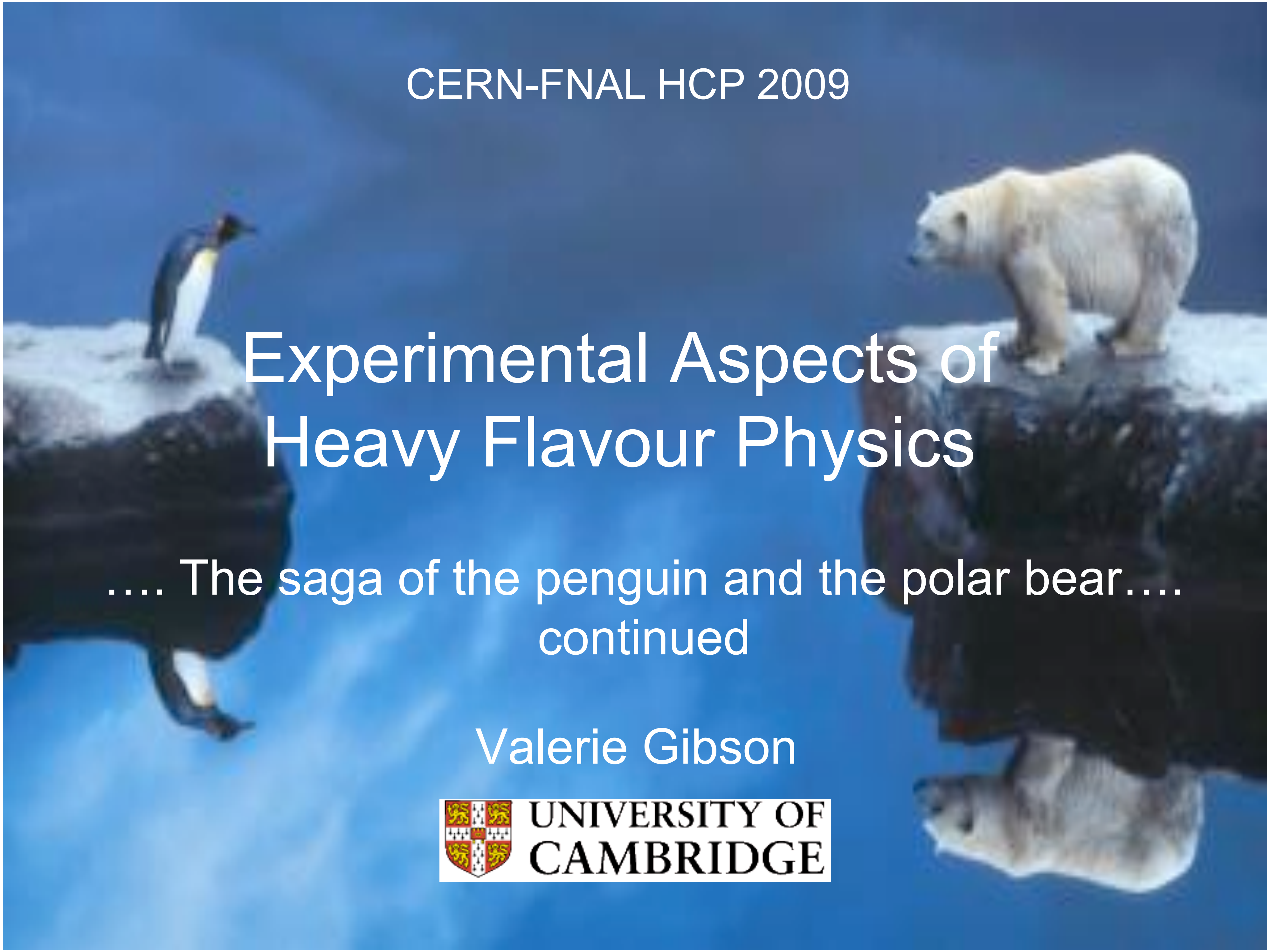


CERN-FNAL HCP 2009

Experimental Aspects of Heavy Flavour Physics

…. The saga of the penguin and the polar bear….
continued

Valerie Gibson

UNIVERSITY OF CAMBRIDGE

Overview

- Introduction
- The Standard Model
- B Physics
- Celebrating the B factories

Lecture 1

- What have we learnt from the Tevatron ?
- The LHC era
- and beyond….
- Summary

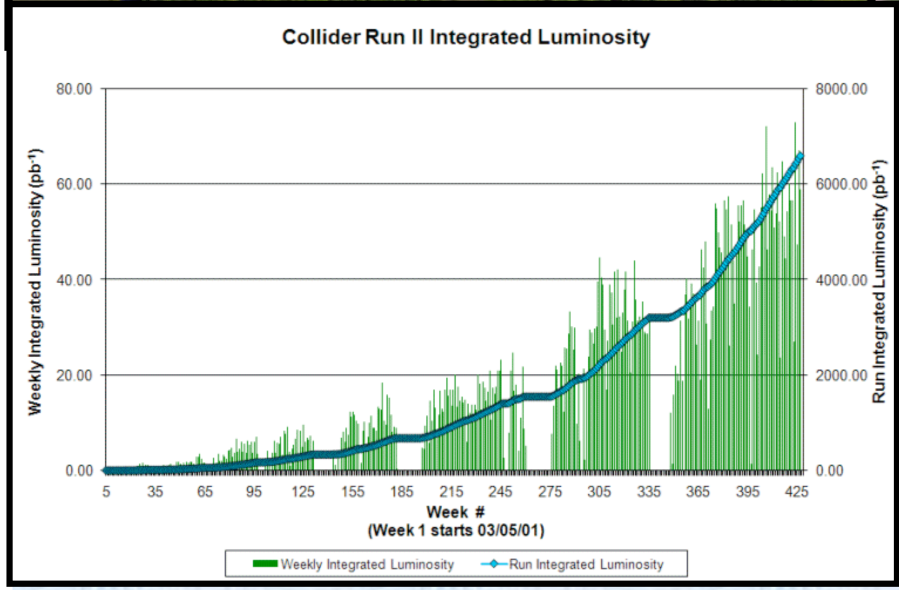
Lecture 2

Where to look next ?

The Tevatron

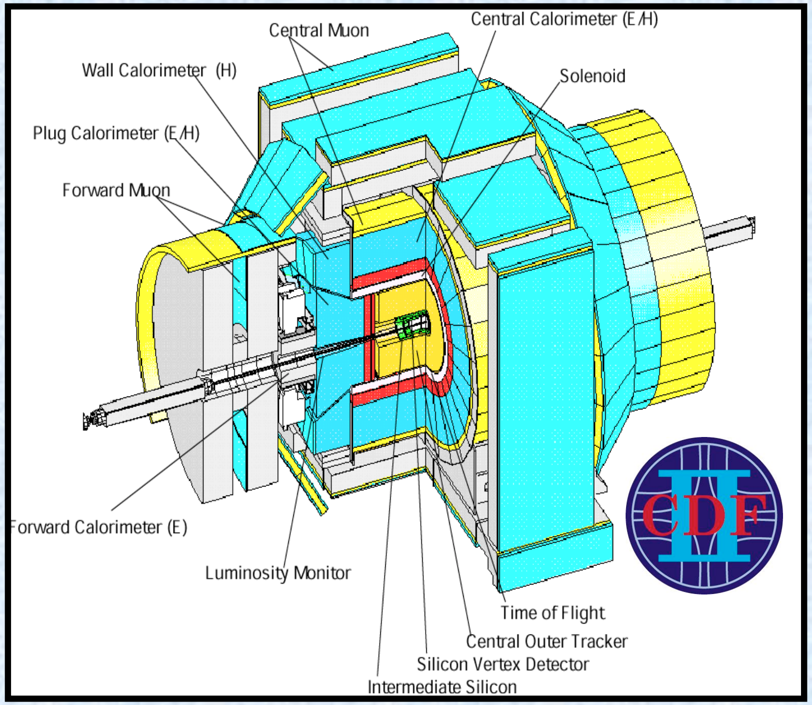
The Tevatron

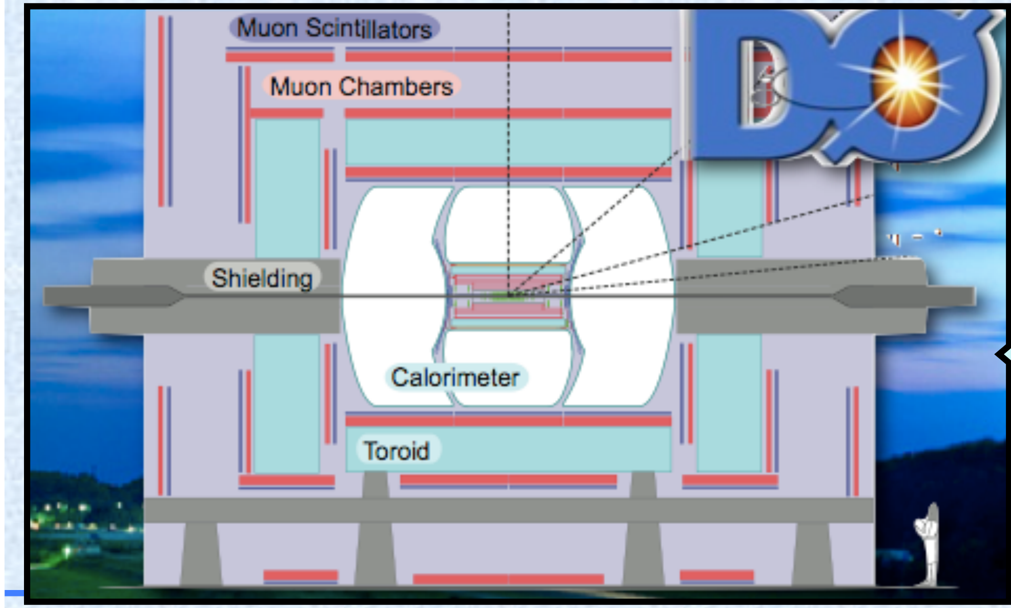
Run II: start March 2001, end ??
Integrated luminosity > 6 fb^{-1}
Peak luminosity ~ 3.5 x 10^{32} $cm^{-2}s^{-1}$



CDF and D0

Silicon detector (SVX)
Drift chambers (excellent mass resol.)
Magnetic field 1.4 T
Muon identification
dE/dx +TOF





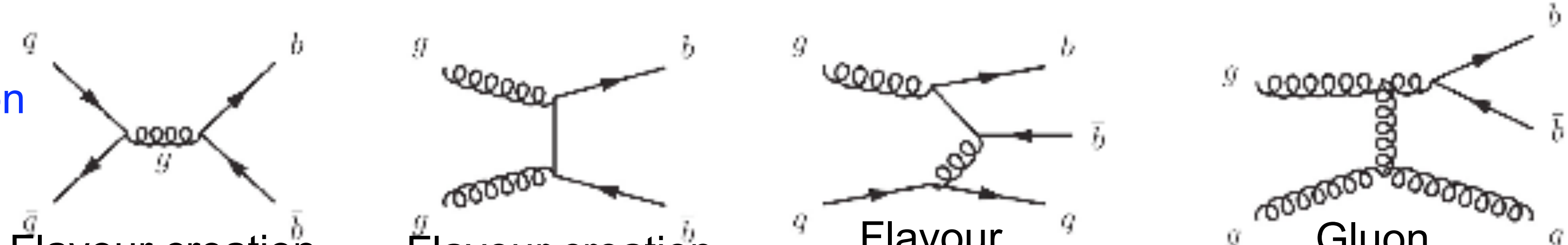
Silicon detector (SMT)
Silicon fibre tracker (CFT)
Muon system

Magnetic polarity reversed regularly

e^+e^- vs Hadron Colliders

	$e^+e^- \to \Upsilon(4s) \to B\overline{B}$ **PEP-II, KEK-B**	$p\overline{p} \to b\overline{b}X \quad (\sqrt{s} = 2\text{ TeV})$ **TeVatron**	$pp \to b\overline{b}X \quad (\sqrt{s} = 14\text{ TeV})$ **LHC**
prod	1 nb	~100 μb	~500 μb
typ. $b\overline{b}$ rate	10 Hz	~100 kHz	~500 kHz
purity	~1/4	$\sigma_{b\overline{b}}/\sigma_{inel} \approx 0.2\%$	$\sigma_{b\overline{b}}/\sigma_{inel} \approx 0.6\%$
pile-up	0	1.7	0.5-20
B content	$B^+B^-(50\%), B^0\overline{B}^0(50\%)$	$B^+(40\%), B^0(40\%), B_s(10\%), B_c(<1\%)$, b – baryons(10%)	
B boost	small, βγ~0.56	large, decay vertices are displaced	
event structure	BB pair alone	many particles non-associated to $b\overline{b}$	
prod. vertex	Not reconstructed	reconstructed with many tracks	
$B^0\overline{B}^0$ mixing	coherent	incoherent→ flavour tagging dilution	

bb production at hadron colliders



Flavour creation (quark annihilation)

Flavour creation (gluon fusion)

Flavour excitation

Gluon splitting

Triggers for B Physics

The trigger at the Tevatron determines the B physics program

Int rate ~2.5 MHz, L1 accept 30 kHz (CDF), 2kHz (D0), Output rate ~150 Hz

CDF trigger exploits the SVT processor to select displaced tracks

D0 trigger based on powerful muon identification

3 main trigger types:

Dimuon (J/Ψ): “Easy” trigger, clean signal

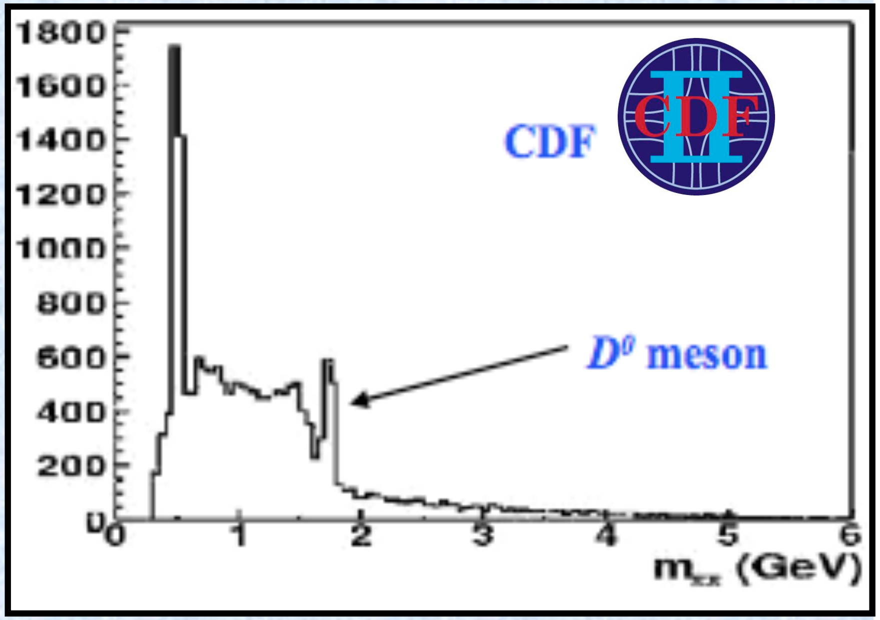
Single lepton: Semi-leptonic B decays

Combine with displaced track (CDF)

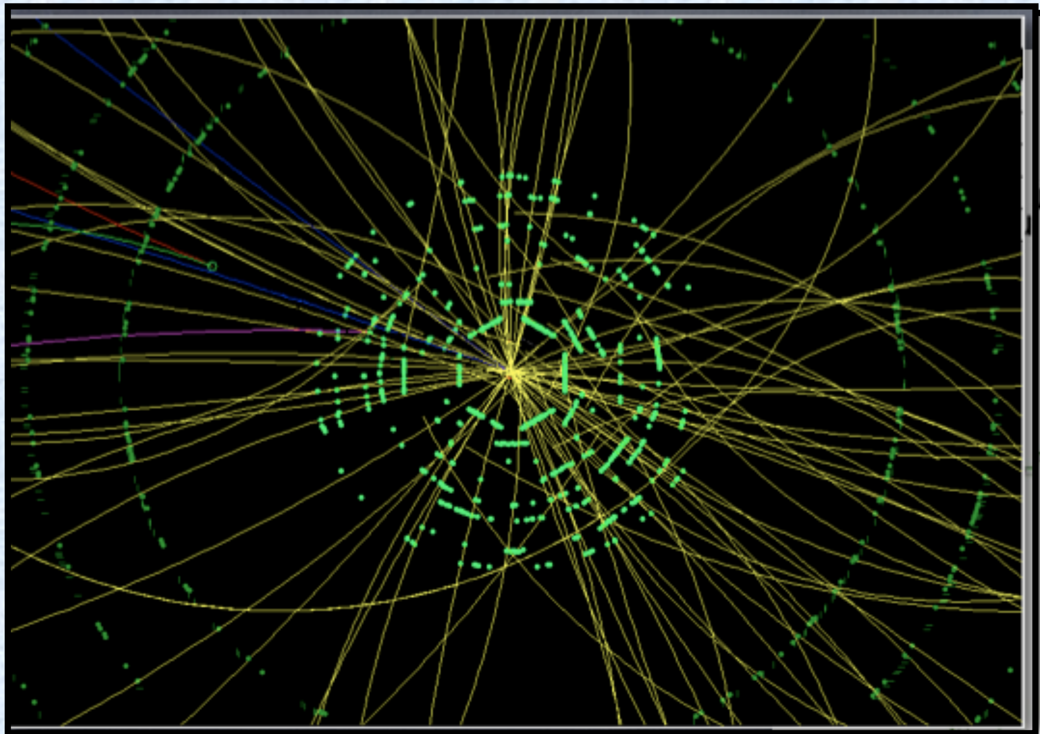
Hadronic B (80% B decays) (CDF)

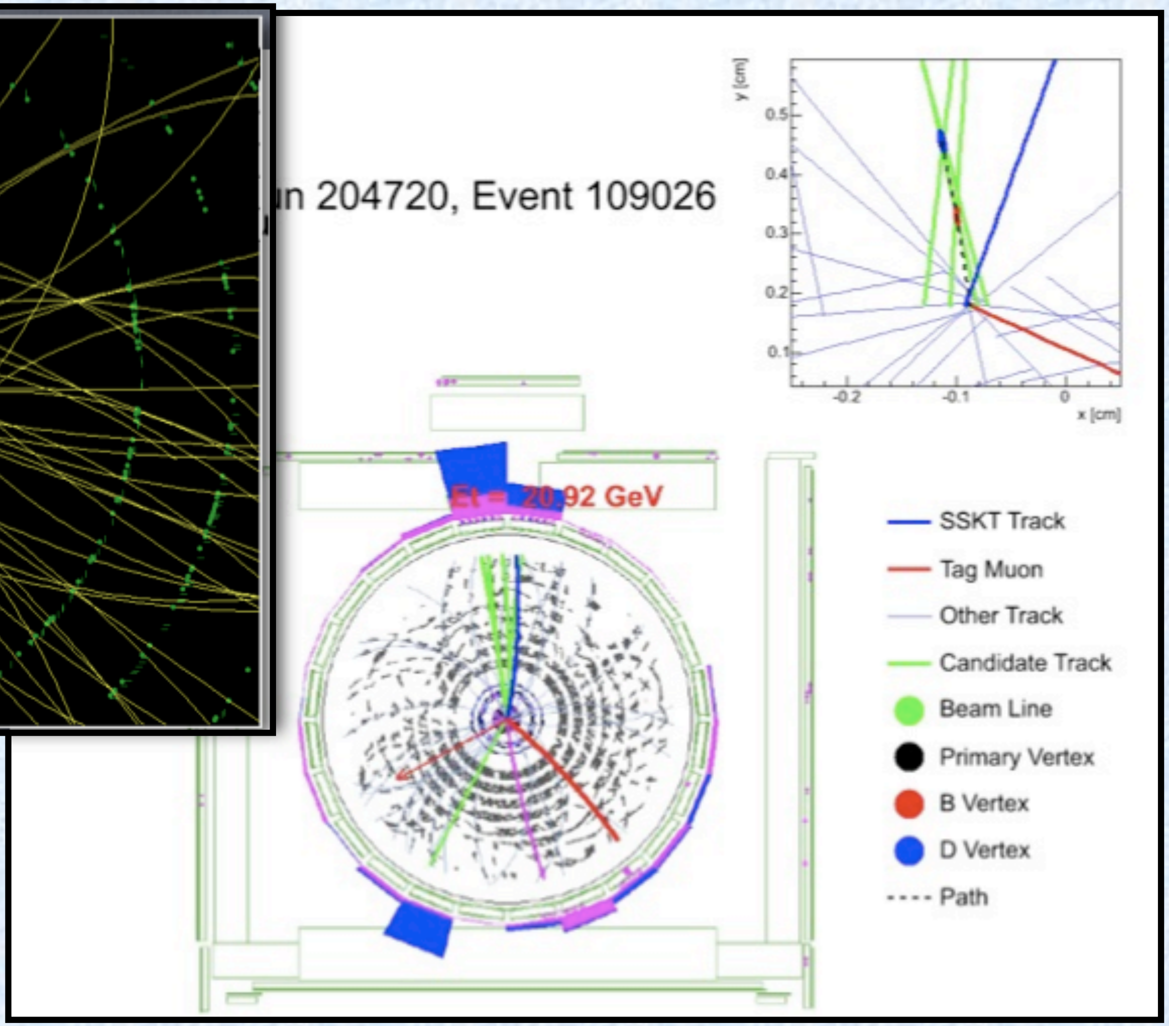
Require several displaced tracks and precision tracking.

Biases lifetimes etc



Tevatron Events





Ω_b

D0: PRL101 (2008) 232002

B physics "soft"

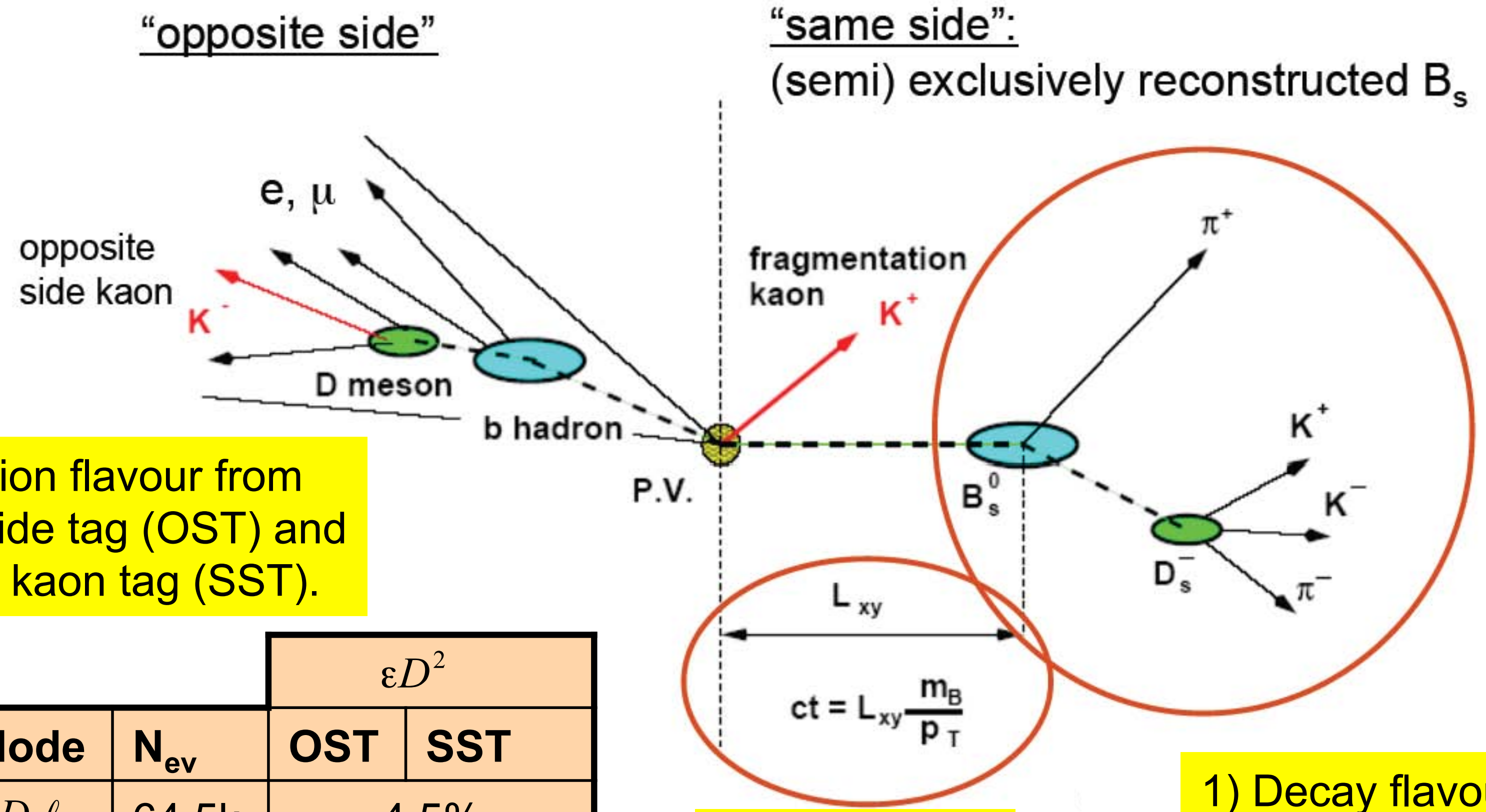
→ No nice jets

B_s oscillations

CDF: PRL97 (2006) 062003

Key ingredients

Lifetimes and mixing measurements



3) Production flavour from opposite side tag (OST) and same-side kaon tag (SST).

2) Proper time measurement

$L_{xy} \approx 500\ \mu m$

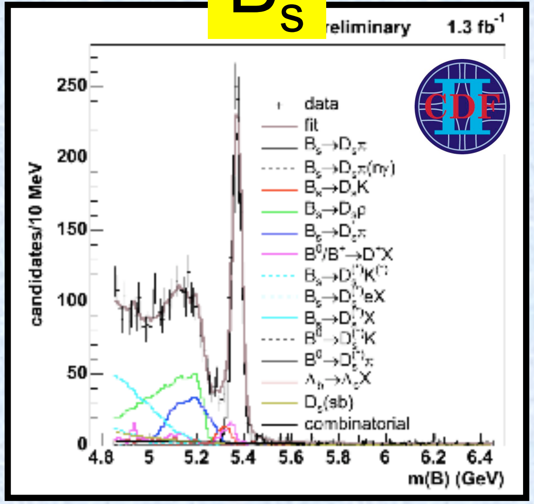
$\langle \sigma_{c\tau} \rangle \approx 25-50\ \mu m$

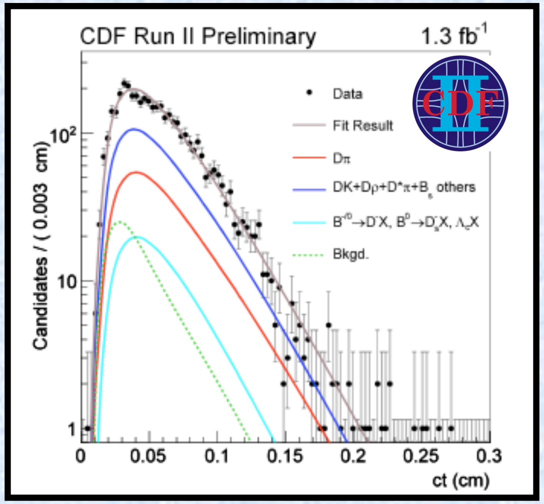
1) Decay flavour from decay products

			εD^2	
Exp	**Mode**	**N$_{ev}$**	**OST**	**SST**
D0	$D_s\ell$	64.5k	4.5%	
	$D_s\pi$	249	2.5%	
CDF	$D_s\ell$	61.5k	1.8%	4.8%
	$D_s(3)\pi$	8.7k	1.8%	3.7%

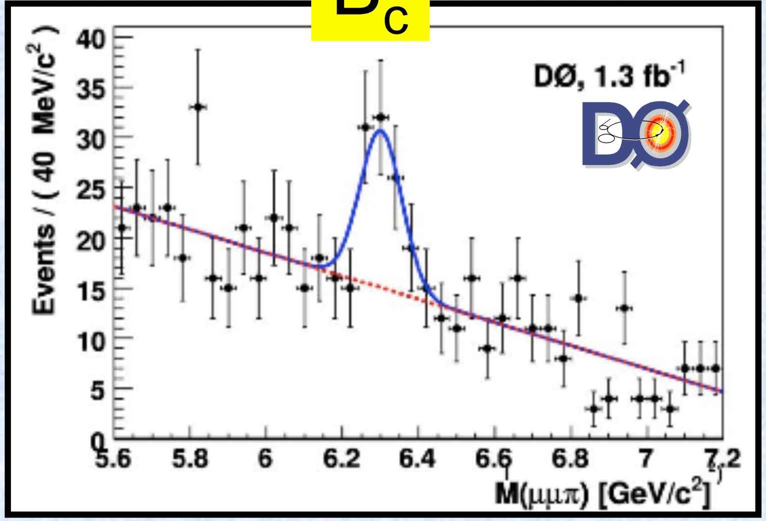
B Hadrons

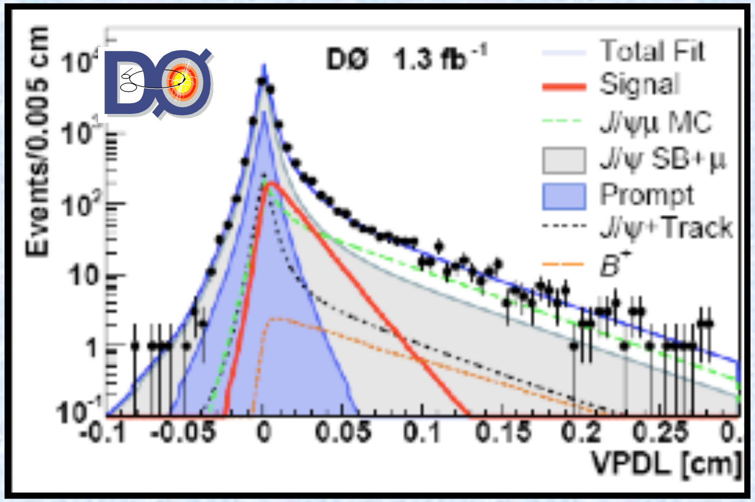
B_s



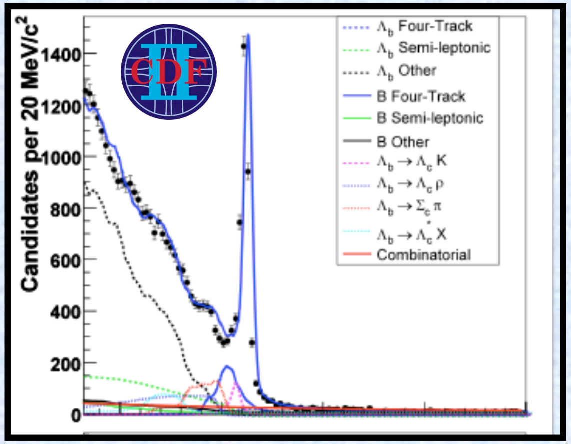


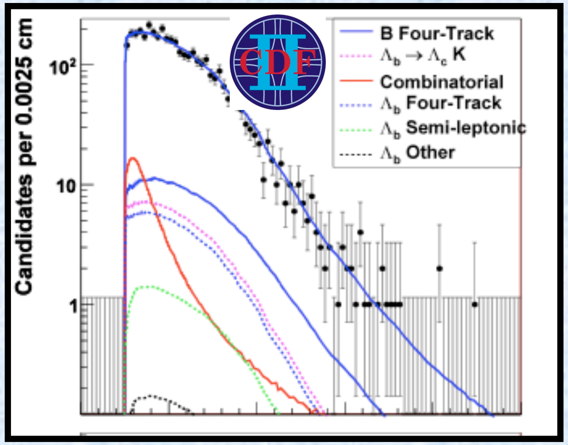
B_c





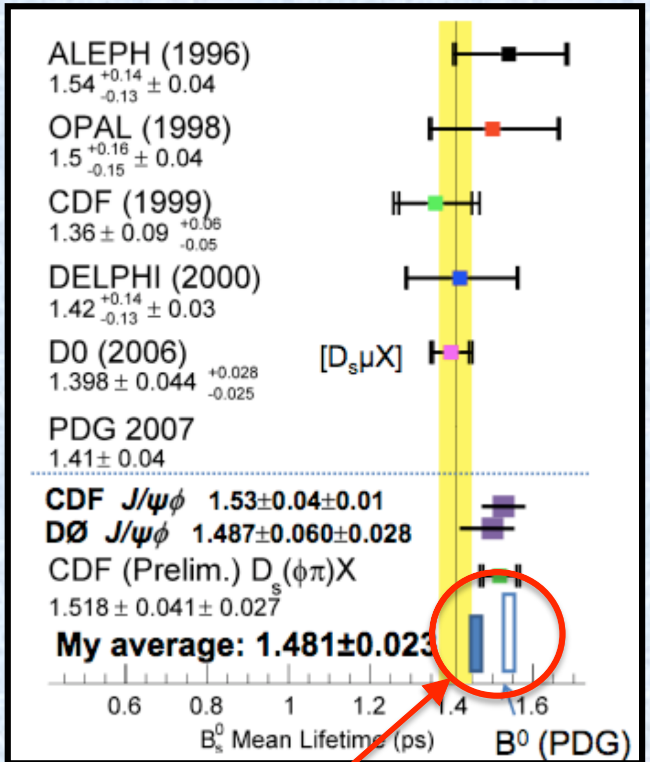
Λ_b





B Hadrons

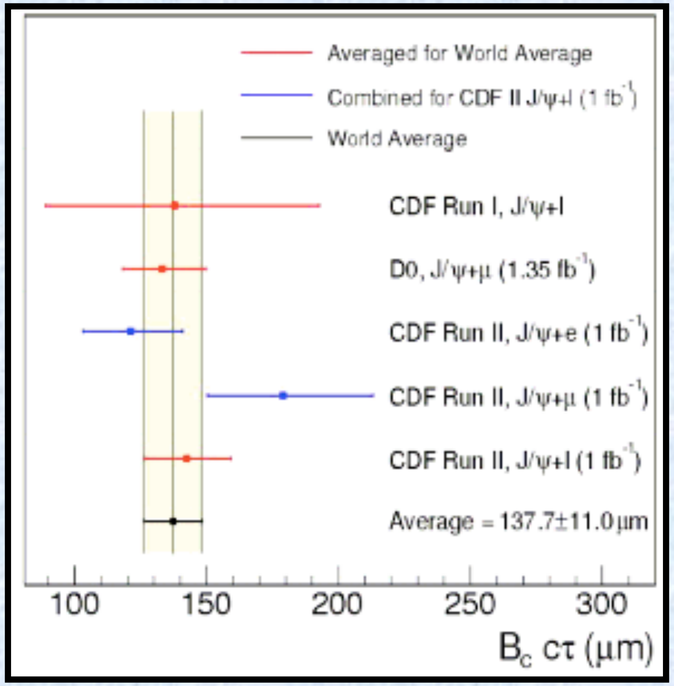
B_s



2σ discrepancy between data and expectation

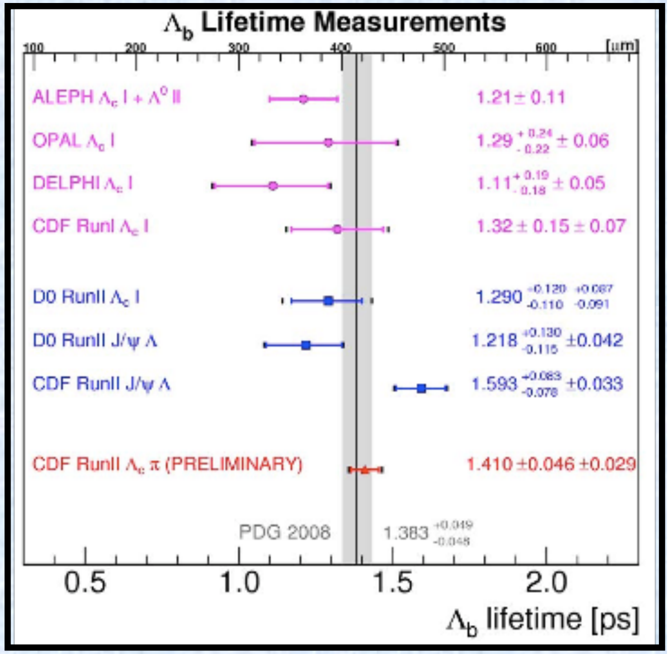
$$\tau(B^0) \approx \tau(B_s)$$

B_c



Agrees with expectation

Λ_b

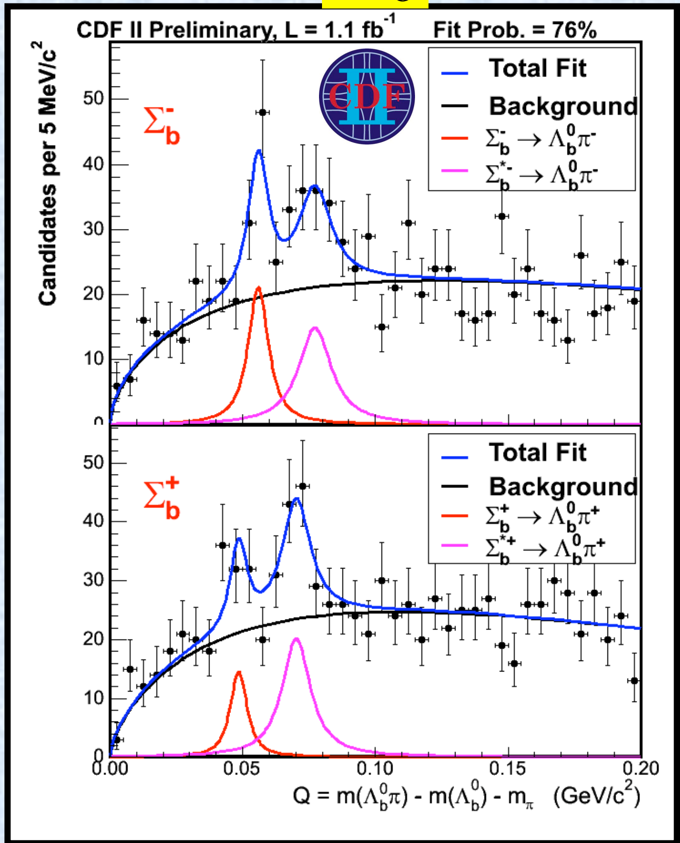


$$\tau(\Lambda_b)/\tau(B^0) = 0.922 \pm 0.039$$

J.Lewis: Moriond EW 2009

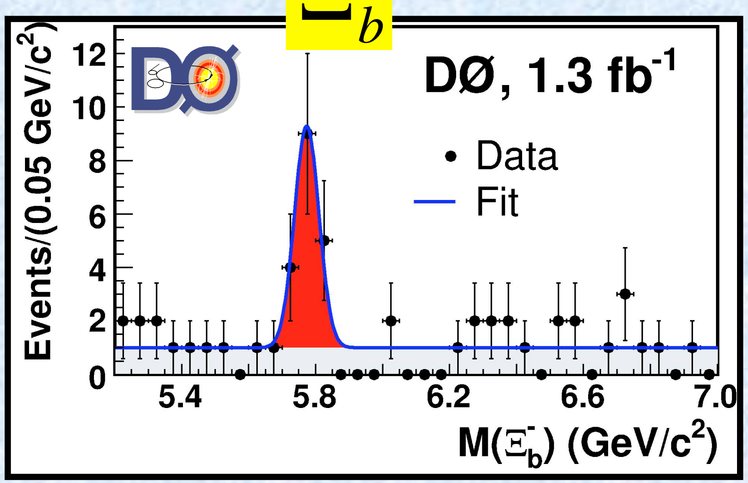
and more…B baryons

$\Sigma_b^{\pm}$



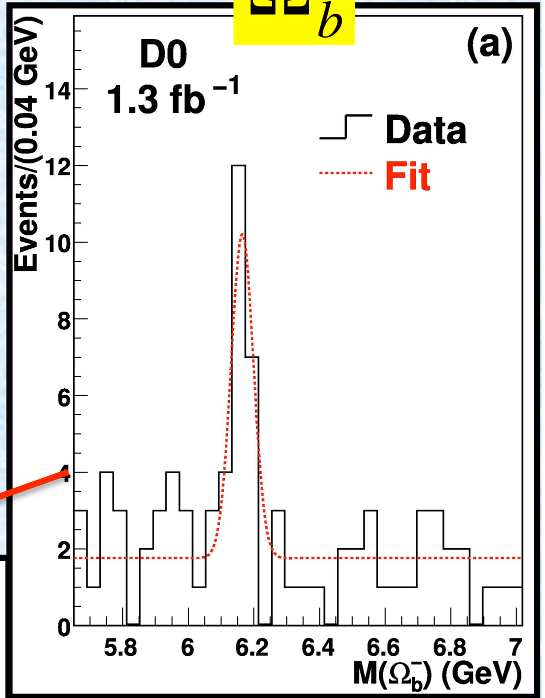
CDF : PRL99 (2007) 202001

$\Xi_b^{\pm}$

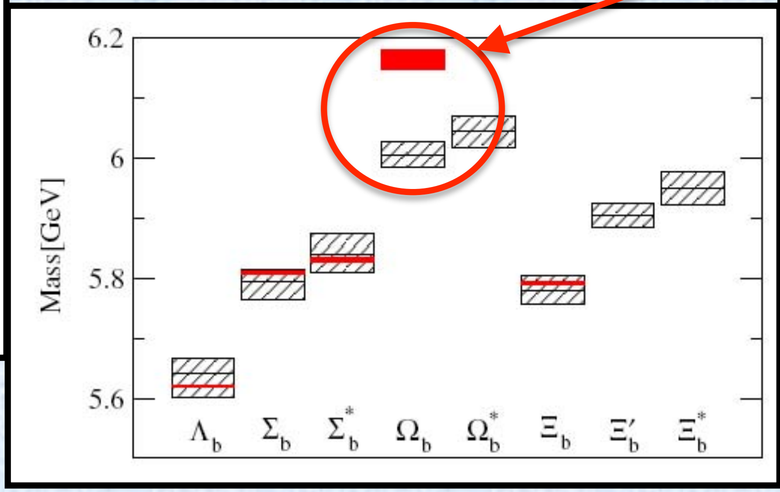


D0 : PRL99 (2007) 052001

$\Omega_b^{\pm}$



D0 : PRL101 (2008) 232002

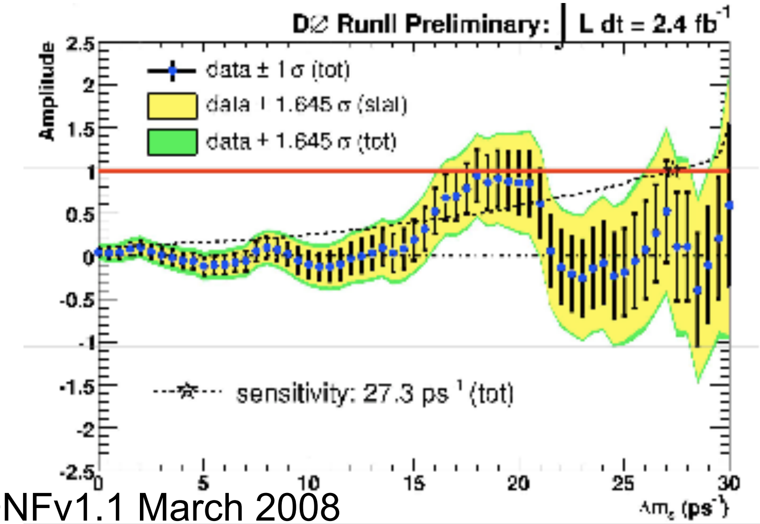


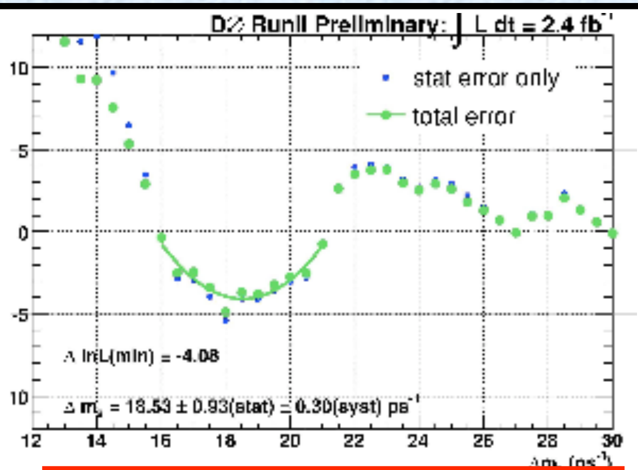
R.Lewis, R.M.Woloshyn PRD79 (2009) 014502

B_s Mixing

One of the most important achievements of the Tevatron

$2.4\ fb^{-1}$

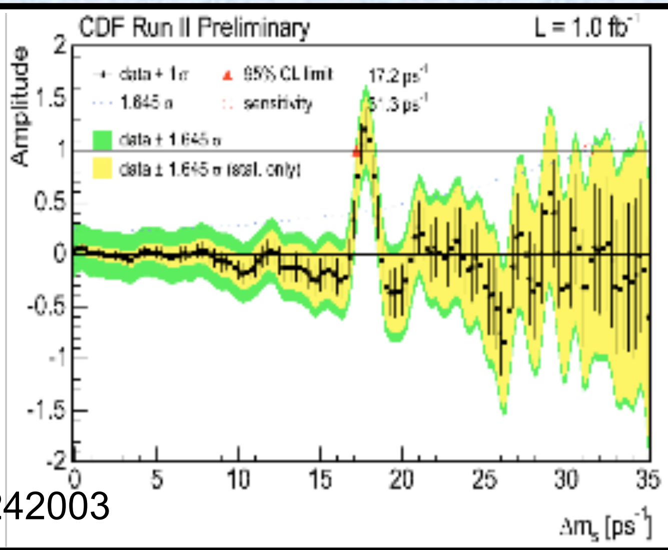


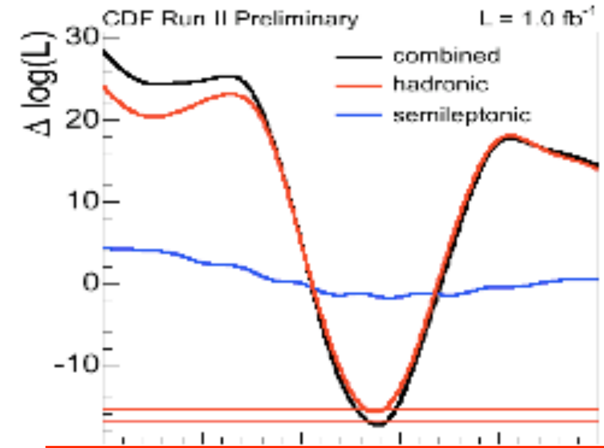


$$\Delta m_s = 18.53 \pm 0.93 \pm 0.30\ \text{ps}^{-1}$$

D0 Note 5618-CONFv1.1 March 2008

$1\ fb^{-1}$





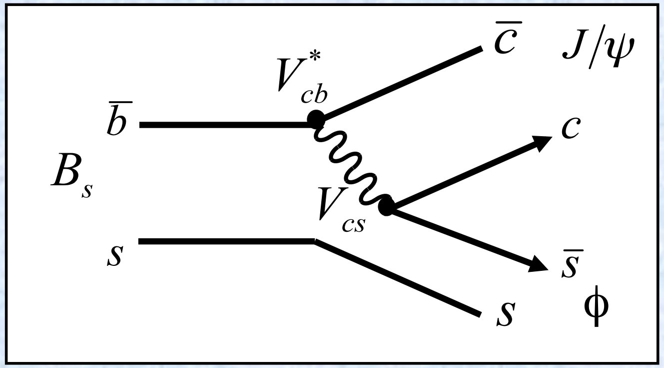
$$\Delta m_s = 17.77 \pm 0.10 \pm 0.07\ \text{ps}^{-1}$$

CDF: PRL97 (2006) 242003

β_s

$B_s \to J/\Psi\phi$ "Gold-plated" decay equivalent to $B_d \to J/\Psi K_s$ for $\sin(2\beta)$

Measures CP violating phase due to interference of mixing and decay amplitudes



$$\beta_s^{SM} = \arg\left[-V_{tb}^* V_{ts} / V_{cb}^* V_{cs}\right]$$

Neglecting SM penguins

Expected to be very small in the SM

$$\beta_S^{SM} \approx 0.02$$

Note: CP violating phase in flavour mixing is also very small in the SM

$$\phi_s^{SM} = \arg\left(-M_{12}/\Gamma_{12}\right) \approx 0.004$$

NP contributions would effect both phases by same quantity

A.Lenz, ArXiv:0705.3802v2

$$2\beta_s = 2\beta_s^{SM} - \phi_s^{NP}$$
$$\phi_s = \phi_s^{SM} + \phi_s^{NP}$$

$$\Rightarrow \; 2\beta_s = -\phi_s$$

If NP phase is dominant

β_s

However, $B_s \to J/\Psi\phi$ analysis is non-trivial.

$P \to VV$ decay, hence a mixture of CP-even and CP-odd final states with significant width $\Delta\Gamma_s$ and mass splitting Δm_s

- $B_s \to J/\Psi\Phi$ decay rate as function of time, decay angles and initial B_s flavor:

$$\frac{d^4P(t,\vec{\rho})}{dt\,d\vec{\rho}} \propto |A_0|^2\mathcal{T}_+ f_1(\vec{\rho}) + |A_\parallel|^2\mathcal{T}_+ f_2(\vec{\rho}) + |A_\perp|^2\mathcal{T}_- f_3(\vec{\rho}) + |A_\parallel||A_\perp|\mathcal{U}_+ f_4(\vec{\rho}) + |A_0||A_\parallel|\cos(\delta_\parallel)\mathcal{T}_+ f_5(\vec{\rho}) + |A_0||A_\perp|\mathcal{V}_+ f_6(\vec{\rho}),$$

time dependence terms

angular dependence terms

terms with β_s dependence

$$\mathcal{T}_\pm = e^{-\Gamma t} \times [\cosh(\Delta\Gamma t/2) \mp \cos(2\beta_s)\sinh(\Delta\Gamma t/2) \mp \eta\sin(2\beta_s)\sin(\Delta m_s t)],$$

terms with Δm_s dependence present if initial state of B meson (B vs anti-B) is determined (flavor tagged)

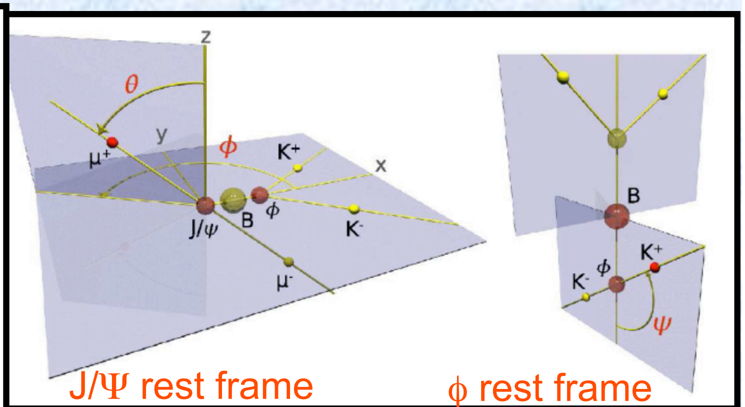
$$\mathcal{U}_\pm = \pm e^{-\Gamma t} \times [\sin(\delta_\perp - \delta_\parallel)\cos(\Delta m_s t) - \cos(\delta_\perp - \delta_\parallel)\cos(2\beta_s)\sin(\Delta m_s t) \pm \cos(\delta_\perp - \delta_\parallel)\sin(2\beta_s)\sinh(\Delta\Gamma t/2)]$$

$$\mathcal{V}_\pm = \pm e^{-\Gamma t} \times [\sin(\delta_\perp)\cos(\Delta m_s t) - \cos(\delta_\perp)\cos(2\beta_s)\sin(\Delta m_s t) \pm \cos(\delta_\perp)\sin(2\beta_s)\sinh(\Delta\Gamma t/2)].$$

'strong' phases:

$$\delta_\parallel \equiv \mathrm{Arg}(A_\parallel(0)A_0^*(0))$$

$$\delta_\perp \equiv \mathrm{Arg}(A_\perp(0)A_0^*(0))$$



3 angles (θ, ϕ, ψ) describe direction of final decay products

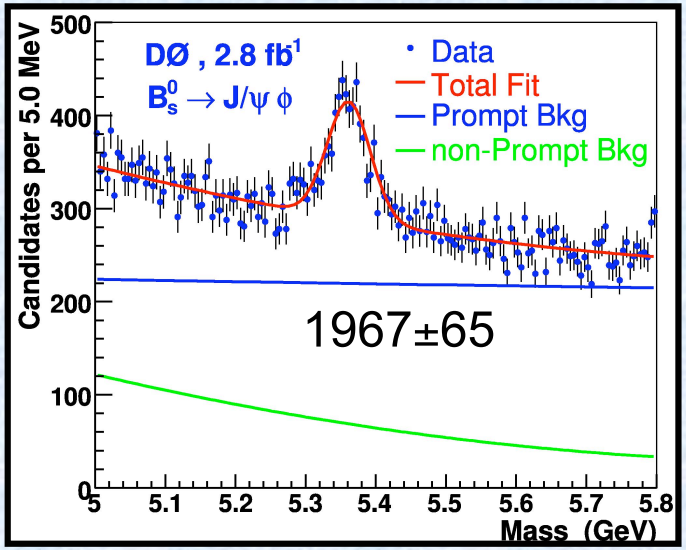
G.Giurgiu, FPCP 2009

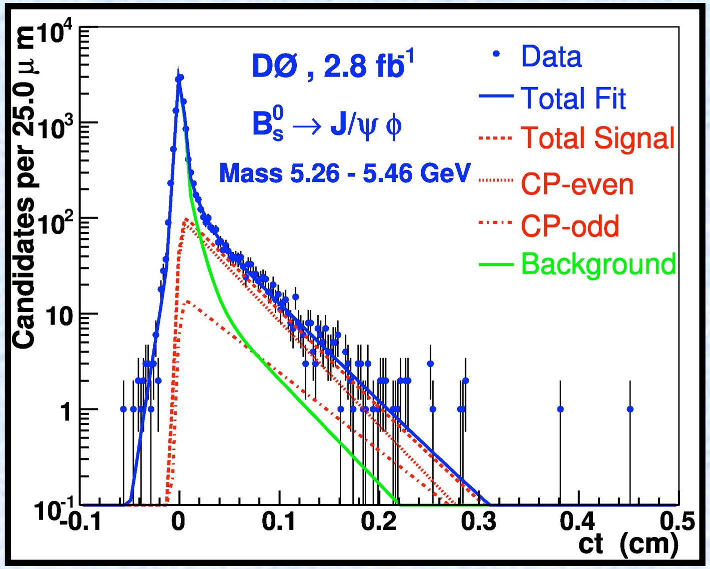
β_s sensitivity has angular dependence, rapidly oscillating in proper time.

β_s

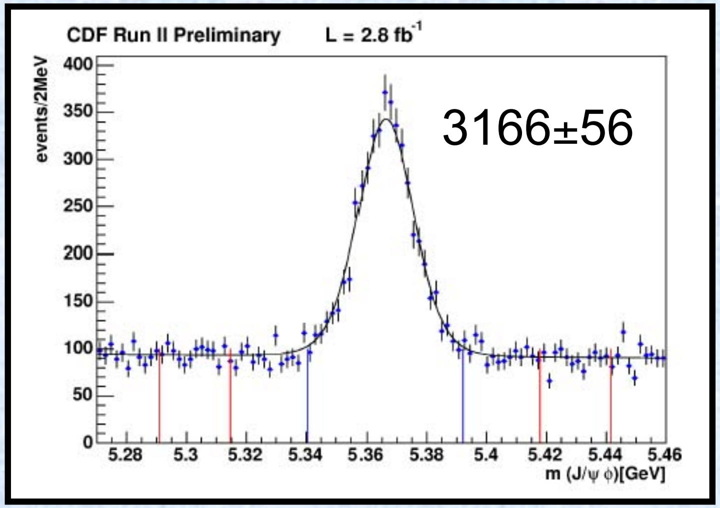
$B_s \rightarrow J//\Psi\phi$ signal reconstruction

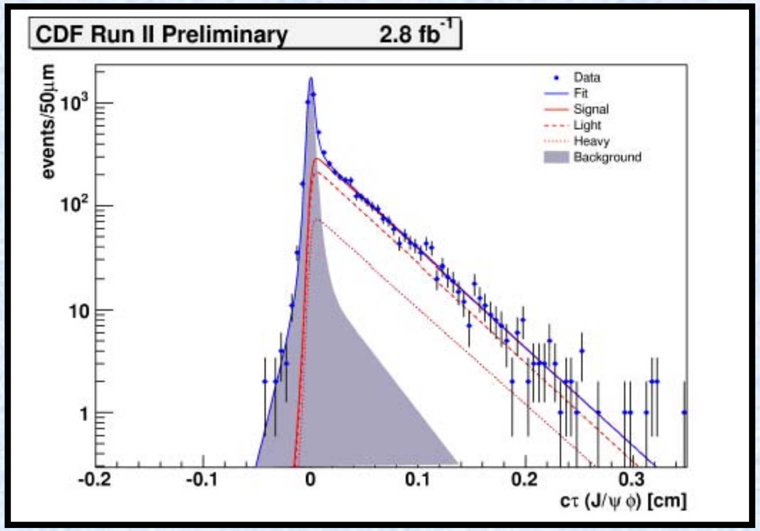
2.8 fb^{-1}





2.8 fb^{-1}

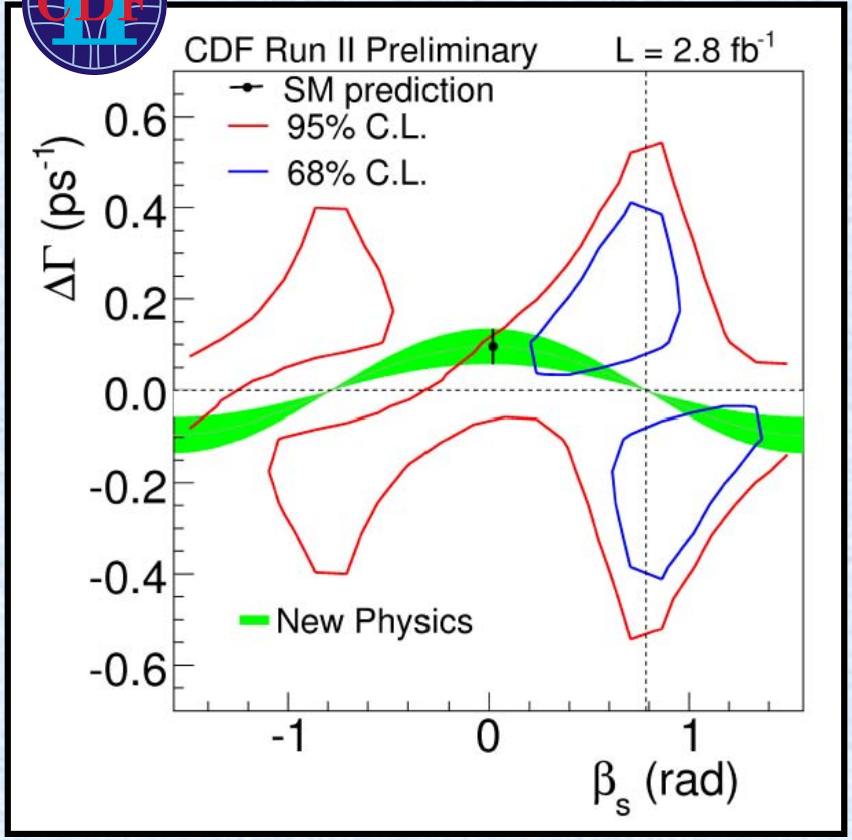


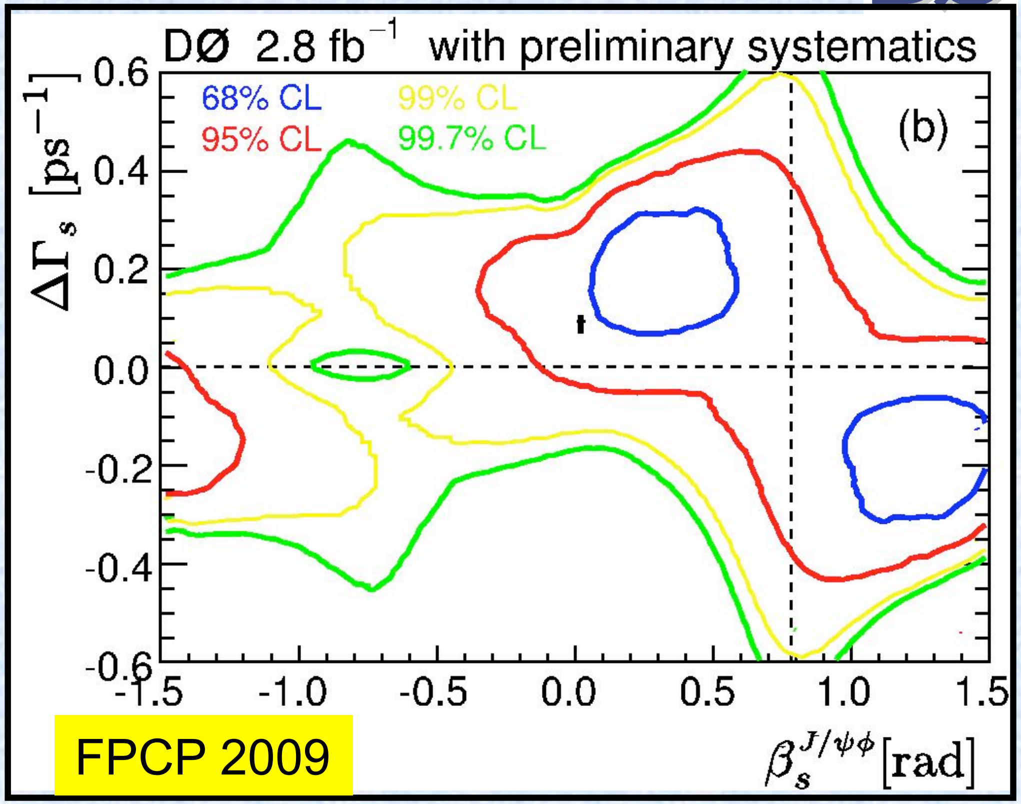


β_s

CDF : CDF/ANAL/BOTTOM/PUBLIC/9458

D0 : D0 Note 5933-CONF





CDF and D0 both favour positive values of β_s

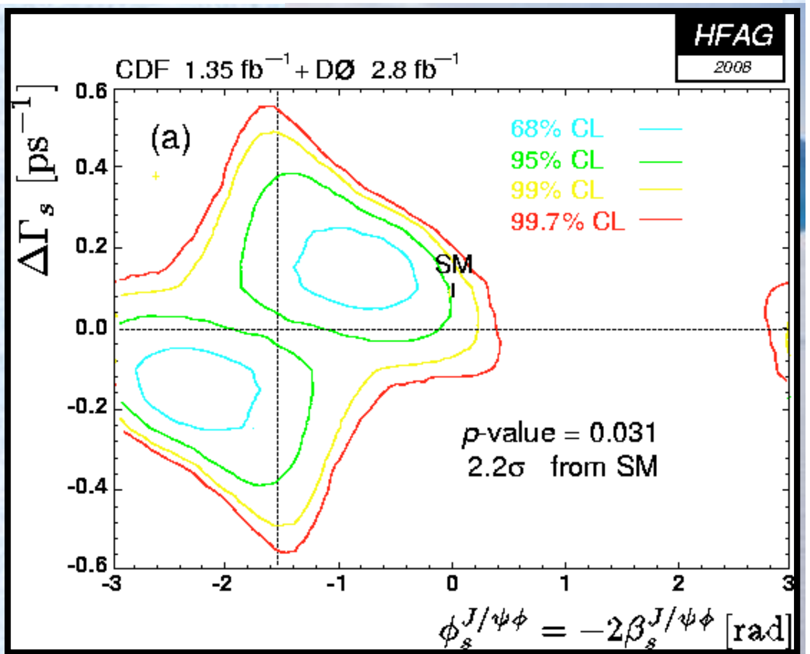
Probability of SM = 7.0%

Probability of SM = 24%
(8.5% w/o systematics)

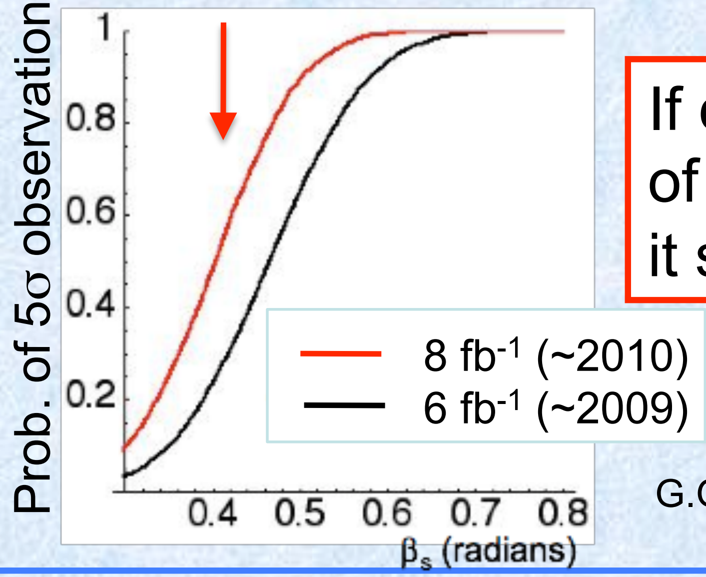
β_s

HFAG combine CDF & D0 results using common assumptions

Expt	Int. Lumi	From SM
CDF	1.35 fb^{-1}	1.5 σ
D0	2.8 fb^{-1}	1.8 σ
Combined		2.2 σ



New combination coming soon

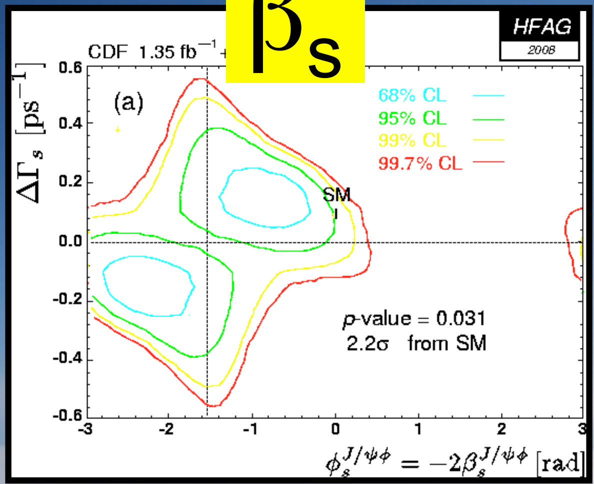


If current preferred value is a fact of nature, the Tevatron will find it soon….

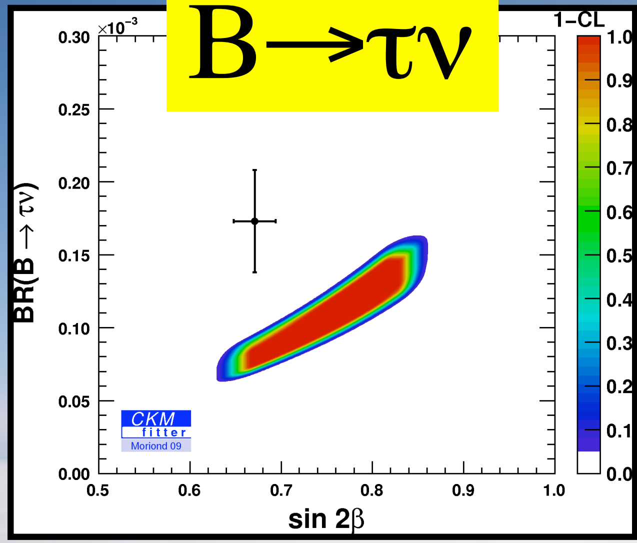
G.Giurgiu, FPCP 2009

Add to the hints/puzzles….

β_s



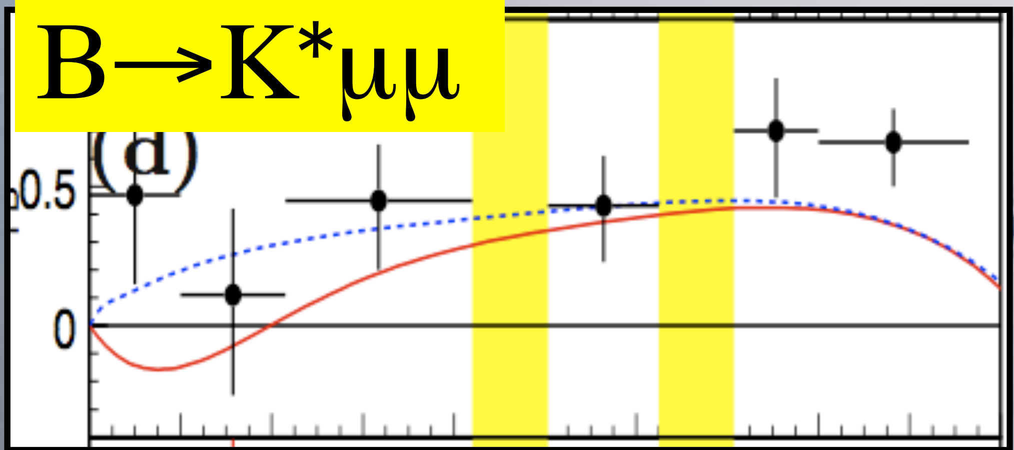
$B \to \tau\nu$



β_{eff}

"Kπ Puzzle"

$B \to K^*\mu\mu$



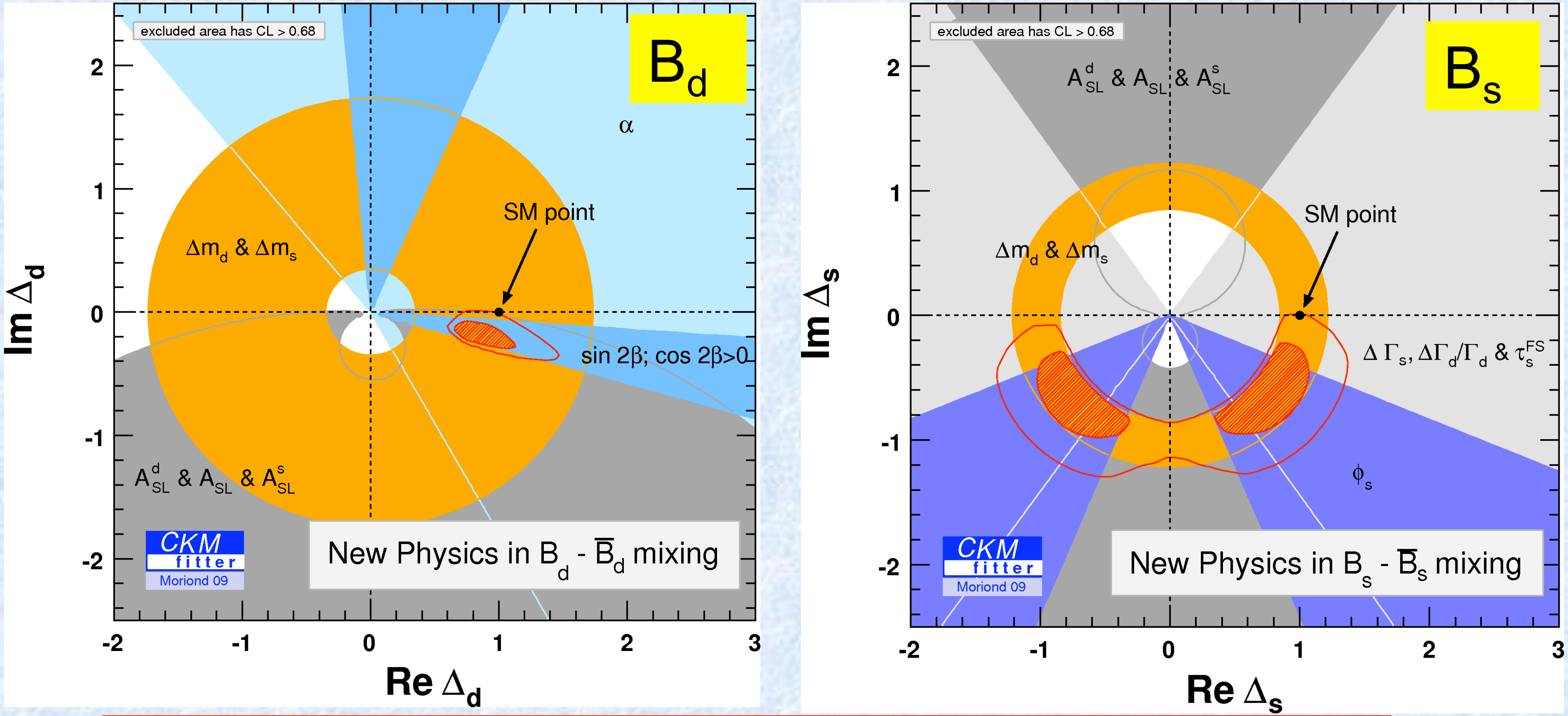
No convincing evidence of New Physics… yet…

Is there still room for New Physics ?

Allowing for New Physics in B mixing in a model independent way

$$\langle B_q | H^{SM+NP}_{\Delta B=2} | \overline{B_q} \rangle \equiv \langle B_q | H^{SM}_{\Delta B=2} | \overline{B_q} \rangle \times \left[\mathrm{Re}\Delta_q + \mathrm{Im}\Delta_q \right]$$

$$\Delta_q = |\Delta_q| e^{2i\phi_q^{NP}}$$



Answer : Yes, there is still plenty of room for NP

Some favourite quotes…

"The whole history of physics proves that a new discovery is quite likely lurking at the next decimal place"

Prof. Floyd. K.Richtmeyer, Cornell.

"Imagine if Fitch and Cronin had stopped at the 1% level, how much physics would have been missed"

A.Soni

A wake up call for New Physics…

The LHC

The search is just about to take a giant leap….

LHC Schedule 2009/10

Expect collisions from end Oct 2009: √s=10 TeV

Month	No. Bunches	Protons per bunch	β* [m]	% Nom	Peak luminosity cm-2s-1	Integrated luminosity
1	Beam Commissioning					
2	43	3×10^{10}	4	0.4	1.2×10^{30}	100 – 200 nb^{-1}
3	43	5×10^{10}	4	0.7	3.4×10^{30}	~2 pb^{-1}
4	156	5×10^{10}	2	2.5	2.5×10^{31}	~13 pb^{-1}
5	156	7×10^{10}	2	3.3	4.9×10^{31}	~25 pb^{-1}
6	720	3×10^{10}	2	6.7	4.0×10^{31}	~21 pb^{-1}
7	720	5×10^{10}	2	11.2	1.1×10^{32}	~60 pb^{-1}
8	720	5×10^{10}	2	11.2	1.1×10^{32}	~60 pb^{-1}
9	720	5×10^{10}	2	11.2	1.1×10^{32}	~60 pb^{-1}
10	Ions					
Total						**200 – 300 pb^{-1}**

Roger Bailey, Oxford IoP, April 2009

Expected delivered int. lumi ≠ physics lumi

B production at the LHC

Huge statistics: σ_{bb} ~ 500 μb at 14 TeV, ~1% of σ_{vis}

All B species: $B^{\pm}$(40%), B^0(40%), B_s(1%), B_c (<1%), Λ_b (10%),…)

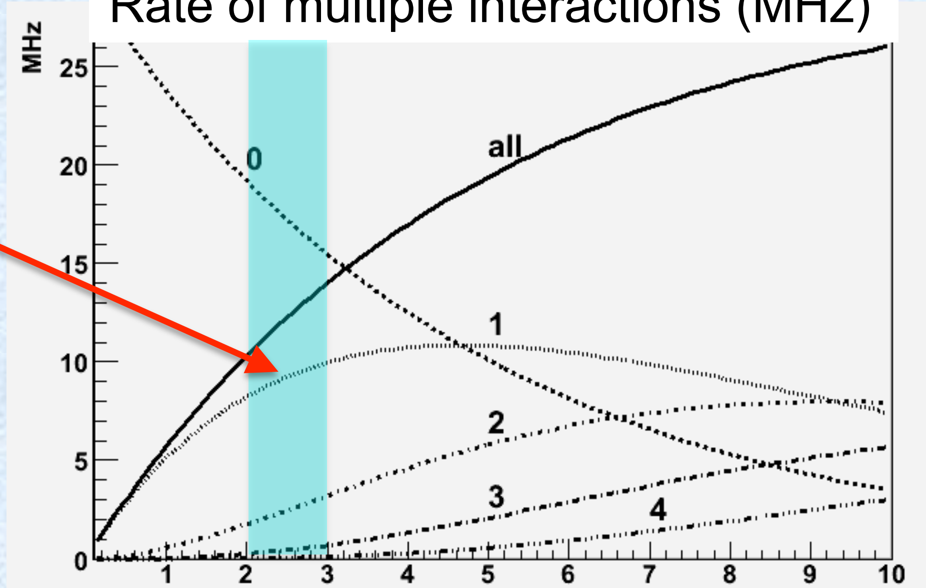
Ultimate luminosity of LHC : 10^{34} $cm^{-2}s^{-1}$

- Up to 10M b-hadrons / per sec / per experiment
- But more than 20 interactions / x-ing

LHCb runs at (2-3) x 10^{32} cm^{-2} s^{-1}

- Mainly single interactions
- Less radiation
- Luminosity is tunable by adjusting beam focus
- Still get 0.1M b-hadrons per sec

Rate of multiple interactions (MHz)



Luminosity x10^{32} cm^{-2} s^{-1}

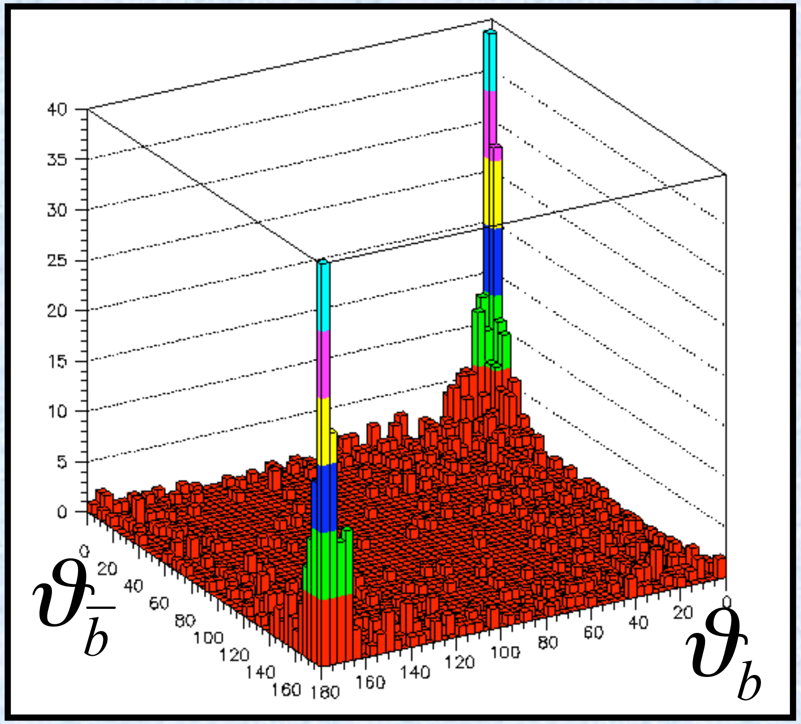
ATLAS/CMS: 10^{33} cm^{-2} s^{-1} in the first 3 years

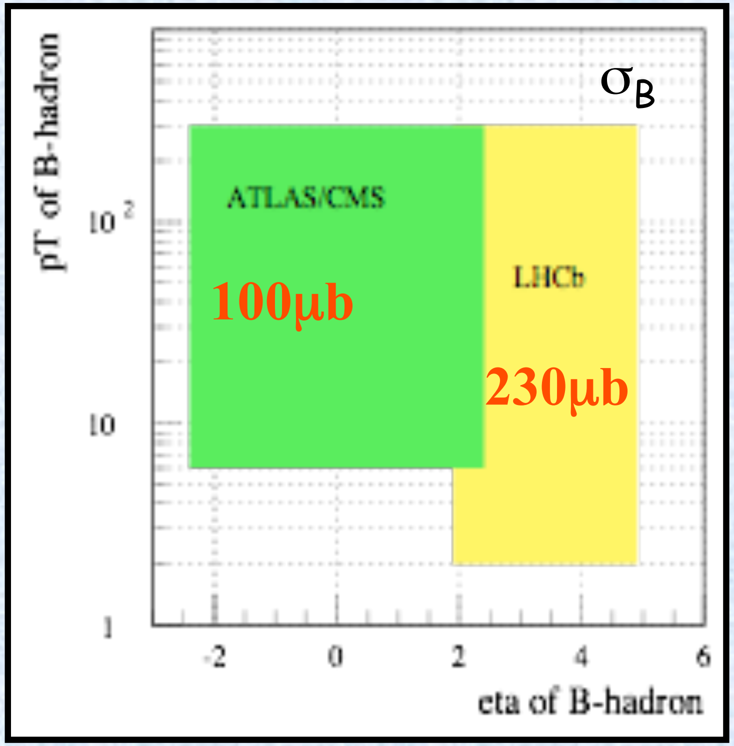
Nominal year: LHCb 2 fb^{-1}, ATLAS/CMS 10 fb^{-1}

B production at the LHC

$b\bar{b}$ production correlated and sharply peaked forward-backward

A forward detector (LHCb) geometry can cover a large fraction of the phase space





ATLAS/CMS: $|\eta| < 2.5$
LHCb : $1.9 < \eta < 4.9$

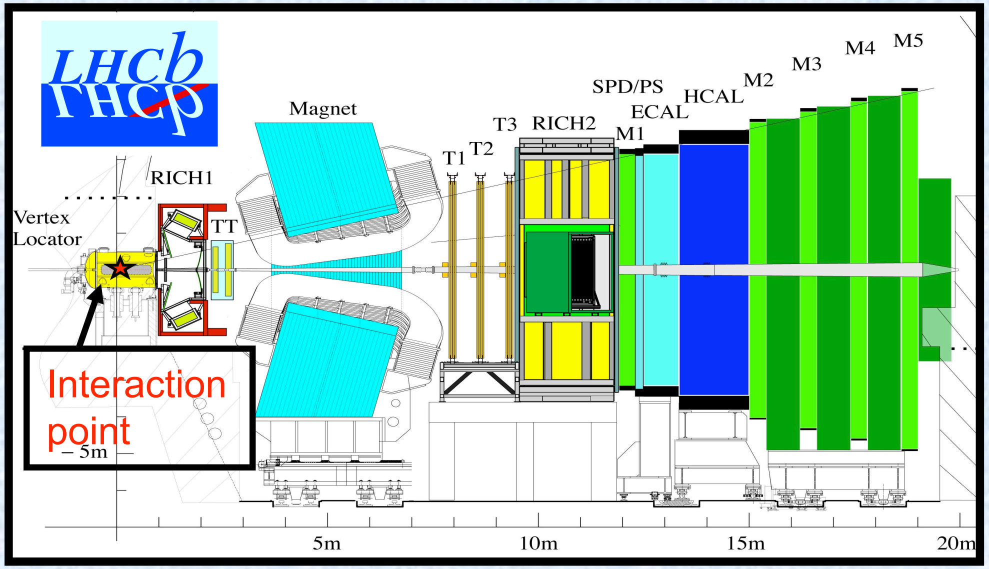

LHCb
A NEW BEGINNING

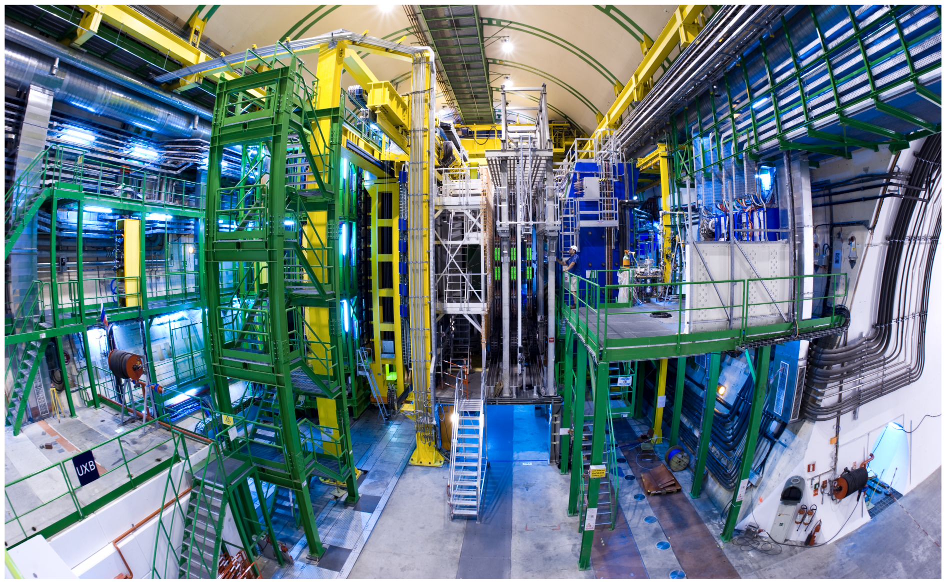
LHCb

An experiment dedicated to the search for New Physics in heavy flavours

Forward single arm spectrometer

Excellent tracking
precision silicon VELO detector



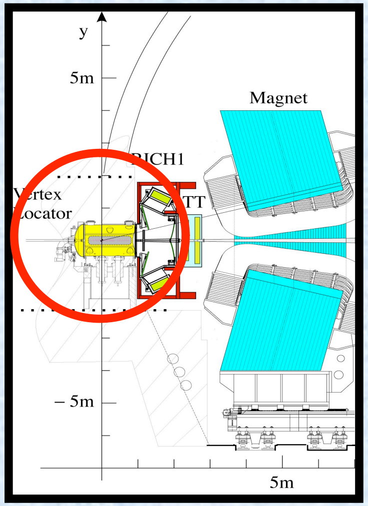


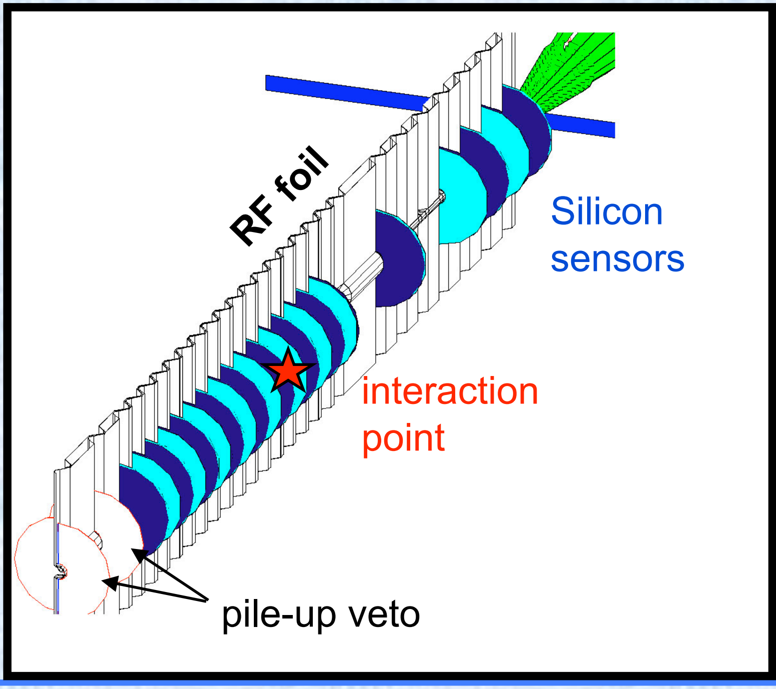
Excellent particle identification
2 RICH detectors
π/K separation over p ~2−100 GeV

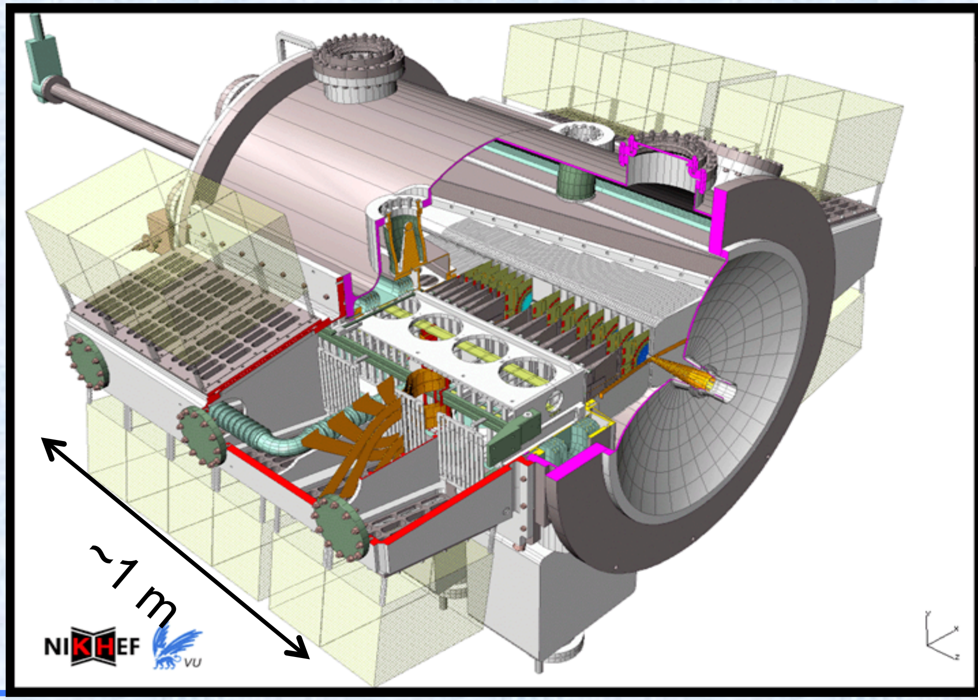
Efficient Trigger
Low p_T lepton, γ/π^0 & hadron thresholds

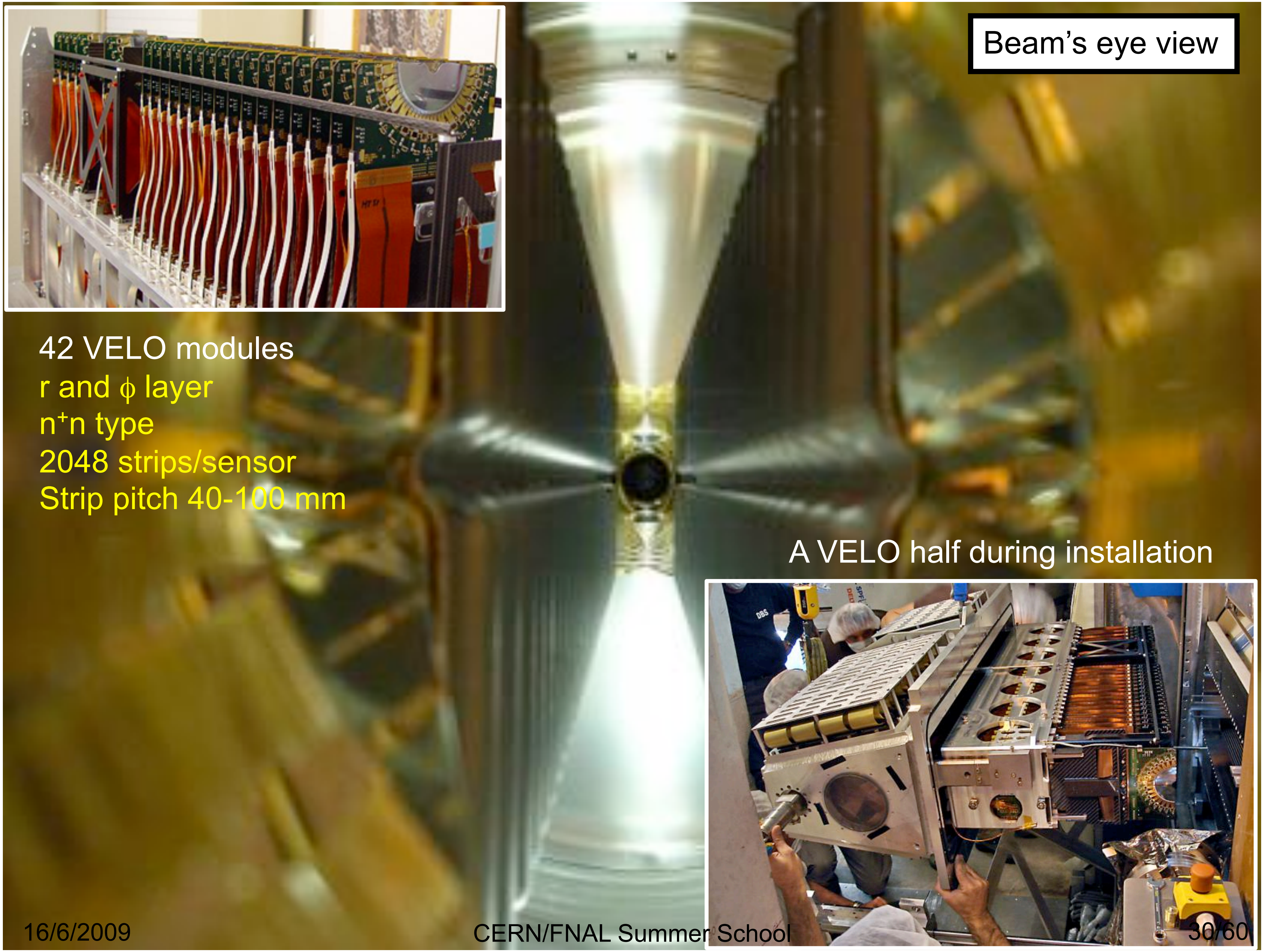
VELO

- 21 VELO stations (r and ϕ silicon sensors)
- placed in a secondary vacuum vessel
- 3cm separation, 8mm from beam
- separated by a 300 μm of Al RF foil
- detector halves retractable for injection









Beam's eye view

42 VELO modules

r and ϕ layer

n^+n type

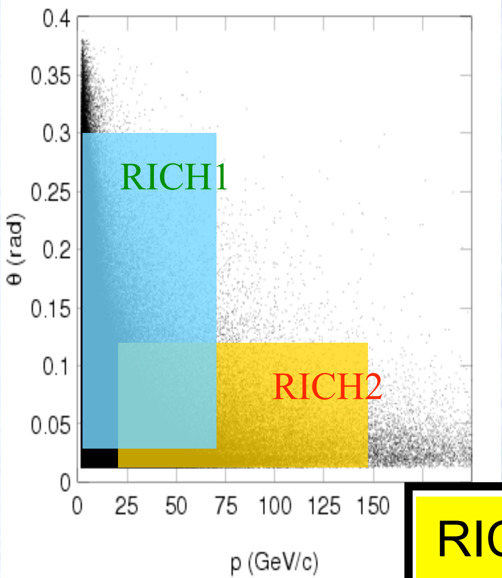
2048 strips/sensor

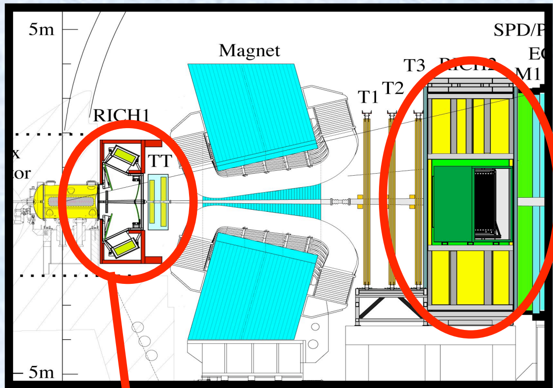
Strip pitch 40-100 mm

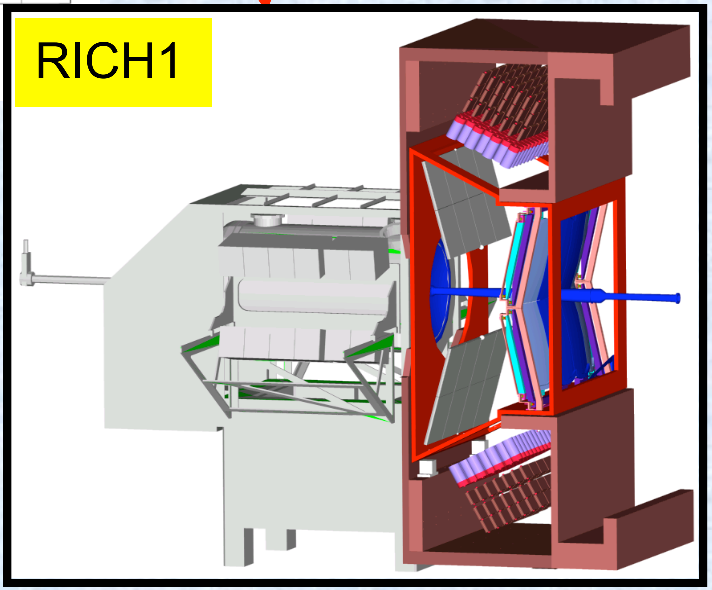
A VELO half during installation

RICH Detectors

Particle ID: p~2-100 GeV provided by 2 RICH detectors







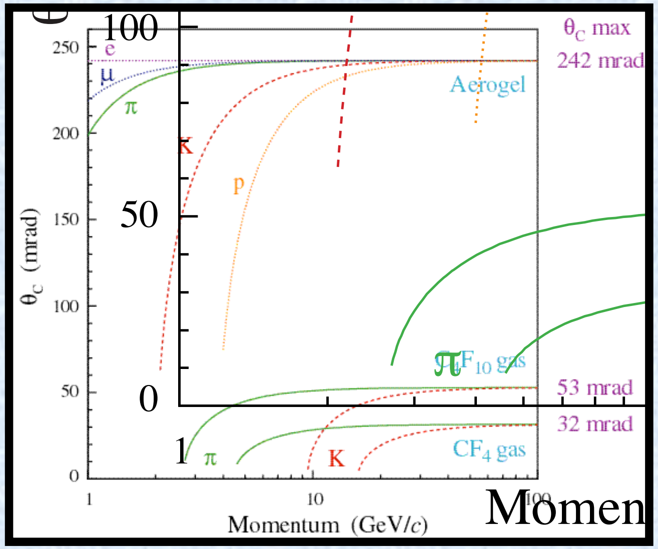
RICH Detectors

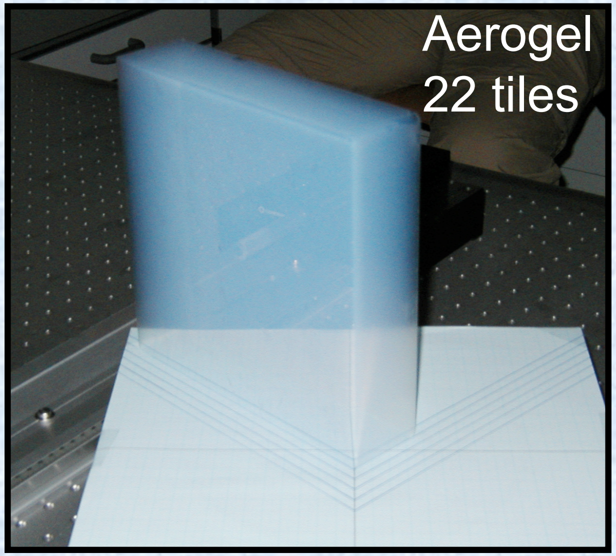
3 radiators

RICH1 Aerogel (2-10 GeV)

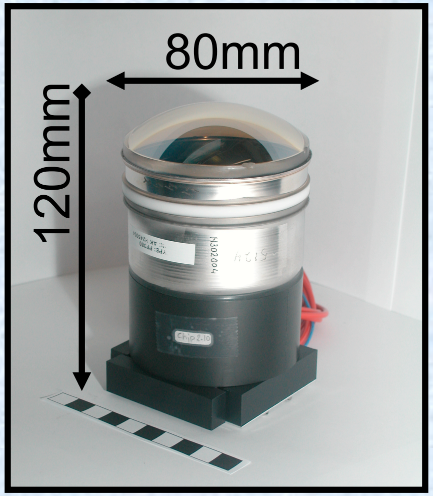
C_4F_{10} (10-60 GeV)

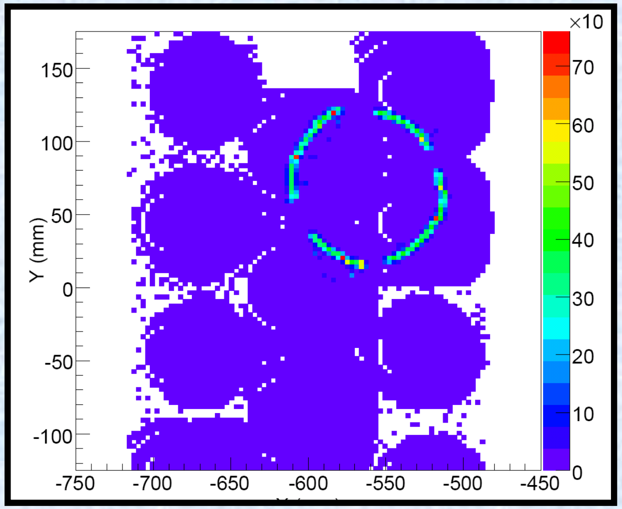
RICH2 CF_4 (16-100 GeV)

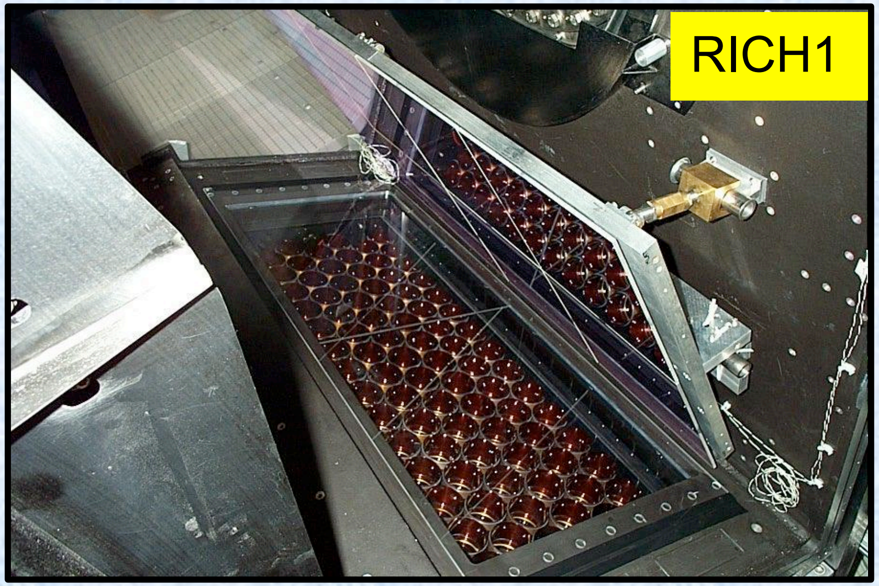




484 Hybrid Photo Detectors (HPD's)







Trigger

Trigger crucial to the successful operation of LHCb

- B fraction is only ~1% of inelastic cross-section.
- Br's of interesting B decays <10^{-4}
- Properties of minimum bias similar to B's

First Level Trigger (Level-0, hardware)

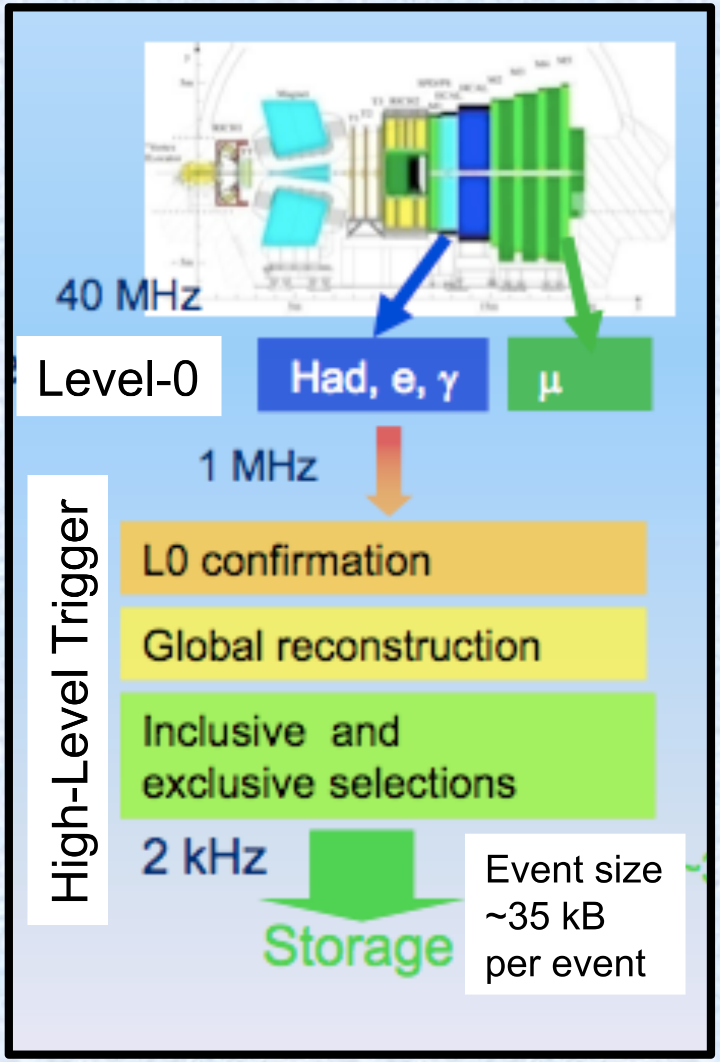
- Largest E_T hadron, e(γ) and (di-)μ
- Pile-up system (not for μ trigger)

Reduces 10 MHz inelastic rate to 1MHz

High Level Triggers (HLT, software)

- Run on CPU farm (1800 nodes)
- Access to all detector data
- Use more tracking to re-confirm L0 decision
- Full event reconstruction; inclusive and exclusive selections

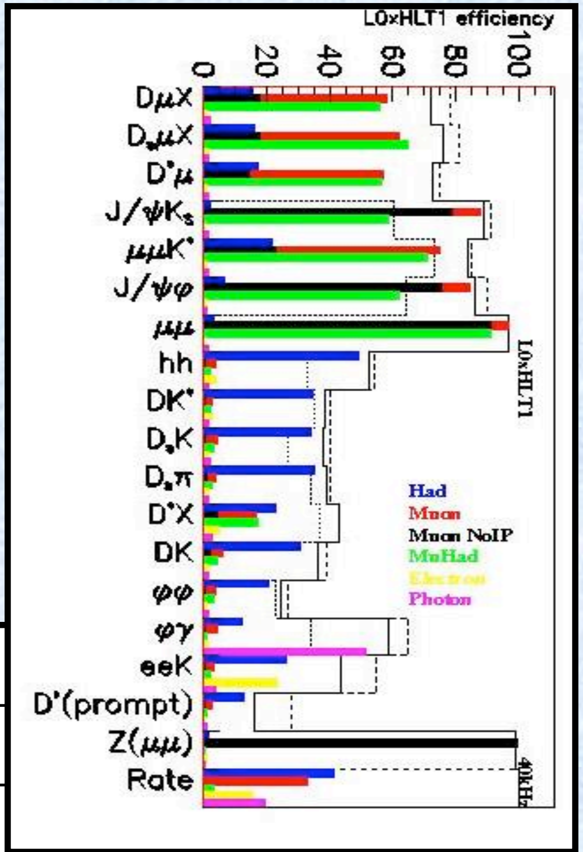
Output rate 2 kHz



Trigger

Expected trigger performance

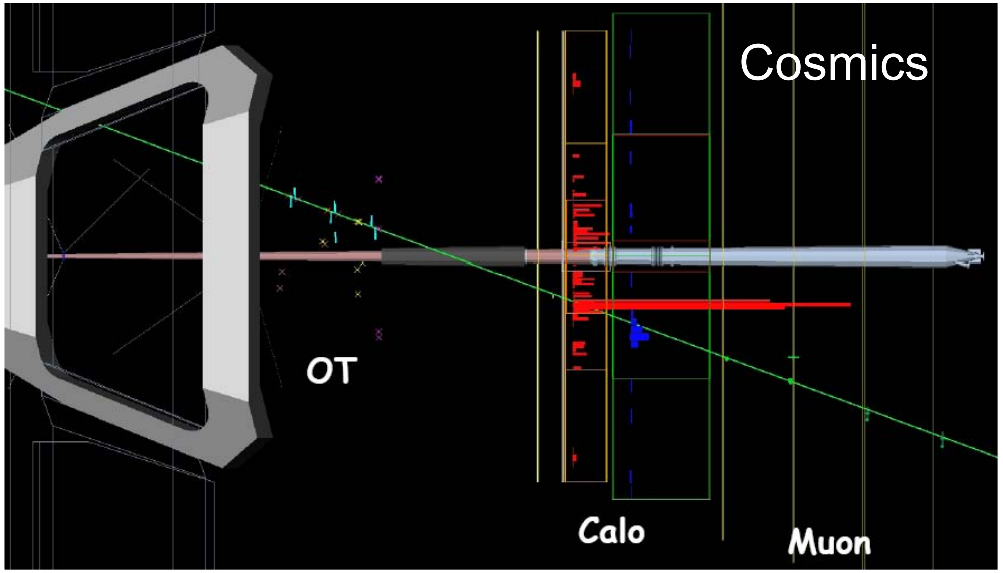
	e(L0)	e(HLT)	e(total)
Hadronic	**50%**	**80%**	**40%**
Electromagnetic	**70 %**	**60%**	**40%**
Muon	**90%**	**80%**	**70%**

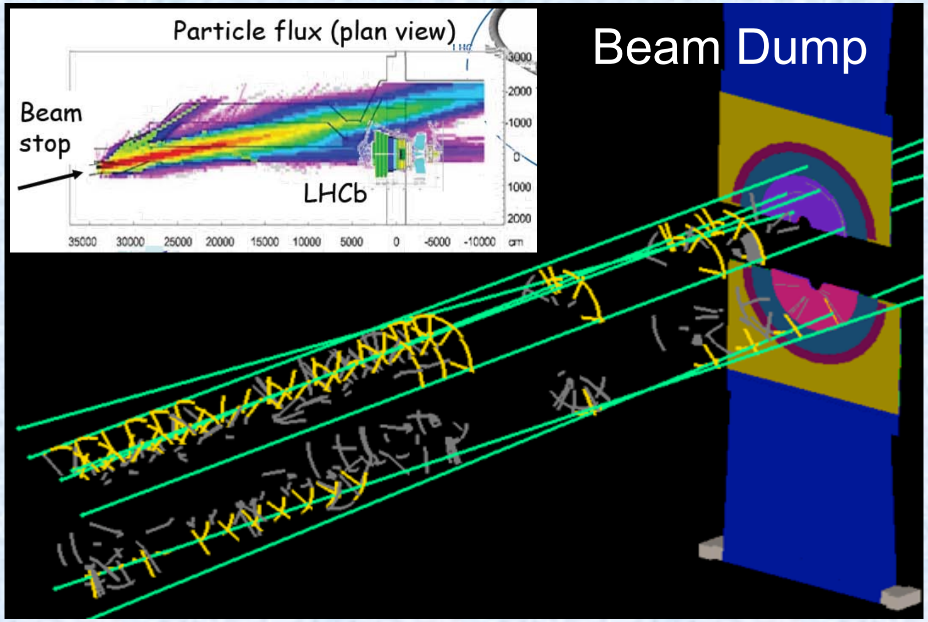


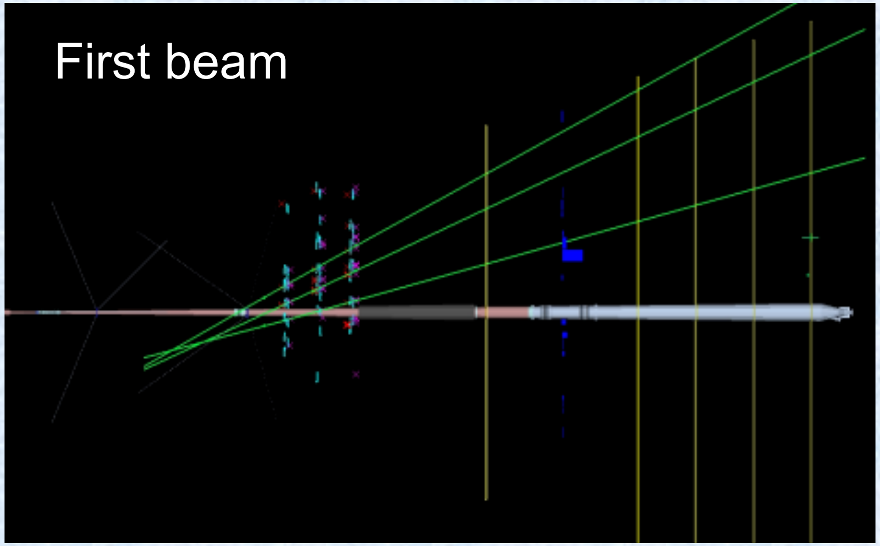
Output rate	**Trigger Type**	**Physics Use**
200 Hz	Exclusive B candidates	Specific final states
600 Hz	High Mass di-muons	J/ψ, $b \rightarrow J/\psi X$
300 Hz	D* Candidates	Charm, calibrations
900 Hz	Inclusive b (e.g. $b \rightarrow \mu$)	B data mining

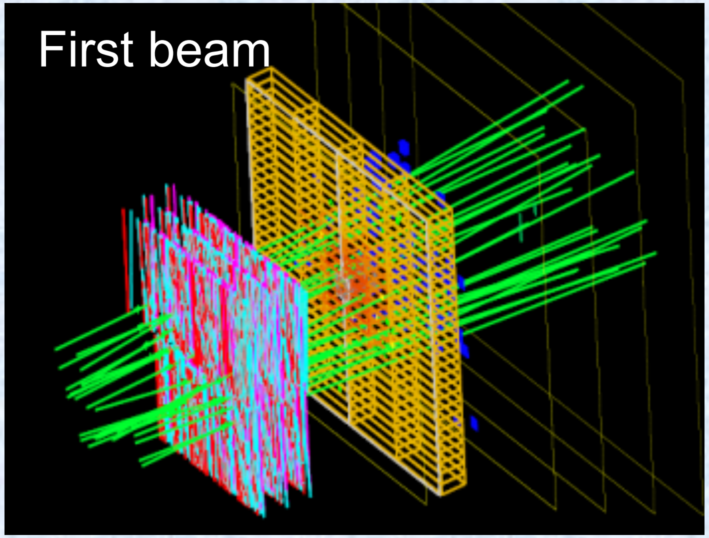
Total 2000 Hz

LHCb Commissioning









Just waiting for collisions…

ATLAS & CMS

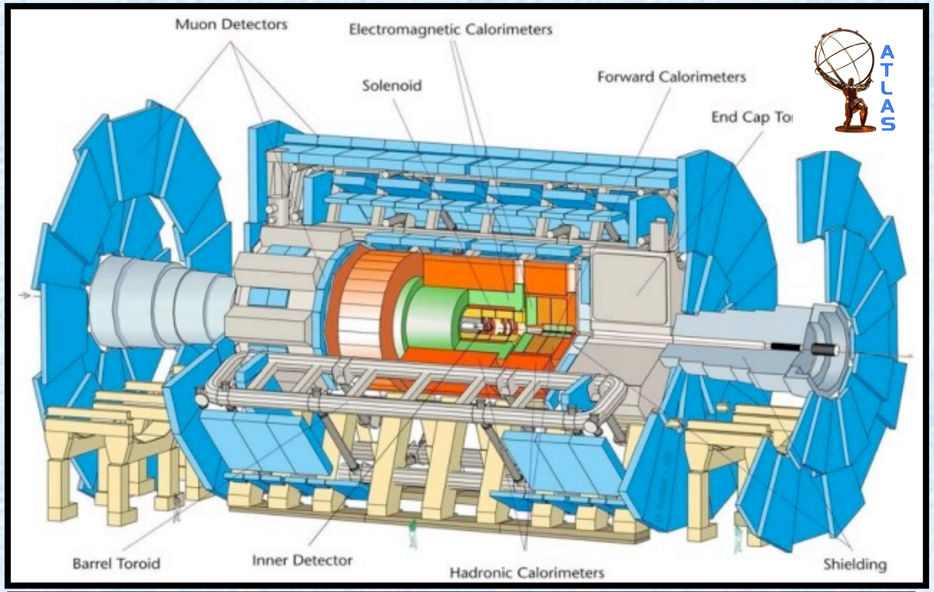
ATLAS and CMS are designed to explore the high energy frontier

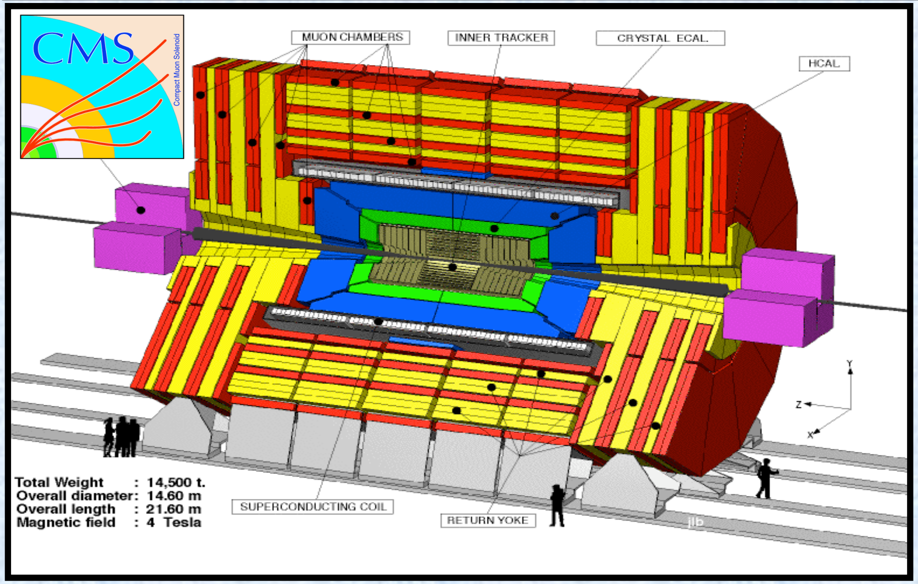
Excellent tracking

- Pixel detectors close to interaction
- Followed by silicon strip detectors
- ATLAS : TRT, straw tubes using transition radiation

High p_T muon triggers

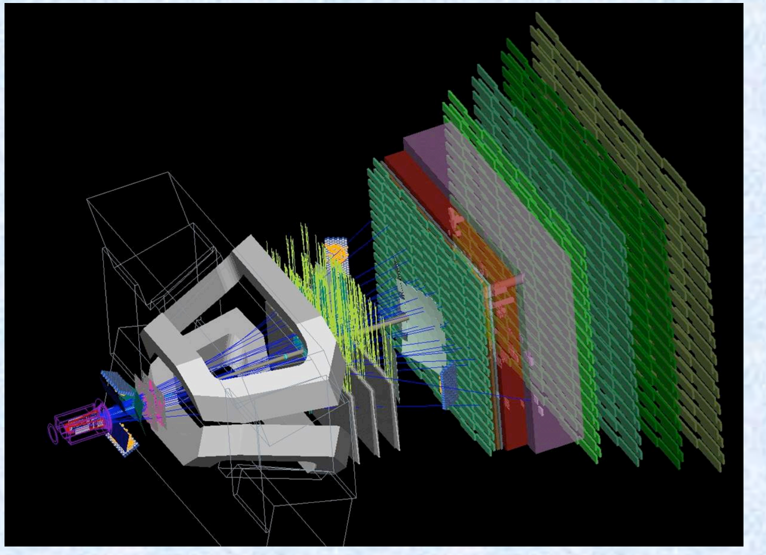
- First level (hardware) di- and single muon high p_T trigger
- Followed by software triggers
- ~ 10Hz to storage for B-physics, ~10% bandwidth





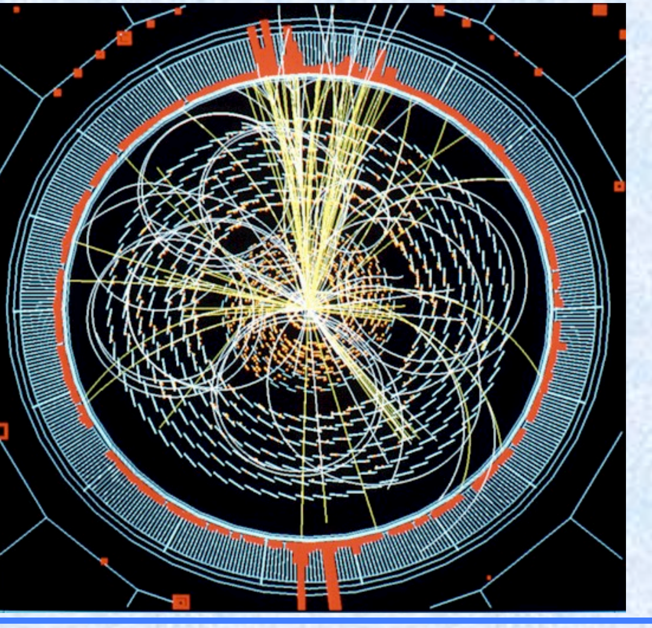
Performances

Mass resolutions (MeV/c^2)



	ATLAS	CMS	LHCb
$B_s \to \mu\mu$	90	36	18
$B_s \to D_s\pi$	53		14
$B_s \to J/\psi\phi$	61	14	16

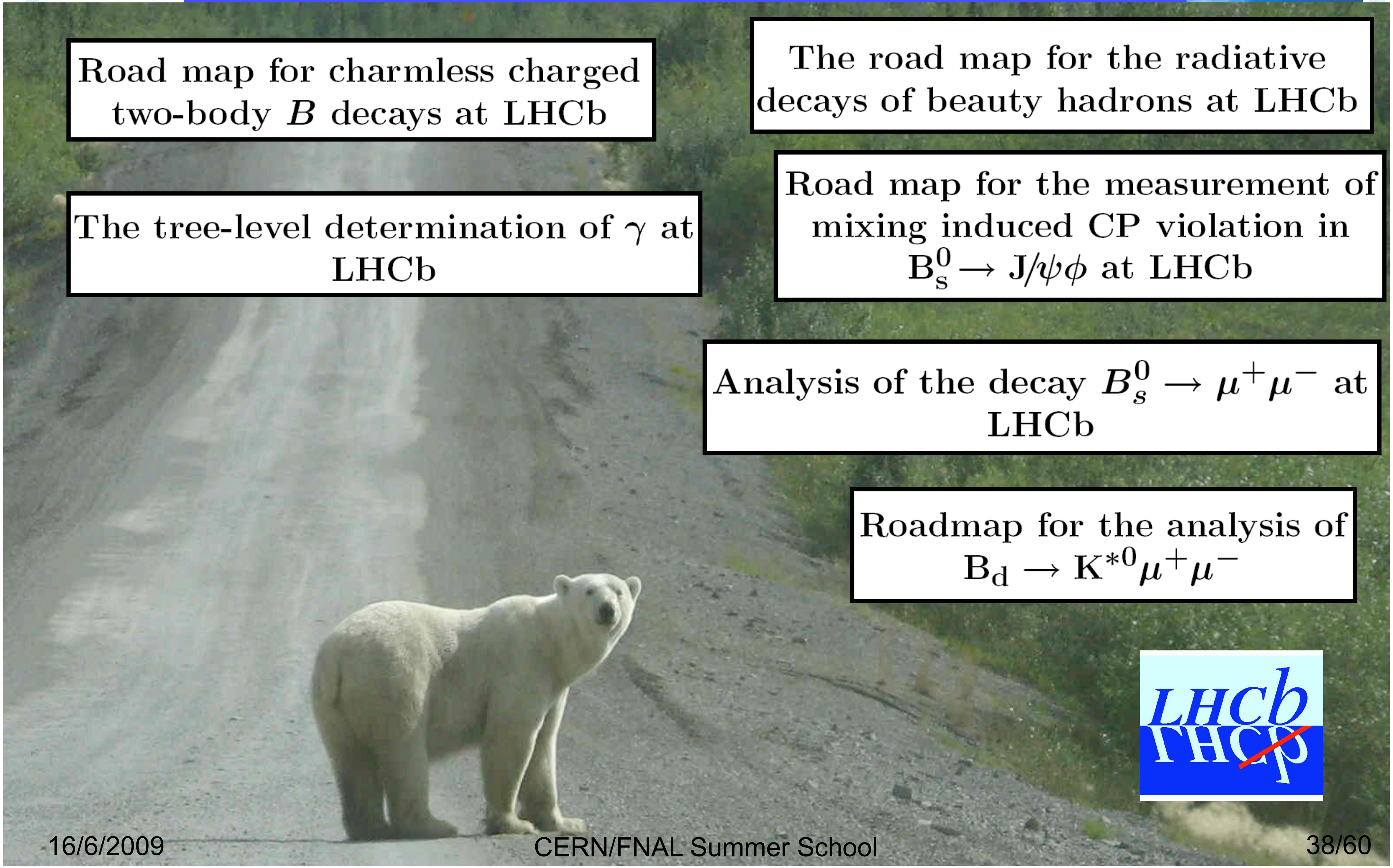
Proper time resolutions (fs)



	ATLAS	CMS	LHCb
$B_s \to D_s\pi$	-	77	36
$B_s \to J/\psi\phi$	152		40

Important for resolving B_s oscillations

LHCb Roadmaps



Road map for charmless charged two-body B decays at LHCb

The road map for the radiative decays of beauty hadrons at LHCb

The tree-level determination of γ at LHCb

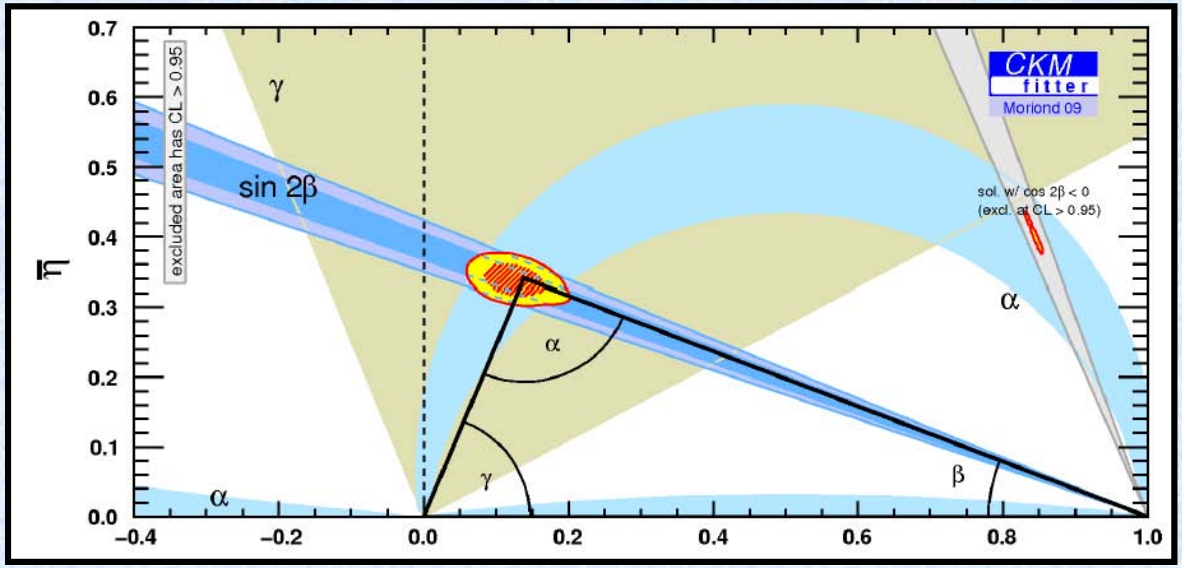
Road map for the measurement of mixing induced CP violation in $\mathrm{B_s^0} \rightarrow \mathrm{J}/\psi\phi$ at LHCb

Analysis of the decay $B_s^0 \rightarrow \mu^+\mu^-$ at LHCb

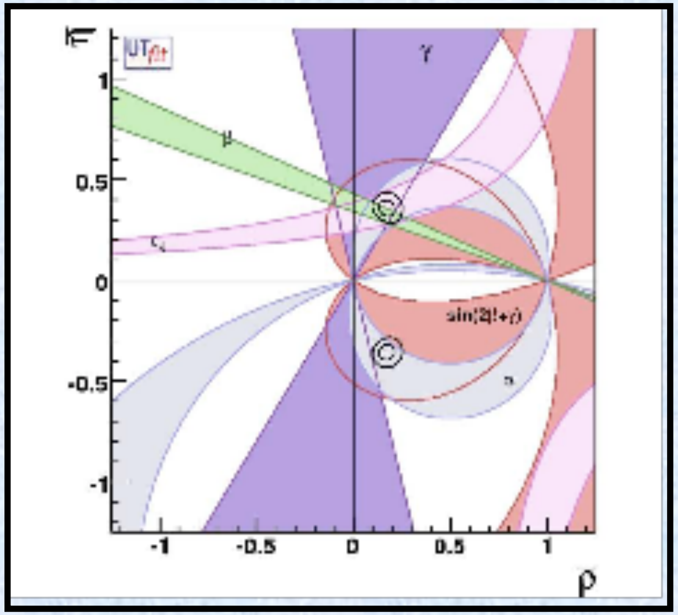
Roadmap for the analysis of $\mathrm{B_d} \rightarrow \mathrm{K}^{*0}\mu^+\mu^-$

Prospects for γ/ϕ_3

γ is the least well-known angle of the Unitarity Triangle… CKMfitter (frequentist) and Utfit (Bayesian) groups do not agree…



$$\gamma = (70^{+27}_{-29})^\circ$$

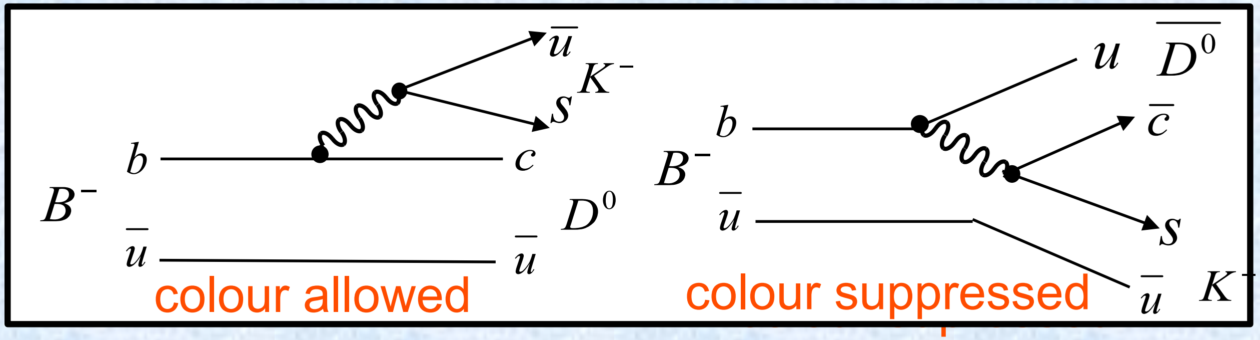


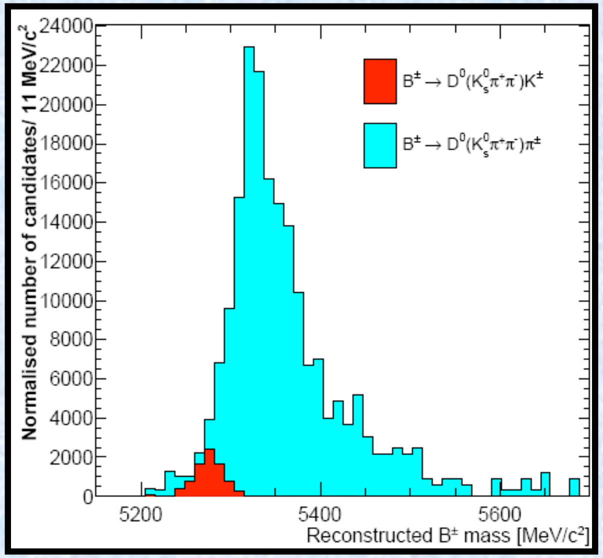
$$\gamma = (78 \pm 12)^\circ$$

γ is the only CP-violating observable that can be measured at tree-level … a benchmark quantity to be measured as well as possible.

γ from trees

B→DK : Time-integrated rates using the GLW/ADS and GGSZ (Dalitz) methods

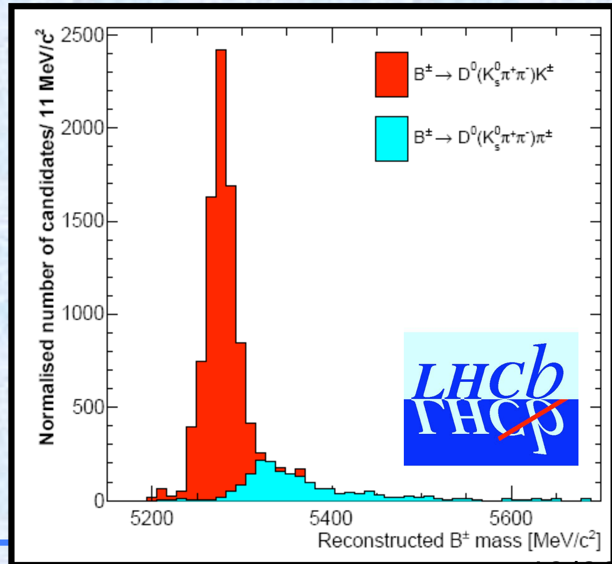




Self-tagging – full statistics can be used

Lots of kaons – particle id (RICH) invaluable

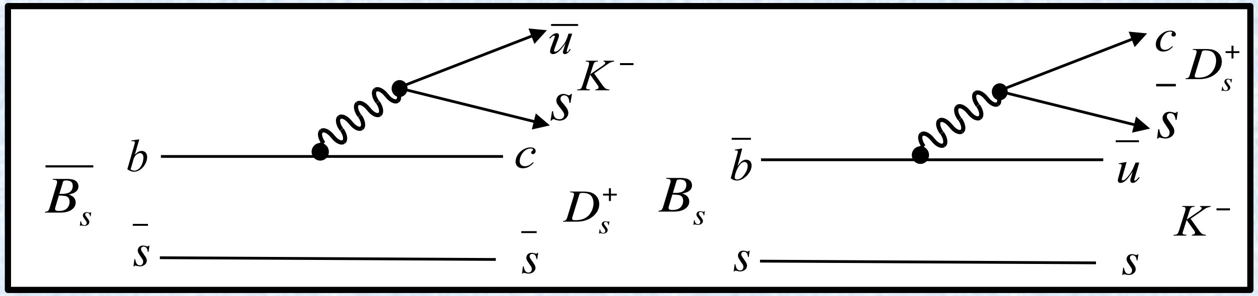
	Mode	Yield (2 fb^{-1})	B/S
ADS/GLW	$B^\pm \to D(K\pi)K^\pm$ (fav.)	84k	0.6
ADS/GLW	$B^\pm \to D(K\pi)K^\pm$ (sup.)	1.6k	0.6
ADS/GLW	$B^\pm \to D(KK)K^\pm$	8.5k	1.2
ADS/GLW	$B^\pm \to D(\pi\pi)K^\pm$	3k	3.2
GGSZ	$B^\pm \to D(K_s\pi\pi)K^\pm$	6.8k	0.4



γ from trees

$B_s \to D_s K$: Time-dependent measurement

Measure $\gamma - 2\beta_s$ from interference between mixing and decay amplitudes.



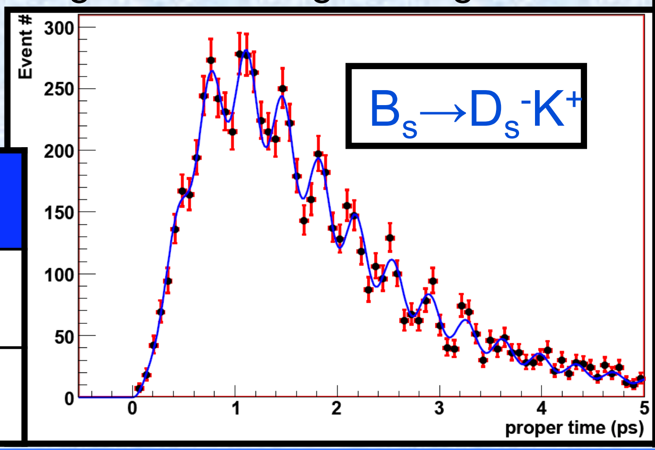
Large interference effects

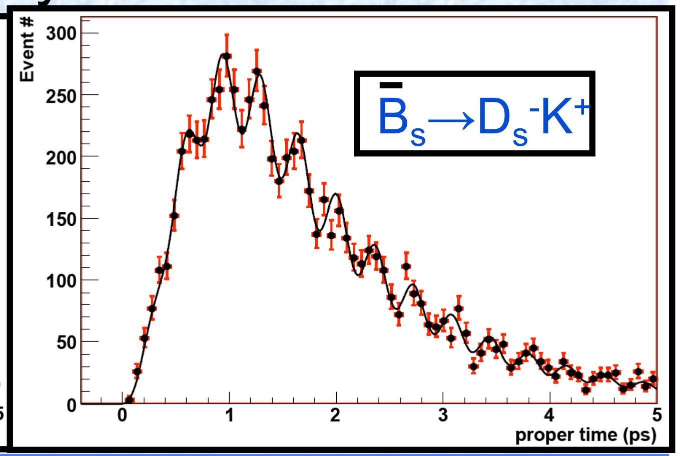
$$r_{DK} \sim \frac{1}{\lambda}\left|\frac{V_{ub}}{V_{cb}}\right| \approx 0.4$$

β_s input from $B_s \to J/\Psi$

Simultaneous fit to $B_s \to D_s\pi$ and $B_s \to D_s K$ decay time distributions (tagged and untagged)

Mode	Yield (2 fb^{-1})	B/S
$B_s \to D_s K$	9k	<10
$B_s \to D_s \pi$	124k	0.2





γ from trees

Expected performance from LHCb with current studies

$B^{\pm} \rightarrow D^0 K^{\pm}$: $D^0 \rightarrow K\pi$, KK, $\pi\pi$, $K\pi\pi\pi$, $K_s\pi\pi$

$B^0 \rightarrow D^0 K^{*0}$: $D^0 \rightarrow K\pi$, KK

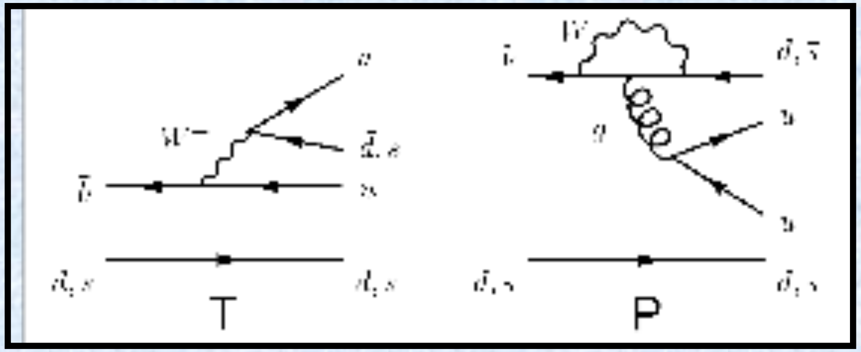
Time dependent measurements: $B^0 \rightarrow D\pi$, $B_s \rightarrow D_s K$

δ_{B^0} (°)	0	45	90	135	180
σ_γ for 0.5 fb^{-1} (°)	8.1	10.1	9.3	9.5	7.8
σ_γ for 2 fb^{-1} (°)	4.1	5.1	4.8	5.1	3.9
σ_γ for 10 fb^{-1} (°)	2.0	2.7	2.4	2.6	1.9

LHCb 10 fb^{-1} : γ precision 2-3°

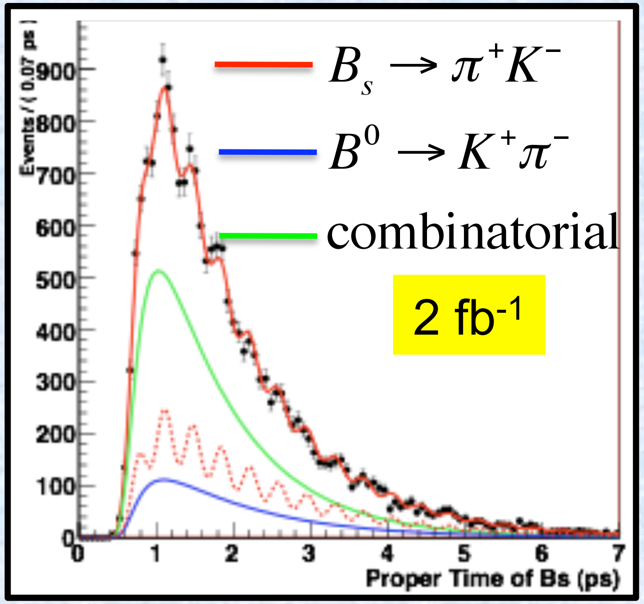
γ from loops : B→hh strategy

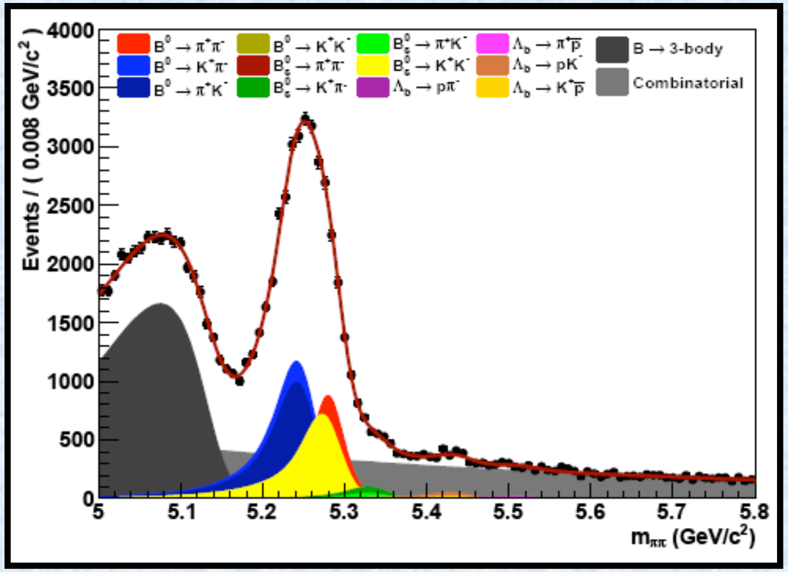
Sensitive to NP in penguin contributions



Time-dependent analysis, particle id crucial

Channel	Yield (2 fb^{-1})
$B^0 \to \pi^+\pi^-$	58.8k
$B^0 \to K^+\pi^-$	216.6k
$B^0 \to \pi^+K^-$	15.1k
$B_s \to K^+K^-$	71.9k
$\Lambda_b \to p\pi^-$	7.0k
$\Lambda_b \to pK^-$	10.9k





γ from loops : B→hh strategy

Use $B_d \to \pi^+\pi^-$ and $B_s \to K^+K^-$ and extract $S_{\pi\pi}$, $C_{\pi\pi}$, S_{KK} , C_{KK} from fit to

$$A_f^{CP}(t) = \frac{\Gamma_f(t) - \bar{\Gamma}_{\bar{f}}(t)}{\Gamma_f(t) + \bar{\Gamma}_{\bar{f}}(t)} = \frac{-C_f \cos(\Delta m t) + S_f \sin(\Delta m t)}{\cosh(\Delta\Gamma t/2) + \Omega_f \sinh(\Delta\Gamma t/2)}$$

$$\Omega_f^2 + S_f^2 + C_f^2 = 1$$

The 4 observables depend on 7 parameters

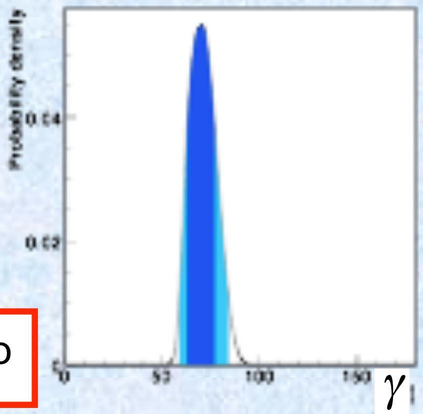
$$C_{\pi\pi} = f_1(d,\vartheta,\gamma), \quad S_{\pi\pi} = f_2(d,\vartheta,\gamma,\beta)$$
$$C_{KK} = f_3(d',\vartheta',\gamma), \quad S_{KK} = f_4(d',\vartheta',\gamma,\beta_s)$$

d ,ϑ (d',ϑ') parametrizes P/T ratio of decay transitions in $B_d \to \pi^+\pi^-$($B_s \to K^+K^-$)

Input β from $B \to J/\Psi K_S$ and invoke Uspin (d↔s) symmetry

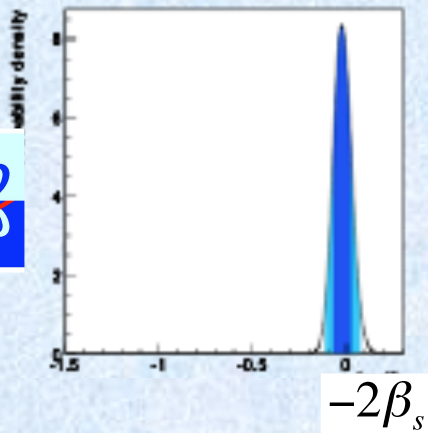
$$d = d' \pm 20\%$$

$$\vartheta = \vartheta' \pm 20^o$$



$\sigma(\gamma)$ = 7°

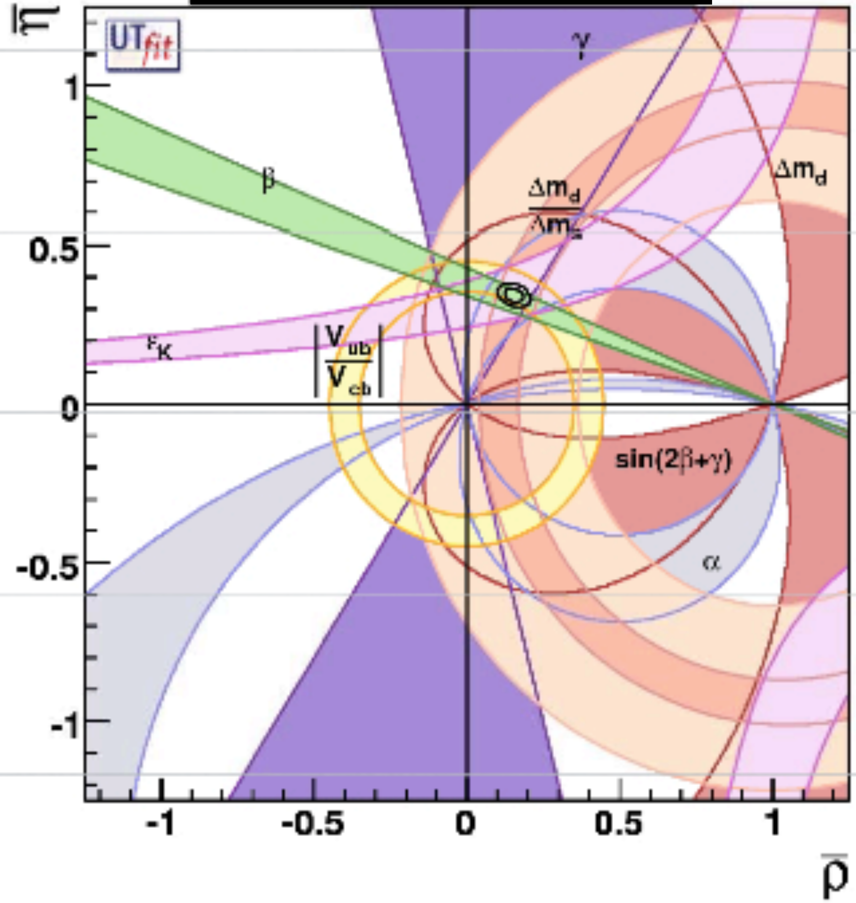
2 fb^{-1}



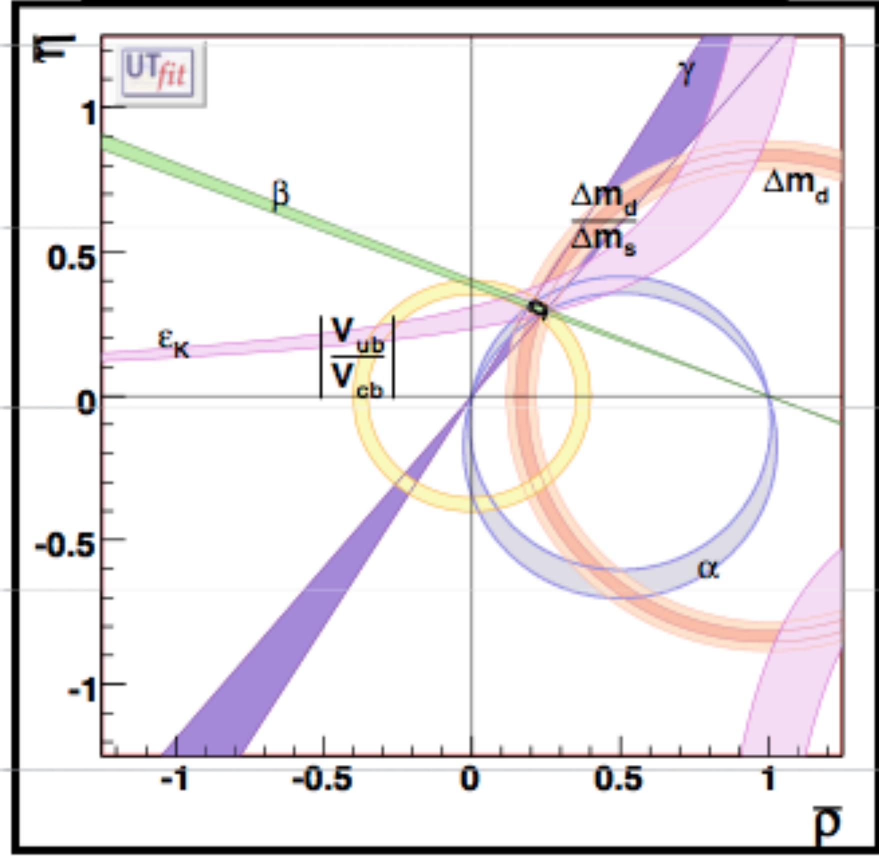
$\sigma(\beta_s)$ = 0.025 rad

CKM 2014

Winter 2009



LHCb at $L=10fb^{-1}$



Lattice QCD improvements assumed: $\sigma(\xi)/\xi=1.5\%$

$\sigma(\sin(2\beta)) = 0.01$; $\sigma(\gamma) = 2.4°$; $\sigma(\alpha) = 4.5°$

β_s

$B_s \to J/\Psi\phi$ is a golden channel for LHCb

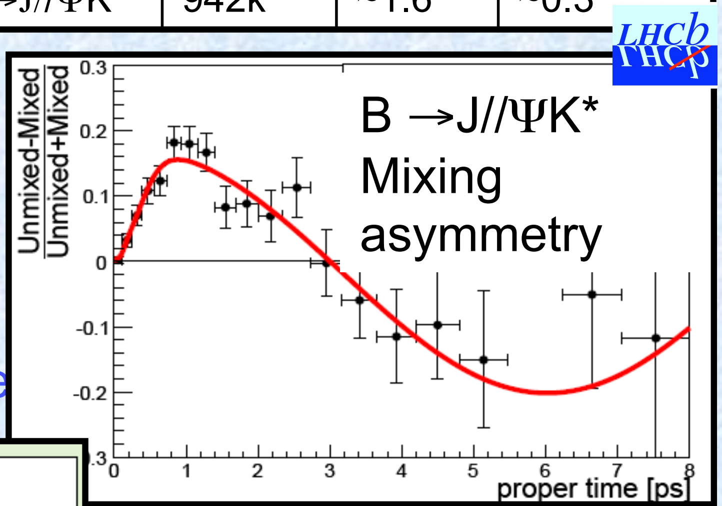
Final state is a mixture of CP-even and CP-odd

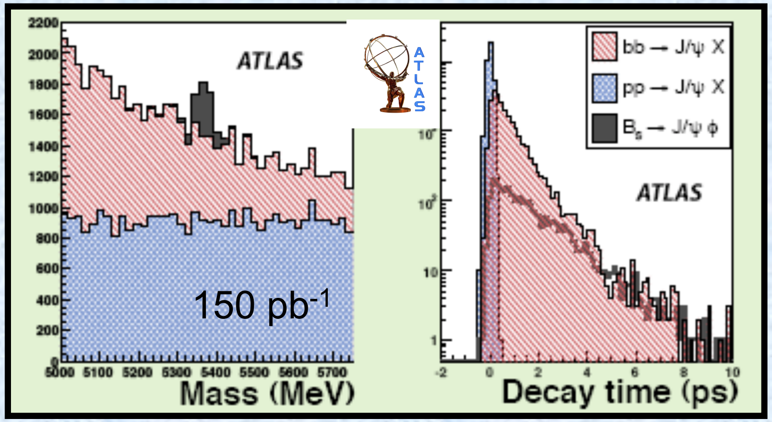
Channel	Yield (2 fb^{-1})	B/S prompt	B/S long-lived
$B_s \to J/\Psi\phi$	117k	~1.6	~0.5
$B \to J/\Psi K^*$	489k	~5.2	~1.5
$B \to J/\Psi K^+$	942k	~1.6	~0.3

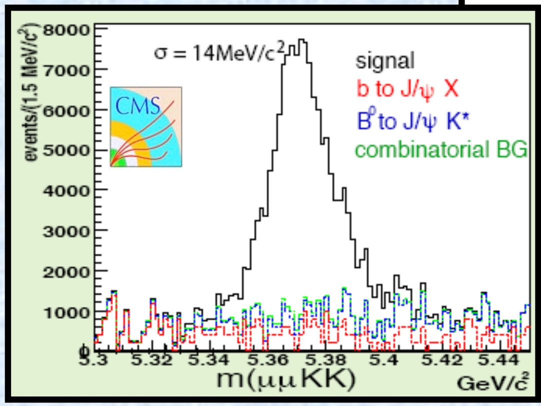
control channels

Key ingredients include

- large signal yield
- excellent proper time resolution (~40 fs)
- good tagging efficiency (εD^2 ~6% OST+SST)
- good control of proper time and angular acceptance



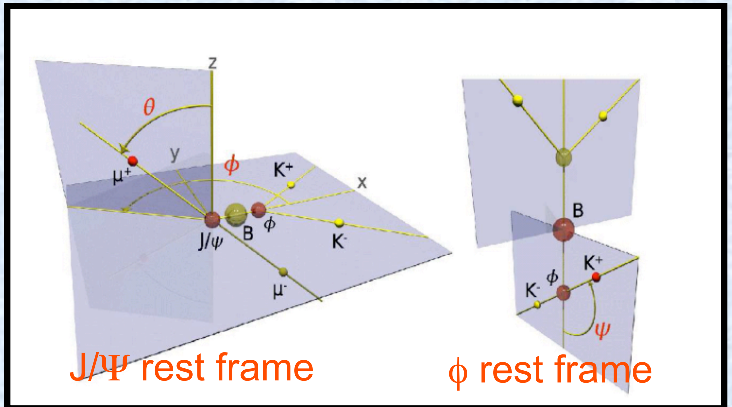




$B_s \to J/\Psi\phi$ in ATLAS & CMS

Expect to measure $\Delta\Gamma_s/\Gamma_s$

β_s

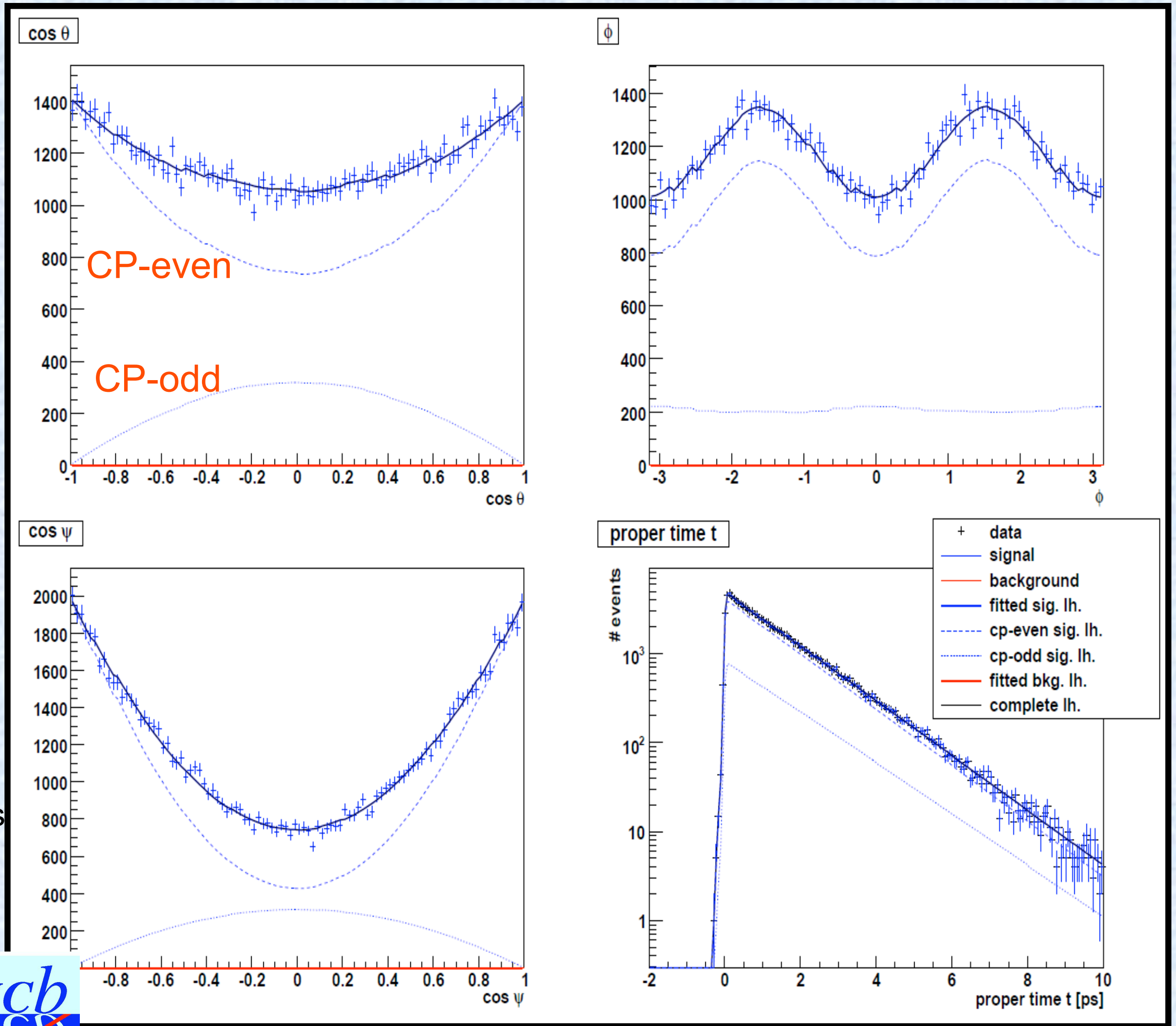


3 angles (θ, ϕ, ψ) describe direction of final decay products

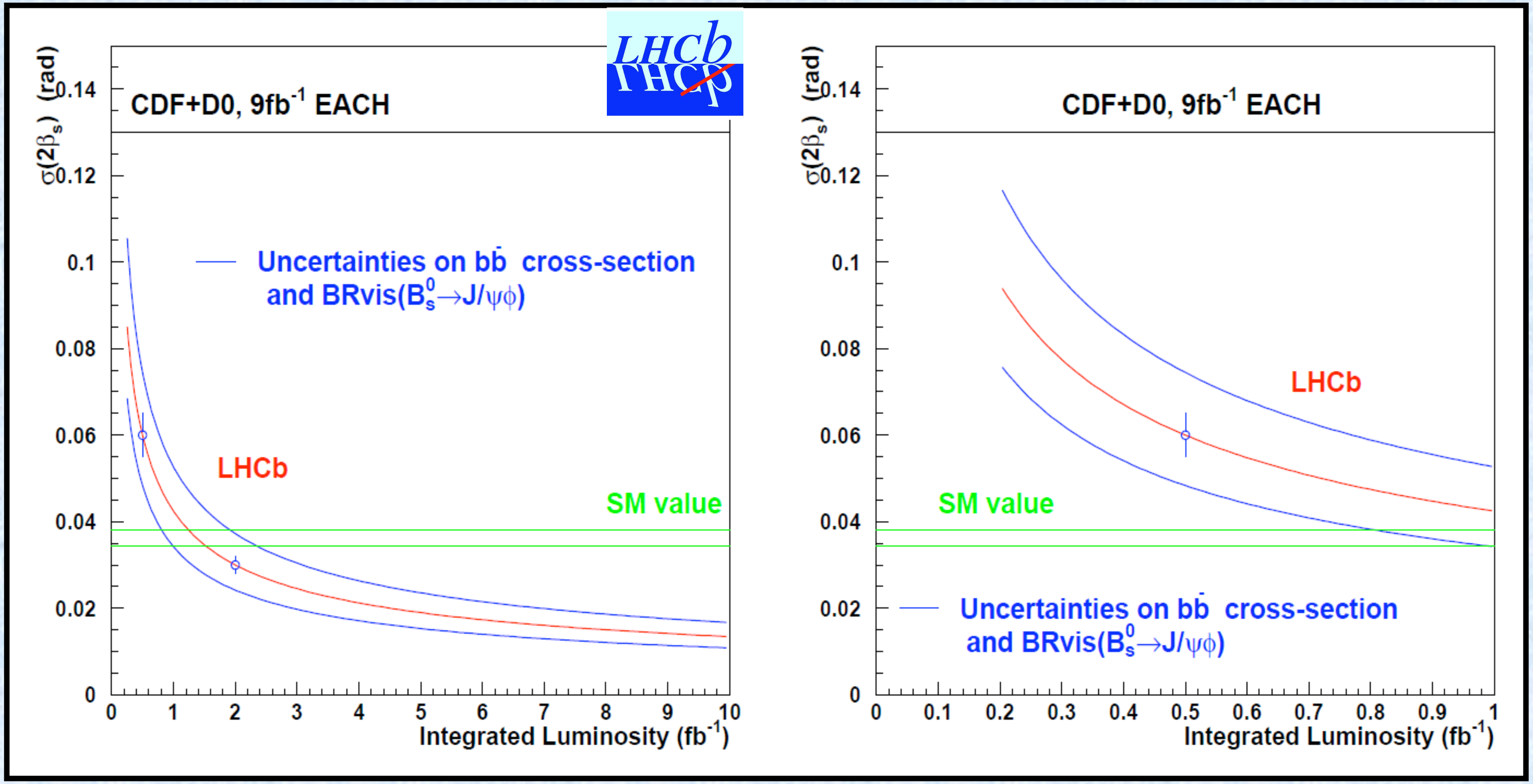
Fit to angular distributions, proper time, flavour tag, mass

→ 7 free parameters including β_s

$\sigma(2\beta_s) = 0.03\ (2fb^{-1})$



β_s



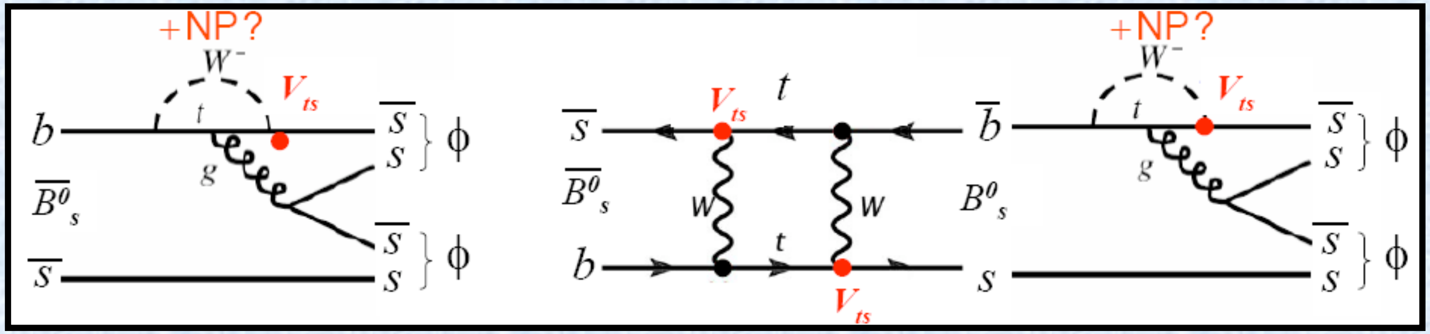
If $2\beta_s$ is in fact the central value measured by the Tevatron (~0.8), then LHCb should have a 5σ observation with 200 pb^{-1}

b→sqq penguins

Currently explored at B factories with time-dependent analyses of tagged decays to CP eigenstates such as $B^0 \to \phi K_S$, etc.

- Expect same result (i.e. $\sin 2\beta$) as $b \to ccs$ tree decays like $B^0 \to J/\psi K_S$ if SM

$B_s \to \phi\phi$ also possible at LHCb



- CPV < 1% in SM; V_{ts} enters both in mixing and decay amplitudes
- significant CP-violating phase can **only** be due to New Physics
- Angular analysis required
- 3k signal events per 2 fb^{-1}, B/S < 0.8

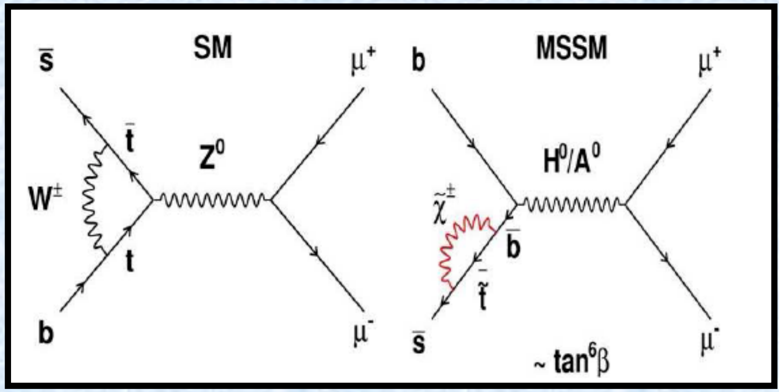
$\sigma(\Phi_{Bs \to \phi\phi}) \cong 0.11\ (0.05)$
$2fb^{-1}$ $10\ fb^{-1}$

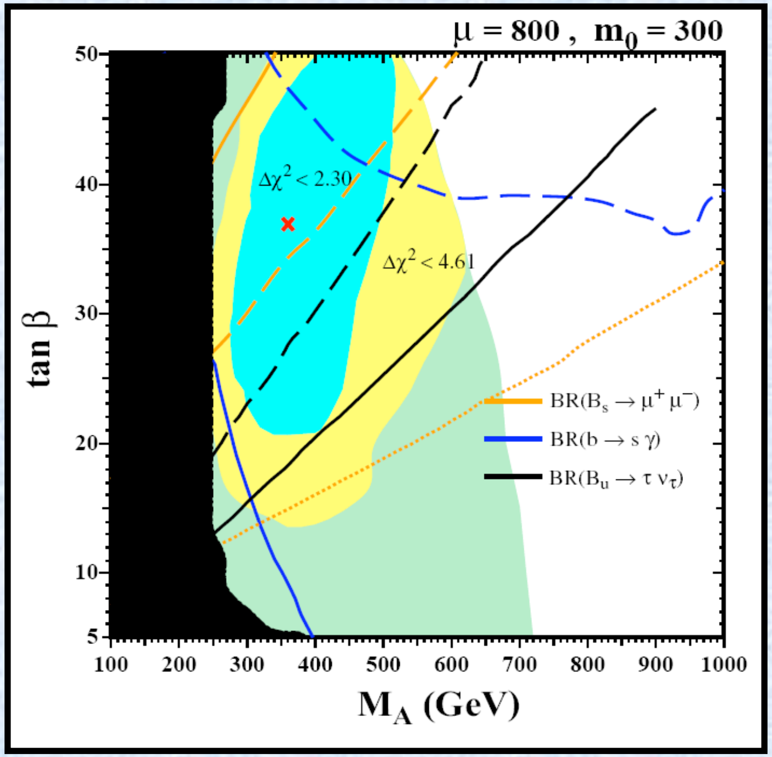
Very Rare $B_s \to \mu\mu$ Decays

Very rare FCNC b→s transition

SM prediction $Br\left(B_s \to \mu^+\mu^-\right) = (3.35 \pm 0.32) \times 10^{-9}$

Strong enhancements in SUSY~ $\tan^6\beta$





J.Ellis et al; JHEP 0710:92 (2007)

CDF: $< 5.8 \cdot 10^{-8}$ 95% CL

PRL 100,101802 (2008)

DØ: $< 9.3 \cdot 10^{-8}$ 95% CL

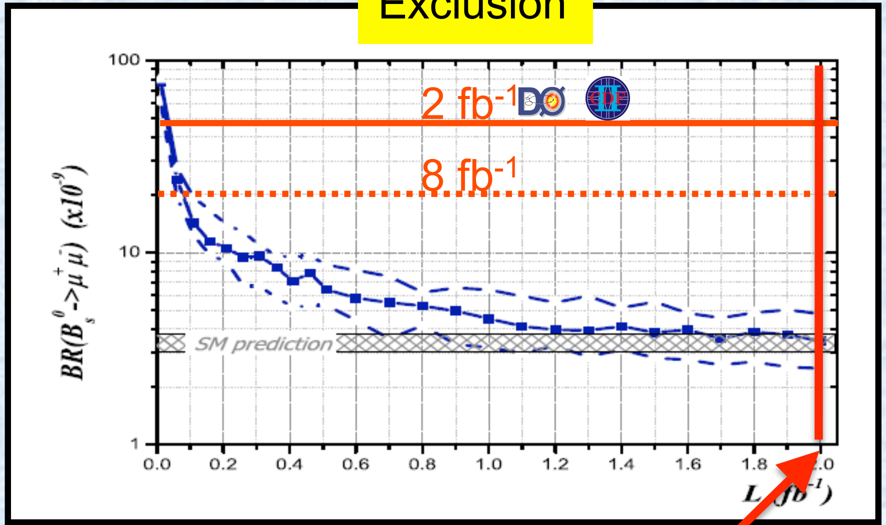
D0 Note 5344-Conf (2007)

2 fb^{-1}

Very Rare $B_s \to \mu\mu$ Decays

Channel	Yield (2 fb^{-1})	B
$B_s \to \mu^+\mu^-$	21 (SM)	180^{+140}_{-80}

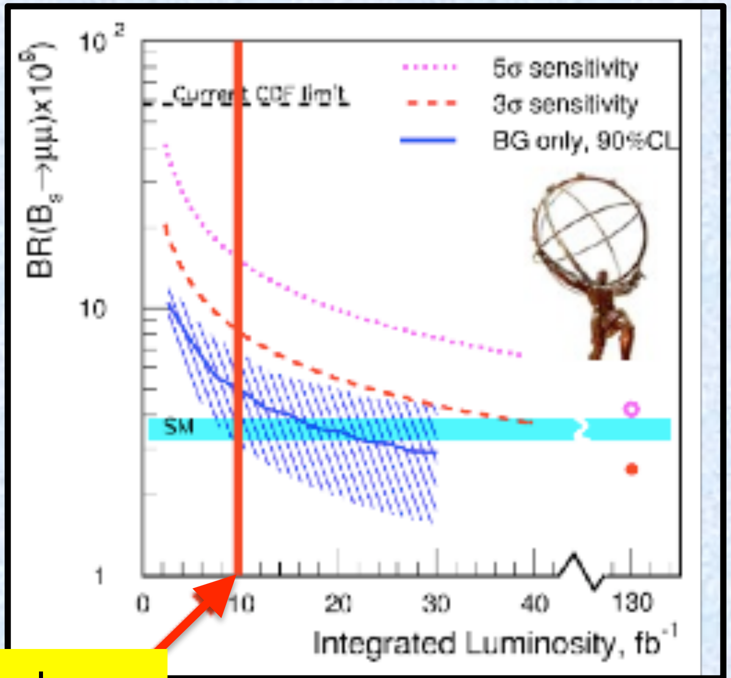
Exclusion



1 nominal year

Main issue is background rejection

With limited MC statistics, indication that main background is $b \to \mu$, $b \to \mu$



1 nominal year

LHCb Exclusion @ 90% c.l.

Reach final CDF/D0 limit @ 0.1 fb^{-1}

Reach SM prediction @ 2fb^{-1}

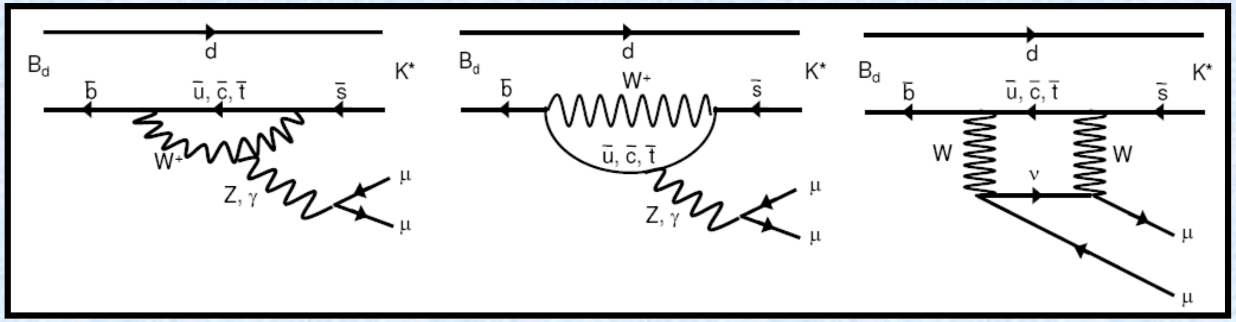
Observation

3σ evidence @ 3 fb^{-1}

5σ discovery @ 10 fb^{-1}

FCNC Rare Decays: B →K*μμ

FCNC b→s transition, very sensitive to NP



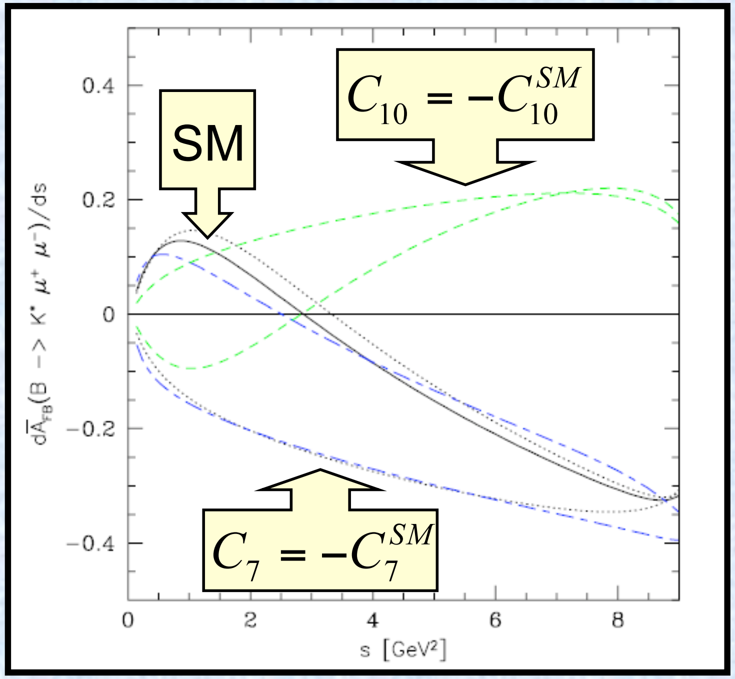
The forward-backward asymmetry arises from the interference between γ and Z^0 contributions

$$A_{FB}\left(s = m_{\mu\mu}^2\right) = -C_{10}\,\xi(s)\left[\mathrm{Re}(C_9)F_1 + \frac{1}{s}C_7F_2\right]$$

The zero crossing point is most theoretically clean

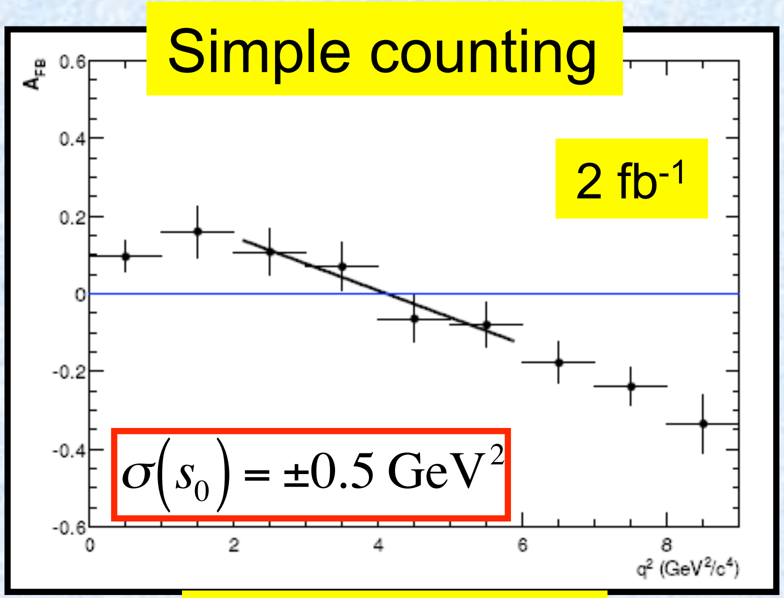
$$s_0^{SM} = 4.36^{+0.33}_{-0.31}\ \mathrm{GeV}^2$$

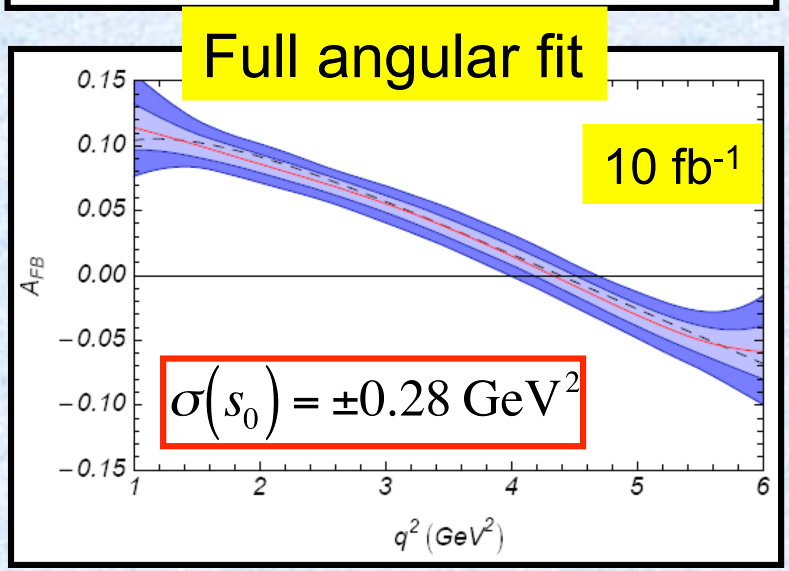
Beneke et al; EPJC41 (2005) 173



Ali et al; PLB273 (1991) 505

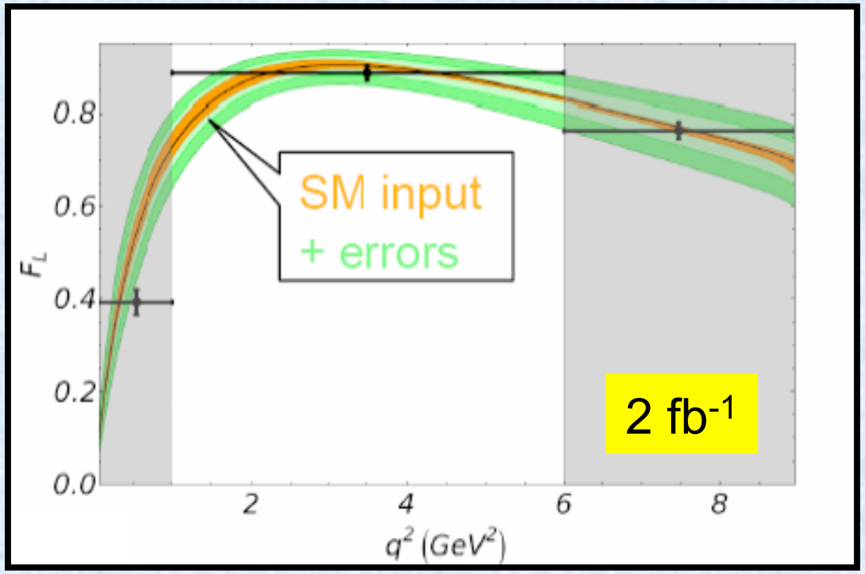
$B^0 \rightarrow K^* \mu^+ \mu^-$ Decays





Channel	Yield (2 fb^{-1})	B/S
$B^0 \rightarrow K^* \mu^+ \mu^-$	7200	~0.2

Fit to decay angular projections
Other angular observables
e.g. K* polarization



The 3rd Generation Experiments

Following the resounding success of the B factories and the Tevatron … and the potential for discovery at the LHC…there is a clear need to continue heavy flavour physics beyond 2015

NP effects are small → need high precision measurements to distinguish between various NP models

"Super KEKB" (Japan)

SuperB (Italy)

"Super" LHCb

Compelling and complementary programmes….

“Super”-LHCb

Can LHCb exploit the full potential of flavour physics at the LHC?

- Many LHCb measurements will be statistically limited with 10 fb^{-1}

“Super” LHCb

LHCb Upgrade

- Upgrade LHCb detector to operate at 10X design luminosity
- Run ~5 yrs at $\mathcal{L}$ ~ $2x10^{33}$ $cm^{-2}s^{-1}$ → ~100 fb^{-1} data sample
- Add Vertex Detector and Tracker to first level of trigger
- Readout full detector at 40 MHz - all front-end electronics must be redesigned
- Much of the detector will need to be replaced due to increased occupancy and/or irradiation

Expression of Interest
for an LHCb Upgrade

The LHCb Collaboration

EoI 2008
TDR in prep 2010

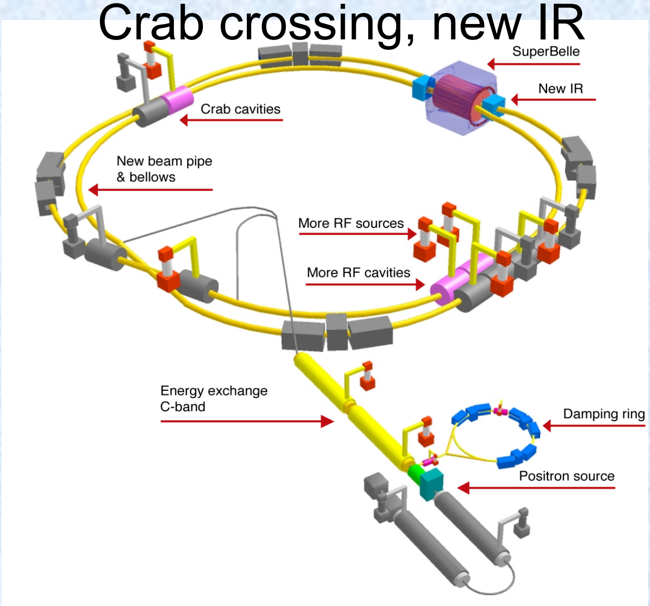
Super B-factories

Two options under consideration

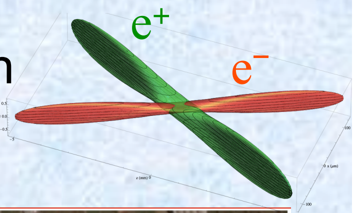
"Super KEKB" (Japan)

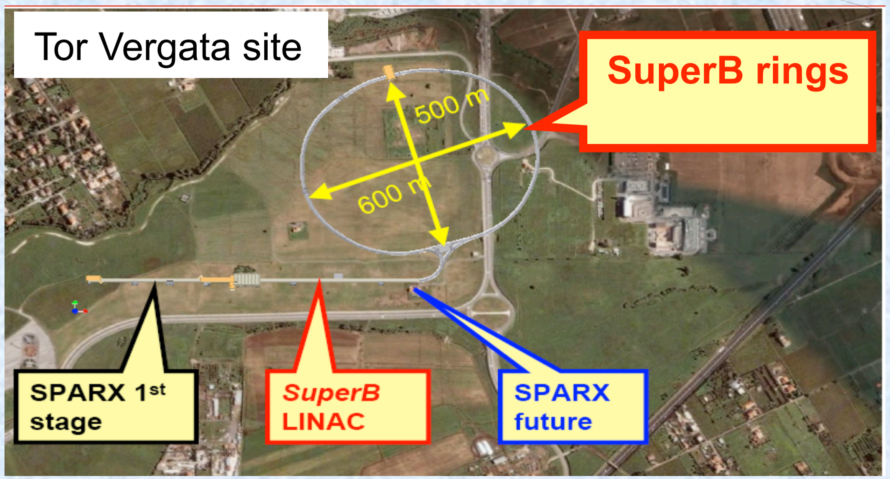
SuperB (Italy)

High current approach
Crab crossing, new IR



Nano-beam approach
Crab waist



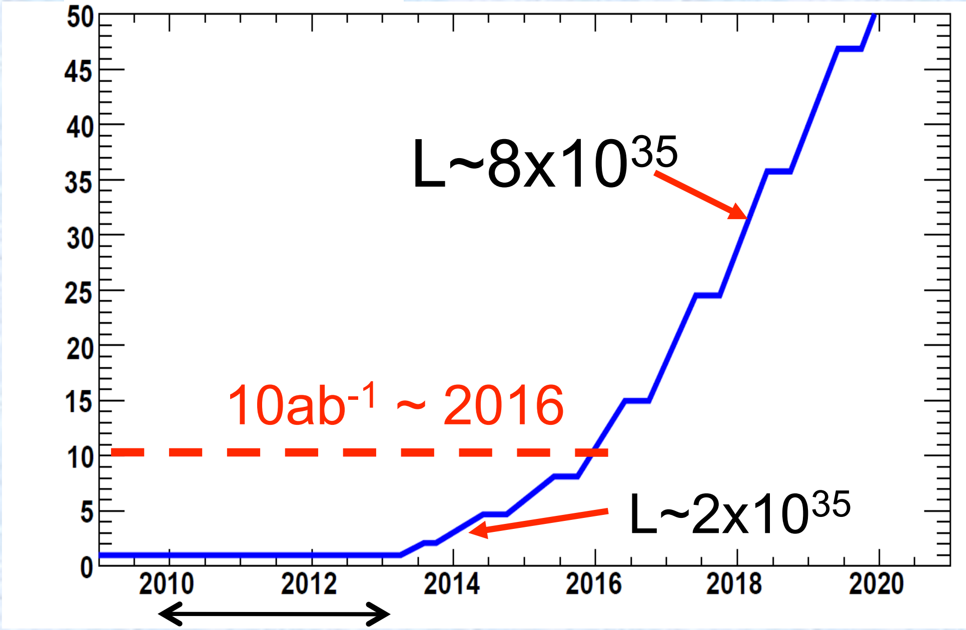


Super B-factories

Luminosity prospects

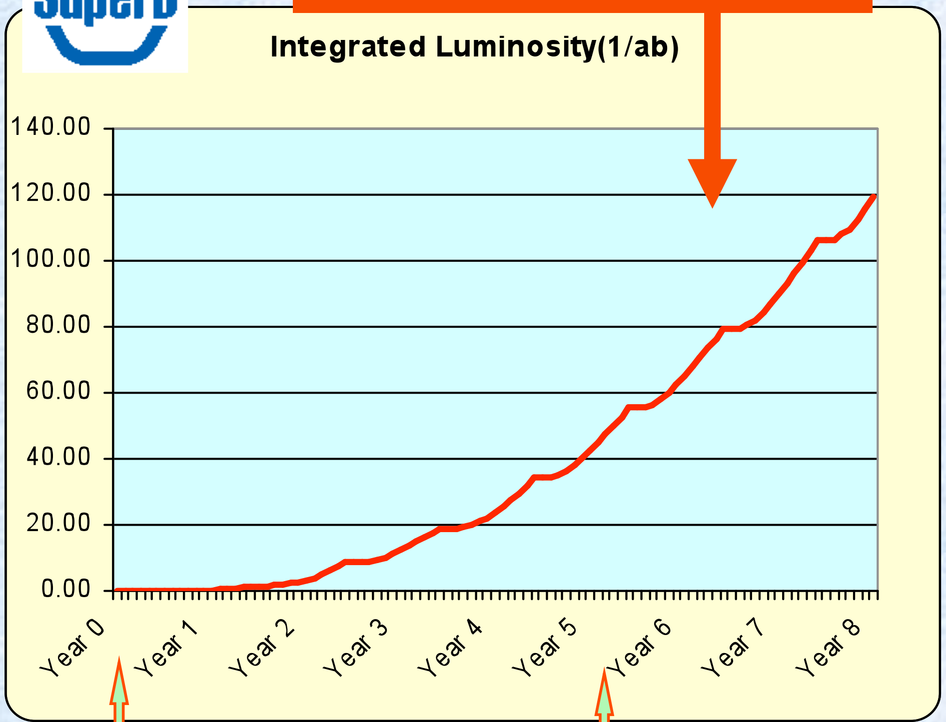
Y.Sakai, FPCP 2009

$50ab^{-1}$ by ~2020



3year shutdown
for upgrade

$>80ab^{-1}$ after 6 years



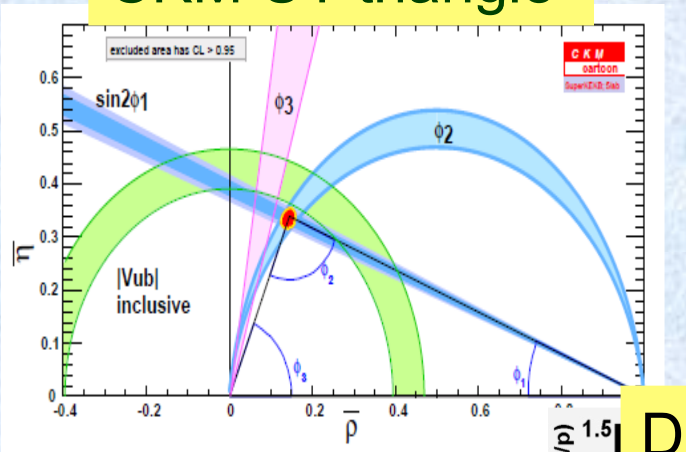
2015?

2020?

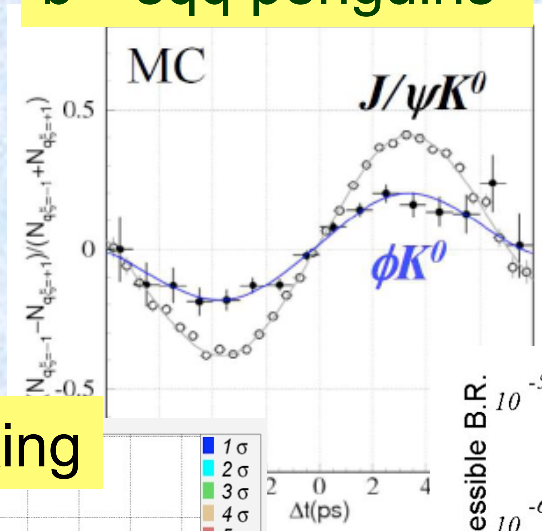
Flavour physics 2020 ?

Maybe New Physics will not be able to hide any longer…

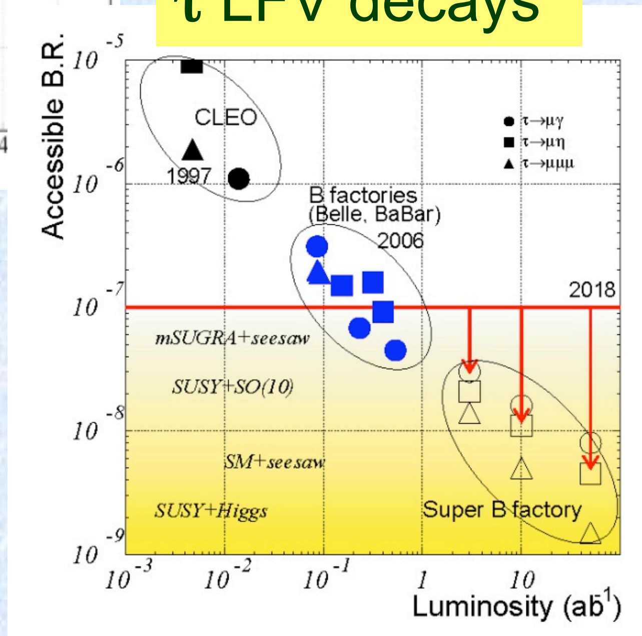
CKM UT triangle

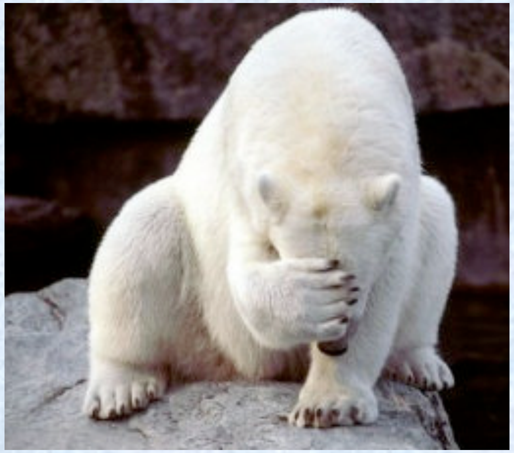


b→sqq penguins

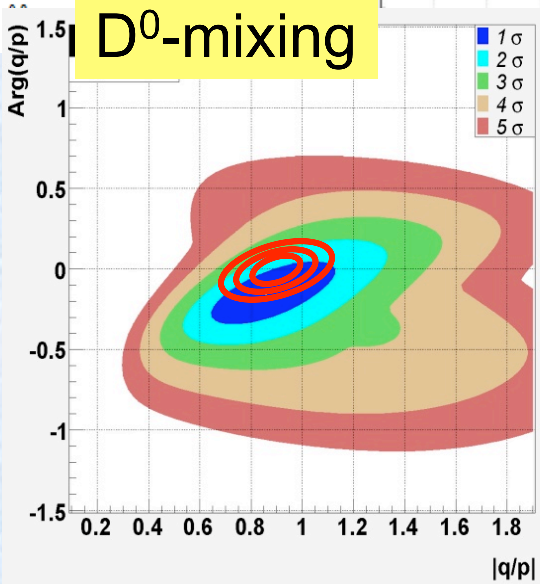


τ LFV decays





D^0-mixing



New Physics … the expected..?

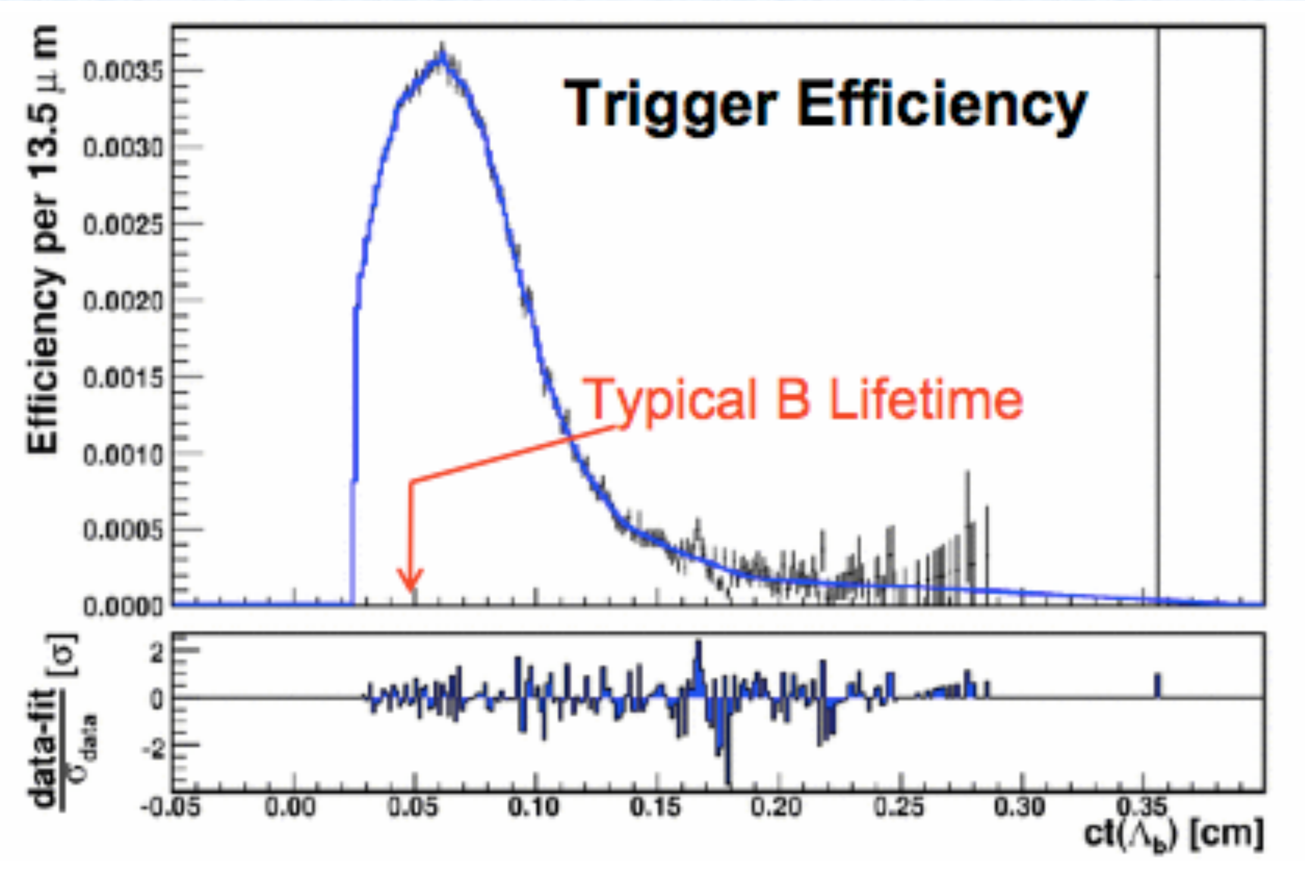
New Physics finally discovered !!

or… the totally unexpected…?

The “Yeti” or
“Abonimable Snowman”

Thank you

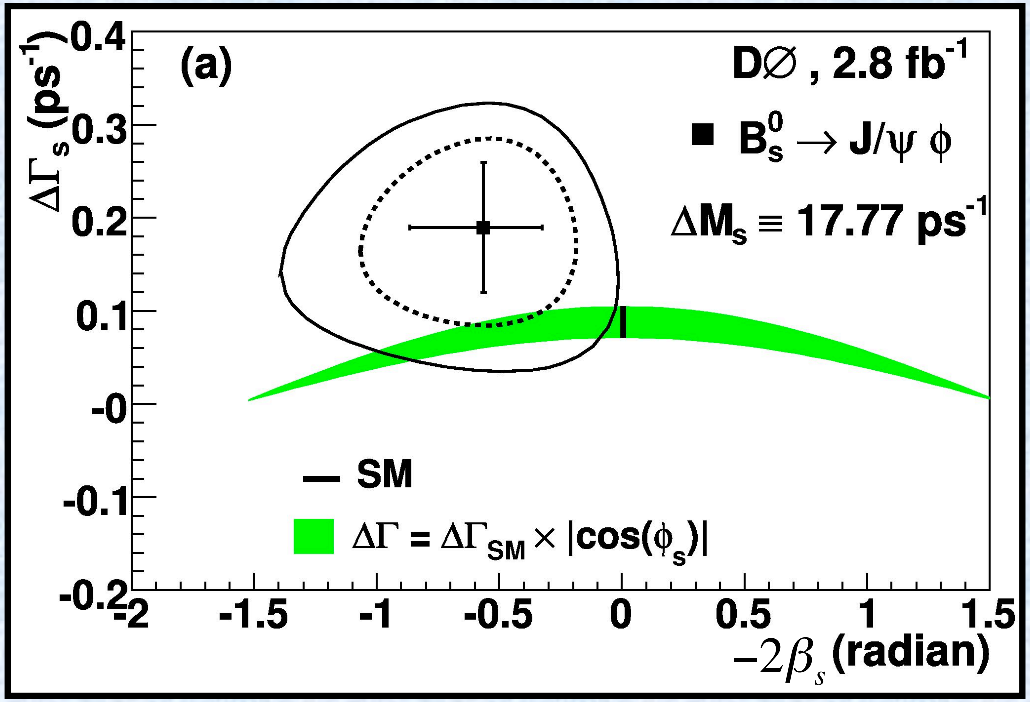
CDF Trigger


Trigger Efficiency
Typical B Lifetime
Efficiency per 13.5 μ m
0.0035
0.0030
0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
data-fit / σdata [σ]
2
0
-2
-0.05
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
ct(Λb) [cm]

β_s

previous analysis

D0 : 2.8 fb^{-1}; PRL101 (2008) 241801



$$-2\beta_s = -0.57^{+0.24}_{-0.30}(stat)^{+0.07}_{-0.02}(sys)\ \text{rad}$$

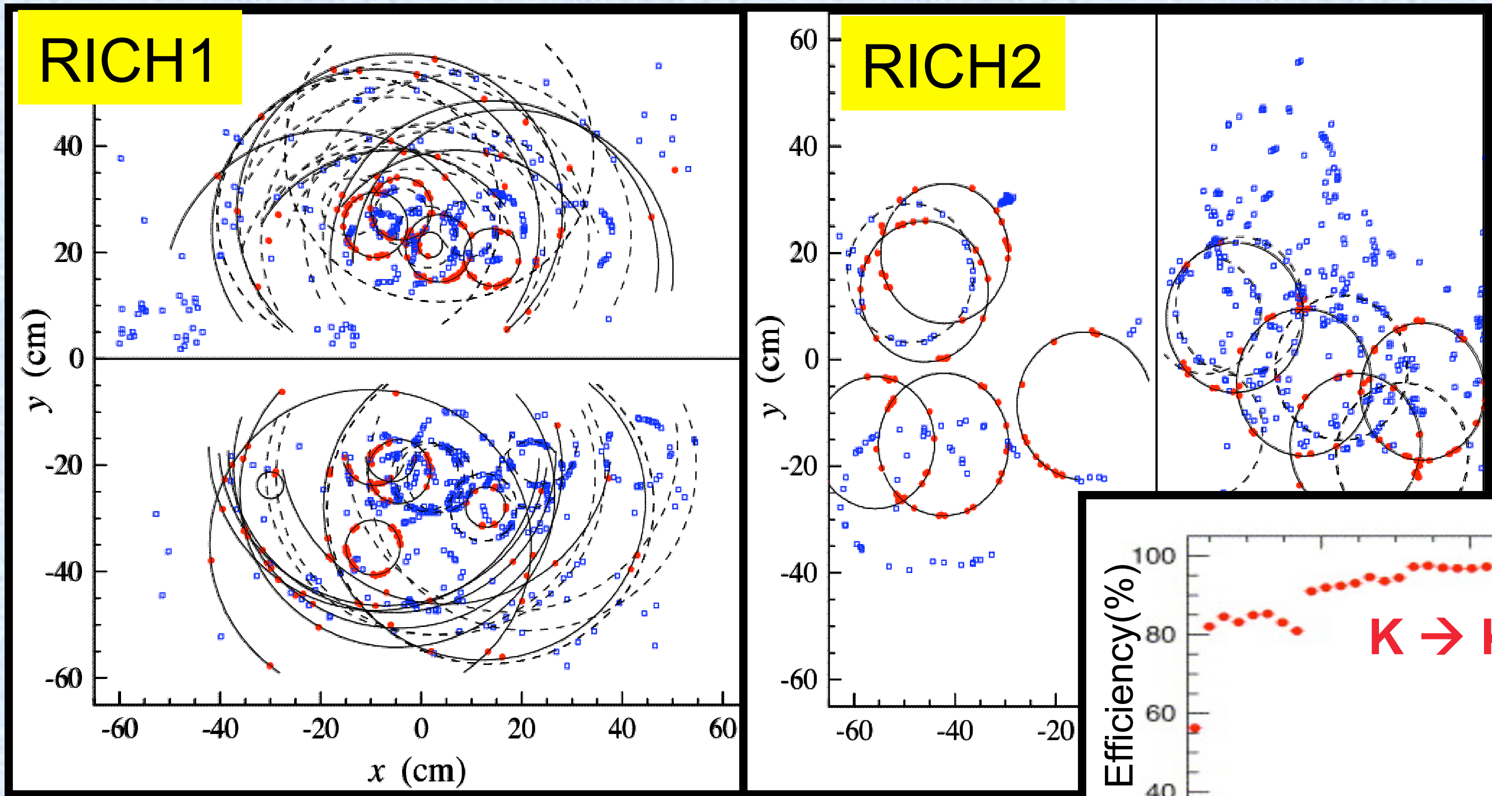
$$\Delta\Gamma_s = 0.19 \pm 0.07(stat)^{+0.02}_{-0.01}(sys)\ \text{ps}^{-1}$$

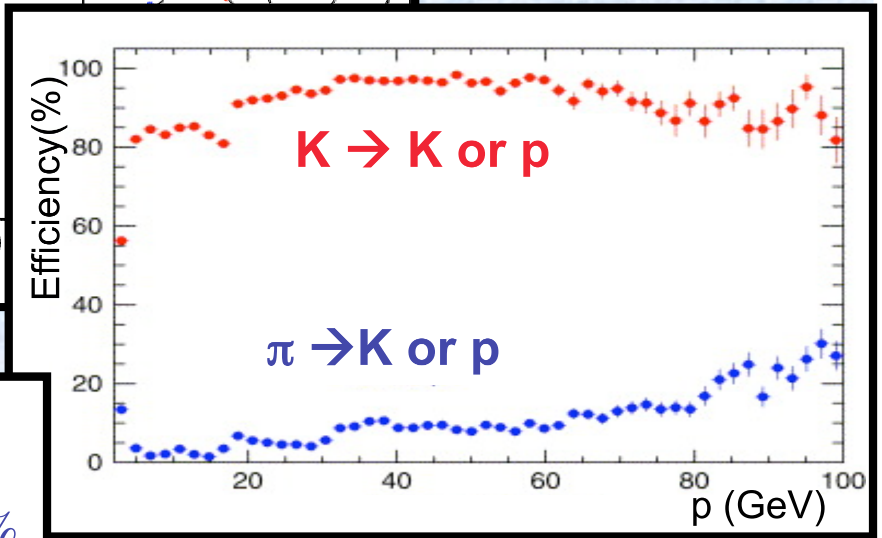
Strong phases constrained

Probability of SM = 6.6% ~1.8σ

RICH Performance

Full MC simulation using “global” fit to Cherenkov rings

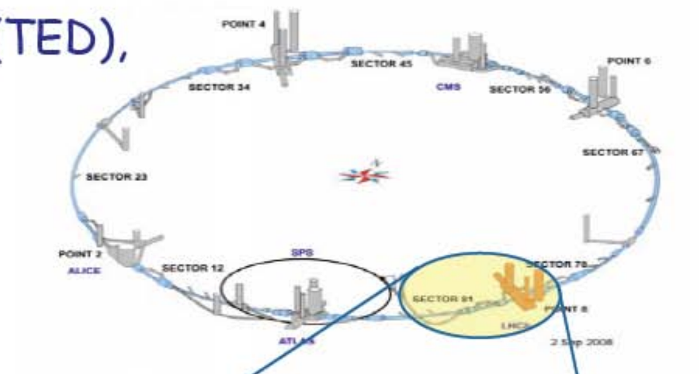


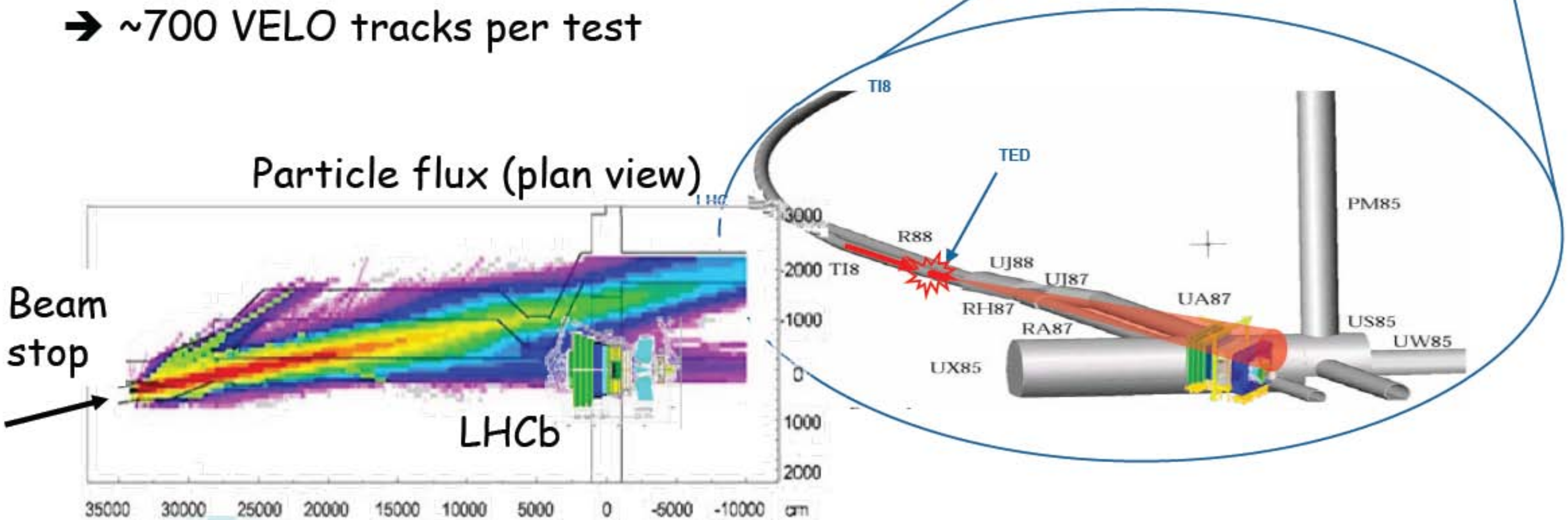


Averages:
K→ K,p eff: 83.1± 0.1%
π → K,π misID: 5.85± 0.03%

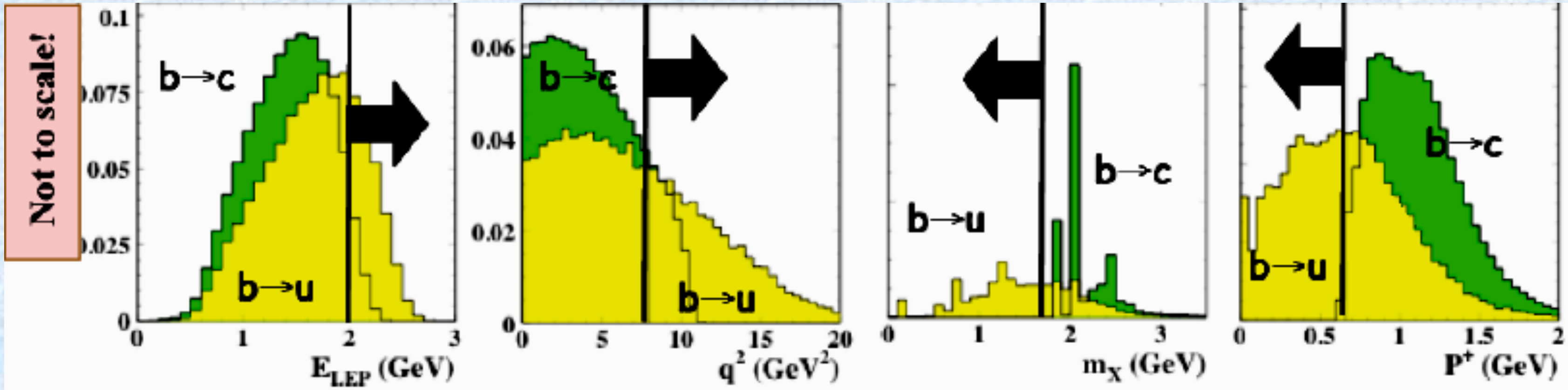
TED

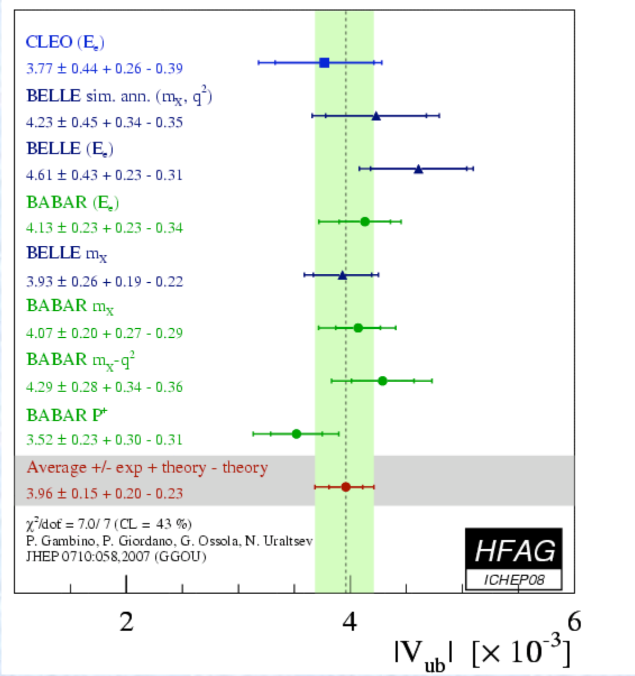
- Beam 2 dumped on injection line beam stopper (TED), i.e. 4m W, Cu, Al, graphite rod in a 1m diameter iron casing
- 340m before LHCb along Beam 2
- Wrong direction for LHCb
- High flux, centre of shower $O(10)$ particles/cm^2
- VErtex LOcator $O(0.1)$ particles/cm^2
  - ➔ ~700 VELO tracks per test

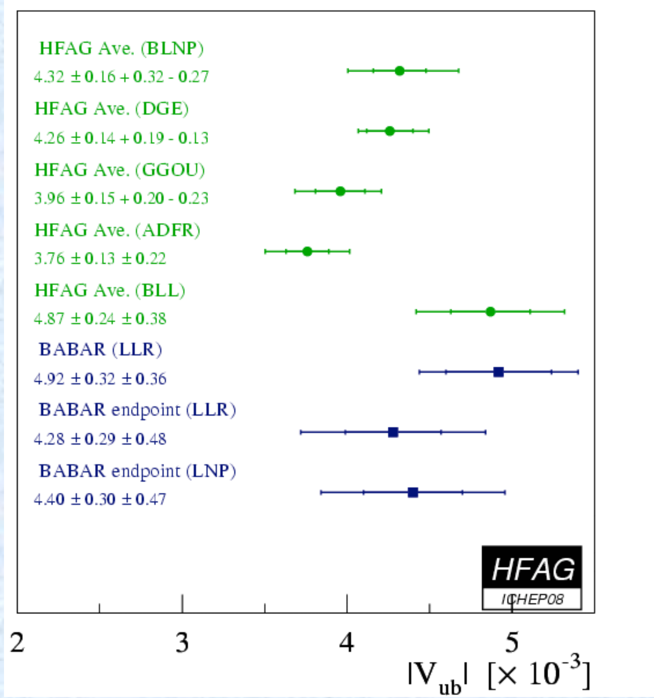




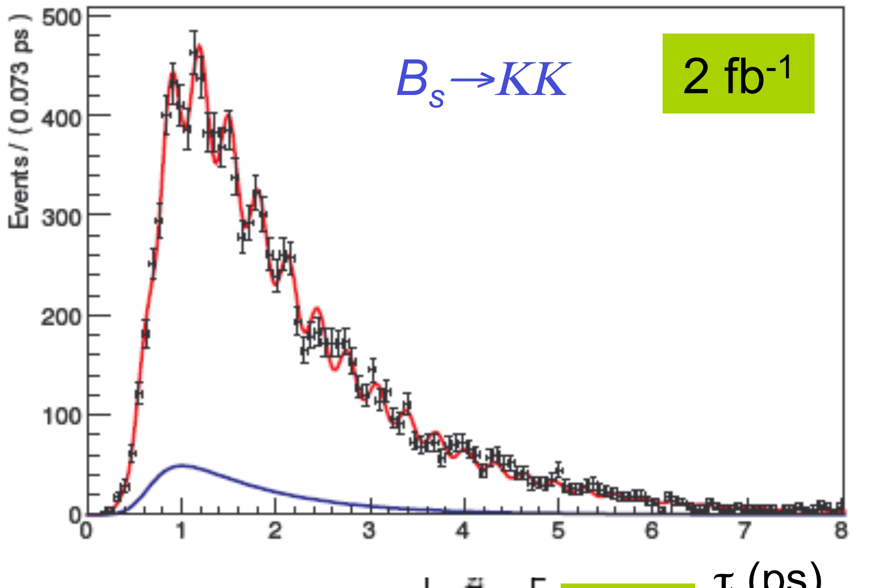
Inclusive Vub



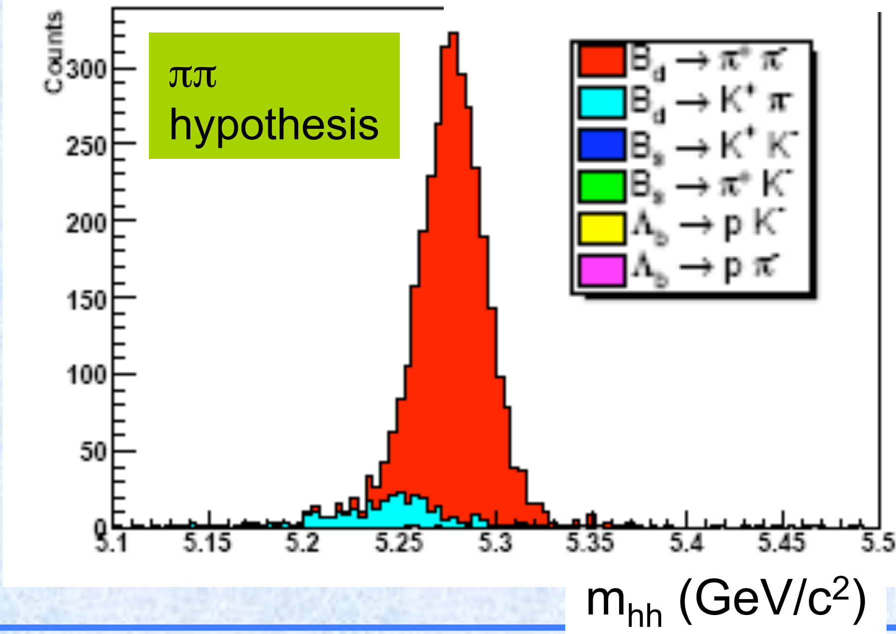




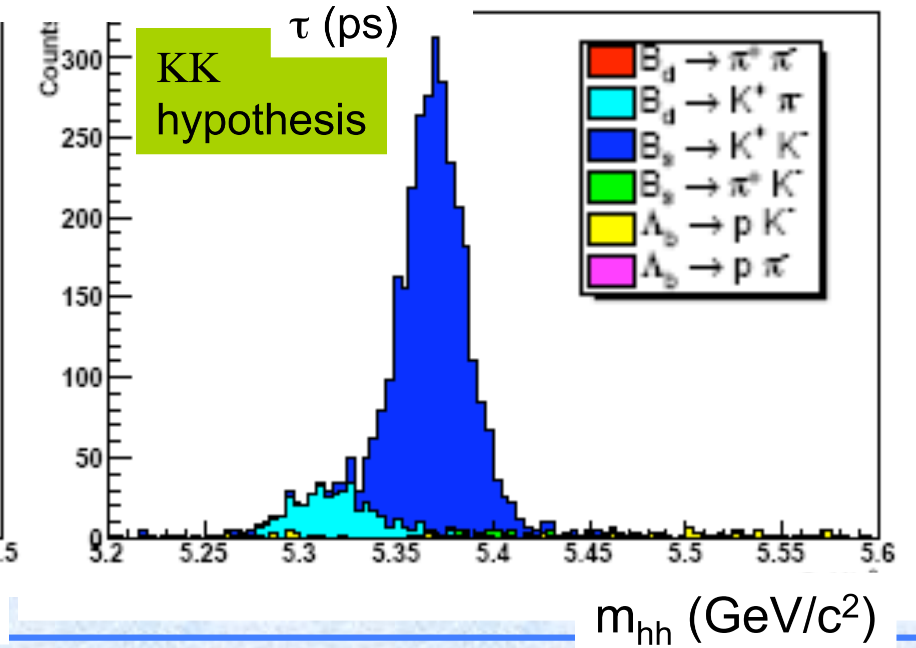
γ from loops



$B_s \to KK$
2 fb^{-1}
Events / (0.073 ps)
τ (ps)

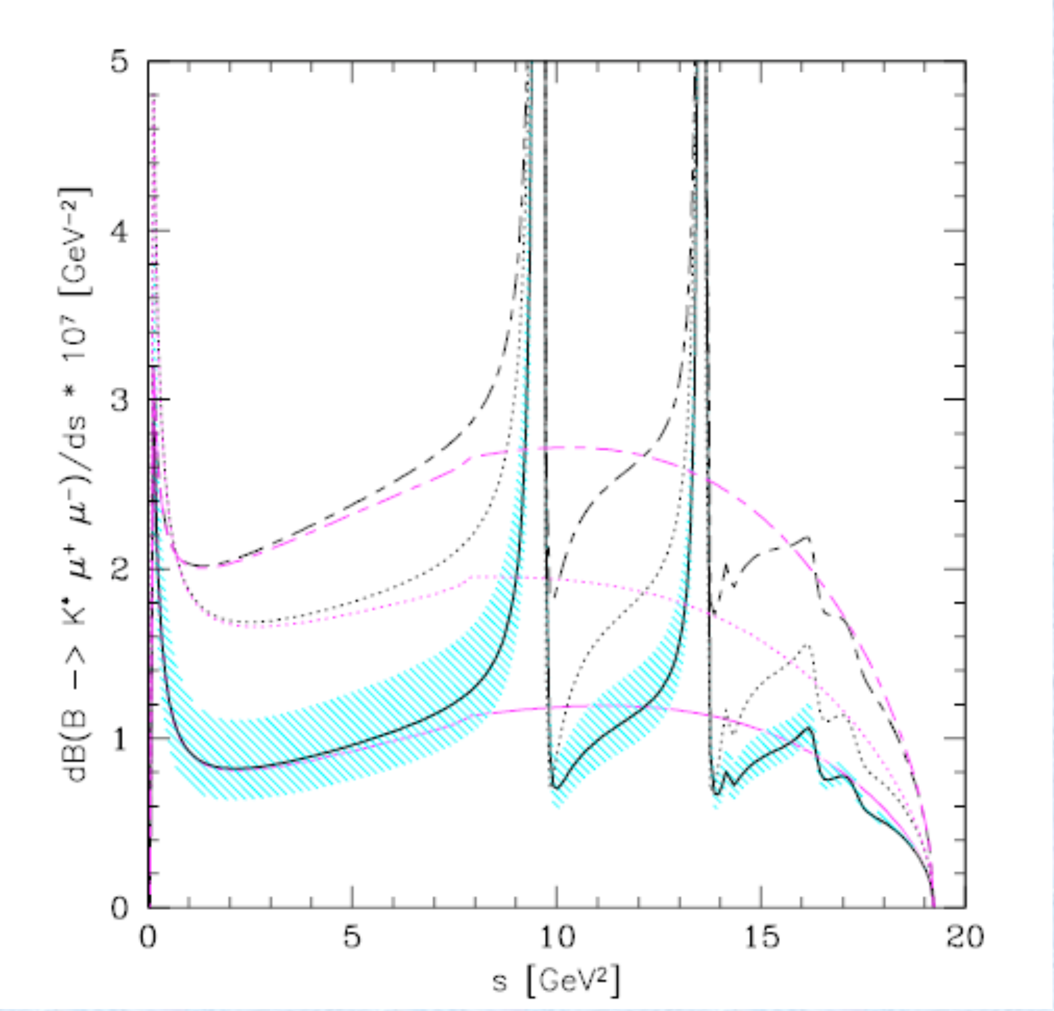


Counts
ππ
hypothesis
$B_d \to \pi^+ \pi^-$
$B_d \to K^+ \pi^-$
$B_s \to K^+ K^-$
$B_s \to \pi^+ K^-$
$\Lambda_b \to p K^-$
$\Lambda_b \to p \pi^-$
m_{hh} (GeV/c^2)



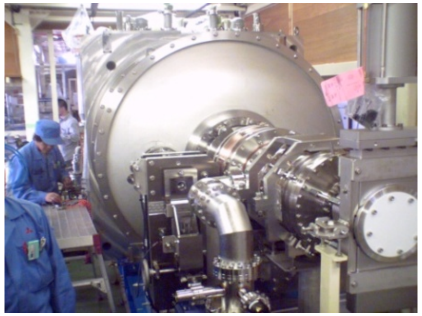
Counts
KK
hypothesis
$B_d \to \pi^+ \pi^-$
$B_d \to K^+ \pi^-$
$B_s \to K^+ K^-$
$B_s \to \pi^+ K^-$
$\Lambda_b \to p K^-$
$\Lambda_b \to p \pi^-$
m_{hh} (GeV/c^2)

$B^0 \rightarrow K^* \mu^+ \mu^-$ Decays

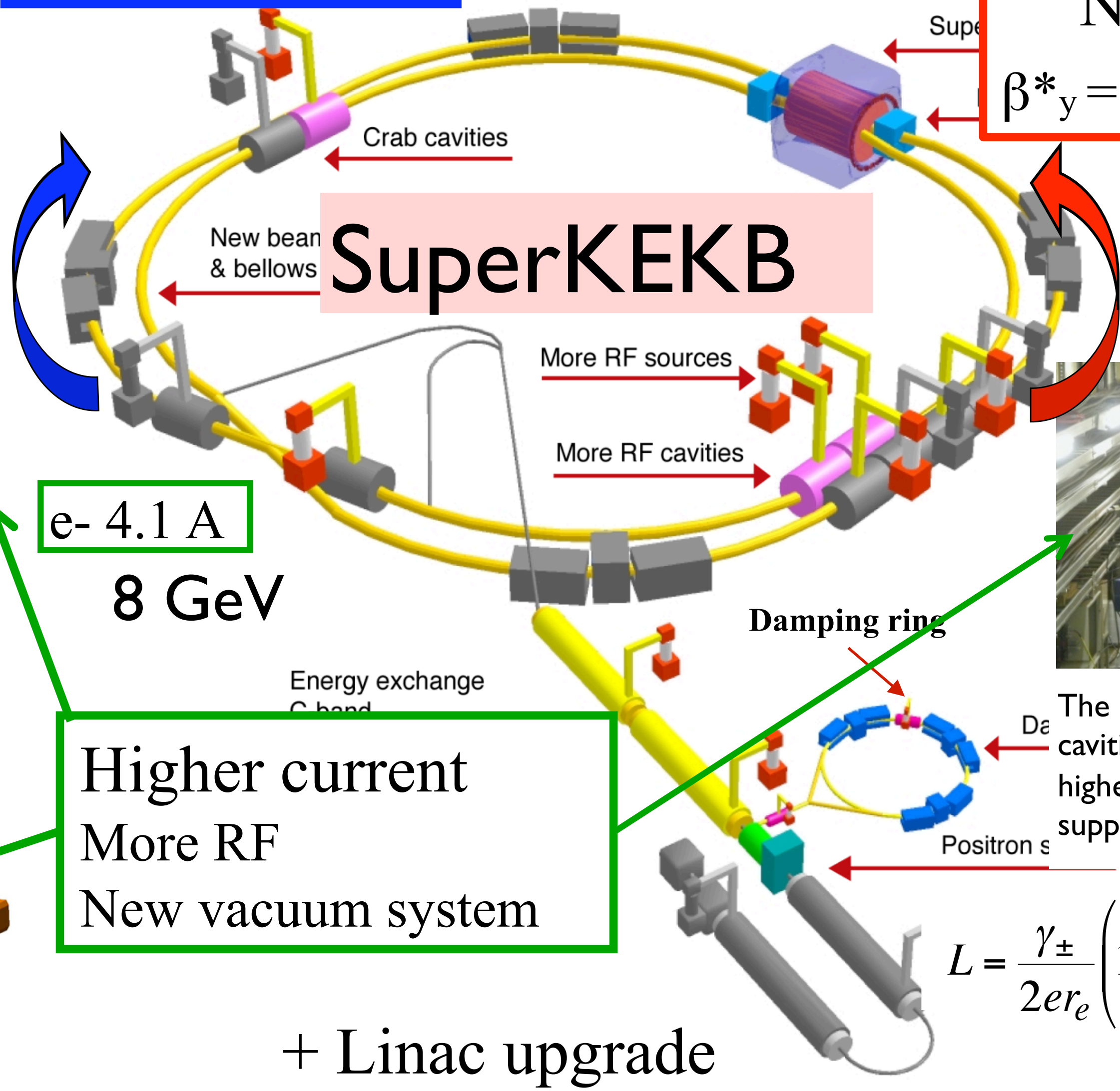


SuperKEKB

Crab crossing



Crab cavities installed and undergoing testing in beam



New IR

$\beta^*_y = \sigma_z = 3$ **mm**

3.5 GeV

e+ 9.4 A

e- 4.1 A

8 GeV

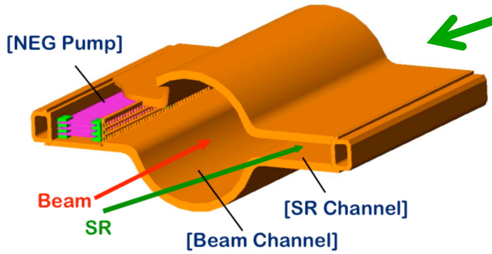
The superconducting cavities will be upgraded to absorb more higher-order mode power up to 50 kW.

The state-of-art ARES copper cavities will be upgraded with higher energy storage ratio to support higher current.

Higher current

More RF

New vacuum system



The beam pipes and all vacuum components will be replaced with higher-current design.

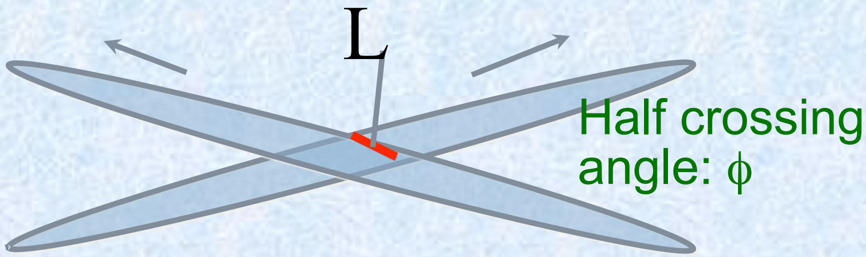
+ Linac upgrade

$$L = \frac{\gamma_\pm}{2er_e}\left(1 + \frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$$

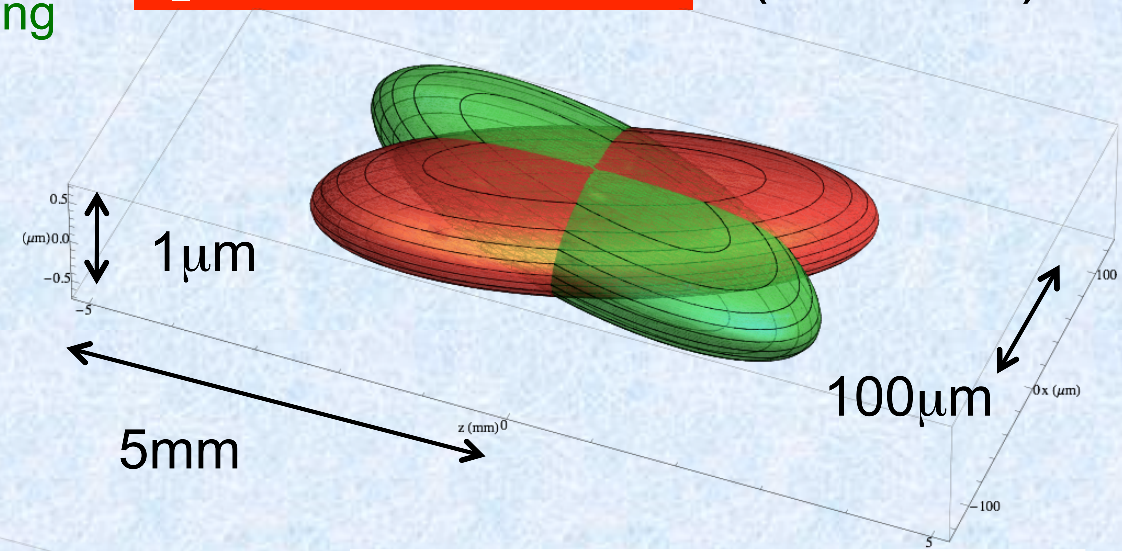
Aiming 8×10^{35} cm^{-2}s^{-1}

Super KEKB Quest for BSM

Nano-Beam Scheme



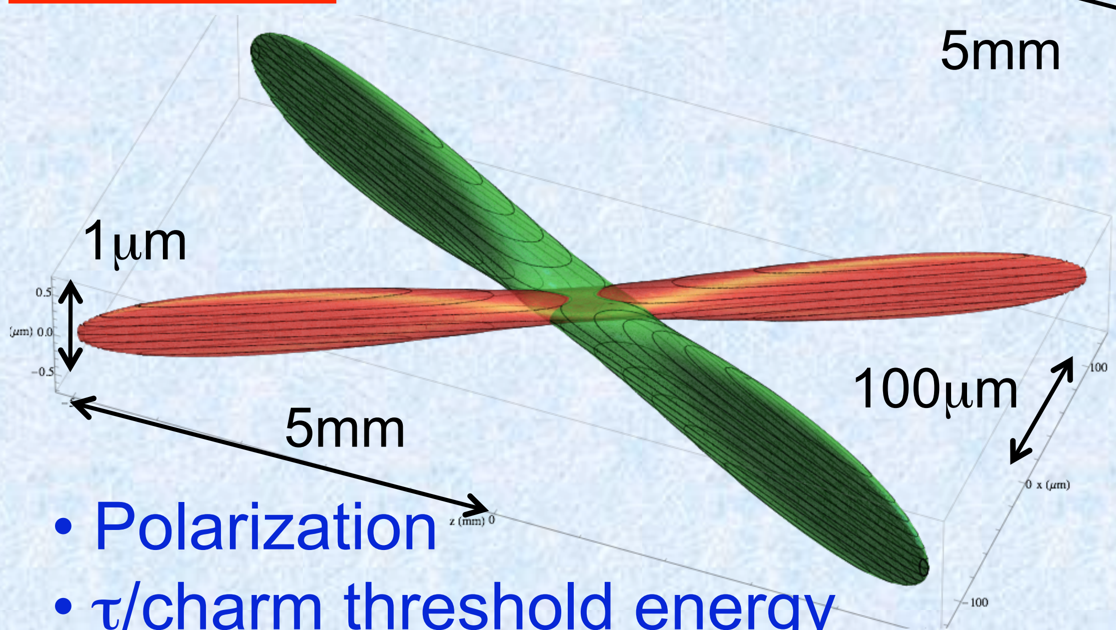
present KEKB (w/o crab)



Hourglass condition:

$\beta_y^* >\sim L = \sigma_x / \phi$

SuperB



- Polarization
- τ/charm threshold energy

$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\left(\frac{R_L}{R_y}\right)$$

⇕

$$L = \frac{N_+ N_- f}{4\pi\sigma_x^*\sigma_y^*} R_L$$