LHCb physics

LHC-The first year of data taking:
IoP HEPP half-day meeting

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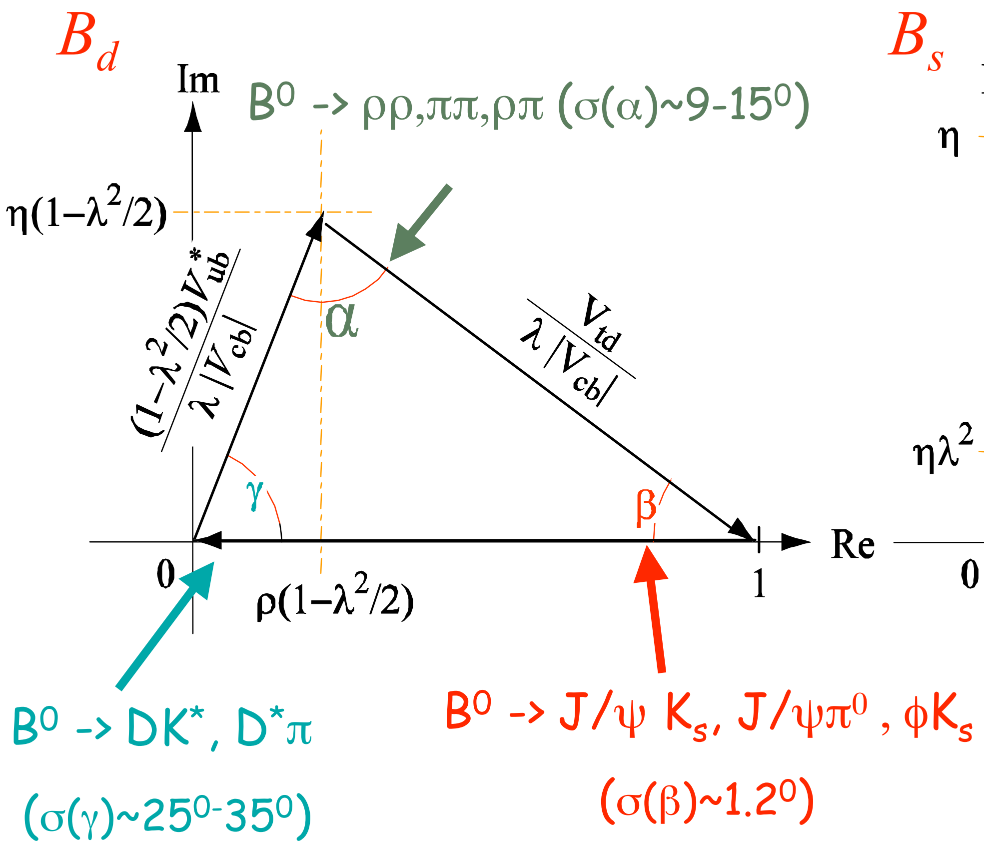
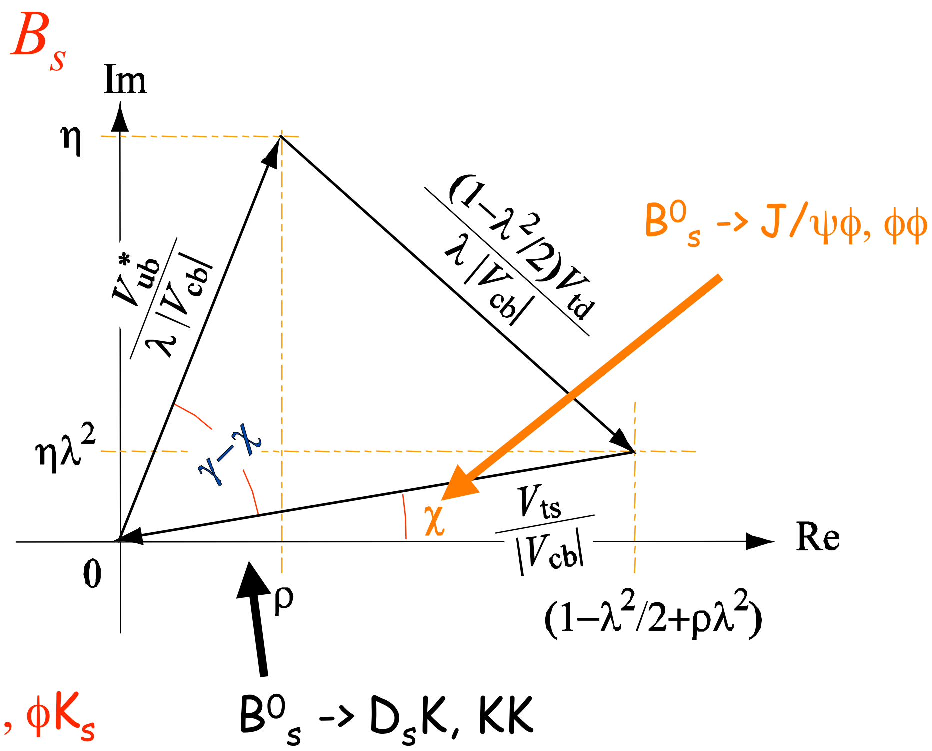
Physics motivation



Current sensitivities from b-factories

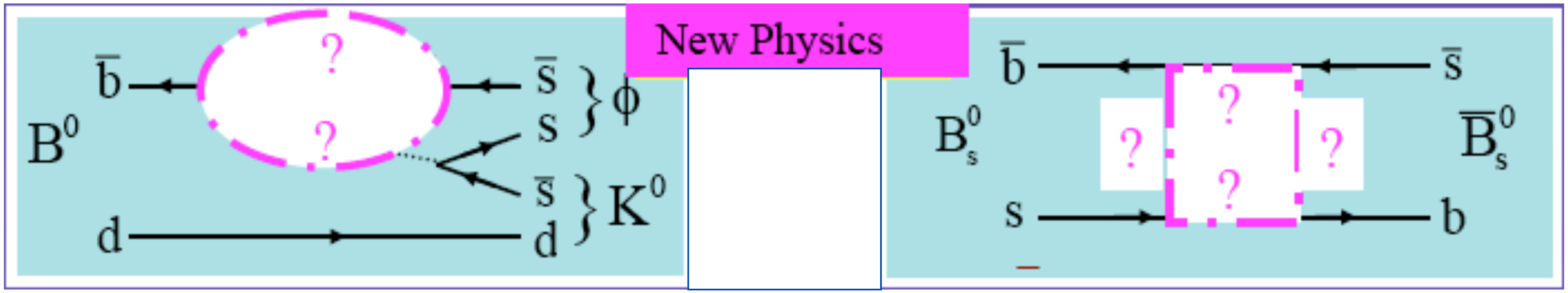


CDF/D0: Δm_s measurement, observation of $B_s \to \phi\phi$

LHCb will study all types of B mesons with excellent precision

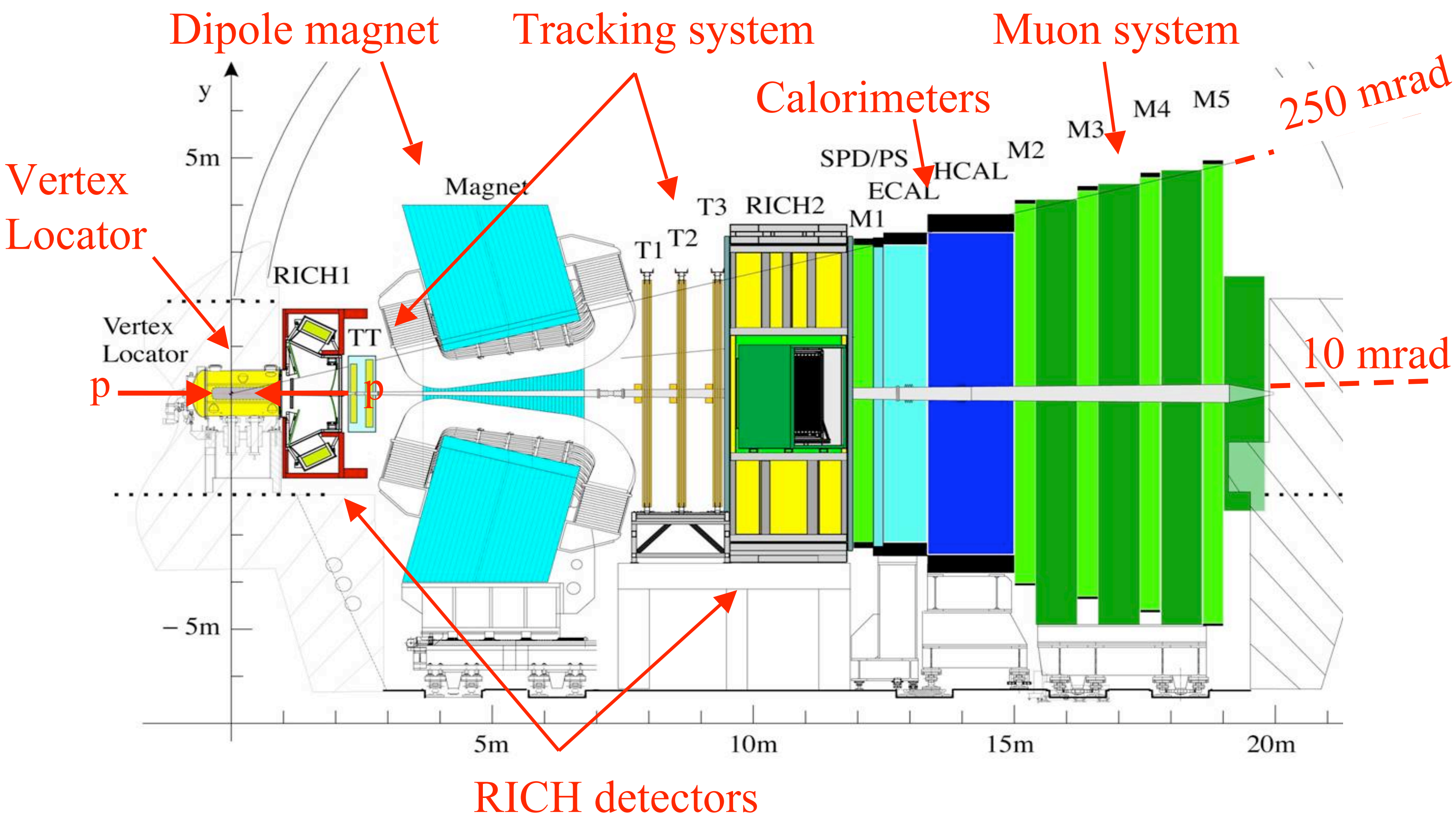
New physics

- Standard model is a low-energy effective theory of a more fundamental theory at higher energy scale (TeV range)
- New physics can be discovered and studied :
  - Direct observation: new physics produced and discovered as real particles
  - Indirect approach: new physics appear as virtual particles in loop processes



- Observable deviations from SM expectations in flavour physics and CPV
- LHCb designed to make precision measurement of CPV and rare decays in B system

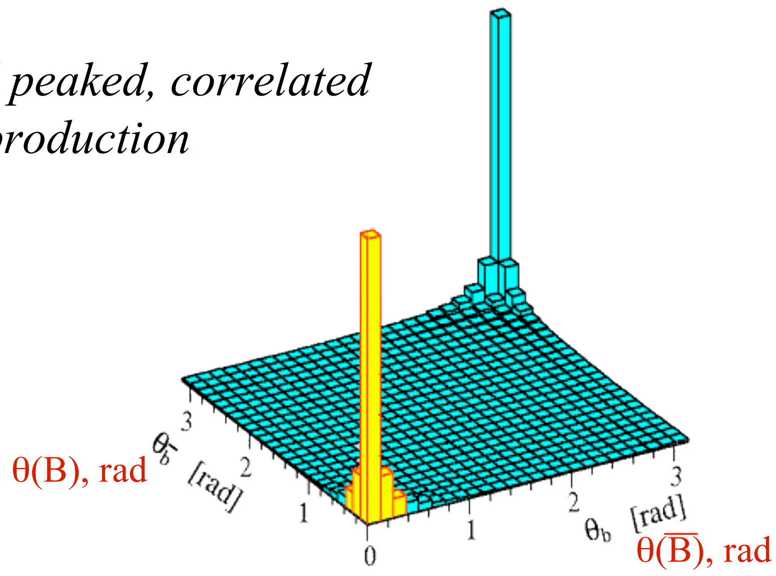
The LHCb detector



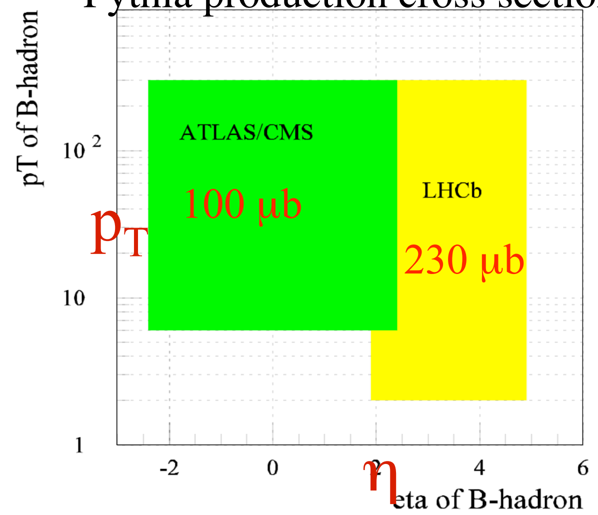
LHCb environment

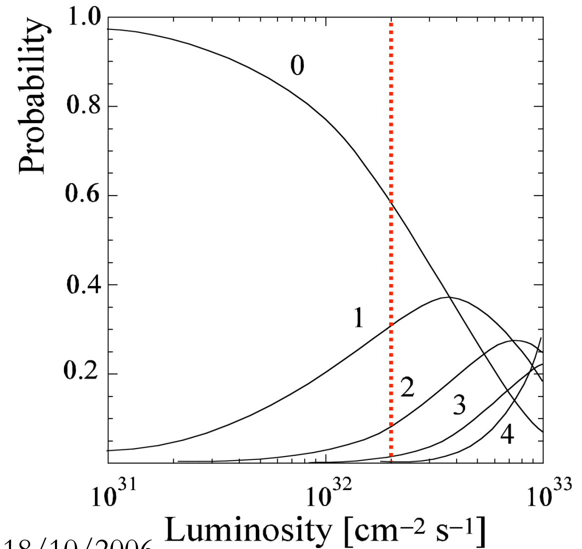
LHCb is a forward spectrometer (10-300 mrad)

Forward peaked, correlated bb pair production



Pythia production cross section





$\sqrt{s}$ = 14 TeV, *pp collisions: large* $\sigma_{bb} \sim 500\ \mu b$

but $\sigma_{bb}/\sigma_{tot} \sim 5\times10^{-3}$

Interesting B decays have low BR $\sim10^{-5}$

LHCb average $\mathcal{L} \sim 2\times10^{32}\ cm^{-2}s^{-1}$

$\rightarrow 2\ fb^{-1}$ / year (10^7 s)

$\rightarrow 10^{12}$ bb *produced/year*

most events due to single interactions per bunch crossing

Trigger overview

40 MHz

↓

Level-0:
p_T of
μ, e, h, γ

← Calorimeter
Muon system
Pile-up system

↓

1 MHz

L0: custom hardware

↓

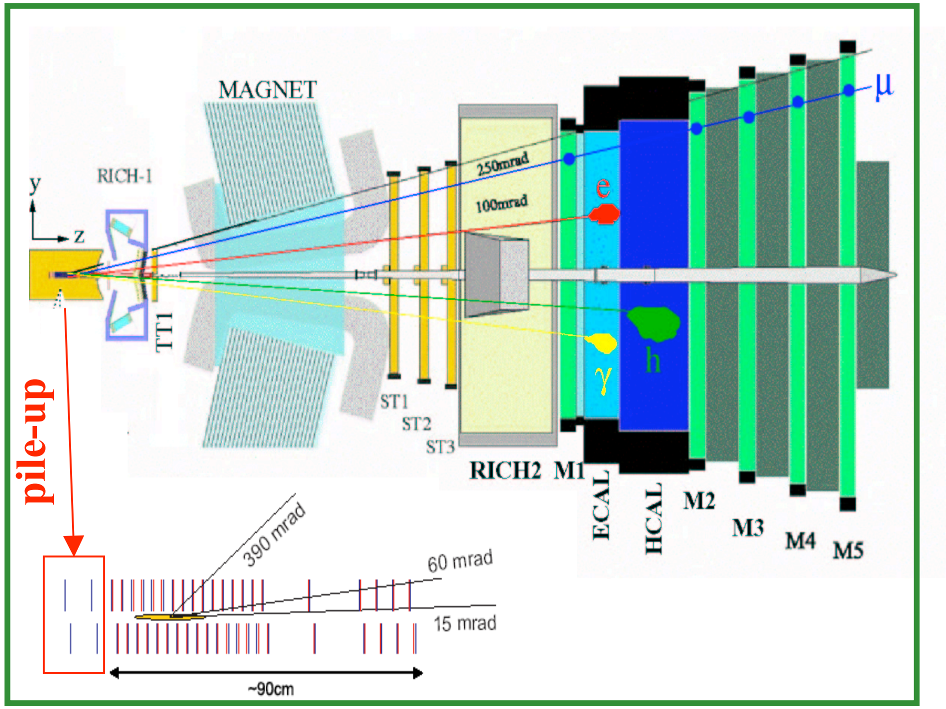
HLT:
Confirm level-0
Associate Pt/IP
μ, e, h, γ alley
Inclusive/exclusive
selections

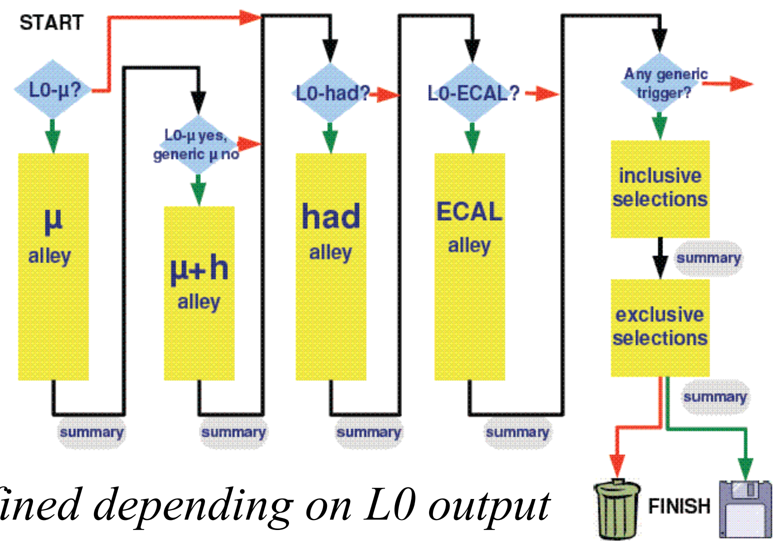
← Full detector
information

HLT: CPU farm

↓

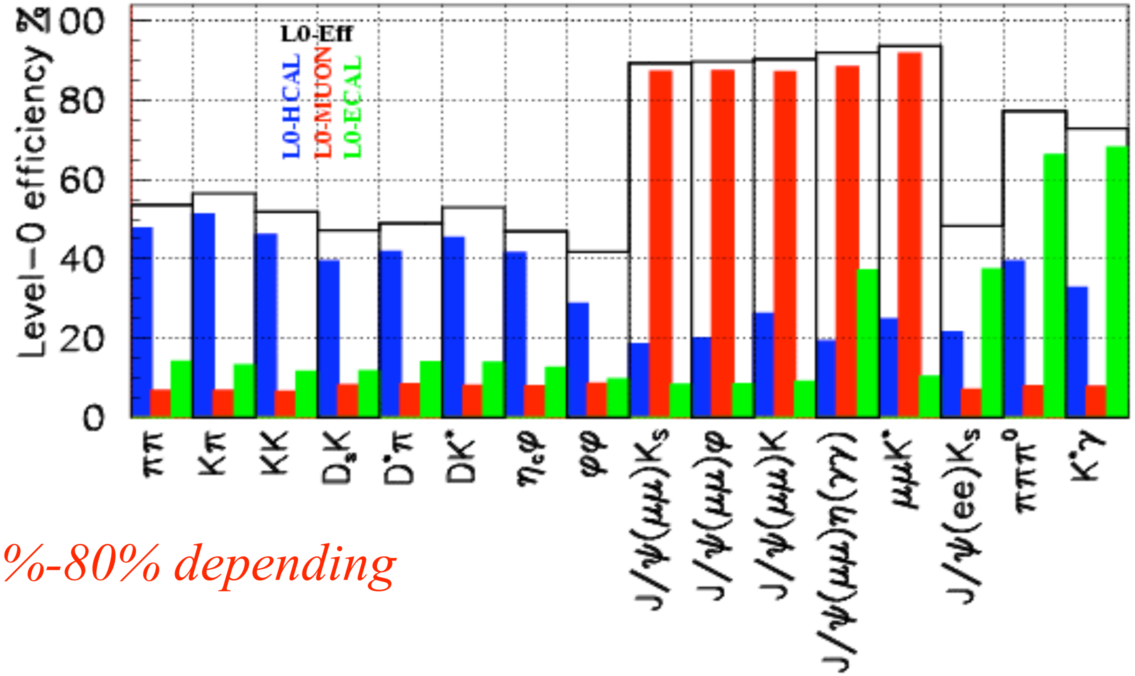
2 kHz output to tape





HLT: 4 independent alleys defined depending on L0 output

Trigger output



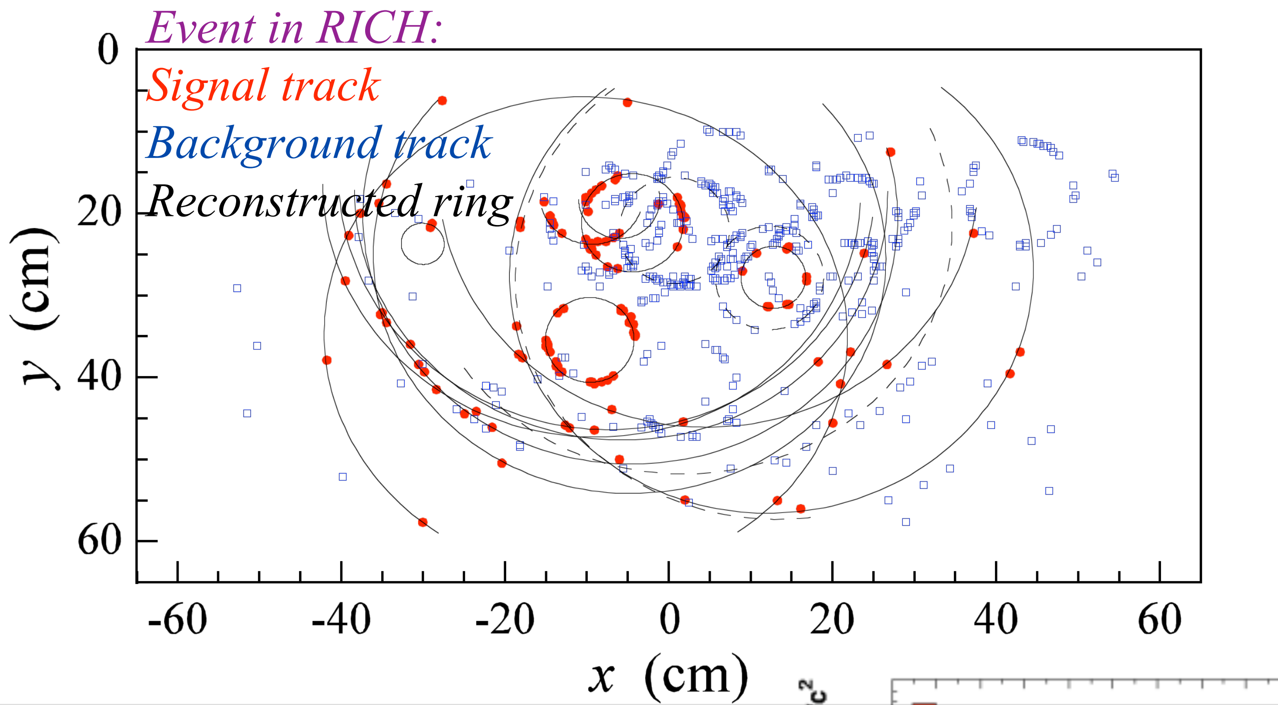
L0 efficiency
Hadronic dominated
Muon dominated
Ecal dominated

Overall trigger efficiency:30%-80% depending on signal channels

HLT Output rate	Trigger Type	Physics Use
200 Hz	Exclusive B candidates	Specific final states
600 Hz	High Mass di-muons	J/ψ, $b \to J/\psi X$
300 Hz	D* Candidates	Charm, calibrations
900 Hz	Inclusive b (e.g. $b \to \mu$)	B data mining

- *Rough estimate at present (split between streams still to de determined)*
- *Inclusive streams used for calibration and control of systematics*

Particle identification



π/K separation provided by RICH for 2<p<100 GeV:

<ε(K→K,p)> = 83%

<ε(π→K,p)> = 6%

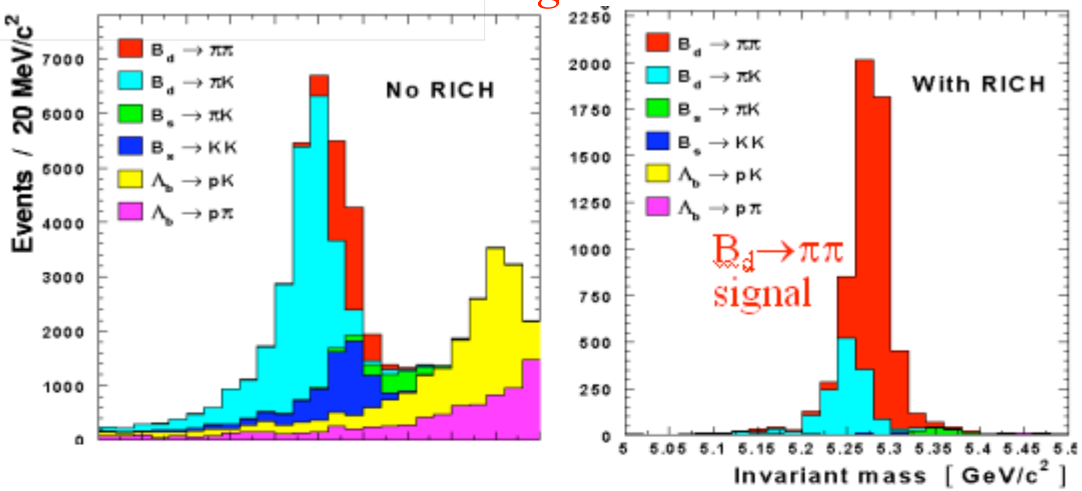
Clean separation of two-body B decays, e. g. B→ ππ

Lepton ID:

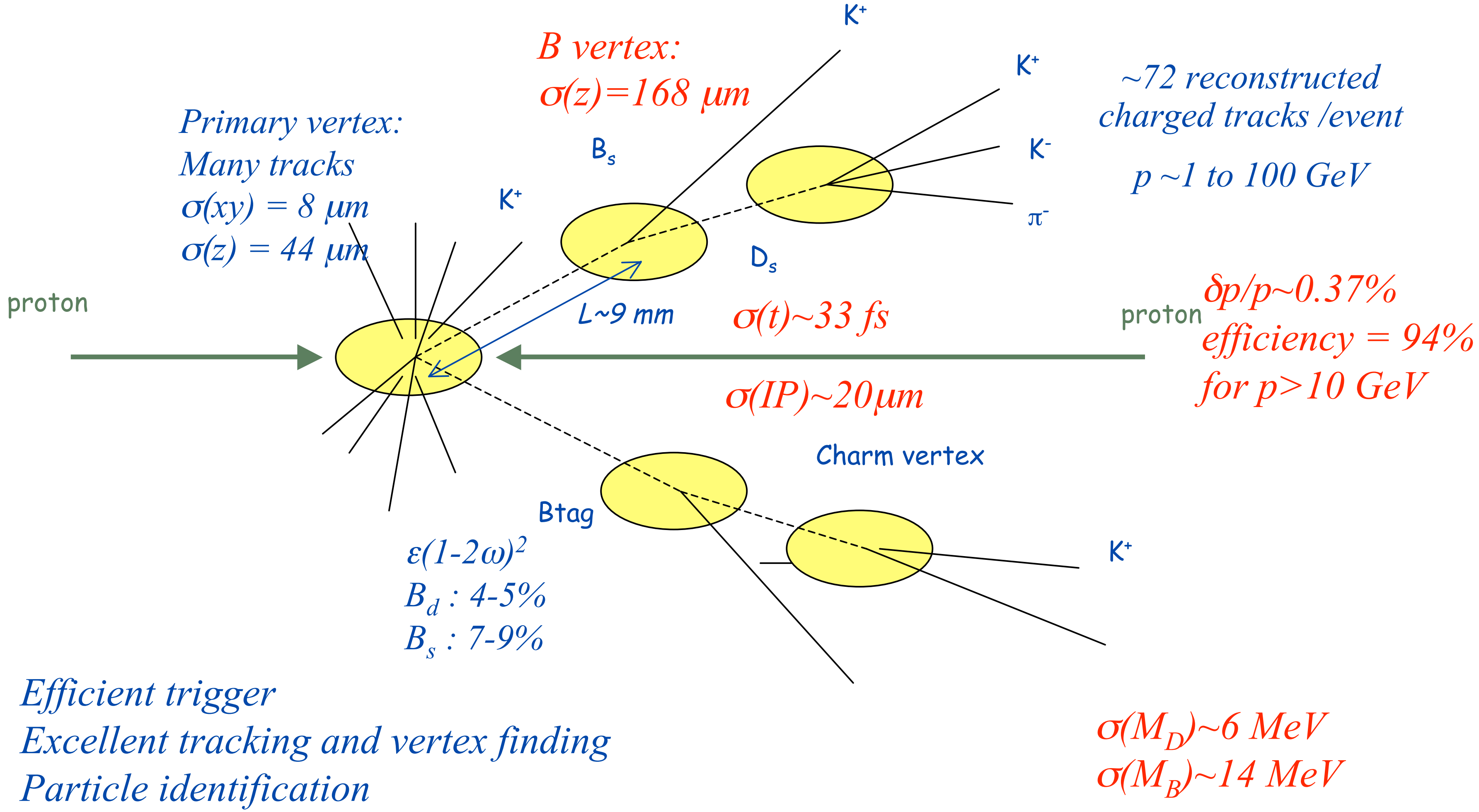
μ efficiency:94%

e efficiency:78%

π mis-id rate:1%

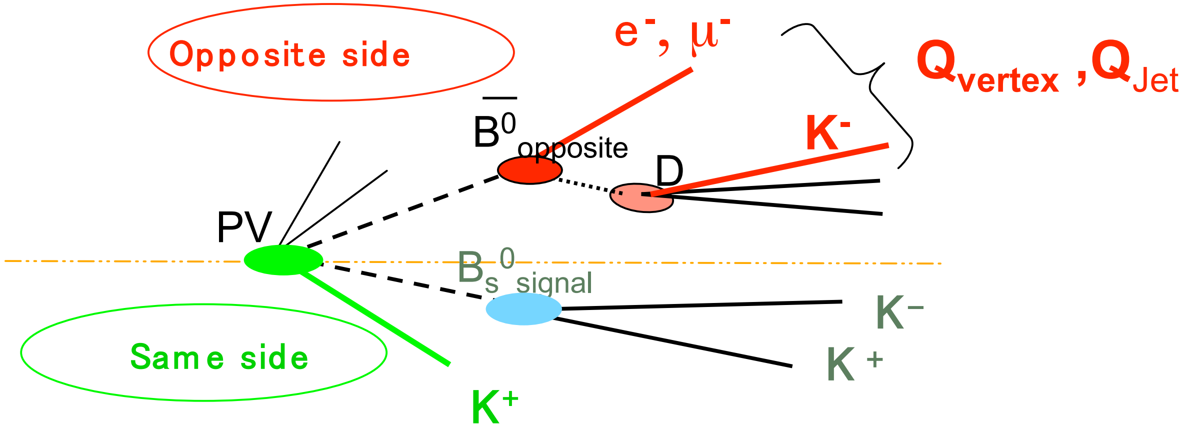


A typical LHCb event



Efficient trigger
Excellent tracking and vertex finding
Particle identification
Excellent resolutions

Flavour tagging



Tag	$\varepsilon D^2=\varepsilon(1-2w)^2$
Opposite μ	0.7%–1.8%
Opposite e	0.4%–0.6%
Opposite K	1.6%–2.4%
Opposite Q_{vtx}	0.9%–1.3%
Same side π (B^0)	0.8%–1.0%
Same side K (B_s)	2.7%–3.3%
Combined (B^0)	4%–5%
Combined (B_s)	7%–9%

Opposite side:

- *High-Pt leptons*
- $K^\pm$ *from* $b \rightarrow c \rightarrow s$
- *Vertex charge*
- *Jet charge*

Same side:

- *Fragmentation* $K^\pm$ *accompanying* B_s
- $\pi^\pm$ *from* $B^{**} \rightarrow B^{(*)} \pi^\pm$

Figure of merit:

$\varepsilon D^2=\varepsilon(1-2\omega)^2$: *tagging power in %*

ε: *tagging efficiency;*

ω: *wrong tagging fraction*

← *Obtained from fully simulated signal events passing trigger and selection*

LHC startup scenario (from the LHCb point of view)

2007: $\sqrt{s}$ = 900 GeV, $\int L\,dt < 1\ \mathrm{nb}^{-1}$

detector alignment and calibration, possibly already with J/y signals from pp collisions

2008: $\sqrt{s}$ = 14 TeV, $L = 1.2\text{-}2 \times 10^{32}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$, $\int L\,dt = 0.25\text{-}0.5\ \mathrm{fb}^{-1}$

complete calibration and trigger commissioning, first physics

2009: 1.0 fb^{-1}

2010: 1.5 fb^{-1}

~3 fb^{-1} *by the end of 2010 at the required average luminosity of* ~$2 \times 10^{32}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

Commissioning plans

Global commissioning without beam in 2006 - 2007:

- *Commission the subdetectors (starting now !)*
- *Test the DAQ*
- *Test the electronics calibration procedures*
- *Check the scalability of the system, improve when needed*
- *Use of circulating beam in summer 2007: LHCb is a forward detector, cosmics can not help: beam-gas gives useful tracks for time and position alignment.*

  Study of beam gas events ongoing: useful also for measuring and monitorng the luminosity (and cross section measurements?)

Pilot Run (low luminosity):

- *Without magnetic field: (time and space) alignments*
- *With magnetic field: Trigger setup and start collecting data*

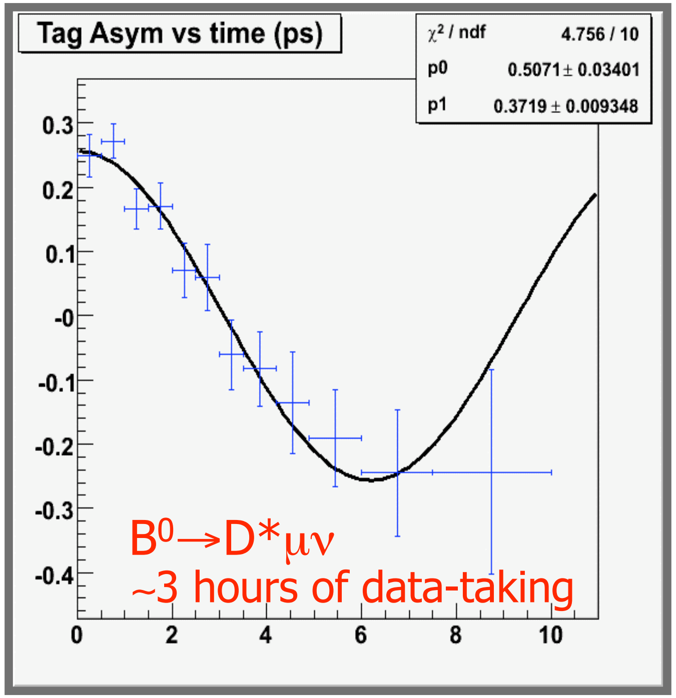
Preparing for physics with 0.1 fb^{-1} of data

1. *Use special samples (mainly from inclusive HLT) for reconstruction and PID calibration and tuning:*
   $J/\Psi \rightarrow \mu\mu$ for μ ID
   $D^* \rightarrow D^0(K\pi)\pi$ for K/π ID and μ mis-ID

2. *Use B^+/B^0 control channels for tagging tuning*

events after triggerxSelection (0.1 fb^{-1}):	
$B^+ \rightarrow J/\Psi(\mu\mu)K^+$	~ 80 k
$B^+ \rightarrow D0^{(*)}\mu\nu$	~ 100 k
$B^0 \rightarrow D^{*+}\mu\nu$	~ 350 k
$B_s \rightarrow D_s^{(*)}\mu\nu$	~ 50 k

σ_ω/ω ~1-2 % per tagger



3. *Use B^0 control channels for oscillation measurement, as a first check of tagging performance*

First physics measurements

LHCb physics program with first data:

- *J/ψ production studies (e.g. prompt vs $B \rightarrow J/\psi X$, bb cross section)*

- *$\sin(2\beta)$ (as a proof of principle of CPV measurements)*

- *Δm_s and ϕ_s (after CDF Δm_s, measurement, recent theoretical papers indicate ϕ_s measurement as very interesting for NP)*

- *$B_s \rightarrow \mu\mu$*

- *γ from $B \rightarrow DK$ and $B \rightarrow KK$, $\pi\pi$*

- *A_{FB} from $B \rightarrow K^* \mu\mu$*

Possible first measurements with 2 fb^{-1}

Sensitivity studies

- *For all the sensitivity studies, we use toy MC with detector resolutions extracted from a full Geant simulation of the events*

- *Annual yields estimated with full simulated Geant events*

- *Sample of 40 million fully simulated and reconstructed b-inclusive decays are used for the B/S estimates*

J/ψ production study

Prompt J/ ψ versus B →J/ ψ X cross section

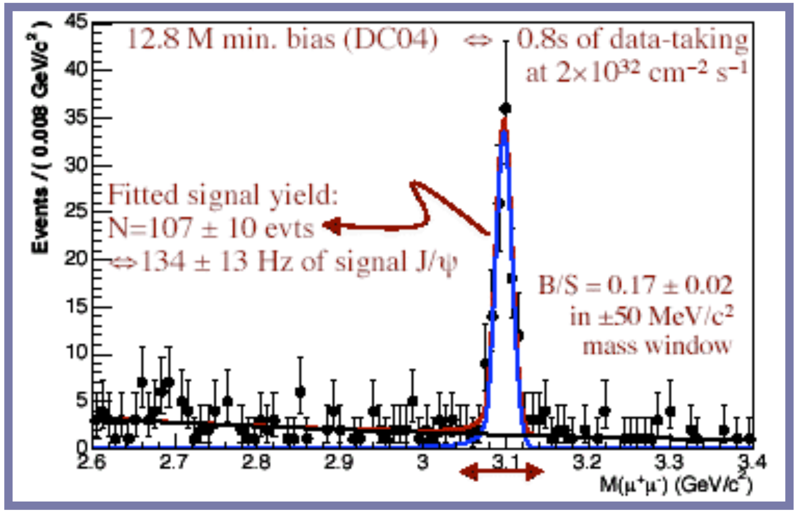
Preliminary generator study shows (prompt J/ψ) ~ 3 times lower with NRQCD models turned on in Pythia for heavy quarkonia
Even rough measurement will be interesting

New region of phase space:
LHCb will measure 2.0 < |h| < 5.3
(ATLAS/CMS will measure |h| < 2.5
ALICE will measure |h| < 0.9
and 2.5 < |h| < 4)

Test of QCD in new region of phase space

Unbiased HLT dimuon stream:
True J/ψ rate = ~130 Hz
2.5 x 10^8 J/ ψ with 0.5 fb^{-1}

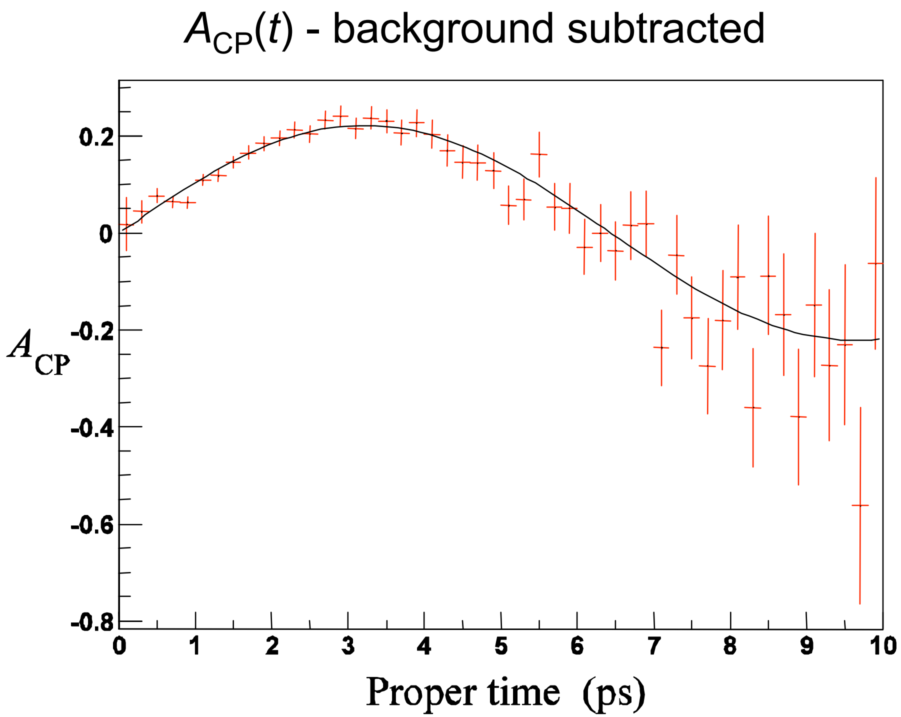
σ(prompt J/ψ)=0.313 mb
σ(J/ψ from B)=10 μb



sin 2β with $B^0 \rightarrow J/\psi K_S$

Very well measured at B-factories

One of the first CP measurements in LHCb: Demonstrate tagging performance and ability of CP physics



~60K $B^0 \rightarrow J/\Psi K_s$ events/0.5 fb^{-1}

$\sigma_{stat}(\sin 2\beta)$~0.04 with 0.5 fb^{-1}

$\sigma_{stat}(\sin 2\beta)$~0.02 with 2 fb^{-1}

Scaling 2 fb^{-1} sensitivity to ϕKs: $\sigma_{stat}(\sin 2\beta_{eff})$~0.4, yield 0.8K, B/S<2.4
May indicate new physics in penguin diagrams

B_s mixing: Δm_s

$$CDF: \Delta m_s = 17.77 \pm 0.10(stat) \pm 0.07(syst)\ ps^{-1}$$

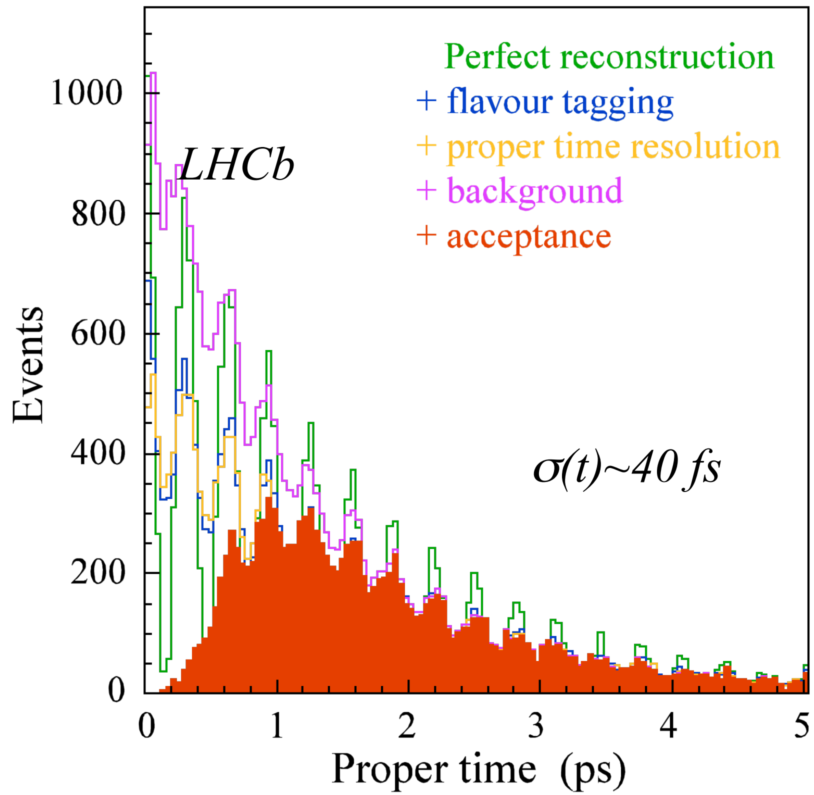
LHCb can reach CDF statistical precision in the first months of data taking:
Measured using $B_s \to D_s^- \pi+$
120k events / 2 fb^{-1},
B/S=0.4

Given the low value of Δm_s, LHCb will be able to measure it with much less than $2fb^{-1}$

$\sigma_{stat}(\Delta m_s)$~$0.01\ ps^{-1} / 2\ fb^{-1}$

$B_s \to D_s^- \pi^+$

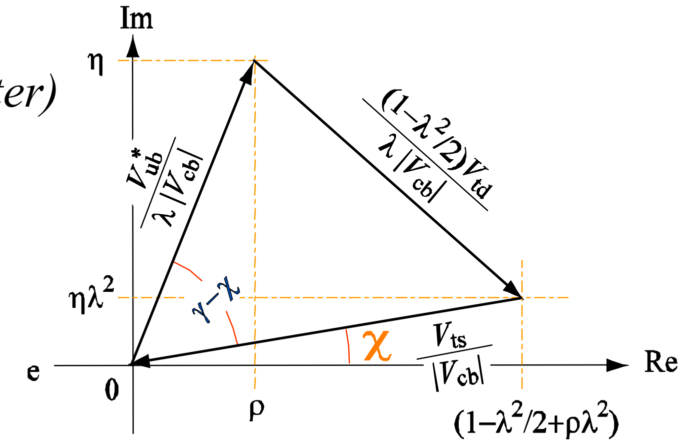
Distribution of unmixed sample for 2 fb^{-1} and for Δm_s= 20 ps^{-1}



Very good resolution for oscillations: time-dependent analyses with B_s decays, B_s mixing phase, CP violation in the mixing...

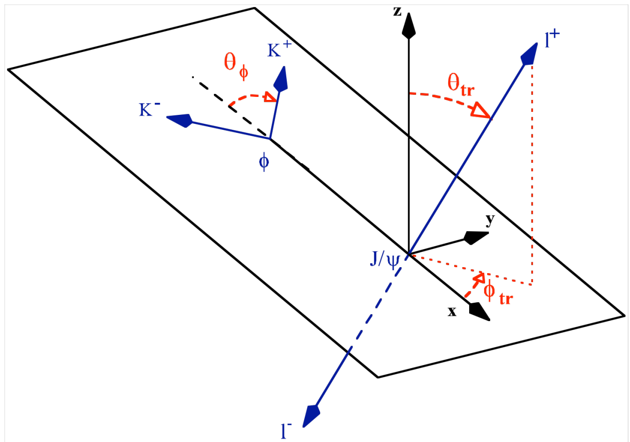
B_s mixing phase

ϕ_s is very small in SM: $\phi_s = -2\chi = -0.036 \pm 0.003$ (CKM fitter)
Sensitive probe of new physics



Use $B_s \rightarrow J/\Psi\phi$ (~130k events/2fb^{-1} expected), B/S=0.12
Final state contains CP-even and CP-odd contributions

Angular analysis to separate CP even and CP odd

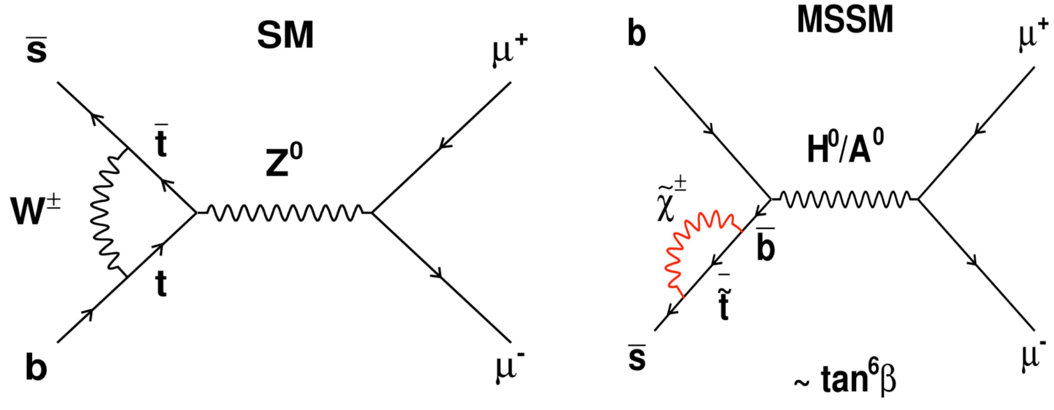


$\sigma(\sin \phi_s)=0.023$ and
$\sigma(\Delta\Gamma_s/\Gamma_s)=0.011$
(with Δm_s = 17.5 ps^{-1}) in 2 fb^{-1}

With 0.2 fb^{-1} set interesting limit
or measure ϕ_s if large: $\sigma(\phi_s) = \pm 0.1$

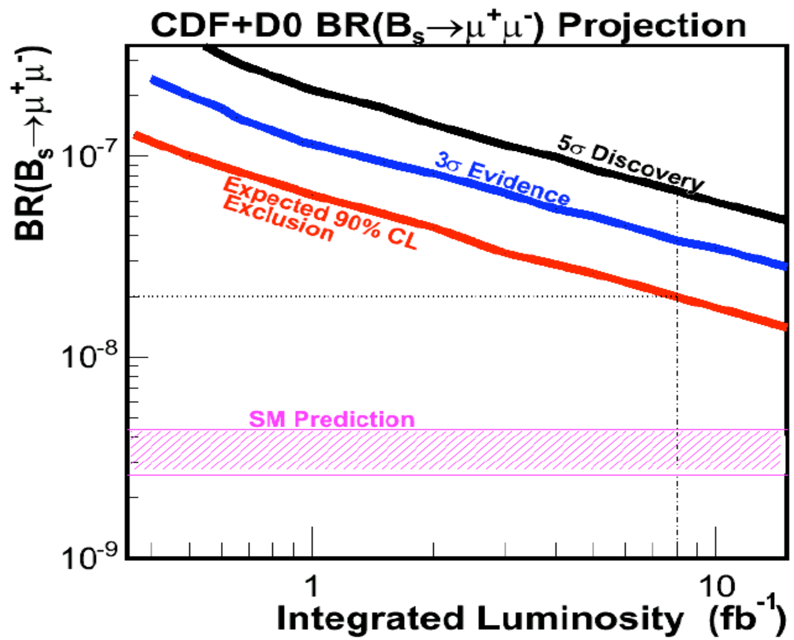
$B_s \to \mu^+\mu^-$

Branching ratio
~ 3.5 x 10^{-9} in SM
Sensitive to new physics,
can be strongly enhanced
by SUSY



Current limit from Tevatron CDF+D0
with 1 fb^{-1} is ~ 7 x 10^{-8} @90% CL
expected limit
with 8 fb^{-1} is ~ 2 x 10^{-8} @90% CL

From B-factories @90%CL:
Babar < 6.1 10^{-8}
Belle < 1.6 10^{-7}



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

O(1) event from 2-body modes (KK, ππ thanks to excellent B mass resolution of 18 MeV) per fb^{-1} in a 2σ mass window

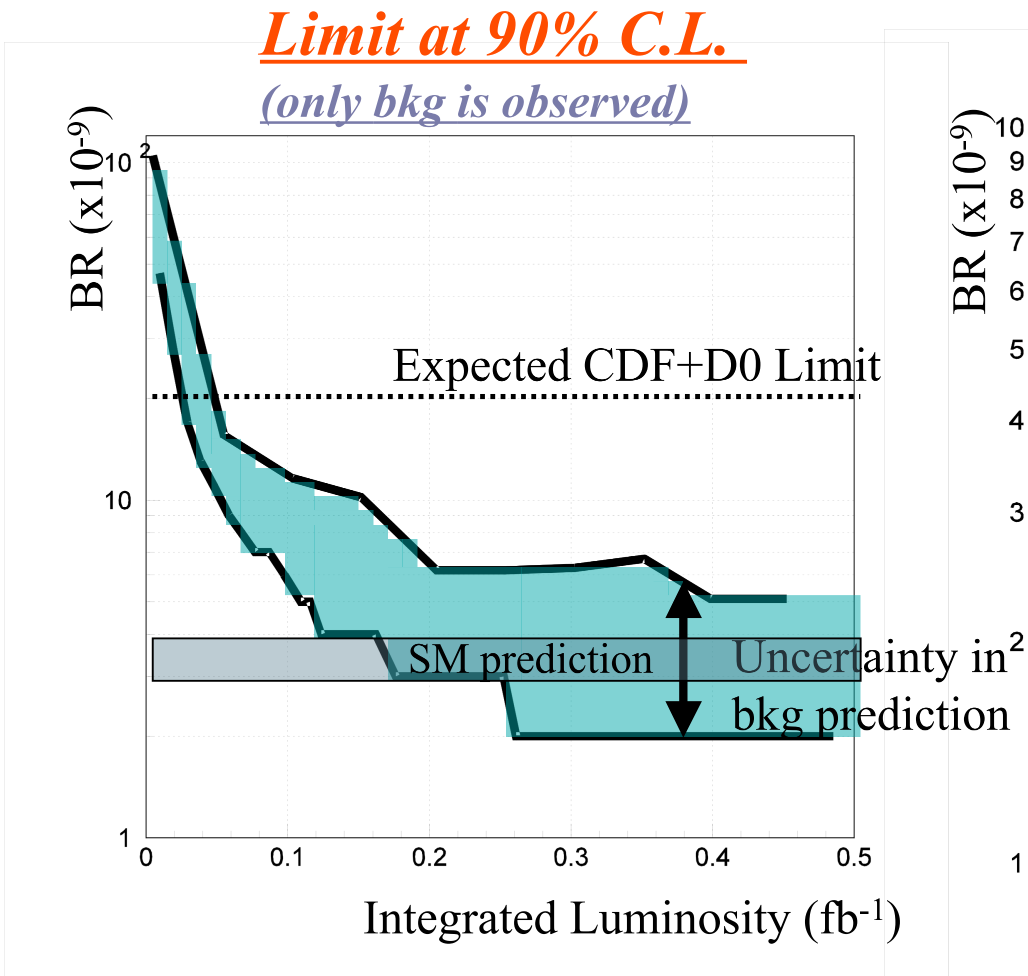
Combinatorial background studied with ~33M inclusive-b events (~7 min at LHCb)

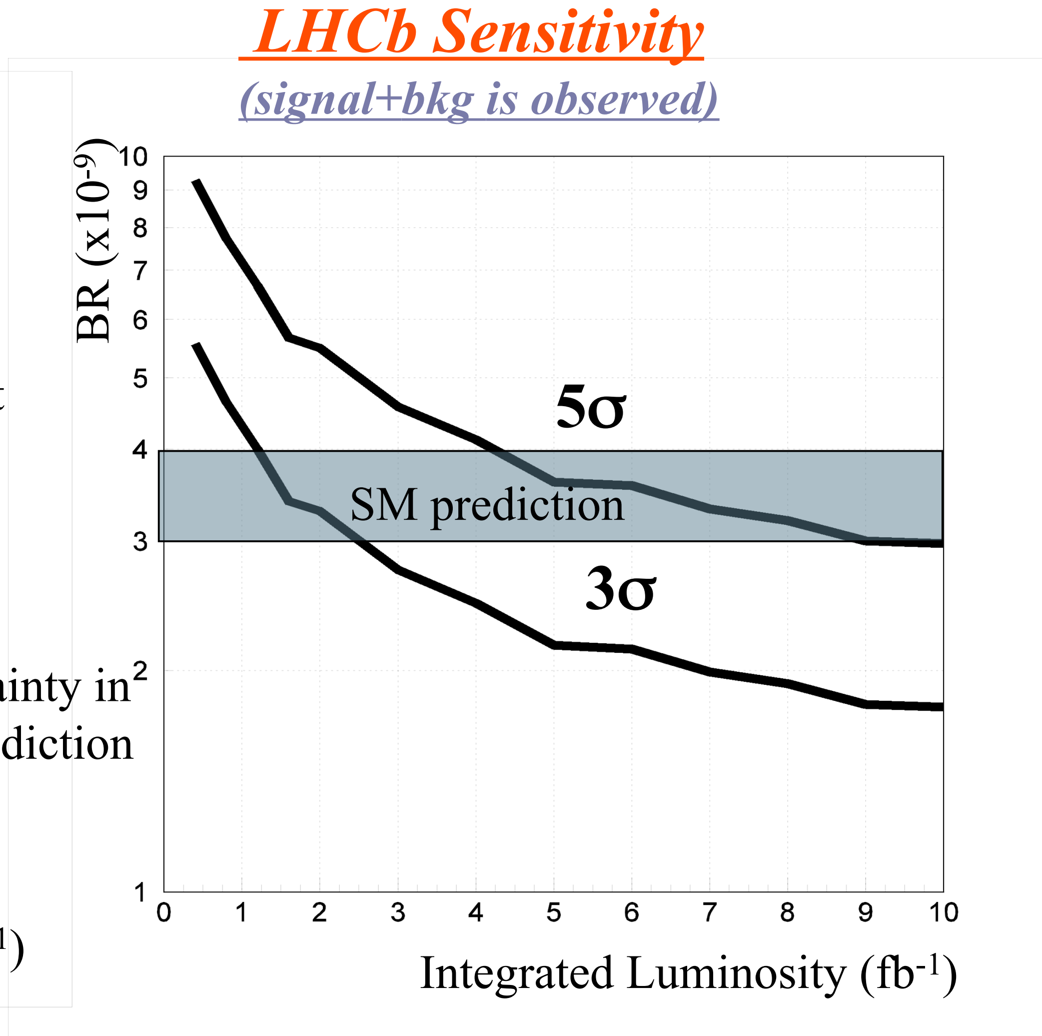
and 10M $b \to \mu X$, $b \to \mu X$ events (~5h at LHCb)

Background estimates limited by statistics

$N(B_s \to \mu^+\mu^-)$ (SM)	=	10.5	per fb^{-1}
$N(b \to \mu^- X, b \to \mu^+ X)$		< 63 @90%CL	per fb^{-1}

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

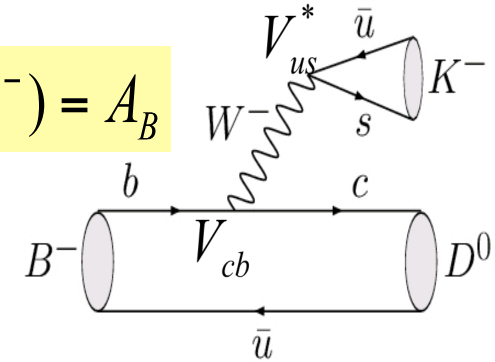




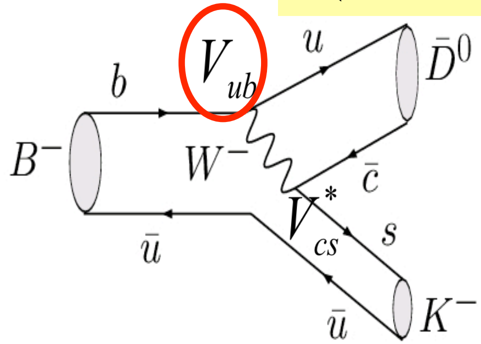
Background is assumed to be dominated by combinations of $b \to \mu^- X$ $b \to \mu^+ X$ events

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

$A(B^- \to D^0 K^-) = A_B$



$A(B^- \to \overline{D}^0 K^-) = A_B r_B e^{i(\delta-\gamma)}$



No need for
a time-dependent
analysis

γ can be extracted from the interference of these two processes in charged $B \to D^0 K$ decays with $D^0/\overline{D}^0$ decaying to a common final state

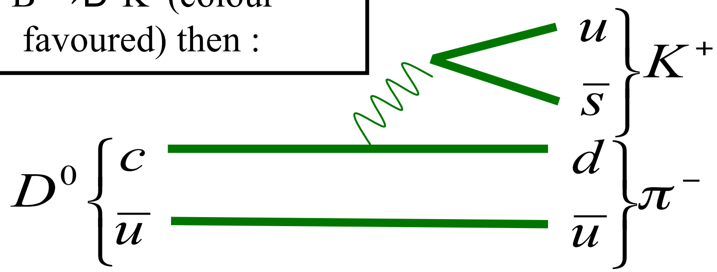
- *r_B is the relative colour and CKM suppression between the two modes $O(0.1)$ – dilutes sensitivity to γ*
- *δ is the strong phase difference - invariant under CP*

- *Two types of D^0 decays under study:*

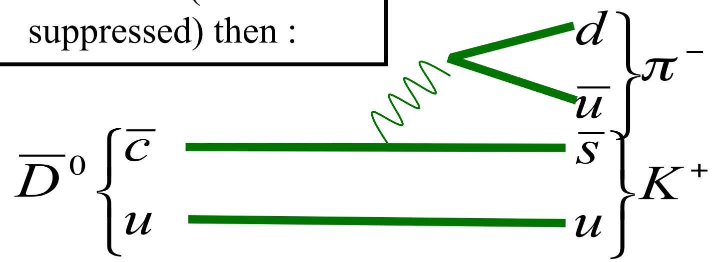
Cabibbo favoured self-conjugate decays e.g. $K_s\pi\pi$ - sensitivity under study
Cabibbo favoured/doubly Cabibbo suppressed modes e.g. $K\pi$,$K\pi\pi\pi$

γ from $B^{\pm} \to D^0 K^{\pm}$, ADS method

$B^- \to D^0 K^-$ (colour favoured) then :



$B^- \to \overline{D}^0 K^-$ (colour suppressed) then :



Reversed suppression of D decays versus B decays results in similar amplitudes,
So big interference effect

Measure relative rates (no need for tagging or time asymmetry)

Rates depend on 5 parameters: γ, r_B, δ_B, $r_D^{K\pi}$ (magnitude of the ratio between two D decays, well known), $\delta_D^{K\pi}$ (CP conserving strong phase difference, will be measured by CLEO or BES III)

↖ *Suppressed rates have O(1) interference effects since $r_B \sim r_D$*
Particularly sensitive to γ

Relative rates have more unknown than equations
Use other decays e.g. $K\pi\pi\pi$ or $KK,\pi\pi$

γ from $B^{\pm} \to D^0 K^{\pm}$

Yields with 2 fb^{-1}:

Suppressed:

~530 $B^{+} \to (K^{-}\pi^{+})_D K^{+}$ B/S ~ 1.5

~180 $B^{-} \to (K^{+}\pi^{-})_D K^{-}$ B/S ~ 4.3

(background mainly combinatorics)

Favored:

~28k $B^{+} \to (K^{+}\pi^{-})_D K^{+}$ B/S ~ 0.6

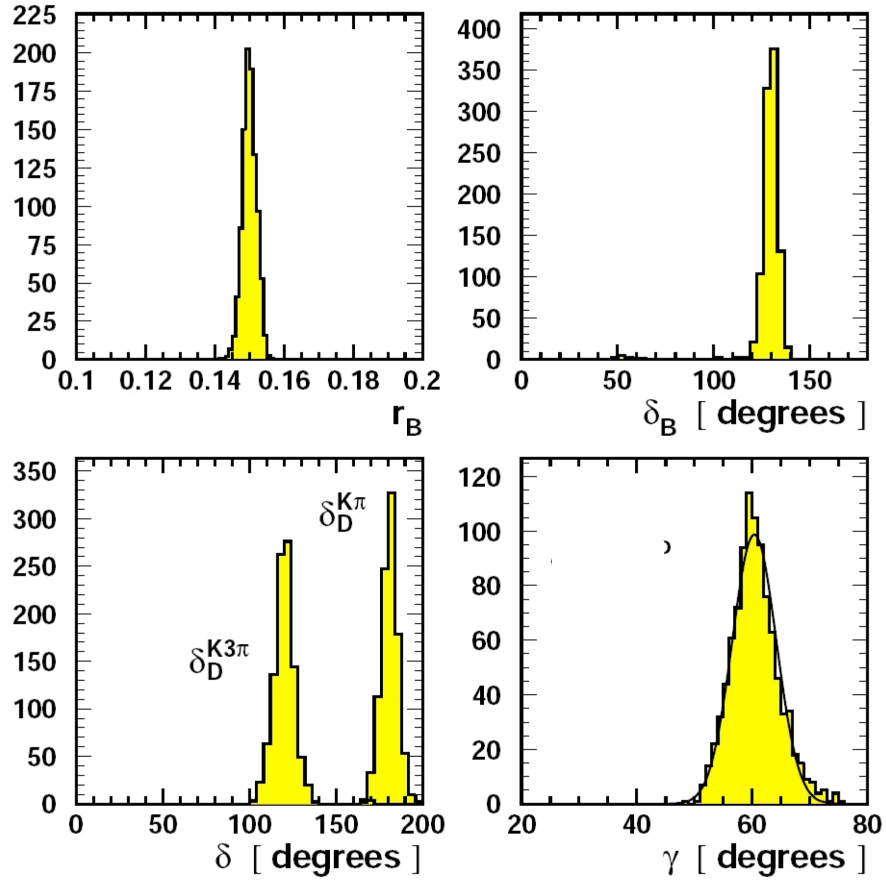
~28k $B^{-} \to (K^{-}\pi^{+})_D K^{-}$ B/S ~ 0.6

(background mainly $D\pi$)

KK and $\pi\pi$ modes:

~4.3K $B^{+} \to D^0(hh)K^{+}$ B/S ~ 1

~3.3K $B^{-} \to D^0(hh)K^{-}$ B/S ~ 1



$\gamma = 60^{o}$, $r_B = 0.077$,

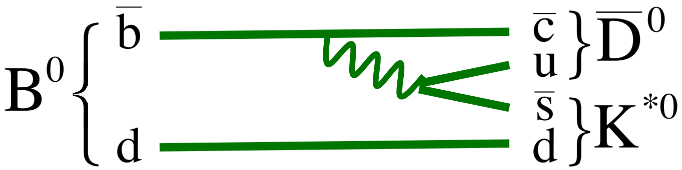
$\delta_B = 130^{o}$, $r_D^{K\pi} = r_D^{K3\pi} = 0.06$,

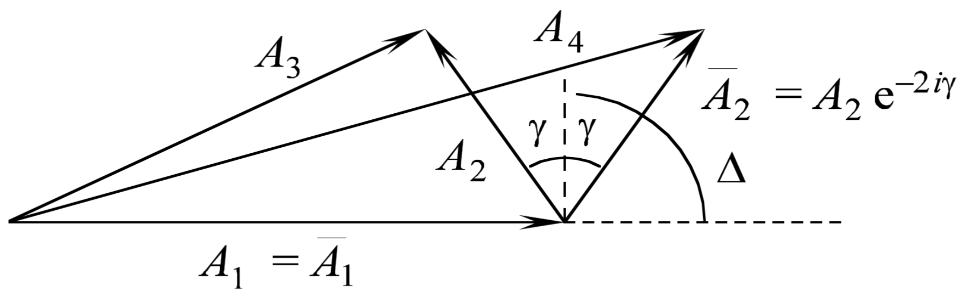
$-25^{o} < \delta_D^{K\pi} < 25^{o}$ *and* $-180^{o} < \delta_D^{K3p} < 180^{o}$

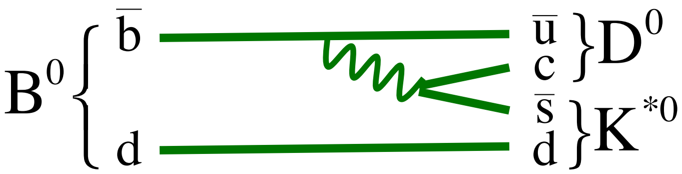
← $\delta(\gamma) \sim 5^{o}$ -15^{o} *in a year, depending on* $\delta_D^{K\pi}$ *and* $\delta_D^{K3\pi}$

GLW method - γ from $B^0 \rightarrow D^0 K^{*0}$

- *Dunietz variant of Gronau-Wyler method makes use of interference between two colour-suppressed diagrams interfering via D^0 mixing :*







$A_1 = A(B^0 \rightarrow \overline{D}^0 K^{*0})$: $b \rightarrow c$ transition, phase 0

$A_2 = A(B^0 \rightarrow D^0 K^{*0})$: $b \rightarrow u$ transition, phase $\Delta + \gamma$

$A_3 = \sqrt{2}\, A(B^0 \rightarrow D_{CP} K^{*0}) = A_1 + A_2$, because $D_{CP} = (D^0 + \overline{D}^0)/\sqrt{2}$

- *Measuring the 6 decay rates $B^0 \rightarrow D^0(K\pi, \pi K, KK)K^{*0}$ + CP conjugates allows γ to be extracted without flavour tagging or proper time determination - $r_B \sim 0.4$ but 8-fold ambiguity*

GLW method - γ from $B^0 \rightarrow D^0 K^{*0}$

- *LHCb expectations for 2 fb^{-1}*
- *($55<\gamma<105^o$, $r_B \sim 0.4$, $-20<\delta_B<20$) :*

Mode (+ cc)	Yield	S/B_{bb} (90%CL)
$B^0 \rightarrow D^0 (K^+\pi^-) K^{*0}$	3.4k	> 2
$B^0 \rightarrow D^0 (K^-\pi^+) K^{*0}$	0.5k	> 0.3
$B^0 \rightarrow D^0_{CP} (K^+K^-) K^{*0}$	0.6k	> 0.3

$\rightarrow \sigma(\gamma) \sim 8°$ *in one year*

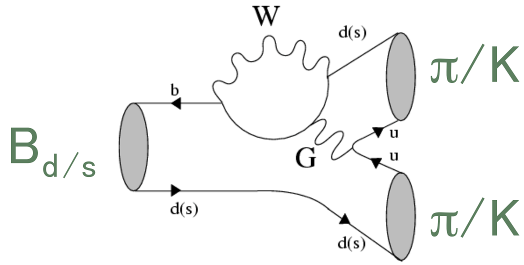
- *Work ongoing to understand biases introduced by DCS amplitude in D->Kπ*

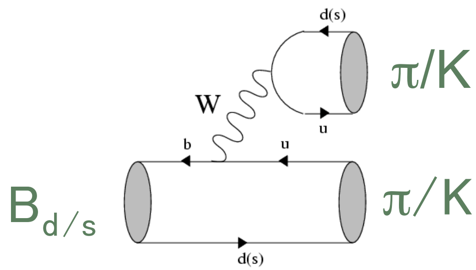
γ from $B \rightarrow KK, \pi\pi$

- *Measure time dependant asymmetries for $B_d \rightarrow \pi\pi$ and $B_s \rightarrow KK$ to determine A_{dir} and A_{mix}*

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

- *A_{dir} and A_{mix} depend on*
  - γ
  - *Mixing phases ϕ_d or ϕ_s*
  - *Penguin/Tree ratio = $de^{i\theta}$*
- *ϕ_d and ϕ_s from $J/\psi\phi$ and $J/\psi Ks$*
- *U-spin symmetry: $d_{\pi\pi} = d_{KK}$, $\theta_{\pi\pi} = \theta_{KK}$*
- *4 observables, 3 unknowns: solve for γ*



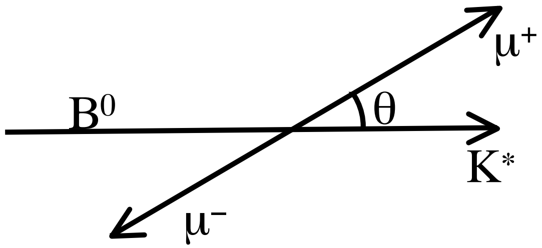


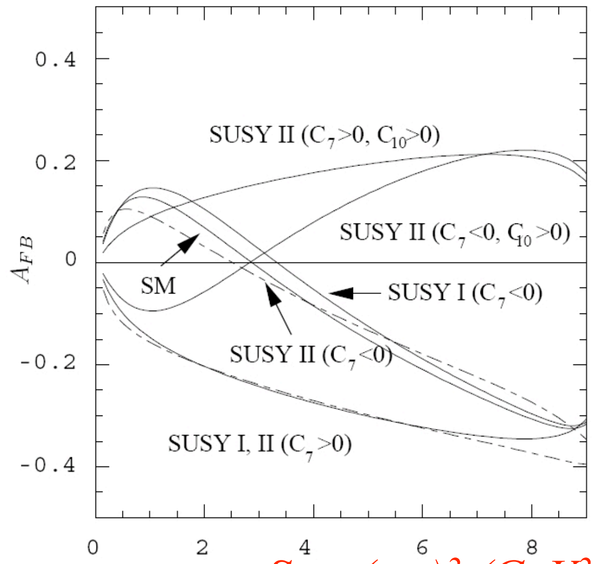
With 2 fb^{-1}:
26K $B_d \rightarrow \pi\pi$ $B/S<0.7$
37K $B_d \rightarrow KK$ $B/S<0.3$

$\sigma(\gamma) \sim 5°$

A_{FB} *in* $B_d \rightarrow K^{*0}\ \mu^+\ \mu^-$

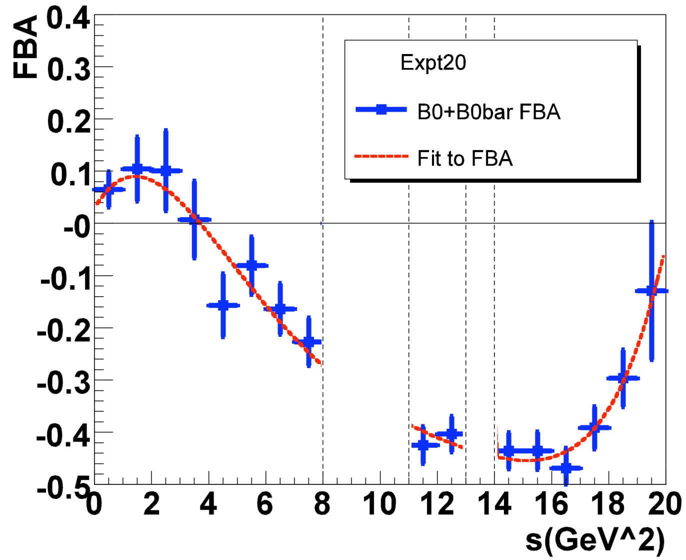
Forward-backward asymmetry A_{FB} in the μμ rest-frame is sensitive to NP





$S = m(\mu\mu)^2$ (GeV^2)

SM branching ratio ~ 10^{-6}



~4400 $B_d \rightarrow K^{*0}\ \mu^+\ \mu^-$ events/year
B/S< 2.6

With 2 fb^{-1}:
zero of $A_{FB}(s)$ located to ±1.2 GeV^2

A_{FB} in $B_d \rightarrow K^{*0} \mu^+ \mu^-$

Recent re-optimization of the selection improves yield by factor ~2, keeping the $m(\mu^+\mu^-)$ shape less biased at low m - sensitivity under study

~7300 $B_d \rightarrow K^{*0} \mu^+ \mu^-$ events/2 fb^{-1}
B/S = [0.86 - 1.10] @90%CL

Background mostly due to $b \rightarrow \mu X$ and non-resonant $K\pi$ (~4400 events)
(BR(non-resonant)=10^{-6} used in simulation, most probably over-estimated)

Recent theoretical development shows that non-res event can be treated as signal if "energetic" $K\pi$ pair is selected - work in progress

Possible measurements with 0.5 fb^{-1}:
rate versus q^2, amount of non-resonant events, study of control samples, A_{FB} in a few bins

Conclusions

- *Commissioning strategy being prepared in details*
- *Strategy for calibrations, alignments, triggers and analysis in view of current LHC startup schedule being devised*
- *Take advantage of machine engineering run in 2007 and commissioning period at 7 TeV in 2008 to be in stable physics operation at end of 2008*
- *Very interesting measurements already with the very first 0.5 fb^{-1} in 2008*

Spares

LHCb performance with $2fb^{-1}$

	Channel	Yield*	B_{bb}/S	Precision
γ	$B_s \to D_sK$ $B_d \to \pi\pi$ $B_s \to KK$ $B_d \to D^0(K^-\pi^+)K^{*0}$ $B_d \to D^0(K^+\pi^-)K^{*0}$ $B_d \to D_{CP}(K^+K^-)K^{*0}$ $B^- \to D^0(K^-\pi^+)K^-$ $B^- \to D^0(K^+\pi^-)K^-$	5.4k 26k 37k 0.5k 2.4k 0.6k 60k 2k	<1 <0.7 0.3 <0.3 <2 <0.3 0.5 0.5	$\sigma(\gamma) \approx 14^\circ$ $\sigma(\gamma) \approx 6^\circ$ $\sigma(\gamma) \approx 8^\circ$ $\sigma(\gamma) \approx 5^\circ$
α	$B_d \to \pi^0\pi^-\pi^+$	14k	0.8	$\sigma(\alpha) \approx 10^\circ$
ϕ_s	$B_s \to J/\Psi\Phi$ $B_s \to J/\Psi\eta$ $B_s \to \eta_c\Phi$	125k 12k 3k	0.3 2-3 0.7	$\sigma(\phi_s) \approx 2^\circ$
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	$\sigma(\sin 2\beta) \approx 0.022$
rare decays	$B_d \to K^*\mu^+\mu^-$ $B_s \to \mu^+\mu^-$ $B_d \to K^*\gamma$	4.4k 17 35k	<2.6 <5.7 <0.7	C_7^{eff}/C_9^{eff} with 13% error NP search $\sigma(A_{CP}^{dir}) \approx 0.01$

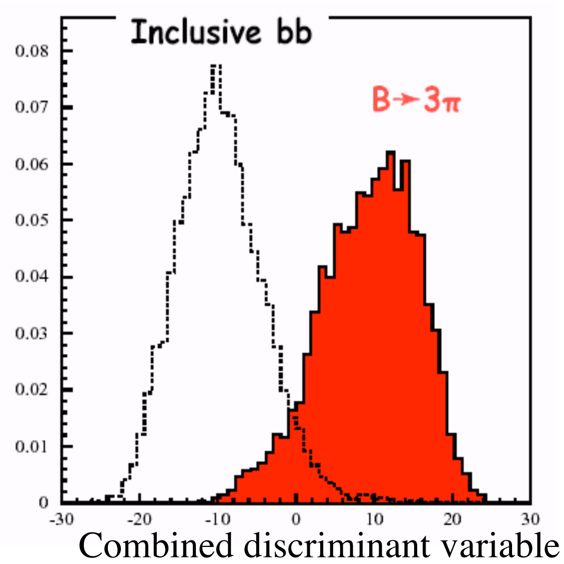
(*)Untagged annual yields after trigger, stat. only

B physics: LHC vs B factories

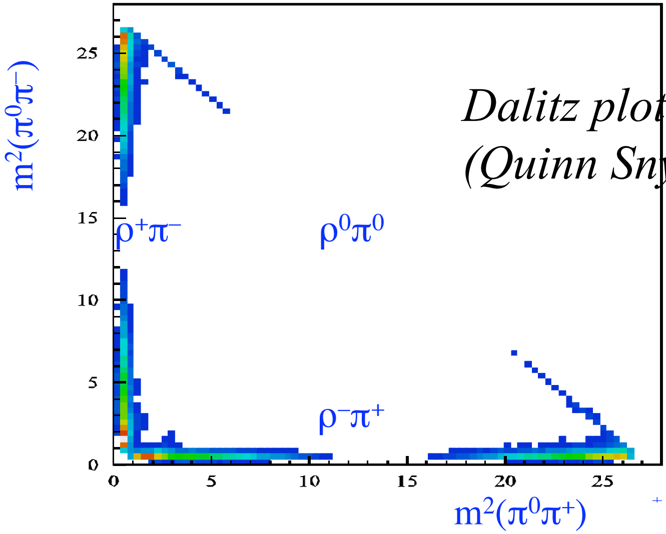
	$e^+e^- \rightarrow \Upsilon(4S) \rightarrow BB$ PEPII, KEKB	pp→bbX ($\sqrt{s}$ = 14 TeV, Δt_{bunch}=25 ns) LHCb	
Production σ_{bb}	1 nb	~500 μb	☺
Typical bb rate	10 Hz	100 kHz	
bb purity	~1/4	$\sigma_{bb}/\sigma_{inel}$ = 0.6% Trigger is a major issue !	☹
Pileup	0	0.5	
b-hadron types	B^+B^- (50%) B^0B^0 (50%)	B^+B^- (40%), B^0 (40%), B_s (10%) B_c (< 0.1%), b-baryons (10%)	☺
b-hadron boost	Small	Large (decay vertexes well separated)	
Production vertex	Not reconstructed	Reconstructed (many tracks)	
Neutral B mixing	Coherent B^0B^0 pair mixing	Incoherent B^0 and B_s mixing (extra flavour-tagging dilution)	☹
Event structure	BB pair alone	Many particles not associated with the two b hadrons	

Angle α from $B_d \to \pi^0 \pi^+ \pi^-$

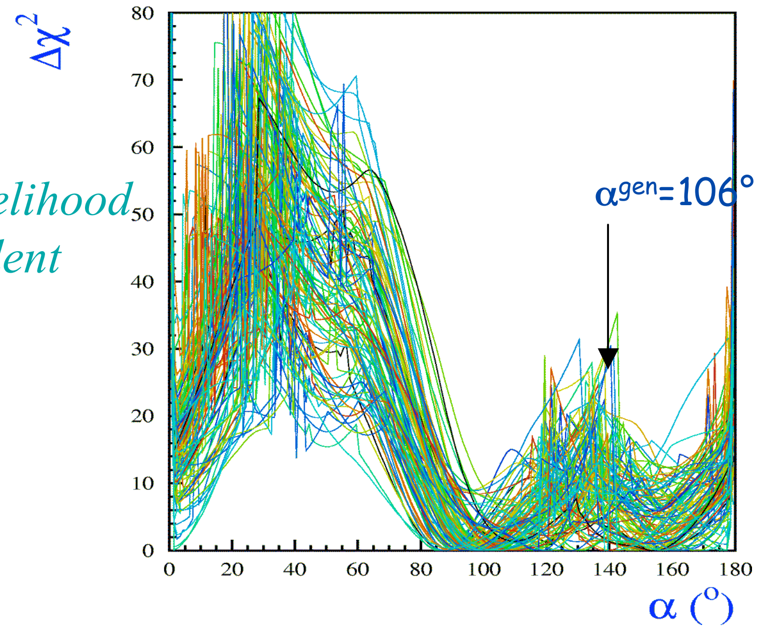
- *Selection based on multivariate analysis*
- *Use resolved and merged π^0*
- *Expect 14k events per year, B/S < 1*



Dalitz plot analysis (Quinn Snyder method)



11-parameter likelihood fit to time-dependent Dalitz plot:



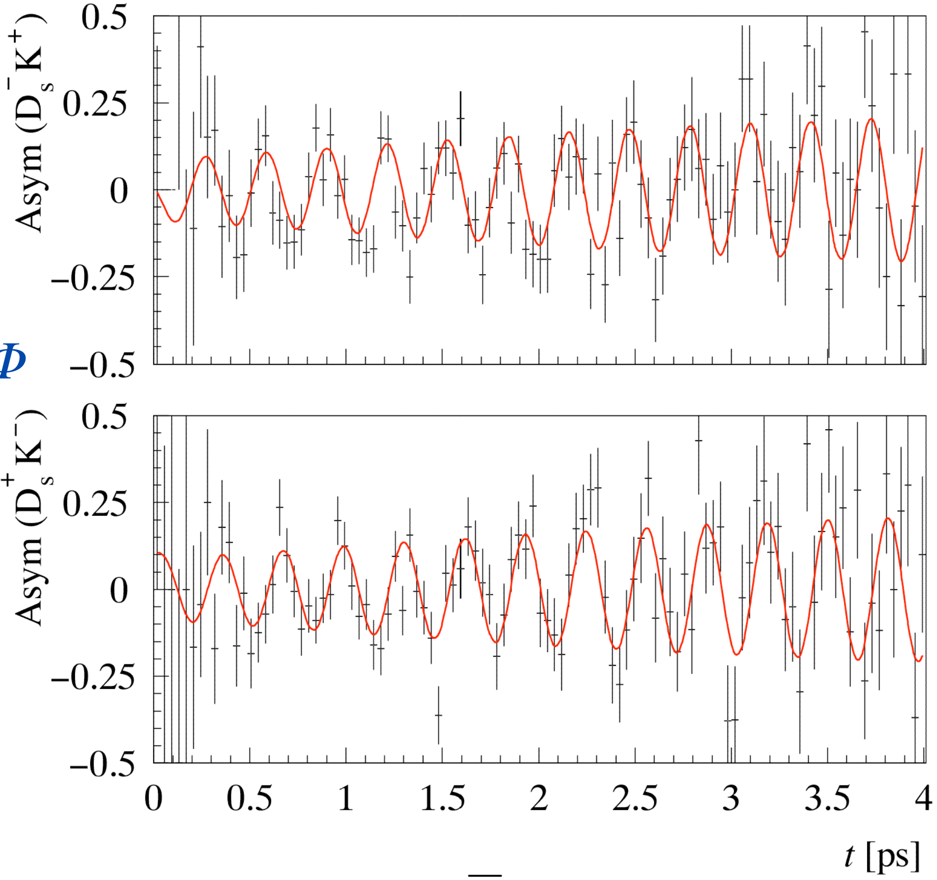
$\sigma(\alpha)$~10° with 2 fb^{-1}

Angle γ from $B_s \rightarrow D_s K$

- *Interference between 2 tree diagrams*
  - *insensitive to NP in Bs mixing*
- *Measure $\gamma + \phi_s$ from time-dependent rates of $B_s \rightarrow D_s^+ K^-$ and $B_s \rightarrow D_s^- K^+$ +cc*
  - *Mistag from $B_s \rightarrow D_s \pi$*
  - *Subtract ϕ_s measured with $B \rightarrow J/\Psi\Phi$*

With 2 fb^{-1}, $\Delta m_s = 20\ ps^{-1}$,
$\Delta\Gamma_s/\Gamma_s = 0.1$, $55° < \gamma < 105°$:

$\sigma(\gamma) \sim 14°$

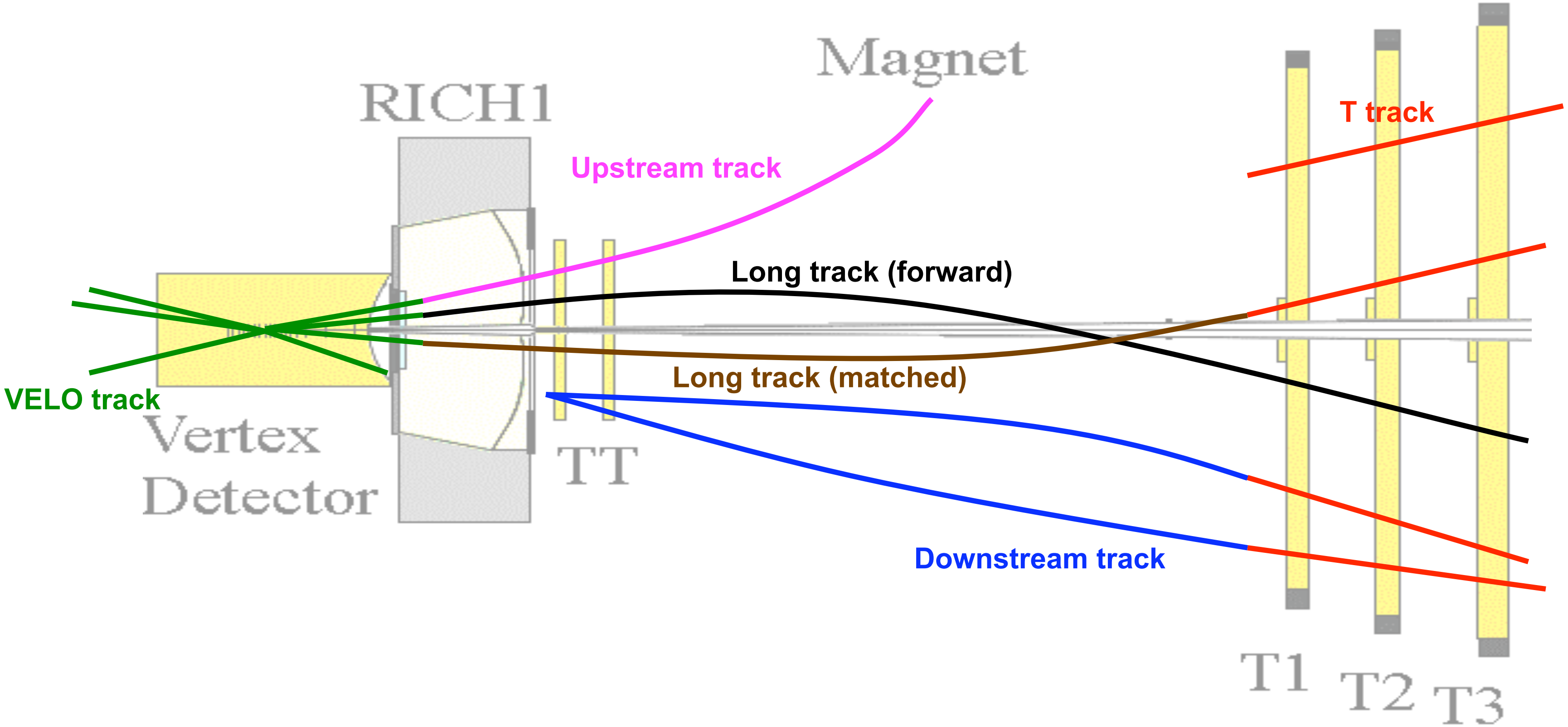


B_s-$\overline{B_s}$ asymmetries
after 5 years of data

LHCb Physics programme

- B_s *oscillation frequency, phase and* $\Delta\Gamma_s$
  - $B_s \to D_s\pi$, $J/\Psi\Phi$, $J/\Psi\eta$, $\eta_c\Phi$
- α *from* $B_d \to \pi^0\pi^-\pi^+$
- β *with* $B_d \to J/\psi K_S$ *as a proof of principle*
  - *And* β *from* $b \to s$ *penguin*
- γ *in various channels, differing sensitivity to new physics:*
  - *Time-dependent CP asymmetry of* $B_s \to D_s^- K^+$ *and* $D_s^+ K^-$
  - *Time dependent CP asymmetries of* $B_d \to \pi^+\pi^-$ *and* $B_s \to K^+K^-$
  - *Comparison of decay rates in the* $B_d \to D^0 K^{*0}$ *system*
  - *Comparison of decay rates in the* $B^- \to D^0 K^-$ *system*
  - *Dalitz analysis of* $B^- \to D^0 K^-$ *and* $B_d \to D^0 K^{*0}$
- *Rare decays*
  - *Radiative penguin* $B_d \to K^* \gamma$, $B_s \to \Phi \gamma$, $B_d \to \omega\gamma$
  - *Electroweak penguin* $B_d \to K^{*0} \mu^+\mu^-$
  - *Gluonic penguin* $B_s \to \Phi\Phi$, $B_d \to \Phi K_s$
  - *Rare box diagram* $B_s \to \mu^+\mu^-$
- B_c , b-*baryon physics + unexpected !*

Tracking

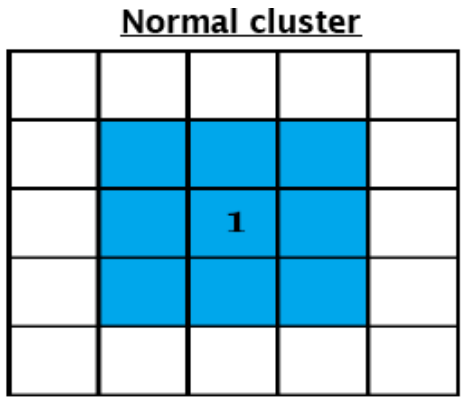


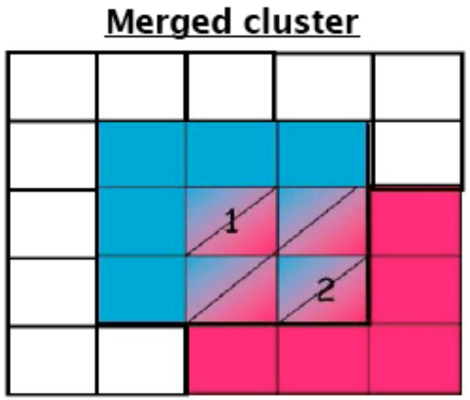
Long tracks ⇒ highest quality for physics
Downstream tracks ⇒ needed for efficient K_S finding
Upstream tracks ⇒ lower p, worse p resolution, useful for RICH1 pattern recognition

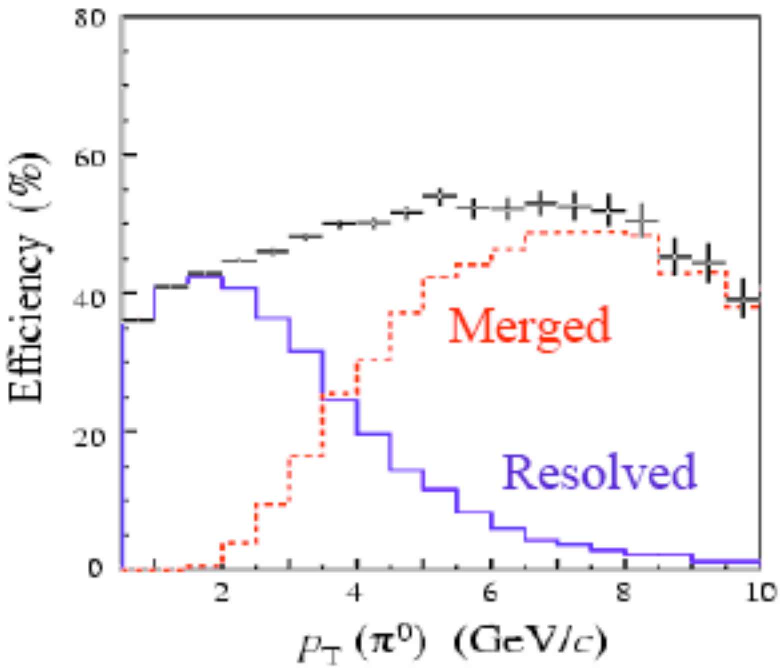
Details on tracking: C.Jones' talk

Neutral reconstruction

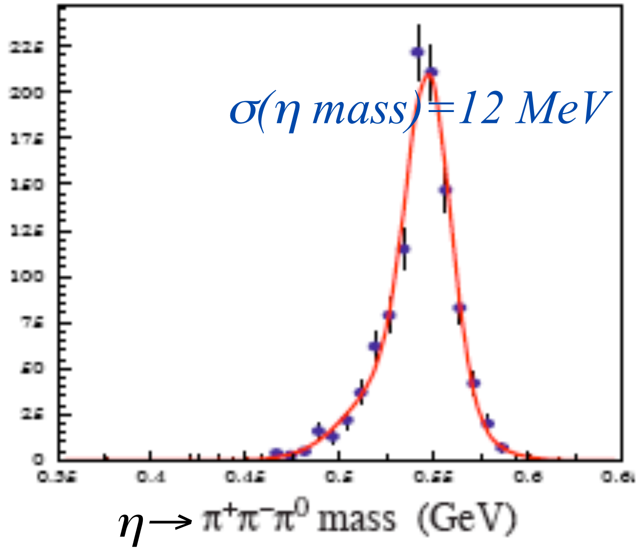
Good efficiency for π^0 in $B^0 \rightarrow \pi^+ \pi^- \pi^0$, using both resolved (separate clusters) and merged cluster shapes in the calorimeter (unassociated to charged tracks)





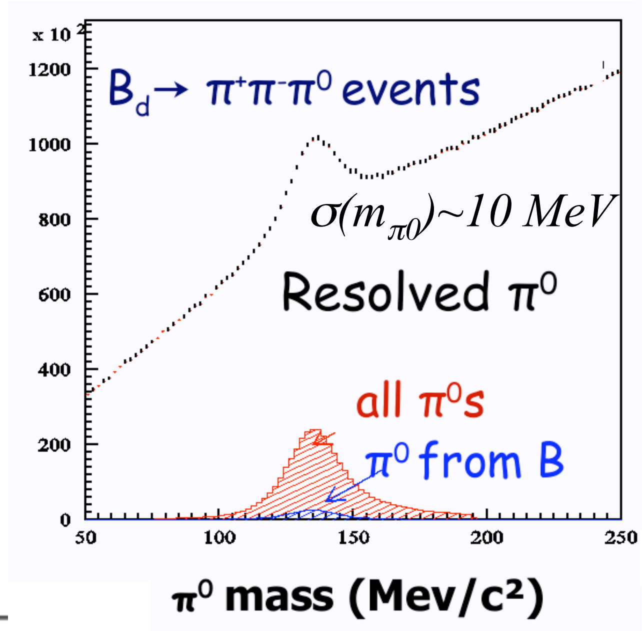


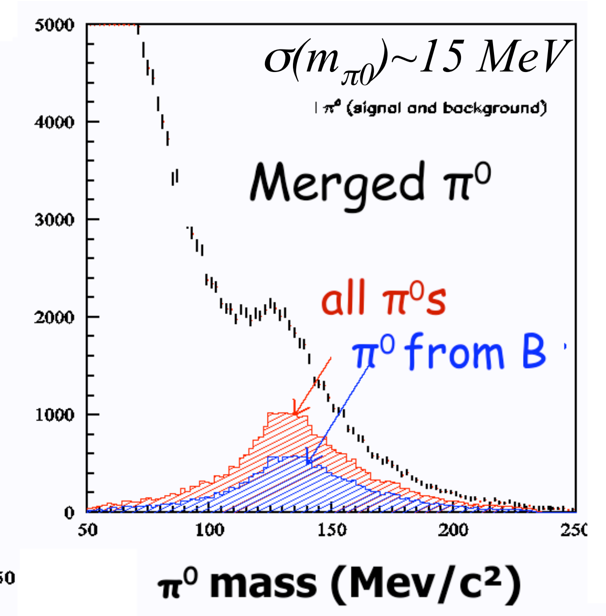
Reconstruction efficiency ~53%

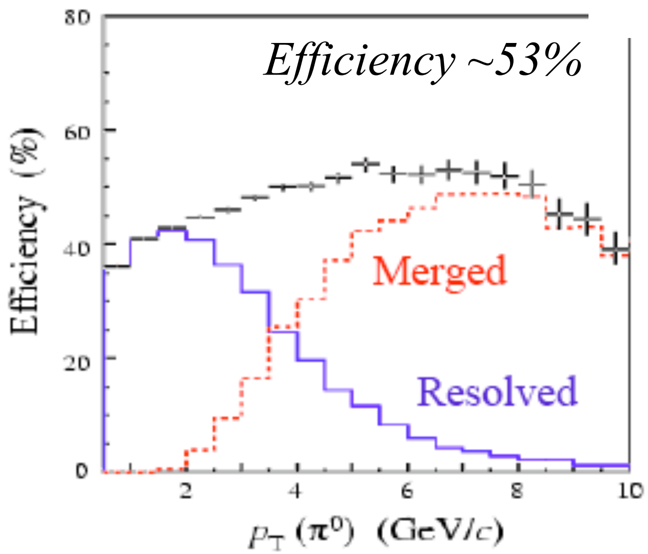


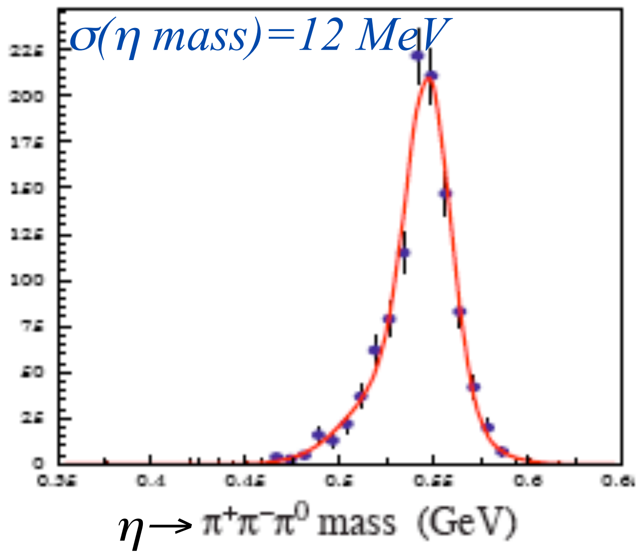
Neutral reconstruction

Good efficiency for π^0 in $B^0 \rightarrow \pi^+ \pi^- \pi^0$, using both resolved (separate clusters) and merged cluster shapes in the calorimeter





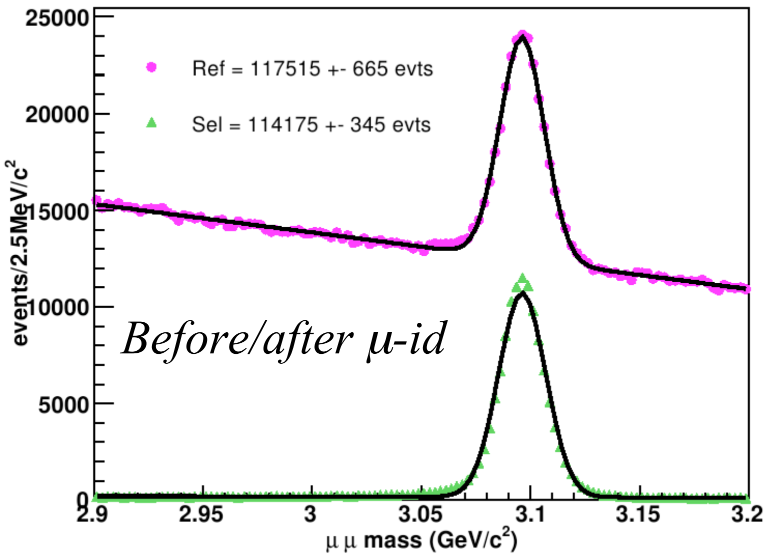




Particle identification: leptons

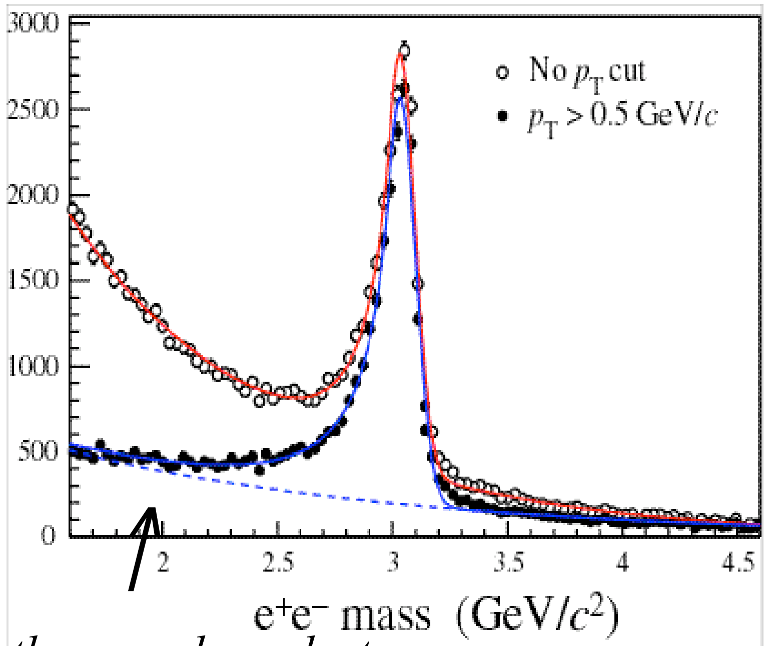
μ Efficiency = 94%

π mis-ID rate 1.0%



Electron Efficiency = 78%

π mis-ID rate 1.0%



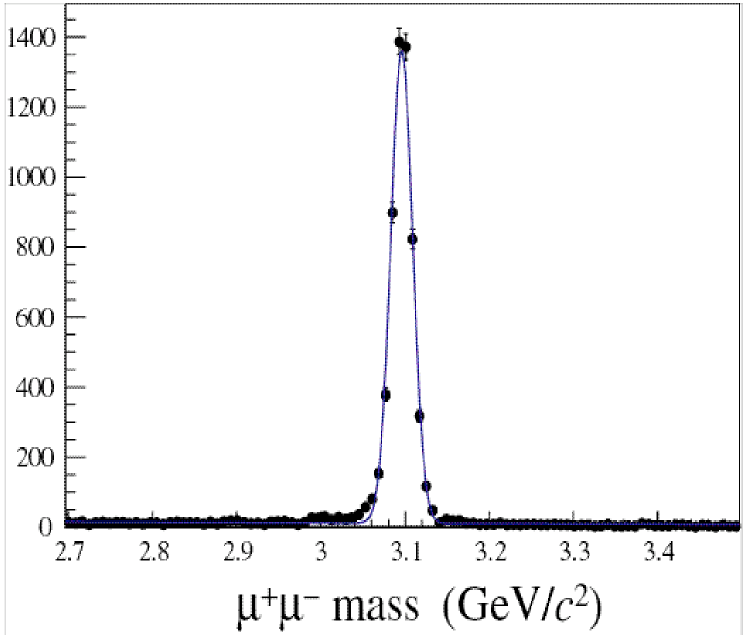
Electron background: mostly secondary electrons and ghosts, rejected by PT cut

Lepton ID: ECAL, Muon chambers
See C.Jones' talk

Particle identification: leptons

μ Efficiency = 94%

π mis-ID rate 1.0%



Electron Efficiency = 78%

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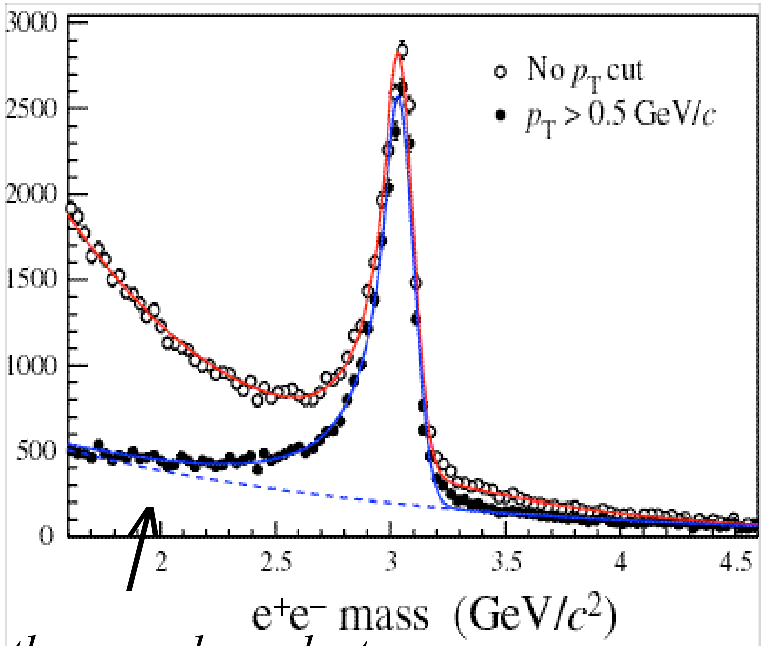
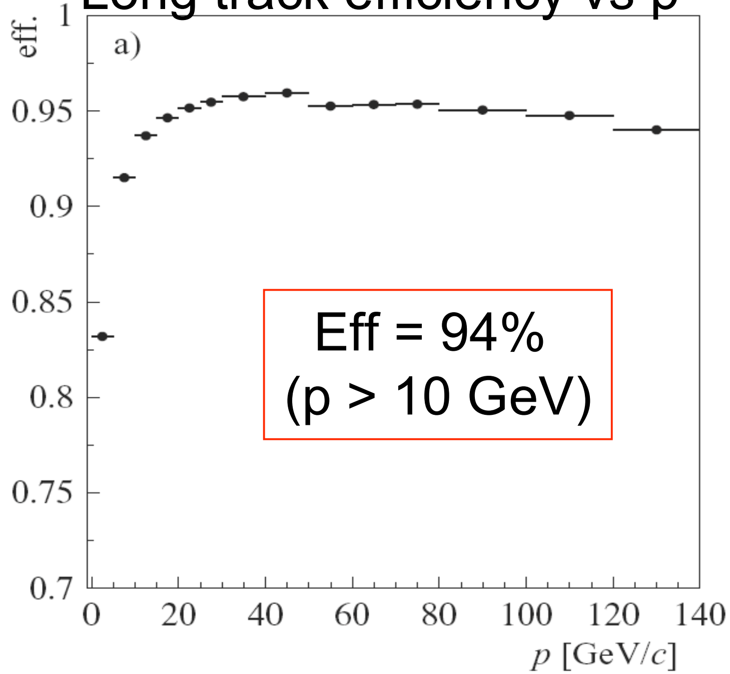


Electron background: mostly secondary electrons and ghosts, rejected by PT cut

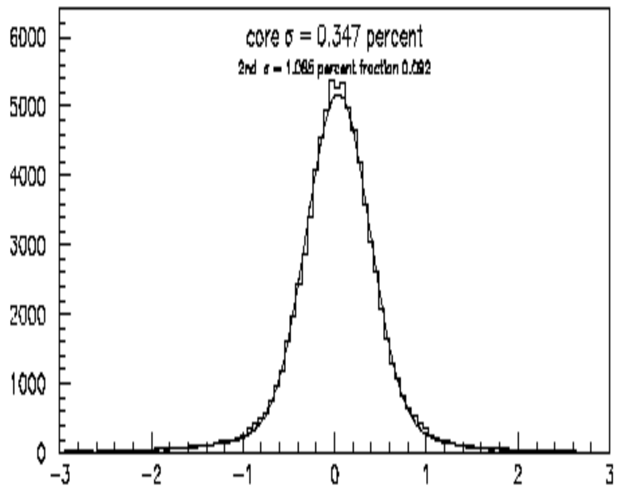
Lepton ID: ECAL, Muon chambers

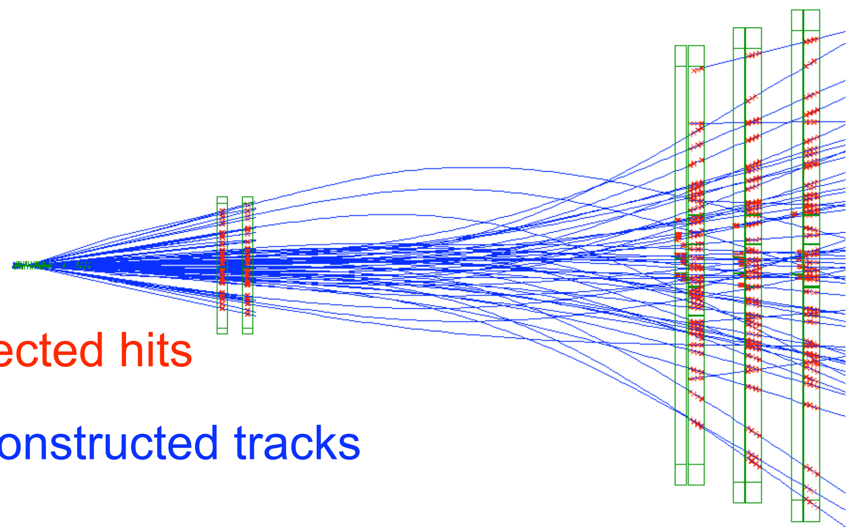
Tracking performance

Long track efficiency vs p



δp/p ~ 0.37%



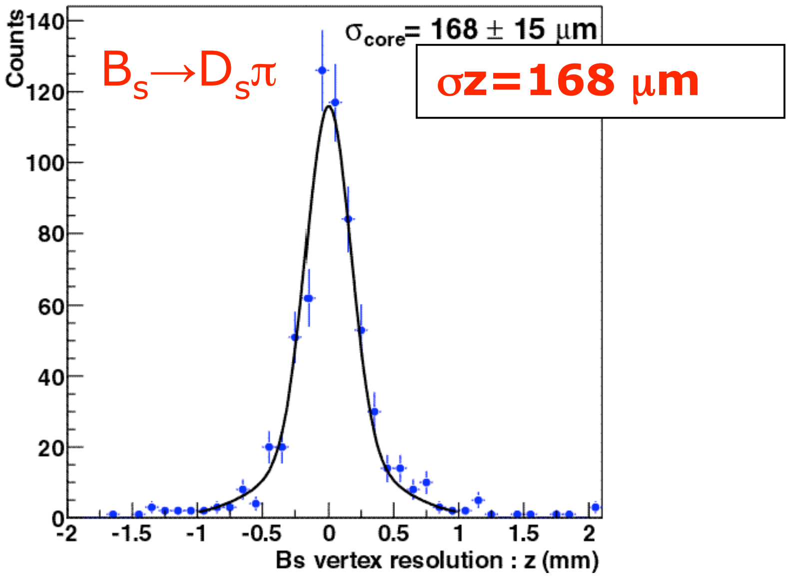


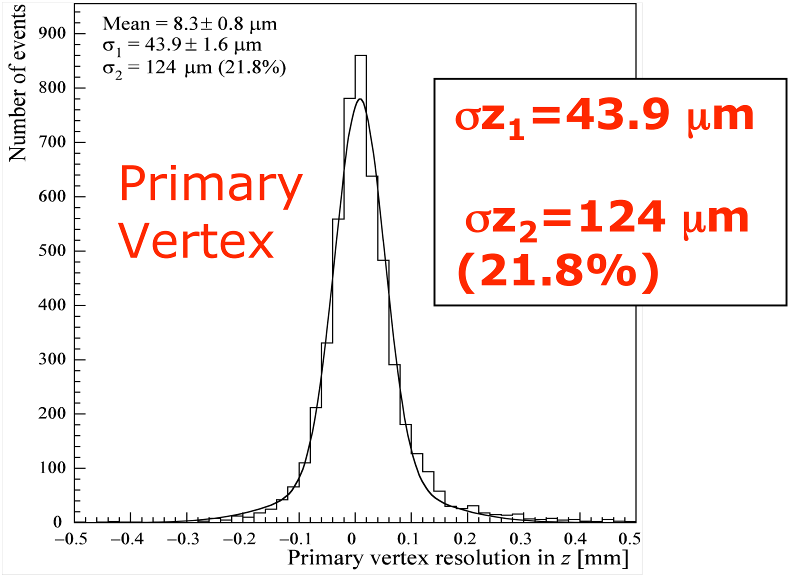
Red = detected hits

Blue = reconstructed tracks

<u>On average</u>:
26 long tracks
11 upstream tracks
4 downstream tracks
5 T tracks
26 VELO tracks

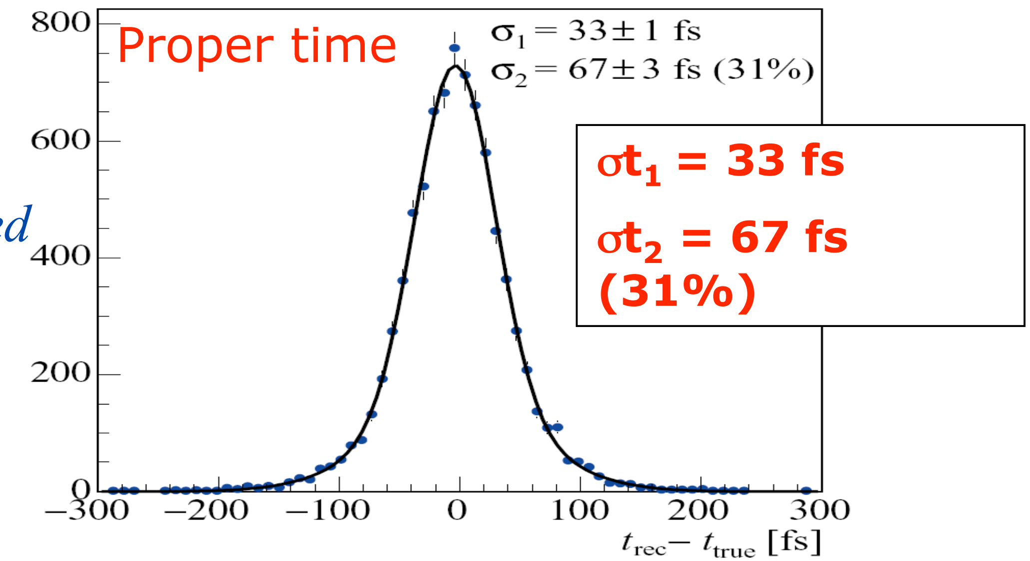
Vertex reconstruction





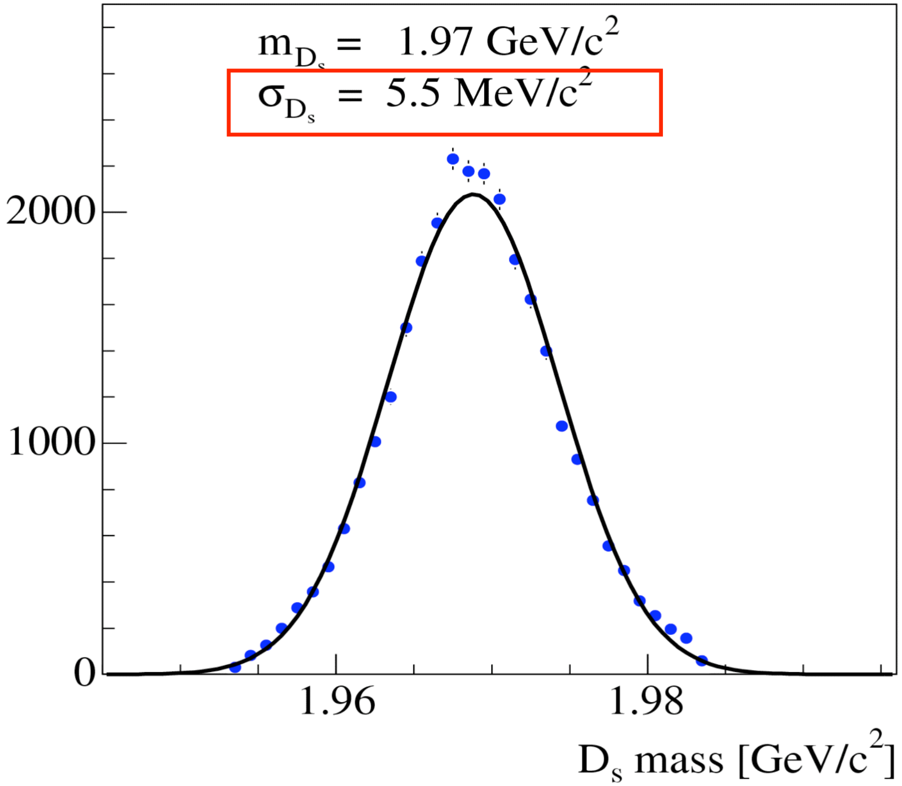
Proper time t=L×m/(p×c)

Proper time resolution is dominated by B vertex resolution

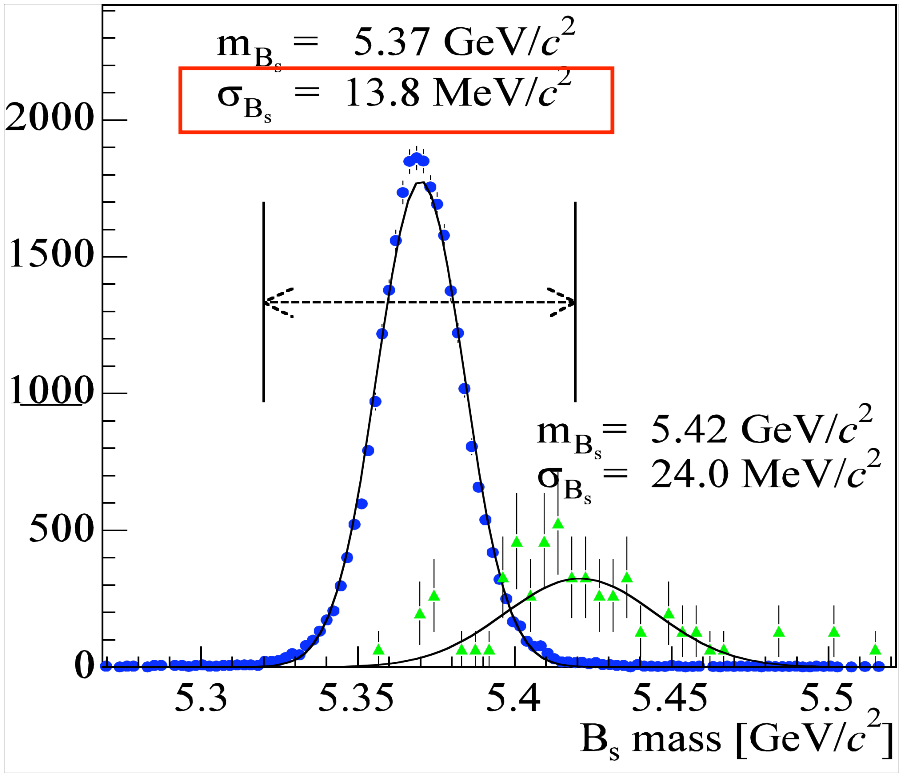


Mass resolution

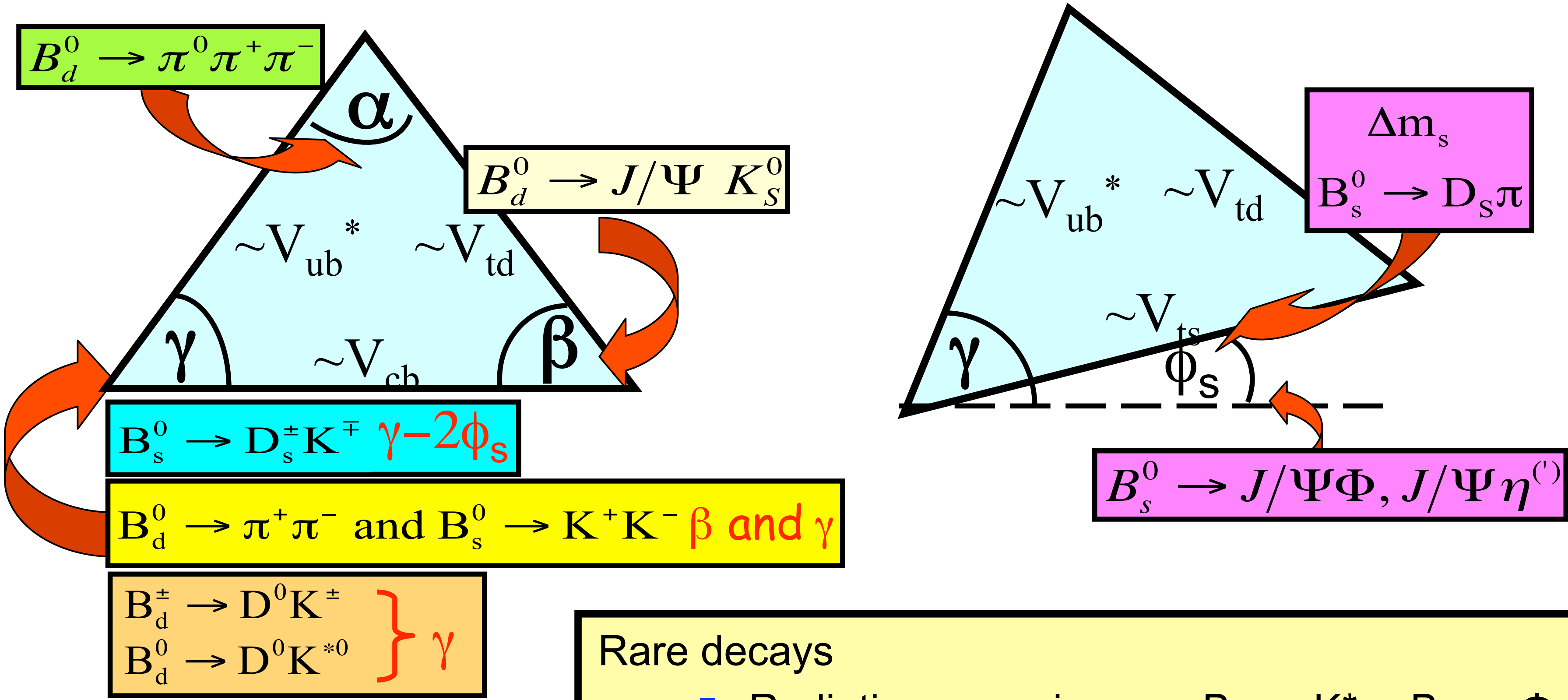
Mass of $D_s^- \rightarrow K^+K^-\pi^-$



Mass of $B_s \rightarrow D_s^-$ (KKπ) K^+



LHCb Physics programme



B production ,
B_c , b-baryon physics

Rare decays

- Radiative penguin e.g. $B_d \to K^* \gamma$, $B_s \to \Phi\ \gamma$
- Electroweak penguin e.g. $B_d \to K^{*0} \mu^+\mu^-$
- Gluonic penguin e.g. $B_s \to \Phi\Phi$, $B_d \to \Phi K_s$
- Rare box diagram e.g. $B_s \to \mu^+\mu^-$

γ from $B \to DK$, ADS method

Rates depend on 5 parameters: g, rB, dD
rDkp (magnitude of the ratio between two D decays)
dDKp (CP conserving strong phase difference)

$$\Gamma(\mathrm{B}^- \to (\mathrm{K}^-\pi^+)_\mathrm{D}\,\mathrm{K}^-) \;\propto\; 1 + (r_B\, r_D^{\mathrm{K}\pi})^2 + 2\, r_B r_D^{\mathrm{K}\pi} \cos\left(\delta_B - \delta_D^{\mathrm{K}\pi} - \gamma\right) \quad (1) \quad \sim 30\mathrm{k}$$

$$\Gamma(\mathrm{B}^- \to (\mathrm{K}^+\pi^-)_\mathrm{D}\,\mathrm{K}^-) \;\propto\; r_B^2 + (r_D^{\mathrm{K}\pi})^2 + 2\, r_B r_D^{\mathrm{K}\pi} \cos\left(\delta_B + \delta_D^{\mathrm{K}\pi} - \gamma\right) \quad (2) \quad \sim 1\mathrm{k}$$

$$\Gamma(\mathrm{B}^+ \to (\mathrm{K}^+\pi^-)_\mathrm{D}\,\mathrm{K}^+) \;\propto\; 1 + (r_B\, r_D^{\mathrm{K}\pi})^2 + 2\, r_B r_D^{\mathrm{K}\pi} \cos\left(\delta_B - \delta_D^{\mathrm{K}\pi} + \gamma\right) \quad (3) \quad \sim 30\mathrm{k}$$

$$\Gamma(\mathrm{B}^+ \to (\mathrm{K}^-\pi^+)_\mathrm{D}\,\mathrm{K}^+) \;\propto\; r_B^2 + (r_D^{\mathrm{K}\pi})^2 + 2\, r_B r_D^{\mathrm{K}\pi} \cos\left(\delta_B + \delta_D^{\mathrm{K}\pi} + \gamma\right) \quad (4) \quad \sim 1\mathrm{k}$$

For 2 fb-1 50 times more than B-factories

Suppressed rates (2) and (4) have O(1) interference effects since rB~rD so particularly sensitive to g

Relative rates more unknown than equations
Use other decays e.g. Kppp or KK,pp

B_s mixing: Δm_s

$$CDF: \Delta m_s = 17.33^{+0.42}_{-0.21} \pm 0.07 \quad ps^{-1}$$

$$D0: 17 < \Delta m_s < 21\ ps^{-1} \quad @90\%\ c.l.$$

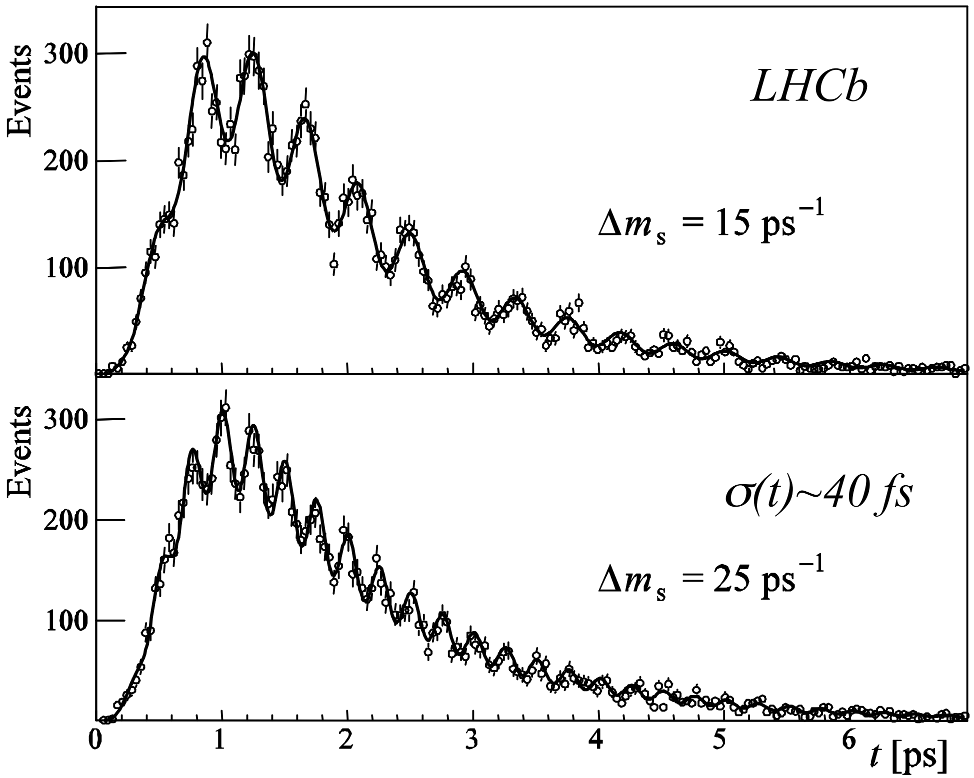
LHCb:
Measured using $B_s \to D_s^- \pi+$
80K events in one year,
B/S<0.3

High precision expected in one year:

$\sigma_{stat}(\Delta m_s) \sim 0.01\ ps^{-1}$

$B_s \to D_s^- \pi^+$

Distribution of unmixed sample after 1 year (2 fb^{-1})



Very good resolution for oscillations, so we can measure CP asymmetry in Bs system

Measuring γ : $B^+ \to D^0(K^0\pi^+\pi^-)K^+$

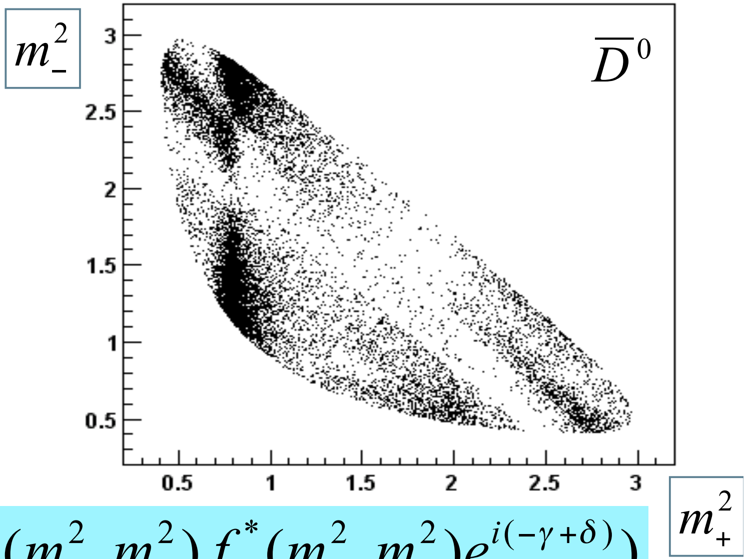
Giri, Grossman, Soffer, Zupan (PRD 68, 054018 (2003))

- Use three body Cabibbo allowed decays of the $D^0/\overline{D}^0$
  - $BR(D^0 \to K^0\pi^+\pi^-)=(5.97\pm0.35)\%$
  - $BR(D^0 \to K^* \pi)=(3.9\pm0.3)\%$, $BR(D^0 \to K_s\, \rho)=(1.55^{+0.12}_{-0.16})\%$…
- Large strong phases between the intermediate resonances allow the extraction of r_B, δ and γ by studying the Dalitz distribution of events

$$A^- = f(m_-^2, m_+^2) + r_B e^{i(-\gamma+\delta)} f(m_+^2, m_-^2)$$
$$A^+ = f(m_+^2, m_-^2) + r_B e^{i(\gamma+\delta)} f(m_-^2, m_+^2)$$

where $m_\pm = K_S^0\pi^\pm$ invariant mass

$f(m_\pm^2, m_\mp^2)$ Dalitz amplitudes



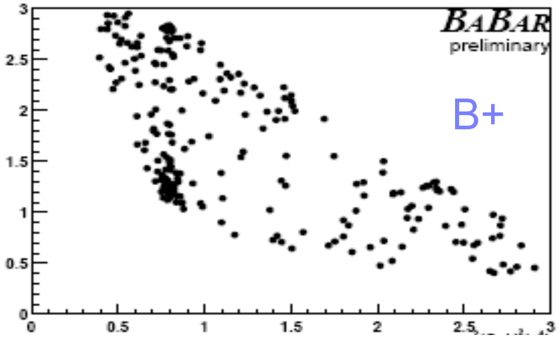
$$|A^-|^2 = |f(m_-^2, m_+^2)|^2 + r_B^2 |f(m_+^2, m_-^2)|^2 + 2 r_B \Re\left(f(m_+^2, m_-^2) f^*(m_-^2, m_+^2) e^{i(-\gamma+\delta)}\right)$$

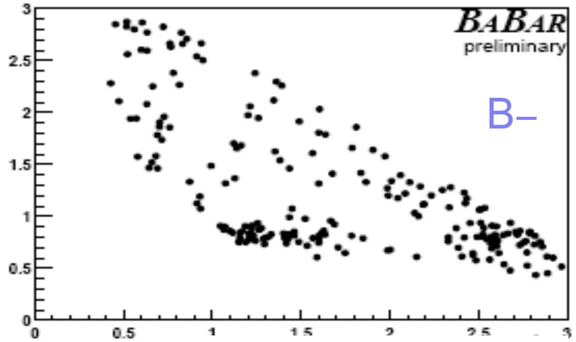
Dalitz model

- B factories consider 16 resonances + non resonant component
- At present dominant systematic error of 11º from model uncertainties
- Scope for improvement:
  - Alternative fit to Dalitz plane with full partial wave analysis of non-resonant component
  - CLEO-C and B factories will improve statistics to measure the Dalitz plot
  - Use model independent binned technique - loss of statistical power
    - CLEO-C correlated data could be used directly in a model independent binned treatment

Measuring γ from B-factories

m_-^2





hep-ex/0507101

*D** and *D* combined

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

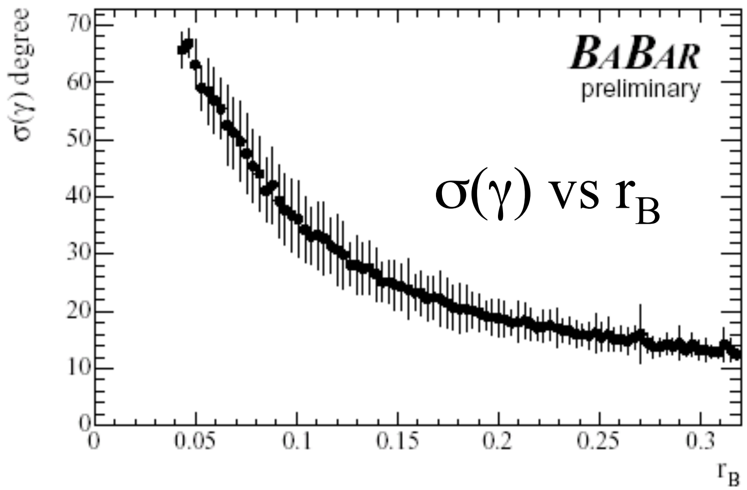
Babar:

γ = 67°±28°±13°±11°

$r_B = 0.05 \pm 0.11$

Exp. systematic

Dalitz Model error



Belle:

PRD 70, 072003 (2004)

γ = 68°±14°±13°±11°

$r_B = 0.21 \pm 0.08$

At present typical event yields / experiment ~ 300

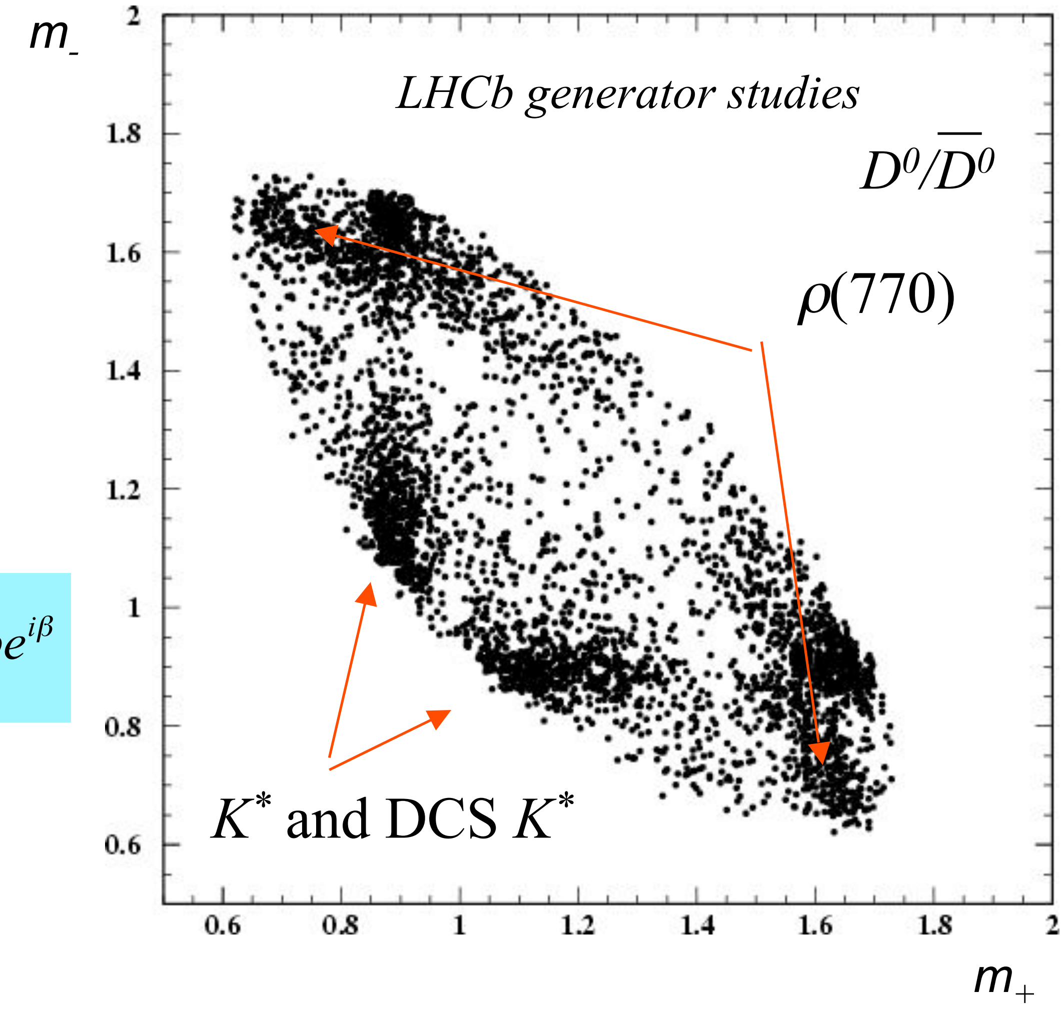
$B^+ \to D^0(K^0\pi^+\pi^-)K^+$: Dalitz plot

- Regions of the Dalitz plot with the largest interference are most sensitive to γ
- Need good understanding of Dalitz amplitudes
- Use isobar model from Belle/Babar with:

$$f(m_+^2, m_-^2) = \sum_{j=1}^{N} a_j e^{i\alpha_j} A_j(m_+^2, m_-^2) + be^{i\beta}$$

Breit-Wigner + non-resonant

- B simulated with $\gamma=64.7^o$, $\delta=150^o$, $r_b=0.16$



Annual yield: $B^+ \rightarrow D^0(K^0\pi^+\pi^-)K^+$

- Acceptance studied with phase space MC

  $\varepsilon_{tot} = 0.10\%$

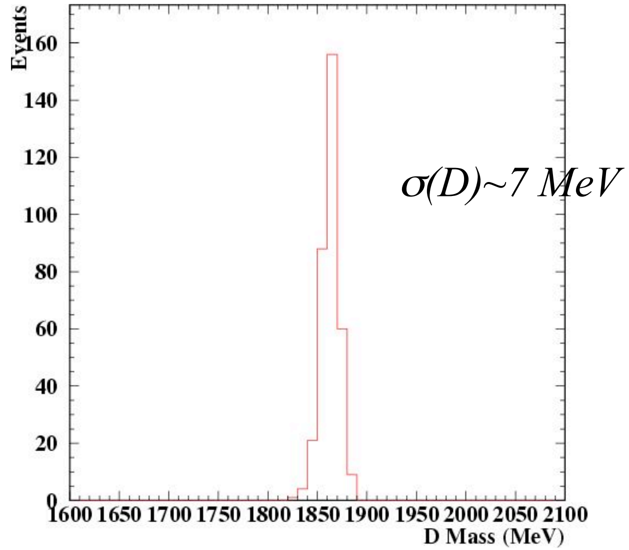
  (selection + L0L1 trigger = 5.8%)

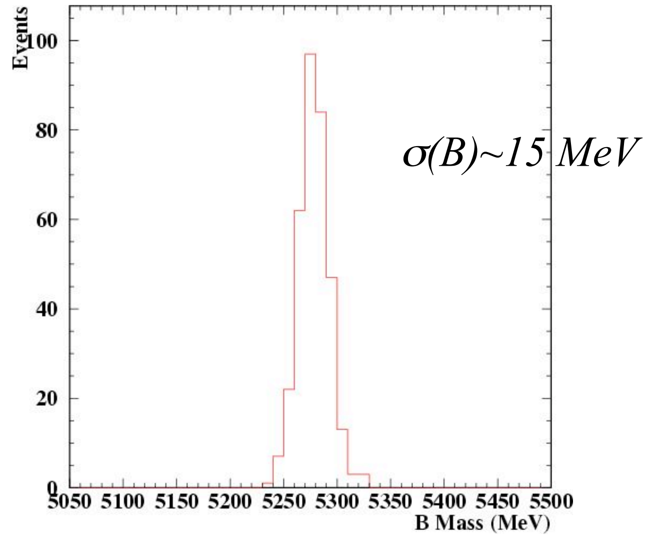
- Luminosity = 2 fb^{-1}

- $BR(B^+ \rightarrow D^0(K_s\pi^+\pi^-)K^+) = 7.5 \times 10^{-6}$

- Expected ~6000 events/year not including High Level Trigger efficiency (or > 1300 including it)

  - 0.5< B/S < 3.2 @ 90%CL





$B^+ \rightarrow D^0(K^0K^+K^-)K^+$

- Same method works for $D^0 \rightarrow K^0K^+K^-$ decay
  - Reduced BR:
    $BR(D^0 \rightarrow K^0K^+K^-) = (1.03 \pm 0.10)\%$
  - But less background because two more particle identification constraints from RICH should substantially reduce background - also narrow phase space
- Acceptance evaluation in progress
- Dalitz model has fewer resonances (ϕ, a_0) but complex threshold effects (Babar hep-ex/0507026)
  - Separate study of sensitivity is necessary