τ physics at LHCb

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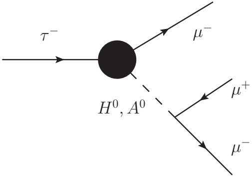
on behalf of the LHCb collaboration

The 7th International Workshop on Charm Physics
Wayne State University, 20th May 2015

τ lepton flavour and baryon number violation at LHCb

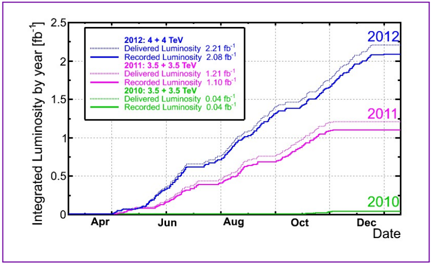
- Lepton flavour violating (LFV) decay $\tau^- \to \mu^-\mu^+\mu^-$ forbidden in SM
- Suppressed in SM + neutrino oscillations to $\mathcal{B} \sim 10^{-54}$
- Enhanced by new physics $\to$ can be as large as 10^{-8}
- Current experimental upper limit of 2.1×10^{-8} from Belle



- Search for baryon number violation (BNV) processes so far unsuccessful
- $\tau^- \to \bar{p}\mu^+\mu^-$ and $\tau^- \to p\mu^-\mu^-$ are both $\Delta(B-L) = 0$ as required in the SM and most of its extensions
- Limits on $\tau \to \Lambda h$ and $B \to \Lambda l$ in the range $10^{-7} - 10^{-8}$ from BaBar and Belle
- $\tau^- \to \mu^-\mu^+\mu^-$ and $\tau \to p\mu\mu$ analyses follow a similar strategy

$\tau \to \mu\mu\mu$ and $\tau \to p\mu\mu$: Analysis strategy

- Inclusive τ cross-section is $(80.0 \pm 9.4)\,\mu$b at $\sqrt{s} = 8$ TeV in LHCb acceptance
- 2.5×10^{11} τ leptons produced during LHC Run 1
- τ mainly from $D_s \to \tau\nu_\tau$ decays ($\sim$ 80%)



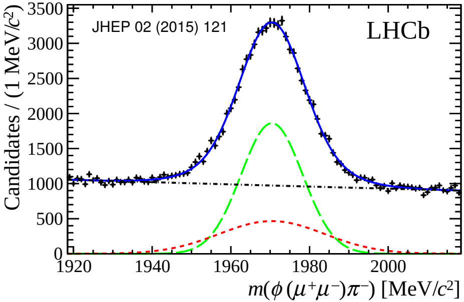
- Relative normalisation to $D_s \to \phi(\mu\mu)\pi$
- Loose cut-based selection followed by 3D classification:
  1) Decay topology and kinematics
  2) Particle identification (replaced by PID cuts for $\tau \to p\mu\mu$)
  3) Invariant mass
- Classifiers trained on simulated signal and calibrated on control channels
- Limit from $\mathrm{CL_s}$ method (J. Phys. G: Nucl. Part. Phys. 28 (2002) 2693)

$D_s \to \phi(\mu\mu)\pi$ decays in data

- Branching fraction of normalisation channel, $\mathcal{B}(D_s \to \phi(\mu\mu)\pi)$, from:

$$\frac{\mathcal{B}(D_s \to \phi(KK)\pi)}{\mathcal{B}(\phi \to KK)}\mathcal{B}(\phi \to \mu\mu) = (1.32 \pm 0.10) \times 10^{-5}$$

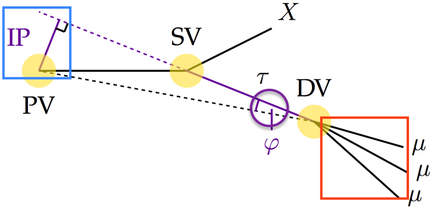
- $N_{D_s \to \phi\pi}$ from a double gaussian fit to data with an exponential background component
- Fit separately for data taking period and $\tau \to \mu\mu\mu$ / $\tau \to p\mu\mu$ selections

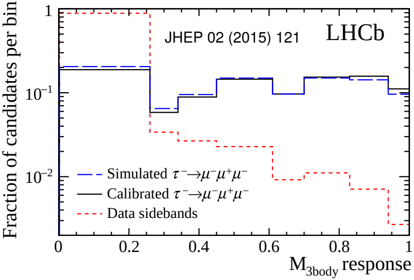


2 fb^{-1}, $\tau \to \mu\mu\mu$ selection

Signal and background discrimination - $\mathcal{M}_{\text{3body}}$

- Two multivariate classifiers, $\mathcal{M}_{\text{3body}}$ and $\mathcal{M}_{\text{PID}}$ ($\tau \to \mu\mu\mu$ only)
- $\mathcal{M}_{\text{3body}}$ includes: vertex and track fit quality, vertex displacement, vertex pointing, vertex isolation and τ p_T
- Blended BDT classifier

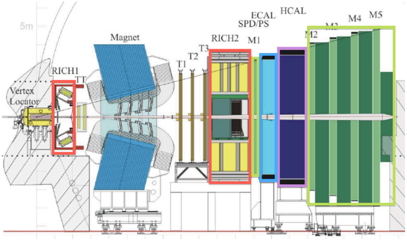


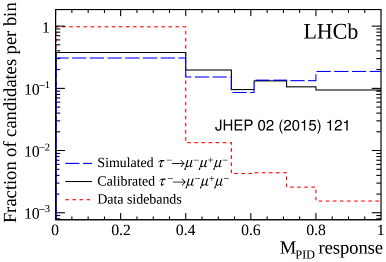


- Trained on signal and background MC
- Response calibrated on $D_s^- \to \phi\pi^-$ data to account for data-MC differences

Signal and background discrimination - $\mathcal{M}_{\text{PID}}$

- $\mathcal{M}_{\text{PID}}$ includes: information from RICH, ECAL, HCAL and muon chambers
- Neural network probability





- Trained on signal and background MC
- Calibrated on $J/\psi \to \mu\mu$ data
- For $\tau \to p\mu\mu$ apply hard PID cuts, optimised on signal MC and data sidebands

Normalisation factor

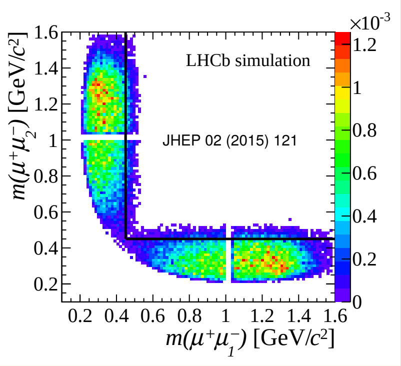
$$\mathcal{B}(\tau \to X\mu\mu) = \mathcal{B}(D_s \to \phi(\mu\mu)\pi) \times \frac{f^{\tau}_{D_s}}{\mathcal{B}(D_s \to \tau\nu_\tau)} \times \frac{\epsilon_{\mathrm{D_s}\to\phi\pi}}{\epsilon_{\tau\to\mathrm{X}\mu\mu}} \times \frac{N_{\tau\to X\mu\mu}}{N_{D_s\to\phi\pi}}$$

- $f^{\tau}_{D_s}$ is the fraction of τ from D_s (80%), from LHCb cross-section measurements and LEP/B-factory branching fractions
- $\mathcal{B}(D_s \to \tau\nu_\tau)$ from arXiv:hep-ex/1201.2401
- ϵ are the efficiencies to select signal and normalisation events, calculated using MC
- Systematics cancel in ratio of efficiencies
- $\mathcal{B}(D_s \to \phi(\mu\mu)\pi)$ and $N_{D_s} \to \phi\pi$ described earlier

Backgrounds

- Backgrounds at LHCb from decays of heavy mesons with either:
  - Three real final state muons ($\tau \to \mu\mu\mu$ only)

- For $\tau \to \mu\mu\mu$ most significant peaking background from $D_s \to \eta(\mu\mu\gamma)\mu\nu_\mu$
- 90% removed by a cut on $m_{\mu^+\mu^-}$ > 450 MeV/c^2

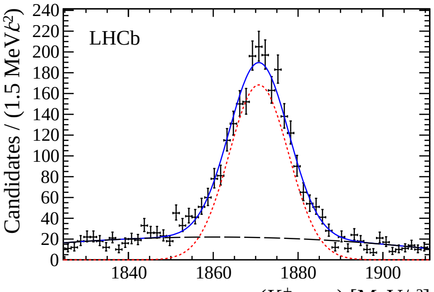


$D_s \to \eta(\mu\mu\gamma)\mu\nu_\mu$ MC

Backgrounds

- Backgrounds at LHCb from decays of heavy mesons with either:
  - Three real final state muons ($\tau \to \mu\mu\mu$ only)
  - One or two real muons and one or two mis-identified particles

- Large mis-ID contribution from $D^+ \to K^-\pi^+\pi^+$ decays in lowest $\mathcal{M}_{\text{PID}}$ bins $\to$ Removed by excluding the lowest $\mathcal{M}_{\text{PID}}$ bins
- No peaking backgrounds expected for $\tau \to p\mu\mu$



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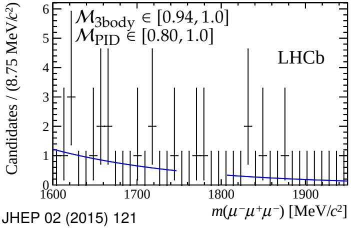
2 fb^{-1}, $D^+ \to K^-\pi^+\pi^+$ hypothesis

Background fits

- Background estimate in signal region from data sidebands
- Most signal-like bin in $2\,\text{fb}^{-1}$ for $\tau^- \to \mu^-\mu^+\mu^-$ (left), and 2 most signal-like bins merged in $1\,\text{fb}^{-1}$ for $\tau^- \to \bar{p}\mu^+\mu^-$ (bottom left) and $\tau^- \to p\mu^-\mu^-$ (bottom right)



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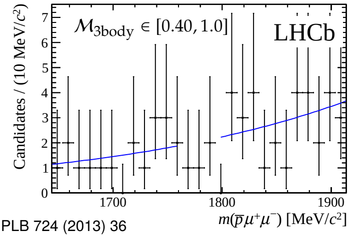

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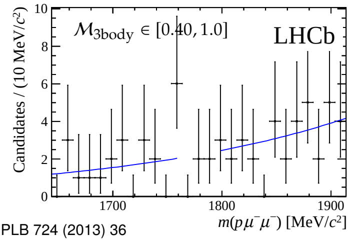

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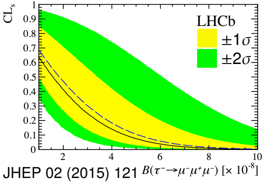
τ LFV and BNV results



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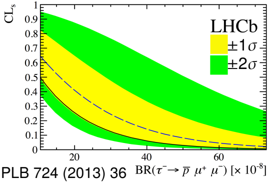

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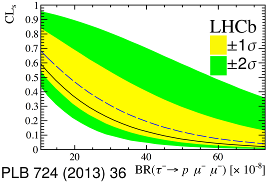

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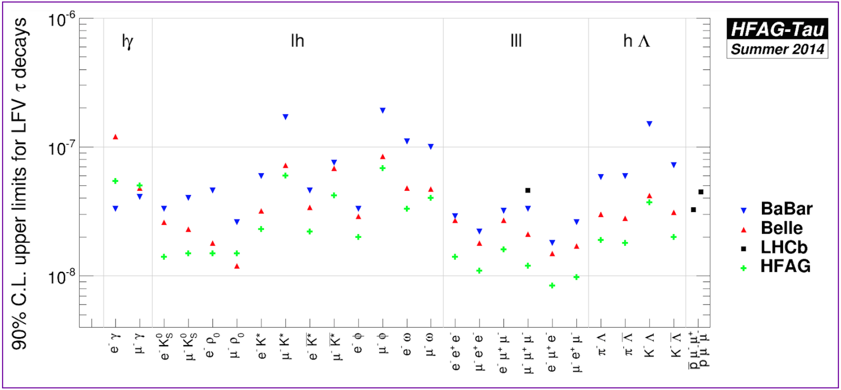
- First τ LFV results at a hadron collider
- First ever constraints on $\tau^- \to \bar{p}\mu^+\mu^-$ and $\tau^- \to p\mu^-\mu^-$
- $\tau^- \to \mu^-\mu^+\mu^-$ results recently updated to use full Run I data sample

Channel	Expected (90% CL)	Observed (90% CL)
$\tau^- \to \mu^-\mu^+\mu^-$	5.0×10^{-8}	4.6×10^{-8}
$\tau^- \to \bar{p}\mu^+\mu^-$	4.6×10^{-7}	3.3×10^{-7}
$\tau^- \to p\mu^-\mu^-$	5.4×10^{-7}	4.4×10^{-7}

Combination of τ LFV results

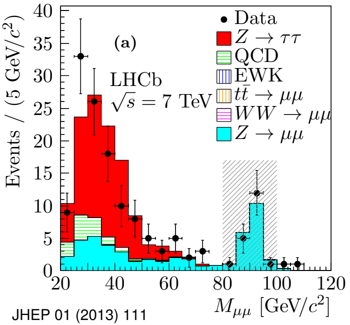


- LHCb and *B*-factory results on τ LFV combined by HFAG using CLs method
  $\rightarrow$ Combined limit on $\tau^- \rightarrow \mu^-\mu^+\mu^-$ of 1.2×10^{-8}

Inclusive $Z \to \tau\tau$ cross-section at 7 TeV

- Measurements of the Z boson production cross-section are important tests of the SM
- LHCb can extend general purpose detector (GPD) results into the forward region

- Split analysis into 5 channels depending on final state:
  1) $\tau_\mu \tau_\mu$
  2) $\tau_\mu \tau_e$
  3) $\tau_e \tau_\mu$
  4) $\tau_\mu \tau_h$
  5) $\tau_e \tau_h$
- Dominant $Z \to \mu\mu$ and QCD backgrounds are estimated from data



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$\tau_\mu \tau_\mu$ channel

$Z \to \tau\tau$ results

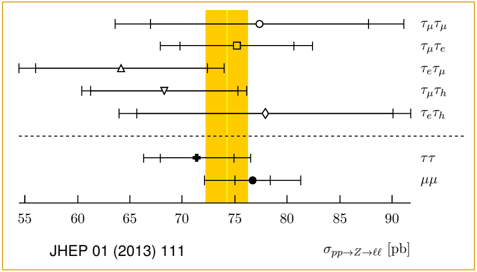
- Individual channel measurements are combined with the BLUE method (Nucl. Instrum. Meth. A 270 (1988) 110) to give:

$$\sigma_{pp\to Z\to\tau\tau} = 71.4 \pm 3.5_{\rm stat} \pm 2.8_{\rm syst} \pm 2.5_{\rm lumi}\ \text{pb}$$

where $2.0 \le \eta^\tau \le 4.5$ and $p_T^\tau > 20\,\text{GeV}/c$ and $60 < M_{\tau\tau} < 120\,\text{GeV}/c^2$

- Ratio of cross-sections, $\frac{\sigma_{pp\to Z\to\tau\tau}}{\sigma_{pp\to Z\to\mu\mu}} = 0.93 \pm 0.09$

$\to$ Consistent with lepton universality (also for $Z \to ee$)



SM predictions from DYNNLO (PRL 98 (2007) 22) with MSTW08 NNL0

Summary

- First τ LFV results at a hadron collider with $\tau^- \to \mu^-\mu^+\mu^-$, $\tau^- \to \bar{p}\mu^+\mu^-$ and $\tau^- \to p\mu^-\mu^-$
- LHCb is closing in on the world's best single-experiment limit for $\tau^- \to \mu^-\mu^+\mu^-$ and contributing to the world average
- First ever constraints on $\tau^- \to \bar{p}\mu^+\mu^-$ and $\tau^- \to p\mu^-\mu^-$
- Measurement of Z boson production in the forward region using τ decays complements results from GPDs
- Studies underway on $B \to D^*\tau\nu_\tau$, $B_{(s)} \to \tau\tau$, $B \to K^*\tau\mu$ and more

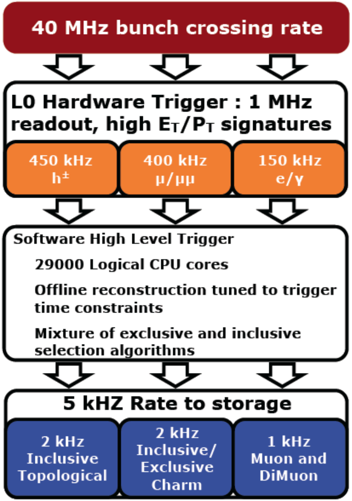
LHCb is making significant contributions to τ physics
$\to$ more to come as we approach the start of Run 2

Backup

The LHCb trigger: 2010 + 2011

➜ The trigger reduces the event rate via:

1) L0: Hardware selection using calo clusters and muon system hits
2) HLT1: Loose software selection using VELO and tracking station tracks
3) HLT2: Full software reconstruction creates composite particles



The LHCb trigger: 2012

- Introduction of partial deferred triggering in 2012
- 20% of events passing L0 saved to disk and processed inter-fill
- Effective 20% increase in CPU power
- Used to reduce track p_T thresholds from 500 to 300 MeV
  $\rightarrow$ significant trigger efficiency improvements for decays with low p_T tracks
- Further improvements for Run II