Search for BR($B_s \rightarrow \mu^+ \mu^-$) at the LHCb Detector

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Journées Jeunes Chercheurs 2010

Outline

1. Introduction
2. LHCb Detector (Trigger)
3. Analysis overview
4. Calibration studies
5. Predictions
6. Conclusion

Motivation

- Good theoretical prediction for $BR(B_s \rightarrow \mu^+ \mu^-)$.
- From experimental point of view is feasible, although represents a challenge in terms of back ground rejection.
- Already tried to measure → CDF/D0 experimental upper limit.
- There is an important gap between the prediction and exp. upper limit.
- $B_s \rightarrow \mu^+ \mu^-$ is a key decay to find indirect indications of New Physics.
- It has become one of the golden channels at LHCb (running conditions).

Introduction

$B_s \rightarrow \mu^+ \mu^-$ within the Standard Model (SM)

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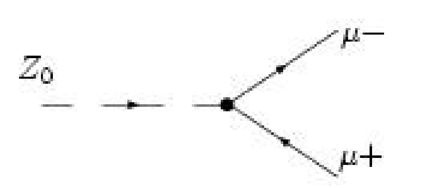

Conservation of charge → a pair of muons comes from a Neutral Current (NC)

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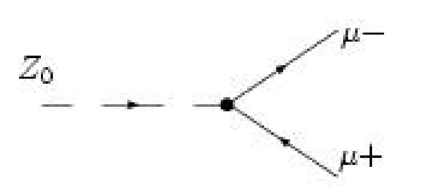

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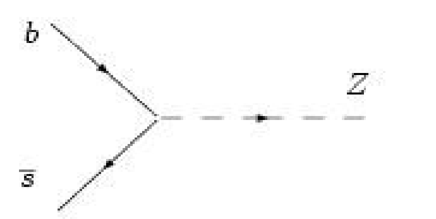

But... a B_s meson cannot couple to a NC (structure of the SM)

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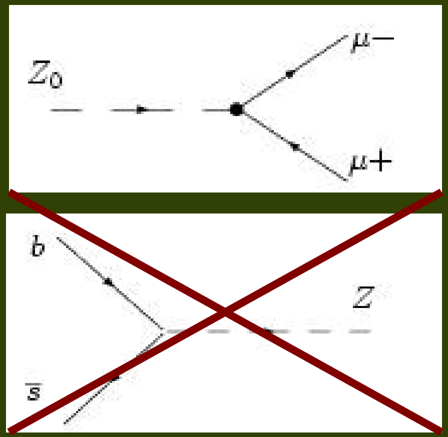

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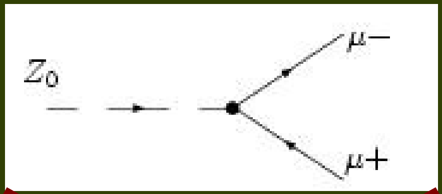

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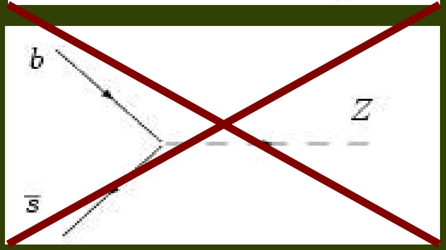

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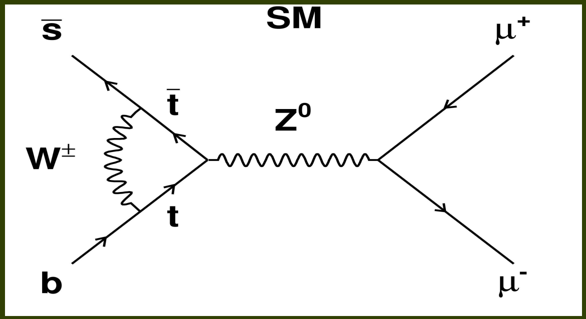

Loop Diagrams (and Box Diagrams)
Flavor Changing NC (**FCNC**)

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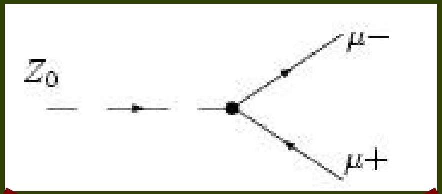

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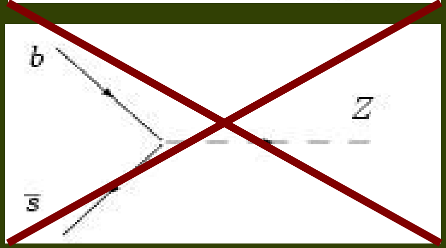

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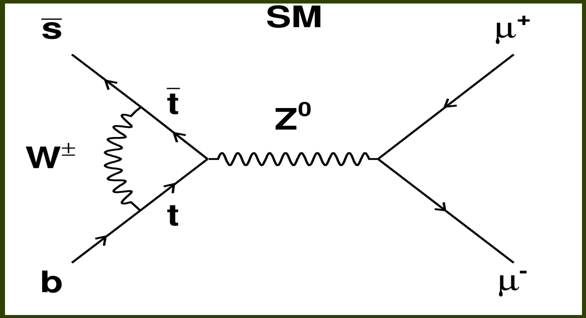

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Loop + Helicity Suppression $(m_\mu/m_{Bs})^2$ → Low BR

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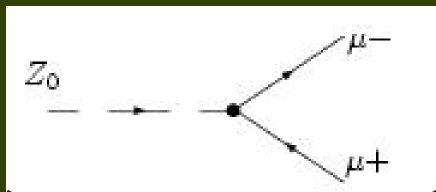

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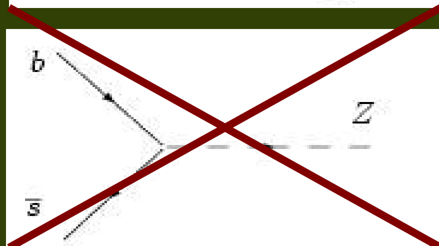

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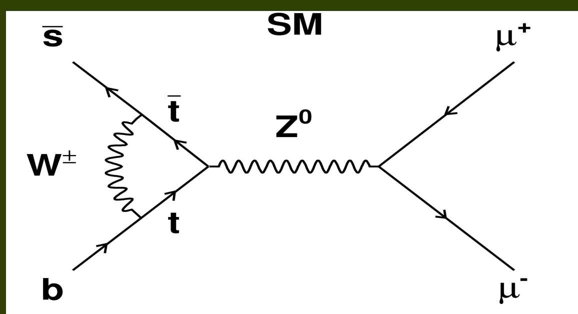

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$BR(B_S \rightarrow \mu+ \mu-)^{SM} = (3.35 \pm 0.32) \cdot 10^{-9}$ [M. Blanke *et al.*, arXiv:hep-ph/0604057]

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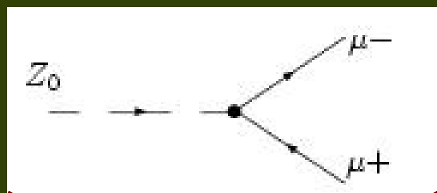

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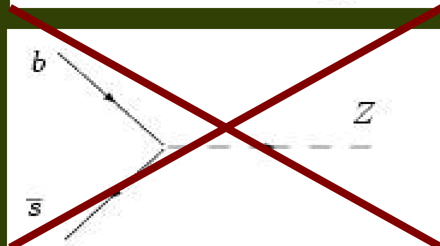

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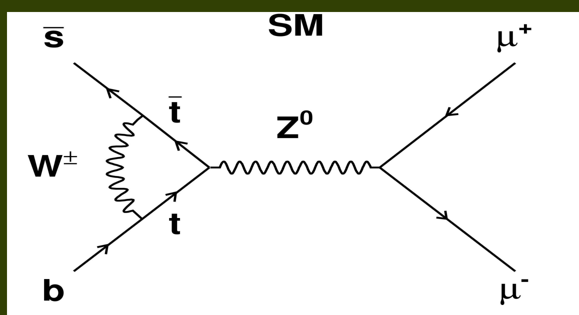

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$BR(B_S \rightarrow \mu+ \mu-)^{90\%CL} < 3.6 \cdot 10^{-8}$ (experimental upper limit) [*CDF Note 9892*]


Found It!!!
Congratulations, it only took you 65298 seconds
www.jolyon.co.uk

$B_s \rightarrow \mu^+ \mu^-$ beyond the SM

Motivations for going beyond the SM

Neutrino flavor oscilations → massive particles

From astronomical observations → Dark Matter

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

NP Scenarios:

Two Higgs Doublet Models (2HDM),

Minimal Flavor Violation,

Minimal Supersymmetric Standard Model (MSSM) – and constrained versions - ,

Extra Dimensions,

Technicolor Models,

Little Higgs Models

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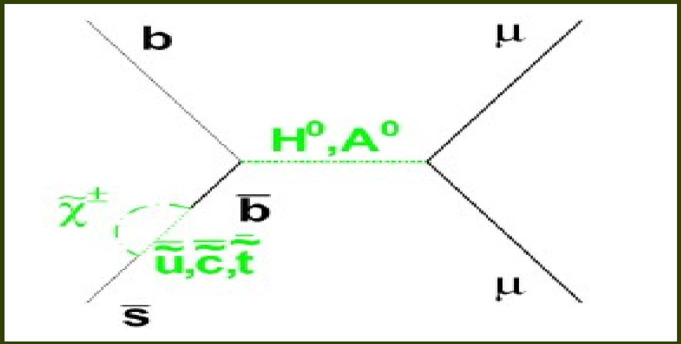
$B_s \to \mu^+ \mu^-$ in the MSSM

General feature in all SUSY gauge theories → Each particle of the SM has a partner

These 'superpartners' have the same quantum numbers but differing by spin 1/2



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

BR values run from lower than the SM prediction to current experimental upper limit

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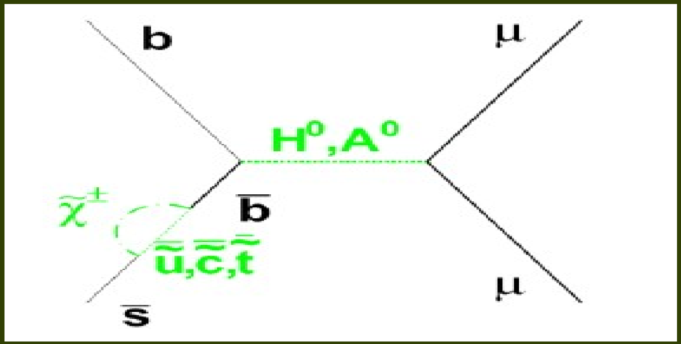

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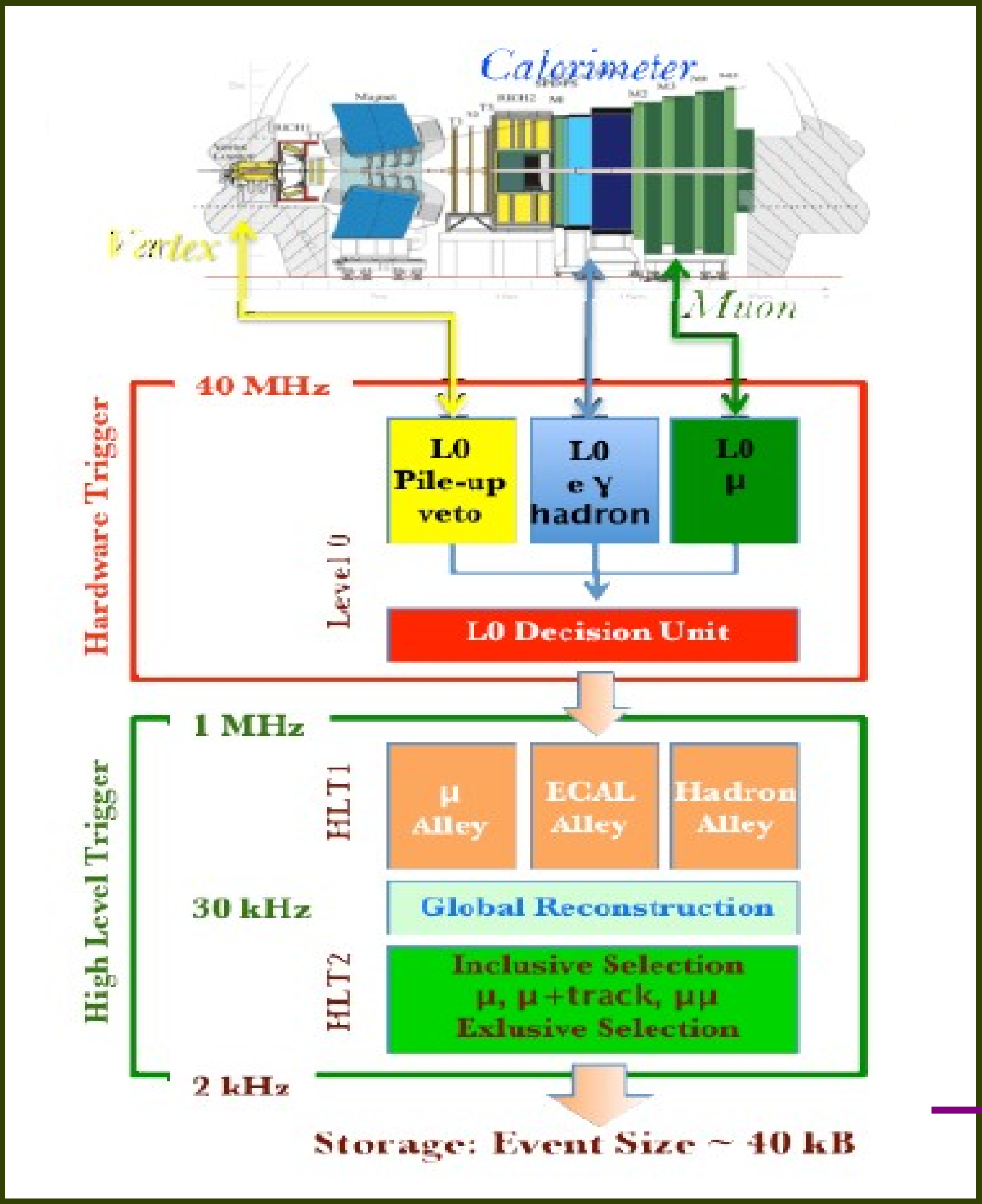
BR values run from lower than the SM prediction to current experimental upper limit

→ Measuring BR($B_s \rightarrow \mu^+ \mu^-$) *could give us a clear indication of NP*

The LHC and the LHCb Experiment

(Emilie's talk)

The Trigger System and the Stripping



Stripping Process

Offline selection with cuts on Impact Parameters, Mass, Distances of flight, χ^2 of Secondary Vertex (SV)

The Analysis Strategy

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

(Recall BR ↓↓)

1. Selection of $B_s \rightarrow \mu^+ \mu^-$ candidates according to the preselection cuts (Stripping).

2. Classification of each event according to:
   - _ Geometry Likelihood (GL): discriminant method that uses the geometry of the event.
   - _ Particle Identification Likelihood (PID): probability that the muons are indeed muons.
   - _ Invariant Mass Likelihood (IML)

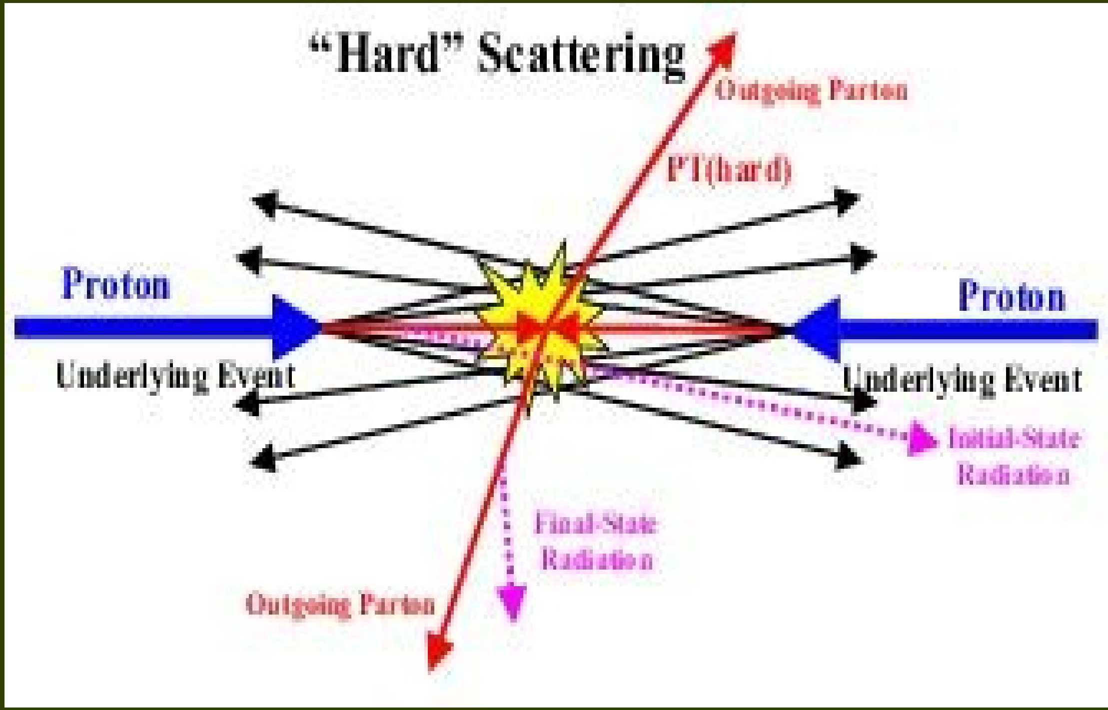
Control Channels (calibration): $B_{s,d} \rightarrow h^+ h^-$ (IML, GL), $J/\psi \rightarrow \mu^+ \mu^-$ (PID) … $D^0 \rightarrow K \pi$ (GL)

3. Normalization

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

Channels	Pros	Cons
$B^+ \rightarrow J/\psi K^+$	Trigger/PID	σ(fd/fs) = 13%
$B_{s,d} \rightarrow h^+ h^-$	Kinematics	Trig/PID
$B_s \rightarrow J/\psi \Phi$	f's cancel, Trig/PID	σ(BR) = 25%

The Geometry Likelihood



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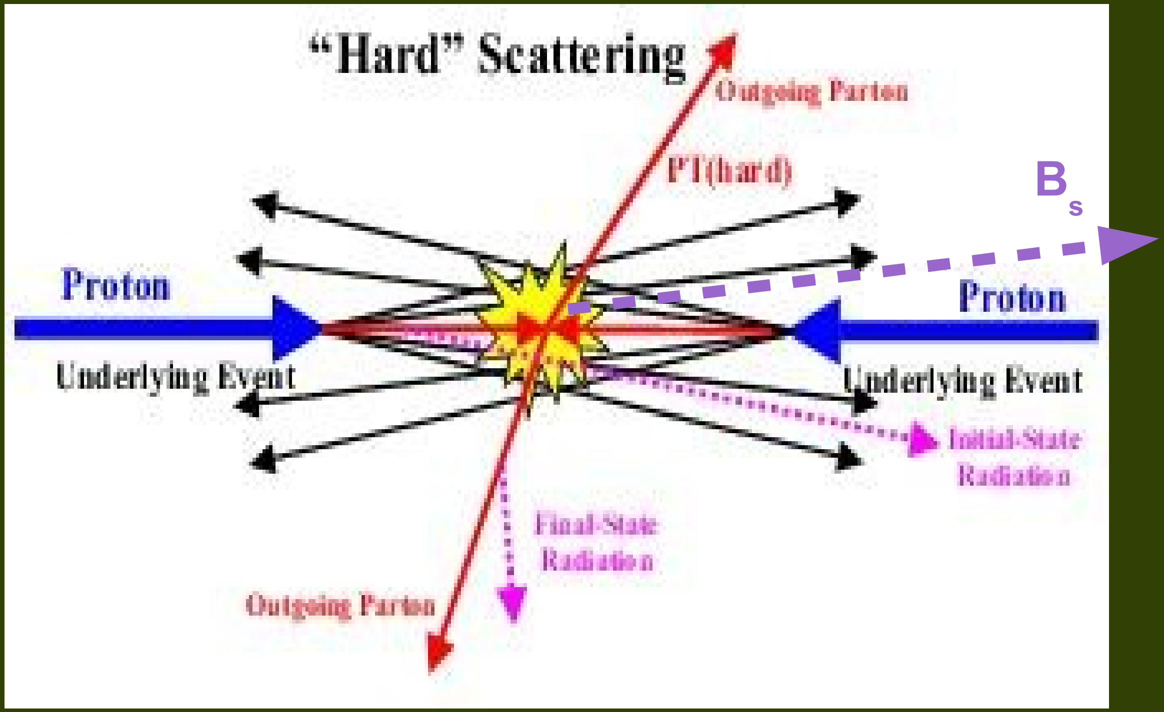

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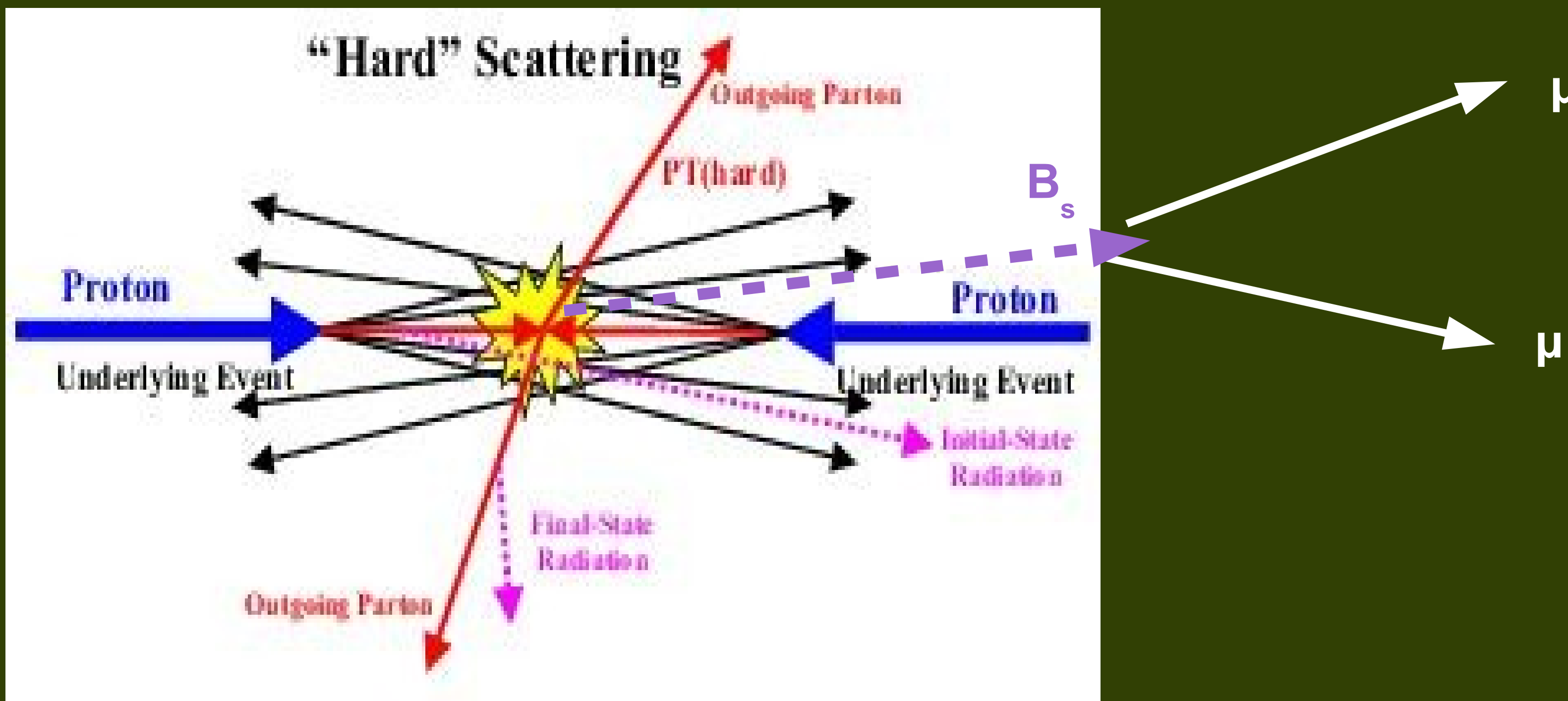

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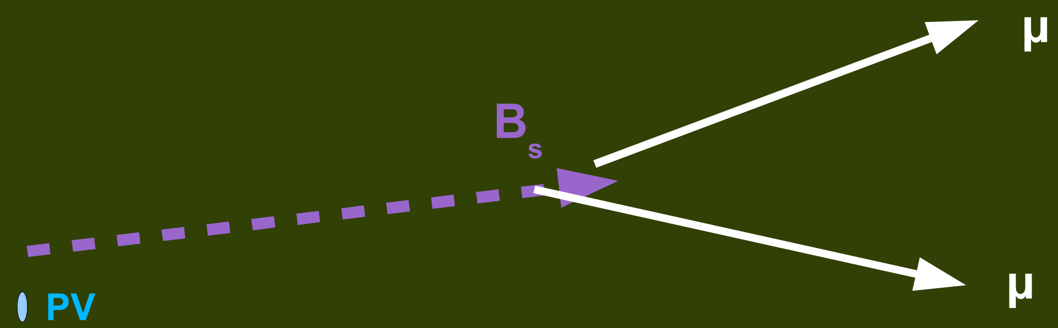

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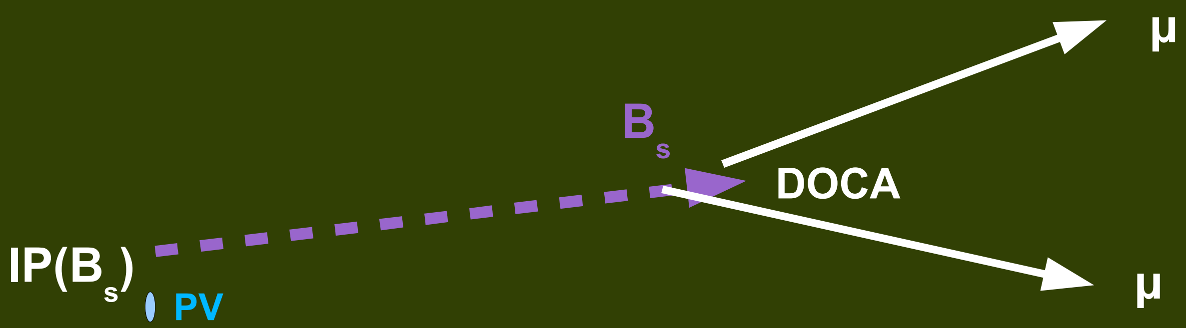

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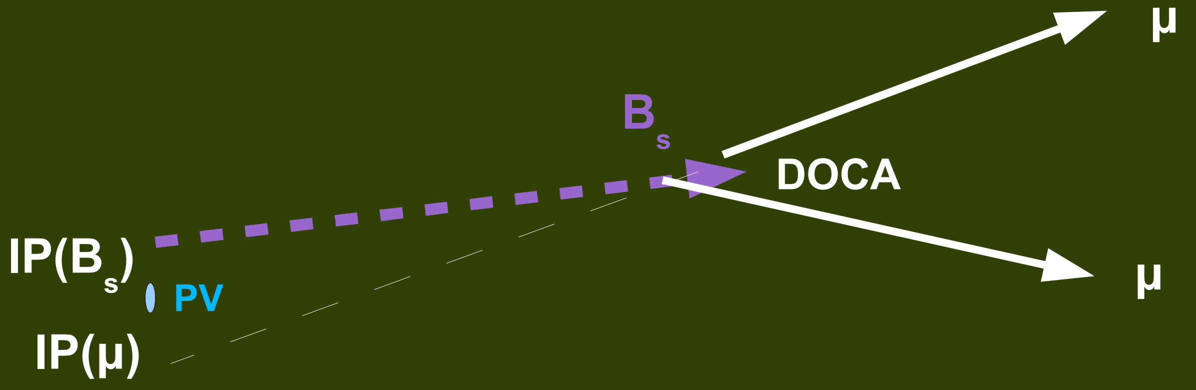

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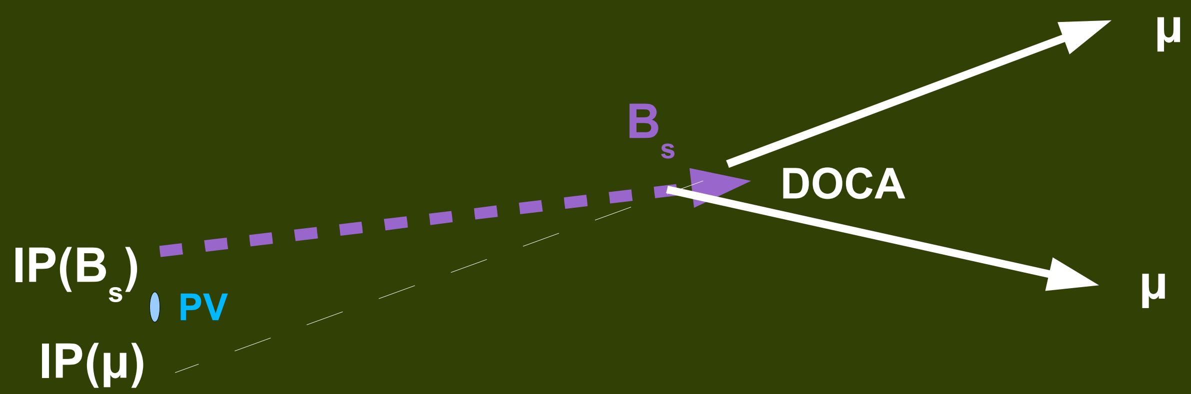


GL: **combine correlated variables to build a variable that contains most of the information related to the geometry of the event.**

Lifetime B_s (*SV-PV, P*)

Isolation (both muons)

$\min(IP(\mu_1)/\sigma(\mu_1), IP(\mu_2)/\sigma(\mu_2))$

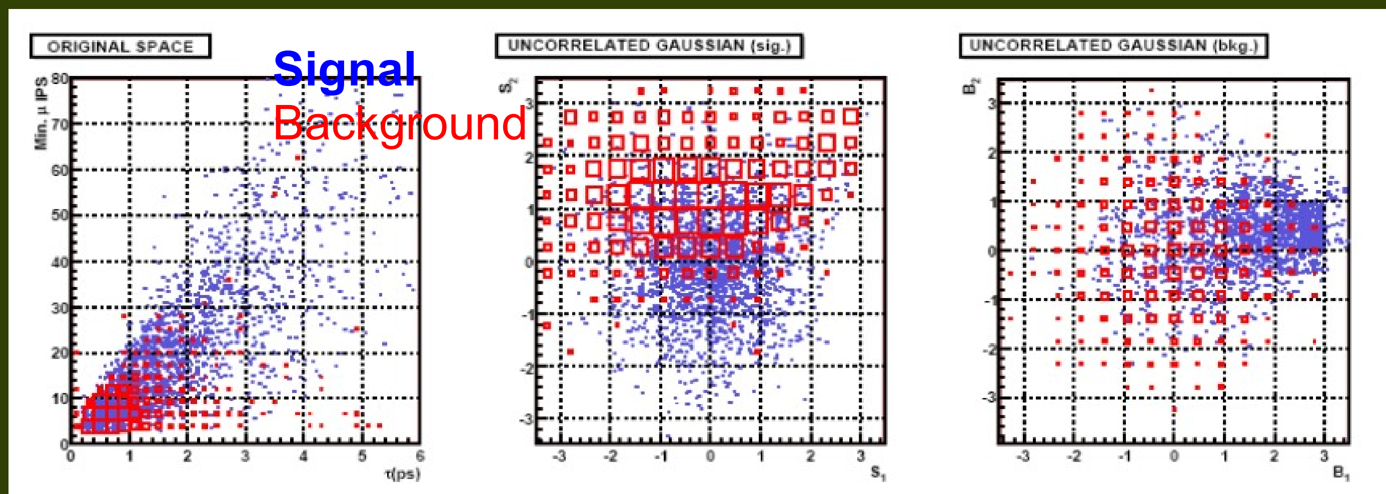
DOCA

IP (mother)

The Geometry Likelihood

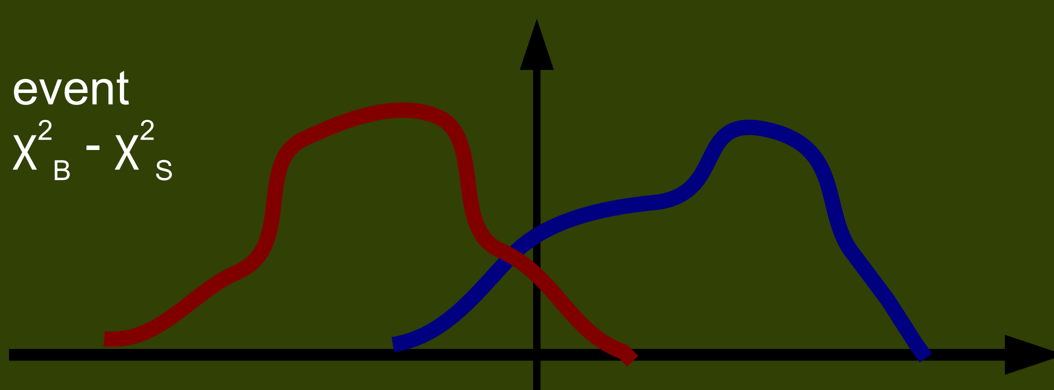
GL: **combine correlated variables to build a variable that contains most of the information related to the geometry of the event.**

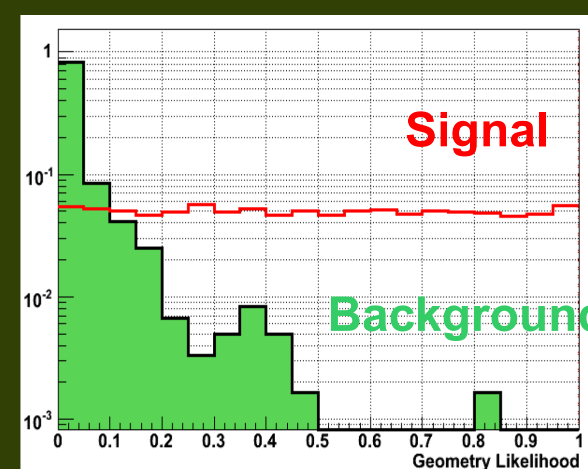
'Gausanization' and decorrelation



For each event

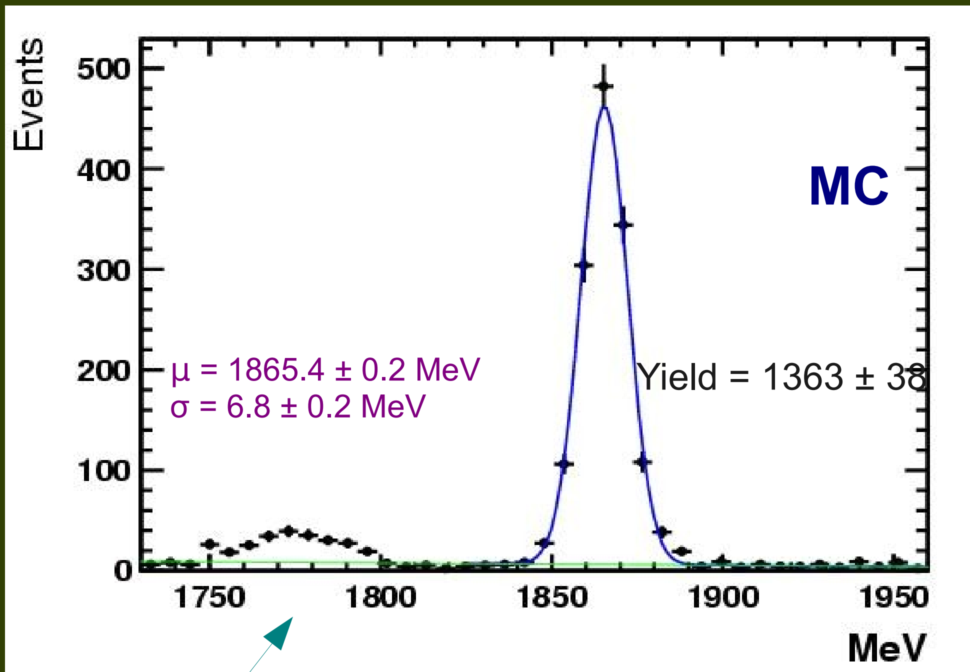
$\rightarrow \Delta\chi^2 = \chi^2_B - \chi^2_S$

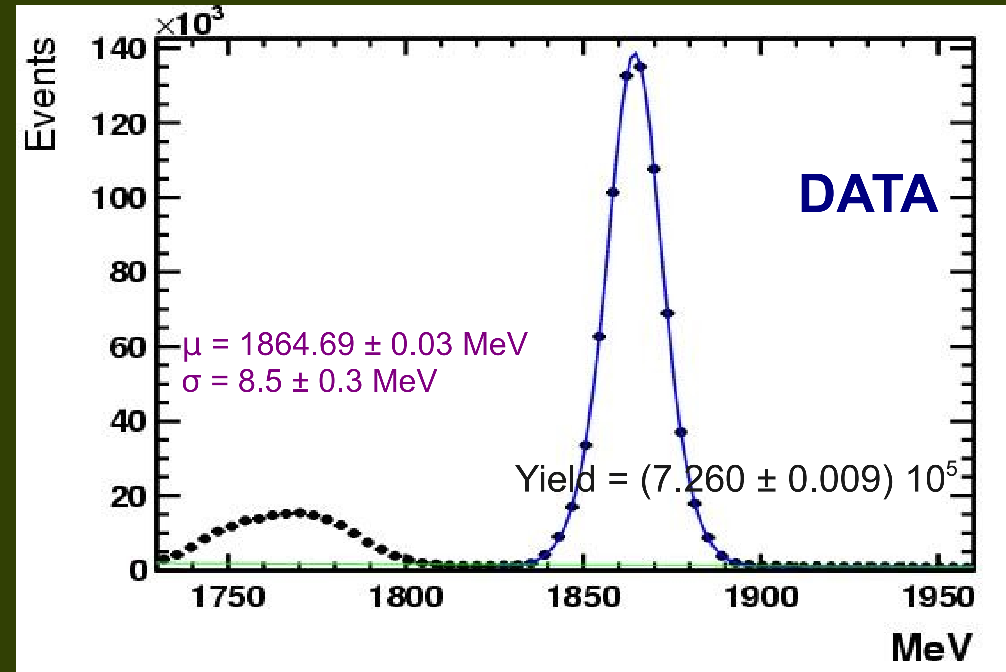




The GL studies using Low Mass Resonances

$D^0 \to K\pi$





Fit: 1Gaussian + linear (higher sideband)

Fit: 2Gaussian + linear (higher sideband)

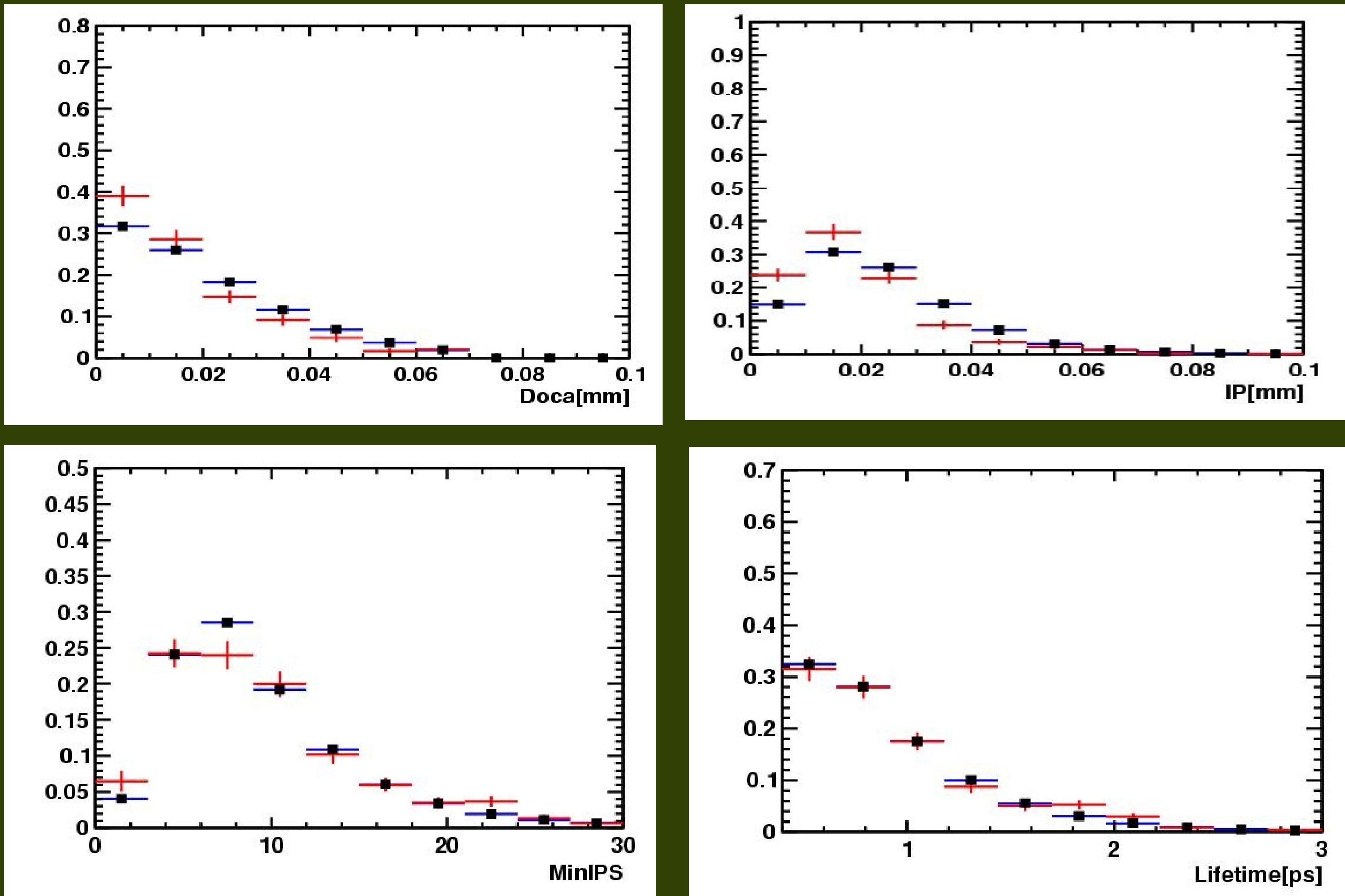
Reflections (~99%) $D^0 \to KK$
<1% $D^0 \to K e\nu, K\mu\nu, \pi\mu\nu, K\pi\pi^0$

<u>Training process of the GL:</u>
MC Truth events as Signal
DATA higher sideband as Background

<u>Testing samples:</u>
MC peak region and MC higher sideband
DATA peak reagion and Data higher sideband **→ Bkg subtraction**

MC
DATA

Input Variables Distributions



MC
DATA

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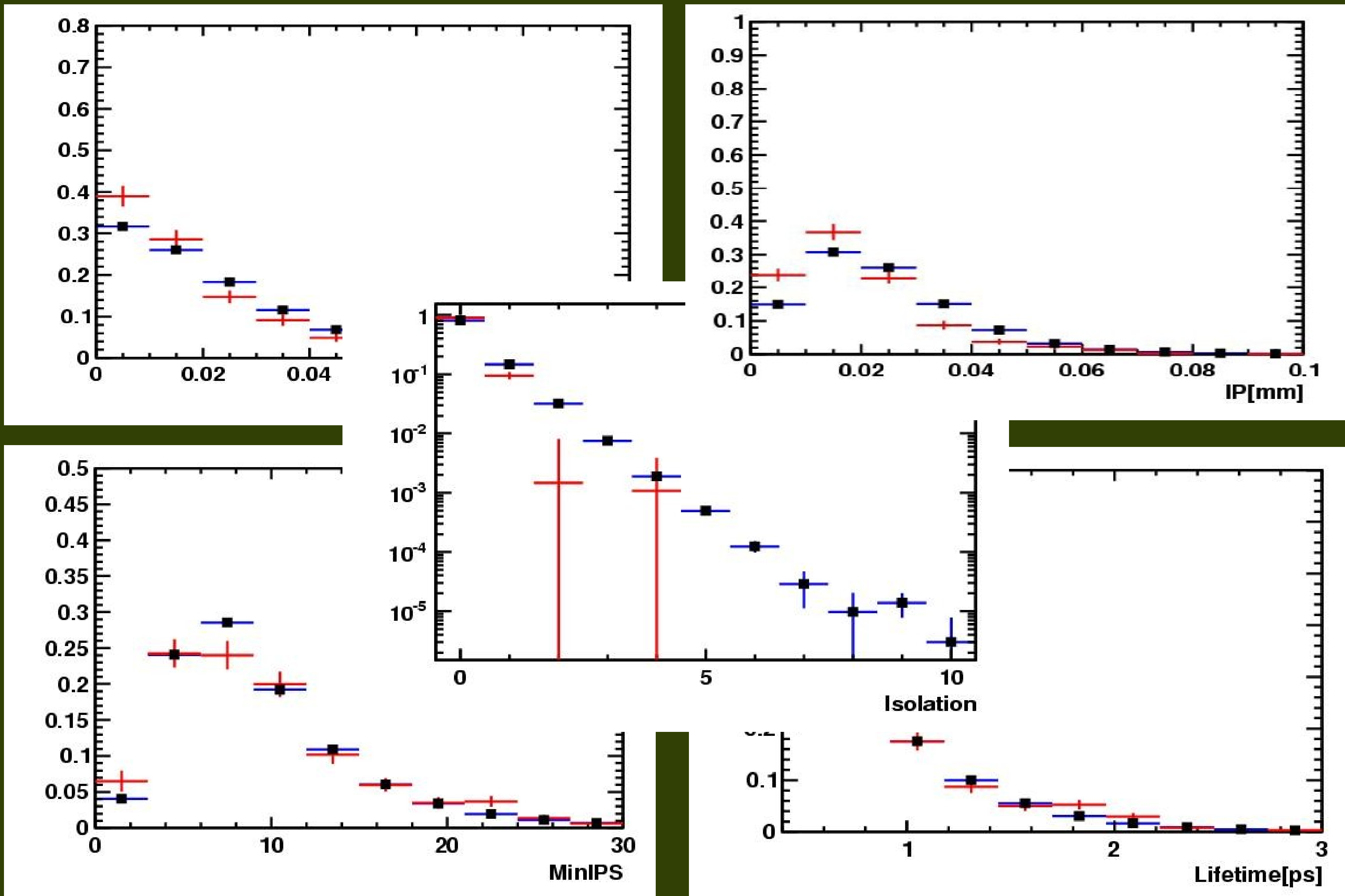
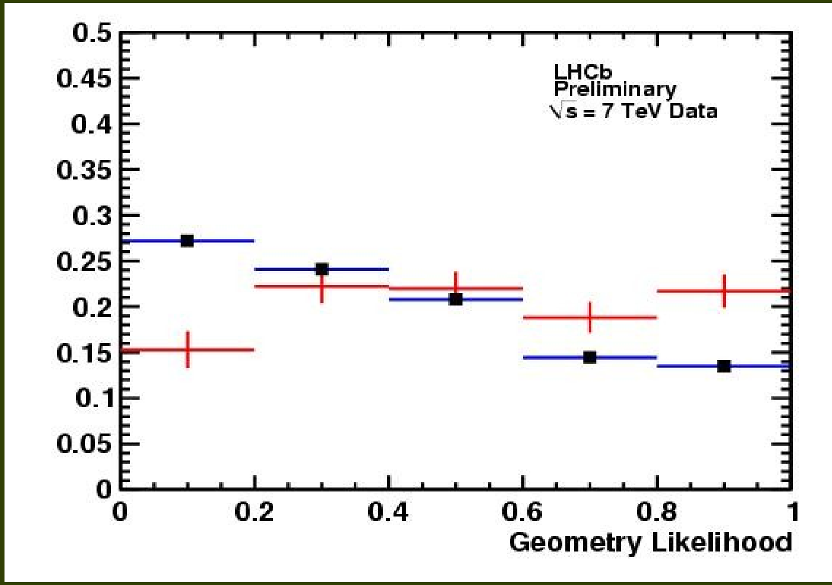
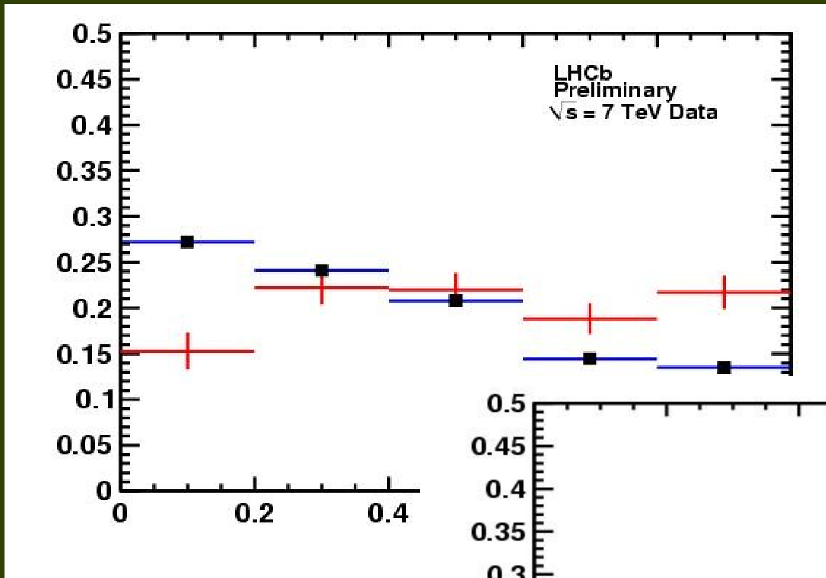


GL Distributions

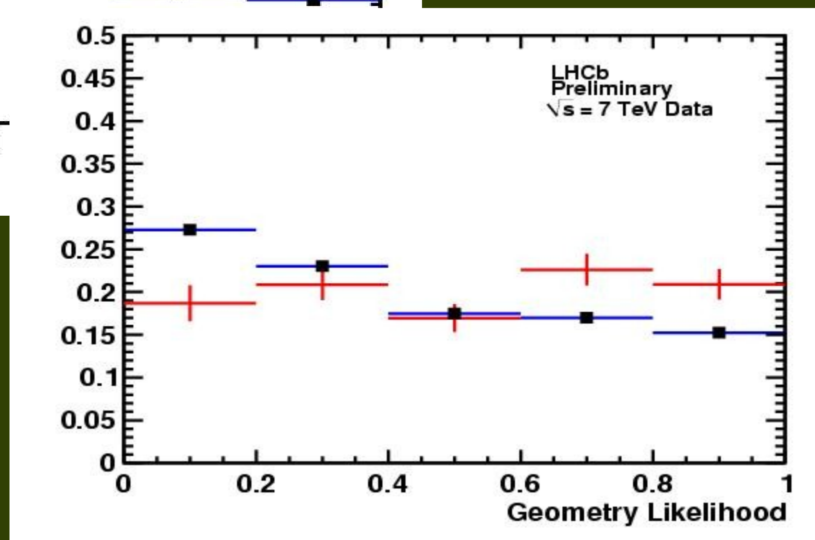


MC
DATA

GL Distributions



No Isolation



MC
DATA

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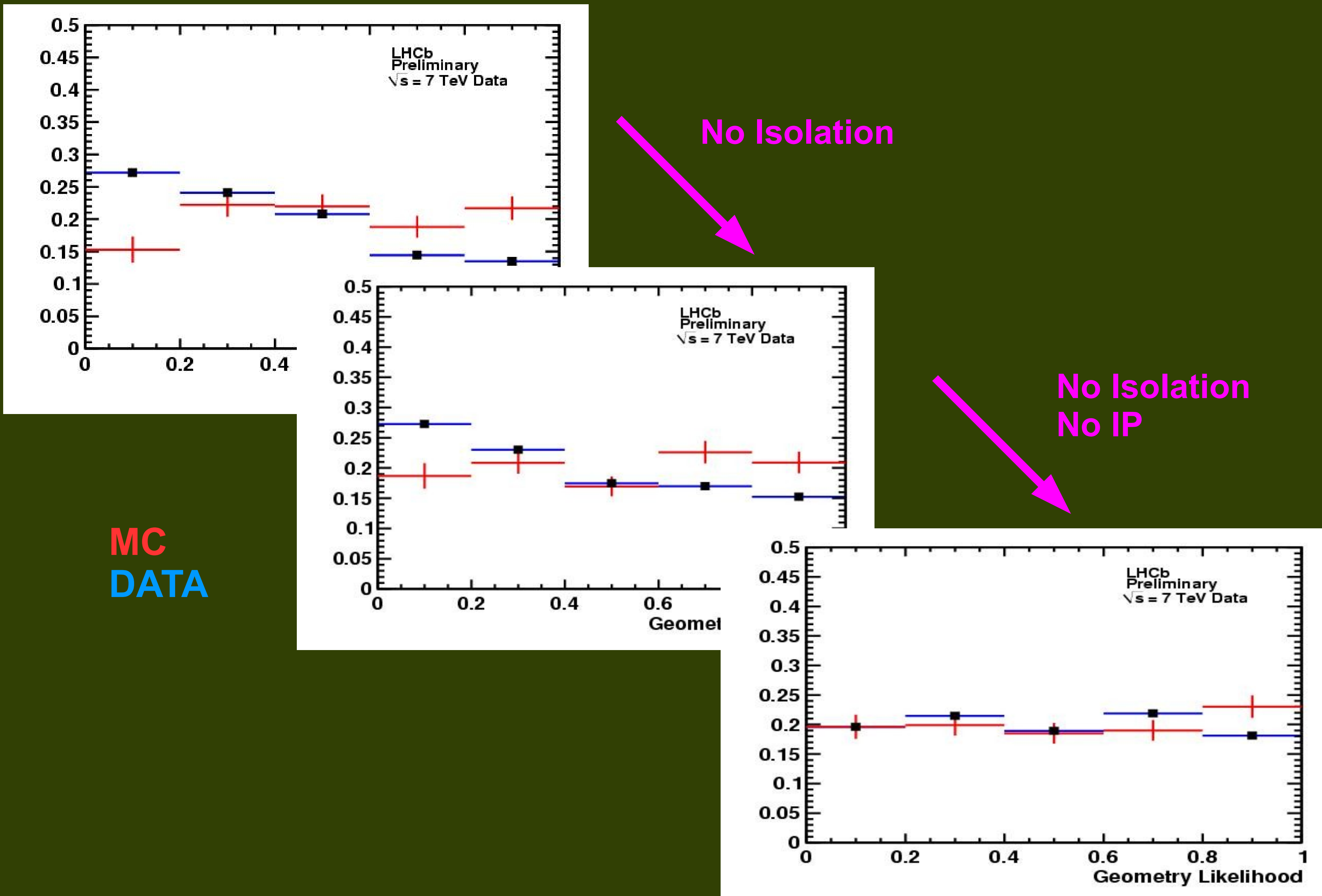

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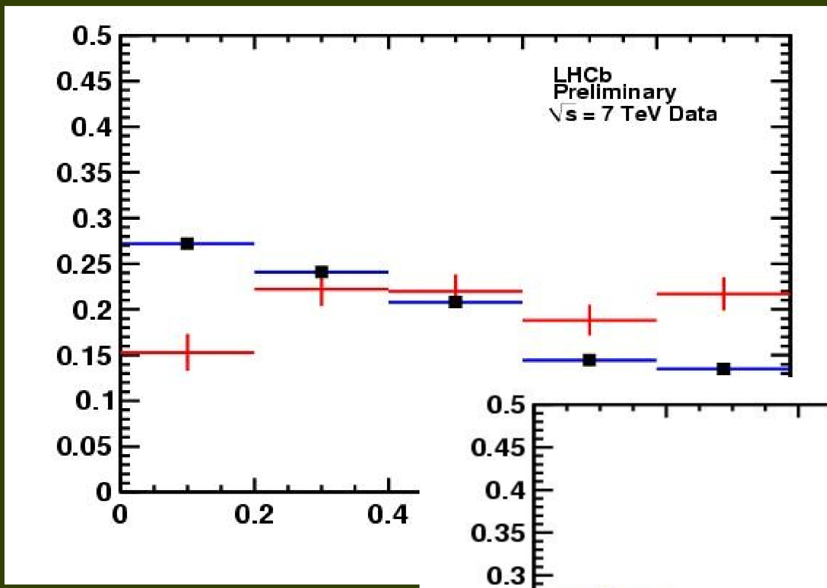

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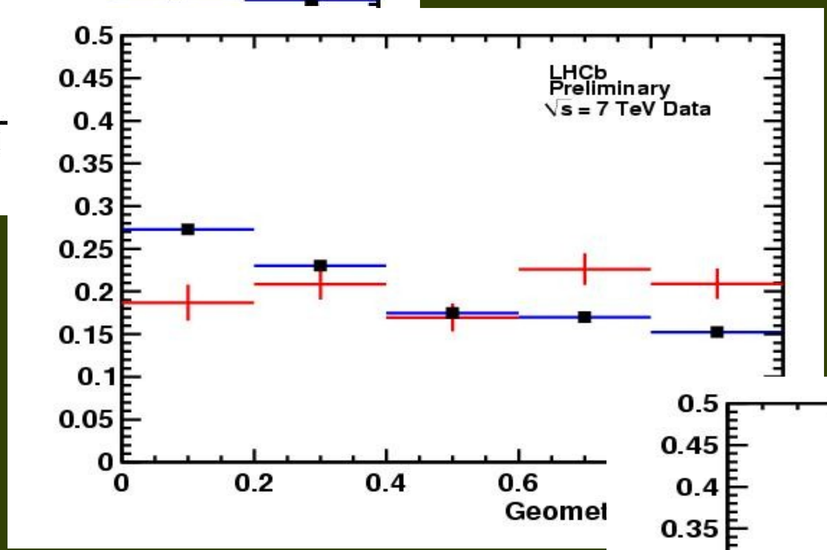
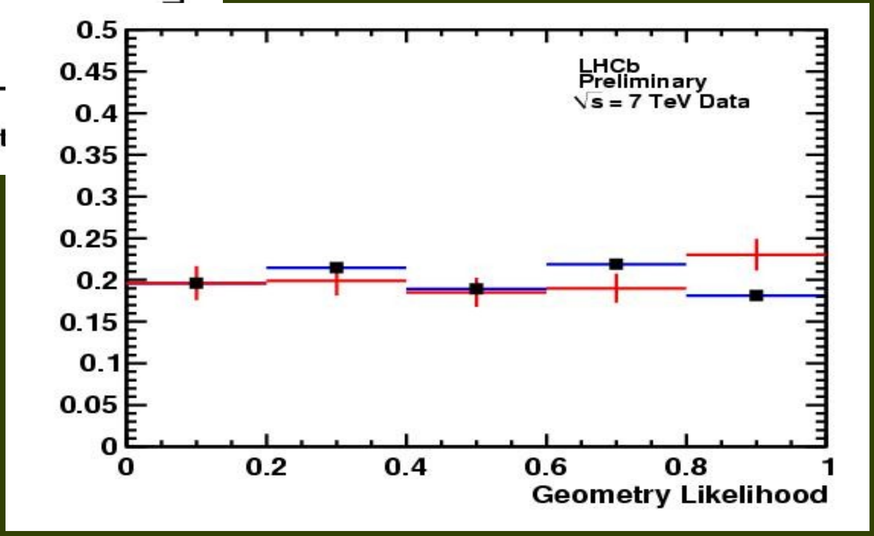


No Isolation
No IP



MC
DATA

$B_s \to h^+ h^-$ GL studies have shown similar results

To do List

1. Better understanding of the Isolation (Number of tracks higher in data than in MC)

2. The same for IP (smearing track resolution?...)

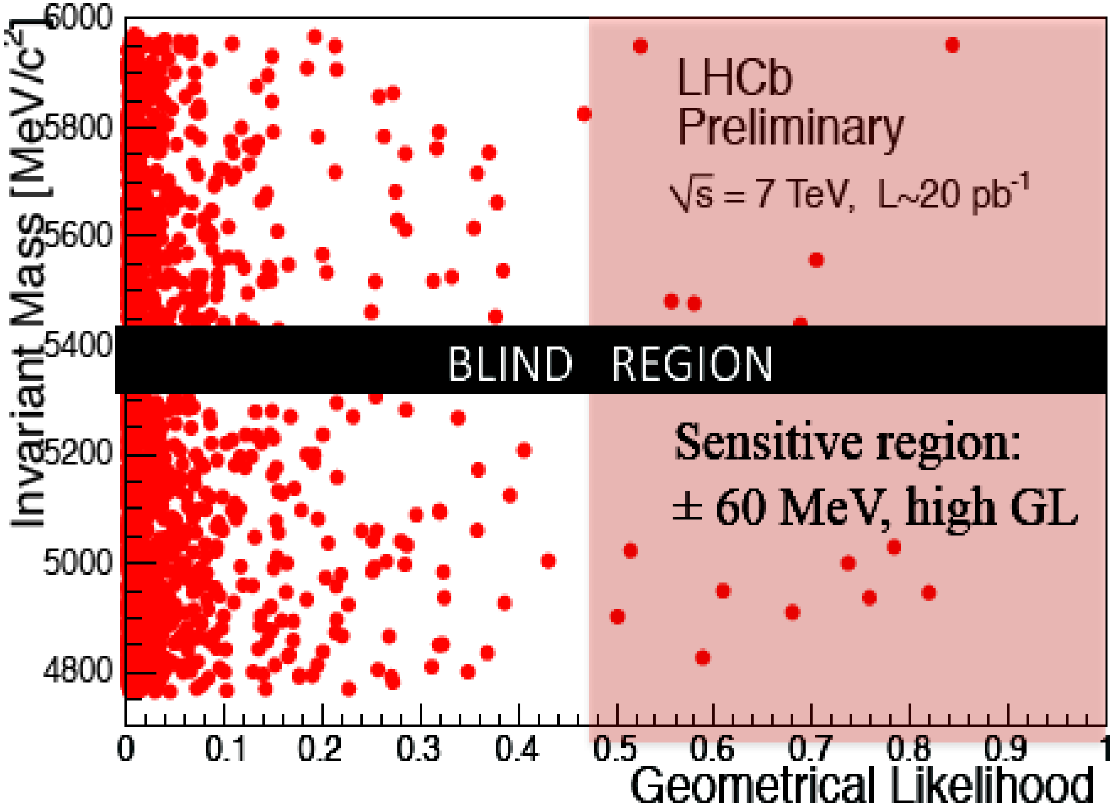
3. Trigger biases (does the trigger favor events at high GL? …)

4. … Systematics !!!

Predictions

How we calculate the Upper Limit

2D plot Invariant Mass vs Geometrical Likelihood:



1. Divide the 2D plane in bins
2. For each bin evaluate the compatibility with the:
   - S+B hypothesis [CL_{S+B}]:

   → here we have the BR
   - B hypothesis only [CL_B]

$CL_S = CL_{S+B}/CL_B$ = compatibility with the signal hypothesis

We are blinding the signal region:

→ Hence we will present only the "expected" UL [not the "observed" one]

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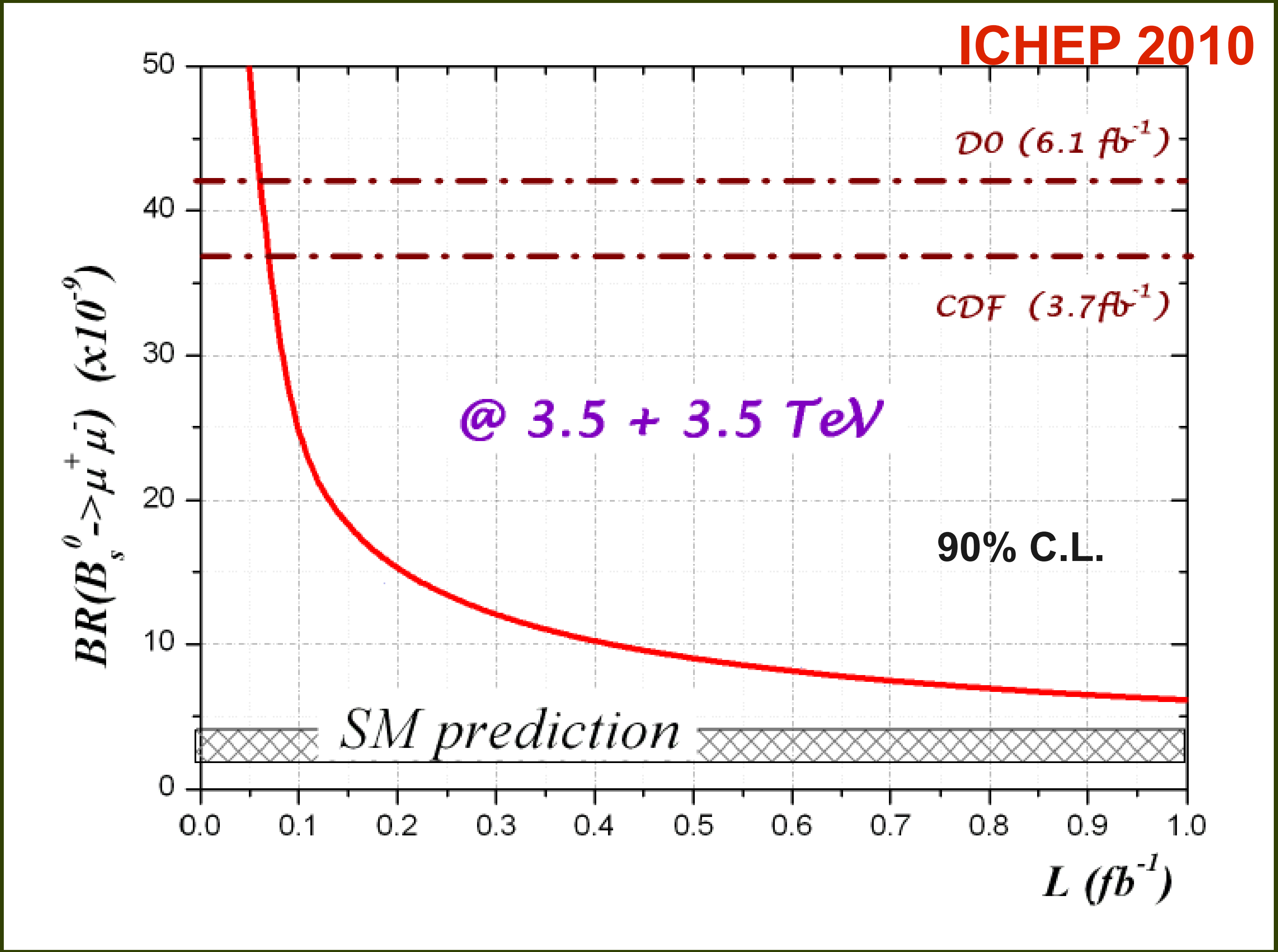
Exclusion limit



Conclusions

_ An overview of the motivations to study $B_s \rightarrow \mu\mu$ it has been presented.

_ I briefly presented the analysis strategy, focusing on the GL.

_ The Expected Upper Limit exclusion has been shown.

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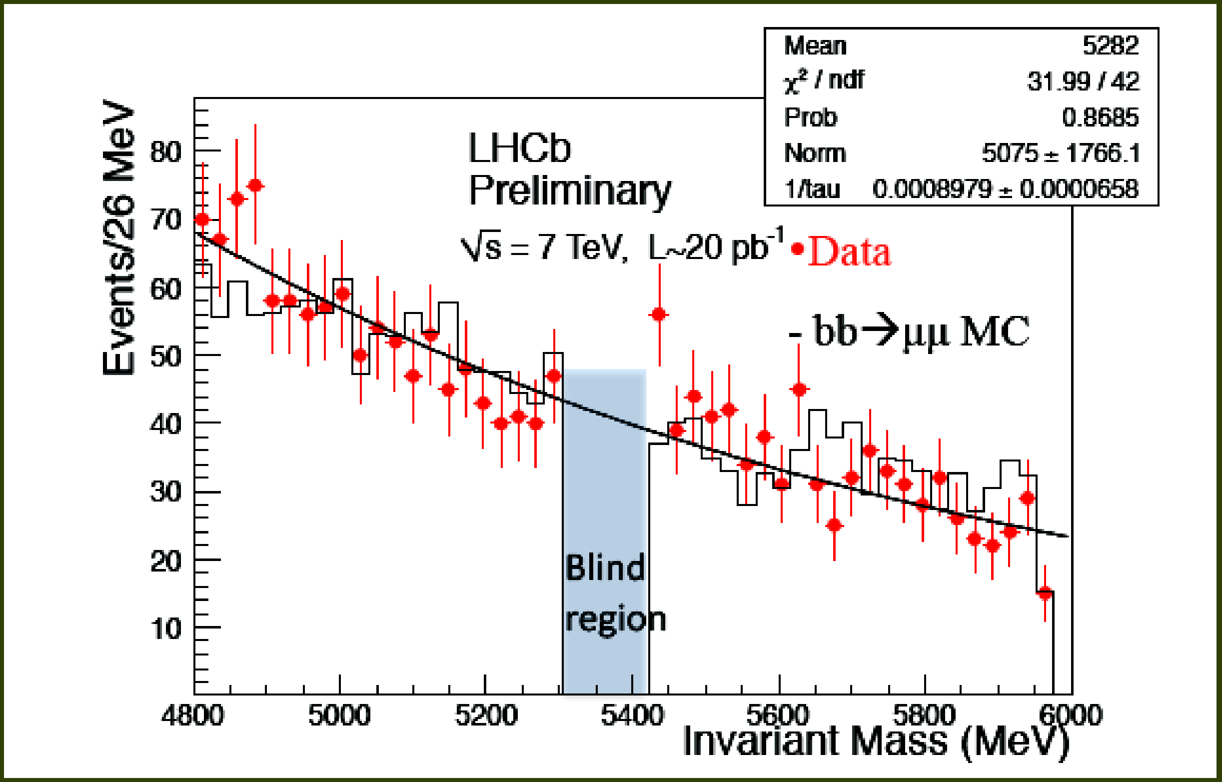
"… Le village se réveille …"

Backup


Mean 5282
χ² / ndf 31.99 / 42
Prob 0.8685
Norm 5075 ± 1766.1
1/tau 0.0008979 ± 0.0000658
LHCb
Preliminary
√s = 7 TeV, L~20 pb⁻¹
•Data
- bb→μμ MC
Blind
region
Events/26 MeV
Invariant Mass (MeV)
4800
5000
5200
5400
5600
5800
6000
10
20
30
40
50
60
70
80

- Other leptonic very rare decays:

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

Reconstruction rather difficult

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

BR ↓↓

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

Reconstruction rather difficult

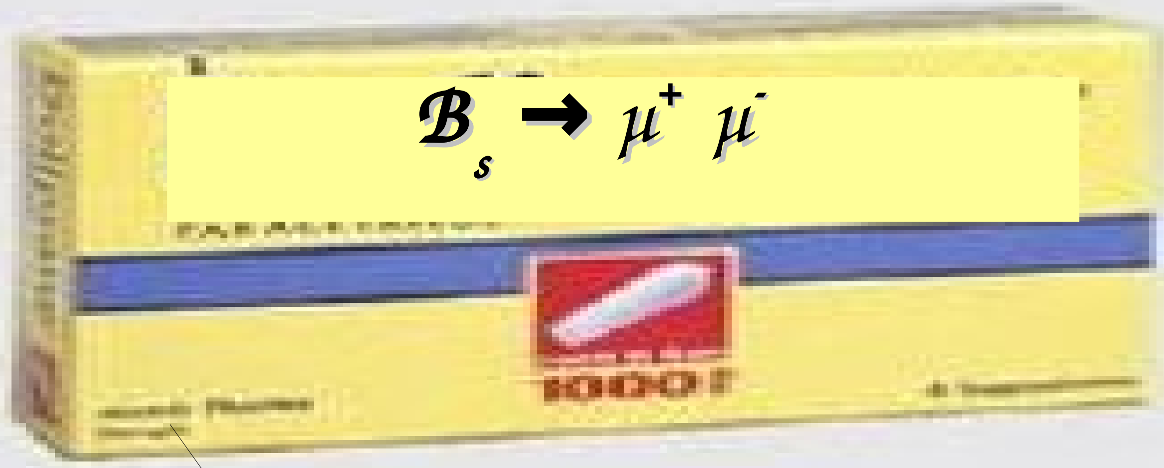
$$B(B_d \to \mu^+\mu^-) = (1.06 \pm 0.04) \cdot 10^{-10}$$

Also a promising mode to test SM !!

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

BR ↓↓

$B_s \to \mu^+ \mu^-$



This study is completely model independent

The Large Hadron Collider Beauty (LHCb)

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

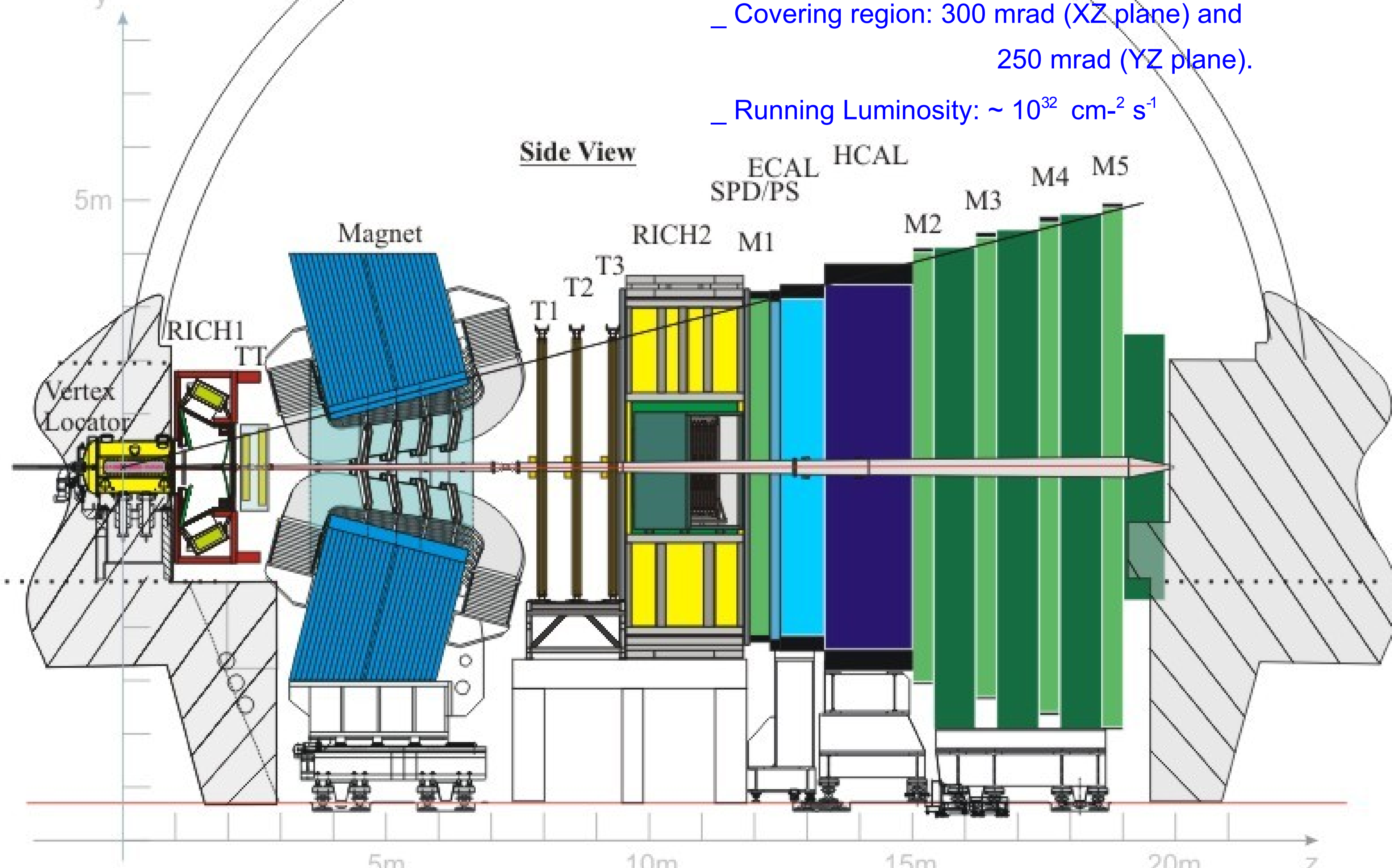
Vertex Locator (VELO)
Muon Chambers

_ Designed for precise study of B decays.

_ Forward geometry.

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

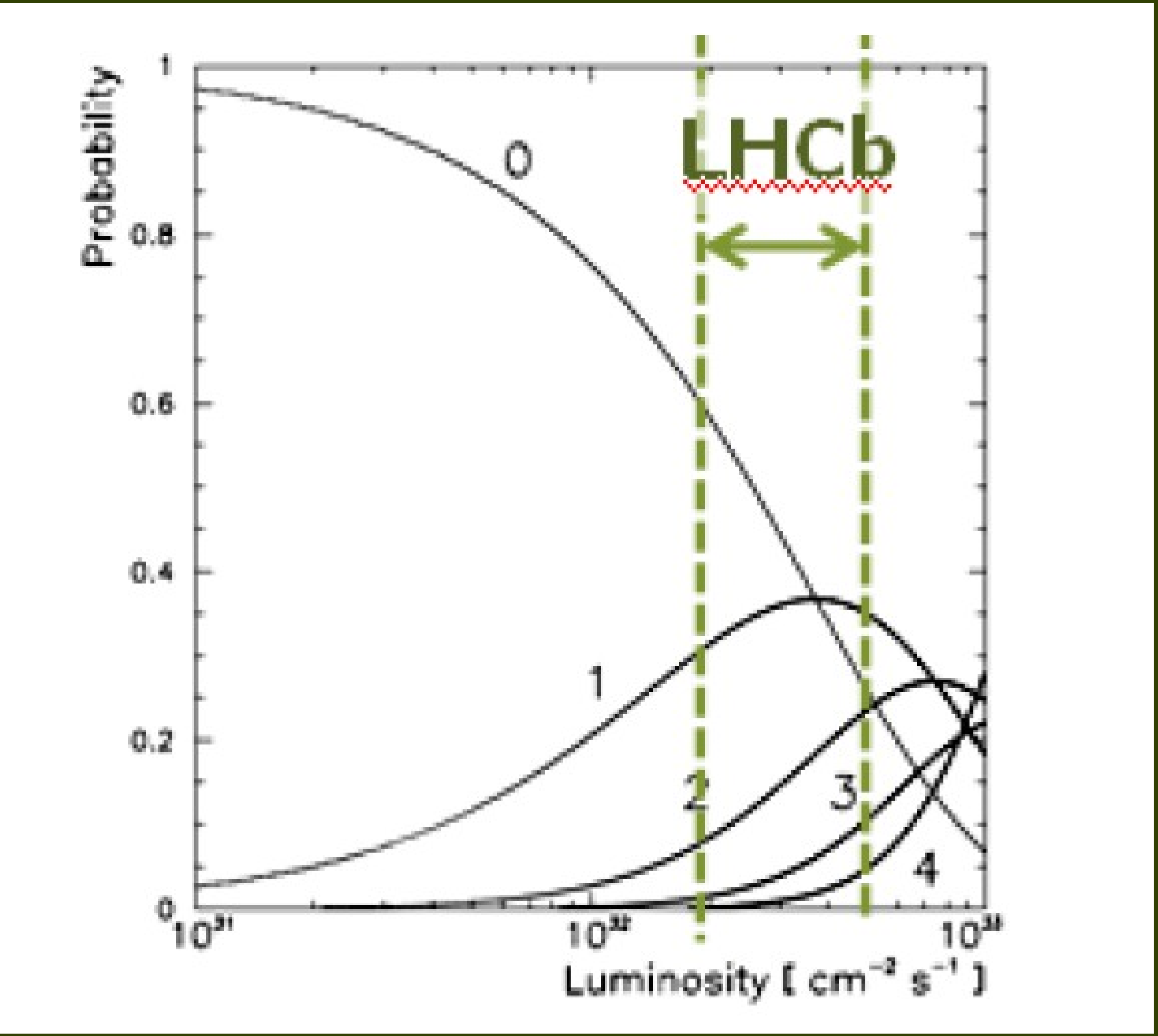
_ Running Luminosity: ~ 10^{32} cm^{-2} s^{-1}



The GL studies using Low Mass Resonances

D0(1865) Bs(5366)

Similarities: IP, DOCA
Differences: Lifetime, minIPS
Isolation ??



LHCb
Probability
0
1
2
3
4
Luminosity [cm⁻² s⁻¹]

7. Sensitivity to the BR($B_s \rightarrow \mu^+\mu^-$)

For each of the luminosities assumed, the two background estimators for each bin, $\mathbf{b_i}$ and $\mathbf{b_i^{90}}$, were computed. For a given BR $\mathbf{s_i(BR)}$ was then evaluated. In order to evaluate the LHCb sensitivity to exclude a given BR, at each luminosity $\mathbf{d_i}$ was assumed to be equal to $\mathbf{b_i}$ or to $\mathbf{b_i}^{\mathbf{90}}$ and the equation $CL_s = 0.1$ was then solved in order to obtain the BR excluded at 90% confidence level. In this case, the assumption is that only the expected background is observed, and no signal is

[20] A.L.Read, CERN Yellow Report 2000-005

In order to compute the sensitivity to a given Branching Ratio, we use the method of reference[20] that was used extensively at LEP in the search for the Higgs boson. For each bin (i) there are three quantities: $\mathbf{d_i}$ (the number of observed events), $\mathbf{s_i}$ (the number of expected signal events) and $\mathbf{b_i}$ (the number of expected background events), which depend on the luminosity and the Branching Ratio assumed. For each bin the quantity