Marina Artuso

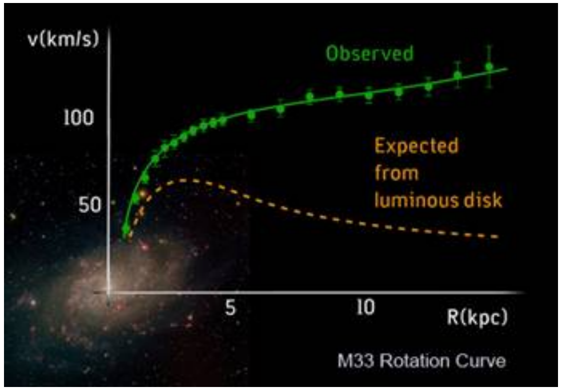
New Physics from beauty, charm and τ decays

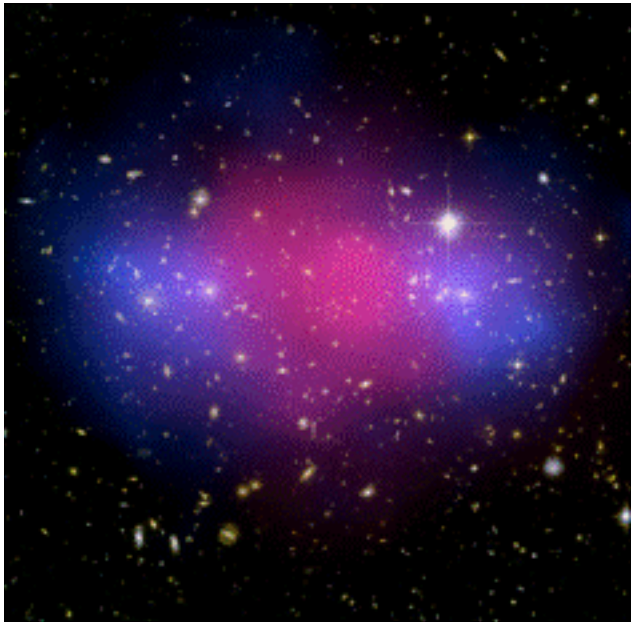
the LHC perspective

M. Artuso, IF Meeting
Argonne, 26 April, 2013

Puzzles that motivate new physics

- Dark Matter and dark energy

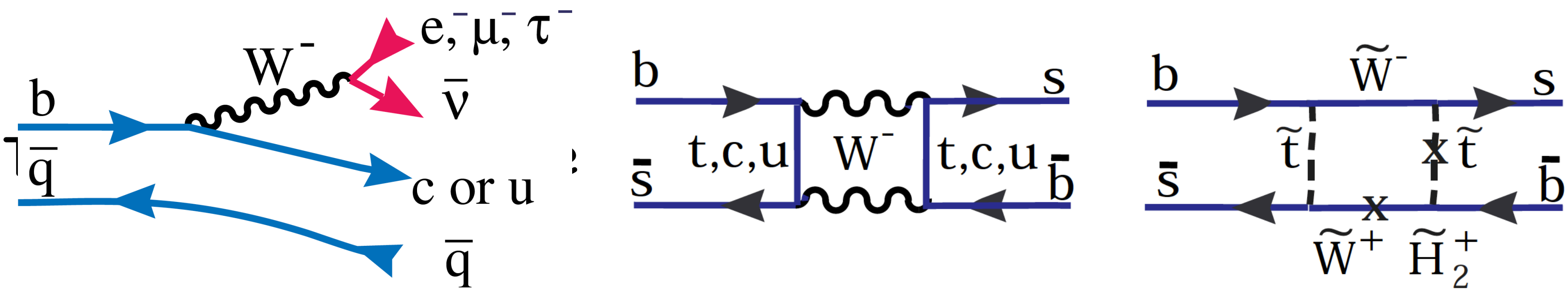




- Hierarchy Problem: We don't understand how we get from the Planck scale of Energy ~10^{19} GeV to the Electroweak Scale ~100 GeV without "fine tuning" quantum corrections
- Baryon asymmetry of the universe

Limits on New Physics

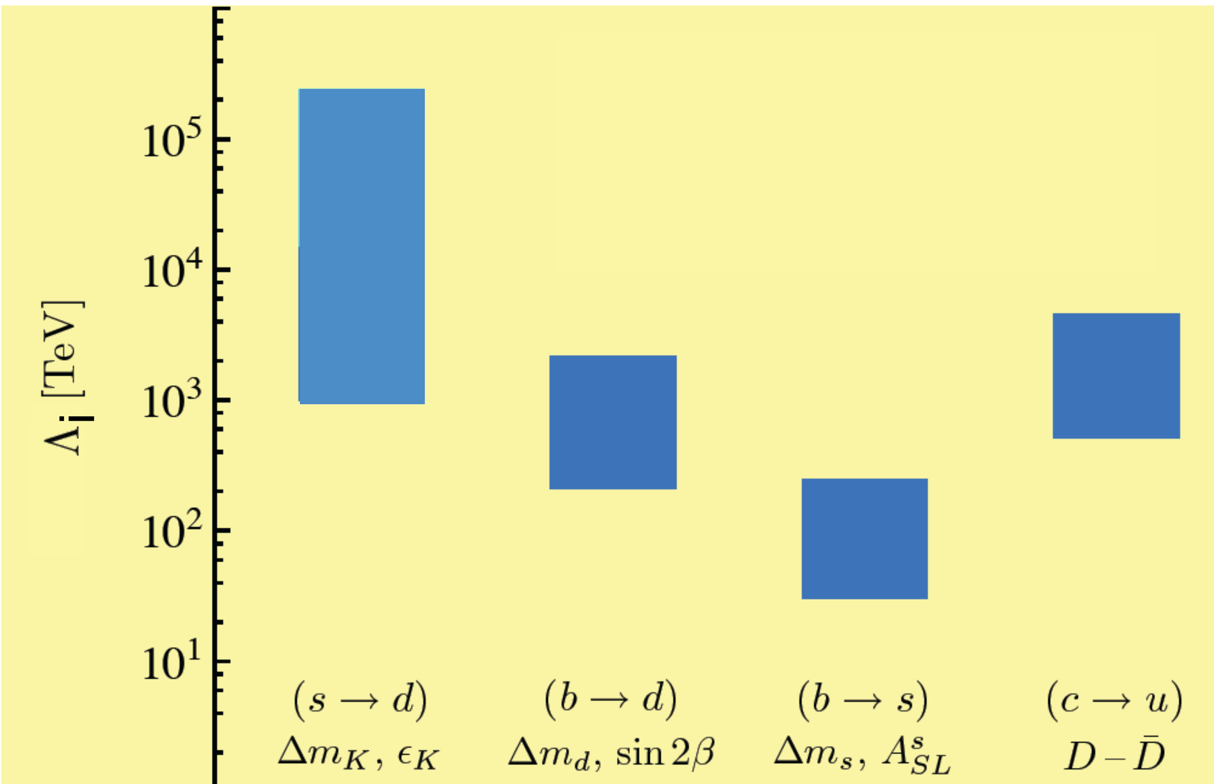
- How can new physics manifest itself in beauty decays?
- One hypothesis: assume that tree level diagrams are dominated by SM and loop diagrams could contain NP



Flavor as a High Mass Probe

$$L_{\text{eff}} = L_{\text{SM}} + \frac{c_i}{\Lambda_i^2} O_i$$

- Already excluded ranges

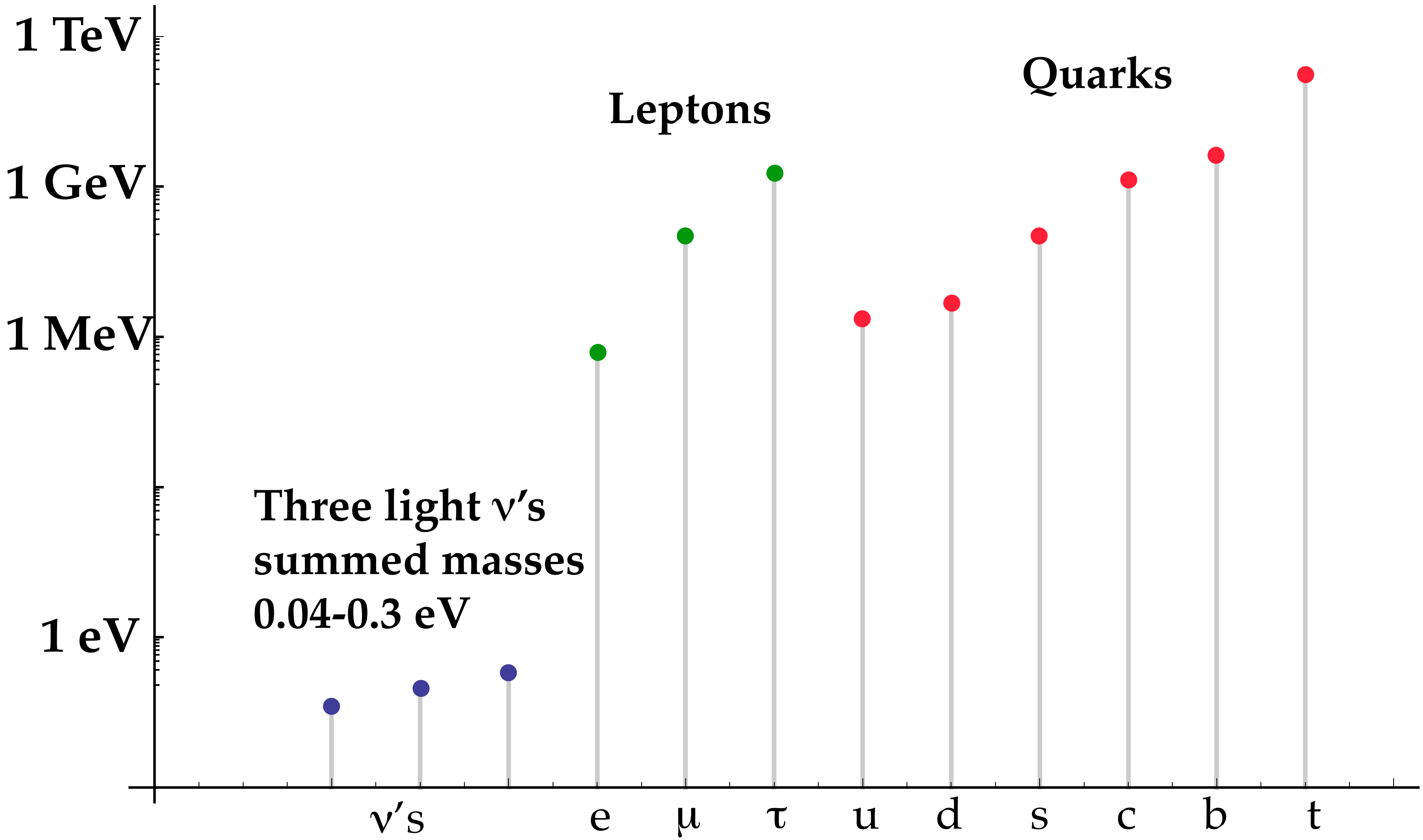


Ways out

1. New particles have large masses >>1 TeV
2. New particles have degenerate masses
3. Mixing angles in new sector are small, same as in SM (MFV)
4. The above already implies strong constrains on NP

See: Isidori, Nir & Perez arXiv:1002.0900; Neubert EPS 2011 talk

Masses

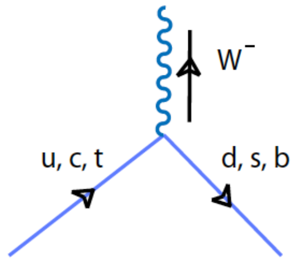


12 orders of magnitude differences not explained; t quark as heavy as Tungsten

Quark Mixing & CKM Matrix

- In SM charge -1/3 quarks (d, s, b) are mixed
- Described by CKM matrix (also ν are mixed)

$$V_{\left(\frac{2}{3},-\frac{1}{3}\right)} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

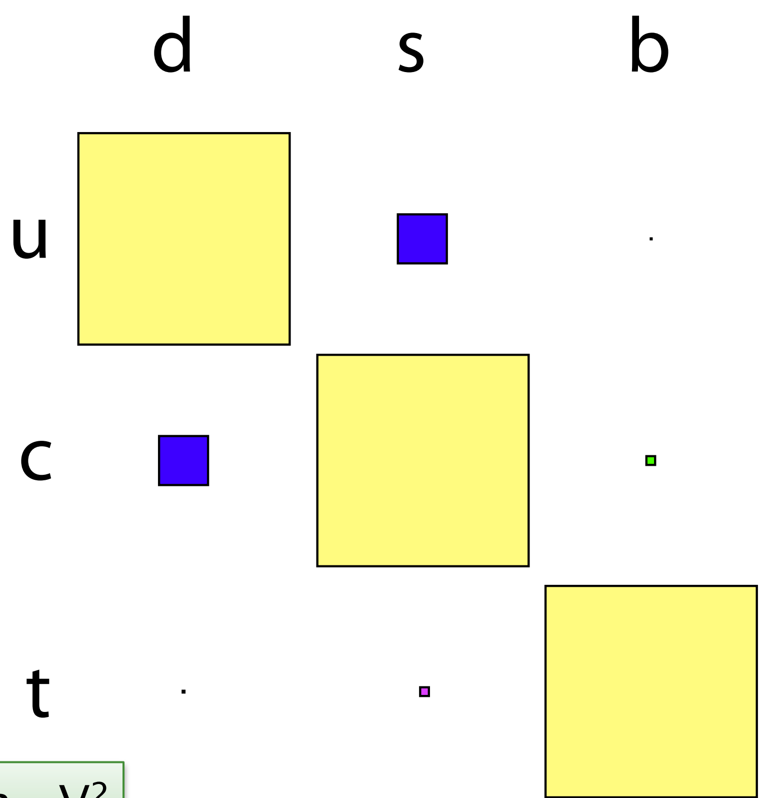


$$= \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

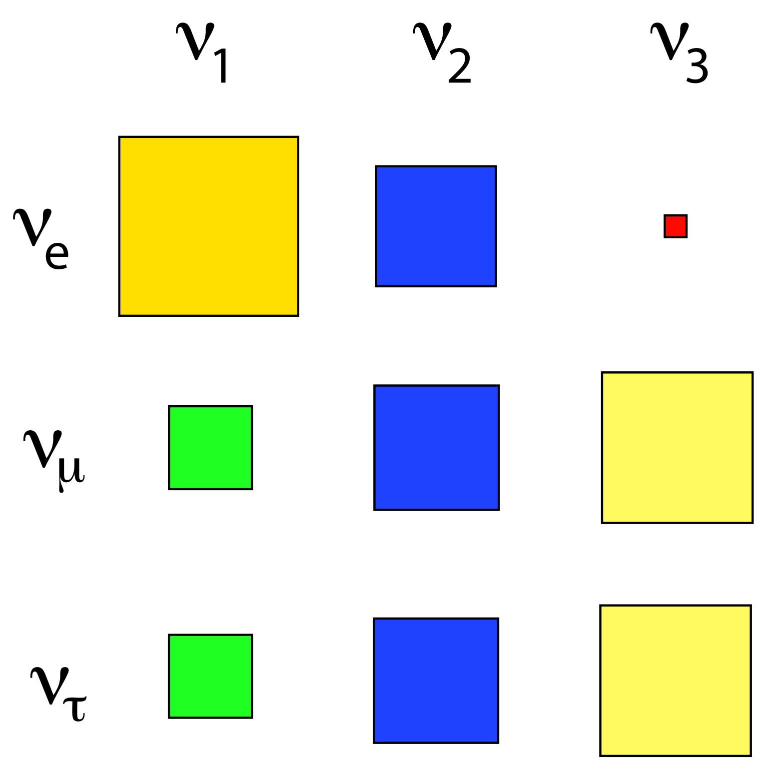
- λ=0.225, A=0.8, constraints on ρ & η
- These are fundamental constants in SM

CKM vs. PMNS

CKM



PMNS

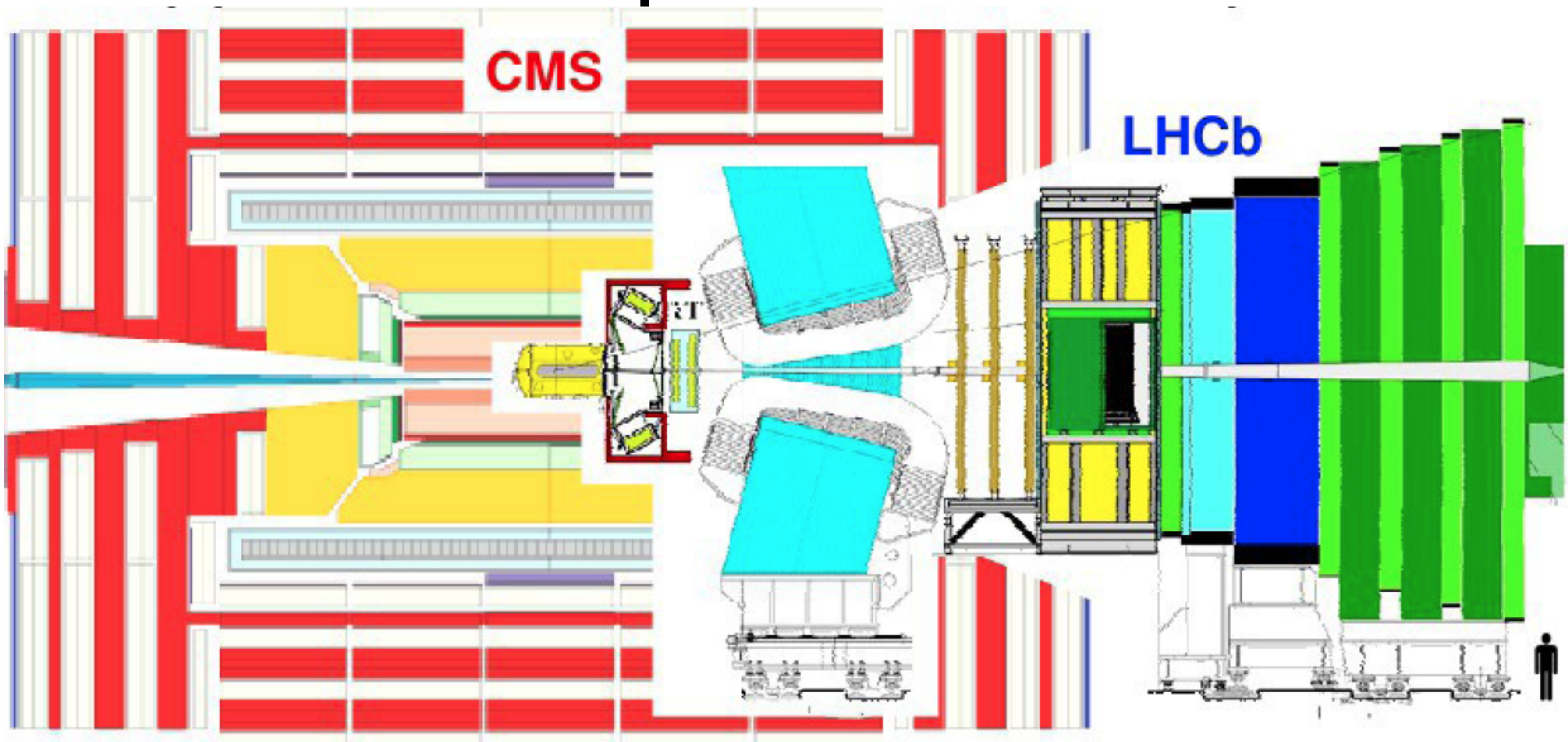


Area ~V^2

Why these values? Are the two related? Are they related to masses?

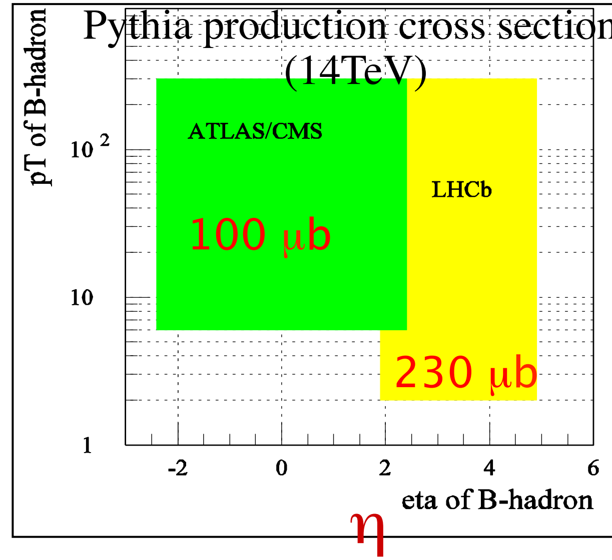
LHCb and ATLAS/CMS

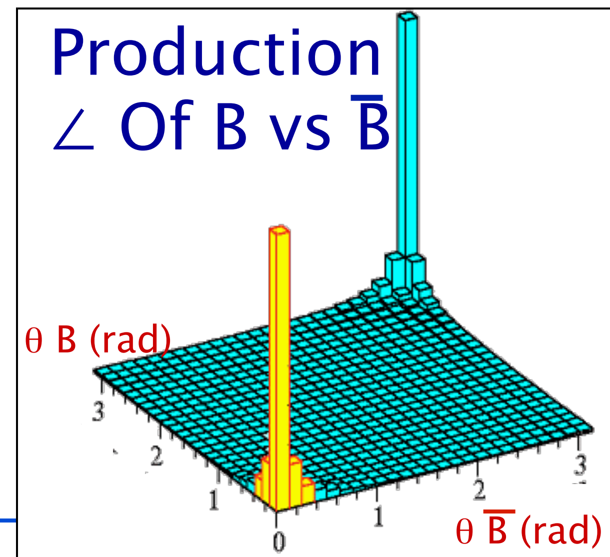
- Complementary to ATLAS & CMS
- Much less expensive



The Forward Direction at the LHC

- In the forward region at LHC the $b\bar{b}$ production σ is large
- The hadrons containing the b & $\bar{b}$ quarks are both likely to be in the acceptance. Essential for "flavor tagging"
- LHCb uses the forward direction where the B's are moving with considerable momentum ~100 GeV, thus minimizing multiple scattering
- At L=2x10^{32}/cm^2/s, we get 10^{12} B hadrons in 10^7 sec



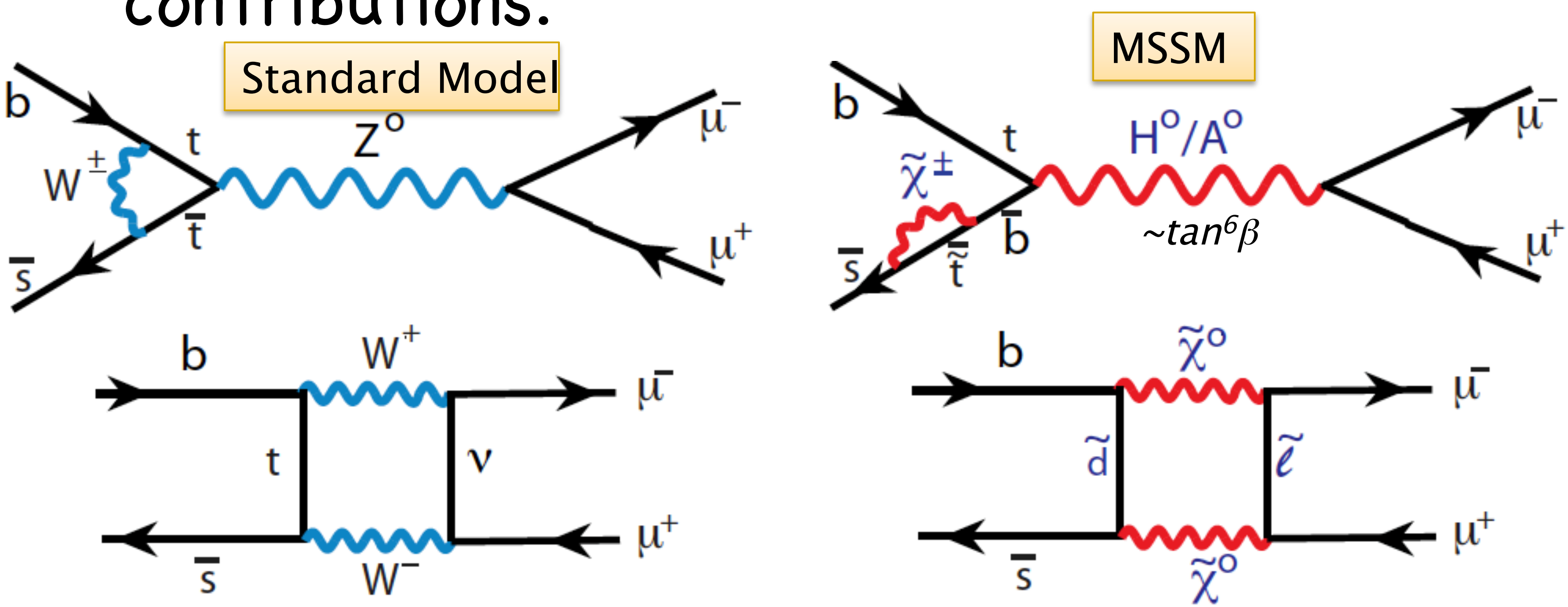


From exploration (now)

TO PRECISION STUDIES: SOME EXAMPLES

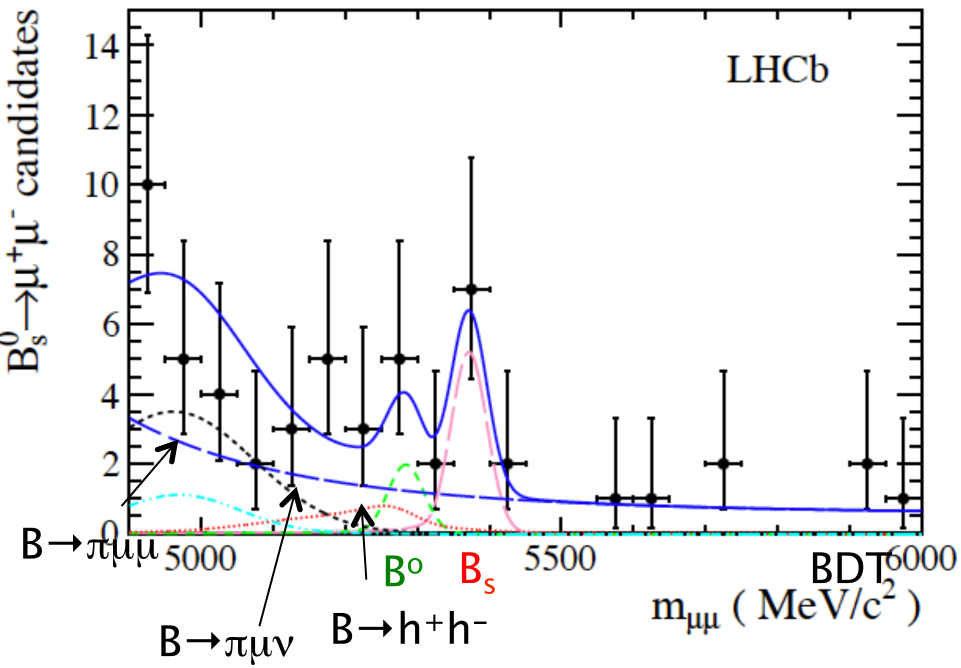
$B_s \rightarrow \mu^+\mu^-$

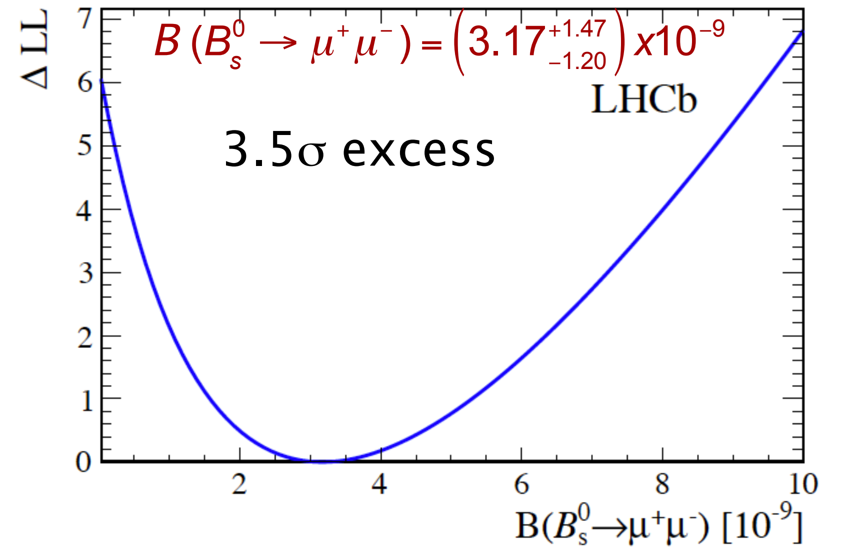
- SM branching ratio is $(3.2\pm0.2)\times10^{-9}$ [Buras arXiv:1012.1447], NP can make large contributions.



- Many NP models possible, not just Supersymmetry

Evidence for $B_s \to \mu^+\mu^-$

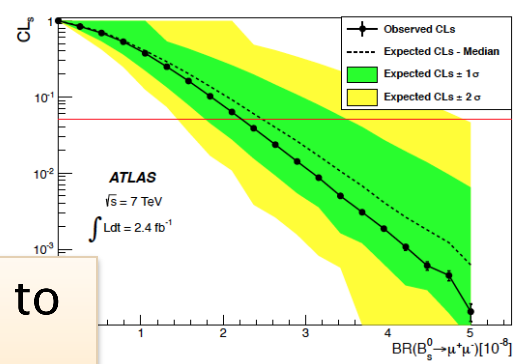




LHCb 1.0 fb^{-1} (2011) + 1.1 fb^{-1} (2012)

ATLAS 2011

- Set limit on BR using CLs approach
- BR(Bs→μμ) < 2.2 × 10^{-8} (95% C.L.)



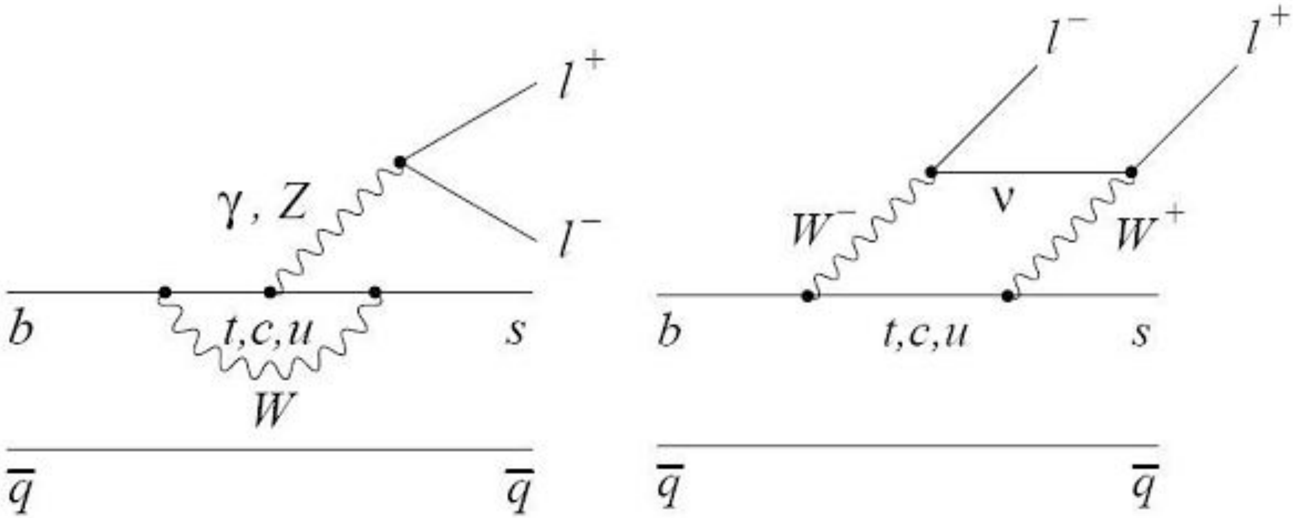
CMS 2011

upper limit (95%CL)	observed	(median) expected
$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	7.7×10^{-9}	8.4×10^{-9}
$\mathcal{B}(B^0 \to \mu^+\mu^-)$	1.8×10^{-9}	1.6×10^{-9}

Next challenge $B^0 \to \mu^+\mu^-$ LHCb Upgrade expected to measure ratio B0/Bs ~35%

$B \to K^{(*)} l^+ l^-$

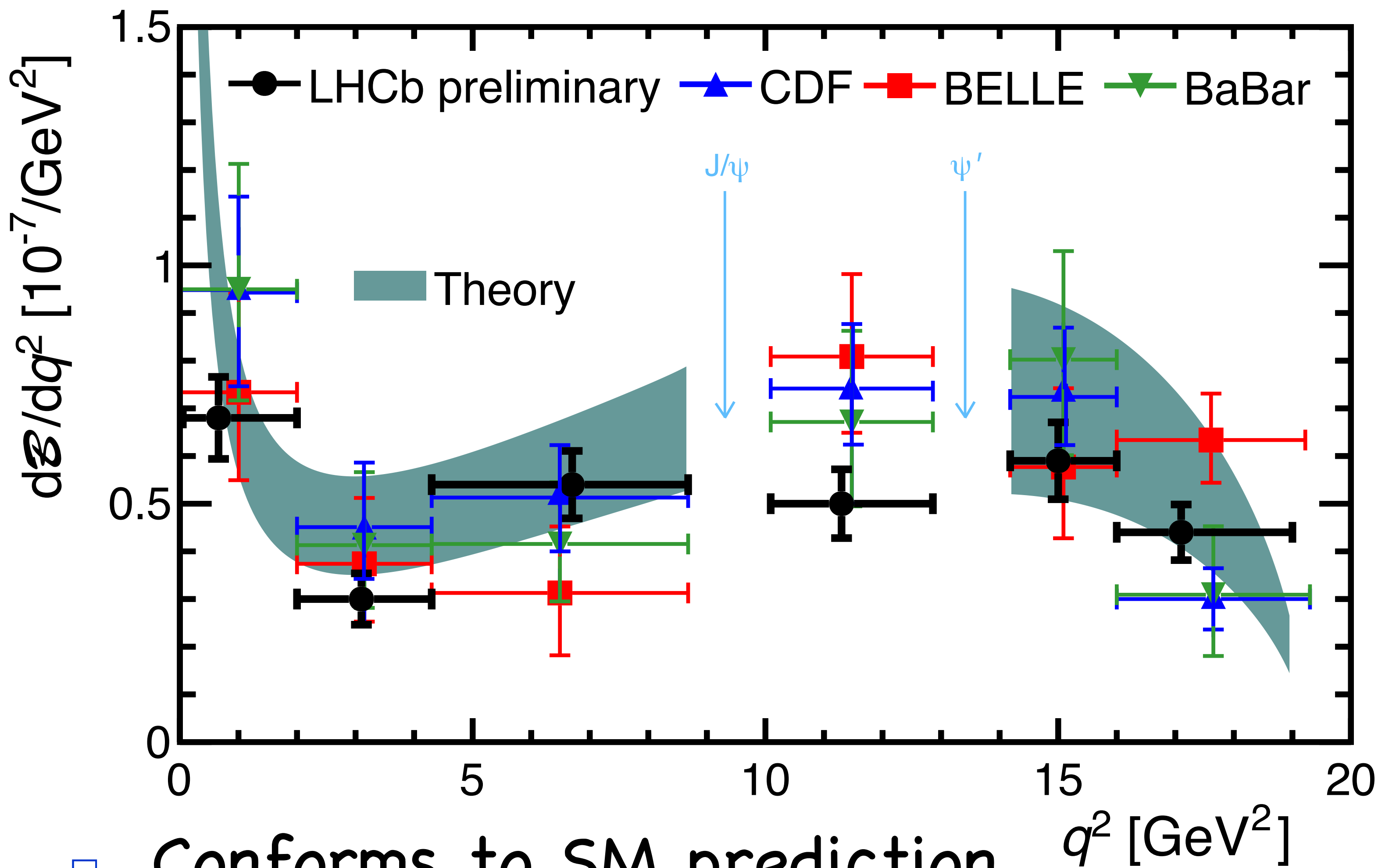
- Similar to $K^*\gamma$, but more decay paths



+ new particles in loops

- Several variables can be examined, e.g. muon forward-backward asymmetry, A_{FB} is well predicted in SM

$B^o \to K^{*o} l^+ l^-$

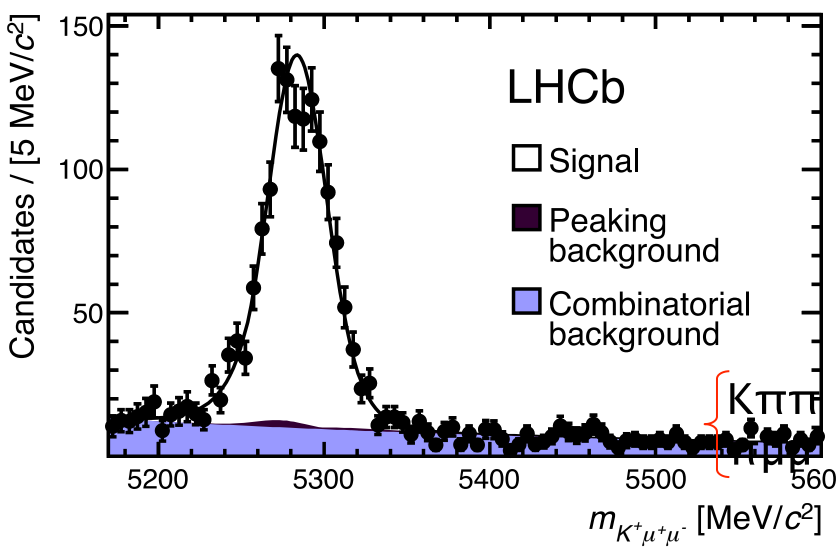


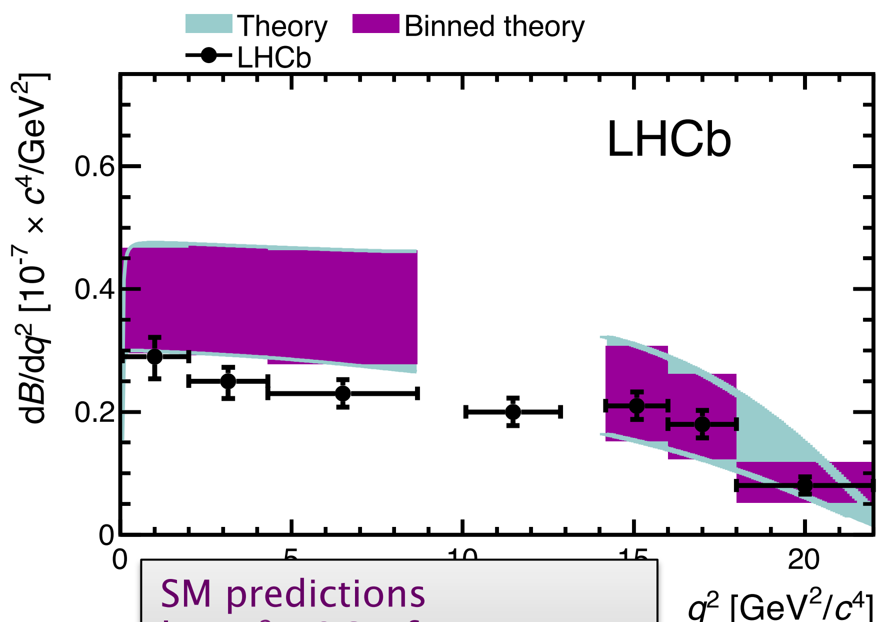
- Conforms to SM prediction

Differential BF for $B^+ \to K^+\mu^+\mu^-$

JHEP 02 (2013) 105

- The measurement is performed in 7 q^2 bins $0.05 < q^2 < 22$ GeV^2





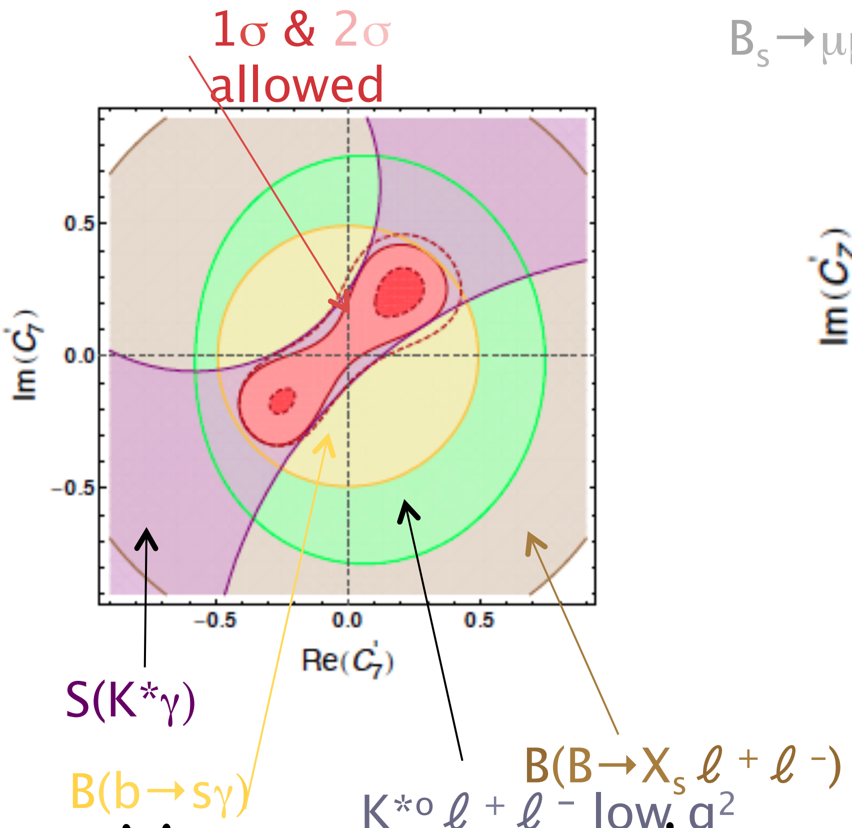
SM predictions
low q^2: QCD factorization
high q^2: OPE.

Result is consistently below the SM in low q^2. Agrees with and more precise with results from other experiments

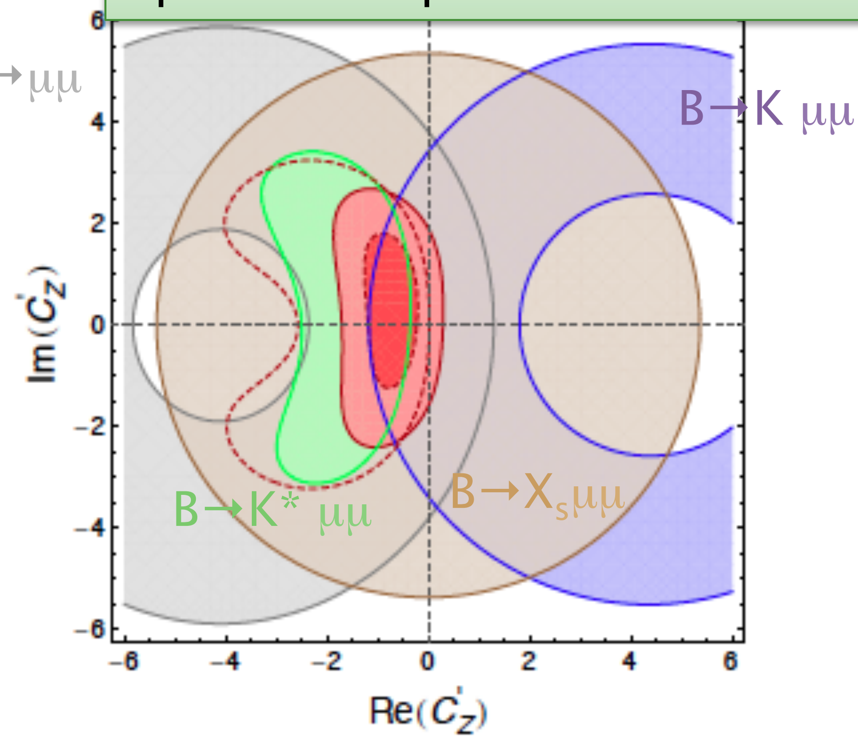
Integrated BF in full q^2 range: $BR(B^+ \to K^+\mu^+\mu^-) = (4.36 \pm 0.15 \pm 0.18)\times 10^{-7}$

Generic constraints to new physics

Altmannshofer and DS 1206.0273]



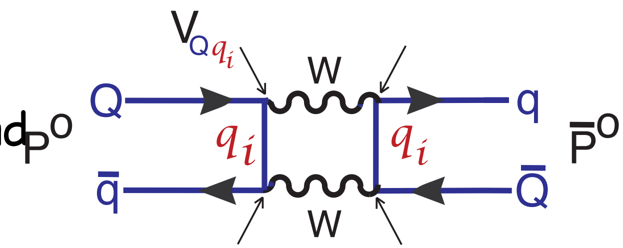
Wilson coefficients of local operators expected to be ~0 in SM



- Many more such generic constraints

Neutral Meson Mixing

- Neutral mesons can transform into their anti-particles via 2nd order weak interactions

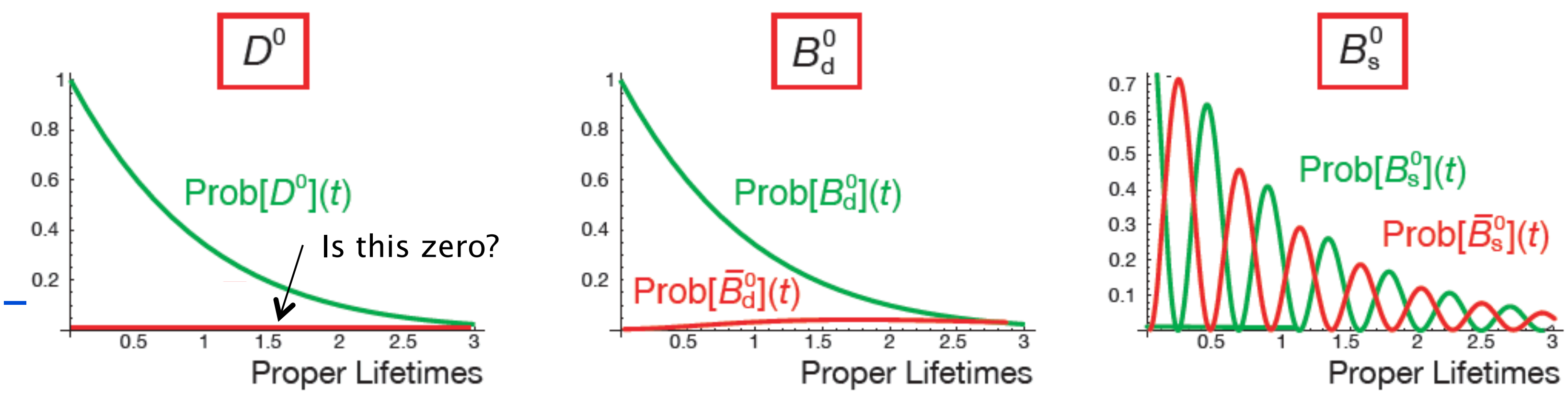


New particles possible in loop

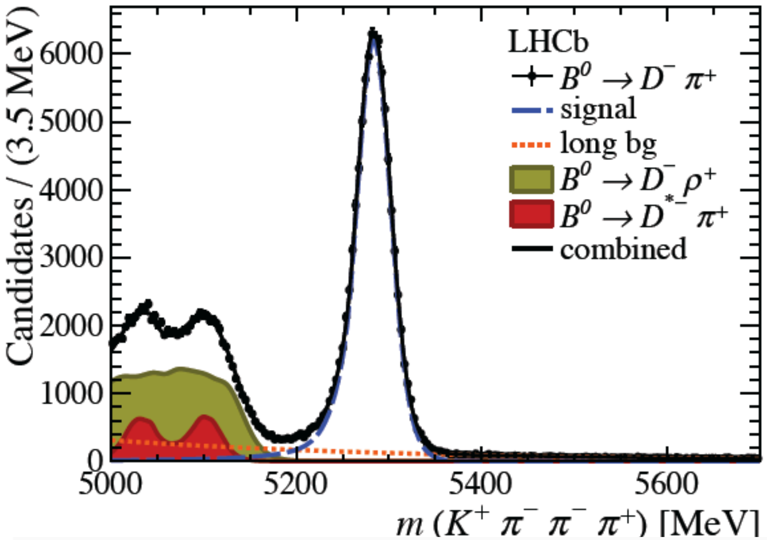
- Short distance transition rate depends on

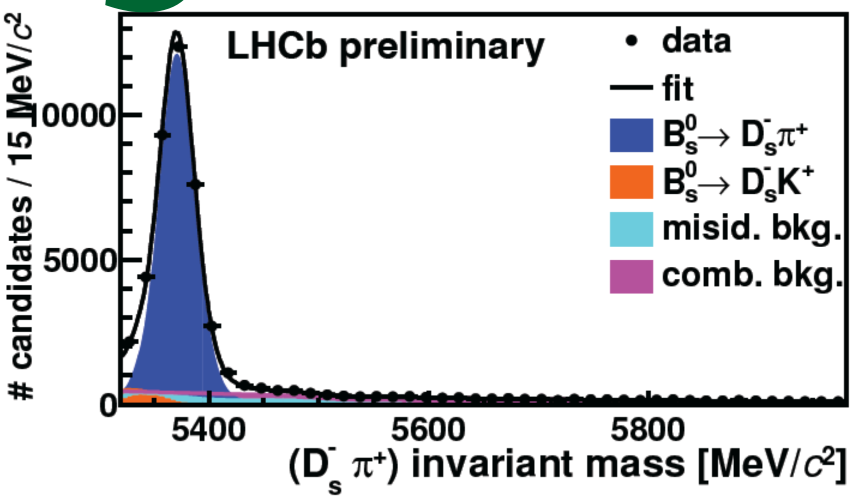
+ "long distance" for D^o

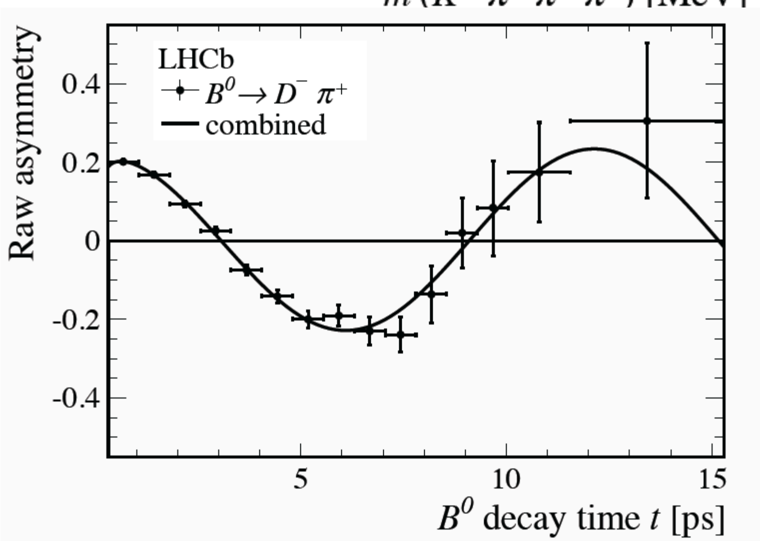
  - mass of intermediate q_i, the heavier the better, favors s & b since t is allowed, while for c, b is the heaviest

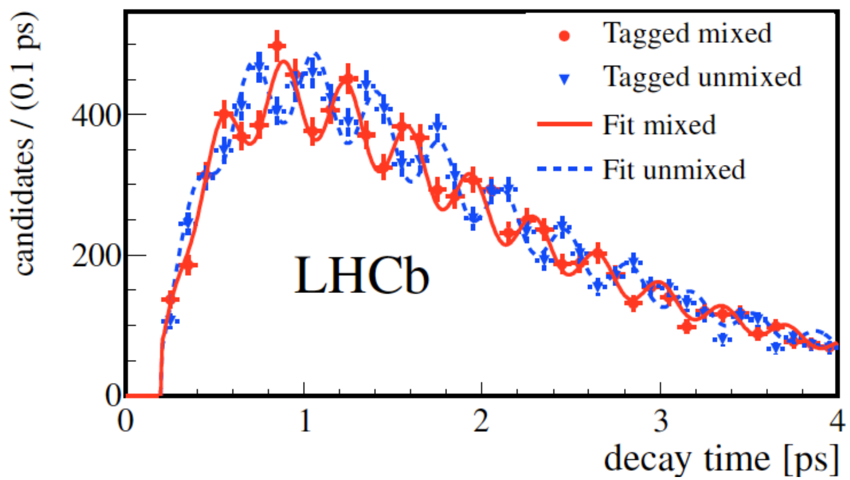


Mixing data







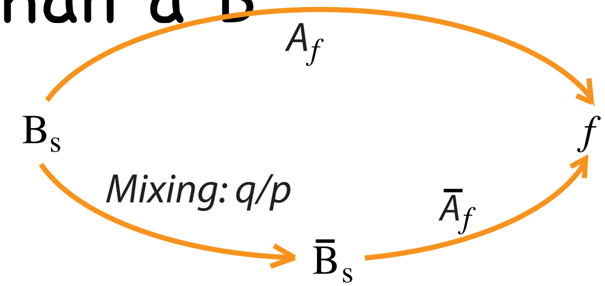


$\Delta m_s = 17.768 \pm 0.023\ (\text{stat}) \pm 0.006\ (\text{syst})\ \text{ps}^{-1}$

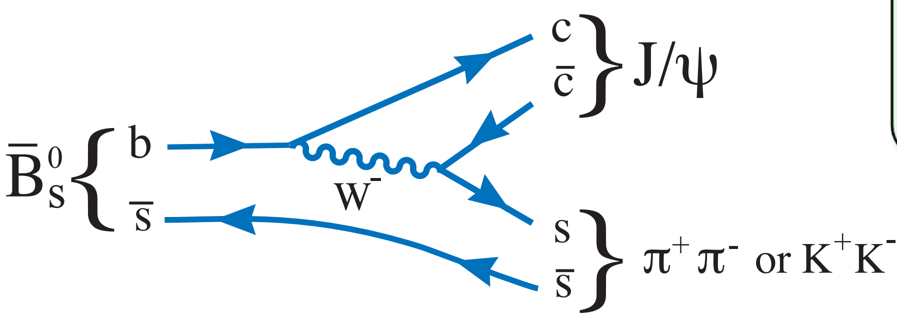
$\Delta m_d = 0.5156 \pm 0.0051\,(\text{stat}) \pm 0.0033\,(\text{syst})\ \text{ps}^{-1}$

CPV in $B_s \to J/\psi\ X$

- CP violation means, for example, that a B will have a different decay rate than a $\overline{B}$



- Can occur via interference between mixing & decay
- For f =J/ψ φ or J/ψ f_0



$$\varphi_s^{SM} \equiv -2\beta_s = -2\arg\left(-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right) = -2^{\circ}$$

- Small CPV expected, good place for NP to appear

ϕ_s results from J/ψ KK/$\pi\pi$

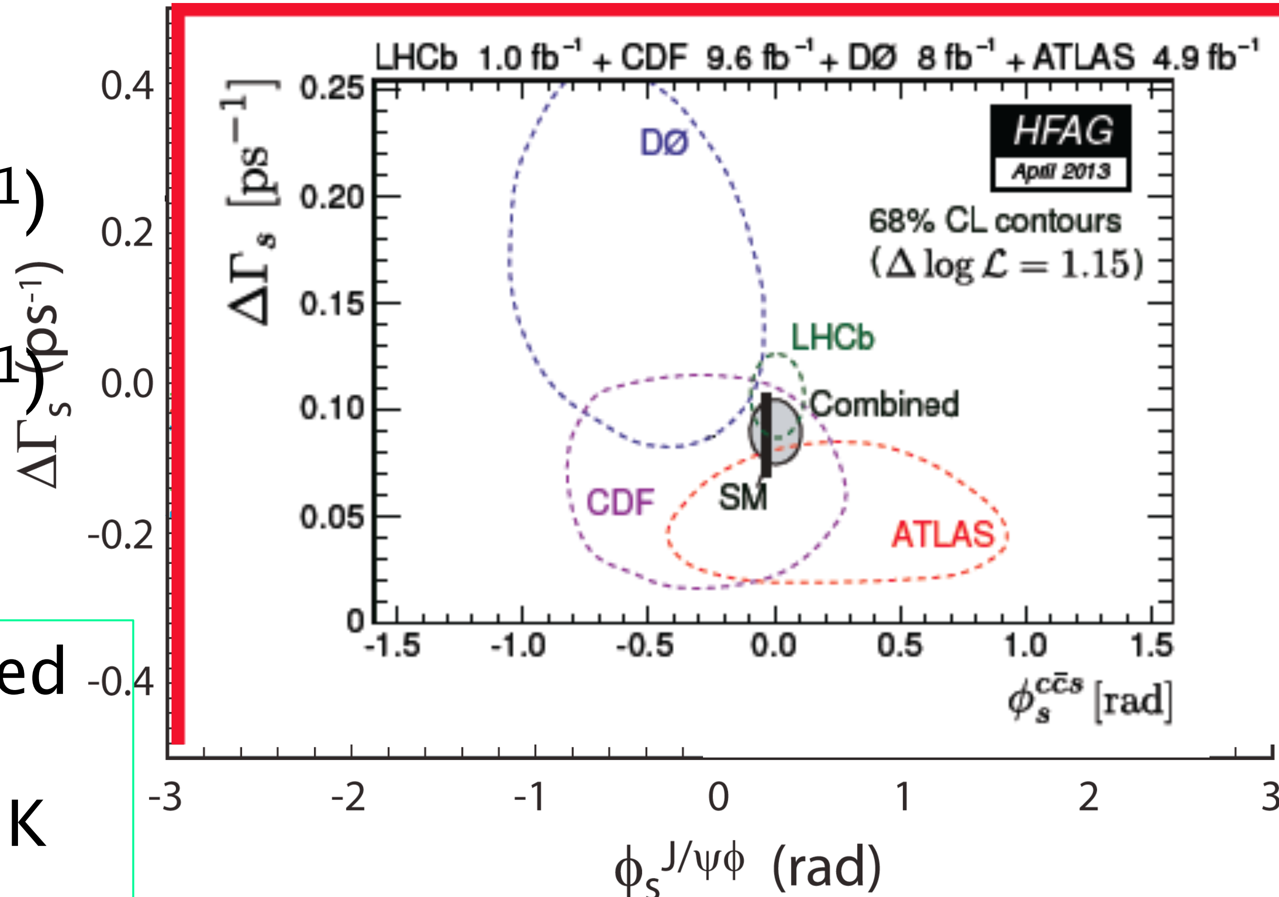
LHCb values

Γ=0.663±0.005 ±0.007 (ps^{-1})

$\Delta\Gamma$=0.100 ±0.015 ±0.003 (ps^{-1})

ϕ_s=0.07±0.09 ±0.01 (rad)

Ambiguity removed using interference with K^+K^- S-wave

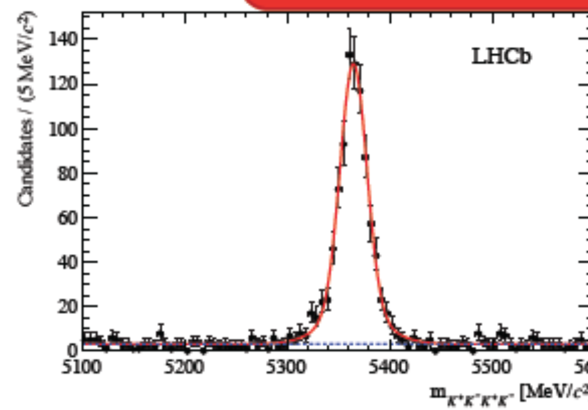


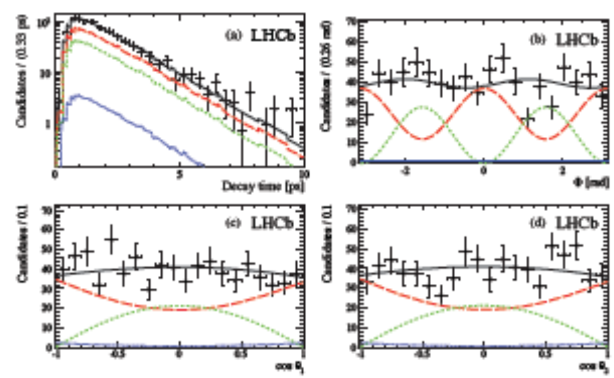
- Combining LHCb results: ϕ_s=-0.01±0.07±0.01 rad

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

LHCB-PAPER-2013-007

- Penguin dominated, particularly sensitive to NP
- SM: cancellation between decay and mixing phases $\rightarrow \phi_s \sim 0$
- We recently made first time-dependent measurement of ϕ_s: [-2.76,-0.76]rad @68%CL
- In the upgrade we expect to approach theoretical error





Measurement	LHCb (1fb^{-1})	LHCb (10fb^{-1})	LHCb Upgrade	Theory
$\sigma(\phi_s)[B_s \rightarrow \phi\phi]$	100%	17%	3%	2%

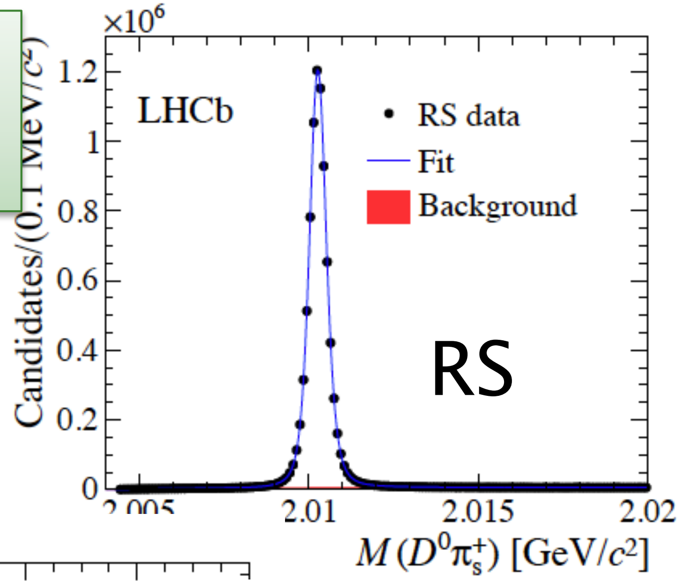
Charm Mixing

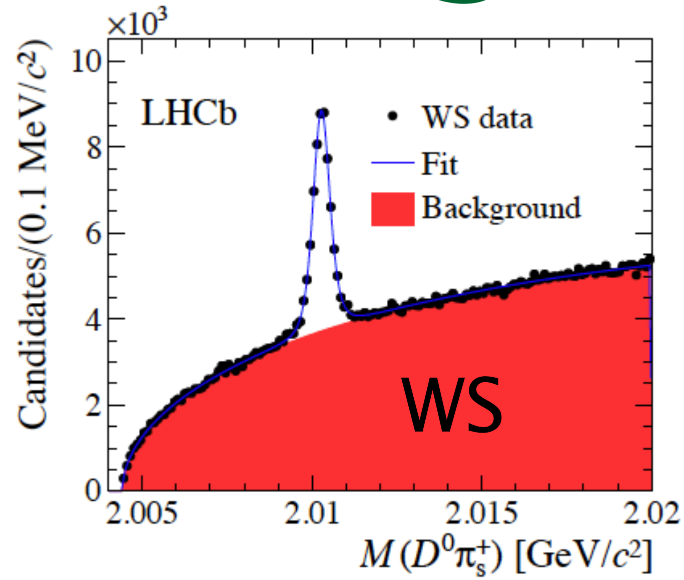
- Various experiments have seen evidence for D^o-$\overline{D}^o$ mixing, but none with significance >5σ.
- $D^{*+}\rightarrow\pi^+D^o$ provides an initial flavor tag
- "Wrong-sign" (WS) D^o can appear via mixing or doubly-Cabbibo suppressed decay (DCS).
- DCS follows ~exp(-t/τ_{D^o}).
  Define R_D=DCS/(Cabibbo favored). Mixing is parameterized as x´ & y´, functions of Δm & $\Delta\Gamma$.
- Measure Wrong-sign/Right-sign, R(t)= (WS/RS)

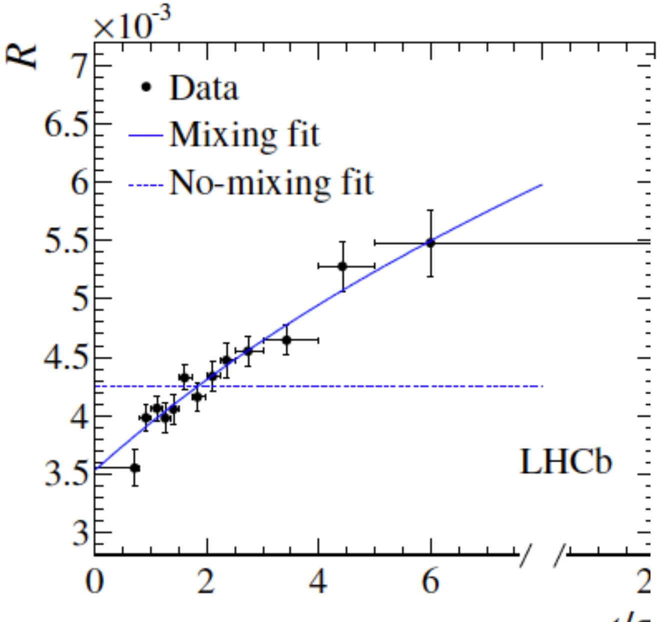
$$R(t) \approx R_D + \sqrt{R_D}\, y' \,\frac{t}{\tau} + \frac{x'^2 + y'^2}{4}\left(\frac{t}{\tau}\right)^2$$

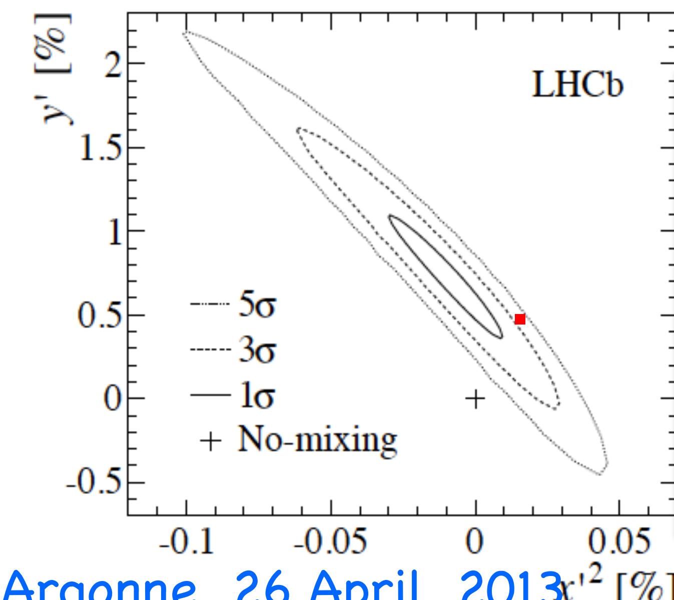
Charm mixing

$D^{*+} \to \pi^+ D^o$, $D^o \to K^- \pi^+$









No mixing excluded at 9.1σ, systematic errors are included
$y' = (0.72 \pm 0.24)\%$
$x'^2 = (-0.9 \pm 1.3) \times 10^{-4}$

Lepton flavor violation

First lepton flavor violation limits at a hadron collider recently reported by LHCb!

Channel	Expected (90% CL)	Observed (90% CL)
$\tau^- \to \mu^-\mu^+\mu^-$	8.3×10^{-8}	8.0×10^{-8}
$\tau^- \to \bar{p}\mu^+\mu^-$	4.6×10^{-7}	3.3×10^{-7}
$\tau^- \to p\mu^-\mu^-$	5.4×10^{-7}	4.4×10^{-7}

c.f. BF$(\tau^- \to \mu^-\mu^+\mu^-) \leq 2.1 \times 10^{-8}$ at 90% CL from Belle

Projected sensitivity in the LHCb upgrade ~$2\text{x}10^{-9}$

Sensitivity of the upgraded LHCb experiment to key observables

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 [137]	0.025	0.008	~ 0.003
	$2\beta_s$ ($B_s^0 \to J/\psi\ f_0(980)$)	0.17 [213]	0.045	0.014	~ 0.01
	a_{sl}^s	6.4×10^{-3} [43]	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguins	$2\beta_s^{\text{eff}}(B_s^0 \to \phi\phi)$	–	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 [43]	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 penguins	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\,\text{GeV}^2/c^4)$	0.08 [67]	0.025	0.008	0.02
	$s_0\, A_{\text{FB}}(B^0 \to K^{*0}\mu^+\mu^-)$	25 % [67]	6 %	2 %	7 %
	$A_{\text{I}}(K\mu^+\mu^-; 1 < q^2 < 6\,\text{GeV}^2/c^4)$	0.25 [76]	0.08	0.025	~ 0.02
	$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$	25 % [85]	8 %	2.5 %	~ 10 %
Higgs penguins	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	1.5×10^{-9} [13]	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	γ ($B \to D^{(*)}K^{(*)}$)	~ 10–$12°$ [243, 257]	4°	0.9°	negligible
	γ ($B_s^0 \to D_s K$)	–	11°	2.0°	negligible
	β ($B^0 \to J/\psi\ K_S^0$)	0.8° [43]	0.6°	0.2°	negligible
Charm *CP* violation	A_Γ	2.3×10^{-3} [43]	0.40×10^{-3}	0.07×10^{-3}	–
	$\Delta\mathcal{A}_{CP}$	2.1×10^{-3} [18]	0.65×10^{-3}	0.12×10^{-3}	–

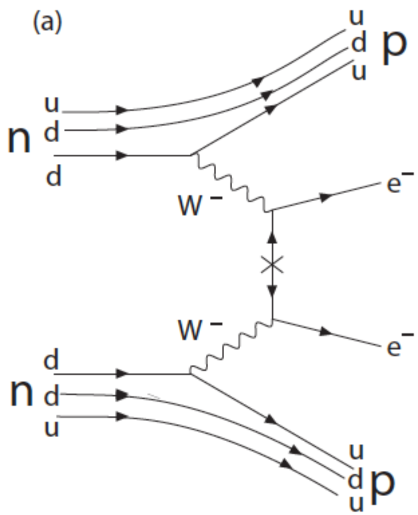
Implications of LHCb measurements and future prospects, LHCB-PAPER-2012-031

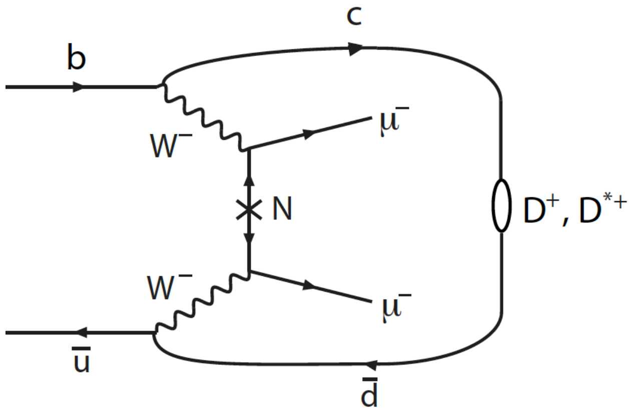
Exploring new vistas

THINKING OUTSIDE THE BOX

Majorana ν's

- Several ways of looking for presence of heavy ν's (N) in heavy quark decays if they Majorana (their own anti-particles) and couple to "ordinary" ν's
- Modes analogous to ν−less nuclear β decay

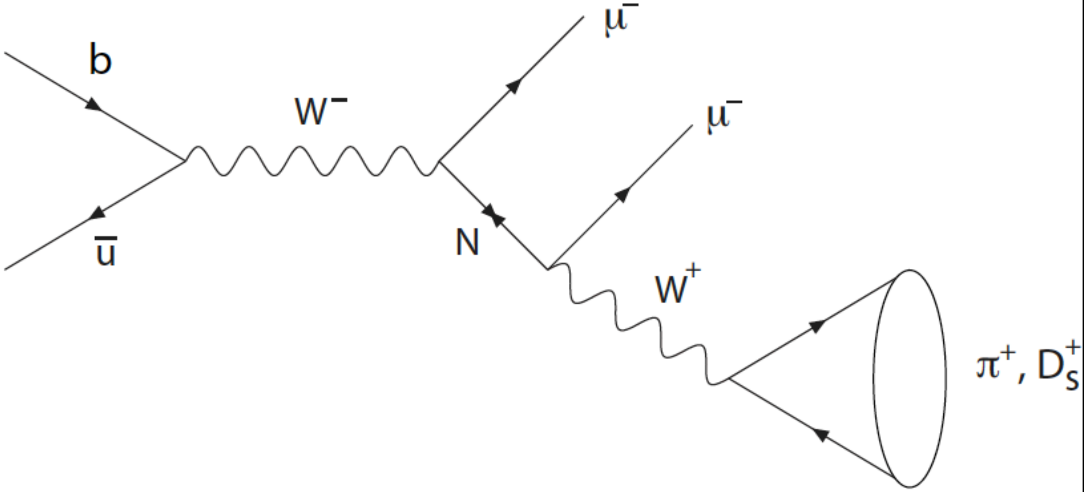


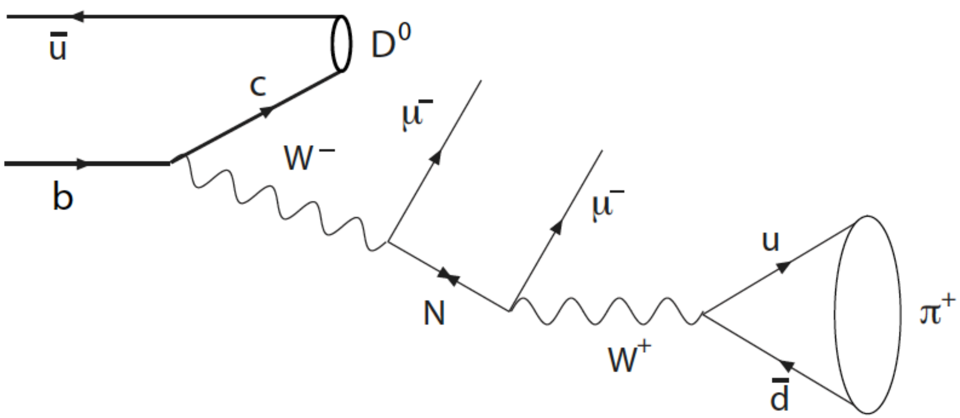


Simplest Channels:
$B^- \rightarrow D^+ l^- l'^-$ &
$B^- \rightarrow D^{*+} l^- l'^-$
l^- & l'^- can be e^-, μ^- or τ^-.

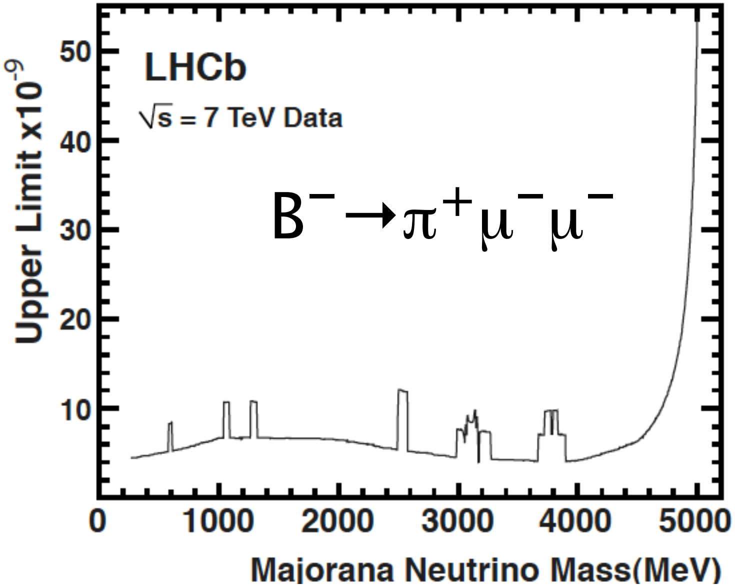
On-Shell ν

- Can also look for Majorana ν (N), where $N \to W^+\mu^-$
- Several ways
- A. Atre, T. Han, S. Pascoli, & B. Zhang [arXiv:0901.3589]
- N. Quintero, G. Lopez & Castro, [arXiv:1108.6009]

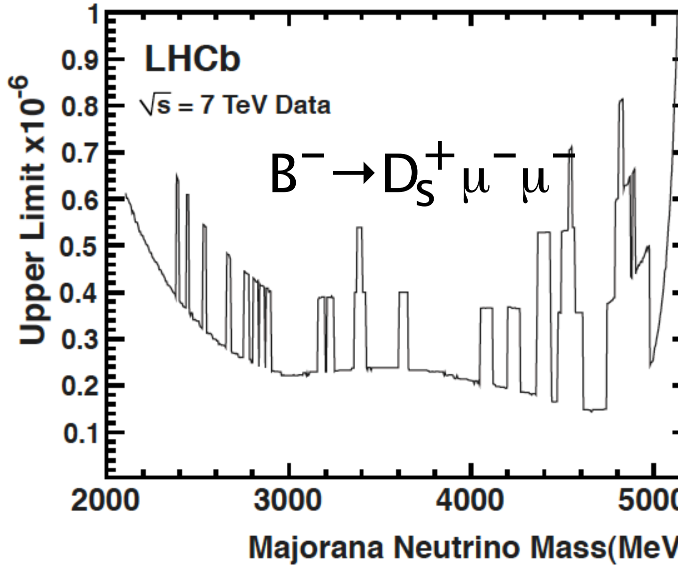


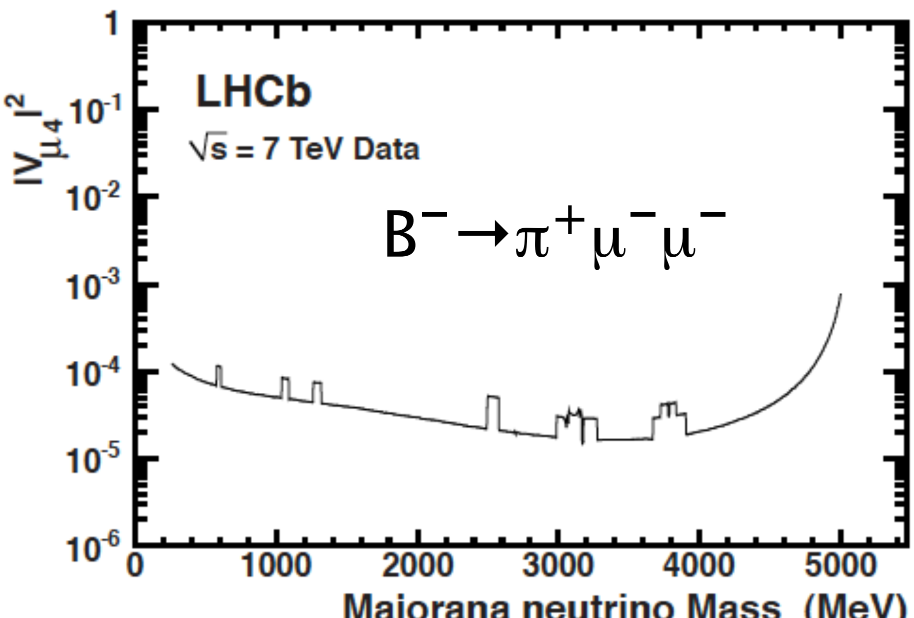


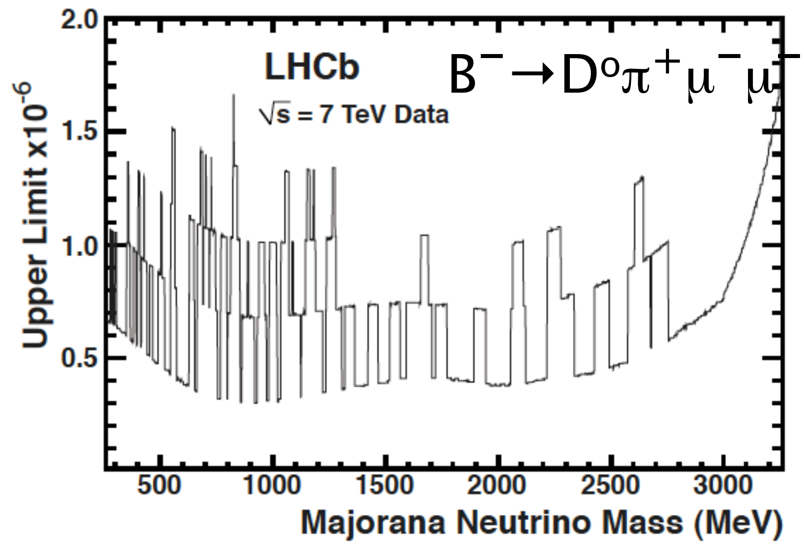
LHCb searches



Nothing yet but only 0.41 fb^{-1} analyzed







Other possibilities

- Search for long lived exotic particles
- QCD exotica
- $t\bar{t}$ production
- Electroweak physics

- “LHCb general purpose detector in the forward direction…“

> The observables are many, we are still at a cross road among many paths

LHCb UPGRADE CONCEPT: FOLLOW THE OPPORTUNITIES AS THEY ARISE

Upgrade goals

- In order to reach the required sensitivity for these measurements we want a ≥ 10 increase in our data sample through:
  - Increase nominal luminosity ($1\text{-}2\times10^{33}$ $cm^{-2}s^{-1}$)
  - Increase efficiency on beauty and charm hadronic final states trigger (≥2)

- Schedule:
  - R&D phase in progress and should end in 2014
  - Installation during long shutdown ~2018.

Running at L ~ $2x10^{33}$ cm^{-2} s^{-1}

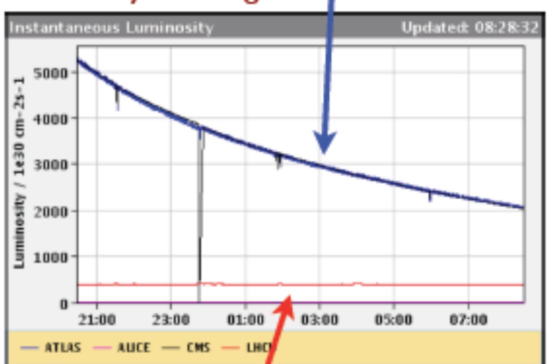
- LHCb Upgrade Event Environment:
  - $\mathcal{L}$ ~ $2x10^{33}$ cm^{-2} s^{-1} with 40 MHZ beam crossing frequency

    ~26 MHz rate for crossings with ≥ 1 interaction

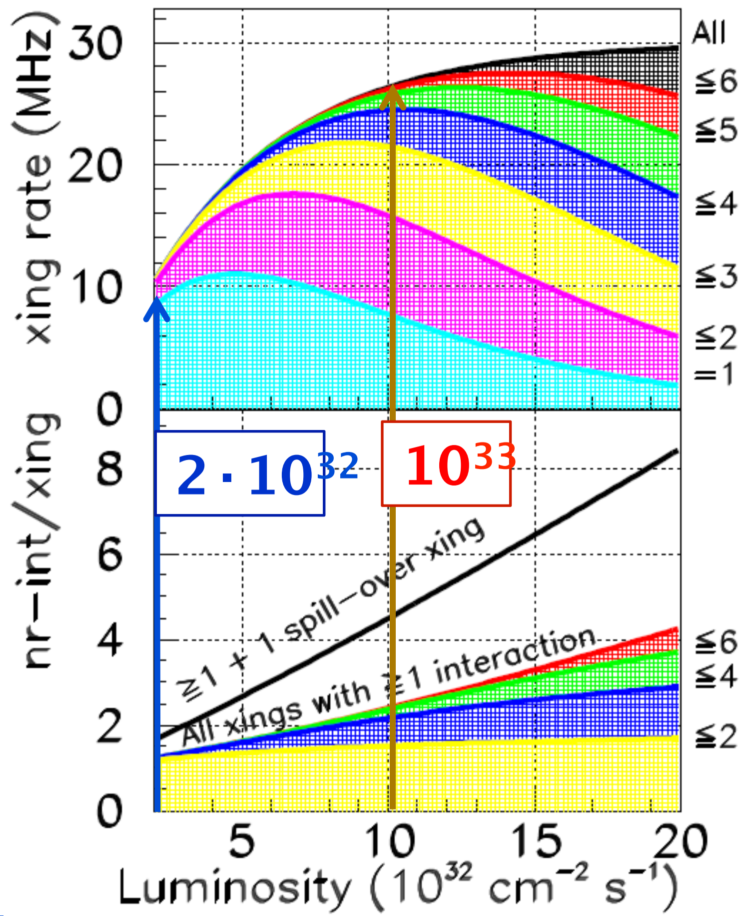
    μ ~ 2.3

ATLAS, CMS

luminosity levelling

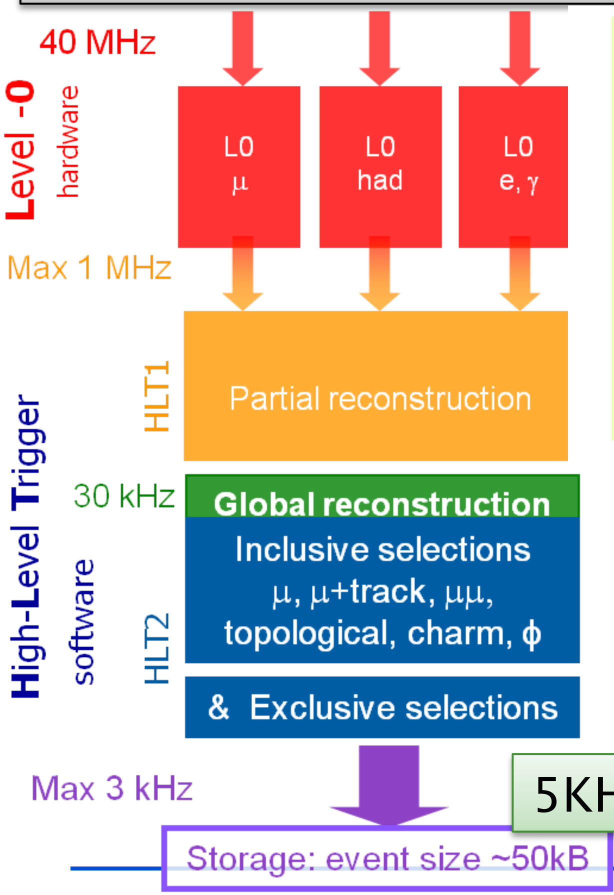


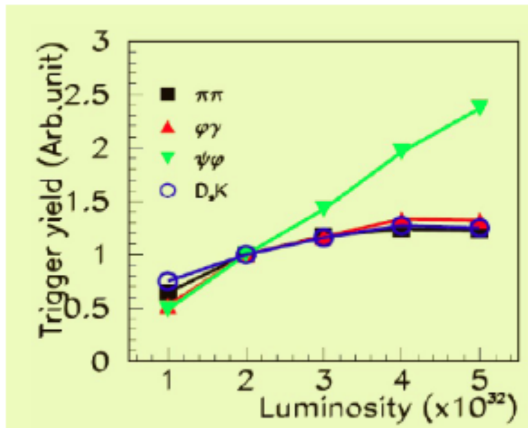
LHCb



LHCb trigger evolution

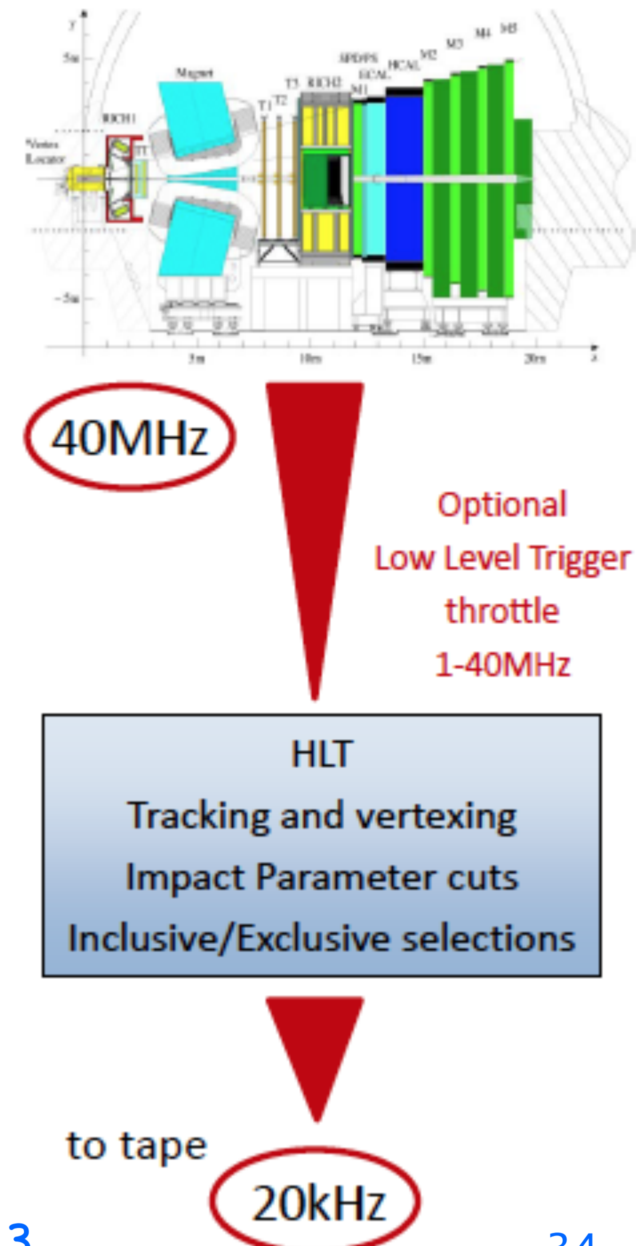
2011 First Trigger Level:
Hardware Muon/ECAL/HCAL
1.1 MHz readout





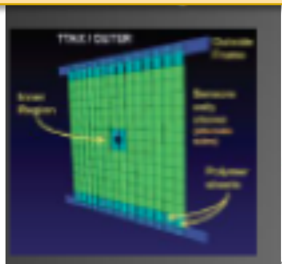
The hadronic channel yields saturate at high luminosity

5KHz in 2012

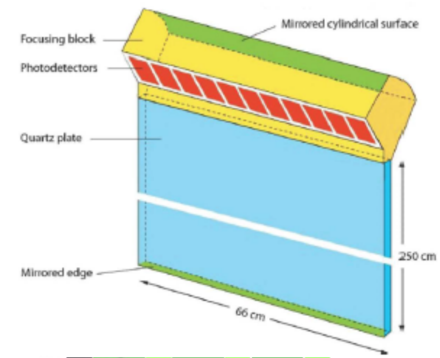


The LHCb upgrade in a snapshot

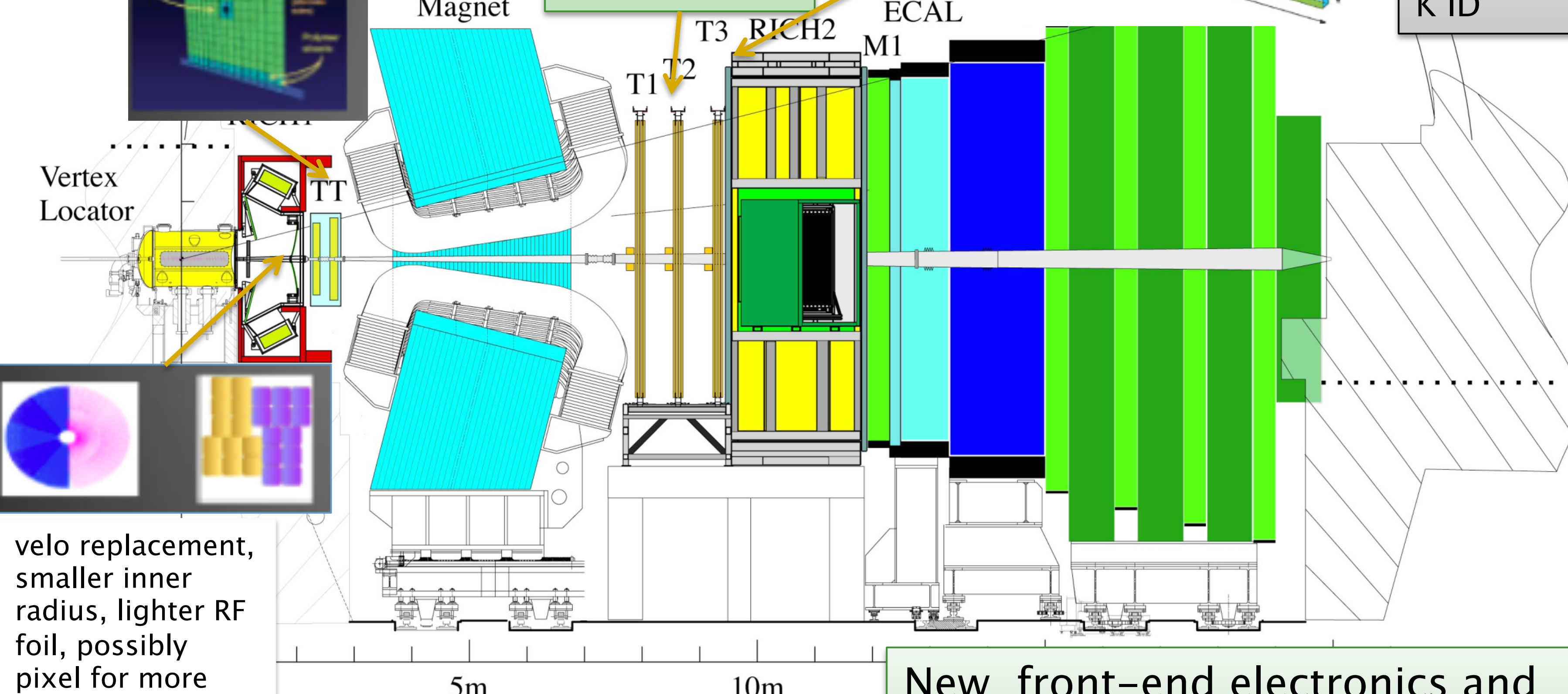
Intermediate tracking replacement: higher granularity and low mass support/cooling



T Stations, inner/whole scintillating fiber option, rad hard SiPM



later stage: torch for lower momentum K ID

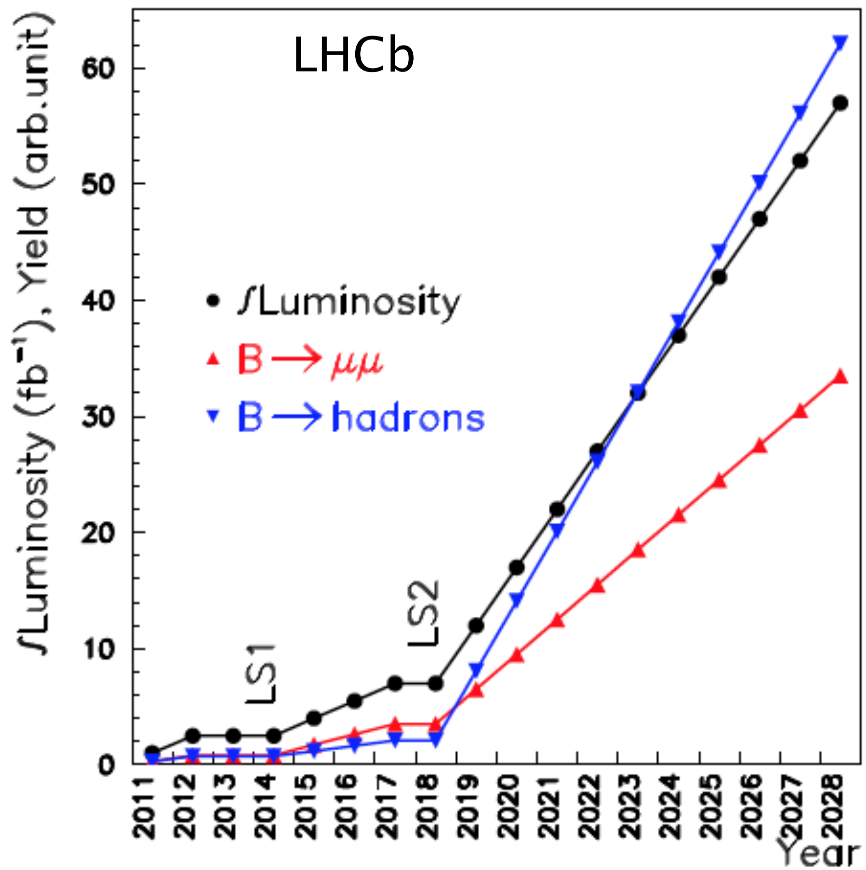


velo replacement, smaller inner radius, lighter RF foil, possibly pixel for more robust pattern recognition

New front-end electronics and data acquisition network, to push the data out at 40 MHz

LHCb expected performance

- LHCb has designed an upgrade path that will enable it to take advantage of a luminosity of $\sim 10^{33} cm^{-2} s^{-1}$ with a flexible software trigger that can be customized to pursue exciting physics clues wherever they come from
- Pile-up and occupancy are very manageable at this luminosity (based on current data taking)
- Sensitivity scalable with CPU & analysis ingenuity (at least CPU should scale with Moore's law!)
- Variety of new channels being considered (e.g. $B_s \rightarrow K\mu\nu$ for Vub, $B \rightarrow D^*\tau\nu$)



Conclusions

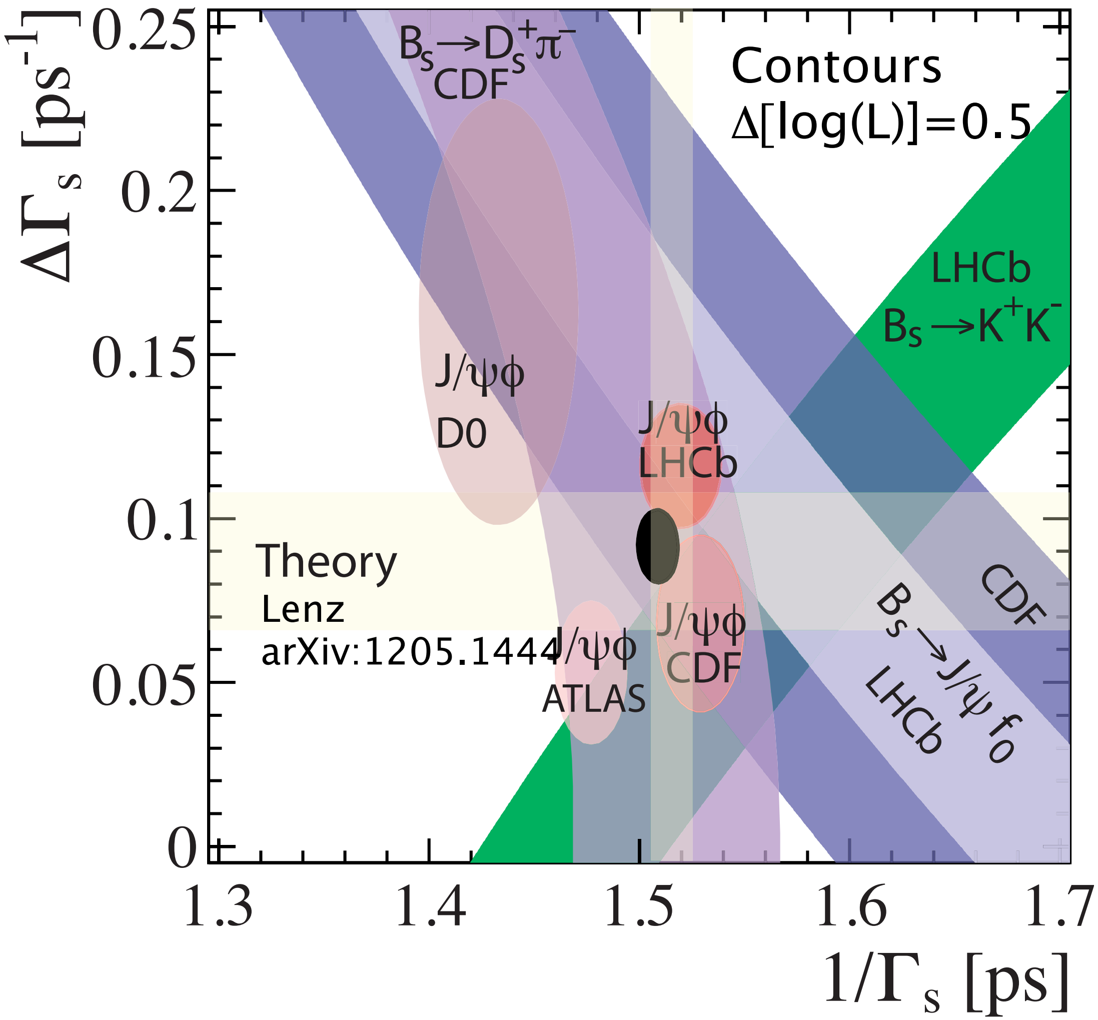
- LHCb is pursuing an upgrade plan that will extend the current exploration of new physics in heavy flavor decays into the precision realm for a vast array of observables
- LHCb has devised an upgrade strategy that can be reoptimized very easily to adjust to the evolving landscape of new physics scenario
- CMS and ATLAS have windows of opportunity to pursue interesting flavor physics observables but implications of the high luminosity upgrade environment need to be studied more extensively

More information in contributions by B.K. Hamilton and K. Stenson

The End

Γ_s & $\Delta\Gamma_s$

- B_s lifetime results here use only fully reconstructed decays
- K^+K^- is taken as CP even ($A_{\Delta\Gamma}$=-1)
- Ovals show 39% cl, while bands 68% cl
- τ_s=1.509±0.010 ps, $\Delta\Gamma_s$ = 0.092±0.011 ps^{-1}, $y_s=\Delta\Gamma_s/2\Gamma_s$= 0.07±0.01



only full reconstructed B_s decays used

a_{sl}

- By definition $$a_{sl} = \frac{\Gamma\left(\bar{M} \to f\right) - \Gamma\left(M \to \bar{f}\right)}{\Gamma\left(\bar{M} \to f\right) + \Gamma\left(M \to \bar{f}\right)}$$

  at t=0 $M \to \bar{f}$ is zero as is $\bar{M} \to f$
- Here *f* is by construction flavor specific, $\bar{f} \neq f$
- Can measure eg. $\bar{B}_s \to D_s^+ \mu^- \nu$, versus $B_s \to D_s^- \mu^+ \nu$,
- Or can consider that muons from two B decays can be like-sign when one mixes and the other decays, so look at $\mu^+\mu^+$ vs $\mu^-\mu^-$
- a_{sl} is expected to be very small in the SM, $a_{sl}=(\Delta\Gamma/\Delta M)\tan\phi_{12}$, where $\tan\phi_{12}=\mathrm{Arg}(-\Gamma_{12}/M_{12})$
- In SM (B^o) a^d_{sl} =-4.1×10^{-4}, (B_s) a^s_{sl} =$+1.9\times10^{-5}$

arXiv:1205.1444 [hep-ph]

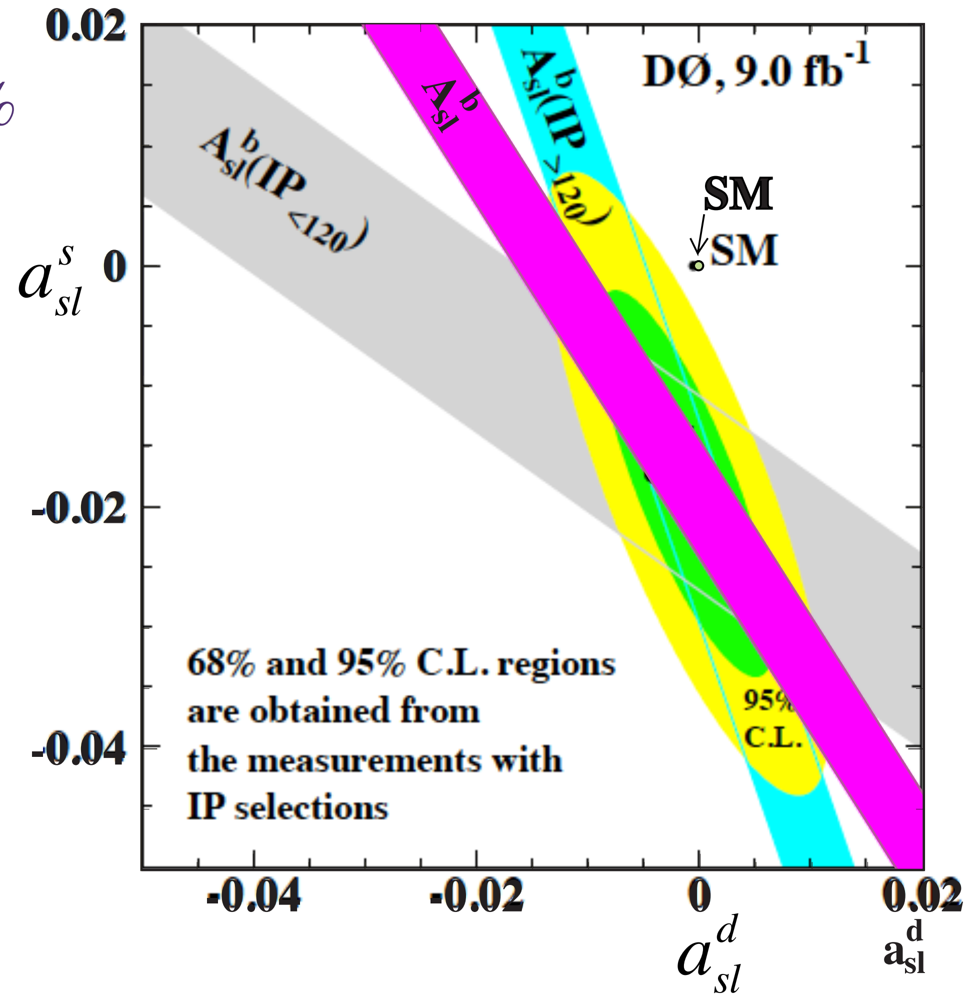
D0 a_{sl}

- Using dimuons (3.9σ)

$$A_{sl}^{b} = (-0.787 \pm 0.172 \pm 0.093)\%$$

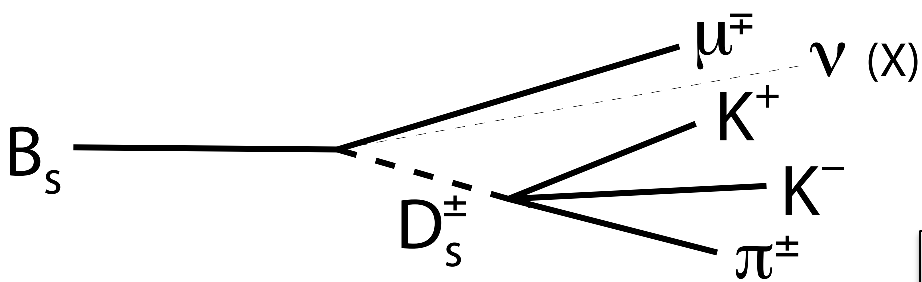
- Indication from D0 that its B_s
- Separate dimuons into B_d and B_s samples using muon impact parameter
- Find $a_{sl}^{d} = (-0.12 \pm 0.52)\%$

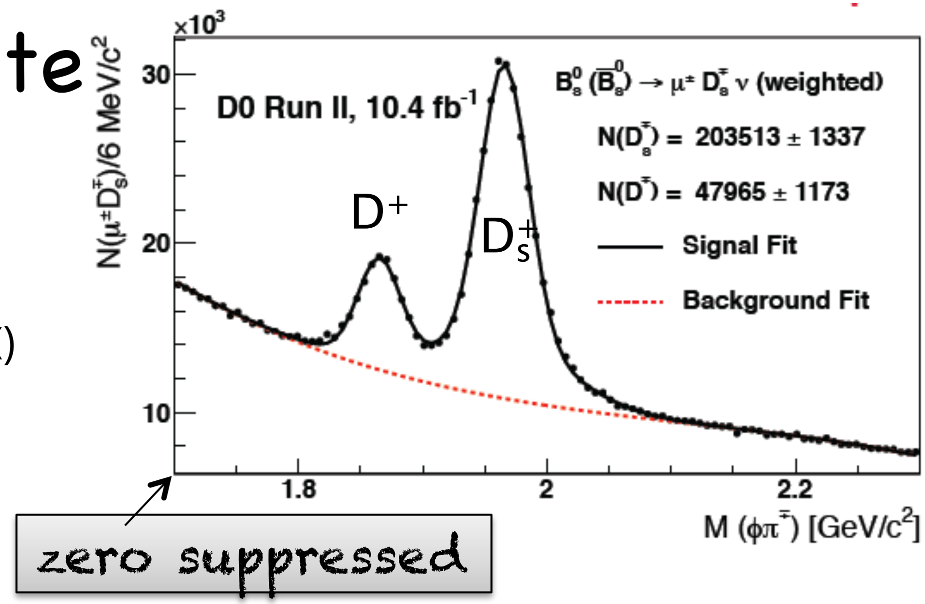
$$a_{sl}^{s} = (-1.81 \pm 1.06)\%$$



New D0 Analysis

- Measure a^s_{sl} using $D_s\mu^-\nu$ events, $D_s \rightarrow \phi\pi^\pm$
- Detect a μ associate with a D_s decay

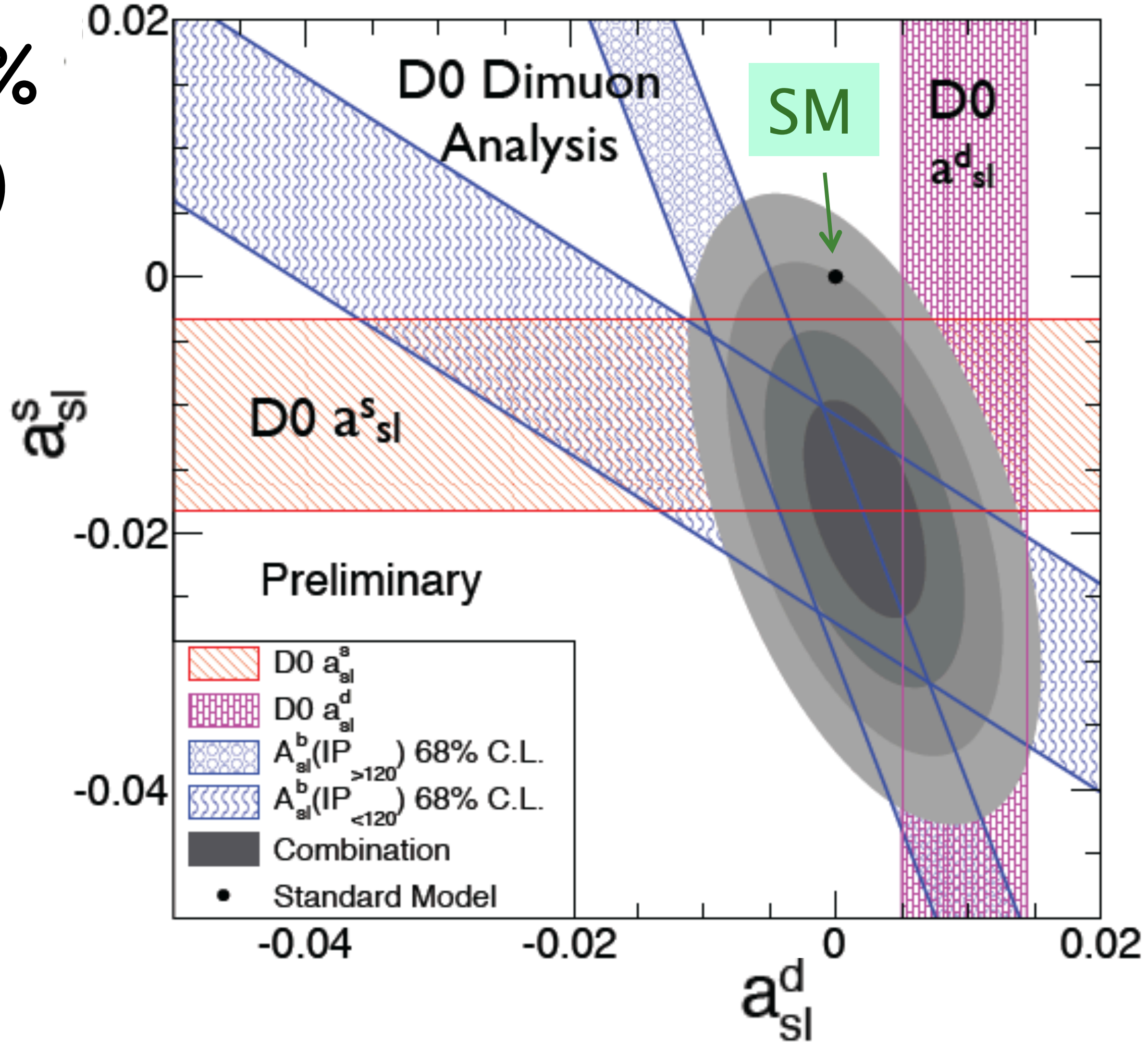




- Find a^s_{sl}=(-1.08±0.72±0.17)%
- Also measure a^d_{sl} using $D^+\mu^-\nu$, $D^+ \rightarrow K\pi^+\pi^+$
- a^d_{sl}=(0.93±0.45±0.14)%

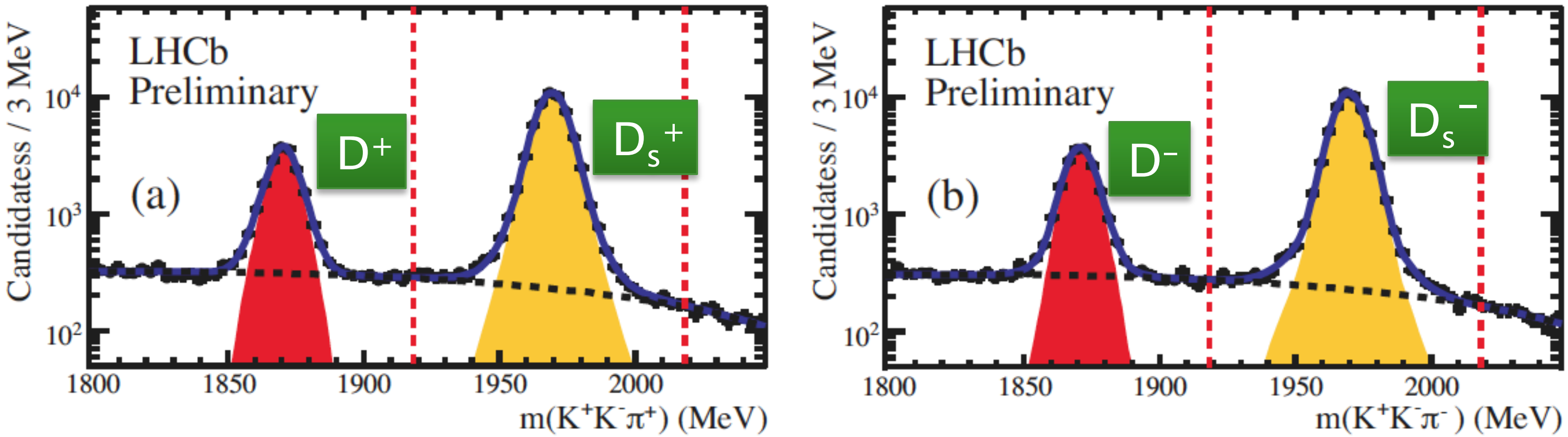
a_{sl} according to D0

- a^s_{sl}=(-1.81±0.56)%
- a^d_{sl}=(-0.22±0.30)%
- 3σ from SM
- arXiv:1208.5813



LHCb measurement

- Use $D_s \mu^- \nu$, $D_s \to \phi\pi^{\pm}$, magnet is periodicaly reversed. For magnet down:



- Effect of B_s production asymmetry is reduced to a negligible level by rapid mixing oscillations
- Calibration samples (J/ψ, D^{*+}) used to measure detector trigger, track & muon ID

a_{sl} not D0

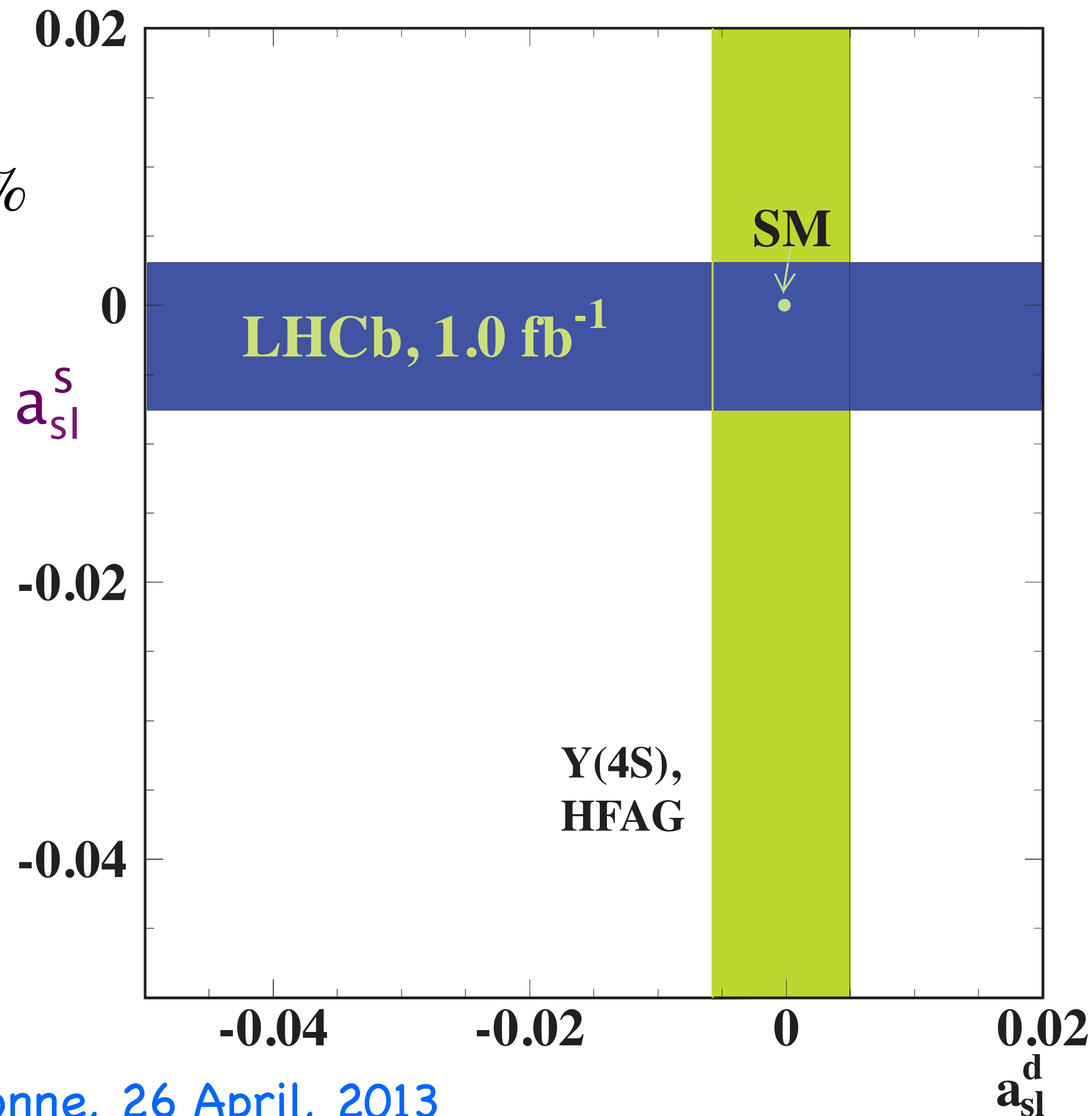
- LHCb finds

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

- B-factory

$$a_{sl}^{d} = (-0.05 \pm 0.56)\%$$

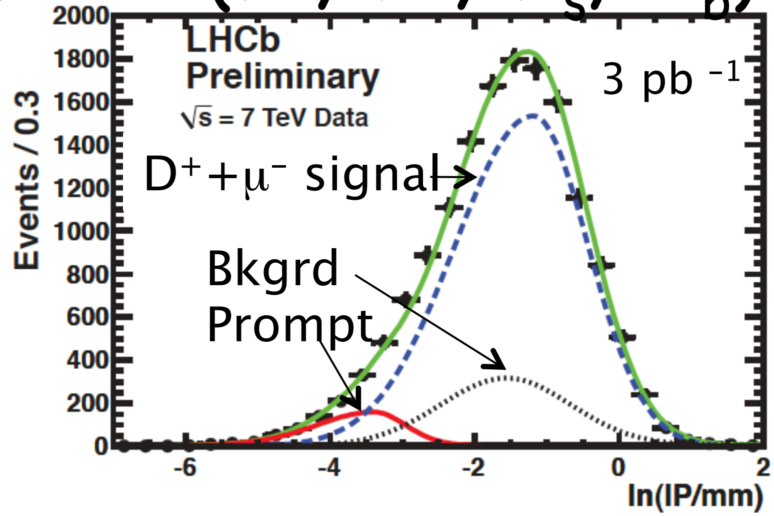
- Results consisten with SM
- Expect ϕ_s to grov as sin[2|β_s| +arg(M_{12}^s)] for finite a_{sl}.



b Fractions (LHCb)

- First measure the b cross-section: 300 μb, then:
- f_s/f_d Using Semileptonics: $b \to (D^0, D^+, D_s, \Lambda_b) X\mu\upsilon$

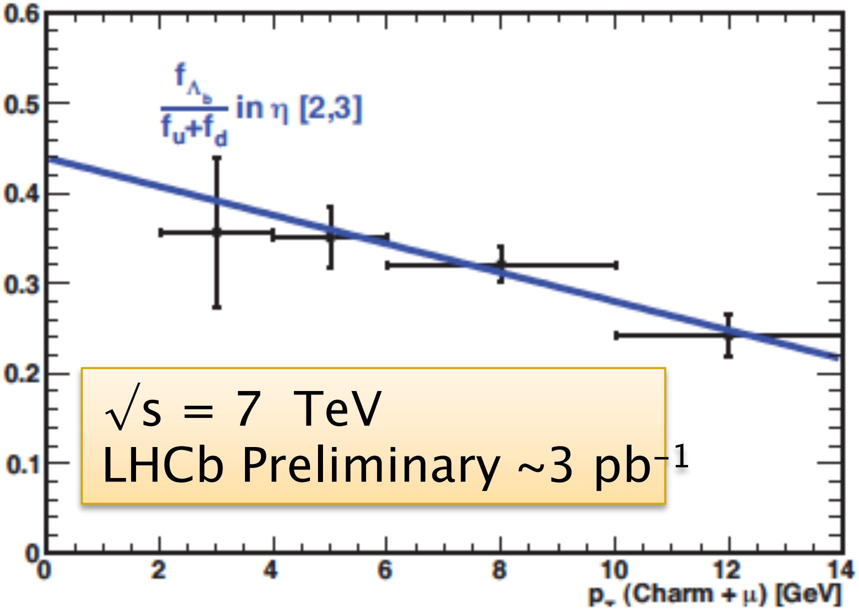
$$f_s / f_d = 0.267^{+0.021}_{-0.020}$$

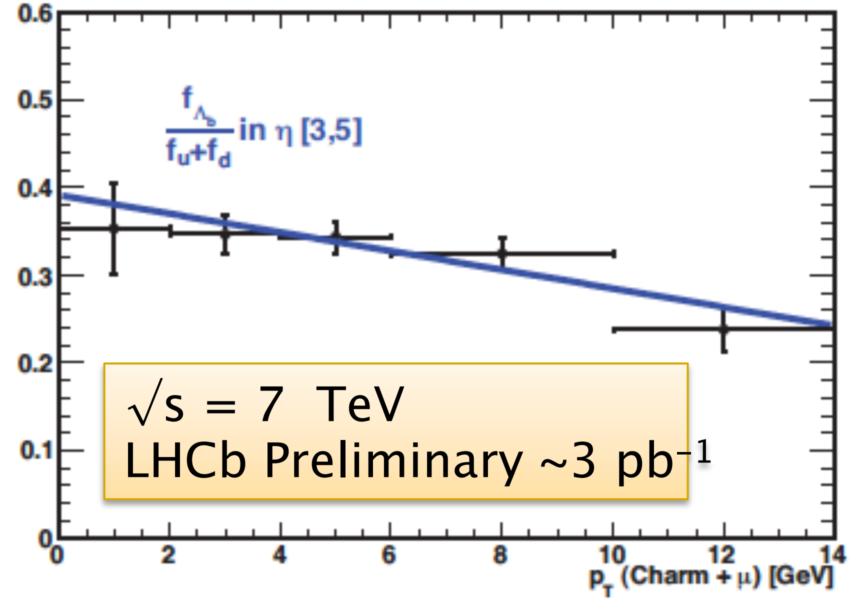


- independent of η & p_t

Λ_b Fraction

- Significant p_t dependence



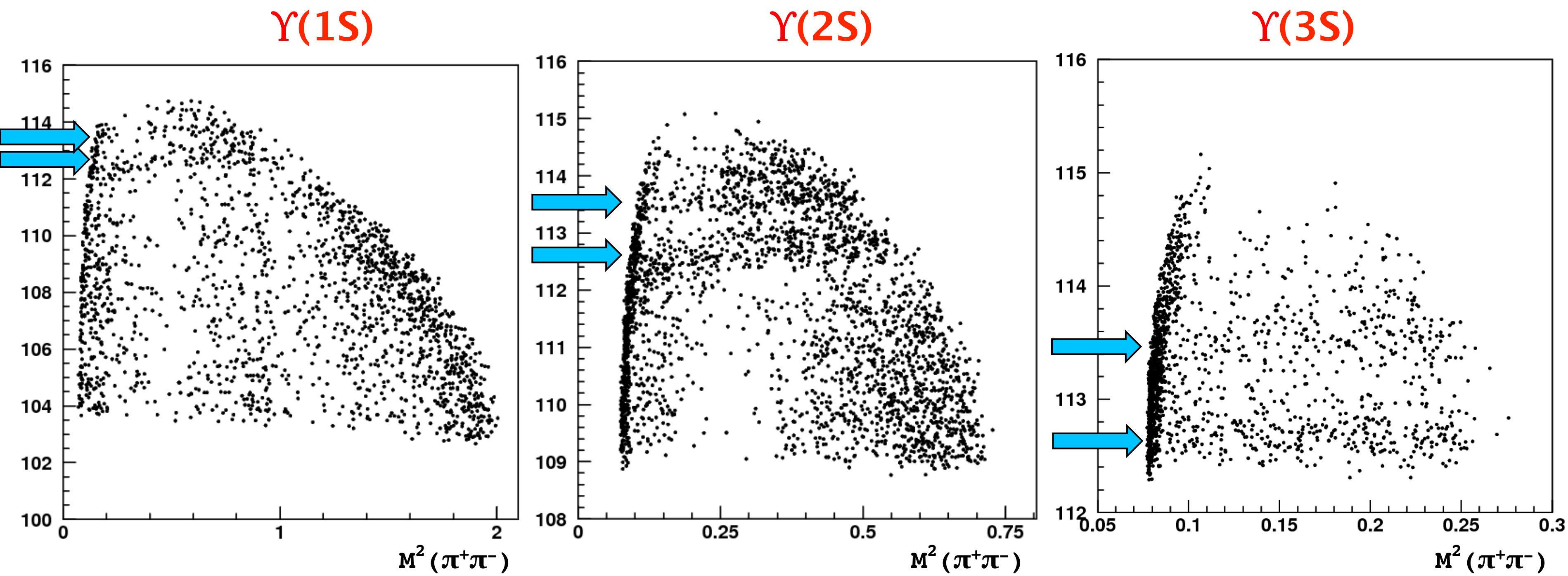


$$[f_{\Lambda_b}/(f_u + f_d)] = 0.401 \pm 0.019 \pm 0.106 - (0.012 \pm 0.0025 \pm 0.0012) \times p_t(\mathrm{GeV})$$

- In general agreement with CDF measured at $<p_t>$~10 GeV $f_{\Lambda_b}/(f_u + f_d) = 0.281 \pm 0.012^{+0.011+0.128}_{-0.056-0.086}$

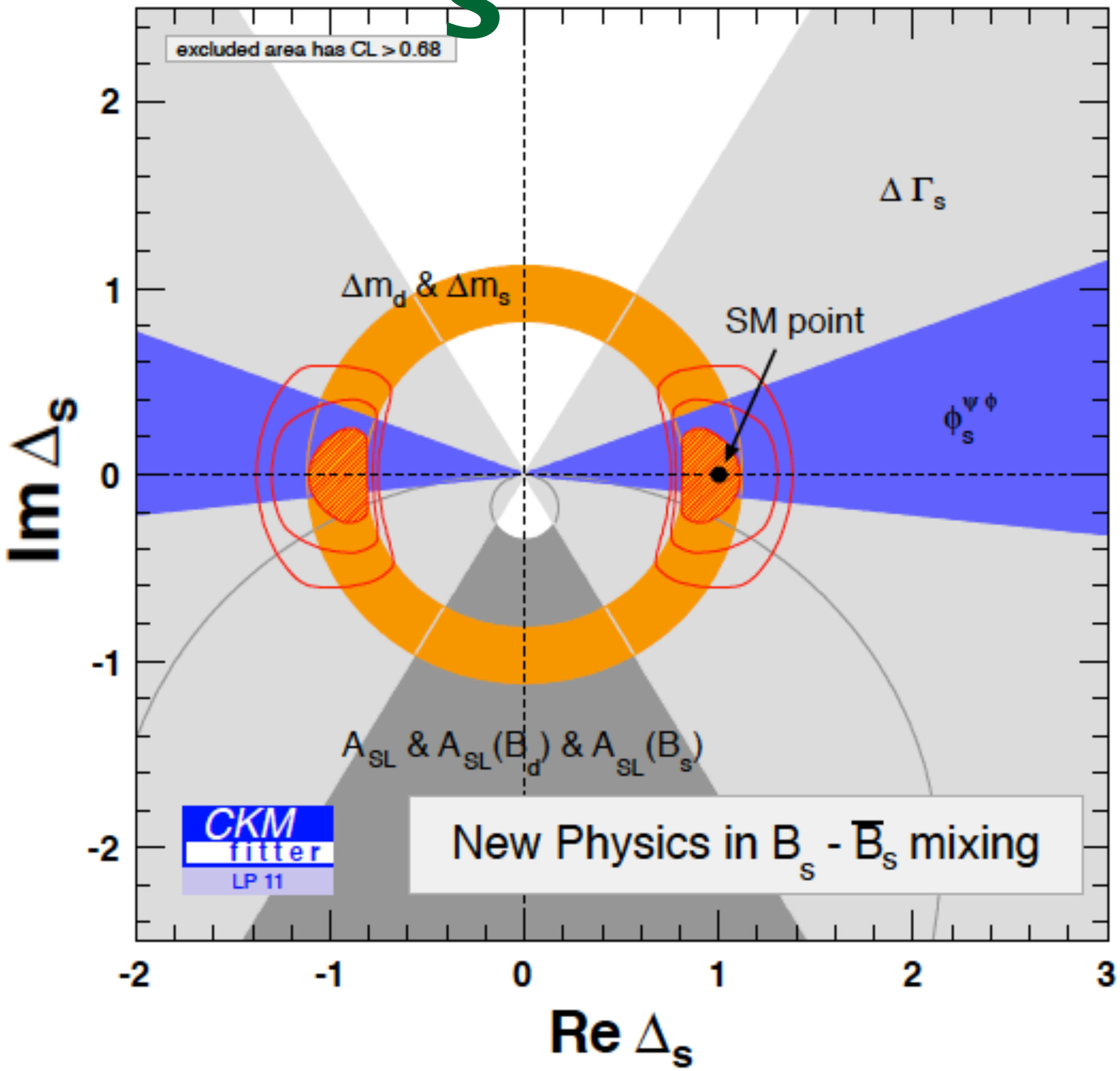
New Exotic States

- Belle discovery of $Z_b(10610)$ and $Z_b(10650)$
- $\Upsilon(5S) \rightarrow \Upsilon(nS)\pi^+\pi^-$ Dalitz plots. See $\Upsilon(nS)\pi^\pm$ states
- Also seen in $h_b(1P)\pi^\pm$ & $h_b(2P)\pi^\pm$ decays arXiv:1105.4583



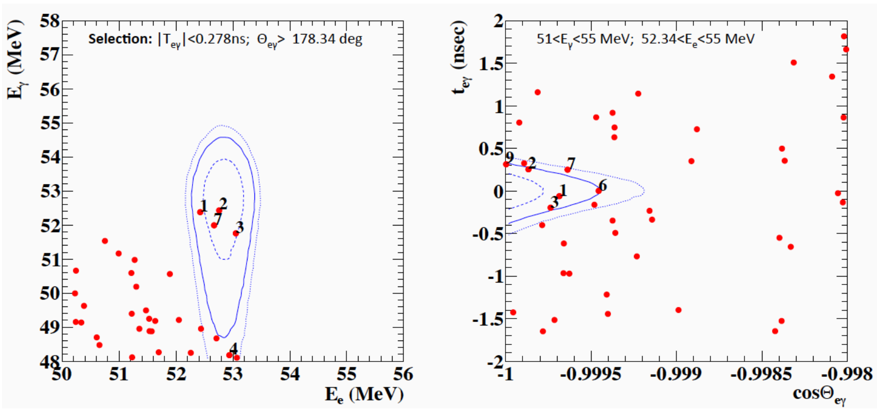
CKM B_s Fit

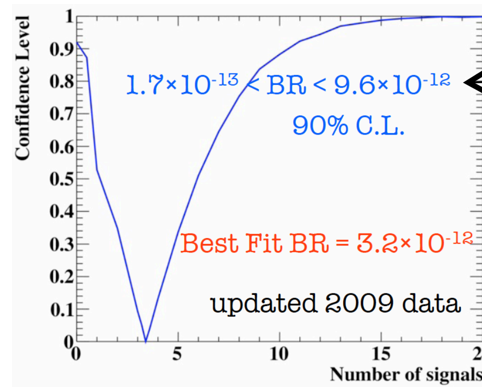
- Now even better consistency with SM than B_d
- However, much more room for NP than in B_d system due to less precise measurements



Lepton Flavor Violation

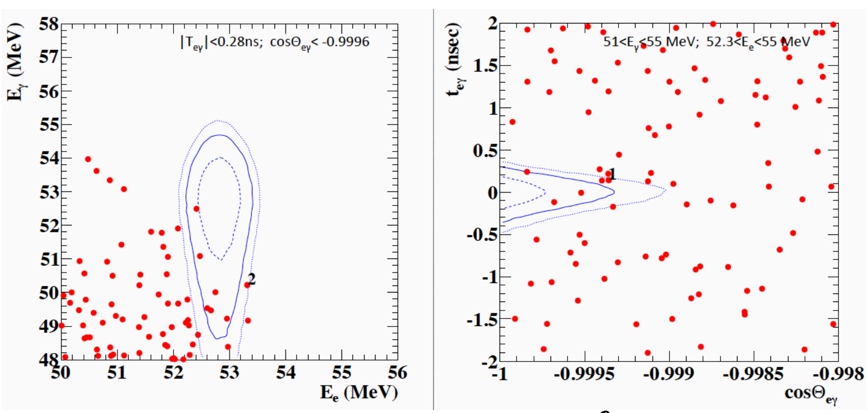
- $\mu \rightarrow e\gamma$ MEG data 2009 results (Mori EPS2011)

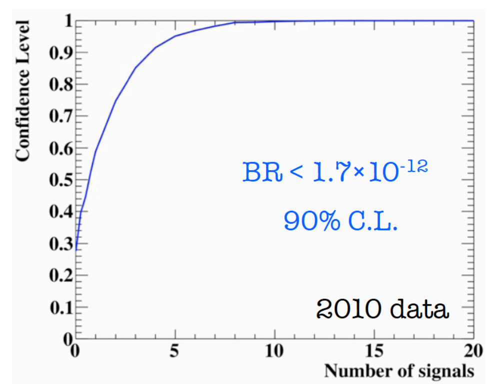




Note 2-sided limit

- Data 2010 Results

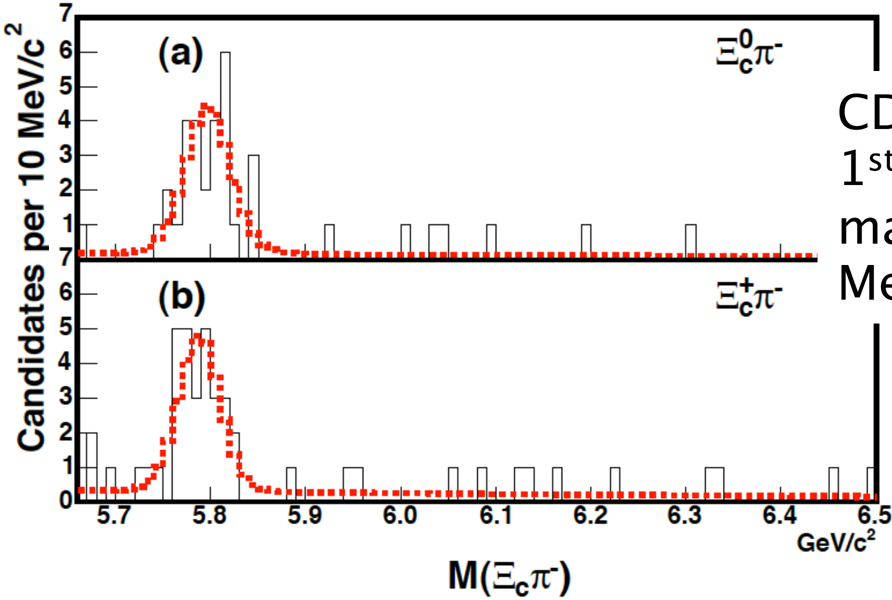




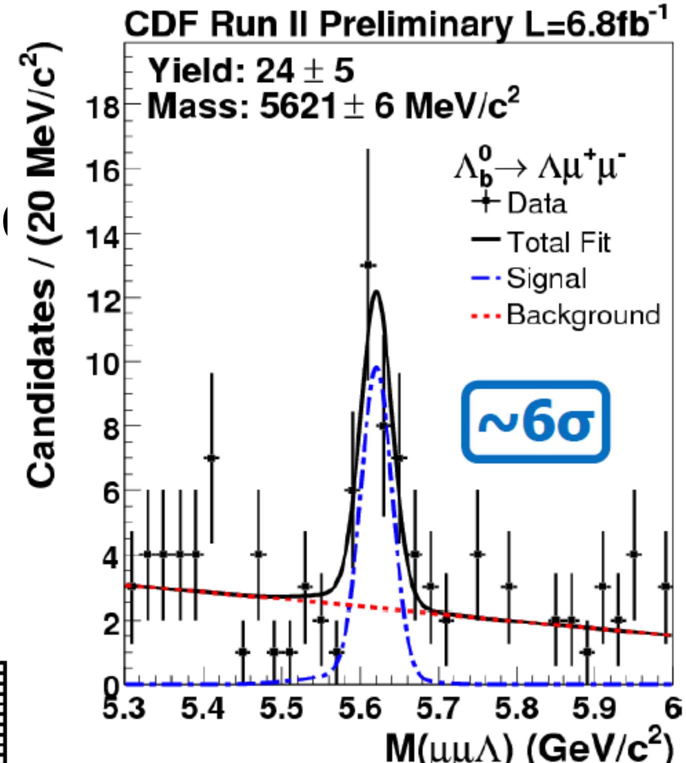
Combined $B<2.4\times10^{-12}$

- Many limits on $\tau \rightarrow \ell hh$, $\bar{\Lambda}h$, Λh, $\mu\gamma$, μh, 3μ, best limits near 10^{-8} (Belle, BaBar)

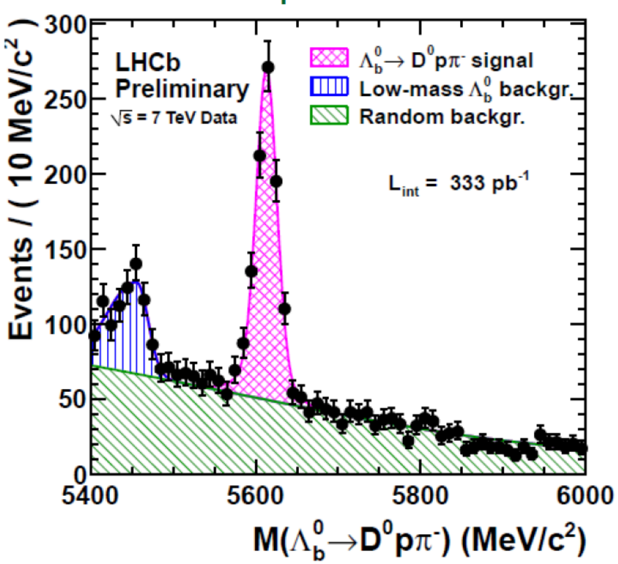
New b-Baryon Decays



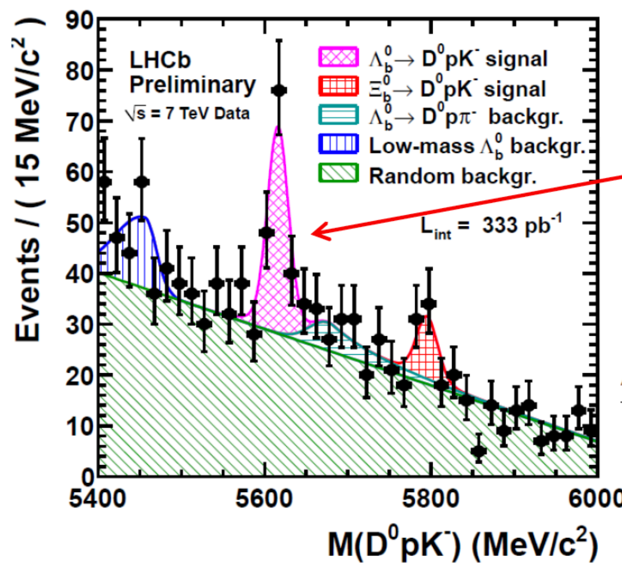
CDF Ξ_b^o
1st observation
mass 5787.8±5.(MeV



$D^0p\pi^-$



D^0pK^-



$\Lambda_b \rightarrow D^0pK$

$\Lambda_b \rightarrow D^0pK$ observed for first time with significance of 6.3σ

$$\frac{\mathcal{B}(\Lambda_b^0 \rightarrow D^0pK^-)}{\mathcal{B}(\Lambda_b^0 \rightarrow D^0p\pi^-)} = 0.112 \pm 0.019^{+0.011}_{-0.014}$$

Basics For Sensitivities

- # of b's into detector acceptance
- Triggering
- Flavor tagging
- Background reduction
  - Good mass resolution
  - Good decay time resolution
  - Particle Identification

CPV Time Evolution

- Consider $$a[f(t)] = \frac{\Gamma\left(\bar{M} \to f\right) - \Gamma\left(M \to f\right)}{\Gamma\left(\bar{M} \to f\right) + \Gamma\left(M \to f\right)}$$
- Define $$A_f \equiv A(M \to f), \bar{A}_f \equiv A(\bar{M} \to f), \quad \lambda_f = \frac{p}{q}\frac{\bar{A}_f}{A_f}$$
- Only 1 A_f & $\Delta\Gamma$=0 $\Gamma\left(M \to f\right) = N_f\left|A_f\right|^2 e^{-\Gamma t}\left(1 - \text{Im}\,\lambda_f \sin\left(\Delta M t\right)\right)$
- Then $a[f(t)] = -\text{Im}\,\lambda_f$, & λ_f is a function of V_{ij} in SM
- For B°, $\Delta\Gamma \approx 0$, but there can be multiple A_f
- If in addition $\Delta\Gamma \neq 0$, eg. B_s

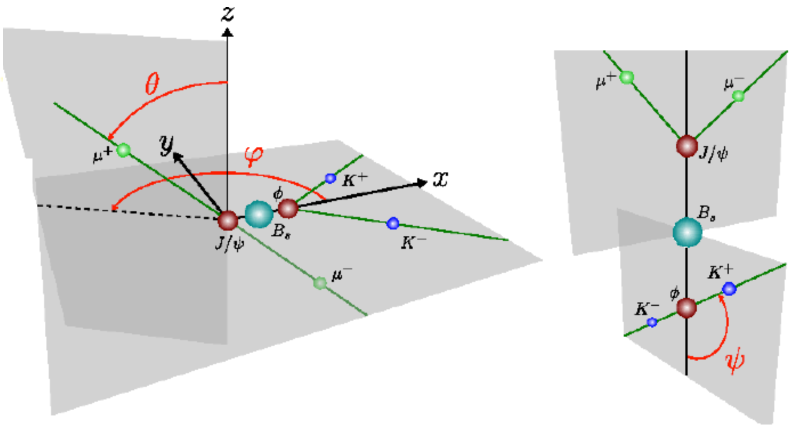
$$\Gamma\left(M \to f\right) = N_f\left|A_f\right|^2 e^{-\Gamma t}\left(\frac{1-\left|\lambda_f\right|^2}{2}\cos\left(\Delta M t\right) - \text{Im}\,\lambda_f \sin\left(\Delta M t\right)\right)$$

$$\Gamma\left(M \to f\right) = N_f\left|A_f\right|^2 e^{-\Gamma t}\left(\frac{1+\left|\lambda_f\right|^2}{2}\cosh\frac{\Delta\Gamma t}{2} + \frac{1-\left|\lambda_f\right|^2}{2}\cos\left(\Delta M t\right) - \text{Re}\,\lambda_f \sinh\frac{\Delta\Gamma t}{2} - \text{Im}\,\lambda_f \sin\left(\Delta M t\right)\right)$$

See Nierste, arXiv:0904.1869 [hep-ph]

Transversity

$$\frac{d^4\Gamma(B_s^0 \to J/\psi\phi)}{dt\, d\cos\theta\, d\varphi\, d\cos\psi} \equiv \frac{d^4\Gamma}{dt\, d\Omega} \propto \sum_{k=1}^{10} h_k(t) f_k(\Omega)$$



k	$h_k(t)$	$f_k(\theta,\psi,\varphi)$
1	$\|A_0\|^2(t)$	$2\cos^2\psi\,(1-\sin^2\theta\cos^2\phi)$
2	$\|A_\parallel(t)\|^2$	$\sin^2\psi\,(1-\sin^2\theta\sin^2\phi)$
3	$\|A_\perp(t)\|^2$	$\sin^2\psi\sin^2\theta$
4	$\Im(A_\parallel(t)\,A_\perp(t))$	$-\sin^2\psi\sin 2\theta\sin\phi$
5	$\Re(A_0(t)\,A_\parallel(t))$	$\frac{1}{2}\sqrt{2}\,\sin 2\psi\sin^2\theta\sin 2\phi$
6	$\Im(A_0(t)\,A_\perp(t))$	$\frac{1}{2}\sqrt{2}\,\sin 2\psi\sin 2\theta\cos\phi$
7	$\|A_s(t)\|^2$	$\frac{2}{3}(1-\sin^2\theta\cos^2\phi)$
8	$\Re(A_s^*(t)A_\parallel(t))$	$\frac{1}{3}\sqrt{6}\sin\psi\sin^2\theta\sin 2\phi$
9	$\Im(A_s^*(t)A_\perp(t))$	$\frac{1}{3}\sqrt{6}\sin\psi\sin 2\theta\cos\phi$
10	$\Re(A_s^*(t)A_0(t))$	$\frac{4}{3}\sqrt{3}\cos\psi(1-\sin^2\theta\cos^2\phi)$

} for S-wave under ϕ predicte by Stone & Zhang PRD 79, 074024 (2009)

Transversity II

$$
\begin{aligned}
|A_0|^2(t) &= |A_0|^2 e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma}{2}t\right) - \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) + \sin\phi_s \sin(\Delta m t)\right], \\
|A_\parallel(t)|^2 &= |A_\parallel|^2 e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma}{2}t\right) - \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) + \sin\phi_s \sin(\Delta m t)\right], \\
|A_\perp(t)|^2 &= |A_\perp|^2 e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma}{2}t\right) + \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) - \sin\phi_s \sin(\Delta m t)\right], \\
\Im(A_\parallel^*(t)\,A_\perp(t)) &= |A_\parallel||A_\perp| e^{-\Gamma_s t}\left[-\cos(\delta_\perp - \delta_\parallel)\sin\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right)\right. \\
&\quad \left. - \cos(\delta_\perp - \delta\_\|)\cos\phi_s \sin(\Delta m t) + \sin(\delta_\perp - \delta_\parallel)\cos(\Delta m t)\right], \\
\Re(A_0^*(t)\,A_\parallel(t)) &= |A_0||A_\parallel| e^{-\Gamma_s t}\cos(\delta_\parallel - \delta_0)\left[\cosh\left(\frac{\Delta\Gamma}{2}t\right) - \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right)\right. \\
&\quad \left. + \sin\phi_s \sin(\Delta m t)\right], \\
\Im(A_0^*(t)\,A_\perp(t)) &= |A_0||A_\perp| e^{-\Gamma_s t}\left[-\cos(\delta_\perp - \delta_0)\sin\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right)\right. \\
&\quad \left. - \cos(\delta_\perp - \delta_0)\cos\phi_s \sin(\Delta m t) + \sin(\delta_\perp - \delta_0)\cos(\Delta m t)\right], \\
|A_s(t)|^2 &= |A_s|^2 e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma}{2}t\right) + \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) - \sin\phi_s \sin(\Delta m t\right], \\
\Re(A_s^*(t)A_\parallel(t)) &= |A_s||A_\parallel| e^{-\Gamma_s t}\left[-\sin(\delta_\parallel - \delta_s)\sin\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) - \sin(\delta_\parallel - \delta_s)\ \cos\phi_s \sin(\Delta m t)\right. \\
&\quad \left. + \cos(\delta_\parallel - \delta_s)\cos(\Delta m t)\right], \\
\Im(A_s^*(t)A_\perp(t)) &= |A_s||A_\perp| e^{-\Gamma_s t}\sin(\delta_\perp - \delta_s)\left[\cosh\left(\frac{\Delta\Gamma}{2}t\right) + \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right)\right. \\
&\quad \left. - \sin\phi_s \sin(\Delta m t)\right], \\
\Re(A_s^*(t)A_0(t)) &= |A_s||A_0| e^{-\Gamma_s t}\left[-\sin(\delta_0 - \delta_s)\sin\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right)\right. \\
&\quad \left. - \sin(\delta_0 - \delta_s)\cos\phi_s \sin(\Delta m t) + \cos(\delta_0 - \delta_s)\cos(\Delta m t)\right].
\end{aligned}
$$

only term for $f=f_{cp}$

CPV in Charm

- Expect largest effects in Cabibbo Suppressed Decays. COULD REVEAL NP (see Grossman Kagan & Nir arXiv:1204.3557)
- Define: $A_{CP}(D \to f) = \dfrac{\Gamma(D \to f) - \Gamma(\bar{D} \to \bar{f})}{\Gamma(D \to f) + \Gamma(\bar{D} \to \bar{f})}$

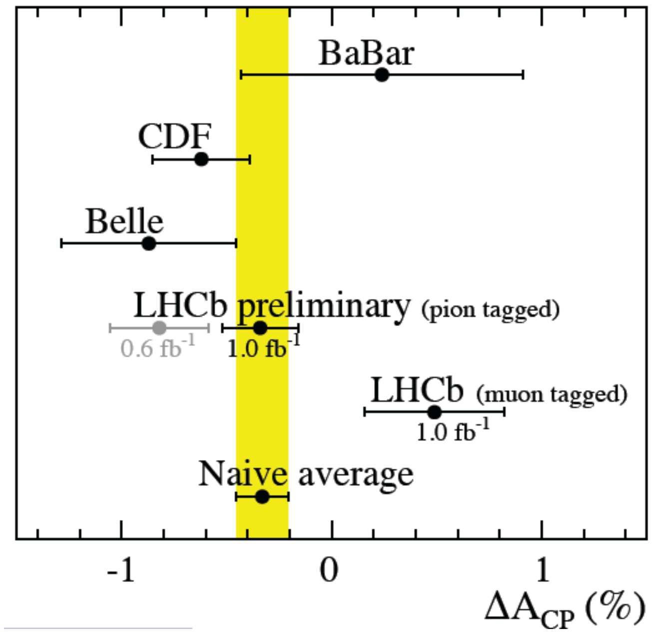
if f is a CP eigenstate then $f = \bar{f}$

- Current data for

$$\Delta A_{CP} \equiv A_{CP}\left(K^+K^-\right) - A_{CP}\left(\pi^+\pi^-\right)$$

do not show much, though

some early measurements gave a 4.5σ effect.



Both SM & NP explanations are prolific

Interpretation

- Prior to result: "CPV in charm is clearly beyond the SM"

New Physics and CP Violation

in Singly Cabibbo Suppressed D Decays

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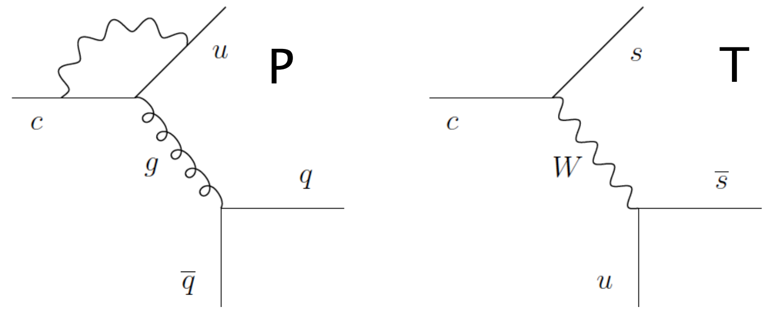
Abstract

We analyze various theoretical aspects of CP violation in singly Cabibbo suppressed (SCS) D-meson decays, such as $D \to KK, \pi\pi$. In particular, we explore the possibility that CP asymmetries will be measured close to the present level of experimental sensitivity of $\mathcal{O}(10^{-2})$. Such measurements would signal new physics.

"New think"

- Direct CP in SM caused by interference between P and T

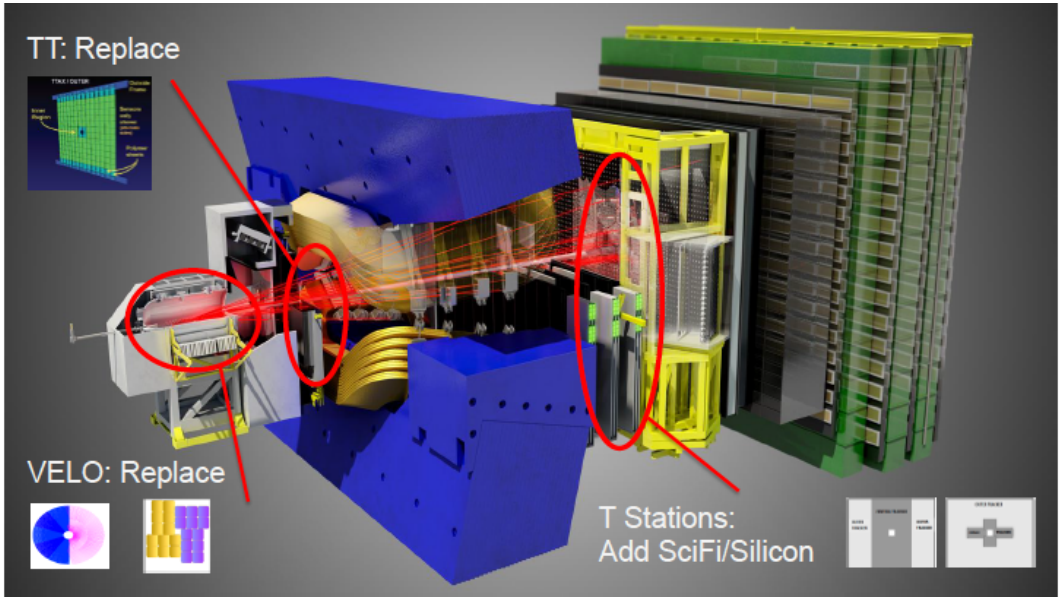


- Since $V_{us}=-V_{cd}$

  $A_{CP}(K^+K^-)= -A_{CP}(\pi^+\pi^-)$
- Still need P/T to be >3, while in B decays it is 0.15….
- But there is the $\Delta I=1/2$ rule in K_L decay which is not understood, so all bets are off (Grossman, CERN seminar Jan. 12, 2012)

Tracking

- At L=2x10^{33} cm^{-2}s^{-1} the event topology is more complex:
  - More primary vertices
  - Increased track multiplicity
  - Bunch-to-bunch spillover
  - Detector occupancy (highly non-uniform, radial dependence)

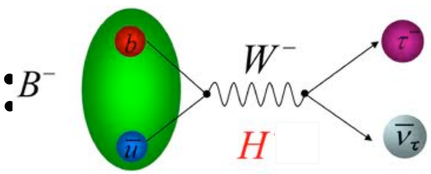


Highlights on technological challenges:

- VELO: high radiation & data rates in the innermost section
- Super think shaped RF foil for VELO
- All tracking layers: closer to the beam line, low mass support and cooling

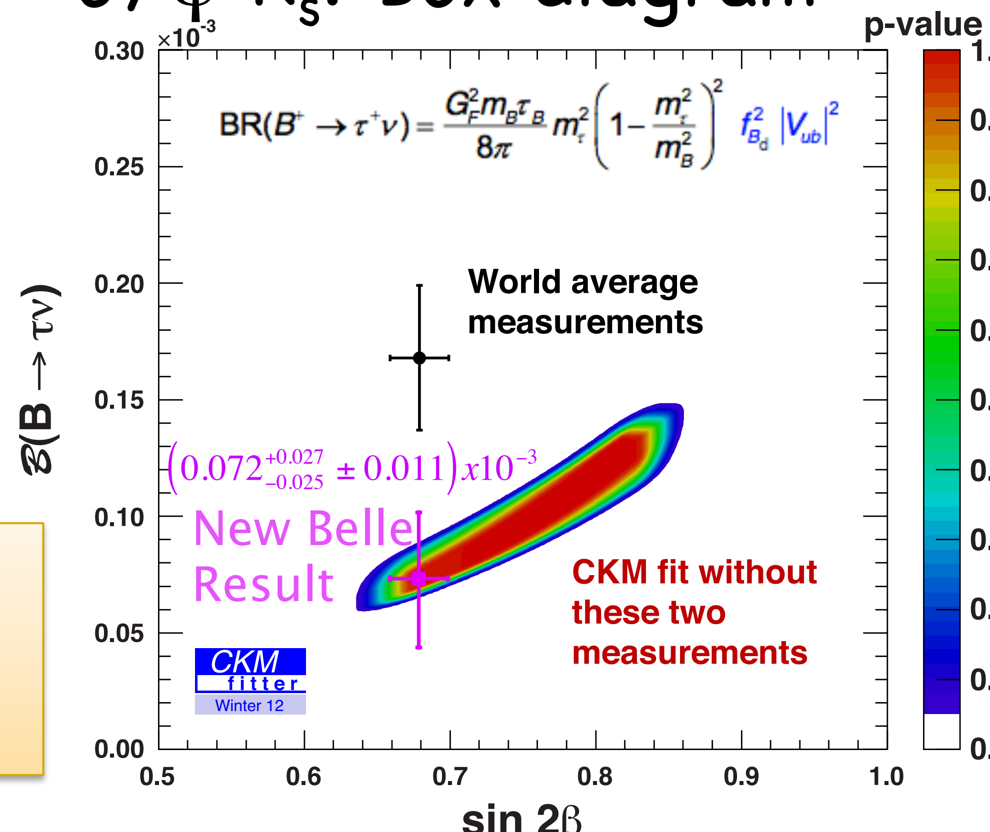
$B^- \to \tau^- \bar{\nu}$ problem?

- $B^- \to \tau^- \nu$, tree process:



Can be new particles instead of W⁻ but why not also in $D^+_{(s)} \to \ell^+ \nu$?

- sin2β, CPV in e.g. $B^o \to J/\psi\ K_s$: Box diagram
- Measurement not in good agreement with SM prediction based on CKM fit



Discrepancy may be resolved; await updated BaBar measurement…

Rare Decays – Generic

- $$\mathcal{H}_{\text{eff}} = -\frac{4\,G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{e^2}{16\pi^2} \sum_i (C_i O_i + C_i' O_i') + \text{h.c.}\ .$$
- $C_i O_i$ for SM, $C_i' O_i'$ are for NP. Operators are for $P_{R,L} = (1 \pm \gamma_5)/2$

$$O_7 = \frac{m_b}{e} (\bar{s} \sigma_{\mu\nu} P_R b) F^{\mu\nu}, \qquad O_8 = \frac{g m_b}{e^2} (\bar{s} \sigma_{\mu\nu} T^a P_R b) G^{\mu\nu\, a},$$

$$O_9 = (\bar{s} \gamma_\mu P_L b)(\bar{\ell} \gamma^\mu \ell)\,, \qquad O_{10} = (\bar{s} \gamma_\mu P_L b)(\bar{\ell} \gamma^\mu \gamma_5 \ell)\,,$$

$$O_S = m_b (\bar{s} P_R b)(\bar{\ell} \ell)\,, \qquad O_P = m_b (\bar{s} P_R b)(\bar{\ell} \gamma_5 \ell)\,,$$

- $O' = O$ with $P_{R,L} \rightarrow P_{L,R}$
- Each process depends on a unique combination

Limits on $D^{(*)+} l^- l'^-$

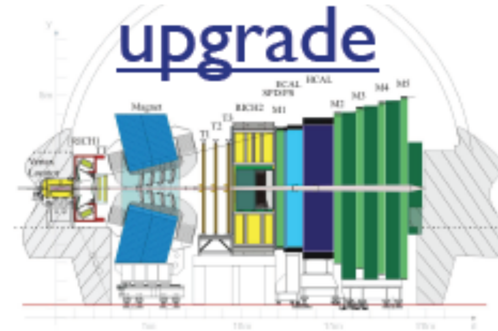
- Upper limits in e^-e^- mode not competitive with nuclear β decay
- Others unique since measure coupling of Majorana ν to μ^-

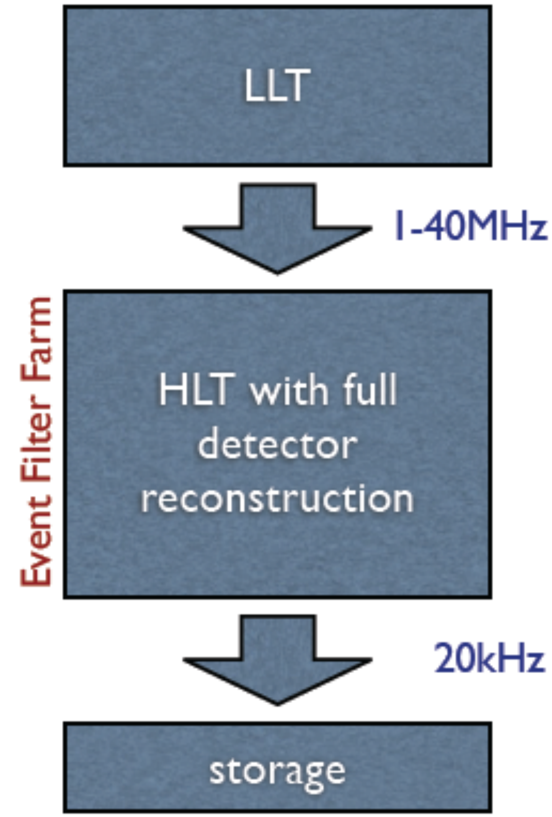
Mode	Exp.	u. l. x 10^{-6}
$B^- \to D^+ e^- e^-$	Belle	< 2.6
$B^- \to D^+ e^- \mu^-$	Belle	< 1.8
$B^- \to D^+ \mu^- \mu^-$	Belle	< 1.0
$B^- \to D^+ \mu^- \mu^-$	LHCb	< 0.69
$B^- \to D^{*+} \mu^- \mu^-$	LHCb	< 3.6

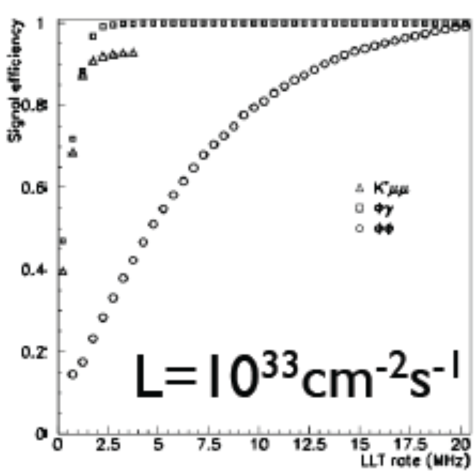
Belle [arXiv:1107.064]

Upgrade trigger information

- change electronics readout to get up to 40MHz and match LHC bunch crossing
- Event Filter Farm reconstructs the event and makes trigger decisions
- Improvements of the CPU computing power are needed

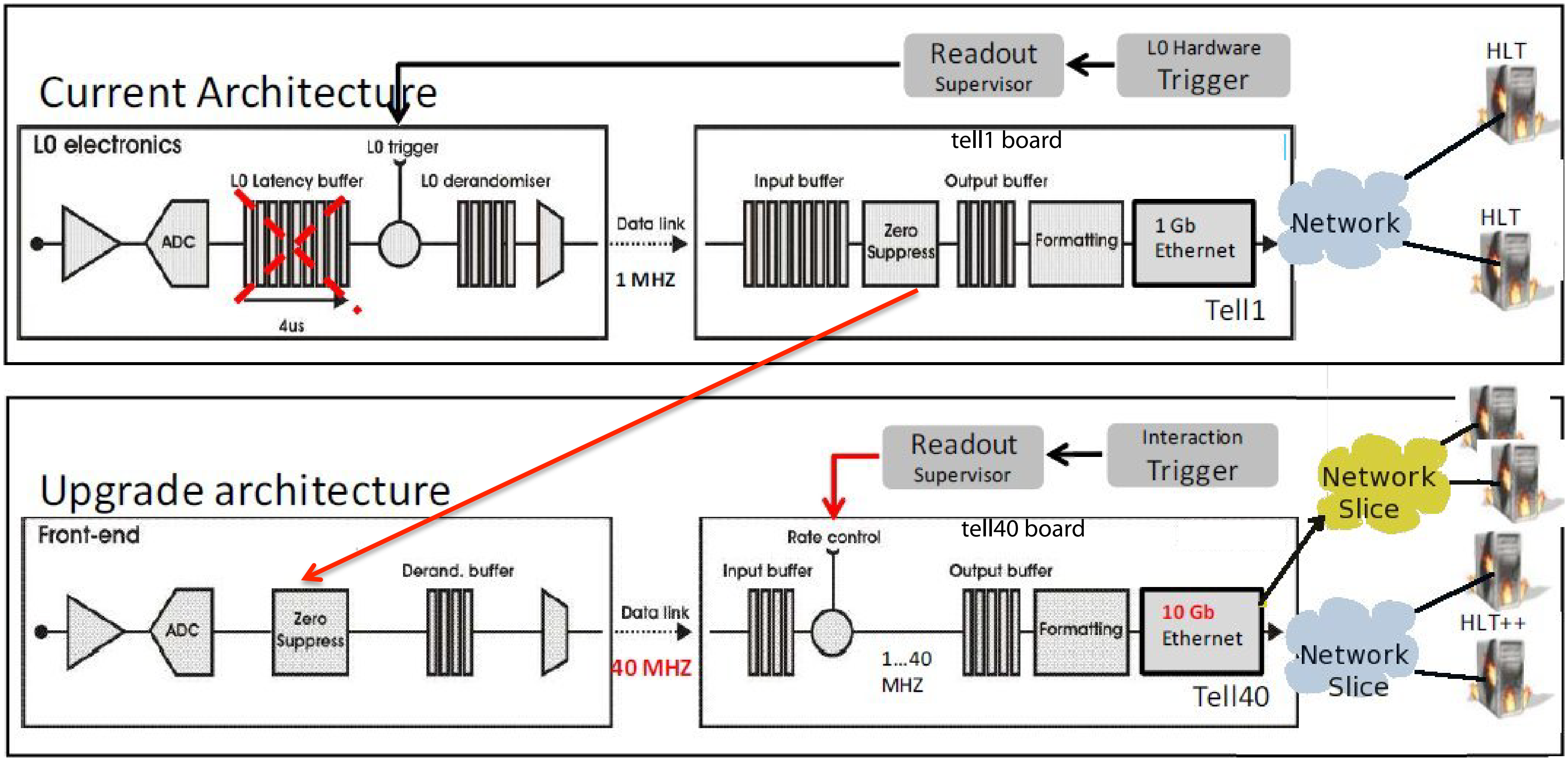






EFF size	5×2011	10×2011
LLT-rate (MHz)	5.1	10.5
HLT1-rate (kHz)	270	570
HLT2-rate (kHz)	16	26
Total signal efficiency		
$B_s \to \phi\phi$	0.29	0.50
$B^0 \to K^*\mu\mu$	0.75	0.85
$B_s \to \phi\gamma$	0.43	0.53

Data acquisition strategy



Detector Requirements – General

- Every modern heavy quark experiment needs:
  - Vertexing: to measure decay points and reduce backgrounds, especially at hadron colliders
  - Particle Identification: to eliminate insidious backgrounds from one mode to another where kinematical separation is not sufficient
  - Muon & electron identification because of the importance of semileptonic & leptonic final states including J/ψ decay
  - γ, π^o & η detection
  - Triggering, especially at hadronic colliders
  - High speed DAQ coupled to large computing for data processing
  - An accelerator capable of producing a large rate of b's