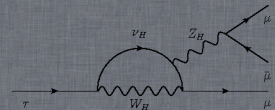
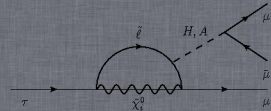
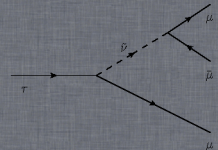
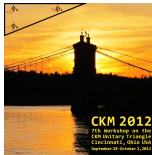


Search for LFV and LNV decays at LHCb

Marcin Chrzęszcz

Institute of Nuclear Physics,
Polish Academy of Science,
on behalf of LHCb collaboration

29th September 2012



B decays

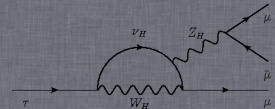
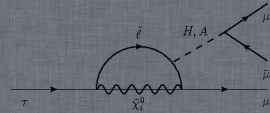
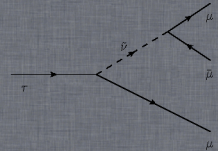
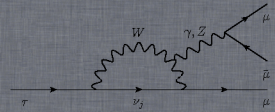
$$B^- \rightarrow h^+ l^- l^-$$

$$B^- \rightarrow D^0 \pi^+ \mu^- \mu^-$$

τ decays

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

$$\tau^- \rightarrow \bar{\nu} \mu^- \mu^+$$



Overview of B and τ decays at LHCb

① LHCb optimised for B decays.

- Relatively low background.
- Efficient trigger.
- Analysis can be made using hard cuts (the case of LNF decays).

② τ decays at LHCb.

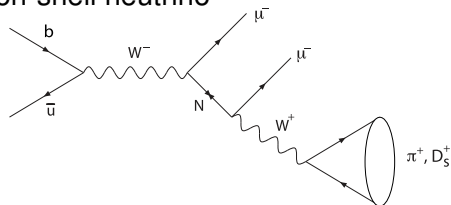
- Many τ killed by trigger.
- Smaller cross section for production.
- Need complicated analysis strategy.

LNV in bottom decays

$$B^- \rightarrow h^+ \ell^- \ell^-$$

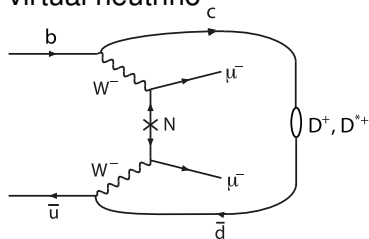
LNV in bottom decays

on-shell neutrino



- resonant production in accessible mass range
- rates depend on Majorana neutrino–lepton coupling $|V_{\mu 4}|$ (e.g. arXiv:0901.3589)
- $m_4 = m_{\ell^-, \pi^+}$

virtual neutrino

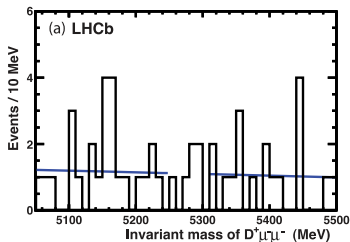


Special for B decays

Diagram without mass restriction
Cabbibo favoured for $B \rightarrow D$
Analogous to double β decay.

Virtual Majorana neutrinos

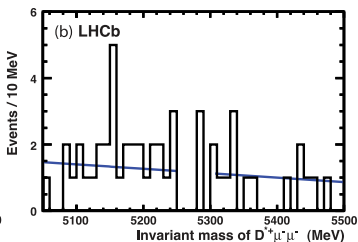
$$B^- \rightarrow D^+ \mu^- \mu^-$$



$$\mathcal{B}(B^- \rightarrow D^+ \mu^- \mu^-) < 6.9 \times 10^{-7}$$

@ 95% CL

$$B^- \rightarrow D^{*+} \mu^- \mu^-$$



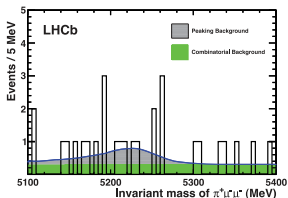
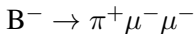
$$\mathcal{B}(B^- \rightarrow D^{*+} \mu^- \mu^-) < 2.4 \times 10^{-6}$$

@ 95% CL

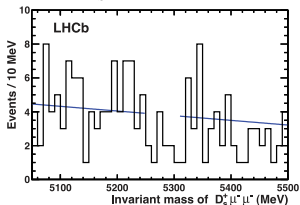
Phys. Rev.D85 (2012)
112004

On-shell Majorana neutrinos

- mis-identification rates from data with mass shape from simulation



$$\mathcal{B}(B^- \rightarrow \pi^+ \mu^- \mu^-) < 1.3 \times 10^{-8} \\ @ 95\% \text{ CL}$$



$$\mathcal{B}(B^- \rightarrow D_s^+ \mu^- \mu^-) < 5.8 \times 10^{-7} \\ @ 95\% \text{ CL}$$

Phys. Rev.D85 (2012)
112004

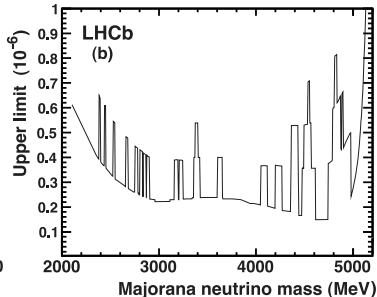
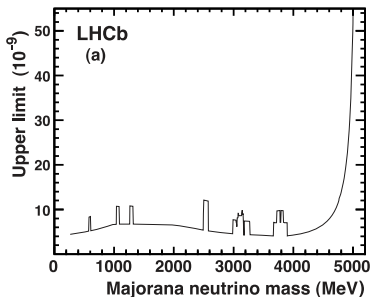
Implications on Majorana mass

mass spectrum

Determine limit as function of $h^+ \mu^-$ mass

$$B^- \rightarrow \pi^+ \mu^- \mu^-$$

$$B^- \rightarrow D_s^+ \mu^- \mu^-$$

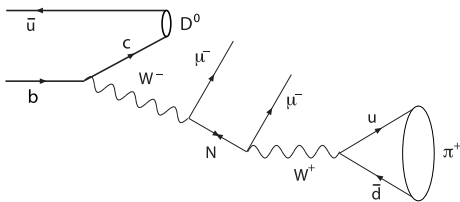


Phys. Rev. D85 (2012)

112004

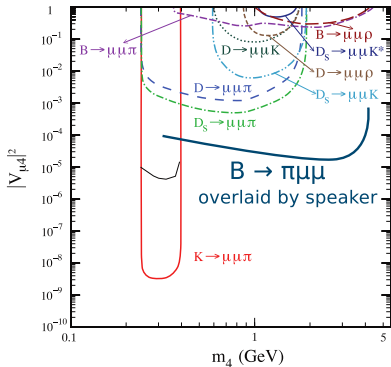
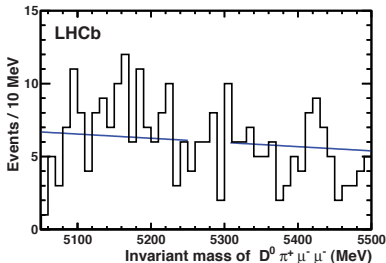
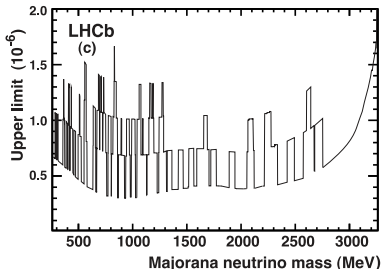
M.Chrzęszcz 2012

$$B^- \rightarrow D^0 \pi^+ \mu^- \mu^-$$



- Four body B decay complementary to three body decay (arXiv:1108.6009)
- $m_4 = m(\pi^+ \mu^-)$
- + enhanced by W couplings
 - smaller mass range accessible ($260 \text{ MeV} < m_4 < 3.3 \text{ GeV}$)
- first performed at LHCb













$$B^- \rightarrow D^0 \pi^+ \mu^- \mu^-$$



$$\mathcal{B}(B^- \rightarrow D^0 \pi^+ \mu^- \mu^-) < 1.5 \times 10^{-6} \text{ @95\% CL}^a$$

^aLHCb, CERN-PH-EP-2012-006,
arXiv:1201.5600

Summary on LNV in B decays

channel	limit		
$\mathcal{B}(B^- \rightarrow \pi^+ e^- e^-)$	$< 2.3 \times 10^{-8}$	@90 % CL	 ^a
$\mathcal{B}(B^- \rightarrow K^+ e^- e^-)$	$< 3.0 \times 10^{-8}$	@90 % CL	 ^a
$\mathcal{B}(B^- \rightarrow K^{*+} e^- e^-)$	$< 2.8 \times 10^{-6}$	@90 % CL	 ^b
$\mathcal{B}(B^- \rightarrow \rho^+ e^- e^-)$	$< 2.6 \times 10^{-6}$	@90 % CL	 ^b
$\mathcal{B}(B^- \rightarrow D^+ e^- e^-)$	$< 2.6 \times 10^{-6}$	@90 % CL	 ^c
$\mathcal{B}(B^- \rightarrow D^+ e^- \mu^-)$	$< 1.8 \times 10^{-6}$	@90 % CL	 ^c
$\mathcal{B}(B^- \rightarrow \pi^+ \mu^- \mu^-)$	$< 1.3 \times 10^{-8}$	@95 % CL	 ^d
$\mathcal{B}(B^- \rightarrow K^+ \mu^- \mu^-)$	$< 5.4 \times 10^{-7}$	@95 % CL	 ^e
$\mathcal{B}(B^- \rightarrow D^+ \mu^- \mu^-)$	$< 6.9 \times 10^{-7}$	@95 % CL	 ^d
$\mathcal{B}(B^- \rightarrow D^{*+} \mu^- \mu^-)$	$< 2.4 \times 10^{-6}$	@95 % CL	 ^d
$\mathcal{B}(B^- \rightarrow D_s^+ \mu^- \mu^-)$	$< 5.8 \times 10^{-7}$	@95 % CL	 ^d
$\mathcal{B}(B^- \rightarrow D^0 \pi^- \mu^- \mu^-)$	$< 1.5 \times 10^{-6}$	@95 % CL	 ^d

^aBaBar, Phys. Rev. D **85**, 071103 (2012)

^bCLEO, Phys. Rev. D **65**, 111102 (2002)

^cBelle, Phys. Rev. D **84**, 071106(R), (2011)

^dLHCb, CERN-PH-EP-2012-006,

arXiv:1201.5600 (2012)

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τ decays

$$\textcircled{1} \tau^- \rightarrow \mu^- \mu^- \mu^+$$

$$\textcircled{2} \tau^- \rightarrow \bar{p} \mu^- \mu^+$$

LFV in τ^- sector

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

LFV in τ^- sector

- 1 In SM small $\mathcal{B}(\tau^- \rightarrow \mu^- \mu^- \mu^+) \sim 10^{-50}$
- 2 NP can enhance \mathcal{B} .
- 3 Nature still hides $\tau^- \rightarrow \mu^- \mu^- \mu^+$ from us.
- 4 Current limits:

Experiment	90% CL limit
BaBar	3.3×10^{-8}
Belle	2.1×10^{-8}

- 5 Can a hadron collider change the picture?

Analysis approach

B factories

- ① Clean signal: $e^+e^- \rightarrow \tau^+\tau^-$
- ② Calculate the thrust axis
- ③ "Partial tag" the other tag
- ④ Small cross section $0.919nb$

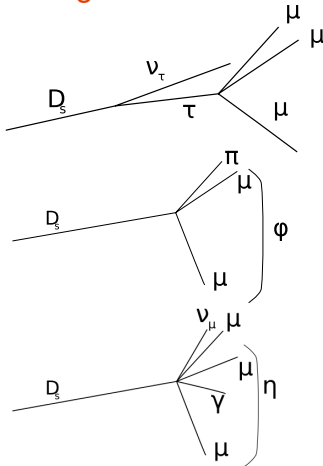
LHCb, ($7TeV$, 2011 data)

- ① Inclusive τ cross section:
 $79.5 \pm 8.3 \mu b$.
- ② $8 \times 10^{10} \tau$ produced.
- ③ Dominant contribution:
 $D_s \rightarrow \tau \nu_\tau$ (78%)
- ④ No tag possible.

Strategy

- Loose cut based selection
- Classification in 3D space:
 - invariant mass
 - decay topology (multivariate)
 - particle identification (multivariate)
- Classifier trained on simulation
- Calibration with control channel
- Normalization with $D_s \rightarrow \phi(\mu\mu)\pi$
- CLs method to extract the result

Signal & Calibration & Background channel



Signal likelihoods

particle identification

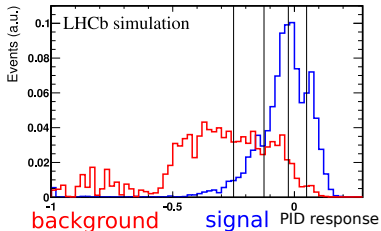
- hits in muon chambers
- energy in calorimeters
 - compatible with MIP
- RICH response

3 body decay likelihood

- vertex properties
 - vertex fit, pointing
- track quality
- isolation

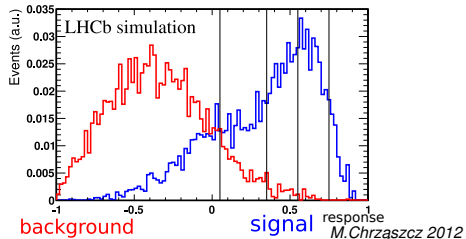
Calibration

$$J/\psi \rightarrow \mu^+ \mu^-$$



Calibration

$$D_s \rightarrow \phi \pi$$

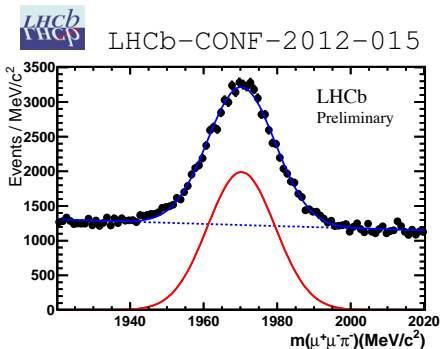


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Normalization channel $D_s^+ \rightarrow \phi(\mu^+\mu^-)\pi^+$

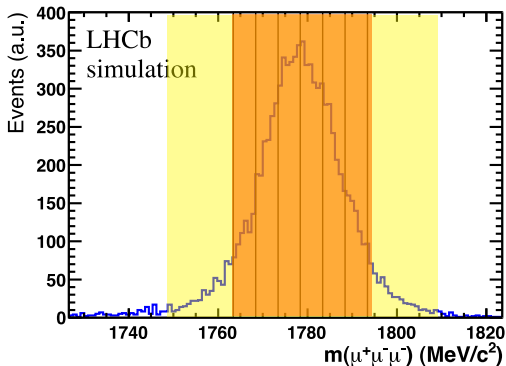
Produced τ leptons

$$\mathcal{B}(\tau \rightarrow \mu\mu\mu) = \underbrace{\frac{\sigma(pp \rightarrow D_s \rightarrow \tau)}{\sigma(pp \rightarrow \tau)}}_{77.9\%} \frac{\mathcal{B}(D_s \rightarrow \phi(\mu\mu)\pi)}{\mathcal{B}(D_s \rightarrow \tau\nu_\tau)} \frac{\varepsilon_{norm}}{\varepsilon_{sig}} \frac{N_{\tau \rightarrow \mu\mu\mu}}{N_{D_s \rightarrow \phi(\mu\mu)\pi}}$$



Invariant mass

- background estimation in sidebands
- different signal likelihood inside signal region



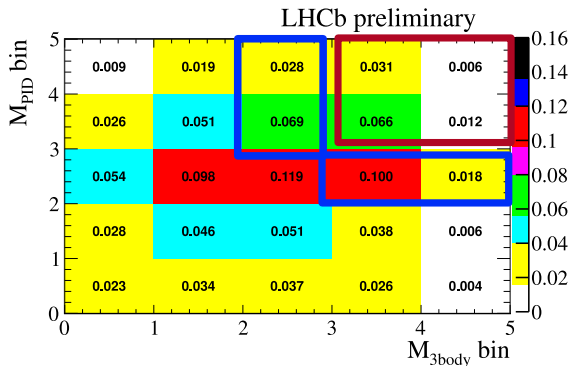
- Mass resolution and mass scale calibrated on data
- Blinded window
- Mass window
- Mass resolution: 9.16 MeV

Signal likelihoods

combined signal distribution

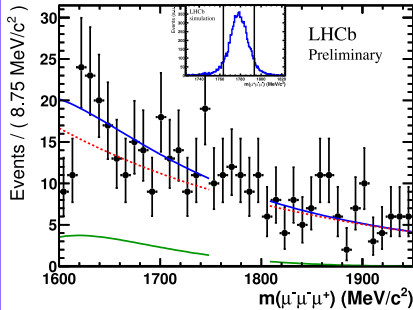
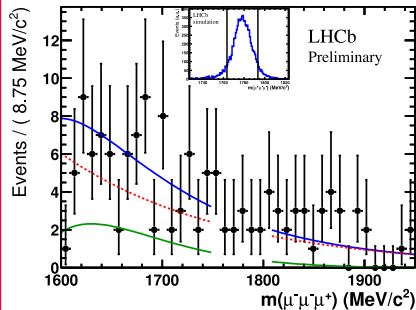
- events distributed over 25 likelihood bins
- background estimate from mass sidebands

Signal efficiency in 3-BODY BDT vs PID BDT plane.

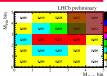


- 11 % signal efficiency
- 21 % signal efficiency
- for illustration: high likelihood range shown

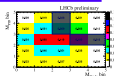
Observed events



11 % of the signal
0.03 % of the background



21 % of the signal
0.14 % of the background



red dashed combinatorial background
green $D_s^+ \rightarrow \eta(\mu^- \mu^+ \gamma)\mu^+ \nu_\mu$
blue combined background



1 fb^{-1}

LHCb-CONF-2012-015

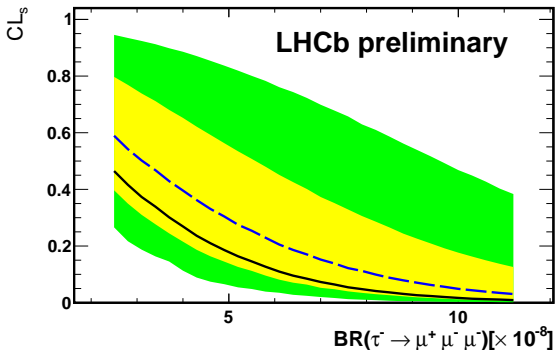
Extracted upper limit



1 fb⁻¹

LHCb-CONF-
2012-015

	observed	expected	CL
$\mathcal{B}(\tau \rightarrow \mu\mu\mu)$	6.3×10^{-8}	8.2×10^{-8}	90%
	7.8×10^{-8}	9.9×10^{-8}	95%



LNV & BNV in τ^- sector

$$\tau^- \rightarrow \bar{\nu} \mu^- \mu^+$$

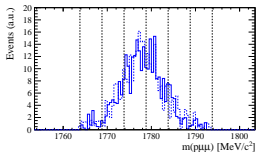
$$\tau^- \rightarrow \nu \mu^- \mu^-$$

LNV & BNV in τ^- sector

- ① Search for baryon number violation processes so far unsuccessful, but must have occurred in the early universe
- ② Decay fall into $|B - L| = 0$ category, which is predicted by many NP models.
- ③ Similar decays $\tau^- \rightarrow \Lambda \ell^-$, previous studied in \mathcal{B} factories.
- ④ Two possible decay and new physics modes: $\tau^- \rightarrow \bar{p} \mu^- \mu^+$,
 $\tau^- \rightarrow p \mu^- \mu^-$.
- ⑤ Analysis adopted from $\tau^- \rightarrow \mu^- \mu^- \mu^+$

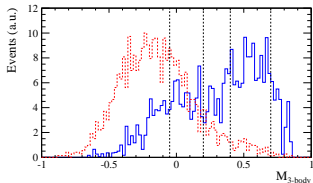
Differences

Mass distribution

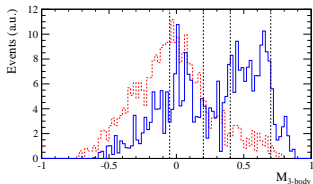


- Use the same \mathcal{M}_{3body} BDT as for $\tau^- \rightarrow \mu^- \mu^- \mu^+$
- Instead of PID BDT use hard PID cut optimised on MC and Data.
- Worse normalization factor, due to hard PID cuts.
- Only combinatorial background expected.

3-body BDT distribution for $\tau^- \rightarrow \bar{p} \mu^- \mu^+$

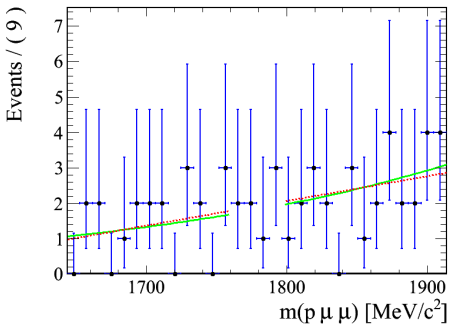


3-body BDT distribution for $\tau^- \rightarrow p \mu^- \mu^-$

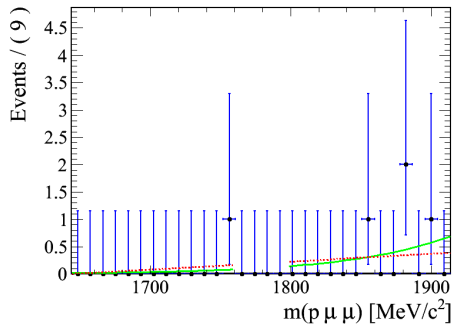


Background Fits

$$\tau^- \rightarrow p\mu^-\mu^-$$



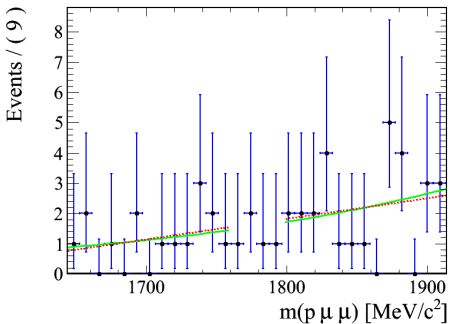
3-body BDT (0.4, 0.7)



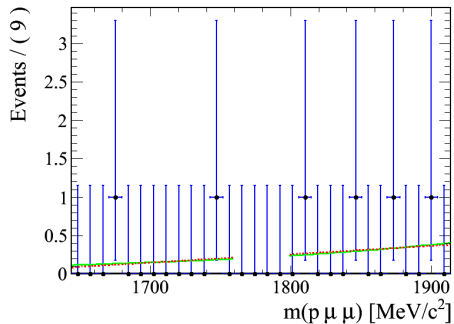
3-body BDT (0.7, 1.0)

Background Fits

$$\tau^- \rightarrow \bar{p} \mu^- \mu^+$$

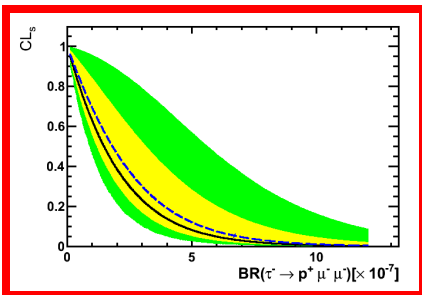
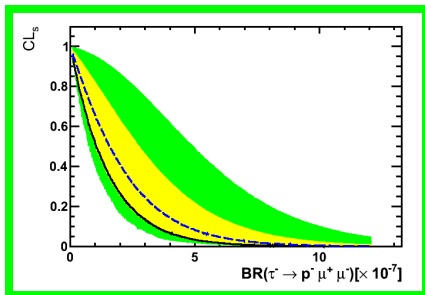


3-body BDT (0.4, 0.7)



3-body BDT (0.7, 1.0)

Limits on $\tau^- \rightarrow \bar{p}\mu^-\mu^+$ and $\tau^- \rightarrow p\mu^-\mu^-$



CL	Observed		Expected	
90%	3.4×10^{-7}	4.6×10^{-7}	4.7×10^{-7}	5.4×10^{-7}
95%	4.5×10^{-7}	6.0×10^{-7}	5.9×10^{-7}	6.9×10^{-7}

First time measured!!

Summary

- ① LNV, LFV and BNV still hidden from us.
- ② First upper limits for τ LFV and LNV in hadron colliders.
- ③ LHCb catching up \mathcal{B} factories.
- ④ First search for $\mathcal{B}(\tau \rightarrow p\mu\mu)$.

Thank you for your attention.

Work partially funded by the Polish Ministry of Science and Higher Education under the "Diamond Grant"

Backup Slides

Tablica: Relative contributions to $\sigma(pp \rightarrow \tau X)$.

Decay chain	Gauss no DPC (%)	Calc (%)	$W_{MC \rightarrow calc}$
$D_s \rightarrow \tau$	72.3 ± 0.1	77.9 ± 4.7	
$D_s \rightarrow \tau$	62.6 ± 0.2	67.8 ± 4.8	1.08 ± 0.08
$B_x \rightarrow D_s \rightarrow \tau$	9.56 ± 0.07	10.1 ± 2.1	1.1 ± 0.2
$D^- \rightarrow \tau$	2.08 ± 0.03	4.6 ± 4.4	
$D^- \rightarrow \tau$	1.90 ± 0.02	4.4 ± 4.2	2.3 ± 2.2
$B_x \rightarrow D^- \rightarrow \tau$	0.18 ± 0.01	0.3 ± 0.3	1.5 ± 1.5
$B_x \rightarrow \tau$	25.5 ± 0.1	17.5 ± 3.3	0.7 ± 0.1