Sixth Workshop on Theory, Phenomenology and Experiments in Flavour Physics - FPCapri2016

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Recent Results on Rare B Decays with BaBar

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on behalf of the BaBar Collaboration

- Motivation
- $B \to K^* l^+ l^-$
- $B^+ \to K^+ \tau^+ \tau^-$
- $B \to K\pi\pi\gamma$

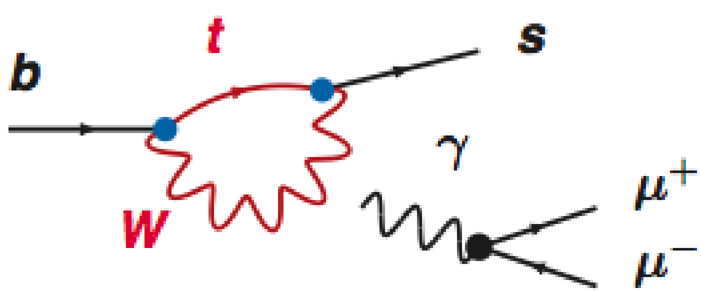
} Radiative Penguins

Motivation

Rare B decays: New Physics probes

- Search for deviations from Standard Model (SM) predictions due to virtual contributions of new heavy particles in loop processes
  - Compare experimental results with very precise SM expectations
- The most interesting processes are those that are strongly suppressed in the SM: FCNC ($X_s l^+ l^-$) [but also $X_s\gamma$, leptonic decays, LFV, CPV in B^0 mixing, c & τ]
  - New Physics (NP) could increase expectations by orders of magnitude [e.g. A. Buras, arXiv:0910.1032]

- Rare B decays can probe high scales potentially sensitive to NP beyond the direct reach of LHC:



$$\Lambda_{NP} \sim \frac{M_W}{g^2}\sqrt{\frac{16\pi^2}{|V_{ts}^* V_{tb}|}} \sim 10\ \text{TeV}$$

Rare B decays: New Physics probes

- Weak decay of hadron M into final state F described via an Effective Hamiltonian expressed by means of Operator Product Expansion:

$$A(M \to F) = \langle F | H_{eff} | M \rangle = \frac{G_F}{\sqrt{2}} \sum_i V^i_{CKM} C_i(\mu) \langle F | Q_i(\mu) | M \rangle$$

$C_i(\mu)$: Wilson Coefficients (perturbative short distance couplings)
$Q_i(\mu)$: Hadronic Matrix Elements (non -perturbative long distance effects)

$i = 1, 2$	Tree
$i = 3-6, 8$	Gluon penguin
$i = 7$	Photon penguin
$i = 9, 10$	EW penguin
$i = S, P$	(Pseudo)scalar penguin

- NP could modify Wilson Coefficients $C_i(\mu)$ and/or add new $Q_i(\mu)$ operators

- Complementary information from different rare decays:
  - $B \to \mu\mu$: Scalar/Pseudoscalar interactions
  - $B \to K^{(*)}ll$: Vector/axial interactions

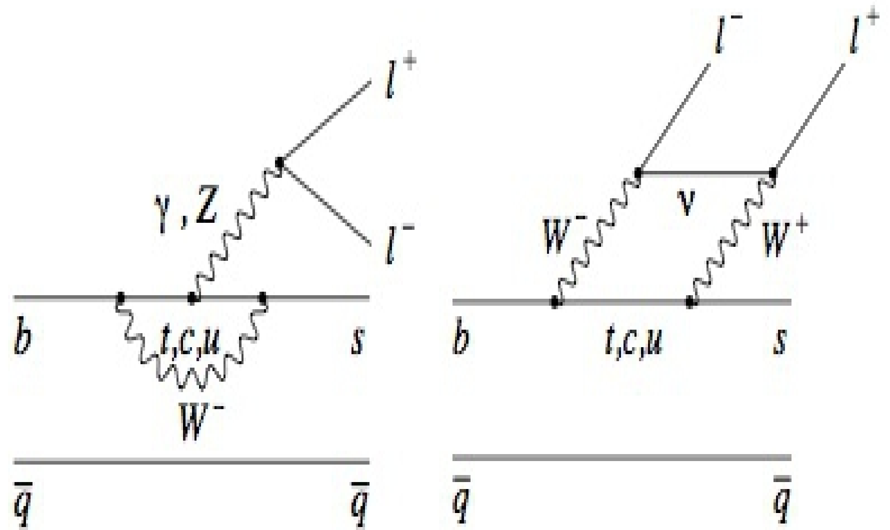
$B \rightarrow K^* l^+ l^-$

"Measurement of Angular Asymmetries in the Decay $B \rightarrow K^* l^+ l^-$"

[471 M $\Upsilon(4S)$ events]

Phys. Rev. D93, 052015 (2016)

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

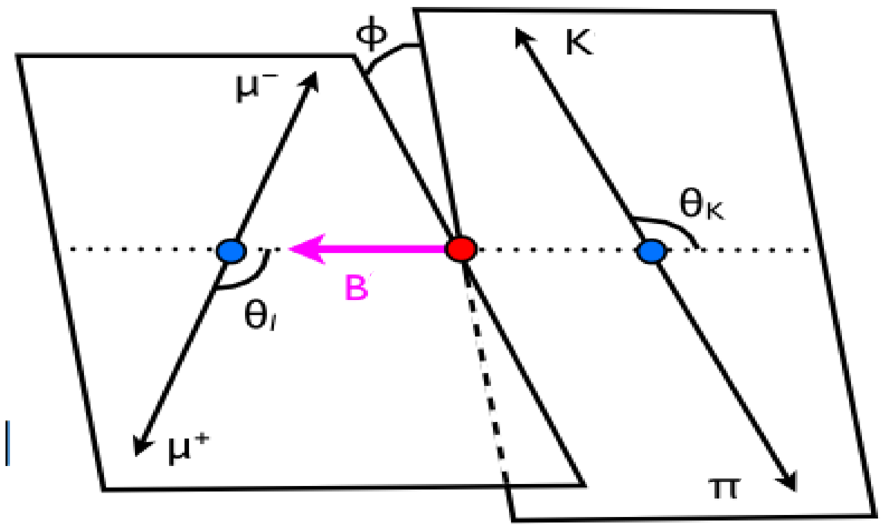


FCNC process forbidden at tree level, BR~10^{-6}: Probe the SM!

- Sensitive to the effects of NP in photon, vector and axial-vector couplings which can enter at the same order as SM contributions
- Complementary information to $B \to \mu^+\mu^-$

- Amplitudes expressed using OPE in terms of:
  - Hadronic Form Factors (accuracy ~20%) [A. Barucha et al. arXiv 1004.3249]
  - Wilson coefficients C^{eff}_{7}, C^{eff}_{9}, C^{eff}_{10} [PRD 61, 074024 (2000), Z. Phys. C 67, 417 (1995)]
  - Clean theoretical predictions expecially at low $q^2=m^2(\mu^+\mu^-)$
  - Experimentally clean signature

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



- Kinematics of the decay $B \to V\, l^+ l^-$ ($V = K^*$, φ, ρ) determined by three angles:
  - θ_l, θ_K, ϕ
- Event Yields reconstructed in bins of $q^2 = m^2(l^+ l^-)$

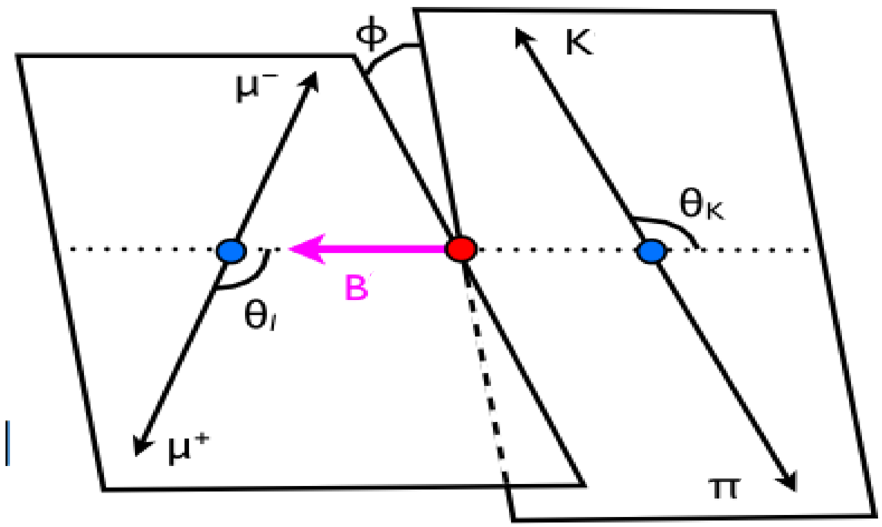
- Differential Amplitudes:

$$\frac{1}{\Gamma(q^2)}\frac{d\Gamma}{d(\cos\theta_K)} = \frac{3}{2}F_L(q^2)\cos^2\theta_K + \frac{3}{4}(1 - F_L(q^2))(1 - \cos^2\theta_K)$$

$$\frac{1}{\Gamma(q^2)}\frac{d\Gamma}{d(\cos\theta_\ell)} = \frac{3}{4}F_L(q^2)(1 - \cos^2\theta_l) + \frac{3}{8}(1 - F_L(q^2))(1 + \cos^2\theta_l) + A_{FB}(q^2)\cos\theta_l\,.$$

- Observables Include:
  - A_{FB} (forward-backward muon asymmetry)
  - F_L (fraction of longitudinally polarized K^*)
  - $P_2 = \frac{-2}{3}\frac{A_{FB}}{1 - F_L}$ (with lower uncertainty from hadronic Form Factors)

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



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$$\frac{1}{\Gamma(q^2)}\frac{d\Gamma}{d(\cos\theta_\ell)} = \frac{3}{4}F_L(q^2)(1-\cos^2\theta_l) + \frac{3}{8}(1-F_L(q^2))(1+\cos^2\theta_l) + A_{FB}(q^2)\cos\theta_l\,.$$

- Non-resonant S-wave $B \to K\pi l^+ l^-$ contribution neglected
  - Reflects in absolute bias ~ 0.01 on F_L & A_{FB} (smaller than statistical & systematic uncertainties)

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

- Measurement performed using 5 modes:
  - $B^+ \to K^{*+} (\to K_s \pi^+) \mu^+\mu^-$, $B^+ \to K^{*+} (\to K_s \pi^+) e^+e^-$, $B^+ \to K^{*+} (\to K^+\pi^0) e^+e^-$
  - $B^0 \to K^{*0} (\to K^+\pi^-) \mu^+\mu^-$, $B^+ \to K^{*0} (\to K^+\pi^-) e^+e^-$
    - $K^* J/\psi$ and $K^* \psi(2S)$ regions used as control samples to validate fitting procedure

q^2 bin	q^2 min (GeV^2/c^4)	q^2 max (GeV^2/c^4)
q_1^2	0.10	2.00
q_2^2	2.00	4.30
q_3^2	4.30	8.12
q_4^2	10.11	12.89
q_5^2	14.21	$(m_B - m_{K^*})^2$
q_0^2	1.00	6.00

- Events reconstructed by means of :
  - $m_{ES} = \sqrt{E_{Beam}^{*\,2} - p_B^{*\,2}}$
  - $\Delta E = E_B^* - E_{Beam}^*$

  * = Υ reference frame

Candidate multiplicity ~ 1.4 (1.1) in dielectron (dimuon) modes.

Best candidate selected based on ΔE

$B \to K^* \ell^+ \ell^-$

- Measurement performed using 5 modes:
  - $B^+ \to K^{*+} (\to K_s \pi^+) \mu^+\mu^-$, $B^+ \to K^{*+} (\to K_s \pi^+) e^+e^-$, $B^+ \to K^{*+} (\to K^+\pi^0) e^+e^-$
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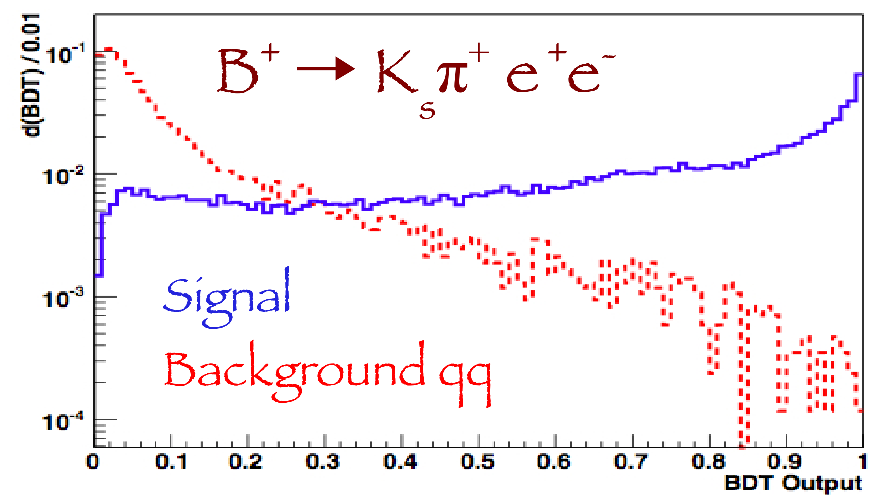
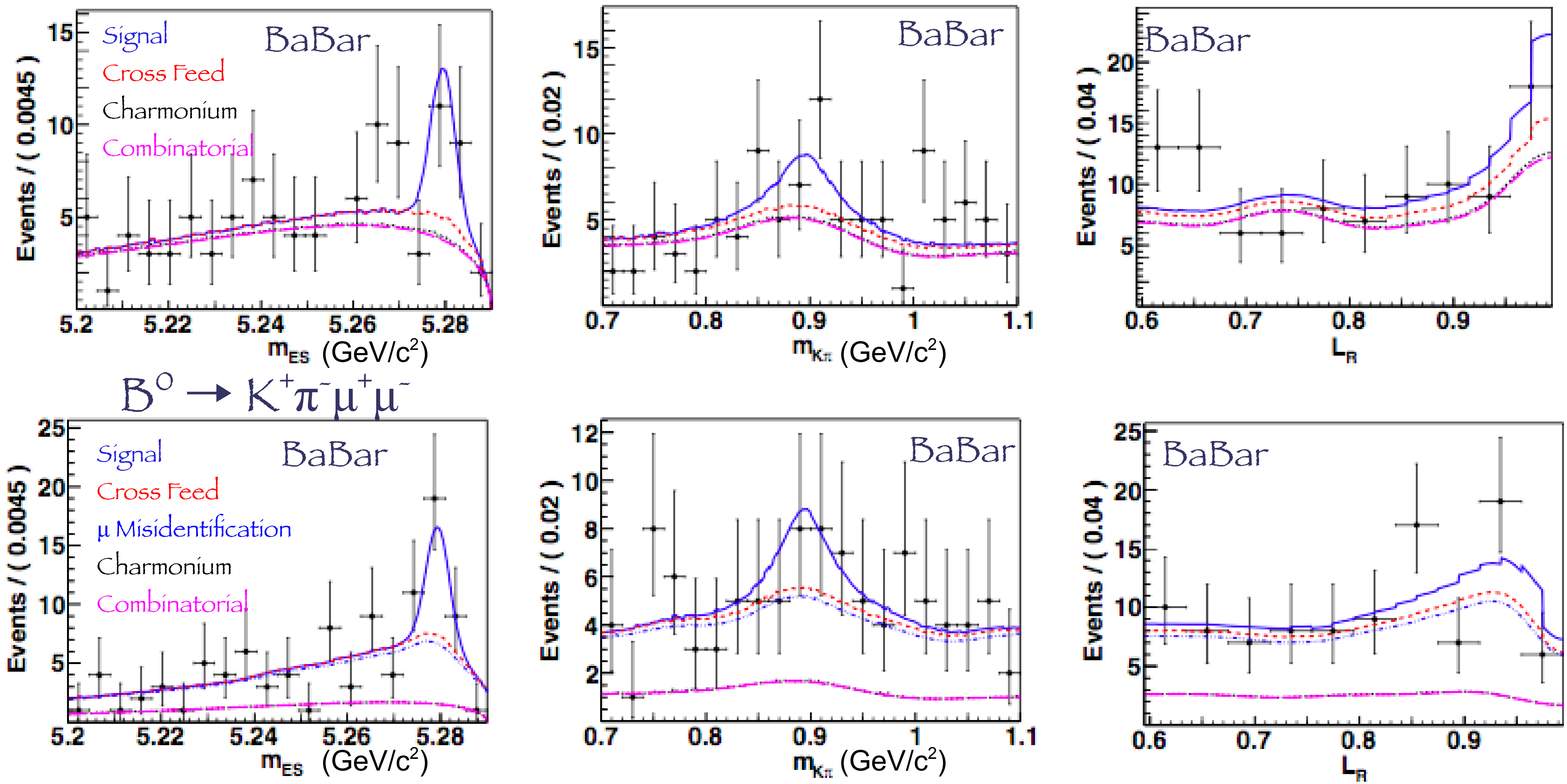
BKG from Continuum and $B\bar{B}$ reduced using a Likelihood Ratio (L_R) defined from outputs of eight BDTs exploiting kinematical and topological quantities



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

- Yields, PDFs shapes & normalizations in the different q^2 bins extracted by a 3D (m_{ES}, $m(K\pi)$, L_R) fit   Example: $q^2 > 14.21$ GeV^2

$B^0 \to K^+\pi^- e^+ e^-$



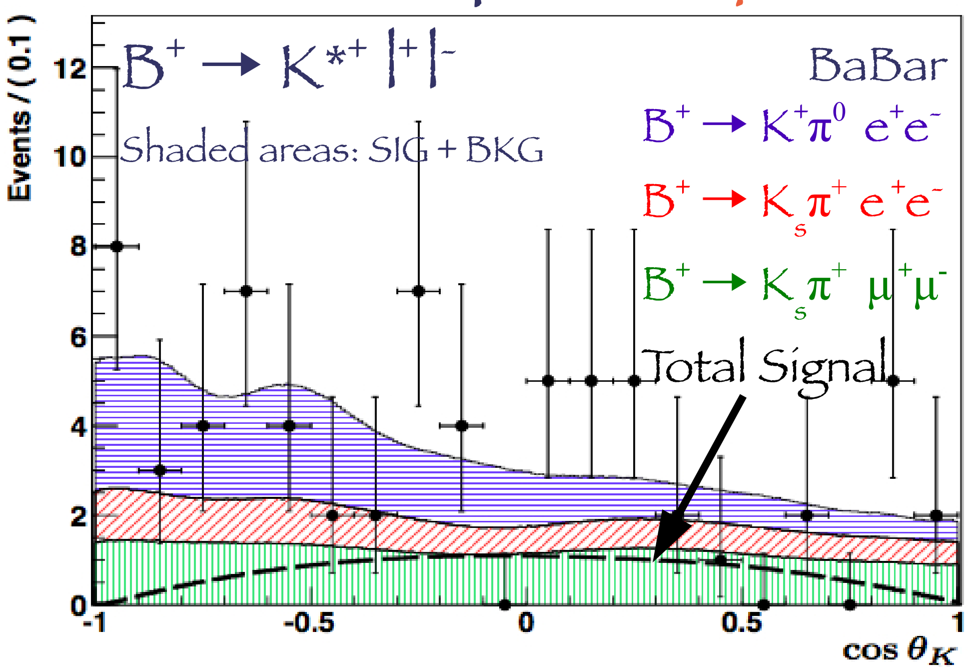
$B \to K^* l^+ l^-$

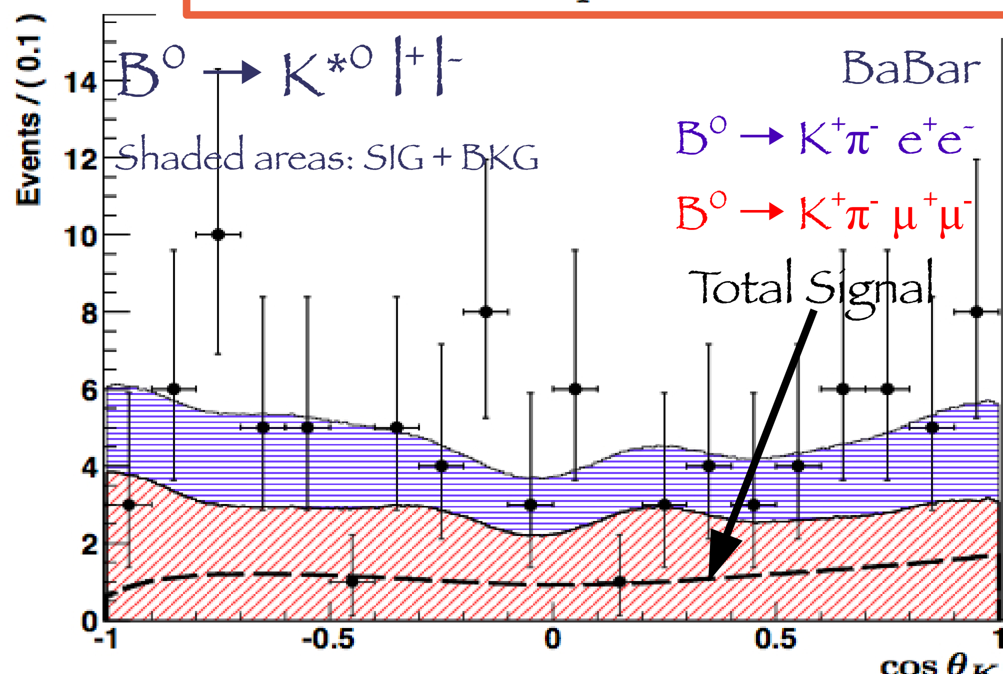
- F_L in the different q^2 bins extracted as only free parameter by a 4D(m_{ES}, $m(K\pi)$, L_R, $\cos(\theta_K)$) fit using PDFs defined in the previous step
- Fit model for F_L and A_{FB} validated on $K^* J/\psi$ and $K^* \psi(2S)$
- BKG shapes from m_{ES} side bands (checked on LFV $B \to K^* e\mu$)

First $B^+ \to K^{*+} l^+ l^-$ angular analysis

$$\frac{1}{\Gamma(q^2)}\frac{d\Gamma}{d(\cos\theta_K)} = \frac{3}{2}F_L(q^2)\cos^2\theta_K + \frac{3}{4}(1 - F_L(q^2))(1-\cos^2\theta_K)$$

Example: $1 < q^2 < 6$ GeV^2





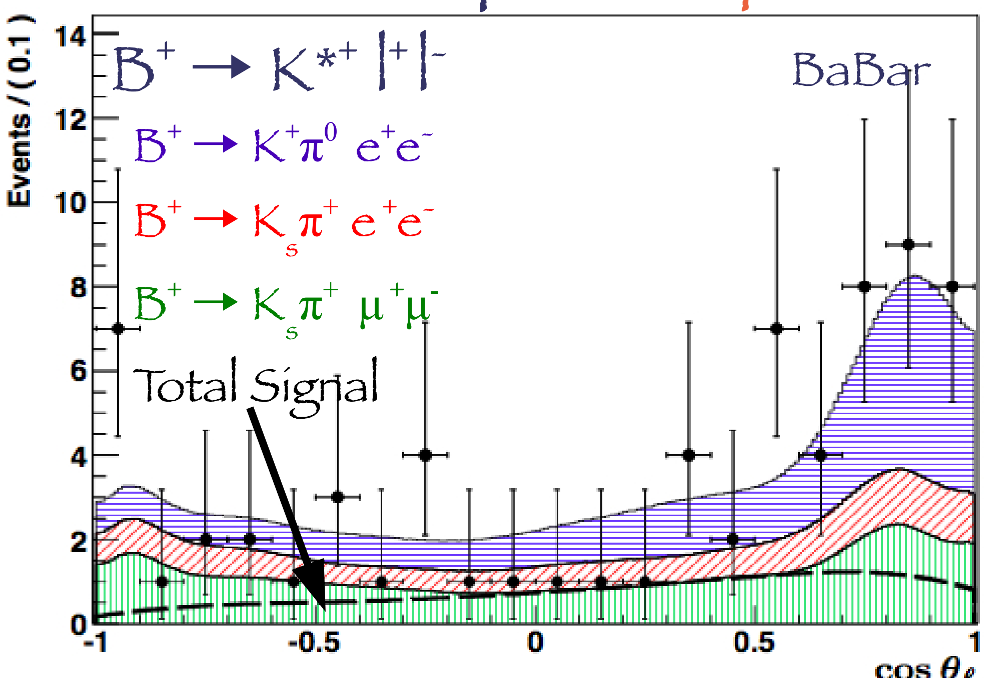
$B \to K^* l^+ l^-$

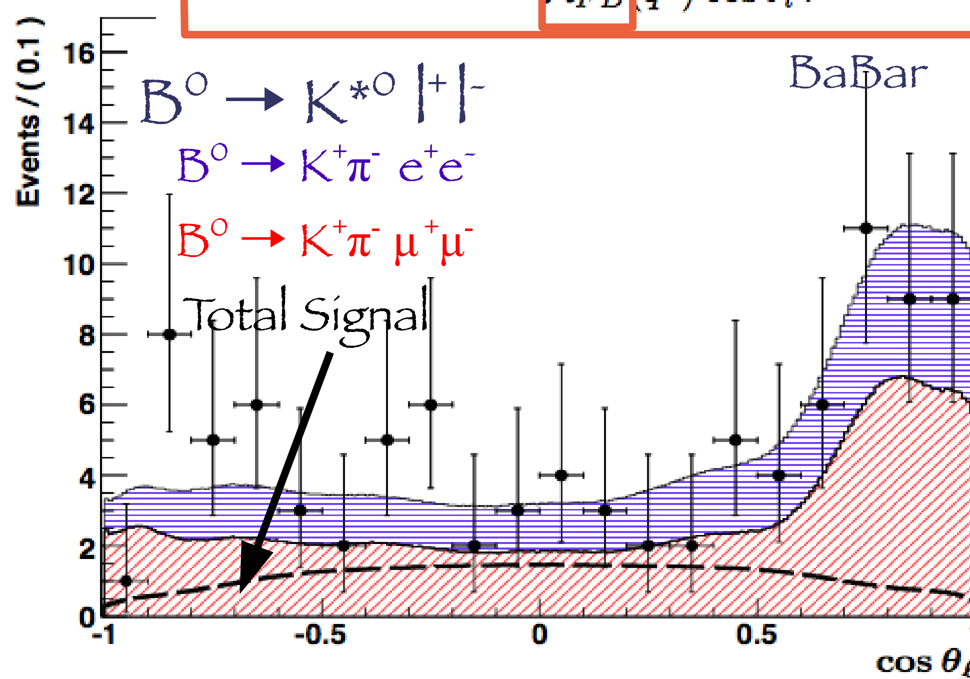
- A_{FB} in the different q^2 bins extracted as only free parameter by a 4D(m_{ES}, $m(K\pi)$, L_R, $\cos(\theta_l)$) fit using PDFs defined in the previous step
- F_L fixed to previous result

$$\frac{1}{\Gamma(q^2)}\frac{d\Gamma}{d(\cos\theta_\ell)} = \frac{3}{4}F_L(q^2)(1-\cos^2\theta_l) + \frac{3}{8}(1-F_L(q^2))(1+\cos^2\theta_l) + A_{FB}(q^2)\cos\theta_l\,.$$

First $B^+ \to K^{*+} l^+ l^-$ angular analysis

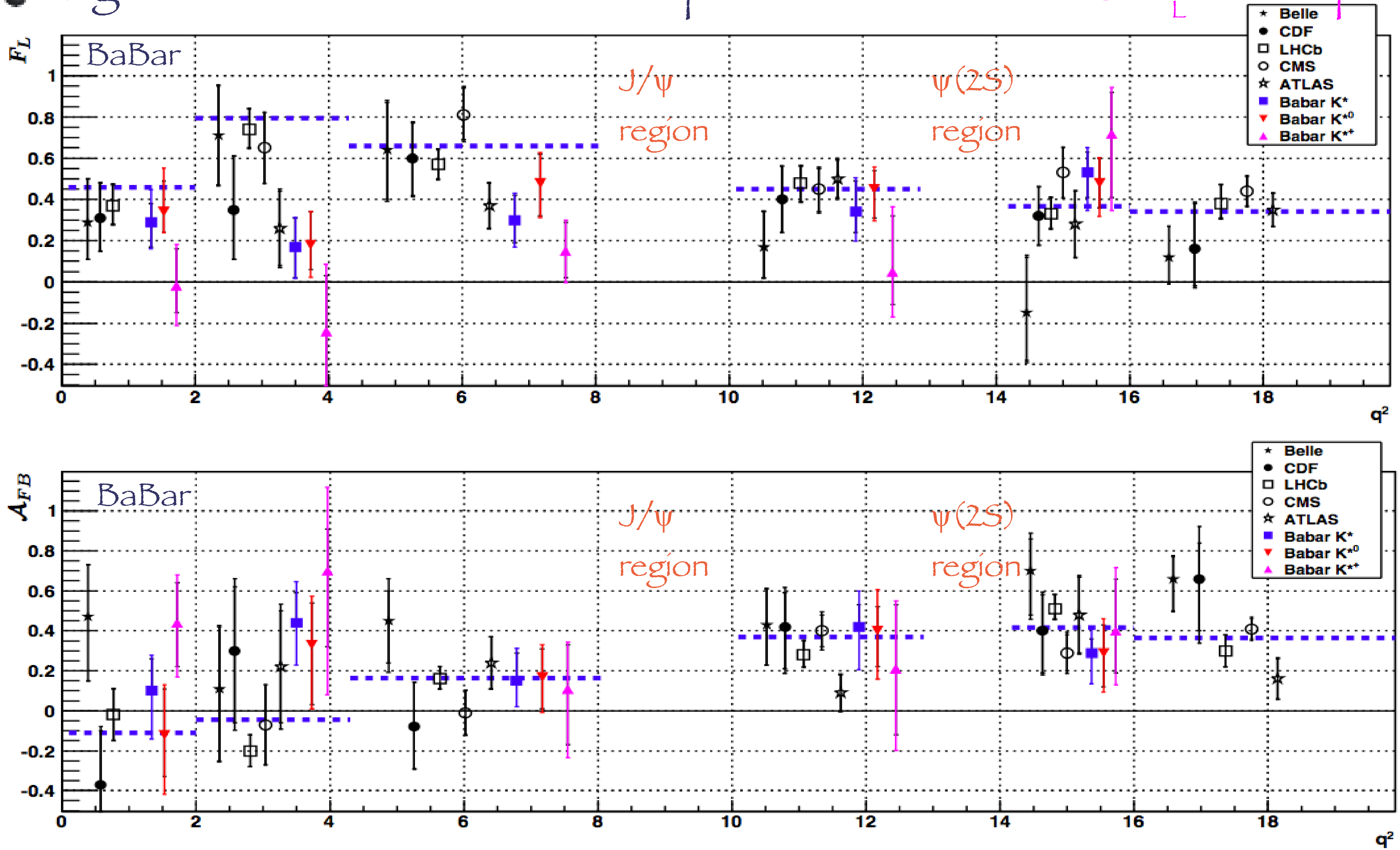
Example: $1 < q^2 < 6$ GeV^2





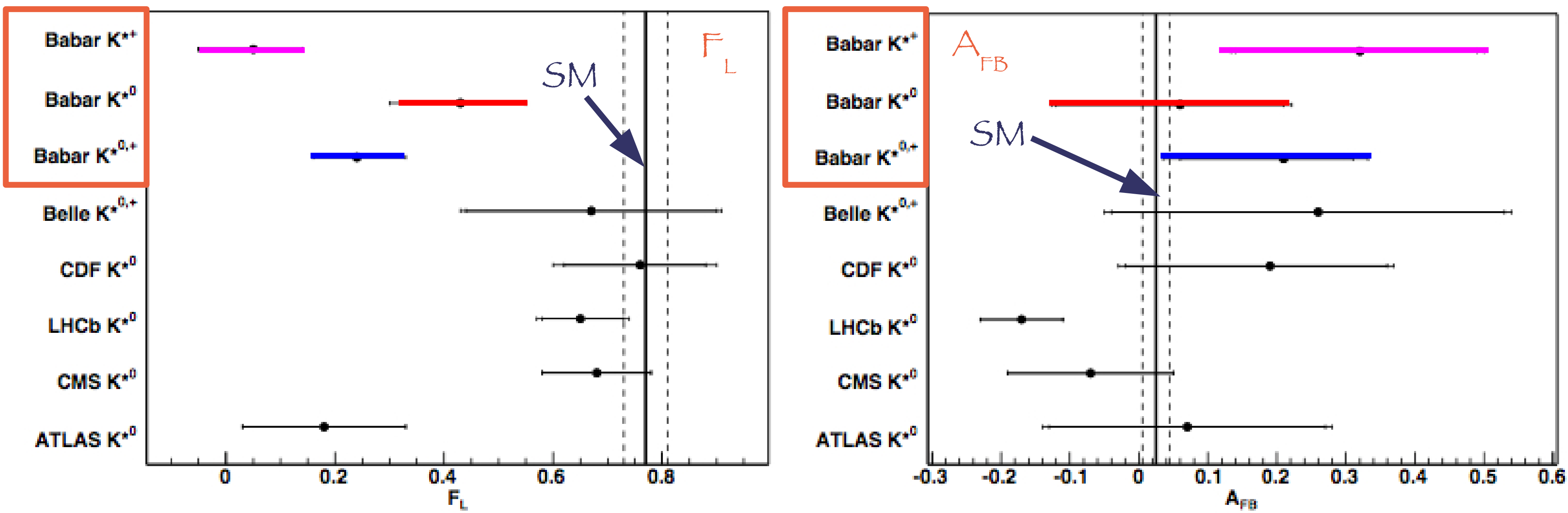
$B \to K^* l^+ l^-$

- Angular Variables Results versus q^2: Tension with SM in B^+ F_L at low q^2



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

- Angular Variable Results for $1 < q^2 < 6$ GeV^2

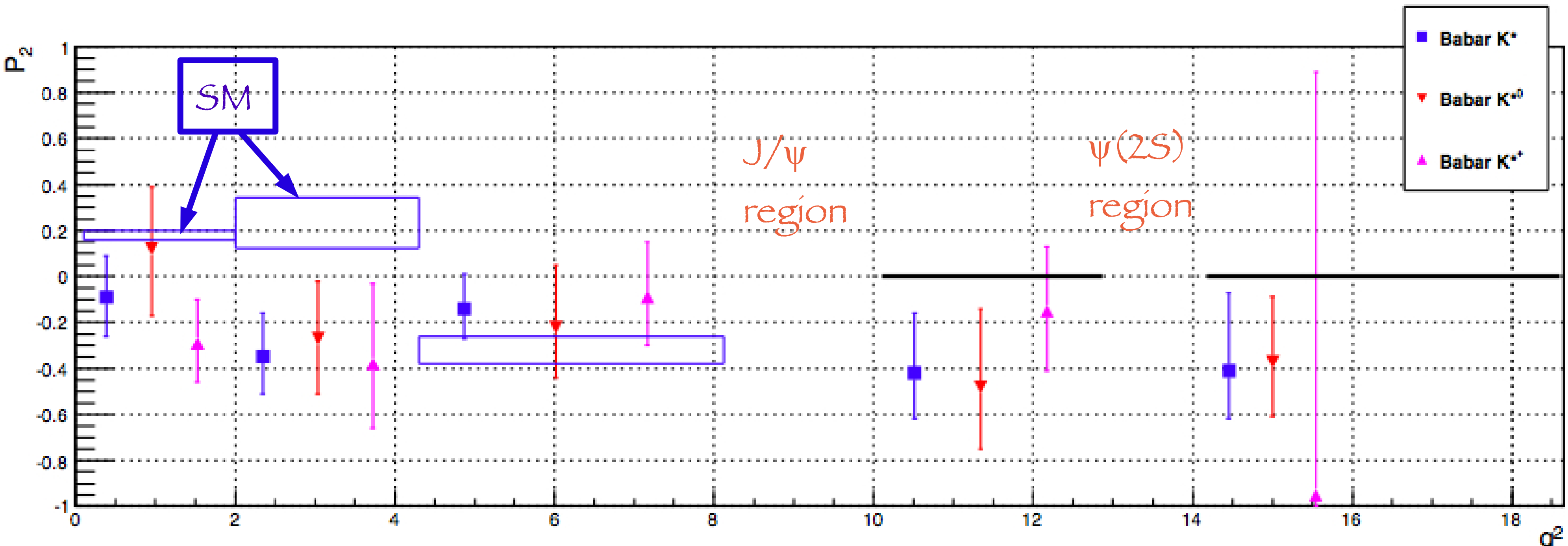


- $1 < q^2 < 6$ GeV^2: Perturbative window with theory error under good control, away from $q^2 \to 0$ photon pole and $c\bar{c}$ resonances at higher q^2
- Small F_L value for $B^+ \to K^{*+} l^+ l^-$ (First Angular Analysis)

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

- $P_2 = \frac{-2}{3}\frac{A_{FB}}{1-F_L}$: Reduced theoretical uncertainty & greater sensitivity to non-SM contributions

[Nucl. Phys. B854, 321 (2012); JHEP 1204, 104 (2012); Phys. Rev. D88, 074002 (2013); JHEP 1412, 125 (2014)]



- Theoretical predictions available only at low q^2 [JHEP 1412, 125 (2014)]
- Slight tension observed with SM

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

- $P_2 = \frac{-2}{3}\frac{A_{FB}}{1-F_L}$: Reduced theoretical uncertainty & greater sensitivity to non-SM contributions

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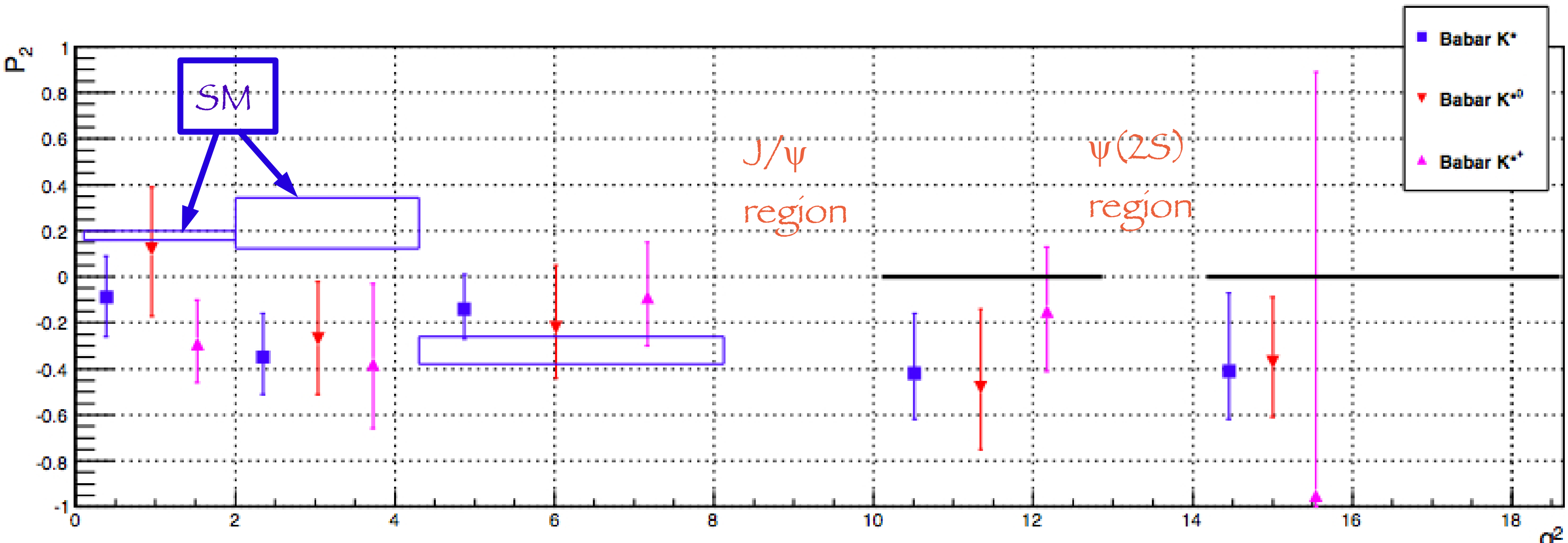


- Result dominated by statistical error
- Systematics from BKG modeling, signal angular efficiency, PDFs parameterization & cross feed from different signal decays

$B^+ \rightarrow K^+\tau^+\tau^-$

"Search for $B^+ \rightarrow K^+ \tau^+\tau^-$ at the BaBar Experiment"

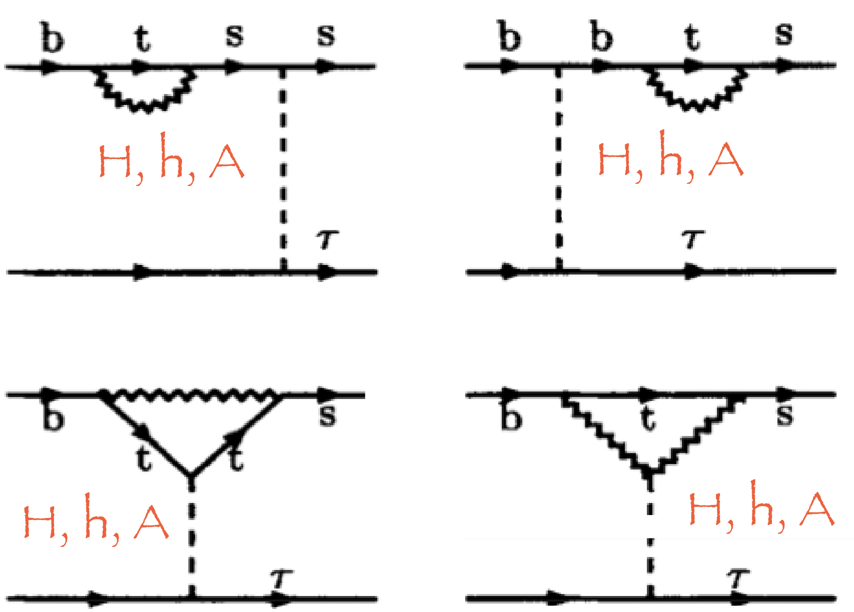
[471 M $\Upsilon(4S)$ events]

arXiv:1605.09637

Submitted to Phys. Rev. Lett.

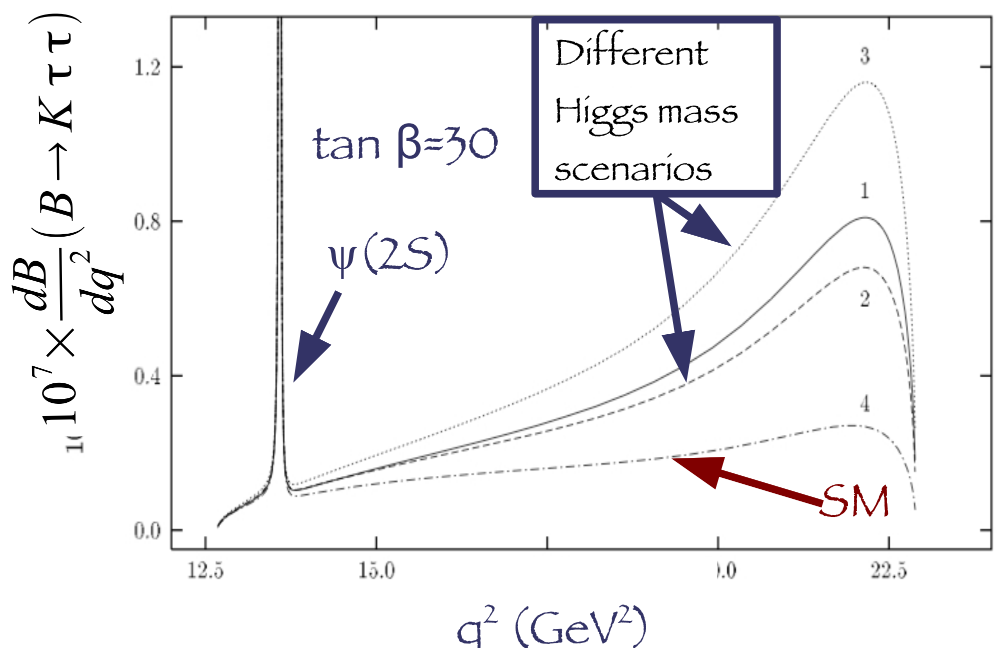
$B^+ \to K^+\tau^+\tau^-$

- Highly suppressed in the SM: BR~(1-2)10^{-7}
- Provides additional sensitivity to New Physics due to third-generation couplings & large τ mass



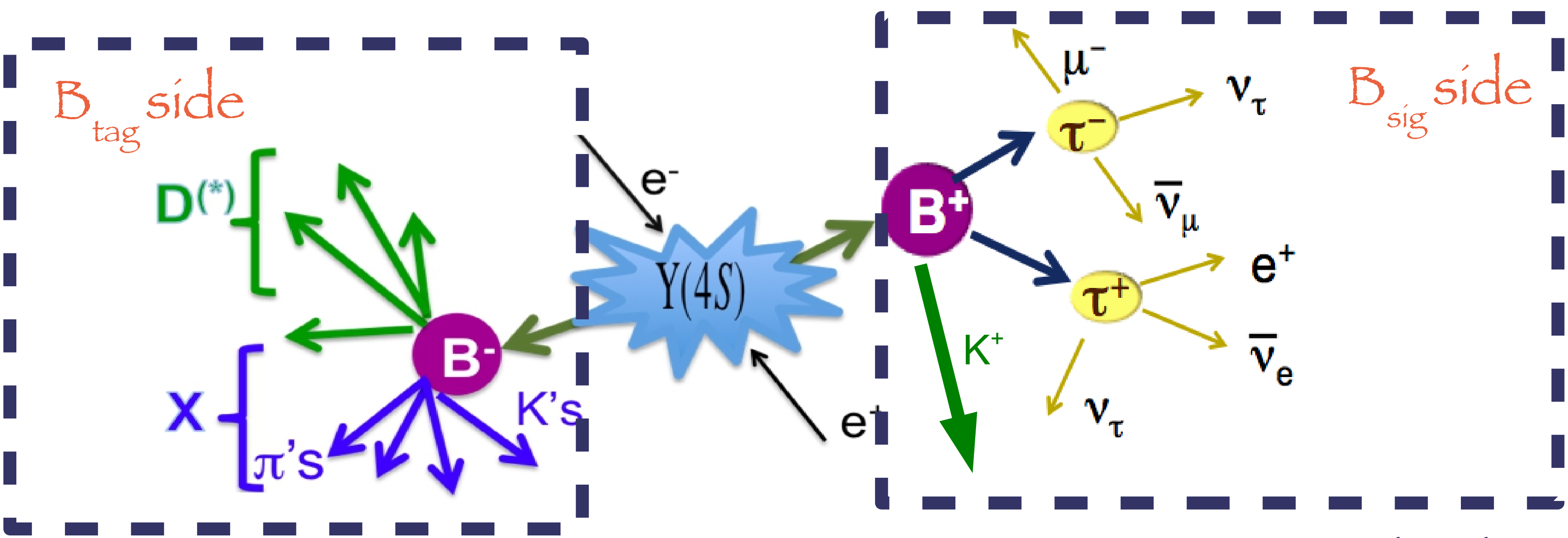
2HDM J. Phys. G24, 49 (1998)

	m_{h^0} (GeV)	$m_{H^\pm}$ (GeV)	m_{H^0} (GeV)	m_{A^0} (GeV)
Mass set-1	80	200	150	100
Mass set-2	250	300	100	350
Mass set-3	100	400	200	150



$B^+ \to K^+\tau^+\tau^-$

- Measurement performed using only leptonic τ decays:
  - $B^+ \to K^+\tau^+\tau^-$, $\tau \to \mu\, \upsilon_\tau\, \upsilon_\mu$, $\tau \to e\, \upsilon_\tau\, \upsilon_e$
  - Three signal modes: ee, μμ, eμ
- Many neutrinos in the final states: lack of kinematic constraints
  - Signal events selected on the recoil of fully reconstructed hadronic $B \to DX$ decays (B_{tag}) ($D = D^{(*)0}$, $D^{(*)\pm}$, $D_S^{(*)}$, J/ψ ; $X < 6\,h$ (h=K, π))



$B^+ \rightarrow K^+\tau^+\tau^-$

- B_{tag} Reconstruction

- B hadronic decays selected by means of m_{ES} & ΔE

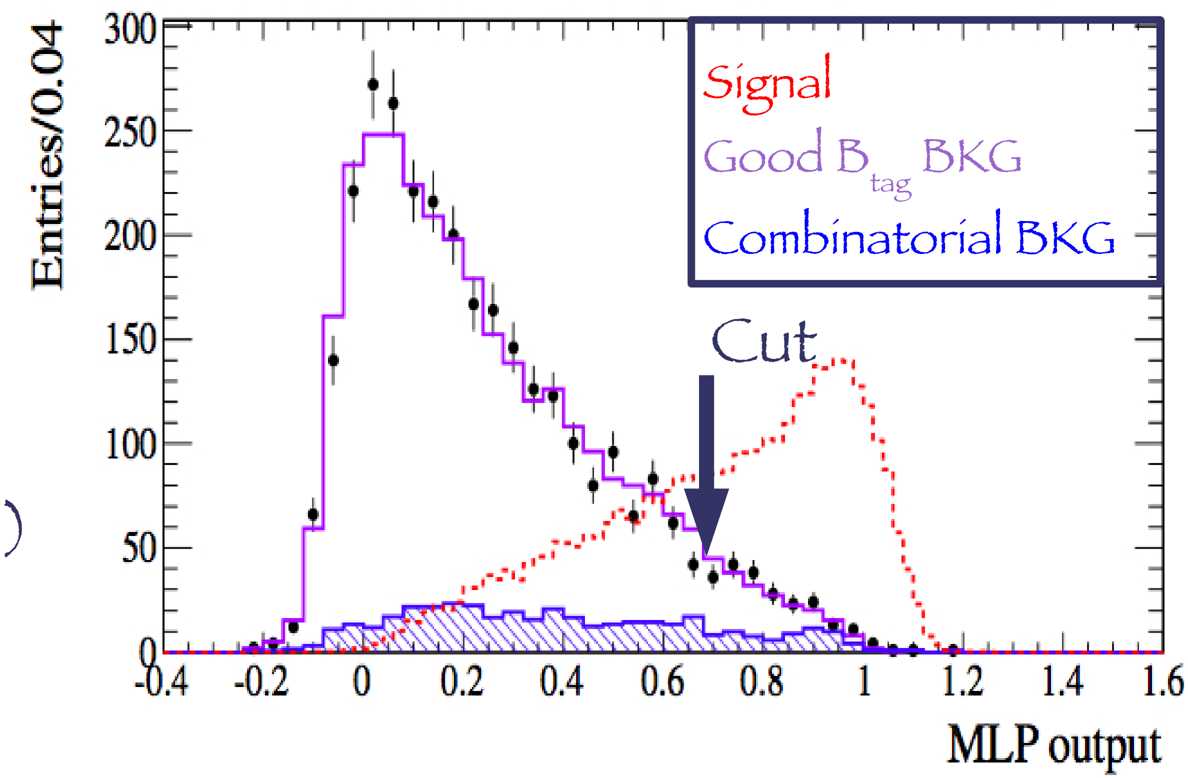
- Best candidate per event retained from the highest purity mode (computed from MC) & ΔE
  - Only B_{tag} candidates with Purity > 40% used → $\varepsilon(B_{tag}) = (0.2 - 0.4)\%$

- Continuum events suppressed by exploiting a Likelihood Selector consisting of six event-shape variables (e.g. Thrust, missing momentum vector, $P(B_{tag})$, angles between them,...)
  - LS > 0.5 removes > 75% of BKG retaining 80% of the signal

$B^+ \to K^+\tau^+\tau^-$

- $B \to K^+\tau^+\tau^-$ Reconstruction
- Signal candidates reconstructed from events with three charged particles, identified as K + two leptons, not belonging to B_{tag}
- Vetos applied against J/ψ, $D^0 \to K\pi$ ($\to \mu$), $\gamma \to e^+e^-$, $\pi^0 \to \gamma\gamma$

- Dominant BKG from $B \to D^{(*)} l \nu$, $D^{(*)} \to K l' \nu$ (same final-state) suppressed by a Neural Network using angles between momenta, $m(K^+l^-)$ and missing energy



$B^+ \to K^+\tau^+\tau^-$

- BR for each of the signal modes:

$$\mathcal{B}_i = \frac{N^i_{\rm obs} - N^i_{\rm bkg}}{\epsilon^i_{\rm sig} N_{B\bar{B}}}$$

$$N_{B\bar{B}} = 471\times 10^6$$

	e^+e^-	$\mu^+\mu^-$	$e^+\ \mu^-$
$N^i_{\rm bkg}$	49.4±2.4±2.9	45.8±2.4 ±3.2	59.2±2.8 ±3.5
$\epsilon^i_{\rm sig}(\times 10^{-5})$	1.1 ±0.2±0.1	1.3±0.2±0.1	2.1±0.2±0.2
$N^i_{\rm obs}$	45	39	92
Significance (σ)	-0.6	-0.9	3.7

- Signal efficiencies and expected Peaking BKG events (92%) obtained from simulation corrected to reproduce B_{tag} data yield
- Expected combinatorial BKG events (8%) from data m_{ES} Side Band

$B^+ \to K^+\tau^+\tau^-$

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- e^+e^-, $\mu^+\mu^-$ yields show consistency with expected BKG events.
- $e\mu$ channel has excess of 3.7 σ:
  - No evident signal-like behaviour or systematic problems from kinematic distributions

$B^+ \to K^+\tau^+\tau^-$

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$$\mathcal{B}_i = \frac{N^i_{\rm obs} - N^i_{\rm bkg}}{\epsilon^i_{\rm sig} N_{B\bar{B}}}$$

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- Overall significance < 2σ :

$BR(B^+ \to K^+\tau^+\tau^-) < 2.25\times10^{-3}$ (90% CL) First Measurement

- Systematics from B_{tag} yield correction, theoretical models for efficiency determination, PID, and Data/MC agreement

$B \rightarrow K\pi\pi\gamma$

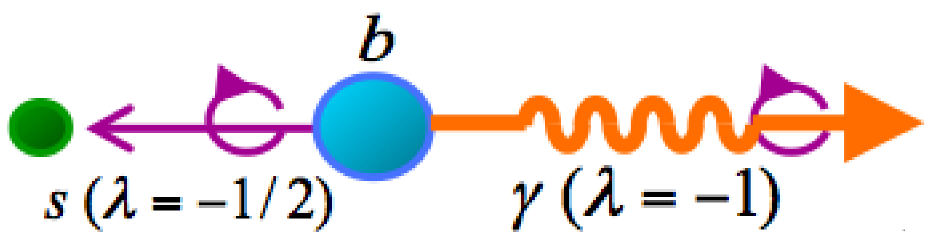
"Time-dependent analysis of $B^0 \rightarrow K_S\pi^-\pi^+\gamma$ and studies of the $K^+\pi^-\pi^+$ system in $B^+ \rightarrow K^+\pi^-\pi^+\gamma$ decays"

[471 M $\Upsilon(4S)$ events]

Phys. Rev. D93, 052013 (2016)

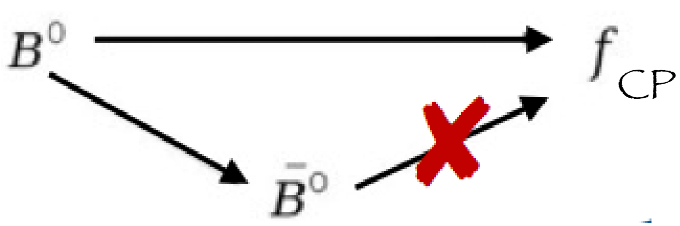
Radiative decays and the γ polarization

- $b \to s\gamma$: described in the SM as an interaction between left-handed quarks and right-handed antiquarks:



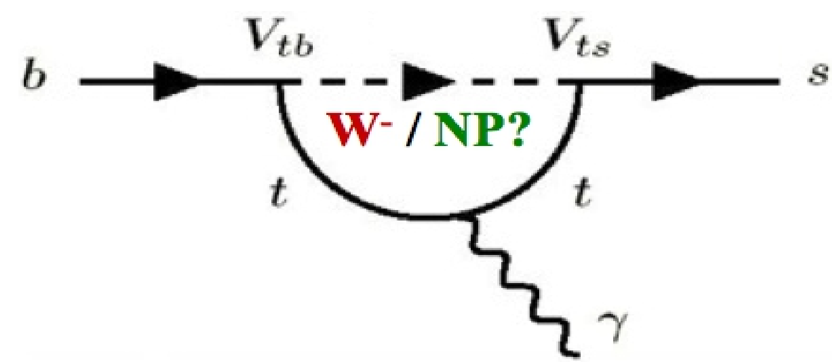
$$\lambda = \frac{\vec{S}\cdot\vec{p}}{|\vec{p}|}$$

- $b \to s\gamma_L$ & $\bar{b} \to \bar{s}\gamma_R$

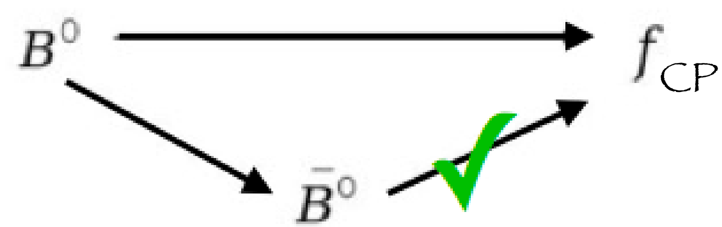


- Mixing induced CP Asymmetry ≈0

- New heavy particles in the loop could enhance opposite helicity γ contribution



- $b \to s\gamma_{L/R}$ & $\bar{b} \to \bar{s}\gamma_{R/L}$



- Mixing induced CP Asymmetry ≠0

Measurement of A_{CP} in $B^0 \to K_S \rho\gamma$

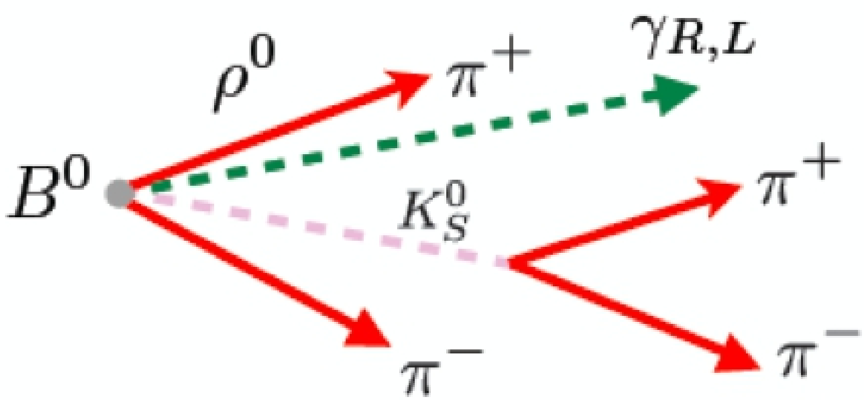
$$
\begin{aligned}
\mathcal{A}_{CP}(\Delta t) &= \frac{\Gamma(\overline{B}^0(\Delta t) \to f_{CP}\gamma) - \Gamma(B^0(\Delta t) \to f_{CP}\gamma)}{\Gamma(\overline{B}^0(\Delta t) \to f_{CP}\gamma) + \Gamma(B^0(\Delta t) \to f_{CP}\gamma)} \\
&= \mathcal{S}_{f_{CP}} \sin(\Delta m_d \Delta t) - \mathcal{C}_{f_{CP}} \cos(\Delta m_d \Delta t)
\end{aligned}
$$

- SM predicts $S_{f_{CP}} = m_s / m_b = 0.02$
- Look for enhancement due to new-particle exchange

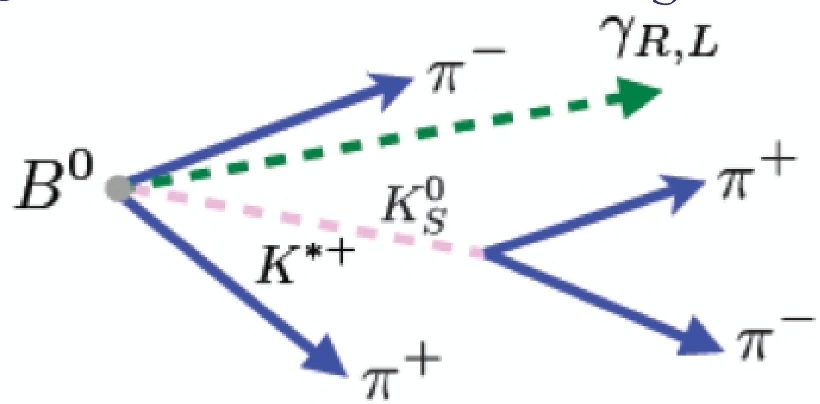
[$\Delta t = t_{Rec} - t_{Tag}$ from distance between the two B^0 decay vertices in the event]

- Experimentally: perform a time-dependent analysis of $B^0 \to K_S \rho\gamma$
- Main Issue: dilution from irreducible BKG from non CP eigenstates:

CP eigenstate $B^0 \to K_S \rho\gamma$



Non CP eigenstate $B^0 \to K^*(K_S\pi)\pi\gamma$



Measurement of A_{CP} in $B^0 \rightarrow K_S \rho\gamma$

$$A_{CP}(\Delta t) = \frac{\Gamma(\overline{B}^0(\Delta t) \rightarrow f_{CP}\gamma) - \Gamma(B^0(\Delta t) \rightarrow f_{CP}\gamma)}{\Gamma(\overline{B}^0(\Delta t) \rightarrow f_{CP}\gamma) + \Gamma(B^0(\Delta t) \rightarrow f_{CP}\gamma)} = S_{f_{CP}} \sin(\Delta m_d \Delta t) - C_{f_{CP}} \cos(\Delta m_d \Delta t)$$

- SM predicts $S_{f_{CP}} = m_s / m_b = 0.02$
- Look for enhancement due to new-particle exchange

[$\Delta t = t_{Rec} - t_{Tag}$ from distance between the two B^0 decay vertices in the event]

- Experimentally: perform a time-dependent analysis of $B^0 \rightarrow K_S \rho\gamma$
- Main Issue: dilution from irreducible BKG from non CP eigenstates:

CP eigenstate $B^0 \rightarrow K_S \rho\gamma$ Non CP eigenstate $B^0 \rightarrow K^*(K_S\pi)\pi\gamma$

Dilution: $$\mathcal{D}_{K_S^0 \rho\gamma} \equiv \frac{\mathcal{S}_{K_S^0 \pi^+\pi^-\gamma}}{\mathcal{S}_{K_S^0 \rho\gamma}}$$

Effective value on inclusive $K_s\pi\pi\gamma$ sample

Signal value

Measurement of A_{CP} in $B^0 \to K_S \rho\gamma$

- Dilution expressed in terms of few resonant decay modes: $\rho^0 K_S$, $K^{*+}\pi^-$, $K^{*-}\pi^+$, $(K\pi)_0^{*+}\pi^-$, $(K\pi)_0^{*-}\pi^+$ S-wave ($K^*_0(1430)$ + NR component) and their interference:

$$\mathcal{D}_{K_S^0\rho\gamma} \equiv \frac{\mathcal{S}_{K_S^0\pi^+\pi^-\gamma}}{\mathcal{S}_{K_S^0\rho\gamma}} = \frac{\int \left[|A_{\rho K_S^0}|^2 - |A_{K^{*+}\pi^-}|^2 - |A_{(K\pi)_0^{*+}\pi^-}|^2 + 2\Re(A^*_{\rho K_S^0} A_{K^{*+}\pi^-}) + 2\Re(A^*_{\rho K_S^0} A_{(K\pi)_0^{*+}\pi^-})\right] dm^2}{\int \left[|A_{\rho K_S^0}|^2 + |A_{K^{*+}\pi^-}|^2 + |A_{(K\pi)_0^{*+}\pi^-}|^2 + 2\Re(A^*_{\rho K_S^0} A_{K^{*+}\pi^-}) + 2\Re(A^*_{\rho K_S^0} A_{(K\pi)_0^{*+}\pi^-})\right] dm^2}$$

[LAL-15-75 (2015)]

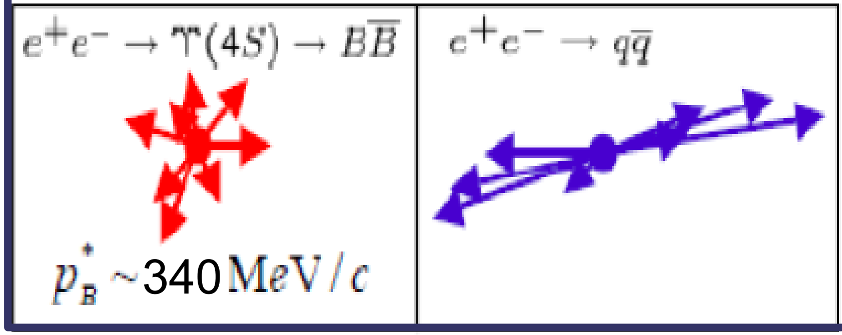
- Ideal World: Perform a time-dependent Amplitude Analysis
- Real World: Not enough statistics, dilution computed from the amplitudes of the intermediate resonances from $B^+ \to K^+\pi^+\pi^-\gamma$ assuming Isospin Symmetry

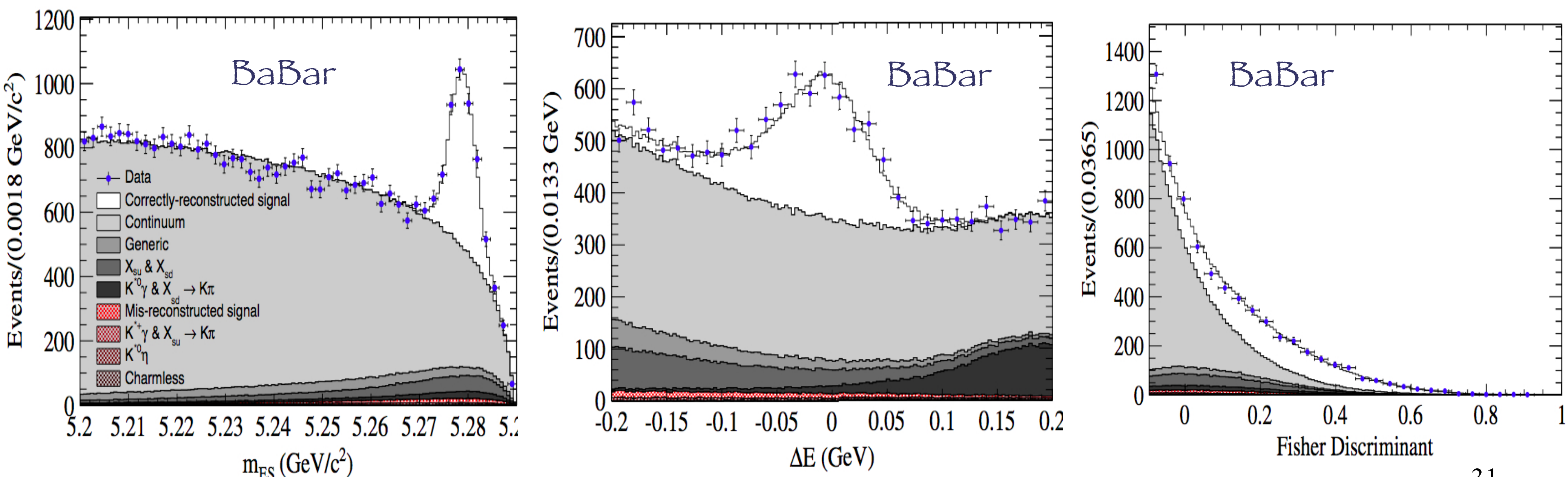
$B^+ \to K^+\pi^+\pi^-\gamma$ Selection

- $B^+ \to K^+\pi^+\pi^-\gamma$ events selected by means of:
  - $1.5 < E_\gamma^* < 3.5\,GeV$

    * = Υ reference frame
  - m_{ES}
  - ΔE

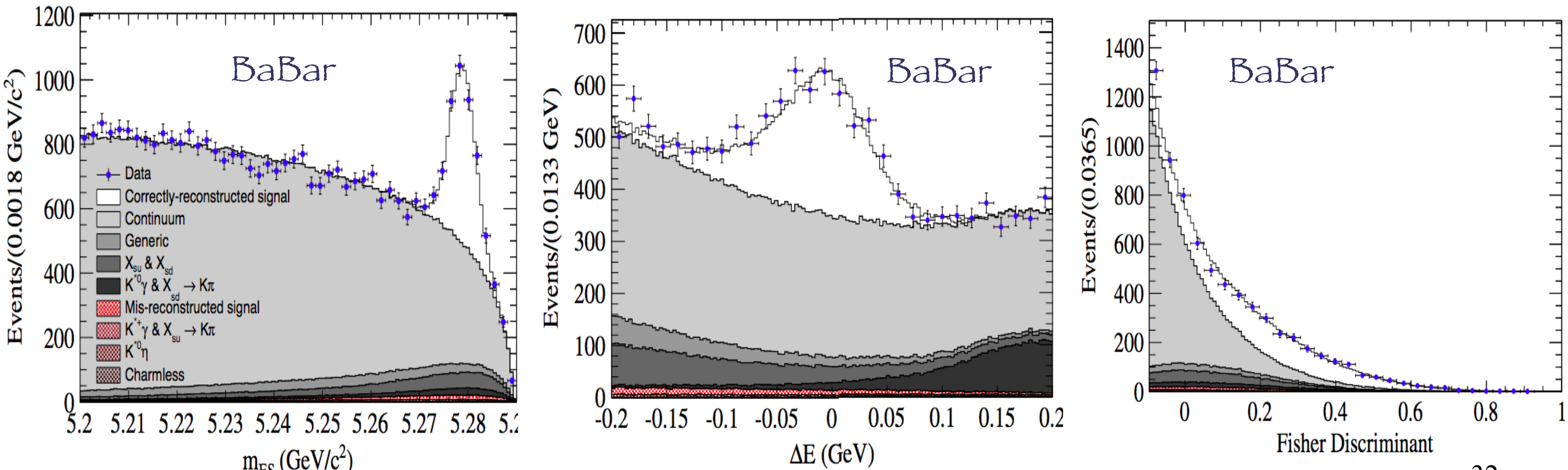
- Continuum BKG suppressed using a Fisher exploiting topological quantities





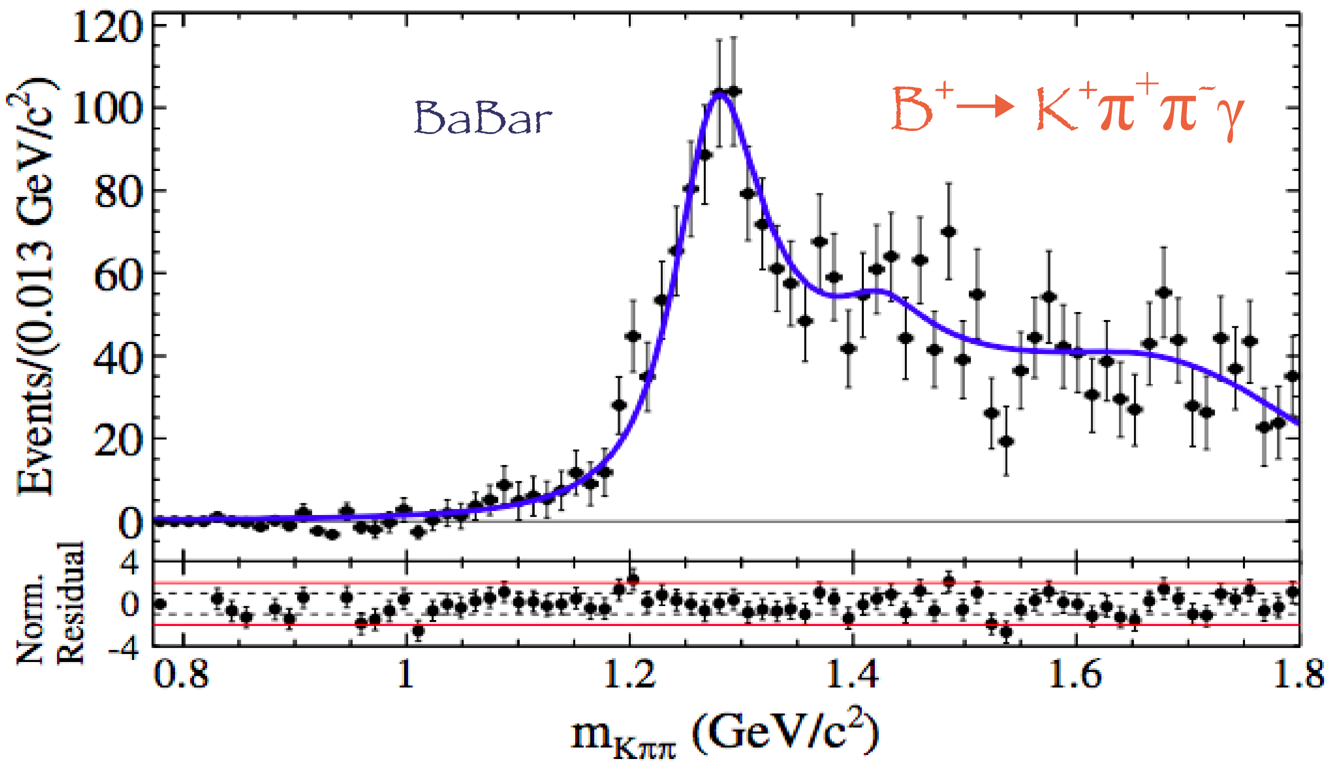
$B^+ \to K^+\pi^+\pi^-\gamma$ Selection

- $B^+ \to K^+\pi^+\pi^-\gamma$ signal yield extracted from an unbinned fit to m_{ES}, ΔE and Fisher discriminant:
  - $N_{sig} = 2441 \pm 91 ^{+41}_{-54}$
  - $BF(B^+ \to K^+\pi^+\pi^-\gamma) = (24.5 \pm 0.9 \pm 1.2)\ 10^{-6}$
- $m(K\pi\pi)$, $m(K\pi)$ and $m(\pi\pi)$ spectra obtained using $_s$Plot technique [NIM A 555, 356-369 (2005)]



$B^+ \to K^+\pi^+\pi^-\gamma$ Analysis

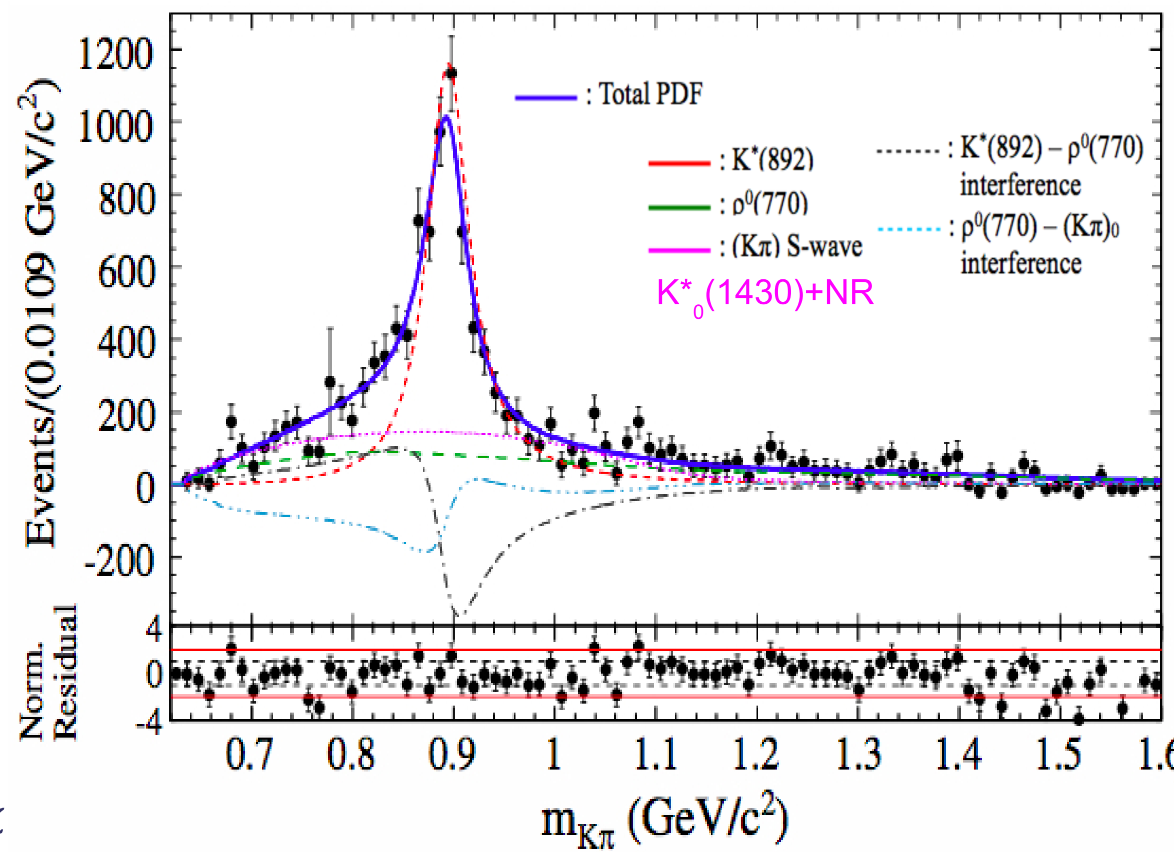
- BFs of the various resonances decaying to $K\pi\pi$ extracted from the $m(K\pi\pi)$ spectrum



Mode	$\mathcal{B}(B^+ \to \text{Mode}) \times \mathcal{B}(K_{res} \to K^+\pi^+\pi^-) \times 10^{-6}$	$\mathcal{B}(B^+ \to \text{Mode}) \times 10^{-6}$	Previous world average [18] ($\times 10^{-6}$)
$B^+ \to K^+\pi^+\pi^-\gamma$	...	$24.5 \pm 0.9 \pm 1.2$	27.6 ± 2.2
$K_1(1270)^+\gamma$	$14.5^{+2.1+1.2}_{-1.4-1.2}$	$44.1^{+6.3+3.6}_{-4.4-3.6} \pm 4.6$	43 ± 13
$K_1(1400)^+\gamma$	$4.1^{+1.9+1.2}_{-1.2-1.0}$	$9.7^{+4.6+2.8}_{-2.9-2.3} \pm 0.6$	<15 at 90% C.L.
$K^*(1410)^+\gamma$	$11.0^{+2.2+2.1}_{-2.0-1.1}$	$27.1^{+5.4+5.2}_{-4.8-2.6} \pm 2.7$	n/a
$K_2^*(1430)^+\gamma$	$1.2^{+1.0+1.2}_{-0.7-1.5}$	$8.7^{+7.0+8.7}_{-5.3-10.4} \pm 0.4$	14 ± 4
$K^*(1680)^+\gamma$	$15.9^{+2.2+3.2}_{-1.9-2.4}$	$66.7^{+9.3+13.3}_{-7.8-10.0} \pm 5.4$	<1900 at 90% C.L.

$B^+ \to K^+\pi^+\pi^-\gamma$ Analysis

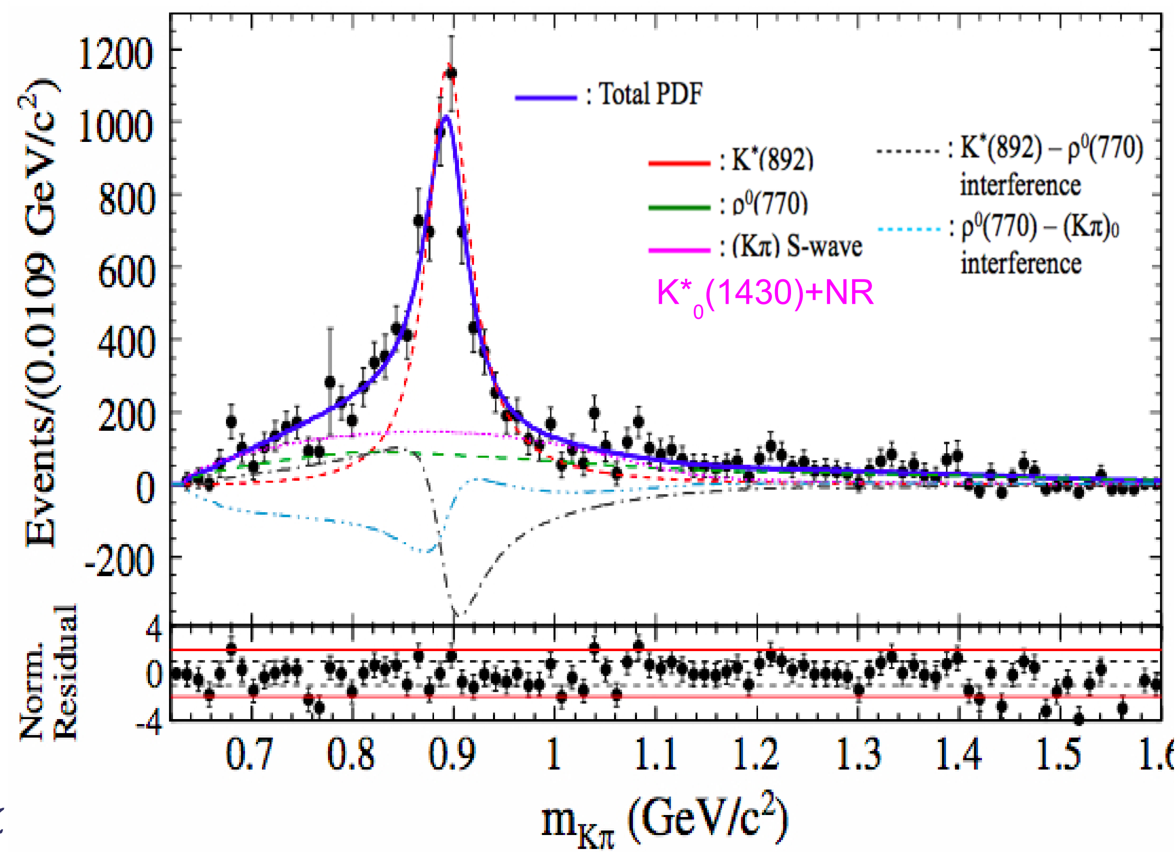
- Extraction of the dilution from amplitudes of intermediate states decaying to Kπ and ππ
- Full amplitude analysis in the m(Kπ)-m(ππ) not possible due to small statistics
  - Perform a 1D fit to m(Kπ) using as inputs the BRs obtained from the m(Kππ) fit



Mode	$\mathcal{B}(B^+ \to \text{Mode}) \times \mathcal{B}(R \to h\pi) \times 10^{-6}$	$\mathcal{B}(B^+ \to \text{Mode}) \times 10^{-6}$	Previous world average [18] ($\times 10^{-6}$)
$K^*(892)^0\pi^+\gamma$	$15.6 \pm 0.6 \pm 0.5$	$23.4 \pm 0.9^{+0.8}_{-0.7}$	20^{+7}_{-6}
$K^+\rho(770)^0\gamma$	$8.1 \pm 0.4^{+0.8}_{-0.7}$	$8.2 \pm 0.4 \pm 0.8 \pm 0.02$	< 20 at 90% CL
$(K\pi)^{*0}_0\pi^+\gamma$	$10.3^{+0.7+1.5}_{-0.8-2.0}$	$\cdots$	n/a
$(K\pi)^0_0\pi^+\gamma$ (NR)	$\cdots$	$9.9 \pm 0.7^{+1.5}_{-1.9}$	< 9.2 at 90% CL
$K^*_0(1430)^0\pi^+\gamma$	$0.82 \pm 0.06^{+0.12}_{-0.16}$	$1.32^{+0.09+0.20}_{-0.10-0.26} \pm 0.14$	n/a

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

- Extraction of the dilution from amplitudes of intermediate states decaying to Kπ and ππ
- Full amplitude analysis in the m(Kπ)-m(ππ) not possible due to small statistics
  - Perform a 1D fit to m(Kπ) using as inputs the BRs obtained from the m(Kππ) fit



$$\mathcal{D}_{K_S^0\rho\gamma} = F(A_\rho, A_{K^*}, A_{(K\pi)S\text{-wave}}) = -0.78^{+0.19}_{-0.17}$$

Measurement of A_{CP} in $B^0 \to K_S \rho\gamma$

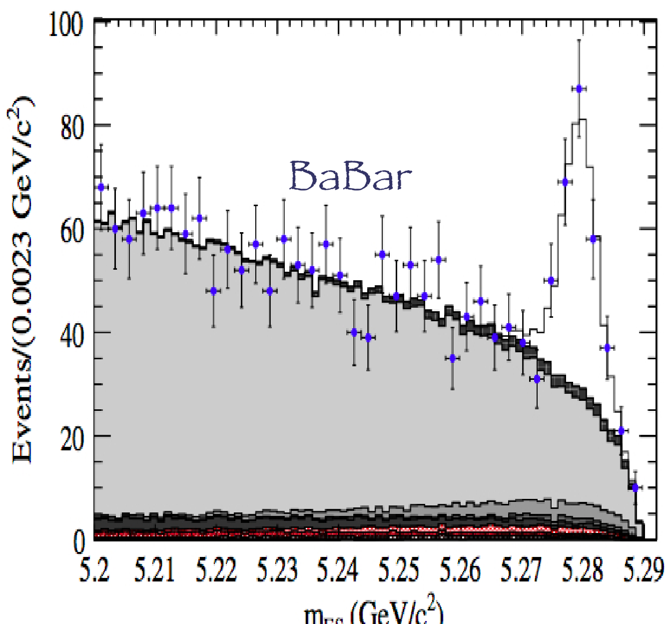
- Time-dependent analysis of $B^0 \to K_s \rho\gamma$ decays
- Event yield and CP parameters C and S extracted from a fit to m_{ES}, ΔE, Fisher and Δt
- Sample divided in 6 mutually exclusive tagging categories c

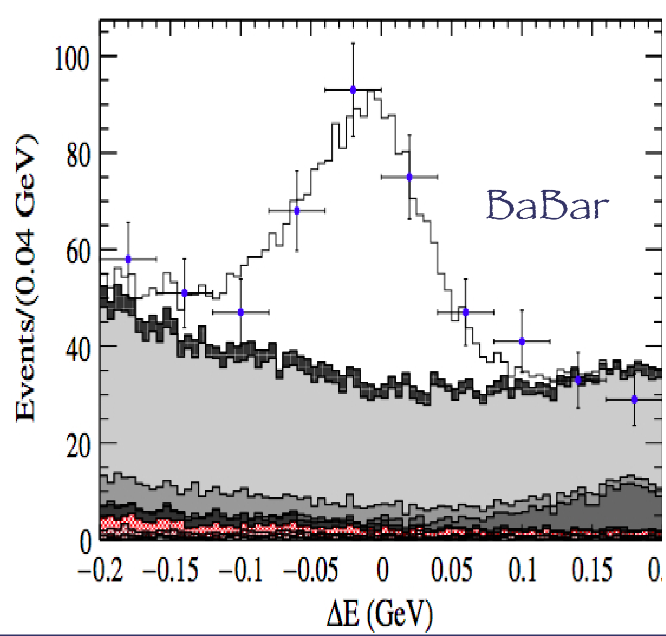
$$\mathcal{P}^i_j(m_{ES}, \Delta E, \mathcal{F}, \Delta t, \sigma_{\Delta t}; q_{tag}, c)$$
$$= \mathcal{P}^i_j(m_{ES})\mathcal{P}^i_j(\Delta E)\mathcal{P}^i_j(\mathcal{F})\mathcal{P}^i_j(\Delta t, \sigma_{\Delta t}; q_{tag}, c)$$

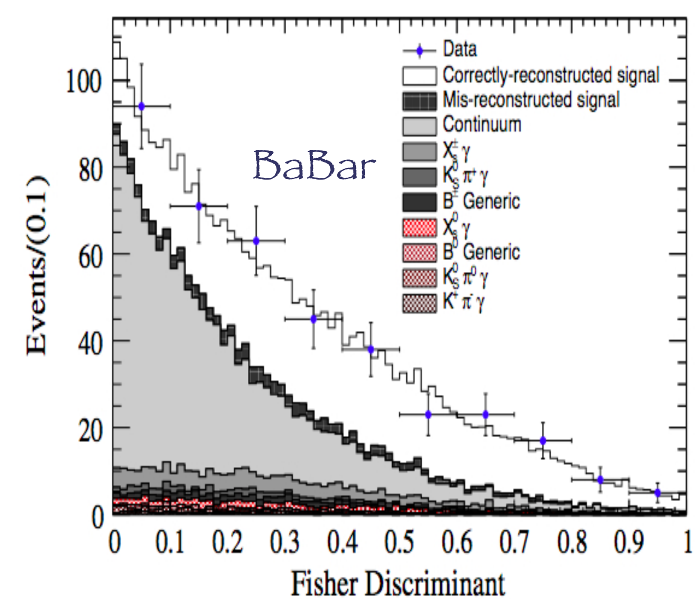
c = tagging category

q_{tag}=1 (B_{Tag}=B^0)

-1 (B_{Tag}=$\bar{B}^0$)







Measurement of A_{CP} in $B^0 \to K_s \rho\gamma$

- Time-dependent analysis of $B^0 \to K_s \rho\gamma$ decays
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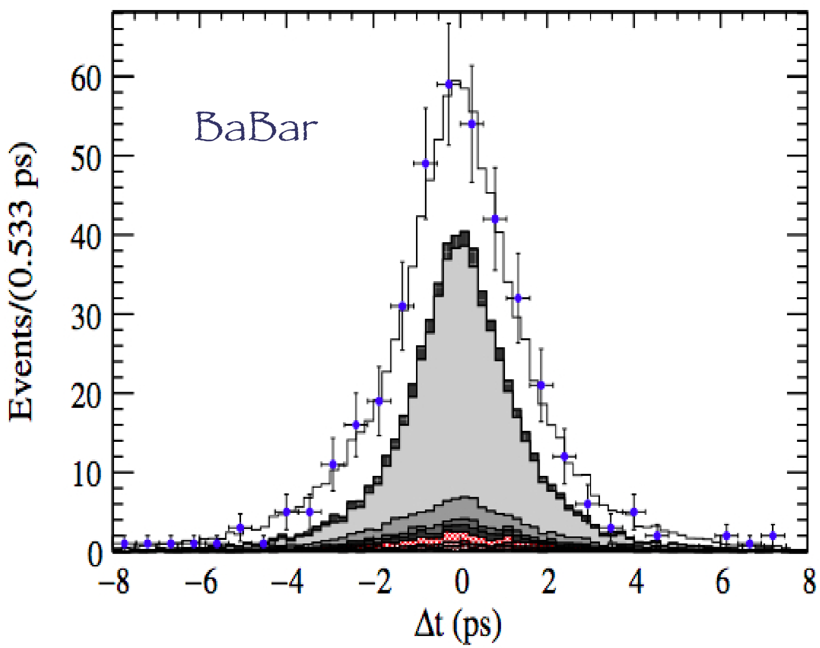


$$\mathcal{P}^i_{\rm sig}(\Delta t, \sigma_{\Delta t}; q_{\rm tag}, c) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}} \left[1 + q_{\rm tag}\frac{\Delta D_c}{2} + q_{\rm tag}\langle D\rangle_c (S\sin(\Delta m_d \Delta t) - C\cos(\Delta m_d \Delta t))\right] \otimes \mathcal{R}^c_{\rm sig}(\Delta t, \sigma_{\Delta t}),$$

ΔD : Difference between D for B^0 and $\overline{B^0}$ tags

c = tagging category

q_{tag}=1 (B_{Tag}=B^0)

-1 (B_{Tag}=$\overline{B^0}$)

- Tagging imperfection D, ΔD & Δt Resolution R_{sig} from quarkonium sin(2β) analysis [PRL 99, 171803 (2007)]

Measurement of A_{CP} in $B^0 \to K_S \rho\gamma$

Results:

$BF(B^0 \to K_s \pi\pi\gamma) = (20.5 \pm 2.0^{+2.6}_{-2.2})10^{-6}$

$S_{K_S\pi\pi\gamma} = 0.14 \pm 0.25 \pm 0.03$

$C_{K_S\pi\pi\gamma} = -0.39 \pm 0.20^{+0.03}_{-0.02}$

- After correcting for $\mathcal{D}_{K^0_S\rho\gamma}$:
  - $S_{K_S\rho\gamma} = -0.18 \pm 0.32^{+0.06}_{-0.05}$

Consistent with SM

- Systematics from resonance modelling and ΔE, m_{ES} and Fisher distributions shape
- Results consistent with Belle [PRL 101, 251601 (2008)]

Conclusions

Conclusions

- Rare B decays are an excellent laboratory for the search for physics beyond the SM
- In the last few years several new measurements from LHC & B-Factories experiments released with impressive experimental precision
- Almost all the results are in agreement with expectations but some tension is present in some sectors: BaBar F_L for $B^+ \to K^{*+} l^+ l^-$ (shown today), $B \to K^{(*)} \mu\mu$ (P5', $BR(B \to K\mu\mu)/BR(B \to Kee)$), (but also $B \to D^{(*)} \tau\nu / B \to D^{(*)} \mu\nu$)

- Strong constraints on NP models from flavor measurements
- Rich program of measurements is expected from LHC/Belle II experiments in the coming years
  - Chances to discover/understand NP in the flavor sector in the near future?

Backup

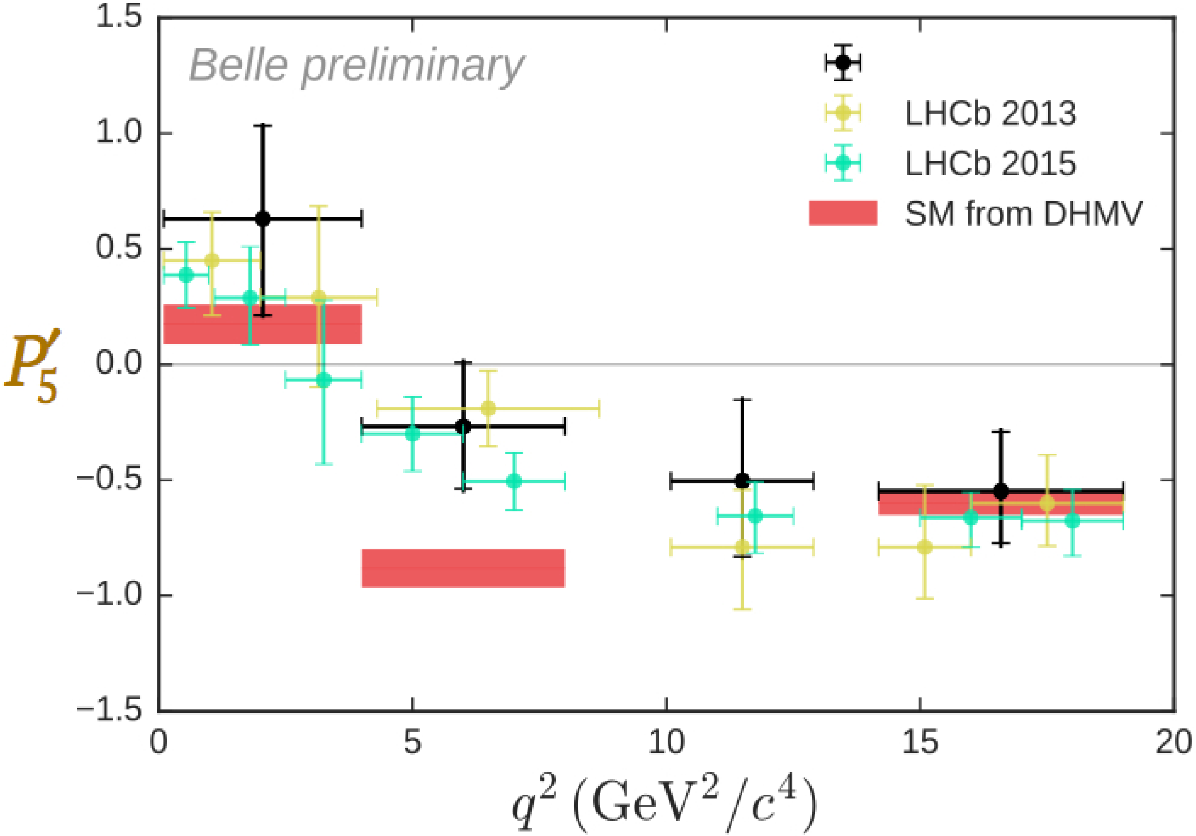
$B \to K^* l^+ l^-$

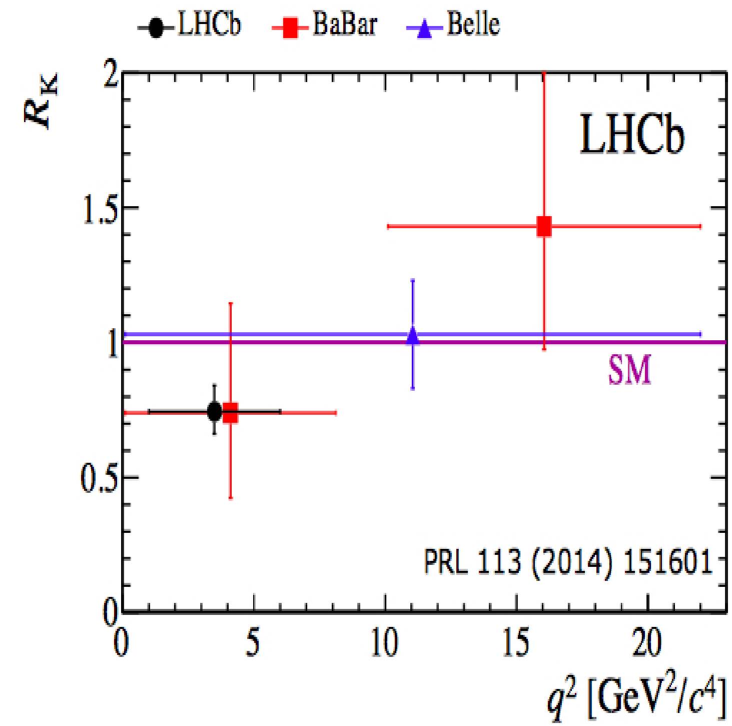
- Event Yields:

Mode	q^2_0	q^2_1	q^2_2	q^2_3	q^2_4	q^2_5
$B \to K^* \ell^+ \ell^-$	40.8 ± 8.4	31.7 ± 7.1	11.9 ± 5.5	21.3 ± 8.5	31.9 ± 9.2	33.2 ± 7.8
$B^+ \to K^{*+} \ell^+ \ell^-$	17.7 ± 5.2	8.7 ± 4.1	3.8 ± 4.0	7.7 ± 5.6	9.0 ± 4.8	9.4 ± 4.2
$B^0 \to K^{*0} \ell^+ \ell^-$	23.1 ± 6.6	22.9 ± 5.8	8.1 ± 3.8	13.7 ± 6.4	22.8 ± 7.8	23.8 ± 6.6

- Systematics:
  - PDF shapes and parameter statistical error
  - F_L statistical error progated in A_{FB} fit
  - Modeling of BKG PDF shape and Signal efficiency
  - Signal crossfeed
  - Fit bias
  - Stability vs cuts

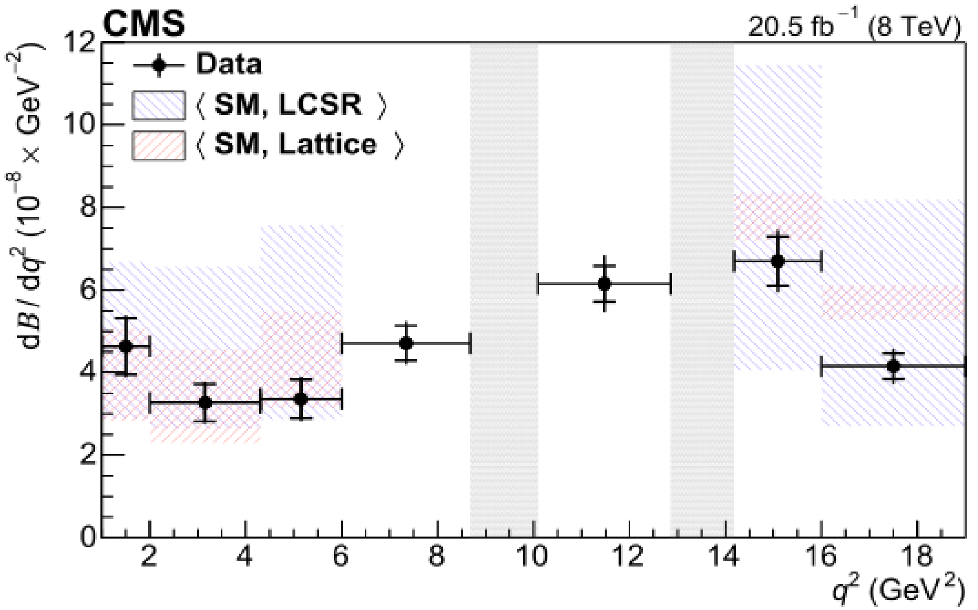
$B \to K^* ll$ Angular Analysis: P5' parameter

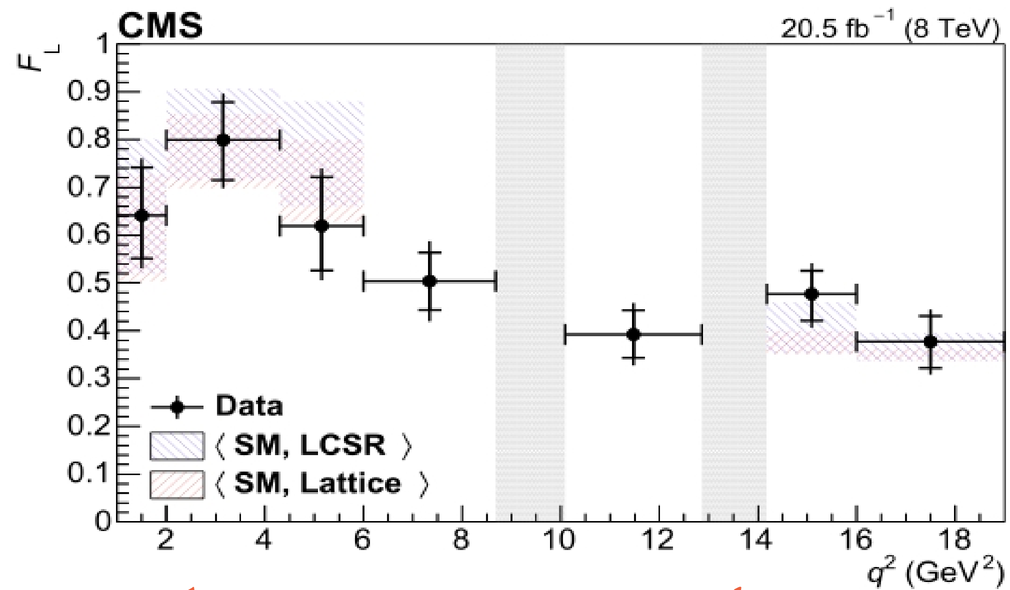


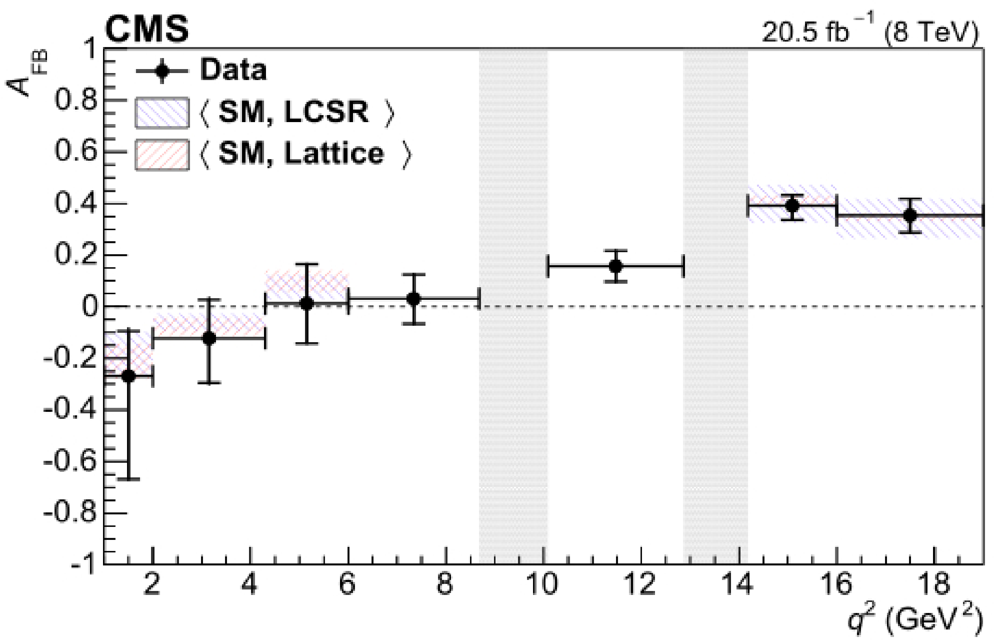


- LHCb full statistics result on P5': discrepancy at 3.4 σ level [JHEP 02, 104 (2016)]
- Belle confirms the tension at 2.1 σ level [arXiv:1604.04042]
- Need to control the charm penguin to disentangle SM from NP in C_7^{eff} and C_9^{eff}

$B \to K^*\mu^+\mu^-$: CMS Results





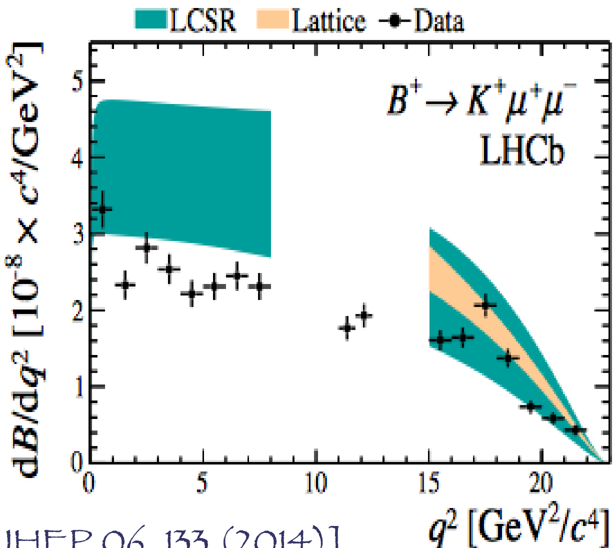


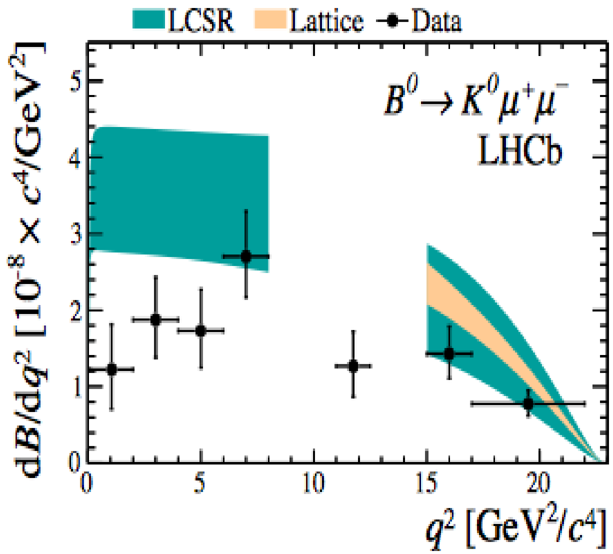
Results consistent with SM

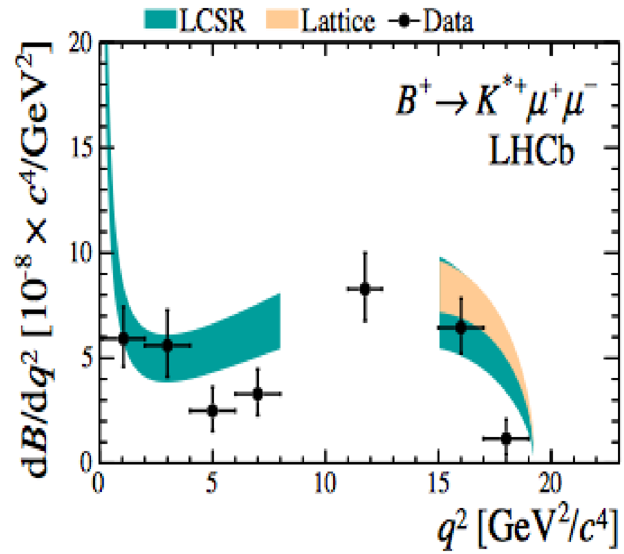
- Systematics from BKG PDF shapes, efficiency, simulation mismodeling and fit bias.
- Theoretical predictions:
  - Light-cone sum rules at low q^2 and extrapolation at high q^2 [JHEP 09 089 (2010), JHEP 02 010 (2013)]
  - Lattice [Phys. Rev. D89 094501 (2014)]

$B \to K^* ll$ Related quantities

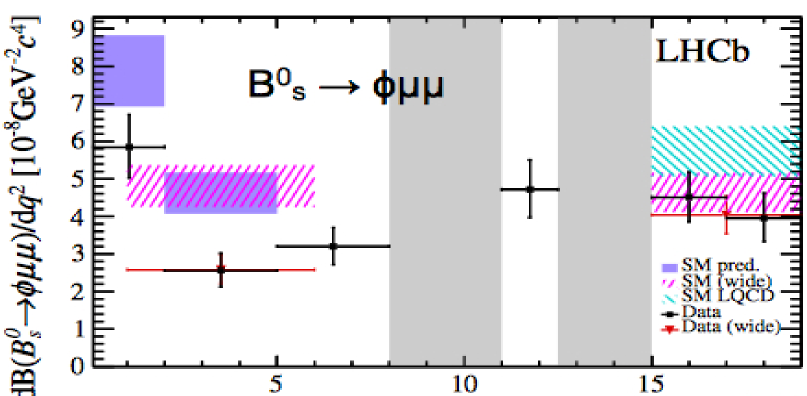
- $K^* \mu^+\mu^-$ tension motivates studies of differential BRs



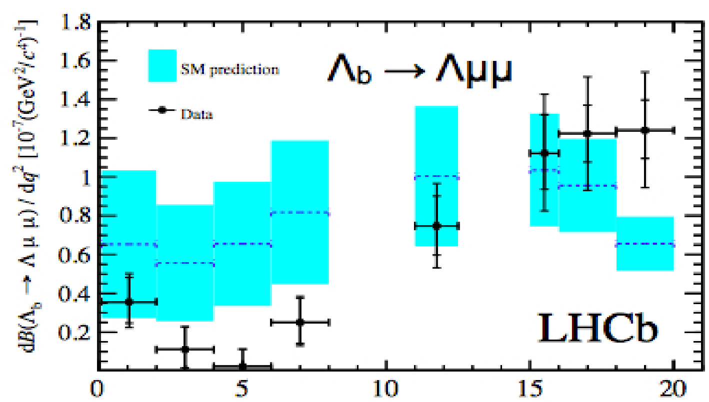




[JHEP 06, 133 (2014)]



[JHEP 09, 179 (2015)]

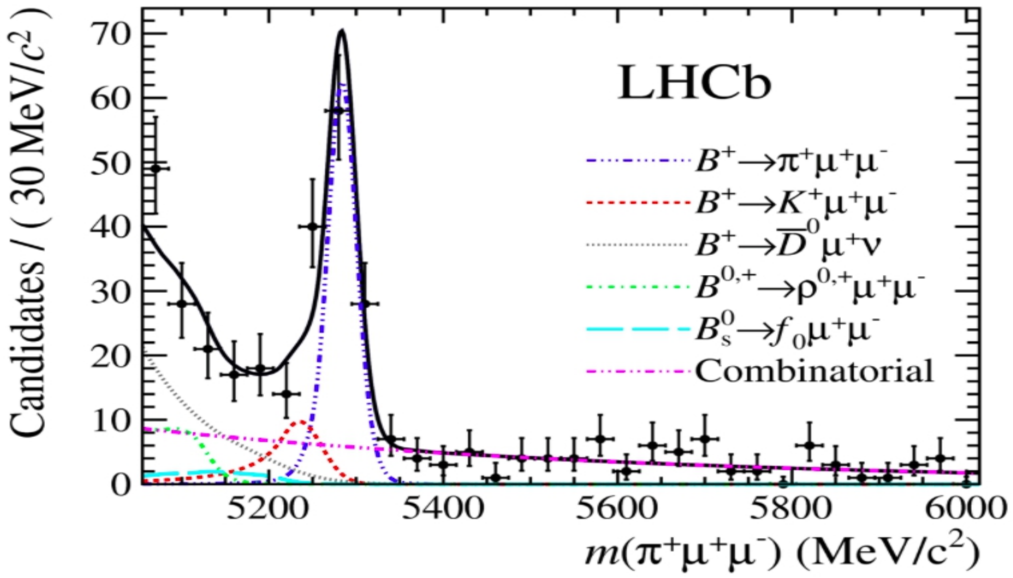


[JHEP 06, 115 (2015)]

- All the results are "consistent" with SM at <2.2 σ
- But all of them are lower than the predictions…

$B \to \pi \, l^+ l^-$

- Measurements of related $b \to d\mu\mu$ channels very useful to reveal information on Minimal Flavor Violation nature of New Physics



LHCb [JHEP 10, 034 (2015)]:

$BR(B^+ \to \pi^+\mu^+\mu^-) = (1.83 \pm 0.24 \pm 0.05) 10^{-8}$ in agreement with MFV

$BR(B^+ \to \pi^+\mu^+\mu^-)/BR(B^+ \to K^+\mu^+\mu^-) = 0.037 \pm 0.008 \pm 0.001$

$|V_{td}|/|V_{ts}| = 0.24^{+0.05}_{-0.04}$ in agreement with box processes $(\Delta m_s/\Delta m_d)$ results

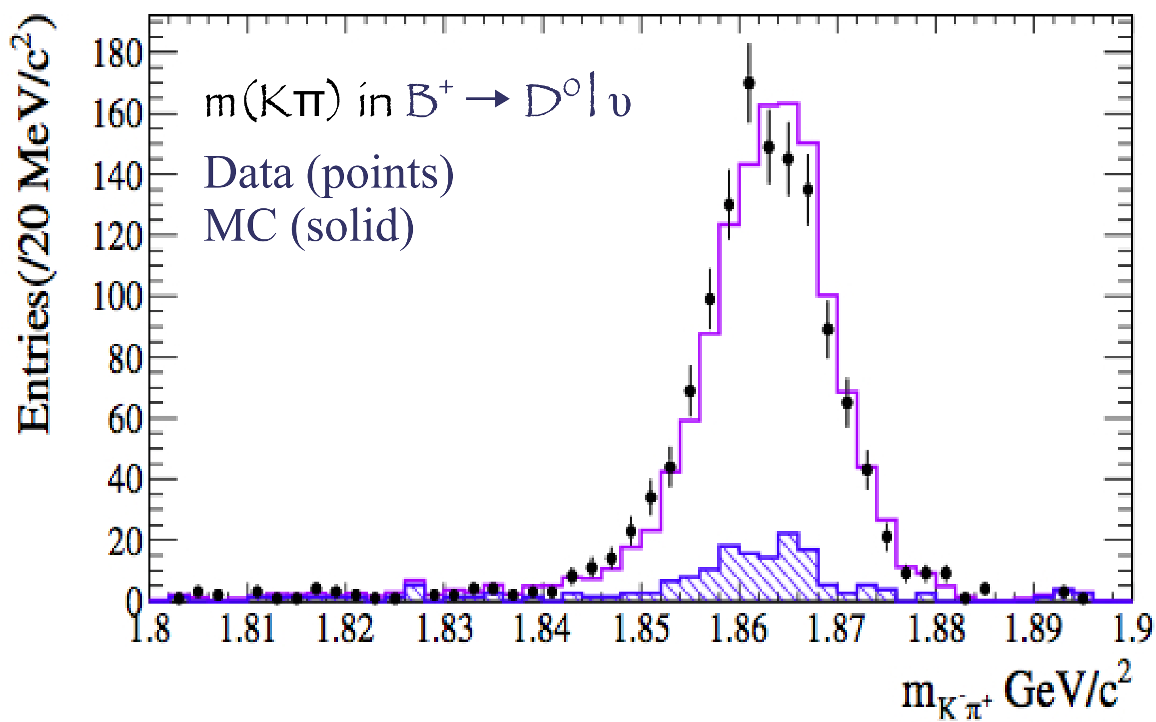
$B^+ \rightarrow K^+\tau^+\tau^-$

- Signal efficiencies and expected Peaking BKG events (92%) from simulation corrected according to Data/MC ratio before NN cut:

$$\left(\frac{N^{Data}}{N^{MC}}\right)_{BKG} = 0.913 \pm 0.020$$

- Expected combinatorial BKG events (8%) from data mEs Side Band

- Data/MC B_{tag} yields cross-checked using $B^+ \rightarrow D^0 l \nu$, $D^0 \rightarrow K\pi$ (before NN cut)



$B^+ \rightarrow K^+\tau^+\tau^-$

- Cross checks to understand the excess:
  - Excess present also in the B_{tag} side band
  - Discriminating variable in the NN:
    - $s_B = \frac{q^2}{m_B^2} = \frac{(p_{B_{\rm sig}} - p_K)^2}{m_B^2}$, $m(K^+l^-)$, K-l angle in the di-tau frame, lepton momentum, missing energy, e.m. energy not associated to B_{tag}
    - All of them compatible with BKG statistical fluctuation

$B^+ \to K^+\tau^+\tau^-$

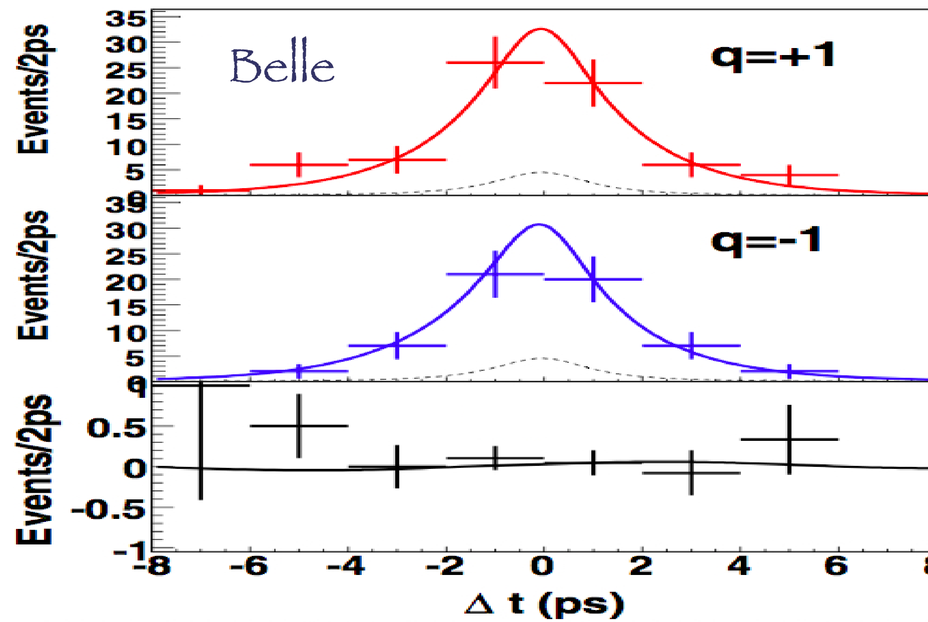
- Systematics:
  - Theory (signal efficiency): 3% from shape of the q^2 distribution (Lattice QCD vs light cone sum rules)
  - Btag Yield: 1.5% from MC correction using m_{ES} sideband
  - PID: 5% from Data/MC comparison
  - π^0 Veto: 3%
  - NN cut: 2.6% from Data/MC checked on $B^+ \to D^0 l \nu$ ($D^0 \to K\pi$)

Measurement of A_{CP} in $B^0 \to K_S \rho \gamma$

Belle [PRL 101, 251601 (2008)]:

$S_{K_S\rho\gamma} = 0.11 \pm 0.33^{+0.05}_{-0.09}$

$A_{CP}(\text{direct}) = 0.05 \pm 0.18 \pm 0.06$

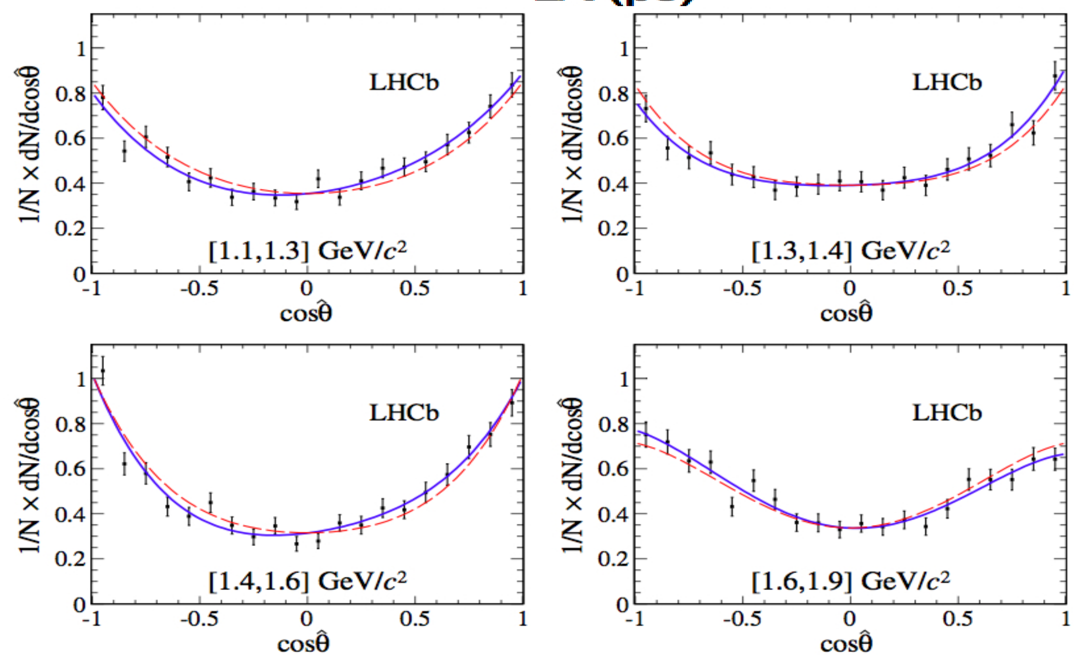


LHCb [PRL 112, 161901 (2014)]:

$$\mathcal{A}_{ud} \equiv \frac{\int_0^1 d\cos\theta \frac{d\Gamma}{d\cos\theta} - \int_{-1}^0 d\cos\theta \frac{d\Gamma}{d\cos\theta}}{\int_{-1}^1 d\cos\theta \frac{d\Gamma}{d\cos\theta}}$$

θ=angle between photon and Kππ plane normal

$m_{K\pi\pi}$	[1.1,1.3]	[1.3,1.4]	[1.4,1.6]	[1.6,1.9]
$\mathcal{A}_{ud}$	6.9 ± 1.7	4.9 ± 2.0	5.6 ± 1.8	-4.5 ± 1.9



5.2 σ significance for nonzero up-down asymmetry

First measurement