Beautiful paths to probe physics beyond the standard model of particles

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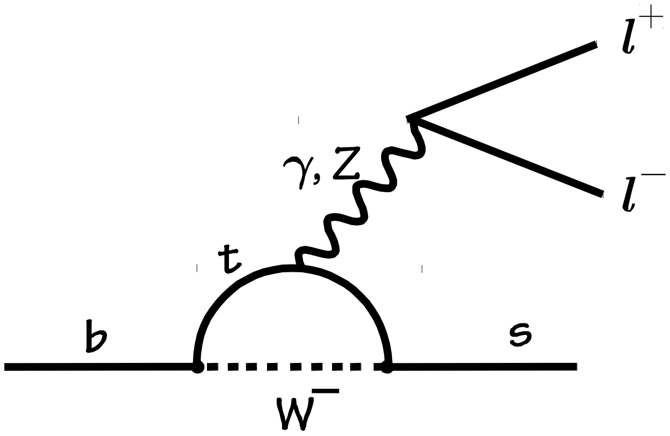
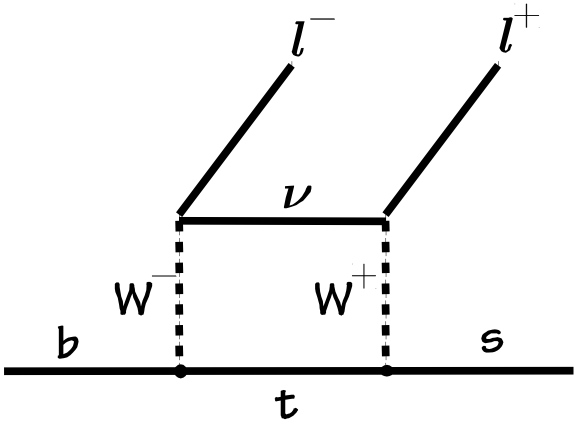
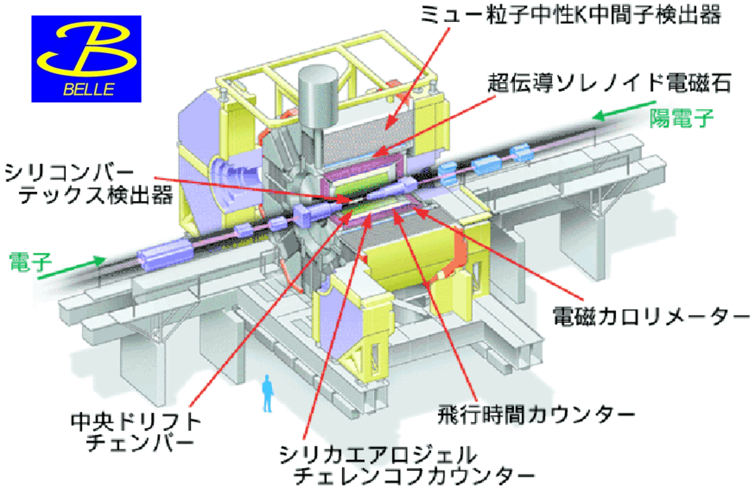
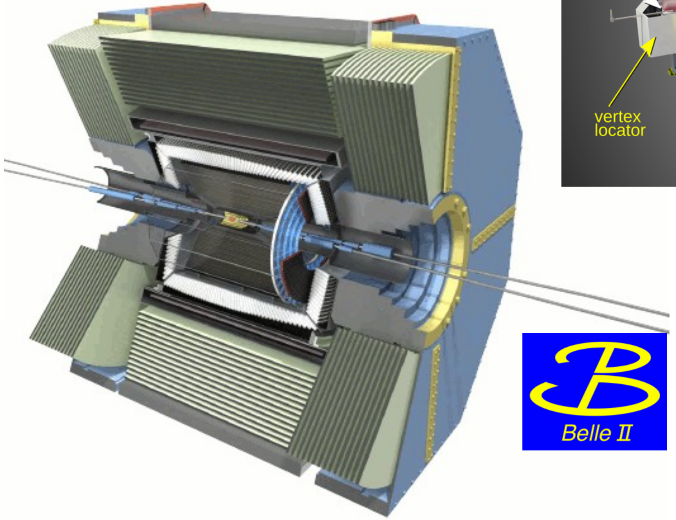
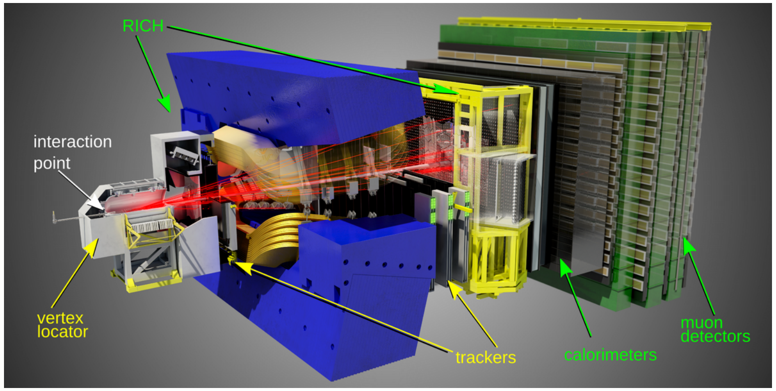




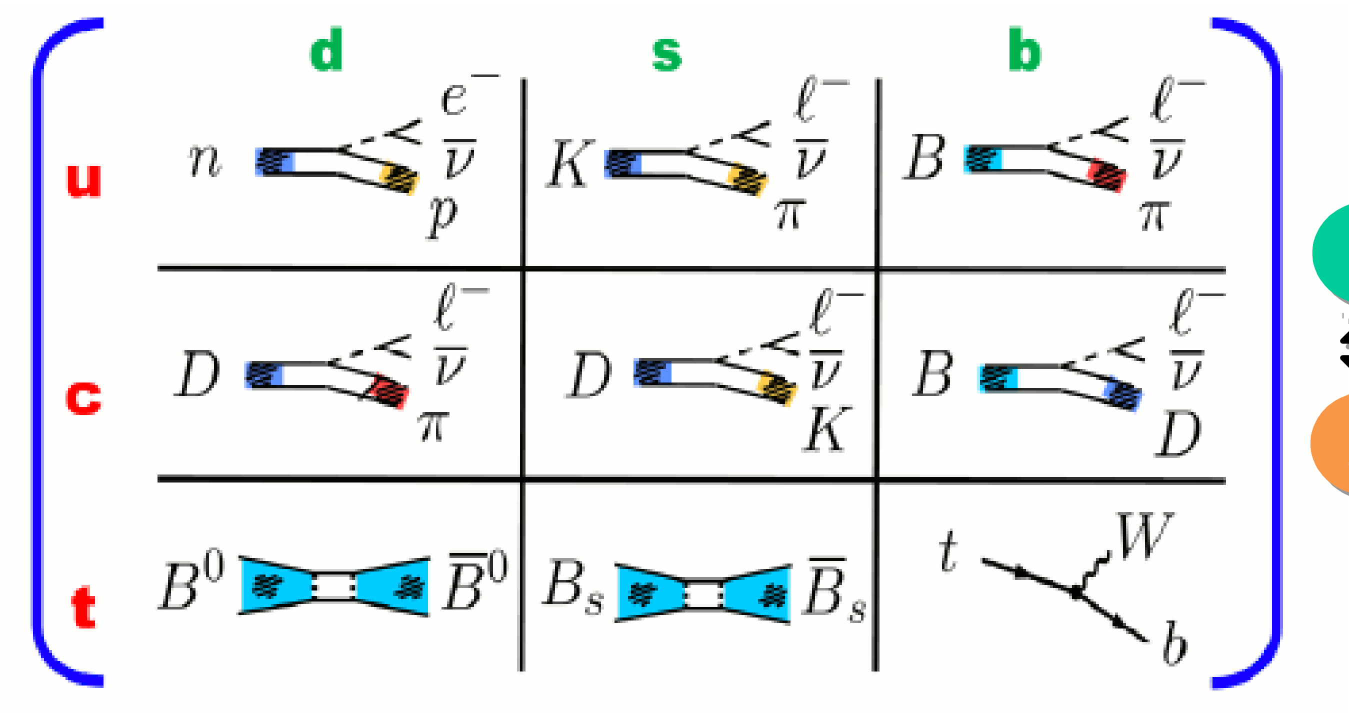


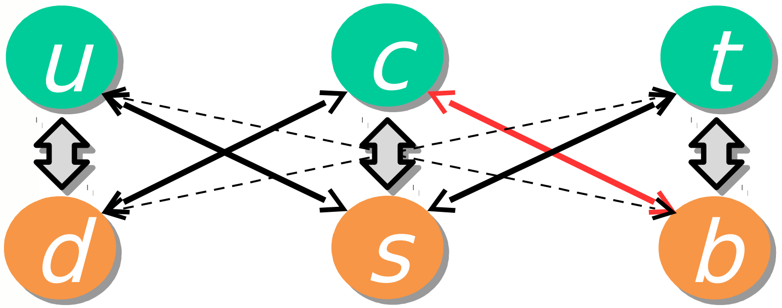




Jennifer school, Trieste, August 3rd 2018

Semileptonic and leptonic

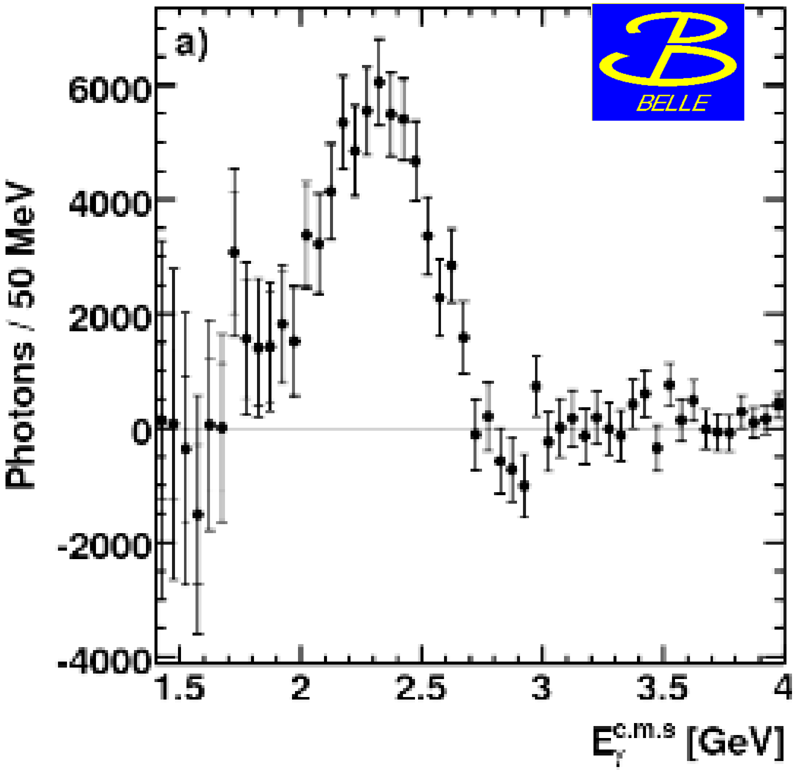


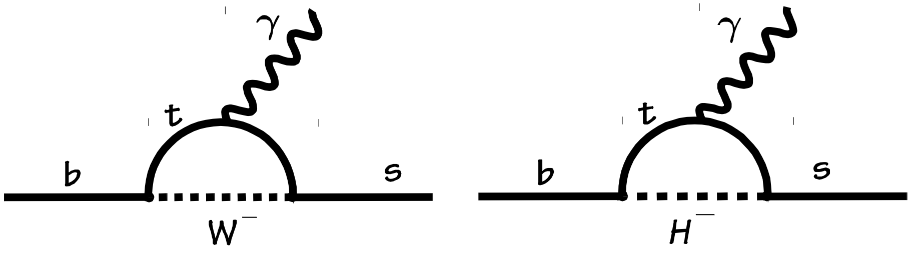


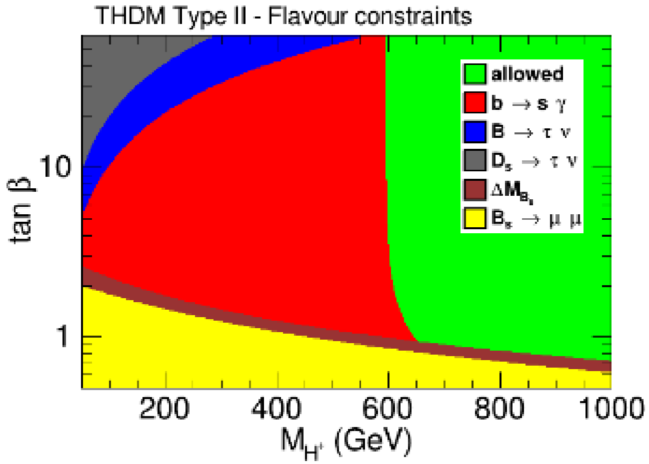
	Process	Obser.	Theory	Discovery (ab^{-1})	Sys. limit (ab^{-1})	vs LHCb BESIII	vs Belle	Anomaly	NP
🟡	$B \to \pi l \nu_l$	$\|V_{ub}\|$	⋆⋆⋆	-	10	⋆⋆⋆	⋆⋆⋆	⋆⋆	⋆
🟡	$B \to X_u l \nu_l$	$\|V_{ub}\|$	⋆⋆	-	2	⋆⋆⋆	⋆⋆	⋆⋆⋆	⋆
🟡	$B \to \tau \nu$	$Br.$	⋆⋆⋆	2	50	⋆⋆⋆	⋆⋆⋆	⋆	⋆⋆⋆
🟡	$B \to \mu \nu$	$Br.$	⋆⋆⋆	5	50	⋆⋆⋆	⋆⋆⋆	⋆	⋆⋆⋆
🟡	$B \to D^{(*)} l \nu_l$	$\|V_{cb}\|$	⋆⋆⋆	-	1	⋆⋆⋆	⋆	⋆	
🟡	$B \to X_c l \nu_l$	$\|V_{cb}\|$	⋆⋆⋆	-	1	⋆⋆	⋆⋆	⋆⋆	⋆⋆
🟡	$B \to D^{(*)} \tau \nu_\tau$	$R(D^{(*)})$	⋆⋆⋆	-	5	⋆⋆	⋆⋆⋆	⋆⋆⋆	⋆⋆⋆
⚪	$B \to D^{(*)} \tau \nu_\tau$	P_τ	⋆⋆⋆	-	15	⋆⋆⋆	⋆⋆⋆	⋆⋆	⋆⋆⋆
⚪	$B \to D^{**} l \nu_l$	$\|V_{cb}\|$	⋆	-	-	⋆⋆	⋆⋆⋆	⋆⋆	

Recent rare B decays results

$b \to s\gamma$

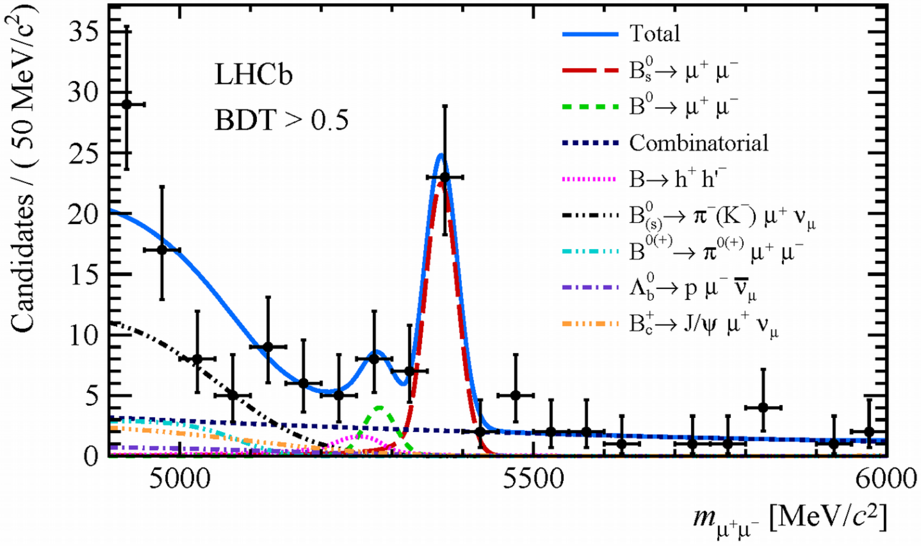






arXiv:1706.07414]

$B_s \to \mu\mu$



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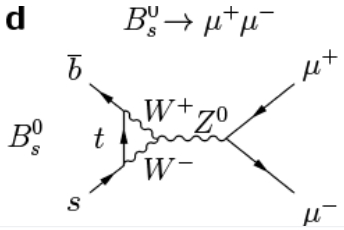
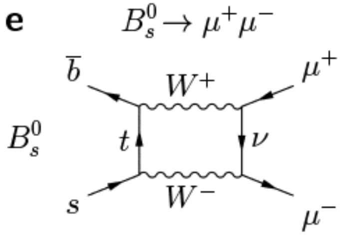
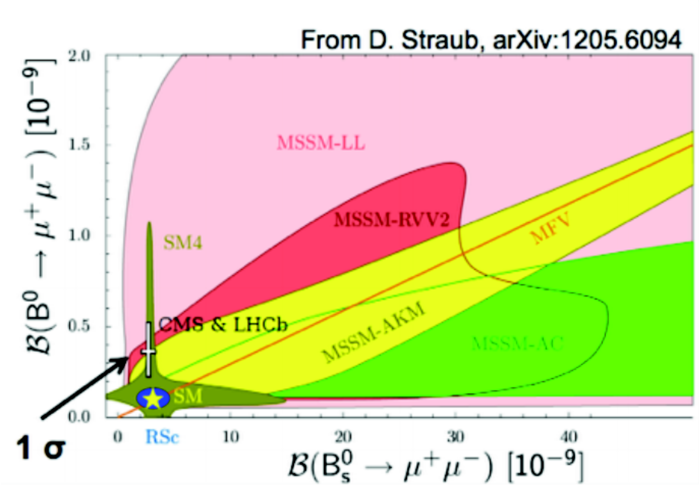


e





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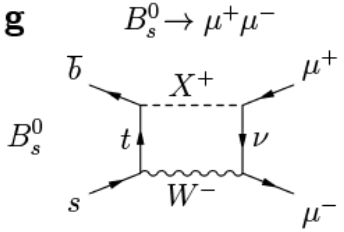
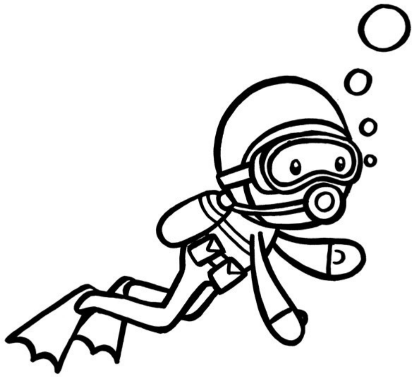
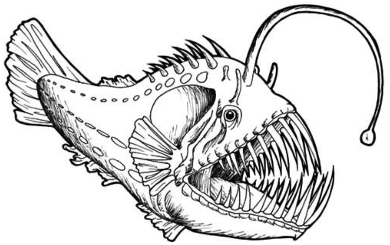
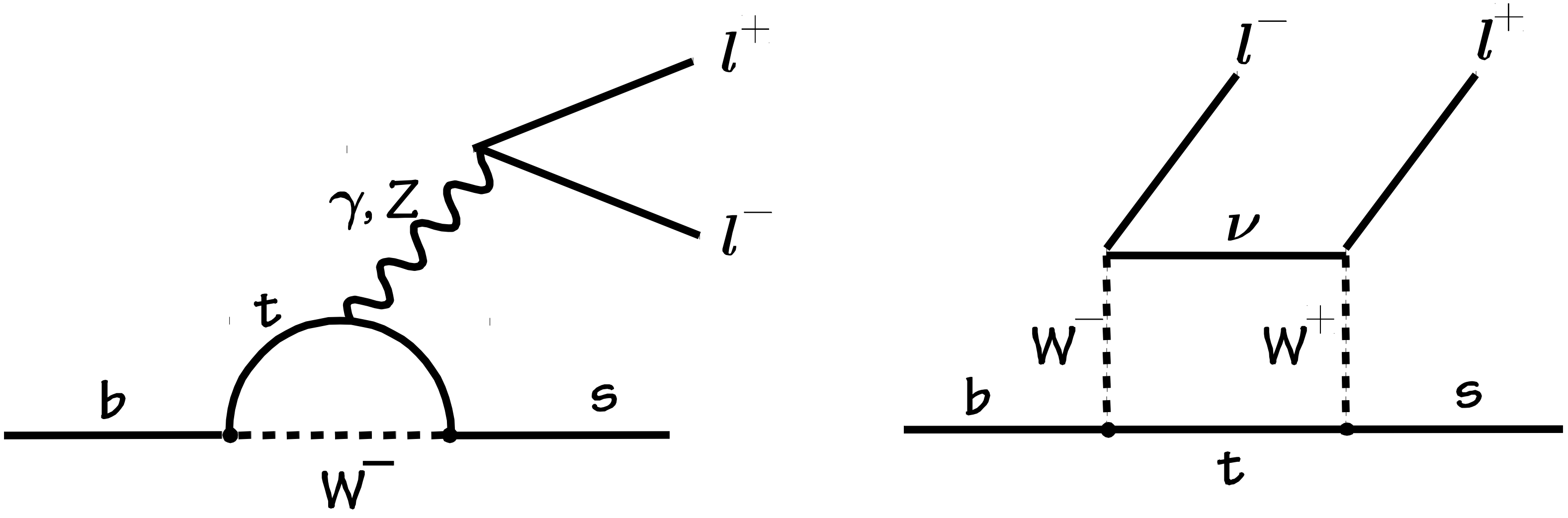






$b \to s l^+ l^-$



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

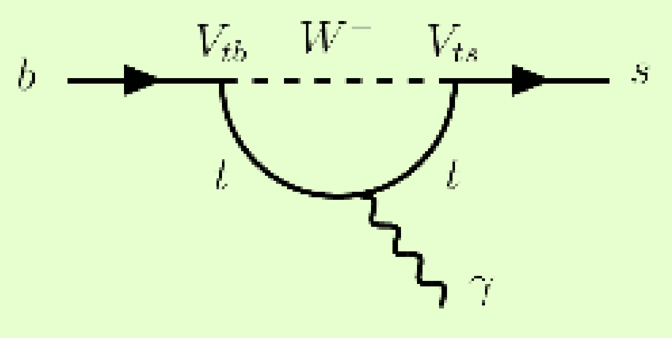
Amplitudes from
- electromagnetic penguin: C_7
- vector electroweak: C_9
- axial-vector electroweak: C_{10}

may interfere
w/ contributions from NP

Many observables:
- Branching fractions
- Isospin asymmetry (A_I), Lepton forward-backward asymmetry (A_{FB}), CP asymmetry…
- and much more…

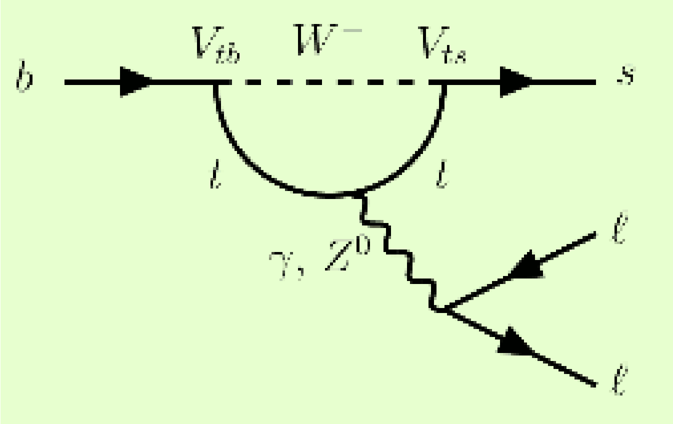
⇒ Exclusive ($B \to K^{(*)} l^+ l^-$), Inclusive ($B \to X_s l^+ l^-$)

b→lls



- Start with b→s γ

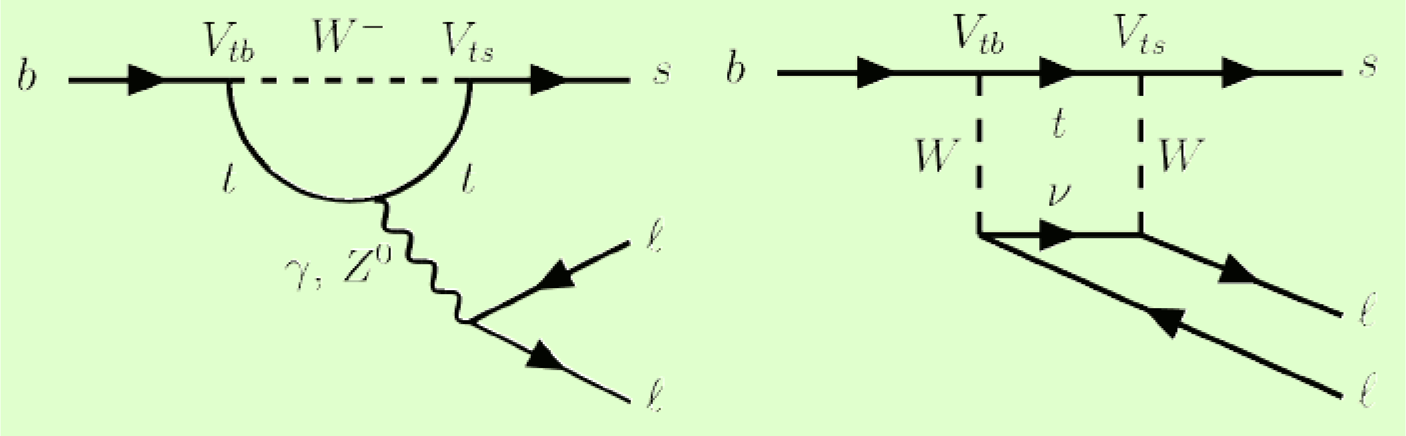
b→lls



- Start with b→sγ, pay a factor $\alpha_{EM} = \frac{1}{137}$

  → Decay the γ into 2 leptons

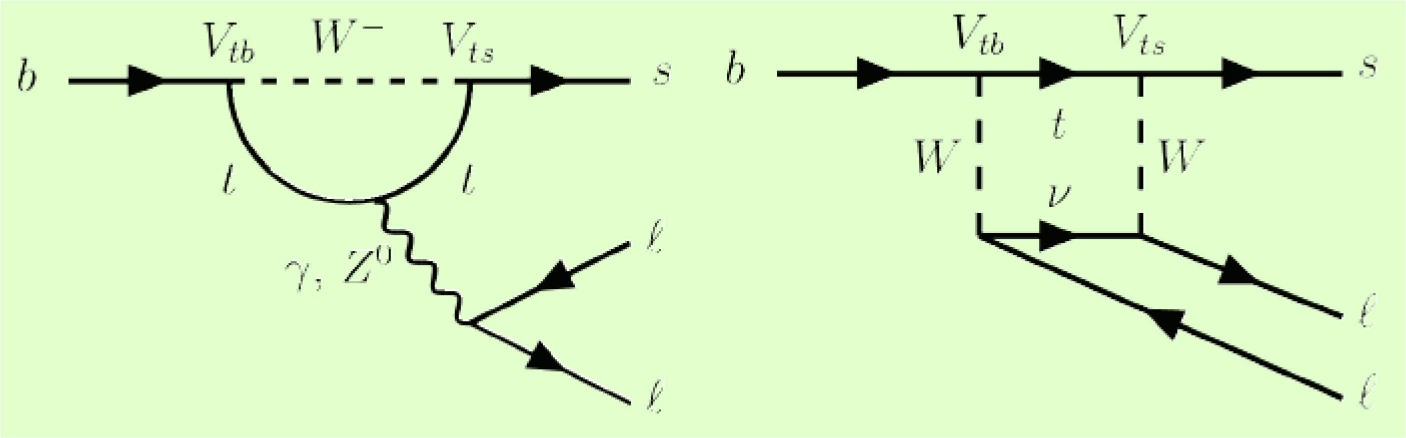
b→lls



- Start with b→sγ, pay a factor α_{EM}
  - → Decay the γ into 2 leptons
  - Add an interfering box diagram
  - → b→lls, very rare in the SM

$\mathcal{B}(B \to llK^*) = (3.3 \pm 1.0) \,.\, 10^{-6}$

b→lls



- Start with b→sγ, pay a factor α_{EM}
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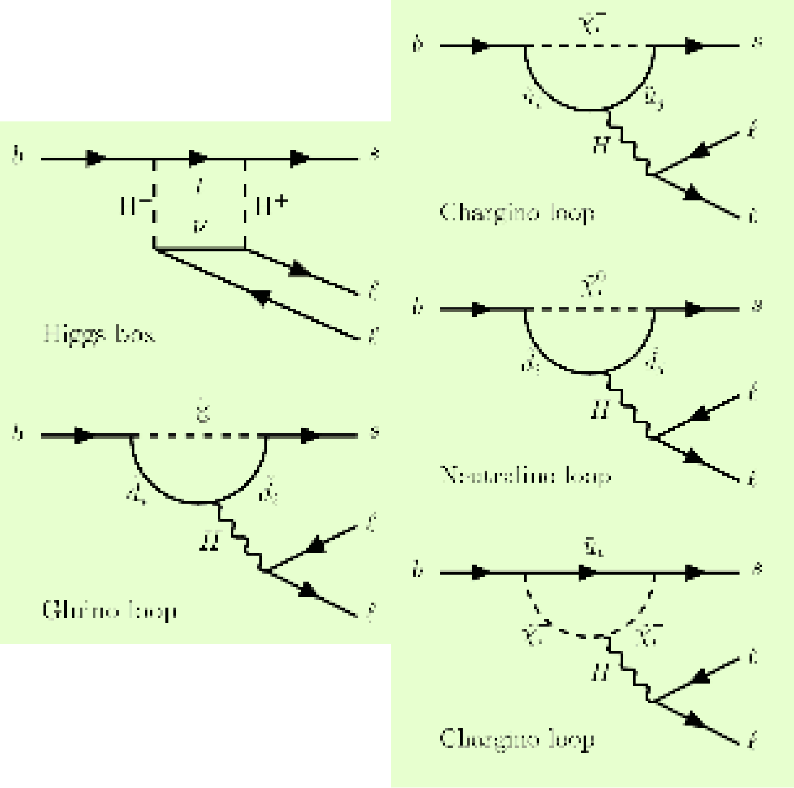
  - → b→lls, very rare in the SM

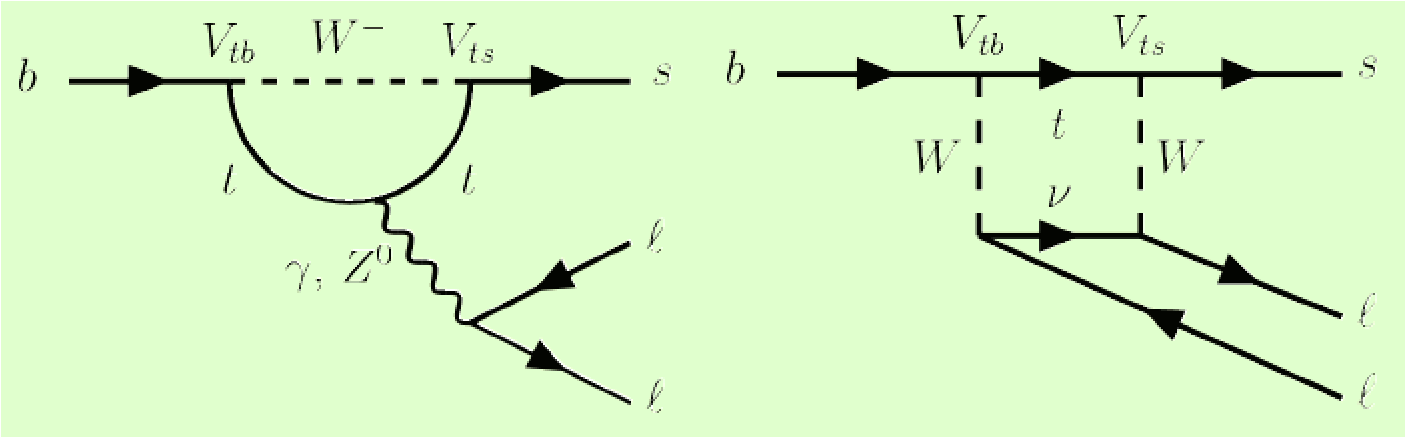
    $B(B\to llK^*) = (3.3 \pm 1.0)\,.\,10^{-6}$

- Sensitive to Supersymmetry, Any 2HDM, Fourth generation, Extra dimensions, Axions…

- Ideal place to look for new physics



b→lls



- Start with b→sγ, pay a factor α_{EM}
  - → Decay the γ into 2 leptons
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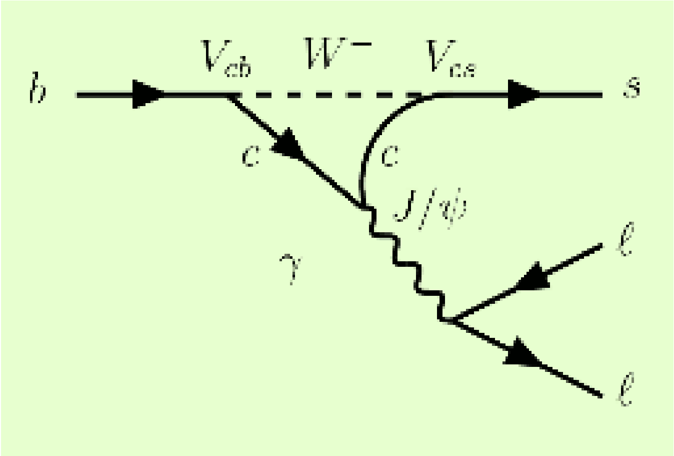
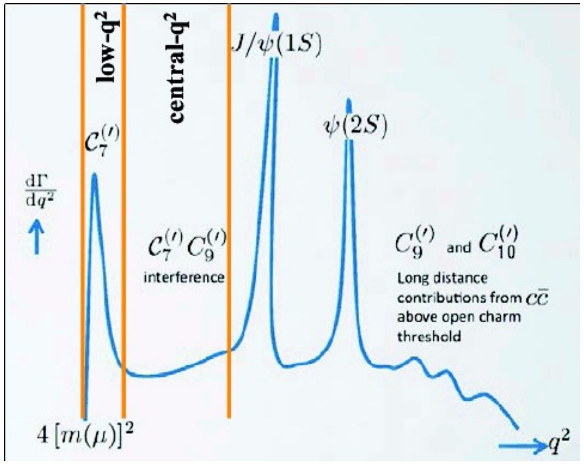
  - → b→lls, very rare in the SM
  - $B(B\to llK^{*}) = (3.3 \pm 1.0)\,.\,10^{-6}$

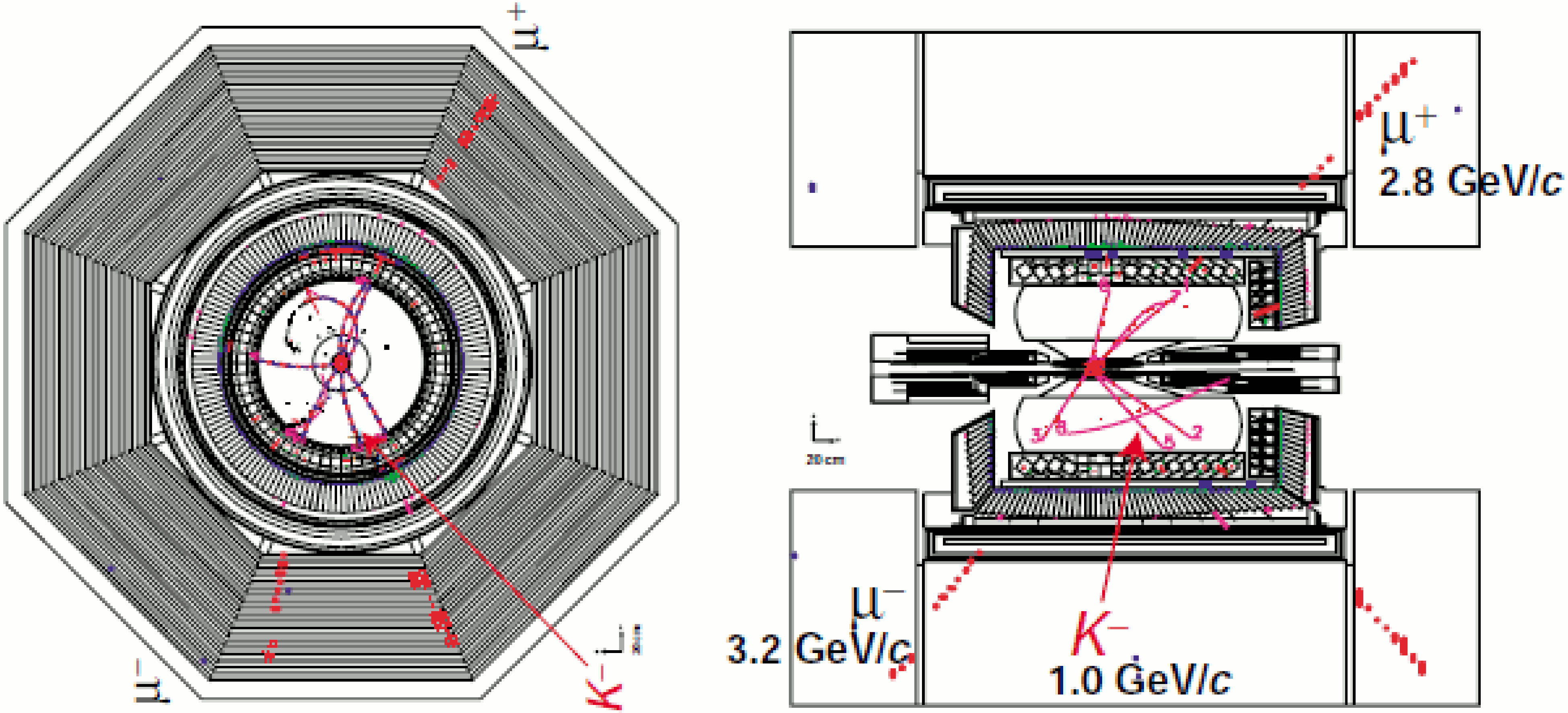


- But beware of LD effects:
  - Tree b→c$\bar{c}$s, (c$\bar{c}$)→ll
  - Can be removed by mass cuts
  - Interferes elsewhere



First observation

$B^+ \to K^+\mu^+\mu^-$ Event



Lepton Photon 01, 2001 July 23, Roma

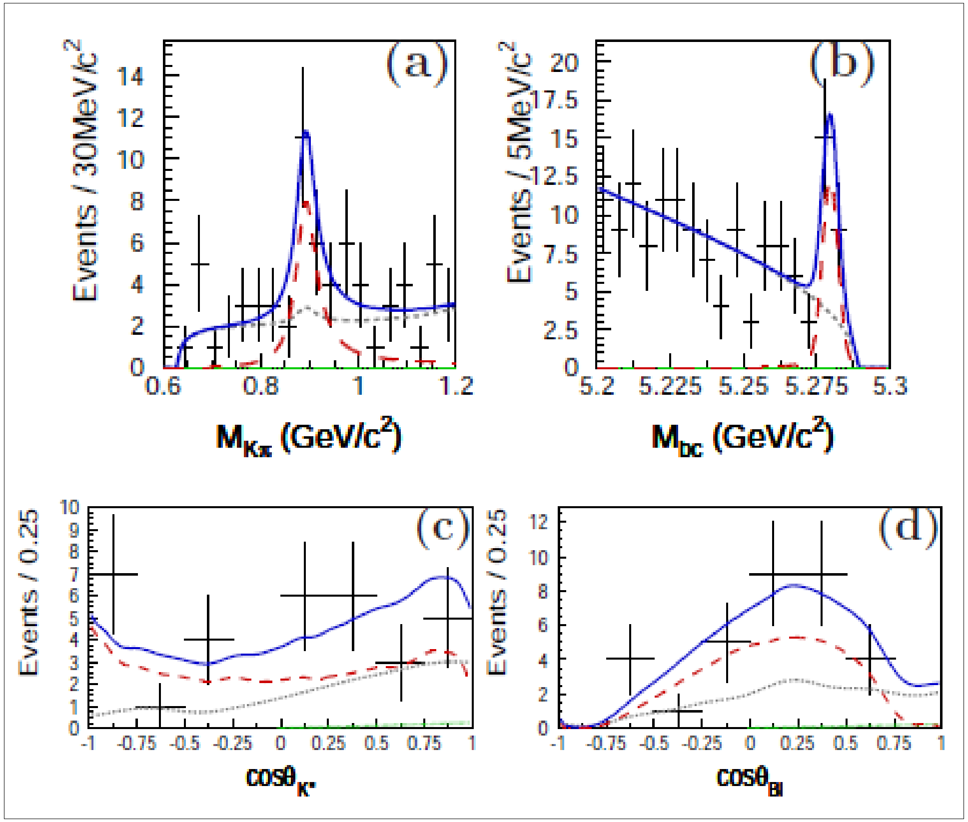
Situation pre-LHCb

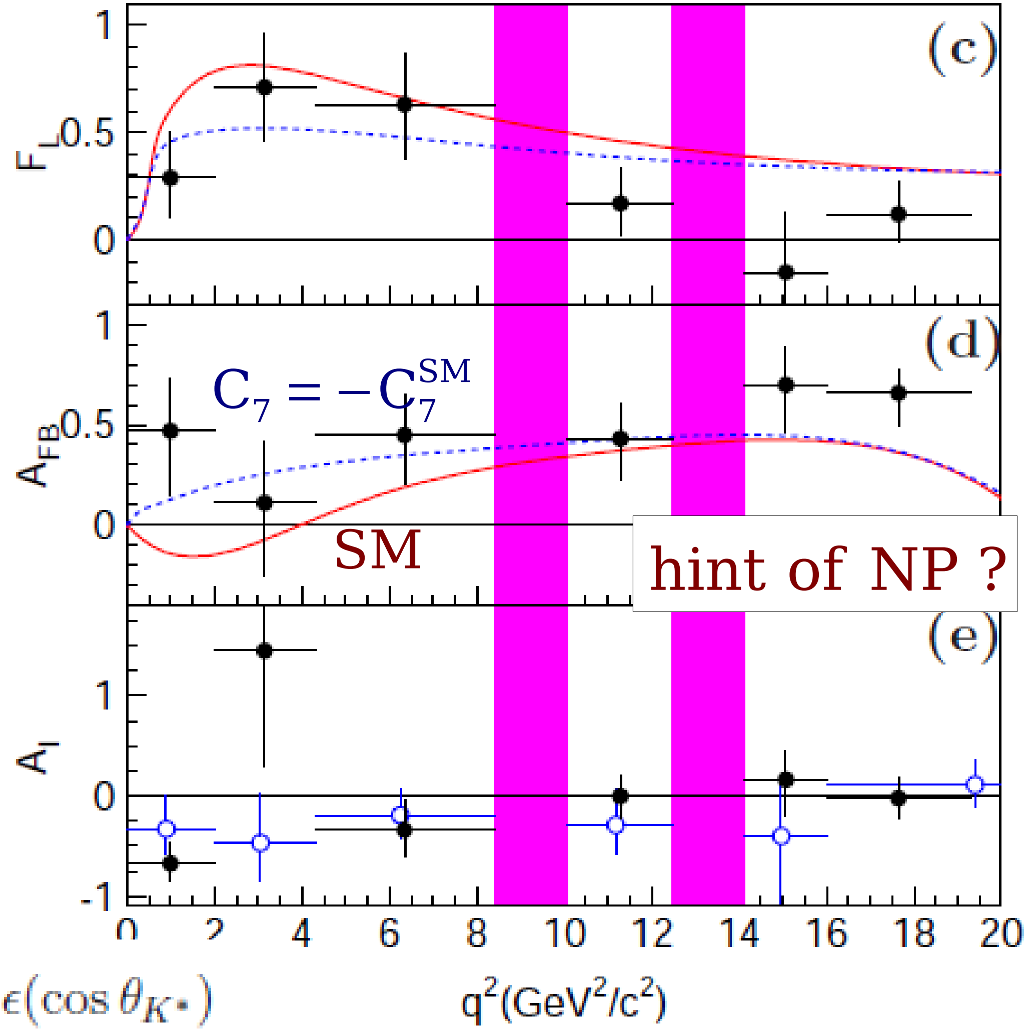
$B \to K^* l^+ l^-$ decays

[arXiv:0904.0770]

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

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





$C_7 = -C_7^{SM}$

SM

hint of NP ?

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

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

$R_{K^*} = 0.83 \pm 0.17 \pm 0.08$

$R_K = 1.03 \pm 0.19 \pm 0.06$

Lepton flavor universality (LFU)

How do the SM gauge bosons couple to charged leptons of different flavors?

Universality in neutral current interactions

$$U^\dagger U = V^\dagger V = \mathbb{I}_{3\times 3} \;\Rightarrow\; \mathcal{L}^\ell_{\rm nc} \equiv \left(\overline{\widehat{e}}\gamma_\mu \widehat{e} + \overline{\widehat{\mu}}\gamma_\mu \widehat{\mu} + \overline{\widehat{\tau}}\gamma_\mu \widehat{\tau}\right)\left(g_\gamma A^\mu + g_Z Z^\mu\right)$$

The photon and Z-boson couple
with the same strength to the three lepton families

Universality

How do we test this feature of the Standard Model?

$$R_Y = \frac{\mathrm{BR}\left(X \to Y e_i^+ e_i^-\right)}{\mathrm{BR}\left(X \to Y e_j^+ e_j^-\right)} \qquad i \neq j$$

SM expectation

$$R_Y = 1 + \mathcal{O}\left(\frac{m^n_{i,j}}{m^n_X}\right)$$

Experimental results

We’ll see...

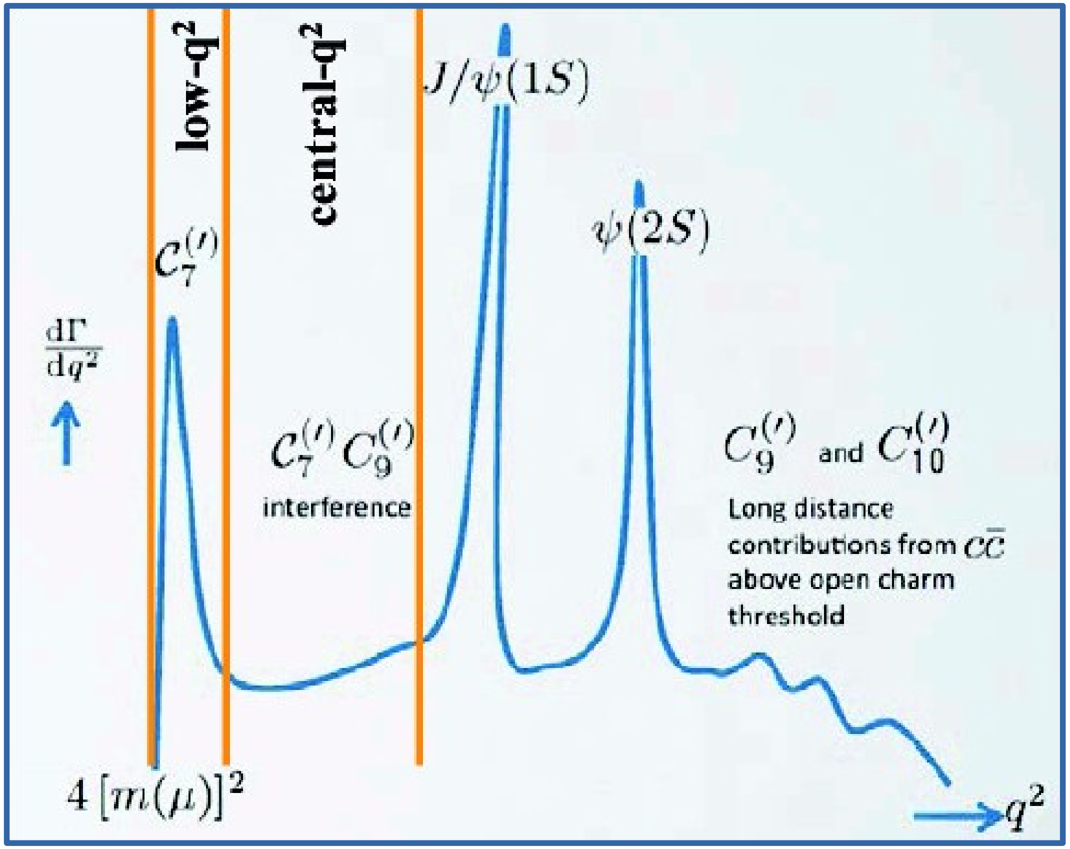
Test of LFU with $B\rightarrow K^{*0}\mu\mu$ and $B\rightarrow K^{*0}ee$, $R_{K^{*0}}$

Two regions of q^2

- Low [0.045-1.1] GeV^2/c^4
- Central [1.1-6.0] GeV^2/c^4

Different q^2 regions probe
different processes
in the OPE framework
short distance contributions
described by Wilson coefficients

$$\mathcal{H}_{eff} = \frac{4G_F}{\sqrt{2}} V_{tb}V_{ts}^{*} \frac{\alpha_e}{4\pi} \sum \left[C_i\mathcal{O}_i + C_i'\mathcal{O}_i'\right]$$

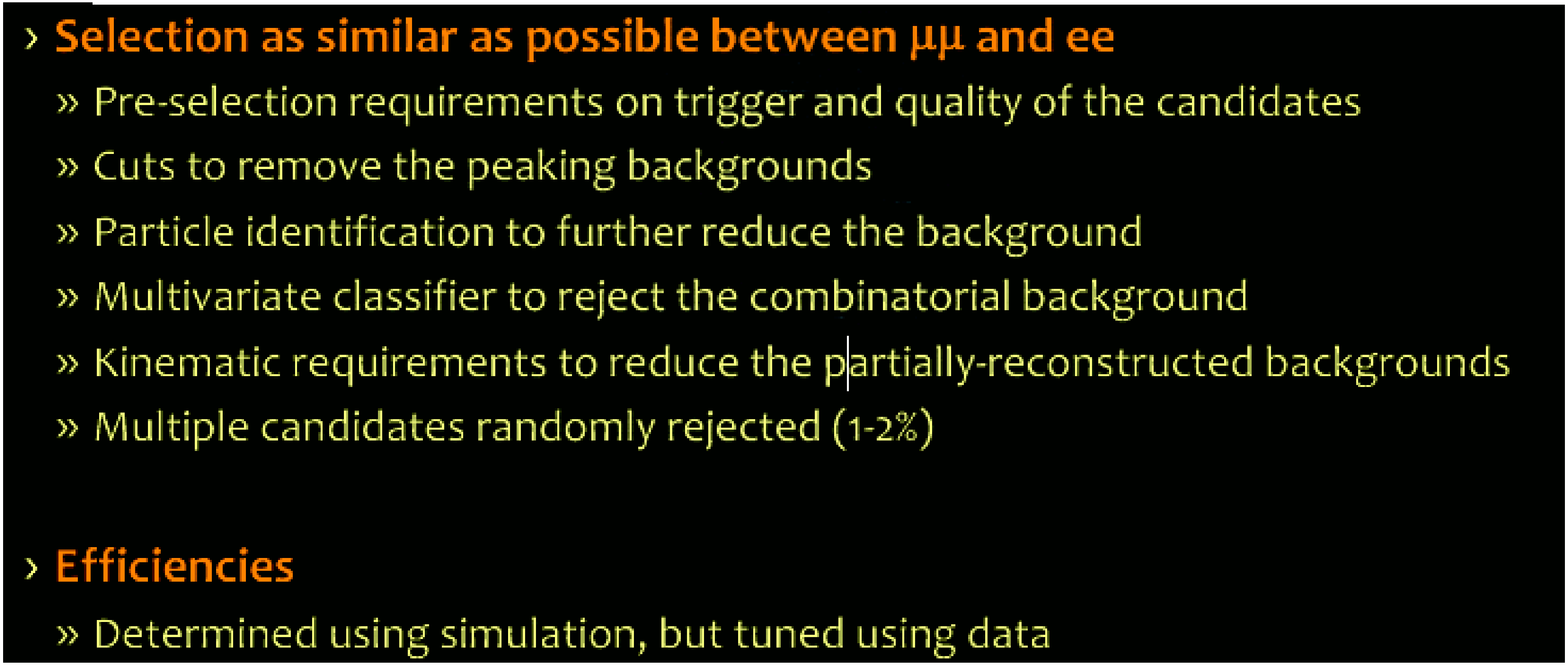


- Measured relative to $B^0 \rightarrow K^{*0} J/\psi(ll)$ in order to reduce systematics
- Challenging:
  - – due to significant differences in the way μ and e interact with detector
  - – Bremsstrahlung
  - – Trigger

Strategy

○ Measured relative to $B^0 \rightarrow K^{*0} J/\psi(ll)$ in order to reduce systematics

$$\mathcal{R}_{K^{*0}} = \frac{\mathcal{B}(B^0 \to K^{*0}\mu^+\mu^-)}{\mathcal{B}(B^0 \to K^{*0}J/\psi(\to \mu^+\mu^-))} \bigg/ \frac{\mathcal{B}(B^0 \to K^{*0}e^+e^-)}{\mathcal{B}(B^0 \to K^{*0}J/\psi(\to e^+e^-))}$$



› **Selection as similar as possible between μμ and ee**
  - » Pre-selection requirements on trigger and quality of the candidates
  - » Cuts to remove the peaking backgrounds
  - » Particle identification to further reduce the background
  - » Multivariate classifier to reject the combinatorial background
  - » Kinematic requirements to reduce the partially-reconstructed backgrounds
  - » Multiple candidates randomly rejected (1-2%)

› **Efficiencies**
  - » Determined using simulation, but tuned using data

Strategy

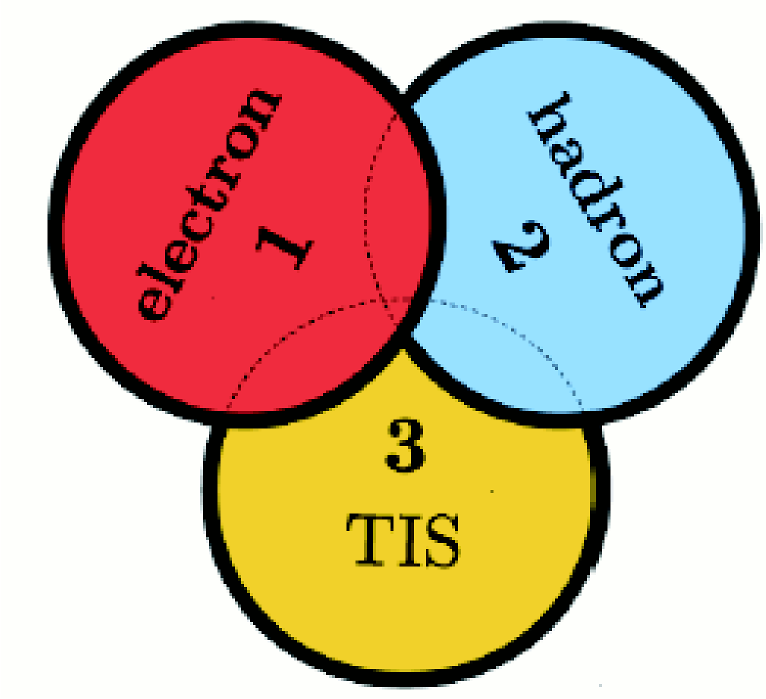
- Measured relative to $B^0 \rightarrow K^{*0} J/\psi(ll)$ in order to reduce systematics

$$\mathcal{R}_{K^{*0}} = \frac{\mathcal{B}(B^0 \to K^{*0}\mu^+\mu^-)}{\mathcal{B}(B^0 \to K^{*0}J/\psi(\to \mu^+\mu^-))} \Bigg/ \frac{\mathcal{B}(B^0 \to K^{*0}e^+e^-)}{\mathcal{B}(B^0 \to K^{*0}J/\psi(\to e^+e^-))}$$

- High occupancy of calorimeters (compared to muon stations)

⇒ hardware thresholds on electron E_T higher than on muon p_T

(L0 Muon, $p_T > 1.5, 1.8$ GeV)



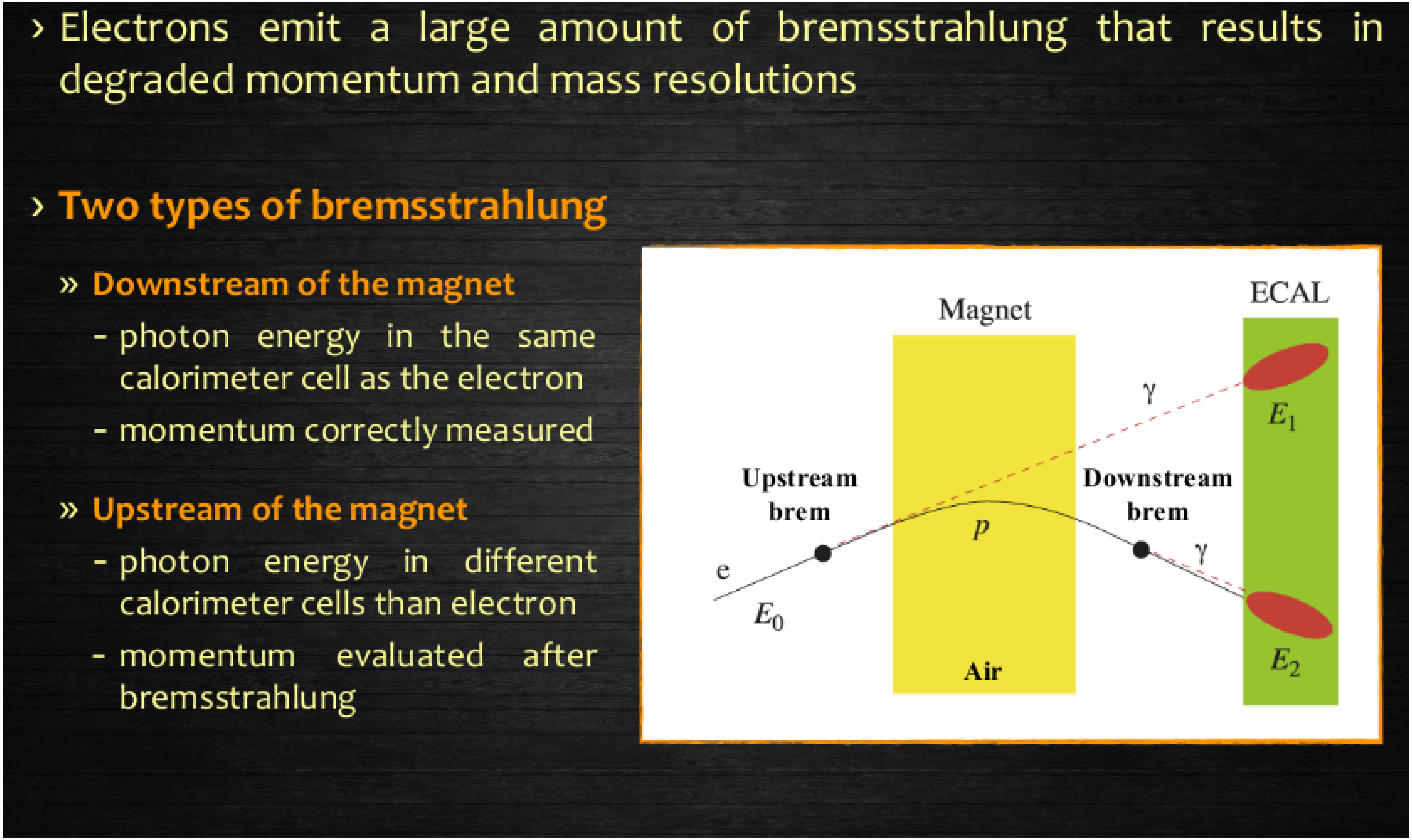
3 exclusive trigger categories:

- L0 Electron: electron hardware trigger fired by clusters associated to at least one of the two electrons ($E_T > 2.5$ GeV)
- L0 Hadron: hadron hardware trigger fired by clusters associated to at least one of the K^{*0} decay products ($E_T > 2.5$ GeV)
- L0 TIS(*): any hardware trigger fired by particles in the event not associated to the signal candidate

(*) TIS = Trigger Independent of Signal

Bremsstrahlung – ee

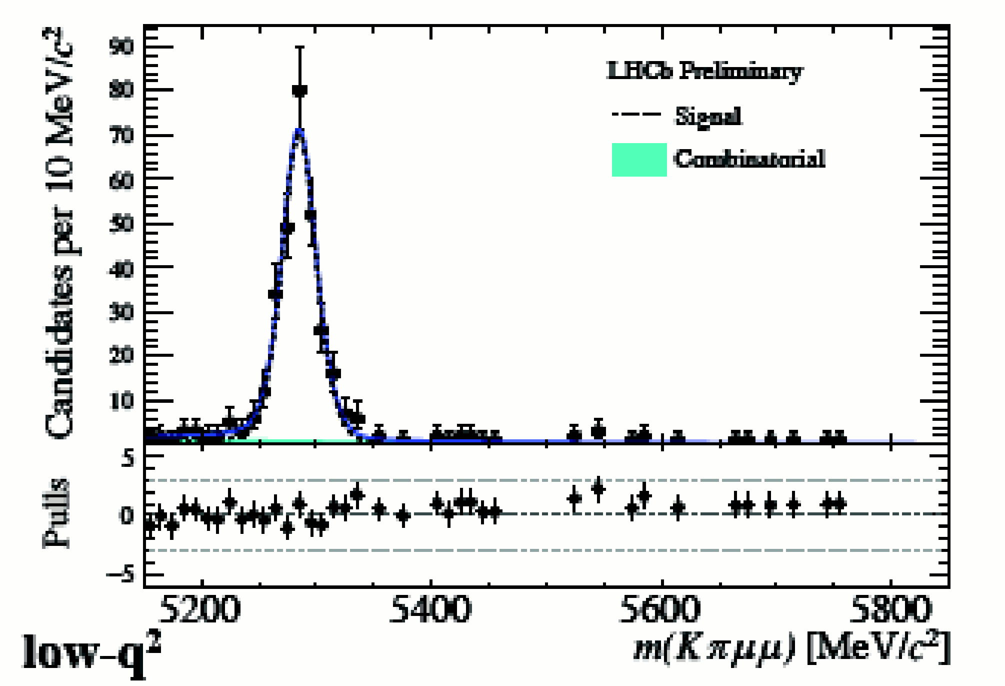
S.Bifani (LHCb)



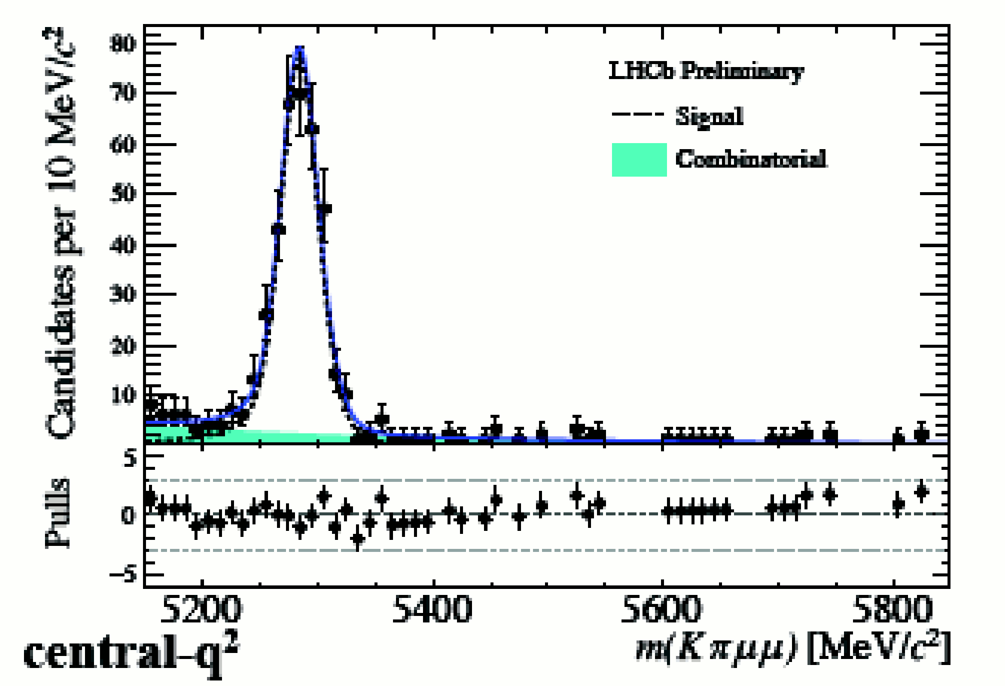
- Electrons emit a large amount of bremsstrahlung that results in degraded momentum and mass resolutions

- Two types of bremsstrahlung
  - Downstream of the magnet
    - photon energy in the same calorimeter cell as the electron
    - momentum correctly measured
  - Upstream of the magnet
    - photon energy in different calorimeter cells than electron
    - momentum evaluated after bremsstrahlung

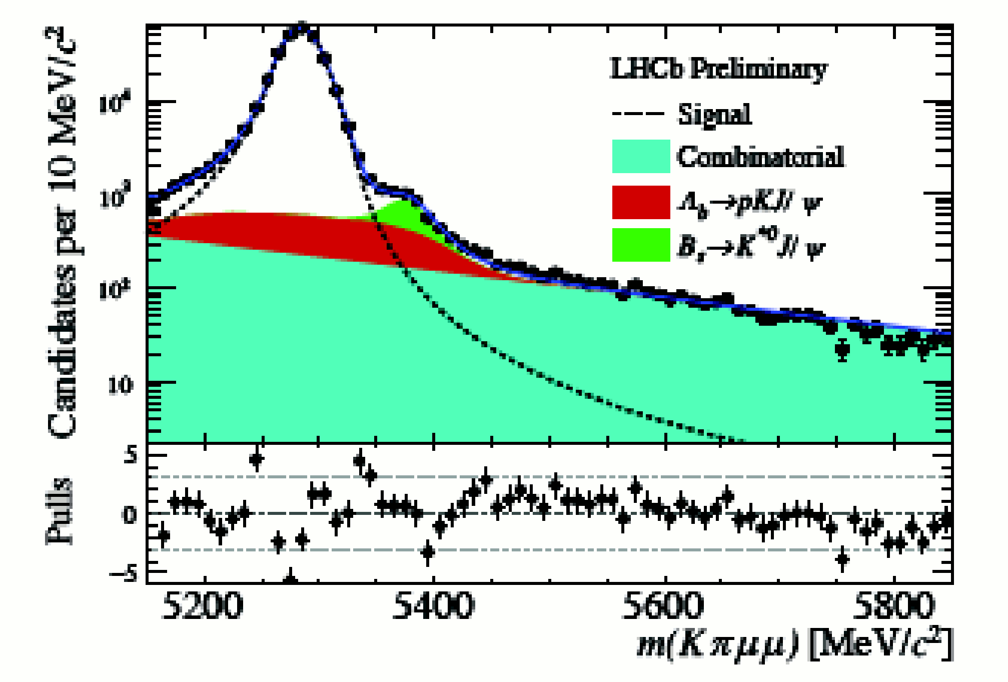
Fit results – μμ



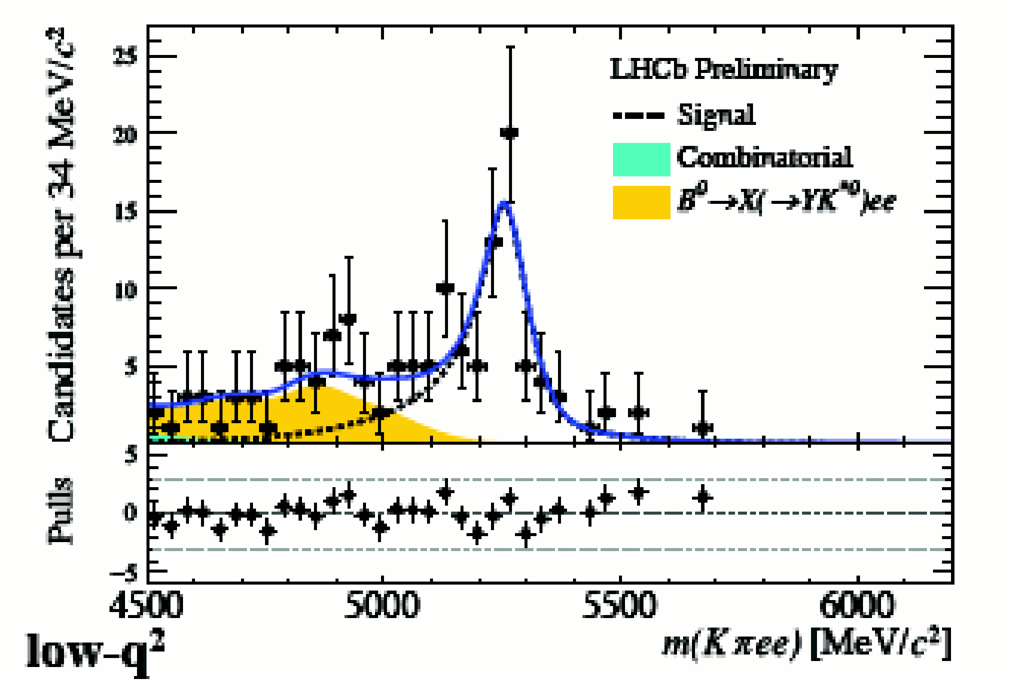
low-q²



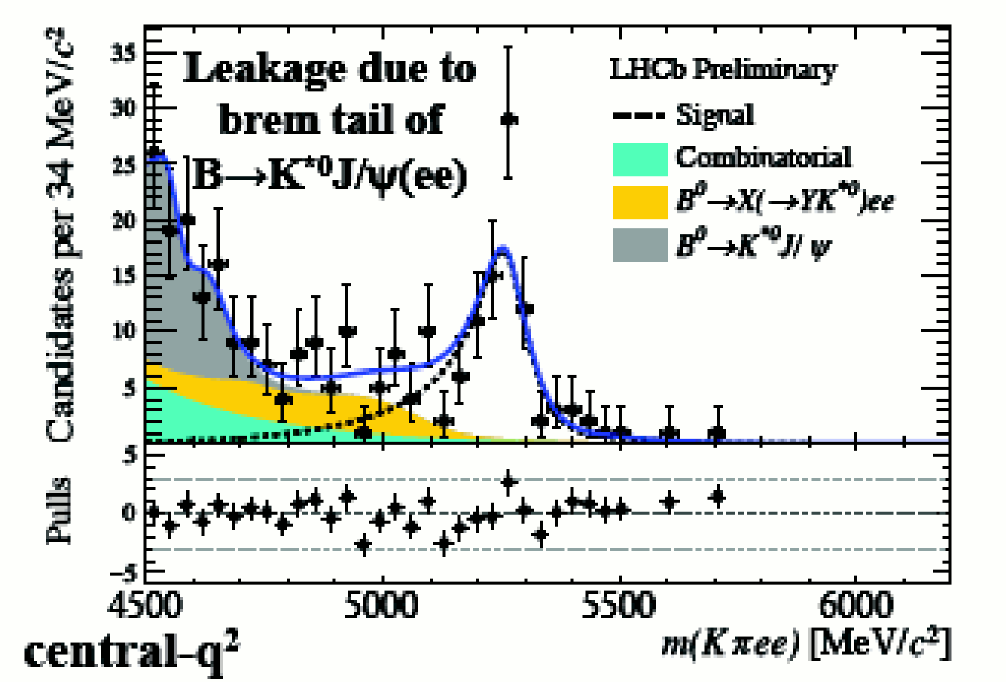
central-q²



Fit results – ee

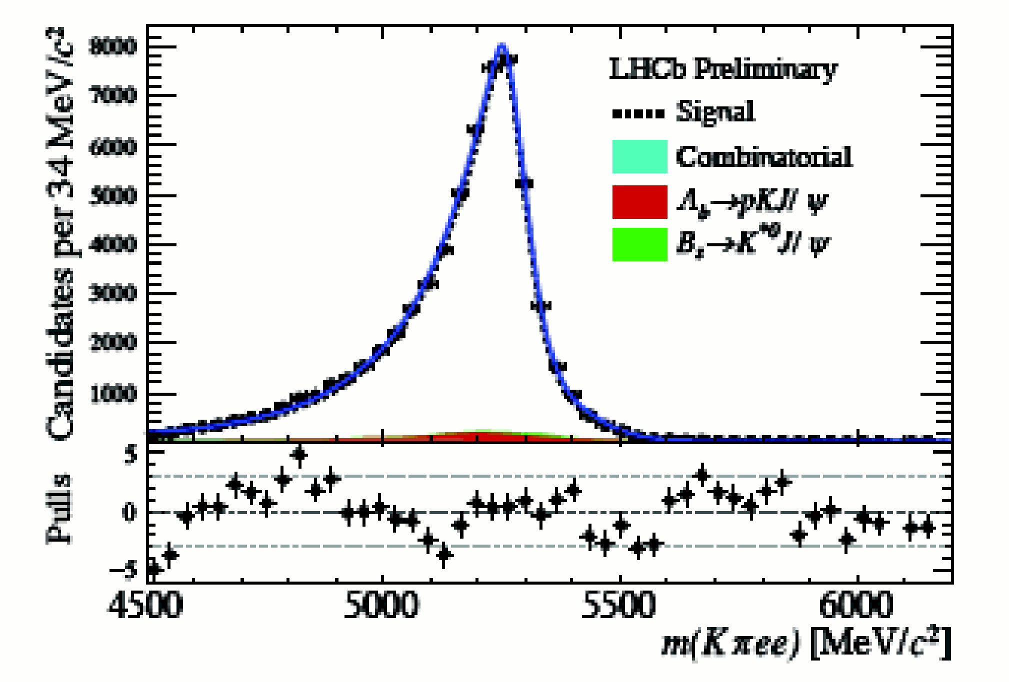


low-q²



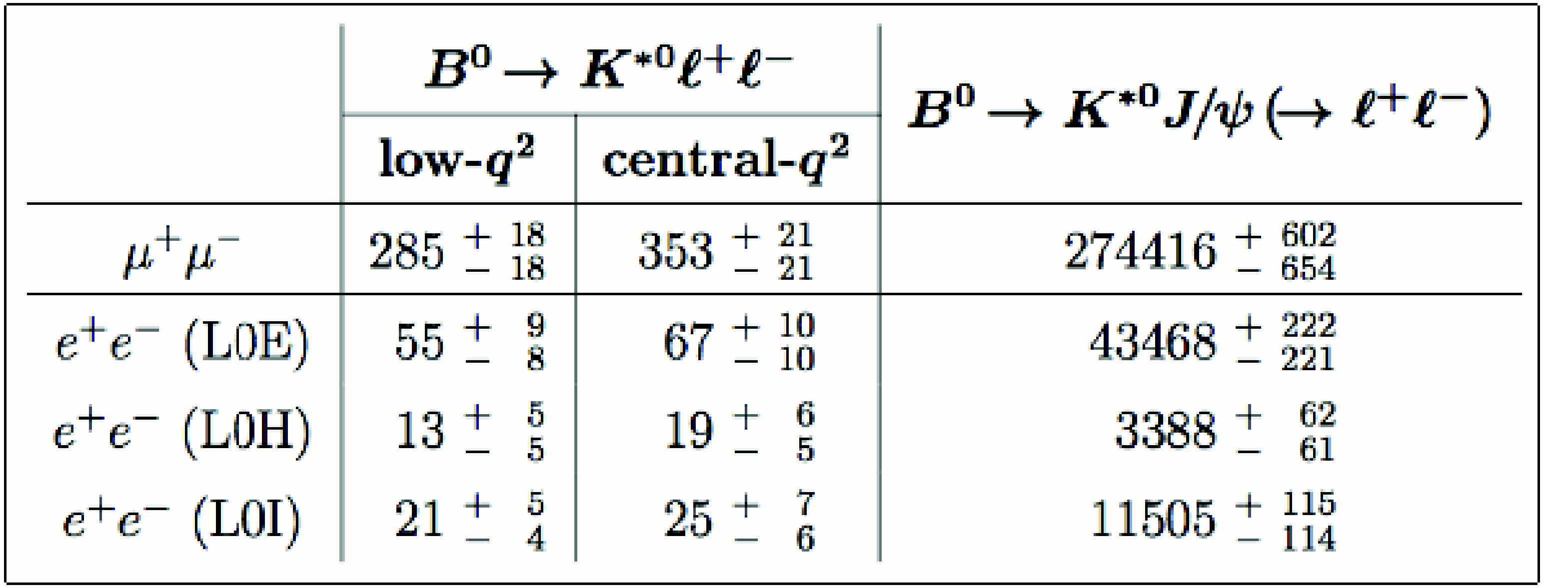
Leakage due to brem tail of $B \to K^{*0} J/\psi(ee)$

central-q²



Yields

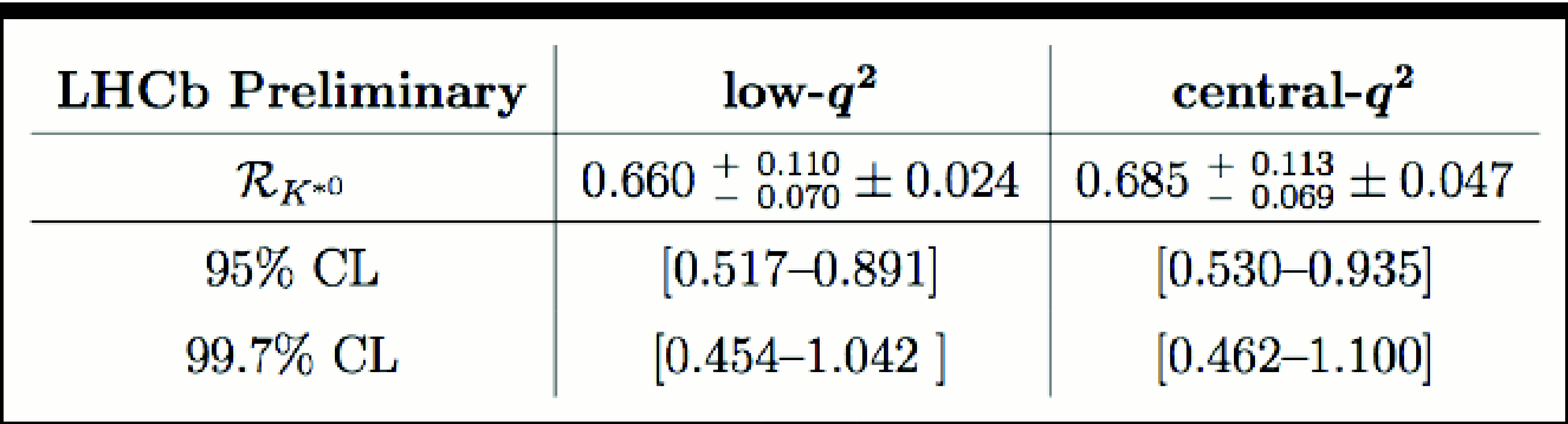
Precision of the measurement driven by the statistics of the electron samples



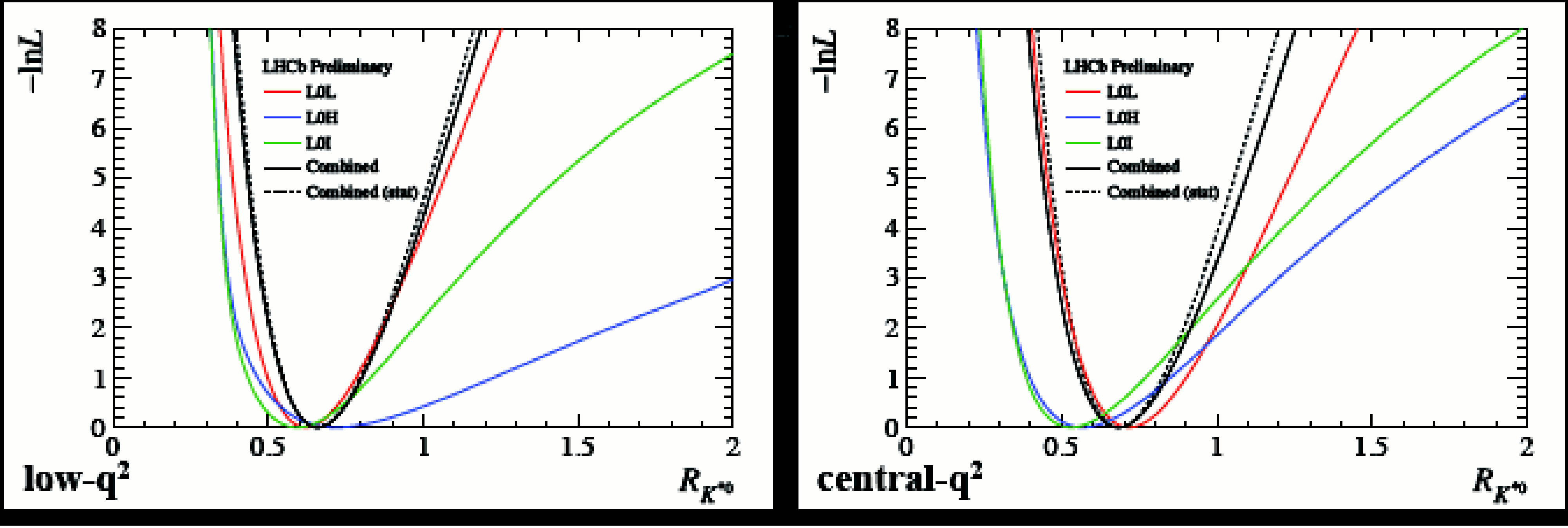
	$B^0 \to K^{*0}\ell^+\ell^-$		$B^0 \to K^{*0} J/\psi(\to \ell^+\ell^-)$
	low-q^2	central-q^2	
$\mu^+\mu^-$	$285\,^{+\,18}_{-\,18}$	$353\,^{+\,21}_{-\,21}$	$274416\,^{+\,602}_{-\,654}$
e^+e^- (L0E)	$55\,^{+\,9}_{-\,8}$	$67\,^{+\,10}_{-\,10}$	$43468\,^{+\,222}_{-\,221}$
e^+e^- (L0H)	$13\,^{+\,5}_{-\,5}$	$19\,^{+\,6}_{-\,5}$	$3388\,^{+\,62}_{-\,61}$
e^+e^- (L0I)	$21\,^{+\,5}_{-\,4}$	$25\,^{+\,7}_{-\,6}$	$11505\,^{+\,115}_{-\,114}$

In total, about 90 and 110 $B^0 \to ee$ candidates at low- and central-q^2, respectively

Results

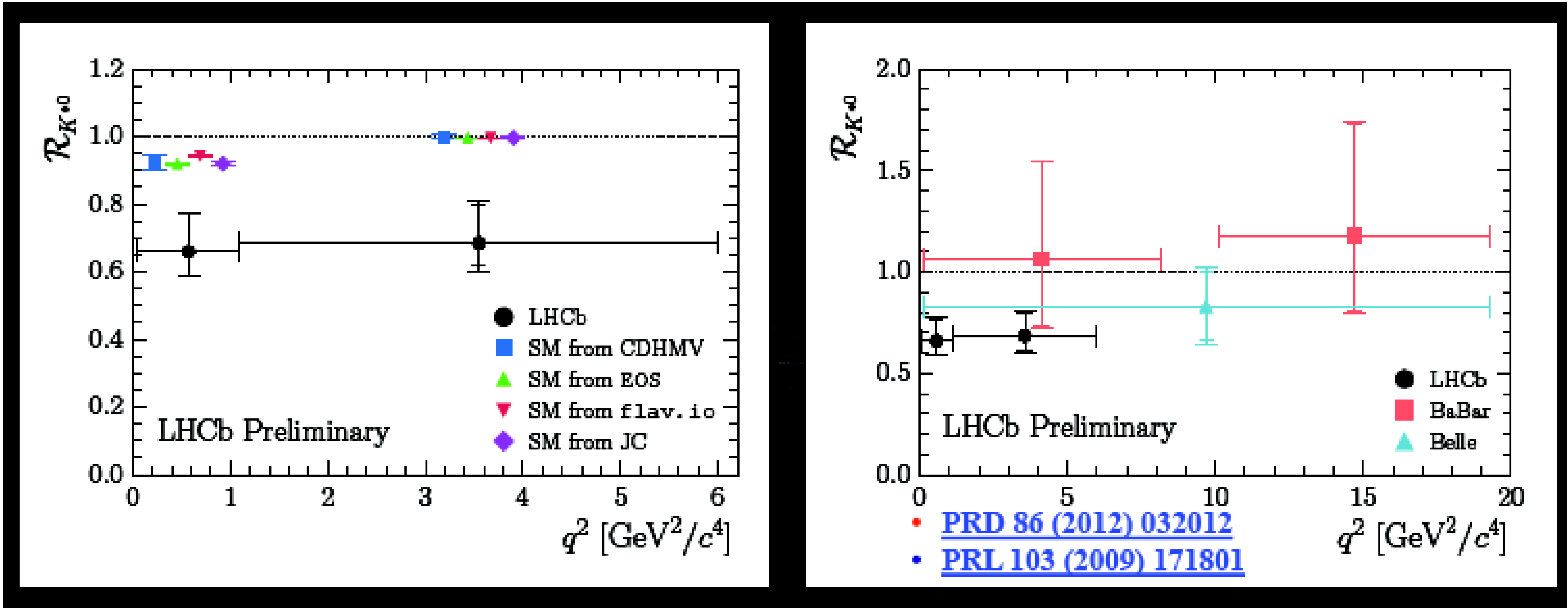


LHCb Preliminary	low-q^2	central-q^2
$\mathcal{R}_{K^{*0}}$	$0.660\ ^{+\ 0.110}_{-\ 0.070} \pm 0.024$	$0.685\ ^{+\ 0.113}_{-\ 0.069} \pm 0.047$
95% CL	[0.517–0.891]	[0.530–0.935]
99.7% CL	[0.454–1.042]	[0.462–1.100]



The measured values of $R_{K^{*0}}$ are found to be in good agreement among the three trigger categories in both q^2 regions

Results



- PRD 86 (2012) 032012
- PRL 103 (2009) 171801

○ The compatibility of the result in the **low-q^2** with respect to the SM prediction(s) is of **2.2-2.4** standard deviations

○ The compatibility of the result in the **central-q^2** with respect to the SM prediction(s) is of **2.4-2.5** standard deviations

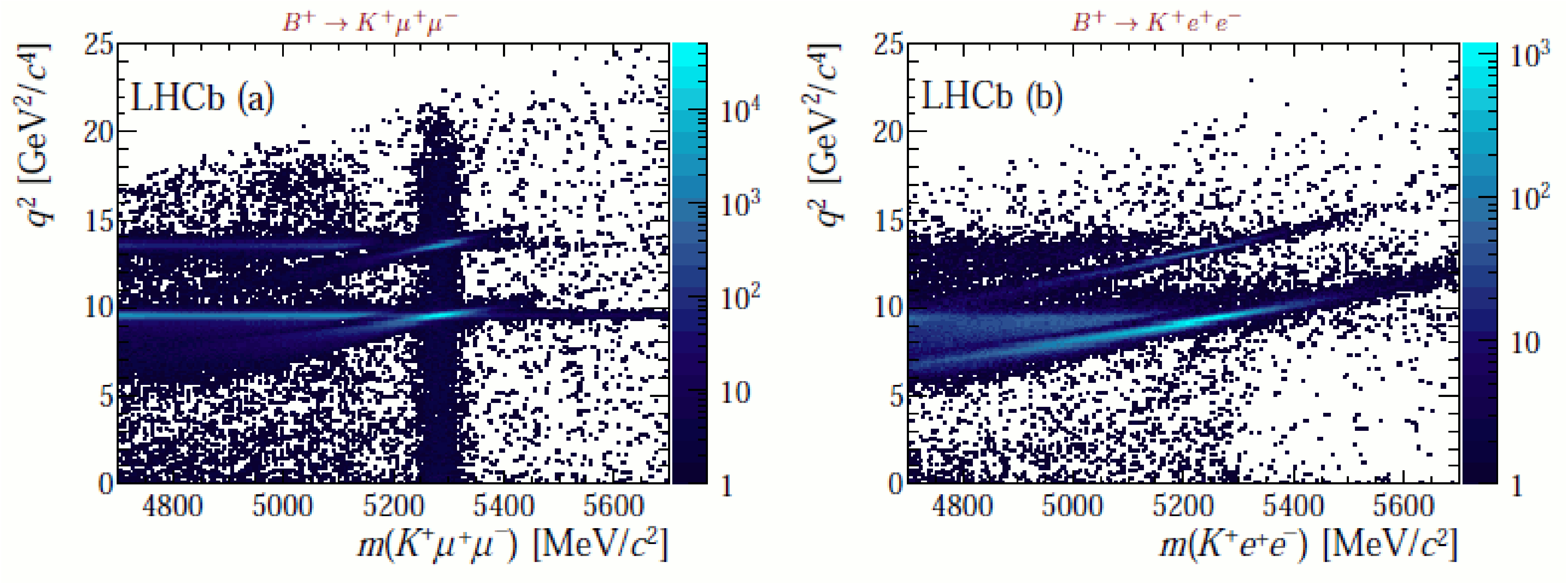
Test of lepton universality using $B^+ \rightarrow K^+ l^+ l^-$ decays

arXiv:1406.6482

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

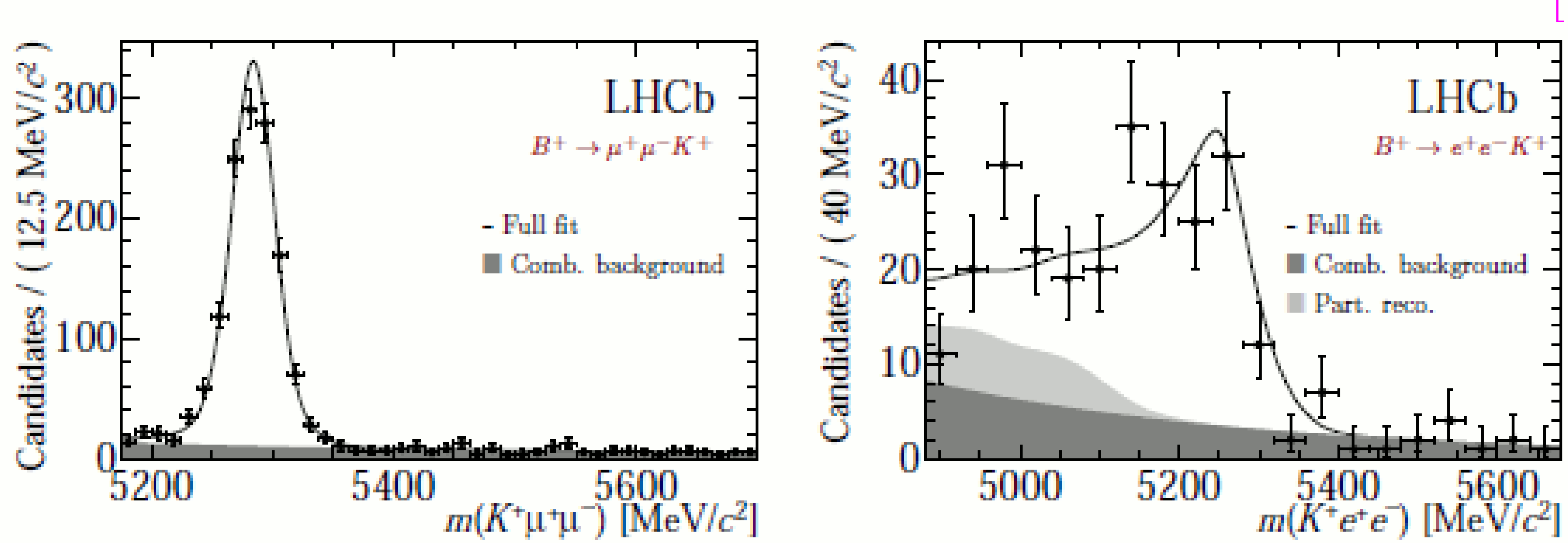
$$R_K = \frac{\int_{q^2_{min}}^{q^2_{max}} \frac{d\Gamma[\mathcal{B}(B^+ \rightarrow K^+ \mu^+ \mu^-)]}{dq^2} dq^2}{\int_{q^2_{min}}^{q^2_{max}} \frac{d\Gamma[\mathcal{B}(B^+ \rightarrow K^+ e^+ e^-)]}{dq^2} dq^2} = \left(\frac{N_{K\mu\mu}}{N_{Kee}}\right) \left(\frac{N_{J/\psi(ee)K}}{N_{J/\psi(\mu\mu)K}}\right)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

- SM prediction is $R_K = 1$ with an uncertainty of $O(10^{-3})$
- Measurement relative to resonant $B \rightarrow J/\psi K$ modes



Test of lepton universality using $B^+ \rightarrow K^+ l^+ l^-$ 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 $1<q^2<6\,\mathrm{GeV}^2/c^4$

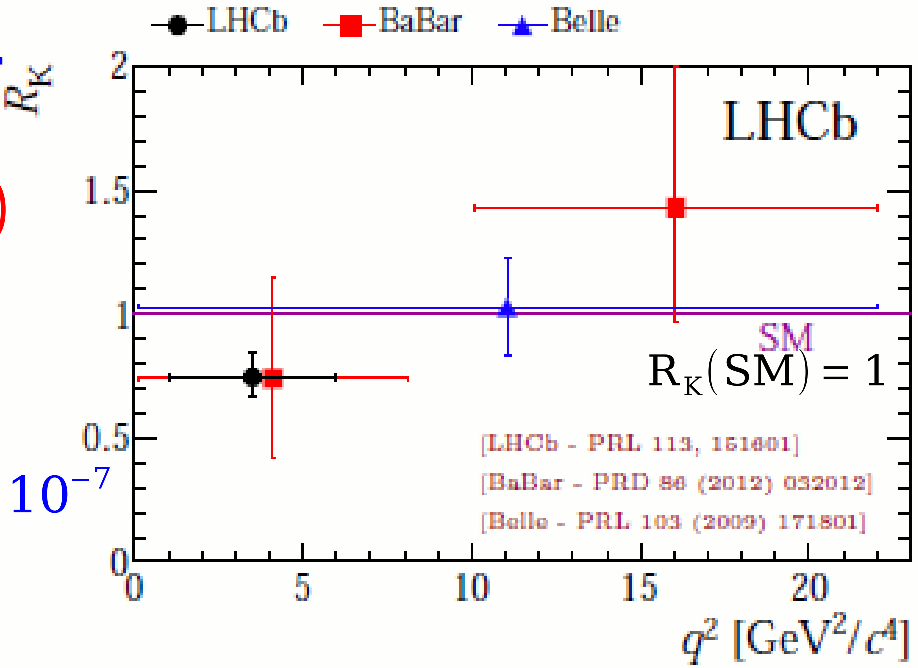
- The combination of the various trigger channels gives:

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

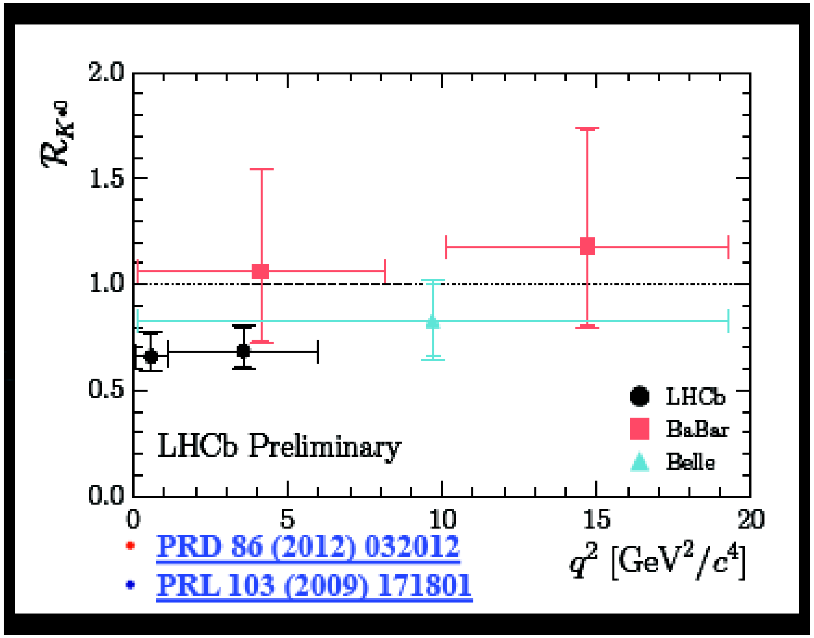
- Most precise measurement to date, disagreement with SM at 2.6σ level

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

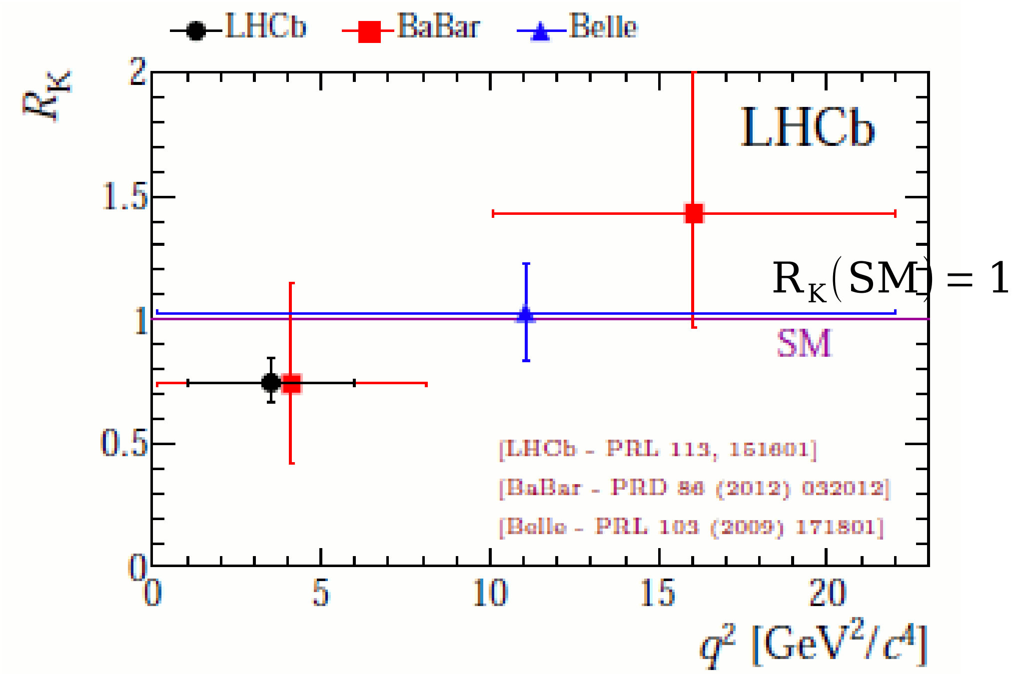
BSM LFNU and effect is in $\mu\mu$, not ee



Test of lepton universality using $B^+ \to K^{(*)} l^+ l^-$ decays

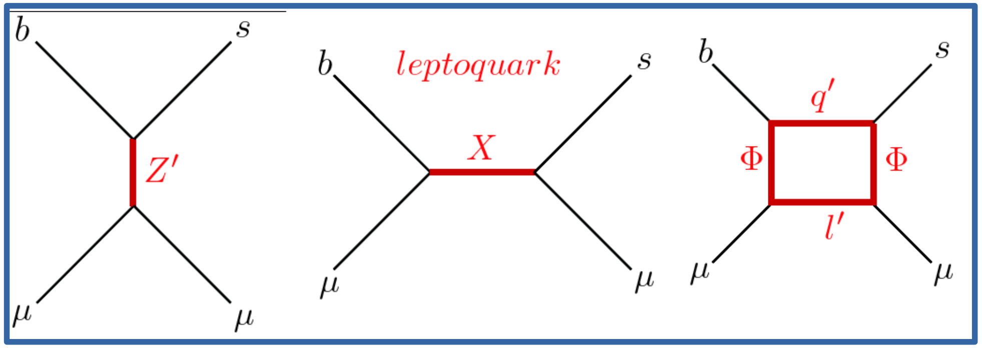


- PRD 86 (2012) 032012
- PRL 103 (2009) 171801



Model candidates

- ✧ **Model with extended gauge symmetry**
  - ✓ Effective operator from Z' exchange
  - ✓ Extra U(1) symmetry with flavor dependent charge
- ✧ **Models with leptoquarks**
  - ✓ Effective operator from LQ exchange
  - ✓ Yukawa interaction with LQs provide flavor violation
- ✧ **Models with loop induced effective operator**
  - ✓ With extended Higgs sector and/or vector like quarks/leptons
  - ✓ Flavor violation from new Yukawa interactions

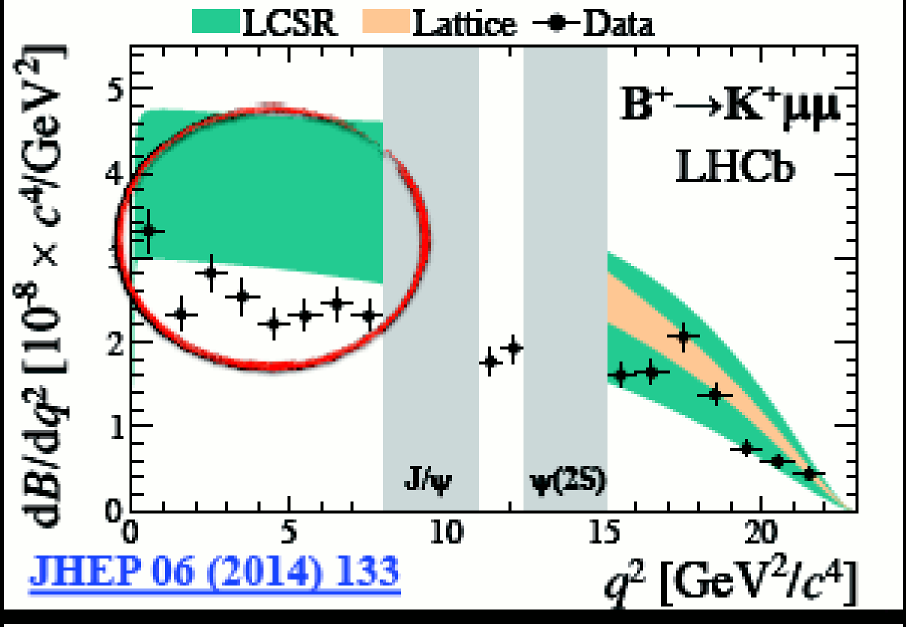


Leptoquarks are color-triplet bosons that carry both lepton and baryon numbers

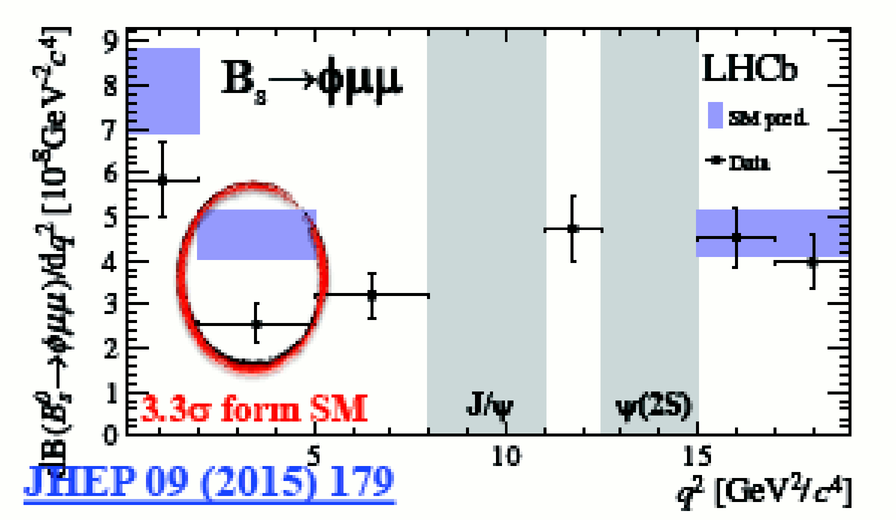
Lot of those models predict also LFV $b \to s e\mu, b \to s\tau$,…

Differential Branching Fractions

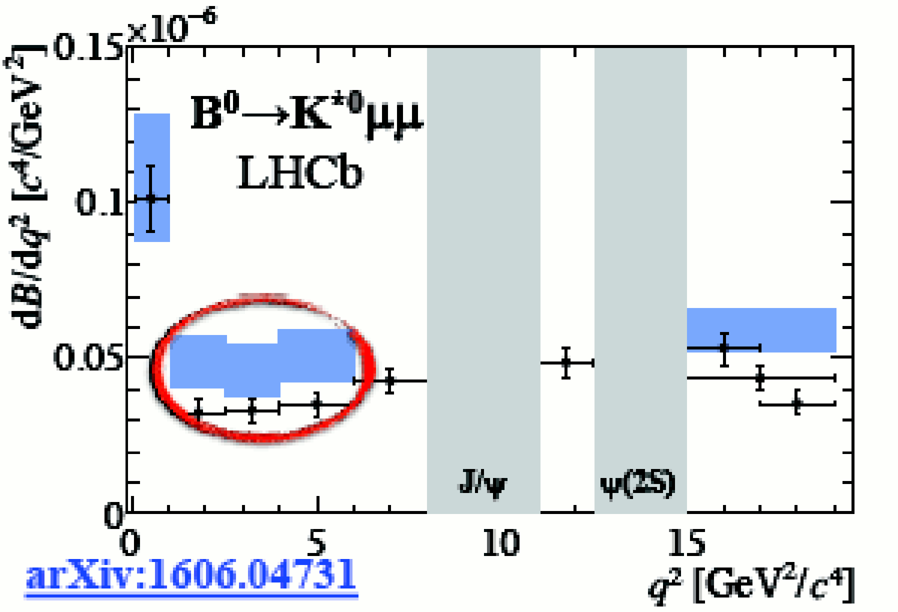
Results consistently lower than SM predictions



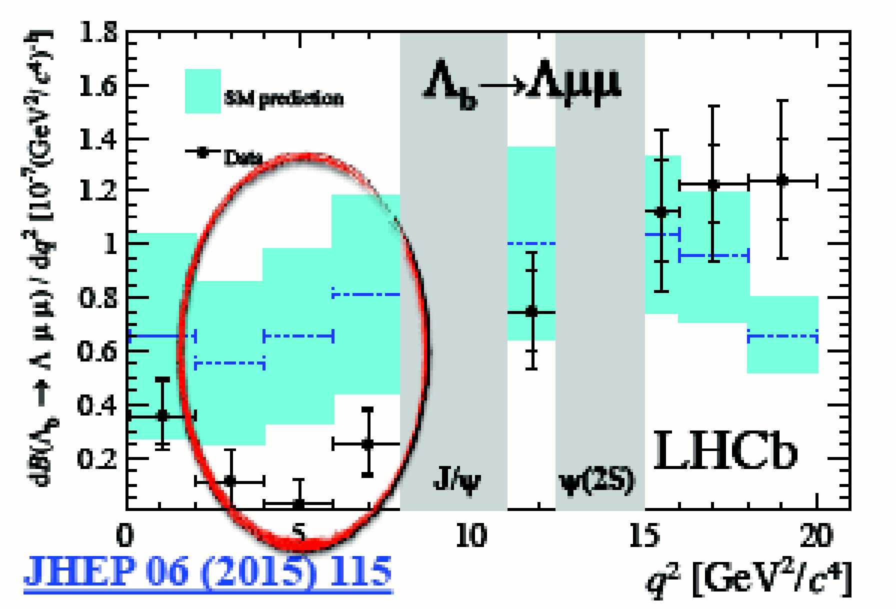
JHEP 06 (2014) 133



JHEP 09 (2015) 179

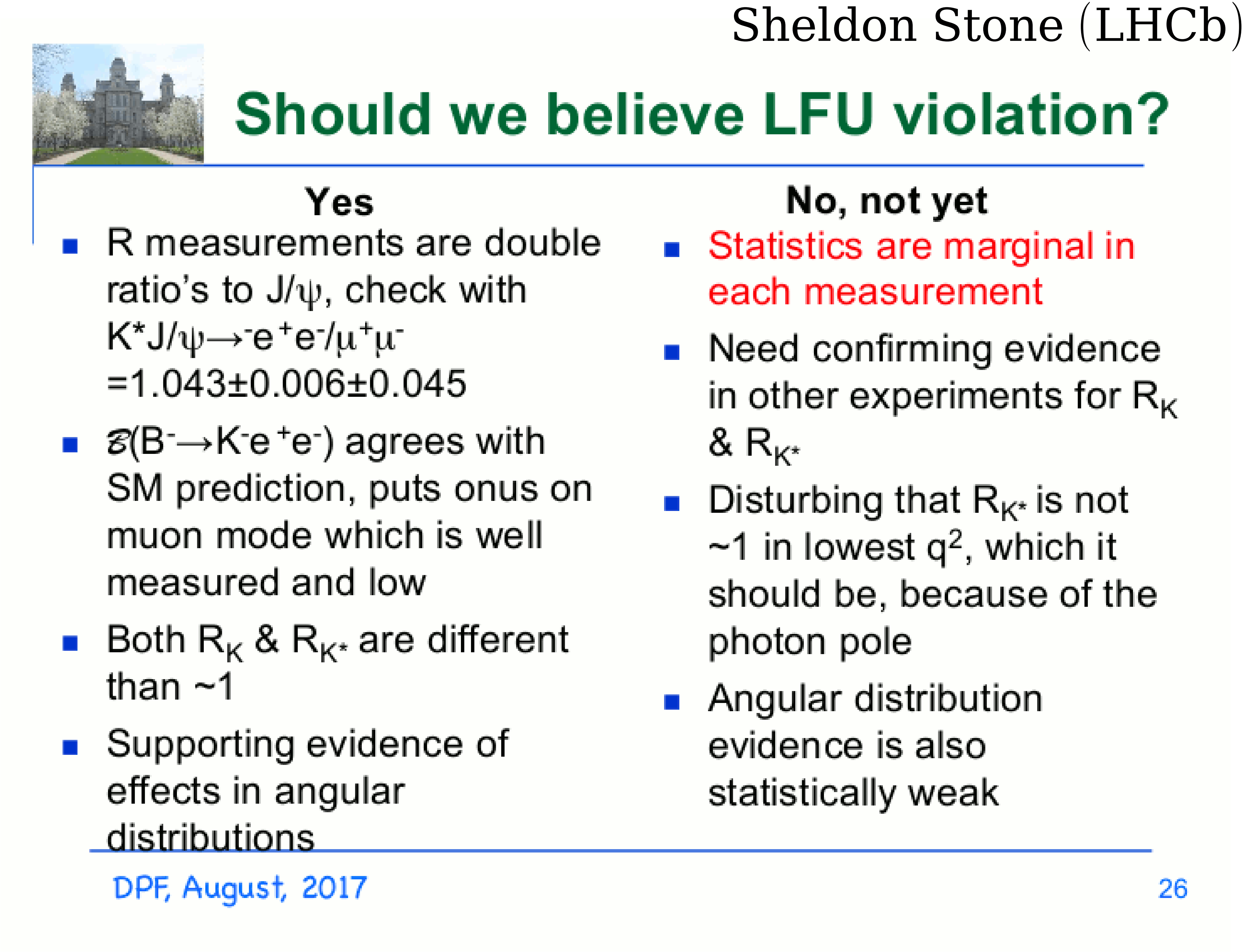


arXiv:1606.04731



JHEP 06 (2015) 115

Sheldon Stone (LHCb)



Should we believe LFU violation?

Yes

- R measurements are double ratio's to J/ψ, check with $K^*J/\psi\rightarrow e^+e^-/\mu^+\mu^-$ $=1.043\pm0.006\pm0.045$
- $\mathcal{B}(B^-\rightarrow K^-e^+e^-)$ agrees with SM prediction, puts onus on muon mode which is well measured and low
- Both R_K & R_{K^*} are different than ~1
- Supporting evidence of effects in angular distributions

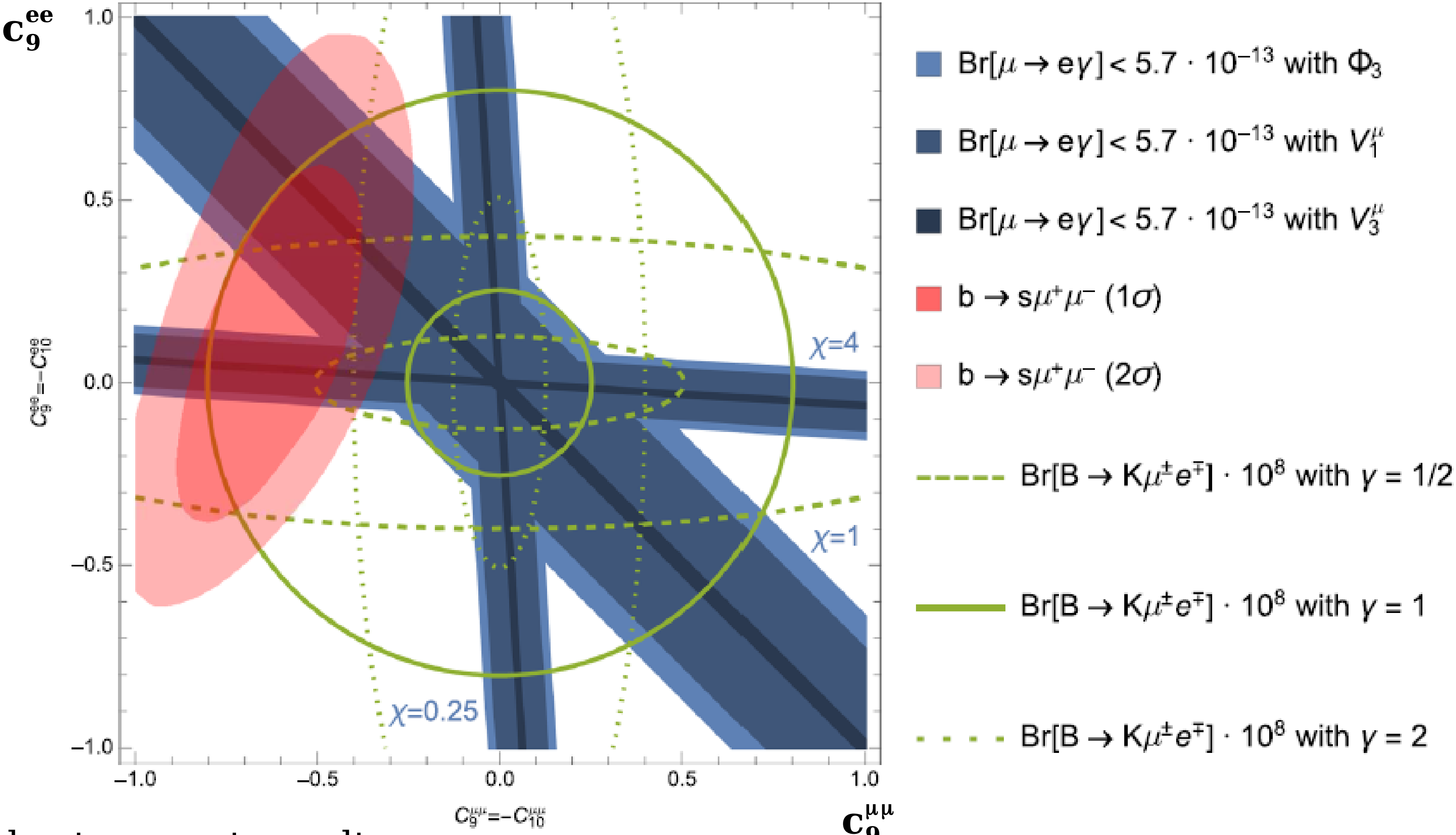
No, not yet

- Statistics are marginal in each measurement
- Need confirming evidence in other experiments for R_K & R_{K^*}
- Disturbing that R_{K^*} is not ~1 in lowest q^2, which it should be, because of the photon pole
- Angular distribution evidence is also statistically weak

LFV b→sll'decays

Glashow, Guadagnoli and Lane, 1411.0565, LUV ⇒ LFV, such as B→Kμe, Kμτ are also generated...

A.Crivellin et al, 1706.08511

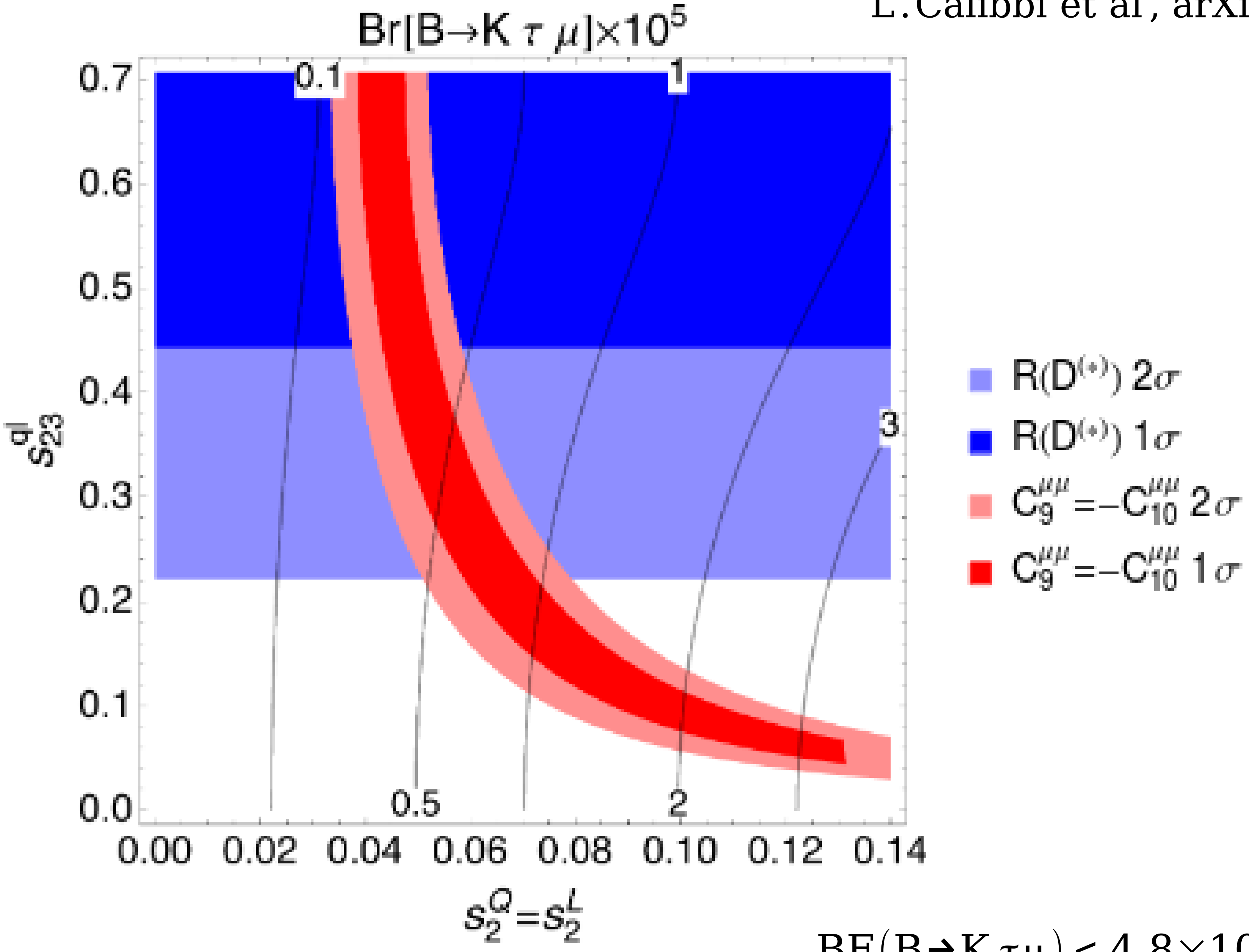


⇒ best current results:

- BaBar: BF(B→K$\mu^{\pm}e^{\mp}$) < 3.8×10^{-8} at 90%CL (arXiv:hep-ex/0604007)
- Belle: BF(B→$K^{*0}\mu^{\pm}e^{\mp}$) < 1.8×10^{-7} at 90%CL (arXiv:1807.03267)

$R(D^*)$ and $b \to s\mu\mu$

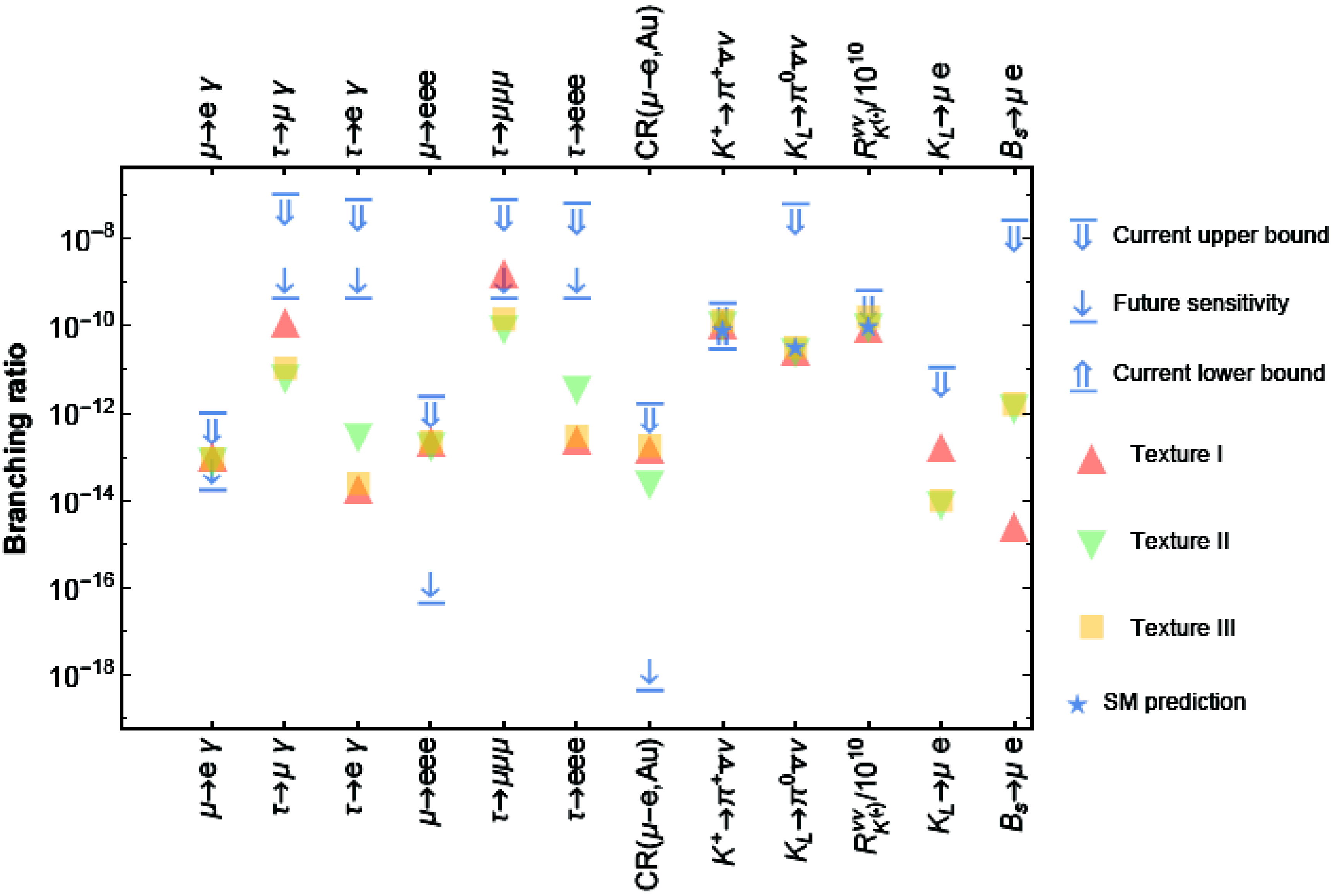
L. Calibbi et al, arXiv: 1709.00692



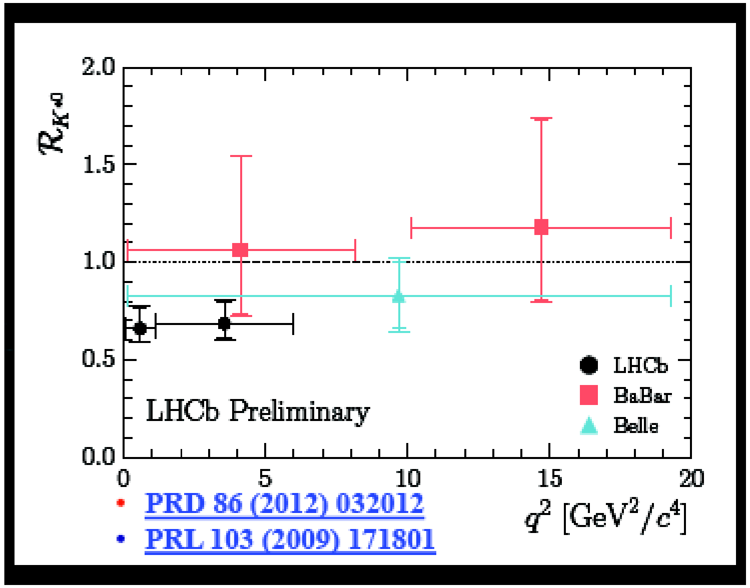
BF(B→K τμ) $< 4.8\times10^{-5}$ @ 90% CL
BaBar, arXiv: 1204.2852
hadronic tag

more observables…

C.Hati et al, arXiv:1806.10146



A.Datta et al, arXiv:1609.09078: interesting modes are $\tau\to 3\mu$, and $\Upsilon(3S)\to\mu\tau$



- PRD 86 (2012) 032012
- PRL 103 (2009) 171801

b → s anomalies

anything else ?

Found by LHCb (and perhaps hinted by Belle)

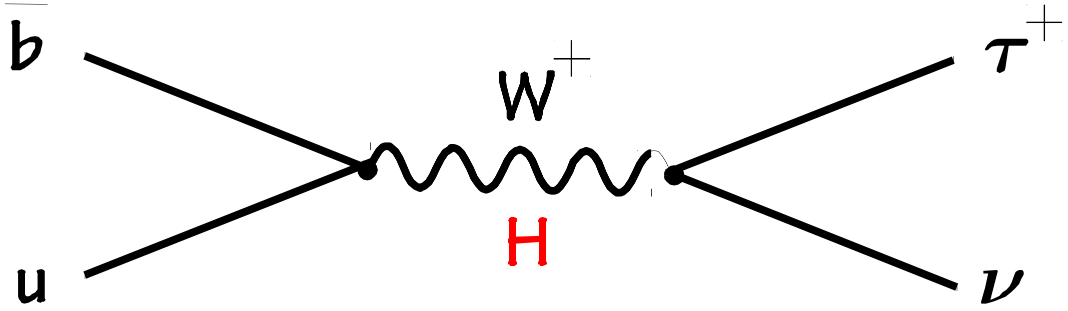
Many observables: global pattern

Neutral current

1-loop (and CKM-suppressed) in the SM

The New Physics can be heavy

$\mathbf{B \rightarrow \tau \nu}$



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

Tree diagram, but quite rare: $\mathcal{B}_{SM}=(1.2\pm0.4)\,.\,10^{-4}$

($\,$for other modes, SM expectations: $10^{-11}\,(e\nu)$, $5\times10^{-7}\,(\mu\nu)$)

Higgs-mediated diagram **reduces** (small $\tan\beta$) or **enhances** the BF

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

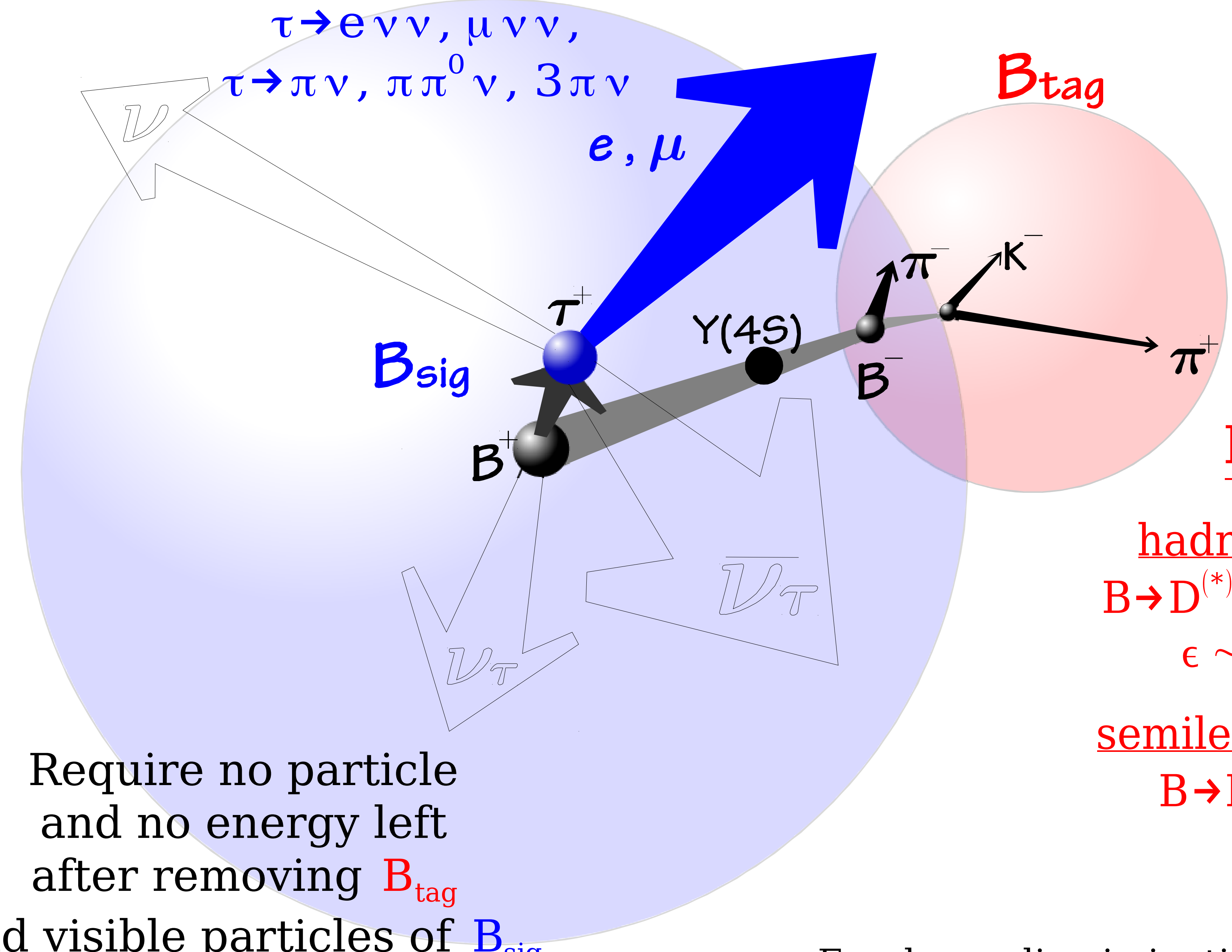
uncertainties from f_B and $|V_{ub}|$ can be reduced to B_B
and other CKM uncertainties by combining with precise Δm_d

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}

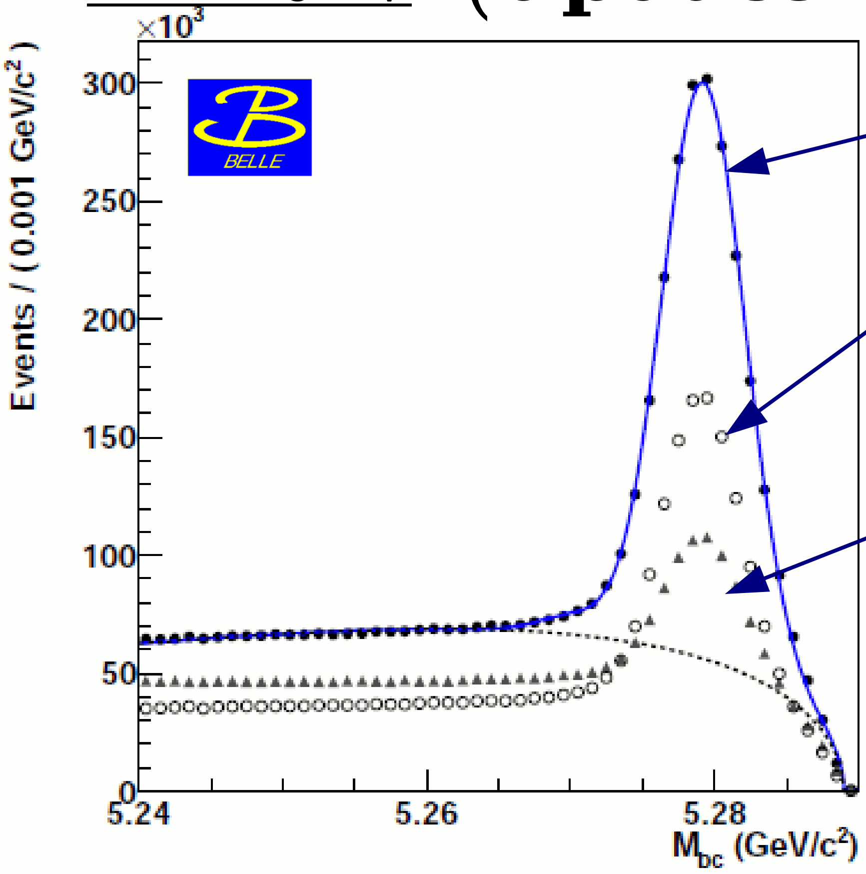
hadronic tag
$B \to D^{(*)}\pi$, $D^{(*)}\rho$....
$\epsilon \sim 0.2\,\%$

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}

E_{ECL} has a discriminating variable…

$B^+ \to \tau^+ \nu$ (update hadronic tag) [arXiv:1208.4678]



new tag algorithm on full data
(reprocessed)

new tag algorithm on previous data

based on neural network & more B/D decays modes, NIM A654, 432 (2011)

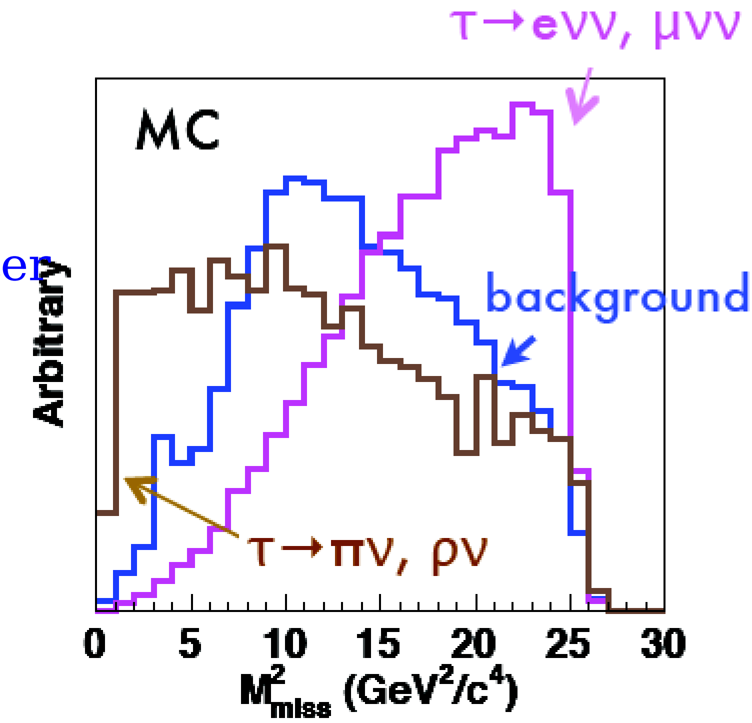
previous tag algorithm on previous data

× 3 B_{tag} sample size

[purity also improved]

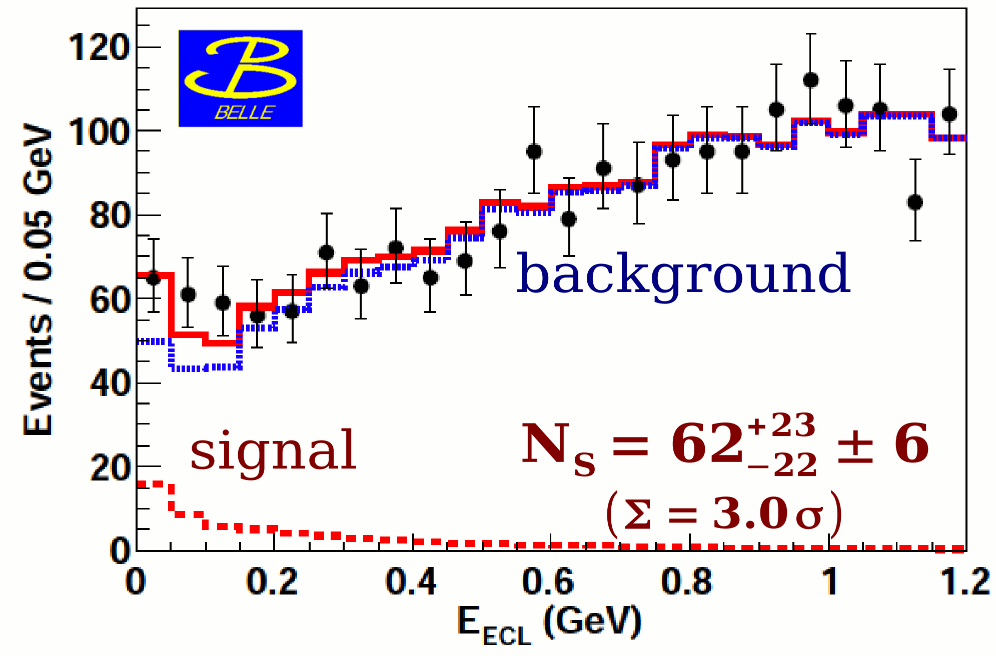
Signal extraction based on two variables:

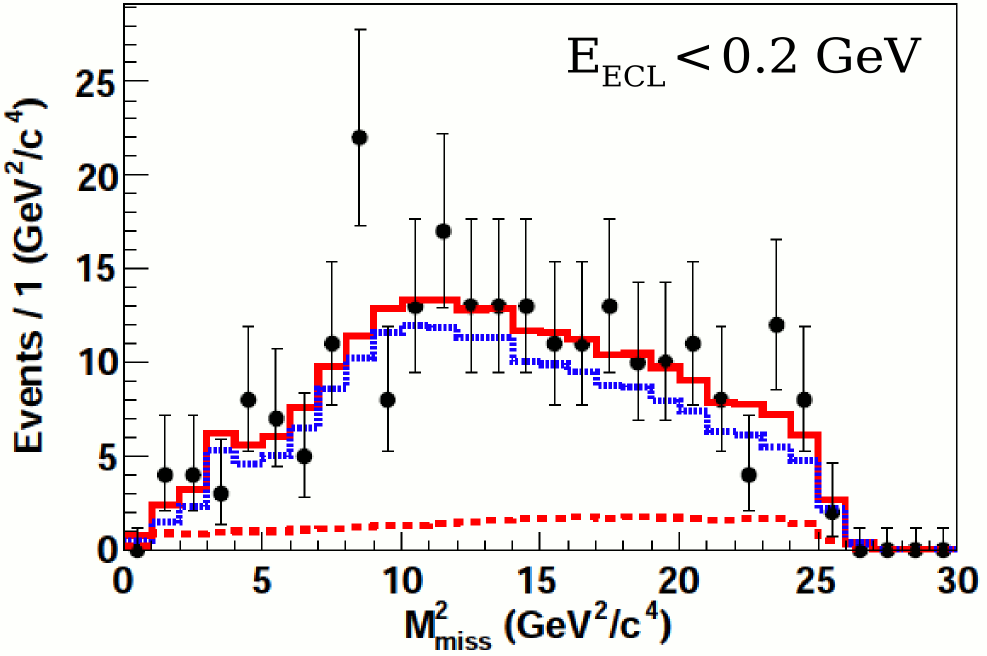
- E_{ECL}: remaining energy in electromagnetic calorimeter
  (peak at $E_{ECL} = 0$ GeV for signal)
- M^2_{miss}: missing mass squared
  (larger for $e\nu\nu/\mu\nu\nu$, smaller for $\pi\nu/\rho\nu$)



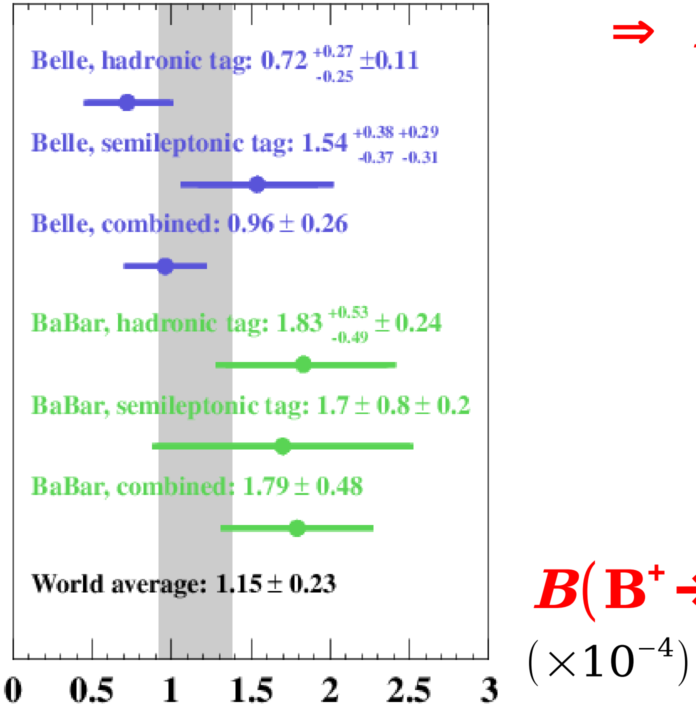
$B^+ \to \tau^+ \nu$ (update hadronic tag) [arXiv:1208.4678]

simultaneous fit to the different τ reconstruction modes ($\tau \to e\nu\nu, \mu\nu\nu, \pi\nu, \rho\nu$)





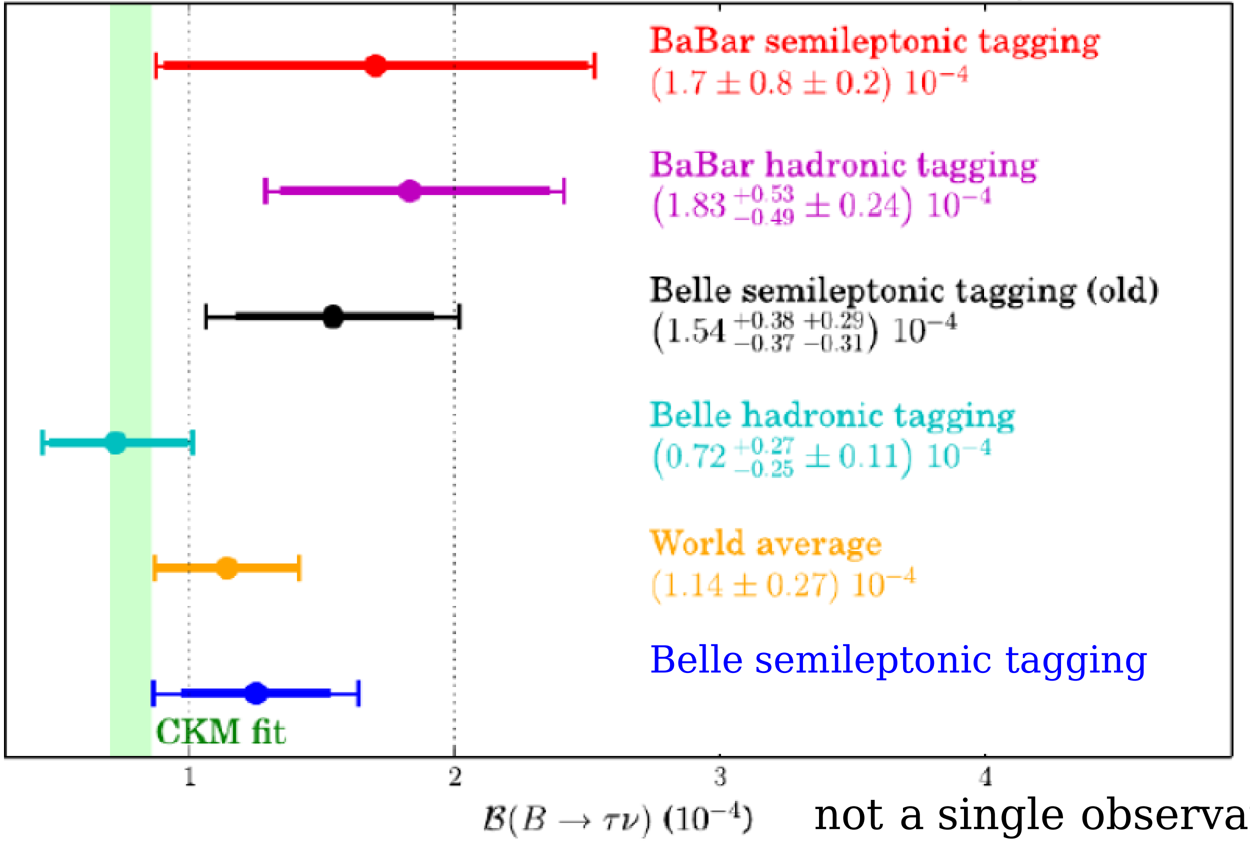
$$\Rightarrow \mathcal{B}(B^+ \to \tau^+ \nu) = (0.72^{+0.27}_{-0.25} \pm 0.11) \times 10^{-4}$$



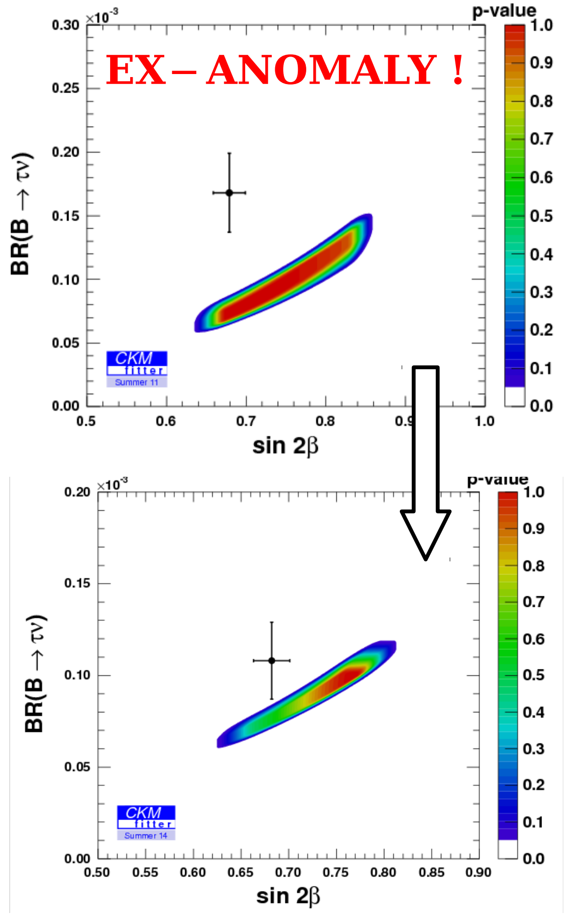
World average:

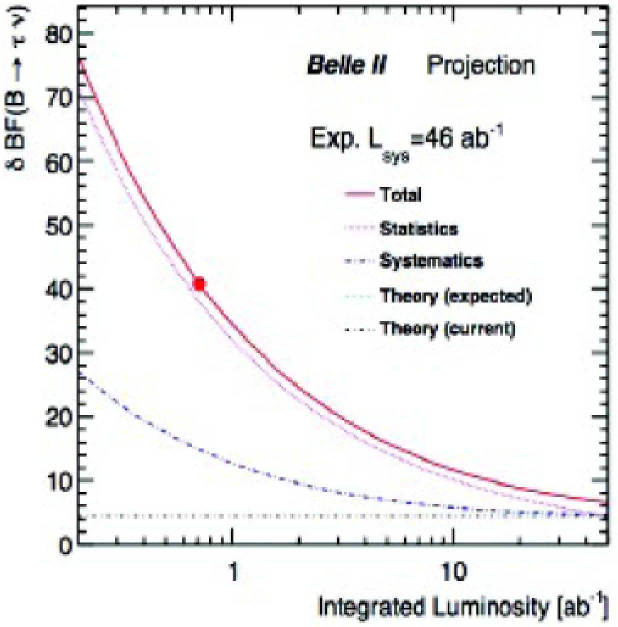
$$\mathcal{B}(B^+ \to \tau^+ \nu) = (1.15 \pm 0.23) \times 10^{-4}$$

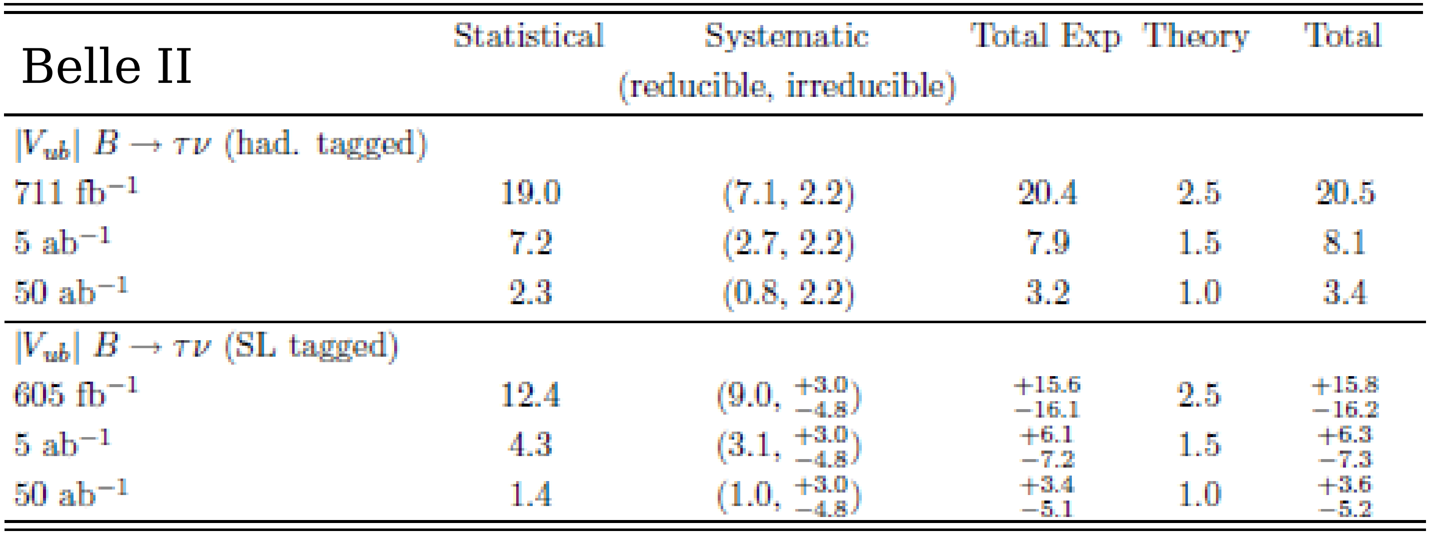
B→τν status and projections



not a single observation !!



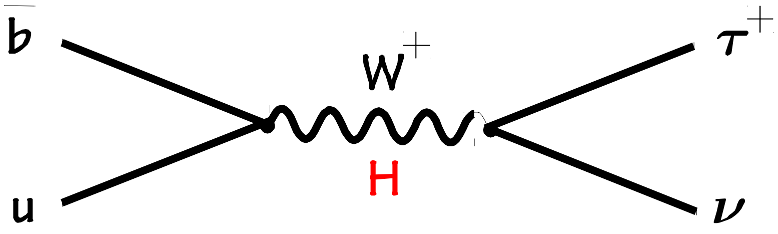




Belle II	Statistical	Systematic (reducible, irreducible)	Total Exp	Theory	Total
$\lvert V_{ub}\rvert$ $B \to \tau\nu$ (had. tagged)					
711 fb^{-1}	19.0	(7.1, 2.2)	20.4	2.5	20.5
5 ab^{-1}	7.2	(2.7, 2.2)	7.9	1.5	8.1
50 ab^{-1}	2.3	(0.8, 2.2)	3.2	1.0	3.4
$\lvert V_{ub}\rvert$ $B \to \tau\nu$ (SL tagged)					
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	$^{+3.6}_{-5.2}$

observation of B→μν is also expected (from 5 ab^{-1})

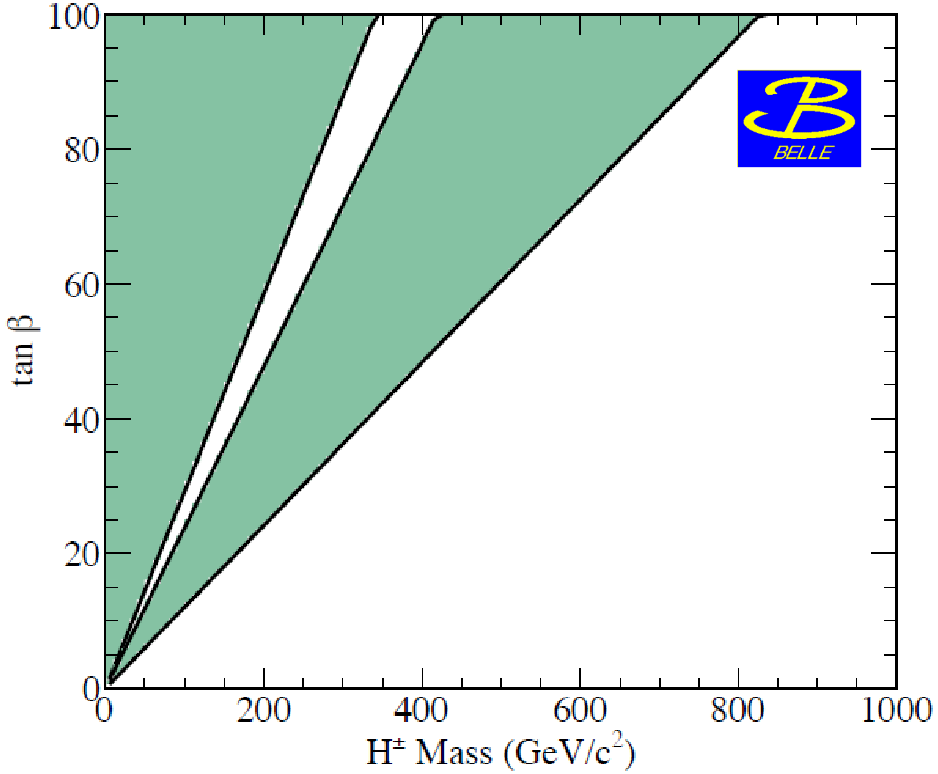
$B^+ \to \tau^+ \nu$ results

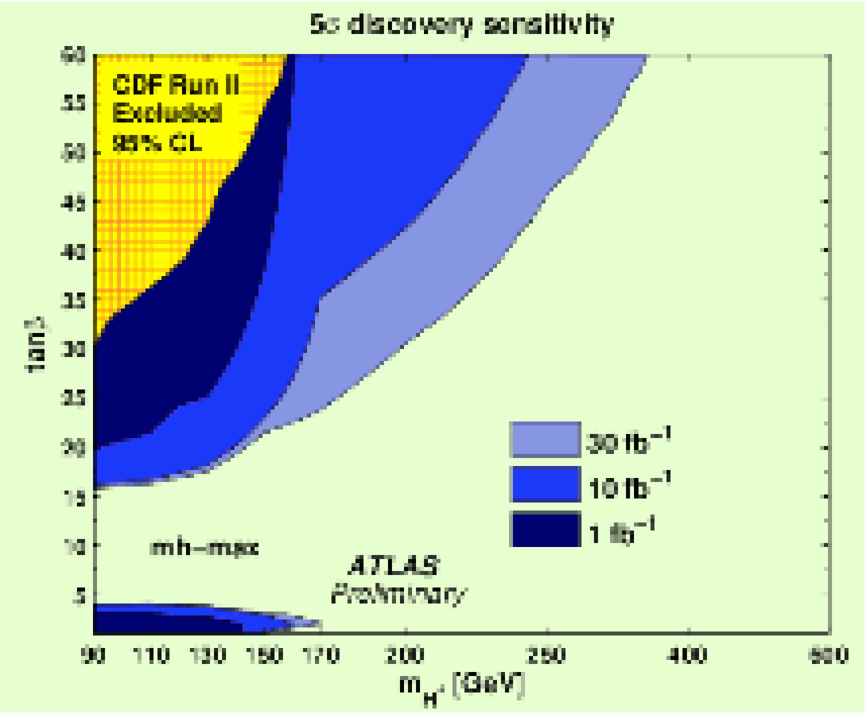


$$\mathcal{B}_{SM}(B^+\to\tau^+\nu) = \frac{G_F^2\, m_B\, m_\tau^2}{8\pi}\left(1-\frac{m_\tau^2}{m_B^2}\right) f_B^2\, |V_{ub}|^2\, \tau_B$$

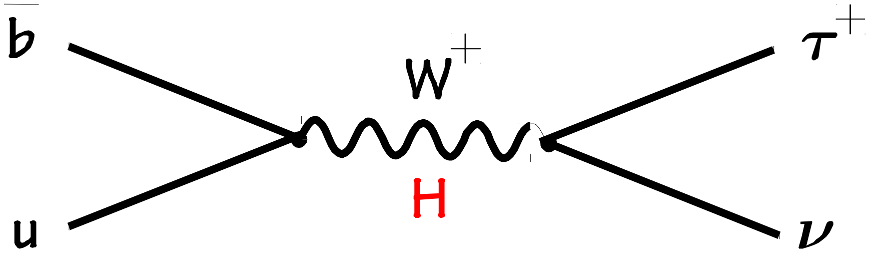
2 HDM (type II): $\mathcal{B}(B^+\to\tau^+\nu) = \mathcal{B}_{SM}\times\left(1-\frac{m_B^2}{m_{H^+}^2}\tan^2\beta\right)^2$

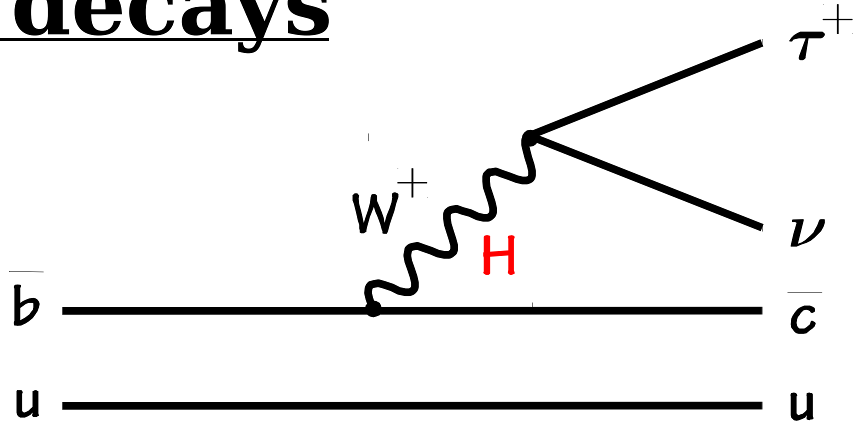
- Charged Higgs are excluded in range of reasonable masses
- Atlas and CMS are still looking [Atlas, CHARGED 2008]





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

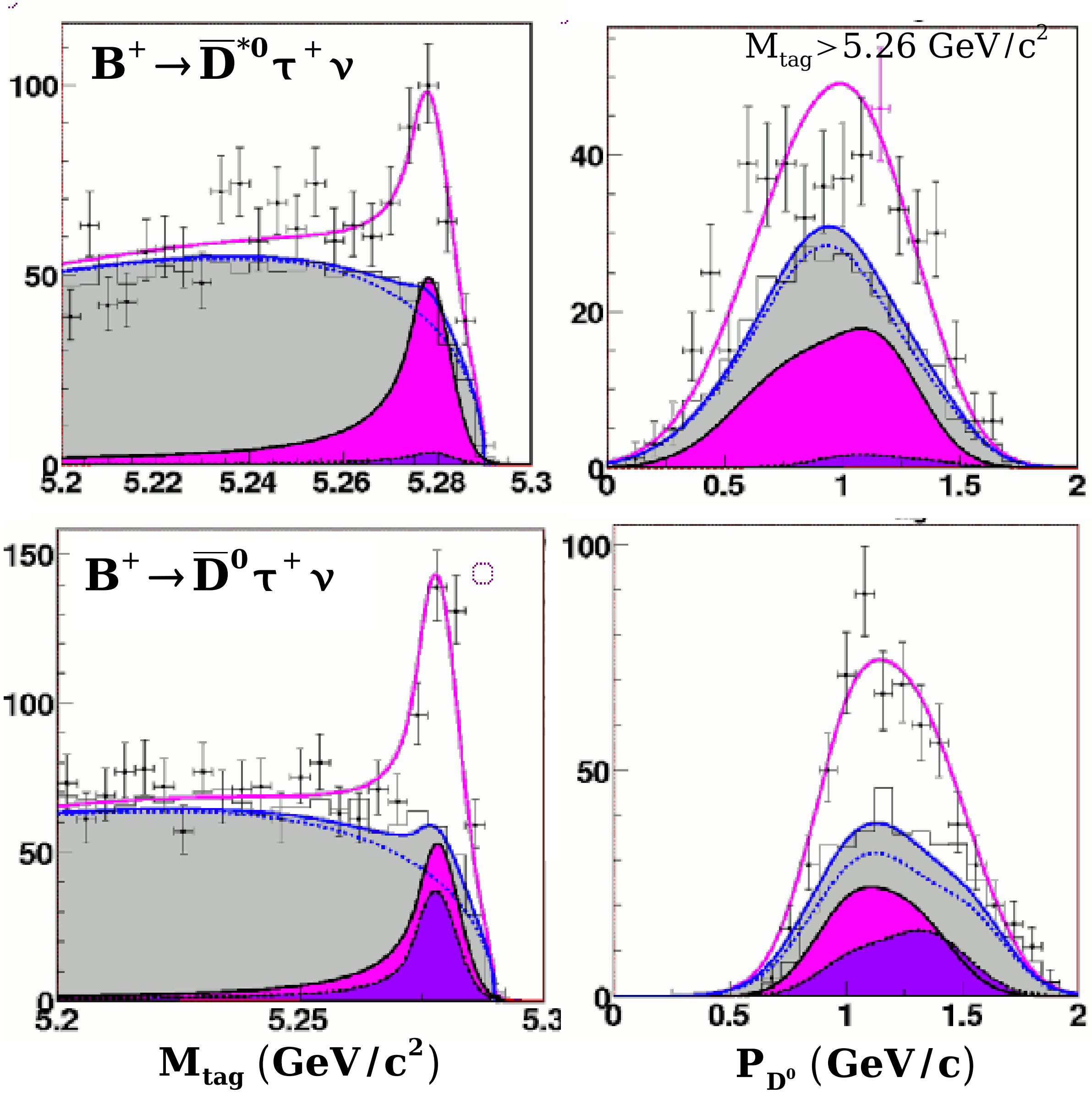
$B\to D^{(*)}\tau\nu$

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

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

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

PRD 82, 072005 (2010)
arXiv:1005.2302



- 657M $B\overline{B}$
- same method than for $B^0 \to D^{*-} \tau^+ \nu$

B_{sig}:

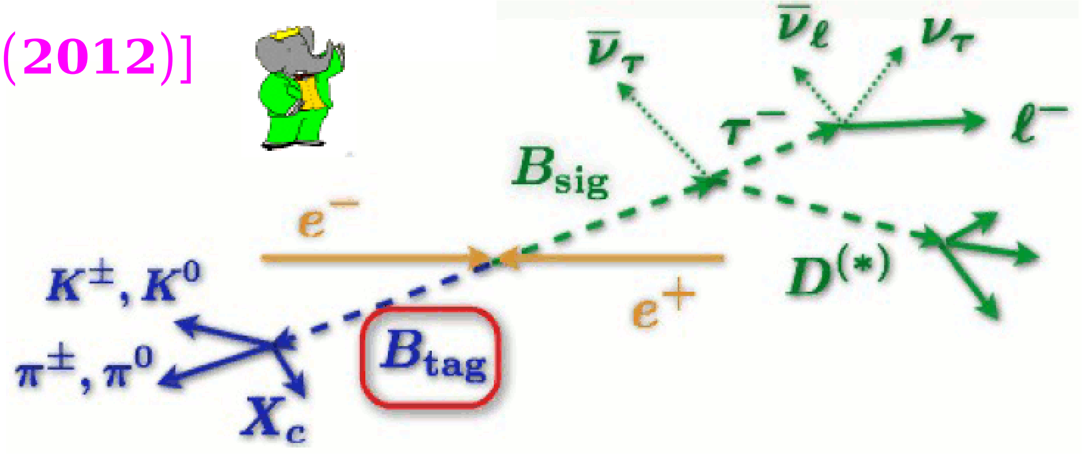
$D^0 \to K\pi,\ K\pi\pi^0$
$\tau^+ \to e^+ \nu_e \overline{\nu}_\tau,\ \mu^+ \nu_\mu \overline{\nu}_\tau,\ \pi^+ \overline{\nu}_\tau,\ \rho^+ \overline{\nu}_\tau$
13 different decay chains

B_{tag}: all remaining particles

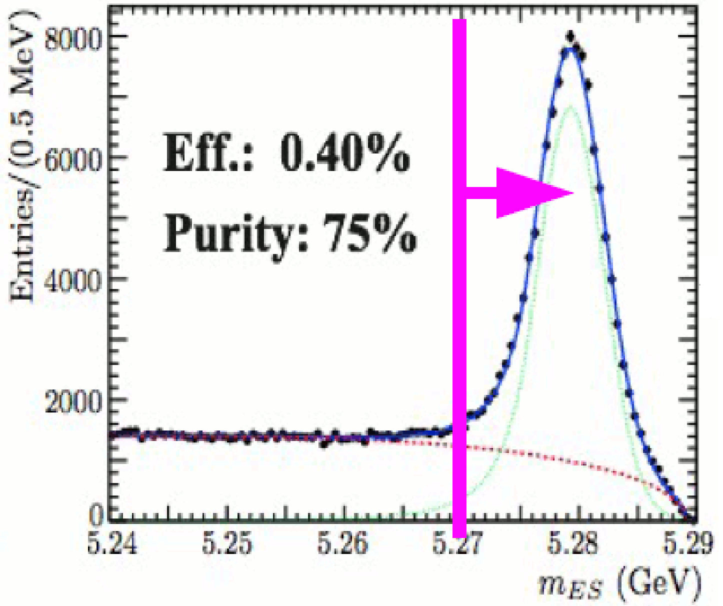
First $B^+ \to \overline{D}^0 \tau\nu$ evidence !

	N_S	$\mathcal{B}(\%)$	$\Sigma(\sigma)$
$B^+ \to \overline{D}^{*0} \tau^+ \nu$	446^{+58}_{-56} (226)	$2.12^{+0.28}_{-0.27} \pm 0.29$	8.1
$B^+ \to \overline{D}^{0} \tau^+ \nu$	146^{+42}_{-41} (15)	$0.77 \pm 0.22 \pm 0.12$	3.5

$B \to D^{(*)} \tau \nu$ [PRL 109, 101802 (2012)]

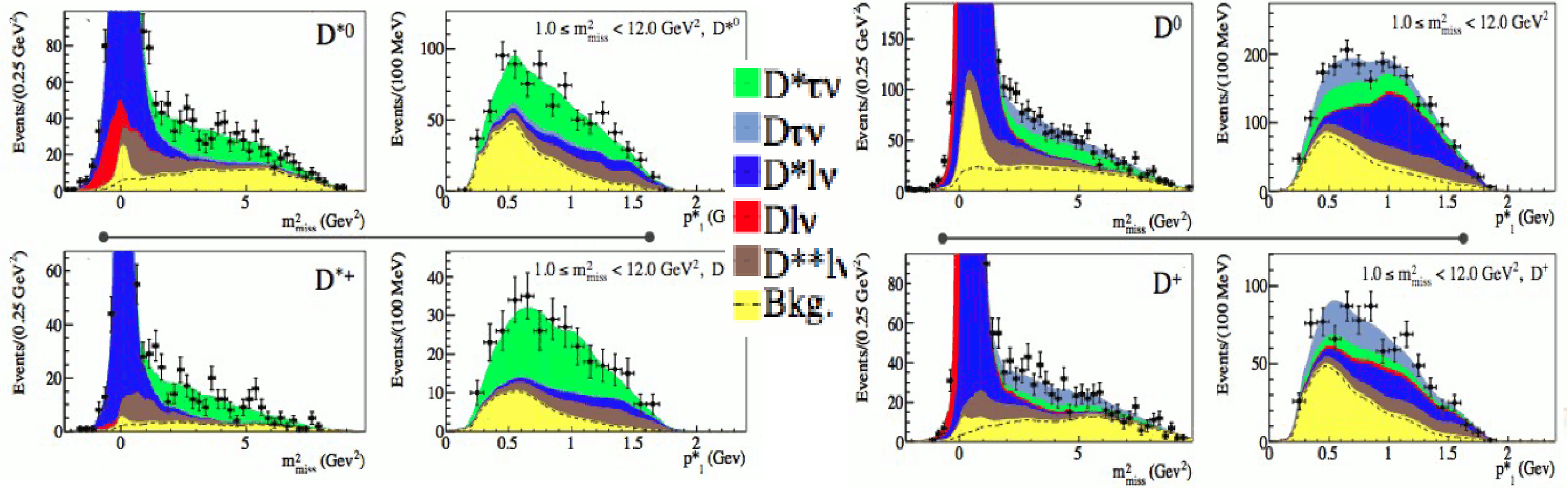


1,768 decay chains

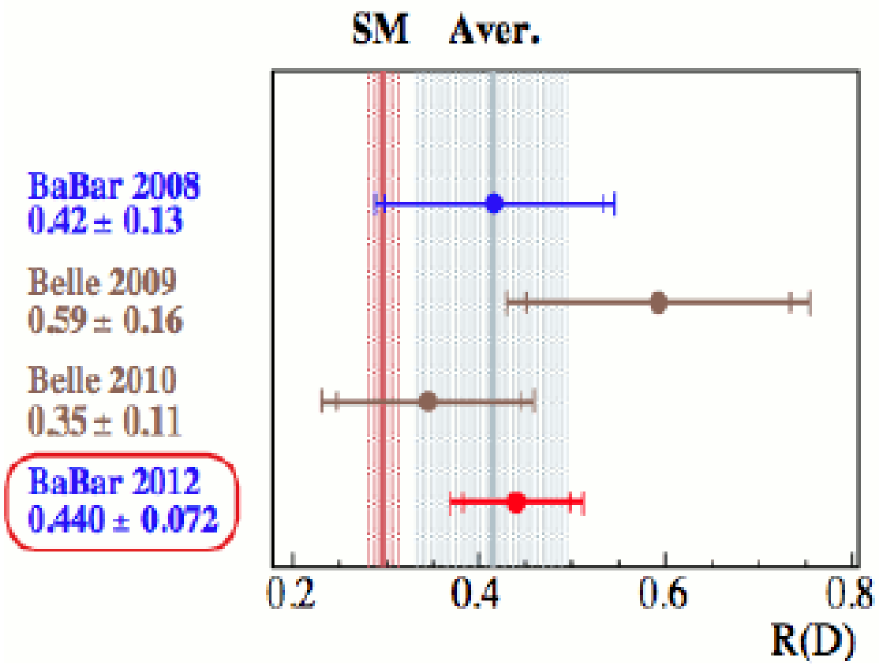


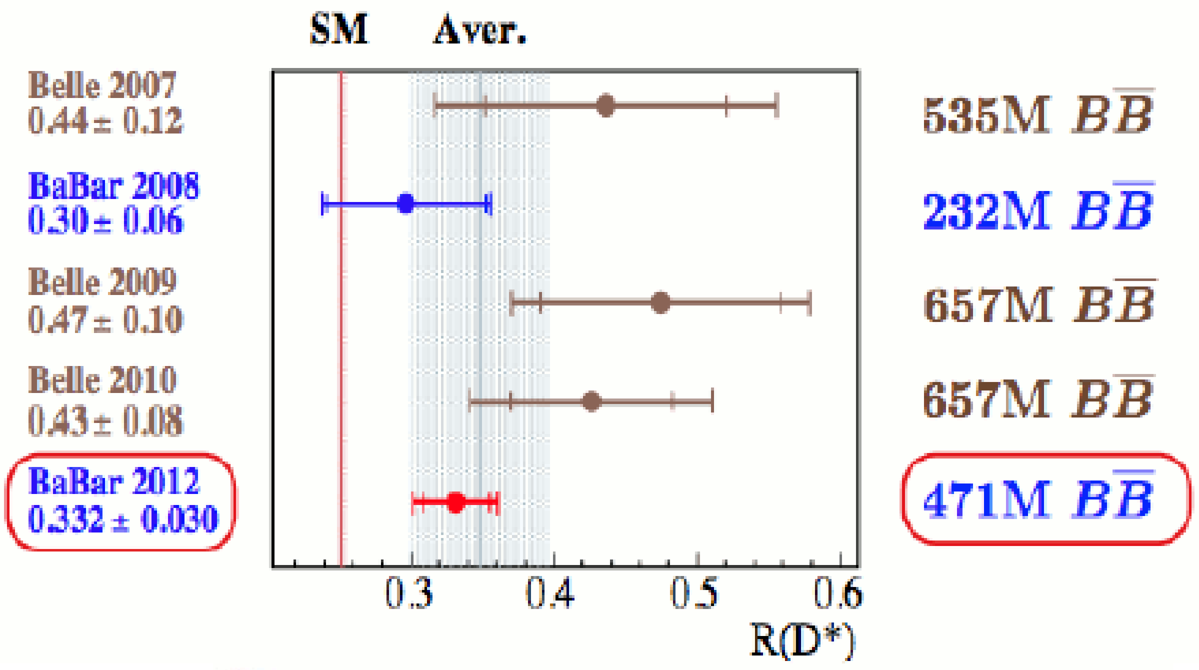
- 2D unbinned fit to m^2_{miss} and p^*_l
- fitted samples
  - 4 $D^{(*)}l$ samples ($D^0 l$, $D^{*0} l$, $D^+ l$ and $D^{*+} l$)
  - 4 $D^{(*)}\pi^0 l$ control samples ($D^{**}(l/\tau)\nu$)

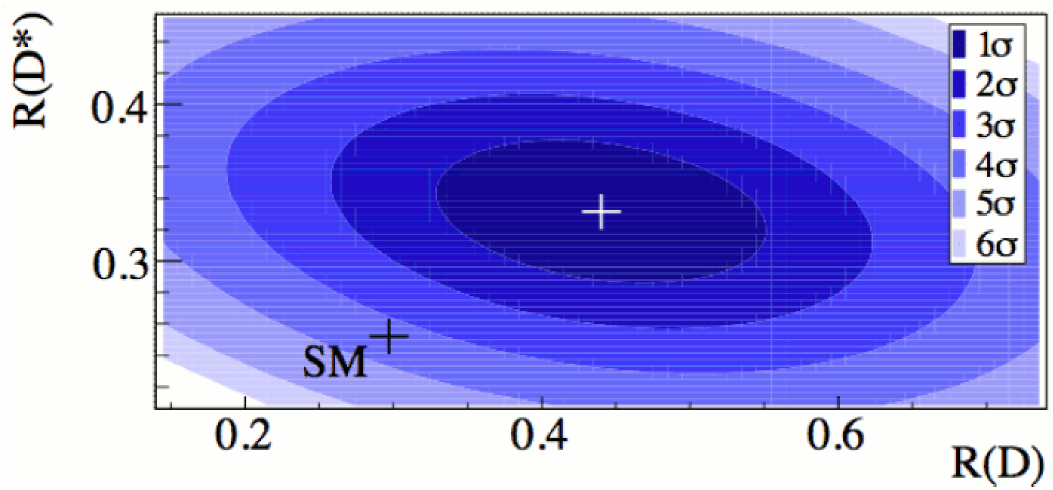
⇒ $D\tau\nu$ and $D^*\tau\nu$ clearly observed

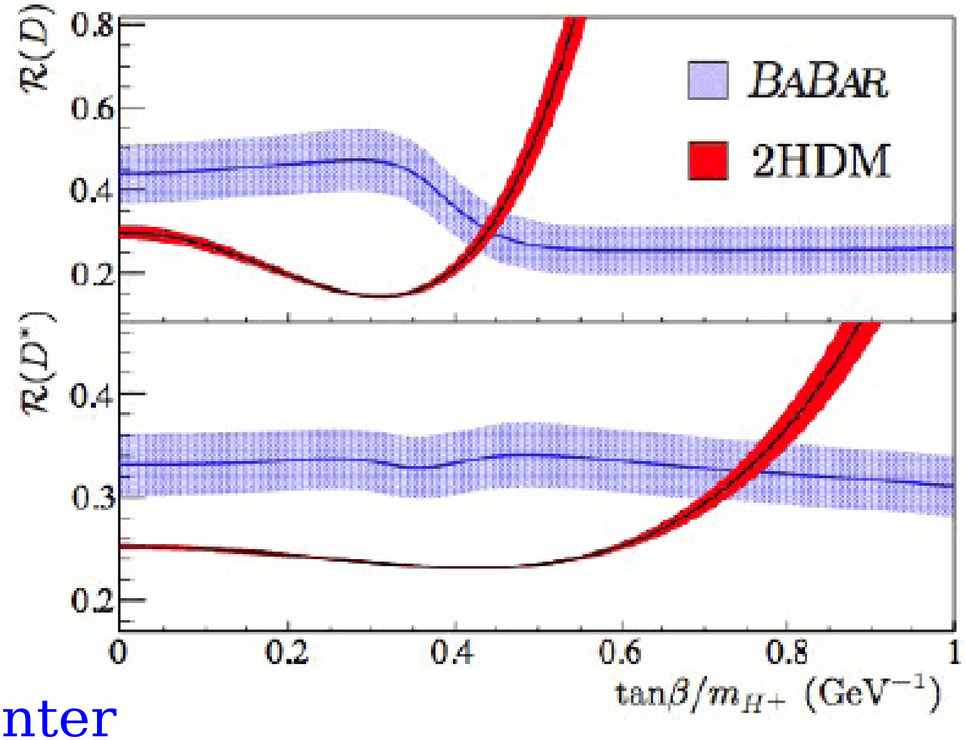


$B \rightarrow D^{(*)} \tau \nu$





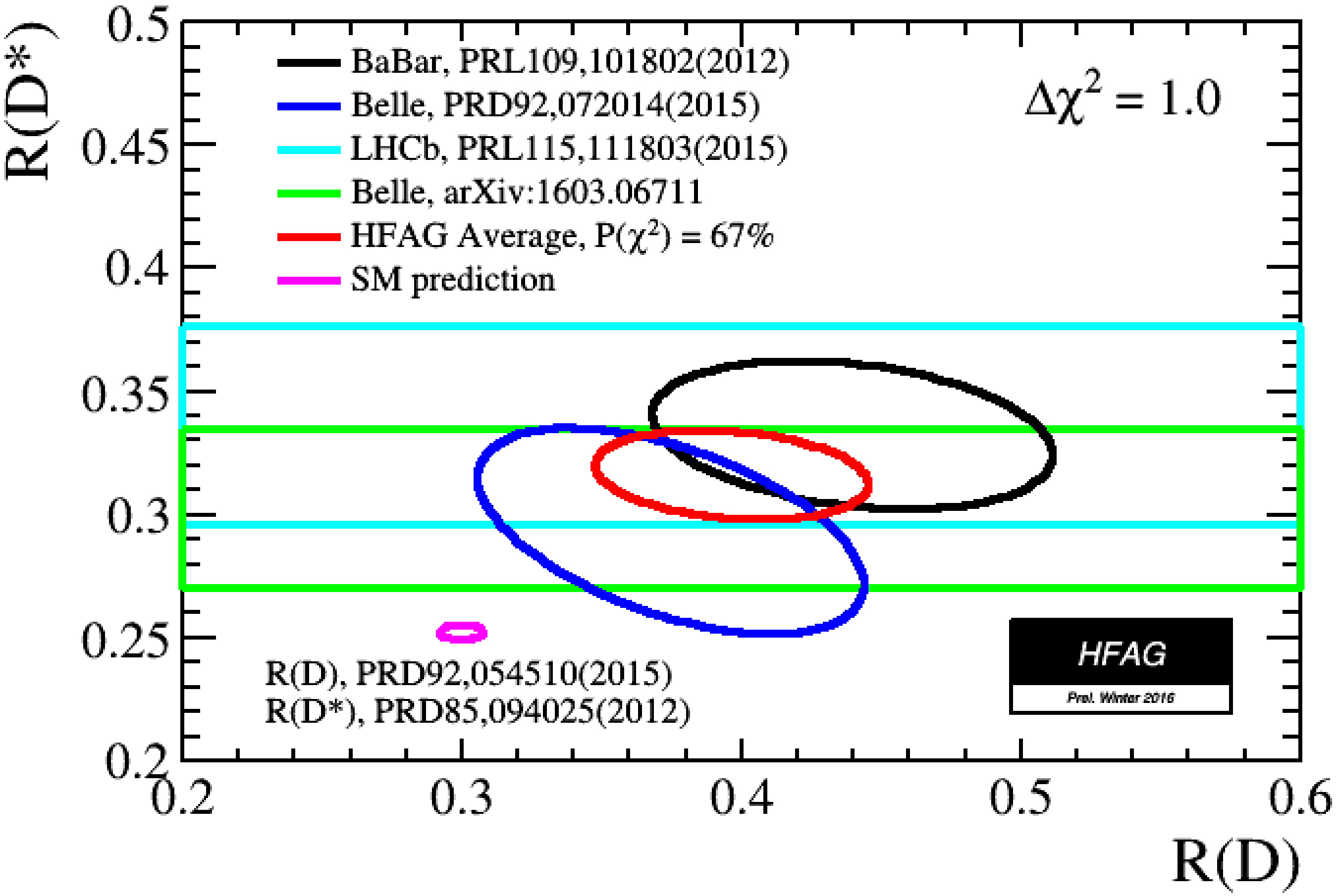




- combined 3.4 σ away from SM
- doesn't fit 2HDM Type II
- Belle will show its new result this winter

Summary for $B \rightarrow D^{(*)} \tau \nu$ in 2016

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



BaBar

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

Belle

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

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

LHCb

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

average

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

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

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

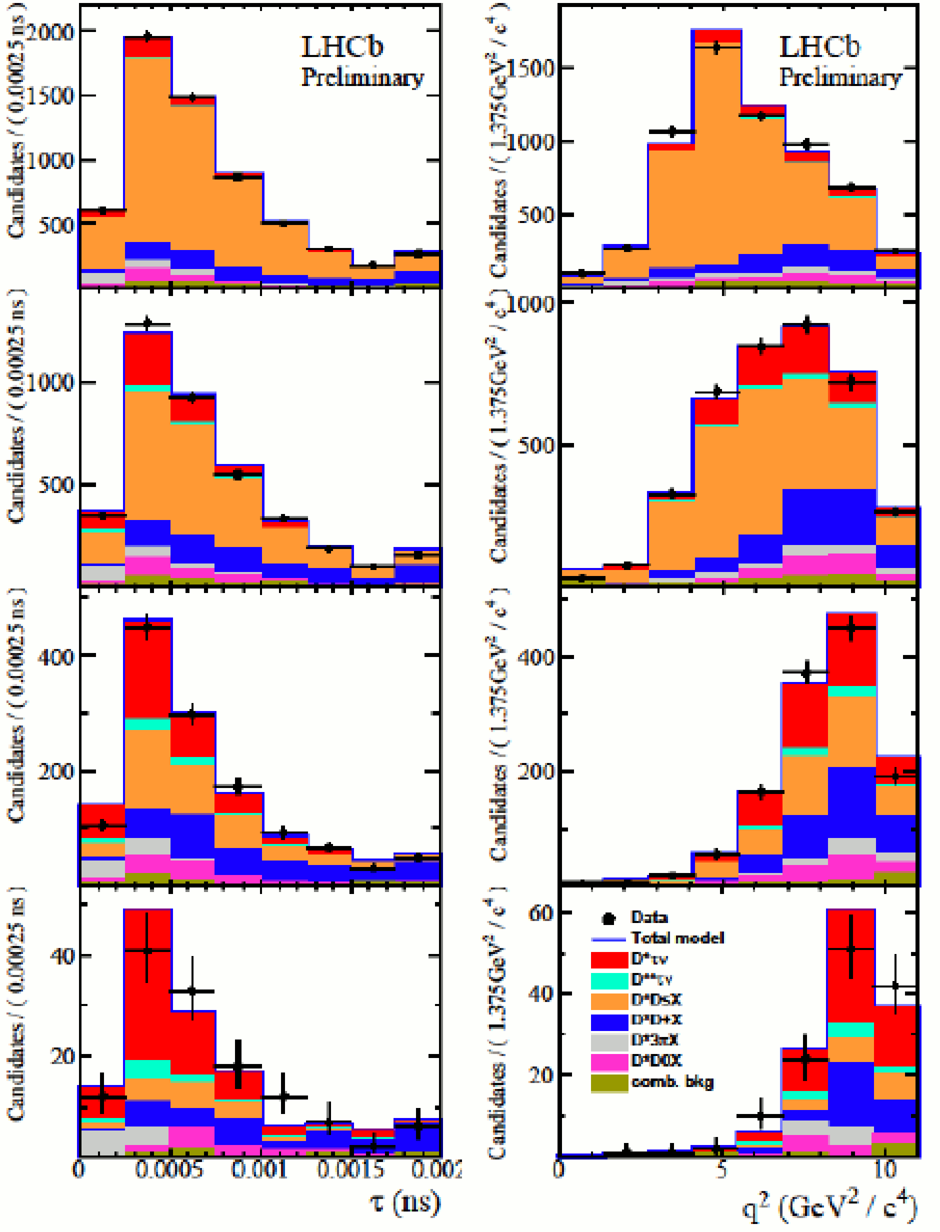
$\tau \to 3\pi(\pi^0)$

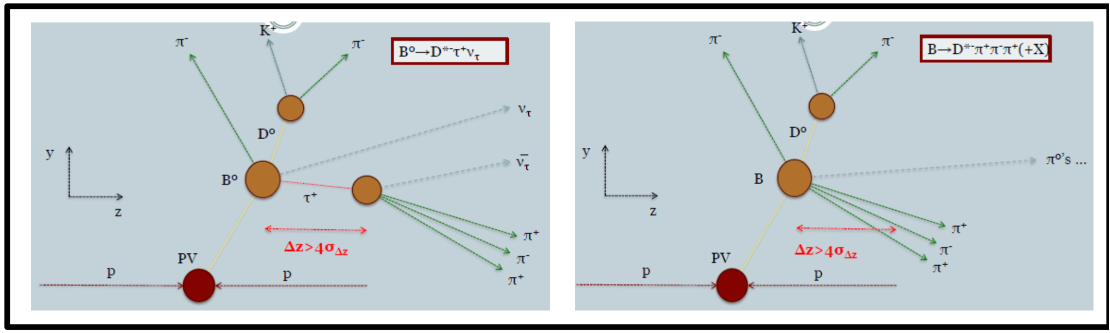
[LHCb-PAPER-2017-017]

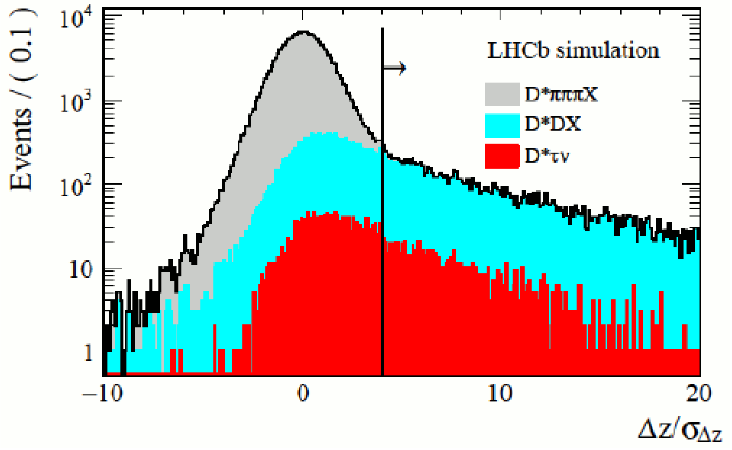
need a strong background suppression:

$B(B^0 \to D^* 3\pi + X)/B(B^0 \to D^* \tau \nu;\ \tau \to 3\pi)_{SM} \sim 100$

⇒ detached vertex method







components of 3D fit (q^2, 3π decay time, BDT):

anti-D_s

$\tau \to \pi^-\pi^+\pi^-\nu_\tau,\ \pi^-\pi^+\pi^-\pi^0\nu_\tau$

$X_b \to D^{**}\tau\nu_\tau$

$B \to D D_{s(J)} X$

$X_b \to D D X$

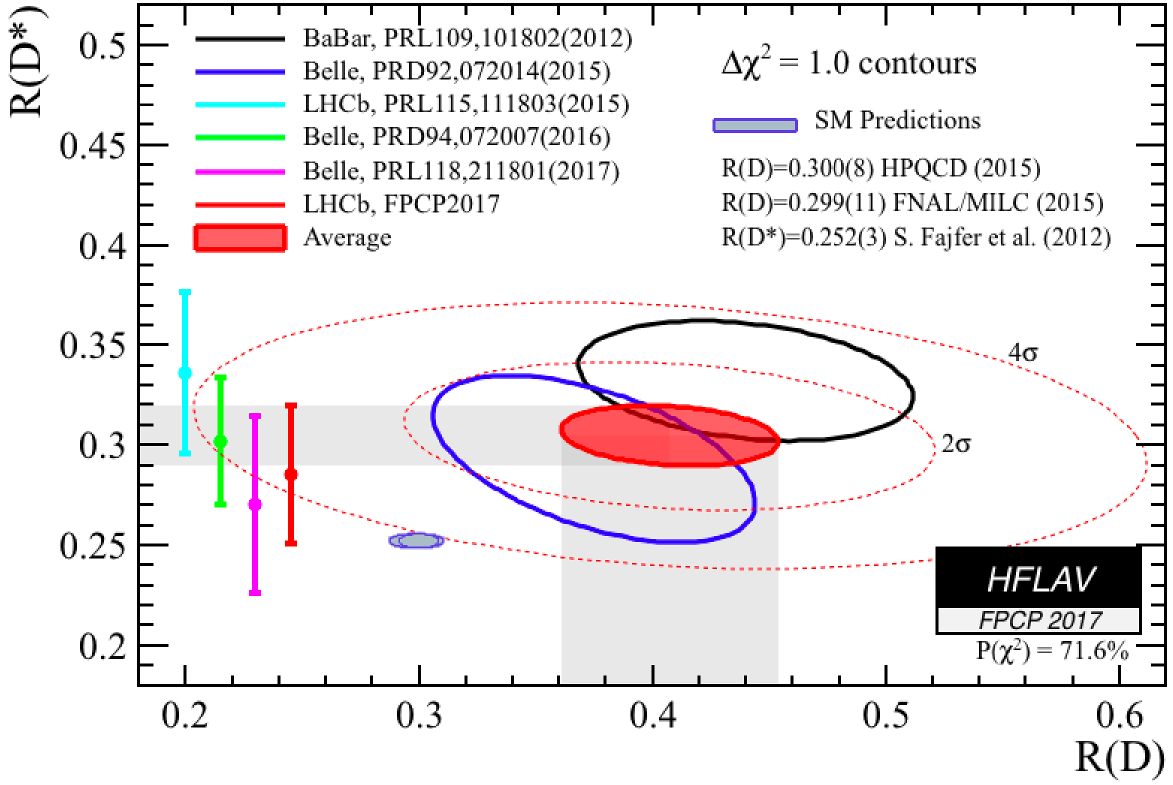
(relative) yields constrained from control samples

$B(B^0 \to D^* \tau \nu)/B(B^0 \to D^* 3\pi) = (1.93 \pm 0.13 \pm 0.17)$

⇒ **$R(D^*) = 0.285 \pm 0.019 \pm 0.025 \pm 0.014$**

$R(D)$, $R(D^*)$ still at 4σ away from SM

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



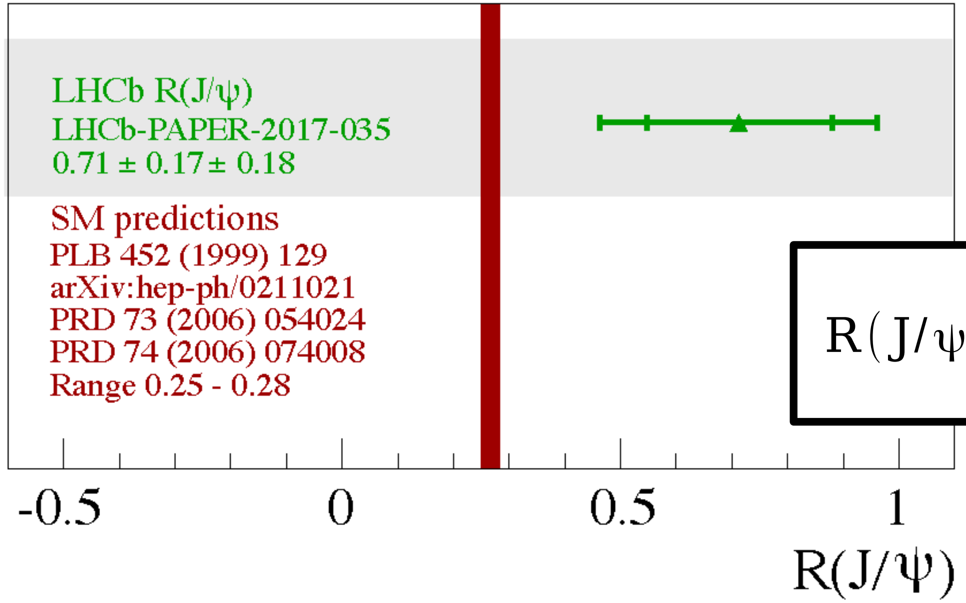
$$R(D^{(*)}) = \frac{BF(B \rightarrow D^{(*)} \tau \nu_\tau)}{BF(B \rightarrow D^{(*)} l \nu_l)}$$

$\mathbf{R(D) = 0.407 \pm 0.039 \pm 0.024}$

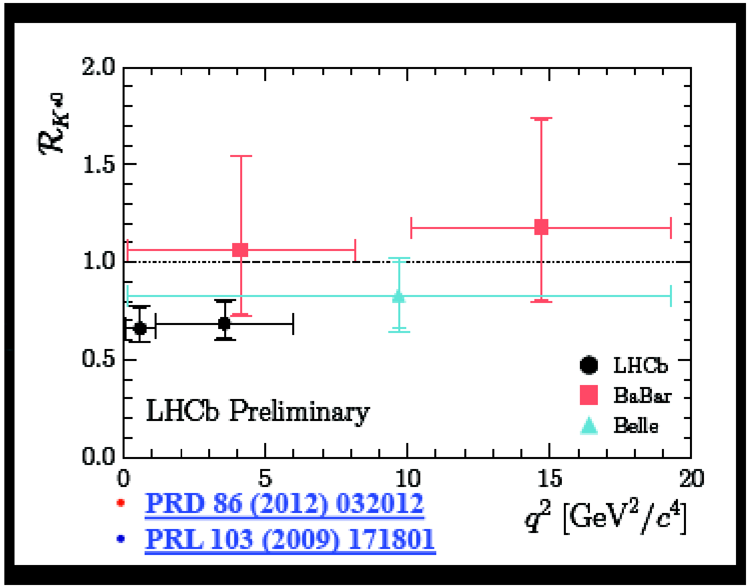
$\mathbf{R(D^*) = 0.304 \pm 0.013 \pm 0.007}$

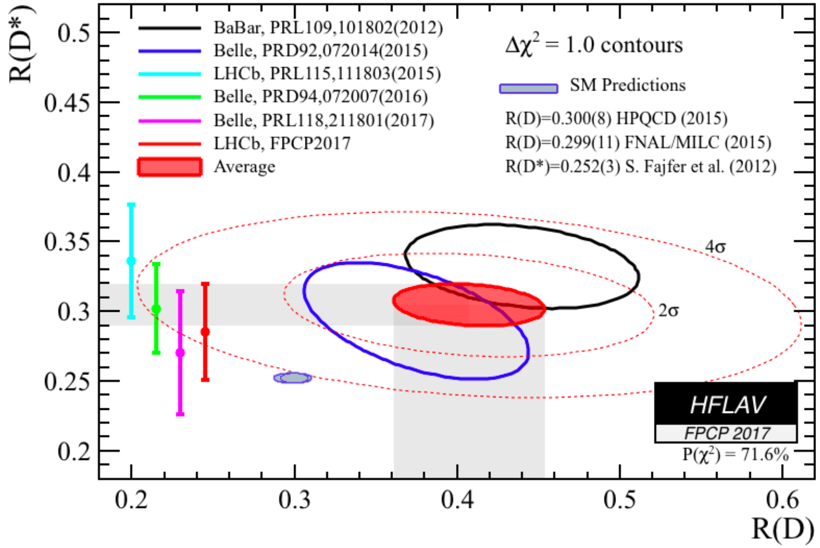
difference with SM predictions is at **4.1σ** level

$B_c \rightarrow J/\psi \tau \nu$



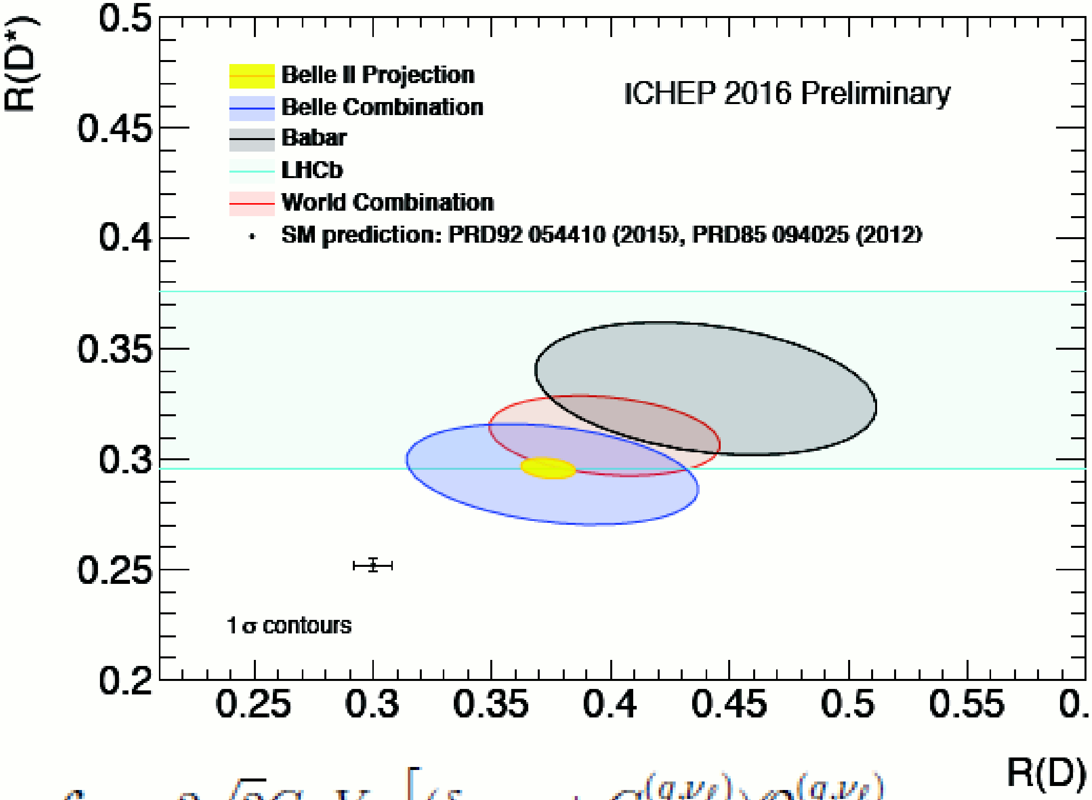
$$R(J/\psi) = \frac{BF(B_c \rightarrow J/\psi \tau \nu_\tau)}{BF(B_c \rightarrow J/\psi l \nu_l)}$$





b → s anomalies	**b → c anomalies**
Found by LHCb (and perhaps hinted by Belle)	Found by several experiments (LHCb, BaBar and Belle)
Many observables: global pattern	Two observables: R(D) and R(D*)
Neutral current	Charged current
1-loop (and CKM-suppressed) in the SM	Tree-level in the SM
The New Physics can be heavy	The New Physics must be light

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

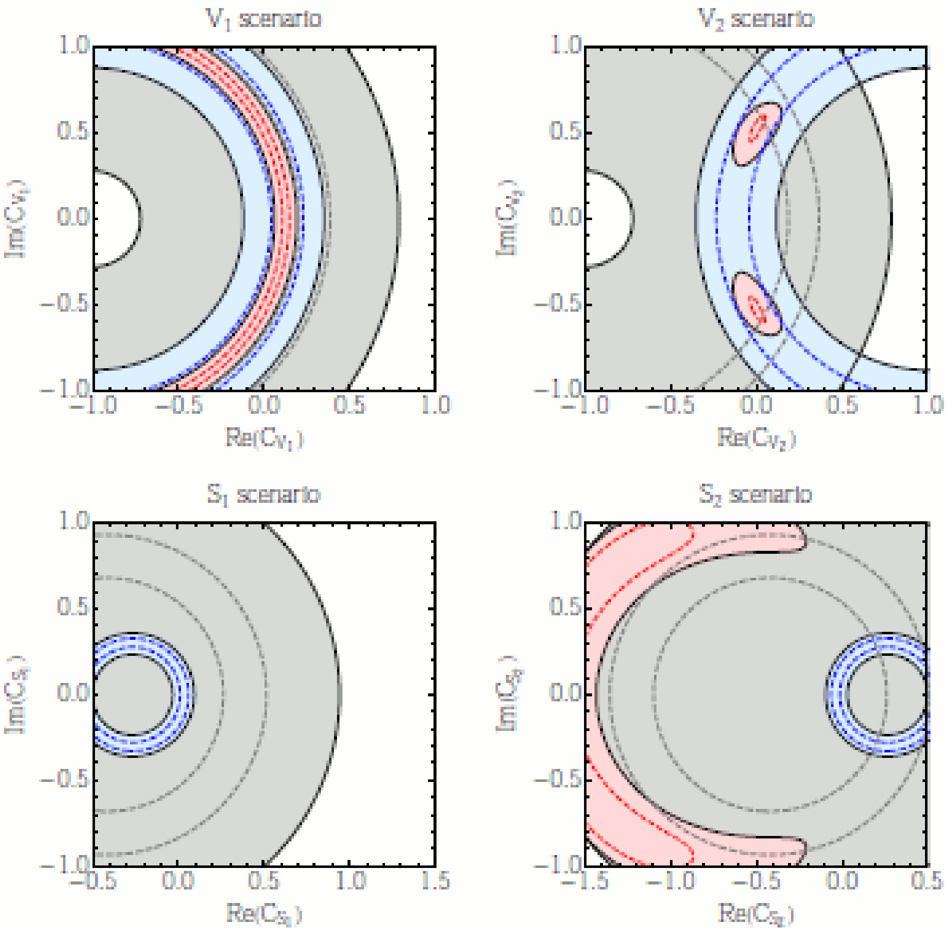


$$R(D^{(*)}) = \frac{B(B\to D^{(*)}\tau\nu)}{B(B\to D^{(*)}l\nu)}, \text{ in red}$$

$$R_{ps} = \frac{\tau_{B^0}}{\tau_{B^-}}\frac{B(B\to\tau^-\nu)}{B(B\to\pi^+l^-\nu)}, \text{ in blue}$$

$$R(\pi) = \frac{B(B\to\pi\tau\nu)}{B(B\to\pi l\nu)}, \text{ in grey}$$

Dashed: Belle II



$$-\mathcal{L}_{\rm eff} = 2\sqrt{2}G_F V_{qb}\Big[(\delta_{\nu_\tau,\nu_\ell} + C_{V_1}^{(q,\nu_\ell)})\mathcal{O}_{V_1}^{(q,\nu_\ell)} + \sum_{X=}^{V_2,S_1,S_2,T} C_X^{(q,\nu_\ell)}\mathcal{O}_X^{(q,\nu_\ell)}\Big],$$

where the four-Fermi operators:

$$\mathcal{O}_{V_1}^{(q,\nu_\ell)} = (\bar{q}\gamma^\mu P_L b)(\bar{\tau}\gamma_\mu P_L \nu_\ell),$$

$$\mathcal{O}_{V_2}^{(q,\nu_\ell)} = (\bar{q}\gamma^\mu P_R b)(\bar{\tau}\gamma_\mu P_L \nu_\ell),$$

$$\mathcal{O}_{S_1}^{(q,\nu_\ell)} = (\bar{q}P_R b)(\bar{\tau}P_L \nu_\ell),$$

$$\mathcal{O}_{S_2}^{(q,\nu_\ell)} = (\bar{q}P_L b)(\bar{\tau}P_L \nu_\ell),$$

$$\mathcal{O}_{T}^{(q,\nu_\ell)} = (\bar{q}\sigma^{\mu\nu} P_L b)(\bar{\tau}\sigma_{\mu\nu} P_L \nu_\ell)$$

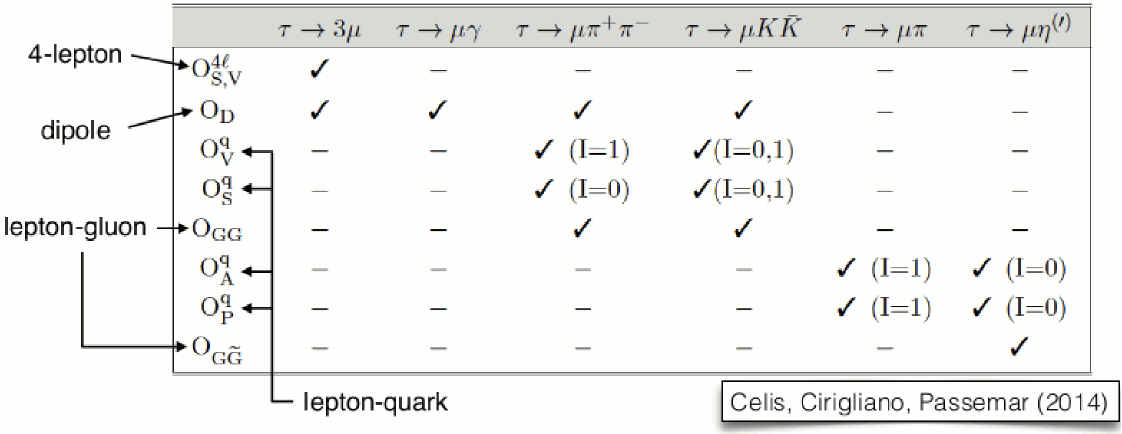
[Details in Watanabe et al, B2TiP theory]

cLFV : beyond the Standard Model

$$\mathcal{B}_{\nu SM}(\tau \to \mu\gamma) = \frac{3\alpha}{32\pi}\left|U^*_{\tau i}U_{\mu i}\frac{\Delta m^2_{3i}}{m^2_W}\right|^2 < 10^{-40}$$

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{C^{(5)}}{\Lambda}O^{(5)} + \sum_i \frac{C_i^{(6)}}{\Lambda^2}O_i^{(6)} + \ldots$$

Model	**Reference**	**τ→μγ**	**τ→μμμ**
SM+ ν oscillations	EPJ C8 (1999) 513	10^{-40}	10^{-14}
SM+ heavy Maj ν_R	PRD 66 (2002) 034008	10^{-9}	10^{-10}
Non-universal Z’	PLB 547 (2002) 252	10^{-9}	10^{-8}
SUSY SO(10)	PRD 68 (2003) 033012	10^{-8}	10^{-10}
mSUGRA+seesaw	PRD 66 (2002) 115013	10^{-7}	10^{-9}
SUSY Higgs	PLB 566 (2003) 217	10^{-10}	10^{-7}



4-lepton

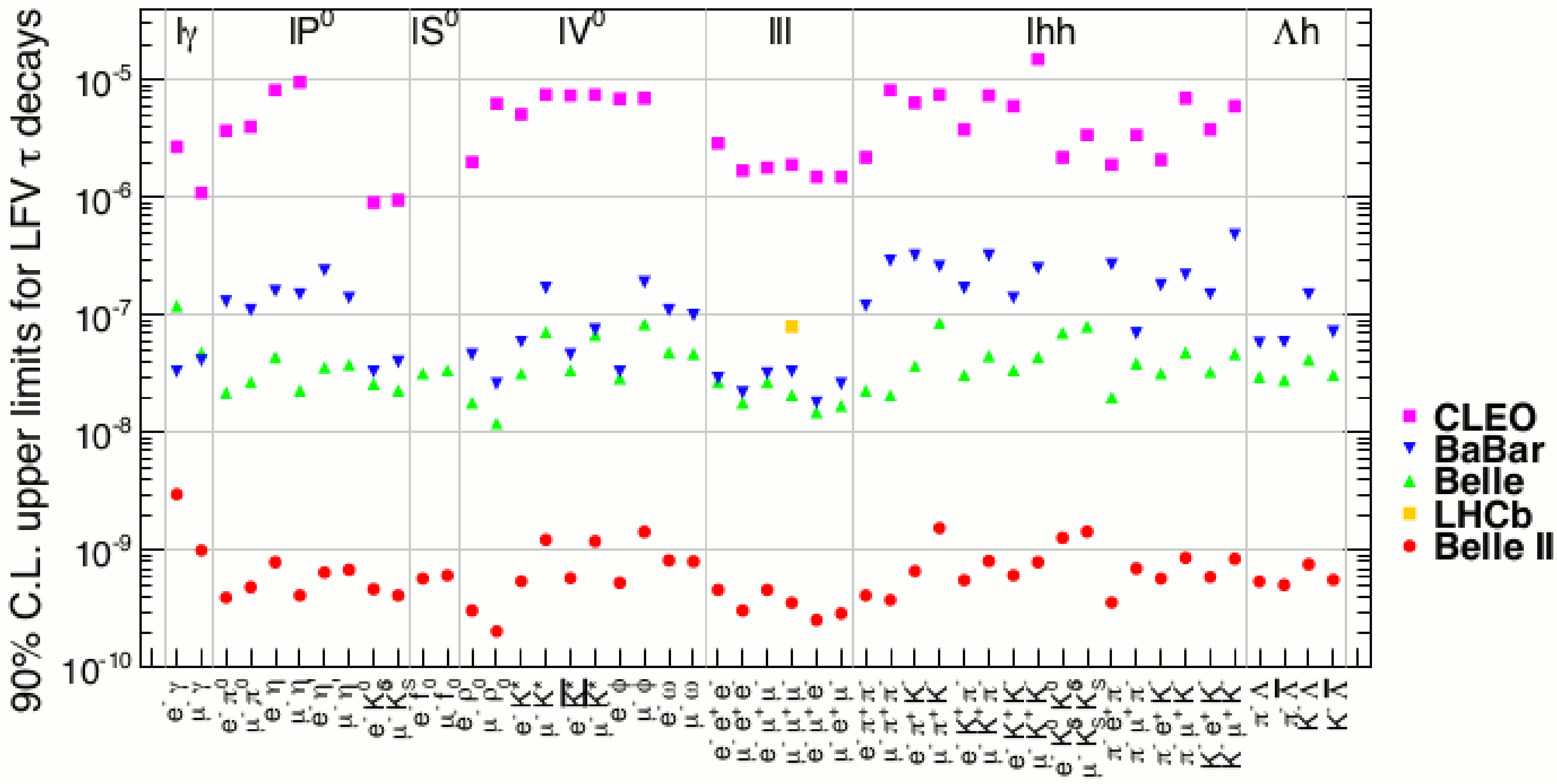
dipole

lepton-gluon

lepton-quark

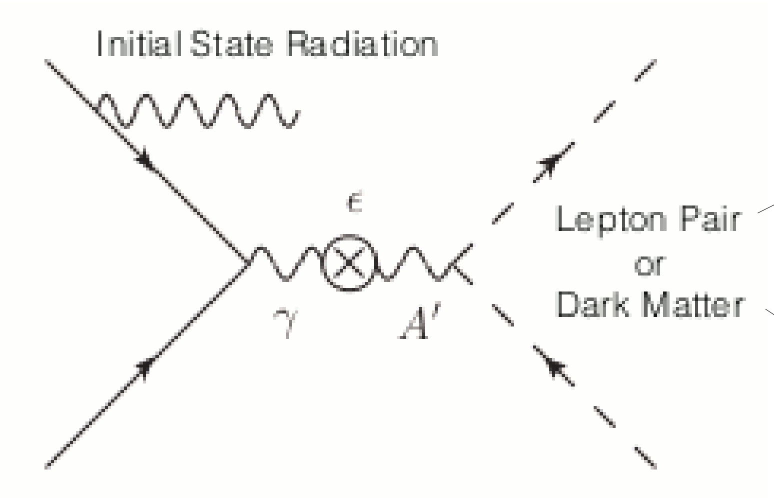
	$\tau \to 3\mu$	$\tau \to \mu\gamma$	$\tau \to \mu\pi^+\pi^-$	$\tau \to \mu K\bar{K}$	$\tau \to \mu\pi$	$\tau \to \mu\eta^{(\prime)}$
$O^{4\ell}_{S,V}$	✓	–	–	–	–	–
O_D	✓	✓	✓	✓	–	–
O^q_V	–	–	✓ (I=1)	✓(I=0,1)	–	–
O^q_S	–	–	✓ (I=0)	✓(I=0,1)	–	–
O_{GG}	–	–	✓	✓	–	–
O^q_A	–	–	–	–	✓ (I=1)	✓ (I=0)
O^q_P	–	–	–	–	✓ (I=1)	✓ (I=0)
$O_{G\tilde{G}}$	–	–	–	–	–	✓

Celis, Cirigliano, Passemar (2014)

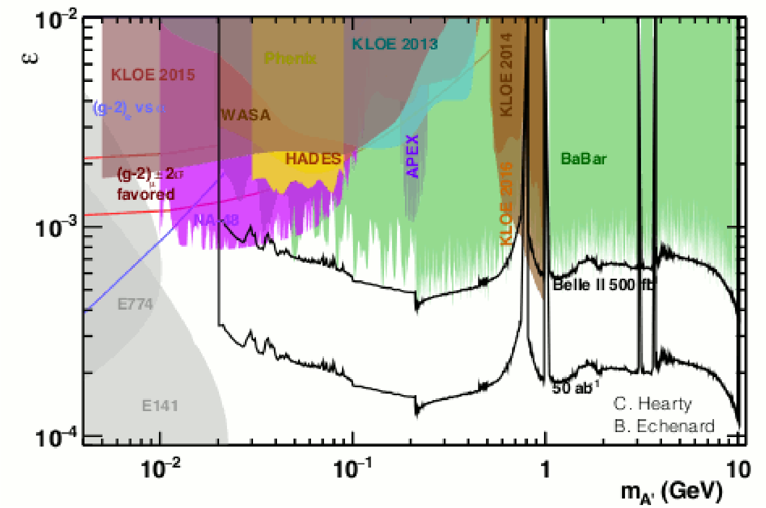


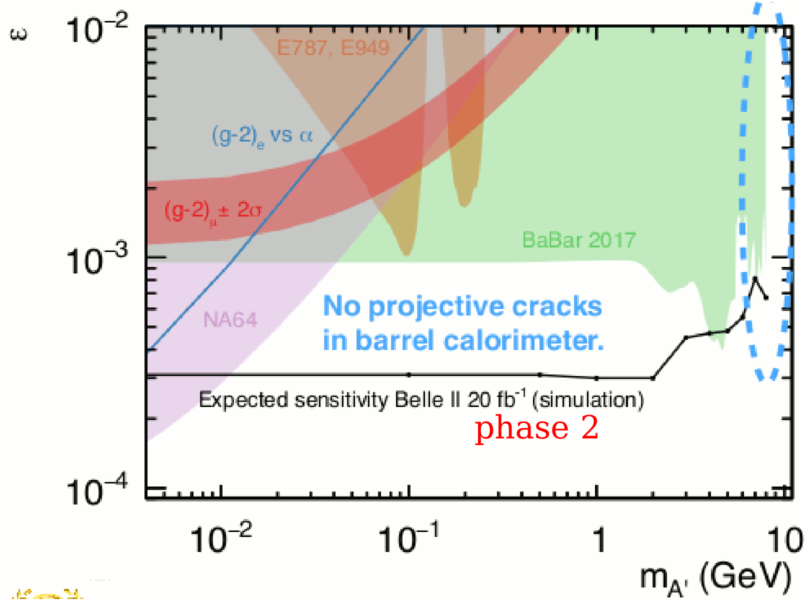
Dark Sector Physics

exploit the clean e^+e^- environment to probe the existence of exotic hadrons, dark photons/Higgs, light Dark Matter particles, ...



dark photon A' mixes with SM photon γ with strength ϵ





No projective cracks in barrel calorimeter.

phase 2

search for a dark photon decaying invisibly, and the search for an axion-like particle may be possible even in "Phase 2"

Summary

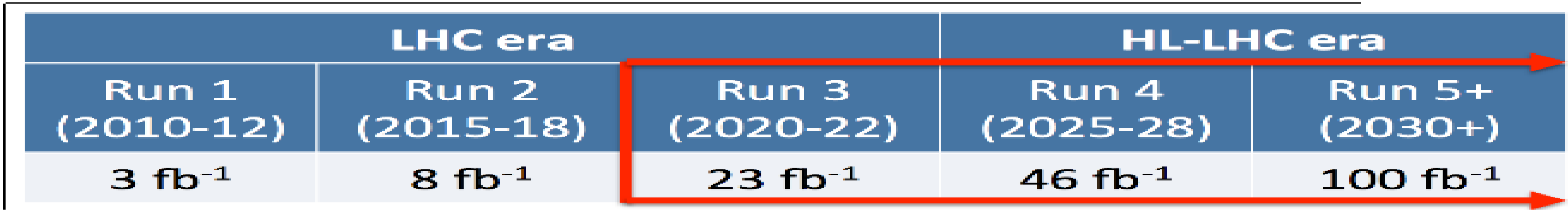
- Impressive results in radiative B decays from B-factories
- Using the full Run 1 data set the $R_{K^{*0}}$ ratio has been measured by LHCb with the best precision to date in two q^2 bins
- The compatibility of the result with respect to the SM prediction(s) is of 2.2-2.5 standard deviations in each q^2 bin
- The result is particularly interesting given a similar behaviour in R_K
- Rare decays will largely benefit from the increase of energy (cross-section) and collected data (~5 fb^{-1} expected in LHCb) in Run2
- LHCb and Belle II have a wide programme of LU tests based on similar ratios, as well as searches for LFV decays
- Similarly, for B decays with tau in final states
- Many improvements and new results to come..

Outlook

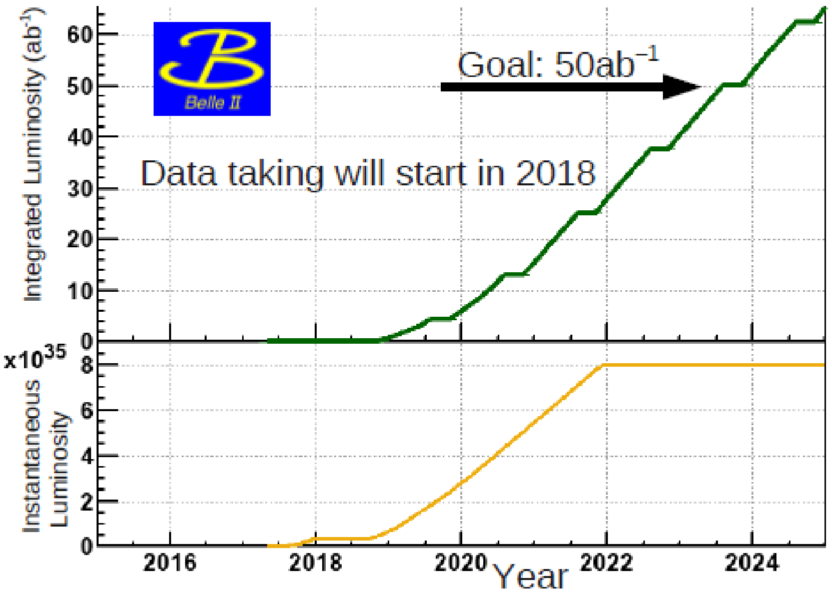
- Few tantalizing results on rare decays in B sector covered in this talk… but much more in B decays: LFV searches, $B \rightarrow K^{(*)} \nu \bar{\nu}$, $B \rightarrow \tau \nu$, $\mu \nu$…

  also in charm, charmonium, bottomonium, light Higgs, τ, DS, kaon sectors…

- Definitely not only complementary, but stimulating competition between (super) B-factories and LHCb (upgrade):
  - for the expected: results on $B_{(s)} \rightarrow \mu\mu$, $B \rightarrow K^* \mu\mu$, $B_s \rightarrow J/\psi \phi$, γ angle…
  - for the less expected: results on $|V_{ub}|$, $D^* \tau \nu$…

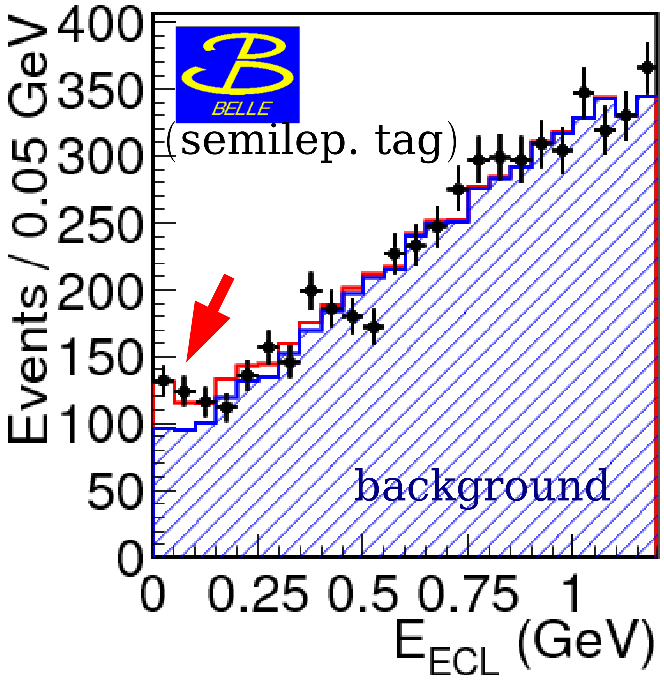


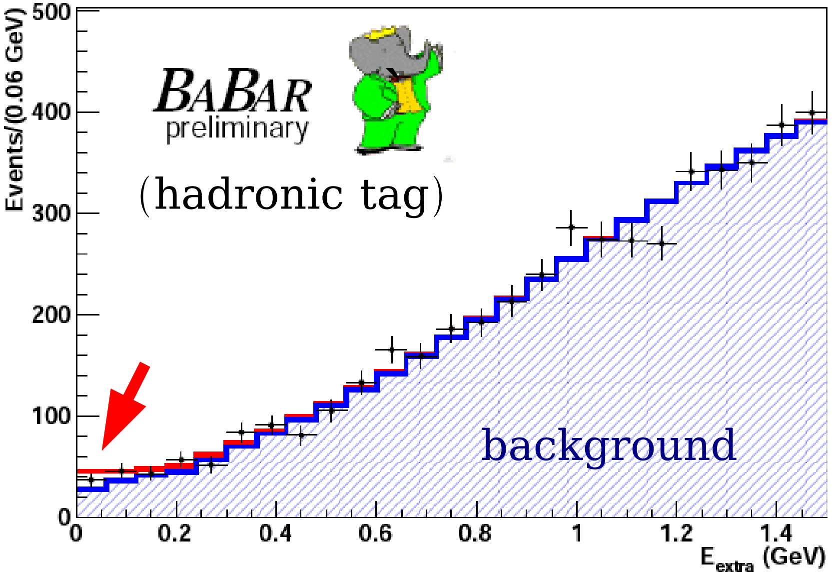
LHC era			HL-LHC era	
Run 1 (2010-12)	Run 2 (2015-18)	Run 3 (2020-22)	Run 4 (2025-28)	Run 5+ (2030+)
3 fb^{-1}	8 fb^{-1}	23 fb^{-1}	46 fb^{-1}	100 fb^{-1}



$B^+ \to \tau^+ \nu$ results

- Fully reconstruct one of the B (hadronic, semi-leptonic)
- Look for a single lepton or pion from $\tau \to l \nu \bar{\nu}$ or $\tau \to \pi \bar{\nu}$
- Require nothing else in the detector $\Rightarrow$ Signal has 0 energy in the ECAL





Extra calorimeter energy: $E_{ECL/extra}$ (GeV)

Belle	$N_{B\bar{B}}$	$\mathcal{B}\,(10^{-4})$	$\Sigma(\sigma)$	
Hadronic tag	(449 M)	$(1.79^{+0.56}_{-0.49}{}^{+0.46}_{-0.51})$	3.5	PRL 97, 251802 (2006)
Semilep. tag	(657 M)	$(1.54^{+0.38}_{-0.37}{}^{+0.29}_{-0.31})$	3.6	PRD 82, 071101 (2010)
BaBar				
Hadronic tag	(468 M)	$(1.80^{+0.57}_{-0.54} \pm 0.26)$	3.6	preliminary
Semilep. tag	(459 M)	$(1.7 \pm 0.8 \pm 0.2)$	2.3	PRD 81, 051101 (2010)

$B^+ \to \tau^+ \nu$ results

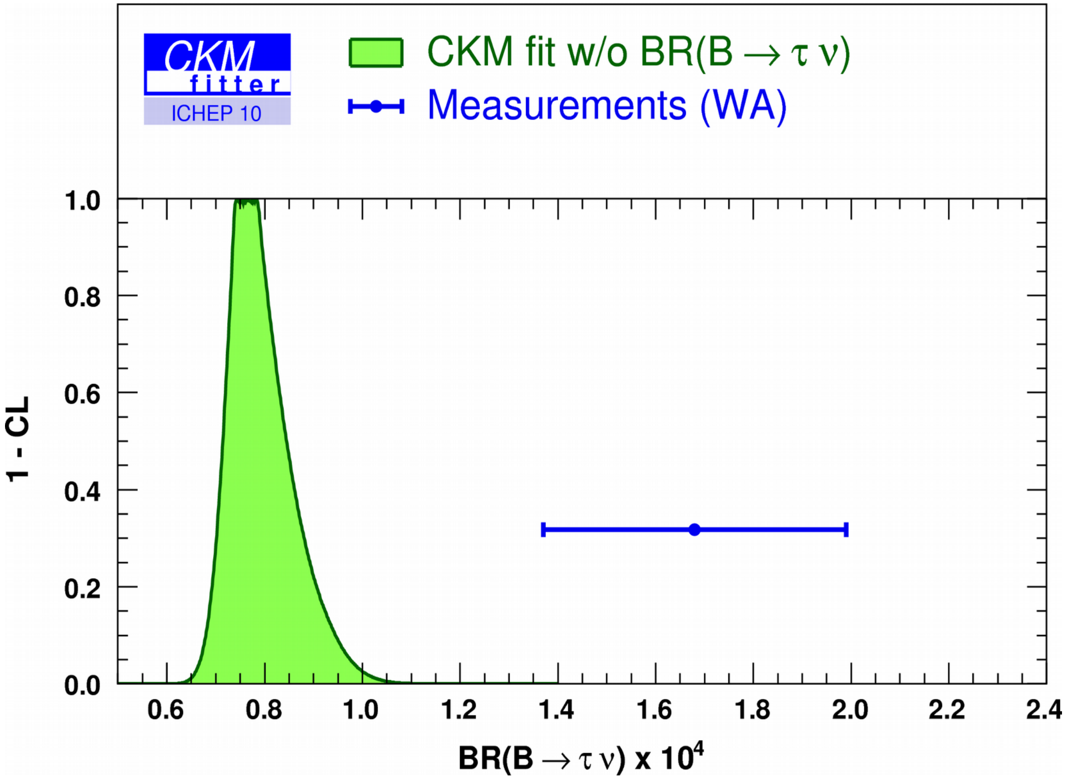
World average: $\mathcal{B}(B^+ \to \tau^+ \nu) = (1.68 \pm 0.31) \times 10^{-4}$

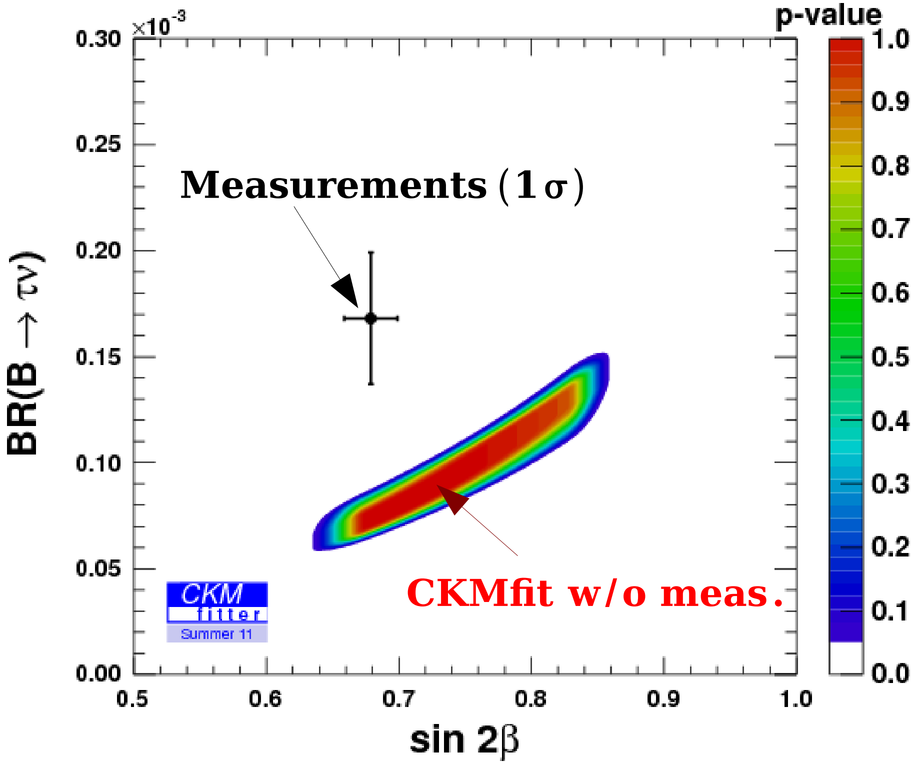
$$\mathcal{B}_{SM}(B^+ \to \tau^+ \nu) = (1.20 \pm 0.25) \times 10^{-4}$$

using f_B (HPQCD), $|V_{ub}|$ (HFAG)

$$\text{CKMfitter}: \mathcal{B}_{SM}(B^+ \to \tau^+ \nu) = (0.76^{+0.11}_{-0.06}) \times 10^{-4}$$

2.8σ difference



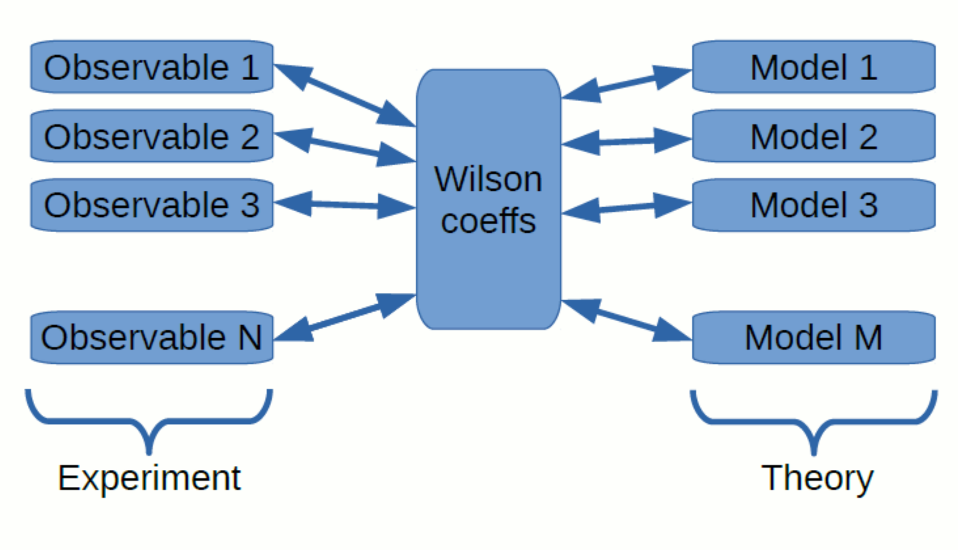


Measurements (1σ)

CKMfit w/o meas.

⇒ within the SM, either the observed BR[$B \to \tau \nu$] is too high, either $\sin 2\beta_{cc}$ is too low

Sensitivity to new physics in rare B decays



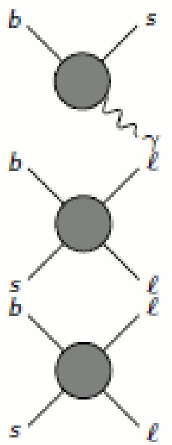
M.Ciuchini et al, arXiv:1512.07157
T.Hurth et al, arXiv:1603.00865
S.Descotes-Genon et al, arXiv:1510.04239...

NP changes short-distance C_i
and/or add new long-distance ops O'_i

- Model-independent description in effective field theory

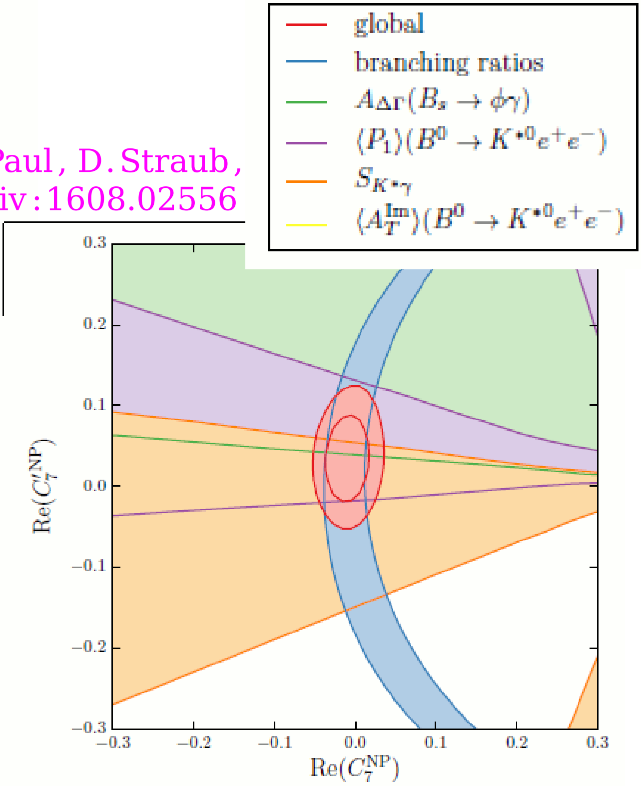
$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{\rm tb}V_{\rm ts}^* \sum_i \underbrace{\mathcal{C}_i\mathcal{O}_i}_{\text{Left-handed}} + \underbrace{\mathcal{C}'_i\mathcal{O}'_i}_{\text{Right-handed, } \frac{m_s}{m_b} \text{ suppressed}}$$

- Wilson coefficients $\mathcal{C}_i^{(\prime)}$ encode short-distance physics, $\mathcal{O}_i^{(\prime)}$ corr. operators



	$b \to s\gamma$	$B \to \mu\mu$	$b \to s\ell\ell$
$\mathcal{O}_7^{(\prime)}$ photon penguin	✓		✓
$\mathcal{O}_9^{(\prime)}$ vector coupling			✓
$\mathcal{O}_{10}^{(\prime)}$ axialvector coupling		✓	✓
$\mathcal{O}_{S,P}^{(\prime)}$ (pseudo)scalar penguin		✓	

A.Paul, D.Straub,
arXiv:1608.02556



Lepton flavor universality in the Standard Model

Fermion masses

In the SM, fermions get their masses via Yukawa couplings with the Higgs doublet Φ

For example, for the leptons:

$$\mathcal{L}_Y^\ell = Y_e \bar{\ell}_L \Phi e_R + \text{h.c.} = \frac{1}{\sqrt{2}}(v+h) Y_e \begin{pmatrix} \bar{\nu} & \bar{e} \end{pmatrix}_L \begin{pmatrix} 0 \\ 1 \end{pmatrix} e_R + \text{h.c.}$$

$$= \mathcal{M}_e \bar{e}_L e_R + \frac{\mathcal{M}_e}{v} h \bar{e}_L e_R + \text{h.c.}$$

where

$$\mathcal{M}_e = \frac{v}{\sqrt{2}} Y_e$$

3x3 charged lepton mass matrix

Similarly, one obtains

$$\mathcal{L}_m^F = \mathcal{M}_e \bar{e}_L e_R + \mathcal{M}_u \bar{u}_L u_R + \mathcal{M}_d \bar{d}_L d_R + \text{h.c.}$$

$$\mathcal{M}_f = \frac{v}{\sqrt{2}} Y_f$$

$$f = e, u, d$$

Fermion masses

- It is remarkable that the same mechanism that gives mass to the gauge bosons (SSB), also gives a mass to the fermions
- Neutrinos do not get a mass. This can be traced back to the absence of right-handed neutrinos.
- In general, these mass mass matrices are not diagonal: they must be diagonalized to get the mass eigenstates and eigenvalues

Biunitary transformations

$$\begin{aligned} f_L &= U_f \widehat{f}_L \\ f_R &= V_f \widehat{f}_R \end{aligned} \quad \Longrightarrow \quad \widehat{\mathcal{M}}_f = U_f^\dagger \mathcal{M}_f V_f$$

gauge eigenstates

mass eigenstates

For example, for the charged leptons:

$$\widehat{\mathcal{M}}_e = U_e^\dagger \mathcal{M}_e V_e = \mathrm{diag}\left(m_e, m_\mu, m_\tau\right)$$

The electroweak currents

In order to find the fermionic currents we must expand the fermion kinetic Lagrangian:

$$\mathcal{L}_{\text{kin}} \supset \bar{\ell}_L \left(g\frac{\vec{\tau}}{2}\vec{W}_\mu - \frac{g'}{2}B_\mu \right) \gamma^\mu \ell_L + \bar{q}_L \left(g\frac{\vec{\tau}}{2}\vec{W}_\mu + \frac{g'}{6}B_\mu \right) \gamma^\mu q_L$$

$$-\bar{e}_R g' B_\mu \gamma^\mu e_R + \bar{u}_R \frac{2}{3} g' B_\mu \gamma^\mu u_R - \bar{d}_R \frac{1}{3} g' B_\mu \gamma^\mu d_R$$

$$= \underbrace{g J^1_\mu W^{1\mu} + g J^2_\mu W^{2\mu}}_{\downarrow \\ \text{Charged current}} + \underbrace{g J^3_\mu W^{3\mu} + g' J^Y_\mu B^\mu}_{\downarrow \\ \text{Neutral current}}$$

The neutral current

$$\mathcal{L}_{\text{nc}} = g J^3_\mu W^{3\mu} + g' J^Y_\mu B^\mu$$

$$\begin{cases} J^3_\mu = \dfrac{1}{2}\left(\overline{\nu}_L\gamma_\mu\nu_L - \overline{e}_L\gamma_\mu e_L + \overline{u}_L\gamma_\mu u_L - \overline{d}_L\gamma_\mu d_L\right) \\[2ex] J^Y_\mu = \dfrac{1}{2}\left(-3\,\overline{\nu}_L\gamma_\mu\nu_L - 3\,\overline{e}_L\gamma_\mu e_L + \overline{u}_L\gamma_\mu u_L + \overline{d}_L\gamma_\mu d_L\right. \end{cases}$$
$$\left. -6\,\overline{e}_R\gamma_\mu e_R + 4\,\overline{u}_R\gamma_\mu u_R - 2\,\overline{d}_R\gamma_\mu d_R\right)$$

After some basic algebra:

$$\boxed{\mathcal{L}_{\text{nc}} = e J^{\text{em}}_\mu A^\mu + \frac{g}{\cos\theta_W}\left(J^3_\mu - \sin^2\theta_W J^{\text{em}}_\mu\right) Z^\mu}$$

with $J^{\text{em}}_\mu = J^3_\mu + J^Y_\mu = \sum_f q_f \overline{f}\gamma_\mu f$ $\boxed{e = g\sin\theta_W = g'\cos\theta_W}$

An observation about the neutral current:

$$U^\dagger U = V^\dagger V = \mathbb{I}_{3\times 3} \quad \Rightarrow \quad \overline{f}_X\gamma_\mu f_X = \overline{\widehat{f}}_X\gamma_\mu \widehat{f}_X$$

(X = L or R)

The neutral currents are diagonal (and universal) in flavor space

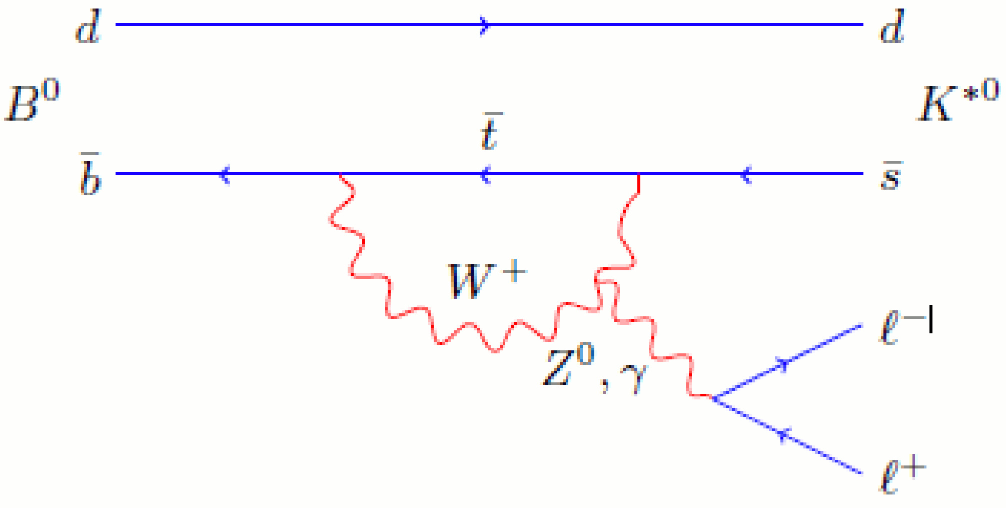
There are no flavor changing neutral currents (FCNC) at tree-level

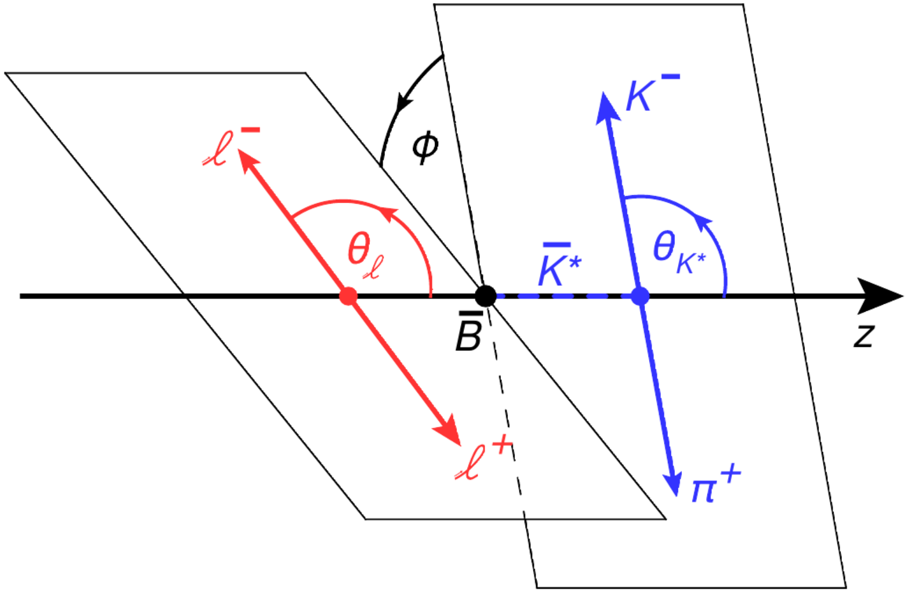
$Z \not\to \overline{u}c$ in contrast to $W \to \overline{s}u$

Fundamentally this is caused by the fact that fermion families are exact replicas.
This was the original motivation that led Glashow, Iliopoulos and Maiani (GIM) to postulate the existence of the charm quark.

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

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





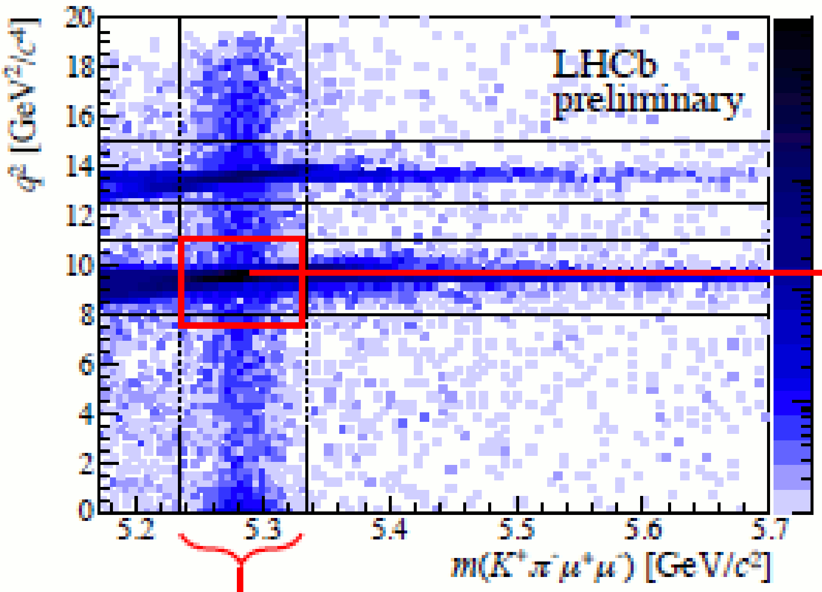
$$\begin{aligned}\frac{1}{\mathrm{d}(\Gamma+\bar\Gamma)/\mathrm{d}q^2}\frac{\mathrm{d}^3(\Gamma+\bar\Gamma)}{\mathrm{d}\vec\Omega} = \frac{9}{32\pi}\Big[&\tfrac{3}{4}(1-F_\mathrm{L})\sin^2\theta_K + F_\mathrm{L}\cos^2\theta_K + \tfrac{1}{4}(1-F_\mathrm{L})\sin^2\theta_K\cos2\theta_\ell\\ &- F_\mathrm{L}\cos^2\theta_K\cos2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos2\phi\\ &+ S_4\sin2\theta_K\sin2\theta_\ell\cos\phi + S_5\sin2\theta_K\sin\theta_\ell\cos\phi\\ &+ \tfrac{4}{3}A_\mathrm{FB}\sin^2\theta_K\cos\theta_\ell + S_7\sin2\theta_K\sin\theta_\ell\sin\phi\\ &+ S_8\sin2\theta_K\sin2\theta_\ell\sin\phi + S_9\sin^2\theta_K\sin^2\theta_\ell\sin2\phi\Big]\end{aligned}$$

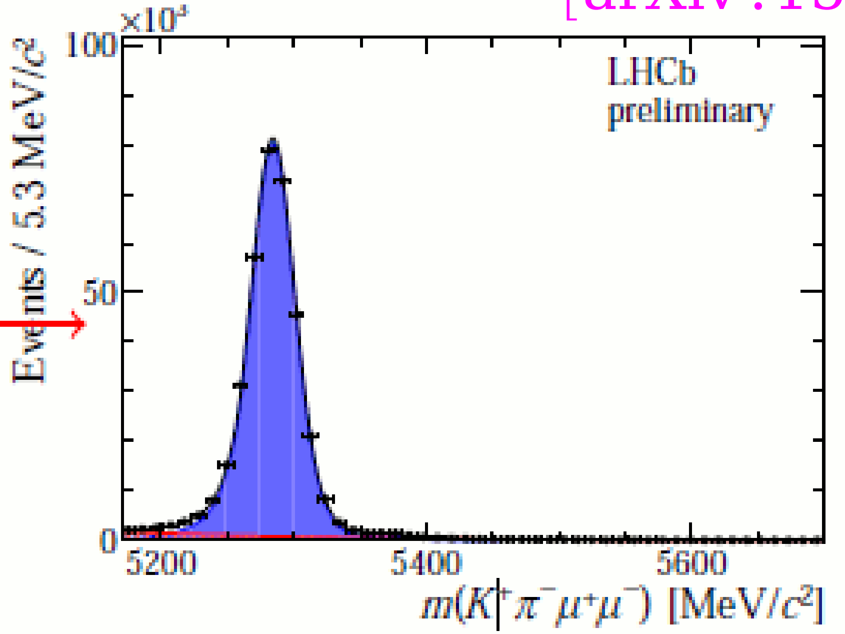
- F_L, A_{FB}, S_i sensitive to $C_7^{(')}$, $C_9^{(')}$, $C_{10}^{(')}$

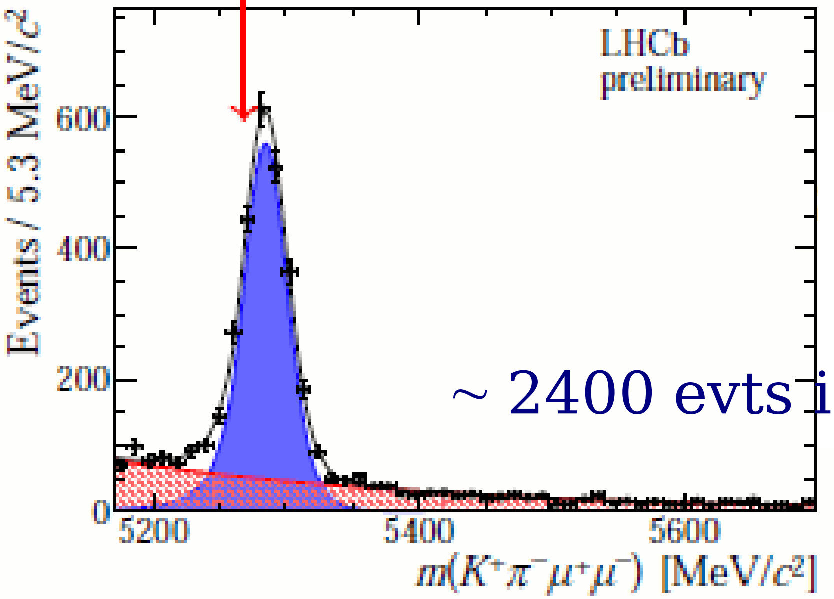
Angular analysis of $B_d^0 \to K^* \mu^+ \mu^-$ decays

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

[arXiv:1512.04442]







Selection:

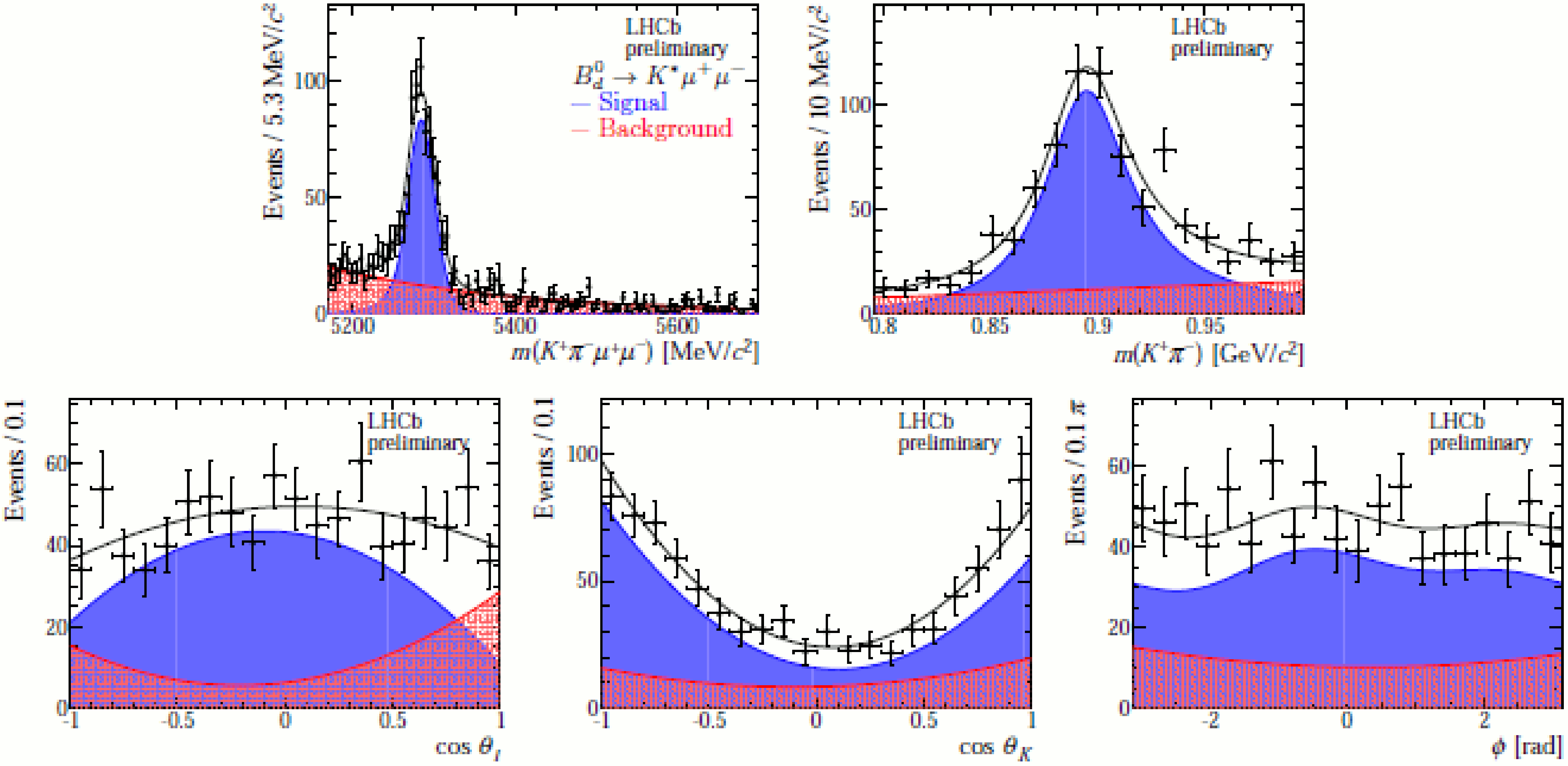
BDT to reject combinatorial background
Veto of resonant modes (control modes)

~ 2400 evts in the full q^2 range

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



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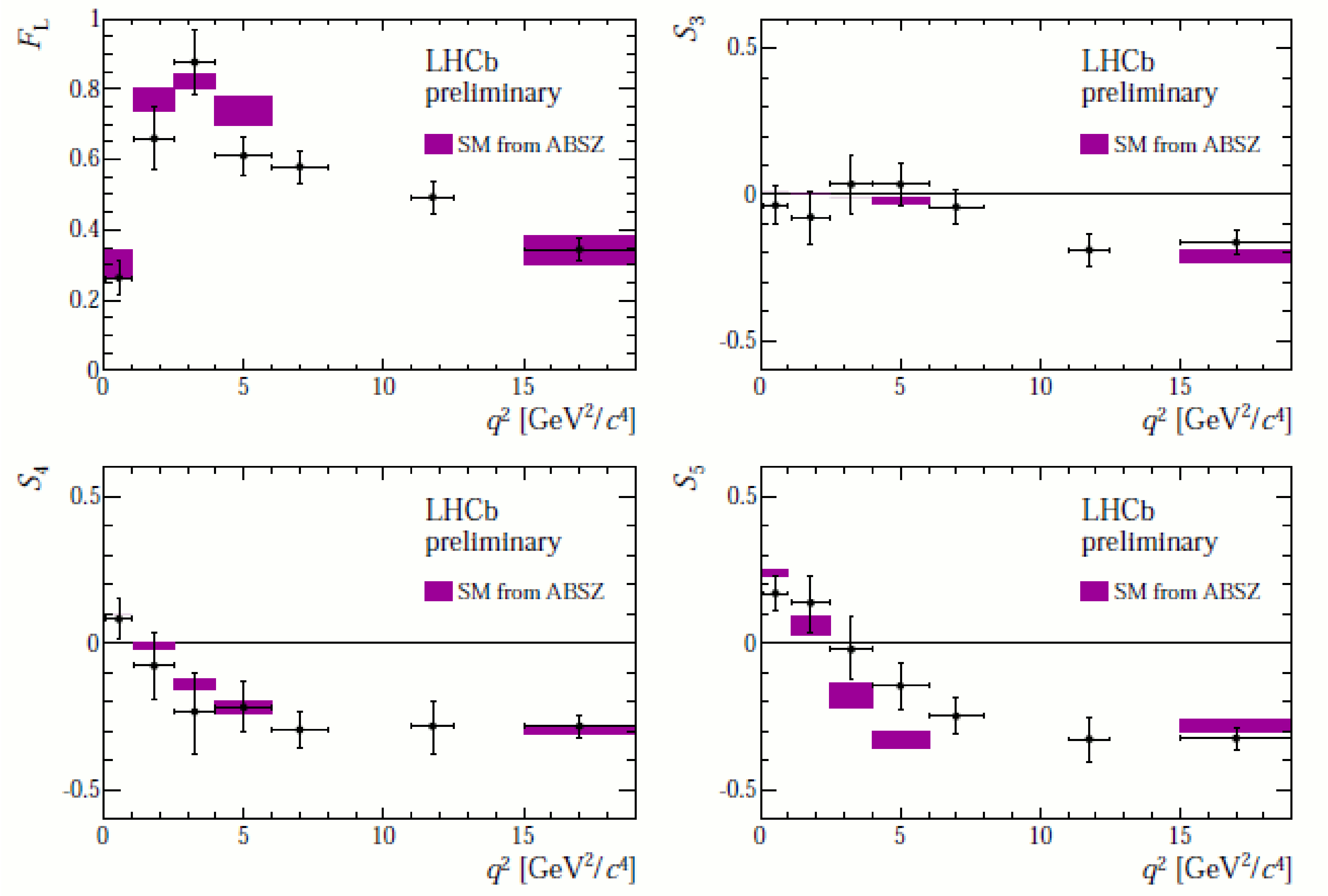

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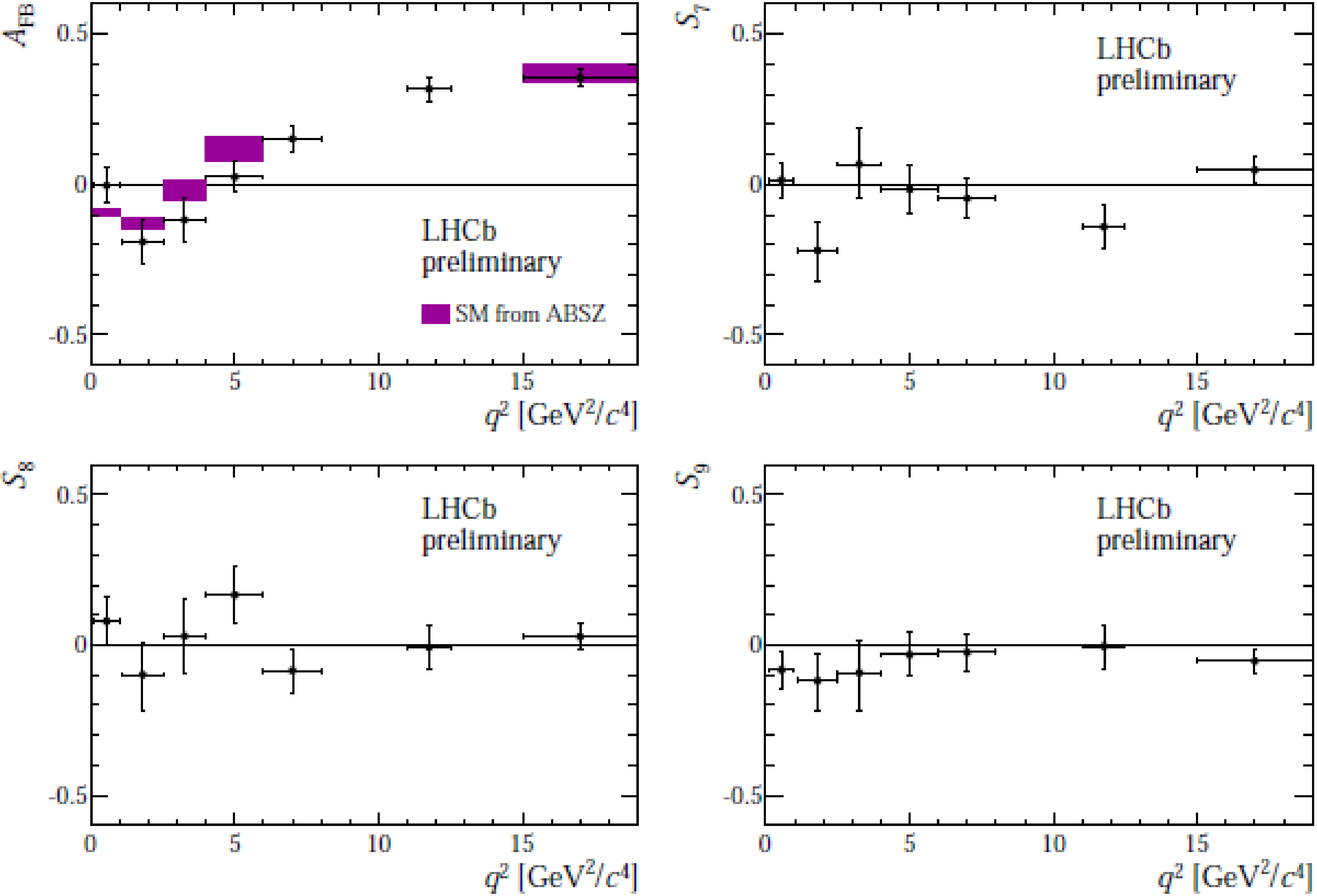
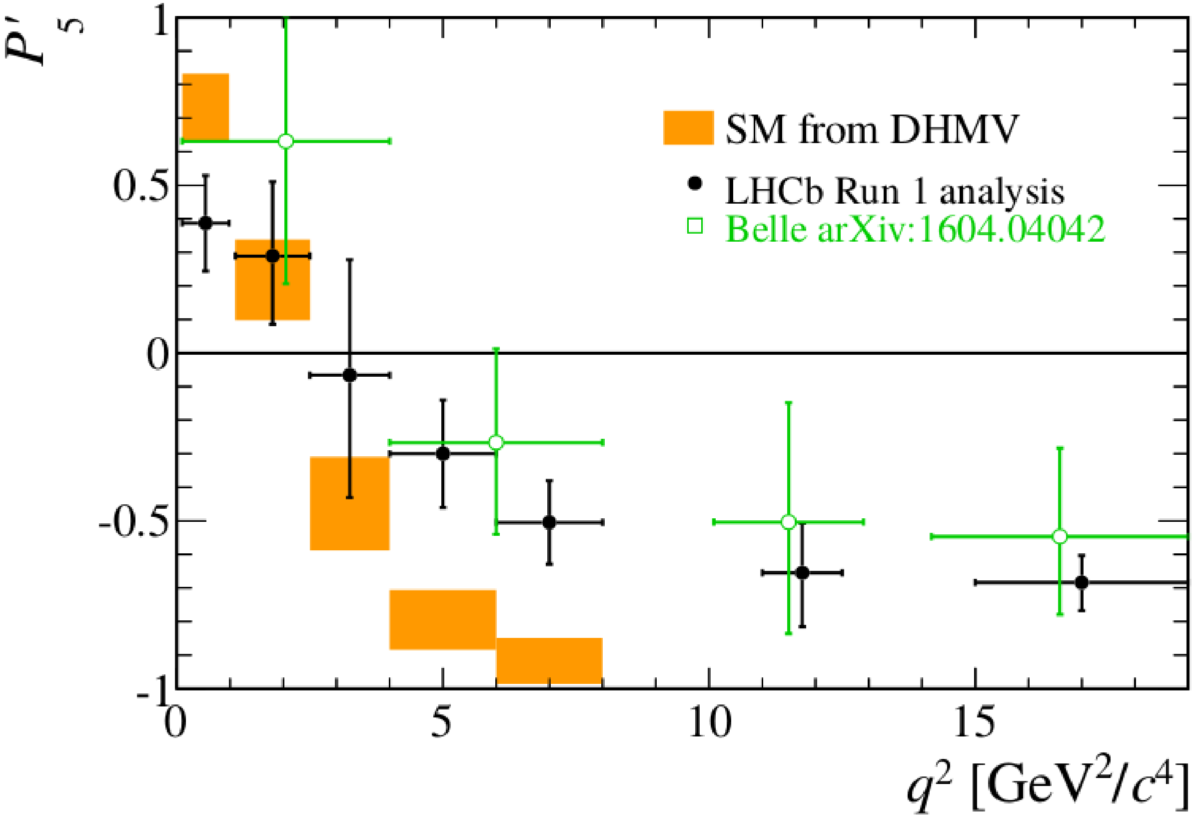
data points systematically lower than SM



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

- Form-factor less dependent observables $P'_5 = \frac{S_5}{\sqrt{F_L(1-F_L)}}$



[LHCb, arXiv:1512.04442]

- Tension in P'_5 seen with 1 fb^{-1} is confirmed
- Local deviations of 2.9σ and 3.0σ for $q^2 \in [4.0, 6.0]$ and $[6.0, 8.0]$ GeV^2
- Naive combination of the two gives local significance of 3.7σ

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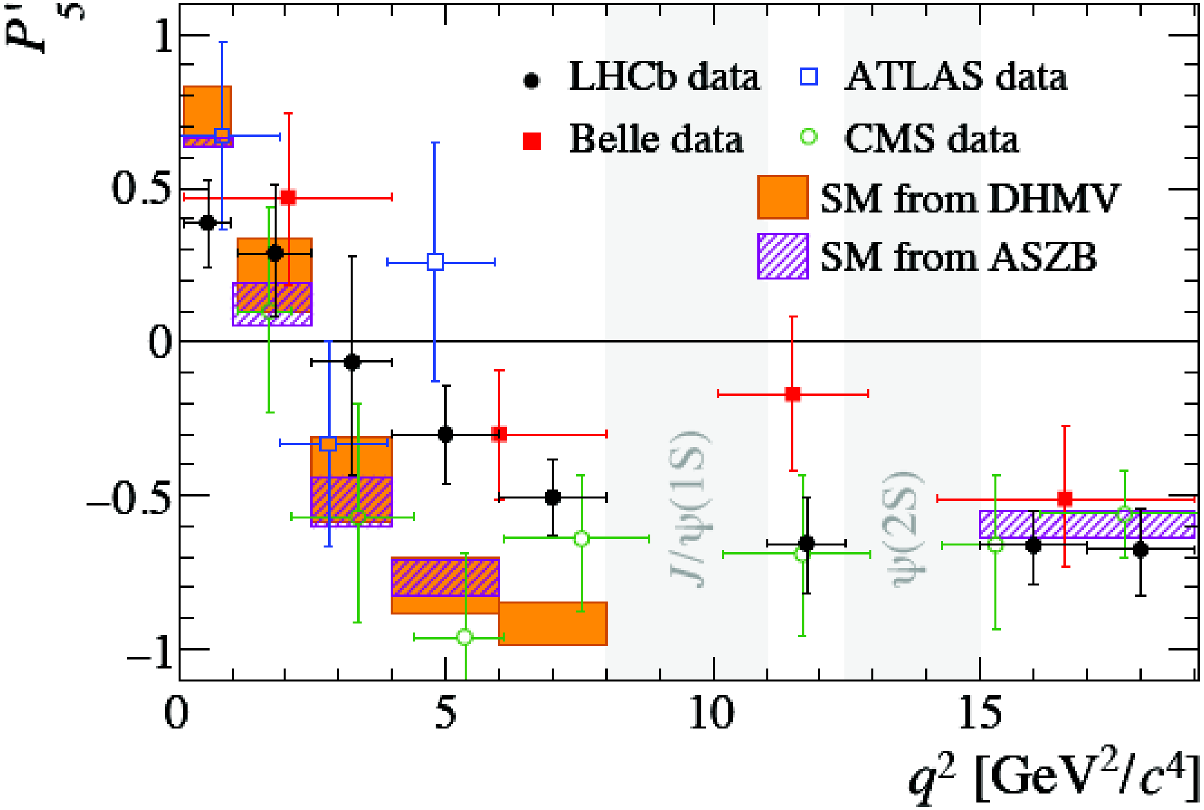

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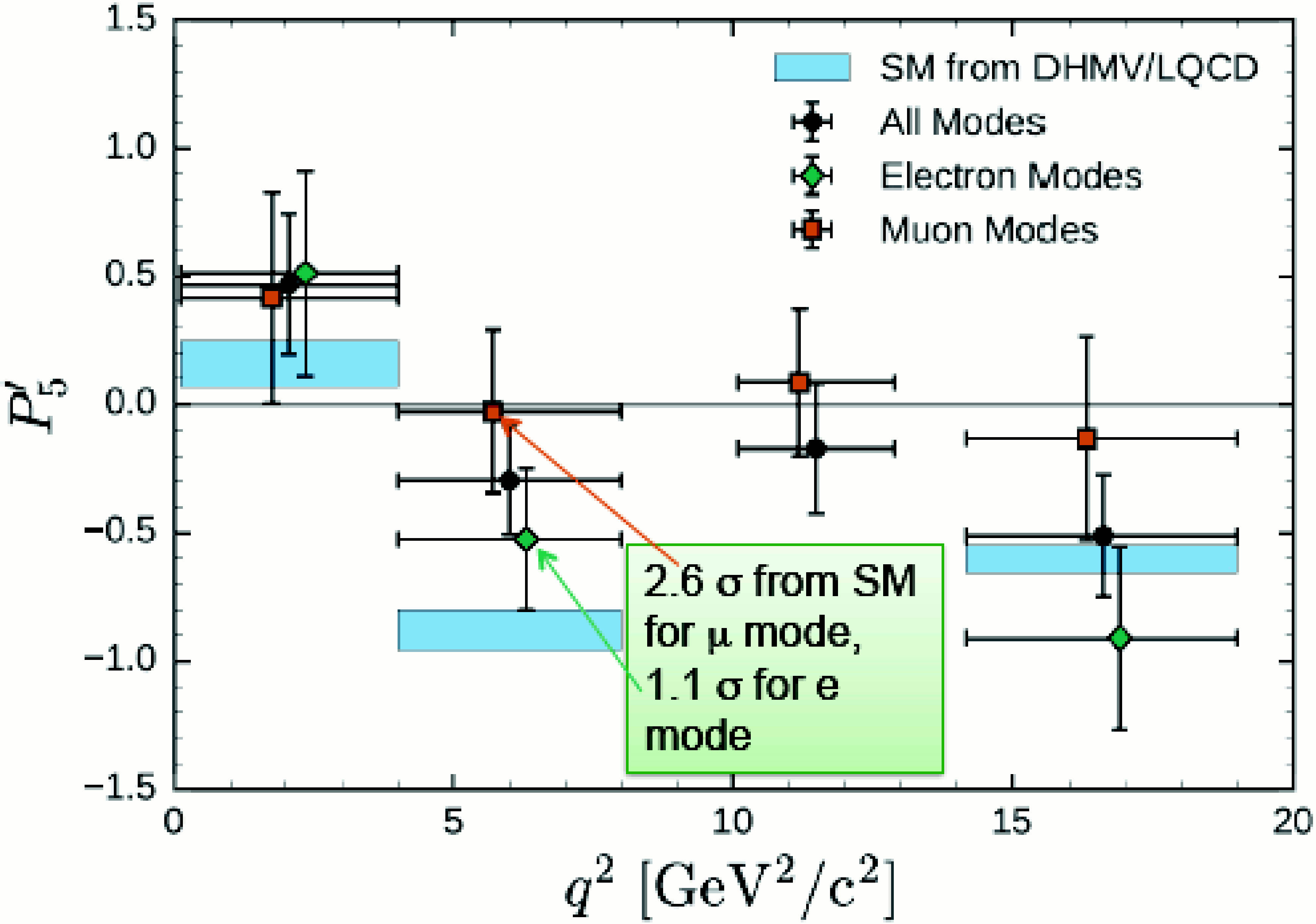
- LHCb, Belle and ATLAS show deviations in $4 < q^2 < 8$ GeV^2/c^4
- CMS shows better agreement

- Belle does both e's & μ's (PRL 118, 111801, 2017)



2.6 σ from SM for μ mode, 1.1 σ for e mode

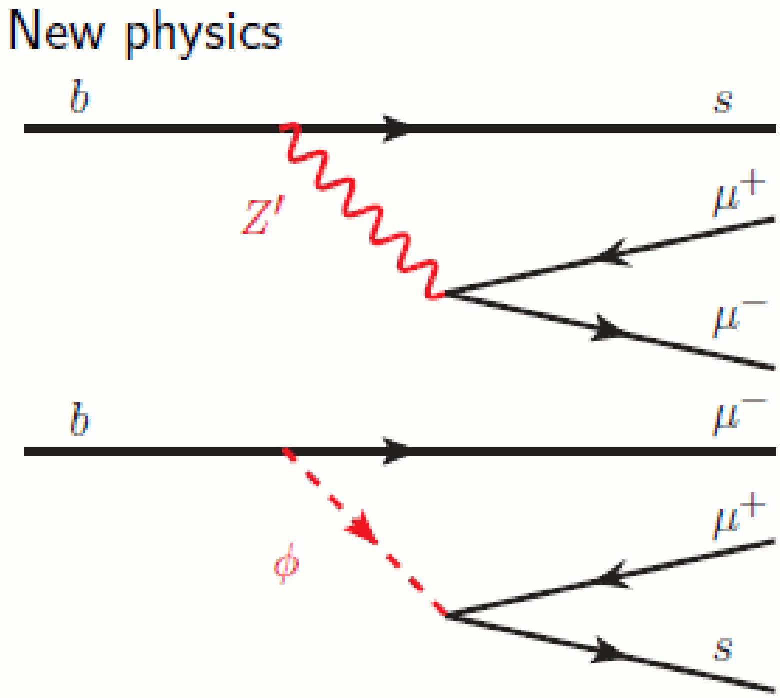
NP or hadronic effect ?

Possible explanations for shift in C_9:

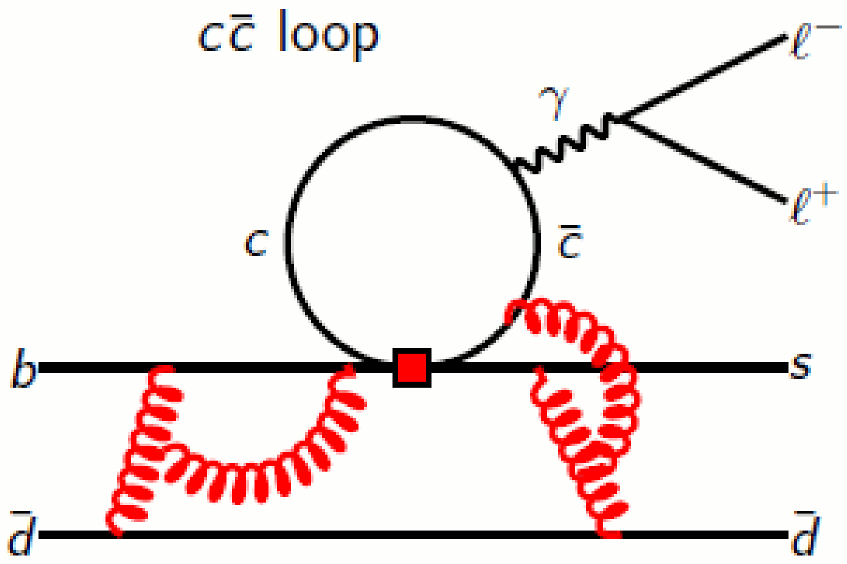
a potential new physics contribution C_9^{NP} enters amplitudes always with

a charm-loop contribution $C_9^{c\bar{c}\ i}(q^2)$

⇒ **spoiling an unambiguous interpretation of the fit result in terms of NP**



NP e.g. Z', leptoquarks

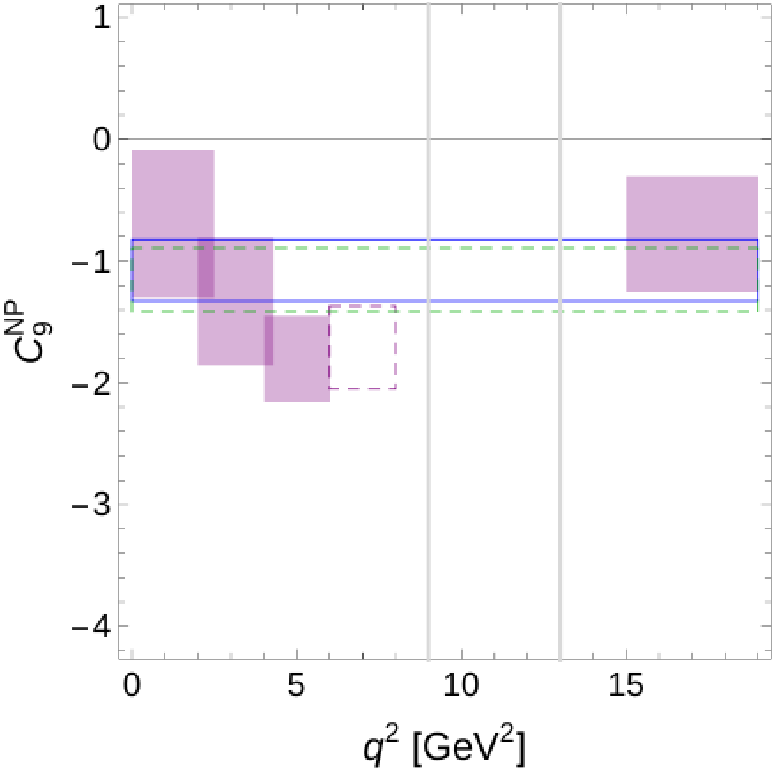


hadronic charm loop contributions

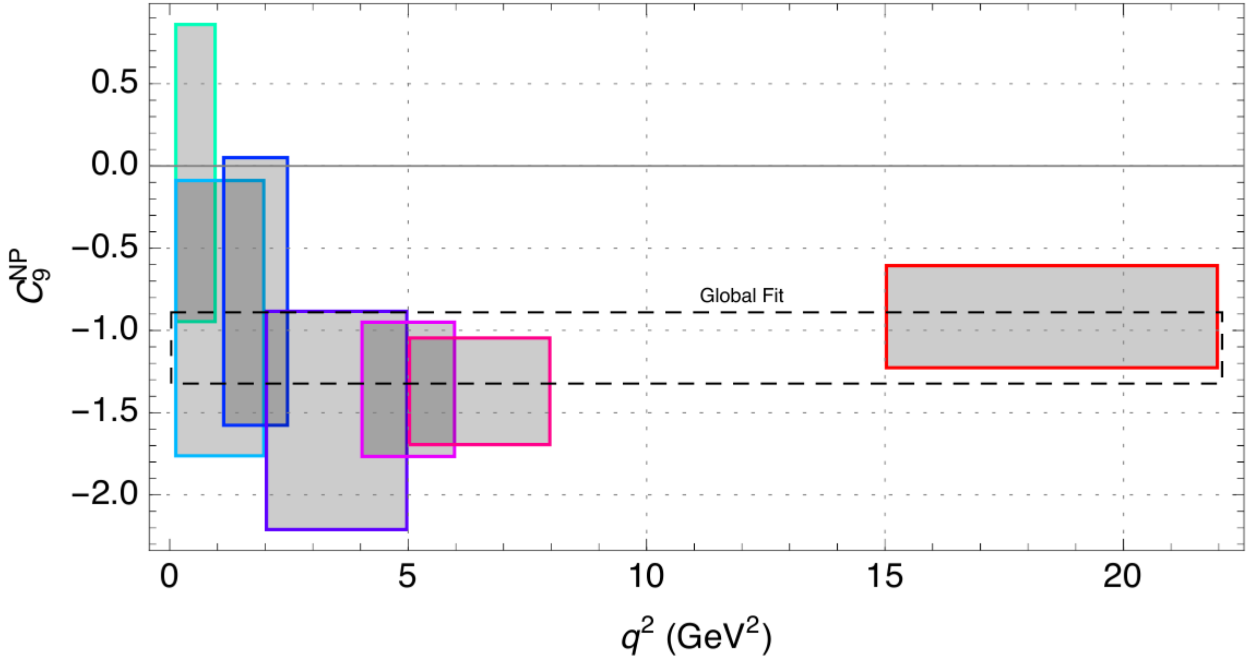
NP or hadronic effect ?

Bin-by-bin fit of the one-parameter scenario with a single coefficient $\mathbf{C_9^{NP}}$

[W.Altmannshofer et al, arXiv:1503.06199]



[S.Descotes-Genon et al, arXiv:1510.04239]



C_9^{NP} doesn't depend on q^2,

$C_9^{c\bar{c}\,i}(q^2)$ expected to exhibit a non-trivial q^2 dependence

⇒ definitely need more stat.