check bias with MC**
  - Accuracy of Fake-Rates estimations.
  - Correlation between ε_{QCD} and τ-ID efficiencies?
    - Possibility to **under-estimate QCD Events**



Summary

- **Generic QCD** is expected to be important background in **$H^{\pm}$ searches.**
- **Data-driven techniques** to estimate QCD background are in place:
  - **"lepton+jets" final state:**
    - Fake-Rate Application recipe, as used in **TTbar "lepton+jets"**
  - **Fully Hadronic final state:**
    - Fake-Rate Application using a τ-Jet + MET Trigger and a QCD-efficiency factor.
    - Methods used for **TTbar "lepton+jets"** channel
      (by replacing the lepton with the tau-Jet)
    - Possibility of using $\boldsymbol{\alpha_T}$ under investigation
- Stay tuned for **updates** & **first results**

References

- *" Study of tau reconstruction algorithms using pp collisions data collected at √s = 7 TeV "*, CMS Physics Analysis Summary: **CMS PAS PFT-10-004**

- *"Towards the measurement of the ttbar cross section in the e-tau and mu-tau dilepton channels in pp collisions at √s = 14 TeV "*, CMS Physics Analysis Summary: **CMS PAS TOP-08-004**

- *" Selection of Top-Like Events in the Dilepton and Lepton-plus-Jets Channels in Early 7 TeV Data "*, CMS Physics Analysis Summary: **CMS PAS TOP-10-004**

- *" Performance of Methods for Data-Driven Background Estimation in SUSY Searches "*, CMS Physics Analysis Summary: **CMS PAS SUS-10-001**

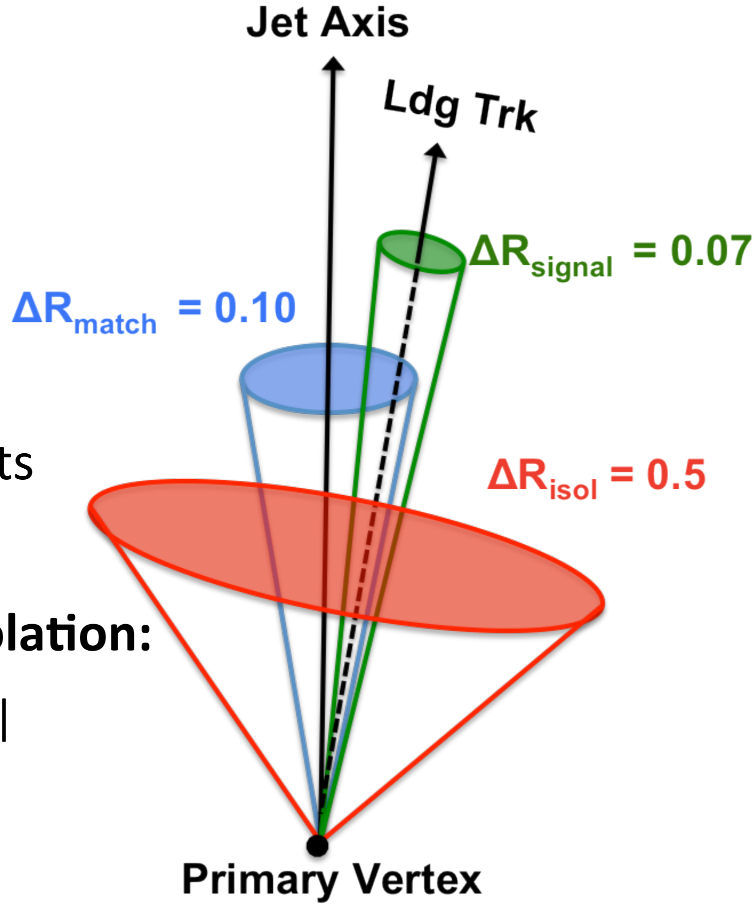
BACK-UP SLIDES

Track Corrected Tau (TCTau)

CMS PAS PFT-10-004

- A robust, cut-based algo that uses Tracker to correct Energy + direction:
  - Uses jets reconstucted from **tracks** and **E-deposits** in ECAL + HCAL
- **Takes reconstructed tracks:**
  - within a cone with $\Delta R_{match} = 0.1$ around jet axis:
  - with $p_T > 0.5$ GeVc^{-1}
- **Ldg Trk of jet** ($p_T^{LdgTrk} > 5$ GeVc^{-1}) is:
  - highest p_T track within cone with $d_0 < 0.1$ mm
- **All Trks** within signal cone considered as tau products

  ($d_{0,z} < 10$mm)
- **All Trks** in isolation annulus considered for **Track isolation:**
  - no Trk with $p_T > 1.0$ GeVc^{-1} **OR** $\Delta d_{0,z} = | d_{0,z}^{LdgTrk} - d_{0,z} |$

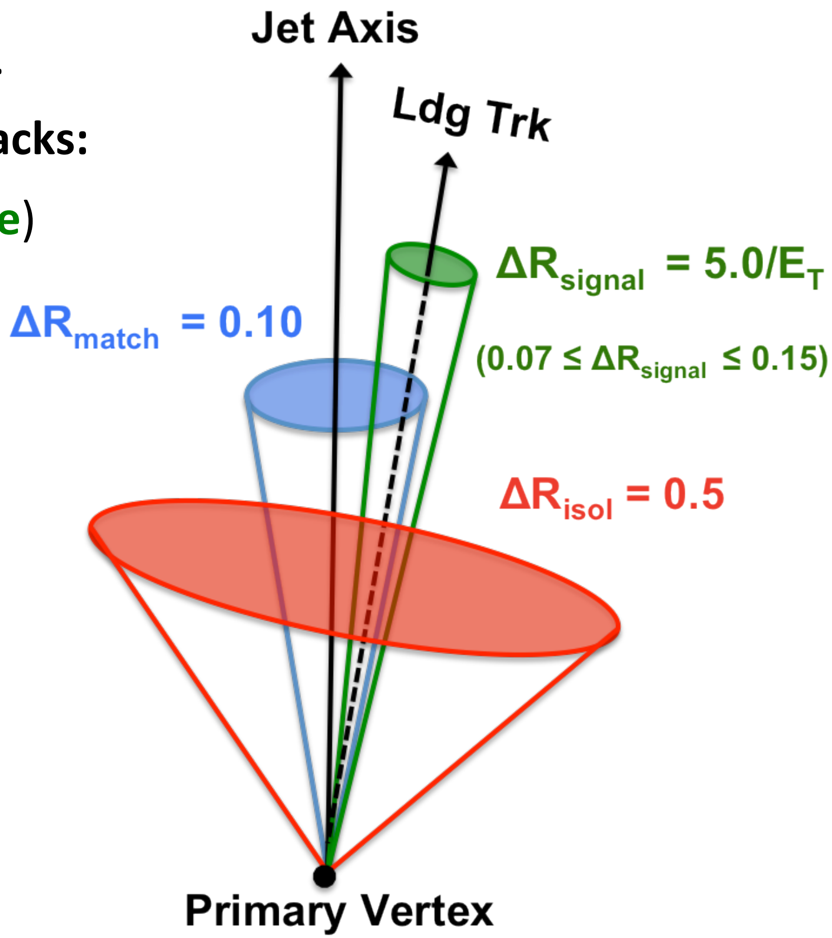


PF Shrinking Signal Cone

CMS PAS PFT-10-004

- The aim PF algo is to Reco and ID all stable particles within an Events using all sub-detectors :
    - e, μ , γ, hadrons (charged and neutral)

  and make them all available in an "Event particle-list".
- **PF Tau 4-Momentum reconstructed using Sum of Tracks:**
    - around direction of the Ldg p_T (within **signal cone**)
    - with $p_T > 0.5$ GeVc^{-1}
    - within a **signal cone $\Delta R = 5.0/E_T$**
- **Ldg Trk of jet** ($p_T^{LdgTrk} > 5$ GeVc^{-1}) is:
    - The highest p_T track within **matching cone**
- **Isolation Requirement**
    - No **charged hadrons** or **γ** with $p_T > 1.5$ GeVc^{-1}
- Compared to **PF Fixed Signal Cone**
    - Has **Higher Efficiency** but **Larger Fake-Rate**



Tau Neural Classifier (TaNC)

CMS PAS PFT-10-004

- A **multivariate** Tau-ID algorithm based on **Neural Networks** (NN)
- Considers **individual** Tau hadronic decay modes
- Looks for **intermediate resonances** ($\rho^{\pm}$, $\alpha^{\pm 1}$) using:

  a) **method** to reconstruct decay mode

  b) **NN** classifiers to identify each decay mode

Decay modes considered

Decay Mode	Resonance	BR (%)
$\tau^- \to \mathrm{h}^-\nu_\tau$		11.6%
$\tau^- \to \mathrm{h}^-\pi^0\nu_\tau$	ρ^-	26.0%
$\tau^- \to \mathrm{h}^-\pi^0\pi^0\nu_\tau$	α^{1-}	10.8%
$\tau^- \to \mathrm{h}^-\mathrm{h}^+\mathrm{h}^-\nu_\tau$	α^{1-}	9.8%
$\tau^- \to \mathrm{h}^-\mathrm{h}^+\mathrm{h}^-\pi^0\nu_\tau$		4.8%
Total		63.1%
Other hadronic modes		1.7%

- **Major task**: Determine number of π^0's in **signal cone**: ($\pi^0 \rightarrow \gamma\gamma$)
  - Examine all photons in **signal cone** with Inv. Mass < 0.2 GeVc^2
  - Tag best pairs as π^0's
- Reconstruct decay mode of tau candidate
- Feed Tau candidate to an enseble of NN, each dedicated to a specific τ-hadronic decay
- Get output of NN according to «chosen working point»
- There are 3 "**working-points**", based on NN output cuts yield:
  - Loose, medium and tight (1.0%, 0.5% and 0.25% **fake-rates**)

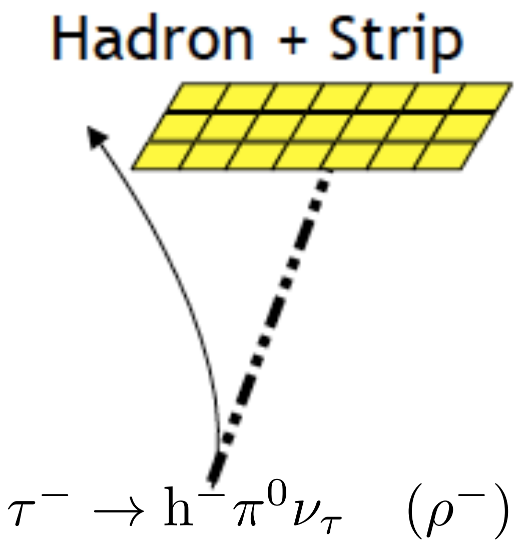
Hadron Plus Strips (HPS)

CMS PAS PFT-10-004

- Starts from PF jet and searches for Tau hadronic decay products
- Reconstruct photons in "strips", built from EM objects
- Start from **most energetic** PF EM particle within jet
  - Search for other PF EM particles within
    $\Delta\eta^{\text{strip centre}} = 0.05$, $\Delta\phi^{\text{strip centre}} = 0.20$
  - Associated most energetic particle with a strip
  - **Re-Calculate** strip position
  - Search for **next most energetic** PF EM particle
- **Combine strips** with charged hadrons ($p_T^{strip} > 1\ GeVc^{-1}$)
- **Reconstruct** Tau 4-Vector using **Hadrons + Strips**
- Three "Working Points". No charged Hadrons within **$\Delta R_{isol} = 0.5$** with
  - $p_T^{Ch.Hadr.} > 1.0\ GeVc^{-1}$, $E_T^{\gamma} > 1.5\ GeV$ **- Loose Isolation**
  - $p_T^{Ch.Hadr.} > 0.8\ GeVc^{-1}$, $E_T^{\gamma} > 0.8\ GeV$ **- Medium Isolation**
  - $p_T^{Ch.Hadr.} > 0.5\ GeVc^{-1}$, $E_T^{\gamma} > 0.5\ GeV$ **- Tight Isolation**

Decay modes considered

Decay Mode	Resonance	BR (%)
$\tau^- \rightarrow h^-\nu_\tau$		11.6%
$\tau^- \rightarrow h^-\pi^0\nu_\tau$	ρ^-	26.0%
$\tau^- \rightarrow h^-\pi^0\pi^0\nu_\tau$	α^{1-}	10.8%
$\tau^- \rightarrow h^-h^+h^-\nu_\tau$	α^{1-}	9.8%
$\tau^- \rightarrow h^-h^+h^-\pi^0\nu_\tau$		4.8%
Total		63.1%
Other hadronic modes		1.7%



Fake-Rates of τ-Jet algorithms

PAS CMS PFT-10-004

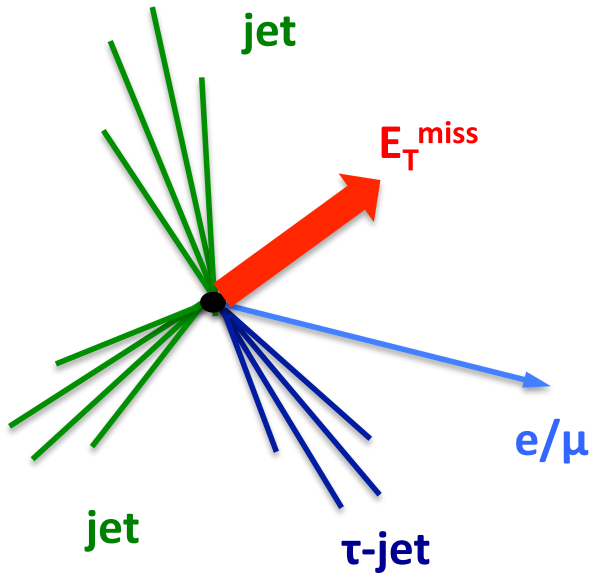
- **Data Sample** & **Event Selection:**
  - Integrated Luminosity of **8.4 nb^{-1} @ 7 TeV**
  - Based on **JetMETTau** SD , **MinBias** PD
  - Events required to pass **HLT_Jet15U** (single jet trigger, $E_T > 15$ GeV)
    (=>dominated by **QCD multi–jet events**)
  - **Jets considered:** $p_T^{jet} > 10\ GeVc^{-1}$, $|\eta^{jet}| < 2.5$
  - Data compared to **QCD Multi-Jet MC** samples using **PYTHIA 8.135**

CMS PAS TOP-08-004

TTbar "lepton+jets" Events (**e/μ + τ-Jet**): $t\bar{t} \rightarrow (l\nu)\,(\tau\nu_\tau)\,b\bar{b} \quad , \quad (l = e/\mu)$

Event-Selection for the **signal channel**:

- HLT1MuonNonIso **OR** HLT1Muon **OR** HLT1ElectronRelaxed **OR** HLT1Electron **OR** HLT1jet
  - a) ≥ **1 isolated lepton** (e/μ with $p_T > 20$ GeV/c and $|\eta| < 2.4$)
  - b) ≥ 2 **jets** with $p_T > 30$ GeV/c , $|\eta| < 2.4$
  - c) One **τ-Jet** with $p_T^{LdgTrk} > 20$ GeV/c , $|\eta| < 2.4$
  - d) **$E_T^{miss} > 60$ GeV**



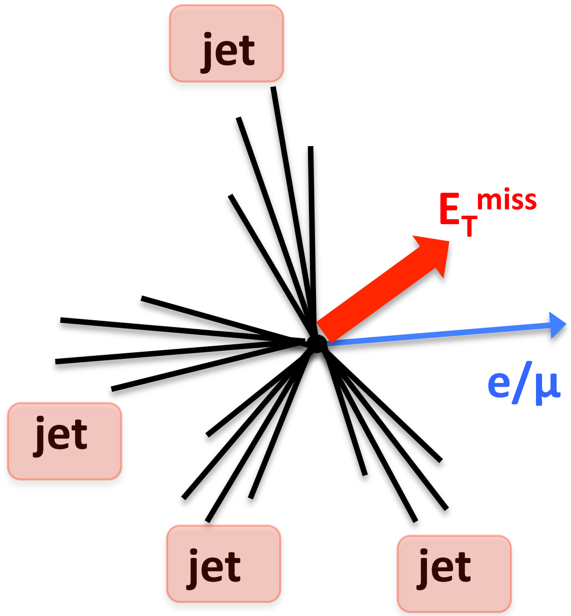
Fake-Rate Application: $t\bar{t}$ "lepton+jets" channel

CMS PAS TOP-08-004

TTbar "lepton+jets" Events (**e/μ + τ-Jet**): $t\bar{t} \rightarrow (l\nu)\,(\tau\nu_\tau)\,b\bar{b} \quad , \quad (l = e/\mu)$

Event-Selection for **QCD Estimation** using **Fake-Rate Application**:

- Use **Multi-Jet** and **γ+Jets** samples & select:
  - a) ≥ **1 lepton** (e/μ with $p_T > 20$ GeV/c and $|\eta| < 2.4$)
  - b) $\mathbf{N_{jets} \geq 2}$ ($p_T > 30$ GeV/c , $|\eta| < 2.4$)
  - c) $\mathbf{N_{jets} \geq 1}$ ($p_T > 10$ GeV/c , $|\eta| < 2.4$) **– >due to Tau**
  - d) $\mathbf{E_T^{miss} > 60}$ **GeV**



CMS PAS TOP-08-004

- **Fake-Rates** estimated for Jets with :
  - $p_T^{Ldg\ Trk} > 20$ GeV/c
  - $p_T^{Ldg\ Trk} > 20$ GeV/c + Iso_{Trk}
- For 1pr or 3pr Jets:
  - $p_T^{Ldg\ Trk} > 20$ GeV/c + Iso_{Trk} + Iso_{ECAL}
- For 1pr Jets:
  - $p_T^{Ldg\ Trk} > 20$ GeV/c + Iso_{Trk} + Iso_{ECAL}
- Main features of **Fake-Rate** curves:
  - approx. **no jet-η** dependence
  - **strong jet-p_T** dependence
    - rise steeply at **low p_T**,
    - asymptotic-like behaviour at **high p_T**
  - **Tighter Isolation** yields lower **Fake-Rates**