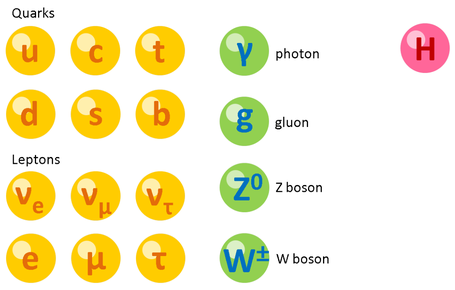
$\tau \to 3\mu$ in Run-1 with the ATLAS detector

Matteo Bedognetti on behalf of the ATLAS Collaboration
Dutch National Institute for Subatomic Physics

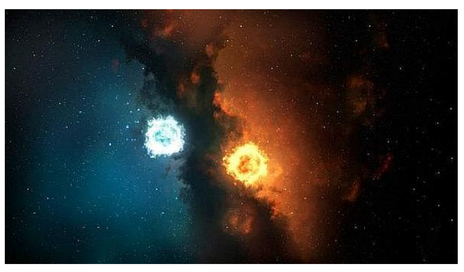
Atlas Collaboration - Eur. Phys. J. C76, no. 5 (2016) - arXiv:1601.03567

The SM and cLFV

- The Standard Model (SM) of particle physics is an incomplete description: e.g. Dark Matter, gravity, the correct scale of Dark Energy are a few of the phenomena that are not accounted for in it. Thus we search for Physics Beyond the SM (BSM).
- In the SM only leptons from the neutral sector mix, hence any observable effect of Lepton Flavour Violation amongst charged leptons (cLFV) would be BSM.
- cLFV may be linked to the origin of the matter-antimatter asymmetry observed in the universe (Leptogenesis).



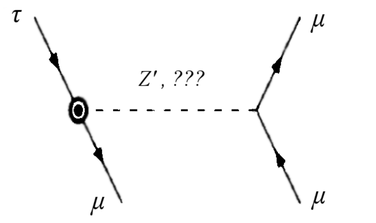
Fundamental particles and force carriers in the SM [a]



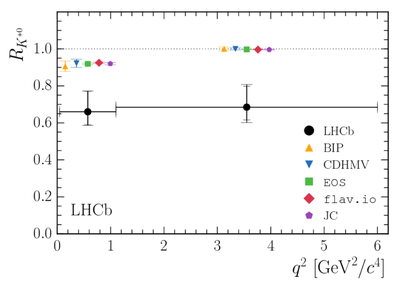
An artist's impression of matter and antimatter [b]. Our universe largely matter dominated: what physics determined this imbalance with respect to antimatter?

The Process and State of LFV Searches

- We performed a model-independent search for $\tau \to 3\mu$ decays with 20.3 fb^{-1} of $\sqrt{s} = 8$ TeV data, motivated by the awareness that any observation of such cLFV decay would indicate physics BSM.
- Non-minimal models extending the SM can predict rates for $\tau \to 3\mu$ presently accessible at experiments. Such models include: Type-III Majorana models for neutrino mass generation [1], triple Pati-Salam (PS^3) models [2] EW extensions of the SM [3] or even multiple-Higgs doublet models [4].
- cLFV may be closely connected to possible BSM in lepton non-universality hints seen at LHCb [5] [6].



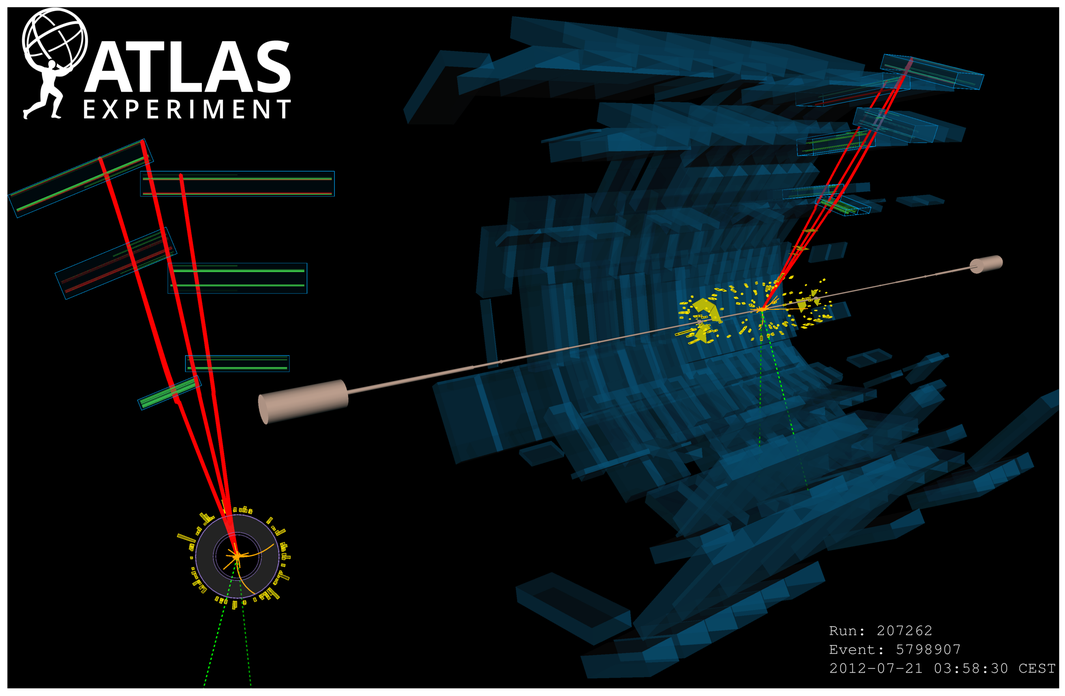
An example of how a BSM diagram for $\tau \to 3\mu$ could look



Deviations from the SM predictions for $R(K^*)$ observed at LHCb [5]

At ATLAS

- Proton-proton collisions make it a very busy environment, especially due to pile-up. We select $\tau \to 3\mu$-like events amongst millions others, on the basis of the outgoing muons.
- This analysis is proof of the capability of ATLAS to perform such challenging searches.

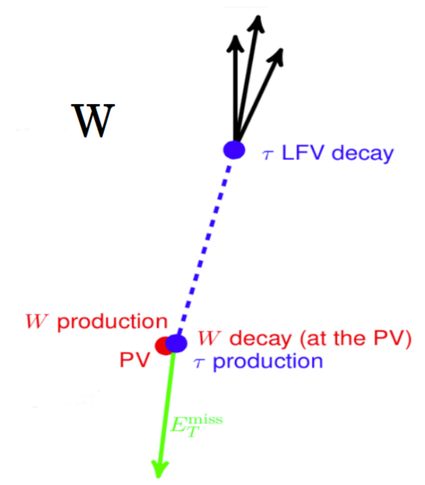


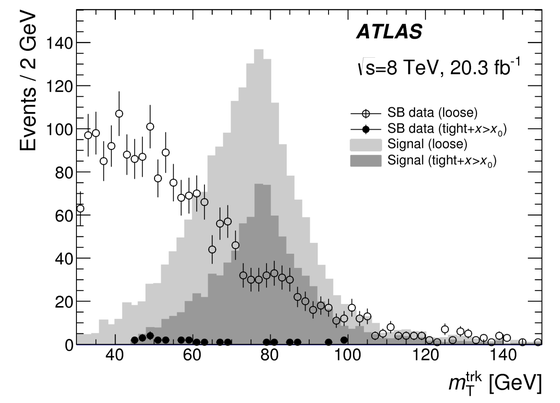
Event display of the single three-muon event passing the complete selection for this analysis; its topology is very similar to a W-originated $\tau \to 3\mu$ event.

The Channel

The analysis targets τ produced in the channel $W \to \tau\nu$:

- Energetic and isolated muons, as well as a characteristic energetic neutrino emitted in the opposite direction. Both are good for identification.

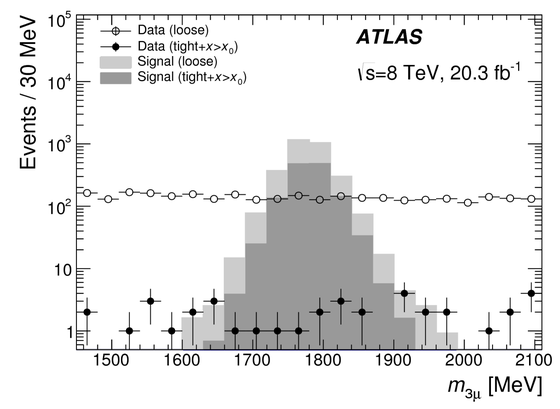




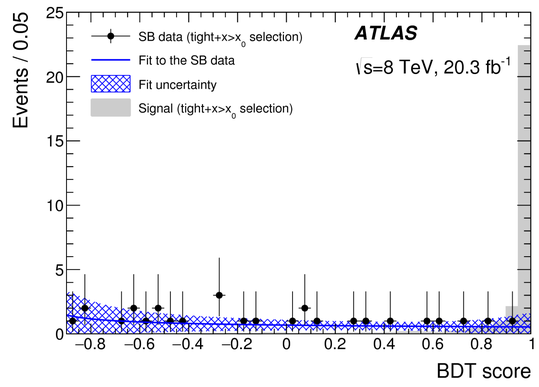
Transverse mass distribution of data-derived background events and simulated signal events at various selection stages. Simulated events are normalized to number of loose-selection background events.

Experimental Technique

- Key is the flatness of the background distribution for invariant masses of three muons (around 1.8 GeV)
- A few background events survive the final selection, thus three progressive stages of tightening are used: two cut-based (loose and tight) selections and a muti-variate selection
- After stringent selections we determine the allowed signal strength from the number of events we observe in a 128 MeV window around M_τ
- The estimation of background events is an extrapolation from side-bands
- Simulation is used to describe $\tau \to 3\mu$ signal
- A final selection is performed through Boosted Decision Trees, trained on the basis of track and vertex likelihoods and missing energy related quantities



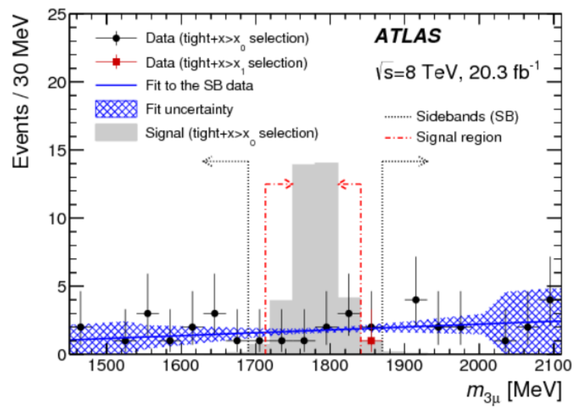
Invariant mass of muons distribution. Same formatting as figure above. The figure visualizes the flatness of the backgrounds.



Response of the multivariate classifier for simulated signal and backgrounds. The blue band displays the uncertainty from the regularization of the number of expected background events.

The Result

- With 20.3 fb^{-1} of data we set a limit on the branching ratio (BR) of $\tau \to 3\mu$ of $3.7x10^{-7}$ at 90% confidence level.
- Run-2 data provides $\sim 7\times$ luminosity, with almost $2\times$ production cross section for $W \to \tau\nu$ events, and trigger efficiency boost. Further gain may come from the inclusion of τ from heavy meson decays.
- For the future, HL-LHC (High-Luminosity LHC) may enable significant reach for this analysis.



Result of the Run-1 analysis. Background data events after unblinding (black) and after the successive application of classifier's selection (red).

References: [1] Nomura and Okada 2018, DOI:10.1016/j.physletb.2018.07.011; [2] Bordone et al. 2018, arXiv:1805.09328; [3] Feruglio et al 2017, DOI:10.1007/JHEP09(2017)061; [4] Zhang et al. 2018, arXiv:1807.00921; [5] LHCb Collaboration 2017, DOI:10.1007/JHEP08(2017)055; [6] Glashow et al. 2014, DOI:10.1103/PhysRevLett.114.091801.
[a] https://www.u-tokyo.ac.jp/content/400021545.jpg, 20/09/2018; [b] https://www.abc.es/Media/201104/26/Antimateria1%20(1)–644x362.jpg, 20/09/2018.

matteo.bedognetti@cern.ch