Tau ID in CMS

Christian Veelken
NICPB Tallinn

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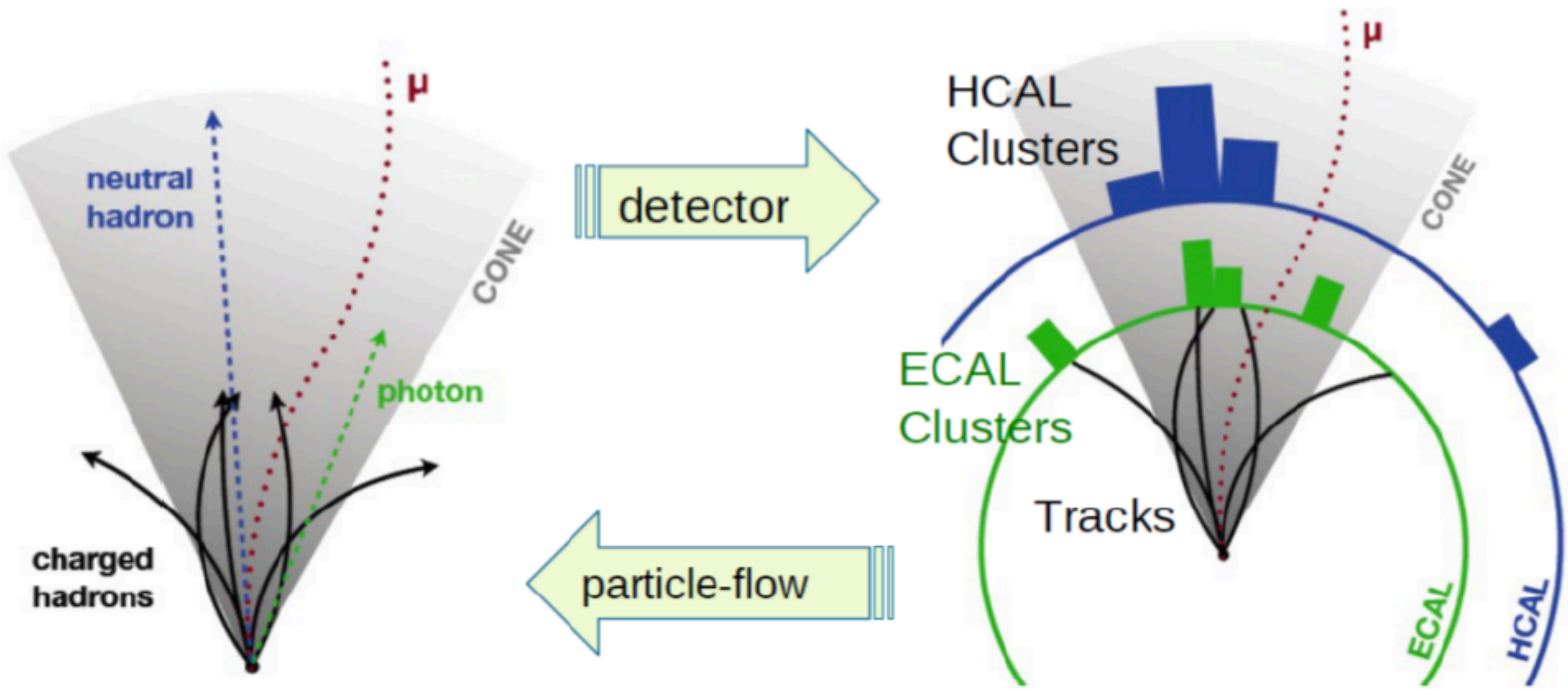
Today's Presentation

- Recap: CMS tau ID
- Latest public CMS : "Reconstruction and identification of τ lepton decays to hadrons and ν_{τ} at CMS" **arXiv:1510.07488**
- Algorithm improvements and first results for run 2
- Reconstruction of boosted taus

Particle-Flow Algorithm

Consistent Interpretation of all detector signal in terms of individual particles:
e, μ, photons, charged hadrons, neutral hadrons



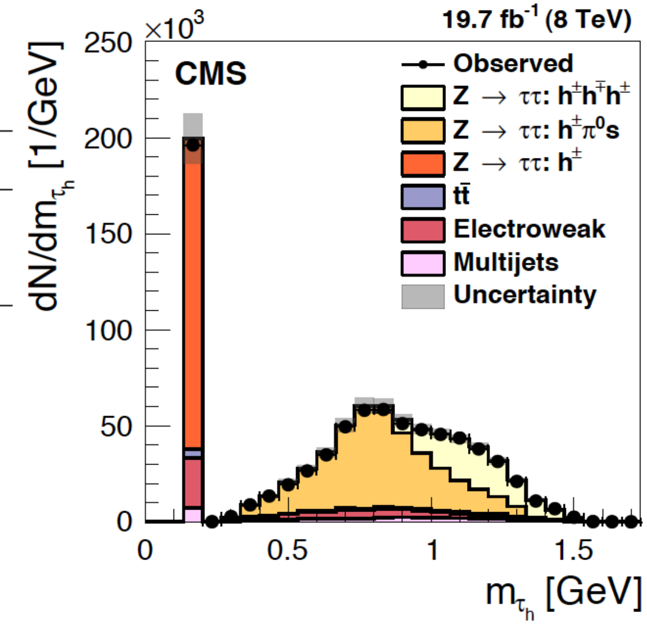
Higher level objects are reconstructed using individual particles as input:
τ_h, jets (incl. b-tagging), E_T^{miss}

Tau Decays

Mass m_τ= 1.78 GeV

Lifetime $c \bullet \tau$ = 87 μm

Decay mode	Meson resonance	$\mathcal{B}$ [%]
$\tau^- \to e^- \bar{\nu}_e \nu_\tau$		17.8
$\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau$		17.4
$\tau^- \to h^- \nu_\tau$		11.5
$\tau^- \to h^- \pi^0 \nu_\tau$	$\rho(770)$	26.0
$\tau^- \to h^- \pi^0 \pi^0 \nu_\tau$	$a_1(1260)$	9.5
$\tau^- \to h^- h^+ h^- \nu_\tau$	$a_1(1260)$	9.8
$\tau^- \to h^- h^+ h^- \pi^0 \nu_\tau$		4.8
Other modes with hadrons		3.2
All modes containing hadrons		64.8



Electrons/muons from $\tau \to e/\mu$ decays reconstructed by standard CMS electron/muon reconstruction

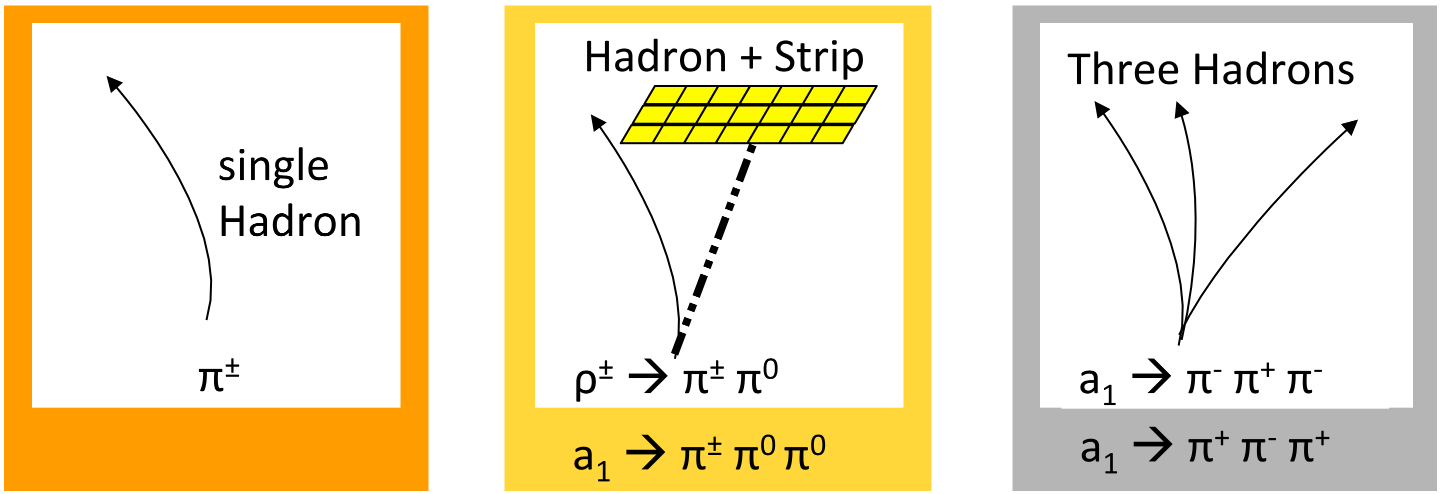
τ_h Identification ≅ reconstruction of $\pi^\pm$, $\rho^\pm$, $a_1^\pm$ signatures

Acceptance of τ_h reconstruction: $P_T^\tau \gtrsim 20$ GeV and $|\eta_\tau| < 2.3$ typically used by physics analyses in CMS

"Hadron plus Strips" (HPS) Algorithm

① Seeded by anti-k_T (R = 0.5) jets build from particle-flow output

② Build combination of charged Hadrons + Strips (= τ_h candidate)



③ Select combinations passing mass window cuts for $\pi^{\pm}$, $\rho^{\pm}$, a_1

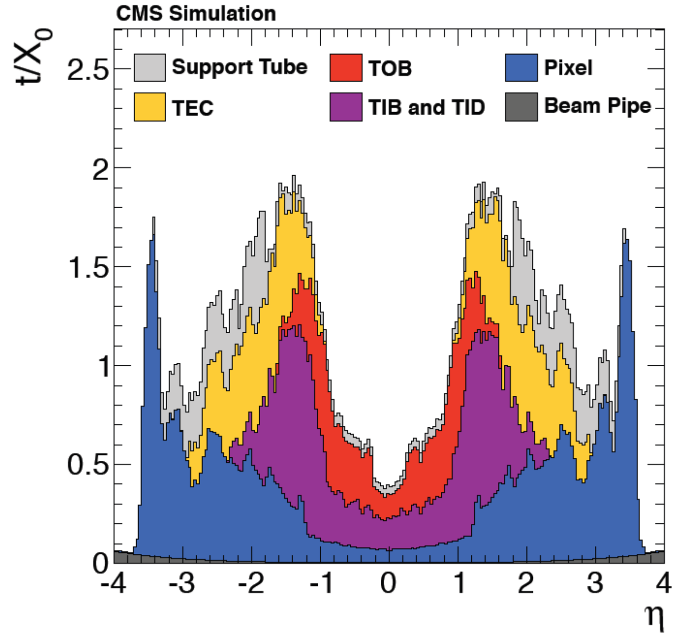
④ Most isolated τ_h kept in case multiple combinations pass mass cuts

⑤ Apply cut-based isolation or MVA based τ_h identification

⑥ Compute discriminators against e and μ

HPS π^0 Reconstruction

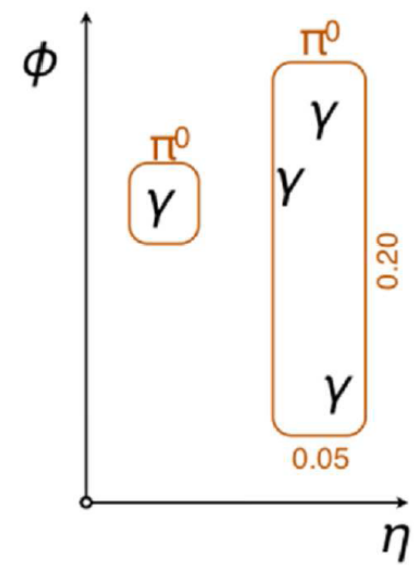
Neutral pions decay via $\pi^0 \rightarrow \gamma\gamma$ almost instantaneously



CMS has all silicon tracking detector

➔ High probability for photons to convert

➔ 3.8 T magnetic field separates e^+e^- pair in ϕ

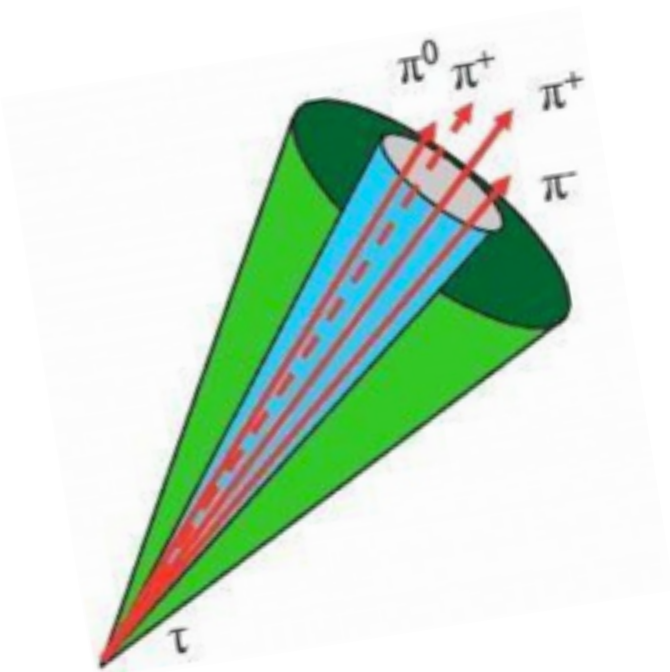


➔ Reconstruct (converted) photons in η-ϕ strips

Strips may contain either both photons from π^0 decay or just one

Cut-based Tau Isolation

$$\text{Iso} = \underbrace{\sum P_T^{h\pm}(|dz| < 2\text{mm})}_{\text{charged particles from PV}} + \max(0, \overbrace{\sum P_T^{\text{neutral}}}^{\text{neutral particles}} - \underbrace{k}_{\text{Factor chosen to make Iso flat vs. number of pileup interactions}} \bullet \underbrace{\sum P_T^{h\pm}(|dz| > 2\text{mm})}_{\text{charged particles from pileup}})$$



Different cuts on Iso define loose, medium and tight tau ID working-points:

WP	Requirement
Loose	Iso < 2.0 GeV
Medium	Iso < 1.0 GeV
Tight	Iso < 0.8 GeV

All 3 WPs are actually quite tight: necessary to reduce large QCD background

MVA Tau ID

Idea: Use tau lifetime information to improve τ_h ID performance

Input Variables:

- ΣP_T(charged contribution).
- ΣP_T(neutral contribution).
- Pile up correction.

Cut based isolation variables

- Reconstructed τ decay mode.
- $P_T(\tau)$
- $\eta(\tau)$

*Used to parameterize P_T and η dependence of the MVA input variables

τ reco and kinematic variables

- abs(d_{xy}) of the τ .
- sign(d_{xy}) of the τ .
- d_{xy} significance.

Variables sensitive to the impact parameter

- Presence of a secondary vertex.
- τ flight length.
- τ flight length significance.

SV sensitive variables

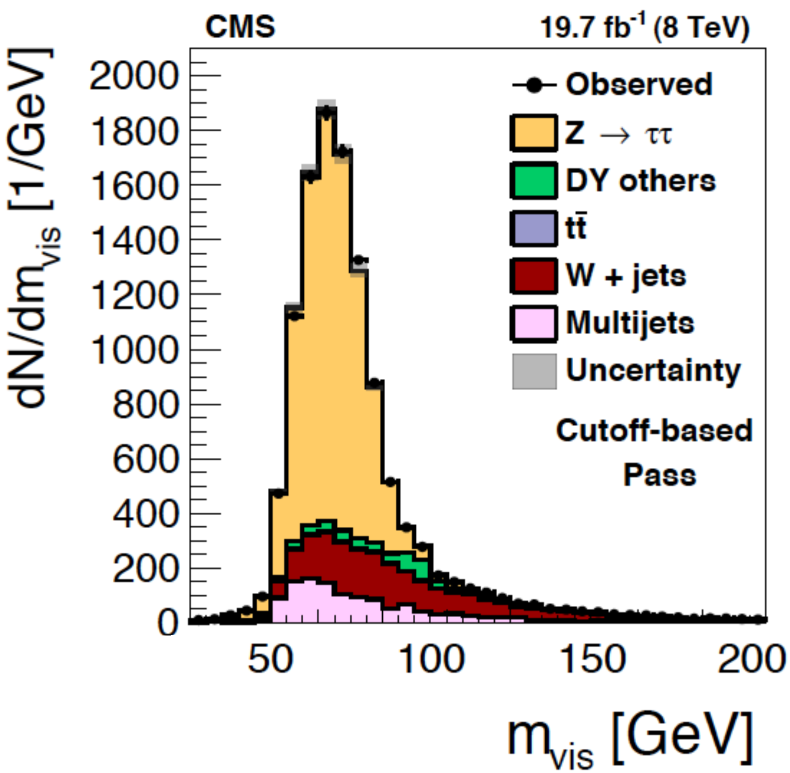
→ Loose, medium, tight WPs defined by cut on BDT output

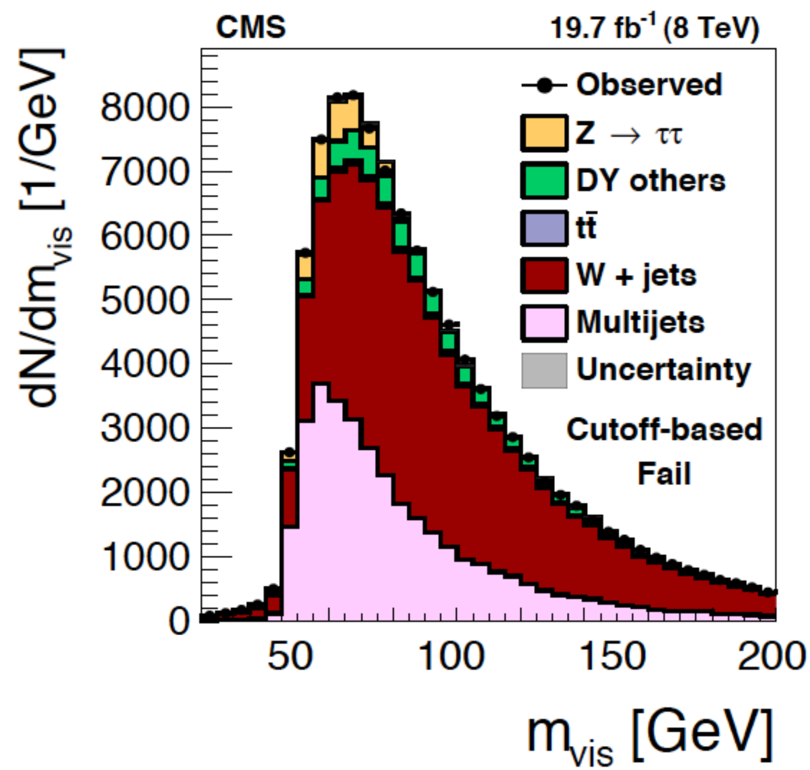
Tau ID Efficiency Measurement

Select sample of Z → ττ → μτ_h candidate events without applying tau ID

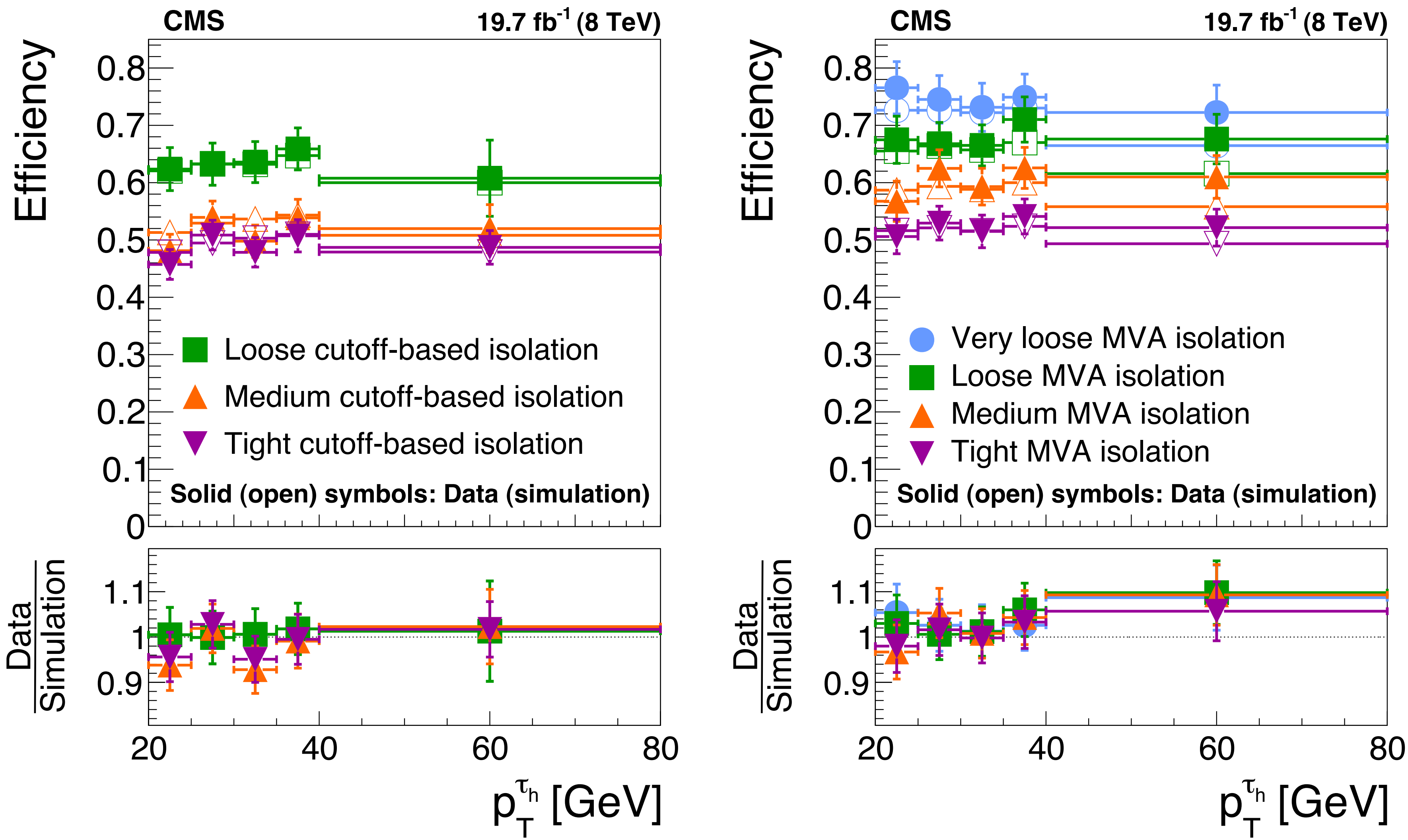
Challenge: sizeable background contributions

➔ Determine tau ID efficiency by simultaneous fit of μτ_h visible mass distribution in "Pass" and "Fail" regions with shape templates for Z → ττ → μτ_h signal and background processed





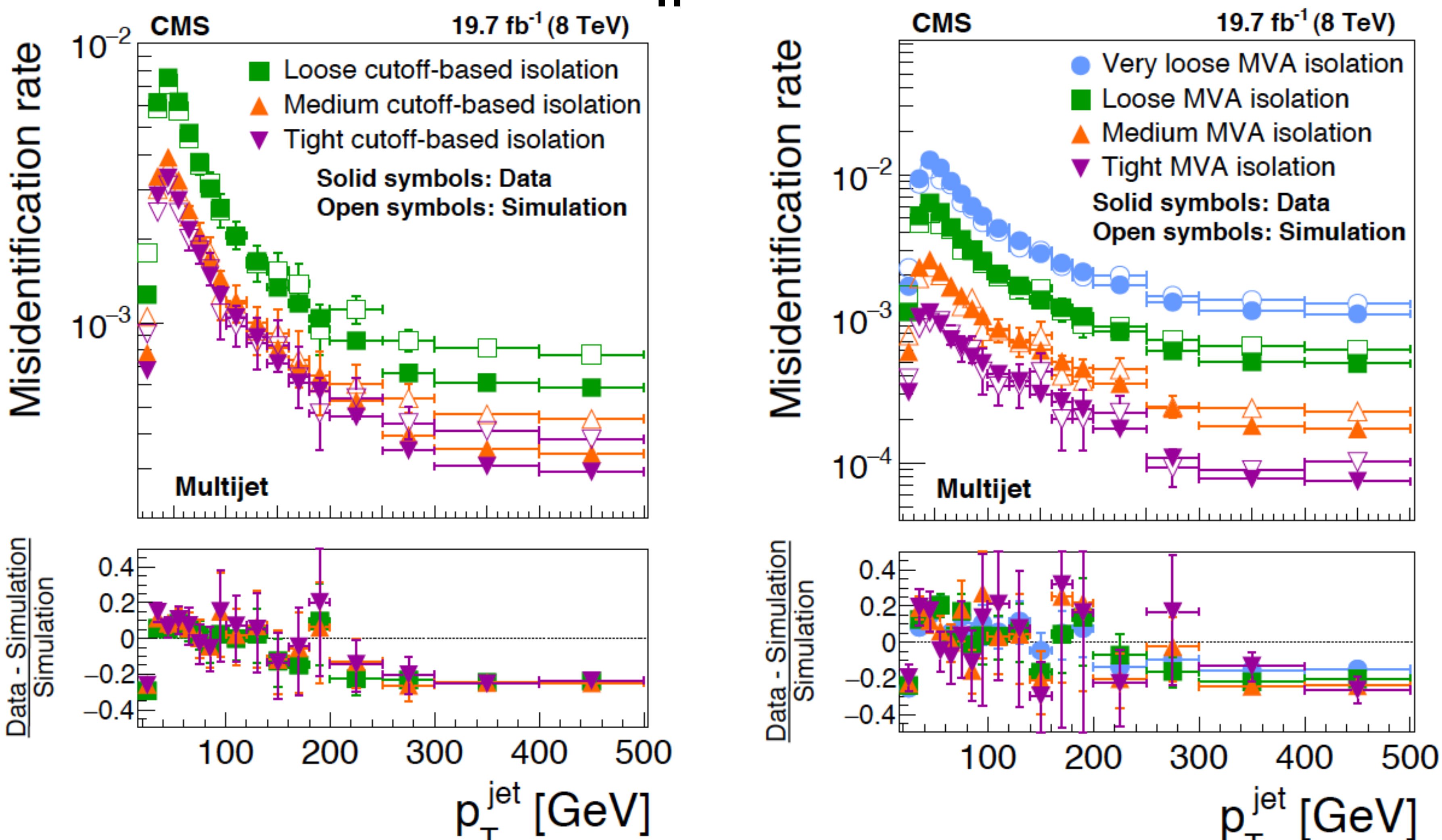
Tau ID Efficiency



➔ Tau ID efficiency 50-60%, flat vs. P_T for $P_T \geq 40$ GeV

➔ Efficiency measured in data in good agreement between MC simulation

Jet → τ_h Fake-rate

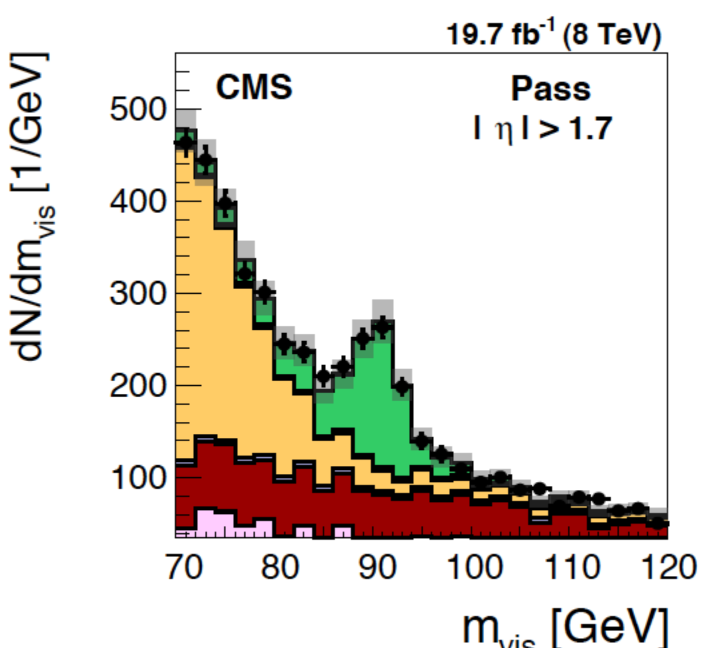


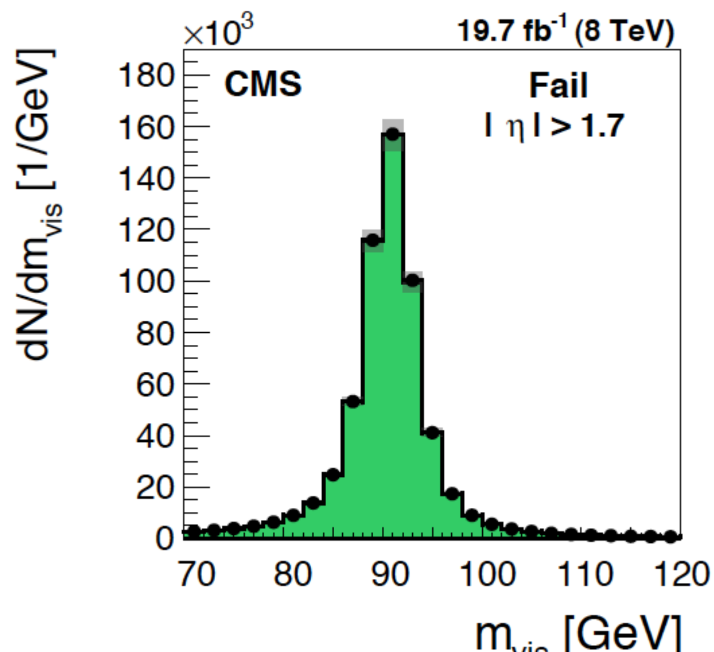
➔ Jet → τ_h fake-rate varies between 10^{-2} and 10^{-4} level, steeply falling with P_T

➔ Up to 20% difference between jet → τ_h fake-rate measured in data and MC simulation

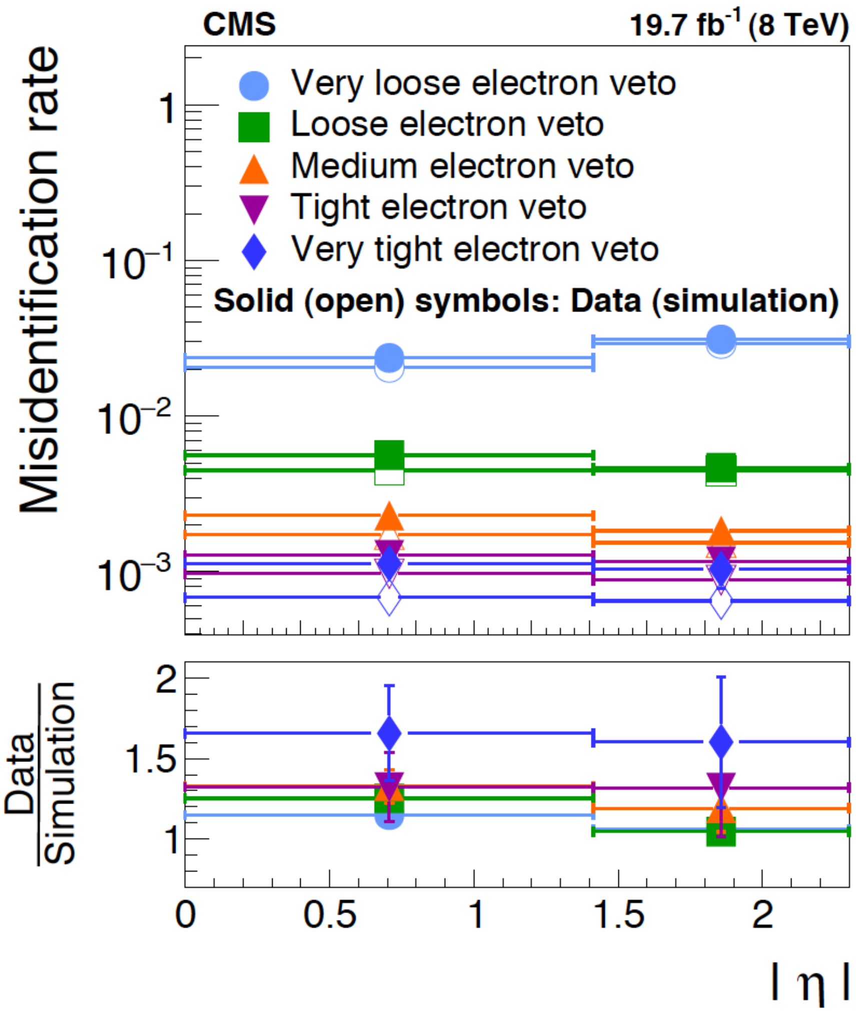
Measurement of e → τ_h and μ → τ_h Fake-rates

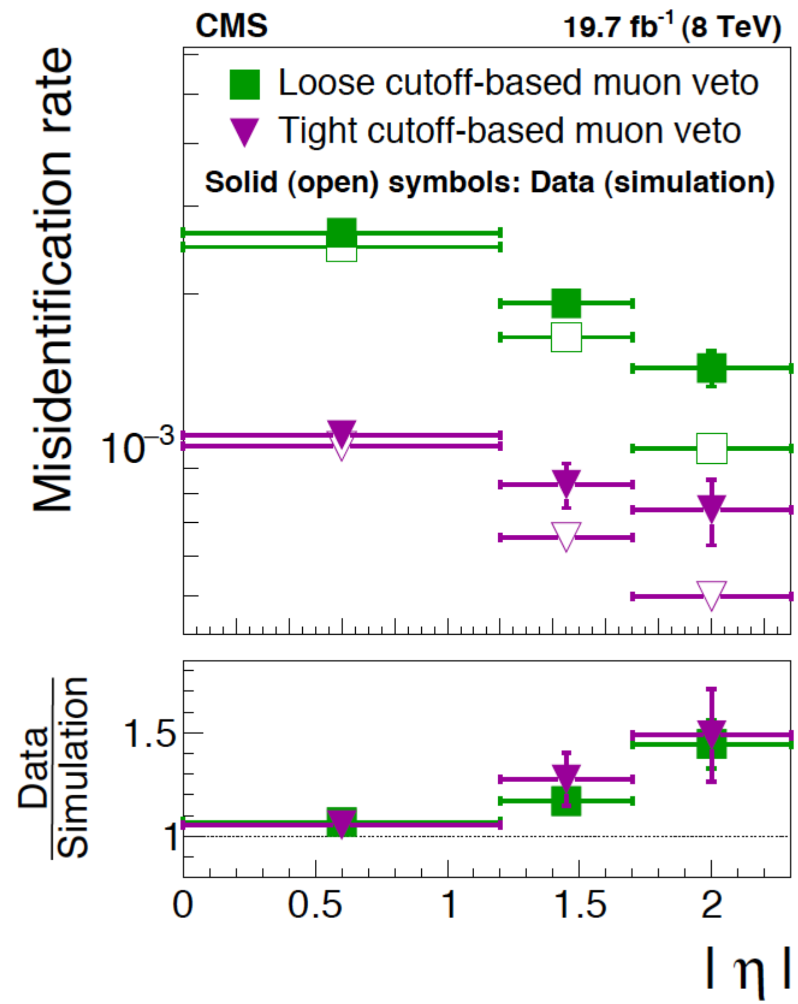
- Select Z/γ* → ee (Z/γ* → μμ) events passing single electron (single muon) trigger and containing at least one Tag and Probe pair
- Tag: well identified and isolated electron (muon) of $P_T > 30$ GeV ($P_T > 25$ GeV) && $|\eta| < 2.1$
- Probe: τ_h candidate of $P_T > 20$ GeV && $|\eta| < 2.3$, reconstructed by HPS algorithm, and of opposite charge as the Tag
- Fake-rate obtained from simultaneous fit of Tag+Probe mass distribution with shape templates for Z/γ* → ee (Z/γ* → μμ) signal and background processes





$e \rightarrow \tau_h$ and $\mu \rightarrow \tau_h$ Fake-rates





- ➔ $e \rightarrow \tau_h$ and $\mu \rightarrow \tau_h$ fake-rates reach per mille level
- ➔ Differences between data and MC simulation corrected for by applying suitable scale-factors on analysis level

Tau ID Improvements for Run 2

Tau decay mode reconstruction and charged isolation is affected little by pileup (PU) expected for run 2

➔ Preparation for run 2 concentrated on optimizing neutral isolation:

- ECAL timing cuts
- PU-weighted isolation

Backup

- Isolation based on "Pileup Per Particle Identification" (PUPPI) algorithm

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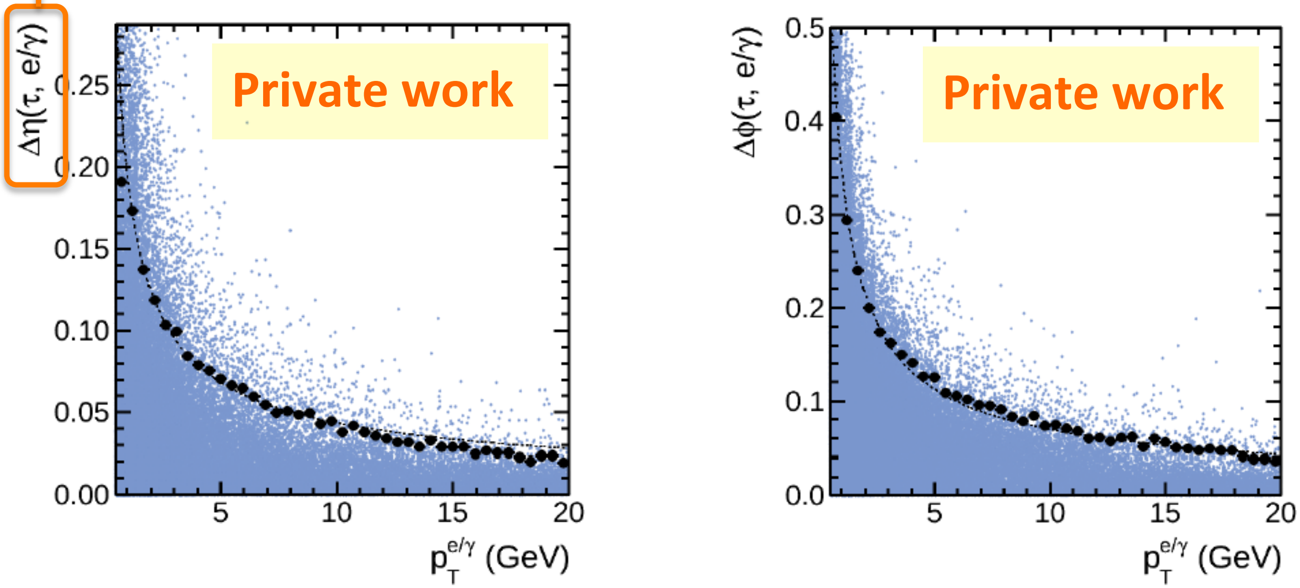
While optimizing the neutral isolation for run 2, we noticed that some ECAL energy deposits that are due to τ decay products fail to get included in the τ_h reconstruction

➔ Effect was on the level of few GeV, but caused significant decrease of tau ID efficiency in case tight neutral isolation cuts are applied

Dynamic Strip Reconstruction

Effect: Bending within 3.8 T magnetic field increases for e^+e^- pairs produced in photon conversions if electrons and positrons have low p_T

Distance between ECAL energy and generator level τ_h direction



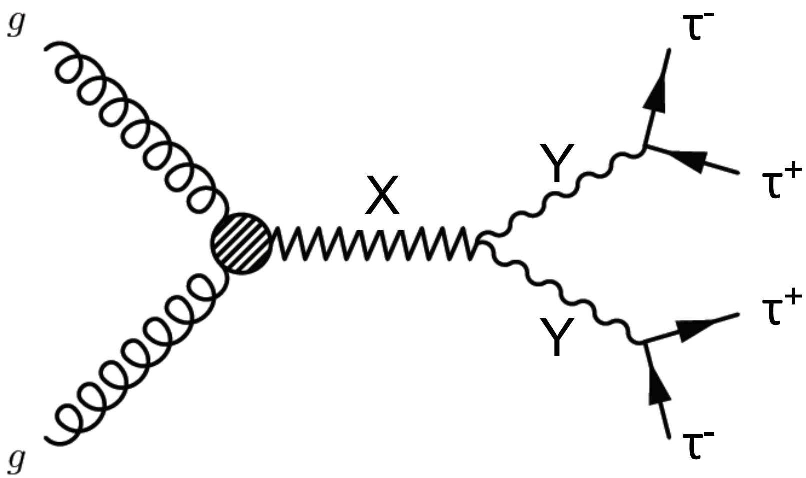
➔ Increase strip size in case photons have low p_T

Dynamic strip reconstruction is the default algorithm for run 2

➔ Allows to tighten neutral isolation cuts, yielding O(20%) reduction in jet → τ_h fake-rate for same tau ID efficiency as during run 1

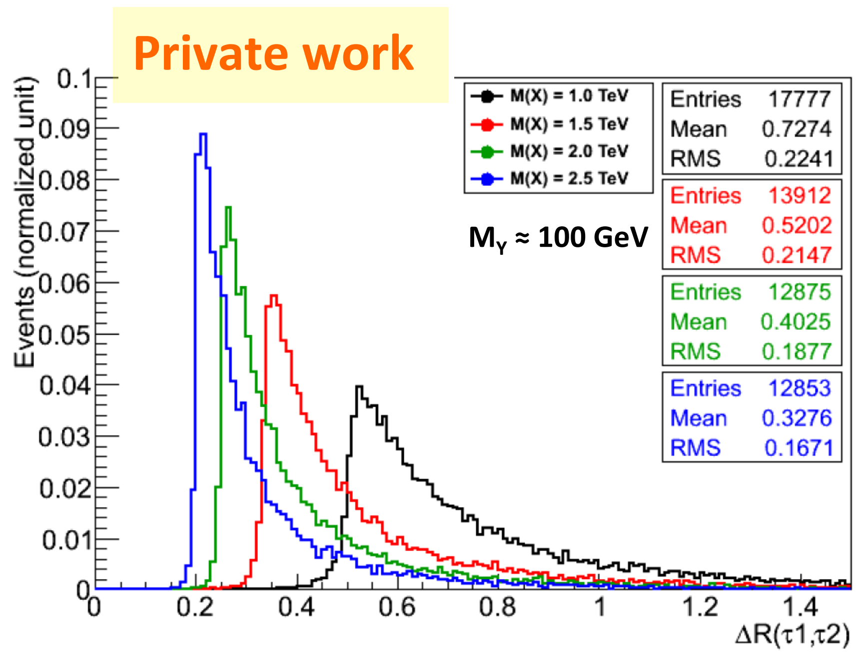
Reconstruction of "boosted" Taus

Taus produced in cascade decays of resonances of high mass($M_X \gg M_Y$) may overlap within dR < 0.5 in the detector, spoiling each other's isolation



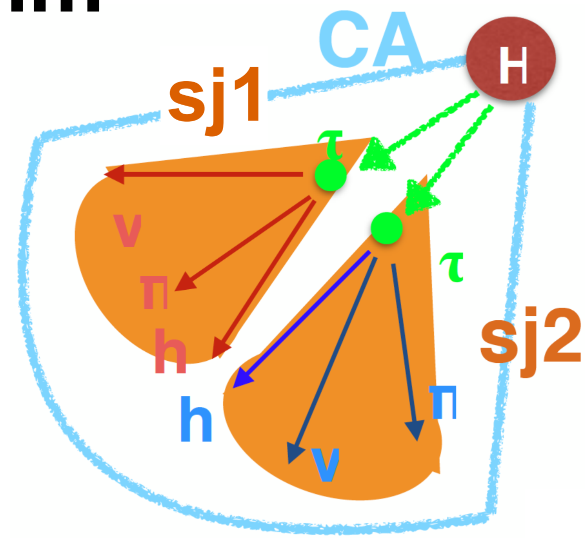
Angular separation between taus from Y decay approximately

$$\Delta R = \frac{2.0 \cdot M_Y}{P_T^Y} \quad , P_T^Y \approx \frac{M_X}{2}$$



➔ Efficiency of "standard" tau isolation decreases significantly when $M_X \geq 10 \cdot M_Y$

Boosted Tau Algorithm



Most analyses of tau lepton production include events with $\tau \rightarrow e\nu\nu$ and $\tau \rightarrow \mu\nu\nu$ decays

➔ Looking for generic approach that handles hadronic tau decays as well as decays to e/μ

Solution:

① Use subjet techniques to find the decay products of the 2 taus in a FatJet (decay products can be either e, μ or τ_h)

NB.: $M_\tau \ll M_Y$

➔ Mass-drop criteria can be very powerful

② Run standard tau reconstruction algorithm on each subjet

③ Match identified electrons and muons to subjets (e.g. by $\Delta R < 0.1$)

④ Compute e, μ and τ_h isolation ignoring particles associated to 2nd subjet within the same FatJet

Status of Boosted Taus in CMS

Algorithm has been used by search for Z' → Zh → qqττ in run 1

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- Subject finding efficiency = 92%
  (This efficiency needs to be "paid" only once for a pair of 2 taus)

- Efficiency to pass e, μ, τ_h isolation is a few % lower than for non-boosted taus ("standard" tau reconstruction and isolation do work)

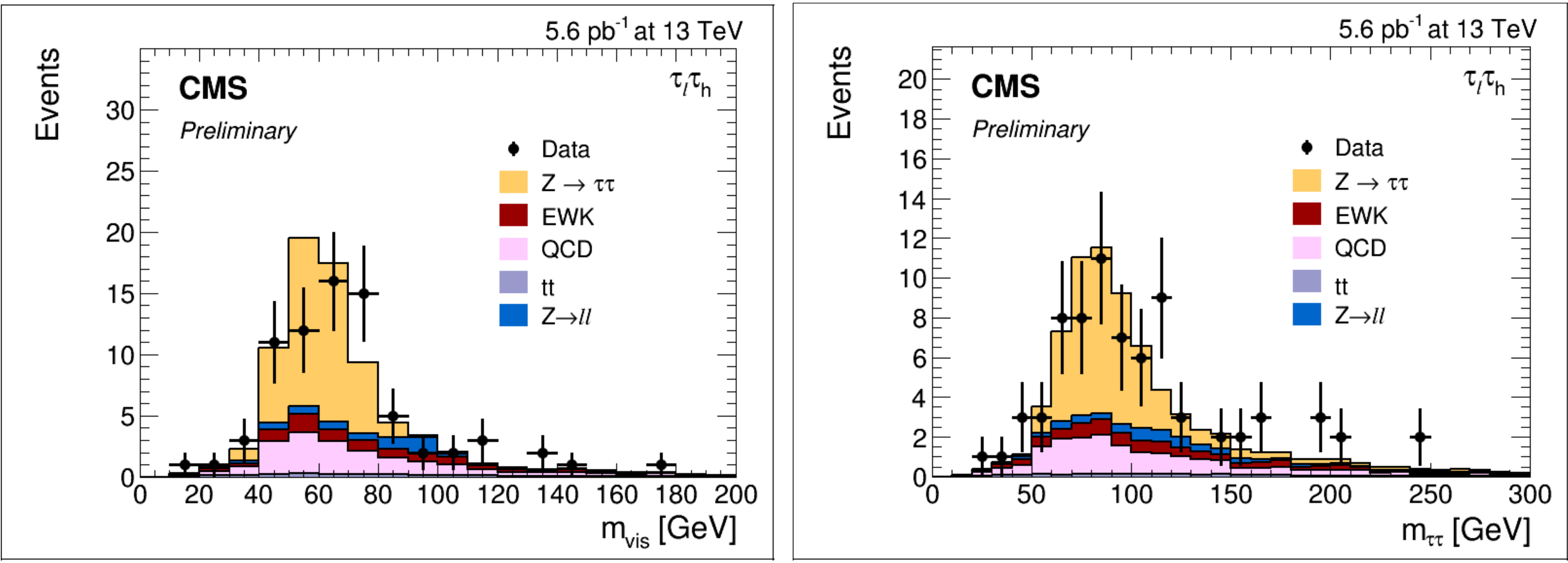
Plan: Boosted tau algorithm will be officially supported for CMS run 2 analyses

At the moment, the software is being finalized

How to validate the algorithm with data (in terms of efficiency and fake-rate) requires more though

$Z \rightarrow \tau\tau$ Signal in Run 2 Data

CMS-DP-2015/016



First $Z \rightarrow \tau\tau$ peak in CMS run 2 data, shown at summer conferences

Events selected in $e\tau_h$ and $\mu\tau_h$ channels (triggered by single lepton triggers)

QCD estimated from data, $Z \rightarrow \tau\tau$ signal and all other backgrounds taken from MC

➔ Tau ID works as expected in run 2 data (and SVfit works as expected too)

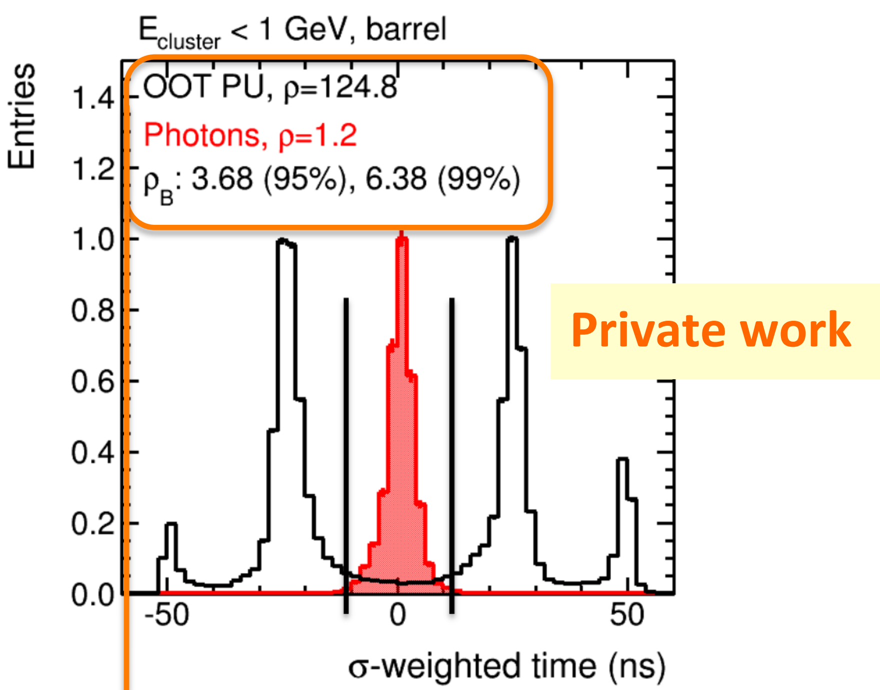
Summary

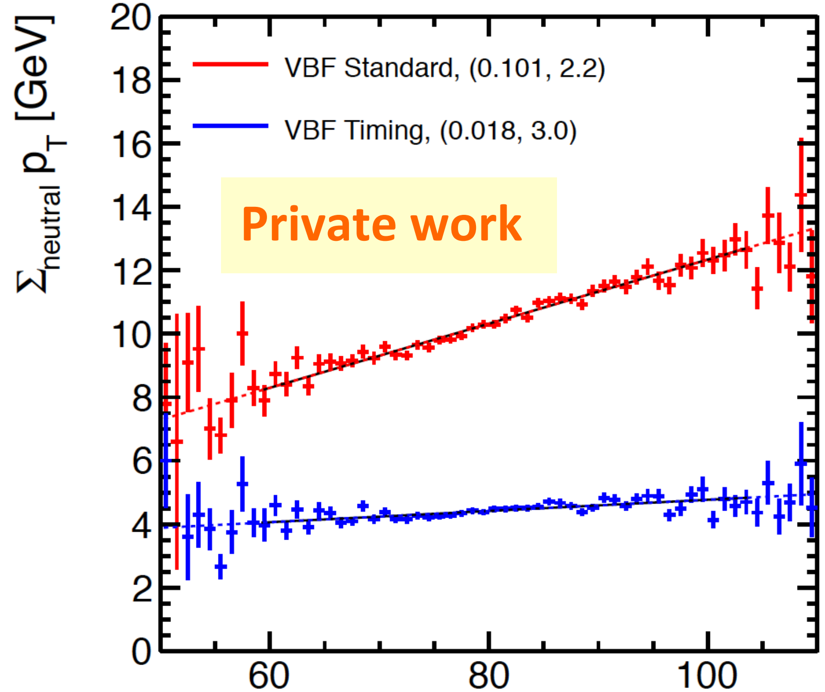
- The "Hadron plus Strips" (HPS) tau ID algorithm used during run 1 has recently been published **arXiv:1510.07488**
- The particle-flow and HPS algorithms will continue to be used for tau reconstruction and identification by CMS in run 2
- The dynamic strip reconstruction allows to tighten the neutral isolation cuts, reducing the jet → τ_h fake-rate by O(20%) for the same tau ID efficiency
- The MVA based tau identification algorithms have been retrained for run 2
- In summary, the CMS tau ID is prepared for run 2 and expected to provide a similar performance as in run 1

Backup

ECAL timing cuts

Neutral particles due to pileup from different bunch-crossings ("out-of-time" pileup) can be removed efficiently using ECAL timing information





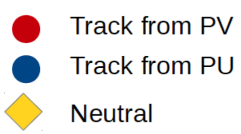
Number PU interactions in previous plus subsequent bunch-crossing

Energy due to out-of-time PU reduced by factor 20 (34) while keeping 99% (95%) of energy from current bunch-crossing

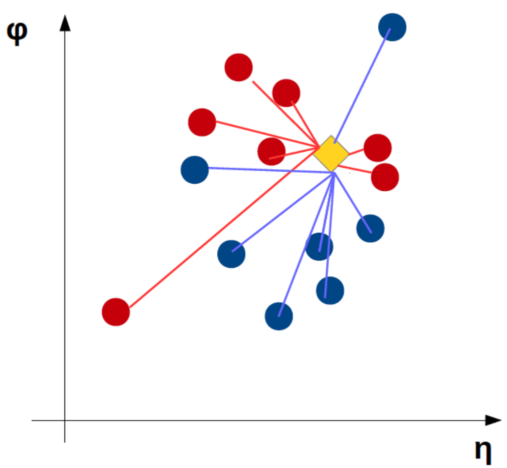
➔ Effect of out-of-time pileup reduced to small level

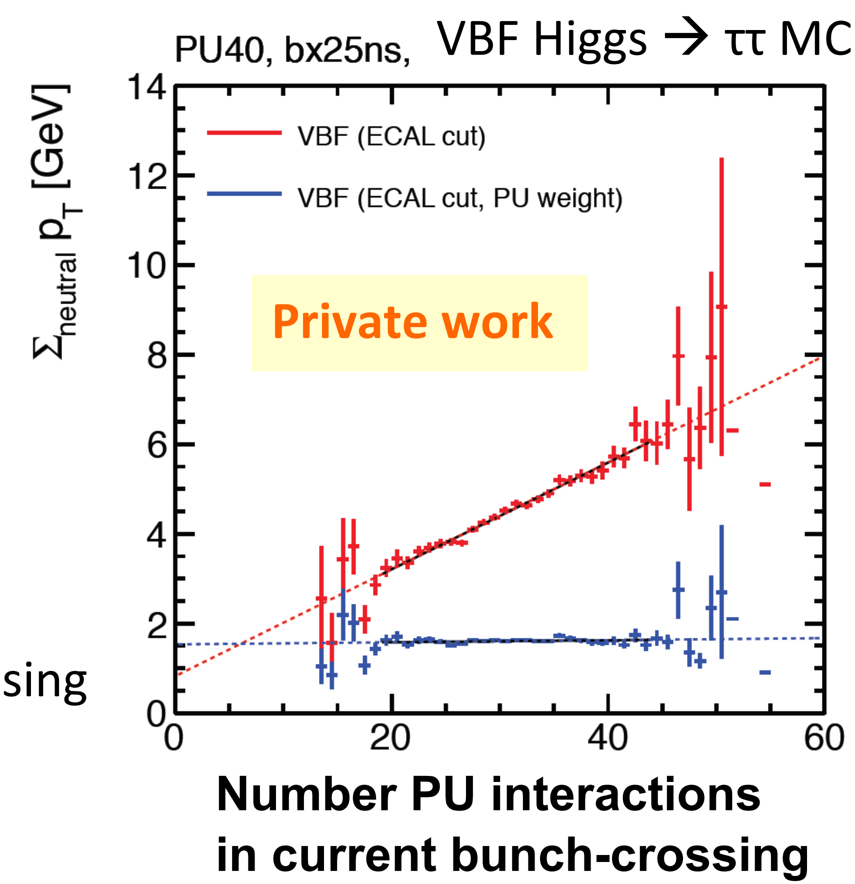
PU-weighted Isolation

Idea: weight neutral particles in isolation cone by local energy density of particles originating from PV and pileup (PU), estimated using tracks



$$w_{i,\log(p_T/\Delta R)} = \frac{\sum_{\mathrm{PV},j} \log(p_T/\Delta R_{ij})}{\sum_{\mathrm{PV},j} \log(p_T/\Delta R_{ij}) + \sum_{\mathrm{PU},k} \log(p_T/\Delta R_{ik})}$$





➔ Effect of pileup in current bunch-crossing ("in-time" PU) reduced to small level