Status and physics potential of the LHCb experiment

Walter M. Bonivento
INFN Cagliari

14th Lomonosov Conference, Moscow 2009

LHC and LHCb Physics Goals

Main LHC Goals:

- Search for the SM Higgs boson in mass range ~ $115 < m_H < 1000$ GeV
- Search for New Physics beyond the SM

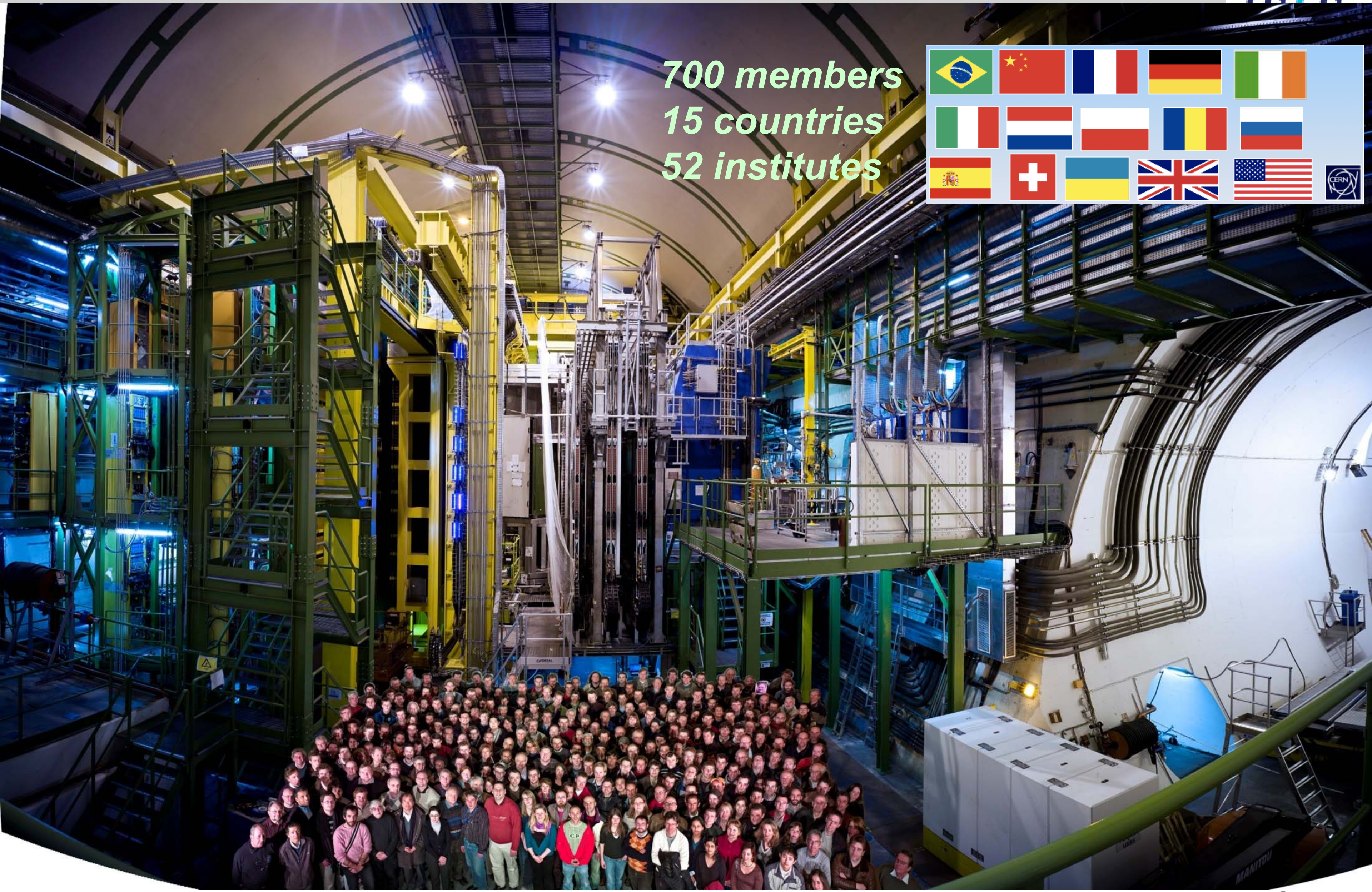
- Explore TeV-scale directly (ATLAS & CMS) and indirectly (LHCb)

Current CPV measurements in agreement with the Standard Model; still, the direct measurement of less constrained elements such as βs and γ, might reveal NP effects

Moreover rare b->s decays, mediated by penguin and box diagrams, might also reveal NP

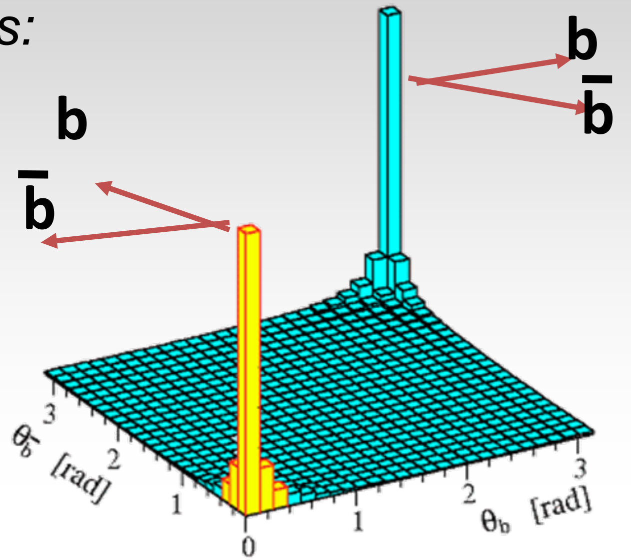
LHCb Collaboration

700 members
15 countries
52 institutes



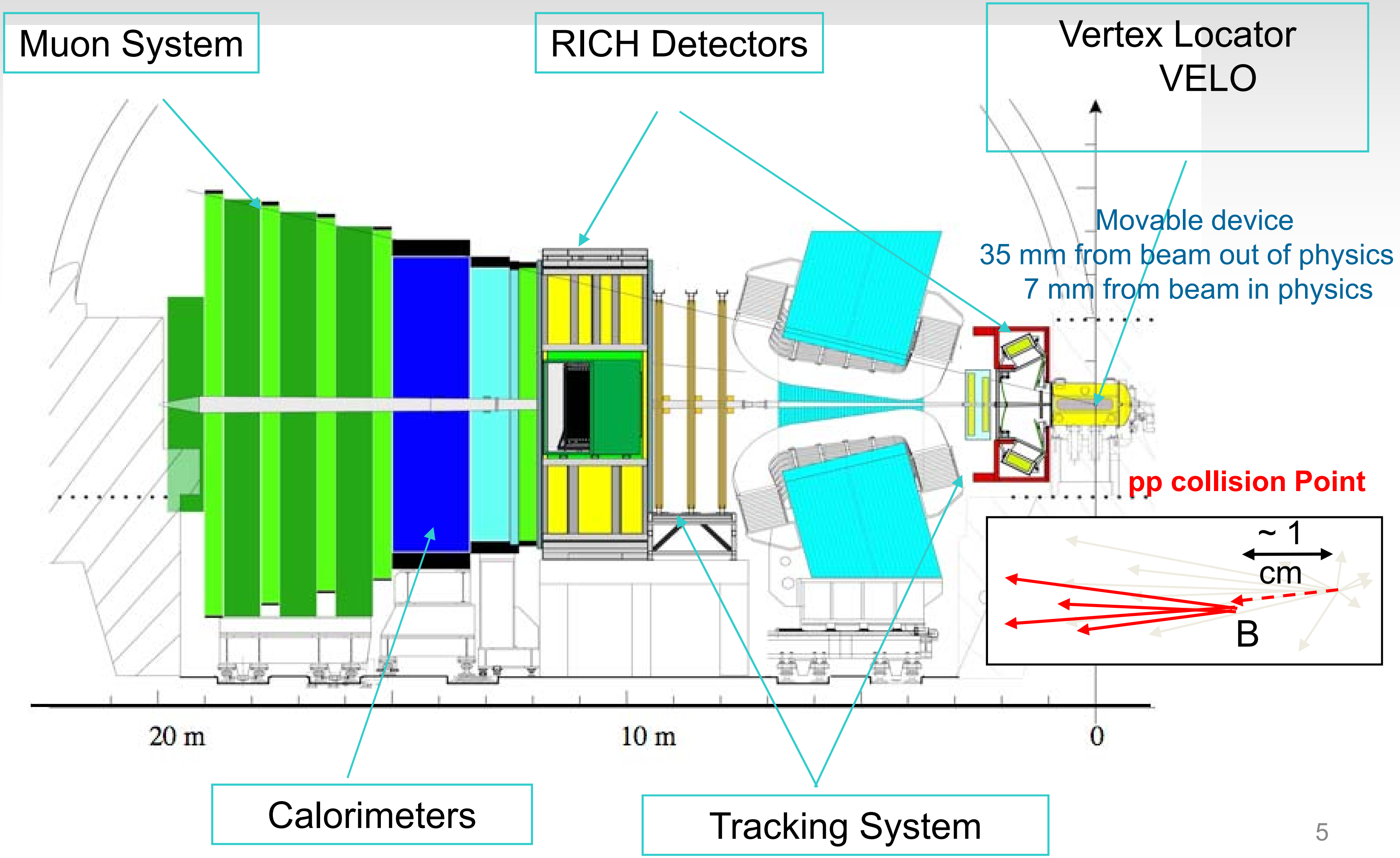
The LHCb Experiment

- Advantages of beauty physics at hadron colliders:
  - High value of bb cross section at LHC:
    σ_{bb} ~ 500 μb at 14 TeV (1mb latest Pythia)
  - Access to all b-flavoured hadrons
- The challenge
  - Multiplicity of tracks (~30 tracks per rapidity unit)
  - Rate of background events: σ_{inel}~ 100 mb



- LHCb running conditions:
  - Luminosity limited to ~2×10^{32} cm^{-2} s^{-1} by focussing the beam less than ATLAS and CMS do
    - Maximize the probability of single interaction per bunch crossing
      At LHC design luminosity pile-up of >20 pp interactions/bunch crossing while at LHCb ~ 0.7 pp interaction/bunch
    - LHCb will reach nominal luminosity soon after start-up
  - **$2fb^{-1}$ per nominal year (10^7s), ~ 10^{12} bb pairs produced per year**

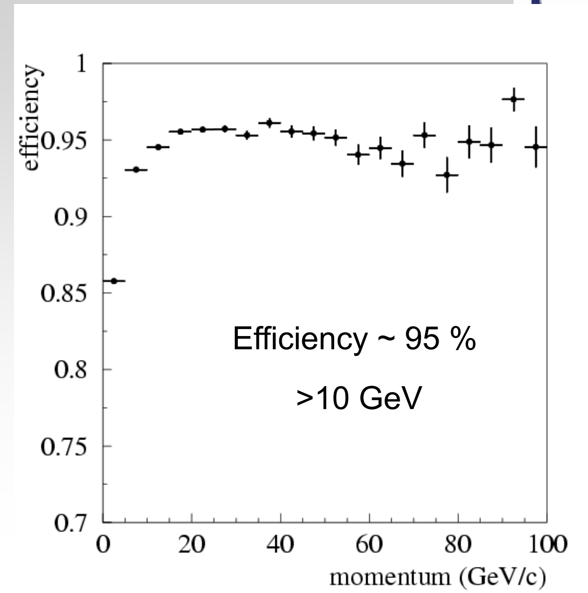
The LHCb Detector

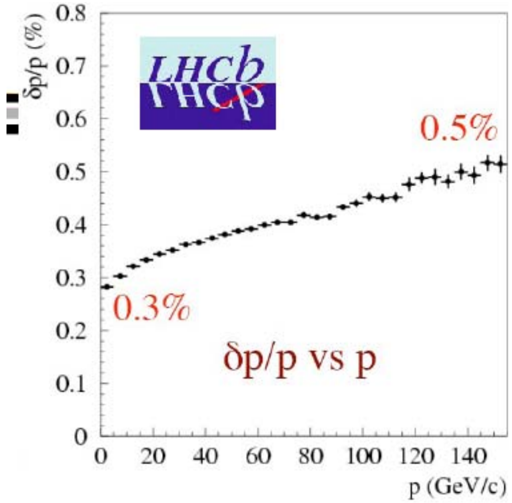


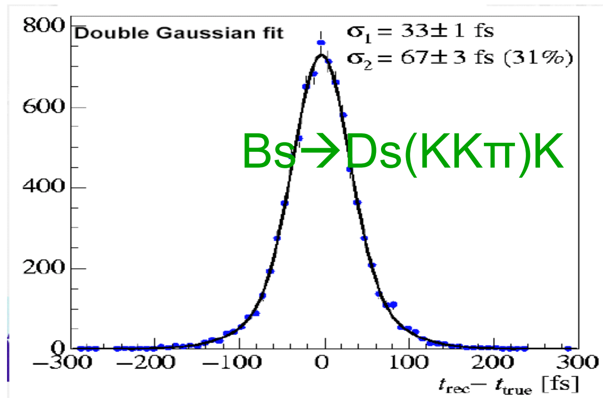
Detector Performances: Tracking

Expected tracking performance:

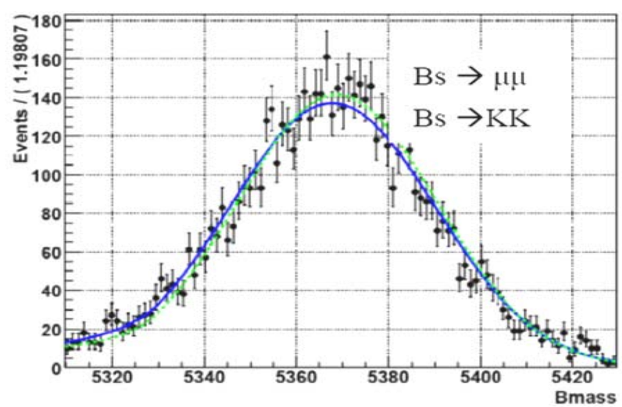
- *Efficiency > 95% for tracks from B decays crossing entire detector*
- *δp/p: 0.3% - 0.5% (depending on p)*
- *Proper time resolution: ~ 40 fs*
- *B Mass resolution: 15-20 MeV/c^2*







Proper time resolution ~ 40 fs



Mass resolution ~ 20 MeV

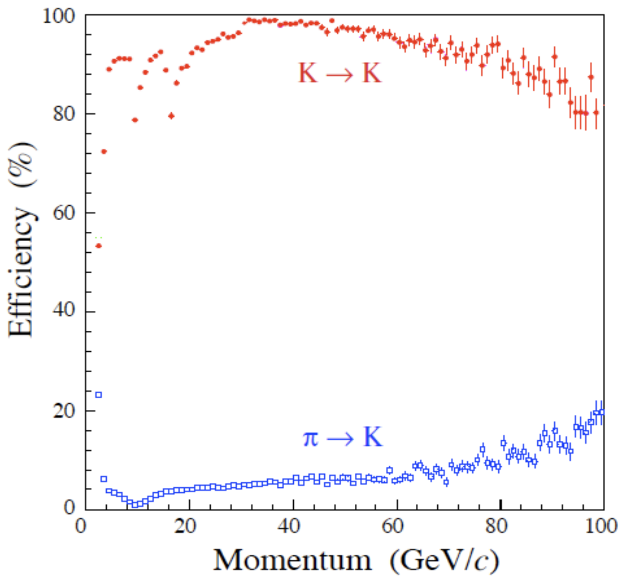
Detector Performances: PID

Two RICH detectors with 3 radiators to cover range 2 < p <100 GeV :

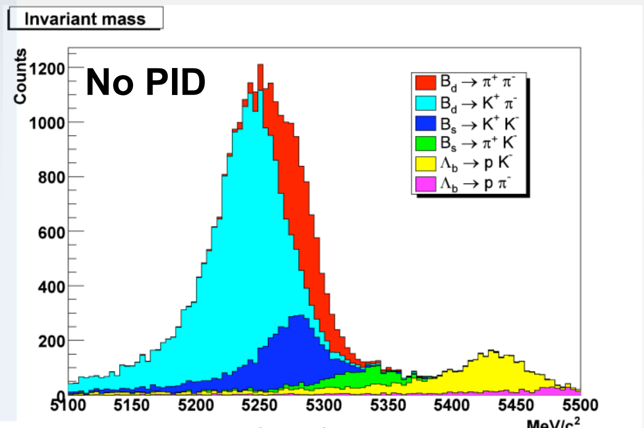
RICH1 Aerogel (2-10 GeV), C_4F_{10} (10-60 GeV)

RICH2 CF_4 (16-100 GeV)

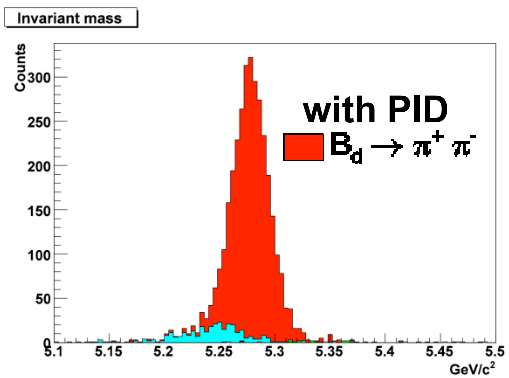
π–K separation



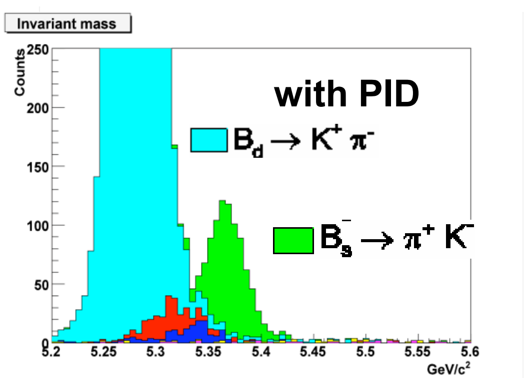
- *Good π–K separation in 2-100 GeV/c range*
- *Low momentum*
  - *Tagging kaons*
- *High momentum*
  - *Clean separation of $B_{d,s} \rightarrow hh$ modes*



ππ invariant mass



ππ invariant mass

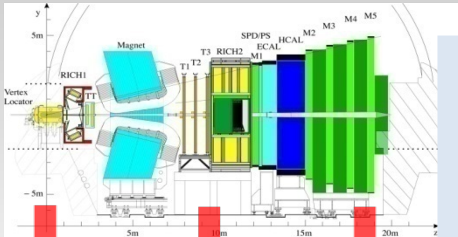


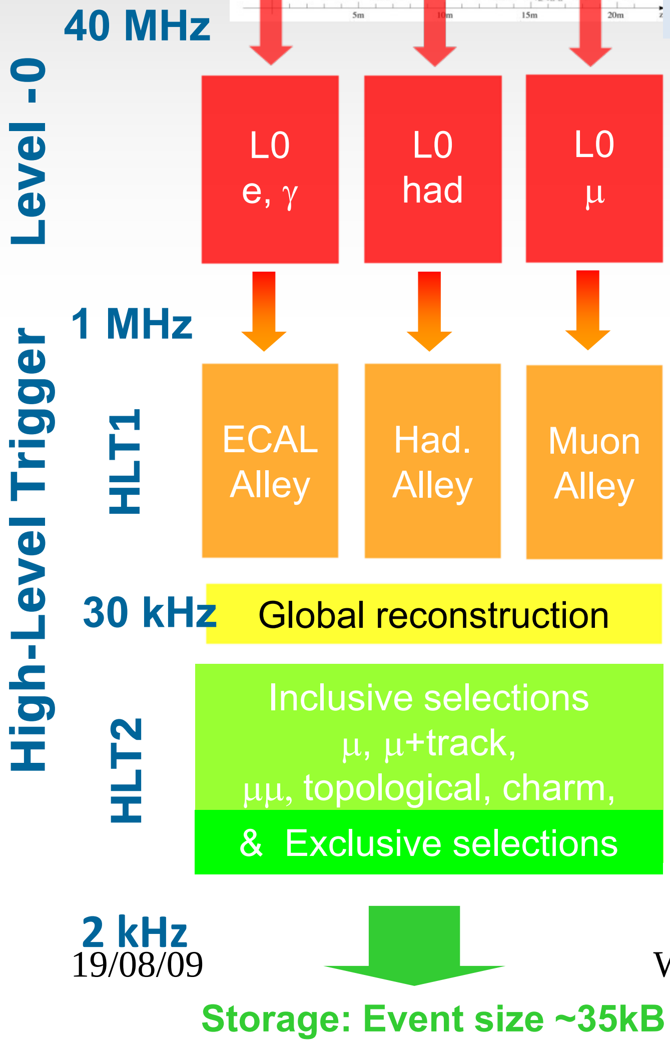
Kπ invariant mass

Kaon ID ~ 90%

Pion mis-ID ~ 3%

LHCb Trigger





Trigger is crucial as σ_{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 μ, e, γ and hadron candidates

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

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

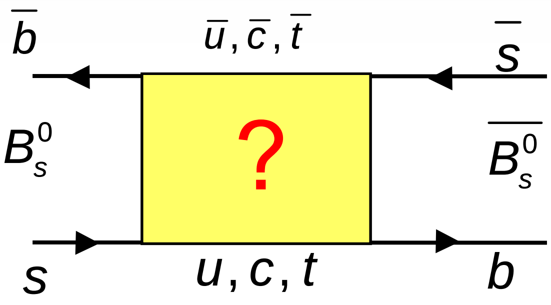
  HLT1: Confirm L0 candidate with more complete info, add impact parameter and lifetime cuts

  HLT2: B reconstruction + selections

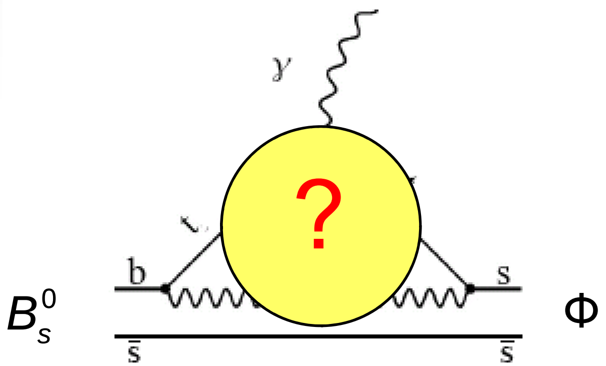
	ε(L0)	ε(HLT1)	ε(HLT2)
Electromagnetic	70 %	> ~80 %	> ~90 %
Hadronic	50 %		
Muon	90 %		

LHCb Physics Programme

Main LHCb objective is to search for the effects induced by New Physics in CP violation (see talk by T.Du Pree) and Rare decays (see talk by N.Serra) using the FCNC processes mediated by loop (box and penguin) diagrams



$\Phi_s \neq \Phi_s^{SM}$



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 β , β_s & γ

- ***Magnitude of the couplings of new particles***
  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 $b \rightarrow s\gamma$

$b \rightarrow \gamma(L) + (m_s/m_b) \times \gamma(R)$ *Similar studies using* $B \rightarrow K^*\mu^+\mu^-$ & $K^*e^+e^-$

CPV measurements: UT angles

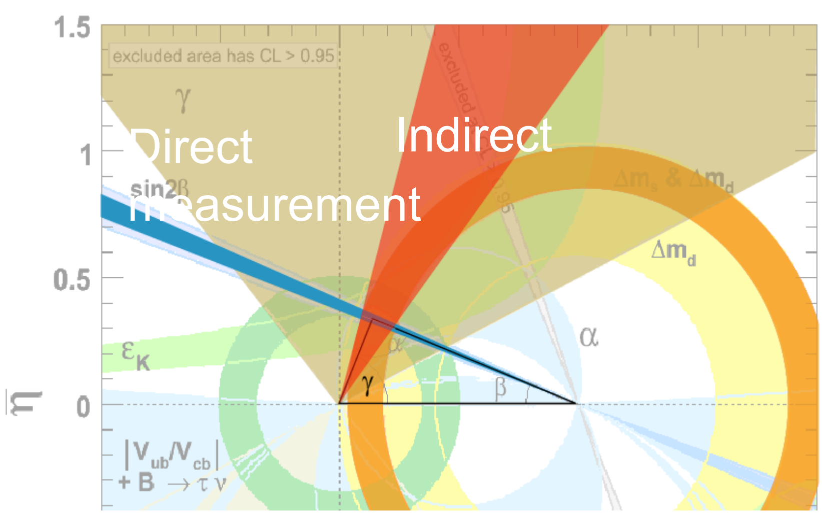
- **Box diagrams (I)**

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

β ***vs*** $|V_{ub} / V_{cb}|$ *is largely limited by theory (~10% precision in* $|V_{ub}|$*)*

Note a discrepancy in $|V_{ub}|$ ***determined in inclusive and exclusive measurements :*** $|V_{ub}|$ ***incl ~ (4.0-4.9)*** $\times 10^{-3}$ ***and*** $|V_{ub}|$ ***excl ~ (3.3-3.6)*** $\times 10^{-3}$

γ ***vs*** $\Delta m_d / \Delta m_s$ *is limited by experiment:* γ *is poorly measured (~30°)*



Indirectly γ ***is determined to be*** $\gamma = (68 \pm 4)^o$ ***from processes involving boxes***

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

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

CPV measurements: B_s mixing

- **Box diagrams (II)**

$\Phi(J/\psi\phi)$ = **$-2\beta_s$** is the B_s meson counterpart of 2β

penguin contribution ≤ 10^{-3}

β_s not measured accurately (indication of large value from CDF/D0)

Theoretical uncertainty is very small

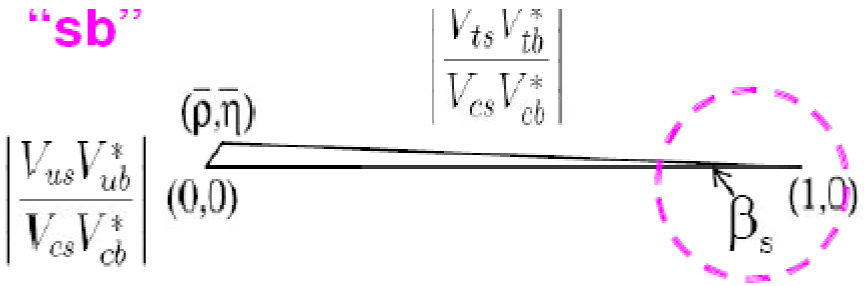
$-2\beta_s$ = - 0.0368±0.0017 (CKMfitter 2009 Moriond)

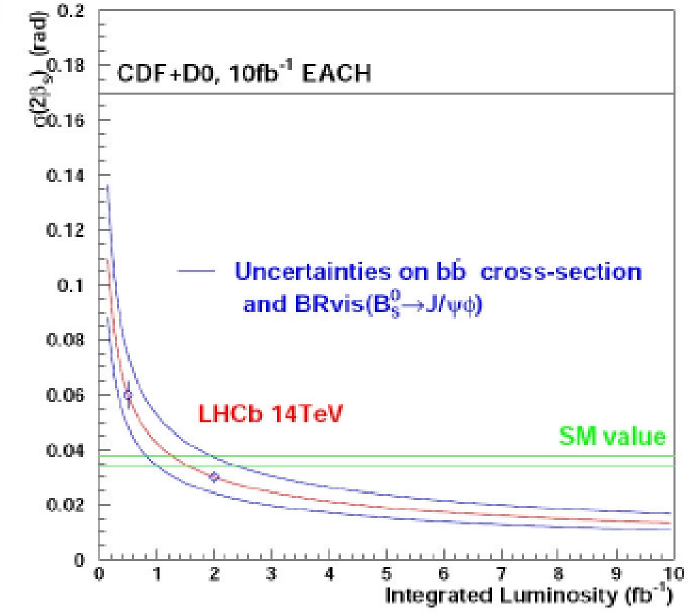
LHCb prospects (2 fb^{-1} sample)

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

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

"sb"



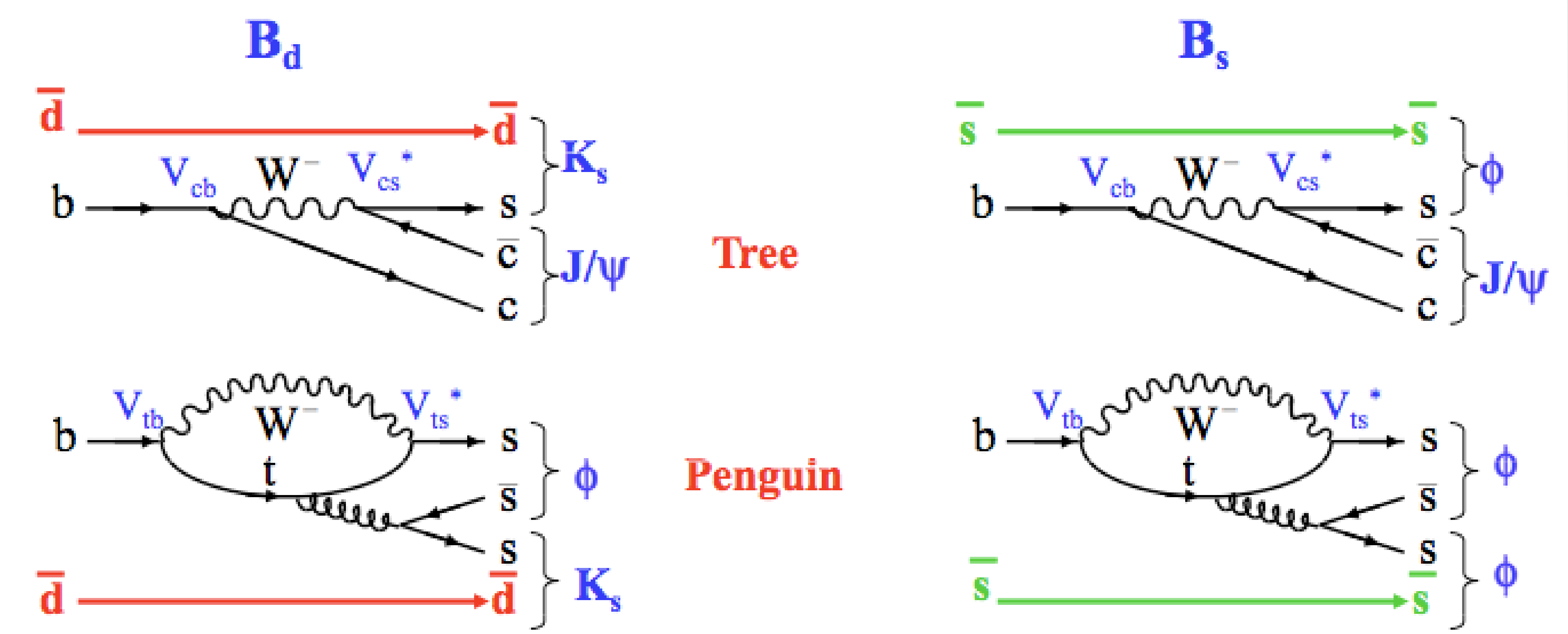


CPV measurements: Penguin vs Tree

- ***Penguin diagrams:***

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

$CPV(B_s\rightarrow\phi\phi) >> 1\%$ is also sign of NP



Thanks to B-factories
$\delta 2\beta(NP)$) ~ - 0.23 ± 0.18 rad

LHCb sensitivity with 2 fb^{-1} ~ 0.11 rad
(stat. limited)

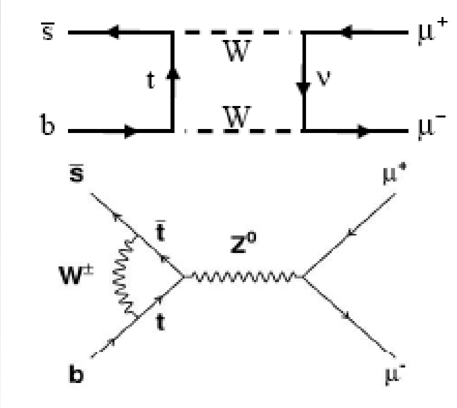
Rare Decays

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

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

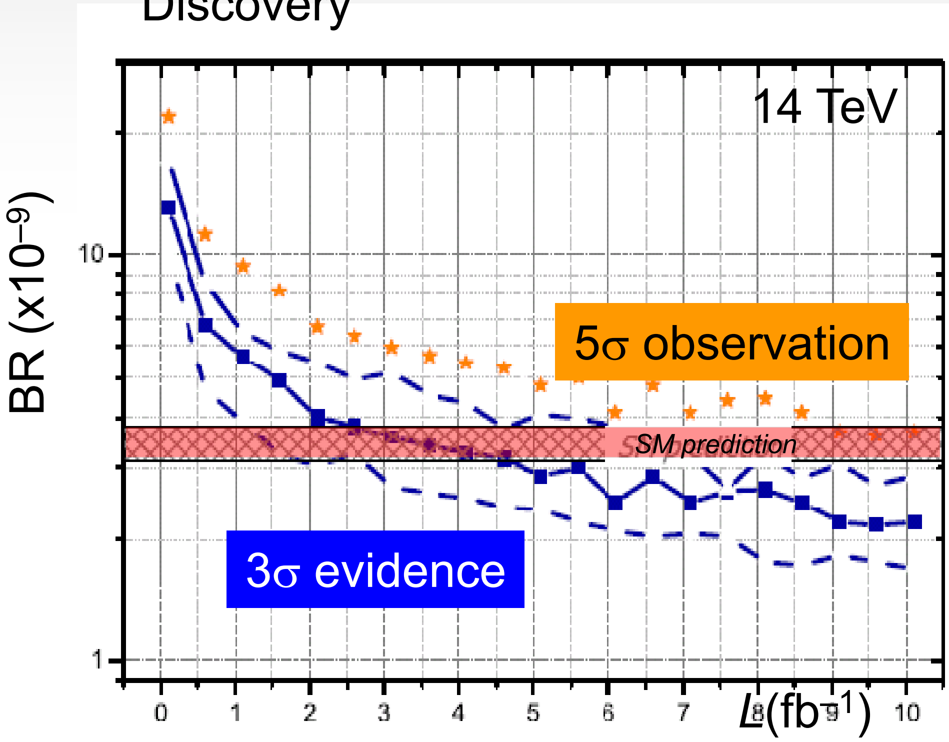
LHCb will study rare decays in depth !!!

$B_s \to \mu\mu$

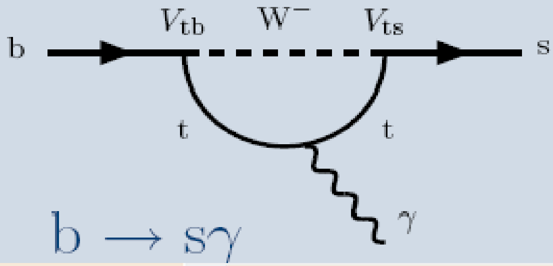


- *Super rare decay in SM with precisely predicted $BR(B_s \to \mu\mu) = (3.55\pm0.33)\times10^{-9}$*
- *Sensitive to NP, in particular new scalars*
  In MSSM: $BR \propto \tan^6\beta / M^4_A$
- *Best present limit is from Tevatron:*
  $BR(B_s \to \mu\mu) < 4.5\times10^{-8}$ @ 95% CL (Punzi, EPS2009)
- *For the SM prediction*
  LHCb expects 21 signal and 180 background events with 2 fb^{-1}.
  Background is dominated by muons from two different semi-leptonic b-decays
- *LHCb sensitivity for the SM BR:*
  3σ evidence with 3 fb^{-1}
  5σ observation with 10 fb^{-1}

Discovery



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



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

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

SM:

- *C = 0 direct CP-violation*
- *S = **sin2**ψ sinϕ*
- *A^{Δ} = **sin2**ψ cosϕ*

For Bd $\Delta\Gamma$ negligible -> only S with $\Phi=\beta$; flavour tagging

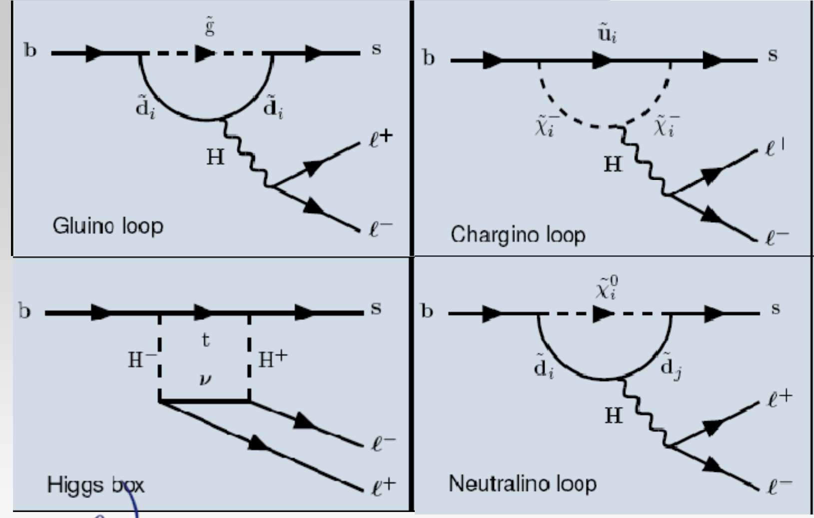
For Bs $\Delta\Gamma$ sizeable -> but S~sin2Φ*(~0)
->sensitivity through A^{Δ} i.e. independent of $\Phi=\beta s$
ALLOWS DISTINCTION BETWEEN NP IN MIXING AND IN RIGHT HANDED CURRENTS
NO FLAVOR TAGGING REQUIRED

- *Expected signal yield at LHCb is 11k for 2 fb^{-1}*

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

cfr. at B factories ~ 0.16

$B \to K^*\mu\mu$



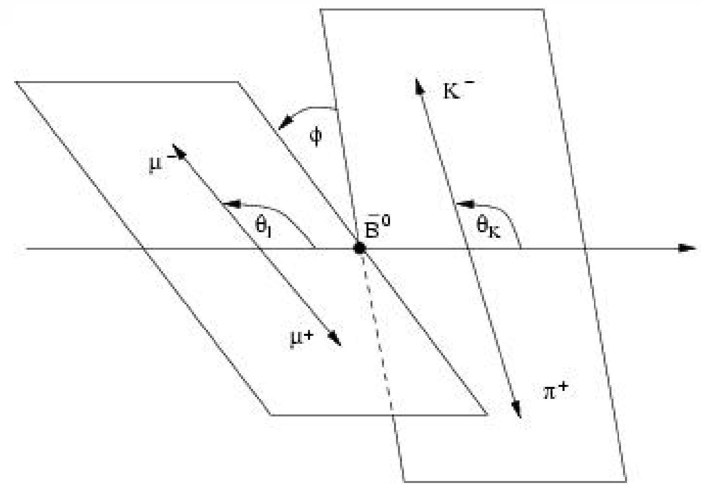
NP: modified angular distributions

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

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

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

- *Described by three angles (θ_l, ϕ, θ_K) and di-μ invariant mass q^2, $\Gamma''=\Gamma''(q^2)$*
- *Forward-backward asymmetry A_{FB} of θ_l distribution of particular interest:*
  - *Varies between different NP models →*
  - *At zero-point, dominant theor. uncert. from hadronic form-factors cancels at LO*



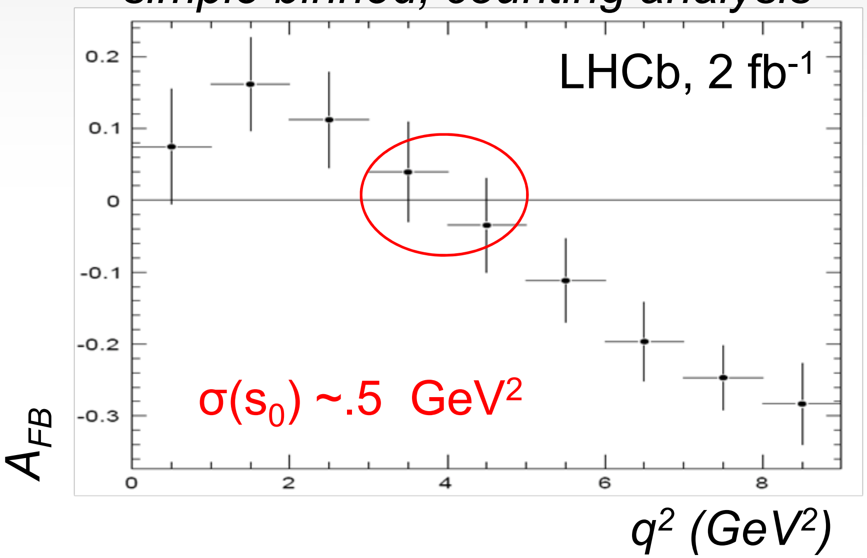
$$A_{FB}\left(s = m^2_{\mu^+\mu^-}\right) = \frac{N_F - N_B}{N_F + N_B}$$

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

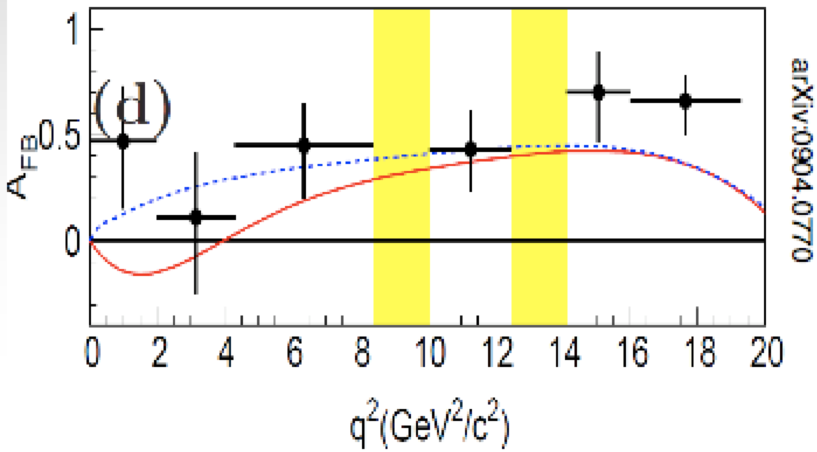
A_{FB} at B-factories defined with opposite sign w.r.t. LHCb

- *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}*

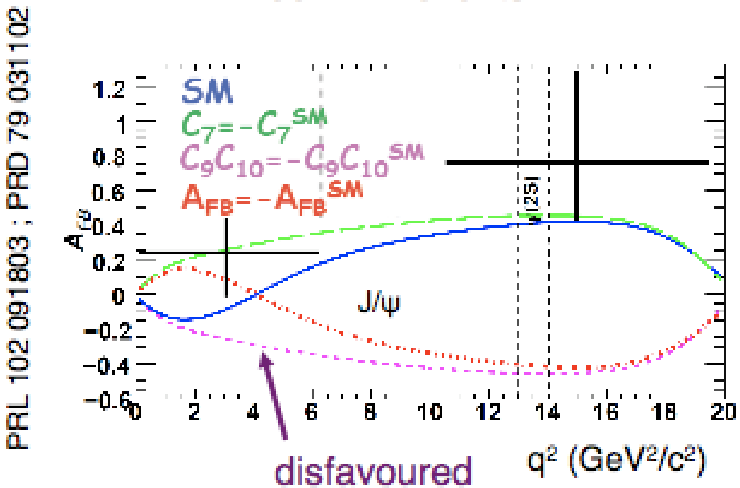
simple binned, counting analysis



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



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



LHCb expects ~7k events / 2fb^{-1} with B/S~0.2

After 2 fb^{-1}zero of A_{FB} located to ±0.5 GeV^2.

Full angular analysis gives better discrimination between models.

Commissioning of LHCb

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

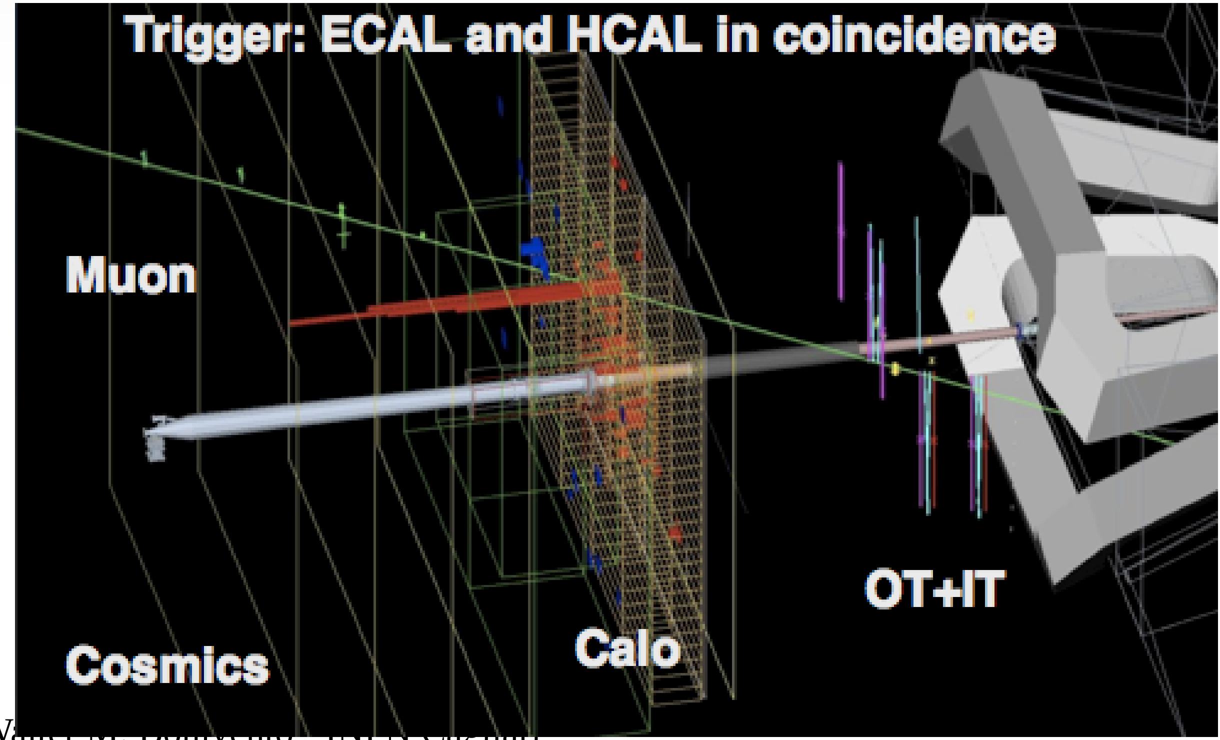
- Use of cosmics non-trivial since LHCb is horizontal and located deep underground → effectively works only for big sub-systems located downward of the magnet: Outer Tracker (OT), Calorimeter and Muon

Few Hz Trigger on "horizontal" cosmic tracks

- Muon & CALO synchronized to a few ns

-OT aligned to ~ 1 mm

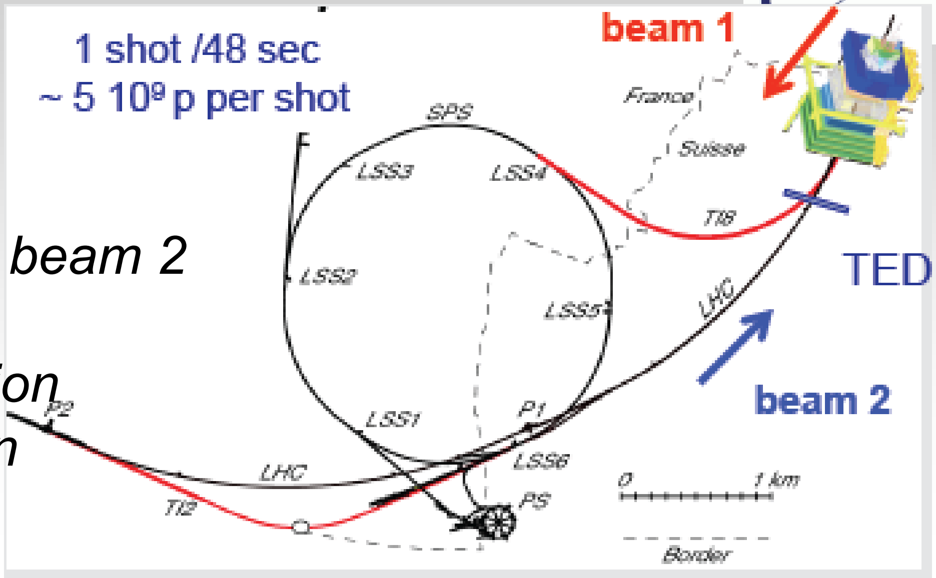
- L0 trigger commissioned

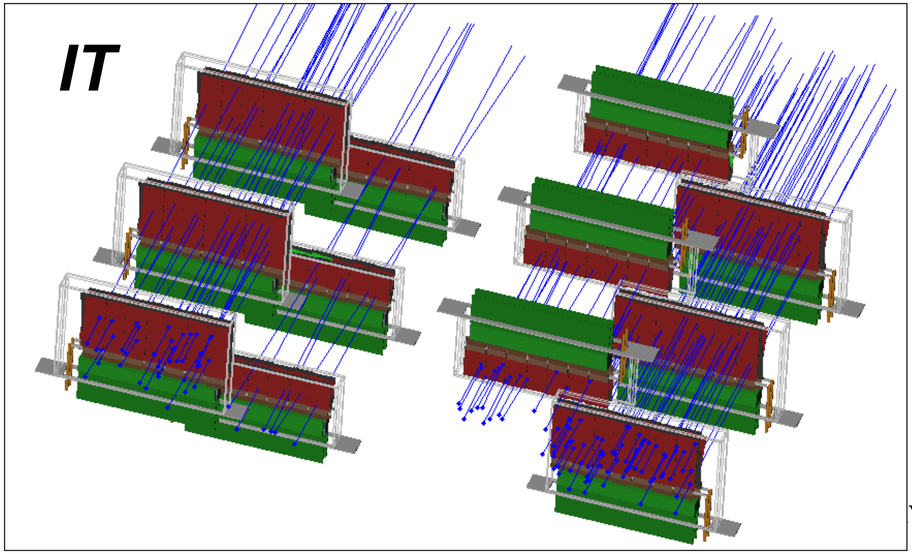


Commissioning of LHCb

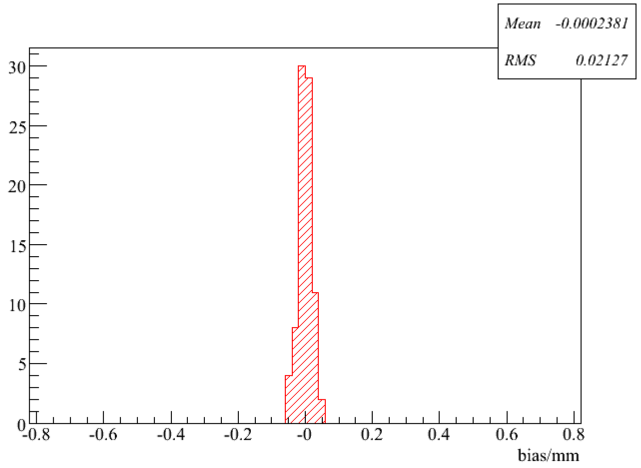
Beam 2 dumped on injection line beam stopper (TED)

- *Located 340 m away from LHCb along beam 2*
- *High flux O(10) particles / cm²*
- *Particles cross LHCb in a wrong direction*
- *~40 k tracks collected and used to align high granular Vertex (VELO) and Inner Tracker (IT) detectors*



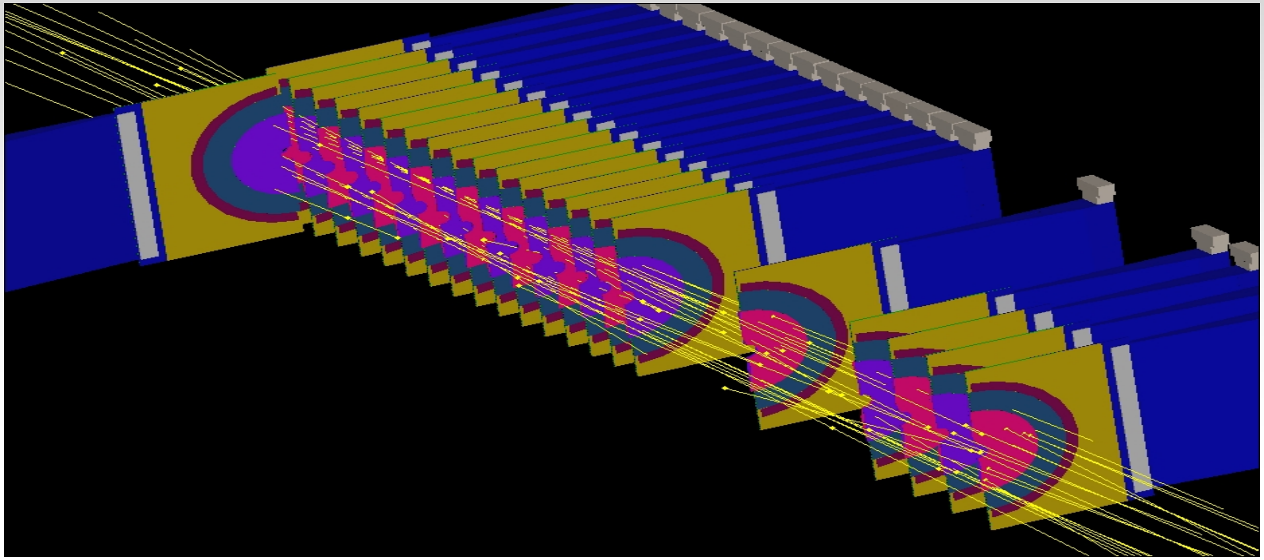


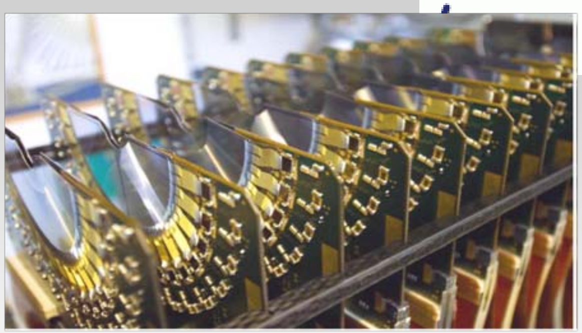
Ladder position in the Inner Tracker is known to 20μ precision



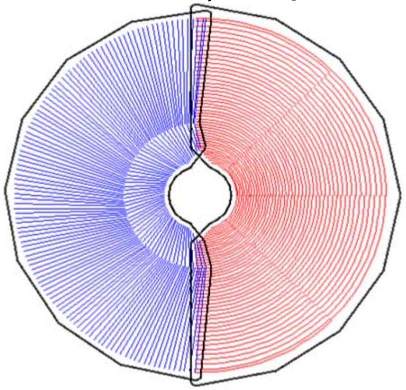
VELO alignment

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

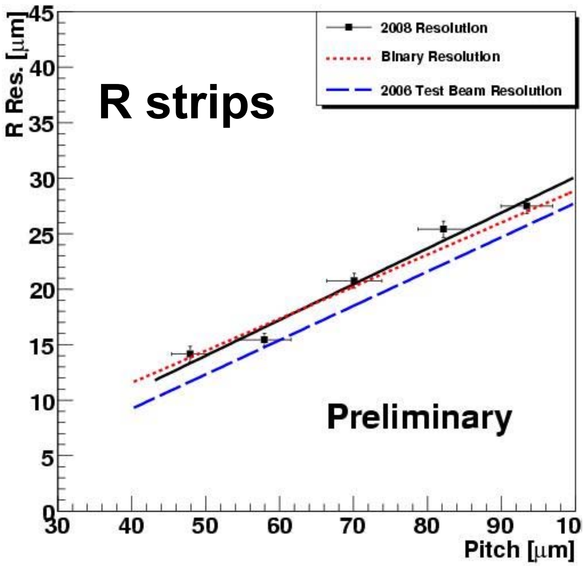


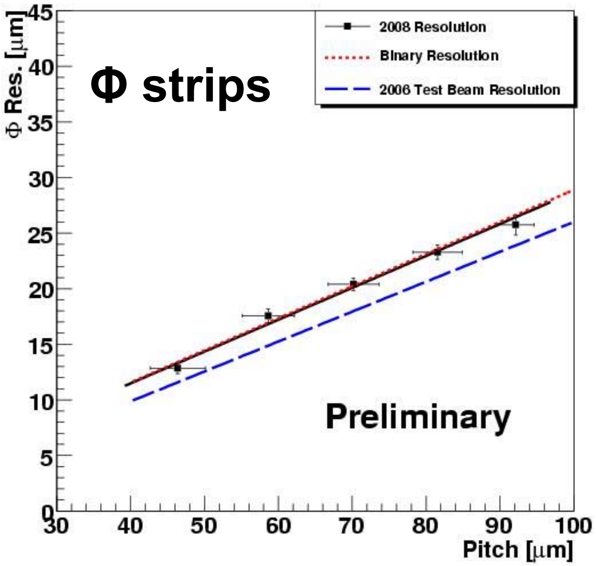


21 stations of Si wafer pairs with r and ϕ strip readout



resolution in μ





Resolution estimated from VELO hit residuals agrees well with expectations

Further improvement possible

Plans with (2009)2010 data

Beam energy expectations:

Recent information from the DG: "The LHC will run at 3.5 TeV per beam until a significant data sample has been collected", then rise at 5TeV.

Some LHCb studies performed at Ebeam=4TeV to assess 2010 physics potential

Early measurements

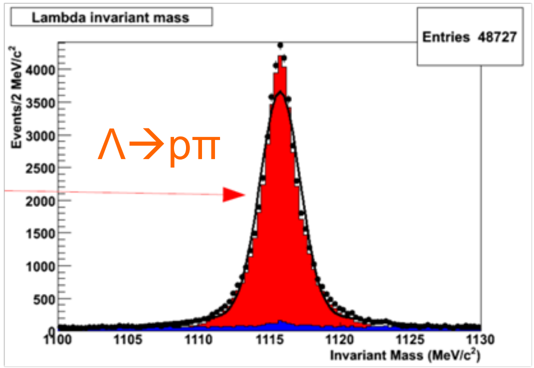
- Calibration signals and minimum bias physics: 10^8 events

Key channels available in min bias data with simple trigger:

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

95% purities achievable using kinematical & vertex cuts alone

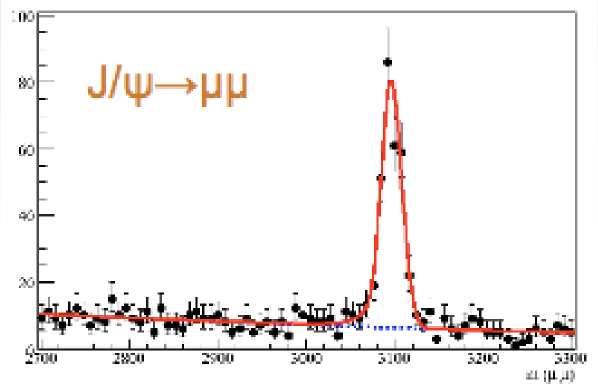
~ 40 mins @ 10^{31}
With 2 kHz random trigger



Plans with (2009)2010 data

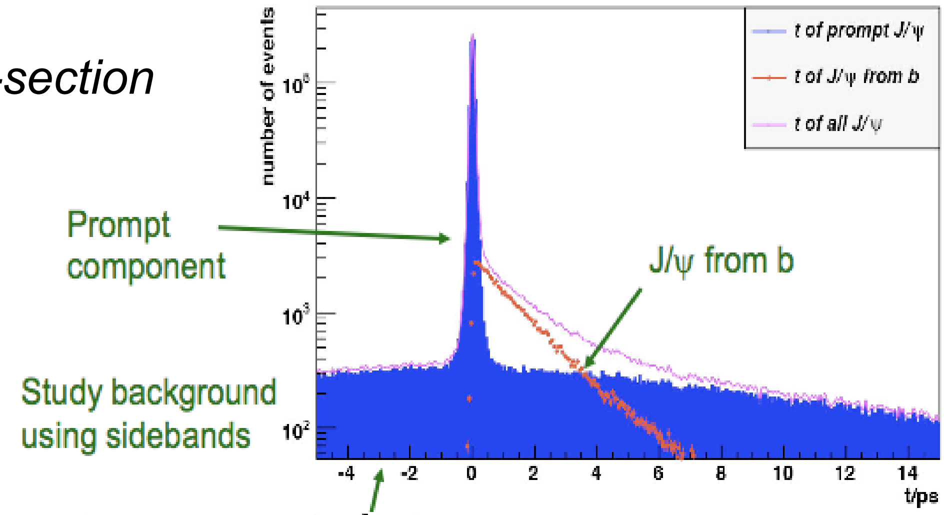
Early measurements(ii)

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

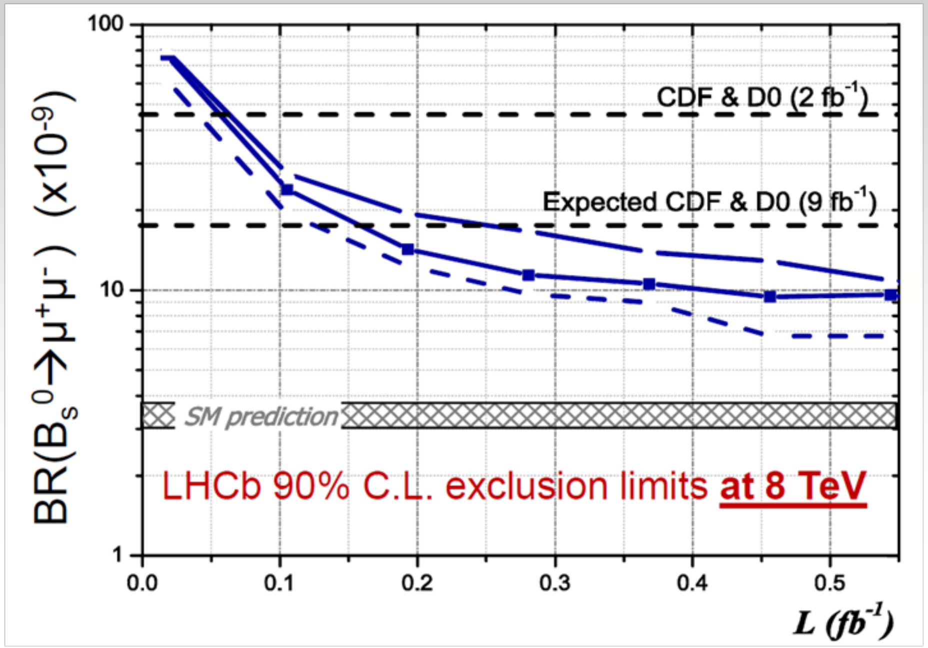


- ***J/ψ physics & production cross-sections: ~ 1-5 pb^{-1}***

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



Prospects for most competitive measurements in 2010

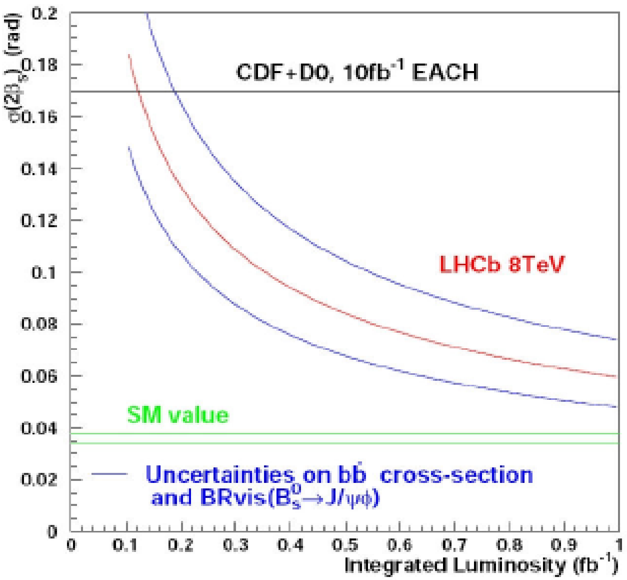


LHCb can exclude ***BR($B_s \to \mu\mu$)*** *at 2×10^{-8} with about 100 – 150 pb^{-1}*

Similar limit is expected from Tevatron on this time scale

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

For β_s from $B_s \to J/\psi\phi$ LHCb assumes data sets of a few 100 pb^{-1}, but the method was shown to extrapolate down to smaller event samples (works at Tevatron as well)



Present 'central value' would be confirmed at 5σ level with ~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 Pt physics at LHC energies. Some high class measurements in the charm sector may be possible*
- *With 150 – 200 pb^{-1} data sample LHCb will reach Tevatron sensitivity in a few golden channels in the beauty sector*
- *LHCb has plenty of room for discoveries of New Physics with a ~ 10 fb^{-1} data sample needed to complete LHCb physics programme*
- *Study of possible LHCb upgrade, in order to collect ~100 fb^{-1} data sample, is under way*