Search for Lepton Flavor Violation in the decay $\tau \to \mu\mu\mu$ at LHCb

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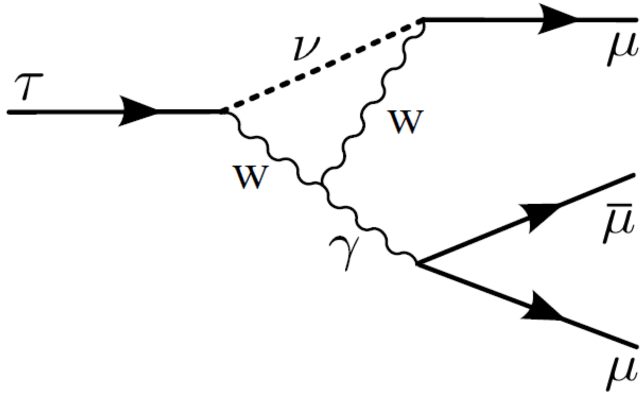
Overview

- Introduction to Lepton Flavor Violation
- Tau-Production at LHCb
- Monte-Carlo study of the $\tau \rightarrow \mu\mu\mu$ decay
  - Signal selection
  - Trigger efficiencies
- Upper limit estimation for the branching fraction
- Conclusion

Introduction

Lepton Flavor Violation (LFV) is forbidden in the Standard Model!

possible with massive neutrinos
but suppressed (GIM)
⟹ BR ~ $O(10^{-50})$

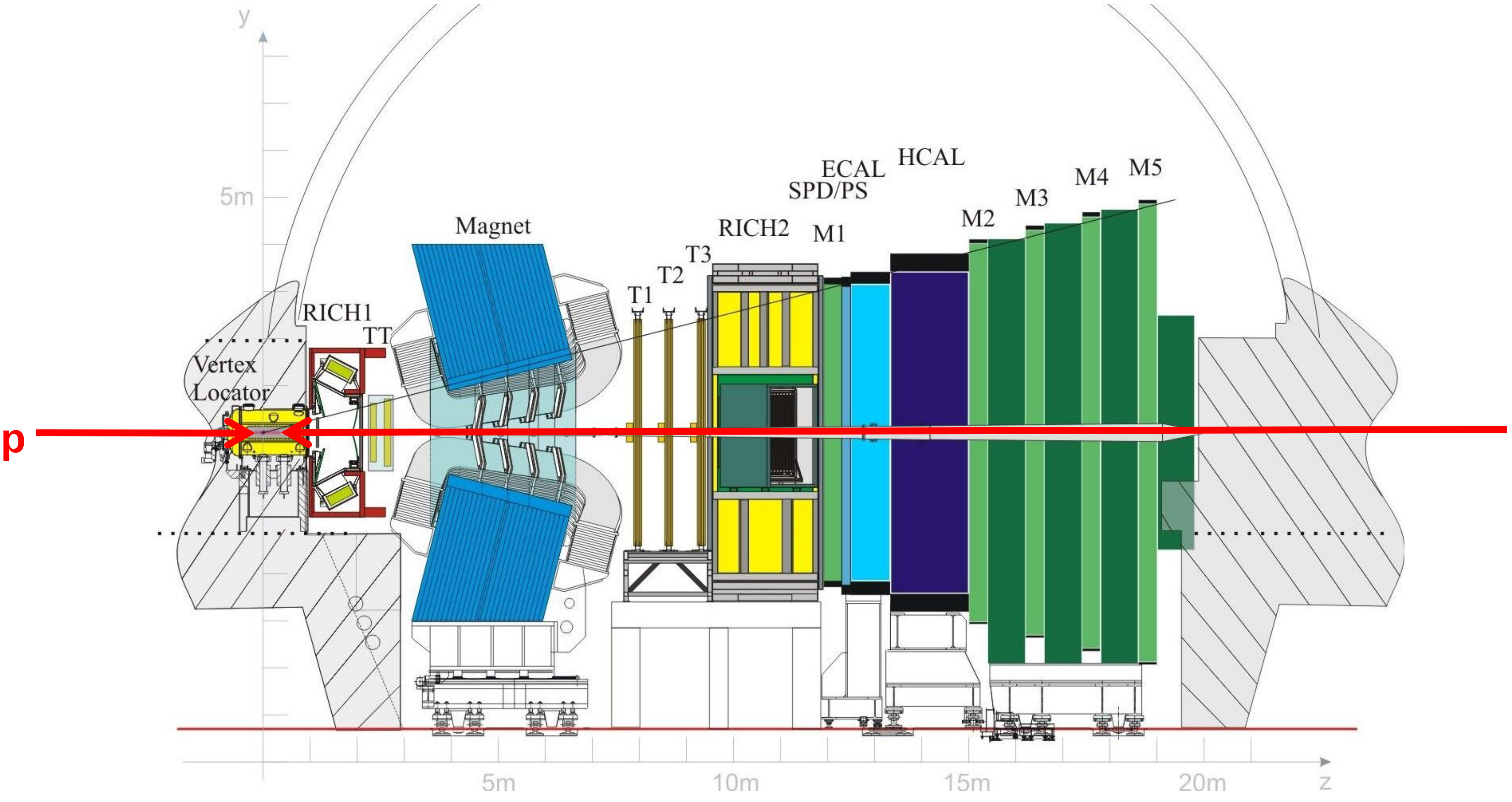


A lot of new physics models predict LFV BR up to $O(10^{-8})$

Any measurement of LFV indicates "new physics"

Current upper limit: $BR(\tau \to \mu\mu\mu) < 3.2 \times 10^{-8}$ (Belle 08)

Tau Production @ LHCb



LHCb is a forward-spectrometer!

Tau Production @ LHCb

Main production channels for Taus:

- Hadrons with b Quark $\sigma_{b->\tau} = 59\mu b$
- Hadrons with c Quark $\sigma_{c->\tau} = 51\mu b$

$$\sigma_{total} = 110\mu b$$

Tau source	Decay channel	Fraction of all taus
$D^{+/-}$	*prompt* $D^{+/-}$ *or* $D^{*+/-}$ *from any* B *hadron*	1.4% 0.5%
$D_s^{+/-}$	*prompt* $D_s^{+/-}$ *or* $D_s^{*+/-}$ *from any* B *hadron*	44.5% 16.4%
$B^{+/-}$	prompt $B^{+/-}$	15.3%
$B^0 / \overline{B}^0$	prompt $B^0 / \overline{B}^0$	15.2%
$B_s^0 / \overline{B}_s^0$	prompt $B_s^0 / \overline{B}_s^0$	4.4%
$\Lambda_b^0 / \overline{\Lambda}_b^0$	prompt $\Lambda_b^0 / \overline{\Lambda}_b^0$	2.4%

Tau Production @ LHCb

Expected number of τ produced in 1 year at an integr. lumi of 2fb^{-1} :

$$110\mu b \times 2\text{fb}^{-1} \times 0.27 \Longrightarrow \underline{\mathrm{N}(\tau) = 5.9 \times 10^{10}}$$

Acceptance (τ within the detector): ~27%

Good opportunity to study rare tau decays!

Monte-Carlo Analysis

$\tau \to \mu\mu\mu$ Signal

➡ data sample with ~50k events in the detector acceptance
generated with phase space model
corresponds to $\sim 53\,\mathrm{fb}^{-1}$ $(BR = 3.2 \cdot 10^{-8})$

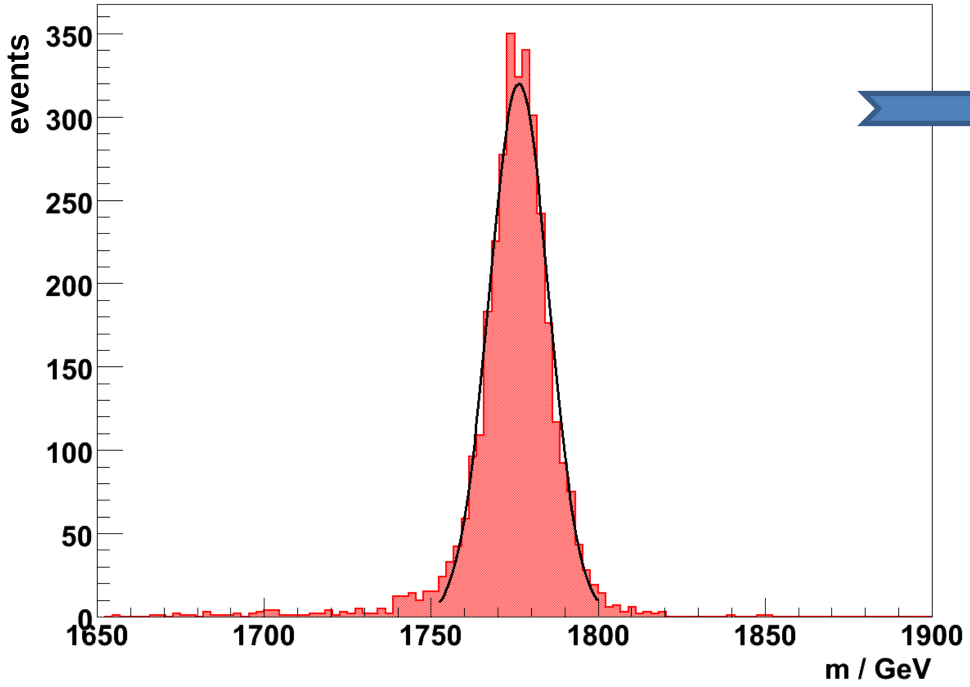
Background

3 Categories for BG muon combination:
- real muons from cascade B- and D-decays
- false reconstructed muons from “ghost” tracks
- misidentification due to pions & kaons

➡ inclusive bb -> dimuon sample
~26M events, corresponds to $5.3\,\mathrm{pb}^{-1}$

Signal selection

Mass distribution for reconstructed $\tau \rightarrow \mu\mu\mu$ events



single Gauss-fit:
resolution of ~9 MeV

Mass window Δm = +/- 30MeV

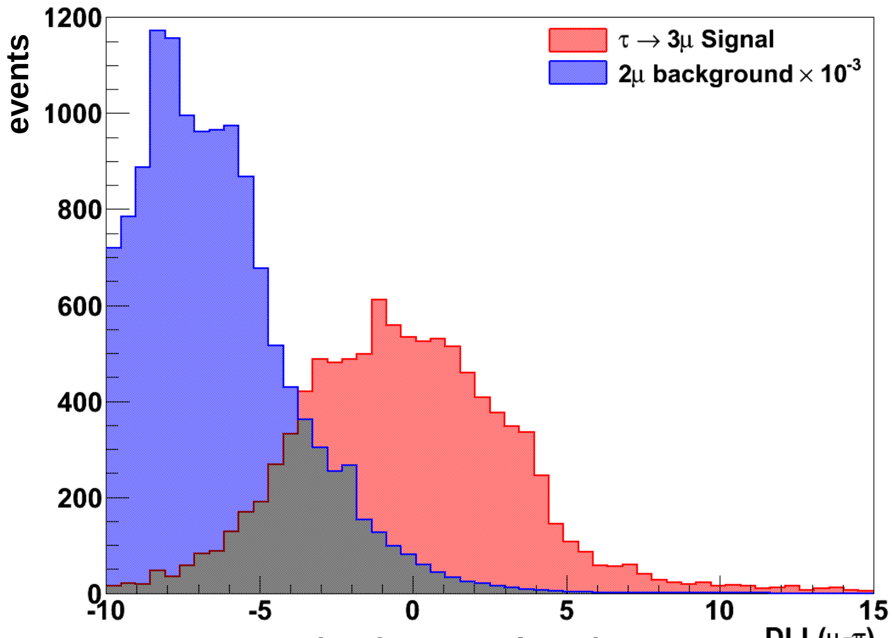
for background estimation:
Δm = +/- 120MeV

Signal selection

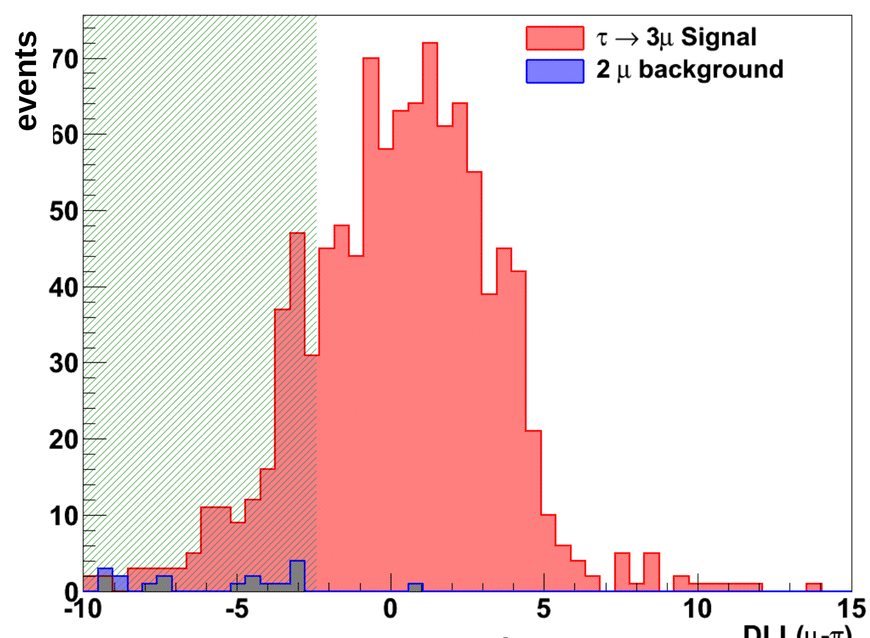
Particle identification

Example: muon misidentification by pions

discriminating variable DLL (delta log likelihood) for worst identified muon



before selection

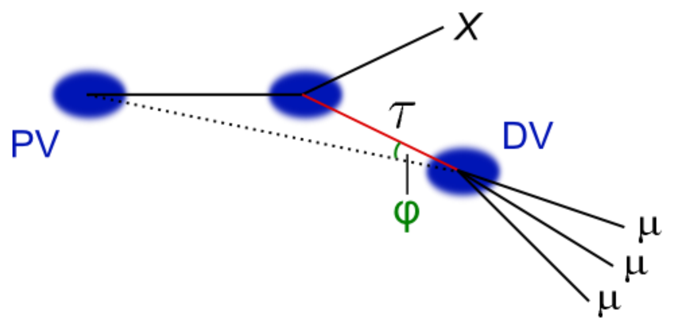


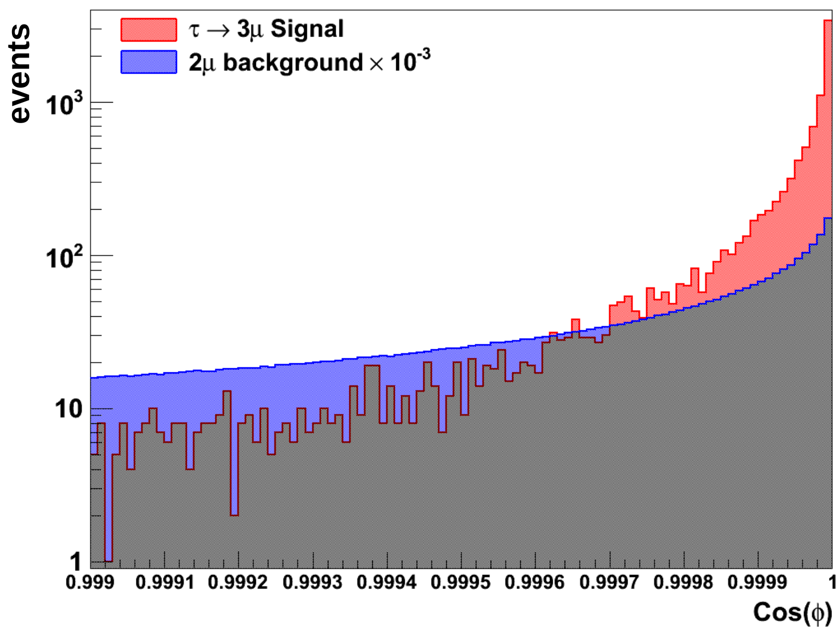
N-1 plot

Signal selection

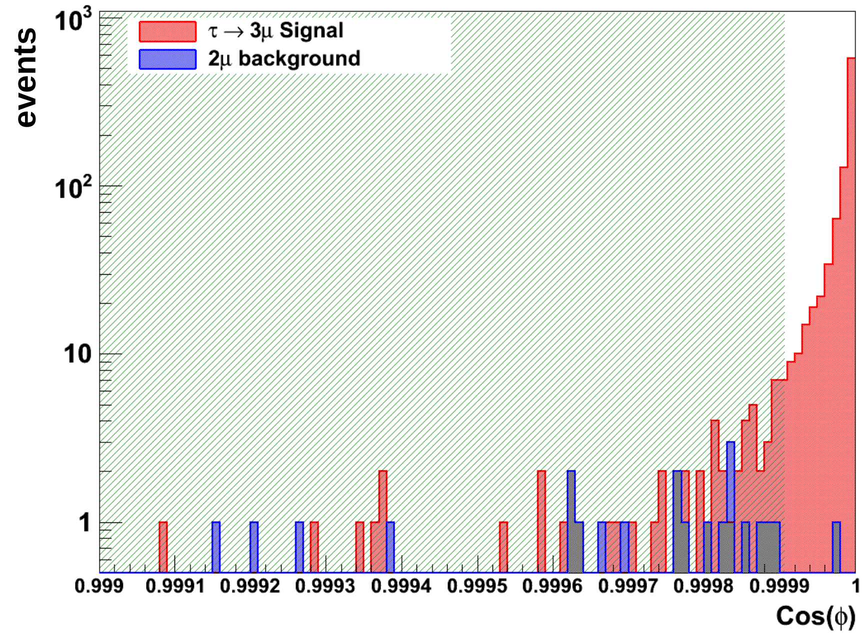
Tau flight direction

→ discriminating variable cos(φ)





before selection



N-1 plot

Signal selection

	Cut variable	Signal rejection (N-1)	BG rejection (N-1)
Muon kinematic & topology	min-Pt(μ) > 0.35 GeV	3.4%	50.0%
	max-Pt(μ) > 1.1 GeV	4.5%	75.0%
	min-IPS(μ) > 2.5	15,2%	85.7%
	max-IPS(μ) > 6.0	4.6%	50.0%
	inv. mass(2μ)>240 MeV	0.3%	50.0%
Particle identification	DLL(μ-pi) > -2.5	5.5%	80.0%
	DLL(μ-K) > 6	21.2%	98.1%
	NShared ≤ 2	1.1%	50.0%
	"clonefinder"	4.0%	75.0%
Vertex Quality	DOCA(μ,μ) < 0,065mm	3.1%	66.7%
	Chi^2(tau vtx) < 5.8	9.6%	90.0%
Tau Topology	cos(ϕ) > 0.99991	0.8%	95.5%
	IPS(tau) > 7.0	18.3%	94.4%

Signal selection

After applying all selection cuts:

858 Signal events (30MeV mass window)

⇨ Reconstruction & selection efficiency: $\varepsilon_{total}^{Sig} = \frac{858}{52 \cdot 10^{3}} = 1.39\%$

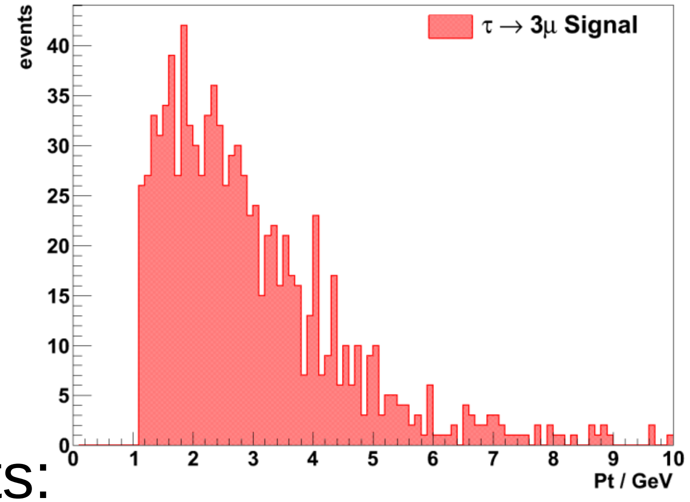
1 Background event (120MeV mass window)

⇨ Reconstruction & selection efficiency: $\varepsilon_{total}^{BG} = \frac{1}{4 \cdot 26.2 \cdot 10^{6}} = 9.5 \cdot 10^{-9}$

Trigger Efficiencies

LHCb trigger system

- Hardware trigger (L0)
  detector readout with 1.1MHz
- Software trigger (HLT)
  confirm L0-decision and reduce rate to 2kHz



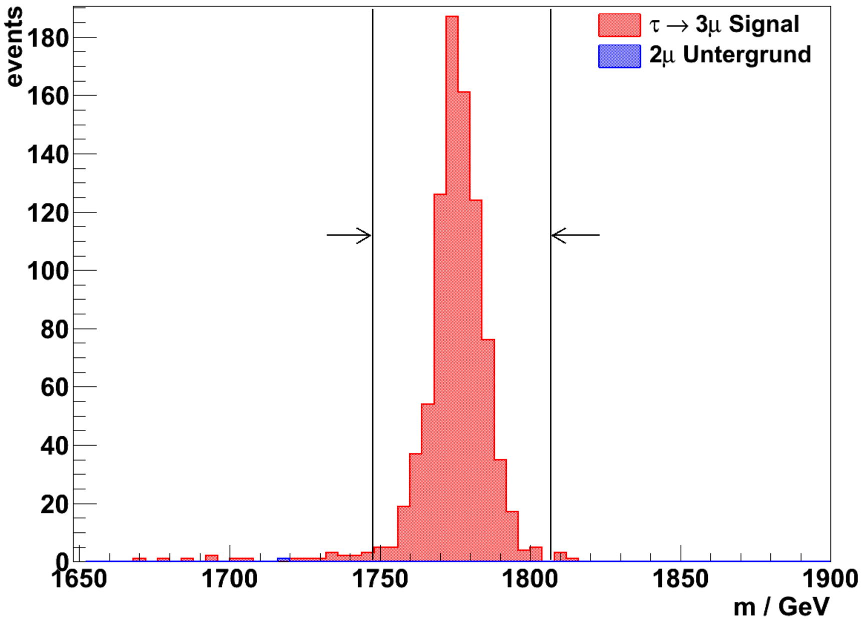
Performance for $\tau \to \mu\mu\mu$ events:

Trigger	Efficiency
L0 trigger	92.7%
HLT	72.2%
HLT + exclusive trigger	86.6%

$\text{di-muon}: |p_t(1)| + |p_t(2)| > 1.5GeV$
$\text{single muon}: p_t > 1.3GeV$

$\text{exclusive } \tau \to 3\mu \text{ trigger}:$
similar to offline selection

Upper limit estimation



<u>in mass window ± 120MeV</u>

1 remaining Background event

3.89 in Poisson limit (90%CL)

scaled for 1 nominal year

<u>in mass window ± 30MeV:</u>

365.7 BG event (in 2fb^{-1})

858 signal events $\varepsilon_{total}^{Sig} = 1.39\%$

upper limit Branching ratio with 2fb^{-1}: $BR \leq 3.9 * 10^{-8}$ (90% CL)

Current upper limit from Belle: $BR \leq 3.2 * 10^{-8}$ (90% CL)

Conclusion

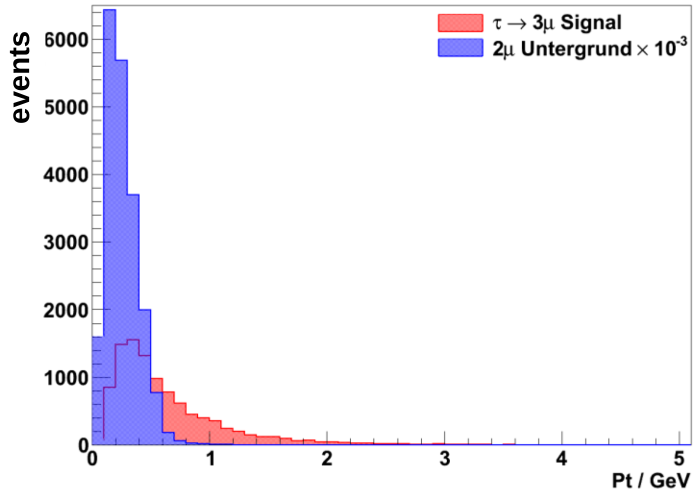
- Sources for τ @ LHCb are B- and D-Mesons
  around $6 \cdot 10^{10}$ τ will be produced in 1 nominal year
- Performed a Monte-Carlo Study
  - built a selection
  - good trigger efficiency for $\tau \rightarrow \mu\mu\mu$ decays
- LHCb could improve upper limit of the BR
  - depending on MC data
  - expect better results with real data

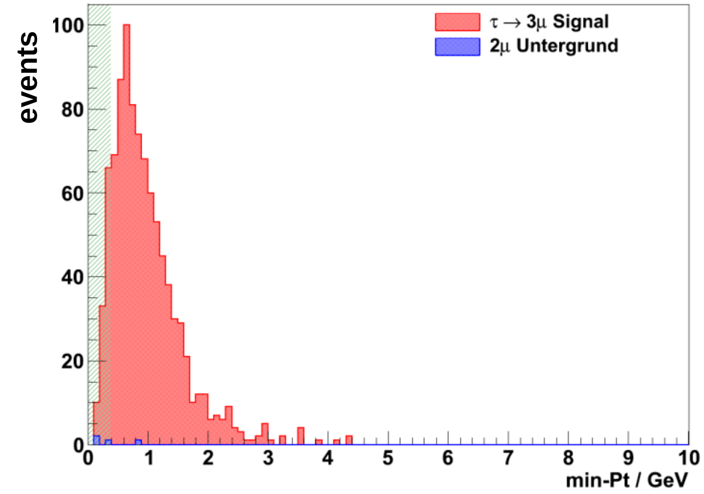
Backup

Backup

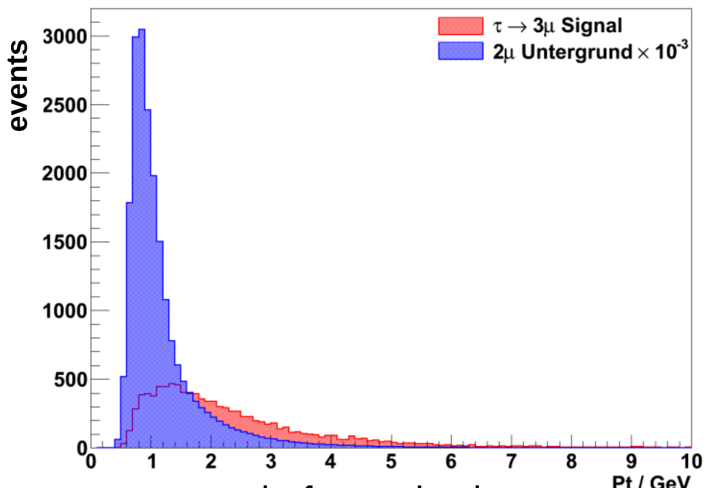
Transverse momentum

smallest Pt
of the 3 muons

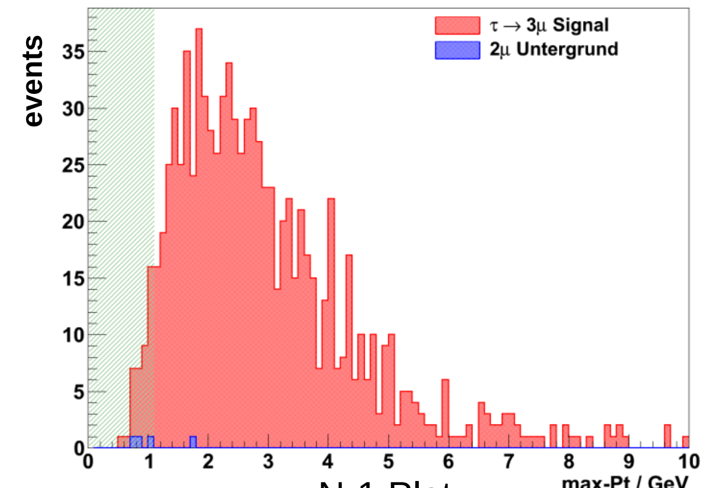




greatest Pt
of the 3 muons



before selection

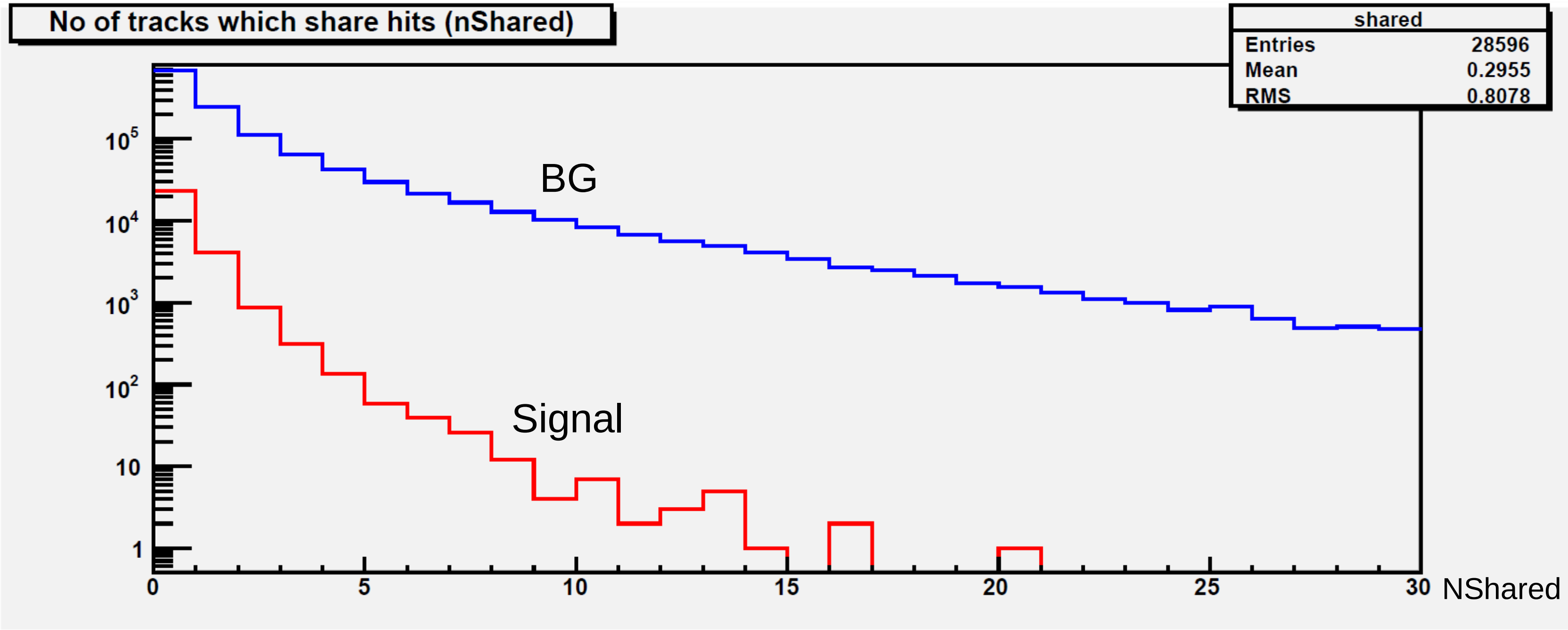


N-1 Plot

Backup

NShared = number of additional tracks, which share hits with this track

small NShared ⟶ high purity & small muon-missidentification rate



⟹ Best result with NShared $\leq$ 2

Muon Clones

Idea:

Some fraction of the background consists of “fake” muons.
These are clones made in the muon system.

Typical event with a “clone”:

μ(1): # of hits = 12
μ(2): # of hits = 12
μ(3): # of hits = 7

identical hits μ(1) & μ(2) = 11
identical hits μ(2) & μ(3) = 0
identical hits μ(1) & μ(3) = 0

⇒ Current criteria for clones:

identical hits of μ(i)&μ(j) = [# total hits μ(i)/μ(j), # total hits μ(i)/μ(j) - 2]

Efficiency of the clonefinder:

For Background:	# of reconstr. events after preselection:	431479
	# of rejected events with a “clone”:	86449 (20%)
For Signal:	# of reconstr. events after preselection:	9532
	# of rejected events with a “clone”:	211 (2,2%)