B Physics with LHCb

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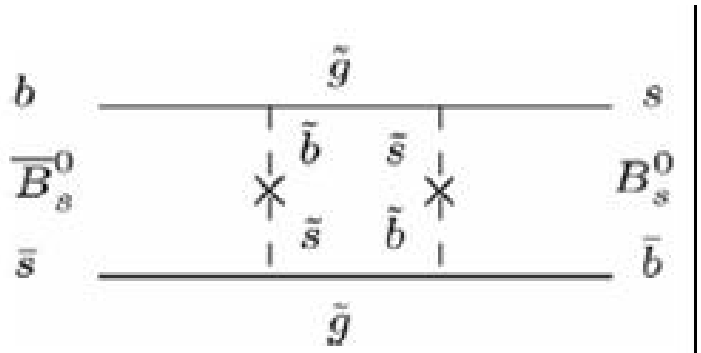
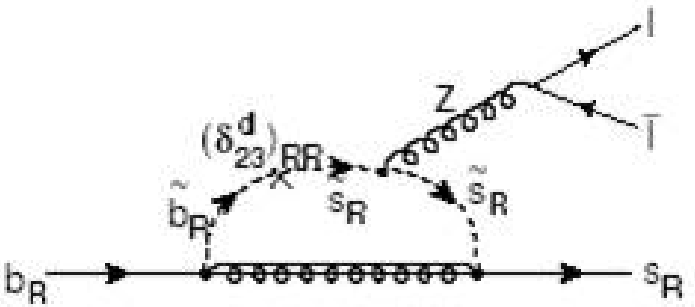
Introduction

- Motivation
- Challenges of LHCb
- LHCb spectrometer
- Expected Results...
- Conclusions

- precise measurement of $B_s^0 - \bar{B}_s^0$ mixing
- precise determination of γ and α
- precise measurement of mixing parameters: $\Delta m_s, \Delta\Gamma_s$
- rare B-decays could yield new physics...

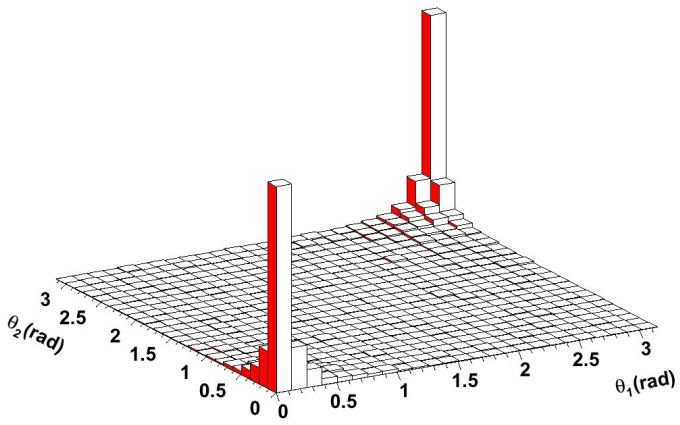
- Sakharov: B, C and CP-violation essential to explain matter over anti-matter abundance in universe
- Level of Standard Model CP-violation seems insufficient (*cf.* Barr, Segrè & Weldon)
- Non SM sources of CP-violation necessary (SUSY?)





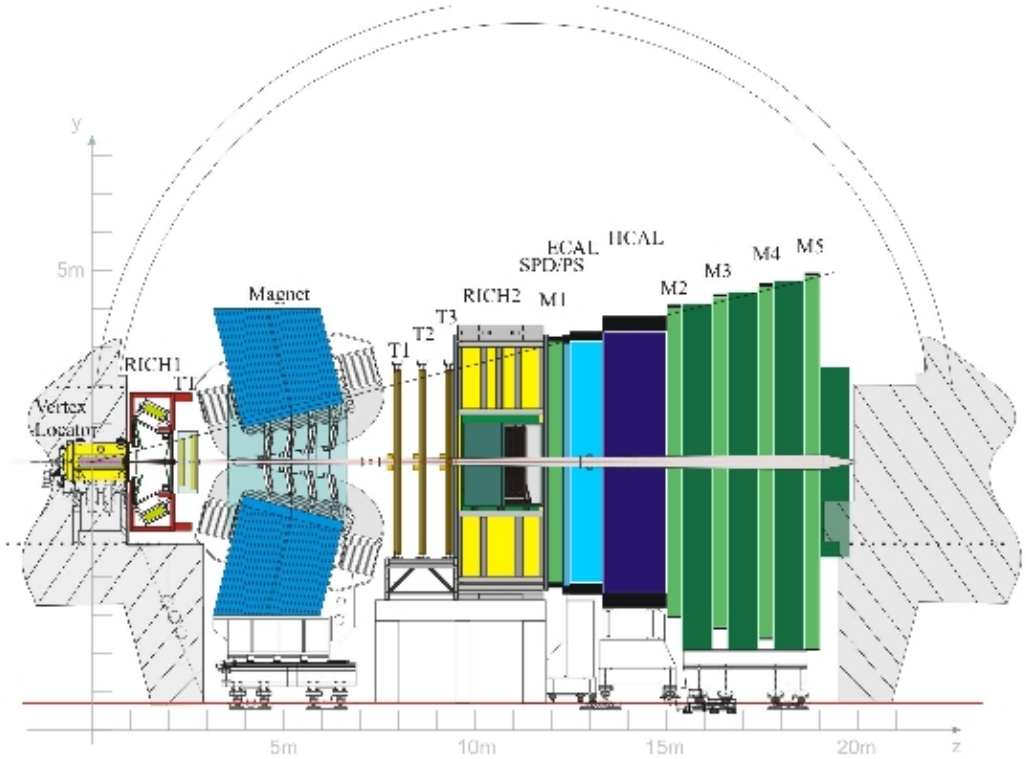
Challenges for LHCb

Large $b\bar{b}$ cross section of $\sigma_{b\bar{b}} = 500\ \mu\text{barn}$ (0.5% of total σ) at $\sqrt{s} = 14\ \text{TeV}$.
pp-collisions at LHC produce $b\bar{b}$'s in forward direction:



- harsh environment from $p\bar{p}$ collisions
- many tracks
- pile up (multiple collisions per bunch crossing)
- select interesting b-physics events among 10^5 $b\bar{b}$/s

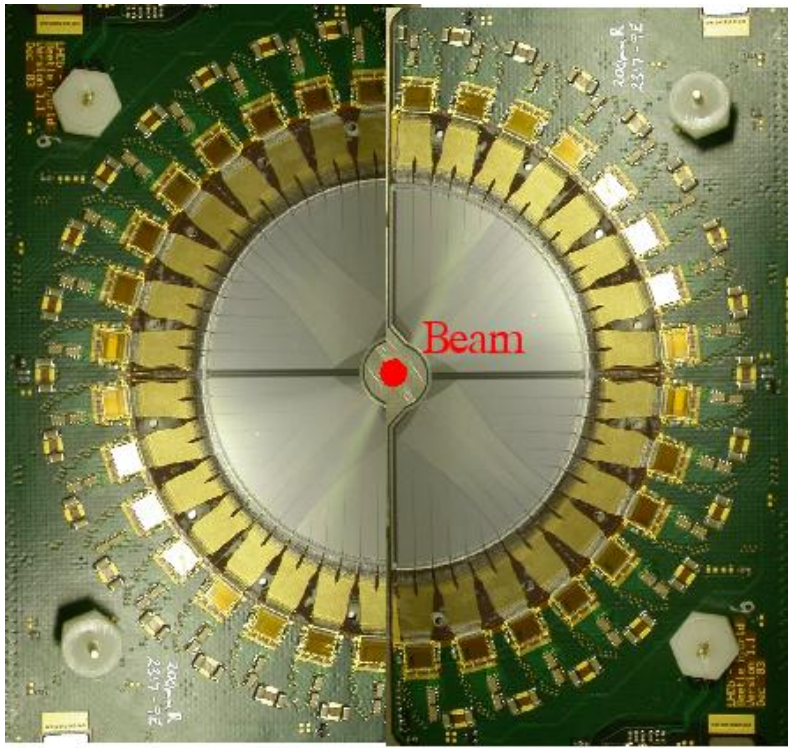
LHCb Spectrometer



- Use low luminosity (2×10^{32} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$)
- trigger: reject minimum bias events
- good IP measurement: $< \delta\mathrm{IP} >= 40\mu\mathrm{m}$
- Good proper time resolution ~ 40 fs
- Good pion/kaon identification from $p = 2 - 100$ GeV

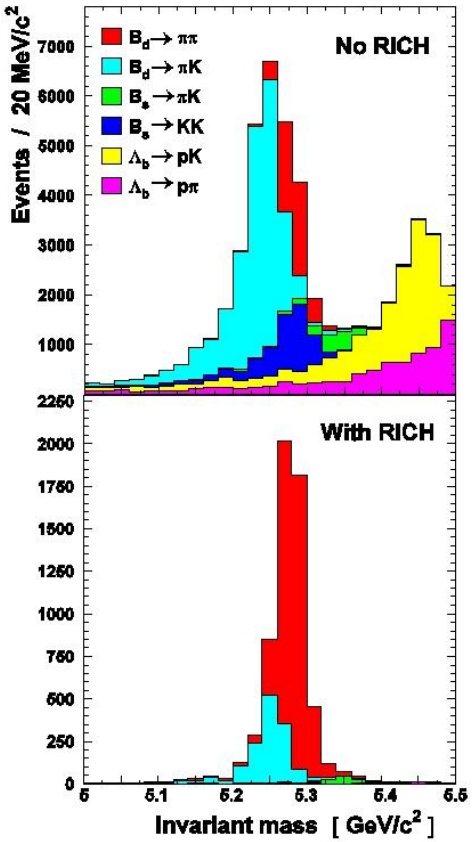
VELO: Silicon Microstrip Detector

- 21 layers of silicon
- use r, ϕ-sensor geometry
- in close proximity to beampipe (8 mm)

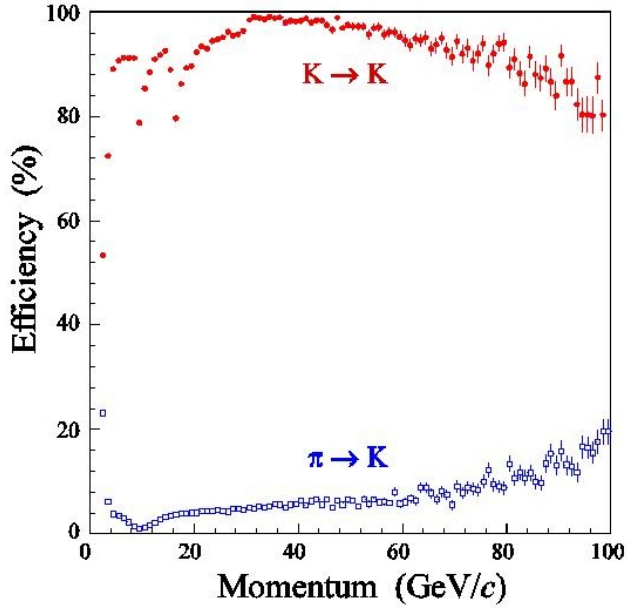


- used for primery vertex information in L1 trigger
- used for IP calculation in HLT

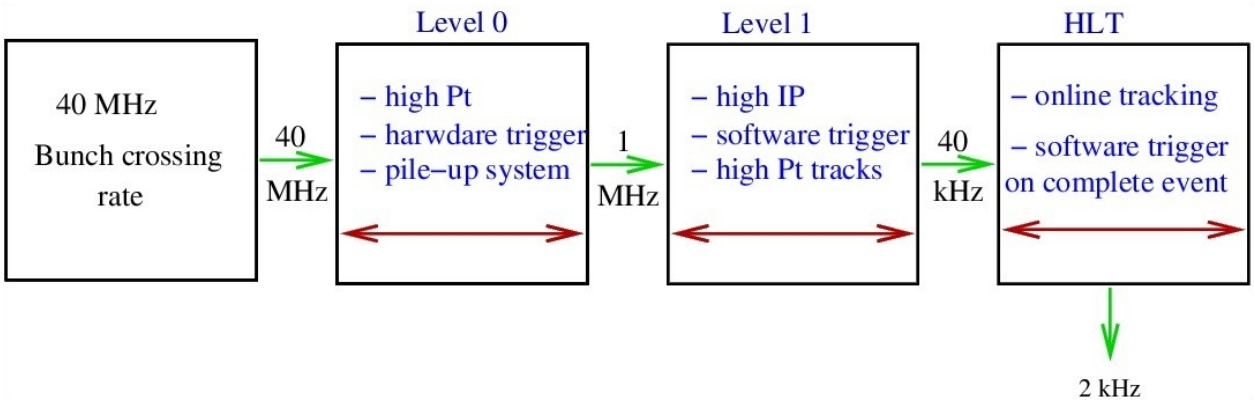
Particle ID: RICH I & II



Good separation of pions & kaons

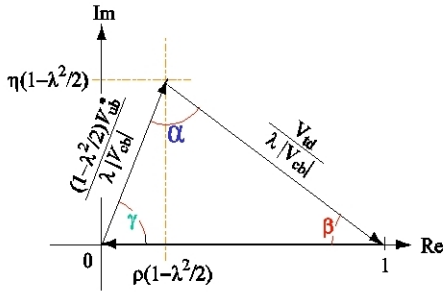


RICH systems use Hybrid Photo Diodes

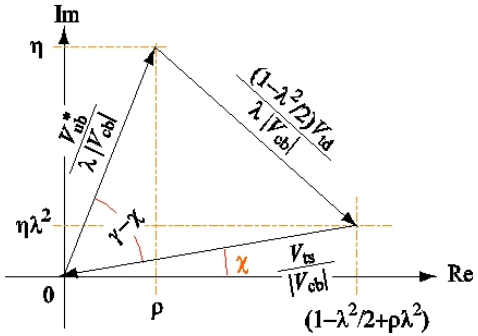


HLT rate	event type	calibration	physics
200 Hz	exclusive B candidates	tagging	core b program
600 Hz	high mass di-muons	tracking	J/Ψ, $B \longrightarrow J/\Psi X$(unbiased)
300 Hz	D^* candidates	PID	Charm, mixing & CPV
900 Hz	inclusive b ($b \longrightarrow \mu$)	Trigger	B (data mining)

$\mathcal{B}^0_d$ system



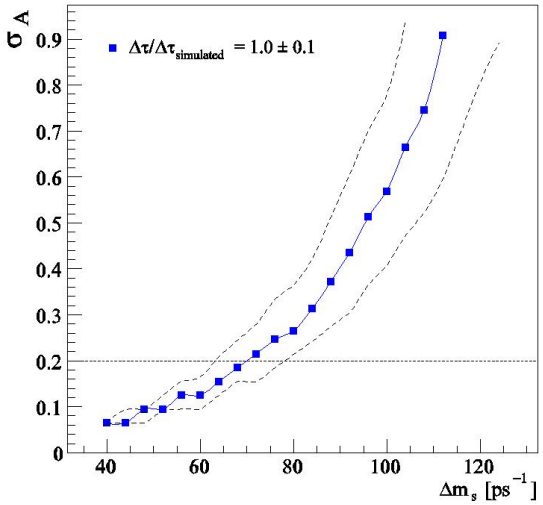
B^0_s system

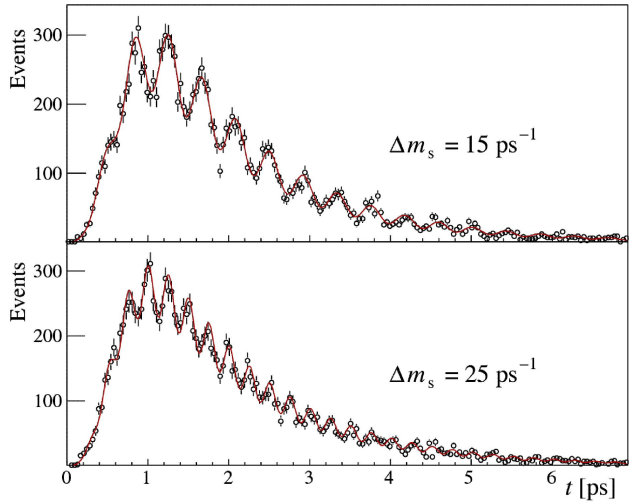


From consulting Pythia (MC calculations), based on 1 fb^{-1}

- Δm_s from $\mathrm{B}^0_s - \bar{\mathrm{B}}^0_s$ oscillations
- ϕ_s and $\Delta\Gamma_s$ from $\mathrm{B}_s \longrightarrow J/\psi\phi$
- $\gamma + \phi_s$ from $\mathrm{D}^+_s\mathrm{K}^-$ and $\mathrm{D}^-_s\mathrm{K}^+$ and CP-conjugates
- ϕ_d, γ from $\mathrm{B}^0 \longrightarrow \pi^+\pi^-$ and $\mathrm{B}^0_s \longrightarrow \mathrm{K}^+\mathrm{K}^-$
- γ from $\mathrm{B}^0 \longrightarrow \mathrm{D}^0\mathrm{K}^{*0}$, $\mathrm{B}^0 \longrightarrow \bar{\mathrm{D}}^0\mathrm{K}^{*0}$, $\mathrm{B}^0 \longrightarrow \mathrm{D}^0_{\mathrm{CP}}\mathrm{K}^{*0}$ and CP-conjugates.
- α from $\mathrm{B} \longrightarrow \rho\pi \longrightarrow \pi^+\pi^-\pi^0$

with $B_s \to D_s^{\pm}\pi^{\mp}$, $D_s^{\pm} \to \phi\pi^{\pm}$ and $\phi \to K^+K^-$



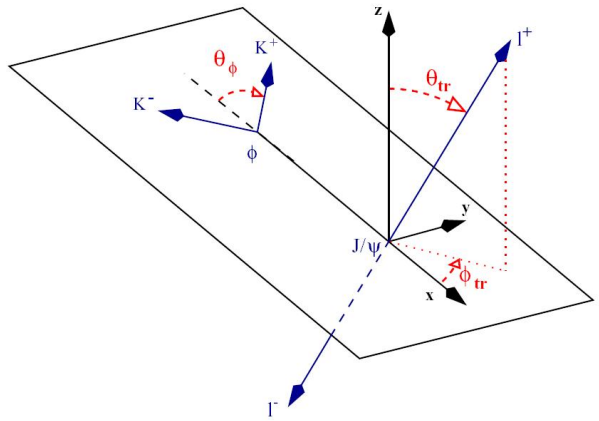


$$\mathcal{A}^{\text{flav}} = -D\frac{\cos(\Delta m_s t)}{\cosh(\Delta\Gamma_s t)}$$

- 80K events/year
- $S/B \approx 3.1$
- 5σ observation possible up to $\Delta m_s = 68\ \text{ps}^{-1}$
- Once measured: $\sigma(\Delta m_s) = 0.01\ \text{ps}^{-1}$.

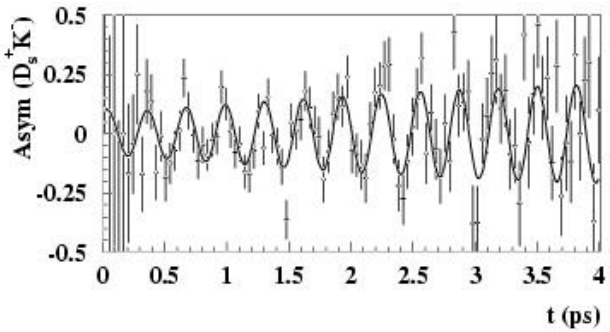
ϕ_s and $\Delta\Gamma_s$ from $B_s \to J/\psi\phi$

- Gold-plated B_s decay: $B_s \to J/\psi\phi$
  - Measure three amplitudes, 2 CP-even, one CP-odd
  - disentangle flavour eigenstates by fitting angular distribution of daughter particles as a function of proper time
- SM prediction: $\phi_s = -2\lambda^2\eta \approx -0.04$; sensitive to NP in B_s mixing
- $\Delta\Gamma_s = \Gamma(B_s^L) - \Gamma(B_s^H)$, SM: $\Delta\Gamma_s/\Gamma_s =\sim 0.2$
  - LHCb 100K events/year for $B_s \to J/\psi\phi$ with $S/B > 3$
  - LHCb: $\sigma(\Delta\Gamma_s/\Gamma_s) = 0.018$
  - can also use $B_s \to J/\psi\eta$ and $B_s \to \eta_c\phi$



Determining $\gamma + \phi_s$ and strong phase Δ

- Need to reconstruct 4 time-dependent decay rates
  - $B_s \to D_s^{\pm} K^{\mp}$ and CP-conjugates
  - phase extracted from $D_s^{+} K^{-}$: $\Delta - (\gamma + \phi_s)$
  - phase extracted from $D_s^{-} K^{+}$: $\Delta + (\gamma + \phi_s)$
- use ϕ_s from $B_s \to J/\psi\phi$

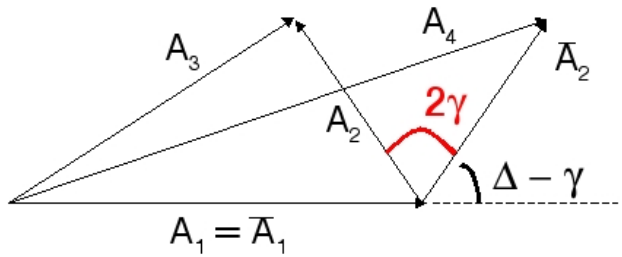


- results in γ independent of NP, since only tree-diagrams contribute
- good pion-kaon separation imperative
- LHCb yield: 5.4K events/year with $S/B > 1.0$

LHCb: $\sigma_\gamma = 14^\circ$ with one year of data

Measure 6 time-integrated decay rates: $B^0 \to D^0 K^{*0}$, $B^0 \to \bar{D}^0 K^{*0}$, $B^0 \to D^0_{CP} K^{*0}$ and CP conjugates. Use the Dunietz variant of the Gronau-Wyler method:

$$
\begin{aligned}
A_1 &= A(B^0 \to \bar{D}^0 K^{*0}) \\
A_2 &= A(B^0 \to D^0 K^{*0}) \\
A_3 &= \sqrt{2} A(B^0 \to D^0_{CP} K^{*0}) \\
A_4 &= \sqrt{2} A(\bar{B}^0 \to D^0_{CP} \bar{K}^{*0})
\end{aligned}
$$



$$A_3 = (|A_1| + |A_2| e^{i(\Delta+\gamma)})$$

Channel	Yield	S/B
$B^0 \to \bar{D}^0(K\pi)K^{*0}(K^+\pi^-)$	3K	> 1.6
$B^0 \to D_{CP}(K^+K^-)K^{*0}(K^+\pi^-)$	0.5K	> 0.3

Result: in 1 year of datataking, $\sigma(\gamma) \approx 7°$-$8°$

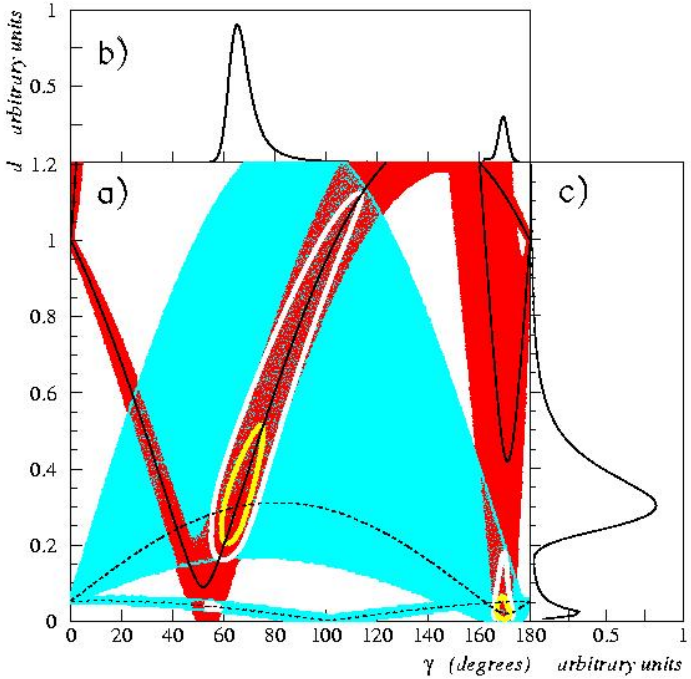
- Assuming U-spin flavour symmetry holds for QCD
- ϕ_s, ϕ_d taken from other measurements

$$\mathcal{A}_{CP}(t) = \mathcal{A}_{dir}\cos(\Delta m t) + \mathcal{A}_{mix}\sin(\Delta m t)$$

$$\mathcal{A}_{CP}(t) = \frac{2d\sin\theta\sin\gamma}{1 - 2d\sin\theta\sin\gamma + d^2}$$

asymmetries depend on

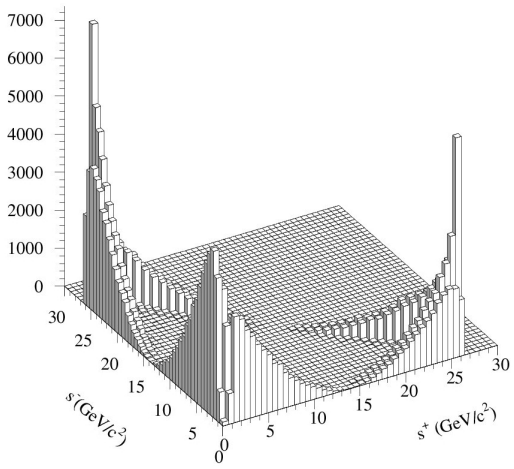
- ϕ_d, ϕ_s and γ
- ratio of penguin and tree amplitudes: $P/T = de^{i\theta}$
- 4 measurements, three variables $\to$ determine γ
- apply unbinned extended likelihood fit to asymmetries including background
- 17 free parameters, including 6 for mass and proper time resolutions of background

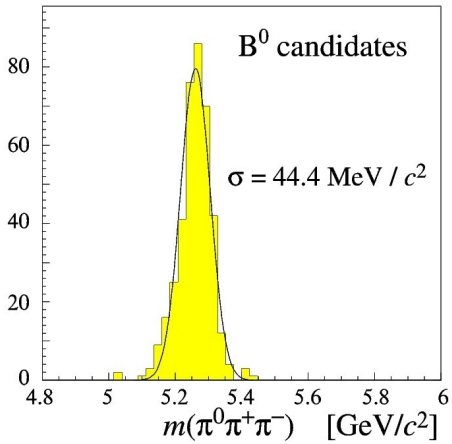


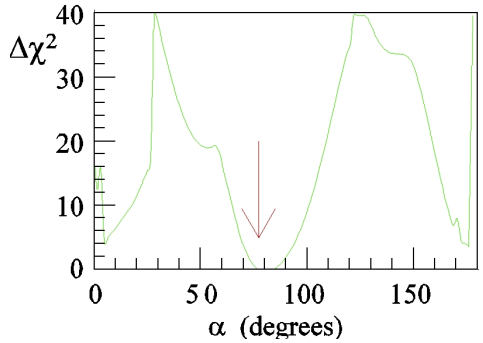
26k $B^0 \to \pi^+\pi^-$, 37k $B_s^0 \to K^+K^-$ $\Rightarrow \sigma(\gamma) = 4° - 6° + \sigma(\text{theory})$

Determining α from B $\rightarrow \rho\pi$

- time-dependent Dalitz plot analysis *cf.* Snyder & Quinn
- extraction of α and strong phases
- multi-parameter fit including (non-)resonant background
- $s^- = M(\pi^0, \pi^-)$ and $s^+ = M(\pi^0, \pi^+)$







- 10.8k events, S/B > 0.3 in one year
- $\sigma(\alpha) < 10^\circ$

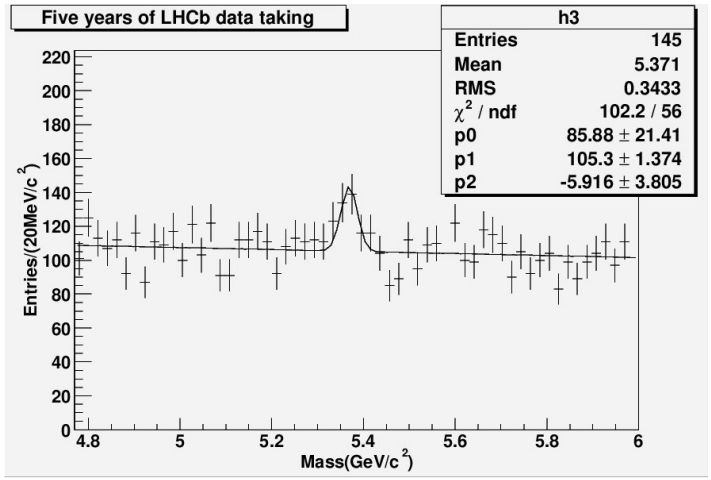
Standard Model prediction for $\mathrm{Br}(\mathrm{B_s} \to \mu^+\mu^-) = 3.5 \times 10^{-9}$

- sensitive to New Physics
- for instance: channel is enhanced in SUSY models

- In one year: 17 SM events...
- $\mathrm{S}/\mathrm{B} \sim 0.2$
- 18 MeV resolution

$\mathrm{B}^0 \to \phi \mathrm{K_S}$

- challenging for trigger
- 1k events per year
- if NP, then also study $\mathrm{B_s} \to \phi\phi, \mathrm{KK}, \phi\gamma$ etc.



Conclusions

- LHCb offers great opportunity for an extensive program on B-physics
- excellent vertex resolution and particle identification
- efficient trigger
- Precise measurements of
  - B_s^0-$\bar{B}_s^0$ mixing: $\Delta\Gamma_s$, Δm_s and ϕ_s
  - compare different measurements on γ to identify possible NP
  - possible NP can be detected in BR measurements of rare decays
  - overconstrain unitarity triangle