B Physics in LHC Era

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What is LHC Era?

LHC is planed to have pp collisions in summer 2007

Although we try to be ready for the beam as much as possible, first collisions are needed for

- -time alignment
- -detector calibration
- -geometry alignment
- -trigger commissioning
- etc.

If all works very well...

by the end of 2007 a J/ψ peak?

At LHC, serious physics run will start in 2008

$\sim\langle L\rangle \times 5 \times 10^6$s of pp dada in 2008

By the end of 2008, BABAR+BELLE could have 2000–2500 fb^{-1}

$\sin 2\beta\ (\phi_1)$ from $B_d \Rightarrow \bar{b} \to \bar{c} + W(c\bar{s})$	tree
$\bar{b} \to \bar{s} + g, \gamma, Z\ (c\bar{c})$	small penguin
$\sin 2\beta\ (\phi_1)$ from $B_d \Rightarrow \bar{b} \to \bar{s} + g, \gamma, Z\ (s\bar{s})$	penguin
$\alpha\ (\phi_2) = 2\pi-\beta-\gamma$ from $B_d \Rightarrow \bar{b} \to \bar{u} + W(u\bar{d})$	tree
$\bar{b} \to \bar{u} + g, \gamma, Z\ (u\bar{u})$	penguin
$\sin(\gamma+2\beta)$ from $B_d \Rightarrow \bar{b} \to \bar{u} + W(c\bar{d})$ and $\bar{b} \to \bar{c} + W(u\bar{d})$	tree
$\times\ B^0$-$\bar{B}^0$ oscillations	

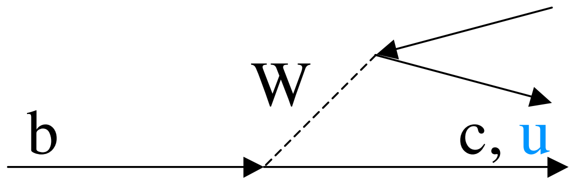
$\gamma\ (\phi_3)$ from $B_{d,u} \Rightarrow \bar{b} \to \bar{u} + W(c\bar{s})$ and $\bar{b} \to \bar{c} + W(u\bar{s})$	tree
+ D-$\bar{D}$ or K-$\bar{K}$ mixing, DCS D decays	

Standard Model

Tree

$\Gamma(b \to c)$

$\Gamma(b \to u)$



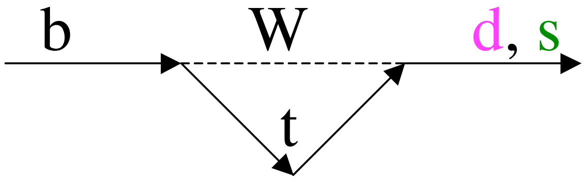
$|V_{cb}|$

$|V_{ub}|$

Penguin

$\Gamma(b \to s)$

$\Gamma(b \to d)$



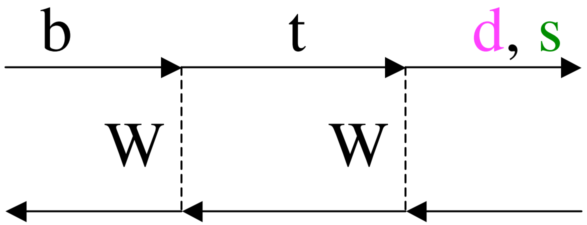
$|V_{td}|$

$|V_{ts}|$

Box

$\omega(B_d\text{-}\overline{B}_d)$

$\omega(B_s\text{-}\overline{B}_s)$



$|V_{td}|$

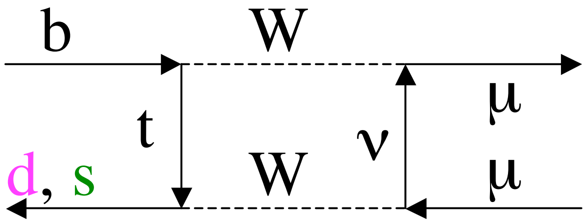
$|V_{ts}|$

$\not{CP}$(Tree⊗Box) $2\arg V_{td}\,(V_{ts}) + \arg V_{cb}\,(V_{ub})$

$\not{CP}$(Peng⊗Box) $2\arg V_{td}\,(V_{ts}) + \arg V_{td}$

$2\arg V_{td}\,(V_{ts}) + \arg V_{ts}$

$\Gamma(B \to \mu\mu)$



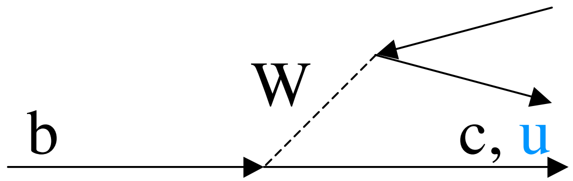
$|V_{td}|$

$|V_{ts}|$

Standard Model

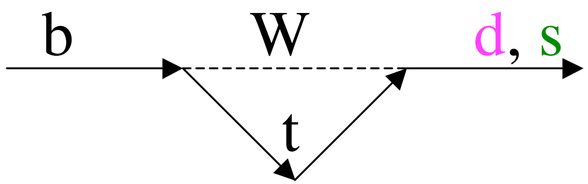
New Physics

Tree
$\Gamma(b \to c)$
$\Gamma(b \to u)$

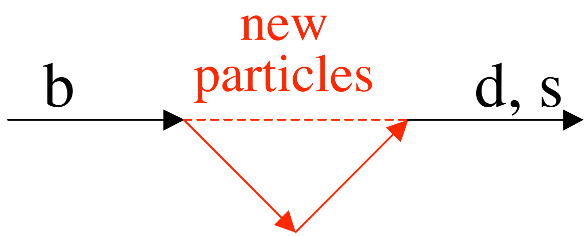


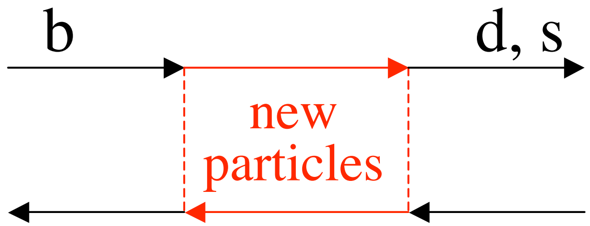
$|V_{cb}|$
$|V_{ub}|$
unaffected

Penguin
$\Gamma(b \to s)$
$\Gamma(b \to d)$

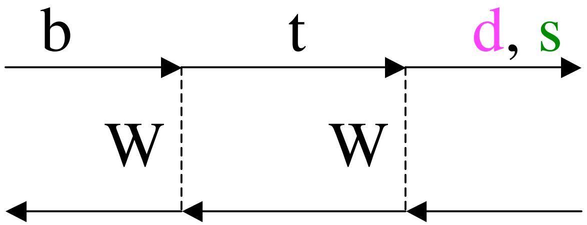


$|V_{td}| + \Delta_{peng(d)}$
$|V_{ts}| + \Delta_{peng(s)}$





Box
$\omega(B_d\text{-}\overline{B}_d)$
$\omega(B_s\text{-}\overline{B}_s)$



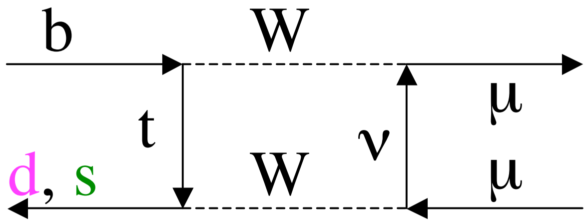
$|V_{td}| + \Delta_{box(d)}$
$|V_{ts}| + \Delta_{box(s)}$

$\not{C}\not{P}$(Tree⊗Box) $2 \arg V_{td}\,(V_{ts}) + \arg V_{cb}\,(V_{ub}) + \Phi_{box(d)}\,(\Phi_{box(s)})$

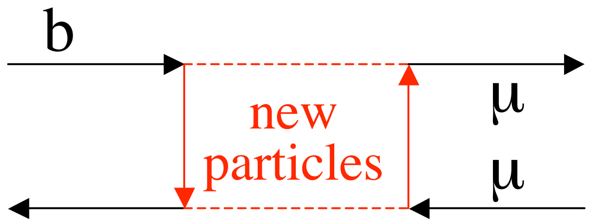
$\not{C}\not{P}$(Peng⊗Box) $2 \arg V_{td}\,(V_{ts}) + \arg V_{td} + \Phi_{box(d)}\,(\Phi_{box(s)}) + \Phi_{peng(d)}$

$2 \arg V_{td}\,(V_{ts}) + \arg V_{ts} + \Phi_{box(d)}\,(\Phi_{box(s)}) + \Phi_{peng(s)}$

$\Gamma(B \to \mu\mu)$



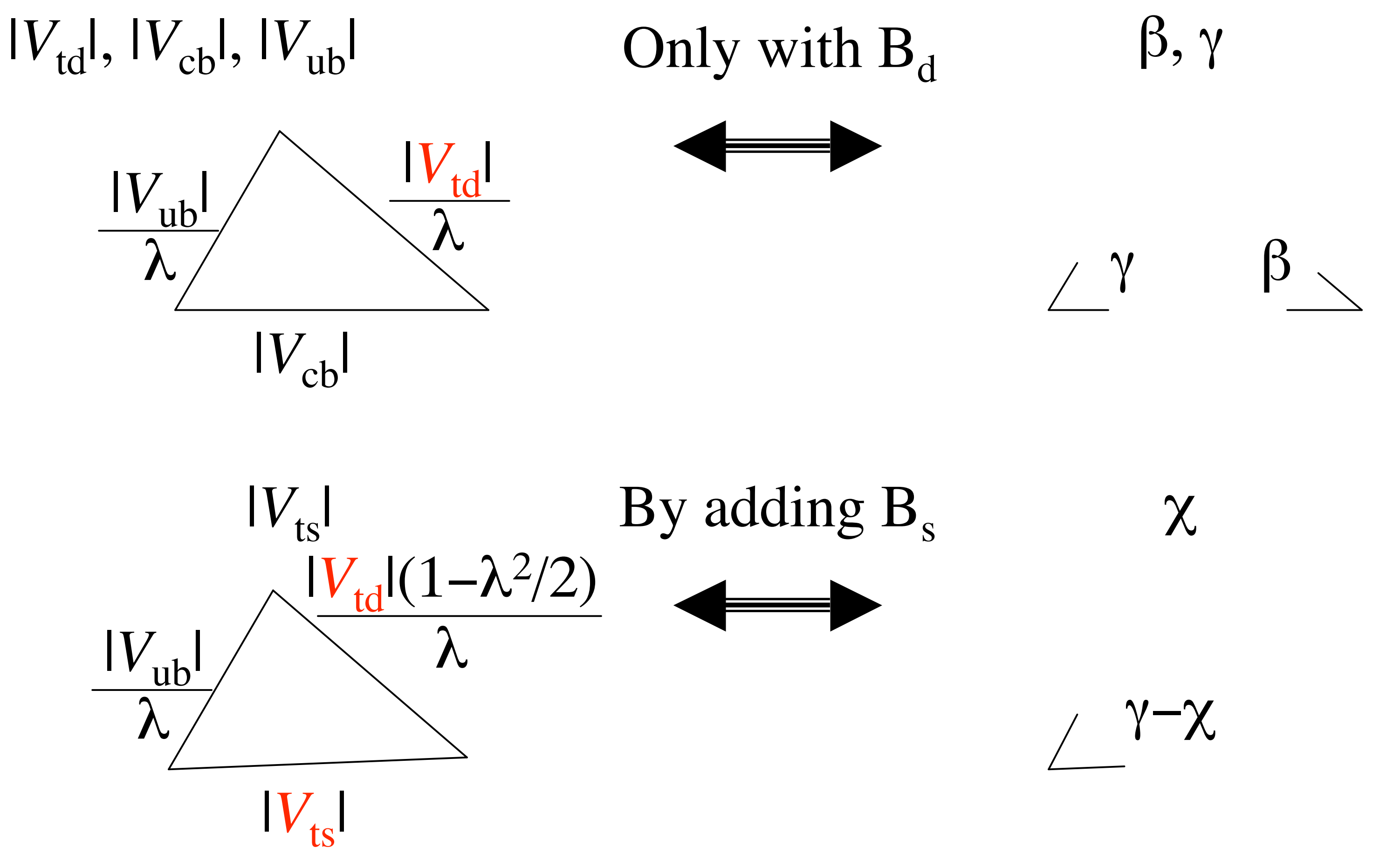
$|V_{td}| + \Delta_{\mu\mu(d)}$
$|V_{ts}| + \Delta_{\mu\mu(s)}$



New Physics can be seen indirectly by

1) Failure of the CKM unitarity consistency test

sides measurement — angles measurement



(from loop processes)

2) Unpredicted phenomena

Branching fractions

very rare decays

e.g. $B_s \rightarrow \mu\mu$, $B_d \rightarrow \mu\mu$

forbidden in the Standard Model

e.g. $B_s \rightarrow \mu e$

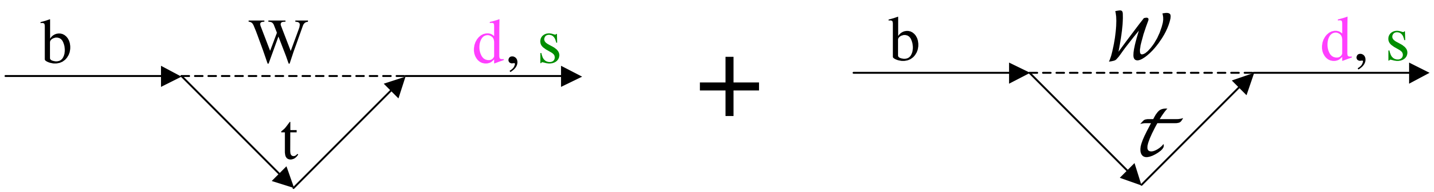
Interference in the decay asymmetries

forward-backward asymmetry in

$B_d \rightarrow K^{*0}\mu\mu$

$B_s \rightarrow \phi\mu\mu$

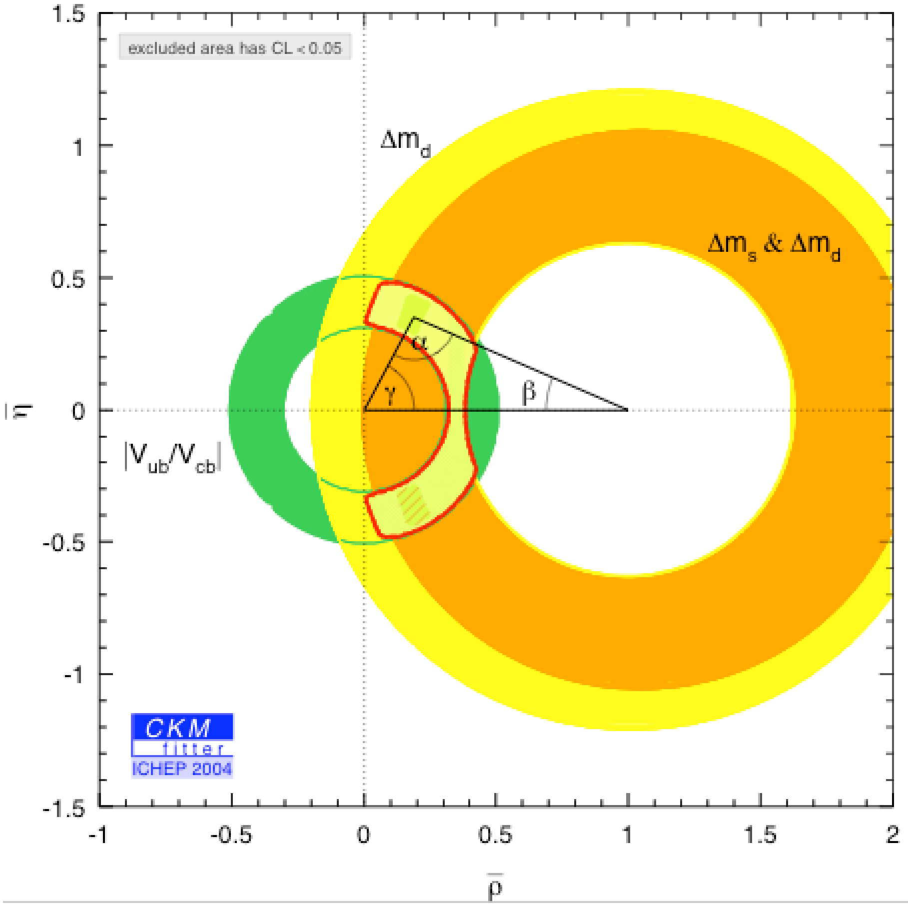
Lorentz structure $\quad V - A \quad\quad \sum_I c_I I \quad (I = S, P, V, A, T)$



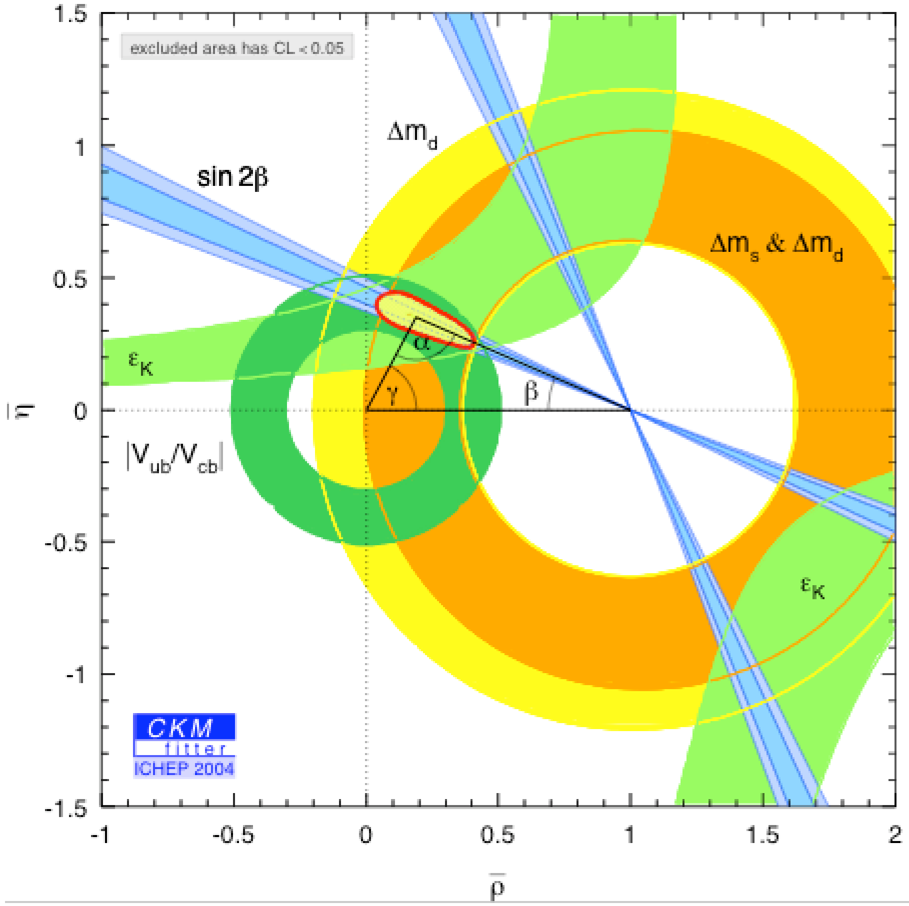
Standard Model $\qquad\qquad$ New Physics

Current Consistency Test

without $\not{CP}$ (side measurements)

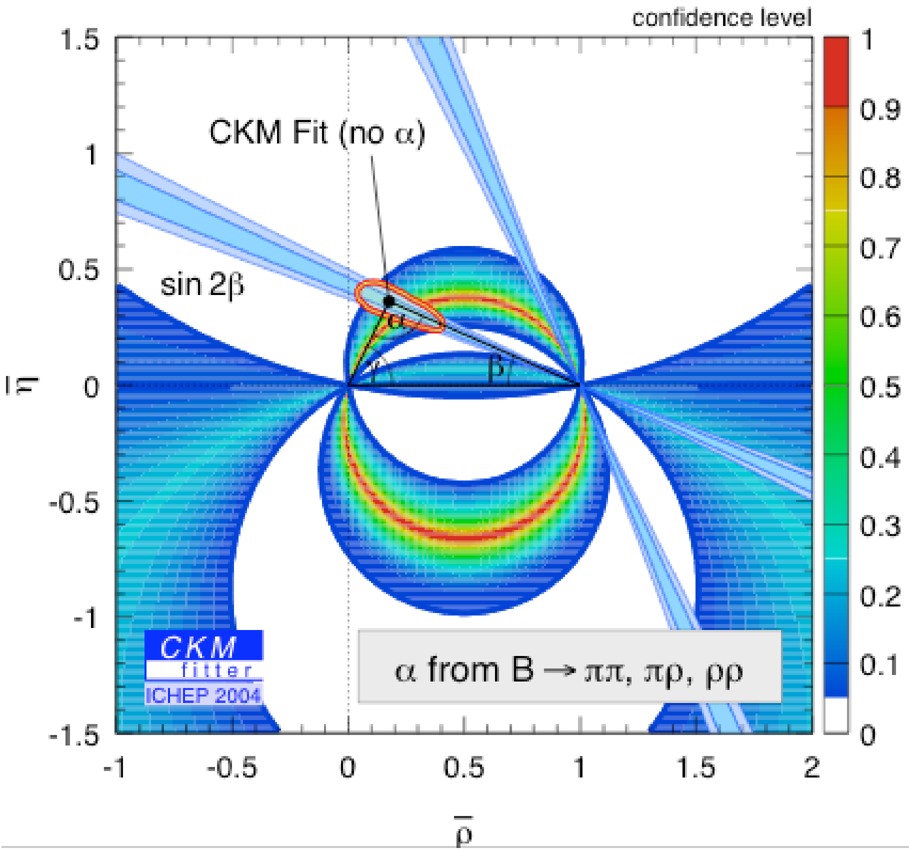


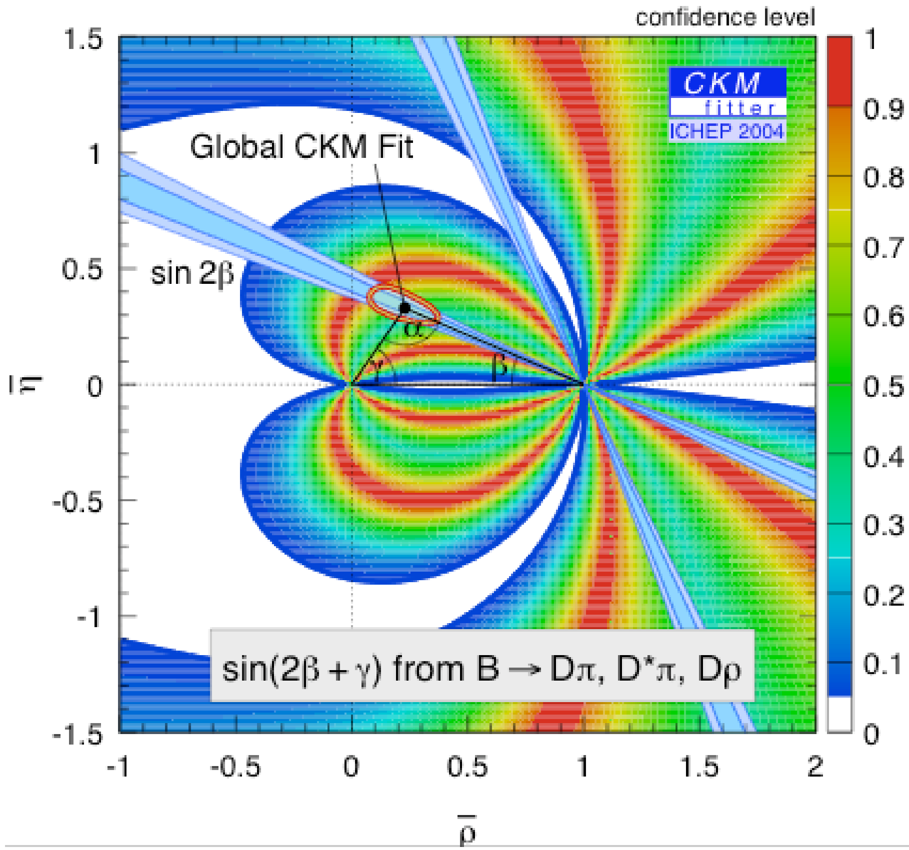
including $\not{CP}$ B and K



CKM fitter group 2004

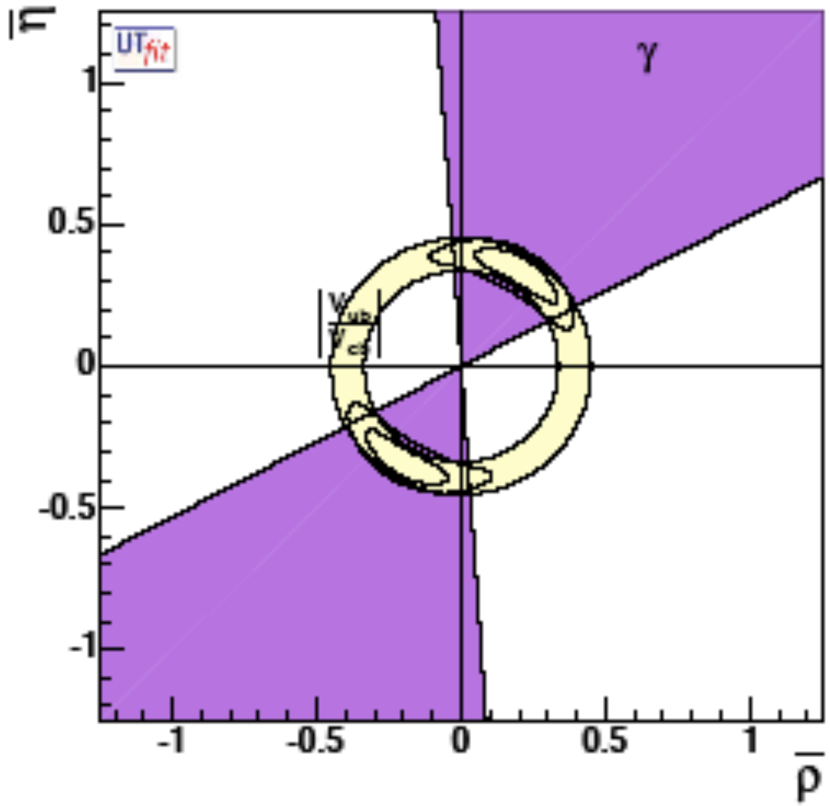
further tests





CKM fitter group 2004

γ measurements from BABAR and BELLE
using $B^{\pm} \to DK^{\pm}$



(UTfit group)

Relatively free from new physics effect....

Errors on the angle measurements will be reduced by a factor of ~3 by the end of 2008.

Experiments at LHC should aim for

-N(B_d → interesting charged decay modes)/one year $> \int_{\text{B factories}}^{2008} N(t)\,dt$

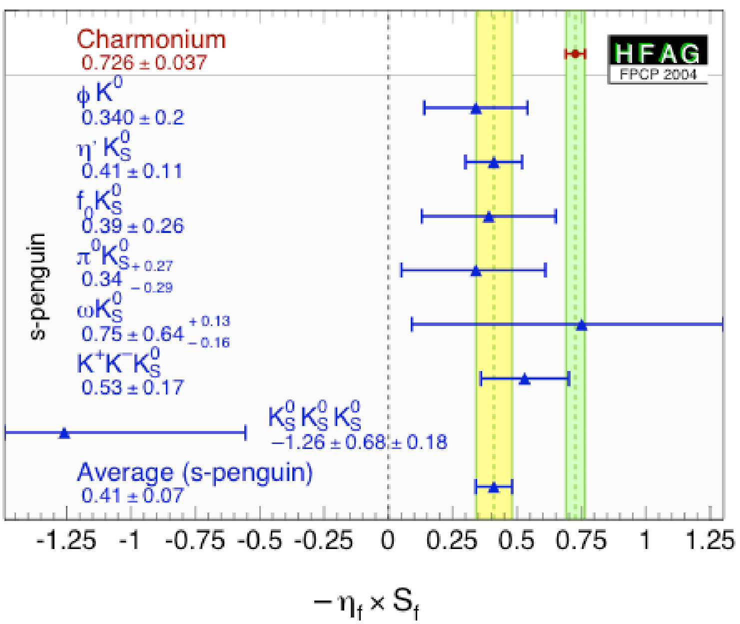
-$\not{C}\!\!P$ measurements with B_s as good as possible

Interesting question is:

will B_s-$\overline{B}_s$ oscillations be observed by CDF/D0?

If "yes", compatible with the Standard Model

If "no", not incompatible with the Standard Model



NB: if $\sin(2\beta)_{b\to c} \neq \sin(2\beta)_{b\to s}$

$b\to s$ penguin process

has New Physics contribution

B_s-$\overline{B}_s$ oscillations could receive a strong non SM contribution

⇒larger Δm_s?

⇒larger $\not{C}\!\!P$ in $B_s \to J/\psi\ \phi$?

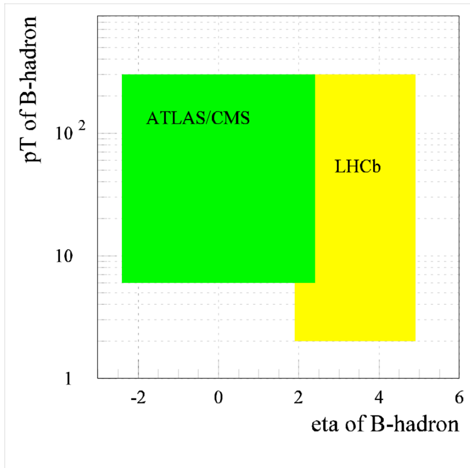
LHC

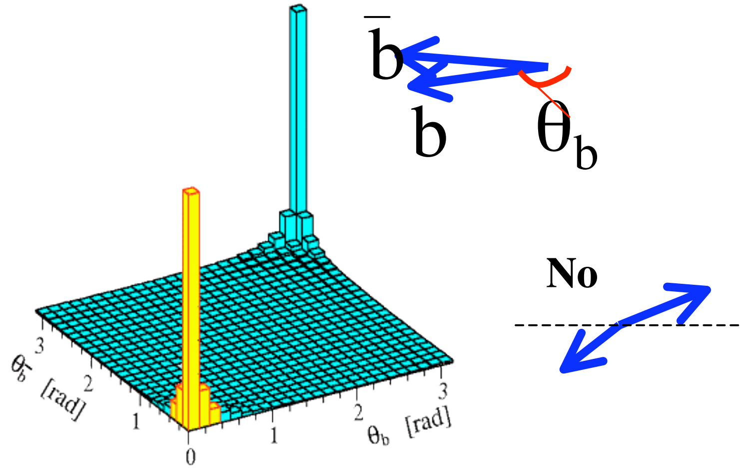
ATLAS, CMS – 4π ‘standard’ colliding beam detectors

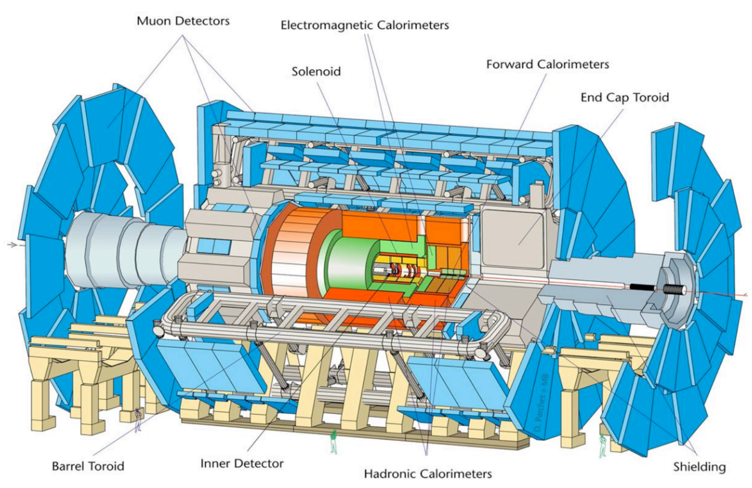
Main aim to search for new particles, always aim to run at maximum luminosity, $10^{33} \rightarrow 10^{34}$

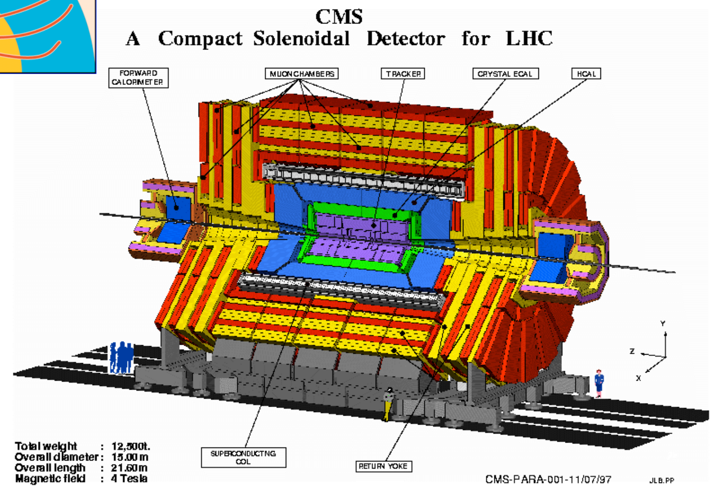
LHCb – forward spectrometer (10 – 300 mrads)

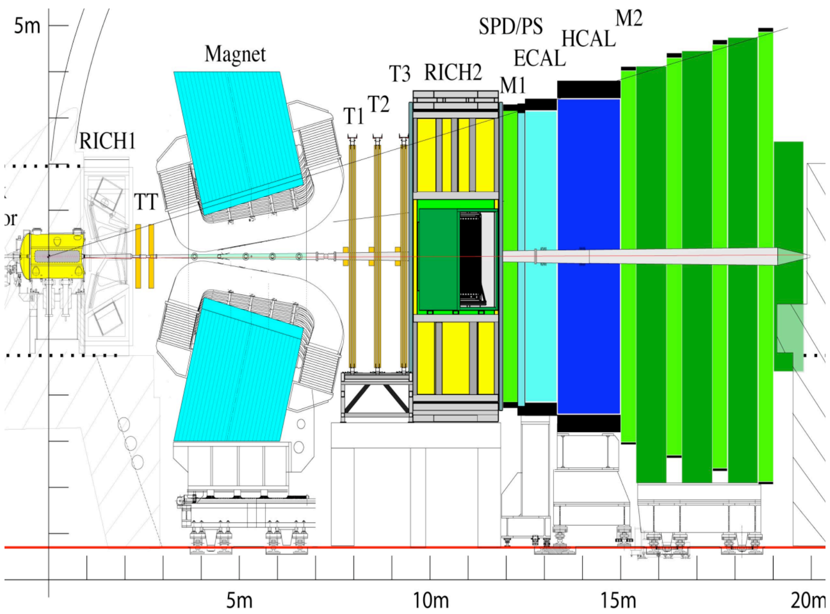
Designed specifically for b-physics. Will always run at low luminosity, nominally $\sim 2\times 10^{32}$






Muon Detectors
Electromagnetic Calorimeters
Solenoid
Forward Calorimeters
End Cap Toroid
Barrel Toroid
Inner Detector
Hadronic Calorimeters
Shielding

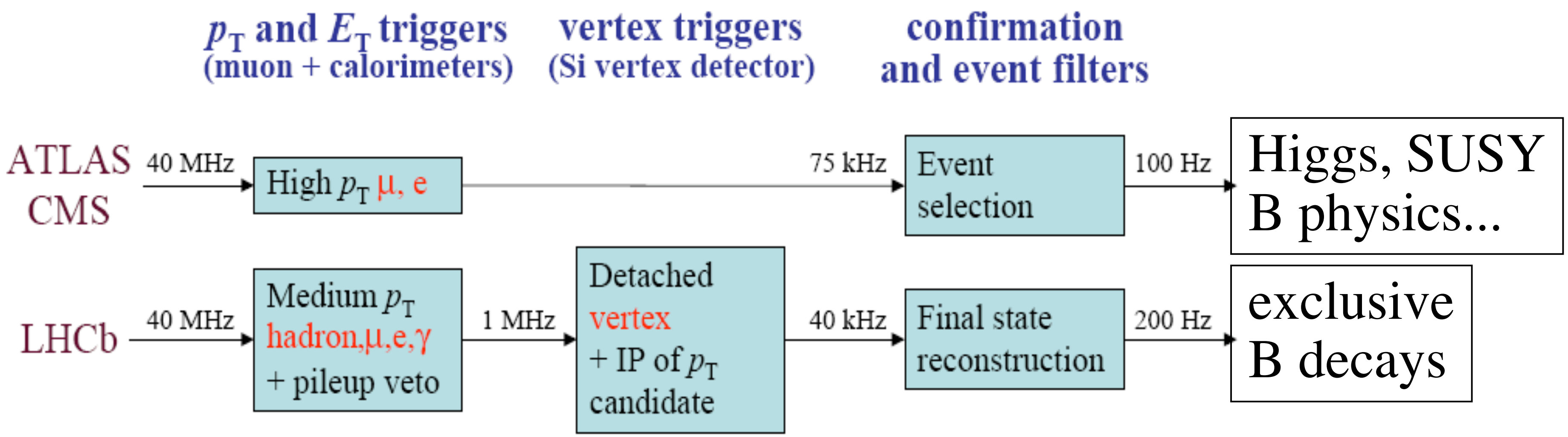

CMS
A Compact Solenoidal Detector for LHC
FORWARD CALORIMETER
MUON CHAMBERS
TRACKER
CRYSTAL ECAL
HCAL
SUPERCONDUCTING COIL
RETURN YOKE
Total weight : 12,500t.
Overall diameter : 15.00m
Overall length : 21.60m
Magnetic field : 4 Tesla
CMS-PARA-001-11/07/97


5m
Magnet
RICH1
TT
T1
T2
T3
RICH2
M1
SPD/PS
ECAL
HCAL
M2
5m
10m
15m
20m

Crucial requirements for hadronic B experiments...

- An excellent vertex detector
  - Background suppression and B_s physics
- Good K-π separation
  - Must for the hadronic channels
    - an essential feature of LHCb
- A good trigger for interesting decay modes
  - Too many b's produced to trigger on all of them
  - High-p_T lepton trigger, relatively easy...
    - ATLAS, CMS, LHCb: good for $J/\psi X$, $\mu\mu$, $K^{*0}\mu\mu$
  - Vertex trigger essential for the hadronic channels
    - LHCb

Basic Trigger philosophy



ATLAS and CMS can study $B \rightarrow \mu^+\mu^-$ at high luminosity (10^{34})

$$\mathrm{BR} = 3.5 \times 10^{-9}\ (B_s^0),\ 1.5 \times 10^{-10} (B_d^0)$$

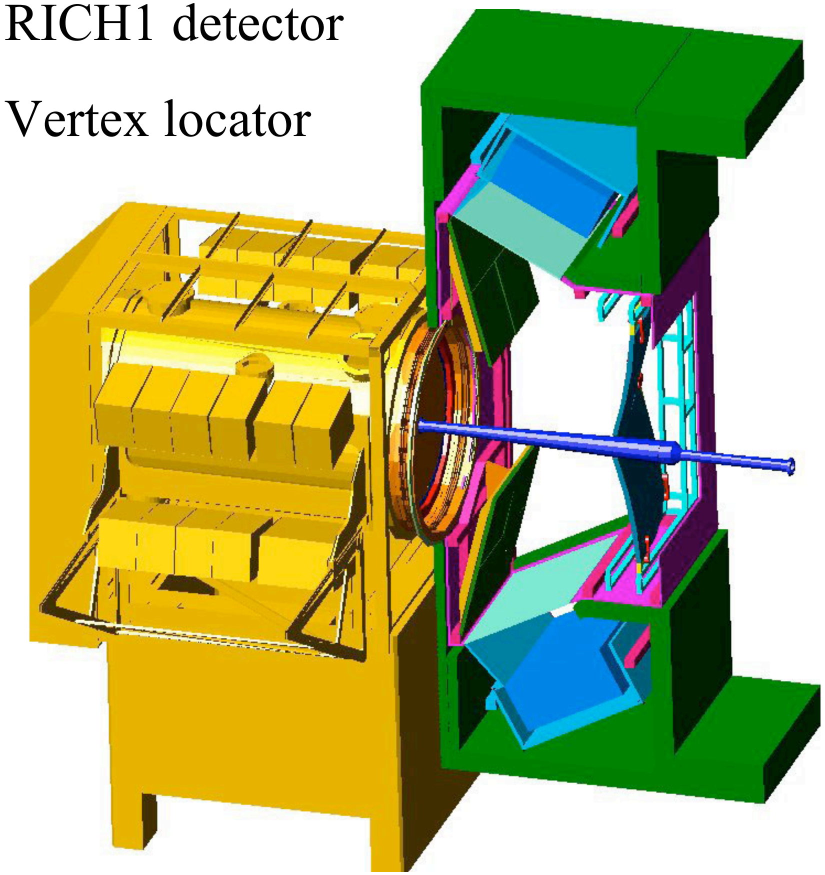
100 fb^{-1}	Signal $B_s \rightarrow \mu^+\mu^-$	Signal $B_d \rightarrow \mu^+\mu^-$	Bkgd
ATLAS	92	14	660
CMS	26	4	< 6.4

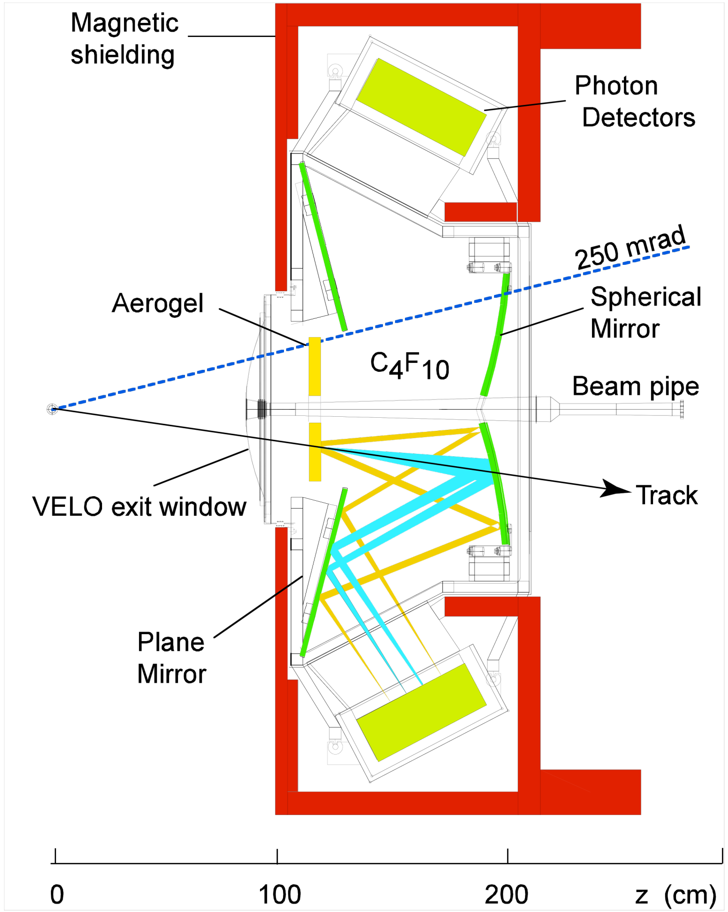
LHCb

RICH1

RICH1 detector

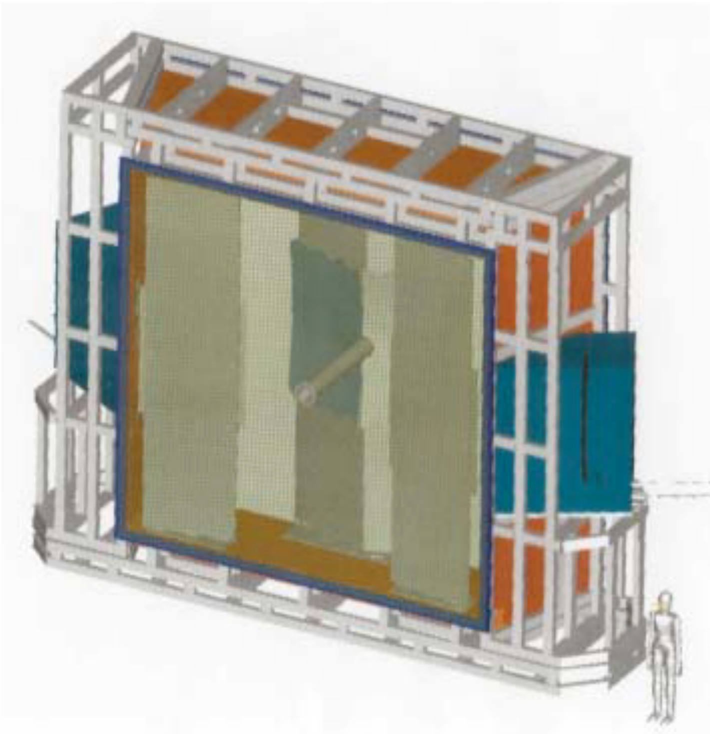
Vertex locator



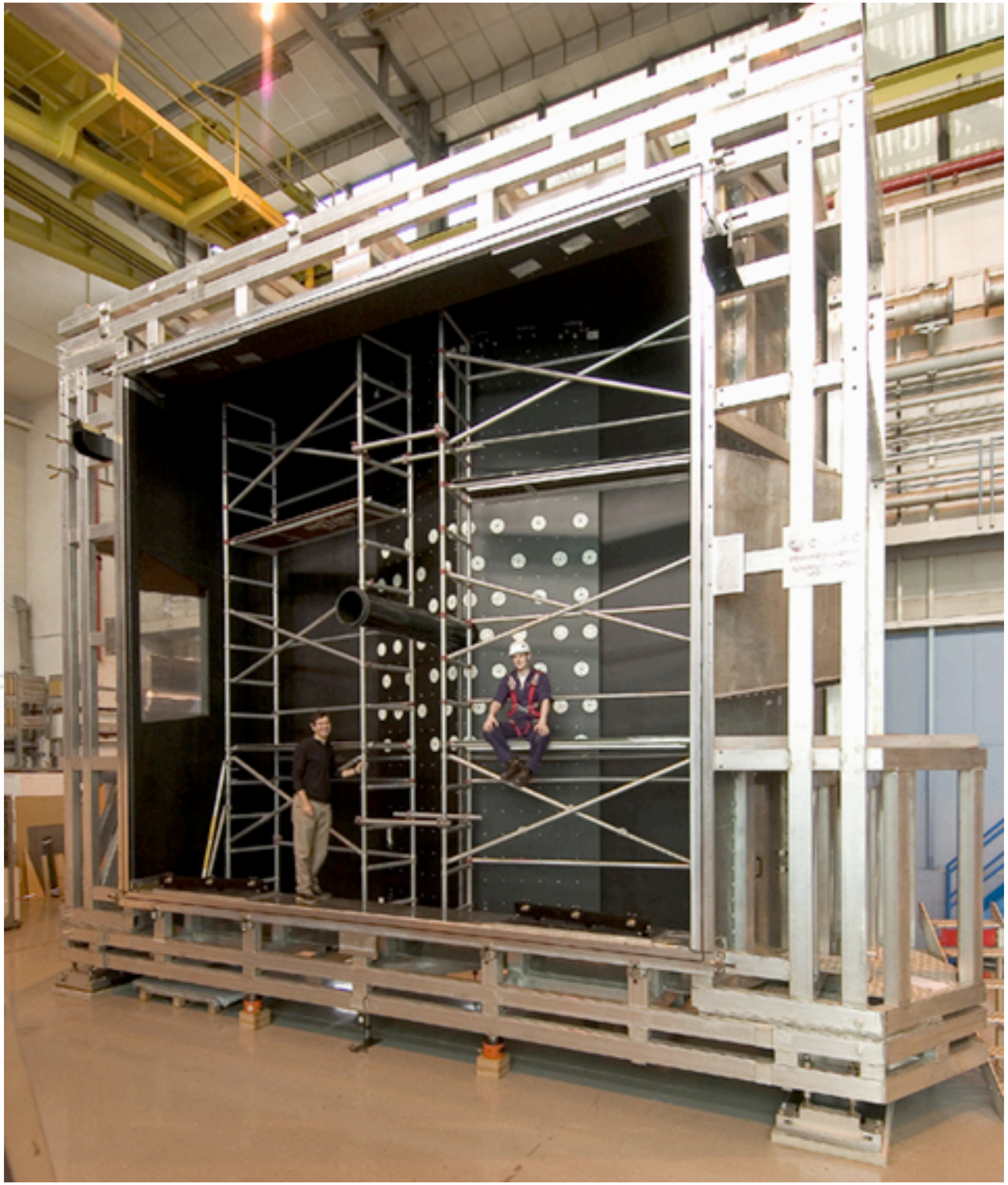


LHCb

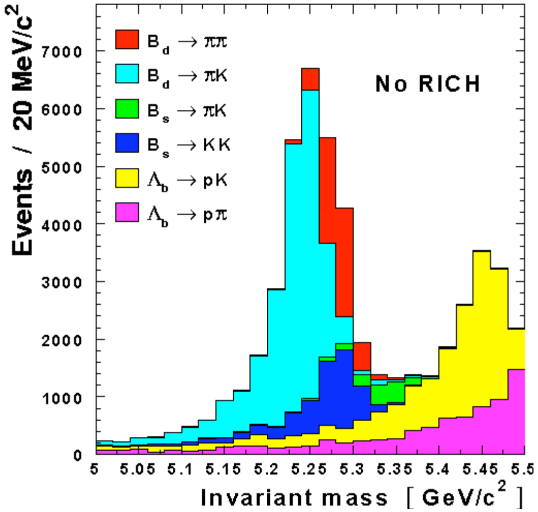
RICH2

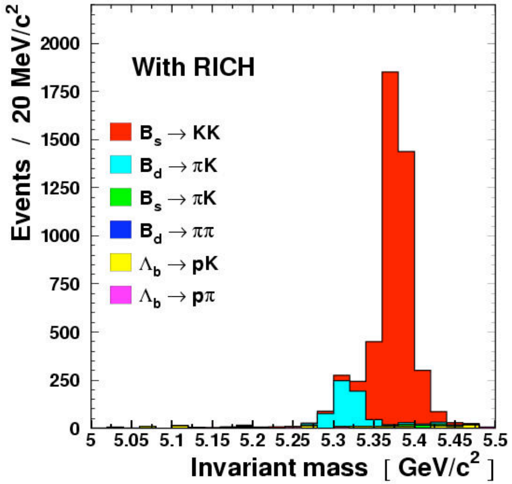


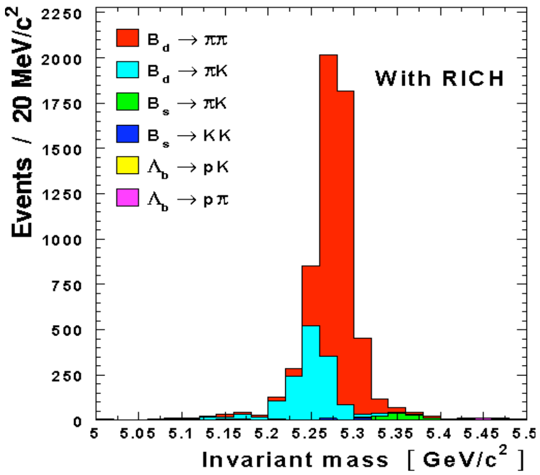
3d CAD model



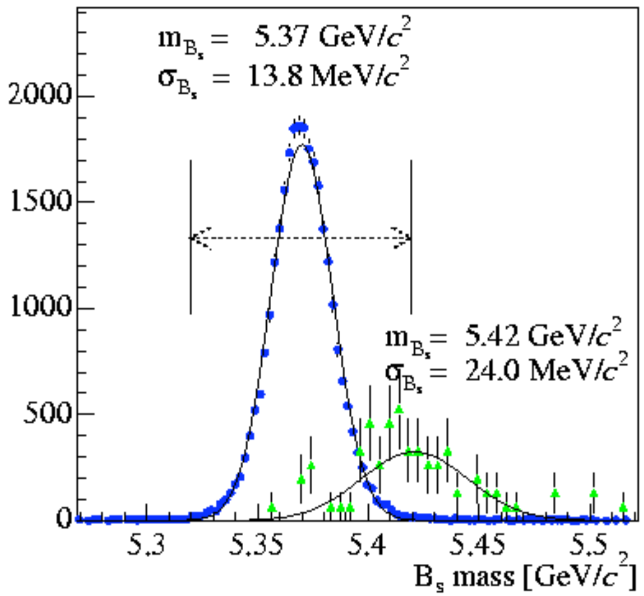
PID for $B \to \pi\pi$ and $B_s \to KK$ reconstruction



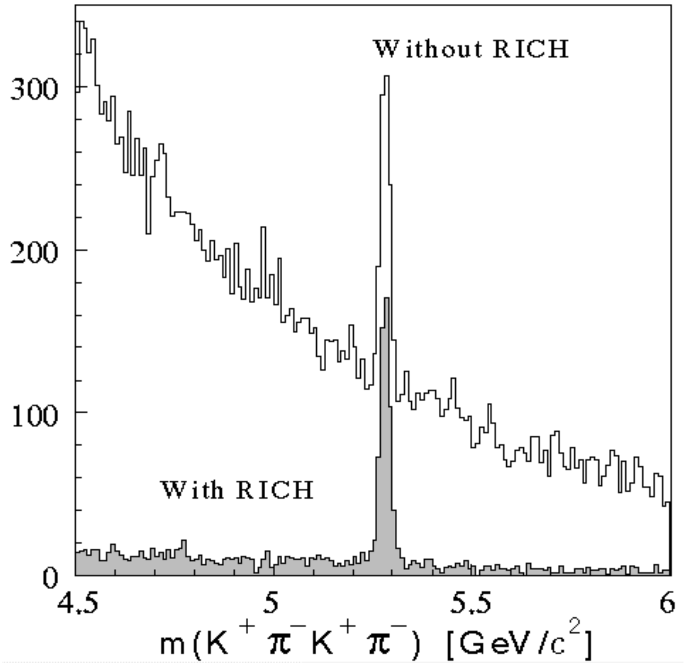


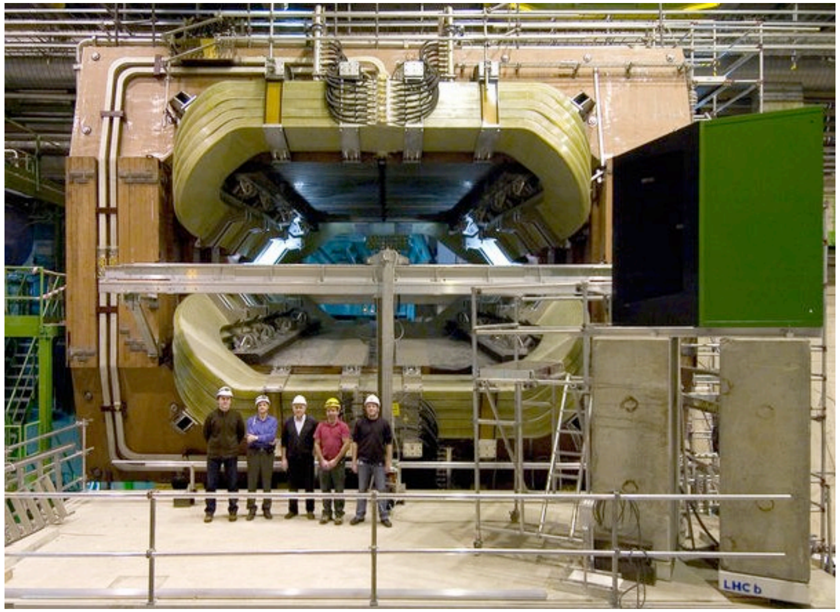


$B_s \to D_s\pi$ suppression with PID for $B_s \to D_sK$



MinB suppression with PID for $B \to DK^{*0}$

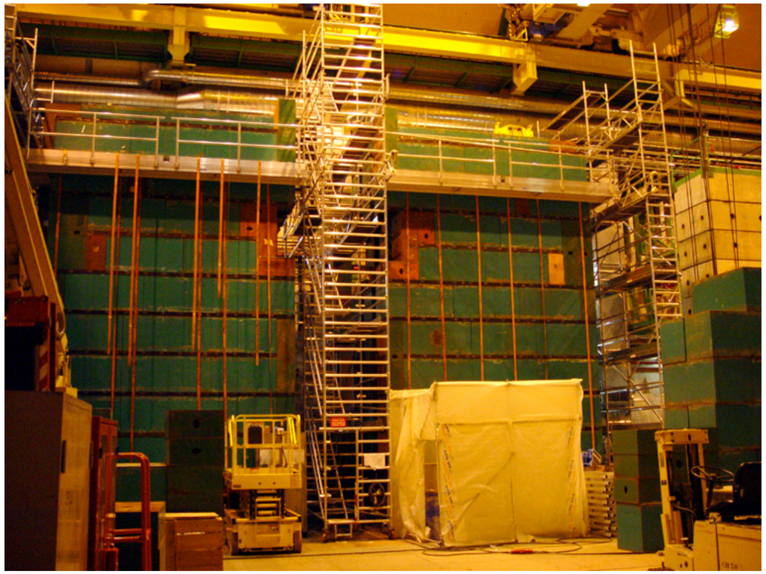




Magnet completed

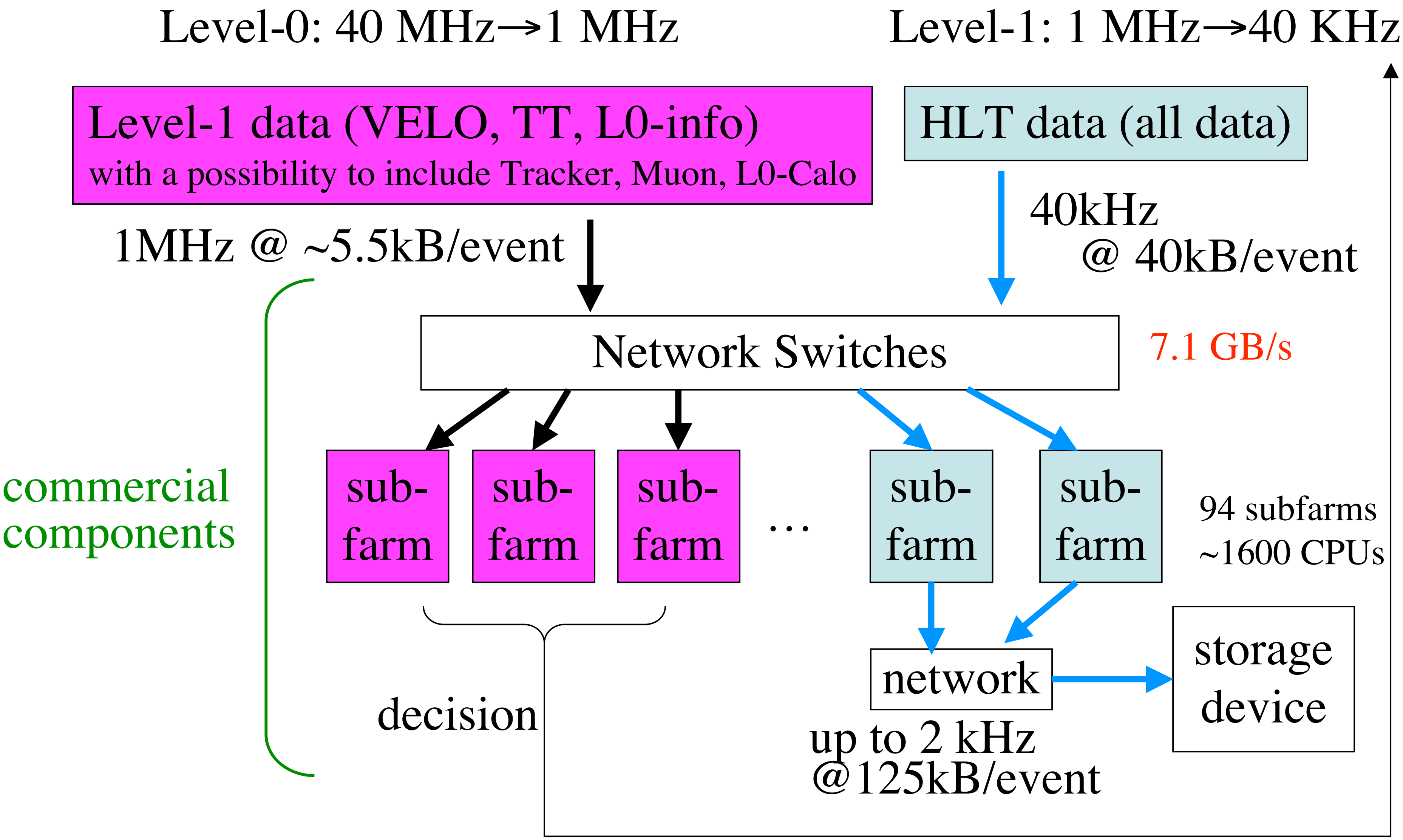
All H-cal module completed

All E-cal module completed



Muon filter completed

LHCb Level-1/High Level Trigger and DAQ



LHCb Efficiencies, event yields and B_{bb}/S ratios (examples)

	Det. eff. (%)	Rec. eff. (%)	Sel. eff. (%)	Trig. eff. (%)	**Tot. eff. (%)**	Vis. BR (10^{-6})	**Annual signal yield**	**B/S from bb bkg.**
$B^0 \to \pi^+\pi^-$	12.2	91.6	18.3	33.6	**0.69**	4.8	**26k**	**< 0.7**
$B_s \to K^+K^-$	12.0	92.5	28.6	36.7	**0.99**	18.5	**37k**	**0.3**
$B_s \to D_s^-\pi^+$	5.4	80.6	25.0	31.1	**0.34**	120.	**80k**	**0.3**
$B_s \to D_s^{-+}K^{+-}$	5.4	82.0	20.6	29.5	**0.27**	10.	**5.4k**	**< 1.0**
$B^0 \to \tilde{D}^0(K\pi)K^{*0}$	5.3	81.8	22.9	35.4	**0.35**	1.2	**3.4k**	**< 0.5**
$B^0 \to J/\psi(\mu\mu)\,K^0_S$	6.5	66.5	53.5	60.5	**1.39**	20.	**216k**	**0.8**
$B^0 \to J/\psi(ee)\,K^0_S$	5.8	60.8	17.7	26.5	**0.16**	20.	**26k**	**1.0**
$B_s \to J/\psi(\mu\mu)\,\phi$	7.6	82.5	41.6	64.0	**1.67**	31.	**100k**	**< 0.3**
$B_s \to J/\psi(ee)\,\phi$	6.7	76.5	22.0	28.0	**0.32**	31.	**20k**	**0.7**
$B^0 \to \rho\,\pi$	6.0	65.5	2.0	36.0	**0.03**	20.	**4.4k**	**< 7.1**
$B^0 \to K^{*0}\gamma$	9.5	86.8	5.0	37.8	**0.16**	29.	**35k**	**< 0.7**
$B_s \to \phi\,\gamma$	9.7	86.3	7.6	34.3	**0.22**	21.	**9.3k**	**< 2.4**

+ few more channels in TDR

Nominal year = 10^{12} bb pairs produced (10^7 s at $L=2\times10^{32}$ cm^{-2}s^{-1} with $\sigma_{bb}=500\ \mu$b)
Yields include factor 2 from CP-conjugated decays
Branching ratios from PDG or SM predictions

ε_{tag}^{eff}
4.3 ± 0.2 B_d
7.5 ± 0.5 B_s

LHCb
example of the 10^7 s performance from the exclusive channels

Δm_s	up to 68 ps^{-1} with 5σ significance	
2χ	σ = 0.02	

ATLAS, CMS
40 ps^{-1} (95% CL)
0.05 0.02

Channel	σ(γ) [degrees]
$B(B_s) \to \pi\pi(KK)$ and U-spin	~5
$B \to DK^*$	~8
$B_s \to D_sK$	~14

Channel	N	B/S @90%CL
$B_d \to K^{*0}\gamma$	35k	< 0.7
$B_s \to \phi\gamma$	9.3k	< 2.4
$B_d \to K^{*0}\mu^+\mu^-$	4.4k	[0.2, 2.0]
$B_s \to \phi K_S$	800	< 1.1 (bb), < 0.3 (b→φX)
$B_s \to \phi\phi$	1.2k	< 0.2
$B_s \to \mu\mu$	17	< 440 (bb), < 6 (b→μX)

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

ATLAS	700	0.14
CMS	4.2k	0.11

LHCb more inclusive trigger

LHCb high data-log rate of 2 kHz motivated by attempt to understand detector from data

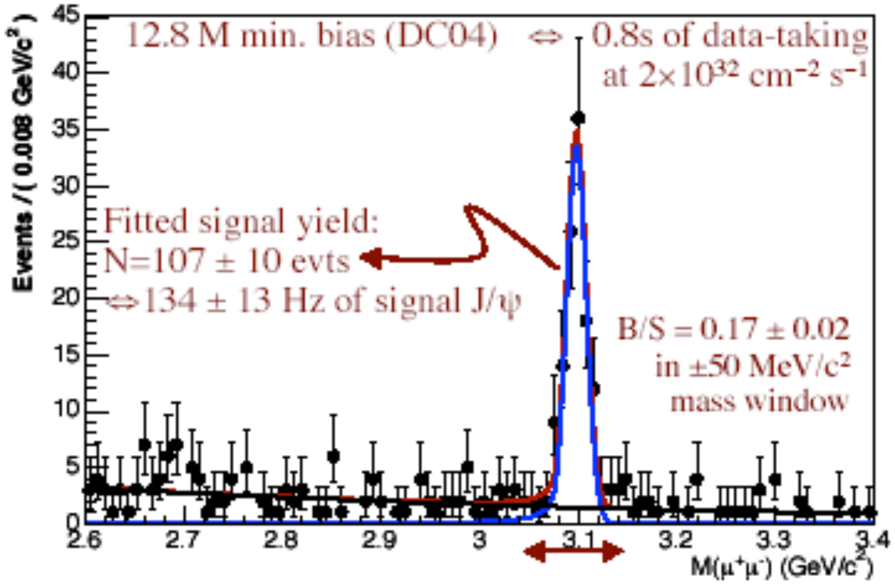
decay time acceptance decay time resolution	} di-muon trigger without IP cut
particle identification	D^* trigger without PID
unbiased sample	inclusive μ with IP cut

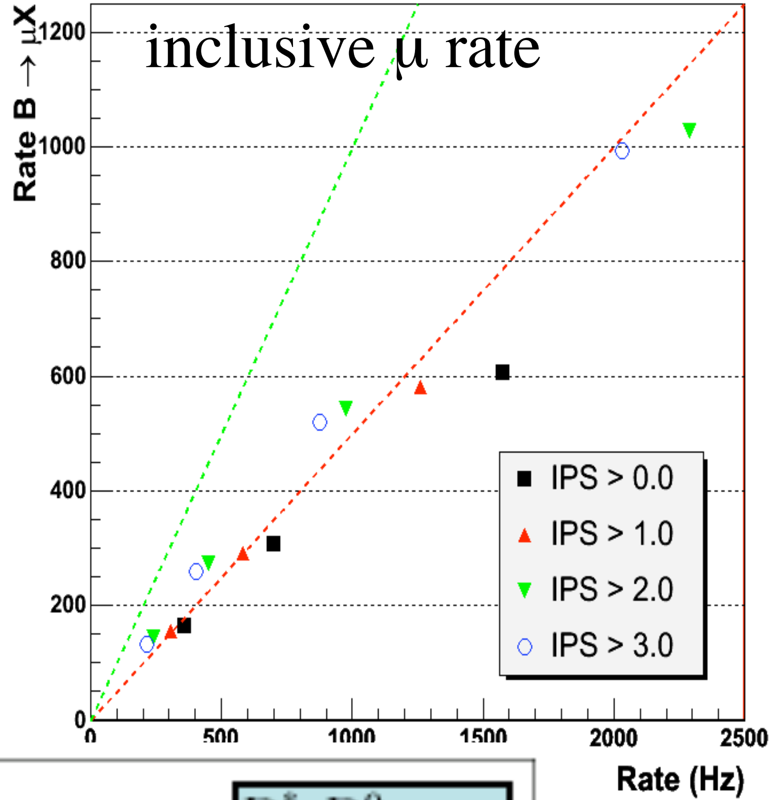
Possible bandwidth division		yields in 10^7 s	
200 Hz	Exclusive B decays		
600 Hz	Di-muon	10^9	$J/\psi \rightarrow \mu\mu$
300 Hz	D^*	500×10^6	$D^*\rightarrow\pi\, D^0(K\pi)$ + c.c.
900 Hz	Inclusive μ	5.5×10^9	$b \rightarrow \mu\, X$

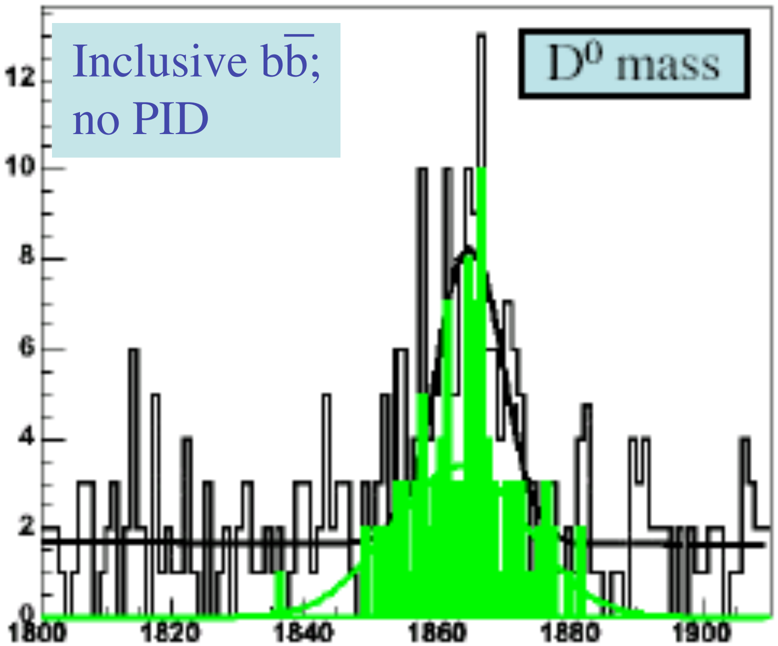
Expectation for $D^0(K\pi)$by 2008

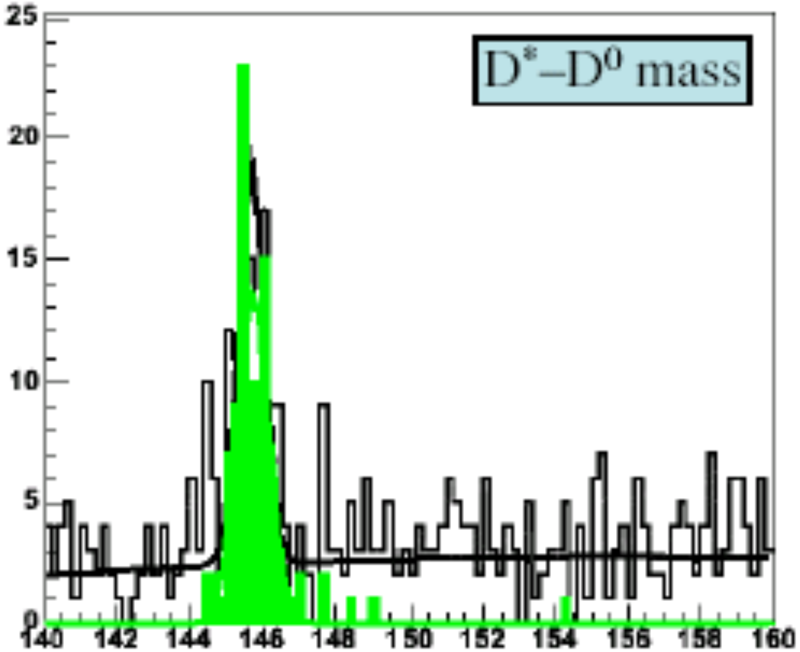
B factories (2000-2500 fb^{-1})	$5.5-6.9\times10^6$
CDF+D0 (8 fb^{-1})	11.8×10^6
CLEO-C (3 fb^{-1})	0.5×10^6

dimuon mass


12.8 M min. bias (DC04) ⇔ 0.8s of data-taking at 2×10^{32} cm^{-2} s^{-1}
Fitted signal yield:
N=107 ± 10 evts
⇔134 ± 13 Hz of signal J/ψ
B/S = 0.17 ± 0.02 in ±50 MeV/c² mass window
Events / (0.008 GeV/c²)
M(μ⁺μ⁻) (GeV/c²)


inclusive μ rate
Rate B → μX
Rate (Hz)
IPS > 0.0
IPS > 1.0
IPS > 2.0
IPS > 3.0


Inclusive $b\bar{b}$;
no PID
D^0 mass


D^*–D^0 mass

Interesting physics option with those data

$D\text{-}\overline{D}$ oscillations

$$y = \frac{\Delta\Gamma}{\Gamma} \qquad x = \frac{\Delta m}{\Gamma} \qquad \text{Standard Model} \sim 10^{-3}$$

Estimated statistical reach of LHCb

$$\sigma_y = 0.0002, \qquad \sigma_x = 0.004$$

CP violation in $D \to K^+K^-$ decays

$$A_{CP} = \frac{(D^0 \to KK - \overline{D}^0 \to KK)}{(D^0 \to KK + \overline{D}^0 \to KK)} \quad \text{Standard Model} \sim 10^{-3}$$

LHCb expects 50×10^6 KK events

Estimated statistical precision 1.4×10^{-4}

Systematics must be controlled by the $K\pi$ mode

Conclusions

At LHC

Direct search for new physics by discovery of new particles

mass, cross section, decay modes etc.

measuring the coupling strengths

Indirect search for new physics through B (and D) $\not{C}\not{P}$ and rare decays

sensitive to the coupling phases

potential sensitivity to a higher energy scale

Since LHC operation is approaching, we need to develop more global view on the two approaches:

i.e. how measurements of one approach influences the other

Future Homework