Supplemental material

Full event selection

The complete set of selection requirements which defines the track-photon and tau-photon Signal Regions (SR) can be found in Table 1 and Table 2, respectively. Background enriched regions are defined for use in the background modelling and its validation. The Generation Region (GR) includes the object and event level requirements listed in the tables, as well as the requirements devised in order to suppress the background from $Z \to e^+e^-$ events. Validation regions (VR) are defined by applying one of the SR requirements to the events in the GR, as summarised in the tables.

Table 1: Summary of the track-photon selection. Photon calorimeter isolation and photon track isolation are imposed by requiring that the sum of transverse energies of calorimeter clusters not associated to the photon candidate but within a cone of $\Delta R = 0.4$ is less than 2.45 GeV $+ 0.022 \times p_{\mathrm{T}}(\gamma)$ and the sum of transverse momenta of tracks within a cone of $\Delta R = 0.2$, excluding possible conversion tracks, is less than 5% of $p_{\mathrm{T}}(\gamma)$, respectively. Track isolation is imposed by requiring that the sum of transverse momenta of tracks within $\Delta R = 0.2$, excluding the candidate track, is less than 14% of its p_{T}.

Baseline selection
Photon requirements: $p_{\mathrm{T}} > 30$ GeV or $p_{\mathrm{T}} > 35$ GeV, dependent on specific trigger $\lvert\eta\rvert < 2.37$, excluding $1.37 < \lvert\eta\rvert < 1.52$ *Tight* identification
Track requirements: $p_{\mathrm{T}} > 30$ GeV, $\lvert\eta\rvert < 2.5$ *Tight Primary* identification
Event requirements: $\eta(M) \times \eta(\gamma) \geq 0$ if track and γ in endcap ($\lvert\eta(M)\rvert > 1.5$ and $\lvert\eta(\gamma)\rvert > 1.37$) $\Delta\Phi(M, \gamma) > \pi/2$
$Z \to e^+e^-$ suppression requirements: TRT electron likelihood discriminant $\leq$ 10% or TRT electron likelihood discriminant > 10% if hadronic leakage > 3%
GR selection: baseline + $Z \to e^+e^-$ suppression requirements **VR1 selection:** GR + $p_{\mathrm{T}}(M) > 33$ GeV **VR2a selection:** GR + Photon calorimeter isolation **VR2b selection:** GR + Photon track isolation **VR3 selection:** GR + Track isolation **SR selection:** all requirements

Table 2: Summary of the tau-photon selection. Photon calorimeter isolation and photon track isolation are imposed by requiring that the sum of transverse energies of calorimeter clusters not associated to the photon candidate but within a cone of $\Delta R = 0.4$ is less than 2.45 GeV $+ 0.022 \times p_{\mathrm{T}}(\gamma)$ and the sum of transverse momenta of tracks within a cone of $\Delta R = 0.2$, excluding possible conversion tracks, is less than 5% of $p_{\mathrm{T}}(\gamma)$, respectively.

Baseline selection
Photon requirements: $p_{\mathrm{T}} > 36$ GeV $\lvert\eta\rvert < 2.37$, excluding $1.37 < \lvert\eta\rvert < 1.52$ *Tight* identification Photon calorimeter isolation Photon track isolation
Tau requirements: $h^{\pm}\pi^{0}$ decay mode $p_{\mathrm{T}} > 26$ GeV $\lvert\eta\rvert < 2.5$, $1.37 < \lvert\eta\rvert < 1.52$ *Medium* identification working point
Event requirements: $\Delta\Phi(\tau_{\text{had-vis}}, \gamma) > 2$
$Z \to e^{+}e^{-}$ suppression requirements: *Tight* electron-tau discriminant working point $E_T(\tau)/p_T(\text{trk}) > 2.4$ $\Delta R_{\tau}^{\max} > 0.036$ TRT electron likelihood discriminant < 0.9
GR selection: baseline + $Z \to e^{+}e^{-}$ suppression requirement **VR1 selection:** GR + $p_{\mathrm{T}}(\tau_{\text{had-vis}}) > 30$ GeV **VR2 selection:** GR + $\Delta R_{\tau}^{\max} < 0.065$ **VR3 selection:** GR + $\log(\lvert d_0(\tau_{\text{had-vis}})\rvert) < -1.2$ **SR selection:** all requirements

Multijet background modeling

Multijet pseudo-events are generated through ancestral sampling using multi-dimensional PDFs. Each pseudo-event is fully described by the meson and photon four-vectors and by the additional variables used in selection criteria applied to GRs that define SRs. The sampling procedures used to generate multijet pseudo-events in the track-photon and tau-photon selections are detailed below and illustrated in Fig. 1. The candidate meson is described in terms of the object used to reconstruct it i.e. a track and a hadronic τ lepton in the track-photon and tau-photon selections, respectively.

Track-photon

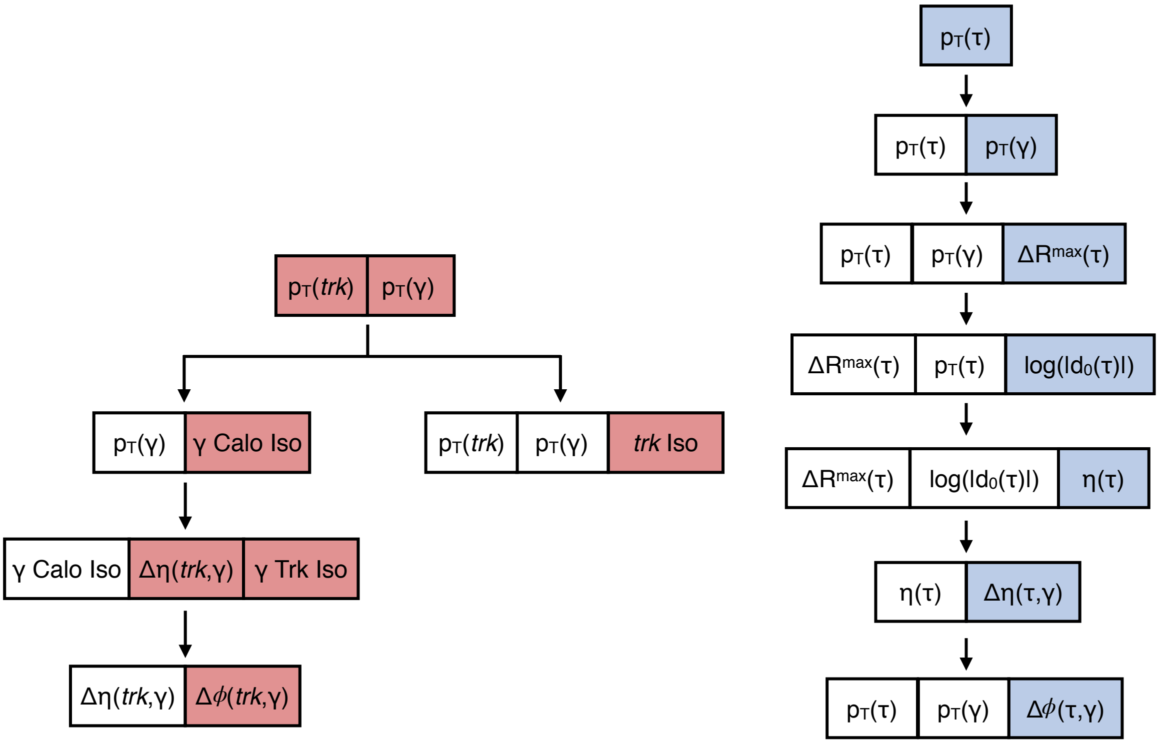
1. $p_{\mathrm{T}}(trk)$ and $p_{\mathrm{T}}(\gamma)$ are sampled simultaneously from a two-dimensional template.
2. Track isolation is described in bins of $p_{\mathrm{T}}(\gamma)$ and $p_{\mathrm{T}}(trk)$ using a three-dimensional template. Given the values sampled in step 1, the template is projected along the track isolation and a value of track isolation is randomly sampled.
3. Photon calorimeter isolation is described in bins of $p_{\mathrm{T}}(\gamma)$. A value for photon calorimeter isolation is sampled from the bin corresponding to the $p_{\mathrm{T}}(\gamma)$ value sampled in step 1.
4. $\Delta\eta(trk,\gamma)$ and photon track isolation are described in bins of photon calorimeter isolation using a three-dimensional template. $\Delta\eta(trk,\gamma)$ and photon track isolation are sampled simultaneously from the two-dimensional projection corresponding to the photon calorimeter isolation value obtained in the step 3.
5. $\Delta\phi(trk,\gamma)$ is described in bins of $\Delta\eta(trk,\gamma)$ using a two-dimensional template. Based on the value of $\Delta\eta(trk,\gamma)$ obtained in step 4, the template is projected along the $\Delta\phi(trk,\gamma)$ and a value for $\Delta\phi(trk,\gamma)$ is sampled.
6. $\eta(trk)$ and $\phi(trk)$ are sampled independently from the corresponding one-dimensional templates.

Tau-photon

1. $p_{\mathrm{T}}(\tau)$ is sampled from the corresponding one-dimensional template.
2. $p_{\mathrm{T}}(\gamma)$ is sampled from the distribution obtained projecting the two-dimensional template of $p_{\mathrm{T}}(\gamma)$, $p_{\mathrm{T}}(\tau)$ along $p_{\mathrm{T}}(\gamma)$ using the value of $p_{\mathrm{T}}(\tau)$ obtained in step 1.
3. $\Delta R_{\tau}^{\max}$, defined as the ΔR between the pion track associated to the τ and the τ axis, is described in bins of $p_{\mathrm{T}}(\tau)$ and $p_{\mathrm{T}}(\gamma)$. Using the values of $p_{\mathrm{T}}(\tau)$ and $p_{\mathrm{T}}(\gamma)$ previously obtained, the three-dimensional distribution is projected along ΔR and a value for ΔR is sampled.
4. $\log(|d_0(\tau)|)$, where d_0 is defined as the track transverse impact parameter of the τ track, is sampled as a function of $p_{\mathrm{T}}(\tau)$ and $\Delta R_{\tau}^{\max}$ using the same technique described in step 3.
5. $\eta(\tau)$ is sampled as a function of $\log(|d_0(\tau)|)$ and $\Delta R_{\tau}^{\max}$ using the same technique described in the previous step.
6. $\Delta\eta(\tau,\gamma)$ is sampled from the projection of the two-dimensional distribution of $\Delta\eta(\tau,\gamma)$ and $\eta(\tau)$ using $\eta(\tau)$ obtained in the previous step.

7. $\Delta\phi(\tau,\gamma)$ is sampled from the projection of the three-dimensional template of $\Delta\phi(\tau,\gamma)$, $p_{\mathrm{T}}(\tau)$, $p_{\mathrm{T}}(\gamma)$ defined by the values previously obtained.

8. $\phi(\tau)$ is sampled independently from the corresponding one-dimensional template.



(a) (b)

Figure 1: Graphical representation of the sampling sequence used in the generation of multijet pseudo-events in the (a) track-photon selection, (b) tau-photon selection. Variables not shown explicitly are sampled in a factorized, uncorrelated manner from one-dimensional templates. Groups of two(three) variables represent two(three)-dimensional templates. Arrows are used to show the sequential order of steps in the sampling. Variables are highlighted with color at the step in which they are defined for each pseudo-candidate.