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The LHCb experiment and its expected physics performance

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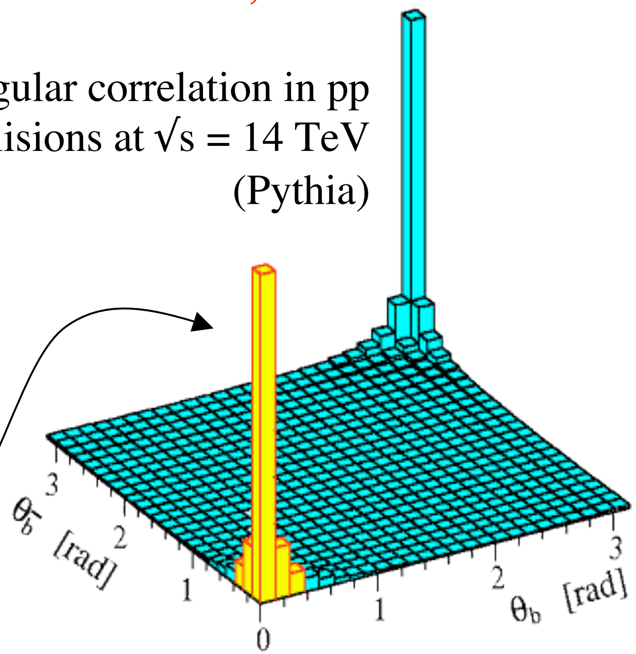
The whole idea (since more than a decade)

- Given the fact that
  - LHC will be producing the largest number of b hadrons (of all types), by far, and for a long time
  - Tevatron experiments have demonstrated the feasibility of B physics at a hadron machine

→ **perform a dedicated B-physics experiment at the LHC**, but with a new challenge:

- exploit the huge bb production in the not-well-known forward region, despite the unfriendly hadronic environment (multiplicity, …) for B physics
  - ~ 230 μb of bb production in one of the forward peaks (~300 mrad), corresponding to nearly 10^5 b hadrons per second at a modest luminosity of 2×10^{32} $cm^{-2}s^{-1}$

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

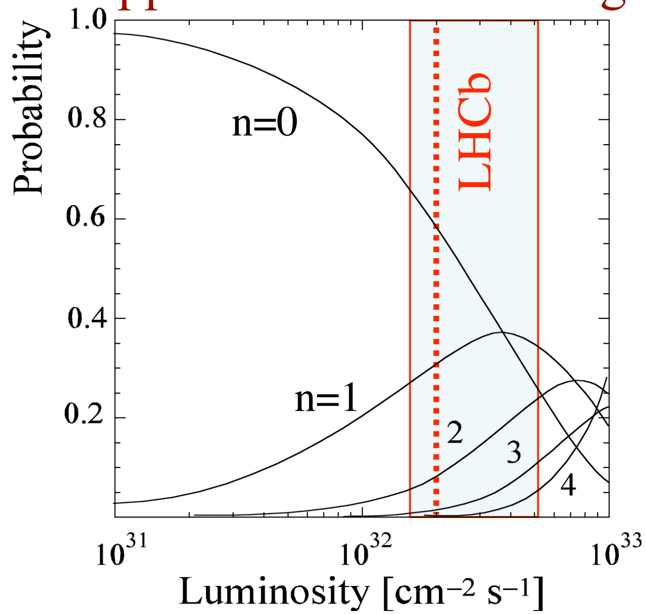


Pileup and luminosity

- LHC machine, pp collisions at $\sqrt{s}$ = 14 TeV:
  - design luminosity = L = 10^{34} cm^{-2}s^{-1}, bunch crossing rate = 40 MHz
  - average non-empty bunch crossing rate = f = 30 MHz (in LHCb)
  - Pileup:
    - n = number of inelastic pp interactions occurring in the same bunch crossing
    - Poisson distribution with mean $\langle n \rangle = L\sigma_{inel}/f$, with σ_{inel} = 80 mb
    - $\langle n \rangle$ = 25 at 10^{34} cm^{-2}s^{-1} → not good for B physics

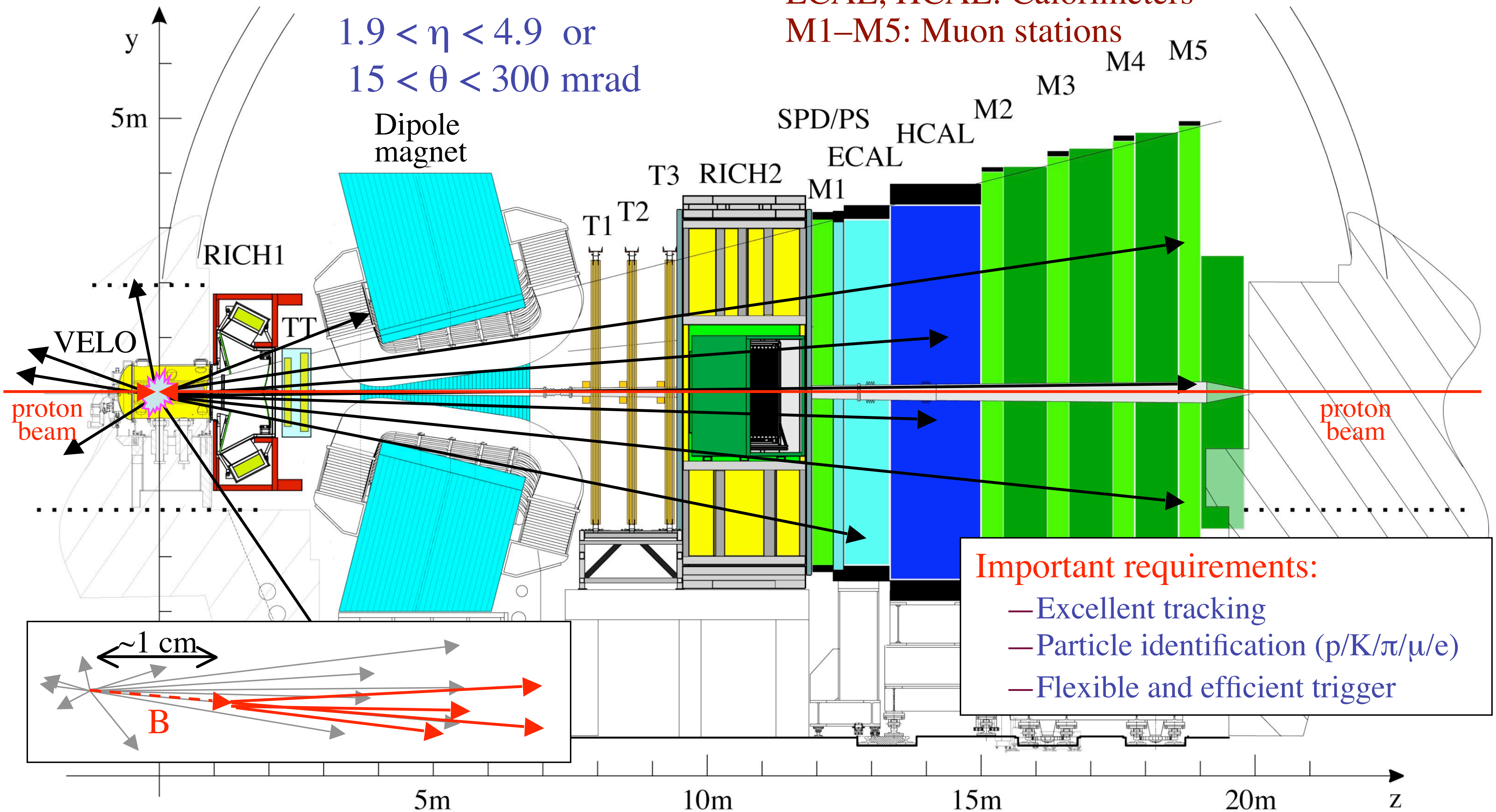
- At LHCb:
  - L tuneable by adjusting final beam focusing
  - Choose to run at $\langle L \rangle \sim$ **2×10^{32} cm^{-2}s^{-1}** (max. 5×10^{32} cm^{-2}s^{-1})
    - Clean environment: $\langle n \rangle$ = 0.5
    - Less radiation damage
    - Expected to be available from "first" physics run
  - 2 fb^{-1} of data in 10^7 s (= nominal year)

pp interactions/crossing



LHCb spectrometer

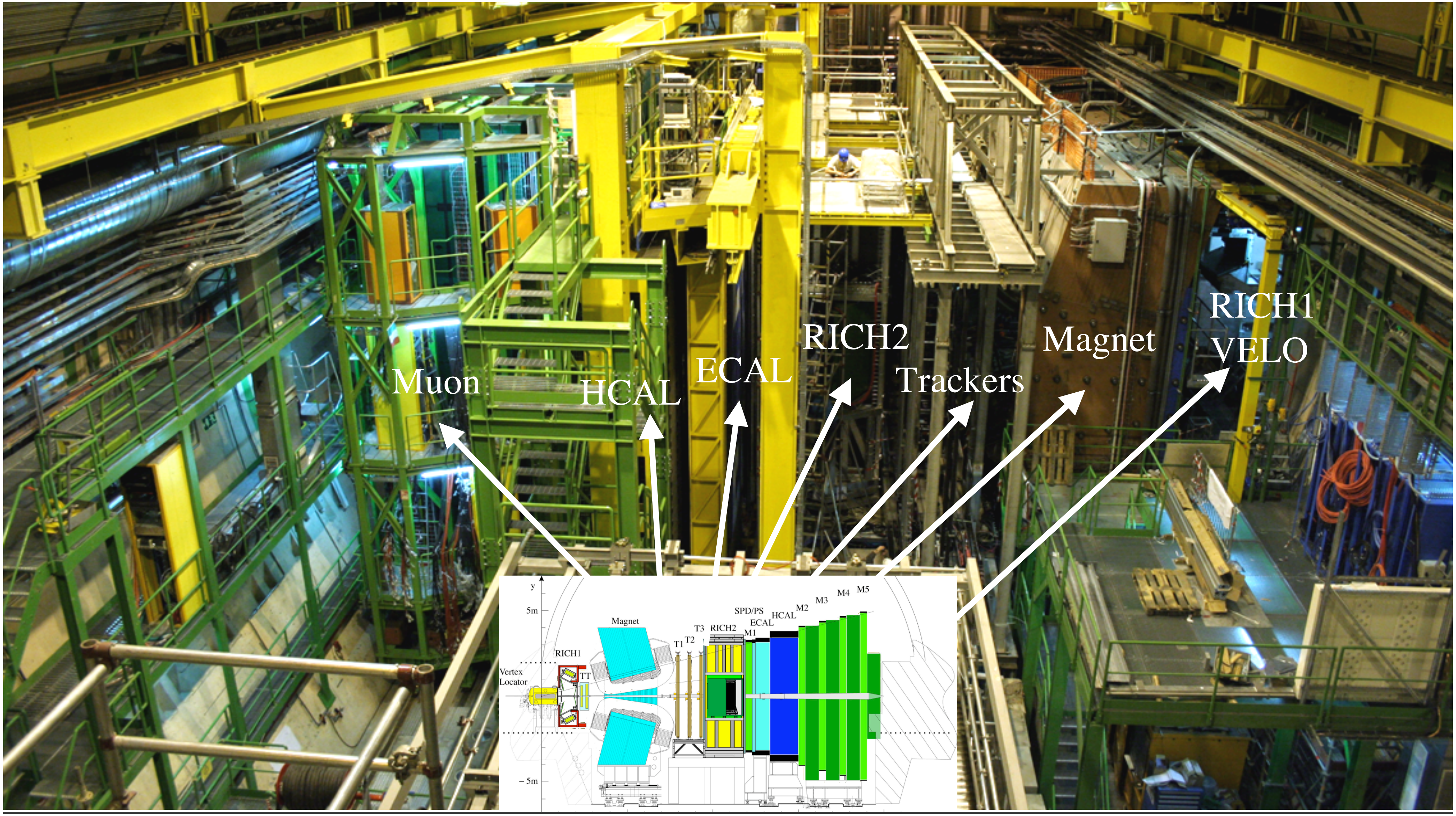
VELO: Vertex Locator (around interaction point)
TT, T1, T2, T3: Tracking stations
RICH1–2: Ring Imaging Cherenkov detectors
ECAL, HCAL: Calorimeters
M1–M5: Muon stations



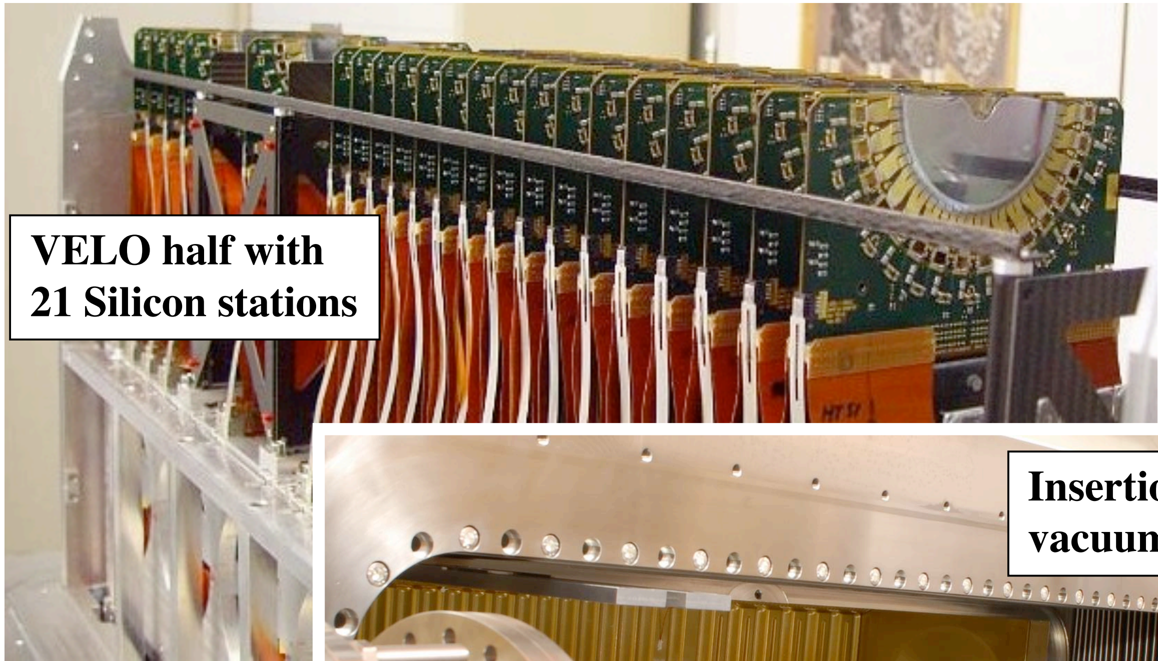
Important requirements:

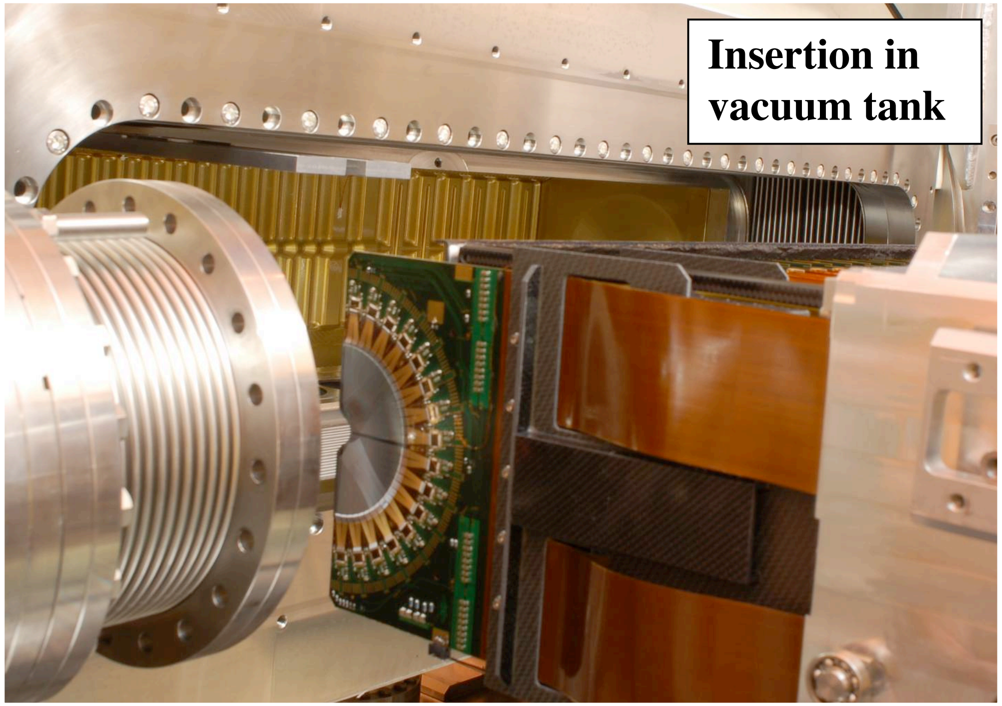
- Excellent tracking
- Particle identification (p/K/π/μ/e)
- Flexible and efficient trigger

LHCb construction on schedule



VELO installation (Oct 30–31, 2007)





Monte Carlo studies: a long way

- Technical proposal (1998):
  - Rough detector description
  - No trigger simulation
  - No pattern recognition in tracking
  - Parametrized PID performance
- Re-opt. Technical Design Report (2003)
  - Final detector design
  - Simulation of L0 and L1 trigger only
  - First version of full pattern recognition
- **"DC04" MC datasets (2004–2006):**
  - **Detailed material description**
  - **First simulation of High-Level Trigger**
- "DC06" MC datasets (2006–2007):
  - Close-to-final geometry and material description
  - Redesigned High-Level Trigger
  - Close-to-final reconstruction algorithms
- …

Today's numbers from DC04 MC performance studies:

- Tuned PYTHIA
- $\langle L \rangle = 2\times10^{32}$ cm^{-2}s^{-1} with pileup included
- Full detector simulation (spillover effects included)
- Background estimates:
  - based on a sample of inclusive bb events equivalent to a few minutes of data taking !
  - sometimes can only set upper limits

In 2007, large push to describe all these studies in public LHCb notes

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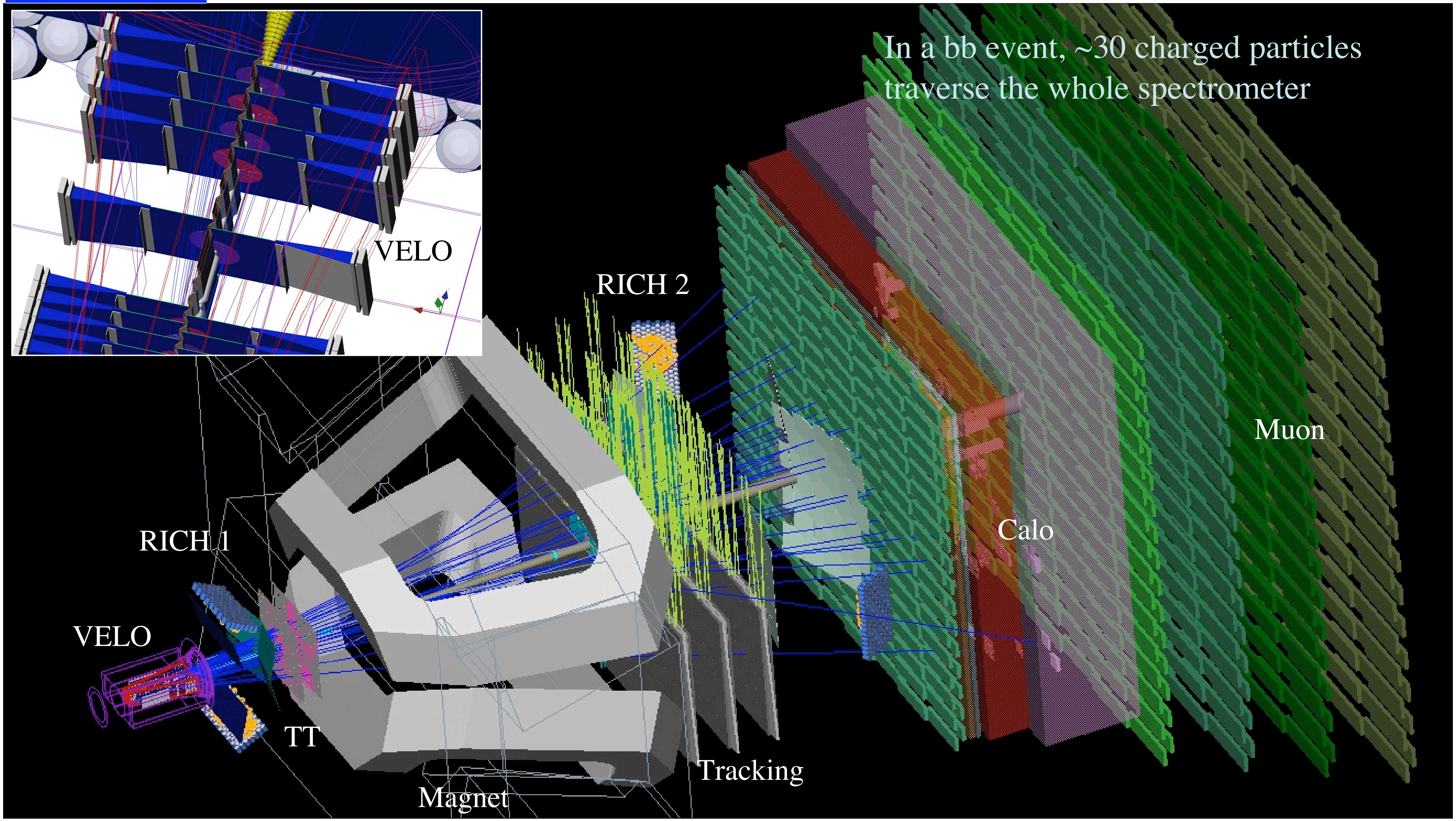
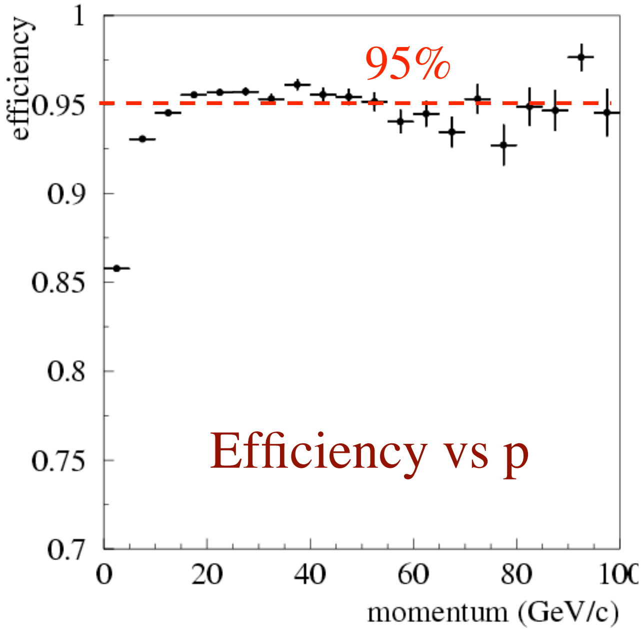
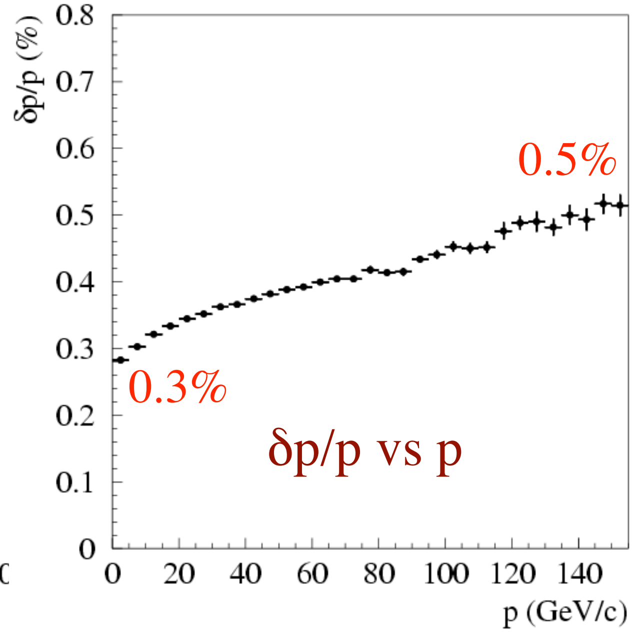
PYTHIA + GEANT4 full simulation



Expected tracking performance

- Track finding:
  - efficiency > 95% for long tracks from B decays
    - ~ 4% ghosts for $p_T > 0.5$ GeV/c
  - $K_S \rightarrow \pi^+\pi^-$ reconstruction 75% efficient for decay in the VELO, lower otherwise
- Average b-decay track resolutions:
  - Impact parameter: ~ 30 μm
  - Momentum: ~ 0.36%
- Typical B resolutions:
  - Proper time: ~ 40 fs (essential for B_s physics)
  - Mass: 8–18 MeV/c^2





	Mass resolution
$B_s \rightarrow \mu\mu$	18 MeV/c^2
$B_s \rightarrow D_s \pi$	14 MeV/c^2
$B_s \rightarrow J/\psi\, \phi$	16 MeV/c^2
$B_s \rightarrow J/\psi\, \phi$	8 MeV/c^2 *

* with J/ψ mass constraint

Particle ID performance with RICH

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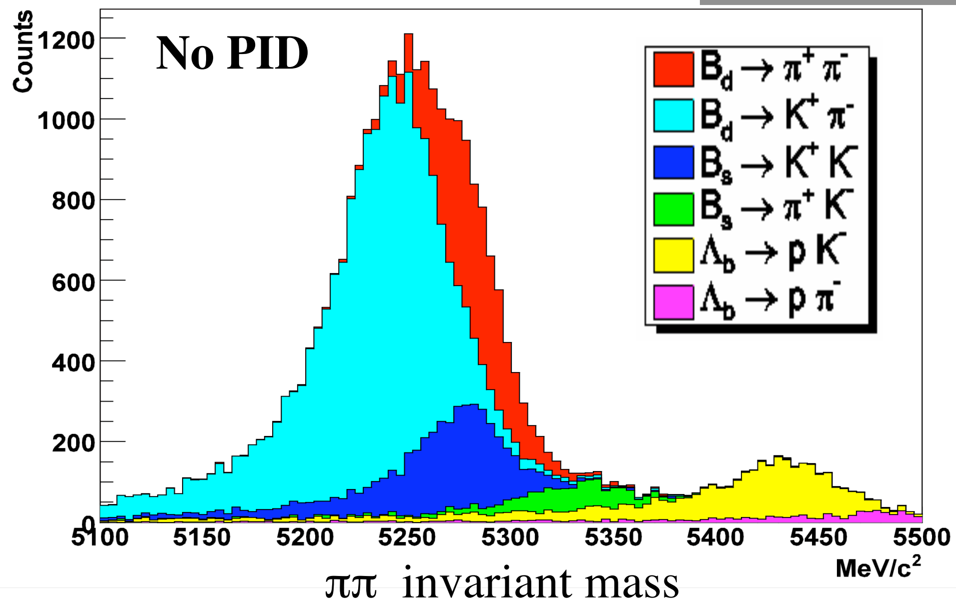
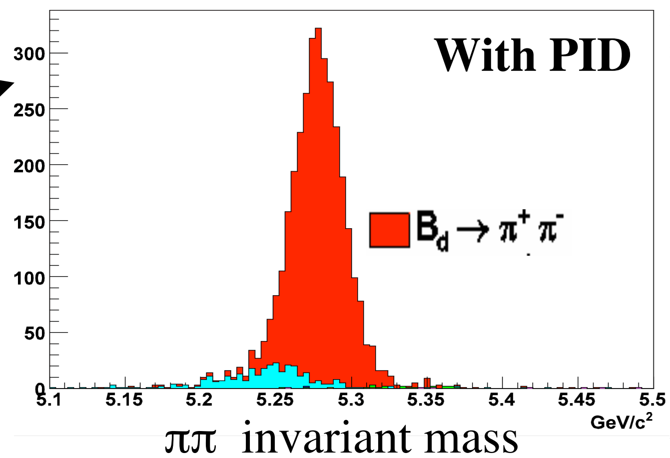
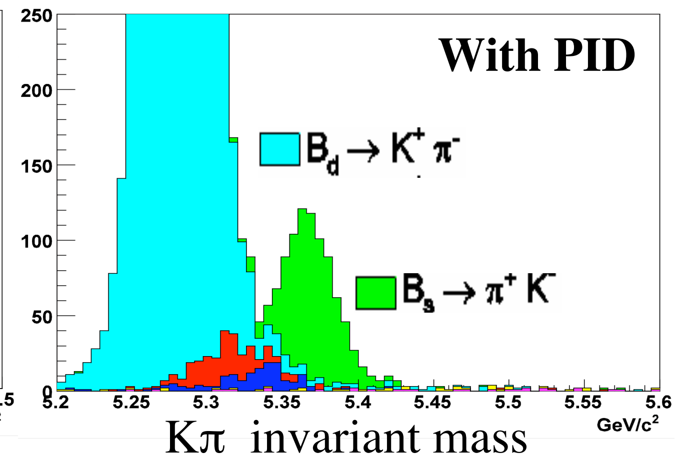
- Average performance:
  - kaon ID eff. = 88%
  - π mis-ID = 3%

- Good K/π separation in 2–100 GeV/c range
  - Low momentum
    - Tagging kaons
  - High momentum
    - clean separation of the different $B_{d,s} \rightarrow hh$ modes
    - will be best performance ever achieved at a hadron collider







Flavour tagging

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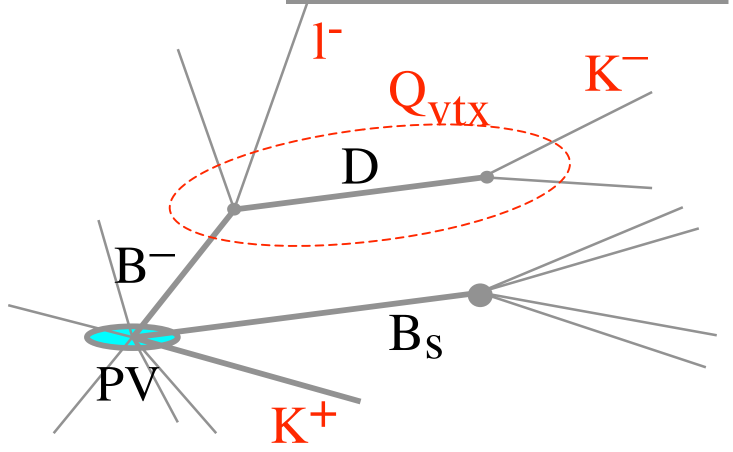
CERN-LHCb-2006-058
CERN-LHCb-2007-127
CERN-LHCb-2007-036
CERN-LHCb-2007-029

- Several tags, combined with neural network:
  - Opposite side (OS): electron, muon, kaon, vertex charge
  - Same side (SS): pion (B^0) or kaon (B_s)
    - Kaon tags most powerful

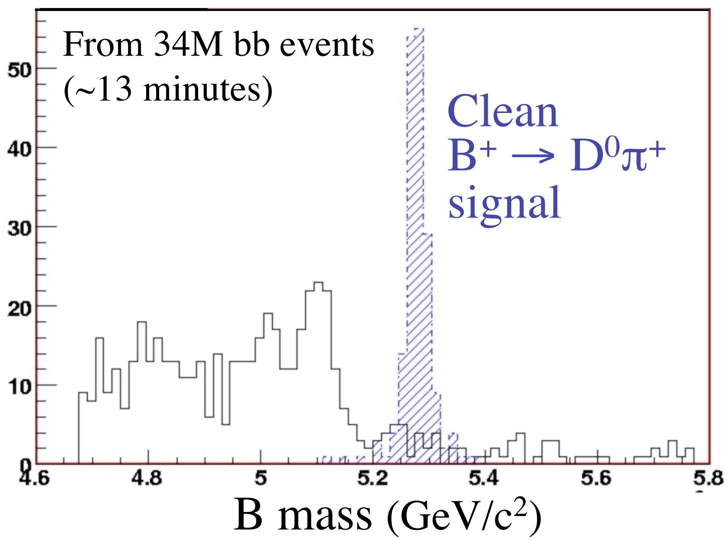


- Full MC performance on triggered and selected events:
  - **εD^2= 4–5% for B^0**
  - **εD^2= 7–9% for B_s**

  depending on channel

- Mistag rate (w) will be measured in data using several high-statistics control channels:
  - **$\sigma(w_{OS})/w_{OS}$ ~ 0.2%**
  - **$\sigma(w_{SS})/w_{SS}$ ~ 1.2%**

  ($2\ fb^{-1}$)



Control channel	Yield in $2\ fb^{-1}$	B_{bb}/S
$B^0 \to J/\psi(\mu\mu)K^{*0}$	0.9 M	0.16
$B^+ \to J/\psi(\mu\mu)K^+$	1.7 M	0.4
$B^+ \to D^0\pi^+$	1.0 M	0.13
$B^0 \to D^{*-}\mu^+\nu$	9.2 M	0.26
$B^+ \to D^0\mu^+\nu X$	2.4 M	0.75
$B_s \to D_s\mu^+\nu X$	1.1 M	0.36
$B_s \to D_s^+\pi^-$	0.14 M	0.2

Trigger performance & rates

- Algorithms and performance:
  - Hardware level (L0), max. 1 MHz output rate:
    - algorithms mature
  - Software level (HLT = High Level Trigger):
    - prototype available within time budget for a limited set of channels
  - L0*HLT efficiencies:
    - typically **30%–80%** for offline-selected signal events, depending on channel

- HLT output rates:
  - Indicative rates
    - split between streams still to be determined
  - Large inclusive streams to control calib. & syst.
    - trigger, tracking, PID, tagging

Output rate	Event type	Physics
200 Hz	Exclusive B candidates	B (core program)
600 Hz	High mass di-muons	J/ψ, $b \to J/\psi X$ (unbiased)
300 Hz	D^* candidates	Charm
900 Hz	Inclusive b (e.g. $b \to \mu$)	B (data mining)

Integrated luminosity scenario

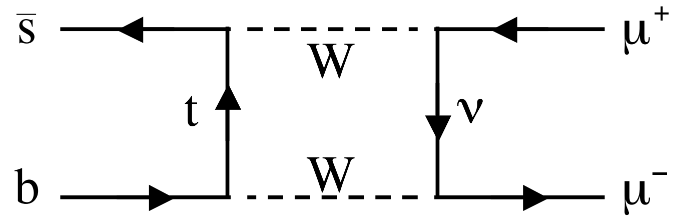
[personal and unofficial guess]

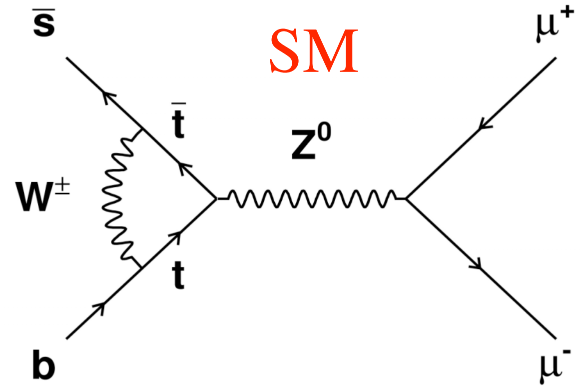
- 2008:
  - LHC startup with full detector installed
  - Establish running procedures, time and space alignment of the detectors
  - Calibration of momentum, energy and particle ID
  - Integrated luminosity for physics **~ 0.1 fb^{-1}**
- 2009:
  - Complete commissioning of trigger
  - Start of significant physics data taking, assume **~ 0.5 fb^{-1}**
- 2010–:
  - Stable running, assume **~ 2 fb^{-1}/year**
  - If found to be advantageous for physics, push average luminosity from 2×10^{32} to 5×10^{32} $cm^{-2}s^{-1}$
- Availability of physics results:
  - with 0.5 fb^{-1} in ~2010
  - with 2 fb^{-1} in ~2011
  - with 10 fb^{-1} in ~2015

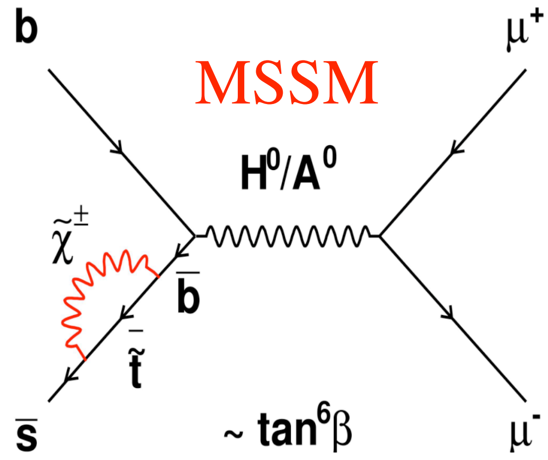
followed by 100 fb^{-1} LHCb upgrade ?

$B_s \to \mu^+\mu^-$

- **Very rare loop decay, sensitive to new physics:**
  - BR $=(3.4\pm0.4)\times10^{-9}$ in SM,
    can be strongly enhanced in SUSY:
    - e.g. current measurement of $g_\mu - 2$
      suggests BR($B_s \to \mu^+\mu^-$) up to 100×10^{-9}
      within the CMSSM for high $\tan\beta$
      $\to$ see next slide
  - Current 90% CL limit:
    - CDF note 8956 (2 fb^{-1}): $47\times10^{-9} = 14 * BR_{SM}$
    - D0 note 5344-CONF (2 fb^{-1}): $75\times10^{-9} = 20 * BR_{SM}$





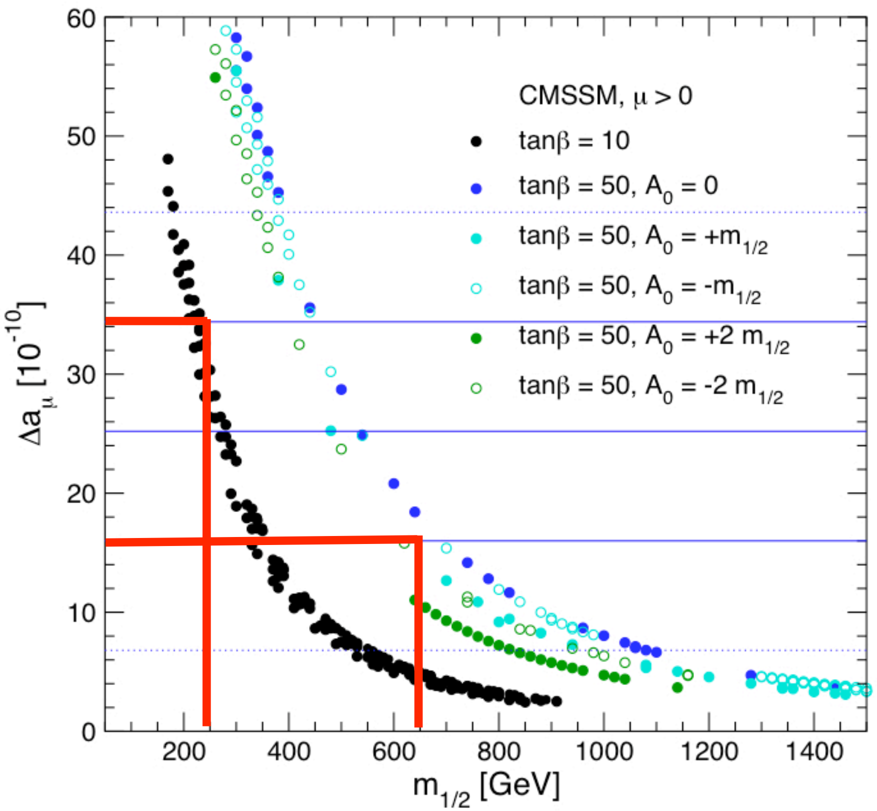


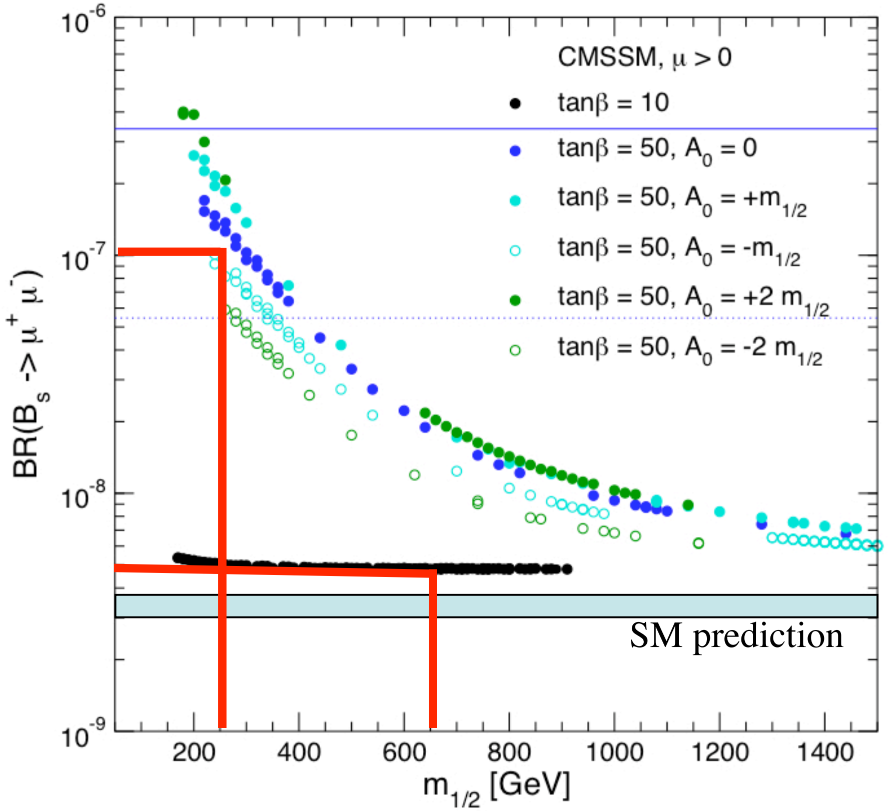
- **Easy for LHCb to trigger and select**
- **Main issue is background rejection**
  - with limited MC statistics,
    indication that largest background is b→μ, b→μ
  - specific background dominated by $B_c \to J/\psi(\mu\mu)\mu\nu$

$B_s \to \mu^+\mu^-$

- Anomalous magnetic moment of the muon
  - Muon g–2 collab. measurement deviates by 2.7σ from SM: $\Delta a_\mu = (25.2\pm9.2)\times10^{-10}$
- Implications on $B_s \to \mu^+\mu^-$ within constrained MSSM:
  - $\Rightarrow 250 < m_{1/2}$(gaugino mass) < 650 GeV $\Rightarrow BR(B_s \to \mu^+\mu^-) = 5\times10^{-9}$–$10^{-7}$

[J. Ellis et al., hep-ph/0411216]





$B_s \to \mu^+\mu^-$

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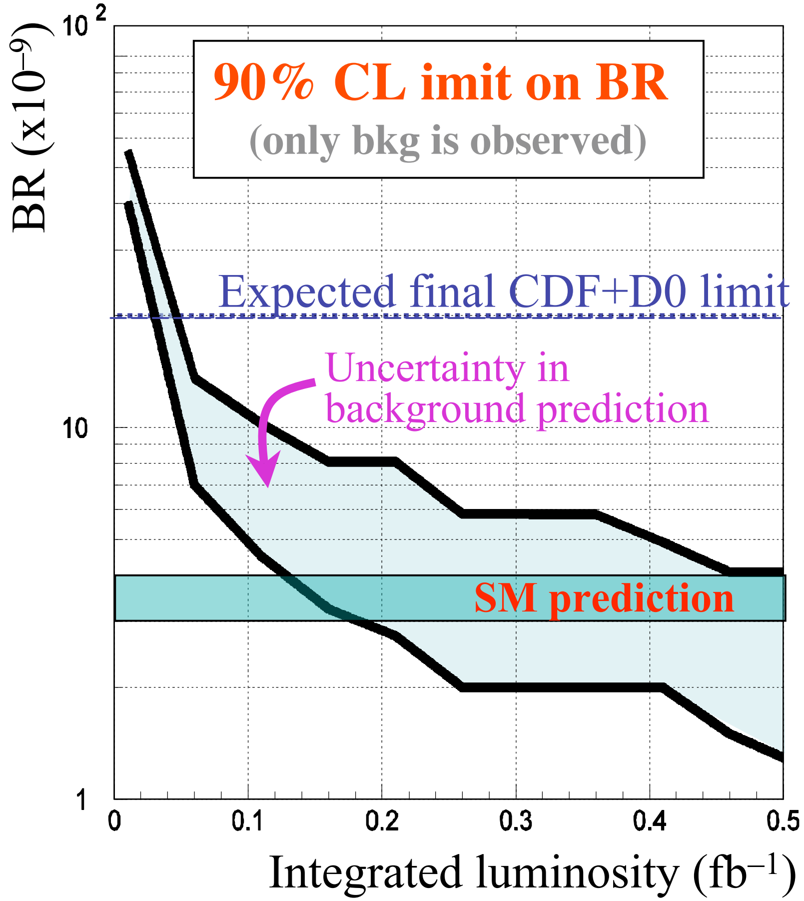
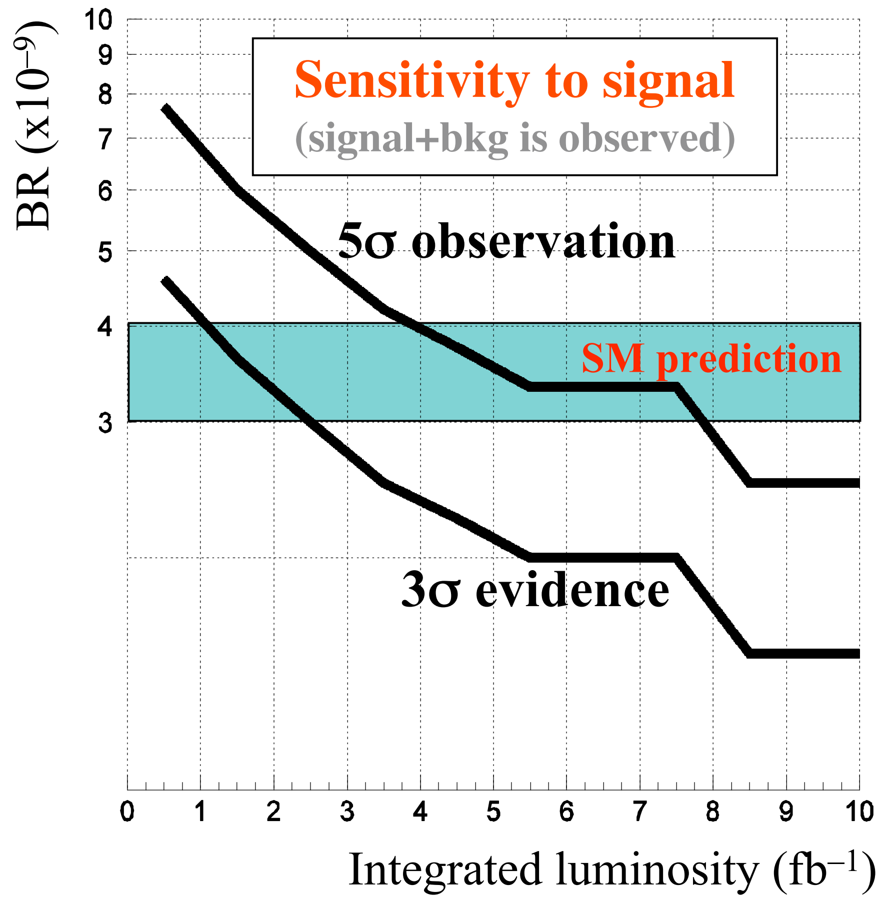




0.05 fb^{-1} ⇒ overtake CDF+D0
0.5 fb^{-1} ⇒ exclude BR values down to SM

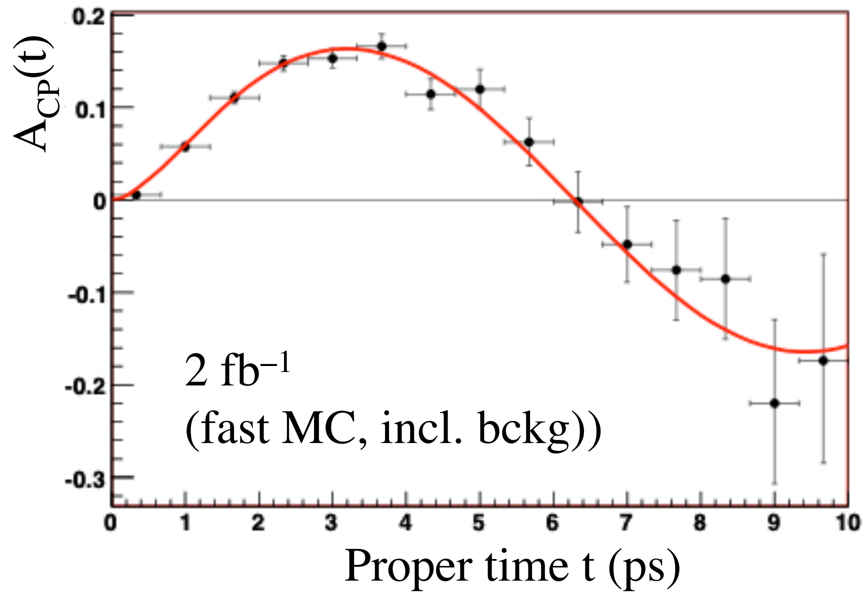
2 fb^{-1} ⇒ 3σ evidence of SM signal
6 fb^{-1} ⇒ 5σ observation of SM signal

$\sin(2\beta)$ with $B^0 \rightarrow J/\psi K_S$

CERN-LHCb-2007-045

- Expected to be one of the first CP measurements:
  - Demonstrate (already with ≤ 0.5 fb^{-1}) that we can keep under control the main ingredients of a CP analysis
    - in particular tagging performance extraction from control channel $B^0 \rightarrow J/\psi K^{*0}$
  - Sensitivity:
    - 236k signal events/2 fb^{-1} with B/S = 0.6(bb)+7.7(J/ψ) $\Rightarrow \sigma_{stat}(\sin(2\beta)) = 0.020$
    - to be compared with 0.019 from final BaBar+Belle $B^0 \rightarrow J/\psi K_S$ statistics

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



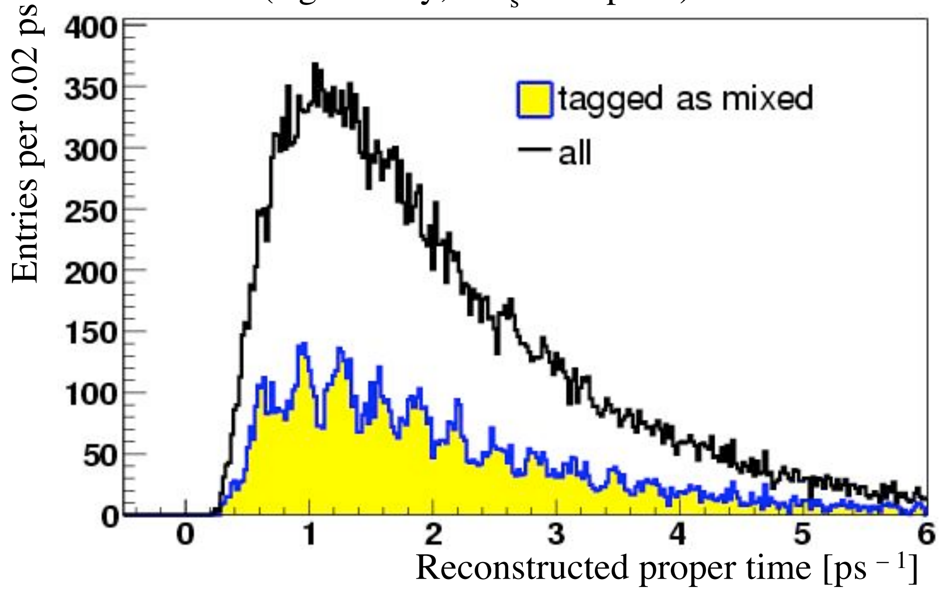
- With 10 fb^{-1}:
  - Should be able to reach $\sigma(\sin(2\beta)) \sim 0.010$
  - Can also push further the search for direct CP violating term $\propto \cos(\Delta m_d t)$

$B_s \rightarrow D_s^- \pi^+$ sample and Δm_s

- Important control channel for all time-dependent B_s analyses
  - Flavour-specific decay:
    → can use to measure dilution of B_s oscillations
    → once mistag known (from other channels) can **isolate resolution effect**
  - Expect 140k events in 2 fb^{-1}
    with $B_{bb}/S < 0.05$ at 90% CL
    and average $\sigma_t \sim 40$ fs

CERN-LHCb-2007-017

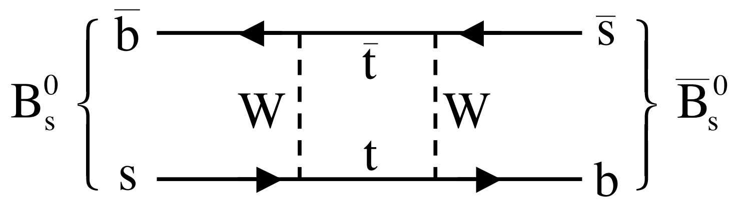
Full simulation 0.5 fb^{-1}
(signal only, $\Delta m_s = 20\ ps^{-1}$)



- Other uses of $B_s \rightarrow D_s^- \pi^+$:
  - Measurement of Δm_s (with 0.5 fb^{-1})
    - $\sigma_{stat}(\Delta m_s) = 0.012\ ps^{-1}$
    - will be dominated by systematics on proper time scale
  - Normalization channel for all B_s branching fraction measurements
    - ~10% absolute measurement of $BR(B_s \rightarrow D_s^- \pi^+)$ expected from Belle's current data

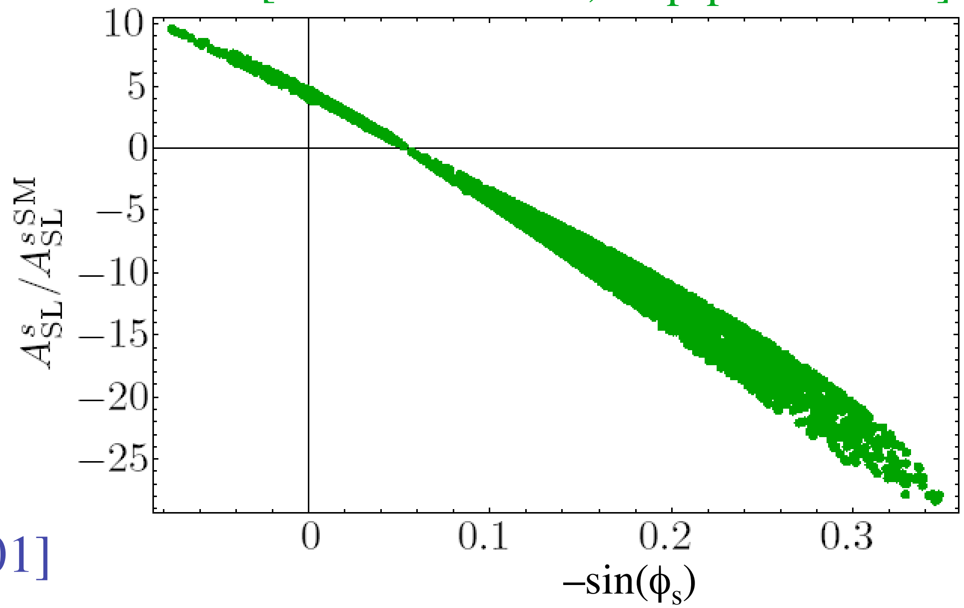
New physics in B_s mixing

- B_s mixing phase $\phi_s = -2\beta_s$ is the strange counterpart of $\phi_d = 2\beta$:
  - ϕ_s very small in SM, and very precisely predicted: $\phi_s^{SM} = -\arg(V_{ts}^2) = -2\lambda^2\eta$ $= \mathbf{-0.0368 \pm 0.0018}$ [CKMfitter, summer 2007]



- ϕ_s very sensitive to New Physics contributions:
  - Some models can predict large ϕ_s, while satisfying all existing constraints:
    - e.g. Little Higgs model with T-parity provides significant enhancement of both ϕ_s and B_s semi-leptonic asymmetry A_{SL} while Δm_s measurement is found to be smaller than SM value

[Blanke & Buras, hep-ph/0703117]



- Current experimental situation:
  - No evidence of CP violation found
  - $\phi_s = -0.70\ ^{+0.47}_{-0.39}$ [D0, PRD 76 (2007) 057101]

B_s mixing phase ϕ_s with $b \to c\bar{c}s$

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

- Golden $b \to ccs$ mode is $B_s \to J/\psi\phi$:
  - Single weak phase in decay amplitude
  - Angular analysis needed to separate CP-even and CP-odd contributions
  - Expect ~130k $B_s \to J/\psi(\mu\mu)\phi$ events/2fb^{-1} with $B_{bb}/S = 0.12$
- Sensitivity after 10 fb^{-1}:

  $\sigma_{stat}(\phi_s) = 0.009$

  - Includes also pure CP modes such as $B_s \to J/\psi\eta^{(')}$, $\eta_c\phi$, D_sD_s, but dominated by $B_s \to J/\psi\phi$
  - Systematics (tagging, resolution) need to be tackled
  - > 3σ evidence of non-zero ϕ_s, even if only SM

Statistical sensitivities on ϕ_s for 2 fb^{-1}

B_s decay mode	$\sigma(\phi_s)$
$J/\psi\eta(\gamma\gamma)$	0.109
$J/\psi\eta(\pi^+\pi^-\pi^0)$	0.142
$J/\psi\eta'(\rho^0\gamma)$	0.080
$J/\psi\eta'(\eta\pi^+\pi^-)$	0.154
$\eta_c(4h)\phi$	0.108
$D_s^+D_s^-$	0.133
pure CP modes	**0.046**
$J/\psi(\mu\mu)\phi$	**0.023**
All modes	**0.021**

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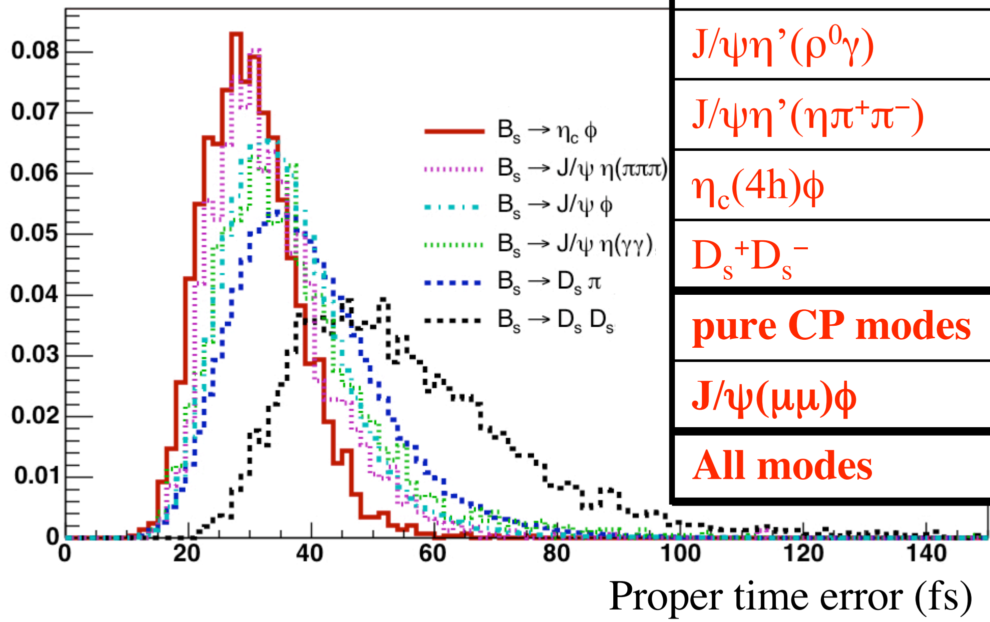
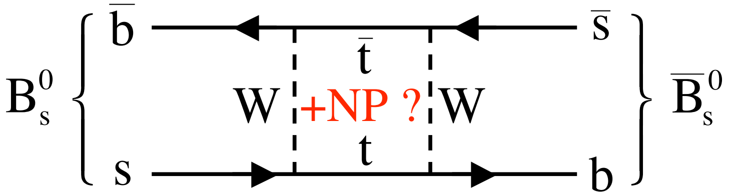


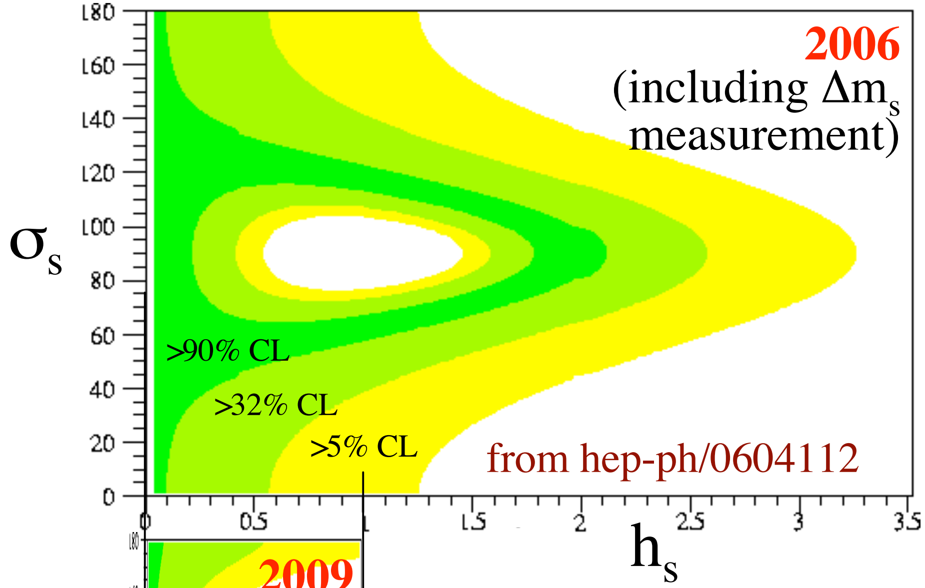
Constraints on New Physics in B_s mixing from ϕ_s measurement

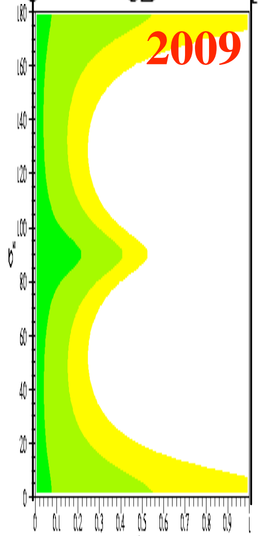


- New Physics in B_s mixing amplitude M_{12} parametrized with h_s and σ_s:

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

- Can exclude already significant region of allowed phase space with the very first data





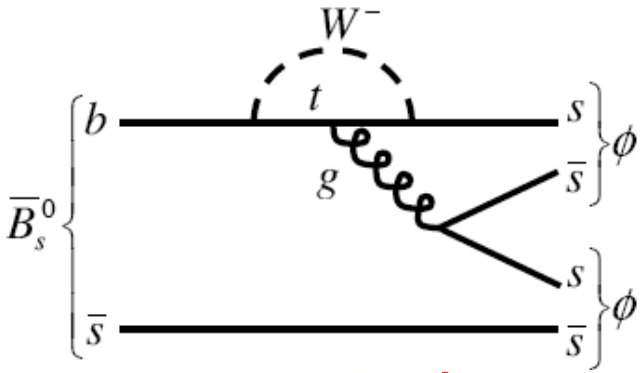
After LHCb measurement of ϕ_s with $\sigma(\phi_s)= \pm 0.1$ ($\sim$ 0.2 fb^{-1})

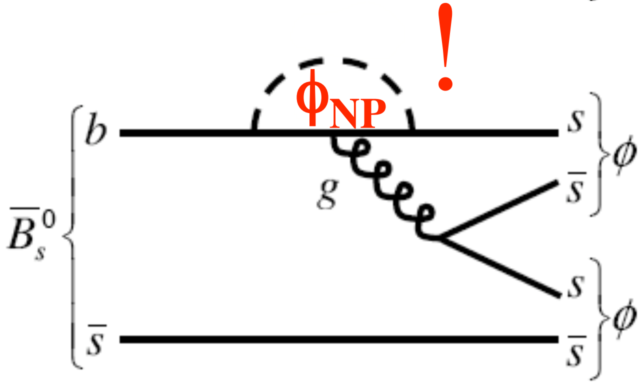
courtesy Z. Ligeti

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

- Time-dependent CP analysis of pure penguin decays to CP eigenstates

- "Golden mode" is $B_s \to \phi\phi$
  - CP violation < 1% in SM
    (V_{ts} enters both in mixing and decay amplitudes)
  - significant CP-violating phase difference $\Delta\phi^{NP}$ can only be due to New Physics
  - Angular analysis required
  - 3.1k signal events per 2 fb^{-1} ($BR=1.4\times10^{-5}$), $B/S < 0.8$ at 90%CL
  - After 10 fb^{-1}: $\boldsymbol{\sigma_{stat}(\Delta\phi^{NP}) = 0.05}$





- $B^0 \to \phi K_S$:
  - 920 signal events per 2 fb^{-1}, $B/S < 1.1$ at 90% CL
  - After 10 fb^{-1}: $\boldsymbol{\sigma_{stat}(\sin(2\beta_{eff})) = 0.10}$
    - to be compared with 0.12 from final BaBar+Belle analysis

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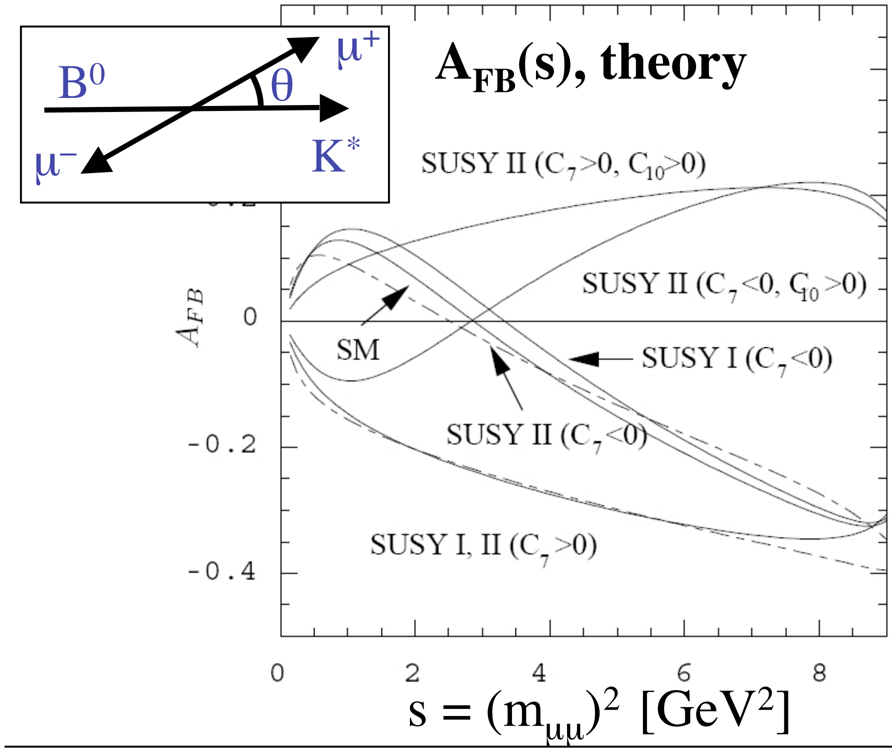
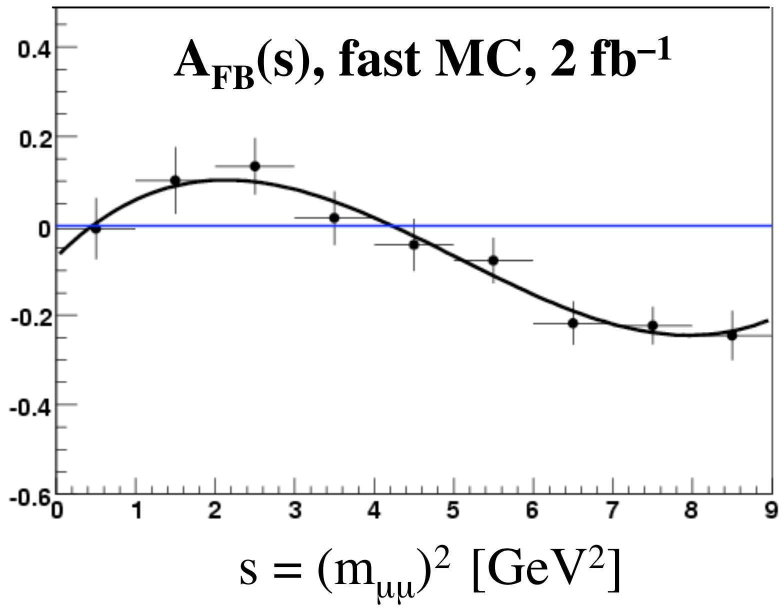
CERN-LHCb-2007-130

$B^0 \to K^{*0}\mu^+\mu^-$

- **Suppressed loop decay**
  - Forward-backward asymmetry $A_{FB}(s)$ in the $\mu\mu$ rest-frame
    - sensitive probe of New Physics
    - zero of A_{FB} gives access to ratio of Wilson coefficients C_7^{eff}/C_9^{eff}



- **Sensitivity**
  (ignoring non-resonant $K\pi\mu\mu$ evts for the time being)
  - **7.2k signal events/2fb^{-1}**, $B_{bb}/S = 0.2 \pm 0.1$
    - NB: expect 0.3k/1ab^{-1} at B factories



  - With 10 fb^{-1}, the zero of $A_{FB}(s)$ can be measured to ± 0.27 GeV^2 (~7% of SM value)

$B^0 \to K^{*0}\mu^+\mu^-$

CERN-LHCb-2007-057

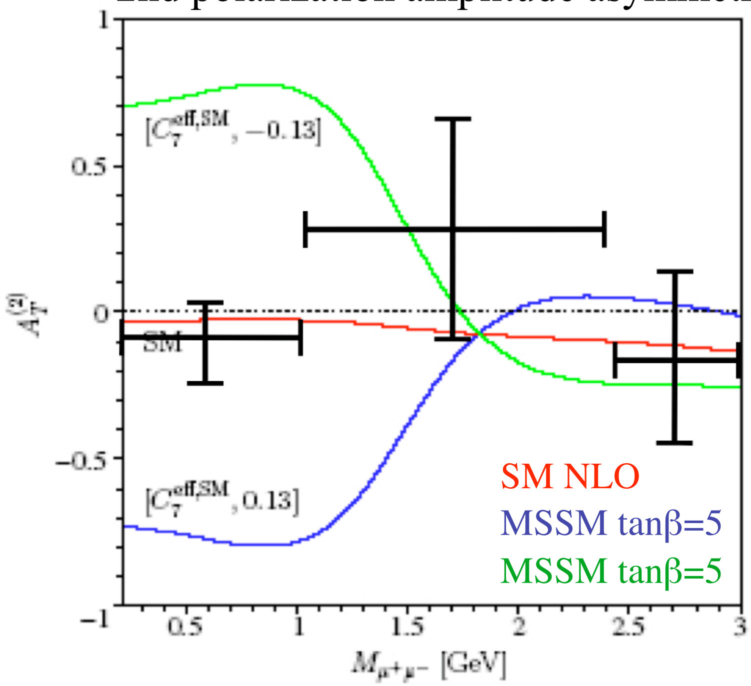
- Other observables based on transversity amplitudes ($A_\perp$, $A_{//}$, A_0) extracted from a 3-angle analysis:
  - small theoretical errors in the SM,
  - sensitive to right-handed FCNC

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

	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

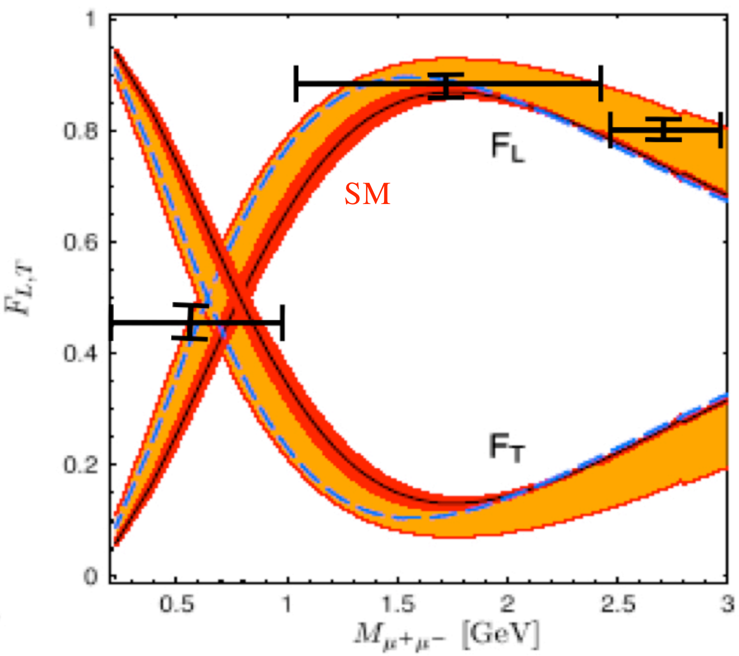
$$A_T^{(2)}(s) = \frac{|A_\perp|^2 - |A_{//}|^2}{|A_\perp|^2 + |A_{//}|^2}$$

2nd polarization amplitude asymmetry



$$F_L(s) = \frac{|A_0|^2}{|A_0|^2 + |A_{//}|^2 + |A_\perp|^2}$$

K^* longitudinal polarization fraction



Error bars:
LHCb 2 fb^{-1}

Curves:
theory

[Lunghi & Matias, hep-ph/0612166]

Other rare decays

CERN-LHCb-2007-034
CERN-LHCb-2007-030
CERN-LHCb-2006-012
CERN-LHCb-2006-013
CERN-LHCb-2006-028

- $B^+ \rightarrow K^+l^+l^-$ decays
  - $\mu\mu$/ee ratio in SM: $R_K = \int_{4m_\mu^2}^{q^2_{max}} ds \frac{d\Gamma(B \rightarrow K\mu\mu)}{ds} \Big/ \int_{4m_\mu^2}^{q^2_{max}} ds \frac{d\Gamma(B \rightarrow Kee)}{ds} = 1.000 \pm 0.001$

    Hiller & Krüger, hep-ph/0310219
  - New Physics can have O(10%) effect
  - After 10 fb^{-1}: $\sigma_{stat}(R_K) = 0.043$

Decay	2 fb^{-1} yield	B_{bb}/S
$B^+ \rightarrow K^+\mu\mu$	3.8k	1.7
$B^+ \rightarrow K^+ee$	1.9k	15
$B_d \rightarrow K^*\gamma$	68k	0.60
$B_s \rightarrow \phi\gamma$	11.5k	< 0.55
$\Lambda_b \rightarrow \Lambda(1115)\gamma$	0.75k	< 42
$\Lambda_b \rightarrow \Lambda(1670)\gamma$	2.5k	< 18

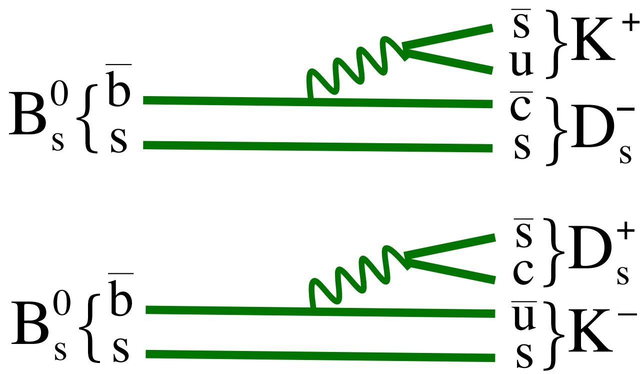
- Radiative decays:
  - $K^*\gamma$: A_{CP} < 1% in SM, up to 40% in SUSY; can measure at <% level
  - $\phi\gamma$: No mixing-induced CP asymmetry in SM, up to 50% in SUSY
  - $\Lambda\gamma$: Right-handed component of photon polarization O(10%) in SM; can get 3σ evidence down to 21% (10 fb^{-1})
- Leptonic LFV decays

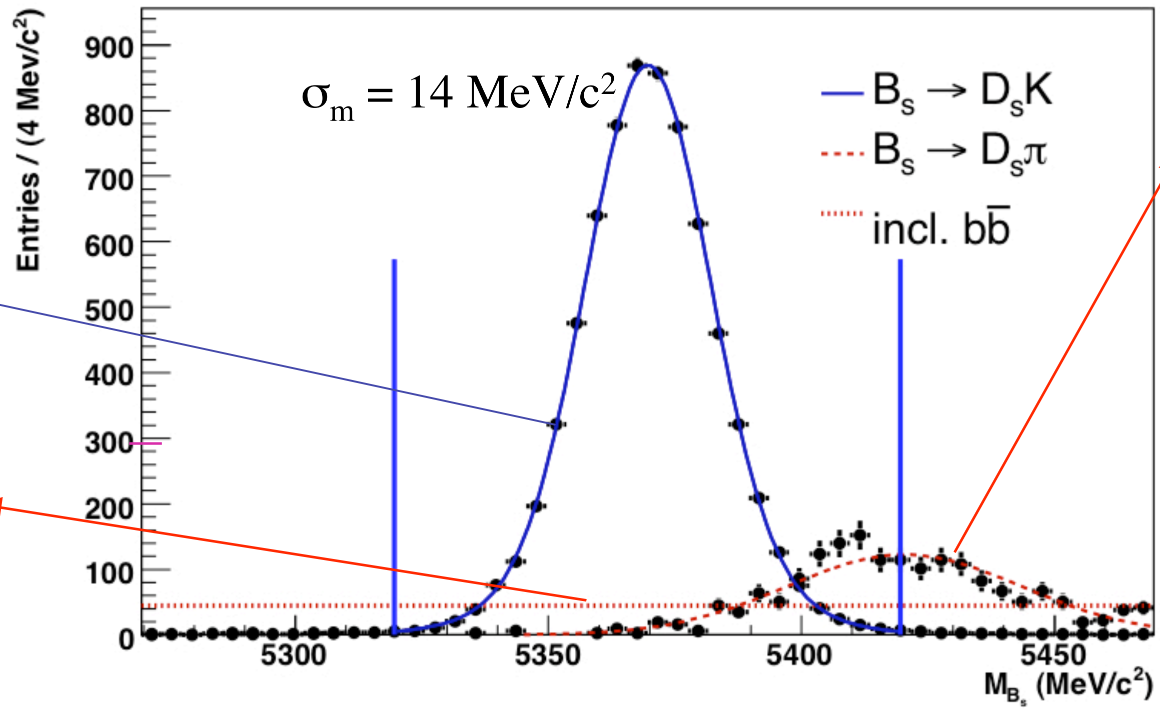
	LHCb 90%CL limit	Current 90%CL limit
$BR(B^0 \rightarrow e\mu)$	1.6×10^{-8} (2 fb^{-1})	1.7×10^{-7} (Belle 03)
$BR(B_s \rightarrow e\mu)$	6.5×10^{-8} (2 fb^{-1})	6.1×10^{-6} (CDF 98)

γ from $B_s \to D_s K$

CERN-LHCb-2007-017
CERN-LHCb-2007-041

- Two tree decays ($b \to c$ and $b \to u$), which interfere via B_s mixing:
  - can determine $\gamma + \phi_s$, hence γ in a very clean way
    - similar to $2\beta+\gamma$ extraction with $B^0 \to D^*\pi$, but with the advantage that the two decay amplitudes are similar ($\sim\lambda^3$) and that their ratio can be extracted from data





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

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

$B_s \to D_s^-\pi^+$ background (with ~15 × larger BR) suppressed using PID:
→ residual contamination only (15±5)%

All specific backgrounds B/S = [0.08,3] at 90% CL

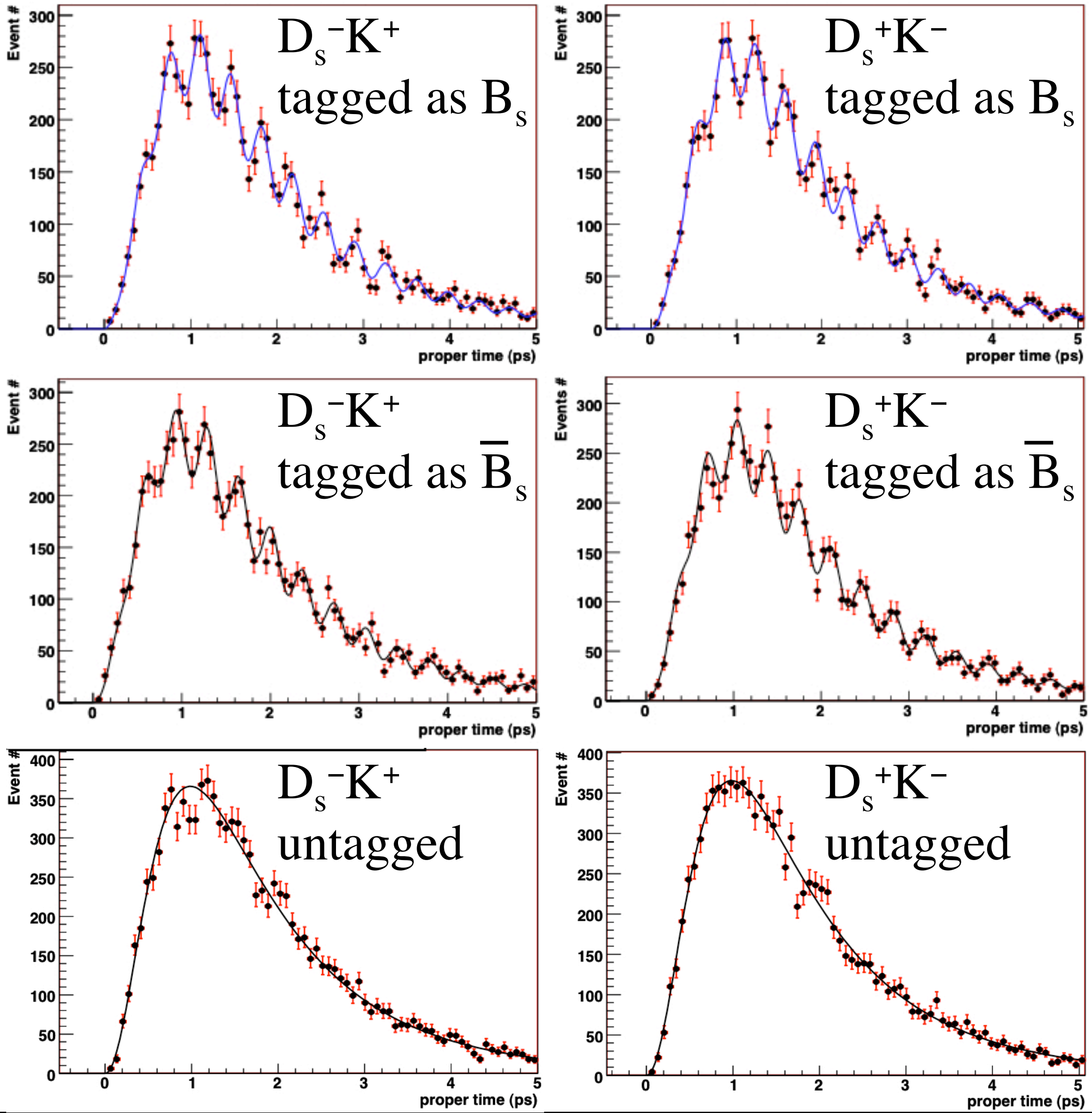
γ from $B_s \rightarrow D_s K$

CERN-LHCb-2007-041

- Fit 4 tagged and 2 untagged time-dependent rates:
  - Extract $\gamma+\phi_s$, strong phase difference Δ, amplitude ratio $|\lambda|$
    - $B_s \rightarrow D_s\pi$ also used in the fit to constrain other parameters (mistag rate, Δm_s, $\Delta\Gamma_s$ …)
- With 10 fb^{-1}:

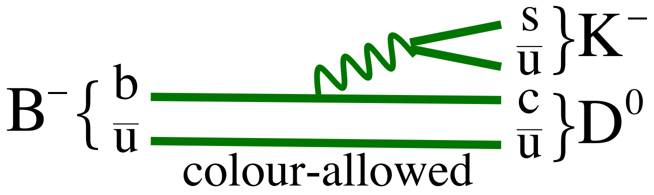
	Tagged & untagged	Tagged only
$\phi_s + \gamma$	**± 4.6°**	± 5.7°
Δ	± 4.6°	± 5.4°
$\lvert\lambda\rvert$	± 0.027	± 0.029

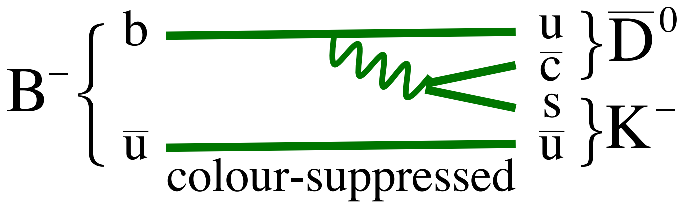
(γ=60°, Δ=0, $|\lambda|$=0.37, Δm_s=17.5 ps^{-1}, $\Delta\Gamma_s/\Gamma_s$=0.1)



γ from $B^\pm \to DK^\pm$ (ADS)

CERN-LHCb-2006-066
CERN-LHCb-2007-004
CERN-LHCb-2007-043





Weak phase difference = $-\gamma$
Strong phase difference = δ
Magnitude ratio = $r_B \sim 0.08$

❑ "ADS+GLW" strategy:

- Measure the relative rates of $B^- \to DK^-$ and $B^+ \to DK^+$ decays with neutral D's observed in final states such as: $K^-\pi^+$ and $K^+\pi^-$, $K^-\pi^+\pi^-\pi^+$ and $K^+\pi^-\pi^+\pi^-$, K^+K^-
- These depend on:
  - Relative magnitude, weak phase and strong phase between $B^- \to D^0K^-$ and $B^- \to \bar{D}^0K^-$
  - Relative magnitudes (known) and strong phases between $D^0 \to K^-\pi^+$ and $\bar{D}^0 \to K^-\pi^+$, and between $D^0 \to K^-\pi^+\pi^-\pi^+$ and $\bar{D}^0 \to K^-\pi^+\pi^-\pi^+$
- Can solve for all unknowns, including the weak phase γ:

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

  – depending on D strong phases
- Use of $B^\pm \to D^*K^\pm$ under study

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

γ from $B^\pm \to DK^\pm$ (GGSZ)

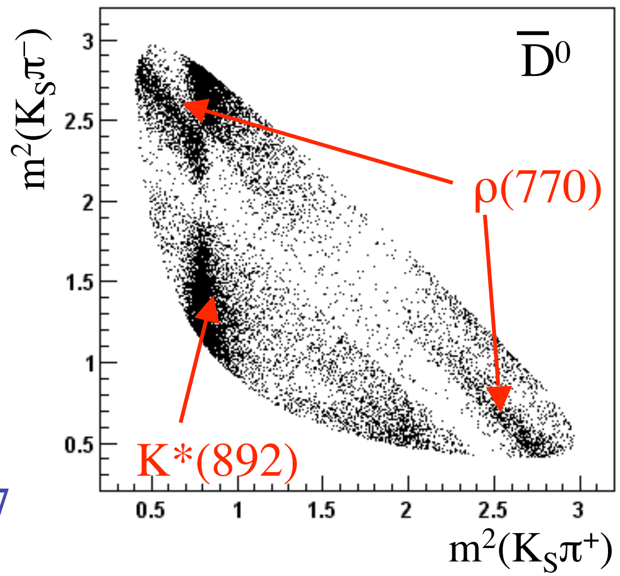
CERN-LHCb-2007-048

- Giri-Grossman-Soffer-Zupan method with 3-body $\mathbf{D^0 \to K_S\pi^+\pi^-}$ decay
  - Large strong phases between the intermediate resonances allow the extraction of r_B, γ and δ by studying the D-Dalitz plots from B^+ and B^- decays

$$A(B^\pm \to DK^\pm) = f(m_\pm^2, m_\mp^2) + r_B e^{i(\pm\gamma+\delta)} f(m_\mp^2, m_\pm^2)$$

$$m_\pm^2 = m(K_S^0 \pi^\pm)$$

$$f(m_\pm^2, m_\mp^2) = \text{Dalitz amplitudes}$$



  - Clean, but need to assume $D^0 \to K_S\pi^+\pi^-$ 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 ($D^0\pi$), $B_{bb}/S < 0.7$

$\sigma_{stat}(\gamma)$ = 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 $B^\pm \to D$(4-Dalitz)$K^\pm$

CERN-LHCb-2007-004
CERN-LHCb-2007-098

$\sigma(\gamma)$ = 18° with 2 fb^{-1}

4-body Dalitz analysis of 1.7k $B^+ \to D^0(K^+K^-\pi^+\pi^-)K^+$ signal events, $B/S = 0.9\pm0.4$ (for $r_B = 0.1$)

γ from $B^0 \to D^0K^{*0}$

CERN-LHCb-2007-050

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

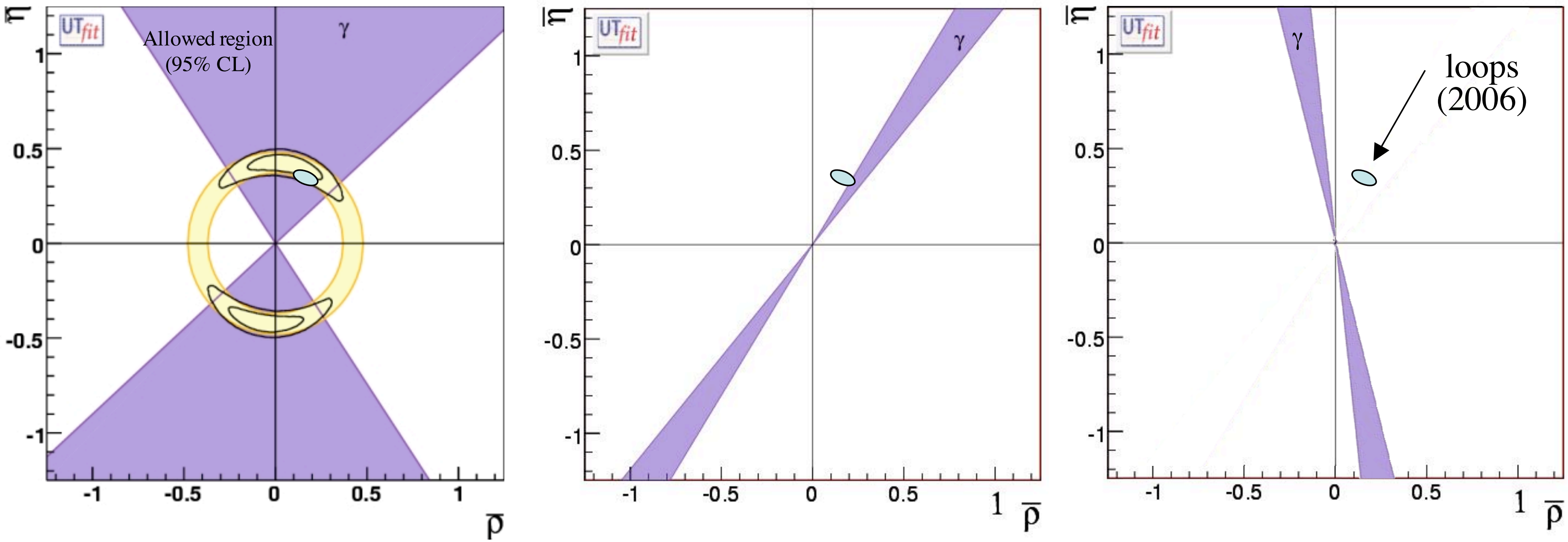
- Envisage also GGSZ analysis

Impact of LHCb on CKM angle γ

- Precise measurement of γ missing in UT evaluation so far
- Combined LHCb sensitivity to γ with tree decays only (educated guess):
  - $\sigma(\gamma)$ ~5° with 2 fb^{-1}, ~2.5° with 10 fb^{-1}

Current situation
(Summer 2006)

γ from B→DK at LHCb after 10 fb^{-1}
(two possible scenarios for the central value)



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

CERN-LHCb-2007-059

- **Measure CP asymmetry in each mode:**

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

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

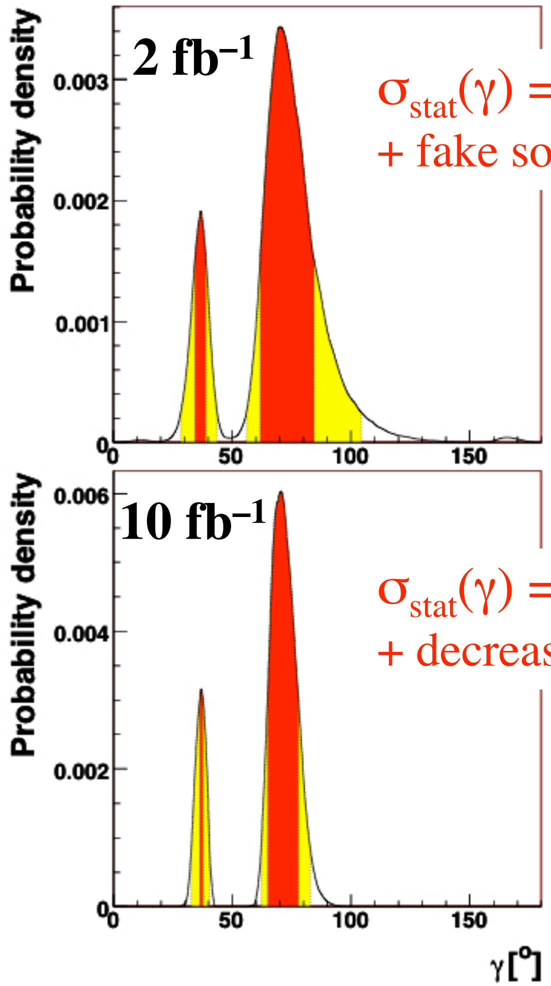
$\sigma(\mathcal{A}^{dir}_{\pi\pi})$	0.043	$\sigma(\mathcal{A}^{dir}_{KK})$	0.042
$\sigma(\mathcal{A}^{mix}_{\pi\pi})$	0.037	$\sigma(\mathcal{A}^{mix}_{KK})$	0.044

~ 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 $d\,e^{i\theta}$

- **Exploit U-spin symmetry (Fleischer):**
  - If $d_{\pi\pi}=d_{KK}$ and $\theta_{\pi\pi}=\theta_{KK}$ assumed:
    - 4 measurements and 3 unknowns
      $\to$ can solve for γ
      (taking 2β and ϕ_s from other modes)

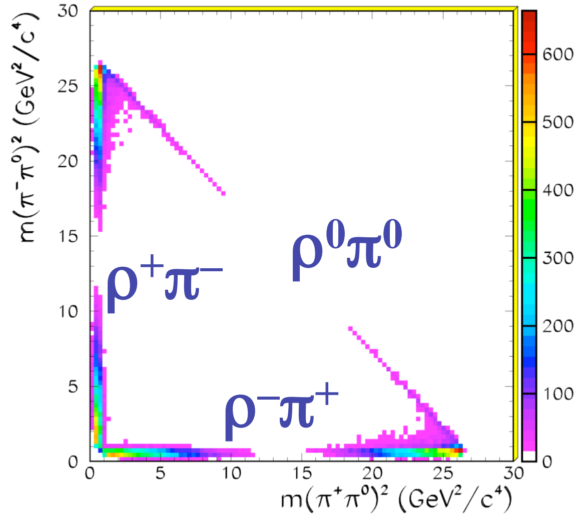
Assume only $0.8 < d_{KK}/d_{\pi\pi} < 1.2$:

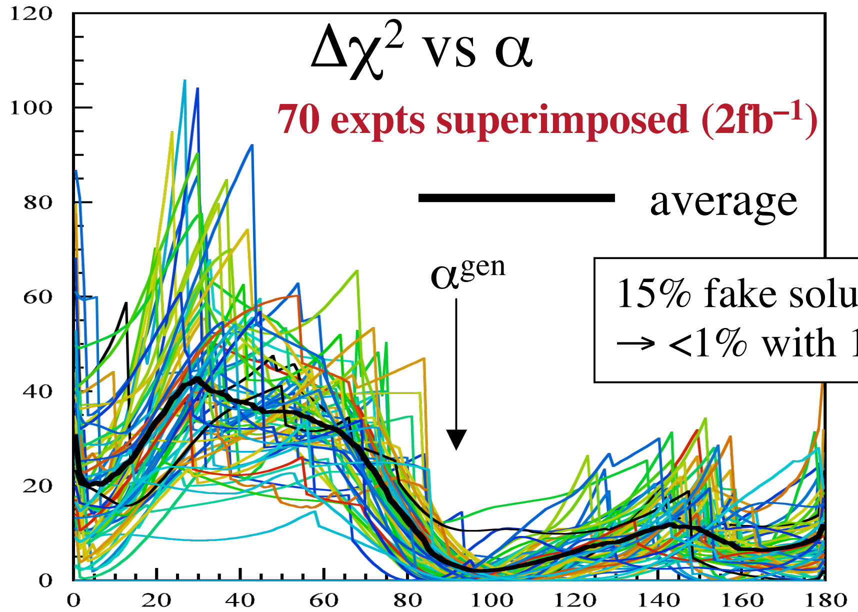


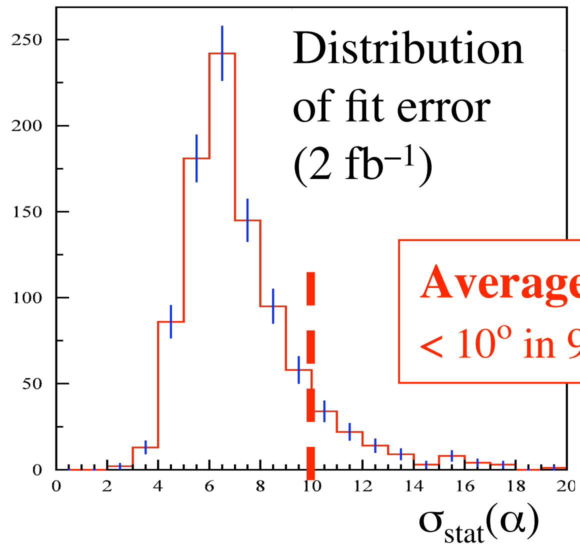
Sensitivity to α

CERN-LHCb-2007-046

- SU(2) analysis of $B^0 \to \rho^+\rho^-, \rho^\pm\rho^0, \rho^0\rho^0$:
  - Main LHCb contribution could be $B^0 \to \rho^0\rho^0$
    1.2k evts/2 fb^{-1}, B/S < 5
- Time-dependent Dalitz plot analysis of
  $B^0 \to \rho\pi \to \pi^+\pi^-\pi^0$ (Snyder & Quinn)
  - 14k signal events/2fb^{-1}, $B_{bb}/S < 0.8$ (< 1.6 charmless)







Average $\sigma_{stat}(\alpha) = 8.5^o$
< 10^o in 90% of the cases

Charm physics

CERN-LHCb-2007-049

- Foresee dedicated D* trigger with substantial bandwidth:
  - Huge sample of $D^0 \to h^+h^-$ decays
  - Tag D^0 or anti-D^0 flavor with pion from $D^{*\pm} \to D^0\pi^\pm$

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

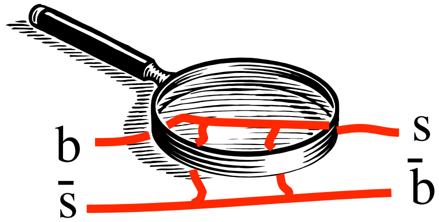
- Interesting (sensitive to NP) and promising searches/measurements:
  - D^0 mixing parameters from time-dependence
    -

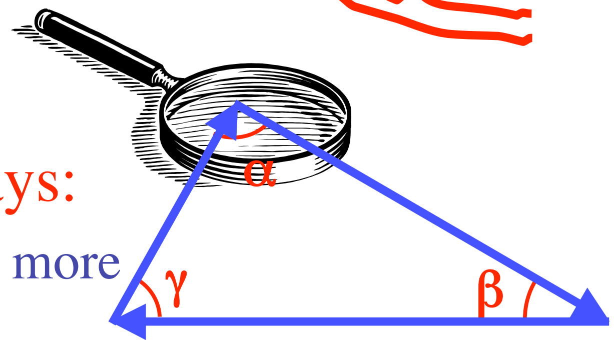
	$\sigma(x'^2)\times10^3$	$\sigma(y')\times10^3$	$\sigma(y_{CP})\times10^3$
LHCb (10 fb^{-1})	0.064 (stat)	0.87 (stat)	0.5 (stat)
B fact. (2 ab^{-1})	0.15	3.0	3.0

  - Direct CP violation in $D^0 \to K^+K^-$
    - $A_{CP} \leq 10^{-3}$ in SM, up to 1% (~current limit) with New Physics
    - Expect $\sigma_{stat}(A_{CP}) \sim O(10^{-3})$ with 2 fb^{-1}
  - $D^0 \to \mu^+\mu^-$
    - $BR \leq 10^{-12}$ in SM, up to 10^{-6} (~current limit) with New Physics
    - Expect to reach down to $\sim 5\times10^{-8}$ with 2 fb^{-1}

Summary for now

- **LHCb can chase New Physics in loop decays:**
  - couple **superb** highly-sensitive b→s observables
    - $B_s \to \mu\mu$
    - B_s mixing phase
  - several other exciting windows of opportunity:
    - Exclusive b → sss Penguin decays (limited, even with 10 fb^{-1})
    - Exclusive b→sll and b→sγ
    - B→ hh Penguins
    - High statistics charm physics
- **LHCb can improve significantly on γ from tree decays:**
  - use together with other UT observables to test CKM even more





But … this is only MC !
Looking forward to start working with real data next year, with complete LHCb detector and successful machine startup

Next step, beyond 10 fb^{-1} ?

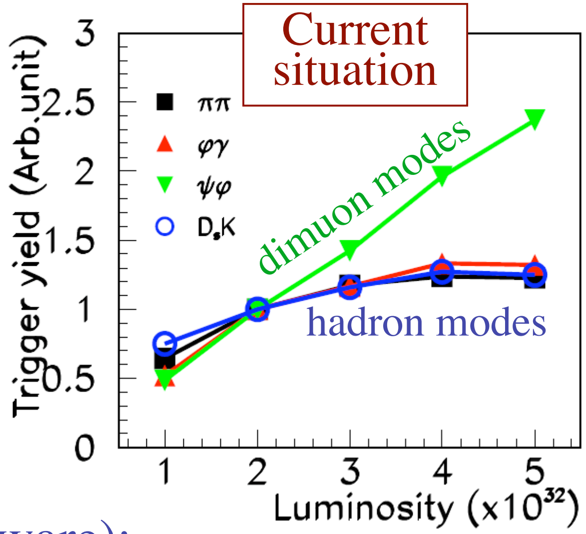
- New physics:
  - expected to be discovered by ATLAS/CMS and/or LHCb in first phase of LHC
  - will contribute to flavour observables, even in MFV scenario

  ⇒ **Better flavour physics sensitivity will be required to probe or further elucidate New Physics flavour structure**

- LHCb:
  - several measurements expected to remain statistically limited after 10 fb^{-1}:
    - CPV in B_s mixing, in particular in $b \to sss$ penguins
      - aim for 0.01 (0.002) precision on $B_s \to \phi\phi$ ($B_s \to J\psi/\phi$) CP asymmetry
    - γ with theoretically clean methods, e.g. $B_s \to D_sK$, $B \to D(K_S\pi\pi)K$, $B \to D(hh)K$
      - aim for $< 1°$ precision on angle γ [+ count on improvements in LQCD]
    - Chiral structure of $b \to s\gamma$ ($b \to sl^+l^-$) using polarization of real (virtual) photon
      - more detailed and precise analysis of exclusive modes, e.g. $A_T^{(2)}$ in $B^0 \to K^*\mu\mu$
    - Hunt for more rare and difficult modes:
      - $B^0 \to \mu\mu$, exclusive $b \to d\gamma$, …

LHCb upgrade baseline

- Aims:
  - Increase luminosity by factor 10:
    - 5 years at 2×10^{33} $cm^{-2}s^{-1}$ = 100 fb^{-1}
  - Improve trigger efficiency



- 3 main issues to be addressed:
  - Trigger bottleneck (1 MHz max. output rate of L0 hardware):
    - Need 40 MHz readout of all detector sub-systems + full trigger on CPU farm to get improved hadron trigger (×2) with yield proportional to luminosity
    - Event building & CPU power OK, but implies replacement of all FE electronics !
  - Radiation damage
    - Need to replace VELO, inner parts of Si tracker, inner part of calorimeter, …
  - Detector occupancy (increased due to pileup ~4 int./crossing + spillover)
    - Need replacement/solution for inner part of Outer Tracker (straws)
    - Need new reconstruction algorithms in high occupancy environment

LHCb upgrade timescale

- LHCb has set up an upgrade WG in early 2007:
  - Examine physics case and required detector R&D
    - 1st LHCb upgrade workshop in Jan 2007
  - Ramp up R&D, feasibility studies, …
- Possible timescale:
  - Decision after having seen some significant results from first phase of LHC
  - Start data-taking with upgraded detector ~4 years later
  - Accumulate 100 fb^{-1} by ~2020
- Note:
  - LHCb upgrade independent of LHC machine luminosity upgrade (SLHC)
    - SLHC not needed for LHCb upgrade & LHCb upgrade compatible with SLHC