Searches for Lepton flavour violating $H/Z \to \tau l$ decays with the ATLAS detector at 8 TeV

On behalf of ATLAS collaboration

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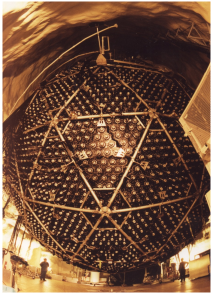
Lepton Flavour Violation is an established fact

- 2001 at Sudbury Neutrino Observatory

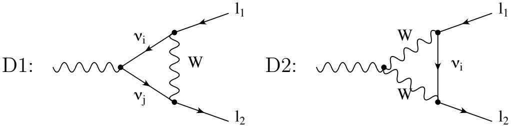


- nobel prize 2015: *for the discovery of neutrino oscillations, which shows that neutrinos have mass*

- neutrino mixing can be incorporated by introducing PMNS matrix

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = V_{\text{PMNS}} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

- This makes LFV Z & H decays possible:

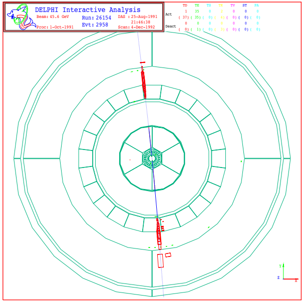


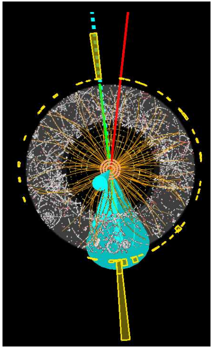
- However, prediction νSM of $\text{BF}(Z \to \tau l) \sim 10^{-54}$ [1]

Collider experiments well suited for production of leptons

most sensitive $Z \to \tau l$ searches stem from LEP

- $\mathrm{Br}(Z \to \tau\mu) < 1.2 \times 10^{-5}$, $\mathrm{Br}(Z \to \tau e) < 9.8 \times 10^{-6}$ [2, 3]
- they had a cleaner environment, we have more statistics

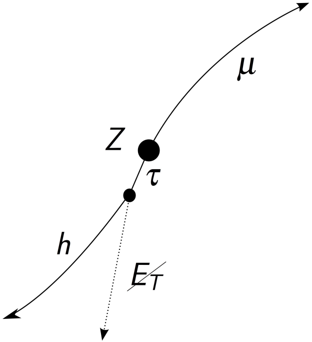




$H \to \tau l$ new measurement

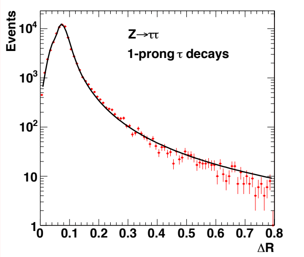
- CMS found 2.4σ excess : $\mathrm{Br}(H \to \tau\mu) = 0.84^{+0.39}_{-0.37}$ % [4].
- no excess in electron channel: $\mathrm{Br}(H \to \tau e) < 0.7$ % (preliminary results [5])

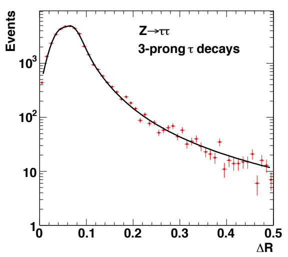
Search for $H/Z \to e\tau/\mu\tau$ decays in the τ_{had} channel



Missing Mass Calculator [6]

$M_{\tau l}^{\text{MMC}}$: invariant mass of the Z or H
quadratic equation $p_{z,\nu}^2 + \alpha p_{z,\nu} + \beta = 0$
most likely solution $\mathscr{L} = \mathscr{P}(\Delta R) \times \mathscr{P}(\not{E}_T)$





Data–driven methods & Monte Carlo corrections

Data–driven

$Z \to \tau\tau$:

☞ from $Z \to \mu\mu$

QCD multi-jets:

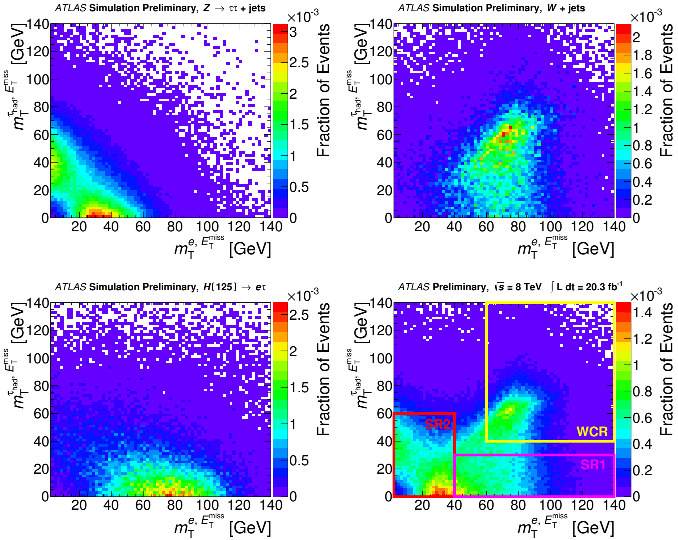
☞ OS/SS symmetry

Control Regions

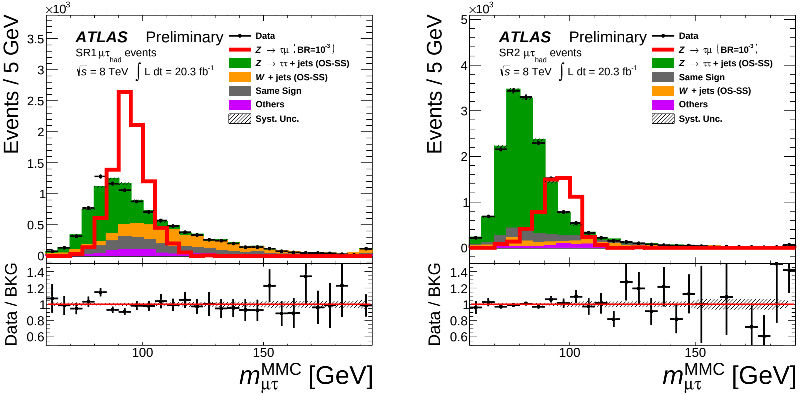
$t/t\bar{t}$

$W+$jets

$Z/VV \to ll$

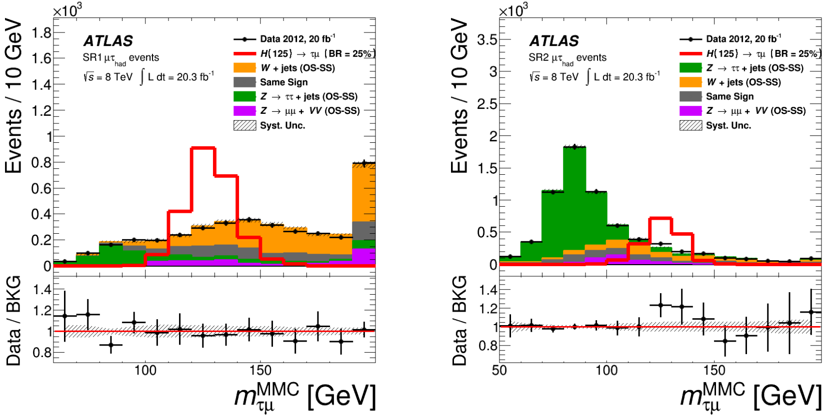


$Z \to \mu\tau_{had}$ [7]



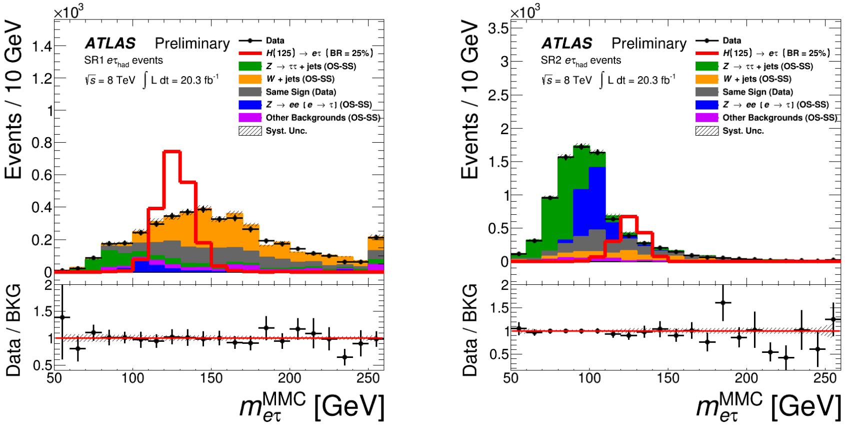
- $\mathrm{Br}(Z \to \tau\mu) = -1.6^{+1.3}_{-1.4} \times 10^{-5}$, best fit value
- $\mathrm{Br}(Z \to \tau\mu) < 1.69\,(2.58) \times 10^{-5}$, observed (expected) 95 % C.L

$H \to \mu\tau_{had}$ [8]



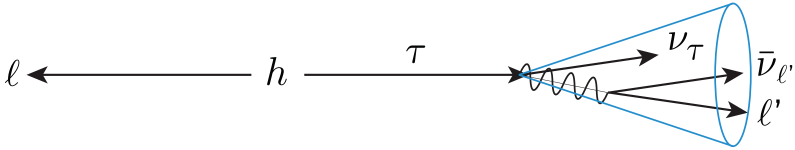
- $\mathrm{Br}(H \to \tau\mu) = 0.77 \pm 0.66$ %, best fit value
- $\mathrm{Br}(H \to \tau\mu) < 1.85\,(1.24)$ %, observed (expected) 95 % C.L.

$H \to e\tau_{\rm had}$ [7]



- $Br(H \to \tau e) = -0.47^{1.08}_{-1.18}$ %, best fit value
- $Br(H \to \tau e) < 1.81\,(2.07)$ %, observed (expected) 95 % C.L.

Search for $H \to e\tau/\mu\tau$ decays in the τ_{lep} channel



The final discriminant used in this channel is the collinear mass $\mathrm{m}_{\mathrm{coll}}$ defined as:

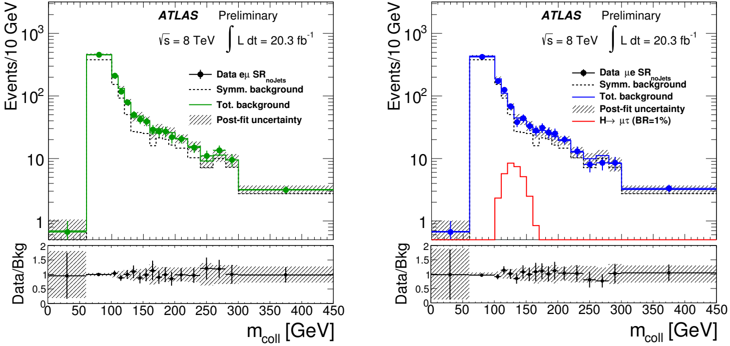
$$m_{\text{coll}} = \sqrt{2p_{\mathrm{T}}^{\ell_1}\left(p_{\mathrm{T}}^{\ell_2} + E_T^{\text{miss}}\right)(\cosh\Delta\eta - \cos\Delta\phi)}. \tag{1}$$

This quantity is the invariant mass of two massless particles, τ and l_1, computed with the approximation that the decay products of the τ lepton, l_2 and ν, are collinear to the τ, and that the E_T^{miss} originates from the ν.

$H \to e\tau_{\mathrm{lep}}/\mu\tau_{\mathrm{lep}}$ [7]

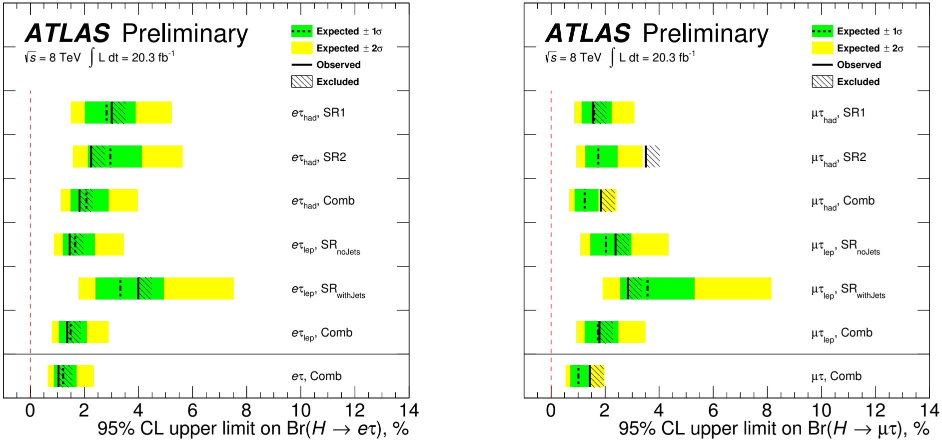
Dilepton events are divided into two mutually exclusive samples:

- **μe sample**: $p_T^\mu \geq p_T^e$: $H \to \mu\tau \to \mu e \nu\nu$ would be here
- **$e\mu$ sample**: $p_T^e > p_T^\mu$



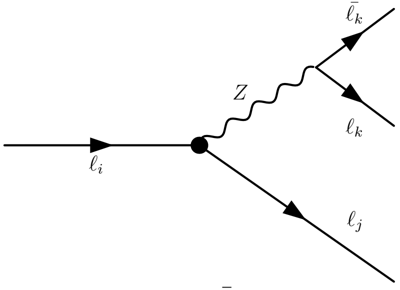
- $\mathrm{Br}(H \to \mu\tau) < 1.79\,(1.73)$ %, $\mathrm{Br}(H \to e\tau) < 1.36\,(1.48)$ %

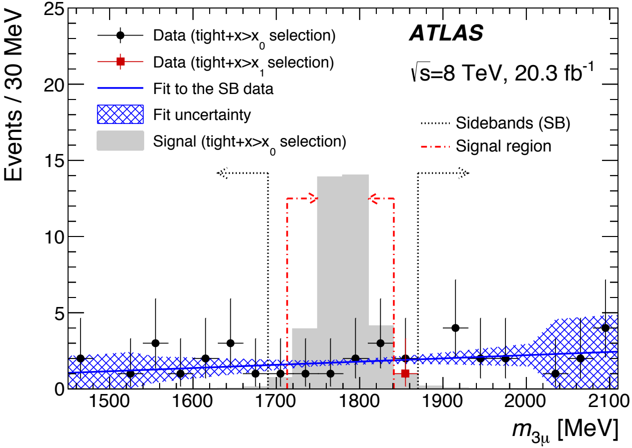
Combined Results



- Combined result: $\text{Br}(H \to \mu\tau) < 1.43\,(1.01)$ %, $\text{Br}(H \to e\tau) < 1.21\,(1.48)$ %

Complementary low energy decay: $\tau \to 3\mu$ [9]





- trained BDT, predict event count from sidebands invariant mass $m_{3\mu}$
- $\mathrm{Br}(\tau \to 3\mu) < 3.76 \times 10^{-7} (3.94 \times 10^{-7})$ observed (expected) at 90% C.L.

Conclusion

- LHC offers a new opportunity to look for charged lepton flavour violating decays
- interesting from the standpoint of new physics models w.r.t. neutrino oscillations
  $\rightarrow$ unambiguous sign of new physics
- several searches[1] have been performed at ATLAS with different techniques

$H/Z \rightarrow l\tau_{\text{had}}$:	template fit using $M^{\text{MMC}}_{\tau l}$
$H \rightarrow l\tau_{\text{lep}}$:	completely data–driven technique on symmetry argument
$\tau \rightarrow 3\mu$:	counting experiment after BDT selection
$Z \rightarrow e\mu$:	bump hunting

- no significant excess found
- determining more Higgs properties at ATLAS
- $Z \rightarrow \tau\mu$ will be competitive with LEP after Run 2 and/or τ_{lep}
- $\tau \rightarrow 3\mu$: expected to be competitive with Belle result with Run2 data and trigger improvement

[1] $Z \rightarrow e\mu$ is an older analysis,see backup, most sensitive limit

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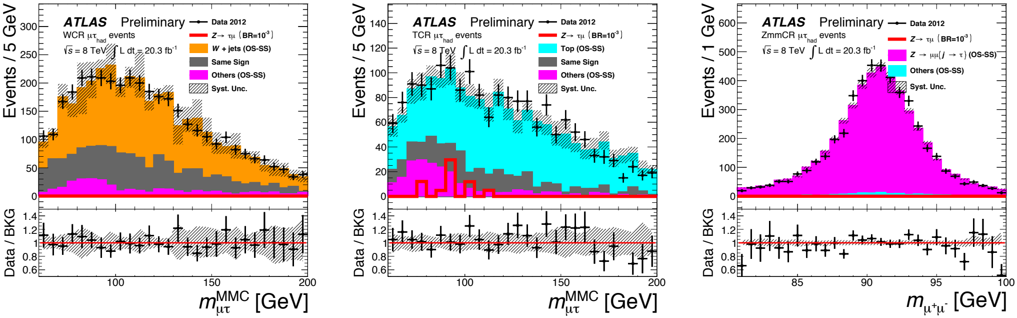
Backup

Lepton Flavour Violation

Isidor Isaac Rabis famous question about the muons existence, Who ordered that?, was prescient and deep. His question, in modern terms, asked why are there flavours and generations? Why are there muons and taus in addition to the electron? The same question applies to the quark and neutrino sectors. We believe there are three generations in each sector, and that the number in each sector must be the same. We see quarks changing generations, as codified in the Cabibbo-Kobayashi-Maskawa matrix, and neutrinos changing from muon to electron to tau neutrinos according to the Pontecorvo-Maki-Nakagawa-Saka matrix. Lepton Flavour Violation is an established fact, but only in the neutral neutrinos. What about their charged partners? Is there Charged Lepton Flavour Violation? [10]

Control regions



- a jet faking a τ_{had} is not well modelled by MC simulation

SM backgrounds

$Z \to \tau\tau$
$t/t\bar{t}$
$W+$jets
$Z/VV \to ll$
$H \to \tau\tau$
QCD multi-jets

Event classes

real lepton and τ_{had}
jet misidentified as a τ_{had}
lepton misidentified as a τ_{had}

Processes where a jet fakes a τ_{had} are not well modelled by Monte Carlo simulation, we use the following assumptions:

- The shape of the $M_{\tau l}^{\text{MMC}}$ distribution in the signal regions is the same for OS and SS events for the QCD multi-jet background.
- The scale factor $k = N(\text{data})/N(\text{MC})$ is the same for the processes in the signal and corresponding control regions for the electroweak backgrounds.

The symmetry method [11] is completely data–driven, has very few background systematics and mostly limited by statistics. It is based on the following two premises:

1. Standard Model processes are to a good approximation symmetric under the exchange $e \leftrightarrow \mu$ [11].
2. $\mathrm{Br}(H \to \mu\tau) \neq \mathrm{Br}(H \to e\tau)$ [2]

Dilepton events are divided into two mutually exclusive samples:

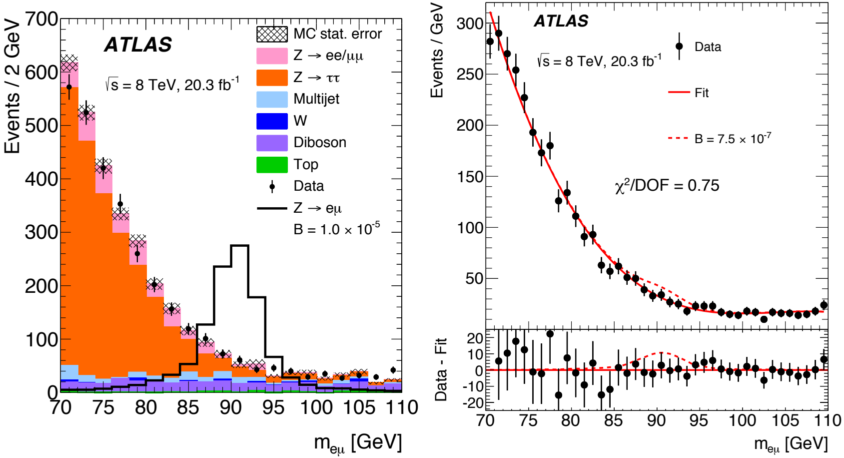
- **μe sample**: $p_T^{\mu} \geq p_T^{e}$: $H \to \mu\tau \to \mu e\nu\nu$ would be here
- **$e\mu$ sample**: $p_T^{e} > p_T^{\mu}$: $H \to e\tau \to e\mu\nu\nu$ would be here

small asymmetries that need to be accounted for:

- misidentified and non-prompt leptons
- trigger and reconstruction efficiency

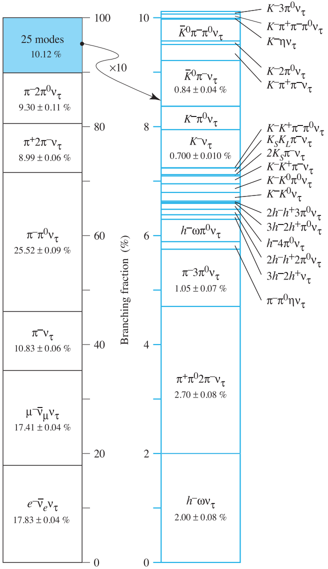
[2] The bound on $\mu \to e\gamma$ decays suggests that the presence of a $H \to \mu\tau$ signal would exclude the presence of a $H \to e\tau$ signal, and vice versa, at an experimentally observable level at the LHC [12].

$Z \to e\mu$ [14]

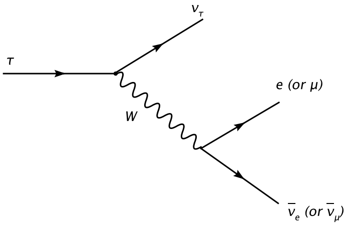


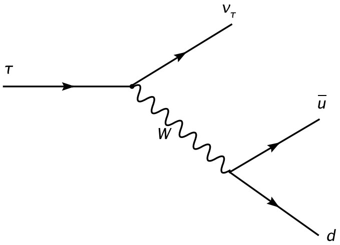
$\mathrm{Br}(Z \to e\mu) < 7.5 \times 10^{-7}$, observed 95 % C.L., significantly more restrictive than that from the LEP experiments [13].

Reconstructing τ



- hadronic: 1 ν, leptonic: 2 ν
- missing energy $\to$ sideband analysis not possible
- performing a template fit





FitModel

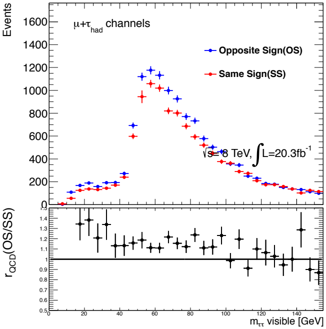
$$N_{\mathrm{OS}}^{\mathrm{bkg}} = r_{\mathrm{QCD}} \cdot N_{\mathrm{SS}}^{\mathrm{data}} + N_{\text{add-on}}^{Z\to\tau\tau} + N_{\text{add-on}}^{W+\mathrm{jets}} + N_{\text{add-on}}^{t/t\bar{t}} + N_{\text{add-on}}^{VV\to ll} + N_{\text{add-on}}^{H\to\tau\tau}$$
$$+ N_{\text{add-on}}^{Z\to ll(l\to\tau_{\mathrm{fake}})} + N_{\text{add-on}}^{Z\to ll(j\to\tau_{\mathrm{fake}})},$$

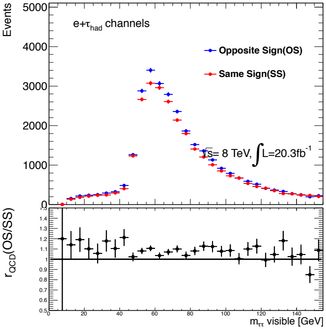
where the ratio $r_{\mathrm{QCD}} = N_{\mathrm{OS}}^{\mathrm{QCD}}/N_{\mathrm{SS}}^{\mathrm{QCD}}$ accounts for the rate difference in QCD multi-jets when requiring OS or SS events, which is caused by their different flavour composition.

- $N_{\text{add-on}}^{W+\mathrm{jets}} = k_{W+\mathrm{jets}}^{\mathrm{OS}} \cdot N_{\mathrm{OS}}^{W+\mathrm{jets}} - r_{\mathrm{QCD}} \cdot k_{W+\mathrm{jets}}^{\mathrm{SS}} \cdot N_{\mathrm{SS}}^{W+\mathrm{jets}}$. Because the $W+\mathrm{jets}$ background consists of a jet misidentified as a τ_{had}, a rate correction is applied. The quark and gluon composition differ for OS and SS events causing some charge asymmetry $N_{\mathrm{OS}} > N_{\mathrm{SS}}$. Therefore two separate corrections are obtained from a control region, namely $k_{W+\mathrm{jets}}^{\mathrm{OS}}$ and $k_{W+\mathrm{jets}}^{\mathrm{SS}}$.

QCD multi-jet: data driven

- virtually impossible to model by Monte Carlo simulation
- make use of symmetry between same and oppositely charged $\tau_{had} l$ events





Signal: $Z \to \tau_{had} l$

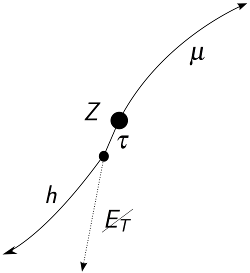
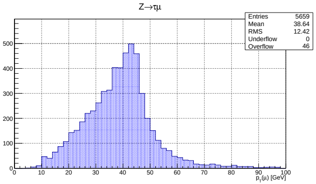
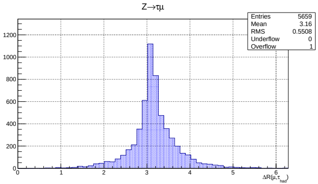
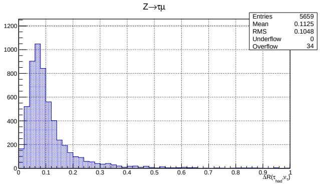


Figure: Artist's Impression

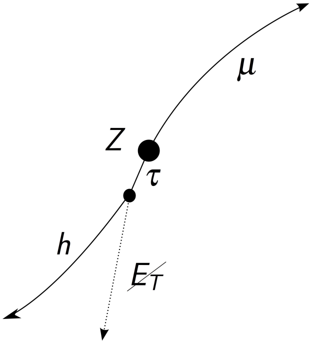
- ☞ $p_T(\mu) \sim m_Z/2$
- ☞ $\mu\tau_{\text{had}}$ back to back
- ☞ $\nu\tau_{\text{had}} \sim$ collinear

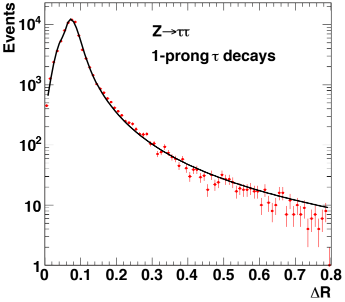


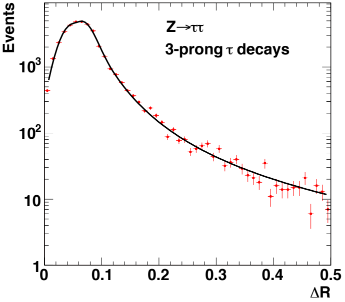




Reconstructing Z







- 2 solutions from quadratic equation
- model angle between hadron - neutrino: $\mathscr{P}(\Delta R)$
- model missing energy resolution: $\mathscr{P}(\not{E}_T)$
- take most likely according $\mathscr{L} = \mathscr{P}(\Delta R) \times \mathscr{P}(\not{E}_T)$