The LHCb experiment

(selected topics)

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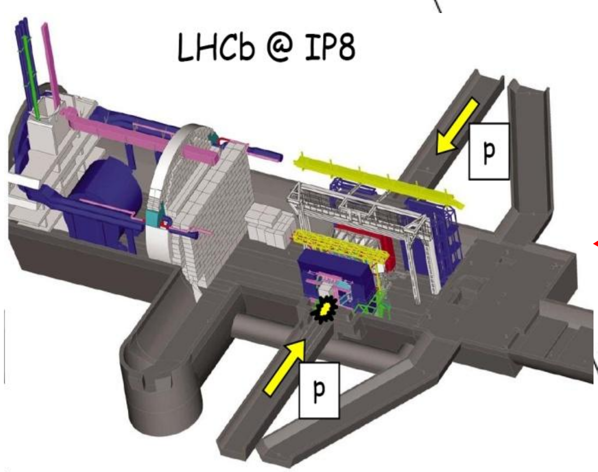
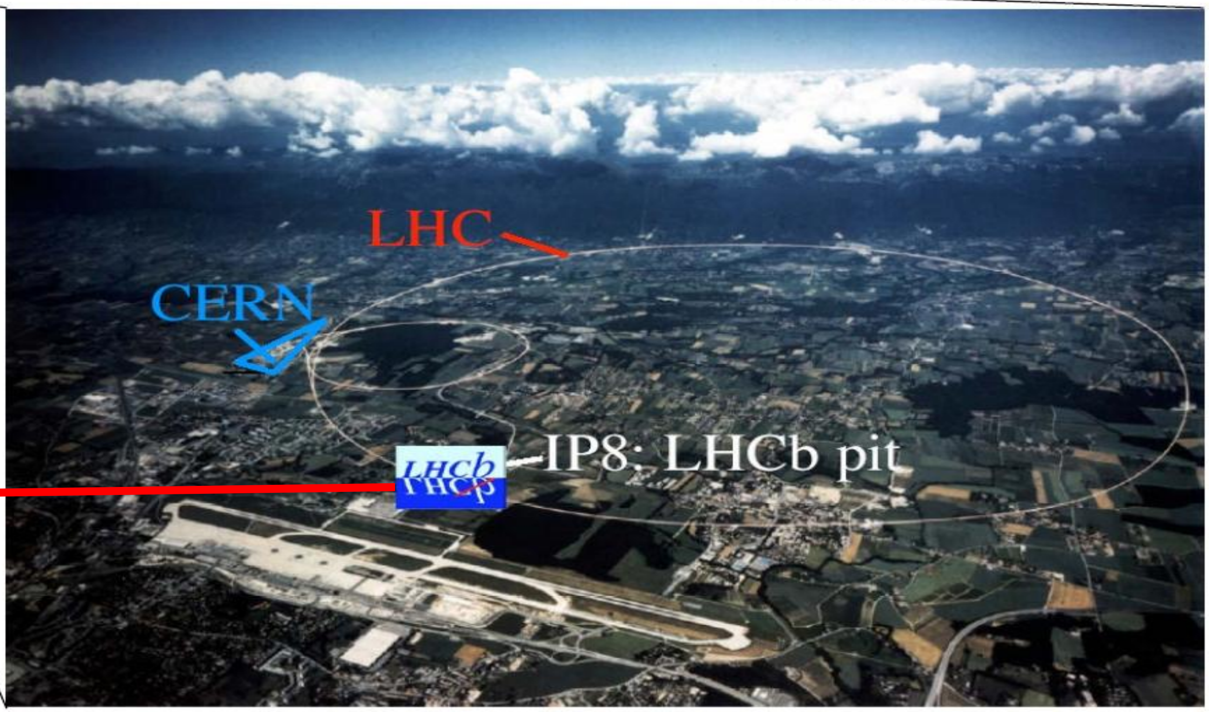
Outline

- **LHCb** Collaboration & **LHCb** Experiment
- The precise ***CP*** measurements and hunting for New Physics
  - ***CP***-measurements
    - the measurement of γ
    - the measurement of β_s (ϕ_s, χ)
  - Rare (loop) decays of beauty hadrons and the tests for the Lorentz structure for $\mathbf{b\to s}$ transitions
- Current Status of **LHCb**

LHCb Collaboration

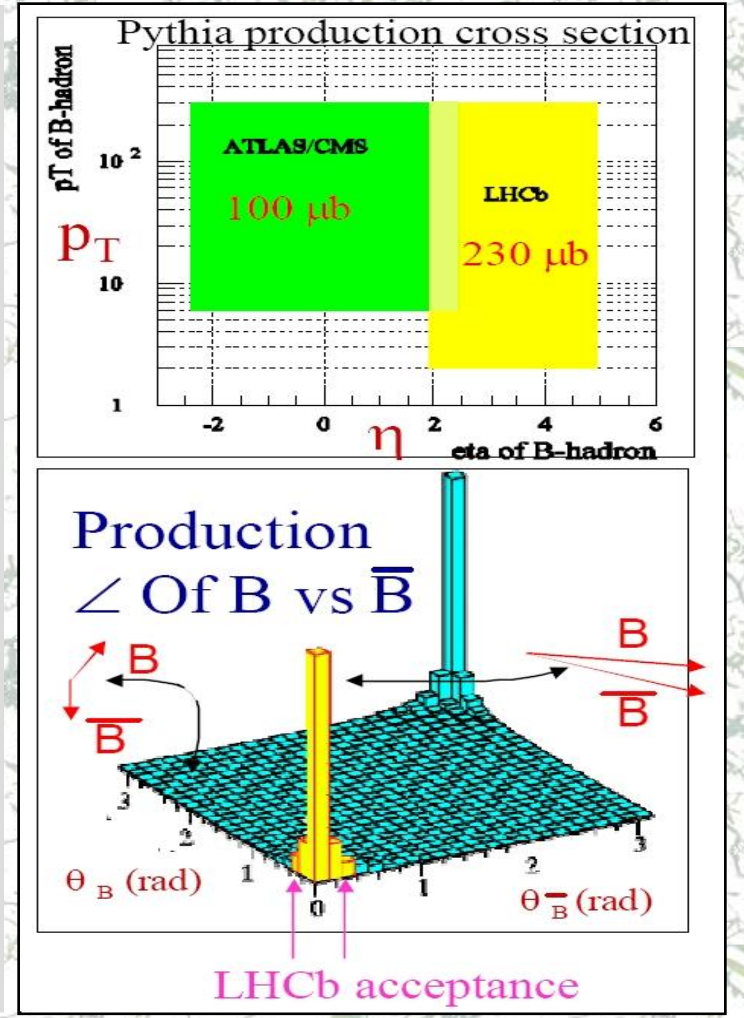
14 countries
48 institutions
~600 people



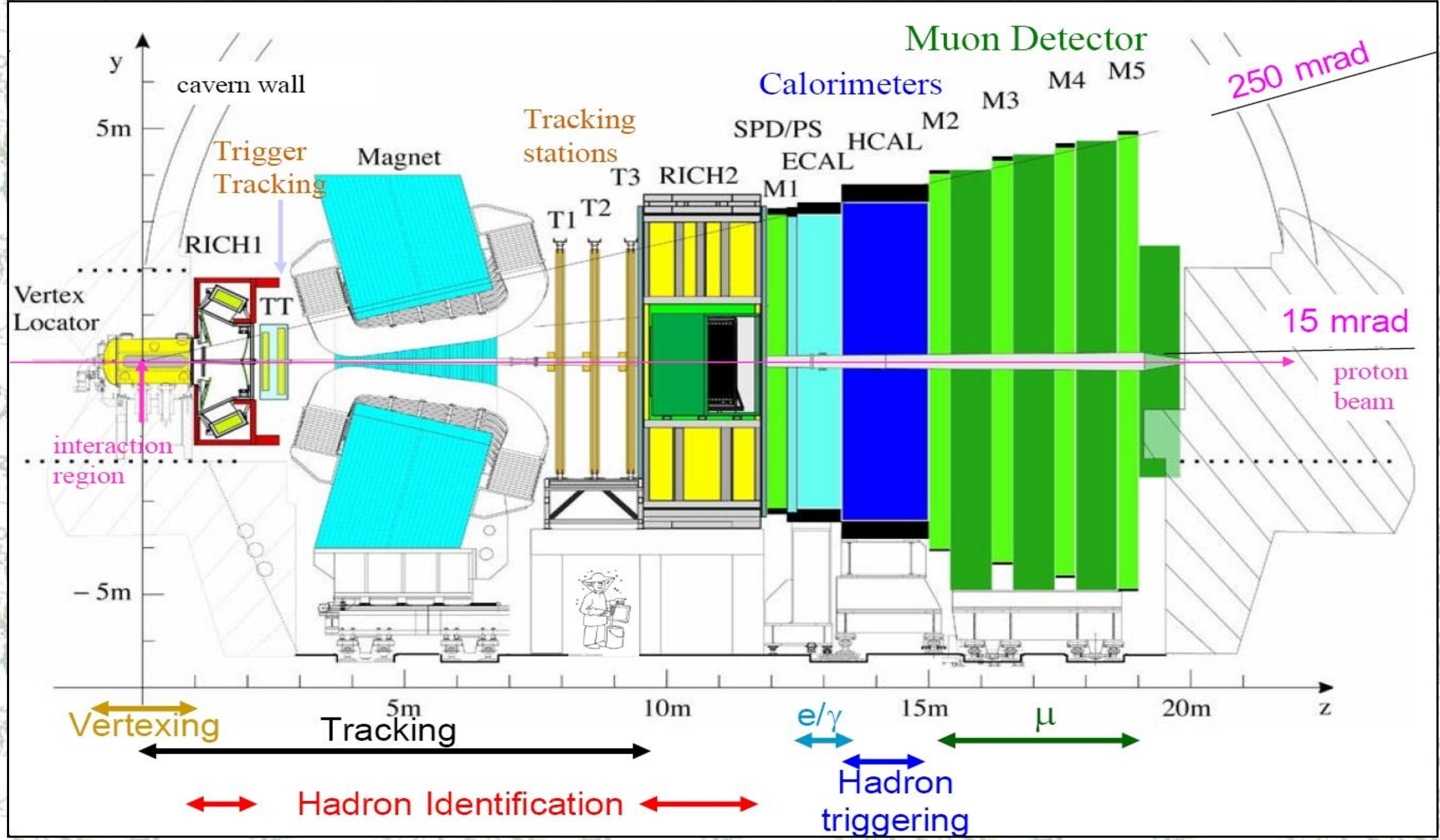


b-production pp@√s=14TeV

- In the forward region σ_b is large
  - $O(10^{12})$ B-hadrons per 10^7 s at $L=2*10^{32}$
  - Limited solid angle → Limited cost
- Both B-hadrons in events are likely to be in acceptance
  - b-flavor tagging!
- B-hadrons are moving with large momentum $\beta\gamma=O(20)$, $l_B\sim 1$cm
  - Minimize the multiply scattering
  - Background rejection via detached vertex
  - Improved decay time resolution



LHCb Detector (sketch)



LHCb Detector in Cavern

The (sub)detectors are being commissioned ***now***. Data taking with cosmic events.
Webcam at **http://cern.ch/lhcb/web-cam.htm**

Physics case

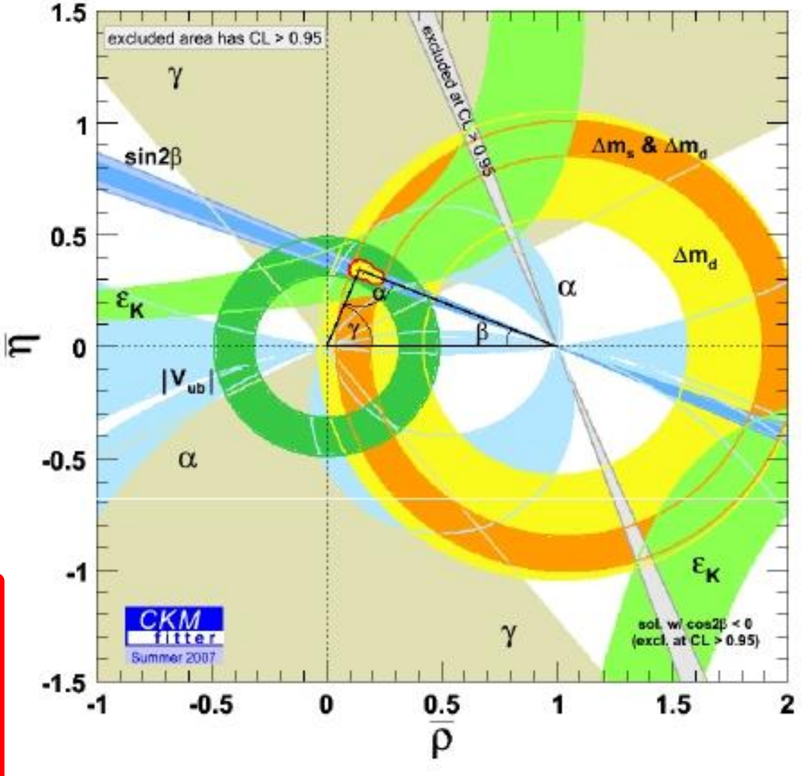
- We know that SM requires some "extensions"
  - New Physics should be somewhere around
- Two complementary ways of NP hunting:
  - The direct hunt, "energy frontier"
    - large universal high-p_T experiments:
      - CDF&D0 now,
      - CMS&ATLAS from summer 2008
  - The *precise* measurements at "low" energy m_b, decays of beauty hadrons
      - BaBar(till April)&Belle
      - LHCb(from summer 2008), SuperBF/SuperFF

The direct production

The detection through the loops

CKM paradigm & Unitarity Triangle

Parameter	Value
α (°)	$87.5^{+6.2}_{-5.3}$
$\sin(2\beta)$	0.688 ± 0.025
γ (°)	$76.8^{+30.4}_{-31.5}$
ϕ_s (rad)	$-0.79\pm0.56^{+0.01}_{-0.14}$



Plot and precisions taken from the CKMFitter Summer 2007 update

- Thanks to **BaBar&Belle** we know that **CKM** paradigm is able to describe current data
  - NP effects are “small”
- Need for precise measurements and new observables, e.g. B_s or Λ_b decays
  - Large statistics
  - Excellent detectors
- On Market
  - **LHCb**
  - SuperB/SuperFF

Measurement of γ

$B_s \to K^+K^-$ & $B_d \to \pi^+\pi^-$

$B^\pm \to D^0K^\pm$

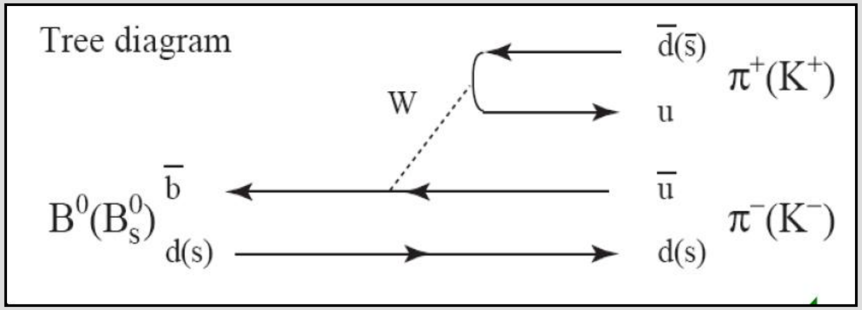
$B_d \to D^0K^*$

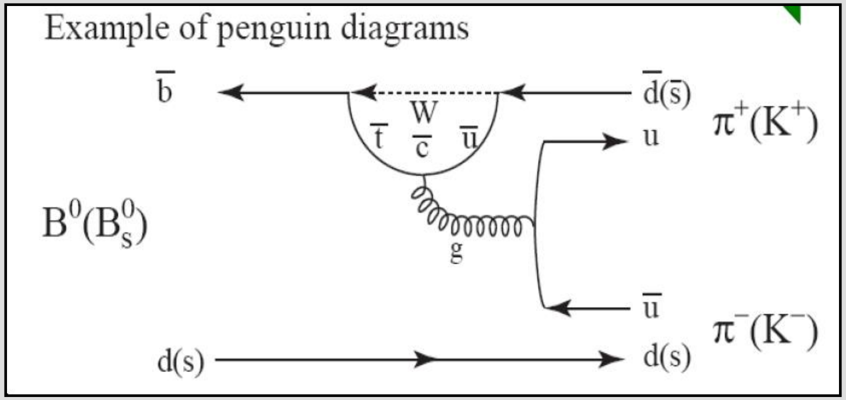
$B_s \to D_sK$

Complementary measurements:

- Hunt for discrepancy, NP affects differently

$B_s \to K^+K^-$ & $B_d \to \pi^+\pi^-$ (I)





- Due to large *penguin* contribution is sensitive to NP in penguins
- Extract γ from A_{CP}

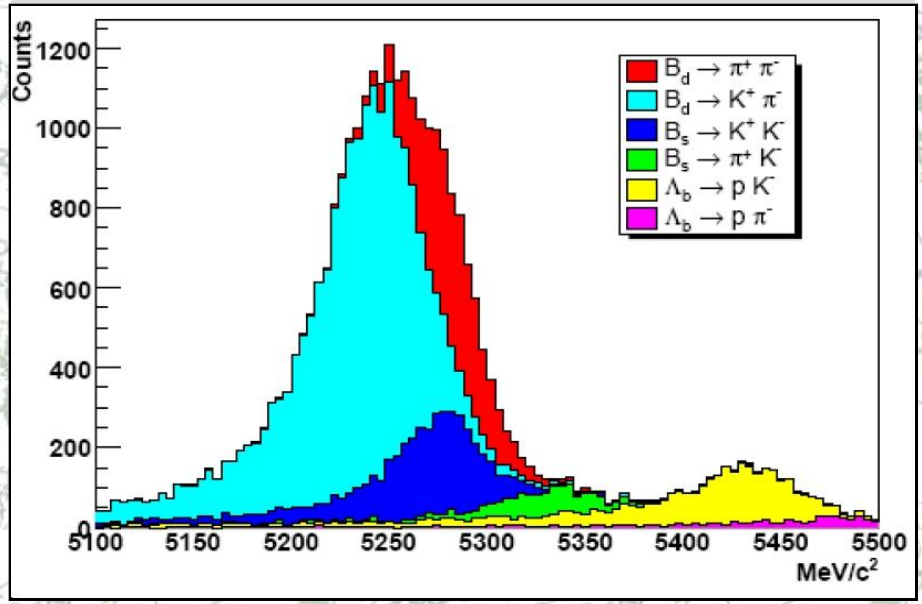
$$A_{CP}(t) = \frac{A_{dir}\cos(\Delta m t) + A_{mix}\sin(\Delta m t)}{\cosh(\Delta\Gamma t/2) + A_{\Delta\Gamma}\sinh(\Delta\Gamma t/2)}$$

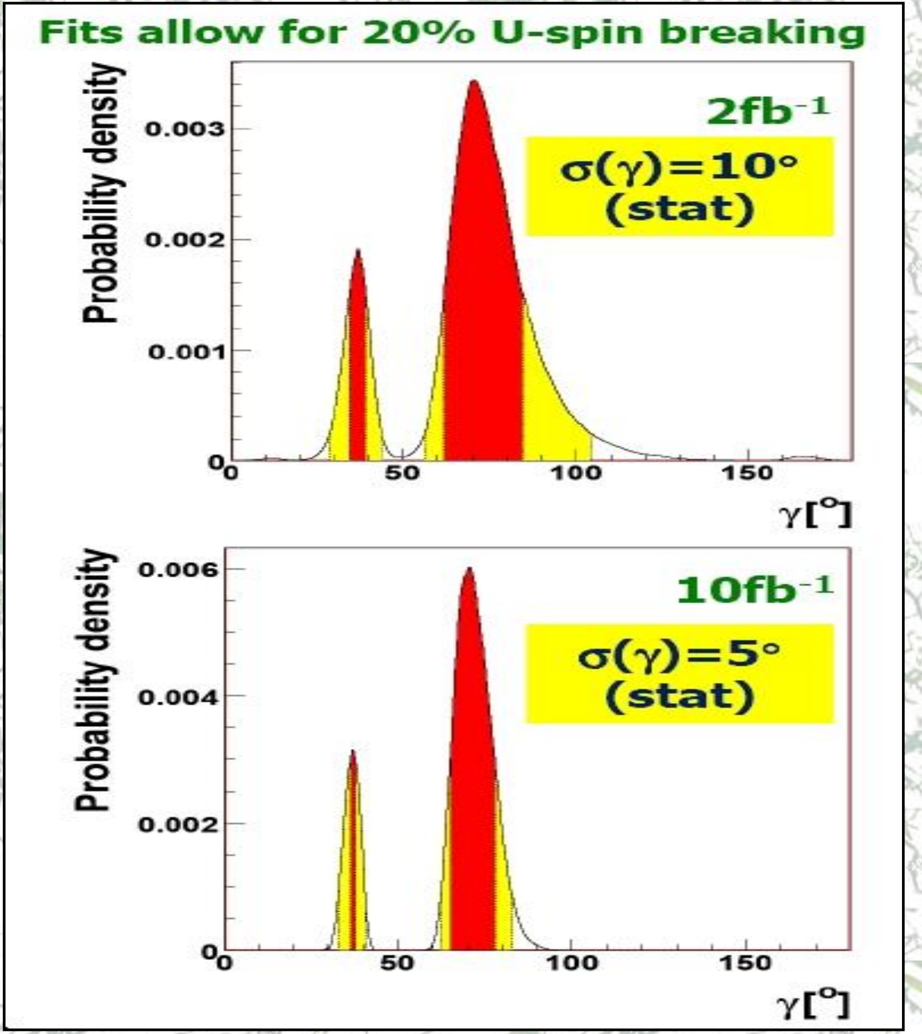
- A_{mix} & A_{dir} depends on ***P/T*** ratio $de^{i\theta}$
  - Different for each mode
- U-spin (Fleischer):
  - $d_{\pi\pi} = d_{KK}$ & $\theta_{\pi\pi} = \theta_{KK}$

$B_s \to K^+K^-$ & $B_d \to \pi^+\pi^-$ (II)

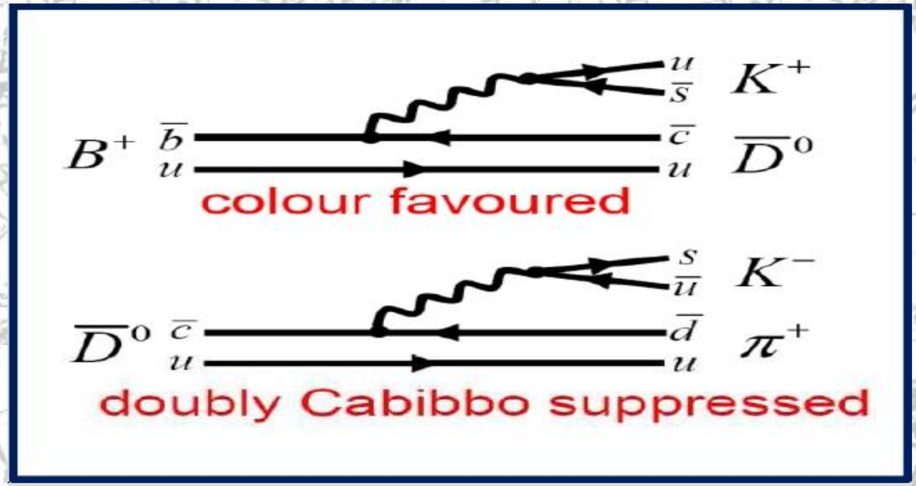
Channel	Yield ($2fb^{-1}$)	B/S
$B_s \to KK$	36k	0.06
$B_d \to \pi\pi$	36k	0.46

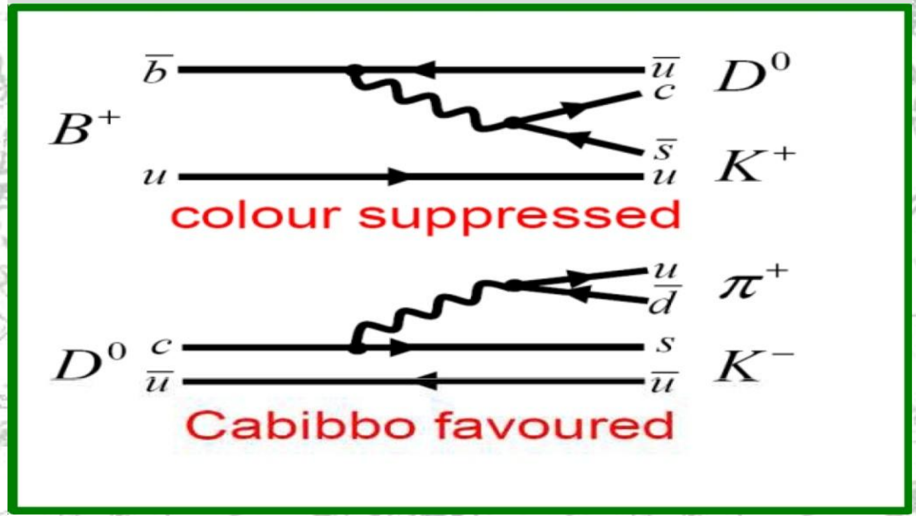
$\sigma(\mathcal{A}^{dir}_{\pi\pi})$	0.043	$\sigma(\mathcal{A}^{dir}_{KK})$	0.042
$\sigma(\mathcal{A}^{mix}_{\pi\pi})$	0.037	$\sigma(\mathcal{A}^{mix}_{KK})$	0.044





$B^{\pm} \to D^0 K^{\pm}$ ADS+GLW





- Trees only!
  - Only D^0-mixing box
- The measured rates depend on γ, strong phases in **B** and **D** decays, and the relative magnitudes
- More information from ***CP***-eigenstates of **D**

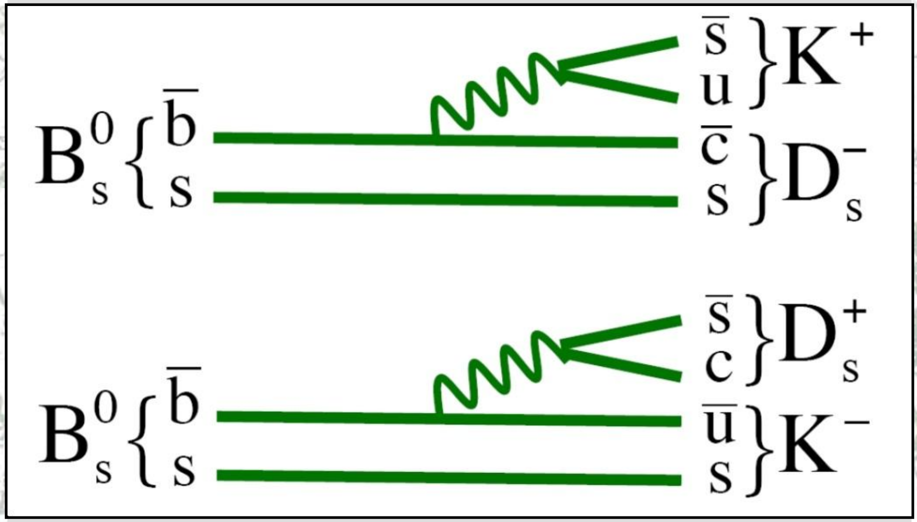
$B^{\pm}\rightarrow D^0K^{\pm}$ ADS+GLW

	Signal Yield (2fb^{-1})	Background Yield (2fb^{-1})
$B\rightarrow D(K\pi)K$, favoured	56k	35k
$B\rightarrow D(K\pi)K$, suppressed	0.71k	1.5k
$B\rightarrow D(K\pi\pi\pi)K$, favoured	62k	40k
$B\rightarrow D(K\pi\pi\pi)K$, suppressed	0.76k	2.4k
$B\rightarrow D(hh)K$	7.8k	14k

- Can achieve $\sigma(\gamma)=5^o\text{-}13^o$ for 2fb^{-1}
  - depending on strong phases in D-decays

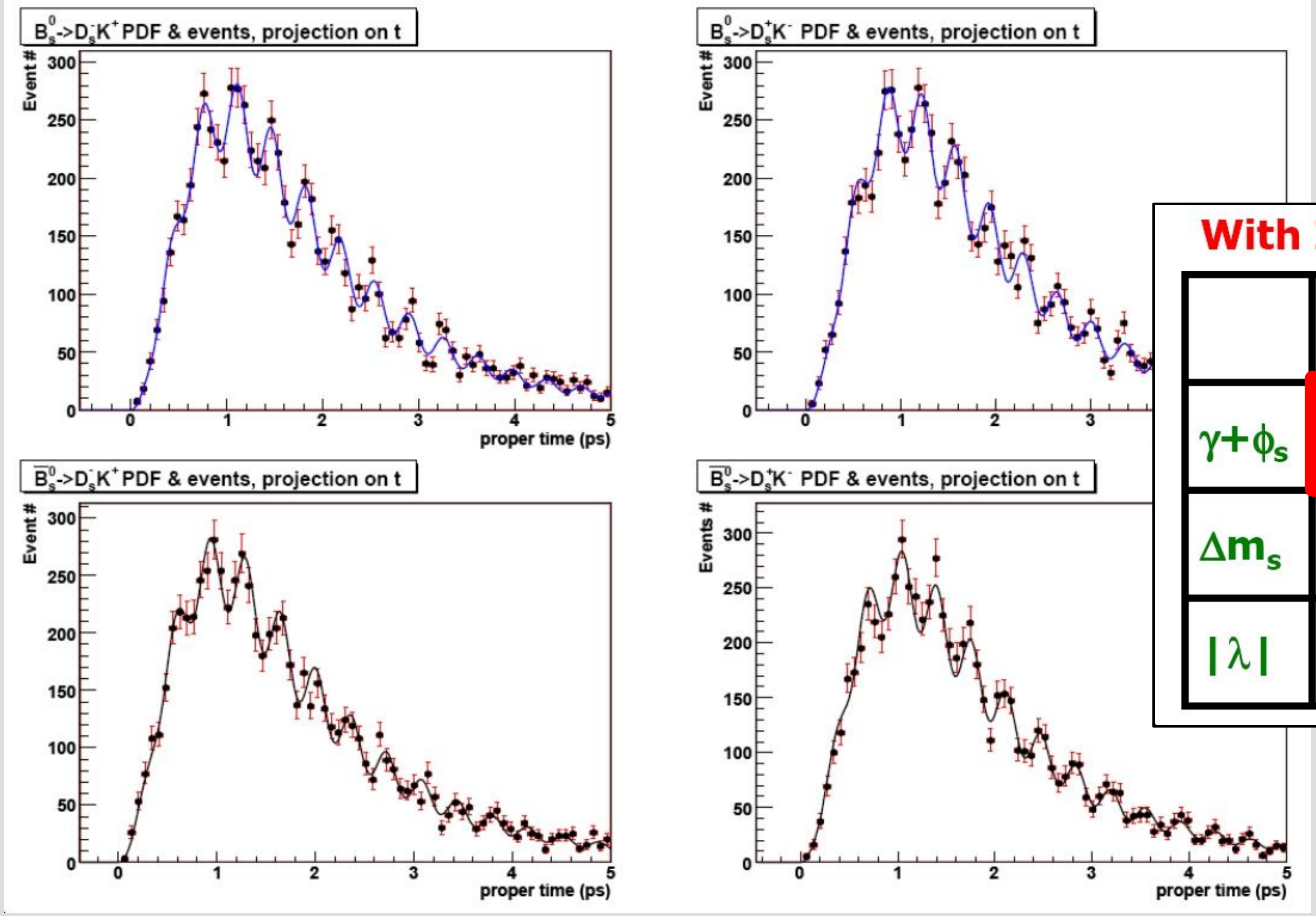
- $B^{\pm}\rightarrow DK^{\pm}$, with $D\rightarrow K_S\pi\pi$
- $B^{\pm}\rightarrow DK^{\pm}$, with $D\rightarrow KK\pi\pi$
- $B^{\pm}\rightarrow D^*K^{\pm}$, with $D\rightarrow KK,K\pi,\pi\pi$
- $B^0\rightarrow DK^{*0}$, with $D\rightarrow KK,K\pi,\pi\pi$

$B_s \rightarrow D_s K$



- Tree level, "NP-free"
- Fit for 4 time dependent asymmetries
  - Extract γ, strong phase difference, and amplitude ratio $|\lambda|$
- Use the lifetime difference $\Delta\Gamma_s$ to resolve some ambiguities
  - Simultaneous fit with $B_s \rightarrow D_s \pi$ events to constraint $\Delta\Gamma_s$ and Δm_s

$B_s \rightarrow D_s K$



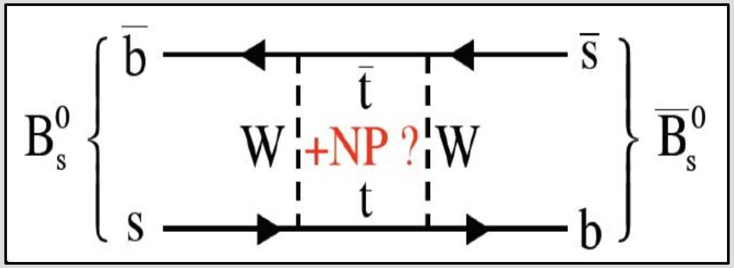
With $2fb^{-1}$ of data:

	tagged & untagged sensitivity
$\gamma+\phi_s$	$\boxed{10.3^\circ}$
Δm_s	$0.007\ ps^{-1}$
$\vert\lambda\vert$	0.06

β_s

Hot topic for the last few weeks …

- The phase of B_s oscillations, aka ϕ_s, χ, …
  - Very small in SM: $\phi_s = -0.037 \pm 0.002$

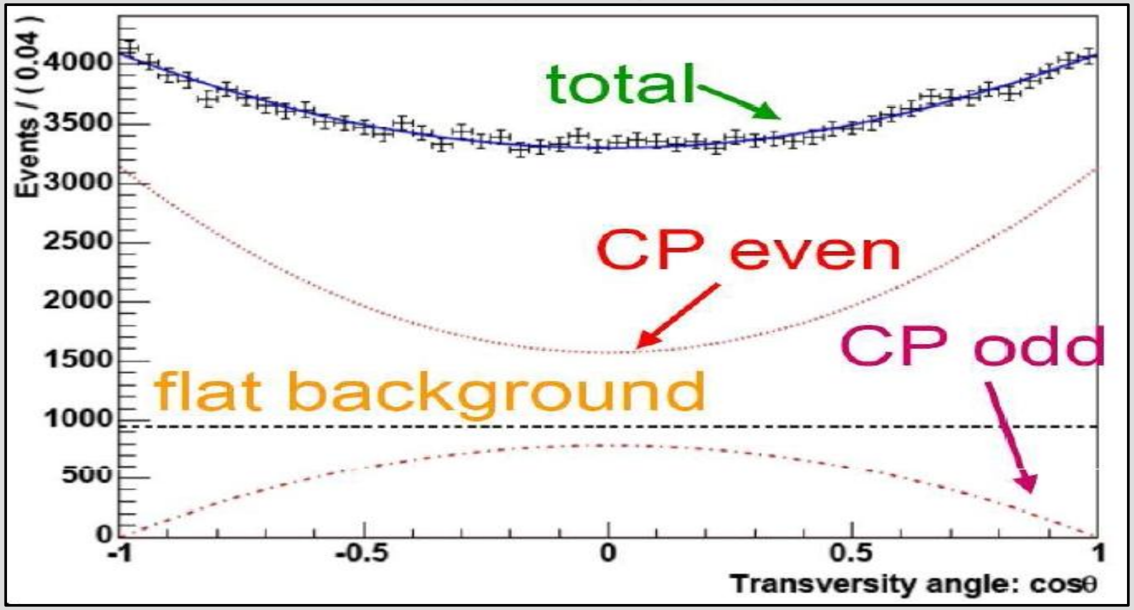


- Can get sizeable contribution from NP
  - B_s is still "*terra incognita*"
- Measure β_s from the time dependent *CP*-asymmetry:

$$A_{CP}(t) = -\frac{\eta_f \sin\phi_S \sin(\Delta m_S t)}{\cosh\left(\frac{\Delta\Gamma_S t}{2}\right) - \eta_f \cos\phi_S \sinh\left(\frac{\Delta\Gamma_S t}{2}\right)}$$

β_s: the golden mode $B_s \to J/\psi\phi$

- Yield (for $\mu\mu KK$ mode) 130k/2fb^{-1}, B/S=0.12
- However it is not pure *CP*-eigenstate
- Need angular analysis to disentangle *CP*-even and *CP*-odd contributions

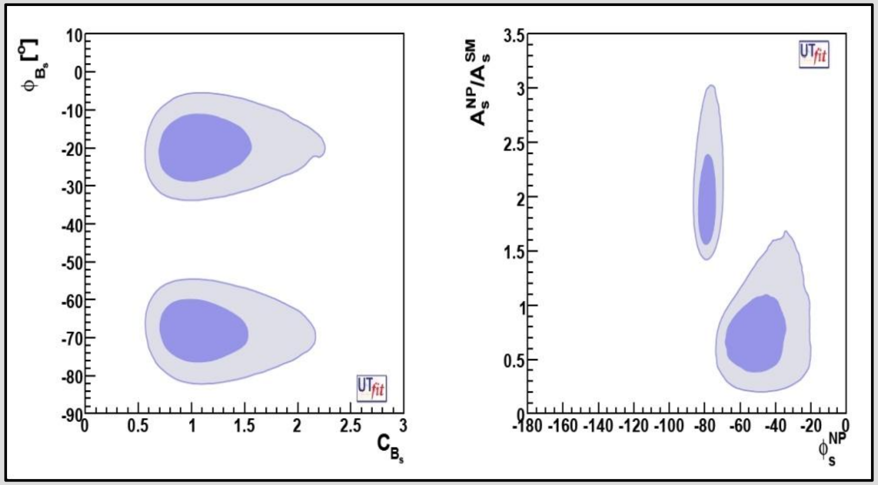


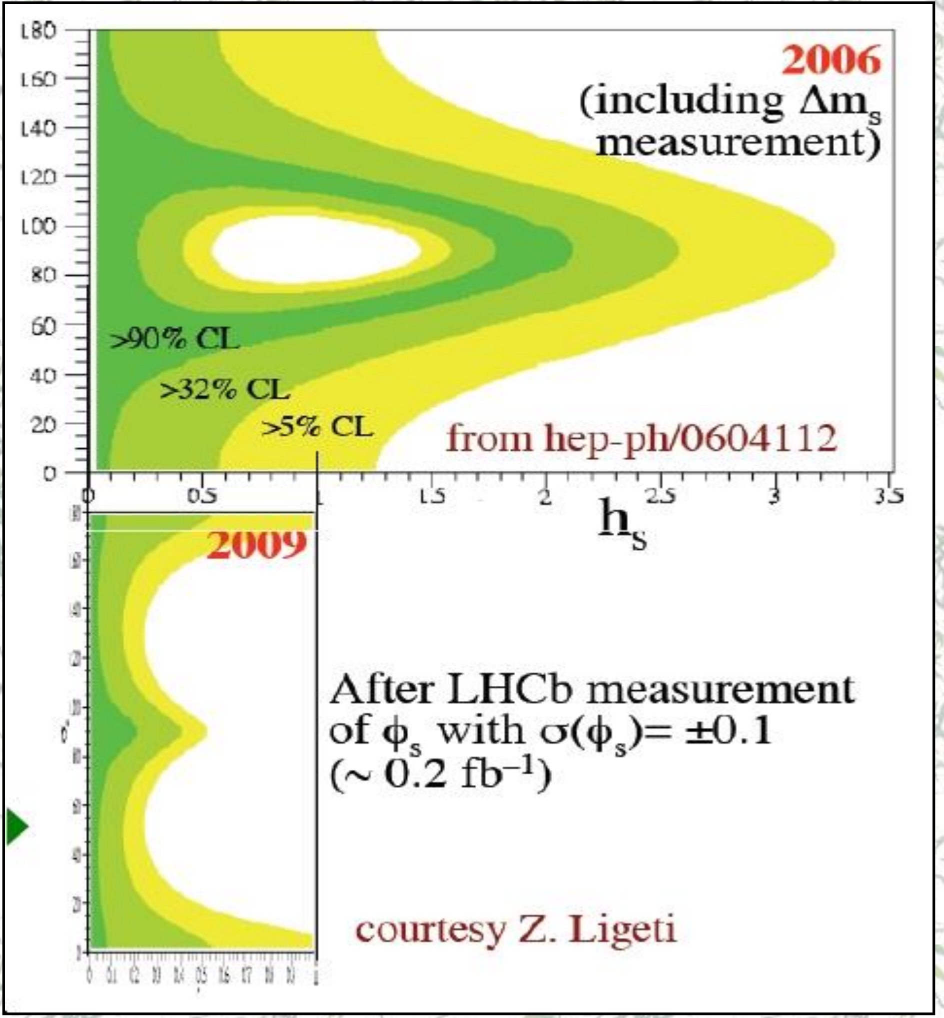
Data sample	$\sigma(\phi_s)$
0.5fb^{-1}	0.046
2fb^{-1}	0.023
10fb^{-1}	0.009

New Physics in B_s-oscillations

- NP in B_s oscillations can be parameterized as:

$$M_{12} = M_{12}^{SM}(1+h_s e^{i\sigma})$$

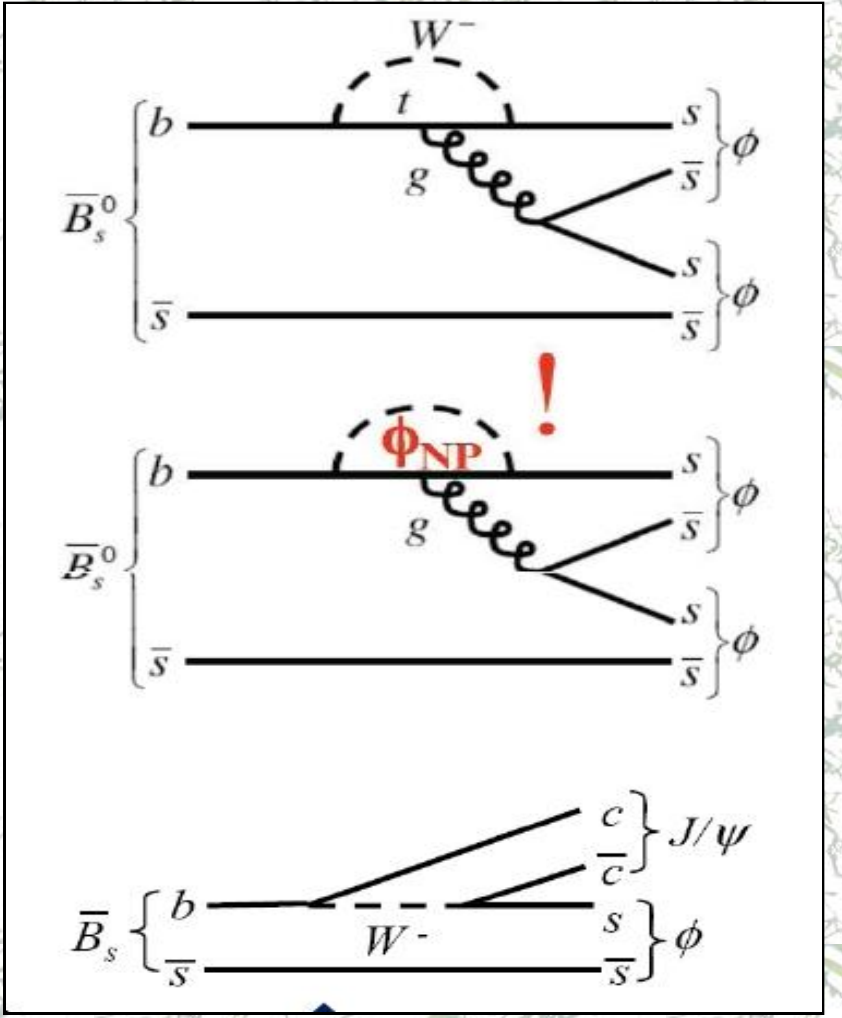




Mixing phase from penguins

$B_s \to \phi\phi$

- Pure gluonic penguin
- SM: A_{CP}<1% due to fine cancellation of the penguin and the box
  - NP acts differently!
- Yield/2fb^{-1} ~3k
- σ("β_s")=0.05/10fb^{-1}



Other *CP*-measurements

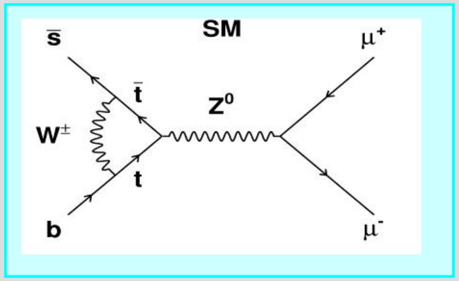
	Measurement Channel	Precision after $2fb^{-1}$	Precision after $10fb^{-1}$
α	$B^0 \rightarrow \pi^+\pi^-\pi^0$	8.5°	~5°
$\sin(2\beta)$	$B^0 \rightarrow J/\psi K_s$	0.020*	0.010

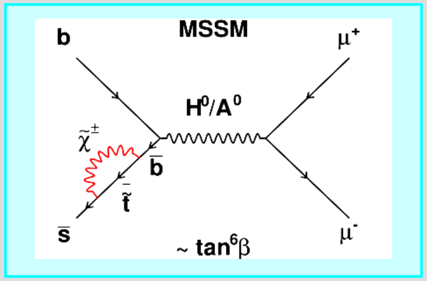
Rare decays or $b \to s$ FCNC

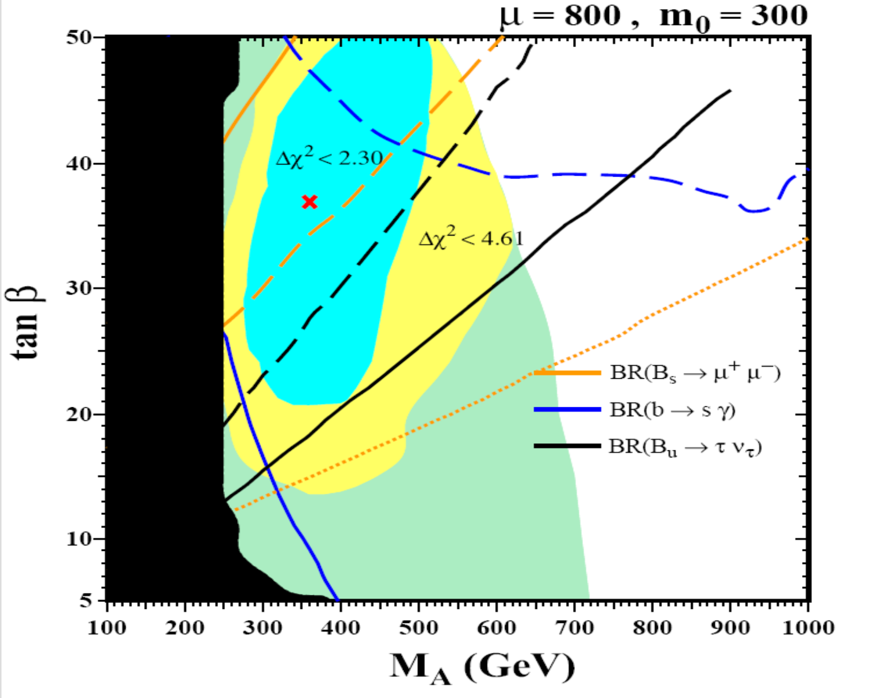
- SM: no tree level $b \to s$ transitions
  - boxes and penguins: highly suppressed ("rare"), however often one has definite SM predictions
- NP effects could be comparable
  - There is no "evident" NP suppression:
    - NP particles appears in loops
- NP can modify the rates, asymmetries or the Lorentz structure of $b \to s$ transitions

$B_s \to \mu\mu$ (I)

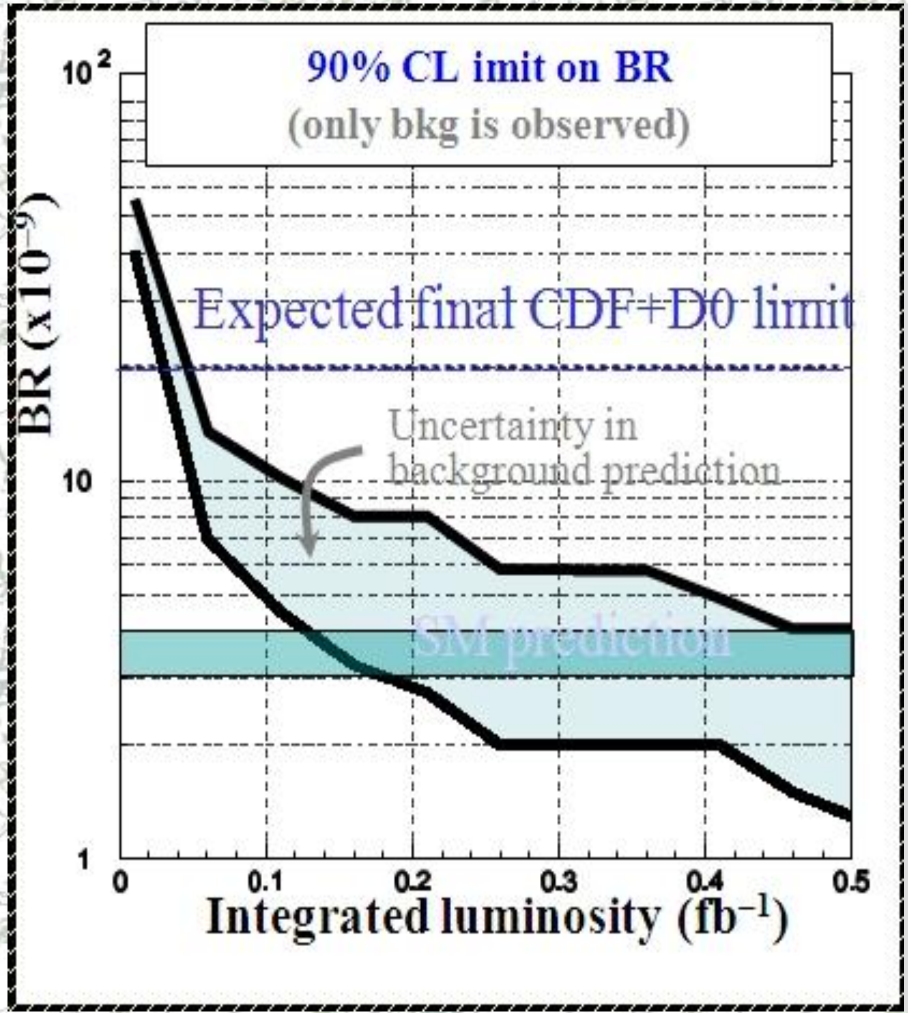
- Precisely calculated in SM:
  $B(B_s \to 2\mu) = (3.55 \pm 0.33) \times 10^{-9}$
  - $(m_\mu/m_B)^2$ helicity suppression
  - small QCD uncertanities
- Clear NP predictions: e.g. MSSM:
  - tan^{6}b enhancement







$B_s \to \mu\mu$ (II)



- Exclusion:
  - 0.1fb^{-1} < 10^{-8}
  - 0.5fb^{-1} < SM
- SM agreement
  - 30 events/2fb^{-1}
  - 2fb 3σ evidence
  - 6fb 5σ observation

Lorentz Structure of $b \to s\gamma$ (I)

- In SM the photon from $b \to s\gamma$ is predominantly left-handed $\mathcal{O}(m_s/m_b)$
- The photon polarization can be easily probed by study of time dependent rates of $B_s \to \phi\gamma$:

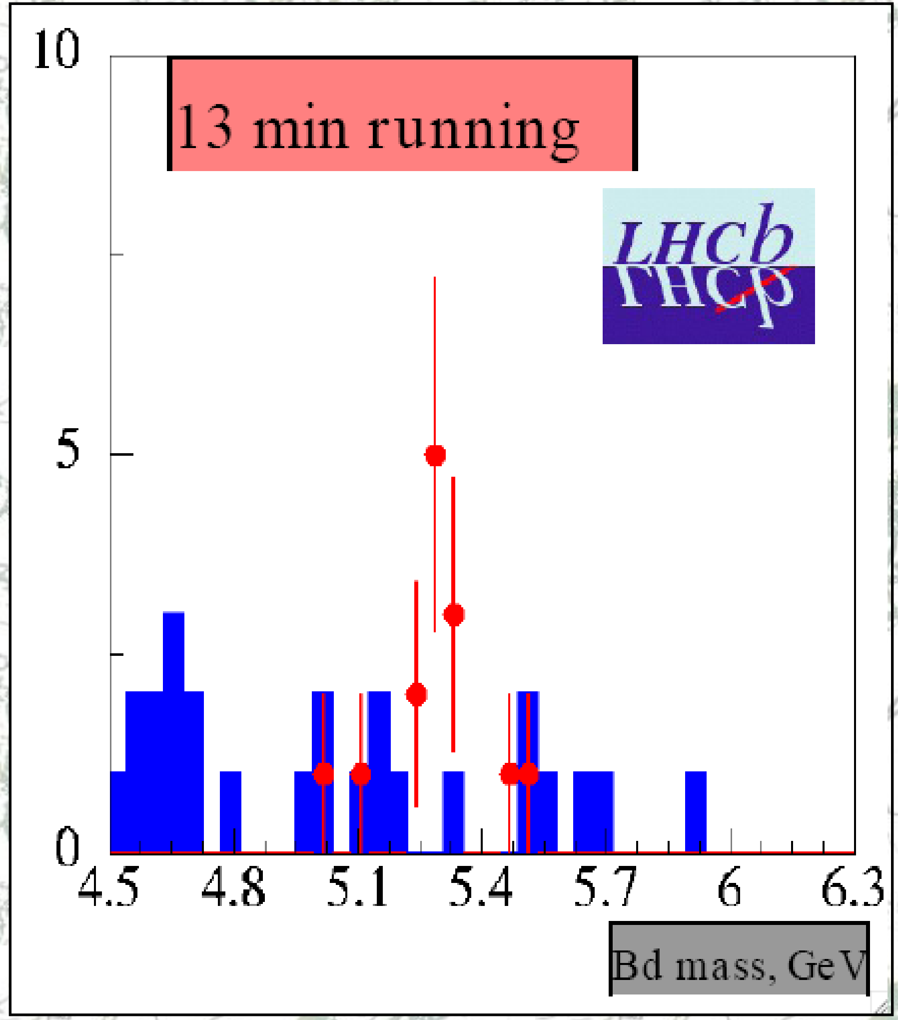
$$\Gamma(\mathrm{B}_q(\bar{\mathrm{B}}_q) \to f^{CP}\gamma) \propto e^{-\Gamma_q t}\left(\cosh\frac{\Delta\Gamma_q t}{2} - \mathcal{A}^{\Delta}\sinh\frac{\Delta\Gamma_q t}{2} \pm \right.$$
$$\left. \pm \mathcal{C}\cos\Delta m_q t \mp \mathcal{S}\sin\Delta m_q t\right)$$

SM:

- $\mathcal{C}$ = 0 direct CP-violation
- $\mathcal{S}$ = $\sin 2\psi \ \sin\phi$
- $\mathcal{A}^{\Delta}$ = $\sin 2\psi \cos\phi$

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

Lorentz Structure of $b \to s\gamma$ (II)

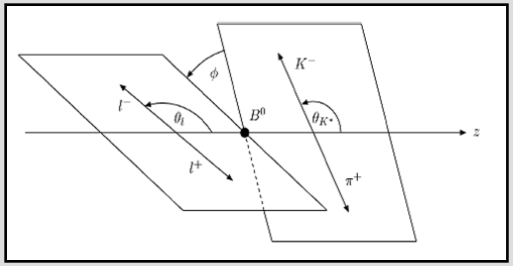


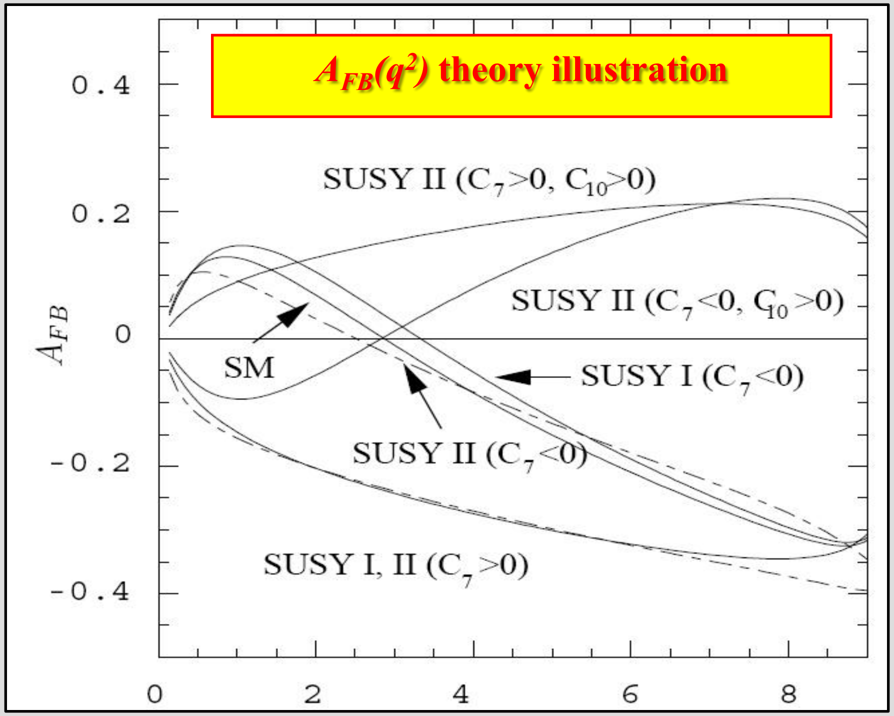
- Yields/2fb^{-1}
  - $B_d \to K^{*}\gamma$ 75k
  - $B_s \to \phi\gamma$ 11k, B/S=0.55
- Sensitivity:
  - $\sigma(A^{\Delta}) = 0.2$
  - $\sigma(S,C)=0.1$

Lorentz Structure of b→sμμ (I)

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

- Many observables are sensitive to NP, e.g. the dimuon mass spectrum or *transversity amplitudes*
- $A_{FB}(q^2)$ – the forward backward asymmetry
  - The shape is very sensitive to NP
  - The zero crossing is well predicted in SM and not affected by hadronic uncertainties



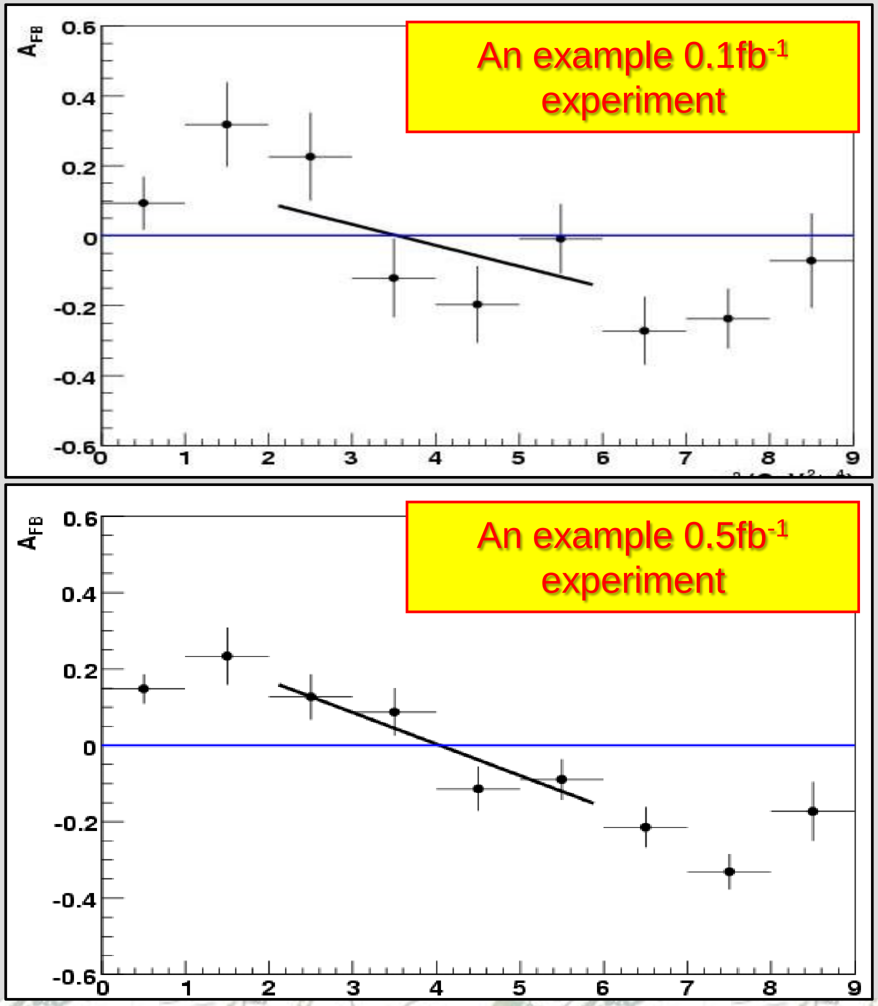


Lorentz Structure of b→sμμ (II)

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

- Yield/$2fb^{-1}$
  - 7.3k, B/S =0.5

	$0.5\ fb^{-1}$	$2\ fb^{-1}$	$10\ fb^{-1}$
σ(s0)	0.8 GeV^2	0.5 GeV^2	0.3 GeV^2



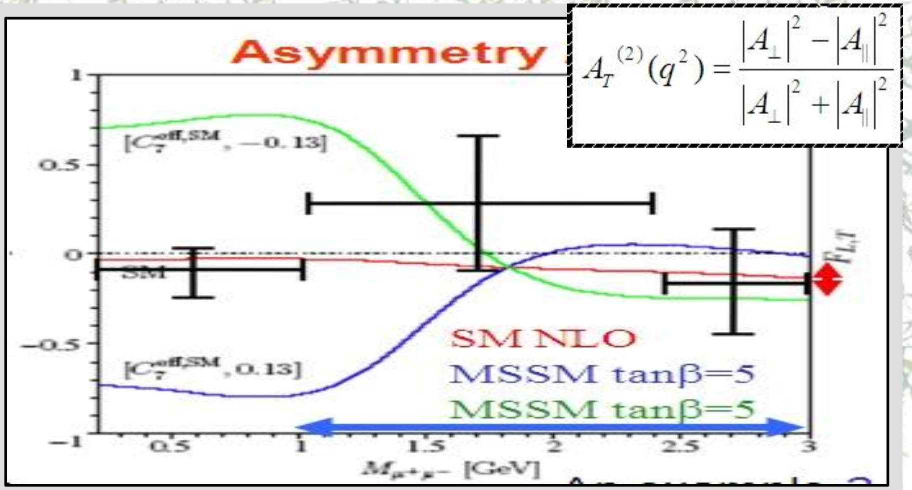
Lorentz Structure of b→sμμ (III)

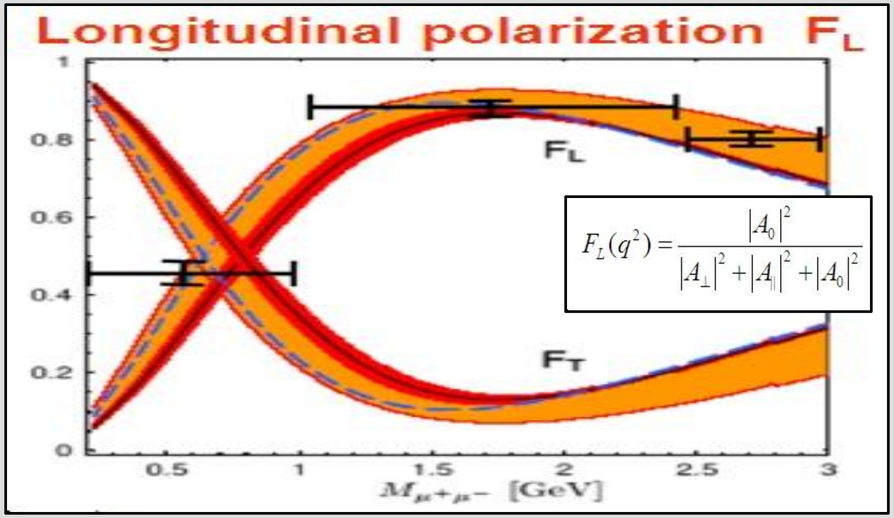
$B_d \to K^* \mu\mu$

- Other observables from full 3-angle fit

θ_l, θ_K, ϕ

	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





Summary

- **LHCb** has the reach program for the precise measurements and hunting for New Physics
  - CP-violation measurements
  - rare decays
- **LHCb** is finishing preparation for the real data taking
  - The first collisions are expected this summer

Stay tuned !