LHCb Physics prospects

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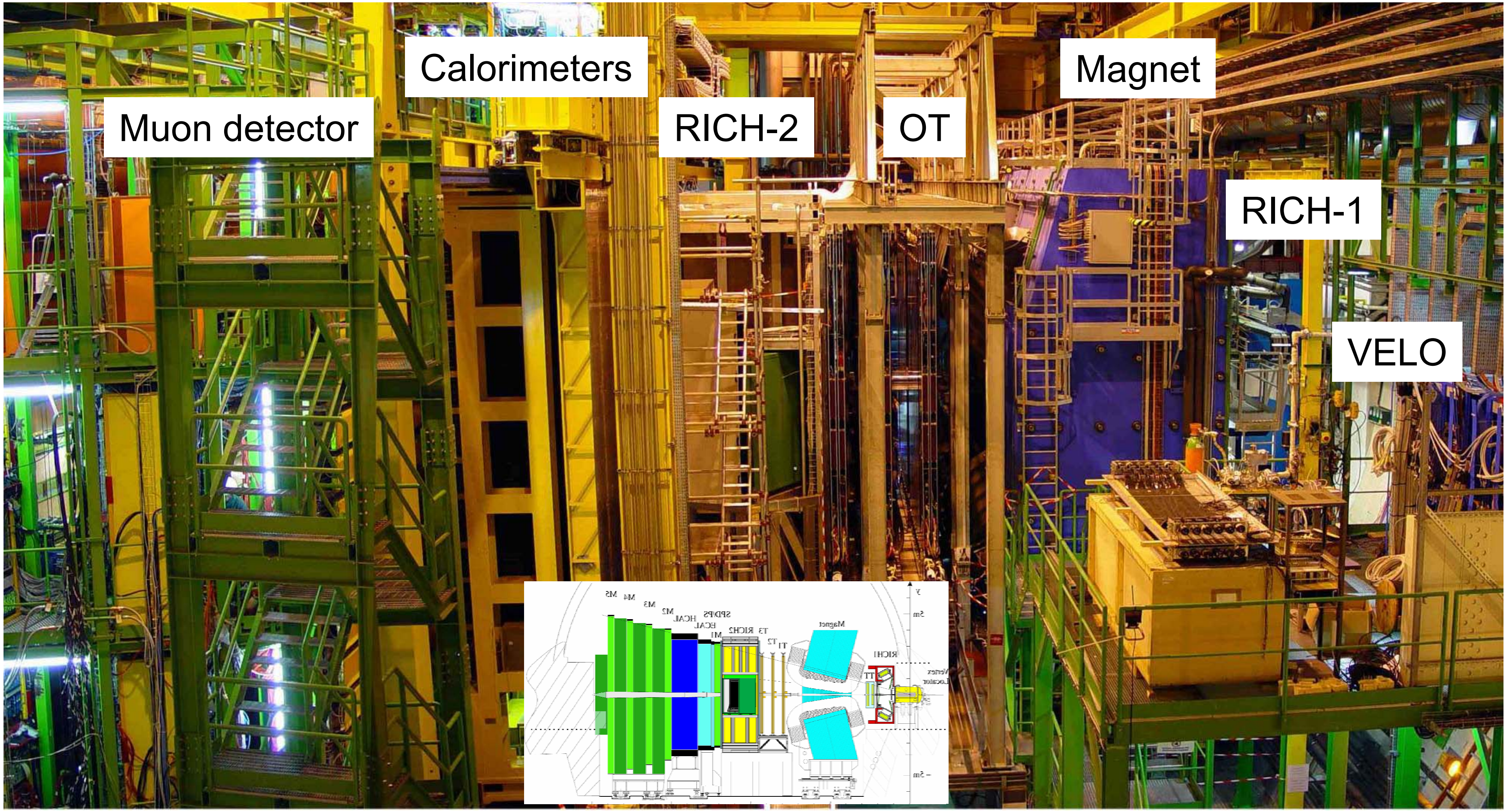
On behalf of the LHCb collaboration

Interplay of Collider and Flavour Physics Workshop
CERN, 3-4 December 2007

LHCb detector in place

The cavern is full: construction on schedule. Commissioning ongoing.
Will be ready for data-taking at 2008 LHC start-up.



A possible running scenario

2008

Calibration and Trigger commissioning

Assume to integrate ~ 0.1 fb^{-1}

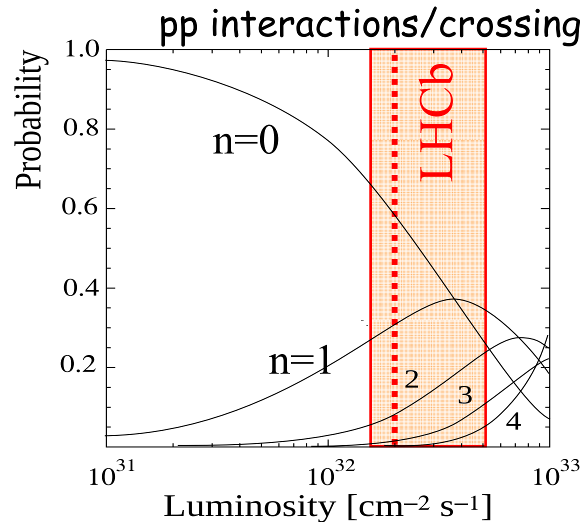
2009

Start first significant physics data taking: >~ 0.5 fb^{-1}

2010–

Stable running. Expect ~ 2 fb^{-1}/ year

If found to be advantageous for physics, push average luminosity from 2×10^{32} to 5×10^{32} $cm^{-2}s^{-1}$



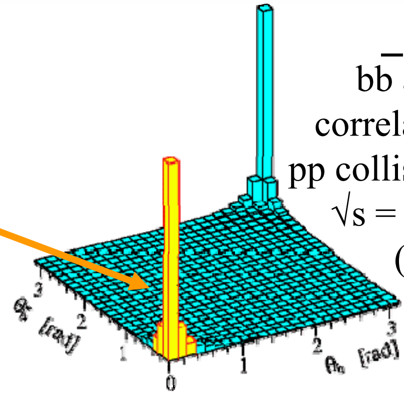
LHCb should collect an integrated luminosity 10 fb^{-1} for year 2014±1

Physics with "first year" data (~0.5 fb^{-1})

Huge $b\bar{b}$ production at $\sqrt{s}$=14TeV, in the forward region

~230 μb in ~300 mrad

→ Corresponding to ~10^{11} $b\bar{b}$ events in L=0.5 fb^{-1}



$b\bar{b}$ angular correlation in pp collisions at $\sqrt{s}$ = 14 TeV (Pythia)

Very interesting B_s results already with first 0.5 fb^{-1}

Examples are:

- CP violation in $B_s \to J/\psi\,\phi$ (ϕ_s measurement)
- Search for $B_s \to \mu\mu$ decays, extending CDF+D0 limit
- $s_0(A_{FB}=0)$ in $B_d \to K^{0*}\mu\mu$ overtaking B-Factories

Before, high statistics channels will be used to calibrate the detector performance and to demonstrate LHCb physics capabilities

LHCb expected performance

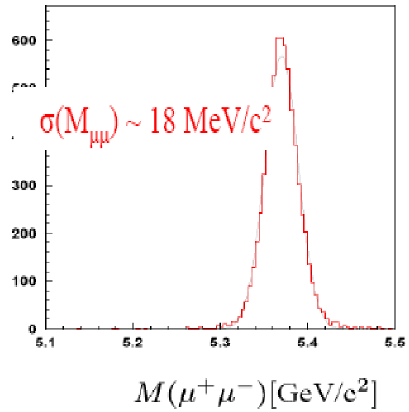
Results obtained from MC simulation (full Detector simulation):

b-decay track resolutions:

impact parameter ~ 30 μm
momentum resolution ~ 0.36%

Reconstructed B resolutions:

mass res. ~14-18 MeV/c²
proper time res. ~ 40 fs



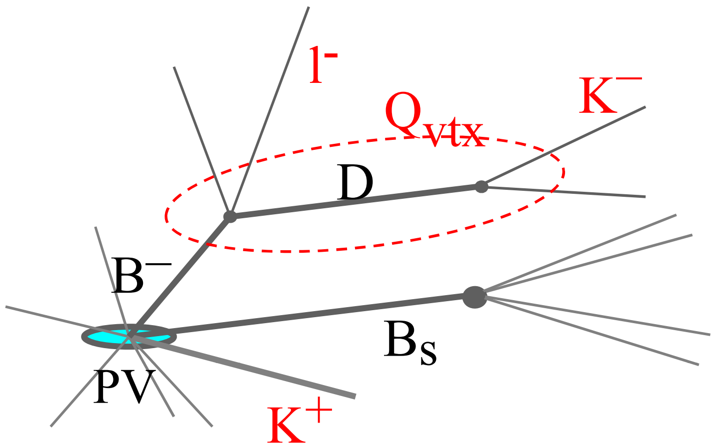
Particle ID performance with RICH

kaon ID eff. ~ 88%, pion mis-ID ~3%
→ Good K/π separation in 2-100 GeV/c range

Flavour Tagging performance

from combination of several methods:

εD^2 =4–5% for B_d
εD^2 =7– 9 % for B_s depending on channel



The search strategy for New Physics

- **Measurements with New Physics discovery potential**

FCNC transitions and rare decays, where standard model contributions are suppressed enough to allow potential small NP effects to emerge:

- B_s mixing phase (ϕ_s)
- Very rare leptonic decays: eg. $B_s \to \mu\mu$
- Rare semi-leptonic decays: $b \to s\ell\ell$ (eg. $B_d \to K^{0*}\mu\mu$, $B_u \to Kee/B_u \to K\mu\mu$)
- Radiative decays: $b \to s\gamma$ (eg. $B_d \to K^*\gamma$, $B_s \to \phi\gamma$, $\Lambda_B \to \Lambda\gamma$, …)
- LFV decays (eg. $B_{s,d} \to e\mu$)
- CPV in D^0 decays and rare D decays….

- **Precision measurements of CKM parameters, including γ angle determination from tree level decays.**

- Compare gamma from $B_{(s)} \to D_{(s)}K$ decays and gamma from $B_d \to \pi\pi$ and $B_s \to KK$
- Compare $\sin(2\beta)$ from $B_d \to J/\psi K_S$ and $\sin(2\beta)$ from $B_d \to \phi K_S$
- Hadronic penguin $b \to s\bar{s}s$ decays (eg. $B_s \to \phi\phi$)

B Mixing phase ϕ_s with $b \to c\bar{c}s$

- Very small in SM: $\phi_s = -2\lambda^2\eta = -0.037 \pm 0.002$ rad
- Could be much larger if New Physics contributes to B_s^0-$\bar{B}_s^0$ transitions
- No CP violation observed yet: $\phi_s = -0.79 \pm 0.56_{stat}{}^{+0.01}_{-0.14\,syst}$ D0 with 1.1 fb^{-1}

Measure time-dep. asymmetry in decay rates: $$A_{CP}(t) = -\frac{\eta_f \sin\phi_S \sin(\Delta m_S t)}{\cosh\left(\frac{\Delta\Gamma_S t}{2}\right) - \eta_f \cos\phi_S \sinh\left(\frac{\Delta\Gamma_S t}{2}\right)}$$

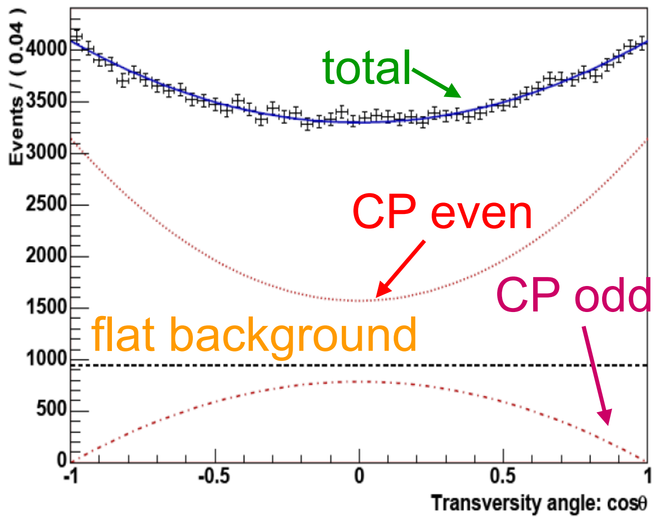
Use flavour tagged and untagged events.

Need very good proper time resolution to resolve B_s^0 oscillations.

Non pure CP modes (as $B_s \to J/\Psi\phi$) need angular analysis to disentangle the mixture of CP-even (η_f=-1, A_0, $A_{||}$) and CP odd (η_f=+1, $A_\perp$)

1-angle analysis: θ_{tr}

Increased precision from full 3-angles analysis under study.



$B_s \to J/\Psi\phi$ and CP eigenstates

$B_s \to J/\psi(\mu^+\mu^-)\phi(K^+K^-)$ is the golden channel. Can add pure CP modes, but much lower statistics.

Decay Channel	*Yield 2fb^{-1}*	*B/S*	*Sensitivity $\sigma(\phi_s)$*
$J/\psi(\mu^-\mu^+)\ \eta(\gamma\gamma)$	8.5k	2.0	0.109
$J/\psi(\mu^-\mu^+)\ \eta(\pi^+\pi^-\pi^0)$	3.0k	3.0	0.142
$J/\psi(\mu^-\mu^+)\ \eta'(\rho^0\gamma)$	4.2k	<0.42	0.080
$\eta_c(h^-h^+h^-h^+)\phi(K^+K^-)$	3.0k	0.6	0.108
$D_s(K^+K^-\pi^-)\,D_s(K^+K^-\pi^+)$	4.0k	0.3	0.133
Pure CP modes			0.048
$J/\psi(\mu\mu)\ \phi$	131k	0.12	0.023
All modes			0.021

Sensitivity to other fit parameters (from $J/\psi\phi$)

Parameter	***Sensitivity with 2 fb^{-1}***
$\Delta\Gamma_s/\Gamma_s$	0.0092
R_T	0.00040

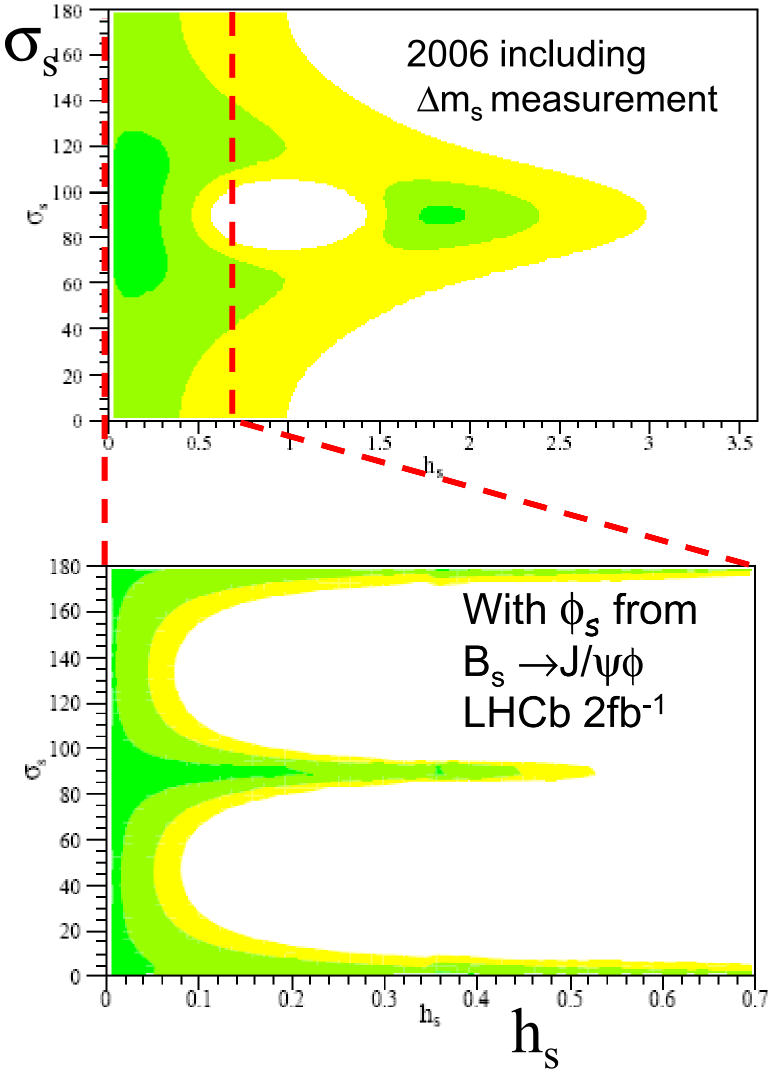
In 0.5 fb^{-1}: $\sigma(\phi_s)$~0.046 from $B_s \to J/\psi(\mu\mu)\phi$

After 10 fb^{-1} $\sigma_{stat}(\phi_s)$ = 0.009

> 3σ evidence of non-zero ϕ_s, even if only SM

New Physics in B_s mixing

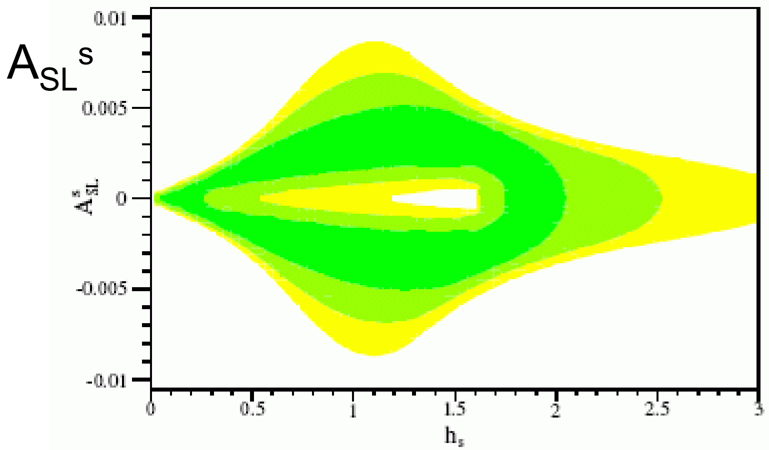
Ligeti, Paucci,Perez, hep-ph/0604112



New Physics in B_s mixing amplitude M_{12} parameterized with h_s and σ_s:

$$M_{12} = (1 + h_s \exp(2i\sigma_s))\, M_{12}^{SM}$$

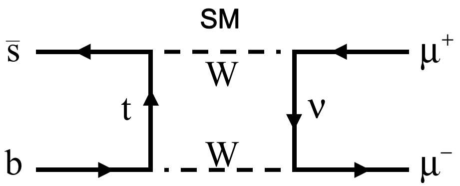
Additional constraints can come from semileptonic Asymmetry. In SM: $A_{SL}^s \sim 10^{-5}$.

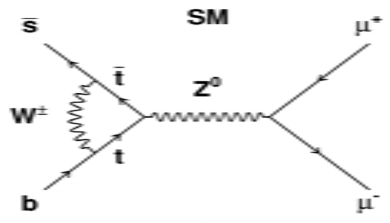


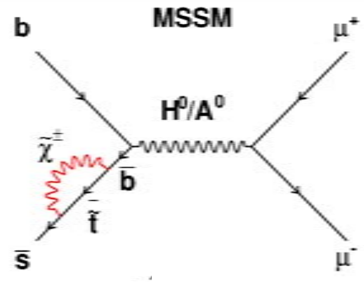
Preliminary results on the LHCb measurement of time dependent charge asymmetry in $B_s \rightarrow D_s \mu\nu$

Expect 10^9 events/ 2fb^{-1} → $\delta(A_{SL}^s) \sim 2\times10^{-3}$ in 2fb^{-1}

$B_s \rightarrow \mu\mu$



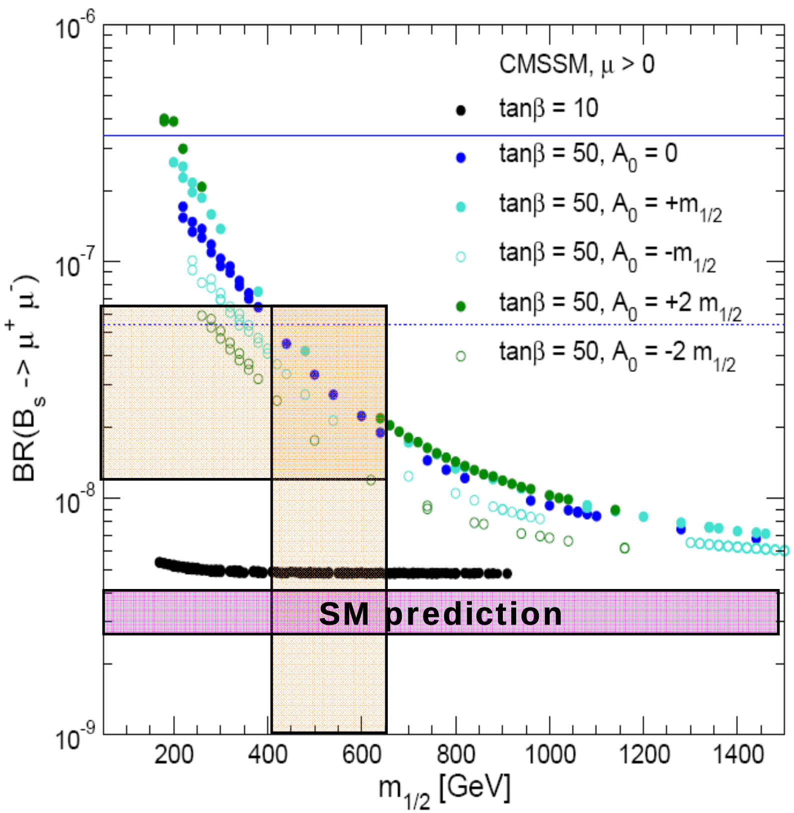




- Highly suppressed in SM: $BR(B_s \rightarrow \mu\mu) = (3.55 \pm 0.33) \times 10^{-9}$
- Could be strongly enhanced by SUSY:

  $BR(B_s \rightarrow \mu\mu) \propto \tan^6\beta / M_H^2$

  - Within Constrained MSSM: current g-2 measurement (which deviates by 3.4 σ from SM) suggest gaugino mass in the range 450-650GeV → at $\tan\beta \sim 50$ $BR(B_s \rightarrow \mu\mu)$ in the range $\sim 10^{-8}$ to10^{-7}



- Current Limit Tevatron ~2 fb^{-1}:

  CDF BR < 4.7×10^{-8} 90% CL

  D0 BR < 7.5×10^{-8} 90% CL

$B_s \to \mu\mu$

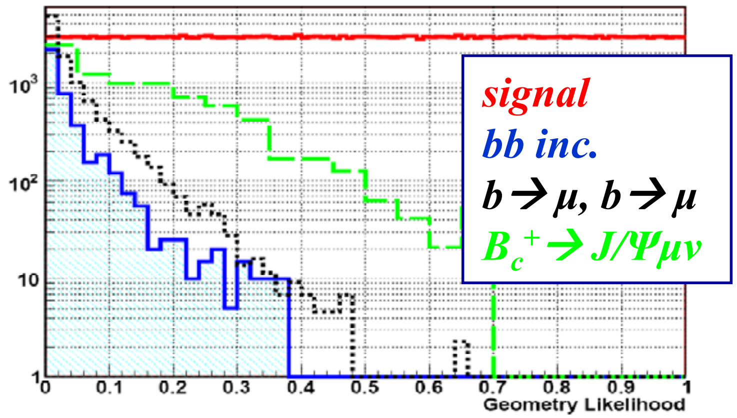
LHCb: high efficiency trigger for the signal, but main issue is background rejection.
Exploit good mass resolution and vertexing, and good particle ID.

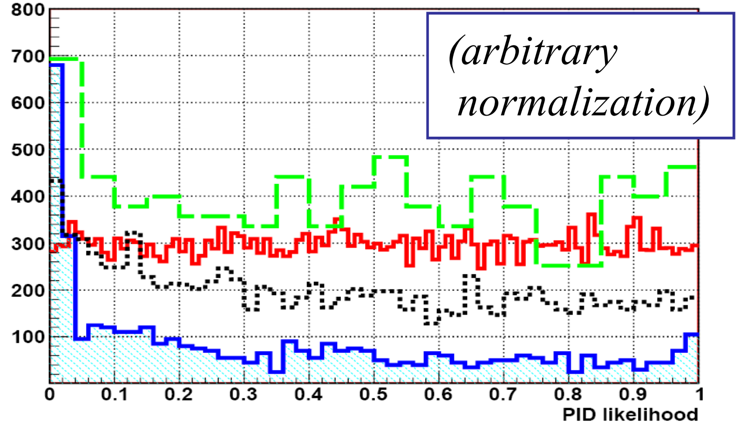
Largest background is $b \to \mu$, $b \to \mu$.
Specific background dominated by $B_c^{\pm} \to J/\psi(\mu\mu)\, \mu^{\pm}\nu$

Analysis in a Phase Space with 3 axis:

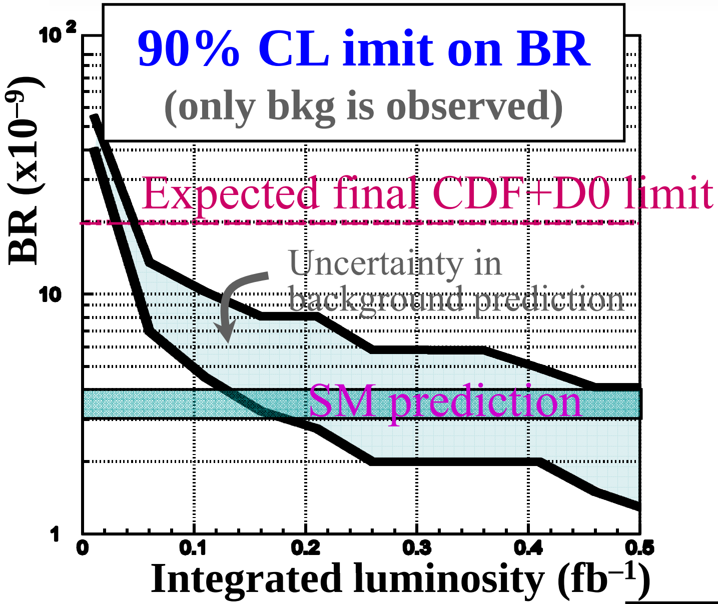
- Geometrical Likelihood (GL) (impact parameters, distance of closest approach between $\mu\mu$, lifetime, vertex isolation)
- Particle-ID Likelihood
- Invariant Mass Window around B_s peak

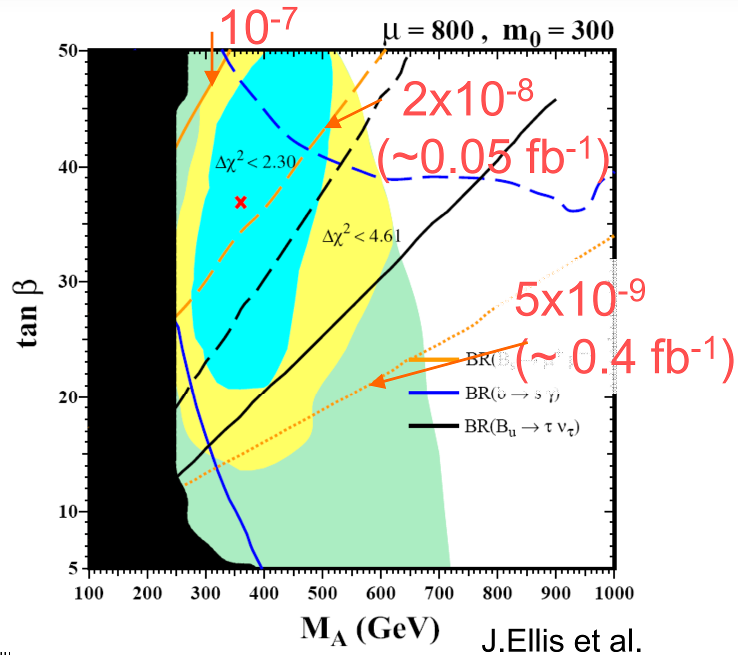
- Sensitive Region: GL > 0.5
- Divide in N bins
- Evaluate expected number of events for signal/background in each bin.





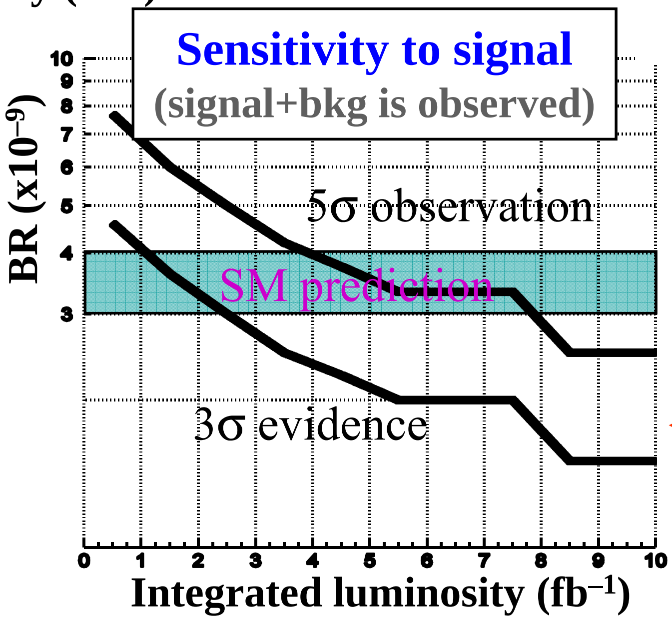
$B_s \to \mu\mu$





J.Ellis et al.
arXiv:0709.0098v1
[hep-ph] (2007)

0.5 fb^{-1}
⇒ exclude BR values down to SM



2 fb^{-1} ⇒ 3σ evidence of SM signal
6 fb^{-1} ⇒ 5σ observation of SM signal

$b \to s\ell\ell$

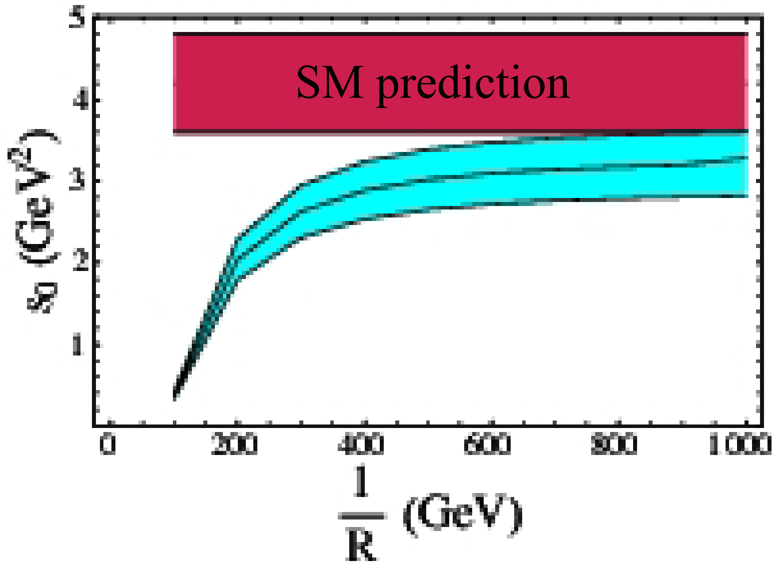
Suppressed loop decay in SM.
NP could contribute at the same levels, could modify BR and angular distributions.
Sensitive to SUSY, gravitation exchange, extra-dimensions.

Inclusive decay difficult to access at hadron collider.
Good prospects for exclusive decays ($B \to K\ell\ell$, $K^*\ell\ell$).
Hadronic uncertainty reduced in:

- Forward-backward asymmetry A_{FB}
- Position of zero crossing of A_{FB} (s_0)
- Transversal asymmetries
- Ratio of $\mu\mu$ and ee modes

Predicted shift in the zero of the A_{FB} in $B_d \to K^*\mu^+\mu$, in ACD model with a single universal **extra dimension**, a MFV model.
(Colangelo et al PhysRevD73,115006(2006))

$s_0 = m^2_{\mu\mu}$ for which $A_{FB}=0$

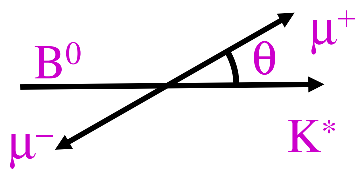


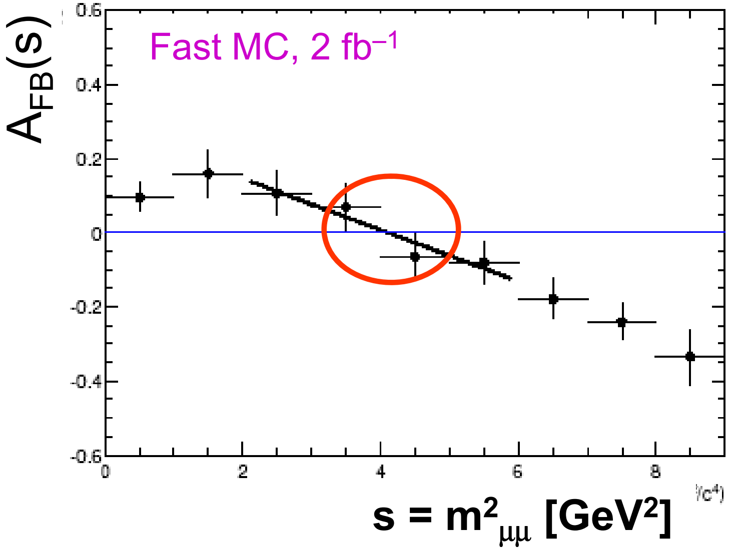
$B_d \rightarrow K^*\mu\mu$

In SM: BR(Bd→K*μμ)=$(1.22\ ^{+0.38}_{-0.32})\times10^{-6}$ $s_0 = s_0(C_7,C_9) = 4.39\ ^{+0.38}_{-0.35}$ GeV^2

Beneke et al hep-ph/0412400

Measure forward-backward Asimmetry as a function of the μμ invariant mass. Determine s_0, the $m^2_{\mu\mu}$ for which A_{FB}=0





LHCb: 7200 signal events/2fb^{-1}

$B_{bb}/S = 0.2 \pm 0.1$ (ignoring non-resonant Kπμμ events for the time being).

With L= 0.5 fb^{-1} 1800 events (B-Factories projected 2ab^{-1} yield ~450 events.)

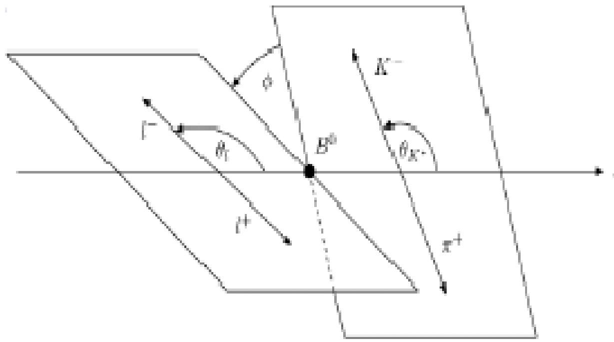
L= 2fb^{-1} $\sigma(s_0) = \pm0.46$ GeV^2

L=10 fb^{-1} $\sigma(s_0) = \pm0.27$ GeV^2 → at the level of present theoretical precision

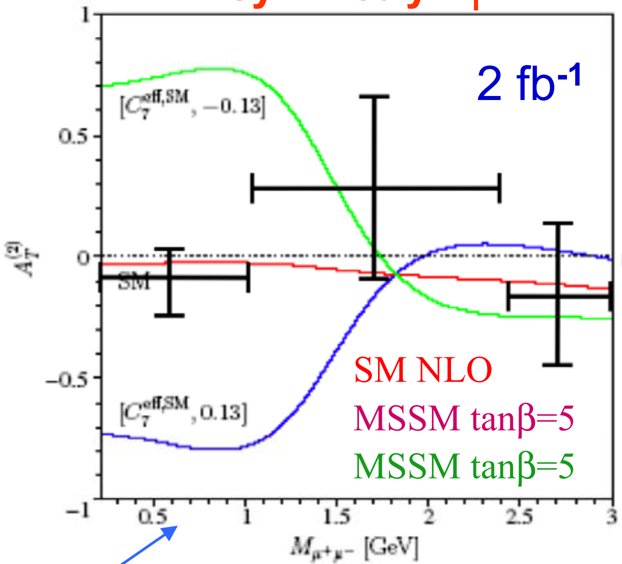
$B_d \to K^* \mu\mu$ transverse asymmetries

Fit to full angular distributions (Θ_{K-}, $\Theta_{\mu-}$, ϕ) expressed in terms of transversity amplitudes ($A_\perp$, $A_{//}$, A_0).
Can measure:

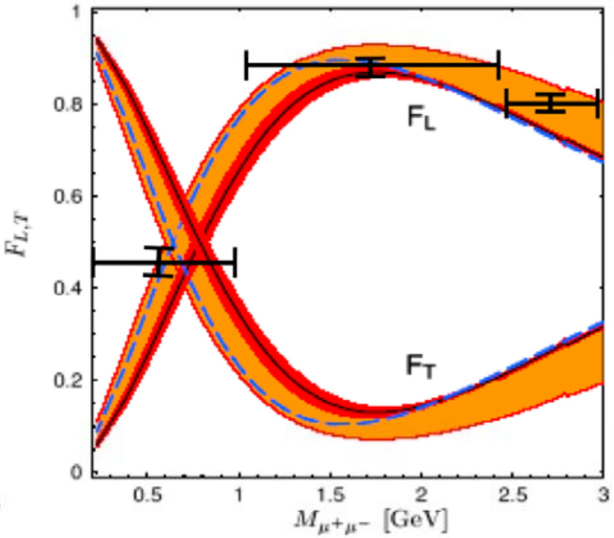
$$A_T^{(2)}(q^2) = \frac{|A_\perp|^2 - |A_\parallel|^2}{|A_\perp|^2 + |A_\parallel|^2} \qquad F_L(q^2) = \frac{|A_0|^2}{|A_\perp|^2 + |A_\parallel|^2 + |A_0|^2}$$



Asymmetry $A_T^{(2)}$



Longitudinal polarization F_L



Stat. precisions in the region $s = m^2_{\mu\mu} \in [1, 6]$ $(GeV/c^2)^2$ where theory calculations are most reliable

	Sensitivity with	
	$2\ fb^{-1}$	$10\ fb^{-1}$
$A_T^{(2)}$	±0.42	±0.16
F_L	±0.016	±0.007
A_{FB}	±0.020	±0.008

Curves from Lunghi & Matias JHEP 0704(2007)058.
Points LHCb 2 fb^{-1}

R_K in $B^+ \to K^+\ell\ell$

$$R_K = \frac{\int_{4m_\mu^2}^{q_{max}^2} \frac{d\Gamma(B \to K\mu^+\mu^-)}{ds} ds}{\int_{4m_\mu^2}^{q_{max}^2} \frac{d\Gamma(B \to Ke^+e^-)}{ds} ds} = 1 \pm 0.001 \text{ in SM}$$ (Hiller,Krüger PRD69 (2004) 074020)

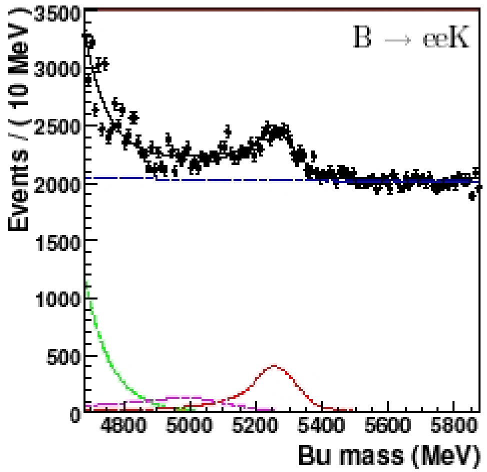
- Large corrections O(10%) possible in models that distinguish between lepton flavours (eg.MSSM at large tanβ). Constraints to NP also from R_K and BR($B_s \to \mu\mu$) combined.

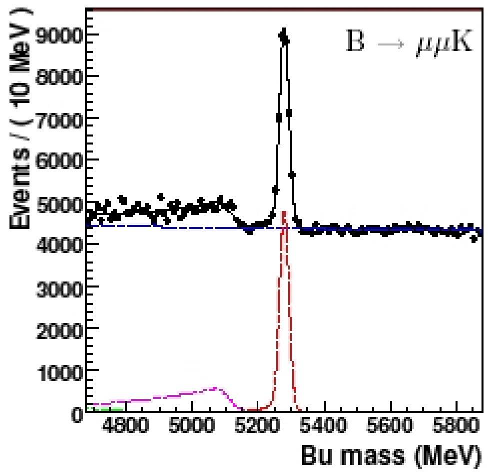
LHCb 10 fb^{-1}

$B_u \to eeK$ 9.2 k events

$B_u \to \mu\mu K$ 19 k events

$\sigma_{stat}(R_K) = 0.043$





$4m_{\mu\mu}^2 < m_{ll}^2 < 6$ $(GeV/c^2)^2$

- Trigger eff ~70% on ee channel under study - not included.
- Similar sensitivity expected for $R_{K^*} = B_d \to \mu\mu K^* / B_d \to eeK^*$.
- To be compared with ~15% error on R_K&R_{K^*} combined, expected from B-Factories with $2ab^{-1}$.

Radiative decays

- $B_d \to K^*\gamma$ $A_{CP} < 1\%$ in SM, up to 40% in SUSY
  Can measure at <% level.
  Reference channel for all radiative decays.

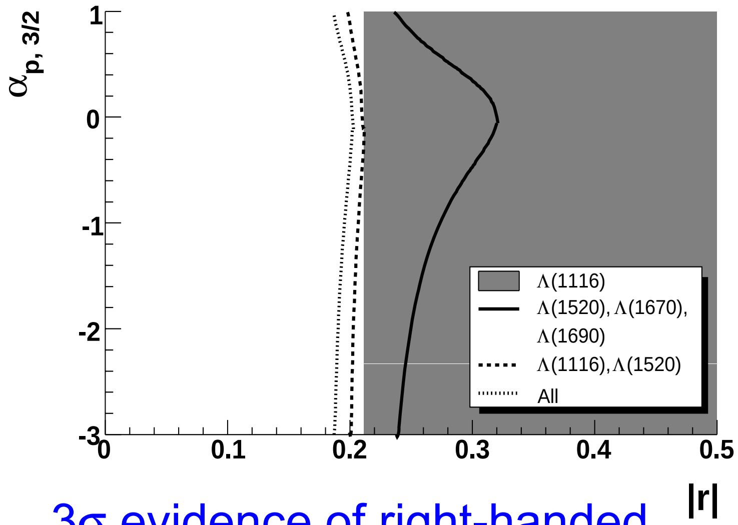
- $B_s \to \phi\gamma$ No mixing-induced CP asymmetry in SM, up to 50% in SUSY.
  Sensitivity for $A_{CP}(t)$ measurement under study.

- $\Lambda_b \to \Lambda\gamma$ Right-handed component of photon polarization O(10%) in SM. Can be higher BSM.

$$\alpha_\gamma = \frac{P(\gamma_L) - P(\gamma_R)}{P(\gamma_L) + P(\gamma_R)} \qquad \alpha_\gamma^{\rm LO} = \frac{1-|r|^2}{1+|r|^2}$$

Measure photon asymmetry α_γ from angular distributions of γ and hadron in $\Lambda_b \to \Lambda(p\pi,pK)\gamma$ decays.

Decay	Yield 2 fb^{-1}	B_{bb}/S
$B_d \to K^*\gamma$	68k	0.60
$B_s \to \phi\gamma$	11.5k	< 0.55
$\Lambda_b \to \Lambda(1116)\gamma$	0.75k	< 42
$\Lambda_b \to \Lambda(1670)\gamma$	2.5k	< 18



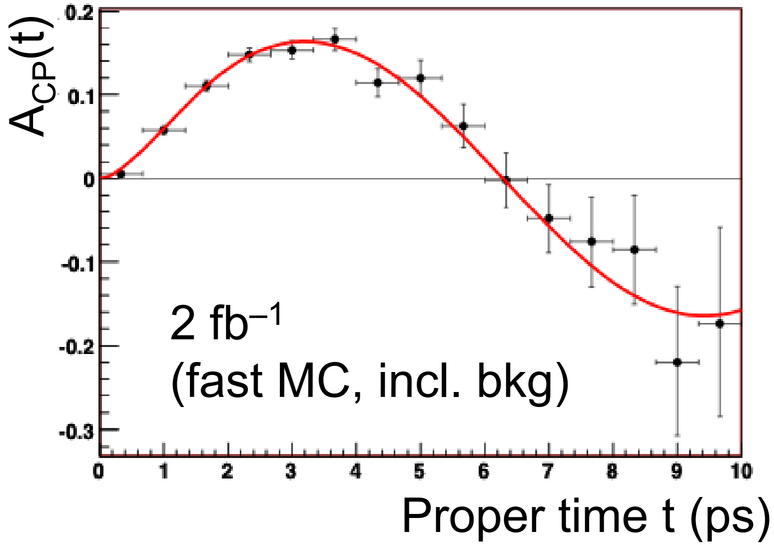
3σ evidence of right-handed component to 21% with 10 fb^{-1}

sin(2β) from Tree and Penguing

$B^0 \to J/\psi K_S$

Time dependent CP asymmetry in $B^0 \to J/\psi K_S$ is expected to be one of the first CP measurements at LHCb.

$$A_{CP}(t) = \frac{N(\overline{B}^0 \to J/\psi K_S) - N(B^0 \to J/\psi K_S)}{N(\overline{B}^0 \to J/\psi K_S) + N(B^0 \to J/\psi K_S)}$$



236k signal events / 2 fb^{-1}
B/S=0.6(bb)+7.7(J/ψ)

→ $\sigma_{stat}(\sin(2\beta)) = 0.020$ in 2 fb^{-1}

Compare to ~0.019 expected from B-Factories with 2ab^{-1}

After 10 fb^{-1}: **σ(sin(2β)) ~ 0.010**

Can also push further the search for direct CP violating term ∝ $\cos(\Delta m_d t)$

$B^0 \to \phi K_S$:

- 920 signal events per 2 fb^{-1}, B/S < 1.1 at 90% CL
- After 10 fb^{-1}: **$\sigma_{stat}(\sin(2\beta_{eff})) = 0.10$**

  to be compared with ~0.12 expected from B-Factories with 2ab^{-1}

$b \to s\bar{s}s$ hadronic penguin decays

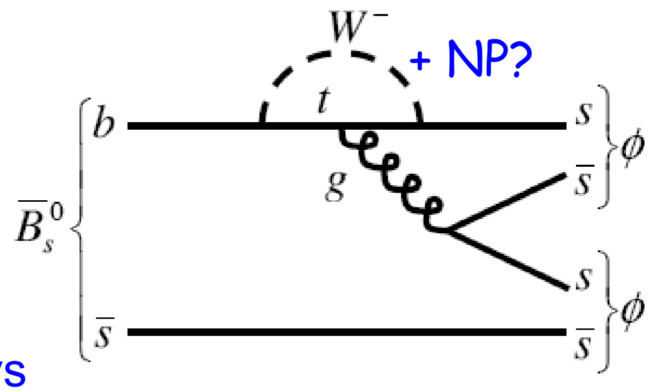
$B_s \to \phi\phi$

CP violation < 1% in SM due to cancellation of the mixing and penguin phase

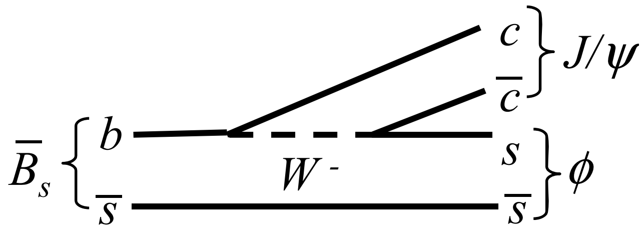
In SM: $\phi_{Bs \to \phi\phi}^{SM} \approx 2\arg(V_{ts}^* V_{tb}) - \arg(V_{tb} V_{ts}^* / V_{tb}^* V_{ts}) \approx 0$

NP in general affect differently B_s mixing and $b \to s$ decays

→ $\Delta\phi^{NP} \neq 0$



Combining $B_s \to \phi\phi$ with $B_s \to J/\psi\phi$ measurements can disentangle NP contributions in mixing & decays.



LHCb expects 3.1k signal events / 2 fb^{-1} ($BR=1.4\times10^{-5}$), B/S<0.8 at 90%CL

From time dependent angular distribution of flavour tagged events:

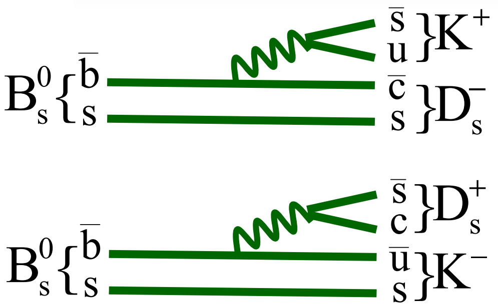
$\sigma_{stat}(\Delta\phi^{NP}) = 0.05$ in 10 fb^{-1}

Different ways to γ at LHCb

tree decays only (brace spanning rows 1–7)

B mode	D mode	Method
$B_s \rightarrow D_s K$	$K K \pi$	tagged, A(t)
$B^+ \rightarrow D K^+$	$K\pi$+ $K3\pi$+ $KK/\pi\pi$	counting, ADS+GLW
$B^+ \rightarrow D^* K^+$	$K\pi$	counting, ADS+GLW
$B^+ \rightarrow D K^+$	$K_s \pi\pi$	Dalitz, GGSZ
$B^+ \rightarrow D K^+$	$KK\pi\pi$	4 body Dalitz
$B^+ \rightarrow D K^+$	$K\pi\pi\pi$	4 body Dalitz
$B^0 \rightarrow D K^{*0}$	$K\pi$ + KK + $\pi\pi$	counting, ADS+GLW
$B \rightarrow \pi\pi, KK$	–	Tagged, A(t)

γ from $B_s \to D_s K$



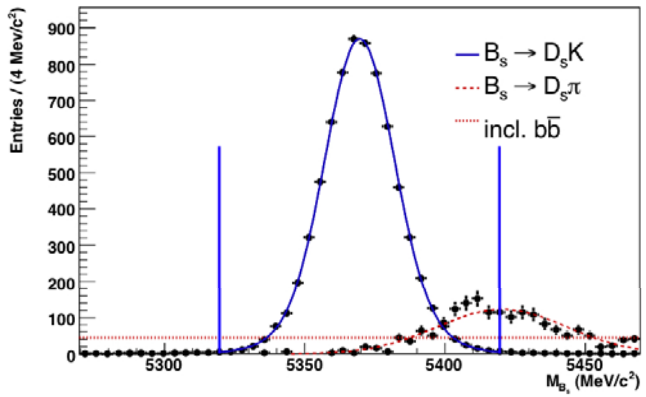
Two tree decays which interfere via B_s mixing

Can determine $\gamma+\phi_s$, hence γ in a very clean way

LHCb expects 6.2k signal events in 2 fb^{-1}

$B_{bb}/S < 0.18$ at 90% CL

$B_s \to D_s^- \pi^+$ background 15±5 % after PID cuts

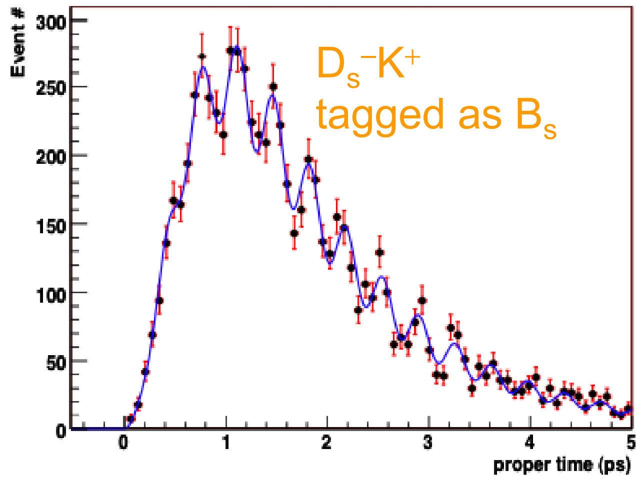


Fit 4 tagged and 2 untagged time-dependent rates.

With 10 fb^{-1}:

	Tagged & untagged	Tagged only
$\phi_s + \gamma$	**± 4.6°**	± 5.7°
Δ	± 4.6°	± 5.4°
$\lvert\lambda\rvert$	± 0.027	± 0.029

(Inputs: γ=60°, strong phase difference Δ=0, amplitude ratio $|\lambda|$=0.37)



Different ways to γ at LHCb

B mode	D mode	Method	$\sigma(\gamma)$ 2fb^{-1}
$B_s \to D_s K$	$KK\pi$	tagged, A(t)	10º
$B^+ \to D K^+$	$K\pi$+ $K3\pi$ +$KK/\pi\pi$	counting, ADS+GLW	5º - 13º
$B^+ \to D^* K^+$	$K\pi$	counting, ADS+GLW	Under study
$B^+ \to D K^+$	$K_s\pi\pi$	Dalitz, GGSZ	7-12º
$B^+ \to D K^+$	$KK\pi\pi$	4 body Dalitz	18º
$B^+ \to D K^+$	$K\pi\pi\pi$	4 body Dalitz	Under study
$B^0 \to D K^{*0}$	$K\pi$ + KK + $\pi\pi$	counting, ADS+GLW	9º
$B \to \pi\pi, KK$	–	Tagged, A(t)	10º

tree decays only (rows $B_s \to D_s K$ through $B^0 \to D K^{*0}$)

Combined LHCb sensitivity to γ with tree decays only (educated guess):

$\sigma(\gamma) \sim 5^\circ$ with 2 fb^{-1}

$\sim 2.5^\circ$ with 10 fb^{-1}

Charm physics

- LHCb will collect a large tagged $D^* \rightarrow D^0\pi$ sample (also used for PID calibration).

  A dedicated D* trigger is foreseen for this purpose.
  - Tag D^0 or anti-D^0 flavour with pion from $D^{*\pm} \rightarrow D^0 \pi^\pm$

D*-tagged signal yield in 2 fb^{-1} (from b hadrons only)	
$D^0 \rightarrow K^-\pi^+$ right sign	12.4 M
$D^0 \rightarrow K^+\pi^-$ wrong sign	46.5 k
$D^0 \rightarrow K^+K^-$	1.6 M

- Performance studies not as detailed as for B physics.

- Interesting (sensitive to NP) & promising searches/measurements:
  - Time-dependent D^0 mixing with wrong-sign $D^0 \rightarrow K^+\pi^-$ decays
  - Direct CP violation in $D^0 \rightarrow K^+K^-$
    - $A_{CP} \leq 10^{-3}$ in SM, up to 1% (~current limit) with New Physics
    - Expect $\sigma_{stat}(A_{CP}) \sim O(10^{-3})$ with 2 fb^{-1}
  - $D^0 \rightarrow \mu^+\mu^-$
    - BR $\leq 10^{-12}$ in SM, up to 10^{-6} (~current limit) with New Physics
    - Expect to reach down to $\sim 5\times10^{-8}$ with 2 fb^{-1}

LHCb physics performance summary

- "DC04" full MC simulation datasets (2004-2006) used for extensive studies of LHCb Physics performance reported in more than 30 public notes (`CERN-LHCb-2007-xxx`) available on LHCb web page

Can easly found from LHCb page of Physics performance:
http://lhcb-phys.web.cern.ch/lhcb-phys/DC04_physics_performance/

Eg. Some of the measurements which I have not mentioned:

α	$B_d \to \rho\pi \to \rho\pi\pi\pi$, $B_d \to \rho\rho$	CERN-LHCb-2007-046
γ	$B_d \to \pi\pi$ $B_s \to KK$	CERN-LHCb-2007-059
Δm_s	$B_s \to D_s\pi$	CERN-LHCb-2007-017,2007-041
LFV	$B_d \to e\mu$,$B_s \to e\mu$	CERN-LHCb-2007-028

- New set of analysis starting with "DC06" full MC simulation datasets (2006-2007) (close-to-final detector and trigger description). Additional channels under study (eg. $B_s \to \phi\mu\mu$, $\Lambda_b \to \Lambda\mu\mu$, $B^+\to K^+\phi\gamma$, $B^+\to K^+ \pi^-\pi^+ \gamma$, $B_u \to D\tau\nu$ …)

LHCb upgrade?

- LHCb is designed to run at average luminosity of 2×10^{32} and be able to handle 5×10^{32} $cm^{-2}s^{-1}$.
  – Main physics goals expressed in terms of the reach for 10 fb^{-1} (i.e. 5 nominal years).

- Investigating upgrade of detector to handle higher luminosity: few 10^{33} $cm^{-2}s^{-1}$
  – Not directly coupled to SLHC machine upgrade since luminosity already available, but may well overlap in time with upgrades of ATLAS and CMS.

- Working group set up to identify the R&D required to make an upgrade of LHCb feasible (increase trigger efficiency for hadronic modes by a factor two, fast vertex detection, electronics, radiation dose, pile-up, higher occupancy etc.) and to make the physics case.

- **Input welcome from theorists on:**
  → What is the effective relevance of a statistical increase from 10 to 100 fb^{-1} on the constraints to Physics BSM which could be derived?

  → Which are the measurements which we should push to highest possible precision?

  → Where do we clash against theoretical uncertainties at (or before) 100 fb^{-1} ?

LHCb beyond 10 fb^{-1}?

Several measurements limited by statistical precision after 10 fb^{-1}:

- CPV in B_s mixing, in particular in $b \to s\bar{s}s$ penguins
  - → aim for 0.01 (0.002) precision on $B_s \to \phi\phi$ ($B_s \to J\psi/\phi$) CP asymmetry
- γ angle with theoretically clean methods, e.g. $B_s \to D_s K$, $B \to D(K_S\pi\pi)K$, $B \to D(hh)K$
  - → aim for < 1° precision on angle γ
- Chiral structure of $b \to s\gamma$ ($b \to s l^+ l^-$) using polarization of real (virtual) photon
  - → more detailed and precise analysis of exclusive modes, e.g. $A_T^{(2)}$ in $B^0 \to K^* \mu\mu$

Conclusions

• LHCb is ready for data taking at 2008 LHC start-up.

• Very interesting results will come already with first 0.1-0.5 fb^{-1} of data:

-- $B_s \rightarrow J/\psi\phi$, $B_s \rightarrow \mu\mu$, $B_d \rightarrow K^{0*}\mu\mu$

but also: $B_s \rightarrow \phi\gamma$, $B_d \rightarrow DK$, $B_{d,s} \rightarrow \pi\pi, KK, K\pi$ ….

• Actively preparing for analysis of several channels with high potential for indirect NP discovery and for elucidating its flavour structure.

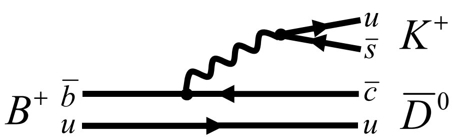
• LHCb results will provide in particular a strong improvement to the knowledge of all B_s sector. Welcome all suggestions from theory side for new interesting channels to explore.

BACK-UP

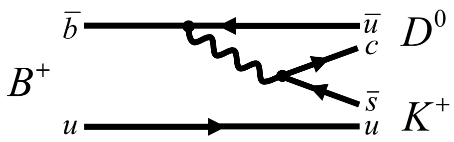
γ from $B^{\pm} \rightarrow D^0 K^{\pm}$ (ADS)

Atwood, Dunietz and Soni, Phys. Rev. Lett. 78, 3257 (1997).

- Charged *B* decay



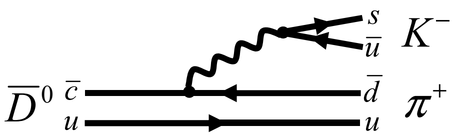
colour favoured



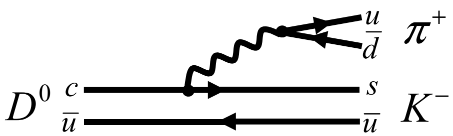
colour suppressed

Weak phase difference – γ
Strong phase difference δ_B Amplitude ratio $r_B \sim 0.08$

- D^0 and $\overline{D}^0$ can both decay into $K^-\pi^+$ (or $K^+\pi^-$)



doubly Cabibbo suppressed



Cabibbo favoured

Strong phase difference $\delta_D^{K\pi}$
Amplitude ratio $r_D^{K\pi} = 0.060 \pm 0.003$

$$\Gamma(B^- \rightarrow (K^-\pi^+)_D K^-) \propto 1 + (r_B r_D^{K\pi})^2 + 2 r_B r_D^{K\pi} \cos(\delta_B - \delta_D^{K\pi} - \gamma),$$
$$\Gamma(B^- \rightarrow (K^+\pi^-)_D K^-) \propto r_B^2 + (r_D^{K\pi})^2 + 2 r_B r_D^{K\pi} \cos(\delta_B + \delta_D^{K\pi} - \gamma),$$
$$\Gamma(B^+ \rightarrow (K^+\pi^-)_D K^+) \propto 1 + (r_B r_D^{K\pi})^2 + 2 r_B r_D^{K\pi} \cos(\delta_B - \delta_D^{K\pi} + \gamma),$$
$$\Gamma(B^+ \rightarrow (K^-\pi^+)_D K^+) \propto r_B^2 + (r_D^{K\pi})^2 + 2 r_B r_D^{K\pi} \cos(\delta_B + \delta_D^{K\pi} + \gamma)$$

right sign, lower sensitivity to γ

wrong sign, high sensitivity to γ

5 parameters (r_B, r_D, δ_B, δ_D, γ), but only 3 relative decay rates.
r_D well-measured, but δ_D poorly constrained by CLEO-c (expect $\Delta\cos\delta_D$~20%)

γ from $B^\pm \to DK^\pm$ (ADS+GLW)

Gronau, London, Wyler, PLB. 253, 483 (1991)

ADS+GLW strategy:

Measure the relative rates of $B^- \to DK^-$ and $B^+ \to DK^+$ decays with neutral D's observed in final states $K^-\pi^+$ and $K^+\pi^-$, and also:

- $D^0 \to K^-\pi^+\pi^-\pi^+$ and $K^+\pi^-\pi^+\pi^-$: add 3 observables,1 unknown strong phase $\delta^{K3\pi}$, 1 well measured rel. decay rate $r_D^{K3\pi}$
- CP eigenstate decays $D^0 \to K^+K^-/\ \pi^+\pi^-$: add 1 observable and 0 unknown

→ Can solve for all unknowns, including the weak phase γ

$\sigma(\gamma)$ = 5–13° with 2 fb^{-1}

depending on D strong phases

(Inputs:
γ=60°, r_B =0.077, δ_B =130°,
$\delta^{K\pi}$ = -8.3°, $\delta^{K3\pi}$ = -60°)

Decay	2 fb^{-1} yield	B_{bb}/S
$B^{-,+} \to D(K\pi)\,K^{-,+}$ favoured	28k, 28k	0.6
$B^{-,+} \to D(K\pi\pi\pi)\,K^{-,+}$ favoured	28k, 28k	0.6
$B^{-,+} \to D(K\pi)\,K^{-,+}$ suppr.	393, 8	2.0, 98
$B^{-,+} \to D(K\pi\pi\pi)\,K^{-,+}$ suppr.	516, 99	1.5, 8
$B^{-,+} \to D(hh)\,K^{-,+}$	4.3k, 3.5k	1.7, 2.1

Use of $B^\pm \to D^*$ $(D\pi^0, D\gamma)$ $K^\pm$ under study

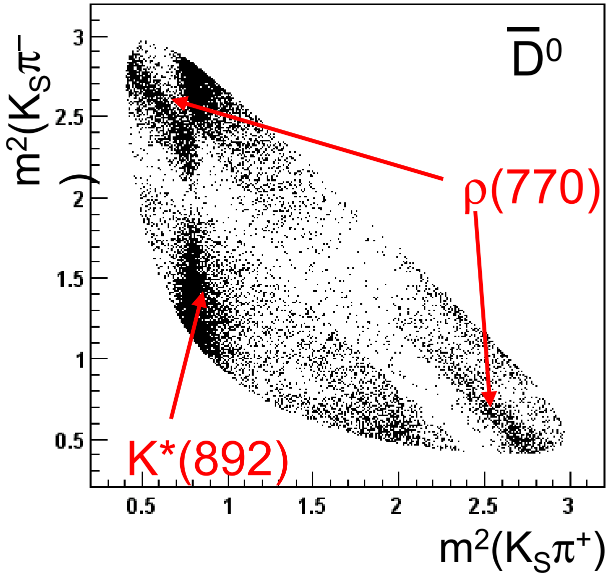
γ from $B^\pm \to D^0K^\pm$ (GGSZ)

Giri, Grossman, Soffer, Zupan, PRD 68, 050418 (2003).

D^0 decays into a 3- body CP eigenmode: $D^0 \to K_S^0\pi^+\pi^-$

Large strong phases between the intermediate resonances allow the extraction of r_B, δ_B, and γ by studying the D-Dalitz plots from B^+ and B^- decays

Assume no CP violation in D^0 decays



B decay amplitudes:

$A(B^- \to DK^-) \propto A_D(m_{K_S\pi-}^2, m_{K_S\pi+}^2) + r_B e^{i(\delta_B - \gamma)} A_D(m_{K_S\pi+}^2, m_{K_S\pi-}^2)$

$A(B^+ \to DK^+) \propto A_D(m_{K_S\pi+}^2, m_{K_S\pi-}^2) + r_B e^{i(\delta_B + \gamma)} A_D(m_{K_S\pi-}^2, m_{K_S\pi+}^2)$

Need to assume a D^0 decay model.

Current isobar model used at B factories $\Rightarrow \sigma_{syst}(\gamma) = 10°$

At LHCb:

5k signal events in 2 fb^{-1}

$B/S = 0.24\ (D^0\pi^\pm)$, $B_{bb}/S < 0.7$

$\sigma_{stat}(\gamma)$ = 7–12° with 2 fb^{-1}

Depending on bkg assumptions

With more statistics plan to do a model-independent analysis and control model systematics using CLEO-c data at $\psi(3770)$

$\sigma_{stat}(\gamma)$ = 4–6° (10 fb^{-1})

$\sigma_{syst}(\gamma)$ = 3–4°

γ from $B^0 \to D^0 K^{*0}$

colour-suppressed

colour-suppressed

Weak phase difference = γ

Magnitude ratio = $r_B \sim 0.4$

- Treat with same ADS+GLW method as charged case:
  - So far used only D decays to $K^-\pi^+$, $K^+\pi^-$, K^+K^- and $\pi^+\pi^-$ final states

$\sigma(\gamma)$ = 9° with 2 fb^{-1}

Decay mode (+cc)	2 fb^{-1} yield	B_{bb}/S
$B^0 \to (K^+\pi^-)_D K^{*0}$	3400	0.4–2.0
$B^0 \to (K^-\pi^+)_D K^{*0}$	540	2.2–13
$B^0 \to (K^+K^-)_D K^{*0}$	470	< 4.1
$B^0 \to (\pi^-\pi^+)_D K^{*0}$	130	< 14

- Envisage also GGSZ analysis

γ from $B^0 \to \pi^+\pi^-$ and $B_s \to K^+K^-$

Measure CP asymmetry in each mode:

$$A_{CP}(t) = \frac{A_{dir}\cos(\Delta m\, t) + A_{mix}\sin(\Delta m\, t)}{\cosh(\Delta\Gamma\, t/2) - A_{\Delta\Gamma}\sinh(\Delta\Gamma\, t/2)}$$

LHCb 2 fb^{-1} 36k $B^0 \to \pi^+\pi^-$, B_{bb}/S ~0.5, B_{hh}/S =0.07
36k $B_s \to K^+K^-$, B_{bb}/S<0.06, B_{hh}/S =0.07

$\sigma(A^{dir}_{\pi\pi})$	0.043	$\sigma(A^{dir}_{KK})$	0.042
$\sigma(A^{mix}_{\pi\pi})$	0.037	$\sigma(A^{mix}_{KK})$	0.044

~ 2x better than current $B\to\pi\pi$ world average

A_{dir} and A_{mix} depend on mixing phase, angle γ, and Penguin/Tree amplitude ratio $de^{i\theta}$

Exploit U-spin symmetry (Fleischer):

If assume: $d_{\pi\pi}=d_{KK}$ and $\theta_{\pi\pi}=\theta_{KK}$
4 measurements and 3 unknowns
$\to$ can solve for γ
(taking 2β and ϕ_s from other modes)

Assume only 0.8< $d_{KK}/d_{\pi\pi}$ <1.2
and let $\theta_{\pi\pi}$, θ_{KK} free