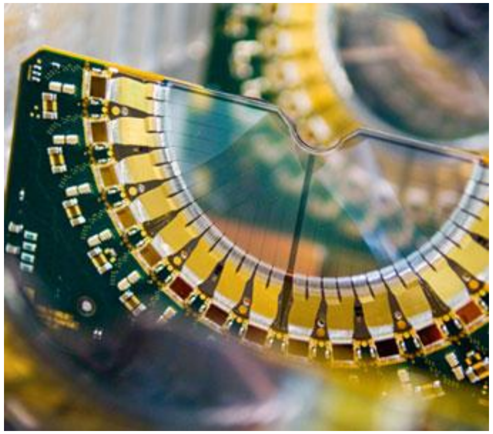
...a flavour of ...

Themis Bowcock

About our Liverpool group ...

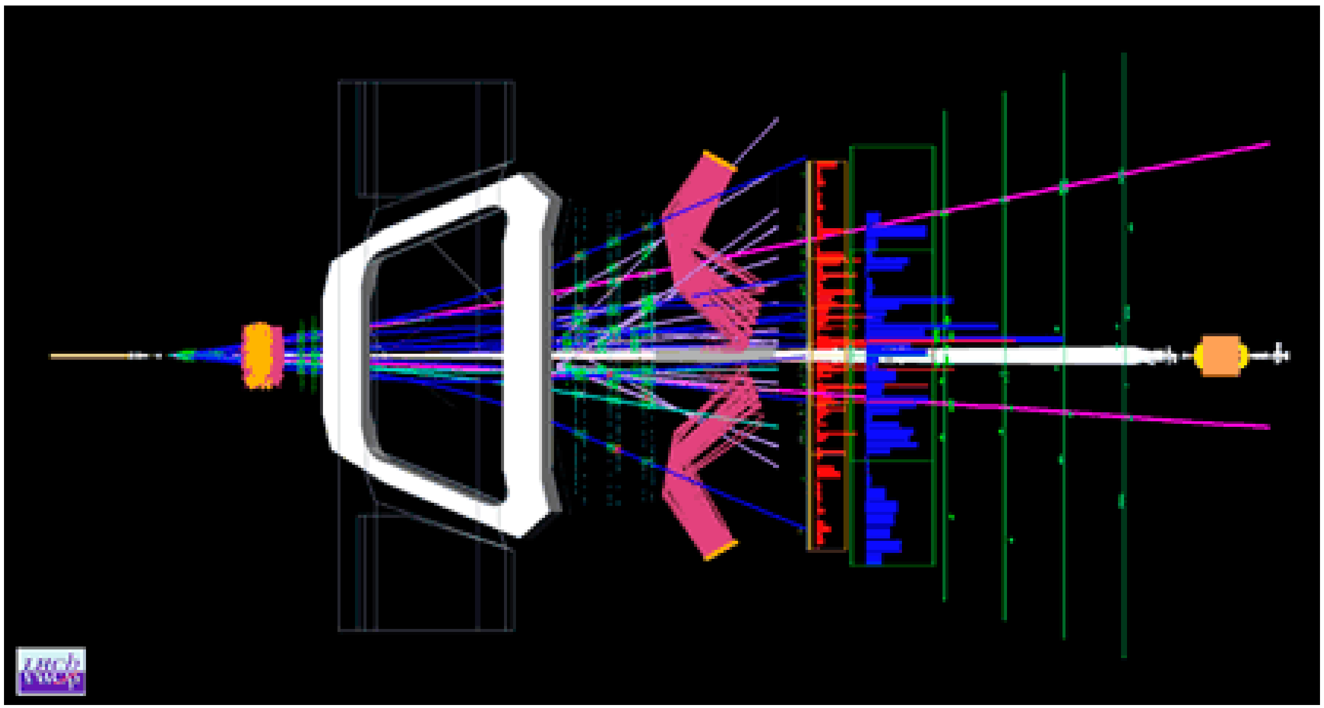
- Built the LHCb Vertex Detector
  - Core enabler of the LHCb B-measurements
- Our primary interest has been
  - EW (W,Z production in forward region)
  - Top (first results due in note next few weeks)
    - Single Top
    - Gateway
      - Higgs
      - Exotics



NP in Quark Flavour (LHCb)

Going to talk about B's...

You; balance against other topics and choices of where to do physics...



Status of Searches

No significant sign of NP at the LHC beyond the Higgs

SUSY > 1TeV

Increaseing (slowly) with luminosity and energy

Before LHC, expectations were that *“naturally” the masses of the new particles would have* to be light in order to reduce the *“fine tuning” of the EW energy scale.*

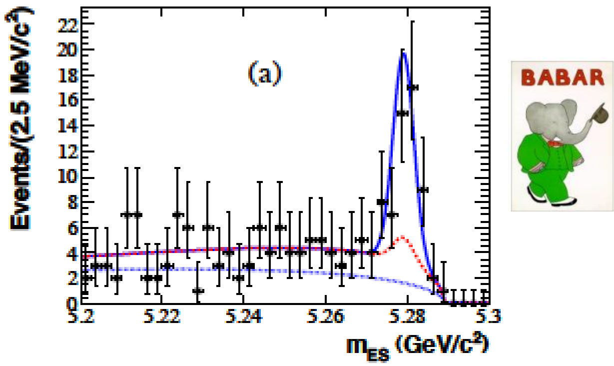
naturalness->anthropic

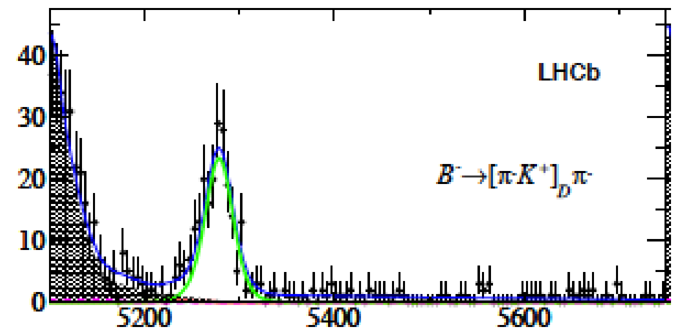
Existing Facilities

Generally

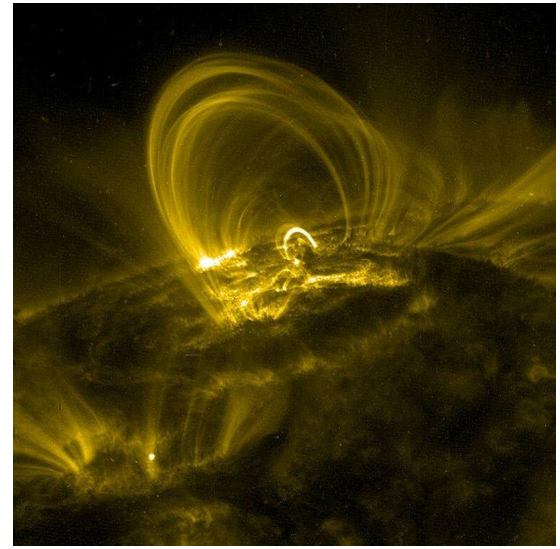
- Lepton colliders (known cm).
  - Elegant for neutrals and missing components
- Hadron colliders (large cross-sections)

1/fb at 7TeV at LHCb is equivalent to (1-5)/ab at the B-factories before tagging





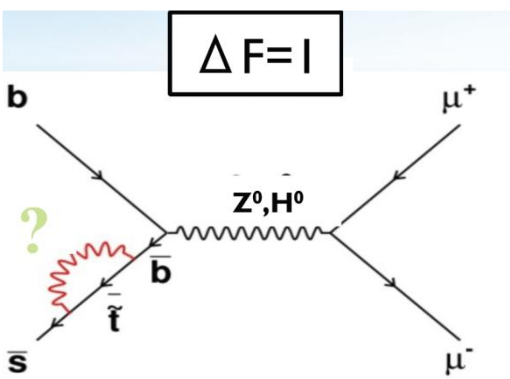
Indirect Search Method

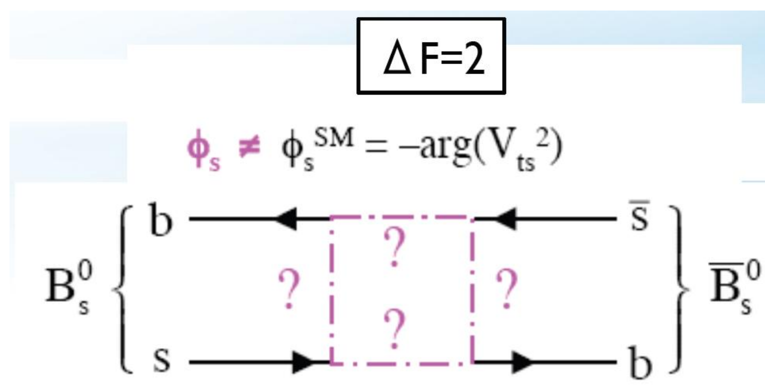


Discovery through "loops"

- Quantum interferometry
- smoking guns (rare decays)

Part of long standing programme of precision measurement of FCNC





B_s–$\overline{B}_s$ oscillations: "Box" diagram

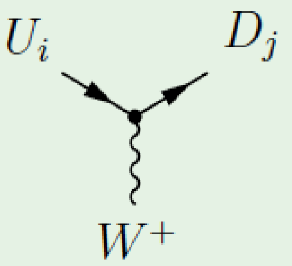
CKM

What accuracy do we need to know these numbers?

$U_i = \{u, c, t\}$: $Q_U = +2/3$

$D_j = \{d, s, b\}$: $Q_D = -1/3$

$$\mathcal{L}_{CC} = \frac{g_2}{\sqrt{2}}(\bar{u}, \bar{c}, \bar{t})\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}\gamma^\mu P_L \begin{pmatrix} d \\ s \\ b \end{pmatrix} W_\mu^+$$



$\sim$ Cabibbo-Kobayashi-Maskawa (CKM) matrix

CP phases

A=0.81±0.02
λ= 0.225±0.001

$$V = \begin{pmatrix} 1-\lambda^2/2-\lambda^4/8 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda & 1-\lambda^2/2-\lambda^4/8(1+4A^2) & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2+A\lambda^4/2(1-2(\rho+i\eta)) & 1-A^2\lambda^4/2 \end{pmatrix} + O(\lambda^5)$$

Wolfenstein Parameterization

Processes

CKM elements

Order in λ

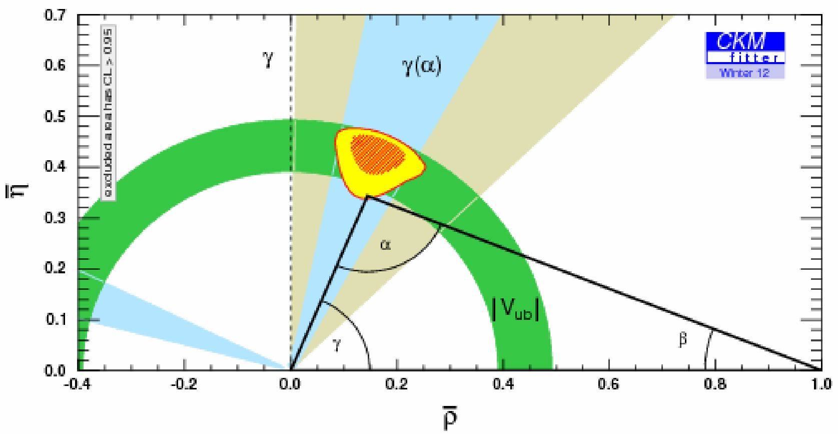
	b→s ($\|V_{tb}V_{ts}\| \alpha \lambda^2$)	b→d ($\|V_{tb}V_{td}\| \alpha \lambda^3$)	s→d ($\|V_{ts}V_{td}\| \alpha \lambda^5$)	c→u ($\|V_{cb}V_{ub}\| \alpha \lambda^5$)
ΔF=2 box	ΔM_{Bs}, $A_{CP}(B_s \to J/\Psi\, \Phi)$	ΔM_B, $A_{CP}(B \to J/\Psi K)$	ΔM_K, ε_K	x,y, q/p, Φ
QCD Penguin	$A_{CP}(B_s \to \Phi\Phi)$, $B \to X_s \gamma$	$A_{CP}(B \to \Phi K)$, $B \to X\gamma$	$K \to \pi^0 ll$, ε'/ε	$\Delta a_{CP}(D \to hh)$
EW Penguin	$B \to K^*ll$, $B \to X_s \gamma$	$B \to \pi ll$, $B \to X\gamma$	$K \to \pi^0 ll$, $K^{\pm} \to \pi^{\pm} \nu \nu$	$D \to X_u ll$
Higgs Penguin	$B_s \to \mu\mu$	$B \to \mu\mu$	$K \to \mu\mu$	$D \to \mu\mu$

Decay Modes

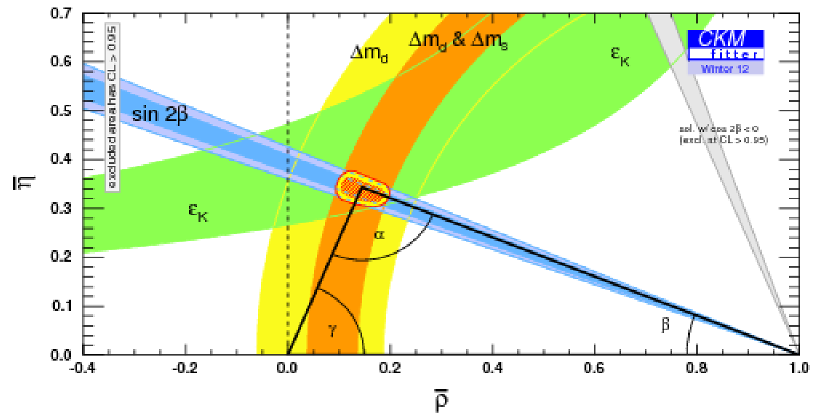
CP Violation/Angles

$$\alpha = \arg\left(\frac{-V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right),\quad \beta = \arg\left(\frac{-V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right)\ \text{and}\ \gamma = \arg\left(\frac{-V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)\qquad \beta_s = \arg\left(\frac{-V_{cb}V_{cs}^*}{V_{tb}V_{ts}^*}\right)$$

In the limit theory as well as measurement limit NPdiscovery

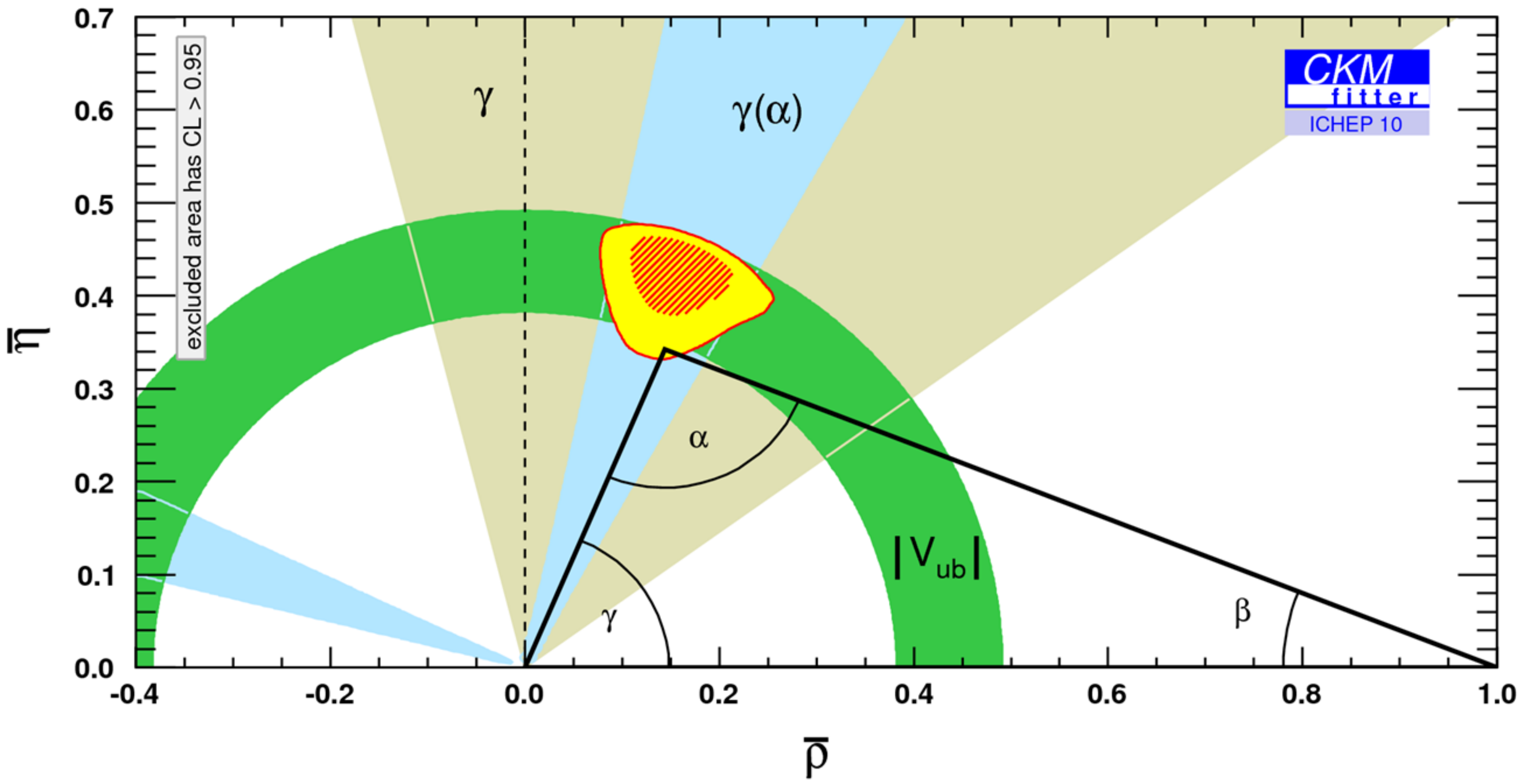


Trees



Loops

Trees and Loops



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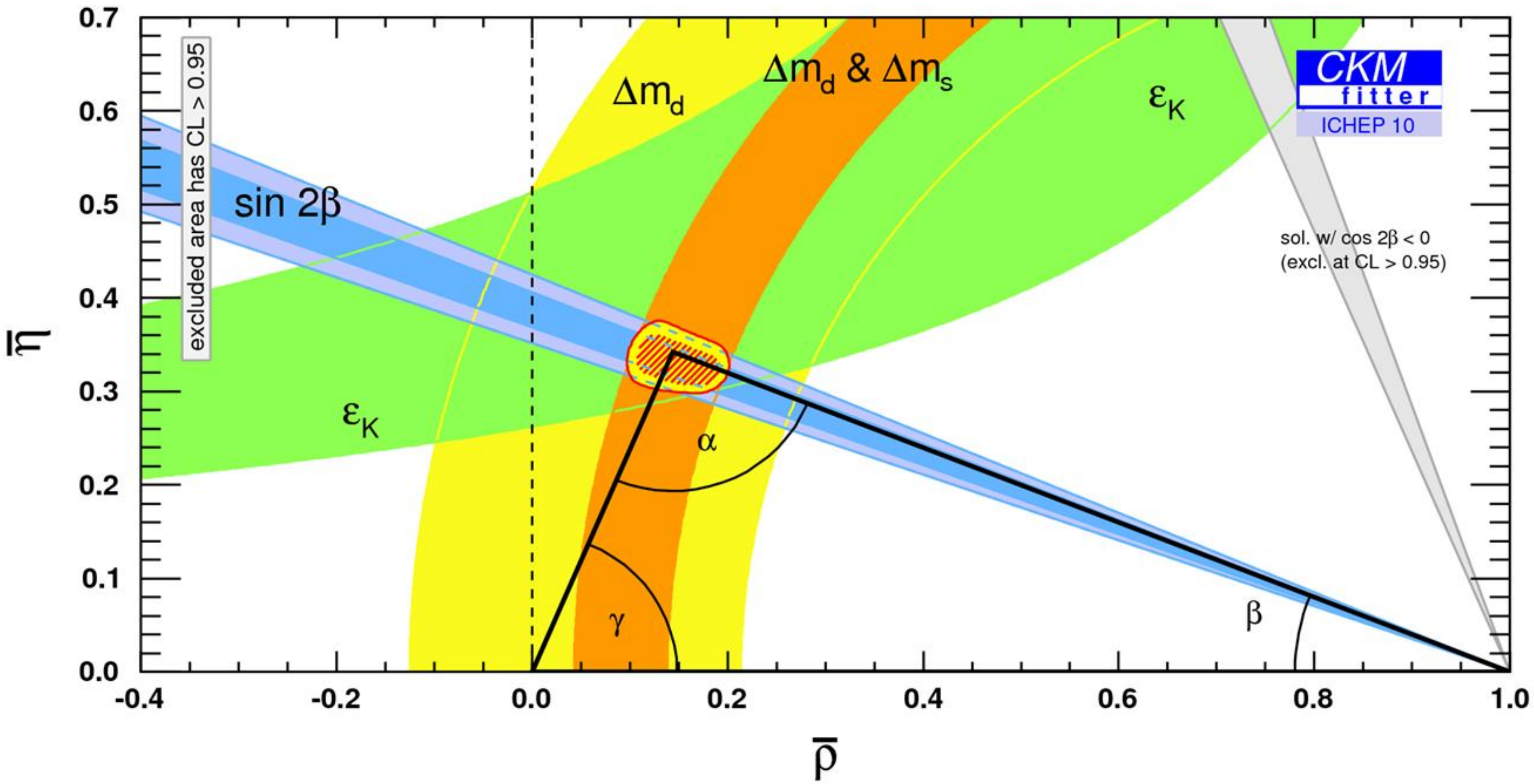
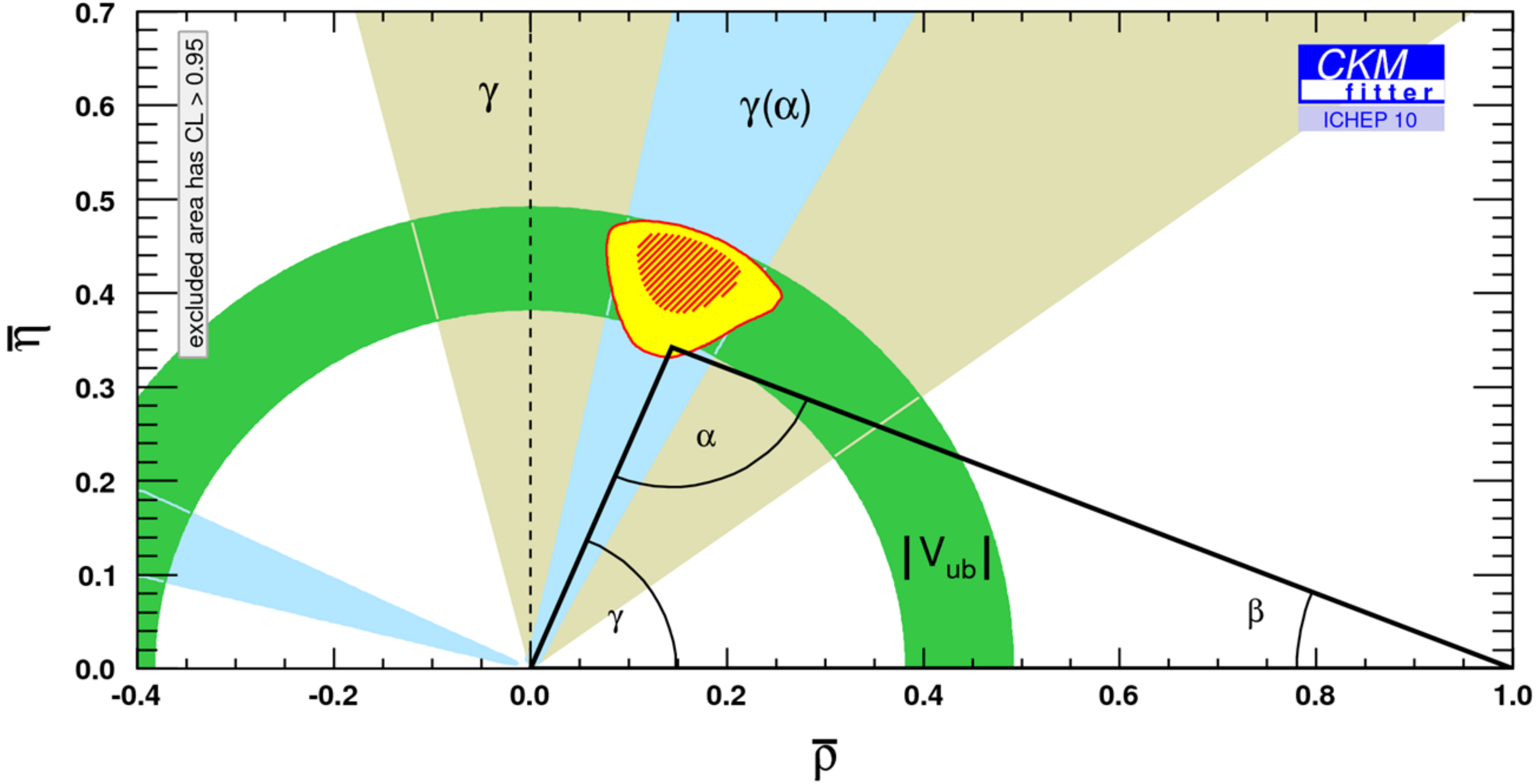
Trees and Loops

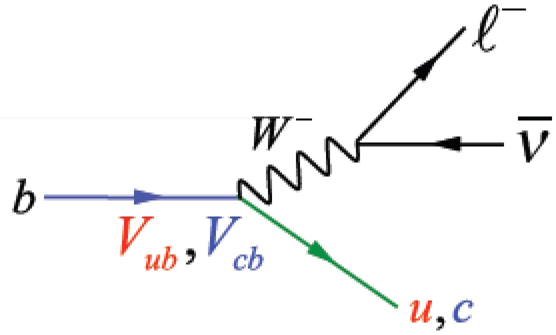


Trees and Loops



ΔF=1, Trees (amplitudes)

$$\Gamma_x \equiv \Gamma(b \to x\ell\nu) \propto |V_{xb}|^2$$



V_{ub} at B-factories using inclusive or exclusive methods show a discrepancy at the 2-3σ level:
V_{ub}(incl.)~1.3V_{ub}(excl.).

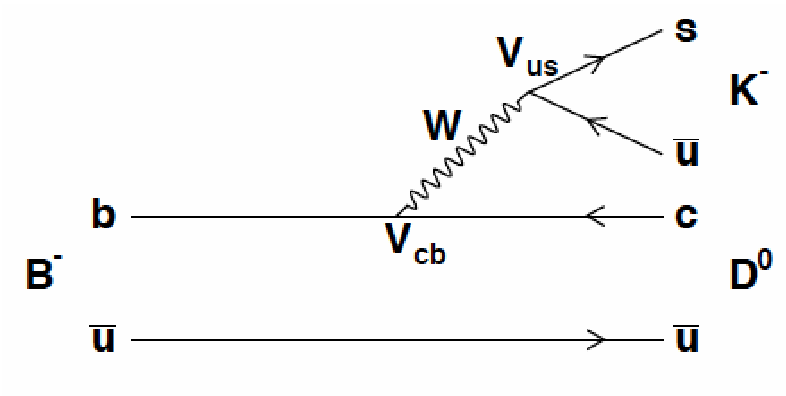
BR(B→τν) BaBar, Belle (τ, D*)

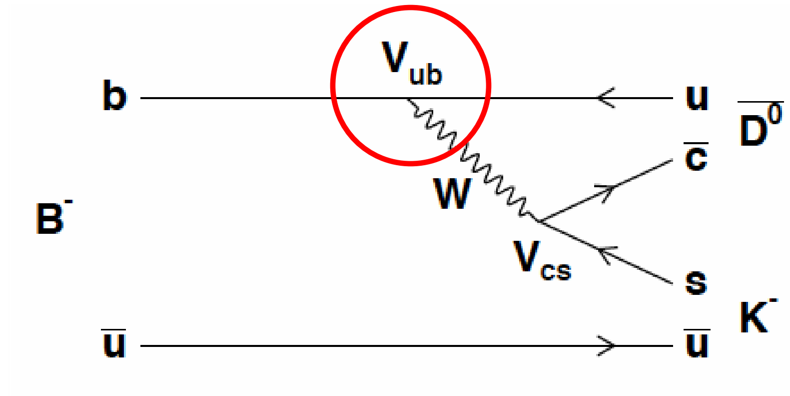
NA62 has measured (2011) the ratio K → eν/K → μν=2.487±0.013 in agreement with SM: 2.477±0.001

Trees

Analysis supposedy simple; is often complicated!

ΔF=1, Trees(phases)

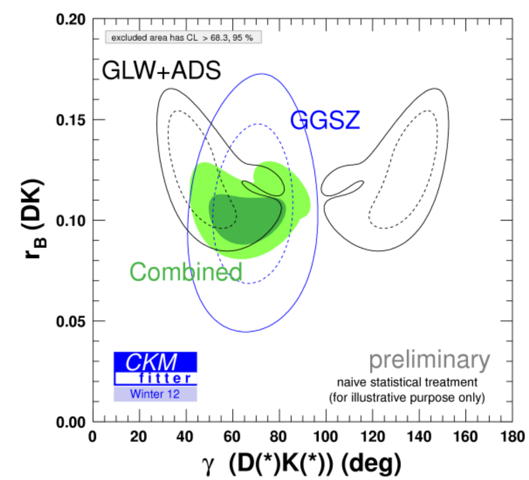




$$\gamma = \arg\left(\frac{-V_{ud}V_{ub}^{*}}{V_{cd}V_{cb}^{*}}\right)$$

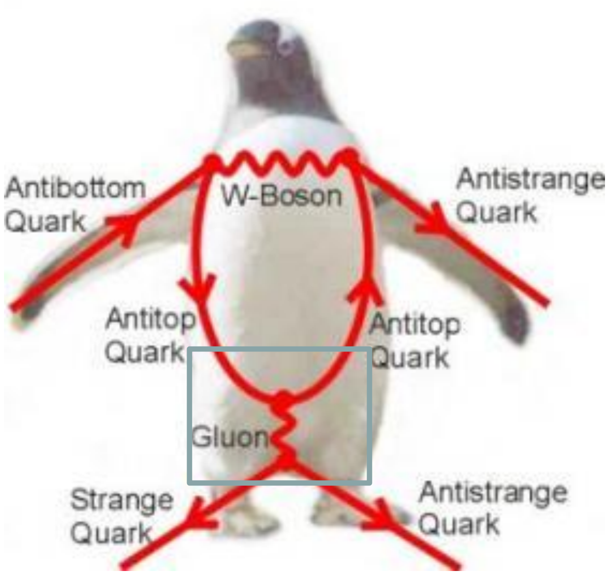
A precise determination of γ(O(1°)) is one of the highest priorities to be able to decide if there is new physics in B-> DK(*)

Simplest analysis count B+/B- ratios

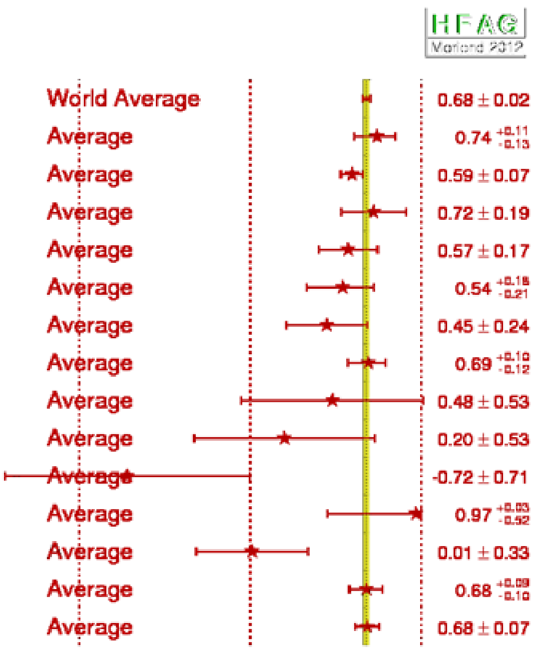


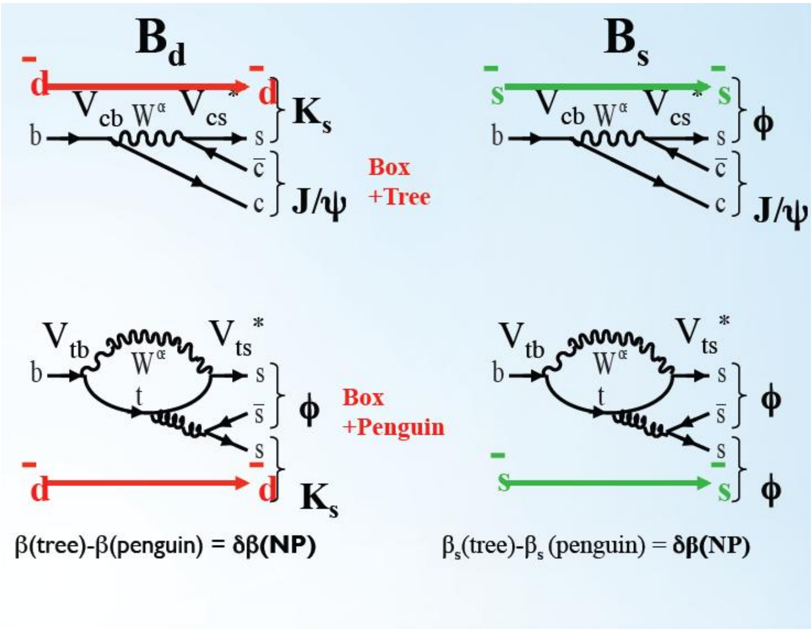
ΔF=1

QCD
Weak
Higgs



ΔF=1, QCD



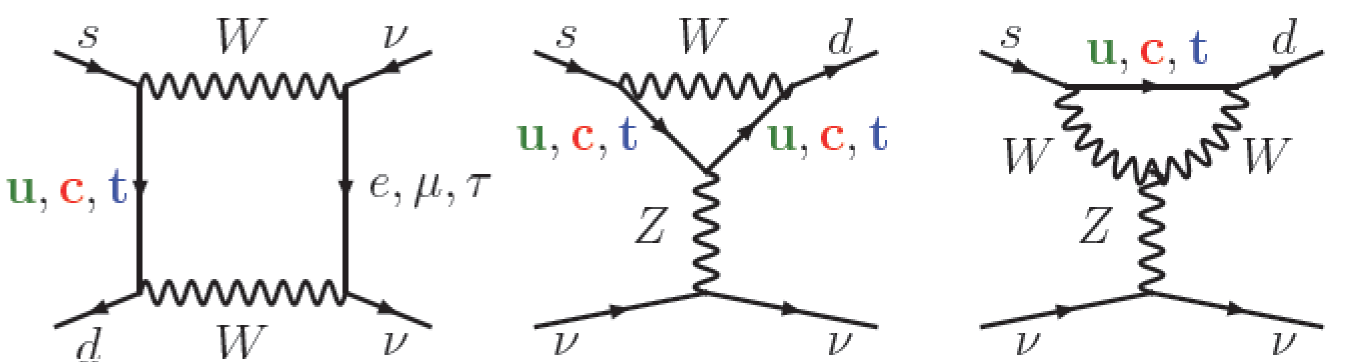


No significant discrepancy between b→ccs and s-penguin

ΔF=1, EW

EW Penguins

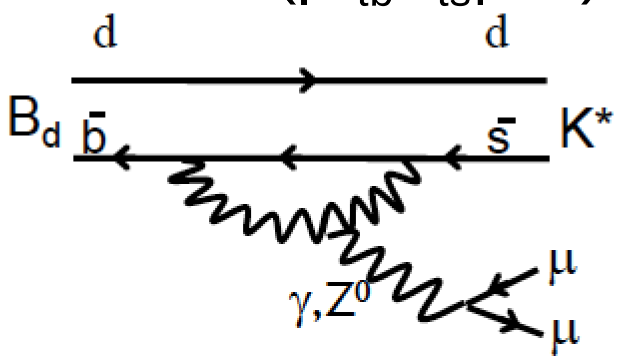
- Kaon Decays, NA62, KOTO, ORKA
- s>d ($|V_{ts}V_{td}| \alpha\ \lambda^5$)
- Very rare decays Br ratios at the 10^{-11} level.



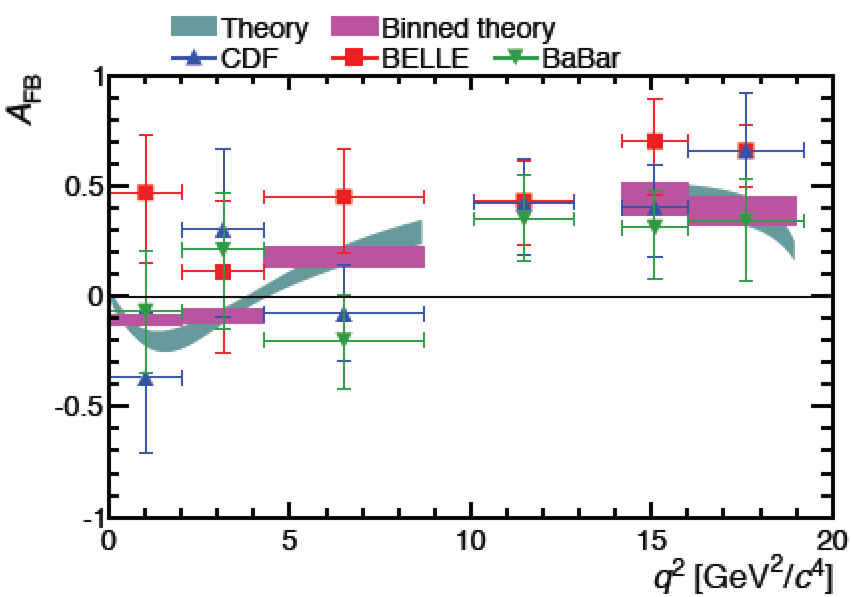
ΔF=1, EW

LHCb

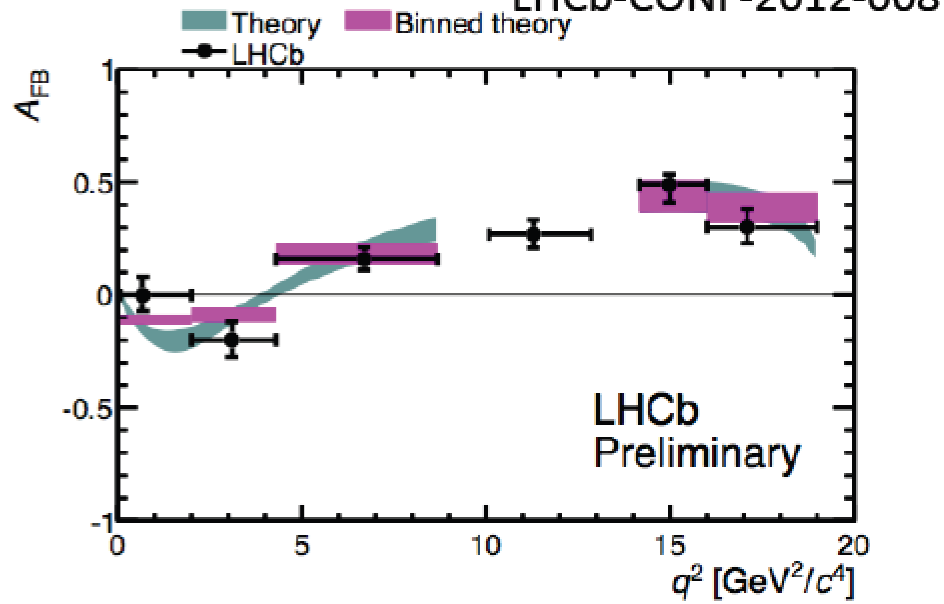
$b \rightarrow s\ (|V_{tb}V_{ts}| \propto \lambda^2)$



B→K*μμ is the golden mode to test new vector(-axial) couplings

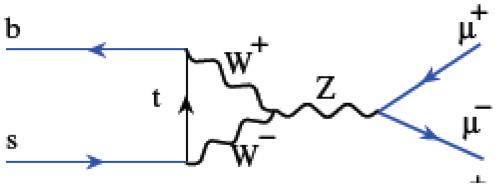


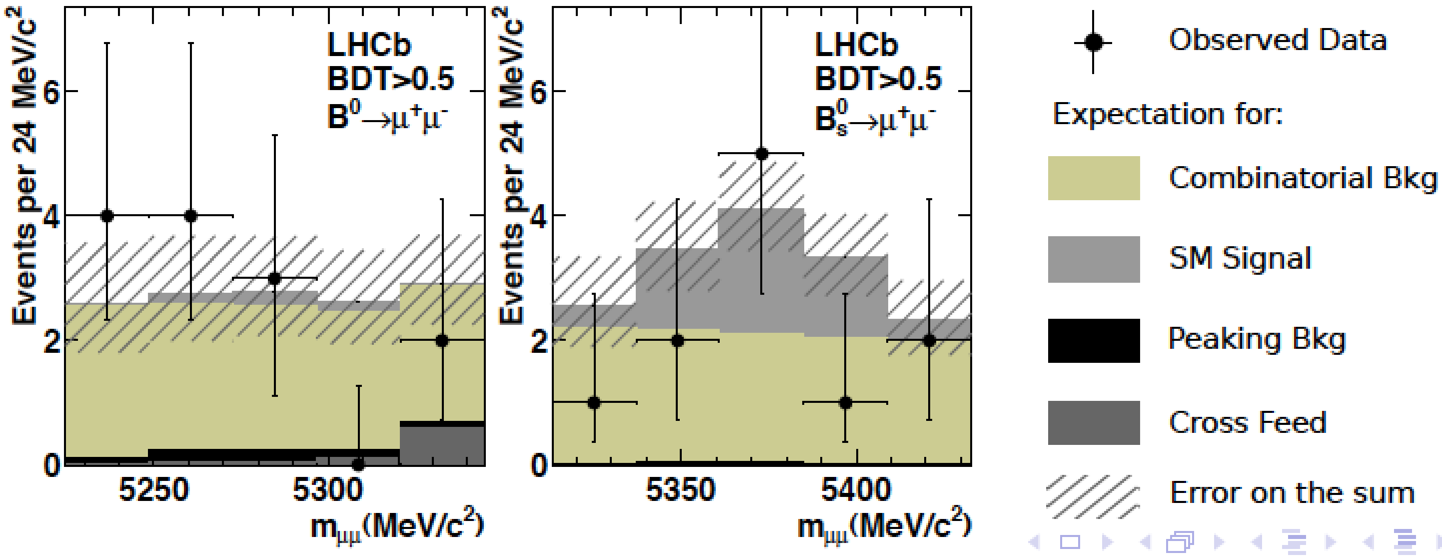
LHCb-CONF-2012-008



ΔF=1, Higgs

Golden Modes: Rare Decay

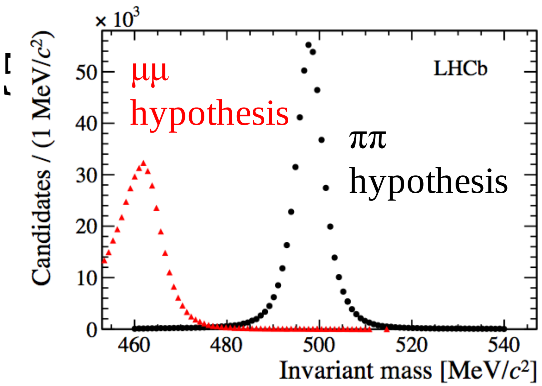




ΔF=1, Higgs

FCNC *family of measurements*

SM prediction $B(K_S^0 \rightarrow \mu^+\mu^-) = (5.0 \pm 1.$



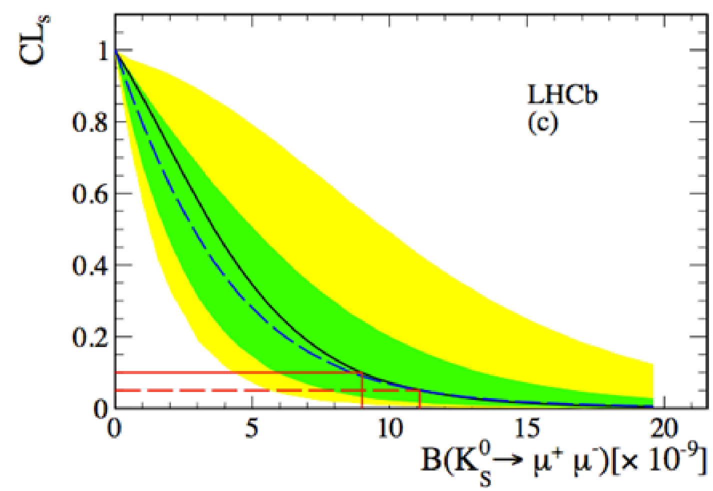
Normalisation:

$$\frac{\mathcal{B}(K_S^0 \rightarrow \mu^+\mu^-)}{\mathcal{B}(K_S^0 \rightarrow \pi^+\pi^-)} = \frac{\epsilon_{\pi\pi}}{\epsilon_{\mu\mu}} \frac{N_{K_S^0 \rightarrow \mu^+\mu^-}}{N_{K_S^0 \rightarrow \pi^+\pi^-}}$$

We measure with 1.0 fb^{-1} :

$B(K_S^0 \rightarrow \mu^+\mu^-) < 11(9) \times 10^{-9}$

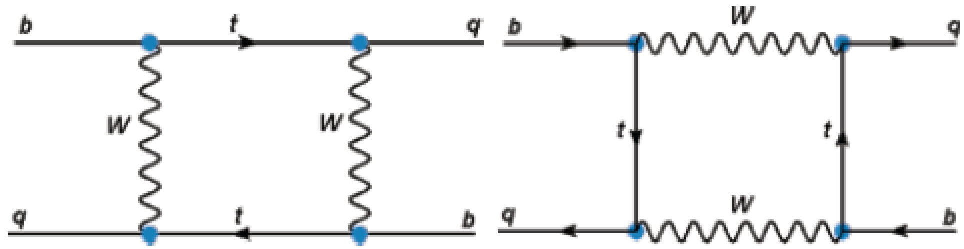
This limit is a factor 30 below the previous measurement !



arXiv:1209.4029v2

K^0_S	K^0_L	D^0	B^0	B^0_s
< 9 x 10^{-9} (90% CL)	(6.84 ± 0.11) × 10^{-9}	< 1.1 x 10^{-8} (90% CL)	< 0.8 x 10^{-9} (90% CL)	< 3.8 x 10^{-9} (90% CL)
LHCb	BNL E871	LHCb	LHCb	LHCb

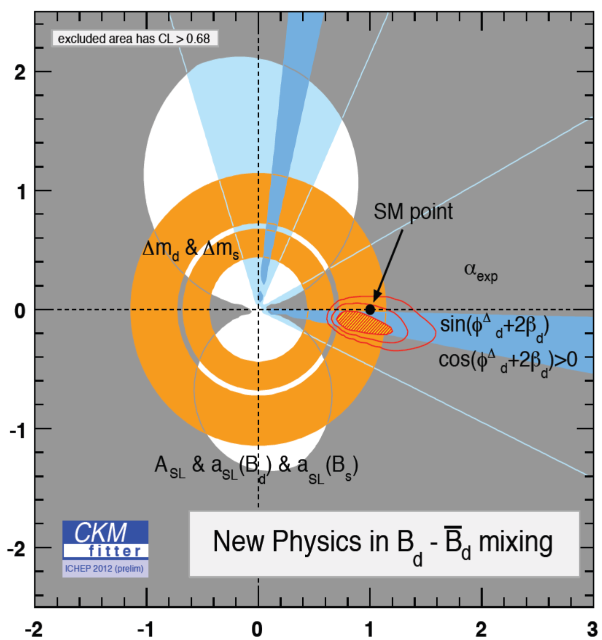
ΔF=2, Box Diagrams

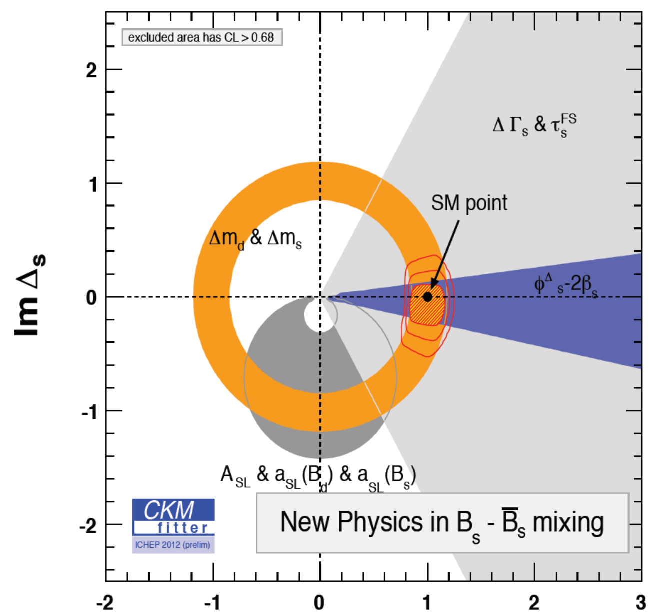


B->u

B->s

c->u

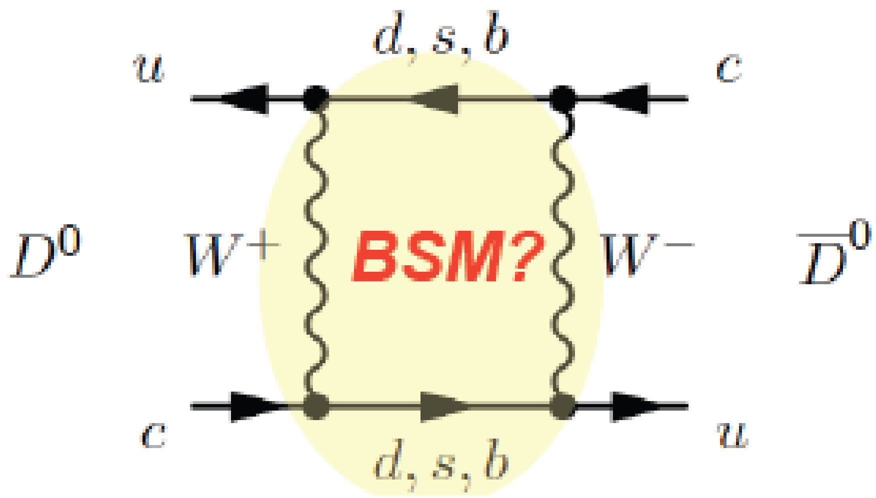




Need "percent" precision to disentangle new CP phases in Bd and Bs mixing, Bs->J/Psiphi etc

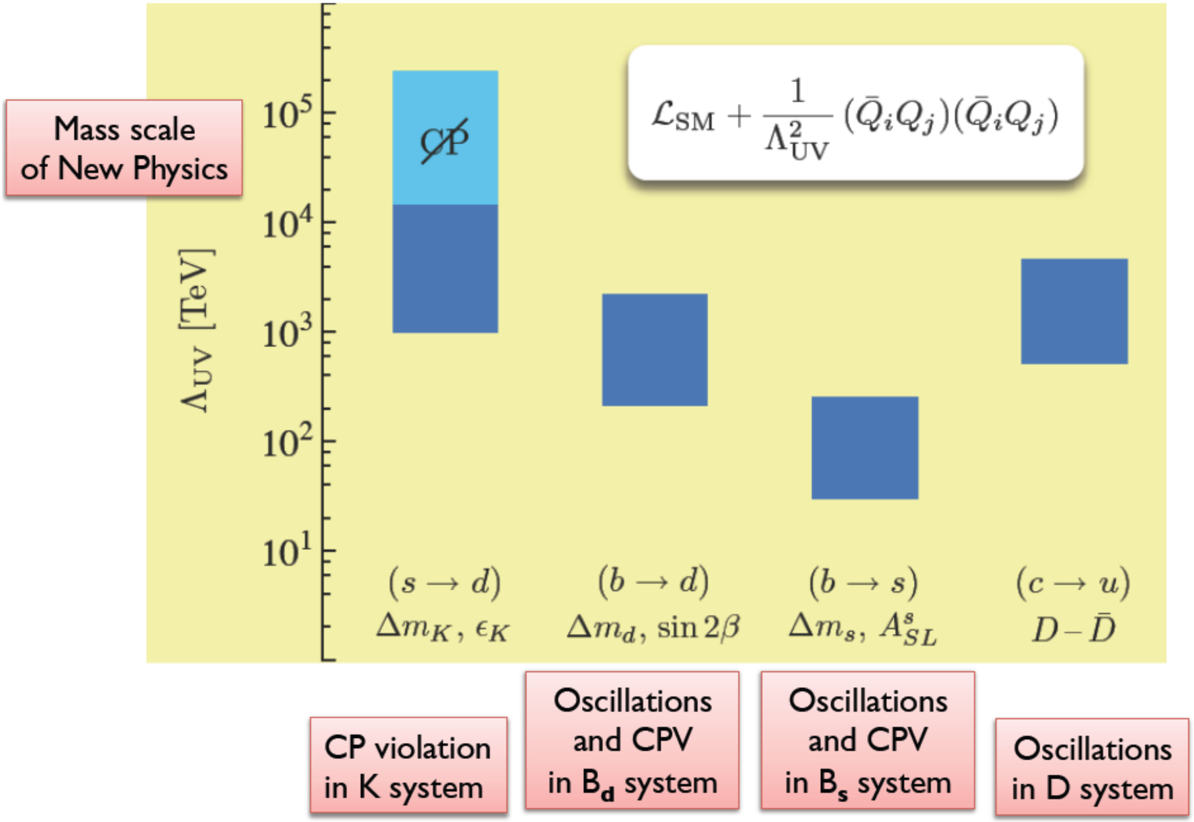
ΔF=2

Also charm



Mass Scales NP

arXiv:1002.0900



Reference ONLY

Observable class of observables)	SM prediction	Ultimate th. error	Present result	Future (S)LHCb	Future SuperB	Future Other
$\lvert V_{us}\rvert$ $[K \to \pi\ell\nu]$	input	$0.1\%_{\text{(Latt)}}$	0.2252 ± 0.0009	-	-	
$\lvert V_{cb}\rvert$ $[\times 10^{-3}]$ $[B \to X_c\ell\nu]$	input	1%	40.9 ± 1.1	-	$1\%_{\text{excl}}, 0.5\%_{\text{incl}}$	
$\lvert V_{ub}\rvert$ $[\times 10^{-3}][B \to \pi\ell\nu]$	input	$5\%_{\text{(Latt)}}$	4.15 ± 0.49	-	$3\%_{\text{excl}}, 2\%_{\text{incl.}}$	
γ $[B \to DK]$	input	$< 1^\circ$	$(70^{+27}_{-30})^\circ$	0.9°	1.5°	
$S_{B_d \to \psi K}$	2β	$\lesssim 0.01$	0.671 ± 0.023	0.0035	0.0025	
$S_{B_s \to \psi\phi, \psi f_0(980)}$	$2\beta_s$	$\lesssim 0.01$	-0.002 ± 0.087	0.008	-	
$S_{[B_s \to \phi\phi]}$	$2\beta_s^{eff}$	$\lesssim 0.05$	-	0.03	-	
$S_{[B_s \to K^{*0}\bar{K}^{*0}]}$	$2\beta_s^{eff}$	$\lesssim 0.05$	-	0.02	-	
$S_{[B_d \to \phi K^0]}$	$2\beta^{eff}$	$\lesssim 0.05$	-	0.03	0.02	
$S_{[B_d \to K_S^0\pi^0\gamma]}$	0	$\lesssim 0.05$	-0.15 ± 0.20	-	0.02	
$S_{[B_s \to \phi\gamma]}$	0	$\lesssim 0.05$	-	0.02	-	
$A_{\text{SL}}^d [\times 10^{-3}]$	-0.5	0.1	-5.8 ± 3.4	0.2	4	
$A_{\text{SL}}^s [\times 10^{-3}]$	2.0×10^{-2}	$< 10^{-2}$	-2.4 ± 6.3	0.2	-	
$\mathcal{B}(B \to \tau\nu)[\times 10^{-4}]$	1	$5\%_{\text{Latt}}$	(1.14 ± 0.23)	-	4%	
$\mathcal{B}(B \to \mu\nu)[\times 10^{-7}]$	4	$5\%_{\text{Latt}}$	< 13	-	5%	
$\mathcal{B}(B \to D\tau\nu)[\times 10^{-2}]$	1.02 ± 0.17	$5\%_{\text{Latt}}$	1.02 ± 0.17	[under study]	2%	
$\mathcal{B}(B \to D^*\tau\nu)[\times 10^{-2}]$	1.76 ± 0.18	$5\%_{\text{Latt}}$	1.76 ± 0.17	[under study]	2%	
$\mathcal{B}(B_s \to \mu^+\mu^-)[\times 10^{-9}]$	3.5	$5\%_{\text{Latt}}$	< 4.2	0.15	-	
$R(B_{s,d} \to \mu^+\mu^-)$	0.29	$\sim 5\%$	-	$\sim 35\%$	-	
$q_0(A^{FB}_{B \to K^*\mu^+\mu^-})[\text{GeV}^2]$	4.26 ± 0.34			2%	-	
$A_{\text{T}}^{(2)}(B \to K^*\mu^+\mu^-)$	$< 10^{-3}$			0.04	-	
$A_{\text{CP}}(B \to K^*\mu^+\mu^-)$	$< 10^{-3}$			0.5%	1%	
$B \to K\nu\bar{\nu}[\times 10^{-6}]$	4	$10\%_{\text{Latt}}$	< 16	-	0.7	
$\lvert q/p\rvert_{D-\text{mixing}}$	1	$< 10^{-3}$	0.91 ± 0.17	$O(1\%)$	2.7%	
ϕ_D	$\lesssim 0.1\%$		$-$	$O(1^\circ)$	1.4°	
$a_{\text{CP}}^{\text{dir}}(\pi\pi)(\%)$	$\lesssim 0.3$		0.20 ± 0.22	0.015	[under study]	
$a_{\text{CP}}^{\text{dir}}(KK)(\%)$	$\lesssim 0.3$		-0.23 ± 0.17	0.010	[under study]	
$a_{\text{CP}}^{\text{dir}}(\pi\pi\gamma, KK\gamma)$	$\lesssim 0.3\%$			[under study]	[under study]	
$\mathcal{B}(\tau \to \mu\gamma)[\times 10^{-9}]$	0		< 44	-	2.4	
$\mathcal{B}(\tau \to 3\mu)[\times 10^{-10}]$	0		< 210(90% CL)	1-80	2	
$\mathcal{B}(\mu \to e\gamma)[\times 10^{-12}]$	0		< 2.4(90% CL)			~ 0.1 MEG ~ 0.01 PSI-future ~ 0.01 Project X
$\mathcal{B}(\mu N \to eN)(Ti)$	0		$< 4.3 \times 10^{-12}$			10^{-18} PRISM
$\mathcal{B}(\mu N \to eN)(Al)$	0		-			10^{-16} COMET, Mu2e
$\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu})[\times 10^{-11}]$	8.5	8%	$17.3^{+11.5}_{-10.5}$			$\sim 10\%$ NA62 $\sim 5\%$ ORKA $\sim 2\%$ Project X
$\mathcal{B}(K_L \to \pi^0\nu\bar{\nu})[\times 10^{-11}]$	2.4	10%	< 2600			$\sim 100\%$ KOTO $\sim 5\%$ Project X
$\mathcal{B}(K_L \to \pi^0 e^+e^-)_{SD}$	1.4×10^{-11}	30%	$< 28 \times 10^{-11}$			$\sim 10\%$ Project X

Table 5: Status and future prospects of selected $B_{s,d}$, D, K, and LFV observables. The SuperB column refers to a generic super B factory, collecting 50ab^{-1} at the $\Upsilon(4S)$.

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LHCb Experiment

Key Components

- A few recent results

Upgrade Proposal (2018)

Issues

Forward Physics @ LHC

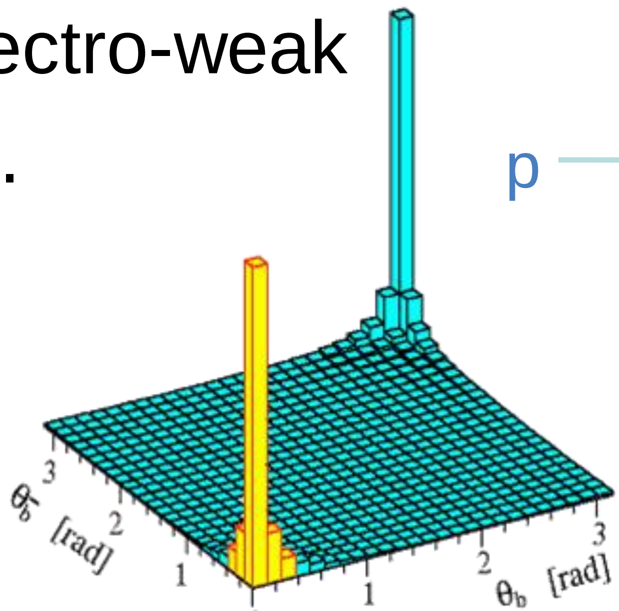
$\theta < 0.3$rad

Flavour

10^{12} B /year

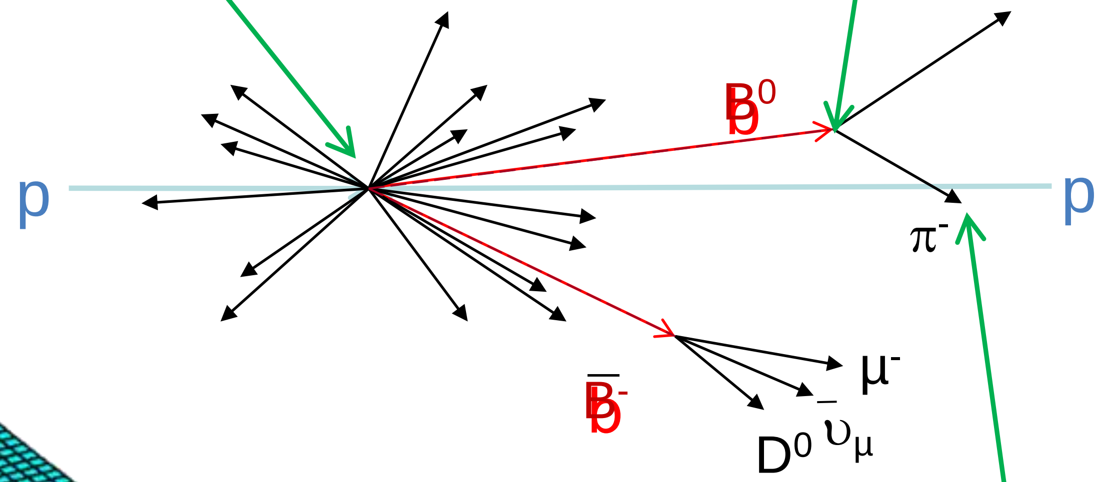
Electro-weak

+...



Primary vertex: many tracks ~50

B decay vertices: a few tracks



K/π separation

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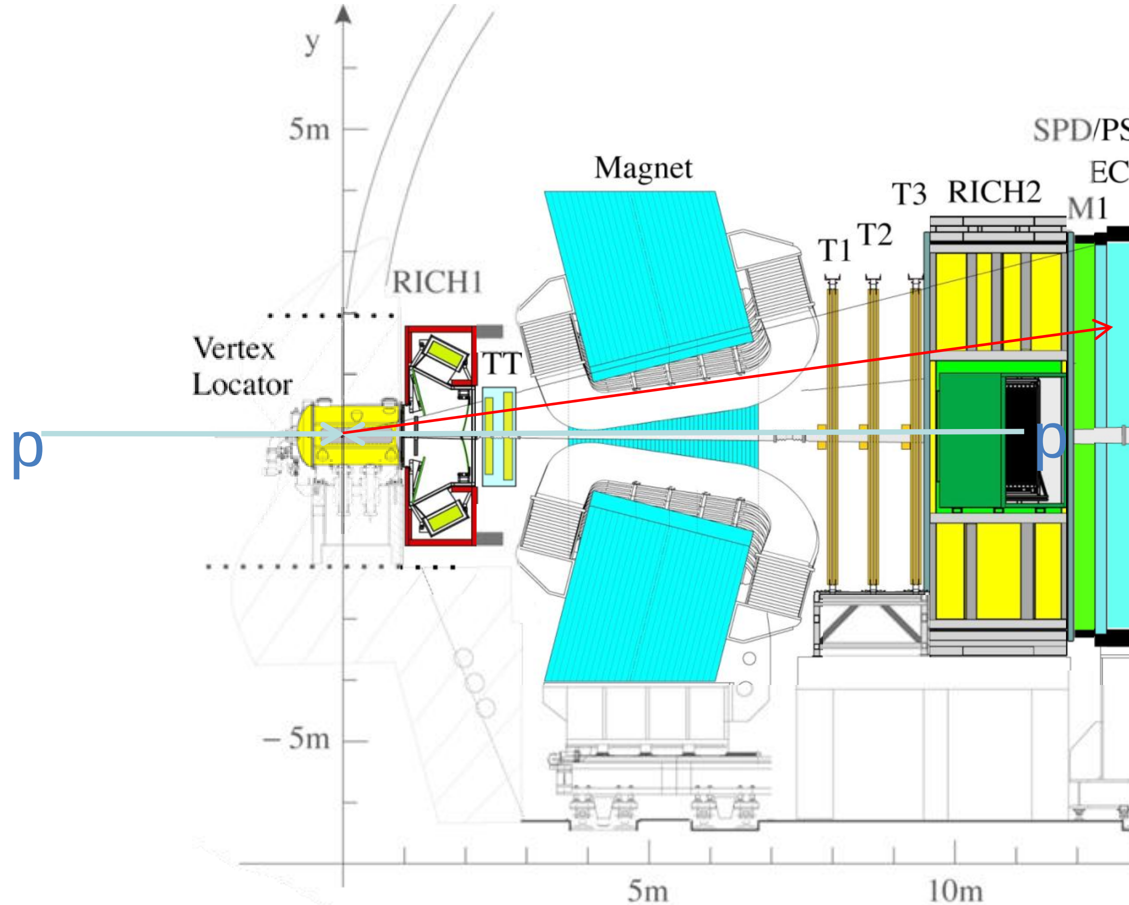
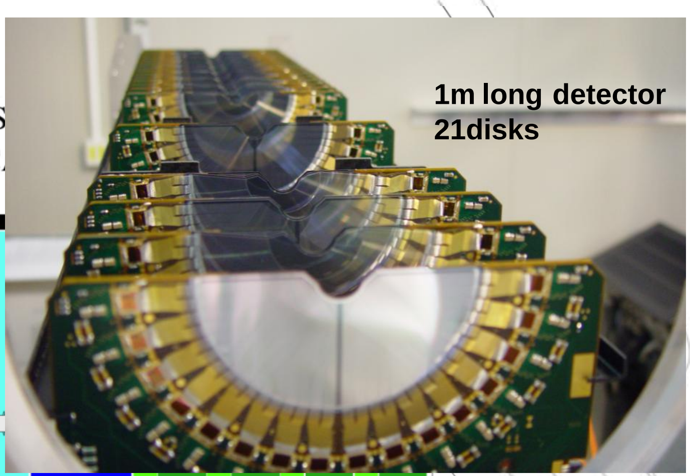
LHCb





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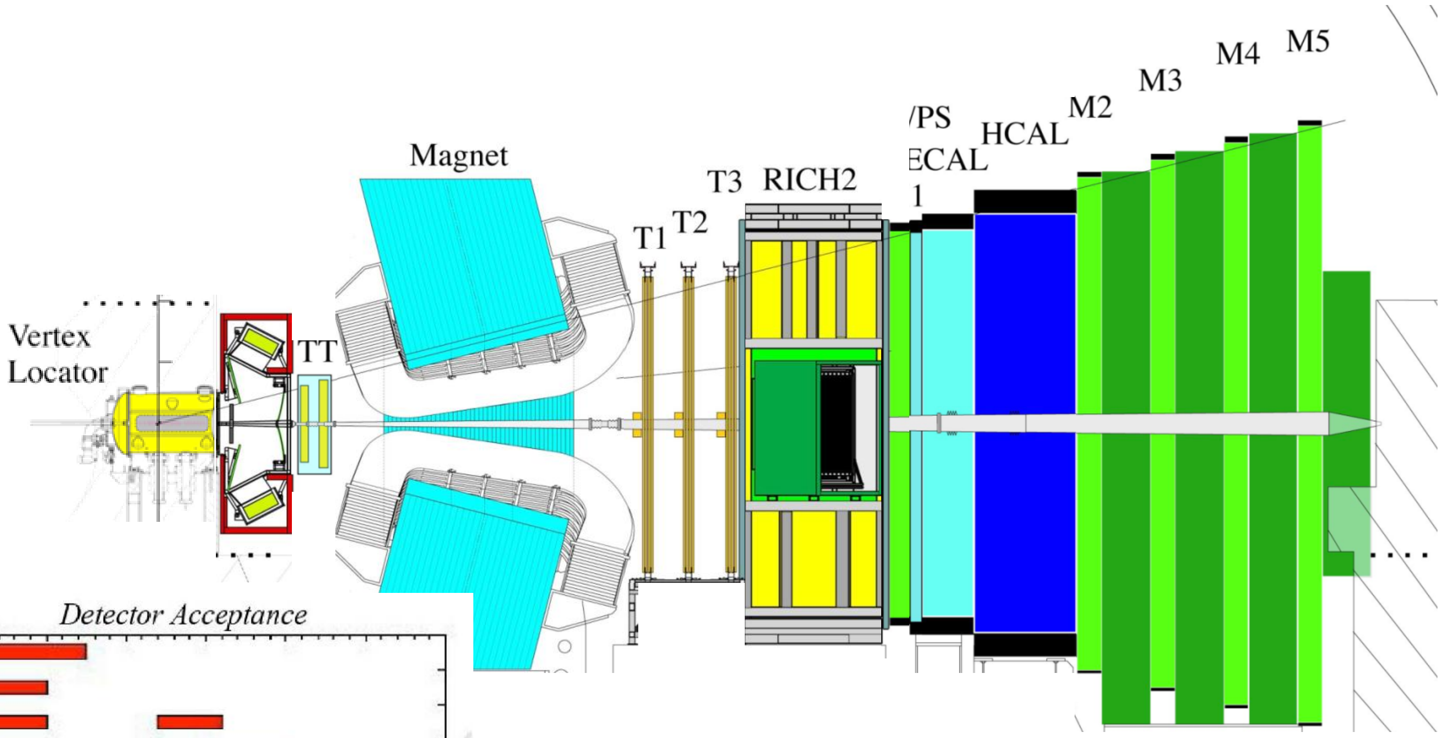
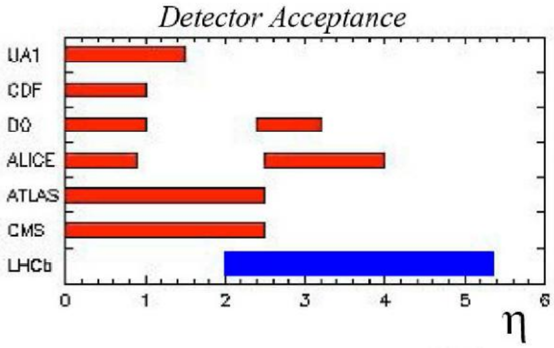
LHCb





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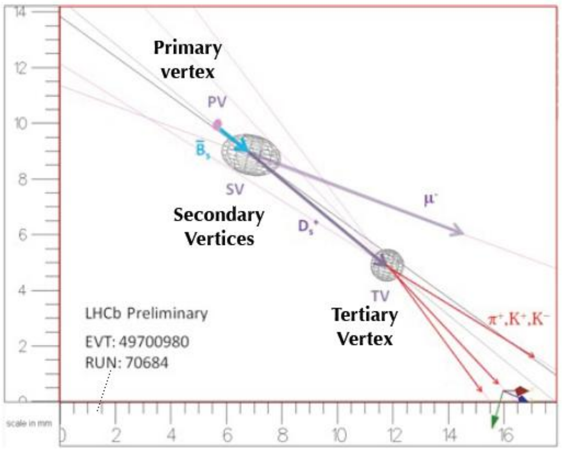
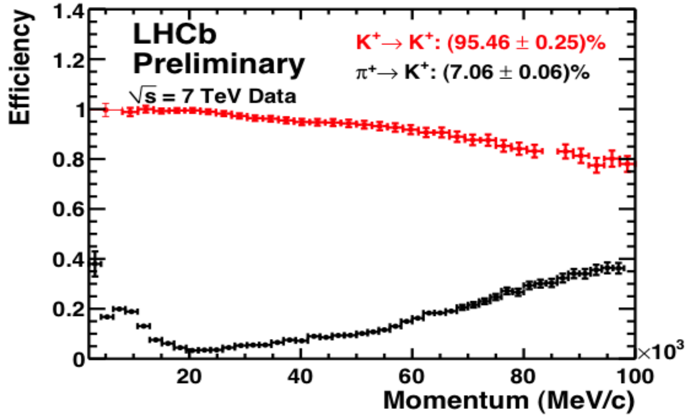
Key Requirements

Vertexing & Tracking

Trigger

- Specialized for B physics
- Adaptable





Particle ID

- K/π for P <100 GeV/c

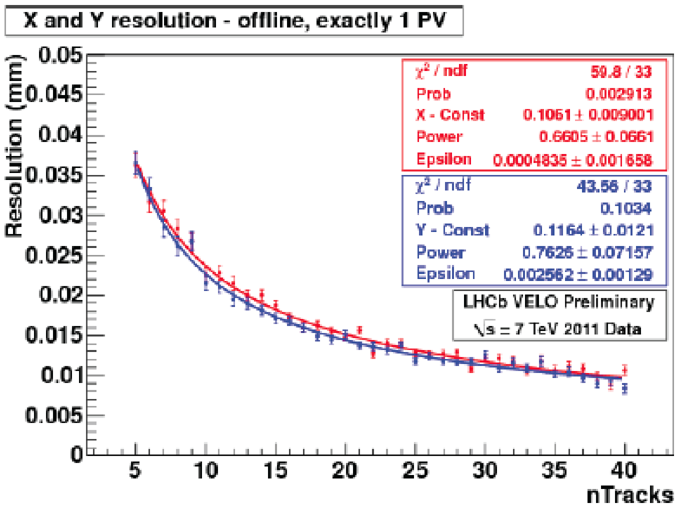
Tagging

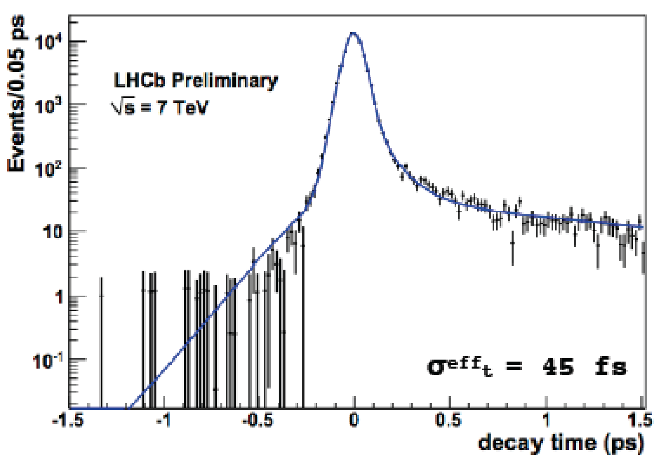
- Get flavour of B at production

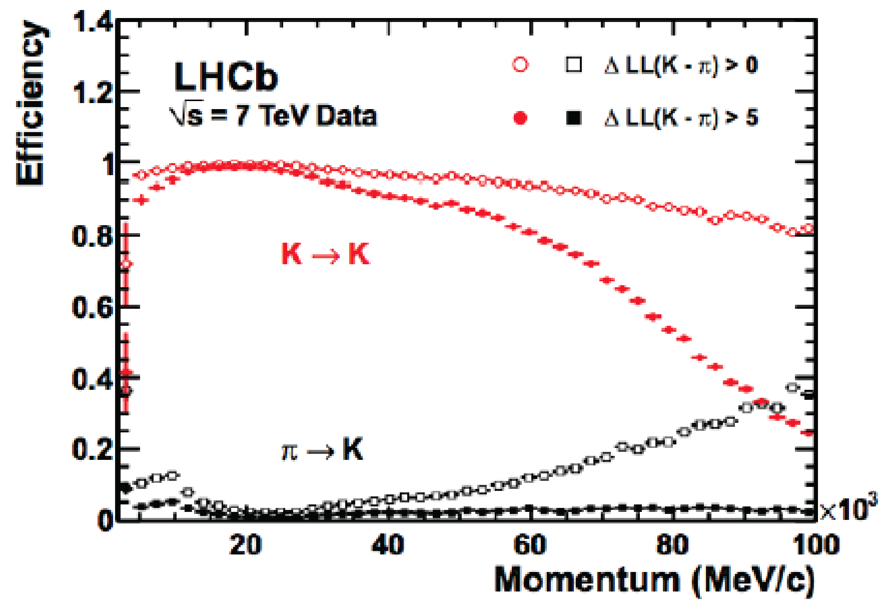
Performance

Vertex Locator	$\sigma_{\mathrm{PV,x/y}} \sim 10\ \mu\mathrm{m}$, $\sigma_{\mathrm{PV,z}} \sim 60\ \mu\mathrm{m}$
Tracking (TT, T1-T3)	$\Delta p/p$: 0.4% at 5 GeV/c, to 0.6% at 100 GeV/c
RICHs	$\varepsilon(K \to K) \sim 95\%$, mis-ID rate $(\pi \to K) \sim 5\%$
Muon system (M1-M5)	$\varepsilon(\mu \to \mu) \sim 97\%$, mis-ID rate $(\pi \to \mu) = 1 - 3\%$
ECAL	$\sigma_E/E \sim 10\%/\sqrt{E} \oplus 1\%$ (E in GeV)
HCAL	$\sigma_E/E \sim 70\%/\sqrt{E} \oplus 10\%$ (E in GeV)

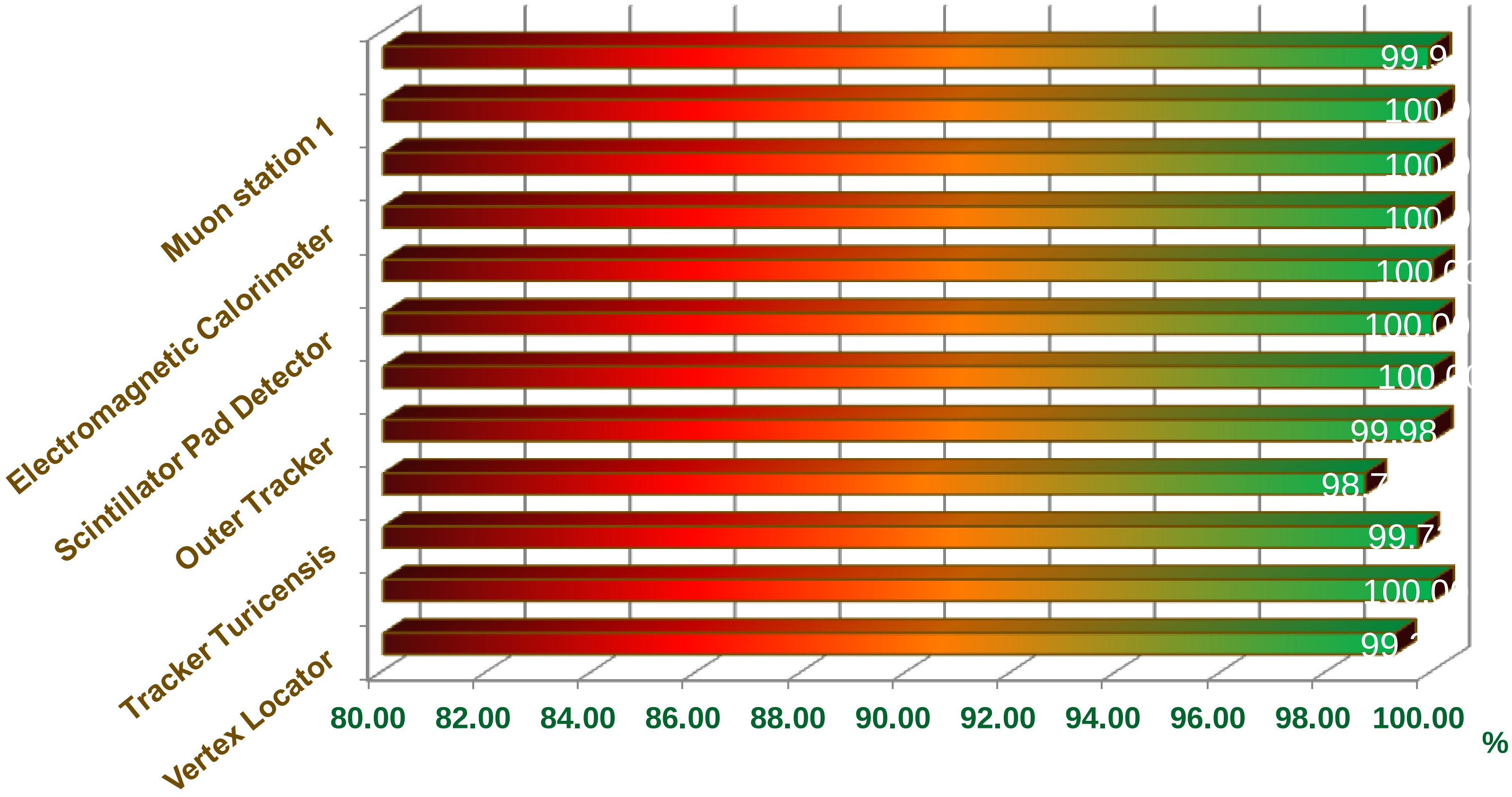
Performance

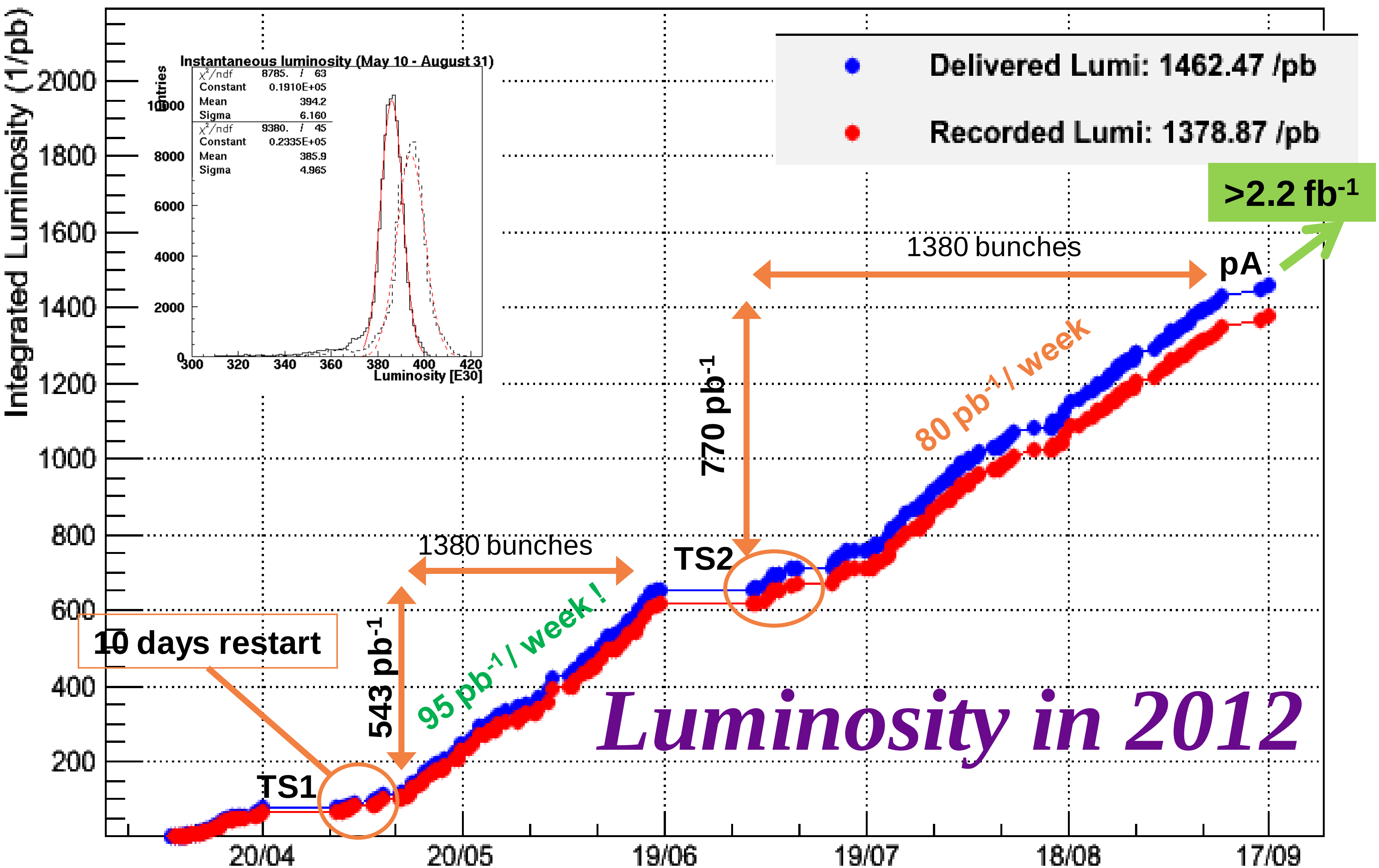




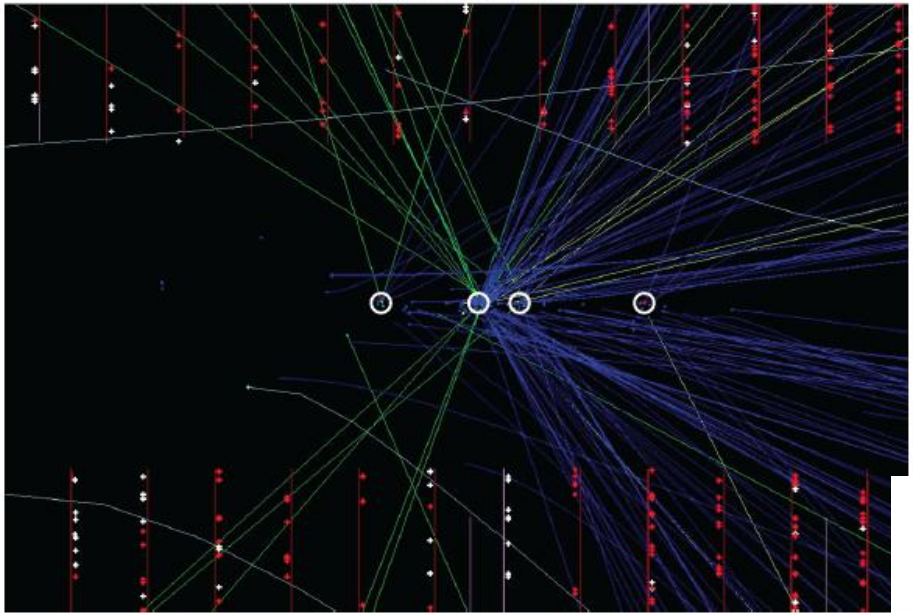


Efficiencies

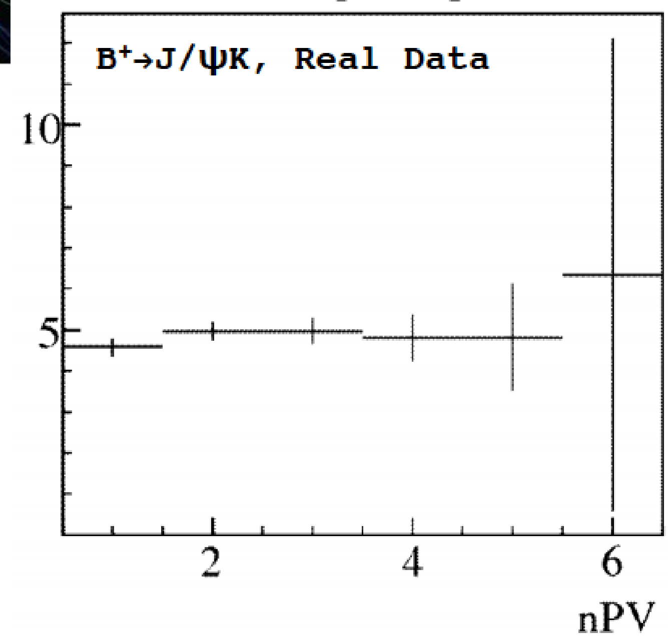



Integrated Luminosity (1/pb)
Instantaneous luminosity (May 10 - August 31)
Entries
Luminosity [E30]
Delivered Lumi: 1462.47 /pb
Recorded Lumi: 1378.87 /pb
>2.2 fb-1
1380 bunches
pA
770 pb-1
80 pb-1 / week
1380 bunches
TS2
95 pb-1 / week !
543 pb-1
10 days restart
TS1
Luminosity in 2012
20/04
20/05
19/06
19/07
18/08
17/09

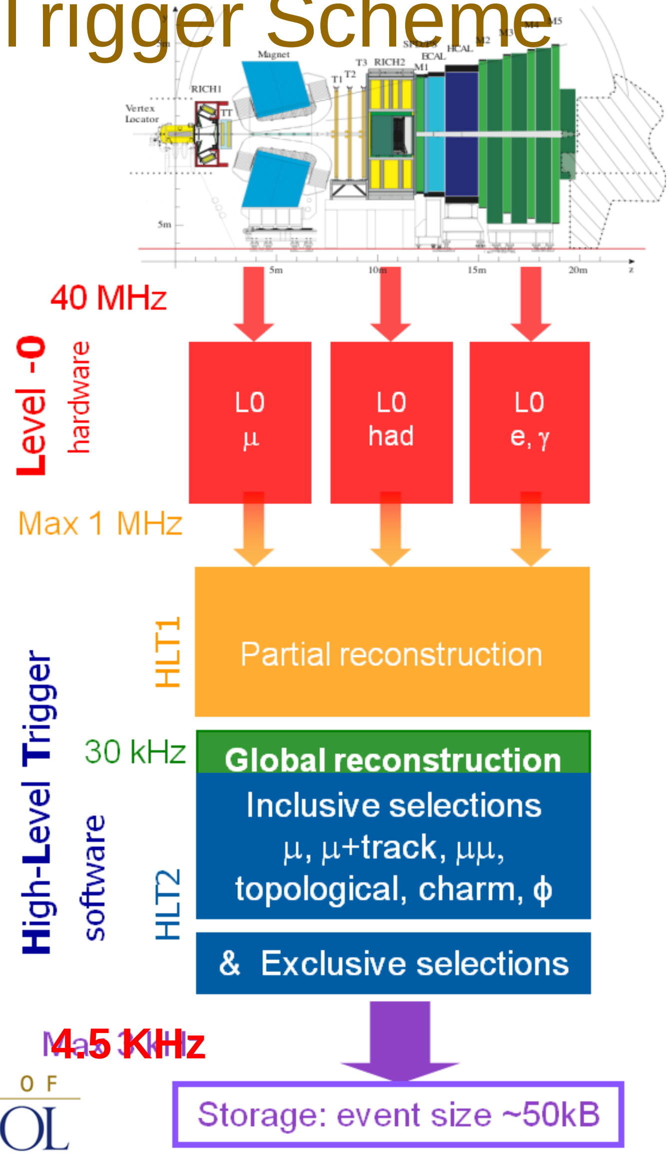
VELO rz view



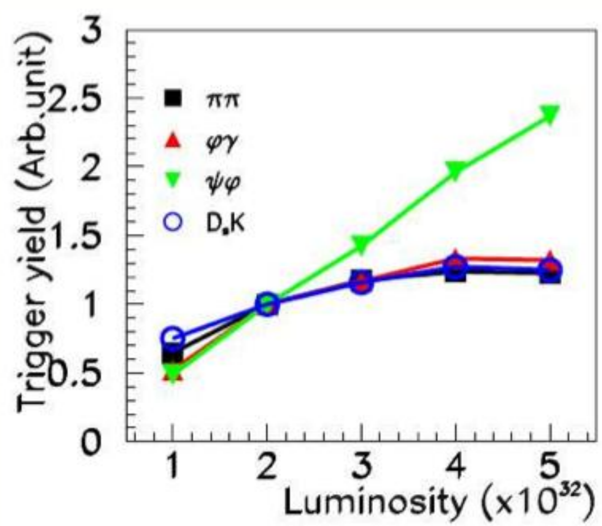
Nsig/Nbkg



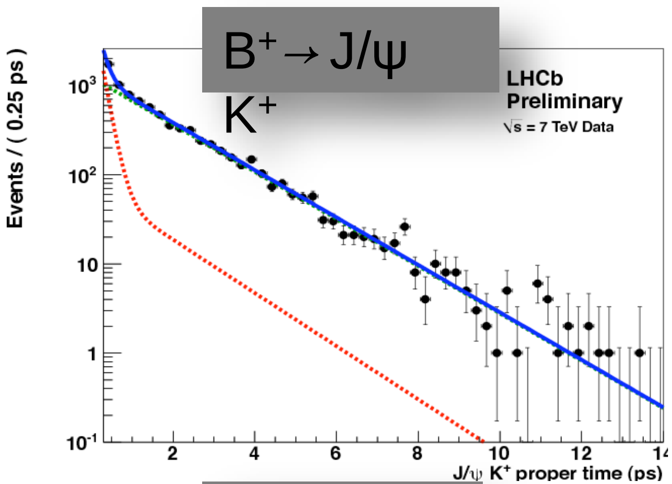
LHCb Trigger Scheme

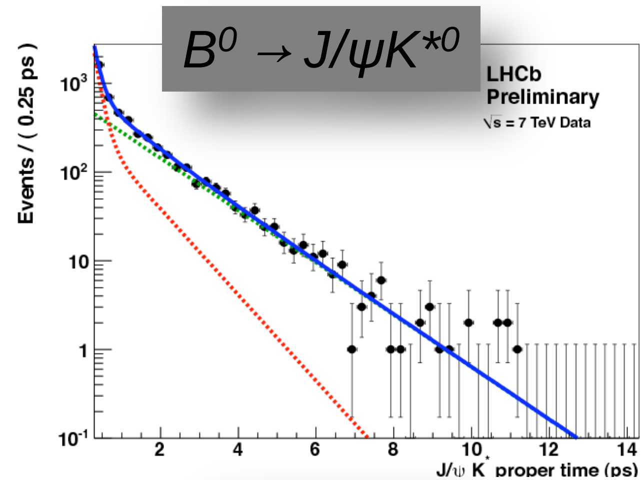


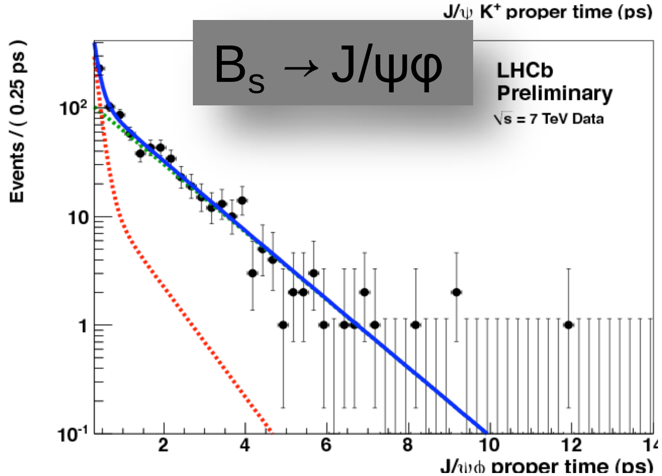
- L0 H/W trigger
  - 4 μs latency in FE electronics
- HLT S/W trigger
  - Implemented in CPU farm
- Luminosity upgrade
  - Event yields saturate
  - Need full event information at L0

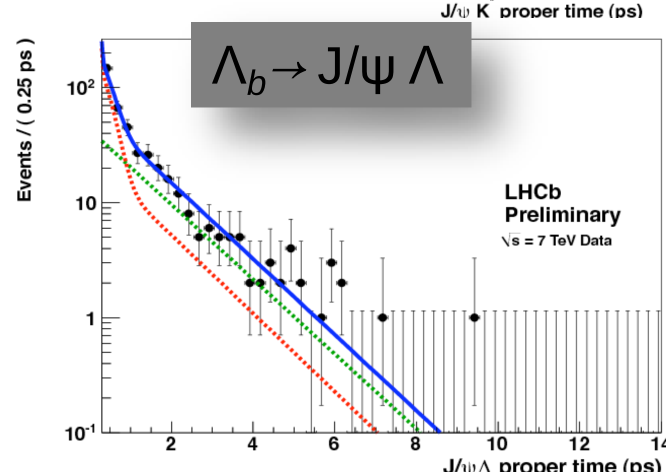


B Lifetimes(2011)







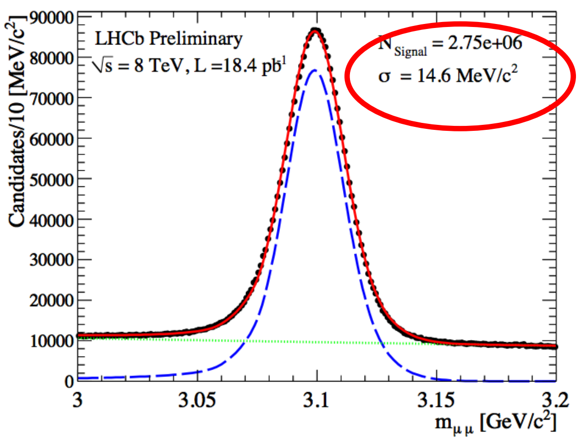


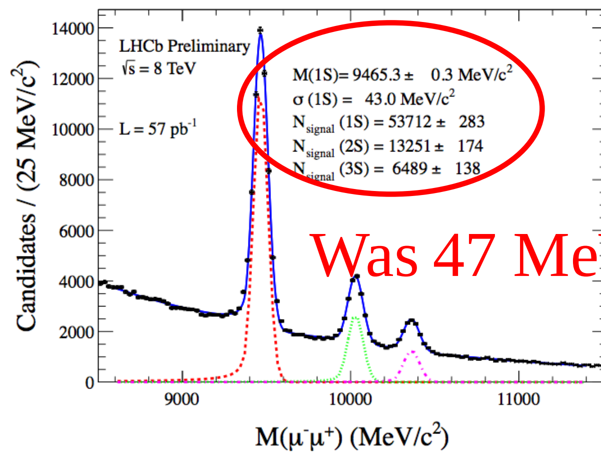
B Lifetimes

Channel	LHCb lifetime, stat and sys (ps)	PDG (ps)
$B^+ \rightarrow J//\psi K^+$	1.689 ± 0.022 ± 0.047	1.638 ± 0.011
$B^0 \rightarrow J//\psi K^{*0}$ $B^0 \rightarrow J//\psi K_s$	1.512 ± 0.032 ± 0.042 1.558 ± 0.056 ± 0.055	1.525 ± 0.009
$B_s \rightarrow J//\psi \phi$	1.447 ± 0.064 ± 0.056	1.477 ± 0.046
$\Lambda_b \rightarrow J//\psi \Lambda$	1.353 ± 0.108 ± 0.035	1.391 ± 0.038

Using lifetime unbiased trigger and t > 0.3 ps

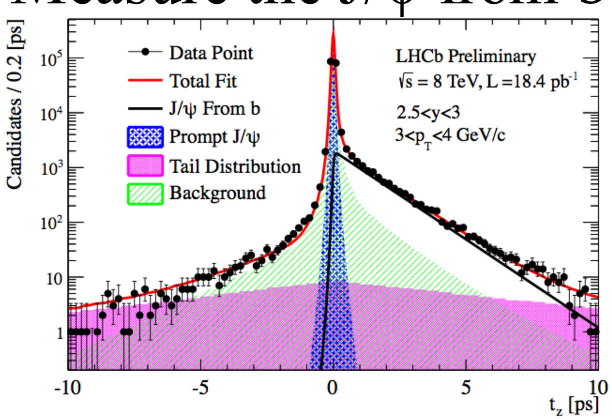
J/ψ, ϒ(1S), ϒ(2S) and ϒ(3S) @ 8 TeV

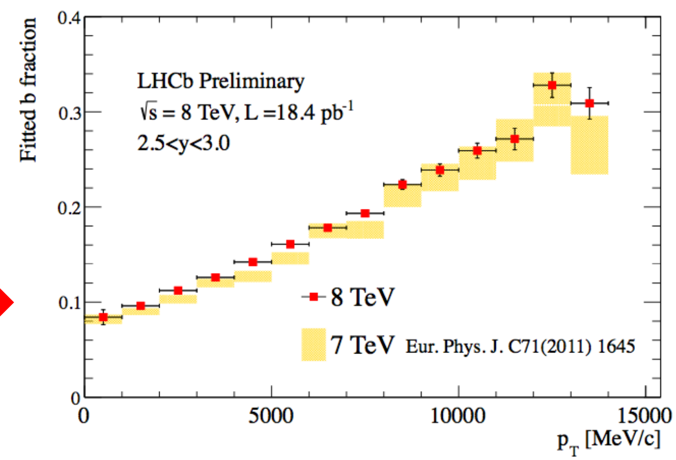




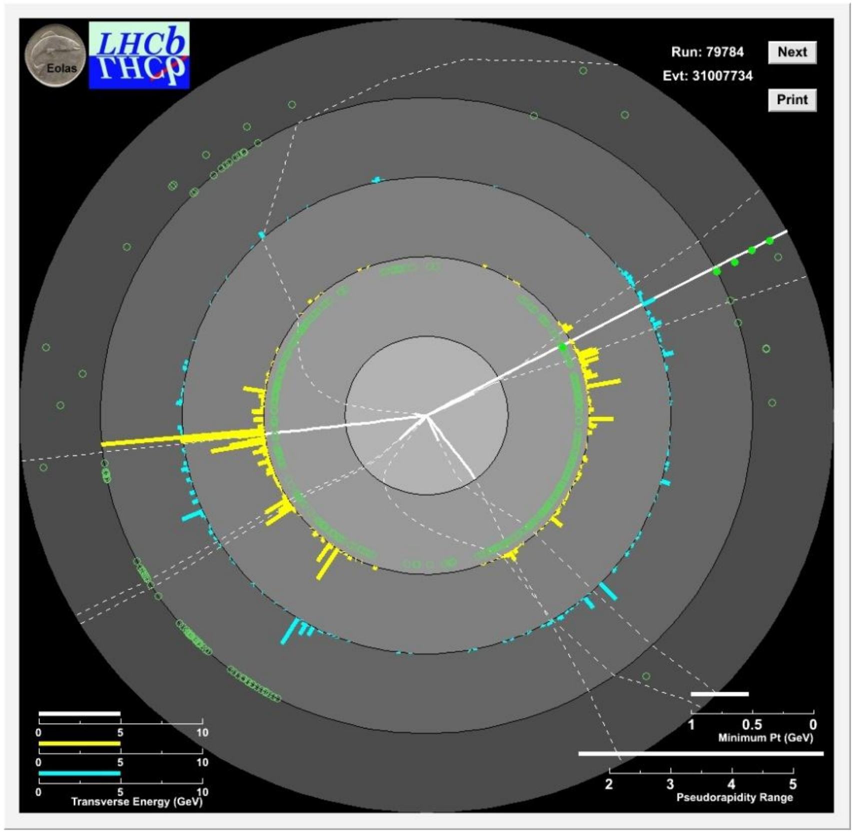
Was 47 MeV/c^2 in 2011

Measure the J/ψ from *b* quarks :





Example: Z Decay



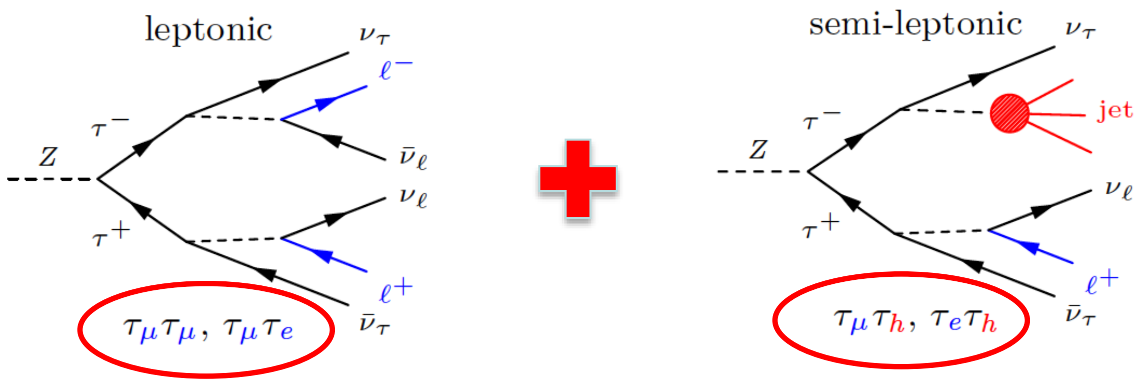
$$Z \rightarrow \tau\tau$$

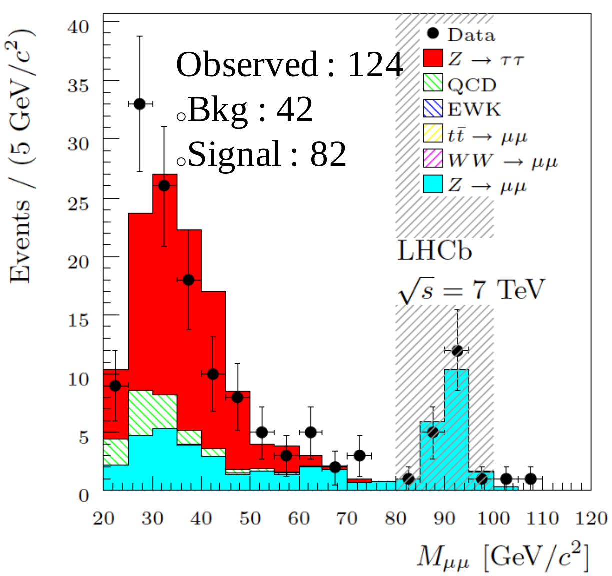
Clean!

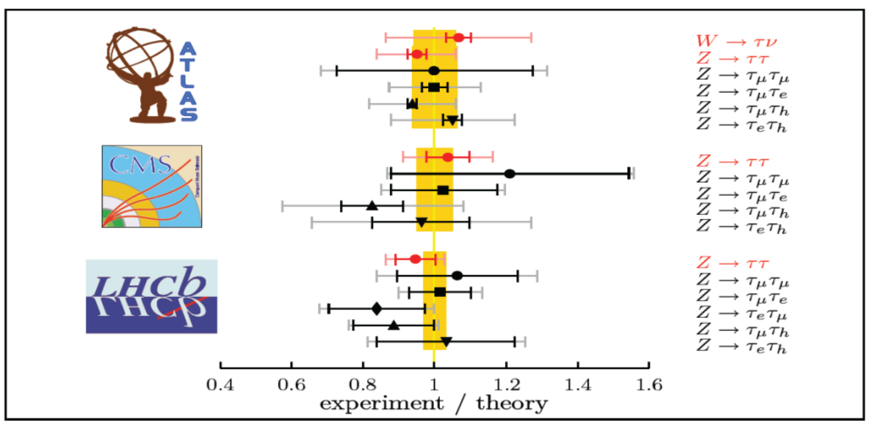
Z⟶ ττ cross section

LHCB-PAPER-2012-029

- Signal topologies and channels





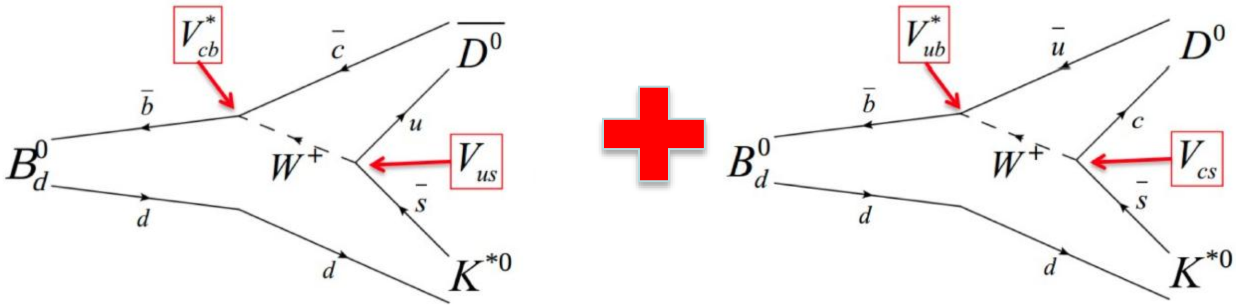


ATLAS : ATLAS-CONF-2012-0

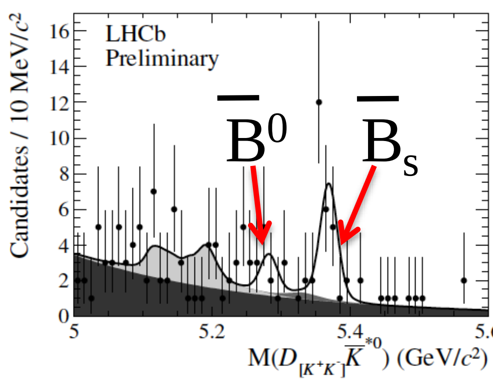
ATLAS : Phys. Rev. D84 (2011)

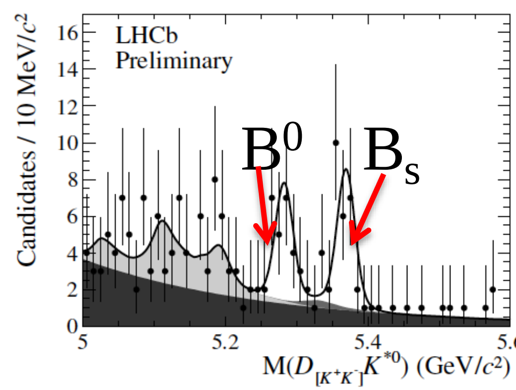
CMS : JHEP 08 (2011) 117

Measurement of CP observables in B0→DK^{*0} with D→K^{+}K^{-}



Two color suppressed decay modes → Interference → Sensitivity to γ





LHCb-CONF-2012-024

$$\mathcal{A}_{d}^{KK} = -0.47^{+0.24}_{-0.25}(stat) \pm 0.02(syst)$$

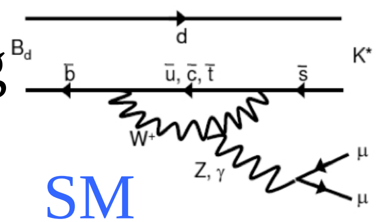
$$\mathcal{A}_{s}^{KK} = 0.04 \pm 0.17(stat) \pm 0.01(syst)$$

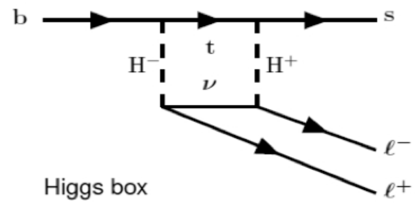
UNIVER LIVEI

ΔF=1, EW

Flavour Changing Neutral Current (FCNC)

SM



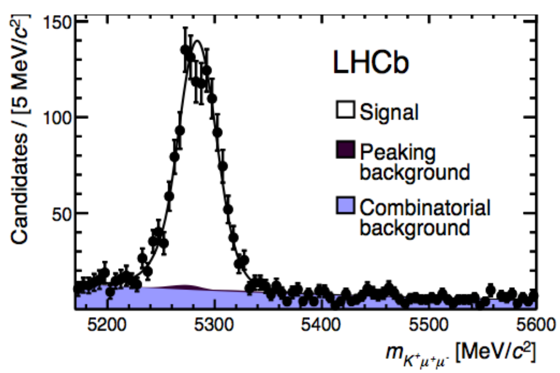


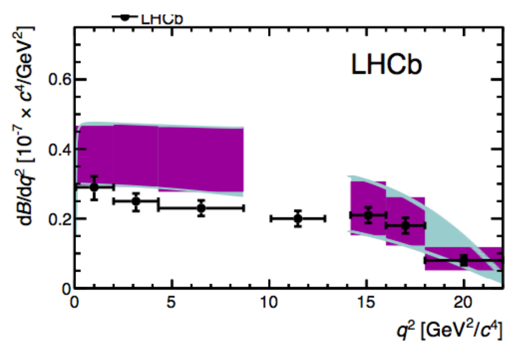
NP

Differential branching fraction of B+→K+μ+ μ−

Measure the differential branching fraction :

$$\frac{d\mathcal{B}}{dq^2} = \frac{1}{q^2_{max} - q^2_{min}} \frac{N_{sig}}{N_{K^+J/\psi}} \frac{\varepsilon_{K^+J/\psi}}{\varepsilon_{K^+\mu^+\mu^-}} \times \mathcal{B}(B^+ \to K^+ J/\psi) \times \mathcal{B}(J/\psi \to \mu^+\mu^-) \, .$$





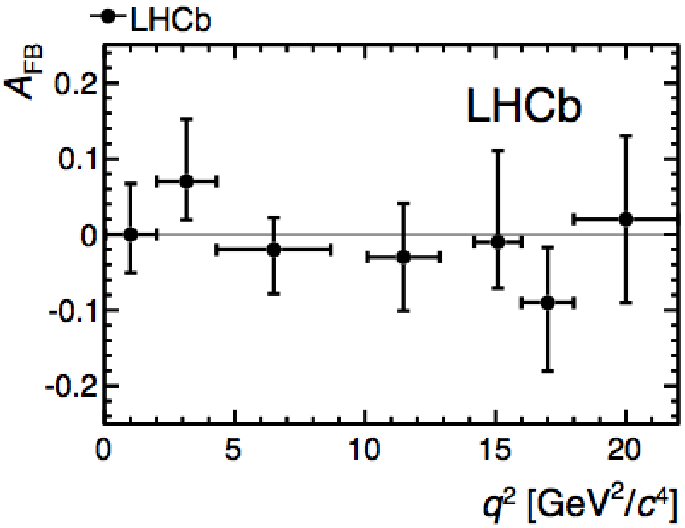
Event yield 1232 ± 40 of $B^+ \to K^+\mu^+\mu$ in 1.0 fb^{-1} and normalise to $B^+ \to J/\psi K^+$

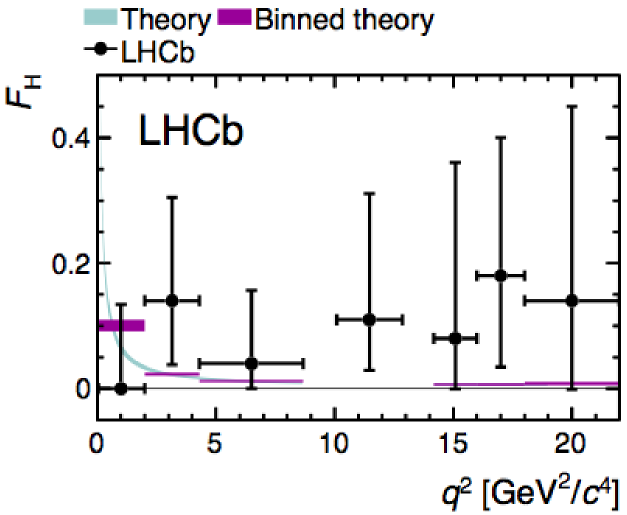
arXiv:1209.4284

DF=1, EW

$$\frac{1}{\Gamma}\frac{d\Gamma[B^+ \to K^+\mu^+\mu^-]}{d\cos\theta_l} = \frac{3}{4}(1-F_H)(1-\cos^2\theta_l) + \frac{1}{2}F_H + A_{FB}\cos\theta_l$$

F_H and the FB asymetry A_{FB} are expected to be null in the SM



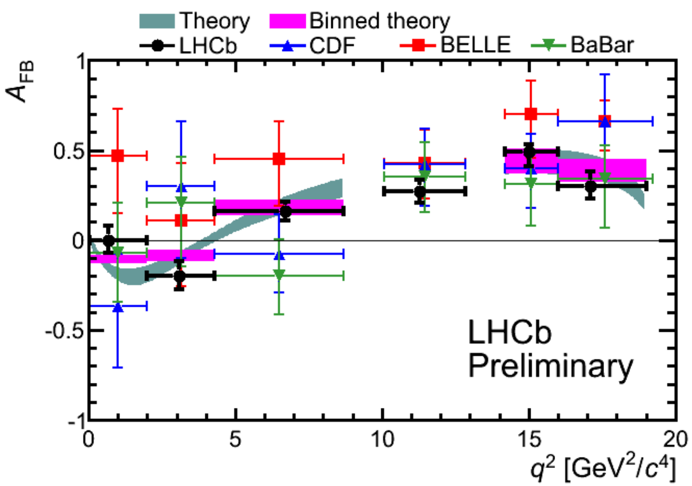


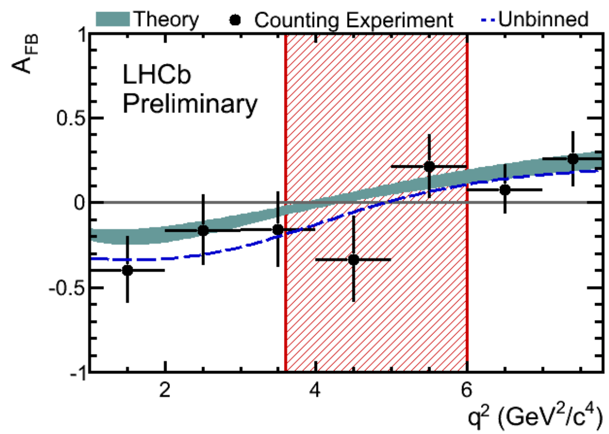
arXiv:1209.4284

If muons were massless, F_H would be proportional to the contributions from (pseudo-)scalar and tensor operators to the partial width, Γ.

ΔF=1, EW

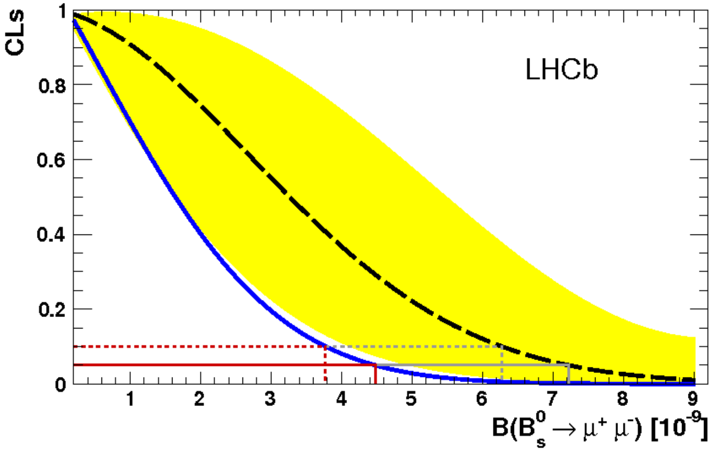
AFB($B^0 \to K^{*0}\mu^+\mu^-$) : An extraordinarily complex but beautiful analysis





First measurement of the zero-crossing point of the forward-backward asymmetry q^2 = (4.9+1.1−1.3) GeV^2
(SM predictions in the range 4.0 – 4.3 GeV2)

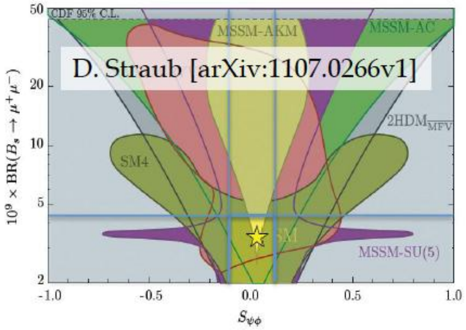
ΔF=1, Higgs



Mode	Limit	at 90 % CL	at 95 % CL
$B_s^0 \to \mu^+\mu^-$	Exp. bkg+SM	6.3×10^{-9}	7.2×10^{-9}
	Exp. bkg	2.8×10^{-9}	3.4×10^{-9}
	Observed	3.8×10^{-9}	4.5×10^{-9}
$B^0 \to \mu^+\mu^-$	Exp. bkg	0.91×10^{-9}	1.1×10^{-9}
	Observed	0.81×10^{-9}	1.0×10^{-9}

Standard Model expectation,
e.g. (3.2 — 0.3) x 10^{-9}

ATLAS B(Bs→μ+μ–) < 2.2 (1.9) × 10^{-8} @ 95% (90%) CL
CMS B(Bs→μ+μ–) < 7.7 (6.4) × 10^{-9} @ 95% (90%) CL



ΔF=2, Semileptonic asymmetries

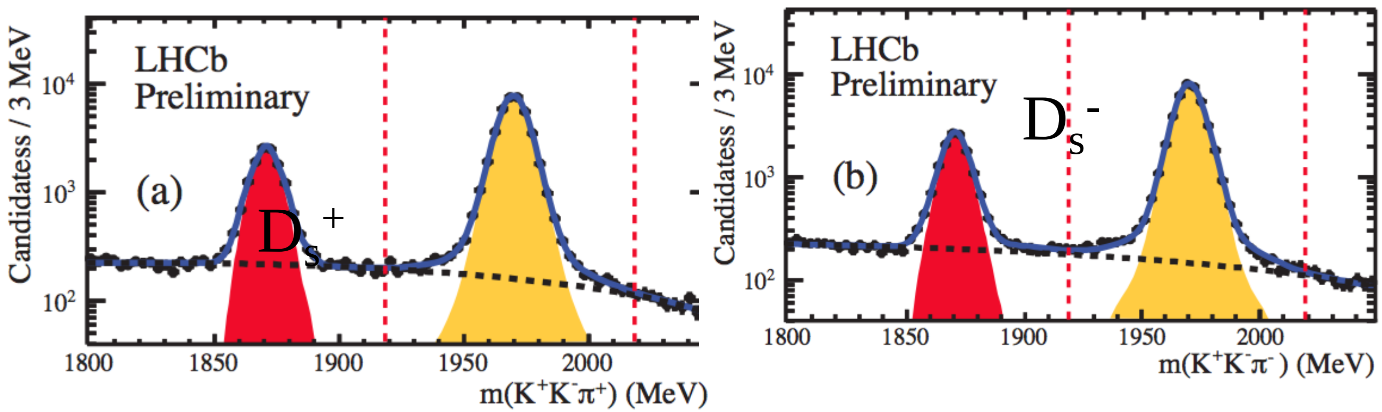
The observables :

$$a_s = 1 - \left|\frac{q}{p}\right|^2 = \mathrm{Im}\left(\frac{\Gamma_{12}^s}{M_{12}^s}\right) + O\left(\left(\mathrm{Im}\frac{\Gamma_{12}^s}{M_{12}^s}\right)^2\right) = \left|\frac{\Gamma_{12}^s}{M_{12}^s}\right| \sin\phi_{12}^s$$

How we measure it :

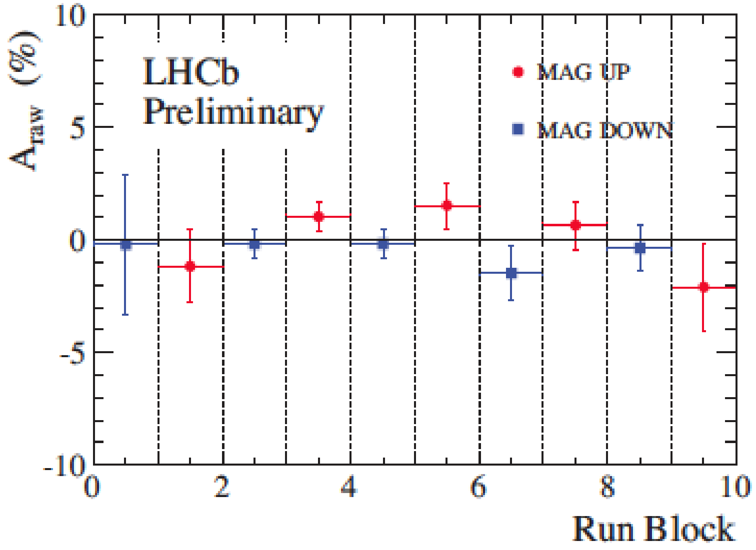
$$A^{s}_{\mathrm{measured}} = \frac{\Gamma[D_s^- \mu^+] - \Gamma[D_s^+ \mu^-]}{\Gamma[D_s^- \mu^+] + \Gamma[D_s^+ \mu^-]} = \frac{a_{sl}^s}{2} + \left[a_p - \frac{a_{sl}^s}{2}\right] \kappa_S$$

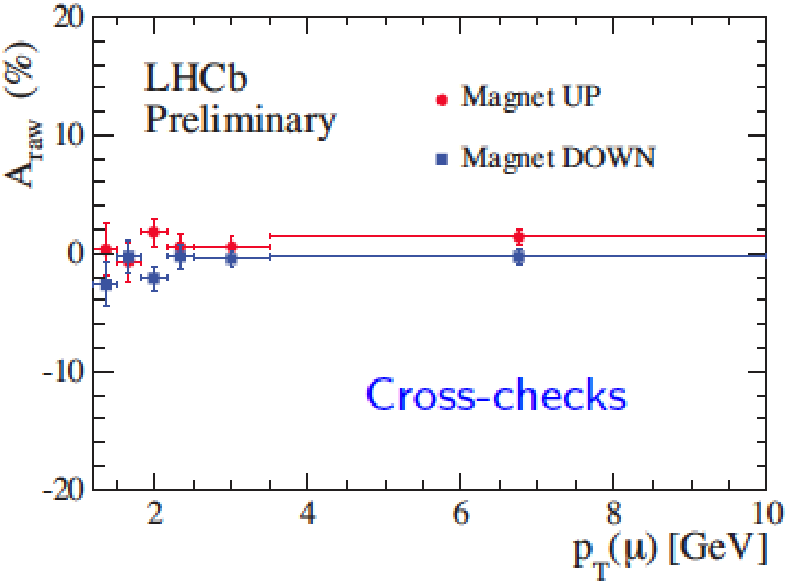
Yields 190 k B_s^0 candidates in 1.0 fb^{-1}:



LHCb-CONF-2012-022

Semileptonic asymmetries





Delicate systematic treatement is needed :

- Obtain any corrections from data/control samples.
- Pay attention to the π and μ detection asymmetries.
- Swap magnetic field to help cancel effects.

Semileptonic asymmetries

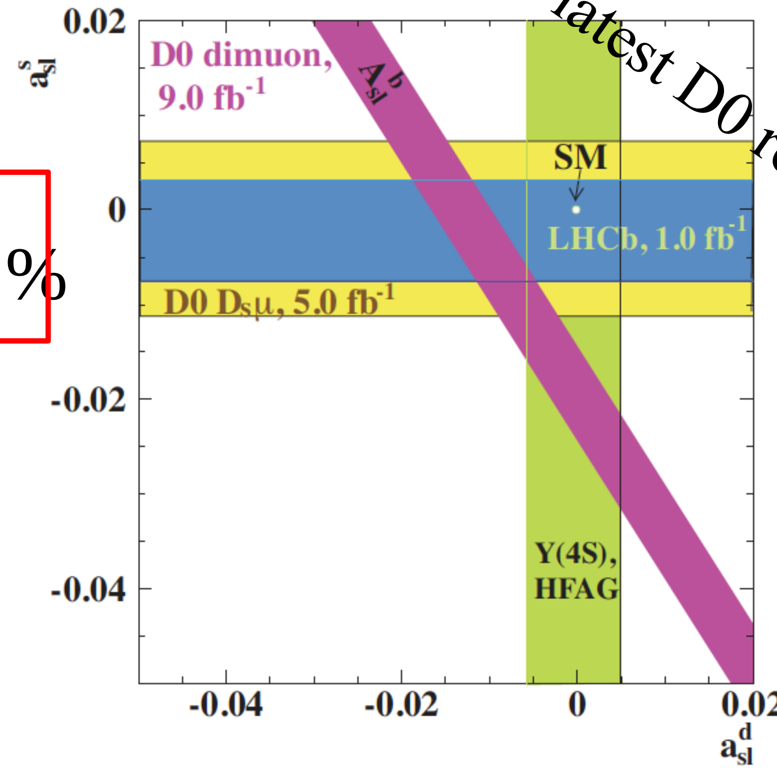
Not latest D0 result

We measure :

$a_{sl}^{s} = (-0.24 \pm 0.54 \pm 0.33)$ %

Most precise measurement !

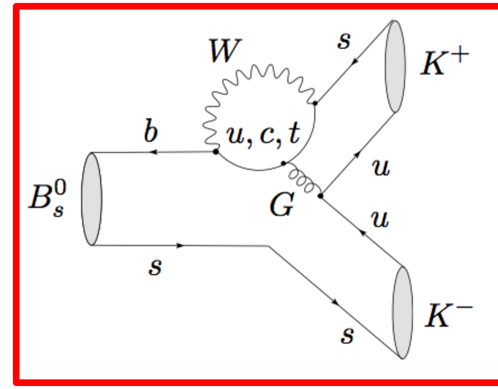
And also in agreement with SM
as quoted in arXiv:1205.1444
$a_{sl}^{s} = (0.0019 \pm 0.0003)$ % and
$a_{sl}^{d} = (-0.0041 \pm 0.0006)$ %



LHCb-CONF-2012-022

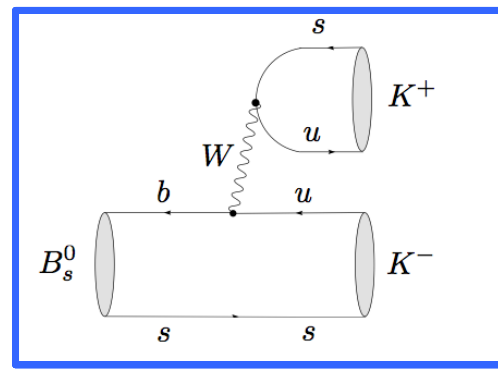
- Dominant systematic is from limited statistics in control sample.
- **3 tension with SM in the D0 result, not confirmed or excluded by LHCb.**
- More decay modes, data are needed. But also the B^0 mode!

$B_s \rightarrow$ KK effective lifetime



- $B_s \rightarrow K^+K^-$ is a *CP* even eigenstate :
  - Dominantly a penguin decay.
  - Doubly Cabibbo suppressed tree decay.

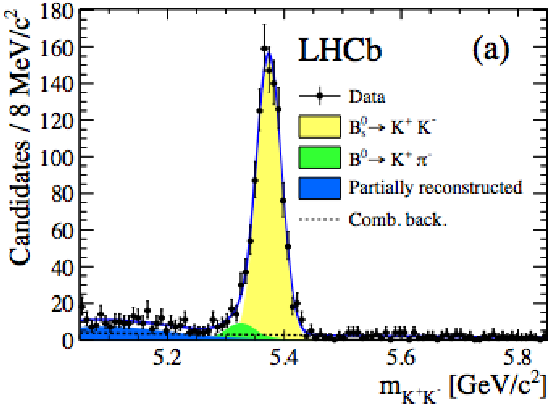
- Analysis uses minimal lifetime biasing selection :
  - No selection on variables biasing the lifetime.
  - Trigger and event selection based on NN using
  - Primiarly particle identification.

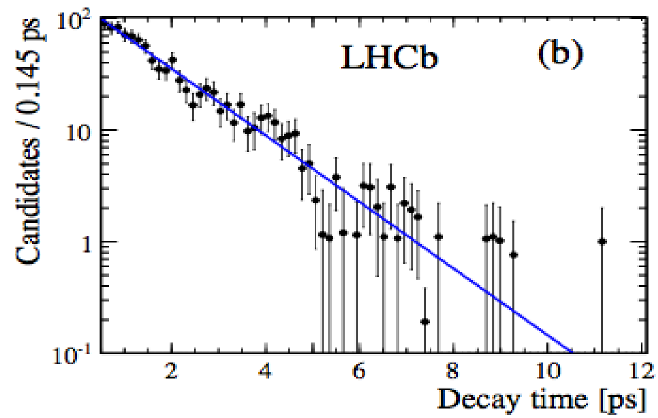


✓ Independent of previous measurement using 40 pb^{-1} of data using a complementary technique in Phys.Lett. B 707 (2012) 349

This independent analysis is currently being updated with 1.0 fb^{-1}

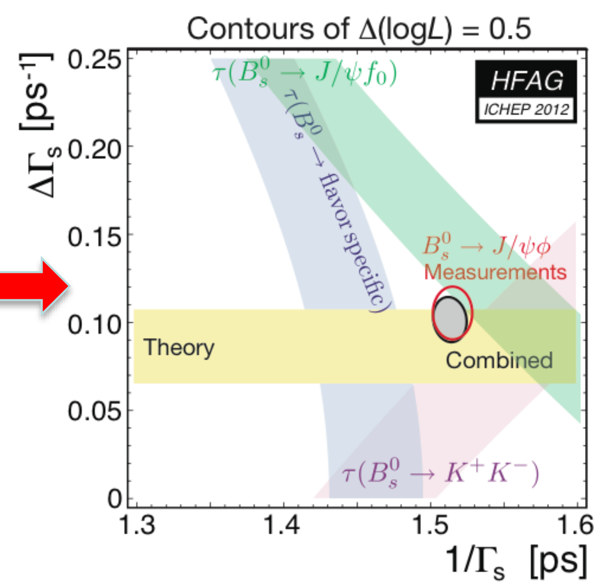
$B_s \rightarrow KK$ effective lifetime





$$\tau_{KK} = 1.455 \pm 0.046\,(\mathrm{stat}) \pm 0.006\,(\mathrm{syst})\ \mathrm{ps}$$

HFAG Combinations
(ICHEP 2012*)



arXiv:1207.5993

LHCb Near Future Highlights

LHCb will dramatically improve the precision of γ measurements from 11º to ~2º in the next years

B_s^0 mixing. Study of the theoretically clean CP-violating phase ϕ_s will be extended to reach SM level precision, stringently constraining new physics models such as

$B_s^0 \rightarrow \phi\phi$ decays

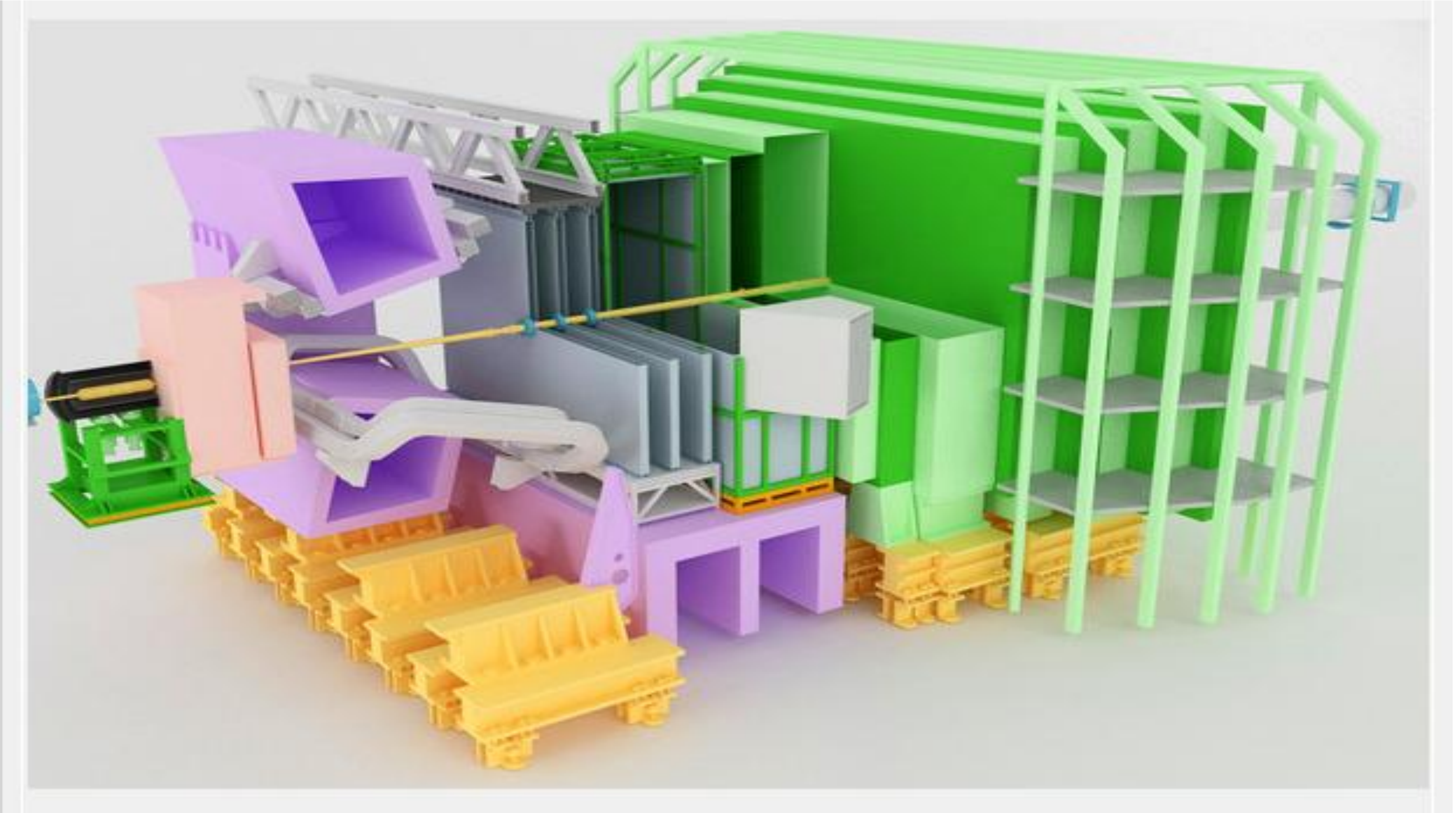
$B^0_d \rightarrow K^*\mu\mu$

$B_{s,d} \rightarrow \mu\mu\gamma$

To complete the programme (e.g. % resolution on angles) need more data. Originally $5fb^{-1}$ now $50fb^{-1}$ ...

(why?)

LHCb Upgrade



Current Operational Conditions

Currently: L = 4 x 10^{32} $cm^{-2}s^{-1}$ @ 50 ns bunch spacing & 8 TeV

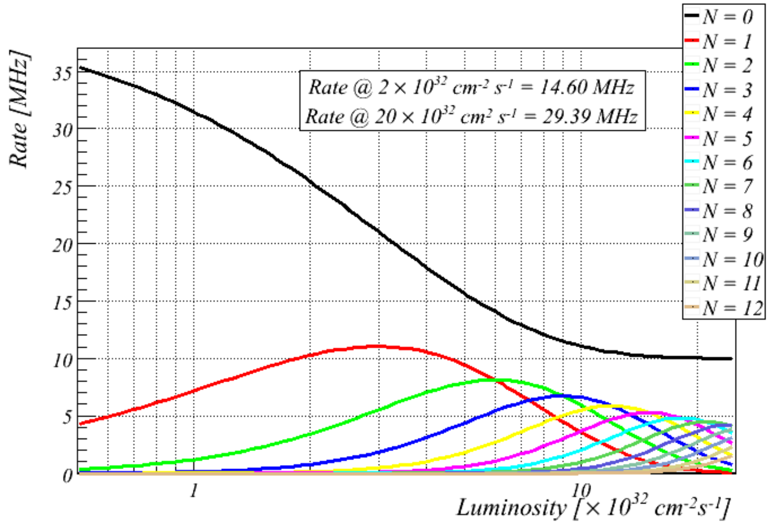
Design value: L = 2 x 10^{32} $cm^{-2}s^{-1}$ @ 25 ns & 14 TeV

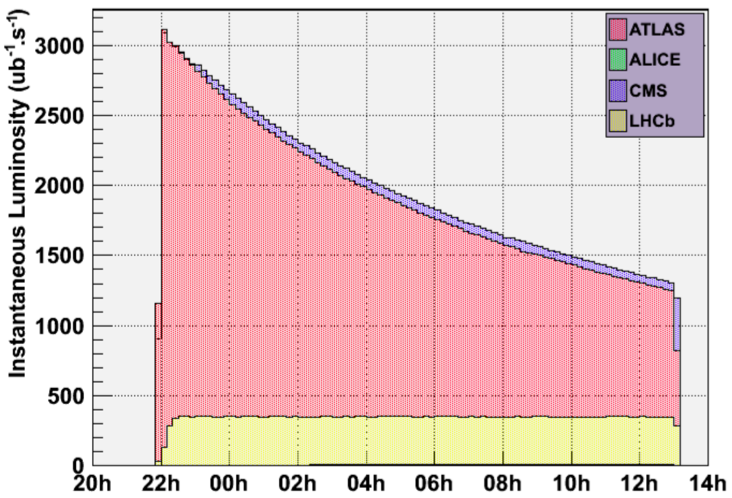
Interactions per bunch crossing: 1.5-2

Design value: 0.4

Luminosity Levelling: constant during the fill

LHCb is not limited by LHC





Aside

What happens if we can't?

- Data doubling argument
- c.f. ATLAS Upgrade

Is flavour physics dead at LHC?

- CMS?

Continue with existing detector

- VELO OK to 25fb-1 (spare!). Note discussion on double metal...

Flexible trigger

- Is it enough?

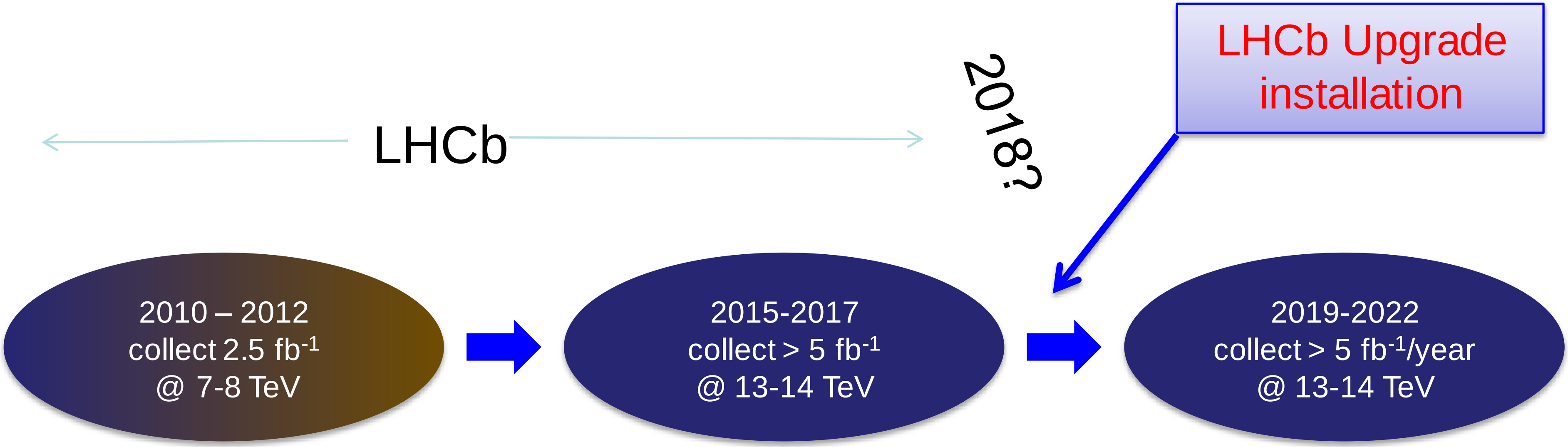
Goals and Timeline

Increase the annual signal yield compared to 2011

- 10 times for muonic channels
- 20 times for hadronic channels

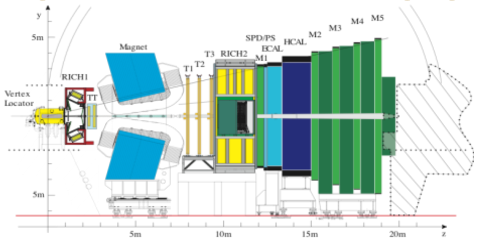
Operate at instantaneous luminosity exceeding 10^{33} $cm^{-2}s^{-1}$

Collect 50 fb^{-1} of integrated luminosity



LS2: Injector and LHC Phase I GPD upgrades

Upgraded Trigger Scheme



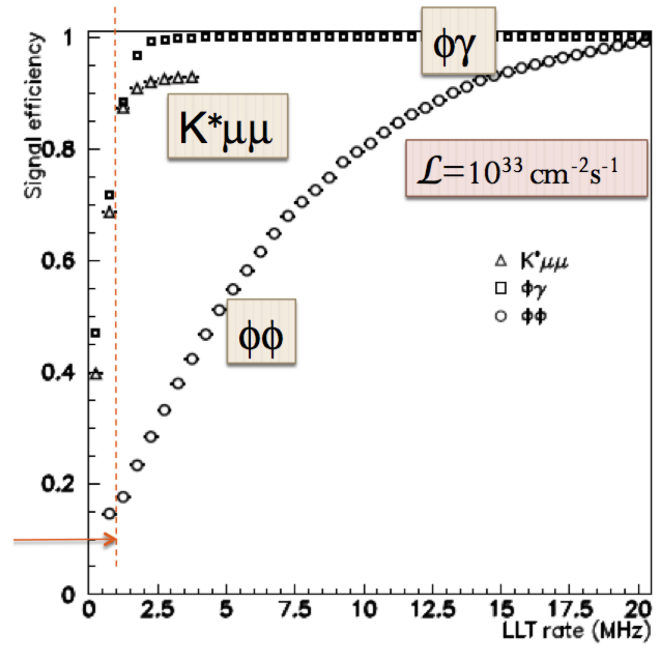
Optional
Low Level Trigger
throttle
1-40 MHz

40 MHz

HLT

Tracking and vertexing
Impact Parameter cuts
Inclusive/Exclusive selections

to tape 20 kHz



Efficiency	Farm Size = 5 x 2011	Farm Size = 10 x 2011
$B_s \rightarrow \phi\phi$	29%	50%
$B^0 \rightarrow K^*\mu\mu$	75%	85%
$B_s \rightarrow \phi\gamma$	43%	53%

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Challenge: Data Rates

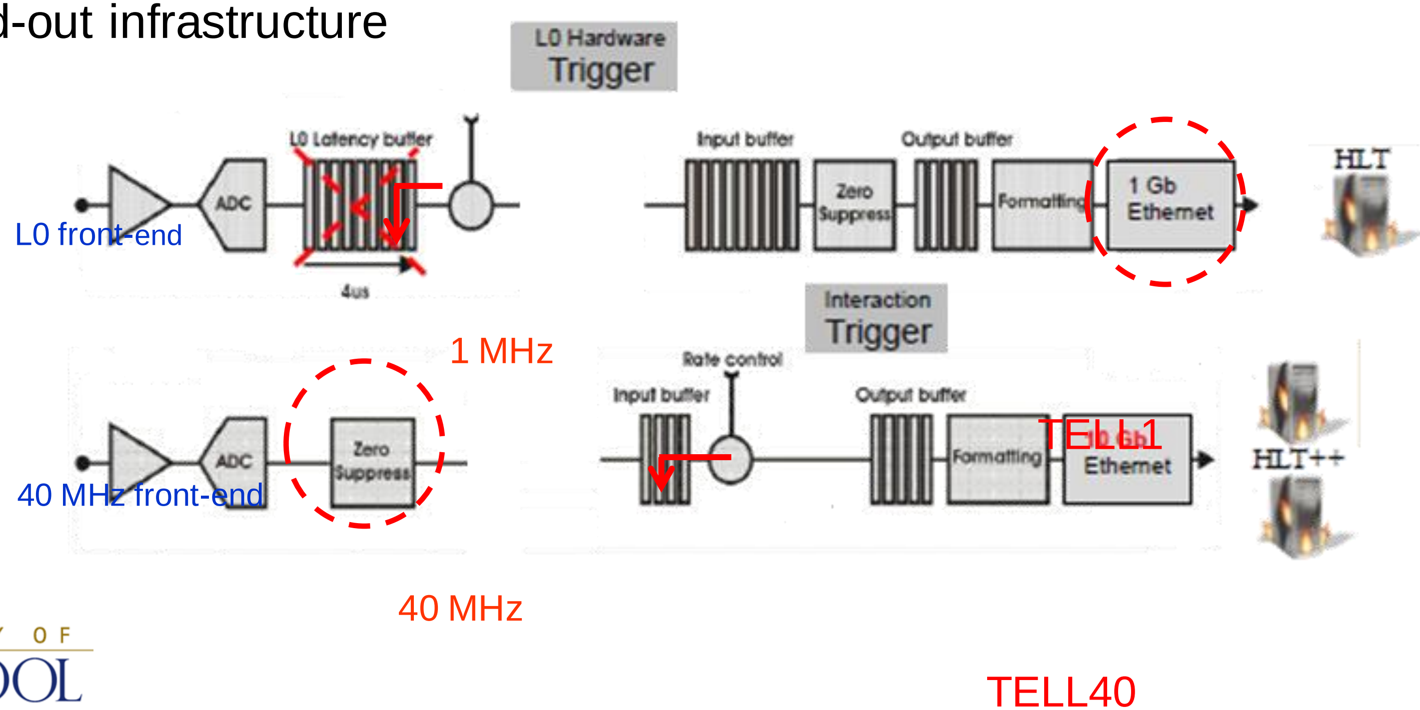
Full detector read-out @ 40 MHz

- Current Vertex Locator: 225 G samples/s (analogue)
- Upgraded Vertex Locator: 2-3 Tbit/s (digital)

On-detector zero-suppression

- Replace (almost) all FE electronics

Massive read-out infrastructure

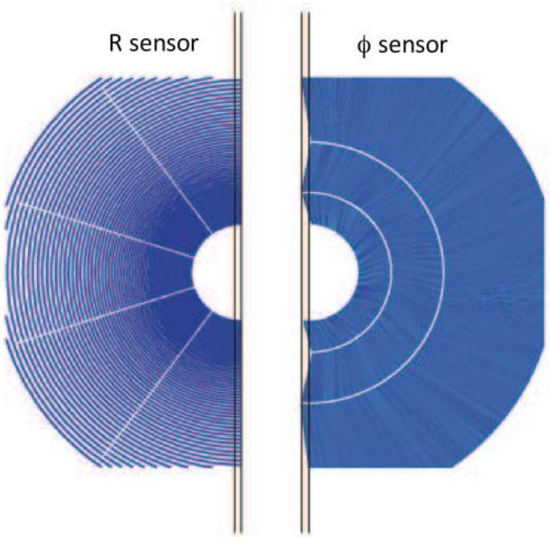


Vertex Locator (Velo) Upgrade

Complete replacement of modules
- Large fraction of the infrastructure remains
- E.g. cooling, motion, vacuum, …

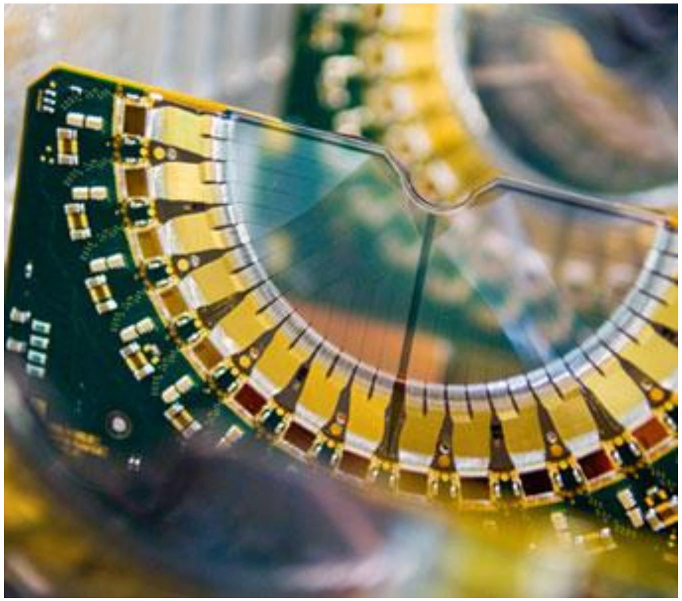
Two options investigated
- Strips: R-Φ geometry with reduced pitch
- Pixel based on TimePix family of chips

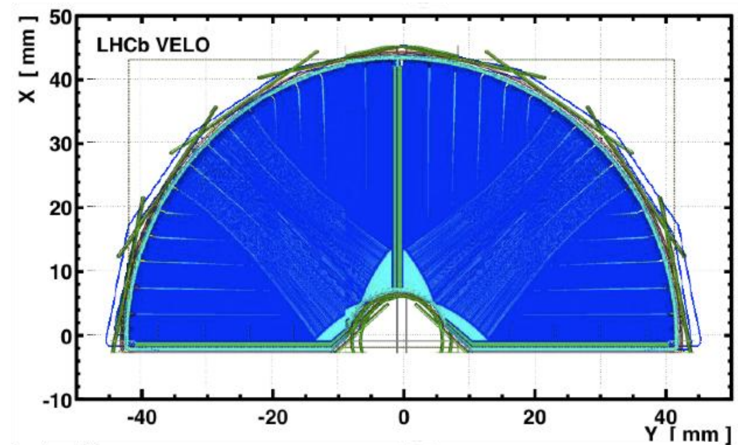
Radiation Hardness
- Up to 3 x 10^15 1MeV n_{eq}/cm^2

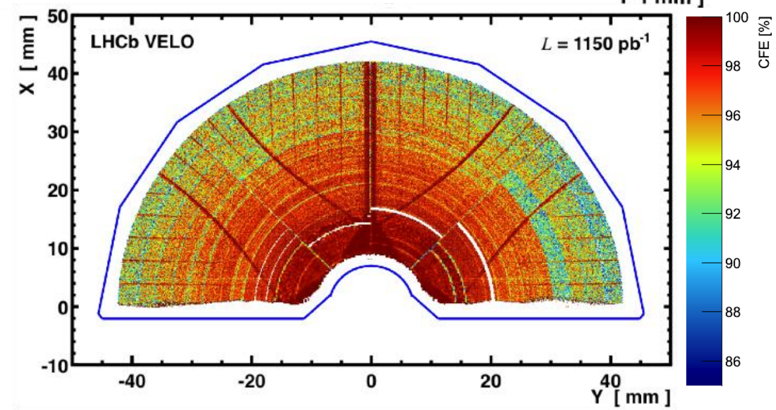


The cooling challenge
- Currently TPG subsrate
- Diamond substrate?
- Micro-channel cooling?

R&D on Strips







Loss of efficiency is artificial in that it could be recovered
By change clustering cuts, increasing voltage (?) etc.
True rad hardness ~ 10fb-1 or more

- Qualified to 5fb-1.
- Does not impact tracking
- Nonetheless R&D Required

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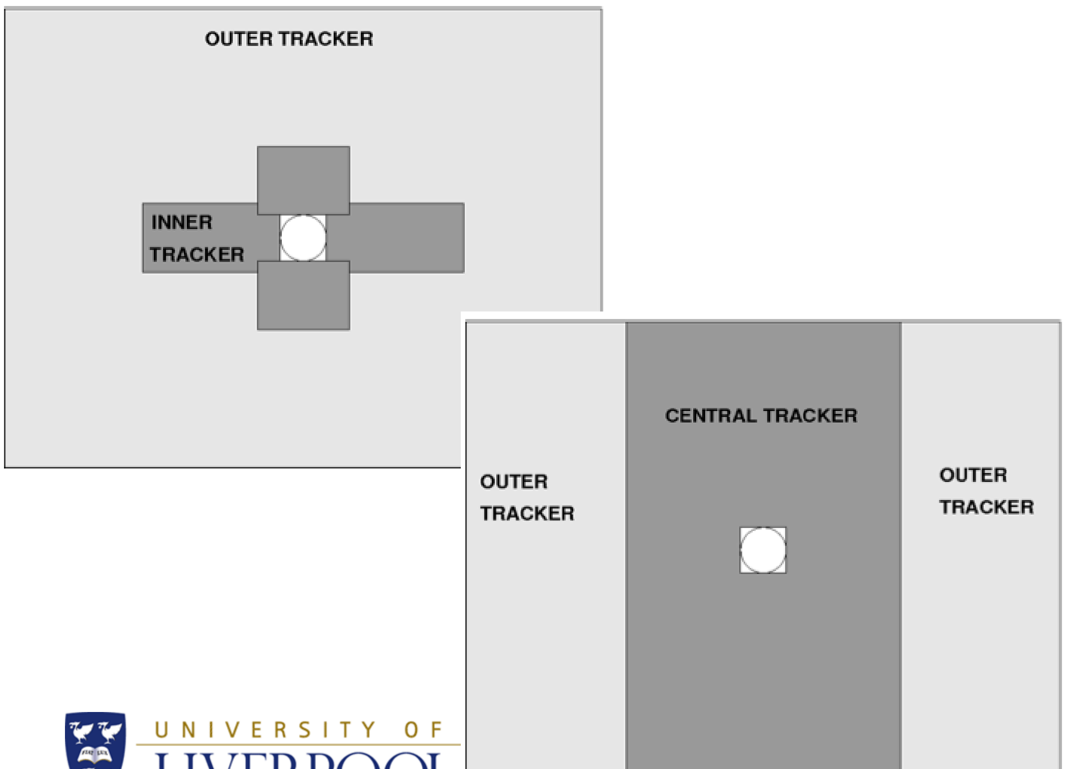
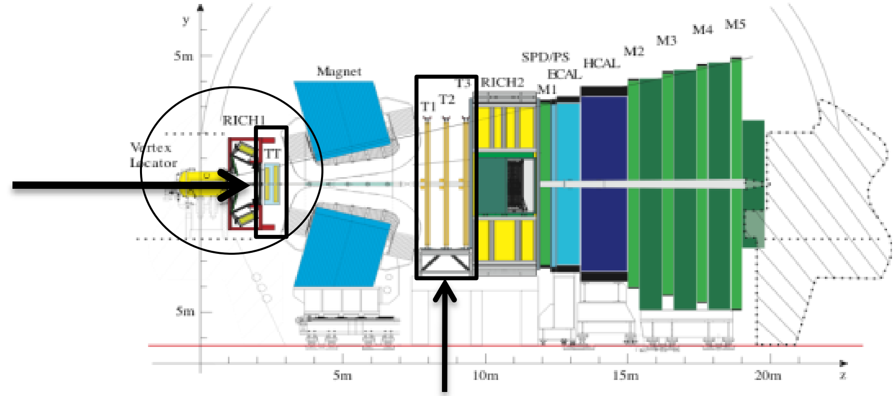
Tracker Upgrade

TT tracking station

- Currently: Silicon strip
- Upgrade Redesigned silicon strips
- Share FE chip with strip Velo



Could we replace th VELO with a "longVELO"



Current main tracker

- Inner tracker: Silicon strip
- Outer tracker: Straw tubes

Two options investigated

- Silicon strip inner tracker + Straw tube outer tracker
- Scintillating fibre central tracker + Straw tube outer tracker

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RICH Upgrade

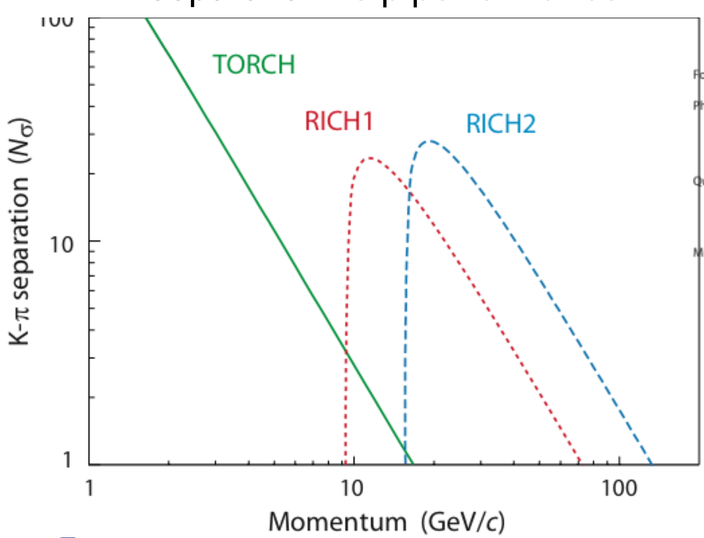
RICH 1 and RICH 2 detectors remain

- Remove aerogel radiator due to occupancy
- Replace photo detectors with MaPMTs with 40 MHz read out

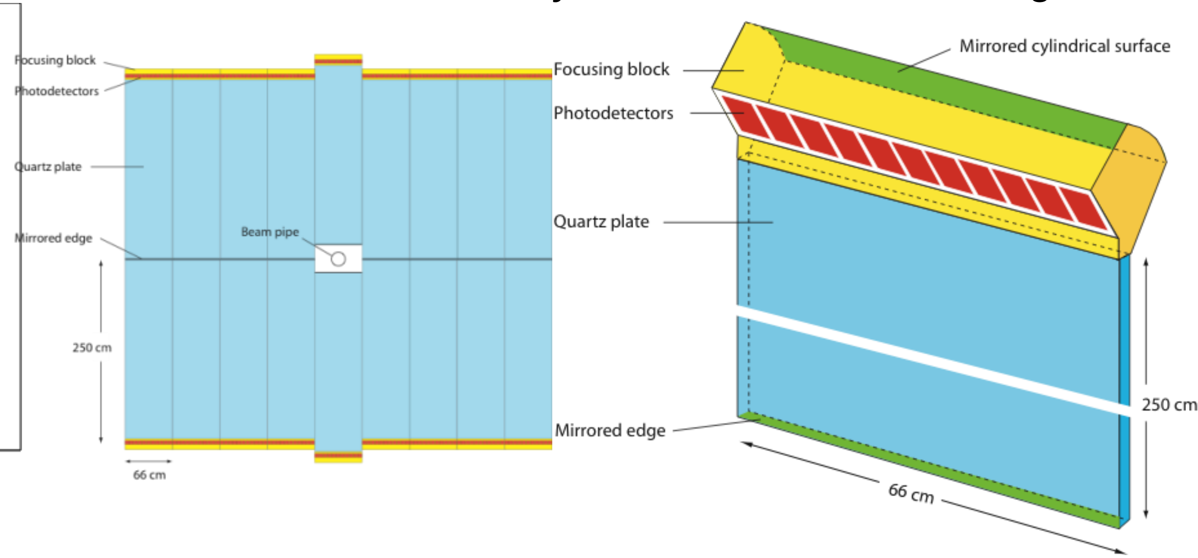
Possible addition (non-baseline): TORCH = DIRC + ToF

- Quarts radiator with MCP photon detectors
- 40 ps time resolution

K-π separation vs p performance



TORCH: Time Of internally Reflected Cherenkov Light



Calorimeter & Muon Upgrade

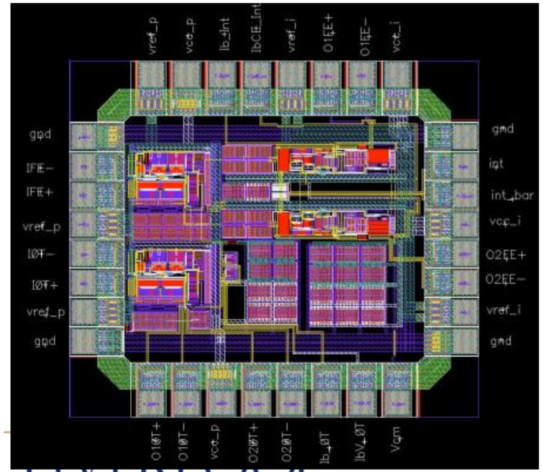
Already used in L0 trigger

HCAL & ECAL: Keep detector modules and PMTs

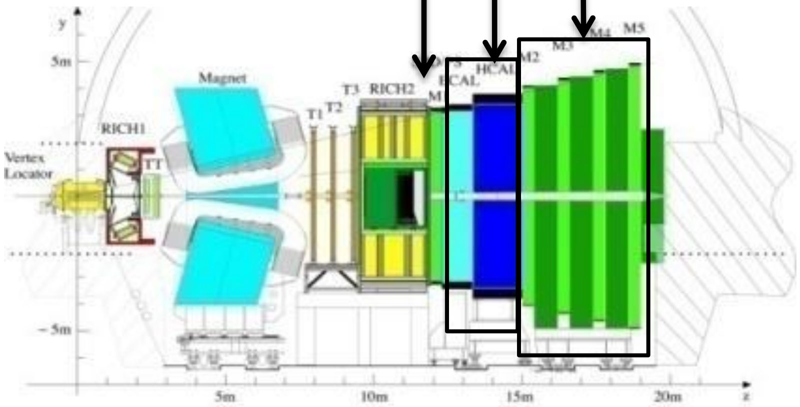
- Reduced PMT gain, increased FE amplification
- Modified 40 MHz FE electronics

Muon Spectrometer: Keep chambers & FE electronics

- Remove first station (M1)
- High occupancy performance and aging under study



Calorimeter FE ASIC prototype



Performance Benchmarks

Type	Observable	Current precision	LHCb 2018	Upgrade $(50\,\mathrm{fb}^{-1})$	Theory uncertainty
B_s^0 mixing	$2\beta_s\ (B_s^0 \to J/\psi\ \phi)$	0.10 [9]	0.025	0.008	~ 0.003
	$2\beta_s\ (B_s^0 \to J/\psi\ f_0(980))$	0.17 [10]	0.045	0.014	~ 0.01
	$A_{\mathrm{fs}}(B_s^0)$	6.4×10^{-3} [18]	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguin	$2\beta_s^{\mathrm{eff}}(B_s^0 \to \phi\phi)$	–	0.17	0.03	0.02
	$2\beta_s^{\mathrm{eff}}(B_s^0 \to K^{*0}\bar{K}^{*0})$	–	0.13	0.02	< 0.02
	$2\beta^{\mathrm{eff}}(B^0 \to \phi K_S^0)$	0.17 [18]	0.30	0.05	0.02
Right-handed currents	$2\beta_s^{\mathrm{eff}}(B_s^0 \to \phi\gamma)$	–	0.09	0.02	< 0.01
	$\tau^{\mathrm{eff}}(B_s^0 \to \phi\gamma)/\tau_{B_s^0}$	–	5 %	1 %	0.2 %
Electroweak penguin	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\,\mathrm{GeV}^2/c^4)$	0.08 [14]	0.025	0.008	0.02
	$s_0\ A_{\mathrm{FB}}(B^0 \to K^{*0}\mu^+\mu^-)$	25 % [14]	6 %	2 %	7 %
	$A_{\mathrm{I}}(K\mu^+\mu^-; 1 < q^2 < 6\,\mathrm{GeV}^2/c^4)$	0.25 [15]	0.08	0.025	~ 0.02
	$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$	25 % [16]	8 %	2.5 %	~ 10 %
Higgs penguin	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	1.5×10^{-9} [2]	0.5×10^{-9}	0.15×10^{-9}	0.3×10^{-9}
	$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	–	~ 100 %	~ 35 %	~ 5 %
Unitarity triangle angles	$\gamma\ (B \to D^{(*)}K^{(*)})$	~ 10–$12°$ [19, 20]	4°	0.9°	negligible
	$\gamma\ (B_s^0 \to D_s K)$	–	11°	2.0°	negligible
	$\beta\ (B^0 \to J/\psi\ K_S^0)$	0.8° [18]	0.6°	0.2°	negligible
Charm *CP* violation	A_Γ	2.3×10^{-3} [18]	0.40×10^{-3}	0.07×10^{-3}	–
	ΔA_{CP}	2.1×10^{-3} [5]	0.65×10^{-3}	0.12×10^{-3}	–

Precision Measurements: Systematic uncertainties are the aim of the game !

Summary: The LHCb Upgrade

Upgrade will read out the full detector @ 40 MHz

Major impact –

2018 (?)

LHCb Upgrade

Too Ambitious or not ambitious enough

Single or Dual Phase?

Expensive or Cheap?

Is its potential output enough to warrant its competition against other experiments...

Discovery Range...

Not yet fully funded by STFC...

CG + £200K

Conclusion

Quark Flavour physics is an important way to search for NP

Currently “tensioned” against host of other proposals

- LHeC
- LC(subject to Japanese Funding)
- LHC HL Upgrades
- Neutrinos

Stronger International(and UK!) Support than a few years ago

UK must make up its mind if it wishes to spend O(£8M) on this ... bearing in mind existing huge investment in LHCb

If we do there is an exciting programme ahead.