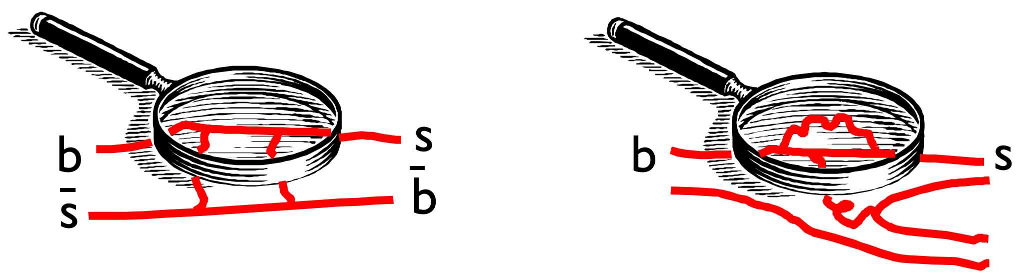
# The LHCb experiment: looking for New Physics in B decays




**Frederic Teubert**

*(CERN, PH Department)*

# Outline

- **Introduction:**
  - B Physics as an indirect probe for New Physics
  - How LHCb will contribute in the search for New Physics?
- **LHCb experimental conditions:**
  - LHC as a B factory
  - Detector requirements
- **Examples of (early) Physics Results:**
  - First physics calibrations and $J/\psi$ measurements
  - $B_s \rightarrow \mu^+\mu^-$
  - $B_s$ mixing phase: $\phi_s$
  - $\gamma$ at tree level
- **Outlook and Conclusions.**

# 0. Preamble

# Wyler and the LHCb physics program

A fast search for Daniel Wyler in SPIRES, according to the number of citations, gives a clear picture of the influence of his work on the LHCb physics program, spanning from CP asymmetries to rare decays, to include even the LHCb online system!!!

SPIRES

1) **On determining a weak phase from CP asymmetries in charged B decays.**
Michael Gronau, (Technion) , Daniel Wyler, (Zurich U.) . TECHNION-PH-91-14, ZU-TH-6-91, Apr 1991. 11pp.
Published in **Phys.Lett.B265:172-176,1991**.

7) **Virtual O (alpha-s) corrections to the inclusive decay b ---> s gamma.**
Christoph Greub, (SLAC) , Tobias Hurth, Daniel Wyler, (Zurich U.) . SLAC-PUB-7144, ZU-TH-7-1996, Mar 1996. 29pp.
Published in **Phys.Rev.D54:3350-3364,1996**.
e-Print: **hep-ph/9603404**

16) **The Rare Decays of B ---> K Lepton anti-Lepton and B ---> K* Lepton anti-Lepton.**
W. Jaus, D. Wyler, (Zurich U.) . Print-89-0938 (ZURICH), (Received Dec 1989). 37pp.
Published in **Phys.Rev.D41:3405,1990**.

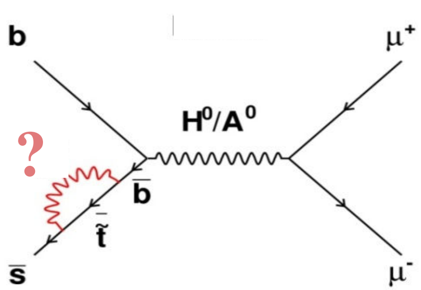
107) **LHCb online system technical design report: Data acquisition and experiment control.**
By LHCb Collaboration (P.R. Barbosa-Marinho *et al.*). CERN-LHCC-2001-040, Dec 2001. 115pp.

# Introduction

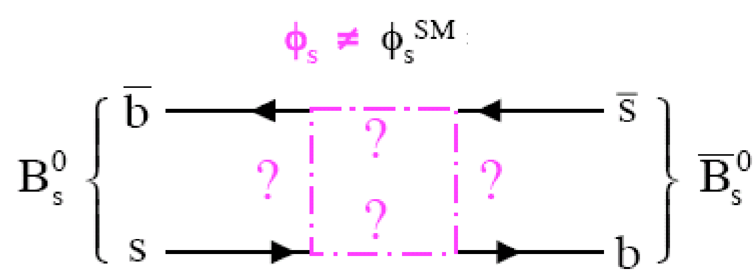
# B Physics as an indirect probe for New Physics

- ***SM cannot be the ultimate theory***
  - must be a *low-energy effective theory* of a more fundamental theory (able to describe dark matter and matter-antimatter asymmetry in the Universe) at a higher energy scale. It may very well be in the TeV region if it has to deal with the *"hierarchy problem"* (accessible at LHC !)

- ***How can New Physics (NP) be discovered and studied ?***
  - NP models introduce new particles, dynamics and/or symmetries at a higher energy scale. These new particles could
    - be produced and observed *as real particles* at energy frontier machines (e.g LHC)
    - appear *as virtual particles* (in loop processes), leading to observable deviations from the pure SM expectations in flavour physics and CP violation.




$B_s \rightarrow \mu^+\mu^-$ Higgs "Penguin"




$B_s$–$\bar{B}_s$ oscillations: "Box" diagram

# CKM picture of CP violation

Using the Wolfenstein parameterisation ($\lambda, A, \rho, \eta$)

$$V = \begin{pmatrix} 1-\lambda^2/2-\lambda^4/8 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda & 1-\lambda^2/2-\lambda^4/8(1+4A^2) & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2+A\lambda^4/2(1-2(\rho+i\eta)) & 1+A^2\lambda^4/2 \end{pmatrix} + O(\lambda^5)$$

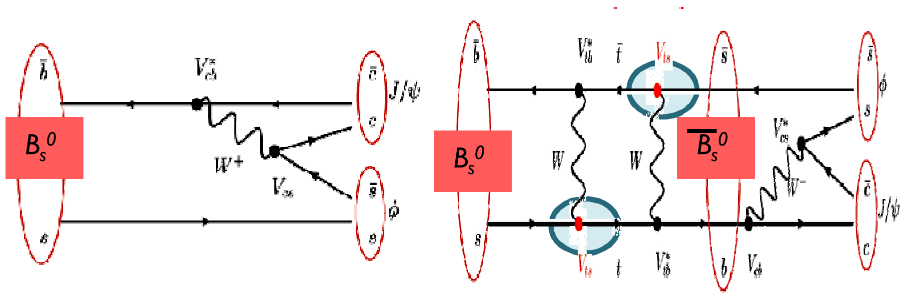
$\arg V_{td} = -\beta$
$\arg V_{ub} = -\gamma$
$\arg V_{ts} = -\phi_s/2+\pi$

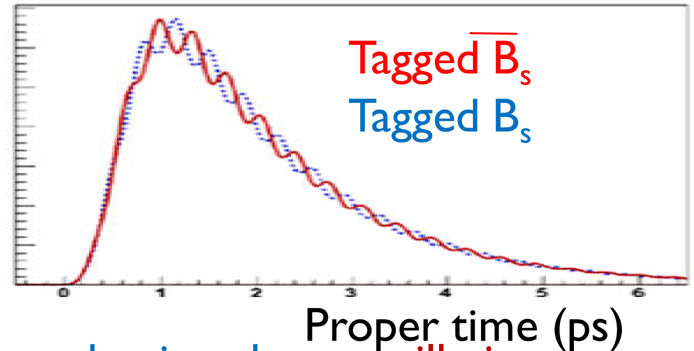
$$\tan\beta \approx \frac{\eta}{1-\rho}\left(1-\frac{\lambda^2}{2}\right) \approx \tan(23.6°)$$

$$\tan\gamma \approx \frac{\eta}{\rho} \approx \tan(57°)$$

$$\phi_s \approx -2\eta\lambda^2 \approx -2.3°$$

# How do we measure these phases?



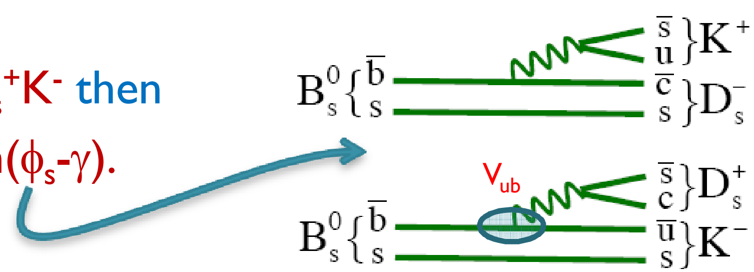

- Lifetime distributions of events with a $B_s$ ($\overline{B}_s$) at production show oscillation pattern due to mixing.
- The frequency of these oscillations is $\Delta m_s$ while the amplitude of the oscillation is proportional to $\sin\phi_s$ due to the phase in the mixing box diagram.
- If we take the asymmetry of the two distributions ($A_{CP}$) many factors cancel out

and we are left with:

$$A_{CP}(t) = \frac{\Gamma[\overline{B}_s(t) \to f] - \Gamma[B_s(t) \to f]}{\Gamma[\overline{B}_s(t) \to f] + \Gamma[B_s(t) \to f]}$$

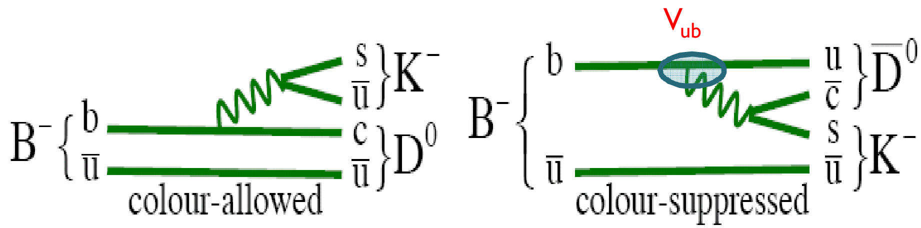
$$A_{CP}(t) = \frac{\eta_f sin\phi_s sin(\Delta m_s)t}{cosh(\Delta\Gamma_s t/2) - \eta_f cos\phi_s sinh(\Delta\Gamma_s t/2)}$$

- If we consider the final state $B_s \to D_s^+ K^-$ then the amplitude is proportional to $\sin(\phi_s-\gamma)$.



# Time-independent methods to measure γ

### γ from $B^\pm \rightarrow D K^\pm$ :



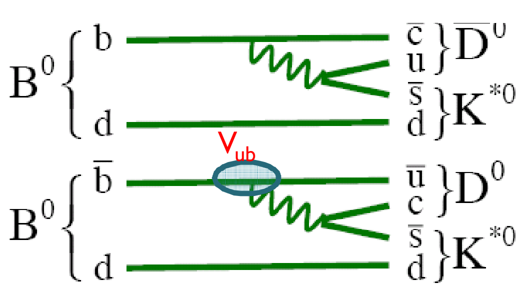

Weak phase difference = γ

Magnitude ratio = $r_B \sim 0.15$

First proposal by Gronau, London and Wyler (GLW, 1991) using D decays to CP eigenstates. Later expanded by Atwood, Dunietz and Sony, (ADS, 1997) to include flavour specific final states and Giri, Grossman, Soffer, Zupan and Bondar (2003) to include Dalitz analysis:
Measure the relative rates of $B^+ \rightarrow DK^+$ and $B^- \rightarrow DK^-$ with neutrals D's observed in finals states such as: $K^\pm\pi^\mp$, $K^\pm\pi^\mp\pi^+\pi^-$, $K^+K^-$.

### γ from $B^0 \rightarrow D K^*$ :

Dunietz variant (1998) of Gronau-Wyler method:
Two colour suppressed diagrams with $|A_2|/|A_1| \cong 0.4$ interfering via $D^0$ mixing



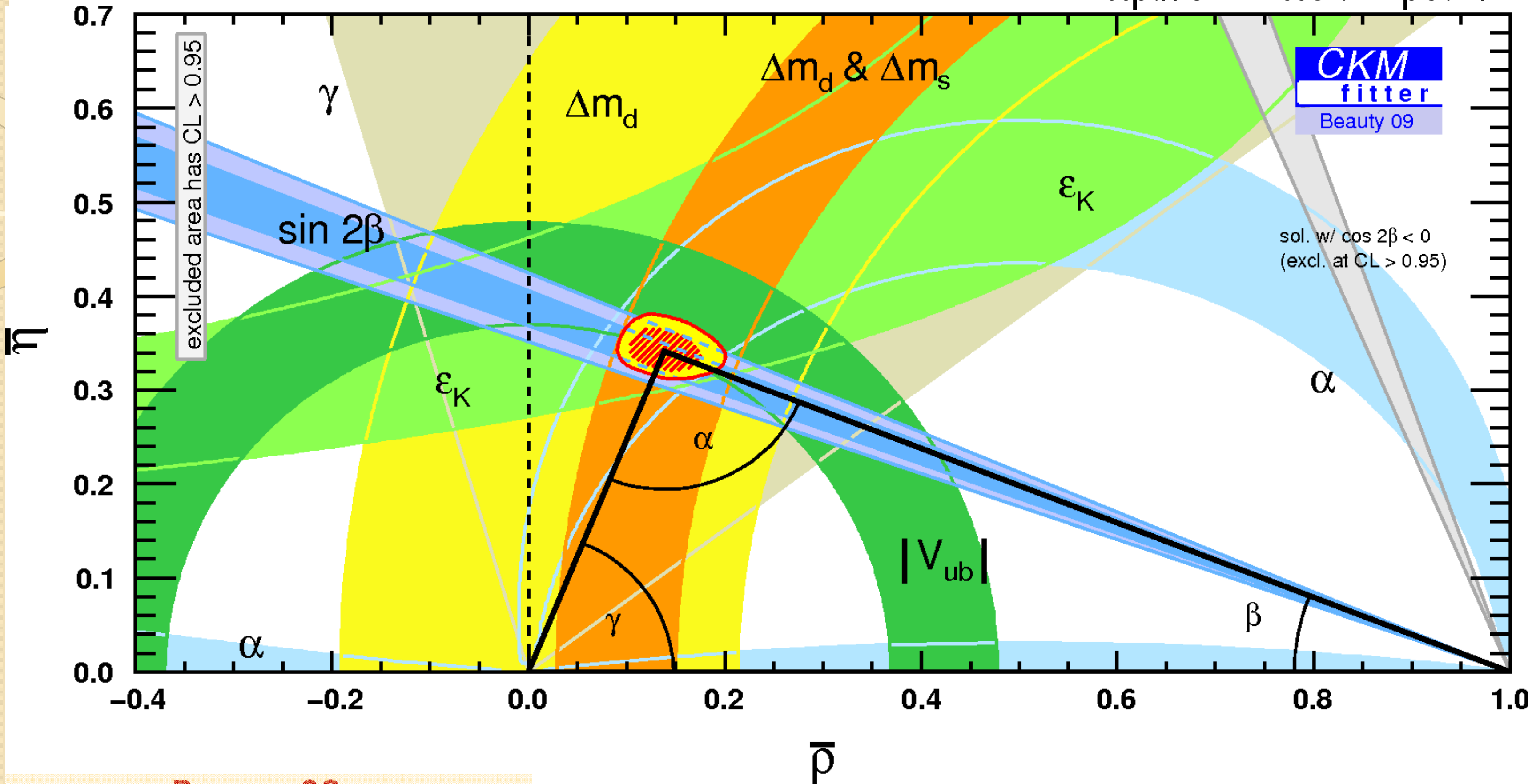

$A_1 = A(B^0 \rightarrow \bar{D}^0 K^{*0})$: b→c transition, phase 0

$A_2 = A(B^0 \rightarrow D^0 K^{*0})$: b→u transition, phase Δ+γ

$A_3 = \sqrt{2}\, A(B^0 \rightarrow D_{CP} K^{*0}) = A_1 + A_2$, because $D_{CP} = (\bar{D}^0 + D^0)/\sqrt{2}$

# What's the status of the CKM parameters now?

http://ckmfitter.in2p3.fr/




Beauty 09

$$A = 0.8123^{+0.0092}_{-0.0243}$$

$$\lambda = 0.22512^{+0.00074}_{-0.00075}$$

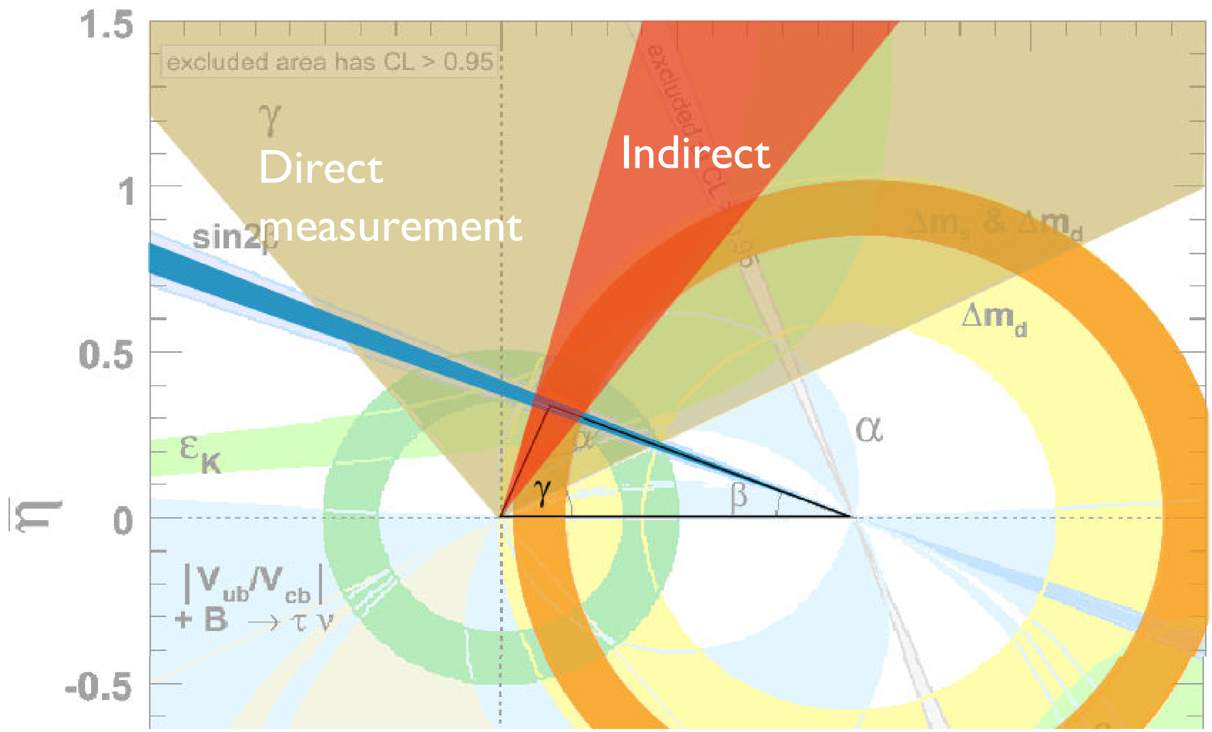
$$\bar{\rho} = 0.139^{+0.024}_{-0.027}$$

$$\bar{\eta} = 0.342^{+0.016}_{-0.015}$$

68 % CL

Certainly, the CKM mechanism is the dominant source of the CP violation observed so far. However...

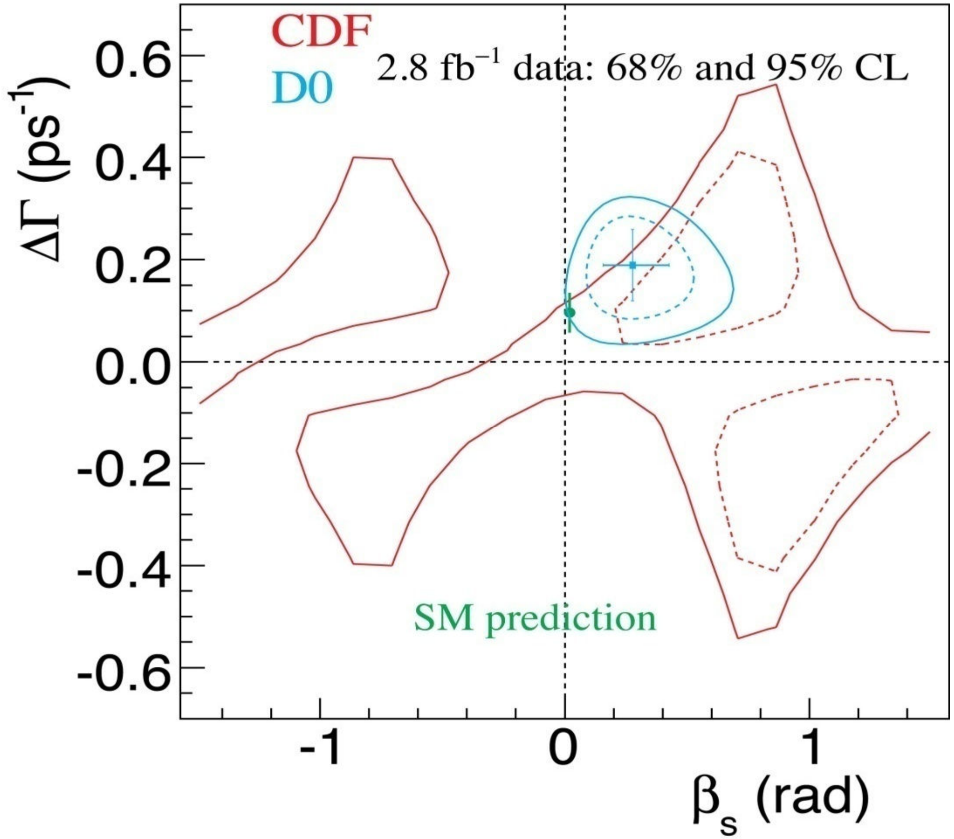
# γ measurement




- All measurements together determine (indirectly) the CKM angle $\gamma = (68 \pm 4)^o$
- However, as processes involve loops, may be affected by new physics
  $\rightarrow$ should be compared with measurement of γ from tree process:
  $B \rightarrow DK$, unaffected by new physics
  Currently only poorly constrained: $\gamma = (75 \pm 21)^o$ (direct measurement)

# $\phi_s$ measurement

- First measurement from CDF/D0 of the phase in the mixing of the Bs system using the time dependent analysis of the decay $B_s \rightarrow J/\psi\phi$ shows tantalizing hints… with only ~3k signal candidates there is ~2$\sigma$ difference w.r.t. the very precise SM prediction.

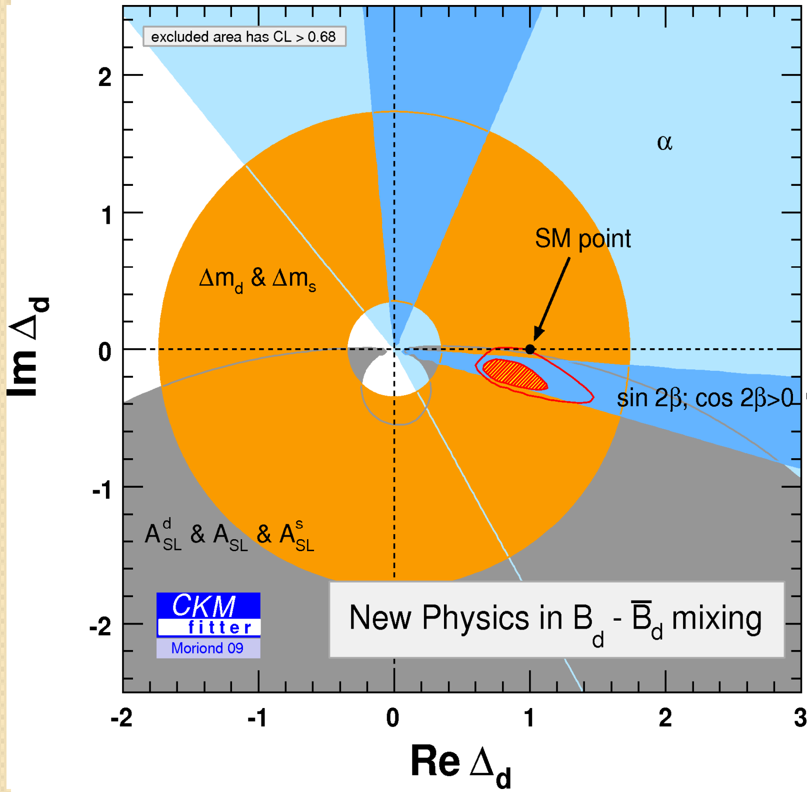


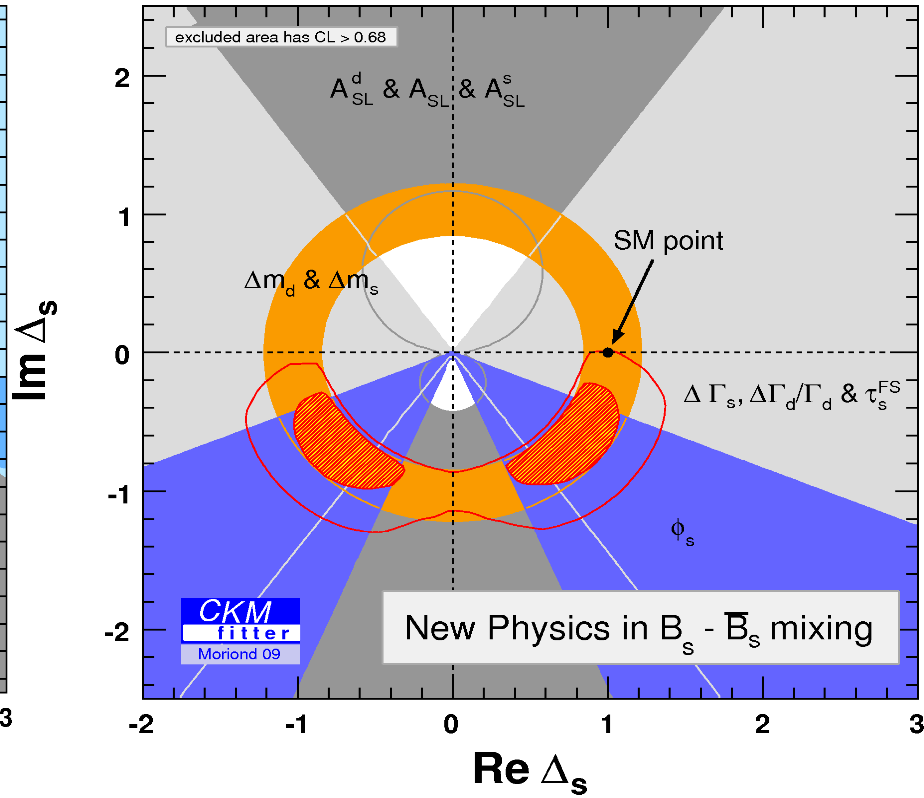
# Parameterization of New Physics in mixing

- The effects of New Physics in the oscillation can be parameterized as:

$$\left\langle B_q^0 \left| M_{12}^{SM+NP} \right| \overline{B}_q^0 \right\rangle \equiv \Delta_q^{NP} \cdot \left\langle B_q^0 \left| M_{12}^{SM} \right| \overline{B}_q^0 \right\rangle$$

$$\Delta_q^{NP} = \mathrm{Re}(\Delta_q) + i\ \mathrm{Im}(\Delta_q) = |\Delta_q| e^{i\phi^{\Delta_q}} = r_q^2 e^{2i\theta_q} = 1 + h_q e^{2i\sigma_q}$$

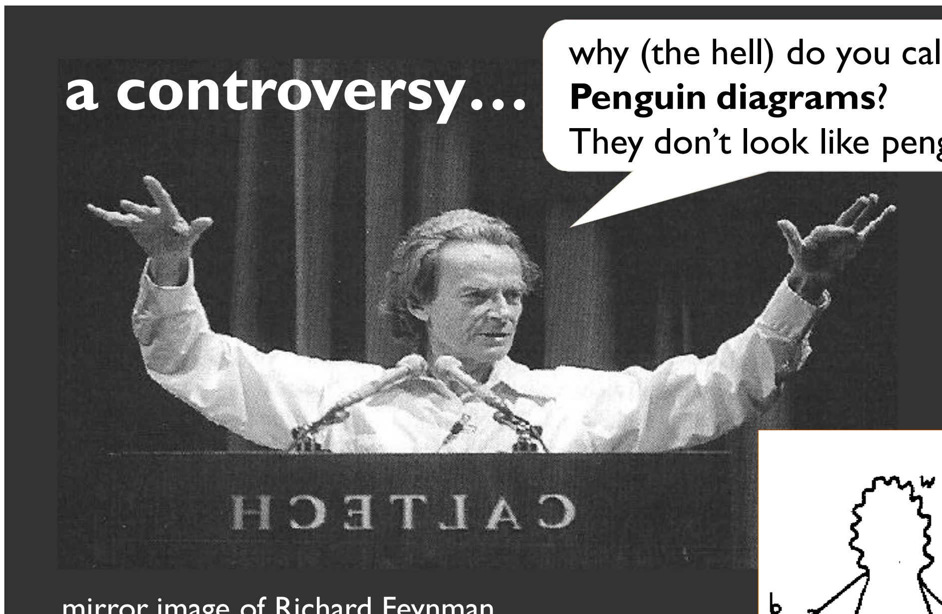


# Rare decays

- The penguin diagram prefers heavy virtual fields in the loop; penguin-to-tree ratio:

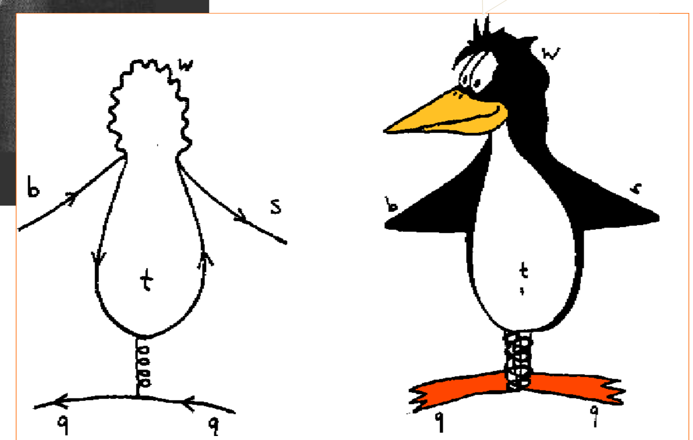
$$\left|\frac{A^{\text{penguin}}_{Q\text{-heavy}} - A^{\text{penguin}}_{q\text{-light}}}{A^{\text{tree}}}\right| \approx \frac{\alpha_s}{12\pi}\ln\left(\frac{m^2_{Q\text{-heavy}}}{m_b^2}\right)$$



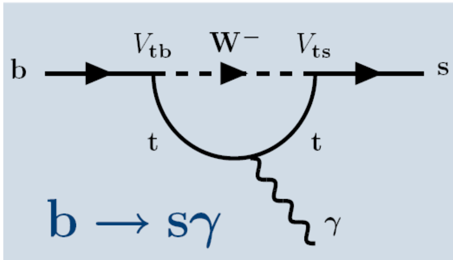

mirror image of Richard Feynman

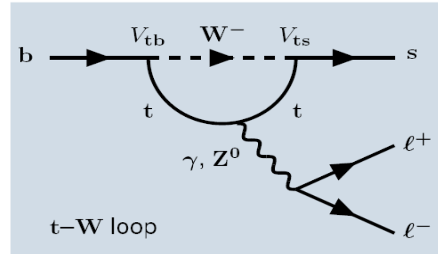
why (the hell) do you call these **Penguin diagrams**? They don't look like penguins!

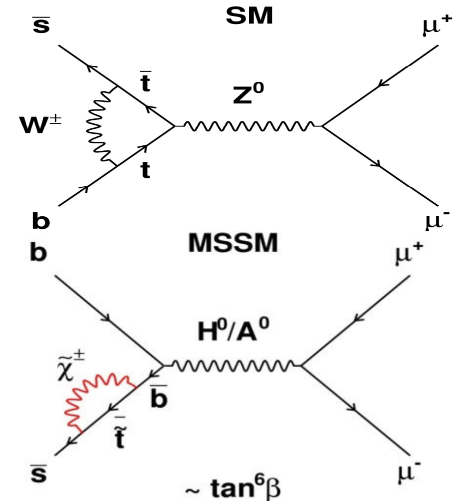
I've never seen a **Feynman diagram** that looks like **you** ☺

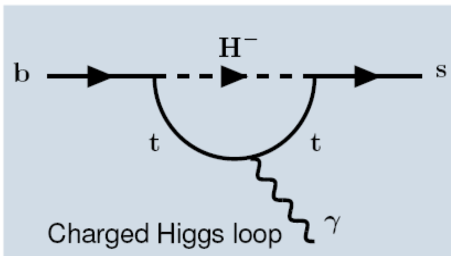


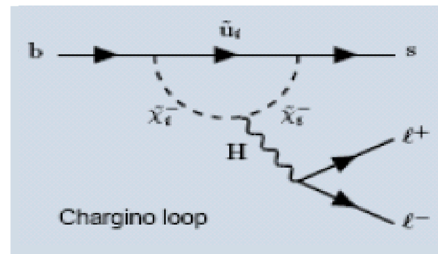
# Three interesting examples of rare decays




| | Relevant Operators | *BR*(SM) | *BR* exp | @ LHCb |
|---|---|---|---|---|
| $B_s \to \phi\gamma$ | $O_{7\gamma} \sim m_b \bar{s}_L \sigma_{\mu\nu} b_R F^{\mu\nu}$ | Large theory errors on exclusive BRs | $(57^{+18}_{-12}{}^{+12}_{-11})\ 10^{-6}$ Belle'08 | γ polarization |
| $B^0 \to K^* \mu^+\mu^-$ | $O_{7\gamma} \sim m_b \bar{s}_L \sigma_{\mu\nu} b_R F^{\mu\nu}$ $O_{9\ell(10\ell)} \sim \bar{s}_L \gamma_\mu b_L \bar{\ell} \gamma^\mu (\gamma_5) \ell$ | | $(9.8 \pm 2.1)\cdot 10^{-7}$ BaBar/Belle | angular distributions |
| $B_s \to \mu^+\mu^-$ | $O_{S(P)} \sim \bar{s}_L b_R \bar{\ell} (\gamma_5) \ell$ | $(3.6 \pm 0.4)\cdot 10^{-9}$ helicity suppressed | TeVatron @ 90% CL (4 $fb^{-1}$) **$< 36\times 10^{-9}$** | BR |

# Search strategies for NP at LHCb

- Measure FCNC transitions where NP may show up as a relatively large contribution, especially in $b \to s$ transitions which are poorly constrained by existing data:
  - $B_s$ mixing phase ($\phi_s$)
  - $b \to s\gamma$, $b \to s l^+ l^-$, $B_{(s)} \to \mu\mu$
  - Also: rare K and D decays, $D^0$ mixing

Single measurements with NP discovery potential

- Improve measurement precision of CKM elements
  - Compare two measurements of the same quantity, one which is insensitive and another one which is sensitive to NP (tree vs loop):
    - $\sin(2\beta)$ from $B^0 \to J/\psi K_S$ and $\sin(2\beta)$ from $B^0 \to \phi K_S$
    - $\gamma$ from $B_{(s)} \to D_{(s)}K$ and $\gamma$ from $B^0 \to \pi^+\pi^-$ and $B_s \to K^+K^-$
  - Measure all angles and sides in many different ways
    - any inconsistency will be a sign of new physics

Precision CKMology, including NP-free determinations of angle $\gamma$

# So… what do we need to fulfil this program?

- High statistics of $B_d$ and $B_s$.

•Trigger sensitive to final states with leptons and only hadrons.

•Excellent proper time resolution to measure the CP violating oscillation amplitudes of the Bs system.

•Good $\pi/K/\mu/e$ separation to reduce the combinatorial background and other B meson decays. K-id is also very useful for flavour tagging.

•Good momentum and vertex resolution to reduce background

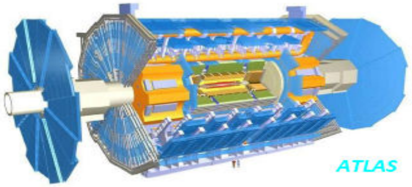
# LHC experimental conditions

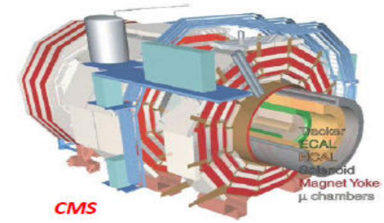
# LHC experiments: B acceptance

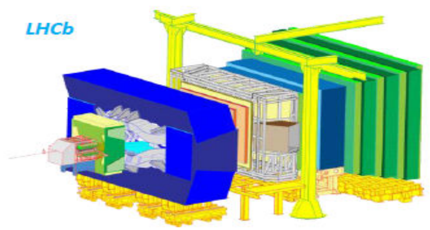
LHC bb cross-section ~ 5x TeVatron

ATLAS/CMS:

- central detectors, $|\eta|<2.5$
- B physics using high-$p_T$ muon triggers, mostly with modes involving dimuon.
- Expect $L<2\times10^{33}$ cm$^{-2}$ s$^{-1}$ for first 3 years, i.e. 10 fb$^{-1}$ per nominal year.



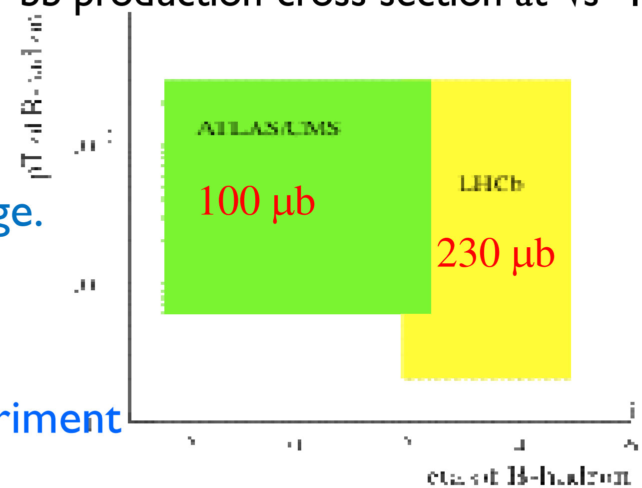




LHCb:

- designed to maximize B acceptance(within cost and space constraints)
- forward spectrometer, $1.9 < \eta < 4.9$
  - more b hadrons produced at low angles
  - single arm OK since bb pairs produced correlated in space
- rely on much softer, lower $p_T$ triggers
- efficient also for purely hadronic B decays.
- Choose to run at $L<5\times10^{32}$ cm$^{-2}$ s$^{-1}$
- Clean environment and less radiation damage.
- Expect 2 fb$^{-1}$ per nominal year.

$b\bar{b}$ production cross section at $\sqrt{s}$=14 TeV




2010 data taking:

- lower $\sqrt{s}$, low L ⇒ similar $L_{int}$ to each experiment

0.2 fb$^{-1}$ at $\sqrt{s}$ = 7 TeV in 2010 (?)

# LHC Experiments: Trigger Strategy

ATLAS Trigger

| Trigger level | Total output rate | Output rate for B physics |
|---|---|---|
| LVL1 | 75 kHz | 10–15 kHz |
| LVL2 | 2 kHz | 1–1.5 kHz |
| EF | 200 Hz | 10–15 Hz |

CMS Trigger

| Trigger level | Total output rate (at startup) | Output rate relevant for B physics |
|---|---|---|
| Level 1 | 50 kHz | 14 kHz (1μ)<br>0.9 kHz (2μ) |
| HLT | 100 Hz | ~ 5 Hz of incl. b,c→μ+jet<br>+ O(1 Hz) for each excl. B mode |

- **ATLAS (CMS) Strategy for B-Physics Trigger:**

L1: dimuon with Pt>6(3) GeV/c each and single muon with Pt>6 GeV/c .

HLT :Limited time budget. Restrict B reconstruction to RoI around the muon

**LHCb Strategy for B-Physics Trigger:**

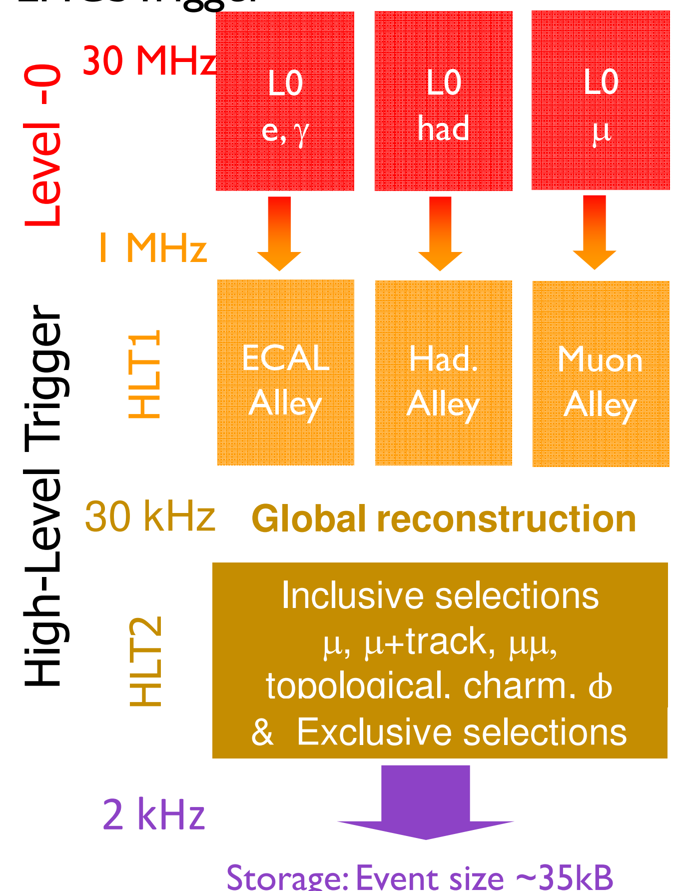
L0: dimuon with ΣPt>1.3 GeV/c and single muon with Pt>1.1 GeV/c.

Hadron with Et>3.6 GeV … also ECAL triggers.

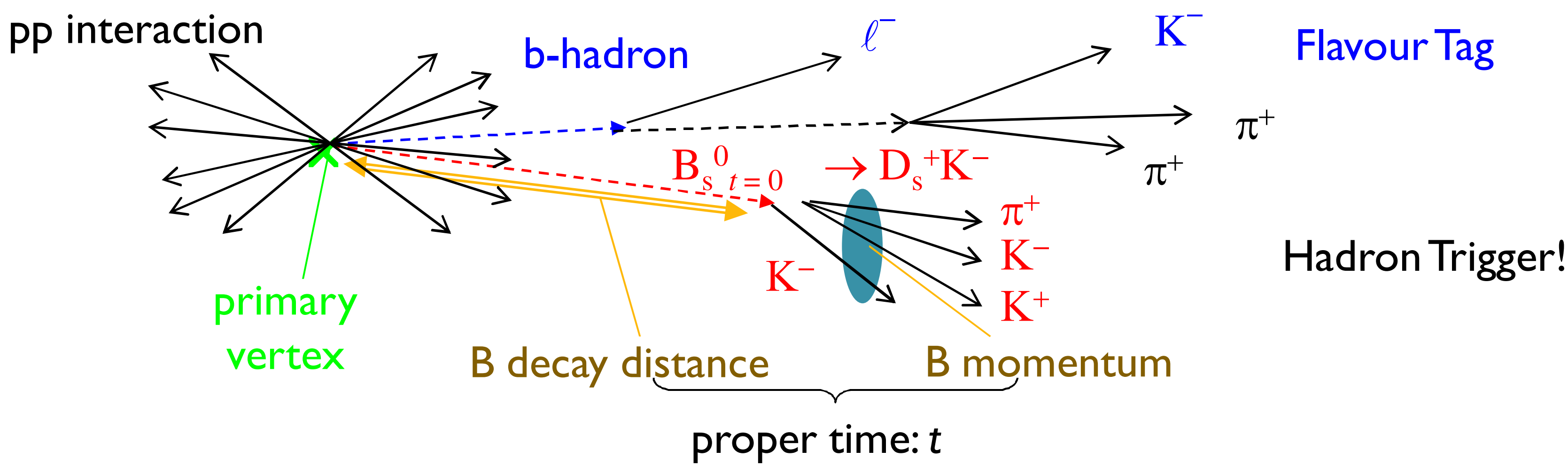
HLT : Inclusive single μ, μ+track and dimuon triggers.
Inclusive topologic and electromagnetic triggers.
Exclusive triggers

| Trigger efficiency | ε(L0) | ε(HLT1) | ε(HLT2) |
|---|---|---|---|
| Electromagnetic | 70 % | > ~80 % | > ~90 % |
| Hadronic | 50 % | | |
| Muon | 90 % | | |

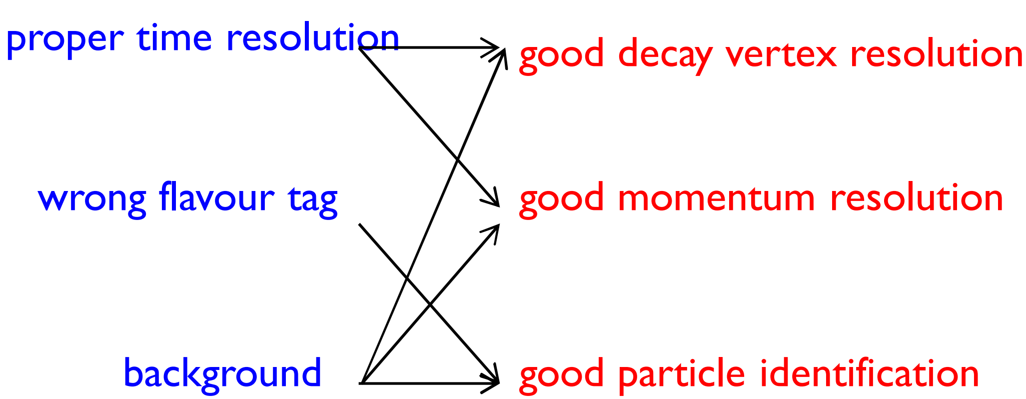
LHCb Trigger

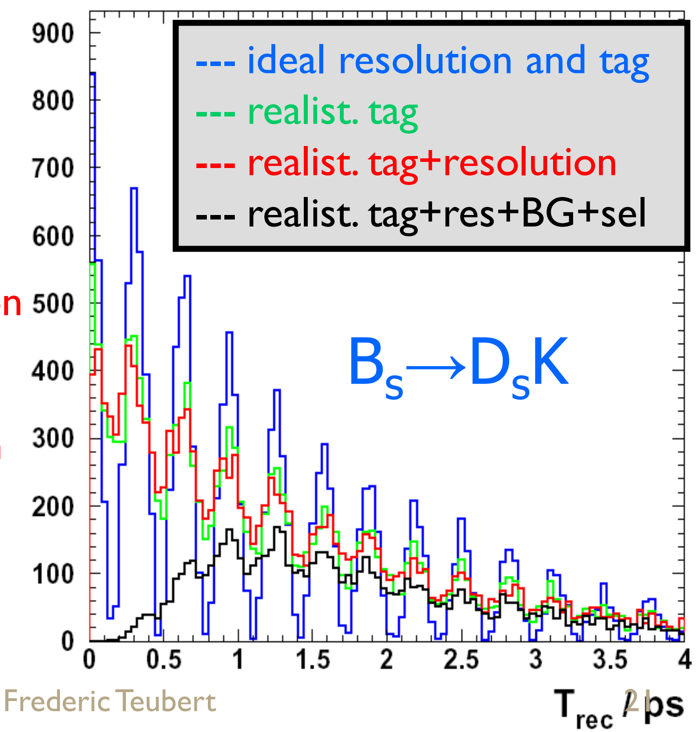


# Detector requirements




CP violating oscillation amplitudes are damped by



# Detector requirements II

Even for CP measurements not using proper time distribution, hadron trigger, mass resolution and hadron PID are crucial!

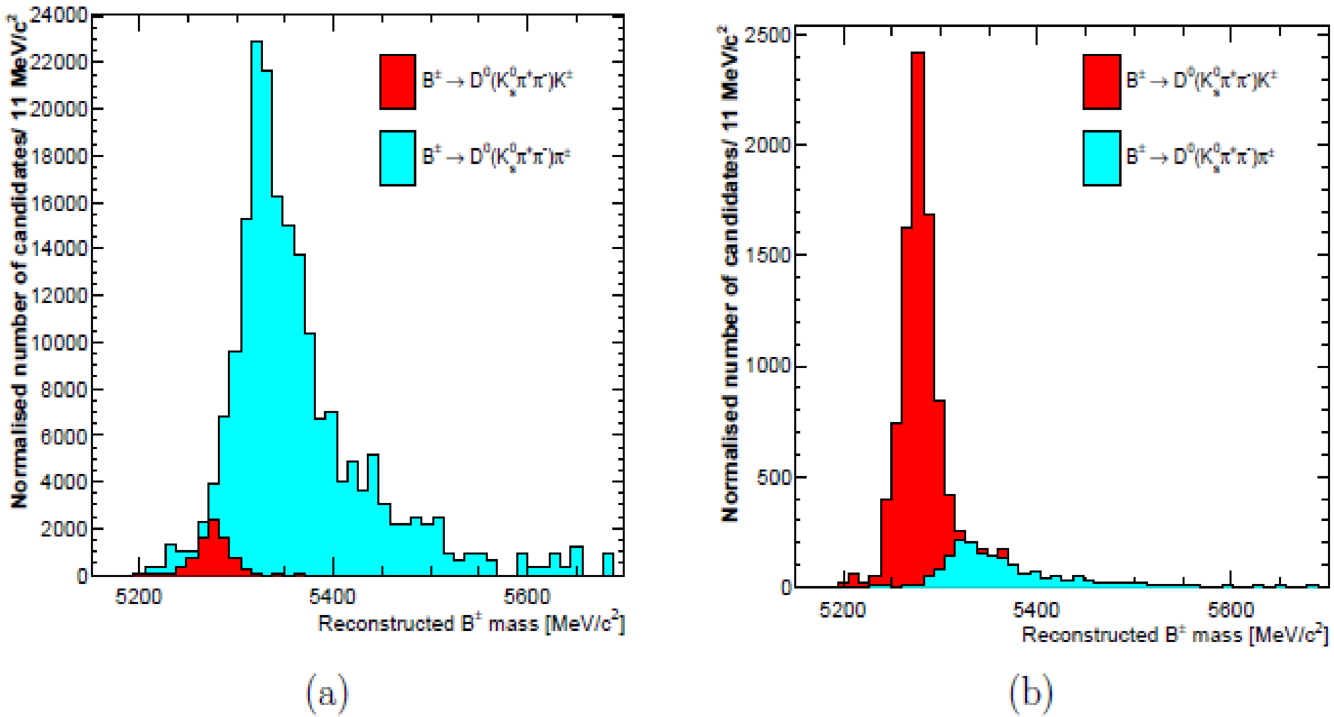


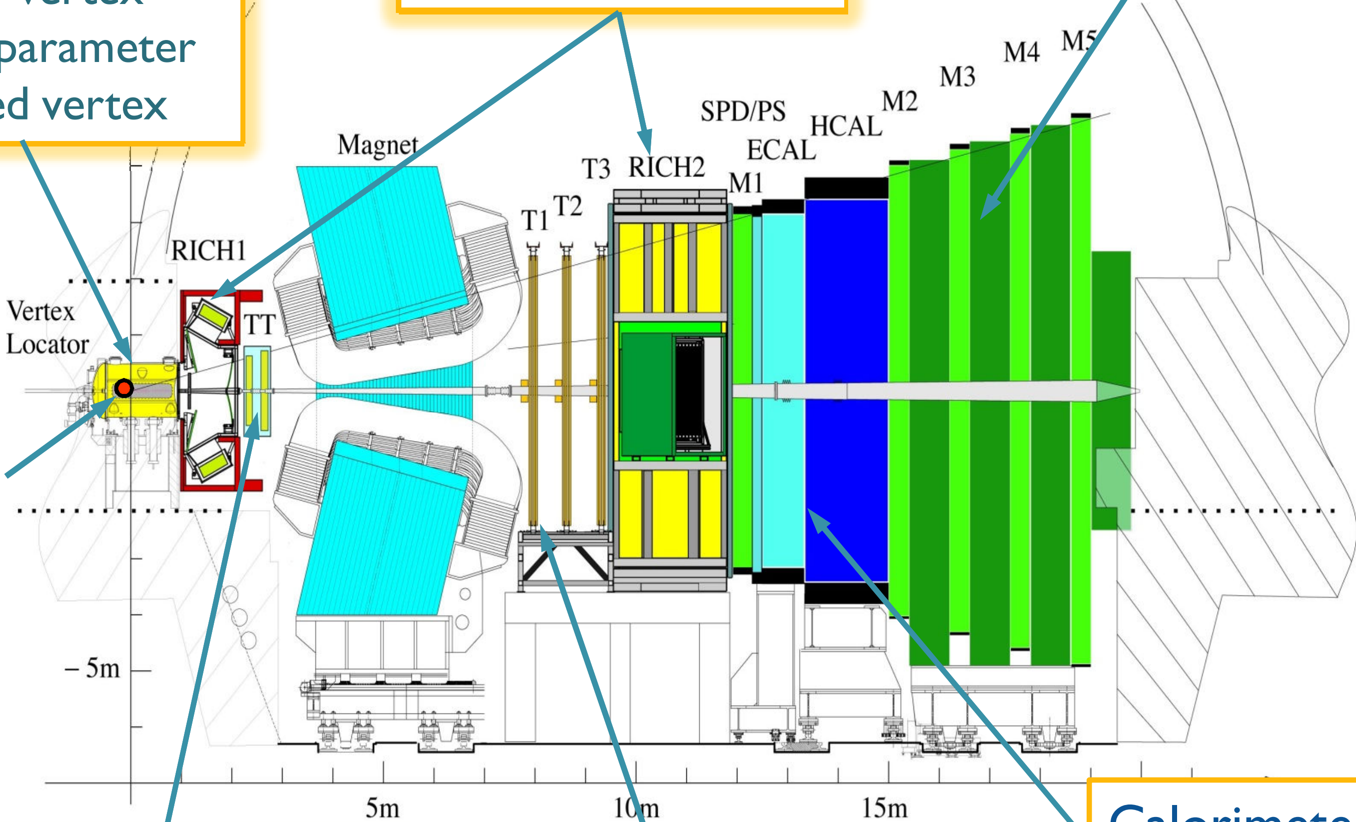

Figure 7: Distributions of reconstructed $B$ mass for $B^- \to DK^-$ and $B^- \to D\pi^-$ (a) without and (b) with PID criteria applied to the bachelor $K^-$.

# The LHCb detector

VELO:
primary vertex
impact parameter
displaced vertex

RICHES:
PID: K,$\pi$ separation

Muon System




Interaction region

Trigger Tracker: p for trigger and $K_s$ reconstruction

Tracking Stations:
p of charged particles

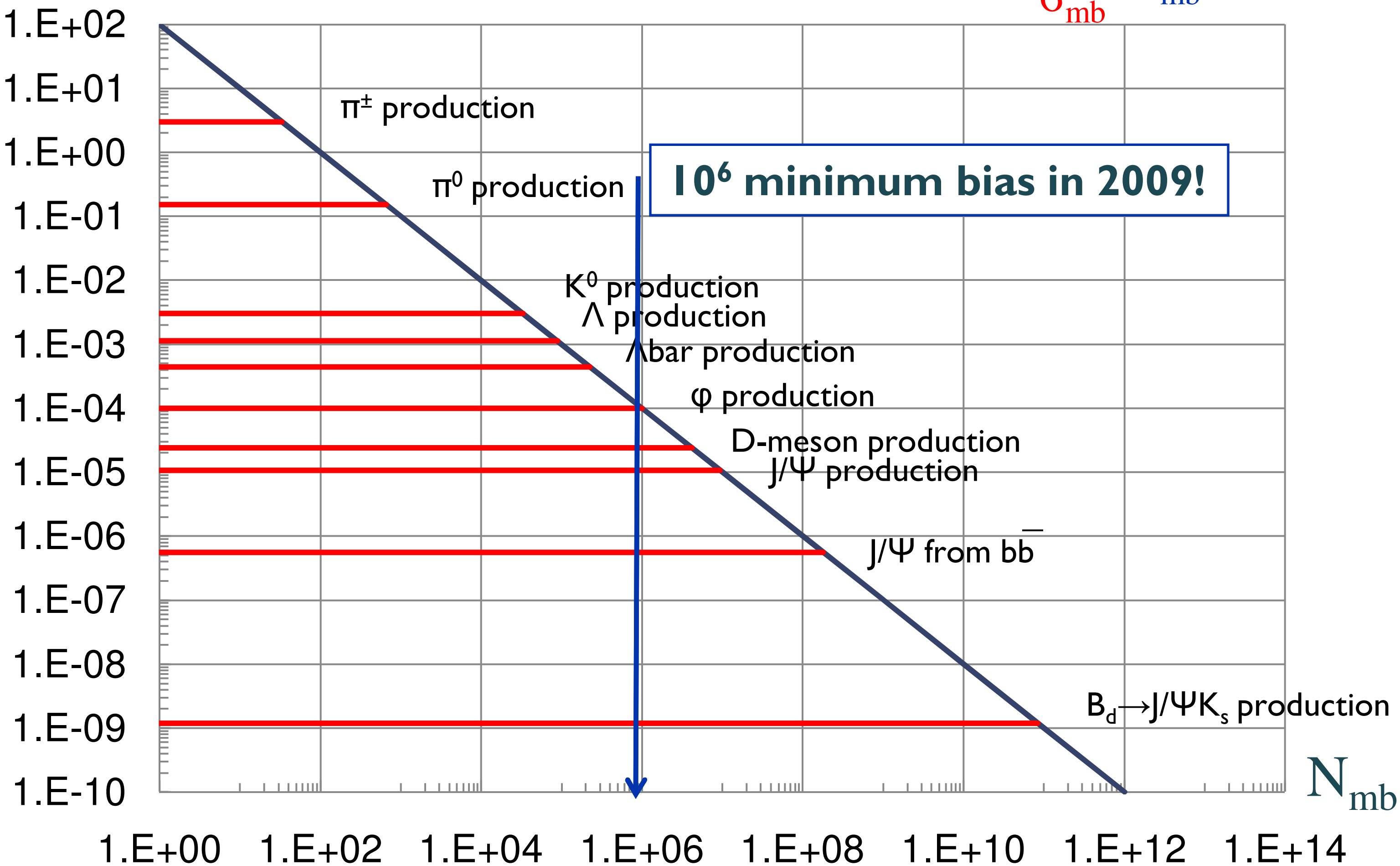
Calorimeters:
PID: h,e,$\gamma$, $\pi^0$

# LHCb (early) Physics Results

# Extracting physics from (very) first data

*Exploit minimum bias data (almost no trigger)*

Number of selected signal events: $S = \frac{\sigma \cdot \varepsilon}{\sigma_{mb}} \cdot N_{mb}$



# Exploiting minimum bias data

**in $10^8$ minimum bias events**

~ 40 mins @ $10^{31}$ cm$^{-2}$ s$^{-1}$
→ ~50k $\Lambda \to p\pi$ events

- plenty of $K_s \to \pi\pi$ and $\Lambda \to p\pi$
- 95% purity with kinematical and vertex cuts only

→ clean & unbiased sample for PID studies

➢ study hadron identification performance and lepton misidentification probability.

- search for $D \to K\pi$, $K\pi\pi\pi$, $K^0{}_S\pi\pi$, $K\pi\pi^0$

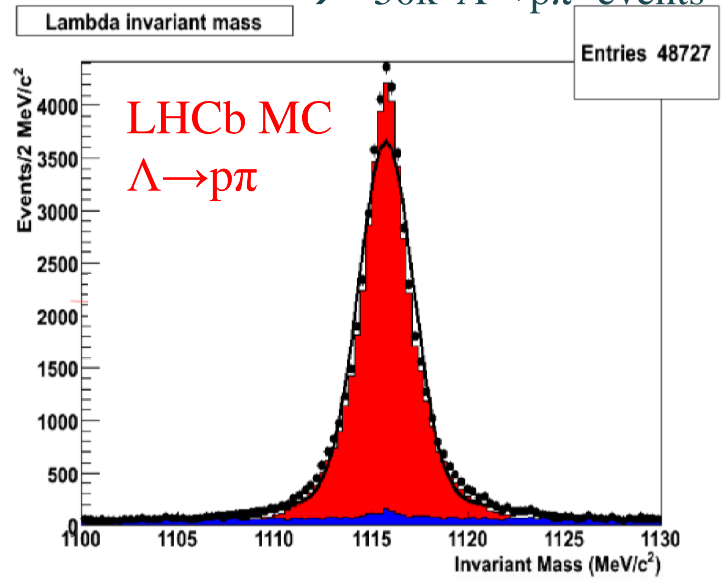
→ assess background levels, resolutions & relative efficiencies

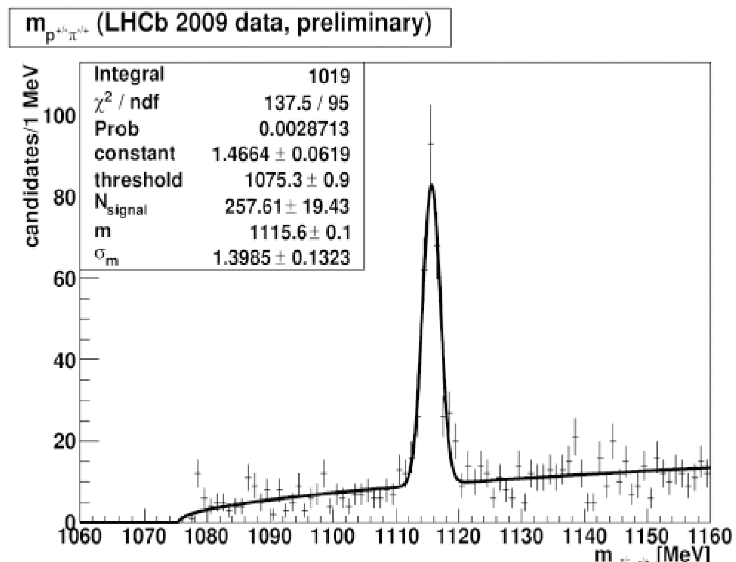
➢ demonstrate capability to reconstruct first final states

- collect ~1.4k prompt $J/\psi \to \mu\mu$

→ second muon unbiased for PID studies

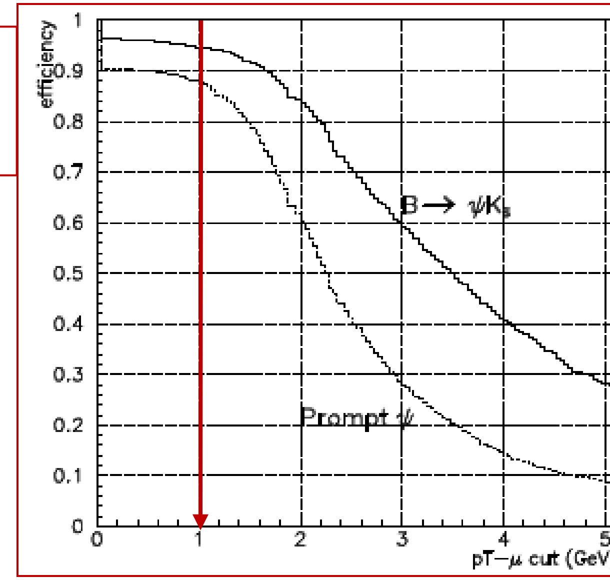
➢ study muon identification performance



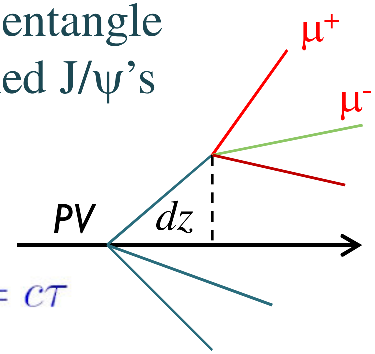



# Exploiting first muon trigger data

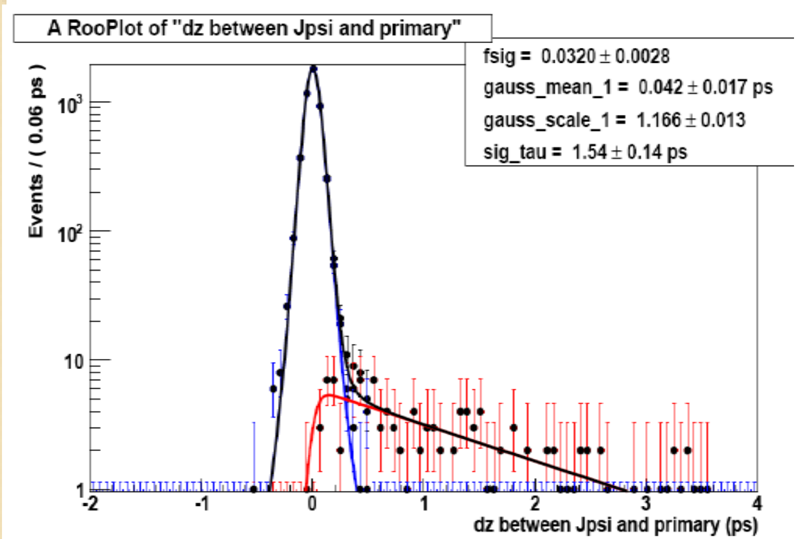
applying J/ψ trigger with $p_t$-cut on single muon
→ expect ~$10^6$ J/ψ→μμ with 1 $pb^{-1}$



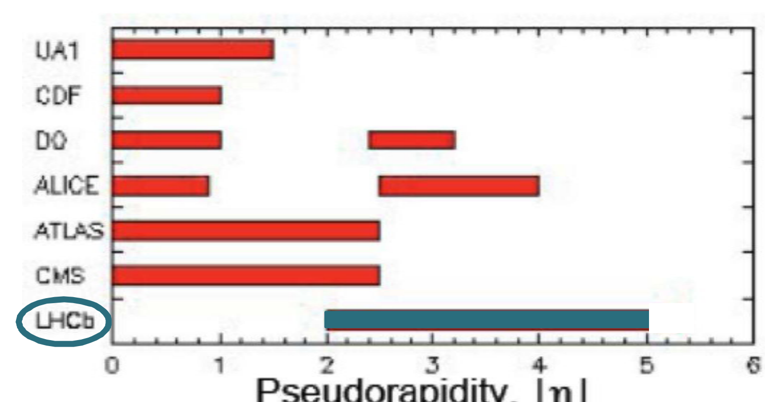

- Reconstruct J/ψ→μμ and disentangle fraction of prompt and detached J/ψ's
- discriminating variable:




$$t = \frac{dz}{p_z} \times M^{J/\psi} \approx \frac{d}{p} \times M^{J/\psi} = c\tau$$




- Measure prompt J/ψ and $b\bar{b}$ cross section in a region not accessible to other collider experiments




- study proper time resolution with prompt component

# Exploiting ~0.5 $fb^{-1}$ of data with full trigger

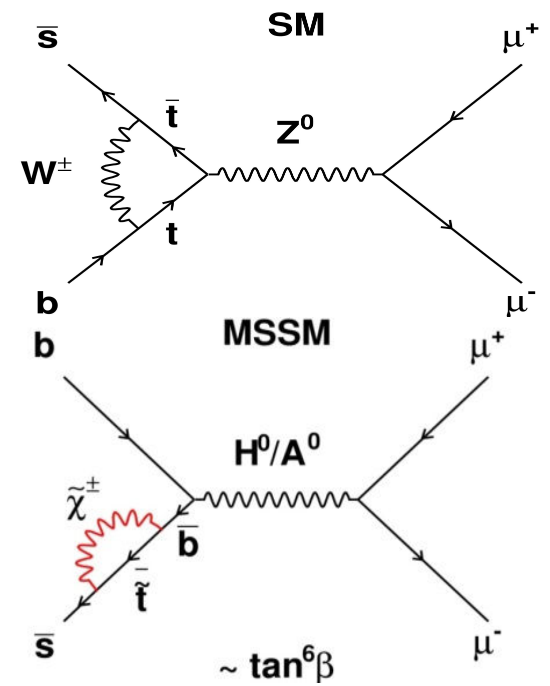
➢ **Search for very rare decay $B_s \to \mu^+\mu^-$**

See arXiv:0912.4179 for more details

- Within the SM the dominant contribution stems from the "Z-penguin" diagram. The "box" diagram is suppressed by a factor $(M_W/m_t)^2$
  - Small BR in SM: **(3.6 ± 0.4) x $10^{-9}$**
- It is very sensitive to New Physics with new scalar or pseudoscalar interactions. Highly interesting to probe models with extended Higgs sector!
- For instance, in the MSSM the branching ratio scales as

$$Br^{MSSM}(Bq \to l^+l^-) \propto \frac{m_b^2 m_l^2 \tan^6 \beta}{M_{A0}^4}$$

- Limit from TeVatron at 90% CL:
  - Current (~3.7 $fb^{-1}$): **< $36\times10^{-9}$**
    - ~ 10 times higher than SM!

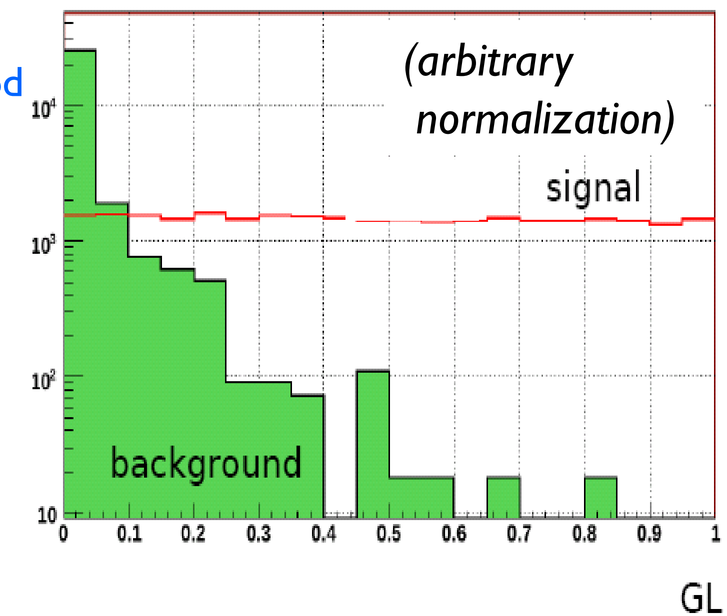


# Search for the very rare decay $B_s \rightarrow \mu^+\mu^-$

1. Selection of $B_s \rightarrow \mu^+\mu^-$ , as common as possible with the control channels: $B^+ \rightarrow J/\psi (\mu^+\mu^-) K^+$, $B \rightarrow J/\psi (\mu^+\mu^-) K^* (K^+\pi^-)$, $B_{(s)} \rightarrow h^+h^-$

2. Each selected and triggered event is given a likelihood to be signal or background like in a 3D space:
   i. Geometry Likelihood (GL) : lowest muon IPS, B lifetime, isolation, B IP, DOCA
   ii. Invariant mass Likelihood
   iii. Particle ID Likelihood

3. Get the background Geometry & Mass likelihood using sidebands




4. Use of control channels to get the probability, for a signal event, to fall in each bin:
   Geometry & Mass: Use of $B_{(s)} \rightarrow h^+h^-$
   PID: Calibration muons ($J/\Psi \rightarrow \mu+\mu-$)
   and misidentification ($\Lambda \rightarrow p\pi$, $B_{(s)} \rightarrow h^+h^- \ldots$)

5. Translate number of observed candidates to a measurement of the Branching Ratio using a known control channel

# Search for the very rare decay $B_s \rightarrow \mu^+\mu^-$

$$BR_{sig} = \frac{N_{sig}}{N_{cal}} \times \frac{\epsilon^{REC}_{cal}\,\epsilon^{SEL|REC}_{cal}\,\epsilon^{TRIG|SEL}_{cal}}{\epsilon^{REC}_{sig}\,\epsilon^{SEL|REC}_{sig}\,\epsilon^{TRIG|SEL}_{sig}} \times \frac{f_{cal}}{f_{sig}} \times BR_{cal}$$

$$BR\left(B^+ \rightarrow J/\psi\, K^+\right) = \left(5.97 \pm 0.02\right) \times 10^{-5}$$

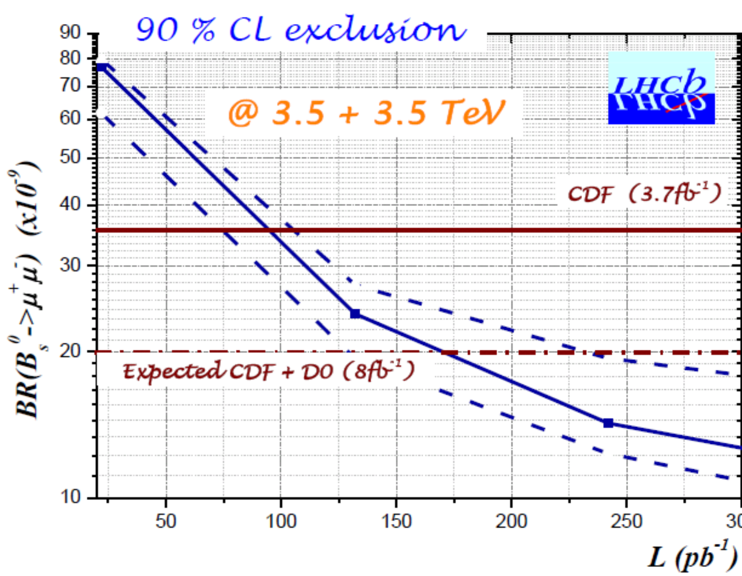
$$BR\left(B^0_d \rightarrow K^+ \pi^-\right) = \left(1.88 \pm 0.07\right) \times 10^{-5}$$

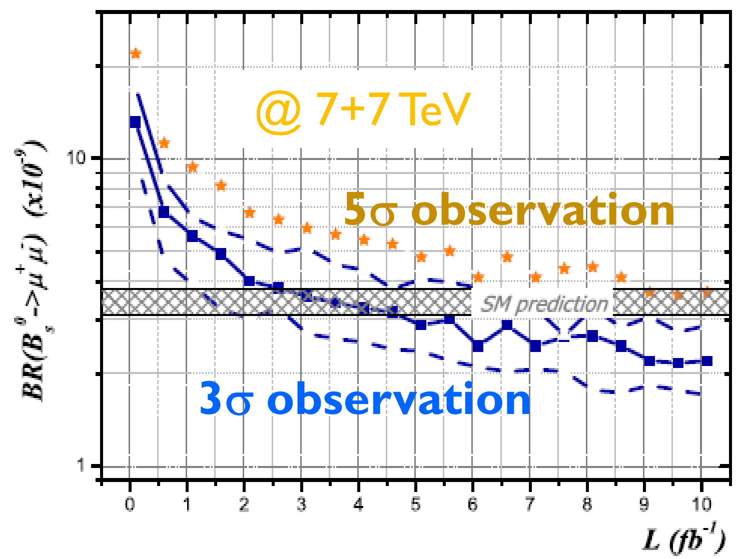
$\alpha$ (efficiency ratio)

$f_{cal}/f_{sig}$: Main systematic uncertainty ~13%

$\alpha(J/\psi\ (\mu^+\mu^-)\ K^+) \cong 0.6 \rightarrow$ Evaluate ratio of tracking efficiency from data

$\alpha(K^+\pi^-) \cong 0.4 \rightarrow$ Evaluate ratio of trigger efficiency from data




The best limit expected from TeVatron in 2010 (~$2\times10^{-8}$) is reached with less than 0.2 $fb^{-1}$ at 7 TeV CoM. If there is a signal, we expect to observe with it 5σ significance down to the SM BR with less than 10 $fb^{-1}$ at 14 TeV CoM.

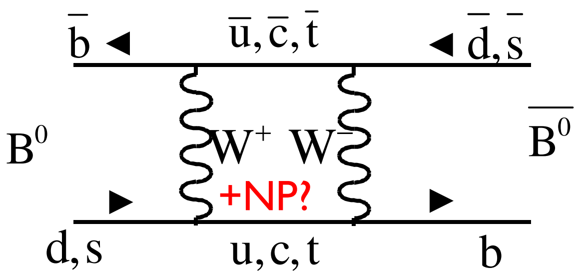
# Exploiting ~0.5 fb$^{-1}$ of data with full trigger

➢ **measure $B_s$-$\overline{B}_s$ mixing phase $\phi_s$ in $B_s \to J/\psi(\mu\mu)\phi$**

See arXiv:0912.4179 for more details

✓ Sensitive to New Physics effects in mixing

➢ $\phi_s = \phi_s(SM) + \phi_s(NP)$



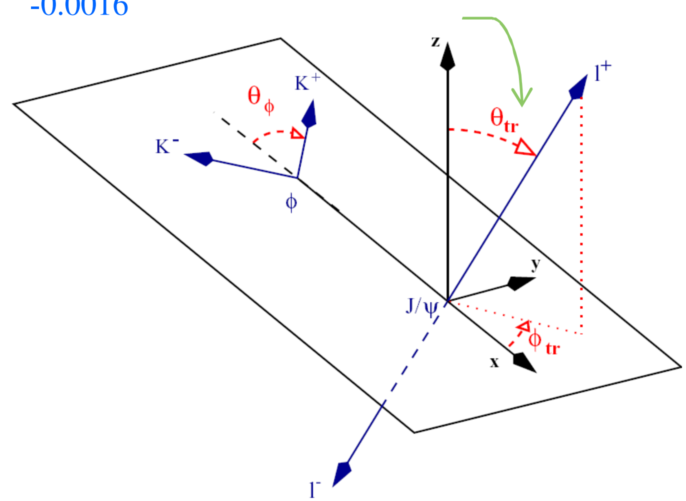

$$A_{CP}(t) = \frac{\Gamma[\overline{B}_s(t) \to f] - \Gamma[B_s(t) \to f]}{\Gamma[\overline{B}_s(t) \to f] + \Gamma[B_s(t) \to f]}$$

$$A_{CP}(t) = \frac{\eta_f sin\phi_s sin(\Delta m_s)t}{cosh(\Delta\Gamma_s t/2) - \eta_f cos\phi_s sinh(\Delta\Gamma_s t/2)}$$

**$\eta_f$ = +, - 1 CP eigenstates**

➢ in SM: $\phi_s = -2\beta_s = -\arg(V_{ts}^2) \sim -0.0360^{+0.0020}_{-0.0016}$

$\Theta_{tr}$= angle between $l^+$ and normal to $\phi$ decay plane




✓ $J/\psi\phi$ is not a pure CP eigenstate (2 CP even, 1 CP odd amplitude)

➢ need to fit angular distributions of decay final states as function of proper time

$$\frac{\partial^4 \Gamma\left(B_s\left(\overline{B}_s\right) \to J/\psi\,\phi\right)}{\partial t\,\partial\cos\theta\,\partial\phi\,\partial\cos\psi}$$

# Measurement of $B_s$ mixing phase ($\phi_s$)

1. Selection of $B_s \rightarrow J/\psi\ (\mu^+\mu^-)\ \phi(K^+K^-)$ , as common as possible with the control channels: $B \rightarrow J/\psi\ (\mu^+\mu^-)\ K^*\ (K^+\pi^-)$, $B^+ \rightarrow J/\psi\ (\mu^+\mu^-)\ K^+$, $B_s \rightarrow D_s^+\pi^-$

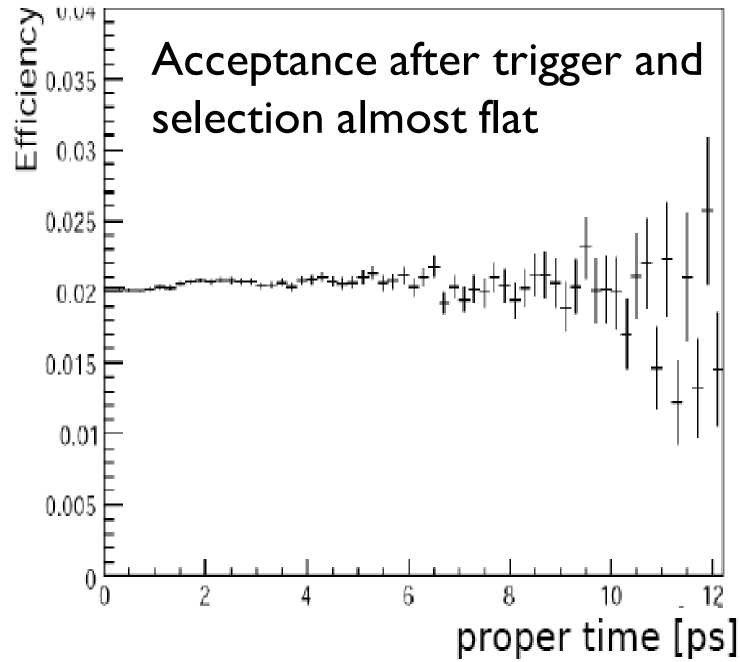
2. Measure proper time, transversity angles and tag the initial $B_s$ flavour;

$$\varepsilon_{\text{eff}} = \varepsilon_{\text{tag}}(1 - 2w_{\text{wrong}})^2 \cong 6\%$$

3. Unbinned Likelihood fit to determine:

$$\phi, \Gamma_s, \Delta\Gamma_s, R_{\parallel}, R_{\perp}, \delta_{\parallel}, \delta_{\perp}$$

4. Use of the MC simulation minimized using control channels:
   - Acceptance: $B \rightarrow J/\psi\ (\mu^+\mu^-)\ K^*\ (K^+\pi^-)$
   - Tagging: $B \rightarrow J/\psi\ (\mu^+\mu^-)\ K^*\ (K^+\pi^-)$, $B^+ \rightarrow J/\psi\ (\mu^+\mu^-)\ K^+$, $B_s \rightarrow D_s^+\pi^-$
   - Background: Sidebands




✓ with 3k reconstructed $B_s \rightarrow J/\psi(\mu\mu)\phi$ signal events (before tagging)

$\rightarrow \sigma_{stat}(\phi_s)\sim 0.2$ with 0.3 $fb^{-1}$ at 7 TeV CoM

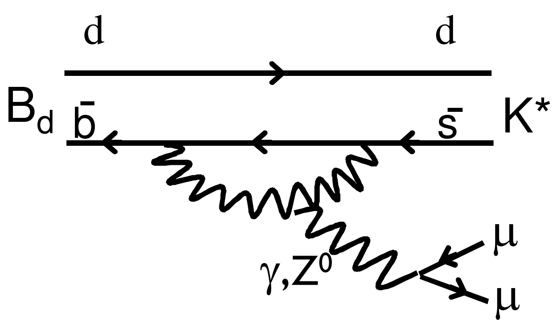
$\sigma_{TeVatron}(\phi_s)\sim 0.2$ expected in 2010

# Exploiting ~0.5 $fb^{-1}$ of data with full trigger

➢ **Study of the rare decay $B \to K^*\mu^+\mu^-$**

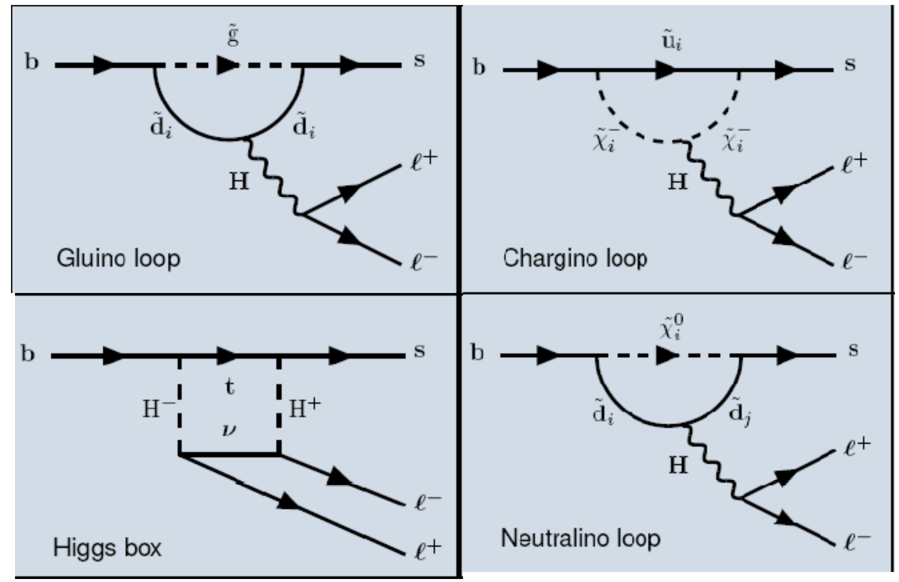
See arXiv:0912.4179 for more details

In SM, the decay is a $b \to s$ penguin diagram




Br:(**9.8±2.1**) ×10^-7

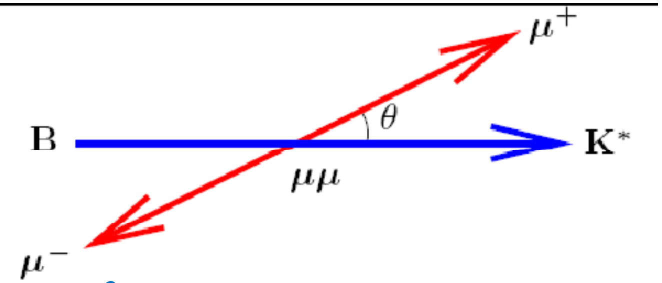
But NP diagrams could also contribute at the same level




- The measured Br agrees within 20% with the SM prediction.
- However, New Physics could **modify the angular distributions** by much more than this!

With 2 $fb^{-1}$ at 14 TeV CoM, **LHCb** expects **(6.2±1.6)k** signal events with B/S ~ 0.3
**(uncertainty mostly due to BR)**

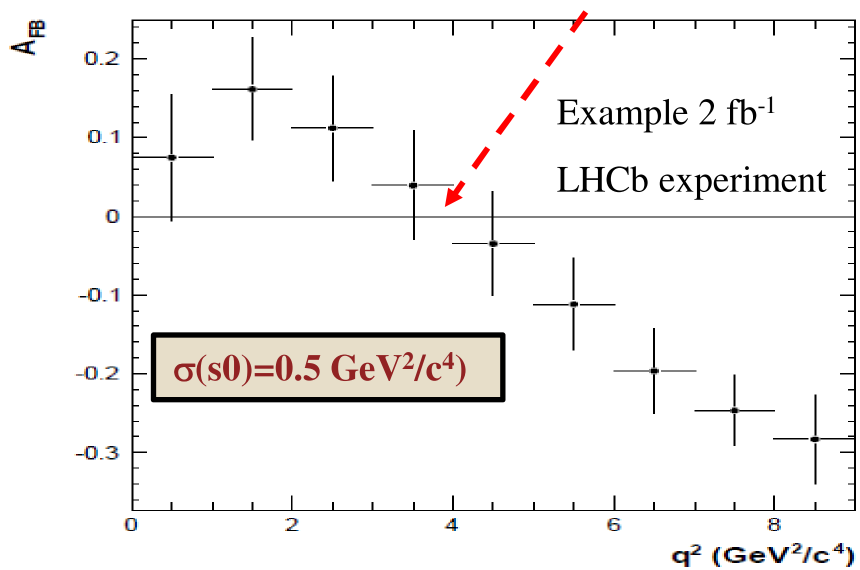
# Study of the rare decay $B \rightarrow K^{*}\mu^{+}\mu^{-}$

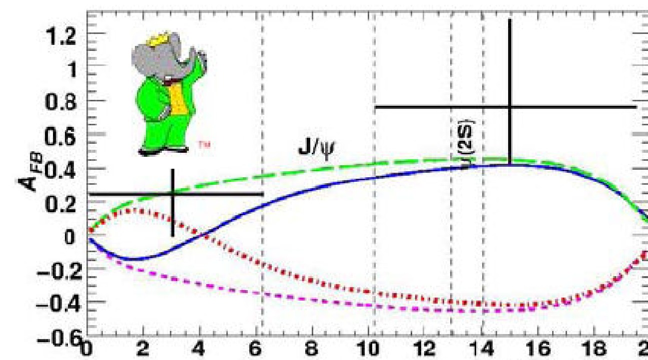


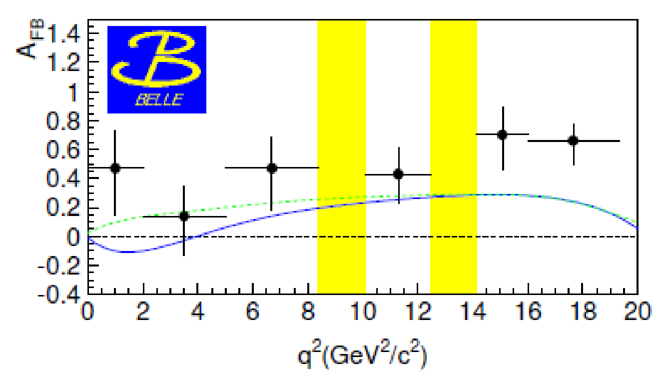

Measure

- the angular distribution of the $\mu^+$ in the $\mu\mu$ rest frame relative to the B direction.
- Measure the Forward – Backward Asymmetry (**FBA**) of this distribution as a function of the $\mu\mu$ invariant mass ($M_{\mu\mu}^2$)
- Determine, $\mathbf{s_0}$, the $M_{\mu\mu}^2$ for which **FBA** = 0.

**SM: $s_0 = 4.36^{+0.33}_{-0.31}$ GeV$^2$/c$^4$**



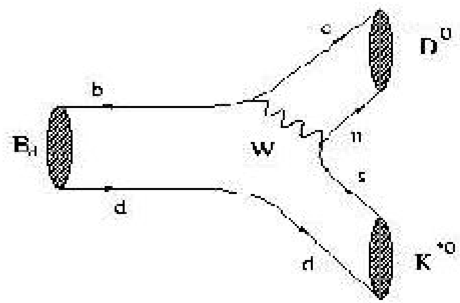

(LHCb @ 0.5 fb$^{-1}$ at 7 TeV ⟶ similar to BELLE/BABAR today

# Exploiting ~0.5 $fb^{-1}$ of data with full trigger

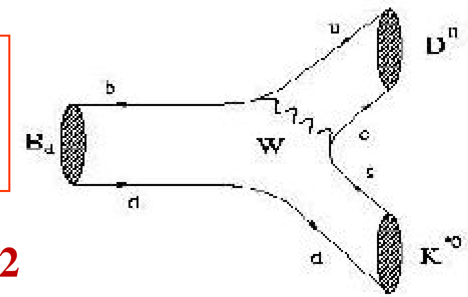
➢ **measure phase γ of $V_{ub}$ using tree decays**

See arXiv:0912.4179 for more details

**γ from B → D K* : crucial hadron trigger and K/π separation**




Both colour suppressed
→ Same magnitude
Good for large interference.




**$D_1=(\overline{D}_0 + D_0)/\sqrt{2}$**

- Observe $B^0 \to D^0 K^{*0}$, $B^0 \to \overline{D}^0 K^{*0}$, $B^0 \to D_1 K^{*0}$ and the 3 charge conjugate reactions.
- The $D^0$ and the $K^*$ are observed in their $K^{+-}\pi^{-+}$ decay modes. The $D_1$ in $\pi^+\pi^-$ or $K^+K^-$
- The flavour of the B is identified by the charge of the K in K* decay.
- The flavour of the D by the charge of the K in D decay → **Self tagging.**

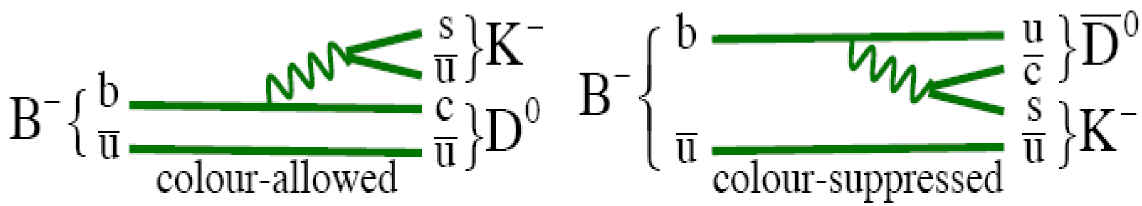
| Mode | Yield / 2$fb^{-1}$ | B/S |
|---|---|---|
| favoured $B^0 \to (K^+\pi^-)_D K^{*0}$ + c.c. | 3200 | 0.2±0.5 |
| suppressed $B^0 \to (K^-\pi^+)_D K^{*0}$ + c.c. | 290 | 10±5 |
| $B^0 \to (K^+K^-/\pi^-\pi)_D K^{*0}$ + c.c. | 370 | 20±10 |

**With $r_B$=0.3,**

# $\gamma$ at tree level from B→DK

➢ **measure phase $\gamma$ of $V_{ub}$ using tree decays**

## $\gamma$ from $B^{\pm} \rightarrow D K^{\pm}$: crucial hadron trigger and K/$\pi$ separation




Weak phase difference = $\gamma$
Magnitude ratio = $r_B \sim 0.1$

•Challenge is to find the suppressed K$\pi$ modes (Br ~ $10^{-7}$)

**With $r_B$=0.1**

| | **K$\pi$ modes** Yield (summing both modes) | **K$\pi$ modes** Bckgd / mode | **$K_s\pi\pi$ modes** Yield (summing both modes) | **$K_s\pi\pi$ modes** Bckgd / mode |
|---|---|---|---|---|
| Favoured | 84k | 50±3k | 6.8k | 2.3±0.3k |
| Suppressed | 1.6k | 1.0±0.5k | | |

Background comes from:
* good D + random bachelor K
* bad D
* D $\pi$ (favoured mode only)

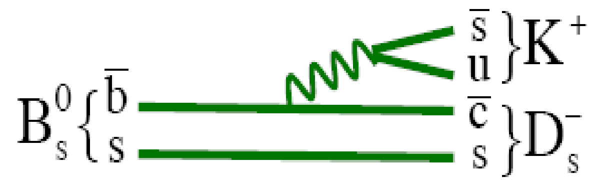
Caveat in the $K_s\pi\pi$ modes the treatment of intermediate resonances needs to be understood and no HLT trigger has been applied

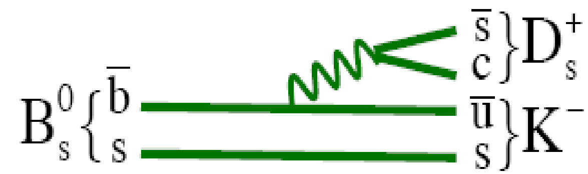
# $\gamma$ at tree level from B→DK

➢ **measure phase $\gamma$ of $V_{ub}$ using tree decays**

**$\gamma$ from $B_s$ → Ds K : crucial hadron trigger and K/$\pi$ separation**

Two tree decays (b→c) and (b→u) that interfere via $B_s$ mixing. Can determine $\phi_s+\gamma$ in the same way than $2\beta+\gamma$ using B→D*$\pi$ done at the B-factories. However in this case, both amplitudes are similar ($\sim\lambda^3$) and their ratio can be extracted easier from data!




Fit $D_sK$ time distributions, simultaneously with 10 x more abundant $D_s\pi$, and the *untagged sample*. This allows simultaneous extraction of :

- $\Delta m_s$, $\Delta\Gamma_s$
- $\omega$ the wrong tag rate
- strong phase difference $\delta\Delta$,
- $\phi_s + \gamma$

**Using $\phi_s$ obtained from $B_s$ to J/$\psi\phi$, and 14k $B_s$→$D_sK$ with B/S = 0.3±0.2**

**$\sigma(\gamma) \sim 10^o$ with 2 $fb^{-1}$**

# γ at tree level from B→DK

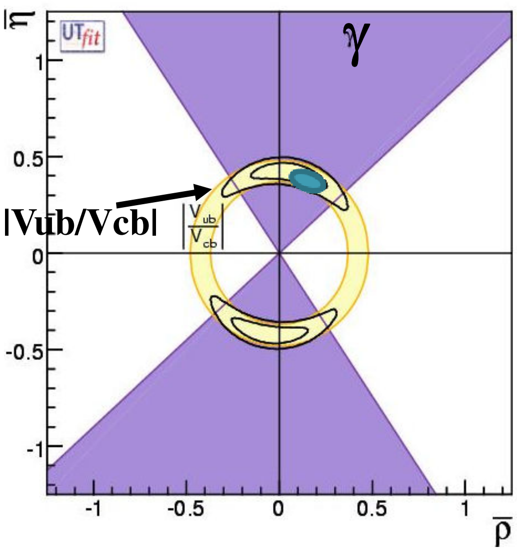
Table 1: The relative weight (in percent) of each contributing analysis in the overall $\gamma$ determination for two values of $\delta_{B^0}$ and a dataset of 2 $\mathrm{fb}^{-1}$. Table is taken from Ref. [9].

| Analysis | $\delta_{B^0} = 0°$ | $\delta_{B^0} = 45°$ |
|---|---|---|
| $B^- \to D^0(K^\pm\pi^\mp)K^-$, $D^0(h^+h^-)K^-$ and $D^0(K^\pm\pi^\mp\pi^+\pi^-)K^-$ | 25 | 38 |
| $B^- \to D^0(K^0_S\pi^+\pi^-)K^-$ | 12 | 25 |
| $B^0 \to D^0(K^\pm\pi^\mp)K^{*0}$ and $D^0(h^+h^-)K^{*0}$ | 44 | 8 |
| $B^0_s \to D^\mp_s K^\pm$ | 16 | 24 |
| $B^0 \to D^\mp\pi^\pm$ | 3 | 5 |

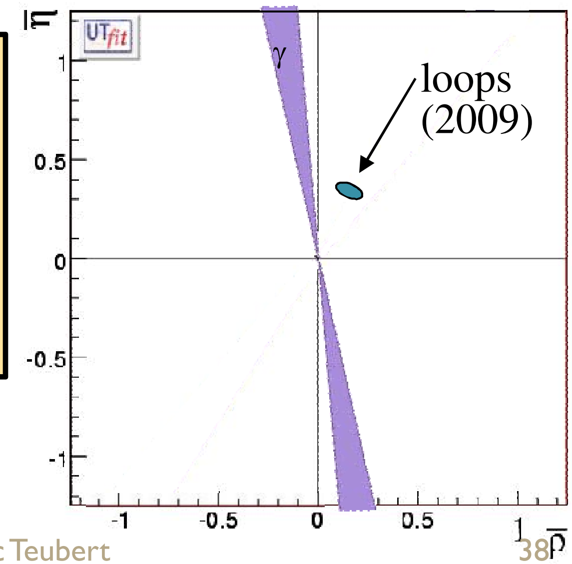
**LHCb overall precision from tree processes: σ(γ) ~ 5° with 2 $\mathrm{fb}^{-1}$**

**σ(γ) ~ 20° with 0.3 $\mathrm{fb}^{-1}$ at 7 TeV CoM → similar than BABAR/BELLE today**

B-factories measurements (tree decays only): **γ = (75± 21)°**
From global fit (2009) (incl. loop processes!): **(68 ± 4)°**




In few years we should know if γ as measured with tree processes is compatible with loop measurements !



# Conclusions

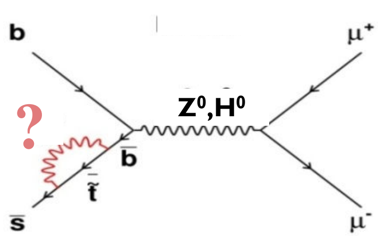
# Conclusions

• LHC is a superb B-factory (~100 kHz), of all types including Bs, and is back online since Nov09!

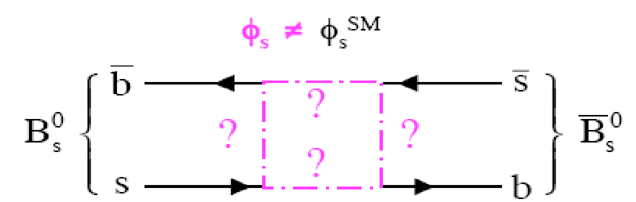
•LHCb is completely installed and taking data!. Hardware and software is being commissioned right now and so far everything looks very promising!

•The B-physics program will certainly contribute significantly to the overall LHC effort to find and study Physics beyond the SM.

•A few highly-sensitive b→s observables are accessible from the very first data:




$B_s \to \mu^+\mu^-$ Higgs "Penguin"


$B_s$–$\bar{B}_s$ oscillations: "Box" diagram

• LHCb will pursue the program and improve precision of CKM angles. Several $\gamma$ measurements from tree decays only may reveal inconsistencies in the CKM picture.