Recent results from LHCb

19th of July 2013

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on behalf of the LHCb collaboration

Dubna International Advanced School of Theoretical Physics / DIAS-TH

Helmholtz International Summer School

“Physics of Heavy Quarks and Hadrons”

Dubna, Russia / July 15-28, 2013

Outline

- Standard Model (SM) and its difficulties [just to remind]
  - Why and where to find New Physics (NP)?
  - Power of indirect measurements
- LHCb setup (apparatus, trigger, physical program etc.) [brief]
- Selected results [main part of the talk]
  - Rare decays ($M\to 2\mu$, $M\to M'2\mu$, $B\to e\mu$)
  - Mixing, CP violation, CKM γ in B systems
  - Mixing and CP violation in charm sector
  - Production and spectroscopy of heavy quarks
- Summary and Outlook (what can be achieved after upgrade?)

Introduction

Standard Model

Параметр	Значение
$\alpha_s(M_Z)$	$0{,}114 \pm 0{,}0007$
$1/\alpha(M_Z)$	$127{,}916 \pm 0{,}015$
$\sin^2\theta_W(M_Z)$	$0{,}23108 \pm 0{,}00005$
Θ	$\lesssim 10^{-10}$
m_u (2 ГэВ)	$2{,}5^{+0{,}8}_{-1{,}0}$ МэВ
m_d (2 ГэВ)	$5{,}0^{+1{,}0}_{-1{,}5}$ МэВ
m_s (2 ГэВ)	105^{+25}_{-35} МэВ
$m_c(m_c)$	$1{,}266^{+0{,}031}_{-0{,}036}$ ГэВ
$m_b(m_b)$	$4{,}198 \pm 0{,}023$ ГэВ
$m_t(m_t)$	$173{,}10 \pm 1{,}35$ ГэВ
m_e	$510{,}998910 \pm 0{,}000013$ кэВ
m_μ	$105{,}658367 \pm 0{,}000004$ МэВ
m_τ	$1{,}77682 \pm 0{,}00016$ ГэВ
θ_{12}	$13{,}02^\circ \pm 0{,}05^\circ$
θ_{23}	$2{,}35^\circ \pm 0{,}06^\circ$
θ_{13}	$0{,}199^\circ \pm 0{,}011^\circ$
δ	$1{,}20 \pm 0{,}08$
$v(m_\mu)$	$246{,}221 \pm 0{,}002$ ГэВ
M_H	115,5 – 127,0 ГэВ (уровень достоверности 95 %)

No doubt that SM is great achievement!

(self consistent, no conflict with HEP)

Reasons for NP:

1) Neutrino sector
   - mass
   - oscillations
2) Astrophysics
   - baryon asymmetry of our Universe
   - dark matter
3) Radiative correction to M(Higgs)
   - fine tuning
   - desert between M_{EW} and M_{GUT}

SUSY good candidate to solve 2) & 3)

Power of indirect measurements

Example #1: CP violation in kaon system

Has been done when only 3 quark were known

1972 Kabayashi-Maskawa 6-quark model

~ 13 years before Upsilon discovery

Example #2: Weak neutral current (Gargamelle bubble chamber)

~ 10 years before Z discovery at UA1/2

Example #3: ARGUS collaboration report large B-mixing

Suggest large mass of top quark

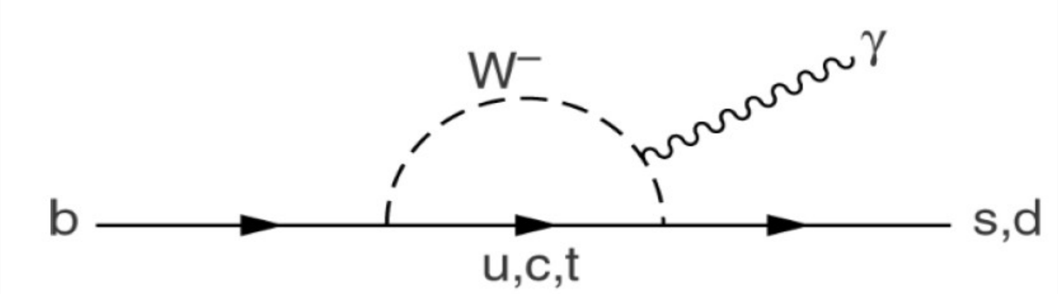
~8 years *t* has been discovered at Tevatron

Indirect measurements at LHC

- How NP related to flavour physics?
- Is NP weakly coupled to flavour sector (MFV) or at very high scale?

  Important to have a **probes beyond LHC energies** (direct observation)!
- Better to use processes which are either forbidden either highly suppressed in SM

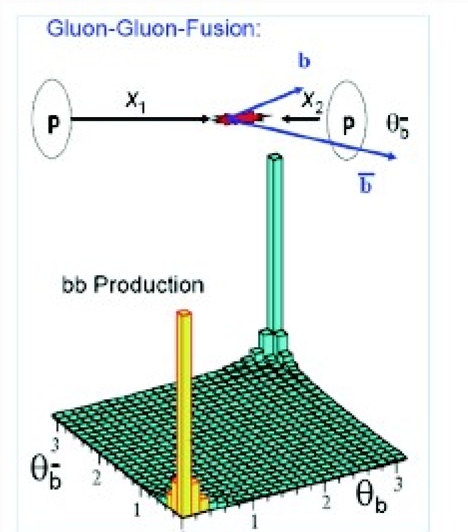
  Flavour Changing Neutral Currents (FCNC) can be such a probe



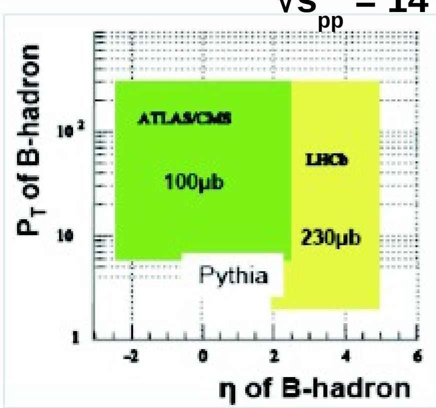
- Other possibilities **Lepton Flavour Violation (LFV), CPV in charm sector**

LHCb features

Beauty and charm production

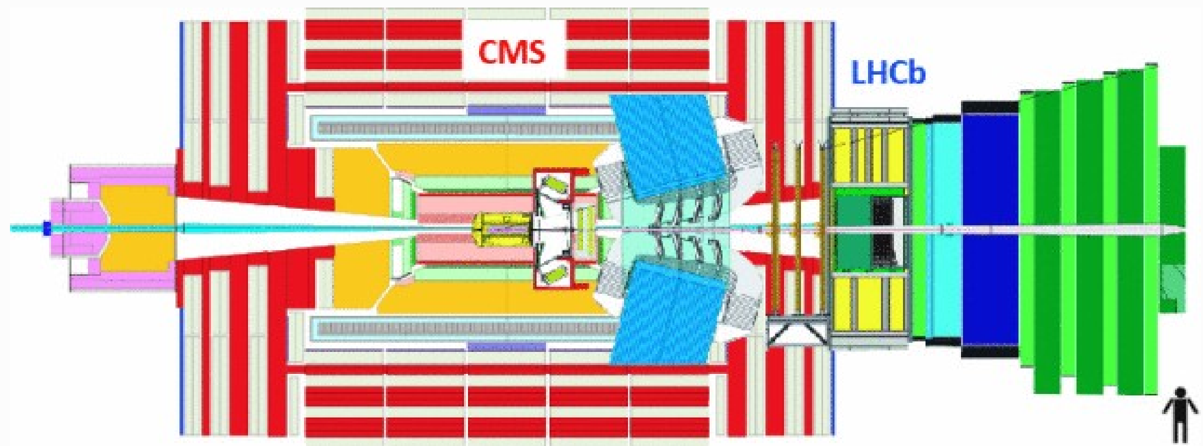


$\sqrt{s}_{pp}$ = 14 TeV



- **LHCb: forward spectrometer** $2 < \eta < 5$

  (ATLAS & CMS: $|\eta|<2.5$)



- In LHCb acceptance (*pp*-collisions $\sqrt{s}$ = 7TeV)

$$\sigma(b\bar{b}) = 75.3 \pm 5.4 \pm 13.0\ \mu b$$

Phys.Lett.B694 (2010) 209-216

$$\sigma(c\bar{c}) = 1419 \pm 12 \pm 116\ \mu b \sim 20 \times \sigma(b\bar{b})$$

Largest charm samples in the world

Nucl.Phys.B871 (2013) 1

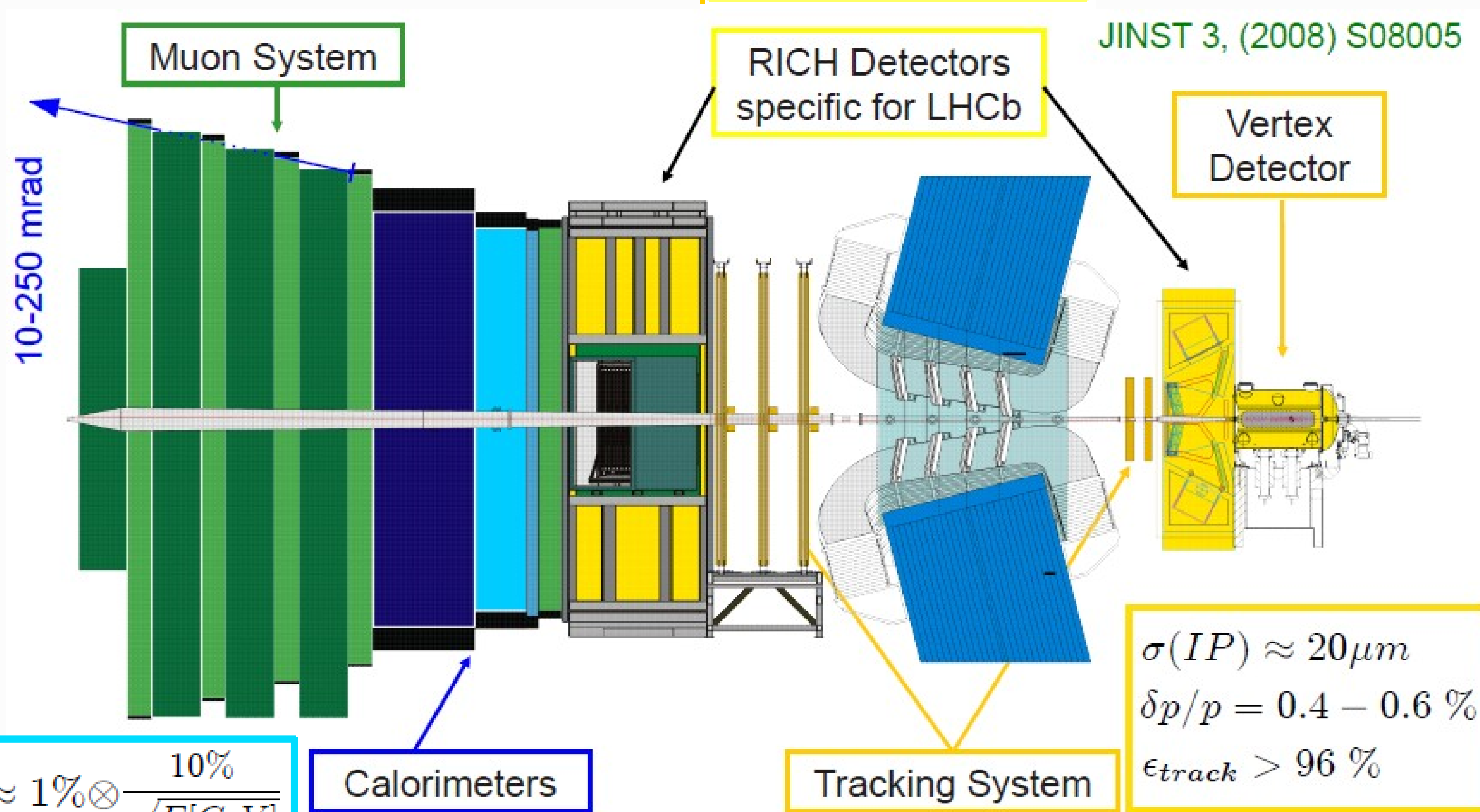
Experimental setup

$\epsilon_{PID}(\mu) \approx 97~\%$

MisID $(\pi \rightarrow \mu) \approx 3~\%$

$\epsilon_{PID}(K) \approx 95~\%$

MisID $(K \rightarrow \pi) \approx 5~\%$



$\sigma(IP) \approx 20 \mu m$

$\delta p/p = 0.4 - 0.6~\%$

$\epsilon_{track} > 96~\%$

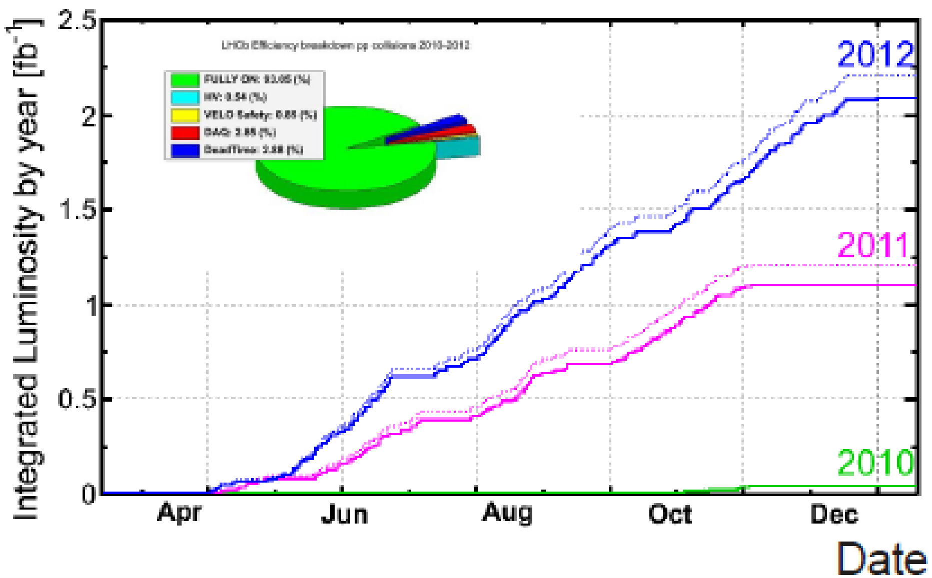
$\frac{\sigma}{E} \approx 1\% \otimes \frac{10\%}{\sqrt{E[GeV]}}$

$\epsilon_{PID}(e) \approx 95~\%$

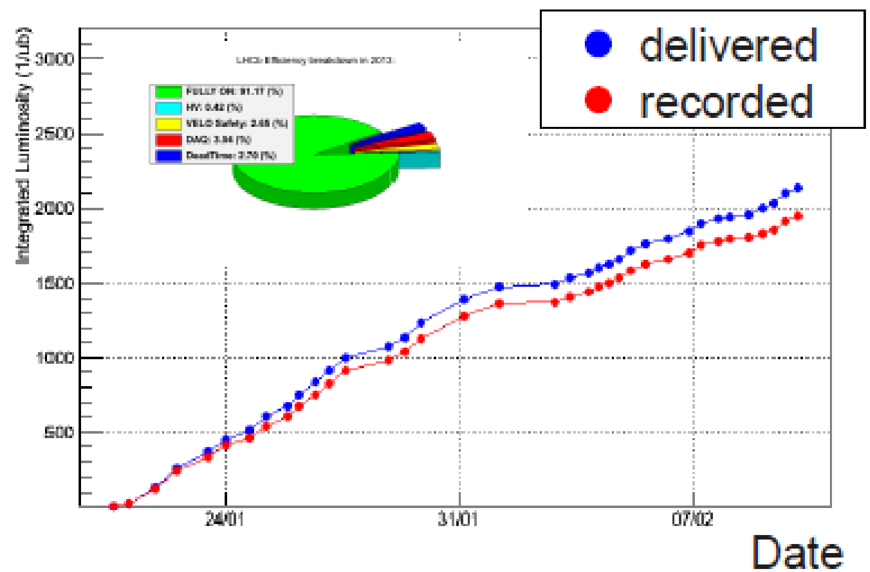
MisID $(e \rightarrow h) \approx 5~\%$

Operation in 2010/12

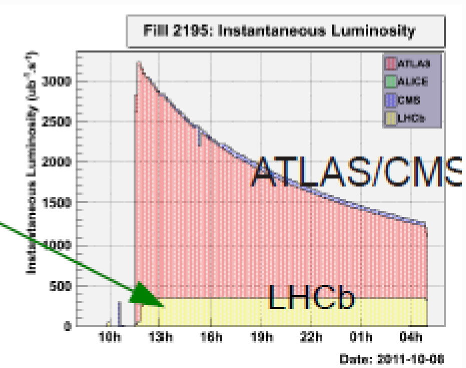
- p-p at 3.5 / 4 TeV



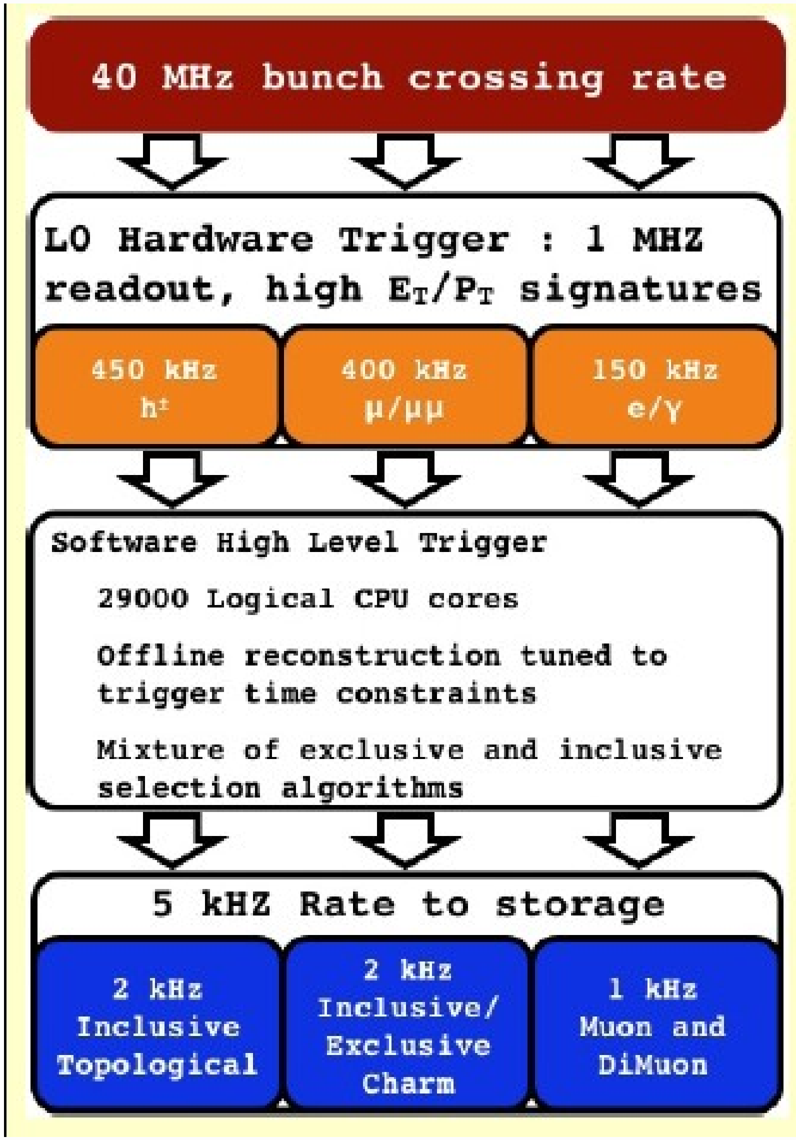
- p-Pb at $\sqrt{s_{NN}} = 5$ TeV in 2013



- LHCb operates with high efficiency
- Take data at constant instantaneous luminosity rate: $\mathcal{L} \approx 4 \times 10^{32}\, cm^{-2} s^{-1}$ (factor 2 larger than design luminosity)
- Visible pp interactions per bunch crossing μ = 1.7 (50 ns bunch spacing)



LHCb trigger



Goal: To select interesting beauty and charm decays while maintaining the managable data rates

Level 0:

- Largest p_T (E) used
- Typical thresholds 1.5 – 3.5 GeV/c

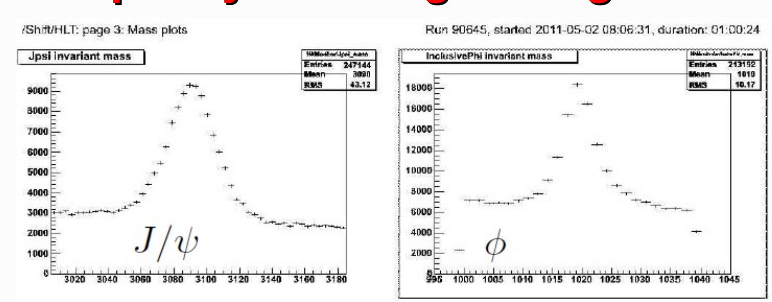
Software HLT1:

- Partial event reconstruction
- Selection based on p_T, IP

Software HLT2:

- Full event reconstruction
- Mass cuts

On-line charm and strange signals
Data quality from sig-to-bkg ratio.



LHCb data analysis

Tagging if needed

Event selection

Kinematical and topological info
(pT, p, IP, vertex and track quality)

PID information

Cut based or multivariate selection
BDT, Neurobayes, *etc.*

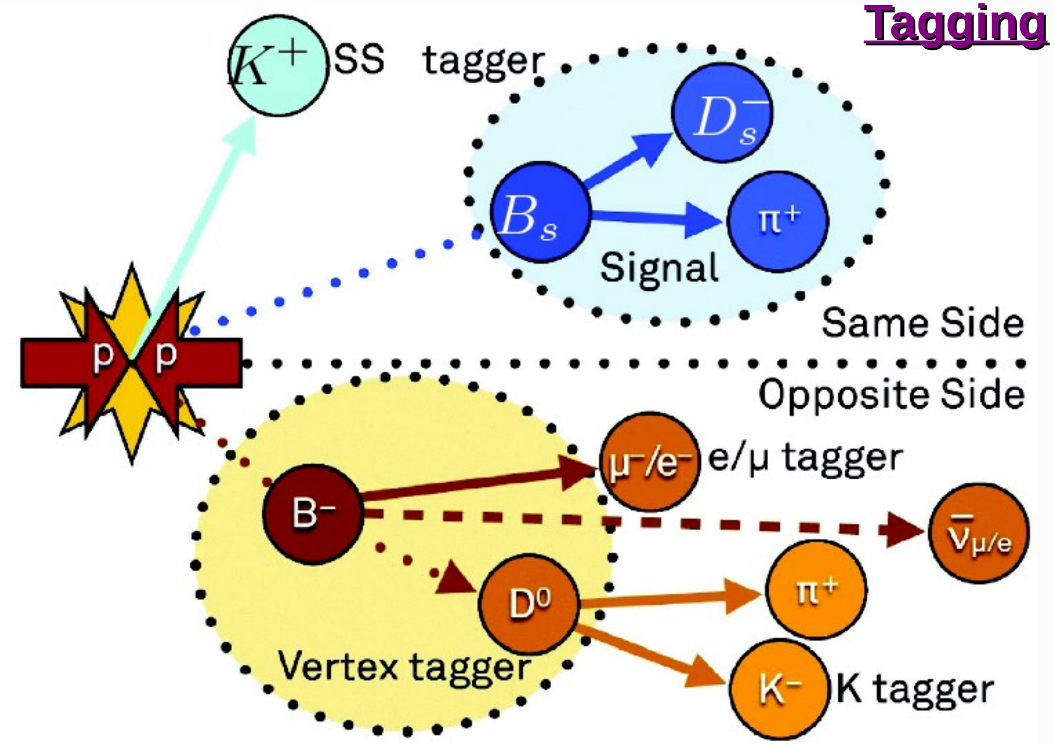
Optimization of selection
Using MC
Using small sample of real data

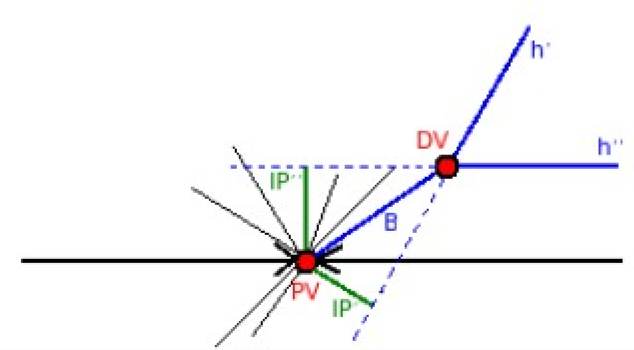
Angular analysis++

Check for systematics

And a lot of other checks!

Tagging





Selection using IP:

PV = Primary Vertex

DV = Daughter Vertex

(secondary vertex)

Physics program of LHCb

GOAL: **Search for evidence of NP in CP violation and rare decays of beauty and charm hadrons.** (Probing large mass scales via study of virtual quantum loops of new particles)

LHCb results are available in more that 130 papers submitted to journals and 110 conference contributions

https://cds.cern.ch/collection/LHCb%20Conference%20Contributions?ln=en
https://cds.cern.ch/collection/LHCb%20Papers?ln=en

Main direction of searches:

1) Rare decays
  RD with di-muons, LFV searches

2) Properties of the B systems
  CPV, Δms; Γs, ΔΓ, φs ; CKM γ determination

3) Mixing and CPV in the D systems
  Mixing observ., ΔA(CP)

4) Spectroscopy and production of heavy quarks
  X(3872) quantum num.; mass of *D* mesons

Partially covered in this talk

5) Electroweak physics

6) Soft QCD physics, pA and Ap results

Not covered =(

Rare decays

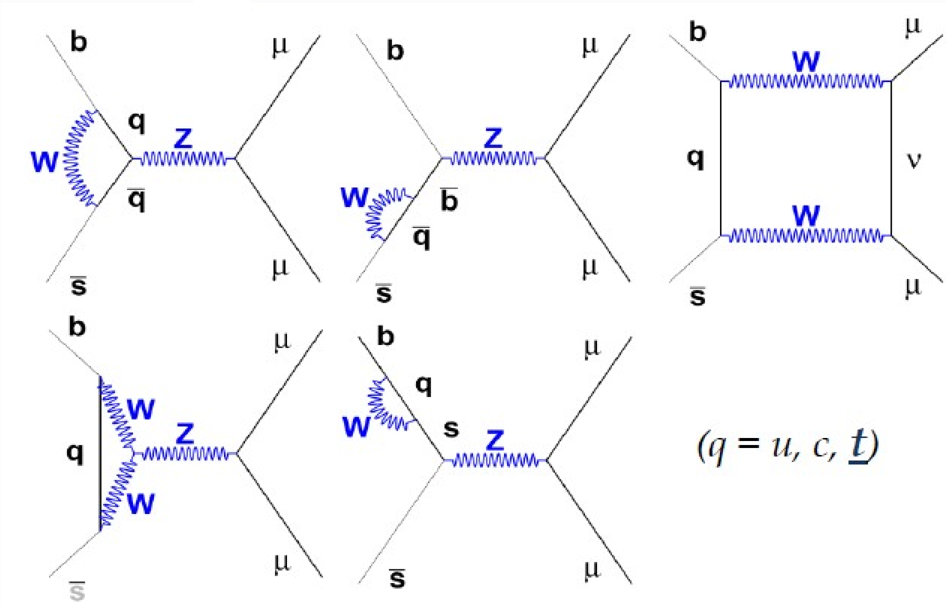
1) $B_{d,s}^0 \to \mu^+\mu^-$, $B \to \mu^+\mu^-\mu^+\mu^-$, $D^0 \to \mu^+\mu^-$, $K_S^0 \to \mu^+\mu^-$

2) B-hadron $\to$ Hadron + $\mu^+\mu^-$, $D \to \pi\mu^+\mu^-$

3) $B \to \mu^+ e^-$

4) $B_s \to \phi K^*$

Rare decays $B_{(s)}^0 \to \mu^+\mu^-$

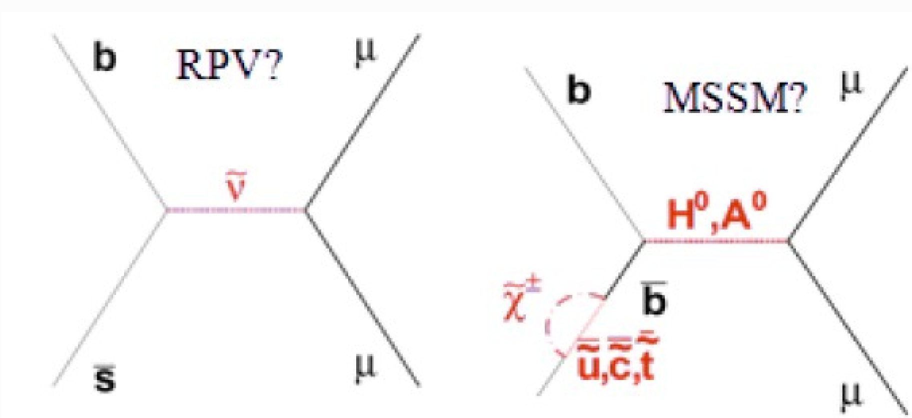


Helicity suppressed in SM [arXiv 1303.3820]

$$\mathcal{B}(B_s \to \mu^+\mu^-) = (3.25 \pm 0.17) \times 10^{-9}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = (1.07 \pm 0.10) \times 10^{-10}$$

$\Delta\Gamma_s$ correction [PRD 86, 014027]

$$\mathcal{B}(B_s \to \mu^+\mu^-)_{<t>} = \frac{1 + \mathcal{A}^{\mu\mu}_{\Delta\Gamma}.\Delta\Gamma_s/2\Gamma_s}{1-(\Delta\Gamma_s/2\Gamma_s)^2}.\mathcal{B}(B_s \to \mu^+\mu^-) = (3.56 \pm 0.18) \times 10^{-9}$$



5% precision SM calculations!

Sensitive to new scalar, pseudoscalar, axial-vector particles in loops

In MSSM:

$$c_{S,P}^{MSSM\,2} \propto \frac{m_b^2 m_\mu^2 \tan^6\beta}{M_A^4}$$

Table with different scenarios

Scenario	*would point to …*
$BR(B_s \rightarrow \mu\mu) >> SM$	*Big enhancement from NP in scalar sector, SUSY high tanβ*
$BR(B_s \rightarrow \mu\mu) \neq SM$	*SUSY (C_S, C_P) , ED's, LHT, TC2 (C_{10})…*
$BR(B_s \rightarrow \mu\mu) \sim SM$	*Anything (→ rule out regions of parameter space that predict sizable departures from SM. Obviously)*
$BR(B_s \rightarrow \mu\mu) << SM$	*NP in scalar sector, but full MSSM ruled out. NMSSM (Higgs singlet) good candidate*
$BR(B_s \rightarrow \mu\mu) / BR(B_d \rightarrow \mu\mu) \neq SM$	*CMFV ruled out. New FCNC sources fully independent of CKM matrix (RPV SUSY, ED's etc…)*

Here we are now!

Scenario	*would point to ...*
$BR(B_s \rightarrow \mu\mu) \neq SM$	SUSY (C_S, C_P) , ED's, LHT, TC2 (C_{10})...
$BR(B_s \rightarrow \mu\mu) \sim SM$	Anything (→ rule out regions of parameter space that predict sizable departures from SM. Obviously)
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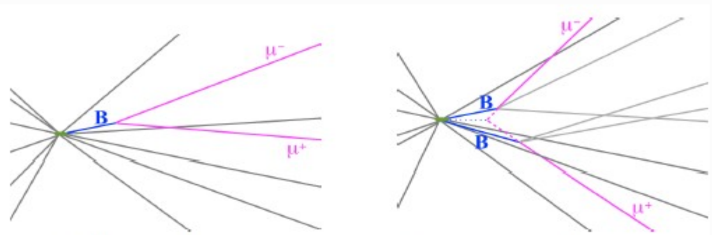
Some words about analysis strategy

$\sim 2/3$ LHCb dataset: $1.0\ \mathrm{fb}^{-1}$ @ 7 TeV + $1.1\ \mathrm{fb}^{-1}$ @ 8 TeV

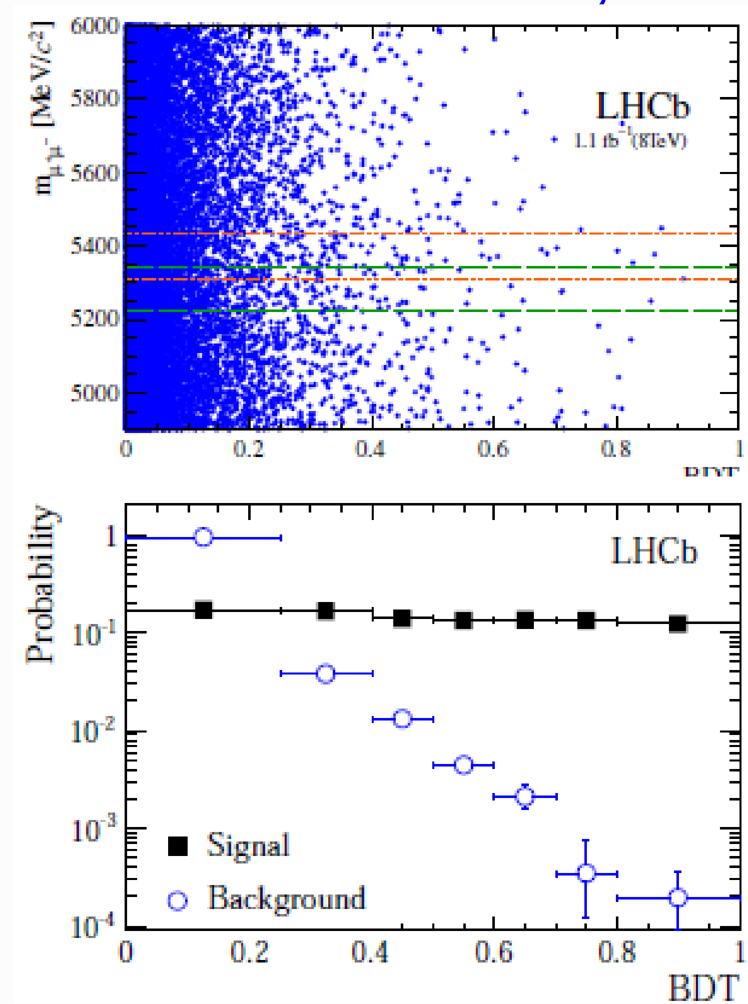
PRL 110, 021801

- Blind analysis
- Robust selection cuts for reduction of combinatorics
- Boosting Decision Tree (BDT) method using 9 topological variables (to avoid correlation with M_{inv})

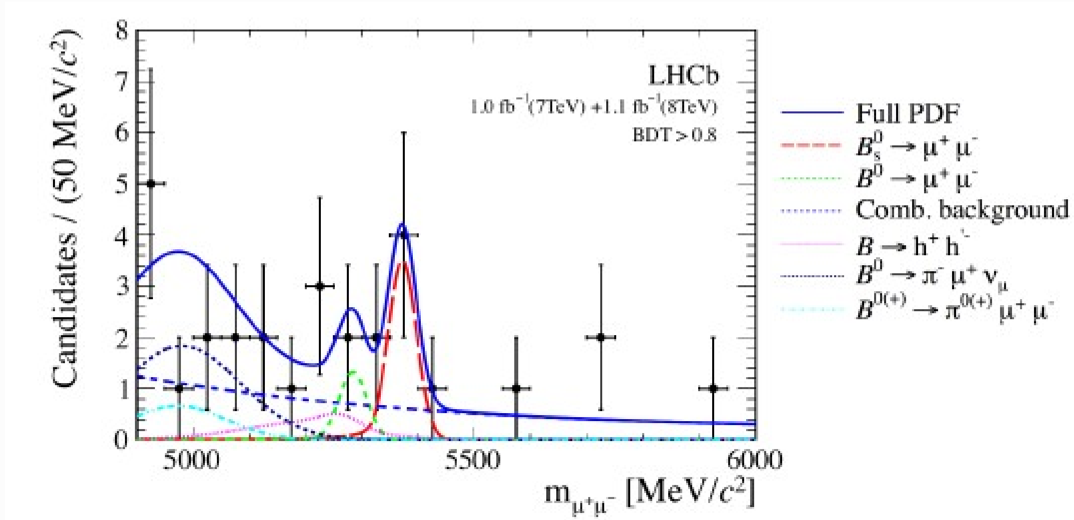


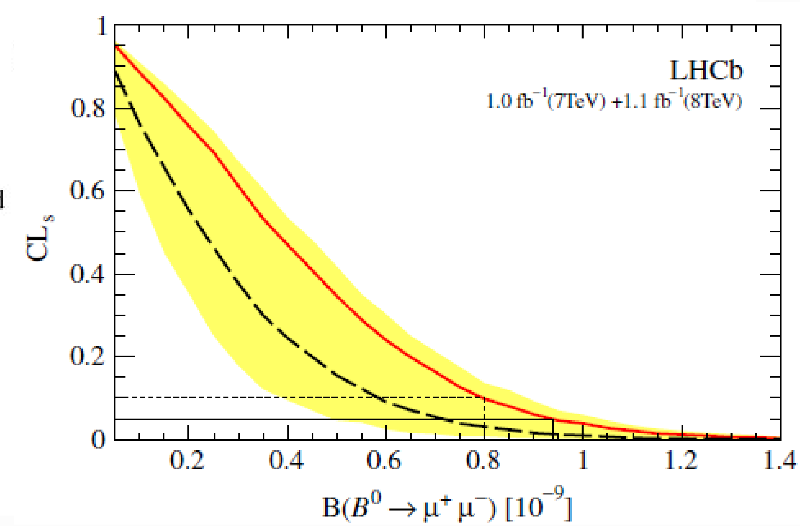
(a) $B^0_{d,s} \to \mu^+\mu^-$ signal (b) $bb \to \mu^+\mu^- X$ background

- BDT *trained* on signal and bkg MC
- BDT *calibrated* on data using *B->h⁺h⁻* as signal and mass sidebands for bkg.
- 15 BDT bins. In each bin, the compatibility of the observed events with <u>bkg only</u> and <u>SM+bkg</u> hypotheses is calculated.



Result: first evidence of $B_s^0 \to \mu^+\mu^-$





PRL 110, 021801

- Compatibility with background only hypothesis (1-CL_b):
  - $B^0 \to \mu^+\mu^-$: 0.11
  - $B_s^0 \to \mu^+\mu^-$: $5.3 \times 10^{-4} \to 3.5\sigma$, evidence of decay!
- $\mathcal{B}(B^0 \to \mu^+\mu^-) < 9.4 \times 10^{-10}$ (at 95 % CL)
  - Set using the CL_s method
- $\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.2^{+1.5}_{-1.2}) \times 10^{-9}$
  - Profile likelihood scan of $\mathcal{B}(B_s^0 \to \mu^+\mu^-)$ by simultaneously fitting $m_{\mu^+\mu^-}$ across all BDT bins for 7 & 8 TeV datasets

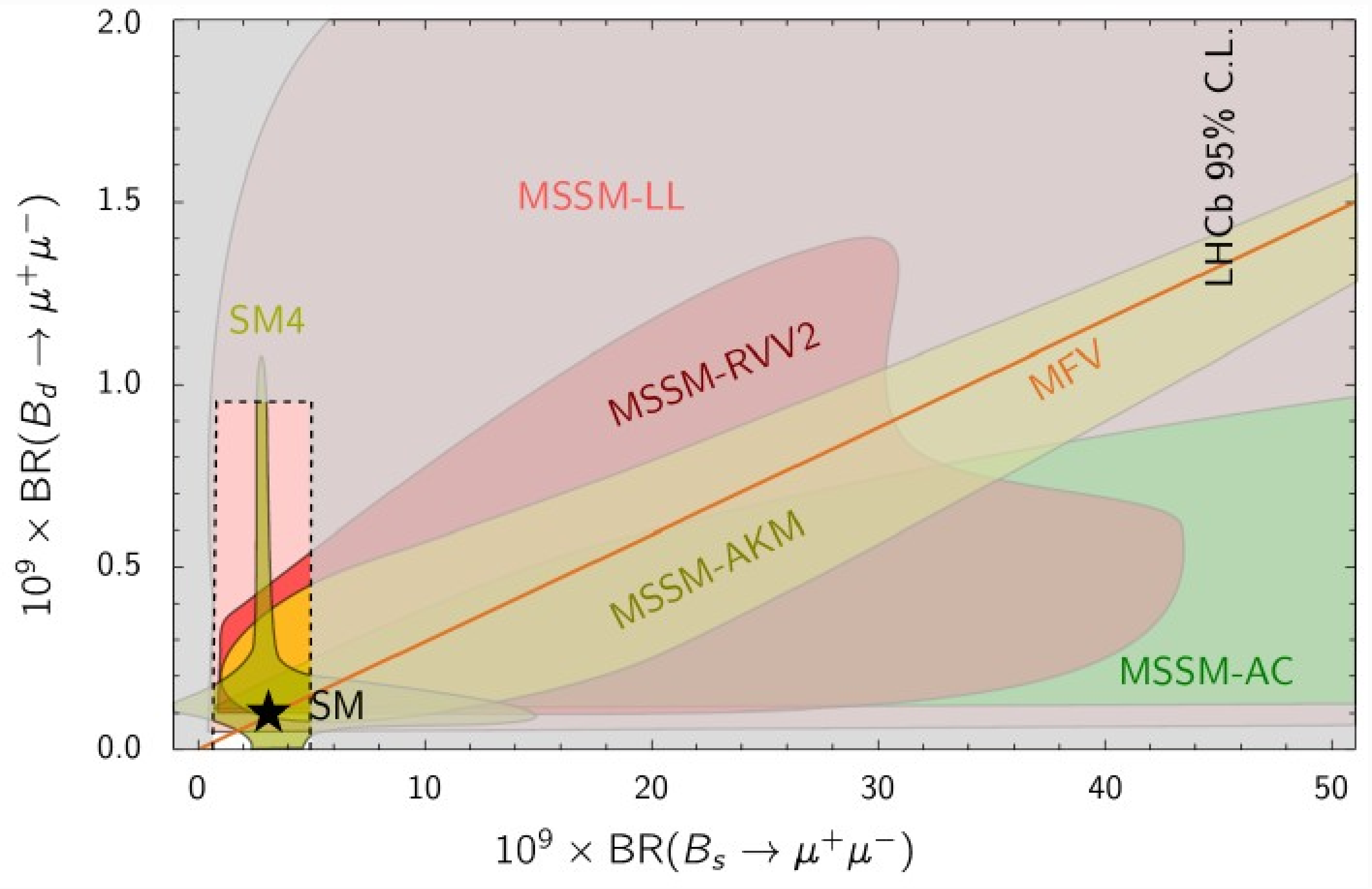
Should be compared with time-integrated branching fraction $(3.54 \pm 0.30) \times 10^{-9}$

Result vs NP

Any model that violates flavour via (pseudo)scalar is constrained.

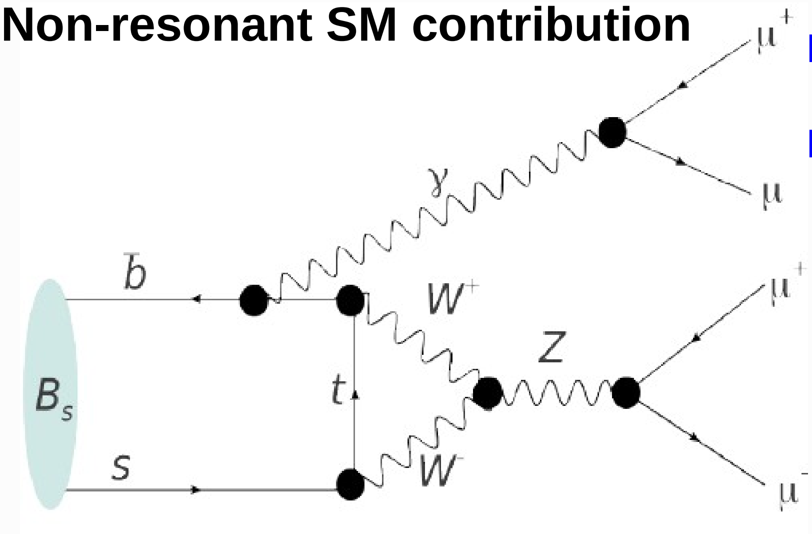
High *tanβ* SUSY too

arXiv:1205:6494



$B_s^0 \to \mu^+\mu^-\mu^+\mu^-$

Non-resonant SM contribution



PDG, JPG 37, 1 $\mathcal{B}(B^0_{(s)} \to J/\psi\phi) = (2.3 \pm 0.9) \times 10^{-8}$

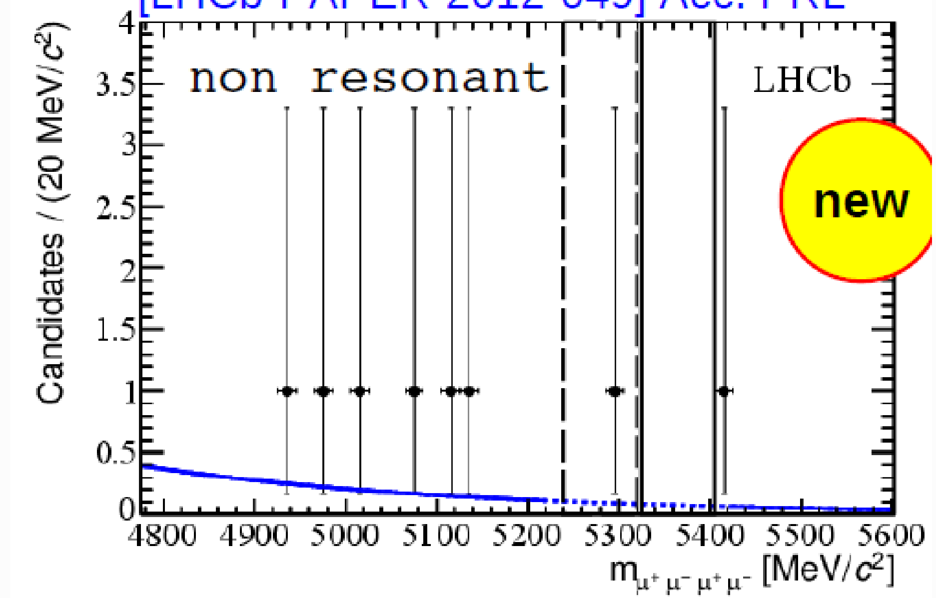
PRD 70, 114028 $\mathcal{B}(B^0_{(s)} \to \mu^+\mu^-\gamma(\to \mu^+\mu^-)) < 10^{-10}$

PRD 85, 077701 & PRL 94, 021801

Possible enhancement scenarios with new particles ($\to$2μ), HyperCP ...

Dataset: 1.0 fb^{-1} @ 7 TeV

[LHCb-PAPER-2012-049] Acc. PRL

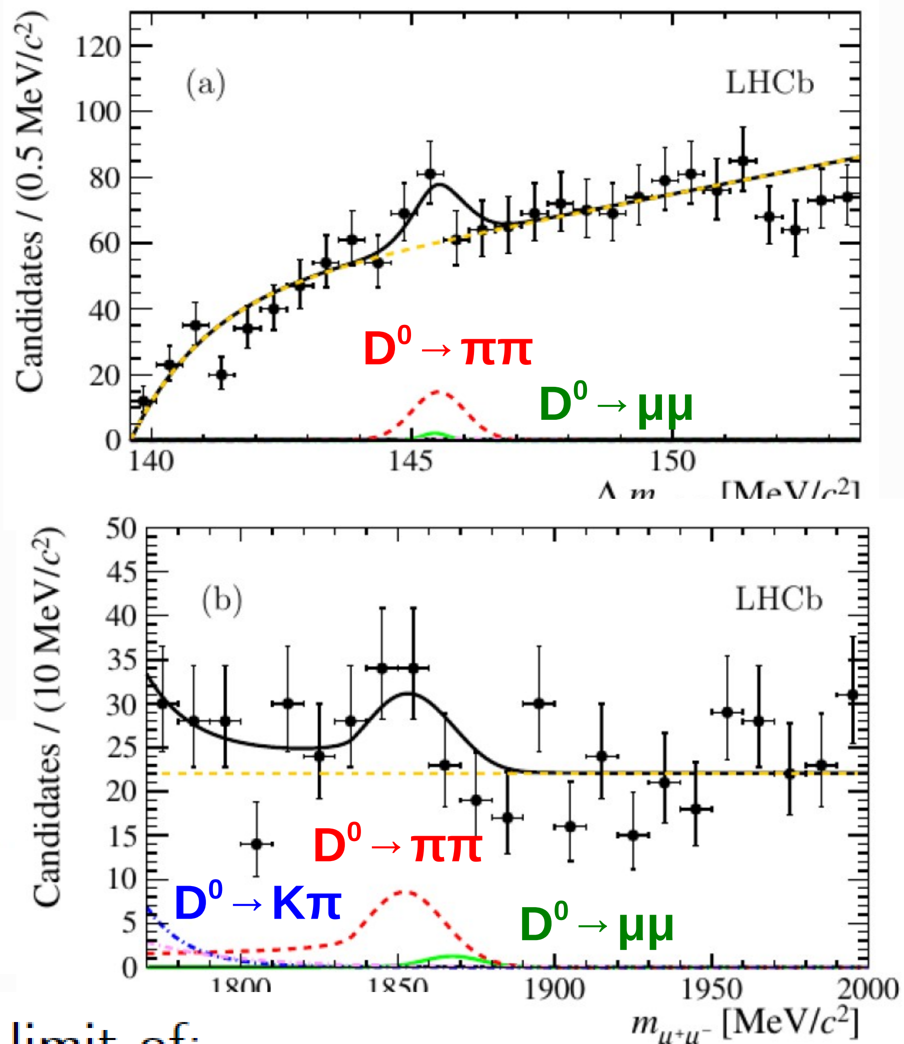


First limits on these decays:

$$\mathcal{B}(B_s^0 \to 4\mu) < 1.6 \times 10^{-8}$$
$$\mathcal{B}(B^0 \to 4\mu) < 6.6 \times 10^{-9}$$

Rare decay $D^0 \to \mu^+\mu^-$

LHCb arXiv:1304.6365



- FCNC in charm sector suppressed by GIM (absence of a high mass downtype quark)
- Small D mixing & small BR
- $D^0 \to \mu\mu$ dominated by long distance contribution (via two-photon intermediate state)
- **SM:** BR ~ 6×10^{-11} ; **Belle:** < 1.4×10^{-7}
- **Three orders of magnitude to go!**
- R-parity violation models

PRD 66,014009, arXiv:hep-ph/0112235

$$\mathcal{B}^{\not R_p}_{D^0 \to \mu^+\mu^-} \leq 4.8 \times 10^{-9} \left(\frac{300 \text{ GeV}}{m_{\tilde{d}_k}}\right)^2$$

supersymmetric partner of down-type quarks

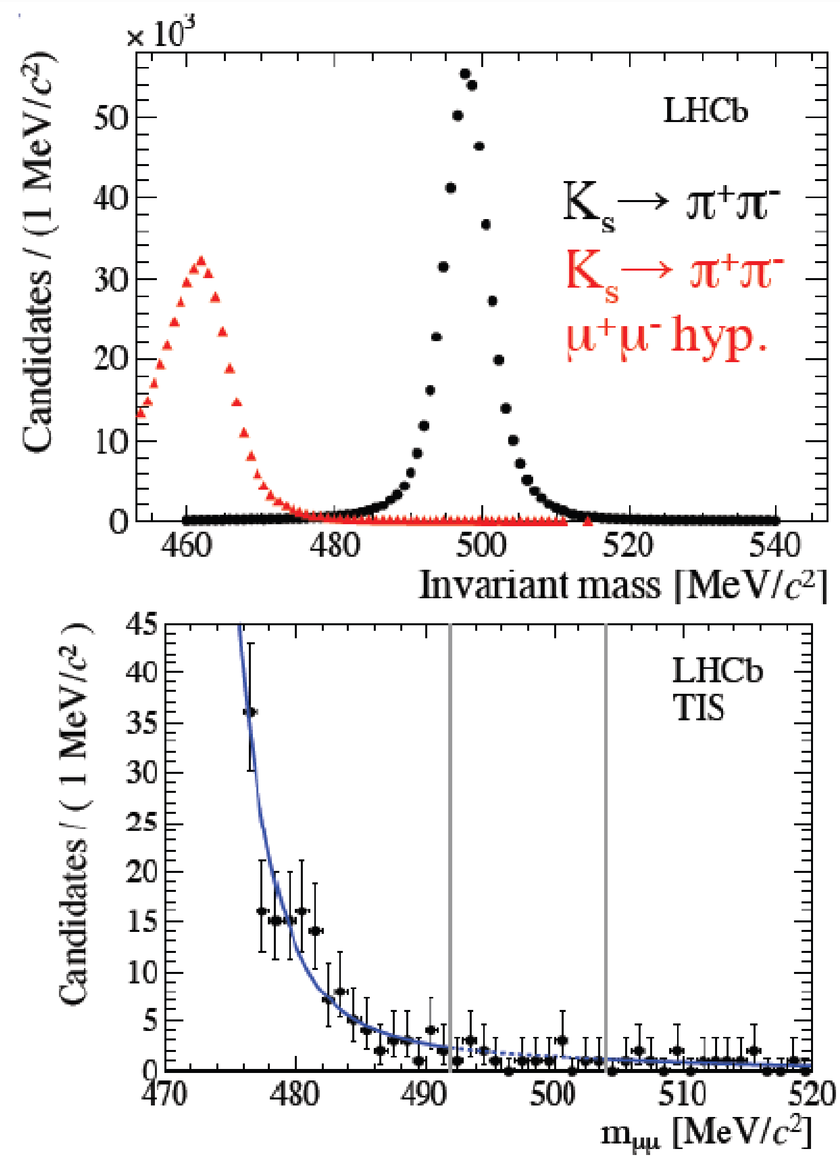
Using 1 fb^{-1} (at $\sqrt{s} = 7$ TeV) LHCb sets a limit of:

$$\mathcal{B}(D^0 \to \mu^+\mu^-) < 6.8 \times 10^{-9} \text{ at } 95\% \text{ CL} \quad \text{(preliminary)}$$

Rare decay $K_S^0 \to \mu^+\mu^-$

JHEP 01 (2013) 090

- FCNC $s \to d$ **is very suppressed**
- **SM:** BF ~ 5×10^{-12} ; **EXP:** < 3.1×10^{-7}
- NP at 10^{-11} level still possible [JHEP 0401, 9]

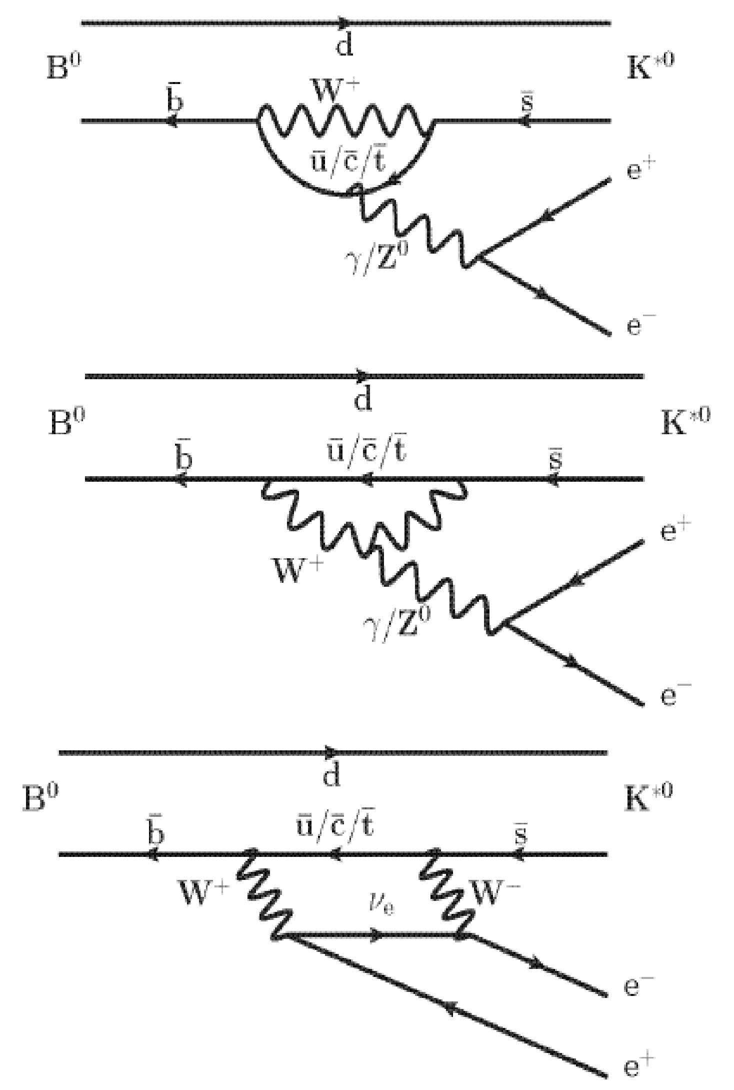


Using 1 fb^{-1} dataset at 7 TeV

BF($K_s \to \mu\mu$) < 9×10^{-9} at 90% CL

New world best limit
Factor ~35 of improvement

B-hadron $\rightarrow$ Hadron + $\mu^+\mu^-$, $D \rightarrow \pi\mu^+\mu^-$



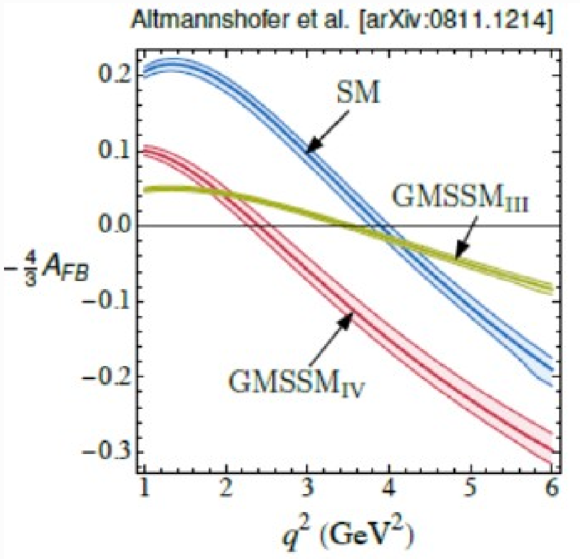
FCNC processes with **a lot of observables**

Clear experimental signatures with low background

Well developed SM calculations

NP can be found in

- Rates
- Angular distributions
- Asymmetries



As an example zero-crossing point at forward-backward asymmetry for $B^0 \rightarrow K^*\mu^+\mu^-$ is well predicted within SM and has potential for NP searches.

$b \rightarrow x l^+ l^-$ and $c \rightarrow x l^+ l^-$ menu @ LHCb

A lot of channels = a lot of new (Apr-Jun 2013) results

$b \rightarrow s l^+ l^-$

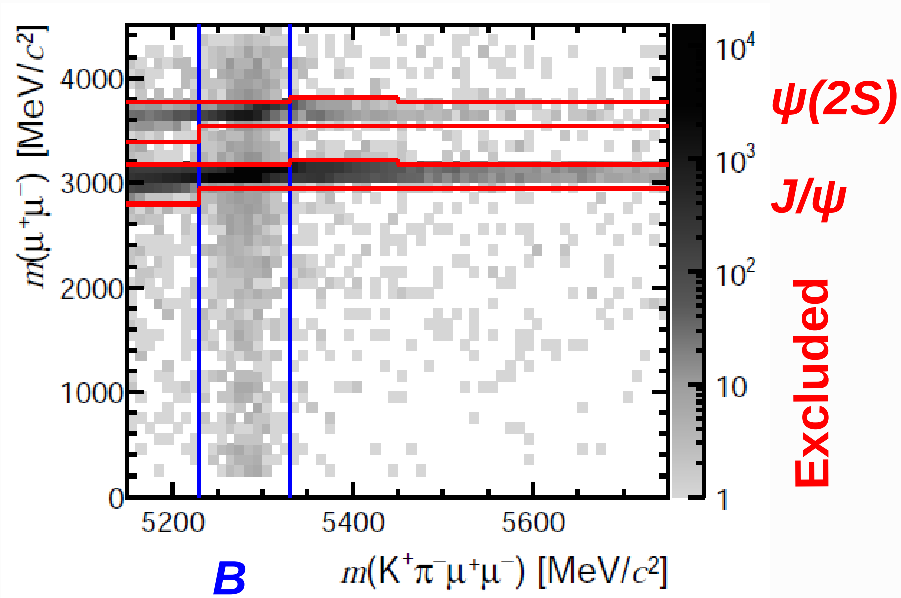
– $B^0 \rightarrow K^* \mu^+ \mu^-$	**arXiv:1304.6325**	**1st multiD angular analysis**
– $B^0 \rightarrow K \mu^+ \mu^-$	PRL 110, 031801	CP asymmetry
– $B^0 \rightarrow \varphi^* \mu^+ \mu^-$	arXiv:1305.2168	1st angular analysis
– $B^0 \rightarrow K^* e^+ e^-$	JHEP 05,(2013)159	1st evidence in low q2
– $\Lambda_b \rightarrow \Lambda \mu^+ \mu^-$	**arXiv:1306.2577**	**baryons, 1st @ LHC**

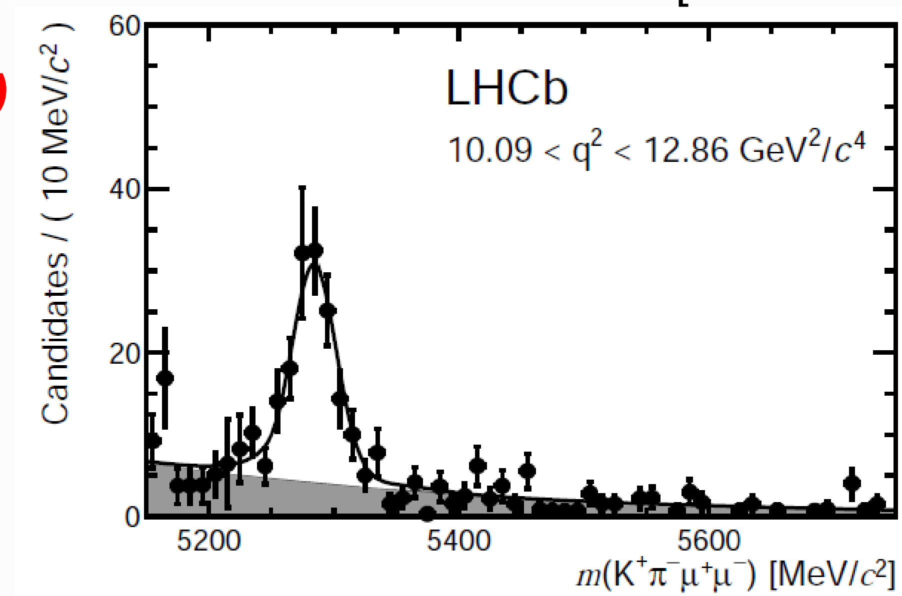
$c \rightarrow u l^+ l^-$

– $D_{(s)}^+ \rightarrow \pi^+ \mu^+ \mu^-$ $D_{(s)}^+ \rightarrow \pi^- \mu^+ \mu^+$	**arXiv:1304.6365**	**factor ~50 improvement in limit**

Analysis of $B \to K^{*}\mu^{+}\mu^{-}$

[arXiv:1304.6325]





$$\frac{d\mathcal{B}}{dq^2} = \frac{1}{q^2_{\max} - q^2_{\min}} \frac{N_{\rm sig}}{N_{K^{*0}J/\psi}} \frac{\varepsilon_{K^{*0}J/\psi}}{\varepsilon_{K^{*0}\mu^+\mu^-}} \times \mathcal{B}(B^0 \to K^{*0}J/\psi) \times \mathcal{B}(J/\psi \to \mu^+\mu^-)$$

- **Loose preselection cuts**
- **Using BDT trained on proxy $B \to K^{*}J/\psi$**
- **Background from upper B sideband**
- **Choice of variables to avoid biases on angles and $q^2=m^2(\mu\mu)$**
- **Final selection from BDT decay time, flight direction, trk/vtx quality, p_T, PID**
- **BR measured relative to $B \to K^{*}J/\psi$**

Analysis of $B \to K^* \mu^+ \mu^-$

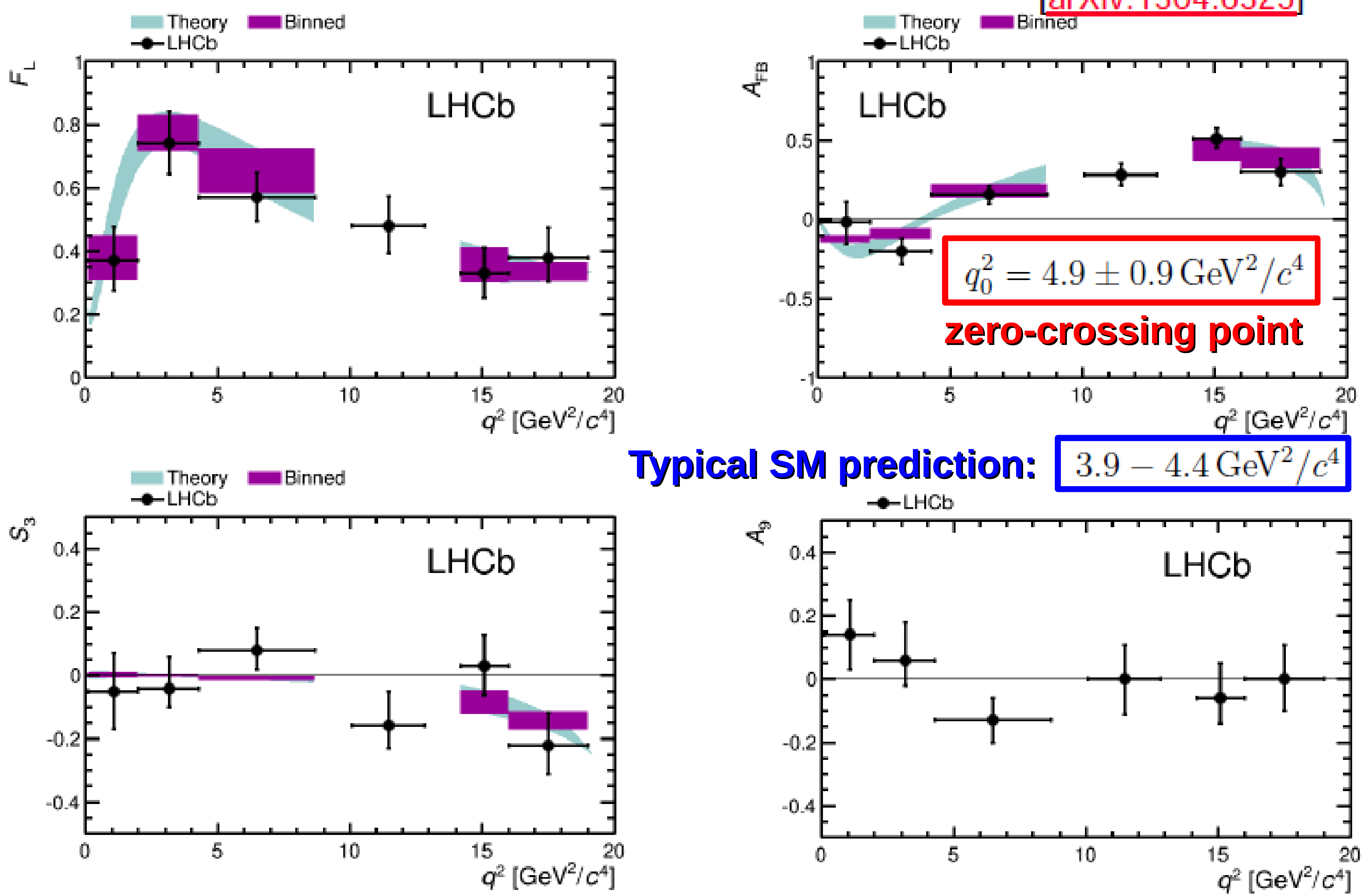
- Branching fraction measured differential in q^2 and 3 decay angles
- Limited statistics: $\phi + \pi \quad \text{if } \phi < 0$
- Parametric in 4 angular observables F_L, A_{FB}, S_3, A_9, from CP asymmetries and averages of decay amplitudes
- Theoretical uncertainties smaller in angular analysis (hadronic form factors)

The first simultaneous fit to all angles

$$\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}q^2\,\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\hat{\phi}} \propto \Big[F_{\mathrm{L}}\cos^2\theta_K + \frac{3}{4}(1-F_{\mathrm{L}})(1-\cos^2\theta_K) - F_{\mathrm{L}}\cos^2\theta_K(2\cos^2\theta_\ell - 1) + \frac{1}{4}(1-F_{\mathrm{L}})(1-\cos^2\theta_K)(2\cos^2\theta_\ell - 1) + S_3(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\cos 2\hat{\phi} + \frac{4}{3}A_{\mathrm{FB}}(1-\cos^2\theta_K)\cos\theta_\ell + A_9(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\sin 2\hat{\phi} \Big]$$

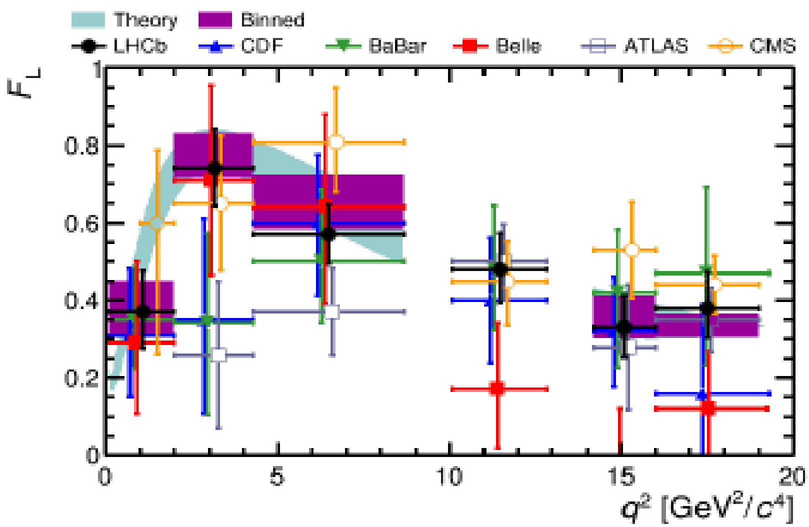
Analysis of $B \to K^* \mu^+ \mu^-$

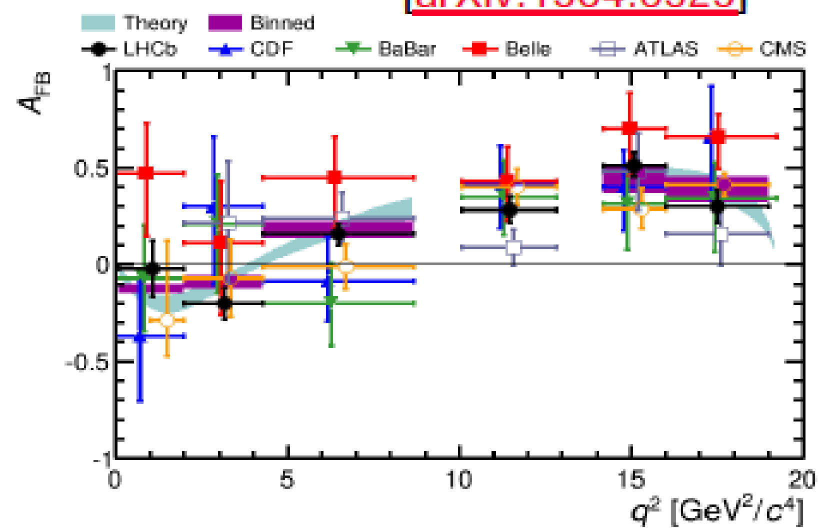
[arXiv:1304.6325]



Analysis of $B \to K^* \mu^+ \mu^-$

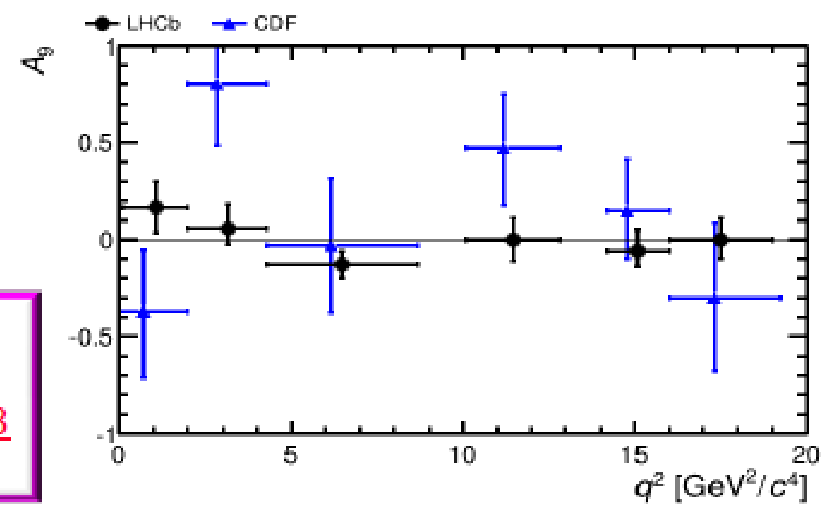
[arXiv:1304.6325]





All experiments consistent with SM

CDF: Phys. Rev. Lett. 108 081807
Babar: Phys. Rev. D. 73. 092001
Belle: Phys. Rev. Lett. 103 (2009) 171801
ATLAS: ATLAS-CONF-2013-038
CMS: CMS-PAS-BPH-11-009



SM predictions

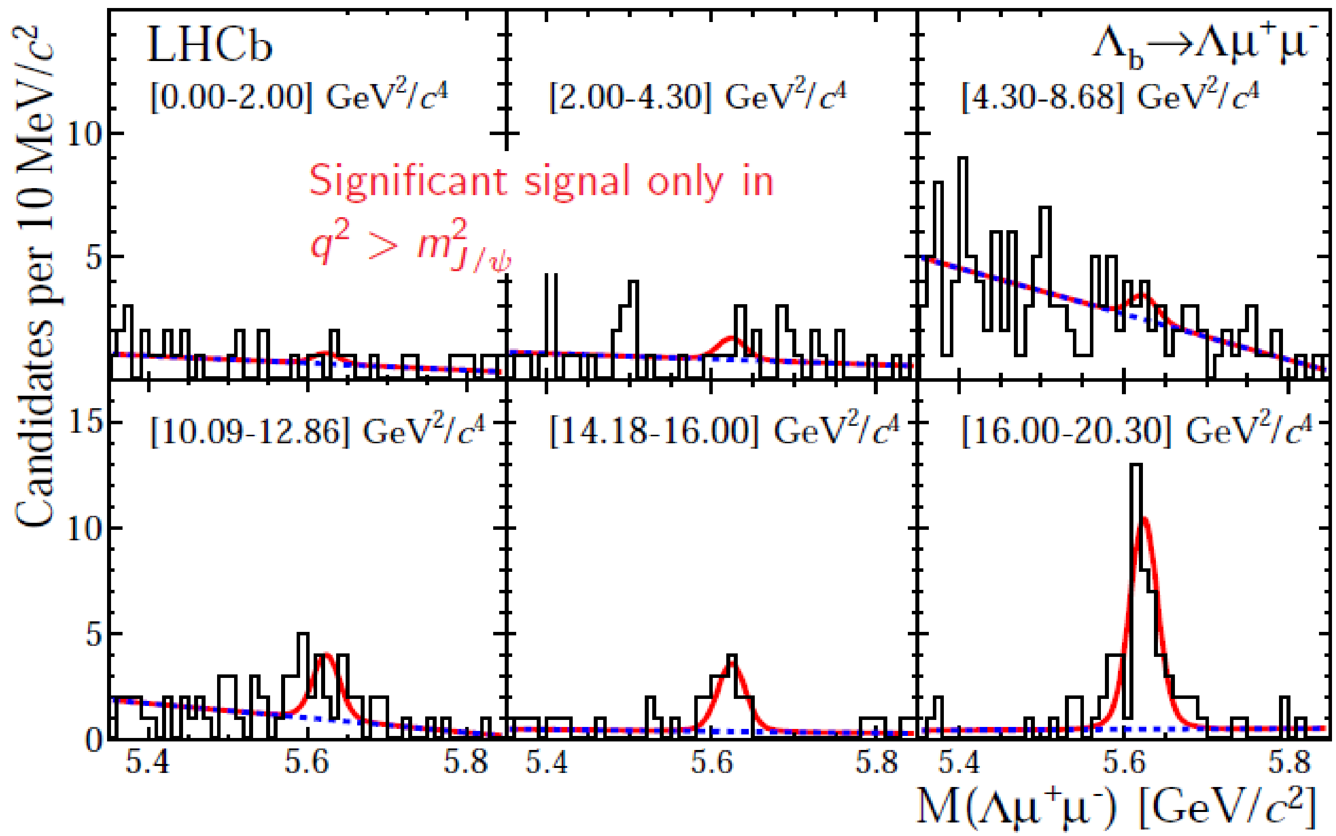
Bobeth, Hiller, van Dyk, Wacker, JHEP 01 (2012) 107
Beneke, Feldmann, Seidel, Eur.Phys.J.C41(2005) 173
Ali, Kramer, Zhu, Eur.Phys.J.C47(2006) 625

Analysis of $\Lambda_b \rightarrow \Lambda\mu^+\mu^-$

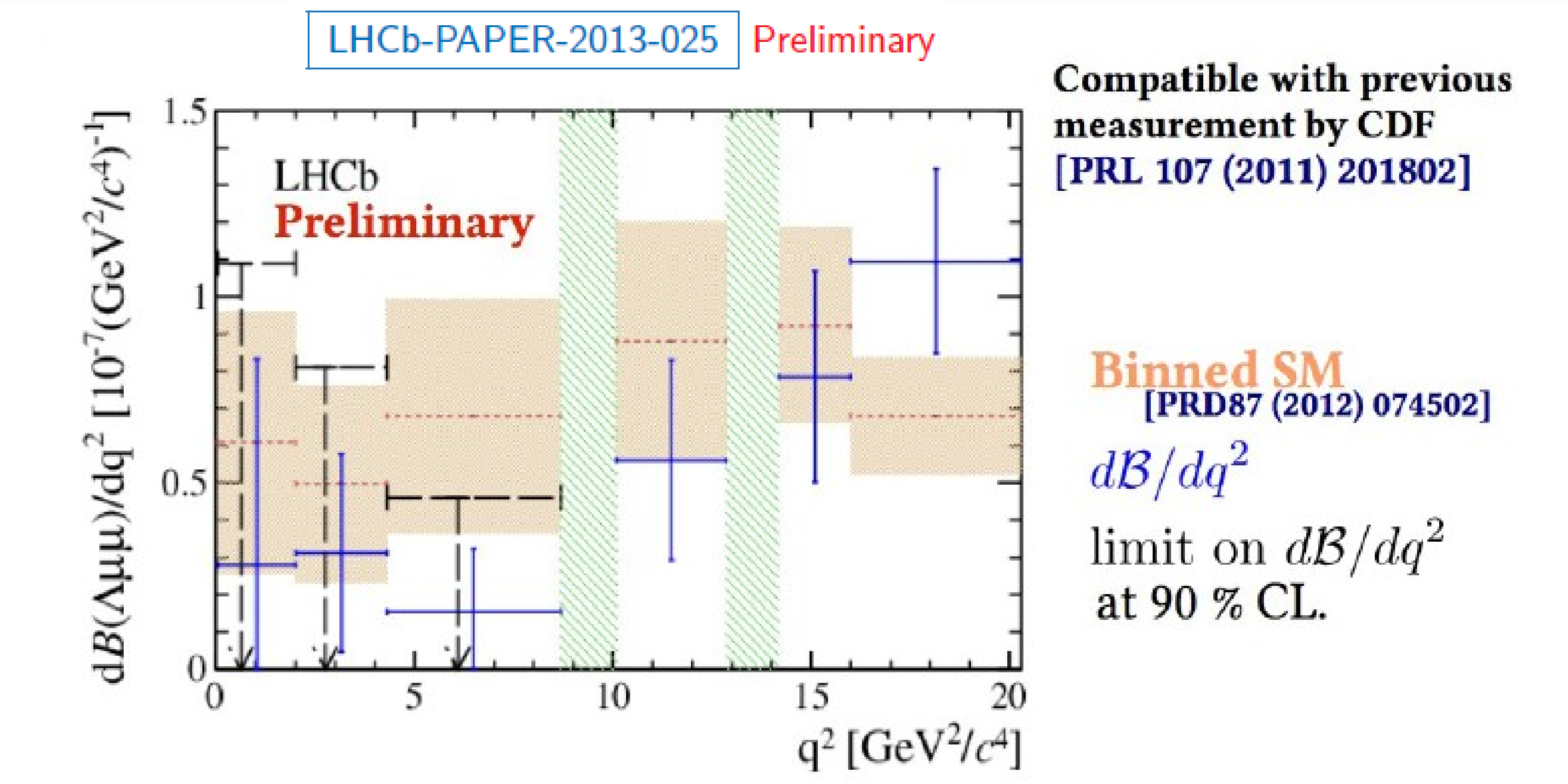
Normalize to $\Lambda_b^0 \rightarrow \Lambda J/\psi(\mu^+\mu^-)$:

LHCb-PAPER-2013-025 Preliminary

$$BR(\Lambda_b^0 \rightarrow \Lambda\mu^+\mu^-) = (0.96 \pm 0.16_{stat} \pm 0.13_{syst} \pm 0.21(BR)) \times 10^{-6}$$

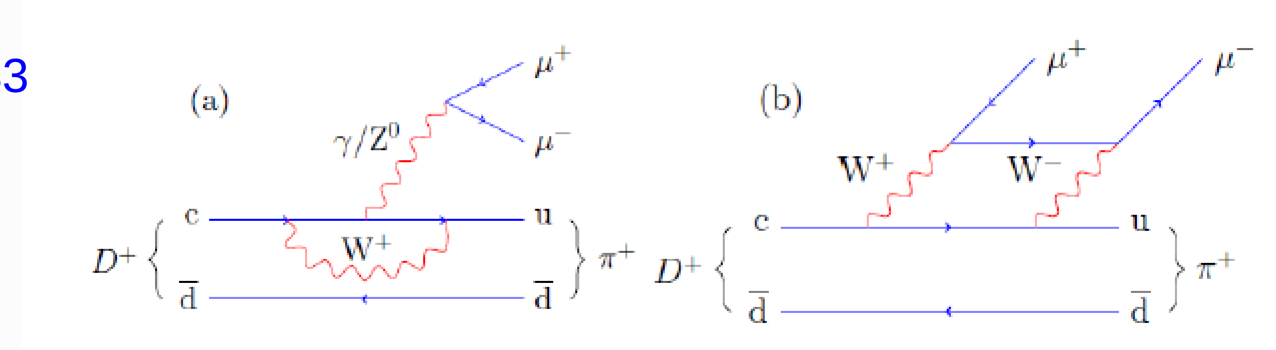


LHCb result


LHCb-PAPER-2013-025
Preliminary
LHCb
Preliminary
Compatible with previous measurement by CDF
[PRL 107 (2011) 201802]
Binned SM
[PRD87 (2012) 074502]
$d\mathcal{B}/dq^2$
limit on $d\mathcal{B}/dq^2$ at 90 % CL.
$d\mathcal{B}(\Lambda\mu\mu)/dq^2$ [$10^{-7}(\mathrm{GeV}^2/c^4)^{-1}$]
q^2 [GeV^2/c^4]
0
0.5
1
1.5
0
5
10
15
20

Search for $D_{(s)}^{+} \to \pi^{+}\mu^{+}\mu^{-}$

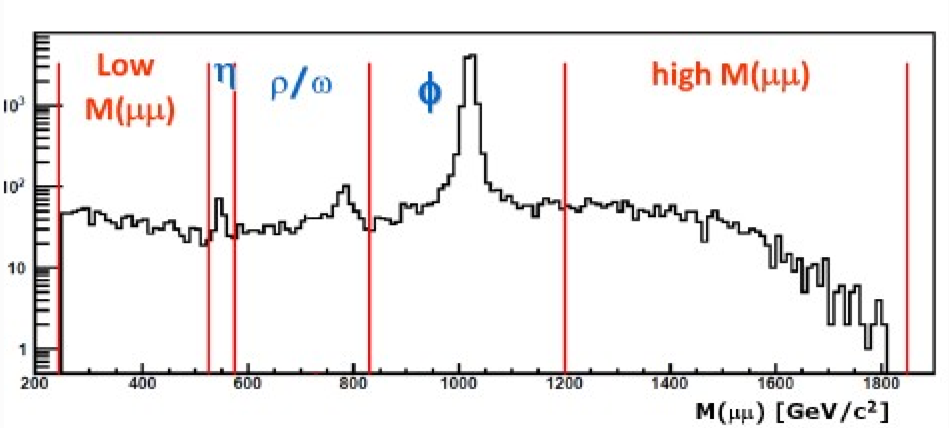
- SM predictions: ~10^{-9}
  hep-ph/0106333, arXiv:0706.1133



- Resonances (η, ρ, ω, φ) : > 10^{-6}
- Low and high M(μμ) regions
- BaBar and D0 gives limits 10^{-6} and 10^{-7} on D^{+} and D_s^{+} respectively
  PRL 100, 101801; PRD 84, 072006

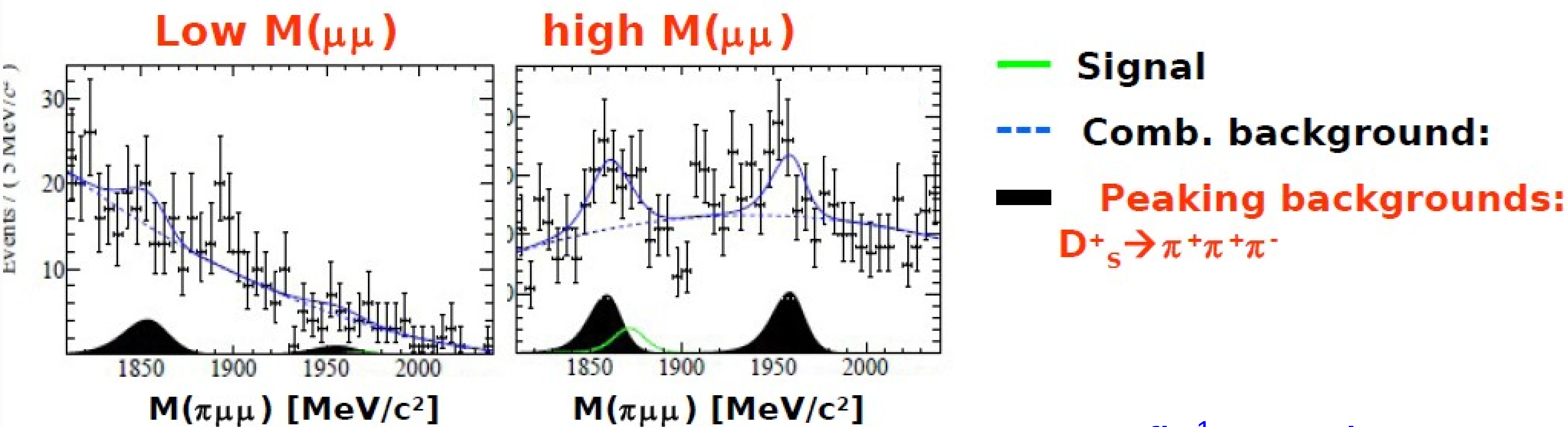
At LHCb:

- Good probe for NP in non-resonant region
- Resonances as control channel
- Low and high M(μμ) regions



LHCb results

Accepted by PLB, arXiv:1304.6365



1 fb^{-1} sample

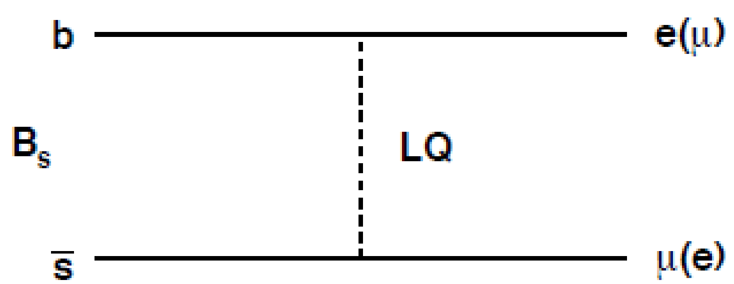
LHCb limits $\times 10^{-8}$ at 90% (95%) CL

Region	$B(D^+ \rightarrow \pi^+\mu^+\mu^-)$	$B(D_s \rightarrow \pi^+\mu^+\mu^-)$
Total [(1)]	7.3 (8.3)	41.0 (47.7)
Low M(μμ)	2.0 (2.5)	6.9 (7.7)
High M(μμ)	2.6 (2.9)	16.0 (18.6)

~ 50 times better than previous measurements

Rare decay $B \to \mu^+ e^-$

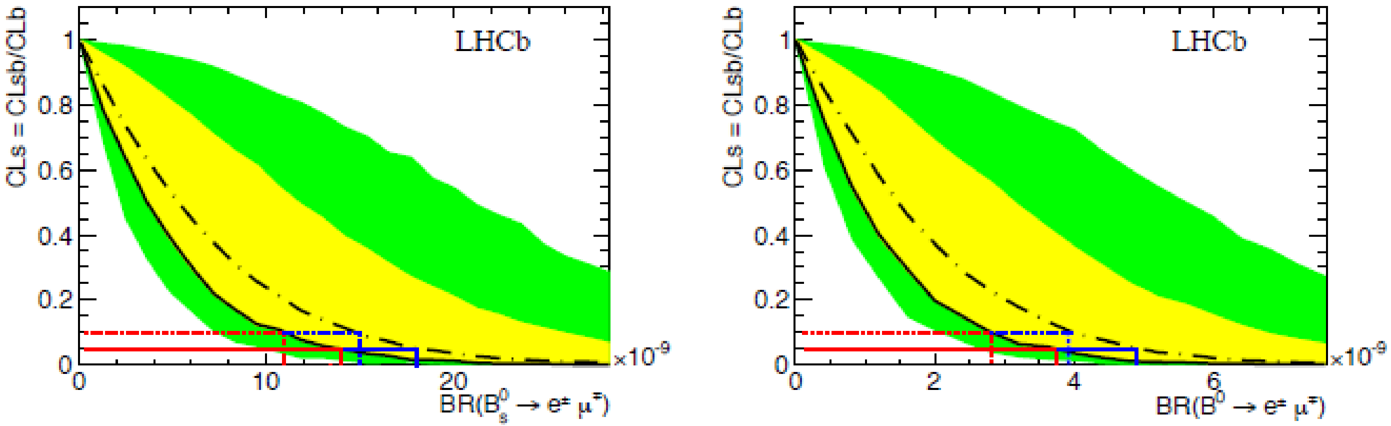
- Lepton flavour violating decays occur at $\sim< 10^{-50}$ in the SM.
- The decay $B_s^0 \to e^+ \mu^-$ is allowed in models with a local gauge symmetry with leptons and quarks.



- So-called lepto-quarks have been directly searched for at the LHC, with limits of around 0.5-1 TeV$/c^2$ (no mixing assumed).

LHCb result on $B \rightarrow \mu^{+} e^{-}$

- Search for $B_s^0 \rightarrow e^+ \mu^-$ at LHCb using 2011 dataset. [LHCb-PAPER-2013-030]



Solid black line: observed, dashed black line: expected

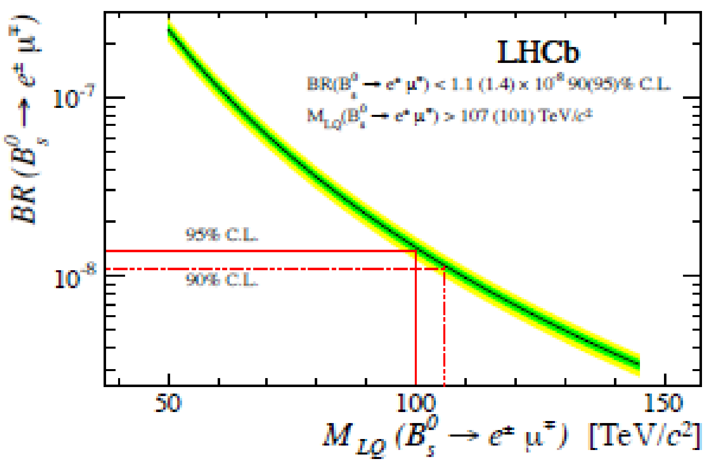
- No significant signal observed, set limits,

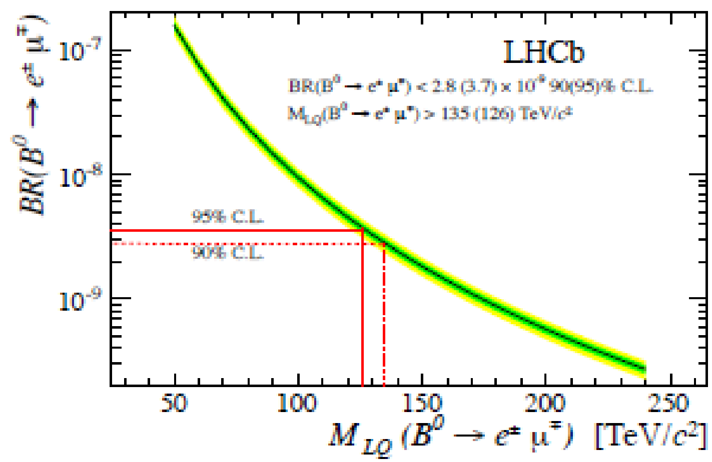
$$\mathcal{B}(B_s^0 \rightarrow e^+\mu^-) < 1.4 \times 10^{-8} \text{ @ } 95\% \text{ CL}$$

$$\mathcal{B}(B^0 \rightarrow e^+\mu^-) < 3.7 \times 10^{-9} \text{ @ } 95\% \text{ CL}$$

Lower limit on m_{LQ} from $B \to \mu^+ e^-$

- Convert branching fraction limits into lepto-quark masses using formula from [arXiv:hep-ph/9409201].





- No significant signal observed , set limits,

$$m_{LQ}(B_s^0 \to e^+\mu^-) > 101\, TeV/c^2 \text{ @ } 95\% \text{ CL}$$

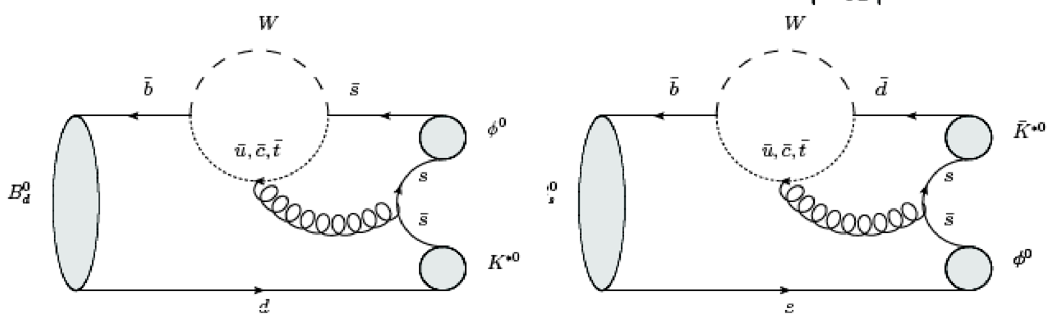
$$m_{LQ}(B^0 \to e^+\mu^-) > 135\, TeV/c^2 \text{ @ } 95\% \text{ CL}$$

[LHCb-PAPER-2013-030]

Gluonic penguin in B->VV

(naïve scaling SM) :

$$\mathcal{B}(B_s^0 \to \phi \bar{K}^{*0}) = \mathcal{B}(B^0 \to \phi K^{*0}) \times \frac{|V_{td}|^2}{|V_{ts}|^2}$$



LHCb has already reported about

1st observation of decays

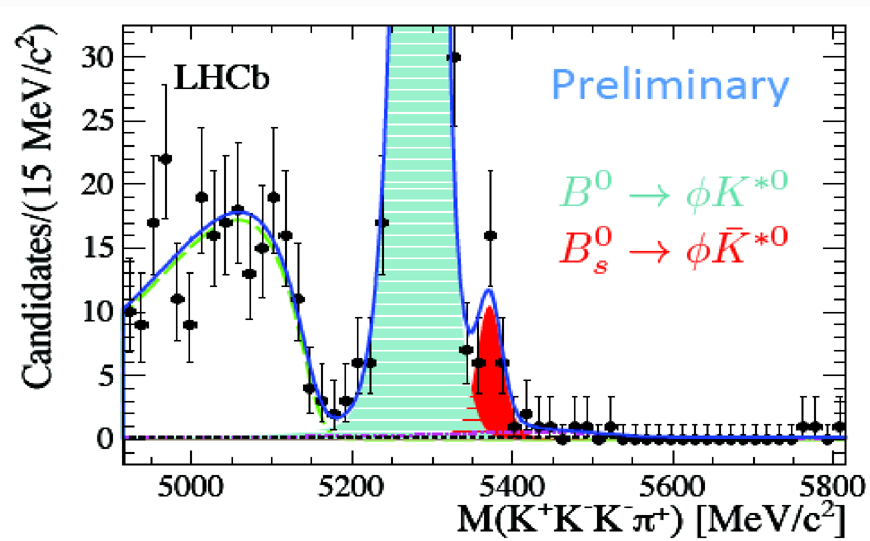
$B^0_s \to \phi\phi$ and $B^0_s \to K^{*0}K^{*0}$

SM prediction:

$$\mathcal{B}(B_s^0 \to \phi \bar{K}^{*0}) = (0.4\,^{+0.1}_{-0.1}\,^{+0.5}_{-0.3}) \times 10^{-6}$$

Nucl. Phys. B774 64 (2007)

LHCb-PAPER-2013-012



30 ± 6 $B^0_s \to (K^+K^-)(K^-\pi^+)$

- **Loose preselection cuts**
- **S-wave KK an Kπ contribution**
- **6.1σ significance, 1σ from SM**

$$\mathcal{B}(B_s^0 \to \phi \bar{K}^{*0}) = (1.10 \pm 0.24(\text{stat.}) \pm 0.14(\text{syst.}) \pm 0.08(\frac{f_d}{f_s})) \times 10^{-6}$$

- **Presented here to demonstrate quite rare gluonic penguin decay, but further analysis of *B→VV* is also very interesting!**

Properties of the B (B^+, B^0, B_s) systems

1) B_s^0 oscillation frequency measurement

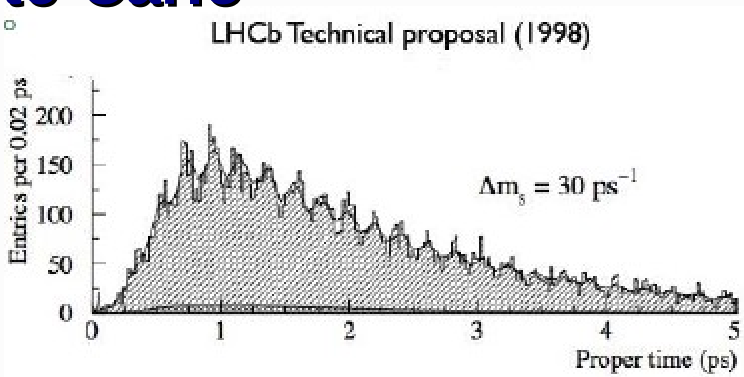
2) Mixing induced CPV in B_s^0, e.g: $B_s^0 \rightarrow J/\psi\phi$ and $B_s^0 \rightarrow J/\psi f\,(980)$

3) Direct CP asymmetry in $B_{(s)}^0$ decays

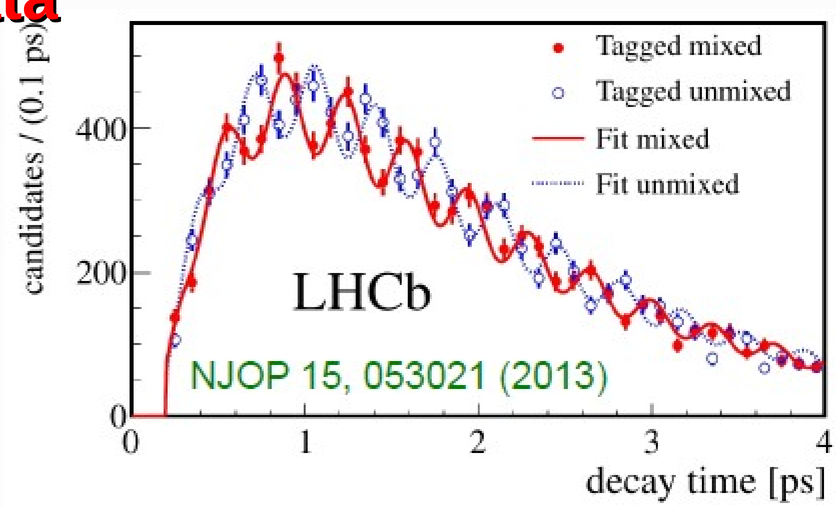
4) CKM angle γ

Oscillation frequency for B_s

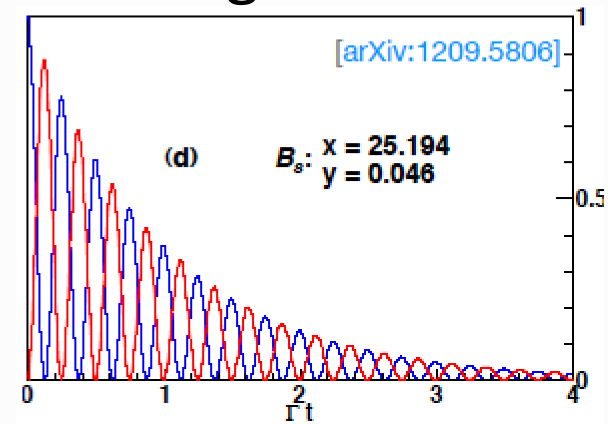
Monte-Carlo



Data



B_s: Fast oscillations



Excellent time resolution required!

$\Gamma = (\Gamma_L + \Gamma_H) / 2;$

$\Delta m_s = M_H - M_L$

$x = (M_H - M_L) / \Gamma;$ $y = (\Gamma_L - \Gamma_H) / 2\Gamma$

Measure time dependent decay rate of $B_s \to D_s^- \pi^+$ and $\bar{B}_s \to D_s^+ \pi^-$

- $PDF \propto \left[e^{-\Gamma t} \cdot \left(cosh \left(\frac{\Delta\Gamma}{2} t \right) \pm D \; cos(\Delta m \, t) \right) \right] \otimes R(\sigma_t)$
- Mean decay time resolution 44 fs

flavour tagging

event-by-event decay time resolution

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

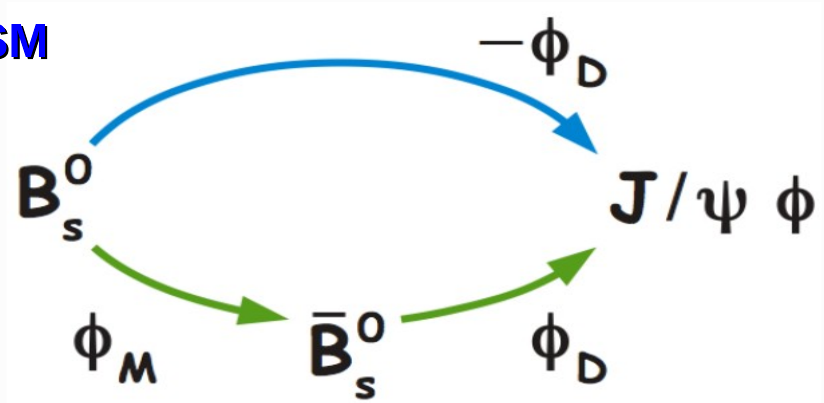
Most precise measurement up to date

Agreement with world average & SM

Mixing induced CP violation in B_s

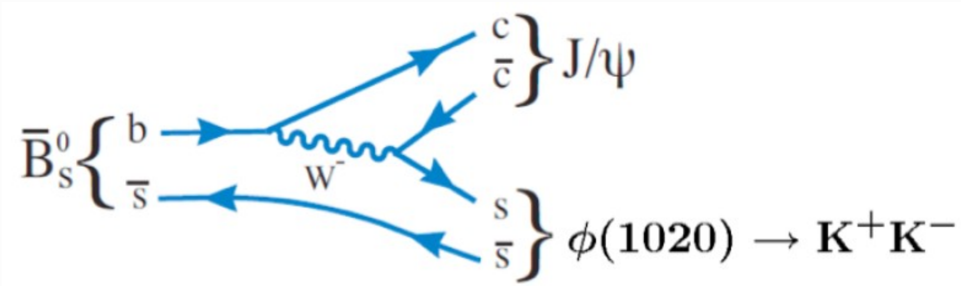
- Decay of particle and antiparticle to same state
- **CP violating phase** predicted to be **very small in SM** [PRD 84, 033005]

$$\phi_s^{SM} = -2\beta_s = (-0.0363 \pm 0.0016)\,\mathrm{rad}$$



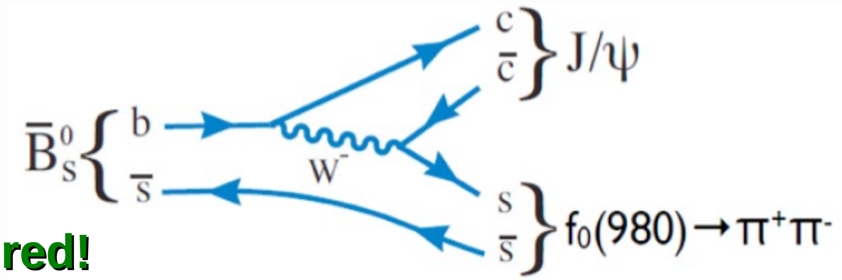
- **Observable very sensitive to NP !**

- LHCb measured it in two modes (1 fb^{-1} dataset) [arXiv: 1304.2600]



- Measurement of time-dependent CP asymmetry

$$A_{CP}(t) \sim (1 - 2\omega_{tag})\,D(\sigma_t)\,\sin(\Delta m_s(t))\,\sin(\phi_s)$$



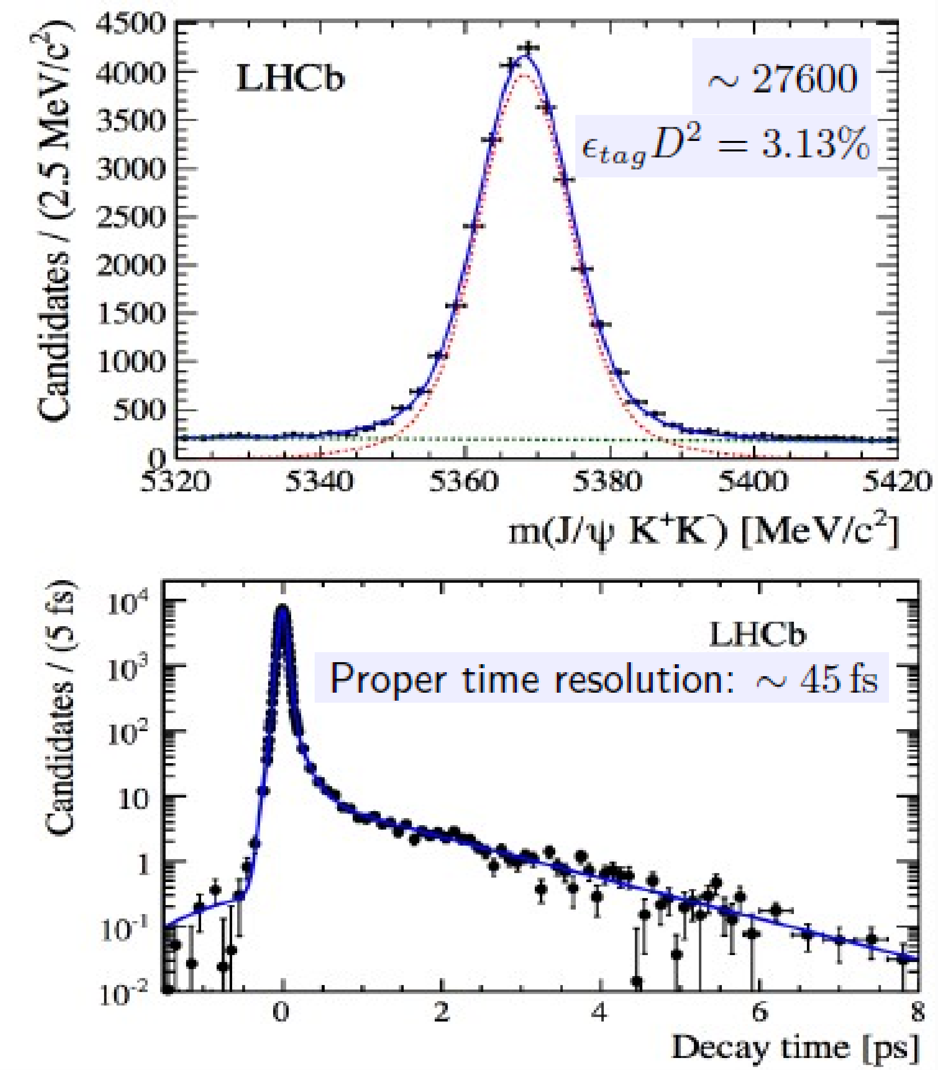
- **Tagging and high decay time resolution required!**

Mixing induced CP violation in B_s

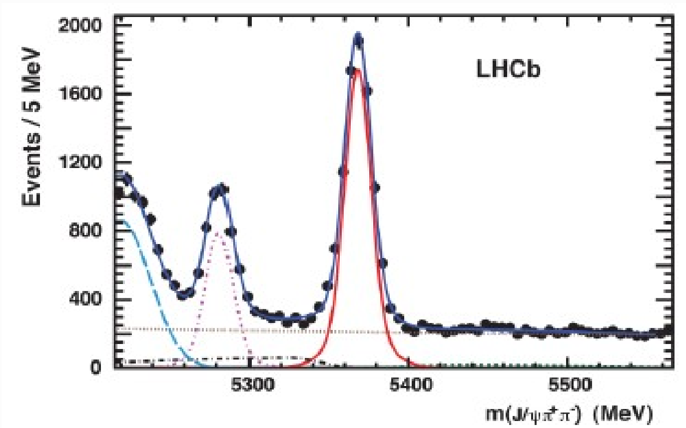
$B_s^0 \to J/\psi\phi$

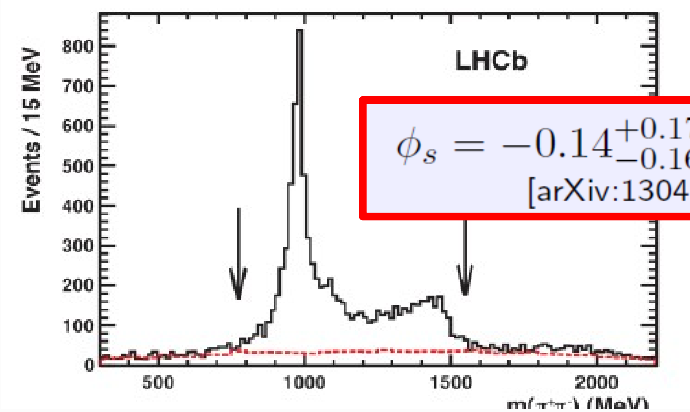
- narrow ϕ resonance: experimentally clean
- VV final state: mixture of CP even/odd components
- Time -dependent angular analysis to disentangle the amplitudes and extract ϕ_s
- Fit for more than 10 physics parameters: amplitudes, Γ_s, $\Delta\Gamma_s$, ϕ_s
- Δm_s taken from $B_s \to D_s\pi$

$$\phi_s = 0.07 \pm 0.09(stat) \pm 0.01(syst)\,\mathrm{rad}$$
$$\Gamma_s = 0.663 \pm 0.005(stat) \pm 0.006(syst)\,\mathrm{ps}^{-1}$$
$$\Delta\Gamma_s = 0.100 \pm 0.016(stat) \pm 0.003(syst)\,\mathrm{ps}^{-1}$$



Mixing induced CP violation in B_s





$\phi_s = -0.14^{+0.17}_{-0.16} \pm 0.01\,\mathrm{rad}$
[arXiv:1304.2600]

$$B_s^0 \to J/\psi\pi\pi$$

- dominated by $f_0 \to \pi^+\pi^-$
- BF $\sim 35\%$ of $B_s^0 \to J/\psi\phi$
- CP-odd final state $[775 < M(\pi\pi) < 1550\,\mathrm{MeV}]$ [arXiv 1204.5643]: no angular analysis is required
- Constrain Γ_s and $\Delta\Gamma_s$ to the $B_s^0 \to J/\psi\phi$ result

Combined fit $B_s^0 \to J/\psi\phi$ e $B_s^0 \to J/\psi\pi\pi$ [arXiv:1304.2600]

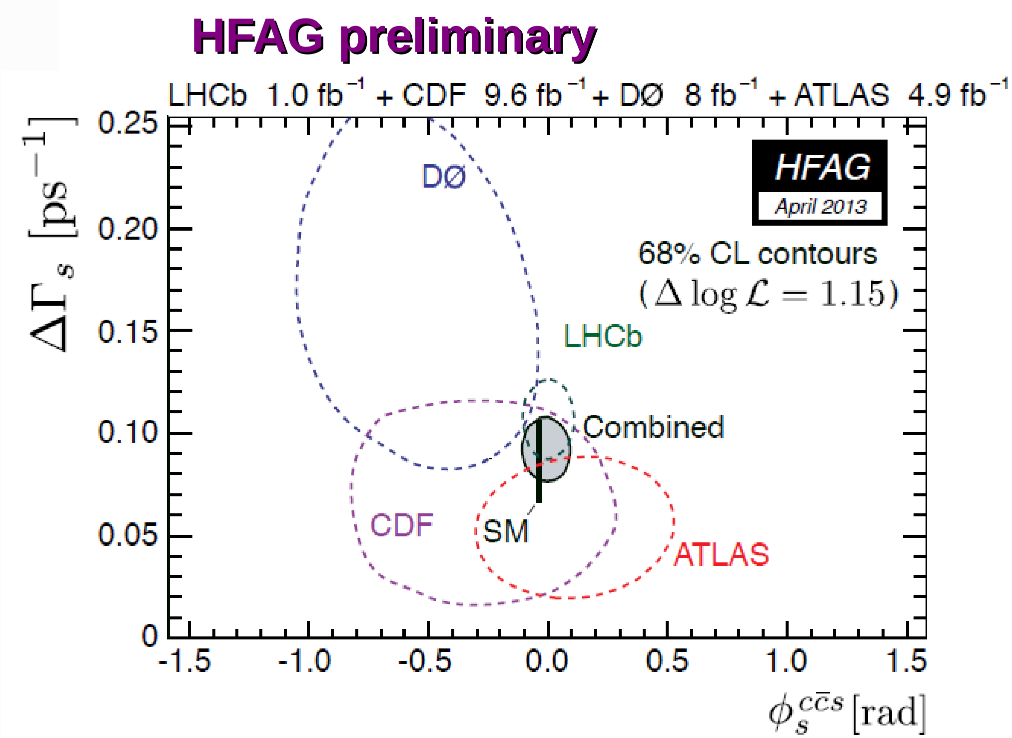
$$\phi_s = 0.01 \pm 0.07(stat) \pm 0.01(syst)\,\mathrm{rad}$$
$$\Gamma_s = 0.661 \pm 0.004(stat) \pm 0.006(syst)\,\mathrm{ps}^{-1}$$
$$\Delta\Gamma_s = 0.106 \pm 0.011(stat) \pm 0.007(syst)\,\mathrm{ps}^{-1}$$

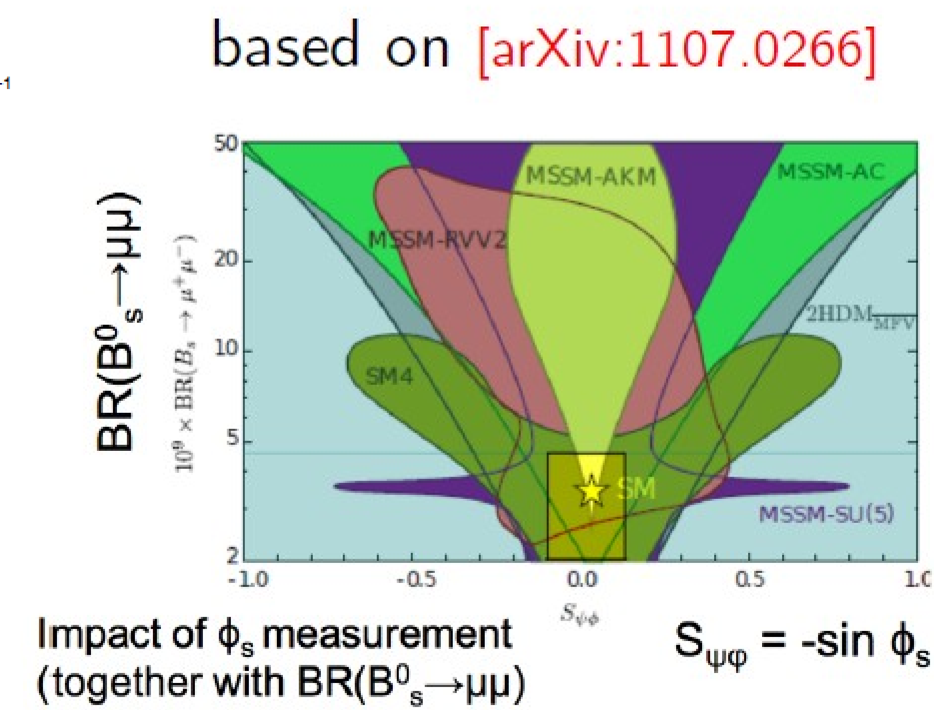
Consistent with SM prediction!

Constrain on NP parameters

Consistent with SM prediction

and data from other experiments!

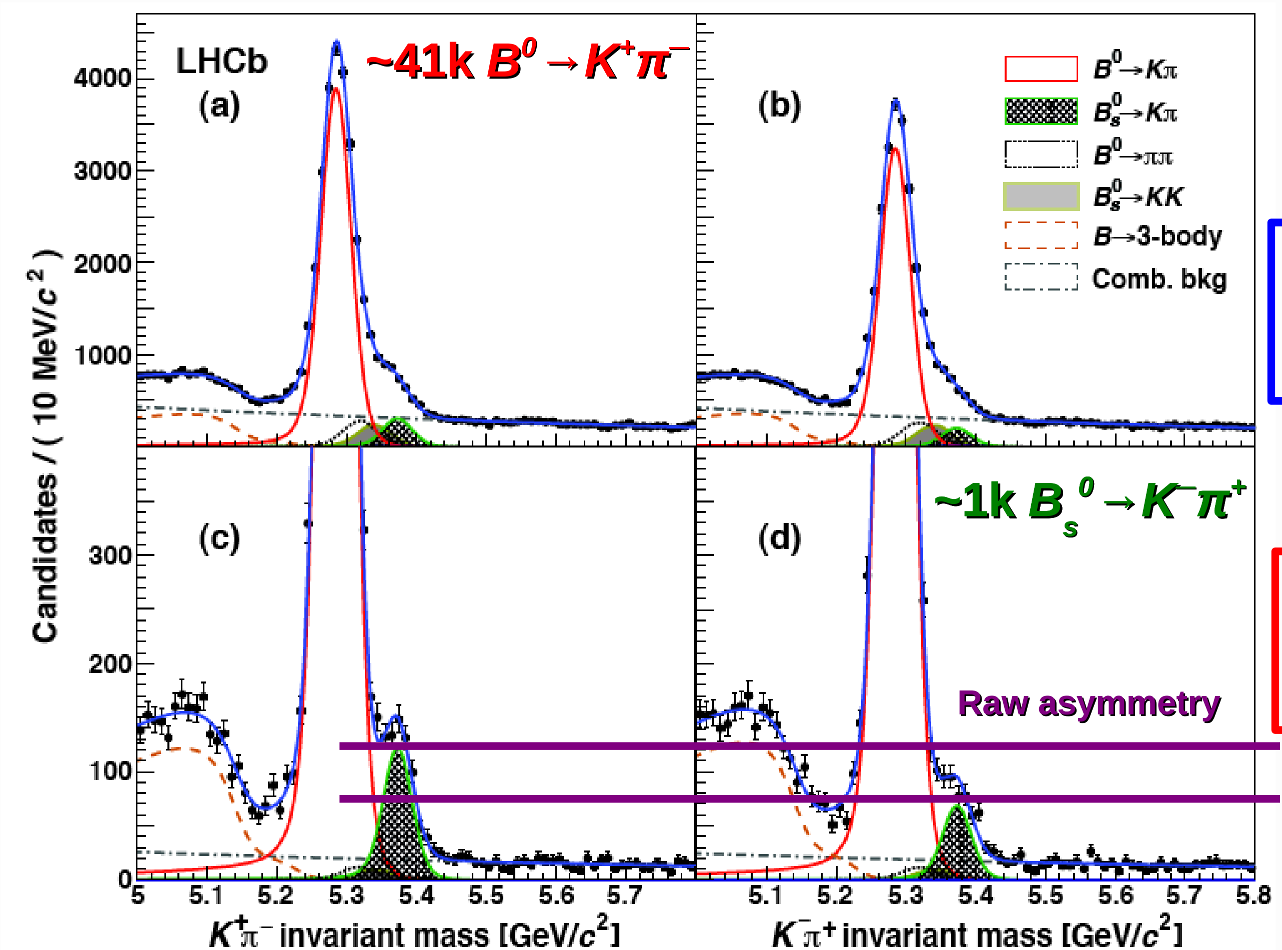




Direct CP asymmetry in $B_{(s)}^0$ *decays*

Direct CP asymmetry hard to calculate, but "easy" to measure

1 fb^{-1} dataset, PRL 110, 221601



CP asymmetry: $A_{CP} = A_{\rm raw} - A_{\Delta}$

$$A_{\Delta}(B^0_{(s)} \to K\pi) = \zeta_{d(s)} A_{\rm D}(K\pi) + \kappa_{d(s)} A_{\rm P}(B^0_{(s)})$$

Detection asymmetry | **Production asymmetry**

Oscillation considered in the analysis!

$A_{CP}(B^0 \to K^+\pi^-) = -0.080 \pm 0.007_{stat} \pm 0.003_{syst}$

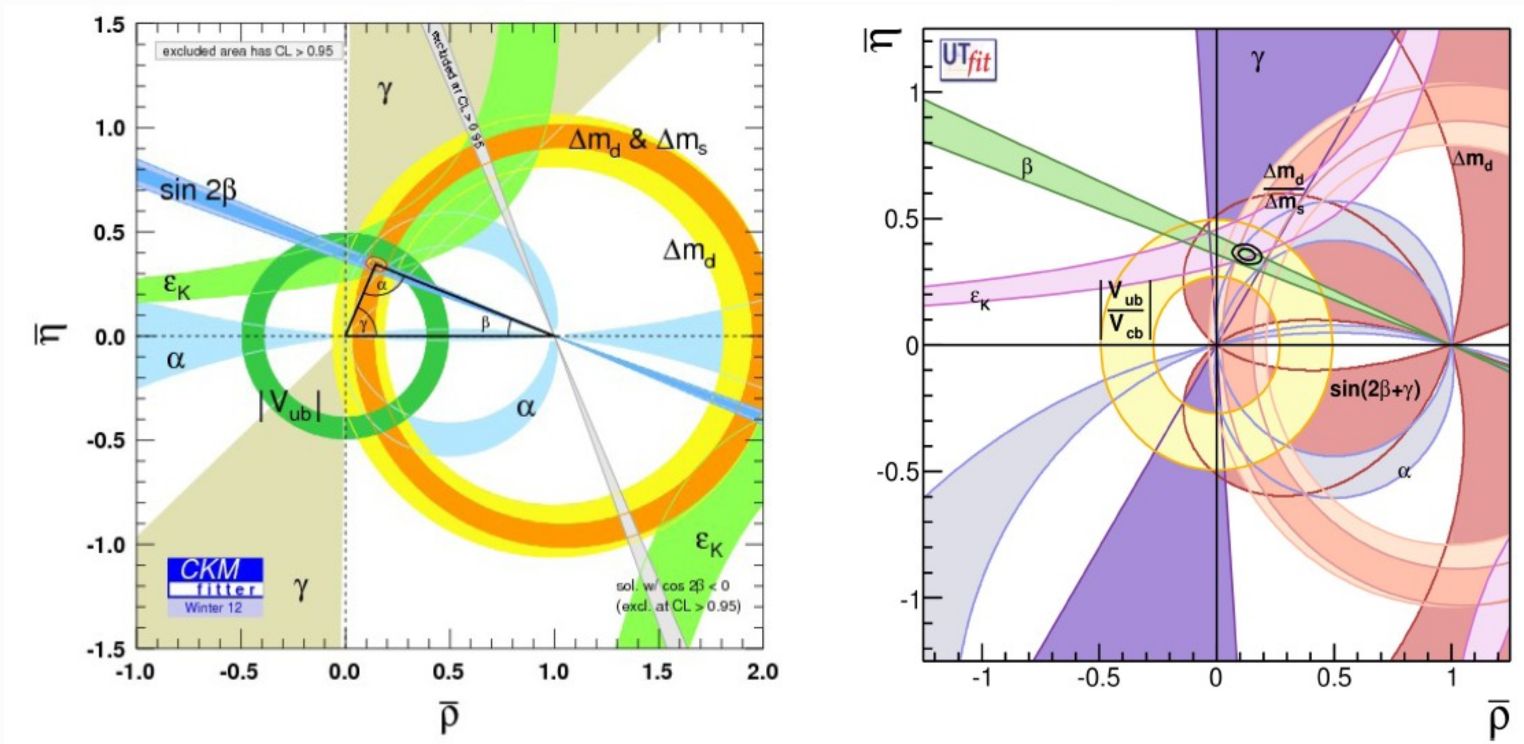
World best precision

$A_{CP}(B_s^0 \to K^-\pi^+) = 0.27 \pm 0.04_{stat} \pm 0.01_{syst}$

1st observation (6.5σ) of direct CP asymmetry in B_s^0 system

Parameters of CKM triangle

CKMfitter ICHEP 2012	UTfit pre-ICHEP 2012
$\gamma = (66\,^{+12}_{-12})^\circ$	$\gamma = (75.5 \pm 10.5)^\circ$



1) There are another fitting group and another triangles

2) CKM angle γ measured with high uncertainty!

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

(but very precise SM prediction for these observable)

Parameters of CKM triangle

CKM angle γ measured with high uncertainty!

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

(but very precise SM prediction for these observable)

Leading diag.

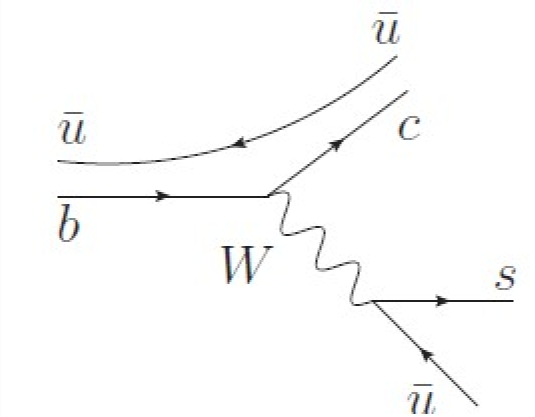
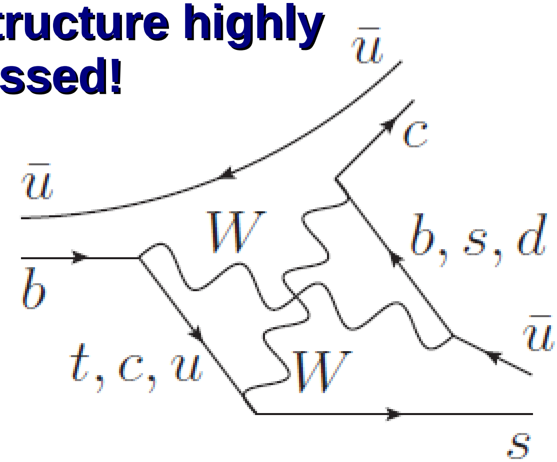


Diagram with other CKM structure highly suppressed!



$$\delta\gamma/\gamma < \mathcal{O}(10^{-6})$$

Very high potential for NP searches!

Probe	Λ_{NP} for (N)MFV NP	Λ_{NP} for gen. FV NP
γ from $B \to DK$ [1)]	$\Lambda \sim \mathcal{O}(10^2\ \text{TeV})$	$\Lambda \sim \mathcal{O}(10^3\ \text{TeV})$
$B \to \tau\nu$ [2)]	$\Lambda \sim \mathcal{O}(1\ \text{TeV})$	$\Lambda \sim \mathcal{O}(30\ \text{TeV})$
$b \to ss\bar{d}$ [3)]	$\Lambda \sim \mathcal{O}(1\ \text{TeV})$	$\Lambda \sim \mathcal{O}(10^3\ \text{TeV})$
β from $B \to J/\psi K_S$ [4)]	$\Lambda \sim \mathcal{O}(50\ \text{TeV})$	$\Lambda \sim \mathcal{O}(200\ \text{TeV})$
$K - \bar{K}$ mixing [5)]	$\Lambda > 0.4$ TeV (6 TeV)	$\Lambda > 10^{3(4)}$ TeV

GLW / ADS / GGLZ methods

Gronau-London-Wyler (GLW) D in $\mathcal{CP}$-eigenstate $(D \to KK, \pi\pi)$

[PLB 265, 172 (1991)]

$$R_{CP\pm} = \frac{2[\Gamma(B^- \to D_{CP\pm}K^-) + \Gamma(B^+ \to D_{CP\pm}K^+)]}{\Gamma(B^- \to D^0K^-) + \Gamma(B^+ \to \overline{D}^0K^+)}$$

$$A_{CP\pm} = \frac{\Gamma(B^- \to D_{CP\pm}K^-) - \Gamma(B^+ \to D_{CP\pm}K^+)}{\Gamma(B^- \to D_{CP\pm}K^-) + \Gamma(B^+ \to D_{CP\pm}K^+)}.$$

$$R_{CP\pm} = 1 + r_B^2 \pm 2r_B \cos\delta_B \cos\gamma$$

$$A_{CP\pm} = \frac{\pm 2r_B \sin\delta_B \sin\gamma}{R_{CP\pm}}.$$

Atwood-Dunietz-Sony (ADS)

[PRL 78, 3257 (1997)]

D Cabibbo-allowed $(D^0 \to K^-\pi^+)$ and doubly Cabibbo-suppressed $(D^0 \to K^+\pi^-)$ states.

$$R_{\rm ADS} = \frac{\Gamma(B^- \to D[\to \pi^-K^+]K^-) + \Gamma(B^+ \to D[\to \pi^+K^-]K^+)}{\Gamma(B^- \to D[\to K^-\pi^+]K^-) + \Gamma(B^+ \to D[\to K^+\pi^-]K^+)}$$

$$A_{\rm ADS} = \frac{\Gamma(B^- \to D[\to \pi^-K^+]K^-) - \Gamma(B^+ \to D[\to \pi^+K^-]K^+)}{\Gamma(B^- \to D[\to \pi^-K^+]K^-) + \Gamma(B^+ \to D[\to \pi^+K^-]K^+)}$$

$$R_{\rm ADS} = r_B^2 + r_D^2 + 2r_B r_D \cos\gamma \cos(\delta_B + \delta_D)$$

$$A_{\rm ADS} = 2r_B r_D \sin\gamma \sin(\delta_B + \delta_D)/R_{\rm ADS}$$

Giri, **G**rossman, **S**offer and **Z**upan (**GGSZ**) deals with self conjugate 3-body final states :
f = D →$K_S\pi\pi$ and K_SKK. Phys.Rev. D68 (2003) 054018

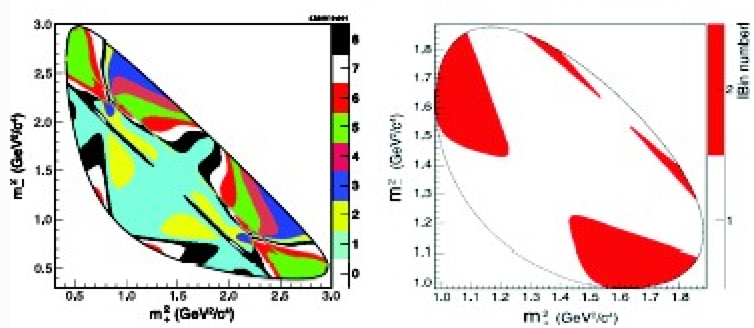
Strong phase varies over the 3-body phase space.

$$x_\pm = r_B \cos(\delta_B \pm \gamma) \quad y_\pm = r_B \sin(\delta_B \pm \gamma)$$

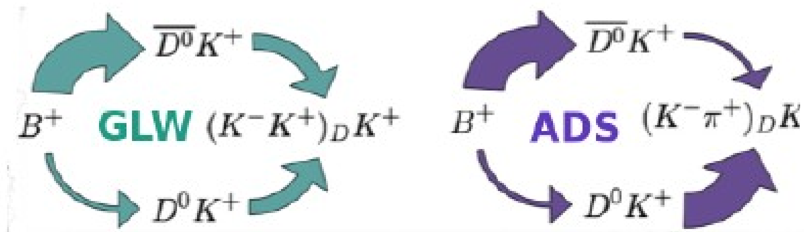
$$N^+_{\pm i} = h_{B^+}[K_{\mp i} + (x_+^2 + y_+^2)K_{\pm i} + 2\sqrt{K_iK_{-i}}(x_+c_{\pm i} \mp y_+s_{\pm i})]$$

$$N^-_{\pm i} = h_{B^-}[K_{\pm i} + (x_-^2 + y_-^2)K_{\mp i} + 2\sqrt{K_iK_{-i}}(x_-c_{\pm i} \pm y_-s_{\pm i})]$$

Binned Dalitz plot phase variation measured by CLEO-c : CLEO, Phys. Rev. D 82 (2010) 112006

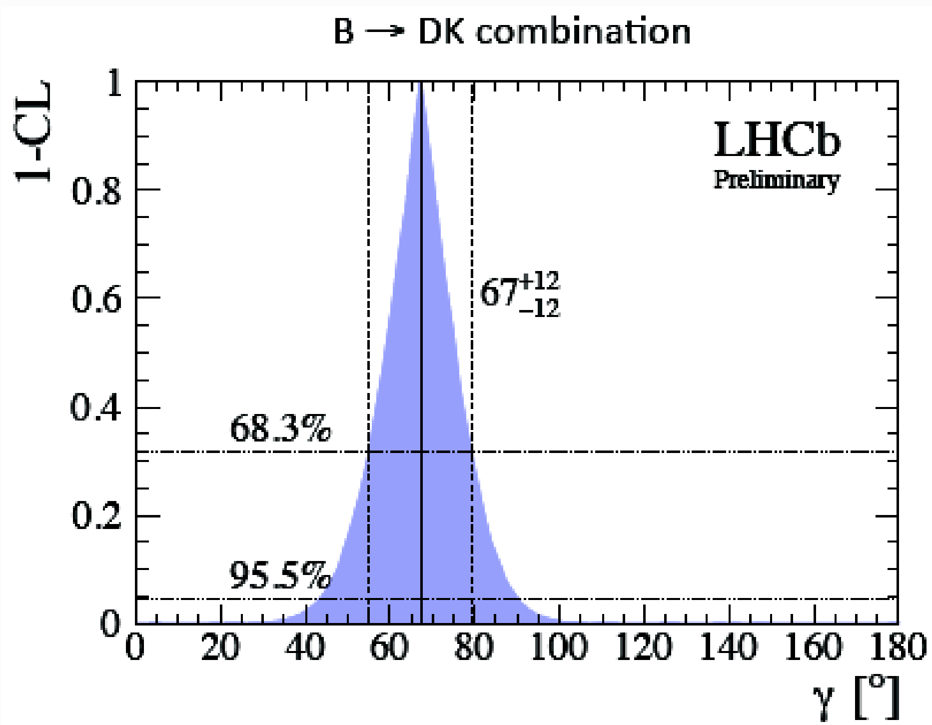


Result on CKM γ



- **(Two-body GLW/ADS) :** B →Dh, D→ hh [**Phys. Lett. B712 (2012) 203**]
- **(Four-body ADS) :** B →Dh, D→ Kπππ [**LHCb-PAPER-2012-055; arxiv:1303.4646**]
- **(GGSZ) :** B →DK, D→ $K_S$hh [**Phys. Lett. B718 (2012) 43**]

The combined results for B → DK decays using 1 fb^{-1} (7 TeV) from GLW/ADS/GGSZ plus 2 fb^{-1} (8 TeV) from GGSZ :



Confidence intervals

$$\gamma \in [43.9, 89.5]^\circ \text{ at } 95\% \text{ CL}$$
$$\gamma \in [55.1, 79.1]^\circ \text{ at } 68\% \text{ CL}$$

Best fit value

$$\gamma = (67 \pm 12)^\circ \text{ at } 68\% \text{ CL}$$

Submitted to Phys. Lett. B - arxiv:1305.2050

LHCb-CONF-2013-006

LHCb-CONF-2013-004

Mixing and CPV in charm sector

D^0 mixing

$|D^0\rangle \ |\bar{D}^0\rangle$

Flavor eigenstates

- Well defined flavor

$|D_1\rangle \ |D_2\rangle$

Hamiltonian eigenstates

- Well defined m and Γ
- Define the mixing parameters

Mixing determines the time evolution of the flavor eigenstates

$$|D_{1,2}\rangle = p|D^0\rangle \pm q|\bar{D}^0\rangle$$

$$x = \frac{m_1 - m_2}{\Gamma} \quad y = \frac{\Gamma_1 - \Gamma_2}{2\Gamma} \quad \Gamma = \frac{\Gamma_1 + \Gamma_2}{2}$$

- Event classes - flavour tagging at production and decay

$D^{*+} \to \pi_s^+ D^0$

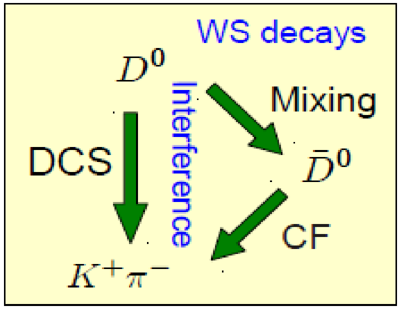
No Mixing: $D^0 \to \pi^+ K^-$ — Right Sign Decay (RS), no D^0 Mixing, $R \approx 1$

Mixing: $\bar{D}^0 \to \pi^- K^+$ — Wrong Sign Decay (WS), D^0 Mixing

DCS 0.3% unmixed

CF 0.006% mixed

- Time evolution of the WS decay rate



- assume CP conservation and $|x| \ll 1$; $|y| \ll 1$

$$T_{WS}(t) \propto e^{-\Gamma t}\left(\underbrace{R_D}_{\text{DCS}} + \underbrace{\sqrt{R_D}\, y'\, \Gamma t}_{\text{Interference}} + \underbrace{\frac{x'^2 + y'^2}{4}(\Gamma t)^2}_{\text{Mixing}}\right)$$

- $\delta_{K\pi}$ is the strong phase between CF and DCS amplitudes ($D^0 \to K\pi$)

$$x' = x \cos\delta_{K\pi} + y \sin\delta_{K\pi}$$
$$y' = -x \sin\delta_{K\pi} + y \cos\delta_{K\pi}$$
$$y'^2 + x'^2 = x^2 + y^2$$

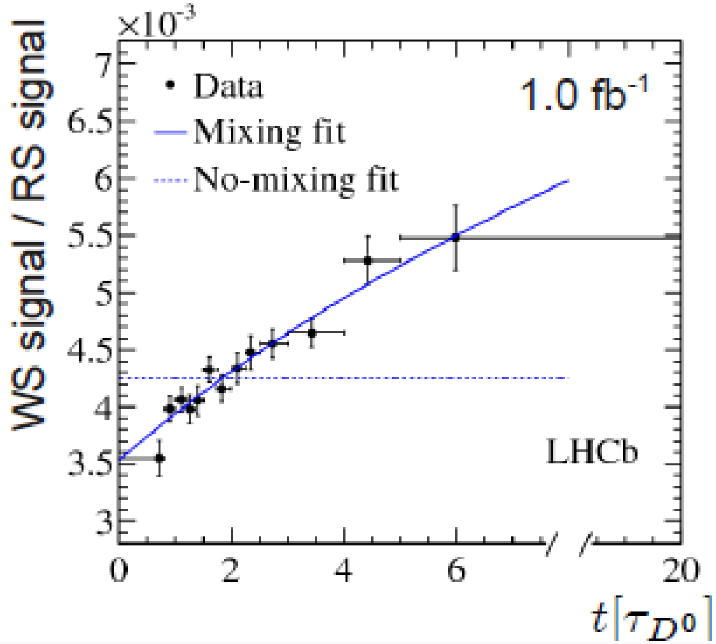
D^0 mixing

- Measure the Number of WS and RS D^0 decays in 13 bins of the lifetime.

$$N_{RS}^{tot} = 8.4 \cdot 10^6 \qquad N_{WS}^{tot} = 3.6 \cdot 10^4$$

- Fit the $N_{WS}^{tot}/N_{RS}^{tot}$ vs the D^0 decay time

$$R(t) \propto e^{-\Gamma t}\left(R_D + \sqrt{R_D}\, y'\, \Gamma t + \frac{x'^2 + y'^2}{4}(\Gamma t)^2\right)$$

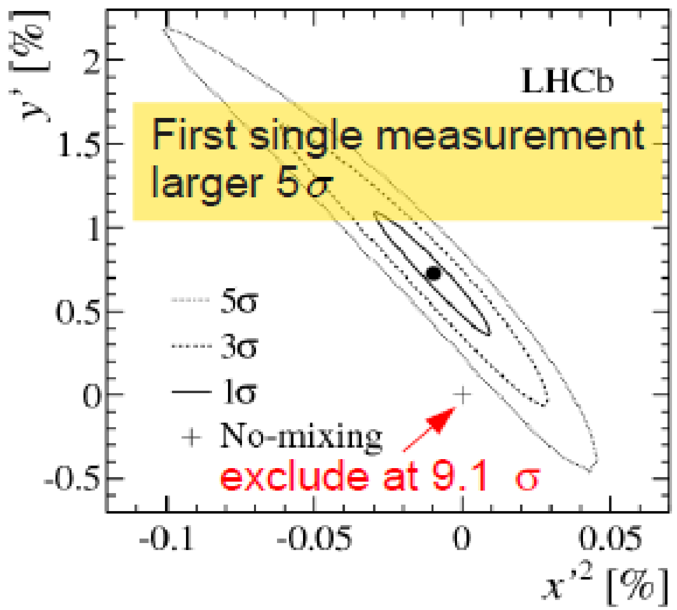


arXiv:1211.1230

- Mixing Parameter

$$R_D = (0.352 \pm 0.015)\%$$
$$y' = (0.72 \pm 0.24)\%$$
$$x'^2 = (-0.009 \pm 0.013)\%$$

Errors include sys. uncertainties



CP violation in *D* decays

In SM direct CP violation predicted to be small ~ 10^{-3} - 10^{-4}

Access via asymmetry measurement

$$A_{CP}(f;t) \equiv \frac{\Gamma(D^0(t)\to f) - \Gamma(\bar{D}^0(t)\to f)}{\Gamma(D^0(t)\to f) + \Gamma(\bar{D}^0(t)\to f)} = \underbrace{a_{CP}^{dir}(f)}_{\text{CPV in decay}} + \underbrace{\frac{t}{\tau}a_{CP}^{ind}}_{\text{CPV in mixing + interfer}}$$

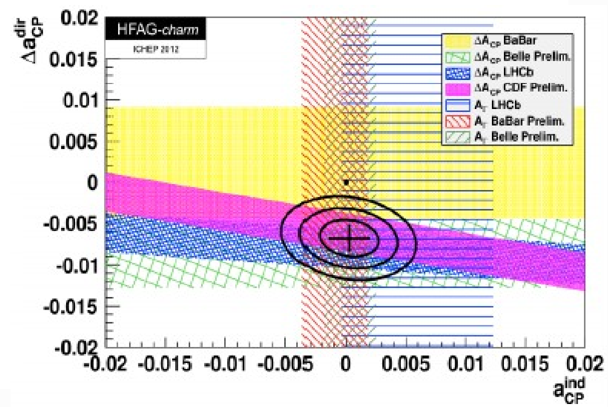
CP eigenstate (f)

LHCb: Time integrated difference of asymmetries

$$\Delta A_{CP} = A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-)$$
$$= [a_{CP}^{dir}(K^+K^-) - a_{CP}^{dir}(\pi^+\pi^-)] + \frac{\Delta < t >}{\tau}a_{CP}^{ind}$$

With 0.6fb^{-1} data sample LHCb found 3.5σ evidence of direct CP violation

$$\Delta(\mathcal{A}^{\mathrm{CP}}) = \mathcal{A}^{\mathrm{CP}}(D^0 \to K^+K^-) - \mathcal{A}^{\mathrm{CP}}(D^0 \to \pi^+\pi^-)$$
$$= [-0.82 \pm 0.21(\mathrm{stat}) \pm 0.11(\mathrm{syst})]\%$$



Later some indication came from other experiments

Led to discussion: “Is it sign from NP?”

CP violation in *D* decays

In **SM direct CP violation** predicted to be **small** ~ 10^{-3} - 10^{-4}

Access via asymmetry measurement

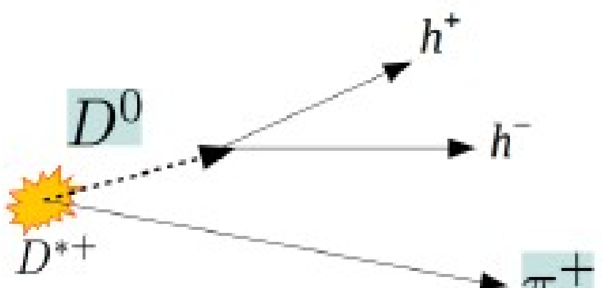
$$A_{CP}(f;t) \equiv \frac{\Gamma(D^0(t) \to f) - \Gamma(\bar{D}^0(t) \to f)}{\Gamma(D^0(t) \to f) + \Gamma(\bar{D}^0(t) \to f)} = \underbrace{a_{CP}^{dir}(f)}_{\text{CPV in decay}} + \underbrace{\frac{t}{\tau} a_{CP}^{ind}}_{\text{CPV in mixing + interfer}}$$

CP eigenstate

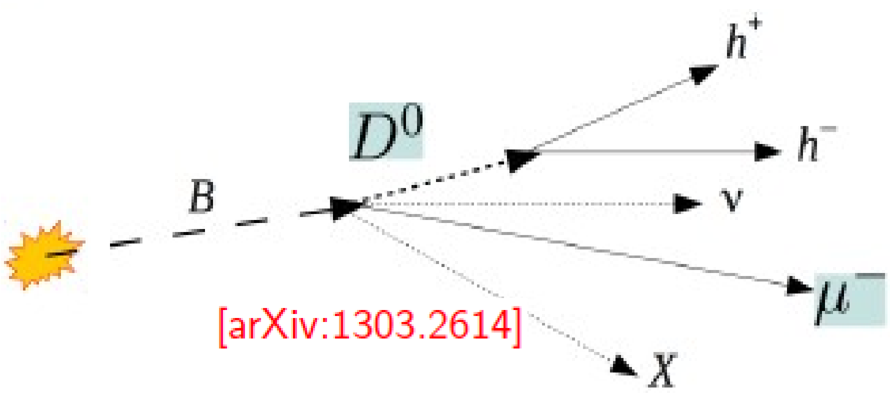
LHCb measured **time integrated difference of asymmetries**

$$\Delta A_{CP} = A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-)$$
$$= [a_{CP}^{dir}(K^+K^-) - a_{CP}^{dir}(\pi^+\pi^-)] + \frac{\Delta < t >}{\tau} a_{CP}^{ind}$$

Two complimentary analysis with 1 fb^{-1} data sample



[LHCb-CONF-2013-003]

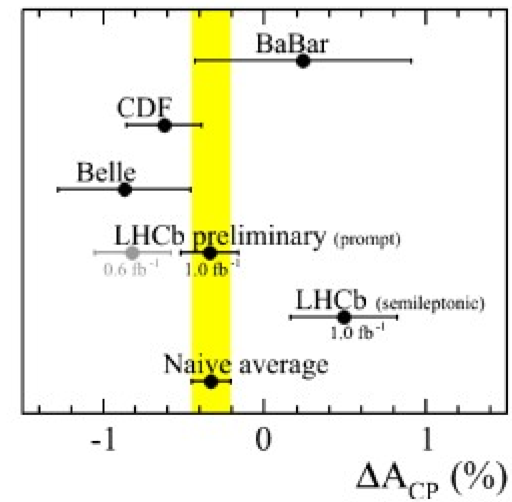


[arXiv:1303.2614]

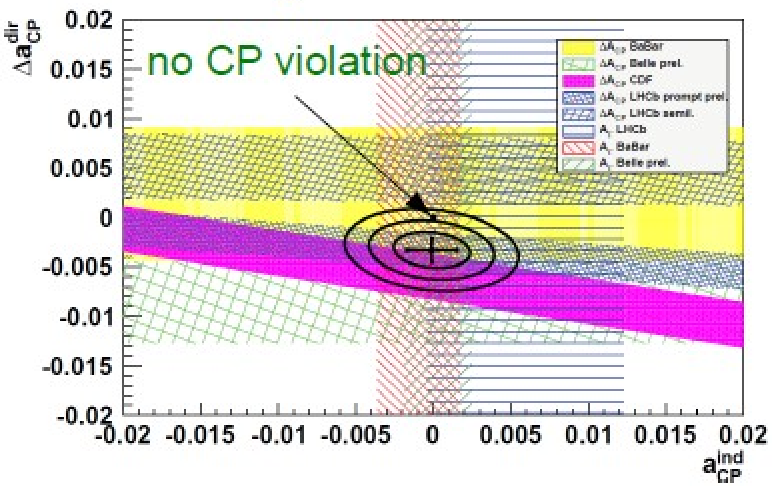
CP violation in *D* decays

LHCb results:

- D^* tagged sample (preliminary)
  $\Delta A_{CP} = (-0.34 \pm 0.15\,(stat) \pm 0.10\,(sys))\ \%$
- μ tagged sample
  $\Delta A_{CP} = (+0.49 \pm 0.30\,(stat) \pm 0.14\,(sys))\ \%$



Consistent with no CPV hypothesis!



HFAG averages:

$$a_{CP}^{ind} = (-0.010 \pm 0.162)\ \%$$

$$\Delta a_{CP}^{dir} = (-0.329 \pm 0.121)\ \%$$

Note: ΔA_{CP} measurements in $D^+ \to \phi\pi^+$ and $D_s^+ \to K_s^0\pi^+$ are compatible with 0 arXiv:1303.4906, not discussed here

Production & Spectroscopy

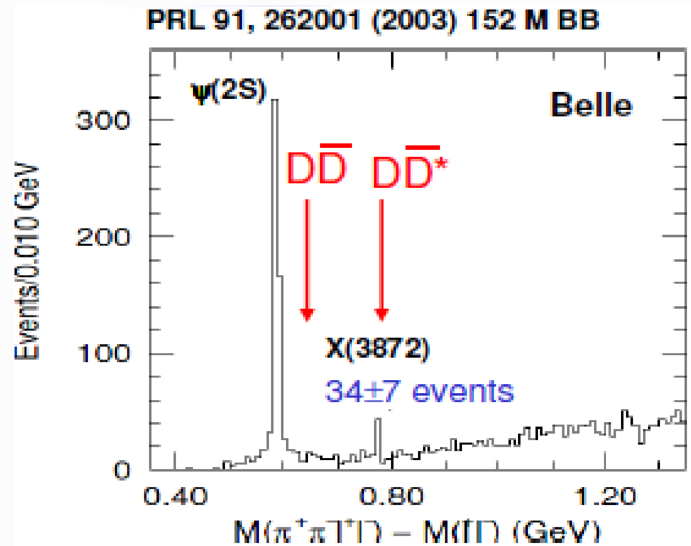
1) *X(3872)* quantum numbers

2) Mass of *D* mesons

X(3872) quantum numbers

Discovered by Belle in 2003 at e^+e^-

- – It is extremely narrow. Only upper limits on its width (<1.2 MeV) None of the known $c\bar{c}$ states above $D\bar{D}$ threshold is so narrow
  - This automatically eliminates all $c\bar{c}$ excitations which can decay to $D\bar{D}$
- – Its mass is not near any of the predicted $c\bar{c}$ masses. Closest predicted $c\bar{c}$ states which could be narrow: $2^3P_1{}^{++}$, $1^1D_2{}^{-+}$
- – Its mass is nearly equal $m(D^0)+m(D^{0*})$:
  - It is loosely bound $D^0\bar{D}^{0*}=(c\bar{u})(\bar{c}u)$ molecule or $(c\bar{c}u\bar{u})$ tetraquark? Both models require $J^{PC}=1^{++}$

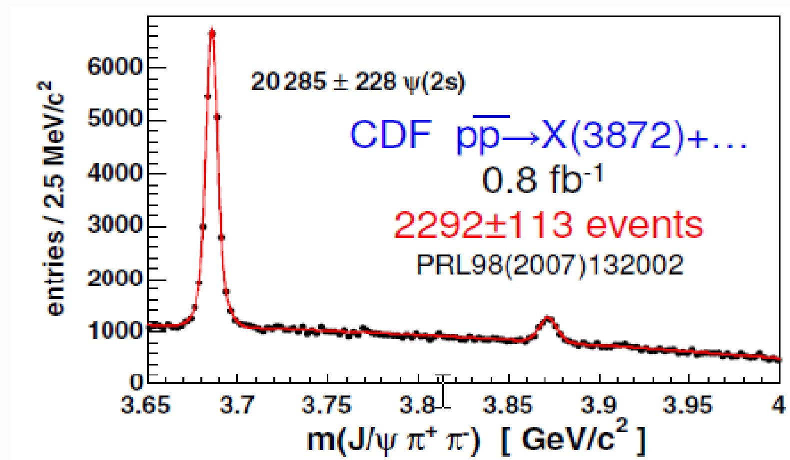


CDF's binned 3D angular χ^2 fit:

J^{PC}	decay	LS	χ^2 (11 d.o.f.)	χ^2 prob.
1^{++}	$J/\psi\rho^0$	01	13.2	0.28
2^{-+}	$J/\psi\rho^0$	11,12	13.6	0.26
1^{--}	$J/\psi(\pi\pi)_S$	01	35.1	2.4×10^{-4}
2^{+-}	$J/\psi(\pi\pi)_S$	11	38.9	5.5×10^{-5}
1^{+-}	$J/\psi(\pi\pi)_S$	11	39.8	3.8×10^{-5}
2^{--}	$J/\psi(\pi\pi)_S$	21	39.8	3.8×10^{-5}
3^{+-}	$J/\psi(\pi\pi)_S$	31	39.8	3.8×10^{-5}
3^{--}	$J/\psi(\pi\pi)_S$	21	41.0	2.4×10^{-5}
2^{++}	$J/\psi\rho^0$	02	43.0	1.1×10^{-5}
1^{-+}	$J/\psi\rho^0$	10,11,12	45.4	4.1×10^{-6}
0^{-+}	$J/\psi\rho^0$	11	104	3.5×10^{-17}
0^{+-}	$J/\psi(\pi\pi)_S$	11	129	$\leq1\times10^{-20}$
0^{++}	$J/\psi\rho^0$	00	163	$\leq1\times10^{-20}$

Cannot distinguish between 1^{++} and 2^{-+}
All other ruled out.

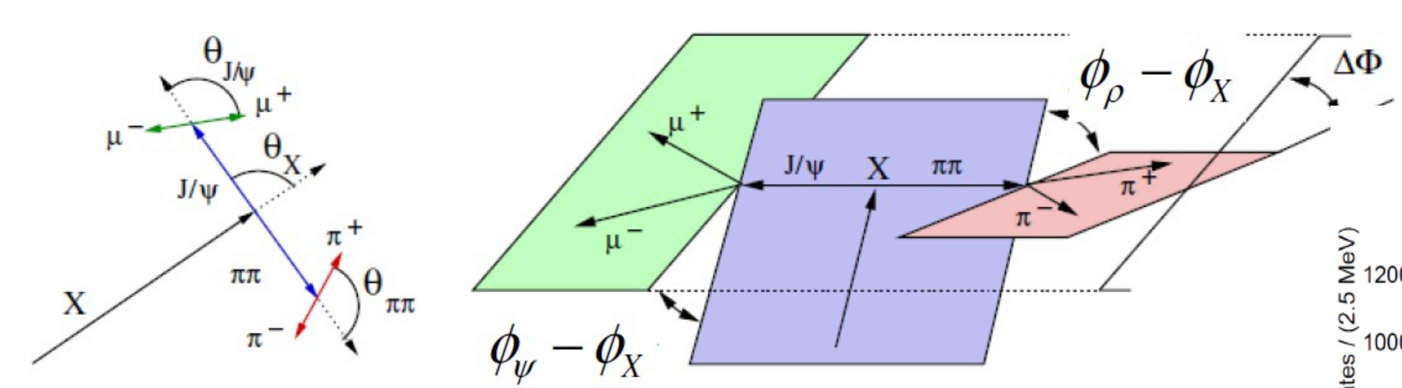
Previous angular analysis - CDF



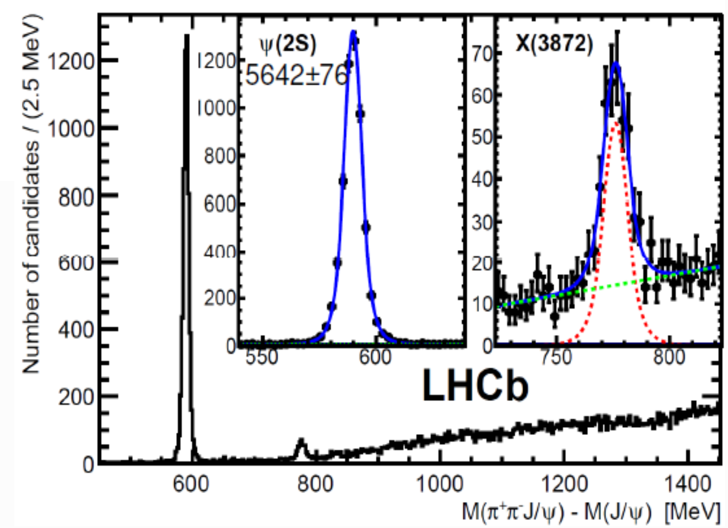
$X(3872)$ quantum numbers

$B^+ \to X(3872)K^+,\ X(3872) \to J/\psi\,\rho\,,\ J/\psi \to l^+l^-\,,\ \rho \to \pi^+\pi^-$

$$P(\Omega \mid J_X, A^{J_X}_{\lambda_\psi,\lambda_\rho}) \propto \sum_{\Delta\lambda_\mu=-1,1} \left| \sum_{\lambda_\psi=-1,0,1} \sum_{\lambda_\rho=-1,0,1} A^{J_X}_{\lambda_\psi,\lambda_\rho} d^{J_X}_{0,\lambda_\psi-\lambda_\rho}(\theta_X) d^{1}_{\lambda_\psi,\Delta\lambda_\mu}(\theta_\psi) e^{i\lambda_\psi(\phi_\psi-\phi_X)} d^{1}_{-\lambda_\rho,0}(\theta_\rho) e^{i\lambda_\rho(\phi_X-\phi_\rho)} \right|^2$$



arXiv:1302.6269
Accepted by PRL



LHCb:

$1fb^{-1}$ sample

313±26 ev.

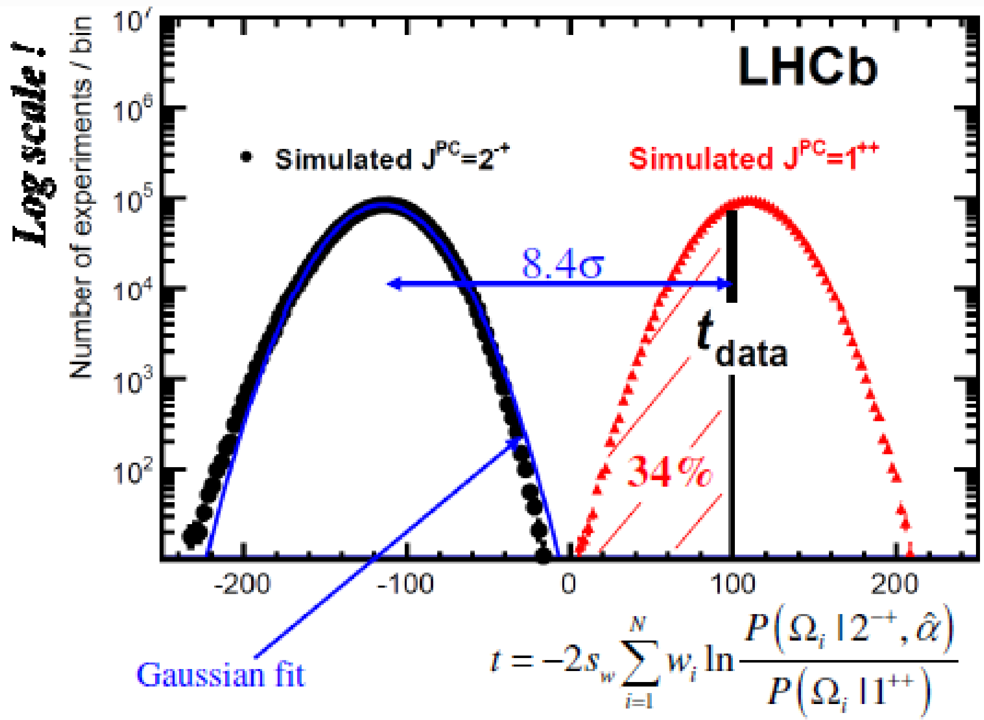
5D analysis

Unbinned data

Likelihood ratio test

X(3872) quantum numbers

$P(t|J_X^P)$



arXiv: 1302.6269
Accepted by PRL

- The Gaussian approximation conservative since the actual distribution to the left of the Gaussian fit.
  - The 2^{-+} hypothesis is ruled out at 8.4σ (>8 after systematics)
- 1^{++} C.L. is high (34%).

The state $\eta_{c2}(1^1D_2)$ is excluded, favour unconventional interpretations $\chi_{c1}(2^3P_1)$, $D^{*0}\bar{D}^0$ molecule, tetra quarks or charmonium-molecules

D meson mass measurement

Interpreting X(3872) as $D^{*0}D^0$ molecule E_B is determined by D mass measurements: $E_B = 0.16 \pm 0.26\, MeV/c^2$

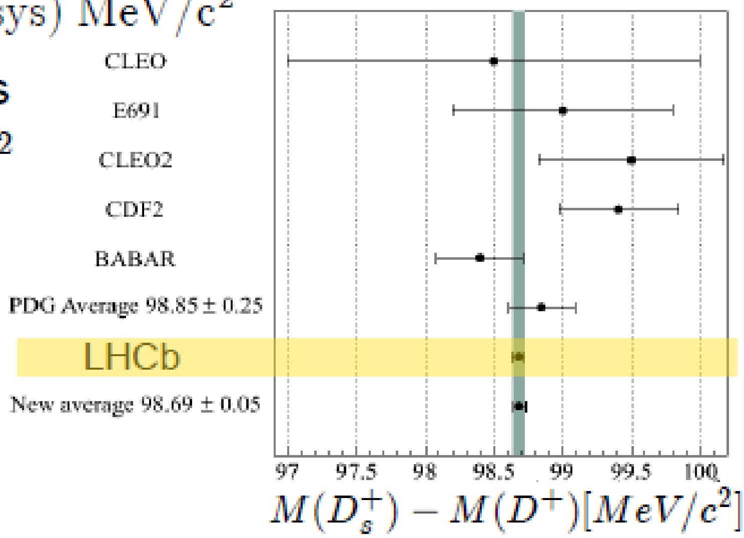
- Mass measurements in the D system   arXiv: 1304.6865 $(\int \mathcal{L} = 1 fb^{-1})$
  - Determine D^0 mass in $D^0 \to K^+K^-K^-\pi^+$
    $M(D^0) = 1864.75 \pm 0.15(\mathrm{stat}) \pm 0.11(\mathrm{sys})\ \mathrm{MeV/c^2}$
  - Mass difference measurements
    $M(D^+) - M(D^0) = 4.76 \pm 0.12(\mathrm{stat}) \pm 0.07(\mathrm{sys})\ \mathrm{MeV/c^2}$
    $M(D_s^+) - M(D^+) = 98.68 \pm 0.03(\mathrm{stat}) \pm 0.04(\mathrm{sys})\ \mathrm{MeV/c^2}$

    Derive a significantly more precise D_s^+ mass
    $M(D_s^+) = 19684.19 \pm 0.20 \pm 0.14 \pm 0.08\ MeV/c^2$

  - Dominant syst. uncertainty on the mass is due to the momentum scale of 0.03 %

    D^0 mass : $0.09\ \mathrm{MeV/c^2}$
    mass difference : $0.04\ \mathrm{MeV/c^2}$

arXiv: 1304.6865



Summary

LHCb, the forward spectrometer for precision studies in flavour physics domain

Excellent performance of the LHC and LHCb has led to a lot of physics results

- **Test of SM (which still holds its ground!)**
- **Search for NP**
- **Make CP violation measurements in b- and c-sectors**

World best quality of the results in charm and beauty physics!

Remember, that presented here measurements use mainly the 1 fb^{-1} dataset

(**70% of the 2010-12 data still in progress**)

OUTLOOK:

1) Plan to have more than 5 fb^{-1} at $\sqrt{s}$ = 13 TeV during next LHC run (2015-18)

=> **8 times higher statistics in 2019** (in comparison with presented results)

2) **Upgrade** (next slide)

Outlook. ***Theory vs. 50 fb^{-1}***

EPJ C 73, 2373

Type	Observable	Current precision	LHCb 2018	Upgrade ($50\,fb^{-1}$)	Theory uncertainty
B_s^0 mixing	$2\beta_s$ ($B_s^0 \to J/\psi\ \phi$)	0.10 [30]	0.025	0.008	~ 0.003
	$2\beta_s$ ($B_s^0 \to J/\psi\ f_0(980)$)	0.17 [32]	0.045	0.014	~ 0.01
	a_{sl}^s	6.4×10^{-3} [63]	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguins	$2\beta_s^{eff}(B_s^0 \to \phi\phi)$	–	0.17	0.03	0.02
	$2\beta_s^{eff}(B_s^0 \to K^{*0}\bar{K}^{*0})$	–	0.13	0.02	< 0.02
	$2\beta^{eff}(B^0 \to \phi K_S^0)$	0.17 [63]	0.30	0.05	0.02
Right-handed currents	$2\beta_s^{eff}(B_s^0 \to \phi\gamma)$	–	0.09	0.02	< 0.01
	$\tau^{eff}(B_s^0 \to \phi\gamma)/\tau_{B_s^0}$	–	5 %	1 %	0.2 %
Electroweak penguins	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\,GeV^2/c^4)$	0.08 [64]	0.025	0.008	0.02
	$s_0\ A_{FB}(B^0 \to K^{*0}\mu^+\mu^-)$	25 % [64]	6 %	2 %	7 %
	$A_I(K\mu^+\mu^-; 1 < q^2 < 6\,GeV^2/c^4)$	0.25 [9]	0.08	0.025	~ 0.02
	$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$	25 % [29]	8 %	2.5 %	~ 10 %
Higgs penguins	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	1.5×10^{-9} [4]	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–$12°$ [40, 41]	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° [63]	0.6°	0.2°	negligible
Charm CP violation	A_Γ	2.3×10^{-3} [63]	0.40×10^{-3}	0.07×10^{-3}	–
	ΔA_{CP}	2.1×10^{-3} [8]	0.65×10^{-3}	0.12×10^{-3}	–

Thank you for your attention!