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Emmy Noether-Programm
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Experimentelle Physik V
Teilchenphysik

LFV searches in tau decays at the LHC

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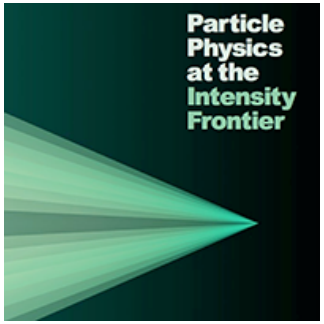


Intensity Frontier Workshop,
Argonne 26.4.2013

Introduction

- LFV searches in tau decays **at the LHC**
  - LHCb recently published the search for $\tau^- \to \mu^-\mu^+\mu^-$ and $\tau^- \to p\,\mu^-\mu^-$ (arXiv:1304.4518)
  - CMS/ATLAS might be able to do $\tau^- \to \mu^-\mu^+\mu^-$, but only pre-data studies are currently public
    → low mass / PT triggers are a challenge at a GPD

- Briefly discuss other tau decay channels in LHCb

- Brief overview on LHCb searches for Lepton Number violation in beauty decays

- Published LHCb results obtained with 1/fb
  → times 3 on tape, extrapolate with future luminosities

LHC(b) long term plan

2009 — ✧ LHC startup, $\sqrt{s} = 900$ GeV

2010–2012 — 50ns

$\sqrt{s}$=7/8TeV; L_{LHCb}= 3-4x10^{32} $cm^{-2}s^{-1}$
→ ~1-2 fb^{-1}/year

$\int L\,dt$ 3.1/fb

2013 — LS1 — Go to design energy, nominal luminosity

2014–2016 — 25ns

$\sqrt{s}$=13/14TeV; L_{LHCb}= 4x10^{32} $cm^{-2}s^{-1}$
→ ≥ 2 fb^{-1}/year

~7/fb

2017–2018 — LS2 — Injector and LHC Phase-1 upgrade to full design luminosity

2019–2021 — 25ns

$\sqrt{s}$=14TeV; L_{LHCb}= 1-2x10^{33} $cm^{-2}s^{-1}$
→ > 5 fb^{-1}/year

50/fb

2022 — LS3 — HL-LHC Phase-2 upgrade, IR, crab cavities?

2023–2030? — ?ns

$\sqrt{s}$=14TeV; L_{LHCb}= ~2x10^{33} $cm^{-2}s^{-1}$

Tau decays at a hadron collider

B factory

- ✗ BaBar and Belle collected $\sim 10^9$ τ pairs
- ✓ $e^+e^- \to \tau^+\tau^-$ extremely clean and nice to investigate
- ✓ tag with opposite site τ possible

LHC

- ✓ LHCb collected $\sim 8 \times 10^{10}$ τ in the detector acceptance in 2011
- ✗ $pp \to \tau + \mathcal{O}(100)$ more particles challenging
- ✗ no "production traces" in $D_s \to \tau\nu_\tau$
- ✗ charm decays with missing particles very similar to τ signatures

Remedies

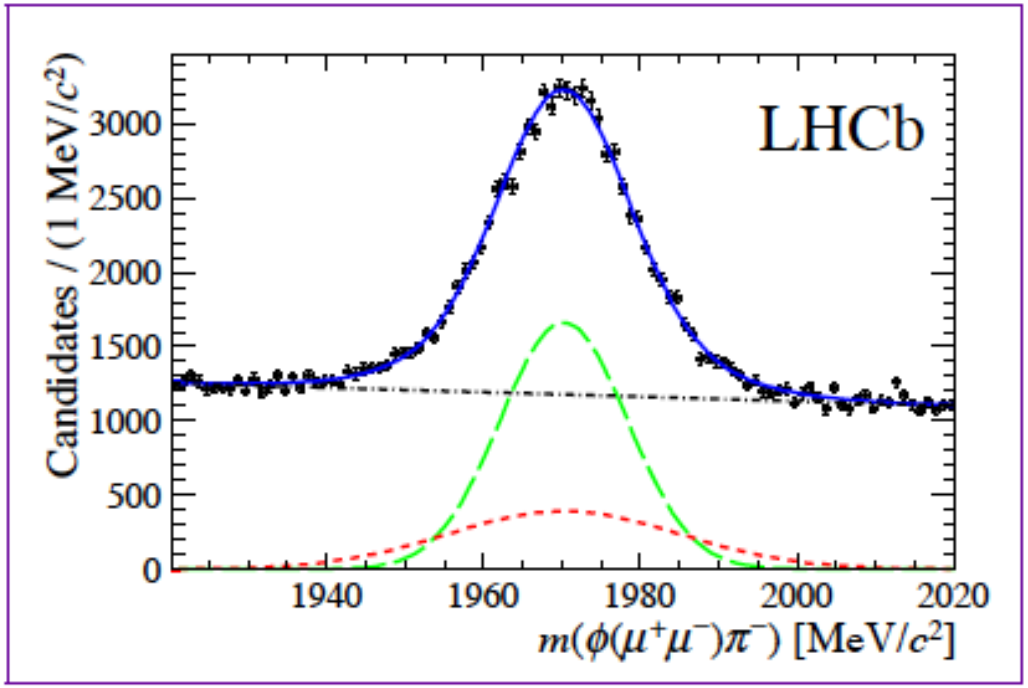
- $\Rightarrow$ tight requirements to event selection
- $\Rightarrow$ develop strategies to suppress τ-less events
- $\Rightarrow$ understand τ production in detail

Search for $\tau^- \to \mu^-\mu^+\mu^-$ and $\tau^- \to p\,\mu^-\mu^-$

arXiv:1304.4518

- 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

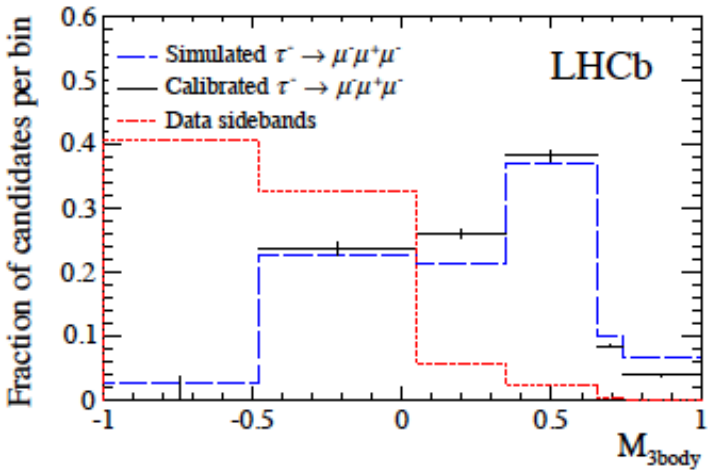
- Different selection for normalization channel for $\tau^- \to \mu^-\mu^+\mu^-$ and $\tau^- \to p\,\mu^-\mu^-$
- $D_s \to \phi(\mu^-\mu^-)\,\pi^-$ candidates
  - $\tau \to \mu\mu\mu$: 48 076 ± 840
  - $\tau \to p\mu\mu$: 8 145 ± 180



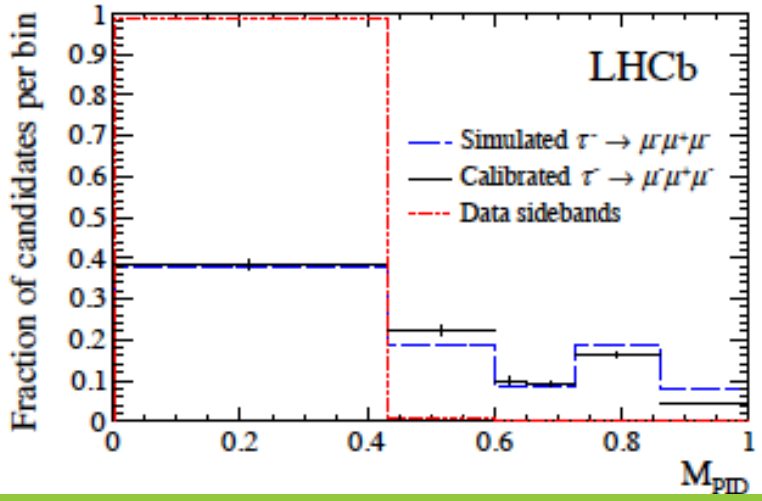
Signal likelihoods

Two multivariate classifiers, $\mathcal{M}_{3\text{body}}$ and $\mathcal{M}_{\text{PID}}$ ($\tau \to \mu\mu\mu$ only)

- $\mathcal{M}_{3\text{body}}$ includes: vertex and track fit quality, vertex displacement, vertex pointing, vertex isolation and τ p_T
- Trained on signal and background MC
- Response calibrated on $D_s^- \to \phi\pi^-$ data data-MC differences



- $\mathcal{M}_{\text{PID}}$ includes: information from RICH, ECAL, HCAL and muon chambers
- Trained on signal and background MC
- Calibrated on $J/\psi \to \mu^+\mu^-$ data
- For $\tau \to p\mu\mu$ apply hard PID cuts

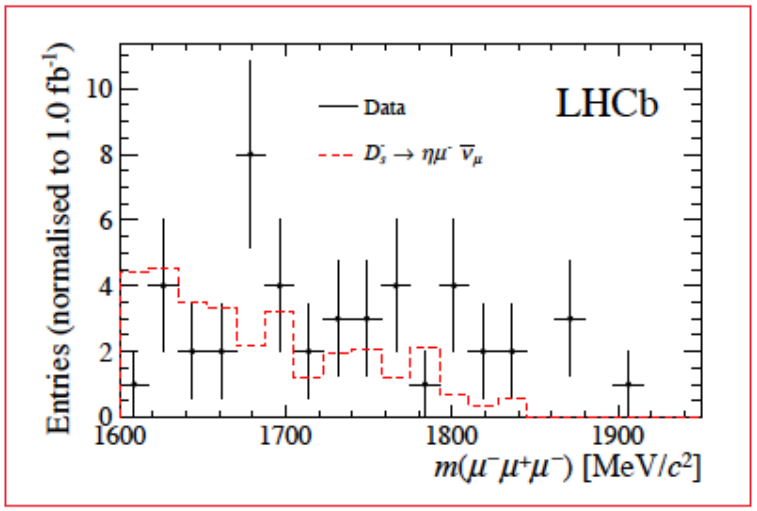


Physical backgrounds

arXiv:1304.4518

For $\tau \to \mu\mu\mu$ most significant peaking background from $D_s^- \to \eta(\mu^+\mu^-\gamma)\mu^-\bar{\nu}_\mu$

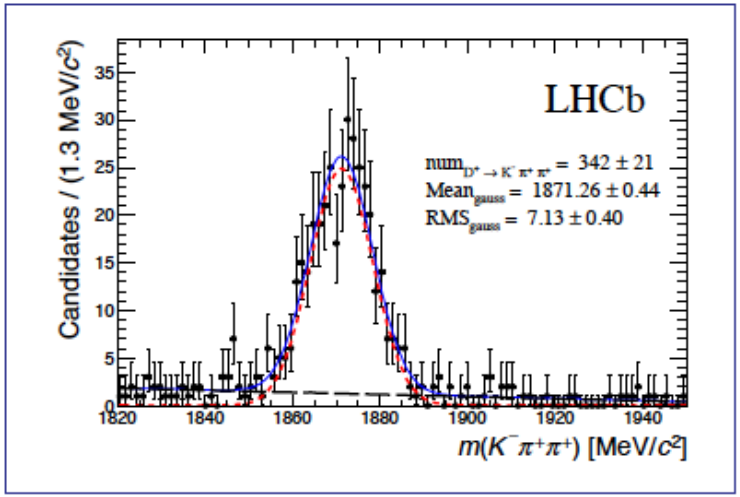
$\to$ 80% removed by a cut on $m_{\mu^+\mu^-} > 450$ MeV/c^2



Large mis-ID contribution from $D^+ \to K^-\pi^+\pi^+$ decays in lowest $\mathcal{M}_{\rm PID}$ bins

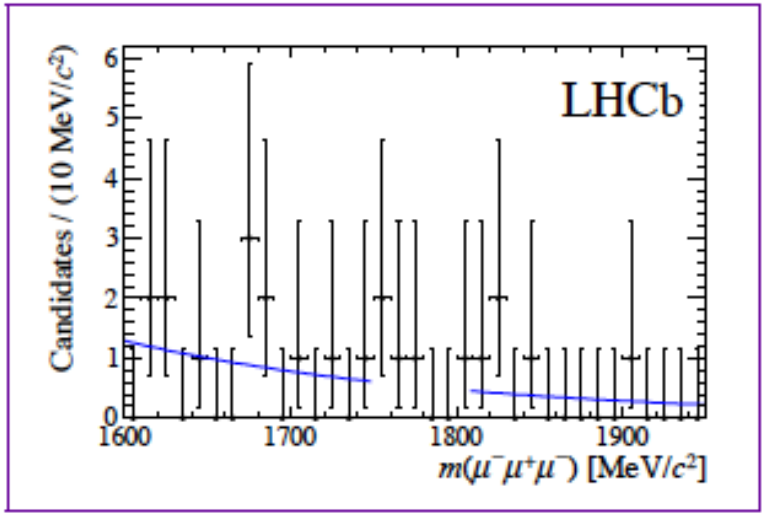
$\to$ Removed by excluding the lowest $\mathcal{M}_{\rm PID}$ bins

No peaking backgrounds expected for $\tau \to p\mu\mu$

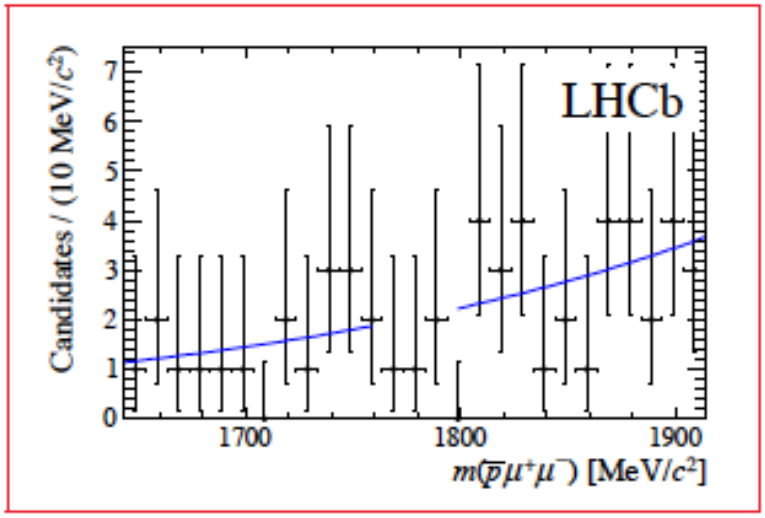


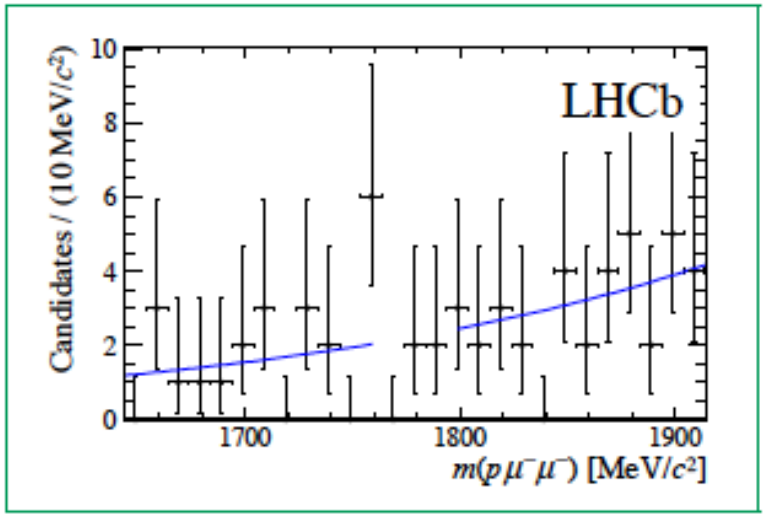
Combinatorial background determination

arXiv:1304.4518



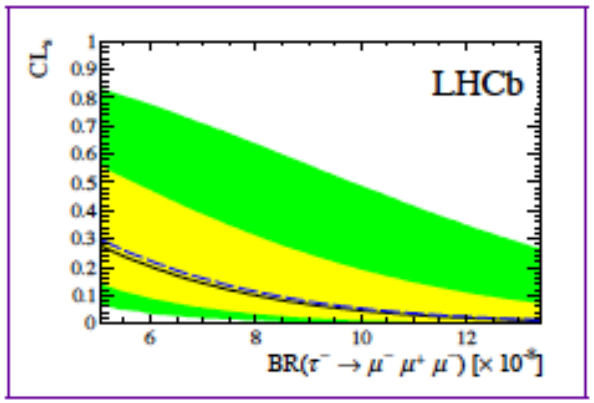
- Background estimate in signal region from data sidebands
- 4 highest bins merged for $\tau^- \to \mu^-\mu^+\mu^-$ (left), and 2 highest bins merged for $\tau^- \to \bar{p}\mu^+\mu^-$ (bottom left) and $\tau^- \to p\mu^-\mu^-$ (bottom right)

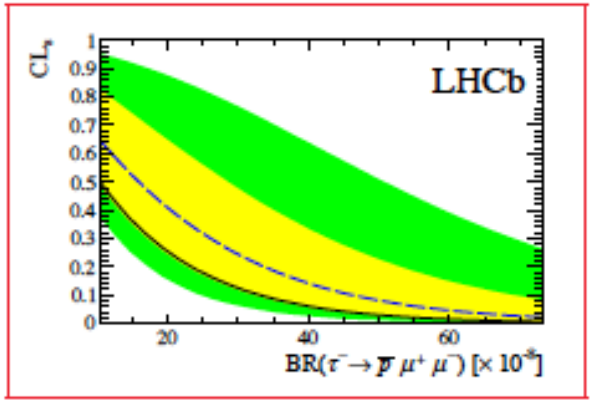


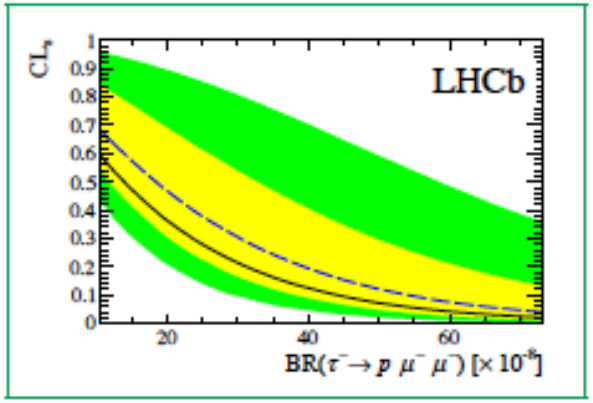


Results

arXiv:1304.4518







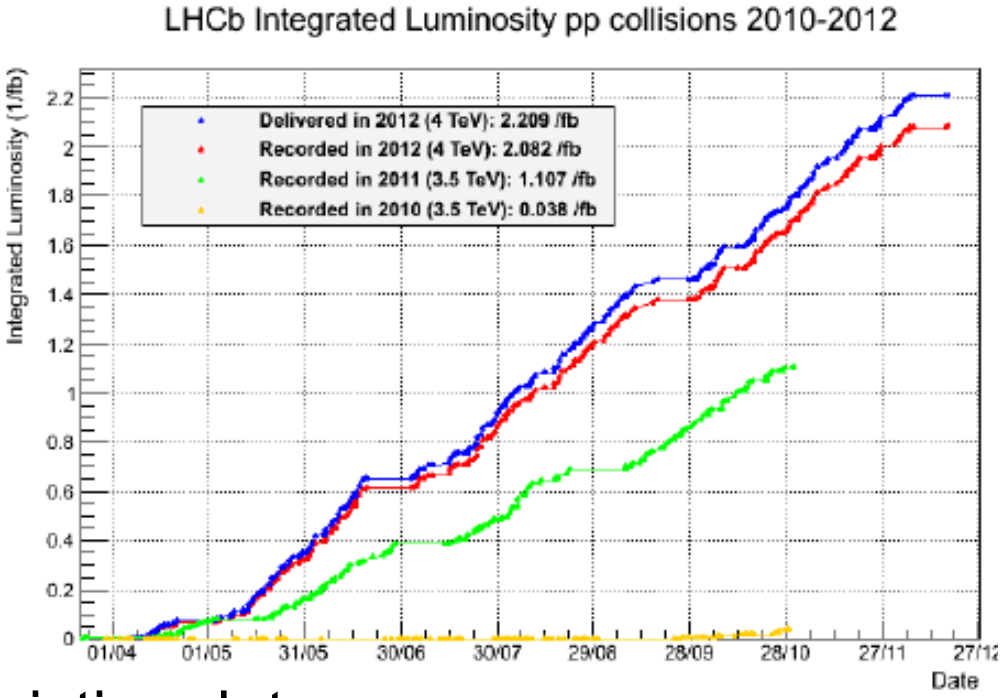
- Limit calculated using CL_s method
- First τ LFV results at a hadron collider!

Channel	Expected (90% CL)	Observed (90% CL)
$\tau^- \to \mu^- \mu^+ \mu^-$	8.3×10^{-8}	8.0×10^{-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}

c.f. BF($\tau^- \to \mu^- \mu^+ \mu^-$) $\leq 2.1 \times 10^{-8}$ at 90% CL from Belle

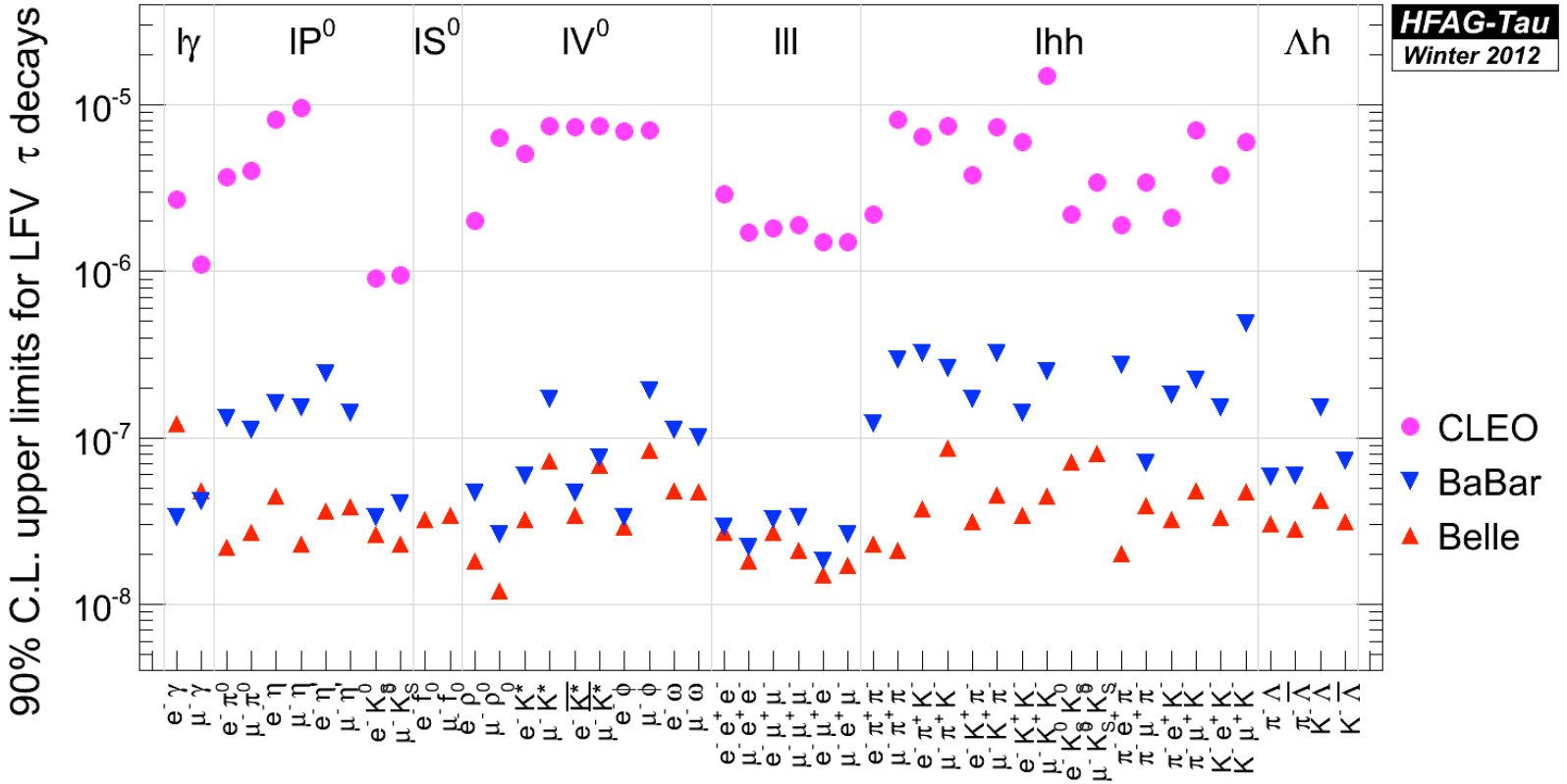
Outlook: $\tau^- \rightarrow \mu^-\mu^+\mu^-$

- Data used: 1/fb @ 7TeV
- On tape: additional 2.1/fb @ 8TeV
  - Cross section scales ~8/7 (+14%)
  - Improved trigger for low mass dimuons (+10%)



- Expect a (small) factor 2 purely from statistics with existing data
- Until 2017: expect another ≥7/fb at 13TeV
  - Pure statistics: $\sqrt{(13/8*10/3)}$=~2.3
- Expect to exceed Belle sensitivity by ~2017 **with existing analysis**
- **Excellent prospects for the upgrade (2018++ → xx * 10^{-9}) (also much improved trigger for soft muons)**

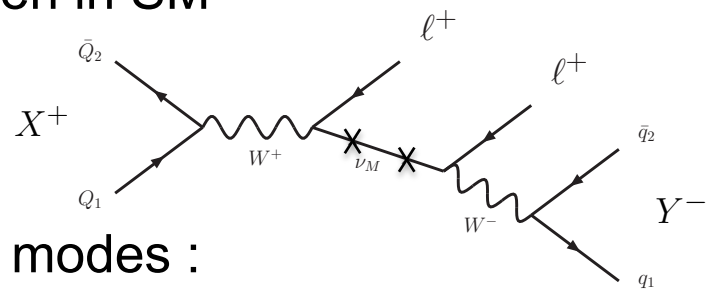
Outlook: other channels



- Charged hadrons LHCb performs almost as well as w/ muons
- Electrons: CDF has a factor ~4 penalty exchanging e by mu → similar for LHCb
- Neutrals in final state: difficult @ hadron collider

LFV in B decays (0.4/fb)

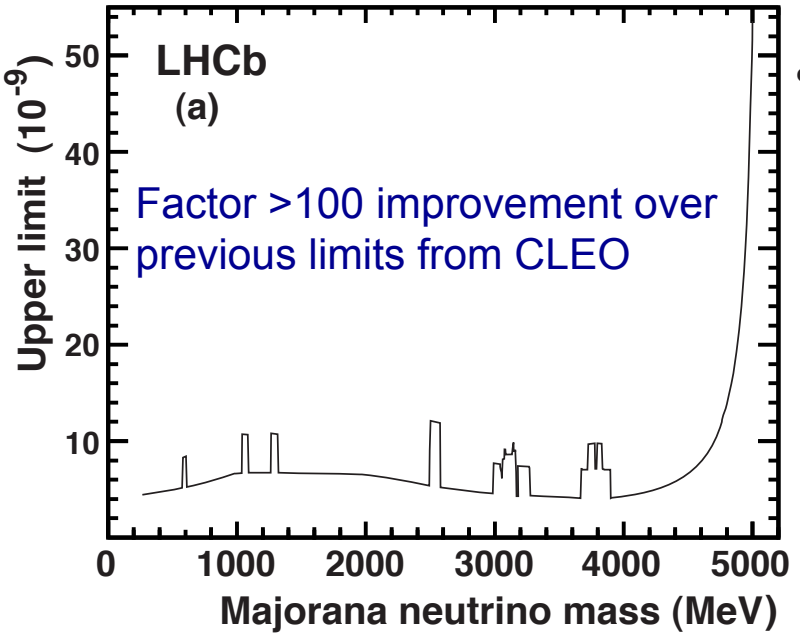
- Decays $B^+ \to h^- \mu^+ \mu^+$ are ($\Delta L=2$) strictly forbidden in SM
  - Sterile Majorana ν of mass O(1GeV/c^2) could enhance branching fraction

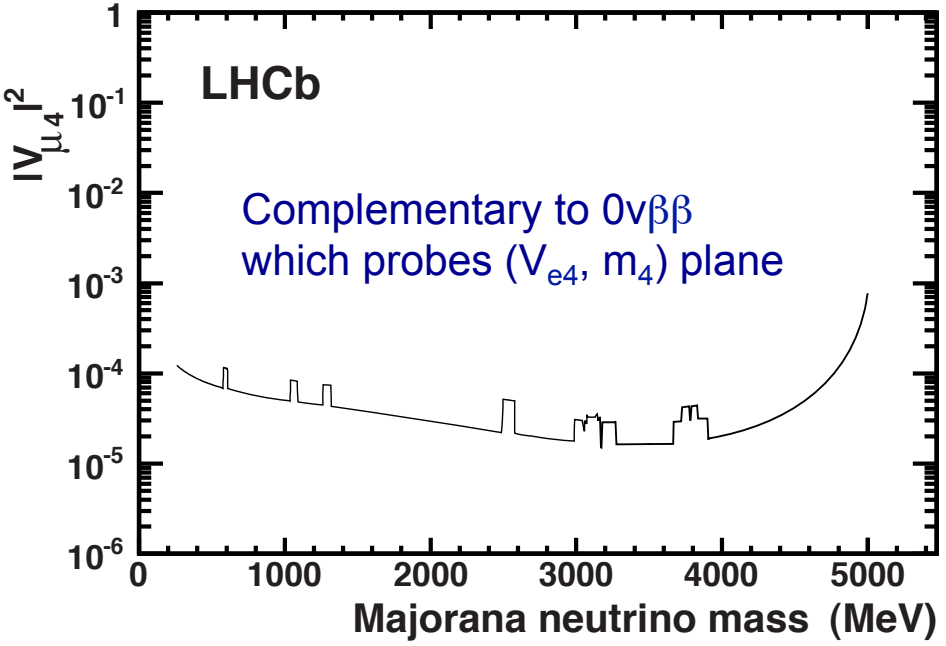


- LHCb search for a wide range of such decay modes :
  $D^- \mu^+ \mu^+$, $D^{*-} \mu^+ \mu^+$, $\pi^- \mu^+ \mu^+$, $D_s^- \mu^+ \mu^+$, $D^0 \pi^- \mu^+ \mu^+$

- No signal found - results for $B^+ \to \pi^- \mu^+ \mu^+$:

[Phys. Rev. Lett. 108 (2012) 101601
arXiv:1201.5600]





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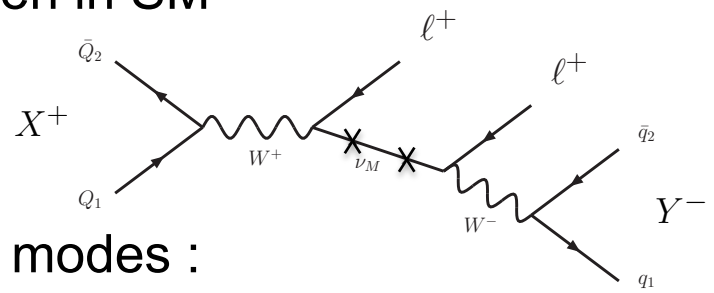

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arXiv:1201.5600]

B decays to

Channel	Observed 95% CL
$K^+ \mu^- \mu^-$	5.4×10^{-8}
$D^+ \mu^- \mu^-$	6.9×10^{-7}
$D^{*+} \mu^- \mu^-$	2.4×10^{-6}
$\pi^+ \mu^- \mu^-$	1.3×10^{-8}
$D_s^+ \mu^- \mu^-$	5.8×10^{-7}
$D^0 \pi^+ \mu^- \mu^-$	1.5×10^{-6}

Conclusions

- LHCb has made a range of LFV and BNV measurements
- First τ LFV result at a hadron collider with $\tau^- \to \mu^-\mu^+\mu^-$
  $\to$ expect to reach/exceed B-factory limits in coming years
- First ever constraints on $\tau^- \to \bar{p}\mu^+\mu^-$ and $\tau^- \to p\mu^-\mu^-$
- Multiple world's best limits on LFV *B*-decays
  $\to$ improved by as much as $\times 100$

LHCb has already made significant contributions to the searches for LFV and BNV

Interesting prospects towards 2018 (and before)