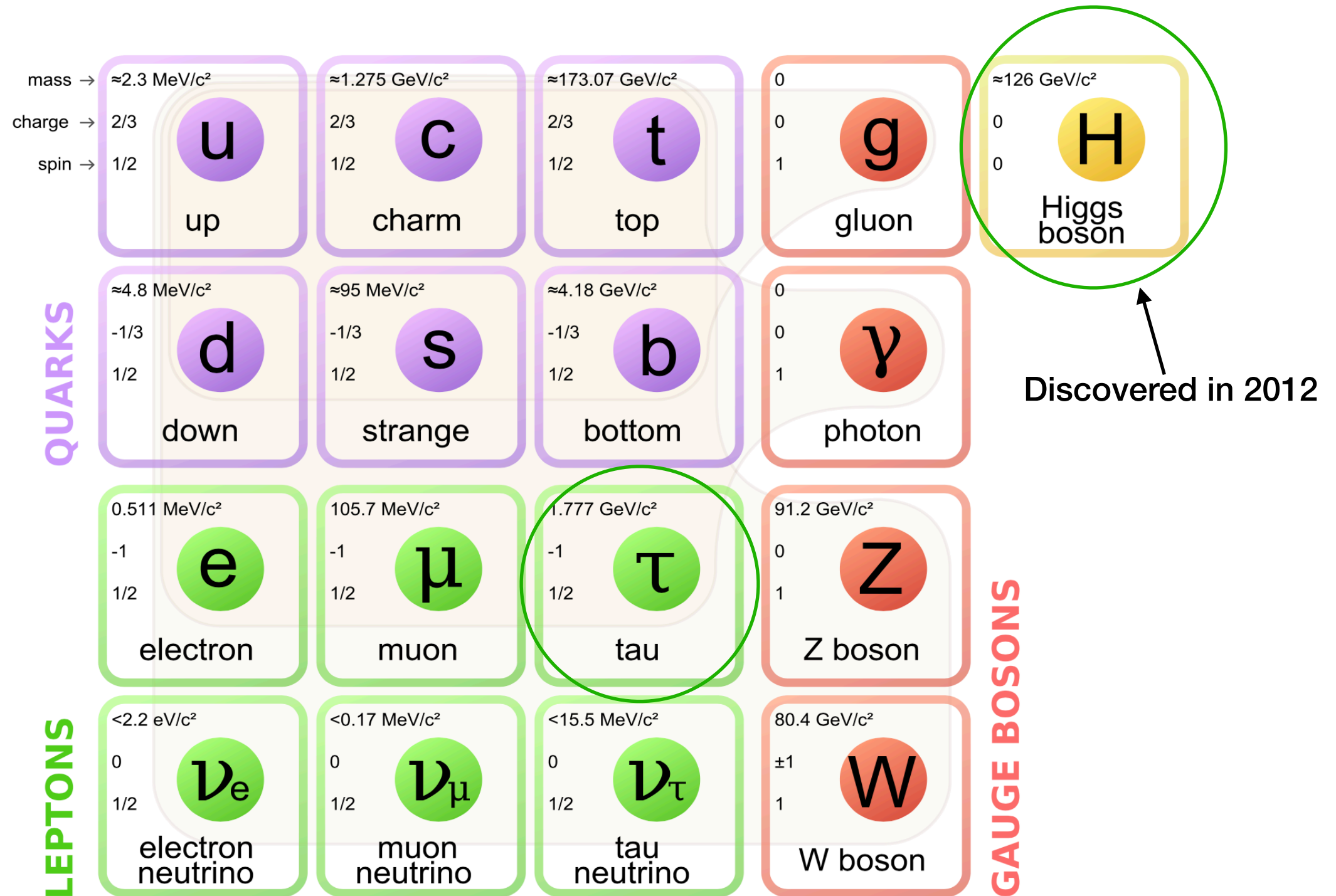# A brief introduction about taus

Feng Zhang, Frank Jensen
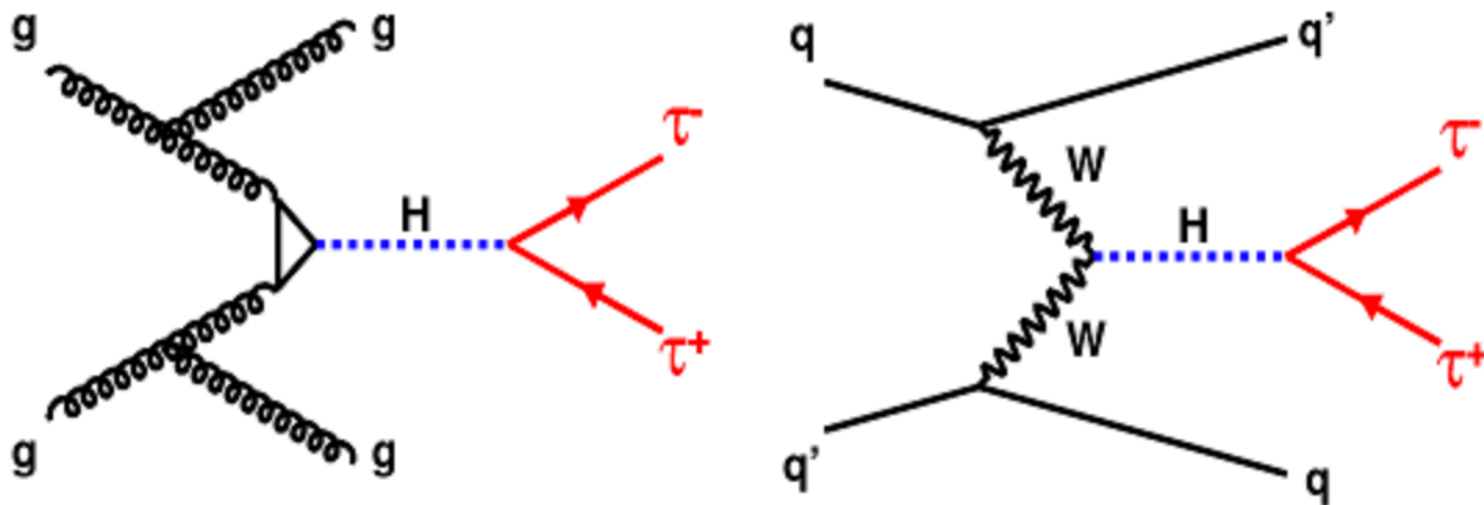
CMS DAS @LPC

09/01/2023

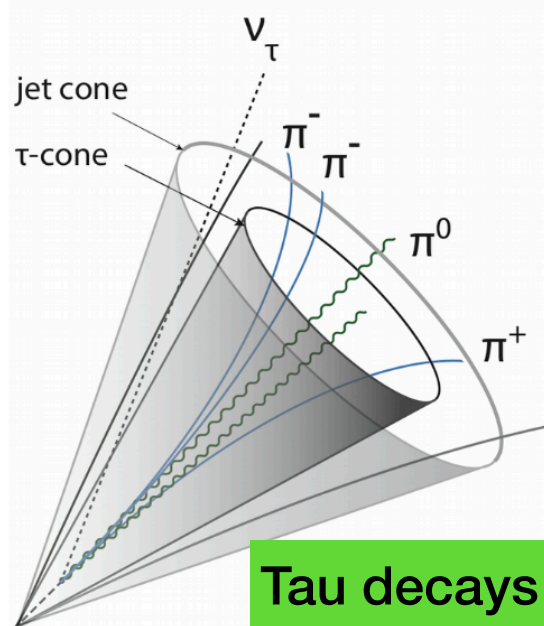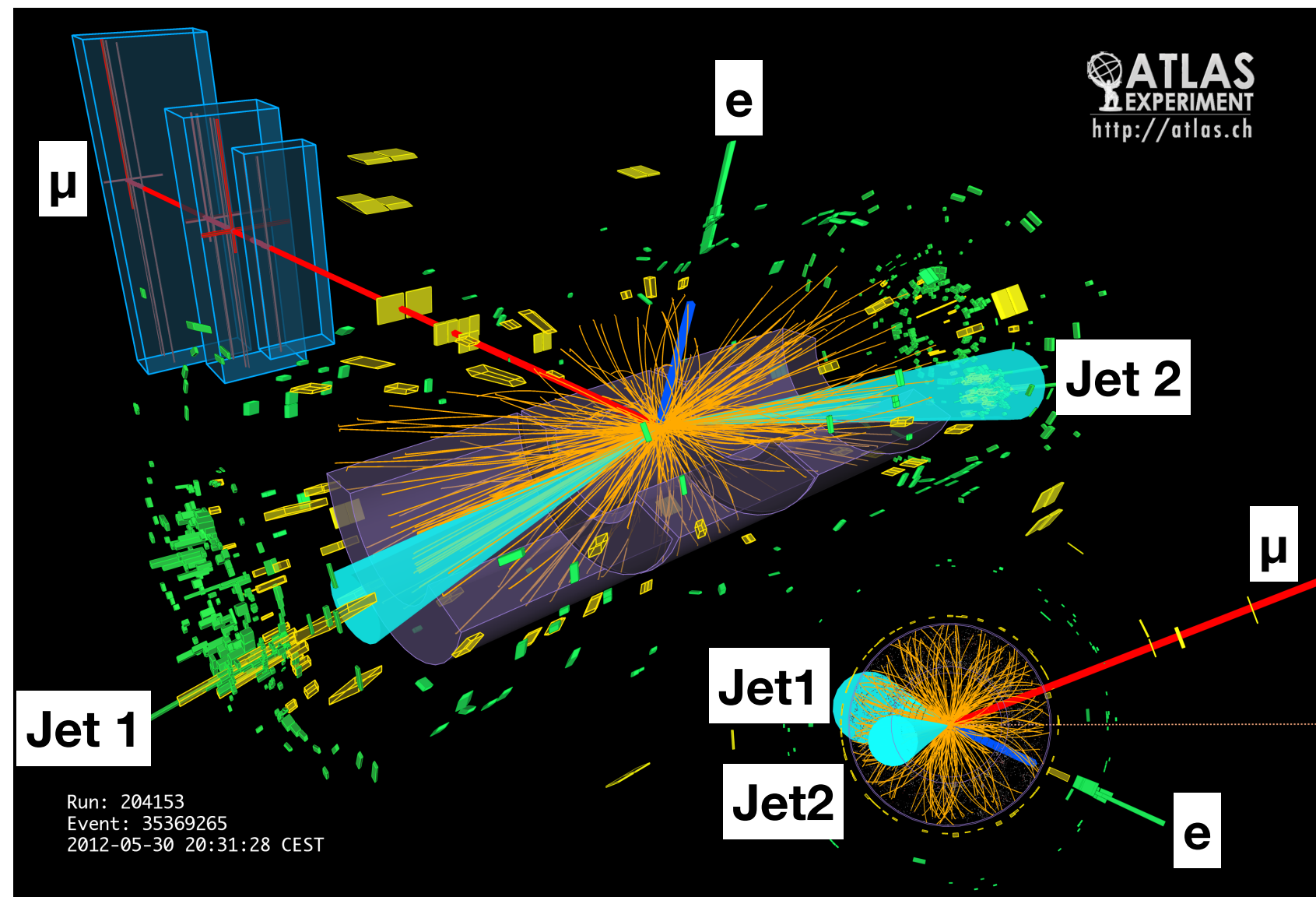# Elementary particle family

Why taus

- Heaviest lepton: 1.78 GeV
- Understanding the nature of Higgs boson
- Search for Higgs-like couplings
- Puzzles about lepton universality and flavor violation

Tau decays to μ/e

$\tau^- \rightarrow \nu_\tau$

$W^- \rightarrow e^-, \mu^-, d$

$\rightarrow \overline{\nu}_e, \overline{\nu}_\mu, \overline{u}$

Tau decays to hadrons

ATLAS EXPERIMENT
http://atlas.ch

Run: 204153
Event: 35369265
2012-05-30 20:31:28 CEST
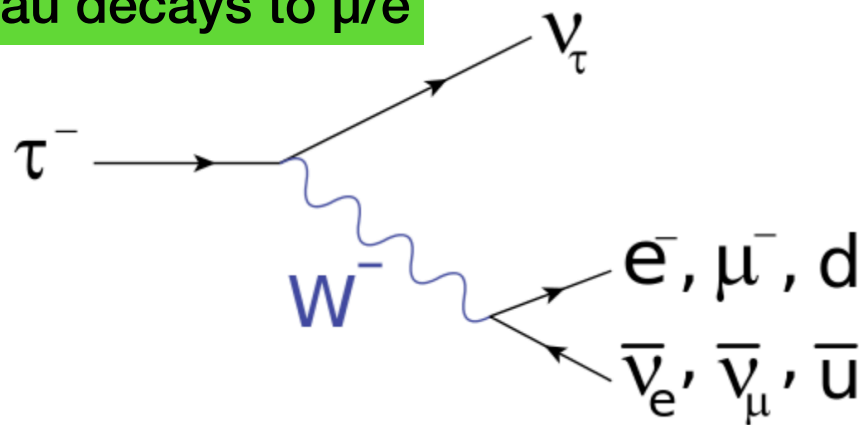
Examples of tau involved analyses

SM H→ττ

LFV H→µτ

X→HH→bbττ

SM H CP measurements

MSSM Φ→ττ

EXO W'/Z' → τν/ττ

MSSM H+→τν

Profile of the tau lepton

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
$\tau^- \to h^- \pi^0 \pi^0 \nu_\tau$	$a_1(1260)$	10.8
$\tau^- \to h^- h^+ h^- \nu_\tau$	$a_1(1260)$	9.8
$\tau^- \to h^- h^+ h^- \pi^0 \nu_\tau$		4.8
Other modes with hadrons		1.8
All modes containing hadrons		64.8

- Tau is the only lepton heavy enough to decay into hadrons

- Finite lifetime 0.29 picosecond, nearly light speed (c ≈ 300K km/s), totally flight distance ≈ 90μm

- Around 35% of tau decays into light leptons and neutrinos

- 65% decays into hadrons + neutrinos

  - Reconstruct different decay modes to identify taus

  - We often say "taus" meaning "hadronic decay taus"

Tau reconstruction: hadrons-plus-strips algorithm


hadron   hadron+strip   3 hadrons
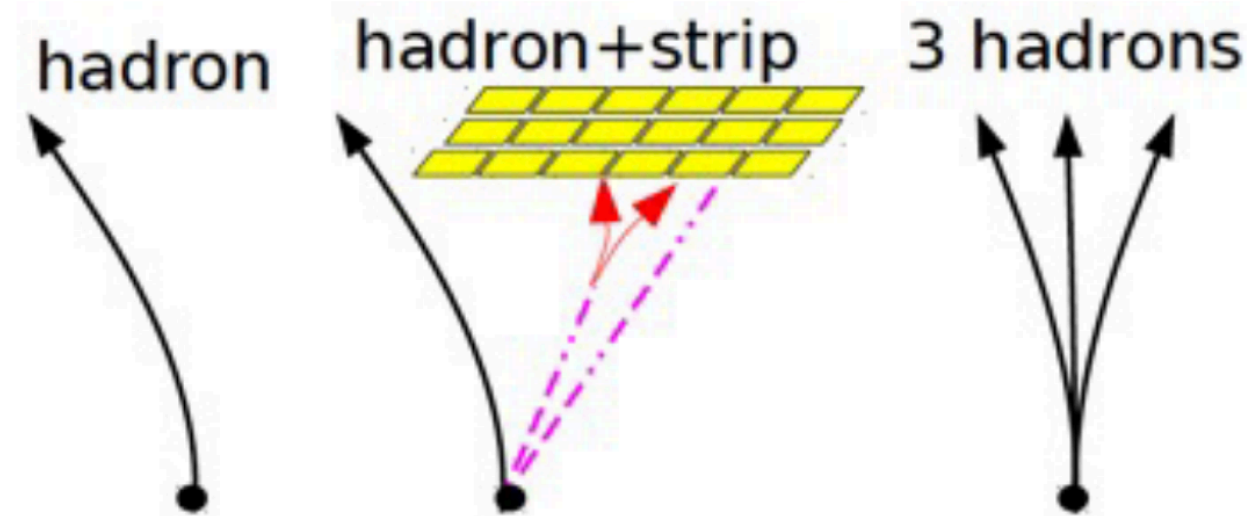
- π^0 are reconstructed from e and γ deposits in rectangular regions in ECAL, called **strips**

- Input: charged hadrons, electrons, and photons reconstructed by the CMS particle-flow algorithm from a jet cone
- Reconstructed decay modes of taus:
  - 1-prong
  - 1-prong + π^0
  - 3-prongs (+ π^0 s)
- Charged hadrons (h) can be pions (predominately), Kaons

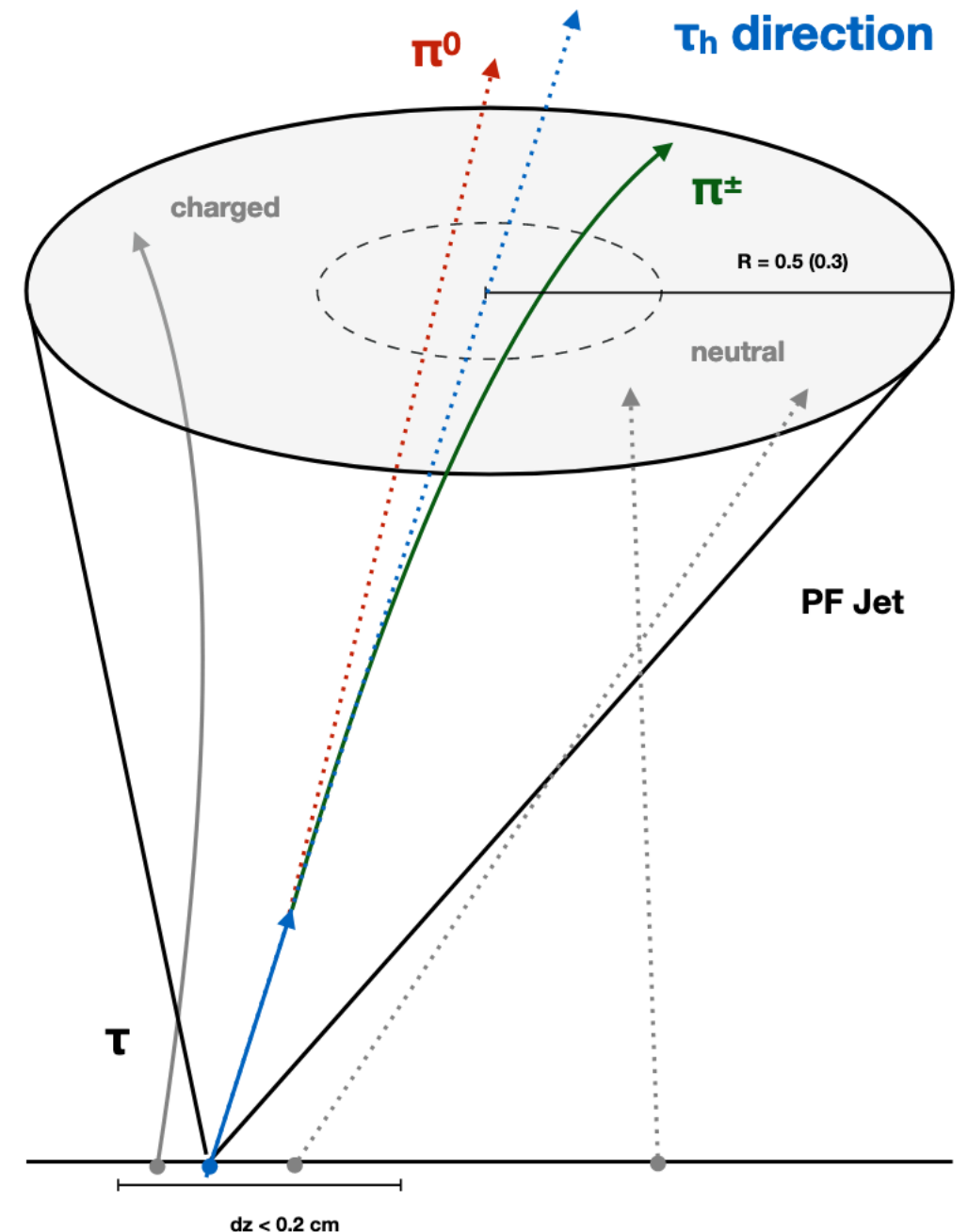| Decay mode	Meson resonance	$\mathcal{B}$ [%]
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- You will learn more about it in the first exercise

Find taus amongst jets, electrons, muons
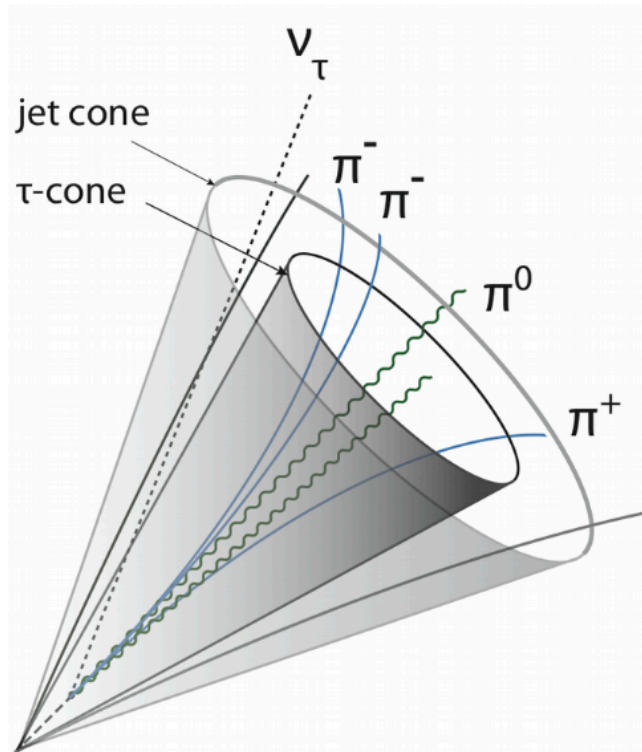
- Quark and gluon formed jets are abundant at the LHC
- They usually contain charged hadrons and π0 s and lead to reconstructed tau candidates

- Distinguishing taus from them are essential:
  - Multiplicity, isolation (transverse momentum sum of particles other than the tau decay products)
  - No intermediate resonances with defined mass
  - Tau lifetime

- Multiplevariable (MVA) classifier:
  - Combine different piece of information above
  - Distinguish taus from jets, electrons, muons
- Deep neural network (DeepTau) classifier:
  - Advanced machine learning technique
  - You will learn more about it in the second exercise

Conclusion

- Tau reconstruction is complex and challenging but well worth the effort given its importance in Higgs physics, lepton universality, and many other new physics searches

- Significant algorithmic advances are still possible as recently demonstrated by new Deep neural network classifiers

- You will learn:
  - How taus are reconstructed and how efficient the tau reconstruction algorithm is
  - How well we can currently distinguish taus from jets (possibly electrons and muons)

- The goal is to:
  - Equip you with basic understanding of tau reconstruction and identification in CMS
  - Give you ideas how you can help improve taus!