The LHCb Upgrade

- Introduction/Overview
- LHCb & Upgrade physics programme
- Detector Upgrade
- R&D and Status
- Conclusions

Franz Muheim
University of Edinburgh

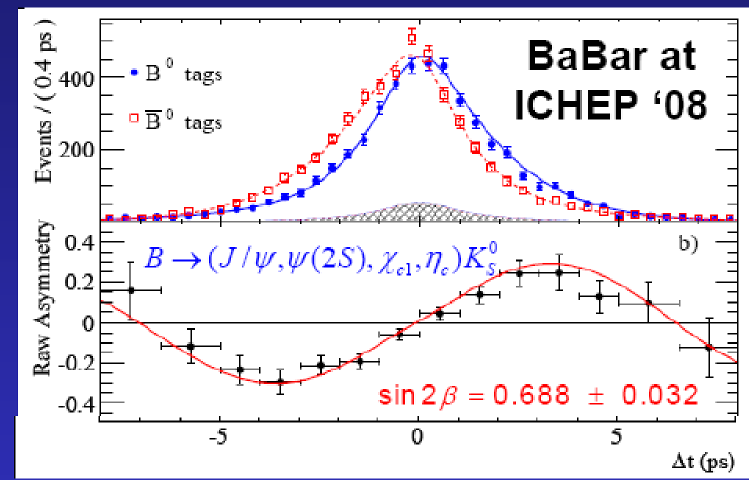
IOP HEPP Beauty Physics in the UK
University of Lancaster, 12th Nov 2008

Nobelprize 2008

"for the discovery of the origin of the broken symmetry which predicts the existence of at least three families of quarks in nature"

Makato Kobayashi

Toshihide Maskawa



- **CKM mechanism = Standard Model of Flavour Physics**
  - predicted and experimentally confirmed
- **Next Stop – New Physics in Flavour Sector**
  - Additional sources of ~~CP~~ required in quarks or leptons to explain matter/antimatter asymmetry

Status of LHC Physics in ~2014

- LHCb
  - will be producing lots of excellent physics results
  - may or may not observe New Physics beyond Standard Model
  - Flavour physics will constrain New Physics models
- ATLAS/CMS
  - will discover Standard Model Higgs (if it exists)
  - may or may not observe New Physics beyond Standard Model
- Branch point
  - Discovery or not of NP at TeV scale
- New Physics beyond the Standard Model
  - will contribute to flavour observables

⇒ Better flavour physics sensitivity will be required to measure/probe New Physics flavour structure

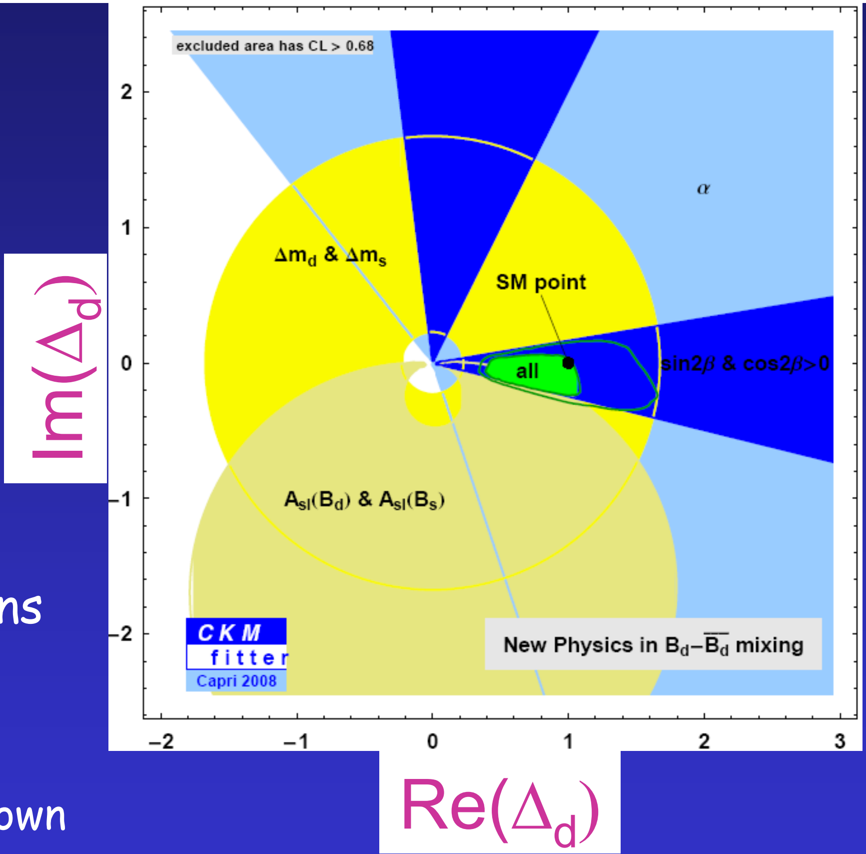
Limits on New Physics from B^0

- Is there NP in B^0-$\bar{B}^0$ mixing?
  - Assume NP in tree decays is negligible

$$\mathrm{Re}(\Delta_q) + i\,\mathrm{Im}(\Delta_q) = \frac{\langle B^0 | H^{\mathrm{full}} | \bar{B}^0 \rangle}{\langle B^0 | H^{\mathrm{SM}} | \bar{B}^0 \rangle}$$

- Existing Measurements
  - Vub, Vcb, angles α, β, γ, Δm_d ...
- All quantities expressed as functions of CKM parameters η & ρ
- Fit to η, ρ, $\mathrm{Re}(\Delta_d)$, $\mathrm{Im}(\Delta_d)$
  - Caveat: only 68% CL regions are shown due to large errors

"Next to minimum flavor violation"

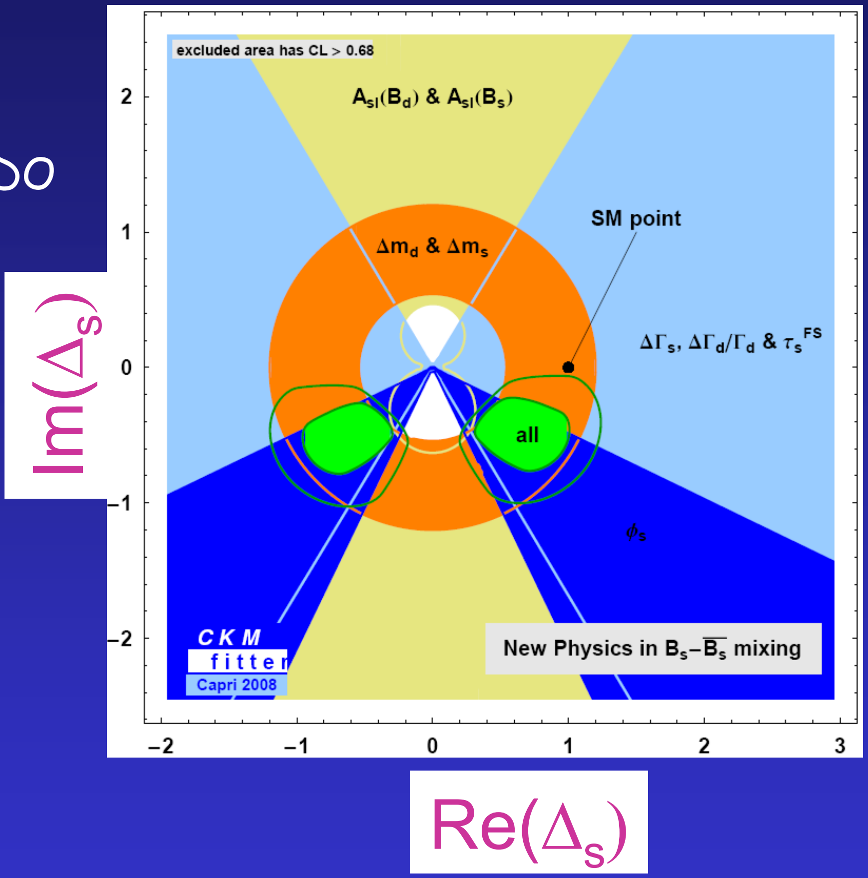


Jérôme Charles, Capri, June 2008

Large Range of NP still allowed

Limits on New Physics from B_s

- Similar study for B_s decays
  - including ΔM_s and ϕ_s measurements from CDF and DO
- Limits much weaker
  - phase in B_s mixing ϕ_s is not well measured yet
  - Caveat: only 68% CL regions are shown due to large errors
- Latest results on ϕ_s
  - Large central values
  - SM prediction close to zero
  - SM CL is at 7%



■ New Physics could be around the corner!

LHCb Physics Prospects

- **LHCb – first five years**
  - Accumulate 10 fb^{-1} data sample
- **Sensitivities**
  - Weak mixing phase ϕ_s in $B_s \to J/\psi\phi$
    If $\phi_s \gg 0 \to$ NP discovery
  - NP search in rare decays
    $B_s \to \mu^+\mu^-$ down to SM level
  - $B_s \to \phi\phi$ probe NP in hadronic penguins
  - Precision measurements of
    CKM angles $\sin 2\beta$, γ and α
    Significant improvement for angle γ
- **10 fb^{-1} data sample**
  - Probe/measure NP at 10% level

Sensitivities for integrated lumi of 2 fb^{-1}

	Decay	Precision
γ	$B_s^0 \to D_s^\mp K^\pm$	$\sigma(\gamma) \sim 10°$
	$B^0 \to \pi^+\pi^-$	$\sigma(\gamma) \sim 5°$
	$B_s^0 \to K^+K^-$	
	$B^0 \to D^0(K^-\pi^+, K^+\pi^-)K^{*0}$	$\sigma(\gamma) \sim 6° - 10°$
	$B^0 \to D^0(K^+K^-, \pi^+\pi^-)K^{*0}$	
	$B^- \to D^0(K^-\pi^+, K^+\pi^-)K^-$	$\sigma(\gamma) \sim 6° - 10°$
	$B^- \to D^0(K^+K^-/\pi^+\pi^-)K^-$	
	$B^- \to D^0(K_S^0\pi^+\pi^-)K^-$	$\sigma(\gamma) \sim 15°$
α	$B^0 \to \pi^+\pi^-\pi^0$	$\sigma(\alpha) \sim 8.5°$
	$B^{+,0} \to \rho^+\rho^0, \rho^+\rho^-, \rho^0\rho^0$	
β	$B^0 \to J/\psi K_S^0$	$\sigma(\sin 2\beta) \sim 0.015$
Δm_s	$B_s^0 \to D_s^-\pi^+$	$\sigma(\Delta m_s) \sim 0.007\ \mathrm{ps}^{-1}$
ϕ_s	$B_s^0 \to J/\psi\phi$	$\sigma(\phi_s) \sim 0.023$ rad
	$B_s^0 \to \phi\phi$	$\sigma(\phi_s) \sim 0.11$ rad
Rare	$B_s^0 \to \mu^+\mu^-$	
Decays	$B^0 \to K^{*0}\mu^+\mu^-$	$\sigma(s_0)) \sim 0.46\ \mathrm{GeV}^2$
	$B^0 \to K^{*0}\gamma$	$\sigma(A_{CP}) \sim 0.01$
	$B_s^0 \to \phi\gamma$	

Flavour in the LHC era
Buchalla et al., arXiv:0801.1833

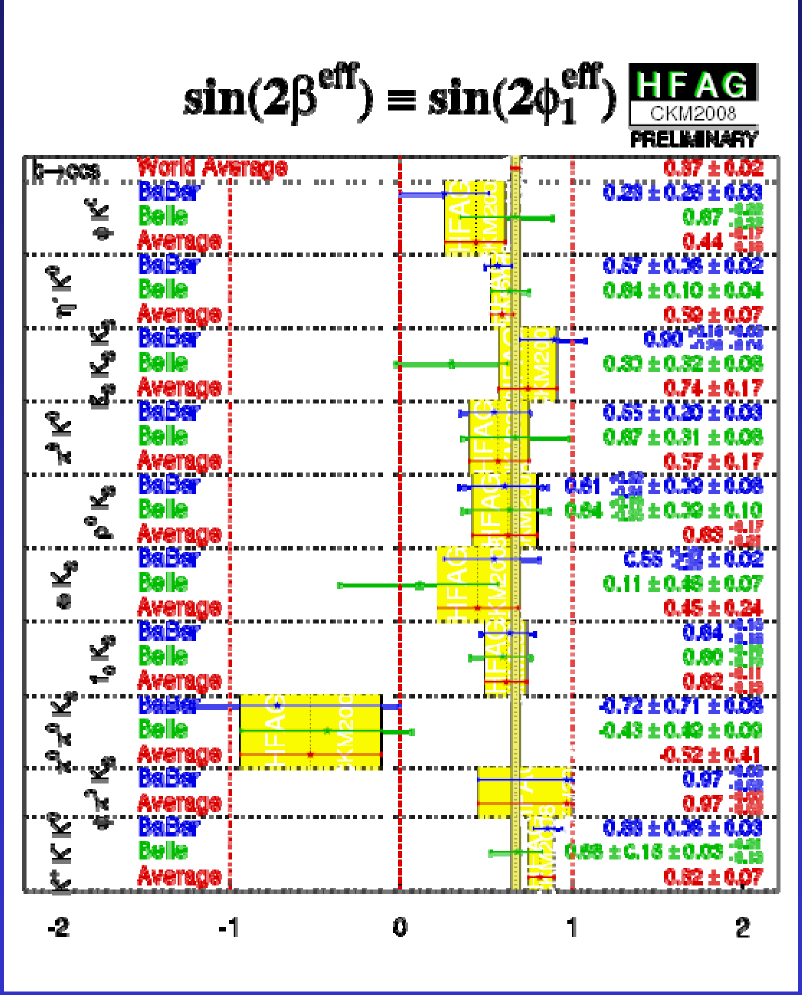
See talks by Jim Libby and
Patrick Koppenburg at this meeting

LHCb Upgrade

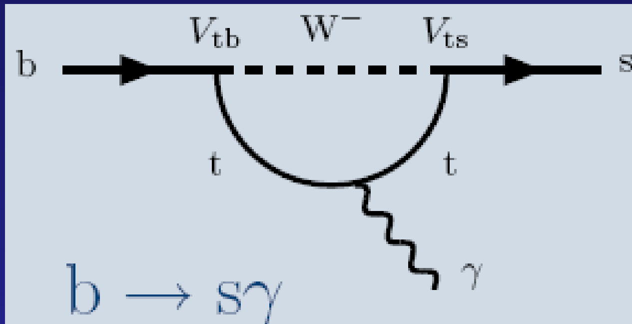
- **Physics Rationale**
  - If NP is discovered by LHCb with 10 fb^{-1}
    NP flavour structure/models should be studied
- **What is LHCb Upgrade?**
  - Run at ten times the design luminosity, namely at $2x10^{33}$ $cm^{-2}s^{-1}$
  - Needs detector and trigger upgrade
  - Increase trigger efficiencies for hadrons by at least a factor two
  - Accumulate data sample of 100 fb^{-1}
- **Sensitivities**
  - LHCb upgrade will provide us with a very powerful microscope
  - Use theoretically clean observables not limited by theoretical or systematic uncertainties
  - **Probe/measure NP at percent level**

Probe New Physics in CP

- In box diagrams
  - $B_s \to J/\psi\phi$
  - $S = \phi_s(J/\psi\phi) = -0.0368 \pm 0.0017$ [SM]
  - $\sigma(\phi_s) \sim 0.010$ with 10 fb^{-1}
- In hadronic penguin diagrams
  - $B_d \to \phi K_S$
  - $\Delta S(\phi K_S) = \sin 2\beta^{eff} - \sin 2\beta(B_d \to J/\psi K_S)$
  - $\Delta S(\phi K_S) \neq 0.23 \pm 0.18$
  - NP if $\Delta S \neq 0$ (+ 0.02 correction)
  - $B_s \to \phi\phi$
  - $\Delta S(\phi\phi) = S(B_s \to \phi\phi) - S(B_s \to J/\psi\phi)$
  - $\Delta S(\phi\phi)$ not measured
- LHCb sensitivities
  - for 10 fb^{-1}
  - $\sigma(\Delta S(\phi K_S)) \sim 0.10$
  - $\sigma(\Delta S(\phi\phi)) \sim 0.05$
  - expect $\Delta S(\phi K_S) \sim \Delta S(\phi\phi)$



Photon polarisation in $B_s \to \phi\gamma$



$b \to \gamma\,(L) + (m_s/m_b) \times \gamma(R)$

V-A: SM mainly left-handed

$$\mathcal{A}_s(t) = \frac{\Gamma_{\overline{B}_s \to \phi\gamma} - \Gamma_{B_s \to \phi\gamma}}{\Gamma_{\overline{B}_s \to \phi\gamma} + \Gamma_{B_s \to \phi\gamma}} = \frac{\mathcal{A}^{\mathrm{dir}} \cos \Delta m_s t + \mathcal{A}^{\mathrm{mix}} \sin \Delta m_s t}{\cosh \frac{1}{2}\Delta\Gamma t - \mathcal{A}^{\Delta\Gamma} \sinh \frac{1}{2}\Delta\Gamma t}$$

$$\tan\psi \equiv \left| \frac{A(\bar{\mathrm{B}} \to f^{CP}\gamma_R)}{A(\bar{\mathrm{B}} \to f^{CP}\gamma_L)} \right|$$

- **SM expectations**
  - $C = A^{\mathrm{dir}} = 0$ direct CP-violation
  - $S = A^{\mathrm{mix}} = \sin 2\psi \ \sin\phi$
  - $A^{\Delta\Gamma} = \sin 2\psi \cos\phi$
- **Expected signal yield**
  - 55k for 10 fb^{-1}
- **Expected Sensitivity (untagged)**
  - $\sigma(A^{\Delta\Gamma}) = \sigma(\sin 2\psi) = 0.09$ for 10fb^{-1} assuming $\cos\phi \approx 1$
  - $\sigma(A^{\mathrm{mix}}) = 0.05$

Probe New Physics in $\not{CP}$

	Sensitivity with 10 fb^{-1}	Do we need 100 fb^{-1}?
• NP in box diagrams		
– ϕ_s from $B_s \to J/\psi\phi$	$\sigma(\phi_s) \sim 0.010$	Yes $\sigma_{theor} \sim 0.002$
• NP in hadronic penguins		
– $\Delta S(\phi\phi)$ from $B_s \to \phi\phi$ has best sensitivity	$\sigma(\Delta S(\phi\phi)) \sim 0.05$	Yes
– $\Delta S(\phi K_S)$ from $B_d \to \phi K_S$	$\sigma(\Delta S(\phi K_S)) \sim 0.10$	Yes $\sigma_{theor} \sim 0.01$
• NP in radiative penguins		
– Photon polarisation in $B_s \to \phi\gamma$	$\sigma(A^{\Delta\Gamma}) \sim 0.09$ $\sigma(A^{mix}) \sim 0.05$	Yes $\sigma_{theor} \sim 0.01$

Lepton Flavour Violation

- Best mode for LHCb
  - $\tau \to \mu\mu\mu$
- Use τ leptons produced in prompt D_s decays:
  - $N_\tau = L\, \sigma_{cc}\, 2\, P(c \to D_s)\, BR(D_s \to \tau\nu)\, \varepsilon_{acc} = 2.8 \times 10^{11}$ in $10 fb^{-1}$
  - this is 60 x $N_{\tau\tau}$ produced at a B-Factory with 5 ab^{-1}
- Background
  - is much more difficult to fight as no strong constraint is available on τ at production
- Performance study is underway
  - Very preliminary results
  - Inclusive bb as main background needs additional suppression
  - Efficiencies as expected
- Expected sensitivities for 10 fb^{-1}
  - No result but expected at $O(10^{-8})$

	$\mathcal{B}(\tau \to \ell\ell\ell)$
SM+ν-mixing (PRL95(2005)41802,EPJC8(1999)513)	10^{-14}
SUSY Higgs (PLB549(2002)159, PLB566(2003)217)	10^{-7}
SM+Heavy Majorana ν_R (PRD66(2002)034008)	10^{-10}
Non-Universal Z' (PLB547(2002)252)	10^{-8}
SUSY SO(10) (NPB649(2003)189, PRD68(2003)033012)	10^{-10}
mSUGRA+seesaw (EPJC14(2000)319, PRD66(2002)115013)	10^{-9}

Probe NP in Rare Decays

	Sensitivity with 10 fb^{-1}	Do we need 100 fb^{-1} ?
• NP in electroweak penguins		
– $B_s \to K^*\mu\mu$	$\sigma(A_T^{(2)}) \sim 0.16$	Yes
– $B_s \to \mu\mu$ ($B_d \to \mu\mu$)	>5σ observation if SM	Yes
• Charm Physics		
– $D^0 \to K\pi, KK, \pi\pi$ $D^0 \to K\pi\pi\pi, KK\pi\pi$	measured CP asymmetries approach SM predictions	Yes
• Lepton Flavour Violation		
– $\tau \to \mu\mu\mu$	BR ~ $O(10^{-8})$	Yes

Physics Reach of LHCb Upgrade

There are many observables where we are not limited by theoretical uncertainties

LHCb Upgrade will be able to probe NP at percent level

Sensitivities for integrated lumi of 100 fb^{-1}

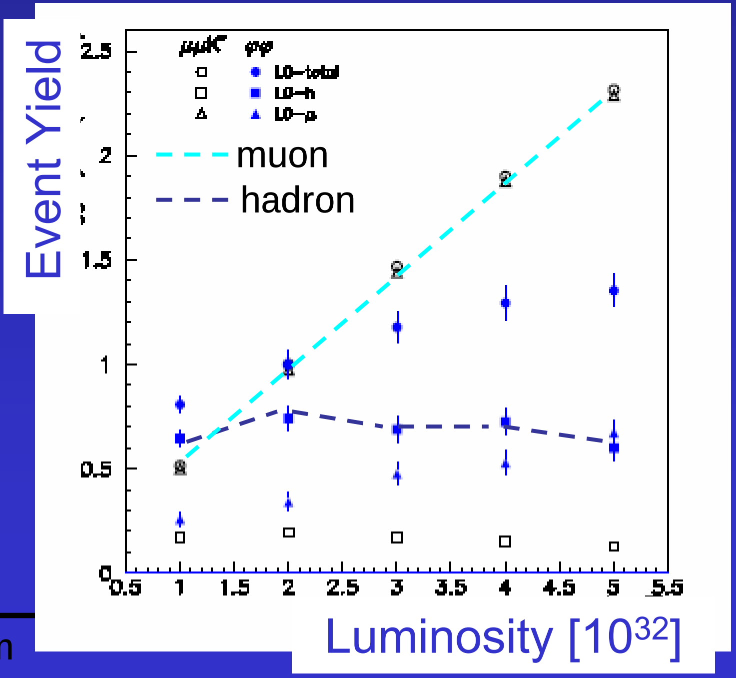
Observable	Sensitivity
$S(B_s \to \phi\phi)$	$0.01 - 0.02$
$S(B_d \to \phi K^0_S)$	$0.025 - 0.035$
$\phi_s\ (J/\psi\phi)$	0.003
$\sin(2\beta)\ (J/\psi K^0_S)$	$0.003 - 0.010$
$\gamma\ (B \to D^{(*)}K^{(*)})$	$< 1^\circ$
$\gamma\ (B_s \to D_s K)$	$1 - 2^\circ$
$\mathcal{B}(B_s \to \mu^+\mu^-)$	$5 - 10\%$
$\mathcal{B}(B_d \to \mu^+\mu^-)$	3σ
$A_T^{(2)}(B \to K^{*0}\mu^+\mu^-)$	$0.05 - 0.06$
$A_{\rm FB}(B \to K^{*0}\mu^+\mu^-)\ s_0$	$0.07\ \mathrm{GeV}^2$
$S(B_s \to \phi\gamma)$	$0.016 - 0.025$
$A^{\Delta\Gamma_s}(B_s \to \phi\gamma)$	$0.030 - 0.050$
charm x'^2	2×10^{-5}
mixing y'	2.8×10^{-4}
CP y_{CP}	1.5×10^{-4}

Also studying Lepton Flavour Violation in $\tau \to \mu\mu\mu$

EoI for an LHCb Upgrade
CERN-LHCC-2008-007

LHCb Upgrade Strategy

- **What is LHCb Upgrade?**
  - Upgrade the detectors and trigger such that LHCb can operate at ten times the design luminosity, namely at $2\text{x}10^{33}$ $cm^{-2}s^{-1}$
- Current LHCb experiment
  - L0 trigger bandwidth cannot exceed 1.1 MHz
  - At $2\text{x}\ 10^{33}$ $cm^{-2}s^{-1}$ rate of interesting hadron clusters with $E_T > 2$ GeV is ~25 MHz
- **Strategy**
  - **Reading out data from all detectors at 40 MHz is the way forward**
  - A **first level detached vertex trigger** will at least double the trigger efficiency for hadron channels
  - Significant gains possible



LHCb Upgrade Strategy

- **LHCb Upgrade Phase 1**
  - Upgrade all front-end detector electronics to 40 MHz
  - Replace all Silicon detectors: VELO, TT, IT
  - Replace RICH photon detectors
  - Operate LHCb at $1x10^{33}$ $cm^{-2}s^{-1}$
  - **Increase hadron data sample by factor ~10**
  - reach detector design lumi of ~20 fb^{-1} (except VELO)
  - Timescale ~ 2014
- **LHCb Upgrade Phase 2**
  - Upgrade all detectors such that LHCb can operate at a luminosity of at least $2x10^{33}$ $cm^{-2}s^{-1}$
  - Operate at highest possible luminosity for five years
  - Timescale ~ 2018
- **LHC high Luminosity upgrade (SLHC)**
  - Upgrade LHC luminosity to 8×10^{34} $cm^{-2}s^{-1}$, also in two phases
  - Two-step approach consistent with LHC schedule
  - LHCb upgrade does not require SLHC

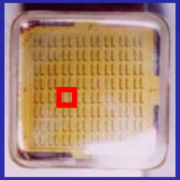
VELO → VESPA

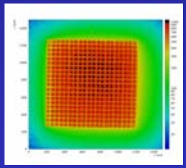
- VErtex LOcator replacement called VESPA
- Solution for first upgrade phase
  - Keep mechanical structure and silicon sensors layout
  - Replace FE chip with 40 MHz readout
  - This device will be rad hard to ~20 fb^{-1} and will collect data until 2017

- Solution for phase 2 upgrade
  - Should add to detector capabilities
  - better resolution lower occupancy (Pixels/3D detectors)
  - Possible magnetic field to improve trigger by taking advantage of improved pattern recognition
  - Remove bulky RF shield and replace with wires?

RICH Upgrade

- 40 MHz Readout
  - The readout chip is encapsulated inside the HPD
  - therefore all photon detectors will need to be replaced
- Choice of Photo sensitive device
  - HPD with 40 MHz pixel chip
  - Vacuum PMTs - Flat-panel MaPMT, MCP
  - Si-photomultiplier
  - Choice must be made soon
- FE electronics
  - development of pixel chip at 40MHz
  - or external front-end chip for commercial devices
- Option for phase 2
  - Remove RICH1, replace with ~few ps TOF?
  - Reduces material for tracking





LHCb Upgrade Status

- Expression of Interest for an LHCb Upgrade
  - Submitted to LHCC on 22nd April 2008
    document CERN/LHCC/2008-007, available on CDS
    http://cdsweb.cern.ch/search?id=1100545
  - LHCC has set up reviews for upgrades (all LHC experiments)
  - R&D has started, e.g. for the 40 MHz readout electronics and a radiation hard vertex detector
- Status in the UK
  - UK groups are leading LHCb upgrade effort
    (LHCb upgrade and Vertex co-ordinator)
  - Mainly focused on vertex (VELO) and RICH detector upgrade and physics/trigger optimisation
  - All LHCb groups about to submit an Statement of Interest to STFC, followed by a bid for R&D resources to PPRP
  - If you are interested, please contact me at f.muheim@ed.ac.uk
- More information available at
  - https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbUpgrade

Conclusions

- LHCb experiment
  - Has many opportunities to discover NP within a few years of data taking (10 fb^{-1} data sample)
  - Physics programme is complementary to ATLAS/CMS
- Physics case for LHCb upgrade
  - Study flavour structure of NP discovered at LHC or probe NP at even higher mass scale
  - Probing/measuring NP at percent level
- LHCb Upgrade Strategy
  - Phase 1 - Upgrade to 40 MHz FE electronics first to run at 10^{33}
  - Phase 2 - Upgrade all detectors such that LHCb can operate at luminosity of at least 2×10^{33} and collect 100 fb^{-1}
- R&D programme is evolving fast
  - High priority is design of FE chips for 40 MHz read out of silicon and photon detectors
  - R&D is essential now to be able to implement the upgrade when the results from the first phase of LHC running have been seen

Status of LHC Physics in ~2014

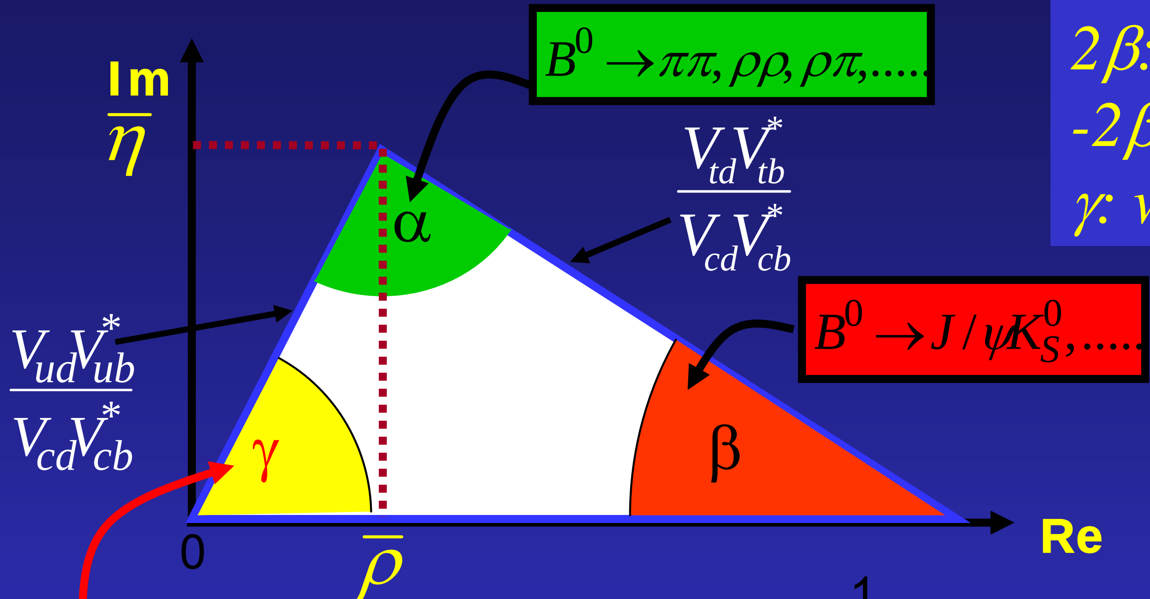
No space left for the 4th possibility

ATLAS CMS high p_T physics	BSM	Only SM	BSM	
LHCb flavour physics	Only SM	BSM	BSM	
Particle Physics	☺	☺	☺	

If 4th possibility → LHCb measurements of virtual effects may be the only way to set scale of BSM physics

Backup slides

Unitarity Triangle

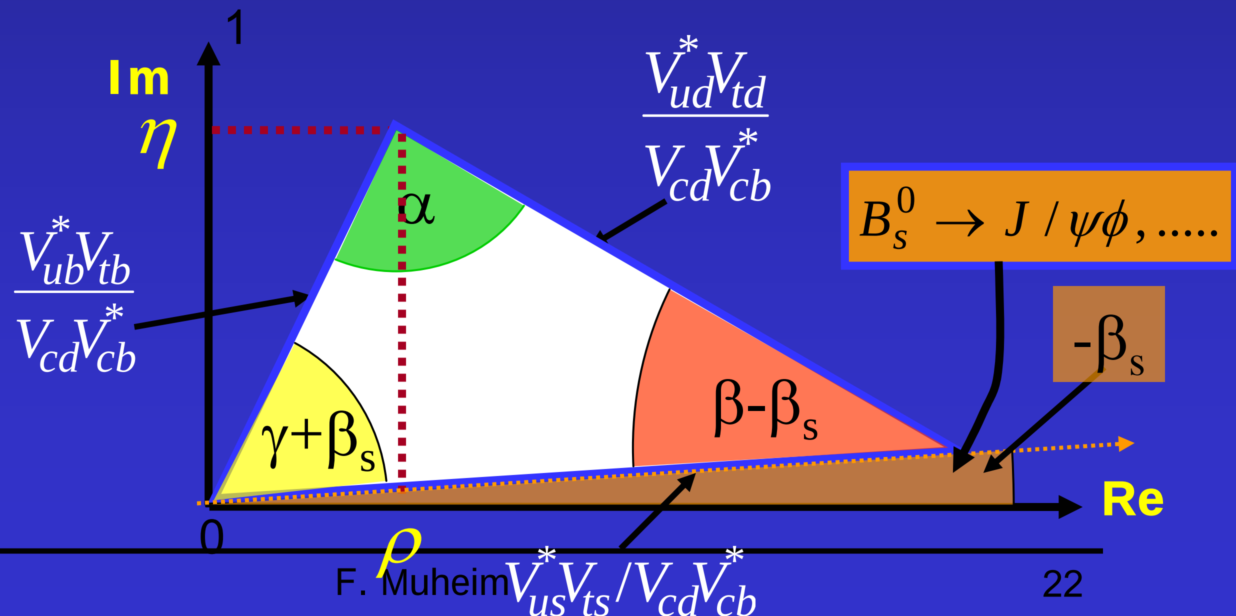


2β: B_d mixing phase
-2β_s: B_s mixing phase
γ: weak decay phase

$B_d \to DK, DK^*$

$B_s \to D_s K \quad (\gamma - 2\beta_s)$

$B_d \to D^*\pi \quad (\gamma + 2\beta)$



The End