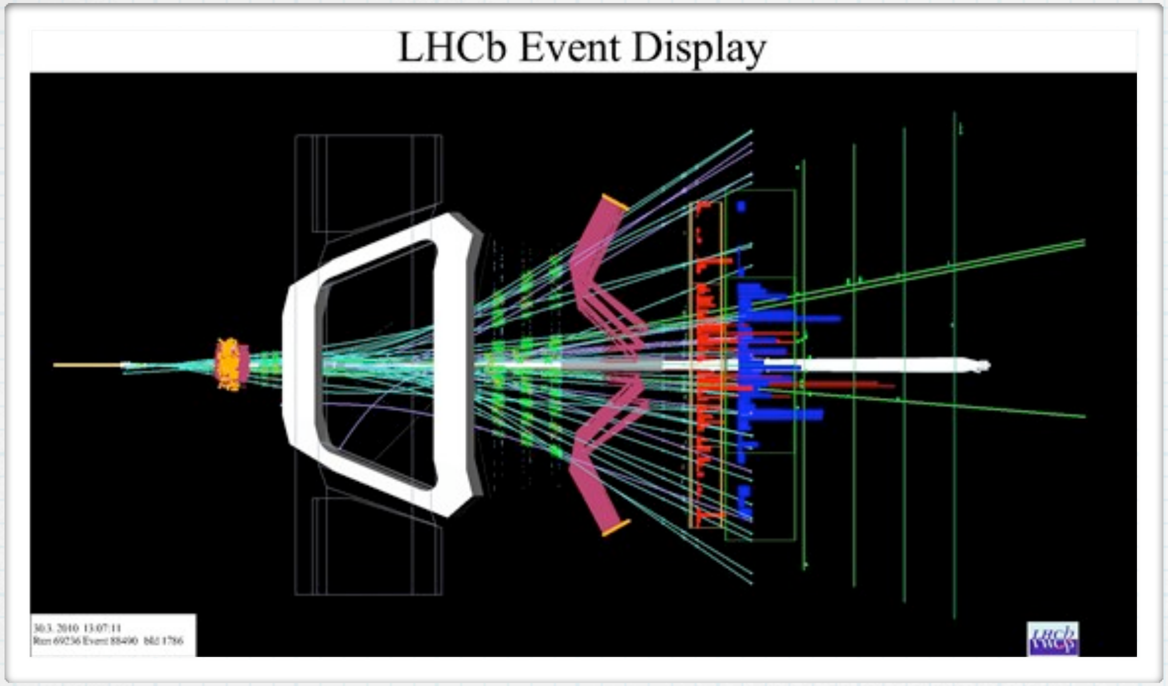


PHYSTAT2011

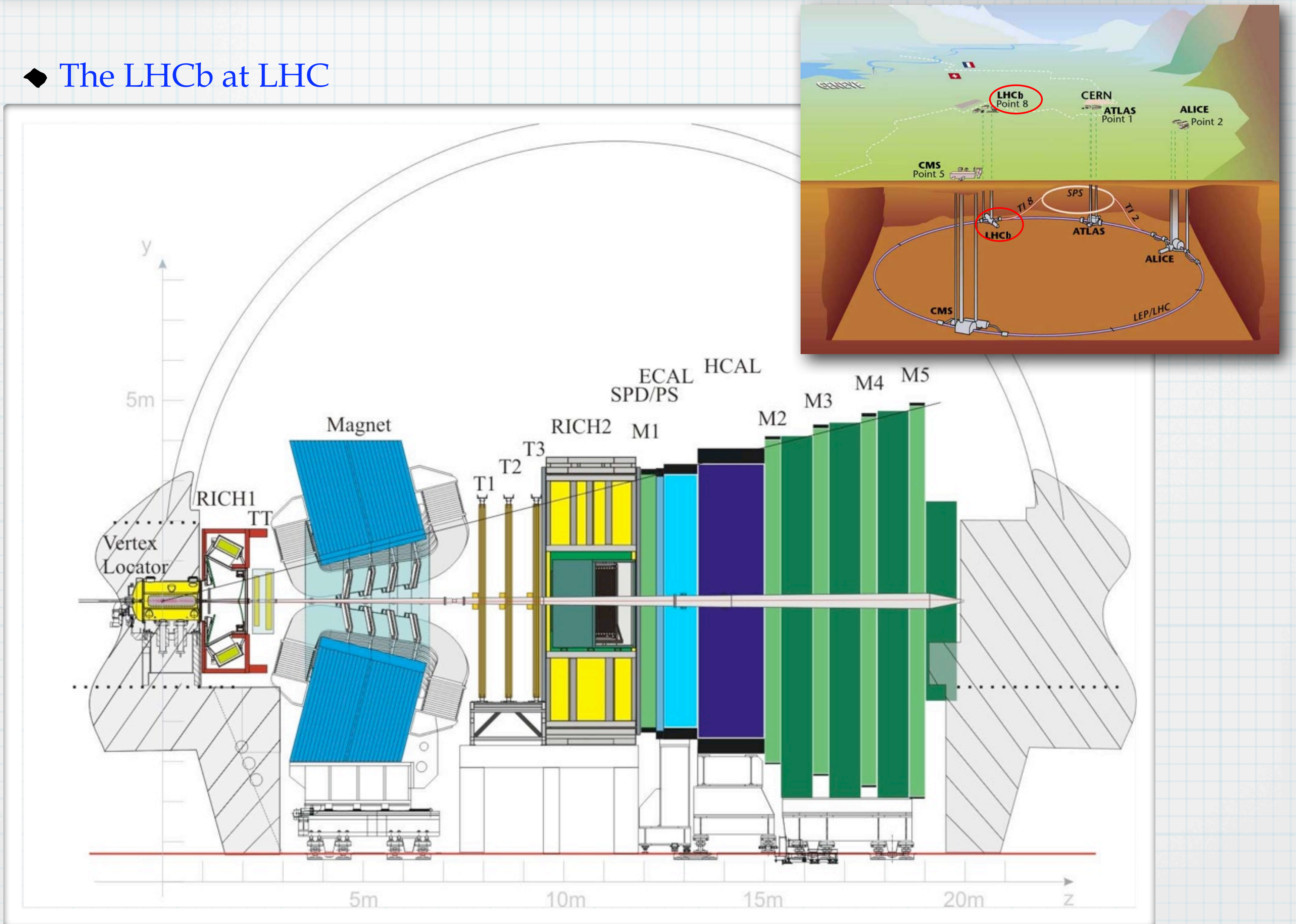
Statistic methods used in the LHCb searches

(with emphasis in the search of the rare decay $B_s \to \mu\mu$)

José Ángel Hernando Morata
Universidade de Santiago de Compostela, Spain
(on behalf of the **LHCb collaboration**)
17/01/2011

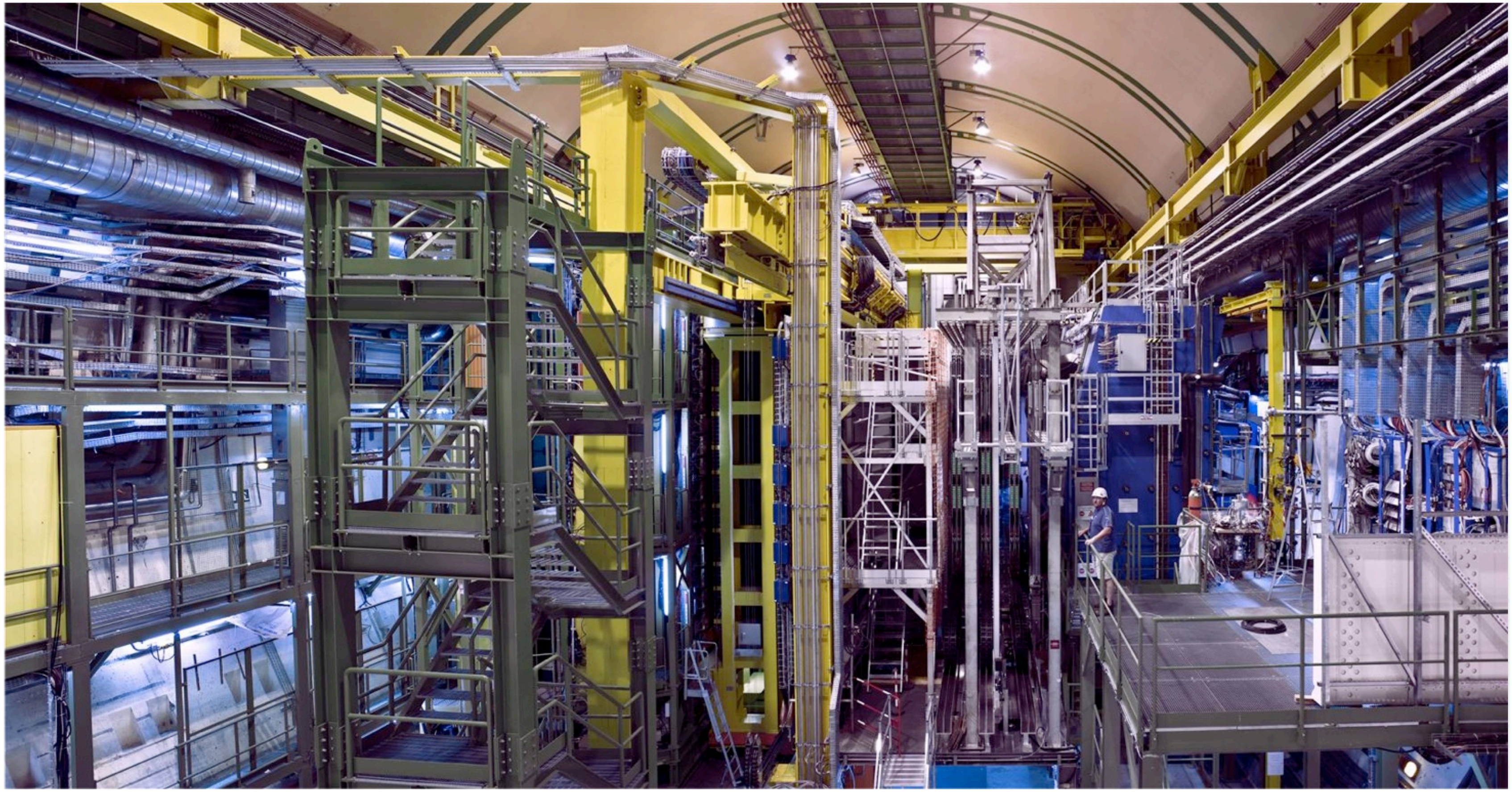
The LHCb experiment

- The LHCb at LHC



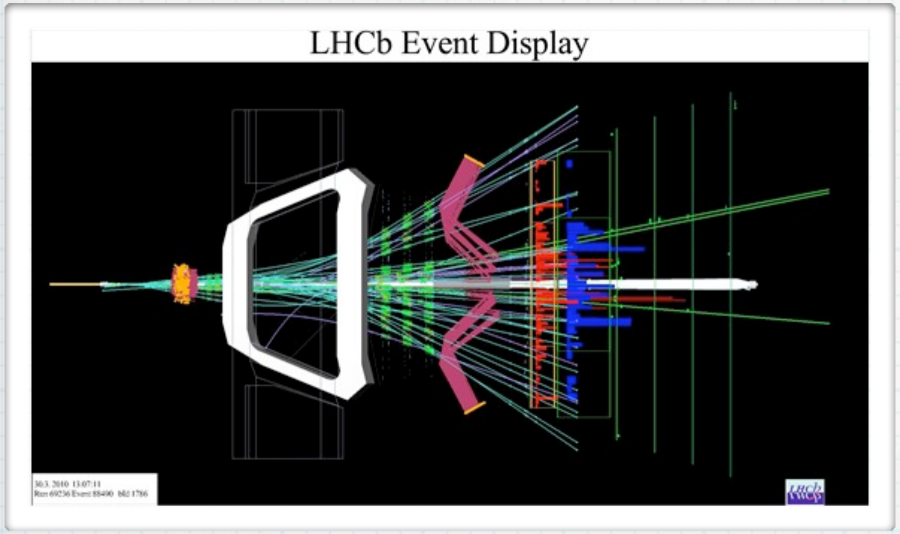
The LHCb detector

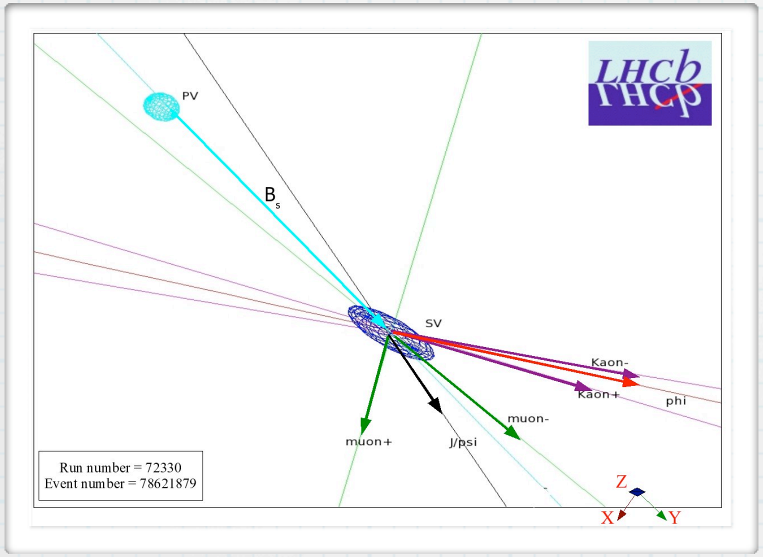
- The LHCb detector



Muon Calo Rich Tracking Magnet Velo

An event display



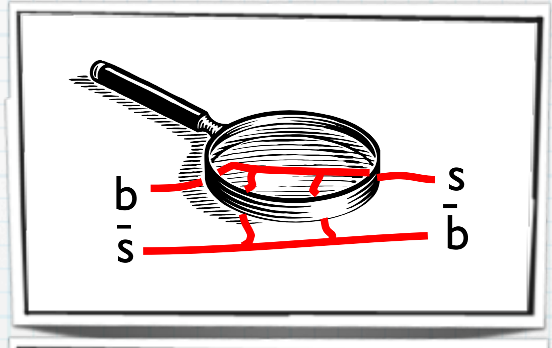


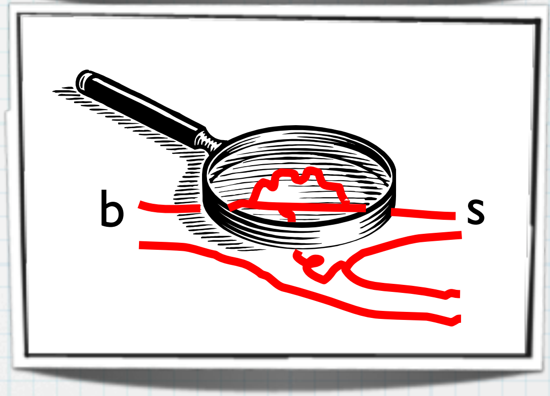
- LHCb designed to study B mesons
  - Forward spectrometer
  - good vertex, momentum resolution, PID
  - Flexible and robust trigger
- First period of data
  - The physics program does not suffer much for running at E = 3.5 TeV
  - Collected ~37 pb^{-1} during 2010

LHCb Physics objectives

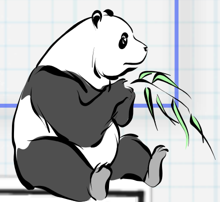
- New Physics (NP) introduces new particles at higher energy scale that enter in the loop processes and can modify the SM predictions of observable
- FCNC
  - B_s phase of the mixing: β_s
  - **Rare Decays**: $BR(B_s \rightarrow \mu\mu)$, $A_{FB}(B \rightarrow K^* \mu\mu)$
    - $BR(B_{s(d)} \rightarrow \mu\mu)$
    - $BR(D \rightarrow \mu\mu)$
    - LFV: $B \rightarrow \mu e$

  - D phase of the mixing: Φ_D
- CKM 'precision' measurements
  - Compare two measurements of the same quantity sensitive and not to the NP (tree vs loop)
  - γ : $B_{(s)} \rightarrow D_{(s)}K$, $B_{(s)} \rightarrow hh$

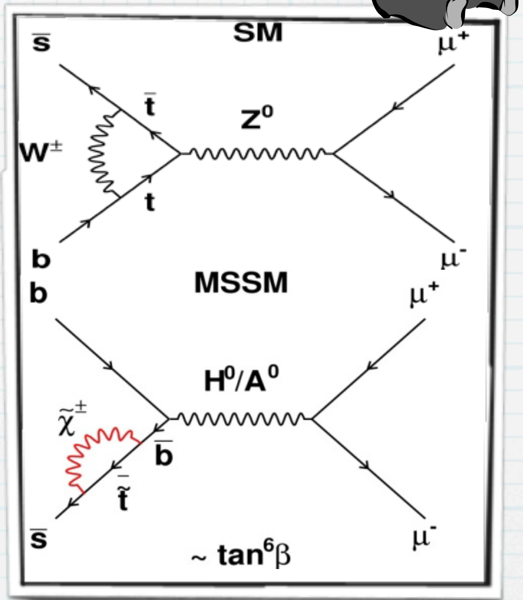


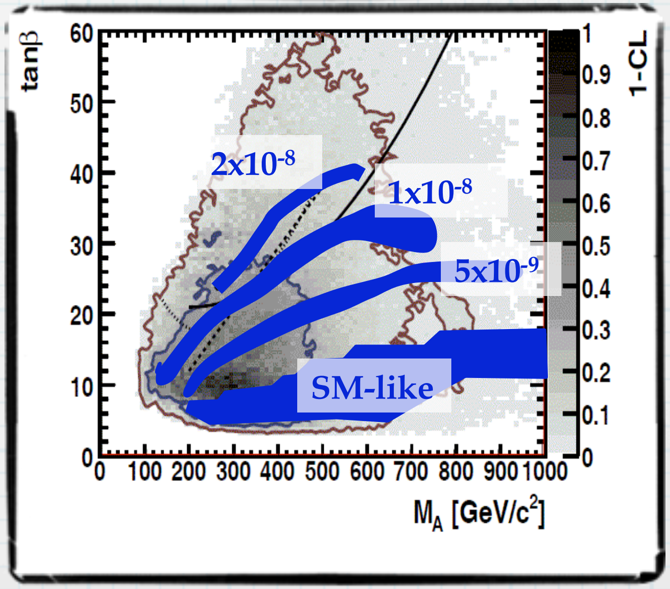


The importance of $B_s \longrightarrow \mu\mu$



- Very rare decay (FCNC+helicity suppress)
  - *BR*(Bs→μμ) = (3.35+-0.32) 10^{-9} (SM)
- High sensitivity to NP with new scalar or pseudoscalar interactions (i.e MSSM)
  - *BR* ∝ $\tan^6 \beta$
- Current limits by Tevatron:
  - *BR* < 3.6 10^{-8} @ 90% CL (CDF 3.7 fb^{-1})
  - *BR* < 4.2 10^{-8} @ 90% CL (D0 6.1 fb^{-1})
- LHCb performance
  - High efficient trigger
  - Good muon identification, mass resolution, vertex capabilities
  - Estimations to we could surpass current limit with 50-70 pb^{-1}



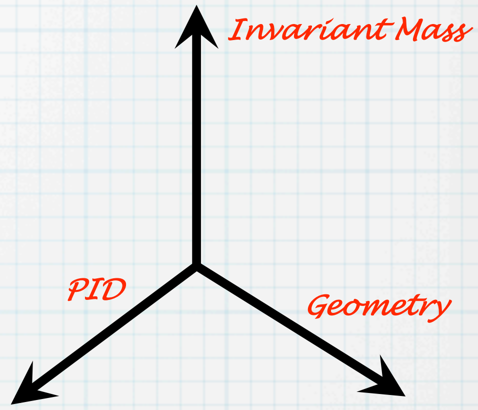


LHCb searches: characteristics

- Search of rare (and 'forbidden') decays:
  - *BR*($B_{s(d)} \to \mu\mu$), $B_s \to \mu e$
- Common characteristics:
  - A tiny signal in a large background
    - After trigger and a 'soft' selection we expect 19 $B_s \to \mu\mu$ events per fb^{-1} for the SM *BR!*
    - And ~12 k $bb \to \mu\mu X$ semileptonics as the dominant bkg for the $B_s \to \mu\mu$
- Some advantages:
  - We know where to search: invariant mass of the resonances
    - Bs mass 5366 MeV with resolution 22 MeV (MC)
  - We can use other B decays to model the signal
    - $B_{s(d)} \to hh$
  - And the background!
    - The sidebands of the $B_s \to \mu\mu$ candidates!

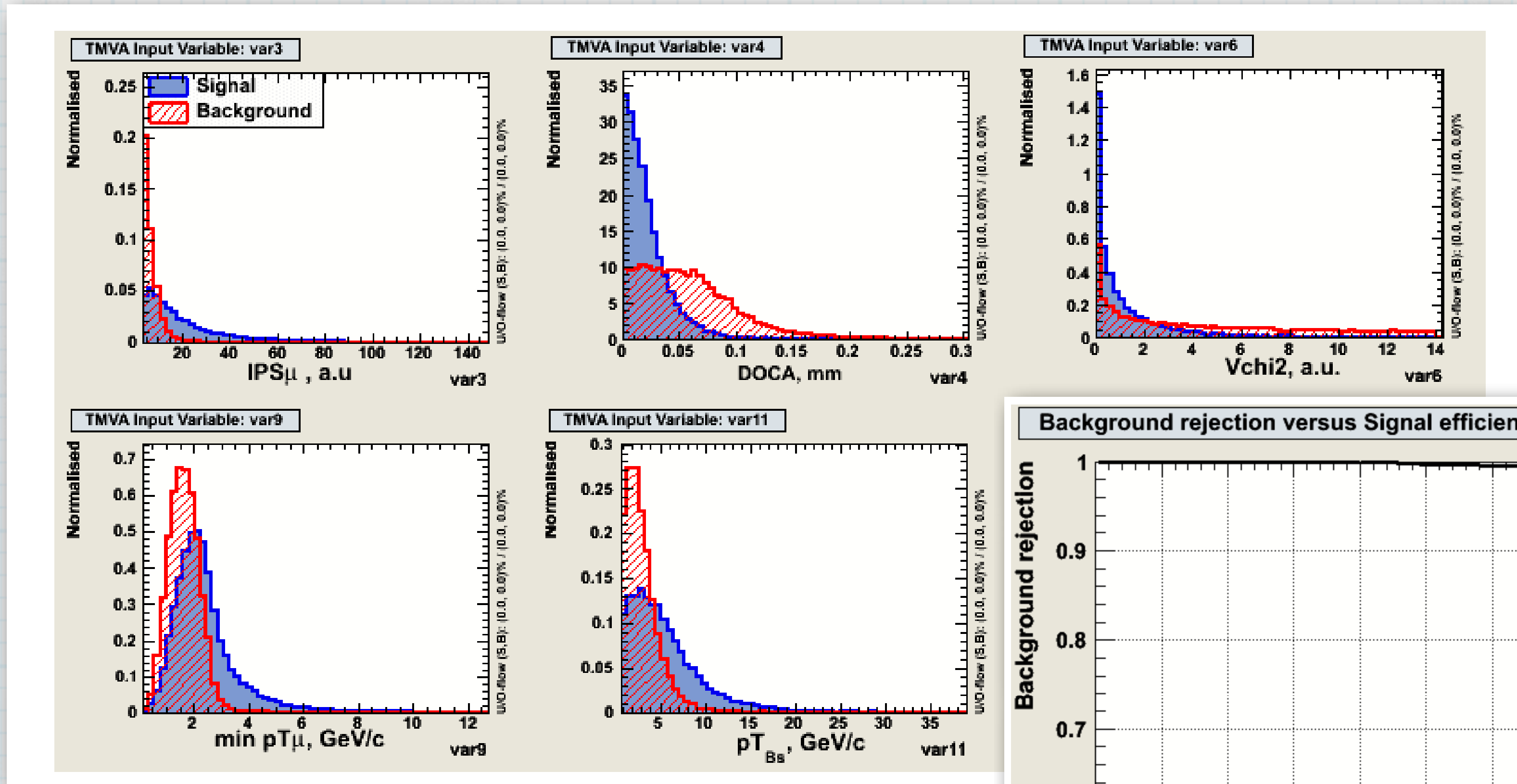
LHCb searches: strategy

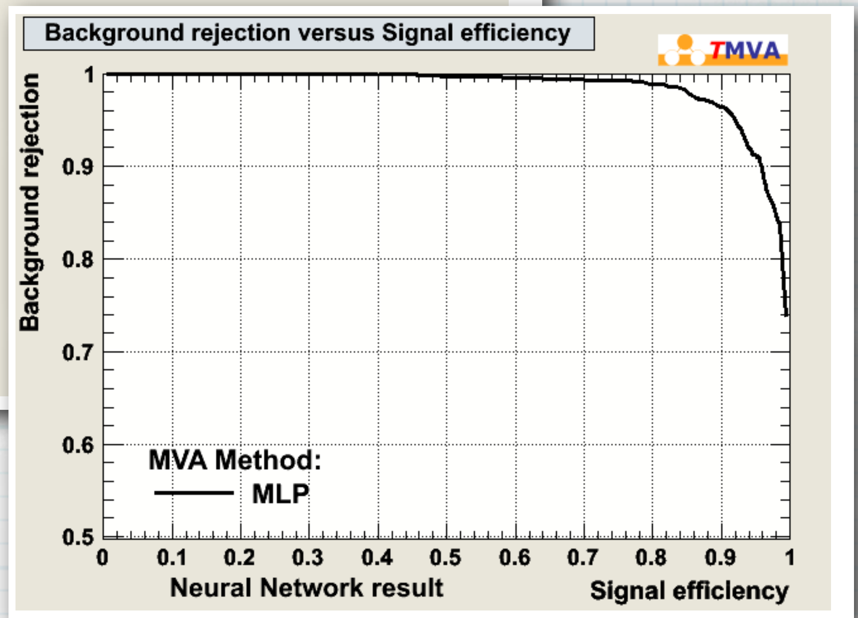
- Rather common approach
  - Similar to the searches for $B_s \to \mu\mu$ performed for at CDF, D0
- A 3(2) dimensional search space:
  - Invariant mass
  - Combine several discriminant geometrical variables
    - Use of MVA methods, GL (Geometrical Likelihood)
  - Particle identification
    - Not needed at this stage, the main bkg is: double semileptonics decays: $bb \to \mu\mu X$
- Normalize to a decay with known *BR*
  - *i.e: BR*$(B^+ \to J/\psi K^+)$ = (5.98+-0.20) 10^{-5}
- Divide the plane mass, GL plane in bins
- Blind the sensitive region (SR) till the analysis is a robust state
  - Estimation of the background and signal in the SR in each bins
- Compute the limit using CL_s method (n-bins counting experiments)
  - Or the discovery with $1-CL_b$



Discrimination using TMVA

- An example: $B_s \to \mu\mu$: using TMVA: NN

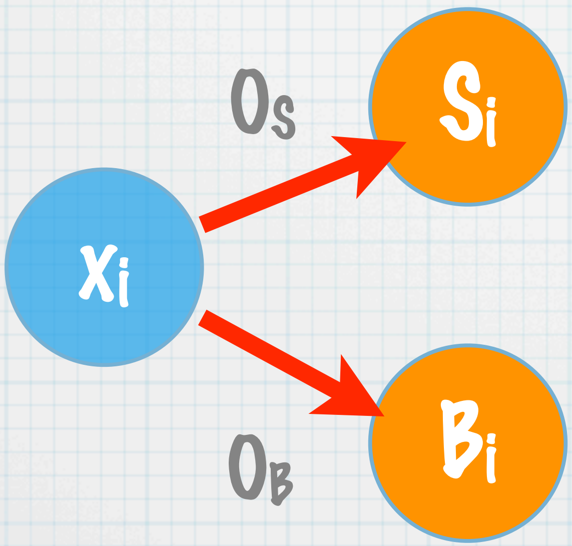




Geometry: GL and the $\Delta\chi^2$ method

- Geometrical axis of: 'GL' a MVA that combine several variables
  - We are currently using a $\Delta\chi^2$ method

- The $\Delta\chi 2$ method
  - Idea: transform the signal and bkg initial distributions into a n-dimensional gaussian



✓ O_S,O_B transformations:
- OS(signal) gaussian distributed

✓ Use $\Delta\chi^2$ as discriminant
- $\Delta\chi^2 = \chi^2_S - \chi^2_B$ $\chi^2_S = \Sigma S^2_i$ $\chi^2_B = \Sigma B^2_i$

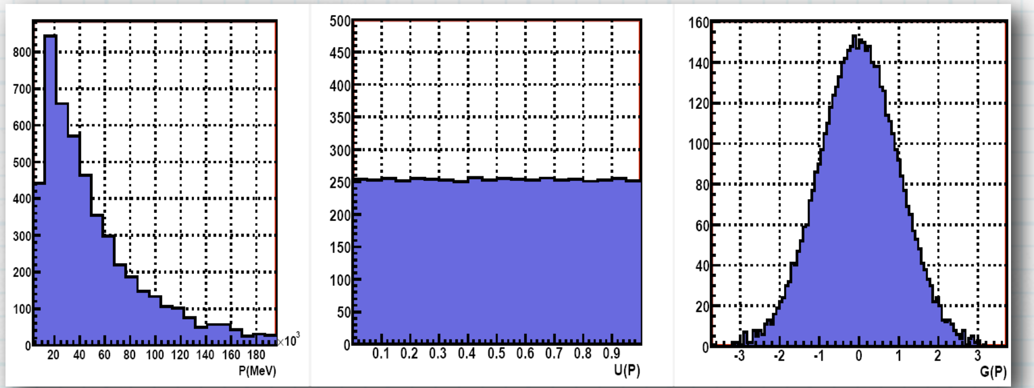
✓ Uniform $\Delta\chi^2$

D.Karlen, Computers in Physics Vol 12, N.4, Jul/Aug 1998 .

D. Martínez Santos, J. A. Hernando, F. Teubert. LHCb-PUB-2007-033.

The $\Delta\chi^2$ method (I)

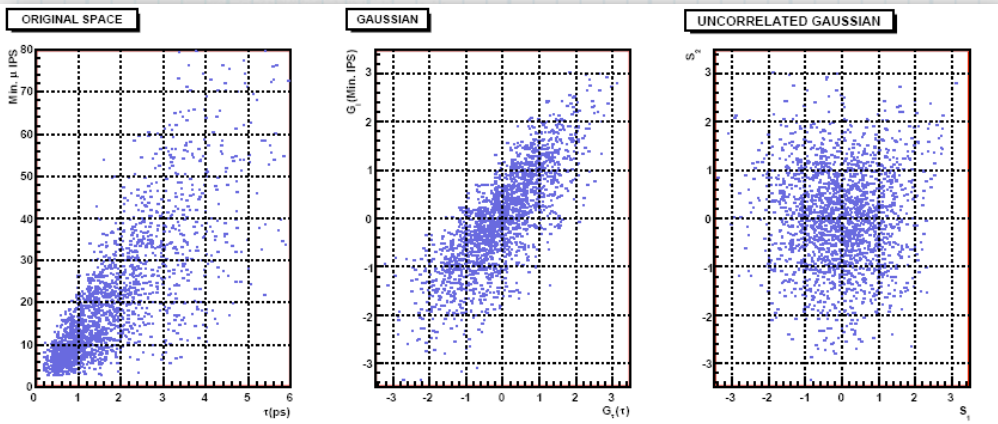
- Gaussianization:
  - transform into unifrom, them into gaussian



$$U_i(X_i) = \frac{\int_{X_i min}^{X_i} \rho(x_i')dx_i'}{\int_{X_i min}^{X_i max} \rho(x_i')dx_i'}$$

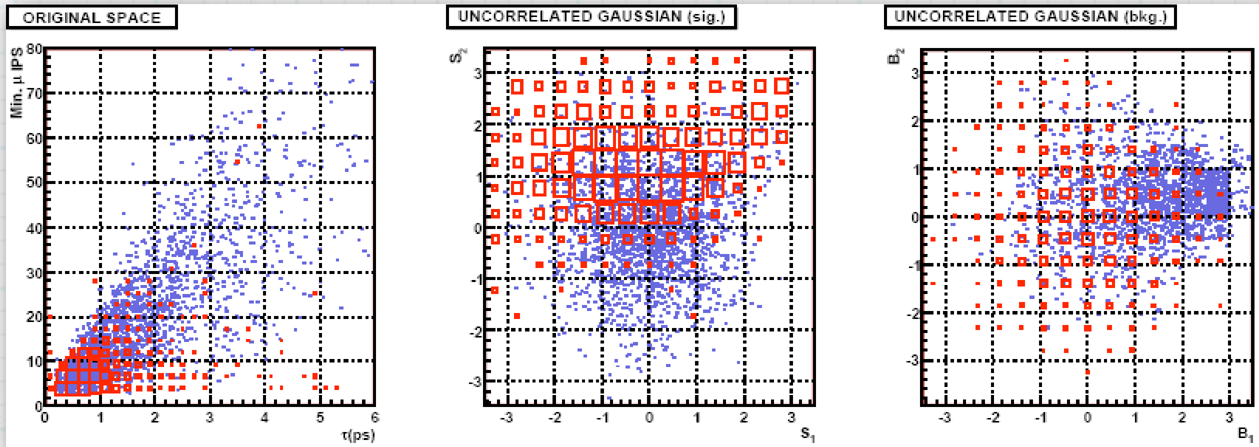
$$G_i = \sqrt{(2)}Erf^{-1}(2U_i(X_i) - 1)$$

- 'decorrelate' and re-gaussianize
  - rotate to the symmetry axis and gaussianize again

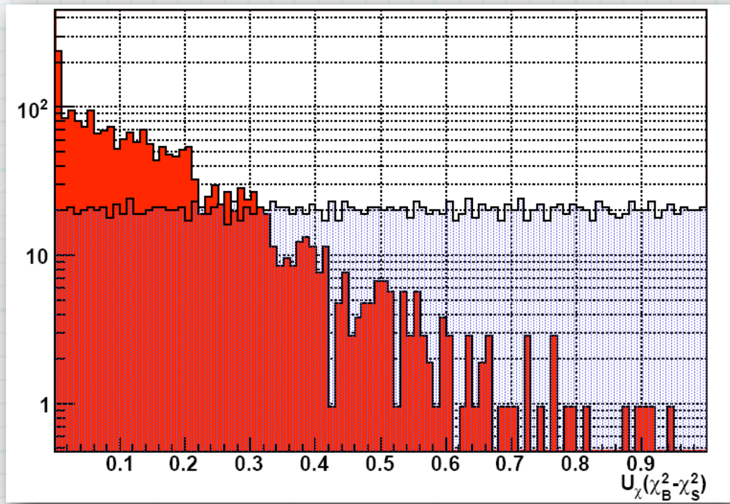


The $\Delta\chi^2$ method (II)

- Do the transformation for signal and background

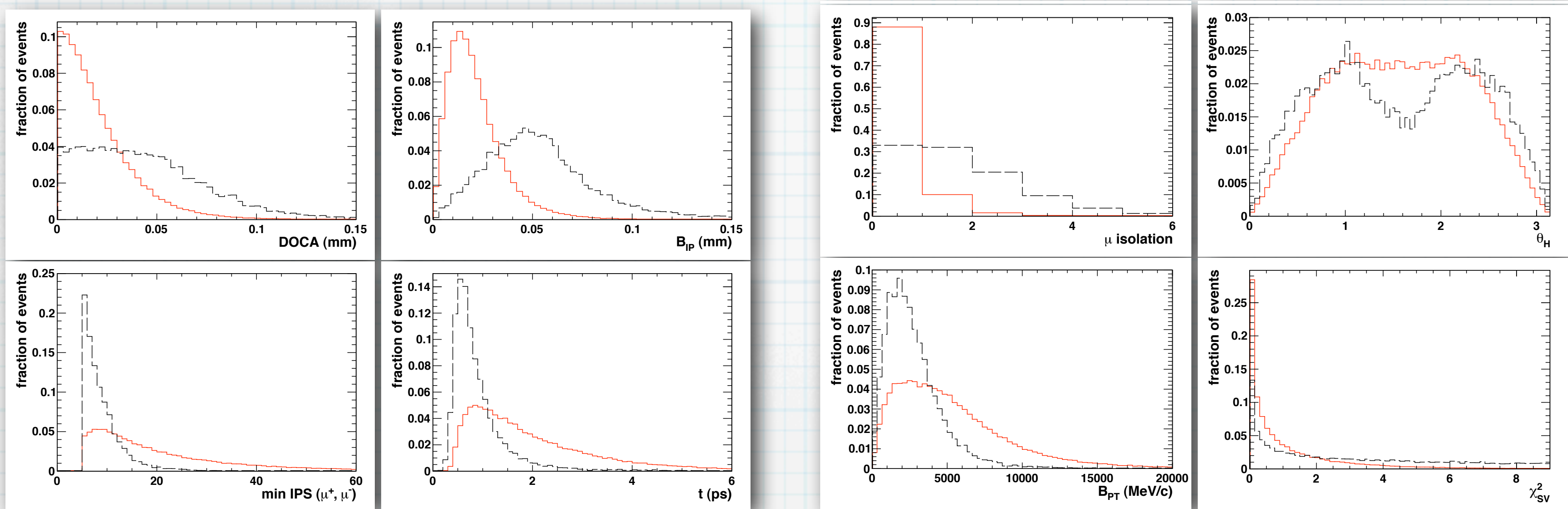


- Compute and uniformize $\Delta\chi^2$



The GL

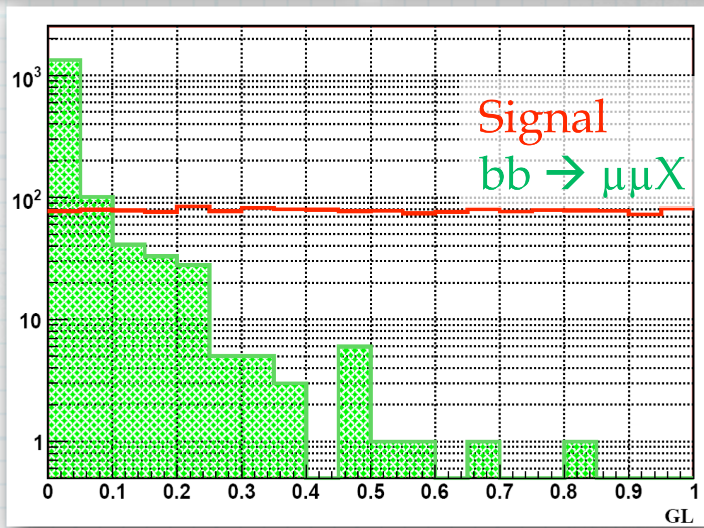
- Input variables: DOCA, IPS(mu), IP(B), PT(B), isolation,...



GL distribution

comparison MC and data sidebands

to be shown soon....



GL

MC

Comparison GL with other TMVA methods

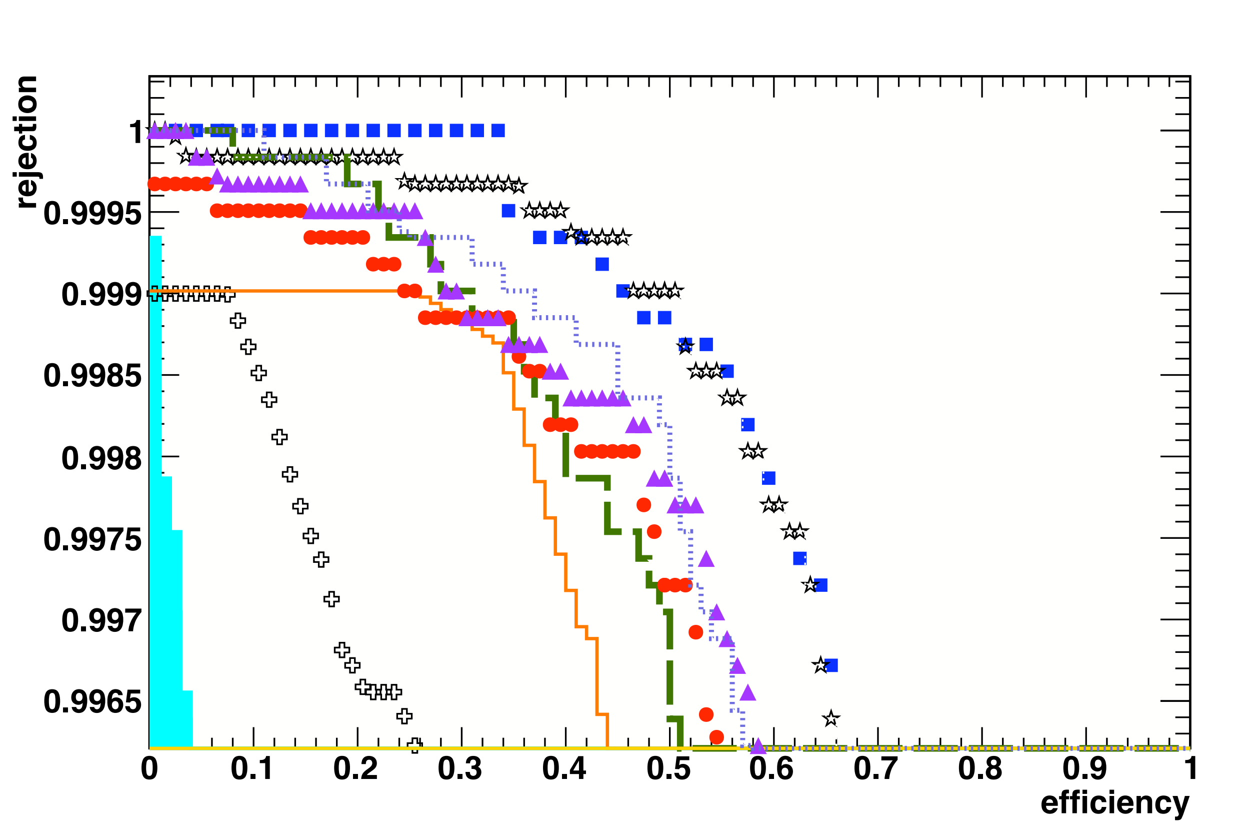


Figure 19: Performance of GL_K and set of other multivariate methods. The X axis shows the efficiency, and the Y axis the rejection. Blue squares: GL_K, Open stars: BDT. Short Dashed: PDERS-PCA. Violet triangles: Fisher Discriminant. Red cyrcles: Best performant NN.Green dashed line: Support Vector Machine.Orange solid line: RuleFit. Open crosses: less performant NN. Filled Cyan histogram: FDA-SA

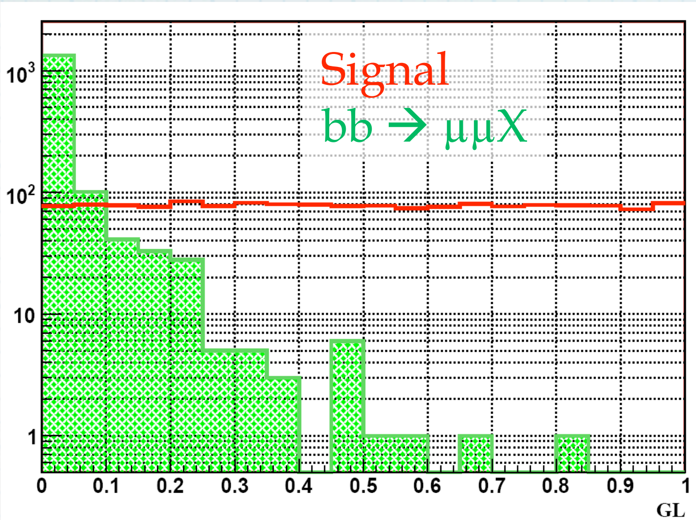
comparison done in identical conditions

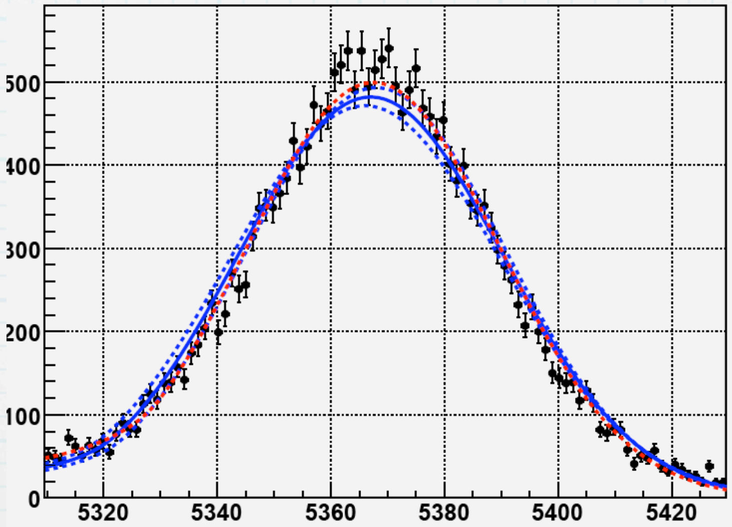
GL vs mass plane

- Divide the GL and mass plane in bins
- Blind the sensitive region (GL> 0.5 and B mass in 60 MeV window)
- Normalize the number of signal events to a decay with known BR

$$\mathrm{BR} = \mathrm{BR}_{\mathrm{cal}} \times \frac{\epsilon_{\mathrm{cal}}^{\mathrm{REC}} \epsilon_{\mathrm{cal}}^{\mathrm{SEL|REC}} \epsilon_{\mathrm{cal}}^{\mathrm{TRIG|SEL}}}{\epsilon_{\mathrm{sig}}^{\mathrm{REC}} \epsilon_{\mathrm{sig}}^{\mathrm{SEL|REC}} \epsilon_{\mathrm{sig}}^{\mathrm{TRIG|SEL}}} \times \frac{f_{\mathrm{cal}}}{f_{B_s^0}} \times \frac{N_{B_s^0 \to \mu^+\mu^-}}{N_{\mathrm{cal}}},$$

- Estimate the number of background and signal events per bin using the data itself: control channels and signal candidates in the sidebands





GL vs mass plane

- Divide the GL and mass plane in bins
- Blind the sensitive region (GL> 0.5 and B mass in 60 MeV window)
- Normalize the number of signal events to a decay with known BR

$$\mathrm{BR} = \mathrm{BR}_{\mathrm{cal}} \times \frac{\epsilon_{\mathrm{cal}}^{\mathrm{REC}} \epsilon_{\mathrm{cal}}^{\mathrm{SEL|REC}} \epsilon_{\mathrm{cal}}^{\mathrm{TRIG|SEL}}}{\epsilon_{\mathrm{sig}}^{\mathrm{REC}} \epsilon_{\mathrm{sig}}^{\mathrm{SEL|REC}} \epsilon_{\mathrm{sig}}^{\mathrm{TRIG|SEL}}} \times \frac{f_{\mathrm{cal}}}{f_{B_s^0}} \times \frac{N_{B_s^0 \to \mu^+\mu^-}}{N_{\mathrm{cal}}},$$

- Estimate the number of background and signal events per bin using the data itself: control channels and signal candidates in the sidebands

mass distribution

(sidebands)

mass distribution

($B_{s(d)} \to hh$)

to be shown soon...

GL distribution

(sidebands)

GL distribution

($B_{s(d)} \to hh$)

Setting limits (or discovery)

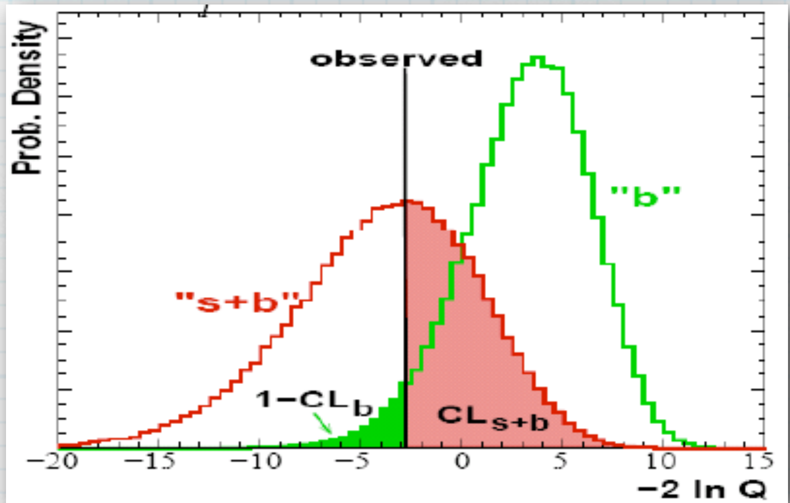
- Using the CLs method (modified frequentist approach)
  - robust: it does not provide an exclusion in the region where the experiment has no sensitivity
  - common method in HEP (LEP, FNL)
- Characteristics:
  - *test-statistics: the likelihood ratio of s+b over b hypothesis of the event*
  - Consider each bin as an independent experiment. The events in each bin follow a Poisson distribution for the s+b and b only hypothesis
  - Consider the statistical and systematical errors of the signal and background estimation

$$X = -2ln\left(\frac{\prod_i poisson(d_i|s_i+b_i)}{\prod_i poisson(d_i|b_i)}\right)$$

$$CL_{s+b} = p_{s+b} = \int_{X_O}^{\infty} \rho_{s+b}(X)\mathrm{d}X$$

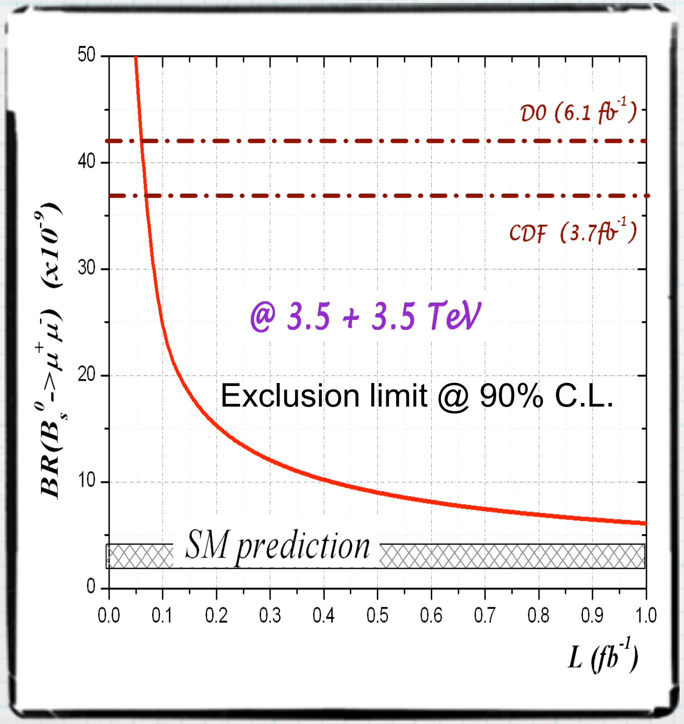
$$CL_b = 1 - p_b = \int_{X_O}^{\infty} \rho_b(X)\mathrm{d}X$$

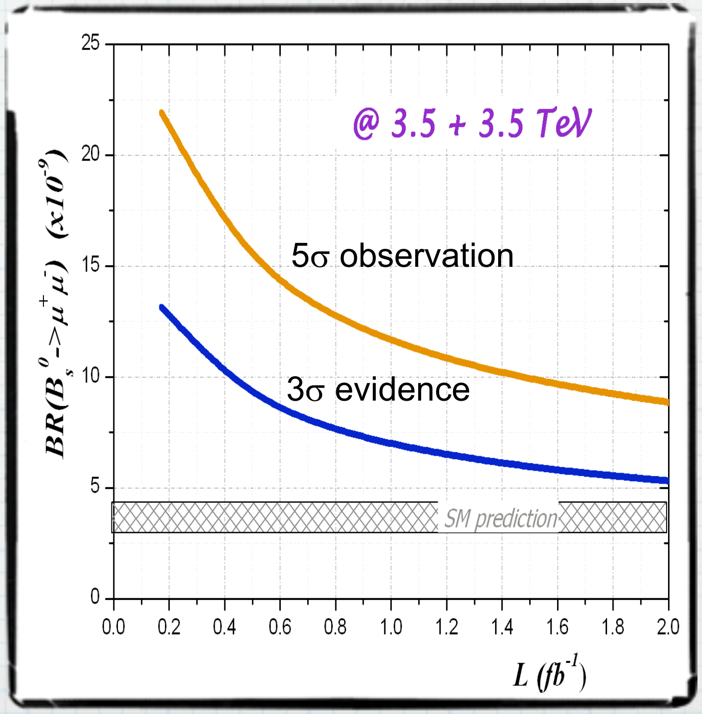
$$CL_s = \frac{CL_{s+b}}{CL_b} = \frac{p_{s+b}}{1-p_b}$$



Expectations according with MC

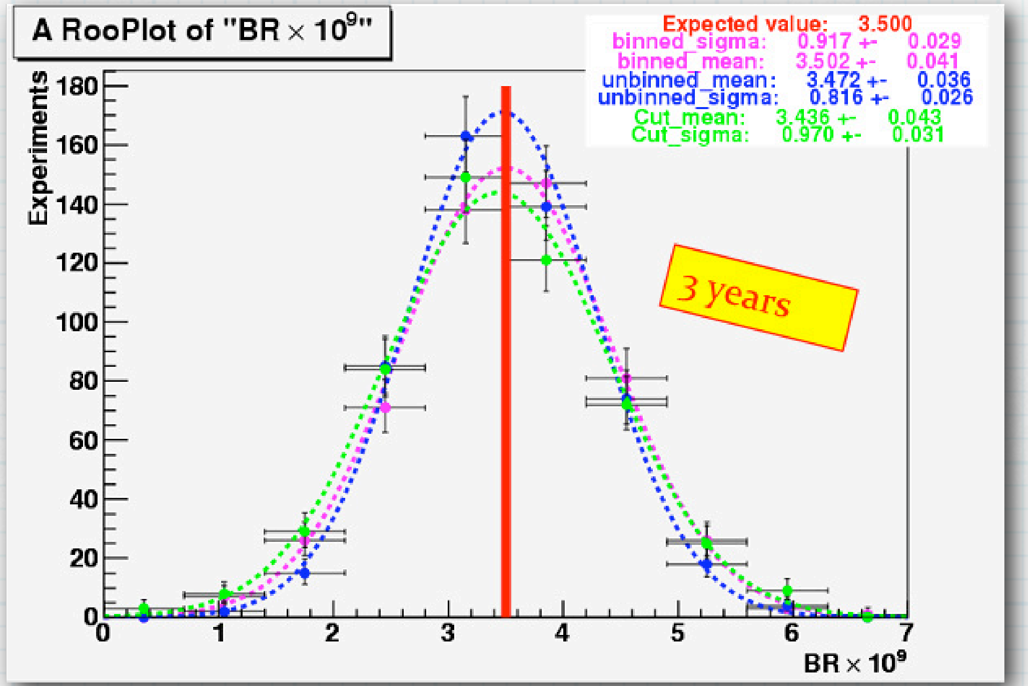
- Estimation of the LHCb limits
  - Consider we observe the expected background events
  - Scan the BR for a given luminosity till the observation has $CL_s = 0.10$
- Estimation of the discovery
  - Consider we observe the expected signal + background events
  - Scan the BR for a given luminosity till the observation has $1\text{-}CL_b$ = (3 or 5 sigmas)





Discovery comparison with other methods

- Study of other methods to measure the *BR*
  - cut based, CLs method, unbinned likelihood fit s+b
- Similar results for measuring *BR* in toys MCs



Errors

- Estimate statistical and systematics errors on the expected signal and background for each bin
- Errors in the signal and background pdf
- Errors in the normalization factor:

$$BR = BR_{cal} \times \frac{\epsilon_{cal}^{REC}\,\epsilon_{cal}^{SEL|REC}\,\epsilon_{cal}^{TRIG|SEL}}{\epsilon_{sig}^{REC}\,\epsilon_{sig}^{SEL|REC}\,\epsilon_{sig}^{TRIG|SEL}} \times \frac{f_{cal}}{f_{B_s^0}} \times \frac{N_{B_s^0 \to \mu^+\mu^-}}{N_{cal}},$$

GL bin	bkg GLK (smeared)	sig GLK (smeared)
0-0.25	2323±48	
0.25-0.5		
0.5-0.75		
0.75-1.0		

	Br ($\times 10^{-5}$)	$\varepsilon^{REC}\varepsilon^{SEL}(cal)$ / $\varepsilon^{REC}\varepsilon^{SEL}(sig)$	$\varepsilon^{TRIG}(cal)$ / $\varepsilon^{TRIG}(sig)$	fd / fs	N_{cal}	$\alpha(\times 10^{-9})$
$B^+ \to J/\psi\, K^+$	5.98±0.22		0.95±0.05	3.59±0.49		
$B_s \to J/\psi\, \phi$	3.35±0.9		0.95±0.05	1		
$B \to K^+\pi^-$	1.94±0.06	0.99±0.02		3.59±0.49		

- Introduce the errors in the computation of the CLs as nuisance parameters

T. Junk CDF/DOC/STATISTICS/PUBLIC/8128

Conclusions

- LHCb detector is a ingood shape, its performance is close to the one expected from MC and we are entering in an era of competitive results with FNL
- Some of the key analysis of LHCb involve searches, one of the most important is the measurement of the $BR(B_s \to \mu\mu)$ and we could improve the limit set by CDF with >50 pb^{-1}
- First results of $BR(B_s \to \mu\mu)$ to be presented in the winter conferences 2011
- The $B_s \to \mu\mu$ search strategy in LHCb is based on
  - In a binned plane where one axis in the mass and the other a 'geometrical likelihood' GL
  - For the GL we use the $\Delta\chi^2$ method (a MVA method)
  - We use a blind technique
  - To set the limit in *BR* (or to claim evidence or discovery) we use the CL_s method