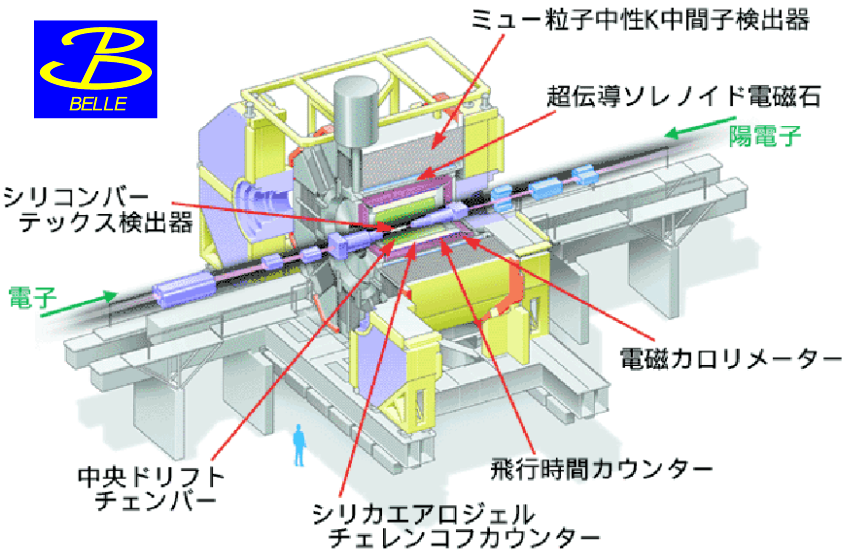
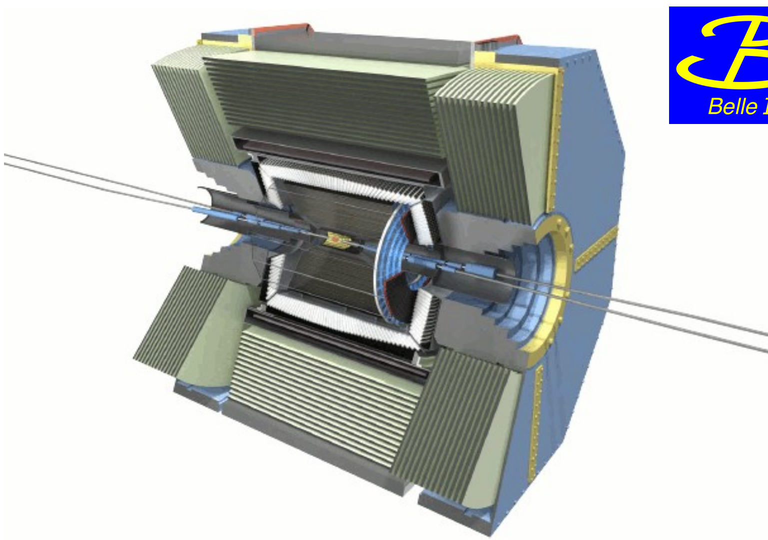
Flavour physics at Belle (II) and LHCb

''Recent results and discussions on their interpretation''





K.Trabelsi
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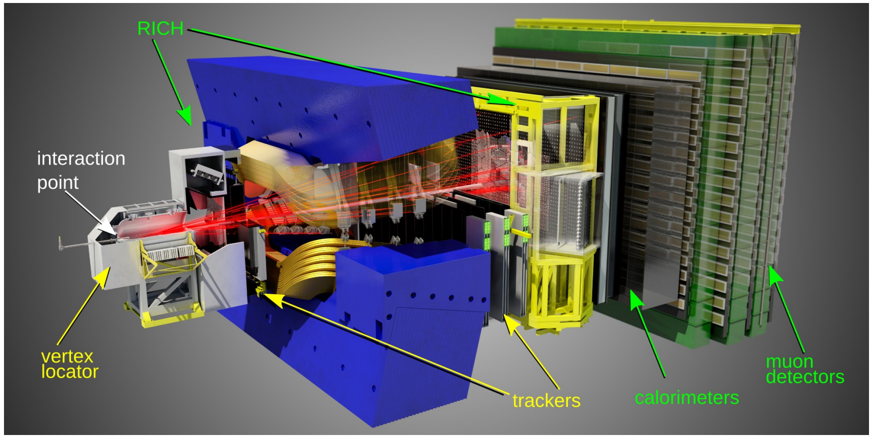
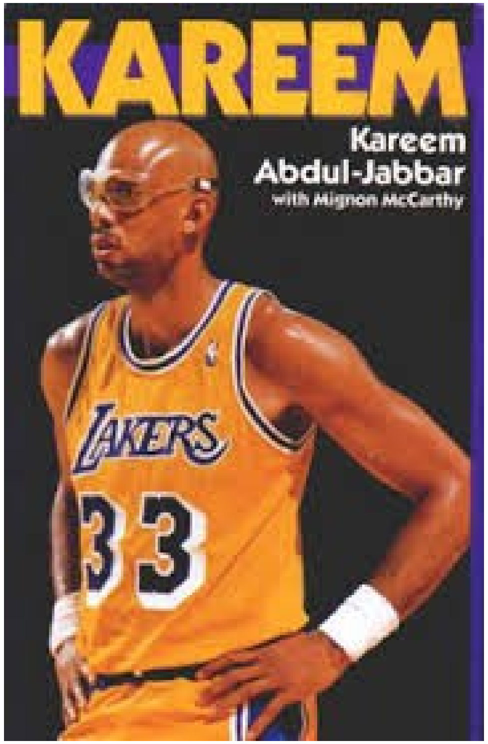
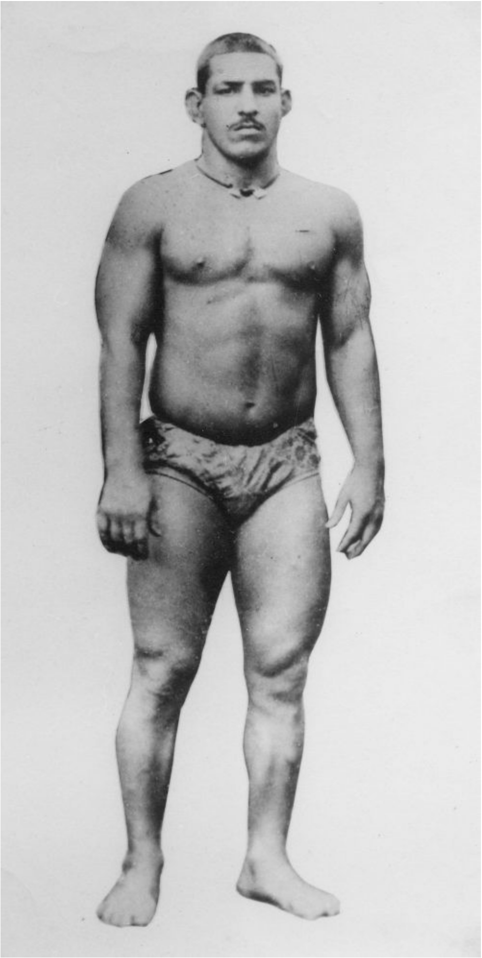


Mumbai, December 4th 2016


KAREEM
Kareem
Abdul-Jabbar
with Mignon McCarthy
LAKERS
33


10

Karim Baksh

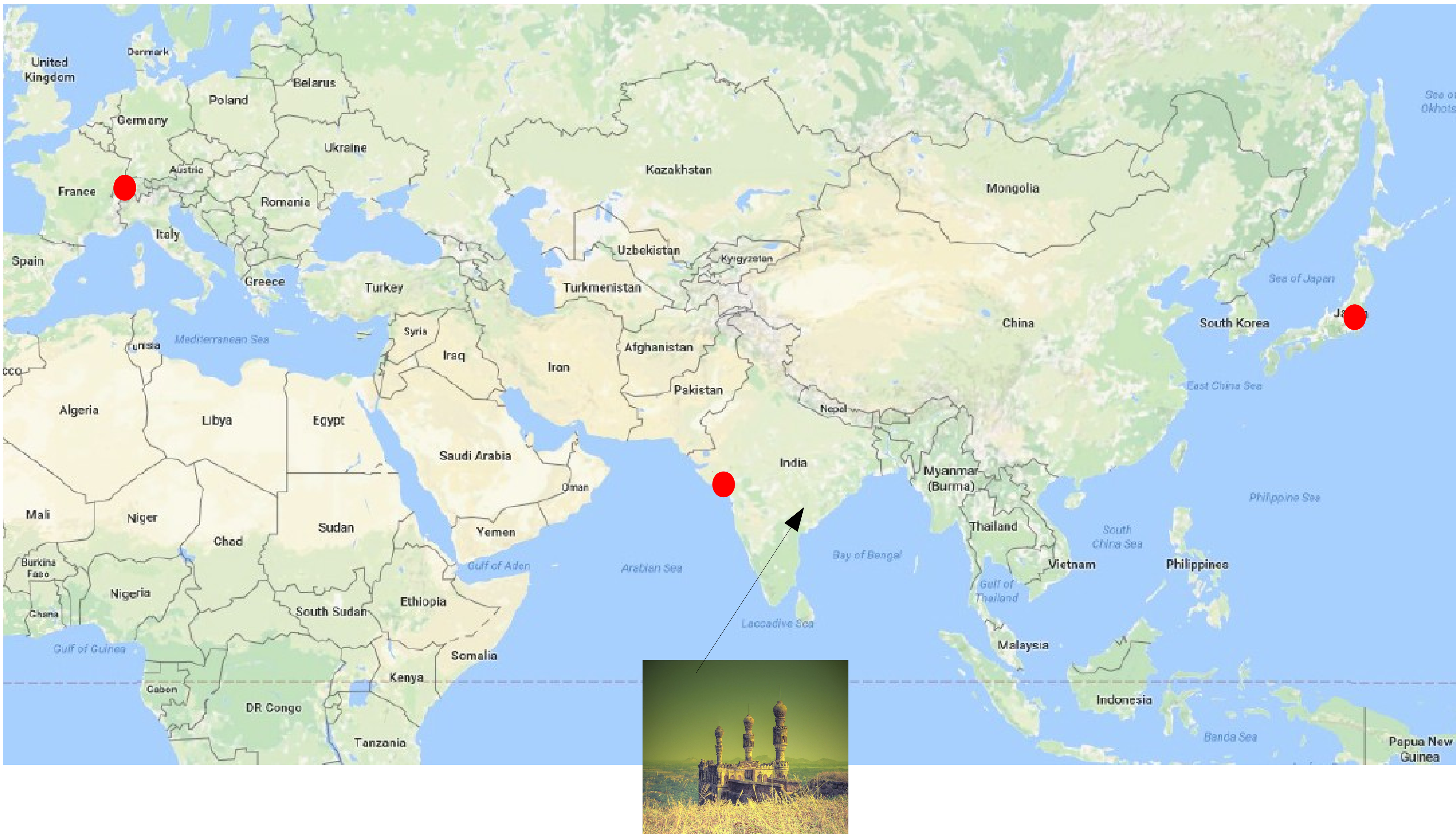


Karim Lala (don of Mumbai)

Lala is the original 'don of Mumbai.'

The guy is the one who founded the country's most notorious and powerful criminal organisation called 'The Indian Mafia'. Lala was born in ~~Afghanistan~~ France and despite being a gangster (like so many of his fellows) he was kind to the poor and needy. He was mostly involved with crimes like extortion…

where ? (well...)
when ? (now...)
what and how will follow in the next slides

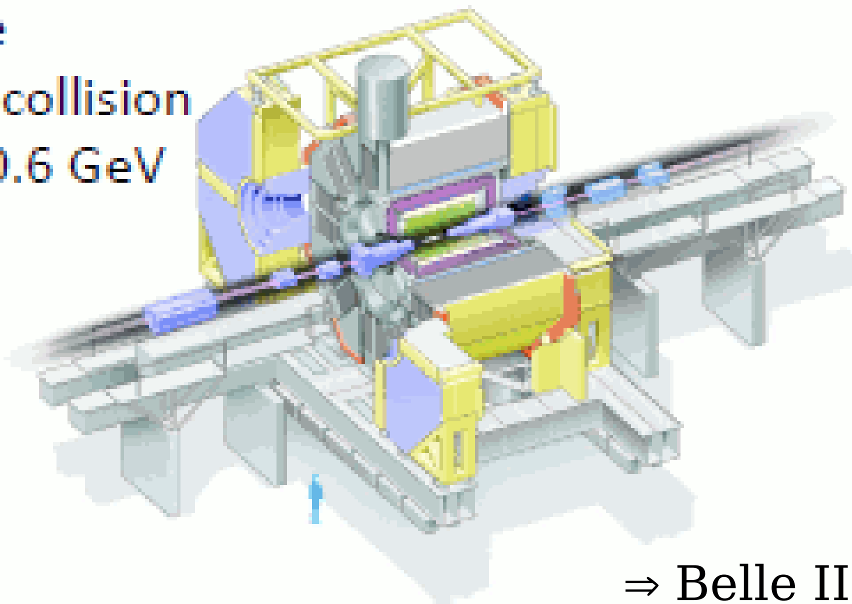


A rich physics program...

- **Studies of CPV in B and B_s decays**
- **$b \to s$ transitions: probe for new sources of CPV and constraints from the $b \to s\gamma$ observables**
- **Forward-backward asymmetry and other observables in $b \to s l^+ l^-$**
- **Search for the charged Higgs in the rare decays $B \to \tau\nu$, $D^{(*)}\tau\nu$**
- Study of B_s, B_c, Λ_b decays
- Study of D^0-$\overline{D}^0$ mixing
- Search for CPV in D and D_s decays
- Studies of exotic charmonium, tetraquark, pentaquark states
- Studies of new bottomonium-like states
- Search for lepton flavor violation (LFV) in τ decays
- Search for CPV and study of hadronic τ decays
- Light Higgs searches, DM searches...
- ...

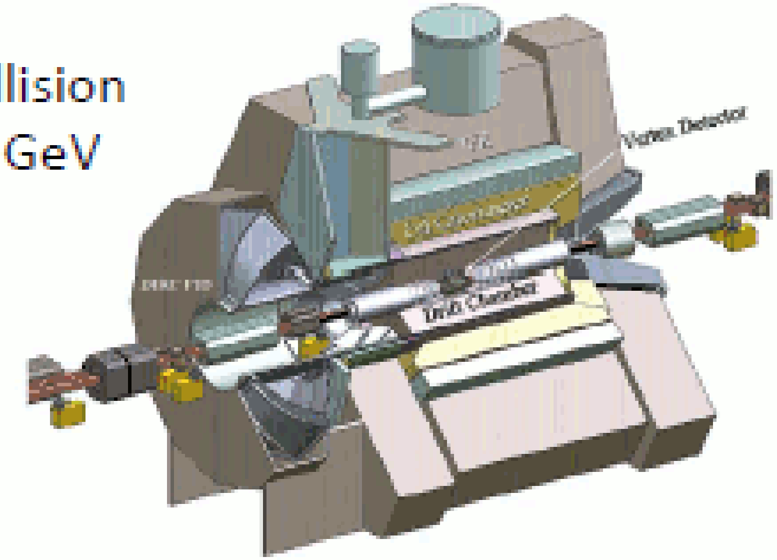
Main actors in B physics

Belle
e^+e^- collision
at 10.6 GeV

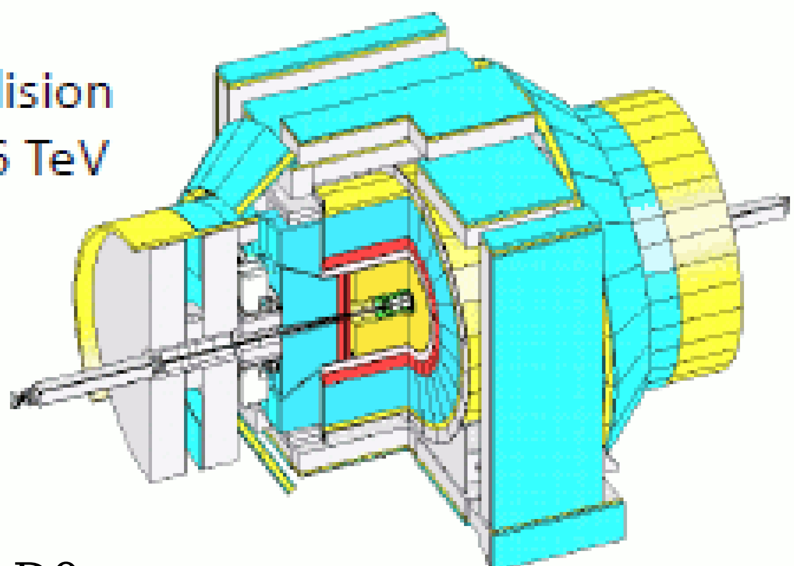


⇒ Belle II

BaBar
e^+e^- collision
at 10.6 GeV

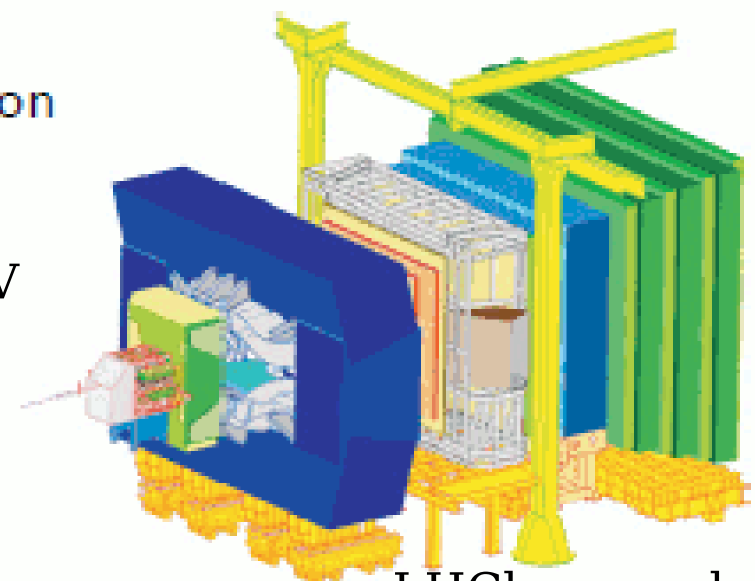


CDF
$p\bar{p}$ collision
at 1.96 TeV



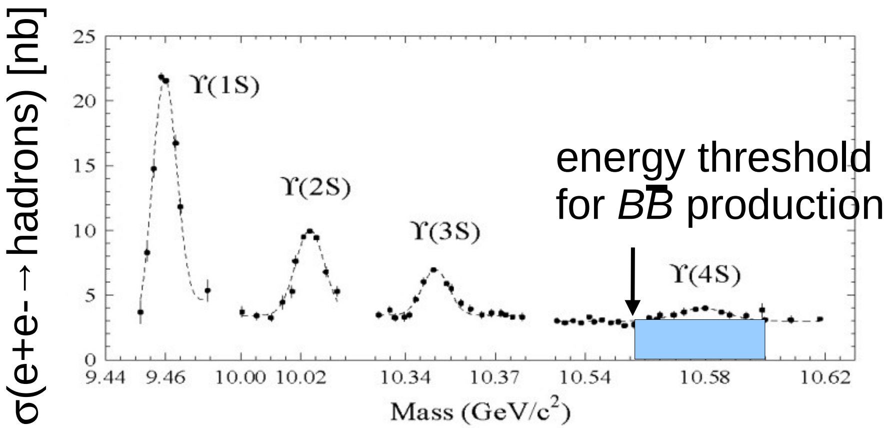
... and D0

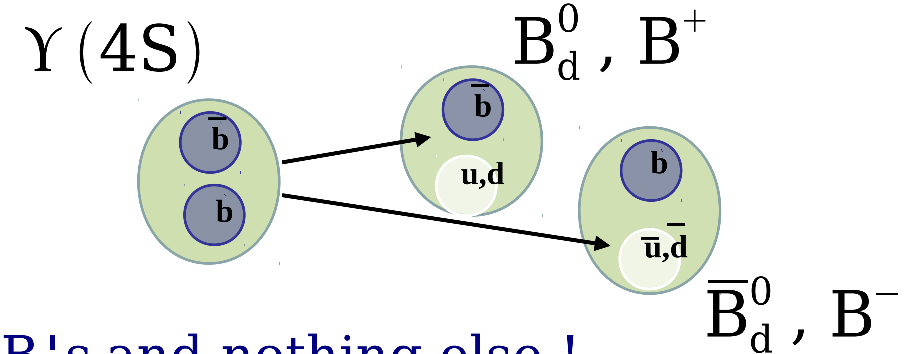
LHCb
pp collision
at 7 TeV
8 TeV
13 TeV



⇒ LHCb upgrade

$\Upsilon(4S)$ B-factory





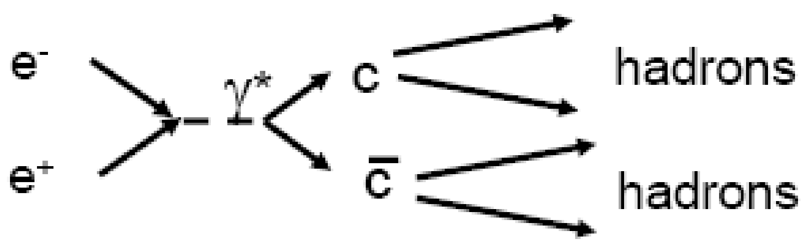
- 2 B's and nothing else !
- 2 B mesons are created simultaneously in a L=1 coherent state
  $\Rightarrow$ before first decay, the final states contains a B and a $\overline{B}$

''on resonance'' production

$$e^+e^- \to \Upsilon(4S) \to B_d^0\overline{B}_d^0,\ B^+B^-$$

$$\sigma(e^+e^- \to B\overline{B}) \simeq 1.1 \text{ nb } (\sim 10^9\ B\overline{B} \text{ pairs})$$

''continuum'' production

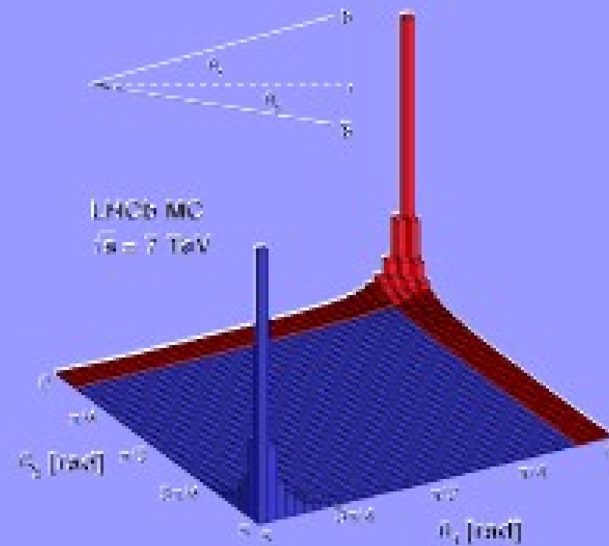


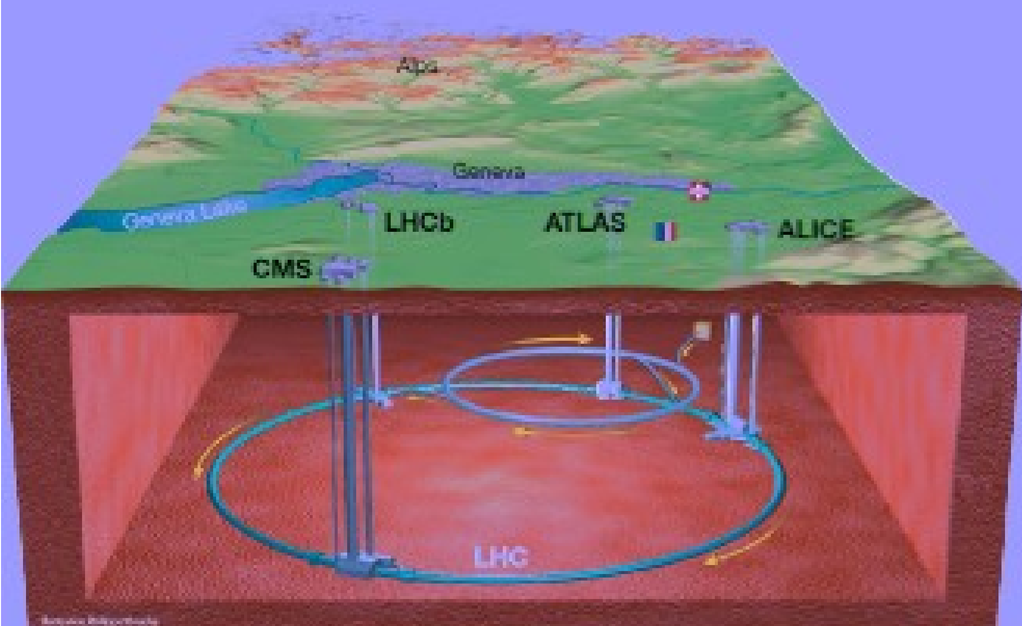
$$\sigma(e^+e^- \to c\overline{c}) \simeq 1.3 \text{ nb } (\sim 1.3\times10^9\ X_c\,Y_c \text{ pairs})$$

$\tau\tau$ production also !

LHCb is …

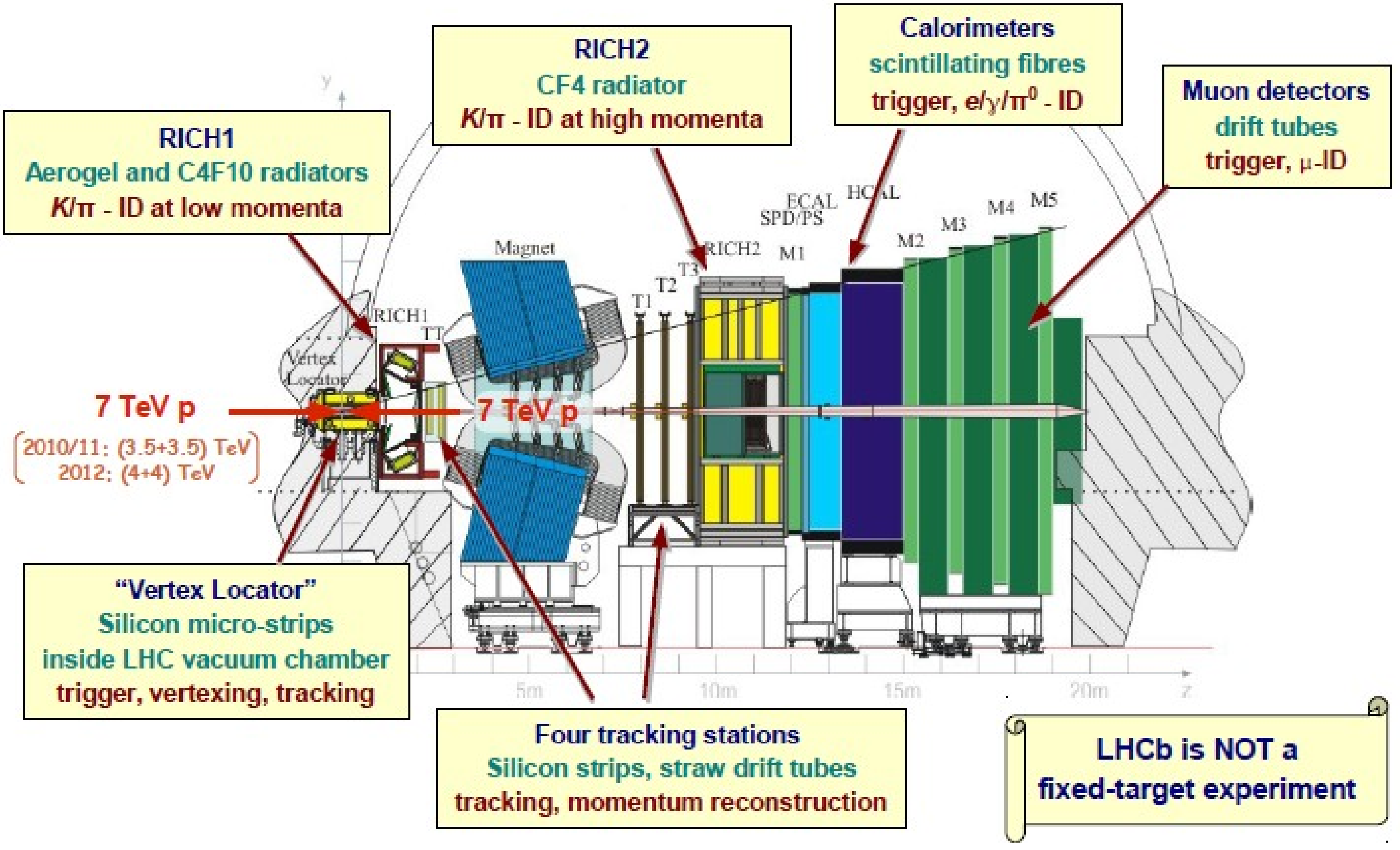
- 1075 members, from 68 institutes in 17 countries (September 2014)
- Dedicated experiment for precision measurements of CP violation and rare decays
- *Beautiful*, *charming*, *strange* physics program





- pp collisions at $\sqrt{s} = 8(13)$ TeV in RunI (RunII)
- $b\bar{b}$ quark pairs produced correlated in the forward region
- Luminosity of $4 \times 10^{32} cm^{-2} s^{-1}$

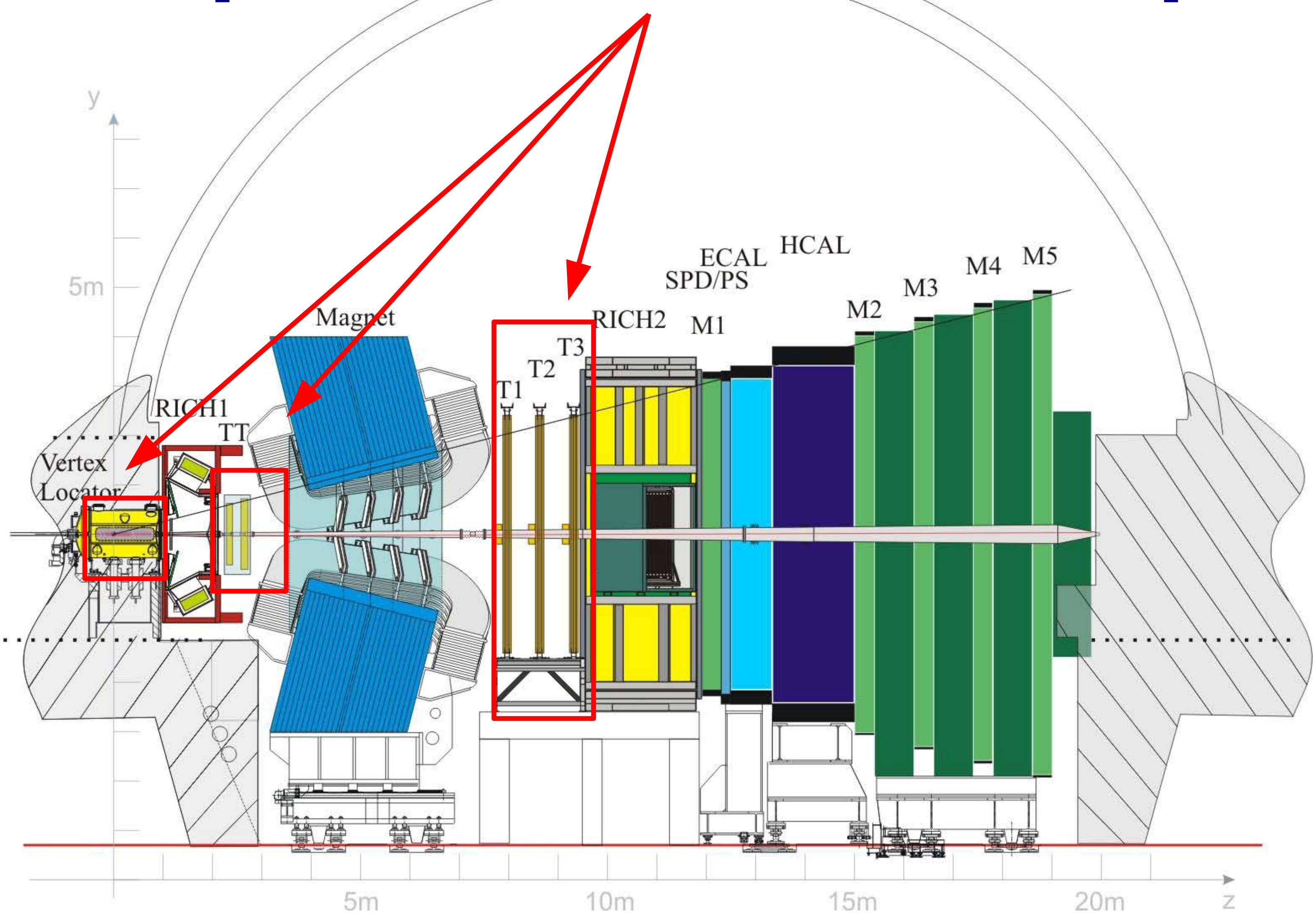
LHCb


RICH1
Aerogel and C4F10 radiators
K/π - ID at low momenta
RICH2
CF4 radiator
K/π - ID at high momenta
Calorimeters
scintillating fibres
trigger, e/γ/π⁰ - ID
Muon detectors
drift tubes
trigger, μ-ID
ECAL
SPD/PS
HCAL
M1
M2
M3
M4
M5
Magnet
RICH1
TT
T1
T2
T3
RICH2
Vertex Locator
7 TeV p
7 TeV p
2010/11: (3.5+3.5) TeV
2012: (4+4) TeV
"Vertex Locator"
Silicon micro-strips
inside LHC vacuum chamber
trigger, vertexing, tracking
Four tracking stations
Silicon strips, straw drift tubes
tracking, momentum reconstruction
5m
10m
15m
20m
z
y
LHCb is NOT a
fixed-target experiment

LHCb

Tracking system

Measure displaced vertices and momentum of particles



Vertex and IP resolution

$\sigma(IP) \sim 24\mu m$ at $P_T = 2$ GeV/c

$\sigma_{BV} \sim 16\mu m$ in x, y

Momentum resolution

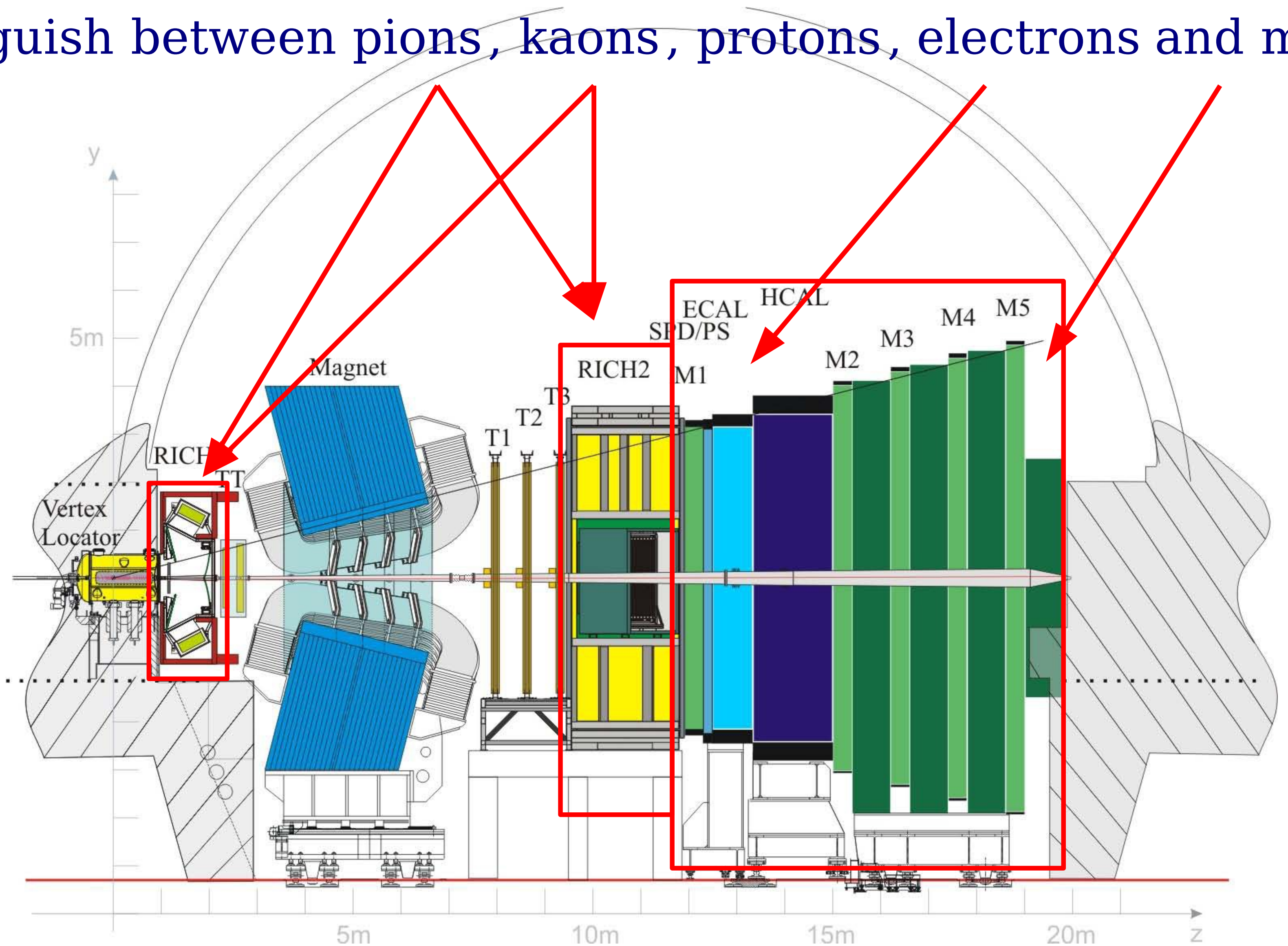
$\sigma(p)/p = 0.4\%-0.6\%$ for $p \in [0, 100]$ GeV/c

$\sigma(m_B) \sim 24$ MeV for two body decays

LHCb

Particle identification

Distinguish between pions, kaons, protons, electrons and muons



Kaon identification

$\epsilon_K \sim 95\%$, $\epsilon_{\pi \to K}$ few %

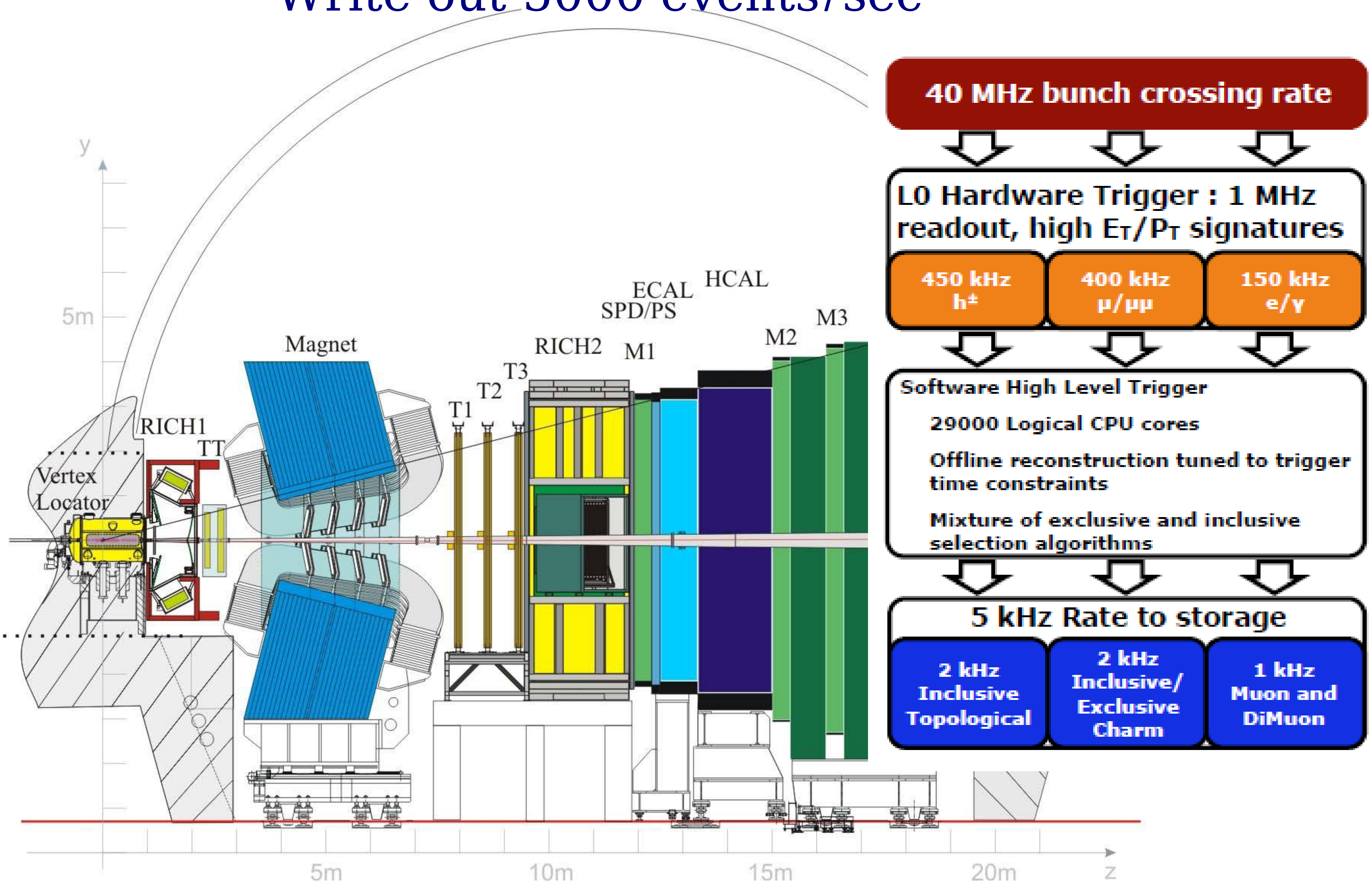
Muon identification

$\epsilon_\mu = 98\%$, $\epsilon_{\pi \to \mu} = 0.6\%$

LHCb

Trigger system

Write out 5000 events/sec



Comparison Belle/LHCb

Belle

$e^+e^- \to \Upsilon(4S) \to b\bar{b}$

at $\Upsilon(4S)$: 2 B's (B^0 or B^+) and nothing else $\Rightarrow$ clean events

$\sigma_{b\bar{b}} \sim 1\,\text{nb} \Rightarrow 1\ \text{fb}^{-1}$ produces $10^6\ B\bar{B}$

$\sigma_{b\bar{b}}/\sigma_{total} \sim 1/4$

LHCb

$pp \to b\bar{b}X$

production of B^+, B^0, B_s, B_c, Λ_b...
but also a lot of other particles in the event

$\Rightarrow$ lower reconstruction efficiencies

$\sigma_{b\bar{b}}$ much higher than at the $\Upsilon(4S)$

	$\sqrt{s}$ [GeV]	$\sigma_{b\bar{b}}$ [nb]	$\sigma_{b\bar{b}}/\sigma_{tot}$
HERA pA	42 GeV	~30	~10^{-6}
Tevatron	2 TeV	5000	~10^{-3}
LHC	8 TeV	~3×10^5	~ 5×10^{-3}
	14 TeV	~6×10^5	~10^{-2}

$b\bar{b}$ production cross-section ~ 5× Tevatron, ~ 500,000 × BaBar/Belle !!

$\sigma_{b\bar{b}}/\sigma_{total}$ much lower than at the $\Upsilon(4S)$

$\Rightarrow$ lower trigger efficiencies

B mesons live relativey long

mean decay length $\beta\gamma c\tau \sim 200\ \mu m$ | mean decay length $\beta\gamma c\tau \sim 7$ mm

data taking period(s)

Belle: [1999-2010] [1 ab^{-1}]

LHCb: [run I: 2010-2012, run II: 2015-2018] [3 fb^{-1}] [5 fb^{-1}]

(near) future

[Belle II from 2018] | [LHCb upgrade from 2020]

CKM matrix and CP violation

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

Wolfenstein parametrisation in terms of $\lambda = 0.2272 \pm 0.0010$:

$$\begin{pmatrix} 1 - \frac{1}{2}\lambda^2 - \frac{1}{8}\lambda^4 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda + \frac{1}{2}A^2\lambda^5\left[1 - 2(\rho + i\eta)\right] & 1 - \frac{1}{2}\lambda^2 - \frac{1}{8}\lambda^4(1 + 4A^2) & A\lambda^2 \\ A\lambda^3\left[1 - \left(1 - \frac{1}{2}\lambda^2\right)(\rho - i\eta)\right] & -A\lambda^2 + \frac{1}{2}A\lambda^4\left[1 - 2(\rho + i\eta)\right] & 1 - \frac{1}{2}A^2\lambda^4 \end{pmatrix} + \mathcal{O}(\lambda^6).$$

$$\lambda^2 = \frac{|V_{us}|^2}{|V_{ud}|^2 + |V_{us}|^2}, \quad A^2\lambda^4 = \frac{|V_{cb}|^2}{|V_{ud}|^2 + |V_{us}|^2} \quad \text{and} \quad \bar{\rho} + i\bar{\eta} = -\frac{V_{ud}V_{ub}^{\text{¿}}}{V_{cd}V_{cb}^{\text{¿}}}$$

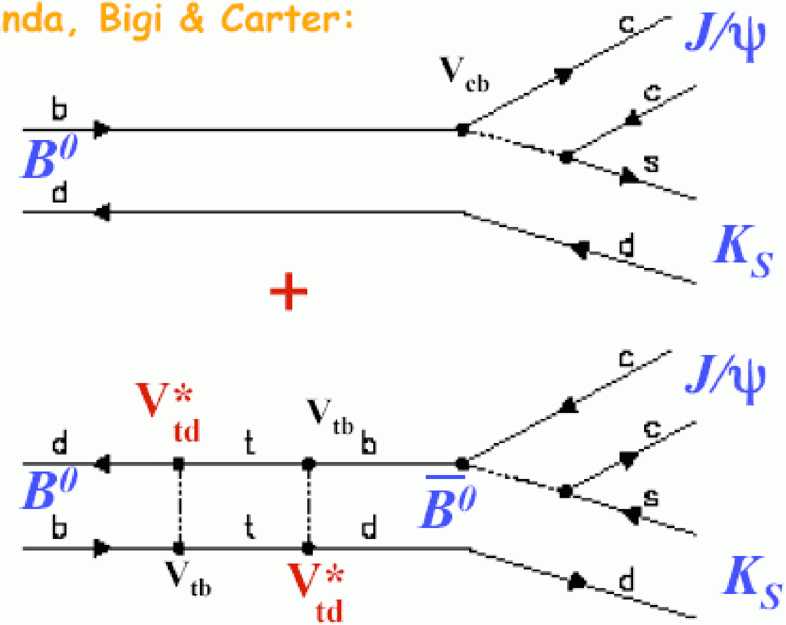
- λ is measured from $|V_{ud}|$ and $|V_{us}|$ in superallowed beta decays and semileptonic kaon decays, respectively.
- A is further determined from $|V_{cb}|$, measured from semileptonic charmed B decays.
- **The last two parameters are to be determined from angles and side measurements of the CKM unitarity triangle**

Time−dependent CP asymmetries in decays to CP eigenstates

$\beta = \varphi_1$

$\sin 2\phi_1$ from $B \to f_{CP} + B \leftrightarrow \overline{B} \to f_{CP}$ interf.

Sanda, Bigi & Carter:



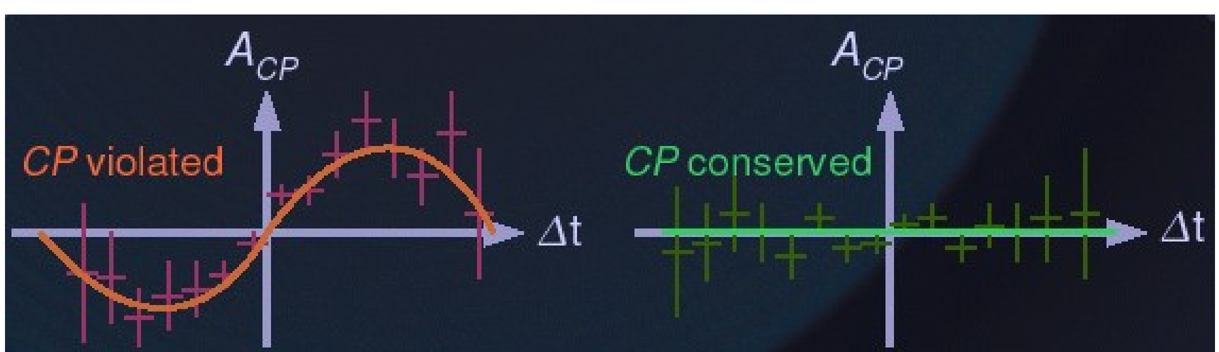
$$A_{CP}(f;t) = \frac{N(\overline{B}^0(t)\to f) - N(B^0(t)\to f)}{N(\overline{B}^0(t)\to f) + N(B^0(t)\to f)}$$

$$= \mathbf{S}\,\sin\Delta m_d t + \mathbf{A}\,\cos\Delta m_d t$$

$$= \frac{2\,\mathrm{Im}\,\lambda}{|\lambda|^2+1}\sin\Delta m_d t + \frac{|\lambda|^2-1}{|\lambda|^2+1}\cos\Delta m_d t$$

$$\lambda = \frac{q}{p}\,\frac{A(\overline{B}^0\to f)}{A(B^0\to f)} = e^{-i2\phi_1}\frac{\overline{A}_f}{A_f}$$

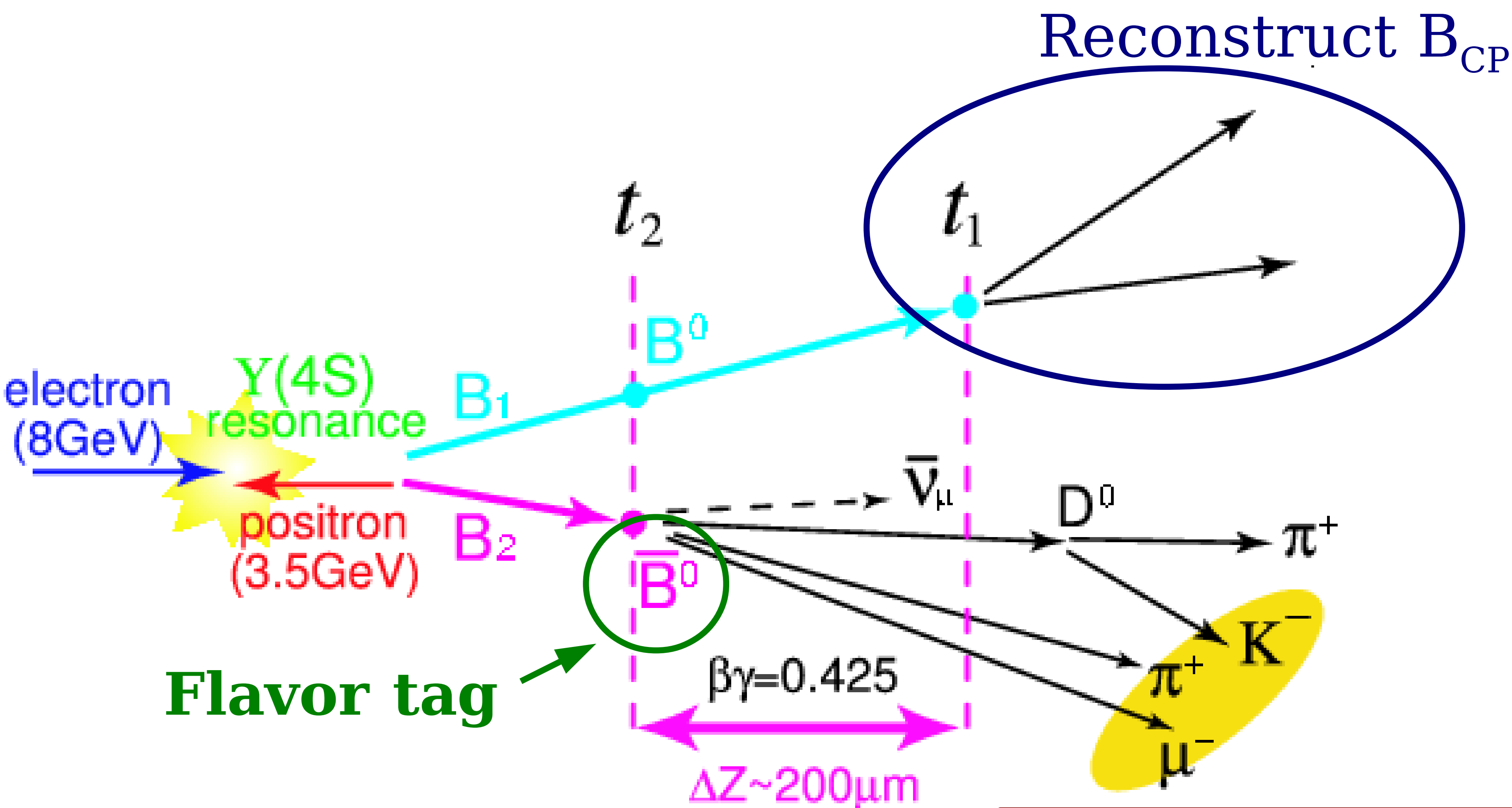
- $\mathbf{A} = 0$ and $\mathbf{S} = -\xi_f \sin 2\beta$ for $(c\bar{c})K_{S/L}$ $(\xi_f = \mp 1)$
- $\mathbf{A} = 0$ and $\mathbf{S} = \sin 2\alpha$ for $\pi^+\pi^-$ (if tree only)



$\mathbf{C} = -\mathbf{A}$

Measuring the CP parameters S and A

$$\frac{dP_{sig}}{dt}(\Delta t, q) = \frac{e^{-|\Delta t|/\tau_B}}{4\tau_B}\left(1 + q\left(S \sin(\Delta m_d \Delta t) + A \cos(\Delta m_d \Delta t)\right)\right)$$

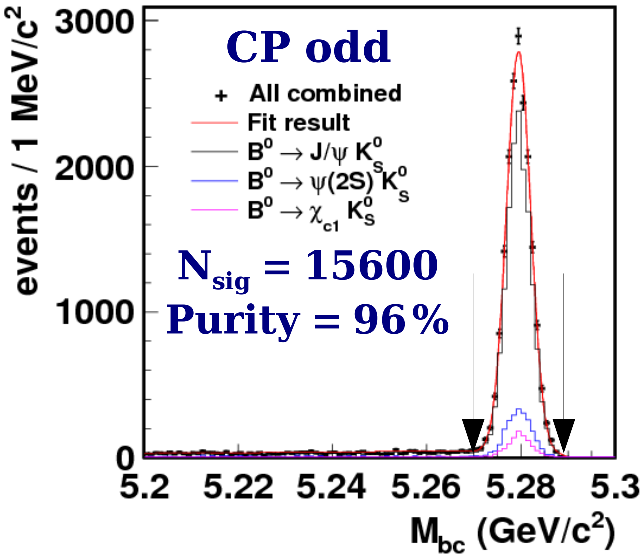


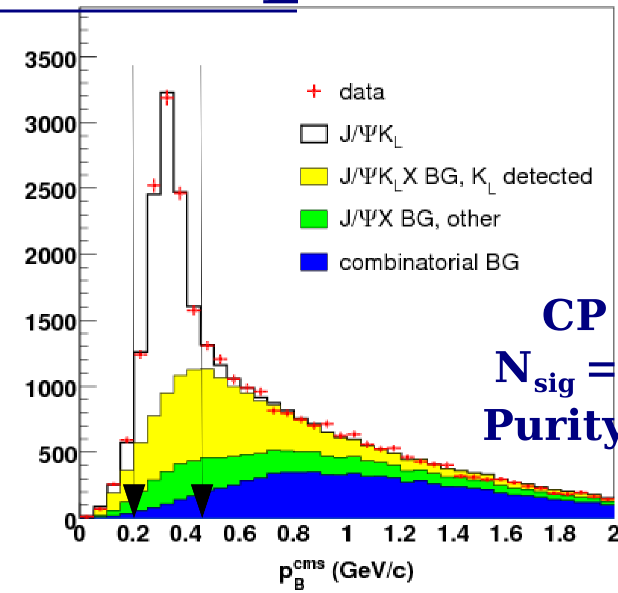
$\Delta z \sim c\beta\gamma\Delta t$

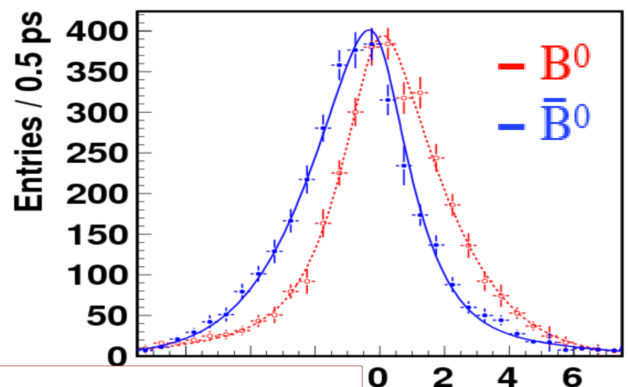
Effective tagging efficiency
$\epsilon_{tag}(1-2\omega_{tag})^2 \sim 30\%$

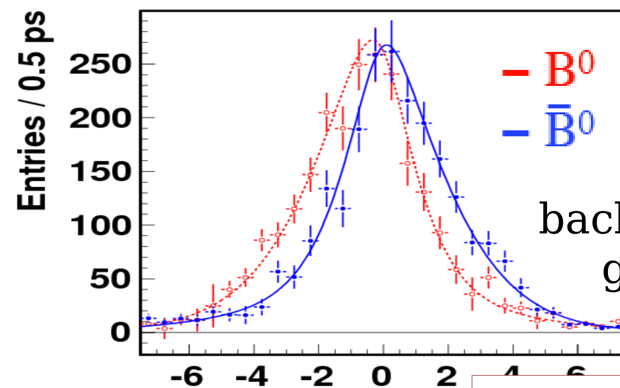
$c\bar{c}\,K_S$ and $J/\psi\,K_L$

$772\times10^6\ B\bar{B}$ pairs





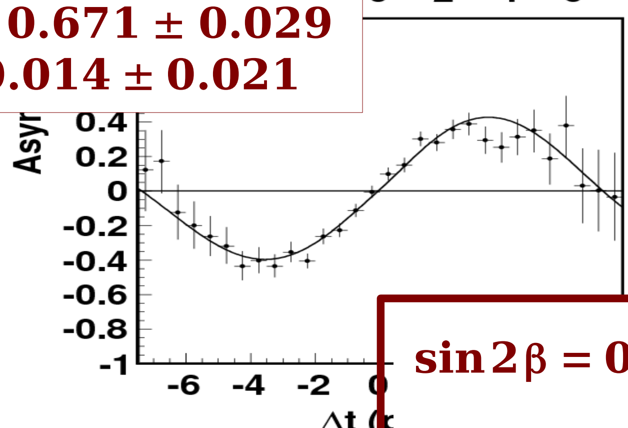


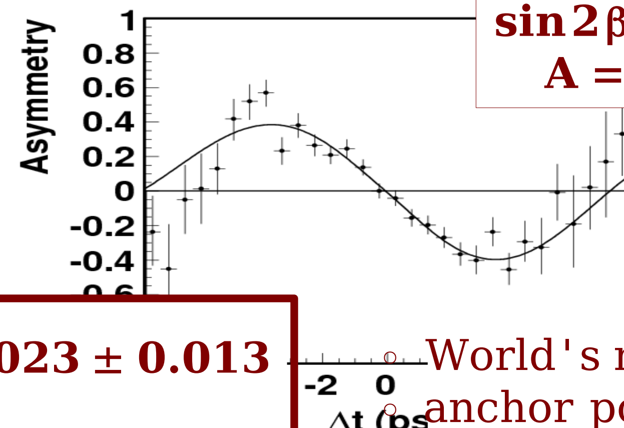


background subtracted
good tagged only

$\sin 2\beta = 0.671 \pm 0.029$
$A = -0.014 \pm 0.021$

$\sin 2\beta = 0.641 \pm 0.047$
$A = 0.019 \pm 0.026$





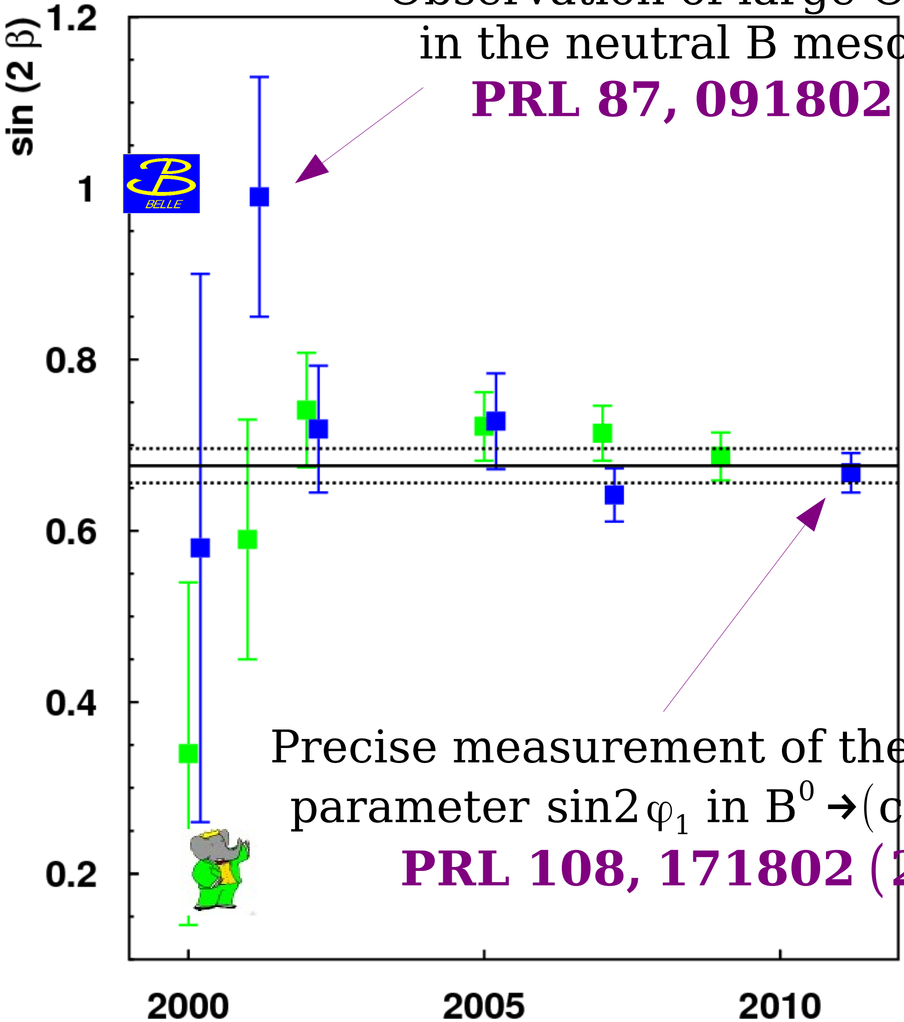
$\sin 2\beta = 0.668 \pm 0.023 \pm 0.013$

$A = 0.007 \pm 0.016 \pm 0.013$

- World's most precise meas^t
- anchor point of the SM
- still statistically limited !

$\sin 2\beta$ in $(c\bar{c})K^0$ ...

Observation of large CP violation in the neutral B meson system
PRL 87, 091802 (2001)

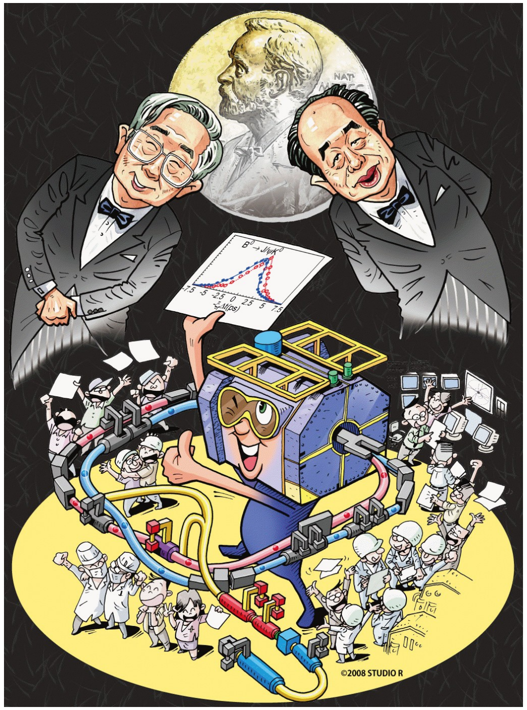


Precise measurement of the CP violation parameter $\sin 2\varphi_1$ in $B^0 \to (c\bar{c})K^0$ decays
PRL 108, 171802 (2012)

$$\beta = (21.4 \pm 0.8)^\circ$$

Critical role of the B factories in the verification of the KM hypothesis

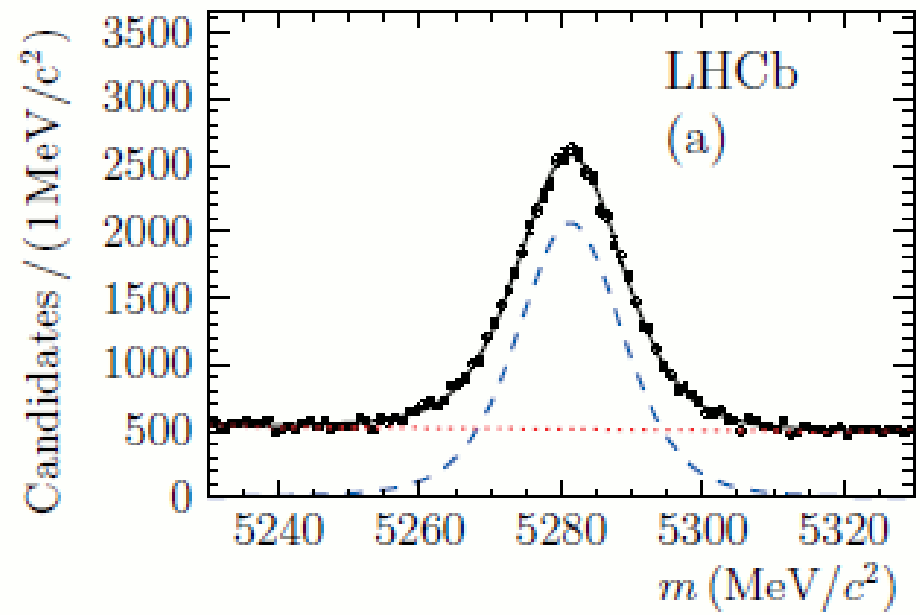
A single irreducible phase in the weak interaction matrix accounts for most of the CPV observed in kaons and B's



Measurement of CPV in $B \to J/\psi K_S^0$ at LHCb

$3\ fb^{-1}$, arXiv:1503.07089

Reconstruct 41560 ± 720 tagged $B \to J/\psi K_S$ events with $J/\psi \to \mu\mu$ and $K_S \to \pi^+\pi^-$ in $3\ fb^{-1}$ (2011-2012 data)

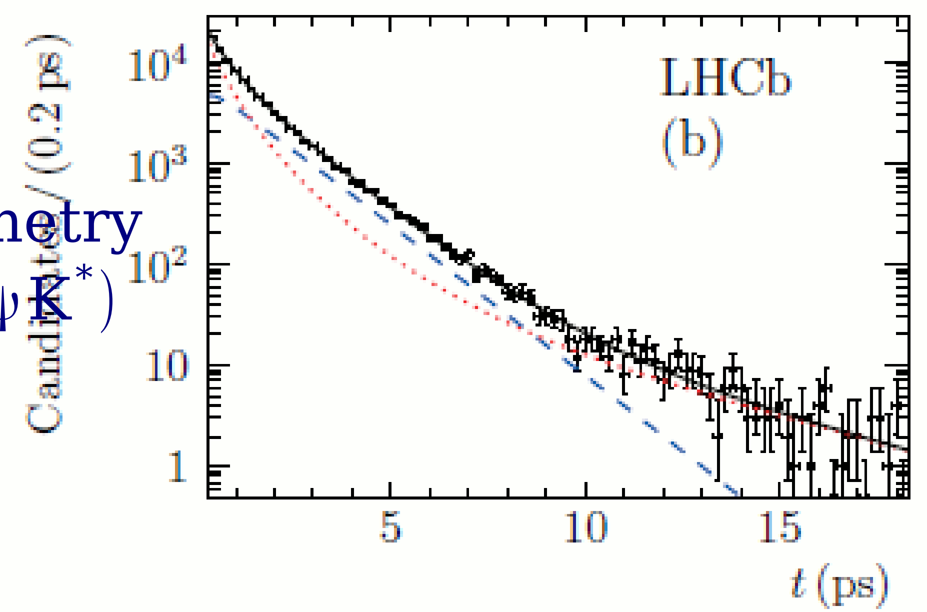


Opposite side flavour-tagging mostly

Magnet polarity reversed periodically to help control detector asymmetries

Need to correct for production asymmetry at p-p collider (measured with $B_d \to J/\psi K^*$)

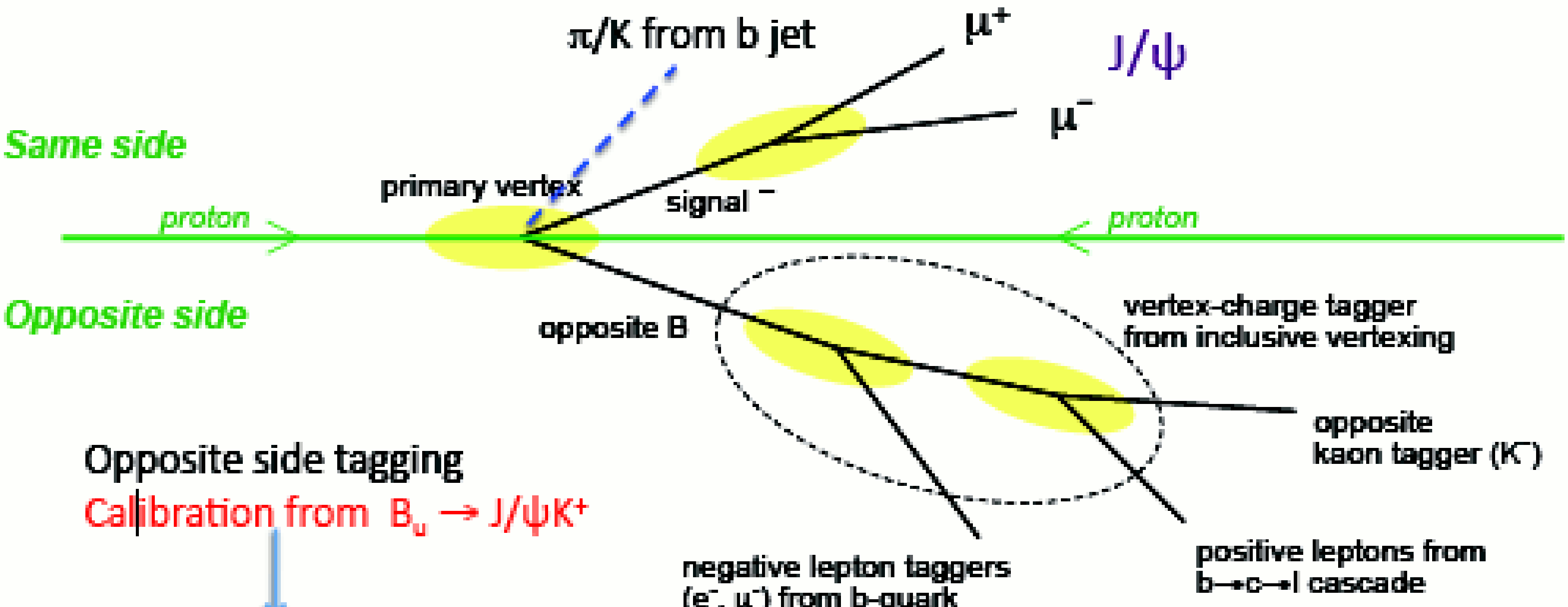
$$A_P = \frac{[\sigma(\overline{B}^0) - \sigma(B^0)]}{[\sigma(\overline{B}^0) + \sigma(B^0)]}$$



Flavour-Tagging at LHCb

tagging efficiency ε_{tag} ~ 50%
effective mistag ω_{tag} ~ 39%
effective tagging power $\varepsilon_{tag}(1-2\omega_{tag})^2$ ~ 2.4%

Same side Kaon tagging
Calibration from $B_s \rightarrow D_s\pi$



Opposite side tagging
Calibration from $B_u \rightarrow J/\psi K^+$

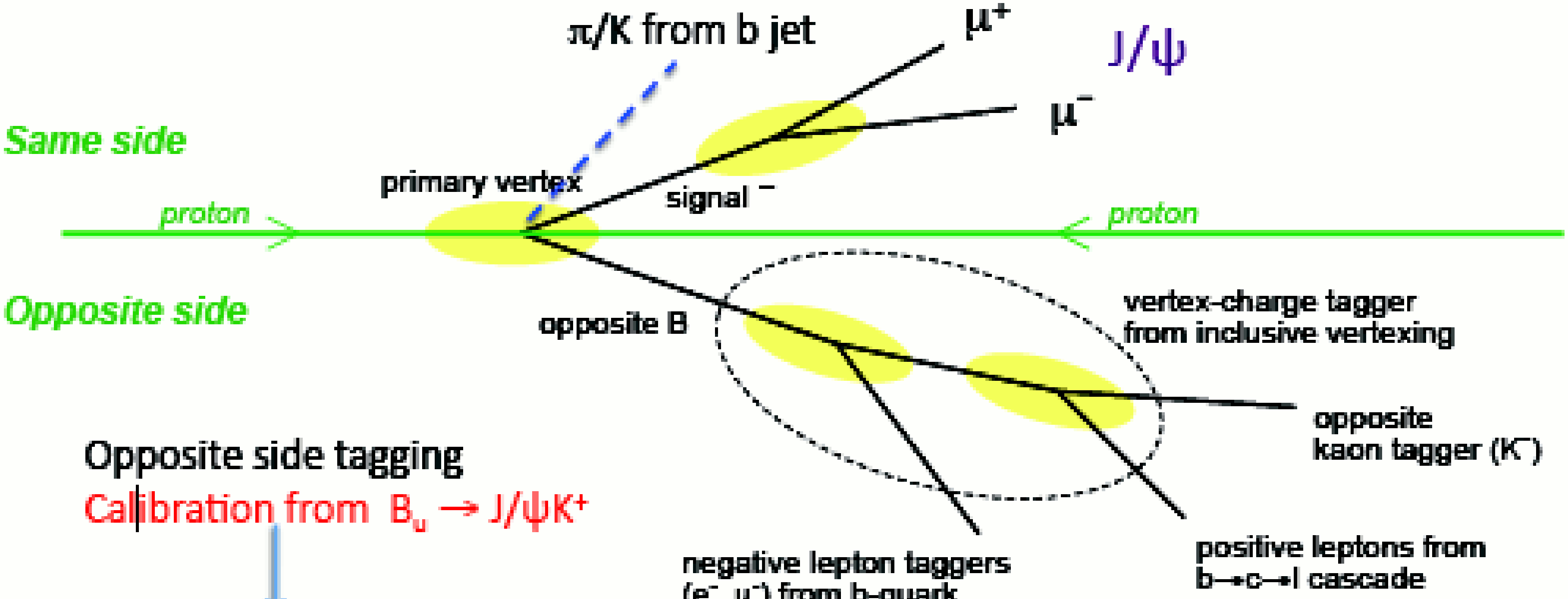
tagging efficiency ε_{tag} ~ 65%
effective mistag ω_{tag} ~ 39%
effective tagging power $\varepsilon_{tag}(1-2\omega_{tag})^2$ ~ 3.0%

Analyses can either use average or per event tagging information

Flavour-Tagging at LHCb

tagging efficiency $\varepsilon_{tag} \sim 50\%$
effective mistag $\omega_{tag} \sim 39\%$
effective tagging power $\varepsilon_{tag}(1-2\omega_{tag})^2 \sim 2.4\%$

Same side Kaon tagging
Calibration from $B_s \to D_s\pi$



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tagging efficiency $\varepsilon_{tag} \sim 65\%$
effective mistag $\omega_{tag} \sim 39\%$
effective tagging power $\varepsilon_{tag}(1-2\omega_{tag})^2 \sim 3.0\%$

Analyses can either use average
or per event tagging information

Measurement of CPV in $B \to J/\psi K_S^0$ at LHCb

$$A(t) = \frac{\Gamma(\bar{B}) - \Gamma(B)}{\Gamma(\bar{B}) + \Gamma(B)}$$

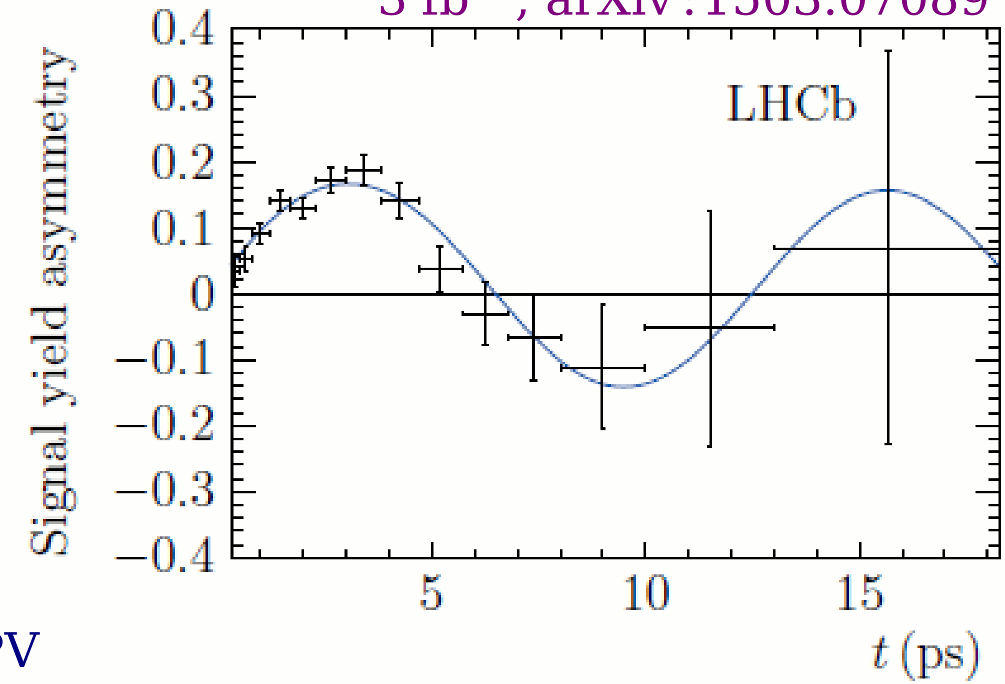
$S = \sin 2\beta$

$C = 0$

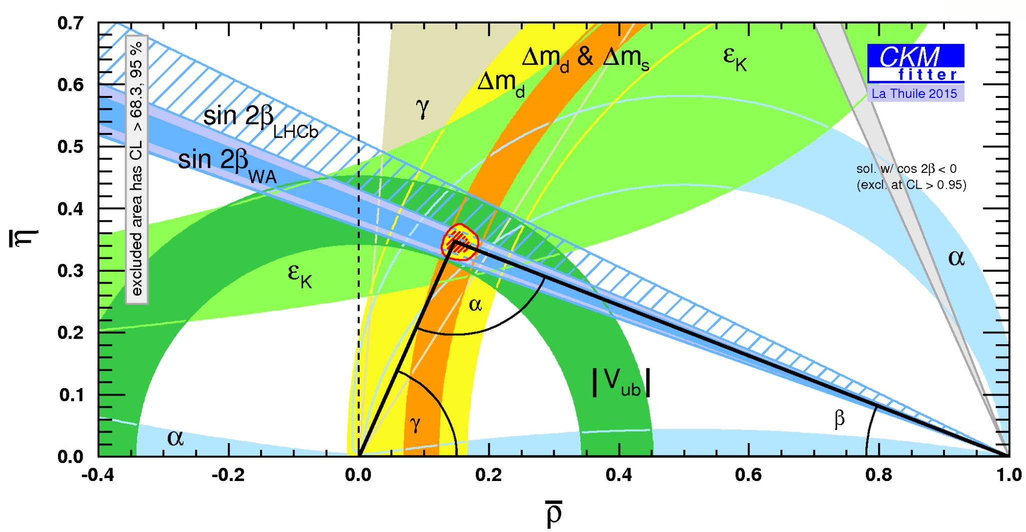
$$A(t) = S \sin(\Delta m_d t) - C \cos(\Delta m_d t)$$

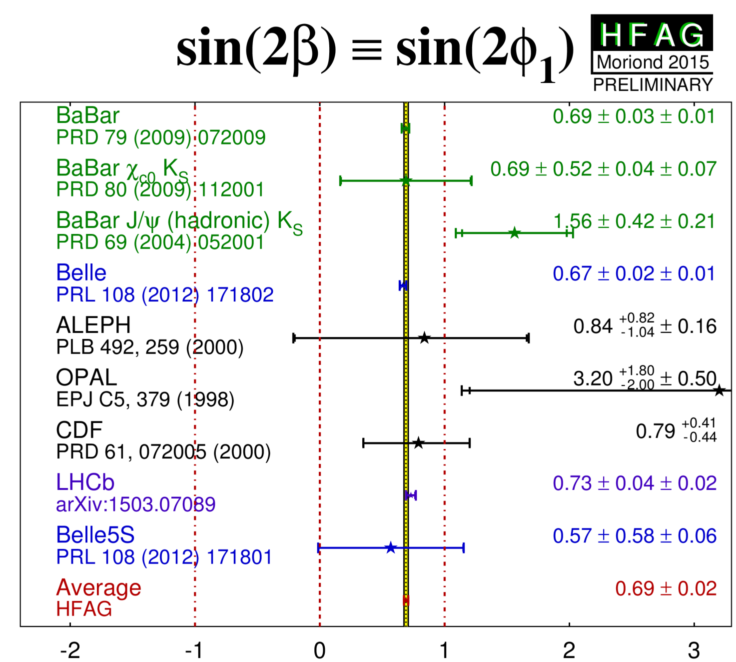
$S = 0.731 \pm 0.035 \pm 0.020$
$C = -0.038 \pm 0.032 \pm 0.005$

3 fb^{-1}, arXiv:1503.07089



⇒ LHCb brings new information for B_s CPV



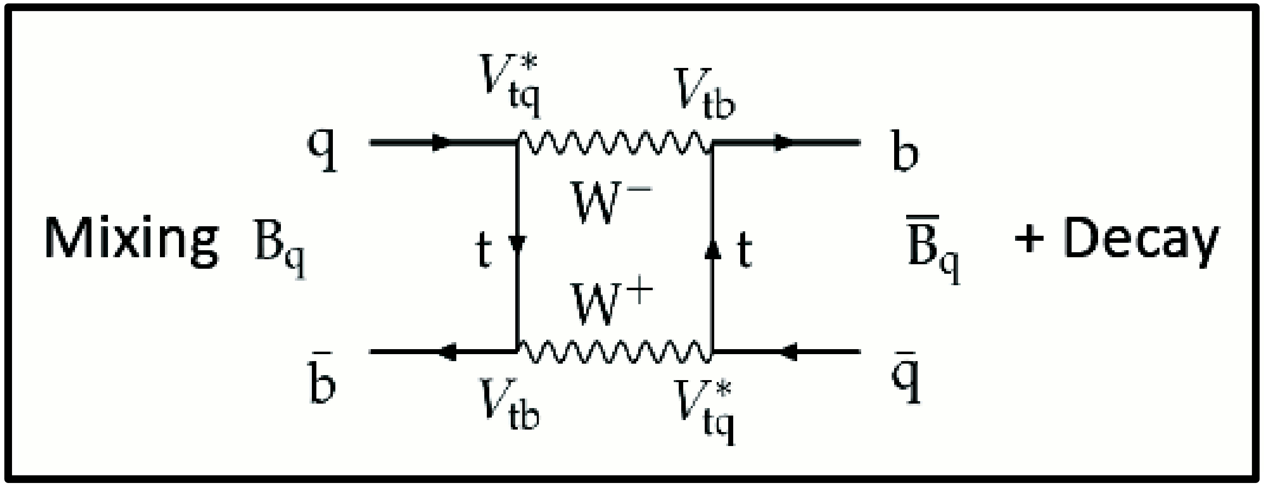


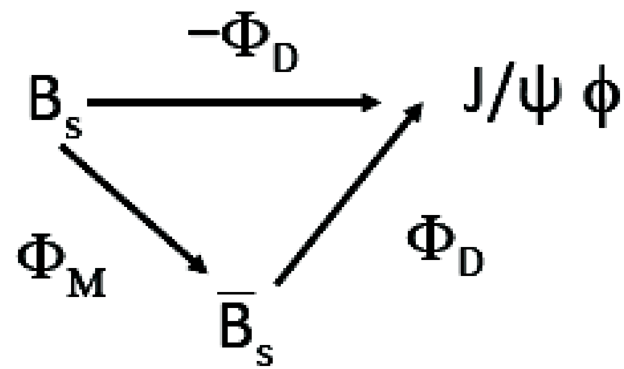
$\beta = (21.9 \pm 0.7)^\circ$

WA 2015

CPV in $B_s \to J/\psi\varphi$ at LHCb

$$-2\arg\left(\frac{-V_{ts}V^*_{tb}}{V_{cs}V^*_{cb}}\right)$$



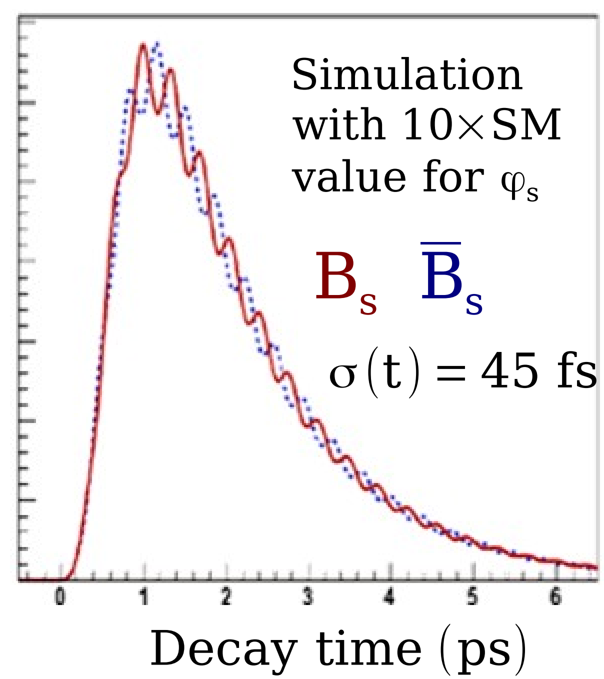


Tag initial flavour and measure decay time distributions, then essentially the measurement is of:

$$\sin(\phi_s) \times D(\sigma_t) \times (1-2\omega_{tag}) \times \sin(\Delta m_s t)$$

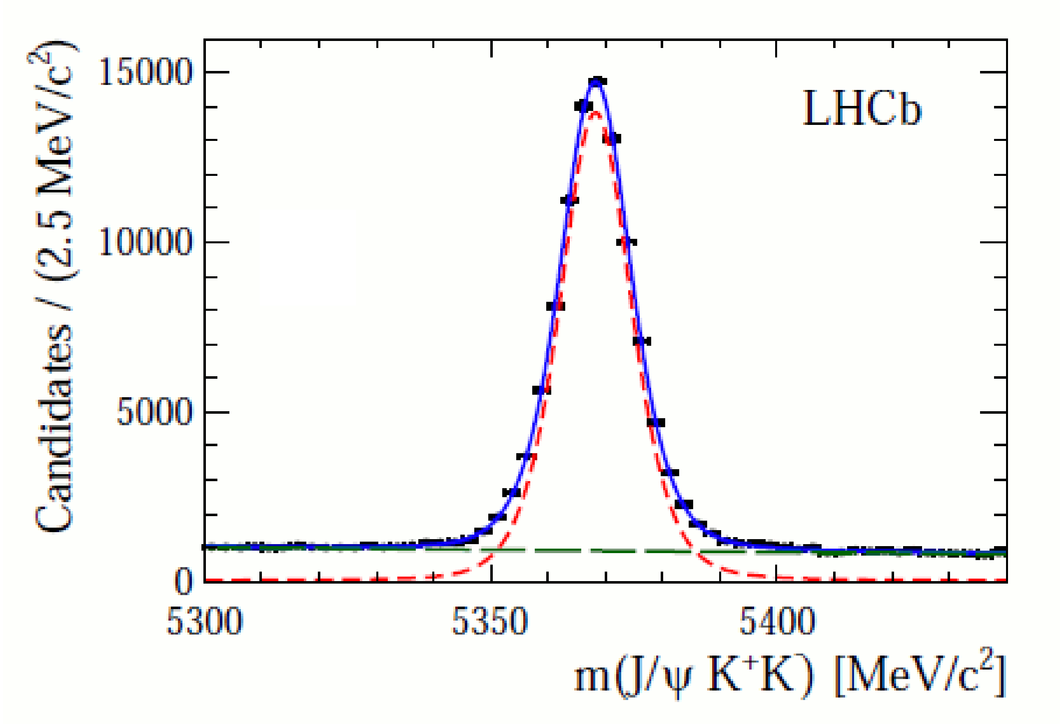
CPV phase $\phi_s = \Phi_M - 2\Phi_D$ | Decay time resolution | Mistag rate | B_s mixing frequency

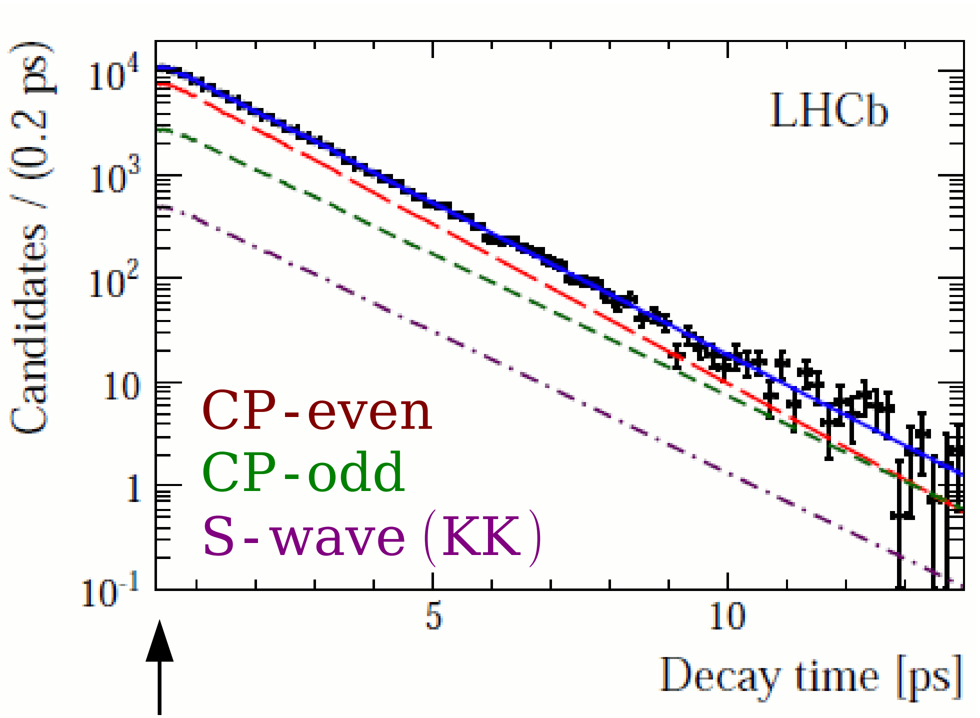
In SM, CPV phase is small $\varphi_s \sim -0.04$ rd



$B_s \to J/\psi\,\varphi$

3 fb^{-1}, arXiv:1411.3104





t > 0.3 ps

Reconstruct 95690 ± 350 tagged $B_s \to J/\psi\,\varphi$ events with $J/\psi \to \mu\mu$ and $\varphi \to K^+K^-$ in 3 fb^{-1} (2011-2012 data)

$\Gamma_s = \Gamma_H + \Gamma_L/2$

$= 0.6603 \pm 0.0027 \pm 0.0015\ ps^{-1}$

consistent with previous measurements

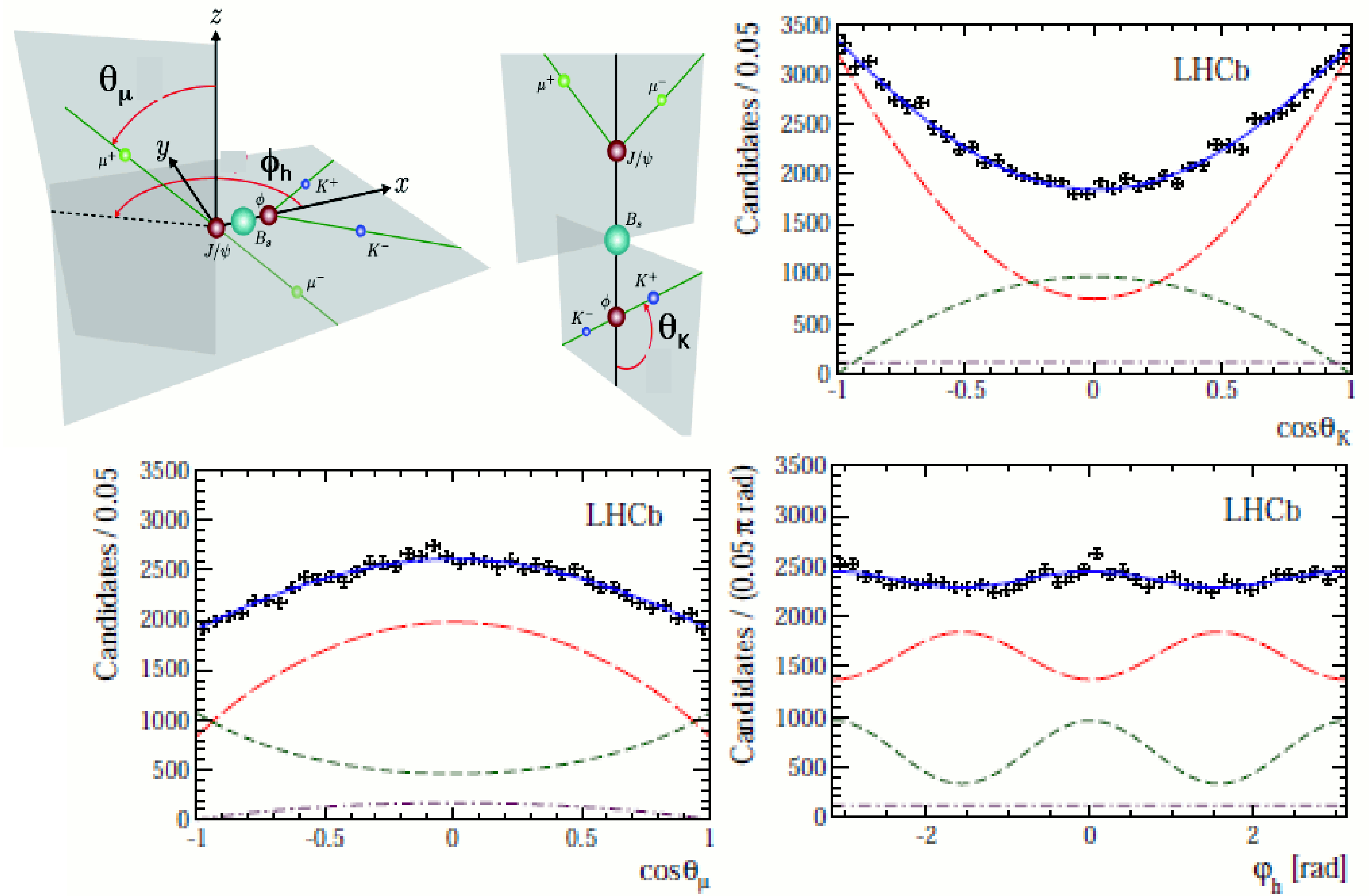
Combinatorial background is flat

CPV in $B_s \to J/\psi\varphi$ at LHCb

[3 fb^{-1}, arXiv:1411.3104]

CP-even
CP-odd
S-wave (KK)

mixture of CP eigenstates ⇒ angular analysis in helicity basis



Results for $B_s \to J/\psi\varphi$ at LHCb

CP violating phase

[$3\ fb^{-1}$, arXiv:1411.3104]

$$\varphi_s = -0.058 \pm 0.049 \pm 0.006$$

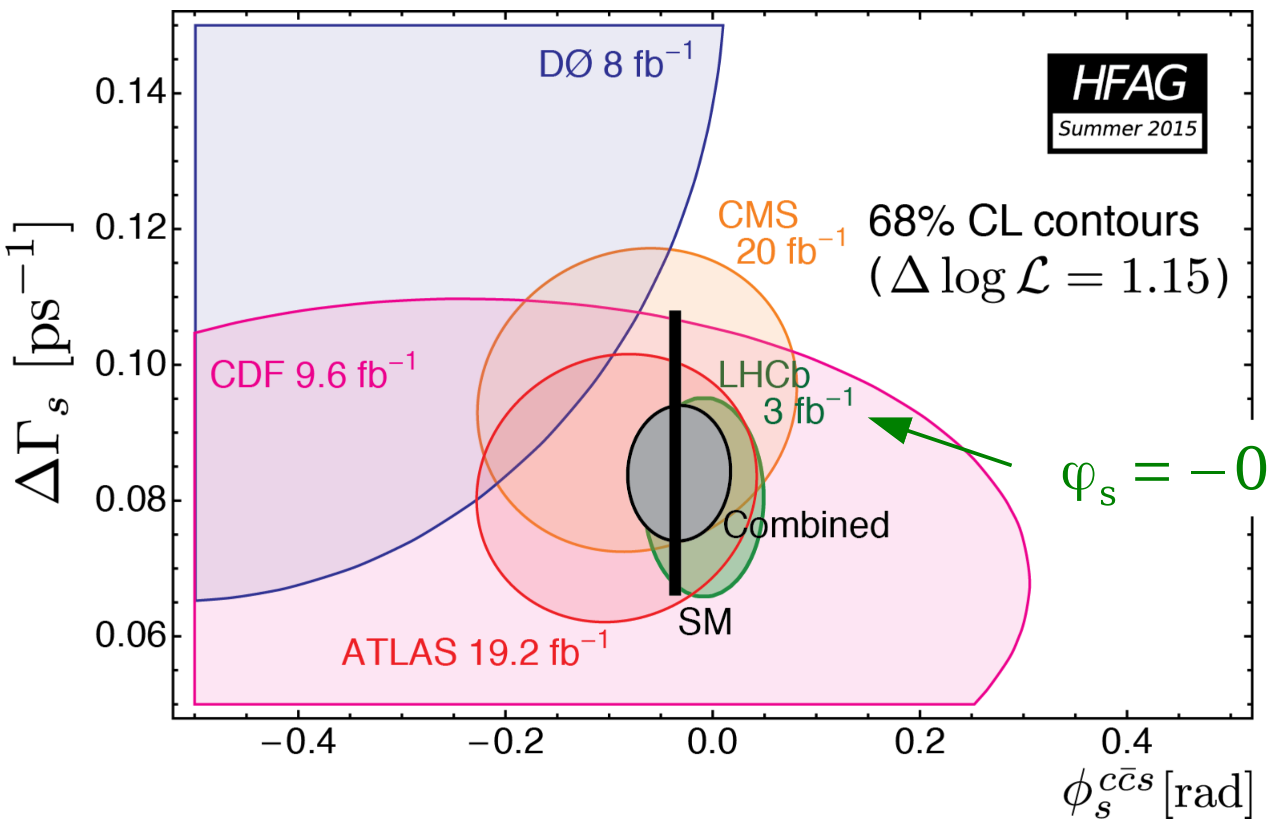
CP violating in mixing or direct decay (no CPV: $|\lambda|=1$)

$$|\lambda| = 0.964 \pm 0.019 \pm 0.007$$

Decay width difference $\Delta\Gamma_s = (\Gamma_L - \Gamma_H) = 0.0805 \pm 0.0091 \pm 0.0032\ ps^{-1}$

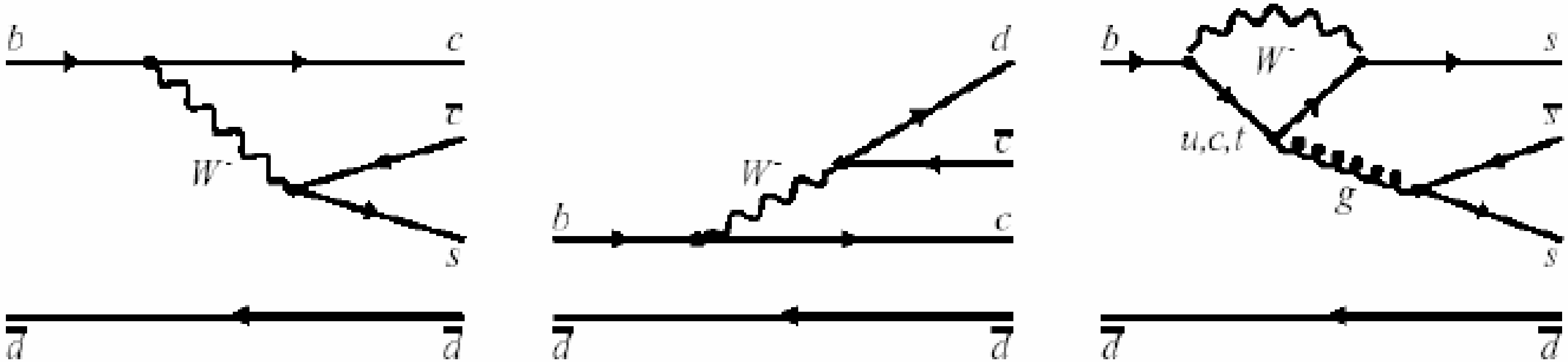
$\Delta\Gamma_s(SM) = 0.087 \pm 0.021\ ps^{-1}$

$\varphi_s(SM) = -0.0363\ ^{+0.0012}_{-0.0014}$ rad



$\varphi_s = -0.010 \pm 0.039$ rad

[combined with $J/\psi\pi\pi$]



$J/\psi K_S^0, \psi(2S)K_S^0, \chi_{c1}K_S^0,$
$\eta_c K_S^0, J/\psi K_L^0,$
$J/\psi K^{*0}(K^{*0} \to K_S^0\pi^0)$

$D^{*+}D^-, D^+D^-$
$J/\psi\pi^0, D^{*+}D^{*-}$

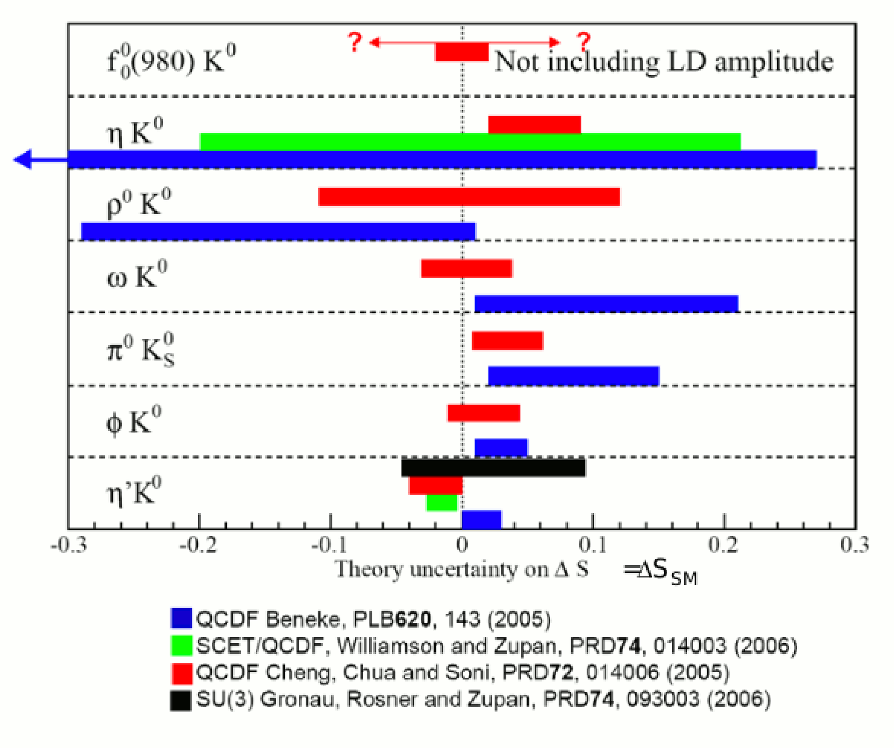
$\phi K^0, K^+K^-K_S^0,$
$K_S^0K_S^0K_S^0, \eta' K^0, K_S^0\pi^0,$
$\omega K_S^0, f_0(980)K_S^0$

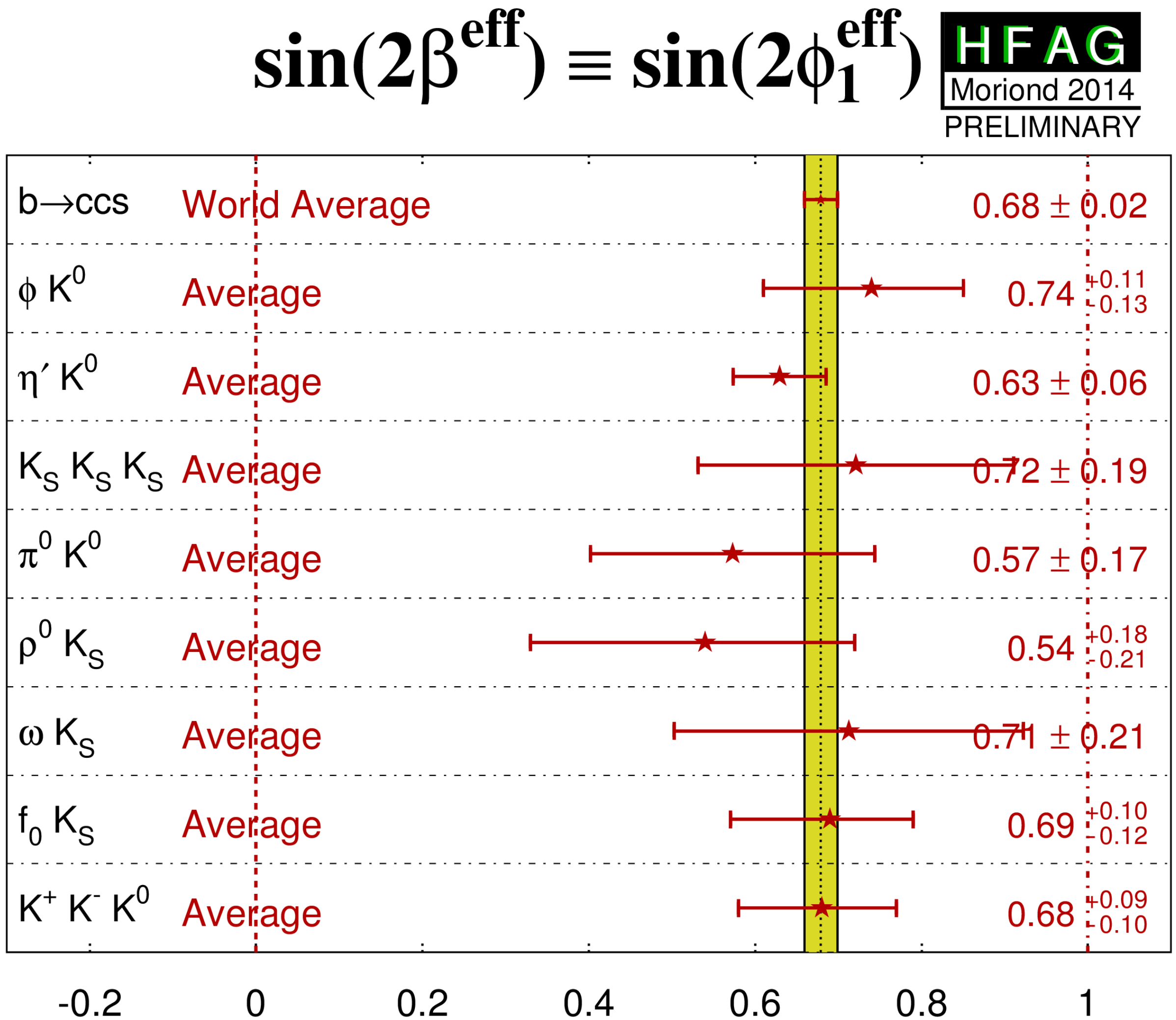
increasing tree diagram amplitude

increasing sensitivity to new physics

sin 2β with b→s penguins

dominated by B-factories





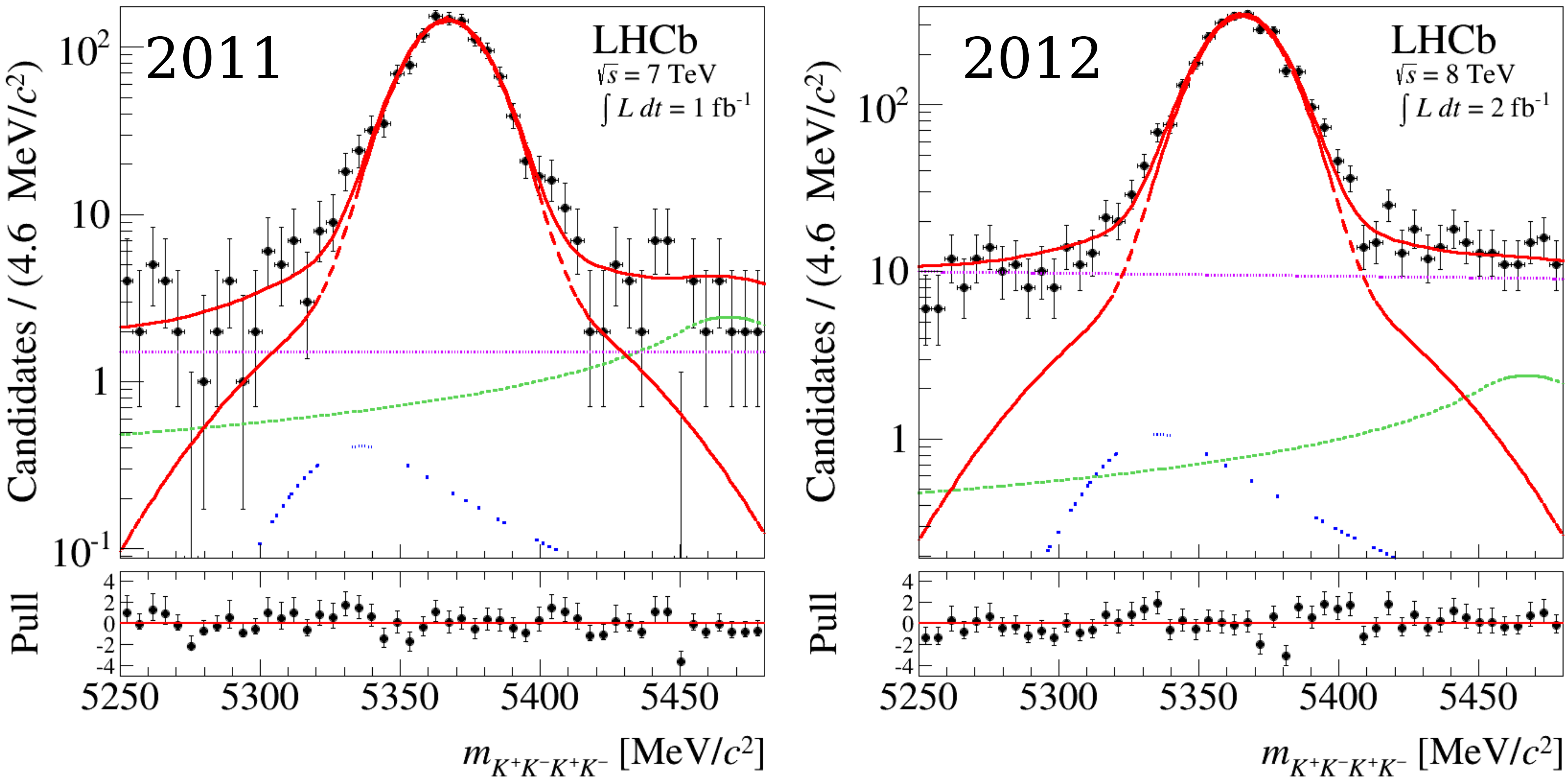
More statistics crucial for mode-by-mode studies

⇒ **Belle II**

$B_s \to \varphi\varphi$

[arXiv:1407.2222]

$\bar{b} \to \bar{s}s\bar{s}$ loop process



- 4000 signal events
- Combinatorial background is flat and small
- Very small contributions from mis-ID of $B_d \to \varphi K^{*0}$ and $\Lambda_b \to \varphi p K$
- mixture of CP eigenstates ⇒ angular analysis in helicity basis

$$\varphi_s = -0.17 \pm 0.15 \pm 0.03 \text{ rad}$$

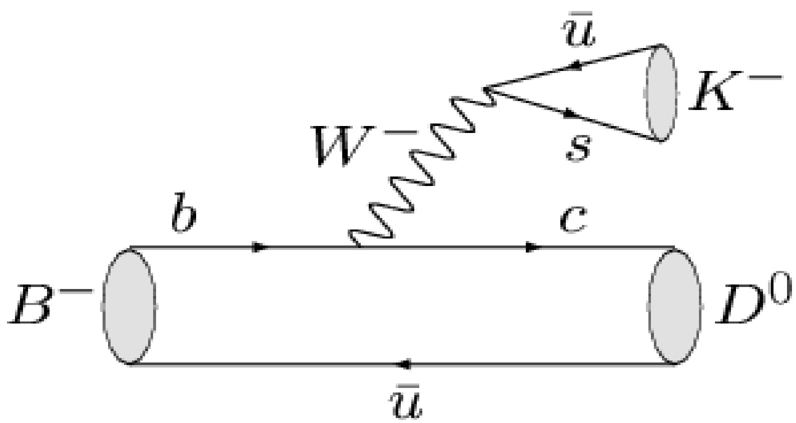
$\varphi_s(c\bar{c}s) \sim -0.01 \pm 0.04$ rad

$\varphi_s(\text{SM}) = -0.0363\,^{+0.0012}_{-0.0014}$

γ measurements from $B^{\pm} \rightarrow DK^{\pm}$

$\gamma = \varphi_3$

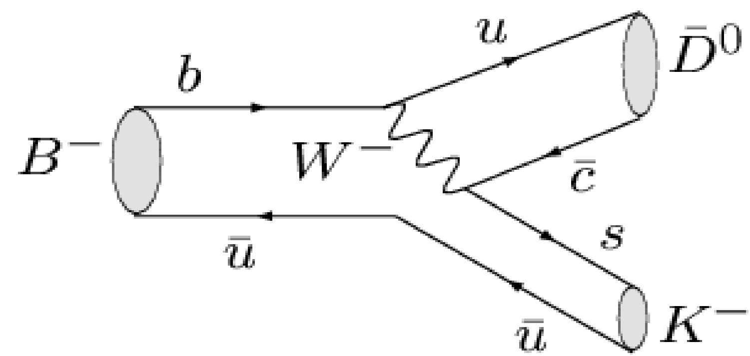
- Theoretically pristine $B \rightarrow DK$ approach
- Access γ via interference between $B^- \rightarrow D^0 K^-$ and $B^- \rightarrow \overline{D}^0 K^-$



color allowed

$B^- \rightarrow D^0 K^- \sim V_{cb} V_{us}^*$

$\sim A\lambda^3$



color suppressed

$B^- \rightarrow \overline{D}^0 K^- \sim V_{ub} V_{cs}^*$

$\sim A\lambda^3(\rho + i\eta)$

relative magnitude of suppressed amplitude is r_B

$$r_B = \frac{|A_{suppressed}|}{|A_{favoured}|} \sim \frac{|V_{ub} V_{cs}^*|}{|V_{cb} V_{us}^*|} \times [\text{color supp}] = 0.1\text{-}0.2$$

relative weak phase is γ, relative strong phase is δ_B

γ measurements from $B^{\pm} \to DK^{\pm}$

- Reconstruct D in final states accessible to both D^0 and $\overline{D}^0$
  - $D = D_{CP}$, CP eigenstates as K^+K^-, $\pi^+\pi^-$, $K_S\pi^0$

    GLW method (Gronau-London-Wyler)
  - $D = D_{sup}$, Doubly-Cabbibo suppressed decays as $K\pi$

    ADS method (Atwood-Dunietz-Soni)
  - Three-body decays as $D \to K_S\pi^+\pi^-$, $K_S K^+K^-$

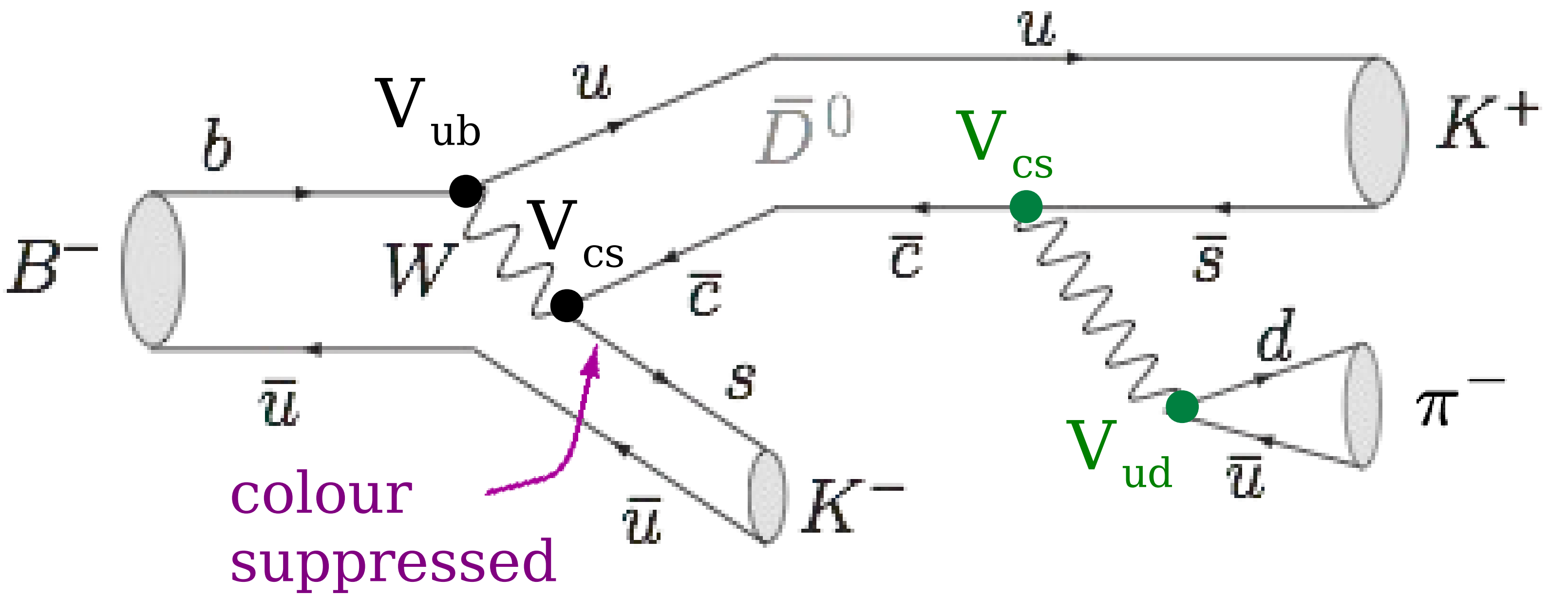
    GGSZ (Dalitz) method (Giri-Grossman-Soffer-Zupan)

- Largest effects due to
  - charm mixing
  - charm CP violation

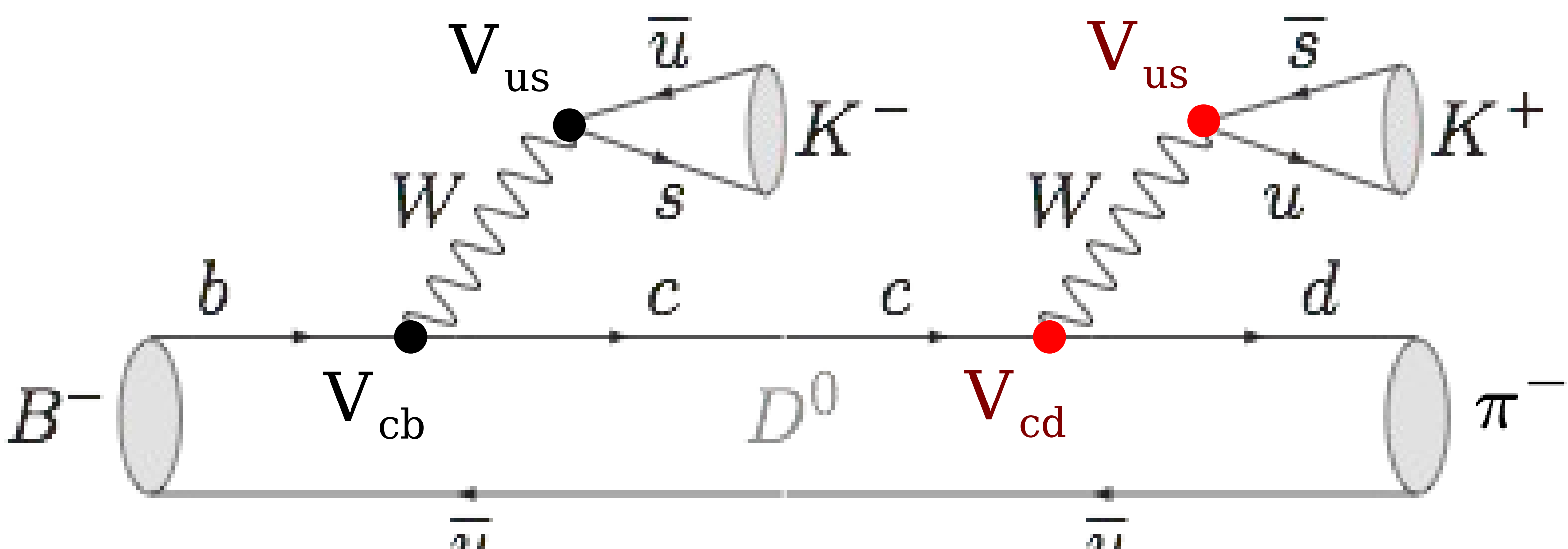
  } small, can be included
  Y.Grossman, A.Soffer, J.Zupan
  [PRD 72, 031501 (2005)]

- Different B decays (DK, D^*K, DK^*)
  - different hadronic factors (r_B, δ_B) for each

ADS method measures ϕ_3 via the interference in rare $B^- \to [K^+\pi^-]_D K^-$ decays



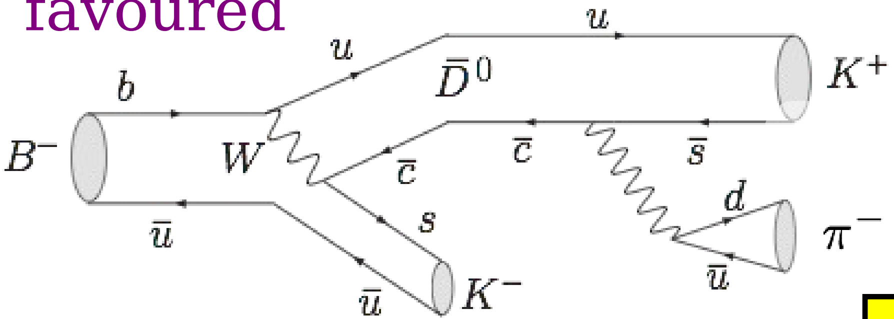
Cabibbo
favoured
D decay



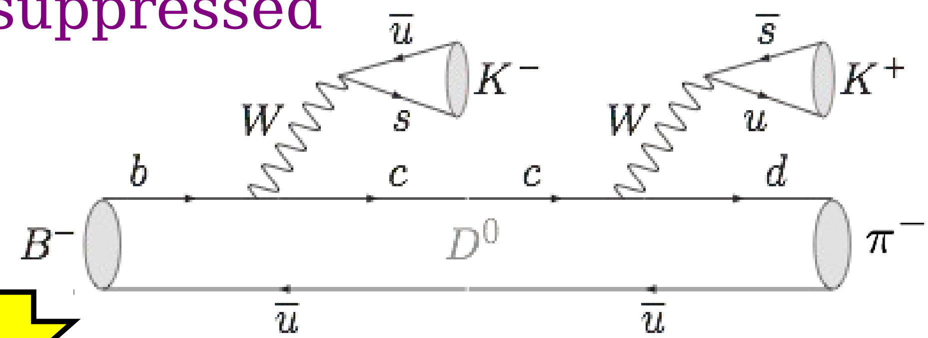
doubly
Cabibbo
suppressed
D decay

ADS rate and asymmetry (relative to the common decay):

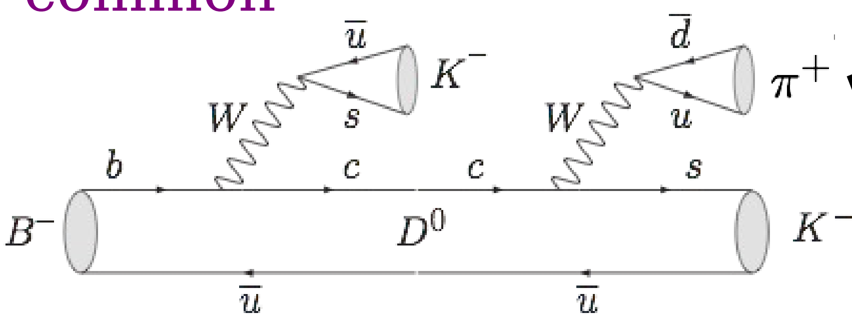
favoured



suppressed



common



$$\mathcal{R}_{DK} = \frac{\Gamma([K^+\pi^-]\,K^-) + \Gamma([K^-\pi^+]\,K^+)}{\Gamma([K^-\pi^+]\,K^-) + \Gamma([K^+\pi^-]\,K^+)}$$

$$= r_B^2 + r_D^2 + 2 r_B r_D \cos(\delta_B + \delta_D) \cos \phi_3$$

$$\mathcal{A}_{DK} = \frac{\Gamma([K^+\pi^-]\,K^-) - \Gamma([K^-\pi^+]\,K^+)}{\Gamma([K^-\pi^+]\,K^-) + \Gamma([K^+\pi^-]\,K^+)}$$

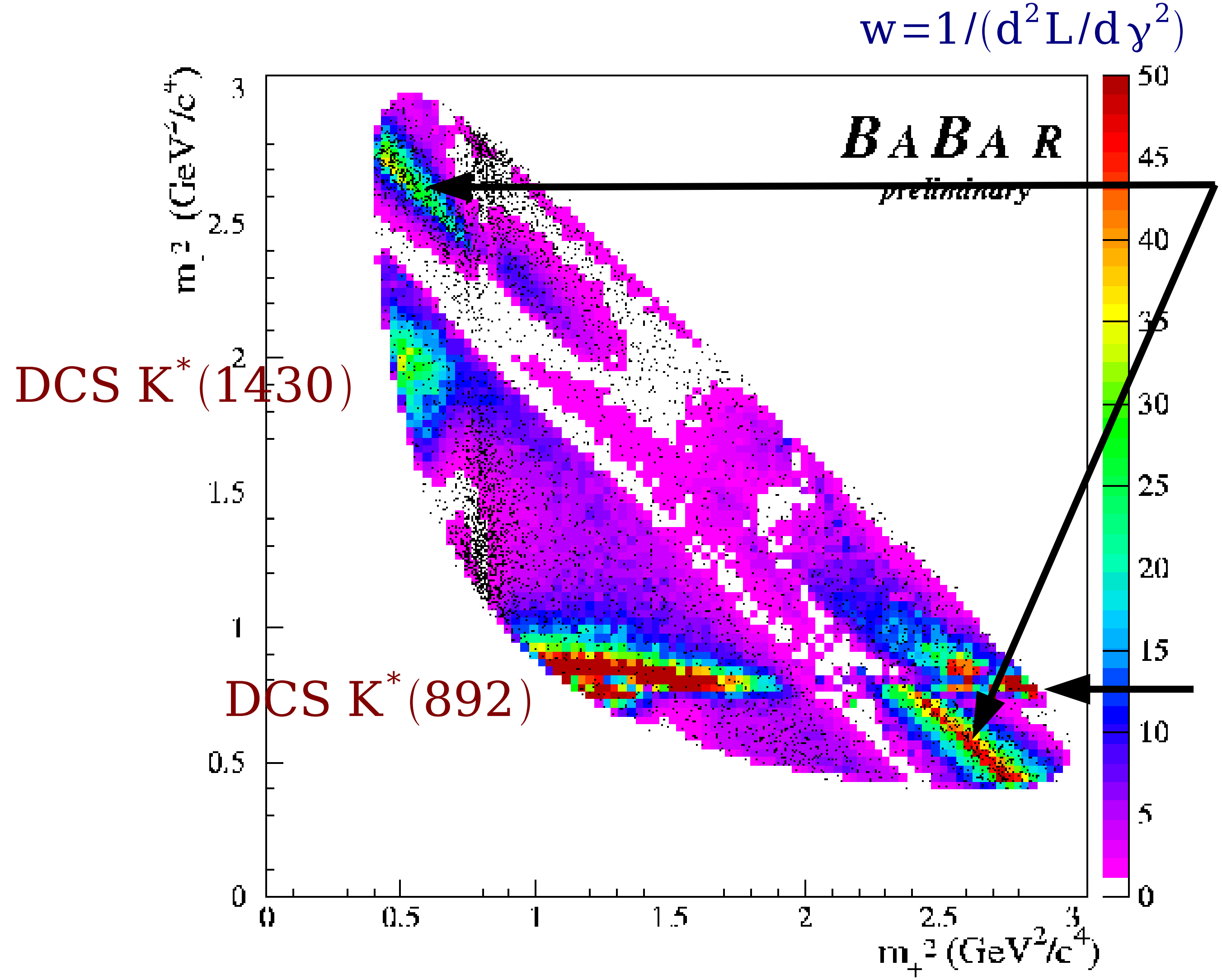
$$= 2\, r_B r_D \sin(\delta_B + \delta_D) \sin \phi_3 \,/\, \mathcal{R}_{DK}$$

where $r_D = \left| \frac{\mathcal{A}(D^0 \to K^+\pi^-)}{\mathcal{A}(\bar{D}^0 \to K^+\pi^-)} \right| = 0.0613 \pm 0.0010$

Sensitivity to γ in $B \to D(K_S \pi\pi)K$ mode

sensitivity to γ/ϕ_3 varies across the Dalitz plot

$\gamma = 75^\circ$, $\delta = 180^\circ$, $r_B = 0.125$



<u>GLW like</u>

Interference of

$B^- \to D^0 K^-$, $D^0 \to K^0_S \rho^0$

with

$B^- \to \overline{D}^0 K^-$, $\overline{D}^0 \to K^0_S \rho^0$

<u>ADS like</u>

Interference of

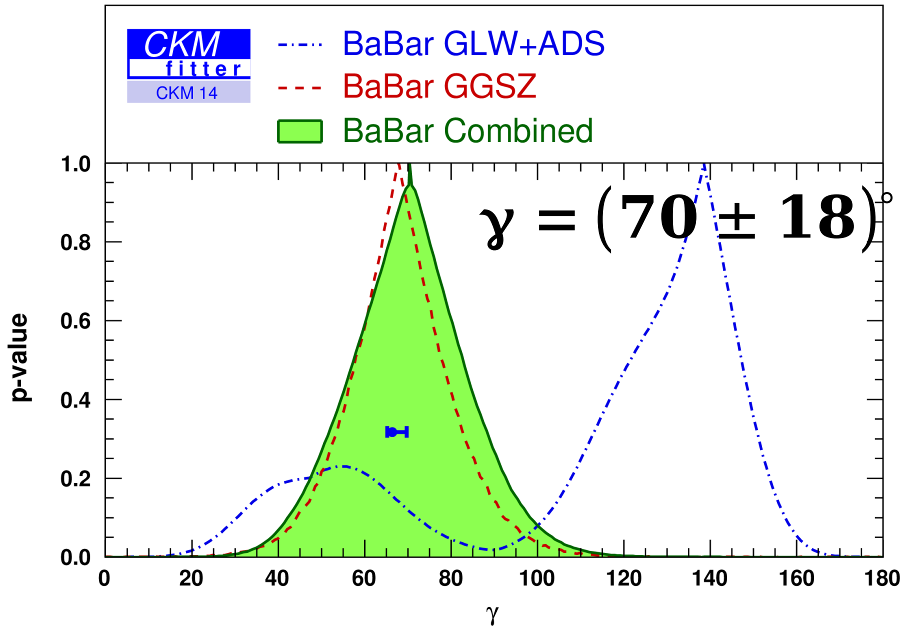
$B^- \to D^0 K^-$, $D^0 \to K^{*+} \pi^-$

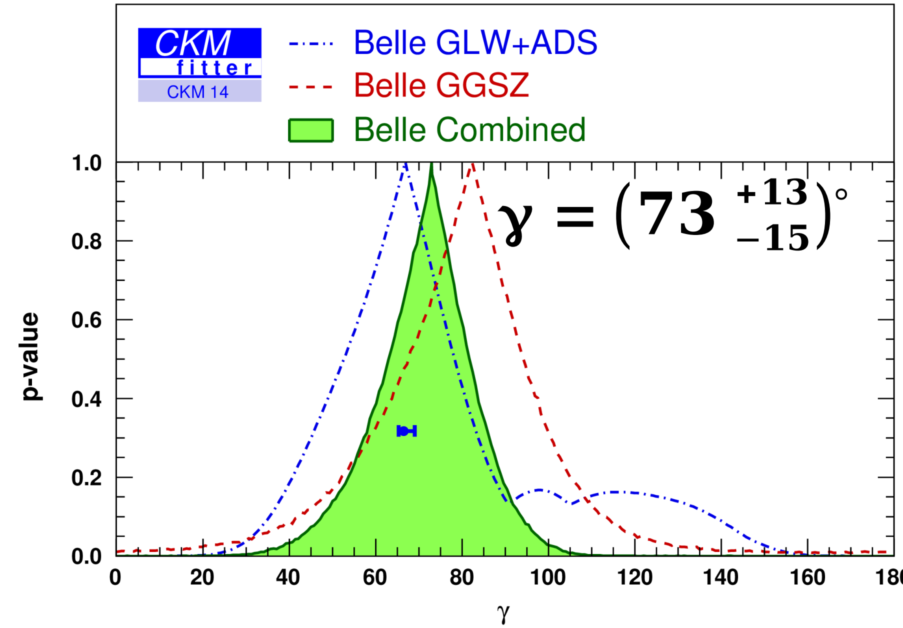
with

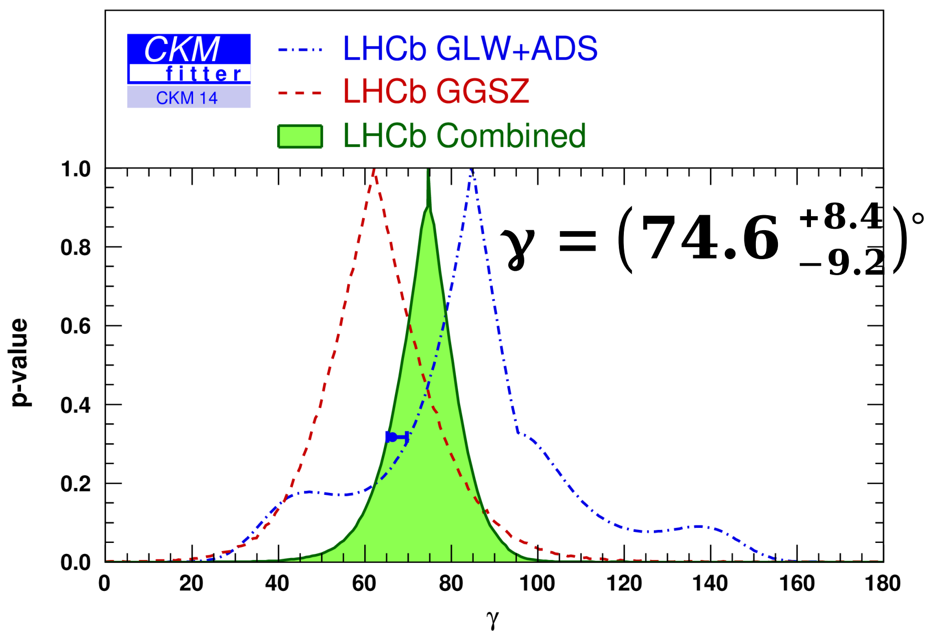
$B^- \to \overline{D}^0 K^-$, $\overline{D}^0 \to K^{*+} \pi^-$

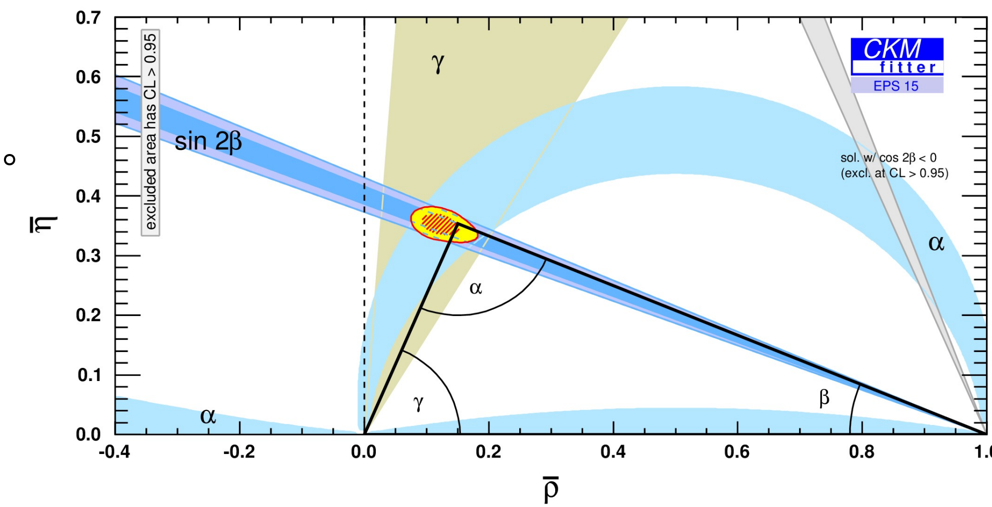
γ angle in the global fit

measurements from B → DK

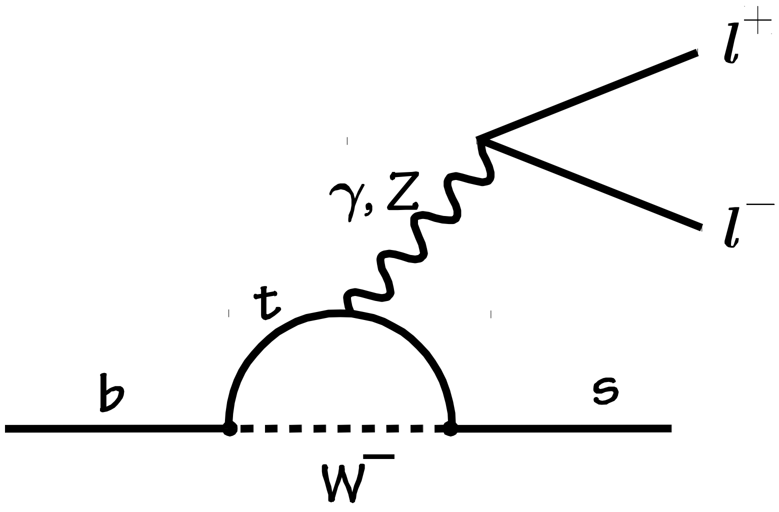


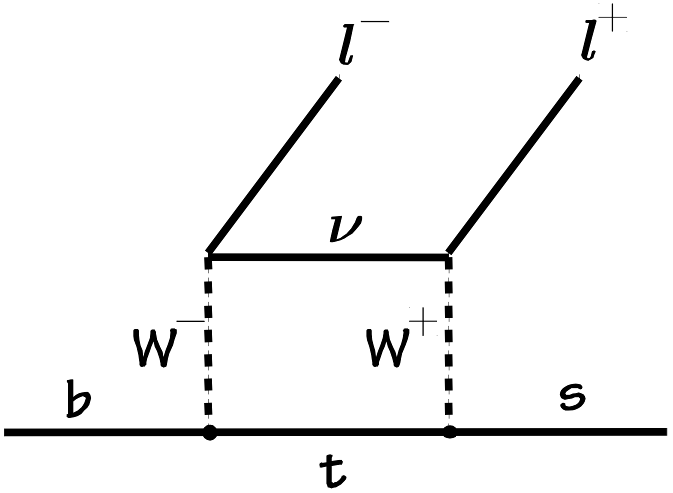






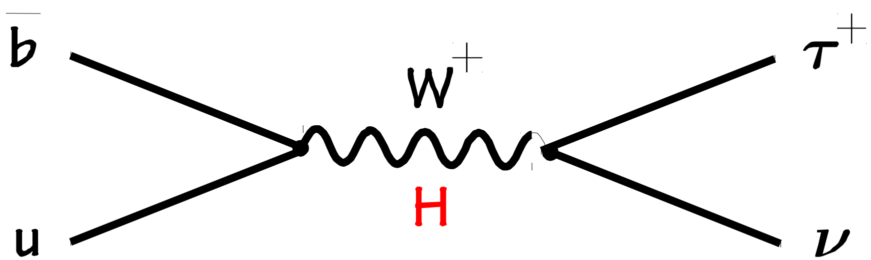
long way to go ... (→ $\sigma_\gamma = 1^\circ$ or less)

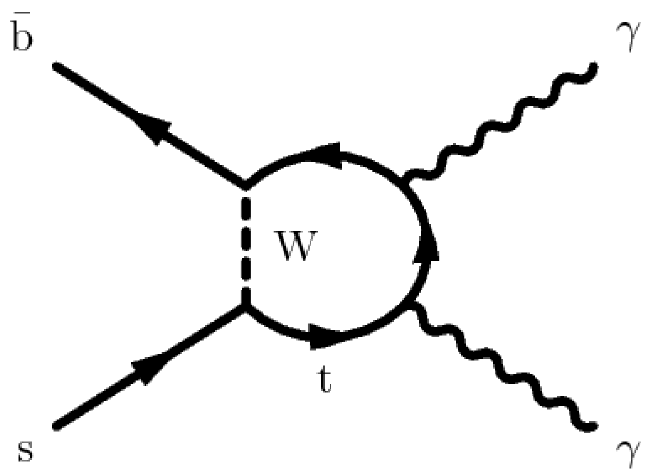


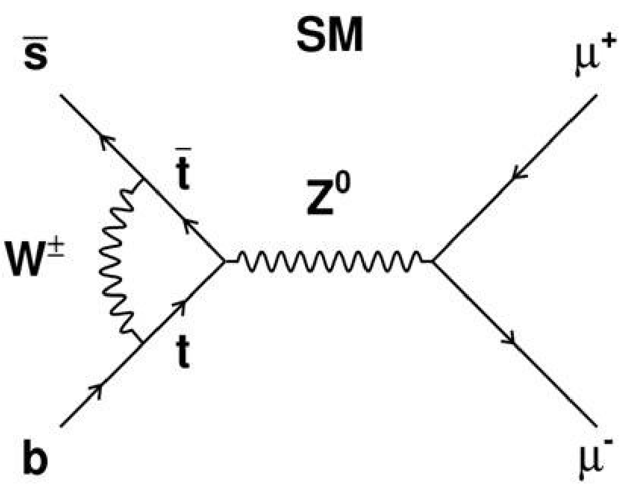


Rare B decays

- FCNC are strongly suppressed in the SM: only loops + GIM mechanism
- Any new particle generating new diagrams can change the amplitudes

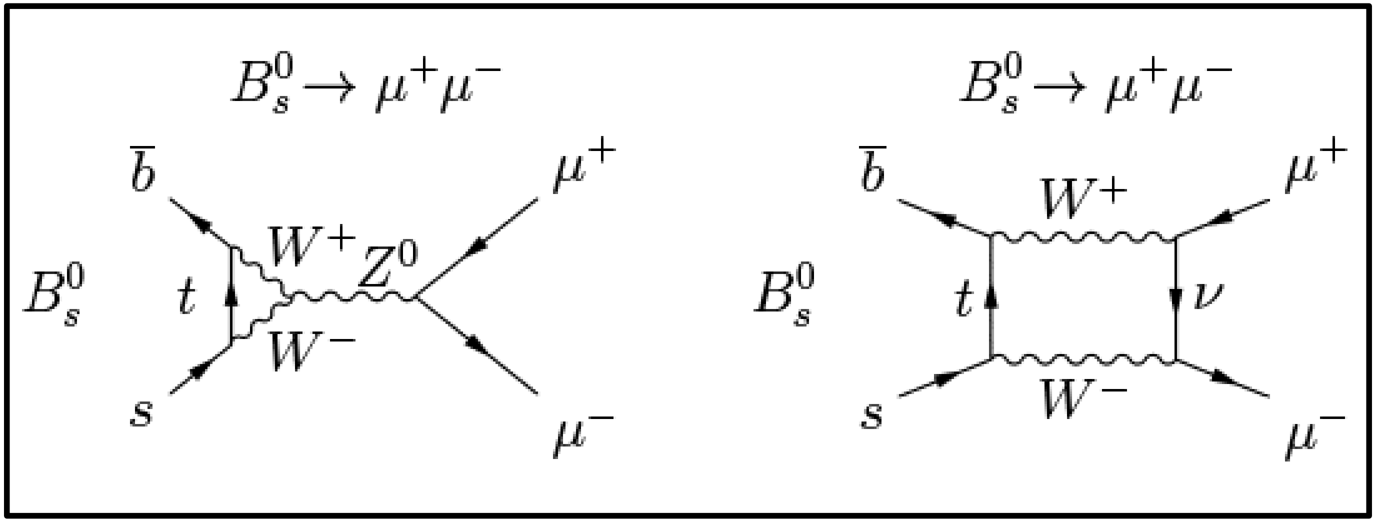






$B_{(s)} \rightarrow \mu\mu$: ultra rare processes...

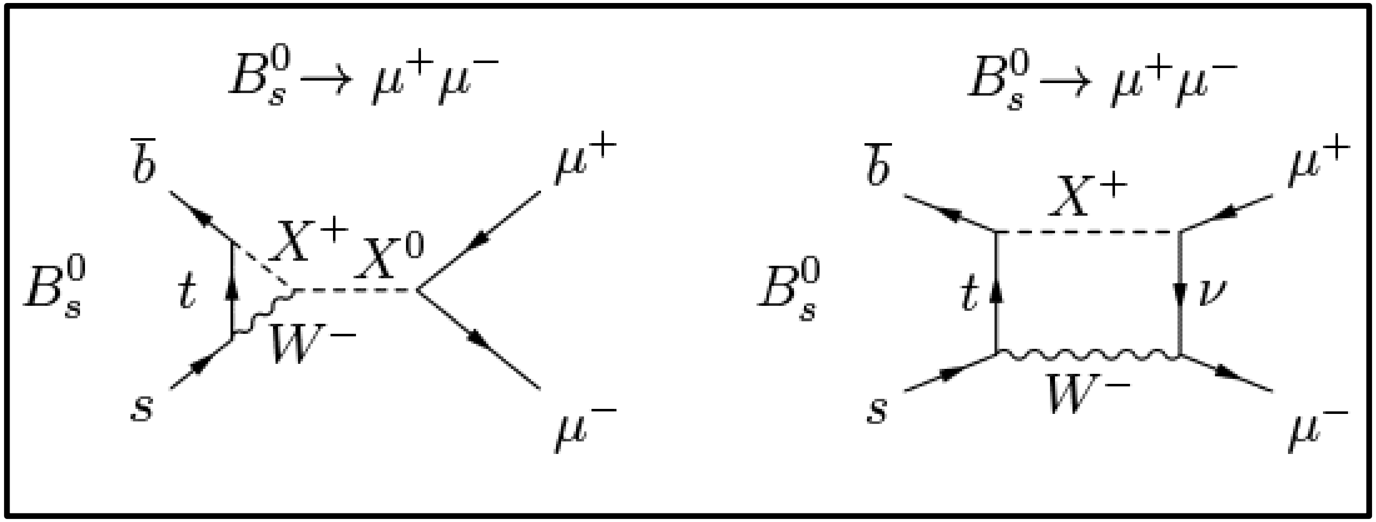
loop diagram + suppressed in SM + theoretically clean =
an excellent place to look for new physics



higher-order FCNC allowed in SM

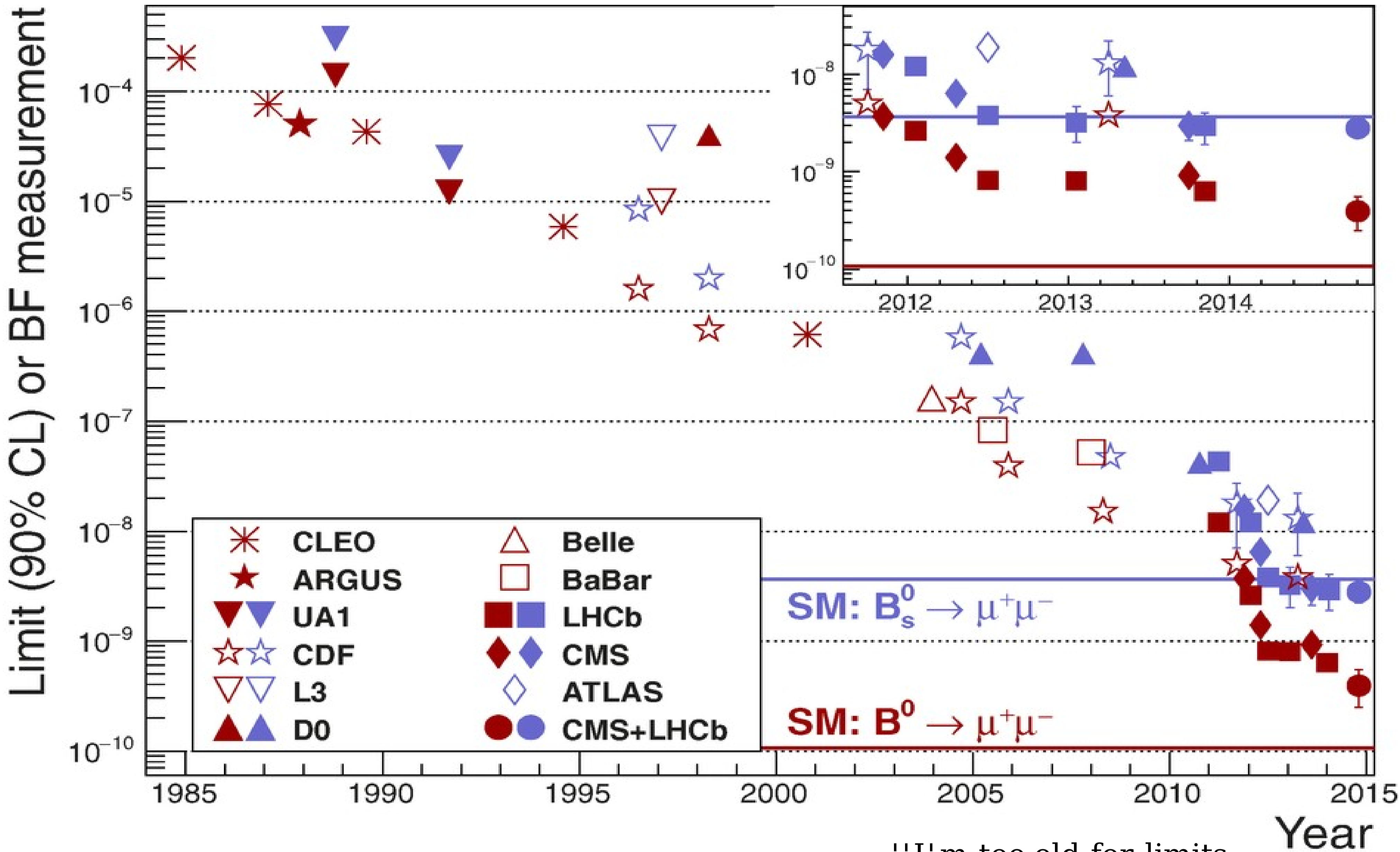
$B(B_s \rightarrow \mu^+\mu^-) = (3.65 \pm 0.23) \times 10^{-9}$
$B(B_d \rightarrow \mu^+\mu^-) = (1.06 \pm 0.09) \times 10^{-10}$

[Bobeth et al, PRL 112 (2014) 101801]



same decay in theories extending the SM (some of NP scenarios may boost the $B \rightarrow \mu\mu$ decay rates)

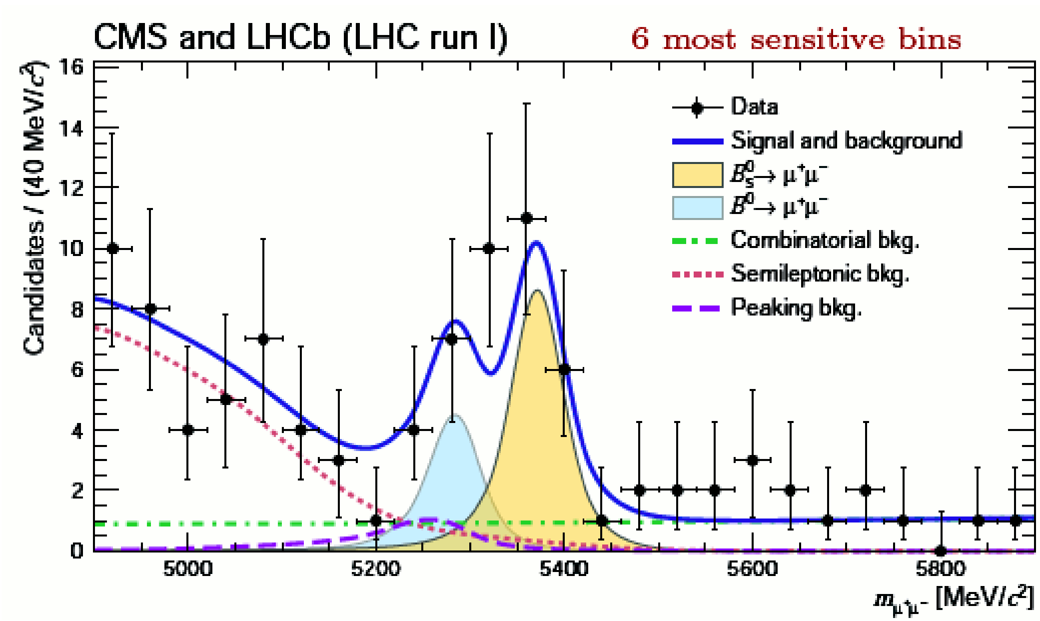
$B_{(s)} \rightarrow \mu\mu$: ultra rare processes...



''I'm too old for limits,
I want to see signals''
(Francis Halzen)

Combination results $B_{(s)} \to \mu^+\mu^-$

[arXiv:1411.4413] published in Nature

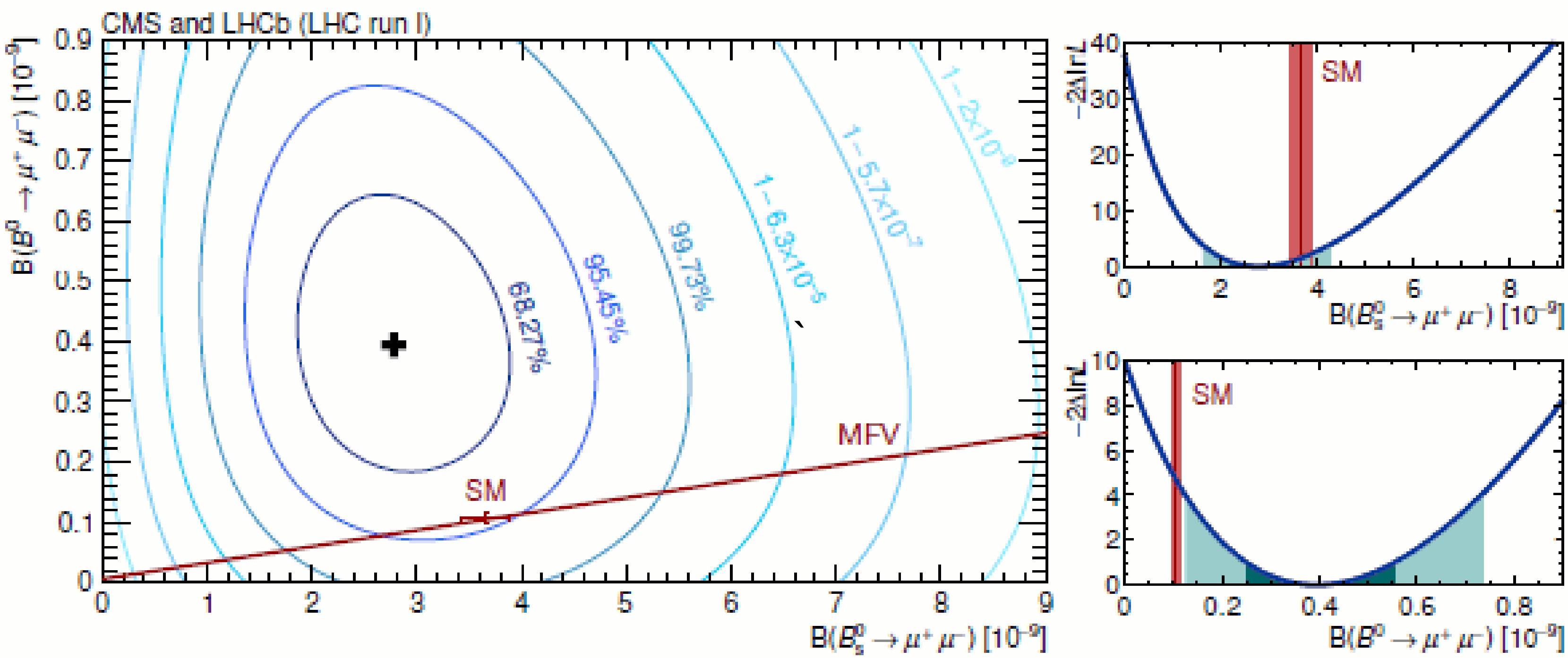


$B(B_s^0 \to \mu^+\mu^-) = (2.8\ ^{+0.7}_{-0.6}) \times 10^{-9}$

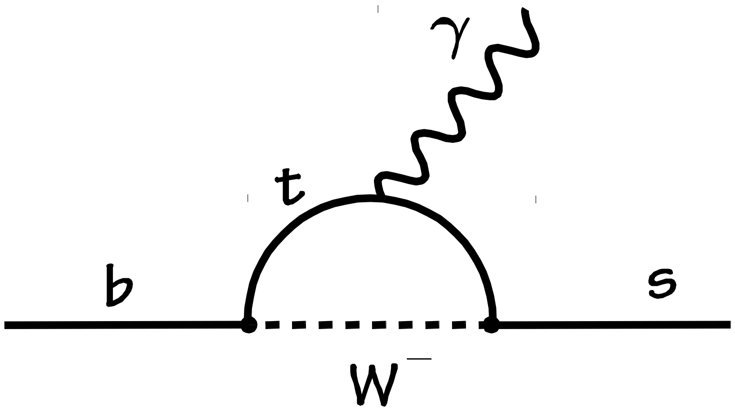
first observation: 6.2σ significance

$B(B^0 \to \mu^+\mu^-) = (3.9\ ^{+1.6}_{-1.4}) \times 10^{-10}$

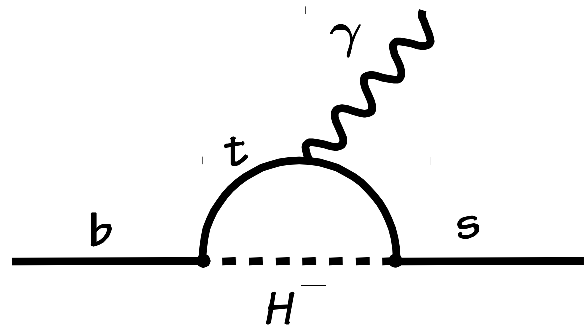
first evidence: 3.0σ significance

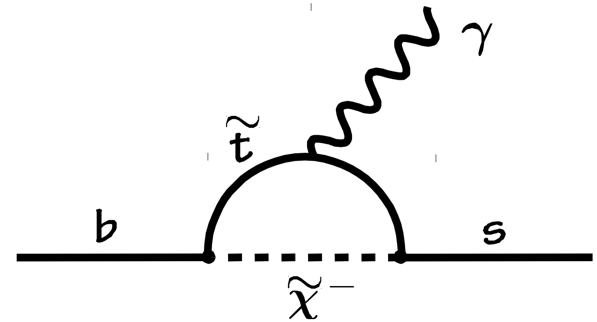


$B \to X_s \gamma$



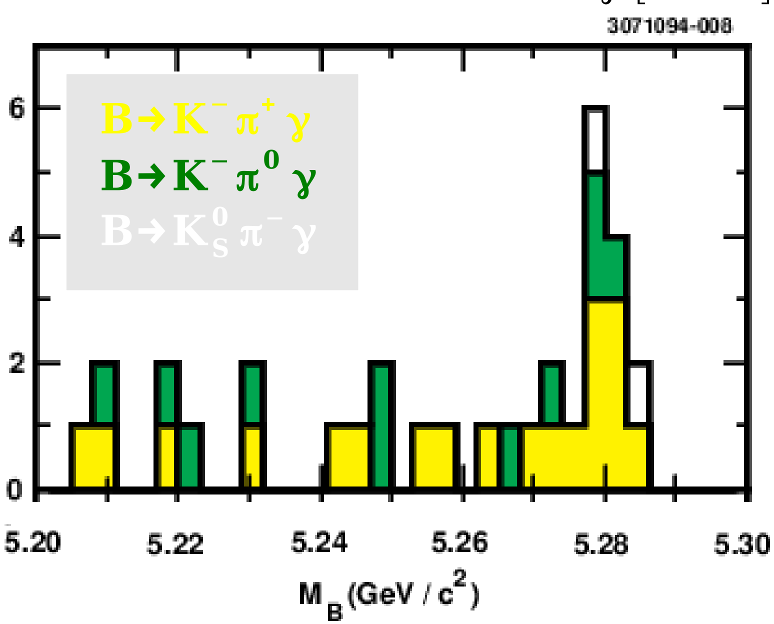
Sensitive to NP



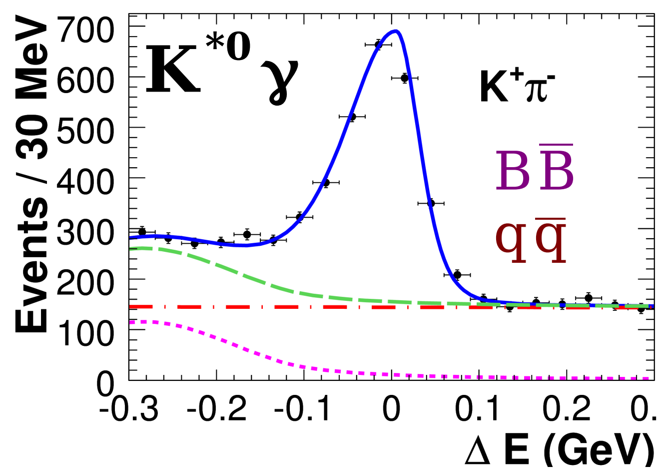


rare ? not that rare...

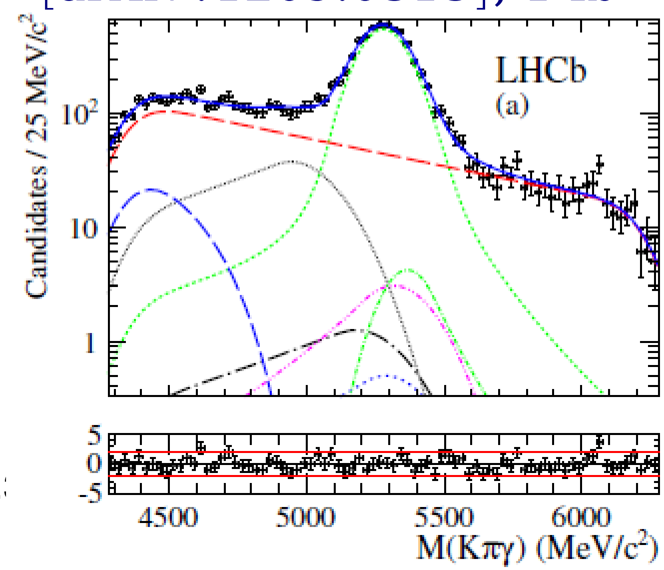
CLEO observation of $B \to K^* \gamma$ [1993]



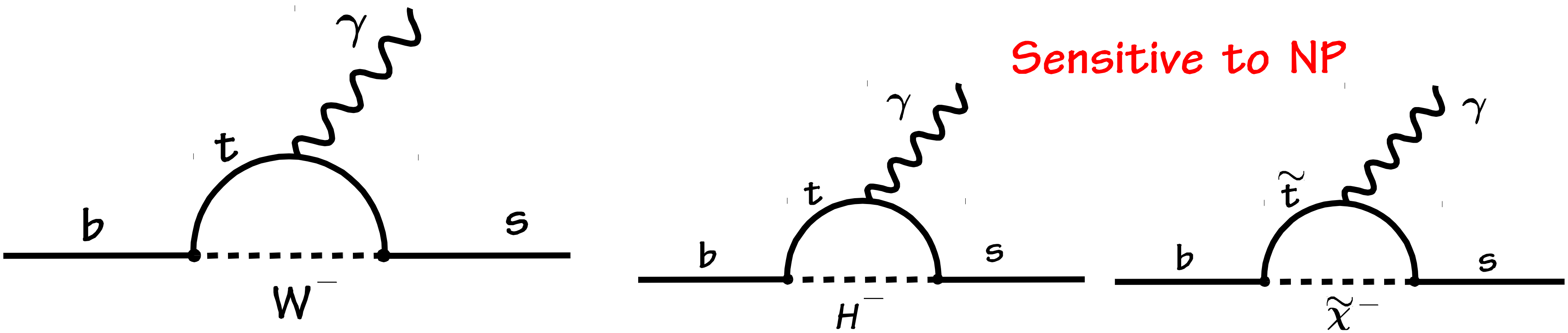
[383 MBB]
[arXiv:0906.2177]



[arXiv:1209.0313], 1 fb^{-1}



$B \to X_s \gamma$



NNLO SM calculation:

$$B_{SM}(B \to X_s \gamma) = (3.36 \pm 0.23) \times 10^{-4}$$

(for $E_\gamma > 1.6$ GeV)

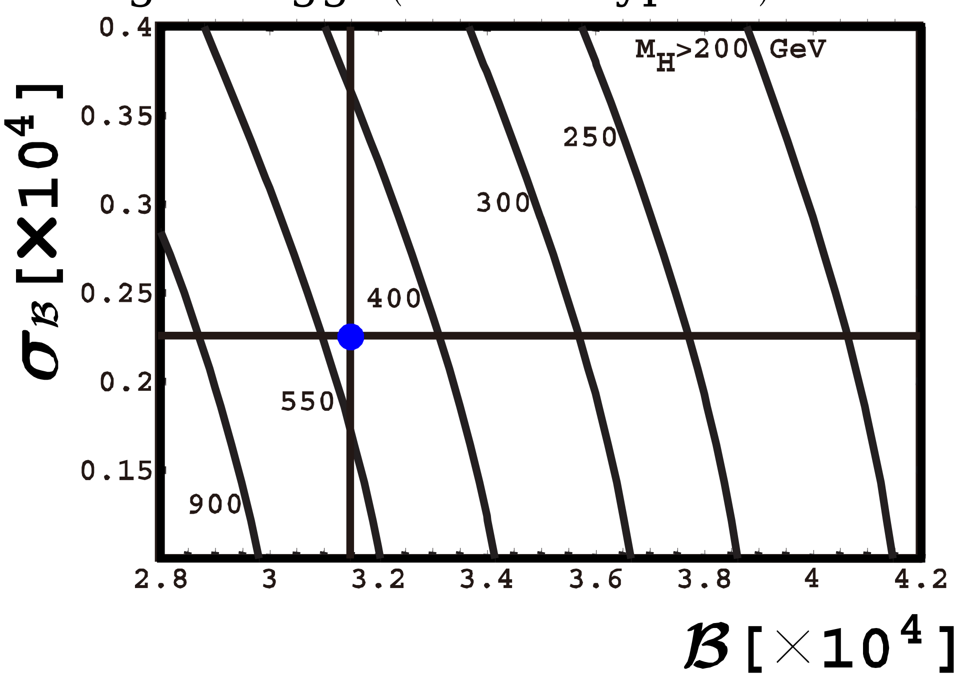
M.Misiak et al.

[arXiv:1503.01789]

(central value increased by 6.4% compared to 2007 value)

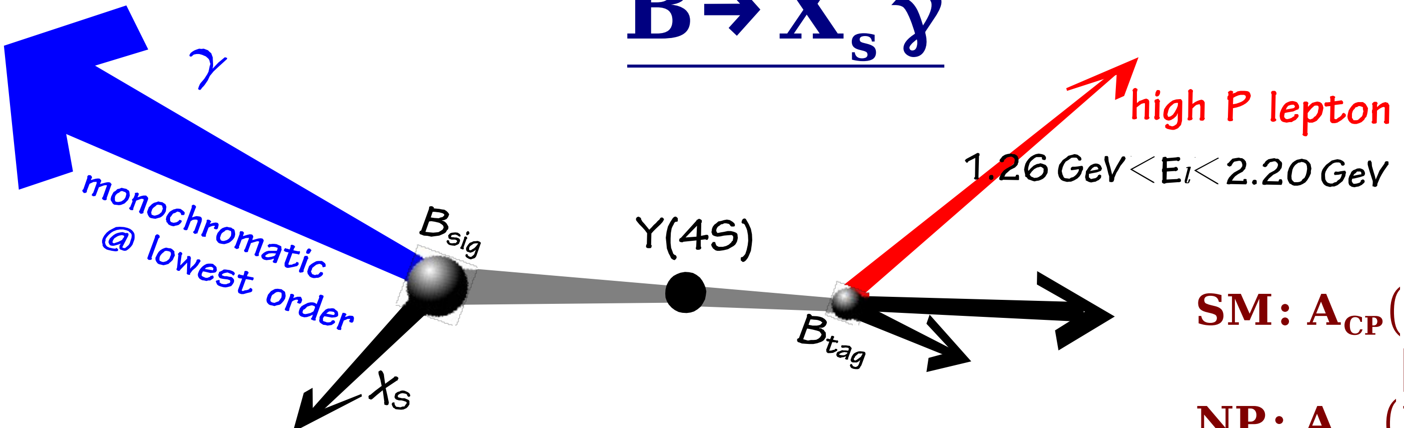
PRL 98, 022002 (2007)

Charged Higgs (2HDM Type II) bound

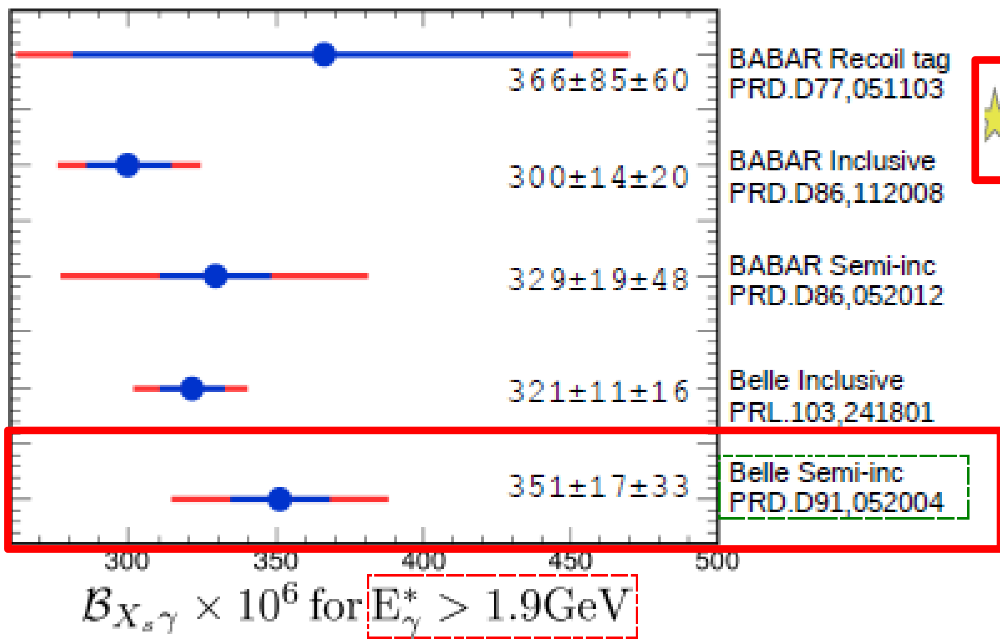


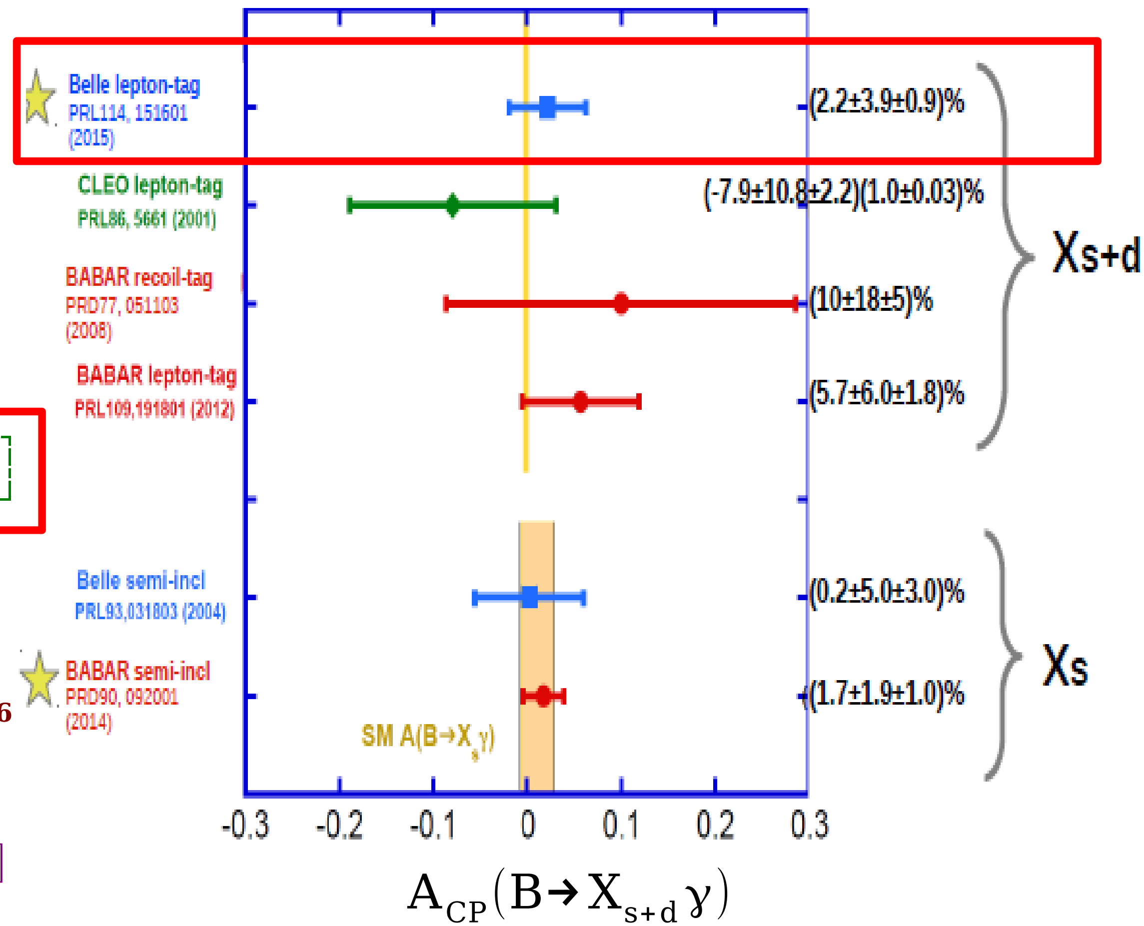
The lower γ energy threshold, the smaller the model uncertainties in SM, but the larger background in measurement

$B \to X_s \gamma$



SM: $A_{CP}(B \to X_{s+d}\gamma) = 0$ to order 10^{-6}
[Hurth and Mannel, 2001]
NP: $A_{CP}(B \to X_{s+d}\gamma)$ as large as 10%





at $E_\gamma > 1.6$ GeV:

$$\mathcal{B}(B \to X_s \gamma) = (341 \pm 15 \pm 4\ (\text{extrap})) \times 10^{-6}$$

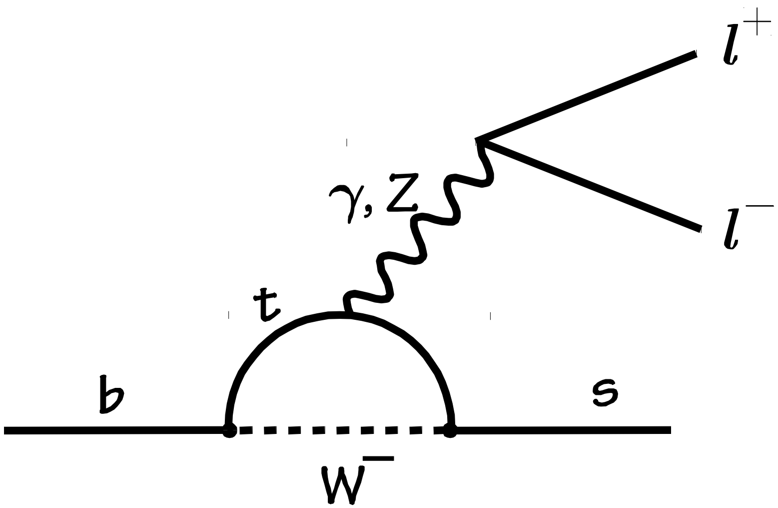
$$B_{SM}(B \to X_s \gamma) = (336 \pm 23) \times 10^{-6}$$

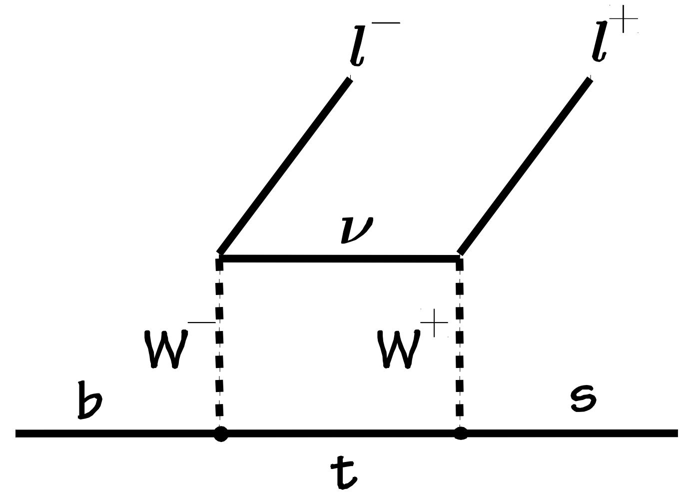
[Misiak et al, arXiv:1503.01789]

For charged Higgs in 2HDM Type II
$M(H^-) > 540$ GeV at 95% CL

⇒ limited by statistics: Belle II...

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





⇒ 2 orders of magnitude smaller than $b \rightarrow s\gamma$ but rich NP search potential

Amplitudes from
- electromagnetic penguin: C_7
- vector electroweak: C_9
- axial-vector electroweak: C_{10}

may interfere w/ contributions from NP

Many observables:
- Branching fractions
- Isospin asymmetry (A_I)
- Lepton forward-backward asymmetry (A_{FB})
- ...

⇒ Exclusive ($B \rightarrow K^{(*)} l^+ l^-$), Inclusive ($B \rightarrow X_s l^+ l^-$)

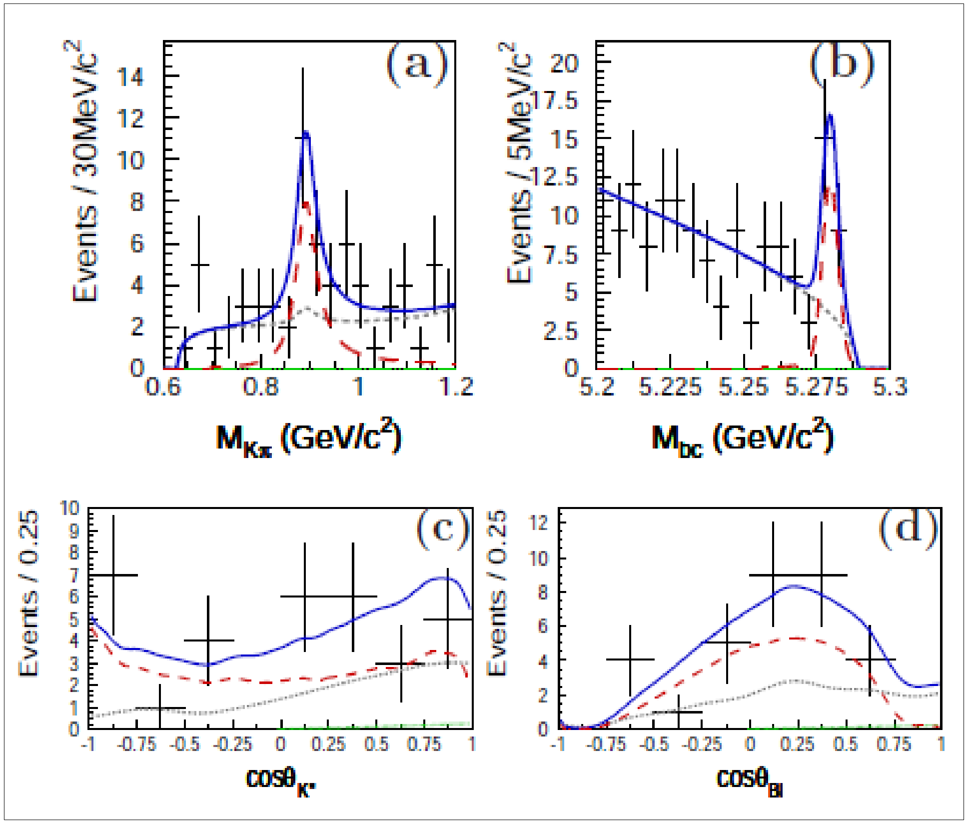
Situation pre-LHCb

$B \to K^* l^+ l^-$ decays

[arXiv:0904.0770]

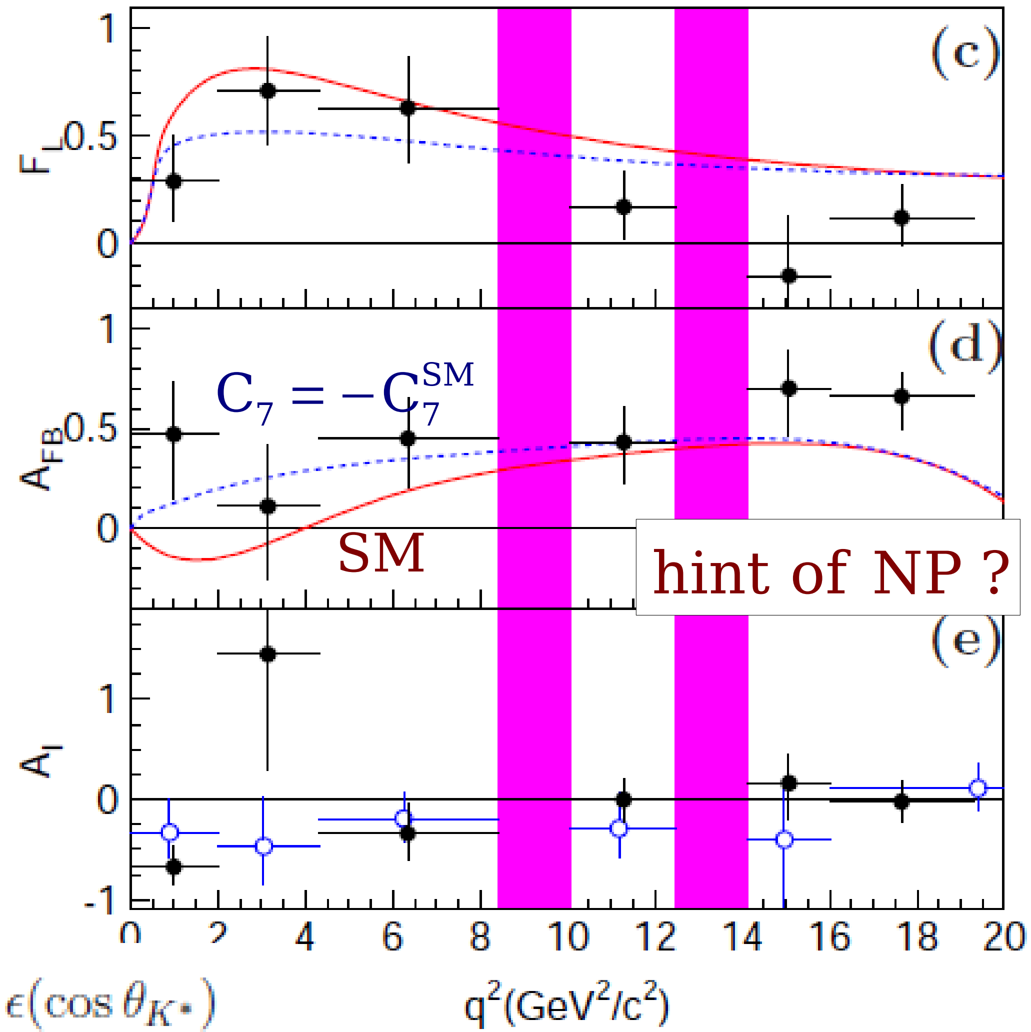
- Channels: $K^* \to K^+\pi^-$, $K^0_S\pi^+$, $K^+\pi^0$, $l = e$ or μ

illustration: $q^2 \in [0.0, 2,0]$ GeV^2



$$\left[\ \tfrac{3}{2}F_L\cos^2\theta_{K^*} + \tfrac{3}{4}(1-F_L)(1-\cos^2\theta_{K^*})\ \right] \times \epsilon(\cos\theta_{K^*})$$

$$\left[\ \tfrac{3}{4}F_L(1-\cos^2\theta_{B\ell}) + \tfrac{3}{8}(1-F_L)(1+\cos^2\theta_{B\ell}) + A_{FB}\cos\theta_{B\ell}\ \right] \times \epsilon(\cos\theta_{B\ell})\ ,$$



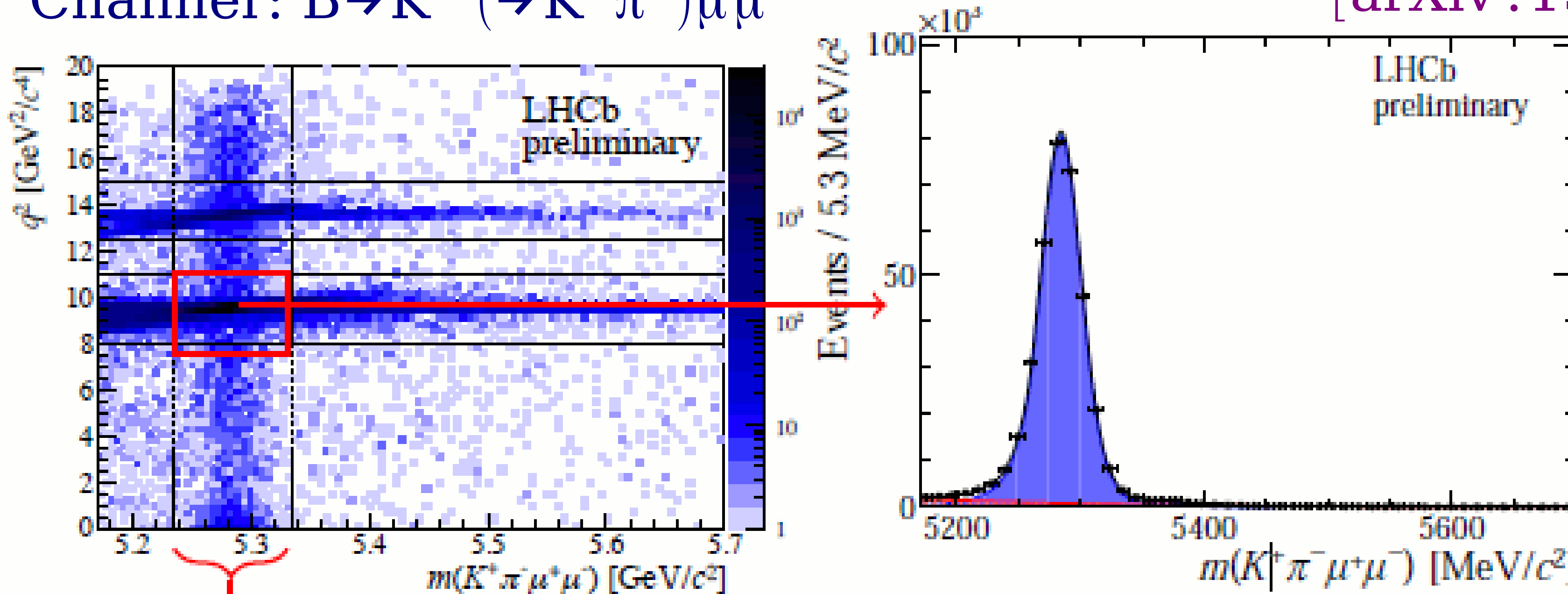
$R_{K^*} = 0.83 \pm 0.17 \pm 0.08$
$R_K = 1.03 \pm 0.19 \pm 0.06$

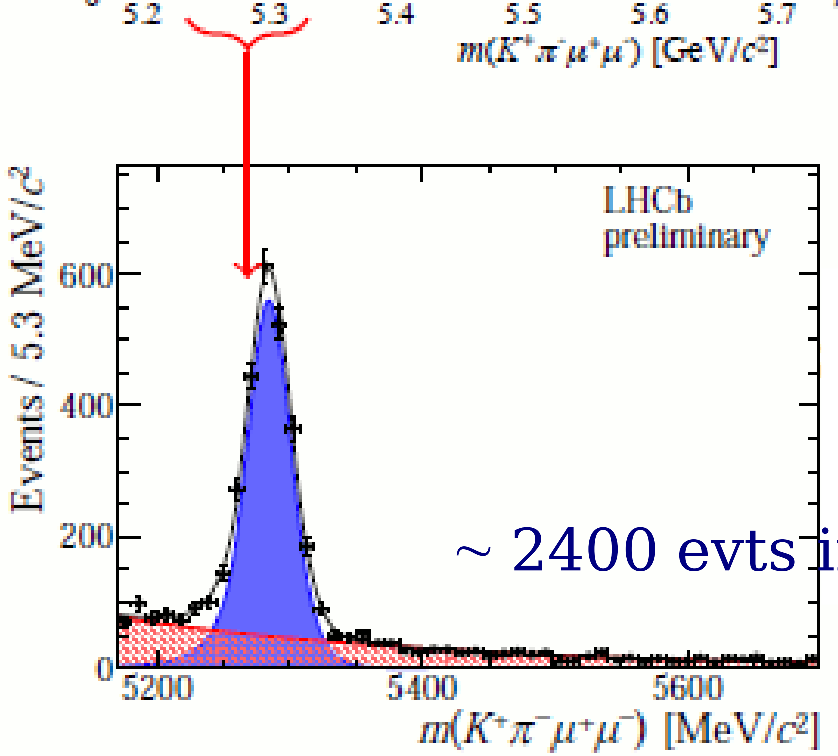
$R_K^{SM} = 1$, $R_{K^*}^{SM} = 0.75$ (photon pole !)

Angular analysis of $B_d^0 \to K^* \mu^+ \mu^-$ decays

- Channel: $B \to K^{*0}(\to K^+ \pi^-)\mu\mu$

[arXiv:1512.04442]





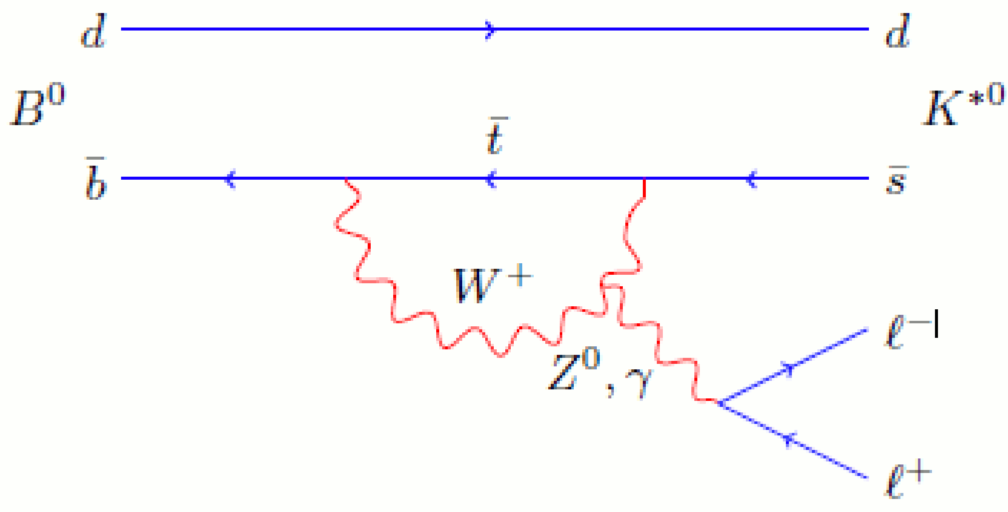
Selection:

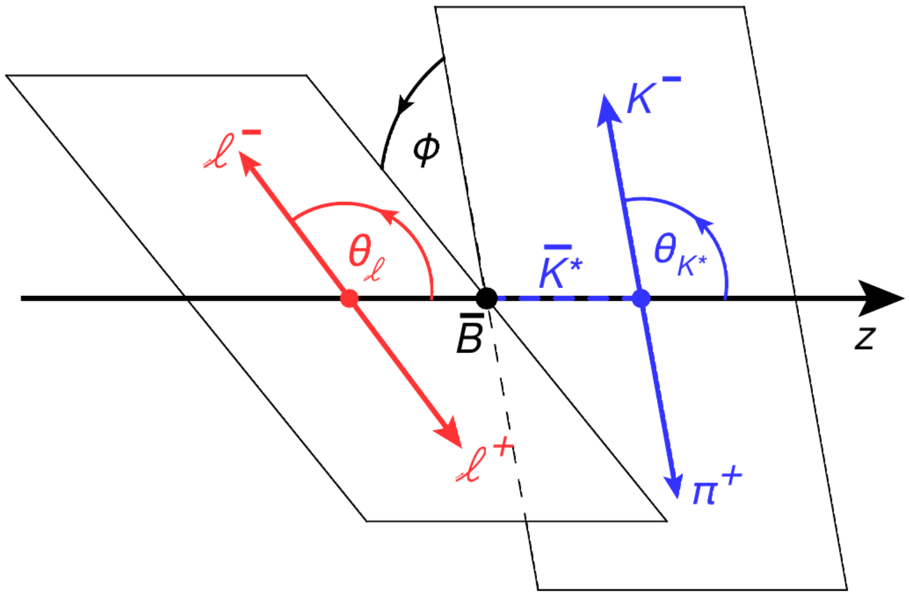
BDT to reject combinatorial background
Veto of resonant modes (control modes)

~ 2400 evts in the full q^2 range

Angular analysis of $B_d^0 \rightarrow K^* l^+ l^-$ decays

- Final state described by $q^2 = m_{ll}^2$ and three angles $\Omega = (\theta_l, \theta_K, \varphi)$





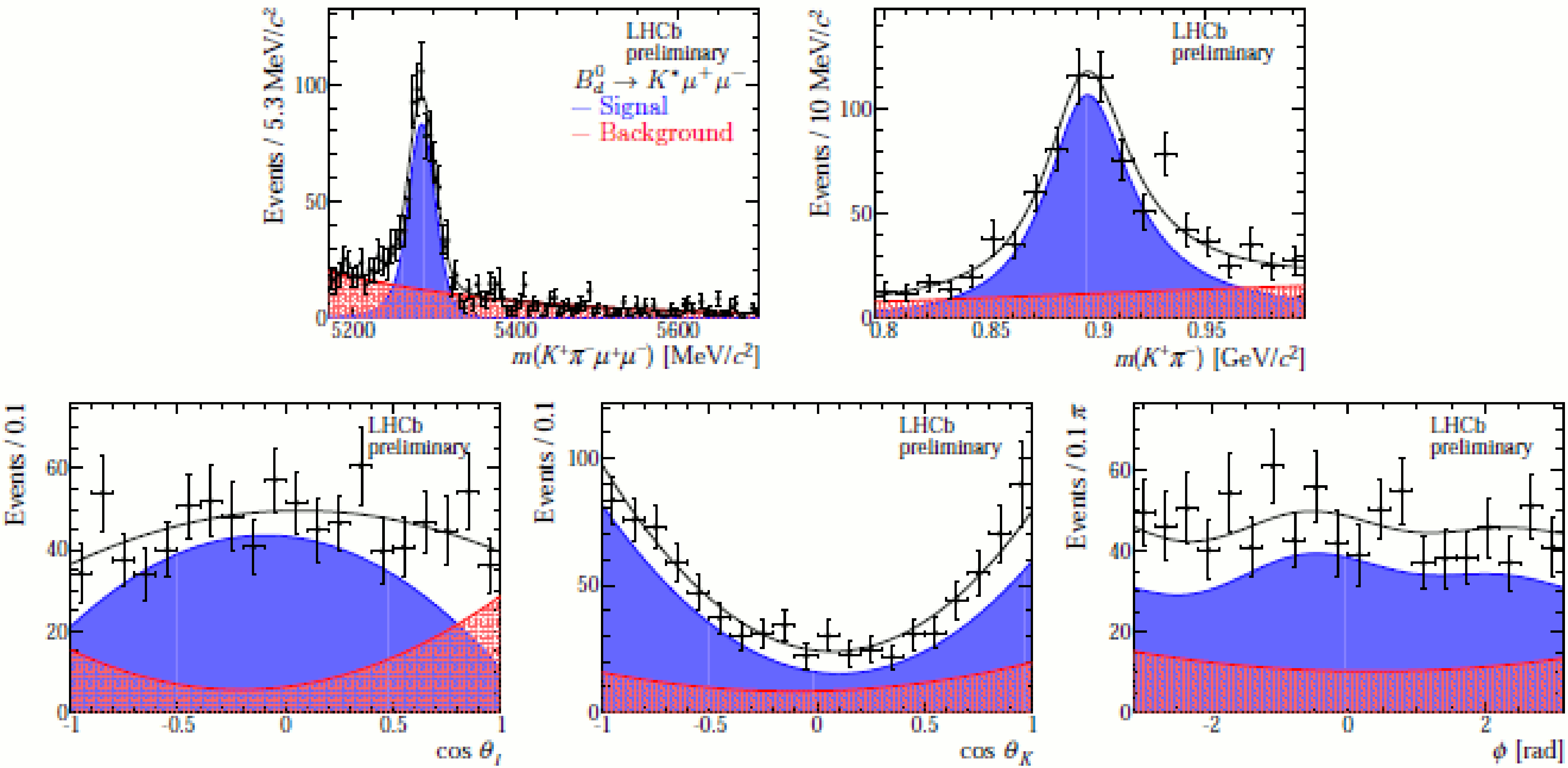
$$\frac{1}{\mathrm{d}(\Gamma+\bar{\Gamma})/\mathrm{d}q^2}\frac{\mathrm{d}^3(\Gamma+\bar{\Gamma})}{\mathrm{d}\vec{\Omega}} = \frac{9}{32\pi}\Big[\tfrac{3}{4}(1-F_\mathrm{L})\sin^2\theta_K + F_\mathrm{L}\cos^2\theta_K + \tfrac{1}{4}(1-F_\mathrm{L})\sin^2\theta_K\cos 2\theta_\ell$$
$$- F_\mathrm{L}\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi$$
$$+ S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi + S_5\sin 2\theta_K\sin\theta_\ell\cos\phi$$
$$+ \tfrac{4}{3}A_\mathrm{FB}\sin^2\theta_K\cos\theta_\ell + S_7\sin 2\theta_K\sin\theta_\ell\sin\phi$$
$$+ S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi + S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big]$$

- F_L, A_{FB}, S_i sensitive to $C_7^{(\prime)}$, $C_9^{(\prime)}$, $C_{10}^{(\prime)}$

Angular analysis of $B_d^0 \to K^* \mu^+ \mu^-$ decays

[arXiv:1512.04442]

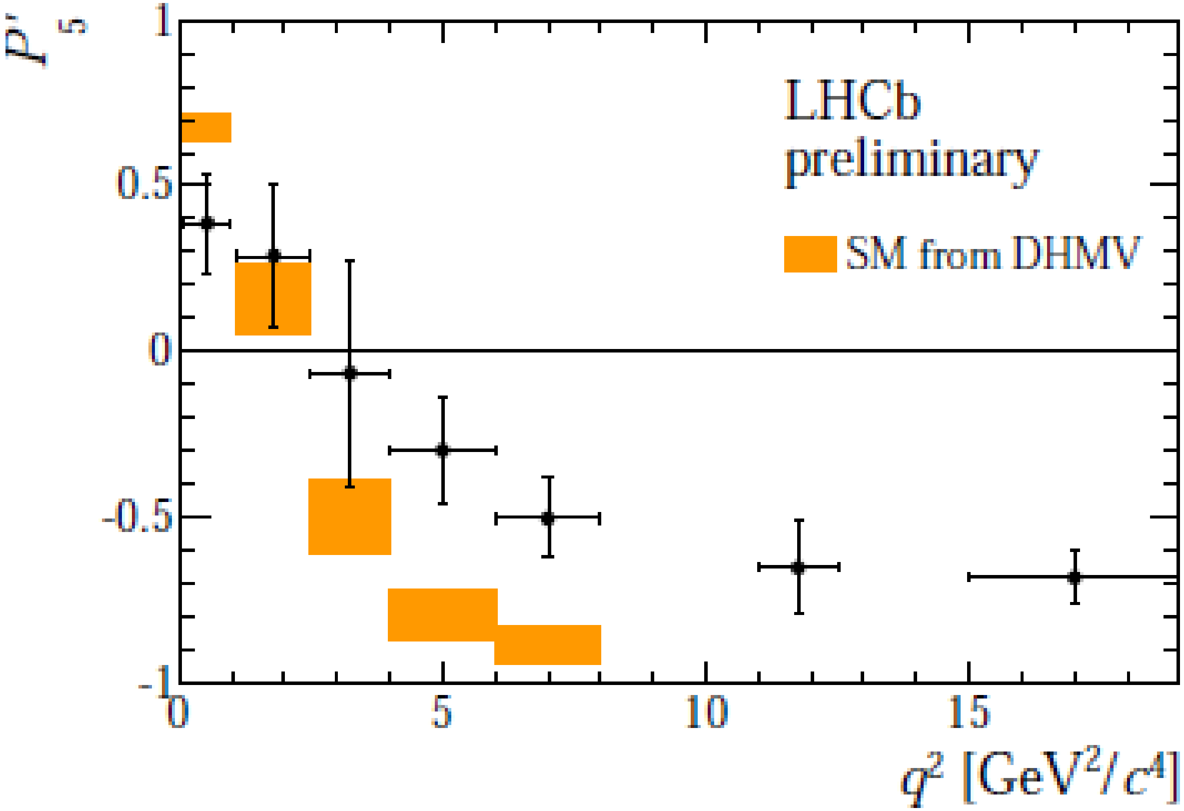
- Projections of fit results for $q^2 \in [1.1, 6.0]$ GeV^2
- Good agreement of PDF projections with data in every bin of q^2

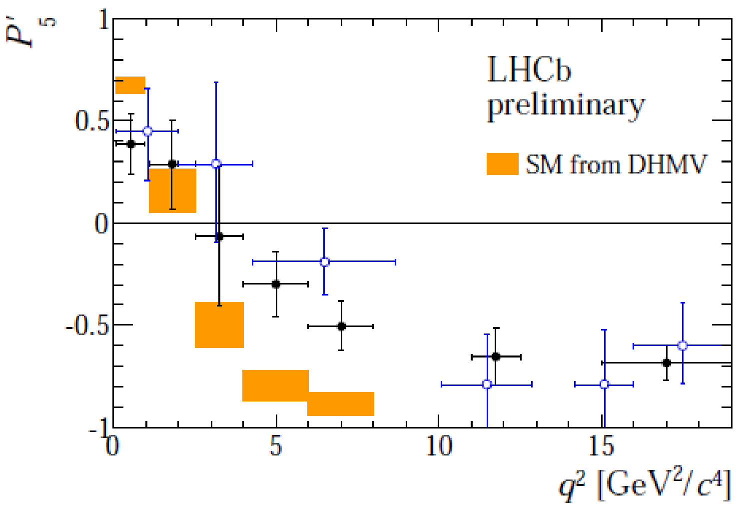


Angular analysis of $B_d^0 \to K^* \mu^+ \mu^-$ decays

[arXiv:1512.04442]

- Form-factor independent observables $P_5' = \frac{S_5}{\sqrt{F_L(1-F_L)}}$





- Tension in P_5' seen with $1\,\text{fb}^{-1}$ is confirmed
- Local deviations of $2.9\,\sigma$ and $3.0\,\sigma$ for $q^2 \in [4.0, 6.0]$ and $[6.0, 8.0]$ GeV^2
- Naive combination of the two gives local significance of $3.7\,\sigma$

Test of lepton universality using $B^+ \to K^+ l^+ l^-$ decays

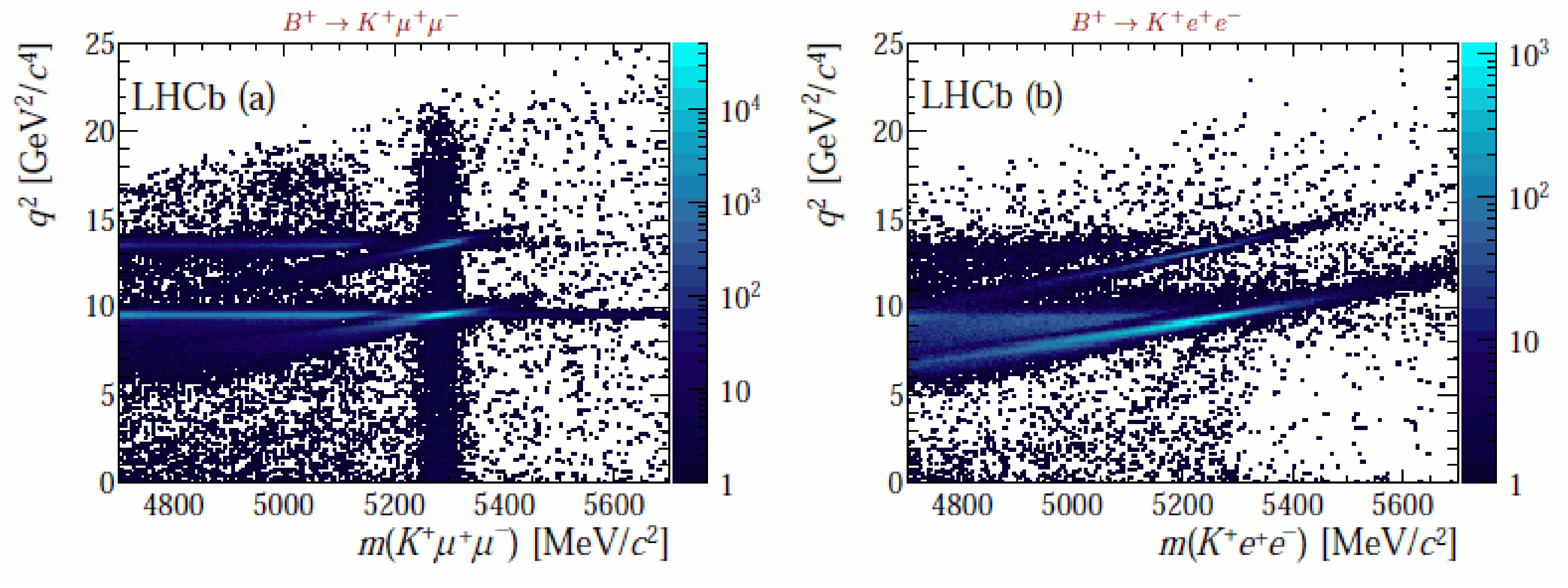
arXiv:1406.6482

- Ratio of branching fractions of $B^+ \to K^+ e^+ e^-$ and $B^+ \to K^+ \mu^+ \mu^-$ sensitive to lepton universality

$$R_K = \frac{\int_{q^2_{min}}^{q^2_{max}} \frac{d\Gamma[\mathcal{B}(B^+ \to K^+ \mu^+ \mu^-)]}{dq^2} dq^2}{\int_{q^2_{min}}^{q^2_{max}} \frac{d\Gamma[\mathcal{B}(B^+ \to K^+ e^+ e^-)]}{dq^2} dq^2} = \left(\frac{N_{K\mu\mu}}{N_{Kee}}\right)\left(\frac{N_{J/\psi(ee)K}}{N_{J/\psi(\mu\mu)K}}\right)\left(\frac{\varepsilon_{Kee}}{\varepsilon_{K\mu\mu}}\right)\left(\frac{\varepsilon_{J/\psi(ee)K}}{\varepsilon_{J/\psi(\mu\mu)K}}\right)$$

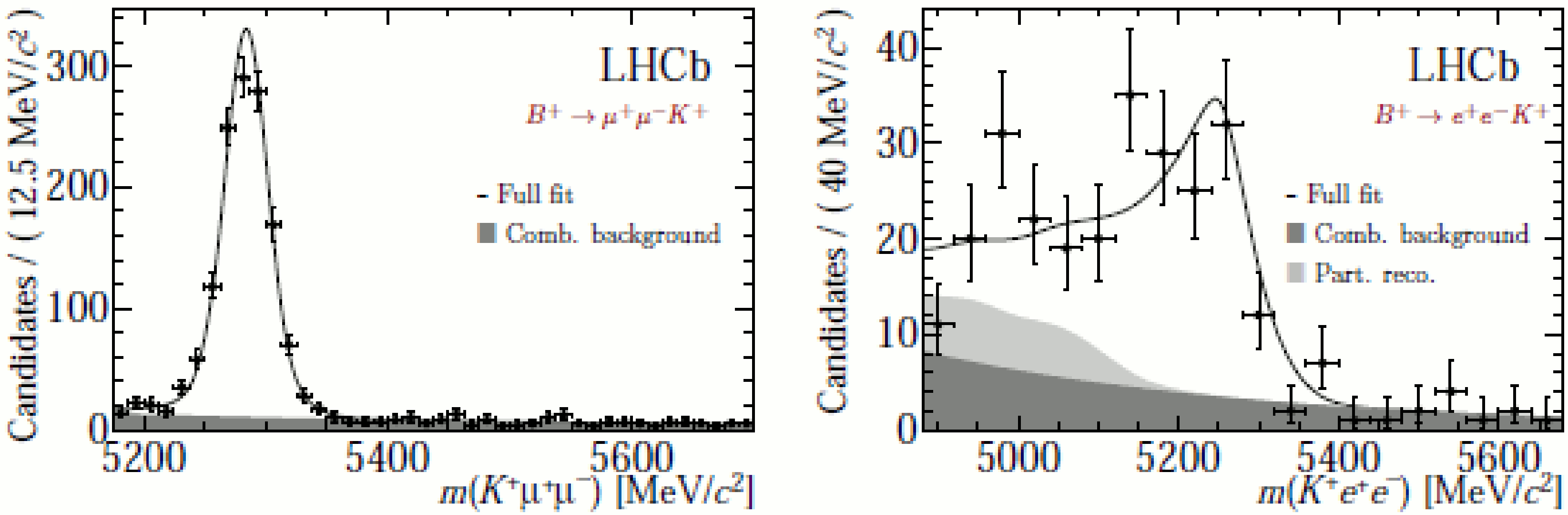
- SM prediction is $R_K = 1$ with an uncertainty of $O(10^{-3})$

- Measurement relative to resonant $B \to J/\psi K$ modes



Test of lepton universality using $B^+ \to K^+ l^+ l^-$ decays

[arXiv:1406.6482]



$q^2 \in [1,6]\mathrm{GeV}^2/c^4$

Electron Trigger

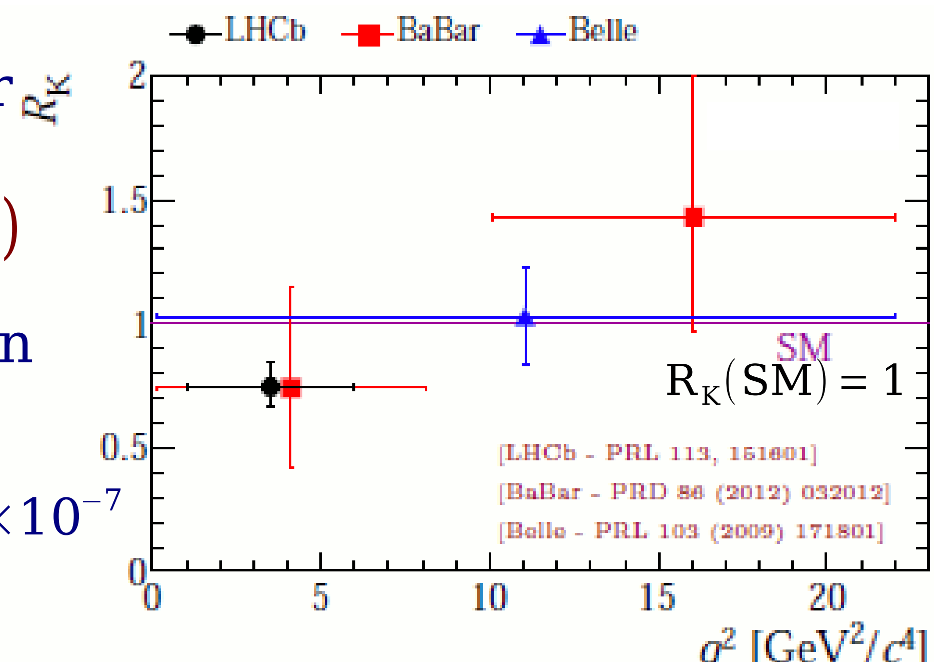
R_K: ratio of branching fractions for dilepton invariant mass squared range $1<q^2<6\,\mathrm{GeV}^2/c^4$

- The combination of the various trigger channels gives:

  $$\mathbf{R_K = 0.745\,^{+0.090}_{-0.074}(stat) \pm 0.036(syst)}$$

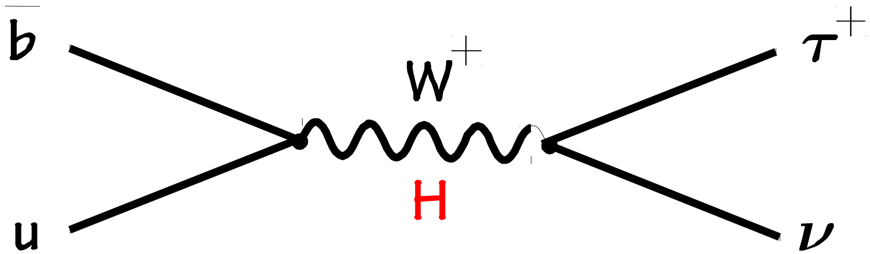
- Most precise measurement to date is in disagreement with SM at 2.6σ level

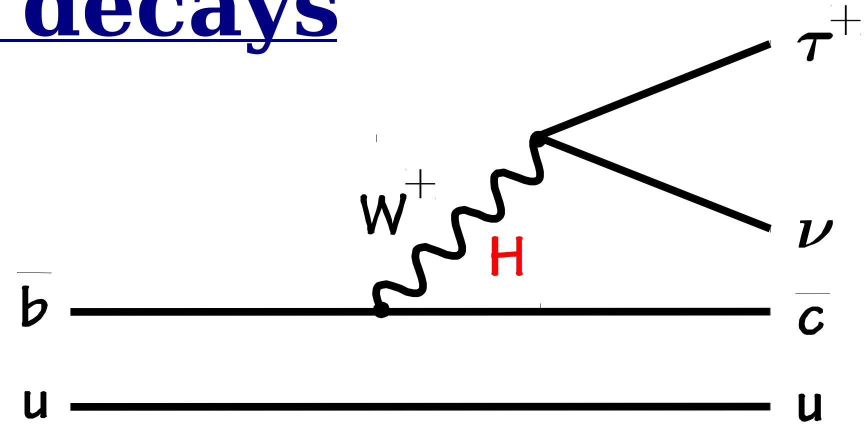
$\Rightarrow$ $B(B^+ \to e^+e^-K^+) = (1.56\,^{+0.19}_{-0.15}(\mathrm{stat})\,^{+0.06}_{-0.05}(\mathrm{syst}))\times 10^{-7}$ compatible with SM predictions



Lepton Flavor Non-Universality ? effect is in $\mu\mu$, not ee

Tauonic B decays





$B \to \tau\nu$

$$\mathcal{B}_{SM}(B^+ \to \tau^+ \nu) = \frac{G_F^2 m_B m_\tau^2}{8\pi}\left(1 - \frac{m_\tau^2}{m_B^2}\right) f_B^2 |V_{ub}|^2 \tau_B$$

$$\text{2HDM (type II)}: \mathcal{B}(B^+ \to \tau^+ \nu) = \mathcal{B}_{SM} \times \left(1 - \frac{m_B^2}{m_{H^+}^2} \tan^2\beta\right)^2$$

uncertainties from f_B and $|V_{ub}|$ can be reduced to B_B and other CKM uncertainties by combining with precise Δm_d

$B \to D^{(*)}\tau\nu$

$$\text{2HDM (type II)}: \mathcal{B}(B \to D\tau^+ \nu) = G_F^2 \tau_B |V_{cb}|^2 f\left(F_V, F_S, \frac{m_B^2}{m_{H^+}^2} \tan^2\beta\right)$$

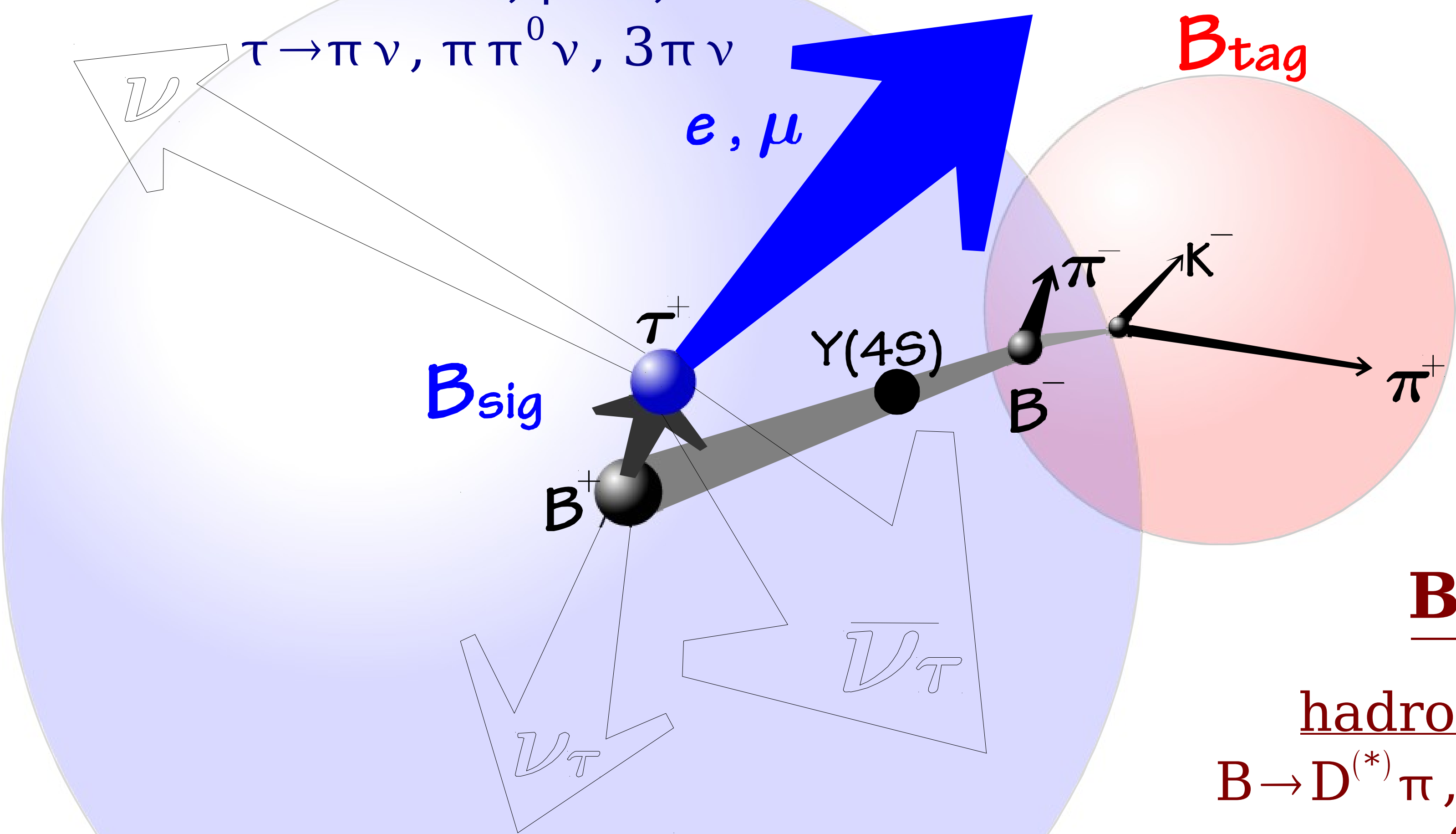
uncertainties from form factors F_V and F_S can be studied with $B \to D l \nu$ (more form factors in $B \to D^* \tau \nu$)

Event reconstruction in $B \to \tau \nu$

$B_{sig} \to \tau \nu$

(70 % of all τ decays)

$\tau \to e \nu \nu$, $\mu \nu \nu$,
$\tau \to \pi \nu$, $\pi \pi^0 \nu$, $3\pi \nu$



B_{tag}

hadronic tag

$B \to D^{(*)} \pi$, $D^{(*)}$rho....

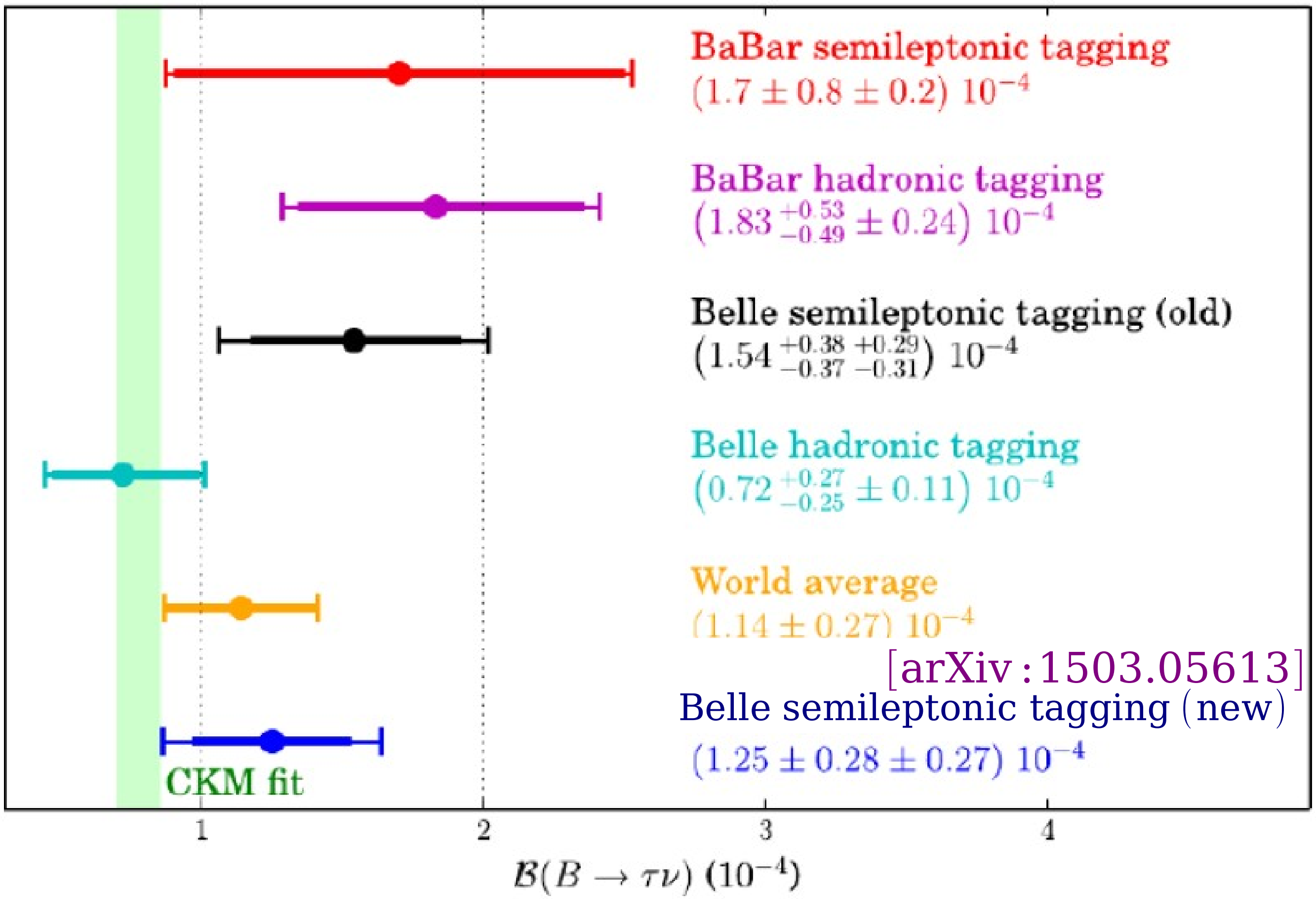
$\epsilon \sim 0.2\%$

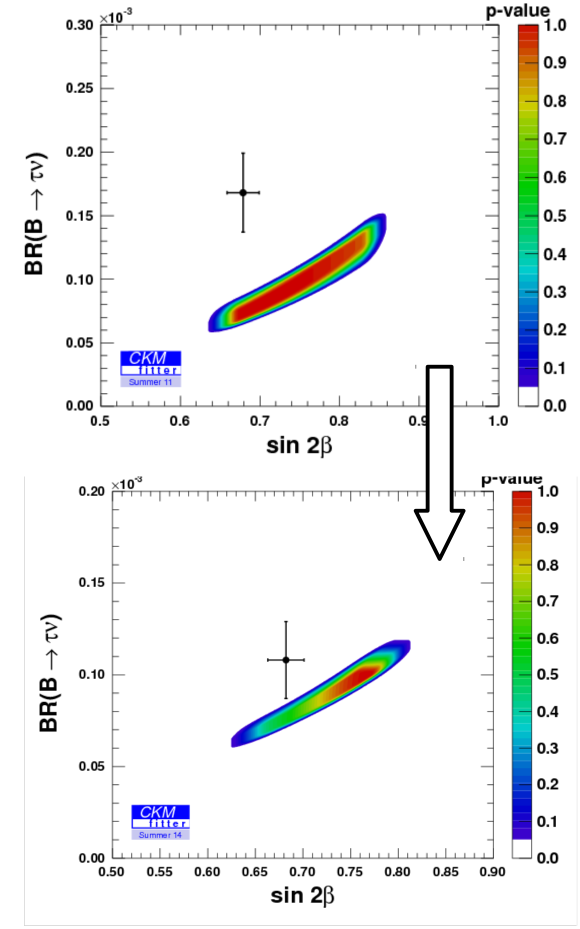
semileptonic tag

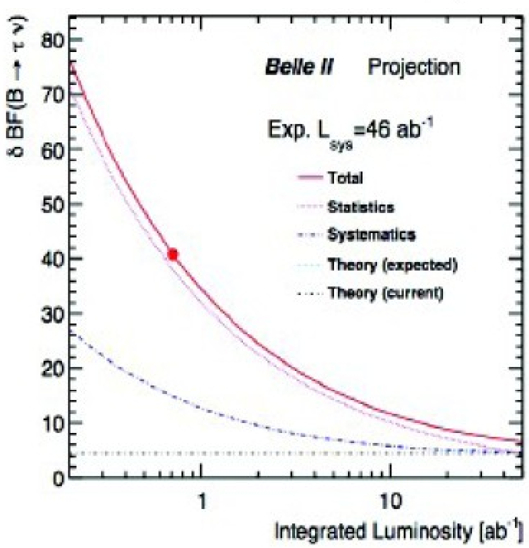
$B \to D^{(*)} l \nu X$

Require no particle
and no energy left
after removing B_{tag}
and visible particles of B_{sig}

B→τν status





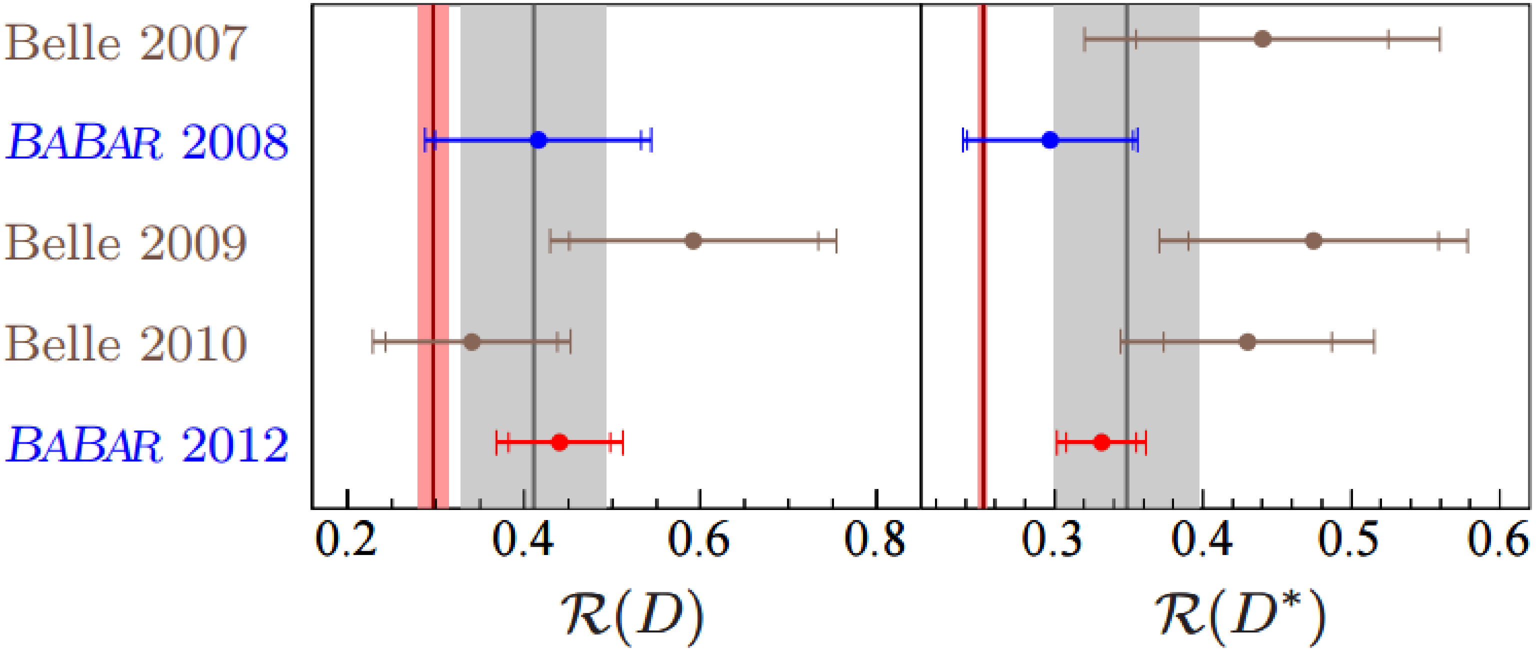


Belle II	Statistical	Systematic (reducible, irreducible)	Total Exp	Theory	Total
$\lvert V_{ub}\rvert$ $B \to \tau\nu$ (had. tagged)					
711 fb^{-1}	19.0	(7.1, 2.2)	20.4	2.5	20.5
5 ab^{-1}	7.2	(2.7, 2.2)	7.9	1.5	8.1
50 ab^{-1}	2.3	(0.8, 2.2)	3.2	1.0	3.4
$\lvert V_{ub}\rvert$ $B \to \tau\nu$ (SL tagged)					
605 fb^{-1}	12.4	$(9.0, {}^{+3.0}_{-4.8})$	${}^{+15.6}_{-16.1}$	2.5	${}^{+15.8}_{-16.2}$
5 ab^{-1}	4.3	$(3.1, {}^{+3.0}_{-4.8})$	${}^{+6.1}_{-7.2}$	1.5	${}^{+6.3}_{-7.3}$
50 ab^{-1}	1.4	$(1.0, {}^{+3.0}_{-4.8})$	${}^{+3.4}_{-5.1}$	1.0	${}^{+3.6}_{-5.2}$

$B \to D^{(*)} \tau \nu$

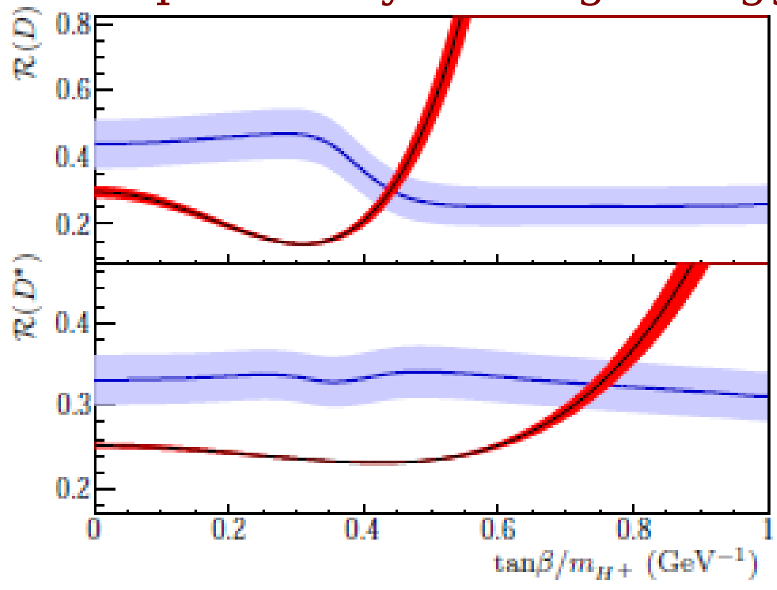
$$R(D^{(*)}) = \frac{B \to D^{(*)} \tau \nu}{B \to D^{(*)} l \nu}$$

Babar and Belle measurements hint to deviation from SM



BaBar (arXiv:1303.0571) observes a 3.4σ excess over SM expectation

''This excess cannot be explained by a charged Higgs boson in the 2HDM type II''



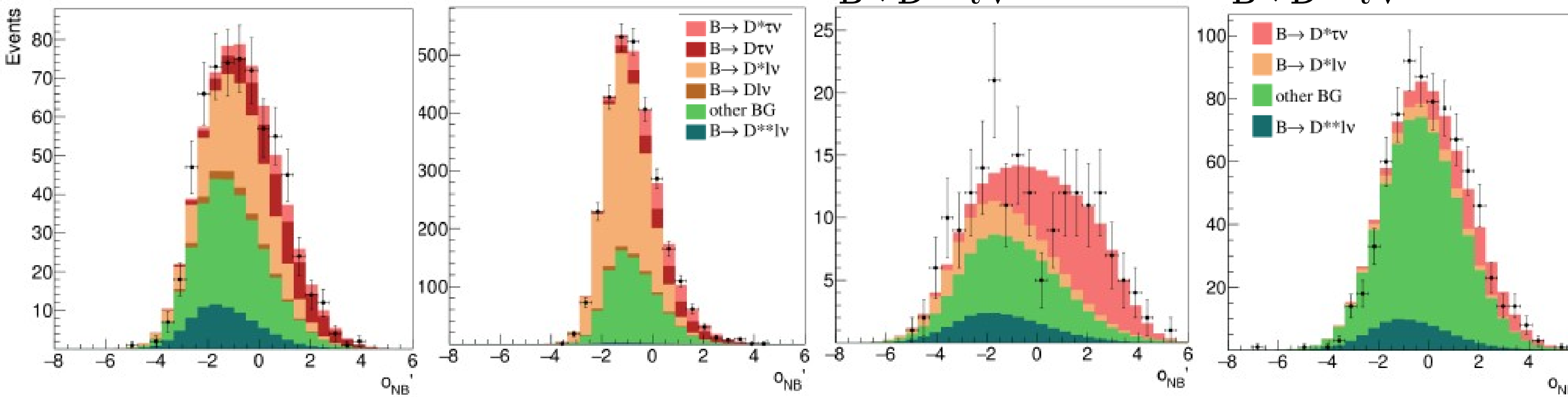
$B \to D^{(*)} \tau \nu$ at Belle

[arXiv:1507.03233]

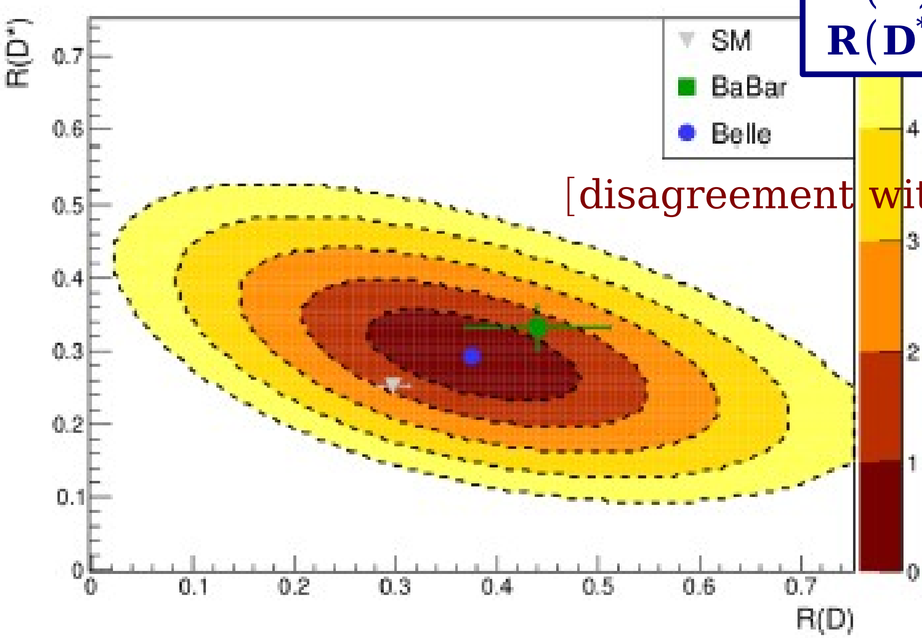
(with hadronic tagging)

projections for large M^2_{miss} region, $N(D\tau\nu) \sim 300$, $N(D^*\tau\nu) \sim 500$

$B \to D^+ \tau \nu$ $B \to D^0 \tau \nu$ $B \to D^{*+} \tau \nu$ $B \to D^{*0} \tau \nu$



$R(D) = 0.375 \pm 0.064 \pm 0.026$
$R(D^*) = 0.293 \pm 0.038 \pm 0.015$

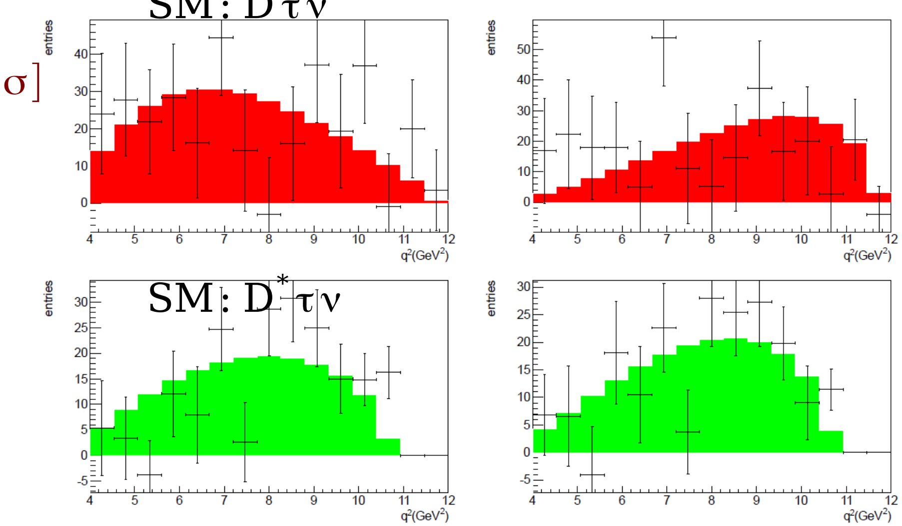


[disagreement with SM at 1.5σ]

stat error only !

SM: $D\tau\nu$

SM: $D^*\tau\nu$



$B \to D^{*+} \tau \nu$ at LHCb

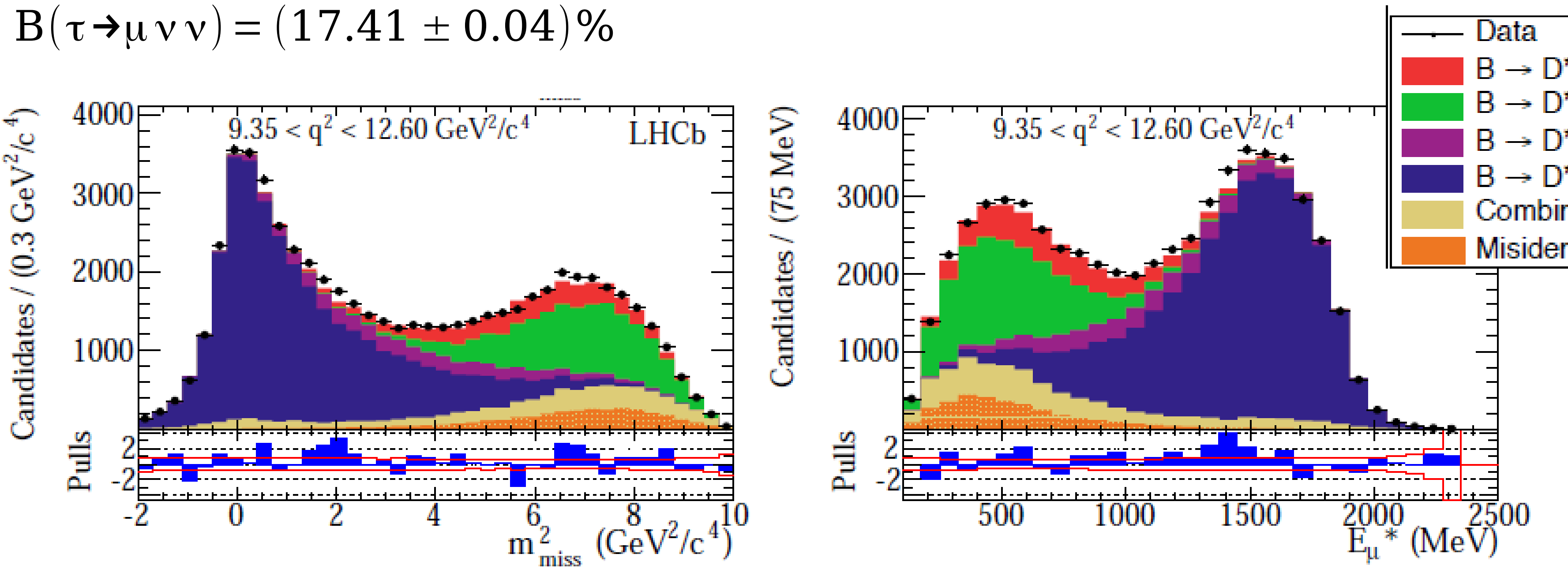
[arXiv:1506.08614]

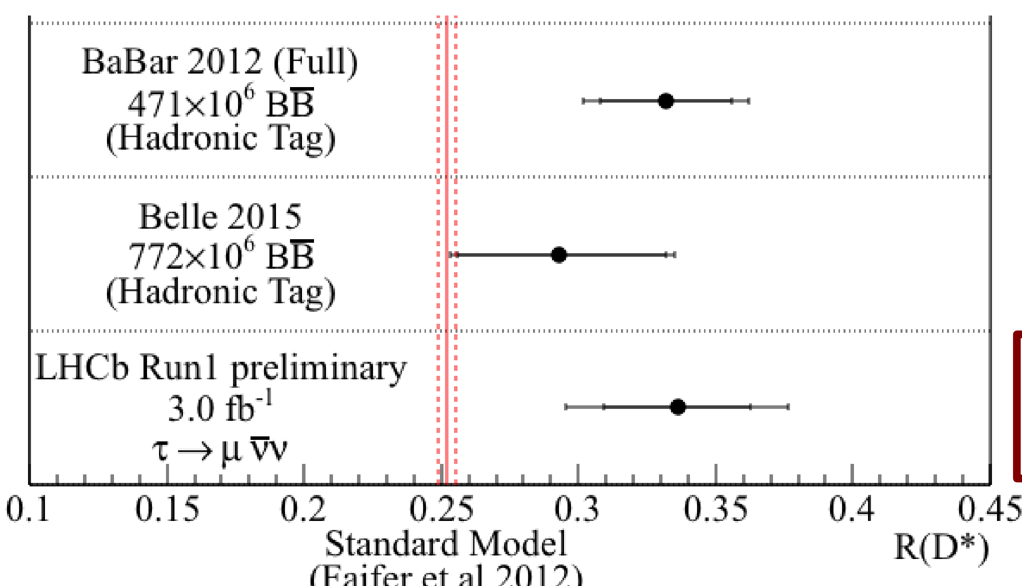
$$R(D^*) \equiv \frac{B\left(\bar{B}^0 \to D^{*+}\tau^-(\mu^-\bar{\nu}_\mu \nu_\tau)\bar{\nu}_\tau\right)}{B\left(\bar{B}^0 \to D^{*+}\mu^-\bar{\nu}_\mu\right)}$$

363,000 ± 1,600 events in $D^*\mu\nu$ sample

$N(D^*\tau\nu)/N(D^*\mu\nu) = (4.54 \pm 0.46)\%$

$B(\tau \to \mu\nu\nu) = (17.41 \pm 0.04)\%$





$R(D^*) = 0.332 \pm 0.024 \pm 0.018$

$R(D^*) = 0.293 \pm 0.038 \pm 0.015$

[arXiv:1507.03233]

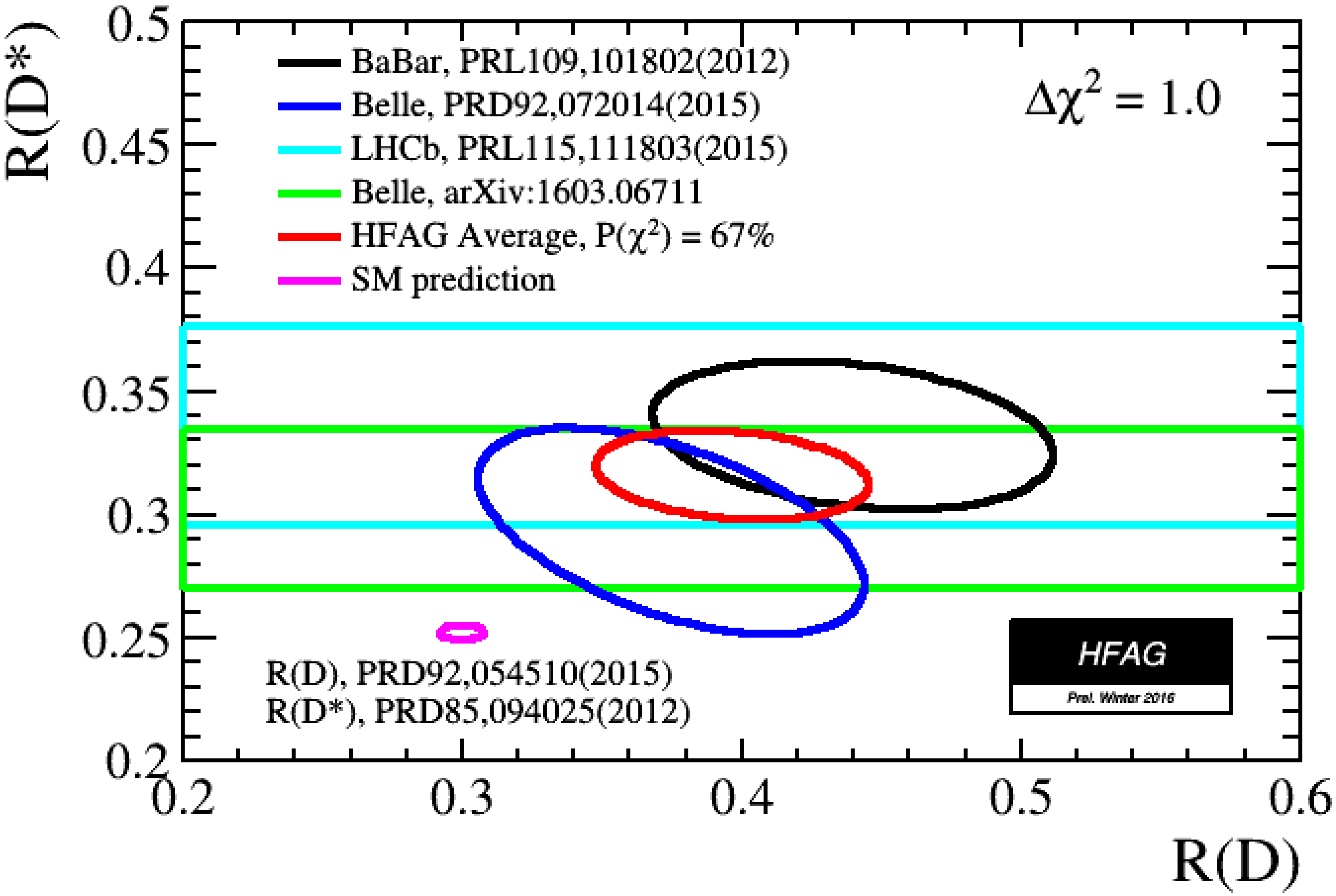
$R(D^*) = 0.336 \pm 0.027 \pm 0.030$

[disagreement with SM at 2.1 σ]

[arXiv:1506.08614]

Summary for $B \to D^{(*)} \tau \nu$

$$\Rightarrow \; R(D^{(*)}) = \frac{BF(B \to D \tau \nu_\tau)}{BF(B \to D l \nu_l)}$$



BaBar

$\mathbf{R(D) = 0.440 \pm 0.058 \pm 0.042}$
$\mathbf{R(D^*) = 0.332 \pm 0.024 \pm 0.018}$

Belle

$\mathbf{R(D) = 0.375 \pm 0.064 \pm 0.026}$
$\mathbf{R(D^*) = 0.293 \pm 0.038 \pm 0.015}$

$\mathbf{R(D^*) = 0.302 \pm 0.030 \pm 0.011}$

LHCb

$\mathbf{R(D^*) = 0.336 \pm 0.027 \pm 0.030}$

average

$\mathbf{R(D) = 0.397 \pm 0.040 \pm 0.028}$
$\mathbf{R(D^*) = 0.316 \pm 0.016 \pm 0.010}$

difference with SM predictions is at **4.0** σ level

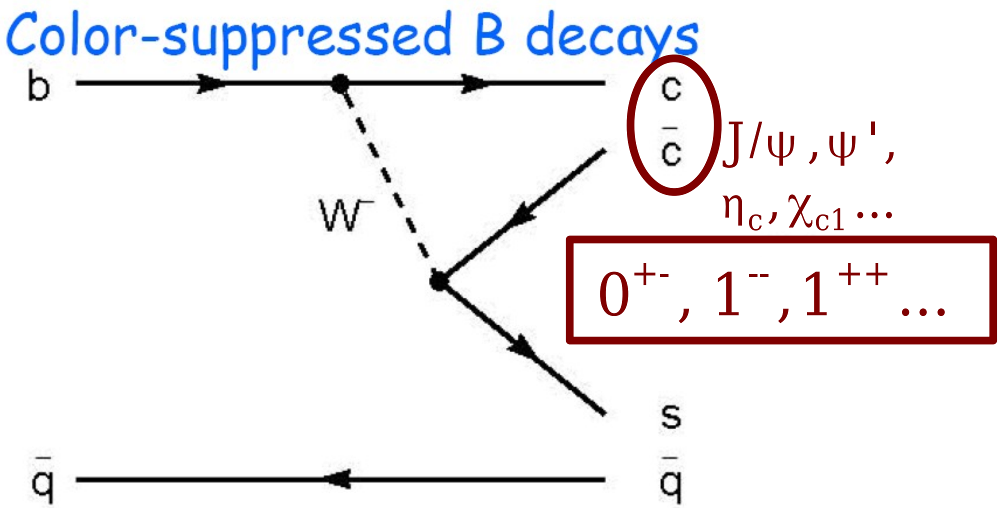
$\Rightarrow$ more measurements to come, more observables (τ polarization...)

Exotic states

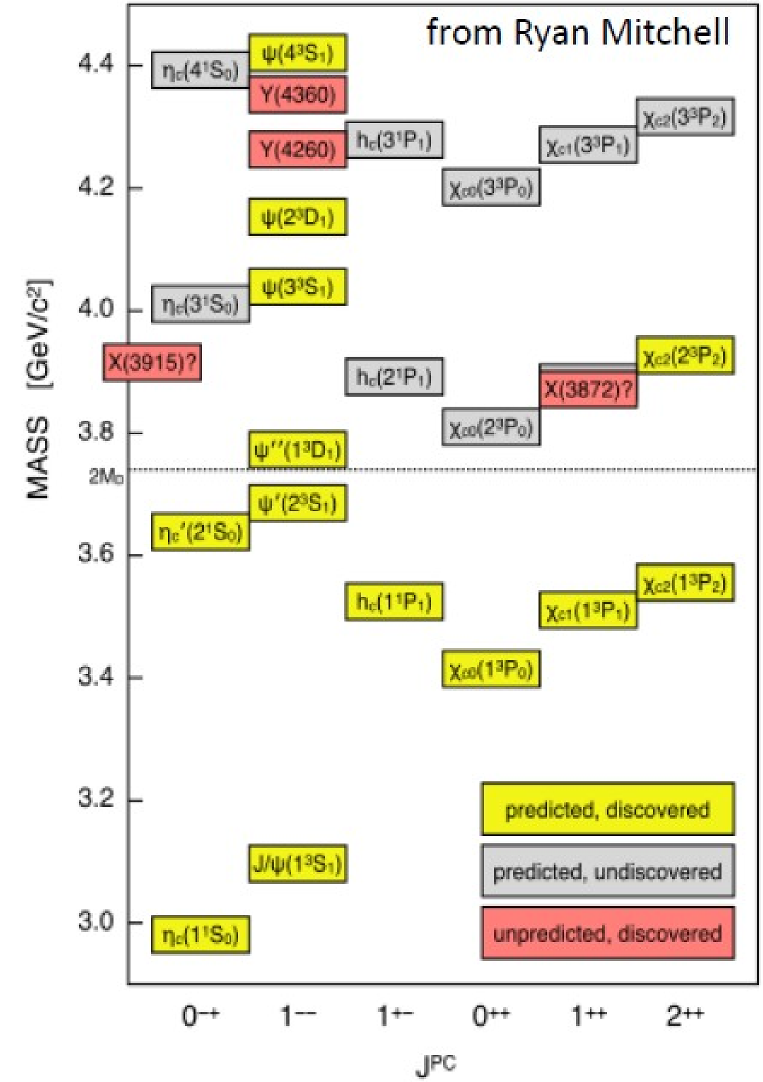
definition of exotic: very different, strange, or unusual

''exotics'': new states of matter beyond the simple quark picture
(tetraquark mesons, pentaquark baryons, glueballs on hybrid states $q\bar{q}g$)
short-lived $\sim 10^{-23}$s ''resonances'' whose presence is detected by mass peaks
and angular distributions showing the presence of unique J^{PC} quantum numbers

Exotic states in B decays



$Brs \sim 10^{-2}$ (inclusive)



B mesons decay with a $\sim 10^{-3}$ probability to $c\bar{c}$ and $K^{(*)}$

$\Rightarrow$ reconstruction with low bckg

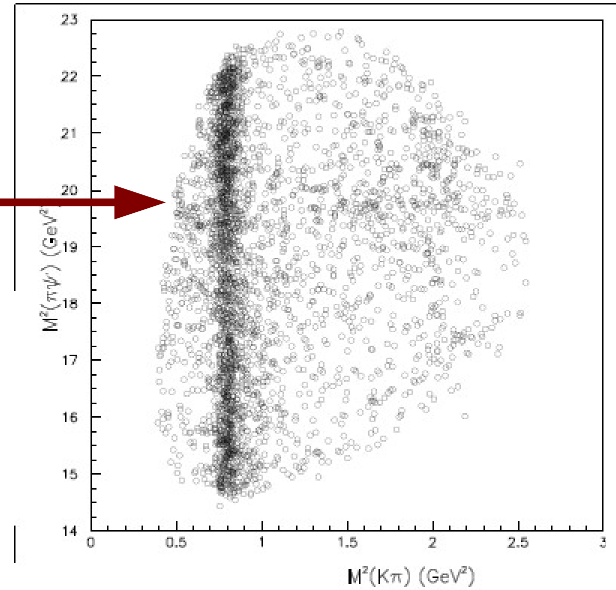
$\Rightarrow$ J^{PC} from angular analysis

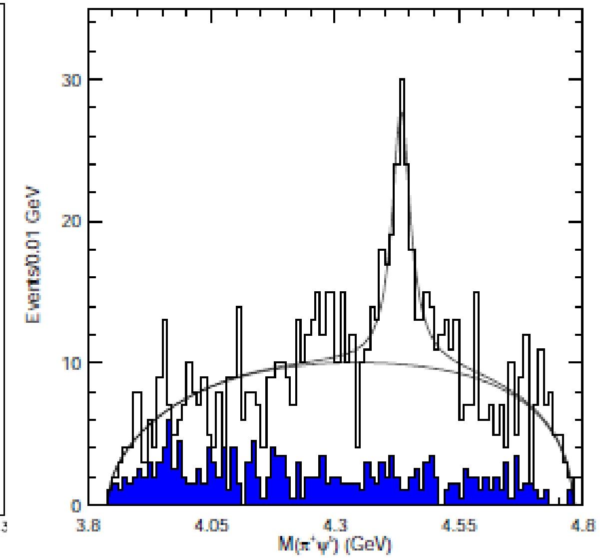
Many charmonium states studied this way
many exotic states also: X(3872), Z(4430)...

Z(4430)$^+$

- In $B \to \psi' \pi^- K^+$, peak in $M(\psi' \pi^-)$

unusual feature





- first observation by Belle: [arXiv:0708.1790]

$M = 4433 \pm 4 \pm 2$ MeV,

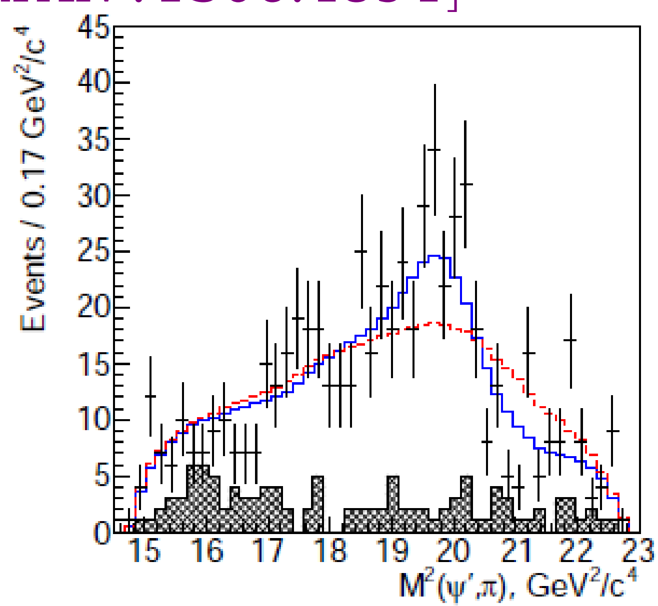
$\Gamma = 45\,^{+18}_{-13}\,^{+30}_{-13}$ MeV

⇒ charged charmonium state must be exotic: $c\bar{c}u\bar{d}$ content

- challenged by BaBar: explanation in terms of K^*'s [arXiv:0811.0564]
- Belle (re)analysis using full amplitude fit: [arXiv:1306.4894]

$M = 4485 \pm 22\,^{+28}_{-11}$ MeV, $\Gamma = 200\,^{+41}_{-46}\,^{+26}_{-35}$ MeV

$J^P = 1^+$ favored over the 0^-, 1^-, 2^- and 2^+ (by more than 3σ)



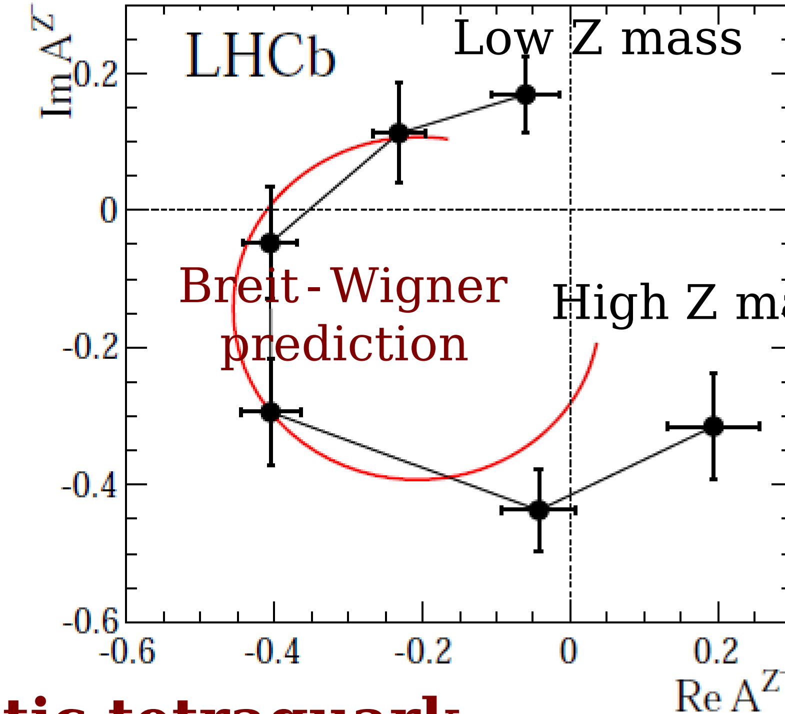
projection of the fit results with K^* veto

Z(4430)$^+$

in $B \to \psi' \pi^- K^+$

[arXiv:1404.1903]

Argand diagram: clear and large phase change



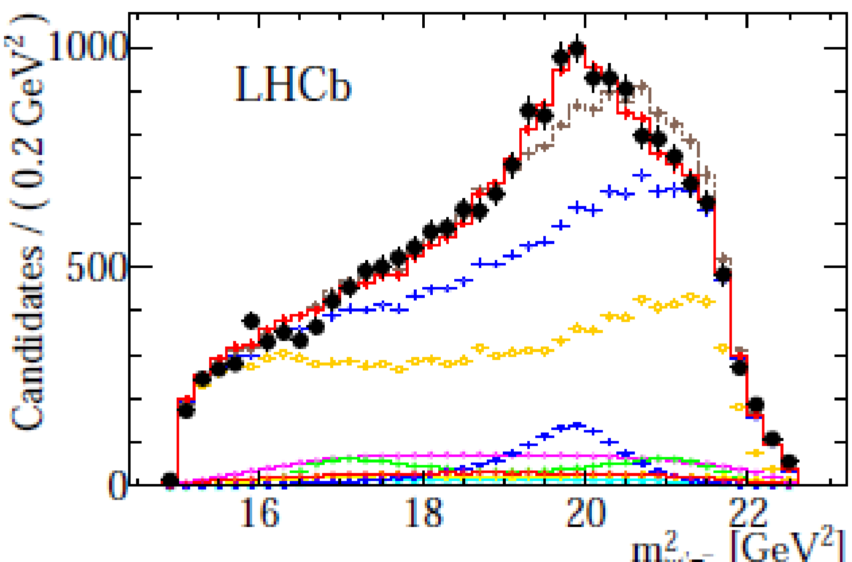
◦ LHCb analysis also uses full amplitude fit:

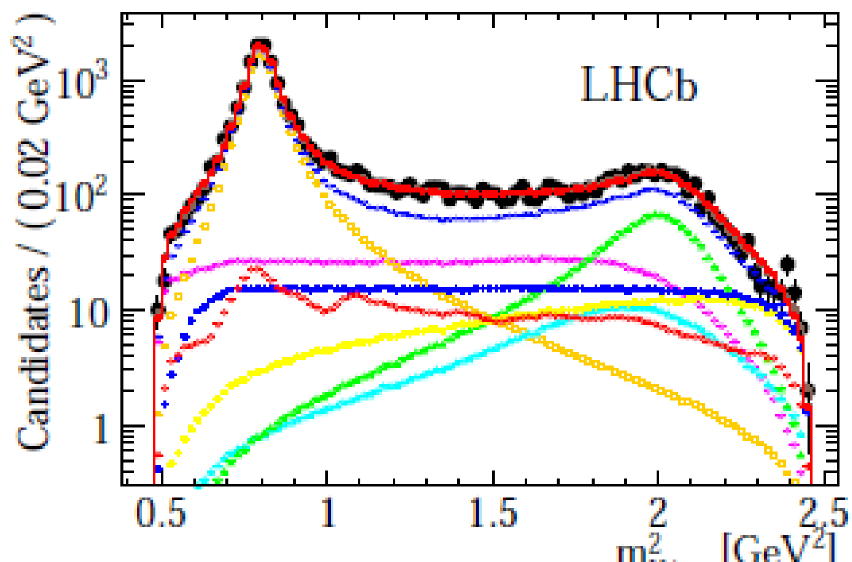
(full 4D fit to both $K^* \to K^- \pi^+$ and $Z \to \psi' \pi^-$ states)

$M = 4475 \pm 7\ ^{+15}_{-25}$ MeV, $\Gamma = 172 \pm 13\ ^{+37}_{-34}$ MeV

J^P is determined unambiguously to be 1^+

⇒ $Z^+(4430)$ appears to be viable exotic tetraquark

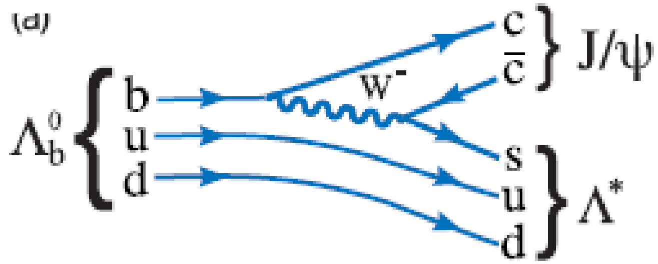


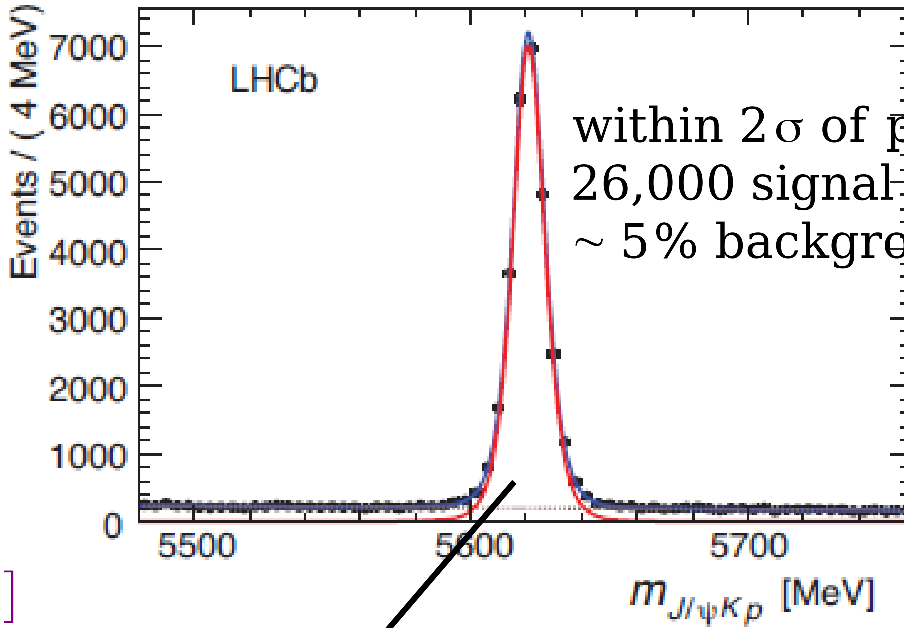


Z^+
$K^*(890)$
total S-wave
$K^*(1410)$
$K^*(1680)$
$K^*_2(1430)$
background

$\Lambda_b \to J/\psi K^- p$

[arXiv:1507.03414]





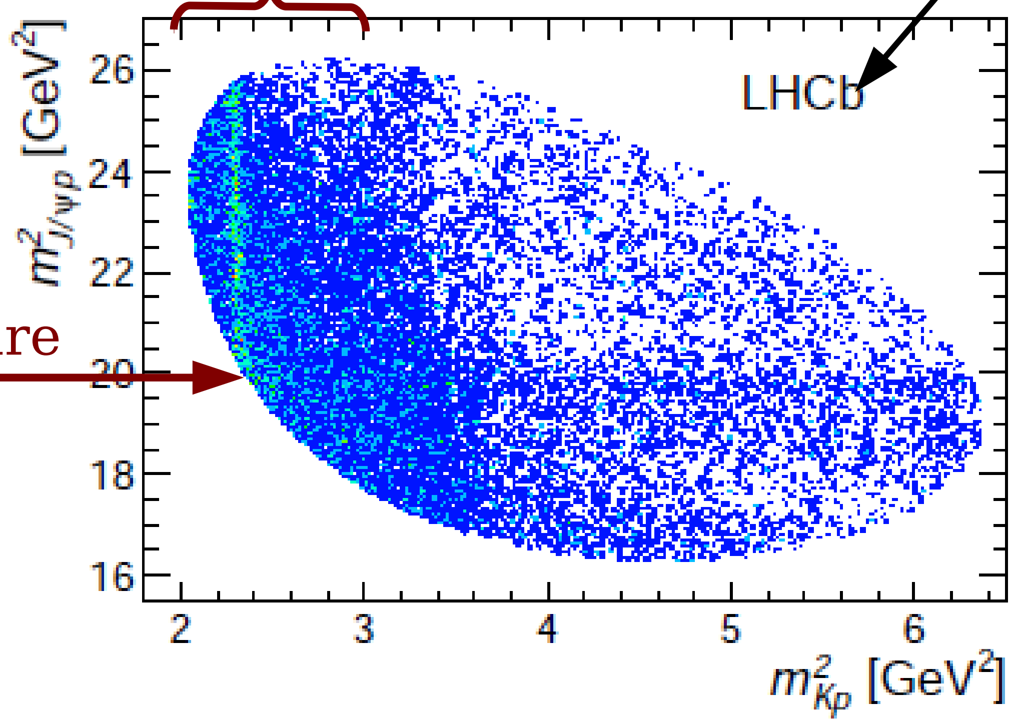
within 2σ of peak
26,000 signal events
~ 5% background

- Large signal found
  → Λ_b lifetime measurement

$\tau_{\Lambda_b} = (1.482 \pm 0.018 \pm 0.012)$ ps

[arXiv:1307.2476]

Λ^*'s



unusual feature

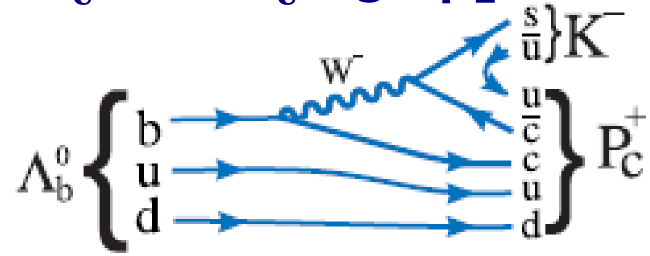
can interferences
between Λ^* resonances
generate a peak in
the $J/\psi p$ mass spectra ?

Observation of $J/\psi\, p$ resonances consistent with pentaquark states in $\Lambda_b^0 \to J/\psi K^- p$ decays

[arXiv:1507.03414]

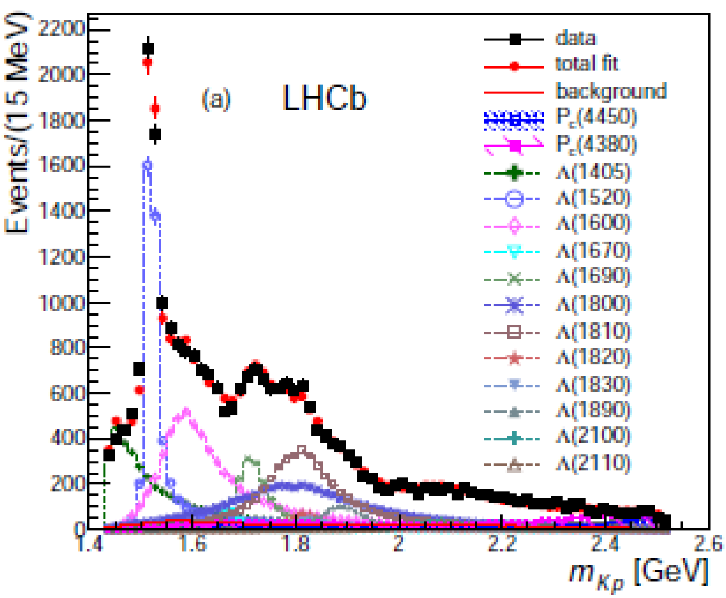
decay amplitude analysis incorporating both decay sequences: $\Lambda_b \to J/\psi\, \Lambda^*$, $\Lambda^* \to K^- p$ and $\Lambda_b \to P_c^+ K^-$, $P_c^+ \to J/\psi\, p$

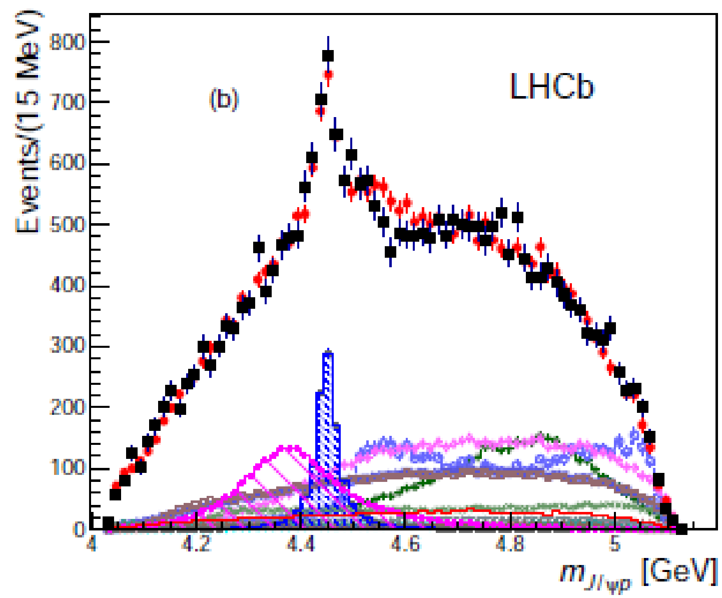
use m(Kp) and 5 decay angles as fit parameters

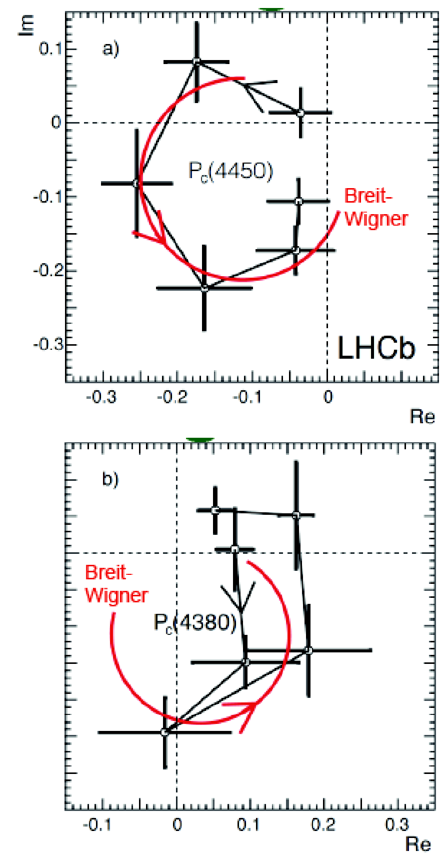


⇒ Best fit with $J^P = (3/2^-, 5/2^+)$

(also $(3/2^+, 5/2^-)$ and $((5/2^+, 3/2^-))$)







Mass (MeV)	Width (MeV)	fit fraction (%)	Σ
4380±8±29	205±18±86	8.4±0.7±4.2	9σ
4449.8±1.7±2.5	39±5±19	4.1±0.5±1.1	12σ

Summary

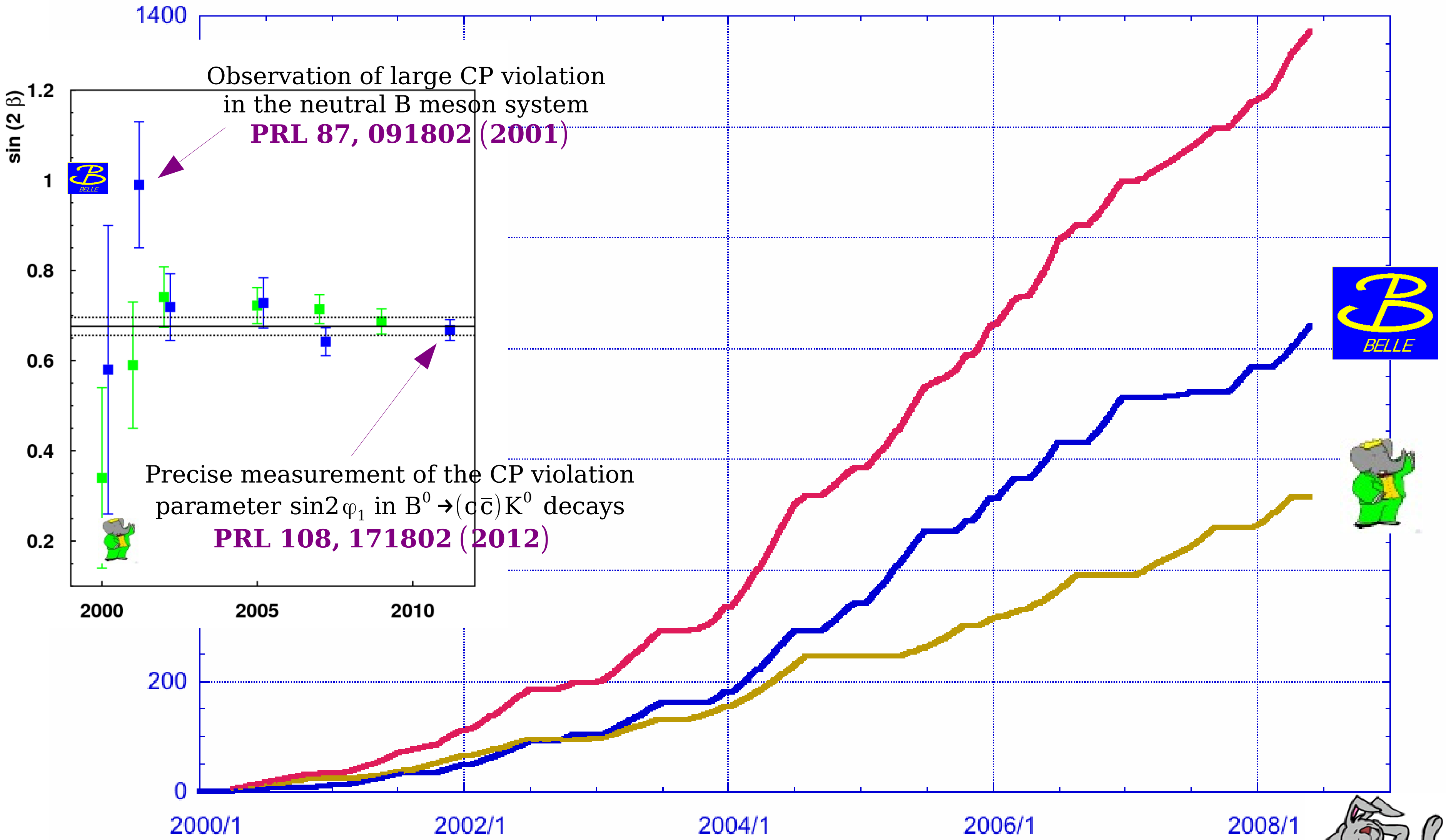
- Few results on CP violation and rare decays in B sector covered in this talk… but much more in B decays, also in charm, charmonium, bottomonium, light Higgs, τ, kaon sectors…
- Almost all analyses of LHCb run I ($3\ fb^{-1}$) completed…
- Definitely not only complementary, but competion between (super) B-factories and LHCb:
  - for the expected: results on $B_{(s)} \to \mu\mu$, $B \to K^* \mu\mu$, $B_s \to J/\psi\varphi$, γ angle…
  - for the less expected: results on $|V_{ub}|$, $D^* \tau \nu$…

2000 - 2010 decade : B-factories era

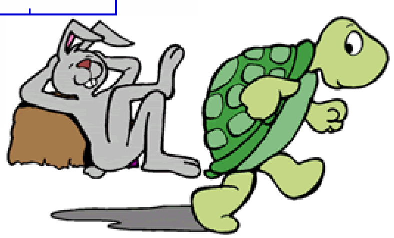
$\Rightarrow$ experiments designed for β extraction !

Luminosity (fb^{-1})

cumulated stat: **>1.4 ab^{-1} !!**



$\Rightarrow$ competition is good... (for us)



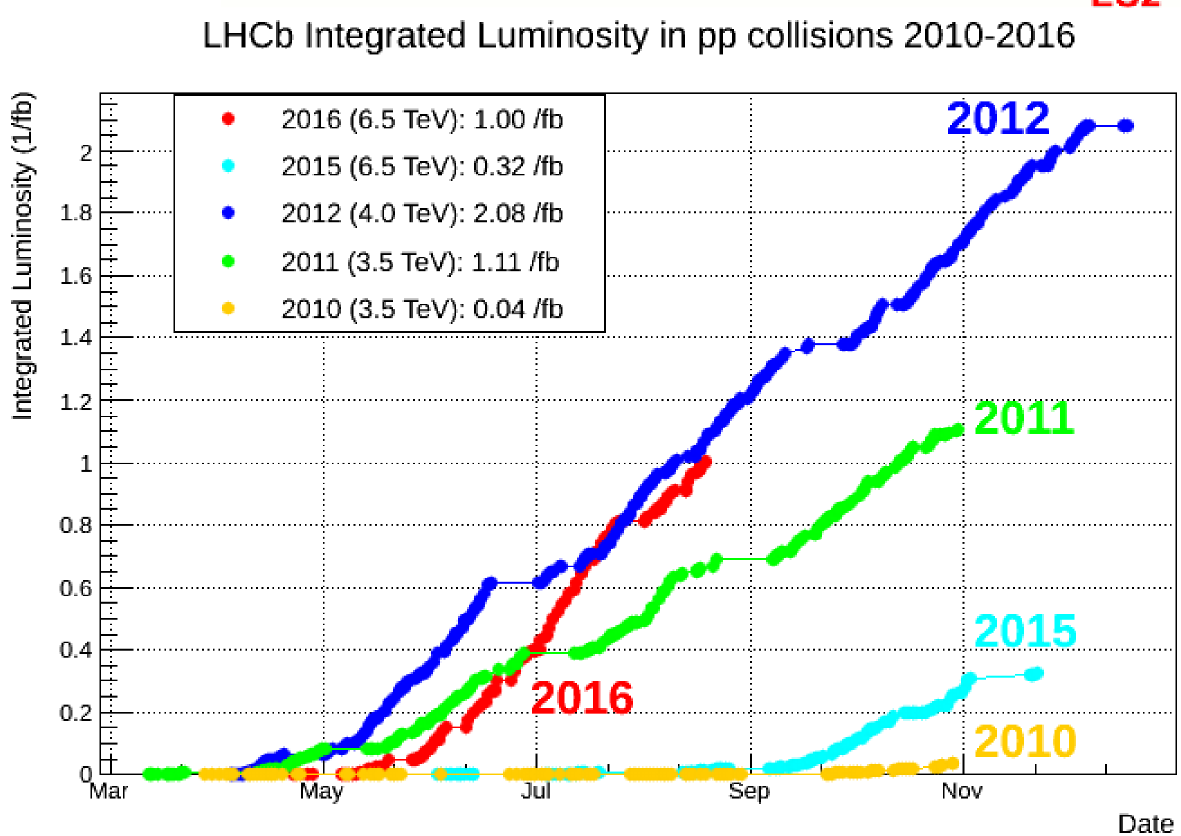
2010 - 2020 decade : LHCb era

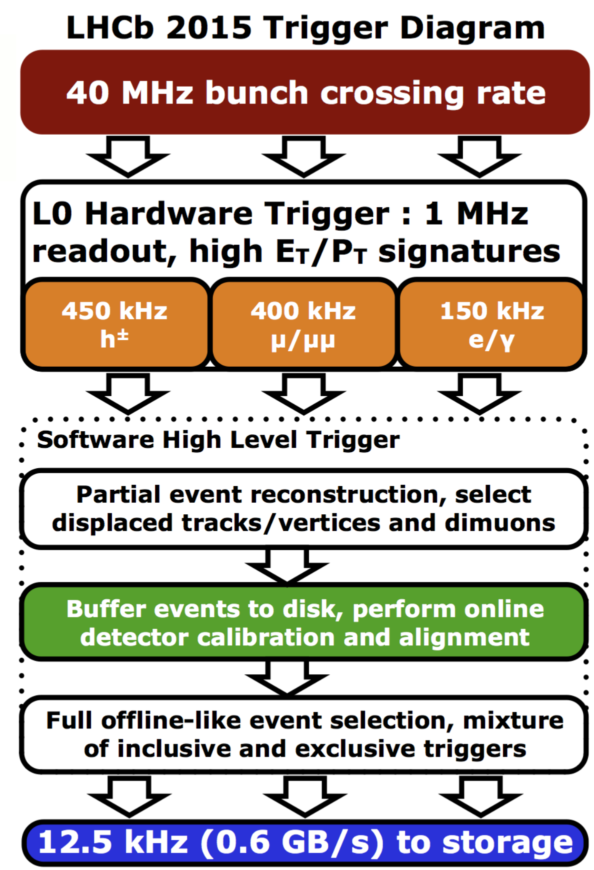
LHC era

Run (years)	Run 1 (2010-2012)	Run 2 (2015-2018)
Integrated luminosity	3 fb^{-1}	8 fb^{-1}
Instantaneous luminosity	4 x 10^{32} cm^{-2}s^{-1}	

Current LHCb

LS2





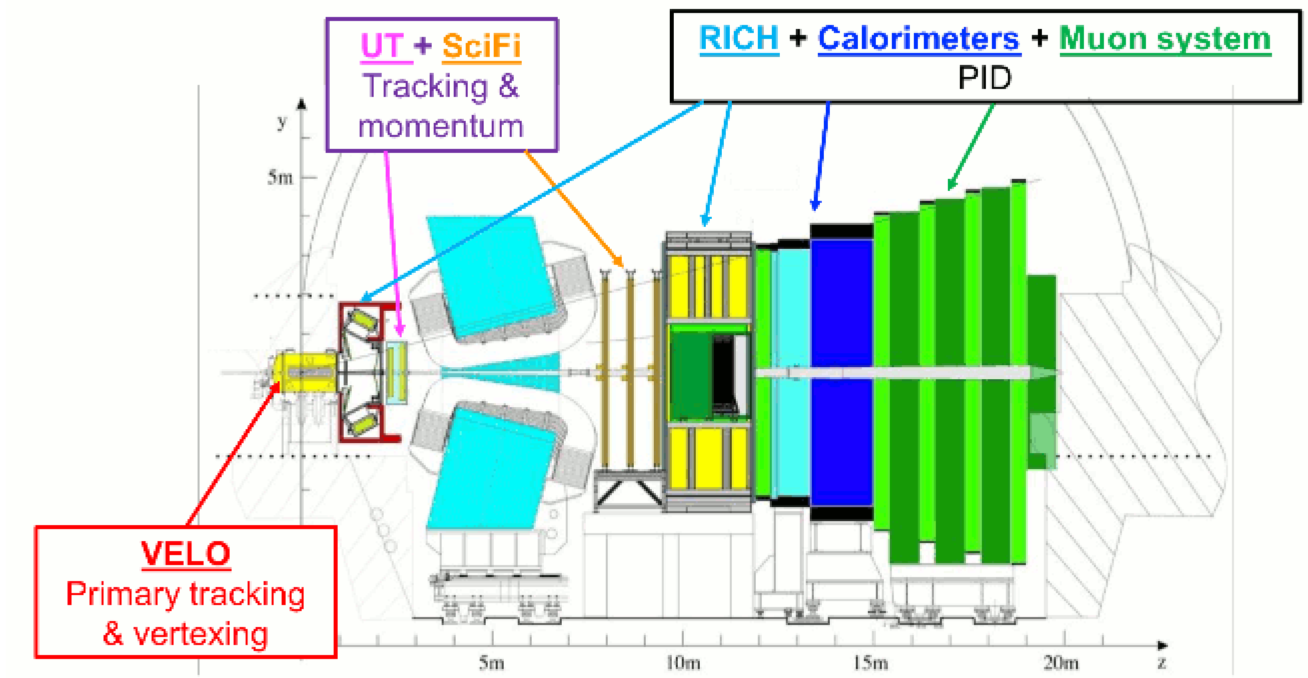
2020 - 2030 decade : LHCb-Belle II era ?

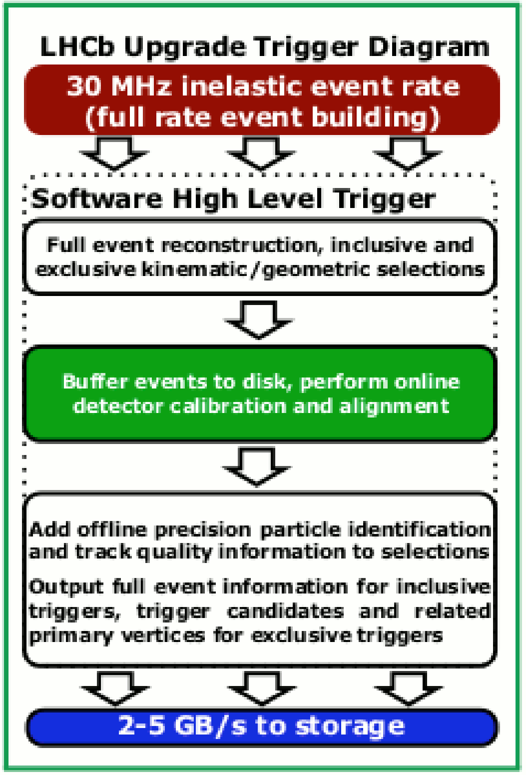
LHC era — HL-LHC era

Run (years)	Run 1 (2010-2012)	Run 2 (2015-2018)	Run 3 (2021-2023)	Run 4 (2027-2029)
Integrated luminosity	3 fb^{-1}	8 fb^{-1}	25 fb^{-1}	50 fb^{-1}
Instantaneous luminosity	4 x 10^{32} cm^{-2}s^{-1}		2 x 10^{33} cm^{-2}s^{-1}	

Current LHCb — Upgraded LHCb

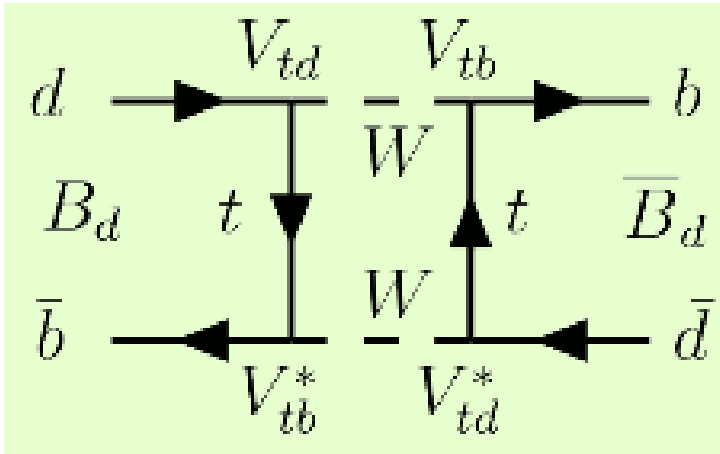
LS2
LHCb Upgrade

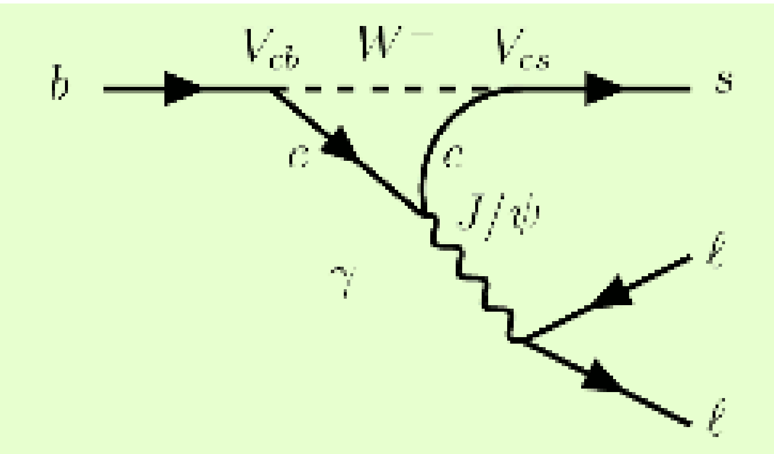




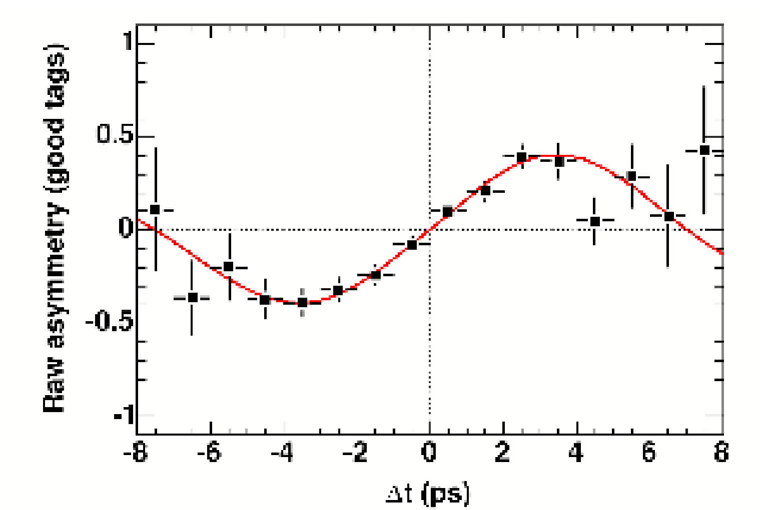
Mixing-induced CP violation

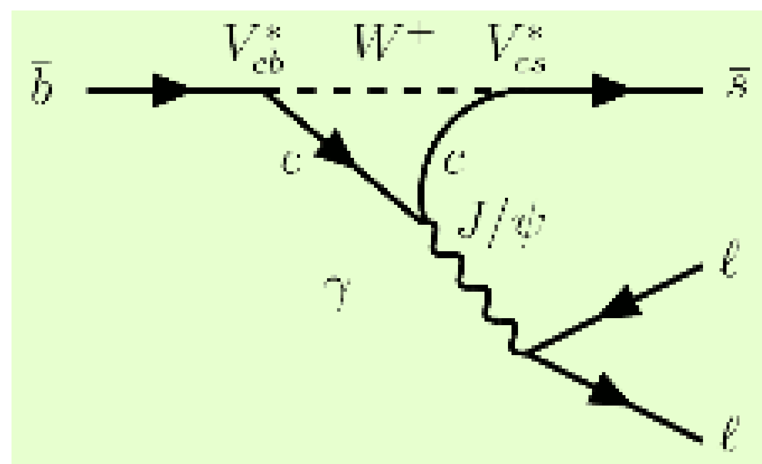
Remember $B^0 \to J/\psi\, K_S^0$:





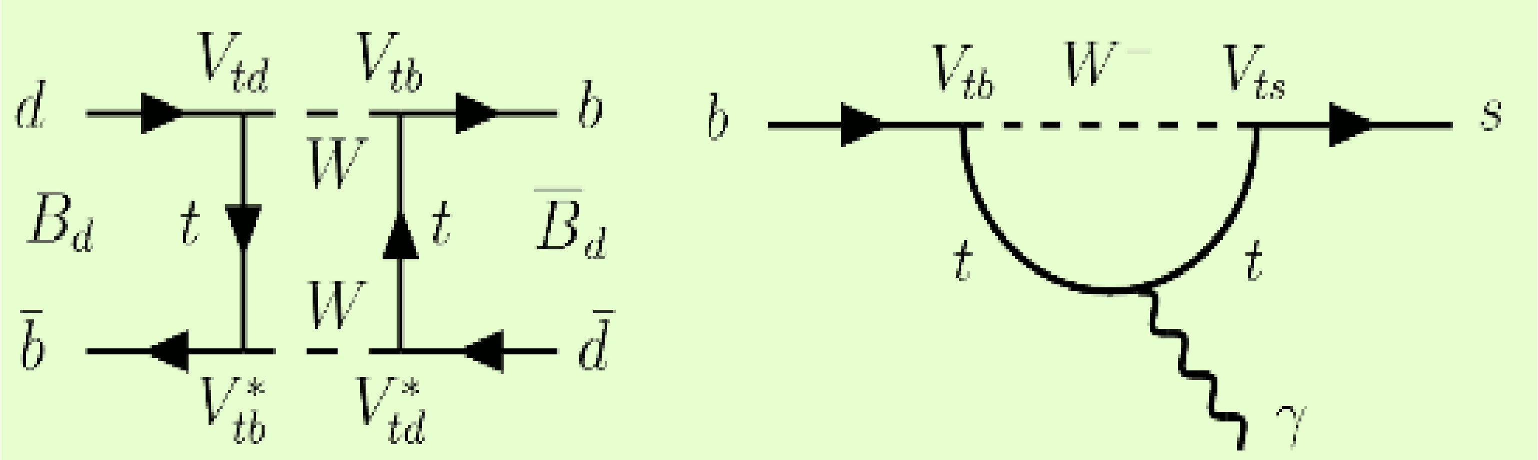
Interferes with



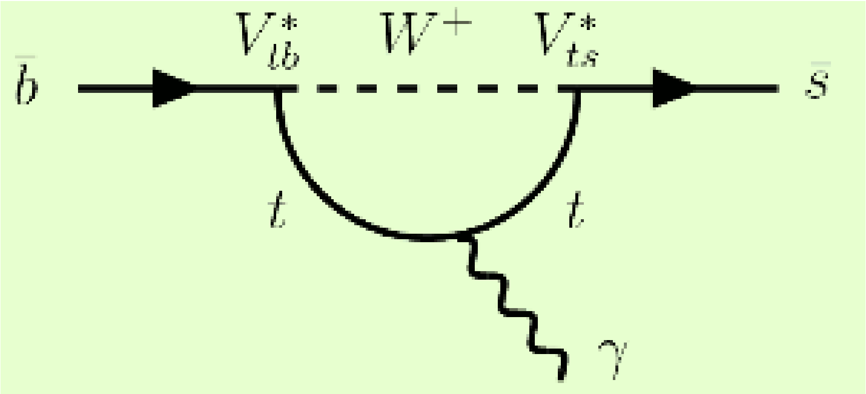


Mixing-induced CP violation

What about $B^0 \to \gamma K_S^0 \pi^0$?



Interferes with right handed component of



In SM mainly $B^0 \to K_S^0 \pi^0 \gamma_R$ and $\overline{B}^0 \to K_S^0 \pi^0 \gamma_L$

$K_S^0 \pi^0 \gamma$ behaves like an effective flavor eigenstate, and mixing-induced CP violation is expected to be small $S \sim -2(m_s/m_b)\sin(2\phi_1)$

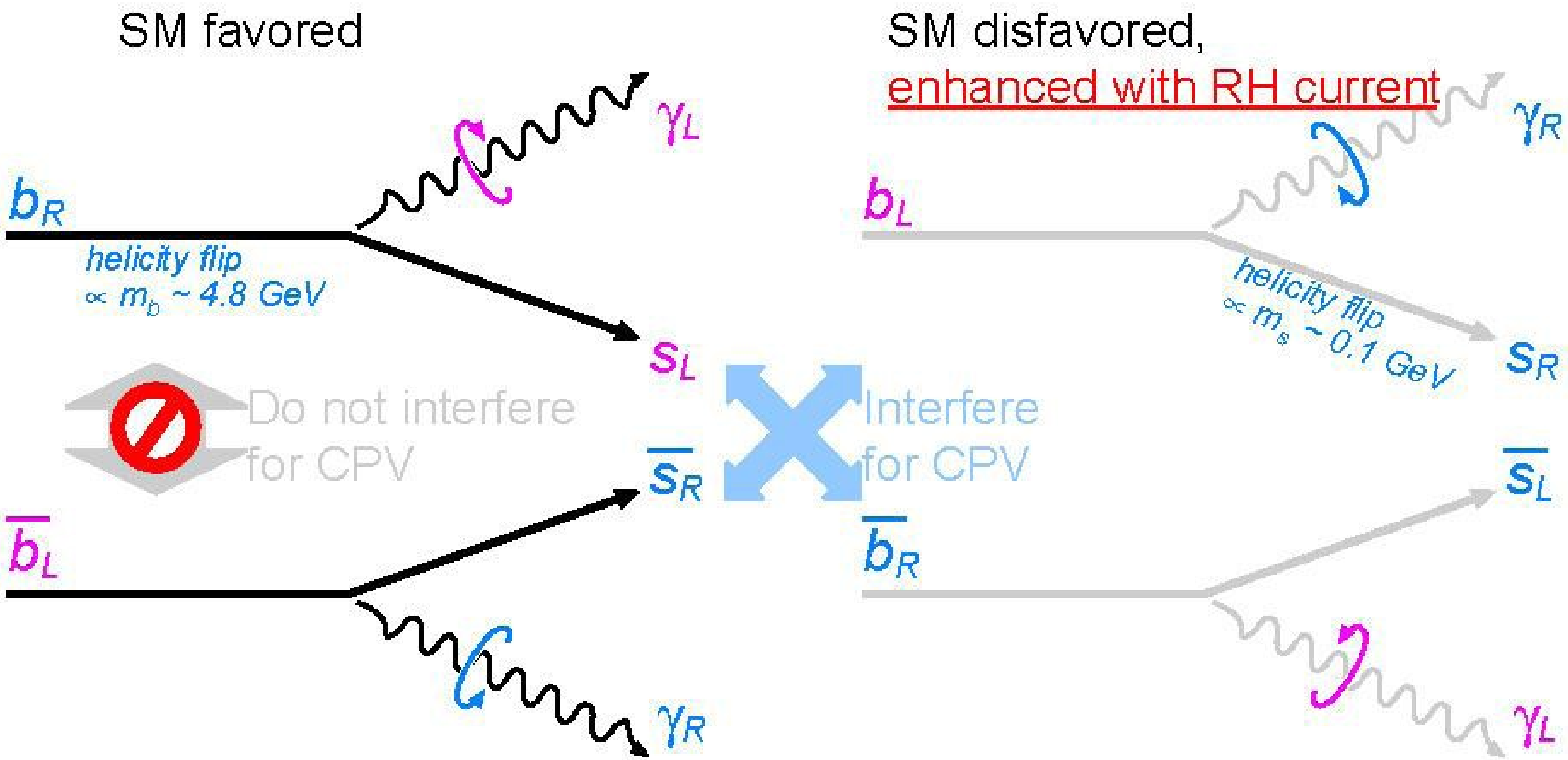
$B \to K^*(K^0_S \pi^0)\gamma$

time−dependent decays rate of $B \to f_{CP}\gamma$

S and A: CP violating parameters

In SM, the photon from $b \to s\gamma$ is (mostly) lefthanded (polarized).

$\Rightarrow$ Mixing induced (time-dependent) CPV does not occur in $B \to f_{CP}\gamma$



$$\text{SM:}\ \ S_{CP}^{K^*\gamma} \sim -(2m_s/m_b)\sin 2\beta \sim -0.04$$

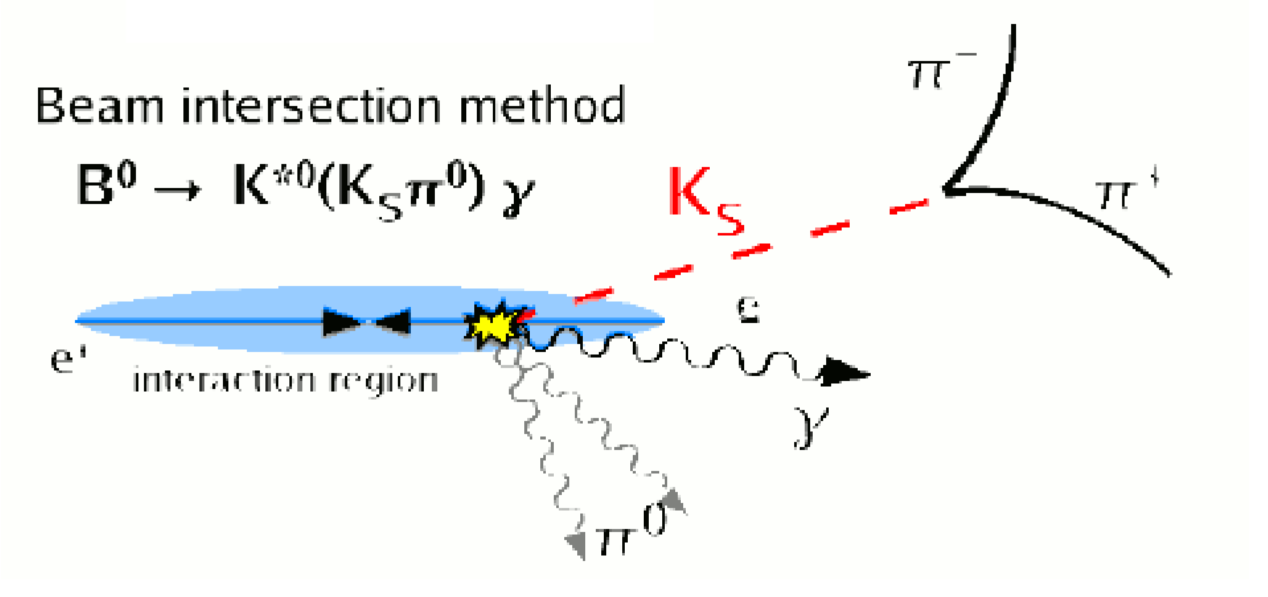
$$\text{Left-Right Symmetric Models:}\ S_{CP}^{K^*\gamma} \sim 0.5$$

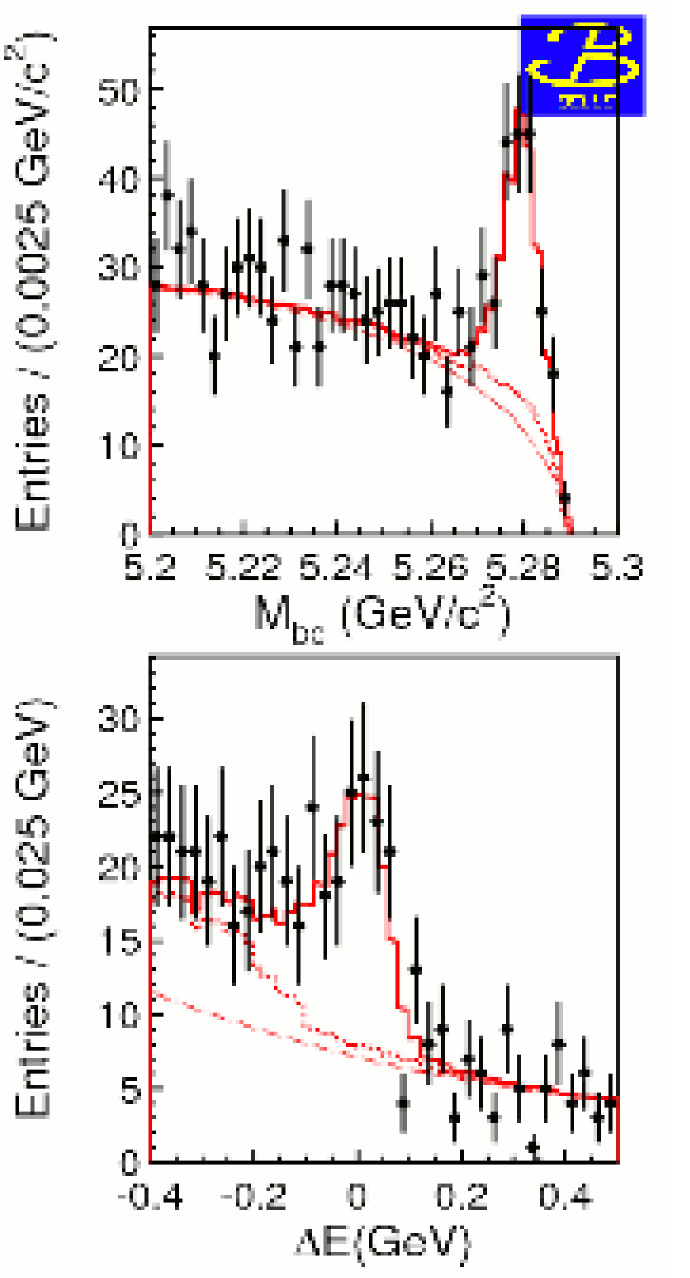
[D. Atwood et al, PRL 79, 185 (1997)]

CP violation in $B \to K^{*}\gamma$

Aim to measure the time-dependent CP asymmetry in $B \to K^{*}(K^{0}_{S}\pi^{0})\gamma$

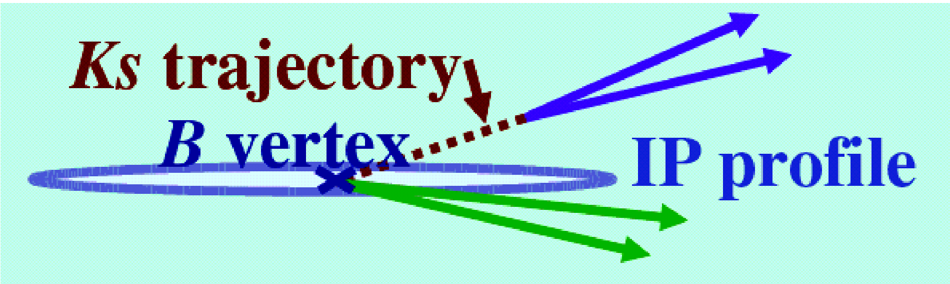
- Select $B^{0} \to K^{*}\gamma$ events with $K^{*} \to K^{0}_{S}\pi^{0}$ and $K^{0}_{S} \to \pi^{+}\pi^{-}$
- Get rid of $B^{0} \to K^{*}\pi^{0}$ background
- Measure time by intersecting the K^{0}_{S} with the beam line

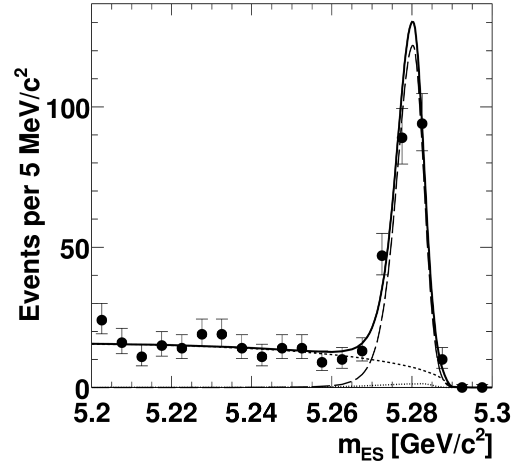


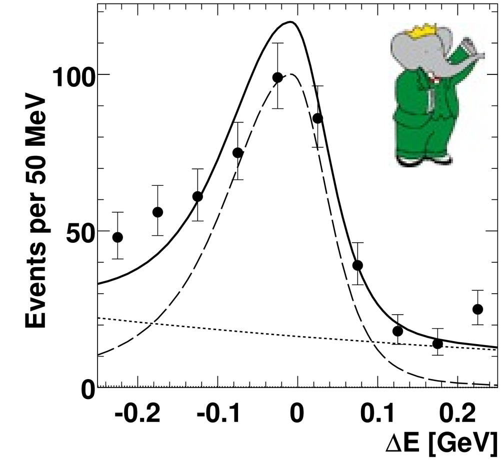


$B \rightarrow K^*(K^0_S \pi^0)\gamma$

time-dependent CPV







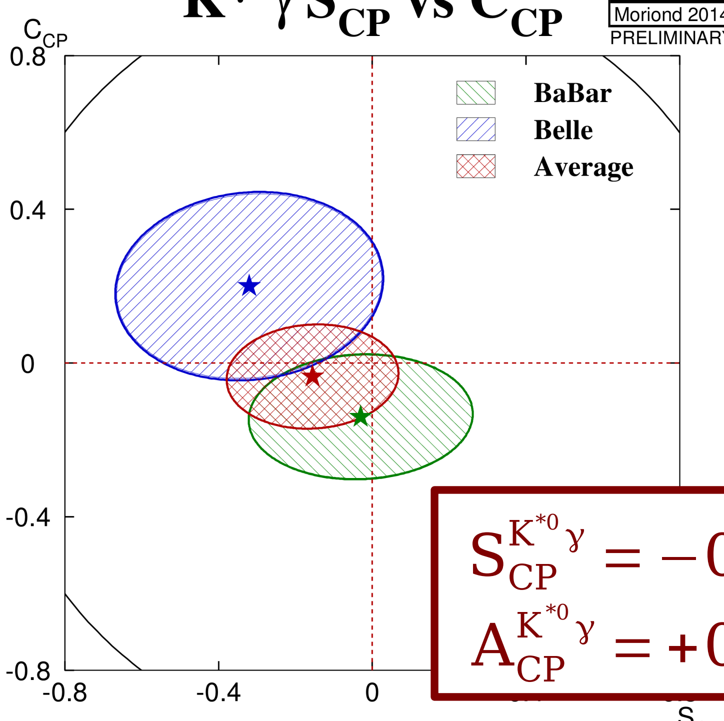
control sample is $J/\psi K^0_S$!!

[467 MBB]
[arXiv:0807.3103]

[535 MBB]
[hep-ex/0608017]

$K^*\gamma$ S_{CP} vs C_{CP}

HFAG Moriond 2014 PRELIMINARY



Contours give $-2\Delta(\ln L) = \Delta\chi^2 = 1$, corresponding to 60.7% CL for 2 dof

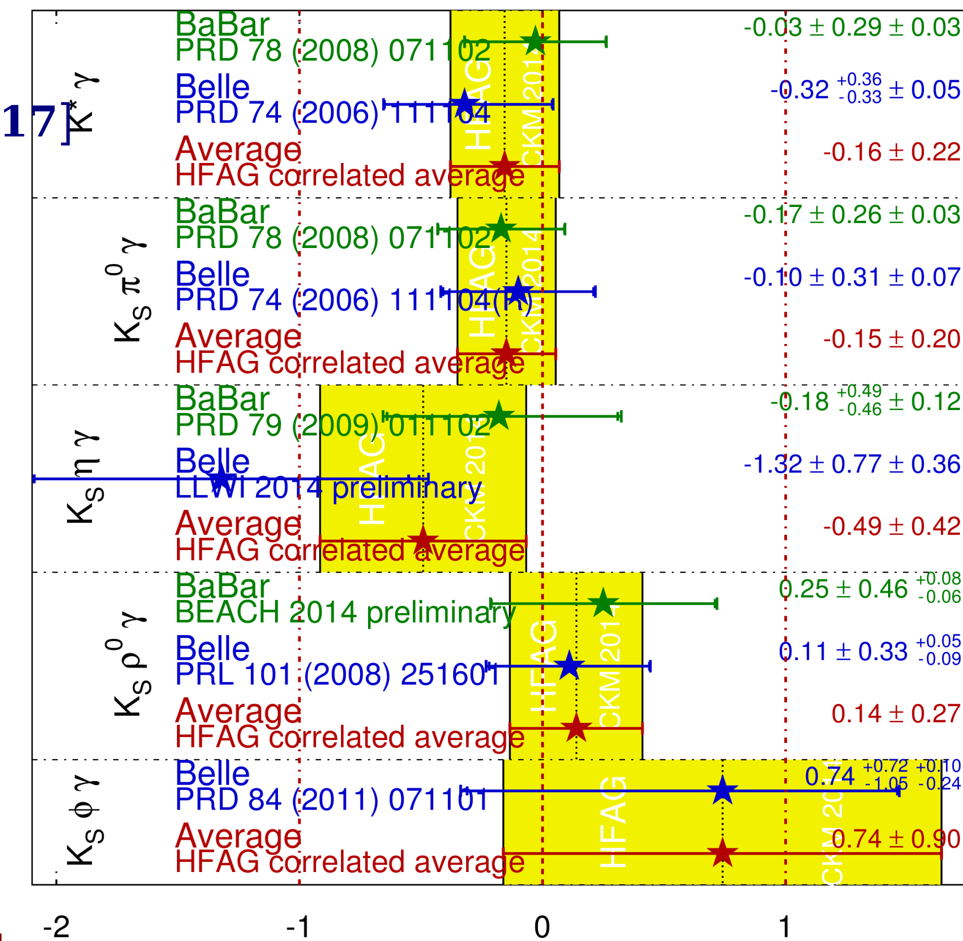
$$S_{CP}^{K^{*0}\gamma} = -0.16 \pm 0.22$$

$$A_{CP}^{K^{*0}\gamma} = +0.04 \pm 0.14$$

HFAG

$b \rightarrow s\gamma$ S_{CP}

HFAG CKM 2014 PRELIMINARY



$B \to D^{(*)} K^{(*)}$ Dalitz analysis

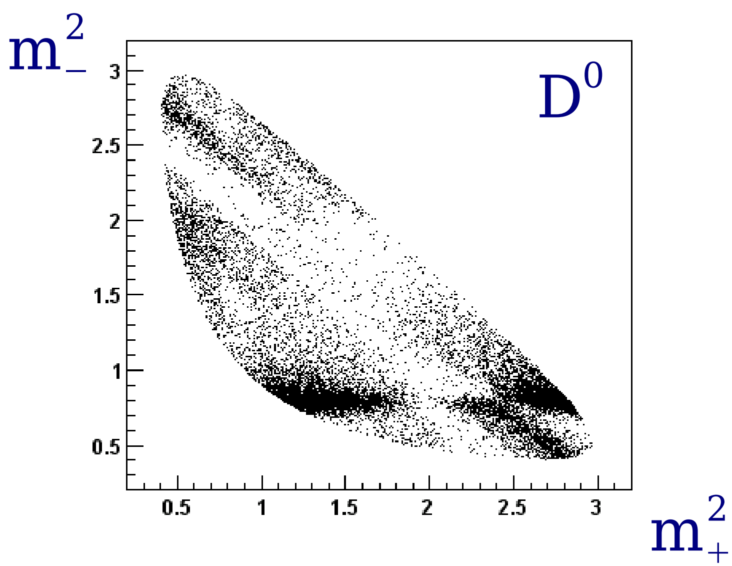
Reconstruction of three−body final states $D^0, \overline{D}^0 \to K_S \pi^+ \pi^-$

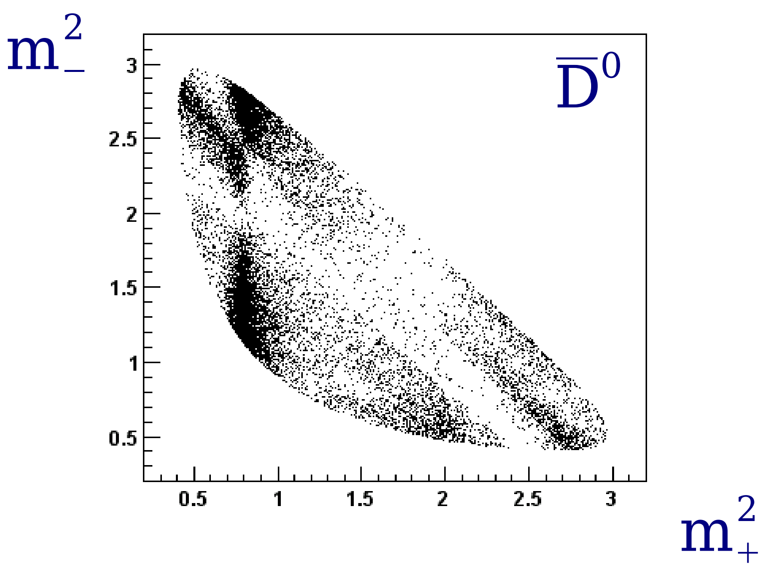
Amplitude for each Dalitz point is described as:

$$\overline{D}^0 \to K_S \pi^+ \pi^- \sim f(m_+^2, m_-^2)$$
$$D^0 \to K_S \pi^+ \pi^- \sim f(m_-^2, m_+^2)$$

$$B^+ \to (K_S \pi^+ \pi^-)_D K^+ : f(m_+^2, m_-^2) + r_B e^{i(\delta_B + \gamma)} f(m_-^2, m_+^2)$$

$m_- = M(K_S \pi^-)$
$m_+ = M(K_S \pi^+)$





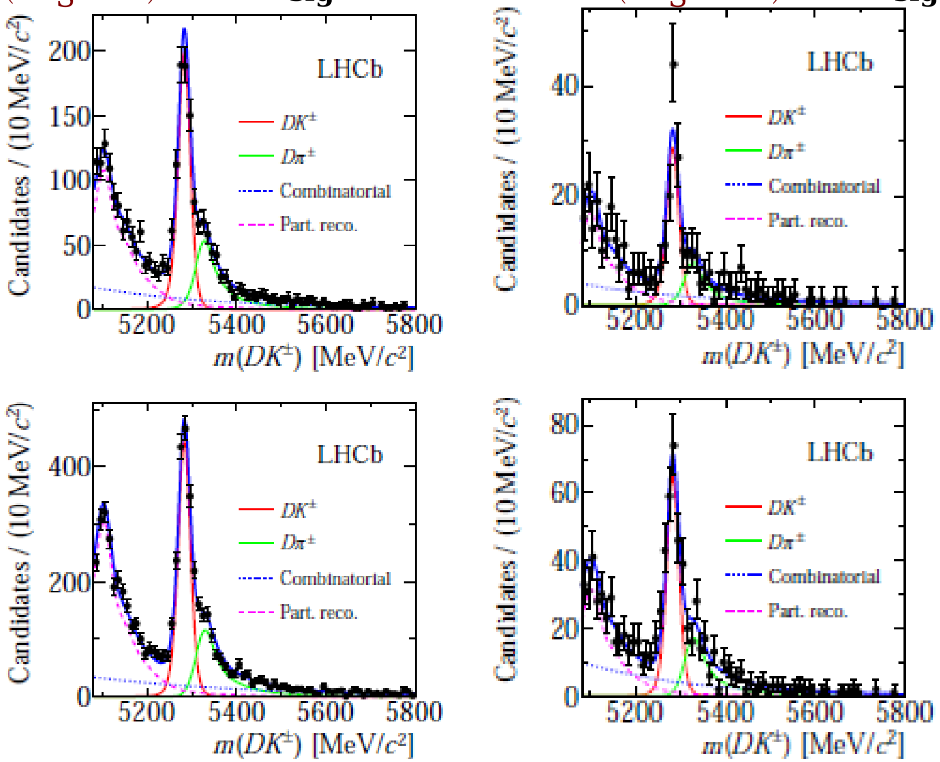
$$B^- \to (K_S \pi^+ \pi^-)_D K^- : f(m_-^2, m_+^2) + r_B e^{i(\delta - \gamma)} f(m_+^2, m_-^2)$$

Simultaneous fit of B^+ and B^- to extract parameters r_B, γ and δ_B

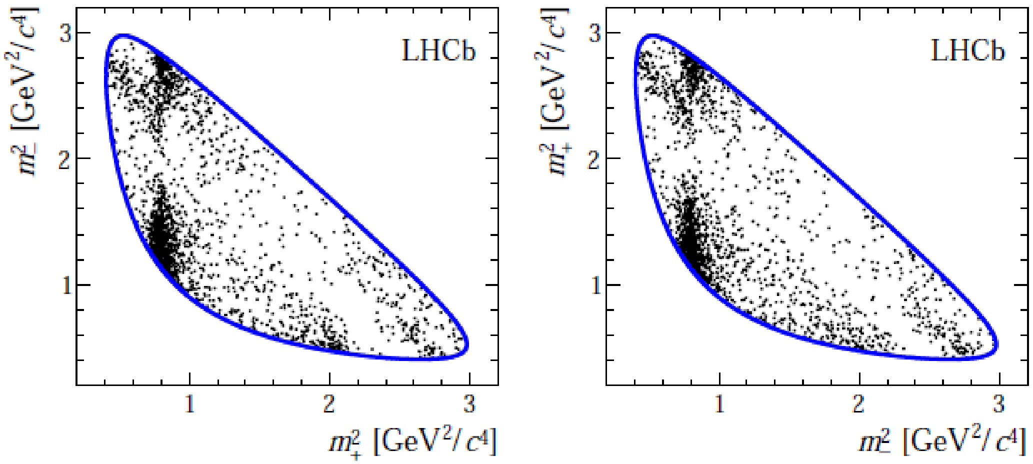
Note: 2 fold ambiguity on γ: $(\gamma, \delta_B) \to (\gamma + \pi, \delta_B + \pi)$

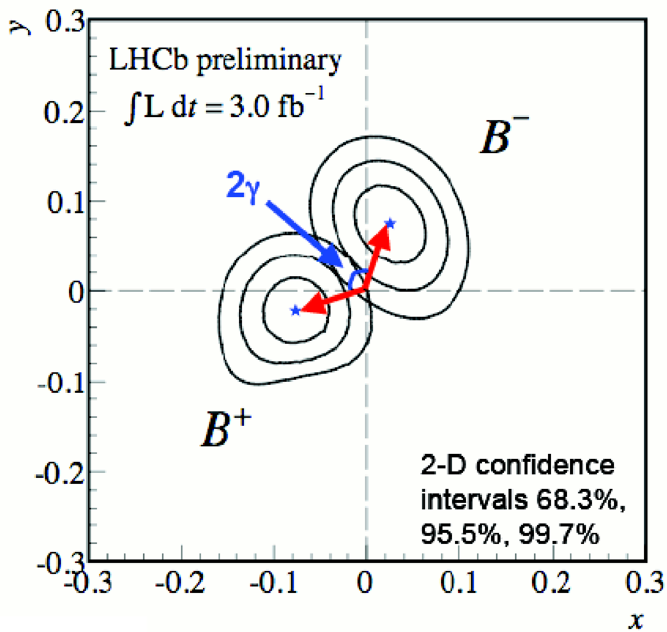
GGSZ LHCb Results [arXiv:1408.2748]

$D(K_S\pi\pi)K$ $\mathbf{N_{sig} \sim 2260}$ $D(K_S KK)K$ $\mathbf{N_{sig} \sim 324}$



$D(K_S\pi\pi)K$





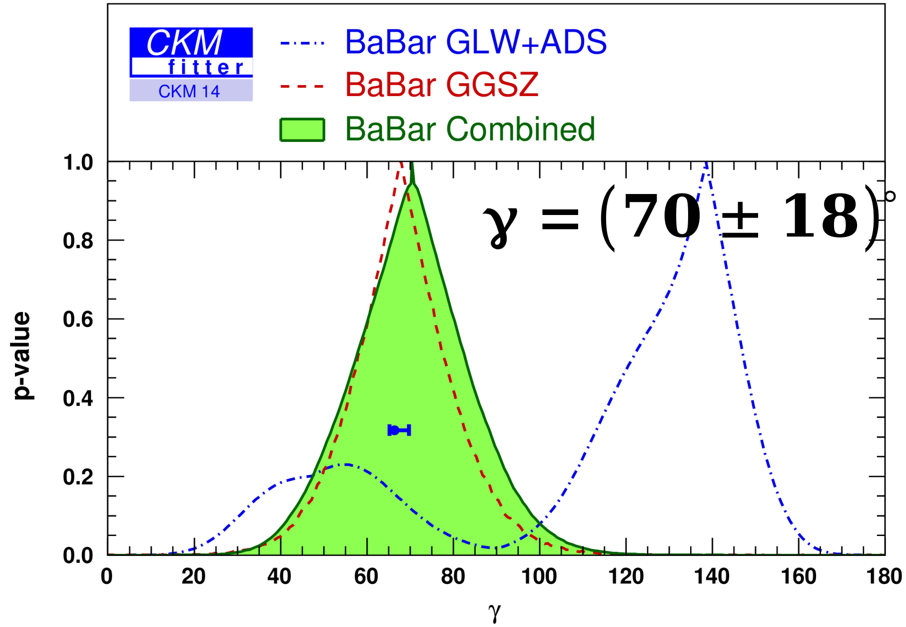
cartesian coordinates

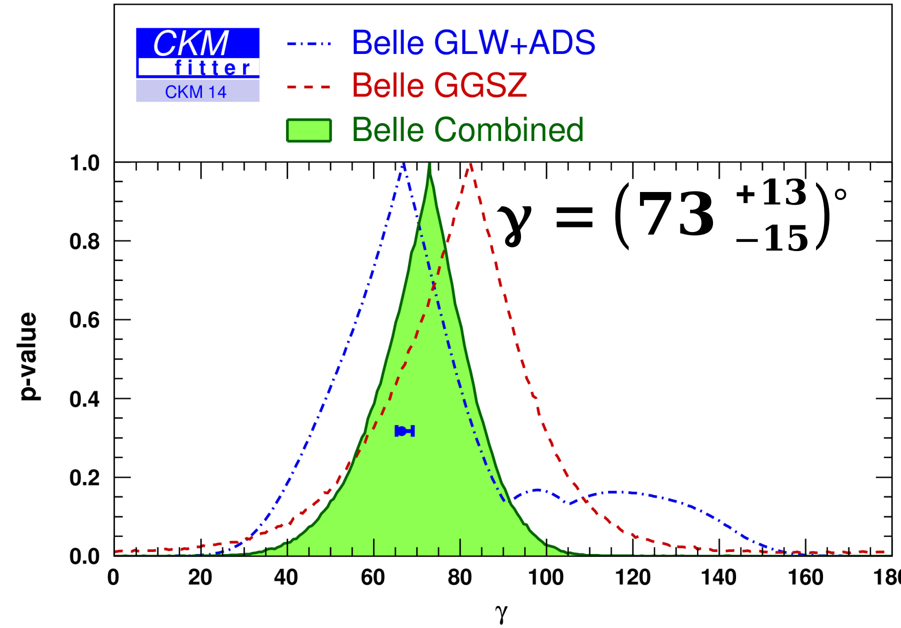
$$x^{\pm} = r_B \cos(\delta_B \pm \gamma)$$
$$y^{\pm} = r_B \sin(\delta_B \pm \gamma)$$

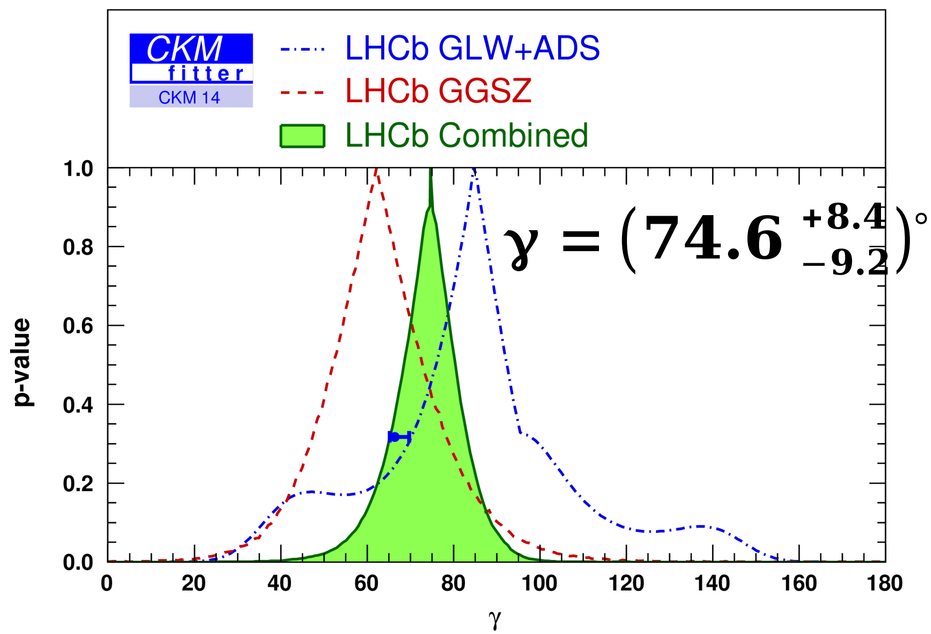
⇒

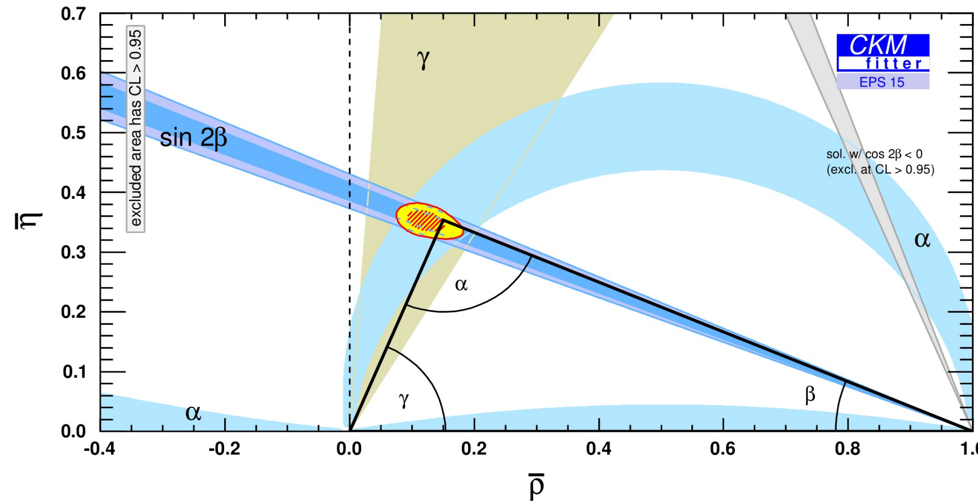
$$\gamma = (62^{+15}_{-14})^{\circ}$$
$$r_B = (8.0^{+1.9}_{-2.1}) \times 10^{-2}$$
$$\delta_B = (134^{+14}_{-15})^{\circ}$$

Experiment by experiment









long way to go ... (→ $\sigma_\gamma = 1^\circ$ or less)

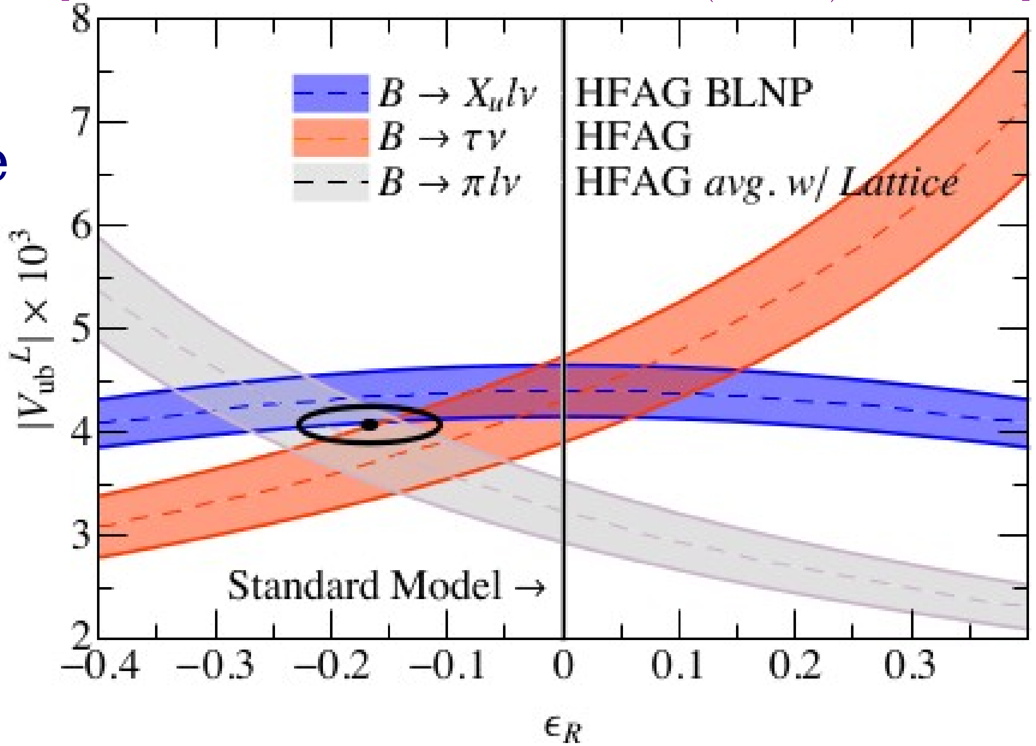
Could it be due to new physics ?

- $B \to \pi l \nu$ is a purely vector current, whereas $B \to X_u l \nu$ is V−A
- Adding right-handed current (V+A), increases vector current but decreases axial-vector current

[F.Bernlochner et al, PRD 90 (2014) 094003]

A negative right-handed current can reduce tension between those two results

Decay	$\|V_{ub}\| \times 10^3$	ϵ_R dependence
$B \to \pi \ell \bar{\nu}$	3.23 ± 0.30	$1 + \epsilon_R$
$B \to X_u \ell \bar{\nu}$	4.39 ± 0.21	$\sqrt{1 + \epsilon_R^2}$
$B \to \tau \bar{\nu}_\tau$	4.32 ± 0.42	$1 - \epsilon_R$



New measurements neeeded, with different approaches also