LFV searches involving tau leptons at LHC

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Mini-Workshop on Tau Physics

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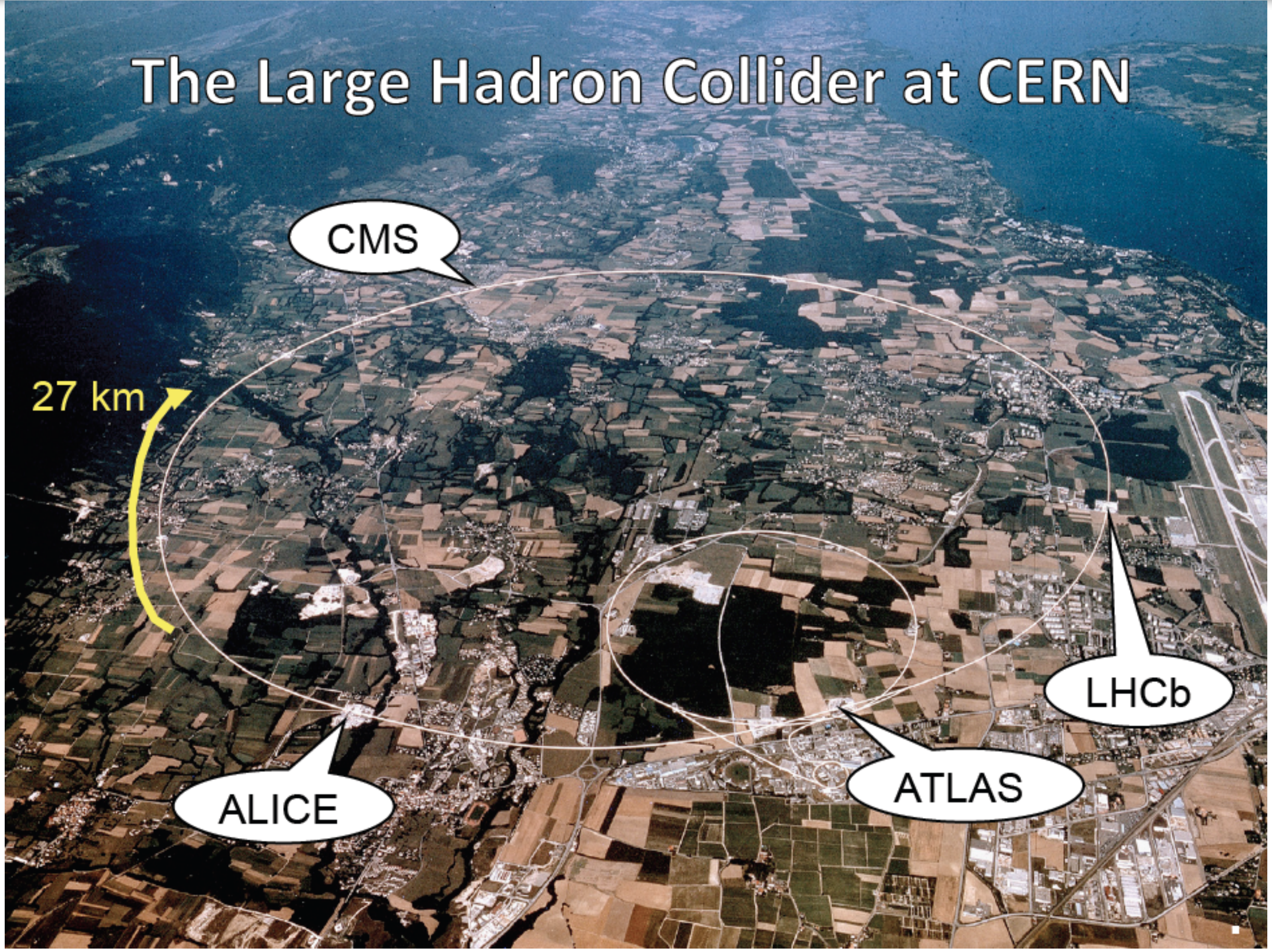
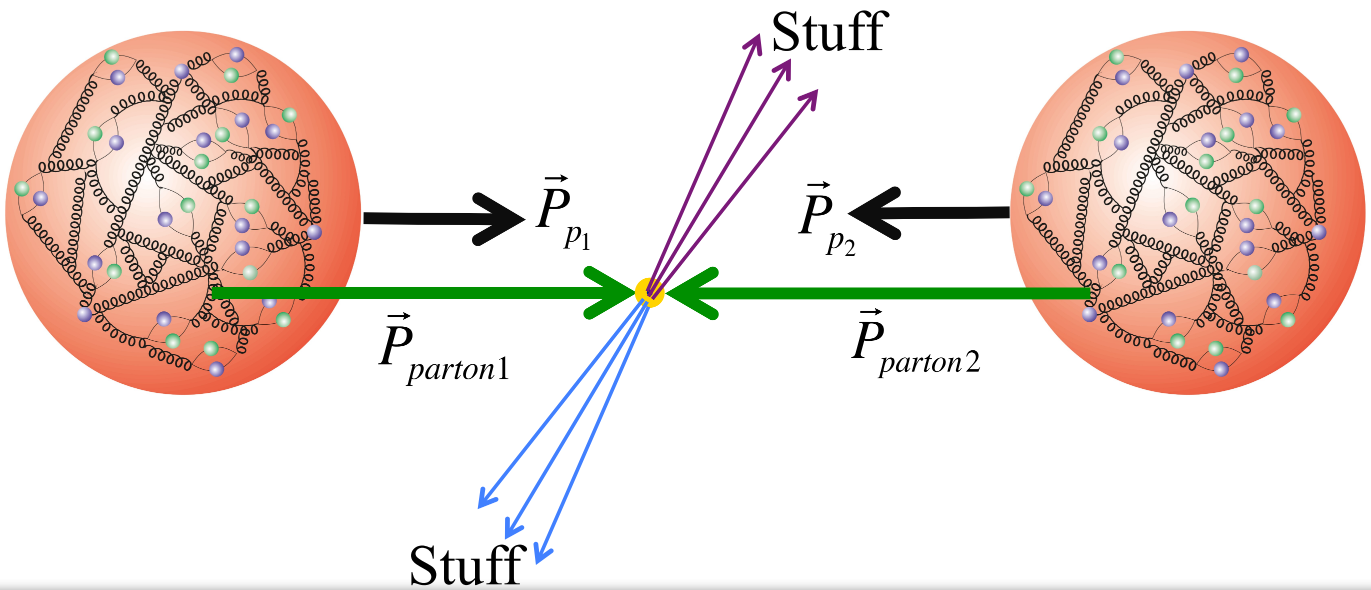
What does the LHC tell us about LFV?





Why are tau's so interesting at LHC?

– best channel for observing Higgs boson fermionic decays

– also the best for finding the neutral MSSM Higgs boson

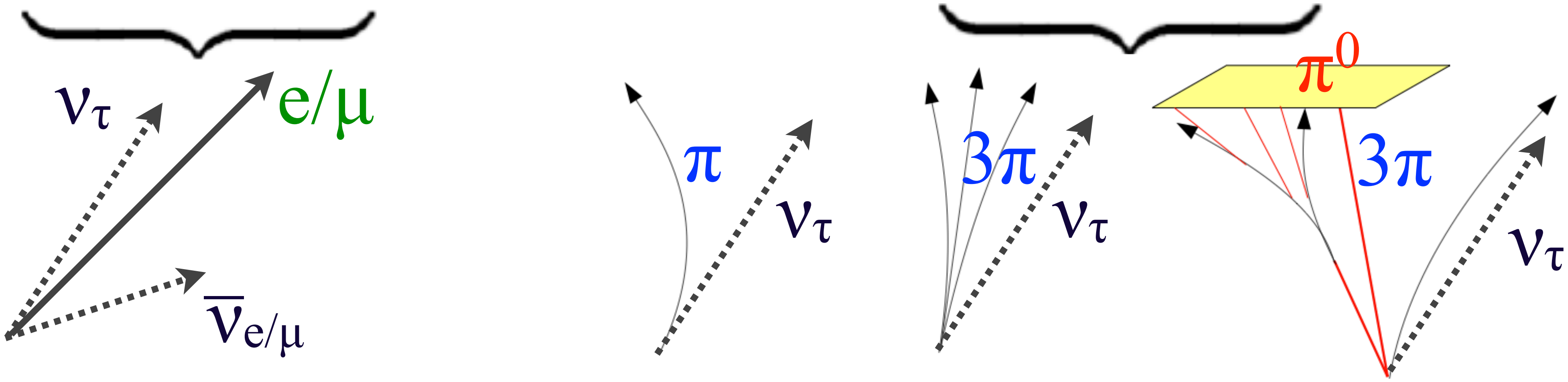
– add another channel to all searches with leptons

– they are really heavy, so they might be special (recent hints of possible lepton non-universality from LHCb...)

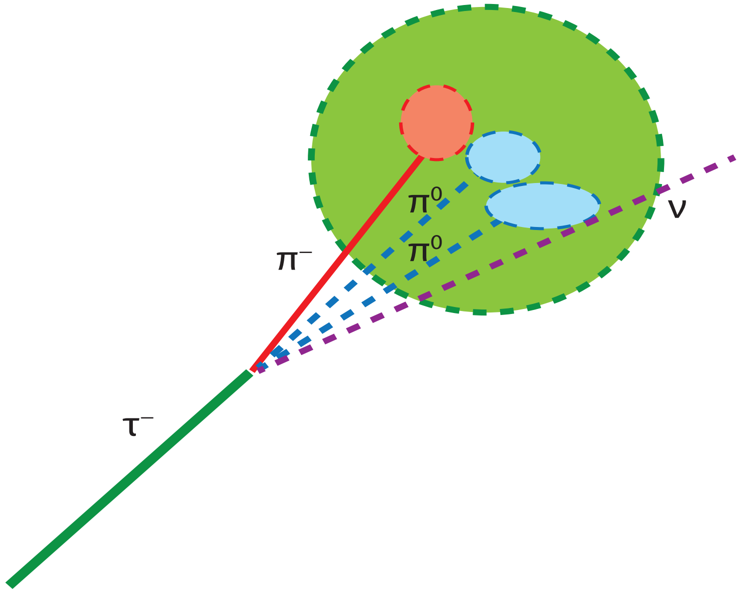
– they are handy for Lepton Flavor Violation searches

Tau decays at LHC

Tau (τ) decays leptonically (35%) as well as hadronically (65%)



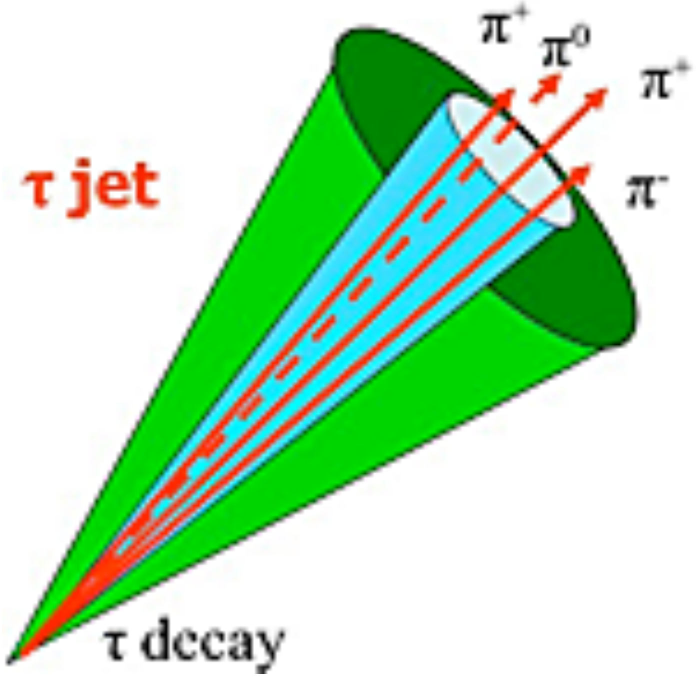
Hadronic decays reconstructed as “tau-jet” in ATLAS/CMS



Specific mix of $\pi^\pm$ and π^0:

Reconstruction & ID:

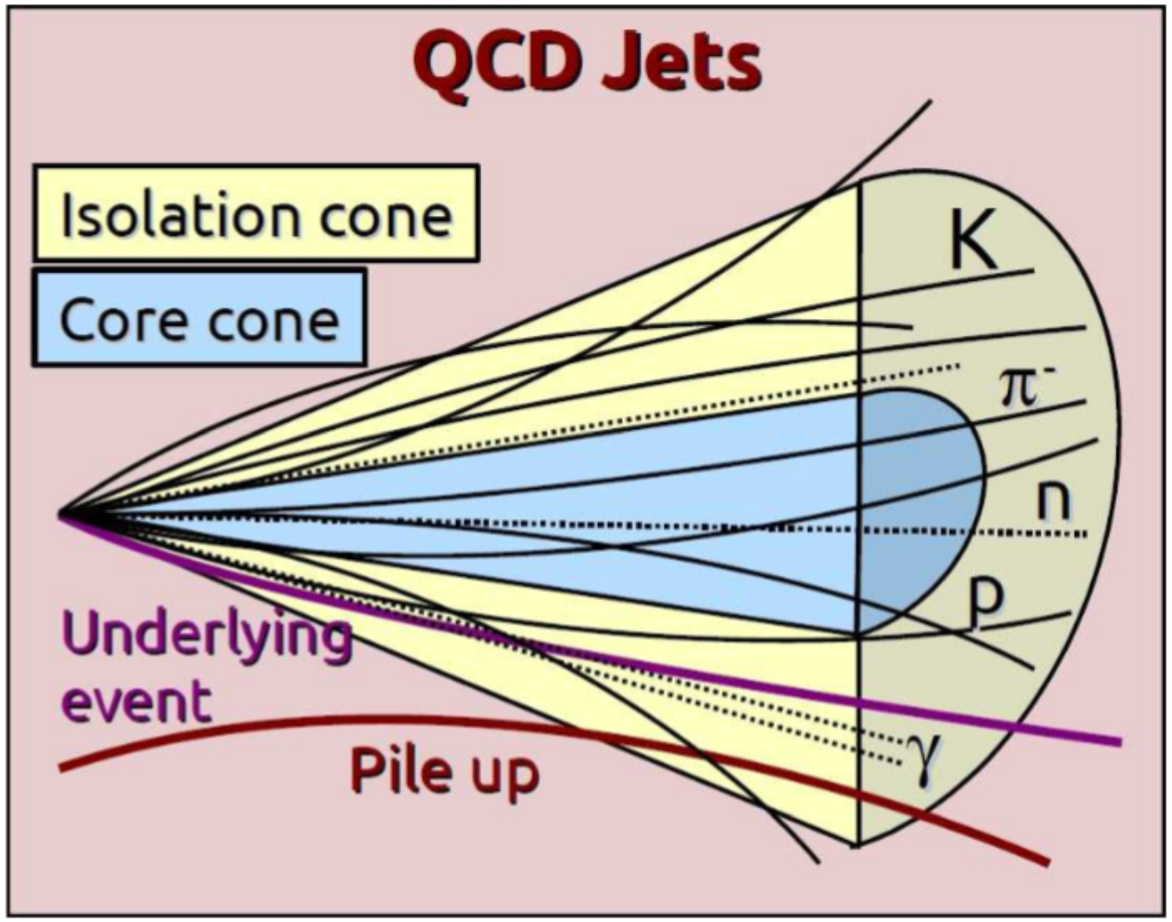
- τ reconstruction seeded by anti-k_T jets
- Identification criteria (BDT)

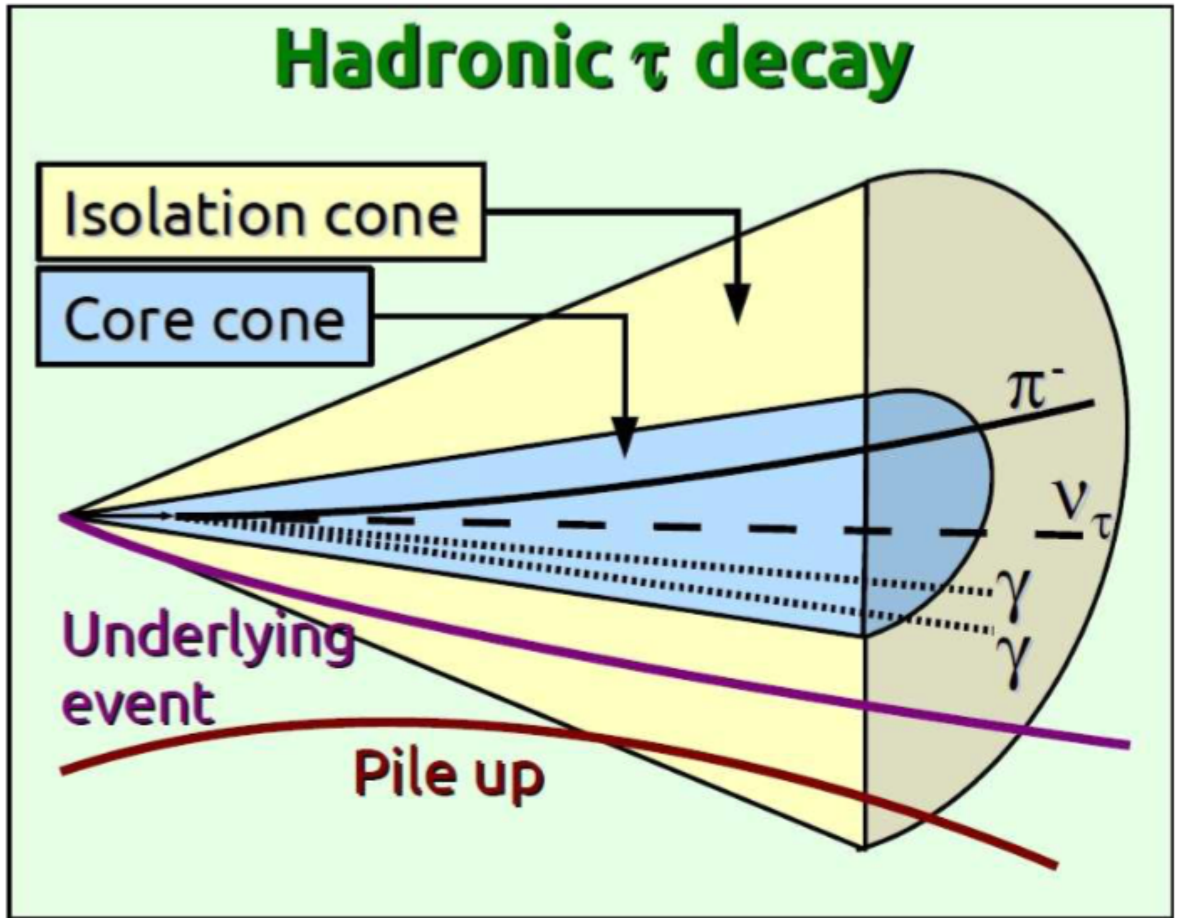


Tau-jet identification

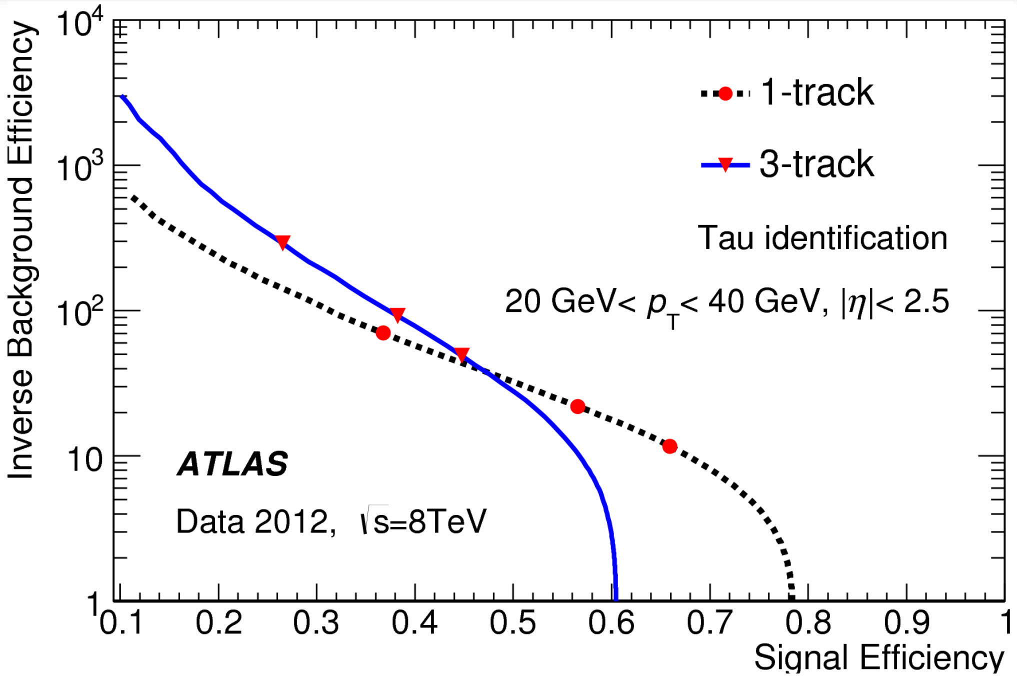
QCD jets have
large multiplicity,
wide energy profile,
uniform shower shape

Tau jets have 1 or 3
charged tracks,
narrow activity,
annular ring
of isolation





Tau-jet performance in ATLAS/CMS

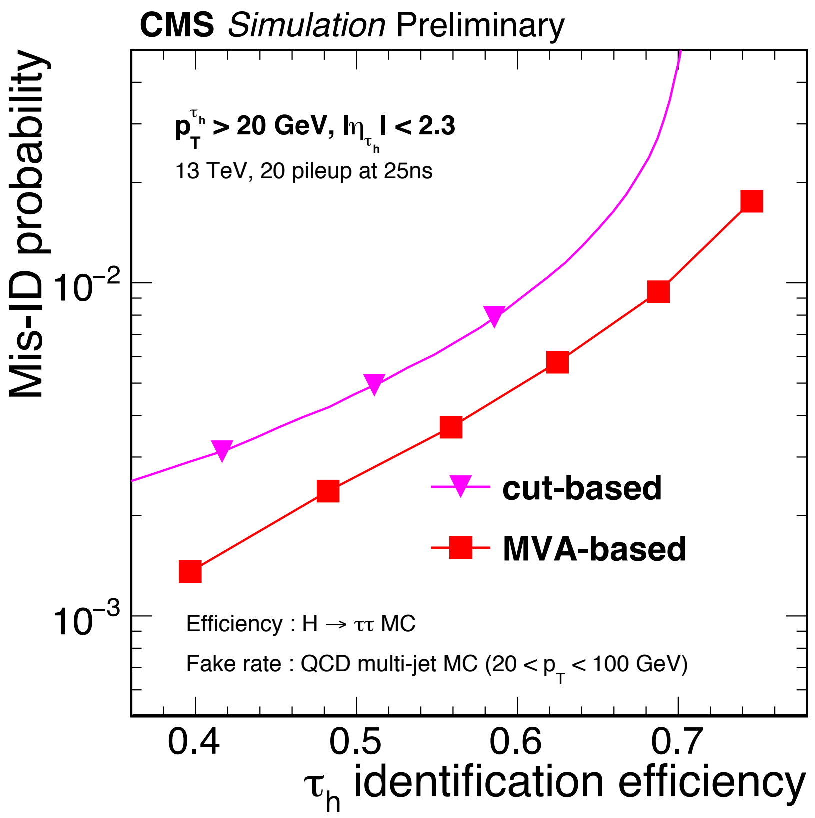


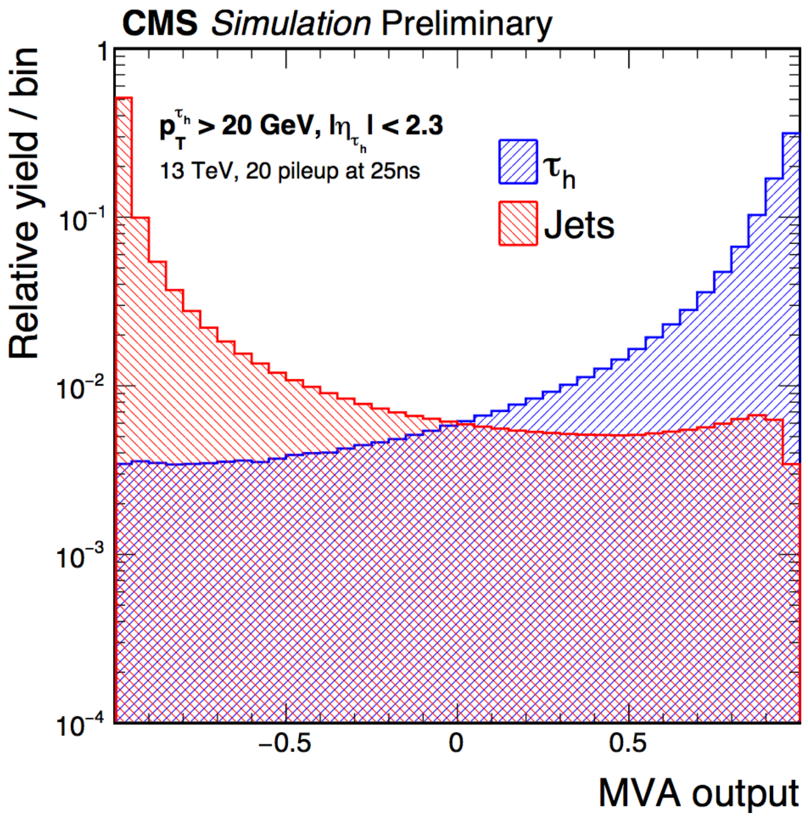
ATLAS:

- Identification efficiency ~ 50%
- Fake rate ~ 2%

arXiv:1412.7086,

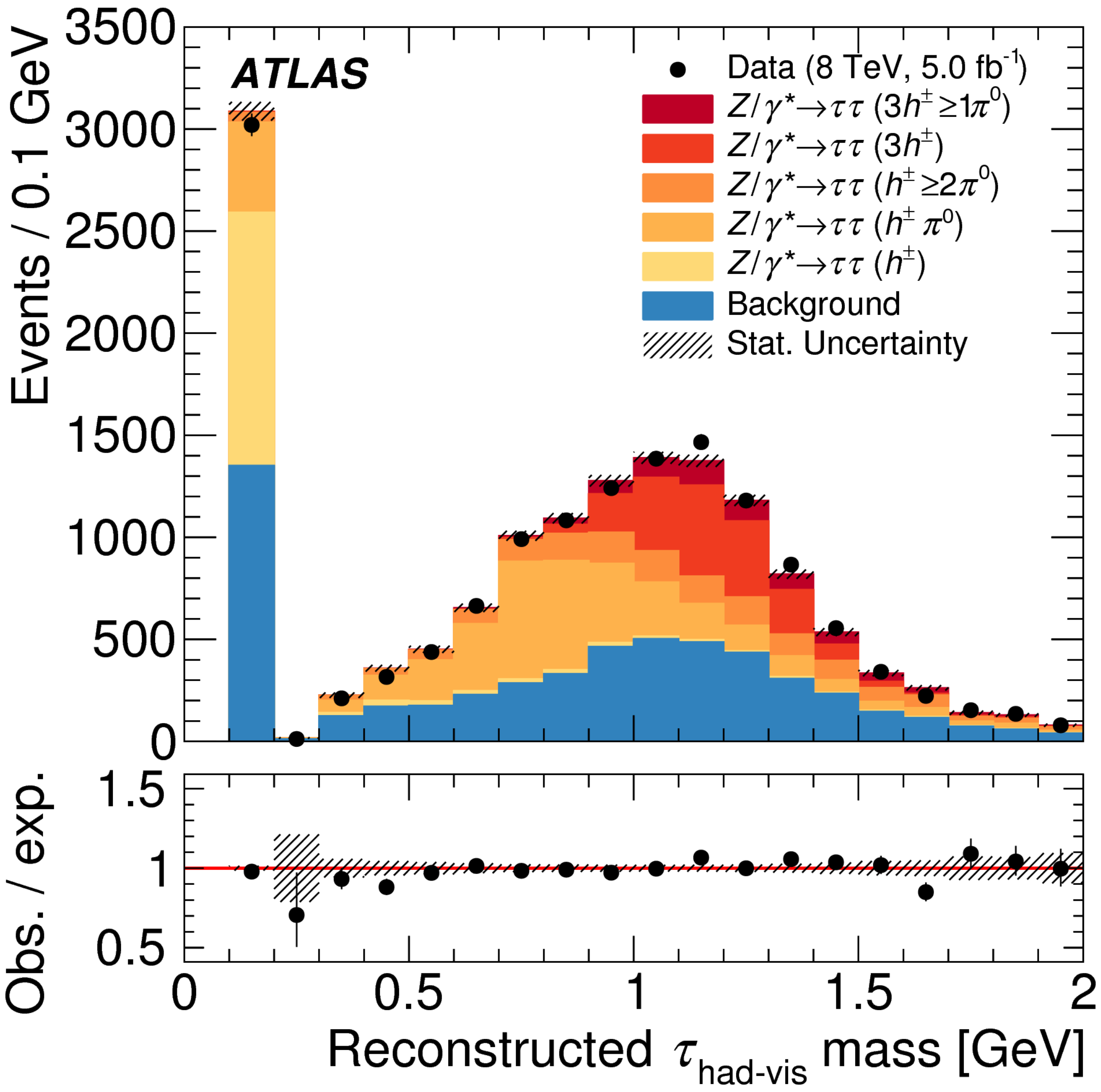
Eur. Phys. J. C75 (2015) 303

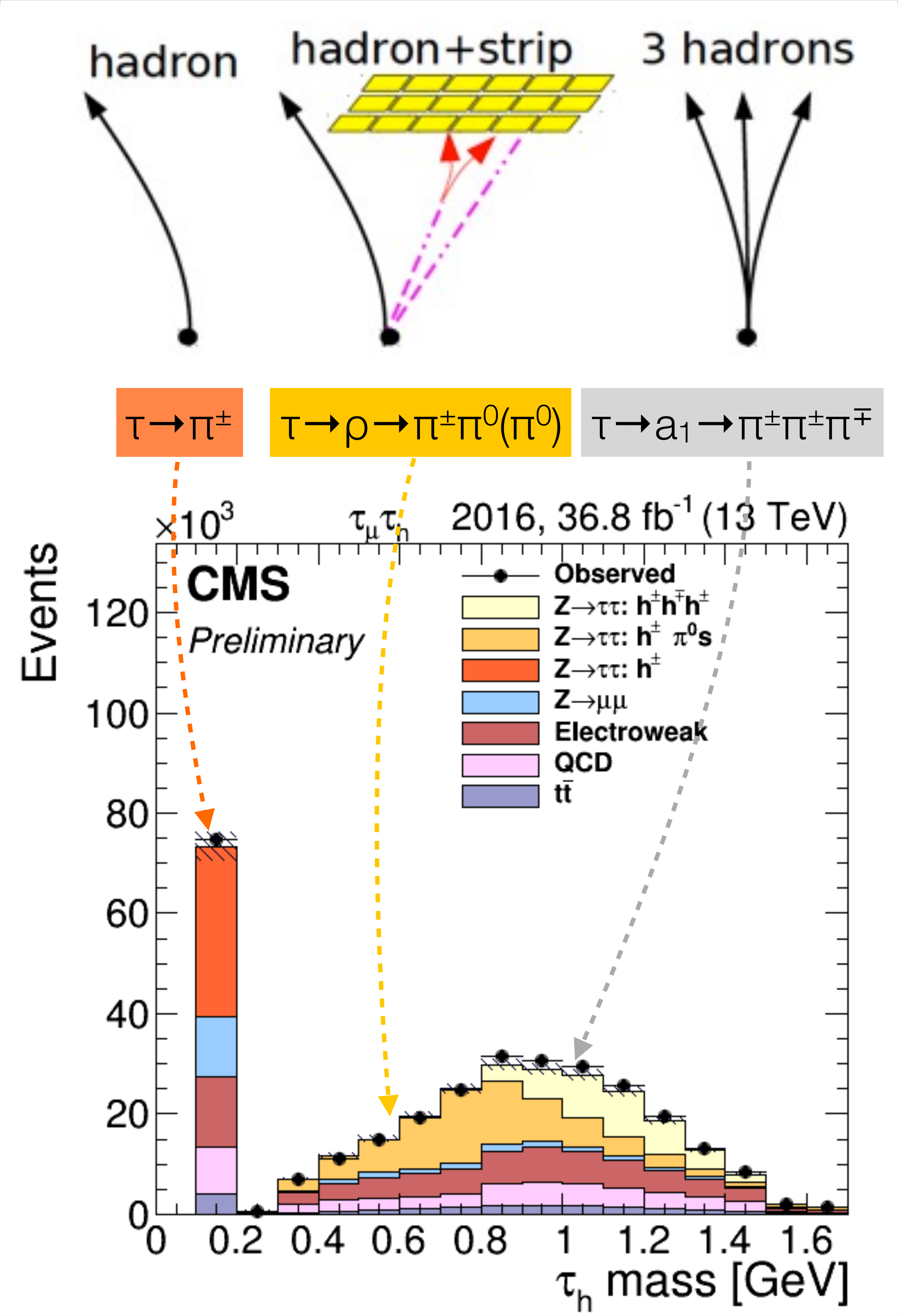




- CMS: Tau-jet identification efficiency ~ 60%, Fake rate ~ 1%

Tau-jet modelling in ATLAS/CMS





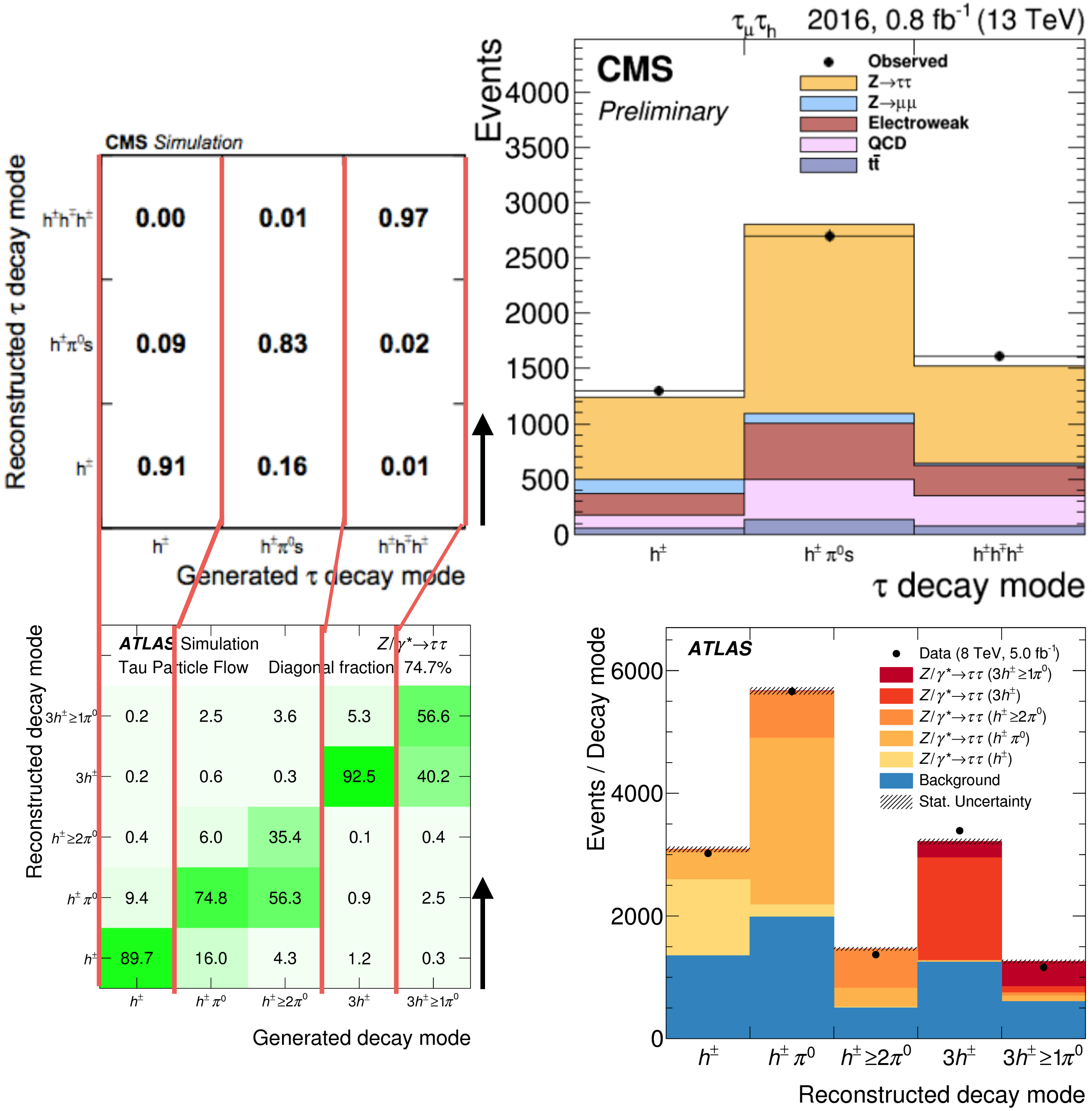
$\tau \to \pi^\pm$

$\tau \to \rho \to \pi^\pm\pi^0(\pi^0)$

$\tau \to a_1 \to \pi^\pm\pi^\pm\pi^\mp$

Tau-jet substructure in ATLAS/CMS

ATLAS: EPJC(2016)76:295; CMS: JINST11(2016)P01019, CMS-DP-2016-015



CMS *Simulation*

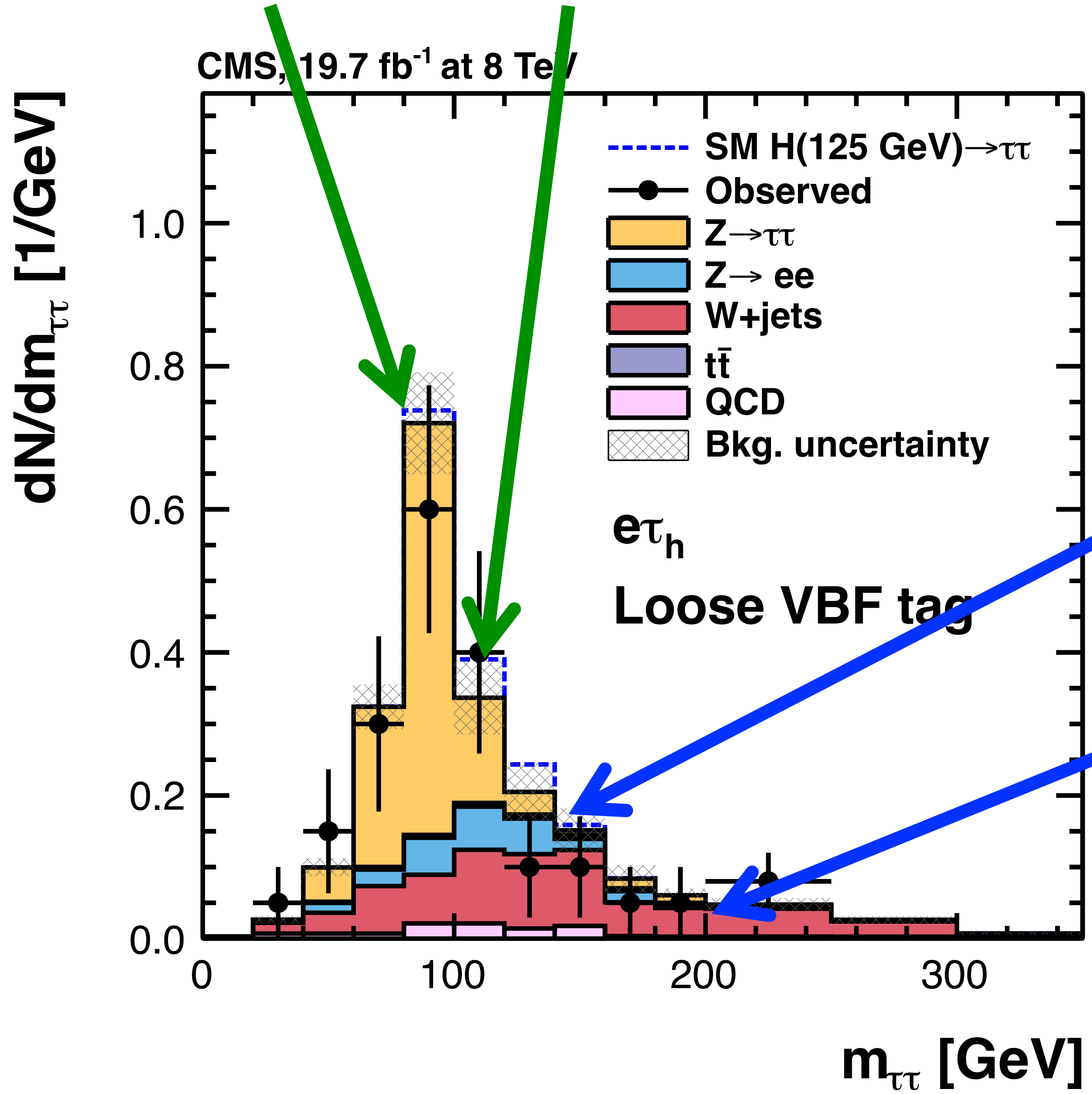
Reconstructed τ decay mode \ Generated τ decay mode	$h^\pm$	$h^\pm\pi^0$s	$h^\pm h^\mp h^\pm$
$h^\pm h^\mp h^\pm$	0.00	0.01	0.97
$h^\pm\pi^0$s	0.09	0.83	0.02
$h^\pm$	0.91	0.16	0.01

ATLAS Simulation, Tau Particle Flow, $Z/\gamma^*\to\tau\tau$, Diagonal fraction 74.7%

Reconstructed decay mode \ Generated decay mode	$h^\pm$	$h^\pm\pi^0$	$h^\pm{\geq}2\pi^0$	$3h^\pm$	$3h^\pm{\geq}1\pi^0$
$3h^\pm{\geq}1\pi^0$	0.2	2.5	3.6	5.3	56.6
$3h^\pm$	0.2	0.6	0.3	92.5	40.2
$h^\pm{\geq}2\pi^0$	0.4	6.0	35.4	0.1	0.4
$h^\pm\pi^0$	9.4	74.8	56.3	0.9	2.5
$h^\pm$	89.7	16.0	4.3	1.2	0.3

Challenges in analyses with tau-jets

Signal: reconstruction of genuine hadronic taus (τ_h)



Backgrounds:

Rejection of fake τ_h from electrons / muons

Rejection of fake τ_h from QCD jets

+ efficient trigger selection

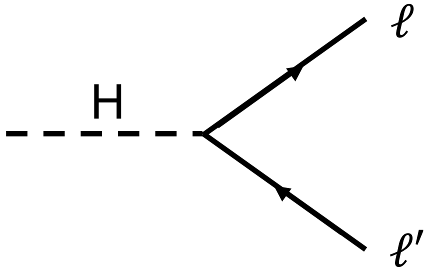
+ rejection of pileup (LHC currently features up to ~40 collisions / bunch crossing)

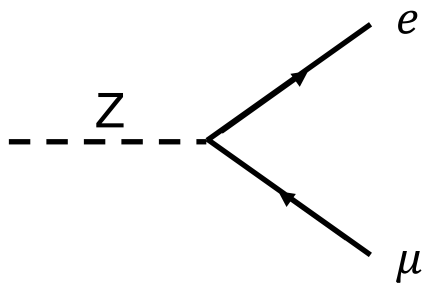
+ reliable description of data using simulation

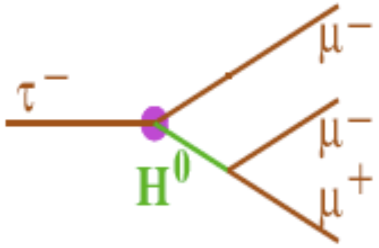
LFV searches at LHC

Searches covered in this talk:

- $H \rightarrow \mu\,\tau$, $e\,\tau$, $\mu\, e$ (ATLAS, CMS)
- $Z \rightarrow \mu\,\tau$, $e\,\tau$, $\mu\, e$ (ATLAS, CMS)
- Heavy $X \rightarrow \mu\,\tau$, $e\,\tau$, $\mu\, e$ (ATLAS, CMS)
- $\tau^- \rightarrow \mu^-\mu^+\mu^-$ (ATLAS, LHCb)
- $\tau^- \rightarrow \bar{p}\,\mu^+\mu^-$, $p\,\mu^-\mu^-$ (LHCb)







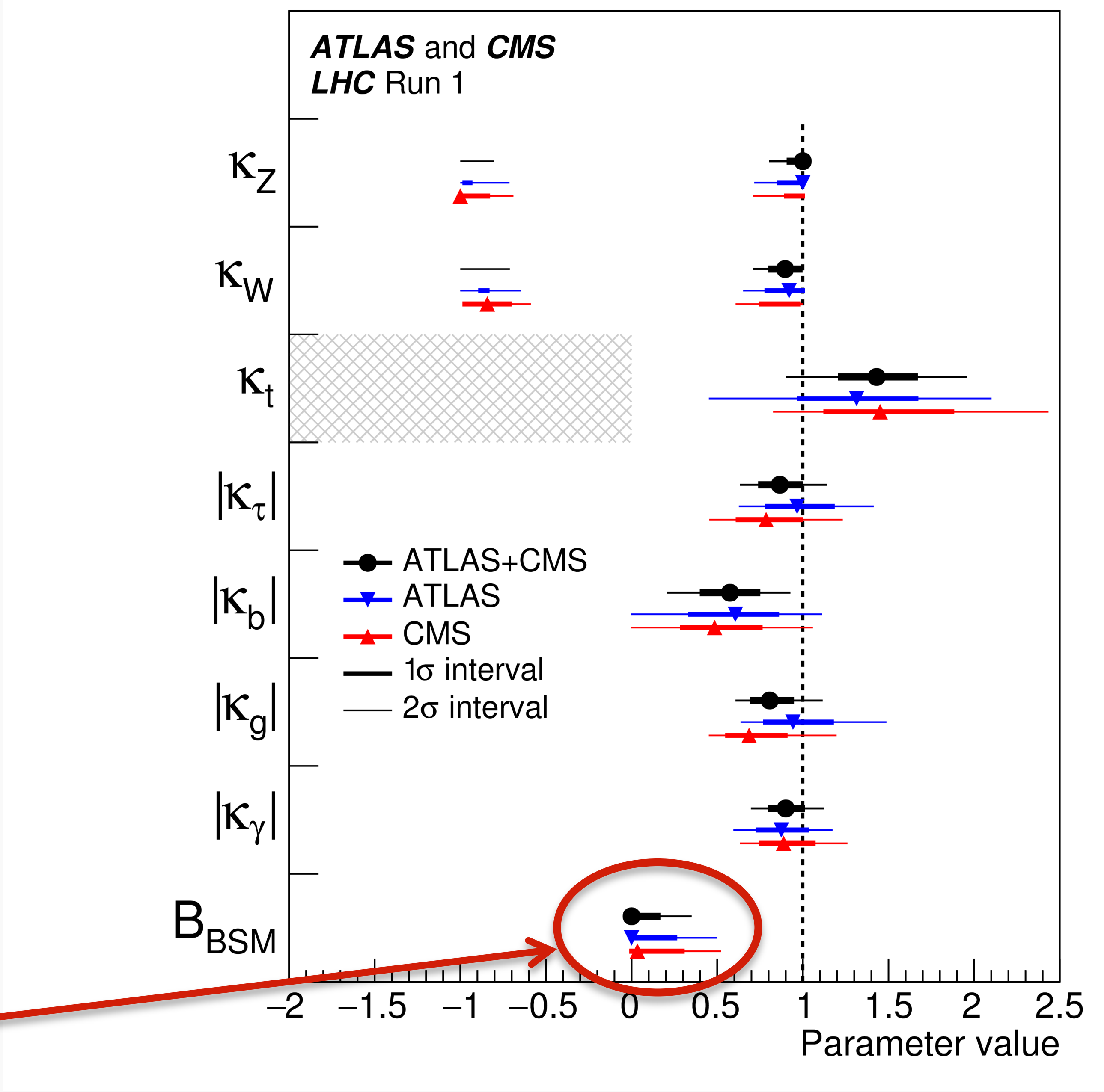
Other non-tau LFV searches from LHCb not covered in this talk:

- $D^0 \rightarrow e^+\mu^-$ (Phys. Lett. B754 (2016) 167)
- $B^0_{(s)} \rightarrow e^+\mu^-$ (Phys. Rev. Lett. 111 (2013) 141801)
- $D^+_{(s)} \rightarrow \pi^+\mu^-\mu^-, \pi^-\mu^+\mu^+$ (Phys. Lett. B 724 (2013) 203)
- $B^- \rightarrow D^{(*)+}\mu^-\mu^-$ (Phys. Rev. D 85 (2012) 112004)
- $B^+ \rightarrow \pi^-(K^-)\mu^+\mu^+$ (Phys. Rev. Lett. 108 (2012) 101601)

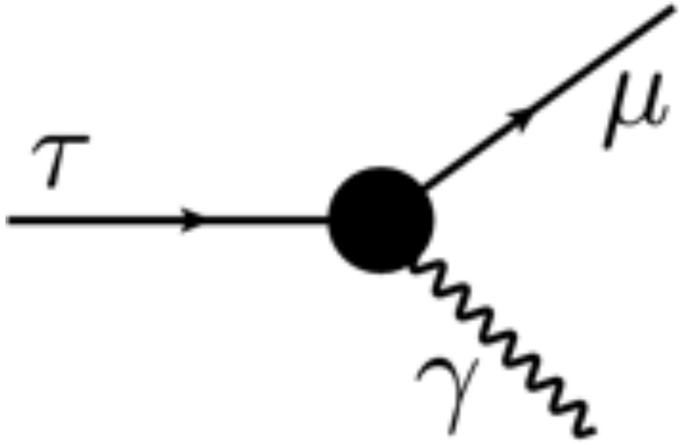
LHC Run 1 : Still room for BSM decays

- Possibilities to highlight BSM physics in the scalar sector:
  - Indirect evidence through observation of deviations in the couplings of the H boson (but precision limited and increasing slowly with additional data)
  - Direct evidence through observation of exotic decays of the Higgs boson
- Large room still viable for exotic Higgs boson decays (~20%)

JHEP 08 (2016) 045



Lepton Flavor Violation & Higgs decays

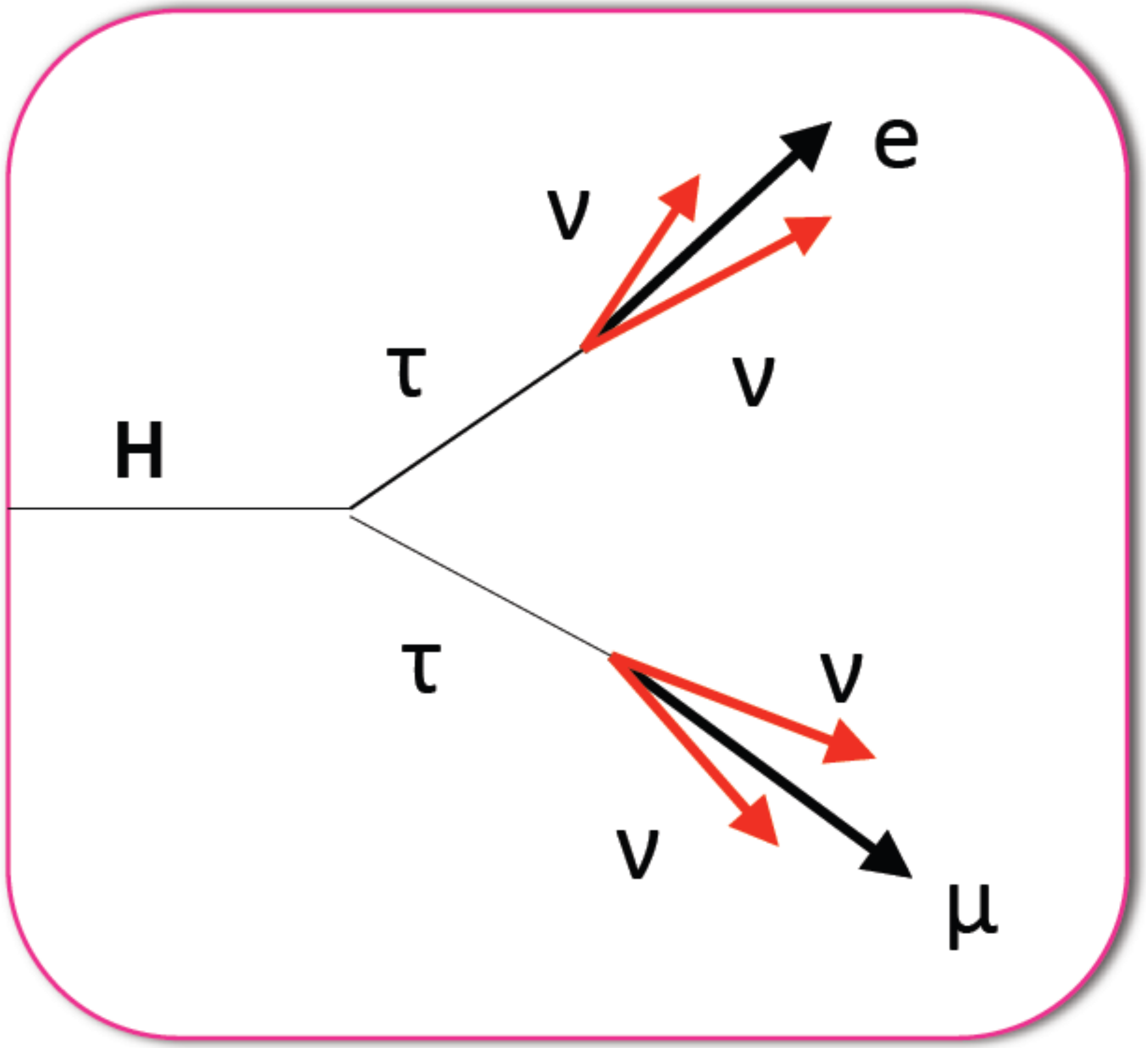


Br $(\tau \to \mu\gamma) < 4.4 \times 10^{-8}$

BaBar Collaboration
Phys. Rev. Lett.
104 (2010) 021802

Br $(H \to \mu\tau) \lesssim 10\%$

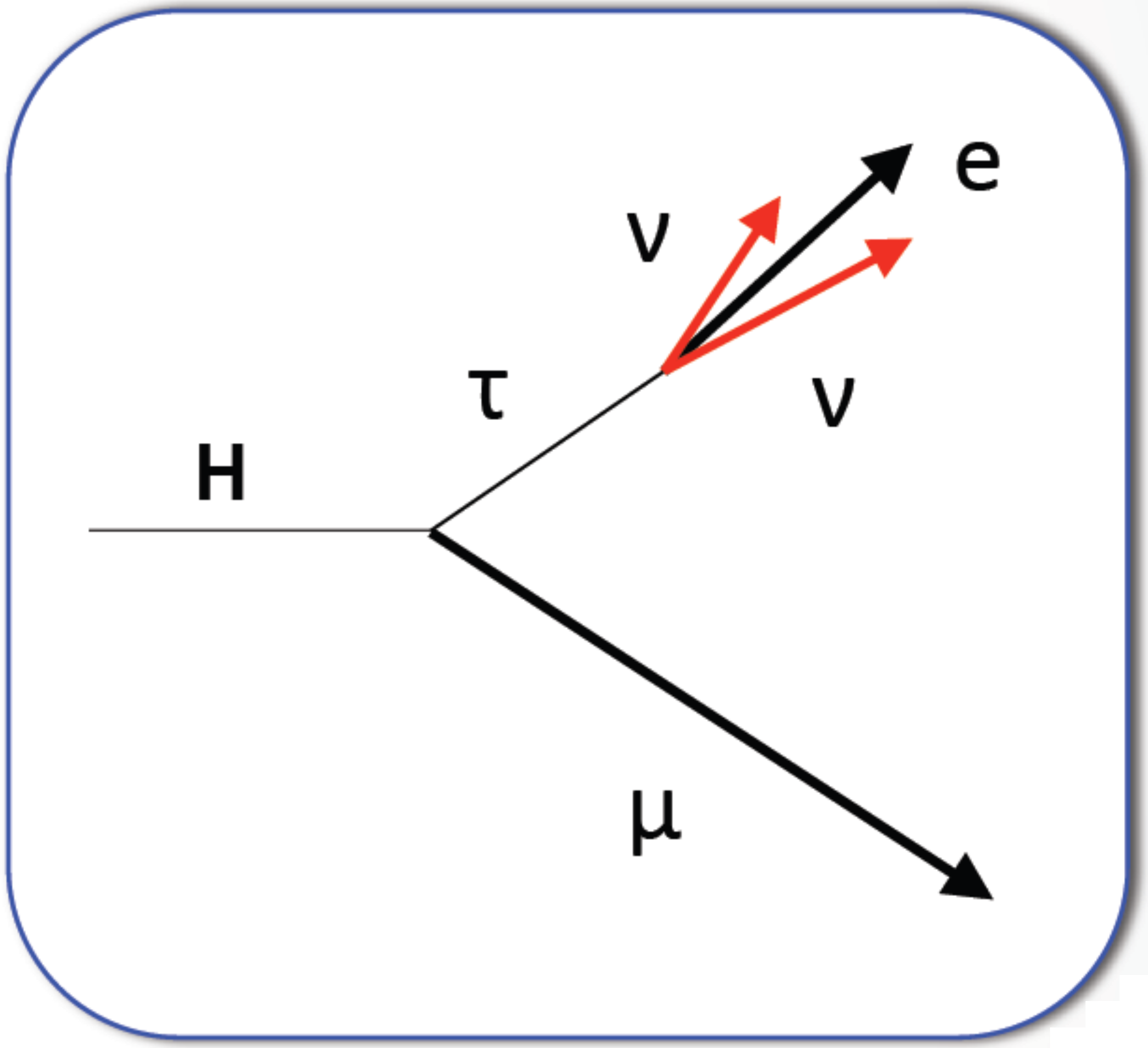
Harnik, Kopp, Zupan (1209.1397)



H→ ττ

How about direct search at LHC ?

vs.



H→μτ

LFV decays of the SM Higgs boson

Flavor Violating Higgs Decays
Roni Harnik , Joachim Kopp , Jure Zupan

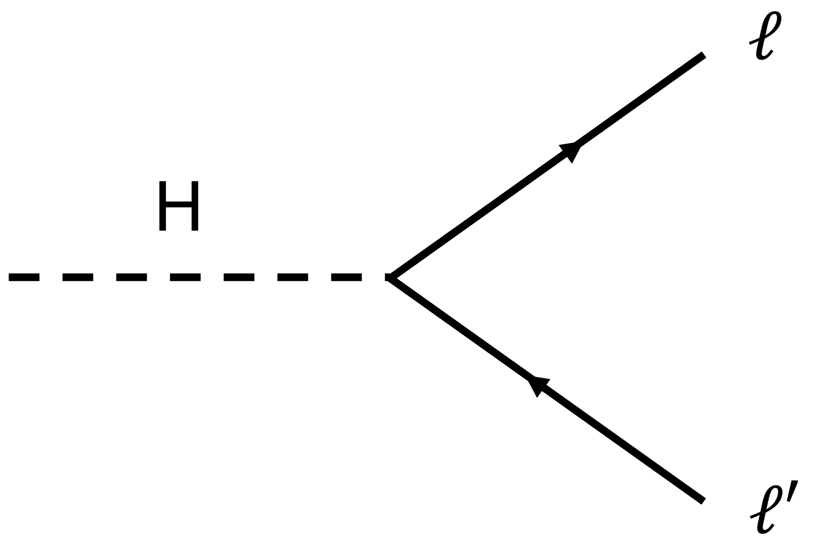
arXiv:1209.1397

Introduction

- LFV couplings to the Higgs possible, e.g. if SM only valid to finite scale Λ

$$Y_{ij} = \frac{m_i}{v}\delta_{ij} + \frac{v^2}{\sqrt{2}\Lambda^2}\hat{\lambda}_{ij}$$

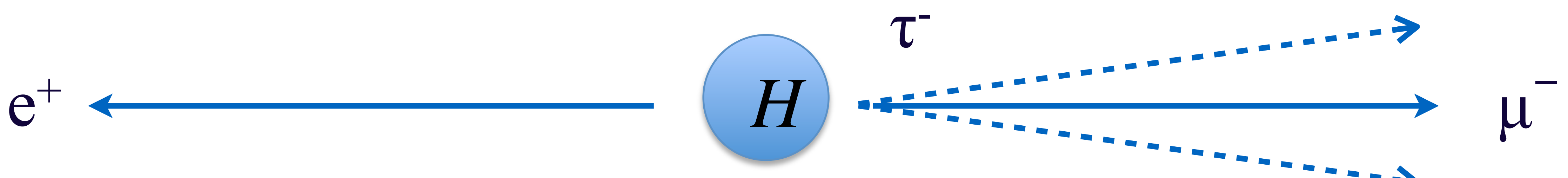
- LFV Higgs couplings would allow processes like $\mu \to e$, $\tau \to \mu$ and $\tau \to e$ via a virtual Higgs boson

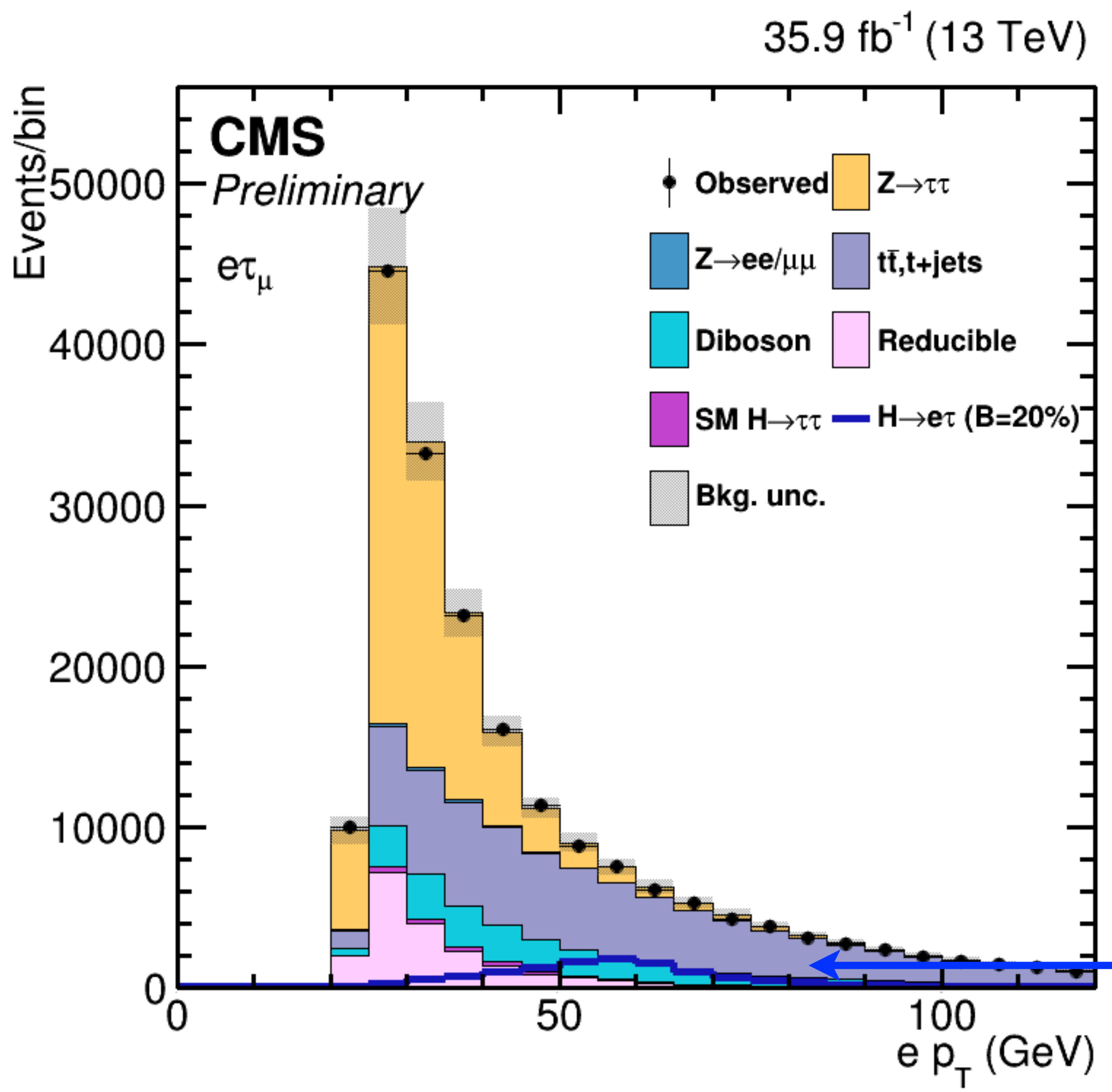


- $\mathcal{B}(H \to e\mu) < \mathcal{O}(10^{-8})$ @ 95% CL from $\mu \to e\gamma$
- $\mathcal{B}(H \to e\tau/\mu\tau) < \mathcal{O}(10\%)$ @ 95% CL from $\tau \to e\gamma/\mu\gamma$ and e/μ g-2 measurements
- $\mathcal{B}(H \to e\tau/\mu\tau) < 13\%$ @ 95% CL from theoretical reinterpretation of $H \to \tau\tau$ search results from ATLAS

→ direct search very promising

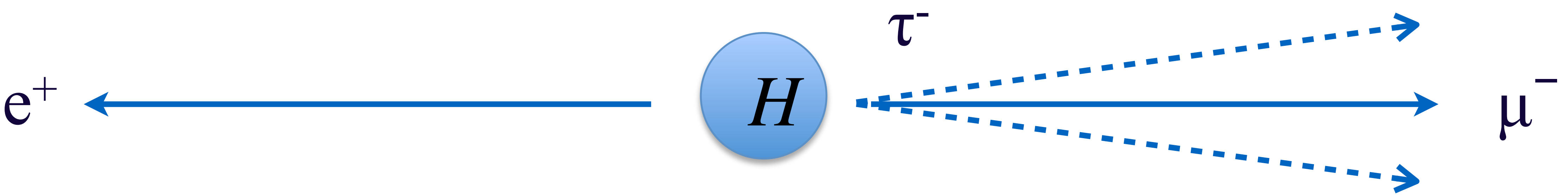
Event topology

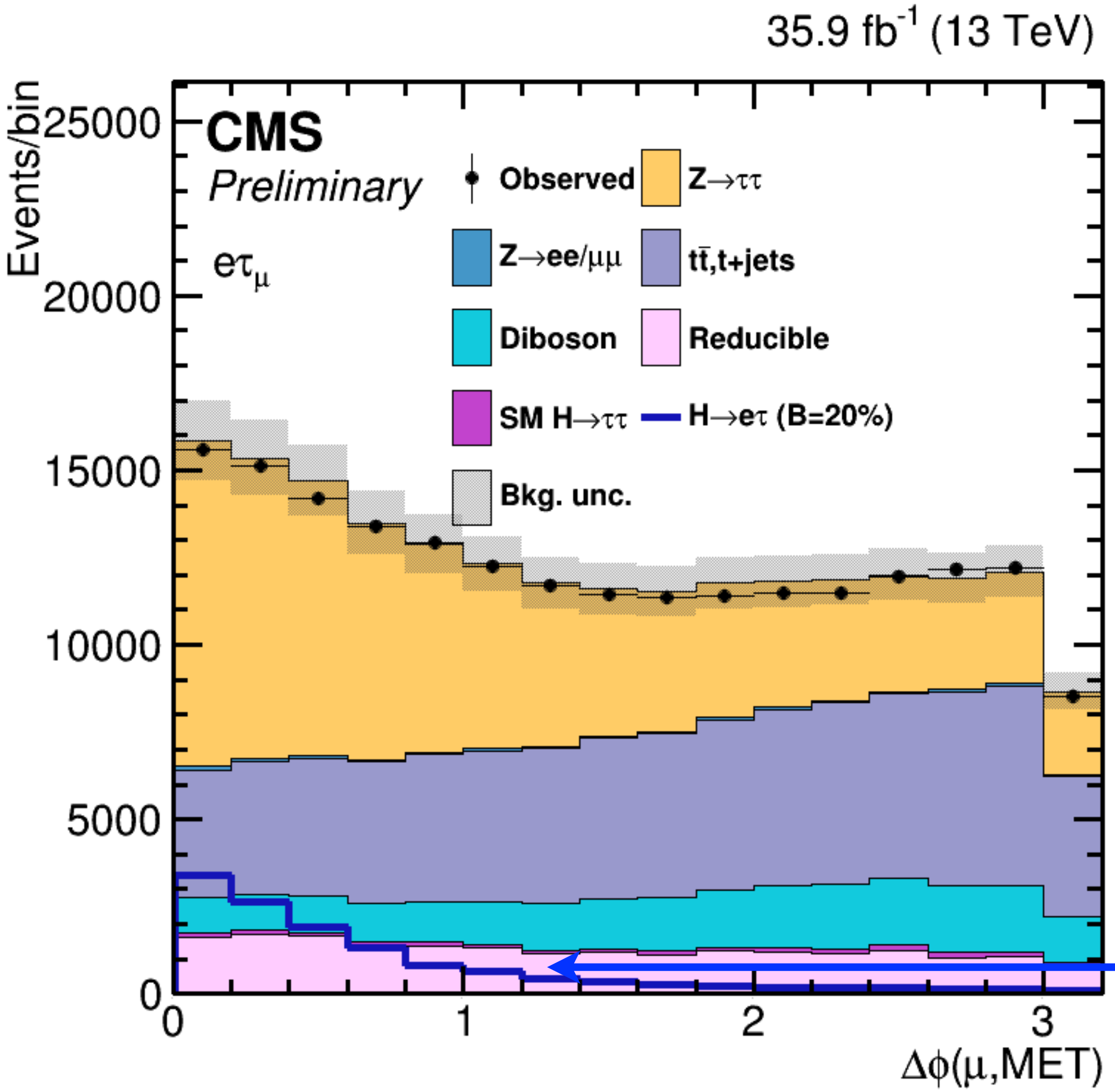


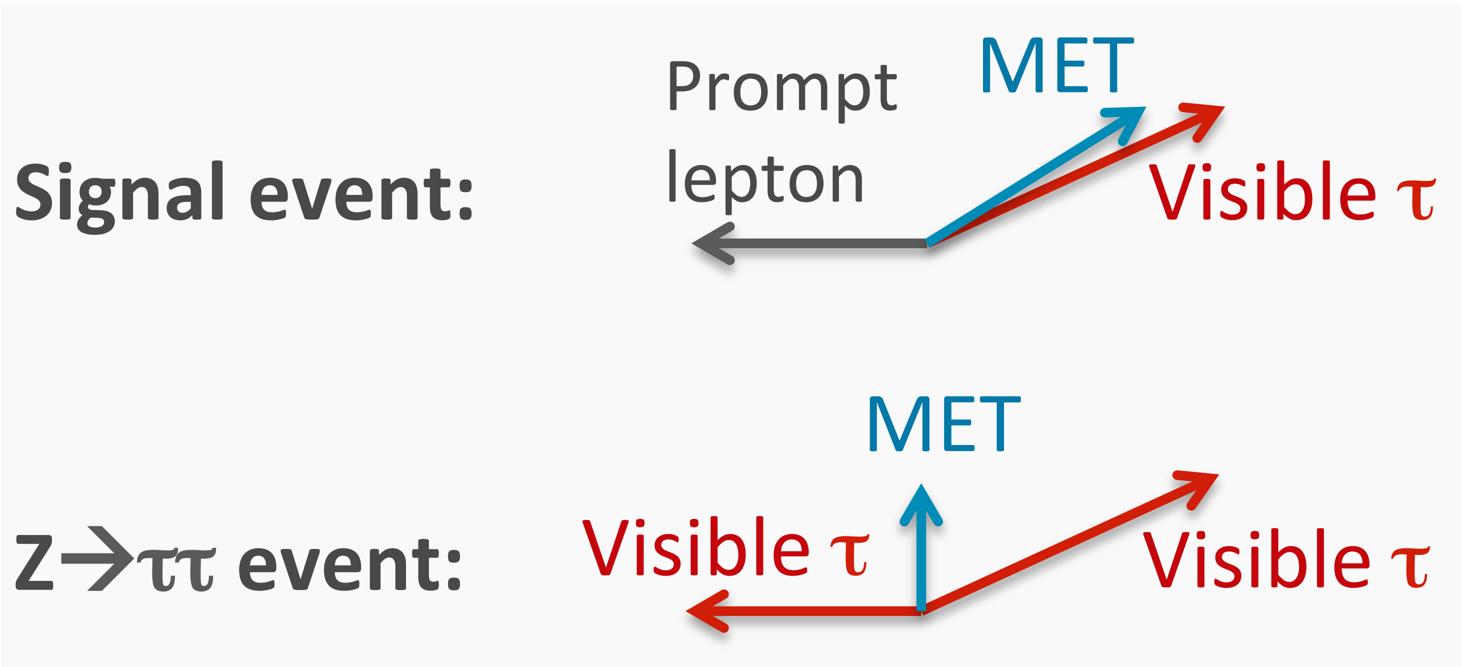


$$H \rightarrow e^+\,\tau^- \rightarrow e^+\,\mu^-\,\bar{\nu}_\mu\,\nu_\tau$$

Event topology







Signal event:

Z→ττ event:

$$H \rightarrow e^+\,\tau^- \rightarrow e^+\,\mu^-\,\bar{\nu}_\mu\,\nu_\tau$$

Search Strategy

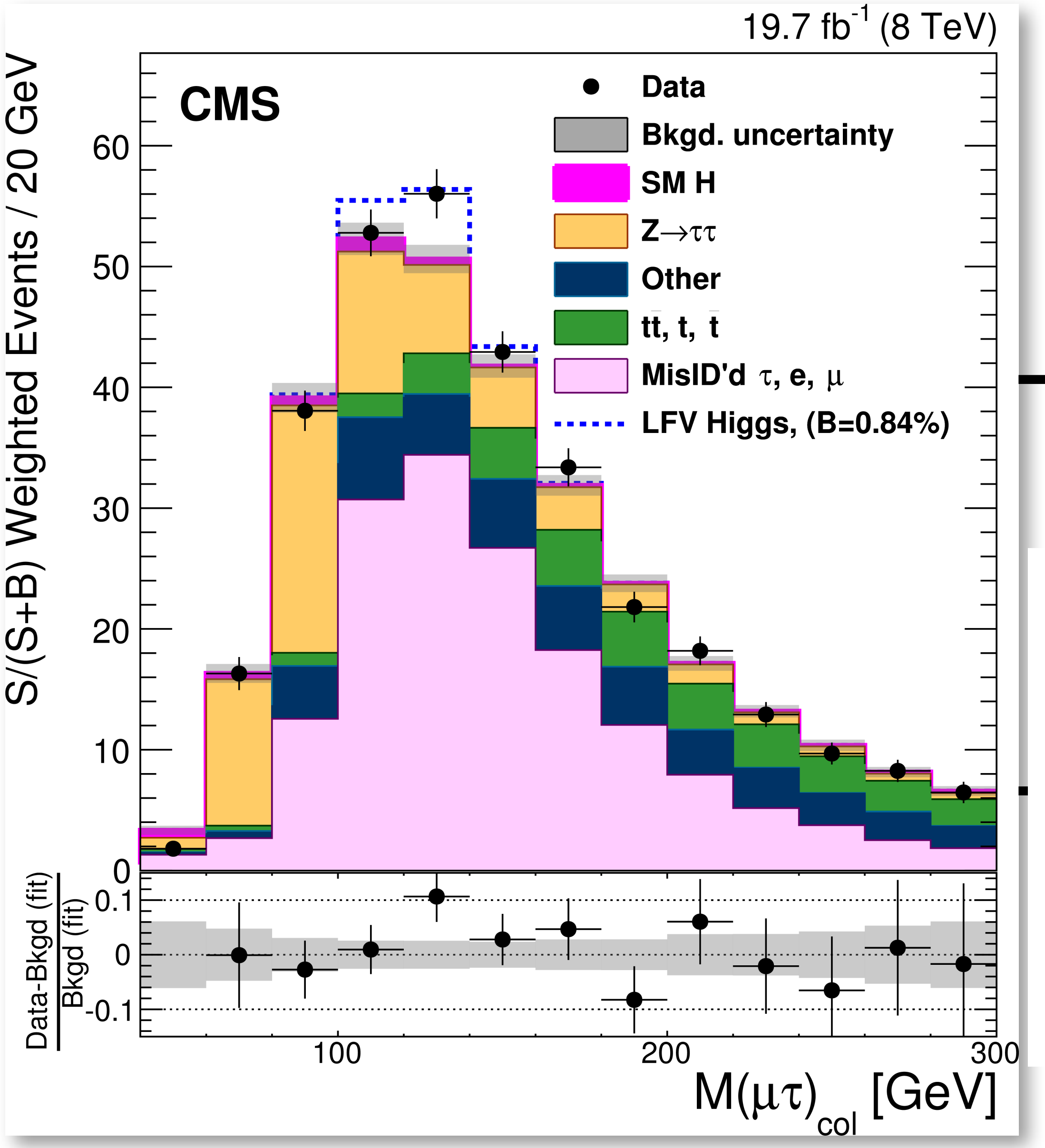
Lepton selection

Categorisation:

CMS: 0-jet, 1-jet, VBF
ATLAS: background type

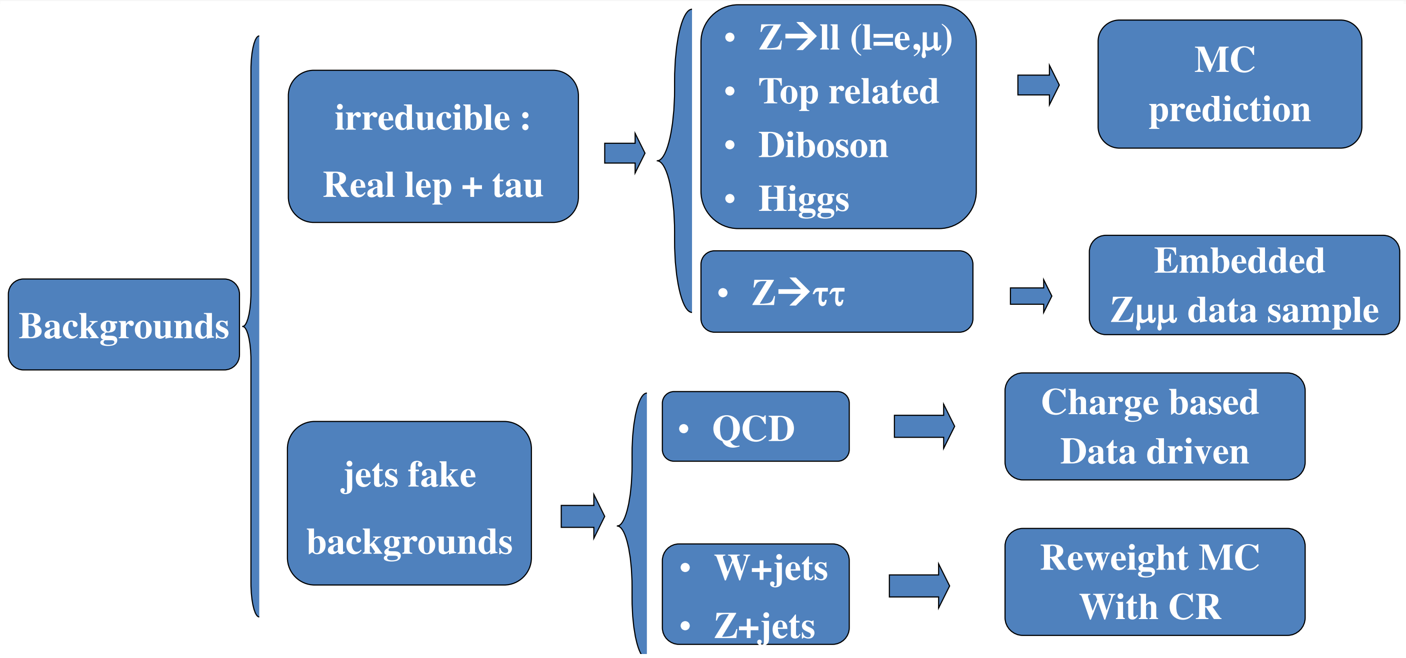
Calculate $m_{\ell\ell'}$

Background suppression



Determine $\mathcal{B}(H \rightarrow \ell\ell')$

ATLAS (8 TeV): H ⟶ e/μ τhad



Backgrounds

irreducible :

Real lep + tau

- Z→ll (l=e,μ)
- Top related
- Diboson
- Higgs

⇒ MC prediction

- Z→ττ

⇒ Embedded Zμμ data sample

jets fake backgrounds

- QCD

⇒ Charge based Data driven

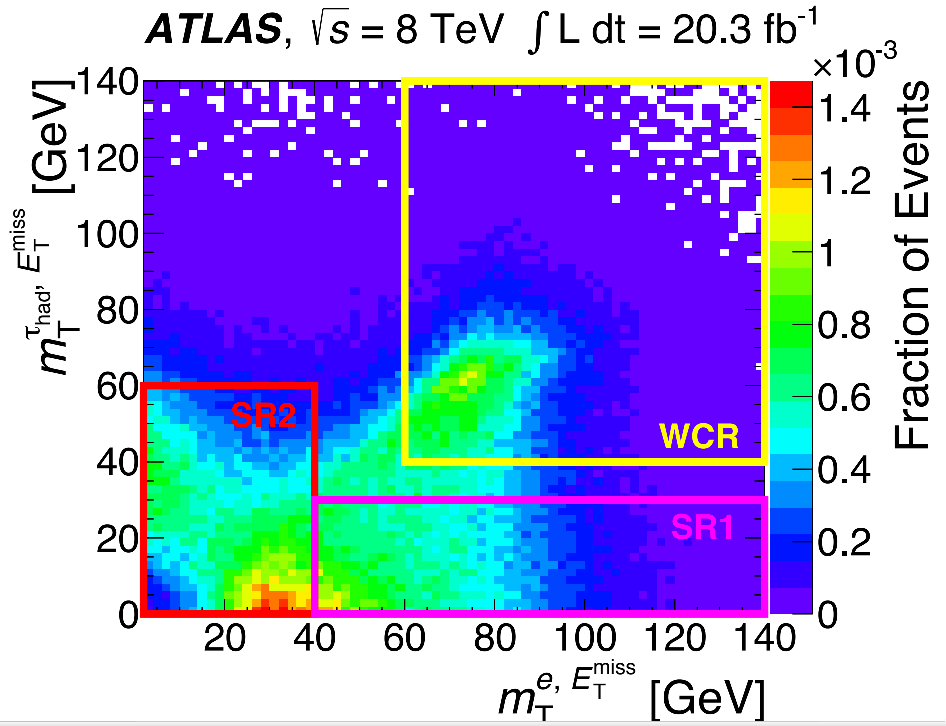
- W+jets
- Z+jets

⇒ Reweight MC With CR

Regions defined in terms of the *transverse mass*

$$m_{\mathrm{T}}^{\ell, E_{\mathrm{T}}^{\mathrm{miss}}} \equiv \sqrt{2 p_{\mathrm{T}}^{\ell} E_{\mathrm{T}}^{\mathrm{miss}} (1 - \cos \Delta\phi)}$$

with $\Delta\phi$ angle between ℓ and the direction of $E_{\mathrm{T}}^{\mathrm{miss}}$



SR1: $m_T(\mu, E_T^{Miss}) > 40$ GeV &

$m_T(\tau_{had}, E_T^{Miss}) < 30$ GeV

dominant bkgd W+jets

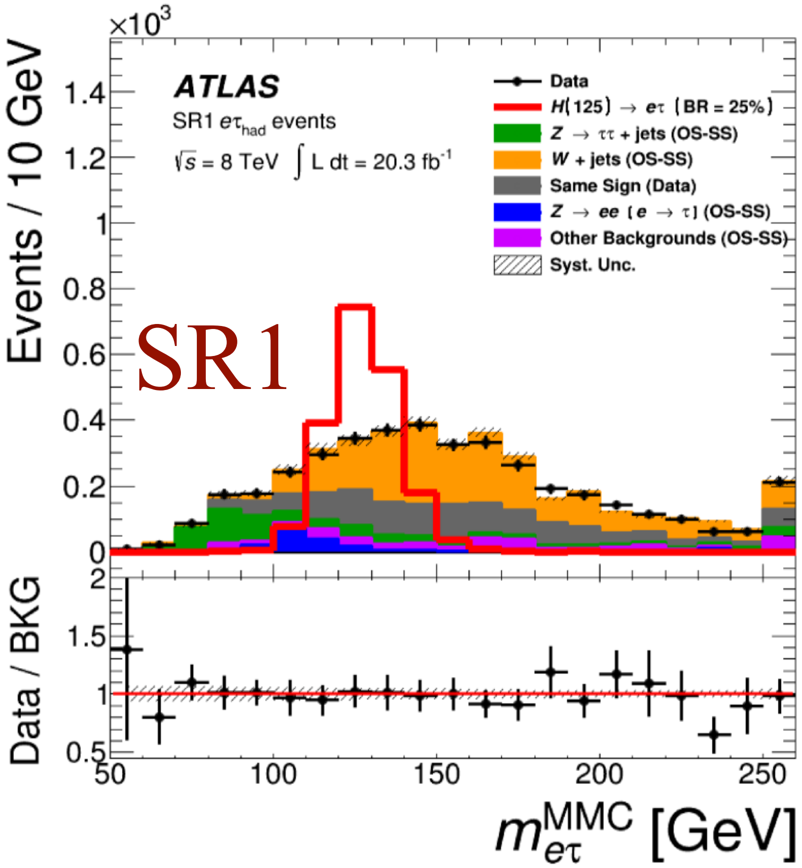
SR2: $m_T(\mu, E_T^{Miss}) < 40$ GeV &

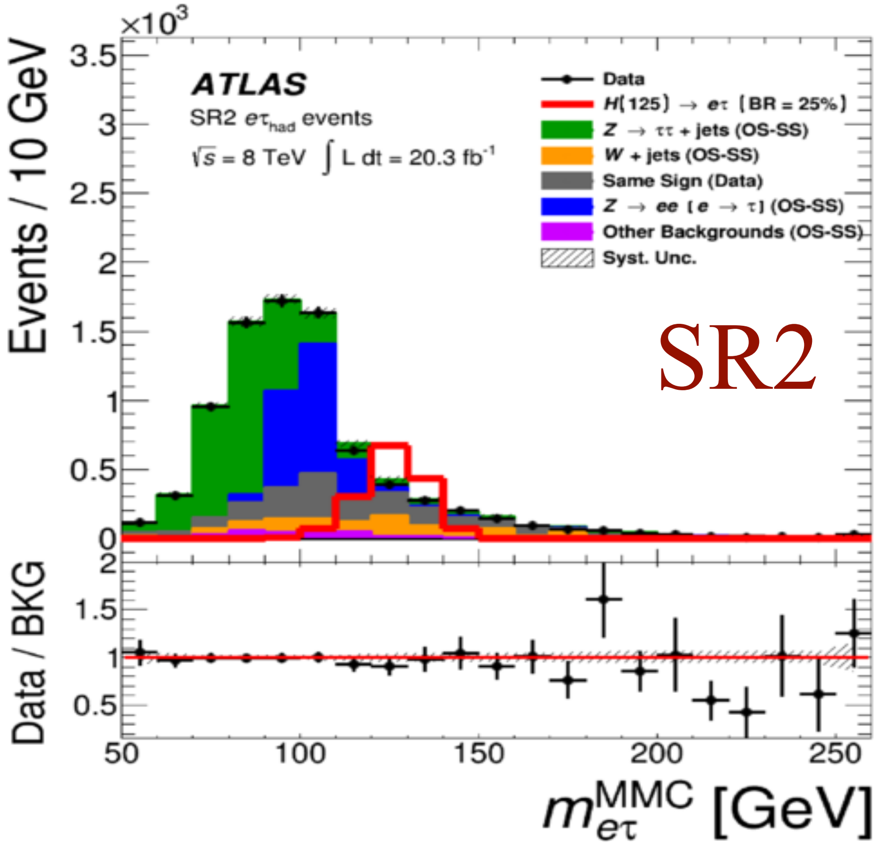
$m_T(\tau_{had}, E_T^{Miss}) < 60$ GeV

dominant bkgd Z+jets

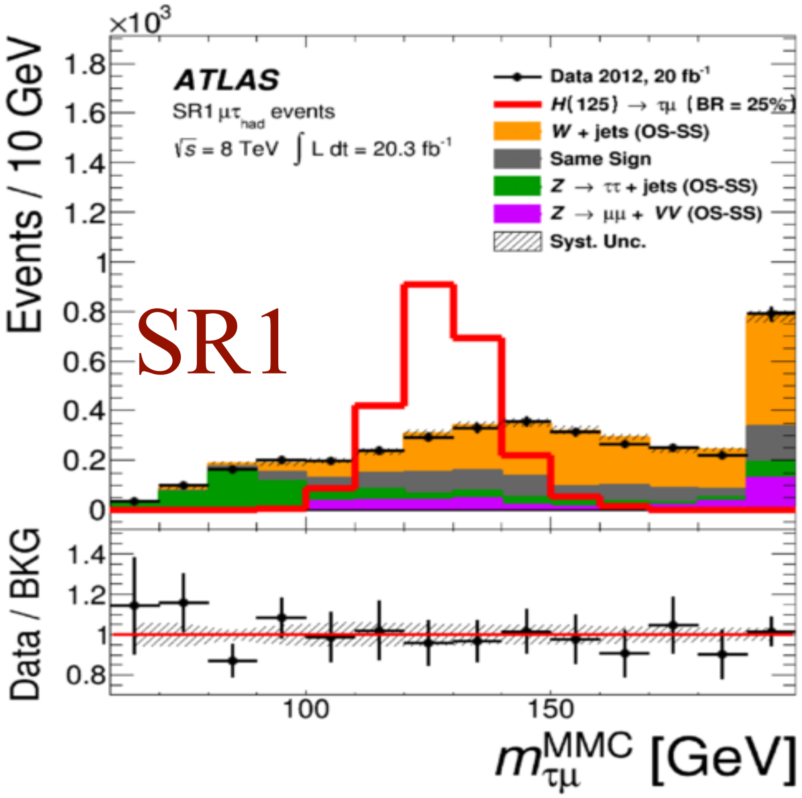
ATLAS (8 TeV): H → e/μ τ_{had}

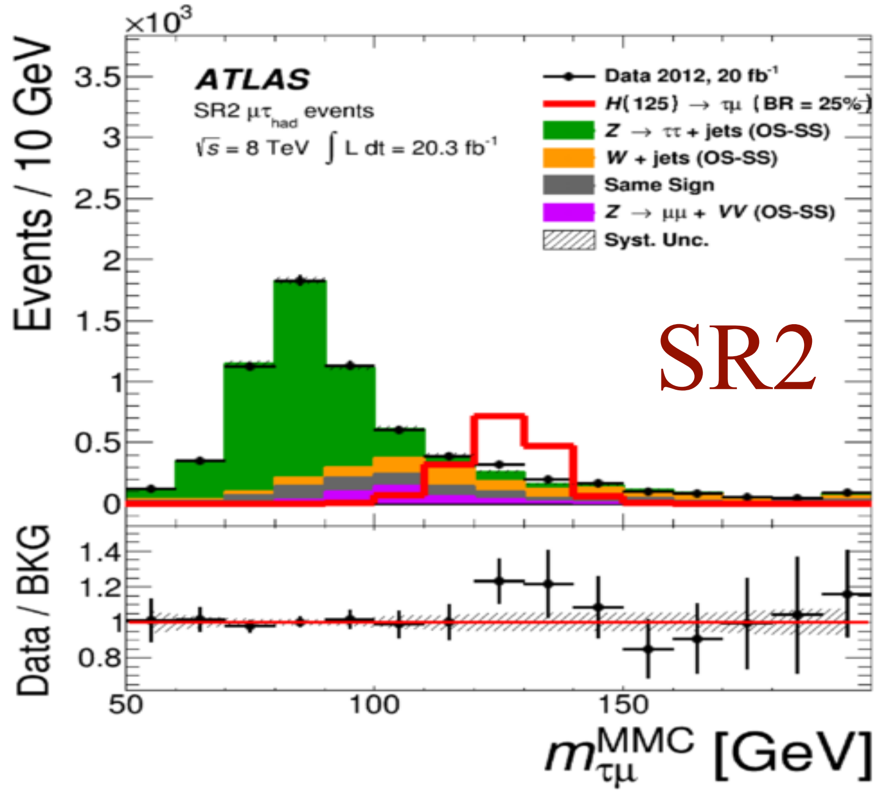
H → e τ_{had}





H → μ τ_{had}

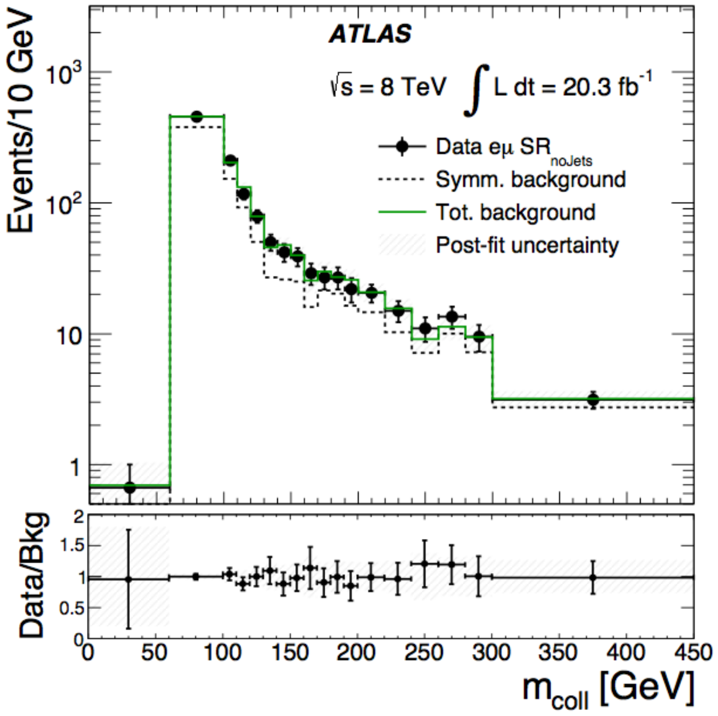


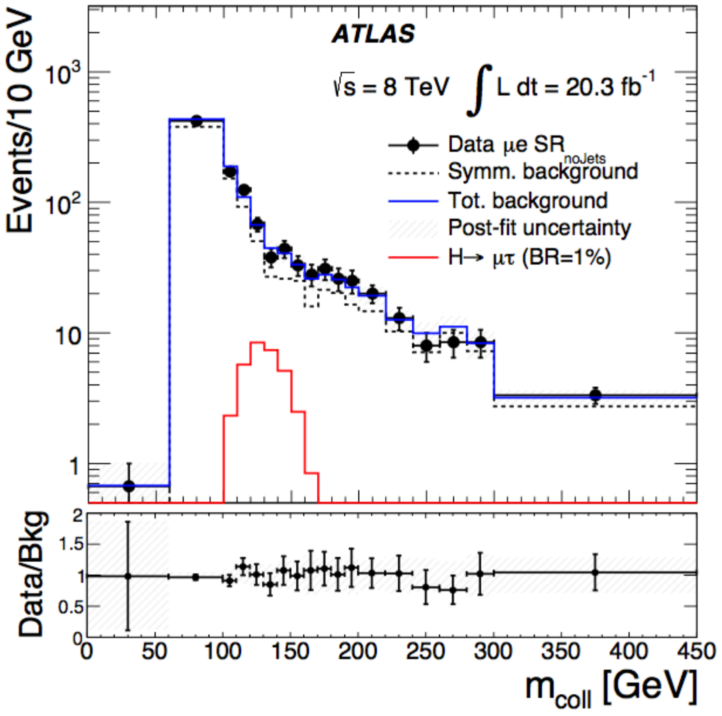


ATLAS (8 TeV): H $\longrightarrow$ e τ_μ , μ τ_e

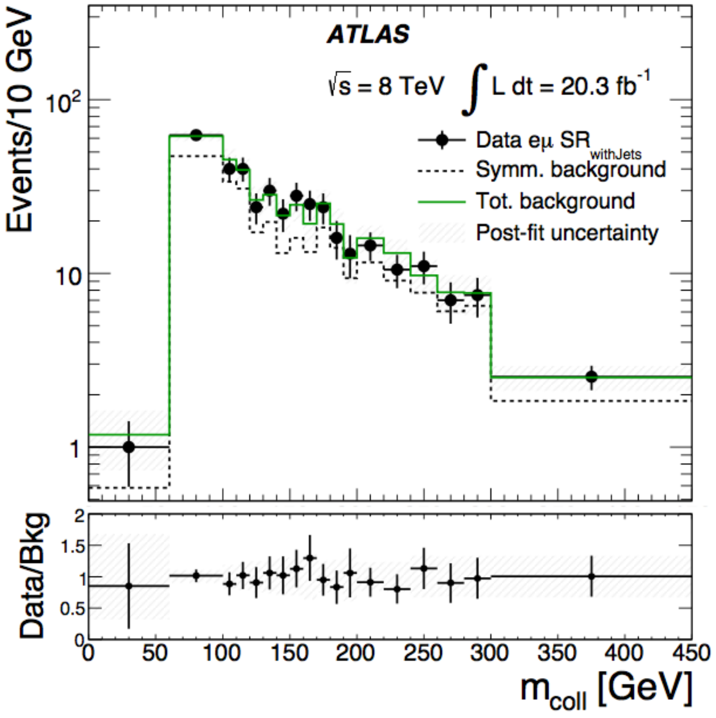
Data driven asymmetry method : SM backgrounds are e/μ symmetric

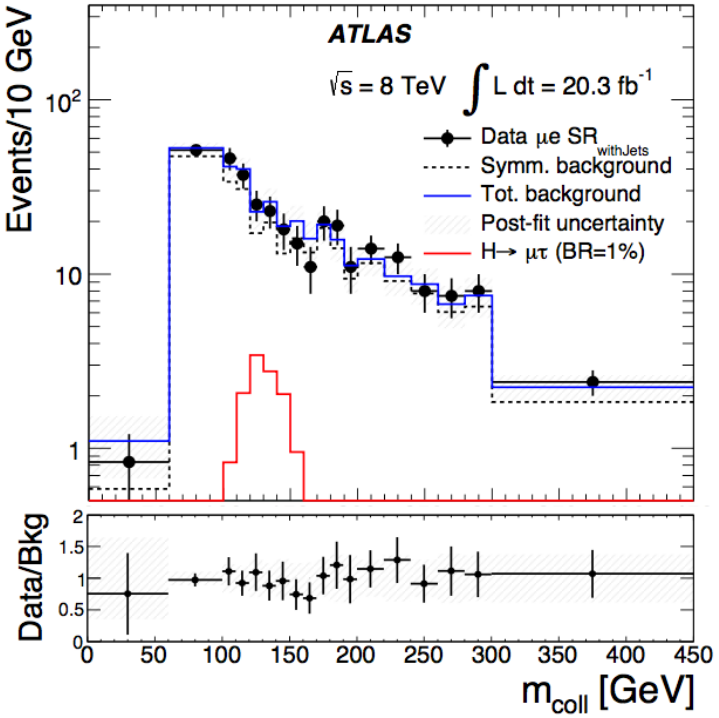
Signal region:
no jets





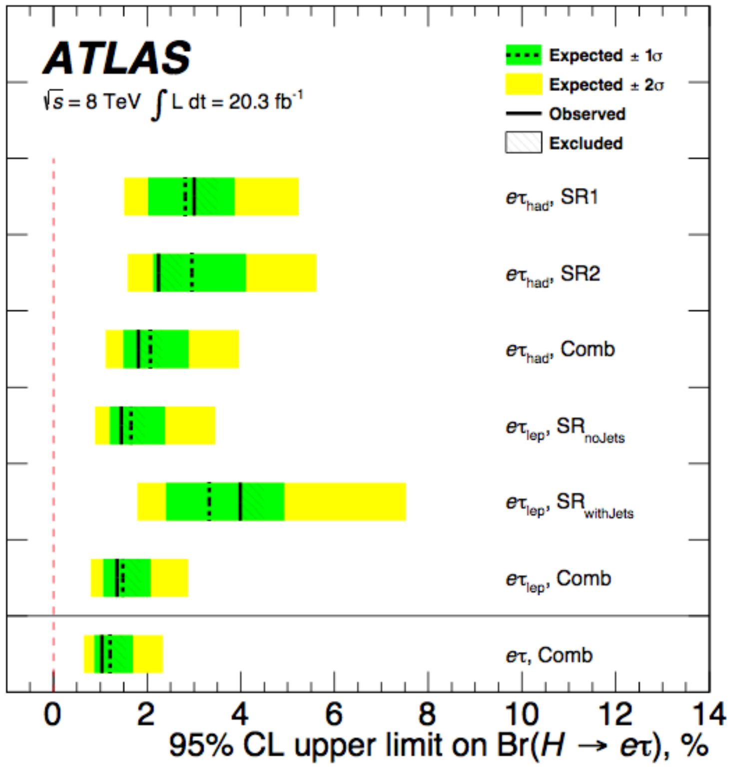
Signal region:
with jets

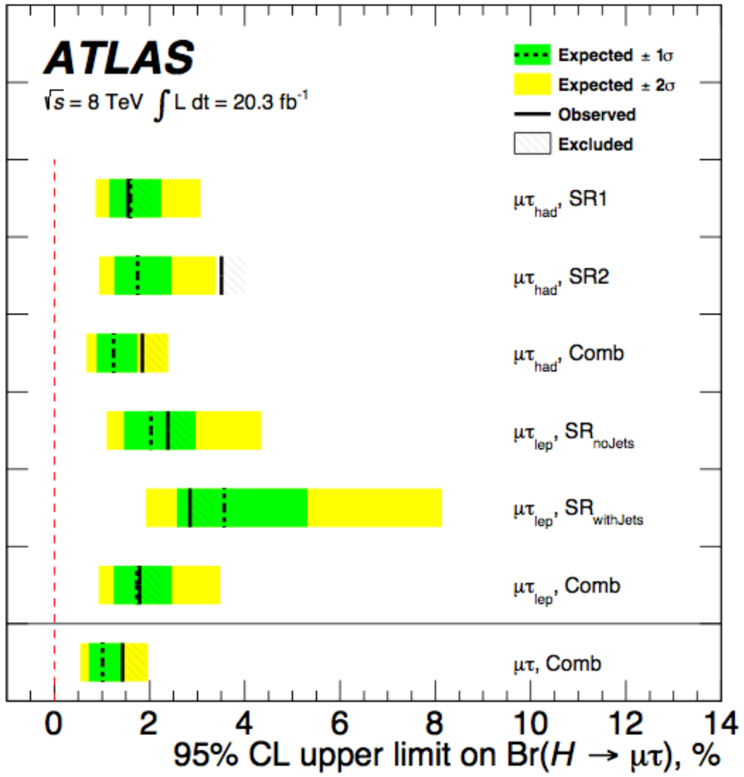




ATLAS (8 TeV): H ⟶ e/μ τ

ATLAS 1604.07730



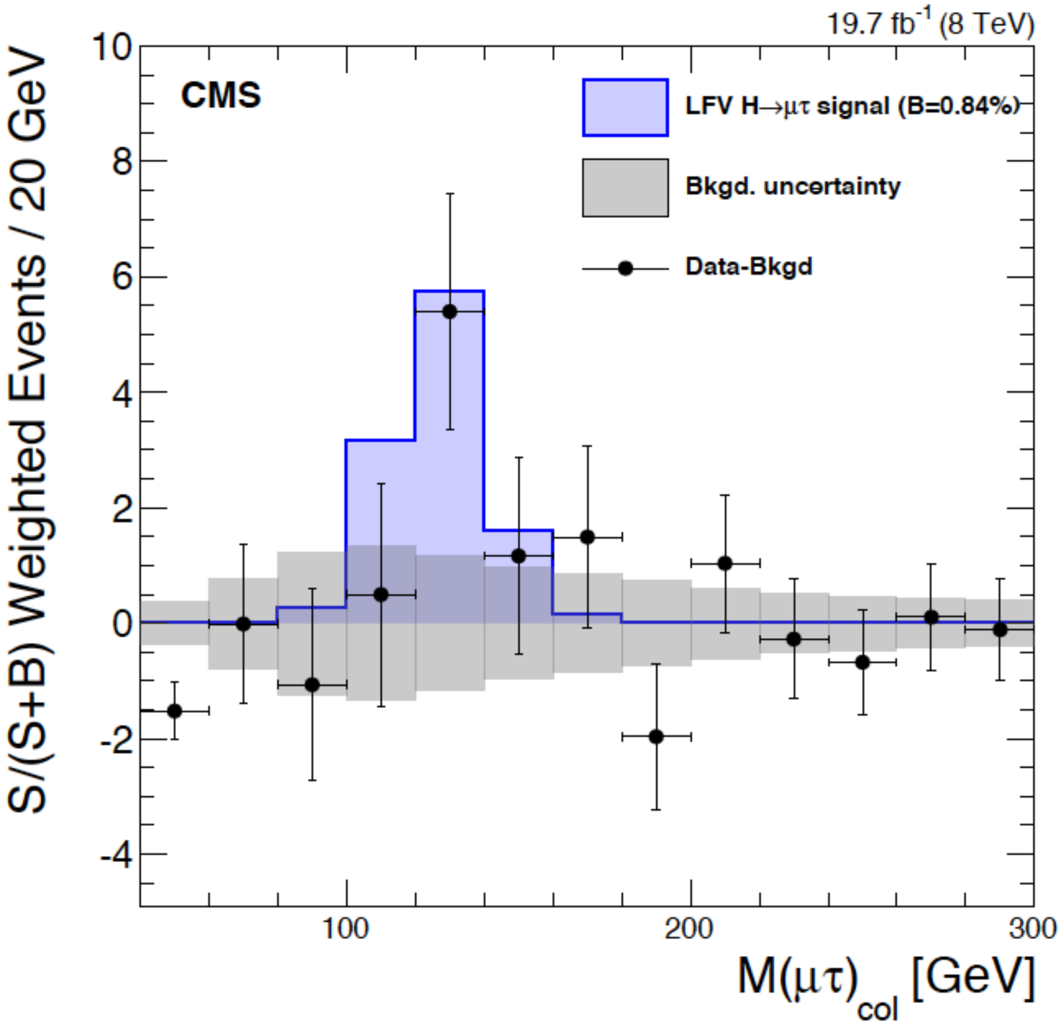


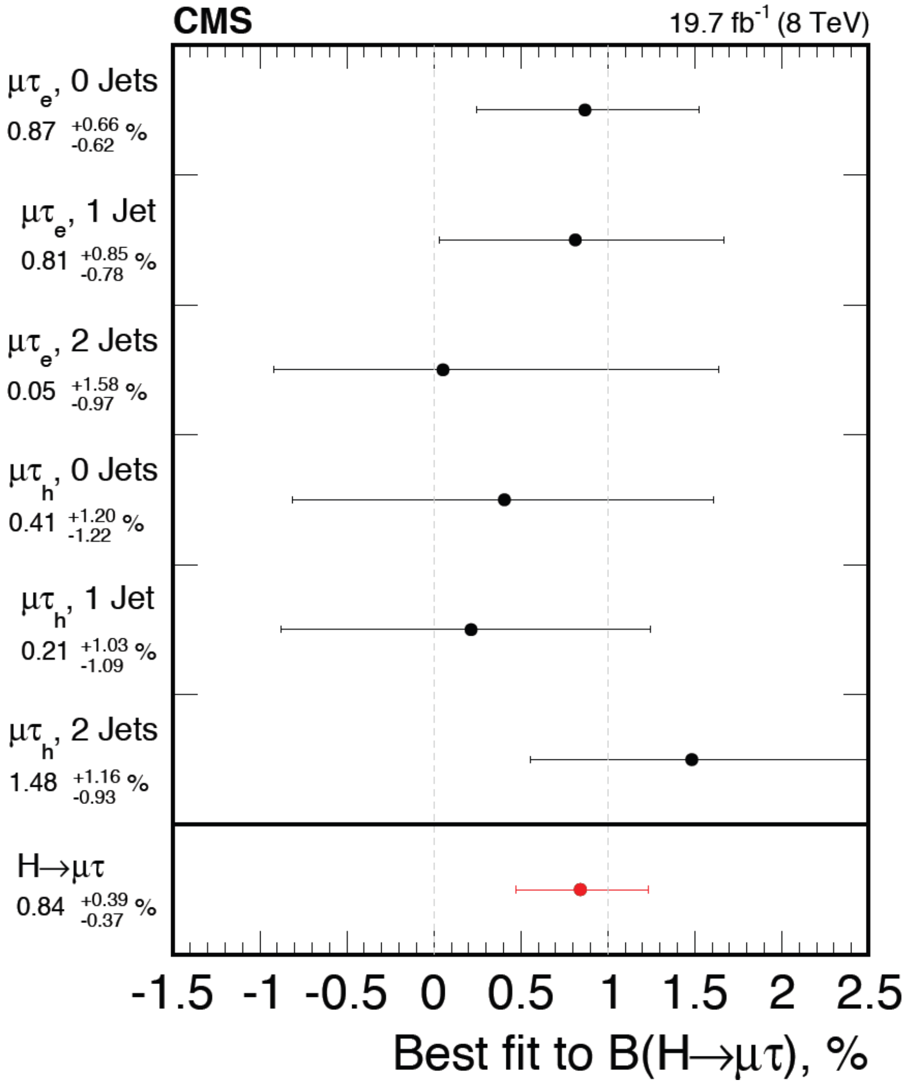
Channel	Category	Expected limit [%]	Observed limit [%]	Best fit Br [%]
$H \to e\tau_{\mathrm{had}}$	SR1	$2.81^{+1.06}_{-0.79}$	3.0	$0.33^{+1.48}_{-1.59}$
	SR2	$2.95^{+1.16}_{-0.82}$	2.24	$-1.33^{+1.56}_{-1.80}$
	Combined	$2.07^{+0.82}_{-0.58}$	1.81	$-0.47^{+1.08}_{-1.18}$
$H \to e\tau_{\mathrm{lep}}$	$\mathrm{SR}_{\mathrm{noJets}}$	$1.66^{+0.72}_{-0.46}$	1.45	$-0.45^{+0.89}_{-0.97}$
	$\mathrm{SR}_{\mathrm{withJets}}$	$3.33^{+1.60}_{-0.93}$	3.99	$0.74^{+1.59}_{-1.62}$
	Combined	$1.48^{+0.60}_{-0.42}$	1.36	$-0.26^{+0.79}_{-0.82}$
$H \to e\tau$	Combined	$1.21^{+0.49}_{-0.34}$	1.04	$-0.34^{+0.64}_{-0.66}$
$H \to \mu\tau_{\mathrm{had}}$	SR1	$1.60^{+0.64}_{-0.45}$	1.55	$-0.07^{+0.81}_{-0.86}$
	SR2	$1.75^{+0.71}_{-0.49}$	3.51	$1.94^{+0.92}_{-0.89}$
	Combined	$1.24^{+0.50}_{-0.35}$	1.85	$0.77^{+0.62}_{-0.62}$
$H \to \mu\tau_{\mathrm{lep}}$	$\mathrm{SR}_{\mathrm{noJets}}$	$2.03^{+0.93}_{-0.57}$	2.38	$0.31^{+1.06}_{-0.99}$
	$\mathrm{SR}_{\mathrm{withJets}}$	$3.57^{+1.74}_{-1.00}$	2.85	$-1.03^{+1.66}_{-1.82}$
	Combined	$1.73^{+0.74}_{-0.49}$	1.79	$0.03^{+0.88}_{-0.86}$
$H \to \mu\tau$	Combined	$1.01^{+0.40}_{-0.29}$	1.43	$0.53^{+0.51}_{-0.51}$

Compatible with 0 at the level of 1σ

CMS (8 TeV): H → μ τ

Sample	$H \to \mu\tau_h$			$H \to \mu\tau_e$		
	0-Jet	1-Jet	2-Jets	0-Jet	1-Jet	2-Jets
SM H background	7.1 ± 1.3	5.3 ± 0.8	1.6 ± 0.5	1.9 ± 0.3	1.6 ± 0.2	0.6 ± 0.1
sum of backgrounds	2125 ± 530	513 ± 114	5.4 ± 1.4	160 ± 19	118 ± 9	5.6 ± 0.9
LFV Higgs boson signal	66 ± 18	30 ± 8	2.9 ± 1.1	23 ± 6	13 ± 3	1.2 ± 0.3
data	2147	511	10	180	128	6





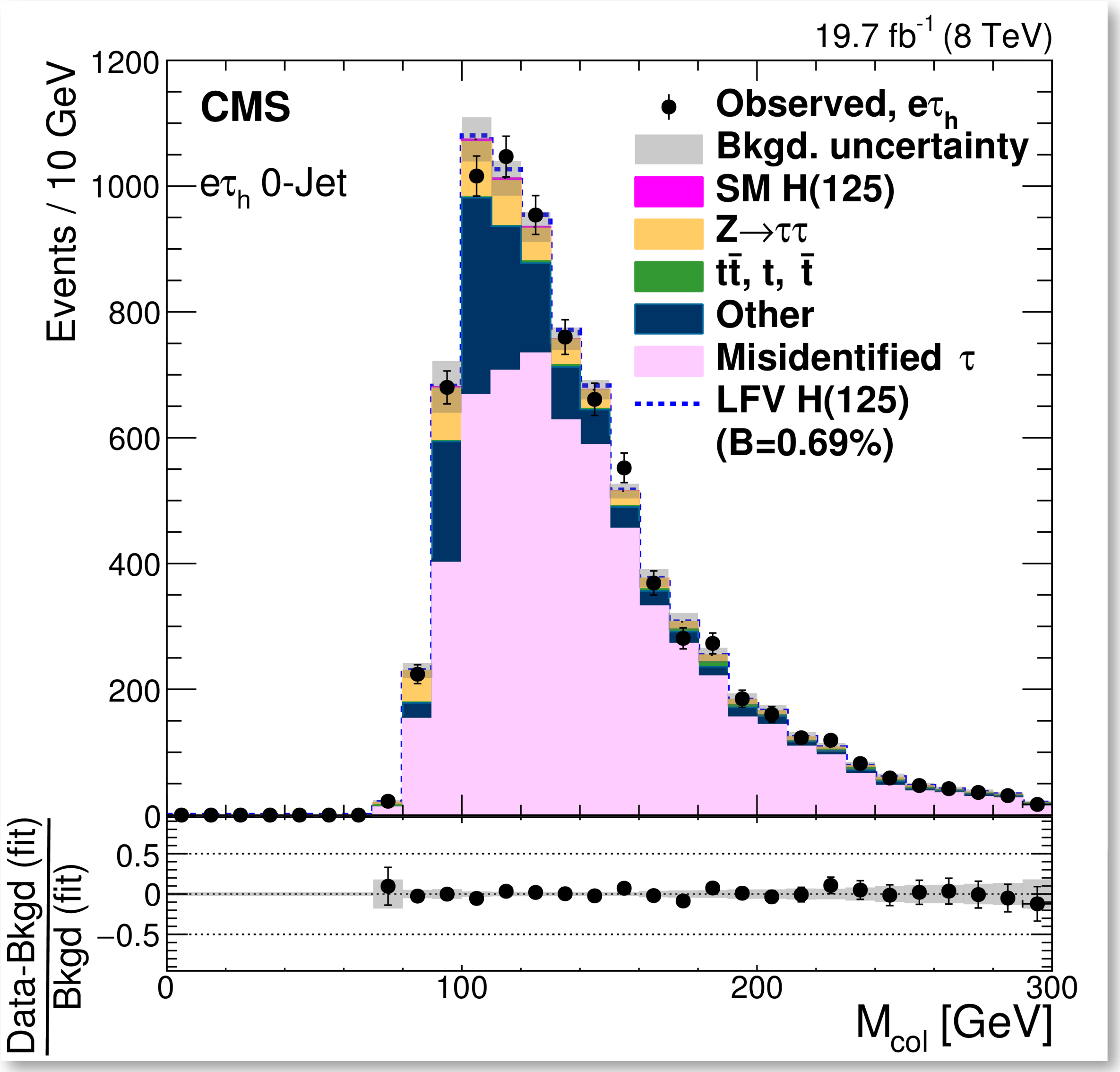
CMS, **arXiv**:1502.07400

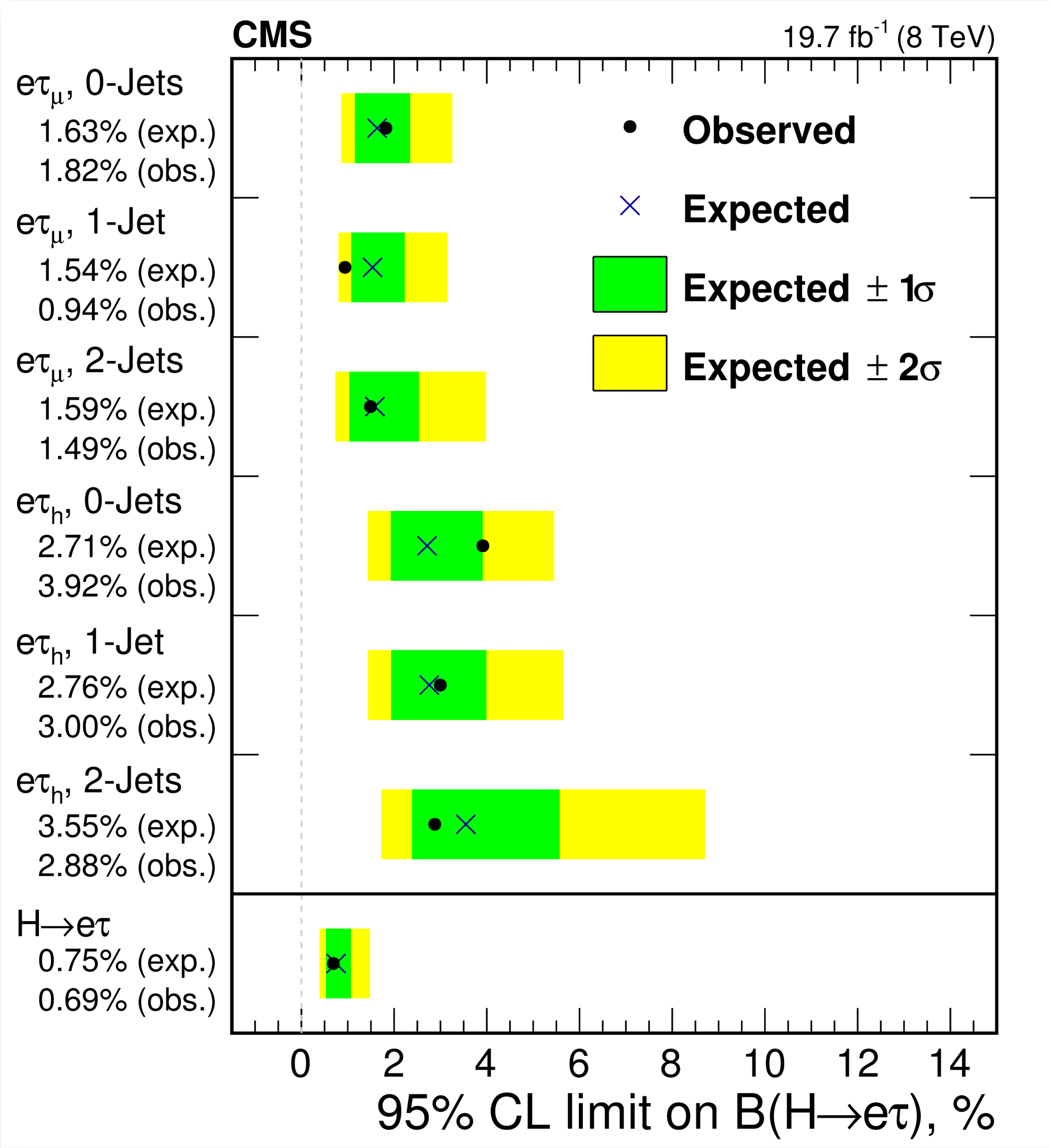
$$\mathcal{B}(H \to \mu\tau) = (0.84^{+0.39}_{-0.37})\%$$

2.4 σ excess

CMS (8 TeV): $H \rightarrow e\,\tau$

Results: $H \rightarrow e\tau$



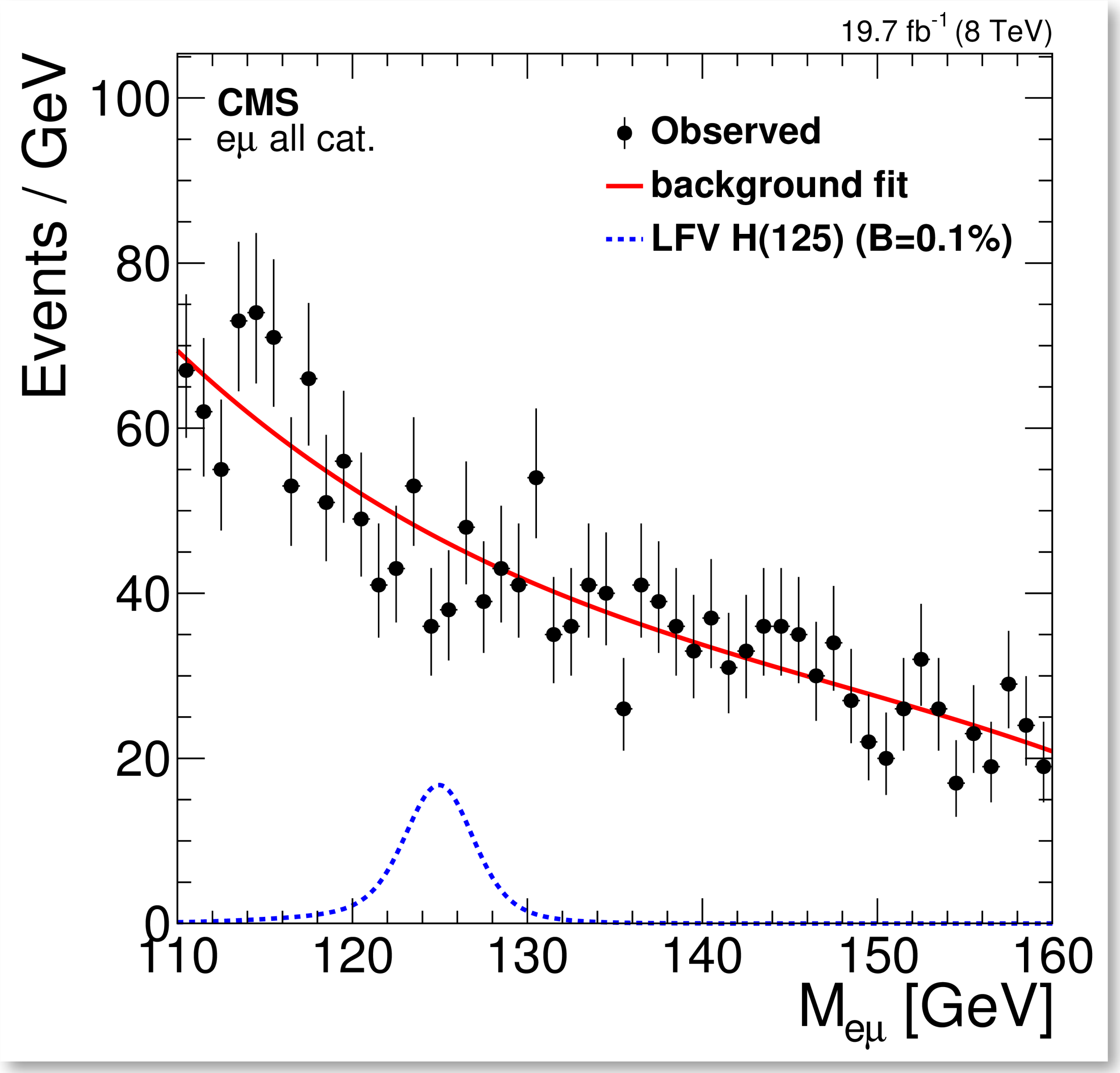


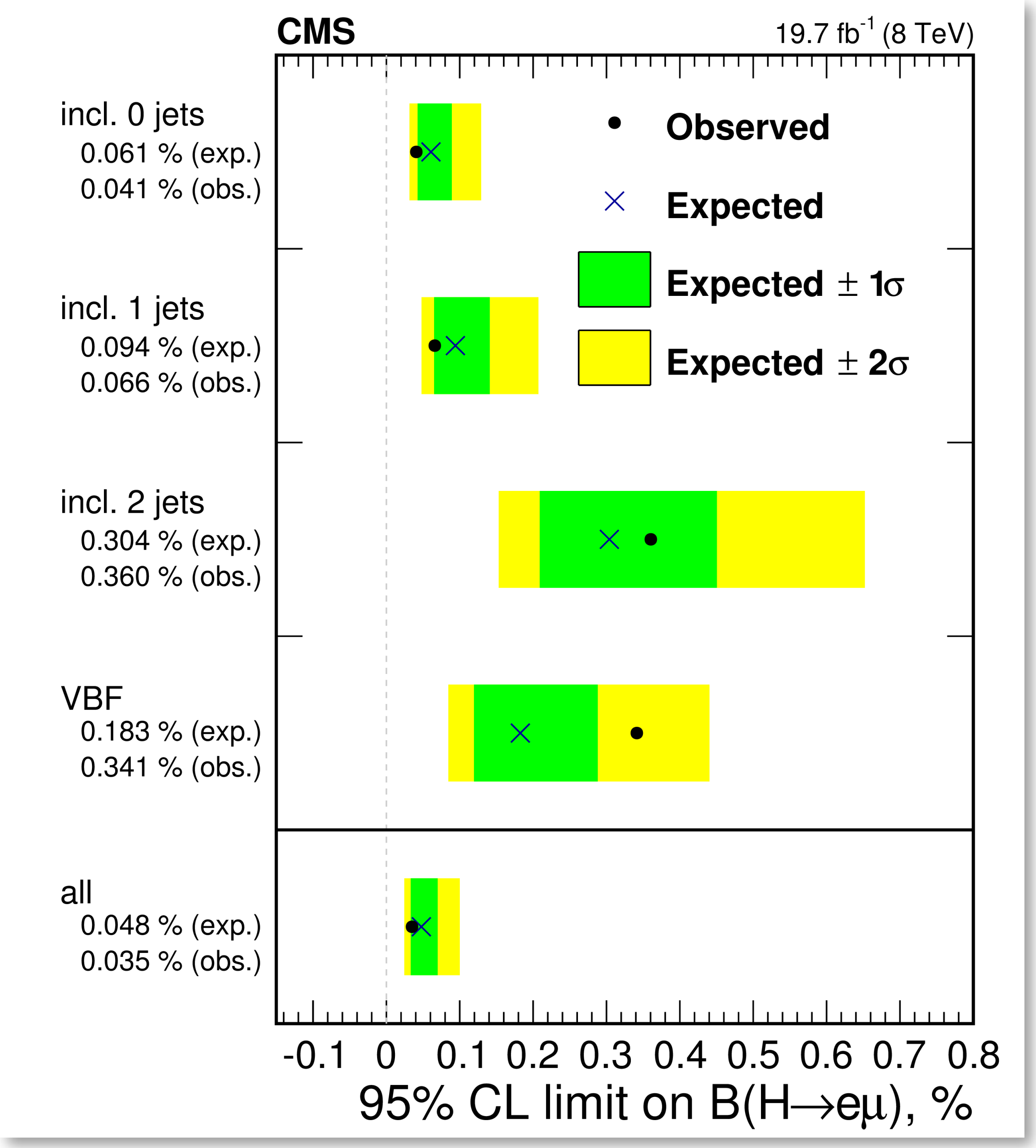
CMS, **arXiv**:1607.03561

$\mathcal{B}(H \rightarrow e\tau) < 0.69\%$ @ 95% CL

CMS (8 TeV): H ⟶ e μ

Results: $H \to e\mu$





CMS, **arXiv**:1607.03561

$\mathcal{B}(H \to e\mu) < 0.035\%$ @ 95% CL

CMS (13 TeV, 2015 dataset): H ⟶ μ τ

$H \to \mu\tau$ @ 13 TeV

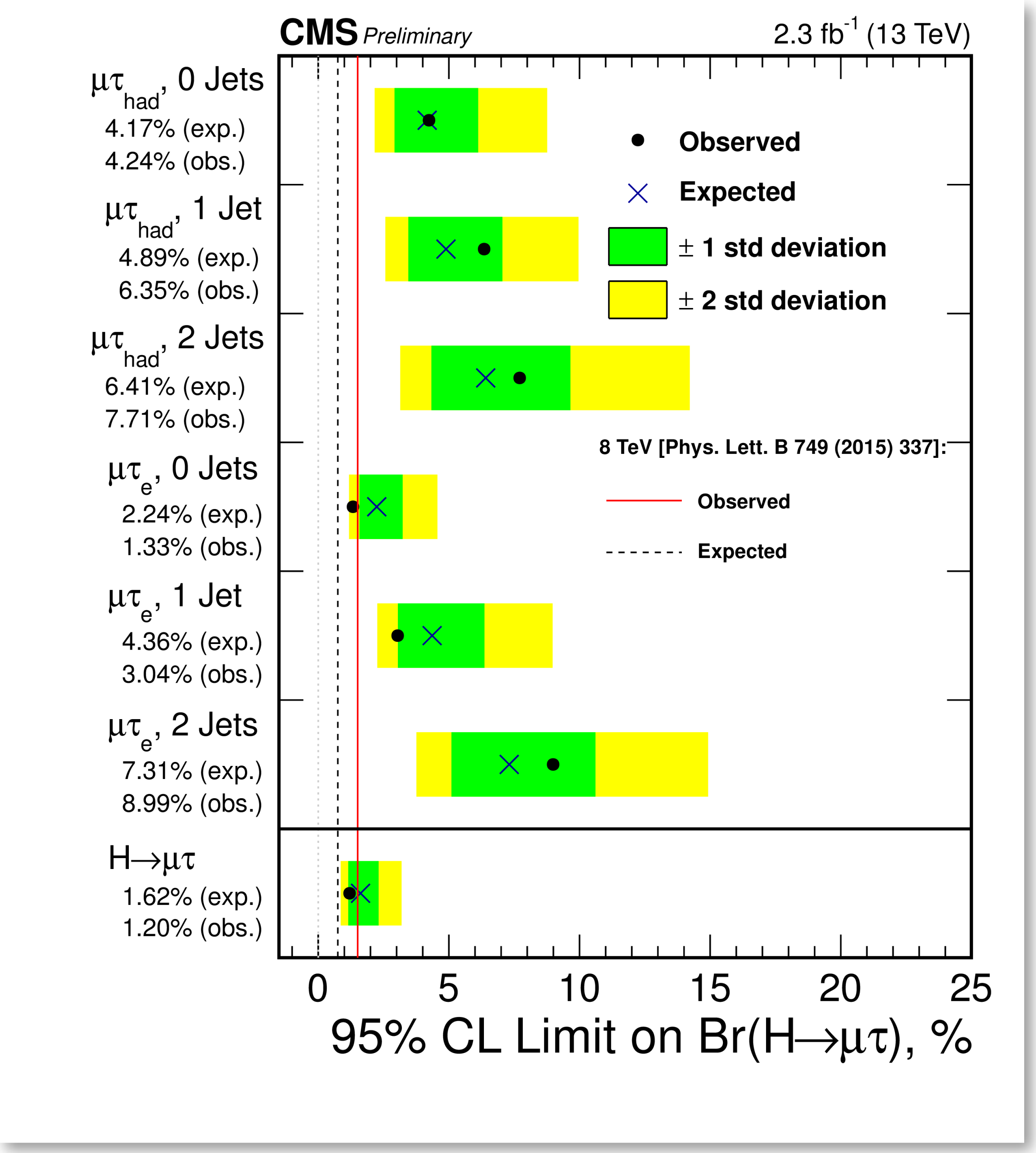
- Very similar analysis
- Uses 2.3 fb^{-1} of data from 2015
- Excess from 8 TeV data not confirmed but also not excluded!

$$\mathcal{B}(H \to \mu\tau) < 1.20\% \text{ @ 95\% CL}$$

Best-fit branching fractions

	0-jet (%)	1-jet (%)	2-jets (%)	Combined (%)
$\mu\tau_h$	$0.12^{+2.02}_{-1.91}$	$1.70^{+2.41}_{-2.52}$	$1.54^{+3.12}_{-2.71}$	$1.12^{+1.45}_{-1.40}$
$\mu\tau_e$	$-2.11^{+1.30}_{-1.89}$	$-2.18^{+1.99}_{-2.05}$	$2.04^{+2.96}_{-3.31}$	$-1.81^{+1.07}_{-1.32}$
$\mu\tau$	$-0.76^{+0.81}_{-0.84}\%$			

CMS-PAS-HIG-16-005



Status as of last week

Datasets studied:

Experiment		**Process**	**√s [TeV]**	**∫L [fb^{-1}]**
CMS	1502.07400	$H\to\tau\mu$	8	20
CMS	1607.03561	$H\to e\mu$ $H\to e\tau$	8	20
CMS	PAS HIG 16 005	$H\to\tau\mu$	**13**	2.3
ATLAS	1508.03372	$H\to\tau\mu$	8	20
ATLAS	1604.07730	$H\to\tau\mu$ $H\to\tau e$	8	20

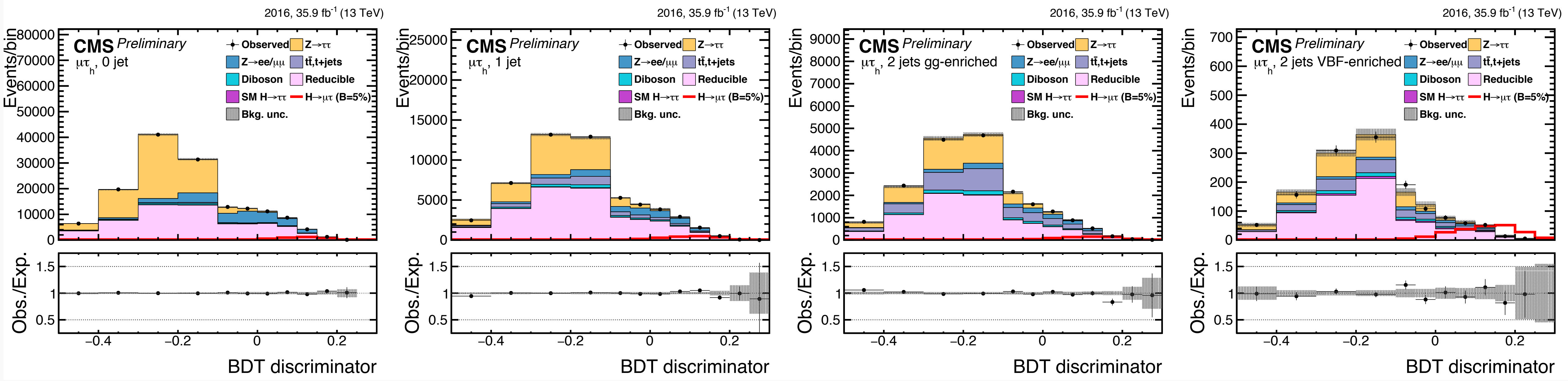
Best Upper Limits:

Process	**CMS**	**ATLAS**
$H\to\tau\mu$	BR<1.20%	BR<1.40%
$H\to\tau e$	BR<0.69%	BR<1.04%
$H\to e\mu$	BR<0.048%	-

CMS (13 TeV, 2016 dataset): H → μ τ

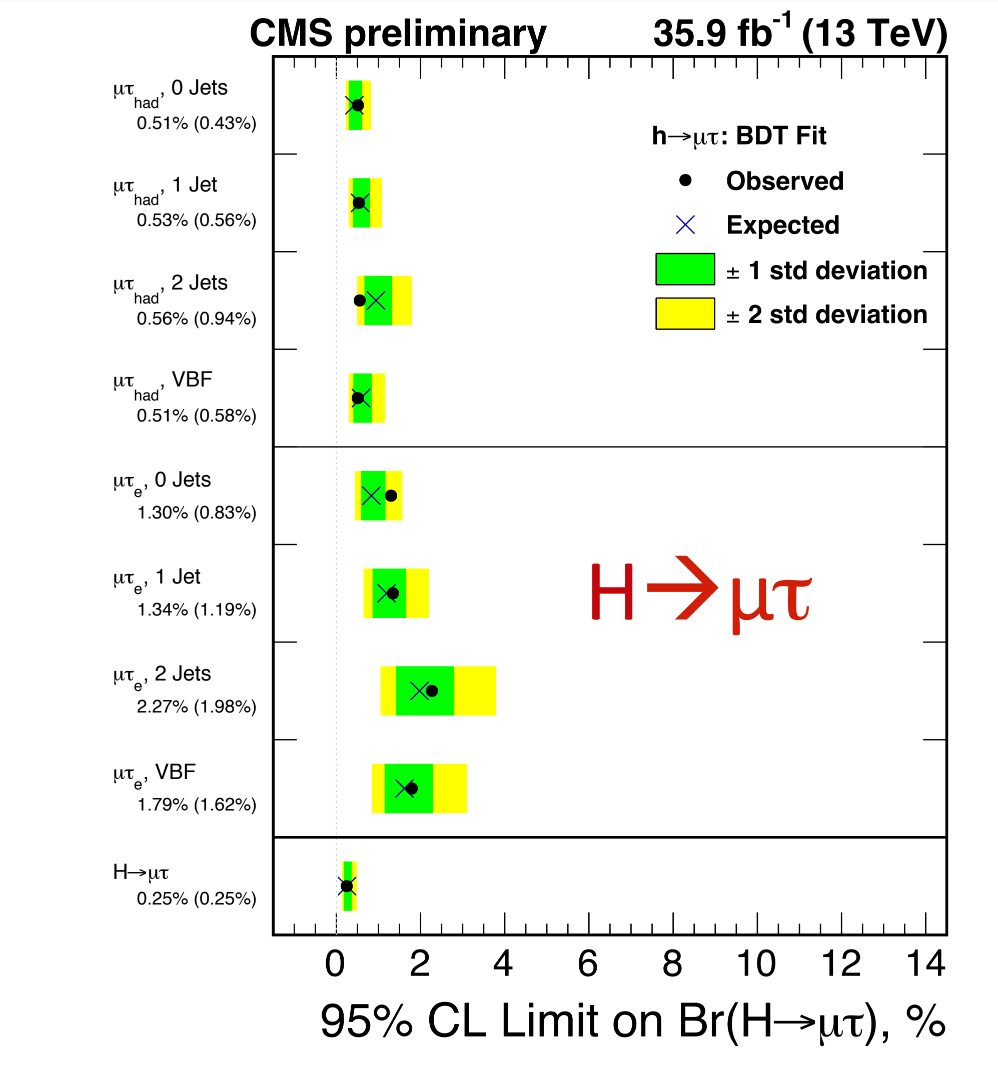
- Events divided into 4 categories to target different productions modes:
  - 0 jet: Targets gg→H events
  - 1 jet: Targets gg→H events produced in association with a jet
  - 2 jets, low m_{jj}: Targets gg→H events with additional jets
  - 2 jets, high m_{jj}: Targets qq→H events

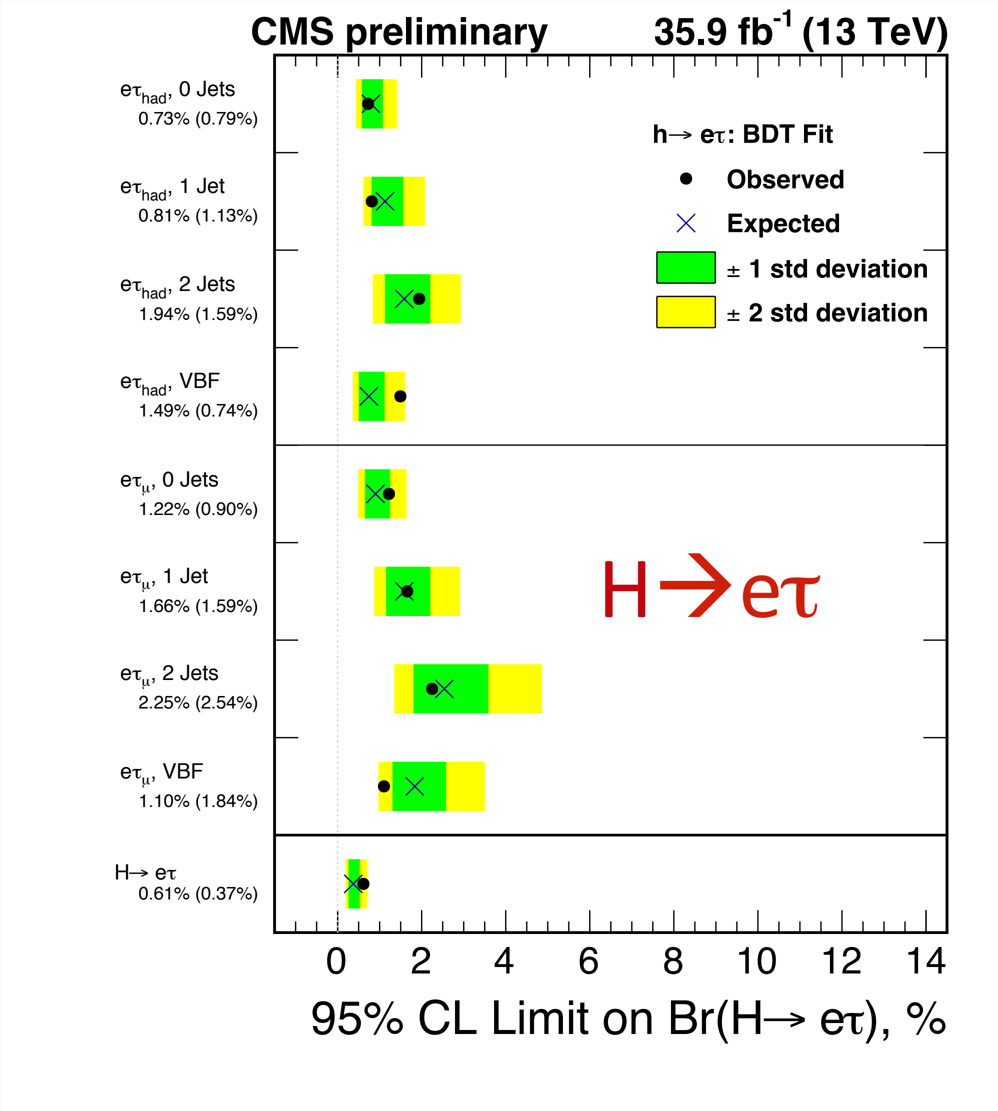
- BDT trained on the signal against a selection of background samples (reducible background for $e\tau_h$ and $\mu\tau_h$, ttbar and/or Z→ττ for $e\tau_\mu$ and $\mu\tau_e$)



CMS-PAS-HIG-17-001

CMS (13 TeV, 2016 dataset): H → e/μ τ



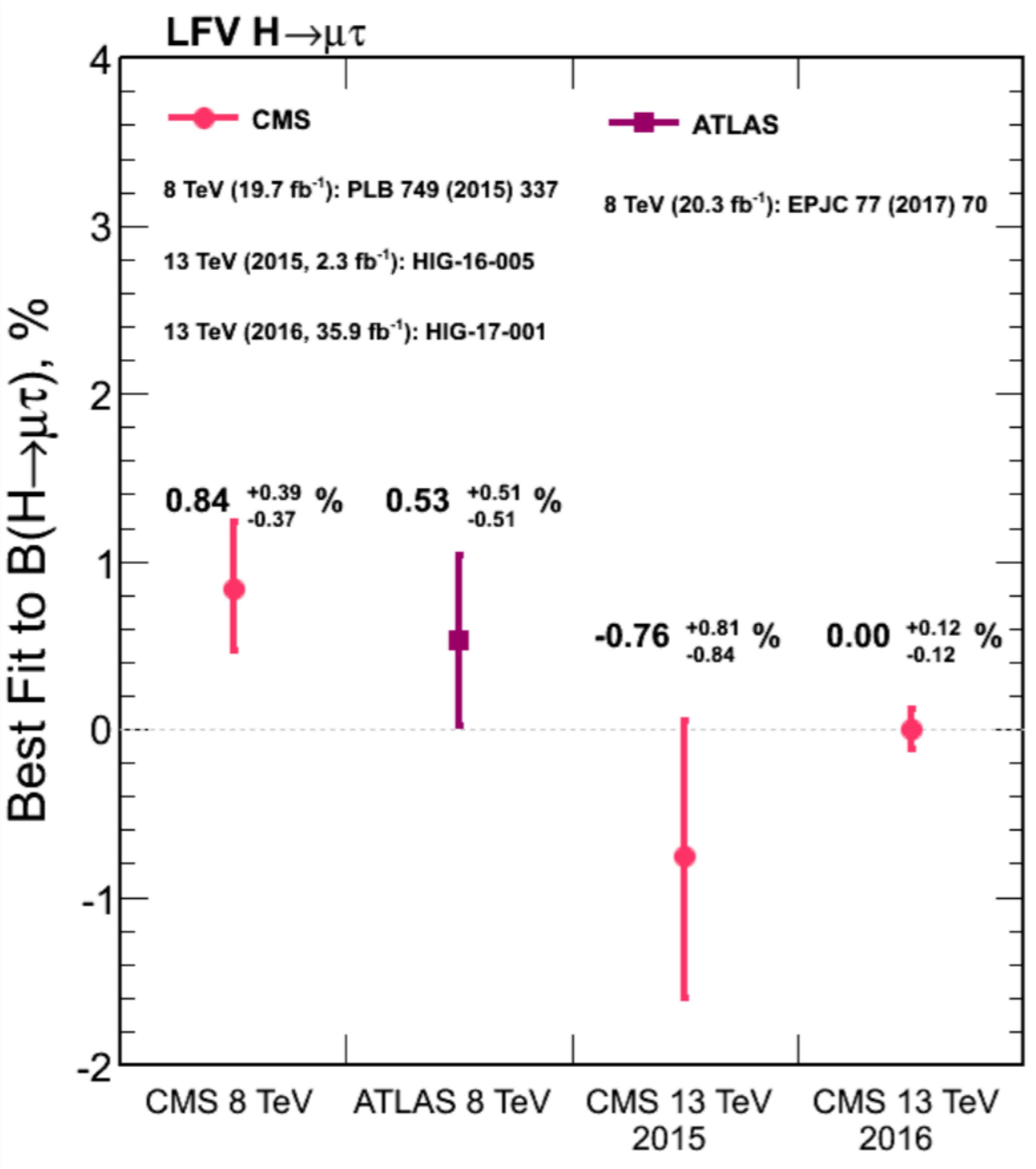


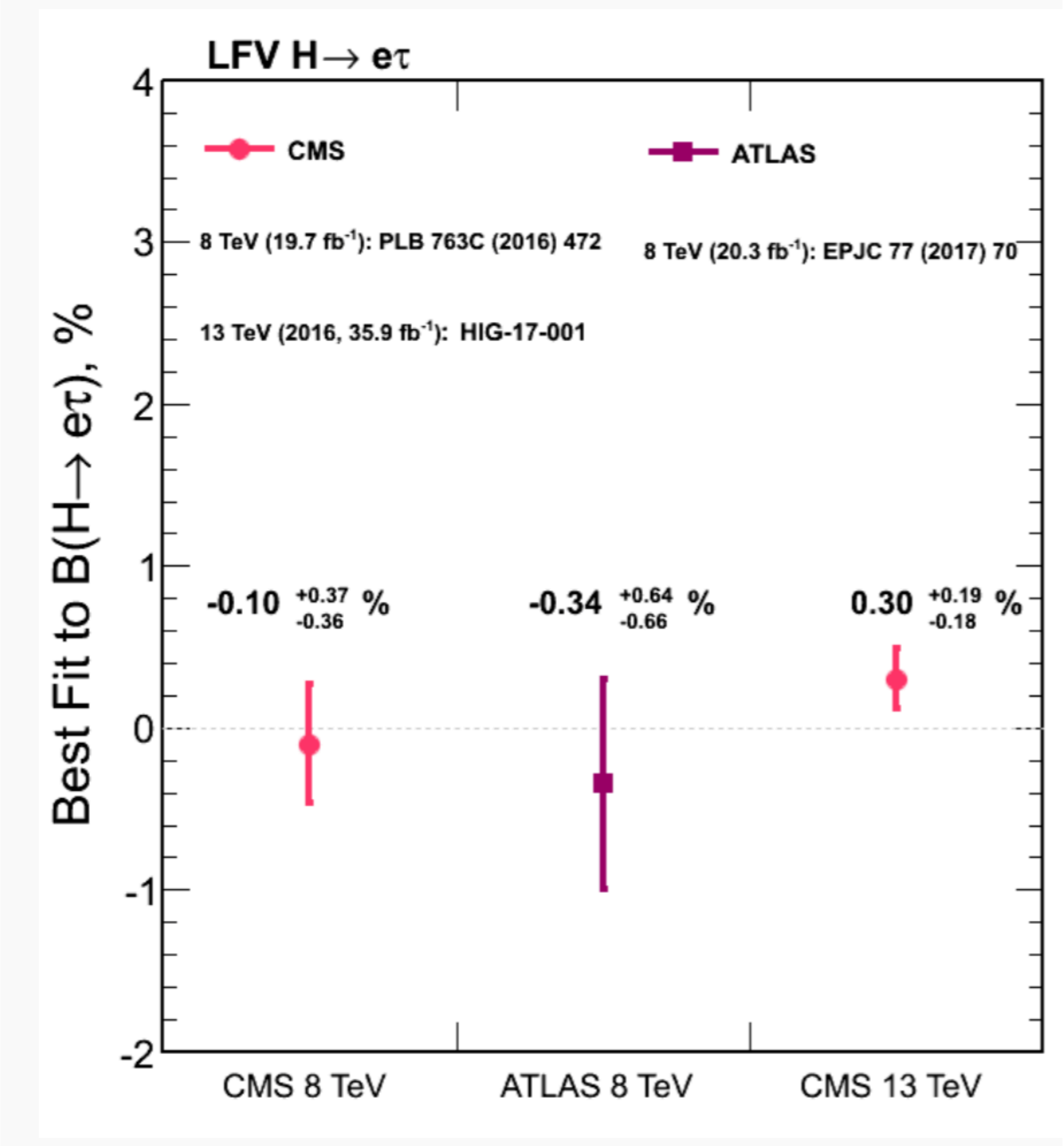
- No excess of data
- Best fit branching fraction: 0.00 ± 0.12%
- B(H→μτ) < 0.25% at 95% CL

- Slight excess of data (1.6 σ)
- Best-fit branching fraction: 0.30 ± 0.18%
- B(H→eτ) < 0.61% at 95% CL

CMS-PAS-HIG-17-001

Updated status (LHCP 2017)



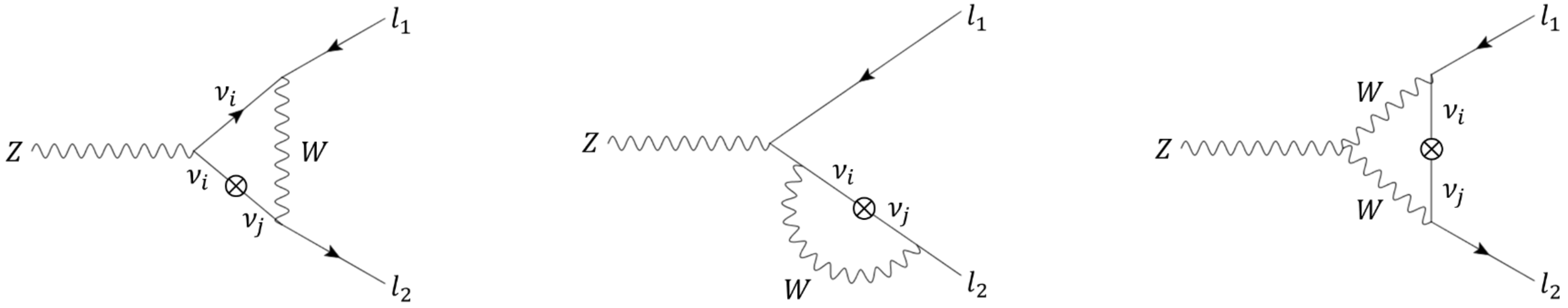


LFV decays of the Z boson

arXiv:hep-ph/0010193

Introduction

- Neutrino oscillation predicts LFV in Z decays, but $\mathcal{B}(Z \to e\mu) < 10^{-60}$



- Good probe for new physics

- Current constraints:
    - Indirect from $\mu \to 3e$: $\mathcal{B}(Z \to e\mu) < 5 \cdot 10^{-13}$

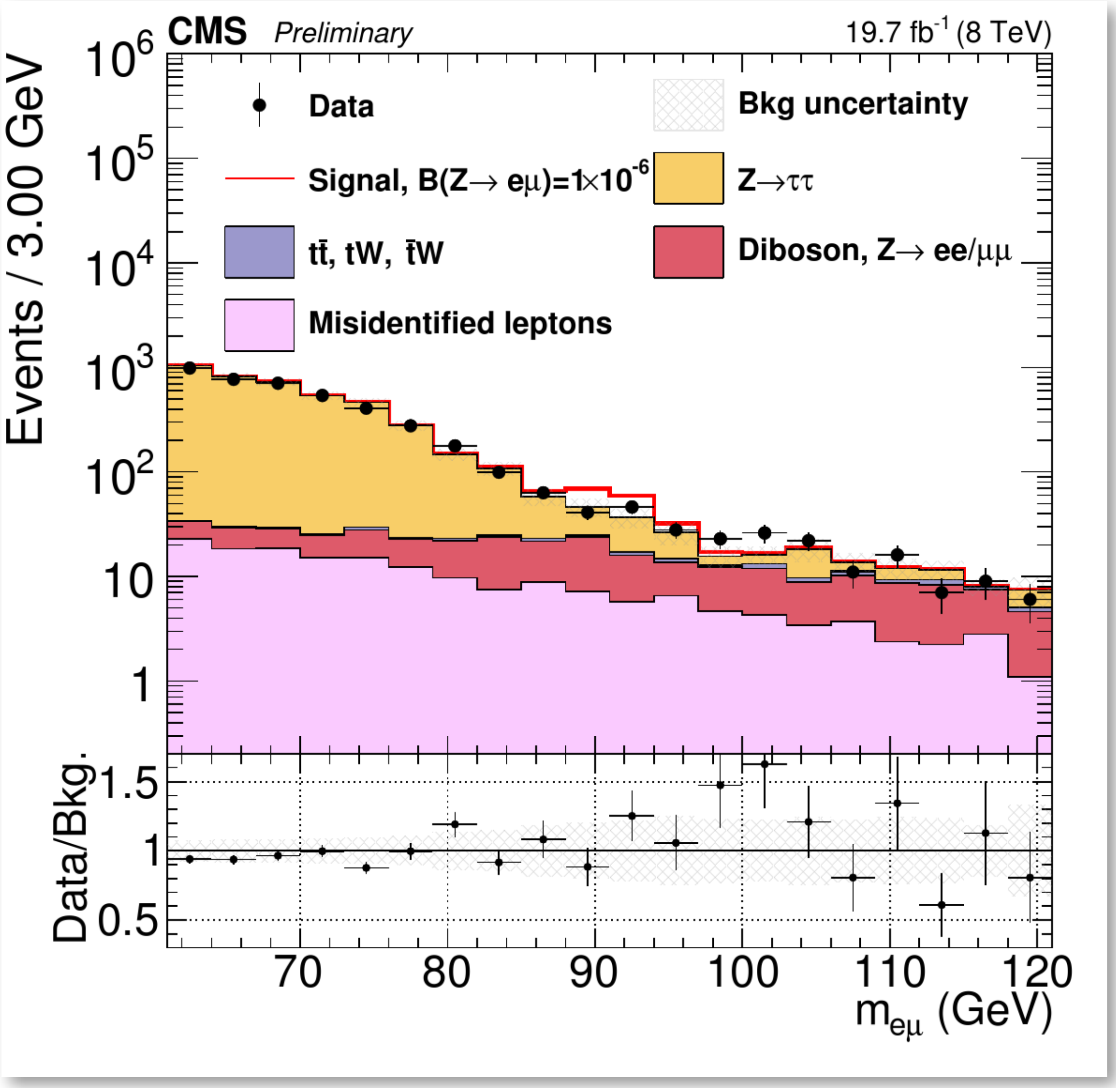
LFV decays of the Z boson (CMS)

CMS-PAS-EXO-13-005

- Count events in window around Z mass: (91 ± 3) GeV
- Background prediction of 83 ± 9
- Events found in data: 87
- Use CLs method to determine limit:

$$\mathcal{B}(Z \to e\mu)_{expected} < (6.7^{+2.8}_{-2.0}) \cdot 10^{-7}$$

$$\mathcal{B}(Z \to e\mu)_{observed} < 7.3 \cdot 10^{-7}$$



LFV decays of the Z boson (ATLAS)

ATLAS 1408.5774

Event selection

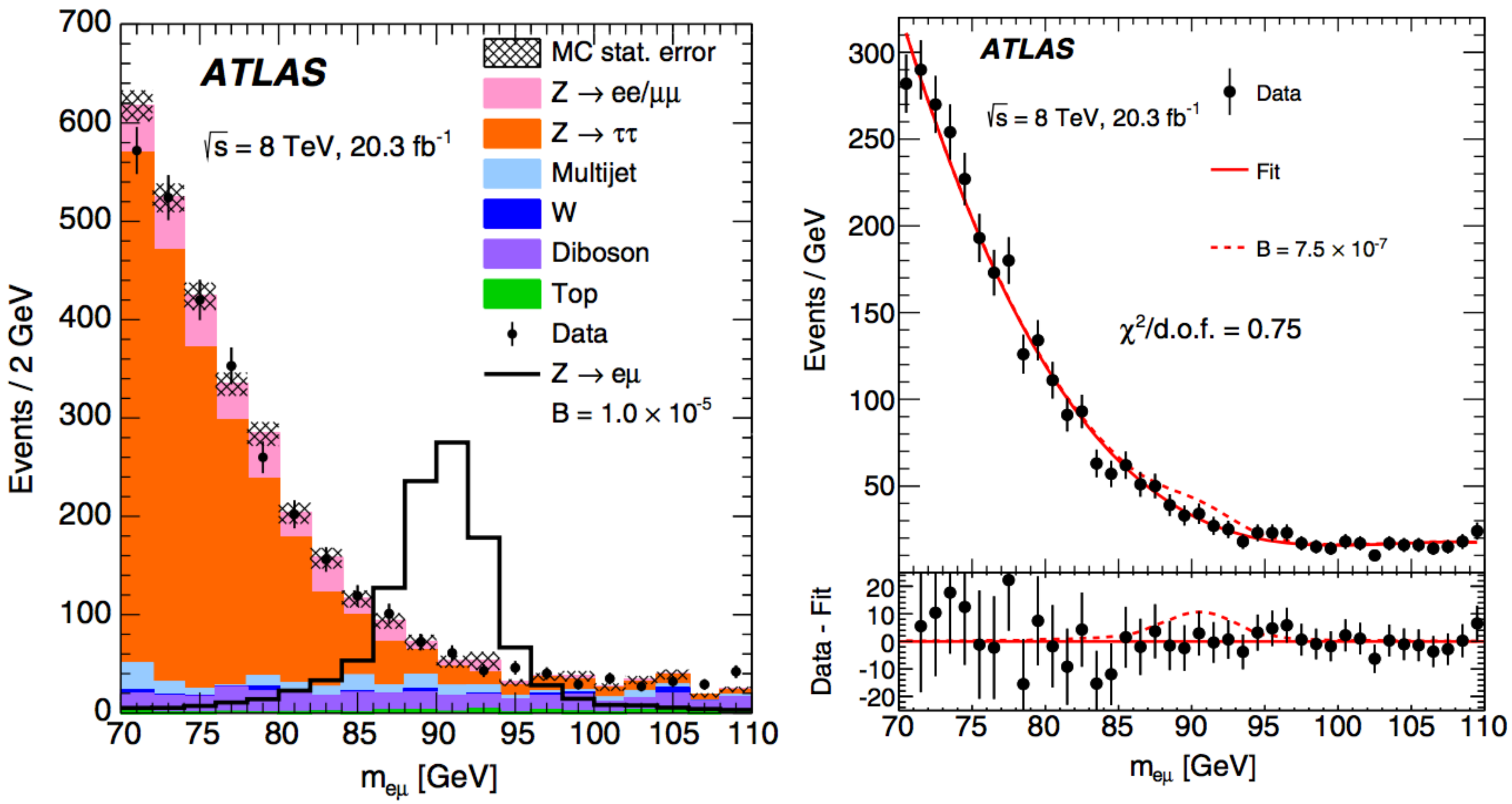
- High p_T e and μ
- Little jet activity
- Little MET

Background estimation

- Side-band fit
  - Possible due to the good mass resolution and the narrow mass range
- Third order polynomial Shape studied in MC

Mass estimator

- Invariant mass (no MET)



$$\boxed{\mathcal{B}(Z \to e\mu) < 7.5 \times 10^{-7}}$$

LFV decays of the Z boson (ATLAS)

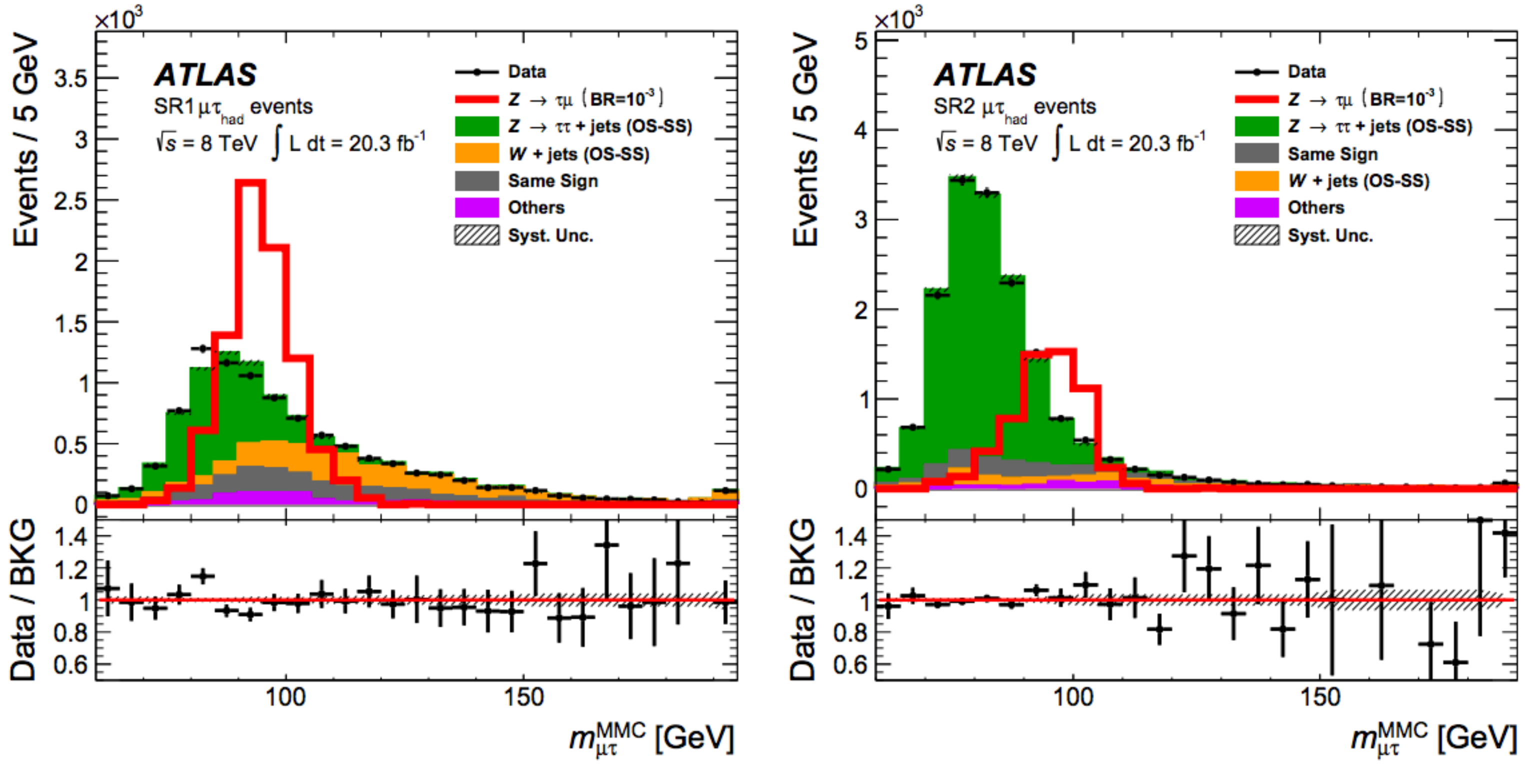
ATLAS 1604.07737

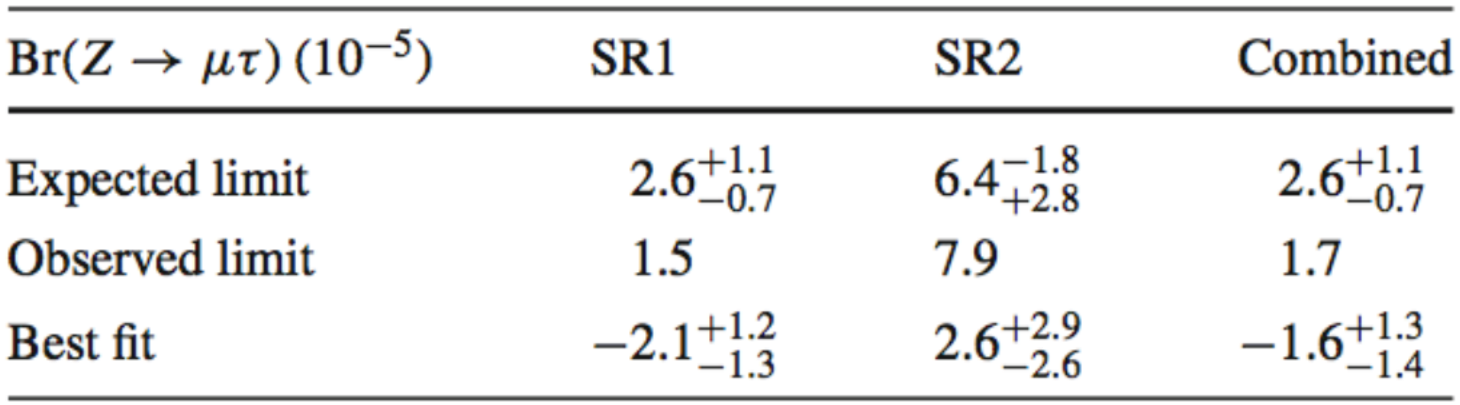
One search channels

- Z→μτhad

Methodology

- Similar to the one employed in the corresponding Higgs search
- Cut values are lowered to match the kinematics of Z decays
  ⇒ Larger background contribution from W+jets
  ⇒ Estimated in more bins





$\mathrm{Br}(Z \to \mu\tau)\ (10^{-5})$	SR1	SR2	Combined
Expected limit	$2.6^{+1.1}_{-0.7}$	$6.4^{-1.8}_{+2.8}$	$2.6^{+1.1}_{-0.7}$
Observed limit	1.5	7.9	1.7
Best fit	$-2.1^{+1.2}_{-1.3}$	$2.6^{+2.9}_{-2.6}$	$-1.6^{+1.3}_{-1.4}$

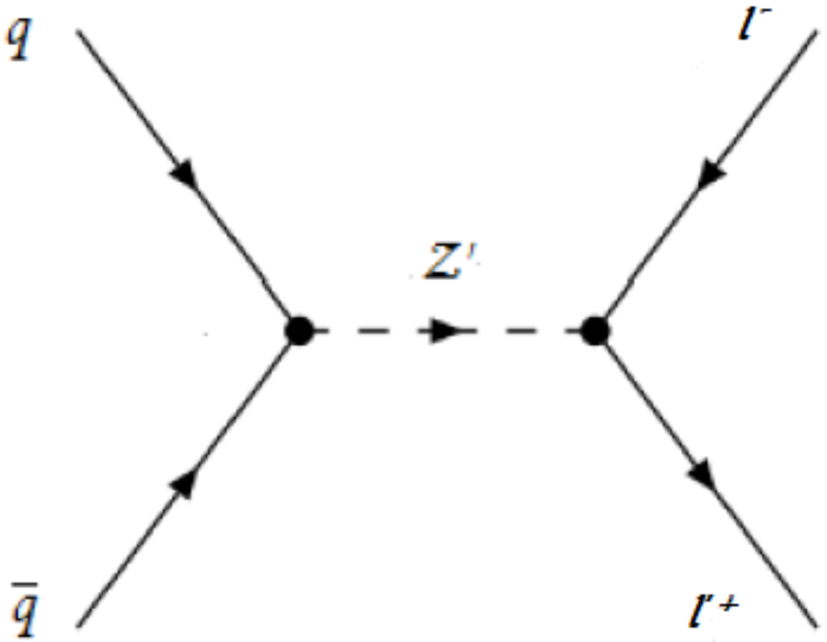
LFV decays of a heavy Z’ boson

Extended SSM Z′

- ✓ the same couplings as the SM Z boson
- ✓ extend to allow for LFV couplings:

Q_{12}, Q_{13} and Q_{23}

$$\sigma(Z' \to l_i l'_j) \propto \frac{g_Z^2 Q_{ij}^2 M_{ll'}^2}{(M_{ll'}^2 - M_{Z'}^2)^2 + M_{Z'}^2 \Gamma_{Z'}^2}$$



- ✓ A general search for heavy resonance
- ✓ Relatively small background due to 2 different flavor leptons

l = e, μ or τ_{had}

Signal: Pythia8

Z′ boson LFV decay search

- ✓ to eμ final states with 7 TeV data (**EPJC Vol.71, 12(2011)1809**)
- ✓ to eμ/eτ_{had}/μτ_{had} final states with 8 TeV (**Phys. Rev. Lett. 115 031801 (2015)**) and 13 TeV data (**accepted by EPJC, arXiv:1607.08079v1**)

LFV decays of a heavy Z’ boson (CMS: 8 TeV)

CMS 1604.05239

Motivations

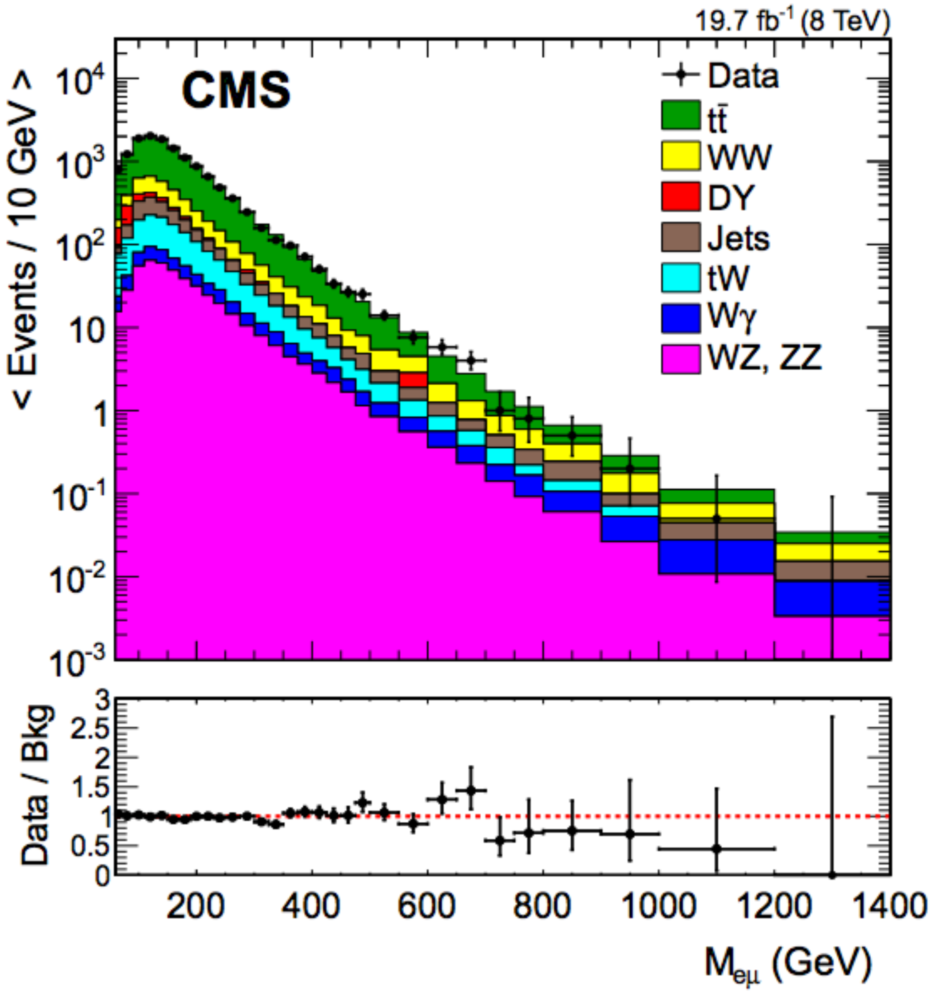
- τ sneutrino in RPV SUSY

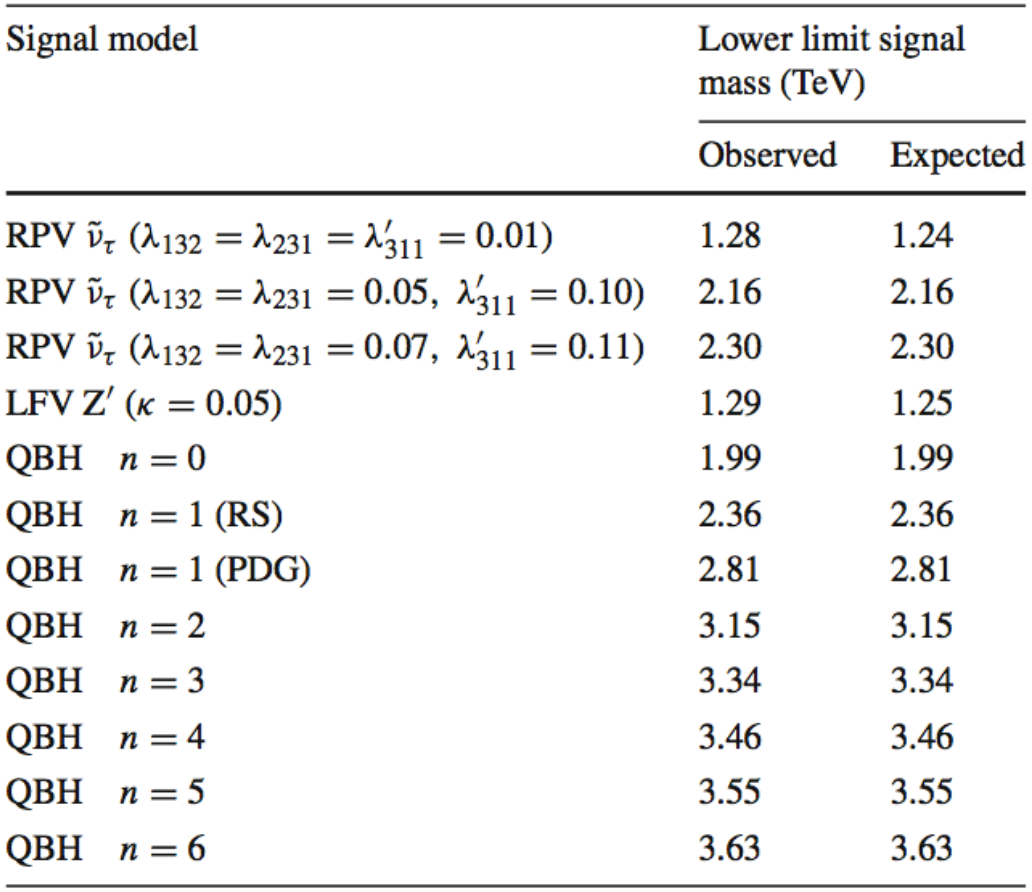
$$W_{\mathrm{RPV}} = \tfrac{1}{2}\lambda_{ijk}L_iL_j\bar{E}_k + \lambda'_{ijk}L_iQ_j\bar{D}_k \; (i,j,k \in 1,2,3)$$

- Z’ and γ’
- Quantum black holes (non resonant)
  - Within a specific model

Background estimation

- Irreducible - MC based
- Reducible - combination





Signal model	Lower limit signal mass (TeV)	
	Observed	Expected
RPV $\tilde{\nu}_\tau$ ($\lambda_{132} = \lambda_{231} = \lambda'_{311} = 0.01$)	1.28	1.24
RPV $\tilde{\nu}_\tau$ ($\lambda_{132} = \lambda_{231} = 0.05,\ \lambda'_{311} = 0.10$)	2.16	2.16
RPV $\tilde{\nu}_\tau$ ($\lambda_{132} = \lambda_{231} = 0.07,\ \lambda'_{311} = 0.11$)	2.30	2.30
LFV Z$'$ ($\kappa = 0.05$)	1.29	1.25
QBH $n = 0$	1.99	1.99
QBH $n = 1$ (RS)	2.36	2.36
QBH $n = 1$ (PDG)	2.81	2.81
QBH $n = 2$	3.15	3.15
QBH $n = 3$	3.34	3.34
QBH $n = 4$	3.46	3.46
QBH $n = 5$	3.55	3.55
QBH $n = 6$	3.63	3.63

LFV decays of a heavy Z' boson (ATLAS: 13 TeV)

Electrons

- Kinematic: pT> 65 GeV
  |η|< 2.47 (no crack region)
- Track and calo quality
- Isolated

Muons

- Kinematic: pT> 65 GeV
  |η|< 2.5
- Combined track quality
- Isolated

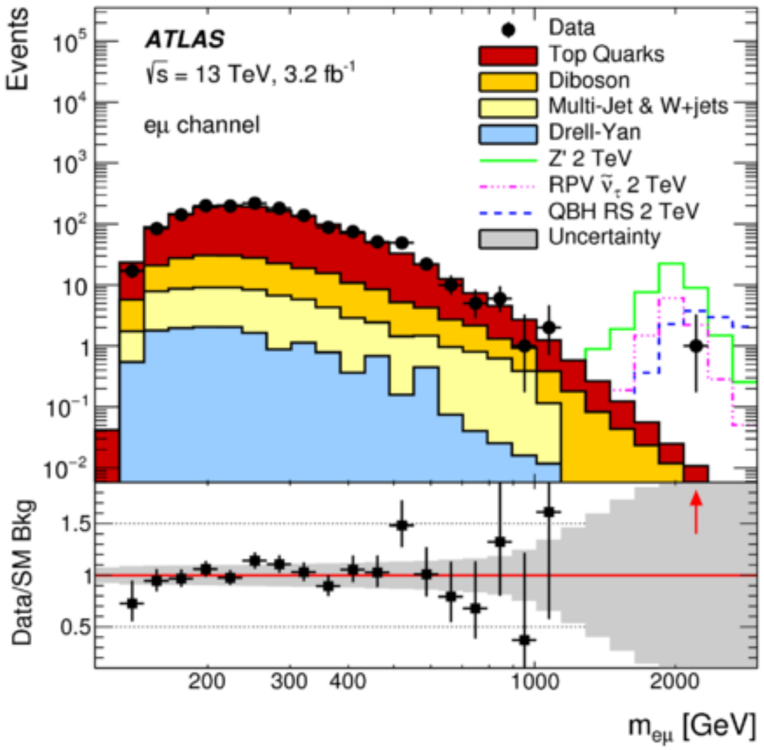
Taus

- Kinematic: pT> 40 GeV
  |η|< 2.47
- 1 and 3 prongs
- Track and calo quality
- Overlap removal with e and μ

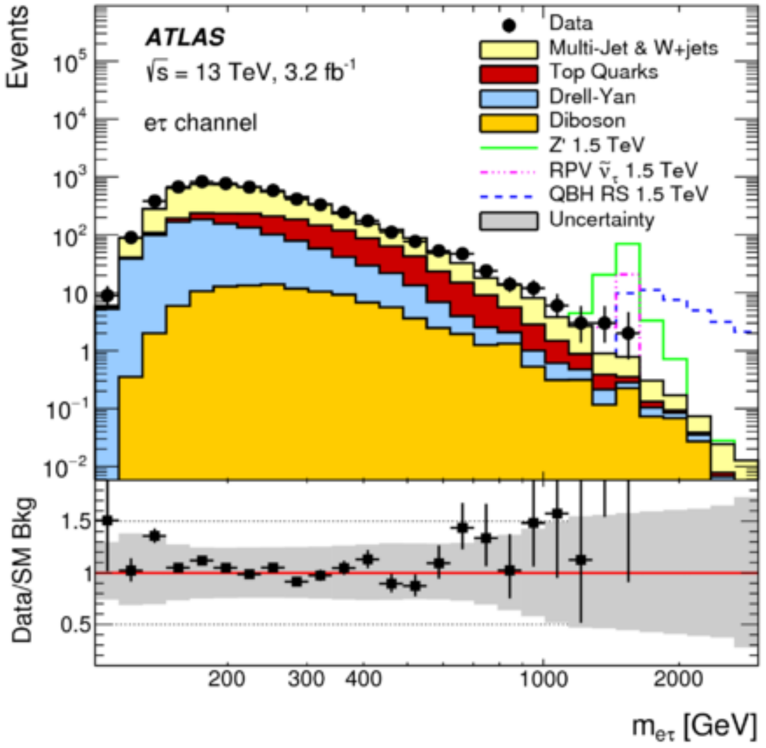
MET: calculated with calibrated objects

Dilepton invariant mass

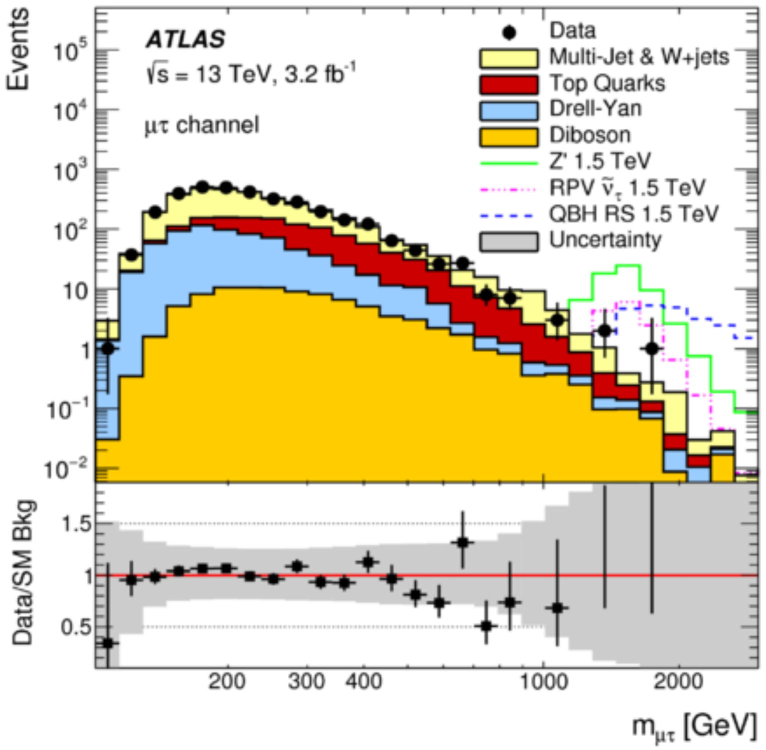
$M_{ll'}$<600GeV: validation region; $M_{ll'}$ >600GeV: signal region



Dominant: Top backgrounds



Dominant: Top + jet fake

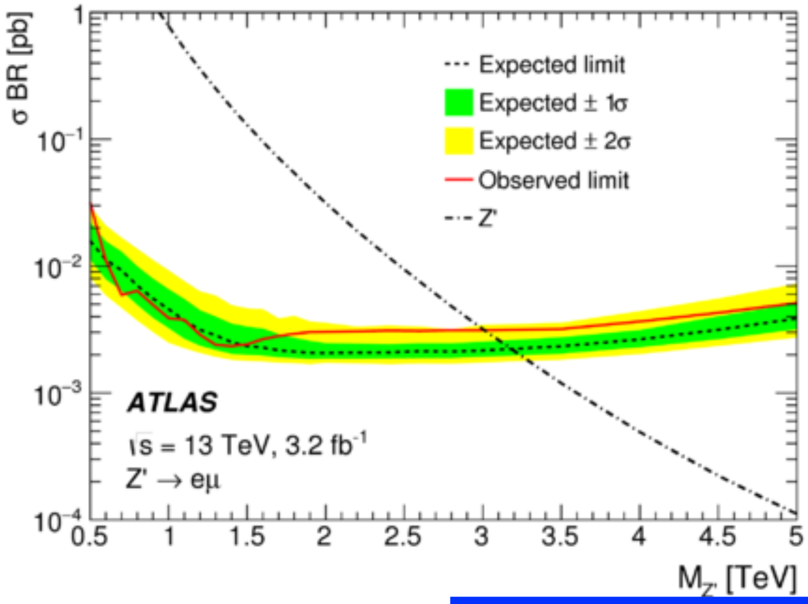


Dominant: Top + jet fake

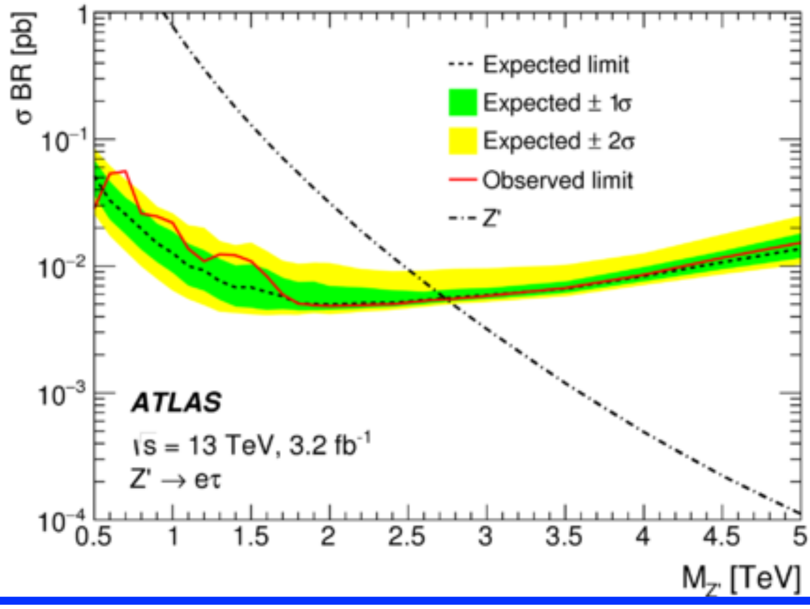
LFV decays of a heavy Z’ boson (ATLAS: 13 TeV)

arXiv: 1607.08079

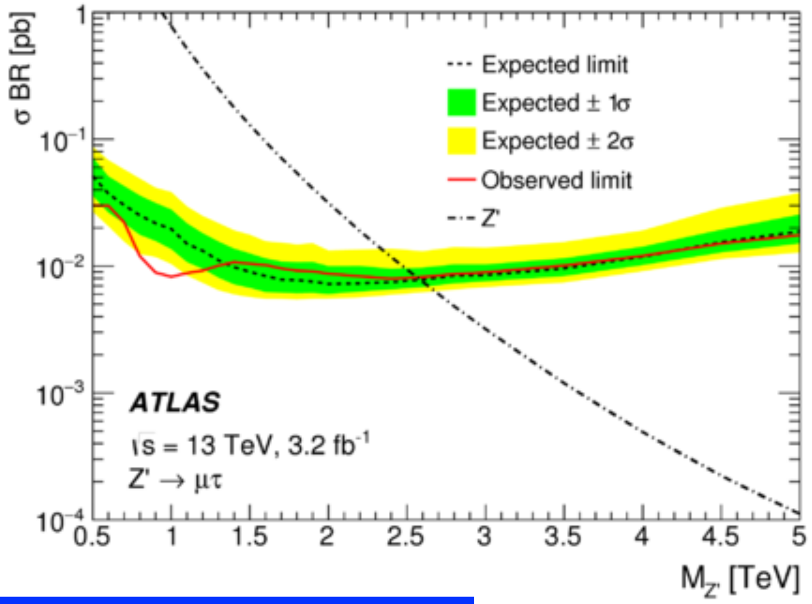
eμ channel



eτ channel



μτ channel



New limits considerably extend the previous ATLAS results

Mass exclusion

Model	Expected Limit [TeV]			Observed Limit [TeV]		
	$e\mu$	$e\tau$	$\mu\tau$	$e\mu$	$e\tau$	$\mu\tau$
Z'	3.2	2.7	2.6	3.0	2.7	2.6

Also interpreted as searches for SUSY RPV or Quantum Black Hole

Model	Expected Limit [TeV]			Observed Limit [TeV]		
	$e\mu$	$e\tau$	$\mu\tau$	$e\mu$	$e\tau$	$\mu\tau$
RPV SUSY $\tilde{\nu}_\tau$	2.5	2.1	2.0	2.3	2.2	1.9
QBH ADD $n = 6$	4.6	4.1	3.9	4.5	4.1	3.9
QBH RS $n = 1$	2.5	2.2	2.1	2.4	2.2	2.1

$\tau^- \longrightarrow \mu^- \mu^+ \mu^-$ (LHCb)

arXiv:1409.8548

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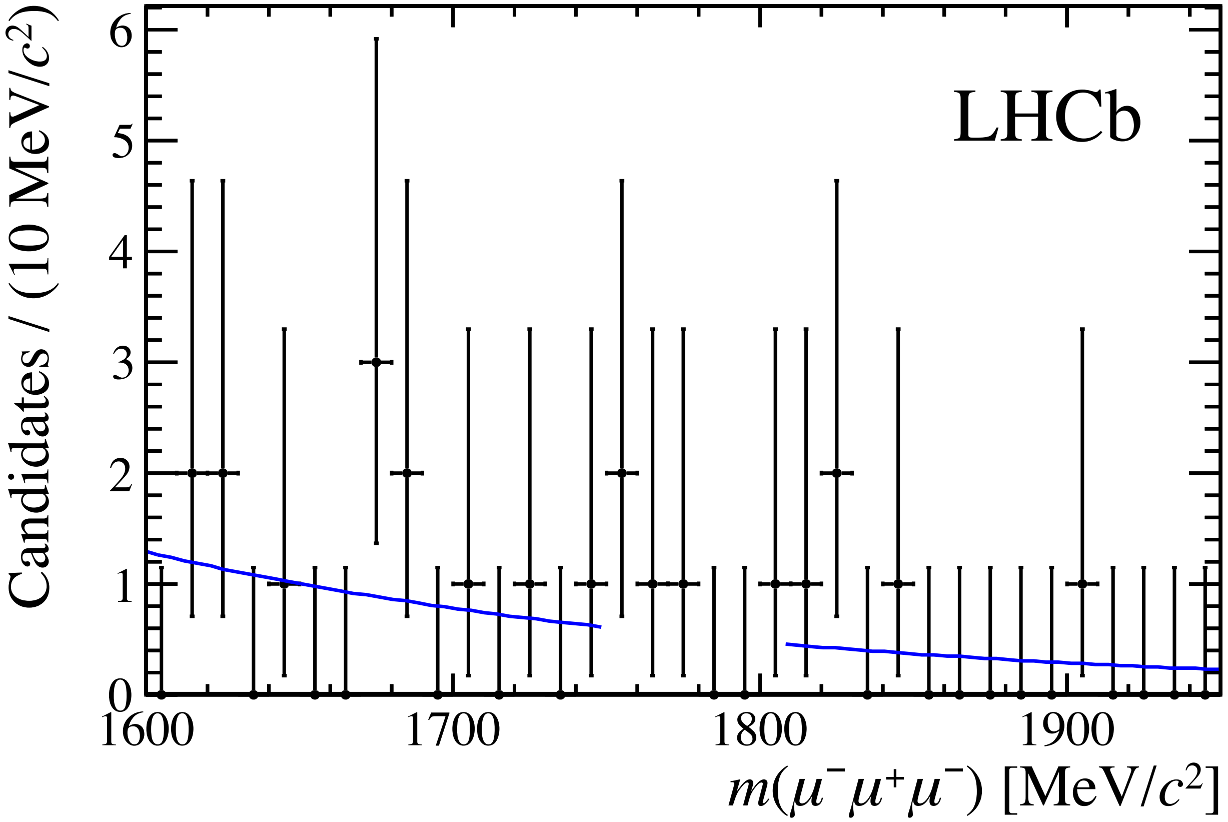
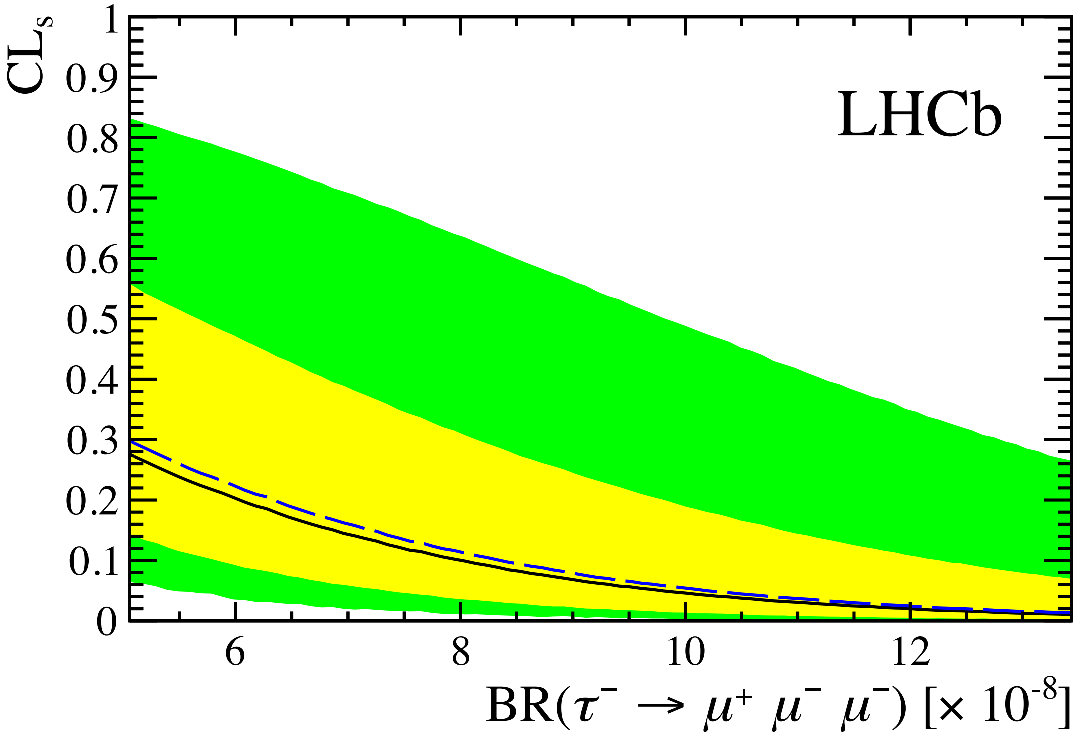


Solid black line: observed, dashed black line: expected



⇒ Best limit from BELLE 2.1×10^{-8}@ 90% CL

⇒ First $\tau^- \to \mu^-\mu^+\mu^-$ limit at a hadron collider

- LHCb limit on the $\tau^- \to \mu^-\mu^+\mu^-$ branching ratio

$$\mathcal{B}(\tau^- \to \mu^-\mu^+\mu^-) < 4.6 \times 10^{-8} \quad \text{@ 90\% C.L.}$$

$\tau^- \longrightarrow \mu^- \mu^+ \mu^-$ (ATLAS)

ATLAS 1601.03567

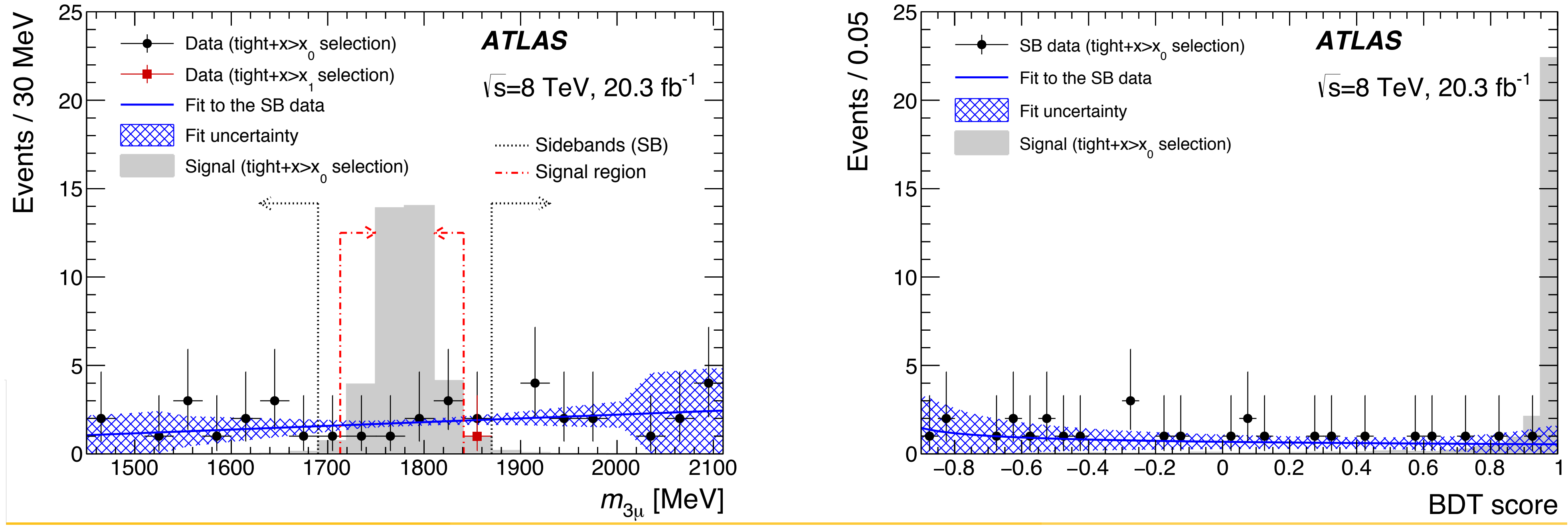
Selection

1. Cut-based *loose* selection
2. Train Boosted Decision Tree and apply loose cut x_0 on BDT output x
3. Cut-based *tight* selection
4. Apply tight cut x_1 on BDT output, optimising for the expected $\mathcal{B}$ limit

Fit Strategy

- Blinded analysis: ignore signal region: $m_{3\mu} \in [1713, 1841]\,\mathrm{MeV}/c^2$

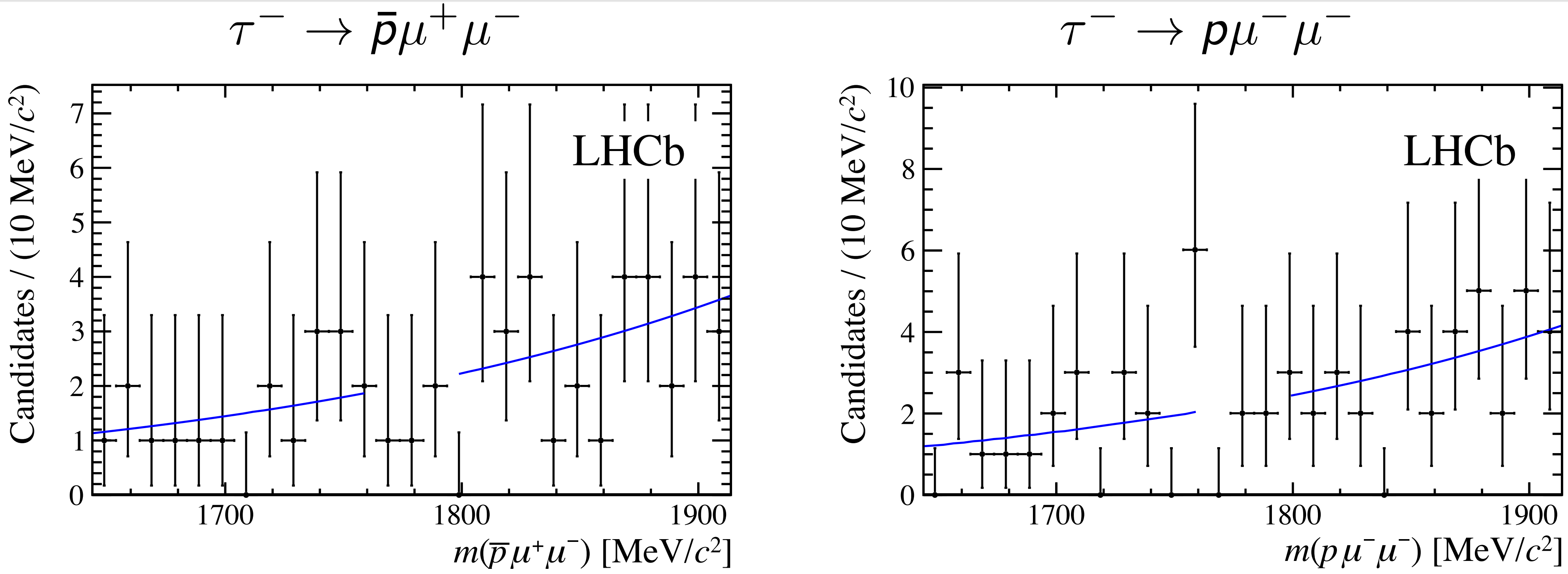
1. Estimate background yield from mass sidebands using "tight $+\ x > x_0$"
2. Fit BDT output in region $x > x_0$
3. Extrapolate background yield for "tight $+\ x > x_1$"



- ATLAS limit on the $\tau^- \to \mu^-\mu^+\mu^-$ branching ratio

$$\mathcal{B}(\tau^- \to \mu^-\mu^+\mu^-) < 3.76 \times 10^{-7} \quad @\ 90\%\ \text{C.L.}$$

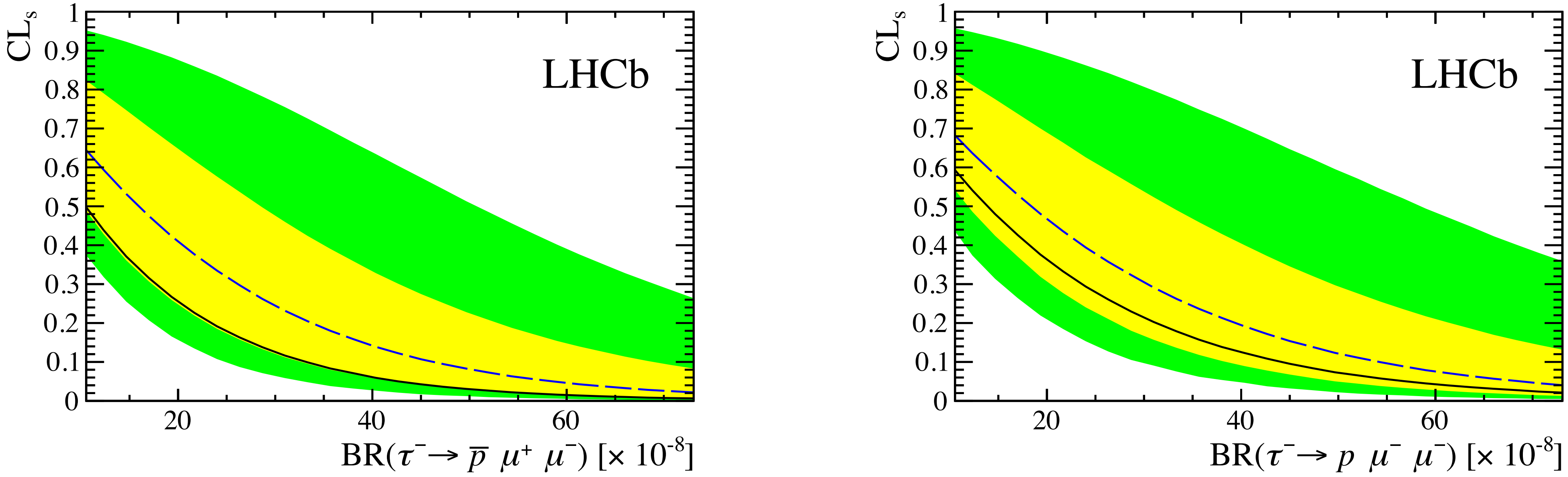
$\tau^- \to \bar{p}\,\mu^+\,\mu^-, p\,\mu^-\,\mu^-$ (LHCb)



Observed limits at 90% CL:

$\mathcal{B}(\tau^- \to \bar{p}\mu^+\mu^-) < 3.3 \times 10^{-7}$ and $\mathcal{B}(\tau^- \to p\mu^-\mu^-) < 4.4 \times 10^{-7}$.

Physics Letters B 724 (2013)



Solid black line: observed, dashed black line: expected

Lots of interesting physics with LFV at LHC