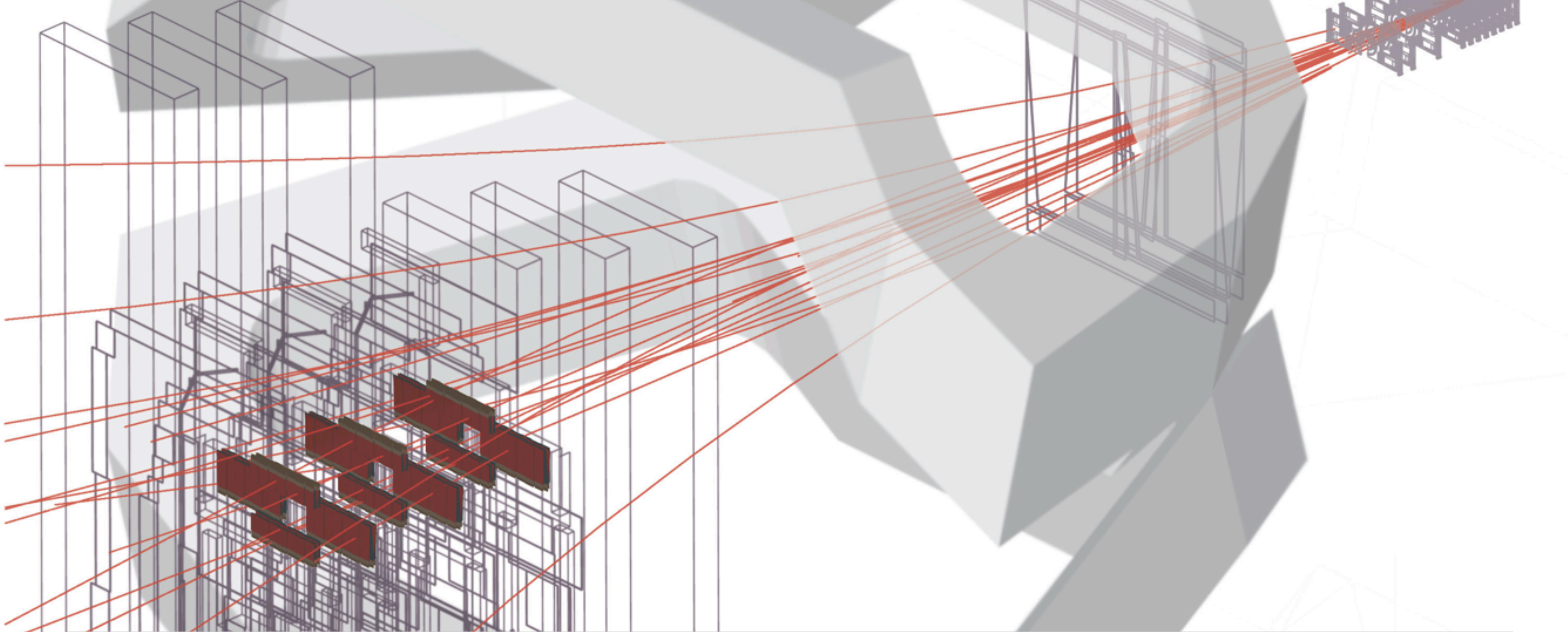
LHCb recent highlights and prospects



M. Needham
PPAP meeting 22nd July 2014
On behalf of LHCb UK

Outline

- Introduction
- Selected (recent) physics highlights
  - CKM measurements
  - Charm
  - Rare decays
  - Exotic spectroscopy
  - W production
- Run 2 preparation
- The upgrade

Tried to focus on analyses/areas with strong UK participation

Many things not covered

Physics Goals

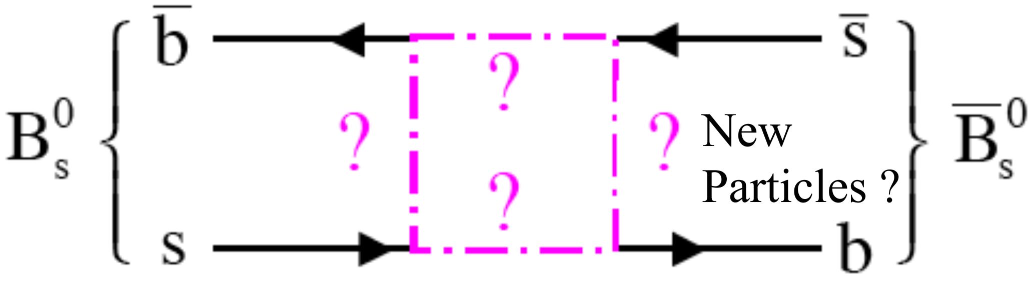
Standard Model completed by discovery of Higgs Boson

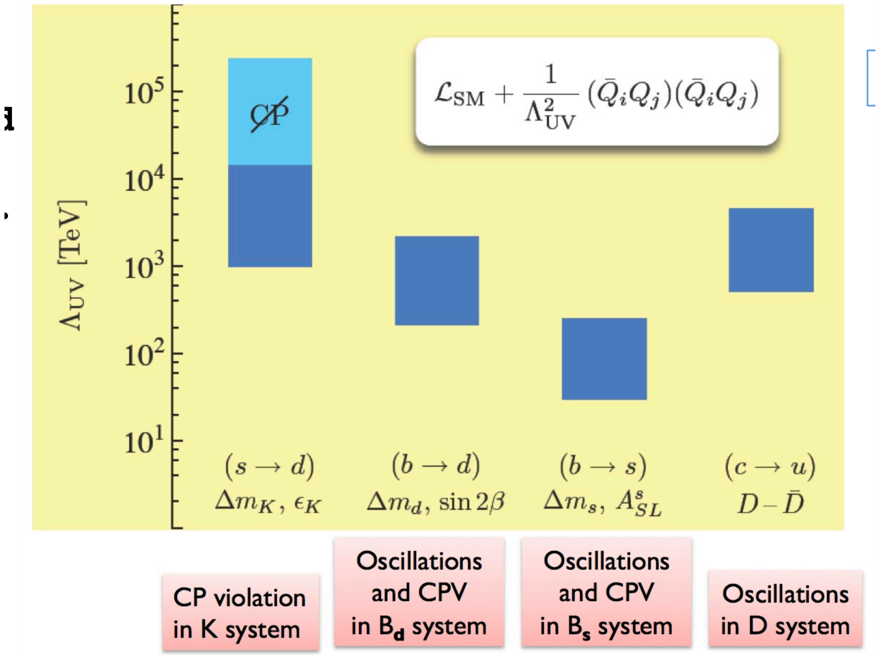
But many reasons to believe SM is not final word

e.g. CP violation in SM not enough to explain absence of anti-matter in visible universe

Precision indirect searches provide telescope to scales of O(100) TeV

Complement direct searches





(Fig. Neubert, EPS-HEP'11

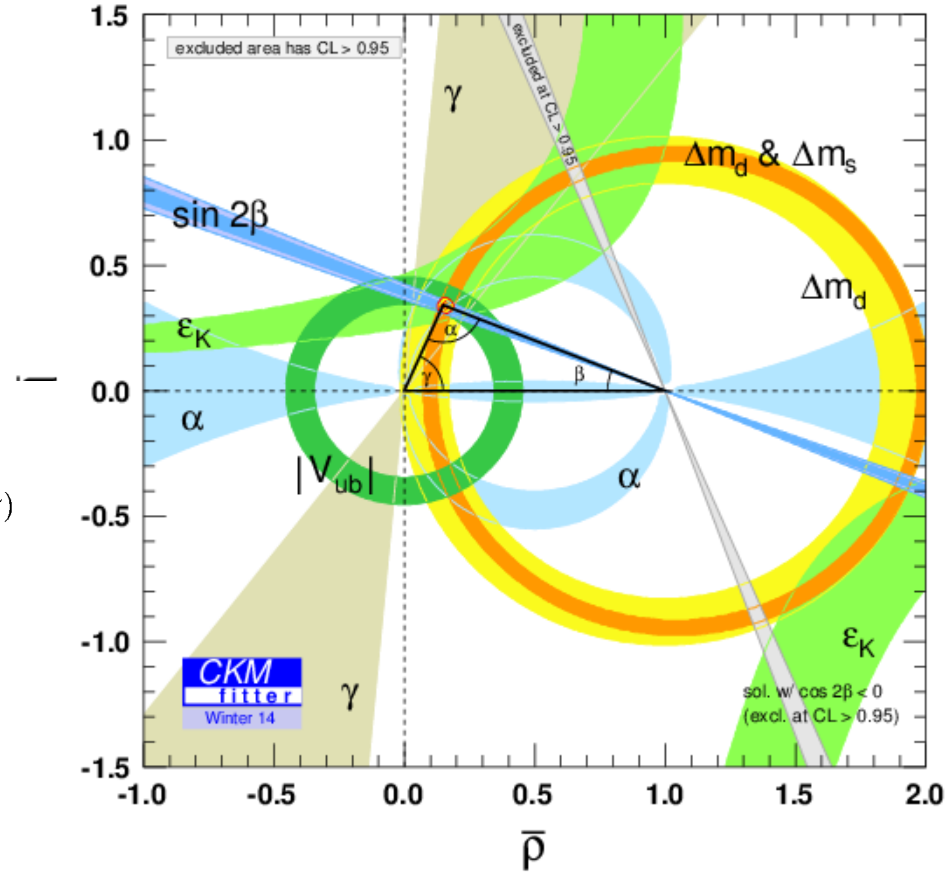
Physics Goals

Search for New Physics and CP violation in rare processes using b and c quark decays

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix} = V_{CKM} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

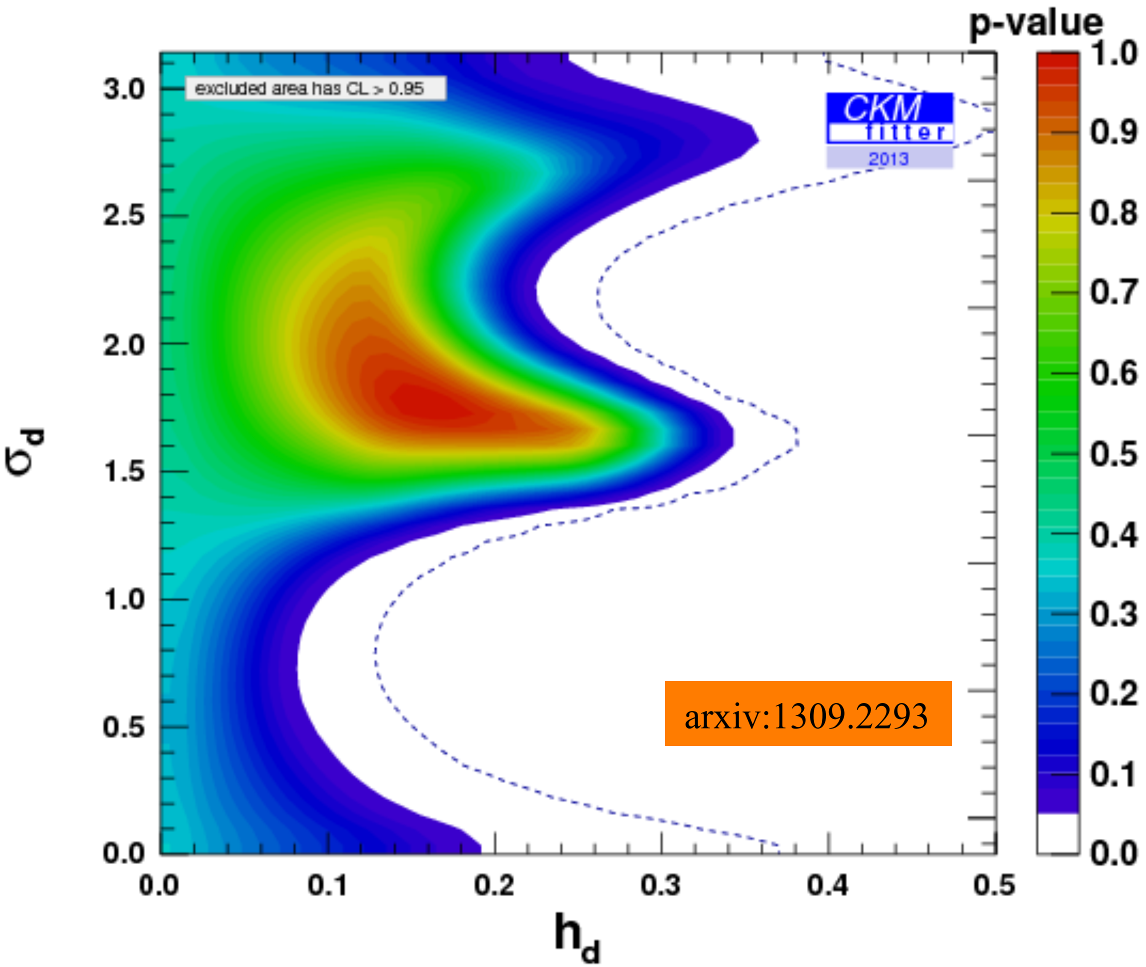
$$\mathbf{V_{CKM}} = \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \sum_{n=4}^{N} O(\lambda^n)$$

arXiv:1309.2293



Physics Goals

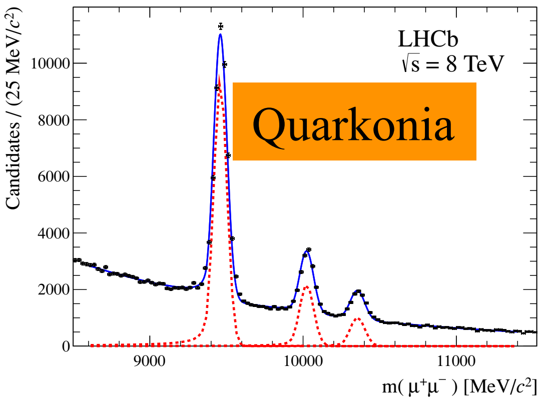
Despite progress from b factories still room for New Physics amplitude at level of 10 % in B_d mixing (Similar story in B_s sector)

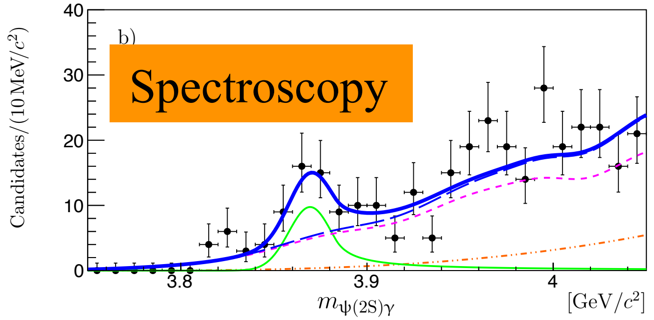


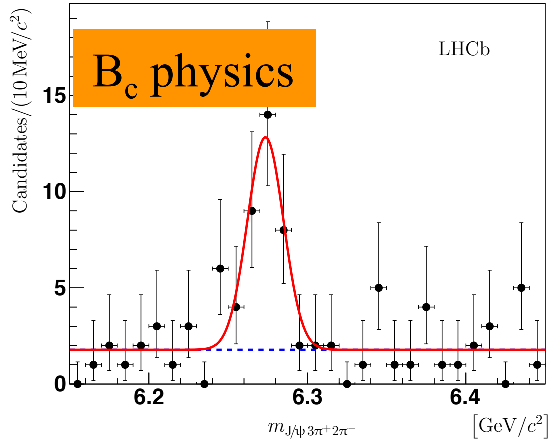
Phase New Physics

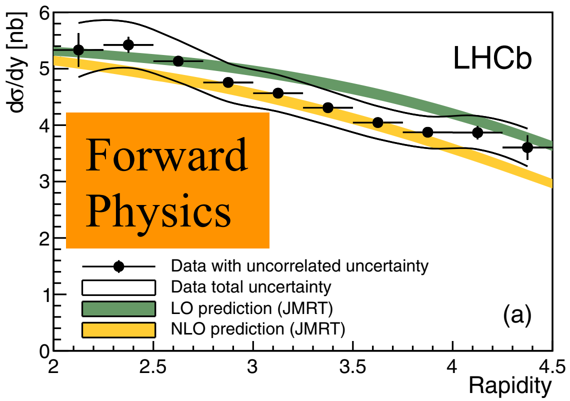
Magnitude New Physics

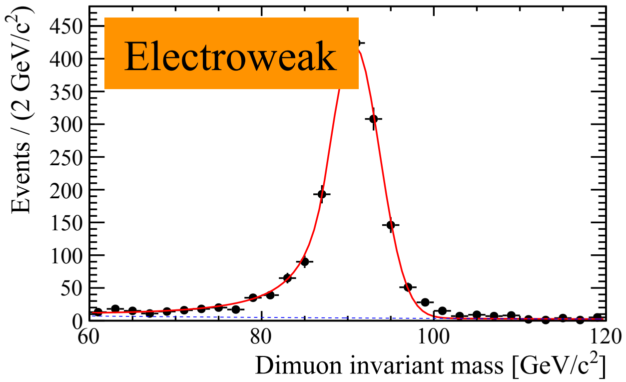
But also….

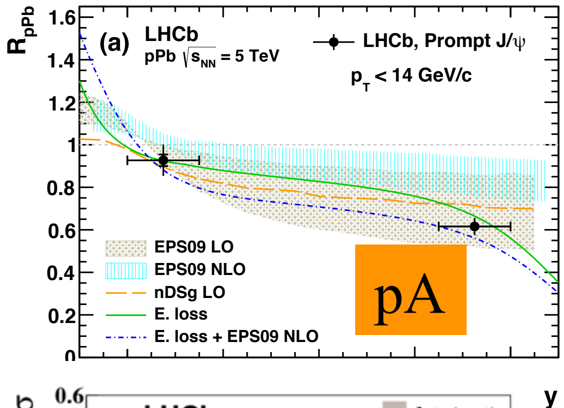

Quarkonia
LHCb
√s = 8 TeV
Candidates / (25 MeV/c²)
m(μ⁺μ⁻) [MeV/c²]

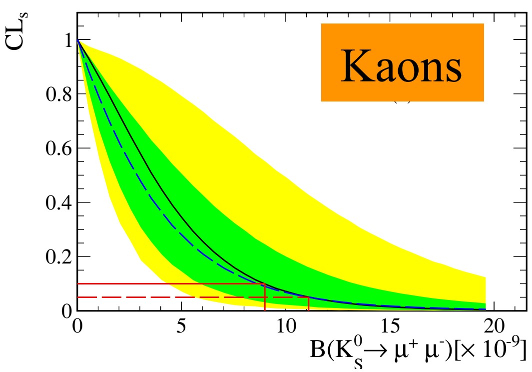

Spectroscopy
b)
Candidates/(10 MeV/c²)
$m_{\psi(2S)\gamma}$
[GeV/c²]

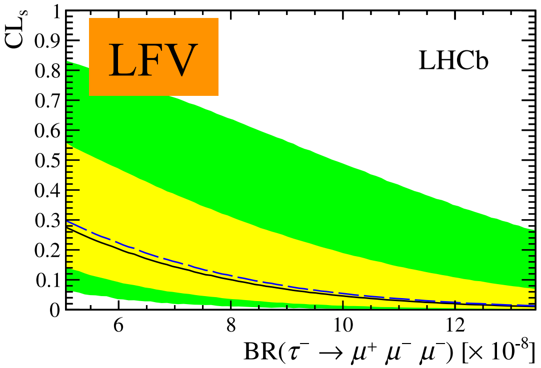

B_c physics
LHCb
Candidates/(10 MeV/c²)
$m_{J/\psi 3\pi^+ 2\pi^-}$
[GeV/c²]

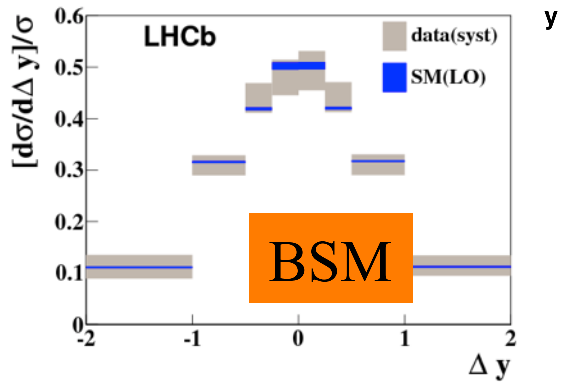

Forward Physics
LHCb
dσ/dy [nb]
Data with uncorrelated uncertainty
Data total uncertainty
LO prediction (JMRT)
NLO prediction (JMRT)
(a)
Rapidity


Electroweak
Events / (2 GeV/c²)
Dimuon invariant mass [GeV/c²]

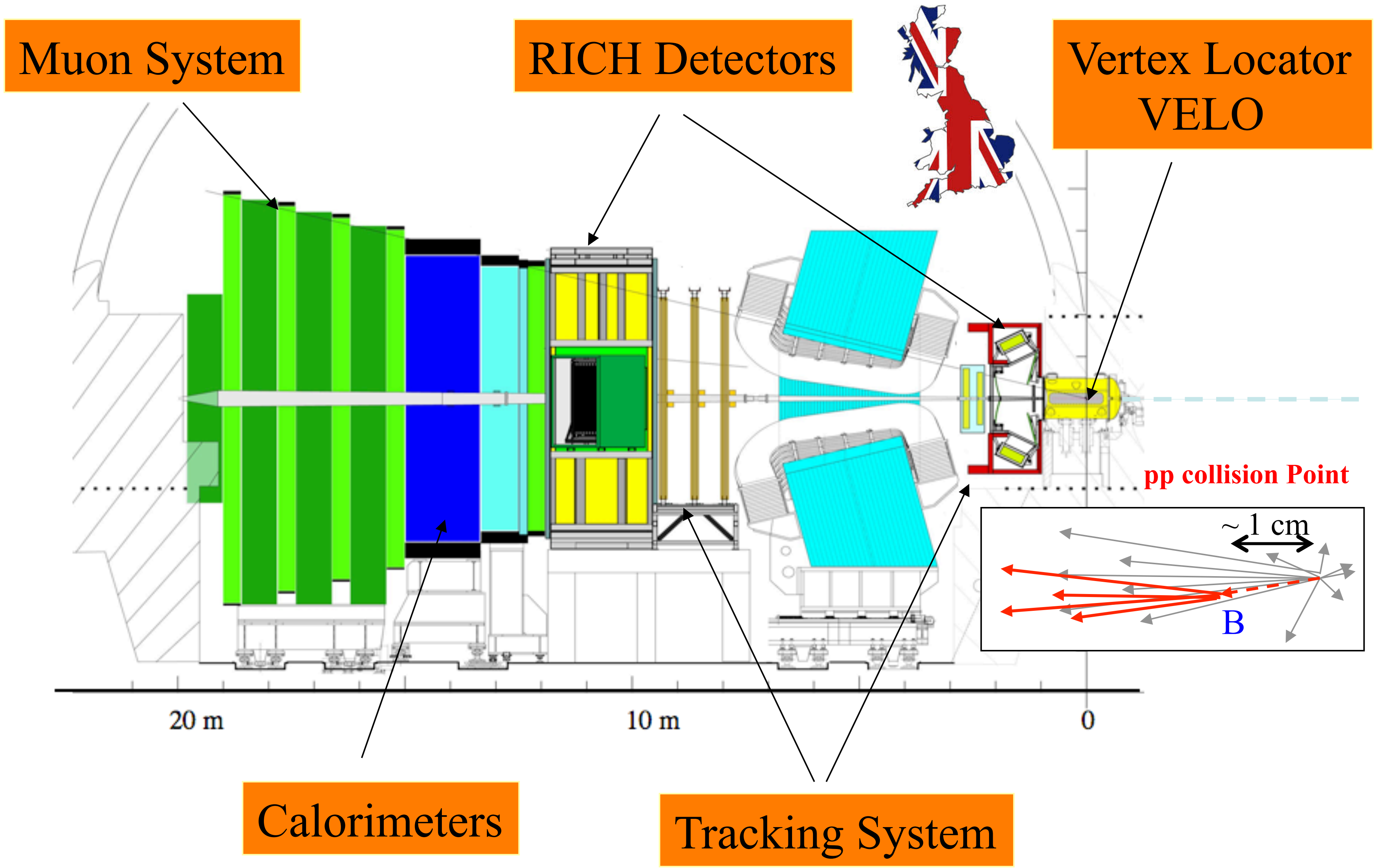

pA
(a)
LHCb
pPb √s_NN = 5 TeV
LHCb, Prompt J/ψ
p_T < 14 GeV/c
R_pPb
EPS09 LO
EPS09 NLO
nDSg LO
E. loss
E. loss + EPS09 NLO
y


Kaons
CLs
B(K⁰S→ μ⁺ μ⁻)[× 10⁻⁹]


LFV
LHCb
CLs
BR(τ⁻ → μ⁺ μ⁻ μ⁻) [× 10⁻⁸]

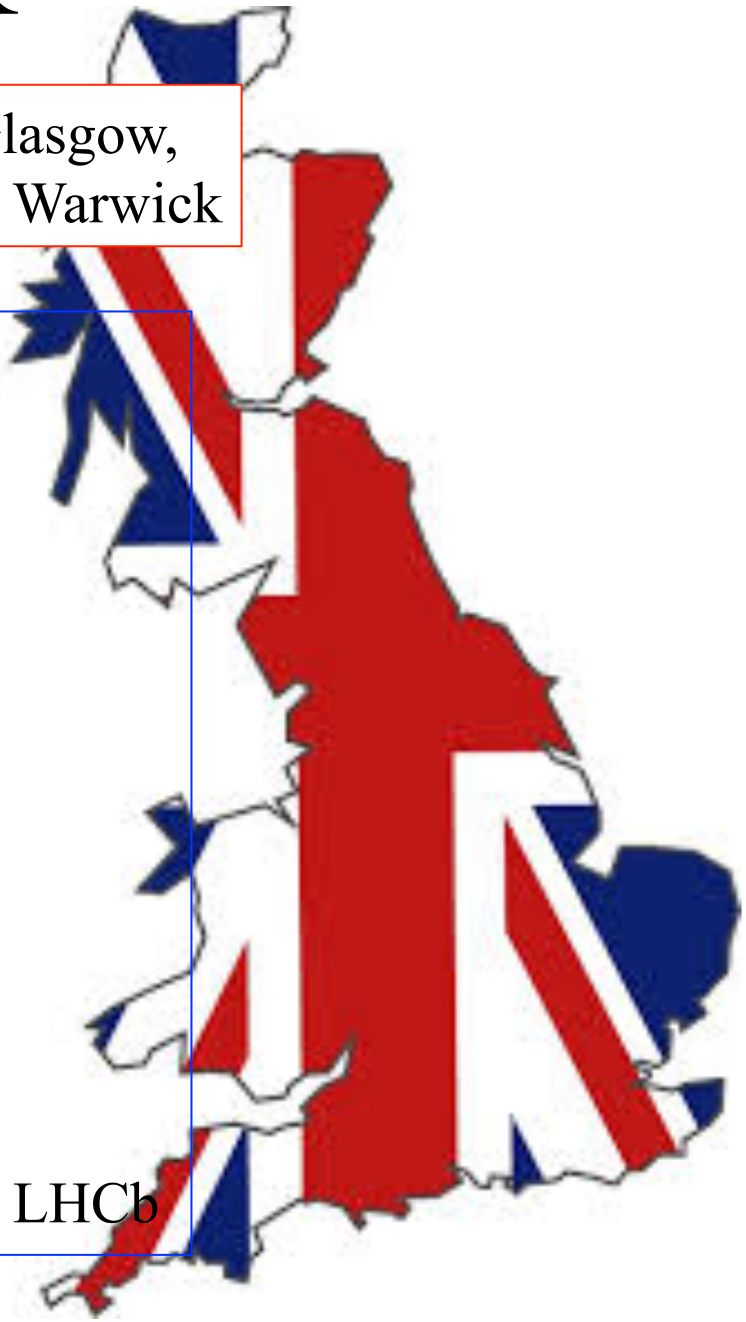

BSM
LHCb
data(syst)
SM(LO)
[dσ/dΔ y]/σ
Δ y

The LHCb Detector



LHCb-UK

Birmingham, Bristol, Cambridge, Edinburgh, Glasgow, Imperial, Liverpool, Manchester, Oxford, RAL, Warwick



Collaboration 700 authors, 20 % UK affiliated

New spokeperson from UK (G. Wilkinson)

Two previous physics coordinators from UK

30 % of physics groups convenors from UK

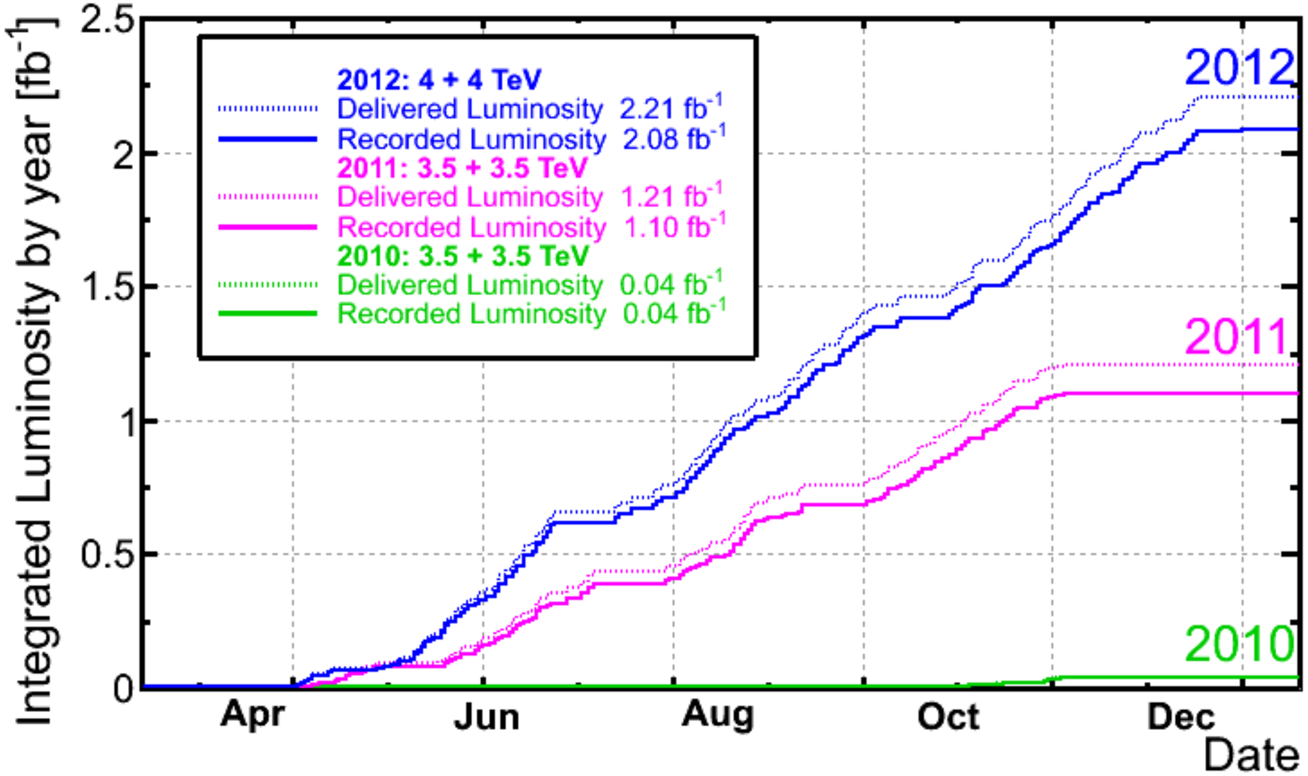
UK led construction and now operation of Vertex detector + RICH. Current project leaders both from UK

UK provides appropriate Tier-1 data storage for LHCb

Run 1 Overview

~ 3.3 fb^{-1} of data collected

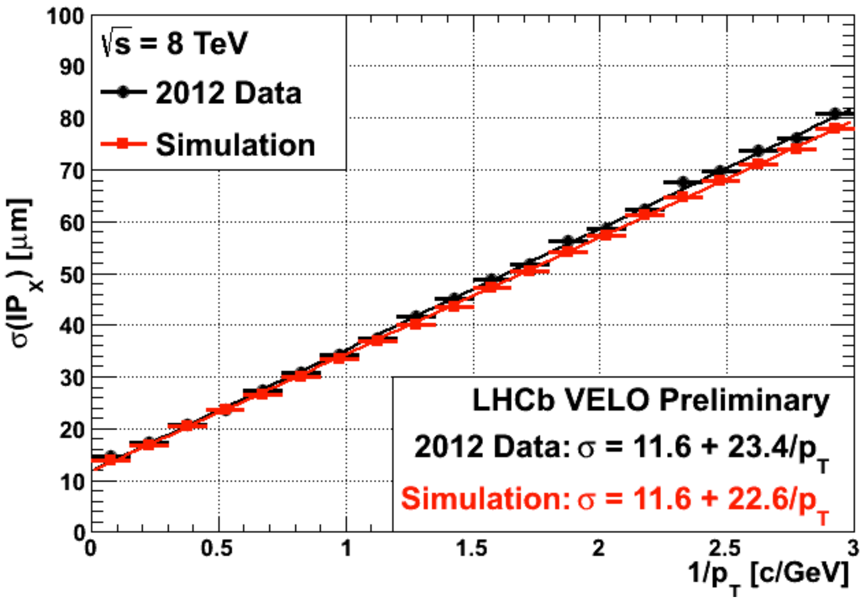
Essentially all data physics quality

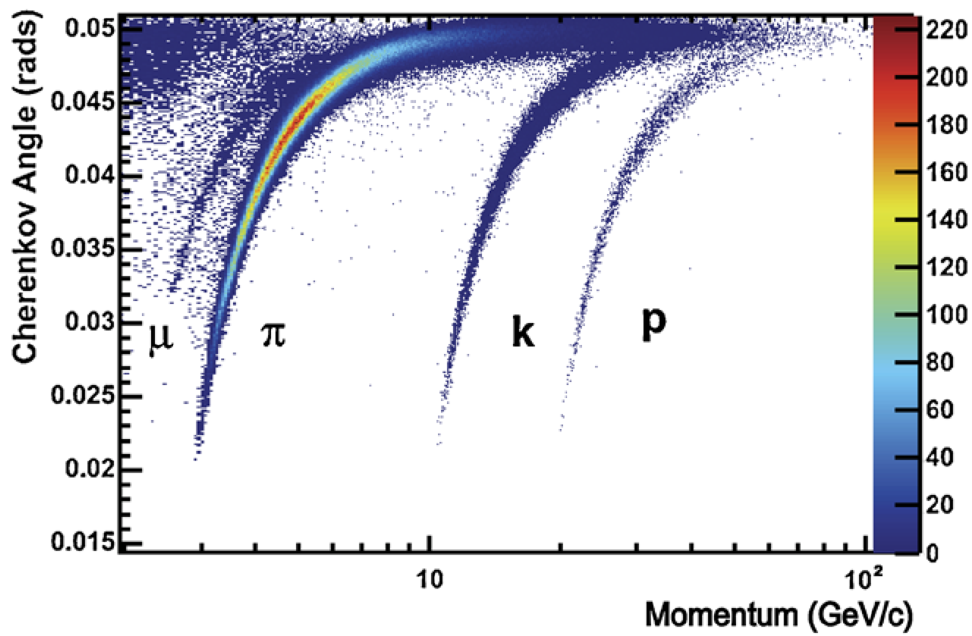


Also data taken in pA run and also at 2.76 TeV pp

Detector Performance

Detector performance close to design expectations ! Superb foundation to do good physics



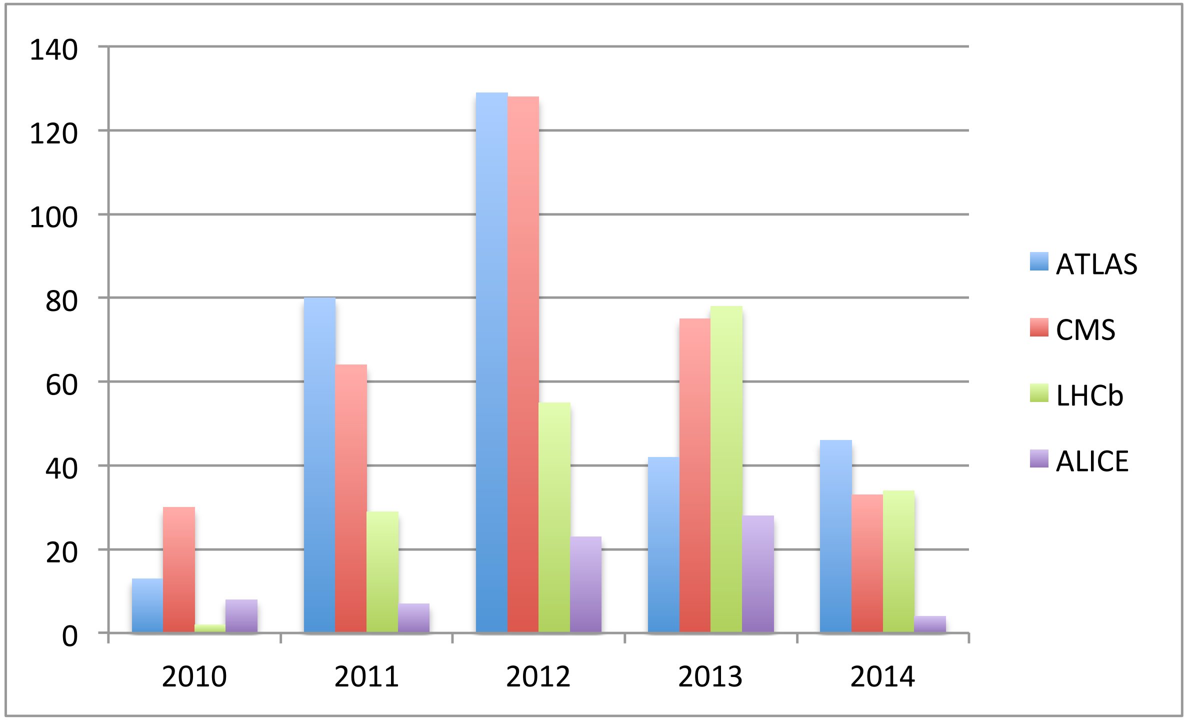


Impact parameter resolution in vertex detector

Cherenkov angle for isolated tracks

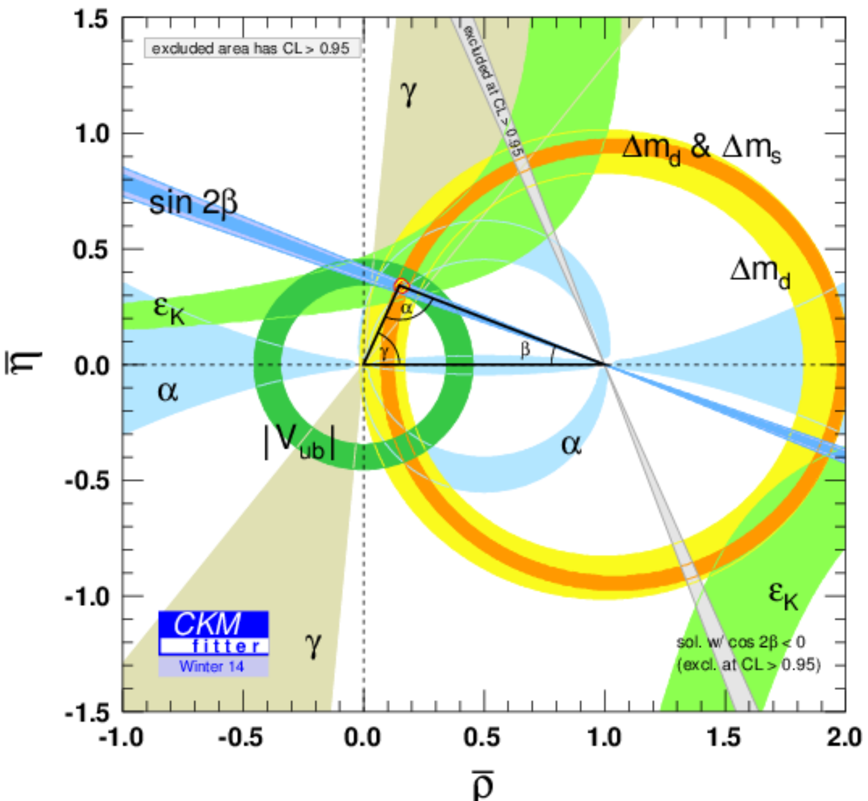
Scientific Output

- Already 196 papers submitted or published papers
  - 200 mark will be reached tommorrow morning
  - Harvest of Run 1 data will continue at 1-2 papers per week



The angle γ

To uncover New Physics important to overconstrain CKM matrix parameters



Least well directly measured CKM angle. Uncertainty around 8^0

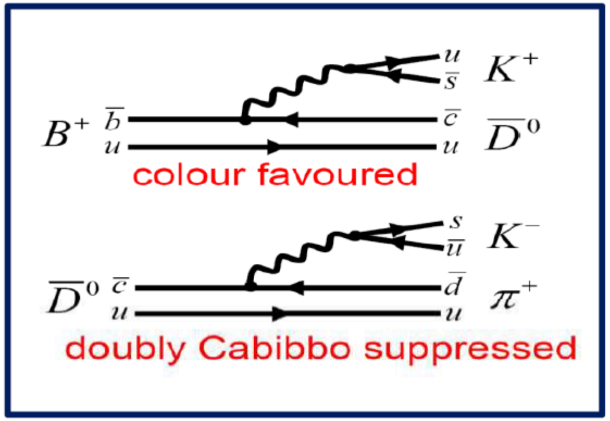
Theoretically clean measurement with B ➔ DK decays

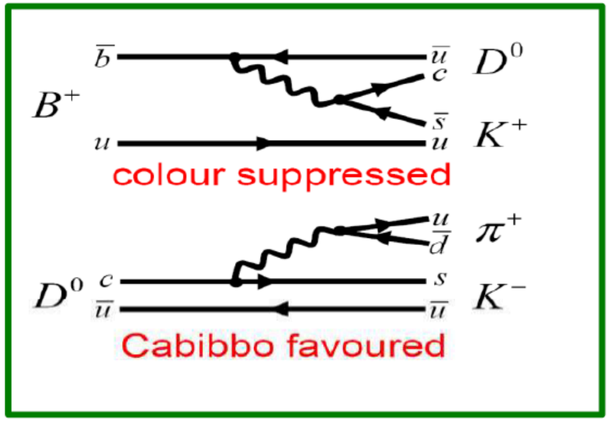
$$|\delta\gamma| \leq \mathcal{O}(10^{-7})$$

Brod+Zupan arXiv:1308.5663

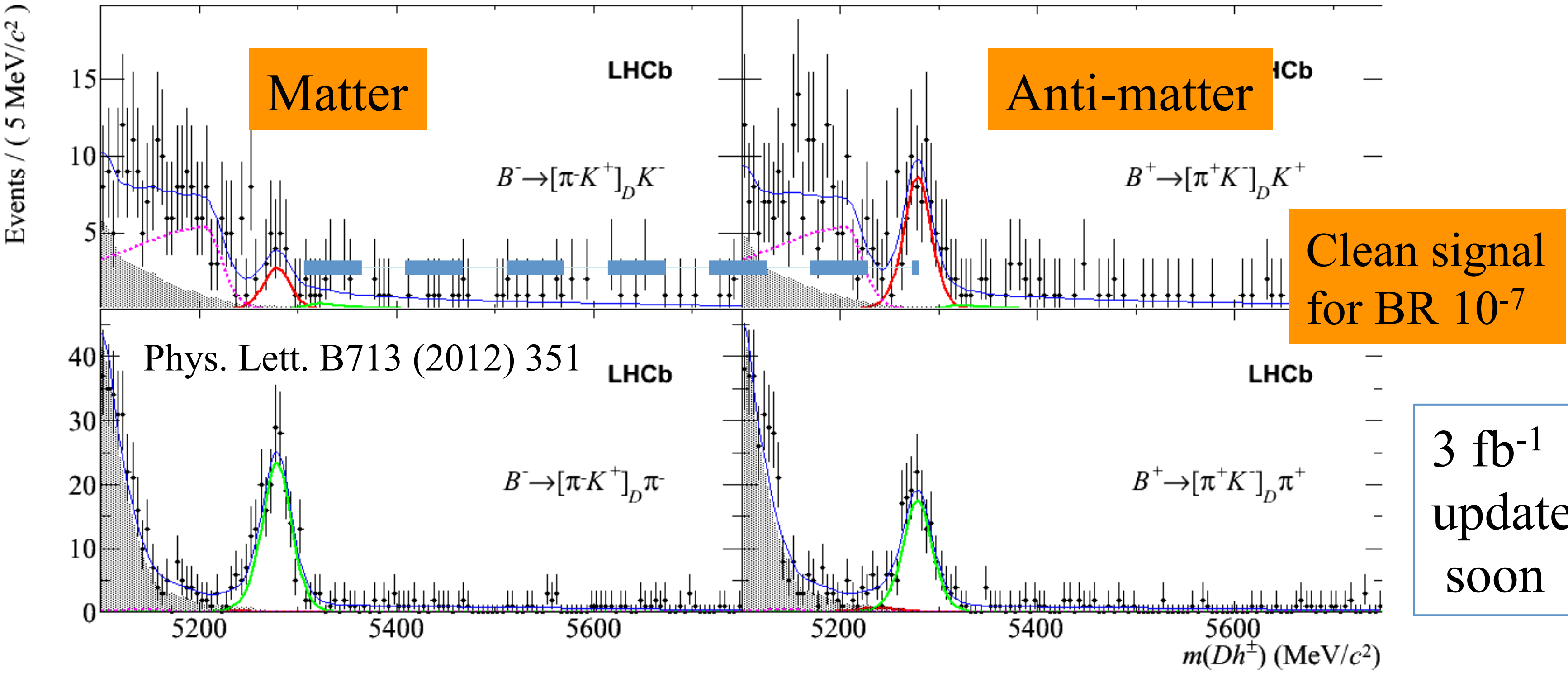
- Key part of LHCb physics program: many analyses ongoing
- Many B decay modes to open charm contributing

The angle γ





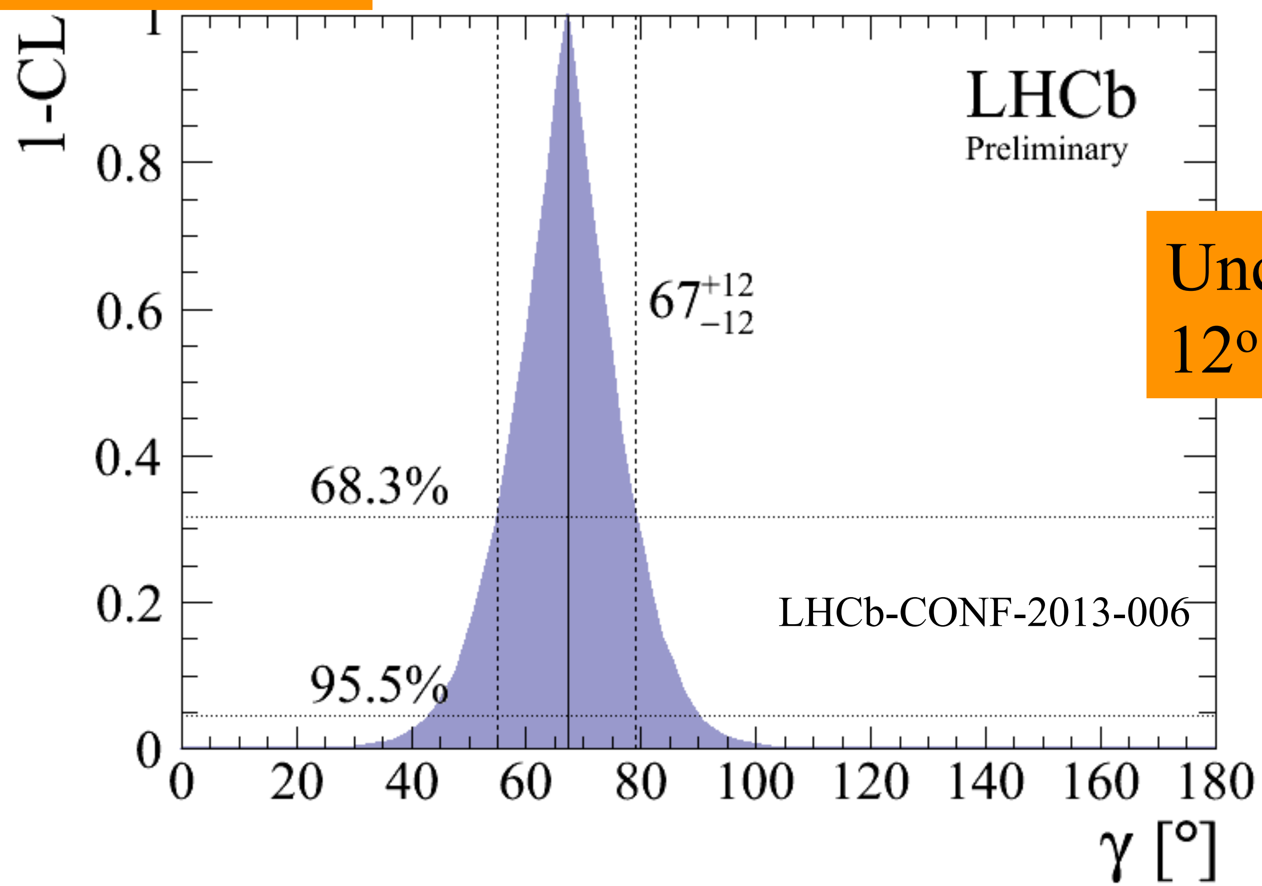
Reversed suppression of the D decays relative to the B decays results in much more equal amplitudes



3 fb^{-1} update soon

The angle γ

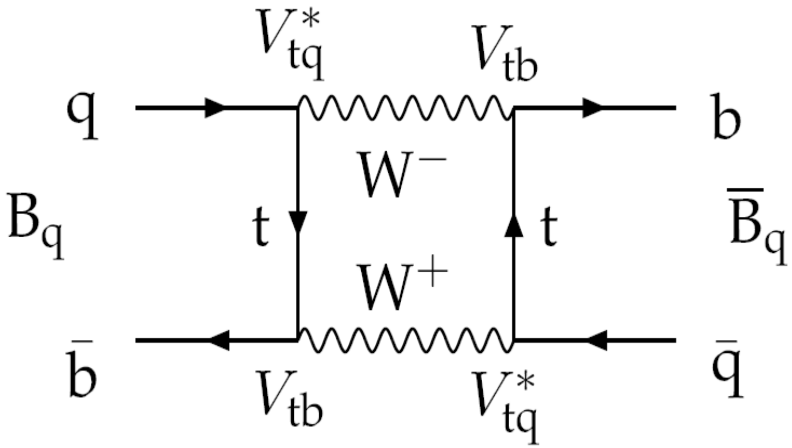
LHCb-CONF-2013-006
γ combination



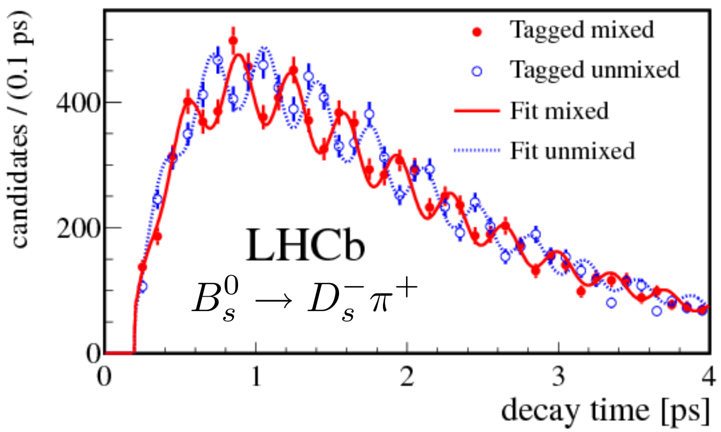
Uncertainty
12^{o} on γ

Updates on many measurements with full Run 1 dataset in progress
Further improvement already with Run 1 data ! 4^{o} precision by end Run 2

CP violation in B_s mixing



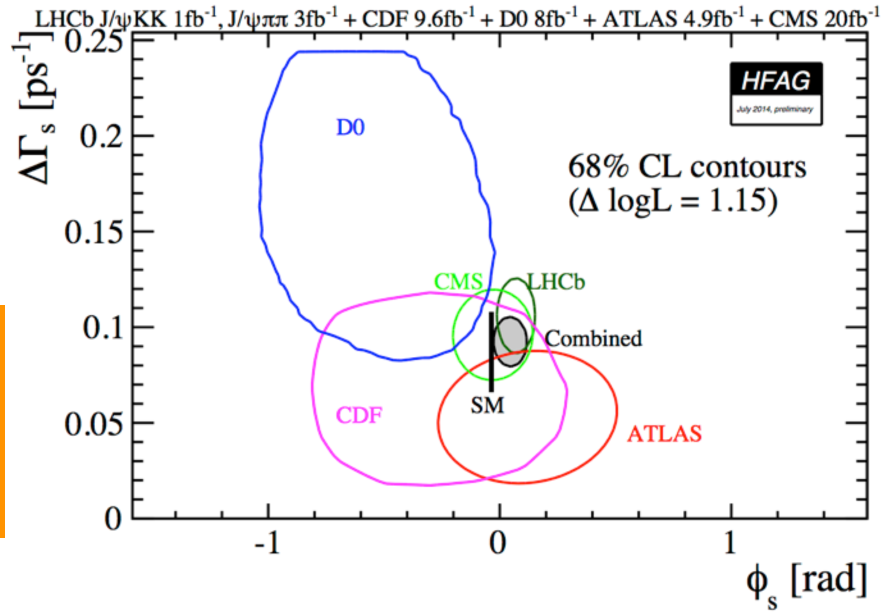
New J. Phys.15 (2013) 053021



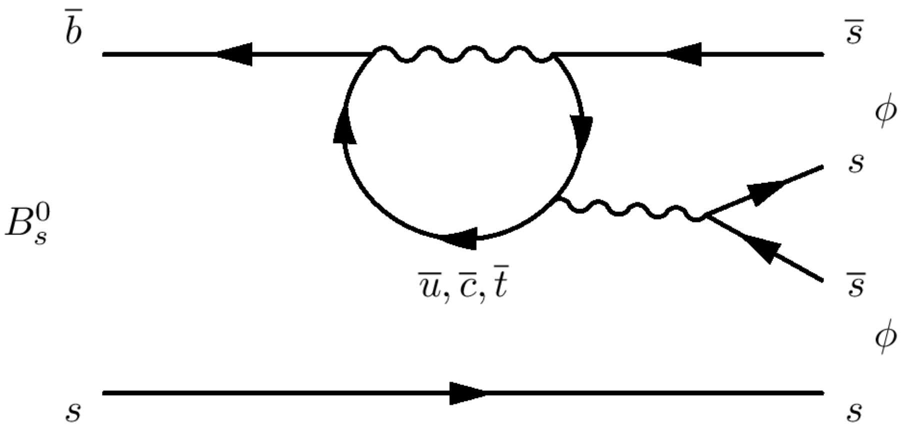
Observable CP violating phase ϕ_s (analogous to sin2β in B^0 case): SM expectation ϕ_s ~ -0.036 rad. Can be enhanced in New Physics models

Measured ϕ_s in J/ψϕ ,J/ψππ modes
New measurement in J/ψππ mode
0.070 ± 0.068 ± 0.008 rad (LHCb-Paper-2014-019)

Update in J/ψϕ mode with 3 fb^{-1}
coming soon precision ~ 0.05 rad level
Run 2 precision ~ 0.015 rad

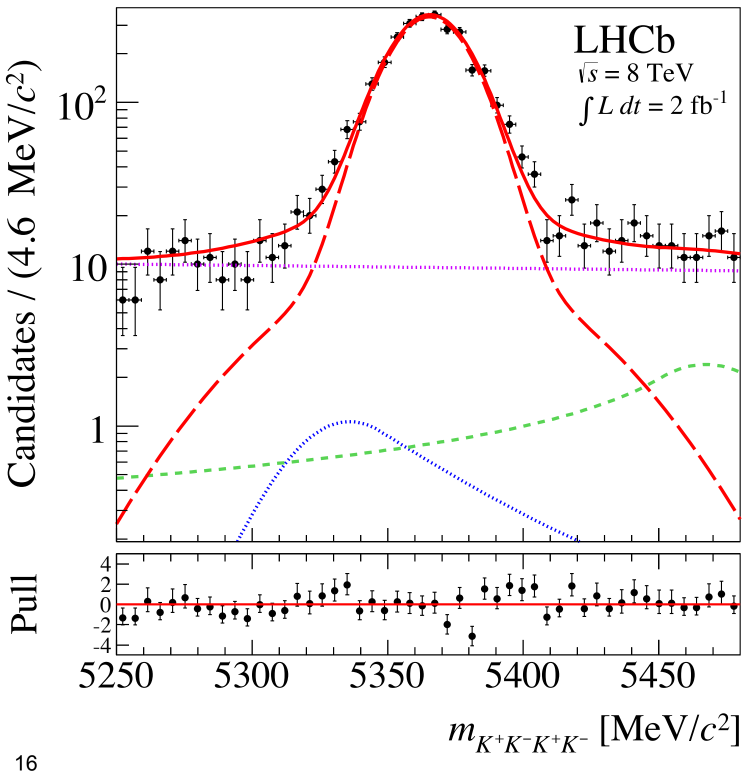


CP violation in $B_s \rightarrow \phi\phi$



Gluonic penguin decay

Standard Model cancellation between decay + mixing phases ϕ_s^{eff} is negligible.



$$\phi_s^{eff} = -0.17 \pm 0.15 \pm 0.03 \text{ rad}$$

Result consistent with Standard Model

Already interesting sensitivity reached for flagship upgrade precision measurement

LHCB-PAPER-2014-026

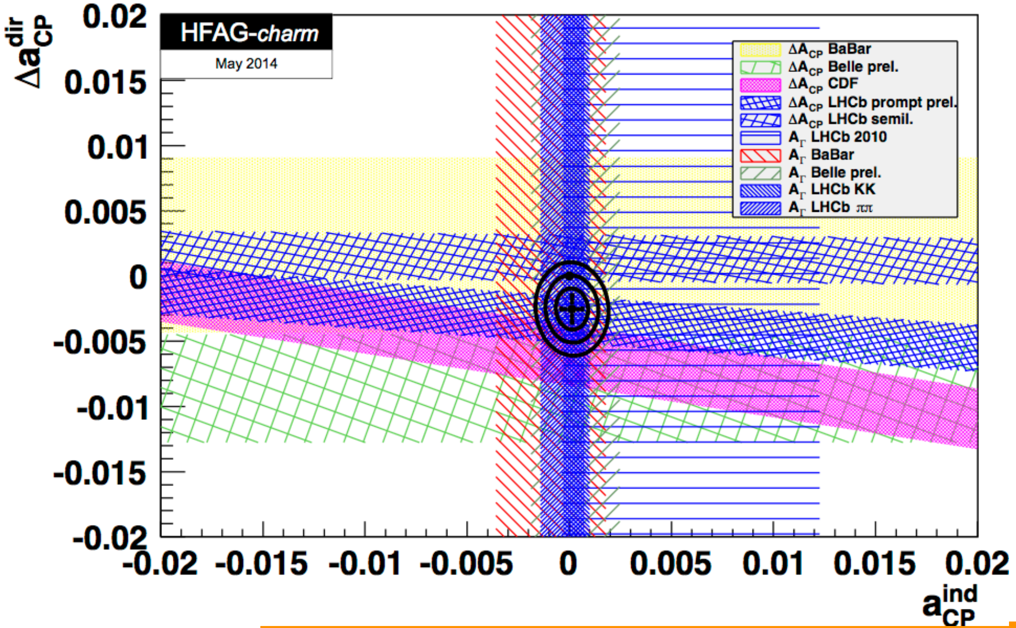
Charm

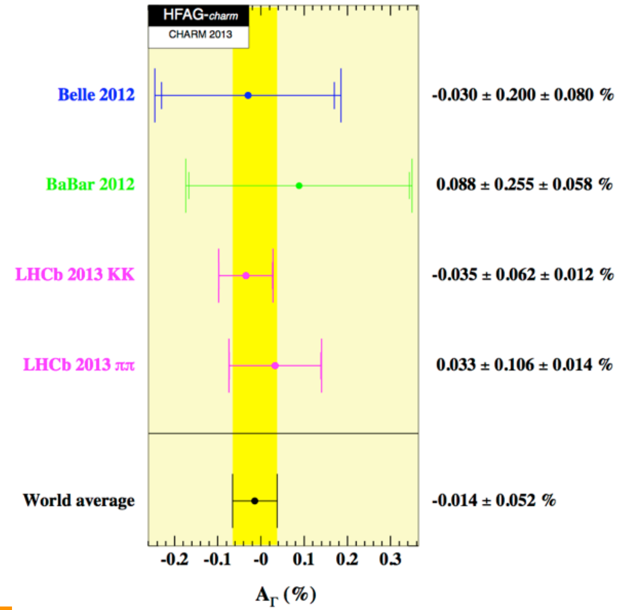
Wide program in charm rare decays and CP violation searches
Huge statistics allowing huge progress e.g. CP violation in Charm mixing

$$A_\Gamma(\pi\pi) = (0.44 \pm 1.06 \pm 0.14) \times 10^{-3}$$
$$A_\Gamma(KK) = (-0.35 \pm 0.65 \pm 0.12) \times 10^{-3}$$

Phys. Rev. Lett.112 (2014) 041801
1fb^{-1} result. 3fb^{-1} update to come

LHCb 4 times better than World average

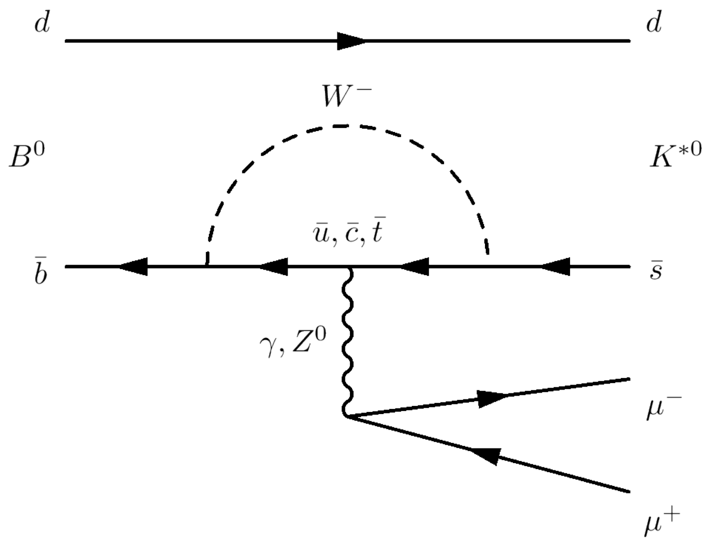




Run 2: higher cross-section and improved trigger !
Reach interesting precision: SM expect $A_\Gamma \sim O(10^{-4})$

$B^0 \rightarrow K^*\mu^+\mu^-$ and friends

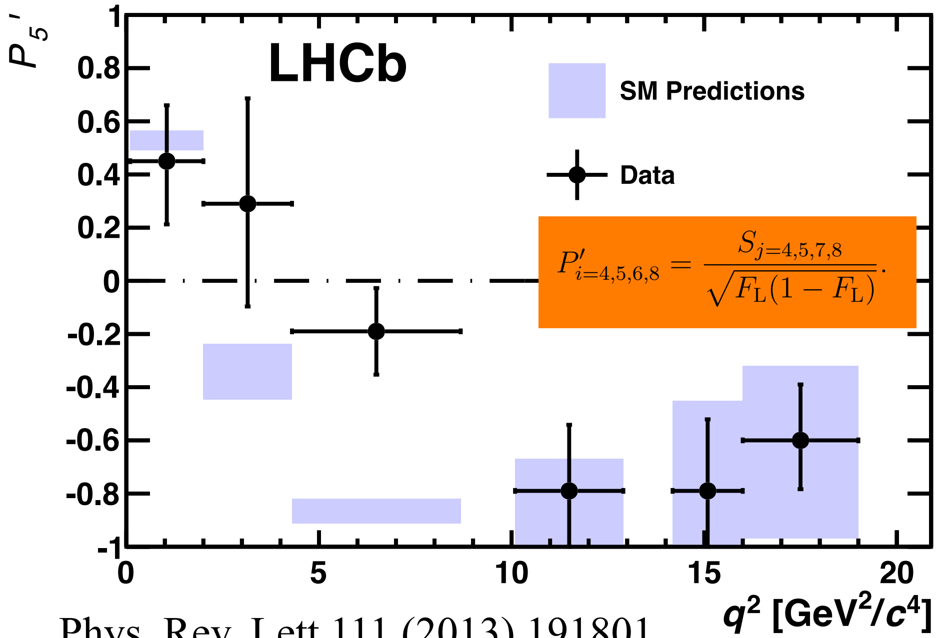
UK Led



$B^0 \rightarrow K^*\mu\mu$ and similar rare decays gives access to wide range of observables sensitive each sensitive to different NP effects

Discrepancy for P5' observable using 1fb^{-1} of data compared to expectation

3.7 σ local significance (probability probability that at least one bin varies by this much is 0.5 %)



Phys. Rev. Lett.111 (2013) 191801

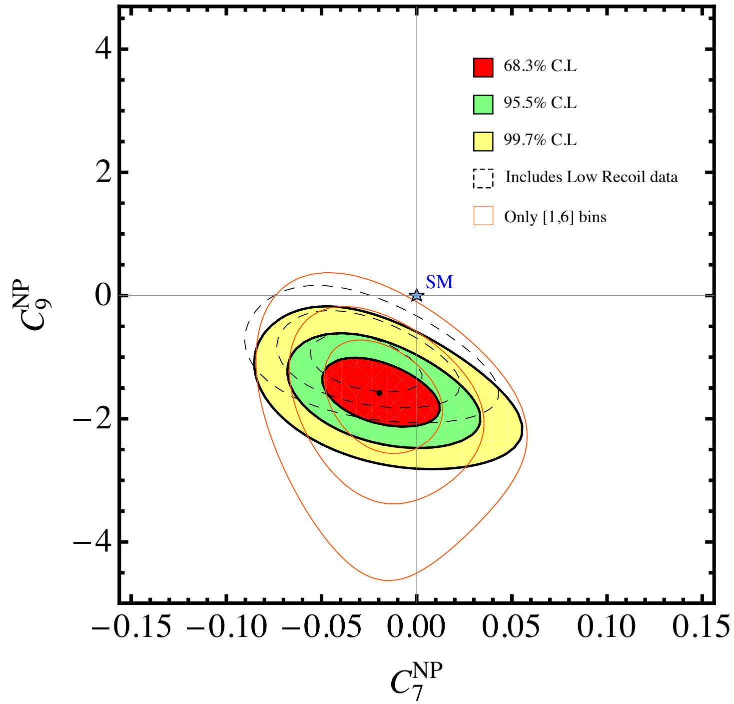
Update with 3 fb^{-1} soon. How will this evolve with more data with Run 2 ?

$B^0 \rightarrow K^*\mu^+\mu^-$ and friends

Result attracted a lot of theory attention, range of interpretations – QCD related or New Physics

Descotes-Genon et al perform global fit
4.5σ discrepancy from SM ?
[PRD 88 074002 (2013)]

Altmannshofer and Straub 3σ discrepancy.
Flavour changing Z' boson
[EPJC 74 2646 (2013)]

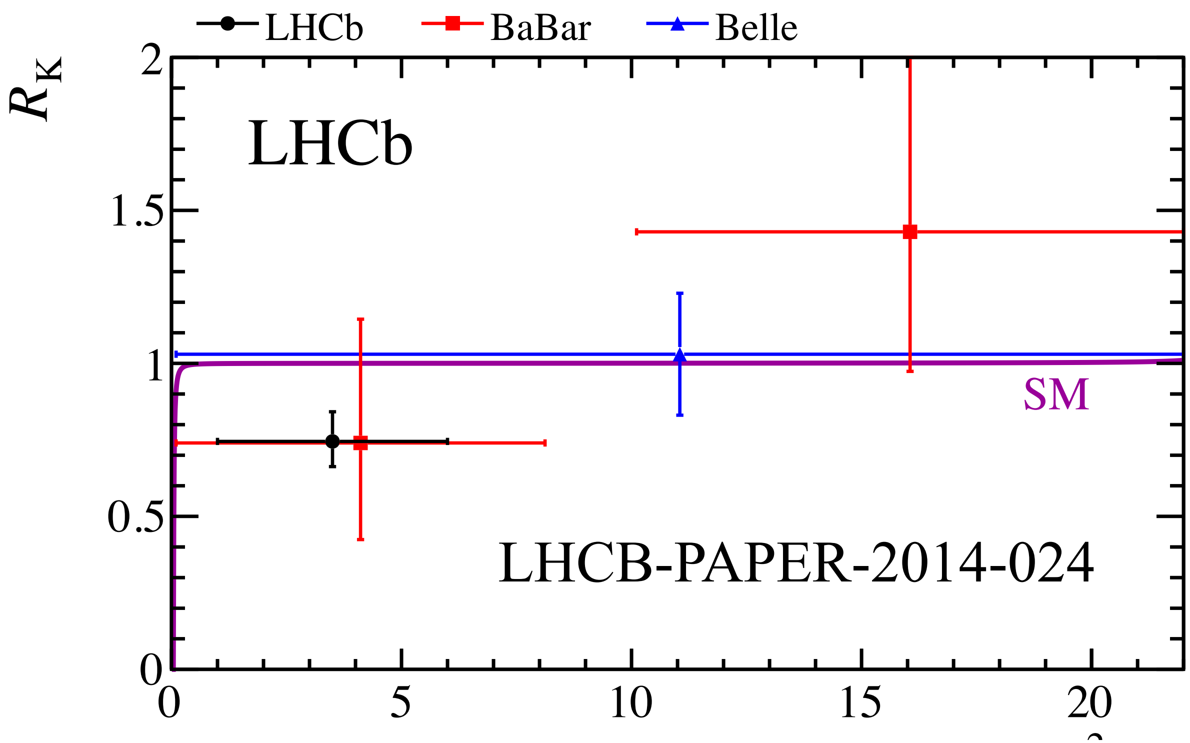


The size of form factor power corrections is currently under extensive study within phenomenology community (e.g. Jaeger et al, JHEP05(2013)043)

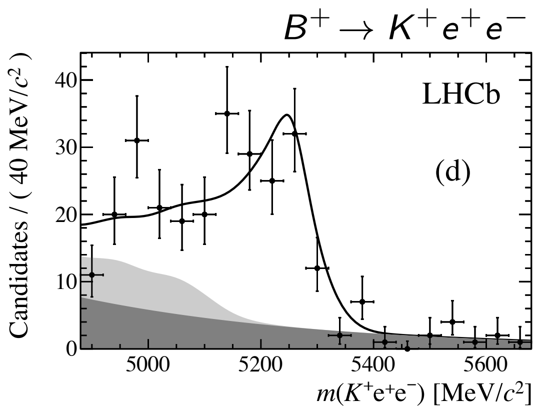
Zwicky/Lyon (arXiv:1406.0566) Anomaly related to discrepancies in $B^+ \rightarrow K^+\mu\mu$ at high q^2 ?

R_K

Wealth of other observables to probe, e.g. R_K which should be 1 in SM [lepton universality]



$$R_K = \frac{\Gamma(B^+ \to K^+\mu^+\mu^-)}{\Gamma(B^+ \to K^+e^+e^-)}$$



$$R_K = 0.745^{+0.090}_{-0.074}(\text{stat}) \pm 0.036(\text{sys})$$

2.6 σ away from SM. Interesting to see how develops with Run 2

Exotic Spectroscopy

Why do quarks come in twos or threes ?

A SCHEMATIC MODEL OF BARYONS AND MESONS *

M. GELL-MANN
California Institute of Technology, Pasadena, California

Received 4 January 1964

A simpler and more elegant scheme can be constructed if we allow non-integral values for the charges. We can dispense entirely with the basic baryon b if we assign to the triplet t the following properties: spin $\frac{1}{2}$, $z = -\frac{1}{3}$, and baryon number $\frac{1}{3}$. We then refer to the members $u^{\frac{2}{3}}$, $d^{-\frac{1}{3}}$, and $s^{-\frac{1}{3}}$ of the triplet as "quarks" 6) q and the members of the anti-triplet as anti-quarks $\bar{q}$. Baryons can now be constructed from quarks by using the combinations $(q\,q\,q)$, $(q\,q\,q\,q\,\bar{q})$, etc., while mesons are made out of $(q\,\bar{q})$, $(q\,q\,\bar{q}\,\bar{q})$, etc. It is assuming that the lowest

Hot topic in recent years @ b-factories and BES

Many candidates claimed – e.g. X(3872), Z(3900)$^+$. But no unambigous candidate

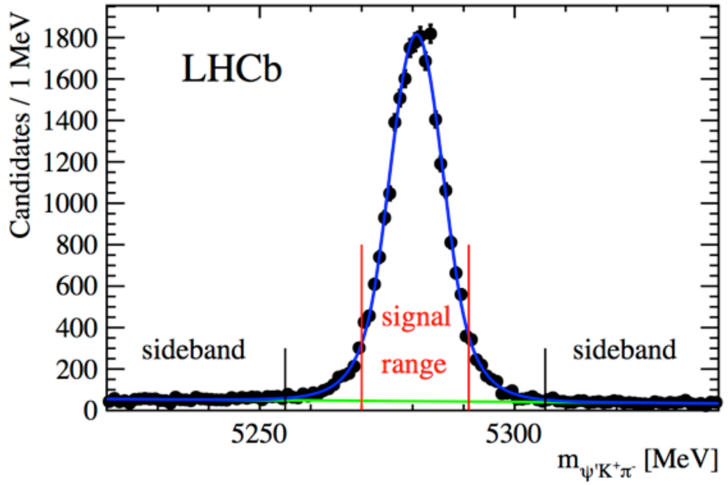
One candidate Z(4430)$^+$ claimed by Belle in $B^0 \rightarrow \psi(2S)K\pi$ decay chain but not seen by Babar.

Charged state, confirmation provides irefutable evidence for four quark states

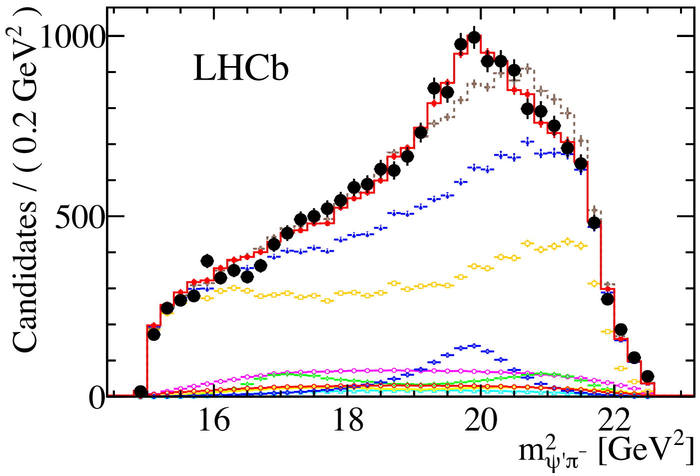
$Z(4430)^+$

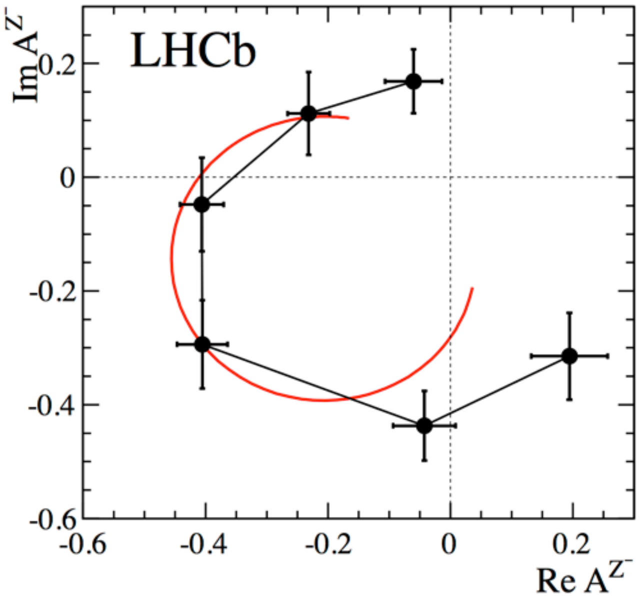
LHCB-PAPER-2014-014

Phys Rev Lett 112 222002 (2014)



- Full angular analysis
- $J^P = 1^+$, rules out cusp interpretation
- Phase shift consistent with resonant behaviour





Four quark states exist: elucidate nature with Run 2 data

$Z(4430)^{+}$

QUANTUM DIARIES

Thoughts on work and life from particle physicists from around the world.

journal diario 전
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« Grosse moisson de trèfles à quatre feuilles

CERN | GENEVA | SWITZERLAND

Major harvest of four-leaf clover

The LHCb Collaboration at CERN has just confirmed the unan… something that looks strangely like a particle being made of fo… particle is sternly called Z(4430)⁻, which gives its mass at 4430… proton, and indicates it is has a negative electric charge. The l… series of particles that are referred to as XYZ states.

How CERN's Discovery of Exotic Particles May Affect Astrophysics

by BRIAN KOBERLEIN *on* APRIL 10, 2014

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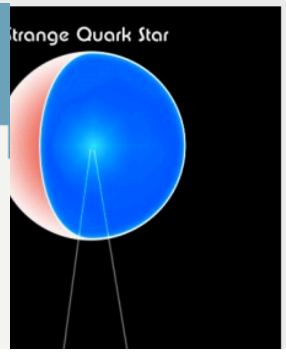

PHYSICAL REVIEW D

particles, fields, gravitation, and cosmology

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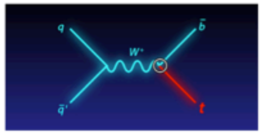
NEWS AND COMMENTARY IN PHYSICS

Top Quarks Go Solo in Rare Events

June 9, 2014



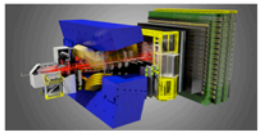
Separate collider experiments observe the top quark without its usual antiparticle partner in unique processes that could give insight into new physics, such as additional sets of quarks.

Viewpoint on S. Chatrchyan *et al.* (CMS Collaboratio… (2014) and …

NEWS AND COMMENTARY IN PHYSICS

Four-Quark State Confirmed

June 4, 2014



The LHCb experiment provides conclusive evidence for the existence of the four-quark particle called Z(4430).

Synopsis on R. Aaij *et al.* (LHCb Collaboration) Phys. Rev. Lett. 112, 222002 (2014)

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NEWS AND COMMENTARY

Major Discovery Announced

The BICEP2 experim… evidence of B-mode…

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Quarks bonding differently at LHCb

The strong force binds quarks together to form hadrons. Until last Monday, only two types of hadron were known, but the LHCb experiment at CERN has just proved there is a third way

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Could this particle rewrite modern physics? Discovery of 4-quark hadron proves we still don't fully understand our universe

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LHC spots particle that may be new form of matter

› 22:31 10 April 2014 by Maggie McKee

› For similar stories, visit the The Large Hadron Collider Topic Guide

A long-sought fugitive has been caught at the world's largest particle accelerator. Experiments at the Large Hadron Collider confirm that a provocative particle called Z(4430) actually exists – and it may be the strongest evidence yet for a new form of matter called a tetraquark.

CERN Physicists Confirm Existence of Exotic Hadrons

Apr 10, 2014 by Sci-News.com « PREVIOUS | NEXT »

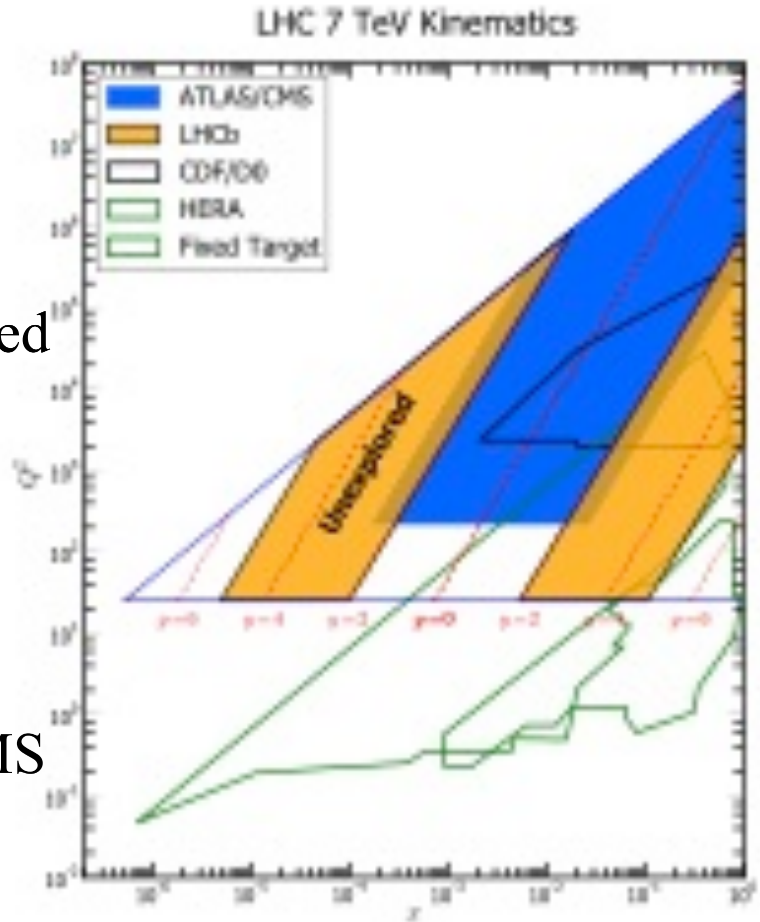
Published in Physics

Tagged as CERN

Scientists from CERN's Large Hadron Collider beauty collaboration have confirmed the unambiguous observation of the long-sought exotic hadron Z(4430), a particle that cannot be classified within the traditional quark model.

Electroweak Physics

- Program of W and Z cross-section measurements
- Unique access to small x-region unexplored by previous experiments
- Test Standard Model and constrain PDF sets
- Measurements complement ATLAS + CMS

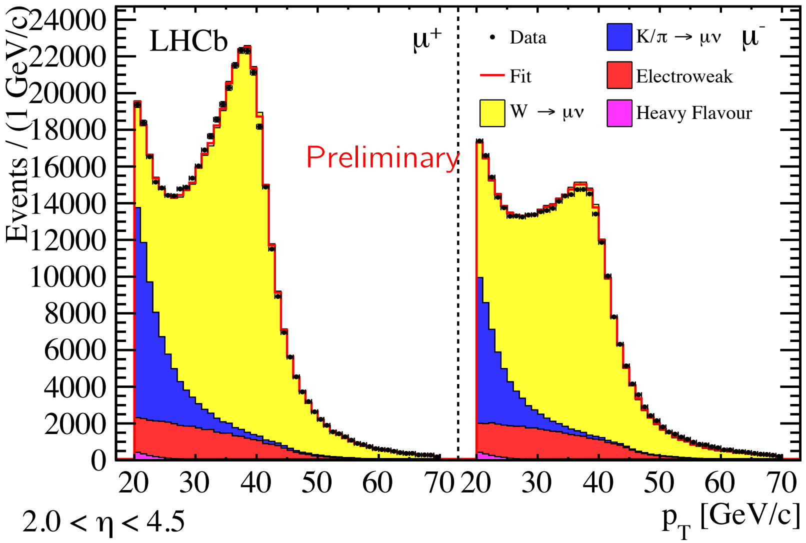


W production

Measure cross-sections + ratios

805,593 events selected

Purity ~ 77 %



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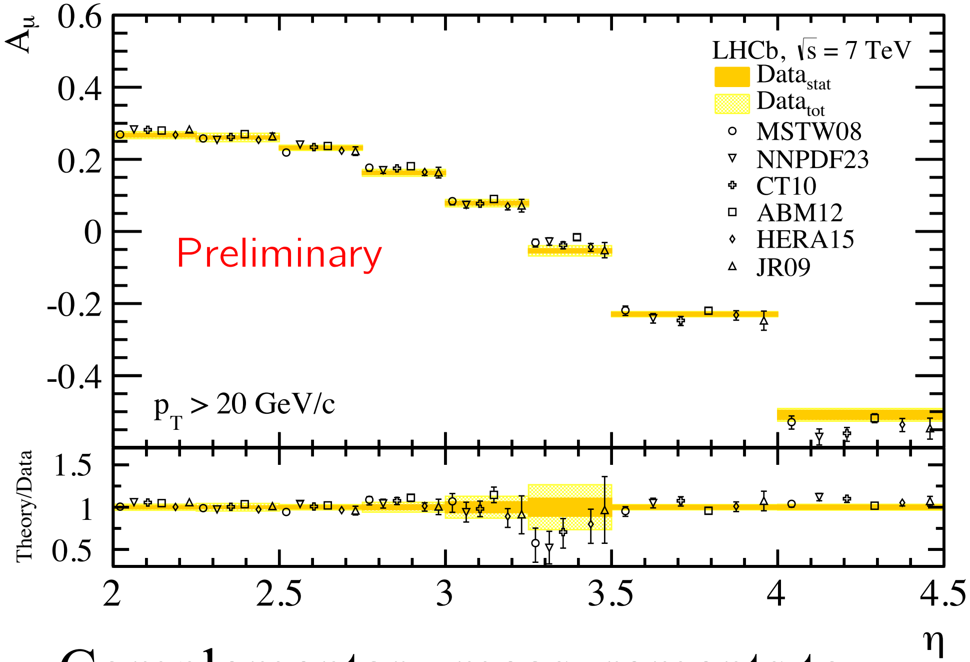
$$A_\mu = \frac{W^+ - W^-}{W^+ + W^-}$$



Complementary measurements to GPDs who go to η ~ 2

Good agreement with NNLO predictions
For variety of PDF

Run 2: New kinematic regime + higher cross-section !

Run II

Detector performed well in Run 1. Work to consolidate this for Run 2

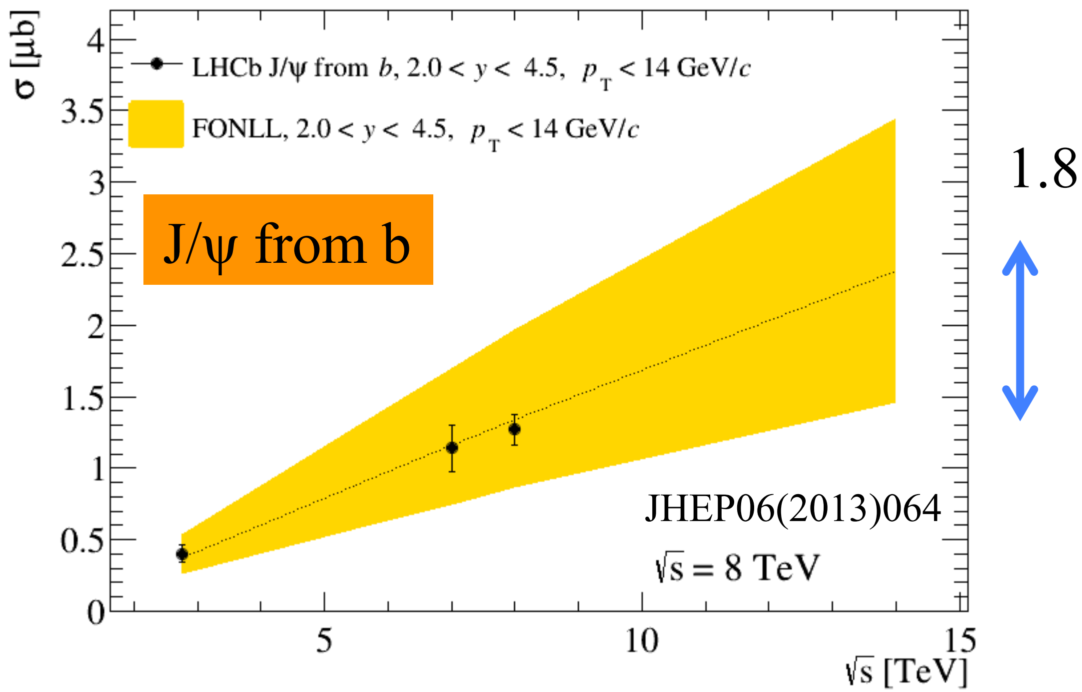
Extend physics program: Herschel forward shower counters

Main challenge:

b cross-section will go up factor by factor 1.8

Charm always benefits from more bandwidth

Want to profit from increased cross-section, and increase the physics reach



More selective trigger, using more RICH information and data parking strategy needed

Run II: Physics

- Collect around 5 - 6 fb^{-1}
- Aim for 1 fb^{-1} already in 2015
- Statistical power of data will more than double !

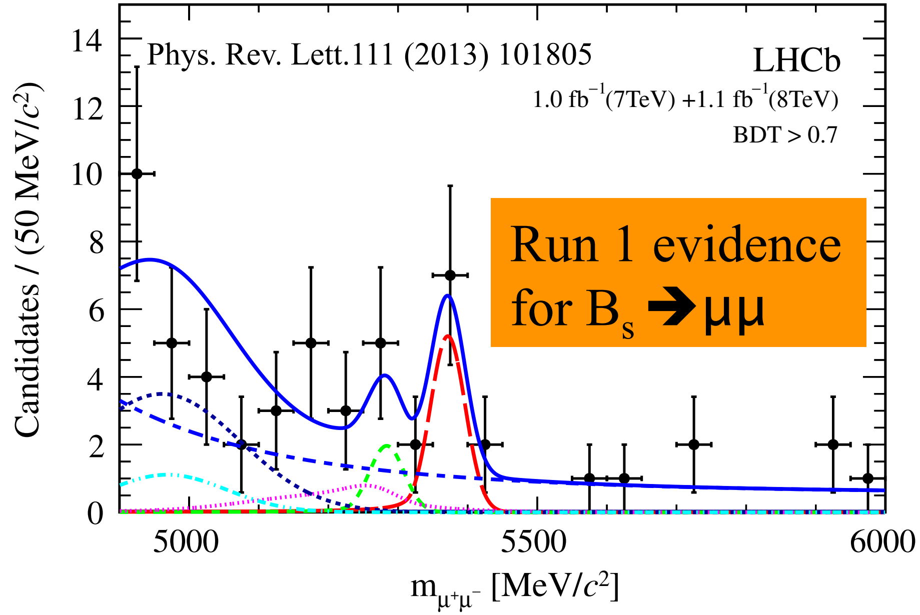
Lots of exciting physics !

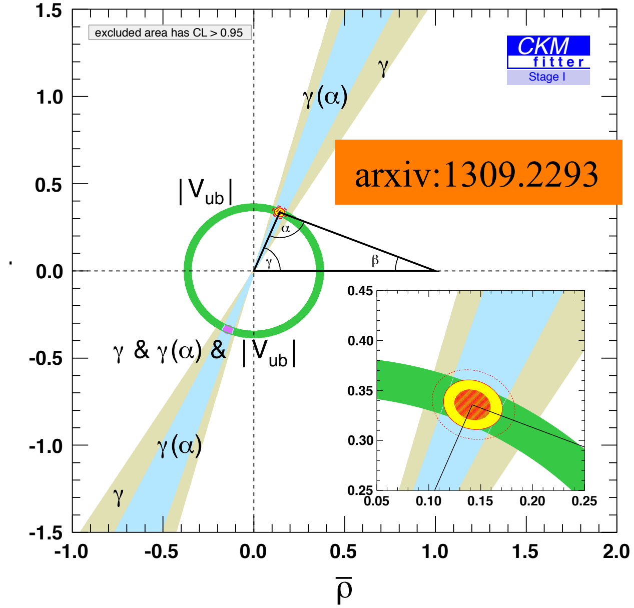
Revisit B(d,s) ➔ μμ. Is ratio consistent with SM ?

R_K and P5 anomalies in B ➔ K*ll

γ with 4° precision !

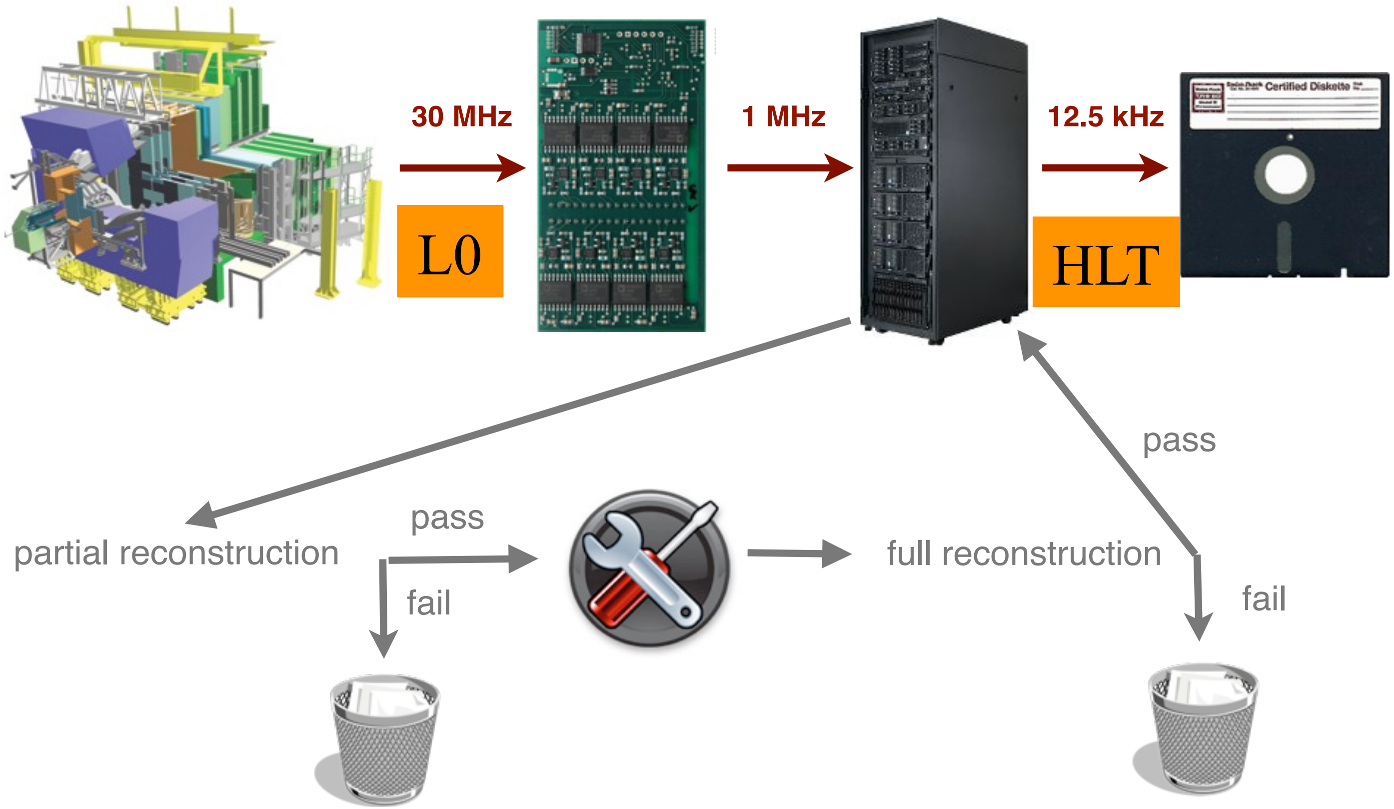
Electroweak + exotic searches





Run II: Trigger

Data from first part of fill will be buffered in HLT farm allowing time to perform online calibration and alignment of full detector. Data quality online will be close to offline – trigger selects the events we want



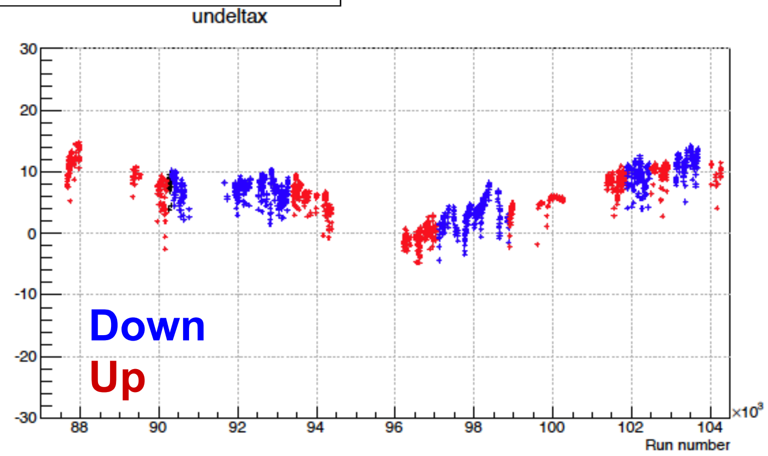
Turbo stream concept for charm: write out microDST/ntuple for analysis at trigger level

Run II

System being prepared to define how often and when alignment/calibration triggered

	Granularity	Update type	DB slice size (kB)	Events needed
VELO alignment	fill-by-fill	Update once parameters exceed tolerance	80	50k tracks traversing VELO + 50k collisions
Tracker alignment	fill-by-fill	Update once parameters exceed tolerance	250	20k $D^0 \rightarrow K\pi$
RICH Mirror Alignment	fill-by-fill	Synchronous with tracker (if needed)	207	A sample of tracks fully covering the mirror area
Muon Alignment	fill-by-fill	Synchronous with tracker (if needed)		20k $J/\psi \rightarrow \mu\mu$
RICH Refractive Index	run-by-run	run-by-run	3	tracks
HPD Image Calibration	run-by-run	run-by-run	386	tracks
OT drift time	every 1-2 weeks	Synchronous with tracker (if needed)	300	10k to monitor 100k-1M to align
Calorimeter	fill-by-fill	fill-by-fill	N/A	

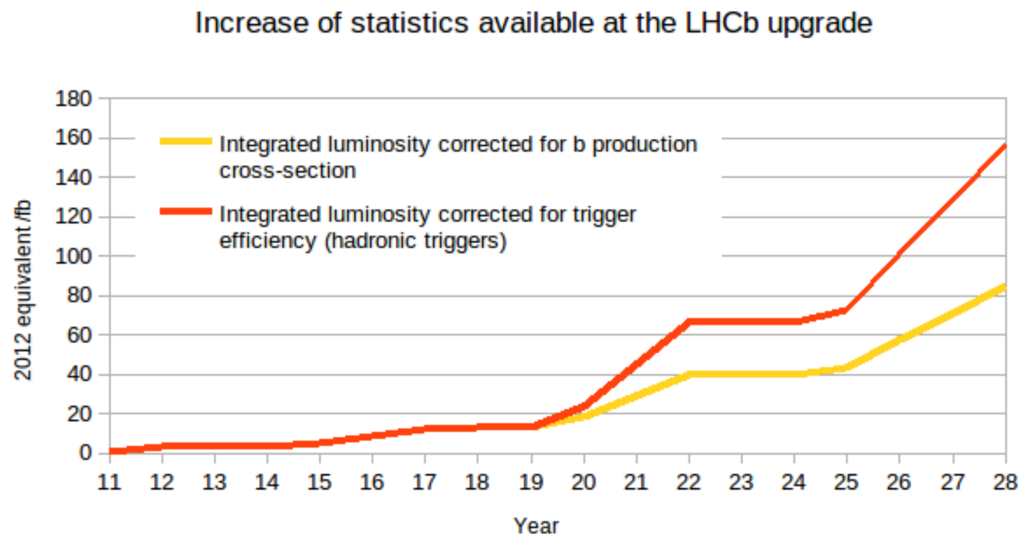
e.g. Velo half alignment stable fill-to-fill
To better than 10 μm



The Upgrade

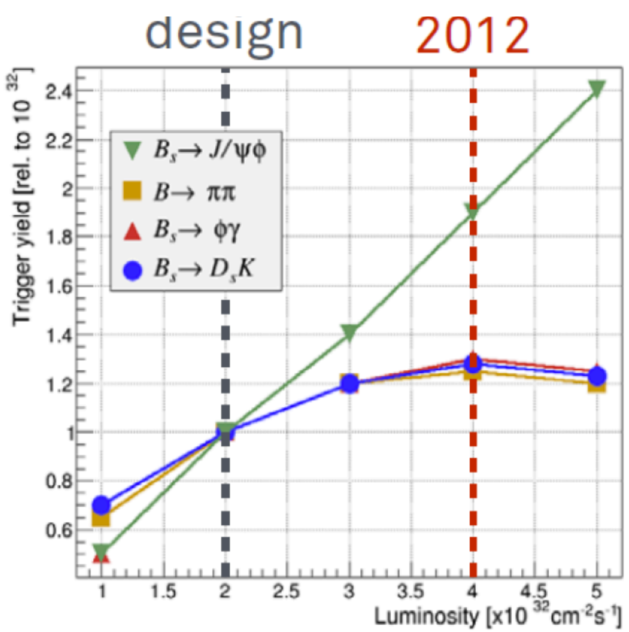
Beyond LS2 dataset doubling time lengthens

- Detector reaching end of design life
- Gain statistics run at higher luminosity (10^{33} cm^2 s^{-1})



Limited by L0 hadron trigger

- Replace front-end electronics to allow full detector readout at 40 MHz crossing rate
- Full software trigger

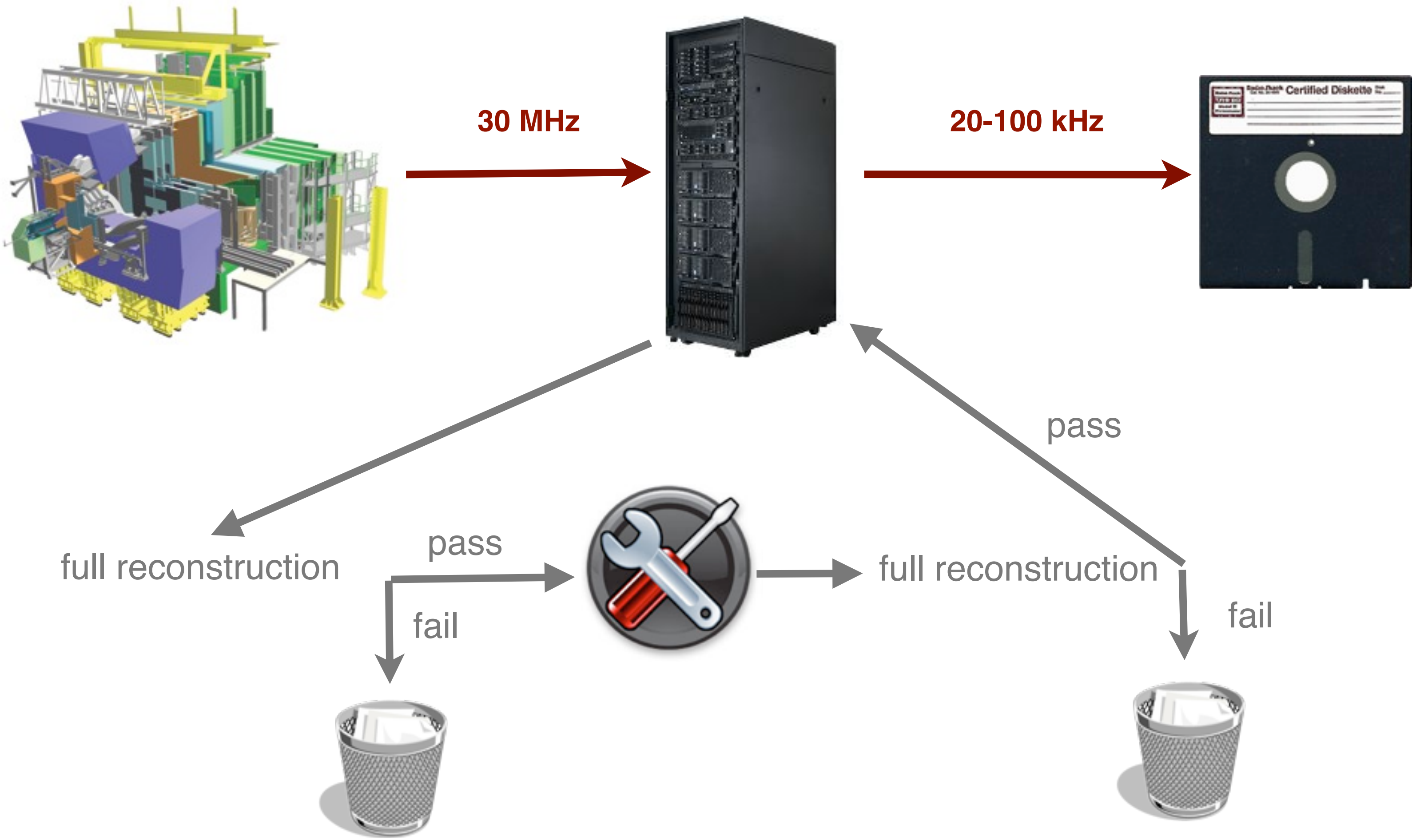


Muon trigger

Hadronic trigger

Upgrade Trigger

Readout full detector @ full collision rate, huge rates to disk

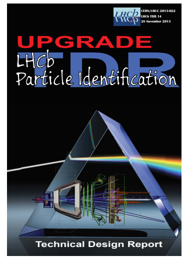


New challenges for reconstruction and computing !

Timeline

2011 Letter of Intent

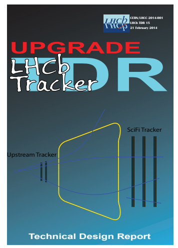
2013-2014 R+D, submission of of TDRs to LHCC



NOW

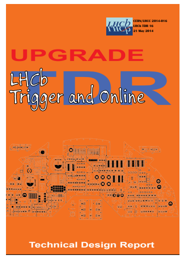
2014-017 Final R+D, production and construction

2019 LS2 Installation and commissioning

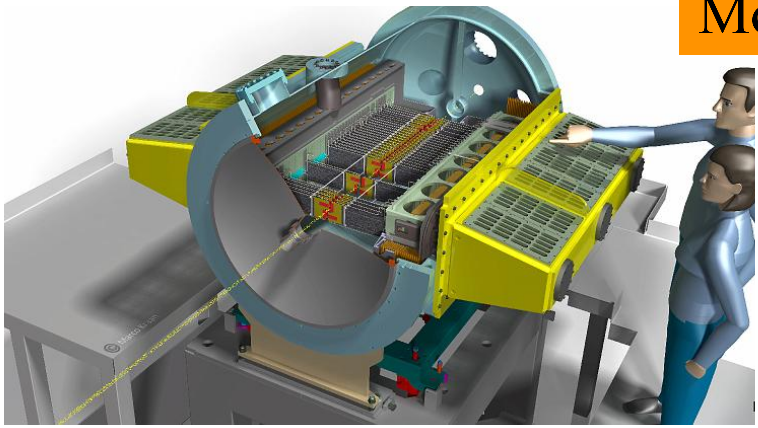


to 2030

10 years running @ luminosity of 10^{33} $cm^{-2}s^{-1}$ to collect 50 fb^{-1}



Pixel Detector



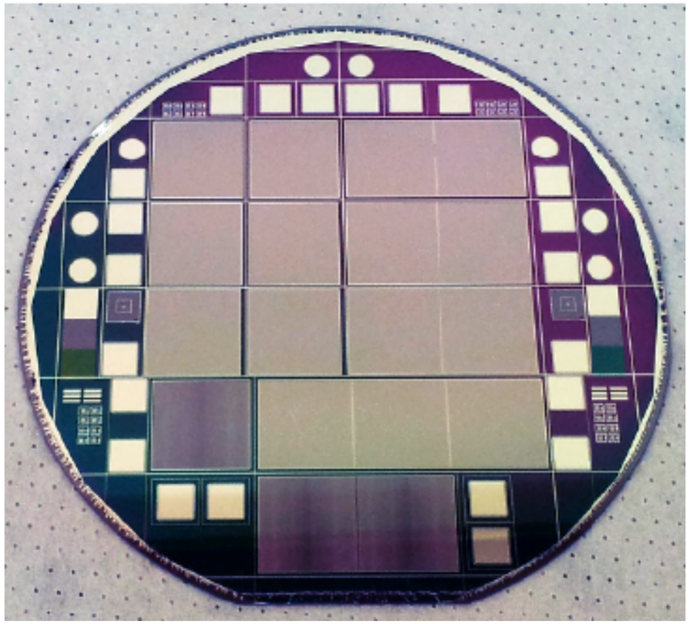
Most advanced pixel detector ever constructed

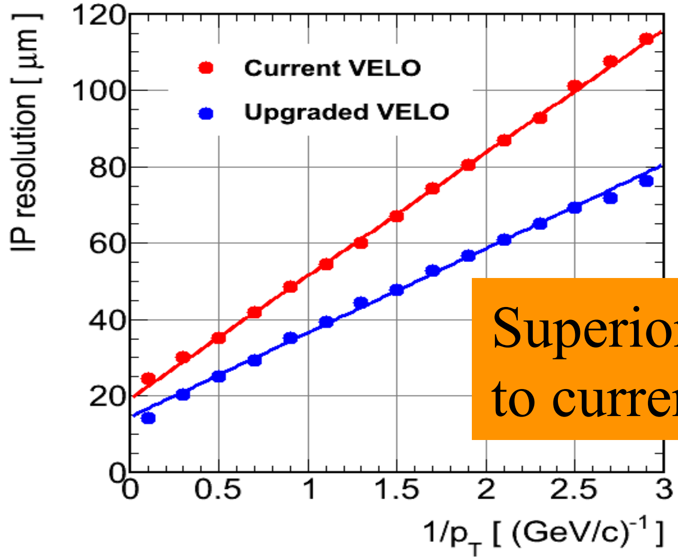
55 µm x 55 µm pixels

Radiation dose 10^{16} protons/cm^2

Detector 5 mm from LHC beam

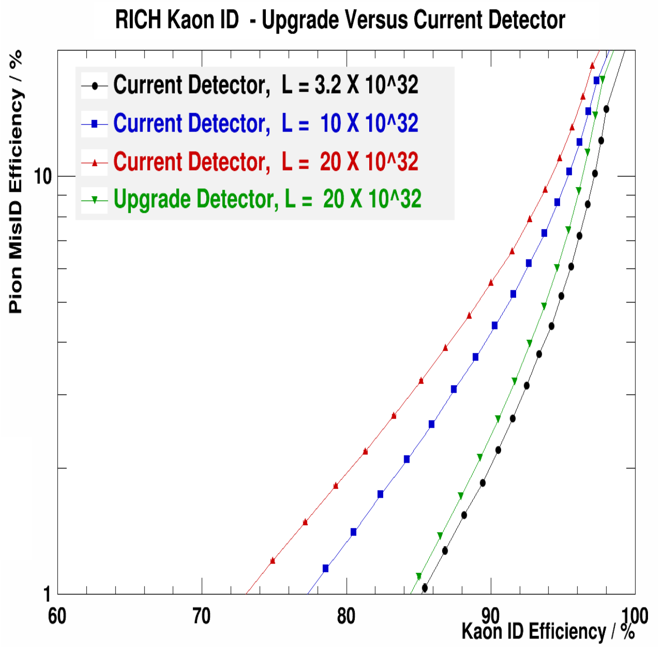
Microchannel cooling





Superior performance to current VELO

RICH

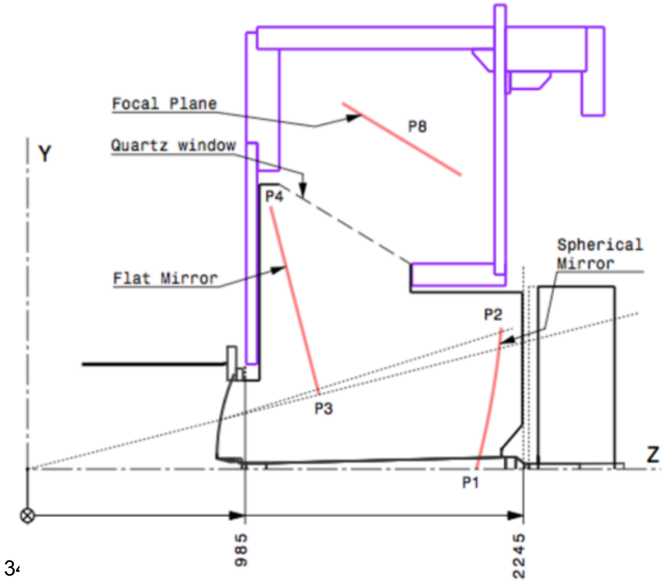


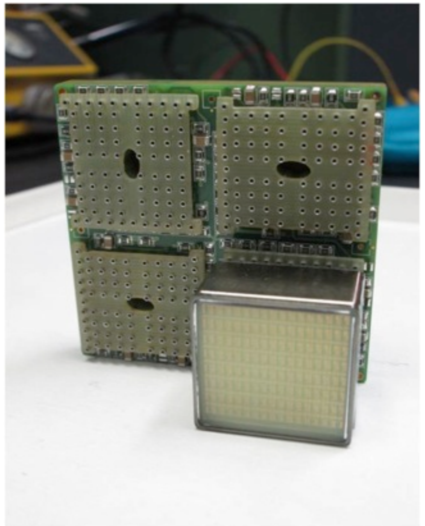
Challenge of high occupancy enviroment

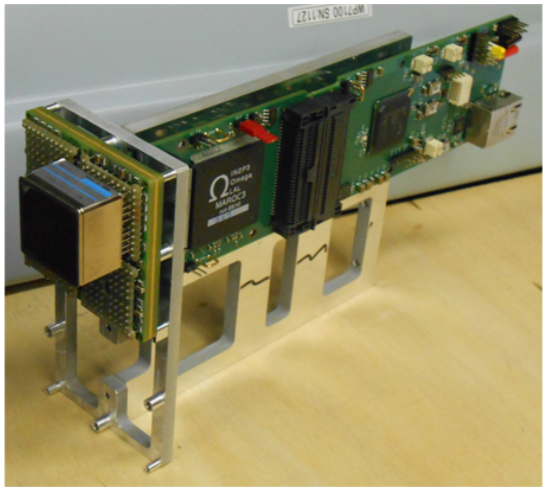
Optimized RICH 1 layout - new mechanics, mirrors, …

New photodetectors (R11265 from Hammatsu)

New readout electronics







Upgrade Reach

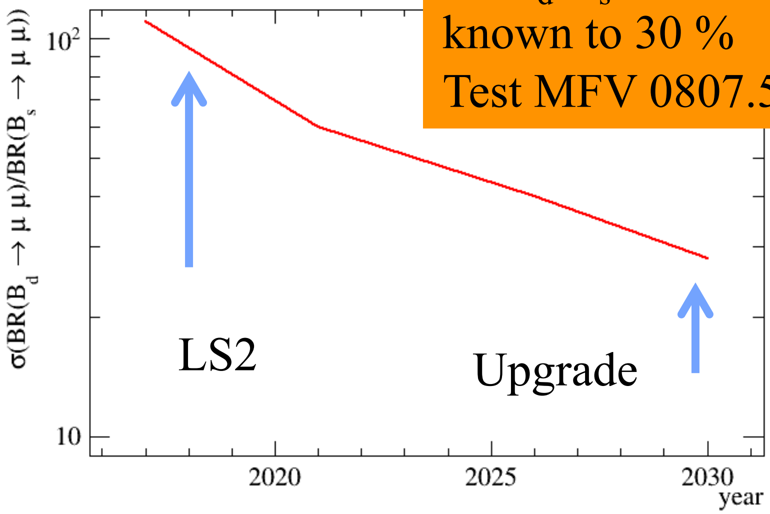
Type	Observable	Current precision	LHCb 2018	**Upgrade** ($50\,\text{fb}^{-1}$)	Theory uncertainty
B_s^0 mixing	$2\beta_s\ (B_s^0 \to J/\psi\ \phi)$	0.10 [9]	0.025	0.008	~ 0.003
	$2\beta_s\ (B_s^0 \to J/\psi\ f_0(980))$	0.17 [10]	0.045	0.014	~ 0.01
	$A_{\text{fs}}(B_s^0)$	6.4×10^{-3} [18]	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguin	$2\beta_s^{\text{eff}}(B_s^0 \to \phi\phi)$	–	0.17	0.03	0.02
	$2\beta_s^{\text{eff}}(B_s^0 \to K^{*0}\bar{K}^{*0})$	–	0.13	0.02	< 0.02
	$2\beta^{\text{eff}}(B^0 \to \phi K_S^0)$	0.17 [18]	0.30	0.05	0.02
Right-handed currents	$2\beta_s^{\text{eff}}(B_s^0 \to \phi\gamma)$	–	0.09	0.02	< 0.01
	$\tau^{\text{eff}}(B_s^0 \to \phi\gamma)/\tau_{B_s^0}$	–	5 %	1 %	0.2 %
Electroweak penguin	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\,\text{GeV}^2/c^4)$	0.08 [14]	0.025	0.008	0.02
	$s_0\, A_{\text{FB}}(B^0 \to K^{*0}\mu^+\mu^-)$	25 % [14]	6 %	2 %	7 %
	$A_{\text{I}}(K\mu^+\mu^-; 1 < q^2 < 6\,\text{GeV}^2/c^4)$	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}	–

LHCB-TDR-012

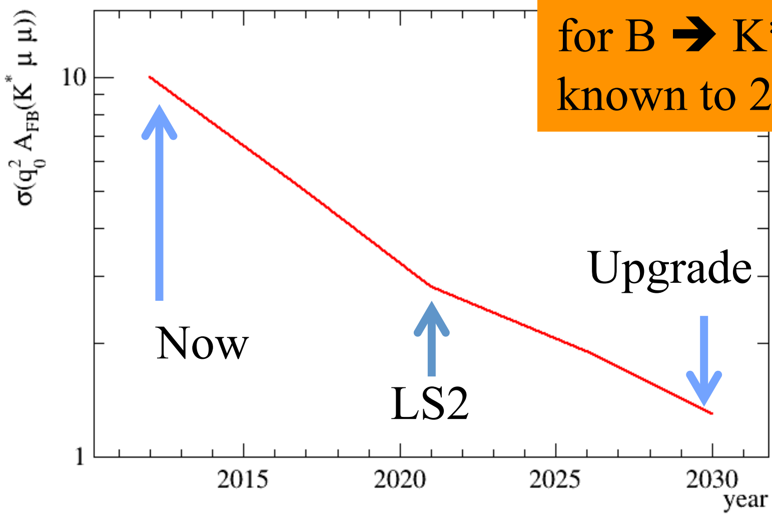
Upgrade Reach

Rare decays

rel B_d/B_s BR
known to 30 %
Test MFV 0807.5039

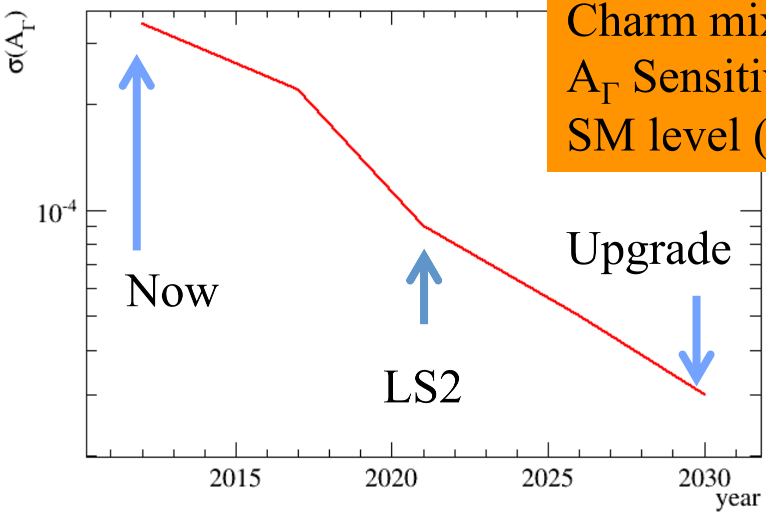


Zero crossing
for B ➔ K*μμ
known to 2 %



Charm

Charm mixing
A_Γ Sensitivity at
SM level (10^{-4})

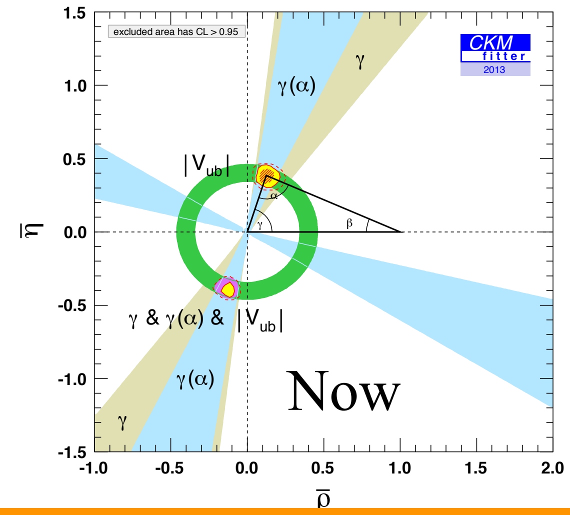


50 billon
reconstructed
charm decays !
Challenge SM
predictions

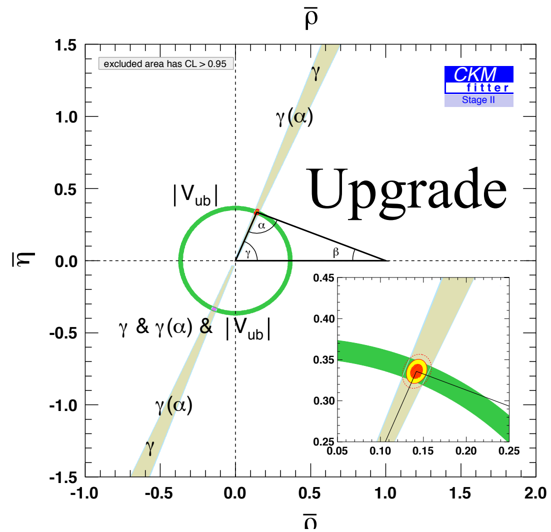
Upgrade Reach

arXiv:1309.2293

Angle γ

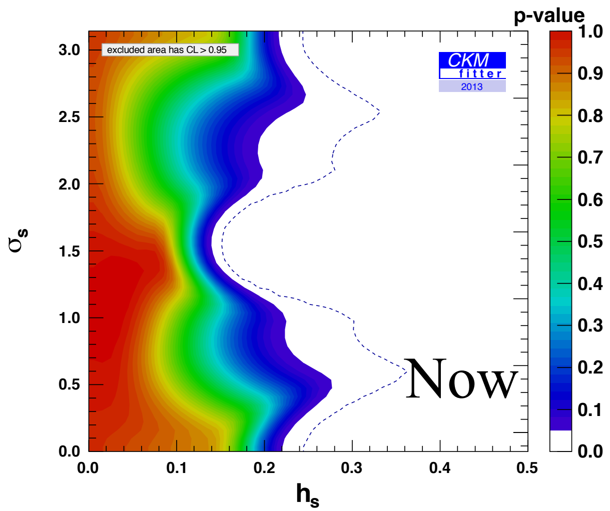


$\gamma \sim 1^{o}$

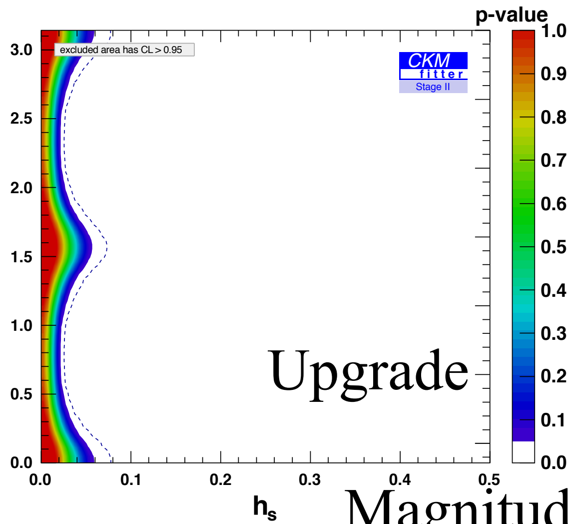


Assuming SM

New Physics in B_s mixing



$\phi_s \sim 0.2^{o}$



Phase NP

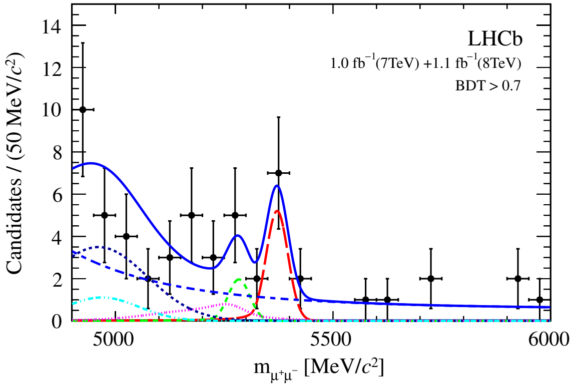
Magnitude NP

Summary

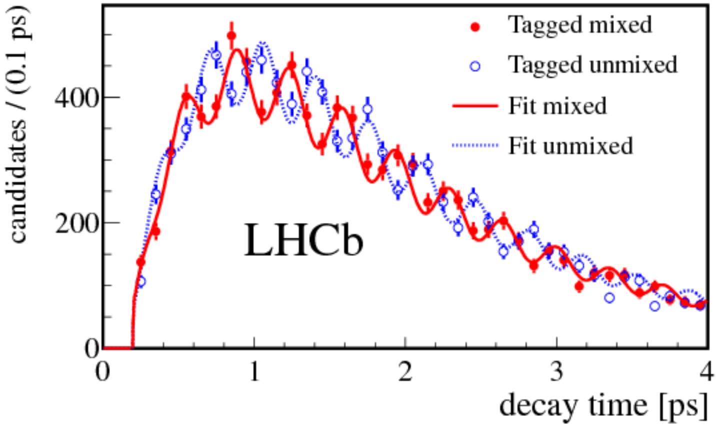
- LHCb had a very successful Run 1
  - 197 papers so far across wide range of topics
  - More to come updates on a^f_s , ϕ_s , sin2β, γ , ΔA_{CP}, B->$K^*\mu\mu$,…
- Looking forward to exciting Run 2
  - Collect 5 fb^{-1} with twice b cross-section
    - ~ 12.5 kHz rate to disk, twice Run 1 rate
  - Double precision. Do anomalies from Run 1 persist ?
  - Online alignment and calibration in real time
- Upgrade for Run 3 to collect 50 fb^{-1} of data
  - Running at 10^{33} cm^2 s^{-1}
  - Readout of full detector at 40 MHz, 100 kHz to disk
  - Order of magnitude increase in precision

Summary

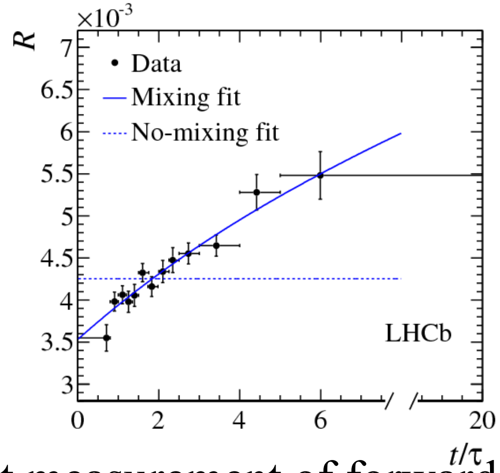
Evidence for $B_s \rightarrow \mu\mu$



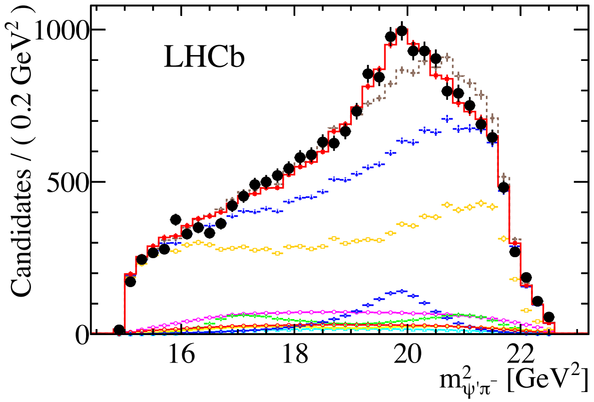
Best measurements of Bd/Bs mixing



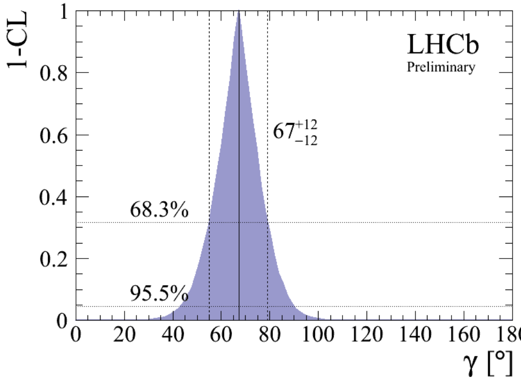
5σ observation charm mixing



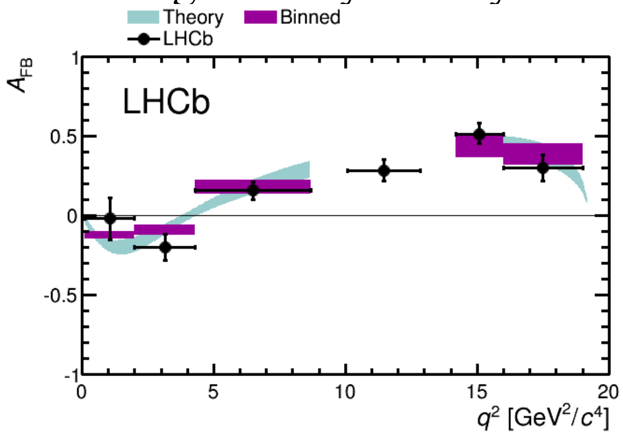
Firm evidence of 4 quark state



Most precise measurement γ



Best measurement of forward background symmetry in B

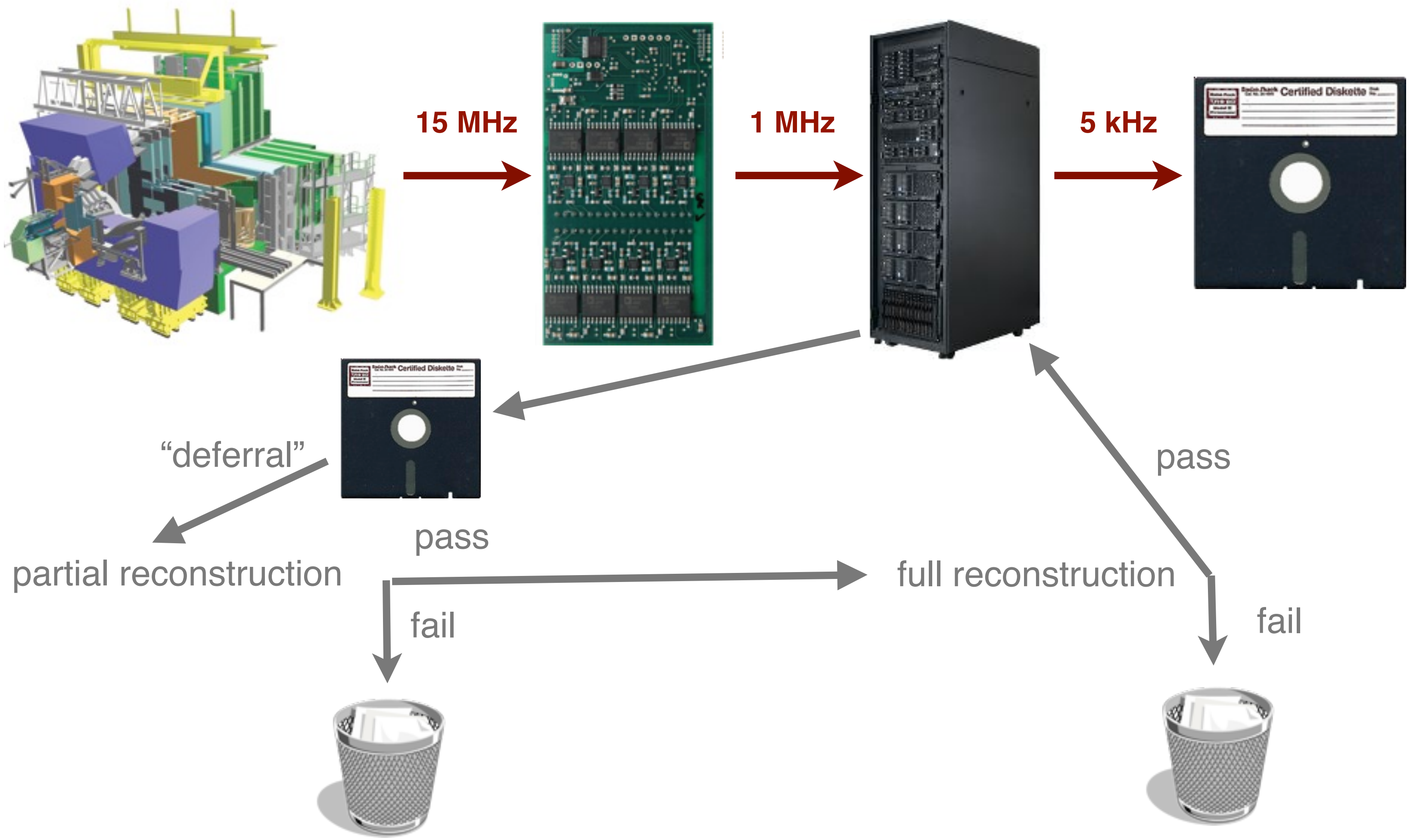


+ observation of several new particles + 50 new decay modes

Backup

Run 1: Trigger

LHCb Trigger Group, JINST 8, P04022 [arXiv:1211.3055]



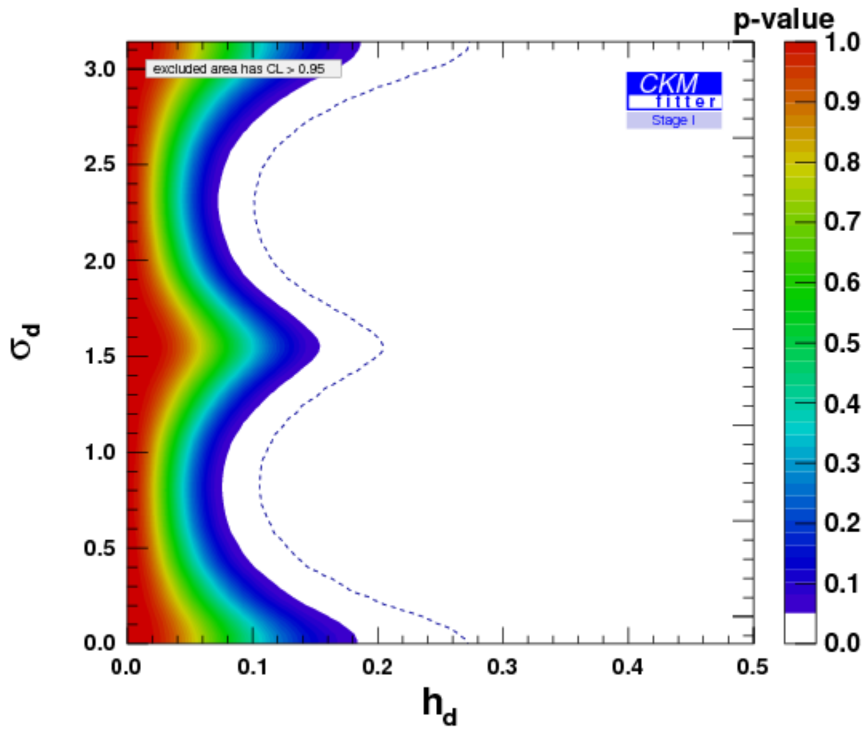
Upgrade

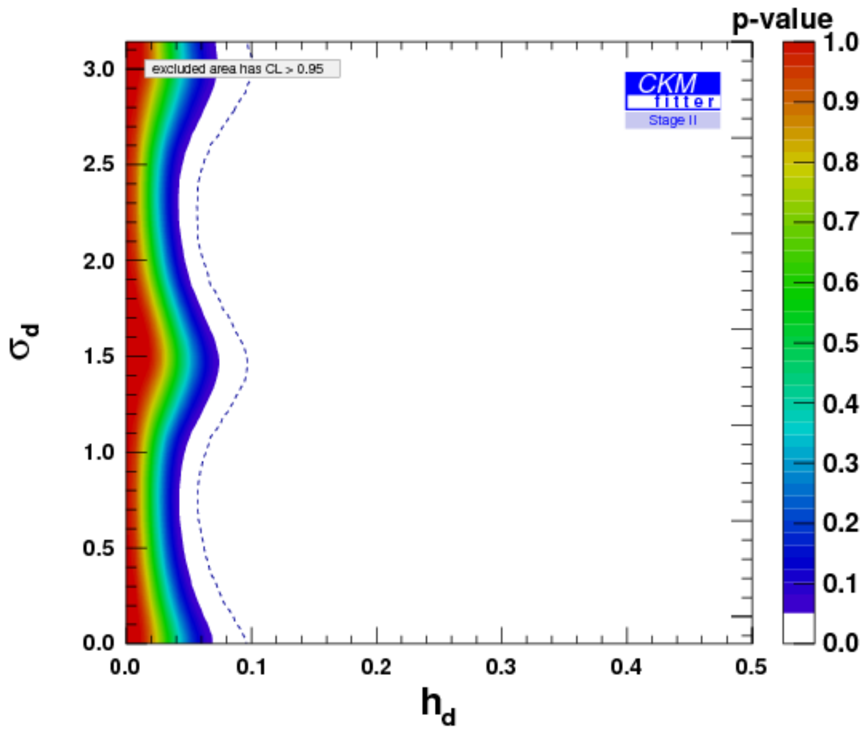
Numbers prepared for ECFA workshop

			LHC era		HL-LHC era	
		Run 1	Run 2	Run 3	Run 4	Run 5+
$\frac{\mathcal{B}(B^0\to\mu^+\mu^-)}{\mathcal{B}(B_s^0\to\mu^+\mu^-)}$	CMS	$>100\%$	71%	47%	...	21%
	LHCb	220%	110%	60%	40%	28%
$q_0^2\ A_{\rm FB}(K^{*0}\mu^+\mu^-)$	LHCb	10%	5%	2.8%	1.9%	1.3%
	Belle II	—	50%	7%	5%	—
$\phi_s(B_s^0\to J/\psi\phi)$	ATLAS	0.11	0.05–0.07	0.04–0.05	...	0.020
	LHCb	0.05	0.025	0.013	0.009	0.006
$\phi_s(B_s^0\to\phi\phi)$	LHCb	0.18	0.12	0.04	0.026	0.017
γ	LHCb	7°	4°	1.7°	1.1°	0.7°
	Belle II	—	11°	2°	1.5°	—
$A_\Gamma(D^0\to K^+K^-)$	LHCb	3.4×10^{-4}	2.2×10^{-4}	0.9×10^{-4}	0.5×10^{-4}	0.3×10^{-4}
	Belle II	—	18×10^{-4}	$4–6\times10^{-4}$	$3–5\times10^{-4}$	—
$t\to qZ$	ATLAS	...	...	23×10^{-5}	...	$4.1–7.2\times10^{-5}$
	CMS	100×10^{-5}	...	27×10^{-5}	...	10×10^{-5}
$t\to q\gamma$	ATLAS	...	...	7.8×10^{-5}	...	$1.3–2.5\times10^{-5}$

https://twiki.cern.ch/twiki/bin/view/ECFA/PhysicsGoalsPerformanceReachHeavyFlavour

Bd mixing in generic models





Run I era

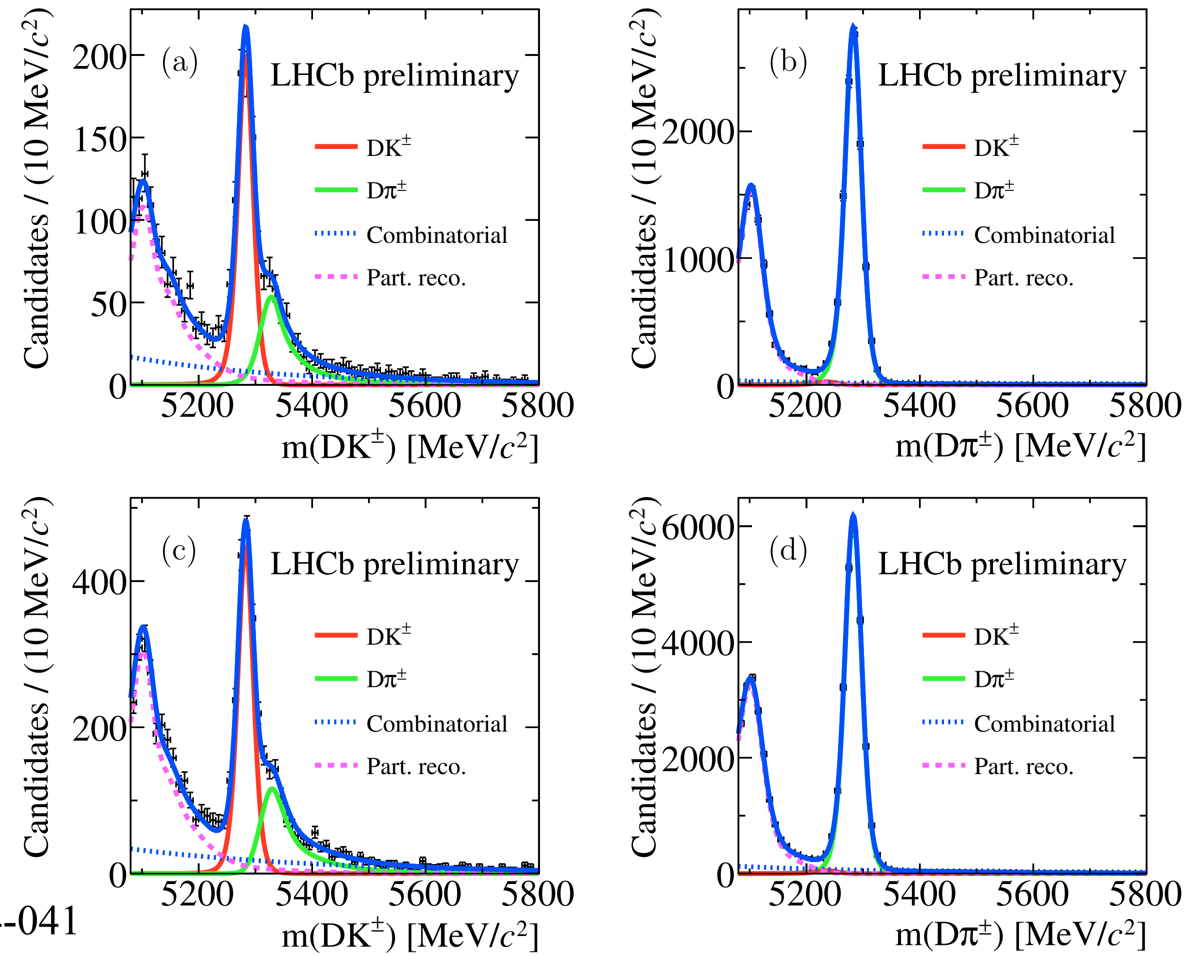
Run II era

The angle γ

Lots of other beautiful results coming out now or soon, e.g. $3fb^{-1}$ update for $B \rightarrow DK$ with $D \rightarrow K_s \pi^+\pi^-$

K_s decay in VELO

K_s decay after VELO



LHCb-PAPER-2014-041

Upgrade Reach

Upgraded detector will have a rich physics program building on studies with current detector

- Precision tests of CP violation and CKM parameters in b decays
- Rare b and c decays
- High statistics charm
- Spectroscopy and b-hadron measurements
- Electroweak
- Quarkonia
- Exotic searches

Full software trigger. Flexible response to discoveries

Run II

Assume 1870 colliding bunches at $\mu \sim 1.35$ (2012 was $\mu \sim 1.6$)

Allowing for increased multiplicity data rates similar to 2012

As in 2012 will level luminosity

Aim to collect 5 fb^{-1} of data at luminosity of 4×10^{32} $cm^{-2}s^{-1}$