Séminaire des thésards de 1ère année

Study of the very rare decay $B_s \rightarrow \mu^+ \mu^-$ at the LHCb Experiment

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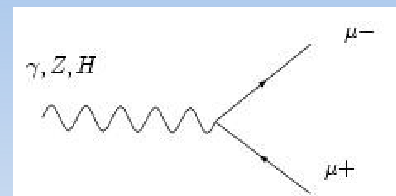
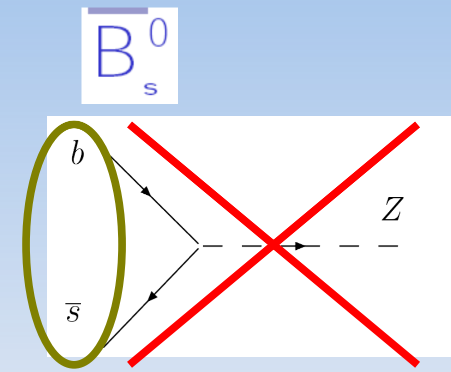
- *Introduction/Motivation*
- *The LHC and the LHCb Experiment*
- *The Analysis Strategy*
- *Some fun with 2010 Data*
- *Conclusions and Prospects*

Introduction

- Why $B_s \rightarrow \mu^+ \mu^-$?





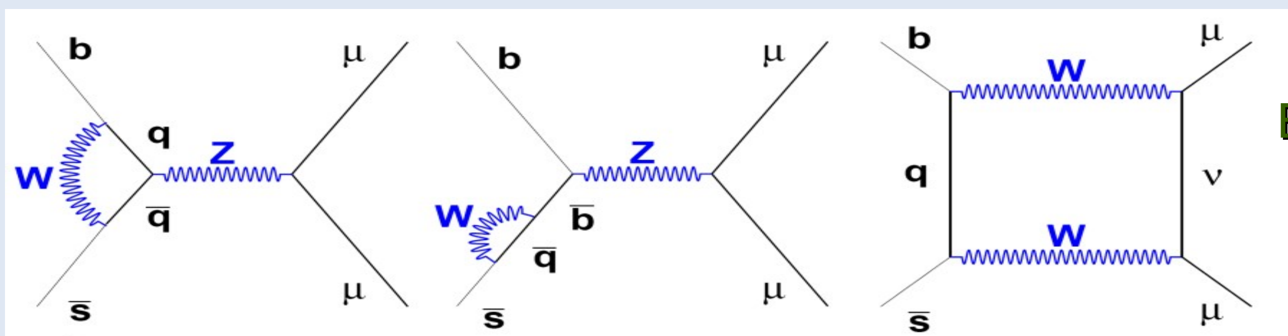
_ 2 muons in the final state

_ In the SM neutral bosons couple to fermions of same flavor

  - No tree diagrams for $B_s \rightarrow \mu^+ \mu^-$ (and FCNC) within the SM

Loop

Diagrams



Box Diagrams

Removing the background is of major importance

BR(SM) = $(3.6 \pm 0.4) \cdot 10^{-9}$ *[A. Buras. arXiv:0910.1032]*

New Physics?

BR(Exp. Upper Limit)$^{90\%\,CL} < 3.6 \cdot 10^{-8}$ *[CDF Note 9892 / DØ]*

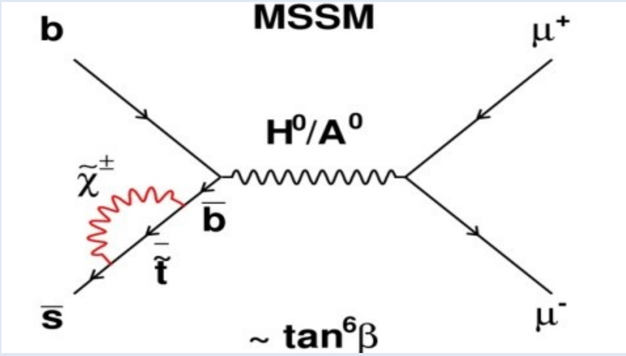
Introduction

Motivation for New Physics Beyond the Standard Model

Experiment	Neutrino flavor oscillations → Neutrino massive? From astronomical observations → Dark Matter
Theory	Large number of free parameters → Effective Low Energy Theory No explanation for the Number of Fermion Families Gravity is not included in the SM Fine Tuning and Hierarchy Problem

New Physics Scenarios

Two Higgs Doublet Models (2HDM), Minimal Flavor Violation,
Minimal Supersymmetric Standard Model (MSSM) – and constrained versions - ,
Extra Dimensions, Technicolor Models, Little Higgs Models

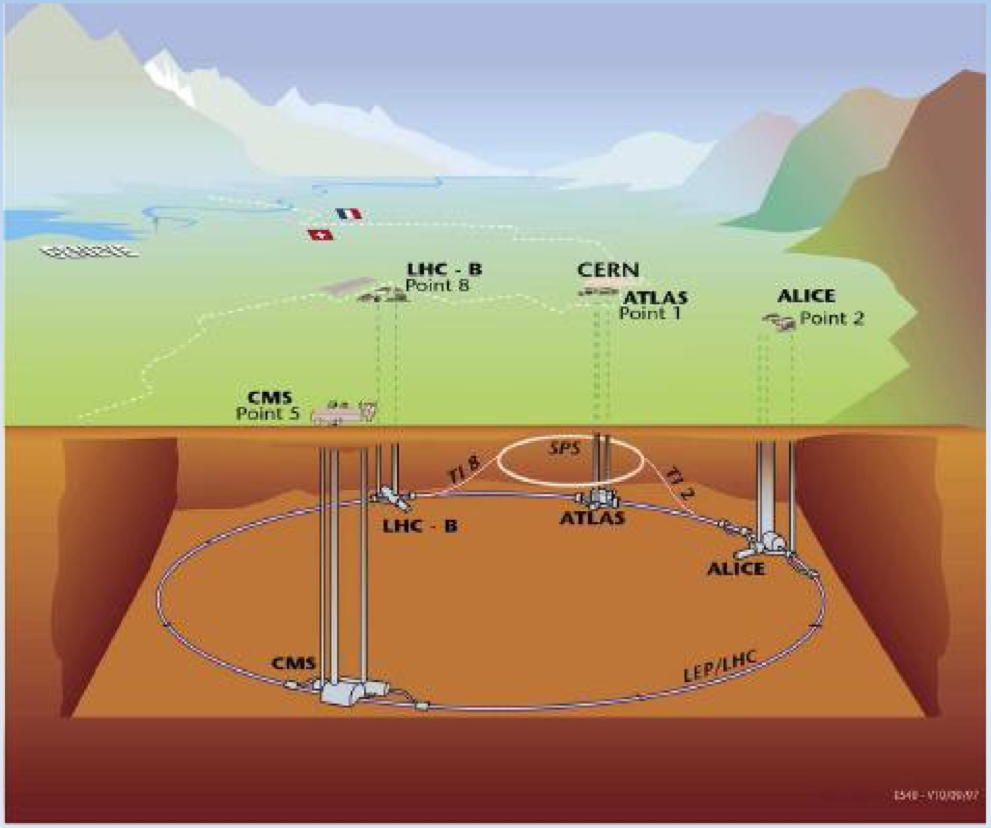


$$B(B_q \to \ell^+\ell^-)_{\rm SUSY} \propto \frac{m_b^2 m_\ell^2 \tan^6\beta}{M_{A^0}^4}$$

(Could exceed SM result by a factor 10^3)

$B_s \to \mu^+ \mu^-$ could show a clear indication of NP

The Accelerator and the Experiment



The Large Hadron Collider (LHC)

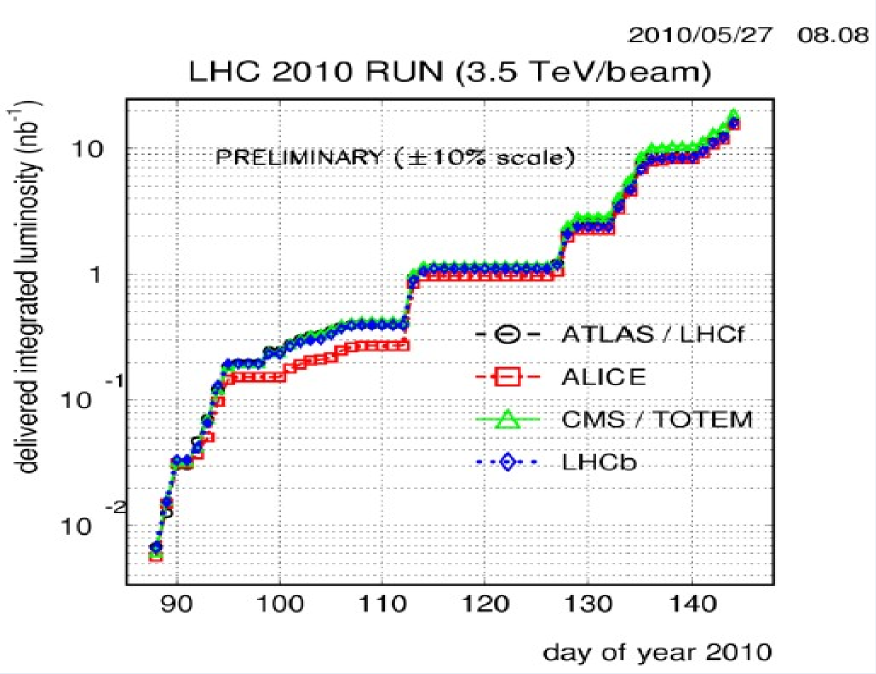
_ 27 km circular accelerator at CERN

_ Proton-Proton collisions at 14 TeV (CM)

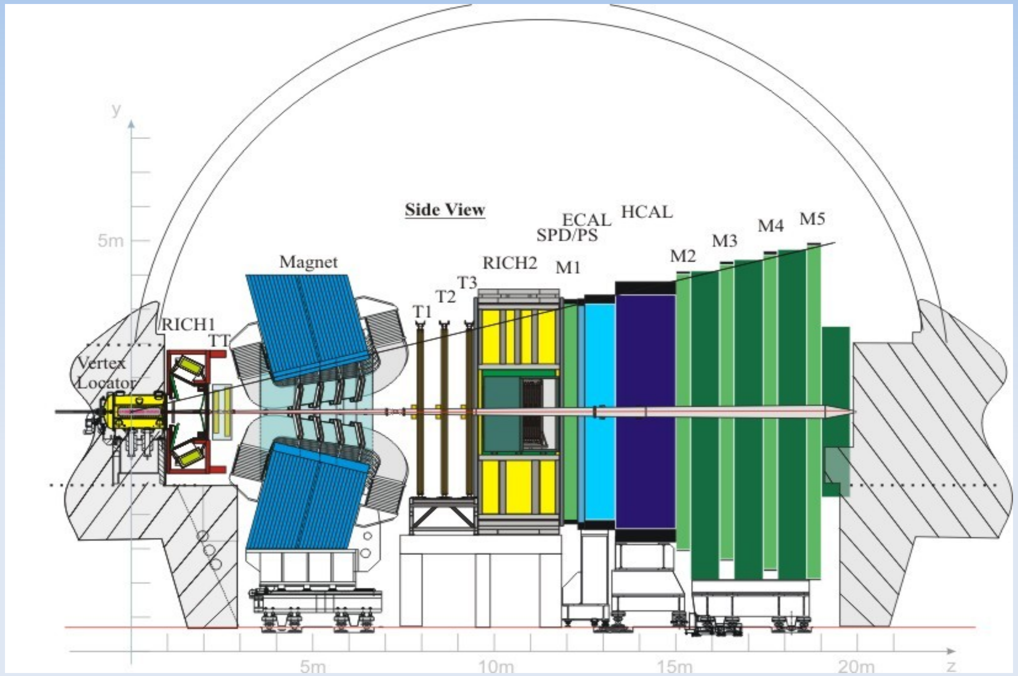
_ $1.15 \cdot 10^{11}$ particles/bunch

_ Crossing frequency: 40 MHz

_ Maximum Luminosity: 10^{-34} cm-^{2} s^{-1}



The Accelerator and the Experiment



The Large Hadron Collider Beauty (LHCb)

_ Designed for precise study of B decays.

_ Forward geometry.

_ Covering region: 300 mrad (XZ plane) and 250 mrad (YZ plane).

_ Running Luminosity: ~ 10 $^{-3\ 2}$ cm-^{2} s^{-1}

Most Relevant for $B_s \rightarrow \mu+\ \mu-$:

Vertex Locator (VELO)
Muon Chambers

The Trigger System:

At 2x10 $^{-3\ 2}$ cm-^{2} s^{-1} → *~ 40 Mhz* event rate
Trigger → Down to *2 kHz*

L0 Trigger
High Level Trigger (HLT)

The $B_s \rightarrow \mu^+ \mu^-$ Analysis

To extract $BR(B_s \rightarrow \mu^+ \mu^-)$:

1. Reconstruction of all μμ combinations

2. Selection of $B_s \rightarrow \mu^+ \mu^-$ candidates according preselection cuts.

3. Classification of each event according to:
   _ Geometry Likelihood (GL): based on a discriminant method that uses the geometry of the event.
   _ Particle Identification Likelihood (PID): probability that the muons are indeed muons.
   _ Invariant Mass Likelihood (μμ)

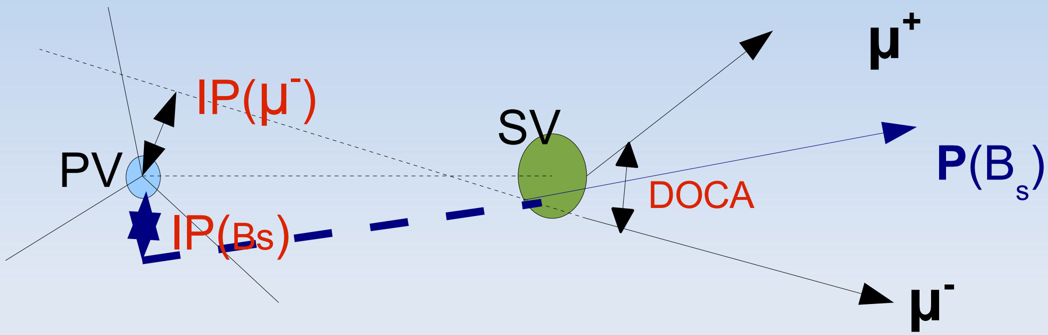
4. Normalization

$$BR = \frac{BR_{cal} \cdot \varepsilon_{cal}^{REC} \varepsilon_{cal}^{SEL/REC} \varepsilon_{cal}^{TRIG/SEL}}{\varepsilon_{sig}^{REC} \varepsilon_{sig}^{SEL/REC} \varepsilon_{sig}^{TRIG/SEL}} \cdot \frac{f_{cal}}{f_{B_s}} \cdot \frac{N_{sig}}{N_{cal}}$$

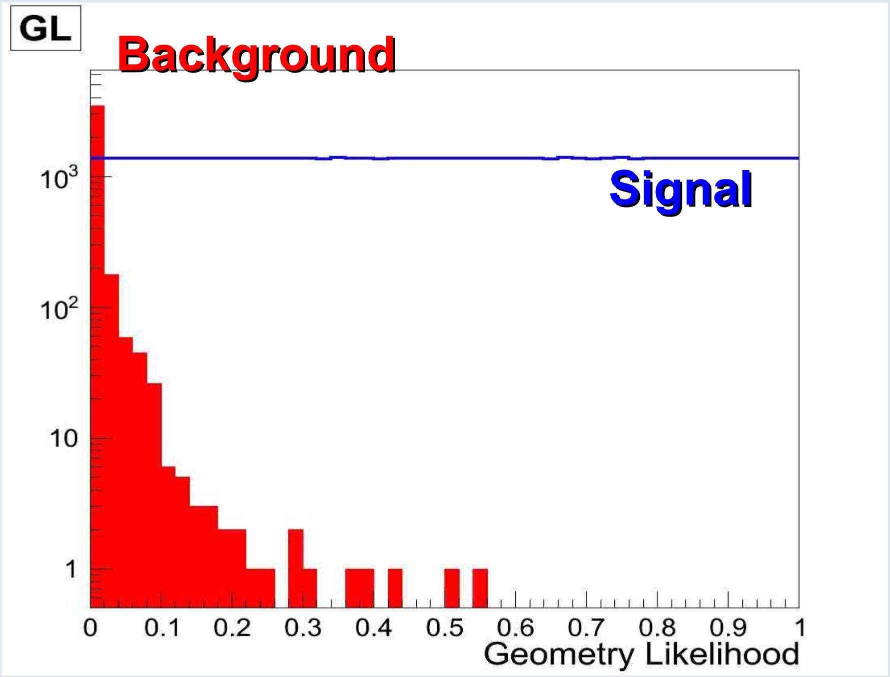
Possible channels:
$B+ \rightarrow J/\psi K+$,
$B_{s,d} \rightarrow h^+ h^-$, ...

The Geometry Likelihood

Geometry Likelihood: variable that contains most of the information related to the geometry of the event.



Proper Time Bs (SV-PV, P)
Isolation (both muons)
Impact Parameter (mother)
Minimum IPS (muons)
Distance Of Closest Approach (muons)

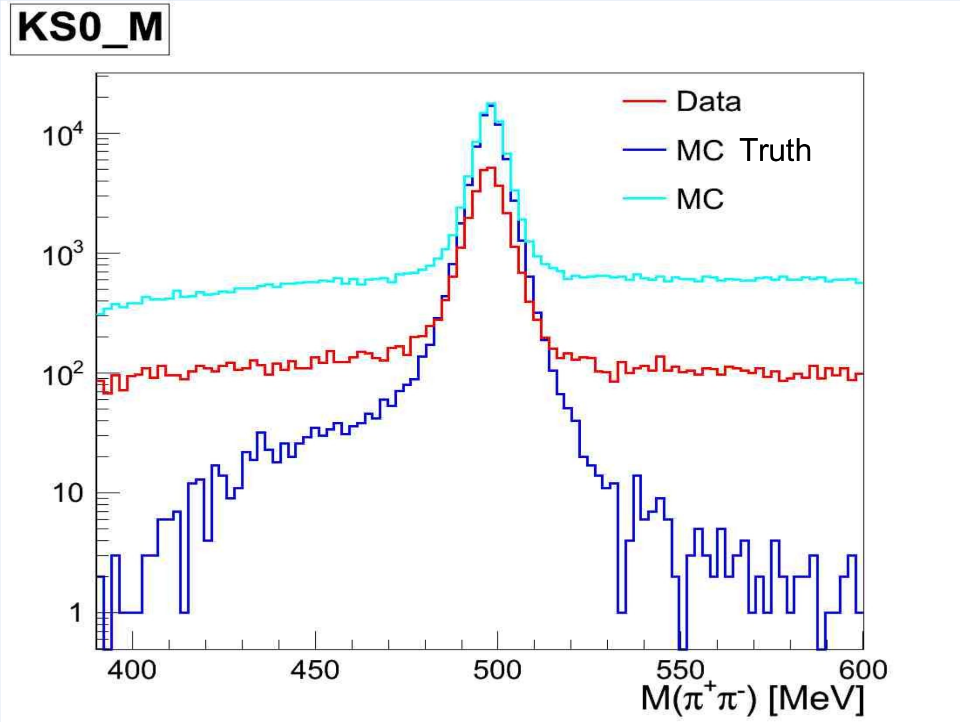


Calibration of the GL using Data @7 TeV

MC/Data Comparison using $K_s \rightarrow \pi^+ \pi^-$

* Reasonable because K_s and B_s are both V0's

Isolation not used

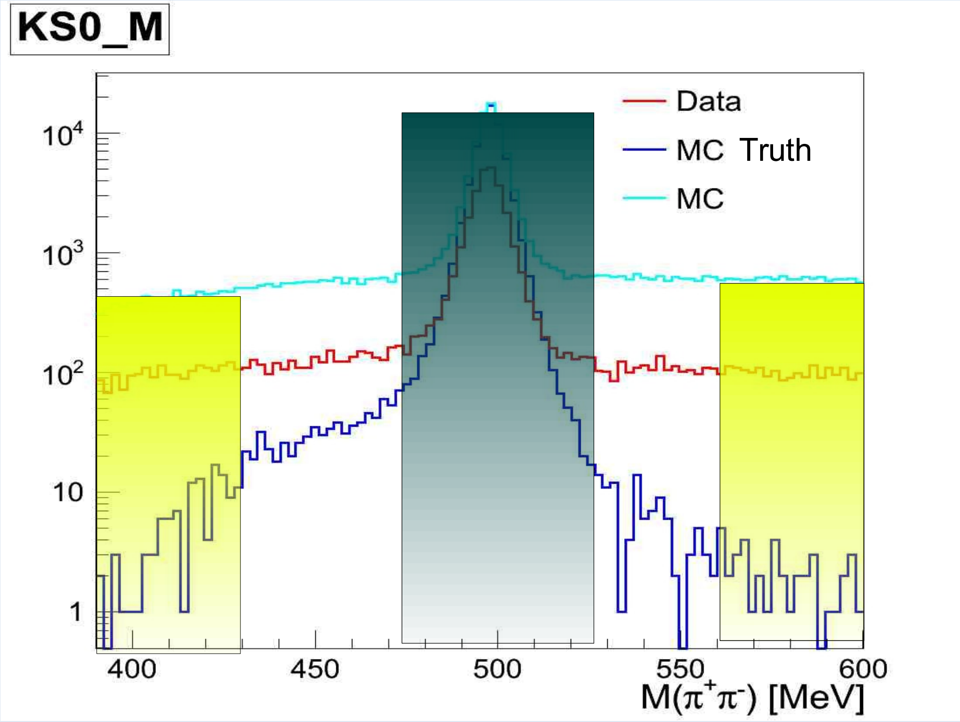


Mass plot distributions obtained from Minimun bias events

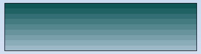
Calibration of the GL using Data @7 TeV

MC/Data Comparison using $K_s \rightarrow \pi^+ \pi^-$

* Reasonable because K_s and B_s are both V0's



"Training":

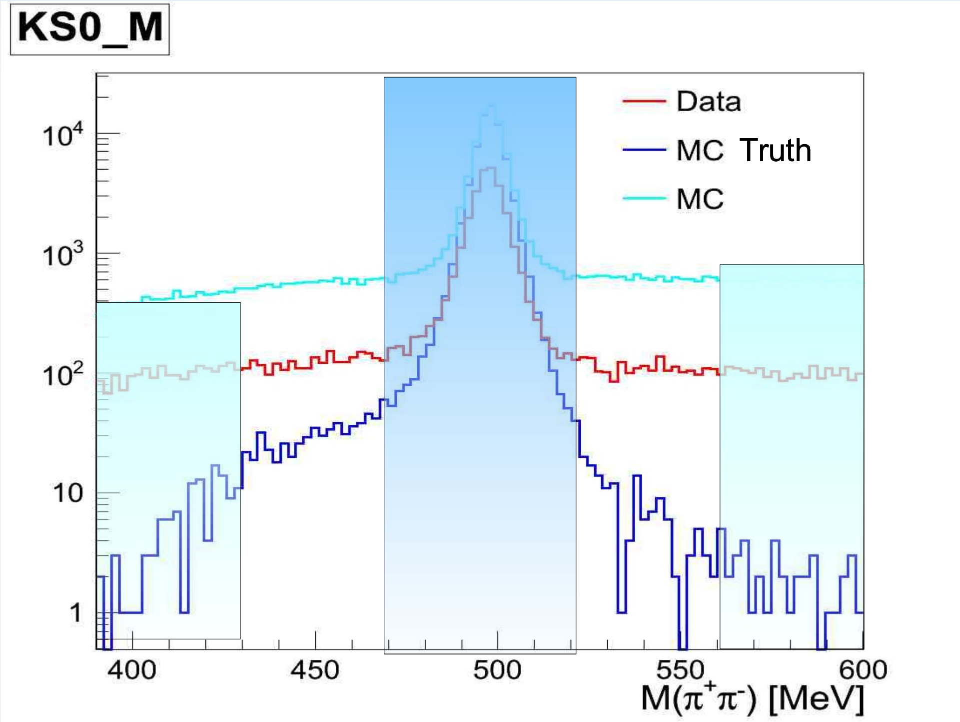

As Signal (in MCtruth)


As Background

Calibration of the GL using Data @7 TeV

MC/Data Comparison using $K_s \to \pi^+ \pi^-$

* Reasonable because K_s and B_s are both V0's



"Training":

As Signal (in MCtruth)

As Background

Then I apply to:

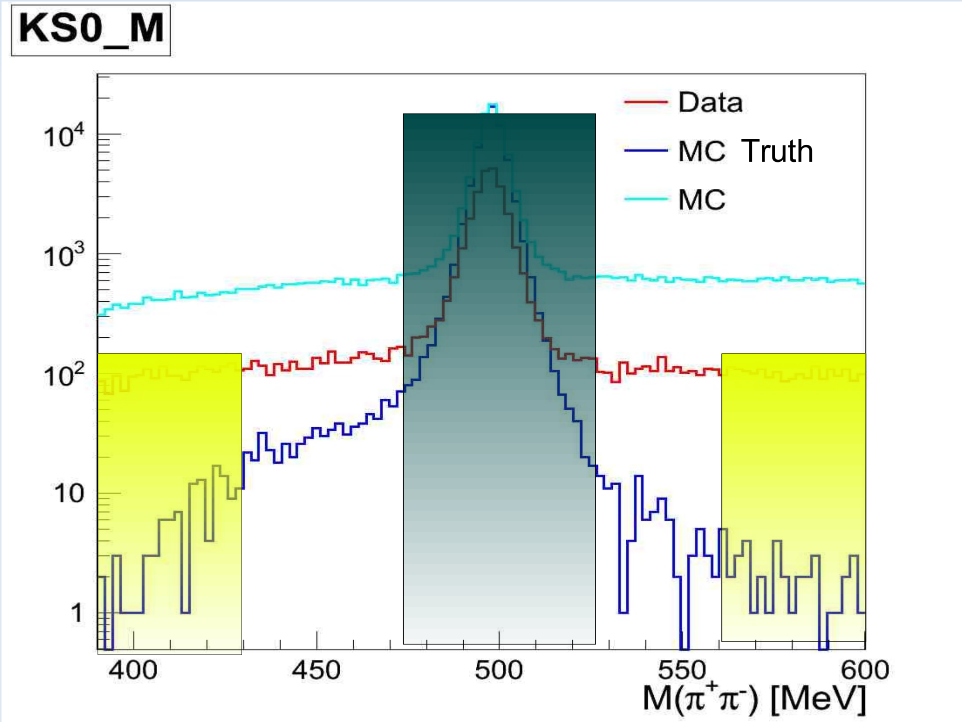
MC peak

MC sides

Calibration of the GL using Data @7 TeV

MC/Data Comparison using $K_s \rightarrow \pi^+ \pi^-$

* Reasonable because K_s and B_s are both V0's



"Training" for Data:

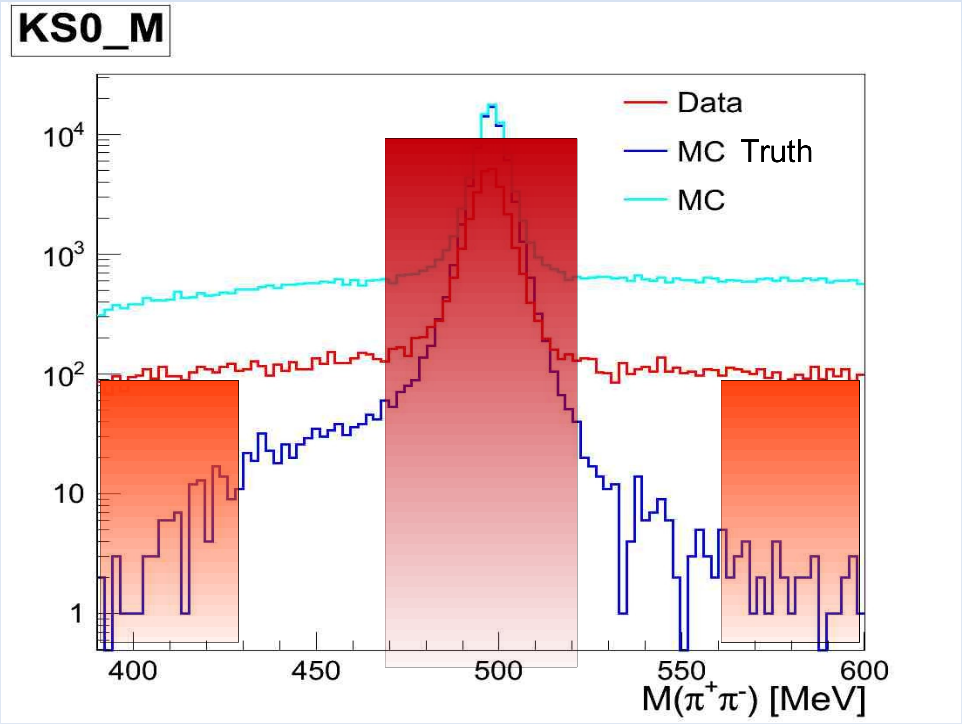
As Signal (in MCtruth)

As Background

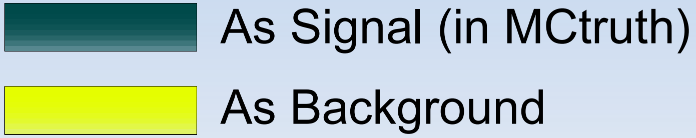
Calibration of the GL using Data @7 TeV

MC/Data Comparison using $K_s \rightarrow \pi^+ \pi^-$

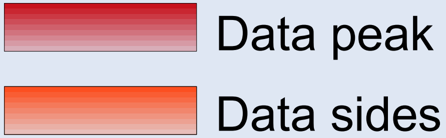
* Reasonable because K_s and B_s are both V0's



"Training" for Data:

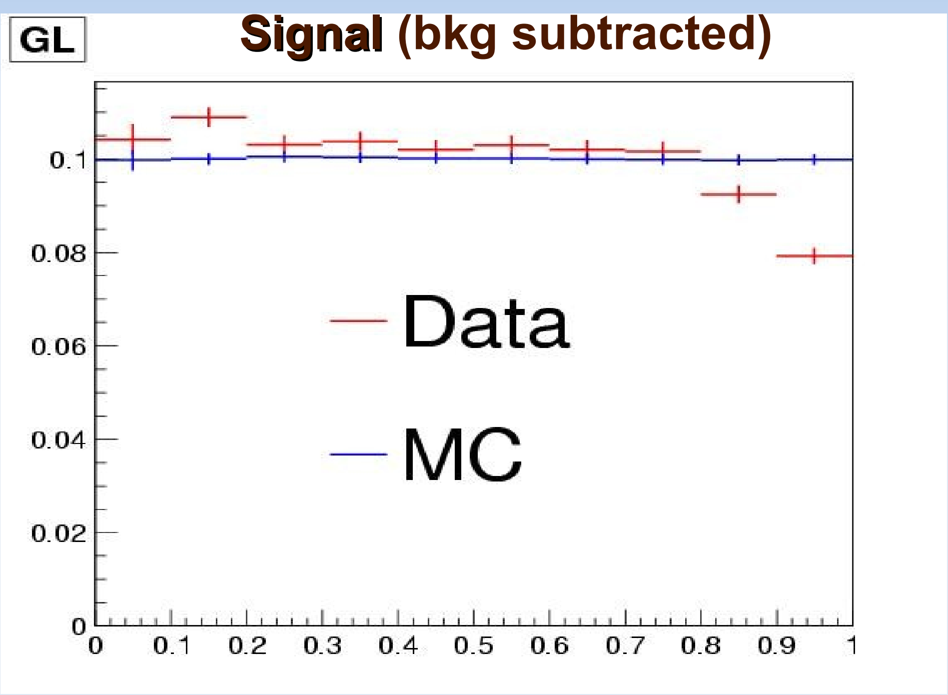


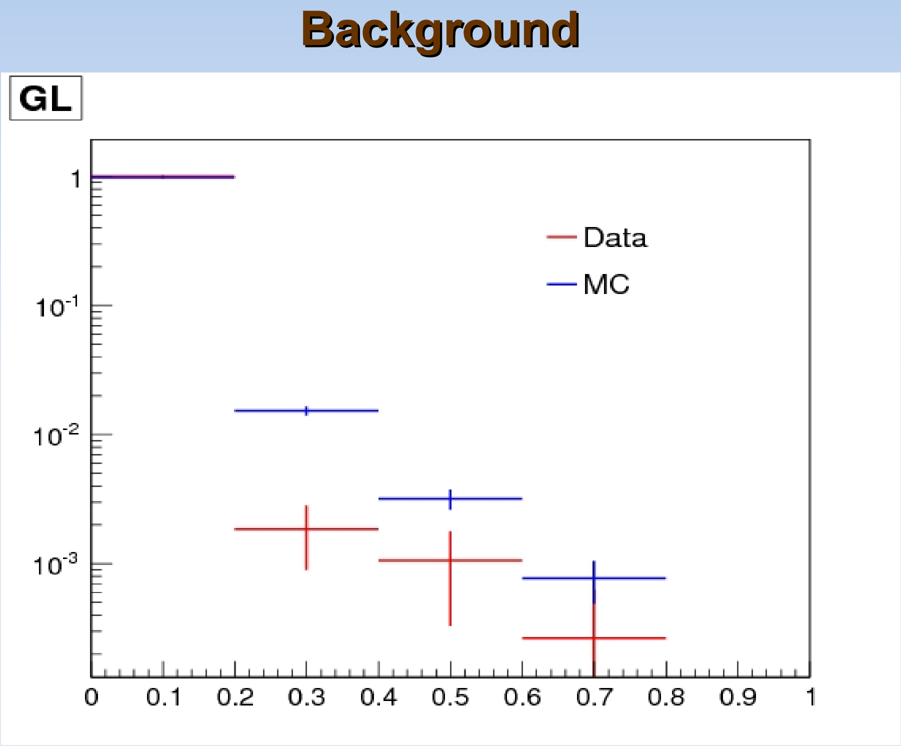
Then I apply to:



Calibration of the GL using Data @7 TeV

MC/Data Comparison using $K_s \rightarrow \pi^+ \pi^-$



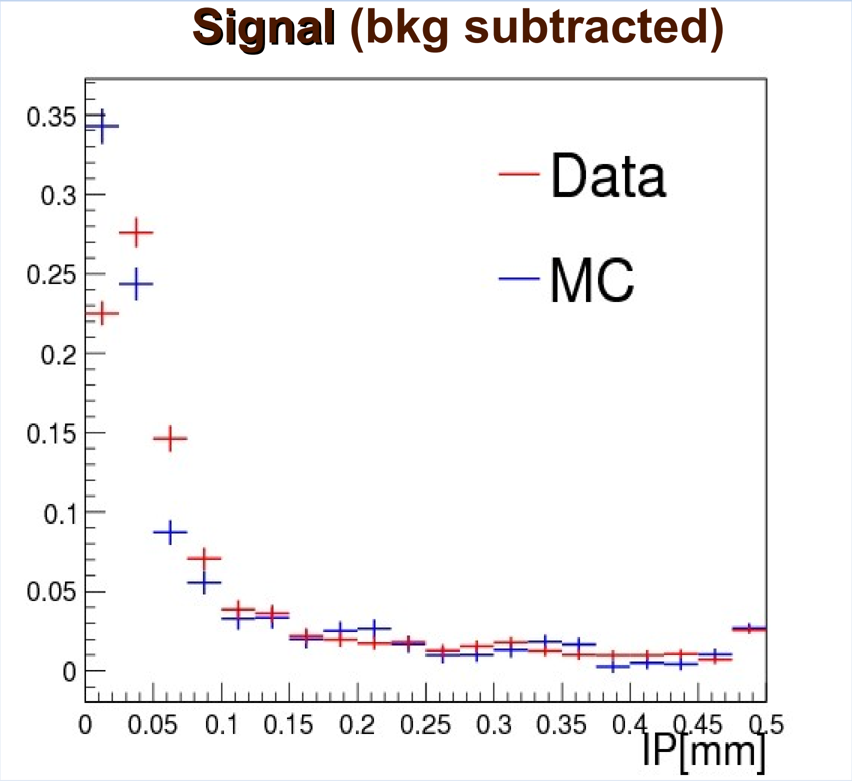


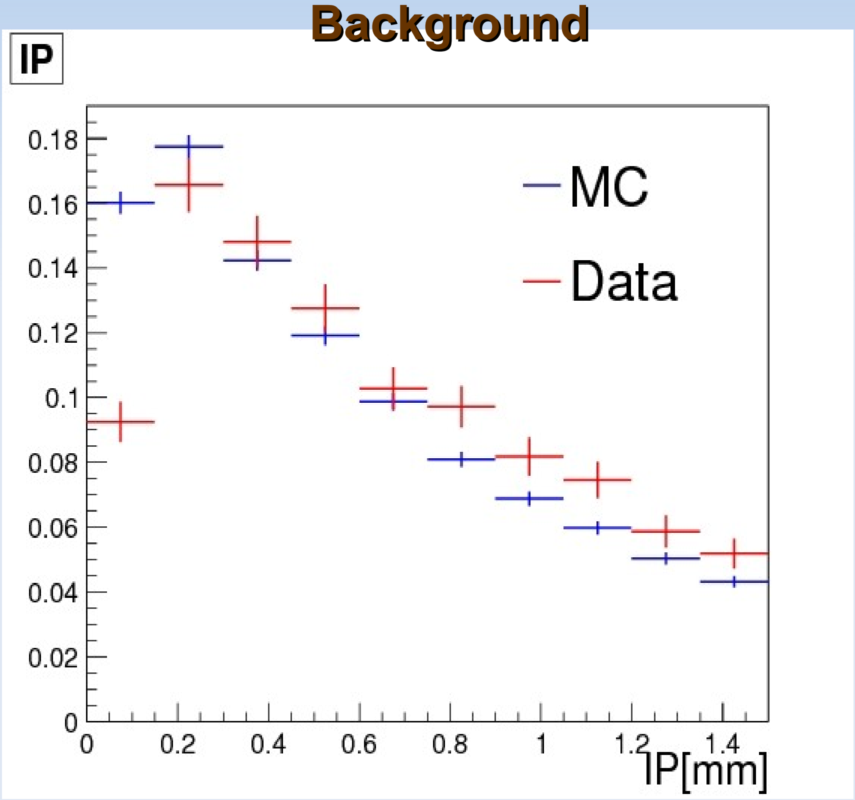
Remarkable good agreement between Data/MC distributions for signal events

Lower contribution in Data for GL values close to 1 (Signal)

Calibration of the GL using Data @7 TeV

MC/Data Comparison using $K_s \rightarrow \pi^+ \pi^-$

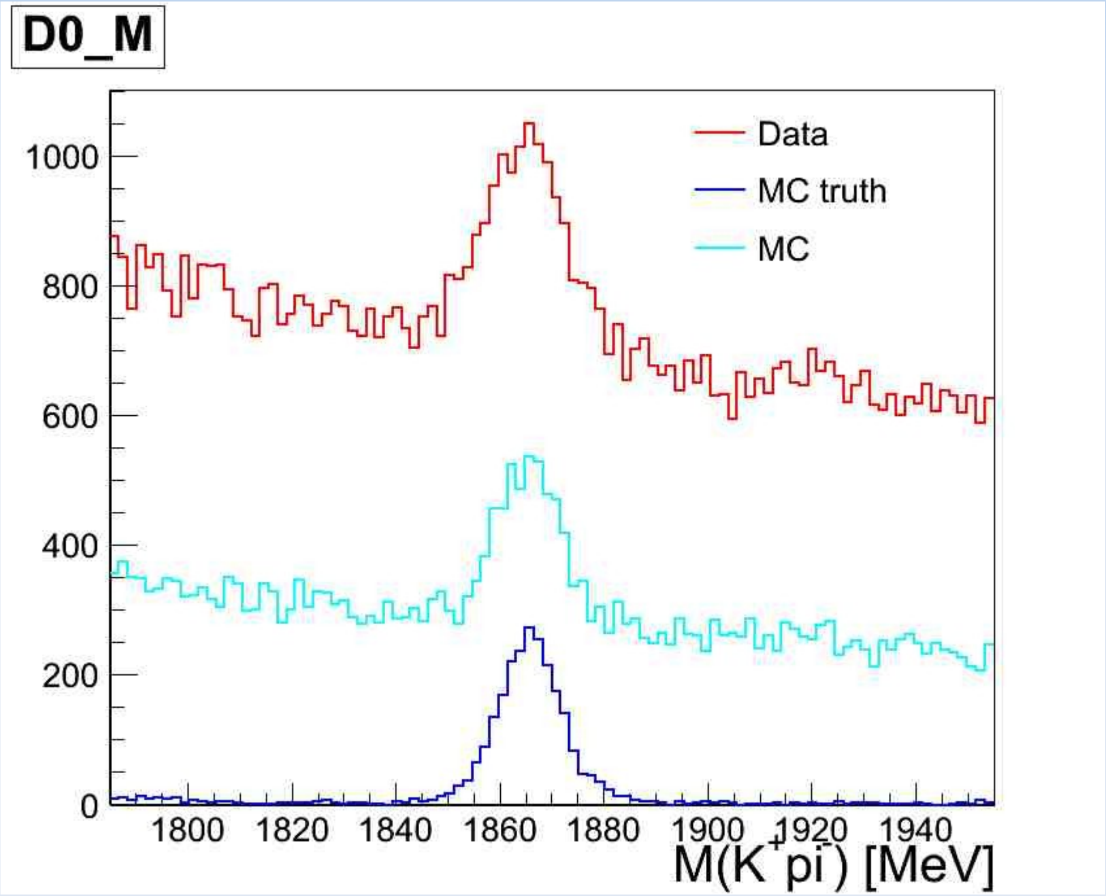




* Important Data/MC Impact Parameter difference.

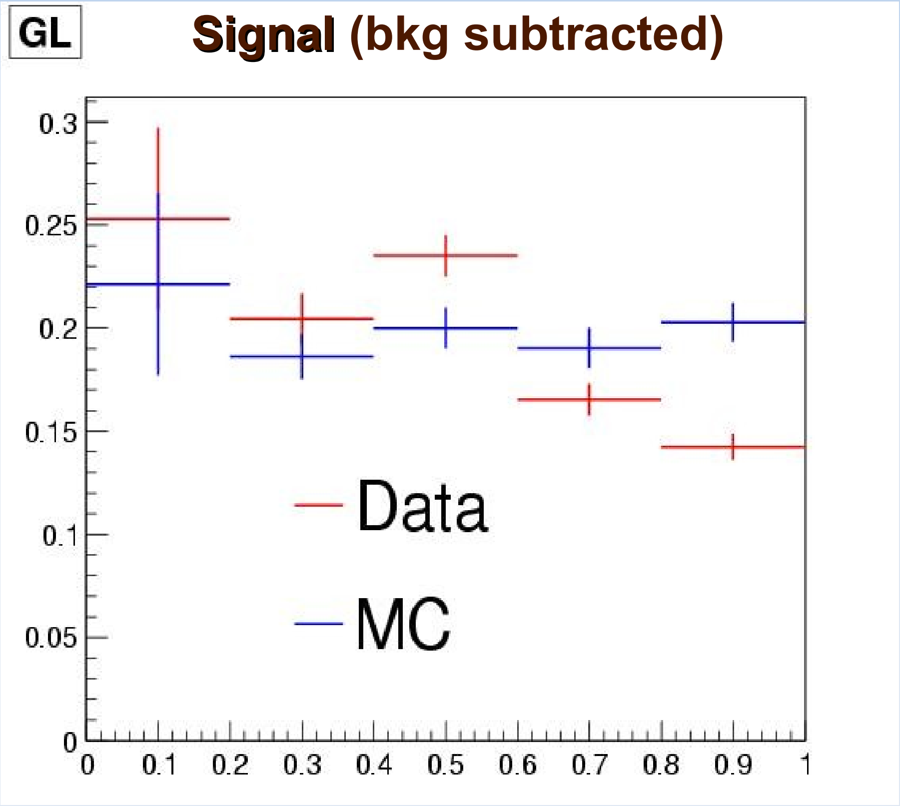
Calibration of the GL using Data @7 TeV

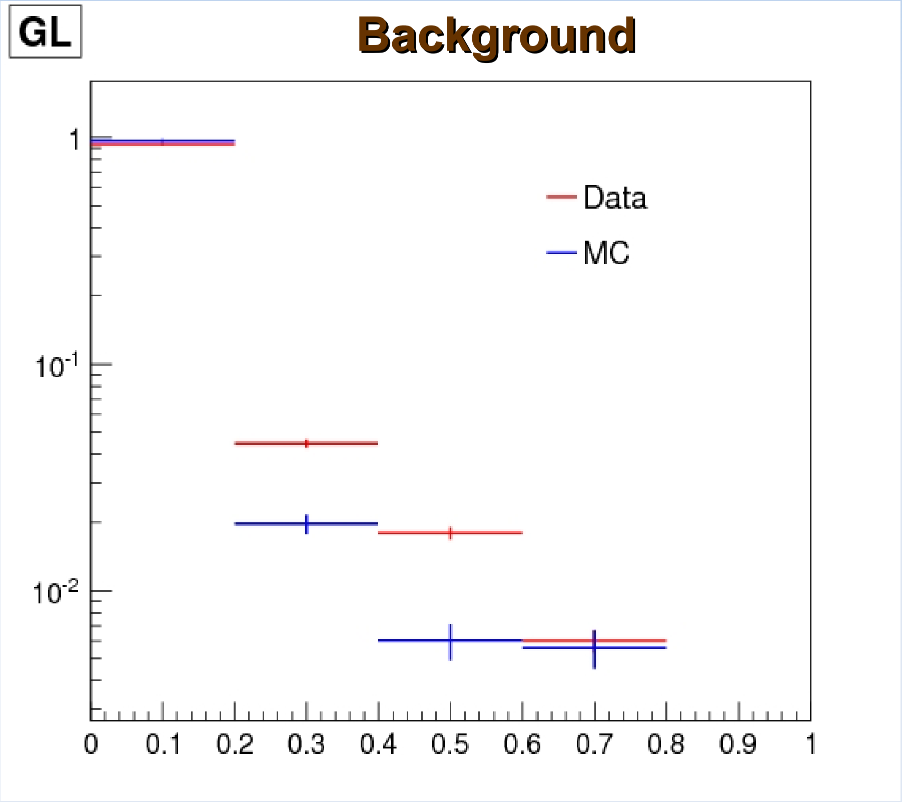
MC/Data Comparison using $D_0 \rightarrow K^+ \pi^-$



Calibration of the GL using Data @7 TeV

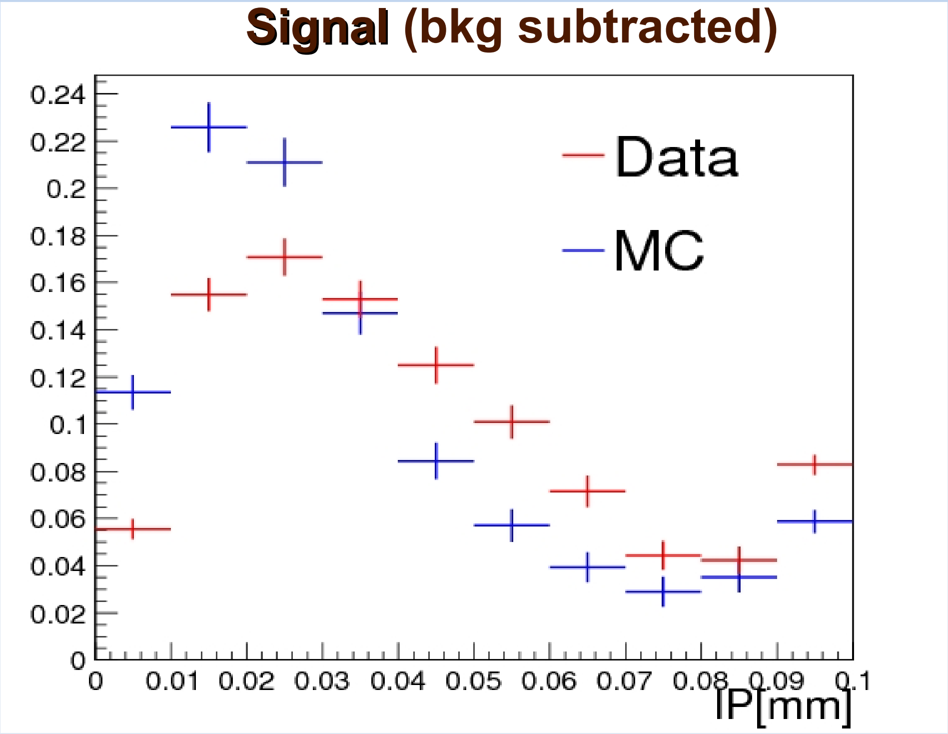
MC/Data Comparison using $D_0 \rightarrow K^+ \pi^-$

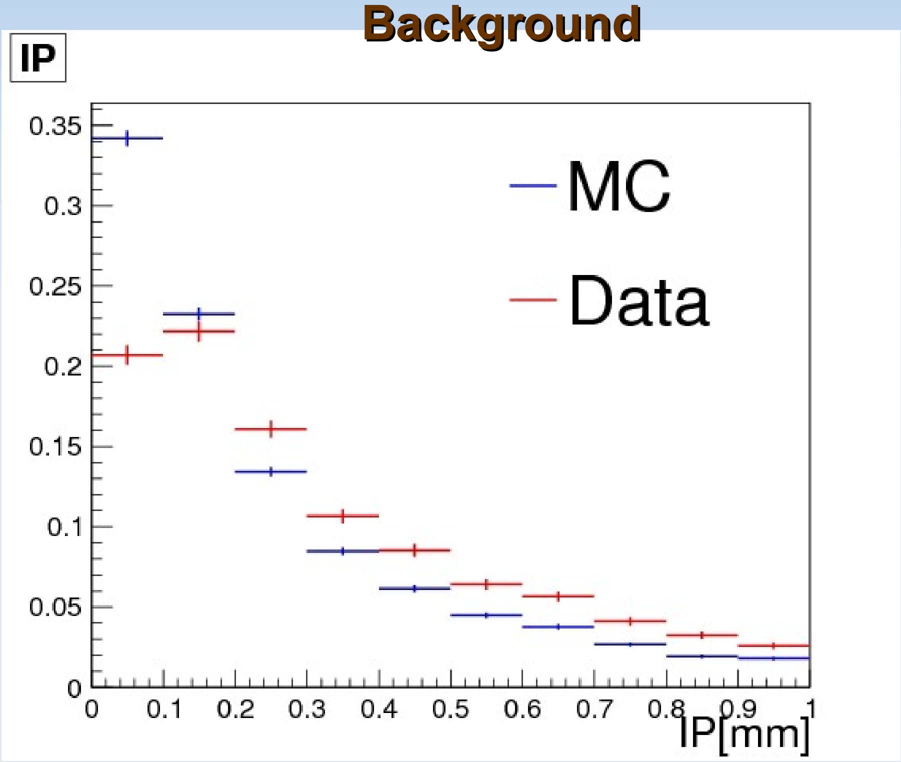




Calibration of the GL using Data @7 TeV

MC/Data Comparison using $D_0 \rightarrow K^+ \pi^-$





Conclusions and Prospects

- An overview of the motivations to study $B_s \to \mu^+ \mu^-$ it has been presented.
- I briefly introduced the analysis strategy.
- It has been discussed one of the key points of the Analysis Strategy which is the Geometry Likelihood.
- First tests of the GL machinery using 2010 Data.
- These tests have shown the 'good shape' of our GL and moreover have pointed out some problems of tracking being studied by the collaboration.
- One of our goals is to try and get a Geometry Likelihood that relies as little as possible on MC, using pdfs for signal derived from Data control samples.
- Going through all the Analysis steps will be my main objective during the near future.


Found It!!!
Congratulations, it only took you 65298 seconds
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Other leptonic very rare B decays: **(in the SM)**

$$B\left(B_s \to \tau^+\tau^-\right) = (8.20 \pm 0.31) \cdot 10^{-7}$$

$$B\left(B_d \to \tau^+\tau^-\right) = (2.23 \pm 0.08) \cdot 10^{-8}$$

Reconstruction rather difficult

$$B\left(B_s \to e^+e^-\right) = (9.05 \pm 0.34) \cdot 10^{-14}$$

$$B\left(B_d \to e^+e^-\right) = (2.49 \pm 0.09) \cdot 10^{-15}$$

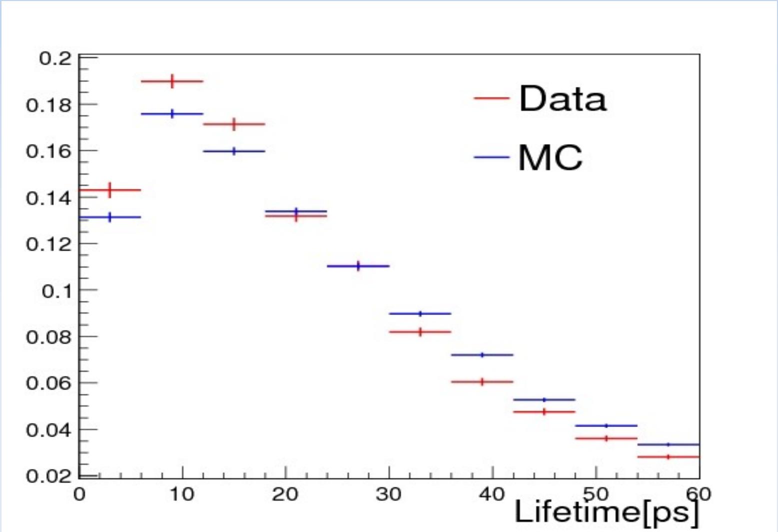
BR ↓↓

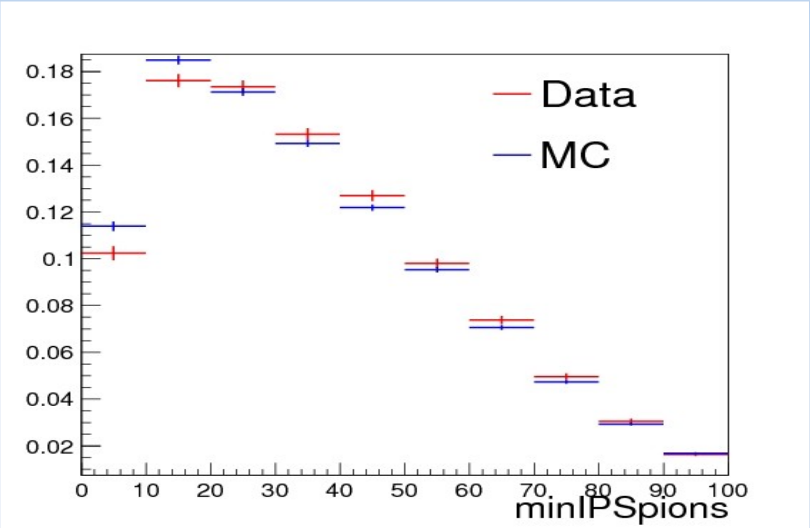
$$B\left(B_d \to \mu^+\mu^-\right) = (1.06 \pm 0.04) \cdot 10^{-10}$$

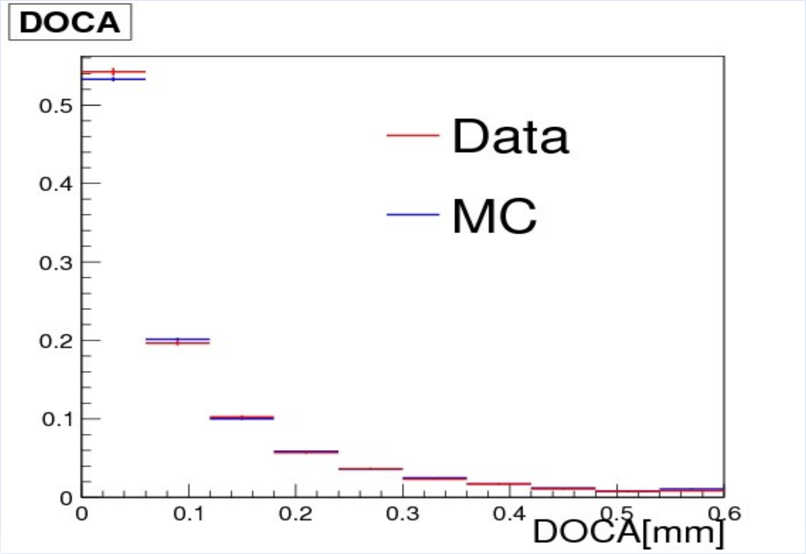
Also a promising mode to test SM !!

Single Variables for Signal (bkg subtracted)

MC/Data Comparison using $K_s \rightarrow \pi^+ \pi^-$

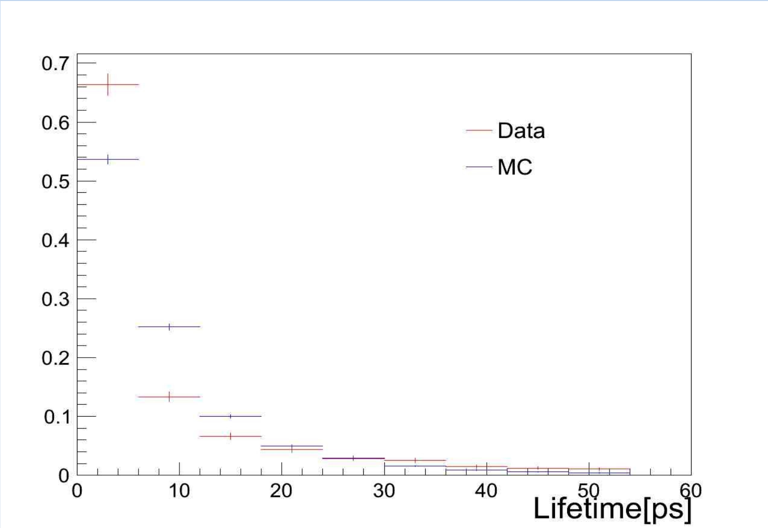


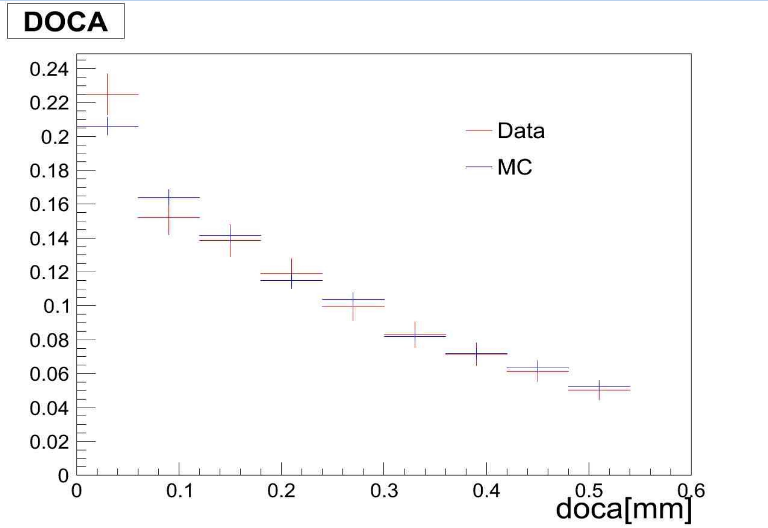


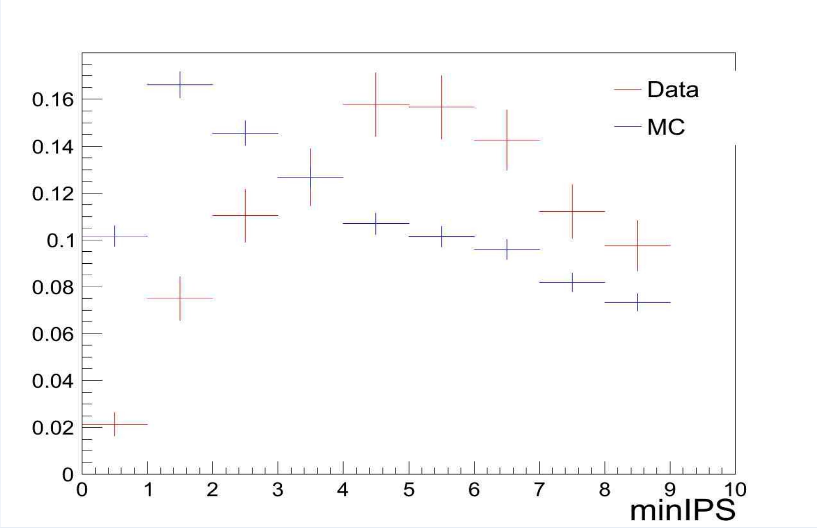


Single Variables for Background

MC/Data Comparison using $K_s \rightarrow \pi^+ \pi^-$

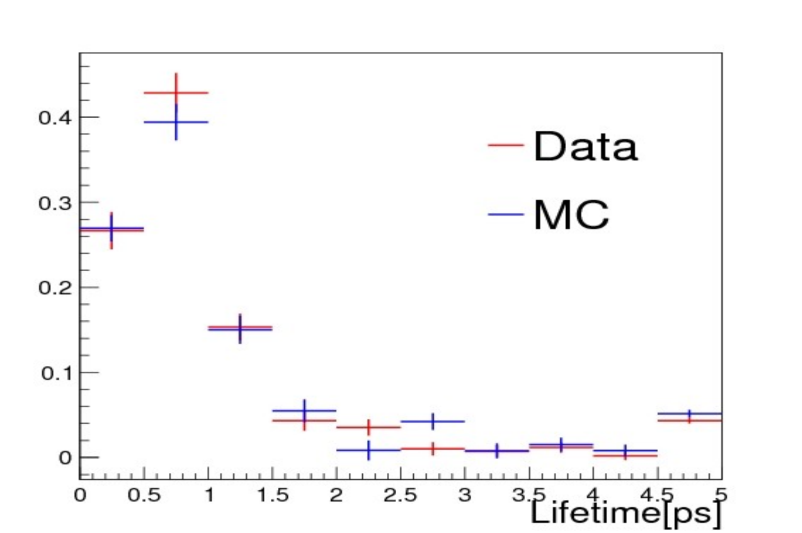


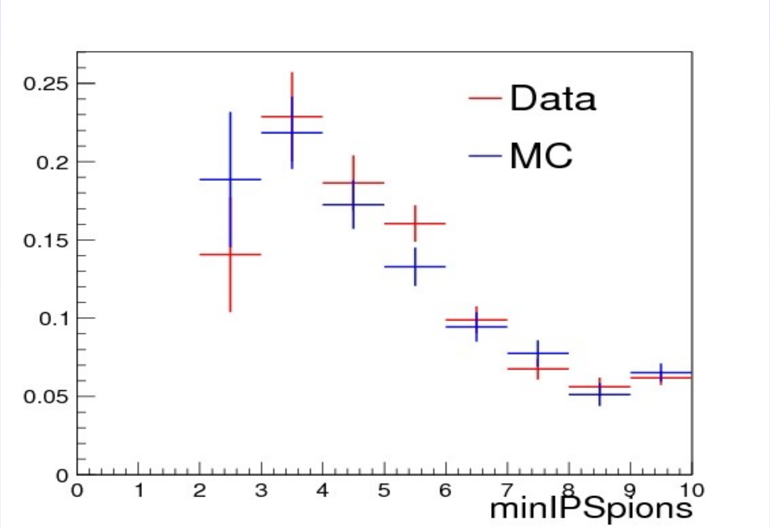


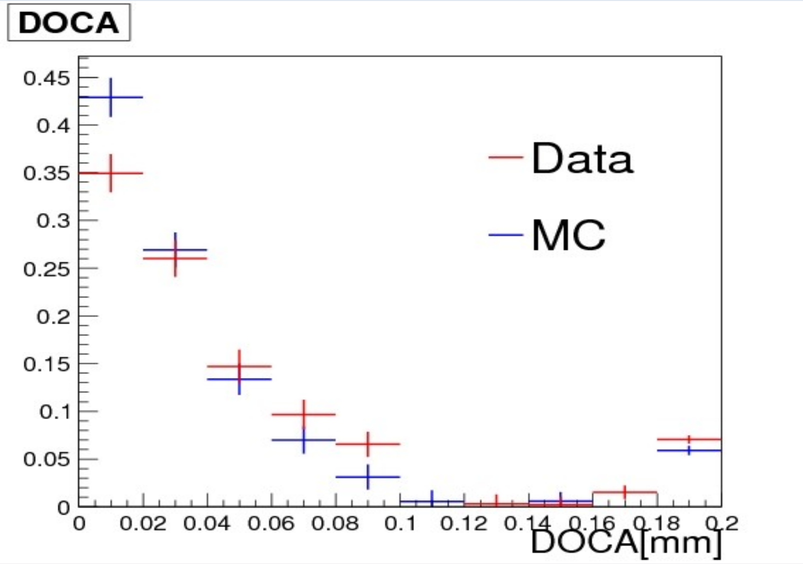


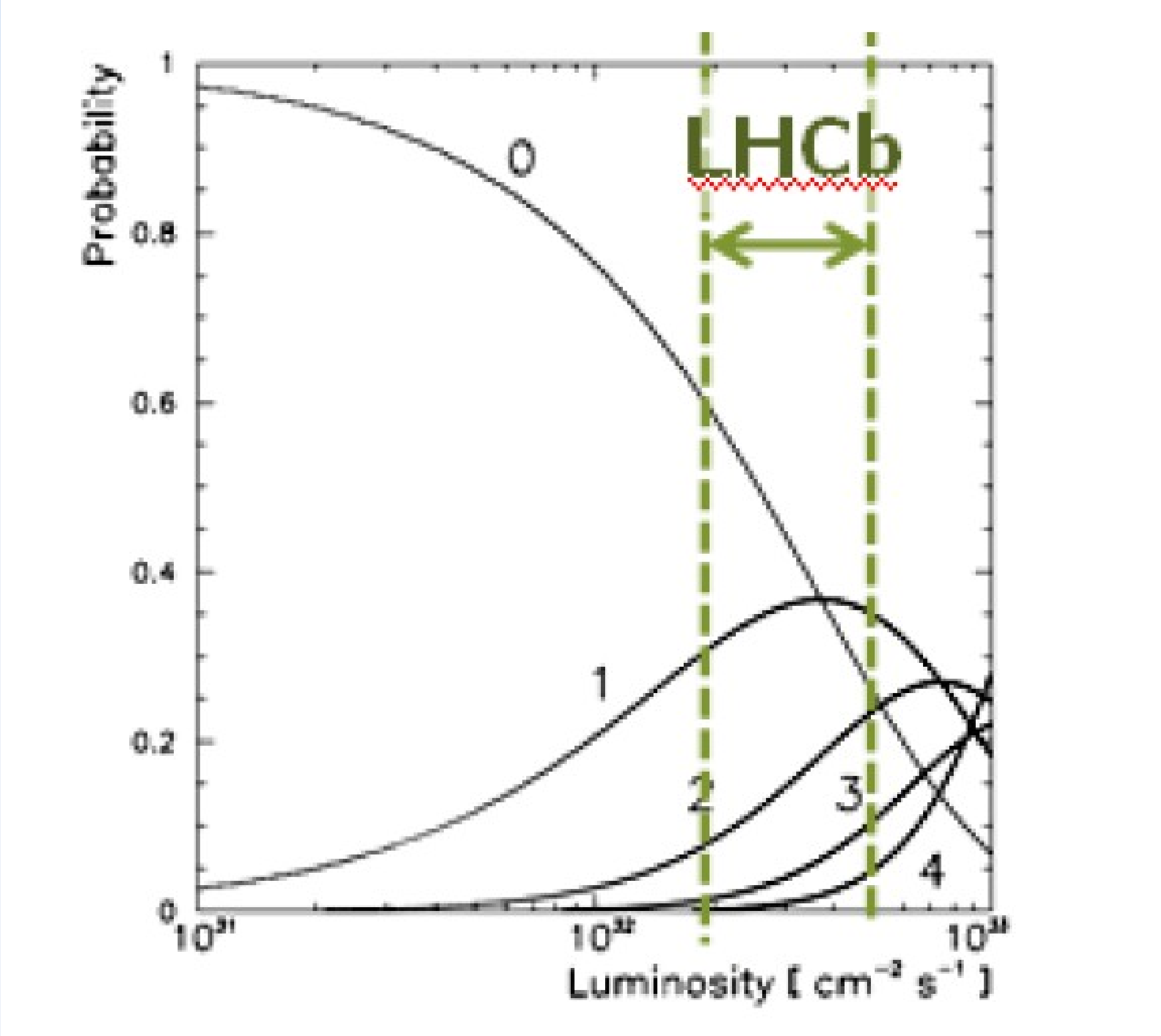
Single Variables for Signal (bkg subtracted)

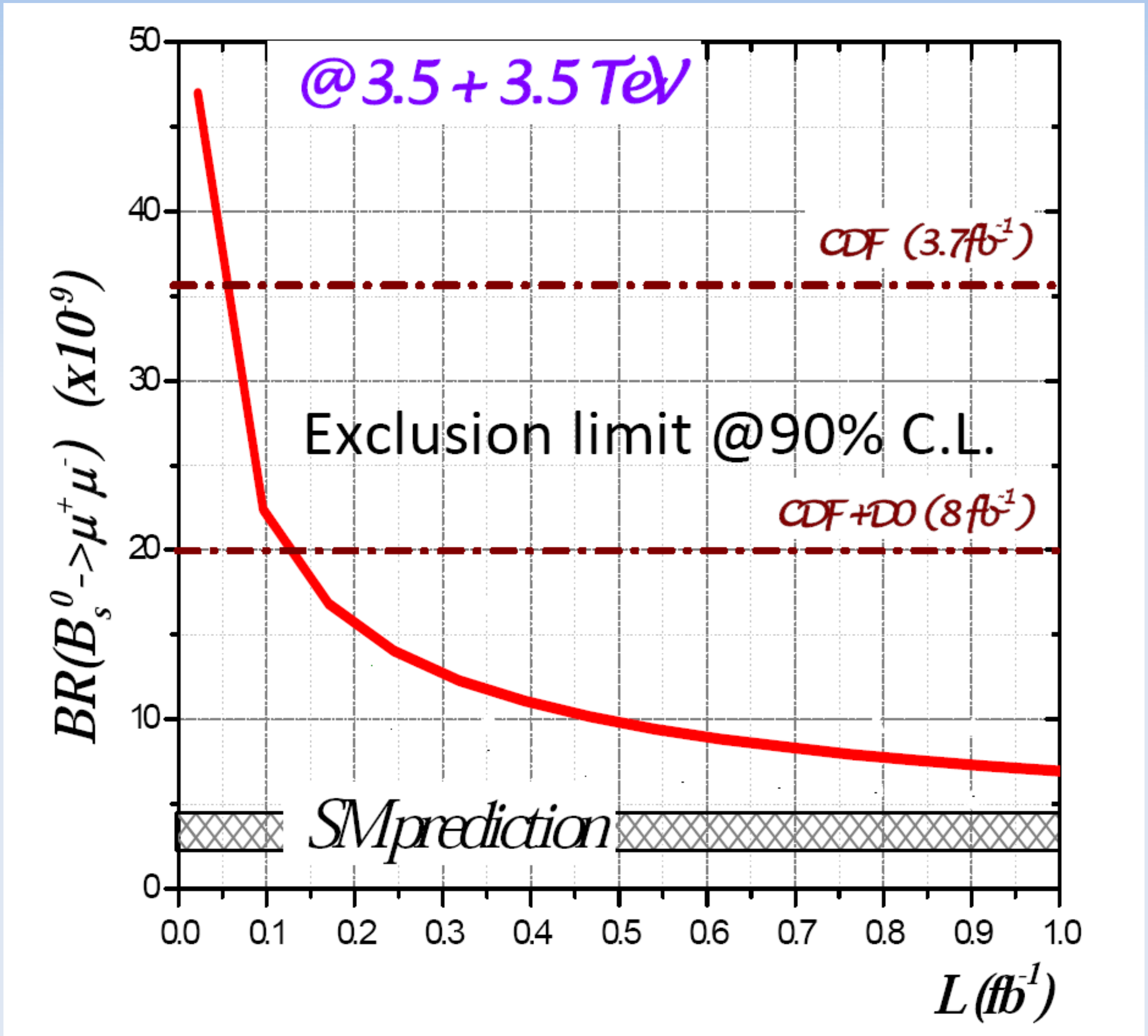
MC/Data Comparison using $D_0 \rightarrow K^+ \pi^-$








LHCb
Probability
Luminosity [cm⁻² s⁻¹]
0
1
2
3
4
0.2
0.4
0.6
0.8



@3.5+3.5 TeV
CDF (3.7fb-1)
Exclusion limit @90% C.L.
CDF+D0 (8fb-1)
SM prediction
BR(Bs0->μ+μ-) (x10-9)
L(fb-1)
0
10
20
30
40
50
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0