

# CMS Draft Analysis Note

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## Search for Higgs boson decays to long-lived scalar particles to SM $\tau$ final state with Regions of Interest construction

S. Kim

Florida State University

### Abstract

We present a search for long-lived particles (LLPs) produced in gluon fusion Higgs production mode (ggH), using the novel Regions of Interest strategy. Regions of Interest (ROIs) are formed as a collection of pair-wise track vertices fitted by the V0Fitter in CMSSW. The analysis focuses on lifetime of LLPs in the tracker region, with concentration on the ggH mode for the highest Higgs production cross-section. Variables of the constructed ROIs become inputs for our Deep Neural Network (DNN) Machine Learning (ML) algorithms, as a main discriminator between the signal and the background. We focus on the  $\tau$  SM fermion final state. This final state is particularly interesting, given  $\tau$  final state exclusion limits are frequently omitted in precedent analysis, due to  $\tau$  fermions' non trivial final state reconstruction. No excess of events over the standard model expectation is observed. The results are interpreted in the context of exotic Higgs decays to a pair of long-lived scalars (S). We set limits on the branching ratio of the Higgs to LLPs,  $\mathcal{B}(H \rightarrow SS)$ , as a function of the proper lifetime.

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## 1 Introduction

Discovery of particles at the electroweak scale, such as the top quark at Fermilab's CDF and D0 [1, 2] and the Higgs Boson at Large Hadron Collider (LHC) in CERN [3, 4], led to discovery of all constituents in the standard model (SM). SM helps to describe the nature of fundamental particles and their interactions with precision. In spite of its success, the SM suffers from a few obstacles. The evidence of neutrino mass and mixing [5], the observation of bullet clusters confirming the presence of dark matter (DM) [6–10], baryon asymmetry [11] remain unsolved in the framework of SM. In addition, SM suffers from the naturalness problem. To solve all such issues, one needs to look for Beyond Standard Model (BSM).

The naturalness problem stems from that the Higgs in the SM is a scalar particle. Unlike fermions or gauge bosons, its mass is not protected by any symmetry and subject to large radiative corrections, especially from top quark loop. Thus, for the SM to be valid up to the Planck or Grand Unification Theory (GUT) scale, the radiative corrections are enormous. One needs un-natural amount of fine tuning to fit the Higgs mass at the observed value of 125 GeV. One of the most popular solutions to this problem is Supersymmetry (SUSY), which assigns chirality to the Higgs particle. SUSY solves correction problem, neutrino masses, and provides candidate of DM. Unfortunately, LHC has found no significant excess over the SM background in their search for SUSY[? ]. Although the non-observation of superpartners does not invalidate SUSY, it makes less attractive among the particle physics community. Non-observation of superpartners, particularly the stop (scalar partner of the top quark) has pushed its mass beyond 1 TeV. This generated problem of "little hierarchy", but an alternative solution of "neutral naturalness" remains.

In framework of neutral naturalness, top partners are not charged under the SM color group. Because of being colorless, its cross-section of production is much less, and the present limits on the top partner particles are well below 1 TeV. Examples of neutral naturalness models are Twin Higgs [12], Folded SUSY [13], and Quirky Little Higgs [14]. Theoretical models provide the possibility of neutral LLPs, which may be produced in the proton-proton collisions of the LHC and decay back into SM particles far from the interaction point (IP).[15]

Interest in neutral naturalness models has increased in recent years after the realization that they can lead to the production of long-lived particles detectable at the LHC [16, 17]. For instance, in many of Mirror and Twin SM models, only SM Higgs boson can interact with both SM QCD and mirror QCD partners. If the mirror QCD gluons could form scalar glueballs, the SM Higgs boson can become a portal between the SM and BSM mirror QCD scalar glueballs. BSM mirror QCD scalar glueballs can only decay back to SM particles via Higgs portal as well. Since the decay like an offshell Higgs boson, its crosssections are highly suppressed. At the same time, decay branching ratio to highest mass fermions will be highest following the Yukawa couplings. Thus, they may decay into b quarks or tau leptons depending on the mirror scalar's mass. The displaced decays of the scalars will lead to exotic signatures in the LHC, such as distant innermost tracker hit, displaced vertices, and displaced jets. The long-lived scalar model is shown in the left-panel of Figure ??.

Searches for LLPs decaying into final states containing jets were carried out at the Tevatron ( $\sqrt{s} = 1.96$  TeV) by both the CDF [18] and D0 [19] Collaborations, at the LHC by the ATLAS and LHCb Collaborations at  $\sqrt{s} = 7$  TeV [20, 21], by the ATLAS, CMS and LHCb Collaborations at  $\sqrt{s} = 8$  TeV [22–28] and more by the CMS Collaboration [29–34] and ATLAS Collaboration [35–46] at  $\sqrt{s} = 13$  TeV. Most recently, CMS Collaboration released a result, in which Higgs are created in association with Z vector boson [47], for better probe into lighter scalar mass with help of clean dilepton trigger. To date, no search has observed evidence of BSM LLPs.

Although exclusion limit on  $b$  and  $d$ -quarks were set below 1 for analysis above, exclusion limit for  $\tau$  final state has been oftenly omitted or published with value above 1. Displaced Jets analysis face challenges for  $\tau$  final state given its hadronic and leptonic decay mode and complicated reconstruction mechanism. However, Leptophilic model for Twin Higgs and other Higgs models are also highly motivated [48]. Continuous neglect of  $\tau$  final state limit is not only a good practice, but also overlooking an important undiscovered phase space. This analysis searches for Higgs Portal model with Higgs' Leptophilic nature with focus on the limit value of  $\tau$  final state. The 55GeV maximum mass is to investigate only on-shell neutral scalar particles from the Higgs. Minimum 7GeV is for scalar particles to create on-shell tau-lepton pairs. Feynman diagram of the scalar particle production mechanism is depicted in figure 1. Since these scalar particles decay from the Higgs Boson, they can only be observed in high-energy particle collider, such as the LHC. The analysis uses data obtained from the Compact Muon Solenoid (CMS), one of the LHCs located in CERN.

Most CMS searches are not optimal for detecting Higgs boson decays to displaced-jets due to the soft  $p_T$  nature of its decays products – the new scalars. Low HT signature becomes particularly more difficult with long lived signature. Higgs produced in association with Z vector boson analysis [47] overcame this barrier with help of dilepton trigger. Although ggH production mode gives the largest Higgs crosssection, it complicates the trigger strategy even further. This analysis exploits the  $\tau$  lepton's leptonic decay mode into a soft muon by with trigger of B Parking HLT Path implemented in 2018.

Another challenge for  $\tau$  lepton analysis is different decay modes of  $\tau$  leptons.  $\tau$  leptons decay hadronically and leptonically with several different sub-decay modes. Developing analysis strategies to optimize search for each sub-decay modes are extremely complicated, a main reason for omission or no good exclusion limit in precedent CMS results. To be inclusive all  $\tau$  leptons' decay modes, displaced vertex search can be more efficient than displace object (jet,muon,electrons). We exploit the newly developed Regions of Interest mechanism in the tracker volume. Regions of Interest (ROI) form displaced vertex candidates by fitting pair-wise tracks of Lost-tracks and PackedPFCandidates class in MINIAOD into a vertex. ROIs save all relevant track and fitted vertex qualities along with isolation information. These variables are used as input for Machine Learning (ML) algorithms, enabling a highly generic and data-scientific search method.

The rest of this note is organized as follows. In Section 2, we describe the datasets and Monte Carlo samples, including those of the signal model, used in the search. The physics objects and formation of Regions of Interest are described in Section 3. The trigger strategy and event selections are presented in Section 4. Section ?? describes the data driven background estimate and its validation. Section ?? describes the systematic uncertainties. Finally, Section ?? presents the results of the search. We conclude with Section ??.

## 2 Data and simulated samples

### 2.1 Data samples

The analysis uses B Parking datasets. Data was collected during 2018 of Run 2 and corresponds to an integrated luminosity of  $41 \text{ fb}^{-1}$ .

Table 1: Datasets used in the analysis: and 2018.

Data sample	Integrated Luminosity ( $\text{fb}^{-1}$ )
/ParkingBPH1/Run2018A-05May2019-v1/MINIAOD	0.866
/ParkingBPH2/Run2018A-05May2019-v1/MINIAOD	0.866
/ParkingBPH3/Run2018A-05May2019-v1/MINIAOD	0.866
/ParkingBPH4/Run2018A-05May2019-v1/MINIAOD	0.866
/ParkingBPH5/Run2018A-05May2019-v1/MINIAOD	0.866
/ParkingBPH6/Run2018A-05May2019-v1/MINIAOD	0.866
Total	5.20
/ParkingBPH1/Run2018B-05May2019-v2/MINIAOD	1.083
/ParkingBPH2/Run2018B-05May2019-v2/MINIAOD	1.083
/ParkingBPH3/Run2018B-05May2019-v2/MINIAOD	1.083
/ParkingBPH4/Run2018B-05May2019-v2/MINIAOD	1.083
/ParkingBPH5/Run2018B-05May2019-v2/MINIAOD	1.083
/ParkingBPH6/Run2018B-05May2019-v2/MINIAOD	1.083
Total	6.49
/ParkingBPH1/Run2018C-05May2019-v1/MINIAOD	1.079
/ParkingBPH2/Run2018C-05May2019-v1/MINIAOD	1.079
/ParkingBPH3/Run2018C-05May2019-v1/MINIAOD	1.079
/ParkingBPH4/Run2018C-05May2019-v1/MINIAOD	1.079
/ParkingBPH5/Run2018C-05May2019-v1/MINIAOD	1.079
Total	5.39
/ParkingBPH1/Run2018D-05May2019promptD-v1/MINIAOD	6.542
/ParkingBPH2/Run2018D-05May2019promptD-v1/MINIAOD	6.542
/ParkingBPH3/Run2018D-05May2019promptD-v1/MINIAOD	6.542
/ParkingBPH4/Run2018D-05May2019promptD-v1/MINIAOD	6.542
/ParkingBPH5/Run2018D-05May2019promptD-v1/MINIAOD	6.542
Total	32.7
ParkingBPH Total	50.78

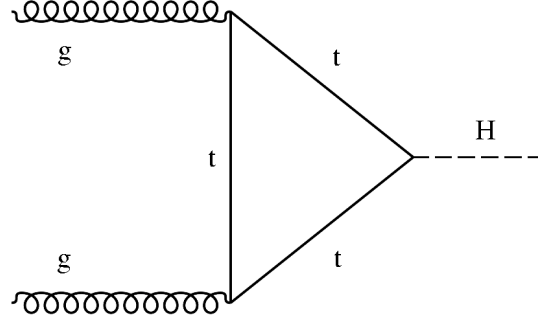
### 2.2 Monte Carlo Samples

#### 2.2.1 Signal Model and Simulation

The ggH process (see Figure 1) is generated at next-to-next-to-leading order (NNLO) and next-to-next-to-leading-log (NNLL) QCD and next-to-leading order (NLO) EW accuracies [49]. The Higgs boson mass is set to 125 GeV for all signal samples. The cross sections, computed at NNLO+NNLL QCD and NLO EW accuracies and obtained from the CERN Report 3, are 4.414 pb. The CMS detector response is modeled with GEANT4 [50].

Table 2 lists the signal Monte Carlo samples.

Figure 1: Leading Feynman diagrams for ggH production mode

Table 2:  $gg(h \rightarrow ss \rightarrow \tau\bar{\tau}\tau\bar{\tau})$  Signal Monte Carlo samples.

Sample
/ggH.HToSSTo4Tau.MH-125.TuneCP5.13TeV-powheg-pythia8/CAMPAIGN/MINIAODSIM
/ggH.HToSSTo4Tau.MH-125.MS-55.ctauS-1.TuneCP5.13TeV-powheg-pythia8/CAMPAIGN/MINIAODSIM
/ggH.HToSSTo4Tau.MH-125.MS-55.ctauS-10.TuneCP5.13TeV-powheg-pythia8/CAMPAIGN/MINIAODSIM
/ggH.HToSSTo4Tau.MH-125.MS-55.ctauS-100.TuneCP5.13TeV-powheg-pythia8/CAMPAIGN/MINIAODSIM
/ggH.HToSSTo4Tau.MH-125.MS-55.ctauS-1000.TuneCP5.13TeV-powheg-pythia8/CAMPAIGN/MINIAODSIM
/ggH.HToSSTo4Tau.MH-125.MS-40.ctauS-1.TuneCP5.13TeV-powheg-pythia8/CAMPAIGN/MINIAODSIM
/ggH.HToSSTo4Tau.MH-125.MS-40.ctauS-10.TuneCP5.13TeV-powheg-pythia8/CAMPAIGN/MINIAODSIM
/ggH.HToSSTo4Tau.MH-125.MS-40.ctauS-100.TuneCP5.13TeV-powheg-pythia8/CAMPAIGN/MINIAODSIM
/ggH.HToSSTo4Tau.MH-125.MS-40.ctauS-1000.TuneCP5.13TeV-powheg-pythia8/CAMPAIGN/MINIAODSIM
/ggH.HToSSTo4Tau.MH-125.MS-15.ctauS-1.TuneCP5.13TeV-powheg-pythia8/CAMPAIGN/MINIAODSIM
/ggH.HToSSTo4Tau.MH-125.MS-15.ctauS-10.TuneCP5.13TeV-powheg-pythia8/CAMPAIGN/MINIAODSIM
/ggH.HToSSTo4Tau.MH-125.MS-15.ctauS-100.TuneCP5.13TeV-powheg-pythia8/CAMPAIGN/MINIAODSIM
/ggH.HToSSTo4Tau.MH-125.MS-15.ctauS-1000.TuneCP5.13TeV-powheg-pythia8/CAMPAIGN/MINIAODSIM
/ggH.HToSSTo4Tau.MH-125.MS-7.ctauS-1.TuneCP5.13TeV-powheg-pythia8/CAMPAIGN/MINIAODSIM
/ggH.HToSSTo4Tau.MH-125.MS-7.ctauS-10.TuneCP5.13TeV-powheg-pythia8/CAMPAIGN/MINIAODSIM
/ggH.HToSSTo4Tau.MH-125.MS-7.ctauS-100.TuneCP5.13TeV-powheg-pythia8/CAMPAIGN/MINIAODSIM
/ggH.HToSSTo4Tau.MH-125.MS-7.ctauS-1000.TuneCP5.13TeV-powheg-pythia8/CAMPAIGN/MINIAODSIM

An example PYTHIA v8.230 fragment for the Higgs decay to scalars (scalars) and their subsequent decay to tau leptons is given below. In this example the mass of the scalar is 15 GeV and its lifetime ( $c\tau$ ) is 10,000 mm.

```
'90000006:all = sk skbar 0 0 0 15 1.9732e-17 1.0 75.0 10000',
'90000006:oneChannel = 1 1.0 101 15 -15',
'90000006:mayDecay = on',
'90000006:isResonance = on',
'25:m0 = 125.0',
'25:onMode = off',
'25:addChannel = 1 0.000000001 101 90000006 -90000006',
'25:onIfMatch = 90000006 -90000006',
'90000006:onMode = off',
'90000006:onIfAny = 5',
```

## 2.2.2 Background Monte Carlo

All samples were processed as recommended in the PPD Run2 Analysis Guideline [51]. Tables ??-6 summarizes the background Monte Carlo used in this analysis.

a



Table 3: QCD MuEnriched Pt5 background Monte Carlo samples, RunIIAutumn18MiniAOD-102X\_upgrade2018\_realistic\_v15

Sample
/QCD_Pt-15to20_MuEnrichedPt5_TuneCP5_13TeV_pythia8/*-v3/MINIAODSIM
/QCD_Pt-20to30_MuEnrichedPt5_TuneCP5_13TeV_pythia8/*-v4/MINIAODSIM
/QCD_Pt-30to50_MuEnrichedPt5_TuneCP5_13TeV_pythia8/*-v3/MINIAODSIM
/QCD_Pt-50to80_MuEnrichedPt5_TuneCP5_13TeV_pythia8/*-v3/MINIAODSIM
/QCD_Pt-80to120_MuEnrichedPt5_TuneCP5_13TeV_pythia8/*_ext1-v2/MINIAODSIM
/QCD_Pt-120to170_MuEnrichedPt5_TuneCP5_13TeV_pythia8/*_ext1-v2/MINIAODSIM
/QCD_Pt-170to300_MuEnrichedPt5_TuneCP5_13TeV_pythia8/*-v3/MINIAODSIM
/QCD_Pt-300to470_MuEnrichedPt5_TuneCP5_13TeV_pythia8/*_ext3-v1/MINIAODSIM
/QCD_Pt-470to600_MuEnrichedPt5_TuneCP5_13TeV_pythia8/*_ext1-v2/MINIAODSIM
/QCD_Pt-600to800_MuEnrichedPt5_TuneCP5_13TeV_pythia8/*-v1/MINIAODSIM
/QCD_Pt-800to1000_MuEnrichedPt5_TuneCP5_13TeV_pythia8/*_ext3-v2/MINIAODSIM
/QCD_Pt-1000toInf_MuEnrichedPt5_TuneCP5_13TeV_pythia8/*-v1/MINIAODSIM

Table 4: W,Z,H background Monte Carlo samples, RunIIAutumn18MiniAOD-102X\_upgrade2018\_realistic\_v15

Sample
/DYJetsToLL_M-50_TuneCP5_13TeV-madgraphMLM-pythia8/*-v1/MINIAODSIM
/WJetsToLNu_M-50_TuneCP5_13TeV-madgraphMLM-pythia8/*-v2/MINIAODSIM
/WW_M-50_TuneCP5_13TeV-madgraphMLM-pythia8/*-v2/MINIAODSIM
/WZ_M-50_TuneCP5_13TeV-madgraphMLM-pythia8/*-v3/MINIAODSIM
/ZZ_M-50_TuneCP5_13TeV-madgraphMLM-pythia8/*-v2/MINIAODSIM
/GluGluHToBB_M125_13TeV_amcatnloFXFX-pythia8/*-v1/MINIAODSIM

Table 5: Top background Monte Carlo samples, RunIIAutumn18MiniAOD-102X\_upgrade2018\_realistic\_v15

Sample
/TTJets_TuneCP5_13TeV-madgraphMLM-pythia8/*-v1/MINIAODSIM
/ST_s-channel_4f_hadronicDecays_TuneCP5_13TeV-madgraph-pythia8/*_ext1-v1/MINIAODSIM
/ST_t-channel_top_5f_TuneCP5_13TeV-powheg-pythia8/*-v1/MINIAODSIM
/ST_t-channel_antitop_5f_TuneCP5_13TeV-powheg-pythia8/*-v1/MINIAODSIM
/ST_tW_antitop_5f_inclusiveDecays_TuneCP5_13TeV-powheg-pythia8/*_ext1-v1/MINIAODSIM
/ST_tW_top_5f_inclusiveDecays_TuneCP5_13TeV-powheg-pythia8/*_ext1-v1/MINIAODSIM



Table 6: Monte Carlo sample summary, RunIIAutumn18DRPremix-102X\_upgrade2018\_realistic\_v15

Sample
/QCD_Pt-15to20_MuEnrichedPt5_TuneCP5_13TeV_pythia8/*-v3/MINIAODSIM
/QCD_Pt-20to30_MuEnrichedPt5_TuneCP5_13TeV_pythia8/*-v4/MINIAODSIM
/QCD_Pt-30to50_MuEnrichedPt5_TuneCP5_13TeV_pythia8/*-v3/MINIAODSIM
/QCD_Pt-50to80_MuEnrichedPt5_TuneCP5_13TeV_pythia8/*-v3/MINIAODSIM
/QCD_Pt-80to120_MuEnrichedPt5_TuneCP5_13TeV_pythia8/*_ext1-v2/MINIAODSIM
/QCD_Pt-120to170_MuEnrichedPt5_TuneCP5_13TeV_pythia8/*_ext1-v2/MINIAODSIM
/QCD_Pt-170to300_MuEnrichedPt5_TuneCP5_13TeV_pythia8/*-v3/MINIAODSIM
/QCD_Pt-300to470_MuEnrichedPt5_TuneCP5_13TeV_pythia8/*_ext3-v1/MINIAODSIM
/QCD_Pt-470to600_MuEnrichedPt5_TuneCP5_13TeV_pythia8/*_ext1-v2/MINIAODSIM
/QCD_Pt-600to800_MuEnrichedPt5_TuneCP5_13TeV_pythia8/*-v1/MINIAODSIM
/QCD_Pt-800to1000_MuEnrichedPt5_TuneCP5_13TeV_pythia8/*_ext3-v2/MINIAODSIM
/QCD_Pt-1000toInf_MuEnrichedPt5_TuneCP5_13TeV_pythia8/*-v1/MINIAODSIM
/DYJetsToLL_M-50_TuneCP5_13TeV-madgraphMLM-pythia8/*-v1/MINIAODSIM
/WJetsToLNu_M-50_TuneCP5_13TeV-madgraphMLM-pythia8/*-v2/MINIAODSIM
/WW_M-50_TuneCP5_13TeV-madgraphMLM-pythia8/*-v2/MINIAODSIM
/WZ_M-50_TuneCP5_13TeV-madgraphMLM-pythia8/*-v3/MINIAODSIM
/ZZ_M-50_TuneCP5_13TeV-madgraphMLM-pythia8/*-v2/MINIAODSIM
/GluGluHToBB_M125_13TeV_amcatnloFXFX_pythia8/*-v1/MINIAODSIM
/TTJets_TuneCP5_13TeV-madgraphMLM-pythia8/*-v1/MINIAODSIM
/ST_s-channel_4f_hadronicDecays_TuneCP5_13TeV-madgraph-pythia8/*_ext1-v1/MINIAODSIM
/ST_t-channel_top_5f_TuneCP5_13TeV-powheg-pythia8/*-v1/MINIAODSIM
/ST_t-channel_antitop_5f_TuneCP5_13TeV-powheg-pythia8/*-v1/MINIAODSIM
/ST_tW_antitop_5f_inclusiveDecays_TuneCP5_13TeV-powheg-pythia8/*_ext1-v1/MINIAODSIM
/ST_tW_top_5f_inclusiveDecays_TuneCP5_13TeV-powheg-pythia8/*_ext1-v1/MINIAODSIM
/ggH_HToSSTo4Tau_MH-125_TuneCP5_13TeV-powheg-pythia8/*-v1/MINIAODSIM

### 3 Physics object definitions

In this section, we provide the definitions of physics objects used in the analysis. We make use of Regions of Interest, muons, taus, and jets.

#### 3.1 Muons

The analysis sources SlimmedMuons from MINIAOD to produce `selectedPatMuons`. Muons require Muon objects require

- $p_T > 12$  GeV to reach BPH trigger plateau
- $|\eta| < 1.5$  due to L1 seed  $|\eta|$  cut in BPH HLT path
- Pass the Loose ID criterion (`isLooseMuon`). As described in the Muon POG [52].

The Isolation requirements on muons are discussed in Section 4.

#### 3.2 Jets

The analysis sources SlimmedJets from MINIAOD to produce `selectedJets`. CMS reconstruct jets from calorimeter energy deposits using the anti- $k_T$  clustering algorithm with a distance parameter of  $R = 0.4$  [53]. Then, the calojets are inputted into the Particle-Flow (PF) algorithms to produce PFJets. Variables in PFJets class are then slimmed to be saved into MINIAOD files. The analysis uses these SlimmedJets for the jets' b-tagging scores and others. Jet objects require

- $p_T > 20$  GeV
- $|\eta| < 2.4$
- $0 \leq \text{emEnergyFraction} \leq 0.9$
- $0 \leq \text{energyFractionHadronic} \leq 0.9$
- No selected electron or muon within  $\Delta R = 0.4$

The energy fraction cuts above are inspired by the recommended Run2 Tight jet-ID cuts for particle flow jets [54–56].

#### 3.3 Taus

The analysis sources `PAT::slimmedTaus` from MINIAOD for MC and `RECO::slimmedTaus` for Data to produce `selectedTaus`.  $\tau$  objects decay hadronically for 64% of its decay. Hadron-Plus-Strip (HPS) algorithm enables the reconstruction of  $\tau$ 's hadronic decay. HPS uses PFJets as its starting point.  $\tau$ 's hadronic decay can be reconstructed with PFJets' charged Hadrons in HCAL and 2  $\gamma$ s from  $\pi^0$  in ECAL. Tau objects require

- $p_T > 20$  GeV
- $|\eta| < 2.4$

#### 3.4 Region of Interest

The complete construction procedures of Regions of Interest are detailed in the following subsections.

- Good quality track selection
- Vertex Fitted from pair-wise tracks by `V0Fitter` in CMSSW
- Cluster the fitted vertices to form a Region of Interest (ROI)

- Look for tracks around  $\Delta R = 0.3$  to save ROI isolation information

### 3.4.1 Tracks

The analysis sources packedPFCandidates and lostTracks from MINIAOD. Track parameters and covariance values will be propagated along the ROI production process and no value should either be infinite or N/A

- `!isinf(tracks.parameter) !isnan(tracks.parameter)`
- `!isinf(tracks.covariance) !isnan(tracks.covariance)`
- Number of valid hits  $> 3$
- $p_T > 0.35$
- Track  $IPSig_{XY} > 2$ .
- Track  $IPSig_Z > -1$ .
- Track normalized  $\chi^2 < 10$ .

### 3.4.2 Vertex Fitter

The analysis sources offlineBeamspot from MINIAOD for beamspot reference. Vertex fitter is KalmanVertexFitter with cuts on the vertex

- Vertex  $\chi^2 < 6.63$
- Transverse Decay distance significance  $> 15$ .
- $V0_{mass} < 13000 \text{ GeV}$
- $\cos(\theta_{XY})$  between x and p of V0 candidate  $> 0$
- $\cos(\theta_{XZ})$  between x and p of V0 candidate  $> -2$

### 3.4.3 ROI formation

Fitted V0s are clustered to form a Region of Interest (ROI). These ROIs have cuts on their parameters as below.

- Radius of ROI  $< 1 \text{ cm}$
- Annulus  $\Delta R < 0.3$

## 4 Event Selection, Signal and Control Regions

The signal process of the analysis contains SM  $\tau$  fermions for its final state. In order to exploit the leptonic decay of  $\tau$  lepton, specifically with muon final state for clean signal, the B-Parking triggers are used. CMS implemented the B-Parking trigger starting in 2018 of Run 2 for research of lepton universalities. For research of  $R(K^*, D^*)$ , muonic final state of B mesons are desired. B trigger requires a soft muon with modest displacement (impact parameter) from primary vertex due to b-quark's long lifetime. B Parking HLT requires a muon with 7-12 GeV with IP 3-6. pp collisions in LHC produce extremely enormous amount of data, which could be triggered by paths above. Current CPU capacity of CMS is limited and not capable of reconstructing the entire event at such high rate at HLT level. CMS scouts events, which passed L1 trigger, and writes them to a temporary dataset. Later, full HLT and RECO schemes are implemented and served as a B-Parking dataset. The prescale factor for HLT is 5-6.

### 4.1 Global Tags

Table 7: Data and MC Global tags used 2018

Data 2018	106X.dataRun2_v29
MC 2018	106X_upgrade2018_realistic_v11_L1v1

### 4.2 Trigger Strategy

We utilize the B-Parking triggers collecting data at L1 and HLT for 2018. The HLT paths of these triggers are listed in Tables 8. We observe that the triggers become efficient around the nominal trigger thresholds.

Table 8: HLT trigger paths used in the analysis 2018.

Data sample	Trigger
ParkingBPH*-Run2018A	HLT_Mu9_IP6_part*
ParkingBPH*-Run2018B	HLT_Mu12_IP6_part*
ParkingBPH*-Run2018C	HLT_Mu12_IP6_part*
ParkingBPH*-Run2018D	HLT_Mu12_IP6_part*

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