university of groningen / faculty of mathematics and natural sciences / van swinderen institute for particle physics and gravity

Nikhef

cLFV @ LHCb

Status & Prospects

Gerco Onderwater

on behalf of the LHCb collaboration

SUSY2016, Melbourne, AUS, 3-8 July 2016

Outline

Intro

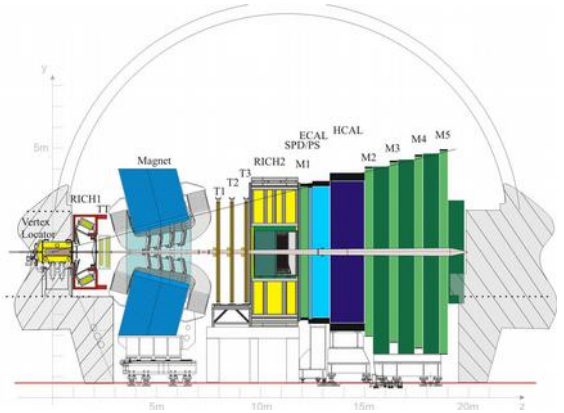
LHCb Experiment

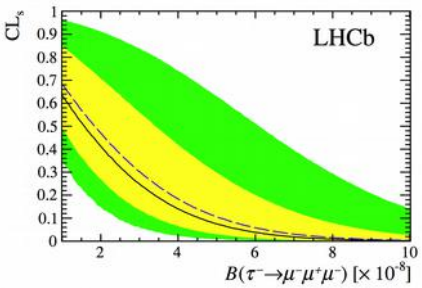
LFV with muons : $\tau \rightarrow \mu\mu\mu$

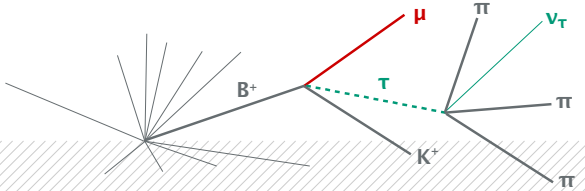
LFV with electrons : $D^0 \rightarrow e\mu$

LFV with taus?

Conclusion







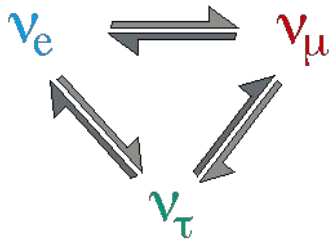
Intro

Standard Model

Remarkably successful,
yet with many unexplained features

Many puzzles, *e.g.* 3 generations quarks & leptons

Rich symmetry-driven phenomenology



Study <u>all</u> generations for full insight

LHCb: can study all three generations

Tensions in Lepton Sector

$B^0 \to D^{(*)} \tau \bar{\nu}_\tau / l \bar{\nu}_l$ **3.9σ** : LHCb + BaBar + Belle

$B^+ \to K^+ \mu\mu$ / ee **2.6σ** : LHCb

Anomalies **b → sll** , esp. P'_5 in **B → K*μμ** @ LHCb

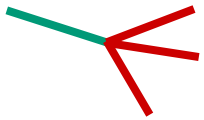
$h^0 \to \mu\tau$ **2.4σ** : CMS

a_μ **2.7σ** : E821

Global fit favors large cLFV

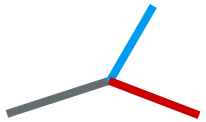
FERMILAB-PUB-16-131-T

Towards studying (c)LFV



Decay $\mu \to e\gamma$, $\mu \to eee$, $\tau \to \mu\mu\mu$, $\tau \to \mu hh$, ...

Conversion $\mu A \to eA$



Production $B_s \to e\mu$, $B \to Ke\mu$, $h^0 \to \mu\tau$, ...

Oscillation $\nu_e \leftrightarrow \nu_\mu \leftrightarrow \nu_\tau$, $M(\mu^+e^-) \leftrightarrow \overline{M}(\mu^-e^+)$

Number violation $0\nu2\beta$, $B^- \to \pi^+\mu^-\mu^-$, ...

Non-Universality $\overline{B}^0 \to D^{*+}\tau^-\overline{\nu}_\tau$ *vs* $\overline{B}^0 \to D^{*+}\mu^-\overline{\nu}_\mu$, ...

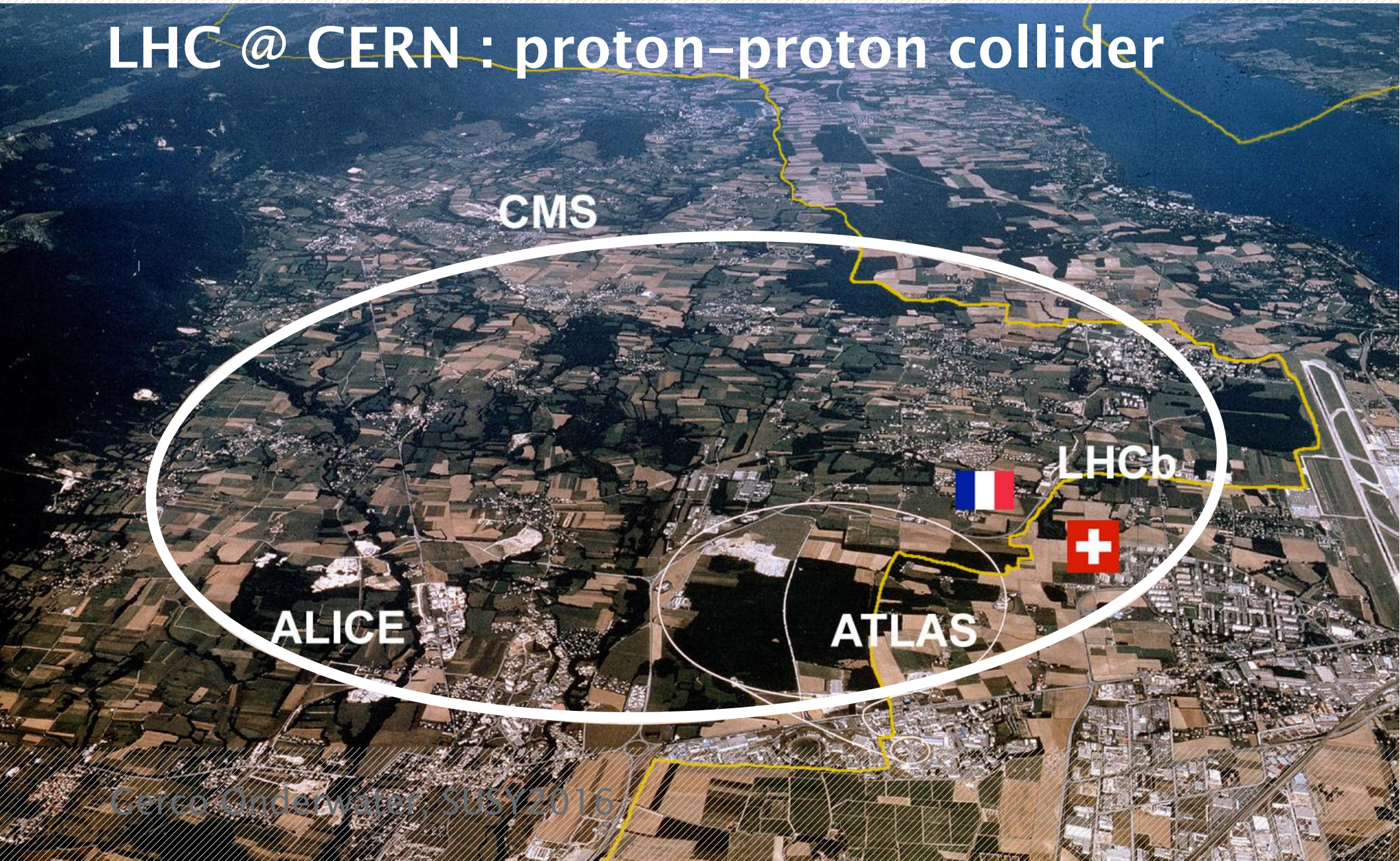
Charges dropped, unless relevant

Recent LHCb results

$D^0 \to e\mu$	PLB 754 (2016) 167	**LFV**	⟸
$\bar{B}^0 \to D^{*+} \tau \bar{\nu}_\tau$ / $\mu \bar{\nu}_\mu$	PRL 115, 111803 (2015)	LNU	
$\tau \to \mu\mu\mu$	JHEP 02 (2015) 121	**LFV**	⟸
$B^+ \to K^+\mu\mu$ / ee	PRL 113, 151601 (2014)	LNU	
$B^- \to \pi^+\mu^-\mu^-$	PRL 112, 131802 (2014)	*LNV*	
$D^+_{(s)} \to \pi^-\mu^+\mu^+$	PLB 724 (2013) 203-212	*LNV*	
$B^0_{(s)} \to e\mu$	PRL 111 (2013) 141801	**LFV**	⟸

LHCb

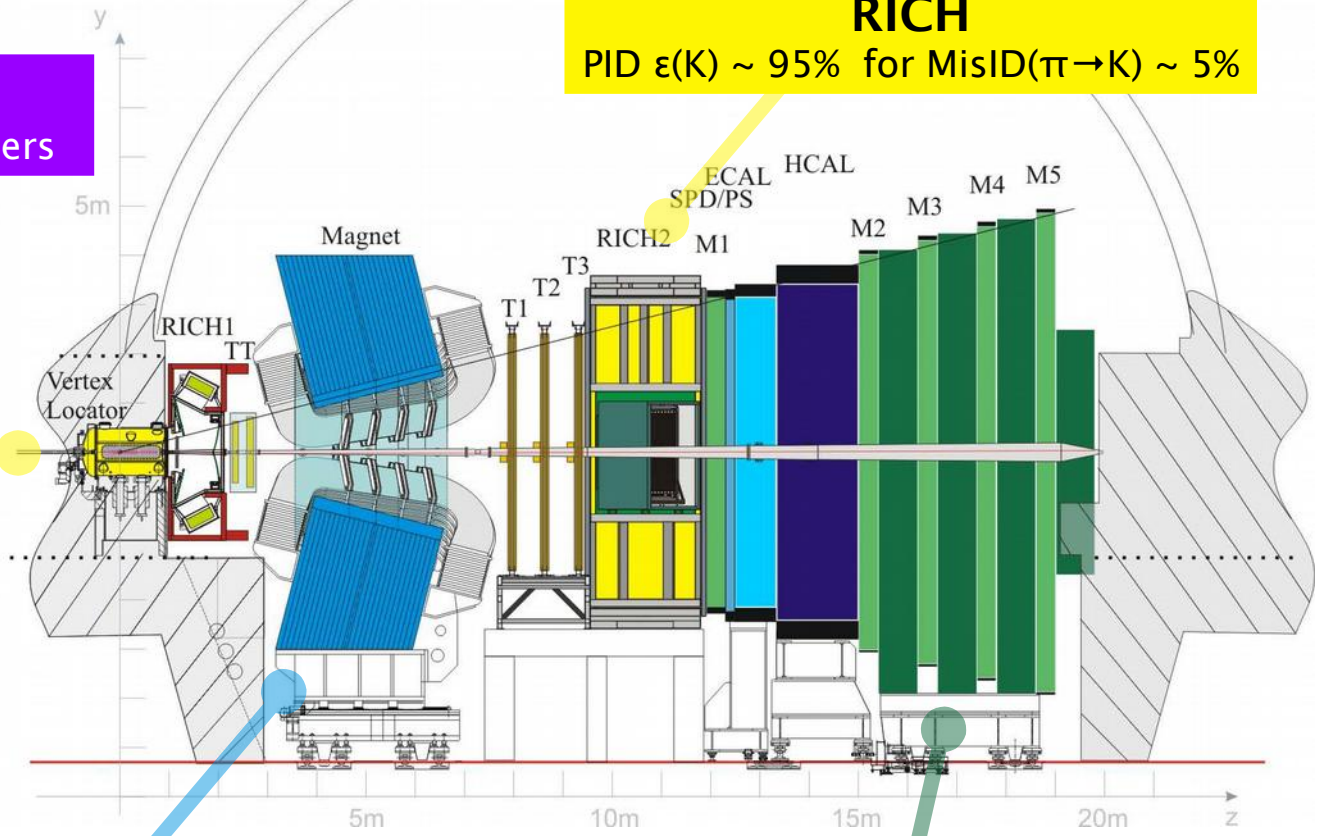
LHC @ CERN : proton-proton collider



LHCb : precision measurement

Trigger
high efficiency *esp.* muon triggers

RICH
PID ε(K) ~ 95% for MisID(π→K) ~ 5%



VELO
IP resolution 15+29/(p_T/GeV) μm

Tracking Δp/p
0.4% @ 5 GeV/*c* – 1.0% @ 200 GeV/*c*

Muon ID
identification ε ~ 97% misID ~ 2%

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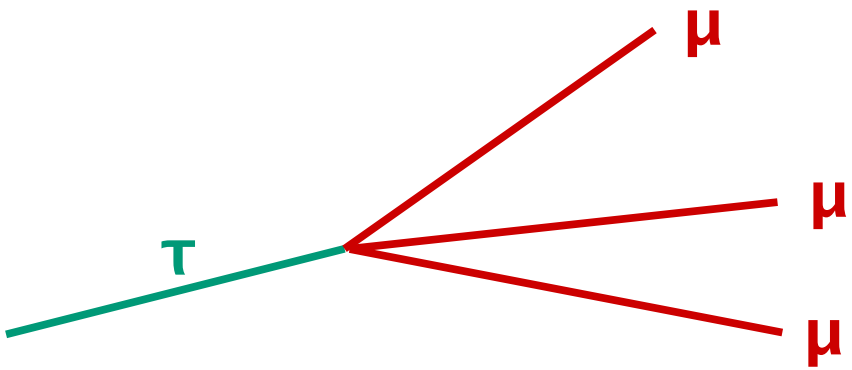
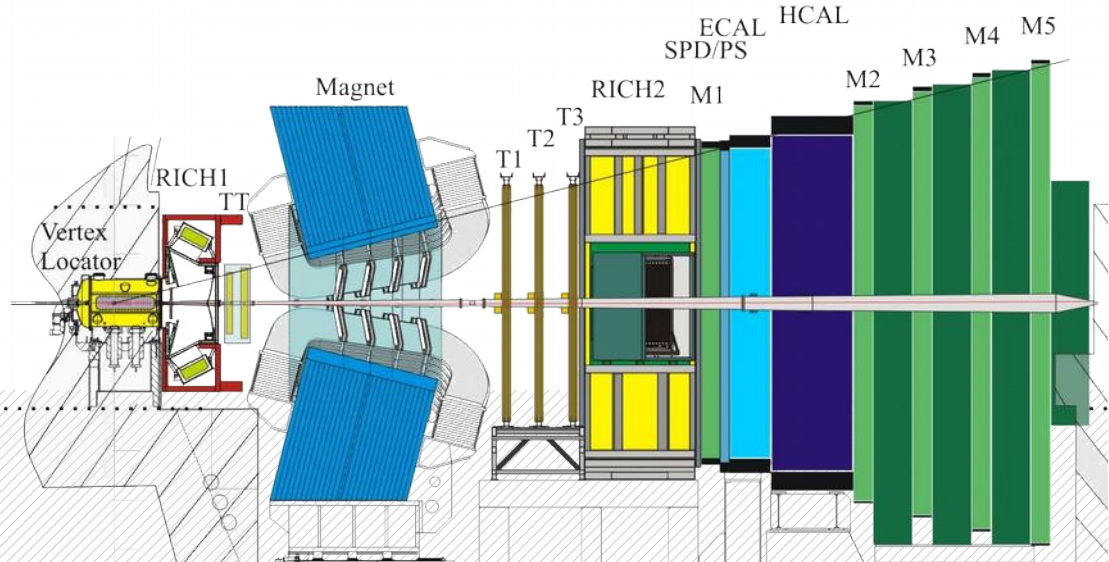
Int. J. Mod. Phys. A 30, 1530022 (2015)

Results


μ
μ
τ
μ

μ detection


ECAL
HCAL
SPD/PS
M5
M4
M3
M2
M1
RICH2
Magnet
T3
T2
T1
RICH1
TT
Vertex
Locator

Challenge : τ decays at hadron collider

B factory

- ✘ Babar & Belle ~3×10^{9} τ−pairs
- ✓ $e^+e^- \rightarrow \tau^+\tau^-$ extremely clean
- ✓ tag with opposite τ possible

LHC

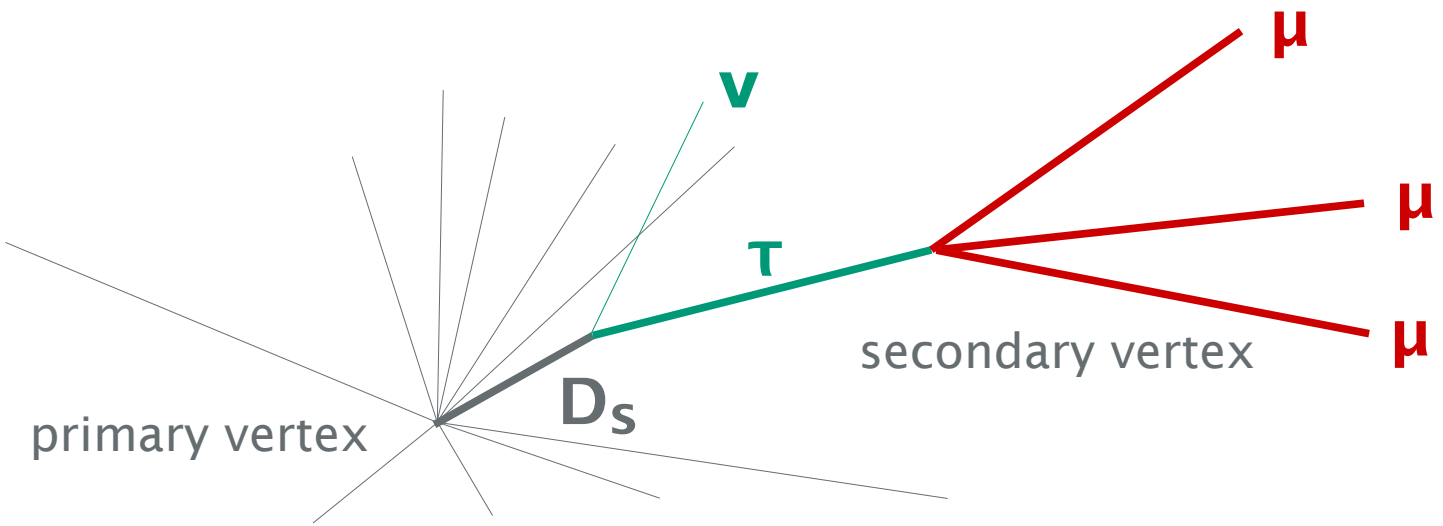
- ✓ LHCb ~3.5×10^{11} τ's in detector acceptance in 2011 & 2012
- ✘ pp → τ + O(100) particles
- ✘ No "production traces" in $D_s \rightarrow \tau\nu_\tau$
- ✘ Charm decay with missing particles similar to τ signature

τ → 3μ search

main tau production via decay of D_s

Approach:

- Use run-I data
- trigger on *muon* and *secondary vertex*
- *multivariate analysis* to discriminate signal and background
- *control sample* for normalization and calibration



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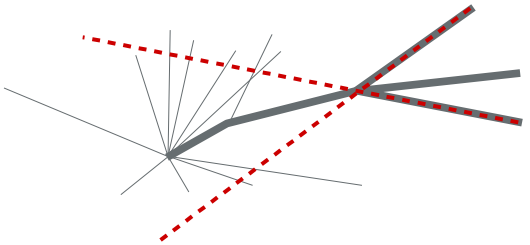
Signal candidate selection

Trigger

- muons not "in beampipe" ($p_T > 1.48$ GeV/c)
- two-, three- or four-track secondary vertex
- at least one particle does not point to collision point

Analysis

- no tracks may point to collision point
- good 3-track vertex
- decay-time compatible with τ decay ($ct > 100$ μm)
- τ momentum must point back to PV



Background elimination

- $|M(\mu^+\mu^-) - M(\Phi)| > 20$ MeV/c^2
- $M(\mu^+\mu^-) > 450$ MeV/c^2
- $M(\mu^-\mu^-) > 250$ MeV/c^2

misID: $D_s^- \to \Phi(\mu^+\mu^-)\pi^-$

missing: $D_s^- \to \eta(\mu^+\mu^-\gamma)\mu^-\bar{\nu}_\mu$

mis-reconstructed: reconstructed from same particle

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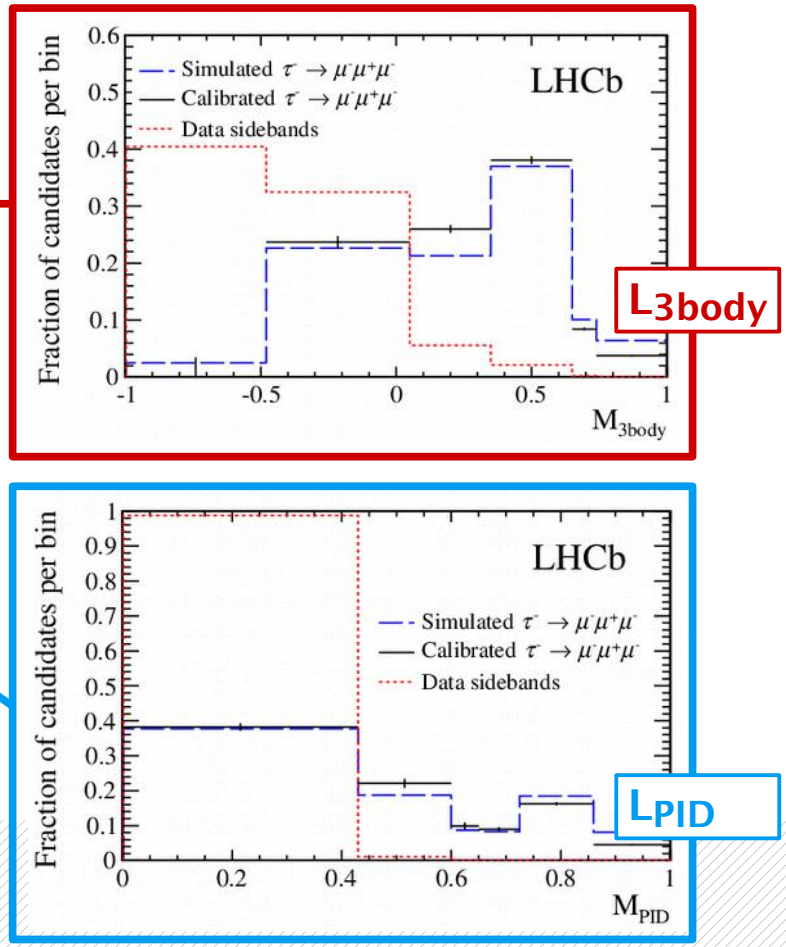
Signal & background discrimination

Three likelihoods to distinguish signal from background

I. L_{3body} : decay topology

II. L_{PID} : μ identification

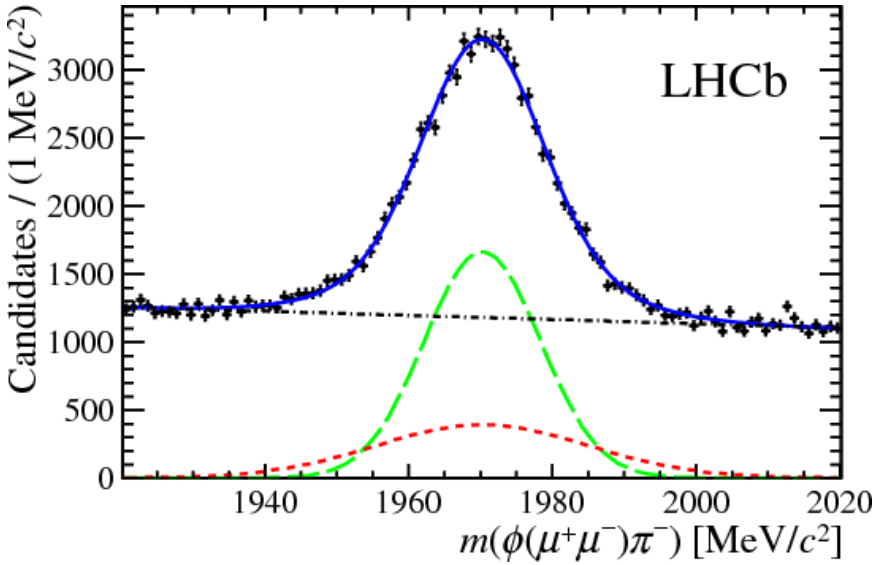
III. $L_{3\mu}$: tau selection

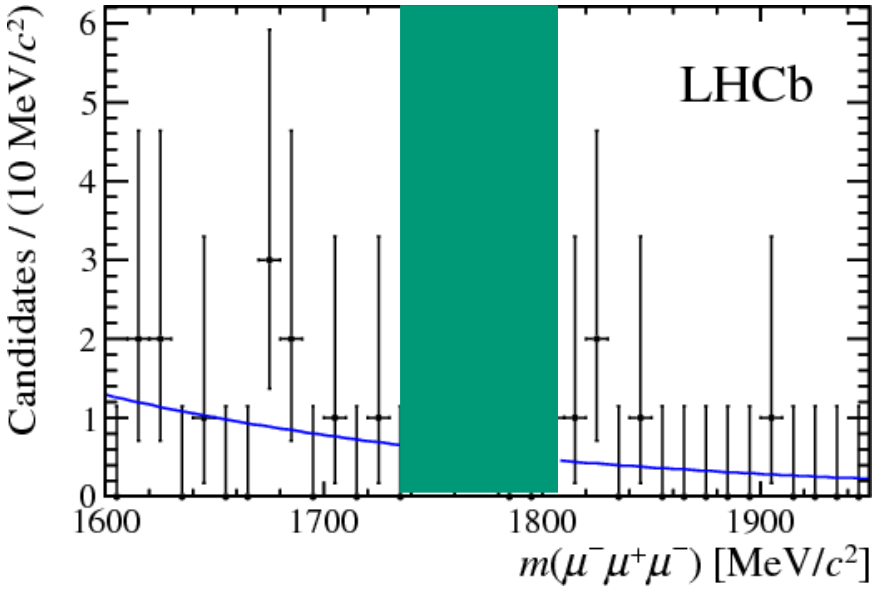


$M_{3\mu}$ distribution

- Shape determined using $D_s^- \to \Phi(\mu^+\mu^-)\pi^-$
- Analyze 5x5 best bins in L_{PID} and L_{3body}

Blind analysis



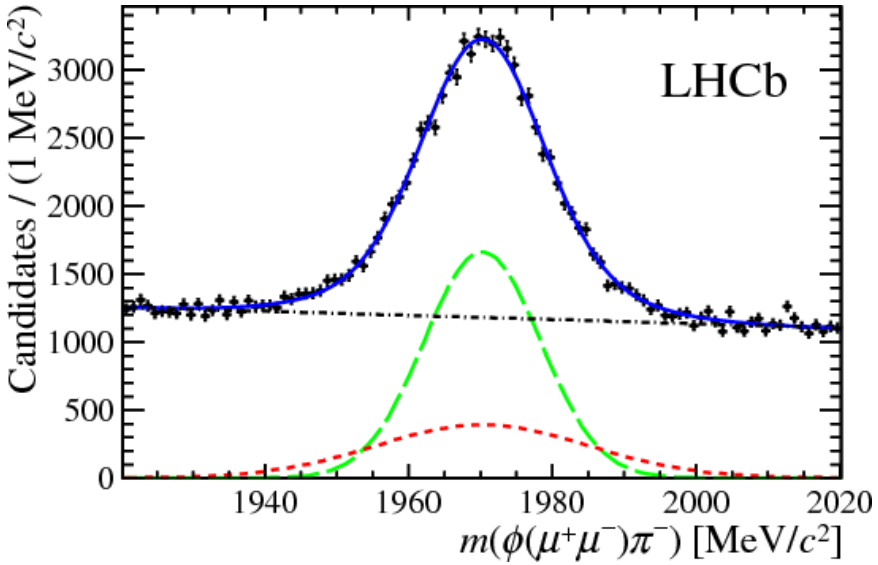


L_{PID} : [0.65, 1.0]
L_{3body} : [0.725, 1.0]

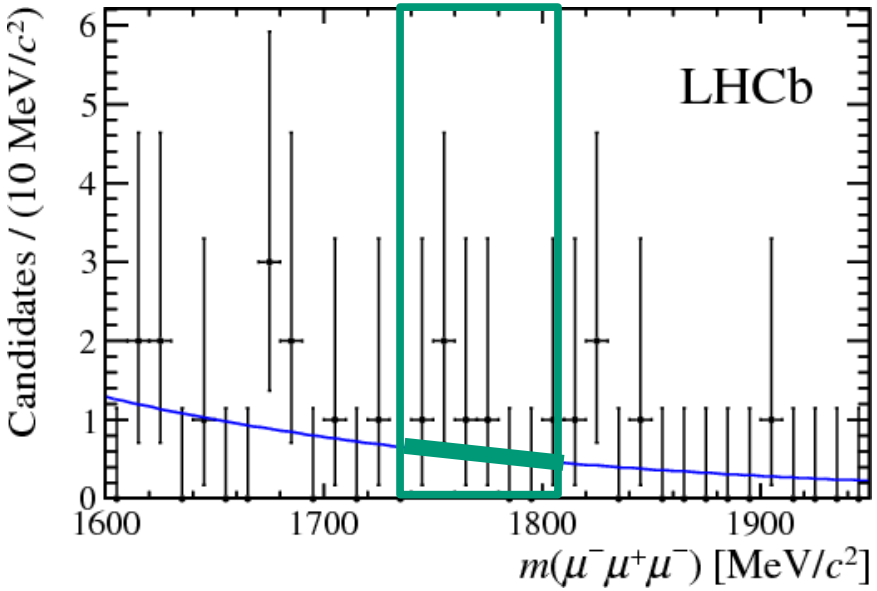
JHEP 02 (2015) 121

$M_{3\mu}$ distribution

- Shape determined using $D_s^- \to \Phi(\mu^+\mu^-)\pi^-$
- Analyze 5x5 best bins in L_{PID} and L_{3body}



Bkgd Signal Bkgd



L_{PID} : [0.65, 1.0]
L_{3body} : [0.725, 1.0]

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Result

$$\frac{\mathbb{P}(\theta_{up}(X) < \theta|\theta)}{\mathbb{P}(\theta_{up}(X) < \theta|0)} \leq \alpha' \text{ for all } \theta.$$

- Robust analysis method
- Statistics limited
- No significant evidence for excess of events

$B(\tau^- \to \mu^-\mu^+\mu^-) < 4.6 \times 10^{-8}$

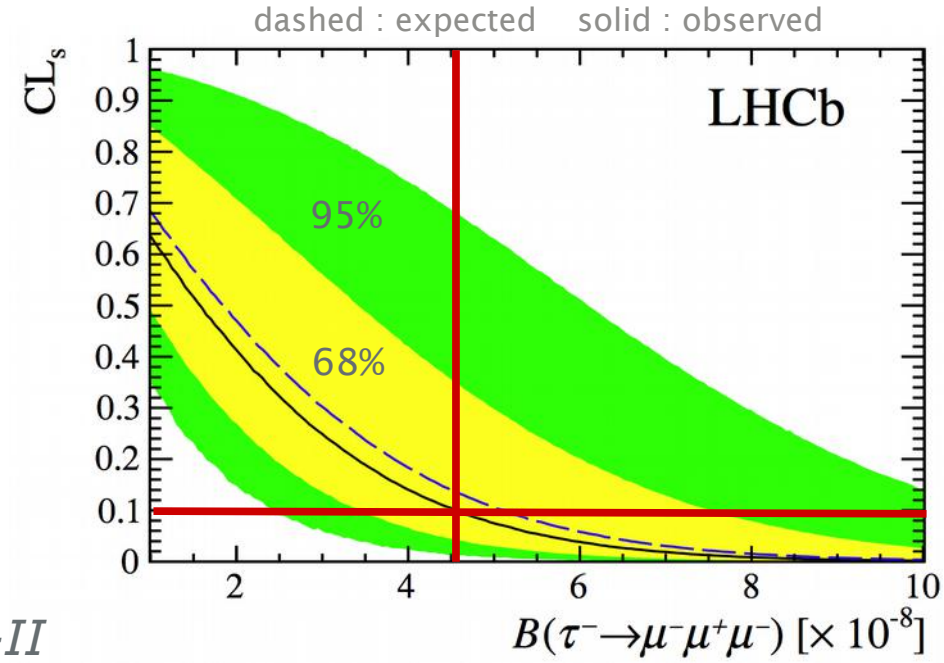
@ 90% C.L.

Belle 2.1 x 10^{-8} @ 90% C.L.

BaBar 3.3 x 10^{-8} @ 90% C.L.

@Run2: LHCb may overtake Belle

… which will then be overtaken by Belle-II



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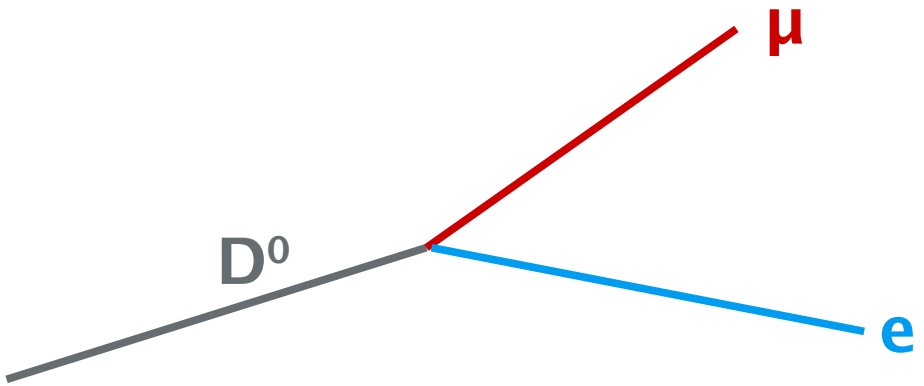
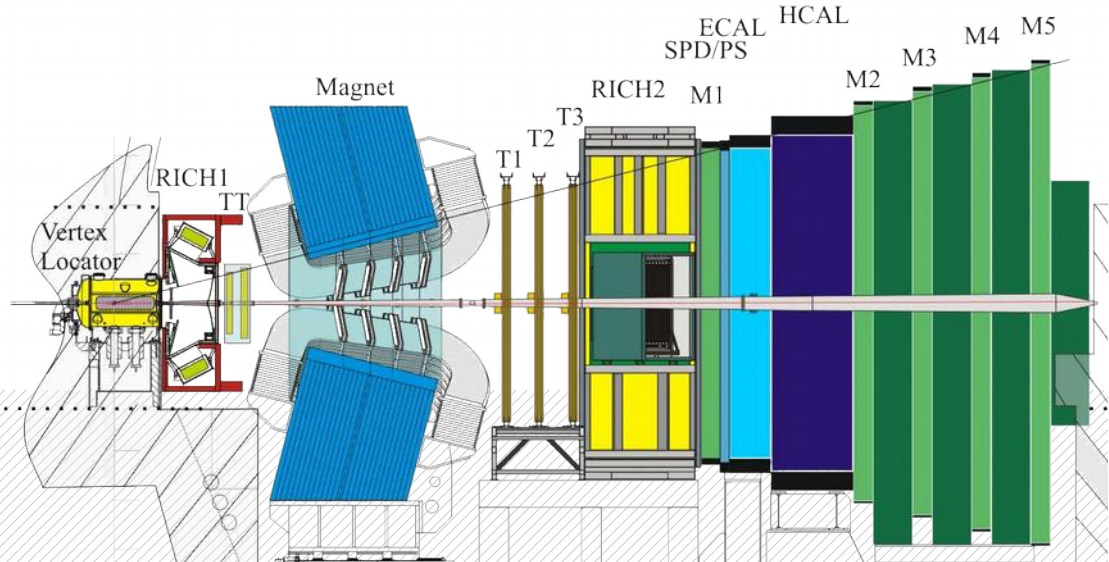

μ
D⁰
e

e detection


Magnet
RICH1
TT
Vertex
Locator
T1
T2
T3
RICH2
M1
ECAL
SPD/PS
HCAL
M2
M3
M4
M5

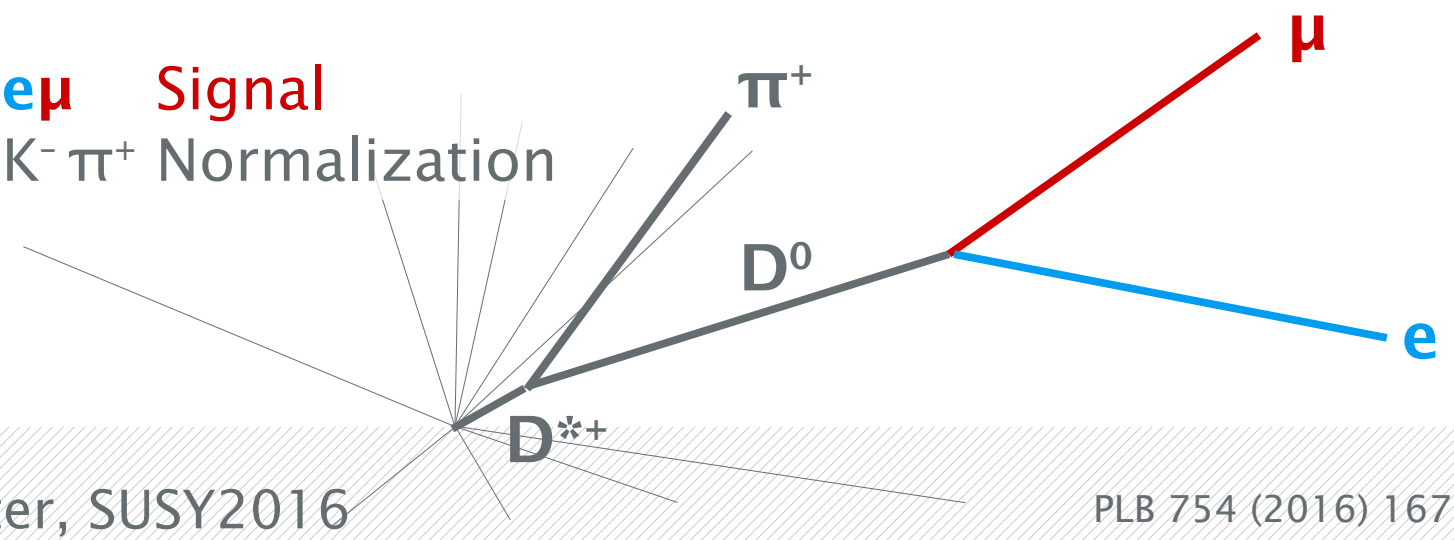
$D^0 \to e\mu$

Belle : $Br(D^0 \to e\mu) < 2.6 \times 10^{-7}$ (90% CL)

RPV SUSY : $\sim 10^{-7}$
Leptoquarks : 4×10^{-8}

LHCb analysis based on 3 fb^{-1} collected @ $\sqrt{s}$ = 7 & 8 TeV

$D^{*+} \to D^0 \pi^+$
↳ $D^0 \to e\mu$ Signal
↳ $D^0 \to K^- \pi^+$ Normalization



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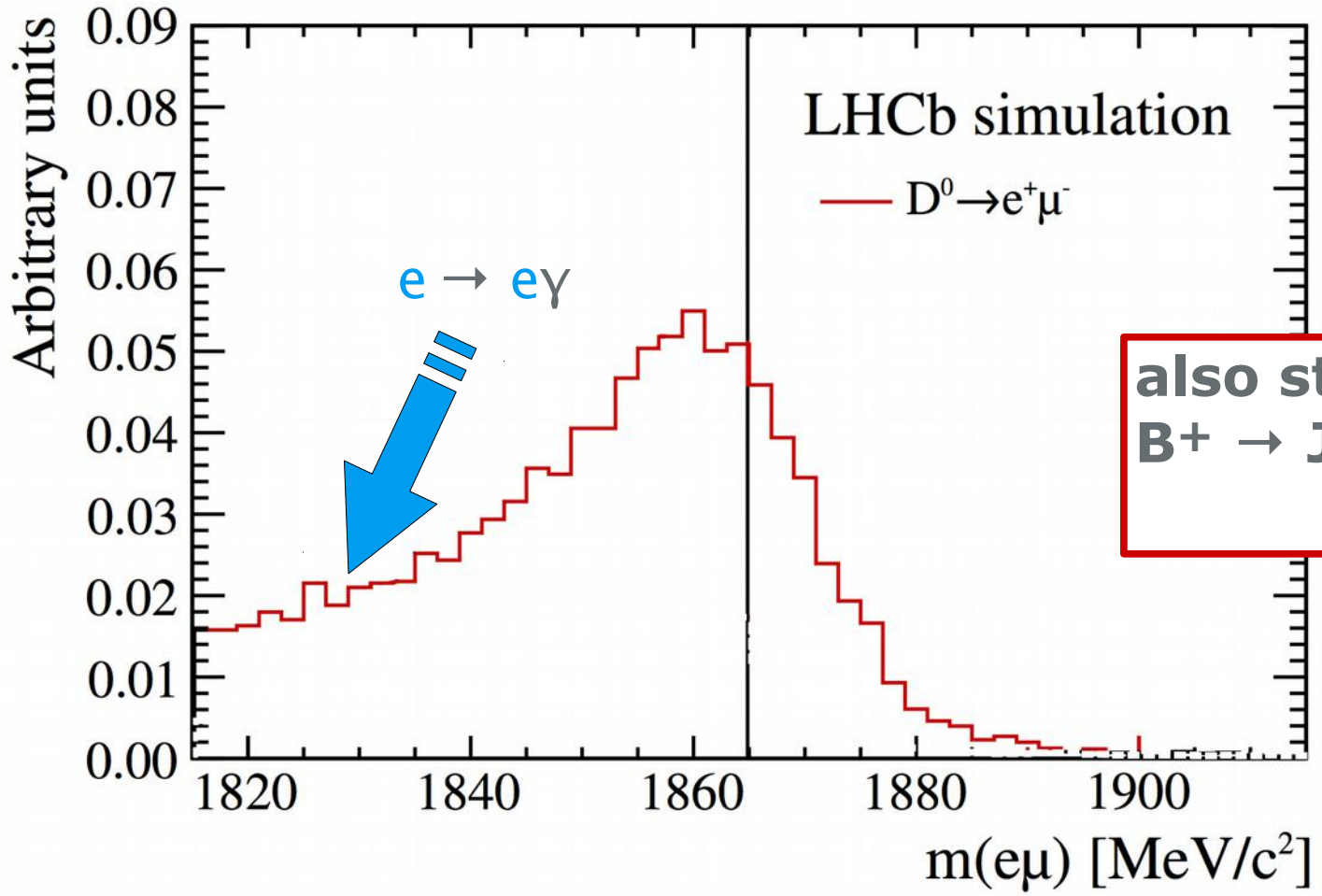
Bremsstrahlung



also study w/
$B^+ \to J/\Psi\, K^+$
↳e^+e^-

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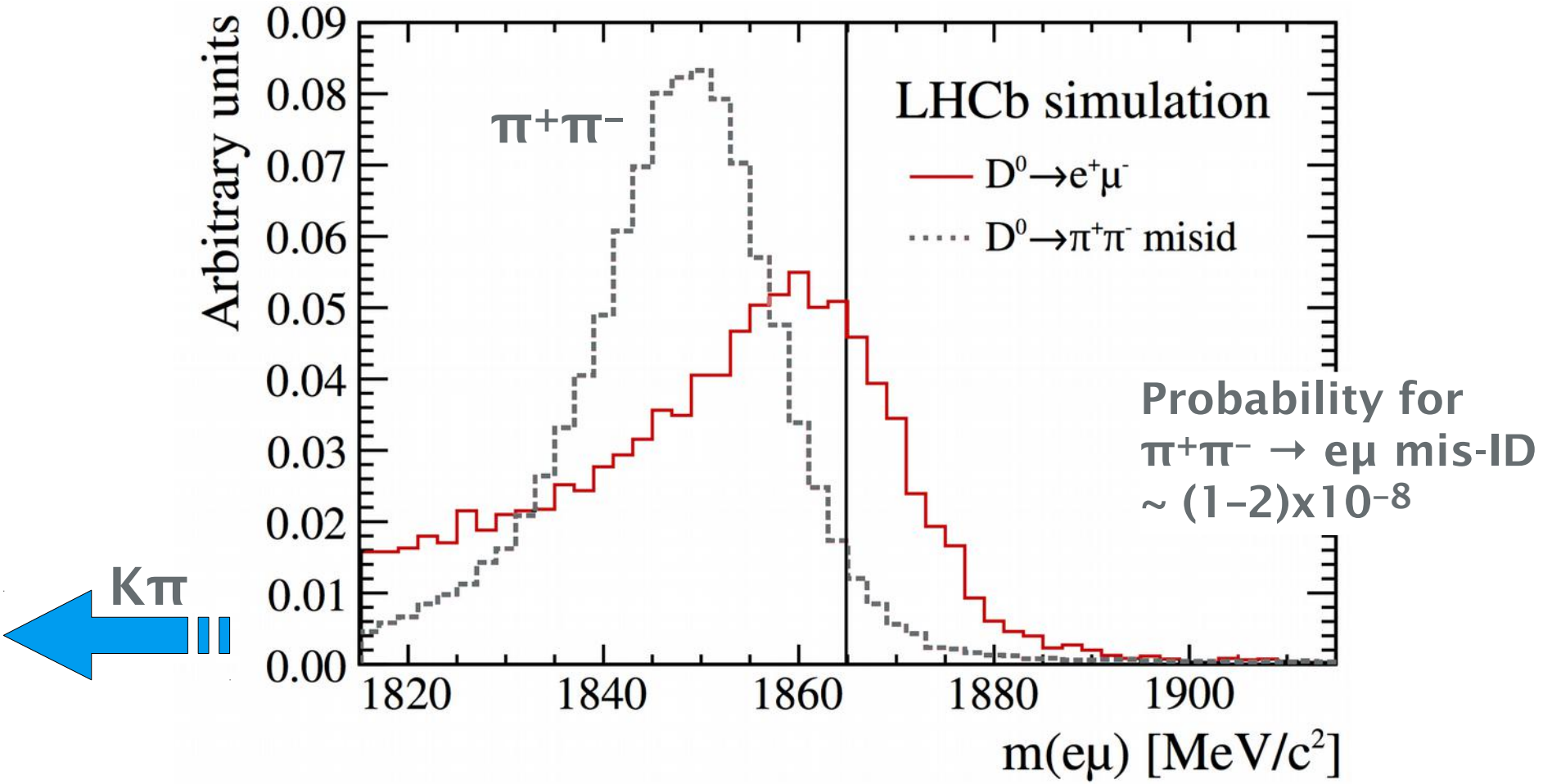
Mis-Identification



Probability for
$\pi^+\pi^- \rightarrow e\mu$ mis-ID
$\sim (1\text{–}2)\times 10^{-8}$

Kπ

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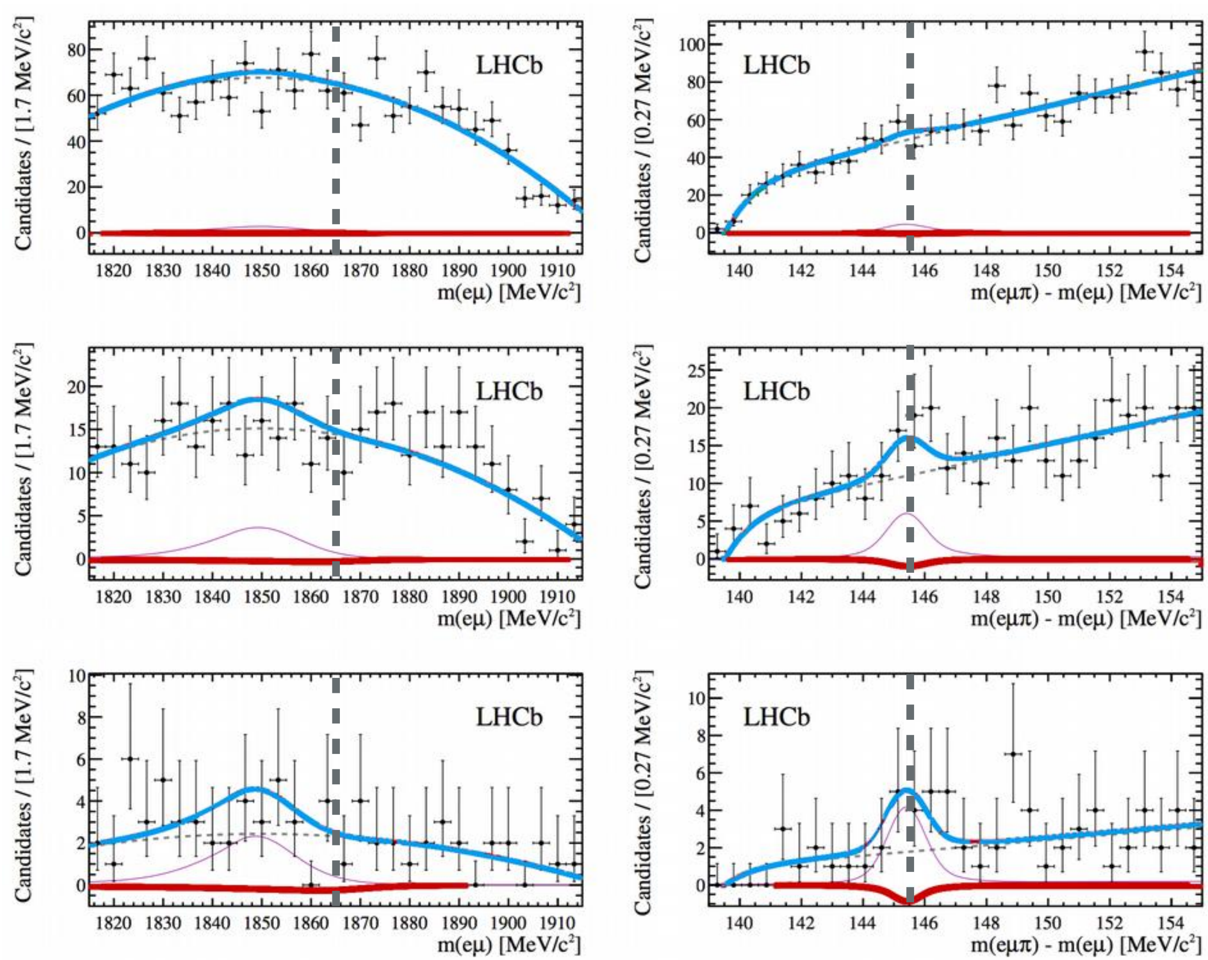
Unbinned simultaneous fits

BKGD-like

intermediate

Signal-like



Signal + bkgd

$D^0 \to e\mu$ (signal)

-7±15 events

m(eμ) → M_D   **m(eμπ)-m(eμ) → M_{D^*}-M_D**

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Result

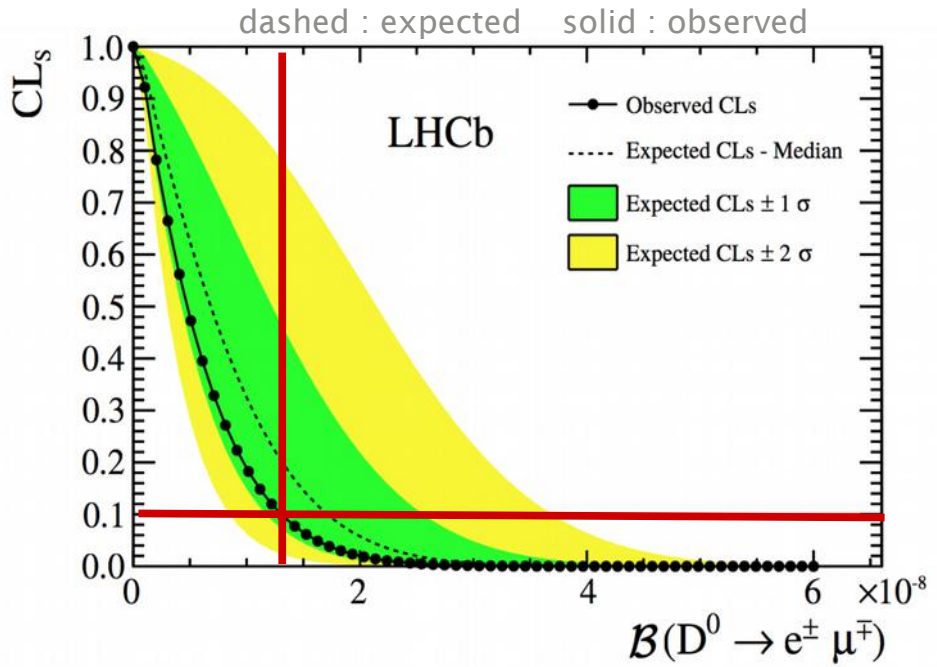
$$\frac{\mathbb{P}(\theta_{up}(X) < \theta|\theta)}{\mathbb{P}(\theta_{up}(X) < \theta|0)} \leq \alpha' \text{ for all } \theta.$$

- Robust analysis method
- Statistics limited
- No significant evidence for excess of events

$B(D^0 \to e\mu) < 1.3 \times 10^{-8}$

@ 90% C.L.

20x improvement over previous result
Effectively deal with backgrounds
Bremsstrahlung complicates analysis
Difficult to do at e^+e^- colliders



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Other channels under investigation

$B_{(s)} \rightarrow e\mu$

$B^0 \rightarrow K^{*0}e\mu$

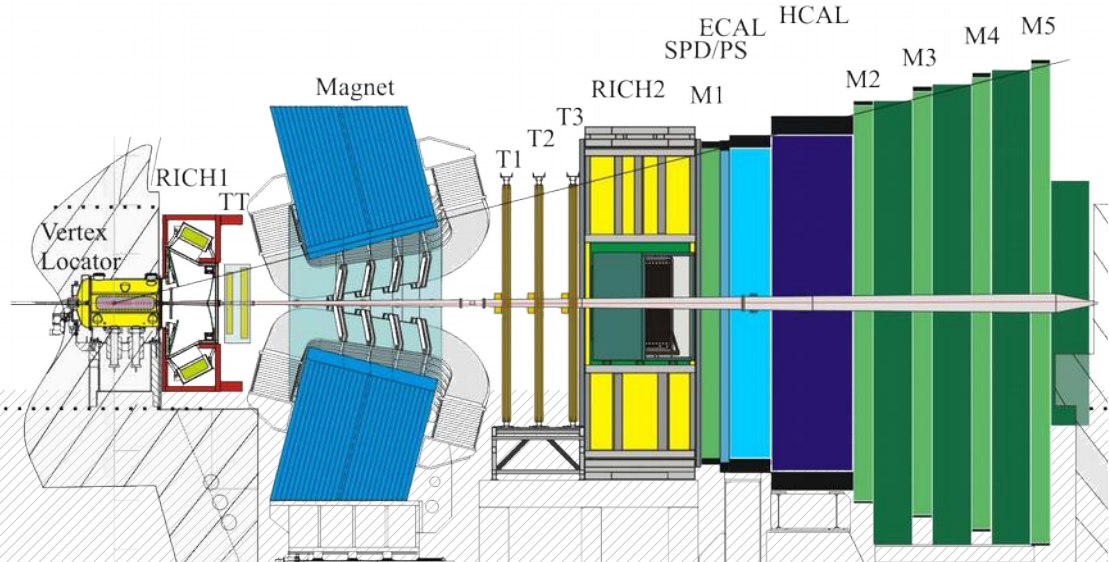
$B_s \rightarrow \Phi e\mu$

$B_{(s)} \rightarrow J/\Psi(\rightarrow e\mu)\, X$

$B^+ \rightarrow K^+e\mu$

Expect to improve existing limits

Opportunities for T detection



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Some existing limits

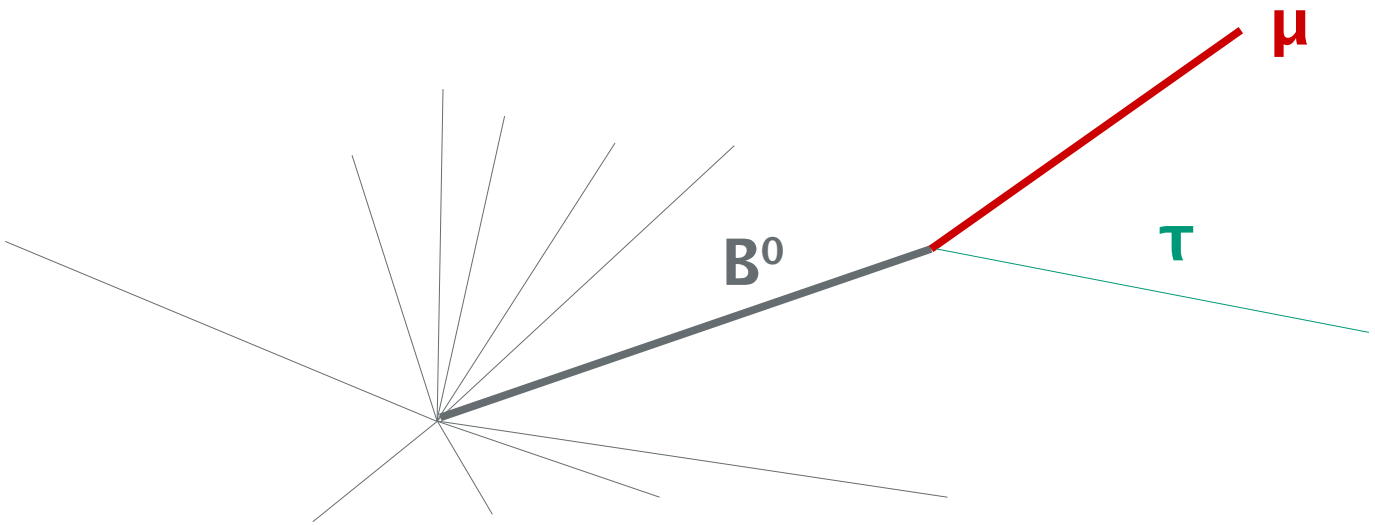
$J/\Psi(1S)$	→	$\mu\tau$	$< 2\times10^{-6}$
$\Upsilon(1S)$	→	$\mu\tau$	$< 6\times10^{-6}$
$\Upsilon(2S)$	→	$\mu\tau$	$< 3\times10^{-6}$
$\Upsilon(3S)$	→	$\mu\tau$	$< 3\times10^{-6}$
Z^0	→	$\mu\tau$	$< 1\times10^{-5}$
h^0	→	$\mu\tau$	$< 1.5\%$
$J/\Psi(1S)$	→	$e\tau$	$< 9\times10^{-6}$
Z^0	→	$e\tau$	$< 1\times10^{-6}$

O(few x 10^{-6})

@ 90-95% CL

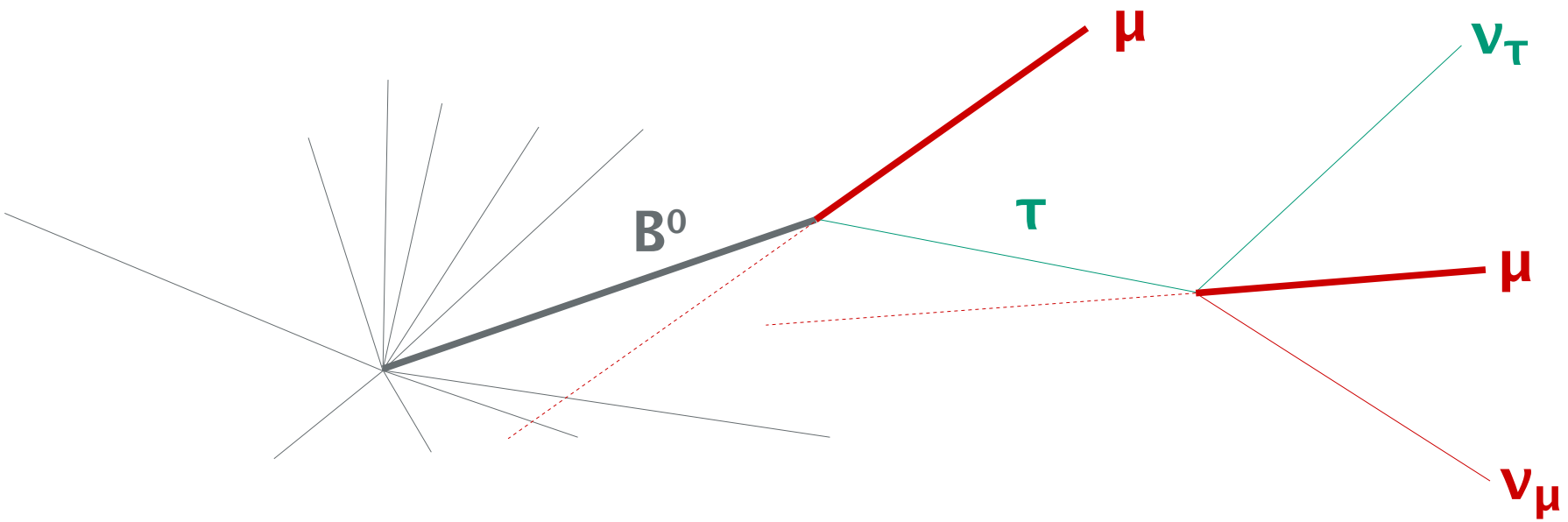
Reconstruction – I

Interesting possibility
Short lifetime prohibits direct detection



Reconstruction – II

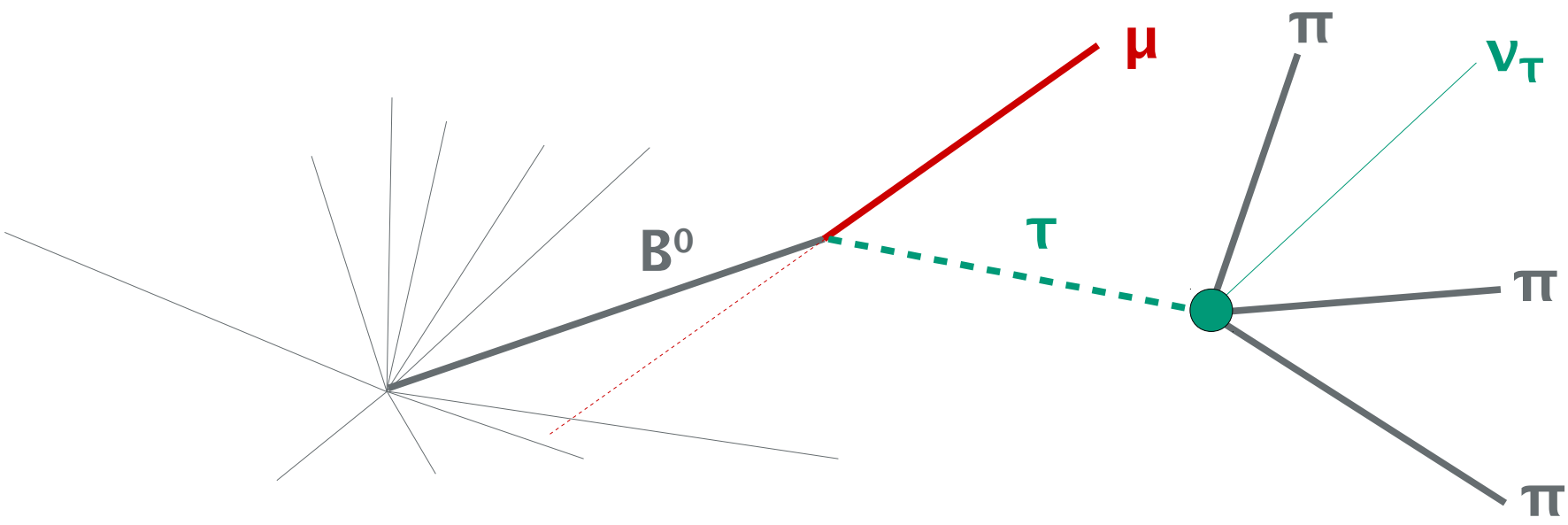
Interesting possibility
Short lifetime prohibits direct detection
Neutrinos remain undetected



Reconstruction – III

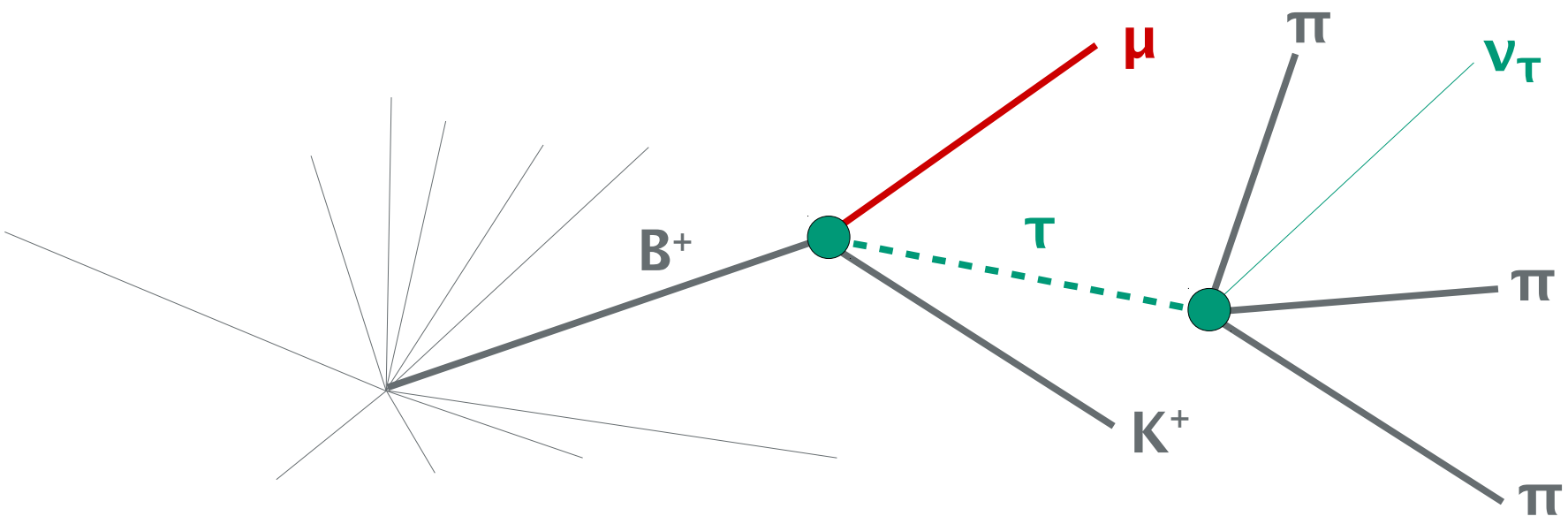
Interesting possibility
Short lifetime prohibits direct detection
Neutrino remains undetected

Br ~ 9%



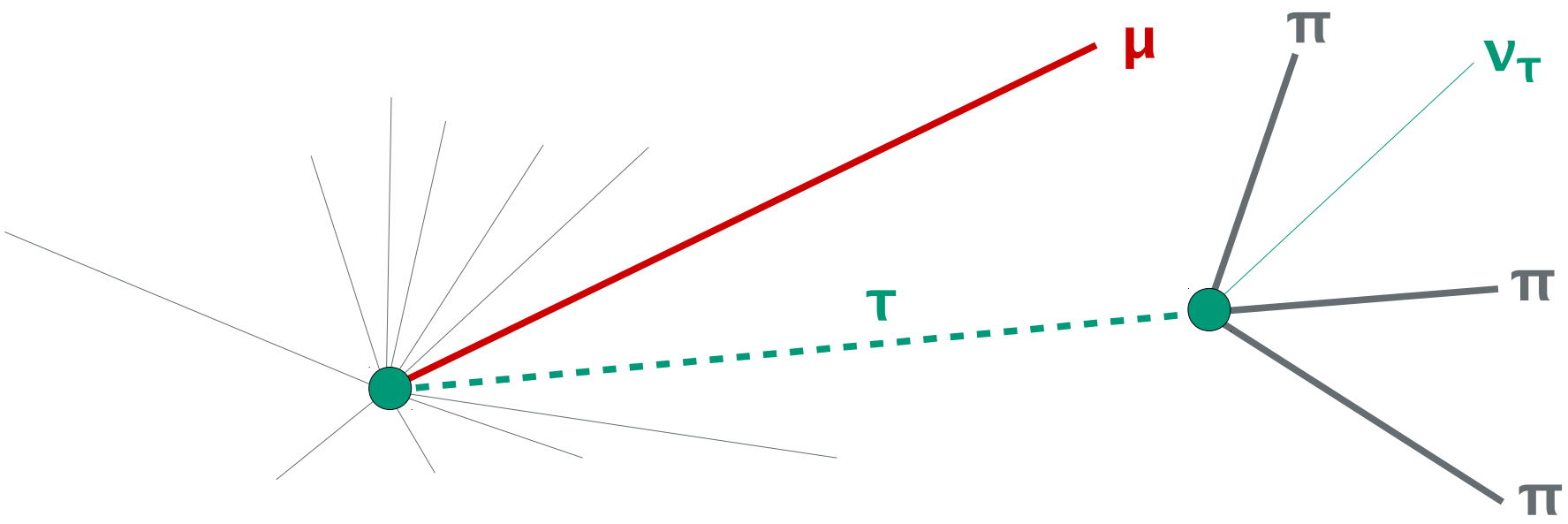
Reconstruction – IV

Interesting possibility
Short lifetime prohibits direct detection
Neutrino remains undetected

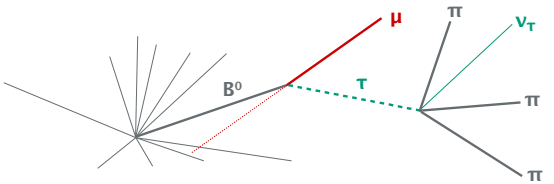


Reconstruction – V

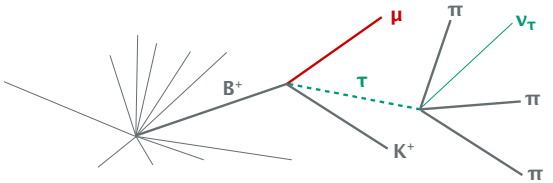
Interesting possibility
Short lifetime prohibits direct detection
Neutrino remains undetected



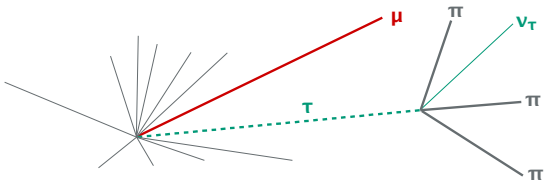
Possibly interesting channels



$B_{(s)} \rightarrow e/\mu\tau$



$B^+ \rightarrow K^+ e/\mu\tau$



$\Upsilon(nS) \rightarrow e/\mu\tau$

Benefit from $\bar{B}^0 \rightarrow D^{*+}\tau\bar{\nu}_\tau$

Phys. Rev. Lett. 115, 111803 (2015)

Conclusion

Take away message

LHCb : diverse program studying flavor physics with all three quark & lepton generations

With LHC **Run-I** data **LHCb** sharpened limits for many LFV, LNV, and BNV channels

No significant deviations from **SM** seen

Demonstrated sensitive **BSM** searches @ hadron collider

Many more options around, lots of additional data expected in **Run-II** (just restarted) & **Run-III**

Thank you for your attention!

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