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*On behalf of the LHCb collaboration*

# ***Status of the LHCb experiment***

- *Detector*
- *Physics programme*
- *Commissioning*
- *Expectations for 2010*

# Successes of the Standard Model

LEP, SLC, Tevatron and B-factories established that Standard Model really describes the physics at energies up to  $\sqrt{s} \sim 200 \text{ GeV}$

State-of-art is given by UT:

- Accuracy of sides is limited by theory:

Extraction of  $|V_{ub}|$

Calculation of  $\xi^2 = \frac{\hat{B}_{B_s} f_{B_s}^2}{\hat{B}_{B_d} f_{B_d}^2}$

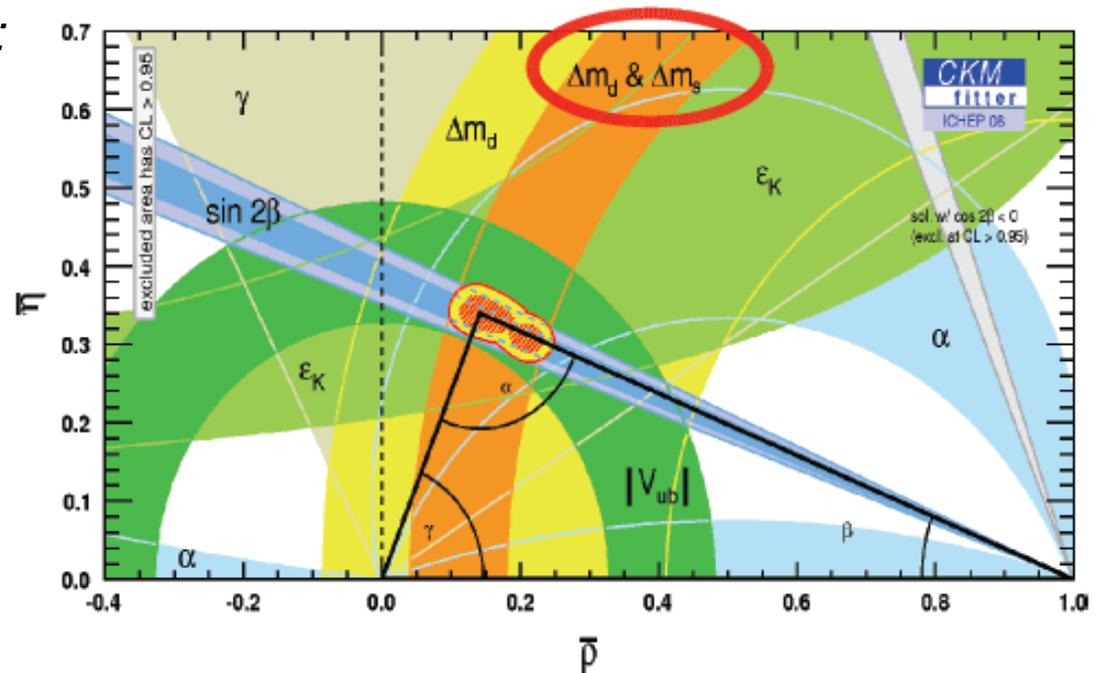
- Accuracy of angles is limited by experiment:

$\sigma(\alpha) \sim 5^\circ, \sigma(\beta) \sim 1^\circ, \sigma(\gamma) \sim 20^\circ$

$\beta_s$  is not measured accurately!  
Hint for a large value (well beyond SM) from Tevatron

**Standard Model is a precisely tested theory  
however does not provide the whole picture...**

The quark sector is well described by the CKM mechanism



Missing ingredient, Higgs particle, has been searched for decades but not yet found

# LHC Physics Goals

## Main Goals:

- Search for the SM Higgs boson in mass range  $\sim 115 < m_H < 1000 \text{ GeV}$
- Search for New Physics beyond the SM

- Explore TeV-scale directly (ATLAS & CMS) and indirectly (LHCb)



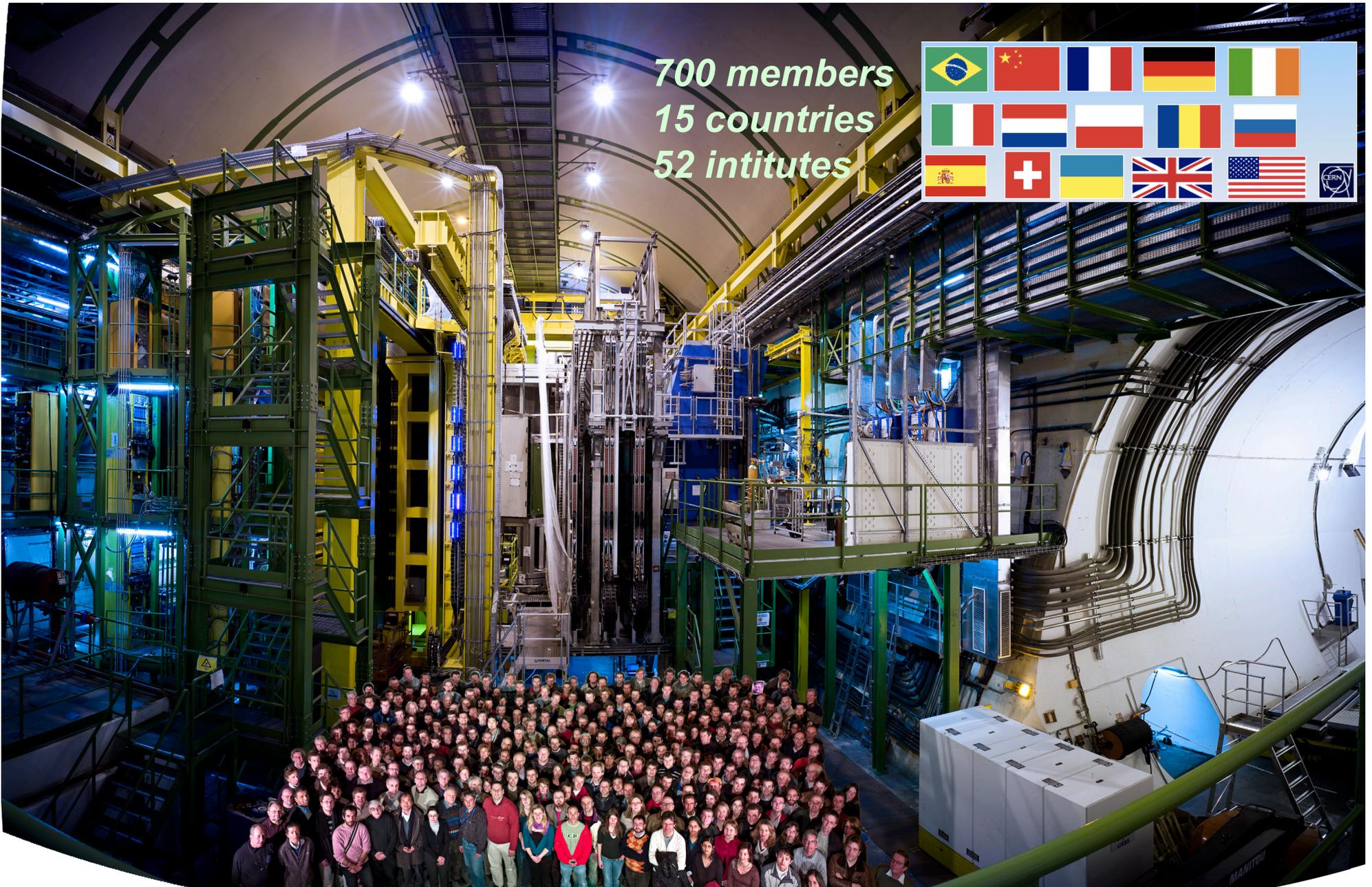
No space left for the 4<sup>th</sup> possibility

ATLAS CMS high $p_T$ physics	BSM	Only SM	BSM	
LHCb flavour physics	Only SM	BSM	BSM	
Particle Physics	☺	☺	☺	

*Even if 4<sup>th</sup> possibility → Measurements of virtual effects will set the scale of New Physics*

# LHCb Collaboration

700 members  
15 countries  
52 institutes



# The LHCb Experiment

## □ Advantages of beauty physics at hadron colliders:

### ■ High value of $bb$ cross section at LHC:

$\sigma_{bb} \sim 300 - 500 \mu\text{b}$  at 10 - 14 TeV

( $e^+e^-$  cross section at  $Y(4s)$  is 1 nb)

### ■ Access to all quasi-stable $b$ -flavoured hadrons

## □ The challenge

### ■ Multiplicity of tracks ( $\sim 30$ tracks per rapidity unit)

### ■ Rate of background events: $\sigma_{inel} \sim 80 \text{ mb}$

## □ LHCb running conditions:

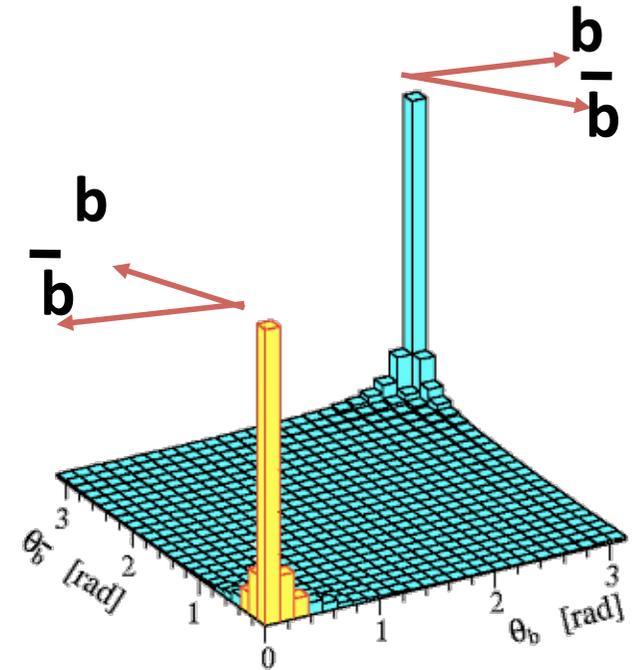
### ■ Luminosity limited to $\sim 2 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$ by not focusing the beam as much as ATLAS and CMS

#### ■ Maximize the probability of single interaction per bunch crossing

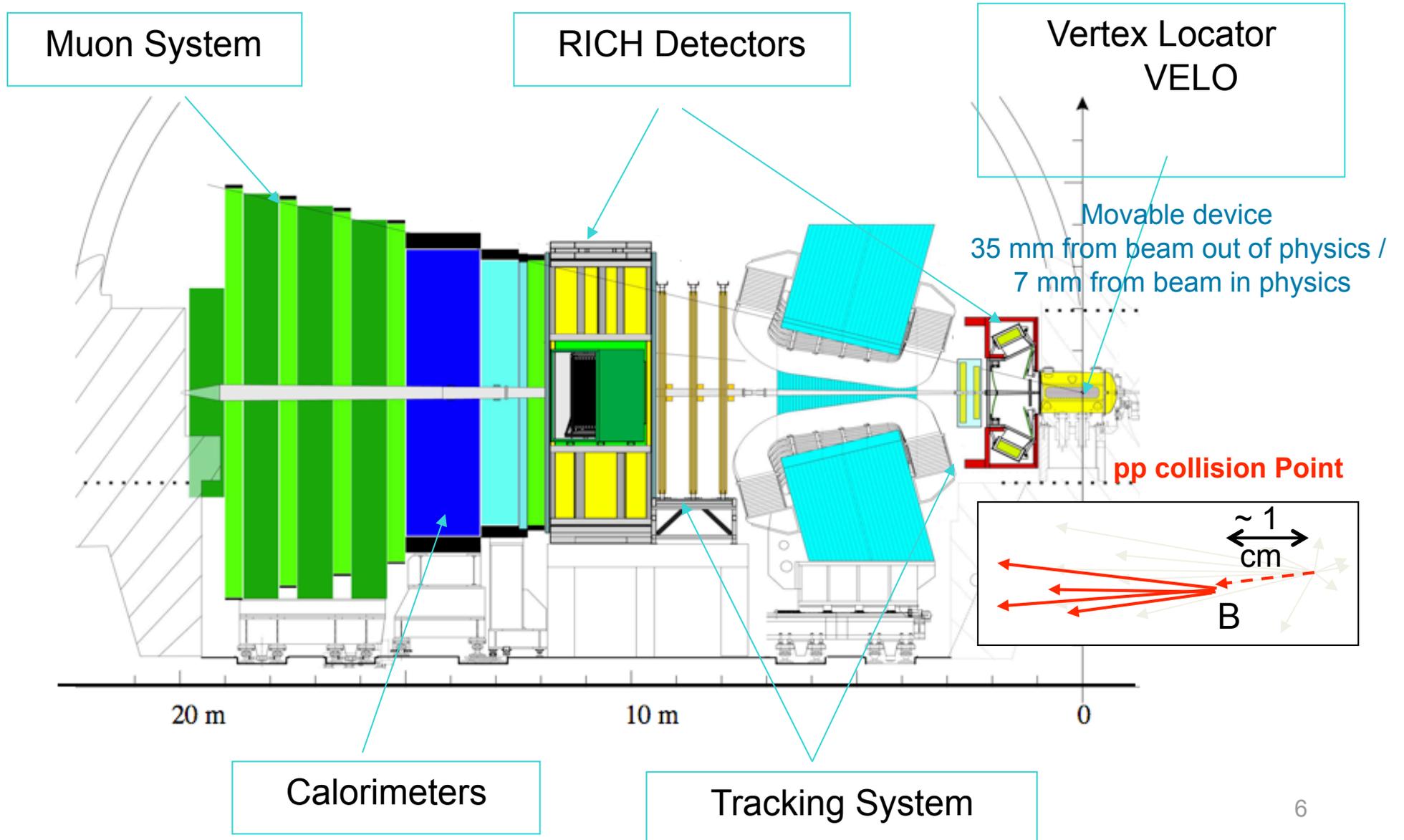
At LHC design luminosity pile-up of  $> 20$  pp interactions/bunch crossing while at LHCb  $\sim 0.7$  pp interaction/bunch

#### ■ LHCb will reach nominal luminosity soon after start-up

### ■ $2 \text{ fb}^{-1}$ per nominal year ( $10^7 \text{ s}$ ), $\sim 10^{12}$ $bb$ pairs produced per year



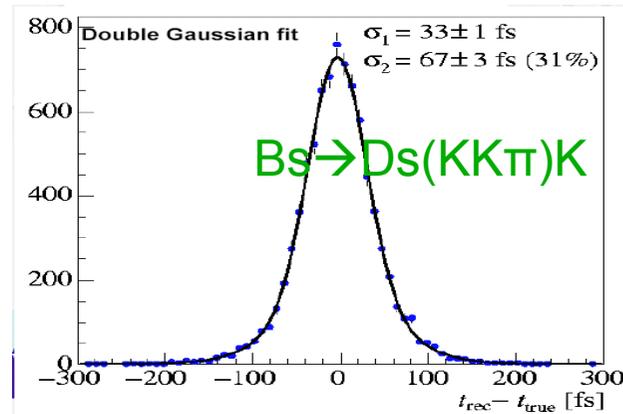
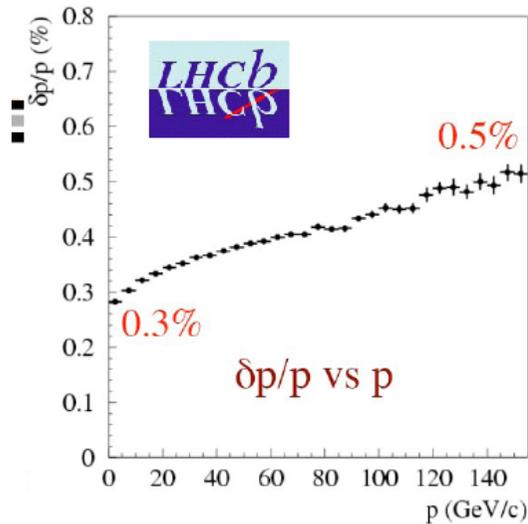
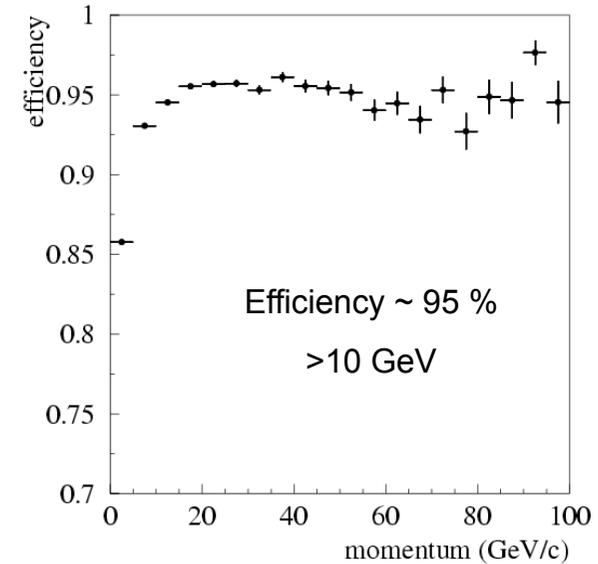
# The LHCb Detector



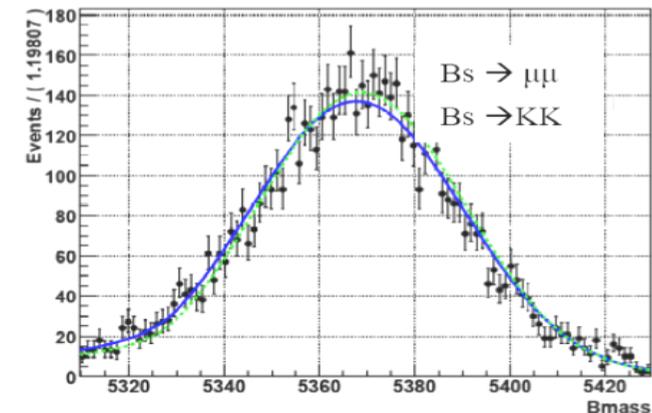
# Detector Performances: Tracking

## Expected tracking performance:

- Efficiency > 95% for tracks from B decays crossing entire detector
- $\delta p/p$ : 0.3% - 0.5% (depending on p)
- Proper time resolution: ~ 40 fs
- B Mass resolution: 15-20 MeV/c<sup>2</sup>



Proper time resolution ~ 40 fs

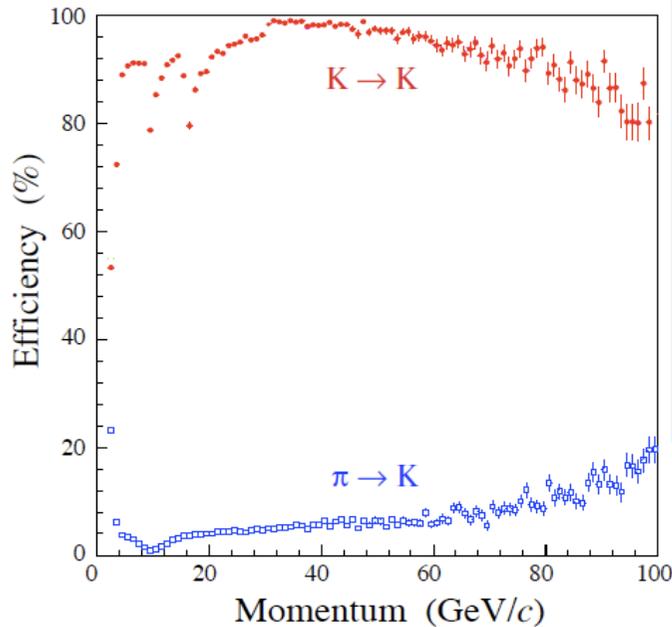


Mass resolution ~ 20 MeV

# Detector Performances: PID

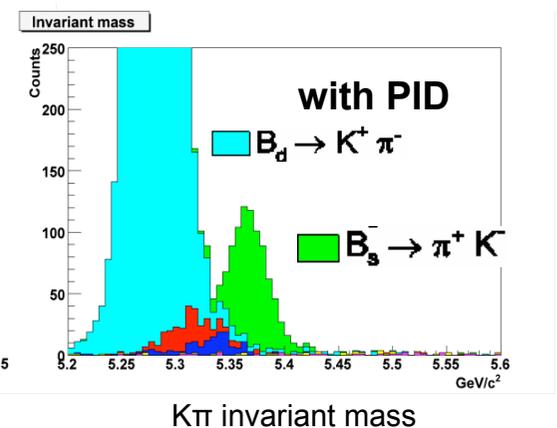
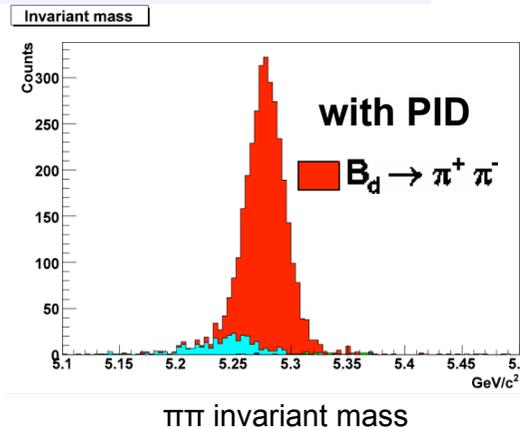
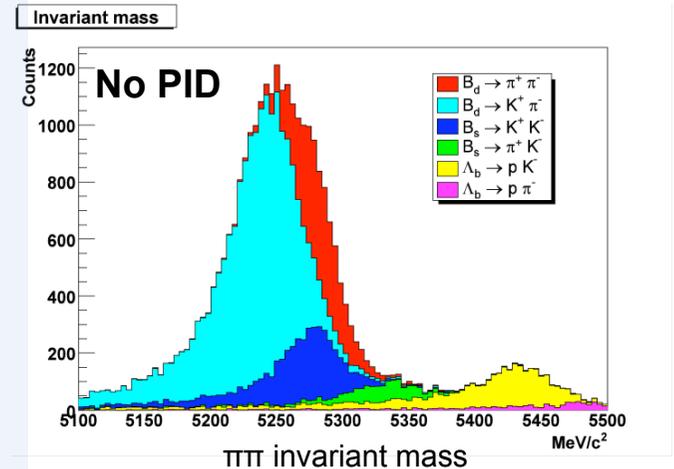
Two RICH detectors with 3 radiators to cover range  $2 < p < 100$  GeV :  
 RICH1 Aerogel (2-10 GeV),  $C_4F_{10}$  (10-60 GeV)  
 RICH2  $CF_4$  (16-100 GeV)

## $\pi$ -K separation



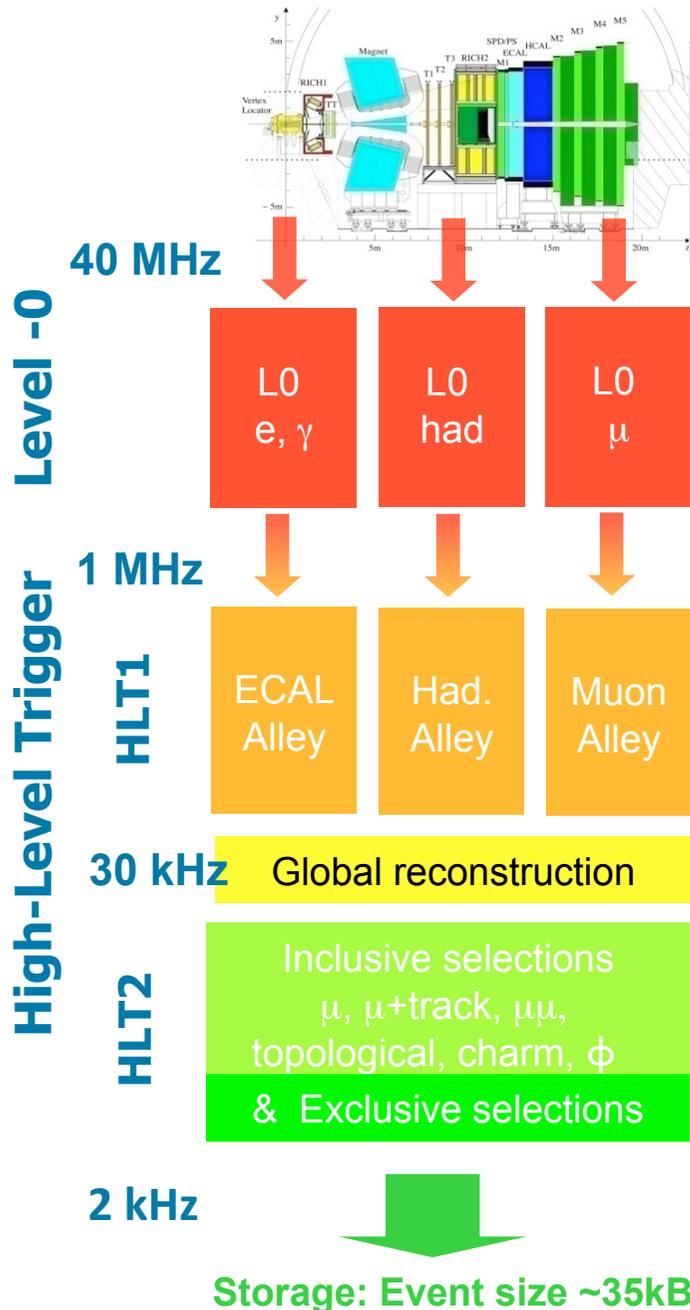
Kaon ID ~ 90%  
 Pion mis-ID ~ 3%

- Good  $\pi$ -K separation in 2-100 GeV/c range
- Low momentum
  - Tagging kaons
- High momentum
  - Clean separation of  $B_{d,s} \rightarrow hh$  modes



# LHCb Trigger

Trigger is crucial as  $\sigma_{bb}$  is less than 1% of total inelastic cross section and B decays of interest typically have  $BR < 10^{-5}$



**Hardware level (L0)**

Search for high- $p_T$   $\mu$ , e,  $\gamma$  and hadron candidates

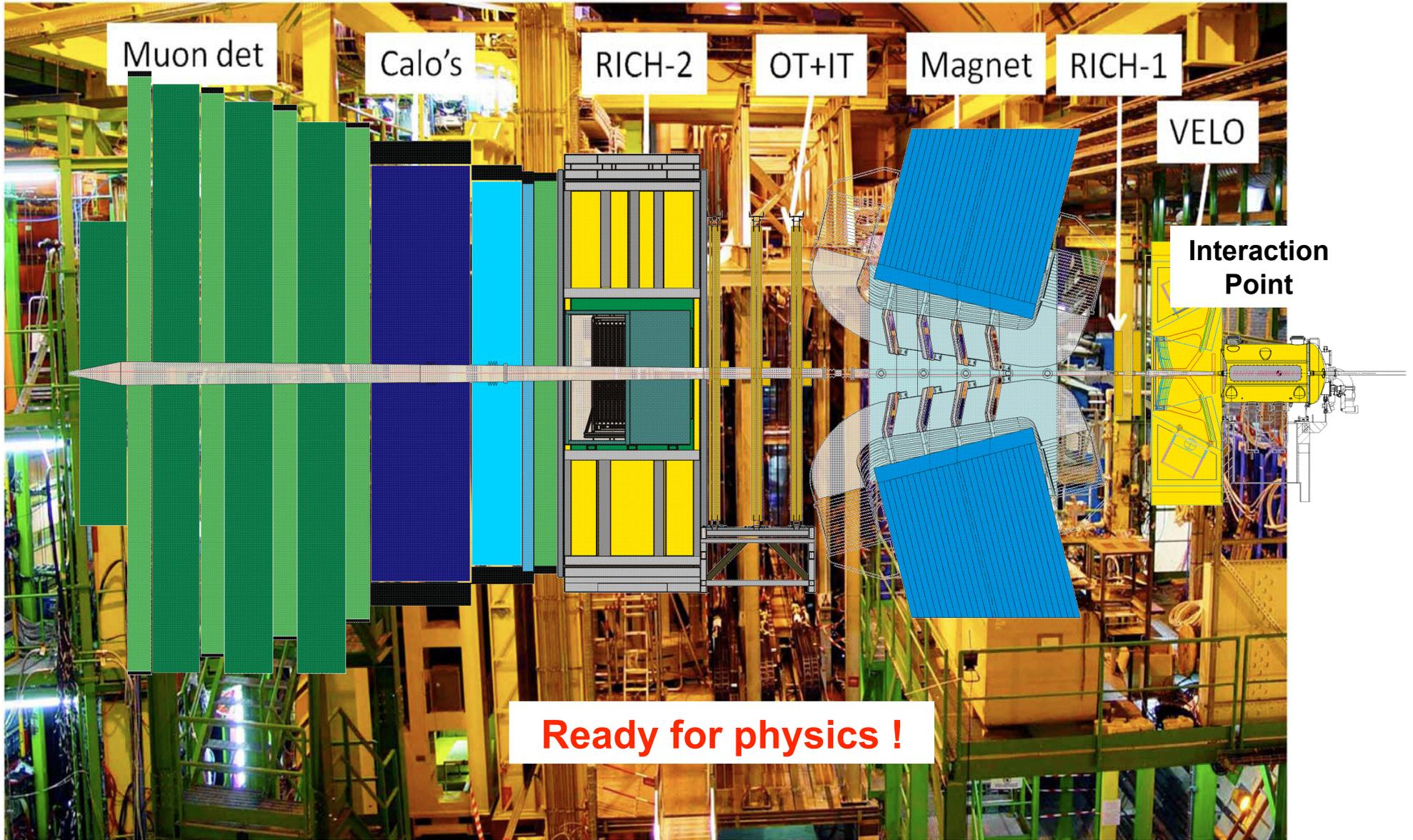
**Software level (High Level Trigger, HLT)**

Farm with  $O(2000)$  multi-core processors

HLT1: Confirm L0 candidate with more complete info, add impact parameter and lifetime cuts

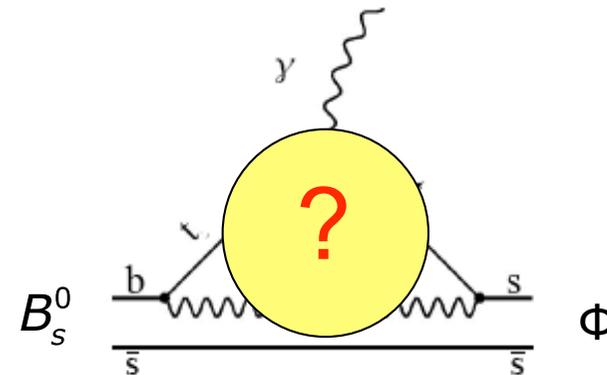
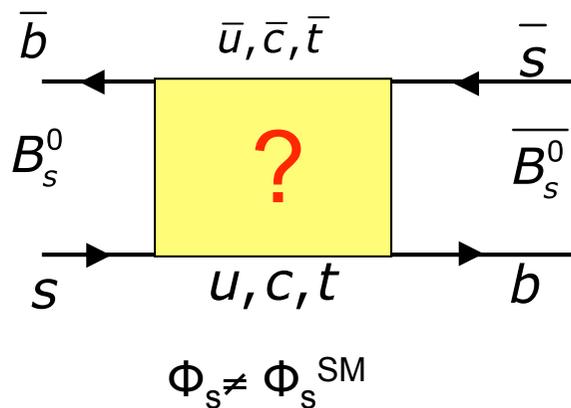
HLT2: B reconstruction + selections

	$\epsilon(L0)$	$\epsilon(HLT1)$	$\epsilon(HLT2)$
Electromagnetic	70 %	> ~80 %	> ~90 %
Hadronic	50 %		
Muon	90 %		



# LHCb Physics Programme

Main LHCb objective is to search for the effects induced by New Physics in CP violation (see talk by M. Calvi) and Rare decays (see talk by M.-H. Schune) using the FCNC processes mediated by loop (box and penguin) diagrams



**Sensitivity to masses, couplings, spins  
and phases of New Particles**

# New Physics Search Strategy

## Phases

CPV processes are the only measurements sensitive to the phases of New Physics e.g. measurements of  $\beta$ ,  $\beta_s$  &  $\gamma$

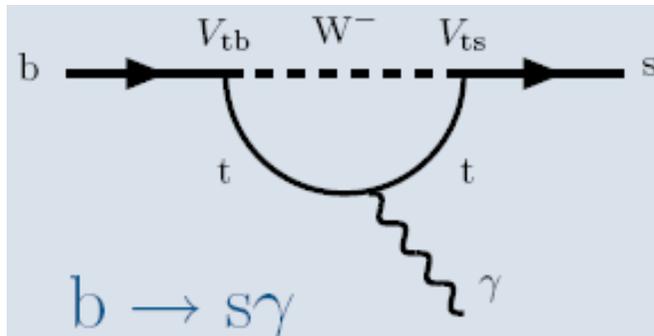
## Masses and magnitude of the couplings of new particles

Inclusive  $BR(b \rightarrow s\gamma)$  indirectly constrains the scale of NP masses  $\Lambda > 10^3$  TeV for generic coupling (flavour problem)

Look at specific cases with enhanced sensitivity e.g. helicity suppression in  $B_s \rightarrow \mu\mu$  decay gives increased sensitivity to SUSY with extended Higgs sector

## Helicity structure of the couplings

Use the correlation between photon polarization and b flavour in  $b \rightarrow s\gamma$



$$b \rightarrow \gamma (L) + (m_s/m_b) \times \gamma(R)$$

$\phi\gamma$  produced in  $B_s$  and  $\bar{B}_s$  decays do not interfere

$\rightarrow$  corresponding CP asymmetry vanishes

**Significantly non-zero  $A_{CP}$  indicates a presence of right-handed current in the penguin loop**

Similar study using  $B \rightarrow K^*\mu^+\mu^-$  &  $K^*e^+e^-$

# CPV measurements: UT angles

## □ Box diagrams (I)

*Note: UT geometry is such that the main constraint on NP comes from the comparison of the opposite elements i.e. angles vs sides*

$\beta$  vs  $|V_{ub}/V_{cb}|$  is largely limited by theory ( $\sim 10\%$  precision in  $|V_{ub}|$ )  
**Note a discrepancy in  $|V_{ub}|$  determined in inclusive and exclusive measurements :**  $|V_{ub}|$  incl  $\sim (4.0-4.9) \times 10^{-3}$  and  $|V_{ub}|$  excl  $\sim (3.3-3.6) \times 10^{-3}$

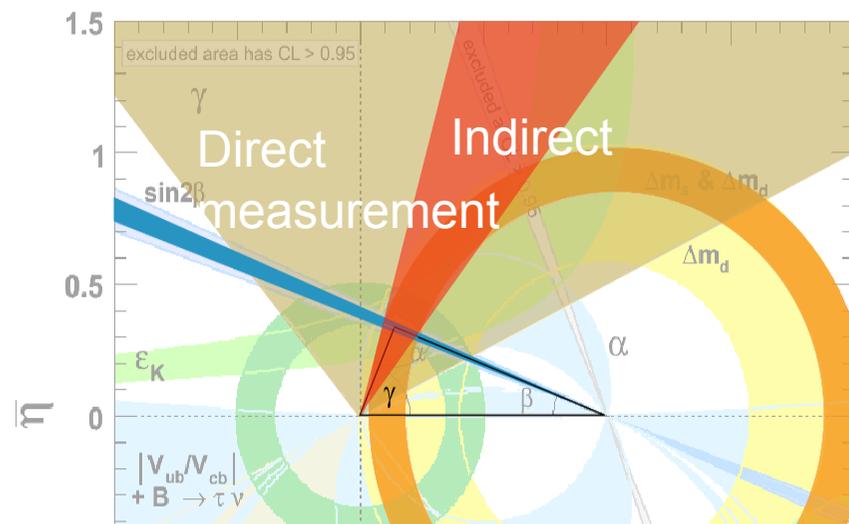
$\gamma$  vs  $\Delta m_d/\Delta m_s$  is limited by experiment:  $\gamma$  is poorly measured ( $\pm 20^\circ$ )

**Indirectly  $\gamma$  is determined to be  $\gamma = (68 \pm 5)^\circ$  from processes involving boxes**

*LHCb will measure  $\gamma$  directly in tree decays using the global fit to the rates of  $B \rightarrow D^0 K, D^0 K^*$  decays and time-dependent measurements with  $B_s \rightarrow D_s K$  and  $B^0 \rightarrow D \pi$  decays*

**Expected  $\sigma(\gamma_{\text{trees}}) \approx 4^\circ$  with  $2 \text{ fb}^{-1}$**

(See poster of M. Gersabeck)



# CPV measurements: $B_s$ mixing

## □ Box diagrams (II)

$\Phi(J/\psi\phi) = -2\beta_s$  is the  $B_s$  meson counterpart of  $2\beta$   
penguin contribution  $\leq 10^{-3}$

$\beta_s$  not measured accurately (indication of large value from CDF/D0)

**Theoretical uncertainty is very small**

$-2\beta_s = -0.0368 \pm 0.0017$  (CKMfitter 2007)

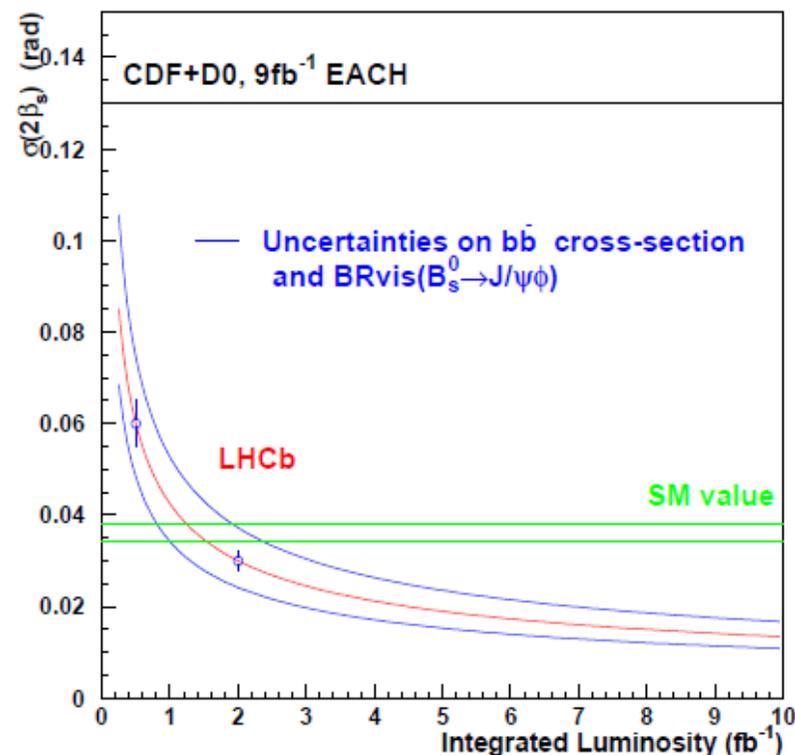
**LHCb prospects ( $2 \text{ fb}^{-1}$  sample)**

Expected yield  $117\text{k } B_s \rightarrow J/\psi\phi$  events

$$\sigma(2\beta_s) \sim 0.03$$

Other channels are under study e.g.

$B_s \rightarrow J/\psi f^0$ ,  $f^0 \rightarrow \pi^+\pi^-$ . Looks promising  
if this CP-eigenstate mode has sufficiently  
large BR as indicated by CLEO (see talk  
by T.Skwarnicki)

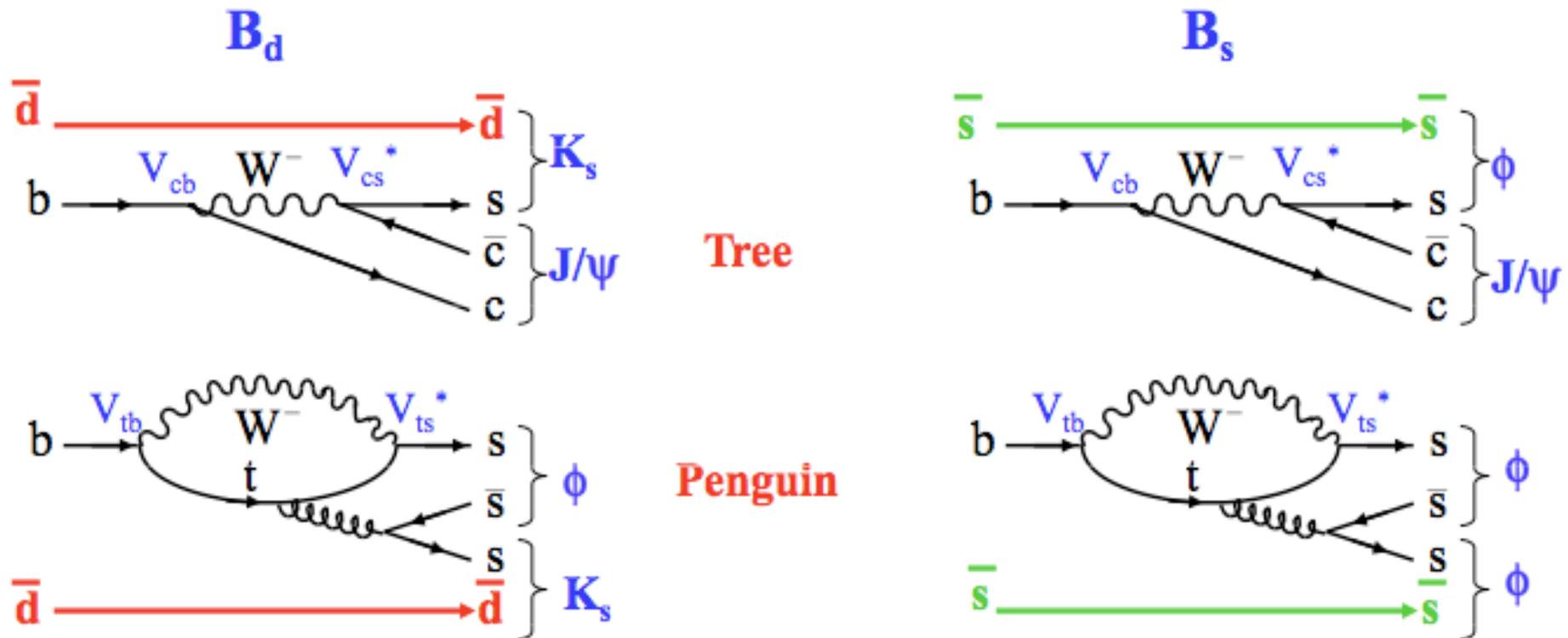


# CPV measurements: Penguin vs Tree

## □ Penguin diagrams:

$$\delta 2\beta(NP) = 2\beta(B \rightarrow \phi K_s) - 2\beta(B \rightarrow J/\psi K_s) \neq 0$$

$$\delta 2\beta_s(NP) \approx 2\beta_s(B_s \rightarrow \phi\phi) - 2\beta_s(B_s \rightarrow J/\psi\phi)$$



$\sigma(\delta 2\beta_s(NP))$  not measured

**LHCb sensitivity with  $2 \text{ fb}^{-1} \sim 0.11 \text{ rad}$**   
(stat. limited)

Thanks to B-factories

$$\delta 2\beta(NP) \sim -0.23 \pm 0.18 \text{ rad}$$

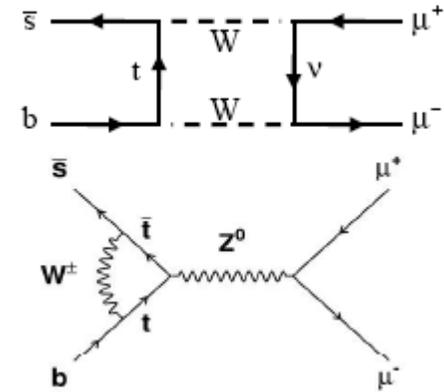
# Rare Decays

**Current experiments are only now approaching an interesting level of sensitivity in exclusive decays:**

- $BR(B_s \rightarrow \mu\mu)$  (CDF /D0)  
 $BR(B_d \rightarrow \mu\mu)$
- *Photon polarization in  $B \rightarrow K^*\gamma$  (BELLE/BaBar)*
- $A_{FB}$  in  $B \rightarrow K^*\mu\mu$  (BELLE/BaBar)
- $BR(D^0 \rightarrow \mu\mu)$  (CDF)

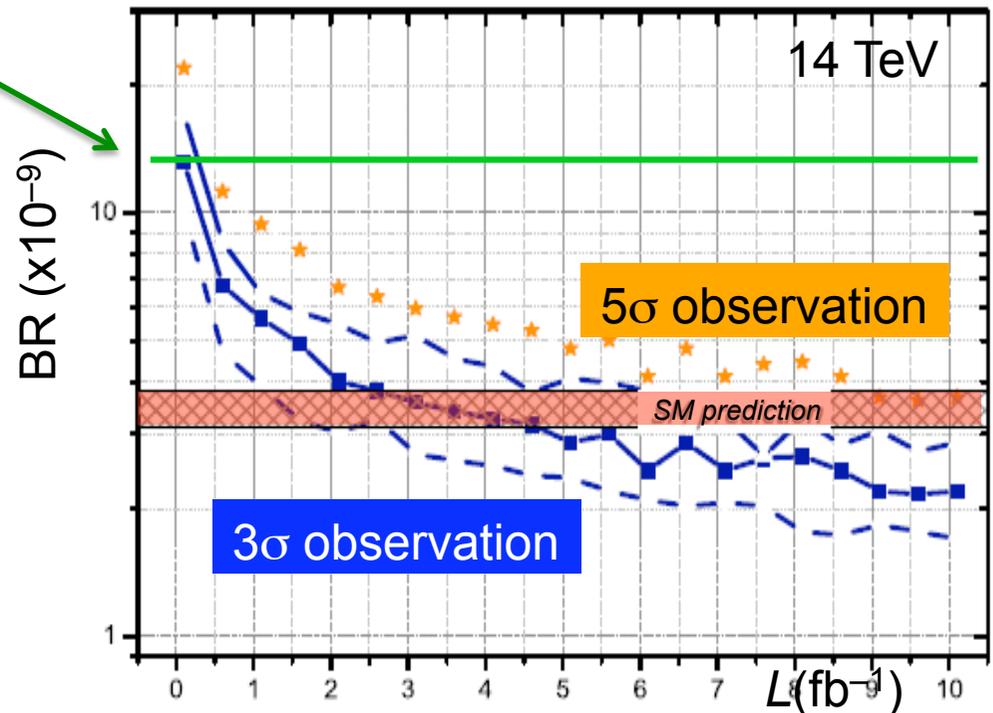
***LHCb will study rare decays in depth !!!***

# $B_s \rightarrow \mu\mu$



- ❑ Super rare decay in SM with well predicted  $BR(B_s \rightarrow \mu\mu) = (3.55 \pm 0.33) \times 10^{-9}$
- ❑ Sensitive to NP, in particular new scalars  
In MSSM:  $BR \propto \tan^6 \beta / M_A^4$
- ❑ Best present limit is from CDF:  
 $BR(B_s \rightarrow \mu\mu) < 4.7 \times 10^{-8}$  @ 90% CL
- ❑ For the SM prediction  
LHCb expects 21 signal and 180 background events with  $2 \text{ fb}^{-1}$ .  
Background is dominated by muons from two different semileptonic  $b$ -decays
- ❑ LHCb sensitivity for the SM BR:  
 $3\sigma$  evidence with  $3 \text{ fb}^{-1}$   
 $5\sigma$  observation with  $10 \text{ fb}^{-1}$

## Discovery



## Measurement of the photon polarization in $B_s \rightarrow \phi\gamma$ decay

- BaBar & BELLE used CPV analysis in  $B \rightarrow K^*(K^0\pi^0)\gamma$  decay  
 $\sigma(A(B \rightarrow f^{CP} \gamma_R) / A(B \rightarrow f^{CP} \gamma_L)) \sim \mathbf{0.16}$  (HFAG)  
 (~0.04 within SM due to  $m_s/m_b$  and gluon effects)
- CPV analysis in the  $B_s \rightarrow \phi\gamma$  decay can be performed without flavour tagging

$$\Gamma(B_q(\bar{B}_q) \rightarrow f^{CP}\gamma) \propto e^{-\Gamma_q t} \left( \cosh \frac{\Delta\Gamma_q t}{2} - \mathcal{A}^\Delta \sinh \frac{\Delta\Gamma_q t}{2} \pm \right. \\ \left. \pm \mathcal{C} \cos \Delta m_q t \mp \mathcal{S} \sin \Delta m_q t \right)$$

### SM:

- $C = 0$  direct CP-violation
- $S = \mathbf{\sin 2\psi} \sin \phi_s$
- $A^\Delta = \mathbf{\sin 2\psi} \cos \phi_s$

$$\tan \psi \equiv \left| \frac{A(\bar{B} \rightarrow f^{CP} \gamma_R)}{A(\bar{B} \rightarrow f^{CP} \gamma_L)} \right|$$

□ Expected signal yield at LHCb is 11k for  $2 \text{ fb}^{-1}$

**Sensitivity:**  $\sigma(A(B \rightarrow f^{CP} \gamma_R) / A(B \rightarrow f^{CP} \gamma_L)) = \mathbf{0.11}$  for  $2 \text{ fb}^{-1}$

# $B \rightarrow K^* \mu \mu$

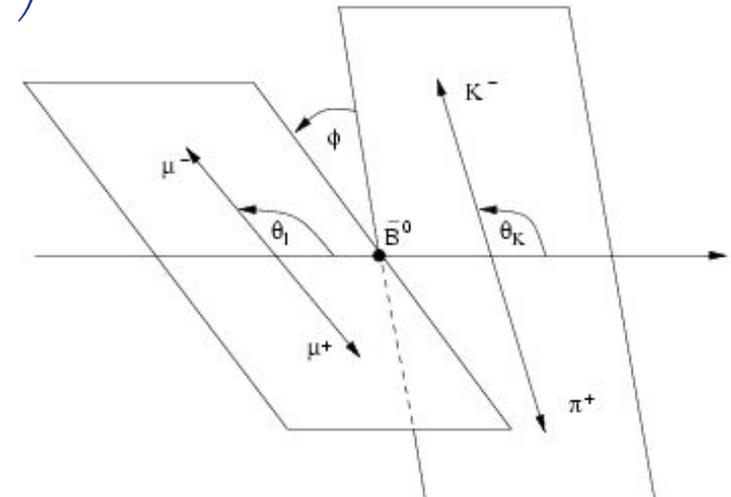
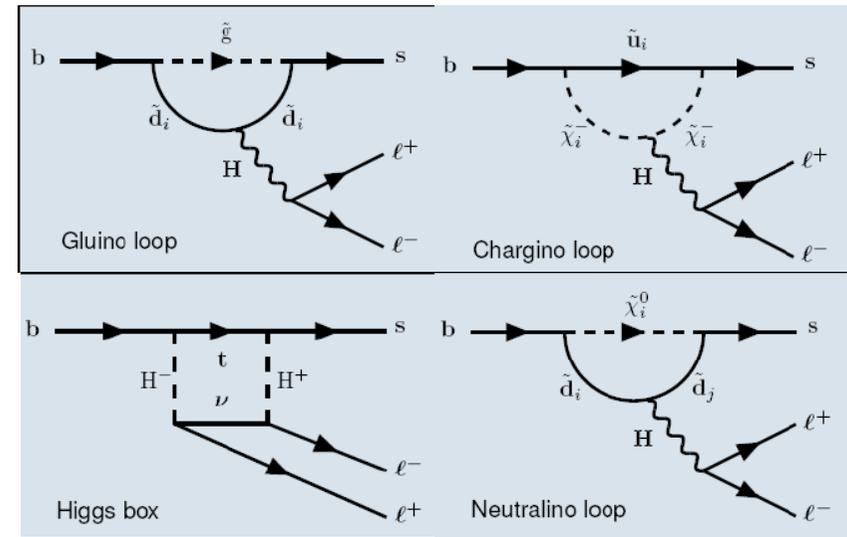
In SM this  $b \rightarrow s$  penguin decay contains well calculable right-handed contribution but this could be added to by NP resulting in modified angular distributions

$$\frac{d\Gamma'}{d\phi} = \frac{\Gamma'}{2\pi} \left( 1 + \frac{1}{2}(1 - F_L) A_T^{(2)} \cos 2\phi + A_{Im} \sin 2\phi \right)$$

$$\frac{d\Gamma'}{d \cos \theta_1} = \Gamma' \left( \frac{3}{4} F_L \sin^2 \theta_1 + \frac{3}{8} (1 - F_L) (1 + \cos^2 \theta_1) + A_{FB} \cos \theta_1 \right)$$

$$\frac{d\Gamma'}{d \cos \theta_K} = \frac{3\Gamma'}{4} (2F_L \cos^2 \theta_K + (1 - F_L) \sin^2 \theta_K)$$

- Described by three angles ( $\theta_\mu$ ,  $\phi$ ,  $\theta_K$ ) and  $di-\mu$  invariant mass  $q^2$
- Forward-backward asymmetry  $A_{FB}$  of  $\theta_1$  distribution of particular interest:
  - Varies between different NP models  $\rightarrow$
  - At zero-point, dominant theor. uncert. from hadronic form-factors cancels at LO



$$A_{FB} \left( s = m_{\mu^+ \mu^-}^2 \right) = \frac{N_F - N_B}{N_F + N_B}$$

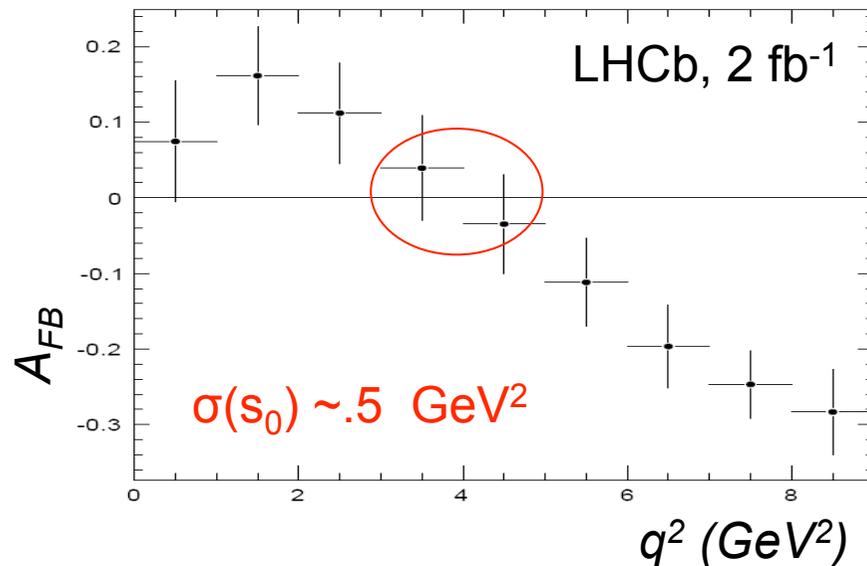
# $B \rightarrow K^* \mu \mu$

$A_{FB}$  at  $B$ -factories defined with opposite sign to LHCb

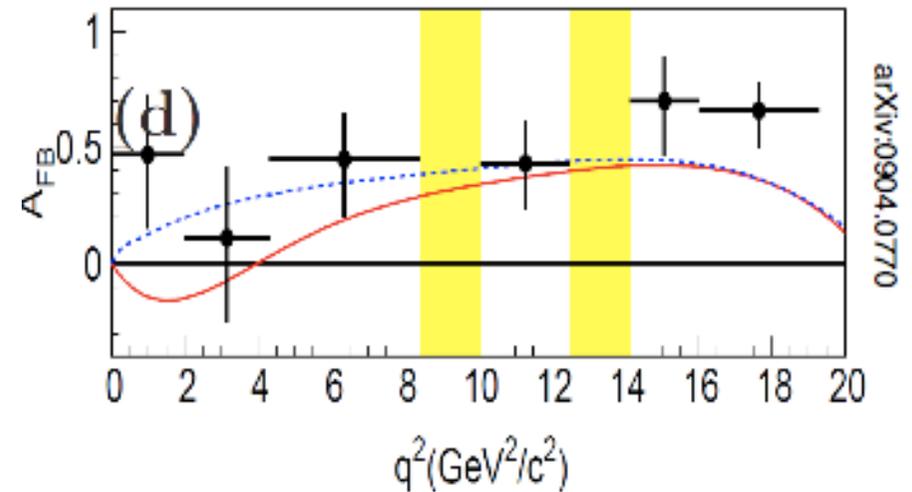
Belle: 657million BBbars analysed  
~250  $K^* l^+ l^-$  events

- Forward-backward asymmetry  $A_{FB}(s)$  in  $\mu\mu$ -rest frame is a sensitive NP probe
- Predicted zero of  $A_{FB}(s)$  depends on Wilson coefficients  $C_7^{eff} / C_9^{eff}$

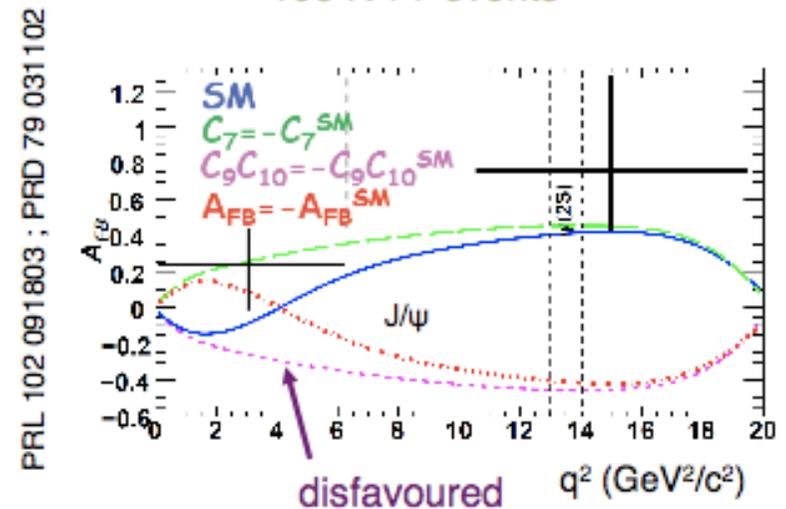
simple binned, counting analysis



LHCb expects ~7k events / 2fb<sup>-1</sup> with  $B/S \sim 0.2$  After 2 fb<sup>-1</sup> zero of  $A_{FB}$  located to  $\pm 0.5 \text{ GeV}^2$ . Full angular analysis gives better discrimination between models.



BaBar: 384 million BBbars analysed  
~100  $K^* l^+ l^-$  events



## Photon polarization from $B_d \rightarrow K^{*0} e^+ e^-$

Contribution not coming from virtual photons can be neglected at low  $q^2 < (1 \text{ GeV})^2$

→ use of final state with electrons is more advantageous wrt muons

$$\frac{d\Gamma'}{d\phi} = \frac{\Gamma'}{2\pi} \left( 1 + \frac{1}{2} (1 - F_L) A_T^{(2)} \cos 2\phi + A_{\text{Im}} \sin 2\phi \right)$$

- In SM at  $q^2 \rightarrow 0$  limit  $A_T^{(2)} \approx -2\text{Re} |H_{+1}/H_{-1}|$   
→ the fraction of right-handed photons in the amplitude
- $A_T^{(2)}$  can be extracted from the fit to the distribution of  $\phi$  – angle between di-lepton and  $K^*$  planes
- LHCb yield with  $2 \text{ fb}^{-1}$ :  $\sim 200 - 250$  events with  $B/S \sim 1$

**Expected sensitivity**  $\sigma(A(B \rightarrow f^{\text{CP}} \gamma_R)/A(B \rightarrow f^{\text{CP}} \gamma_L)) \approx 0.1$   
is limited by statistics and comparable to  $B_s \rightarrow \phi \gamma$  accuracy

# LHCb key measurements

(to search for NP in CP violation and Rare Decays)

## Key Measurements

Accuracy in 1 nominal year  
(2 fb<sup>-1</sup>)

### ☐ In CP – violation

- ✓  $\beta_s$  **0.03**
- ✓  $\gamma$  in trees 4.5°
- ✓  $\gamma$  in loops <10°

### ☐ In Rare Decays

- ✓  $B_s \rightarrow \mu\mu$  **3 $\sigma$  measurement down to SM prediction**
- ✓  $B \rightarrow K^*\mu\mu$   $\sigma(s_0) = 0.5 \text{ GeV}^2$
- ✓ Polarization of photon  
in radiative penguin decays  $\sigma(H_R/H_L) = 0.1$  (in  $B_s \rightarrow \phi\gamma$ )
- $\sigma(H_R/H_L) = 0.1$  (in  $B_d \rightarrow K^*e^+e^-$ )

Measurements highlighted in red will become competitive first

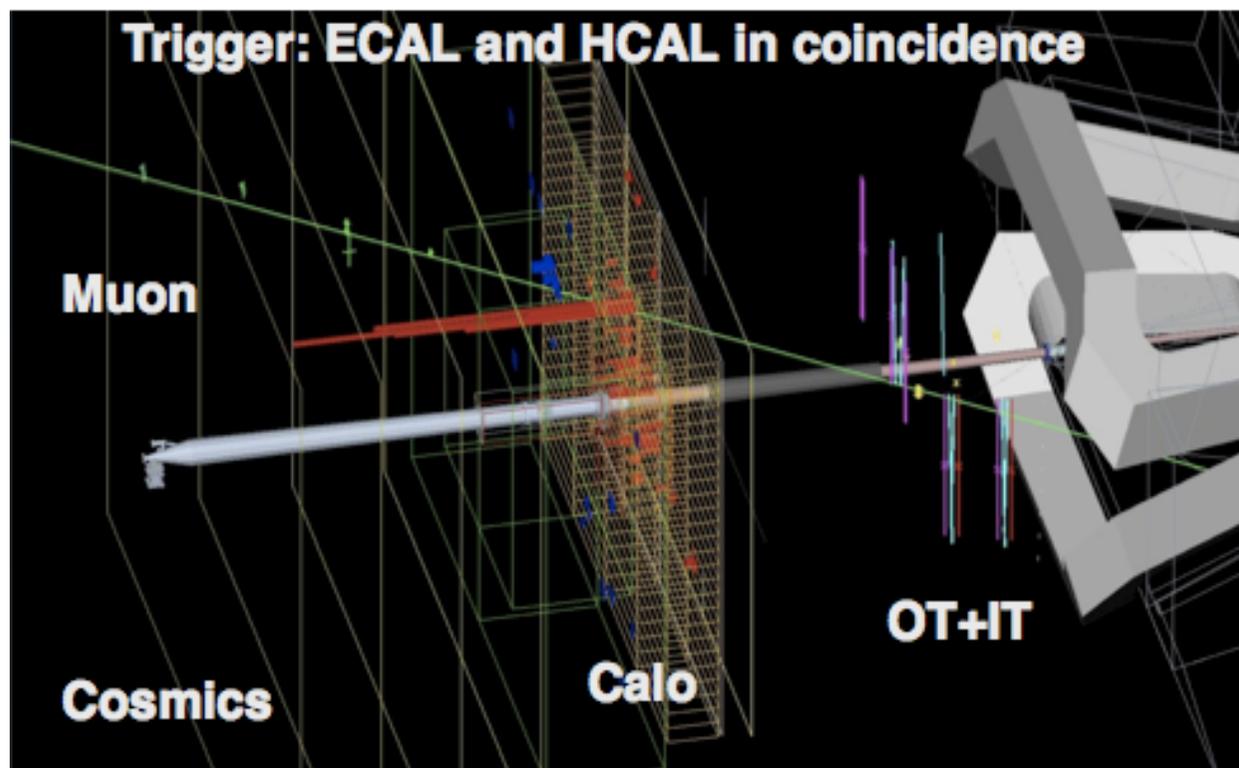
# Commissioning of LHCb

**First attempt to perform time synchronization and space alignment using cosmics and LHC beam induced events**

- Use of cosmics non-trivial since LHCb is horizontal and located deep underground → effectively works only for big sub-systems located downward the magnet: Outer Tracker (OT), Calorimeter and Muon

**Few Hz Trigger on  
“horizontal” cosmic tracks**

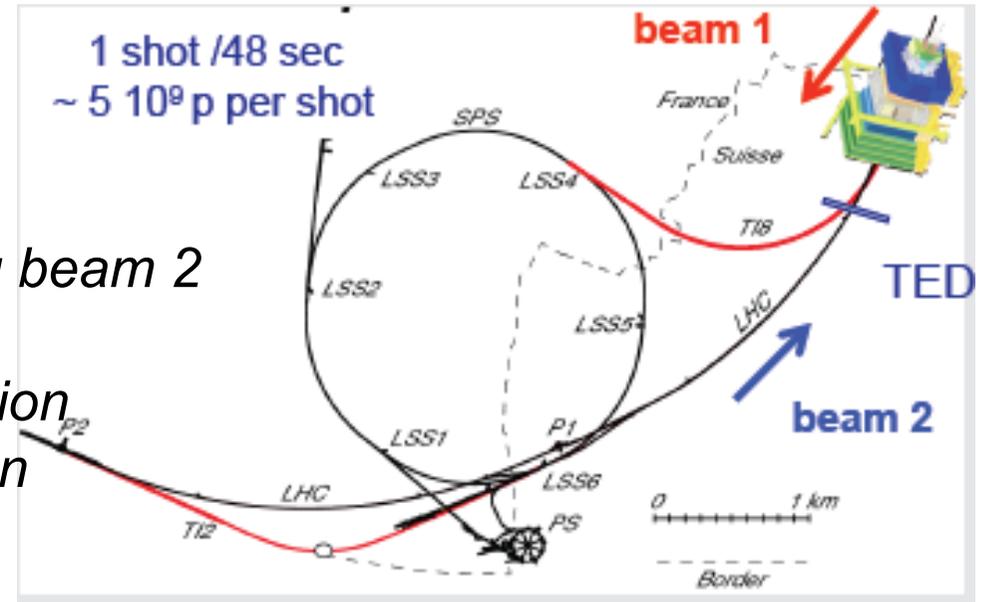
- Muon & CALO synchronized to a few ns
- OT aligned to ~ 1 mm
- L0 trigger commissioned



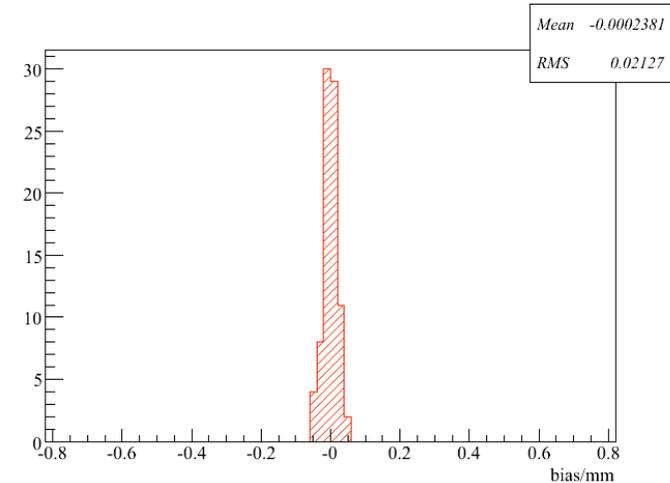
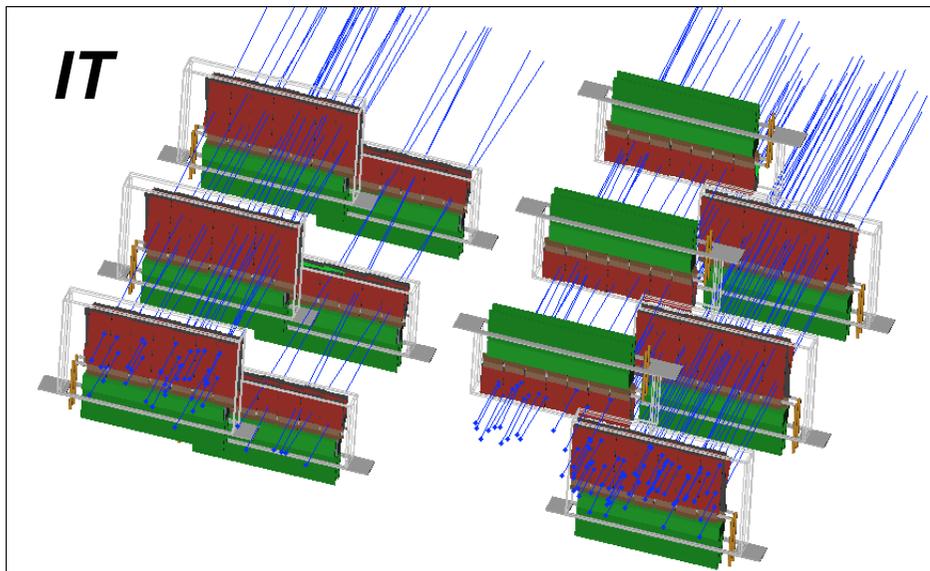
# Commissioning of LHCb

## Beam 2 dumped on injection line beam stopper (TED)

- Located 340 m away from LHCb along beam 2
- High flux  $O(10)$  particles /  $cm^2$
- Particles cross LHCb in a wrong direction
- ~40 k tracks collected and used to align high granular Vertex (VELO) and Inner Tracker (IT) detectors



Ladder position in the Inner Tracker is known to  $20\mu$  precision

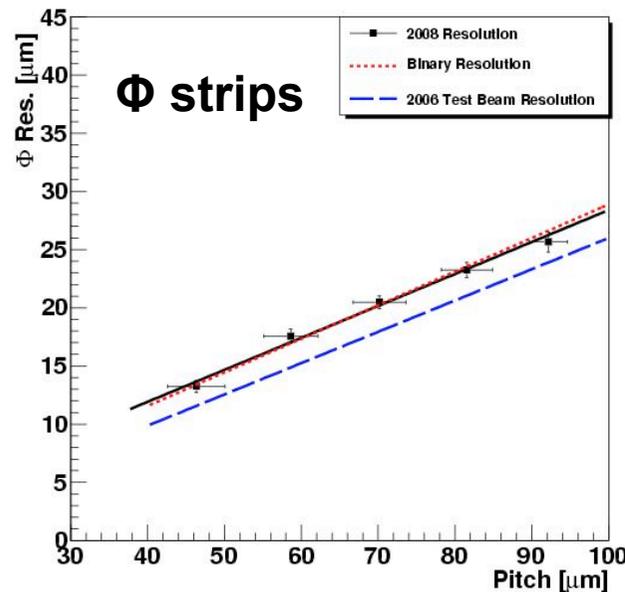
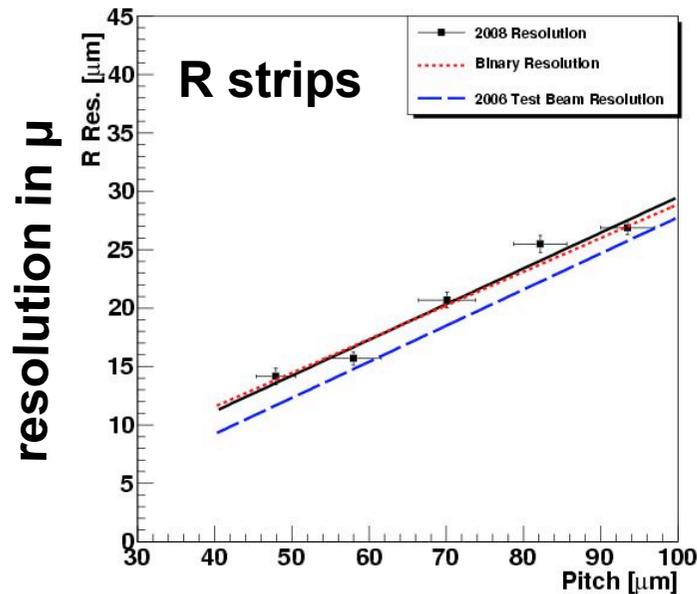
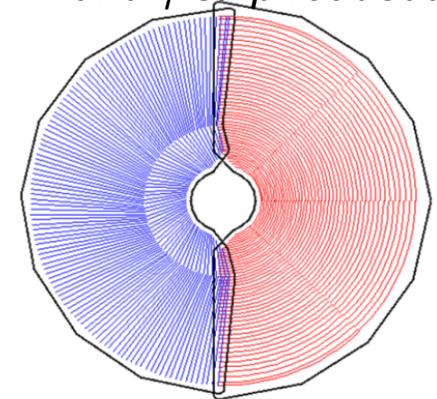
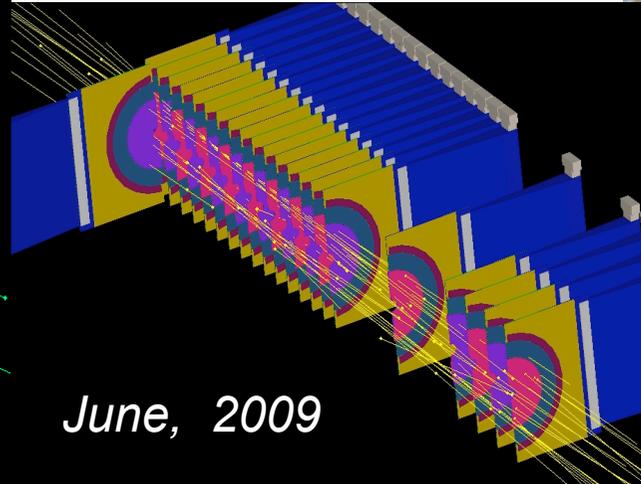
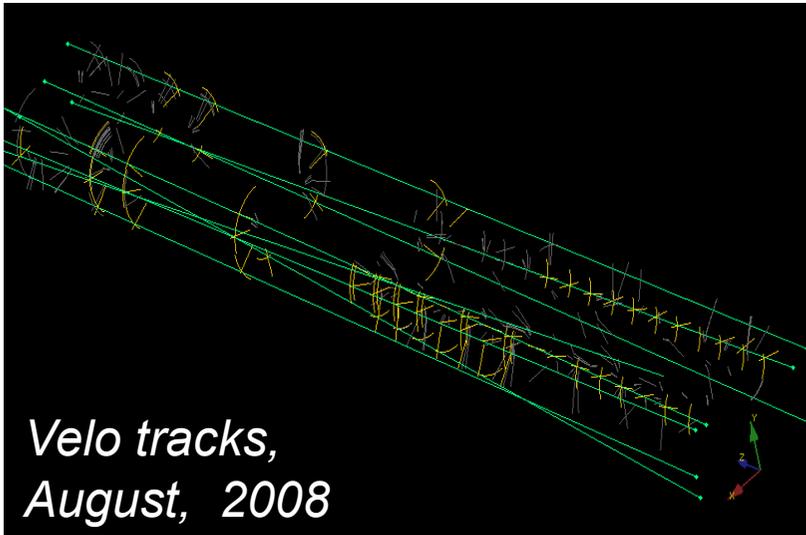


# VELO alignment (see talk by Th. Bowcock)

TED tracks perfect for VELO alignment: cross detector almost parallel to z-axis



21 stations of Si wafer pairs with  $r$  and  $\phi$  strip readout

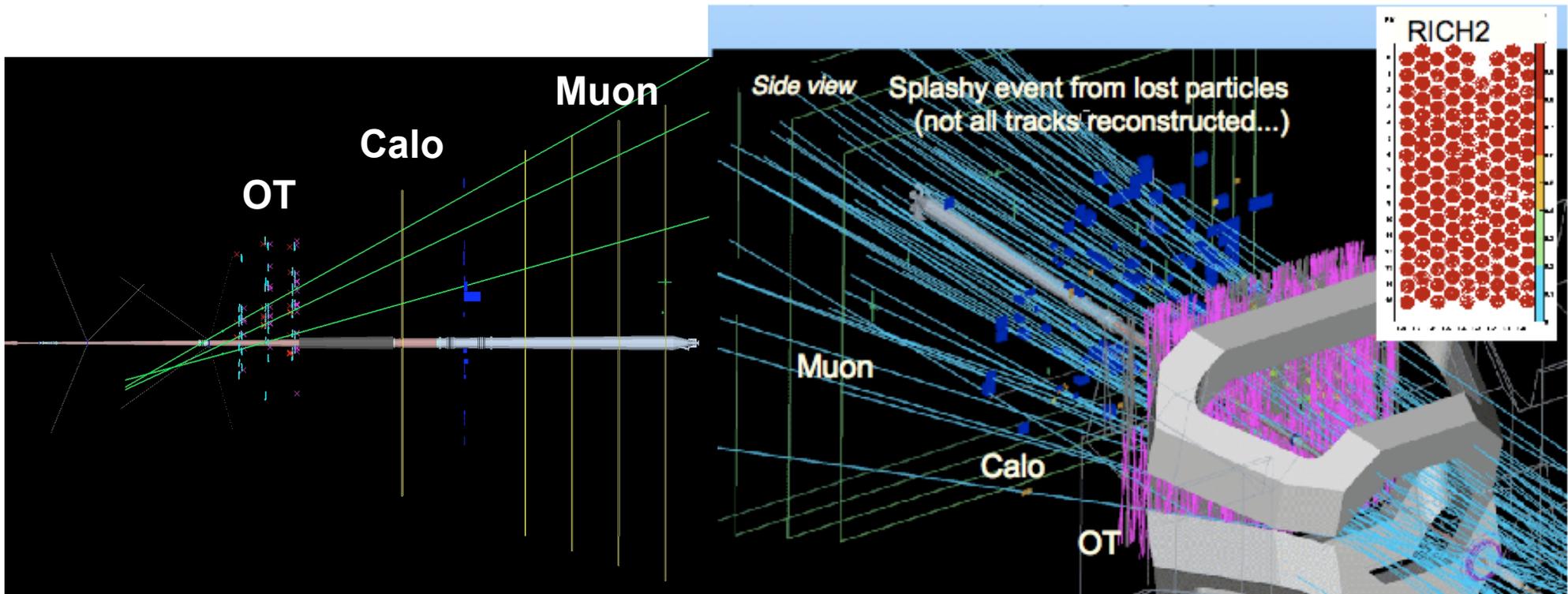


Resolution estimated from VELO hit residuals agrees well with expectations

Further improvement possible

## Events registered on September 10, 2008 for a LHC operation (media day)

- Beam 1 was circulated during few hours (correct direction for LHCb)
- Readout of consecutive triggers, 8 events every 25 ns
- Two types of events have been observed: a'la beam gas events and splashy events hitting on collimator
- **LHCb made very successful start !!!**



# Physics goals of 2010

## Early measurements

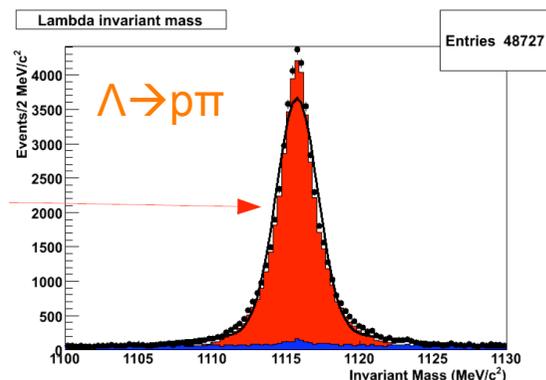
- **Calibration signals and minimum bias physics:  $10^8$  events**

Key channels available in min bias data with simple trigger:

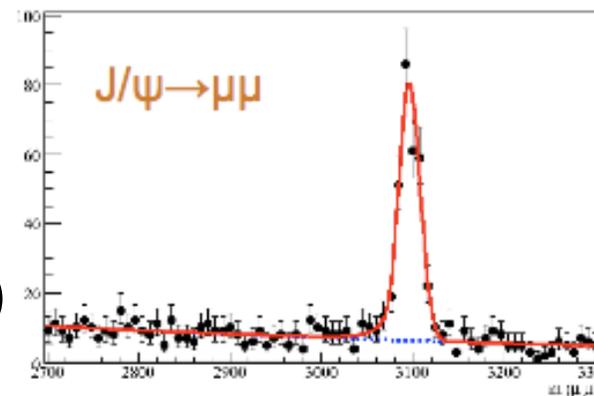
- $K_s \rightarrow \pi\pi$
- $\Lambda \rightarrow p\pi$

~ 40 mins @  $10^{31}$

With 2 kHz random trigger



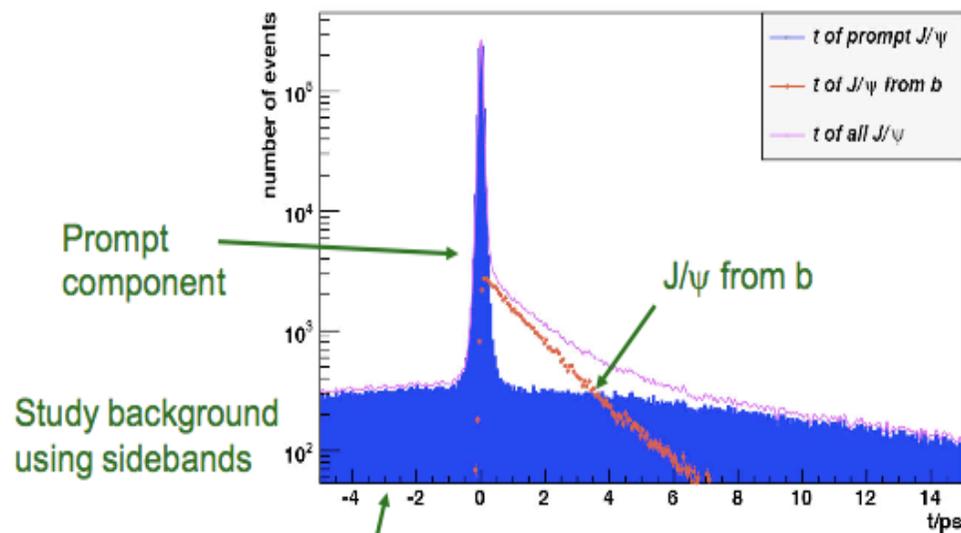
95% purities achievable using kinematical & vertex cuts alone



- $J/\psi$  trigger on single muon with  $p_t$  cut ( $600k \text{ ev./pb}^{-1}$ )  
→ one muon unbiased for PID studies and momentum calibration

-  **$J/\psi$  physics & production cross-sections:  $\sim 1\text{-}5 \text{ pb}^{-1}$**

Measure diff. cross-section for prompt  $J/\psi$  and  $bb$  production cross-section (from secondary  $J/\psi$ ) in region inaccessible to other experiments



# Physics goals of 2010

## □ Analysis commissioning in hadronic modes

Channel	Yield / 10 pb <sup>-1</sup>
$B^0 \rightarrow K\pi$	340
$B \rightarrow D(K\pi)X$	31k
$B^+ \rightarrow D(K\pi)\pi^+$	1900
$B^+ \rightarrow D(K\pi)K^+$	160
$B_s \rightarrow D_s\pi^+$	320

*Detailed studies of  $D \rightarrow hh$  (rehearsal for  $B \rightarrow hh$ )*

- Separate  $K\pi$ ,  $KK$ ,  $\pi\pi$  and DCS  $K\pi$
- Vertex and mass resolutions
- Lifetimes

**Accumulate samples of  $B \rightarrow D(K\pi)\pi$  (“ADS” control mode)**

- Study background environment
- Look for any evidence of  $B^+ / B^-$  asymmetries

## □ Charm physics: 20 pb<sup>-1</sup> and upward

*( Exciting possibilities even with low luminosity)*

*An example: flavour tagged  $D^0 \rightarrow KK$  events for measuring  $y_{CP}$*

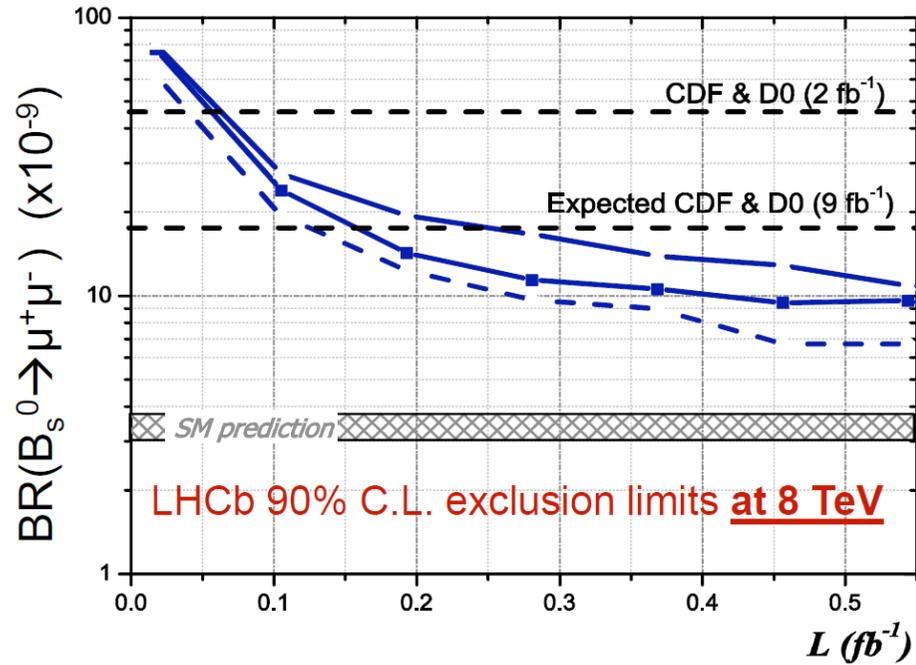
$$y = \tau(D^0 \rightarrow K\pi) / \tau(D^0 \rightarrow KK) - 1$$

*and corresponding CP asymmetry*

*LHCb can collect  $\sim 10^5$  flavour tagged  $KK$  events with 20 pb<sup>-1</sup> (same statistics as BELLE with 540 fb<sup>-1</sup>). Similar data sets for many related channels:*

*$D^0 \rightarrow \pi\pi$ ,  $KK\pi\pi$ ,  $K_S\pi\pi$ ,  $K_SKK$ ,  $D^+ \rightarrow KK\pi$  ...*

# Prospects for most competitive measurements in 2010



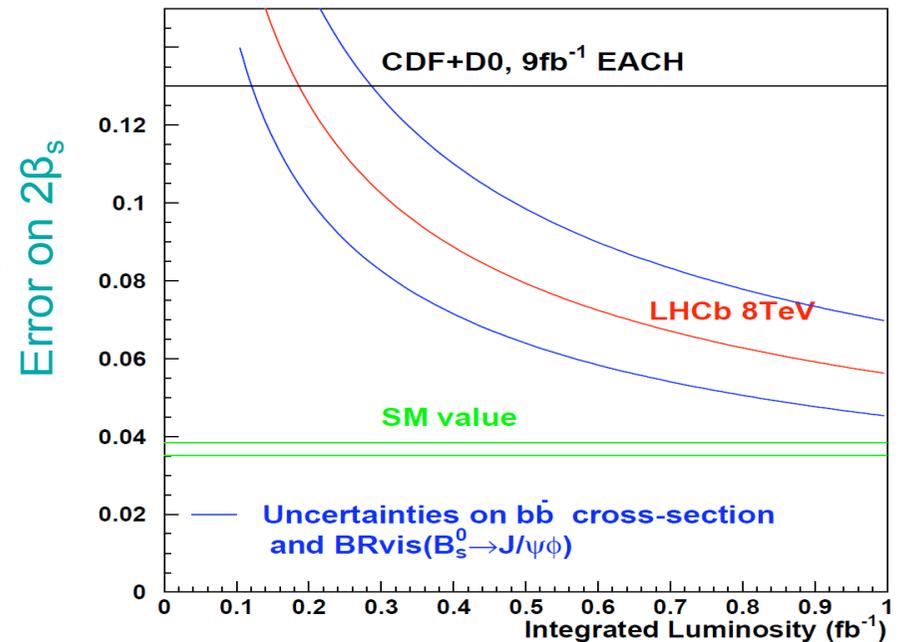
LHCb can exclude  $BR(B_s \rightarrow \mu\mu)$  at  $2 \times 10^{-8}$  with about  $100 - 150 pb^{-1}$

Similar limit is expected from Tevatron on this timescale

→ Sensitive test of SUSY should be possible in a year !!!

Present 'central value' would be Confirmed at  $5\sigma$  level with  $\sim 150-200 pb^{-1}$  Collected at  $E_{cm} = 8 TeV$

Similar sensitivity from Tevatron with  $9 fb^{-1}$



# Conclusions

- ❑ *LHCb is ready for data taking*
- ❑ *First data will be used for calibration of the detector and trigger in particular. First exploration of low  $P_t$  physics at LHC energies. Some high class measurements in the charm sector may be possible*
- ❑ *With  $150 - 200 \text{ pb}^{-1}$  data sample LHCb will reach Tevatron sensitivity in a few golden channels in the beauty sector*
- ❑ *With  $10 \text{ fb}^{-1}$  LHCb has an excellent opportunity to both discover New Physics and to elucidate its nature. LHCb have an important role to complement physics programme of ATLAS and CMS*
- ❑ *Study of possible LHCb upgrade, in order to collect  $\sim 100 \text{ fb}^{-1}$  and investigate further interactions of New Particles with flavours*