

# Prospects for $B_s^0 \rightarrow \mu^+ \mu^-$ at CMS

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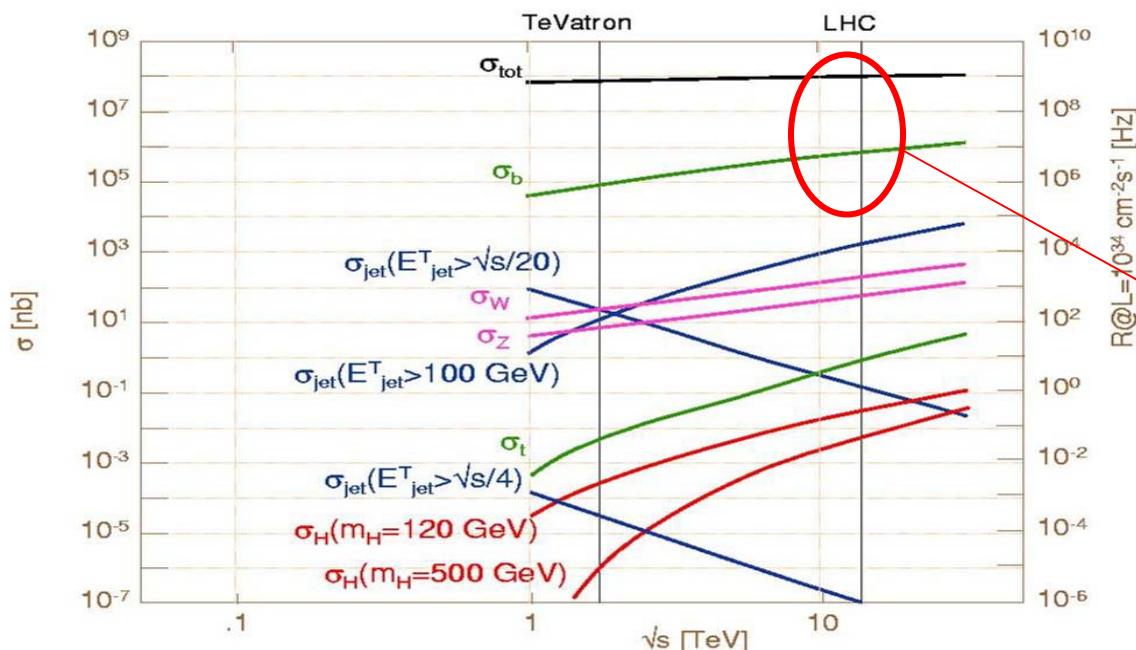
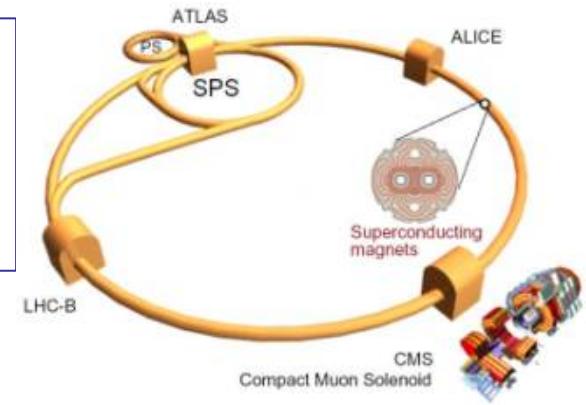
# Outline

- LHC and CMS experiment
  - Key triggers and subsystems
- Prospects for the search of  $B_s^0 \rightarrow \mu^+ \mu^-$ 
  - Physics motivations
  - Analysis flow
  - Results and conclusions

# LHC and $b\bar{b}$ production

pp collider @  $\sqrt{s} = 14$  TeV

- inst. *Low Luminosity* =  $2 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1} \rightarrow 10 \text{ fb}^{-1}$  per year
- inst. *High Luminosity* =  $10^{34} \text{ cm}^{-2}\text{s}^{-1} \rightarrow 100 \text{ fb}^{-1}$  per year



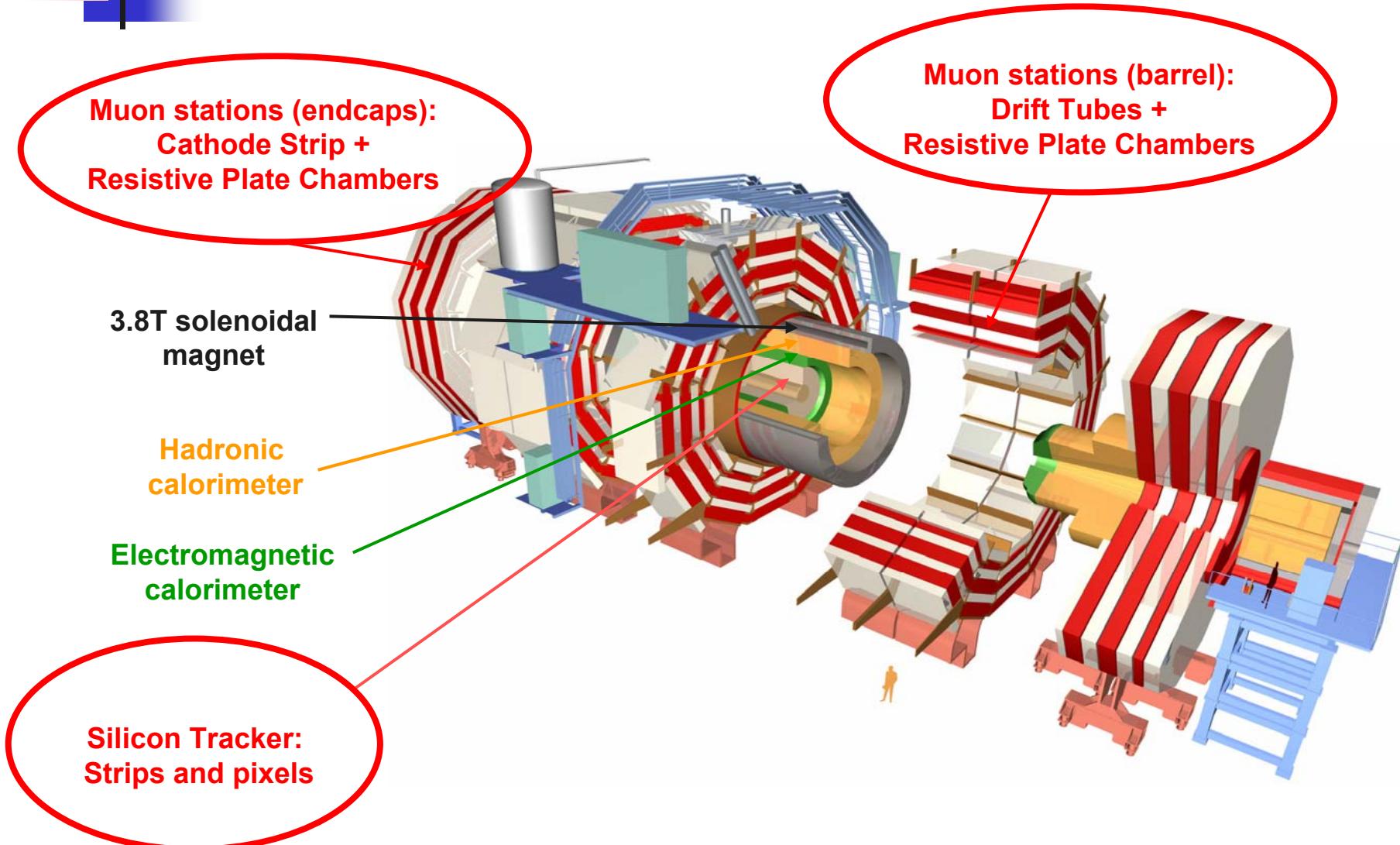
$$\sigma(\text{pp}) \sim 55 \text{ mb}$$

$$\sigma(b\bar{b}) \sim 500 \mu\text{b}$$

**A substantial yield of all  $b$ -flavoured hadrons is expected**

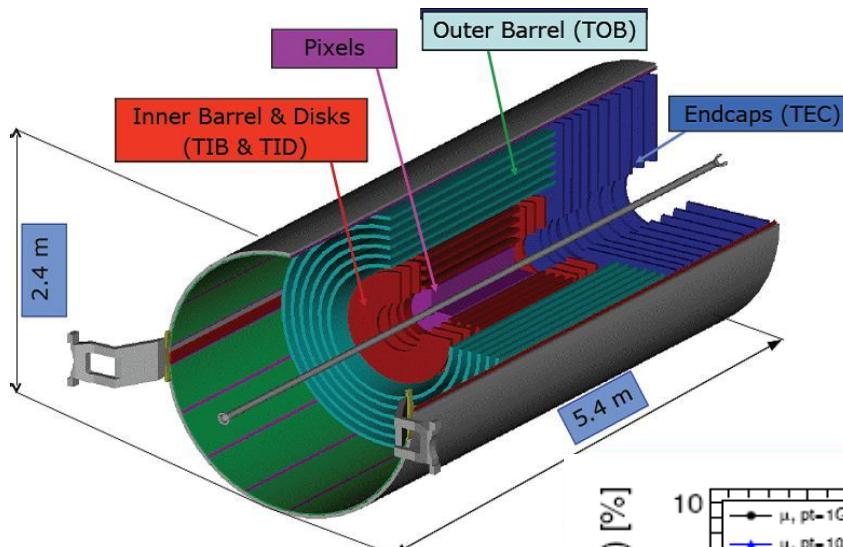
**A high background has to be dealt with**

# CMS detector: key subsystems





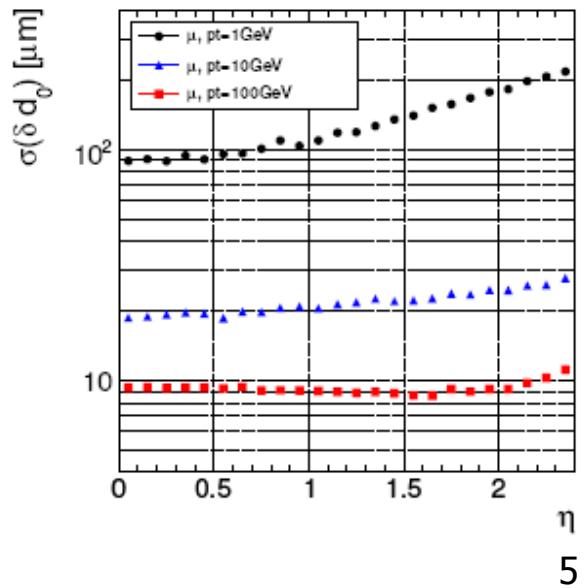
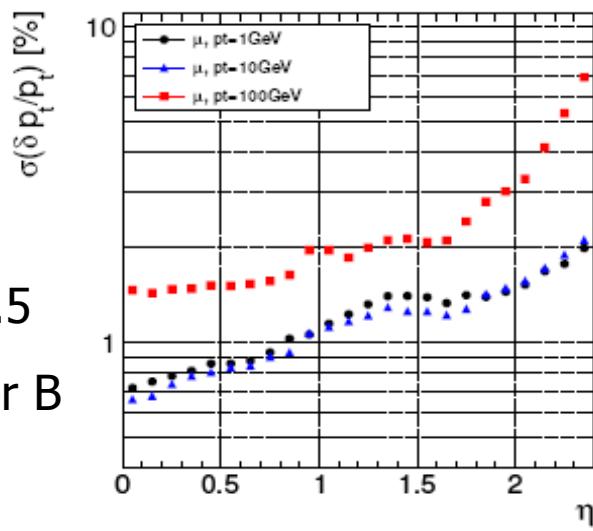
# CMS Tracker



Pixel :	Strip :
■ active area 1 m <sup>2</sup>	■ Active area 198 m <sup>2</sup>
■ 3 cylinders r ~4 ,7 ,10 cm	■ 10 layers :
■ 2x2 disks	■ TIB (4) TOB (6)
■ 1440 modules	■ 12x2 disks :
■ 66 x 10 <sup>6</sup> channels	■ TID (3) TEC (9)
■ Resolution $\sigma = 10 \mu\text{m}$ in $r\phi$	■ 15140 modules

$p_T$  resolution  $\leq 2\%$  in  $|\eta| < 1.5$

$\text{IP}_0$  resolution  $\sim 30\text{-}40 \mu\text{m}$  for B physics typical muon  $p_T$





# The CMS trigger strategy

- Level 1 trigger (L1)
  - hardware based
  - only  $\mu$  chambers and calorimeters
  - 40 MHz  $\rightarrow$  100kHz
- High Level Trigger (HLT)
  - fast local reconstruction
  - all the subdetectors
  - 100 kHz  $\rightarrow$  150 Hz

# B physics trigger at CMS

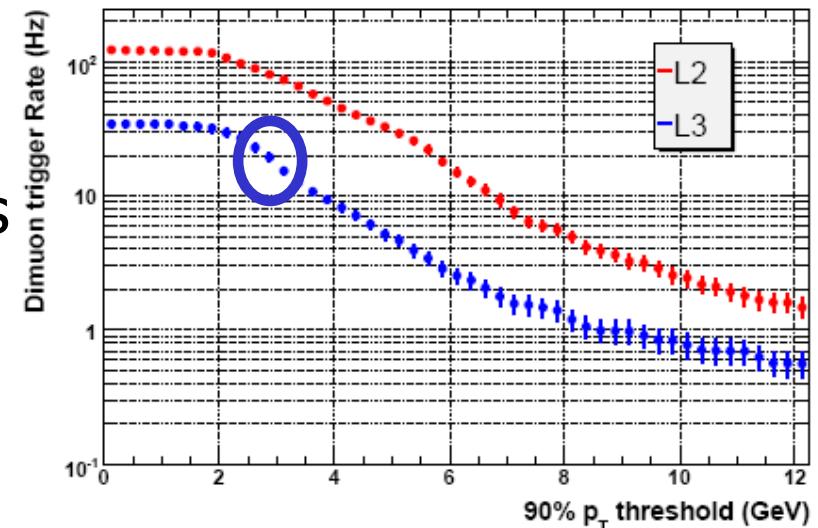
B-physics program will be based on the **muon** trigger

- Level 1

- 1  $\mu$ :  $p_T > 7 \text{ GeV}/c$  (LowLumi) [14  $\text{GeV}/c$  (HighLumi)]
- 2  $\mu$ :  $p_T > 3 \text{ GeV}/c$  (LowLumi) [7  $\text{GeV}/c$  (HighLumi)]

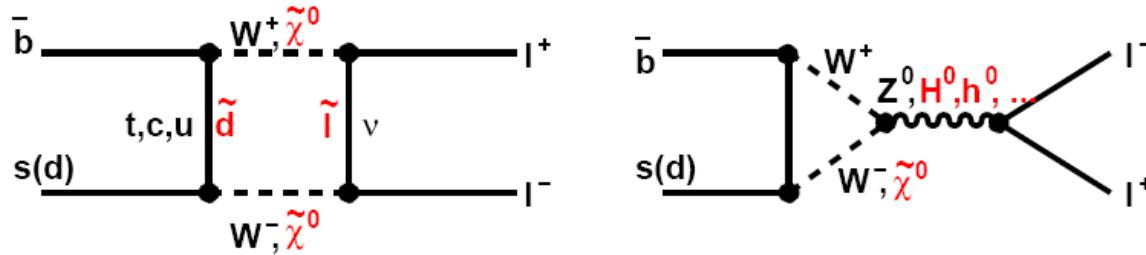
- High Level Trigger

- Exclusive and inclusive triggers
- Partial track reconstruction
- Displaced di-muons

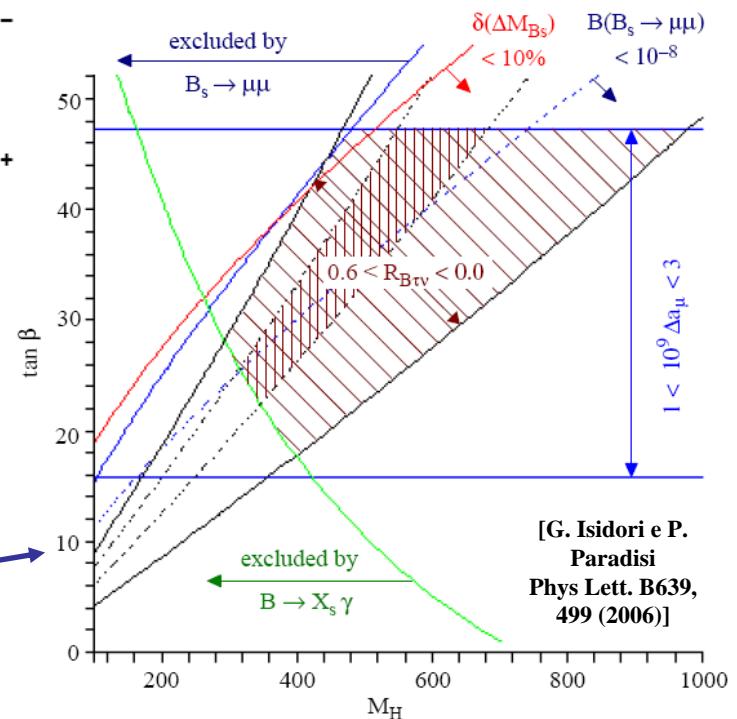


# $B_s^0 \rightarrow \mu^+ \mu^-$ : physics motivations

- The decays of  $B_s^0 \rightarrow \ell^+ \ell^-$  is **forbidden** at tree level
- Can proceed through higher order FCNC process (box and penguin)



- SM prediction
  - $B\Gamma(B_s^0 \rightarrow \mu^+ \mu^-) = (3.55 \pm 0.33) \times 10^{-9}$
- Potentially sensitive probe of physics beyond SM
  - MSSM:  $B\Gamma(B_s^0 \rightarrow \mu^+ \mu^-) \sim (\tan\beta)^6$
  - 2HDM:  $B\Gamma(B_s^0 \rightarrow \mu^+ \mu^-) \sim (\tan\beta)^4, m_H^+$
  - Constraints on masses and  $\tan\beta$





# Results from Tevatron

Current best limits - Tevatron 2 fb<sup>-1</sup>

- CDF

- $Br(B_s^0 \rightarrow \mu^+\mu^-) < 5.8 \times 10^{-8}$  (95% CL)
- PRL 100,101802 (2008)

- D0

- $Br(B_s^0 \rightarrow \mu^+\mu^-) < 9.3 \times 10^{-8}$  (95% CL)
- Preliminary D0 Note 5344-CONF



# $B_s^0 \rightarrow \mu^+ \mu^-$ analysis in CMS

**The analysis scenario :**

**10 fb<sup>-1</sup> in Low Luminosity phase**

- MonteCarlo production of signal and background samples (L1 filter at generator level)
- HLT criteria application
- Off-line selection
- Counting in  $B_s^0$  mass window



# Signal and background

MC events samples generated with Pythia : on average **5 pile-up** events included (LowLumi)

Sample	Generator filter	$\sigma_{\text{eff}} = \sigma \times \text{BR}_{\text{SM}} \times \varepsilon_{\text{geom}}$	$N_{\text{exp}} (10 \text{ fb}^{-1})$
$B_s \rightarrow \mu^+ \mu^-$	$p_T(\mu) > 3 \text{ GeV},  \eta(\mu)  < 2.4$	<b>39.0 fb</b>	<b>390</b>
Rare dec. $B_s$	"	<b>0.58 nb</b>	<b><math>5.8 \cdot 10^6</math></b>
Rare dec. $B_d$	"	<b>1.62 nb</b>	<b><math>1.6 \cdot 10^7</math></b>
Rare dec. $B_{c,u}/\Lambda_b$	"	<b>0.017 nb</b>	<b><math>1.7 \cdot 10^5</math></b>
Generic QCD	$p_T(\mu) > 3 \text{ GeV},  \eta(\mu)  < 2.4,$ $p_T(\mu\mu) > 5 \text{ GeV}, 0.3 < \Delta R < 1.8, 5 < m(\mu\mu) < 6 \text{ GeV}$	<b>17.4 nb</b>	<b><math>1.7 \cdot 10^8</math></b>

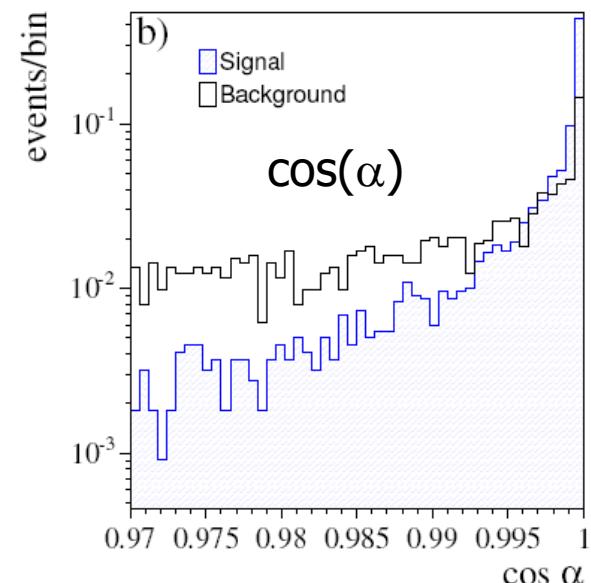
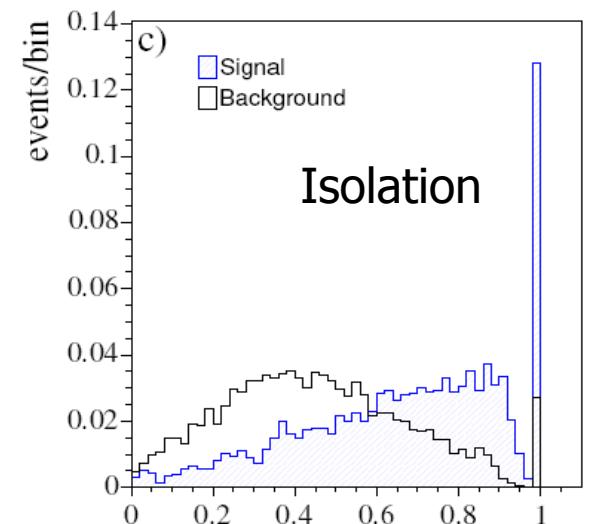
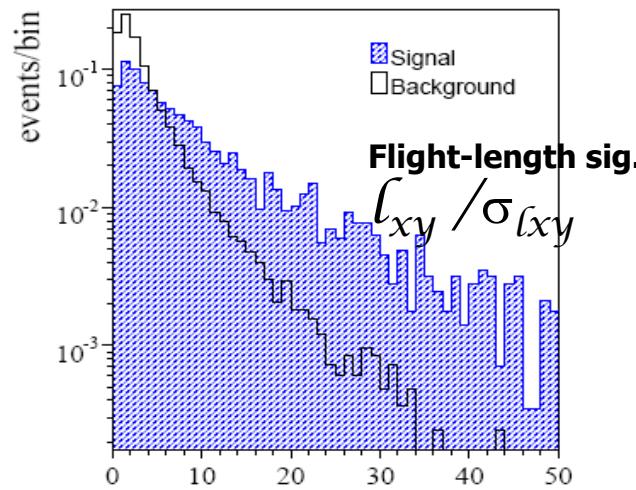


# High Level Trigger

- Di-muon trigger  $p_T(\mu) > 4 \text{ GeV}/c$
- Required opposite charge
- Pixel seeding and partial track reconstruction  
(up to 6 hits or  $\Delta p_t/p_t < 2\%$ )
- $\chi^2$  secondary vertex  $< 20$
- Flight length  $\ell > 150 \text{ }\mu\text{m}$
- $|m(\mu\mu) - m(B_s)| < 150 \text{ MeV}/c^2$

# Off-line selection

- Muons separation  $\Delta R(\mu\mu) = (\Delta\eta^2 + \Delta\phi^2)^{1/2}$
- Secondary vertex quality ( $\chi^2$ )
- $\cos(\alpha)$  (angle btw vector pointing from secondary to primary vertex &  $p_T(B_s)$ )
- Flight-length significance  $\ell_{xy} / \sigma_{\ell_{xy}}$
- Isolation,  $I = \frac{p_T(B_s)}{p_T(B_s) + \sum_{\text{trk}} |p_T|}$





# Selection results

Signal and Background ( $10 \text{ fb}^{-1}$ ) before mass window cut

Selection criteria		Signal		background		2 h from B	
5 < $m(\mu\mu)$ < 6 GeV/c <sup>2</sup>		Events	Efficiency	Events	Efficiency	Events	Efficiency
Gen. kinematics		365.0	/	$1.67 \times 10^8$	/	406.5	/
L1		251.3	0.688	$1.00 \times 10^8$	0.600	406.5	1.000
HLT(w/o mass cut)		150.5	0.412	$1.69 \times 10^7$	0.101	134.6	0.331
Dimuon separation	0.3 < $\Delta R(\mu\mu)$ < 1.2	140.9	0.386	$1.41 \times 10^7$	0.086	125.5	0.309
Pointing angle	$\text{Cos}(\alpha) > 0.9950$	89.4	0.245	$7.34 \times 10^5$	0.004	79.1	0.195
Flight distance	$L_{xy}/\sigma_{xy} > 18.0$	33.7	0.092	$1.20 \times 10^4$	$7.22 \times 10^{-5}$	27.2	0.067
Vertex Fit(diff.norm.)	$\chi^2 < 1.0$		0.627		0.321		0.625
Isolation (diff.norm)	$I > 0.850$		0.288		0.012		0.229
Total efficiency	w/o factorization	7.3	0.019	0.0		3.7	
Total efficiency	w/ factorization	6.1	0.016	47.7	$2.74 \times 10^{-7}$	3.9	$7.74 \times 10^{-3}$

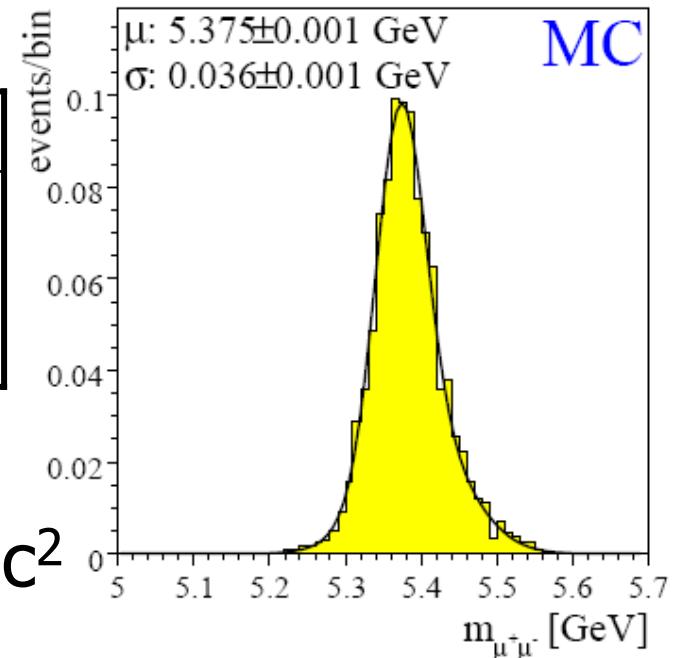
Given the limited statistics of background sample no events remain after the application of all selection requirements : the total rejection factor is calculated by factorization of  $\chi^2$  and isolation requirements (absence of correlation with pre-selection cuts).

# Mass resolution

- The  $\mu^+ \mu^-$  mass distribution is fit with 2 Gaussians

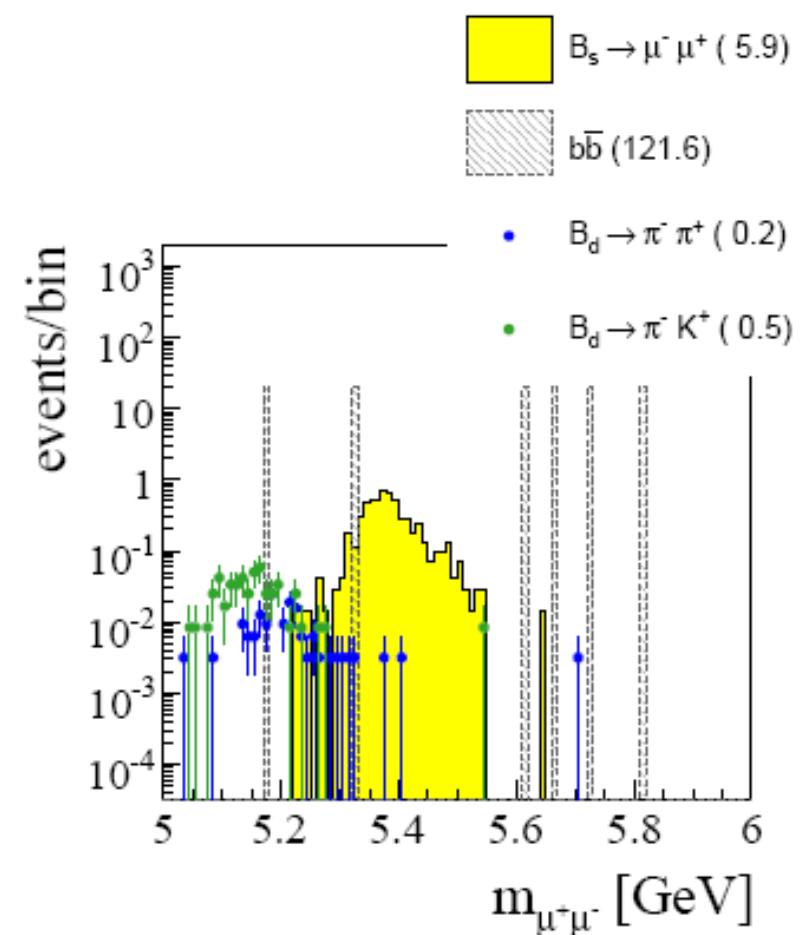
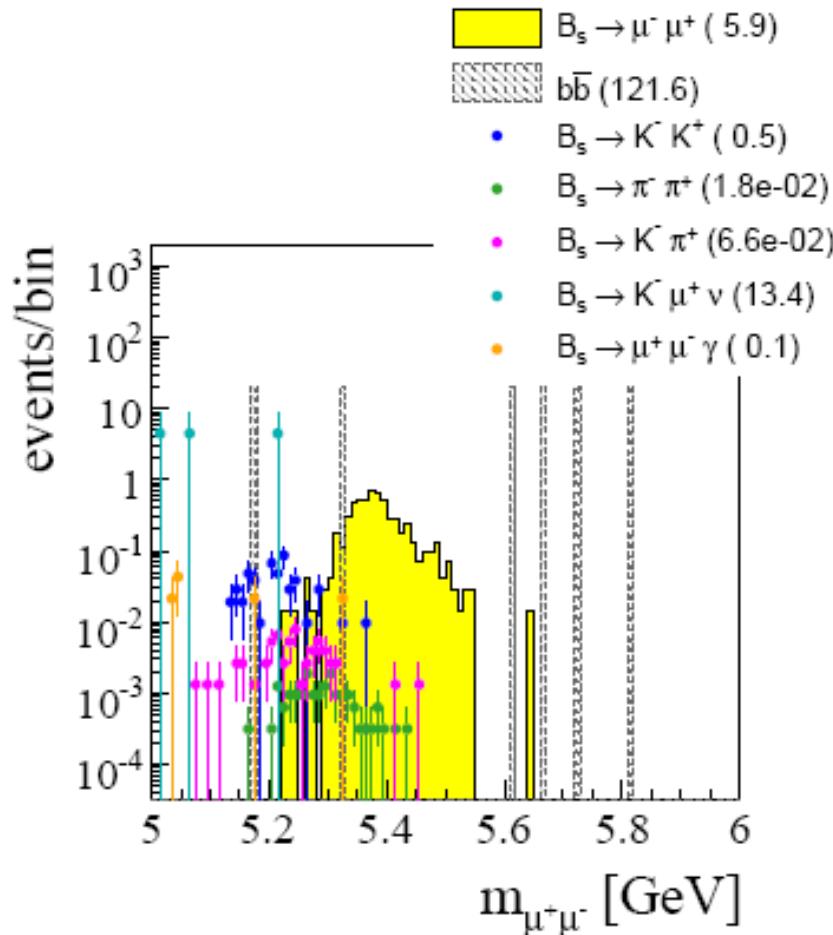
Gaussian	Narrow(MeV/c <sup>2</sup> )	Wide(MeV/c <sup>2</sup> )
Mean	$5381.9 \pm 0.4$	$5409.4 \pm 0.8$
Sigma	$32.1 \pm 0.01$	$60.2 \pm 0.03$
Normalization	0.08	0.03

- average  $\sigma = (36.0 \pm 0.1) \text{ MeV}/c^2$



# Background after cuts

- The  $\mu^+ \mu^-$  mass distribution after selection



# Results

- 10 fb<sup>-1</sup> equivalent luminosity
- Mass window  $\pm 2.3\sigma$  (100 MeV/c<sup>2</sup>):
  - $\varepsilon_s = 0.016 \pm 0.002_{\text{stat}}$  ;  $n_s = 6.1 \pm 0.6_{\text{stat}} \pm 1.5_{\text{syst}}$
  - $\varepsilon_B = 2.6 \times 10^{-7}$  ;  $n_B = 13.8 \pm 0.3^{+22.3}_{-14.1}$
- Upper limit estimation

$$\textcolor{blue}{BR(B_s \rightarrow \mu^+\mu^-) \leq \frac{N(n_{\text{obs}}, n_B, n_s)}{\varepsilon_{\text{gen}} \cdot \varepsilon_s \cdot N(B_s)}}$$

(Bayesian approach)

$$\leq 1.4 \cdot 10^{-8} @ 90\% \text{ CL}$$

# Conclusions

- CMS is competitive in certain B-physics analysis
  - Powerful muon system
  - Precision of silicon tracker
- Search strategy developed for  $B_s^0 \rightarrow \mu^+ \mu^-$
- Expected Limit at 10  $\text{fb}^{-1}$

**$1.4 \cdot 10^{-8}$  @ 90% CL**

With this integrated luminosity the precision of measurement will set constraints on models of new physics



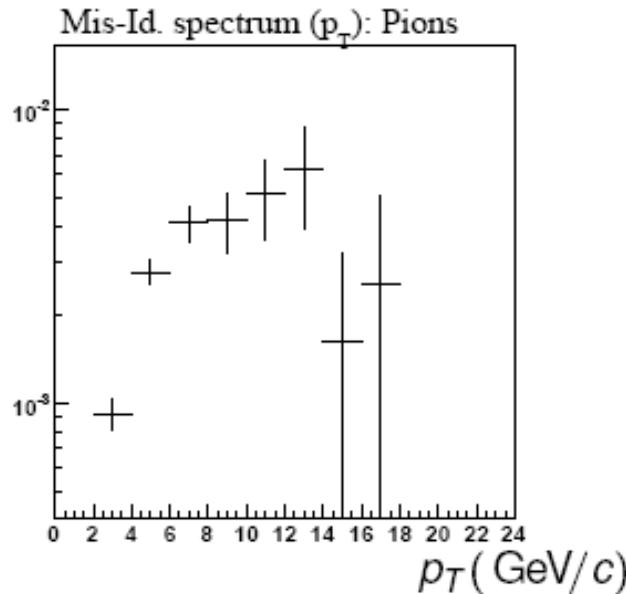
backup



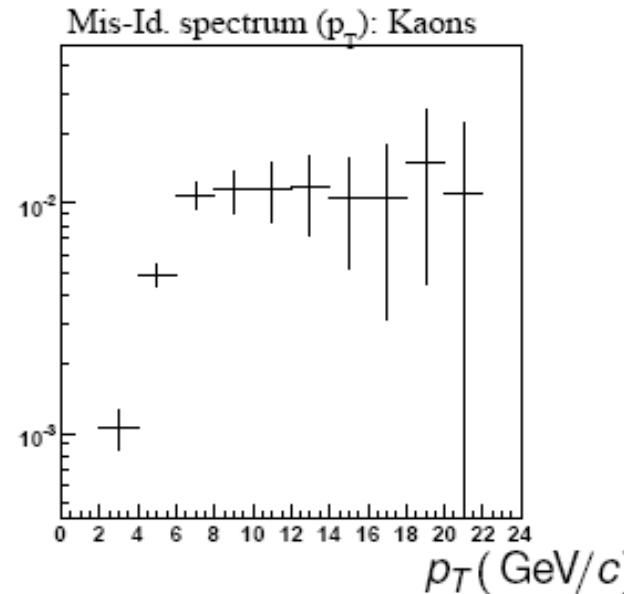
# Background composition

Sample	Generator cuts/channels	$\sigma_{vis} [\text{fb}]$	$N_{\mu ID} (10 \text{ fb}^{-1})$
$b\bar{b} \rightarrow \mu^+ \mu^- + X$	$p_T^\mu > 3 \text{ GeV}/c,  \eta^\mu  < 2.4$ $p_T^{\mu\mu} > 5 \text{ GeV}/c, 0.3 < \Delta R(\mu\mu) < 1.8$ $5 < m_{\mu\mu} < 6 \text{ GeV}/c^2$	1.74E + 07	$1.74 \times 10^8$
$B_s$ decays	$B_s \rightarrow K^- K^+$ $B_s \rightarrow \pi^- \pi^+$ $B_s \rightarrow K^- \pi^+$ $B_s \rightarrow K^- \mu^+ \nu$ $B_s \rightarrow \mu^+ \mu^- \gamma$	2.74E + 05 9.45E + 03 3.08E + 04 2.80E + 05 1.29E + 01	274 3 16 $2.80 \times 10^4$ 130
$B_d$ decays	$B_d \rightarrow \pi^- \pi^+$ $B_d \rightarrow \pi^- K^+$ $B_d \rightarrow \pi^- \mu^+ \nu$ $B_d \rightarrow \mu^+ \mu^- \pi_0$	8.34E + 04 3.74E + 05 1.25E + 06 3.77E + 01	21 187 $6.25 \times 10^4$ 377
$B_u$ decay	$B_u \rightarrow \mu^+ \mu^- \mu^+ \nu$	2.24E + 03	$2.24 \times 10^4$
$B_c$ decays	$B_c \rightarrow \mu^+ \mu^- \mu^+ \nu$ $B_c \rightarrow J/\Psi \mu^+ \nu$	2.01E + 01 1.89E + 03	201 $1.89 \times 10^4$
$\Lambda_b$ decays	$\Lambda_b \rightarrow p \pi^-$ $\Lambda_b \rightarrow p K^-$	4.22E + 03 8.45E + 03	1 1
QCD hadrons	$5 < M(hh) < 6 \text{ GeV}/c^2$	2.24E + 11	$1.12 \times 10^8$

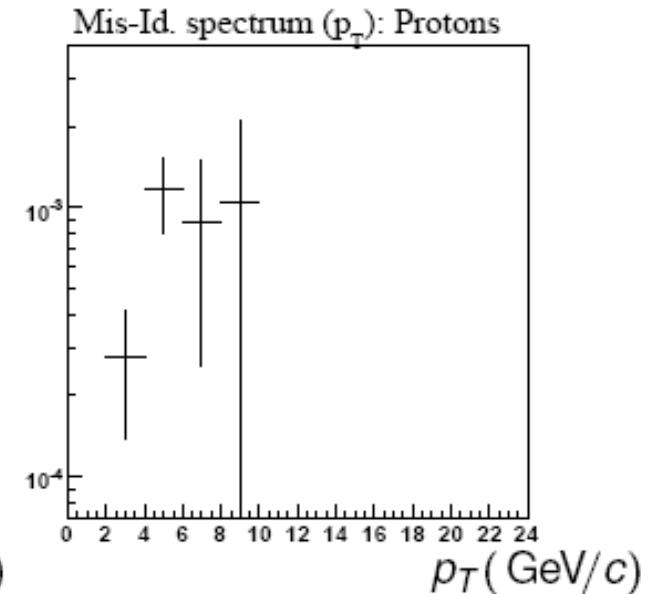
# Misidentification of muon



$$\epsilon_{mis}(\pi) = 0.5\%$$



$$\epsilon_{mis}(K) = 1.0\%$$



$$\epsilon_{mis}(p) = 0.1\%$$