Beautiful paths to probe physics beyond the standard model of particles

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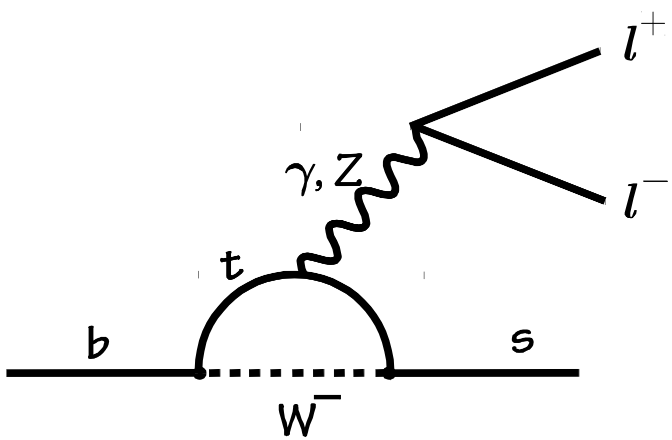
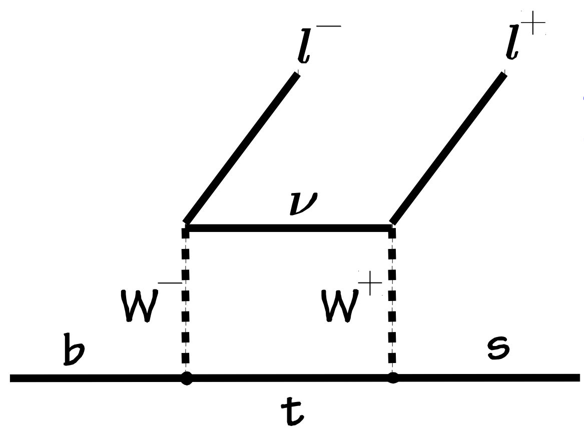
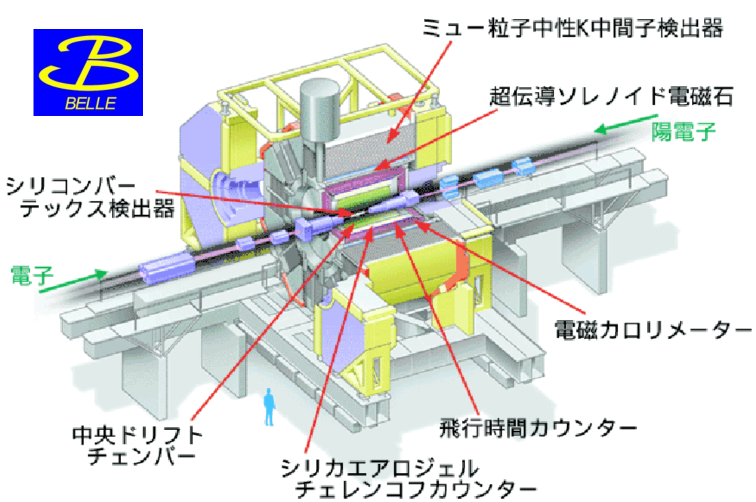
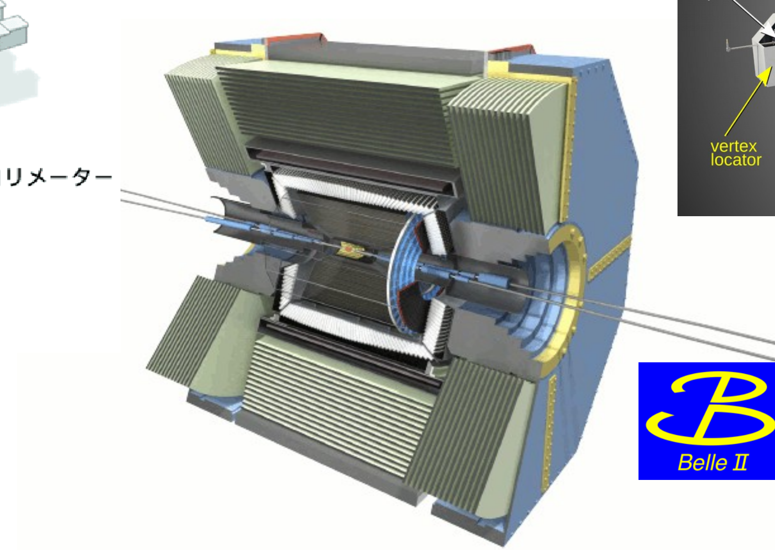
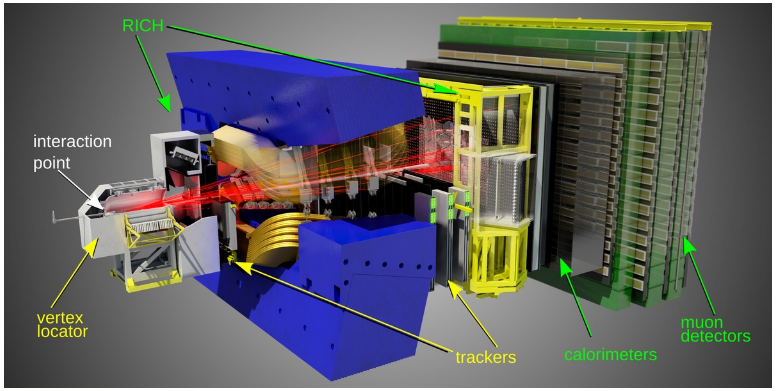








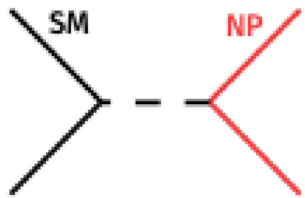


TIFR, Dec 4th 2017

Rare B decays

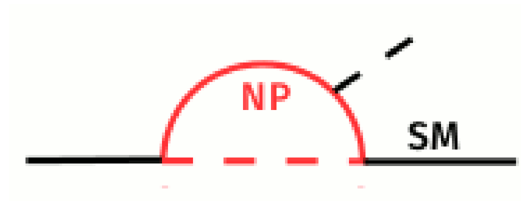
- FCNC are strongly suppressed in the SM: only loops + GIM mechanism
- Any new particle generating new diagrams can change the amplitudes

energy frontier



limited by beam energy

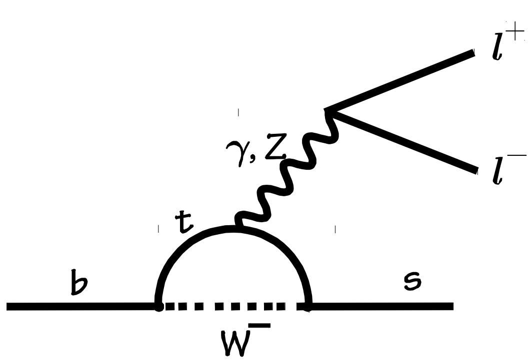
intensity frontier

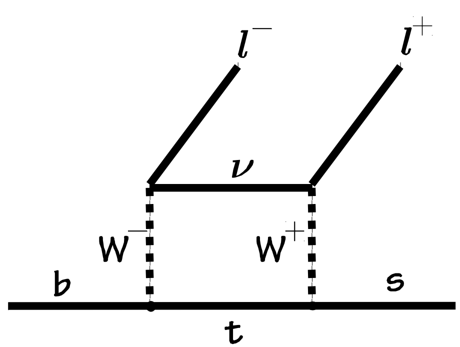


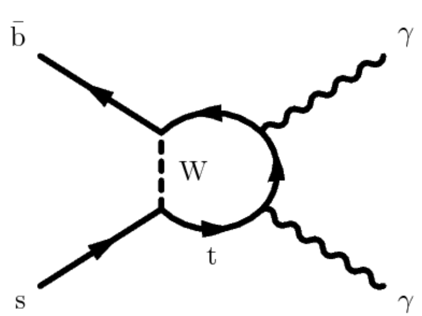
limited by statistics

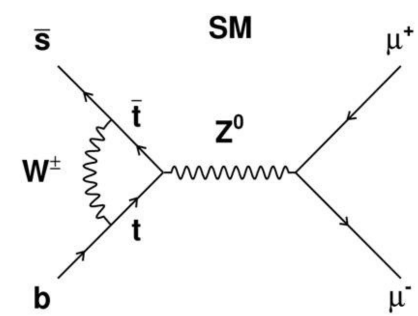
→ NP beyond the <u>direct</u> reach of the LHC

New particles can for example contribute to loop or tree level diagrams **by enhancing/suppressing decay rates, introducing new sources of CP violation or modifying the angular distribution of the final-state particles**







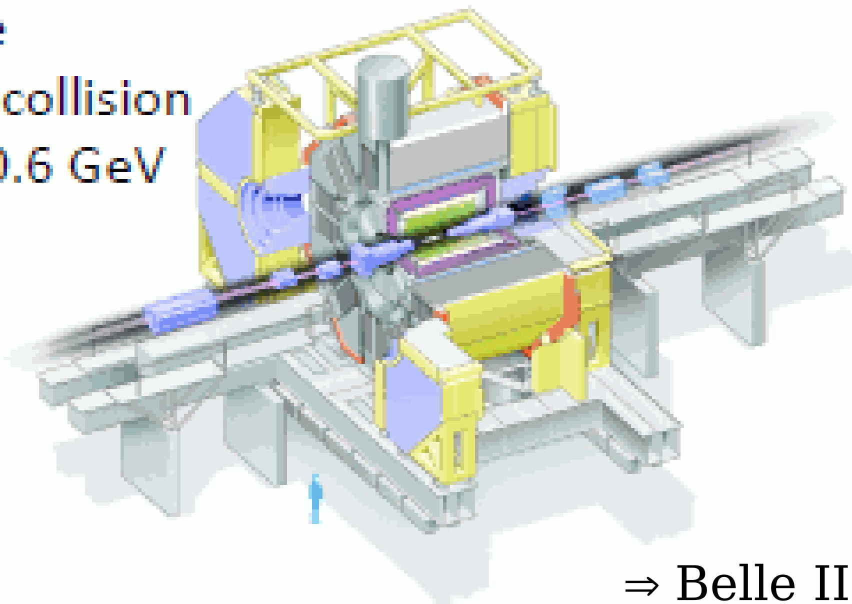


Main actors in B physics

Belle

e^+e^- collision

at 10.6 GeV

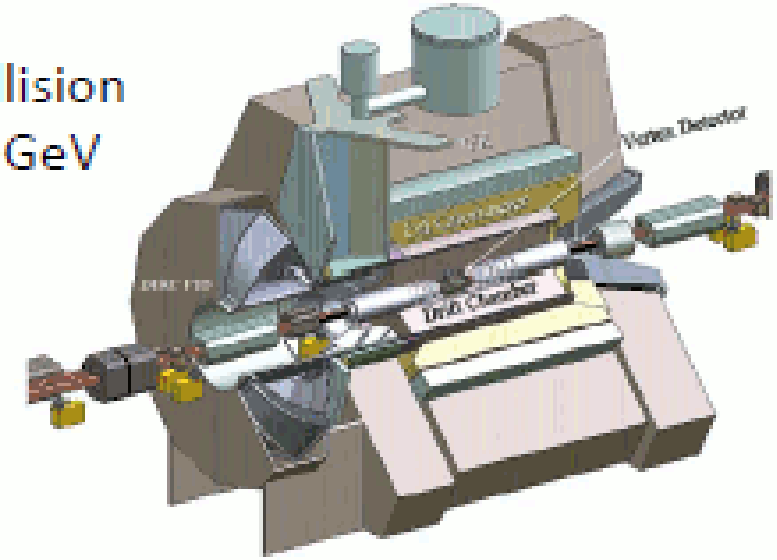


⇒ Belle II

BaBar

e^+e^- collision

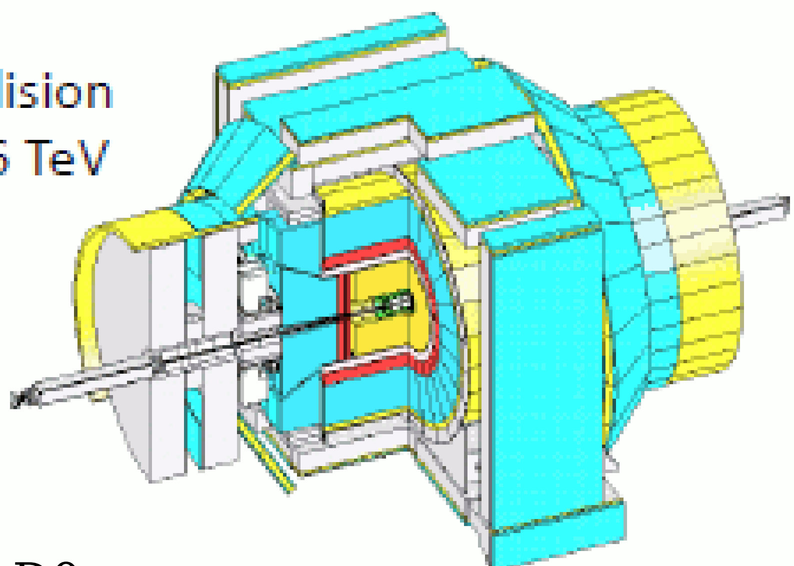
at 10.6 GeV



CDF

$p\bar{p}$ collision

at 1.96 TeV



… and D0

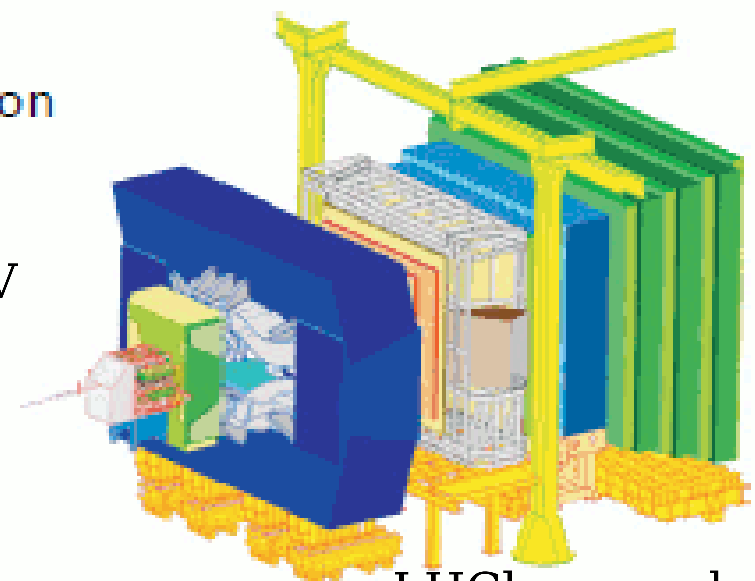
LHCb

pp collision

at 7 TeV

8 TeV

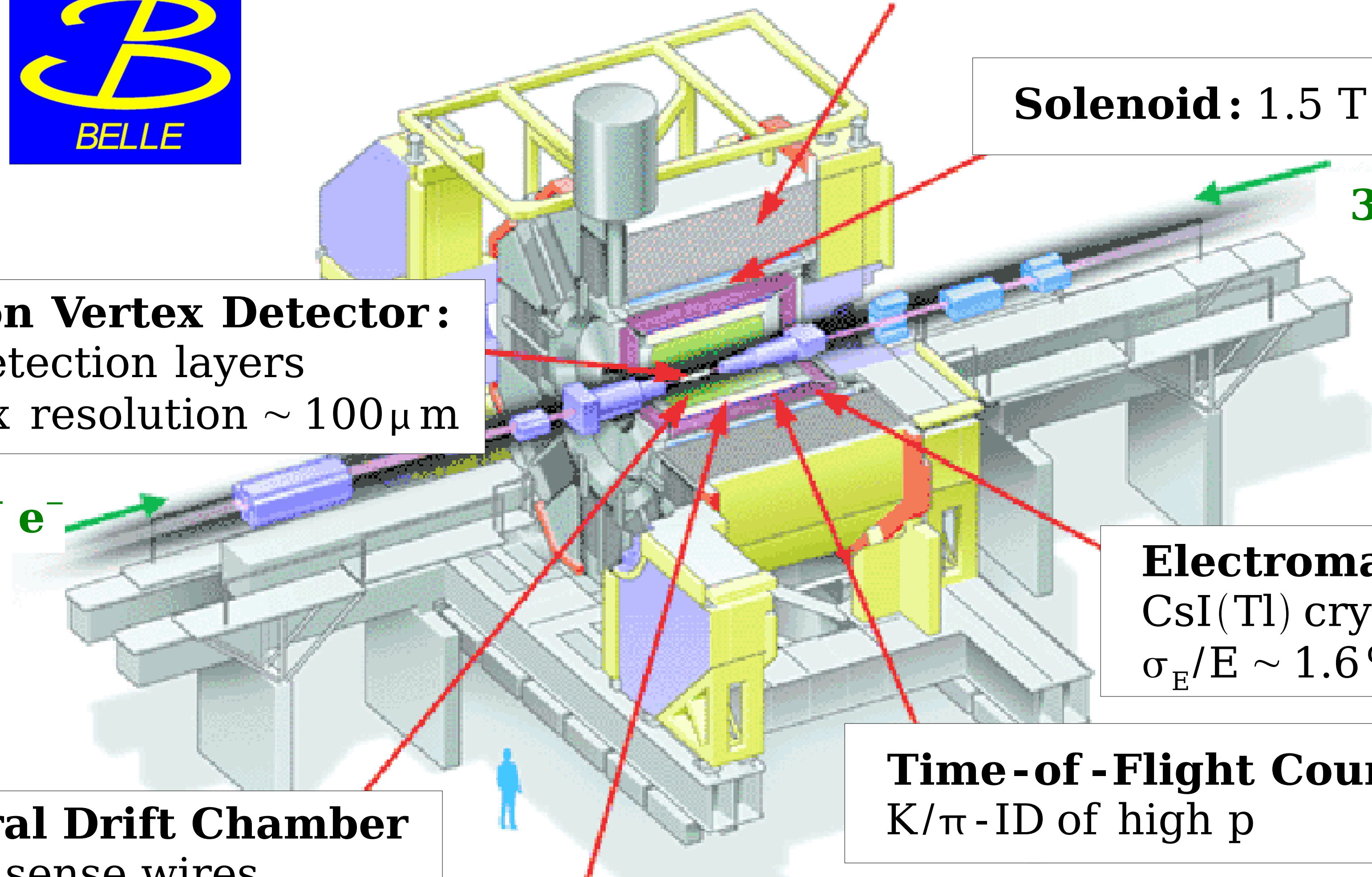
13 TeV



⇒ LHCb upgrade

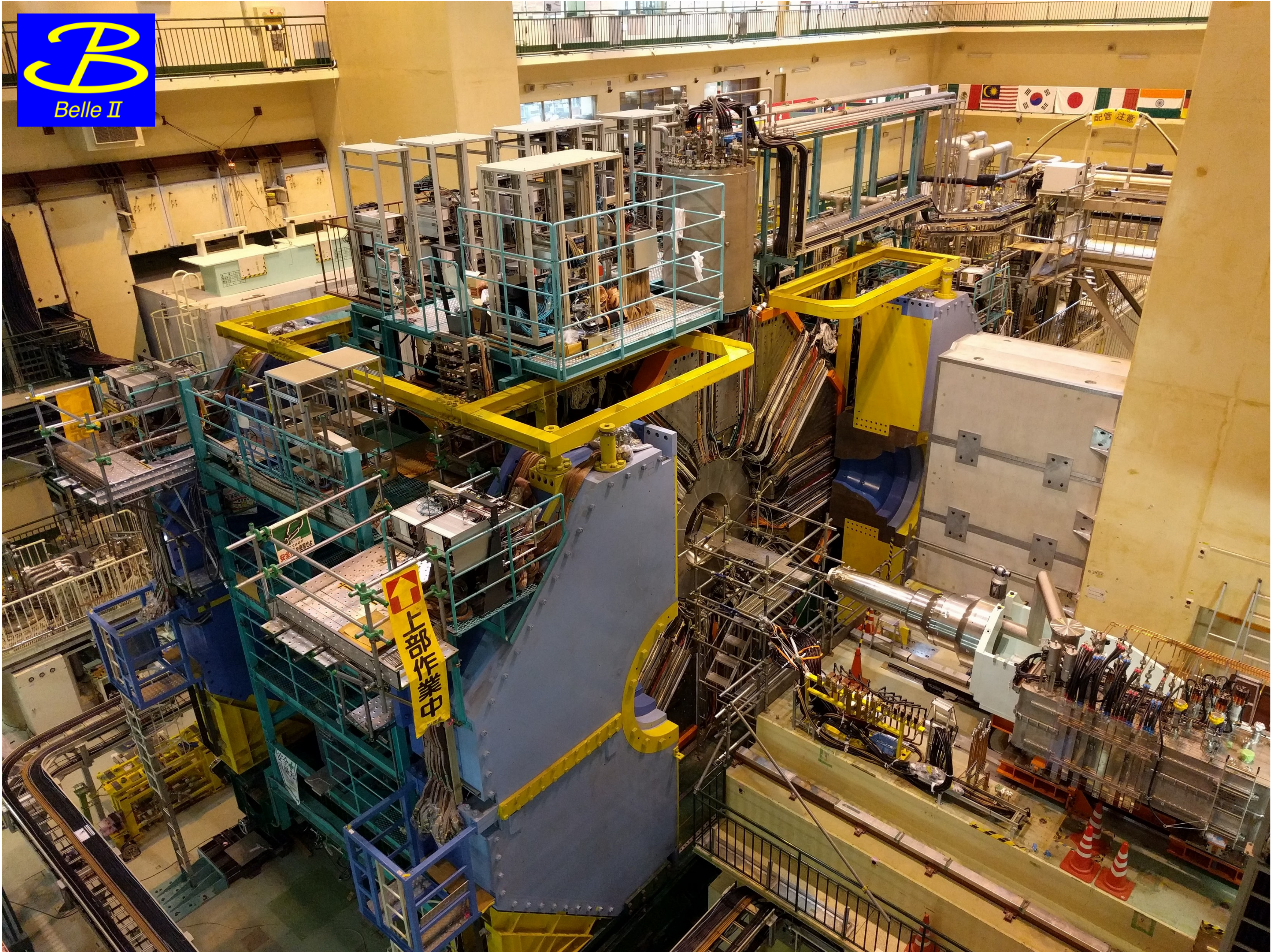
Rare B decays at B-factories

Belle in a nutshell

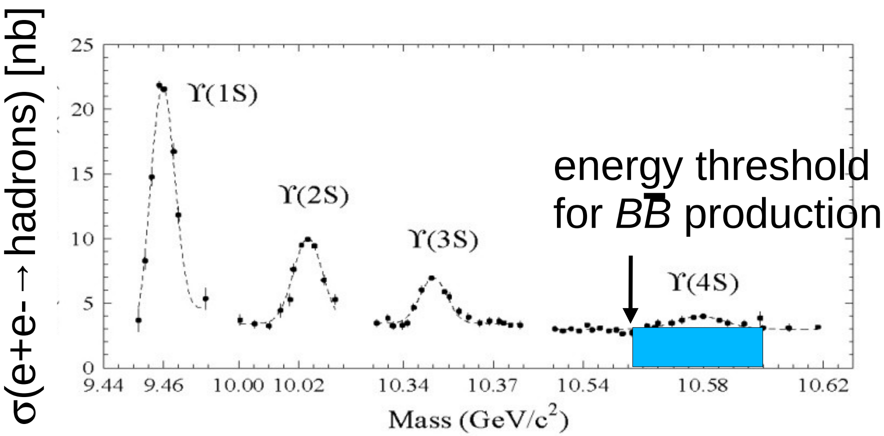


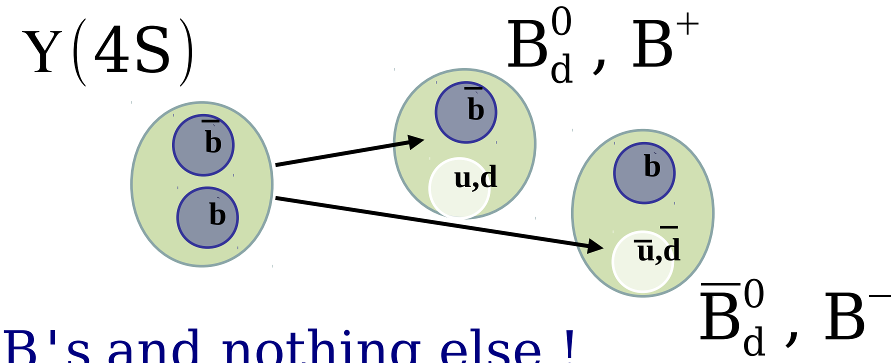
very stable detector, good particle identification, (kaon, pion, electron, muon),

e^+e^- is a clean environment: excellent tracking, triggering, tagging...


Belle II
上部作業中

Υ(4S) B-factory





- 2 B's and nothing else !
- 2 B mesons are created simultaneously in a L=1 coherent state

⇒ before first decay, the final states contains a B and a $\bar{B}$

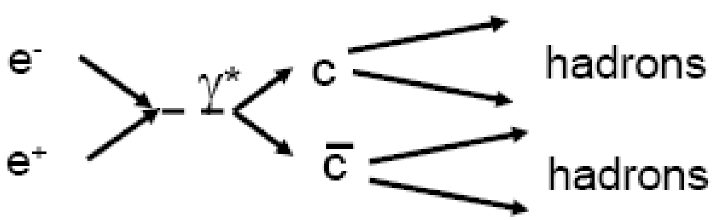
- **"on resonance" production**

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

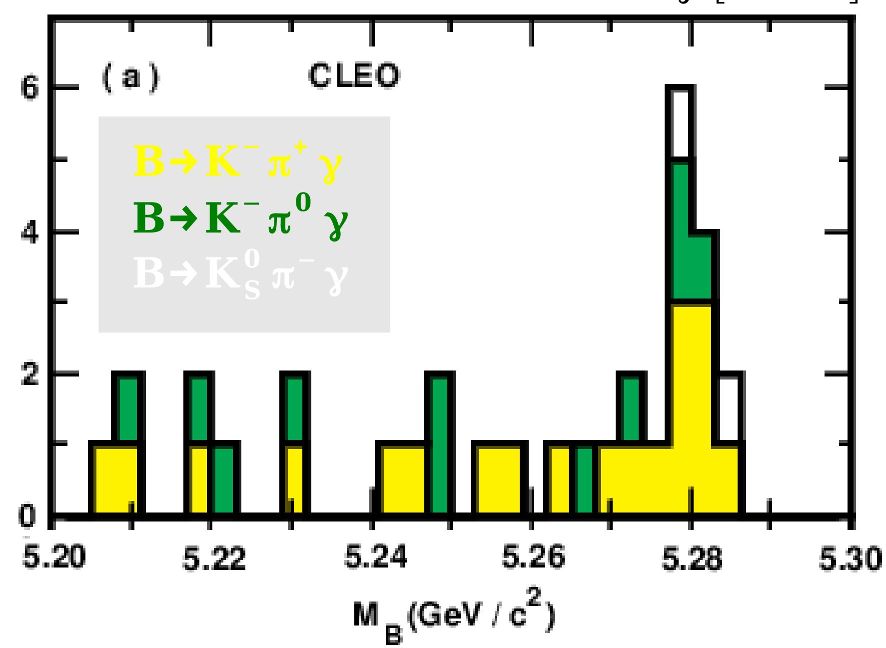
$\sigma(e^+e^- \rightarrow B\bar{B}) \simeq 1.1$ nb ($\sim 10^9$ $B\bar{B}$ pairs)

- **"continuum" production**
  ($q\bar{q} = u\bar{u}, d\bar{d}, s\bar{s}, c\bar{c}$)

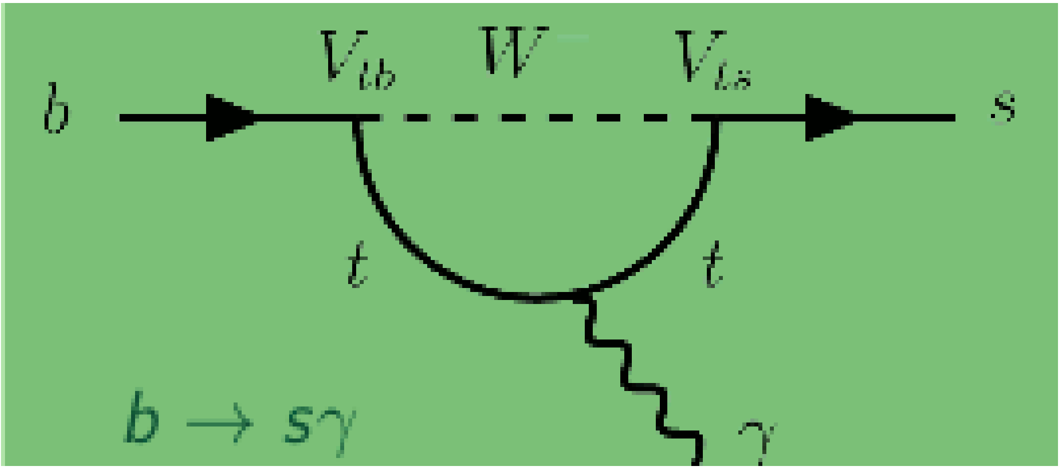
$\sigma(e^+e^- \rightarrow c\bar{c}) \simeq 1.3$ nb ($\sim 1.3\times10^9$ $X_c\bar{Y}_c$ pairs)



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

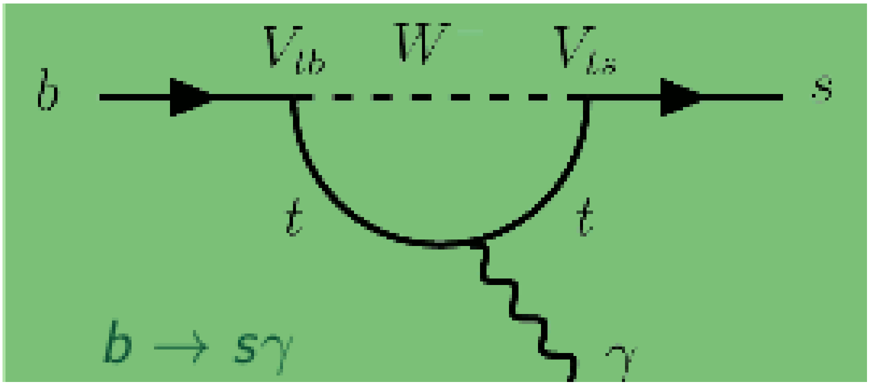


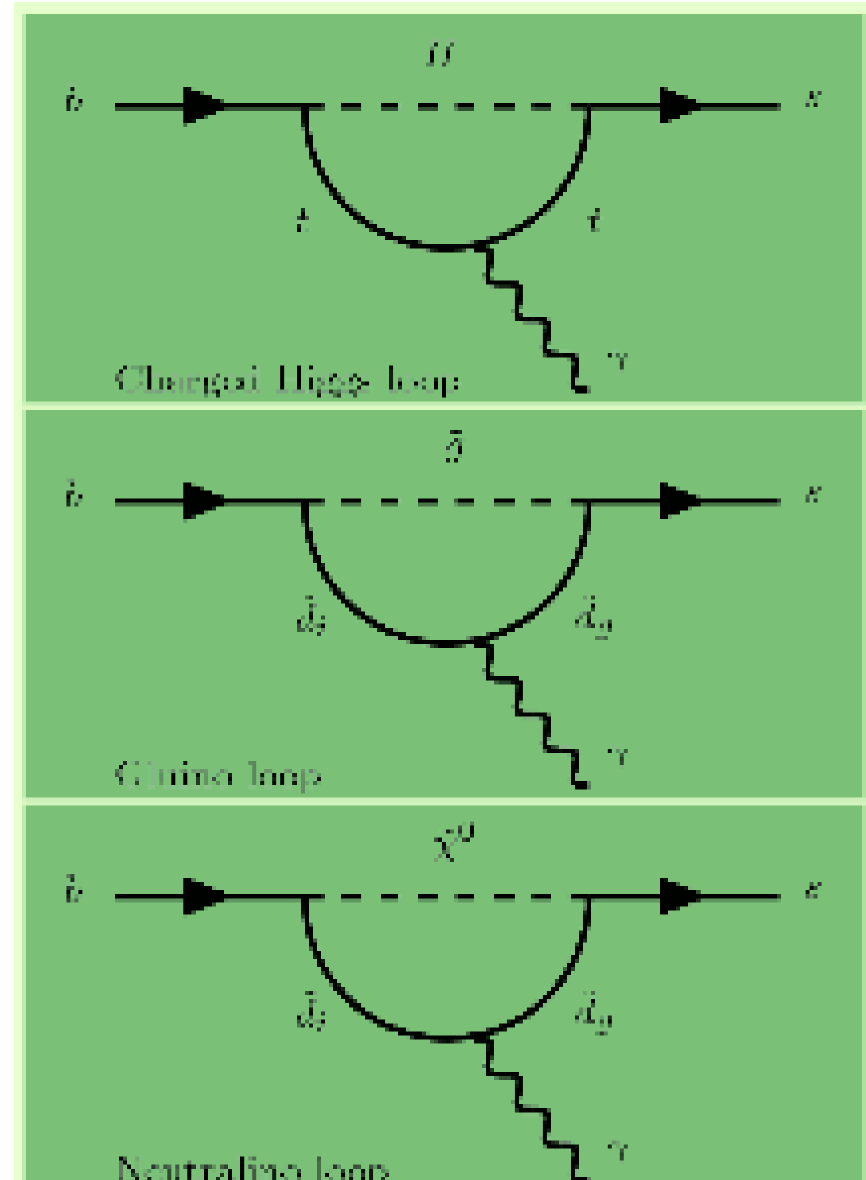
Radiative B decays



inclusive , exclusive …
illusive , elusive …

$b \rightarrow s\gamma$





- Amplitude $\propto V_{ts}|C_7|$
- First penguin ever observed (93)
- Experiment:

$$B \simeq 3\ .\ 10^{-4}$$

- SM: $B = (3.36 \pm 0.23)\ .\ 10^{-4}$
  [Misiak et al., hep-ph/0609232]
  $\Rightarrow$ [Misiak et al, arXiv:1503.01789]
- Strong constraint on New Physics

b→sγ SM branching fraction

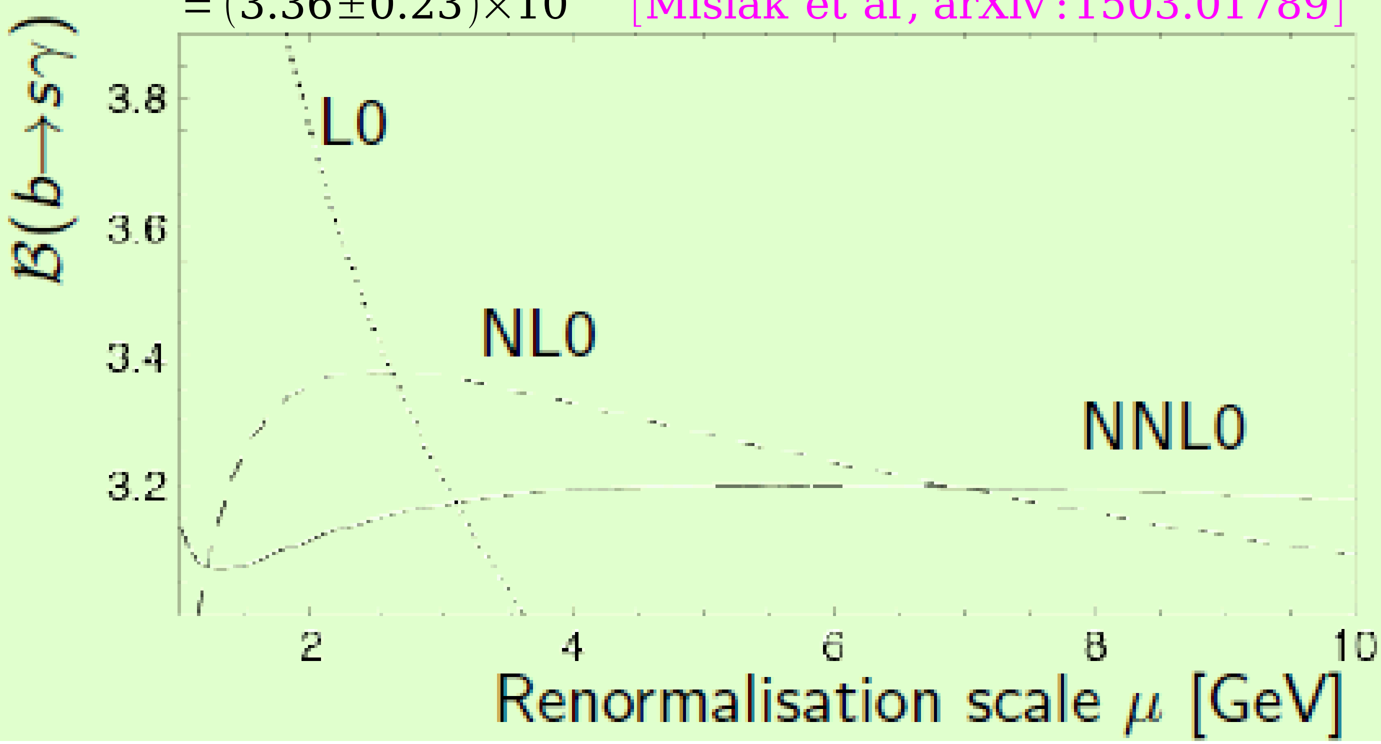
[Misiak et al, PRL98, 02202, 2007]

- From effective Hamiltonian one gets the BF
- Uncertainties due to m_b and m_c: normalise to $b \to ce\nu$ and $b \to ue\nu$ [Misiak & Steinhauser, NPB764:62,2007]
- $b \to s\gamma$ branching fraction calculated at all NNLO orders in 2006

$$\mathcal{B}(B \to X_s\gamma)_{E_\gamma > 1.6\,\text{GeV}} = \sout{(3.15 \pm 0.23) \cdot 10^{-4}}$$

$$= (3.36 \pm 0.23) \times 10^{-4}$$ [Misiak et al, arXiv:1503.01789]

✔ BF very stable versus μ

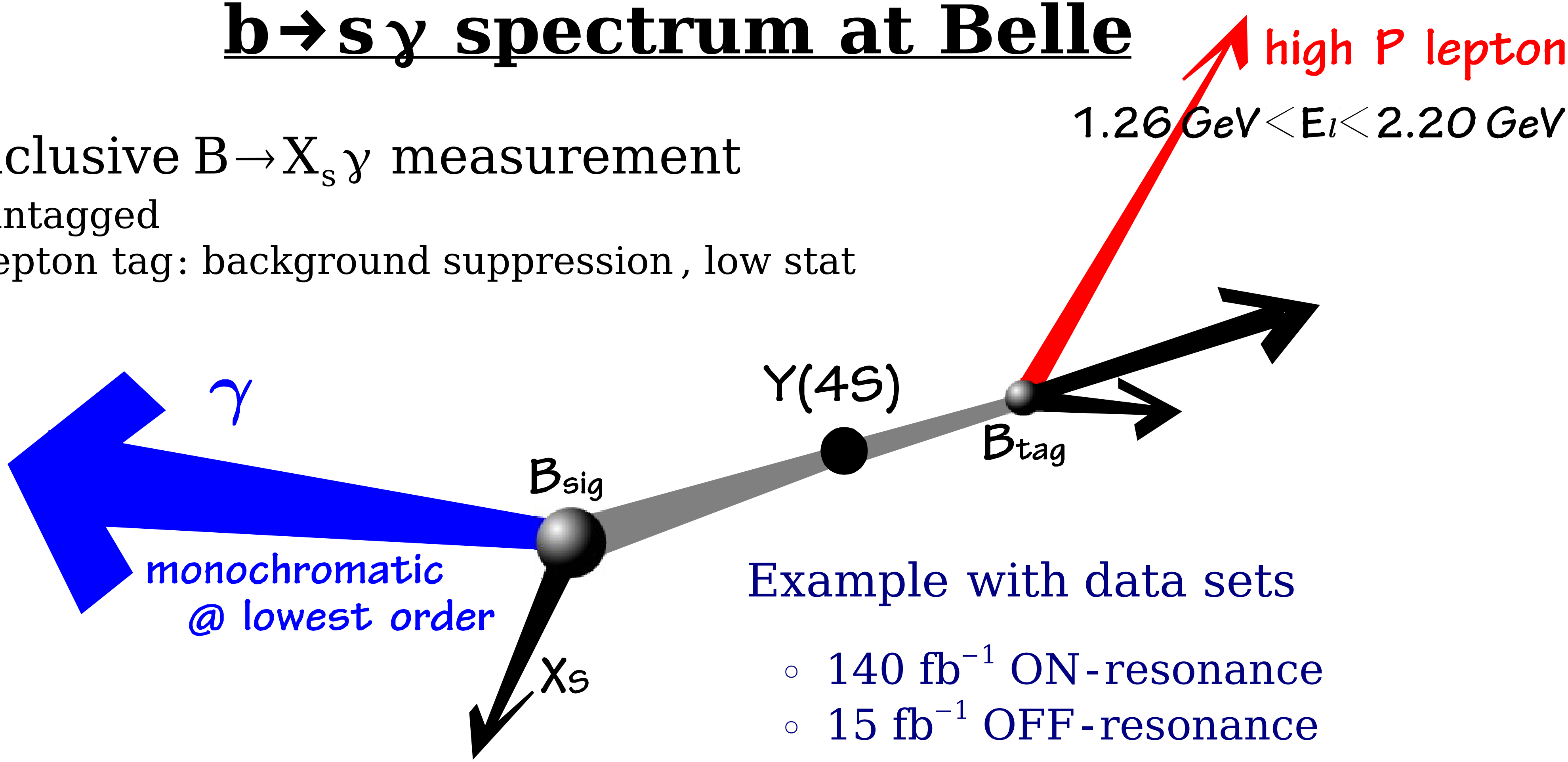


b→sγ spectrum at Belle

inclusive $B \to X_s \gamma$ measurement

untagged

lepton tag: background suppression, low stat



Example with data sets

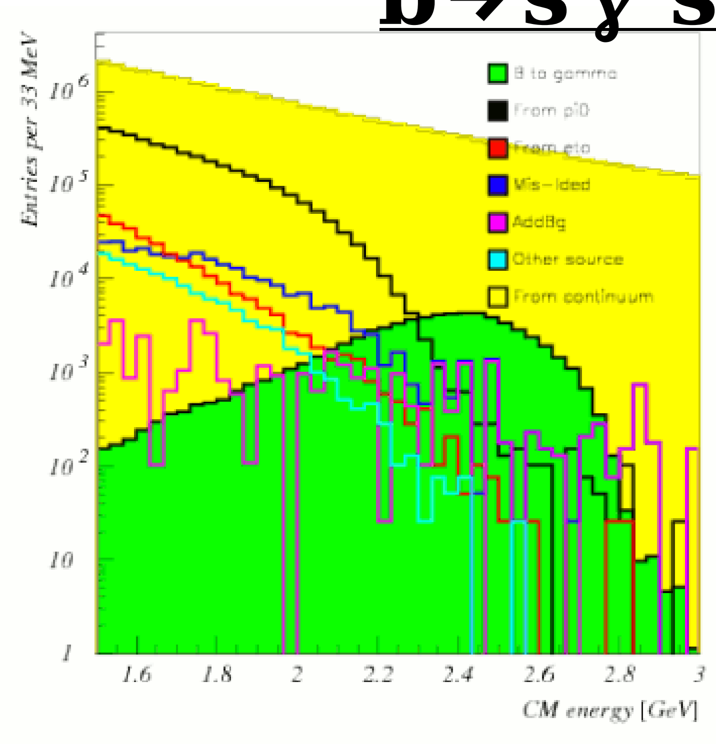
- $140\ fb^{-1}$ ON-resonance
- $15\ fb^{-1}$ OFF-resonance

Event selection:

- Hadronic events with isolated photon(s) in ECL. $E^* > 1.5$ GeV.
- Veto γ from π^0 and η
- Apply event shape cuts to suppress continuum background.

- No kinematic constraints
- Only a high energy photon measured in Υ(4S) rest frame
- Lower E_γ threshold (1.7 GeV)

$b \to s\gamma$ spectrum at Belle

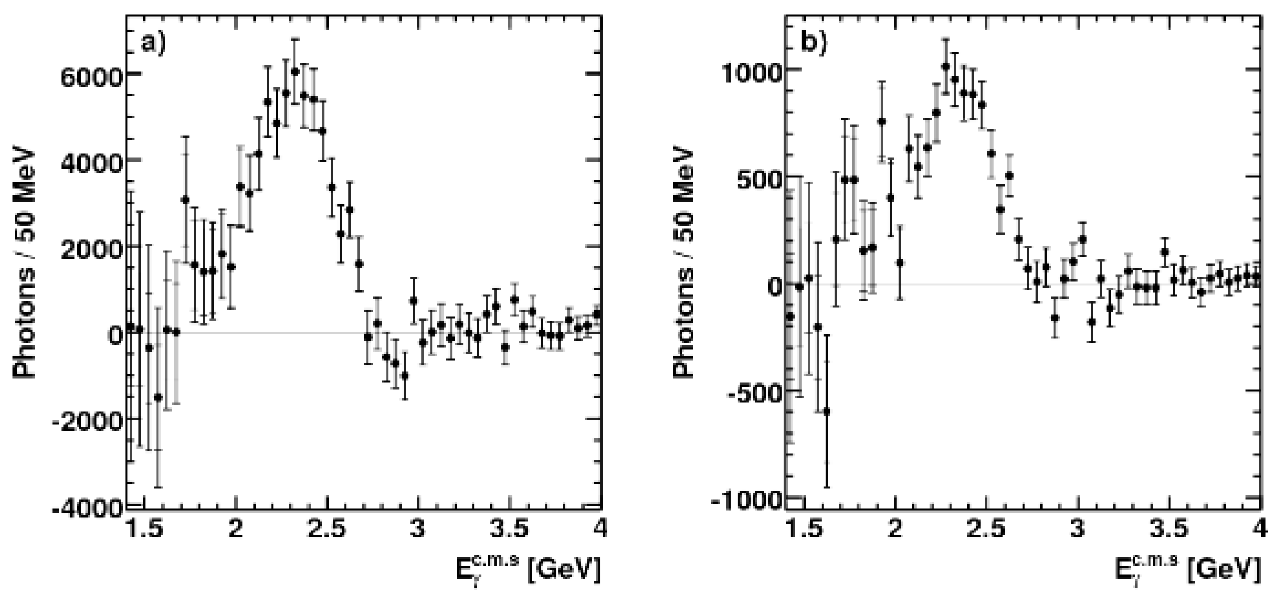


One would like to measure the photon energy spectrum in $b \to s\,\gamma$ decays

- Be unbiased: only look at the γ
- B mesons only decay to γ via $b \to s\gamma$
- But there are indirect γ from π^0 and η in $B\bar{B}$ events
- …and a lot more indirect π^0 and η in non-$B\bar{B}$ events

$\Rightarrow$ Lots of background at low energy

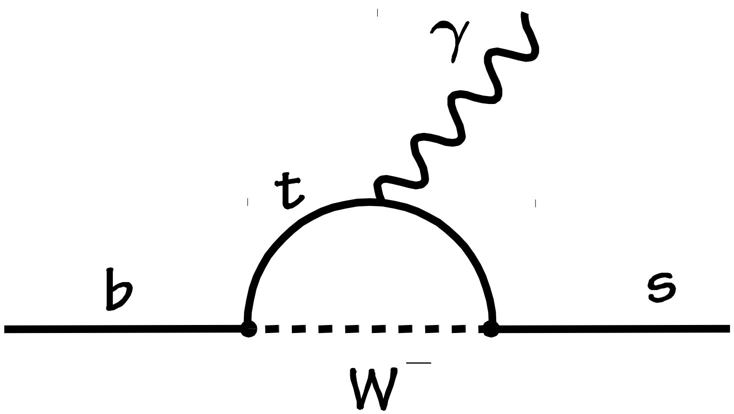
Lower E_γ threshold (1.7 GeV) $\Rightarrow$ 97% of the spectrum !



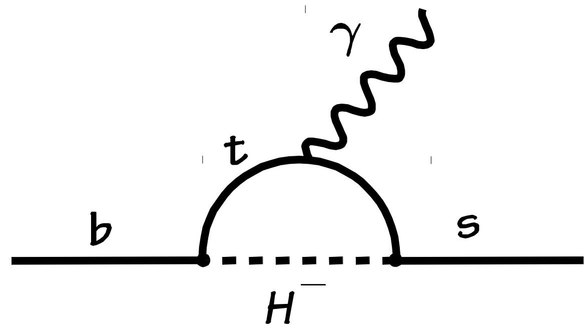
PRL 103, 241801 (2009)
arXiv:0907.1384

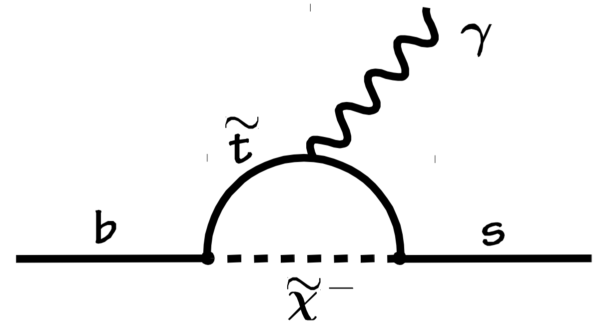
$$\mathcal{B}(B \to X_s\,\gamma) = (3.45 \pm 0.15 \pm 0.40) \times 10^{-4} \quad (\text{for } E_\gamma^* > 1.7 \text{ GeV})$$

$B \to X_s \gamma$ as an illustration



Sensitive to NP





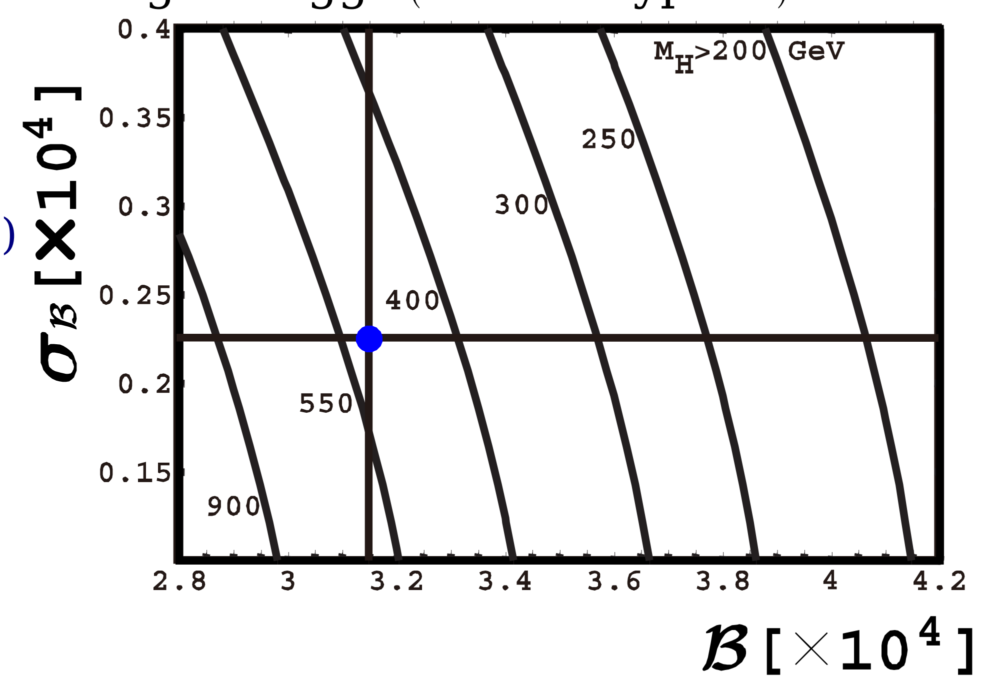
NNLO SM calculation:

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

(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

$\mathbf{B \to X_s \gamma}$

WA: $\mathcal{B}(B \to X_s \gamma) = (3.49 \pm 0.20) \times 10^{-4}$ (for $E_\gamma > 1.6$ GeV)

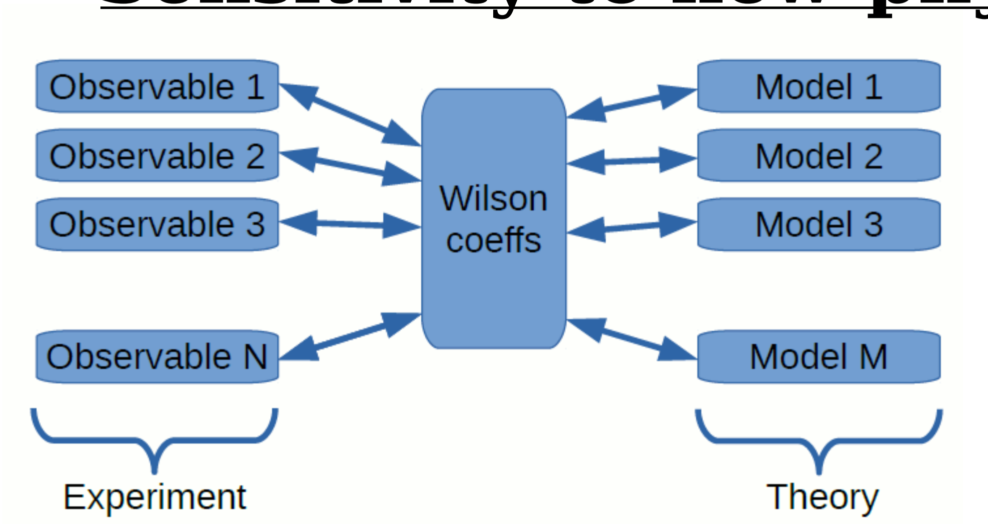
vs

SM: $\mathcal{B}(B \to X_s \gamma) = (3.36 \pm 0.23) \times 10^{-4}$ (for $E_\gamma > 1.6$ GeV)

[Misiak et al, arXiv:1503.01789]

Charged Higss bound (2HDM TypeII): $M_{H^+} > 400$ GeV @ 95% C.L.

Sensitivity to new physics in rare B decays



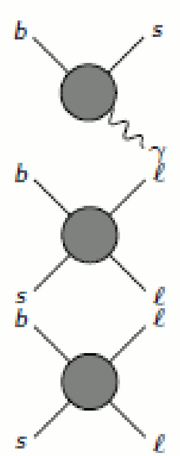
M.Ciuchini et al, arXiv:1512.07157
T.Hurth et al, arXiv:1603.00865
S.Descotes-Genon et al, arXiv:1510.04239...

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

- Model-independent description in effective field theory

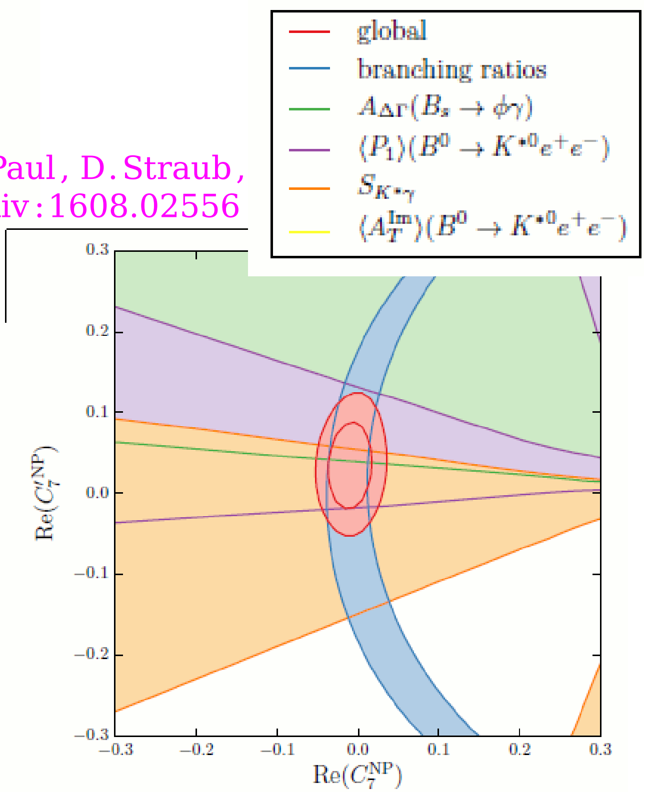
$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i \underbrace{\mathcal{C}_i \mathcal{O}_i}_{\text{Left-handed}} + \underbrace{\mathcal{C}'_i \mathcal{O}'_i}_{\text{Right-handed, } \frac{m_s}{m_b} \text{ suppressed}}$$

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



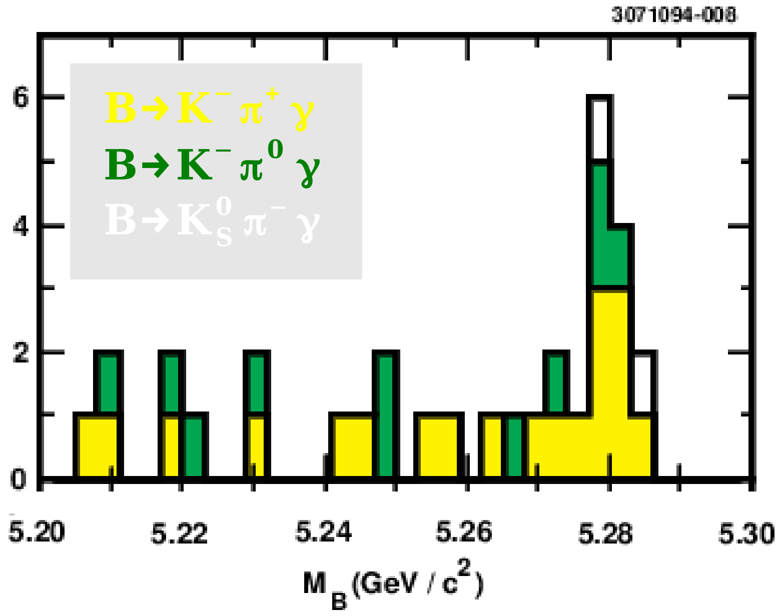
	$b \to s\gamma$	$B \to \mu\mu$	$b \to s\ell\ell$
$\mathcal{O}_7^{(\prime)}$ photon penguin	✓		✓
$\mathcal{O}_9^{(\prime)}$ vector coupling			✓
$\mathcal{O}_{10}^{(\prime)}$ axialvector coupling		✓	✓
$\mathcal{O}_{S,P}^{(\prime)}$ (pseudo)scalar penguin		✓	

A.Paul, D.Straub, arXiv:1608.02556



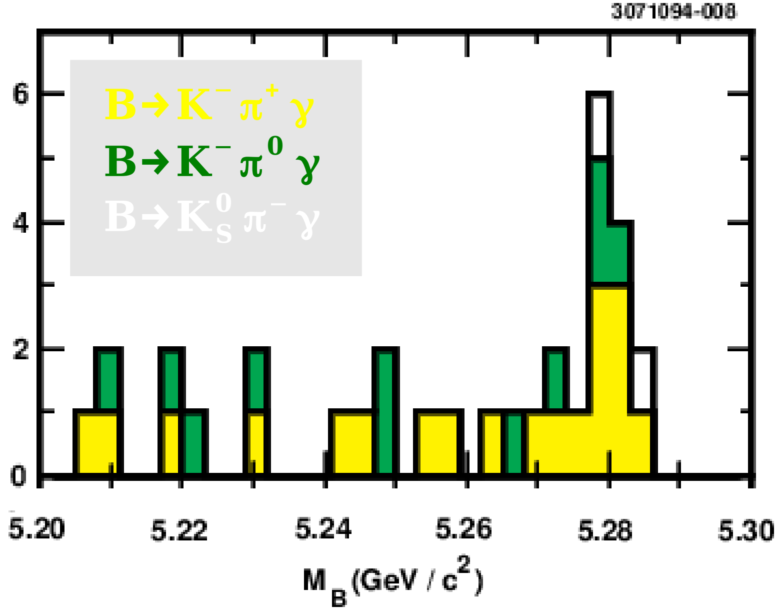
B→K* γ measurements

CLEO observation of B→K* γ [1993]

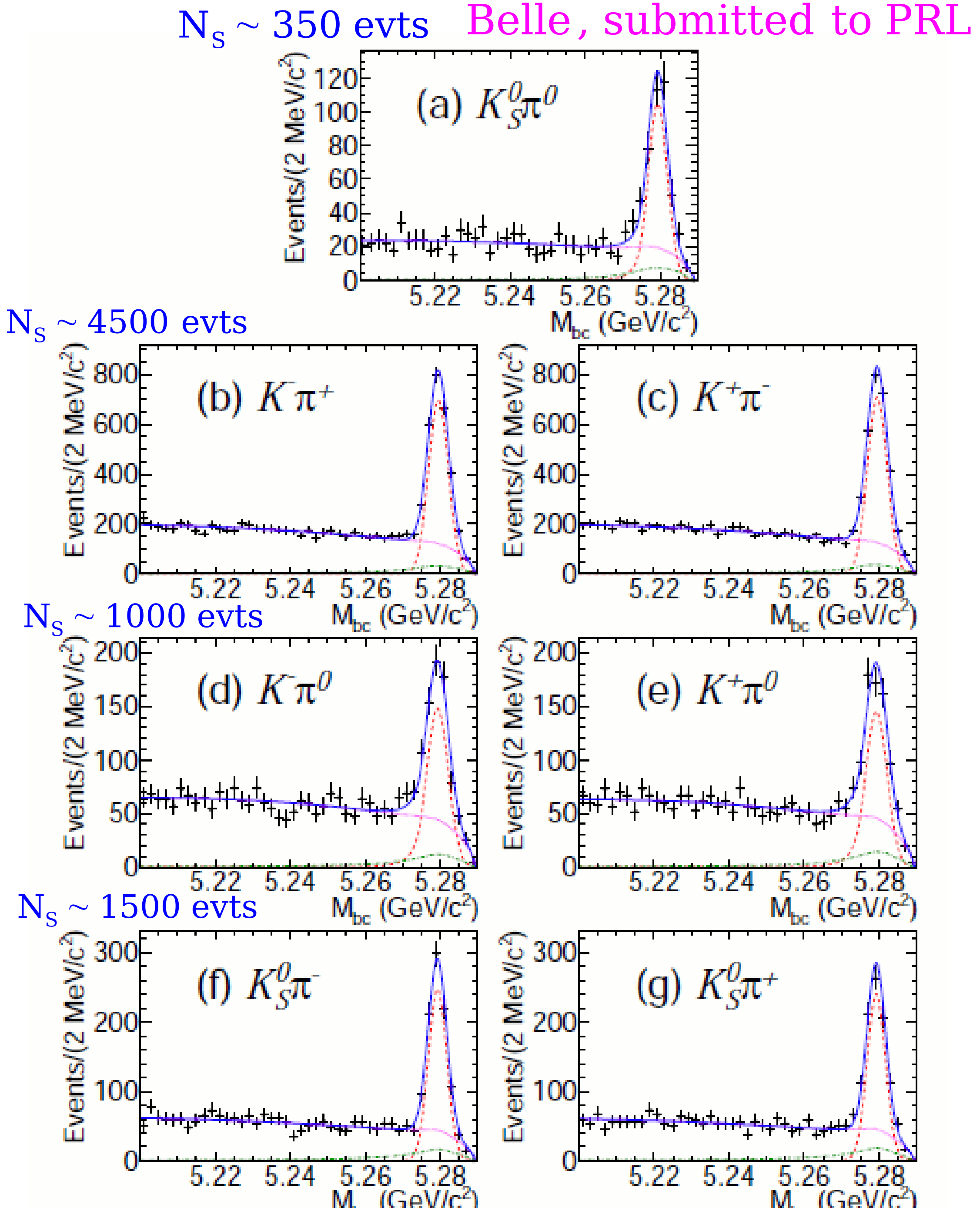


$B\to K^*\gamma$ measurements

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



Belle, submitted to PRL



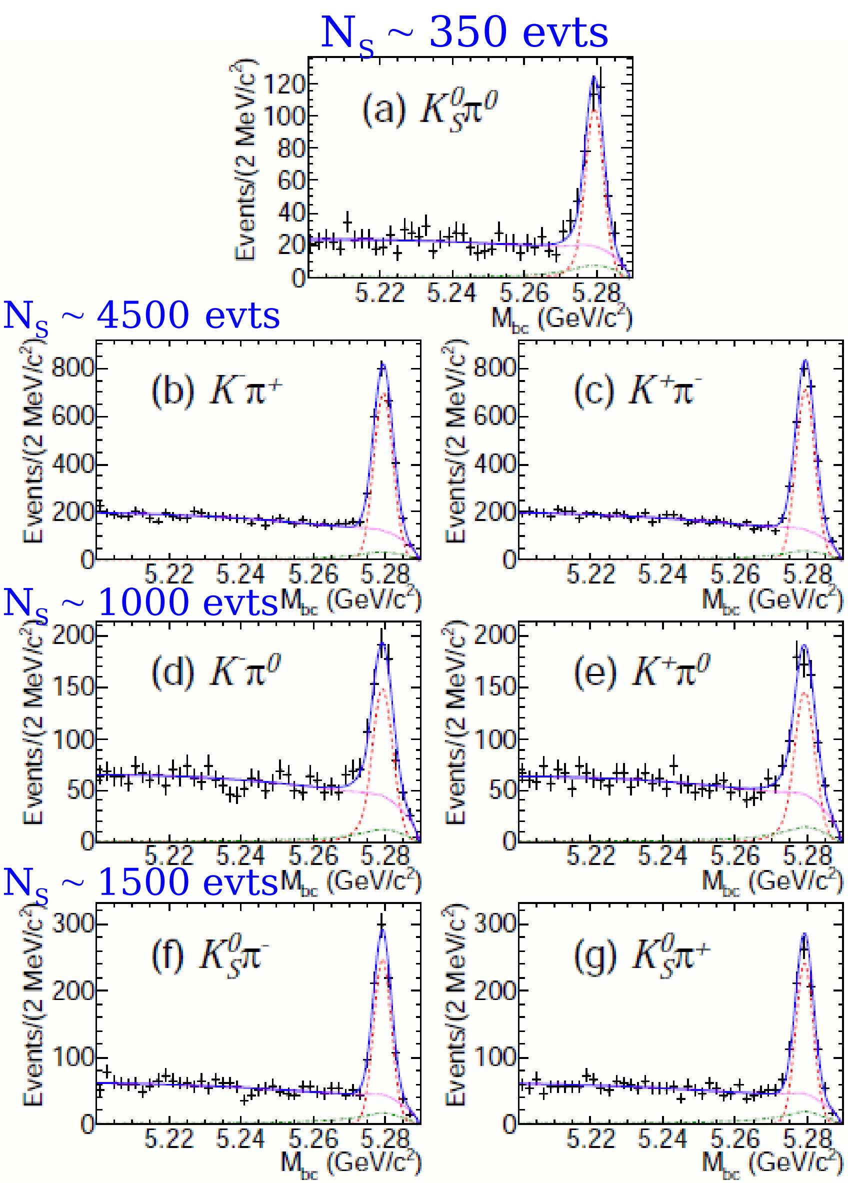
$B \to K^* \gamma$ measurements

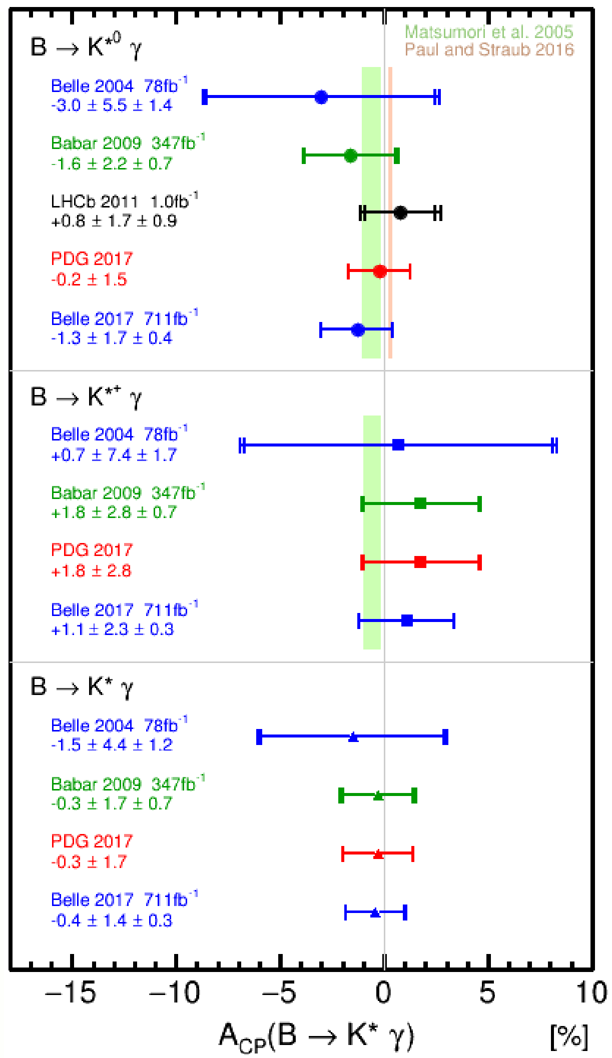
Belle, submitted to PRL

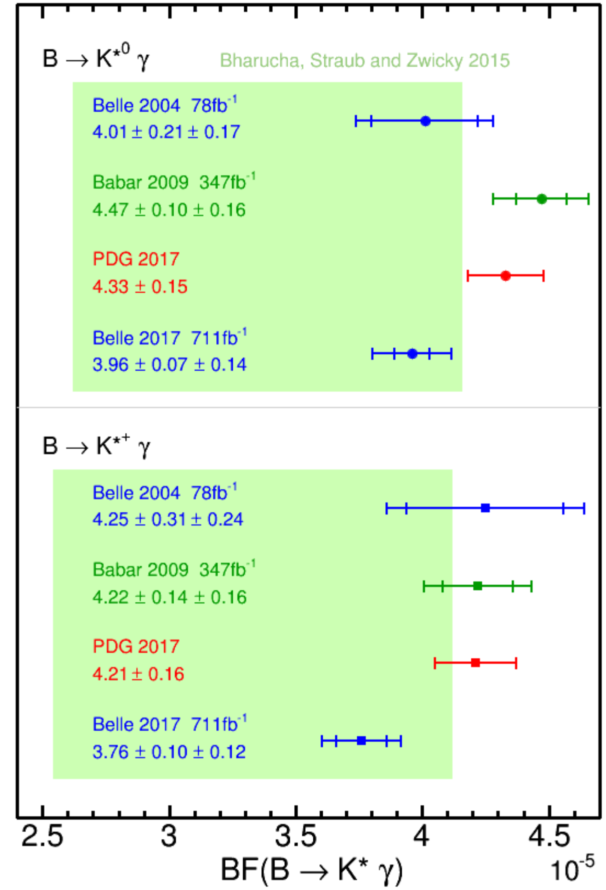
simultaneous fit of 4 final states

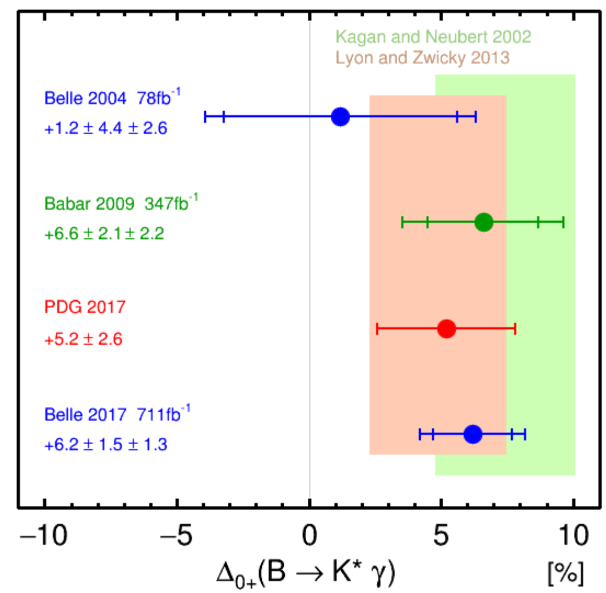
⇒ extraction of BFs, Δ_{0+}, A_{CP}, ΔA_{CP}

isospin asymmetry: $\Delta_{0+} = \dfrac{\Gamma(B^0 \to K^{*0}\gamma) - \Gamma(B^+ \to K^{*+}\gamma)}{\Gamma(B^0 \to K^{*0}\gamma) + \Gamma(B^+ \to K^{*+}\gamma)}$







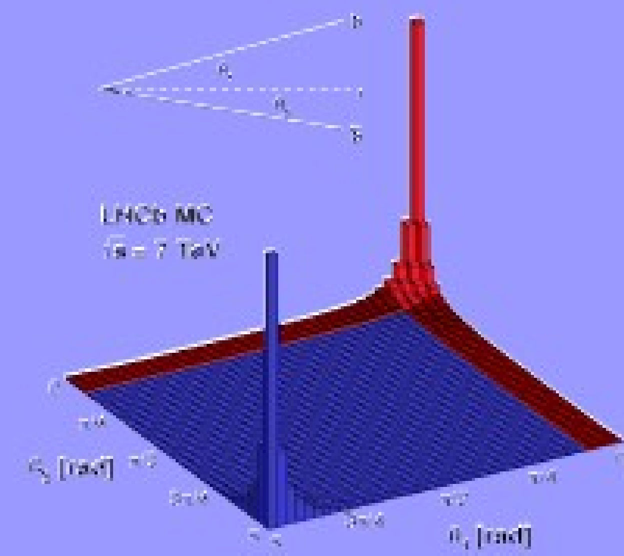


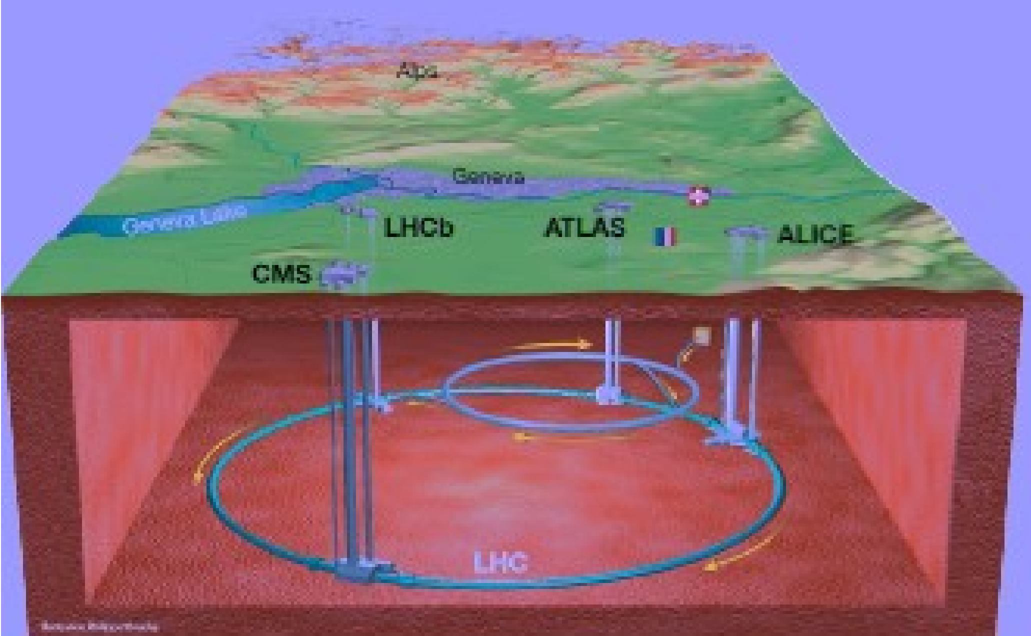
first evidence of isospin violation in $K^* \gamma$!

Rare B decays at LHCb

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



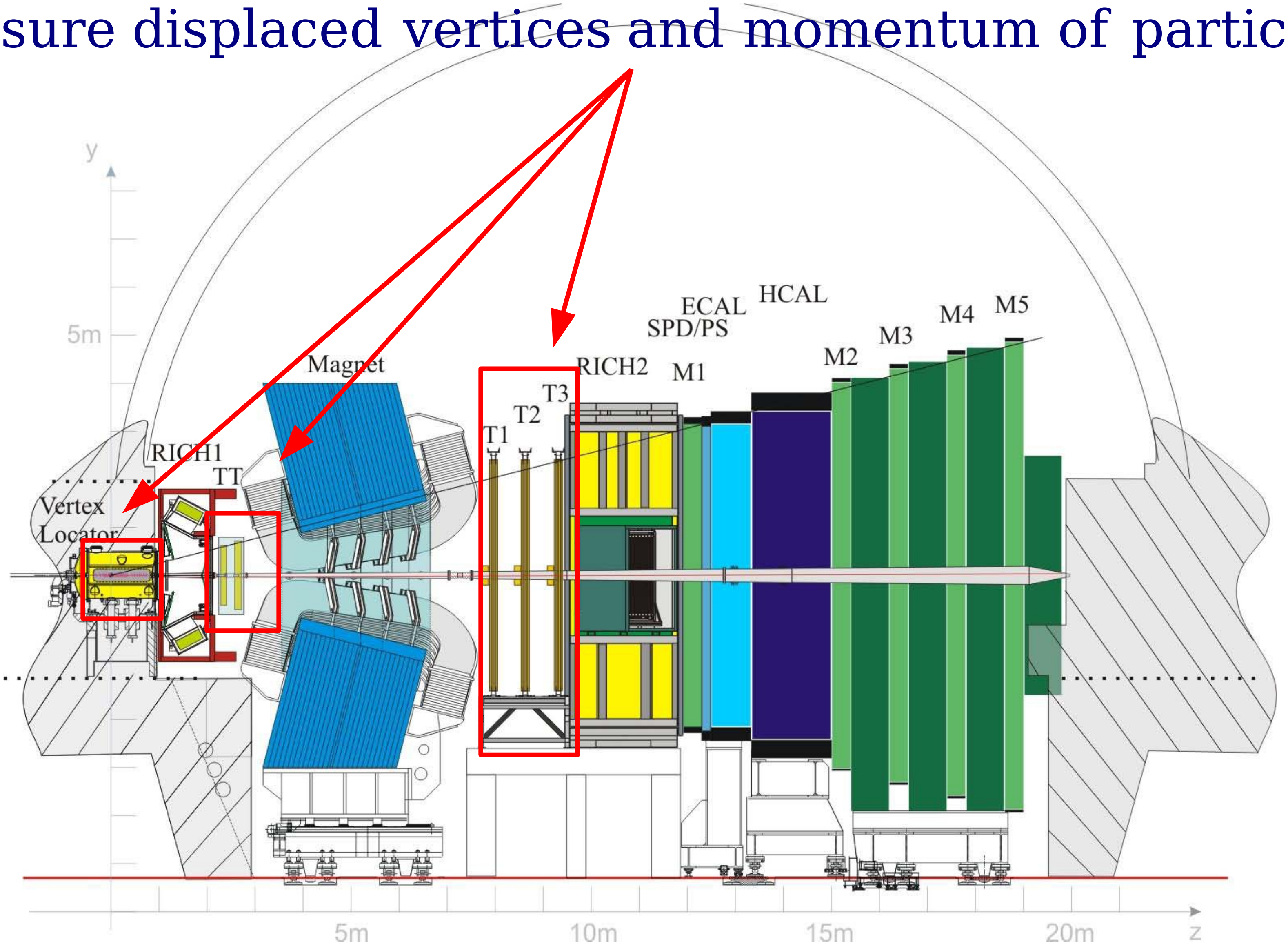


- pp collisions at $\sqrt{s} = 8(13)$ TeV in RunI (RunII)
- $b\bar{b}$ quark pairs produced correlated in the forward region
- Luminosity of $4 \times 10^{32} cm^{-2} s^{-1}$

LHCb

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

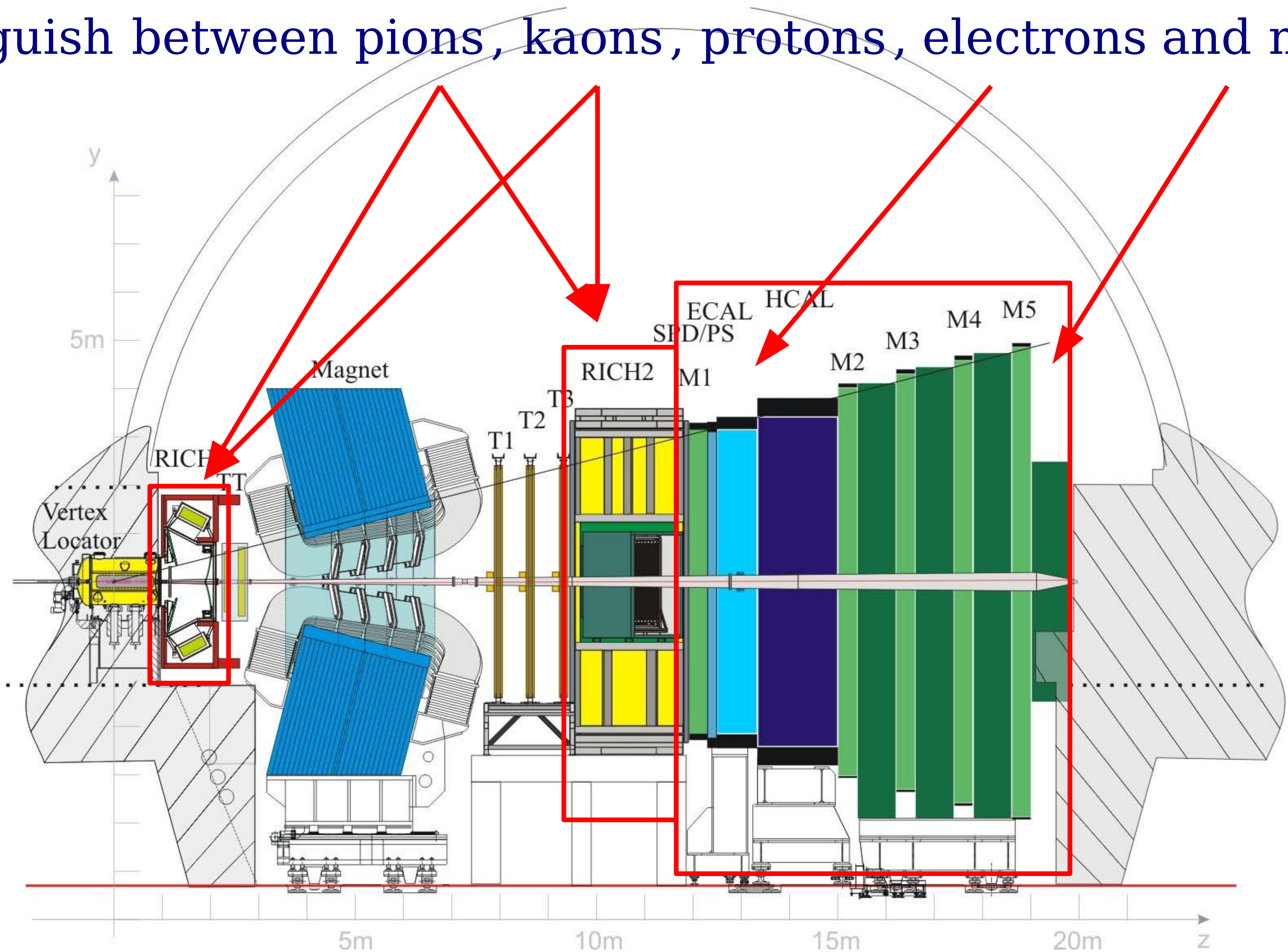
$\sigma(p)/p = 0.4\%$-0.6% for $p \in [0, 100]$ GeV/c

$\sigma(m_B) \sim 24$ 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%

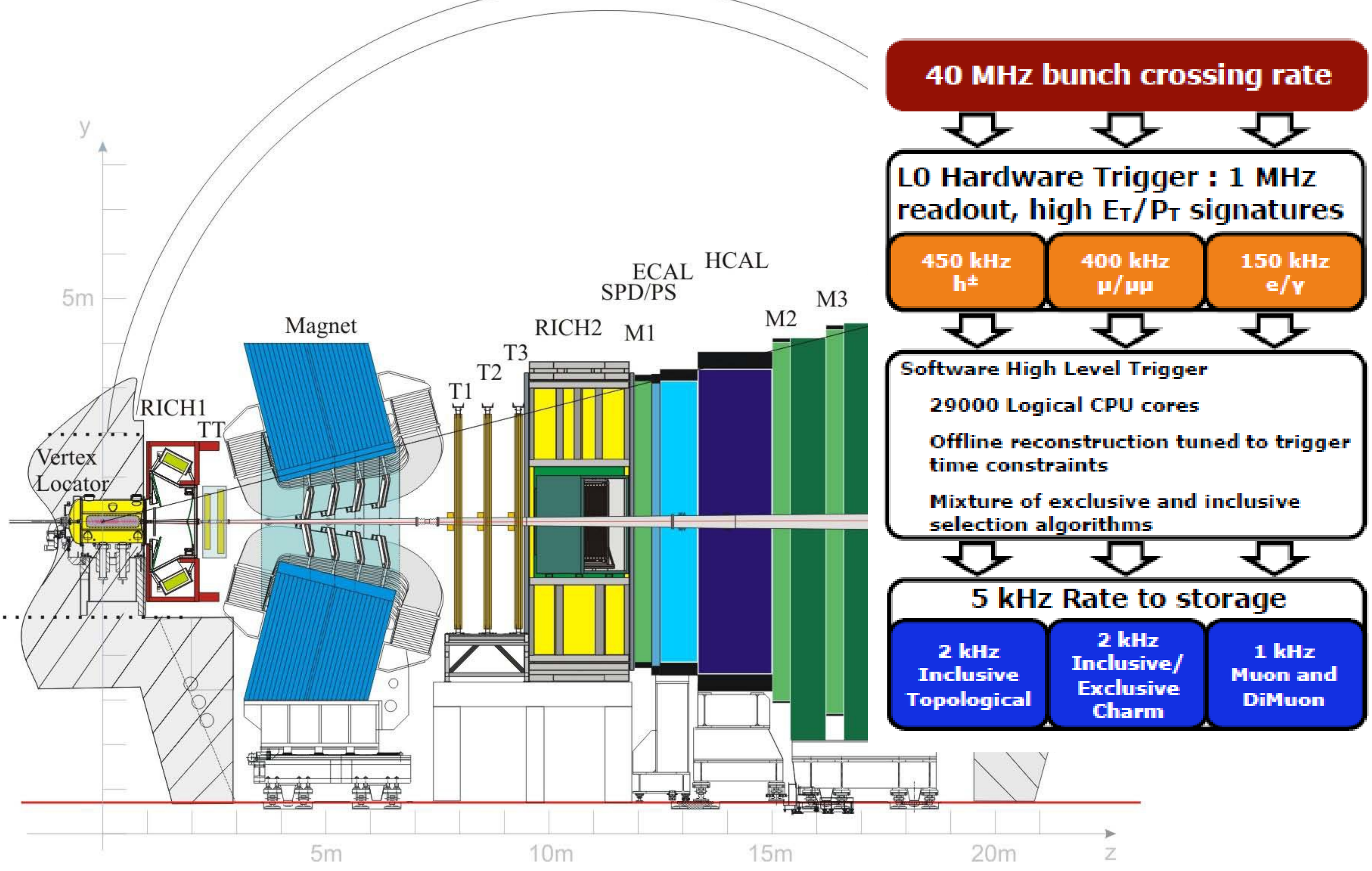
Muon identification

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

LHCb

Trigger system

Write out 5000 events/sec



Belle(II), LHCb side by side

(in the context of B anomalies)

Belle (II)

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

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

⇒ 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	$\sim 10^{-6}$
Tevatron	2 TeV	5000	$\sim 10^{-3}$
LHC	8 TeV	$\sim 3\times10^{5}$	$\sim 5\times10^{-3}$
	14 TeV	$\sim 6\times10^{5}$	$\sim 10^{-2}$

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

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

⇒ 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)

[1999-2010] = 1 ab^{-1}

[run I: 2010-2012] = 3 fb^{-1},
[run II: 2015-2018] = 2 fb^{-1} → 8 fb^{-1} ?

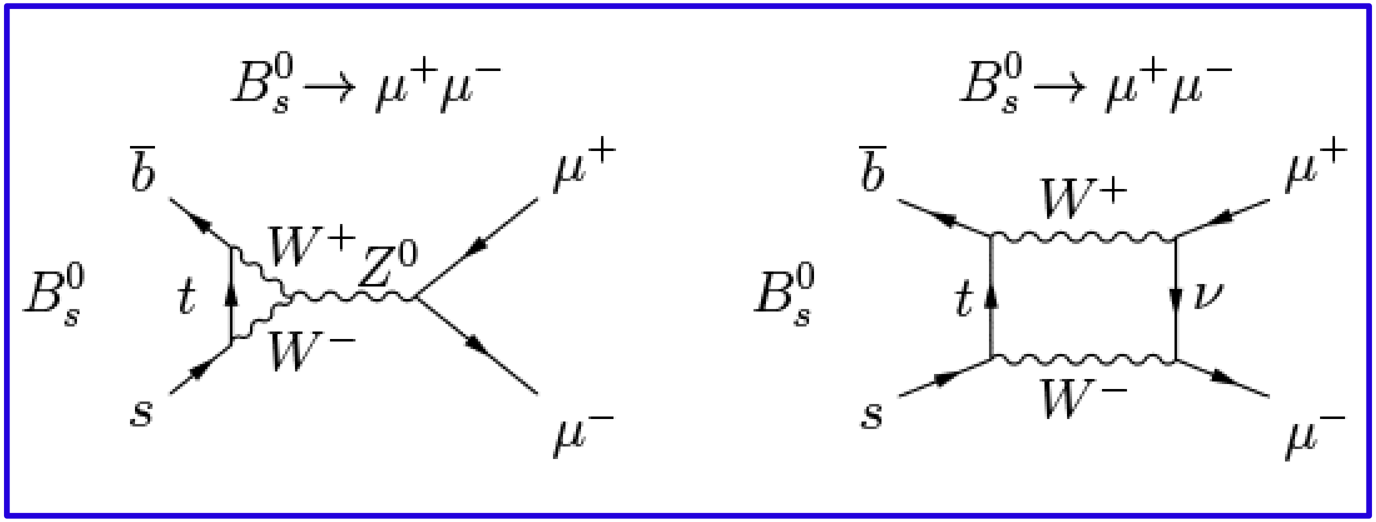
(near) future

[Belle II from 2018] → 50 ab^{-1}

[LHCb upgrade from 2020]

$B_{(s)} \to \mu\mu$: ultra rare processes…

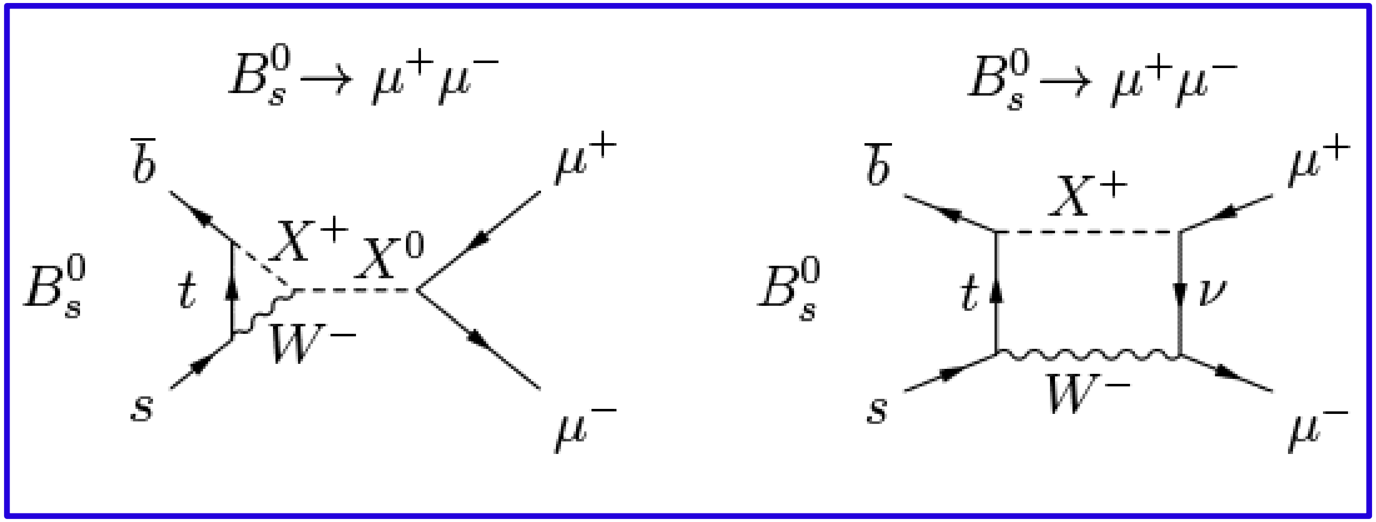
loop diagram + suppressed in SM + theoretically clean =
an excellent place to look for new physics



higher-order FCNC allowed in SM

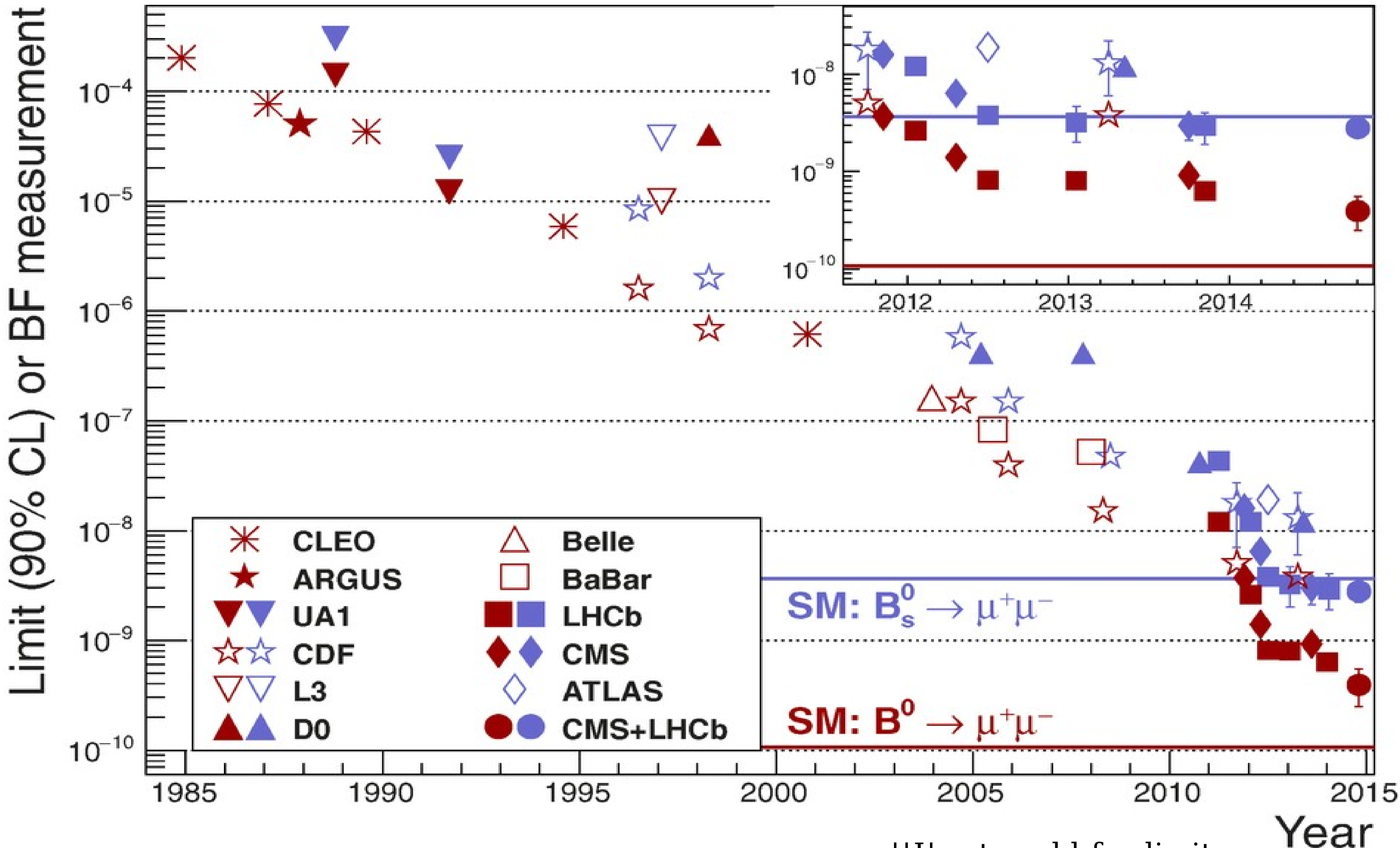
$B(B_s \to \mu^+\mu^-) = (3.65 \pm 0.23) \times 10^{-9}$
$B(B_d \to \mu^+\mu^-) = (1.06 \pm 0.09) \times 10^{-10}$

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



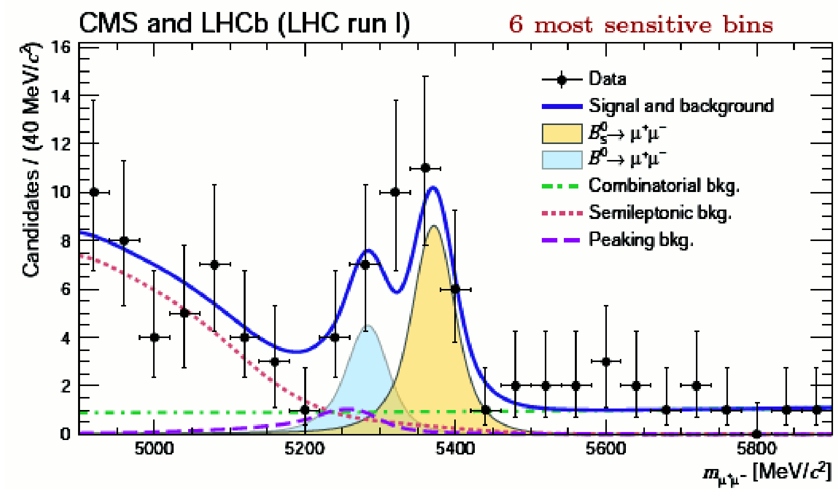
same decay in theories extending the SM (some of NP scenarios may boost the $B \to \mu\mu$ decay rates)

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



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

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



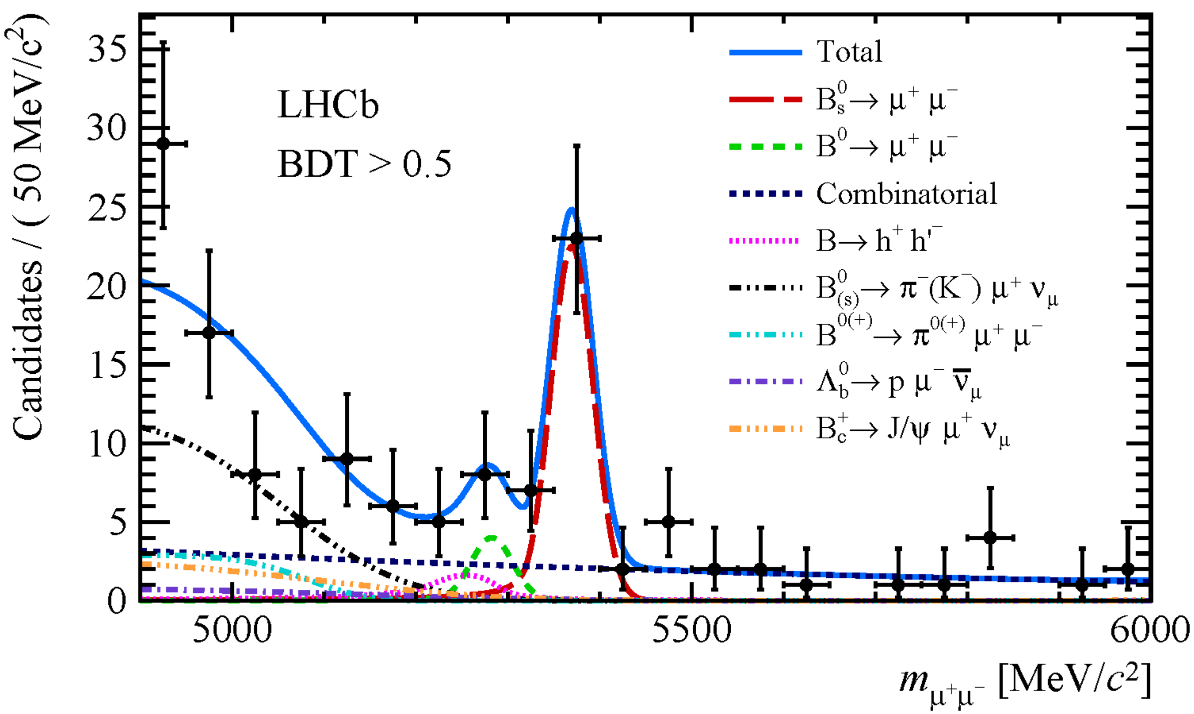
$B(B_s^0 \to \mu^+\mu^-) = (2.8\,^{+0.7}_{-0.6}) \times 10^{-9}$

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

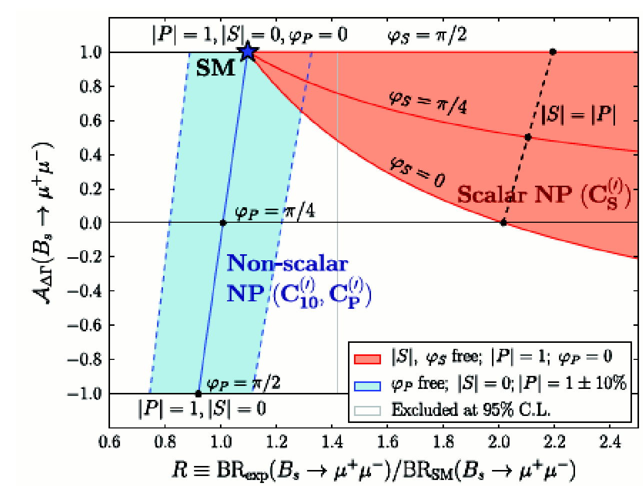
[arXiv:1703.05747]



SM: heavy state decays to $\mu^+\mu^-$

first lifetime measurement:

$\tau(B_s \to \mu^+\mu^\pm) = 2.04 \pm 0.44 \pm 0.05$ ps

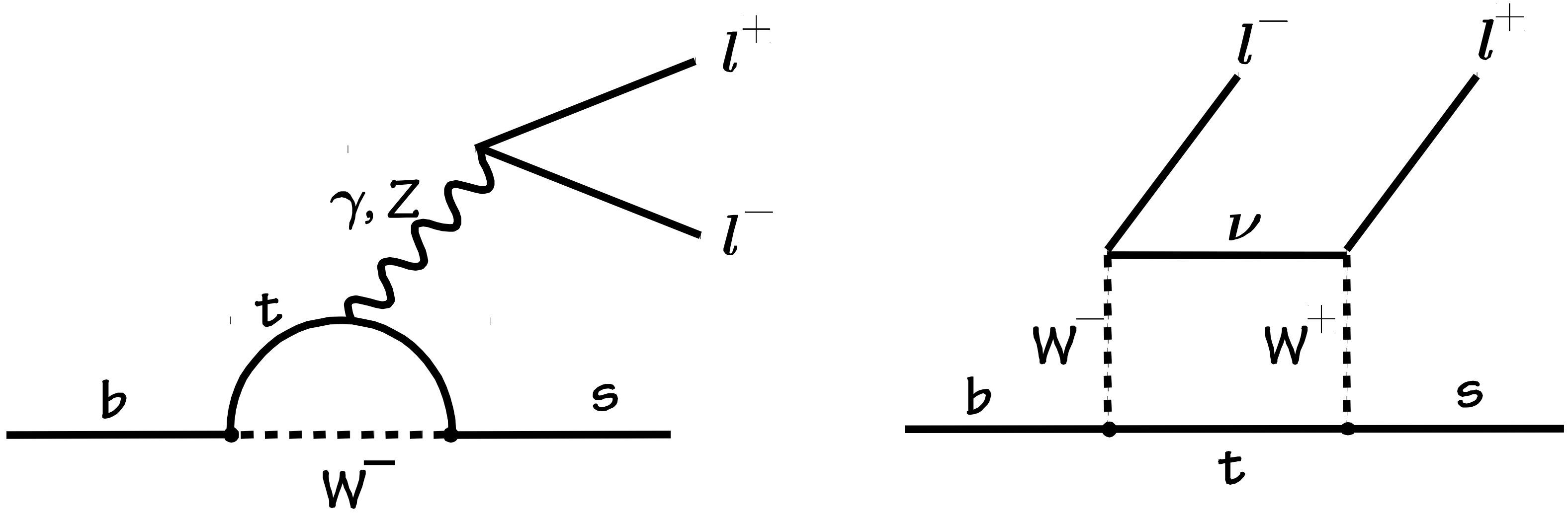


[De Bruyn et al., PRL 109, 041801 (2012)]

$B(B_s^0 \to \mu^+\mu^-) = (3.0 \pm 0.6\,^{+0.3}_{-0.2}) \times 10^{-9}$ (7.8σ significance)

$B(B^0 \to \mu^+\mu^-) < 3.4 \times 10^{-10}$ @ 90% CL

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



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

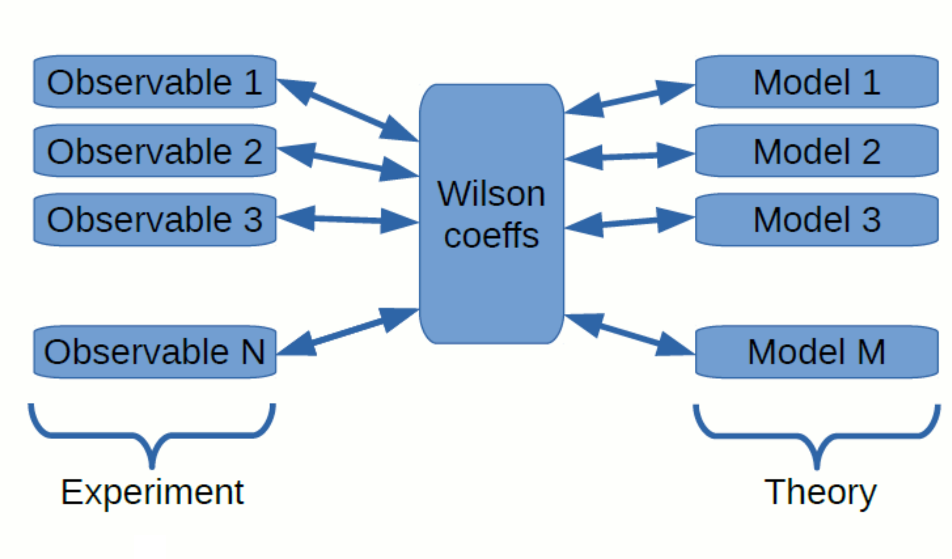
Amplitudes from
- ◦ electromagnetic penguin: C_7
- ◦ vector electroweak: C_9
- ◦ axial-vector electroweak: C_{10}

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 ($B \to X_s\, l^+ l^-$)

Sensitivity to new physics in rare B decays



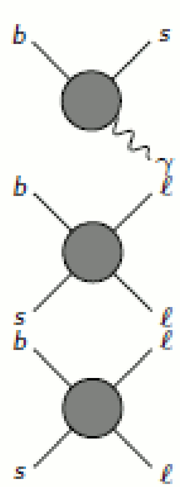
M.Ciuchini et al, arXiv:1512.07157
T.Hurth et al, arXiv:1603.00865
S.Descotes-Genon et al, arXiv:1510.04239...

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

- Model-independent description in effective field theory

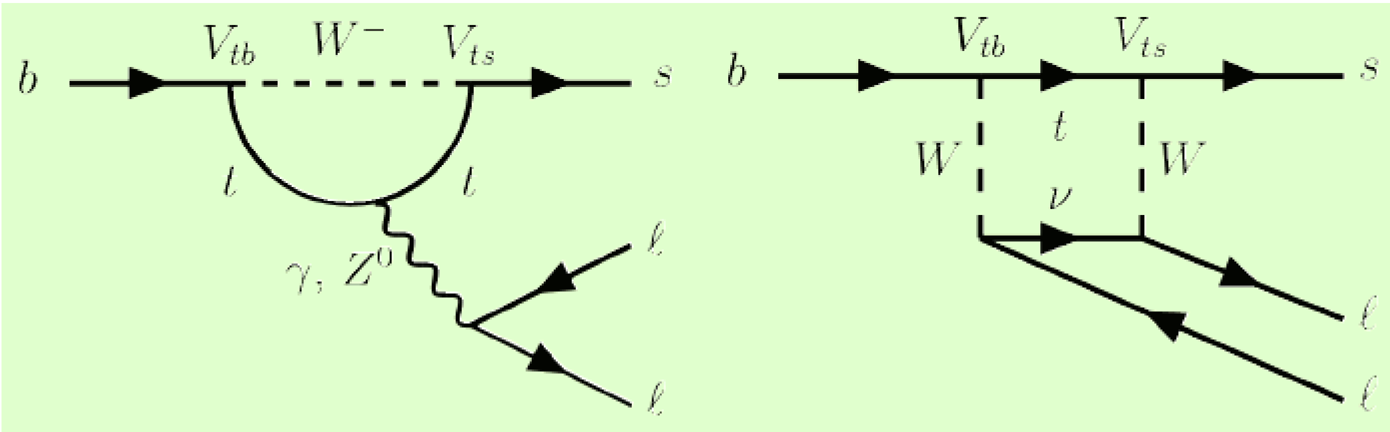
$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{\rm tb} V_{\rm ts}^* \sum_i \underbrace{\mathcal{C}_i \mathcal{O}_i}_{\text{Left-handed}} + \underbrace{\mathcal{C}'_i \mathcal{O}'_i}_{\text{Right-handed, } \frac{m_s}{m_b} \text{ suppressed}}$$

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

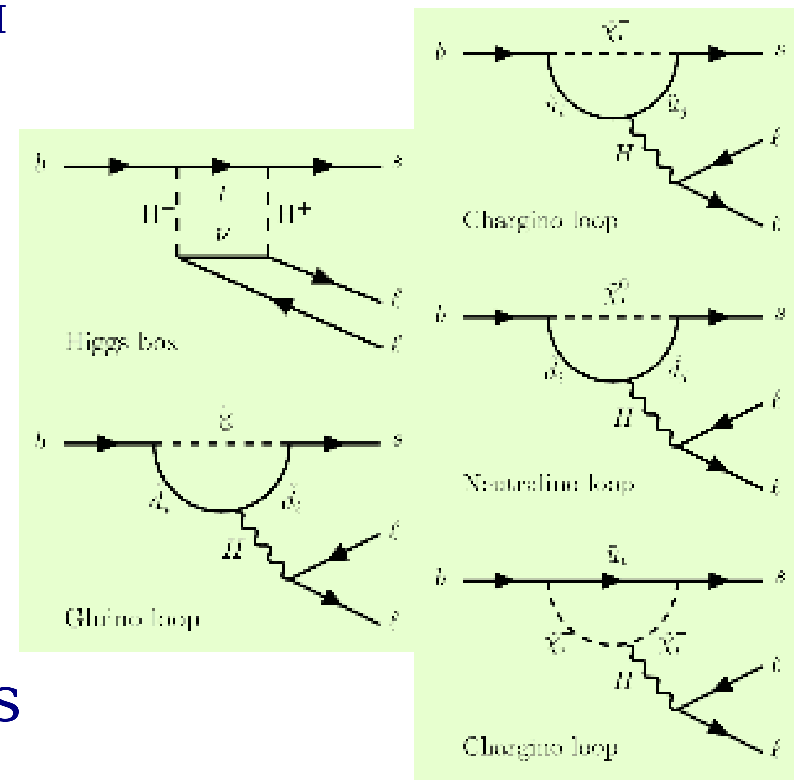


	$b \to s\gamma$	$B \to \mu\mu$	$b \to s\ell\ell$
$\mathcal{O}_7^{(\prime)}$ photon penguin	✓		✓
$\mathcal{O}_9^{(\prime)}$ vector coupling			✓
$\mathcal{O}_{10}^{(\prime)}$ axialvector coupling		✓	✓
$\mathcal{O}_{S,P}^{(\prime)}$ (pseudo)scalar penguin		✓	

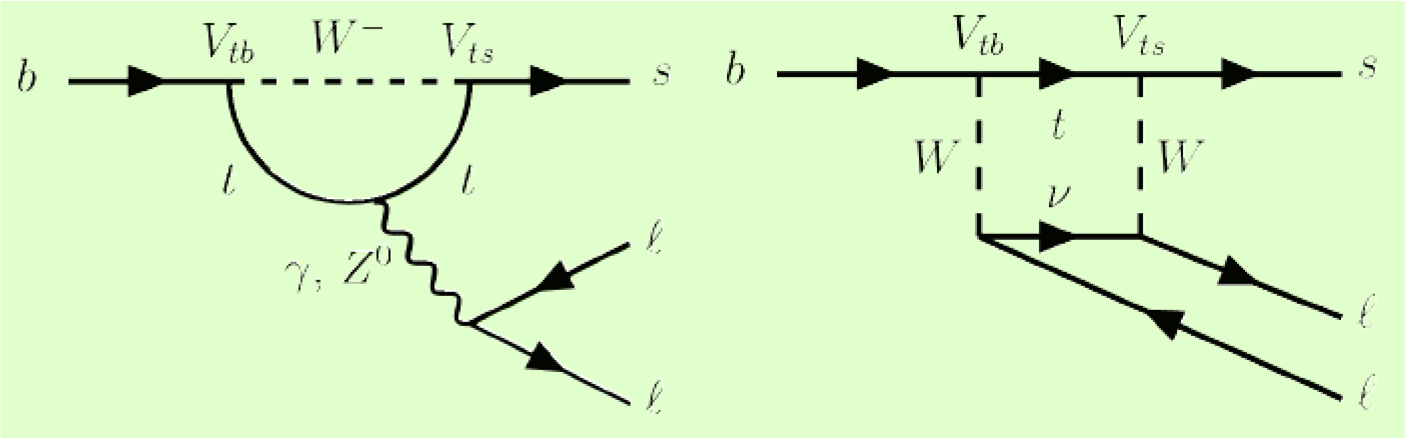
b→lls



- Start with $b \to s\gamma$, pay a factor α_{EM}
  - → Decay the γ into 2 leptons
  - Add an interfering box diagram
  - → $b \to lls$, 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



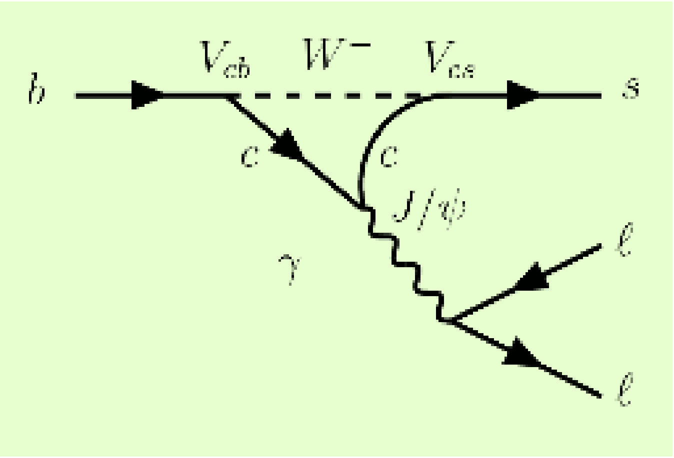
b→lls



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

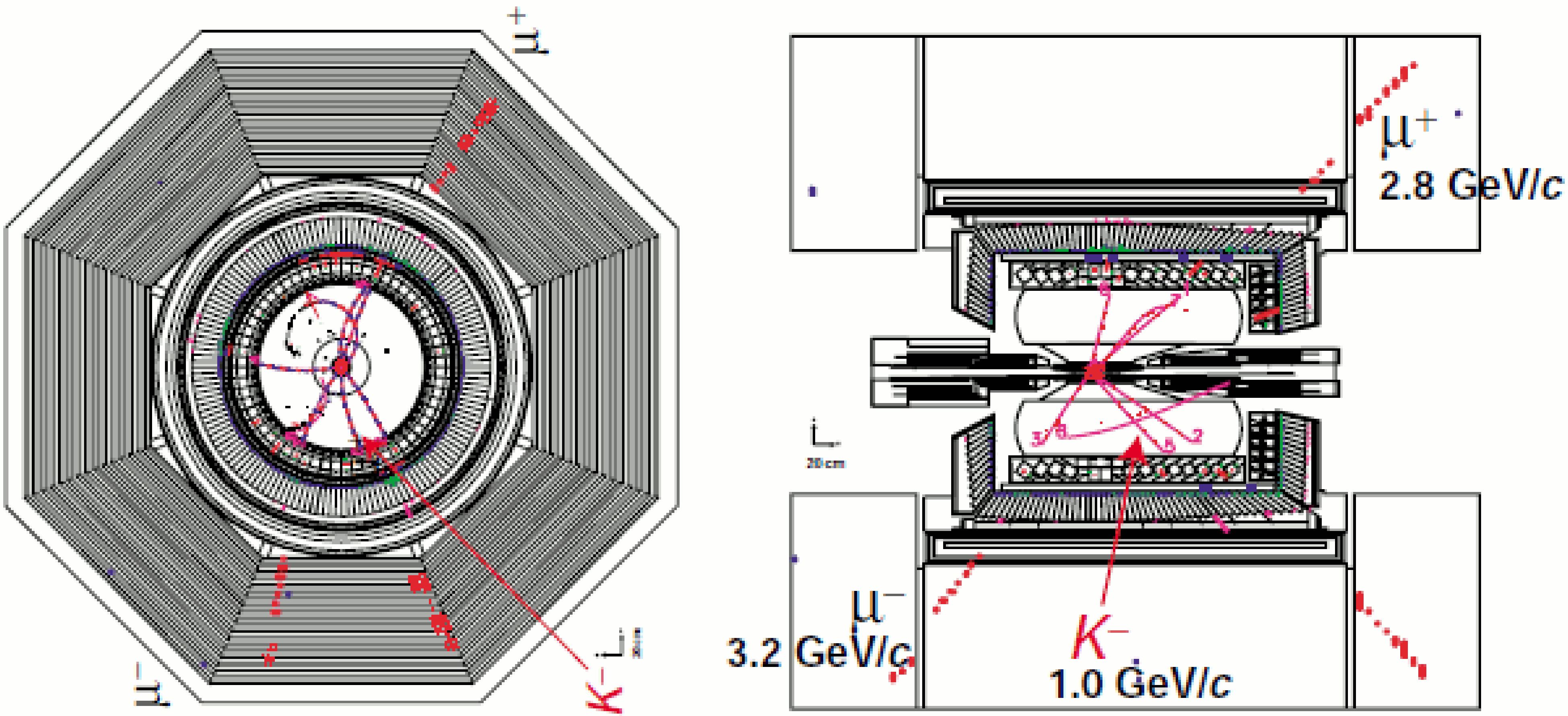
    $B(B \to llK^*) = (3.3 \pm 1.0) \,.\, 10^{-6}$

- 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



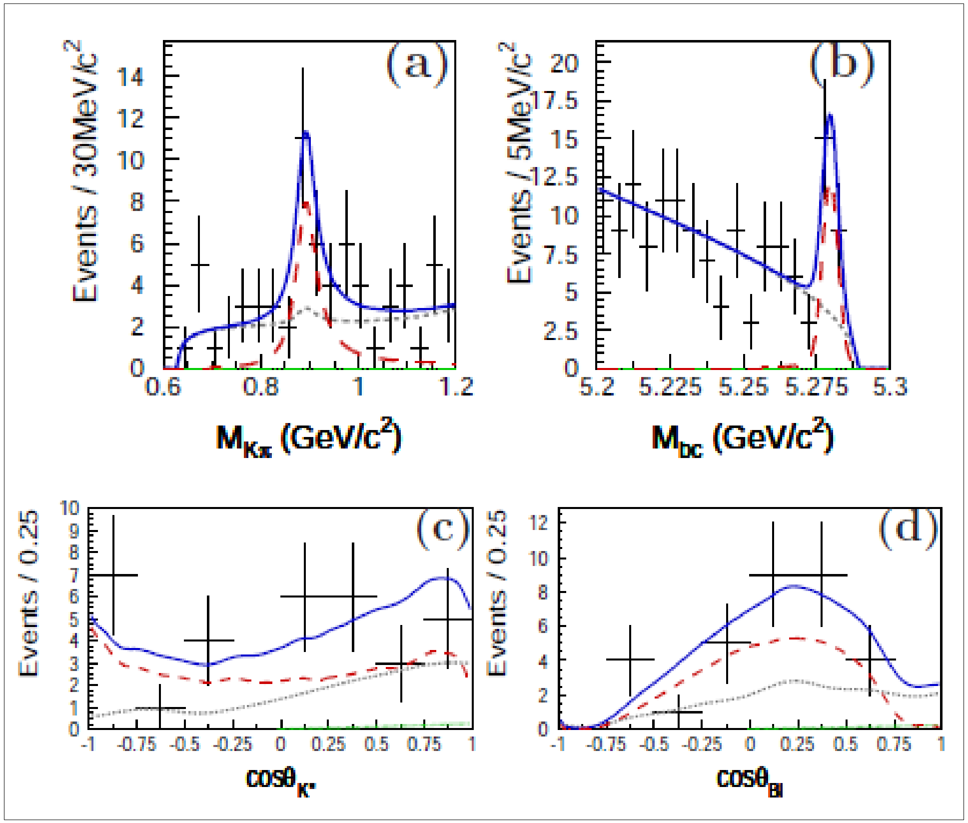
Situation pre-LHCb

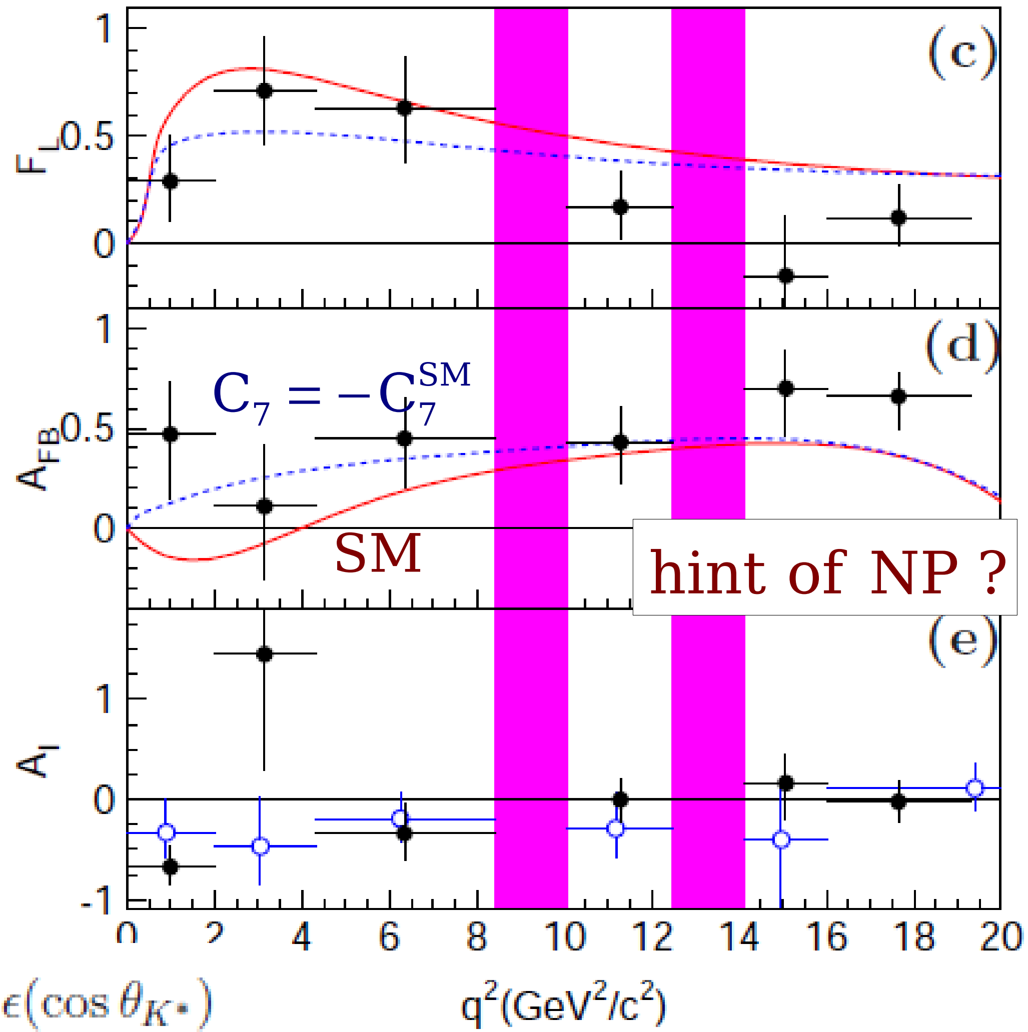
$B \to K^* l^+ l^-$ decays

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

[arXiv:0904.0770]

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





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

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

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

$R_K = 1.03 \pm 0.19 \pm 0.06$

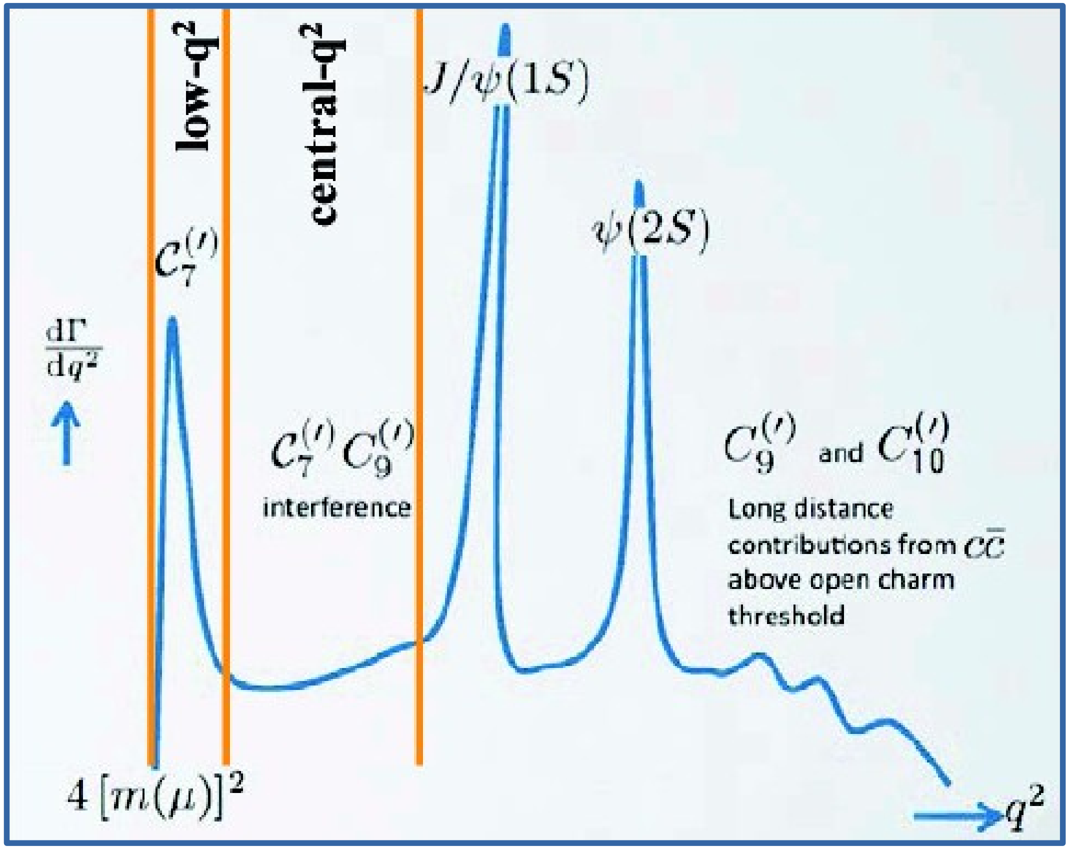
Test of LFU with $B \to K^{*0}\mu\mu$ and $B \to K^{*0}ee$, $R_{K^{*0}}$

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

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



- Measured relative to $B^0 \to K^{*0} J/\psi(ll)$ 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 $B^0 \to K^{*0} J/\psi(ll)$ 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

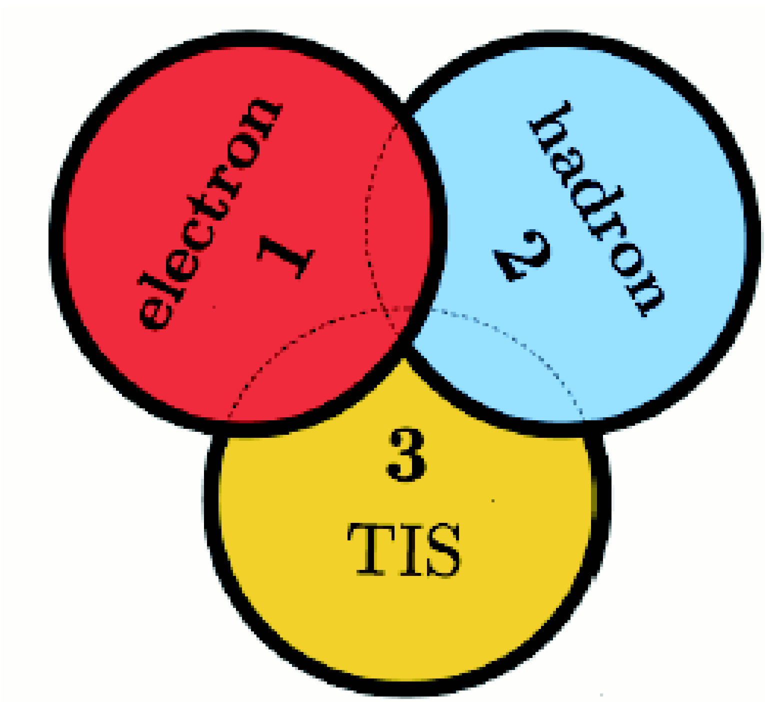
- Measured relative to $B^0 \to K^{*0} J/\psi(ll)$ in order to reduce systematics

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

- 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)

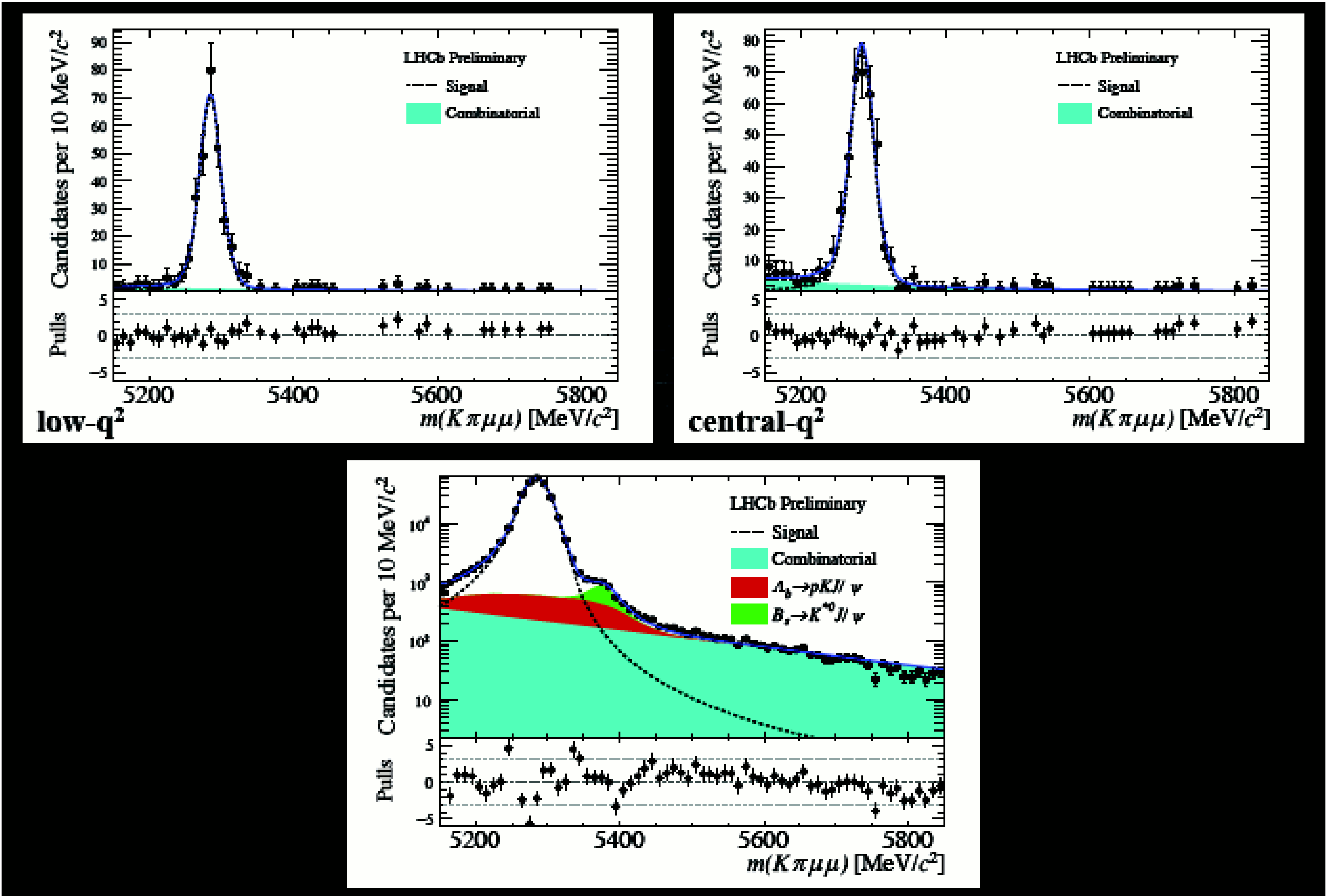


3 exclusive trigger categories:

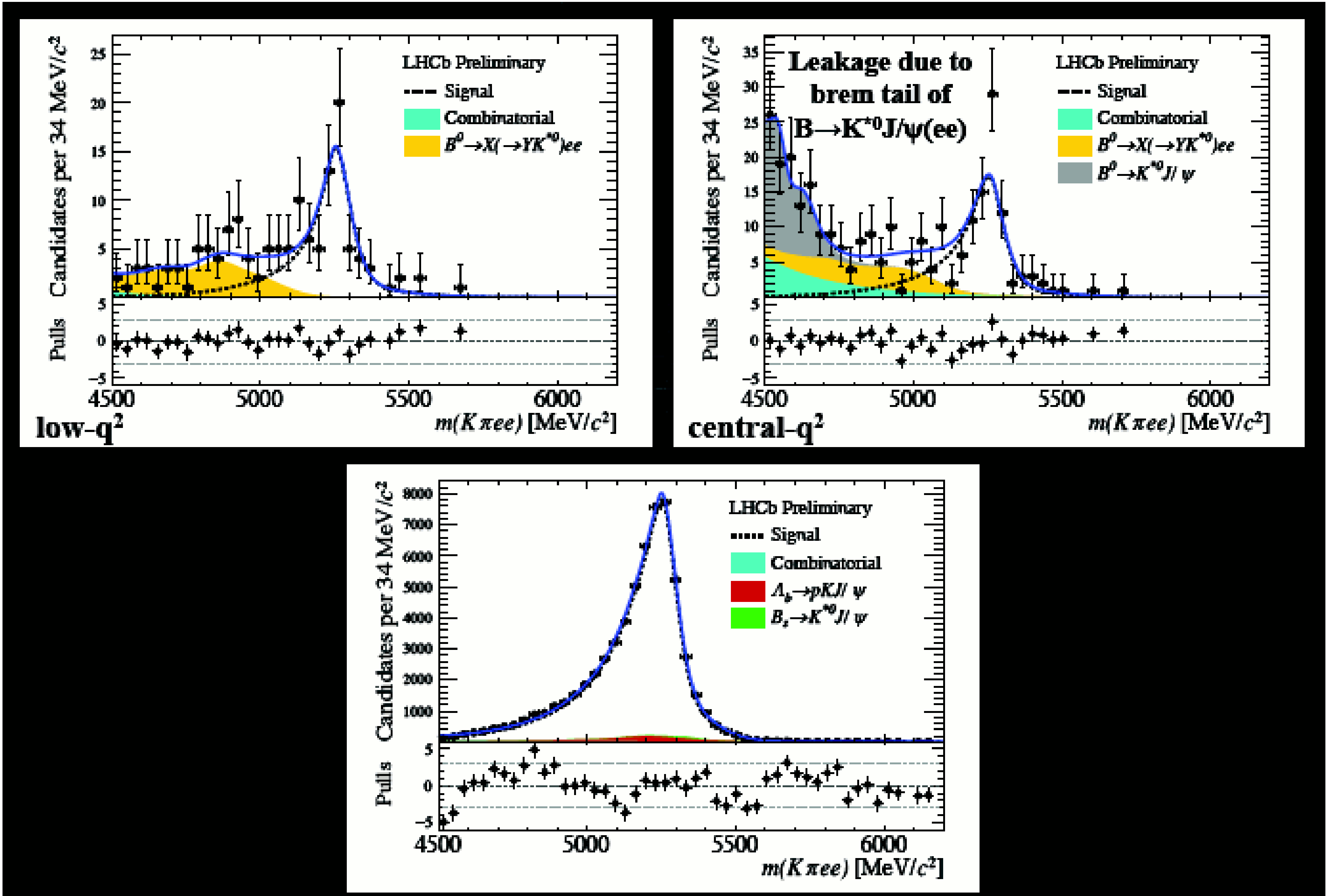
- L0 Electron: electron hardware trigger fired by clusters associated to at least one of the two electrons (E_T >2.5 GeV)
- L0 Hadron: hadron hardware trigger fired by clusters associated to at least one of the K^{*0} decay products (E_T >2.5 GeV)
- L0 TIS(*): any hardware trigger fired by particles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

(*) TIS = Trigger Independent of Signal

Fit results – μμ



Fit results – ee



Yields

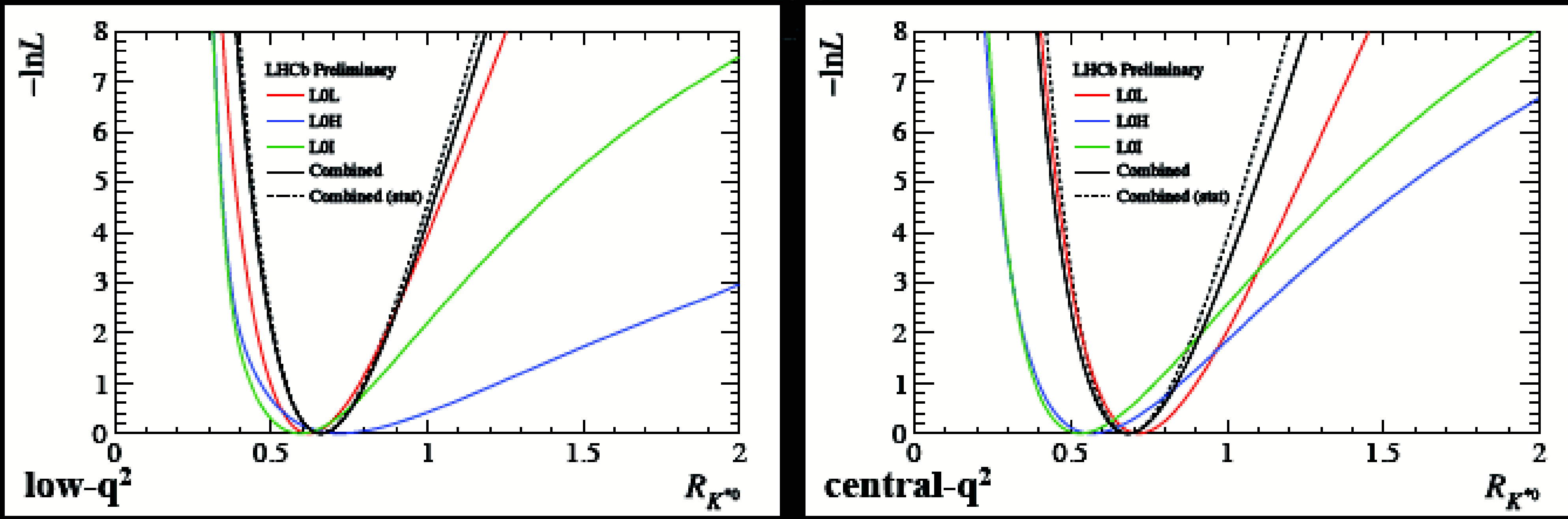
Precision of the measurement driven by the statistics of the electron samples

	$B^0 \to K^{*0}\ell^+\ell^-$		$B^0 \to K^{*0} J/\psi (\to \ell^+\ell^-)$
	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

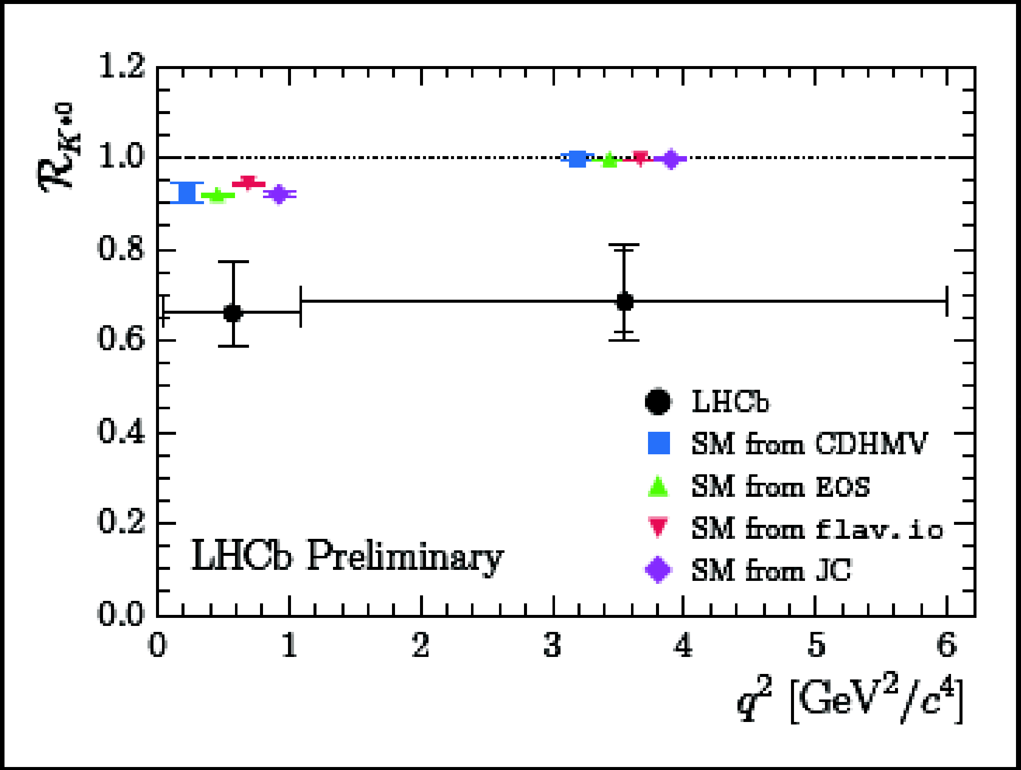
Results

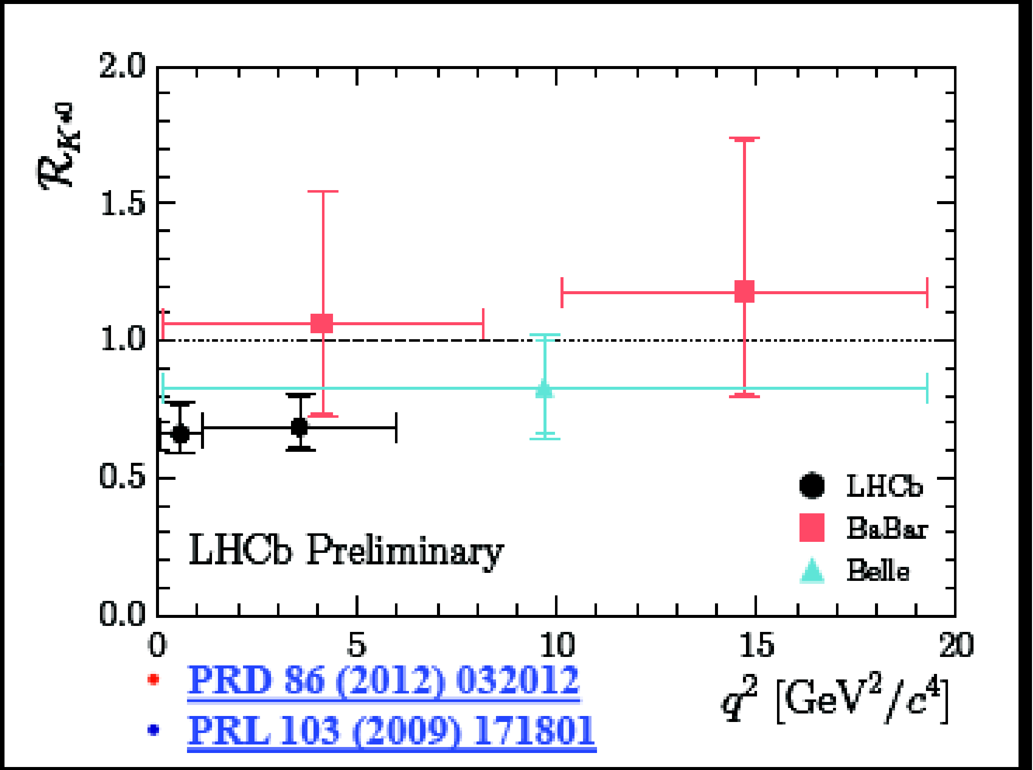
LHCb Preliminary	low-q^2	central-q^2
$\mathcal{R}_{K^{*0}}$	$0.660\ ^{+\ 0.110}_{-\ 0.070} \pm 0.024$	$0.685\ ^{+\ 0.113}_{-\ 0.069} \pm 0.047$
95% CL	[0.517–0.891]	[0.530–0.935]
99.7% CL	[0.454–1.042]	[0.462–1.100]



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





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

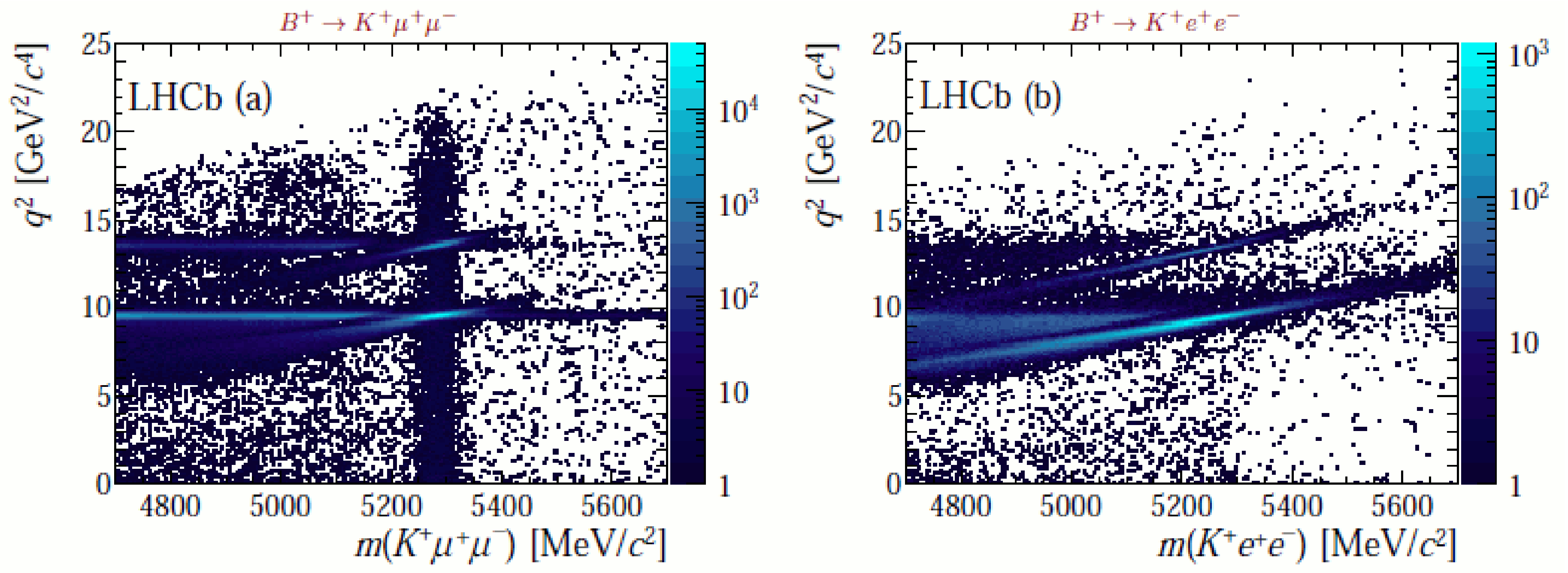
arXiv:1406.6482

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

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

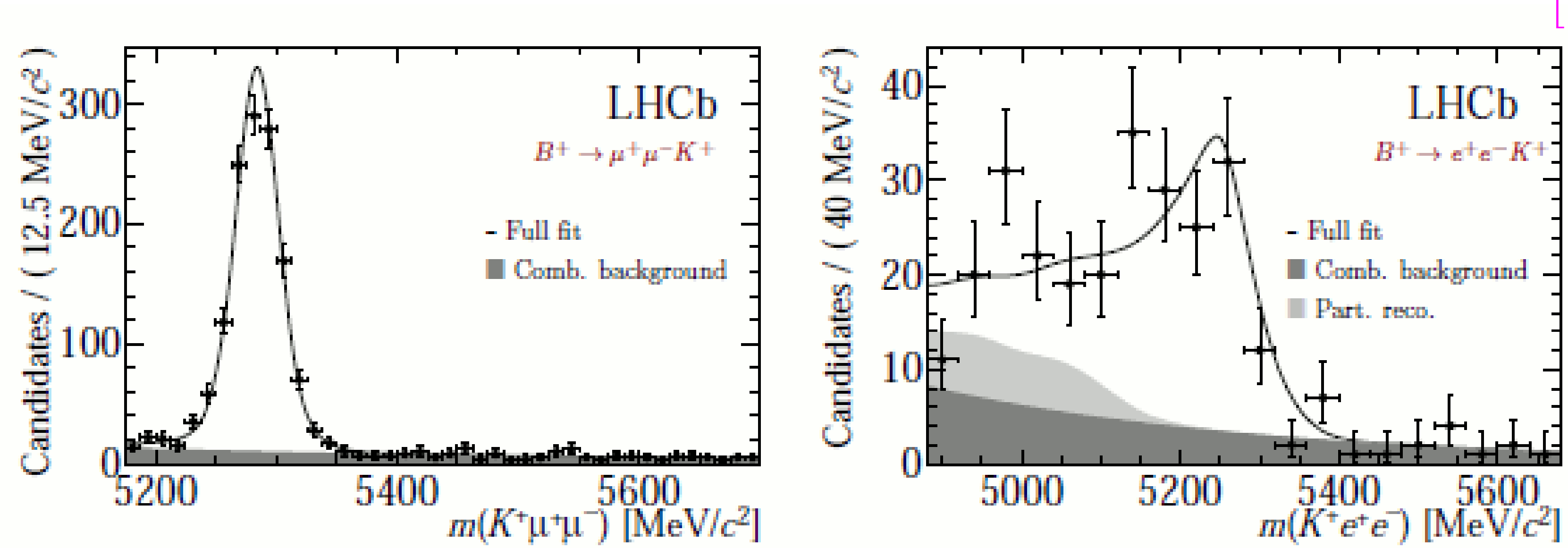
- SM prediction is $R_K = 1$ with an uncertainty of $O(10^{-3})$

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



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

[arXiv:1406.6482]



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

Electron Trigger

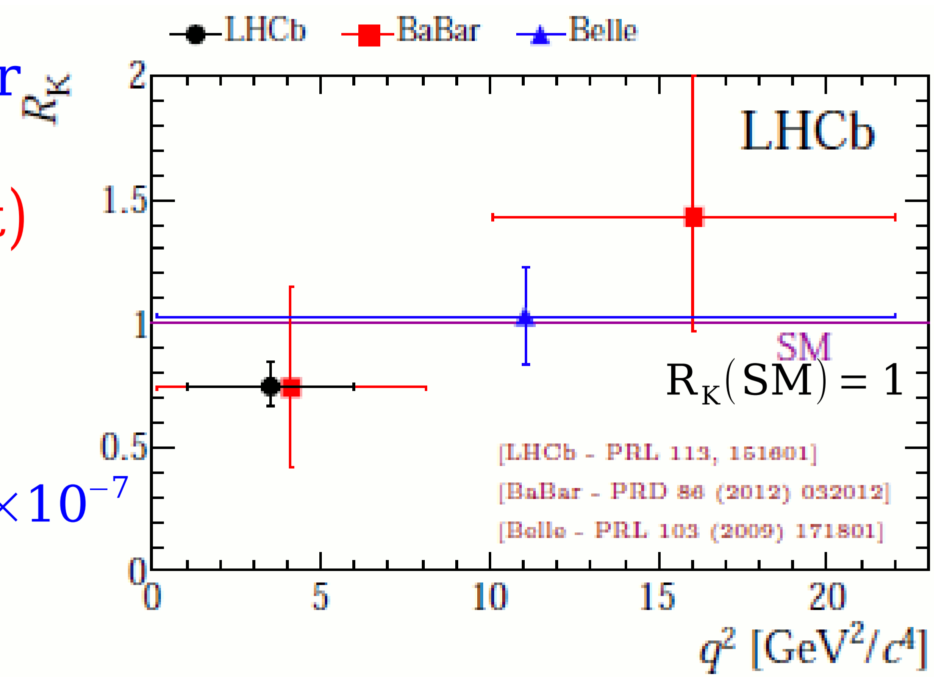
R_K: ratio of branching fractions for dilepton invariant mass squared range $1 < q^2 < 6\,\mathrm{GeV}^2/c^4$

- The combination of the various trigger channels gives:

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

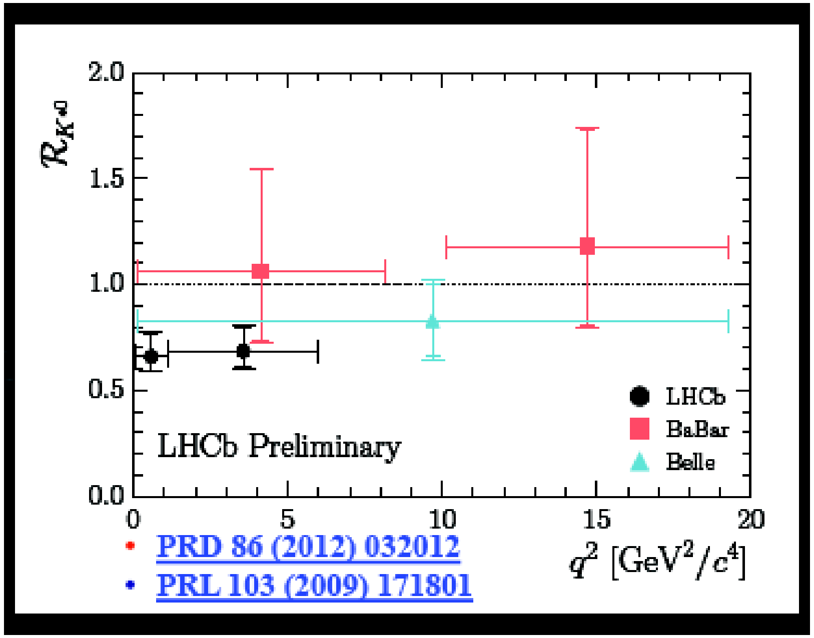
- Most precise measurement to date, disagreement with SM at 2.6σ level

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

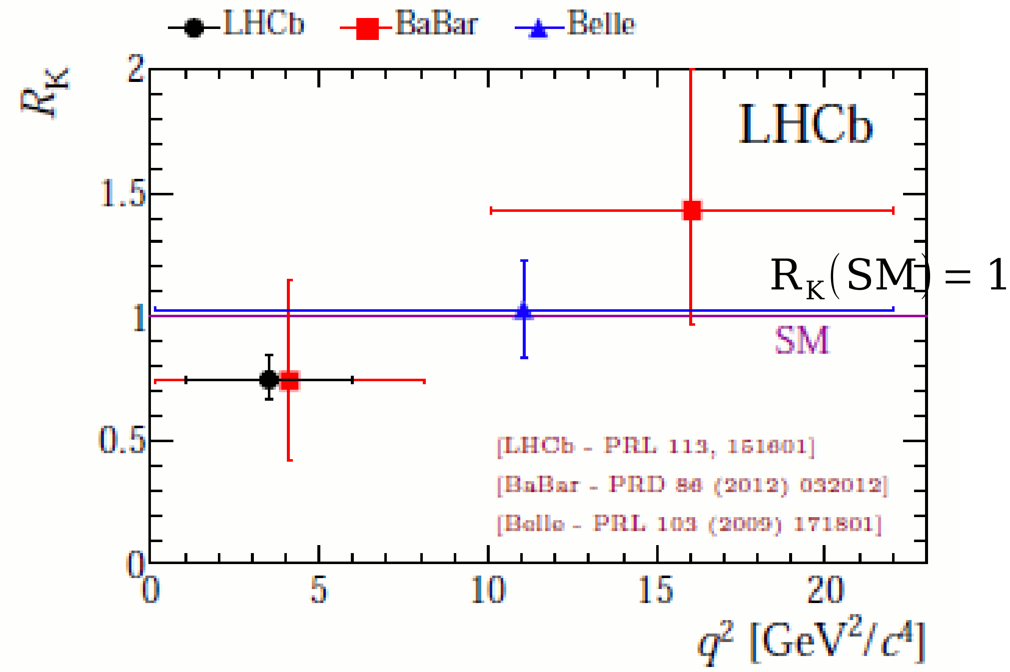


BSM LFNU and effect is in $\mu\mu$, not ee

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

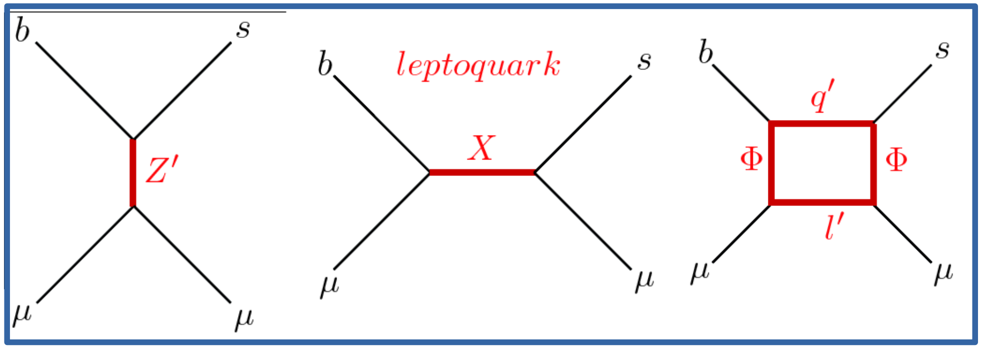


• PRD 86 (2012) 032012
• PRL 103 (2009) 171801



Model candidates

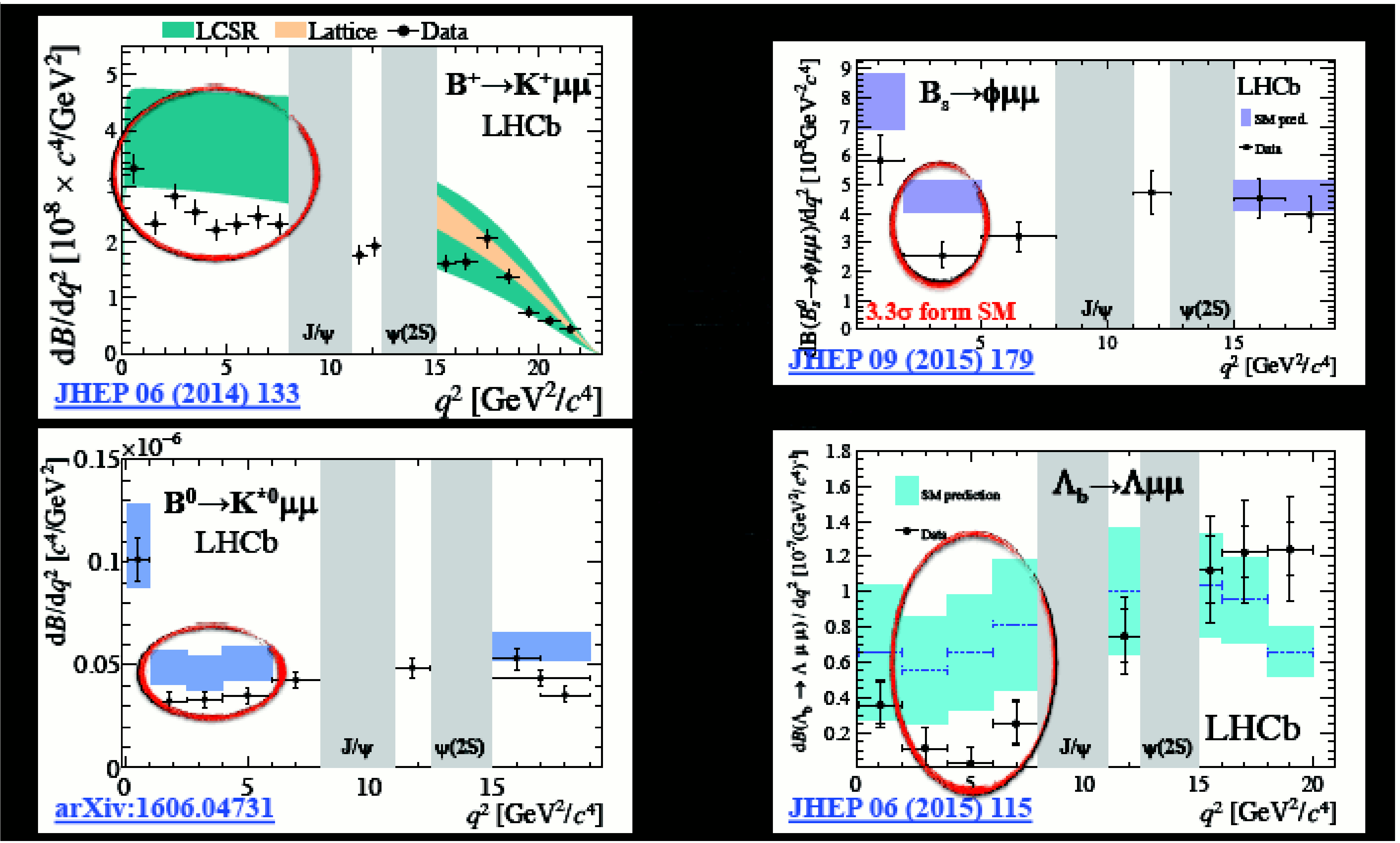
- **Model with extended gauge symmetry**
  - ✓ Effective operator from Z' exchange
  - ✓ Extra U(1) symmetry with flavor dependent charge
- **Models with leptoquarks**
  - ✓ Effective operator from LQ exchange
  - ✓ Yukawa interaction with LQs provide flavor violation
- **Models with loop induced effective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



Lot of those models predict also LFV B decays as $b \to s e \mu$, $b \to s e \tau$, ...

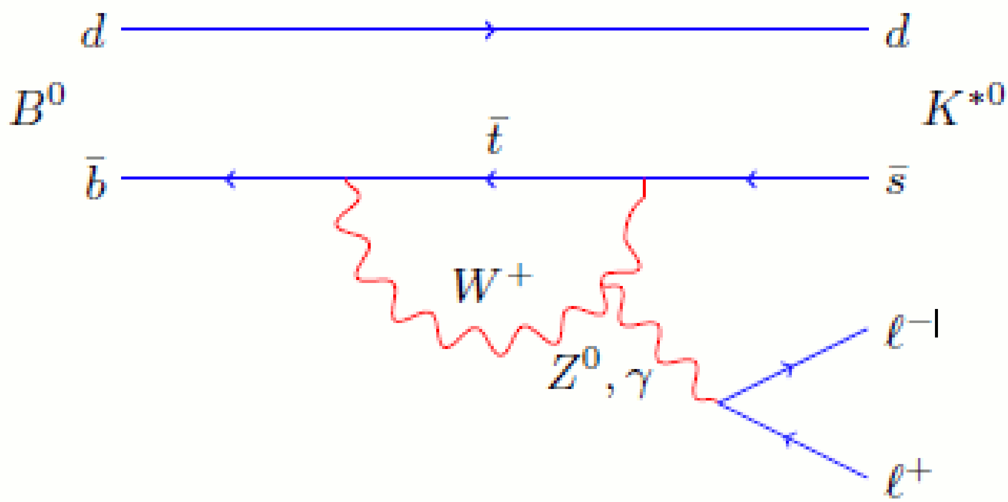
Differential Branching Fractions

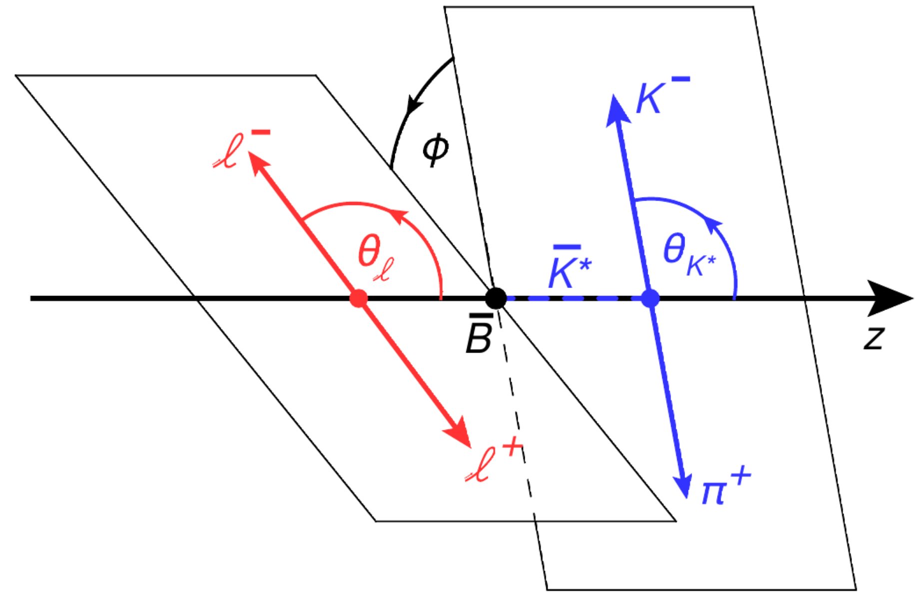
Results consistently lower than SM predictions



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

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





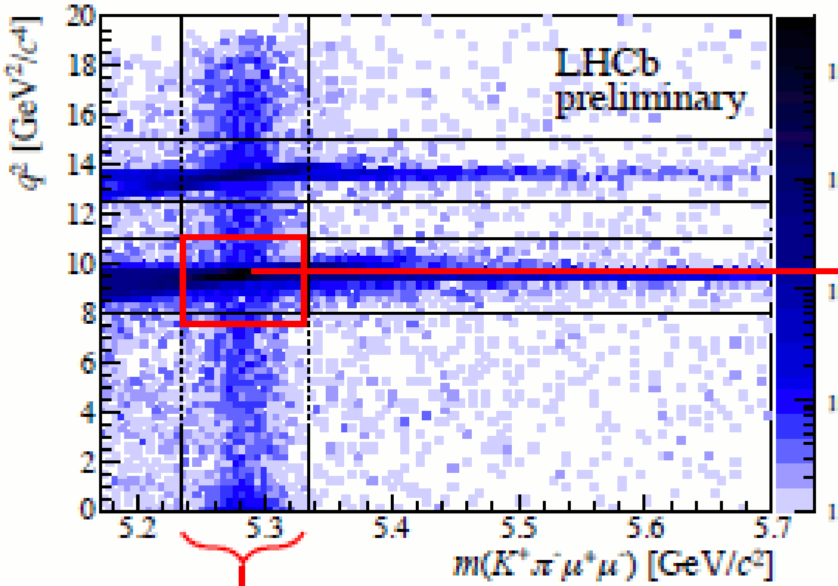
$$\frac{1}{\mathrm{d}(\Gamma+\bar{\Gamma})/\mathrm{d}q^2}\frac{\mathrm{d}^3(\Gamma+\bar{\Gamma})}{\mathrm{d}\vec{\Omega}} = \frac{9}{32\pi}\Big[\tfrac{3}{4}(1-F_{\mathrm{L}})\sin^2\theta_K + F_{\mathrm{L}}\cos^2\theta_K + \tfrac{1}{4}(1-F_{\mathrm{L}})\sin^2\theta_K\cos 2\theta_\ell$$
$$- F_{\mathrm{L}}\cos^2\theta_K\cos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

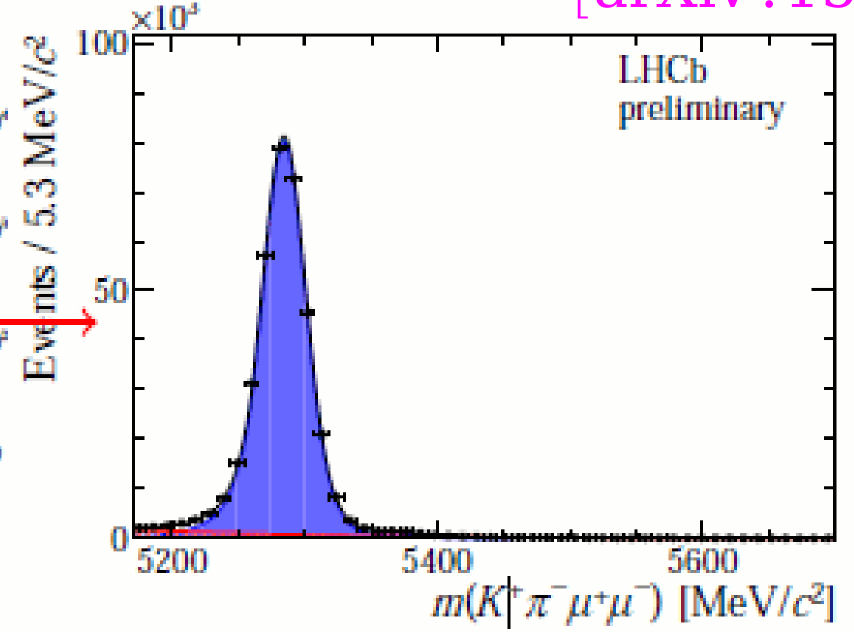
- F_L, A_{FB}, S_i sensitive to $C_7^{(')}$, $C_9^{(')}$, $C_{10}^{(')}$

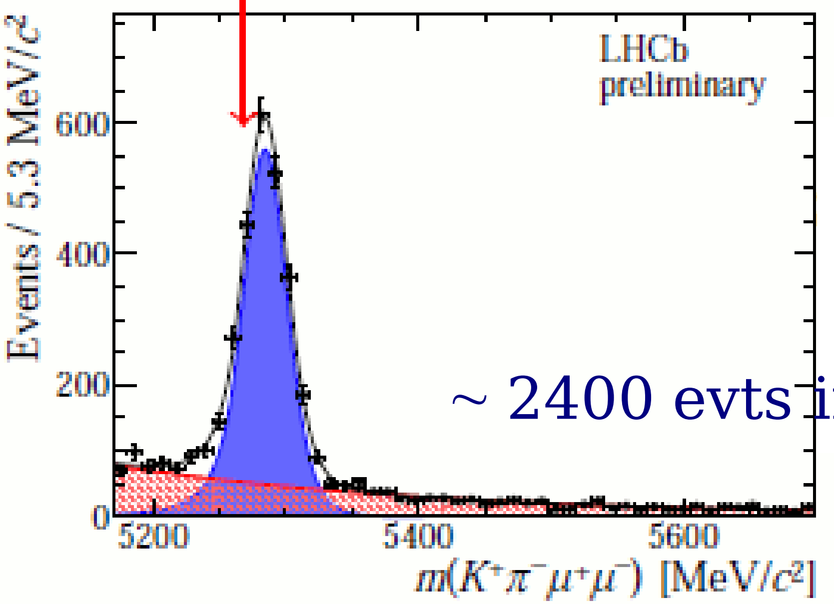
Angular analysis of $B_d^0 \to K^* \mu^+ \mu^-$ decays

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

[arXiv:1512.04442]







Selection:

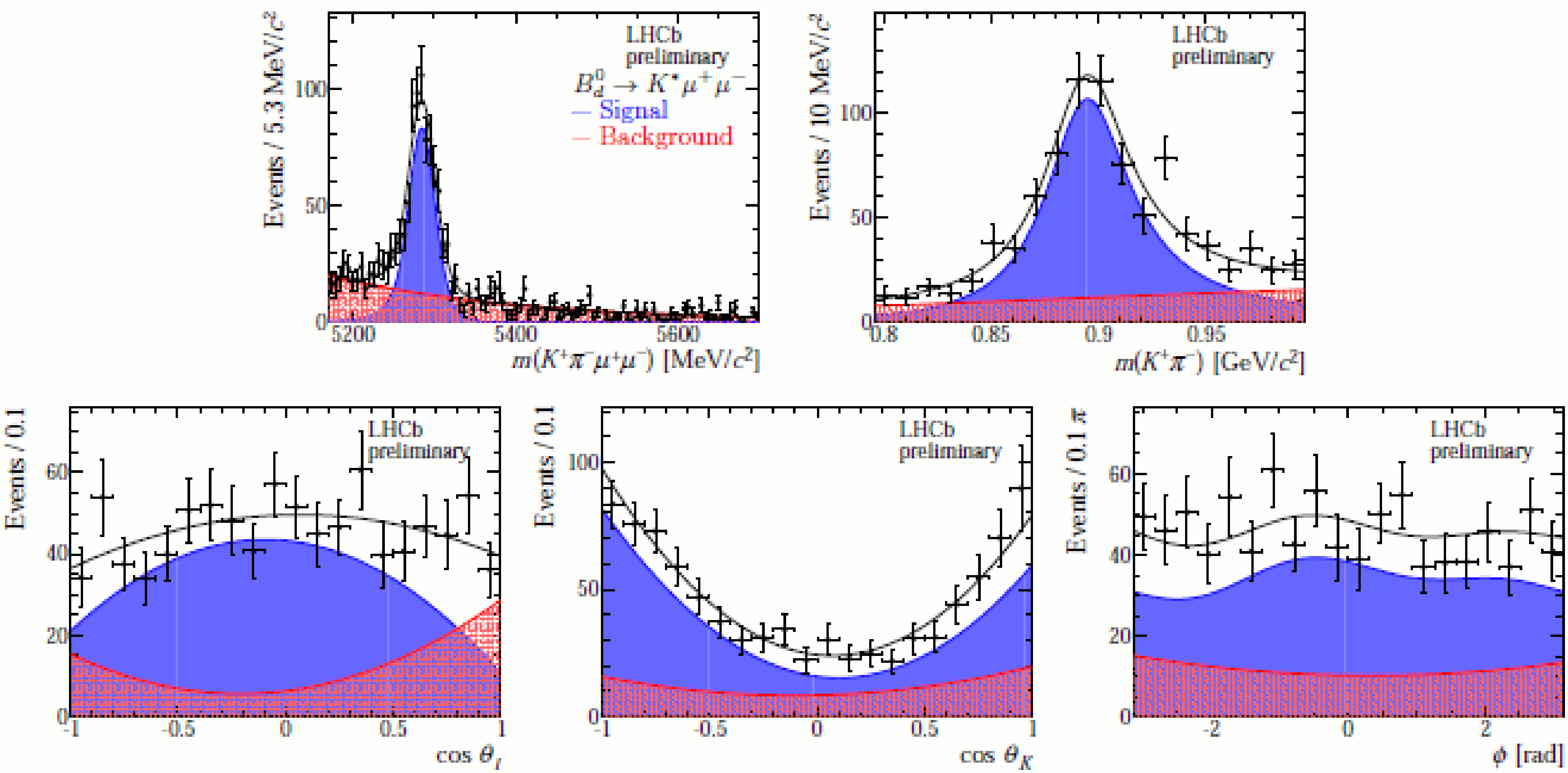
BDT to reject combinatorial background
Veto of resonant modes (control modes)

~ 2400 evts in the full q^2 range

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

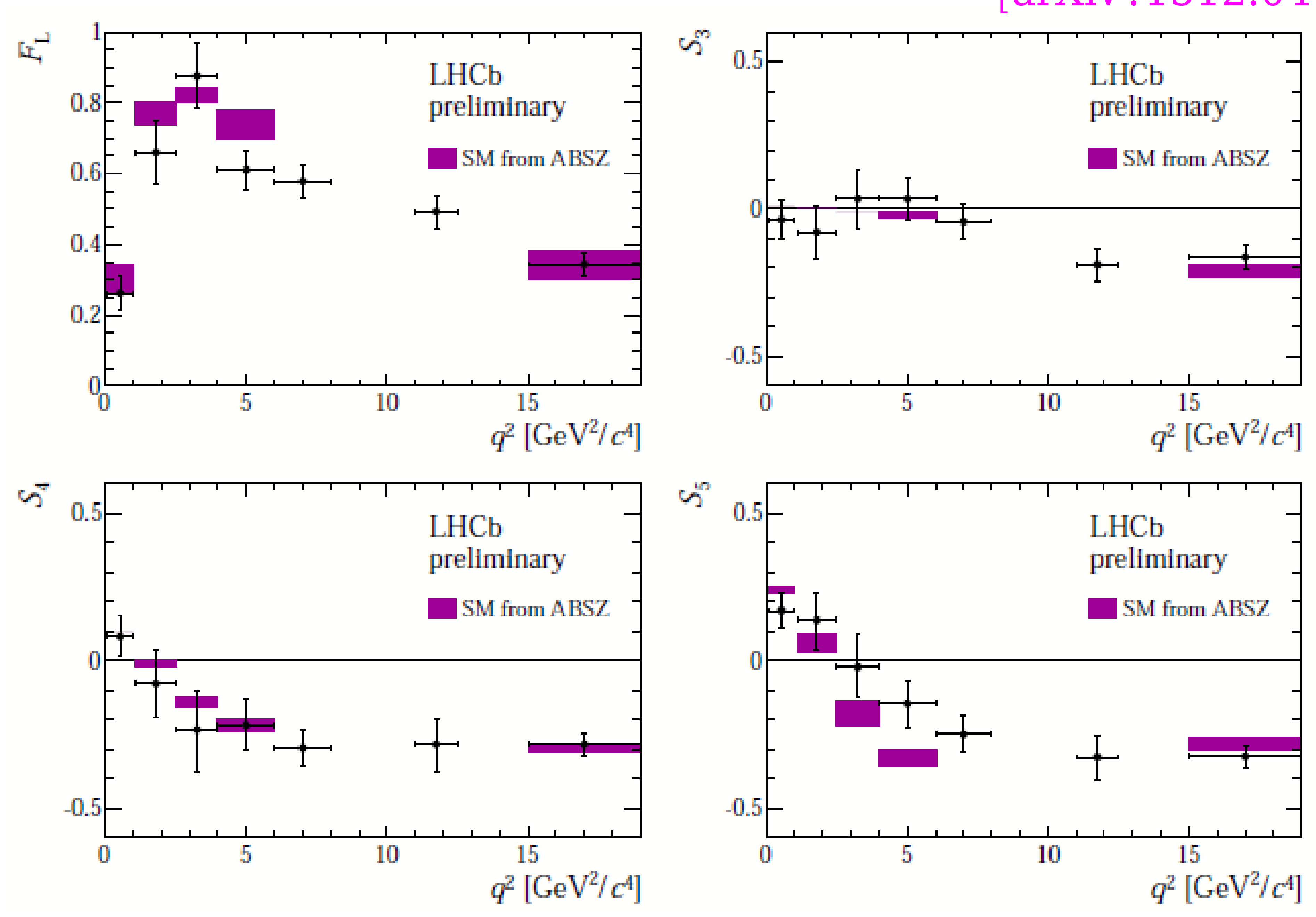
[arXiv:1512.04442]

- 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

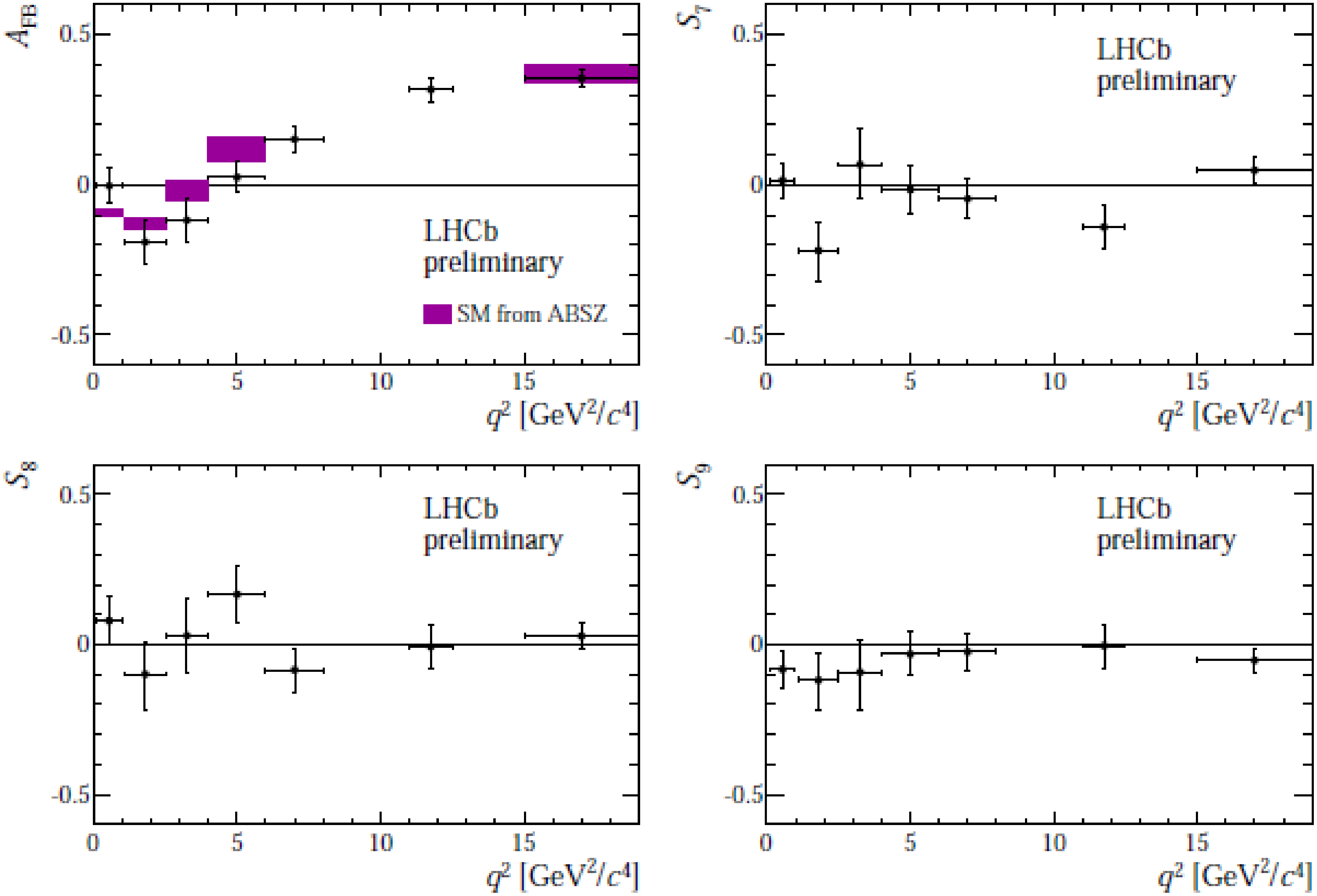
[arXiv:1512.04442]



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

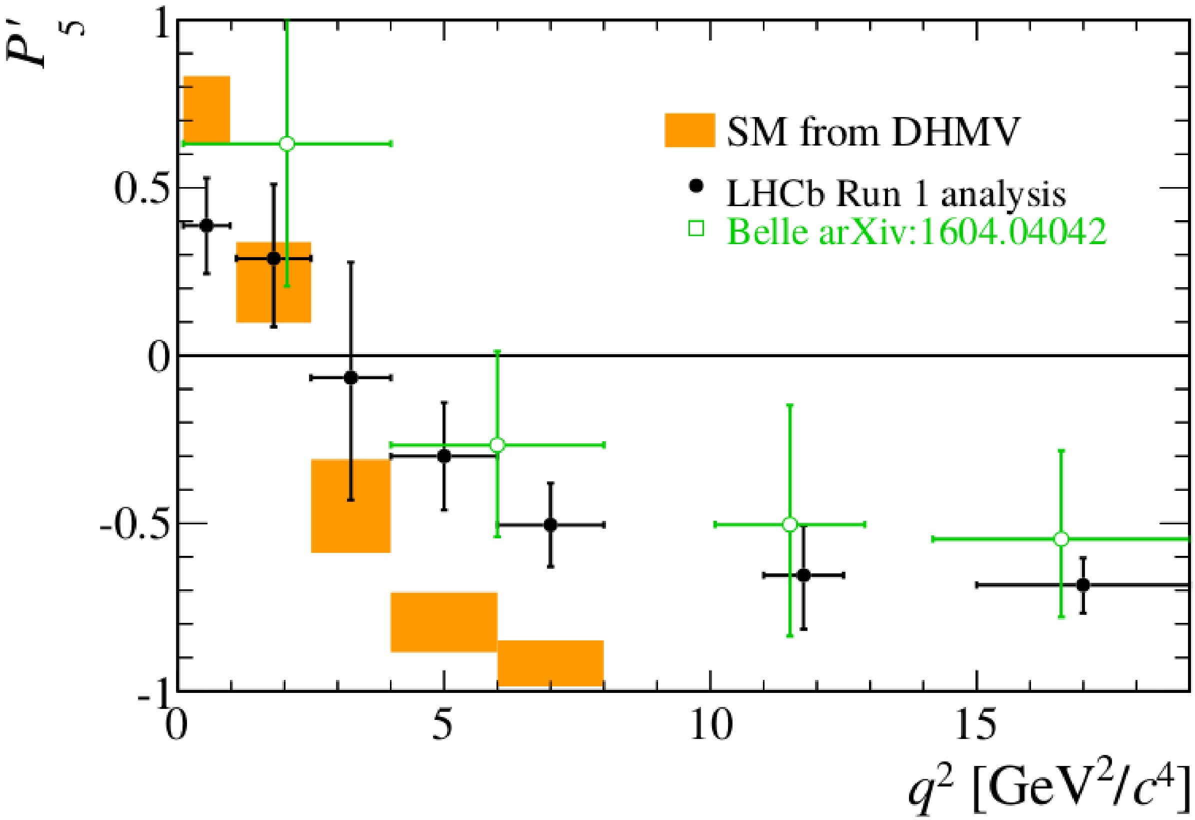
[arXiv:1512.04442]

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

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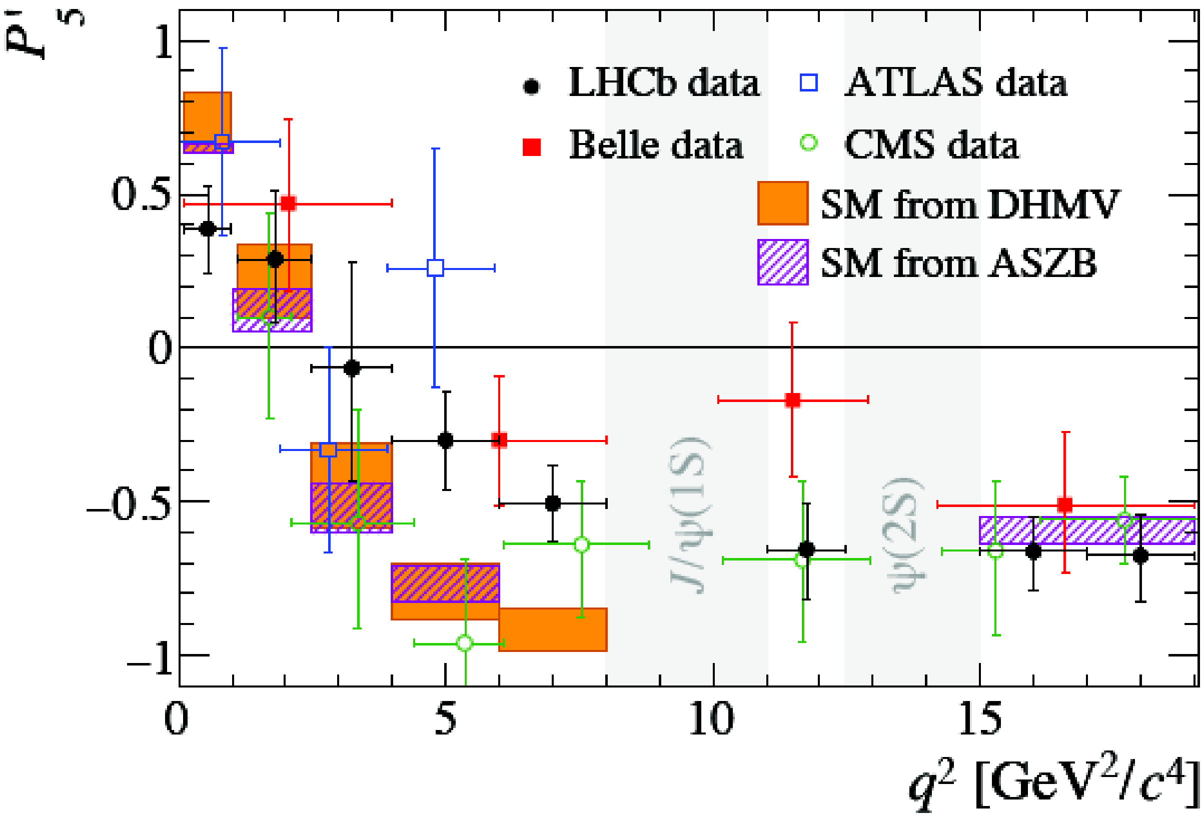
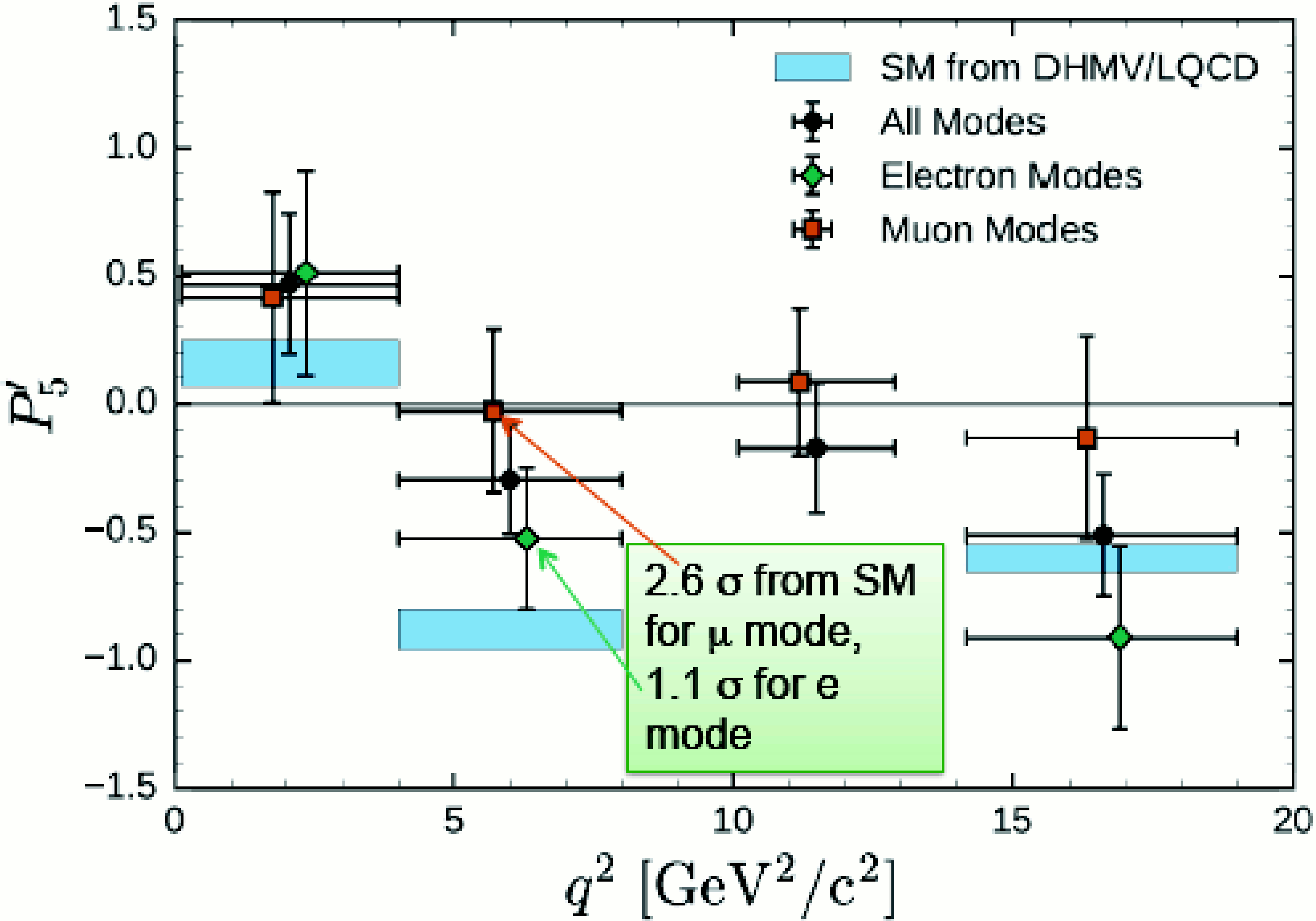


[LHCb, arXiv:1512.04442]

- Tension in P'_5 seen with 1 fb^{-1} is confirmed
- Local deviations of 2.9 σ and 3.0 σ 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 σ

- 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)



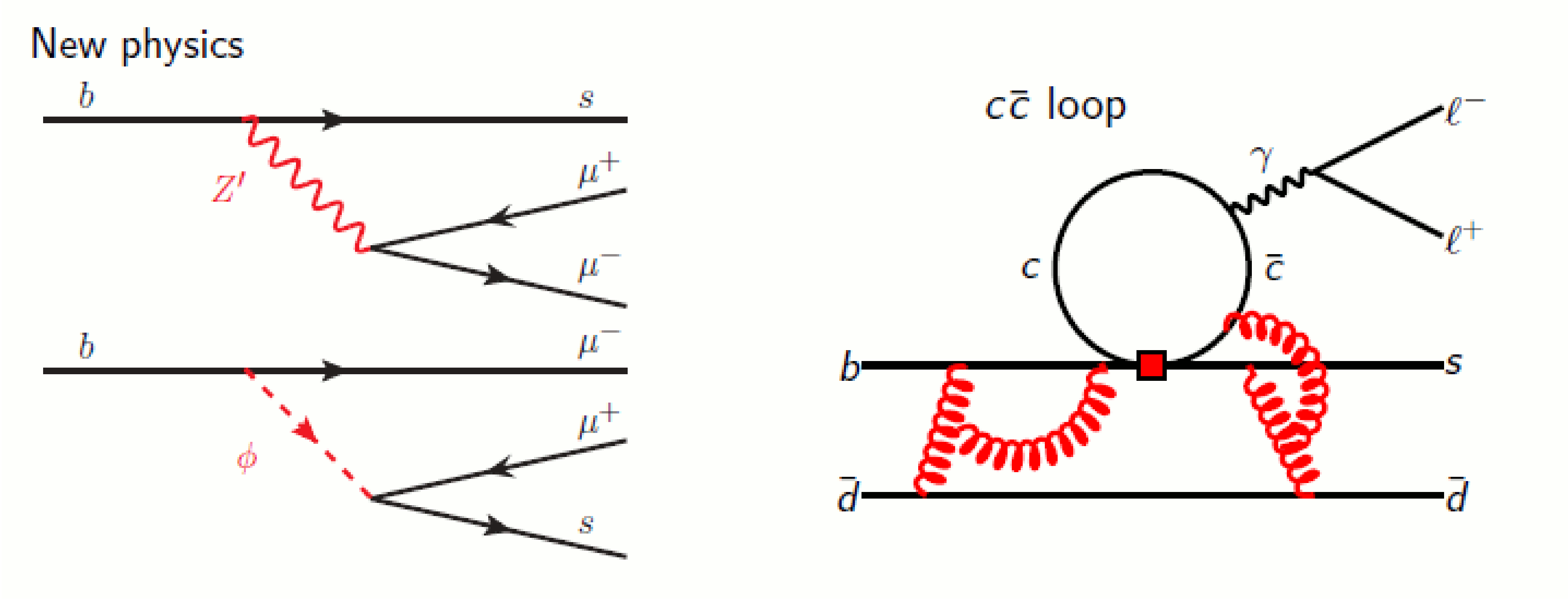
NP or hadronic effect ?

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

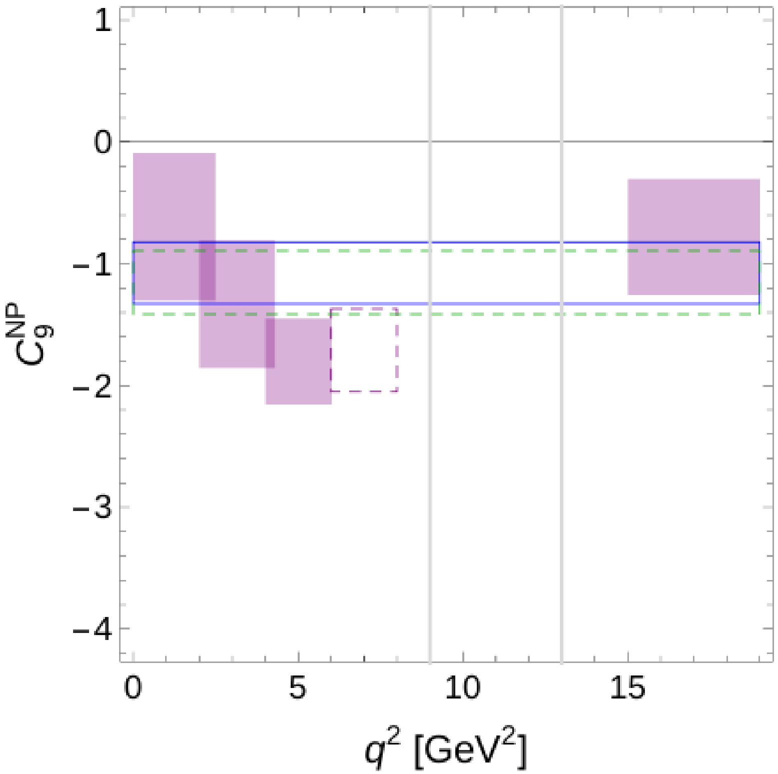


NP e.g. Z', leptoquarks hadronic charm loop contributions

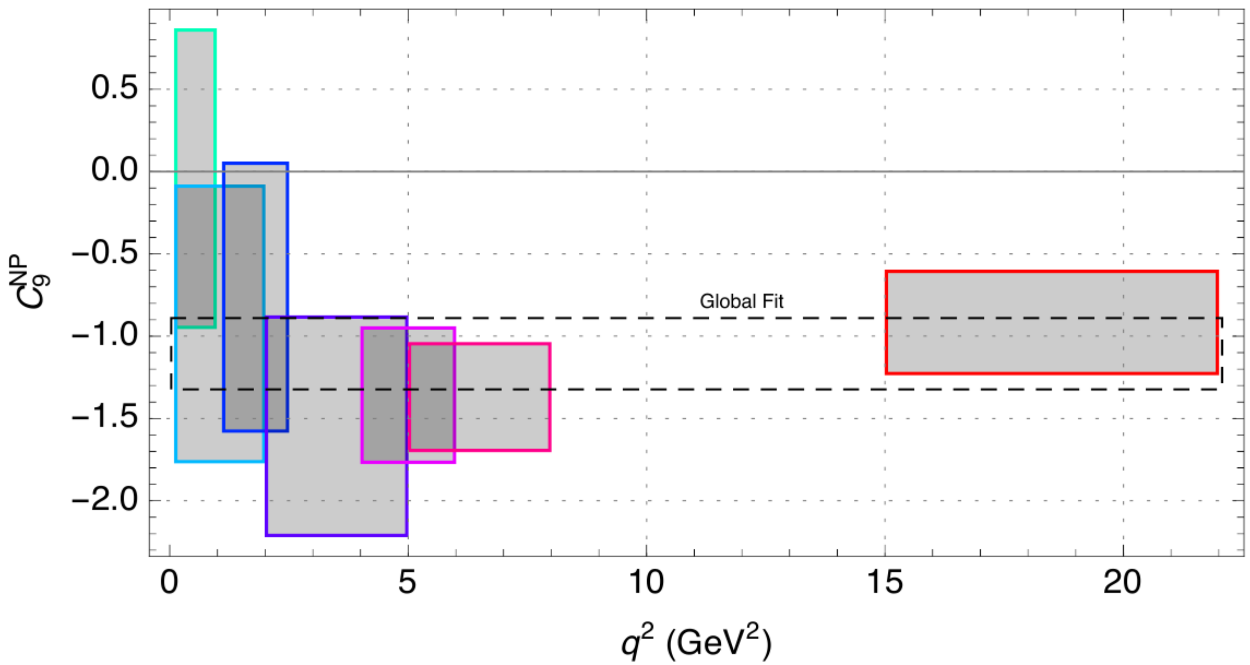
NP or hadronic effect ?

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]

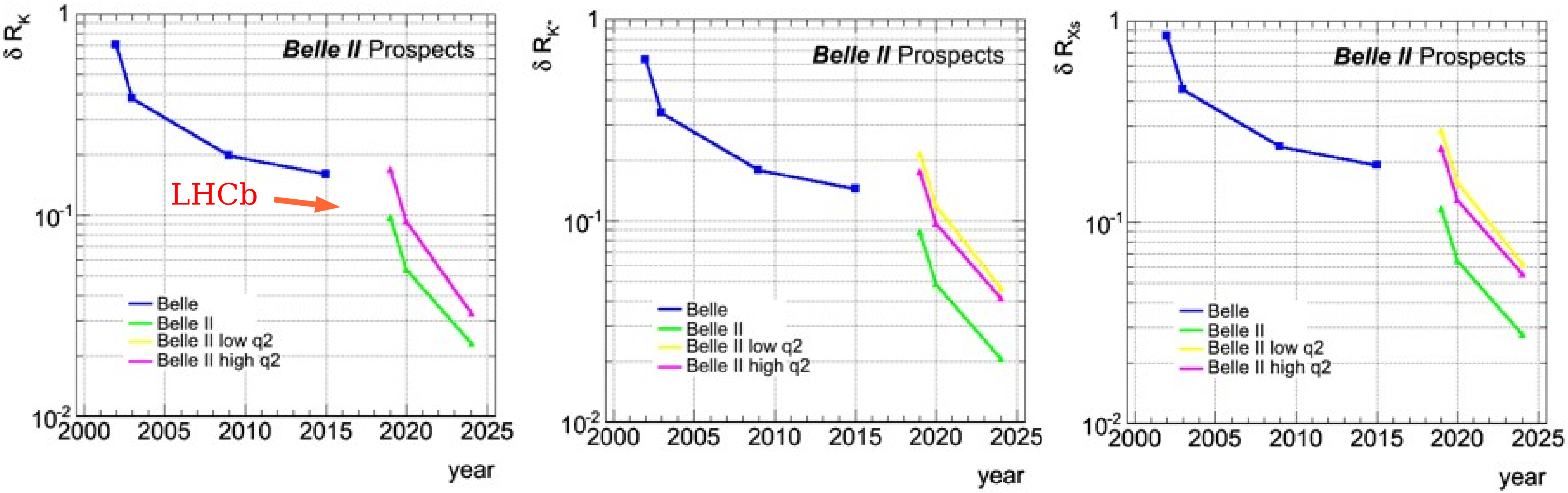


C_9^{NP} doesn't depend on q^2,

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

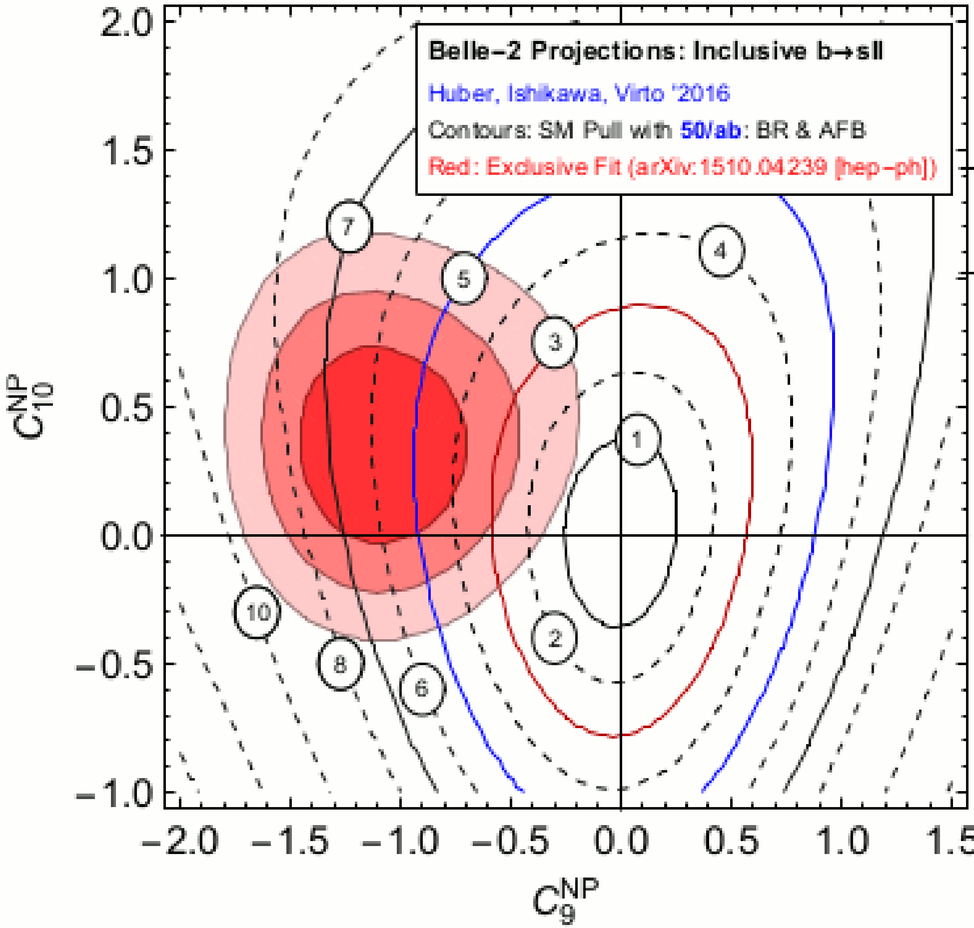
⇒ definitely need more stat.

Test of lepton universality using $b \to s\, l^+ l^-$ decays at Belle II



⇒ great potential also on **LFV B decays**, especially with one τ in final state

Inclusive di-lepton, $B \to X_s l^+ l^-$ (at Belle II)



among the most relevant observables:

	Process	Obser.	Theory	Discovery (ab^{-1})	Sys. limit (ab^{-1})	vs LHCb BESIII	vs Belle	Anomaly	NP
●	$B \to X_s l^+ l^-$	R_{X_s}	★★	-	50	★★★	★★★	★★	★★★
●	$B \to K^{(*)} \nu\nu$	$Br.$	★★★	-	50	★★★	★★★	★	★★
●	$B \to X_s \gamma$	A_{CP}	★★★	-	8	★★★	★★★		★★
●	$B \to X_d \gamma$	$Br.$		-	-				
●	$B \to K_S \pi^0 \gamma$	$S_{K_S \pi^0 \gamma}$	★★	-	50	★	★★★	★	★★★
●	$B \to \rho\gamma$	$S_{\rho\gamma}$	★★	-	50	★★	★★★		★★★
●	$B \to K^* l^+ l^-$	P_5'	★★	-	50	★	★★	★★★	★★★
●	$B \to K e^+ e^-$	$R(K)$	★★★	-	50	★★	★★★	★★★	★★★
●	$B \to K \tau l$	$Br.$	★★★	-	50	★★	★★★	★★	★★
●	$B \to K \tau\tau$	$Br.$	★★★	-	50	★★★	★★★	★★	★★
●	$B \to \nu\nu$	$Br.$	★★★	-	50	★★★	★★★	★★	★★
●	$B \to X_s \gamma$	$Br.$	★★	-	1	★★★	★	★	★★
●	$B_s \to \gamma\gamma$	$Br.$	★★	-	5	★★	★★		★★

Observables	Belle 0.71 ab^{-1}	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$B(B \to X_s \ell^+ \ell^-)$ ($1.0 < q^2 < 3.5$ GeV^2)	29%	13%	6.6%
$B(B \to X_s \ell^+ \ell^-)$ ($3.5 < q^2 < 6.0$ GeV^2)	24%	11%	6.4%
$B(B \to X_s \ell^+ \ell^-)$ ($q^2 > 14.4$ GeV^2)	23%	10%	4.7%
$A_{FB}(B \to X_s \ell^+ \ell^-)$ ($1.0 < q^2 < 3.5$ GeV^2)	26%	9.7%	3.1%
$A_{FB}(B \to X_s \ell^+ \ell^-)$ ($3.5 < q^2 < 6.0$ GeV^2)	21%	7.9%	2.6%
$A_{FB}(B \to X_s \ell^+ \ell^-)$ ($q^2 > 14.4$ GeV^2)	19%	7.3%	2.4%

Sheldon Stone (LHCb)

Should we believe LFU violation?

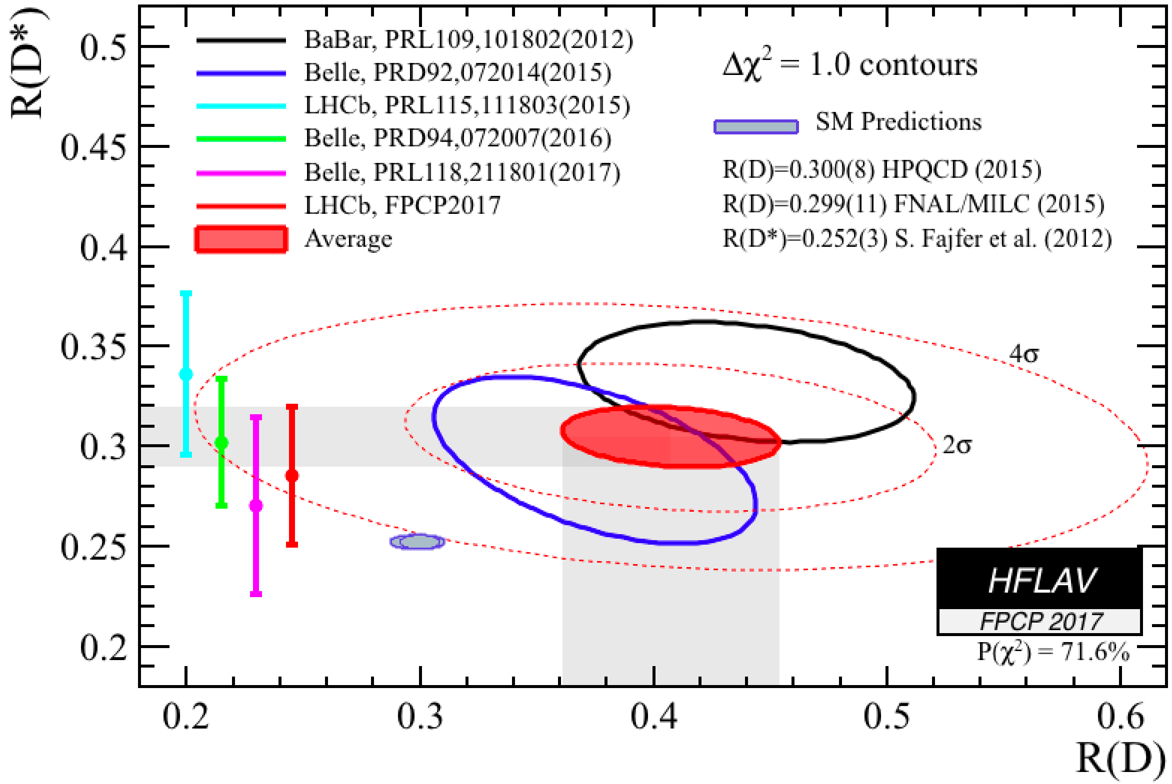
Yes

- R measurements are double ratio's to J/ψ, check with $K^* J/\psi \to e^+e^-/\mu^+\mu^-$ $=1.043\pm0.006\pm0.045$
- $\mathcal{B}(B^-\to K^-e^+e^-)$ 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

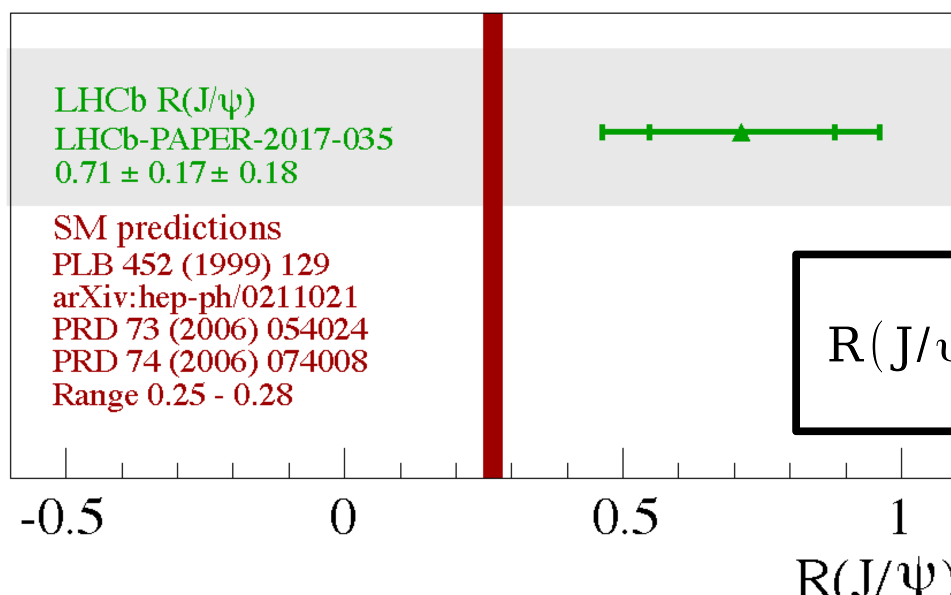
$B \to D^{(*)} \tau \nu$



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

$R(D) = 0.407 \pm 0.039 \pm 0.024$
$R(D^*) = 0.304 \pm 0.013 \pm 0.007$
difference with SM predictions is at **4.1σ** level

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



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

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..

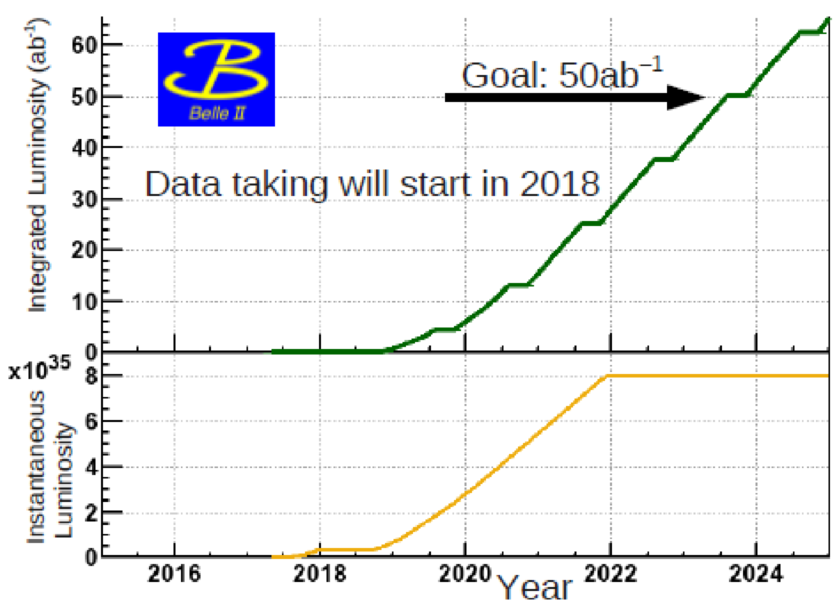
Outlook

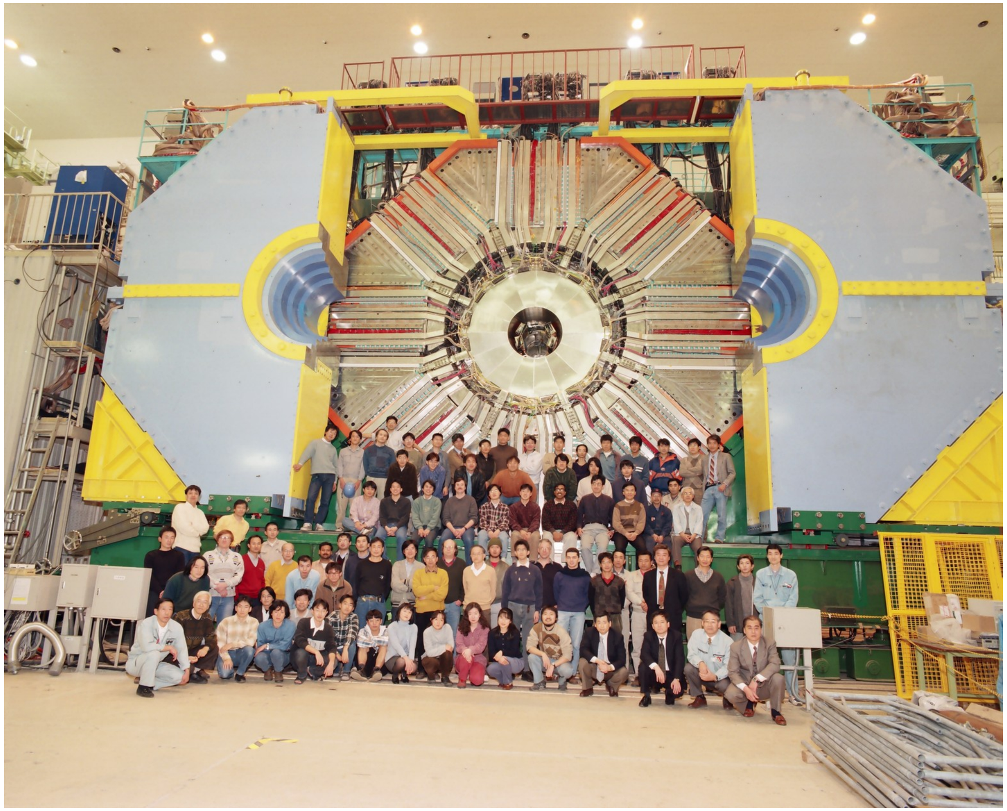
- Few tantalizing results on rare decays in B sector covered in this talk... but much more in B decays: LFV searches, $B\rightarrow K^{(*)}\nu\bar{\nu}$, $B\rightarrow\tau\nu$, $\mu\nu$...

  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}





From Belle to Belle II

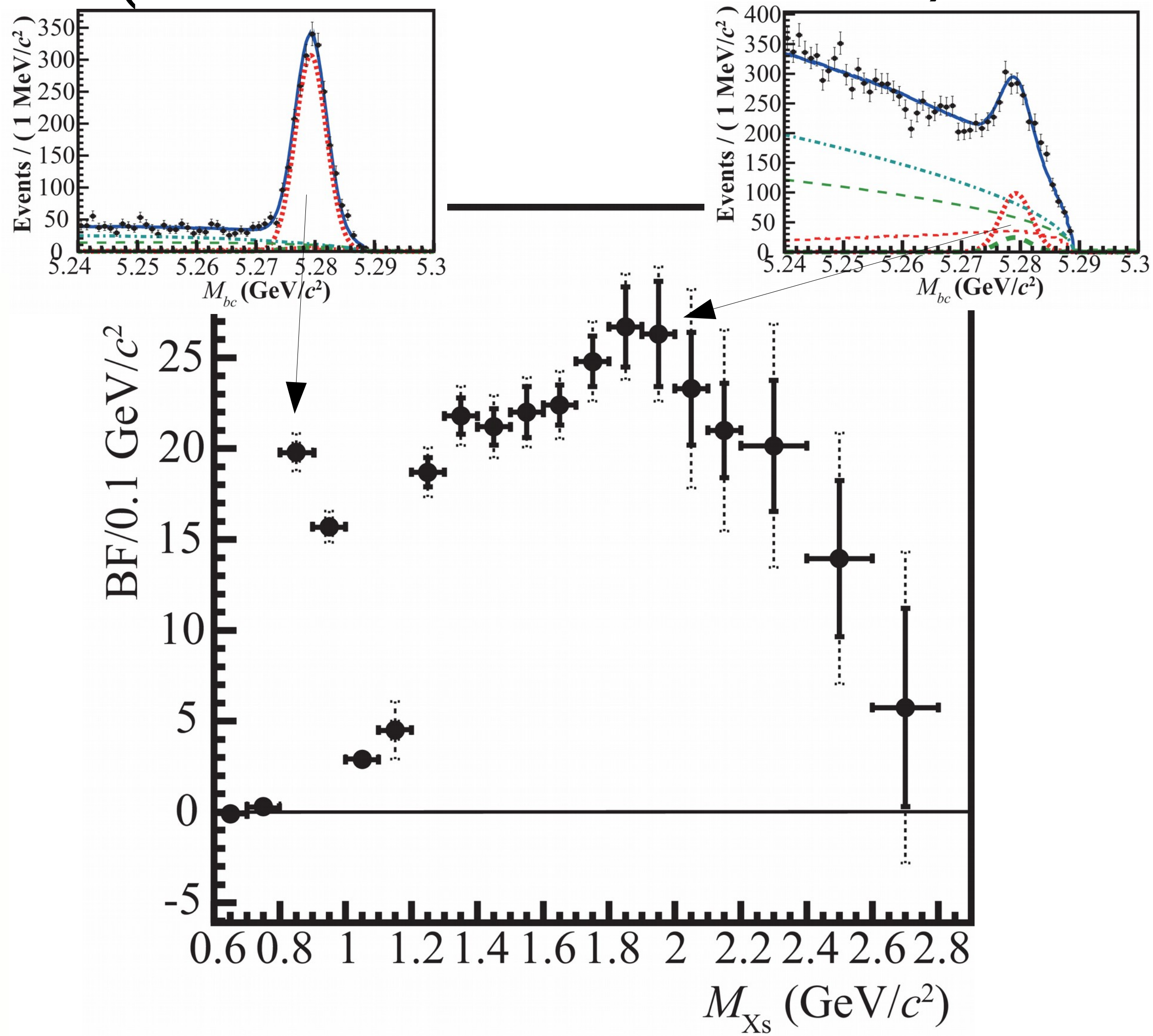
Semi-inclusive (sum-of-exclusive)

[772 MBB]
[arXiv:1411.7198]

38 modes

$M_{X_s} < 2.8\ \mathrm{GeV}/c^2$, $E^* > 1.9\ \mathrm{GeV}$

Mode ID	Final State	Mode ID	Final State
1	$K^+\pi^-$	20	$K_S^0\pi^+\pi^0\pi^0$
2	$K_S^0\pi^+$	21	$K^+\pi^+\pi^-\pi^0\pi^0$
3	$K^+\pi^0$	22	$K_S^0\pi^+\pi^-\pi^0\pi^0$
4	$K_S^0\pi^0$	23	$K^+\eta$
5	$K^+\pi^+\pi^-$	24	$K_S^0\eta$
6	$K_S^0\pi^+\pi^-$	25	$K^+\eta\pi^-$
7	$K^+\pi^-\pi^0$	26	$K_S^0\eta\pi^+$
8	$K_S^0\pi^+\pi^0$	27	$K^+\eta\pi^0$
9	$K^+\pi^+\pi^-\pi^-$	28	$K_S^0\eta\pi^0$
10	$K_S^0\pi^+\pi^+\pi^-$	29	$K^+\eta\pi^+\pi^-$
11	$K^+\pi^+\pi^-\pi^0$	30	$K_S^0\eta\pi^+\pi^-$
12	$K_S^0\pi^+\pi^-\pi^0$	31	$K^+\eta\pi^-\pi^0$
13	$K^+\pi^+\pi^+\pi^-\pi^-$	32	$K_S^0\eta\pi^+\pi^0$
14	$K_S^0\pi^+\pi^+\pi^-\pi^-$	33	$K^+K^+K^-$
15	$K^+\pi^+\pi^-\pi^-\pi^0$	34	$K^+K^-K_S^0$
16	$K_S^0\pi^+\pi^+\pi^-\pi^0$	35	$K^+K^+K^-\pi^-$
17	$K^+\pi^0\pi^0$	36	$K^+K^-K_S^0\pi^+$
18	$K_S^0\pi^0\pi^0$	37	$K^+K^+K^-\pi^0$
19	$K^+\pi^-\pi^0\pi^0$	38	$K^+K^-K_S^0\pi^0$



[471 MBB]
[arXiv:1207.2520]

(for $E_\gamma^* > 1.9$ GeV)

$$\mathcal{B}(B \to X_s\gamma) = (3.51 \pm 0.17 \pm 0.33) \times 10^{-4}$$

$$\mathcal{B}(B \to X_s\gamma) = (3.29 \pm 0.19 \pm 0.48) \times 10^{-4}$$

[syst: cross-feed, peaking BG, X_s fragmentation]

Semi-inclusive (sum-of-exclusive)

[772 MBB]
[arXiv:1411.7198]

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6	$K^0_S\pi^+\pi^-$	25	$K^+\eta\pi^-$
7	$K^+\pi^-\pi^0$	26	$K^0_S\eta\pi^+$
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11	$K^+\pi^+\pi^-\pi^0$	30	$K^0_S\eta\pi^+\pi^-$
12	$K^0_S\pi^+\pi^-\pi^0$	31	$K^+\eta\pi^-\pi^0$
13	$K^+\pi^+\pi^+\pi^-\pi^-$	32	$K^0_S\eta\pi^+\pi^0$
14	$K^0_S\pi^+\pi^+\pi^-\pi^-$	33	$K^+K^+K^-$
15	$K^+\pi^+\pi^-\pi^-\pi^0$	34	$K^+K^-K^0_S$
16	$K^0_S\pi^+\pi^+\pi^-\pi^0$	35	$K^+K^+K^-\pi^-$
17	$K^+\pi^0\pi^0$	36	$K^+K^-K^0_S\pi^+$
18	$K^0_S\pi^0\pi^0$	37	$K^+K^+K^-\pi^0$
19	$K^+\pi^-\pi^0\pi^0$	38	$K^+K^-K^0_S\pi^0$

Mode Category	Definition	Mode ID	Data
1	$K\pi$ without π^0	1,2	4.2±0.4
2	$K\pi$ with π^0	3,4	2.1±0.2
3	$K2\pi$ without π^0	5,6	14.5±0.5
4	$K2\pi$ with π^0	7,8	24.0±0.7
5	$K3\pi$ without π^0	9,10	8.3±0.8
6	$K3\pi$ with π^0	11,12	16.1±1.8
7	$K4\pi$	13-16	11.1±2.8
8	$K2\pi^0$	17-22	14.4±3.5
9	$K\eta$	23-32	3.2±0.8
10	$3K$	33-38	2.0±0.3

$$\mathcal{B}(B \to X_s\gamma) = (3.51 \pm 0.17 \pm 0.33)\times 10^{-4}$$

(for $E^*_\gamma > 1.9$ GeV)

$$\mathcal{B}(B \to X_s\gamma) = (3.29 \pm 0.19 \pm 0.48)\times 10^{-4}$$

[471 MBB]
[arXiv:1207.2520]

[syst: cross-feed, peaking BG, X_s fragmentation]

cLFV : beyond the Standard Model

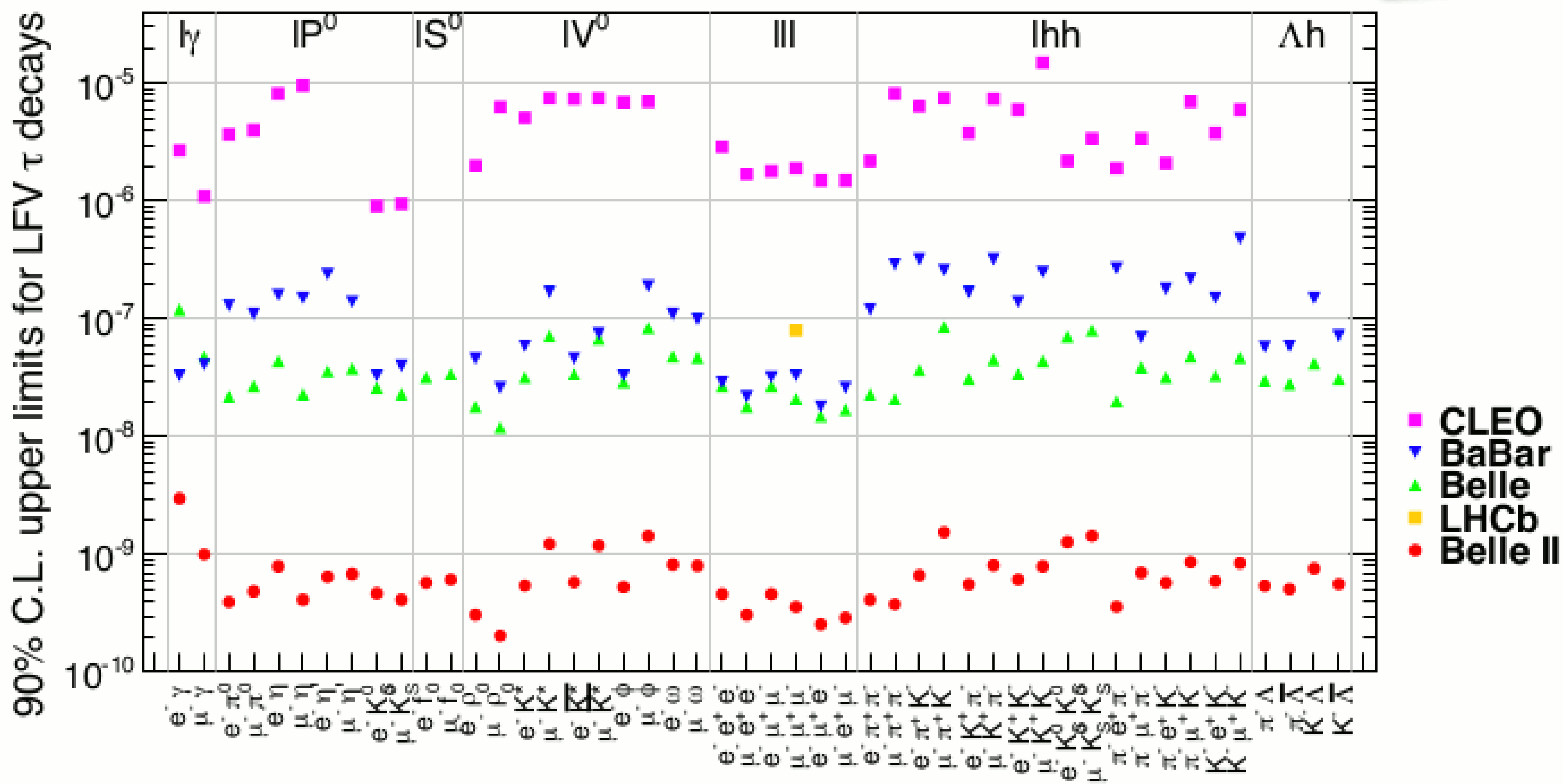
$$\mathcal{B}_{\nu SM}(\tau \to \mu\gamma) = \frac{3\alpha}{32\pi}\left|U^*_{\tau i}U_{\mu i}\frac{\Delta m^2_{3i}}{m^2_W}\right|^2 < 10^{-40}$$

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

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}

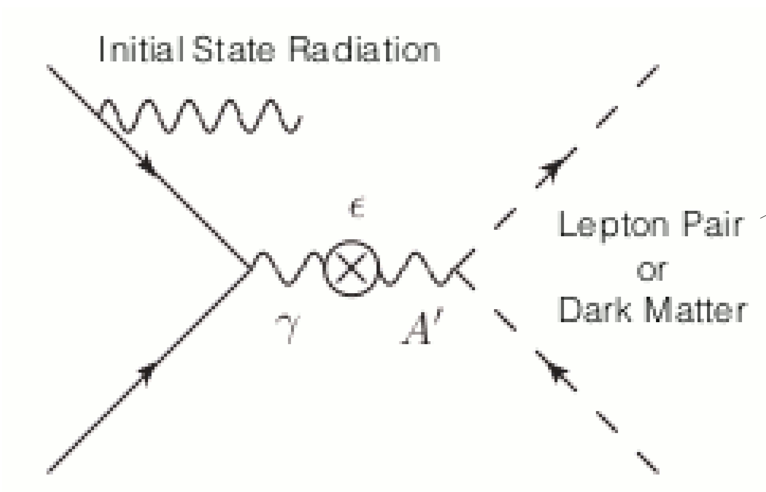
		$\tau \to 3\mu$	$\tau \to \mu\gamma$	$\tau \to \mu\pi^+\pi^-$	$\tau \to \mu K\bar{K}$	$\tau \to \mu\pi$	$\tau \to \mu\eta^{(\prime)}$
4-lepton	$O^{4\ell}_{S,V}$	✓	–	–	–	–	–
dipole	O_D	✓	✓	✓	✓	–	–
lepton-quark	O^q_V	–	–	✓ (I=1)	✓(I=0,1)	–	–
lepton-quark	O^q_S	–	–	✓ (I=0)	✓(I=0,1)	–	–
lepton-gluon	O_{GG}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

Celis, Cirigliano, Passemar (2014)

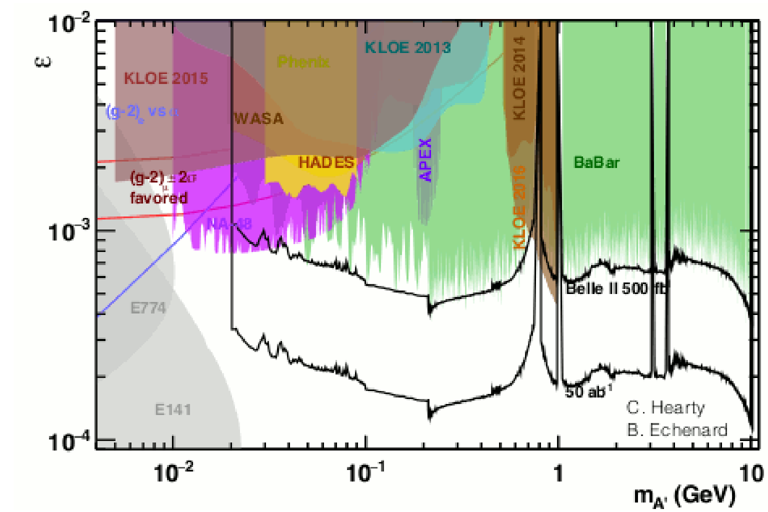


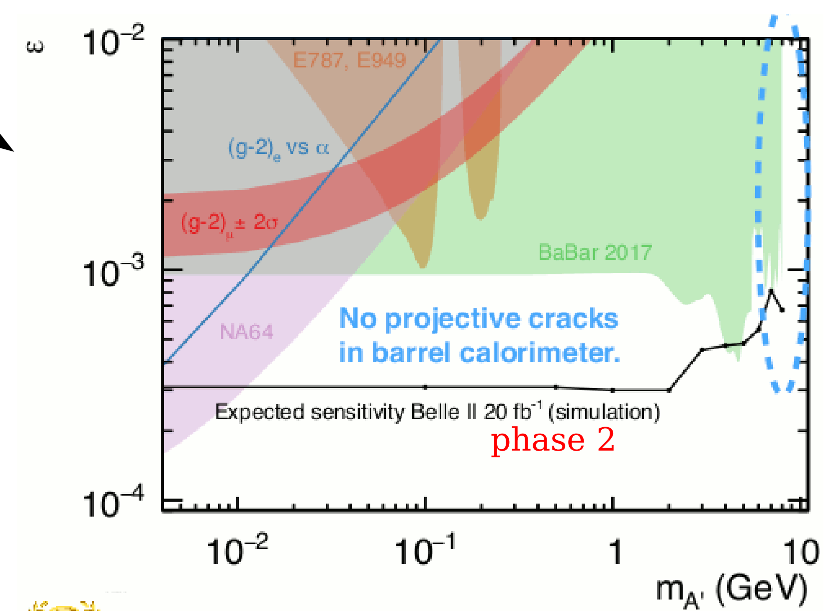
Dark Sector Physics

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

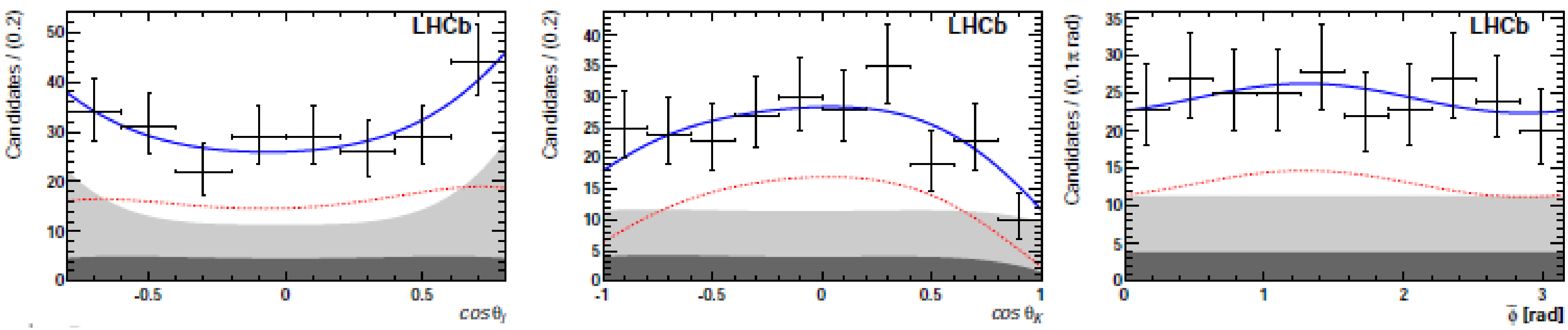


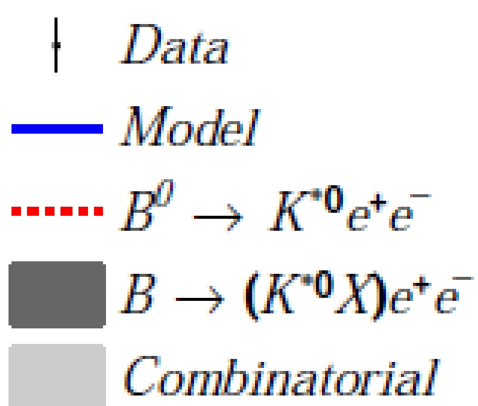


search for a dark photon decaying invisibly, and the search for an axion-like particle may be possible even in "Phase 2"

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

[arXiv:1501.03038]





Observable	Measurement	SM prediction[†]
F_{L}	$+0.16 \pm 0.06 \pm 0.03$	$+0.10^{+0.11}_{-0.05}$
$A_{\mathrm{T}}^{(2)}$	$-0.23 \pm 0.23 \pm 0.05$	$0.03^{+0.05}_{-0.04}$
$A_{\mathrm{T}}^{\mathrm{Re}}$	$+0.10 \pm 0.18 \pm 0.05$	$-0.15^{+0.04}_{-0.03}$
$A_{\mathrm{T}}^{\mathrm{Im}}$	$+0.14 \pm 0.22 \pm 0.05$	$(-0.2^{+1.2}_{-1.2}) \times 10^{-4}$

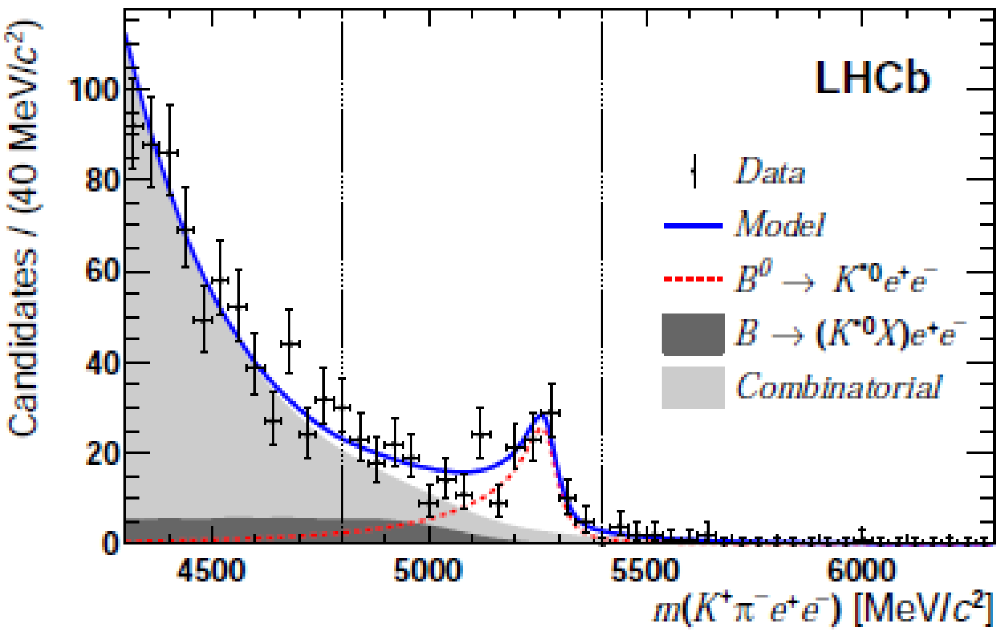
S.Jager, J.M.Camalich [arXiv:1412.3283]

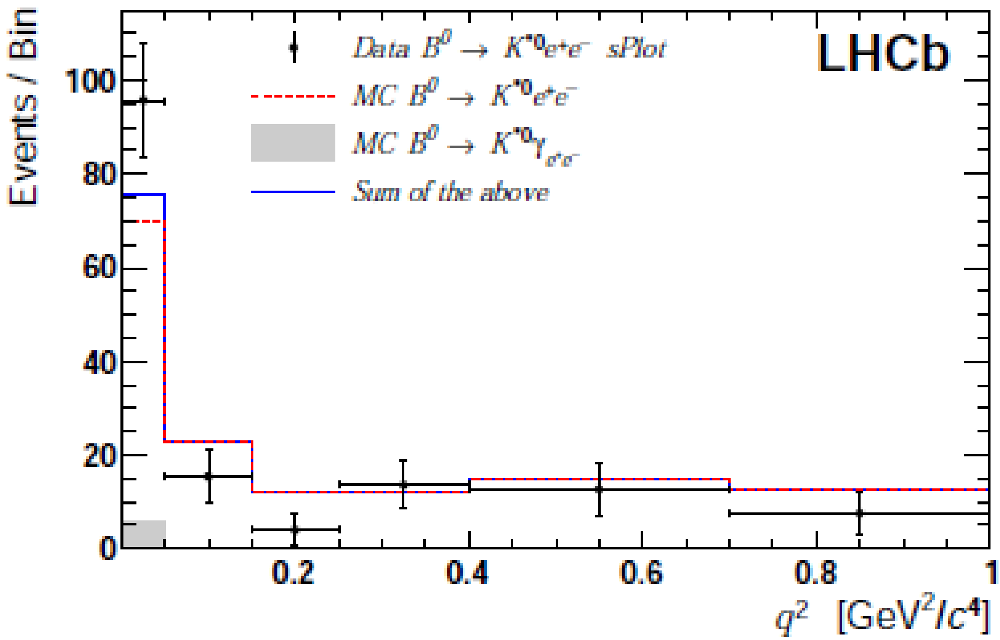
- Measurements well in agreement with SM predictions
- Constraints on C_7' in complementary with radiative decays

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

[arXiv:1501.03038]

- Angular analysis of $B_d^0 \to K^* e^+ e^-$ at very low q^2 ($\in [0.002, 1.120]\ \mathrm{GeV}^2$)
- Folded angular observables ($\phi = \phi + \pi$ if $\phi < 0$)
- Measurement of F_L, $A_T^{(2)}$, $A_T^{(Im)}$, $A_T^{(Re)}$, sensitive to C_7' as $q^2 \to 0$





$$A_T^{(Re)} = \frac{4}{3} A_{FB}/(1-F_L),\quad A_T^{(2)} = \frac{1}{2} S_3/(1-F_L) \text{ and } A_T = \frac{1}{2} S_9/(1-F_L)$$

The LHCb / LHCb upgrade timeline

LHCb future (2012 + end 2014 - 2017)

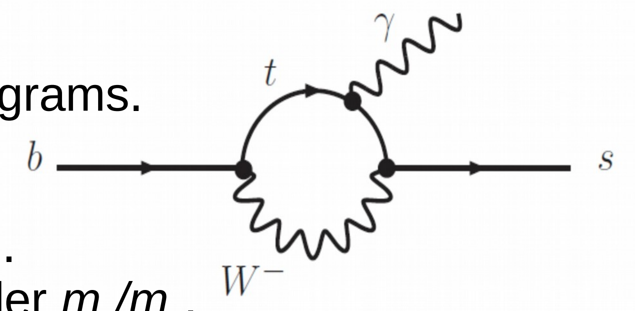
- $\mathcal{L} \geq 4 * 10^{32}$ cm^{-2} s^{-1}
- $L_{int} > 8$ fb^{-1} by the end of 2017
  $\rightarrow$ Factor-4 in statiscal power wrt 1 fb^{-1}

Upgraded LHCb (2019 -)

- Full readout @ 40 MHz with full software trigger $\rightarrow$ trigger efficiency enhanced by a factor-2 for hadronic modes!
- Increase the luminosity by a factor-5
  $\rightarrow \mathcal{L} \geq (1-2) * 10^{33}$ cm^{-2} s^{-1}
  $\rightarrow$ 25 ns bunch spacing $\rightarrow \mu = 2$
  $\rightarrow \sqrt{s} =$ 13-14 TeV
  $\rightarrow$ +100% $b\bar{b}$ x-section wrt $\sqrt{s} = 7$ TeV
  $\rightarrow \geq 5$ fb^{-1}/year
- Run for 10 years
  $\rightarrow L_{int} > 50$ fb^{-1}
  $\rightarrow$ > Factor-10 in stat. power wrt 1 fb^{-1}

Motivation [arXiv:hep−ph/0107254, arXiv:1704.05280]

Rare $b \to s\gamma$ FCNC transitions are expected to be sensitive to NP effects.
In SM, $b \to s\gamma$ are forbidden at the tree level.
However they do proceed at loop level, with internal W bosons diagrams.

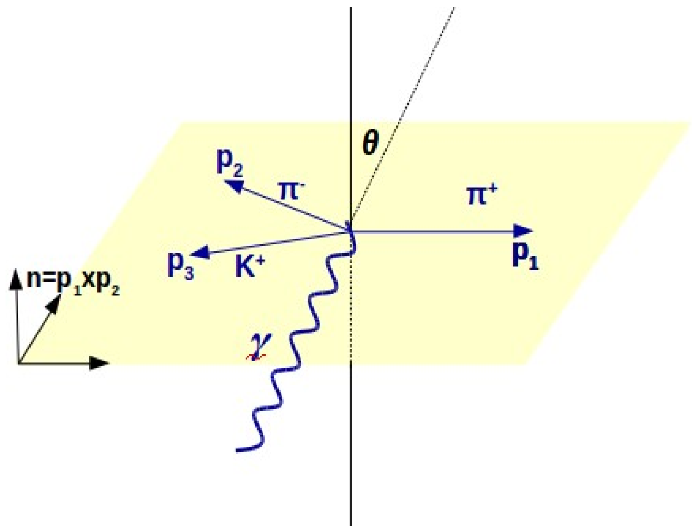


γ emitted from $b \to s\gamma$ transition is predominately left-handed, since the recoiling s quark (which couple to W boson) is left handed.
This implies maximal parity violation up to small corrections of the order m_s/m_b.

Measured inclusive $b \to s\gamma$ rate agrees with the SM calculations.
Few SM extensions are also compatible with the current measurements, but predict that the photon acquires a significant right-handed component, due to the exchange of heavy fermion in the electroweak penguin loop. *Atwood, Gronau and Soni PRL**79**,185(1997)*

*Gronau, Grossman, Pirjol and Ryd PRL**88**,051802(2002),* suggested to measured the up-down asymmetry of the photon direction relative to the $K\pi\pi$ plane in the K resonance rest frame.

- Recently, LHCb has observed so called up-down asymmetry in the $B^+ \to K^+\pi^+\pi^- \gamma$ *PRL **112**,161801(2014)* they found a non-zero up-down asymmetry.



- This result is not enough to provide any quantitative measurement of the photon polarization.
- It has been suggested by Gronau et al that one expect larger asymmetry in mode having neutral pion in the final state.

*PRD**66**,054008(2002)* *PRD **96**, 013002 (2017)*

Motivation

Gronau & Pirjol identify three types of interferences resulting in non-zero up-down asymmetry: *M. Gronau and D. Pirjol, PRD 96, 013002 (2017)*

$\mathcal{A}_a$: Interferences of amplitudes for two $K^*\pi$ intermediate states. Such interferences, involving $K^{*0}\pi^+$ and $K^{*+}\pi^0$ in $K_1^+ \to K^0\pi^+\pi^0$ ($K^{*0}\pi^0$, $K^{*+}\pi^-$ in $K_1^0 \to K^+\pi^-\pi^0$). This occurs only in decays involving final neutral π.

$\mathcal{A}_b$: Interferences of amplitudes for two $K^*\pi$ and $K\rho$ amplitudes. Such interferences occurs in all $K_1 \to K\pi\pi$ decays including both $K_1^+ \to K^+\pi^-\pi^+$, ($K_1^0 \to K^0\pi^-\pi^+$) and $K_1^+ \to K^0\pi^+\pi^0$ ($K_1^0 \to K^+\pi^-\pi^0$).

$\mathcal{A}_c$: Interferences of S and D wave amplitudes in $K_1 \to K^*\pi$. This kind of interferences occurs in all four $K_1 \to K\pi\pi$ charged modes.

Large asymmetry is predicted in $\mathcal{A}_a$ which only occurs in the modes involving a final neutral pion.
Therefore, Belle has potential to contribute and search for up-down asymmetry.
Information from modes with K_S^0 and π^0 will provide crucial information on the photon polarization.

Motivation

[arXiv:1704.05280]

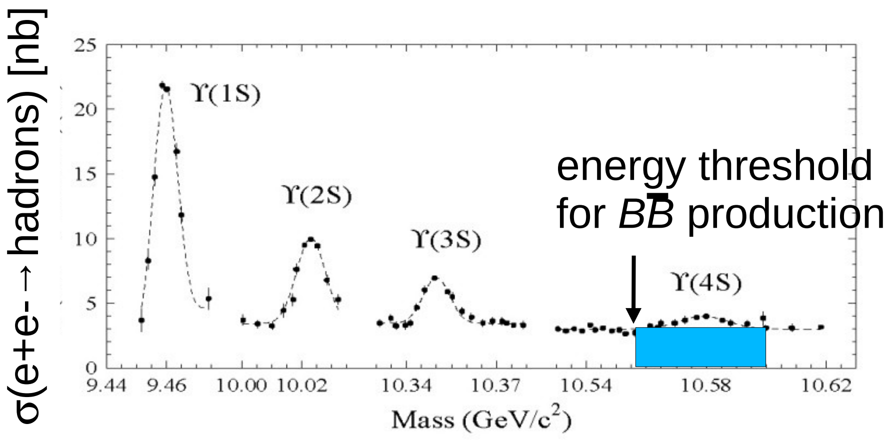
Reexamining the photon polarization in B→Kππγ

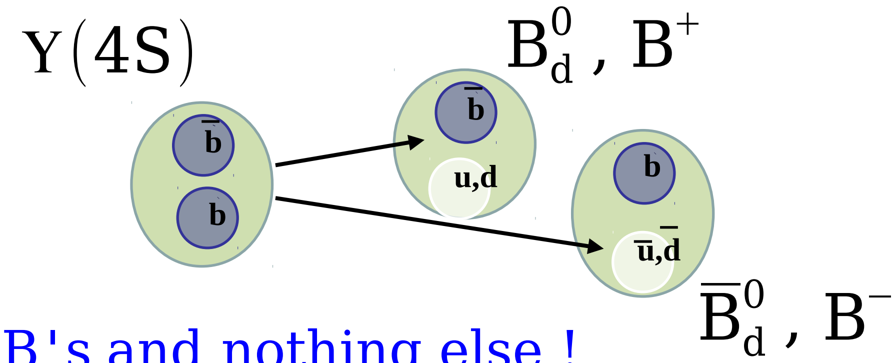
We reexamine, update and extend a suggestion we made fifteen years ago for measuring the photon polarization in $b \to s\gamma$ by observing in $B \to K\pi\pi\gamma$ an asymmetry of the photon with respect to the $K\pi\pi$ plane. Asymmetries are calculated for different charged final states due to intermediate $K_1(1400)$ and $K_1(1270)$ resonant states. Three distinct interference mechanisms are identified contributing to asymmetries at different levels for these two kaon resonances. For $K_1(1400)$ decays including a final state π^0 an asymmetry around +30% is calculated, dominated by interference of two intermediate $K^*\pi$ states, while an asymmetry around +10% in decays including final $\pi^+\pi^-$ is dominated by interference of S and D wave $K^*\pi$ amplitudes. In decays via $K_1(1270)$ to final states including a π^0 a negative asymmetry is favored up to −10% if one assumes S wave dominance in decays to $K^*\pi$ and $K\rho$, while in decays involving $\pi^+\pi^-$ the asymmetry can vary anywhere in the range −13% to +24% depending on unknown phases. For more precise asymmetry predictions in the latter decays we propose studying phases in $K_1 \to K^*\pi, K\rho$ by performing dedicated amplitude analyses of $B \to J/\psi(\psi')K\pi\pi$. In order to increase statistics in studies of $B \to K\pi\pi\gamma$ we suggest using isospin symmetry to combine in the same analysis samples of charged and neutral B decays.

Table 3: Up-down photon asymmetry $\tilde{\mathcal{A}}$ in $B^+ \to K^0\pi^+\pi^0\gamma$ from intermediate $K_1(1400)$. The asymmetry $\tilde{\mathcal{A}}_a$ neglects a contribution of a ρK amplitude as described in the text. For the total asymmetry we use $\alpha_S = 40°$, a value favored by the analysis of [21].

$\delta_{DS}^{(K^*\pi)}$(degrees)	0	45	90	135	180	225	270	315
$\tilde{\mathcal{A}}_a$	0.30	0.21	0.14	0.14	0.19	0.28	0.34	0.35
$\tilde{\mathcal{A}}_{\text{total}}$	0.30	0.21	0.15	0.14	0.20	0.29	0.35	0.36

$\Upsilon(4S)$ B-factory





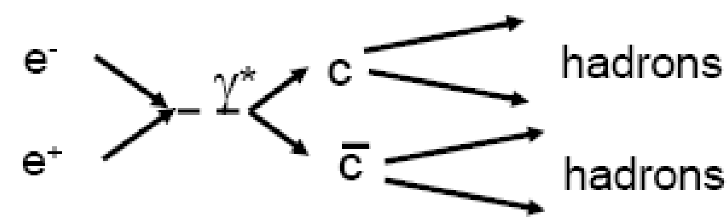
- 2 B's and nothing else !
- 2 B mesons are created simultaneously in a L=1 coherent state

  ⇒ before first decay, the final states contains a B and a $\overline{B}$

- **''on resonance'' production**

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

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



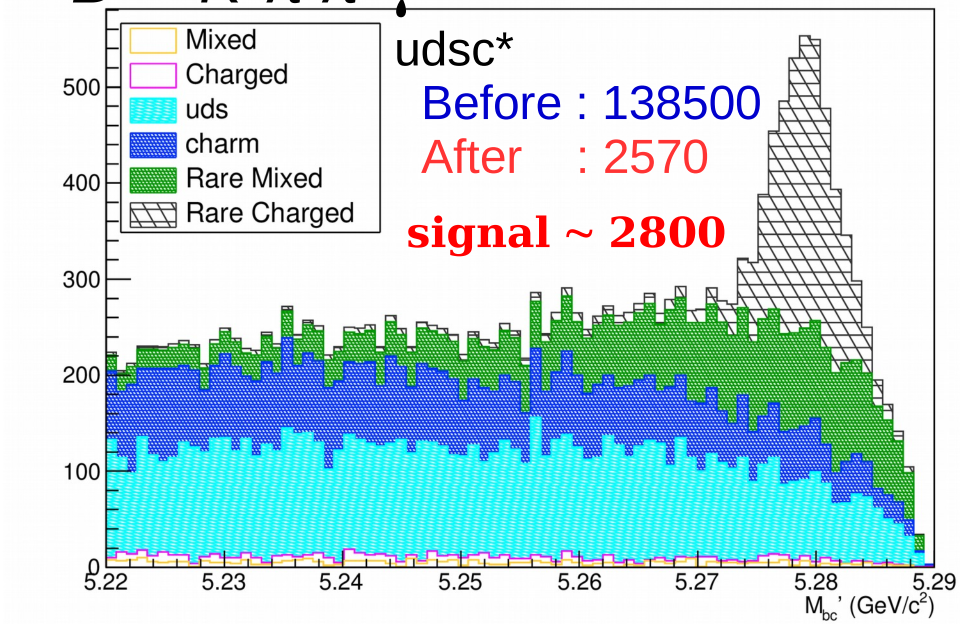
- **''continuum'' production ($q\bar{q} = u\bar{u}, d\bar{d}, s\bar{s}, c\bar{c}$)**

$$\sigma(e^+e^- \to c\bar{c}) = 1.3\text{ nb}$$
$$\sigma(e^+e^- \to s\bar{s}) = 0.4\text{ nb}$$
$$\sigma(e^+e^- \to u\bar{u}) = 1.6\text{ nb}$$
$$\sigma(e^+e^- \to d\bar{d}) = 0.4\text{ nb}$$

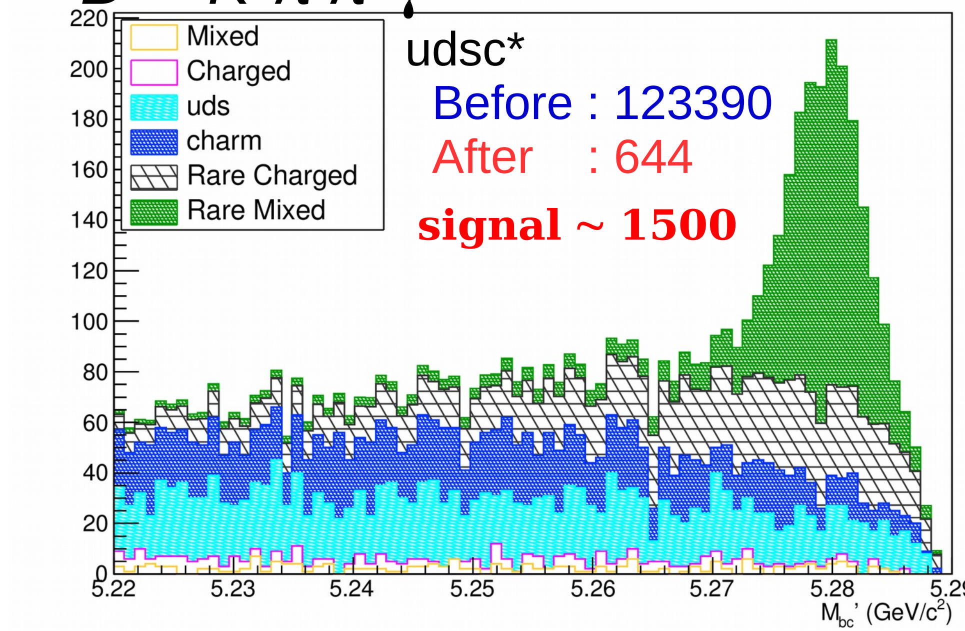
M'$_{bc}$ distribution

After we apply cut at 0.90(0.85) for K^+ (K_S^0).

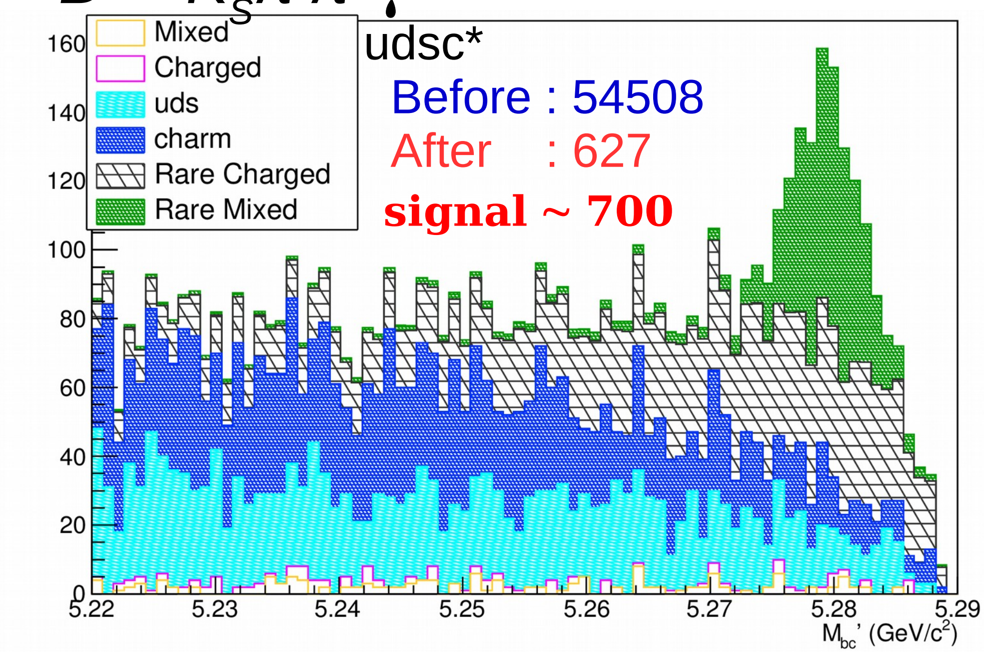
$B^+ \rightarrow K^+\pi^-\pi^+\gamma$



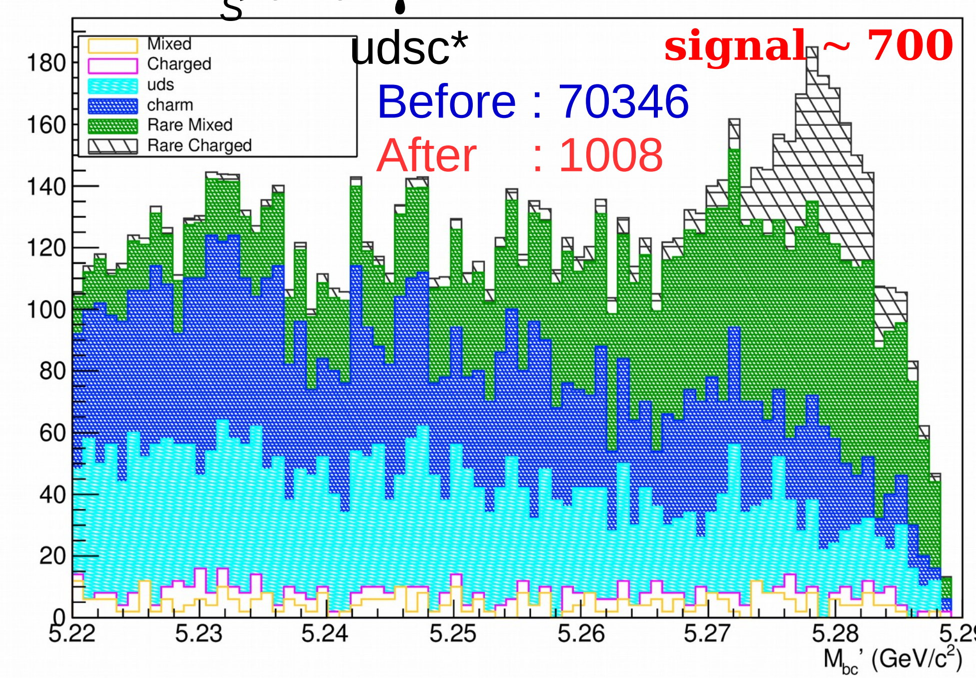
$B^0 \rightarrow K^+\pi^-\pi^0\gamma$



$B^0 \rightarrow K_S\pi^-\pi^+\gamma$



$B^+ \rightarrow K_S\pi^+\pi^0\gamma$



* $M_{bc}' > 5.27$ GeV/c^2

After the cut on DNN, signal looks promising !

Constraints on NP models