CERN-FNAL HCP 2009

Experimental Aspects of Heavy Flavour Physics

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

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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

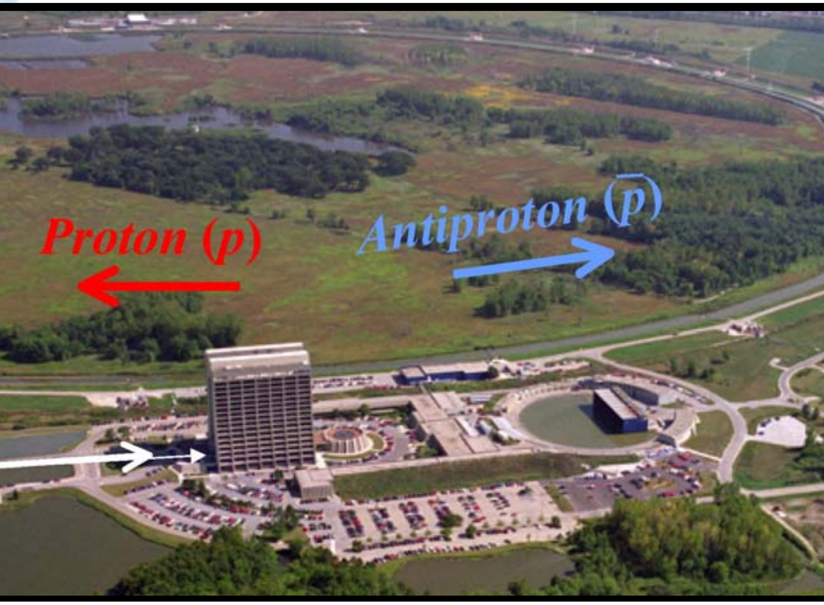
Lecture 2

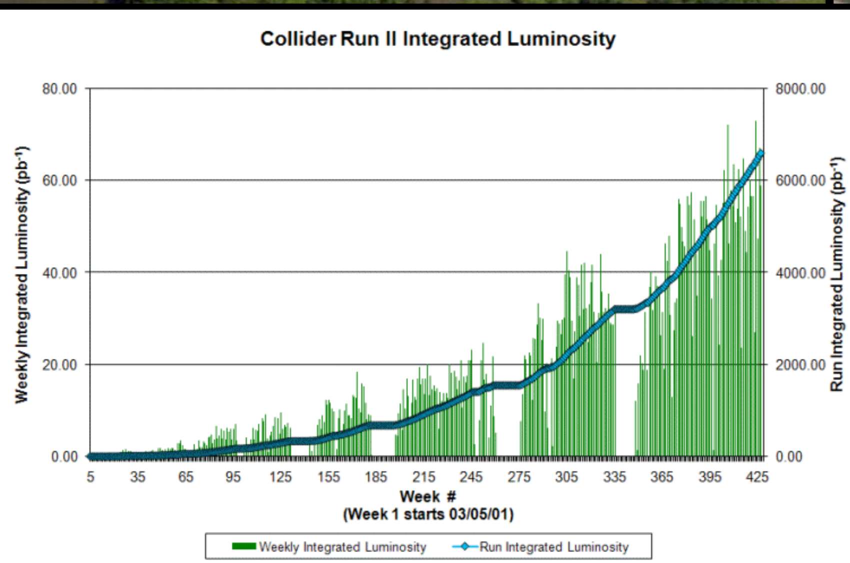
Where to look next ?

The Tevatron

The Tevatron

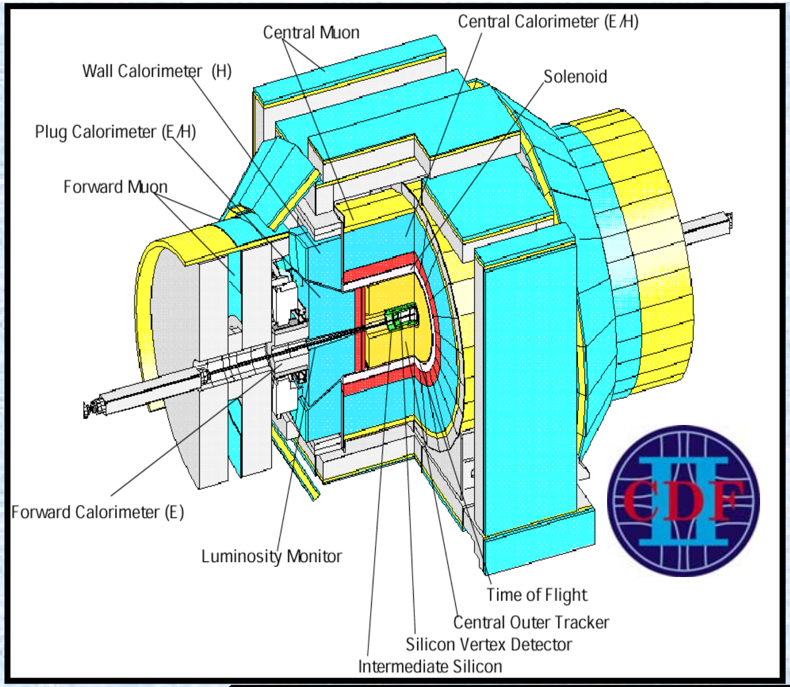
Run II: start March 2001, end ??
Integrated luminosity > 6 fb^{-1}
Peak luminosity ~ 3.5×10^{32} $cm^{-2}s^{-1}$

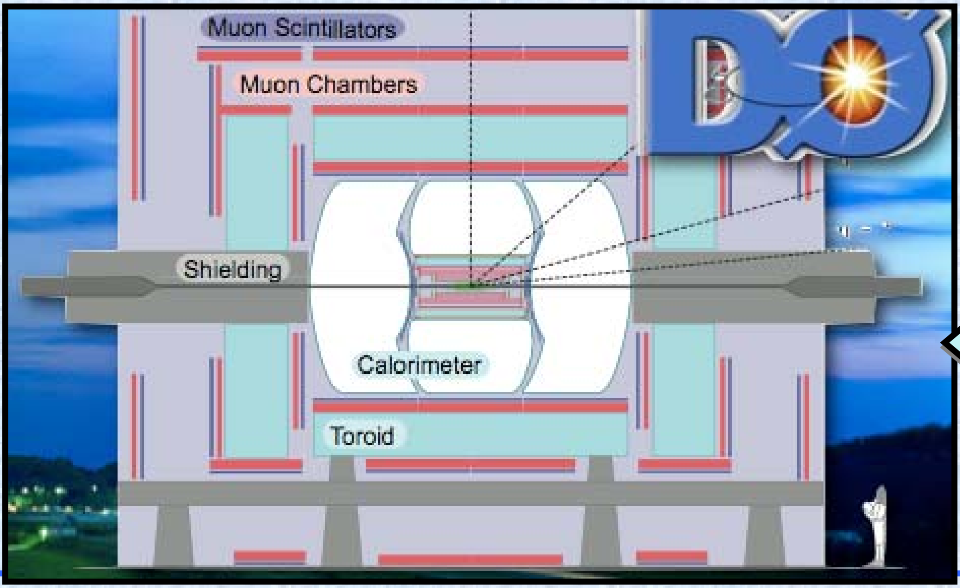




CDF and D0

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

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

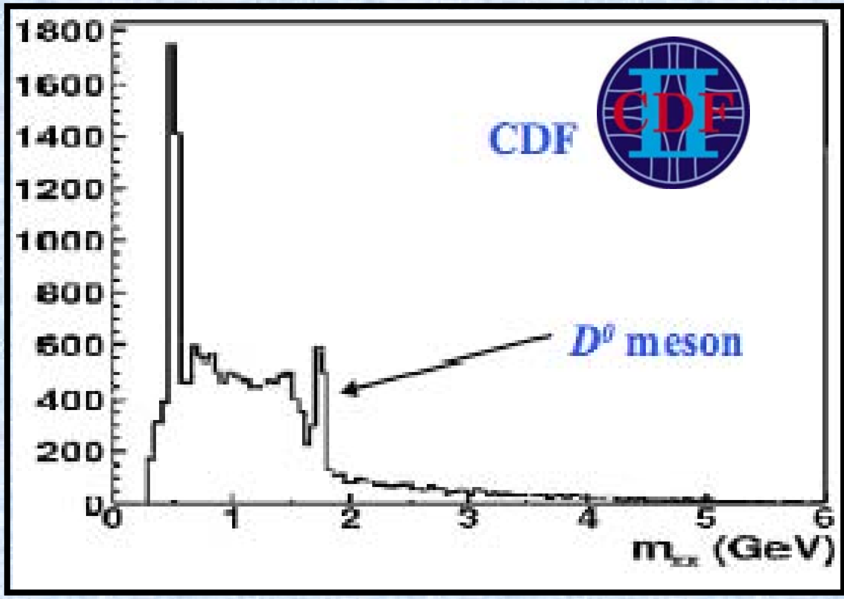
Int rate ~2.5 MHz, L1 accept 30 kHz (CDF), 2kHz (D0), Output rate ~150 Hz

CDF trigger exploits the SVT processor to select displaced tracks

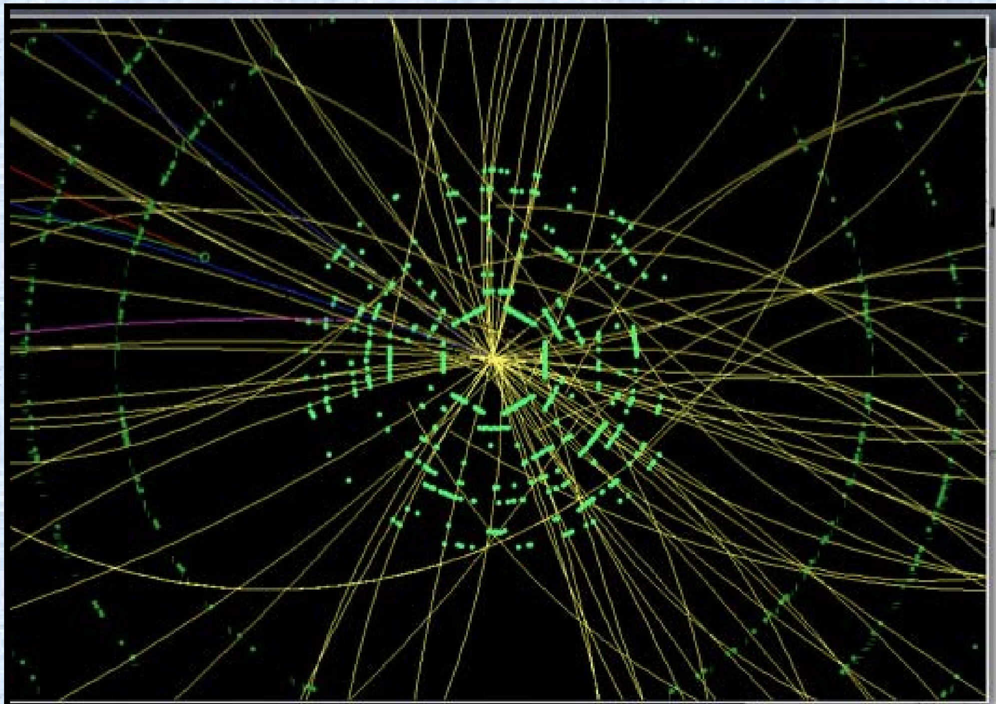
D0 trigger based on powerful muon identification

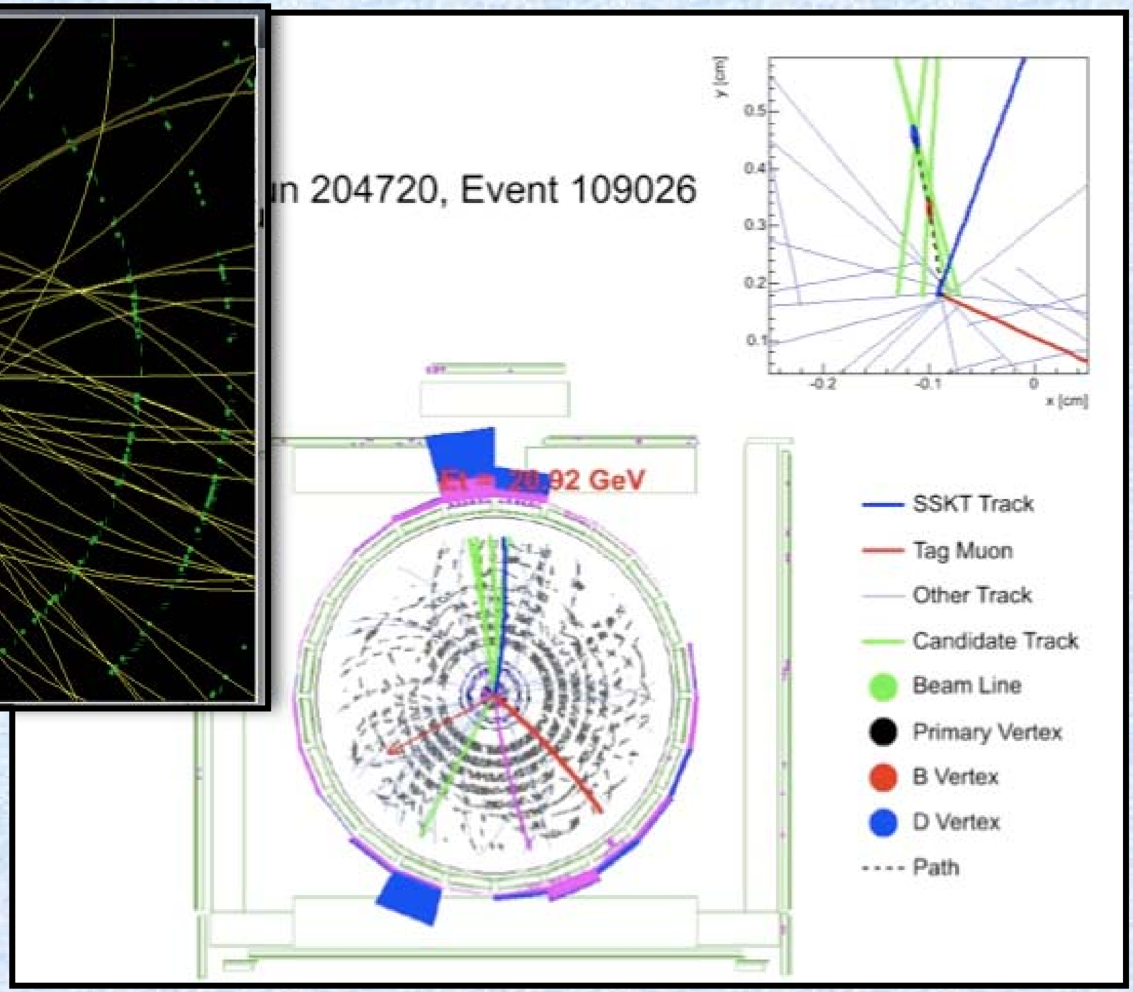
3 main trigger types:

- 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"

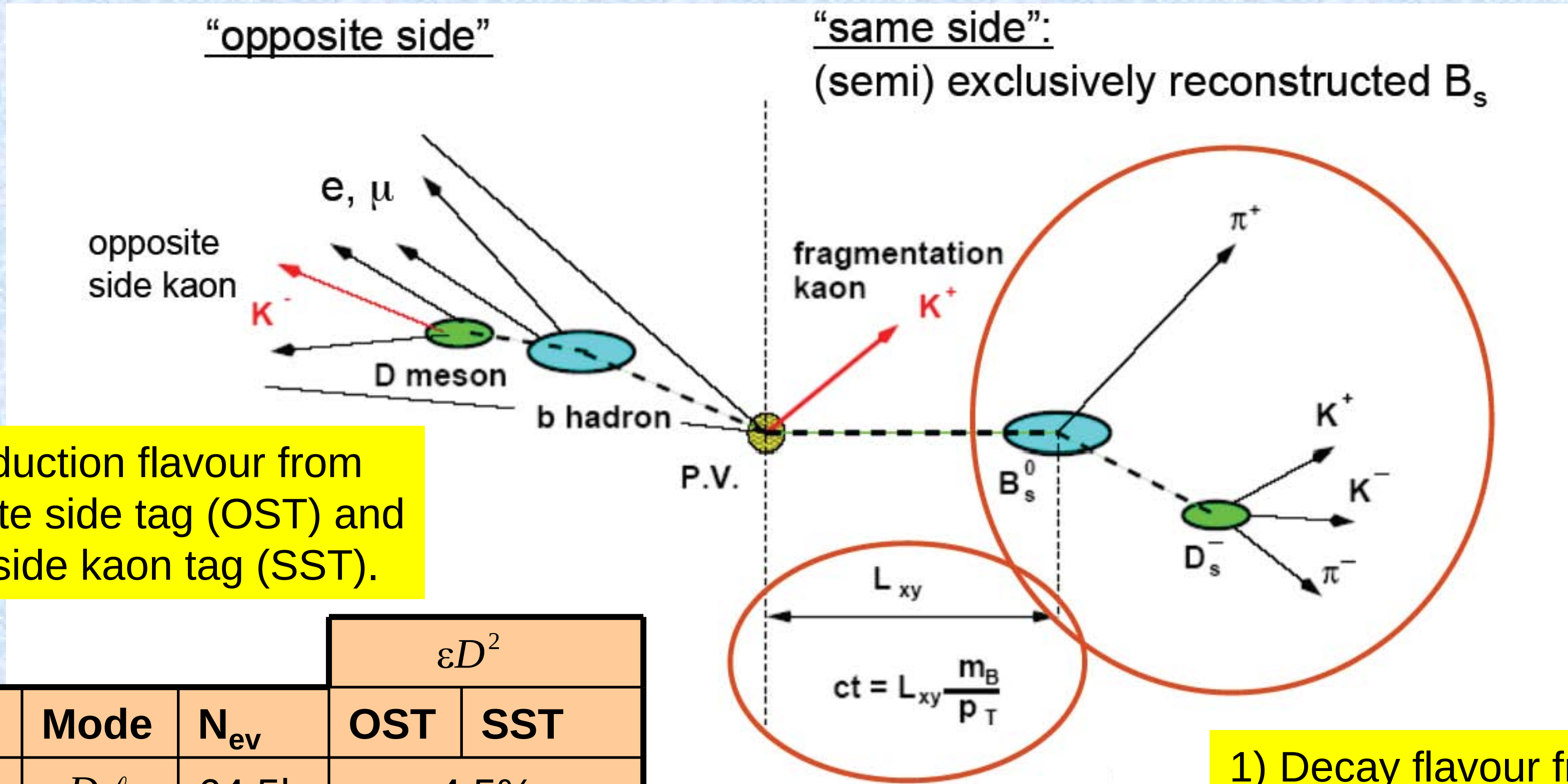
→ No nice jets

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

1) Decay flavour from decay products

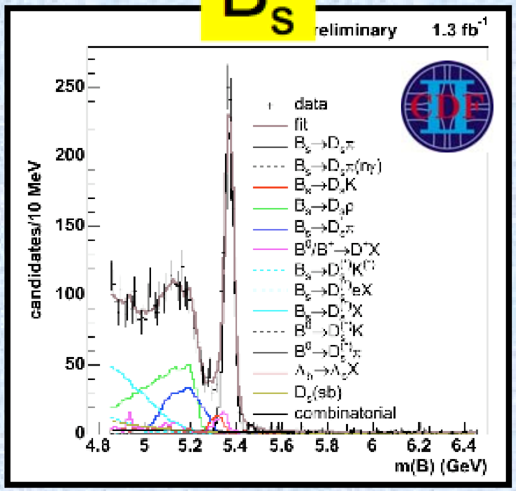
Exp	Mode	N_{ev}	εD^2 OST	εD^2 SST
D0	$D_s \ell$	64.5k	4.5%	
	$D_s \pi$	249	2.5%	
CDF	$D_s \ell$	61.5k	1.8%	4.8%
	$D_s(3)\pi$	8.7k	1.8%	3.7%

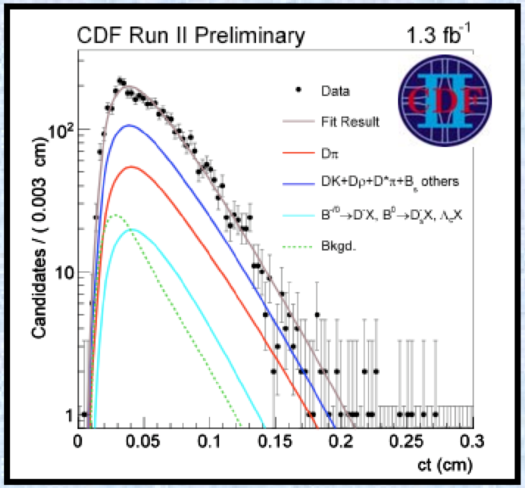
$L_{xy} \approx 500\ \mu m$

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

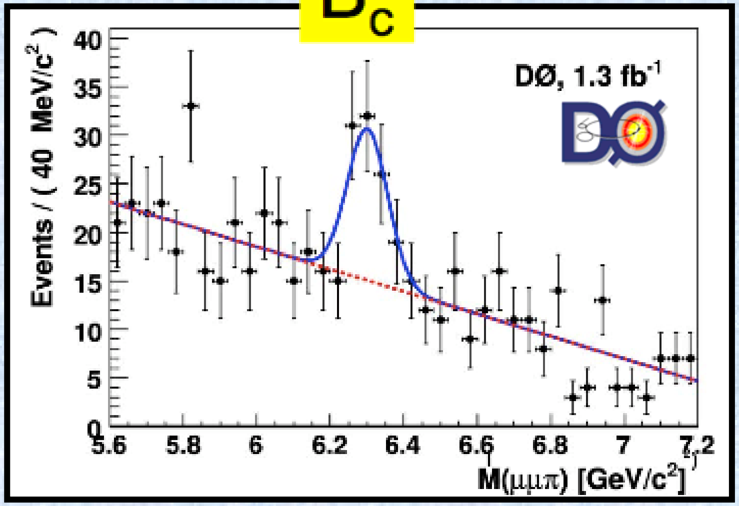
B Hadrons

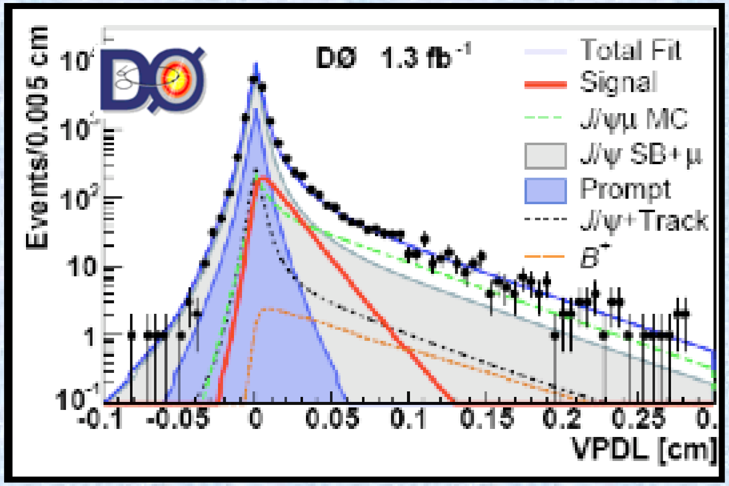
B_s



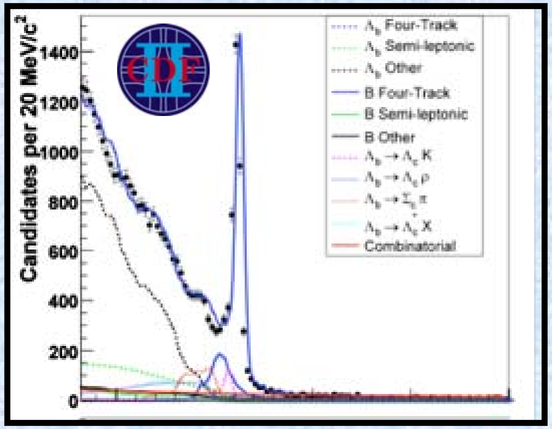


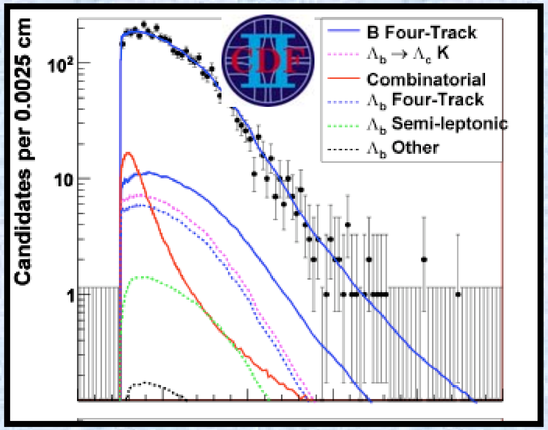
B_c





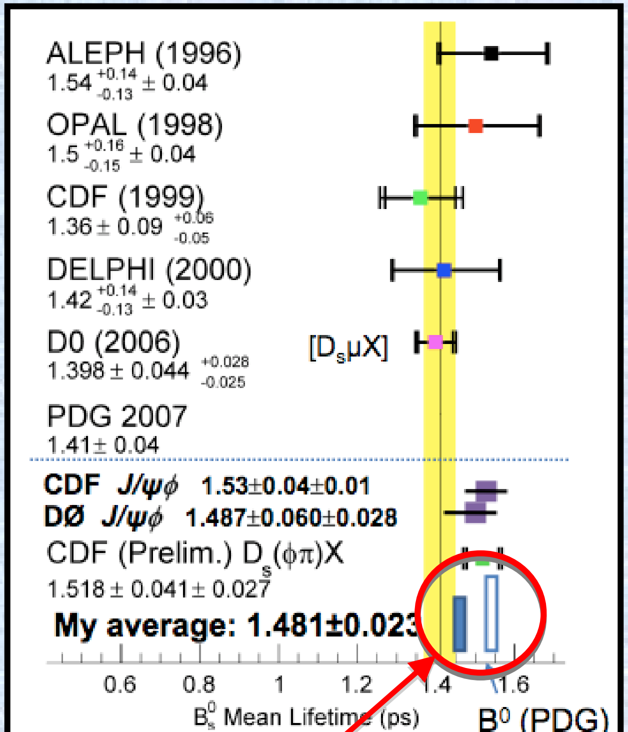
Λ_b





B Hadrons

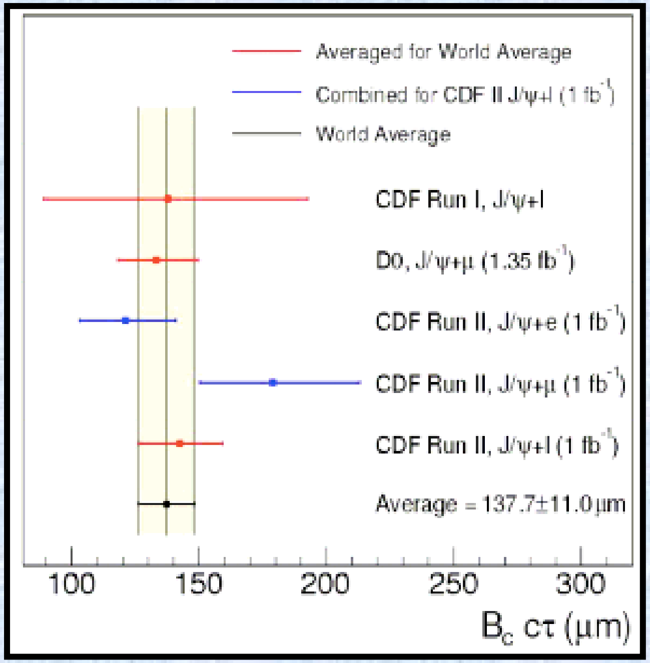
B_s



2σ discrepancy between data and expectation

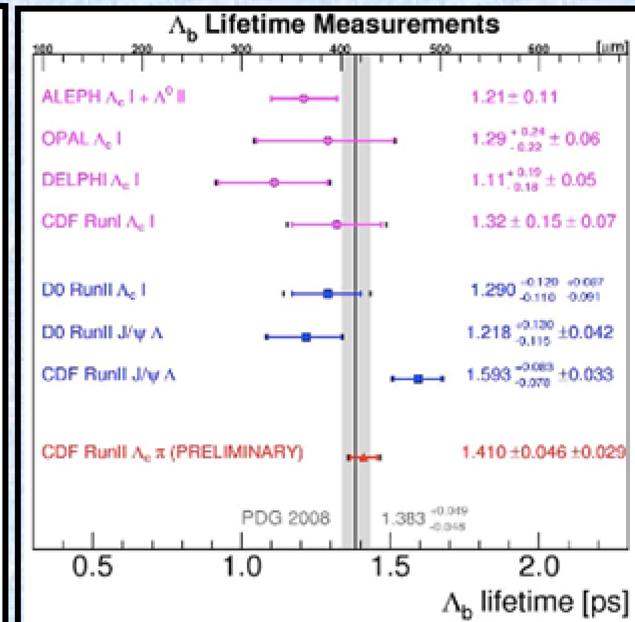
$$\tau\left(B^0\right) \approx \tau\left(B_s\right)$$

B_c



Agrees with expectation

Λ_b

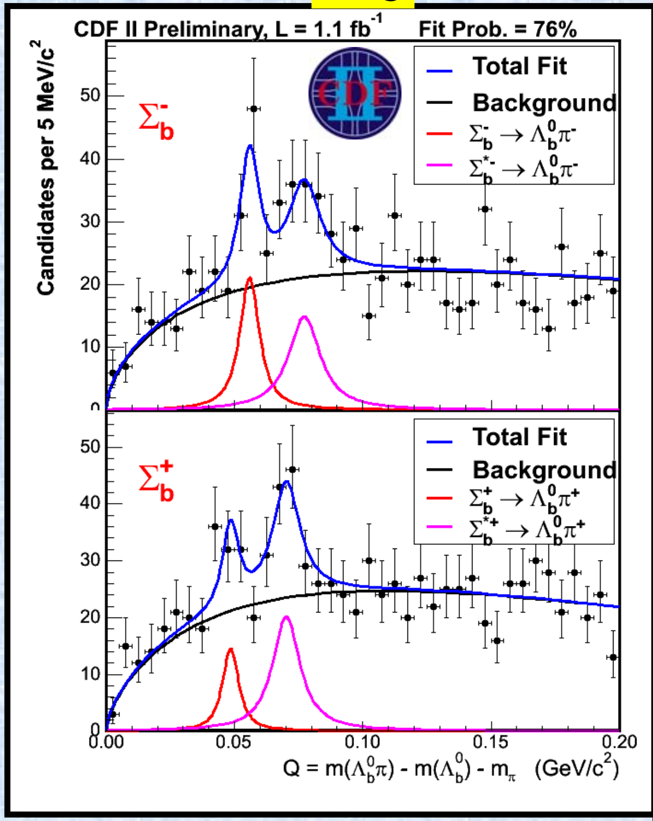


$$\tau(\Lambda_b)/\tau\left(B^0\right) = 0.922 \pm 0.039$$

J.Lewis: Moriond EW 2009

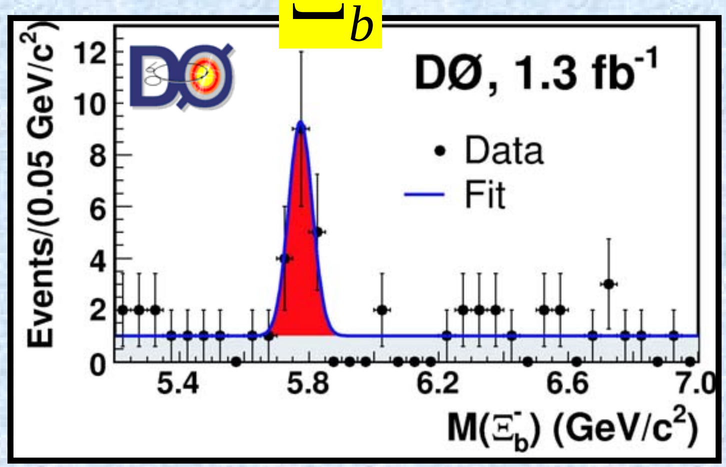
and more…B baryons

$\Sigma_b^{\pm}$



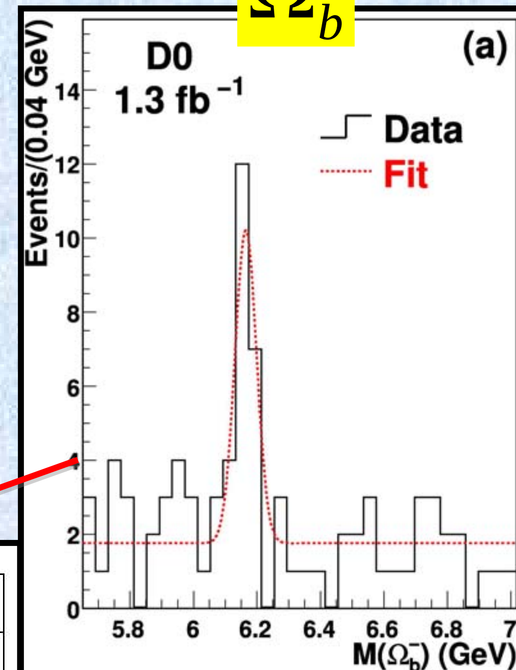
CDF : PRL99 (2007) 202001

$\Xi_b^{\pm}$

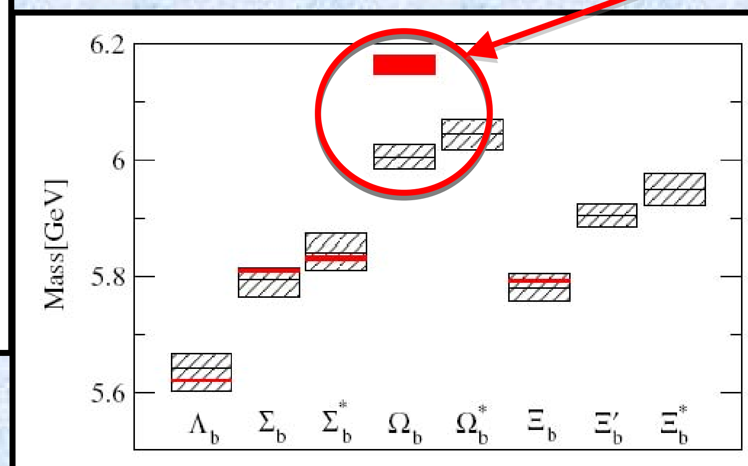


D0 : PRL99 (2007) 052001

$\Omega_b^{\pm}$



D0 : PRL101 (2008) 232002

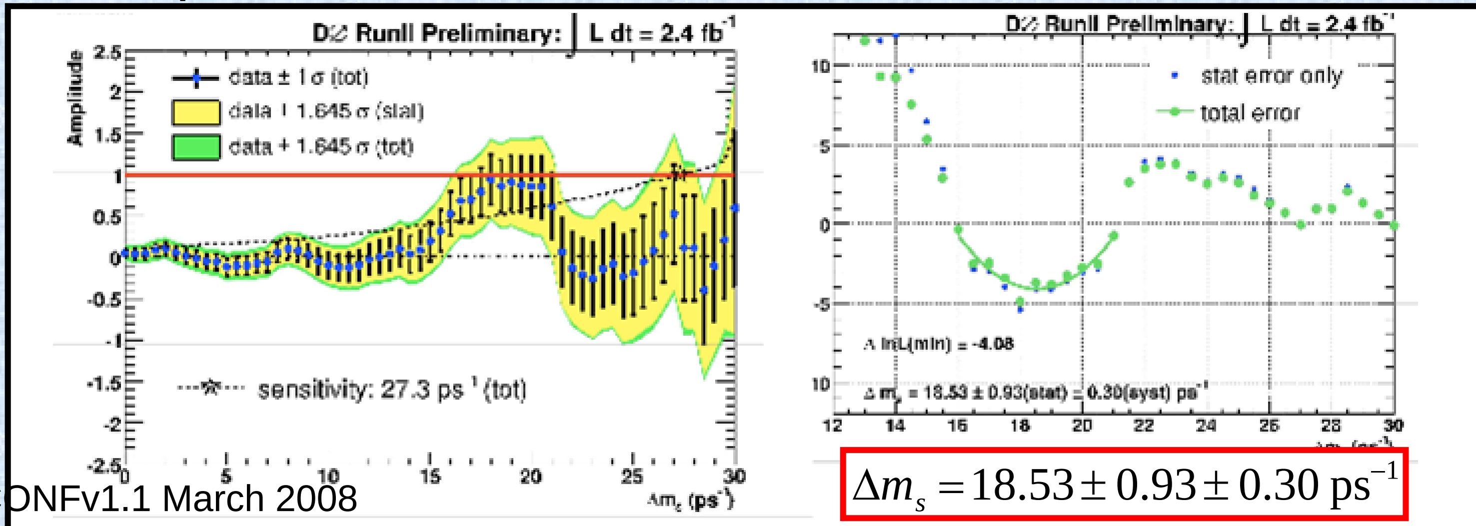


R.Lewis, R.M.Woloshyn PRD79 (2009) 014502

B_s Mixing

One of the most important achievements of the Tevatron

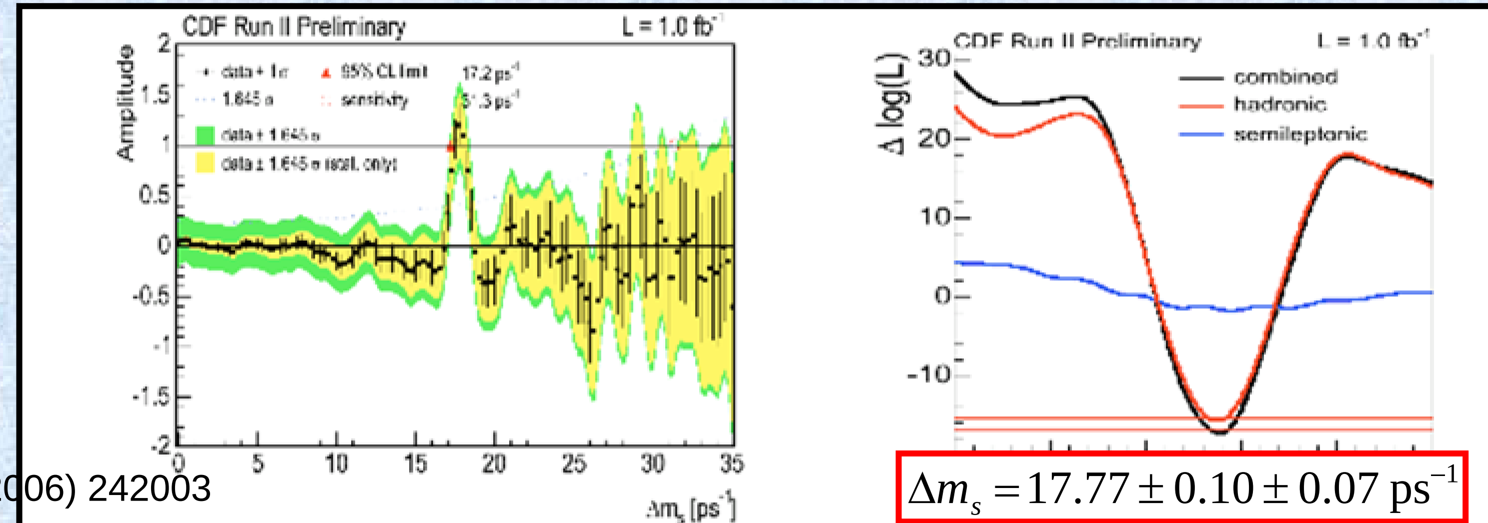
2.4 fb^{-1}



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

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

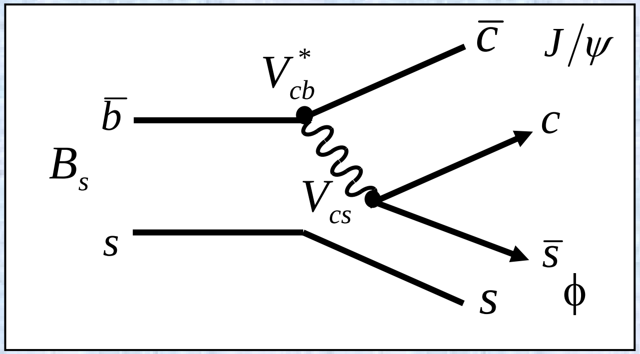
β_s

$B_s \to J/\Psi\phi$ "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

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

NP contributions would effect both phases by same quantity

A.Lenz, ArXiv:0705.3802v2

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

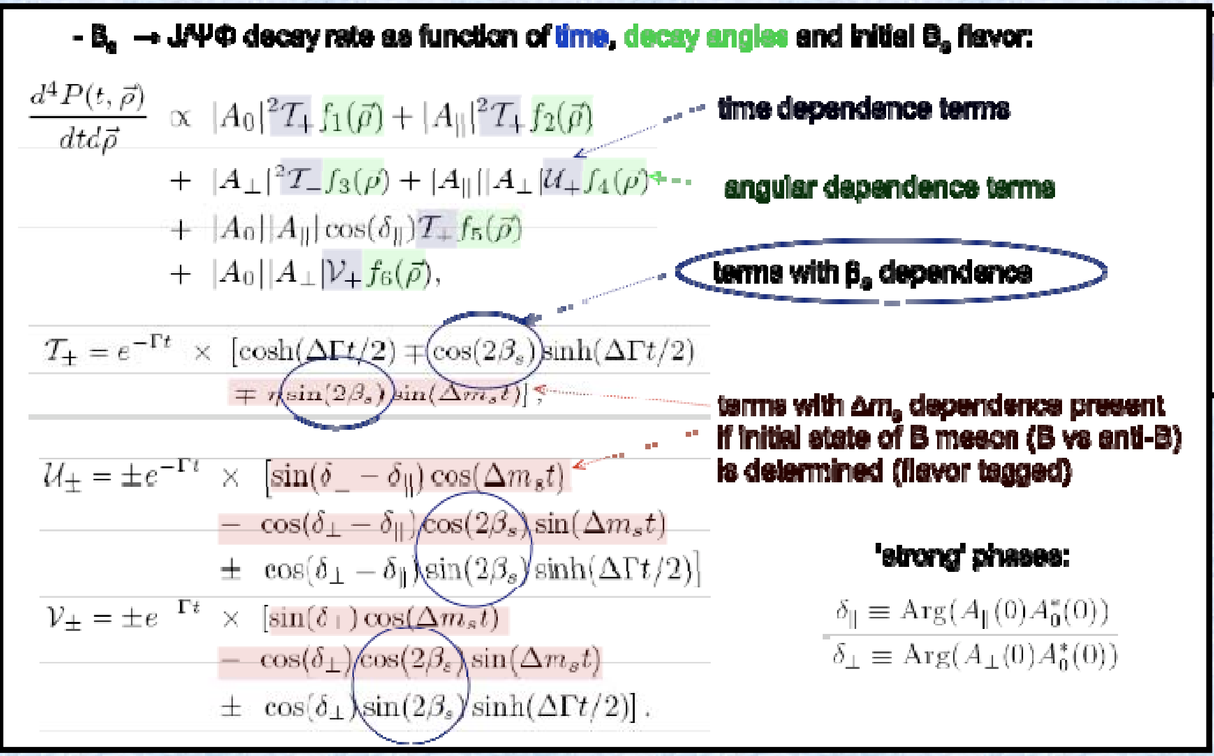
$$\Rightarrow\ 2\beta_s = -\phi_s$$

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

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

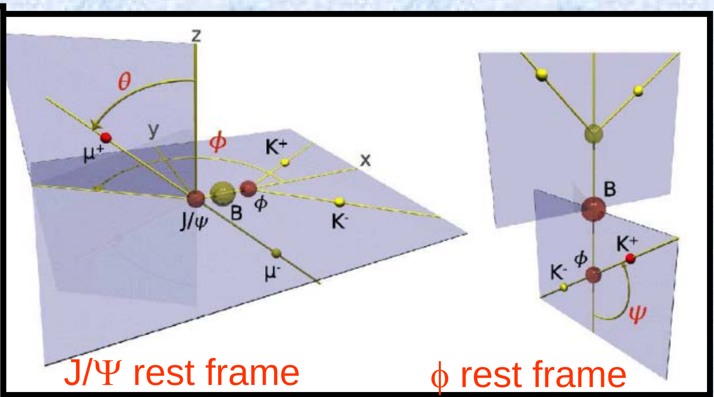
terms with Δm_s dependence present if initial state of B meson (B vs anti-B) is determined (flavor tagged)

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

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

'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

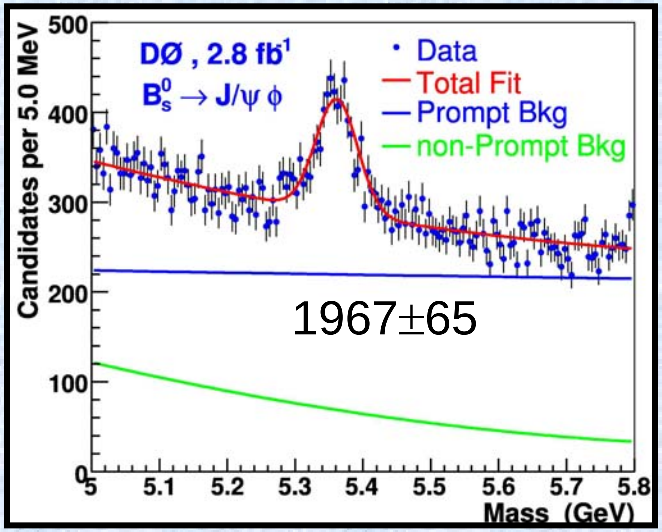
G.Giurgiu, FPCP 2009

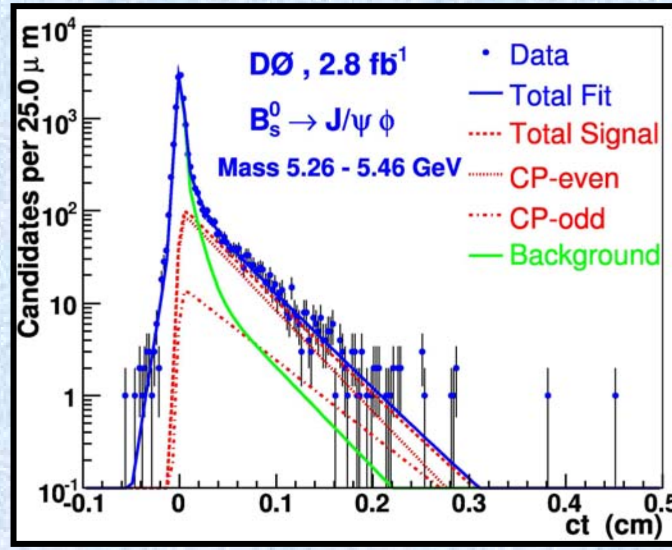
β_s sensitivity has angular dependence, rapidly oscillating in proper time.

β_s

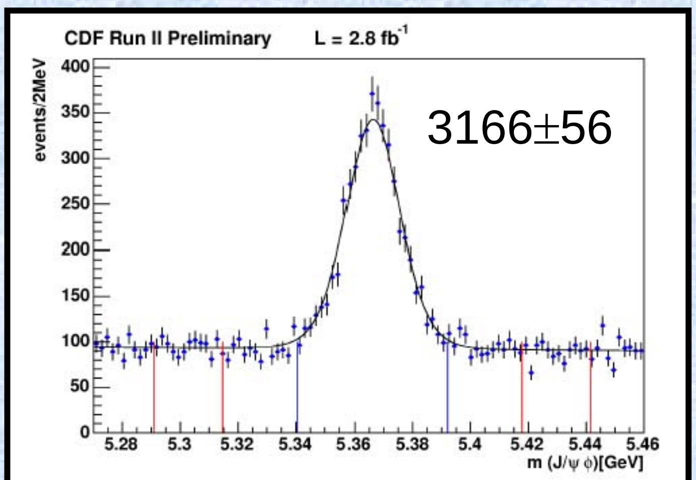
$B_s \to J/\Psi\phi$ signal reconstruction

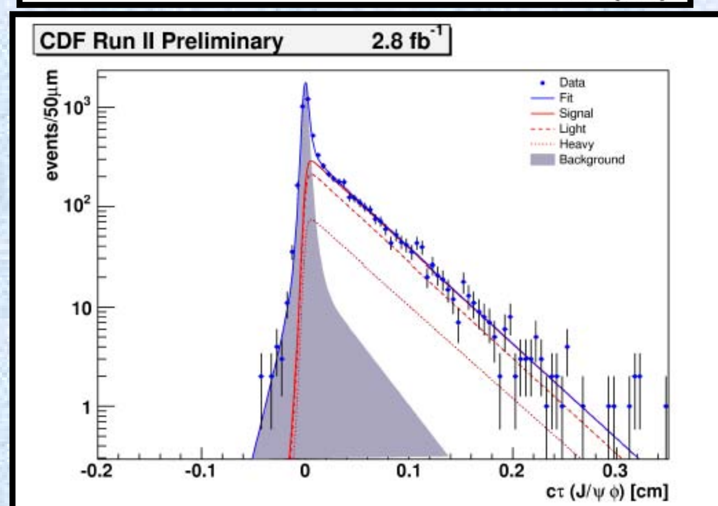
2.8 fb^{-1}





2.8 fb^{-1}

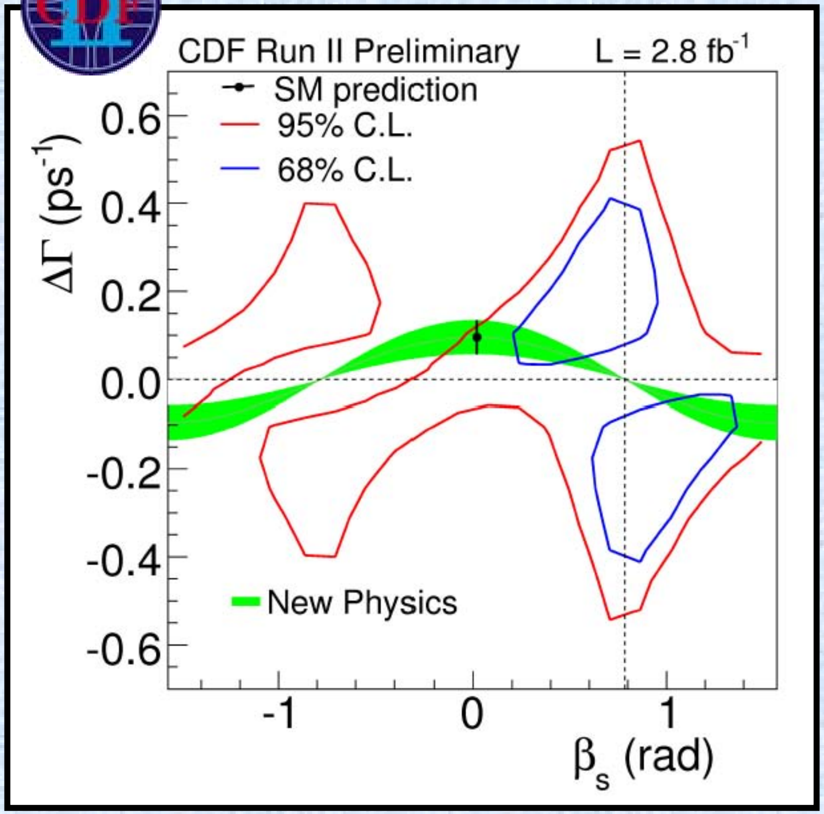


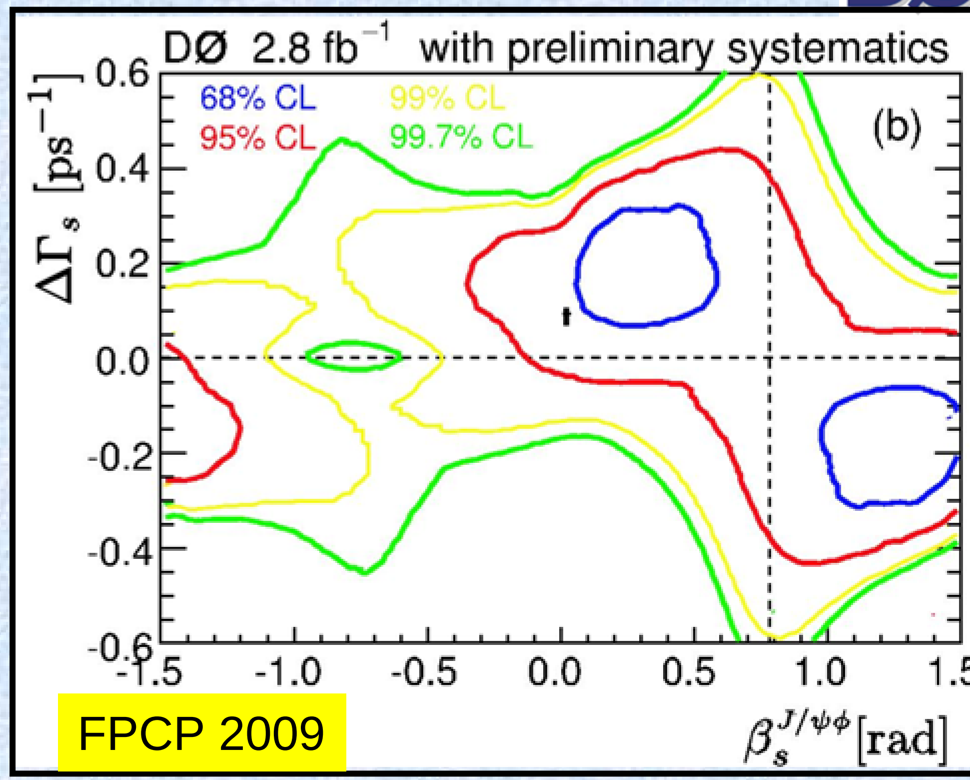


β_s

CDF : CDF/ANAL/BOTTOM/PUBLIC/9458

D0 : D0 Note 5933-CONF





CDF and D0 both favour positive values of β_s

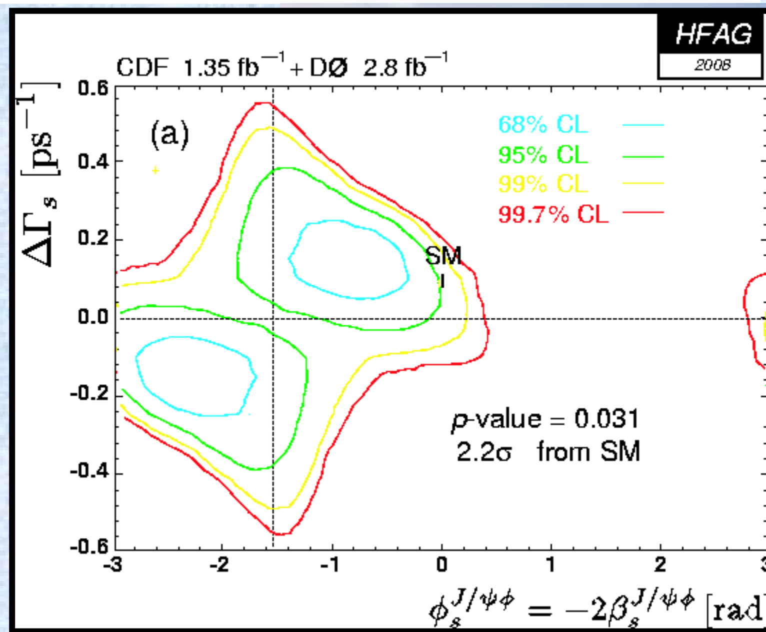
Probability of SM = 7.0%

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

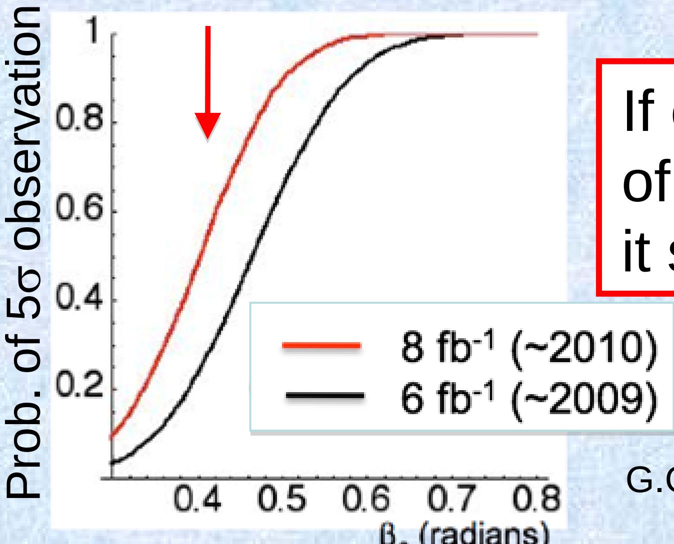
β_s

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

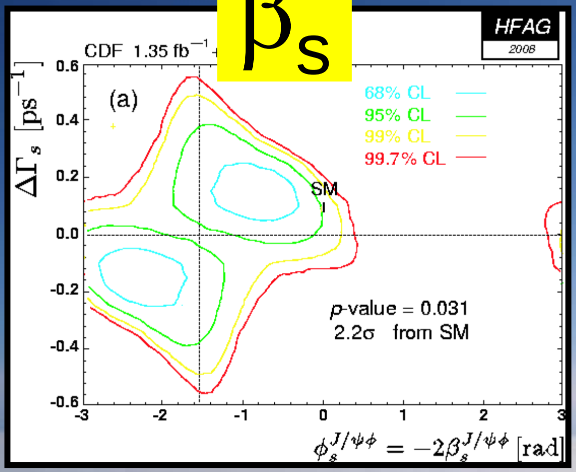


If current preferred value is a fact of nature, the Tevatron will find it soon….

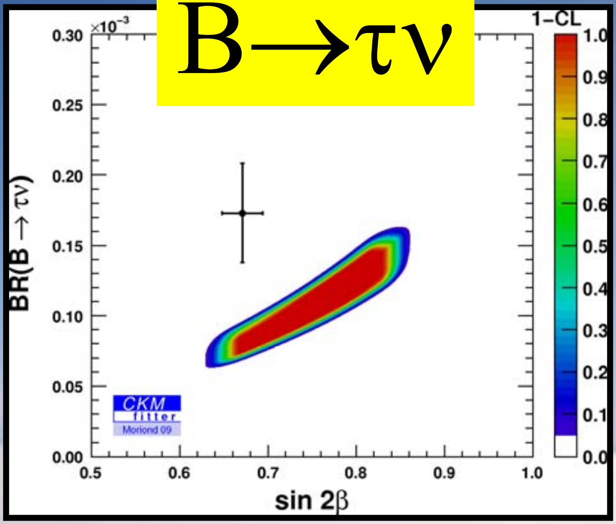
G.Giurgiu, FPCP 2009

Add to the hints/puzzles….

β_s



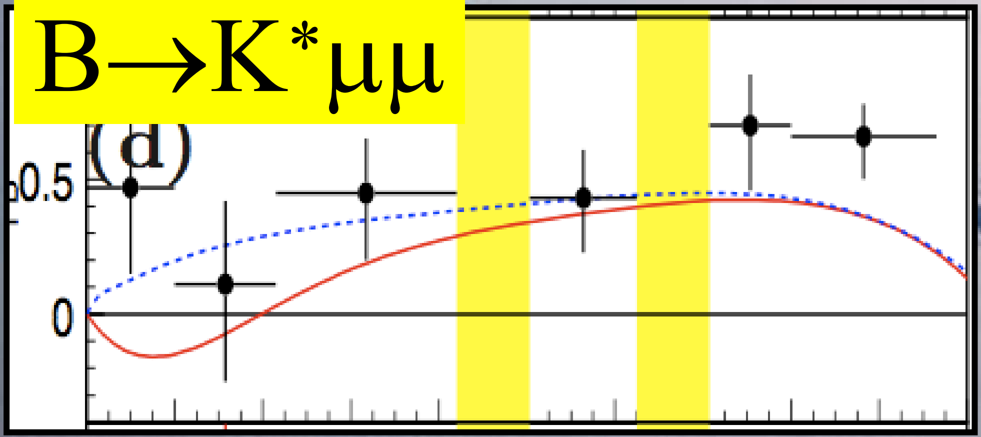
$B \to \tau\nu$



β_{eff}

"Kπ Puzzle"

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



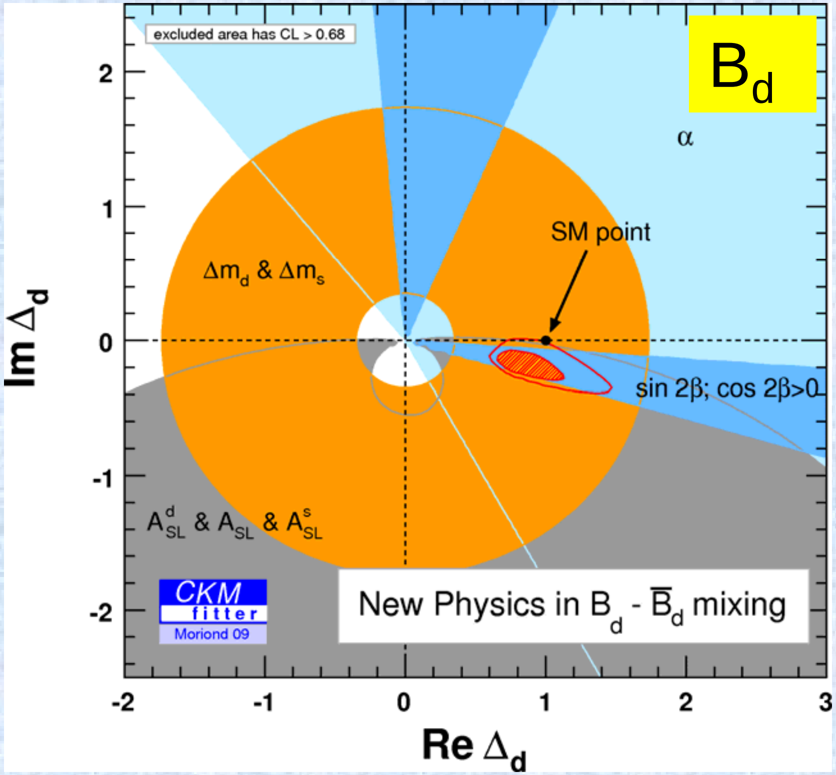
No convincing evidence of New Physics… yet…

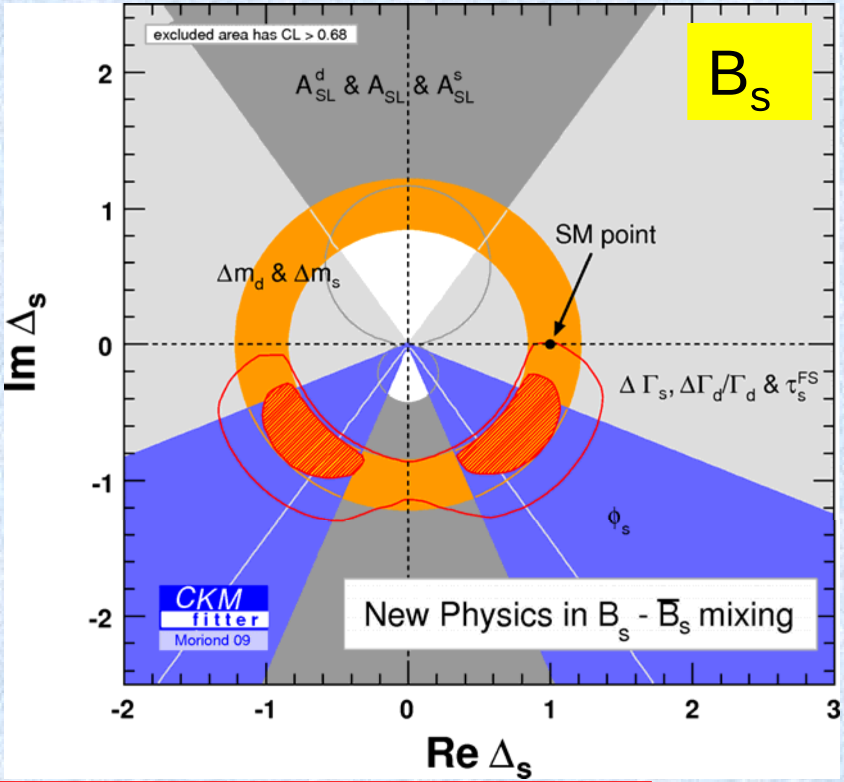
Is there still room for New Physics ?

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: $\sqrt{s}$=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%),…)

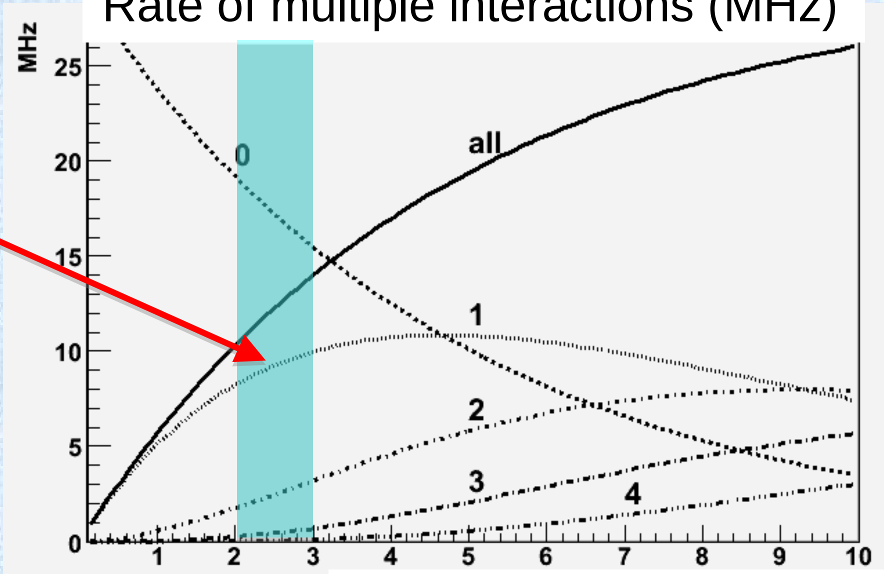
Ultimate luminosity of LHC : 10^{34} cm^{-2}s^{-1}

- 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}

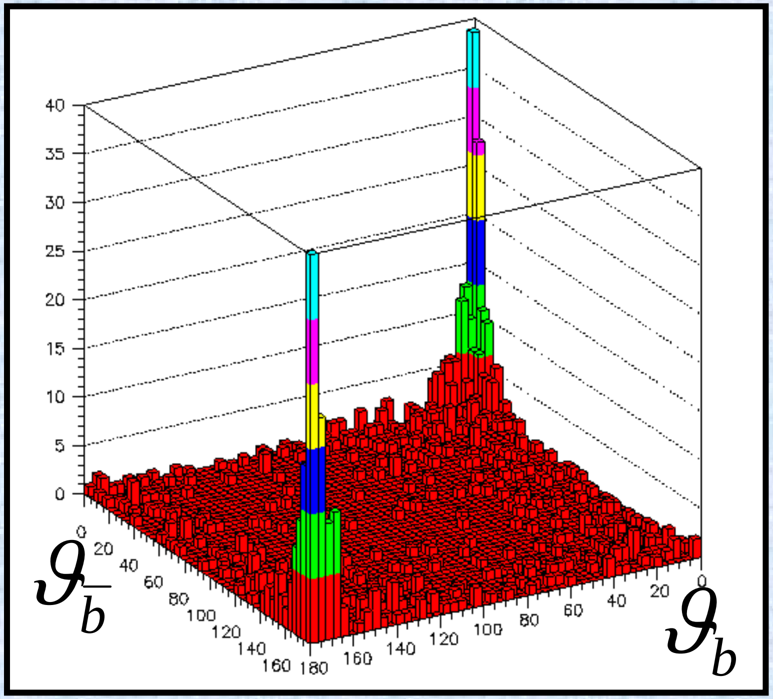
ATLAS/CMS: 10^{33} cm^{-2} s^{-1} in the first 3 years

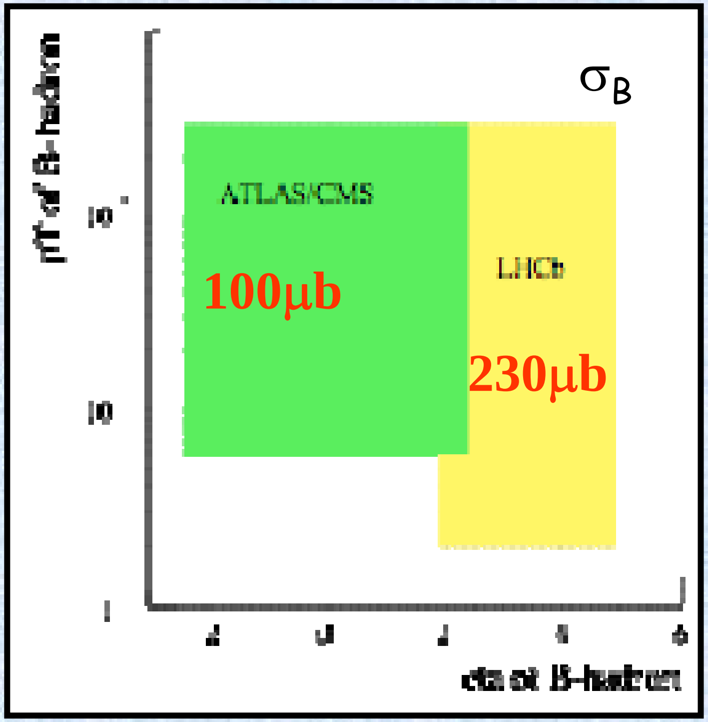
Nominal year: LHCb 2 fb^{-1}, ATLAS/CMS 10 fb^{-1}

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



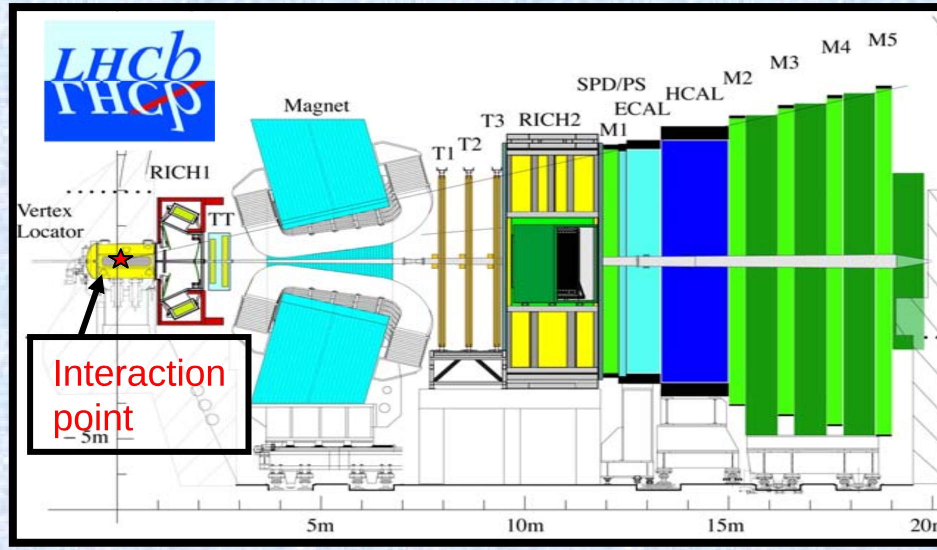


ATLAS/CMS: $|\eta| < 2.5$
LHCb : $1.9 < \eta < 4.9$

LHCb

LHCb

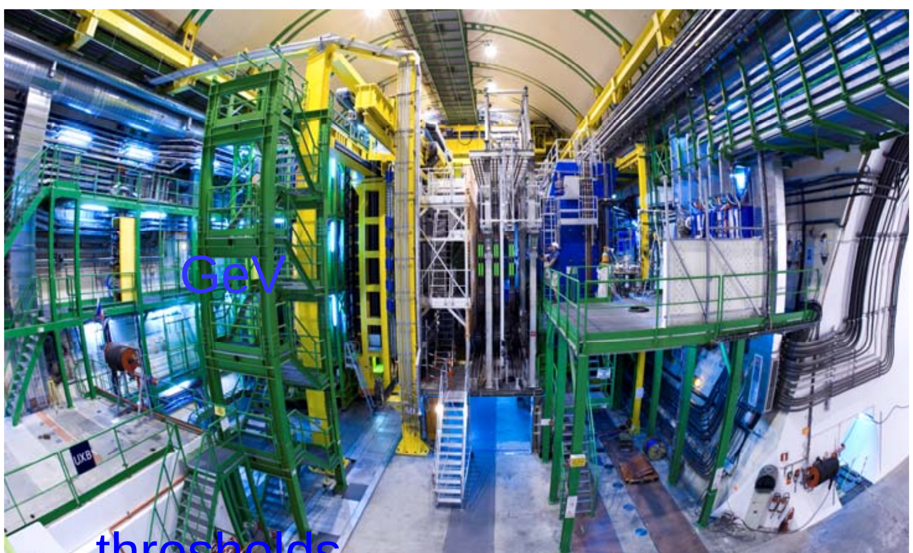
An experiment dedicated to the search for New Physics in heavy flavours



Forward single arm spectrometer

Excellent tracking

precision silicon VELO detector



Excellent particle identification

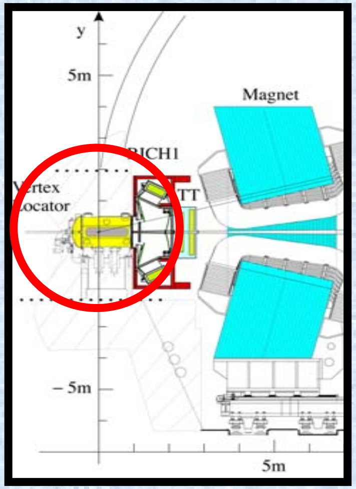
2 RICH detectors

π/K separation over p ~2–100 GeV

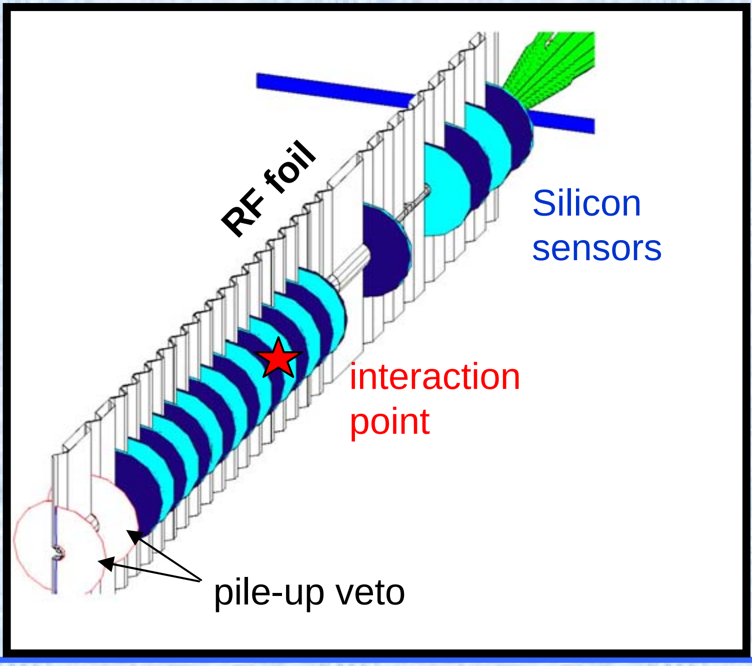
Efficient Trigger

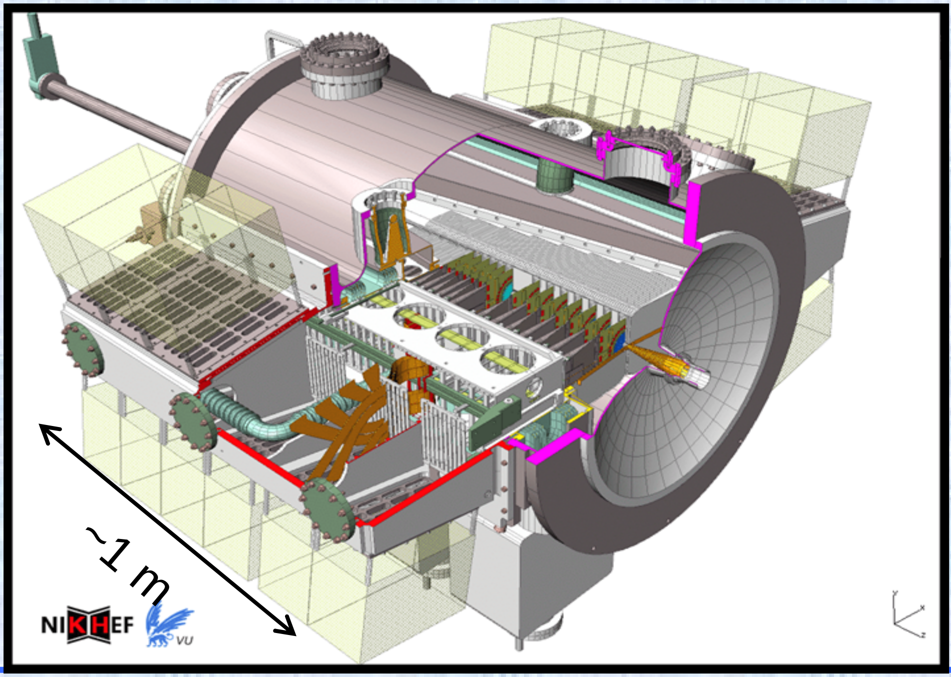
Low p_T lepton, γ/π^0 & hadron thresholds

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



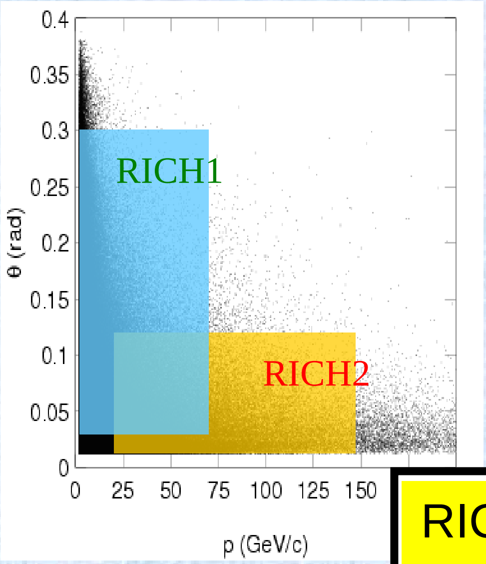


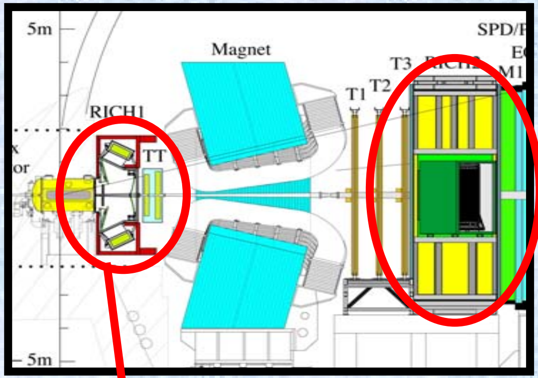
42 VELO modules
r and ϕ layer
n^+n type
2048 strips/sensor
Strip pitch 40-100 mm

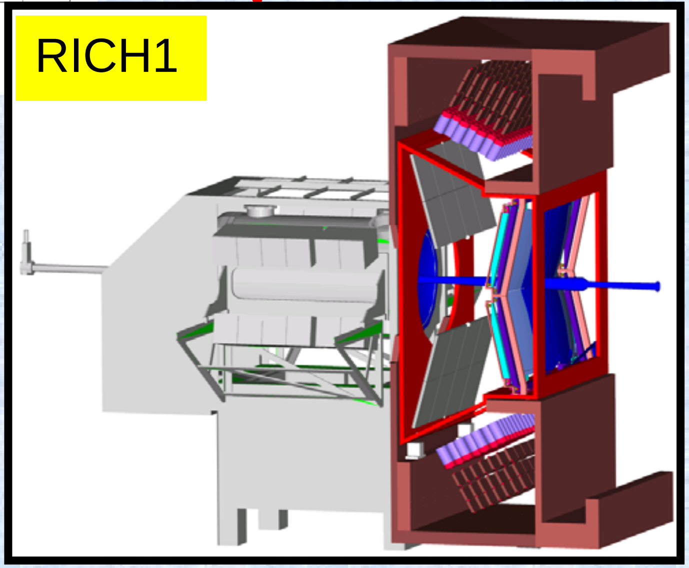
A VELO half during installation

RICH Detectors

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







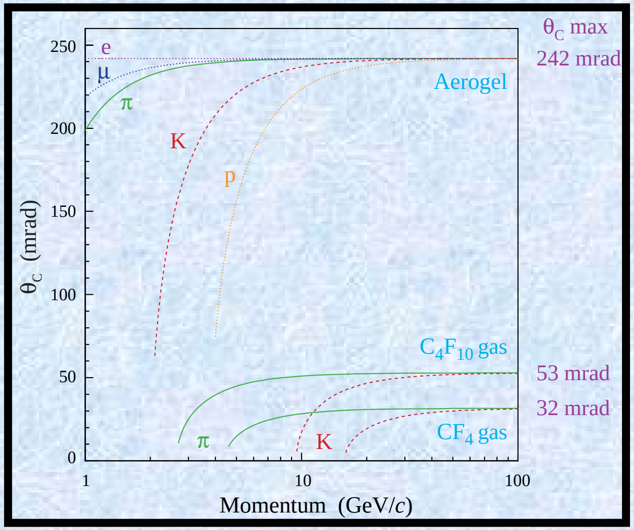
RICH Detectors

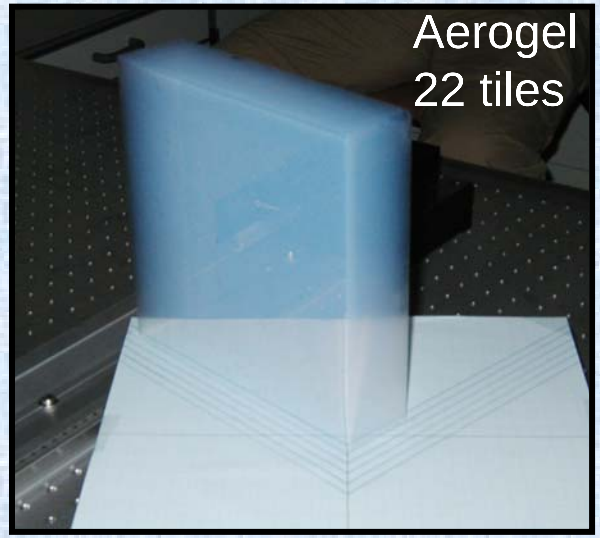
3 radiators

RICH1 Aerogel (2-10 GeV)

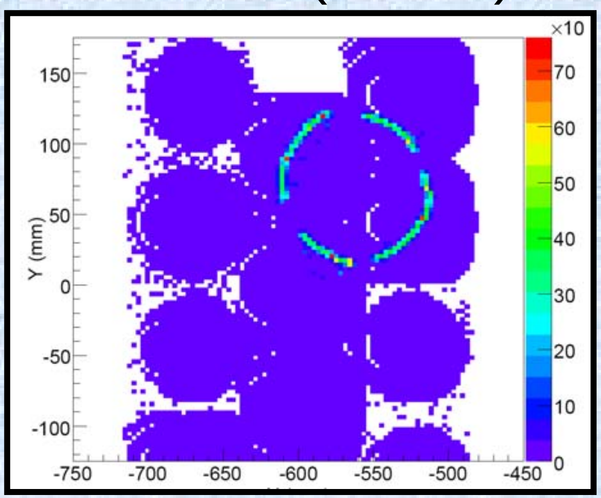
C_4F_{10} (10-60 GeV)

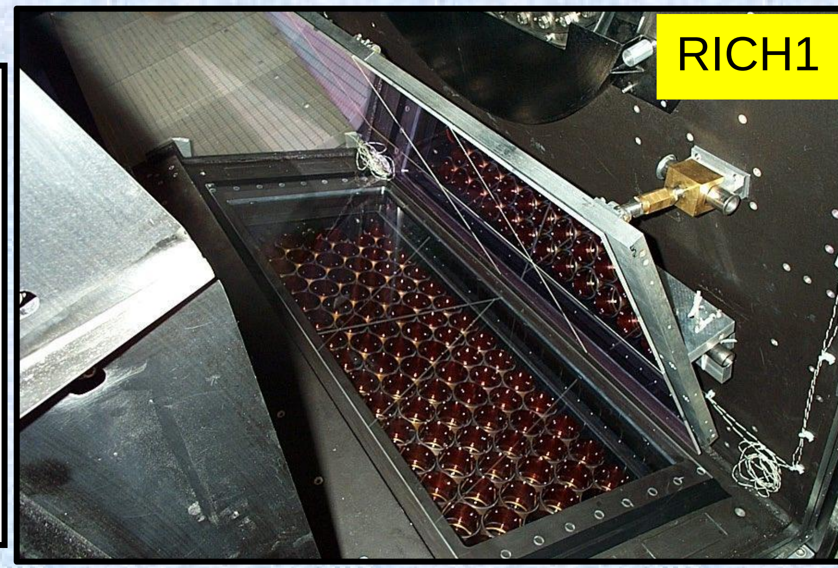
RICH2 CF_4 (16-100 GeV)





484 Hybrid Photo Detectors (HPD's)

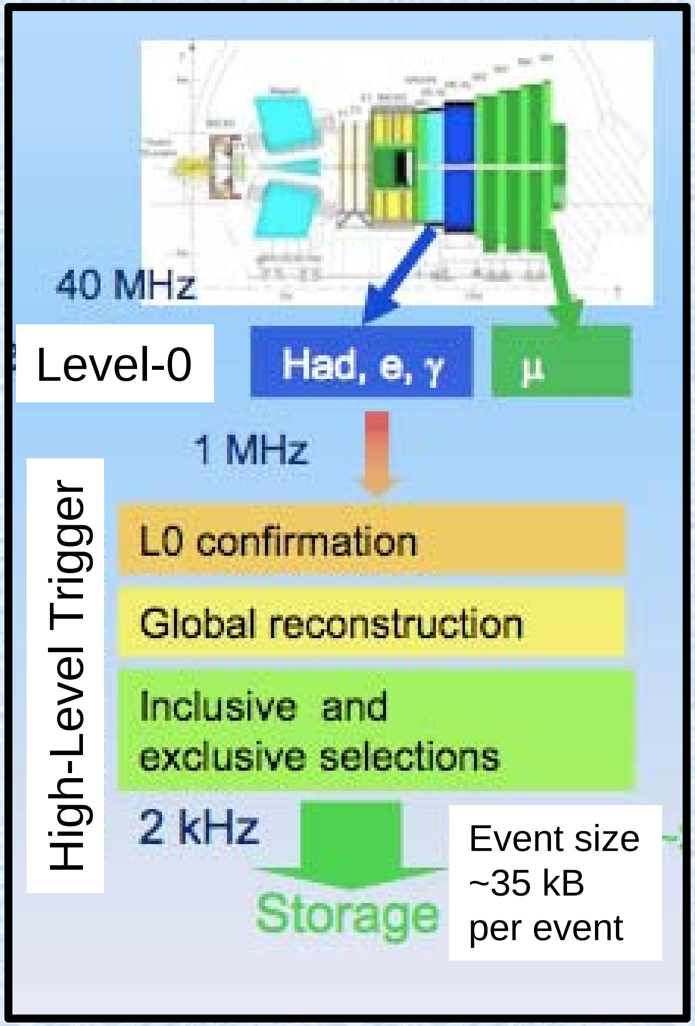




Trigger

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)

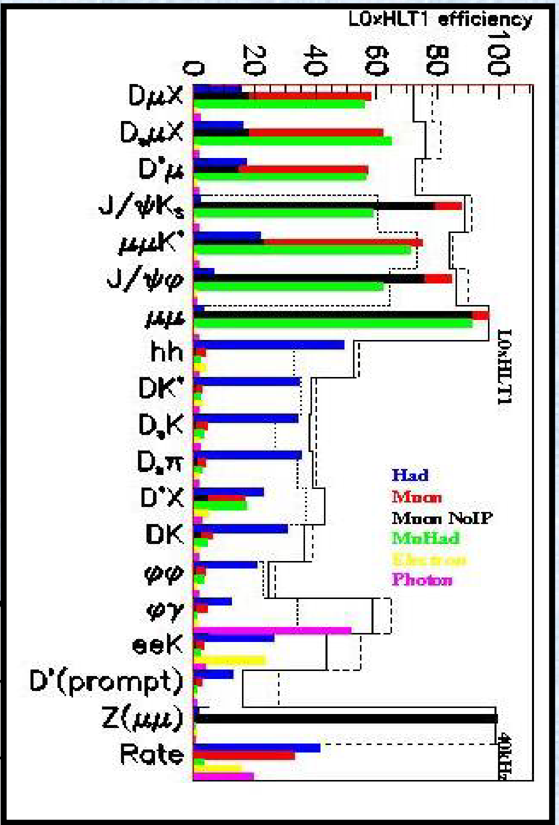
- Run on CPU farm (1800 nodes)
- Access to all detector data
- Use more tracking to re-confirm L0 decision
- Full event reconstruction; inclusive and exclusive selections

Output rate 2 kHz

Trigger

Expected trigger performance

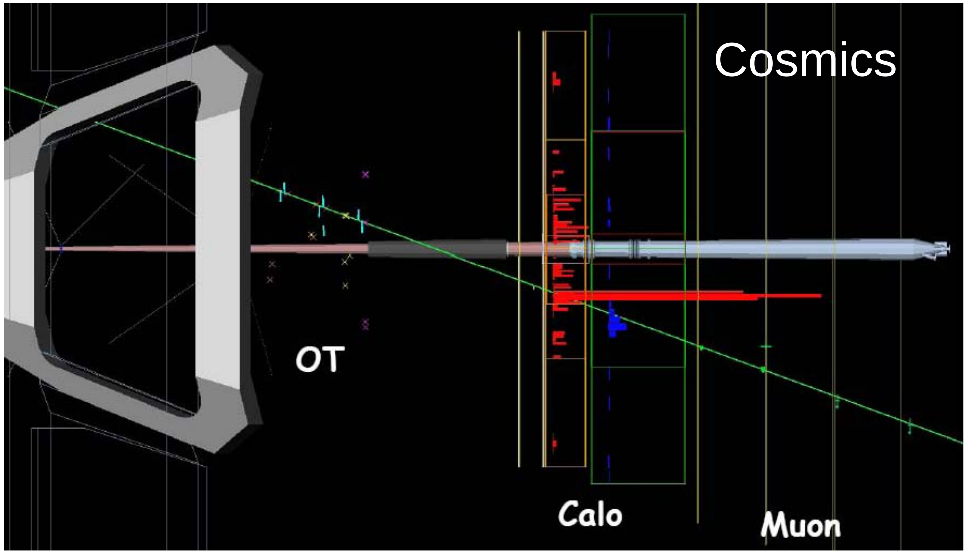
	e(L0)	e(HLT)	e(total)
Hadronic	50%	80%	40%
Electromagnetic	70 %	60%	40%
Muon	90%	80%	70%

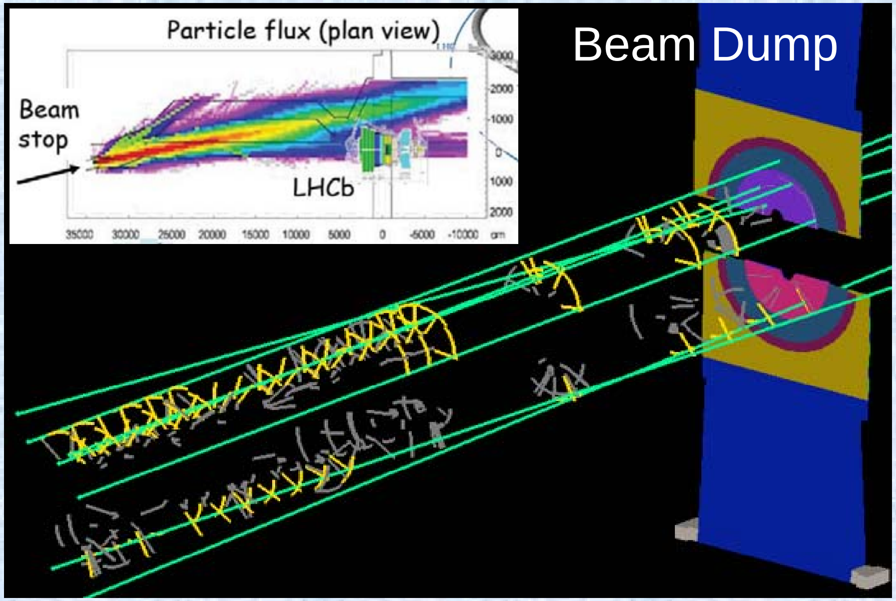


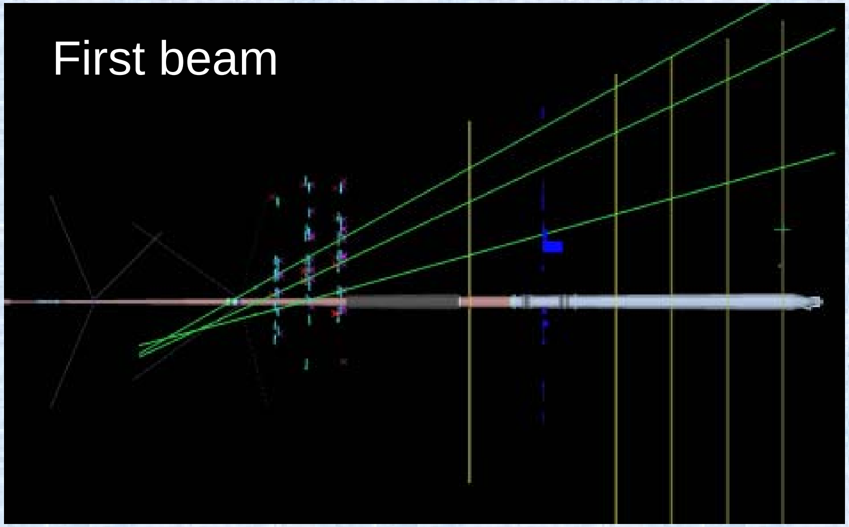
Output rate	Trigger Type	Physics Use
200 Hz	Exclusive B candidates	Specific final states
600 Hz	High Mass di-muons	J/ψ, $b \to J/\psi X$
300 Hz	D* Candidates	Charm, calibrations
900 Hz	Inclusive b (e.g. $b \to \mu$)	B data mining

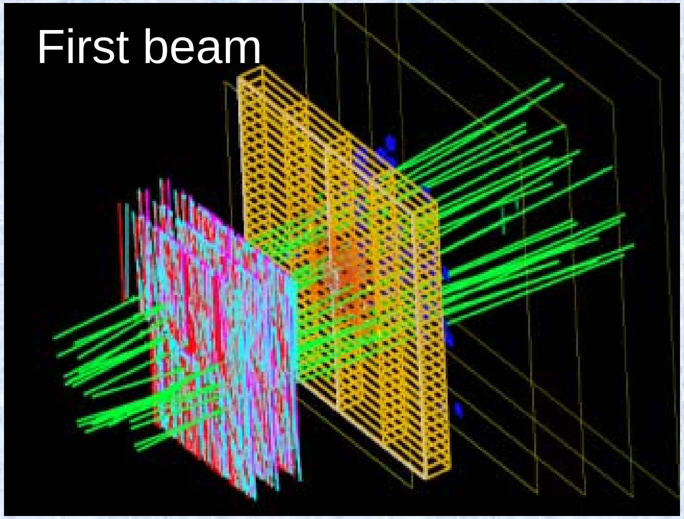
Total 2000 Hz

LHCb Commissioning









Just waiting for collisions…

ATLAS & CMS

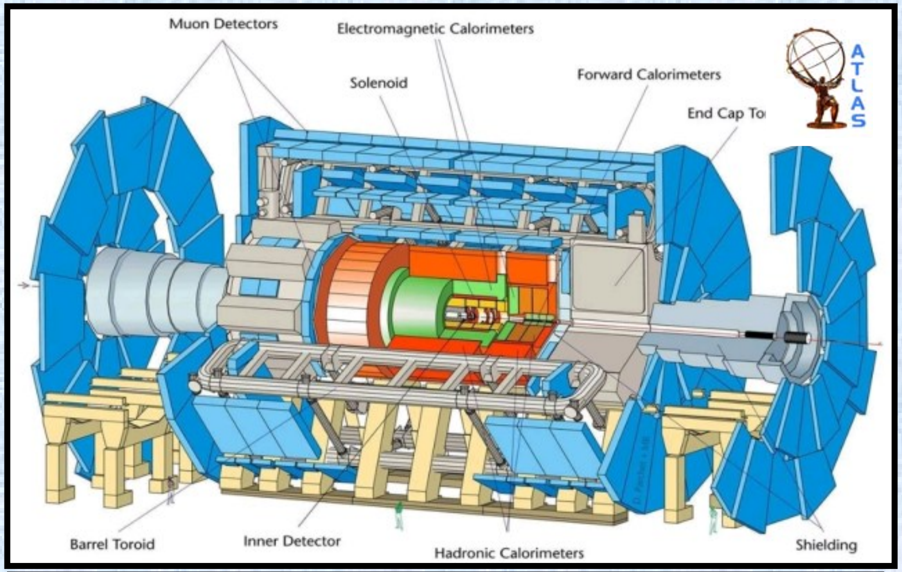
ATLAS and CMS are designed to explore the high energy frontier

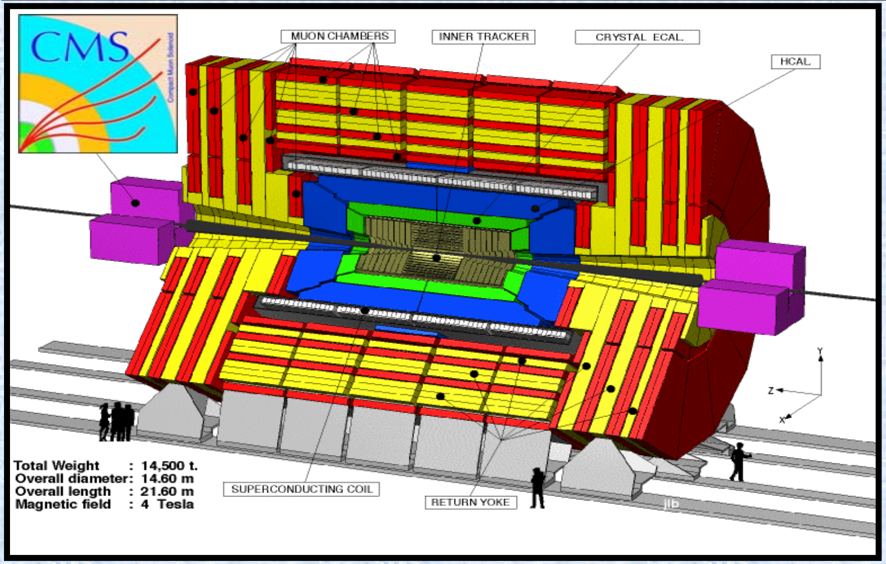
Excellent tracking

- 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

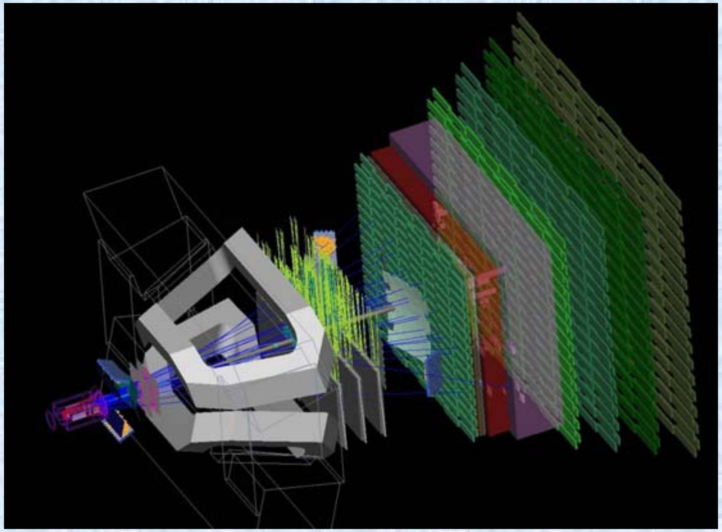




Performances

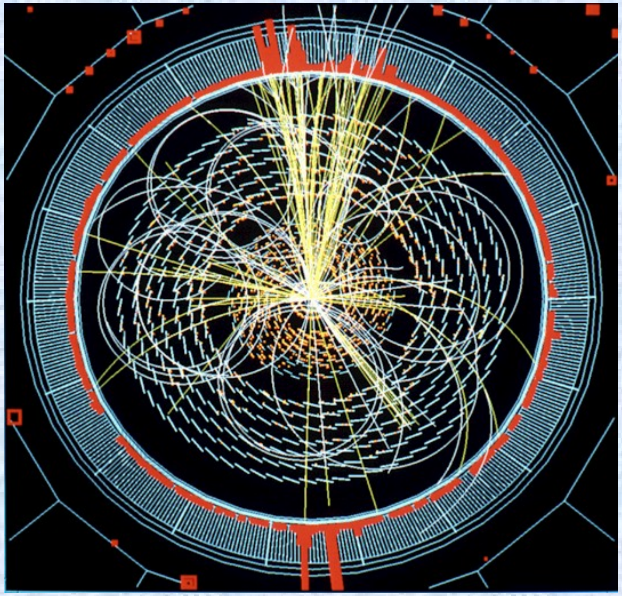
Mass resolutions (MeV/c^2)

	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

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

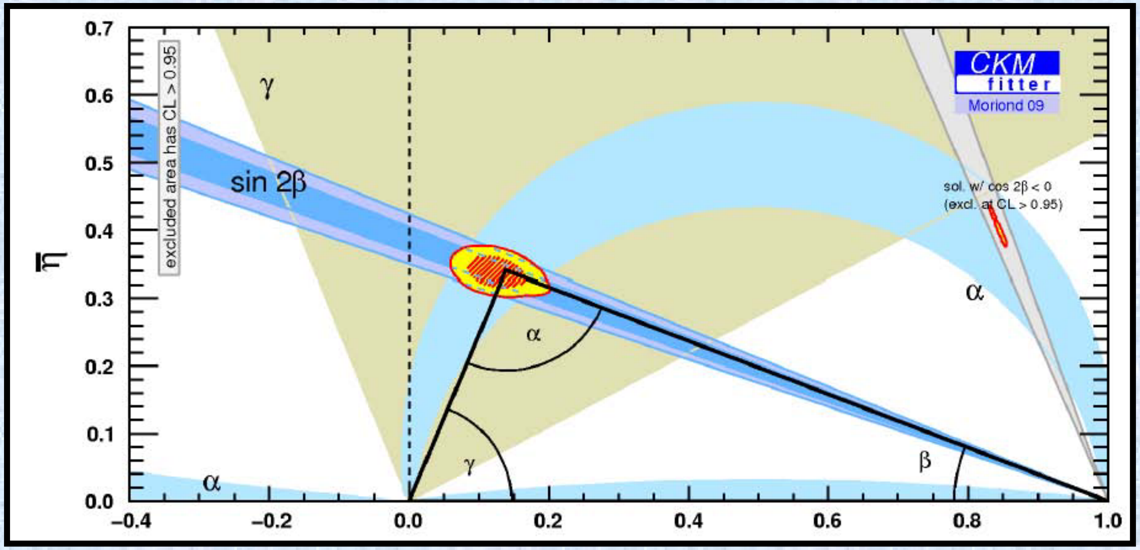
The tree-level determination of γ at LHCb

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

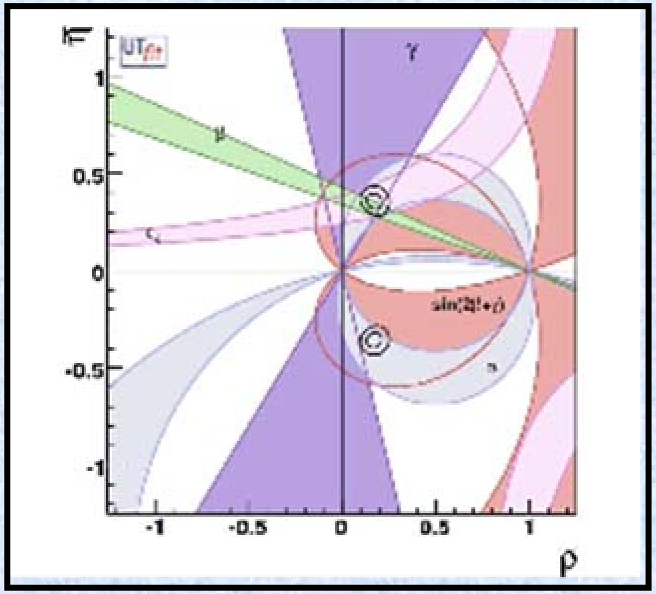
Roadmap for the analysis of $\mathrm{B_d} \to \mathrm{K}^{*0}\mu^+\mu^-$

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…



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



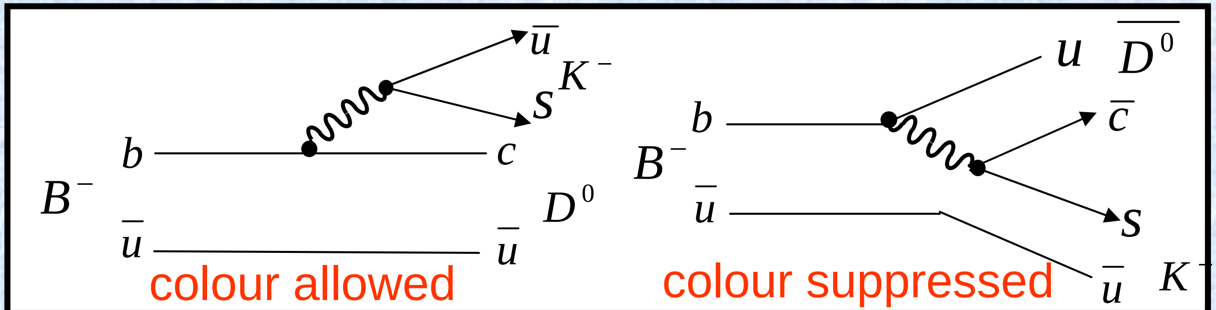
$$\gamma = (78 \pm 12)^\circ$$

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



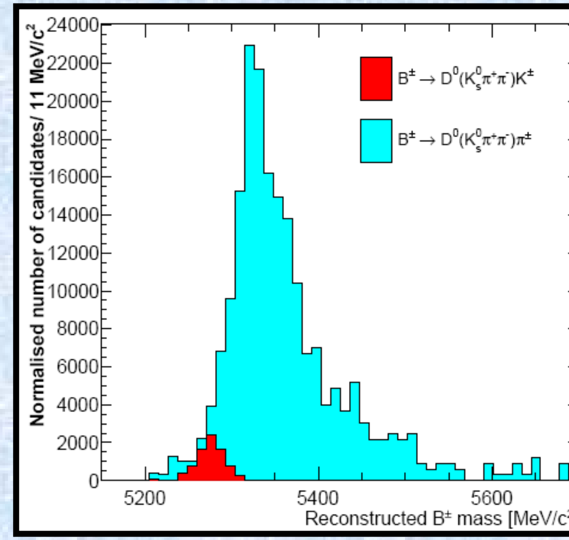
Self-tagging – full statistics can be used

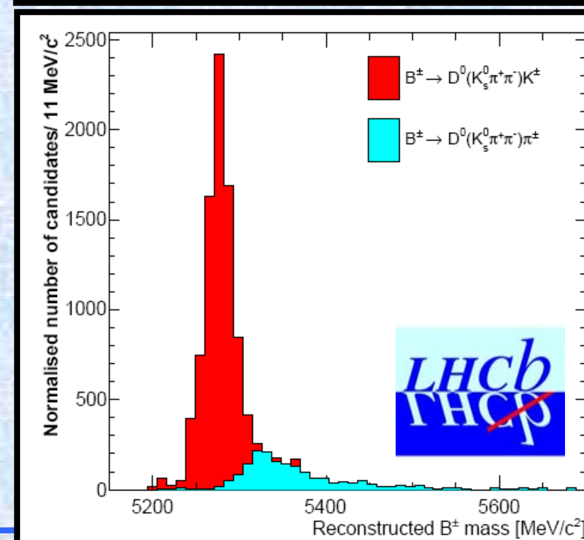
Lots of kaons – particle id (RICH) invaluable

ADS/GLW

GGSZ

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

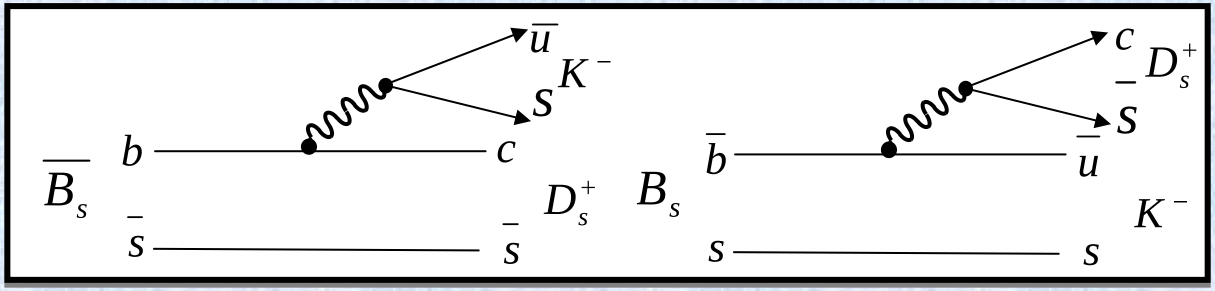




γ from trees

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

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



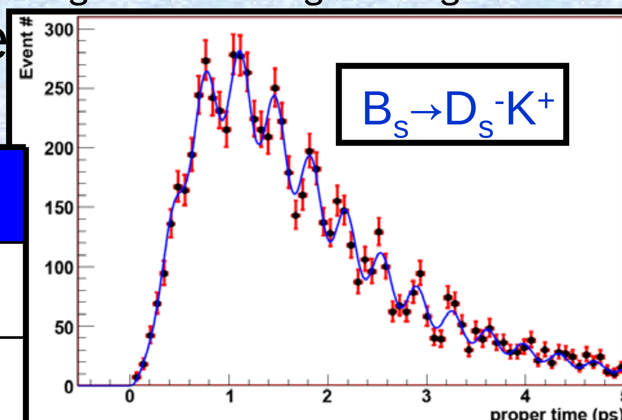
Large interference effects

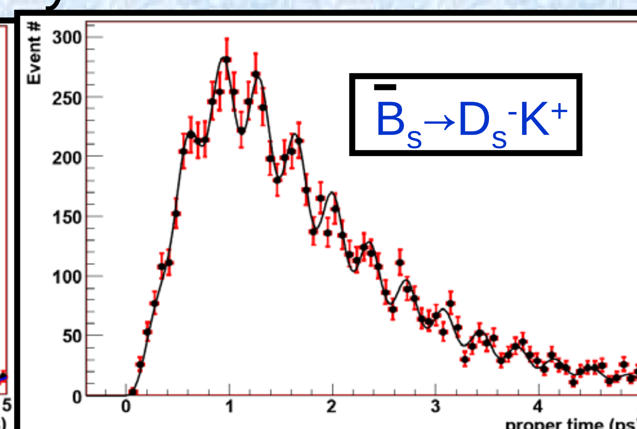
$$r_{DK} \sim \frac{1}{\lambda}\left|\frac{V_{ub}}{V_{cb}}\right| \approx 0.4$$

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

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

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

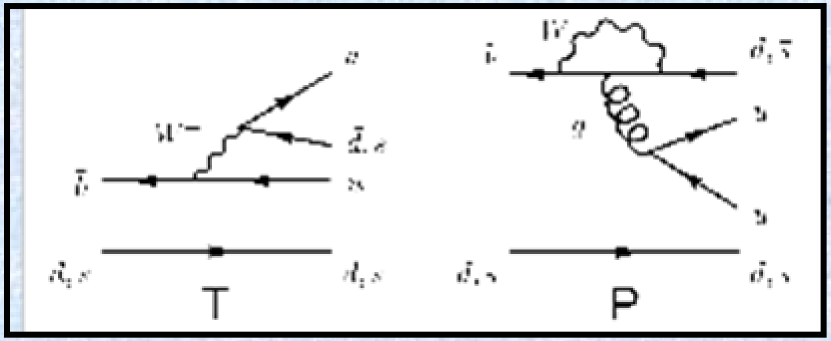
Time dependent measurements: $B^0 \to D\pi$, $B_s \to D_sK$

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

LHCb 10 fb^{-1} : γ precision 2-3

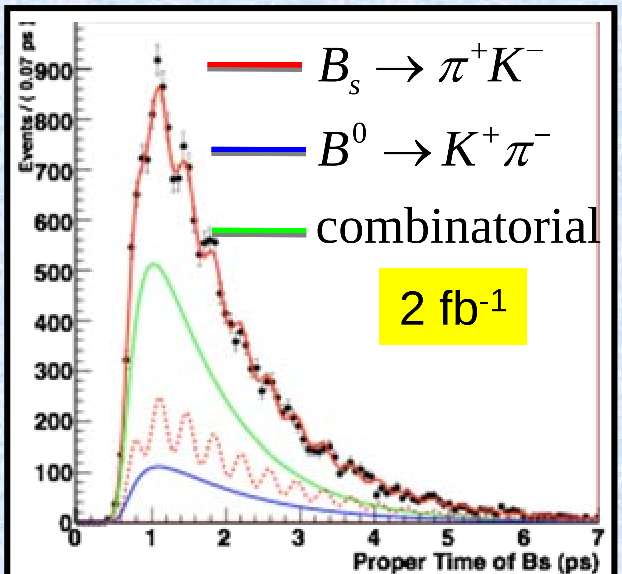
γ from loops : B→hh strategy

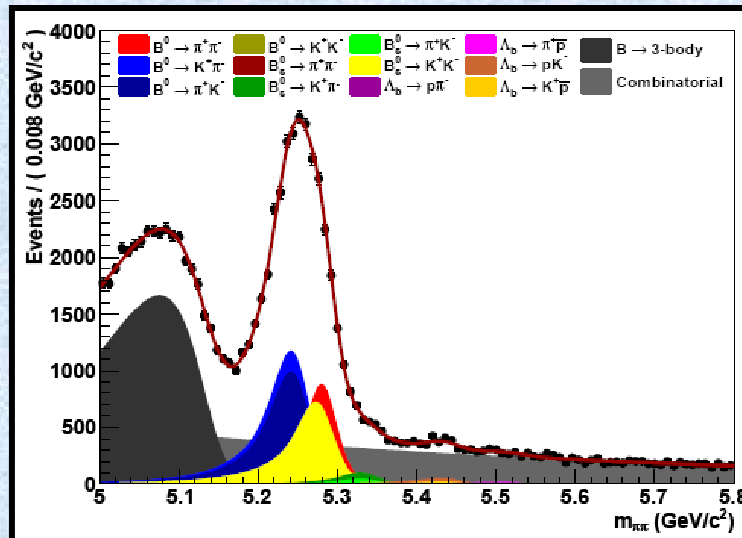
Sensitive to NP in penguin contributions



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

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

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

The 4 observables depend on 7 parameters

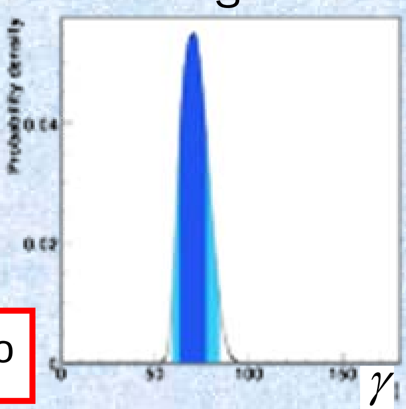
in

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

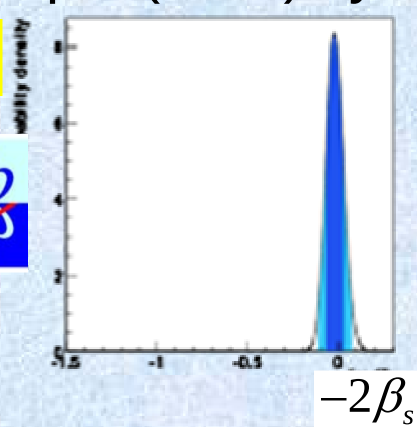
d ,ϑ (d',ϑ') parametrizes P/T ratio of decay transitions $B_d \to \pi^+\pi^-$ ($B_s \to K^+K^-$)

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

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



2 fb^{-1}

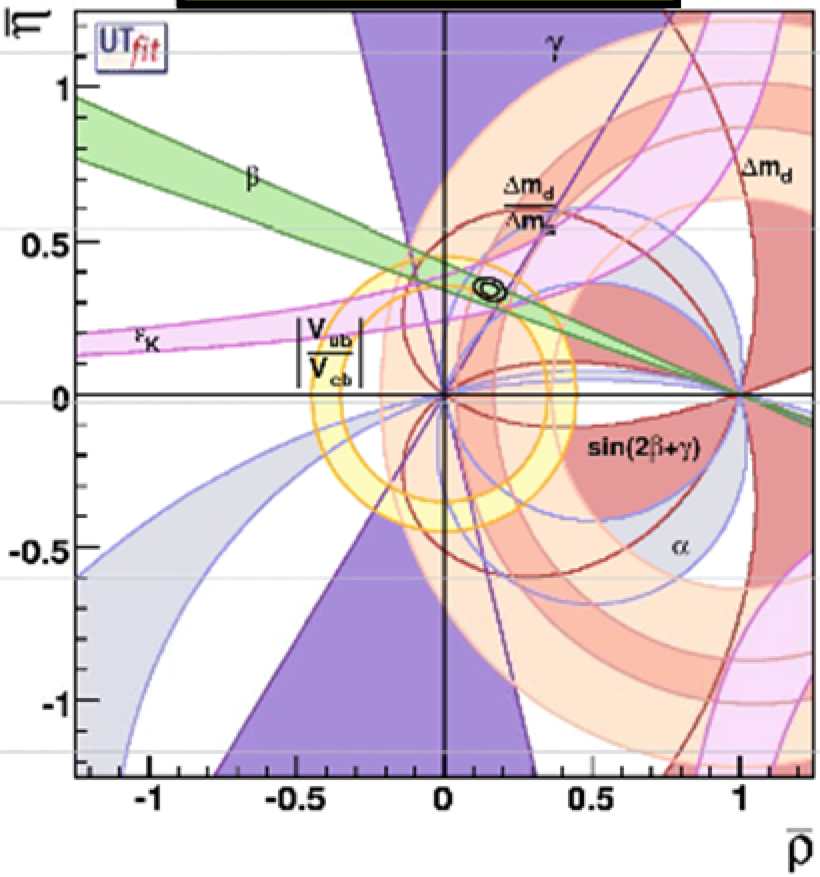


$\sigma(\gamma) = 7^o$

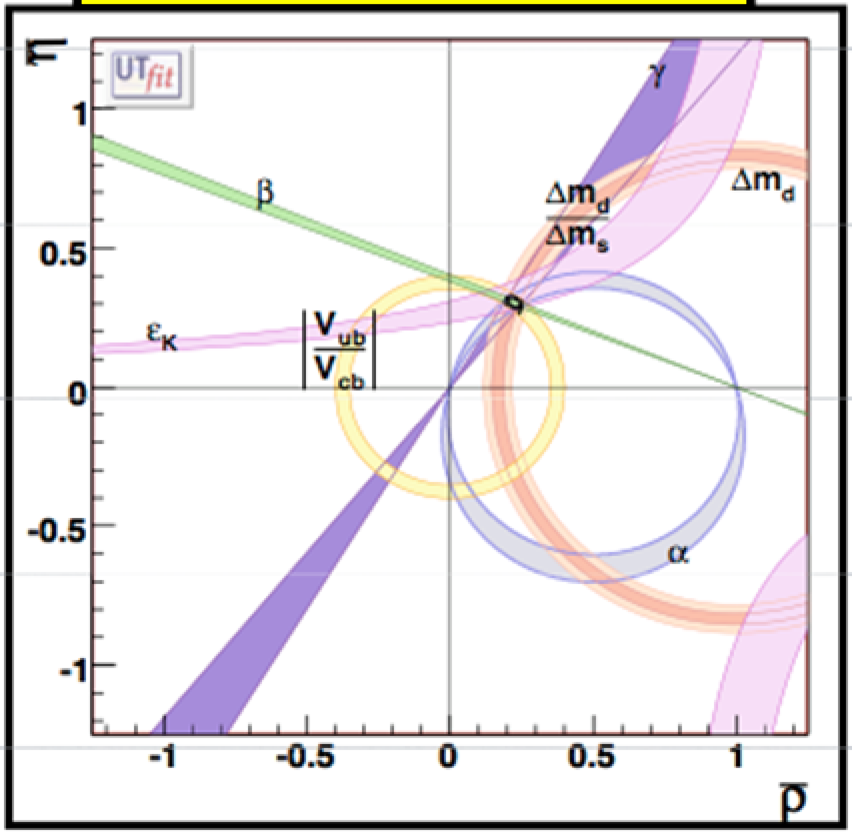
$\sigma(\beta_s) = 0.025$ rad

CKM 2014

Winter 2009



LHCb at L=10fb^{-1}



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

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

β_s

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

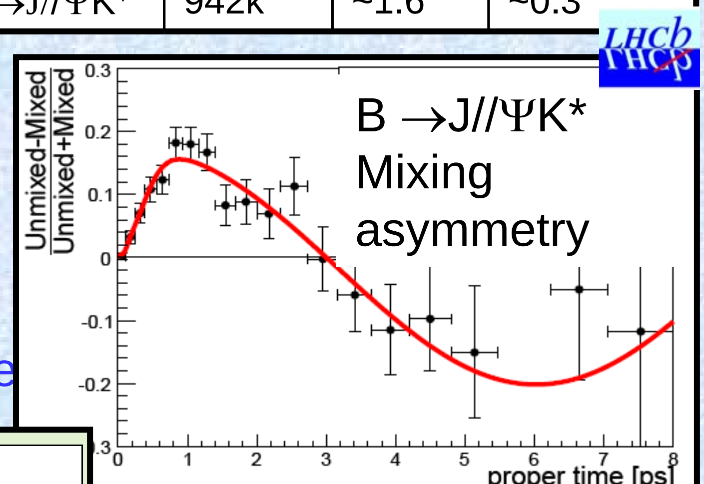
Final state is a mixture of CP-even and CP-odd

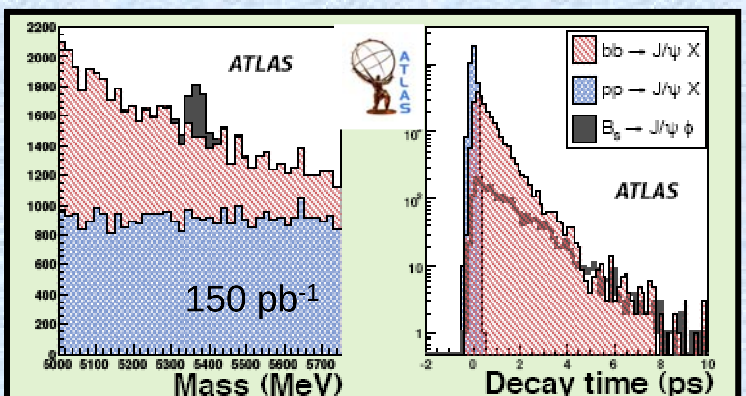
control channels

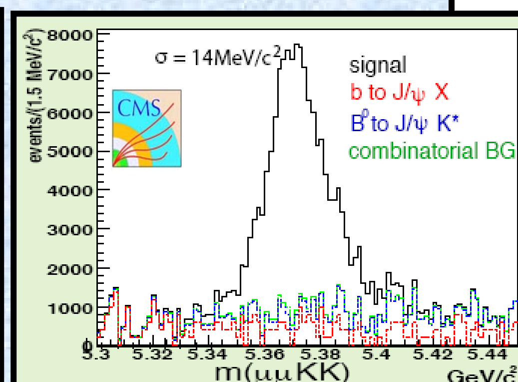
Channel	Yield (2 fb^{-1})	B/S prompt	B/S long-lived
$B_s \to J/\!/\Psi\phi$	117k	~1.6	~0.5
$B \to J/\!/\Psi K^*$	489k	~5.2	~1.5
$B \to J/\!/\Psi K^+$	942k	~1.6	~0.3

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



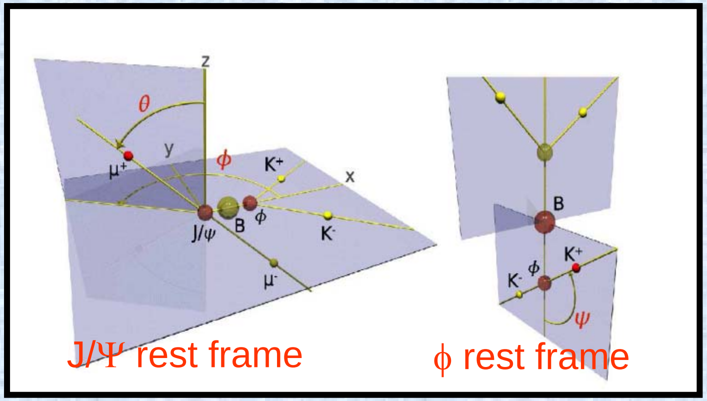




$B_s \to J/\!/\Psi\phi$ in ATLAS & CMS

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

β_s

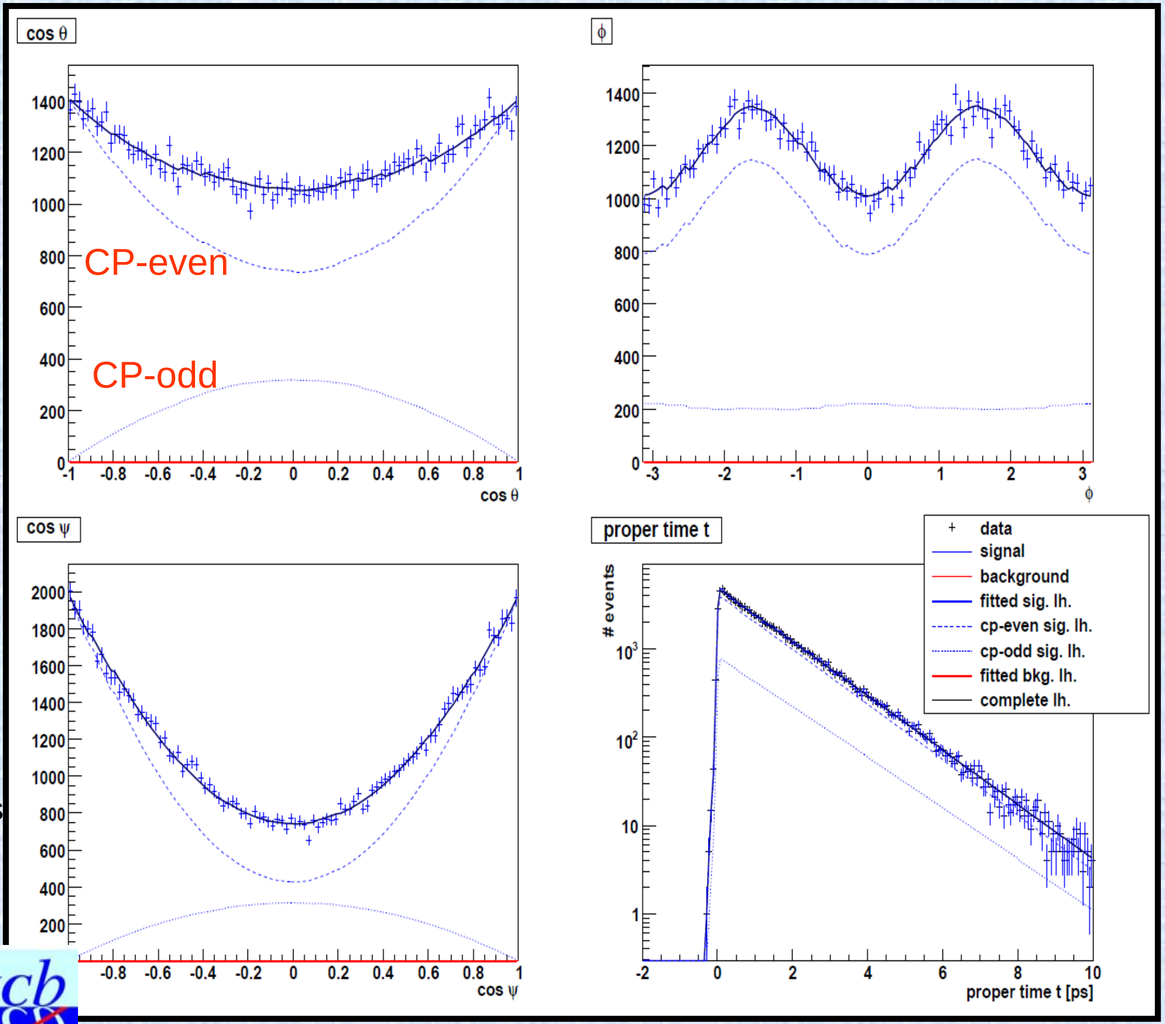


3 angles (θ, ϕ, ψ) describe direction of final decay products

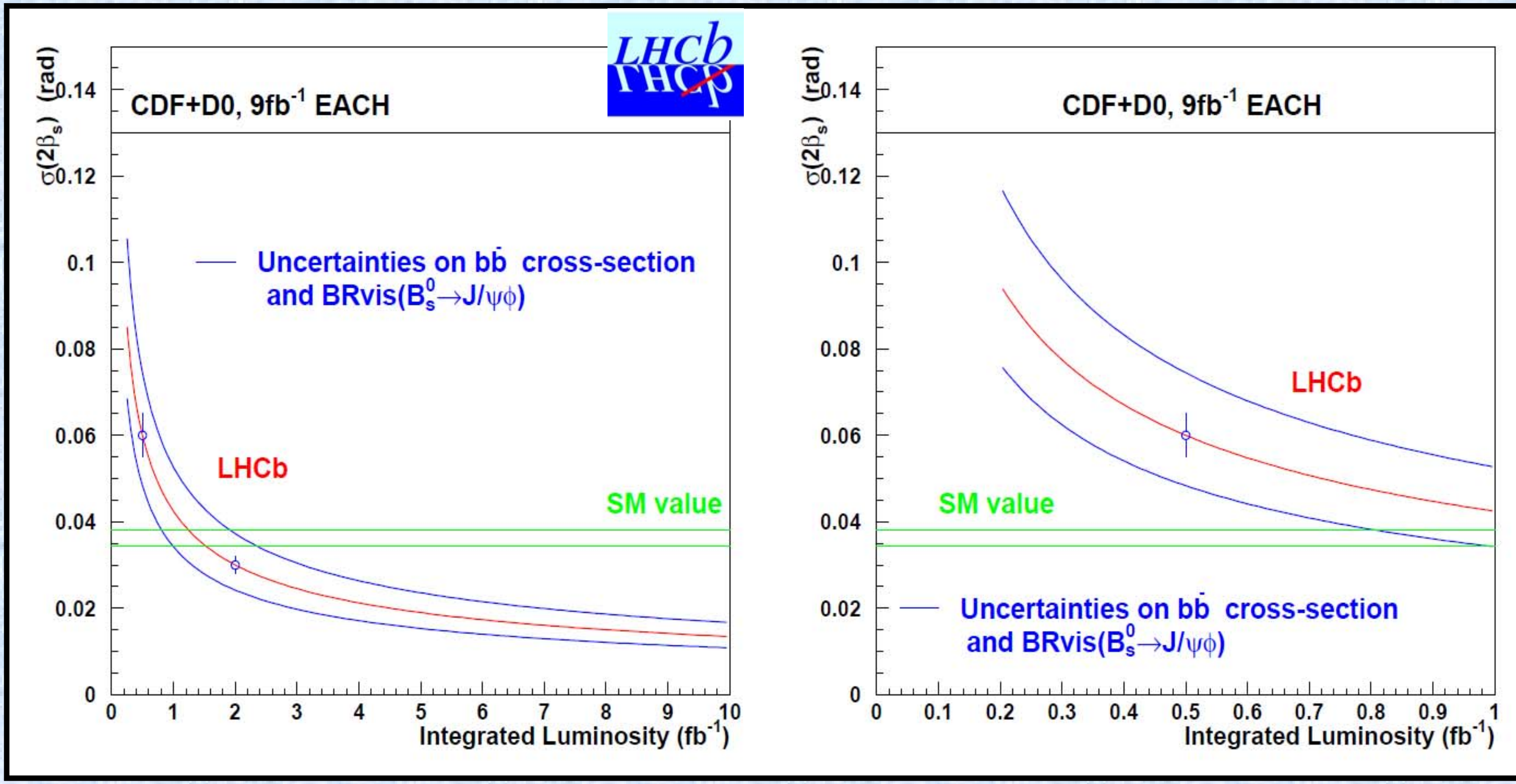
Fit to angular distributions, proper time, flavour tag, mass

→ 7 free parameters including β_s

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



β_s



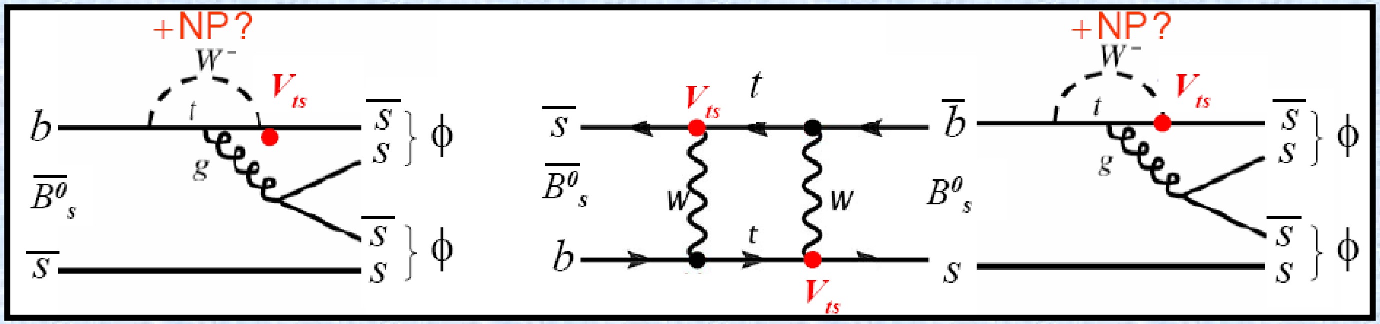
If $2\beta_s$ is in fact the central value measured by the Tevatron (~0.8), then LHCb should have a 5σ observation with 200 pb^{-1}

$b \to sqq$ 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

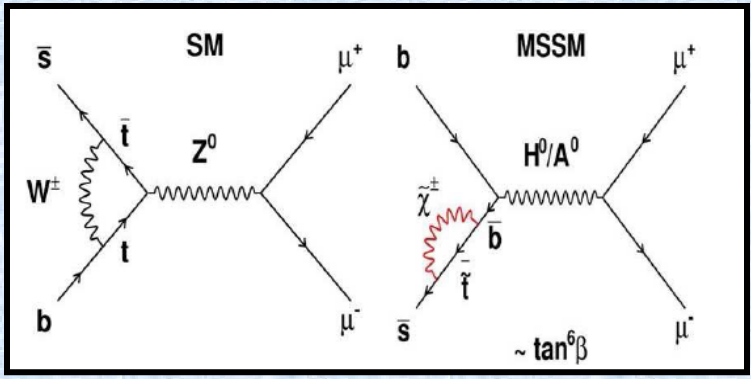
– 3k signal events per 2 fb^{-1}, B/S < 0.8

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

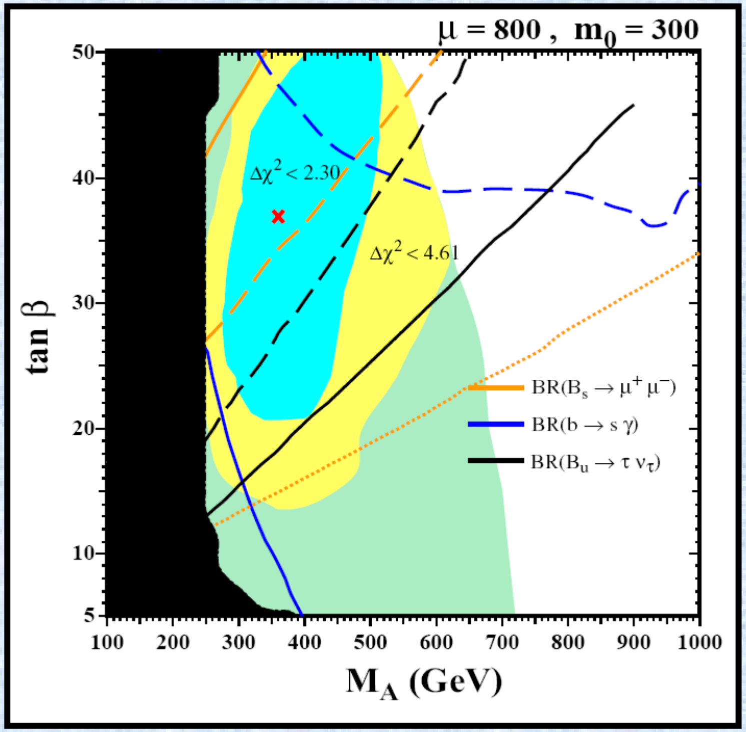
Very Rare $B_s \to \mu\mu$ Decays

Very rare FCNC $b \to s$ transition

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



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)*

D0: $< 9.3 \cdot 10^{-8}$ 95% CL — *D0 Note 5344-Conf (2007)*

2 fb^{-1}

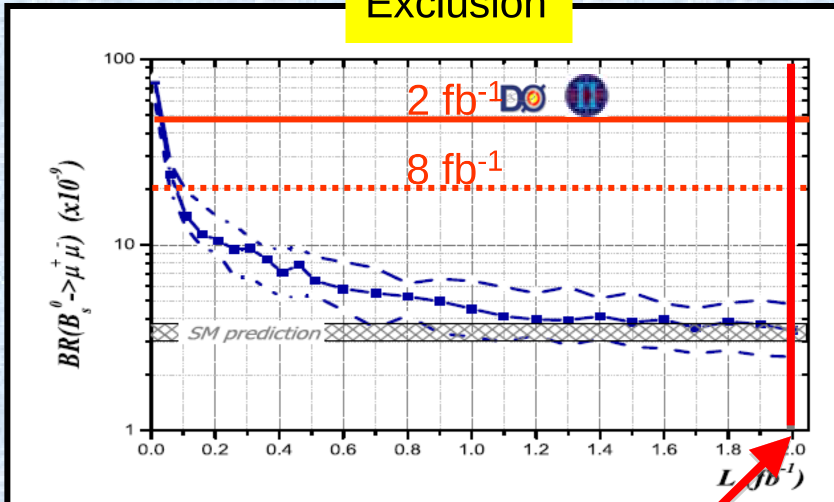
Very Rare $B_s \to \mu\mu$ Decays

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

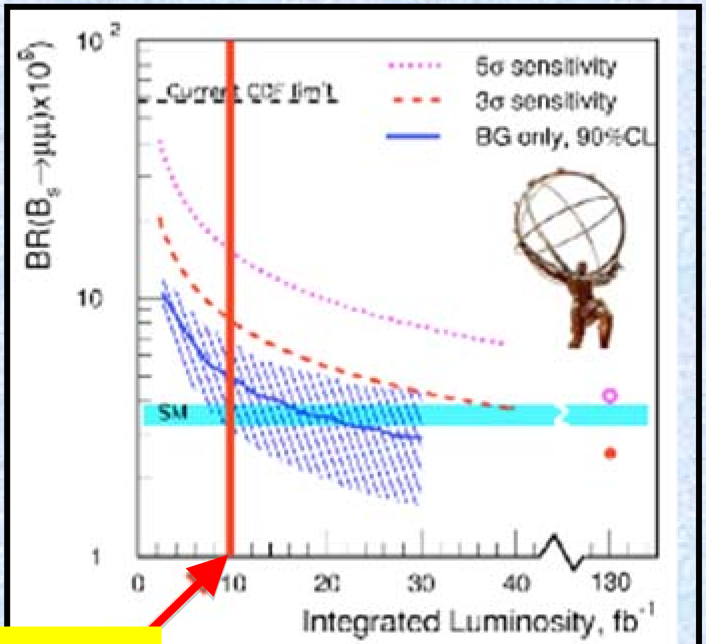
Main issue is background rejection

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

Exclusion



1 nominal year



1 nominal year

LHCb Exclusion @ 90% c.l.

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

Reach SM prediction @ 2fb^{-1}

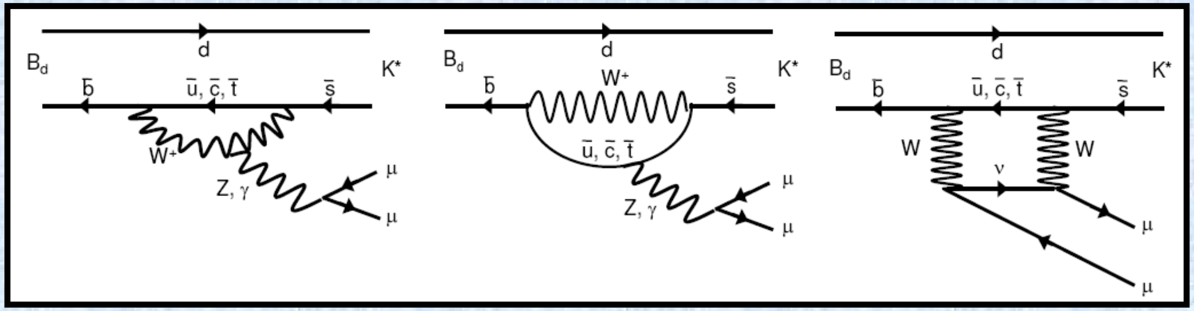
Observation

3σ evidence @ 3 fb^{-1}

5σ discovery @ 10 fb^{-1}

FCNC Rare Decays: B $\rightarrow K^{*}\mu\mu$

FCNC b$\rightarrow$s transition, very sensitive to NP



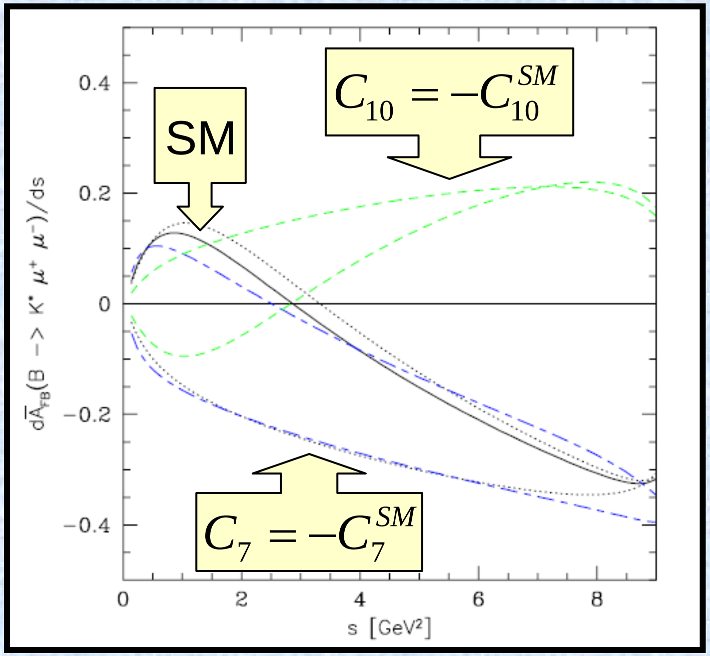
The forward-backward asymmetry arises from the interference between γ and Z^0 contributions

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

The zero crossing point is most theoretically clean

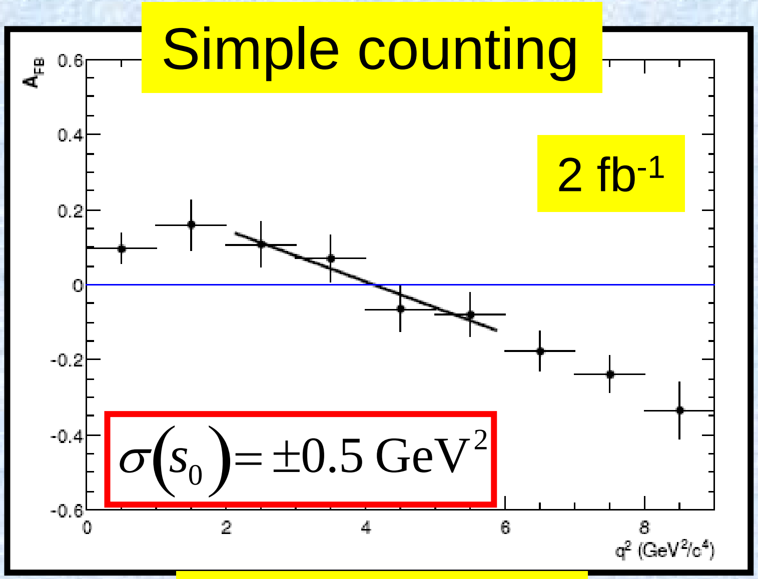
$$s_0^{SM}=4.36_{-0.31}^{+0.33}\ \mathrm{GeV}^2$$

Beneke et al; EPJC41 (2005) 173



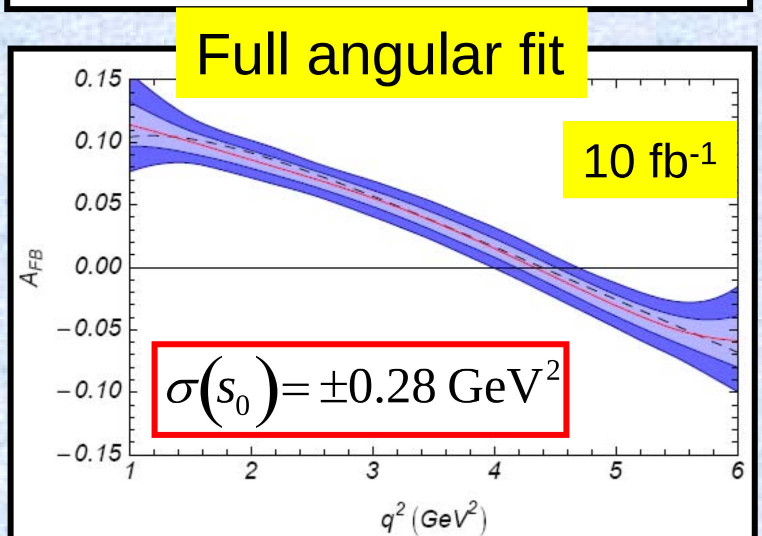
Ali et al; PLB273 (1991) 505

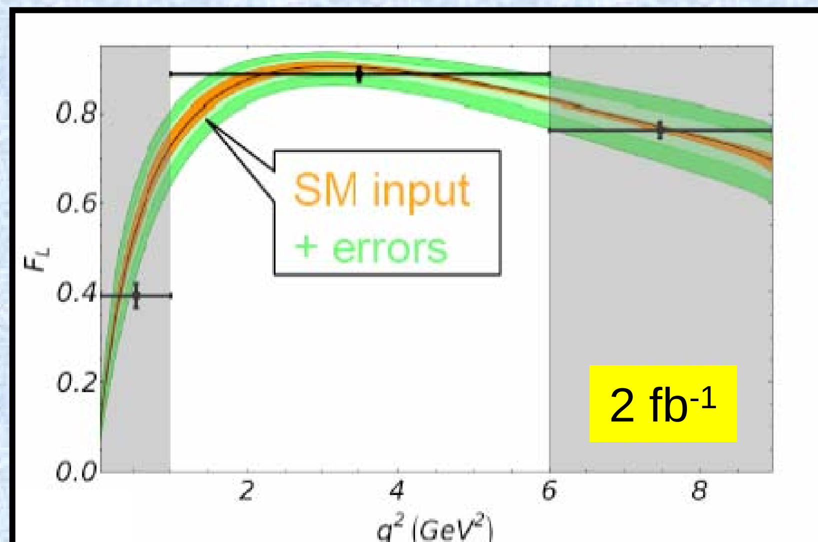
$B^0 \to K^* \mu^+ \mu^-$ Decays



Channel	Yield (2 fb^{-1})	B/S
$B^0 \to K^* \mu^+ \mu^-$	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 $\mathscr{L} \sim 2 \times 10^{33}\ cm^{-2}s^{-1} \rightarrow$ ~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

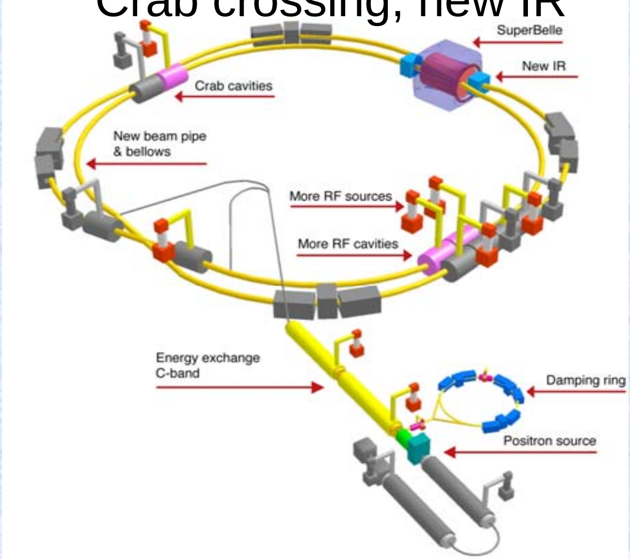
Super B-factories

Two options under consideration

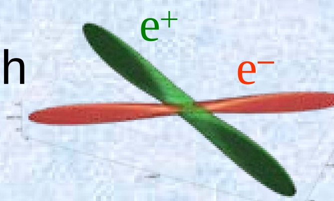
"Super KEKB" (Japan)

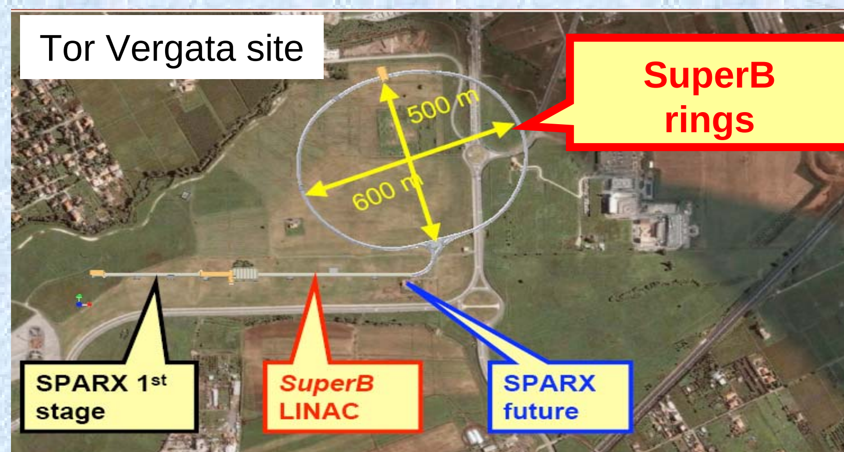
SuperB (Italy)

High current approach
Crab crossing, new IR



Nano-beam approach
Crab waist





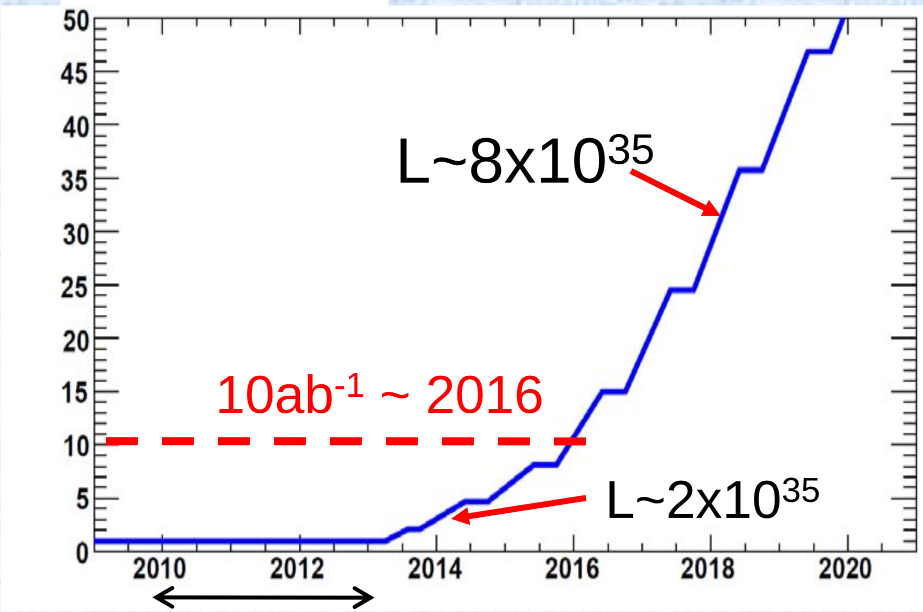
Super B-factories

Luminosity prospects

Y.Sakai, FPCP 2009

Super KEKB
uest for BSM

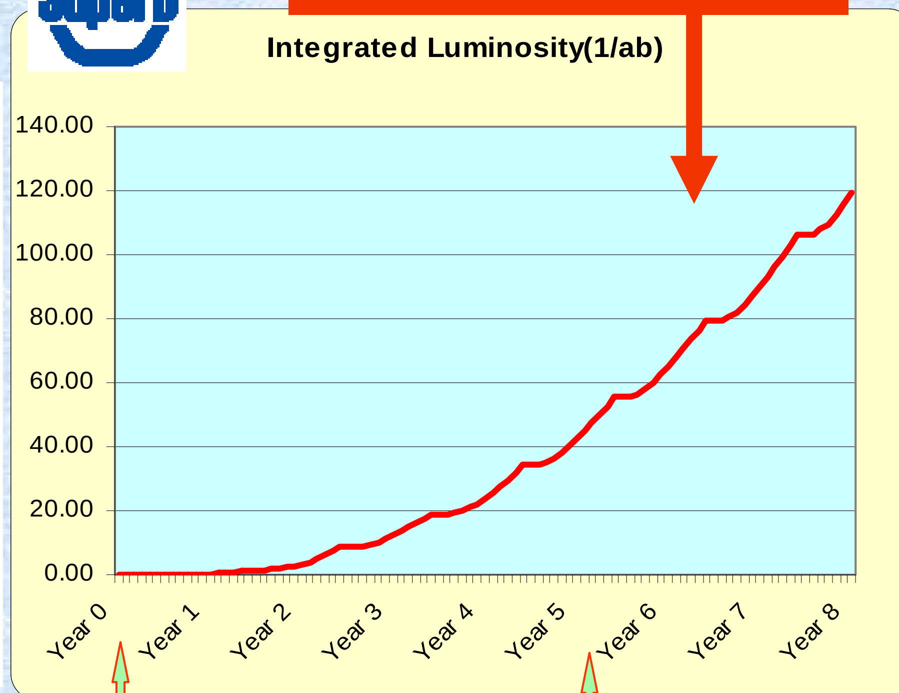
50ab^{-1} by ~2020



3year shutdown
for upgrade

SuperB

>80ab^{-1} after 6 years



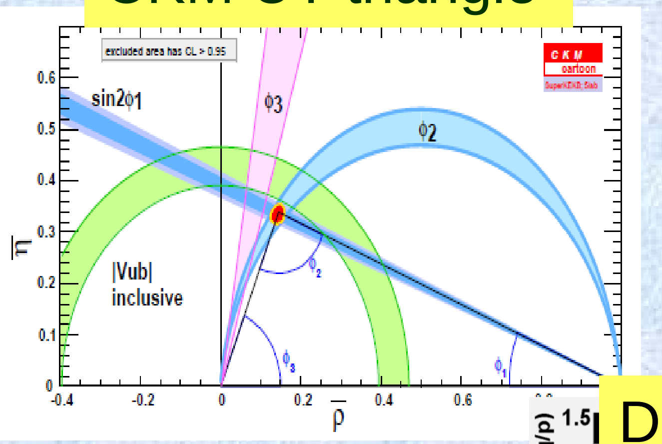
2015
?

2020
?

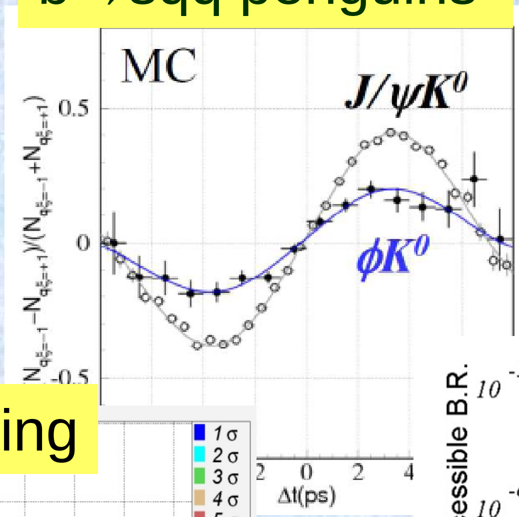
Flavour physics 2020 ?

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

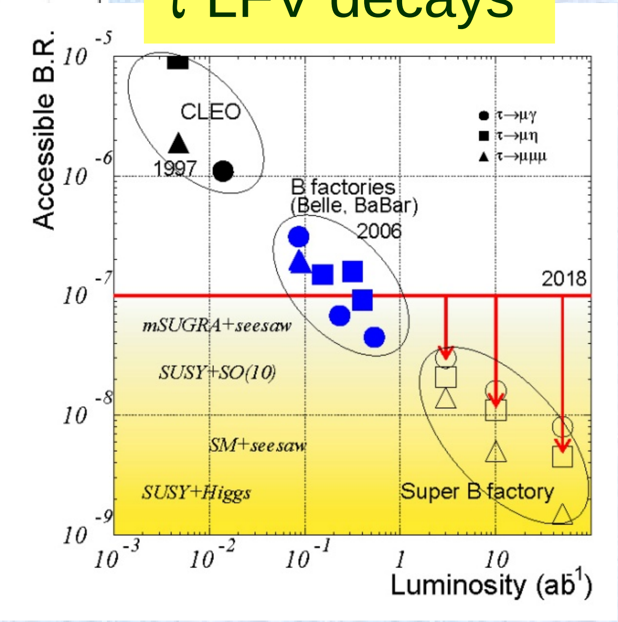
CKM UT triangle



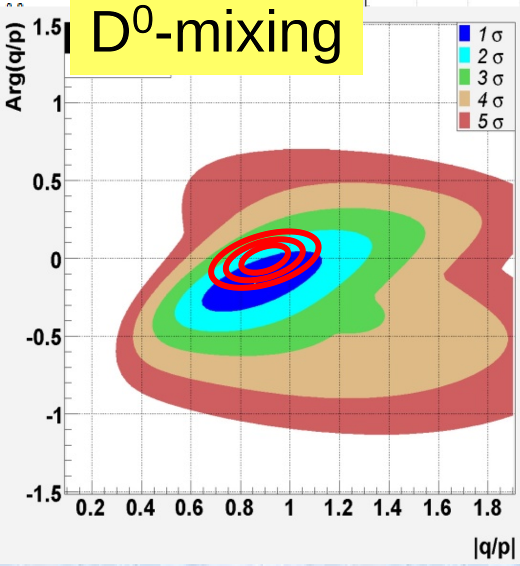
b→sqq penguins



τ LFV decays



D0-mixing



New Physics … the expected..?

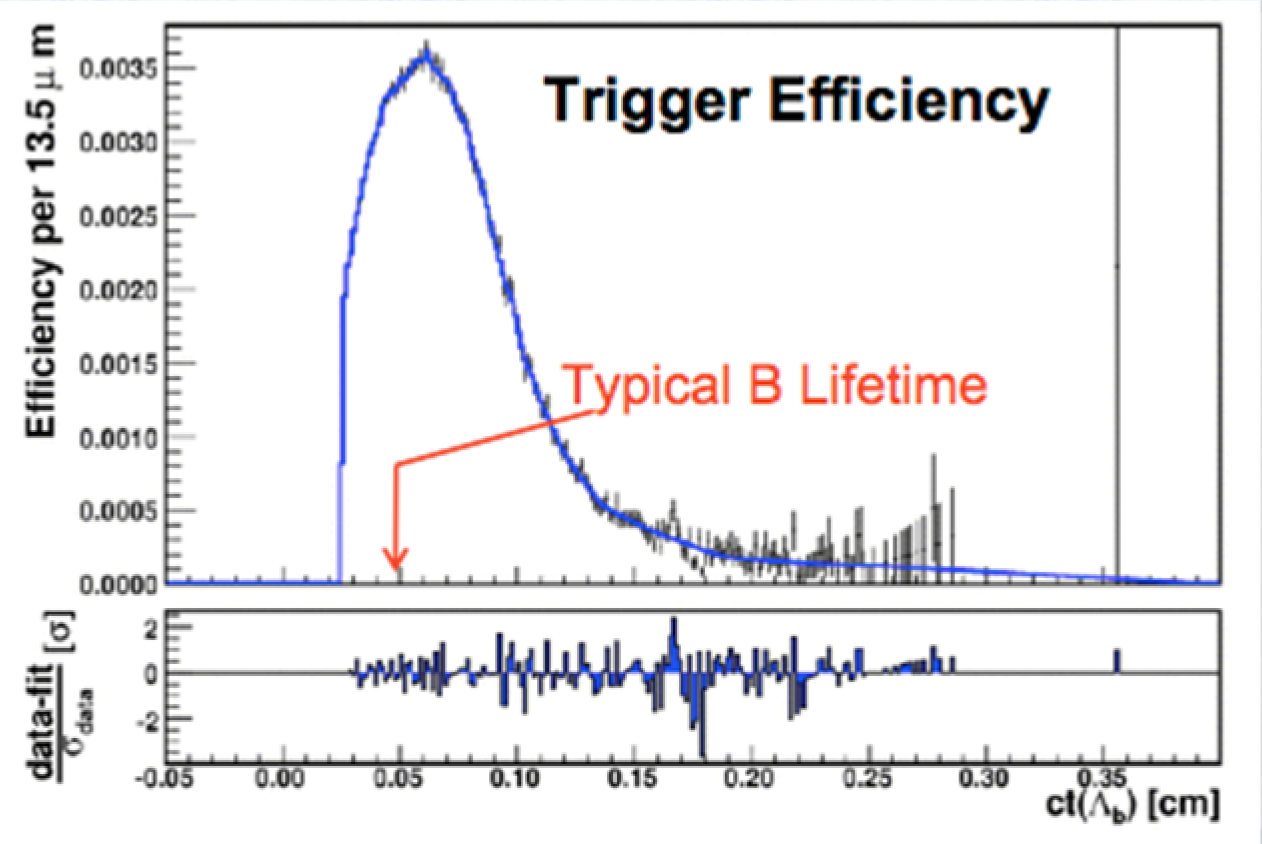
New Physics finally discovered !!

or… the totally unexpected…?

The “Yeti” or
“Abonimable Snowman”

Thank you

CDF Trigger

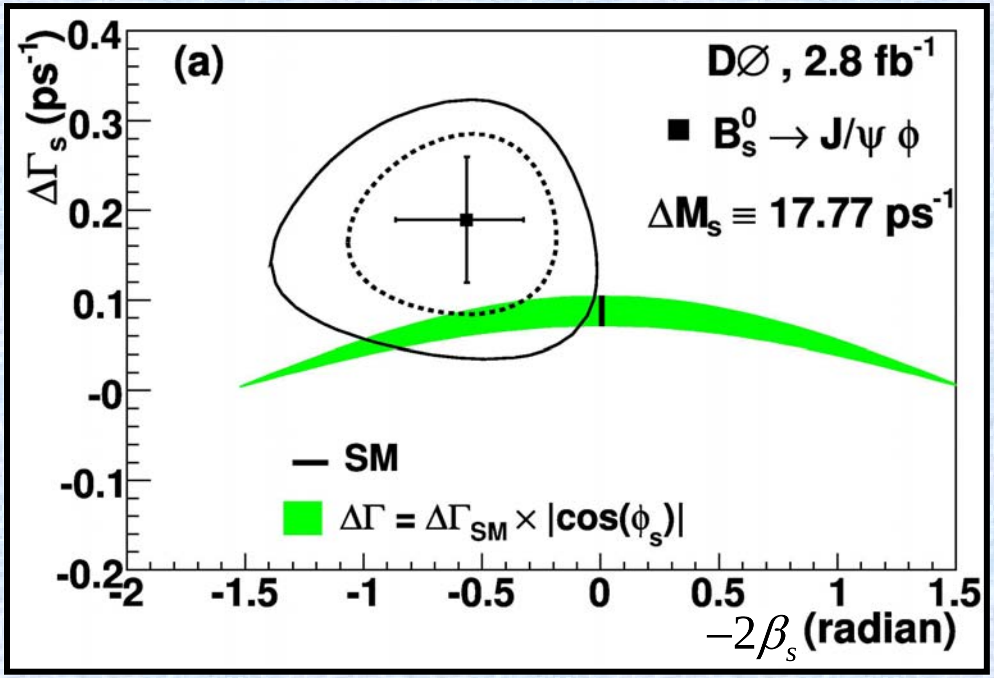


Trigger Efficiency
Typical B Lifetime
Efficiency per 13.5 μ m
0.0035
0.0030
0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
data-fit / σdata [σ]
2
0
-2
-0.05
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
ct(Λb) [cm]

β_s

previous analysis

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



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

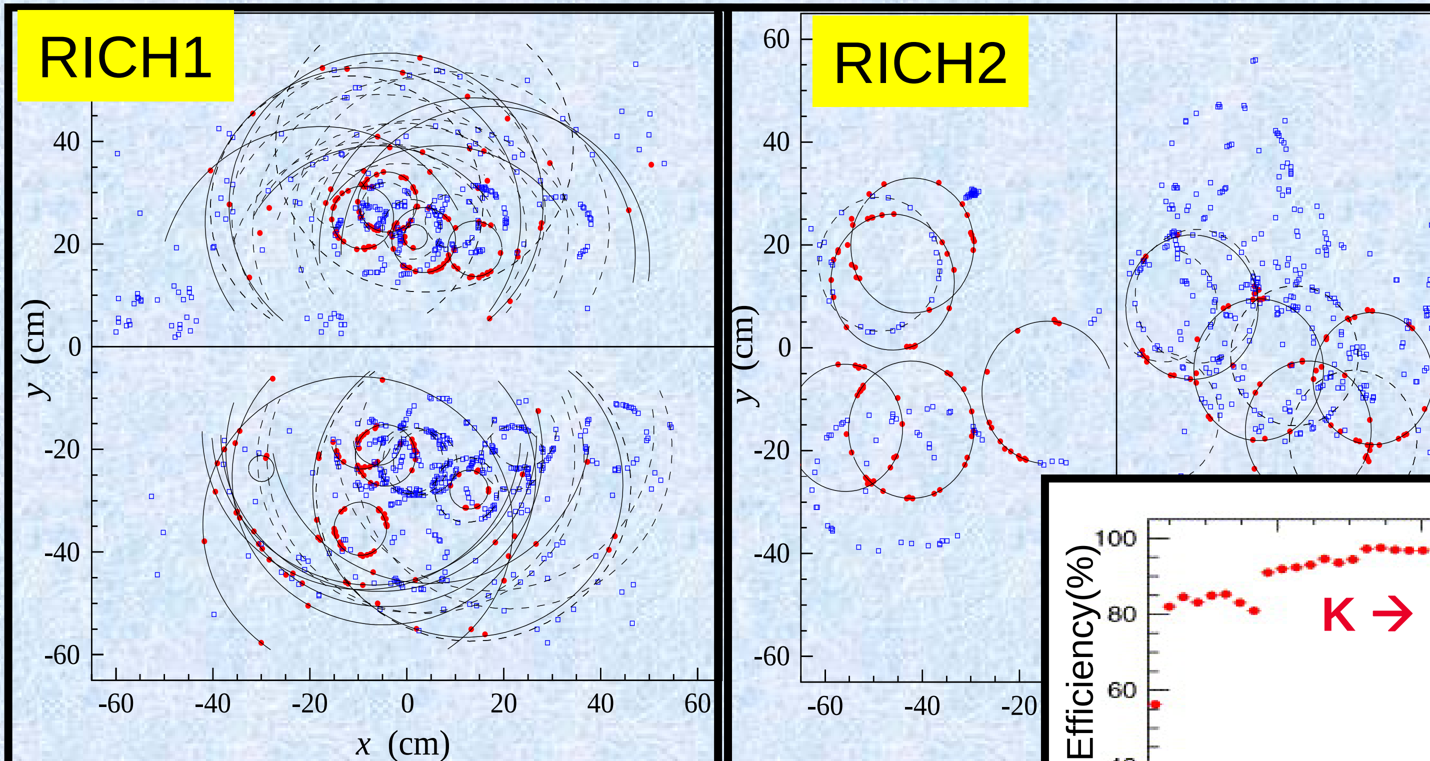
$$\Delta\Gamma_s = 0.19 \pm 0.07(stat)^{+0.02}_{-0.01}(sys)\ \text{ps}^{-1}$$

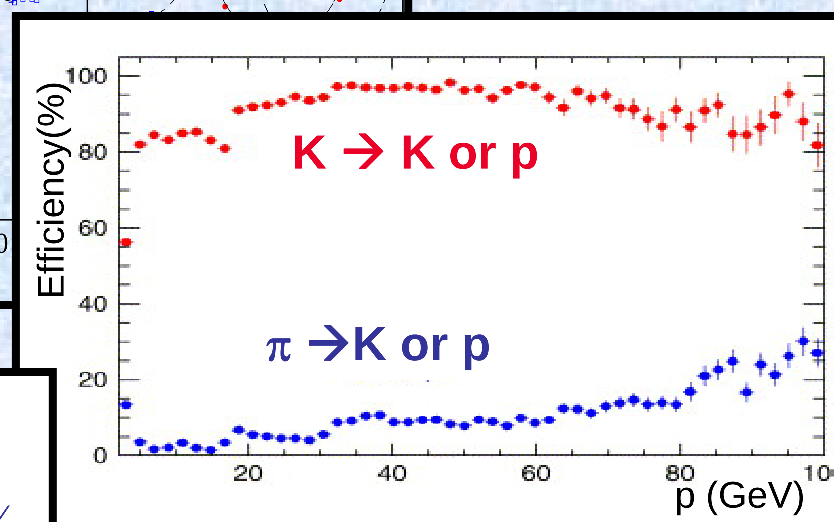
Strong phases constrained

Probability of SM = 6.6% ~1.8σ

RICH Performance

Full MC simulation using “global” fit to Cherenkov rings

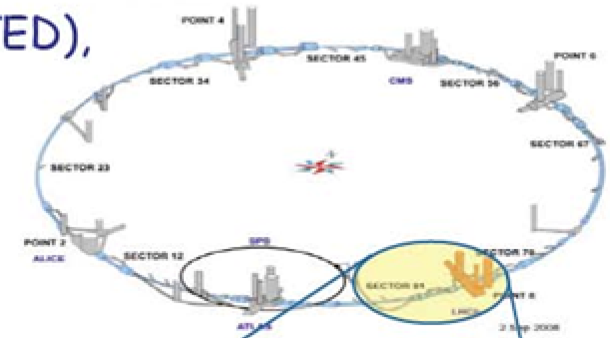


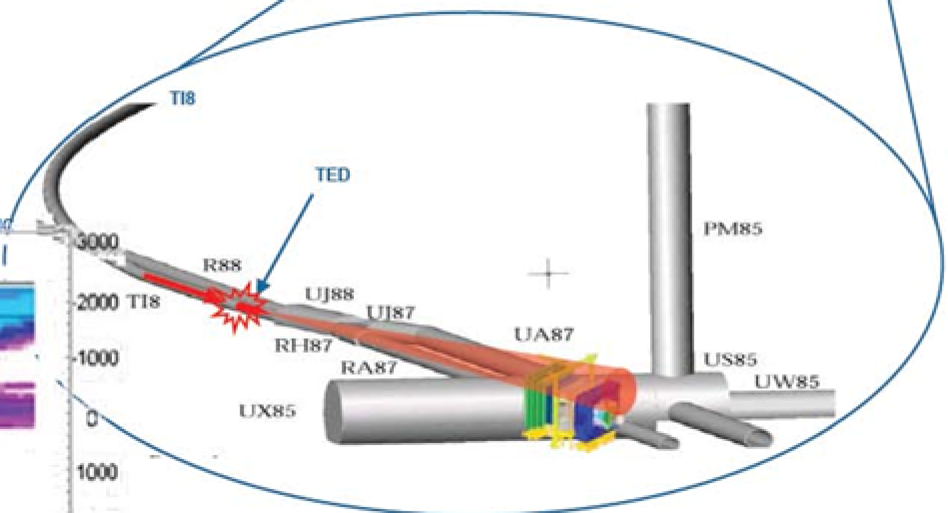


Averages:
K→ K,p eff: 83.1± 0.1%
π → K,π misID: 5.85± 0.03%

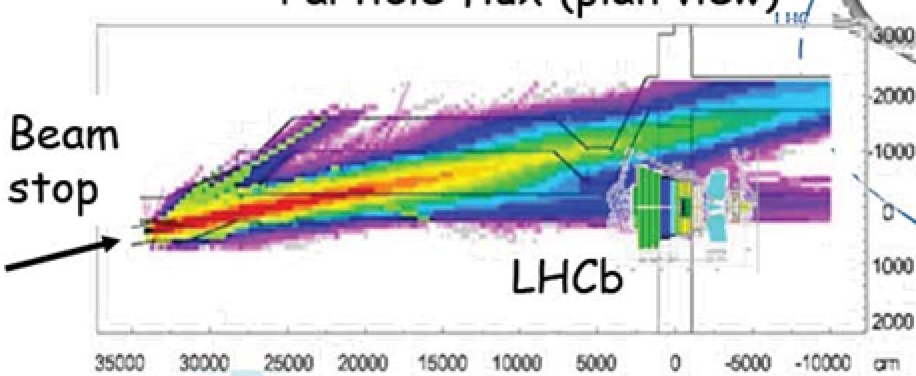
TED

- 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



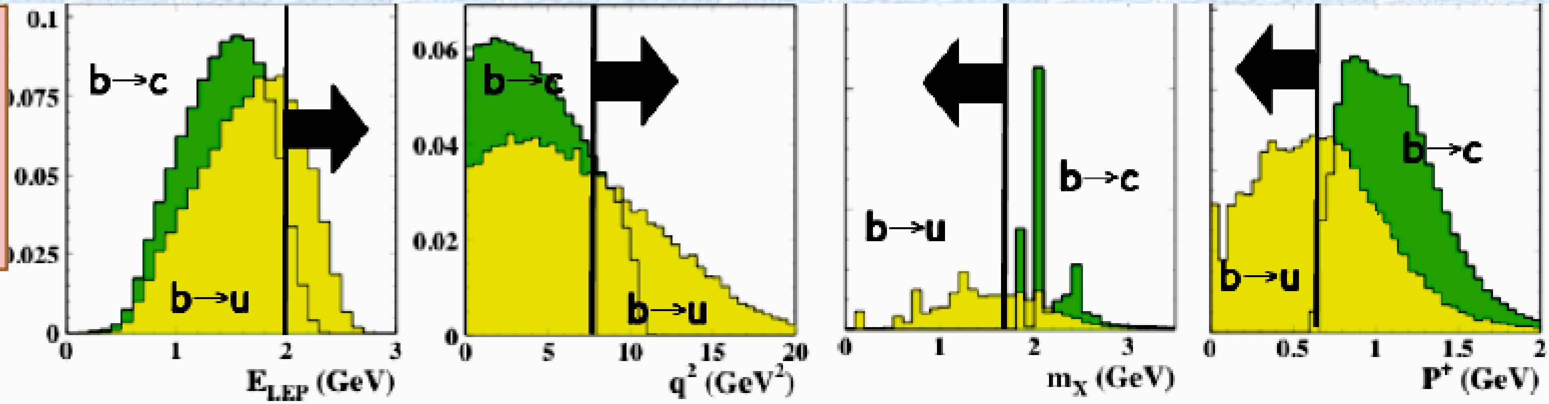


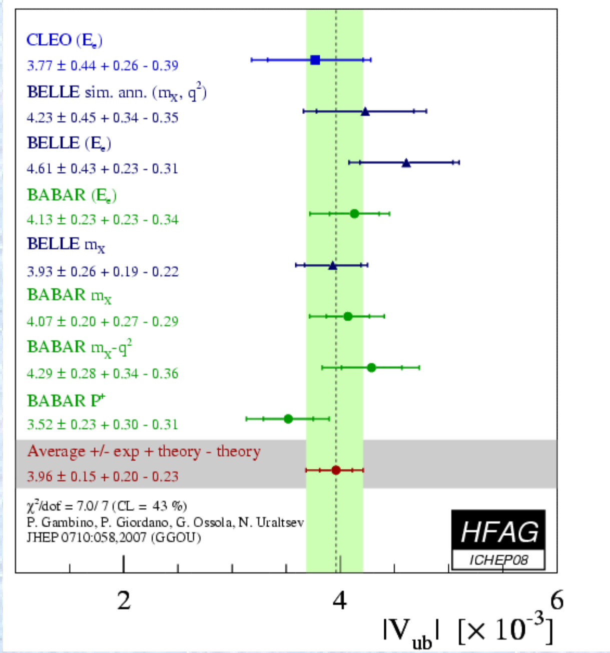
Particle flux (plan view)

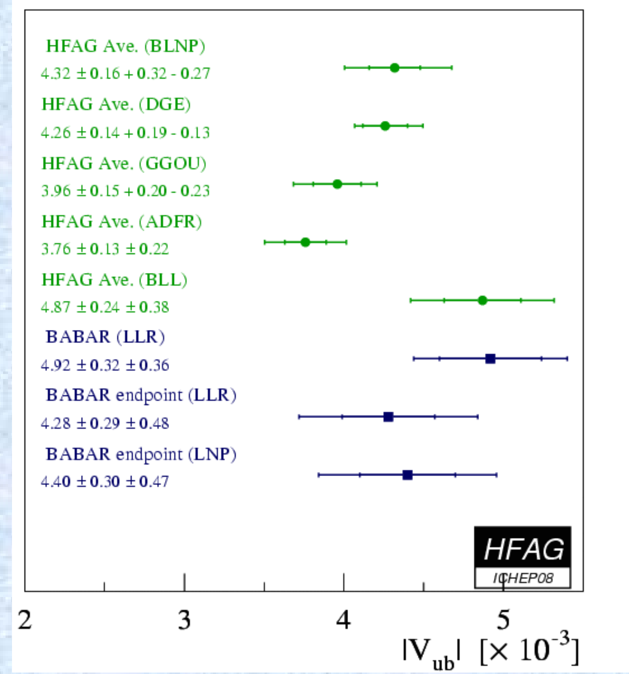


Inclusive Vub

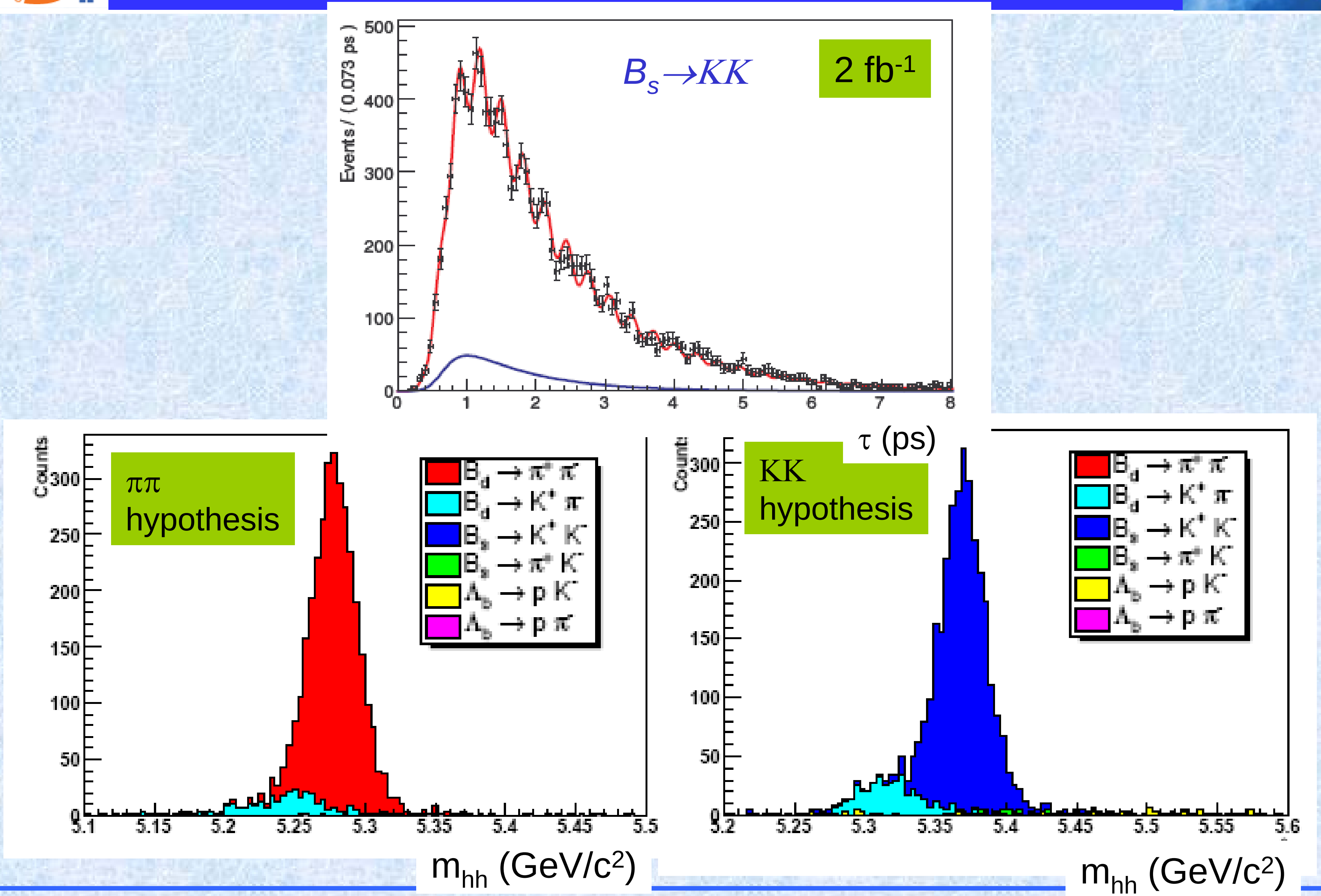
Not to scale!





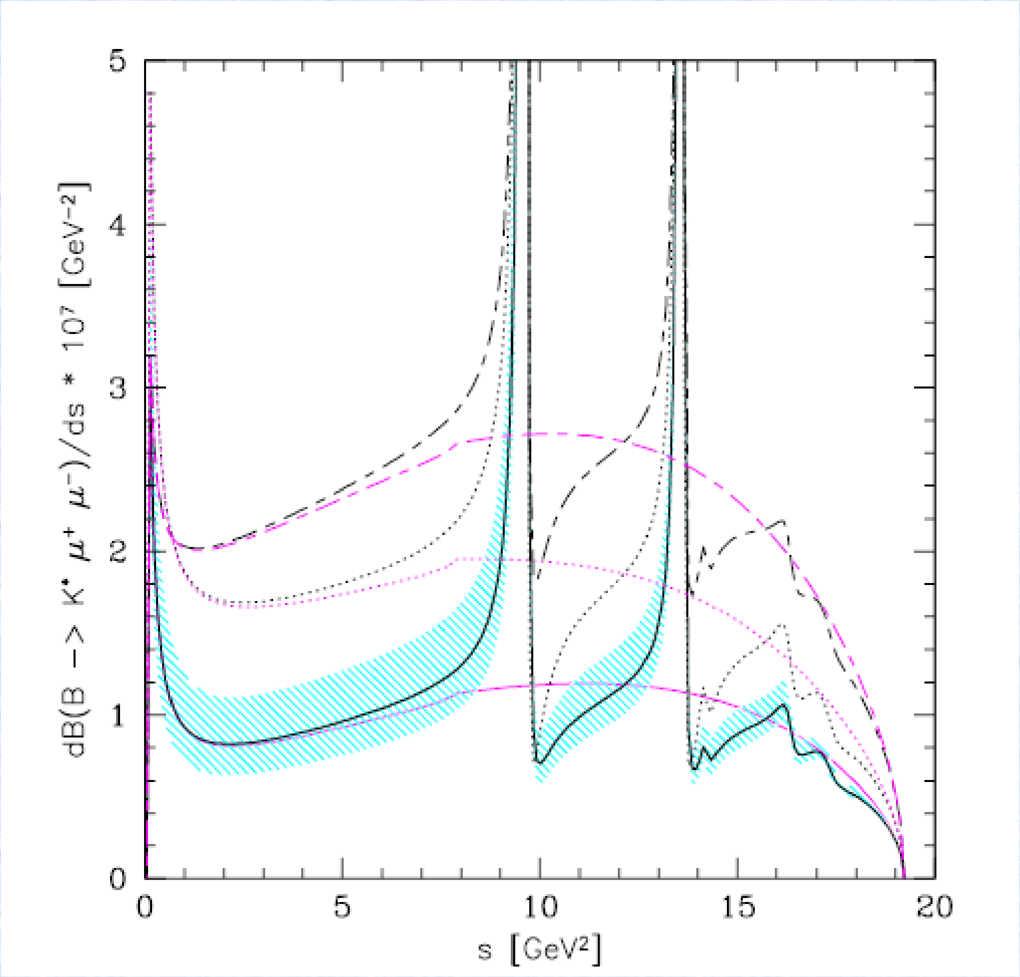


γ from loops

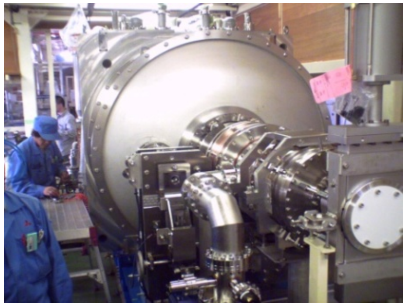


$B_s \to KK$
2 fb^{-1}
Events / (0.073 ps)
τ (ps)
ππ hypothesis
KK hypothesis
Counts
$B_d \to \pi^+ \pi^-$
$B_d \to K^+ \pi^-$
$B_s \to K^+ K^-$
$B_s \to \pi^+ K^-$
$\Lambda_b \to p K^-$
$\Lambda_b \to p \pi^-$
m_{hh} (GeV/c^2)
m_{hh} (GeV/c^2)

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

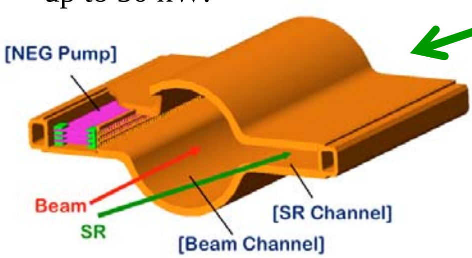


SuperKEKB



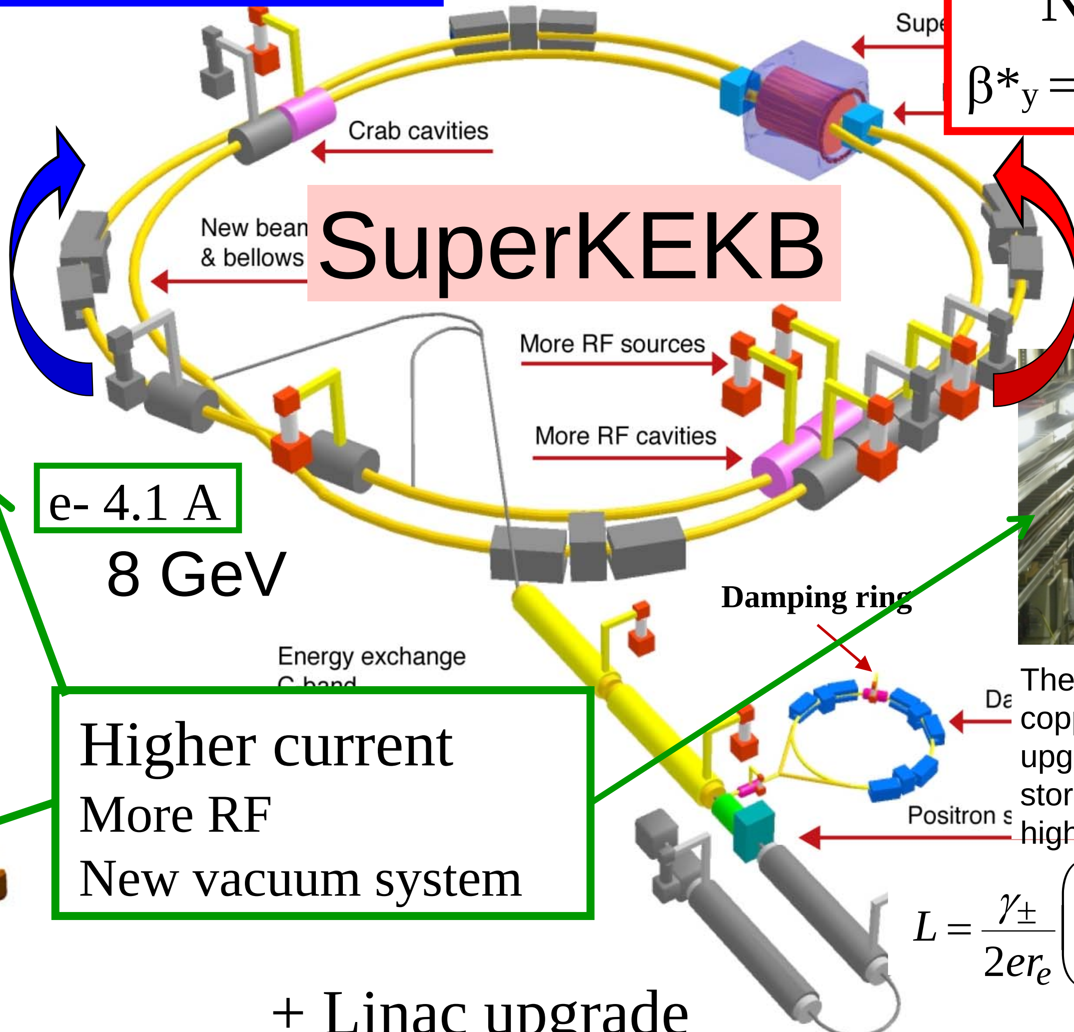
Crab cavities installed and undergoing testing in beam

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



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

Crab crossing



New IR

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

3.5 GeV

e+ 9.4 A

e- 4.1 A

8 GeV

Higher current

More RF

New vacuum system

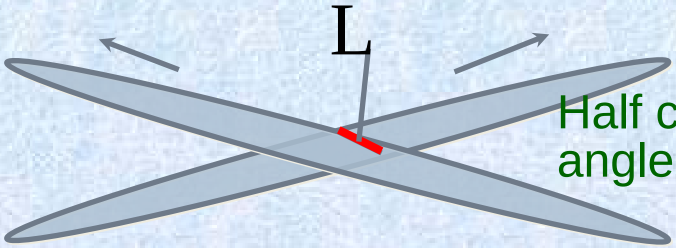
+ Linac upgrade

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

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

Aiming 8×10^{35} cm^{-2}s^{-1}

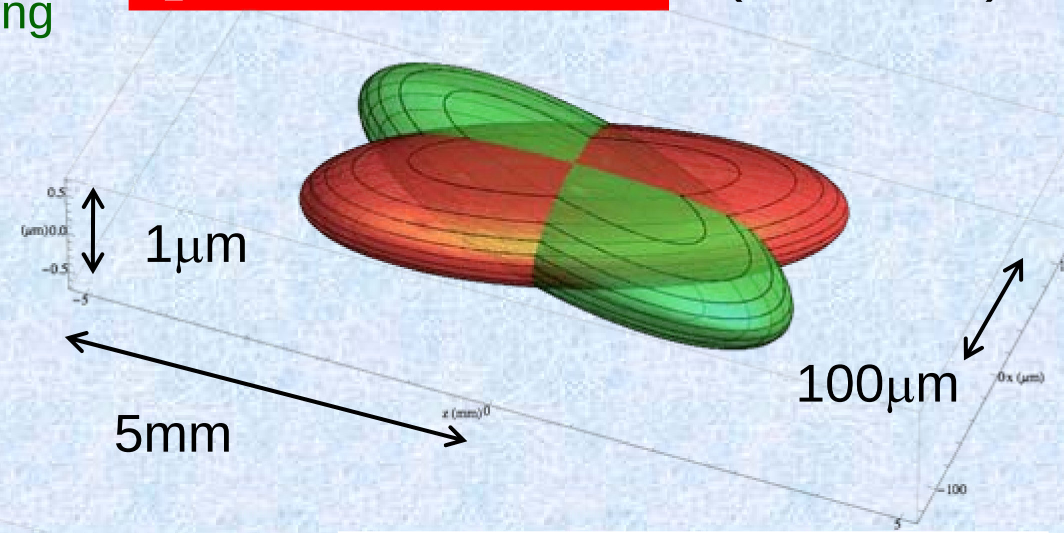
Nano-Beam Scheme



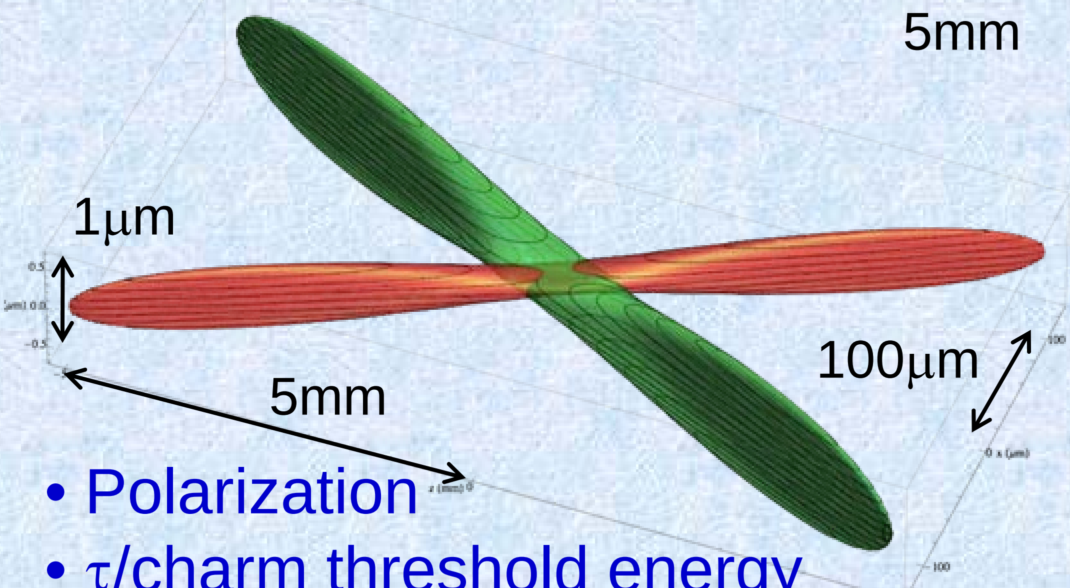
Hourglass condition:

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

present KEKB (w/o crab)



SuperB



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

⇕

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

- Polarization
- τ/charm threshold energy