Overview of Physics @ LHCb Experiment

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Representing the LHCb Collaboration

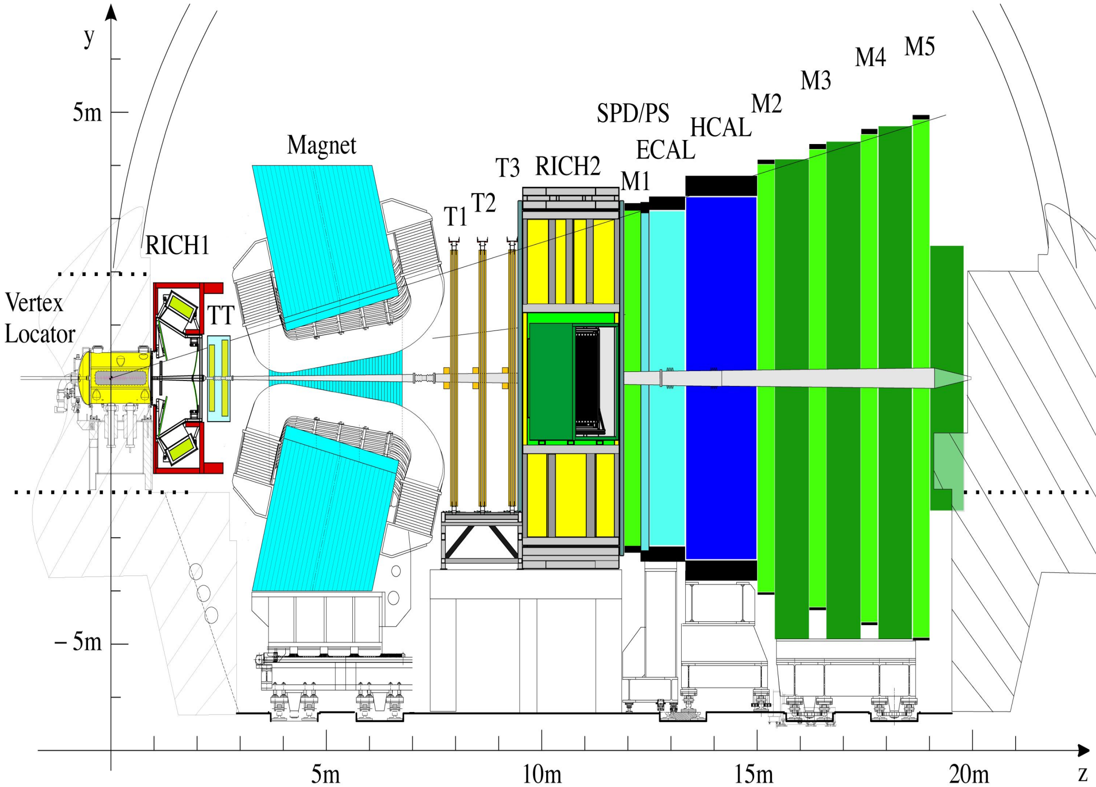
- Detector performance
- CKM triangles
- Other topics (selected)
- Conclusions

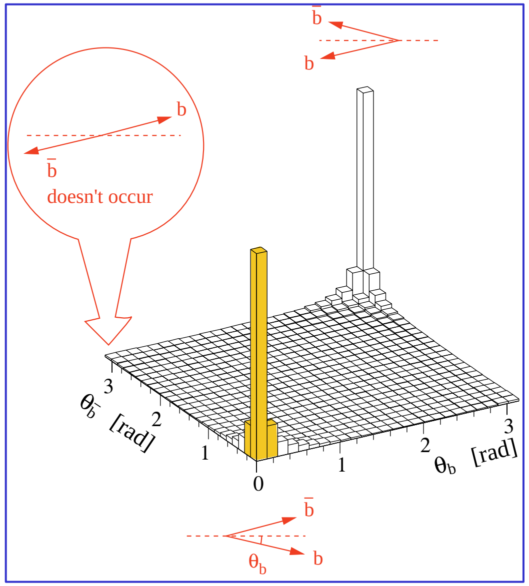
A very selective review !

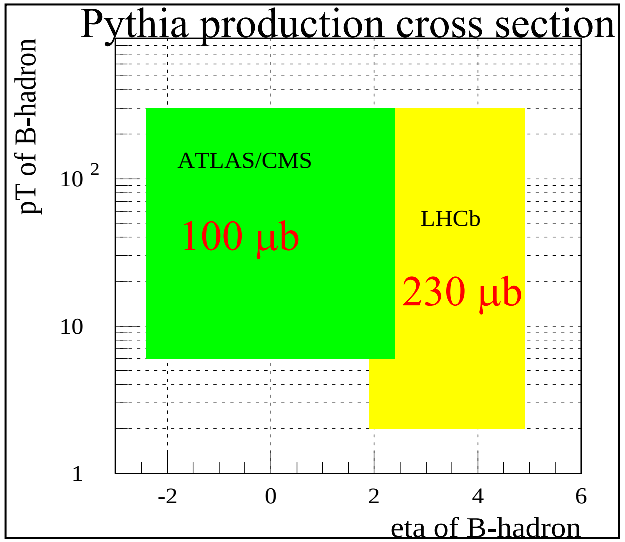
Sino-French workshop on LHC physics and Associated Grid Computing, Beijing, Dec. 11-15, 2006

LHCb is a *dedicated* B physics experiment at the LHC

Forward spectrometer (running in pp collider mode)





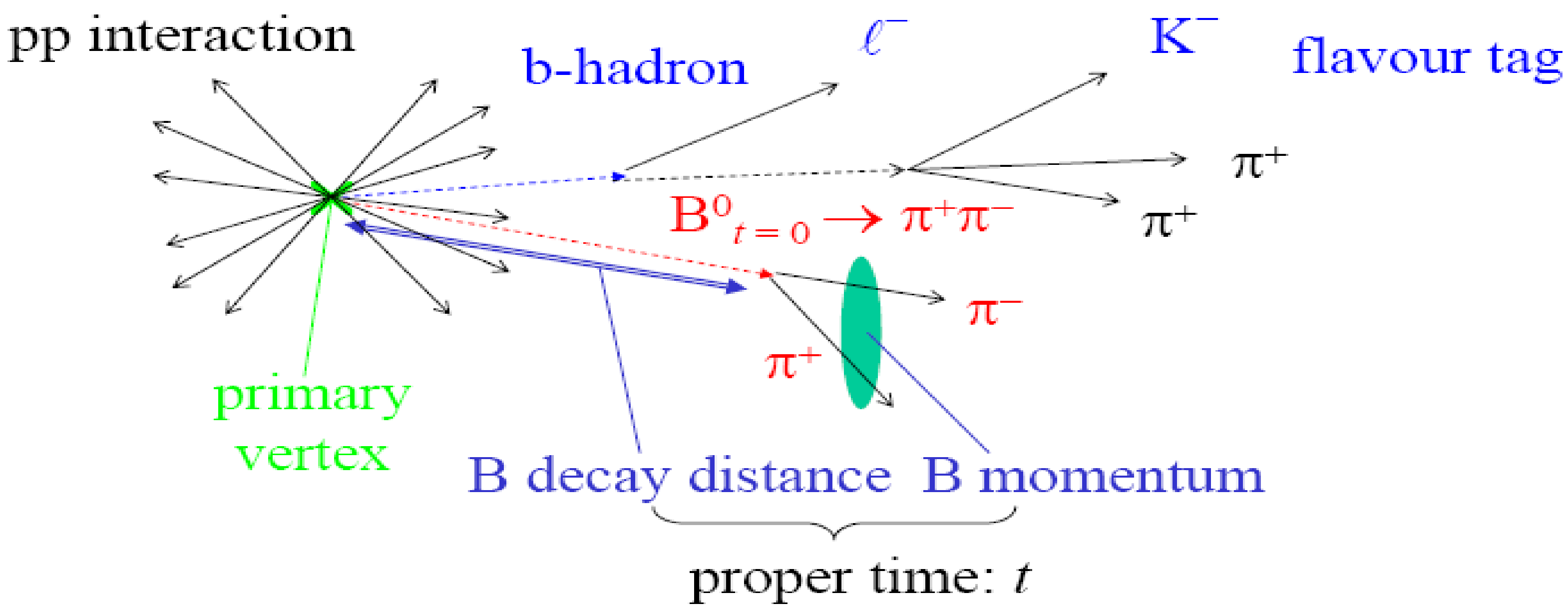


$$\sigma_{b\bar{b}}(14\text{TeV}) \sim 500\,\mu b$$

$$\sim 10^{12}\ b\bar{b}\,/\,\text{year} \quad @\,L = 2\times10^{32}\,\text{cm}^{-2}\text{s}^{-1}$$

Great potential for B physics!

What do we measure? (an example)



As a next generation B experiment, LHCb provides:

- high statistics B_d and B_s samples
- robust and efficient trigger, even for non-leptonic decays
- good decay vertex resolution; good tracking; good particle ID

Examples for detector performance

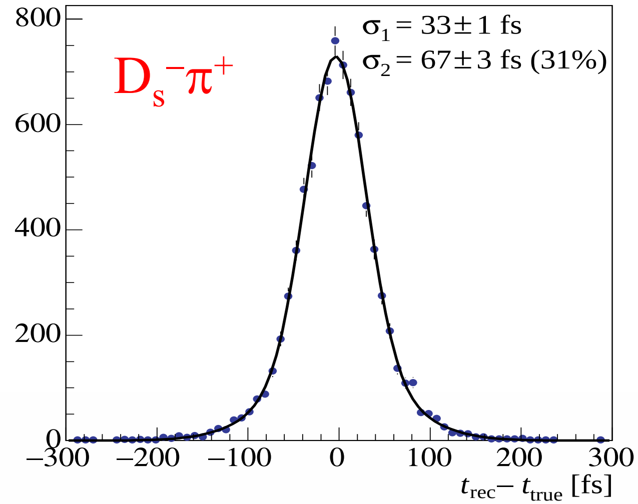
B_s oscillation frequency

- Fully reconstructed decay

→ excellent momentum resolution

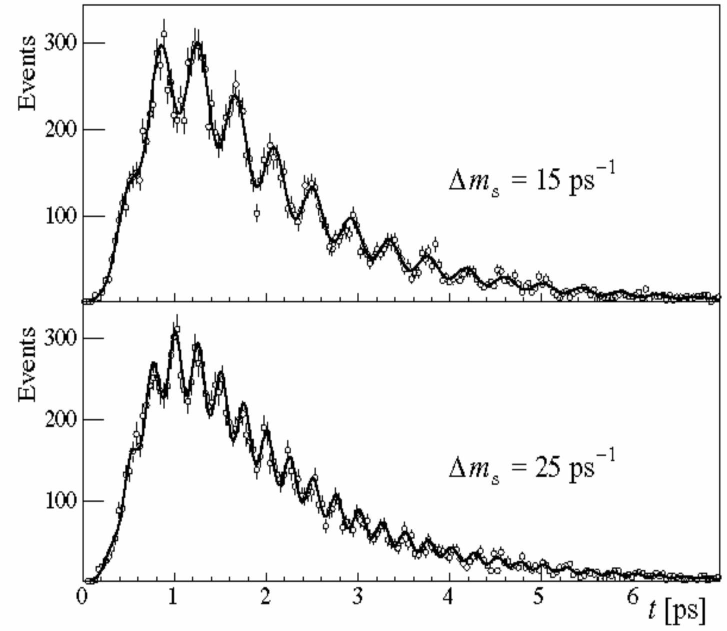
Decay length resolution ~ 200 μm

→ Proper time resolution ~ 40 fs



- 5σ measurement in one year data (2 fb^{-1}) for Δm_s up to

68 ps^{-1}



- CDF result: (PRL 97: 062003)

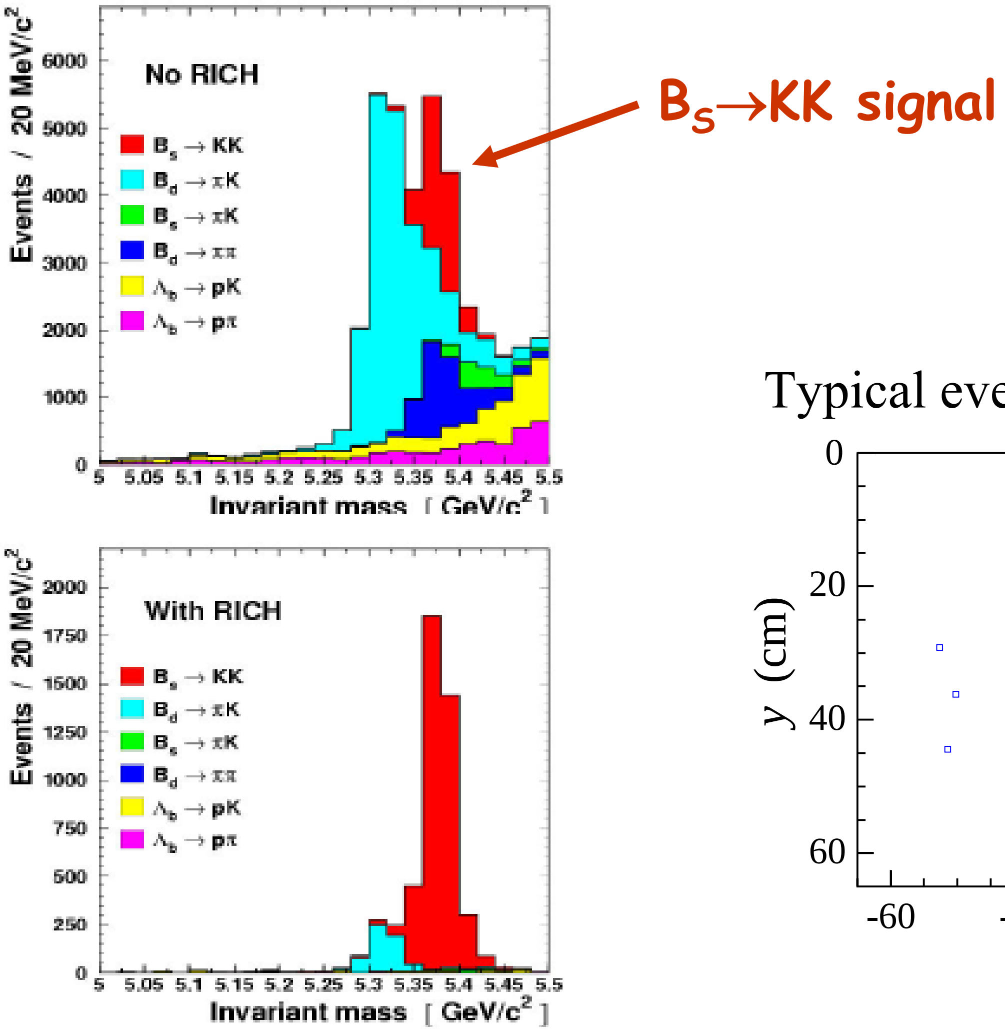
$$\Delta m_s = 17.31^{+0.33}_{-0.18} \pm 0.07\ \mathrm{ps}^{-1}$$

LHCb needs 1 month data to confirm !

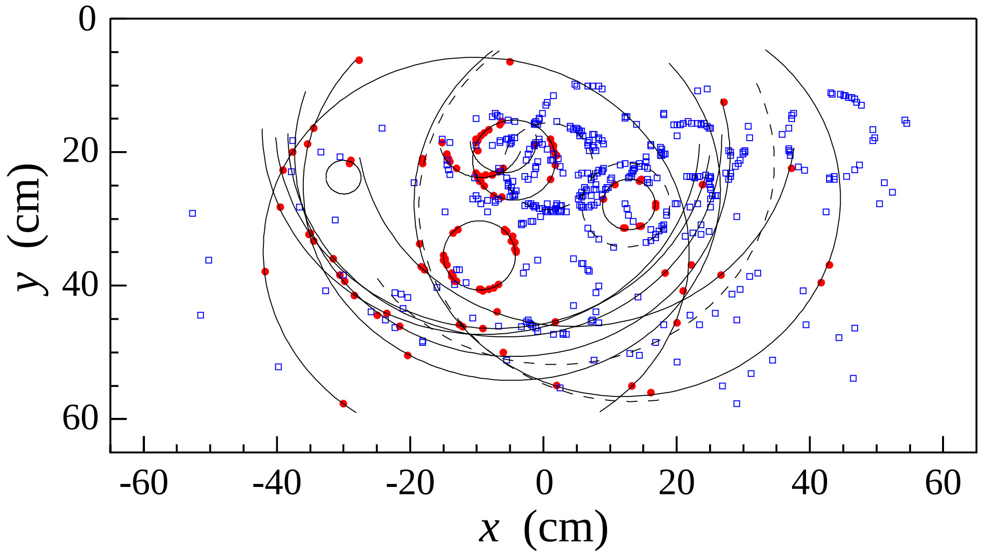
Examples for detector performance

Particle Identification

Performance of particle ID



Typical event in the RICH1 photon detectors

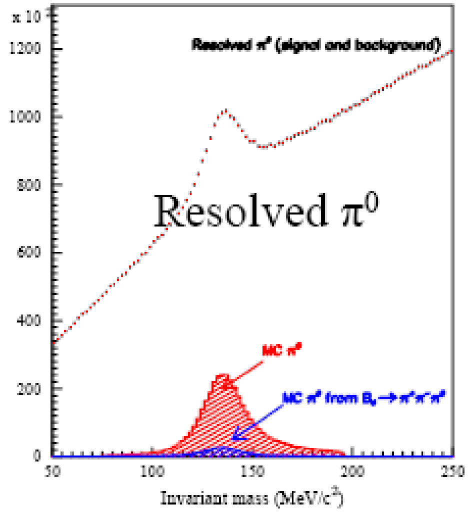


Examples for detector performance

π^0 reconstruction

- Resolved π^0: **reconstructed from 2 isolated photons**

  - **σ_m = 10 MeV/c²**

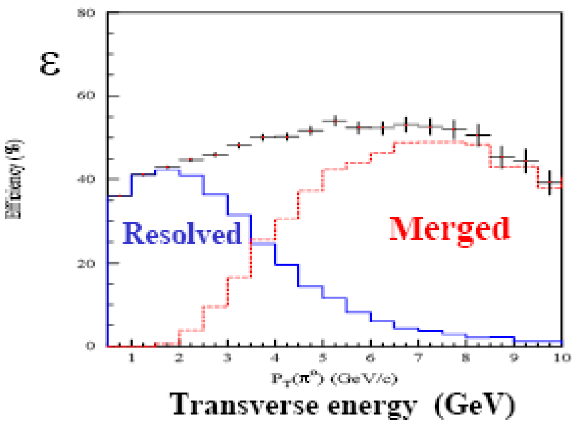


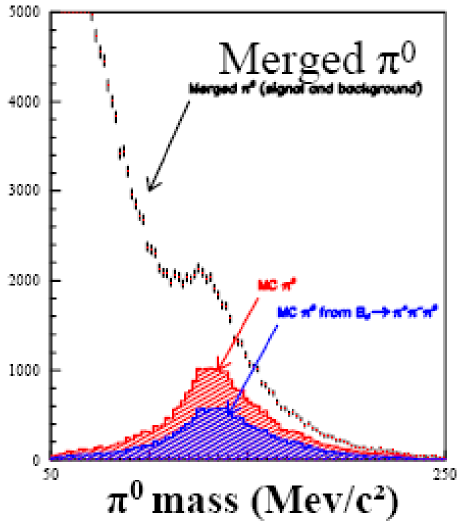
- Merged π^0: pair of photons from high energy pion which forms a single ECAL cluster, where the 2 showers are merged.

The pair is reconstructed with a specific algorithm based on the expected shower shape.

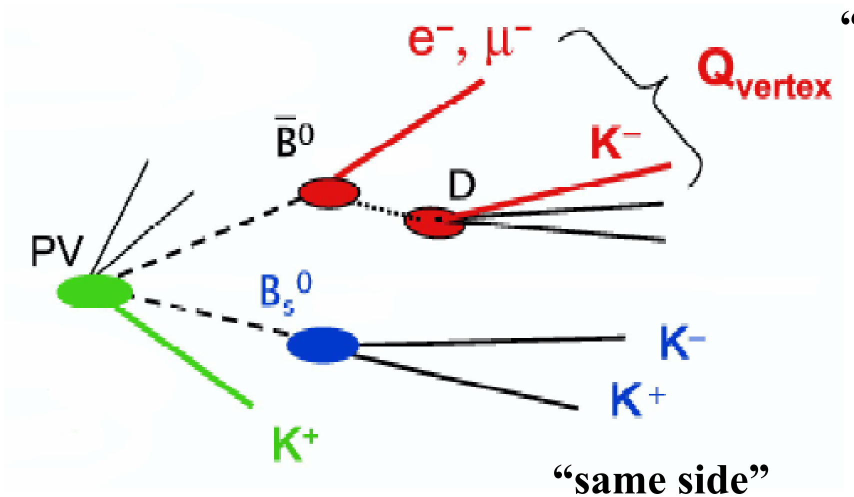
  - **σ_m = 15 MeV/c²**

- Reconstruction efficiency: **$\varepsilon_{\pi}{}^{0}$ = 53 % for $B^0 \rightarrow \pi^+\pi^-\pi^0$**





Flavor Tagging



"opposite side"

"same side"

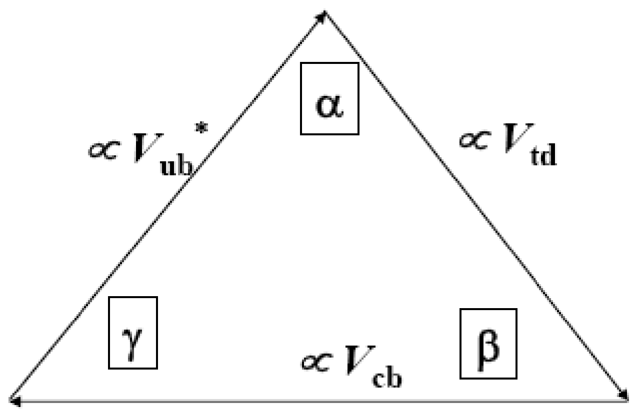
Method (For B_S)	$\mu^{\pm}$	$e^{\pm}$	$K^{\pm}$ same	$K^{\pm}$ opp	Jet charge
εD^2(%)	1.5	0.7	3.1	2.5	0.8

Expect εD^2 ~ 7-9% for B_S & 4-5% for B_d

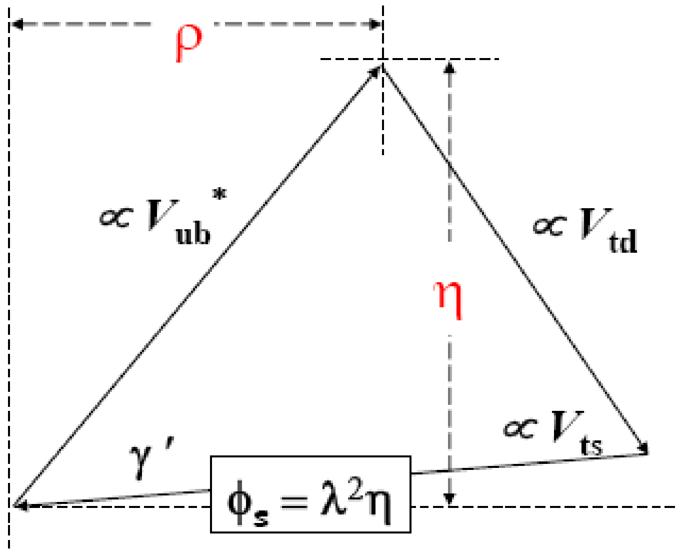
CKM Triangles

- The Standard model CP violation is described by the single complex phase in the CKM matrix, two unitarity triangles relevant to B physics at LHCb statistics

$$V_{td} V_{tb}^* + V_{cd} V_{cb}^* + V_{ud} V_{ub}^* = 0$$



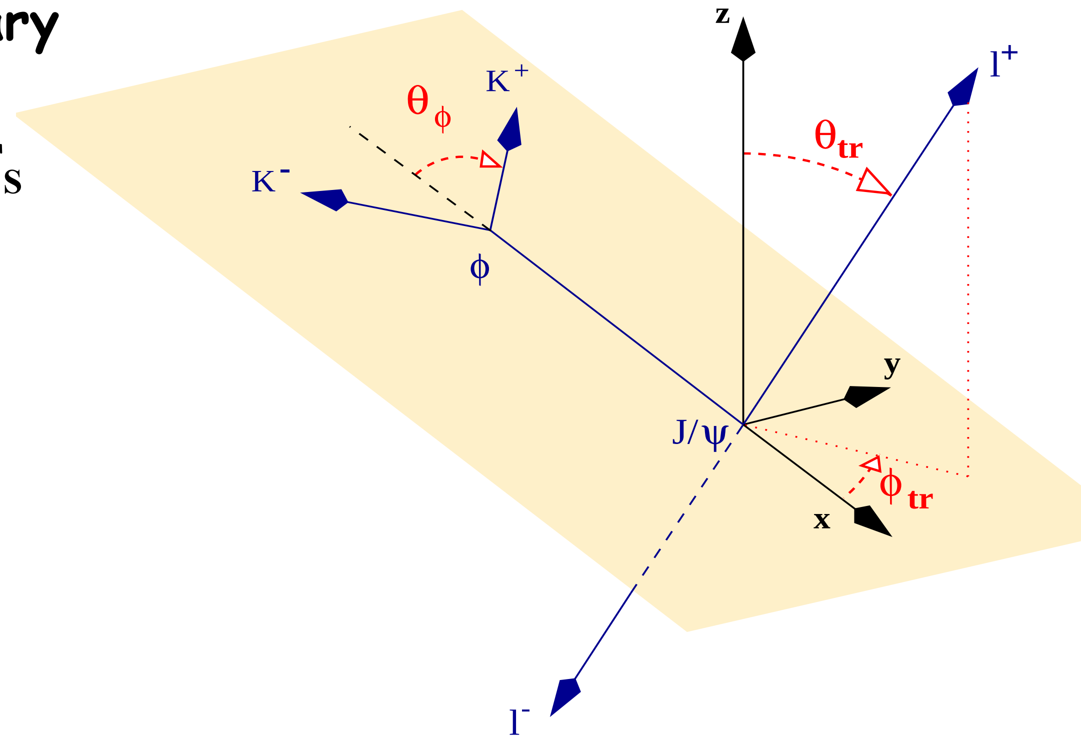
$$V_{td} V_{ud}^* + V_{ts} V_{us}^* + V_{tb} V_{ub}^* = 0$$



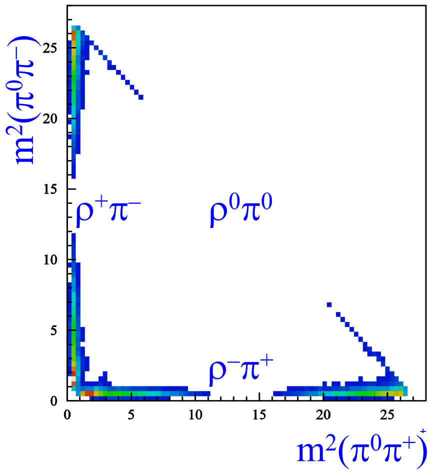
- To test SM and explore possible new physics, The primary goal of the LHCb experiment is to over constraint the unitarity triangles…

CKM Triangles: ϕ_s

- Just as $B^o \rightarrow J/\psi\ K_S$ measures CPV phase β , $B_S \rightarrow J/\psi\ \phi$ measures CPV B_s mixing phase ϕ_S
- Angular analysis is necessary
- The width difference $\Delta\Gamma_S/\Gamma_S$ also enters in the fit
- 120,000 events in $2fb^{-1}$
- **$\sigma(\phi_S) = 0.023$**

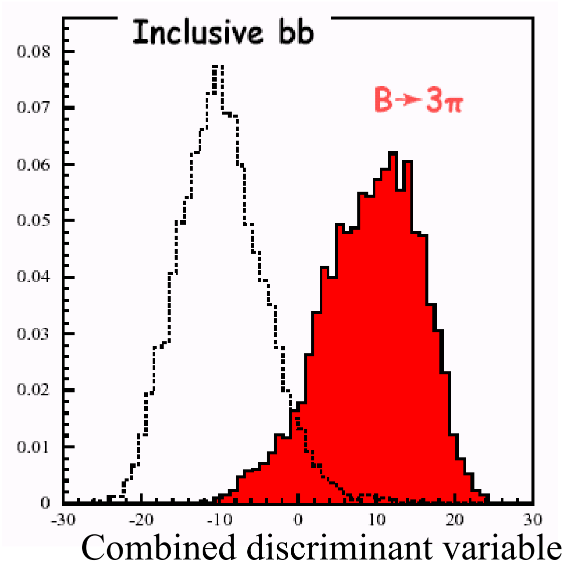


CKM Triangles: α from $B_d \to \pi^0\pi^-\pi^+$ decays



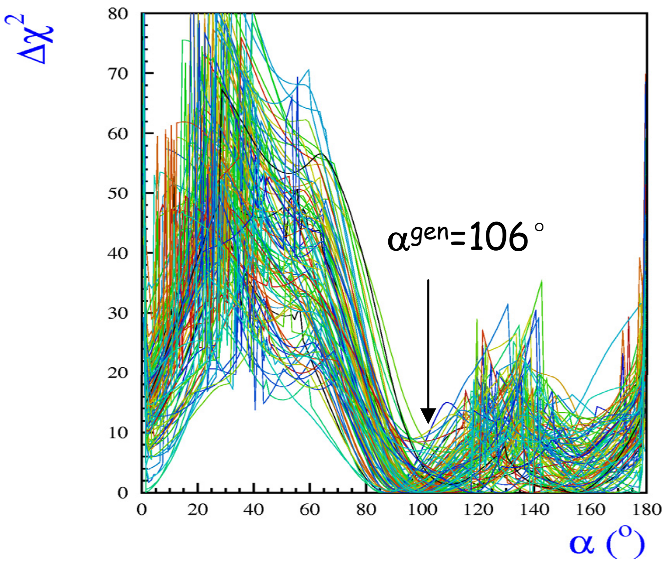
Dalitz plot analysis (Quinn Snyder method)

- $B_d \to \pi^0\pi^-\pi^+$ selection based on multivariate analysis
- Use resolved and merged π^0
- Expect 14k events per year



- 11-parameter likelihood fits performed in time-dependent Dalitz space
- B/S = 0.8 (flat and resonant bkg)

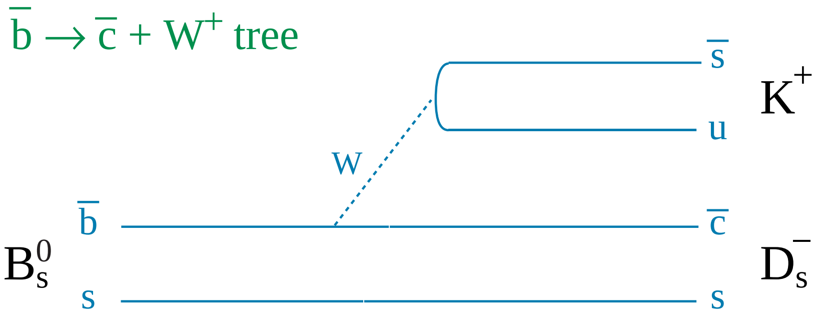
$\sigma(\alpha)$ ~10° with 2fb^{-1}

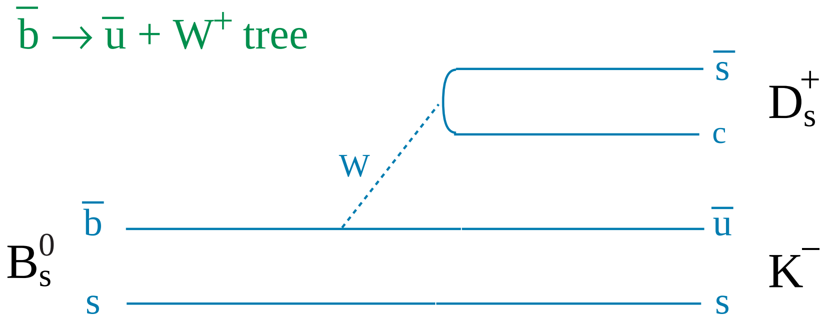


CKM Triangles: γ

1. Measurement of the angle γ from $B_s \to D_s^{\pm} K^{\mp}$

- CP asymmetry arises from interference between two tree diagrams via B_s mixing: $B_s \to D_s^{+}K^{-}$ and $B_s \to D_s^{-}K^{+}$





- Measures $\gamma - 2\,\phi_S \to$ extract γ

- The strong phase difference of the two diagrams can be resolved by fit two time-dependent asymmetries:

  Phase of $D_s^+K^-$ asymmetry is $\Delta - (\gamma - 2\,\phi_S)$

  Phase of $D_s^-K^+$ asymmetry is $\Delta + (\gamma - 2\,\phi_S)$

  $\rightarrow$ can extract both Δ and $(\gamma - 2\,\phi_S)$

- Background from $B_s \rightarrow D_s\,\pi$ is suppressed using PID information from RICH1 & RICH2

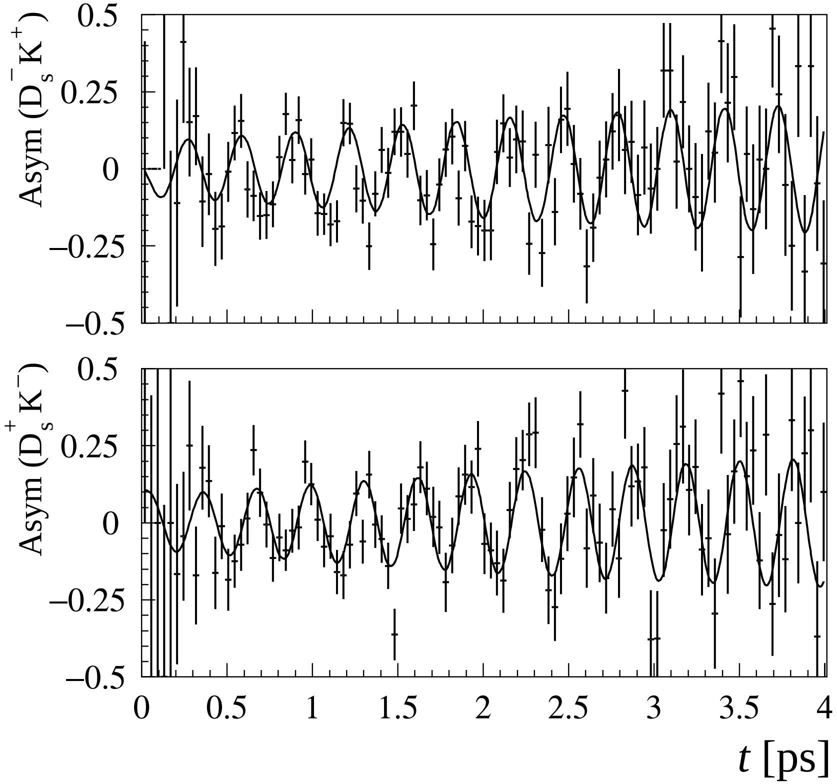
  $\rightarrow$ remaining contamination ~ 10%

- Reconstruct using $D_s^- \rightarrow K^-K^+\pi^-$

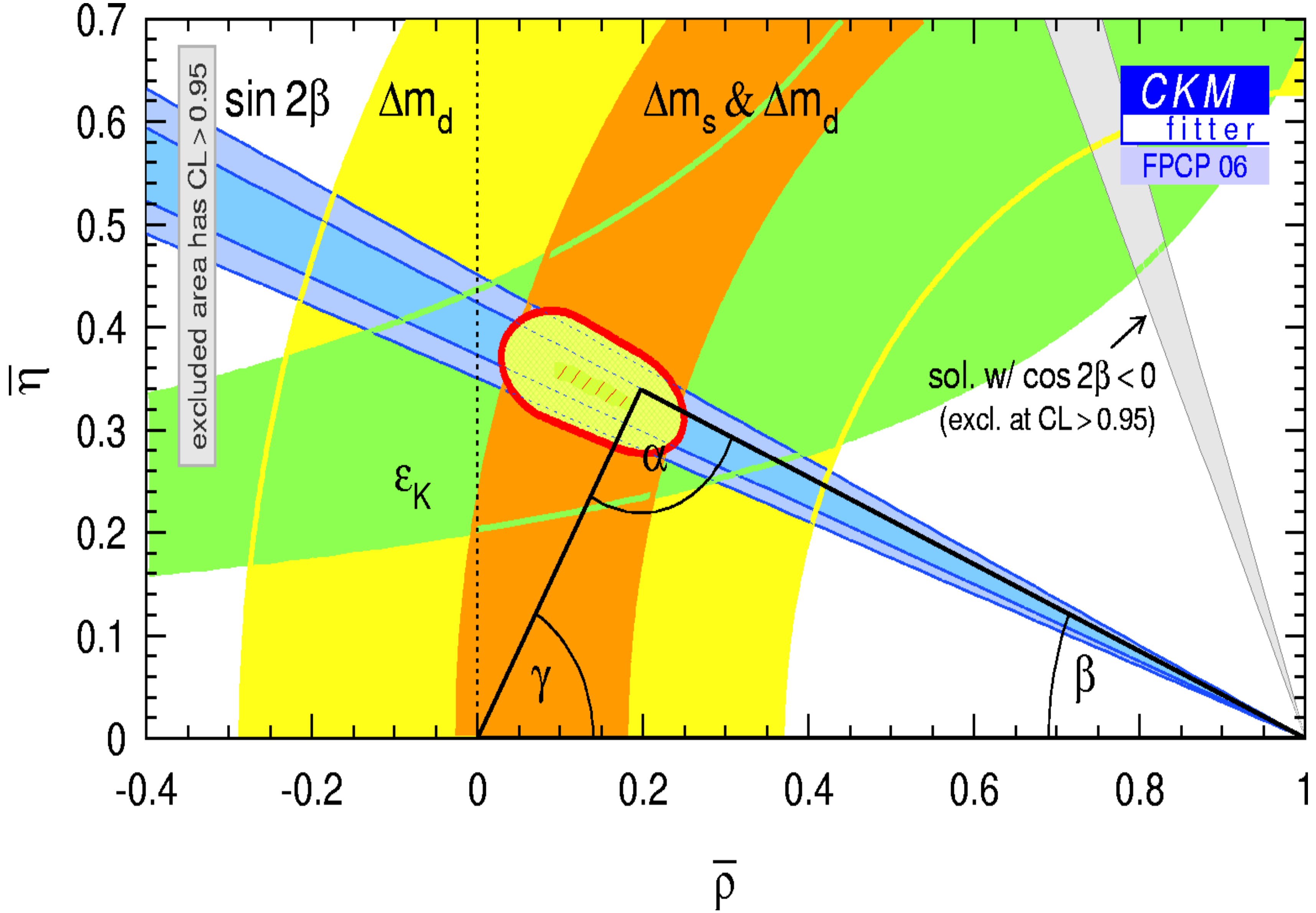
  5400 signal events/year

σ(γ) ~ 14° in one year

Asymmetries for
5 years of simulated data



Theoretically clean; insensitive to new physics



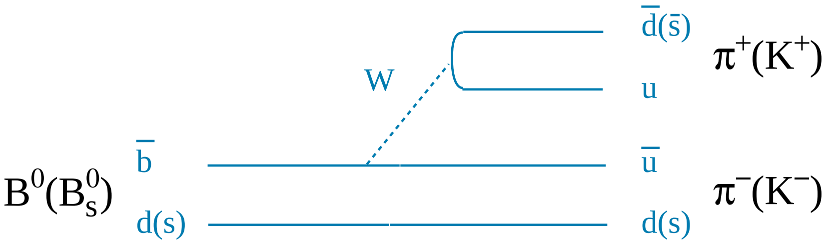
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
η̄
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
ρ̄
excluded area has CL > 0.95
sin 2β
Δm_d
Δm_s & Δm_d
ε_K
α
γ
β
sol. w/ cos 2β < 0
(excl. at CL > 0.95)
CKM
fitter
FPCP 06

CKM Triangles: γ

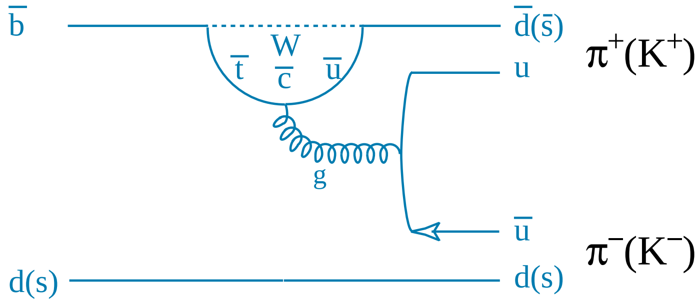
2. Measurement of the angle γ from $B^0 \to \pi^+\pi^-$, $B_s \to K^+ K^-$

- **$b \to u$ processes with possible large $b \to d(s)$ penguin contributions**

Tree diagram



Penguin diagram (example)



- **Measure time-dependent CP asymmetries for $B^0 \to \pi^+\pi^-$ and $B_s \to K^+K^-$**

$$A_{CP}(t) = A_{dir} \cos(\Delta m\, t) + A_{mix} \sin(\Delta m\, t)$$

$\rightarrow$ **extract four asymmetries**

$$A_{dir}(B^0 \to \pi^+\pi^-) = f_1(d, \theta, \gamma)$$
$$A_{mix}(B^0 \to \pi^+\pi^-) = f_2(d, \theta, \gamma, \beta)$$
$$A_{dir}(B_s \to K^+K^-) = f_3(d', \theta', \gamma)$$
$$A_{mix}(B_s \to K^+K^-) = f_4(d', \theta', \gamma, \phi_s)$$

$de^{i\theta}$ = ratio of penguin and tree amplitudes in $B^0 \to \pi^+\pi^-$

$d'e^{i\theta'}$ = ratio of penguin and tree amplitudes in $B_s \to K^+K^-$

- **Assume U-spin flavour symmetry (under interchange of d and s quarks)**
  $d = d'$ **and** $\theta = \theta'$ [R. Fleischer, PLB 459 (1999) 306]

- **Taking β and ϕ_s from other channels**
  → can solve for γ

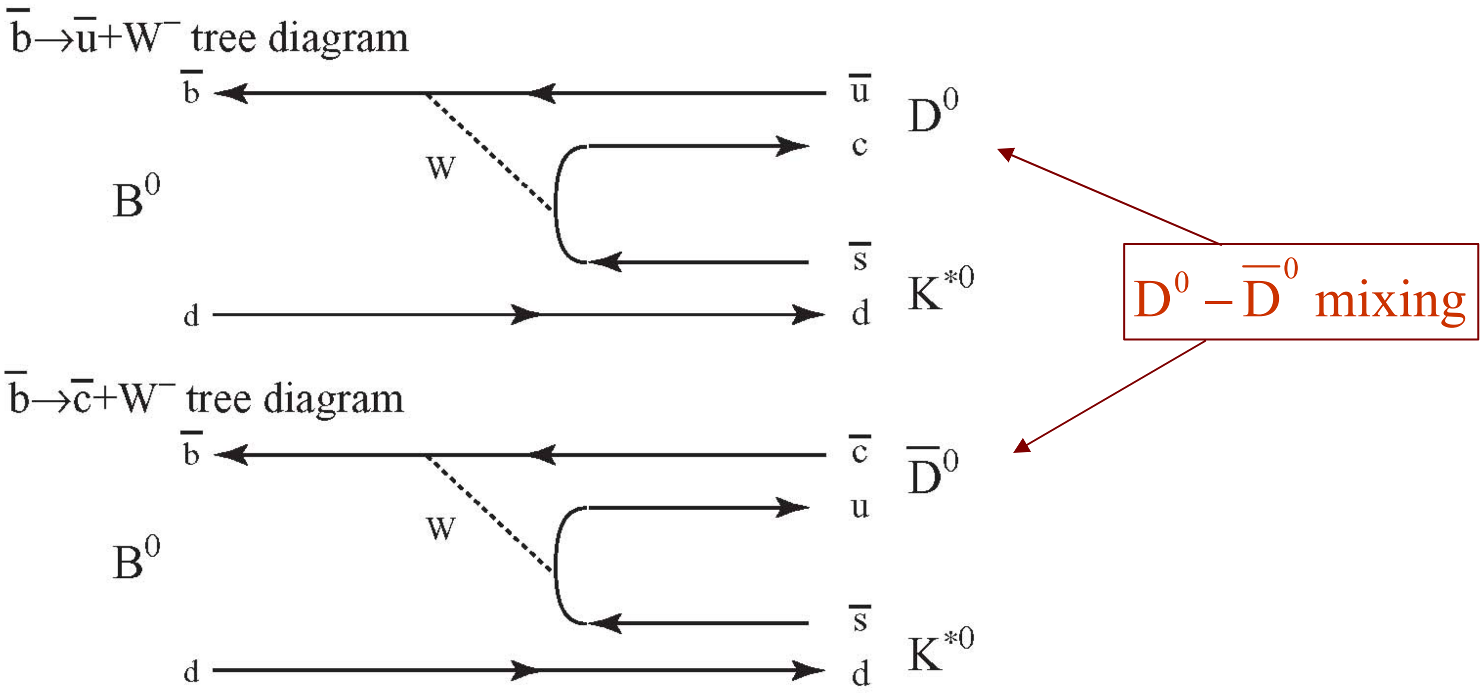
$\sigma(\gamma) \sim 5\text{-}10°$ in one year

Theoretical uncertainty from U-spin assumption (can be tested);
Sensitive to new physics in the penguin loops

CKM Triangles: γ

3. Measurement of the angle γ from $B^0 \to D^0K^{*0}, \bar{D}^0K^{*0}$

- CP asymmetry arises from interference between two tree diagrams via D^0-mixing



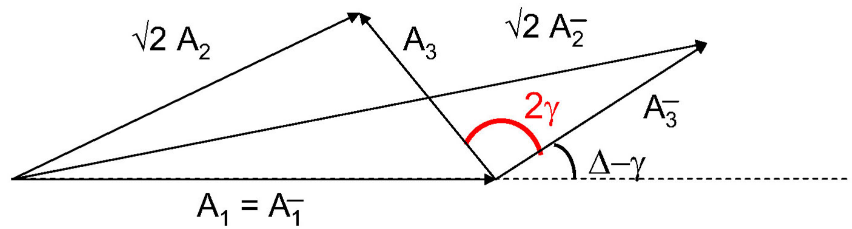
- **Measure six *rates* (following 3 + CP-conjugates)**

  γ can be extracted from triangles [Gronau and Wyler, PLB 265 (1991) 172, Dunietz, PLB 270(1991) 75]

(1) $B^0 \to \overline{D}^0(\to K^+\pi^-) + K^{*0}$

(2) $B^0 \to D^0(\to K^-\pi^+) + K^{*0}$

(3) $B^0 \to D_{CP}(\to K^+K^-) + K^{*0}$



$D_{CP} = (D^0 + \overline{D}^0)/\sqrt{2}$: *CP-even eigenstate of* $D^0 - \overline{D}^0$ *system*

- **3.4K, 0.5K and 0.6K events respectively for one year data taking**

σ(γ) ~ 7-10° in one year

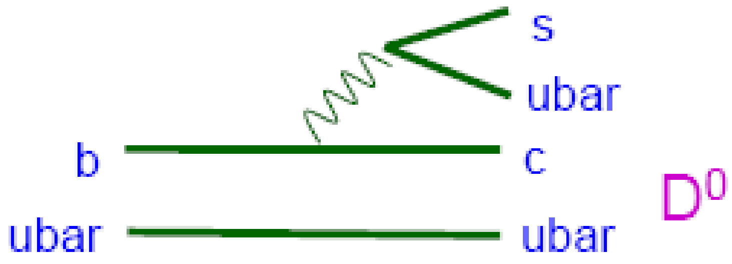
No theoretical uncertainties; sensitive to new physics in D_{CP}

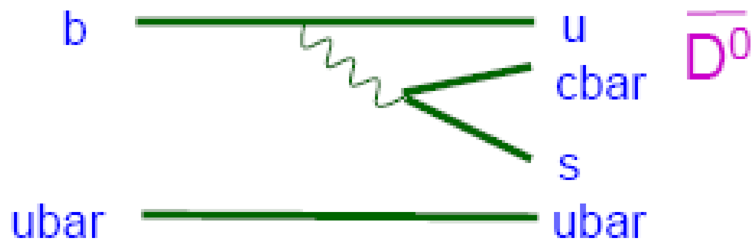
CKM Triangles: γ

4. Measurement of the angle γ via ADS method

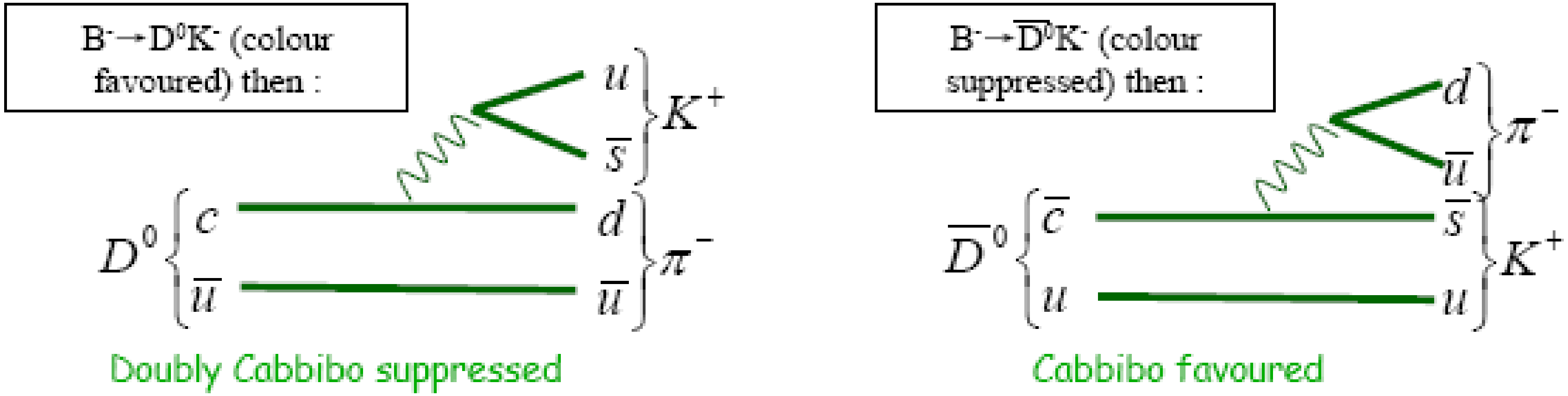
- Three parameters for CKM favoured $B \to \bar{D}K$ and disfavoured $B \to DK$
  - weak phase difference $\gamma = Arg(-(V_{ub}V^*_{cs})/(V_{cb}V^*_{us}))$
  - strong phase difference δ_B and
  - amplitude ratio $r_B = |A(B \to DK)|/|A(B \to \bar{D}K)|$
- Interference allows to extract γ, if same D^0 and $\bar{D}^0$ final states

$B^{\pm}$ decays ($r_B \sim 0.1$)





- **Both D^0 and $\overline{D^0}$ decay to $K^+\pi^-$:**



- **For these decays the reversed suppression of the D decays relative to the B decays results in similar amplitudes → big interference effects**
- **Counting experiment (no need tagging nor proper time)**
- **Interference depends on 5 parameters :**
  - From the B decays γ , r_B and δ_B
  - $r_D^{K\pi}$ – the ratio in magnitude of two D decay processes
    - Well measured (PDG value 0.060)
  - $\delta_D^{K\pi}$ – a CP conserving strong phase difference

- Measure the following rates:

			2fb^{-1}
$\Gamma(B^- \to (K^-\pi^+)_D K^-)$	$\propto 1 + (r_B r_D^{K\pi})^2 + 2 r_B r_D^{K\pi} \cos\left(\delta_B - \delta_D^{K\pi} - \gamma\right)$	(1)	60k
$\Gamma(B^- \to (K^+\pi^-)_D K^-)$	$\propto r_B^2 + (r_D^{K\pi})^2 + 2 r_B r_D^{K\pi} \cos\left(\delta_B + \delta_D^{K\pi} - \gamma\right)$	(2)	2k
$\Gamma(B^+ \to (K^+\pi^-)_D K^+)$	$\propto 1 + (r_B r_D^{K\pi})^2 + 2 r_B r_D^{K\pi} \cos\left(\delta_B - \delta_D^{K\pi} + \gamma\right)$	(3)	60k
$\Gamma(B^+ \to (K^-\pi^+)_D K^+)$	$\propto r_B^2 + (r_D^{K\pi})^2 + 2 r_B r_D^{K\pi} \cos\left(\delta_B + \delta_D^{K\pi} + \gamma\right)$	(4)	2k

- Two rates are favoured (1) and (3)
- Two rates are suppressed (2) and (4)
  - but have *O(1)* interference effects as $r_B \sim r_D$
  - so particularly sensitive to $\delta_D^{K\pi}$ and γ
  - ~50 times more statistics than current b-factories !
- Taking the relative rates have more unknowns than equations
  - need information from other decays
    e.g. $D \to K\pi\pi\pi$ or the CP eigenstates KK, $\pi\pi$ ($r_D^{KK}=1$, $\delta_D^{KK}=0$)

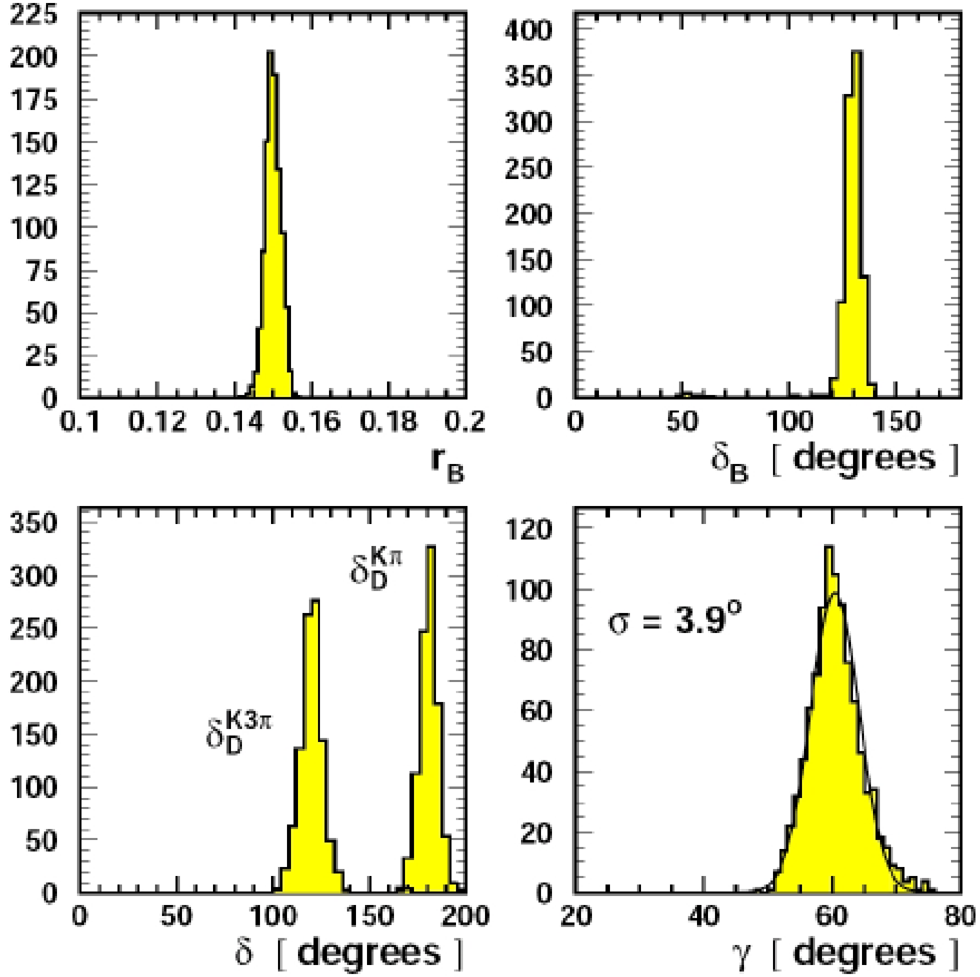
- Inputs $\gamma=60°$, $\delta_B=130°$, $r_B=0.15$
- Fit: r_B, δ_B, $\delta_D^{K\pi}$, $\delta_D^{K3\pi}$ and γ
- No background

$\Rightarrow \sigma(\gamma) \sim 3.9°$

- Adding background:

		B/S πK, KK, ππ			
		0	1	2	5
B/S Kπππ	0	3.9°	4.0°	4.0°	4.1°
	1	4.6°	4.8°	4.8°	5.0°
	2	5.0°	5.1°	5.3°	5.5°
	5	5.6°	5.9°	6.0°	6.3°

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



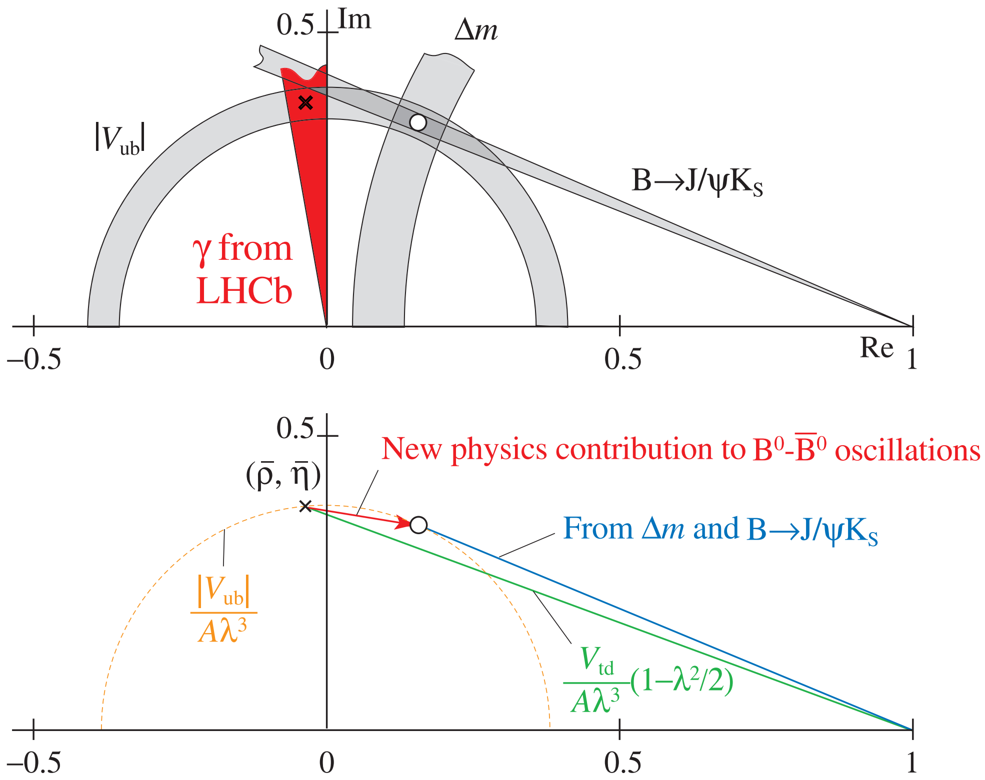
- Kπππ selection studies underway

LHCb performance for CKM Triangles with 2fb-1 (1 year)

	Channel	Yield*	B_{bb}/S	Precision
γ	$B_s \to D_s K$	5.4k	<1	$\sigma(\gamma) \approx 14^\circ$
	$B_d \to \pi\pi$	26k	<0.7	Fleischer
	$B_s \to KK$	37k	0.3	$\sigma(\gamma) \approx 6^\circ$
	$B_d \to D^0(K^-\pi^+)K^{*0}$	0.5k	<0.3	
	$B_d \to \bar{D}^0(K^+\pi^-)K^{*0}$	2.4k	<2	GLW+D $\sigma(\gamma) \approx 8^\circ$
	$B_d \to D_{CP}(K^+K^-)K^{*0}$	0.6k	<0.3	
	$B^- \to D^0(K^-\pi^+)K^-$	60k	0.5	ADS
	$B^- \to D^0(K^+\pi^-)K^-$	2k	0.5	$\sigma(\gamma) \approx 5^\circ$
α	$B_d \to \pi^0\pi^-\pi^+$	14k	0.8	Snyder Quinn $\sigma(\alpha) \approx 10^\circ$
ϕ_s	$B_s \to J/\Psi\Phi$	125k	0.3	
	$B_s \to J/\Psi\eta$	12k	2-3	$\sigma(\phi_s) \approx 2^\circ$
	$B_s \to \eta_c\Phi$	3k	0.7	
Δm_s	$B_s \to D_s\pi$	80k	0.3	Δm_s up to 68 ps^{-1}
β	$B_d \to J/\Psi K_S$	216k	0.8	$\sigma(\sin 2\beta) \approx 0.022$

CKM Triangles: Outlook

- A possible scenario *after* the LHCb measurement: new physics?

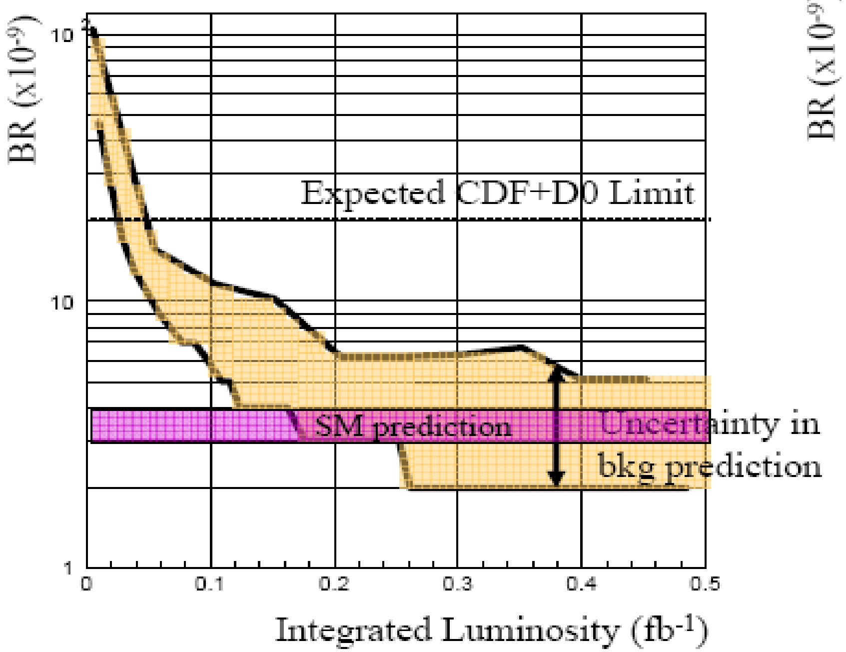


Other topics: $B_s \to \mu^+\mu^-$

small branching ratios in the Standard Model
simple and experimentally clean final states
➜ $B_d \to \mu^+\mu^-$, BR(SM)=1.5×10^{-10}
➜ $B_s \to \mu^+\mu^-$, BR(SM)=3.5×10^{-9}
potentially large enhancements in SUSY models $\sim \tan^6 \beta$

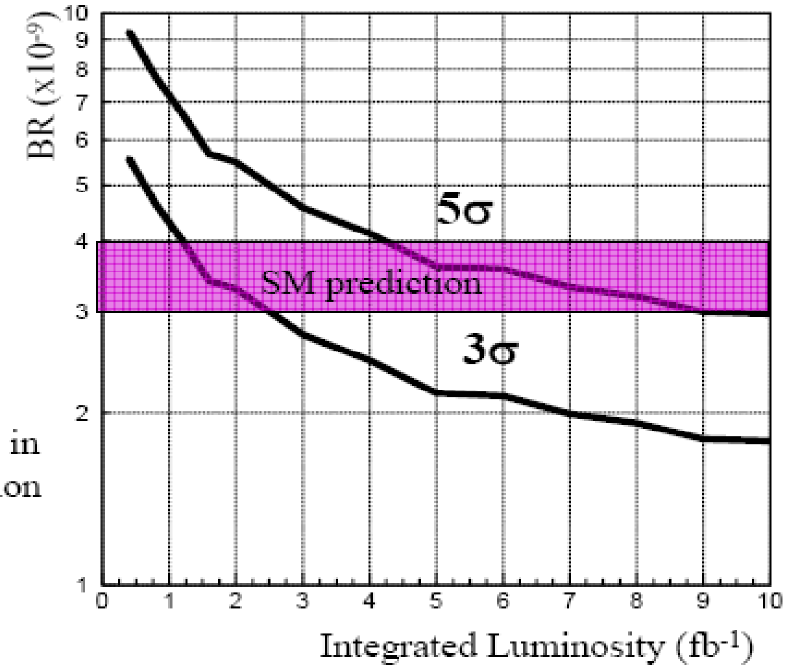
Limit at 90% C.L.

(only bkg is observed)



LHCb Sensitivity

(signal+bkg is observed)



Background is assumed to be dominated by combinations of $b \to \mu^- X$ $b \to \mu^+ X$ events.

Other topics: B_c

- In addition to B and B_s, LHCb also records B_c, and b baryons
- Working in progress on exploring the "by-product"
- *A joint efforts on B_c:*

  LAL-Tsinghua

  Theoreticians from China and France

Potential for Charm physics

- LHCb can also trigger and collect charm events

  Estimated $D^* \to D^0(hh)\pi$ yields, events to tape, @ 2 fb^{-1} from b-hadrons:

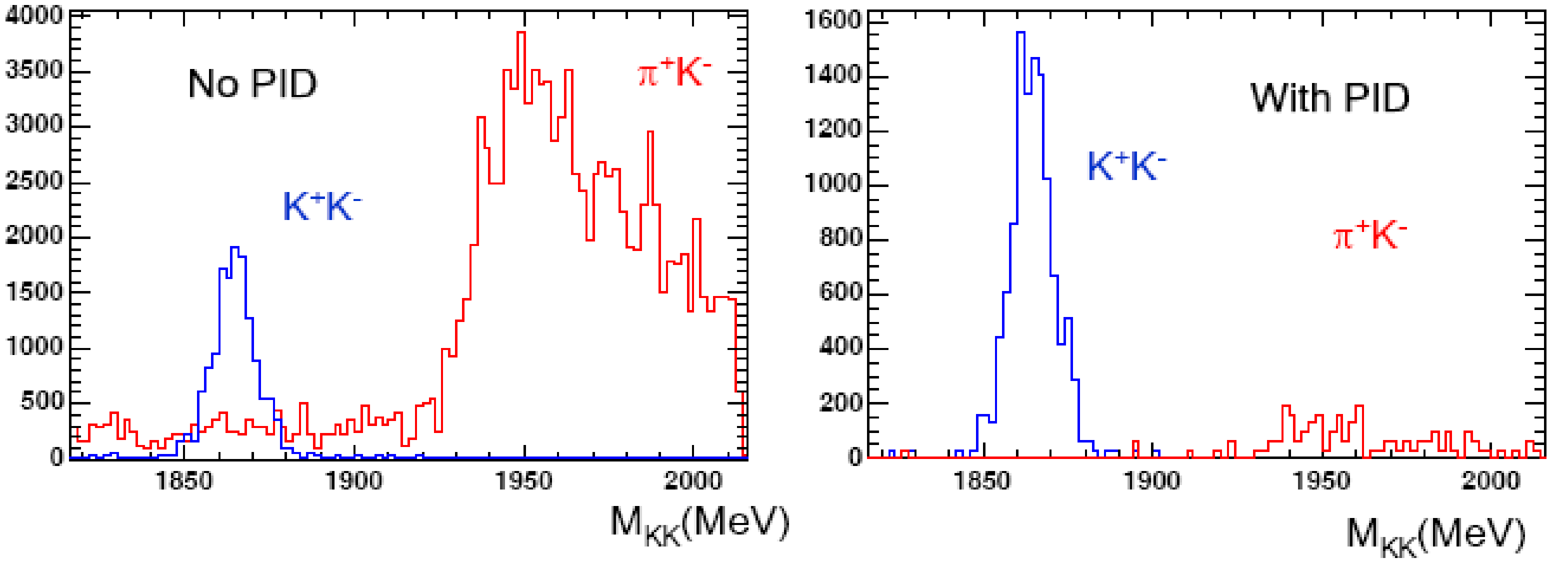
$D^0 \to K^- \pi^+$	50	$\times 10^6$;
$D^0 \to K^- K^+$	5	$\times 10^6$;
$D^0 \to \pi^- \pi^+$	2	$\times 10^6$;
$D^0 \to K^+ \pi^-$	0.2	$\times 10^6$.

  Similar number of prompt D^* are expected.

- $D^* \to D^0(K\pi)\pi$ events are essential for the calibration of RICH detectors

- High statistics (~10^8 events), with precise vertexes and particle identification, for
  - ✓ Mixing searches
  - ✓ Direct CPV
  - ✓ Rare decay $D^0 \to \mu\mu$

- **The power of PID**



PID RICH information essential for eliminating the background

Conclusions

- LHCb is dedicated to the study of B physics, with a devoted trigger,excellent vertex and momentum resolution, and particle identification

- LHCb will give unprecedented statistics for B decays, including access to the B_s meson, unavailable to the B factories

- B_s–$\overline{B}_s$ oscillations will be measured precisely

- Many measurements of rare decays and CP asymmetries will be performed

- CP angles determined via channels with different sensitivity to new physics
  $\rightarrow$ detailed test of the CKM description of the quark sector

- "by-products" are under exploring