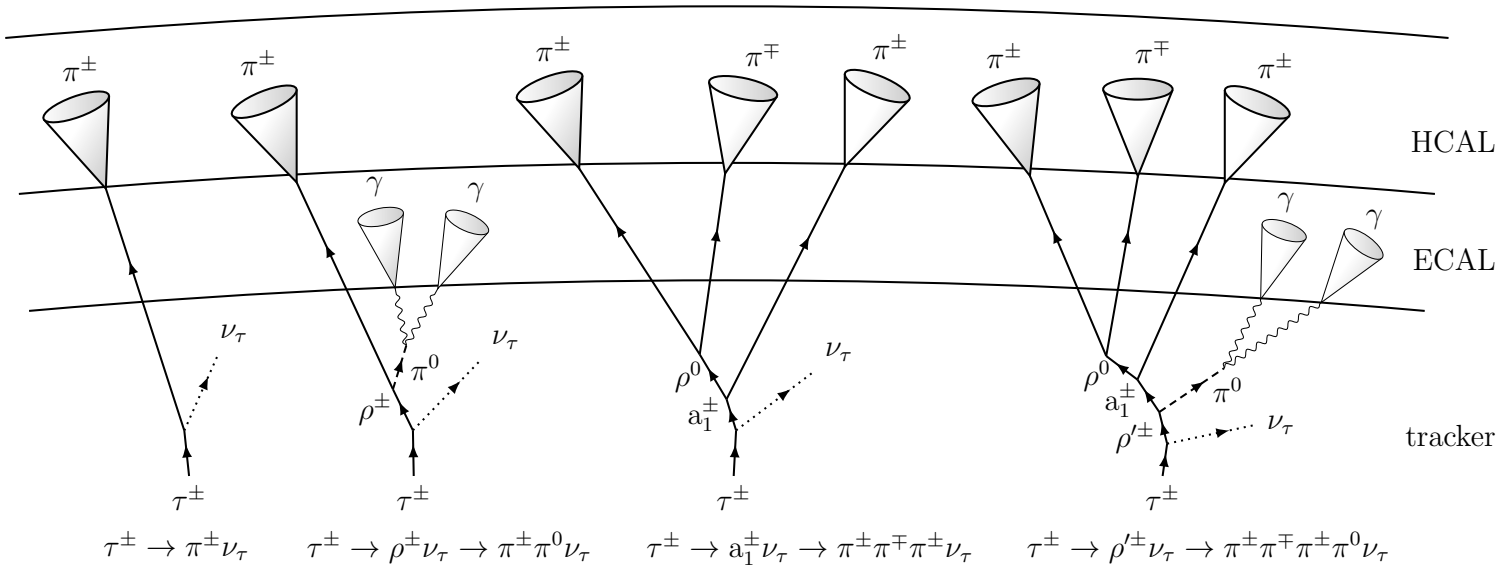


Hadronic tau reconstruction and identification performance at ATLAS & CMS

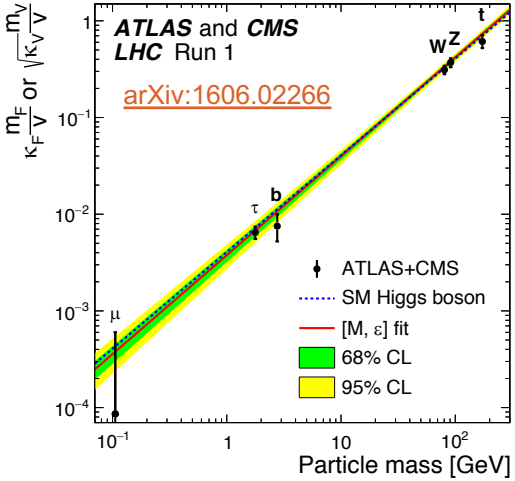
Izaak Neutelings, on behalf of the ATLAS & CMS Collaborations

Paris/online, LHCP2020

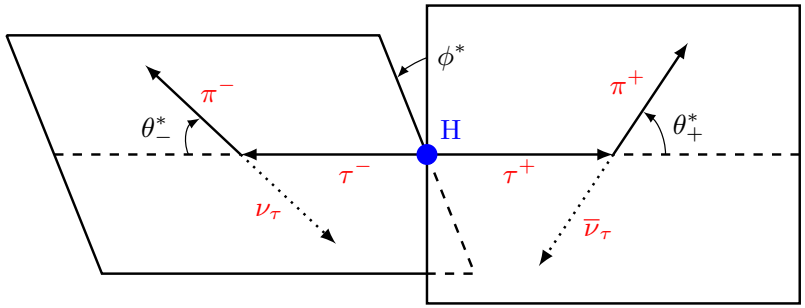
25/05/20

Zoom meeting room for further discussion
https://cern.zoom.us/j/95831387772

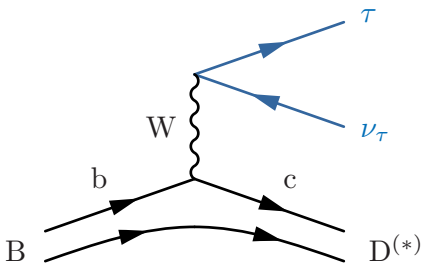
Why taus ?



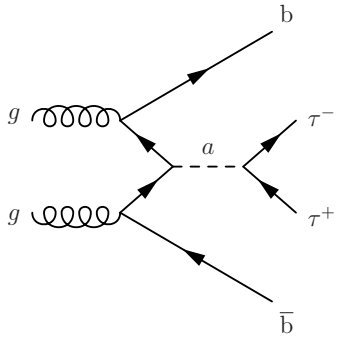
- test Higgs-fermion Yukawa couplings and Higgs CP properties

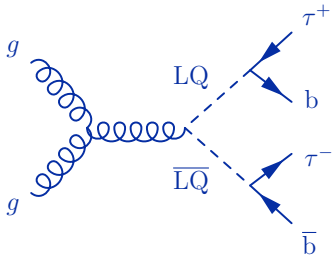


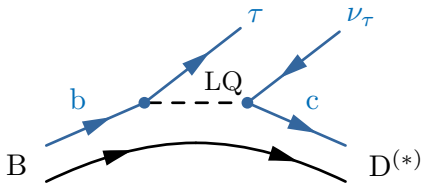
- test lepton universality, e.g. R(D*)



- some BSM might have enhanced τ-coupling:
  - Yukawa coupling to scalar, e.g. neutral MSSM Higgs
  - leptoquarks
  - Z' or W'
  - …

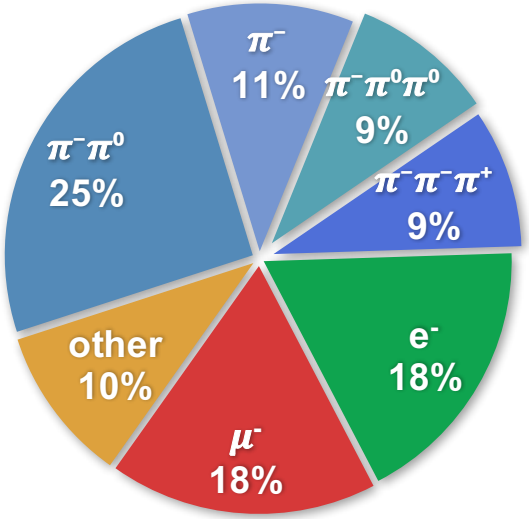


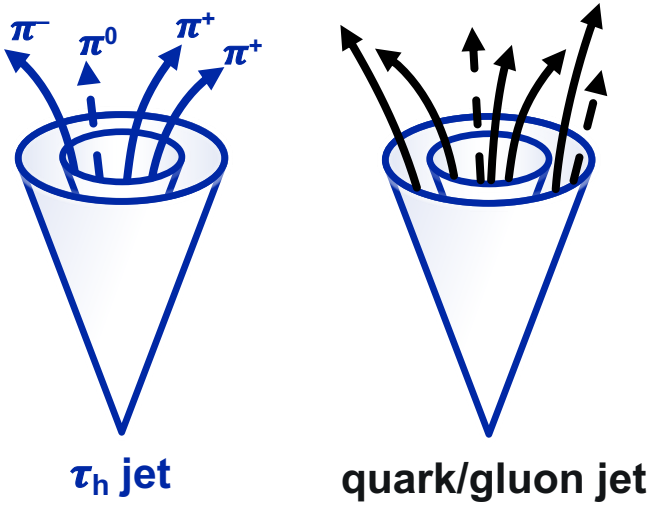




τ-lepton properties

- **mass 1.776 GeV**
  ⇒ can decay to hadrons (m_π = 140 MeV)
- **decay**:
  – 65% hadronically ("τ_h")
  – 35% fully leptonically
- **lifetime $\tau = 2.9 \times 10^{-13}$ s**
  ⇒ $\gamma c\tau$ ~ **1 mm** (20 GeV)
  ⇒ secondary vertex
- τ_h is a collimated, **isolated jet**





τ_h reconstruction

AK4 jet

- anti-k_T, R = 0.4
- seed for τ_h candidate

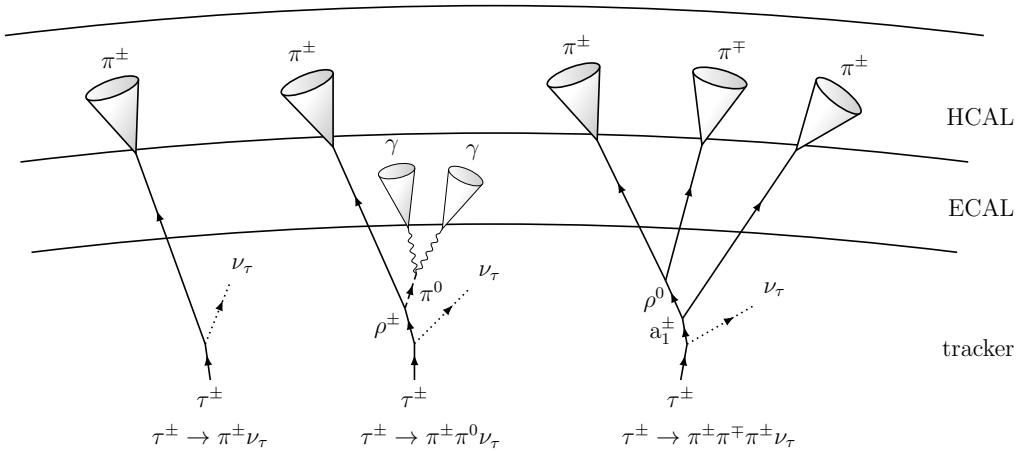
Decay mode reconstruction

- charged tracks ($\pi^{\pm}$)
- ECAL clusters (π^0)

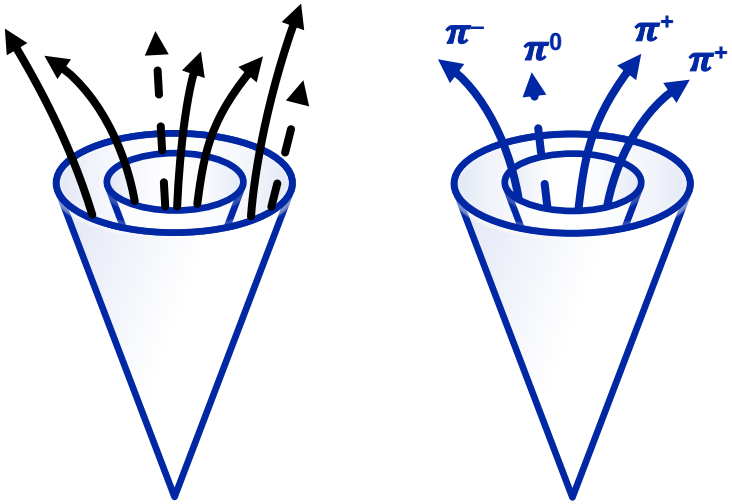
Identification

MVA to reject jets, e or μ

- lifetime
- isolation
- energy fractions

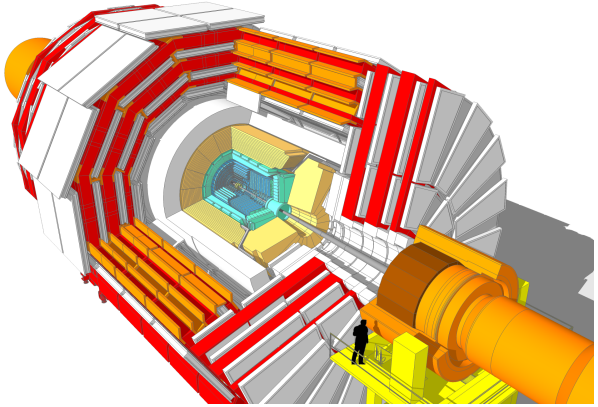


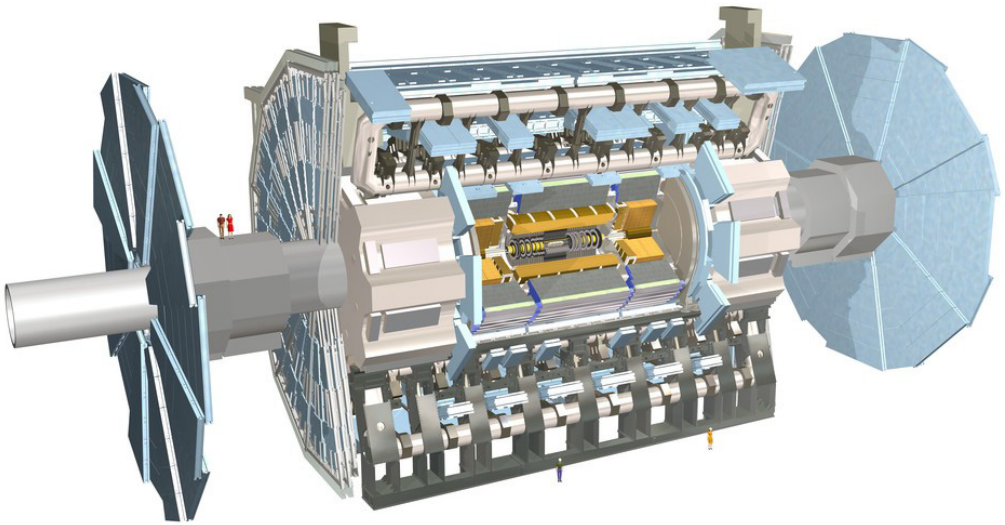
detector interactions of different decay modes



quark/gluon jet **τ_h jet**

Map to τ_h reconstruction & identification





HPS algorithm

→ BDT against jet
+ BDT against e
+ cut-based against μ

→ DNN "DeepTau" against jet/e/μ

"Baseline" algorithm

→ BDT against jet
+ overlap removal e/μ

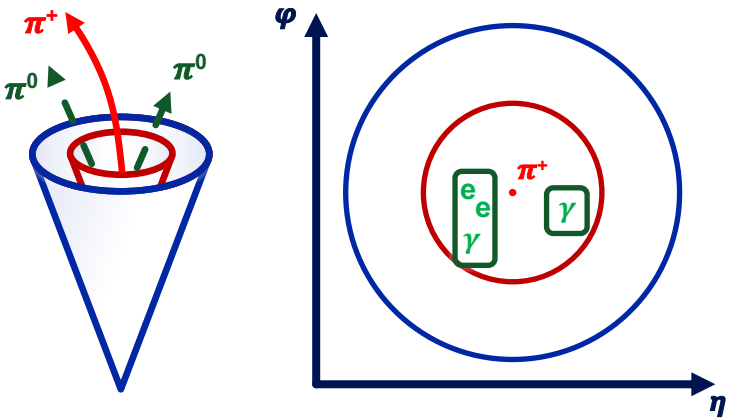
→ RNN against jet
+ BDT against e

Tau Particle Flow

CMS: τ_h reconstruction & identification

Hadron-plus-strips (HPS) algorithm

- seed: AK4 jet of particle flow (PF) hadrons, e/γ
- **signal cone** + **isolation cone**
- assign τ_h decay mode by counting
  - charged hadrons
  - ECAL clusters (e/γ merged into "strips")

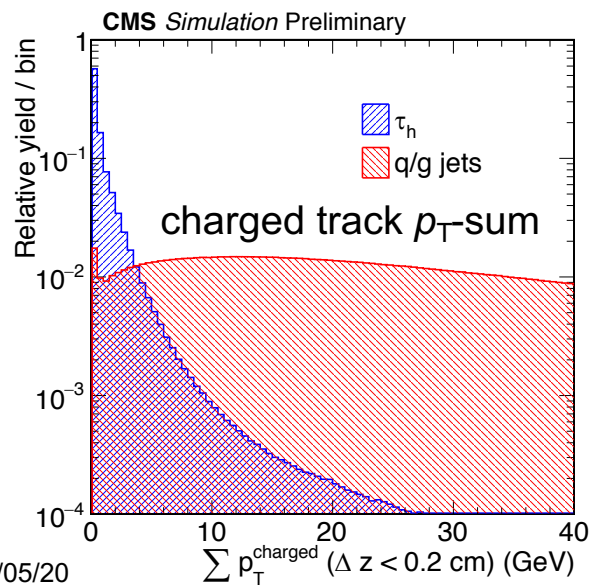


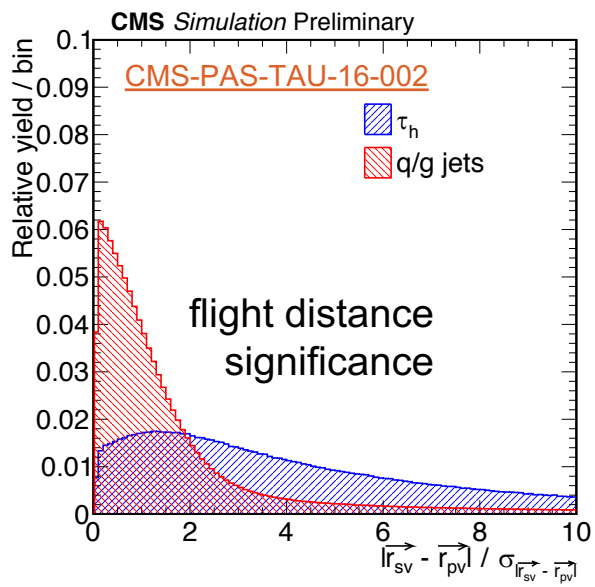
p_T(h) > 0.5 GeV
p_T(e/γ) > 1.0 GeV

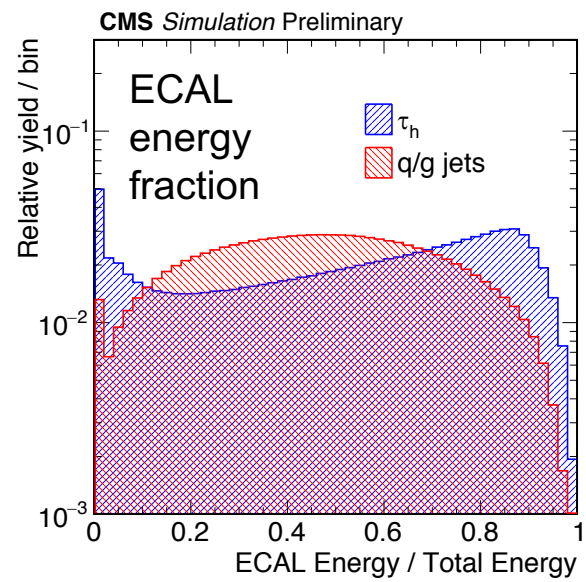
0.05 < ΔR_{sig} < 0.2
ΔR_{iso} = 0.4

DeepTau algorithm

- convolutional deep neural network (DNN)
  - high level: τ lifetime, isolation, e/γ kinematics, …
  - PF hadron/μ/e/γ information in small $\eta\times\varphi$ cells of τ_h
- multiclassifier into τ_h, μ, e, or jet probabilities







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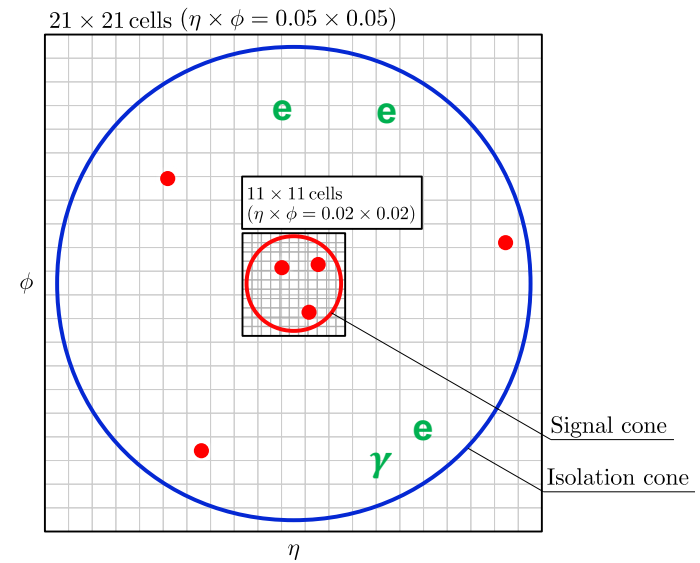

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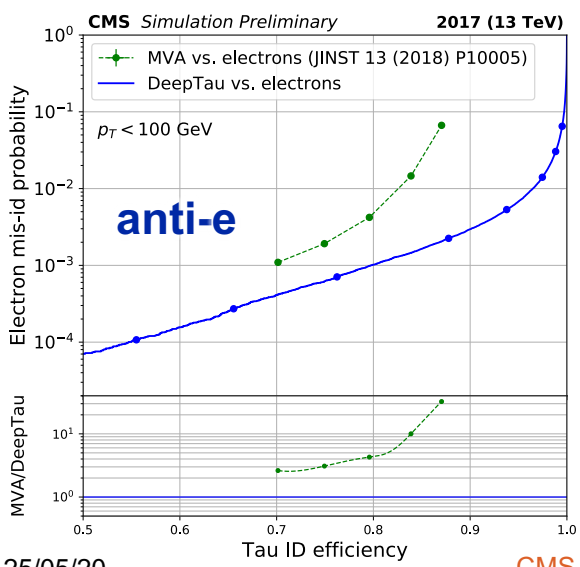
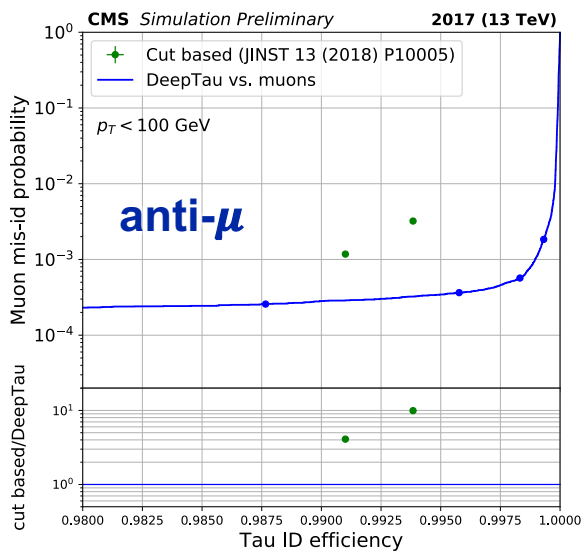
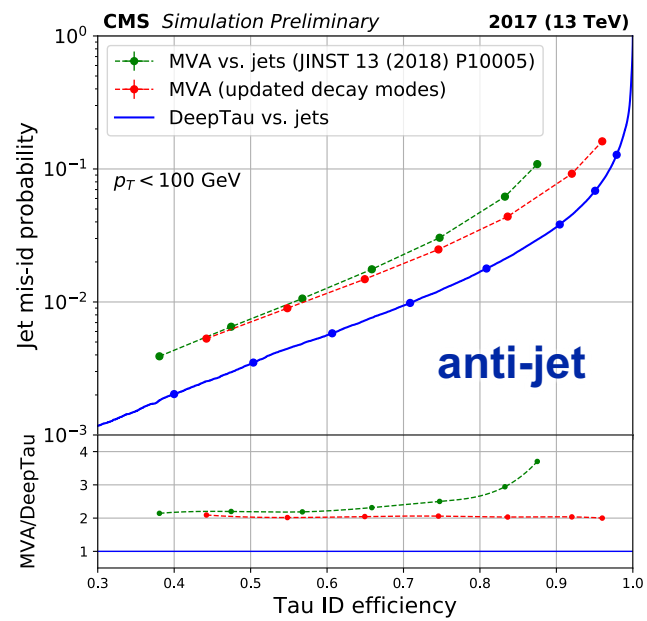
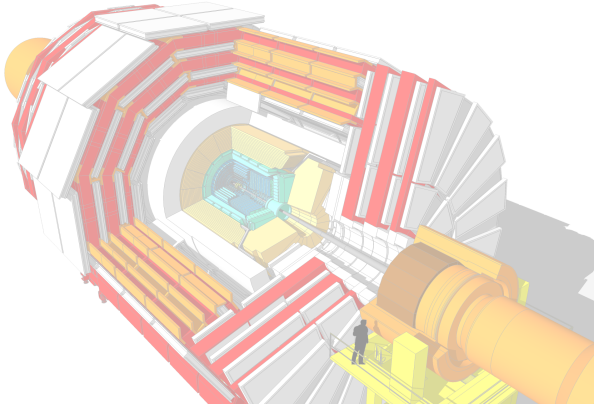


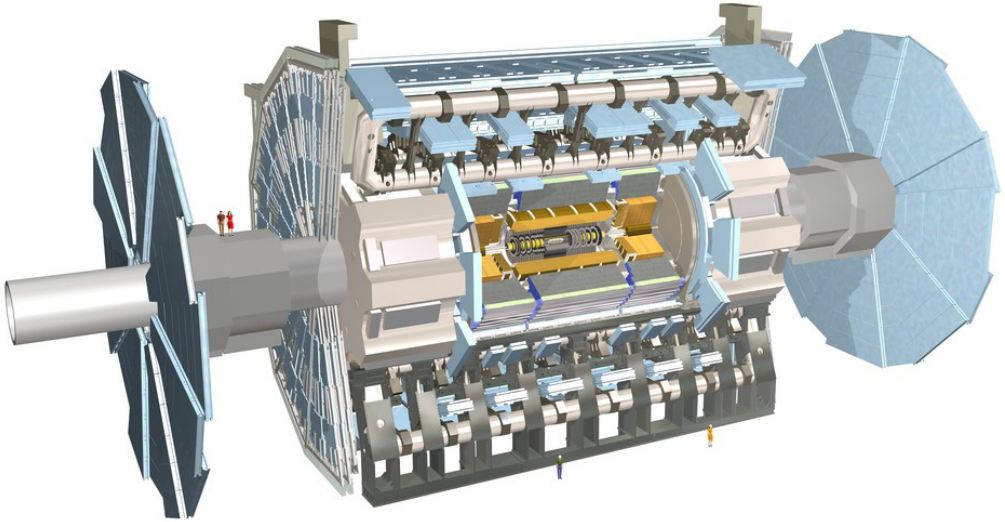




CMS-DP-2019-033

Map to τ_h reconstruction & identification





HPS algorithm

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"Baseline" algorithm

→ BDT against jet
+ overlap removal e/μ

→ RNN against jet
+ BDT against e

Tau Particle Flow

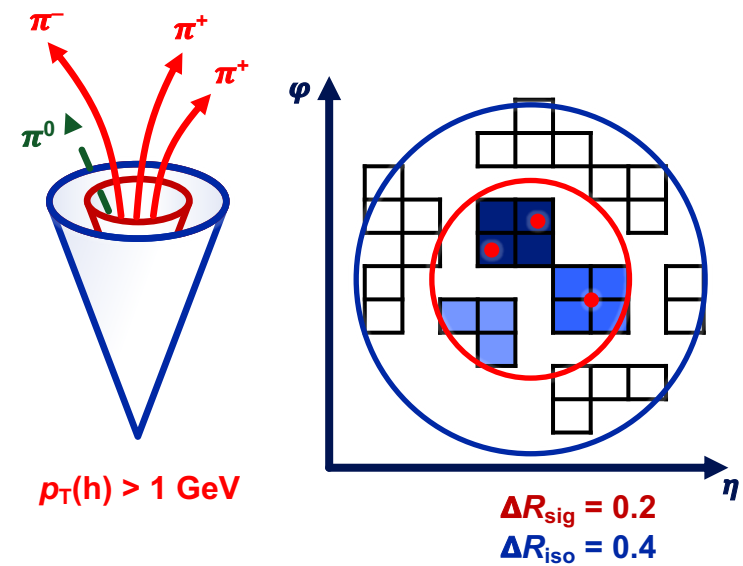
ATLAS τ_h reconstruction & identification

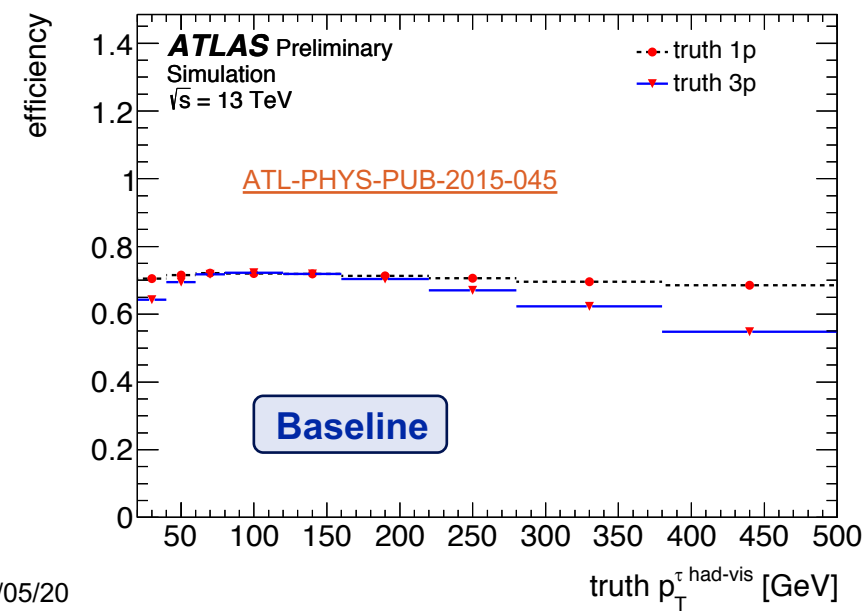
"Baseline" reconstruction algorithm

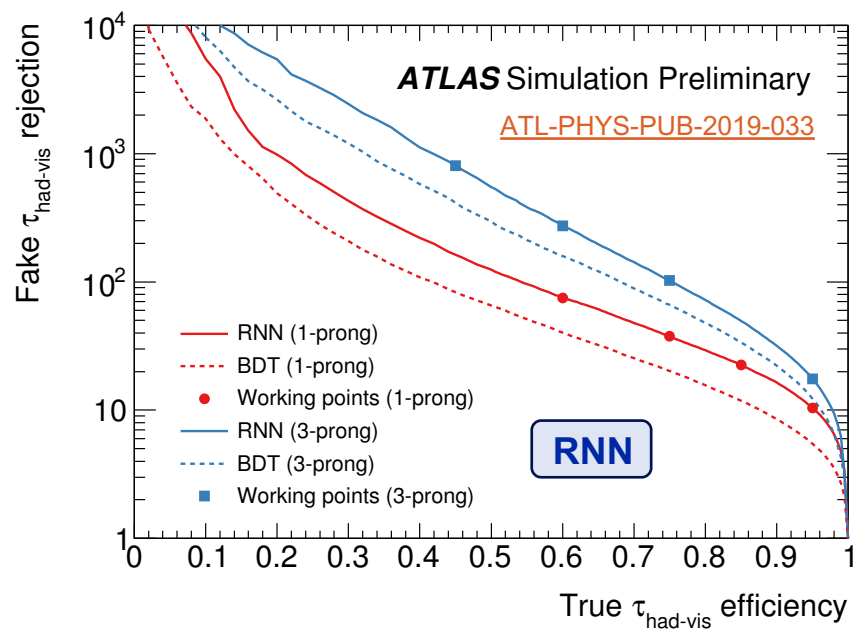
- seed: AK4 jet of clusters
- **signal cone** + **isolation cone**
- BDTs used for track classification
  ⇒ τ_h decay mode: 1 or 3 prong (inclusive in π^0)

RNN algorithm

- recurrent neural networks discriminating jets
- input variables related to
  - high-level: τ lifetime, isolation, energy fractions, …
  - low-level: tracks and clusters



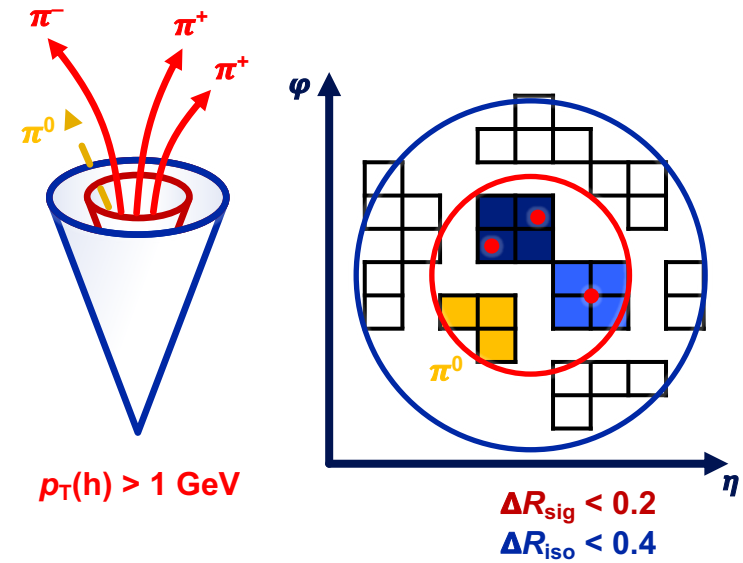


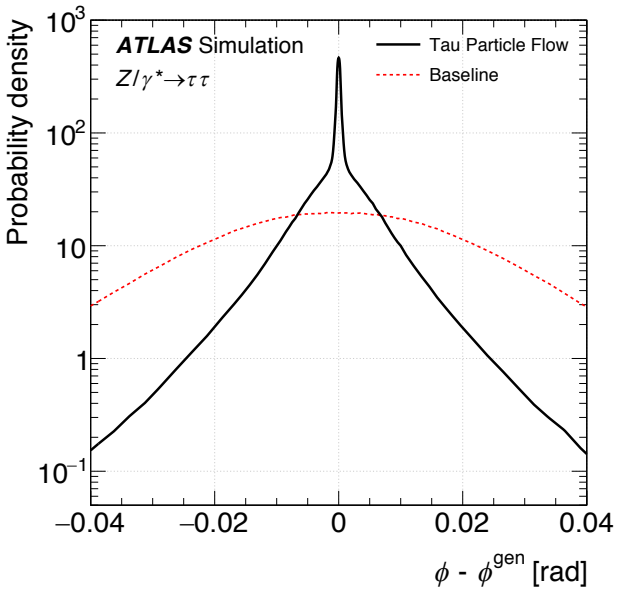


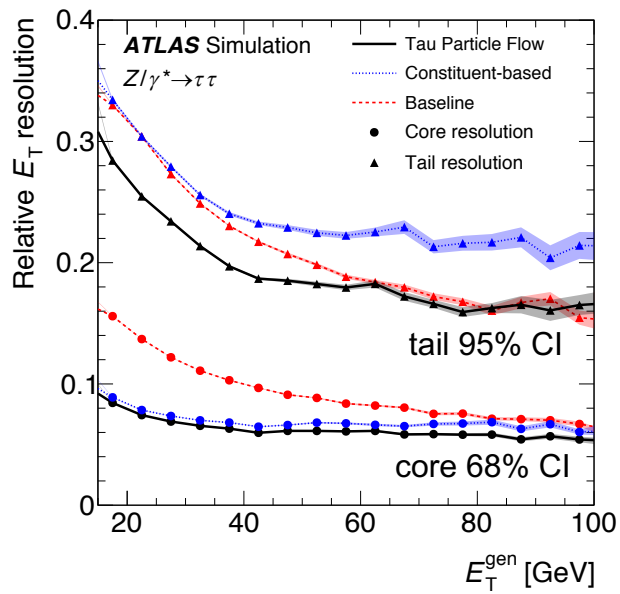
ATLAS τ_h reconstruction: Tau Particle Flow

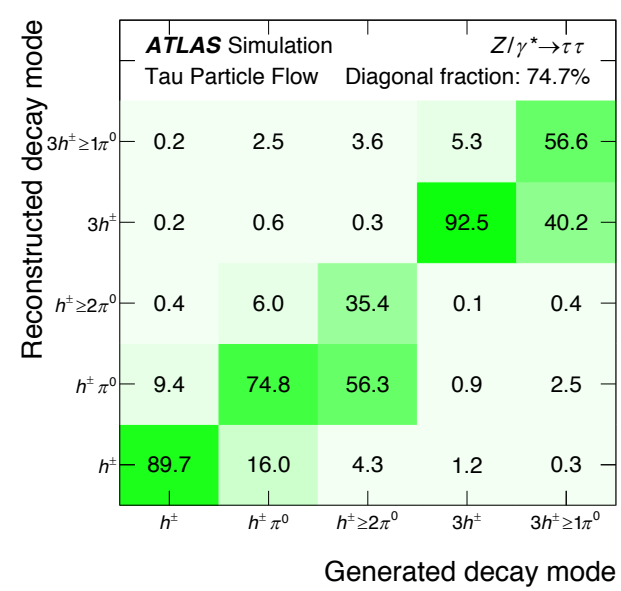
Tau Particle Flow (TPF) algorithm

- seed: baseline τ_h candidate
- reconstruct & identify individual particles
  - $\pi^{\pm}$: tracks + clusters
  - π^0: BDT identifies remaining clusters
- additional BDTs assign decay mode
- improved momentum resolution p_T < 100 GeV









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Detector description for τ_h identification

efficiency measurement

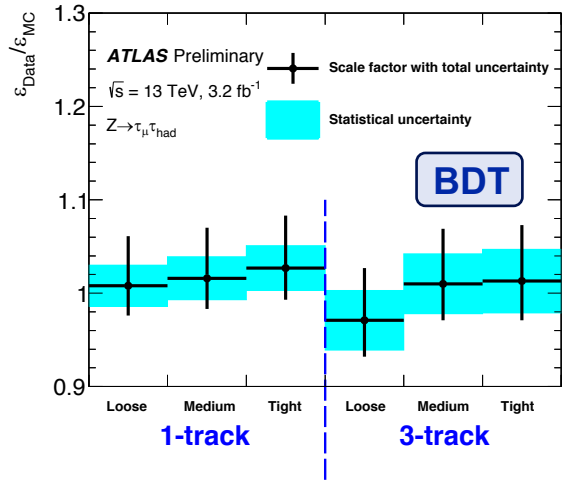
- use $Z/\gamma^* \rightarrow \tau_\mu \tau_h$ events with well-measured μ as tag
- ML fit to discriminating observable

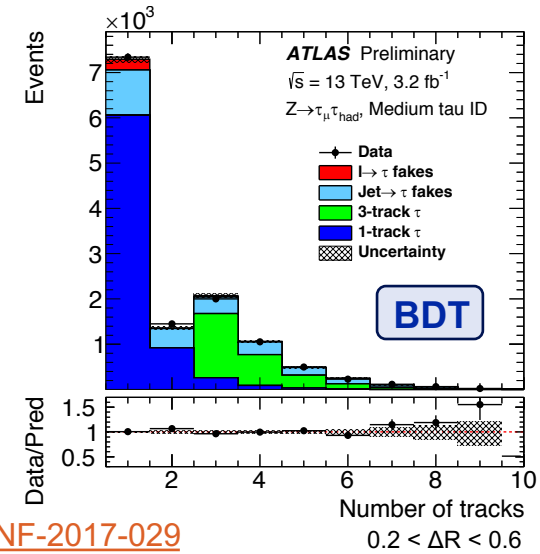
ATLAS

- fit to N_{tracks}
- RNN anti-jet **SF ~1.0** with ~3% total uncertainty

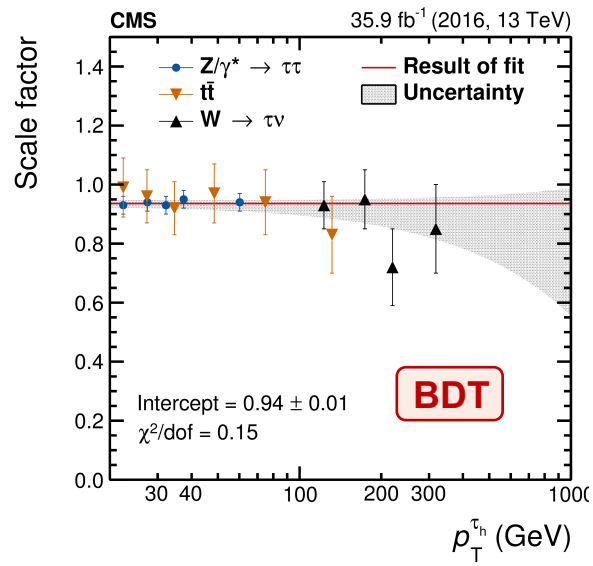
CMS

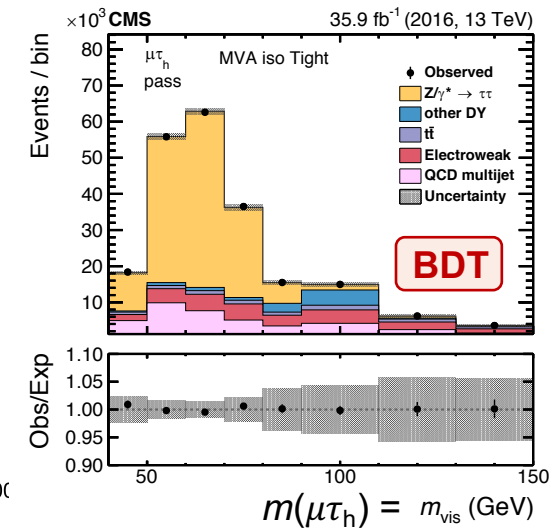
- fit to $m(\mu\tau_h)$
- DNN anti-jet **SF ~0.9–1.0** with ~6% total uncertainty





ATLAS-CONF-2017-029





CMS-PAS-TAU-16-003

τ_h reconstruction

AK4 jet

- anti-k_T, ΔR = 0.4
- seed for τ_h

Decay mode reconstruction

- charged tracks ($\pi^{\pm}$)
- ECAL clusters (π^0)

Identification

MVA to reject jets, e or μ

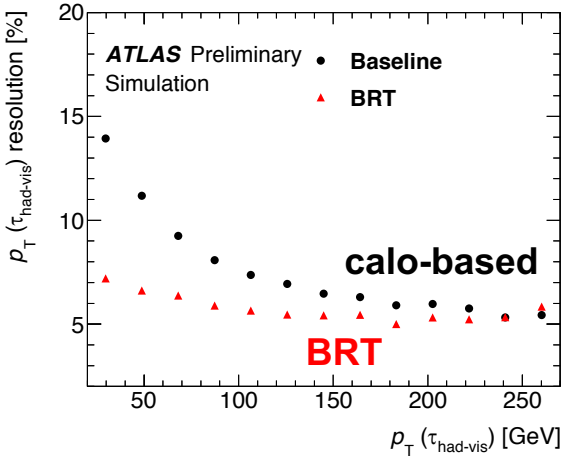
- lifetime
- isolation

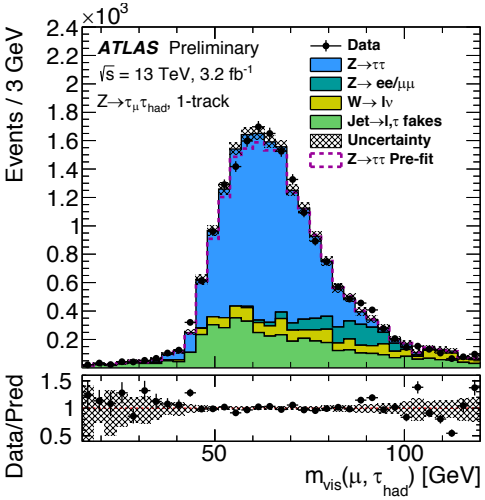
Energy calibration

Energy calibration

ATLAS

- τ_h p_T^{reco} is interpolated between **calo-** and TPF-based p_T
- calibrated for p_T^{gen} with boosted regression tree (**BRT**)
  - interpolated, calo & TPF p_T
  - calorimeter-related variables
  - N_{PV}, N_{track}, $N_{\pi 0}$, …
- **resolution ~6%**
- energy scale in MC ~1-3%

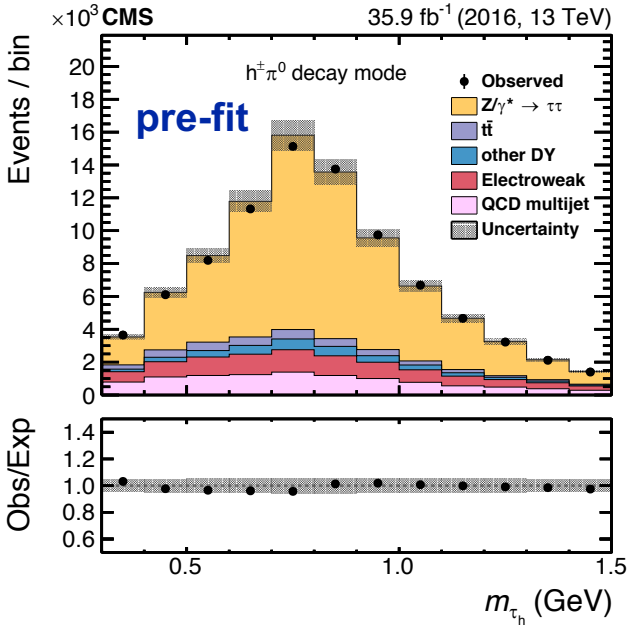




ATLAS-CONF-2017-029

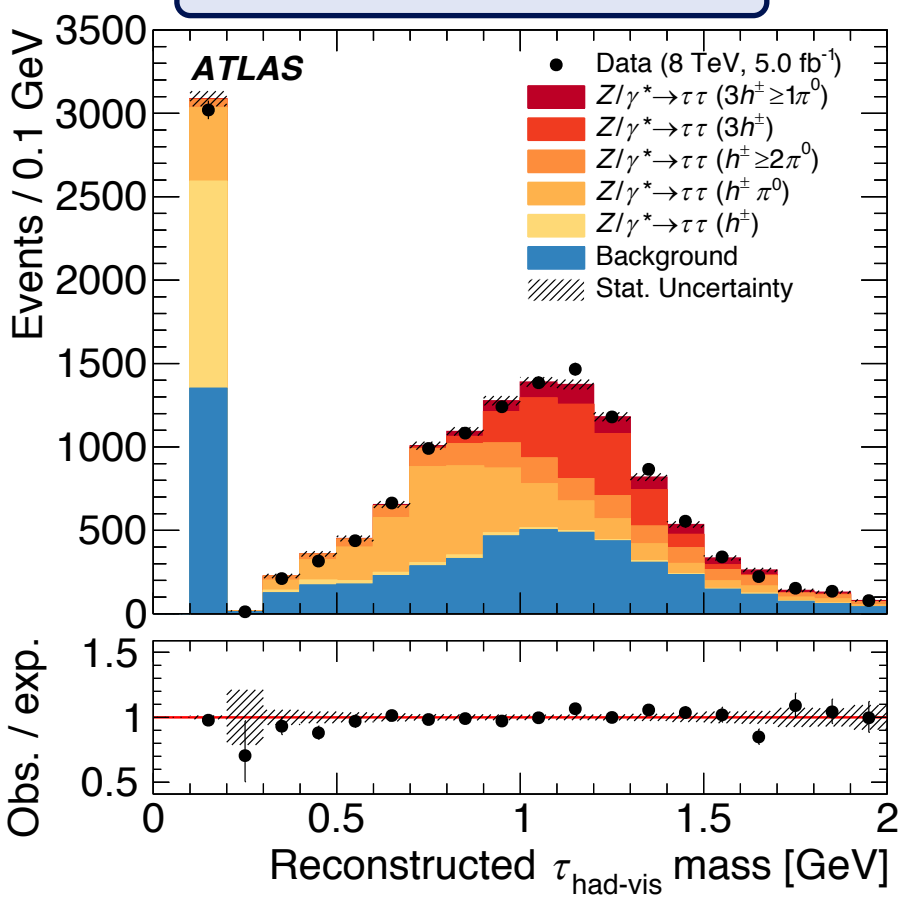
CMS

- τ_h p_T^{reco} is sum of PF constituents
- PF constituents are already calibrated
  ⇒ τ_h p_T^{reco} well modeled, **resolution ~10%**
- energy scale in MC ~1-3%

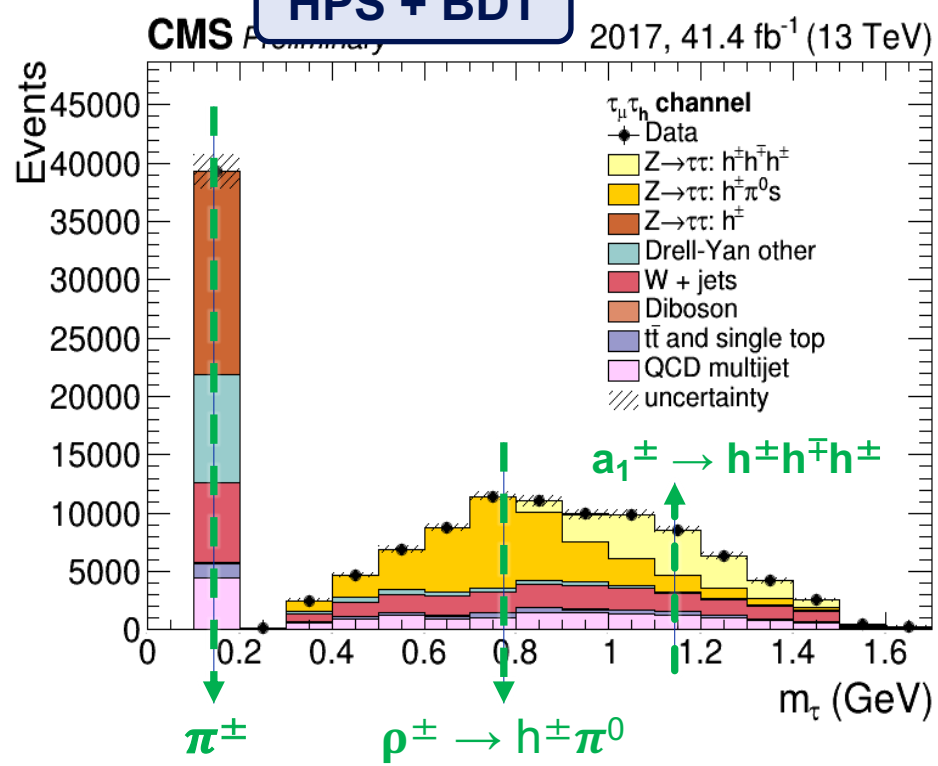


τ_h mass @ ATLAS and CMS

Tau Particle Flow + BDT



HPS + BDT



intermediate resonances

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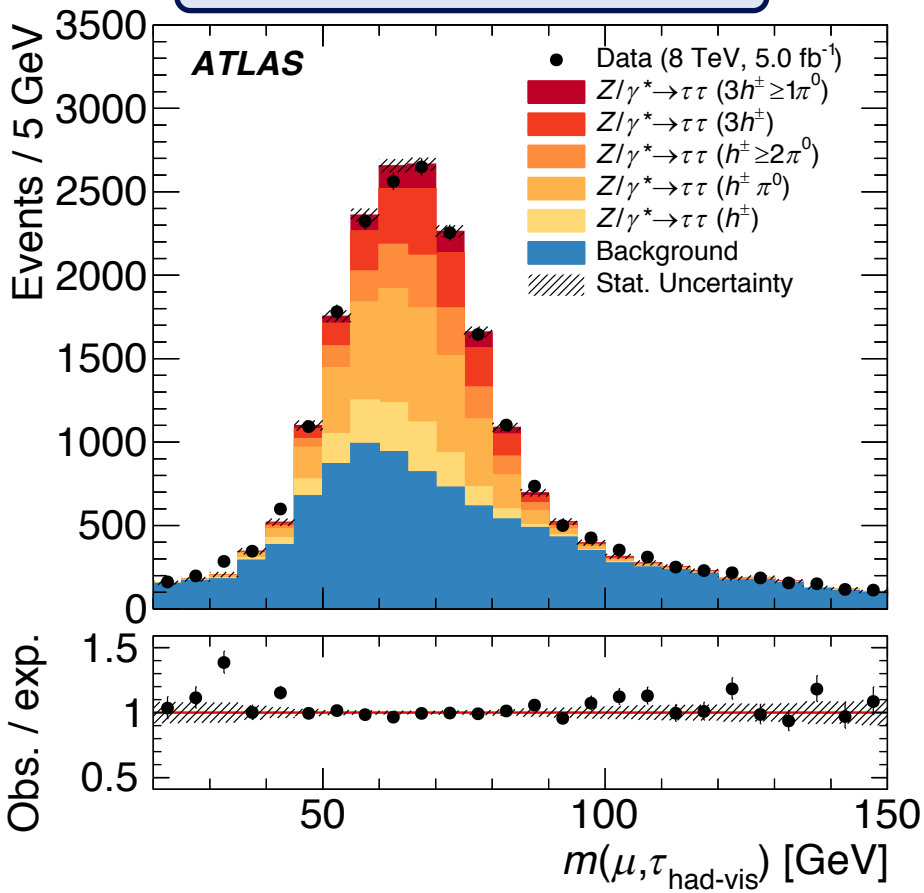
CMS-DP-2018-026

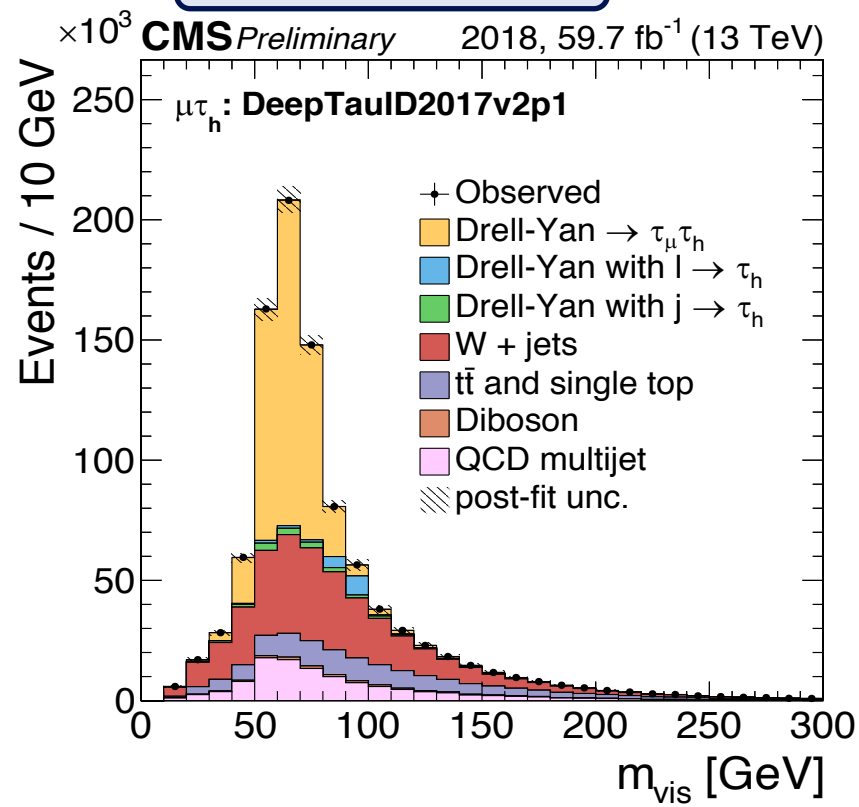
Visible Z → $\tau_\mu \tau_h$ mass @ ATLAS and CMS

μ + τ_h events

Tau Particle Flow + BDT



HPS + DeepTau



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CMS-DP-2019-033

Summary

- study of τ leptons is important for new physics searches and measurements
- each detector has its unique approach
  - **CMS**: PF provides ready-made, and well-calibrated τ_h constituents
  - **ATLAS**: Baseline more calorimeter-based, but Tau Particle Flow exploits tracking to improve momentum resolution below 100 GeV
- excellent understanding of the detector allows for a good description of τ_h reconstruction
- recent development of NNs significantly improved jet rejection, ~1% misidentification for 60% efficiency

References

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http://pdg.lbl.gov/2019/tables/rpp2019-sum-leptons.pdf

ATLAS tau publications
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TauPublicResults
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TauPublicCollisionResults

ATLAS tau reconstruction (2015)
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/PERF-2014-06/
https://arxiv.org/abs/1512.05955, Eur. Phys. J C 76 (2016) 295

ATLAS performance of tau reconstruction & identification (2017)
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ATLAS tau dentification with RNN (2019)
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ATLAS tau reconstruction (Christian Limbach, Tau 2014)
https://indico.cern.ch/event/300387/contributions/686196

ATLAS & CMS tau reconstruction (Camilla Galloni, LHCP 2018)
https://indico.cern.ch/event/681549/contributions/2930926/

CMS tau publications
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsPFT

CMS performance of tau reconstruction and identification (2016)
http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/TAU-16-002/

CMS performance of tau reconstruction and identification (2018)
http://cms-results.web.cern.ch/cms-results/public-results/publications/TAU-16-003/, https://arxiv.org/abs/1809.02816

CMS tau identification with DeepTau DPS note (2019)
https://cds.cern.ch/record/2694158/

Zoom meeting room for further discussion (25/05/2020)
https://cern.zoom.us/j/95831387772

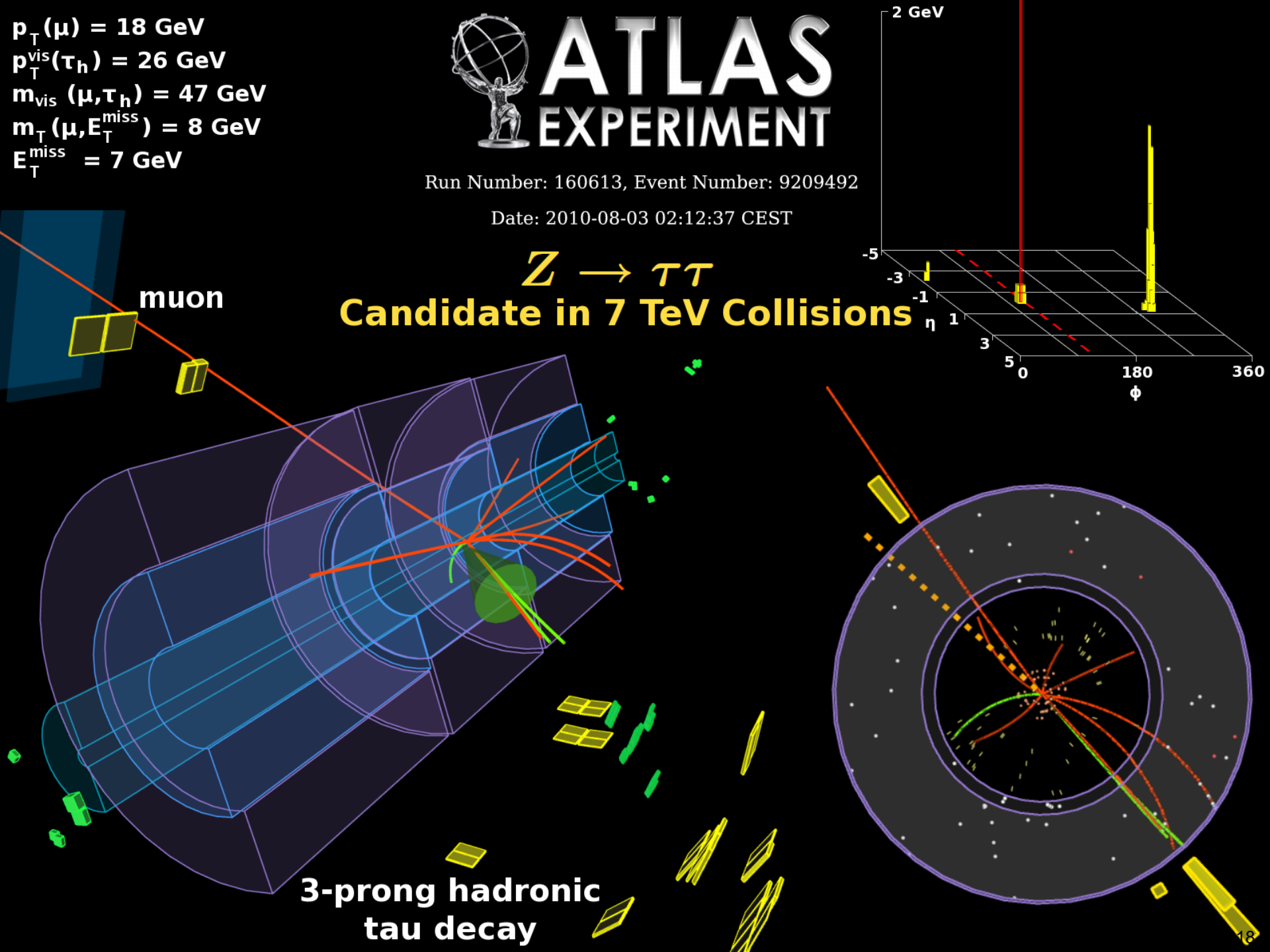
$p_T(\mu) = 18$ GeV
$p_T^{vis}(\tau_h) = 26$ GeV
$m_{vis}(\mu,\tau_h) = 47$ GeV
$m_T(\mu,E_T^{miss}) = 8$ GeV
$E_T^{miss} = 7$ GeV

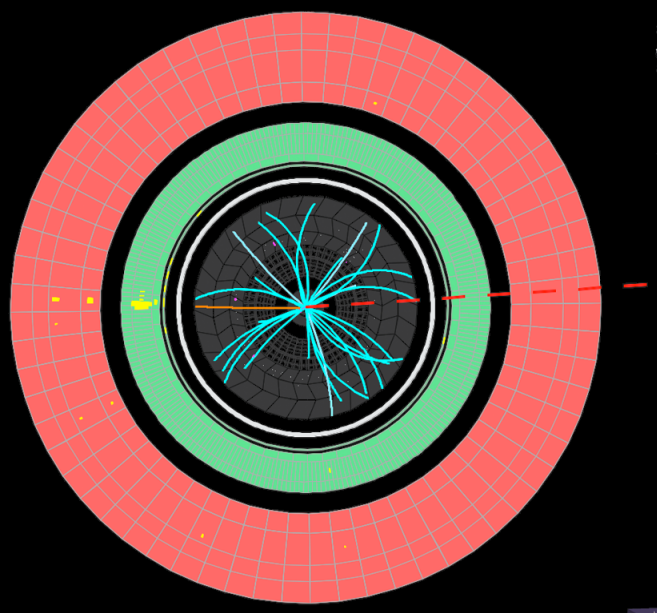
ATLAS EXPERIMENT

Run Number: 160613, Event Number: 9209492

Date: 2010-08-03 02:12:37 CEST

$Z \rightarrow \tau\tau$ Candidate in 7 TeV Collisions

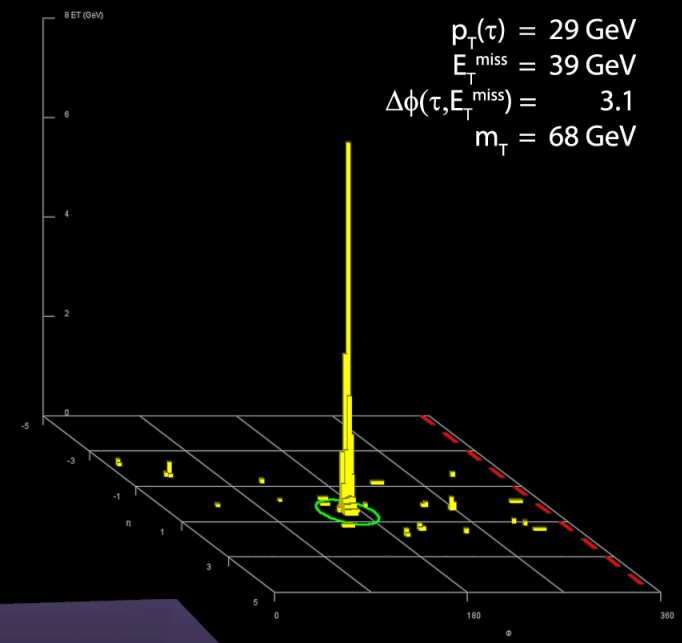


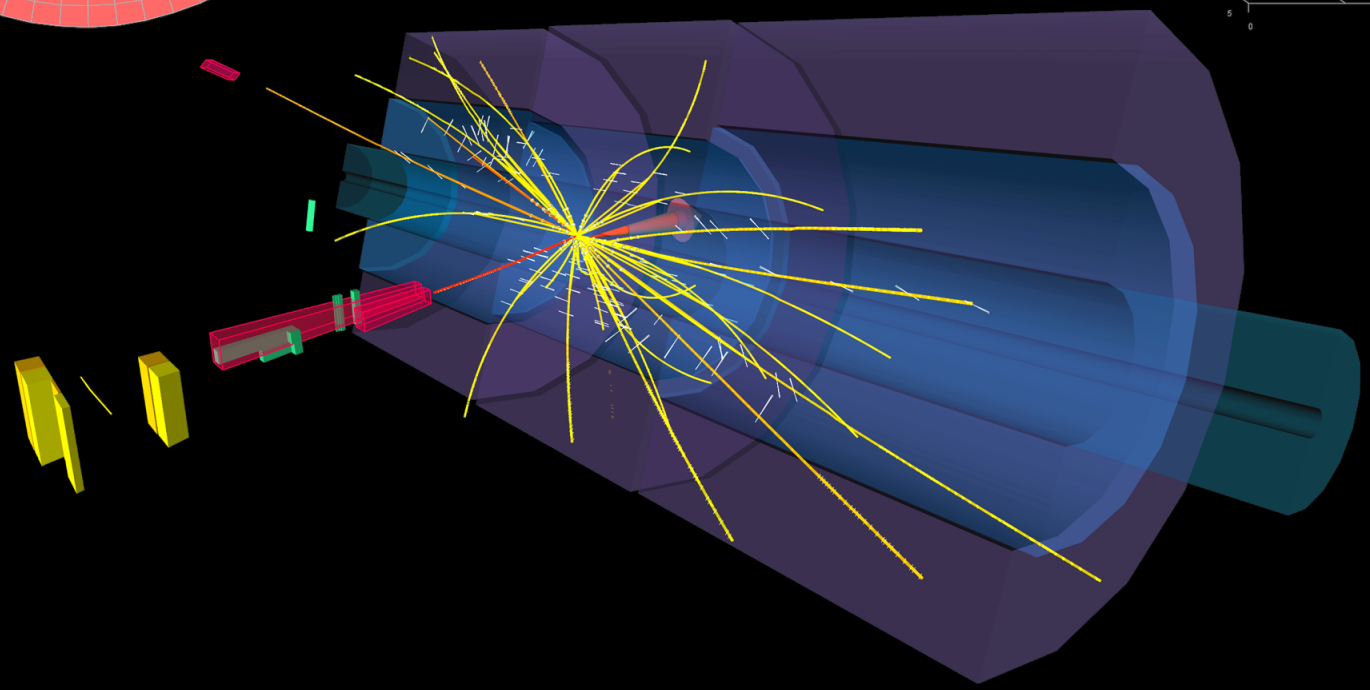


ATLAS EXPERIMENT

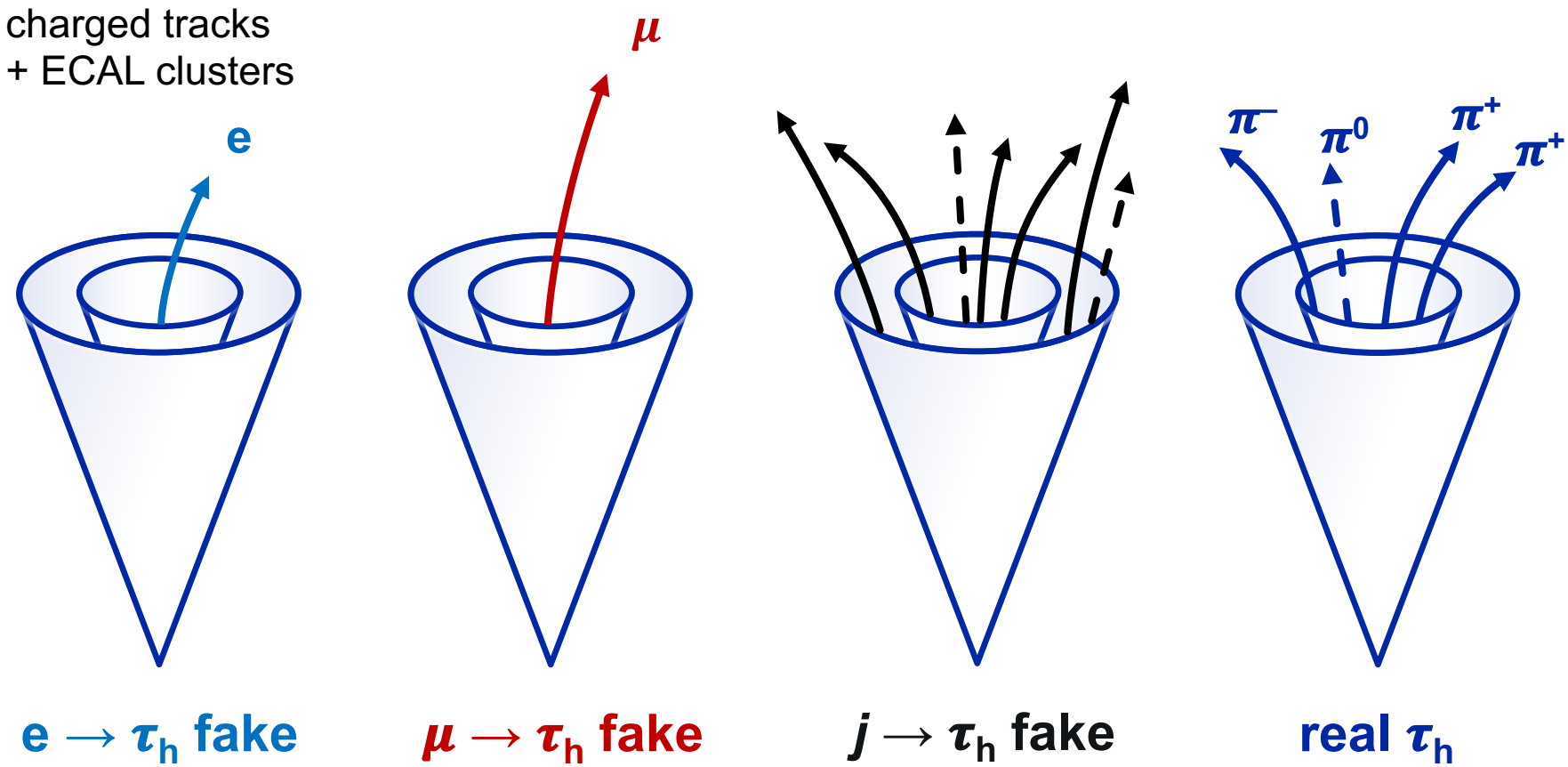
Run 155697, Event 6769403
Time 2010-05-24, 17:38 CEST

$W \rightarrow \tau\nu$ candidate in 7 TeV collisions





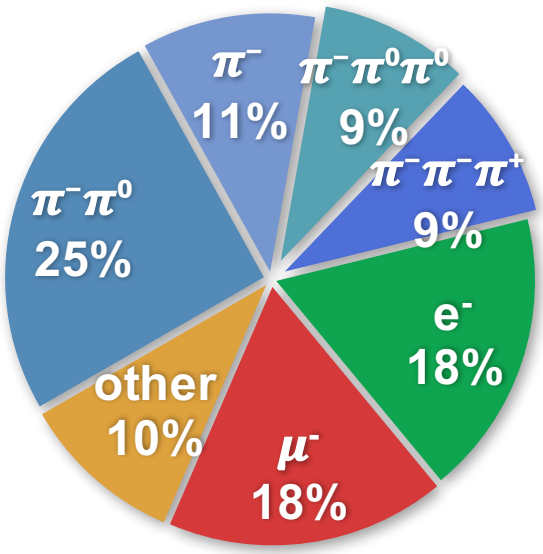
Tau fakes



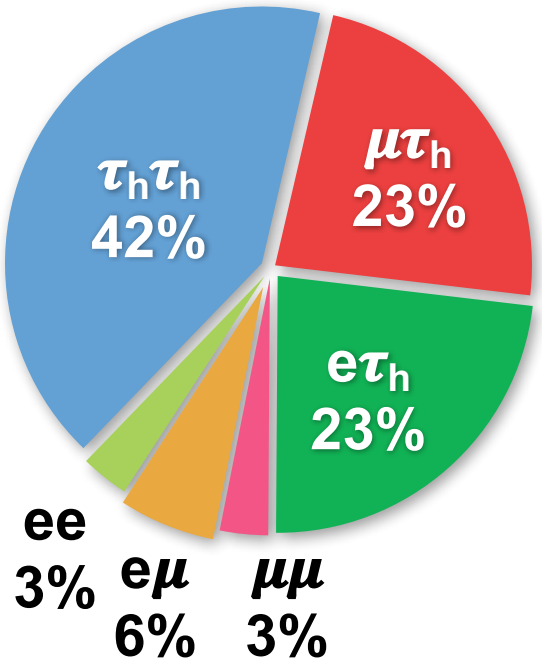
many other objects can fake tau
⇒ exploit τ's isolation & impact parameter

τ lepton pair decay modes

one τ lepton



pair of τ leptons

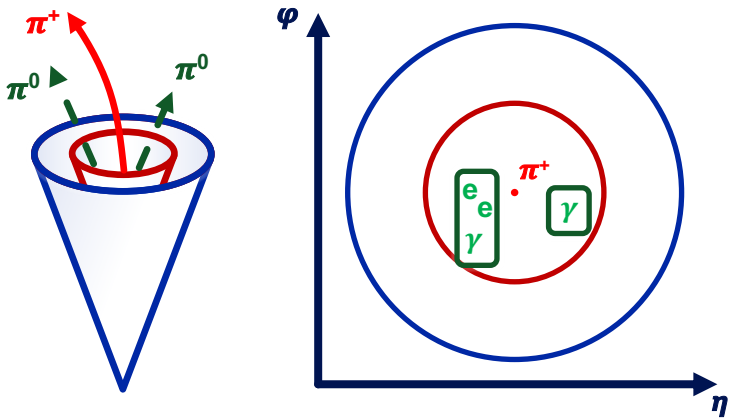


CMS

CMS: τ_h reconstruction & identification

Hadron-plus-strips (HPS) algorithm

- seed: AK4 jet of PF hadrons, e/γ
- **signal cone** + **isolation cone**
- assign decay mode by counting
  - charged hadrons
  - ECAL clusters (e/γ merged into "strips")

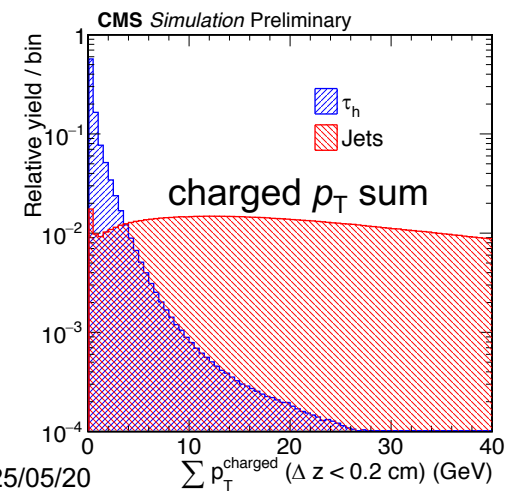


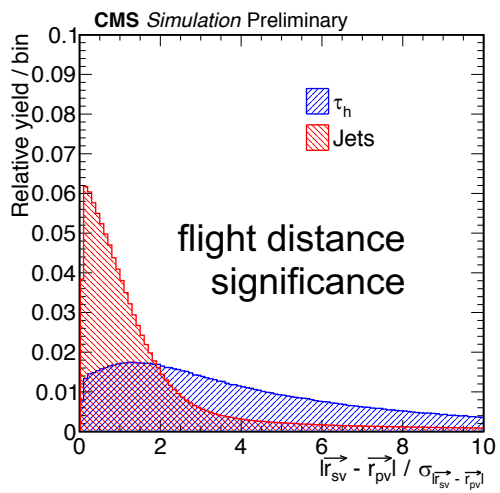
$p_T(h) > 0.5$ GeV
$p_T(e/\gamma) > 1.0$ GeV

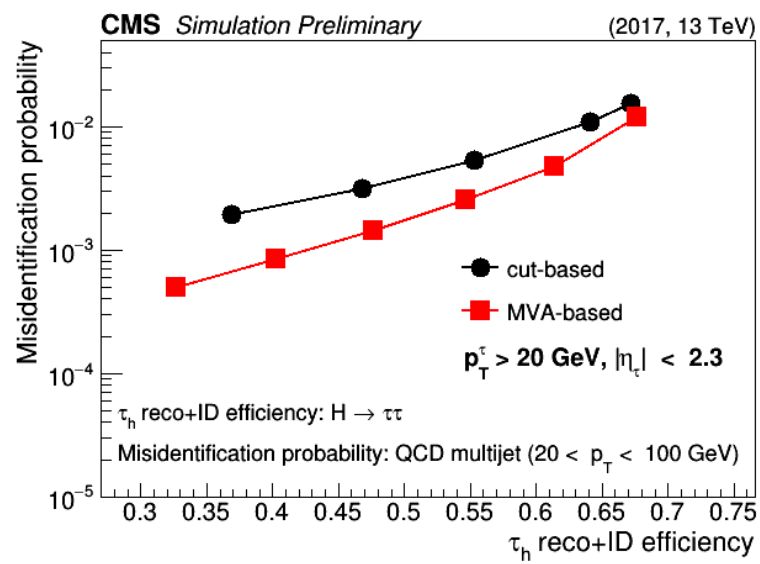
$0.05 < \Delta R_{sig} < 0.2$
$\Delta R_{iso} < 0.4$

BDT-based isolation

- discriminate against jets
- input variables related to
  τ lifetime, isolation, e/γ kinematics, …

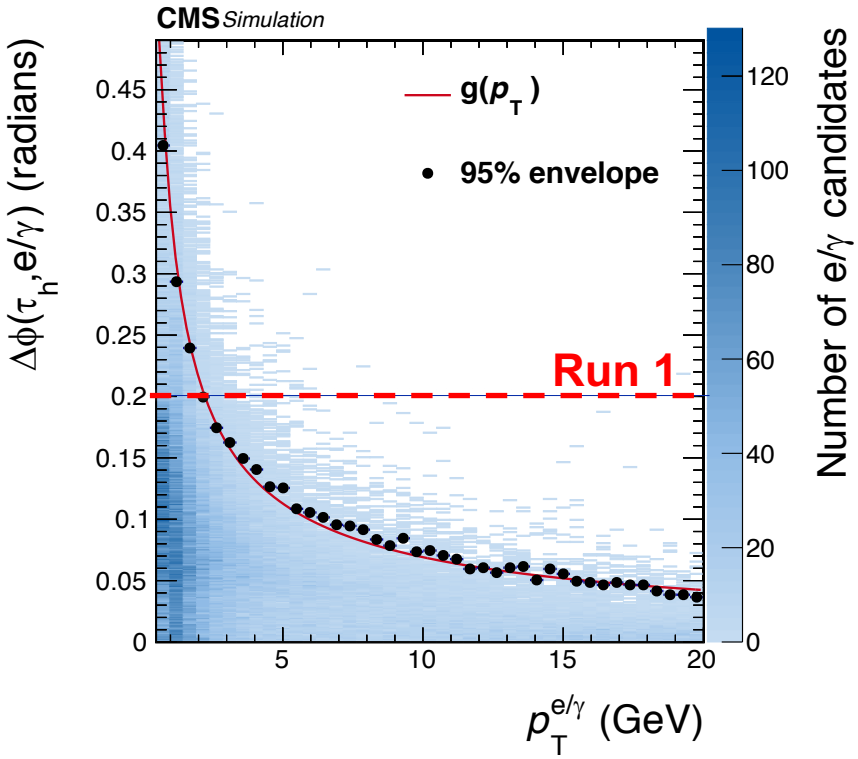


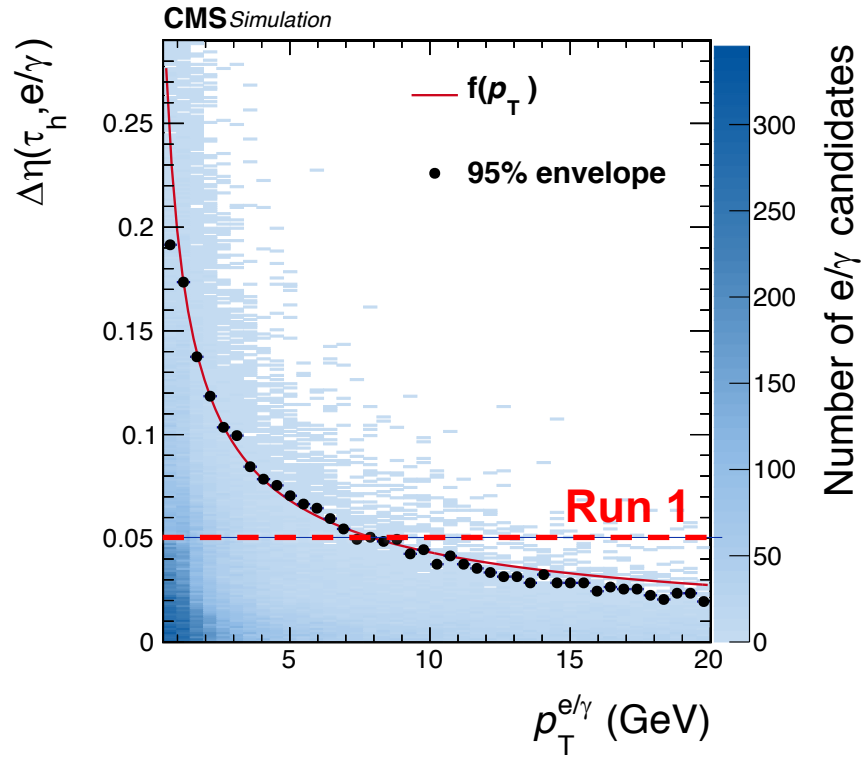




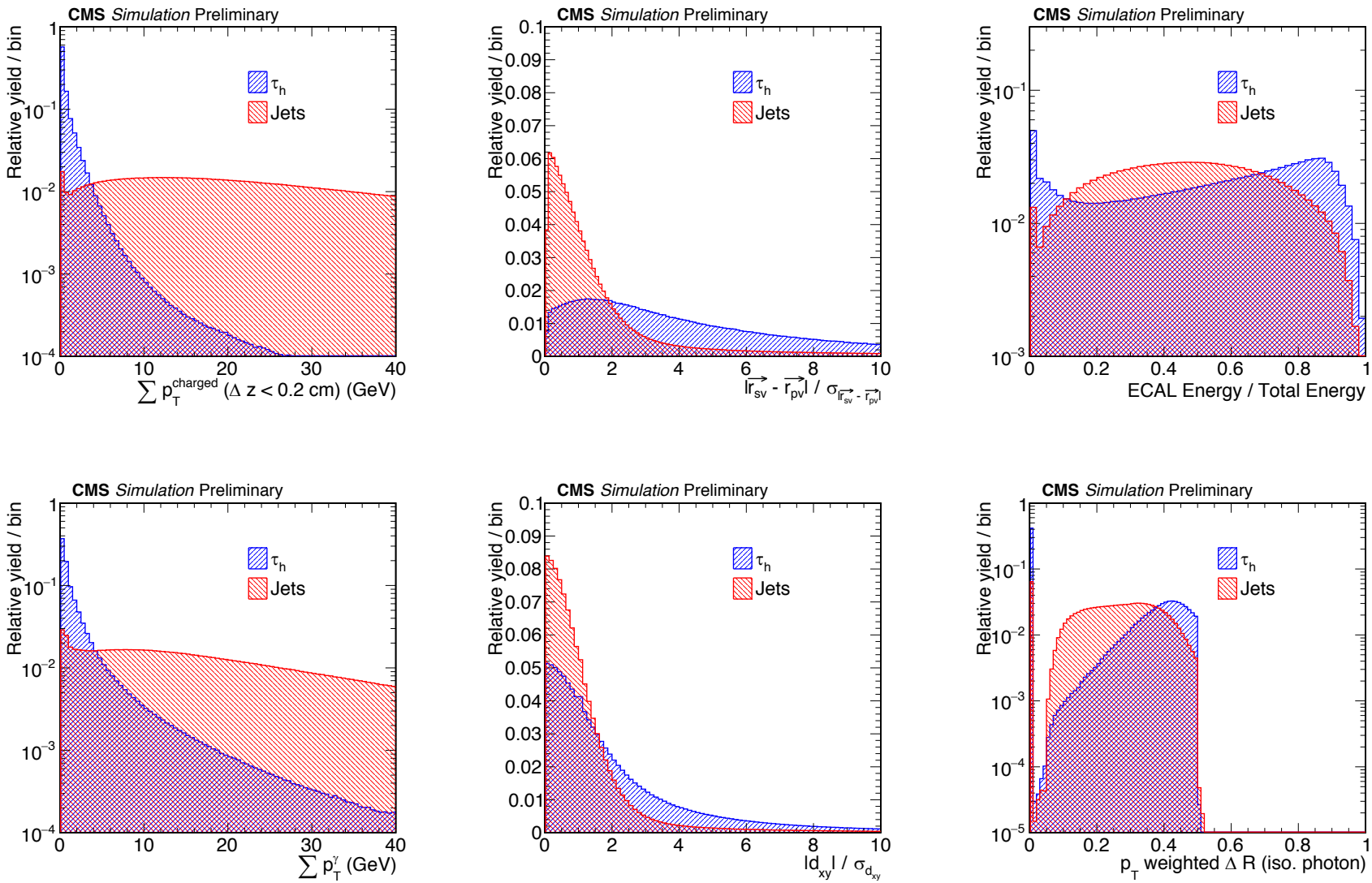
CMS-PAS-TAU-16-002

Run-2: Dynamic strip reconstruction





CMS: BDT input variables

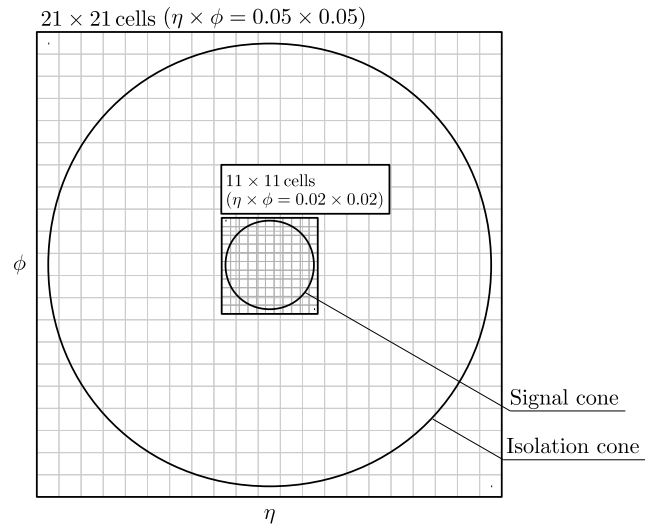


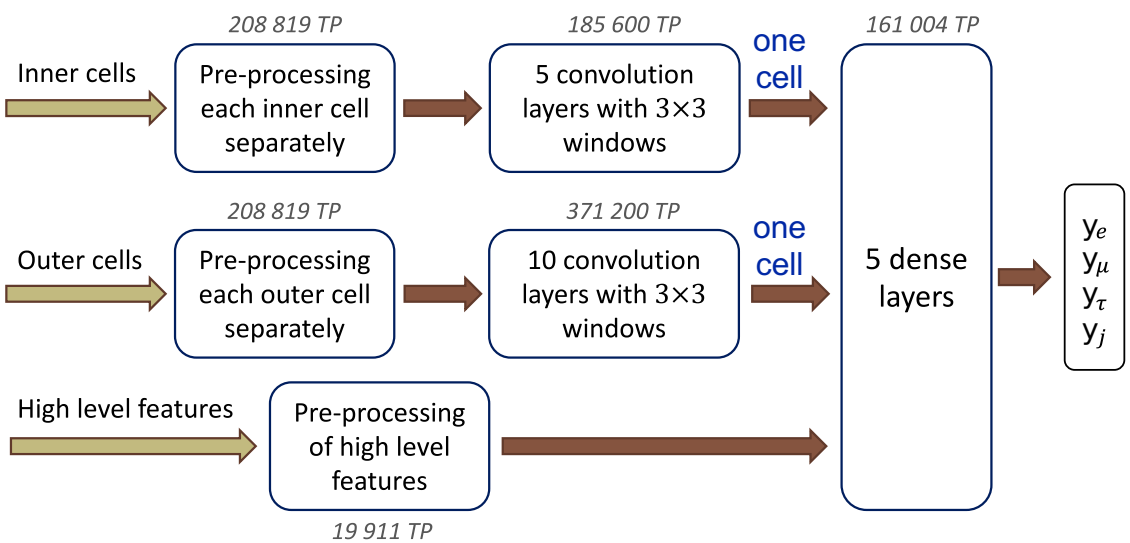
CMS-PAS-TAU-16-002

CMS τ_h identification: DeepTau

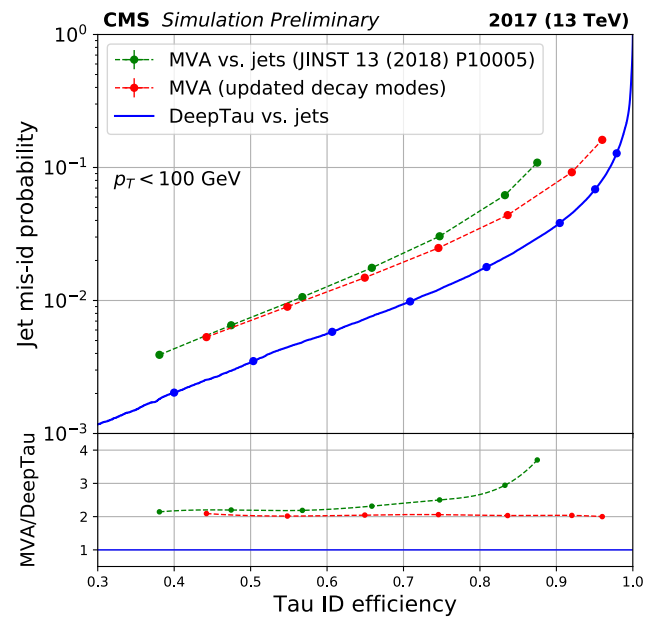
DeepTau algorithm

- deep neural network
- multiclassifier into τ_h, μ, e, or jet probabilities
- input:
  - high level variables similar to BDT
  - hadron/μ/e/γ information in $\eta\times\varphi$ cells of τ_h
- outperforms BDT

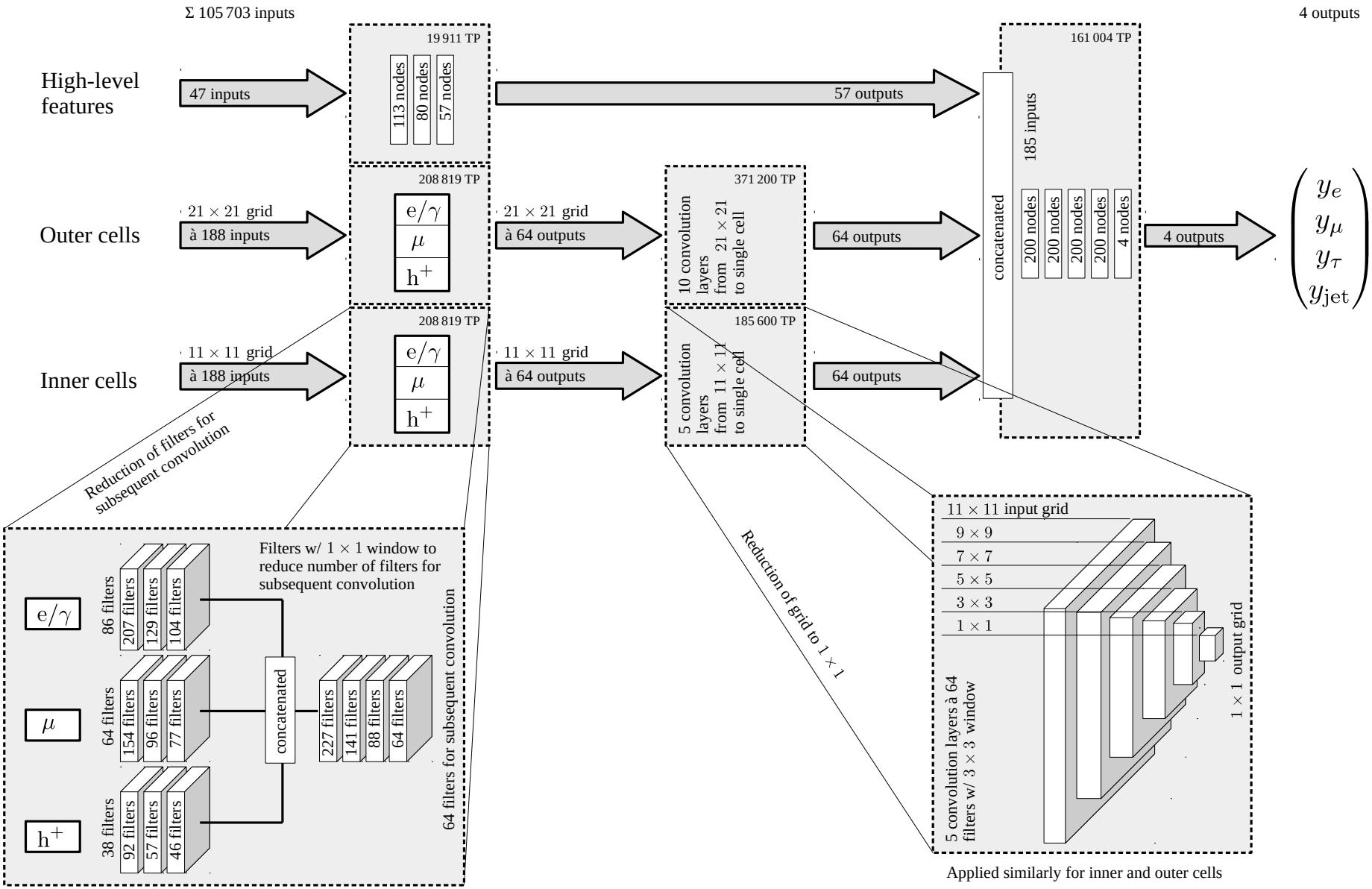




TP = trainable parameter



DeepTau: DNN architecture

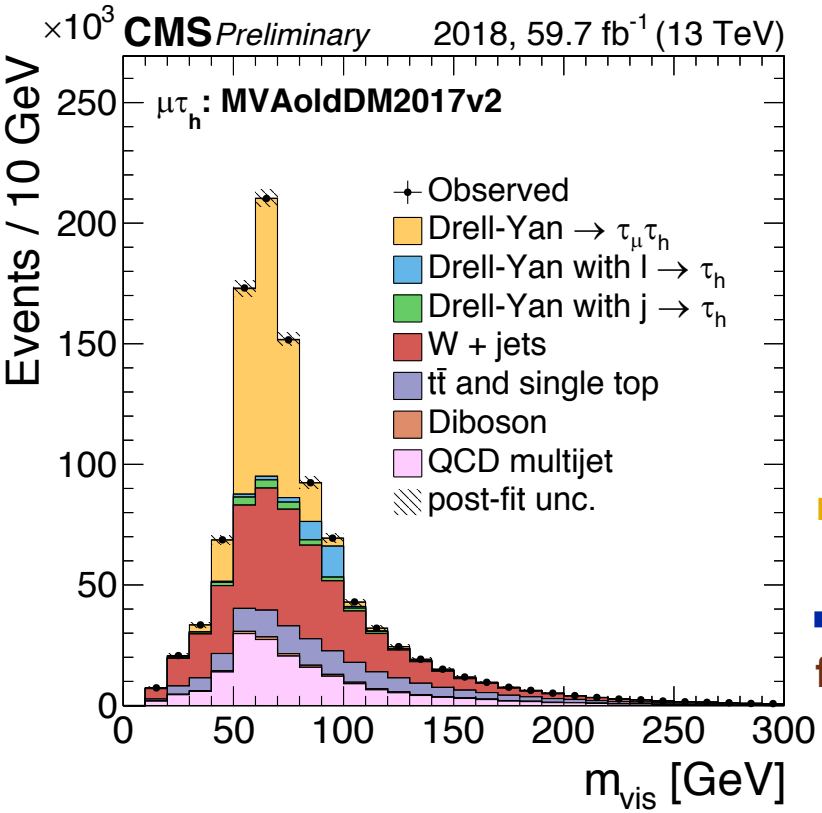


TP: trainable parameter

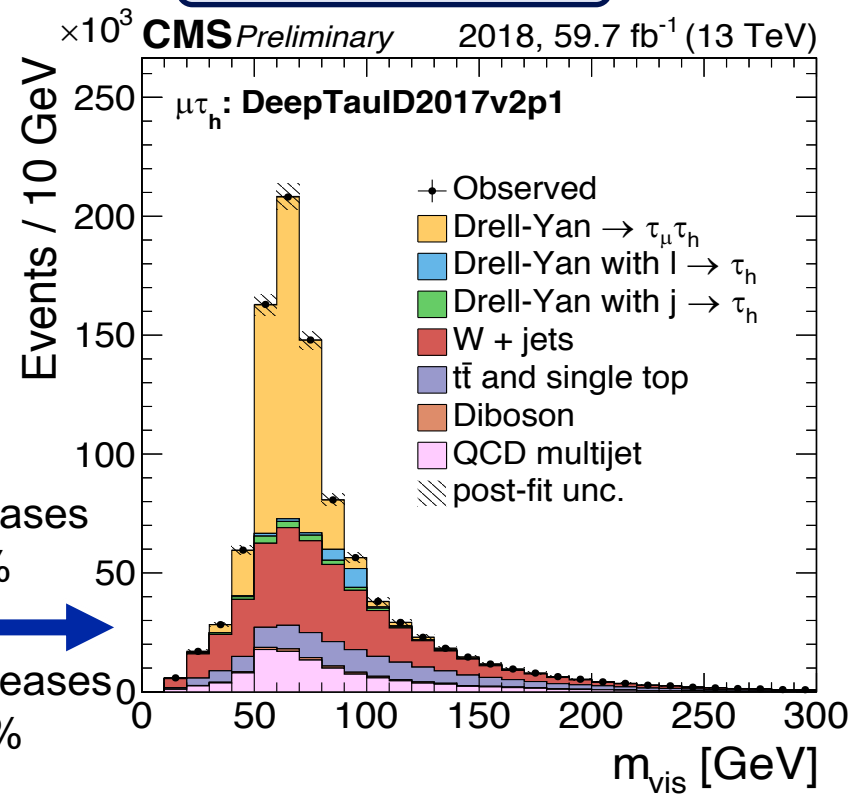
Visible Z → $\tau_\mu \tau_h$ mass @ ATLAS and CMS

μ + τ_h events

HPS + BDT



HPS + DeepTau



real τ_h increases by ~20%

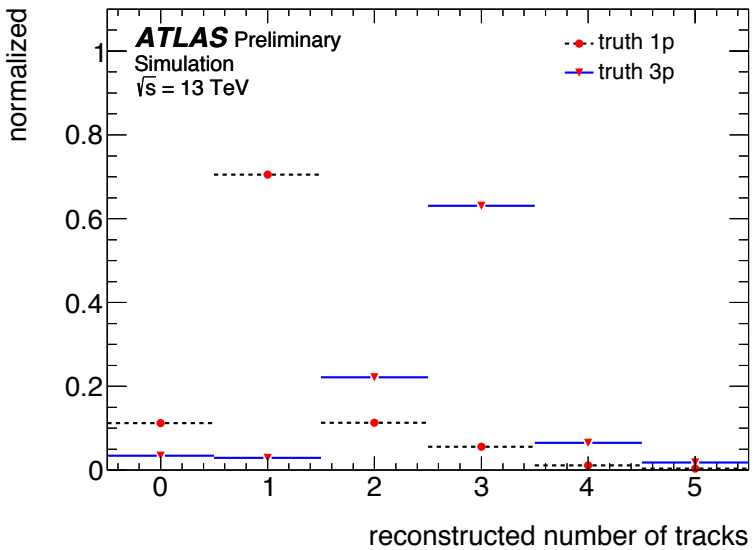
fake τ_h decreases by ~23%

ATLAS

τ_h decay mode reconstruction

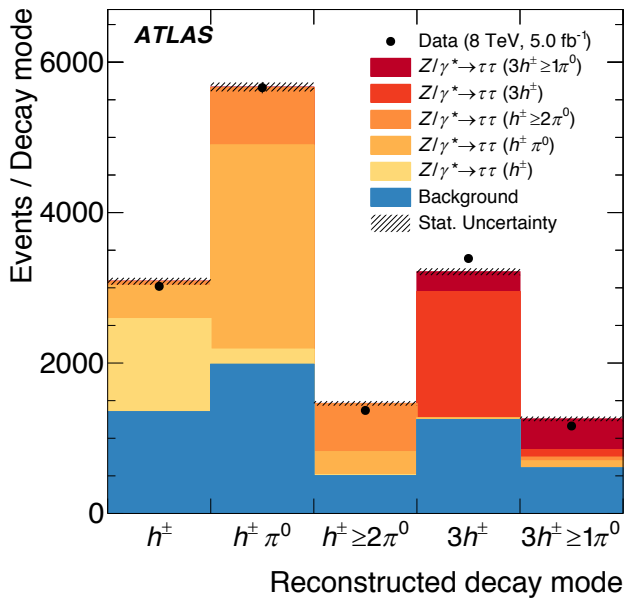
"Baseline" τ_h reconstruction

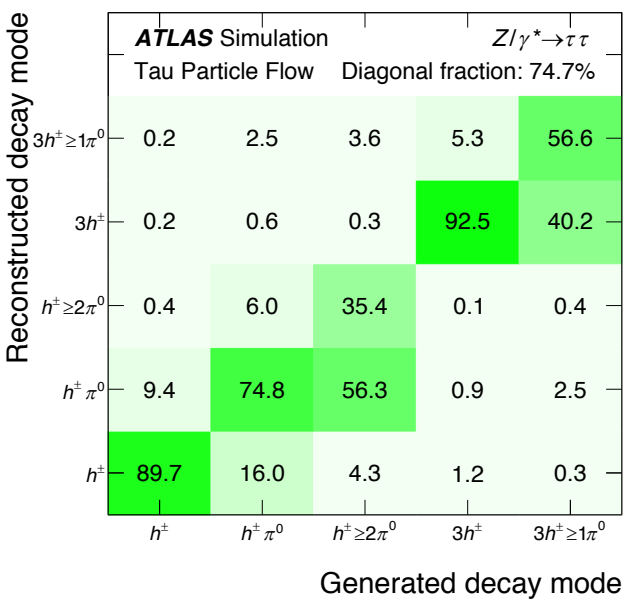
(no π^0 reconstruction)



Tau Particle Flow

(π^0 reconstruction)



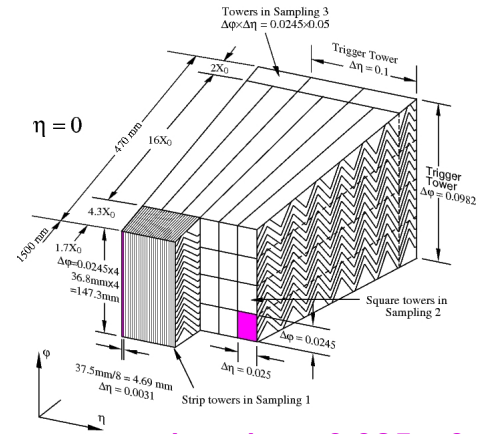


ATLAS Run-I τ_h reconstruction

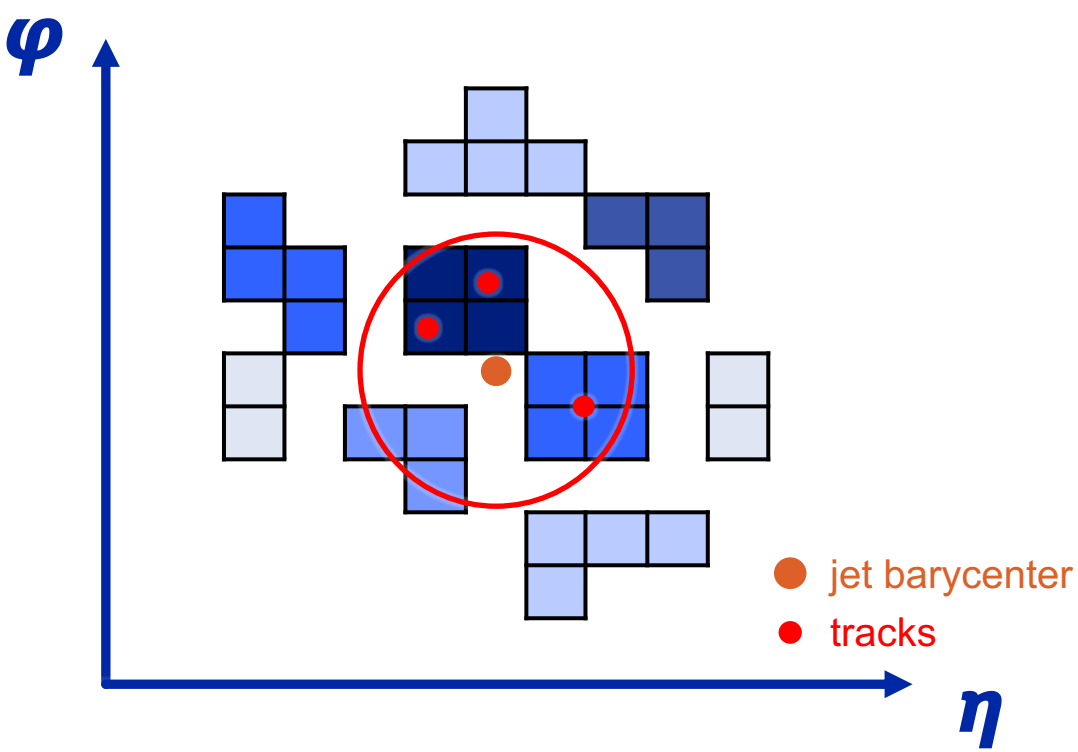
- τ_h objects are seeded by AK4 jets (just like CMS!)
- τ_h vertex = track vertex with largest momentum fraction in **ΔR < 0.2**
- τ_h four-momentum = calorimeter clusters

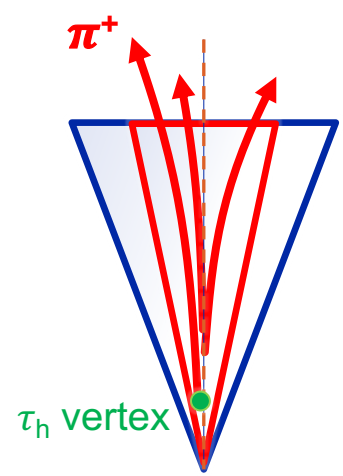
  → ATLAS does not have a particle flow

LAr calorimeter



$\Delta\eta \times \Delta\varphi = 0.025 \times 0.025$





ΔR < 0.2

ΔR < 0.4

p_T > 1 GeV

ATLAS: RNN architecture

- recurrent neural network (RNN)
- three branches:
  - tracks (p_T-ordered)
  - clusters, ordered by (E_T-ordered)
  - high-level variables related to lifetime, isolation, …