Rare decays at BaBar and Belle

Tim Gershon,
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on behalf of the BaBar & Belle collaborations

CKM2018, 17th September 2018

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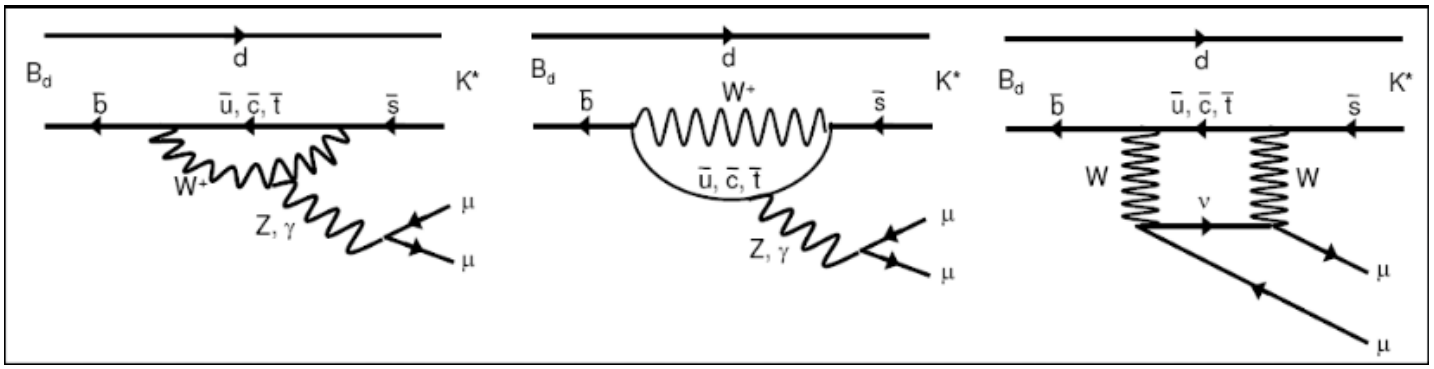
Outline

- Flavour-changing neutral current B decays are sensitive to physics beyond the Standard Model
- Various observables can be constructed to test the SM: rates, asymmetries (kinematic, isospin, CP)
  - Results can be used to constrain Wilson coefficients
  - Null tests, such as lepton flavour violation, also possible
- B factories have produced many results in this area
  - Unique datasets which continue to be mined!



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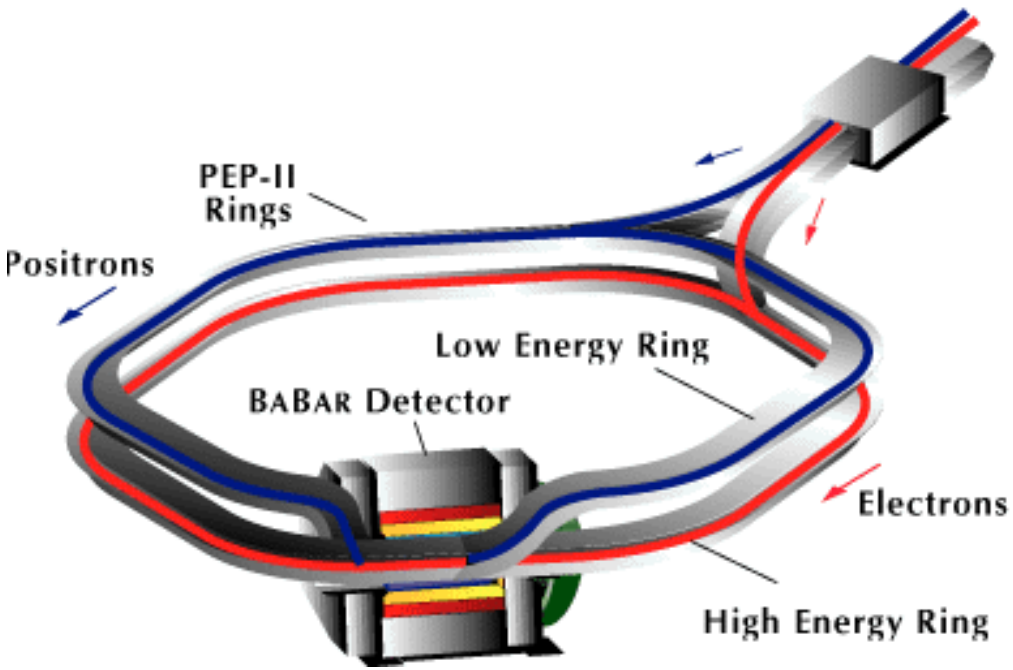
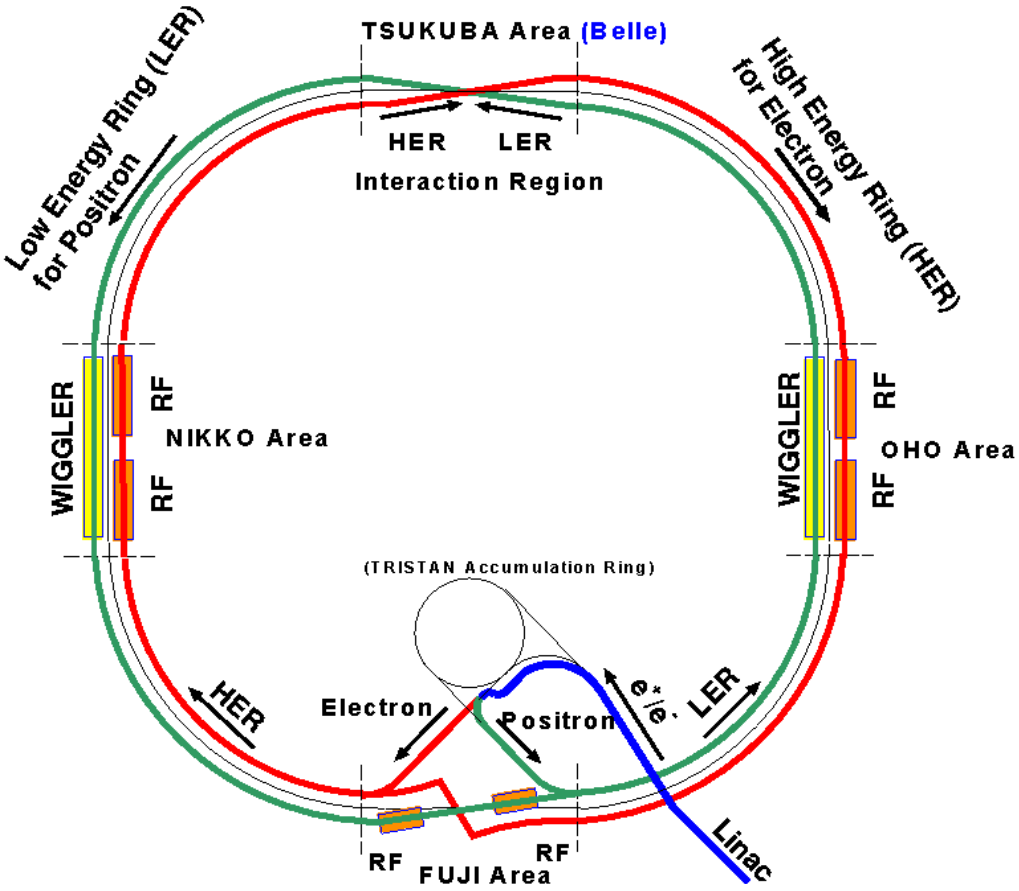
Asymmetric B Factories

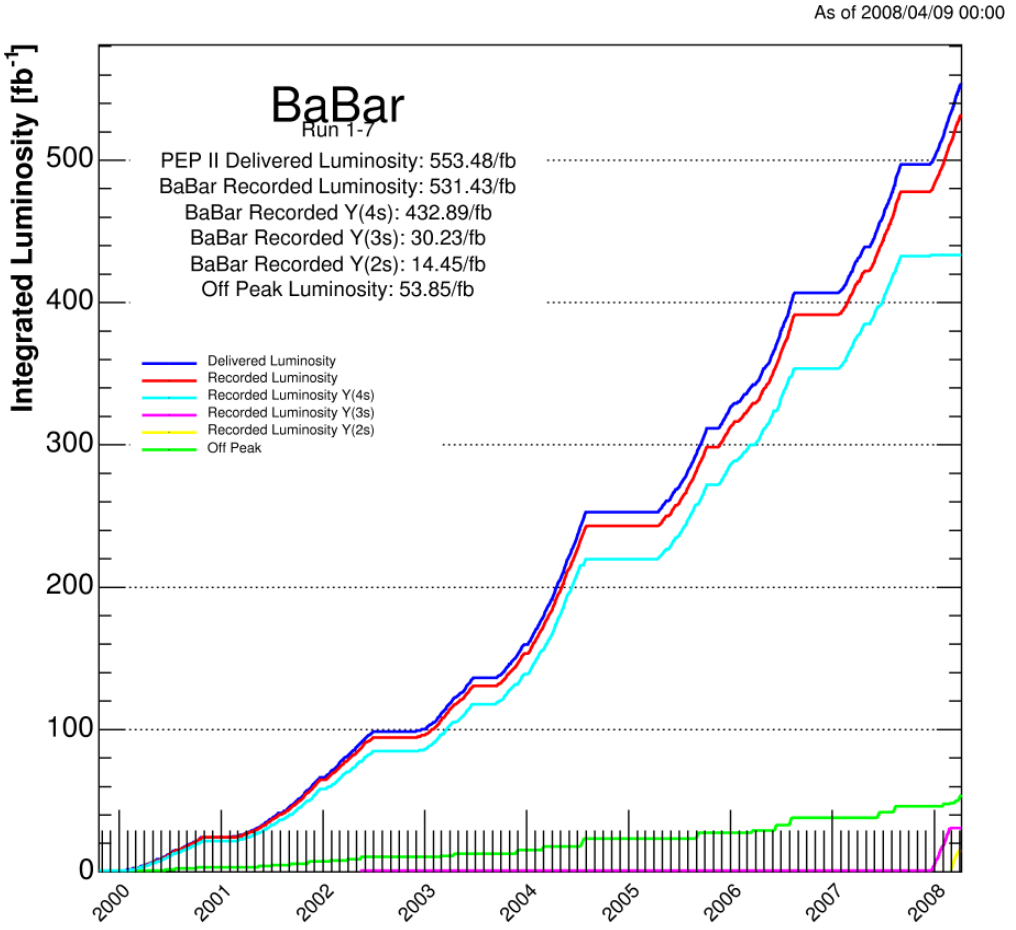
PEPII at SLAC
9.0 GeV e^- on 3.1 GeV e^+

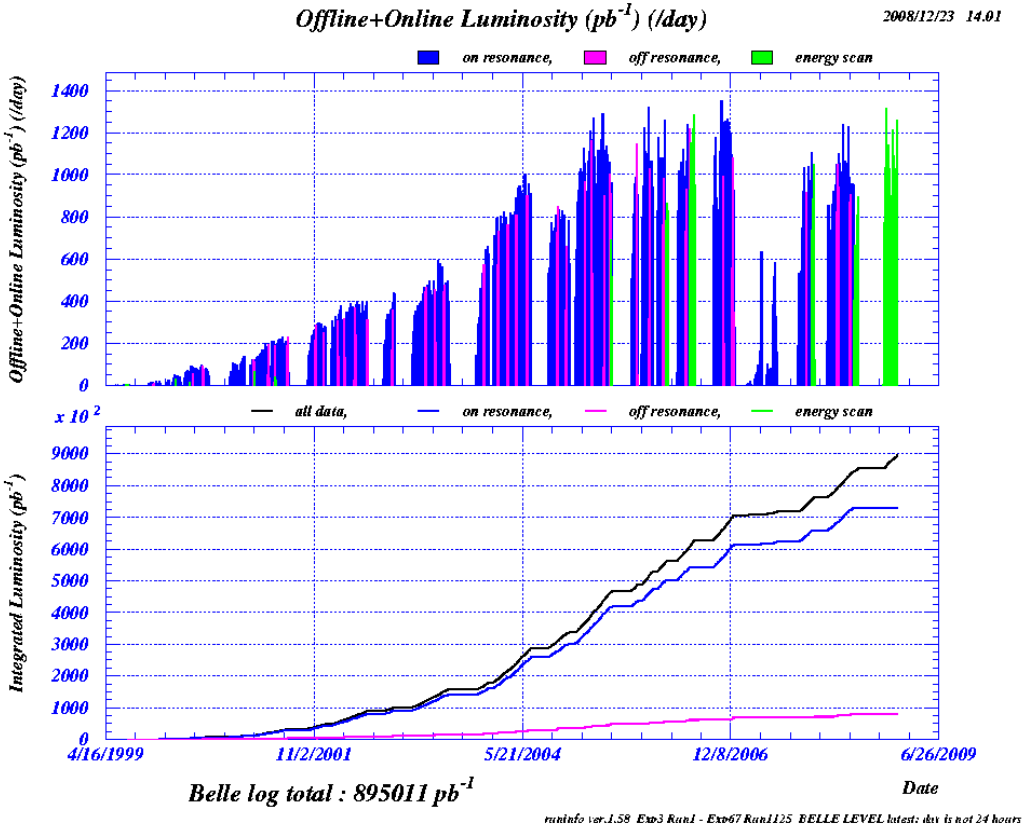
KEKB at KEK
8.0 GeV e^- on 3.5 GeV e^+





B factories – world record luminosities





~ 433/fb on Y(4S)

~ 711/fb on Y(4S)

Total over 10^9 $B\bar{B}$ pairs recorded
plus special runs at other energies

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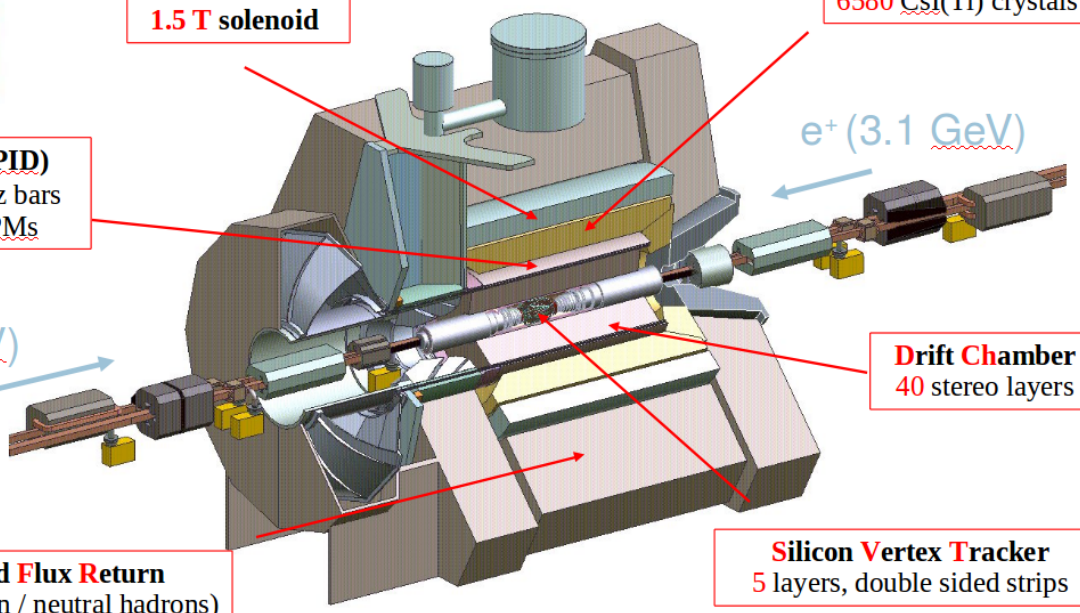
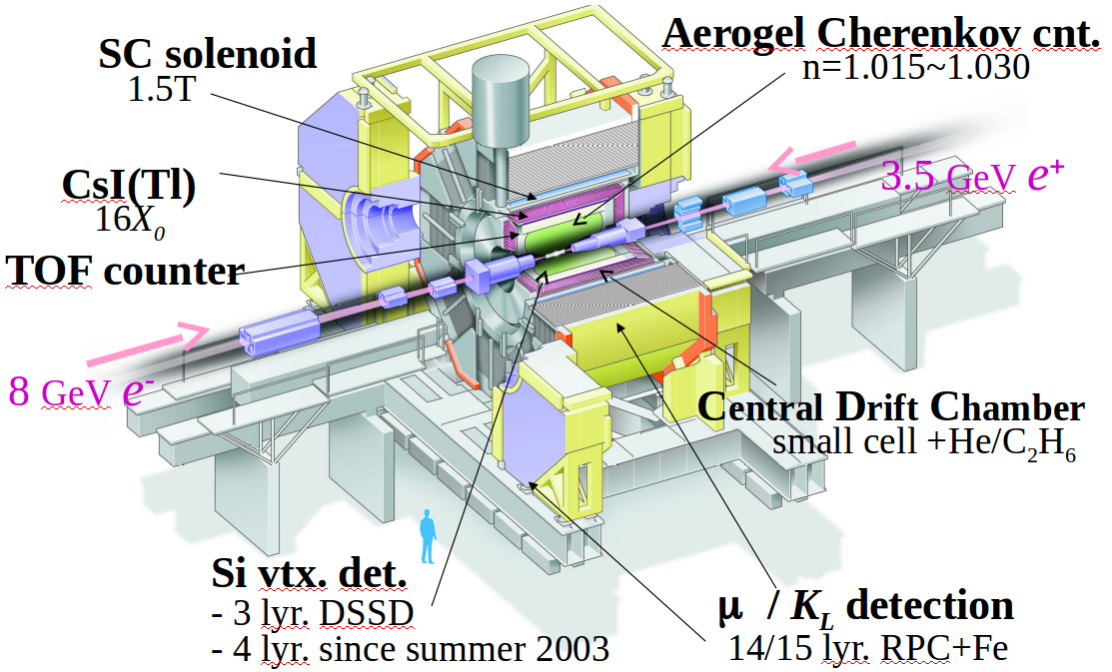
BaBar and Belle detectors





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PRL 119 (2017) 191802

Isospin & ΔA_{CP} asymmetries in $B \rightarrow K^*\gamma$

- $b \rightarrow s\gamma$ transitions excellent probe for physics beyond the Standard Model
  - strong history of measurements of rates and asymmetries from 1st (CLEO, ARGUS) and 2nd (BaBar, Belle) generation B factories
  - but still some observables not fully studied
    - e.g. isospin rate asymmetry Δ_{0+} and ΔA_{CP}
  - Reconstruct K^* as $K^+\pi^-$, $K^+\pi^0$, $K_S\pi^+$, $K_S\pi^0$
    - $m(K\pi) < 2.0$ GeV
    - $-0.2 < \Delta E < 0.1$ GeV requirement
    - MVA to reject $q\bar{q}$ background

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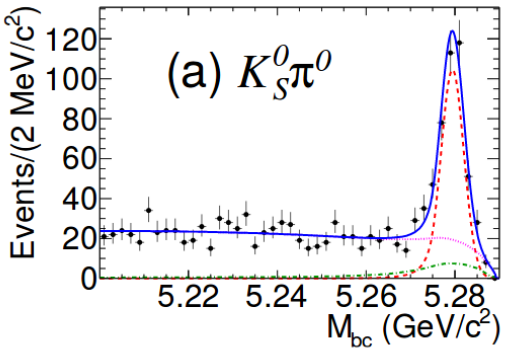
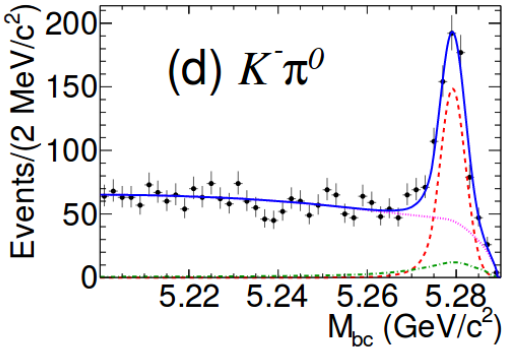
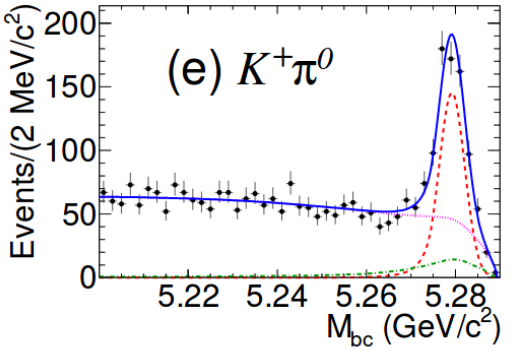
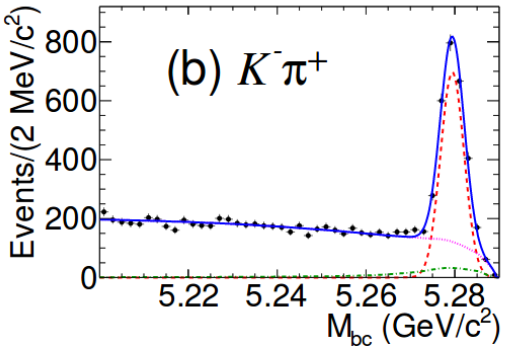
PRL 119 (2017) 191802

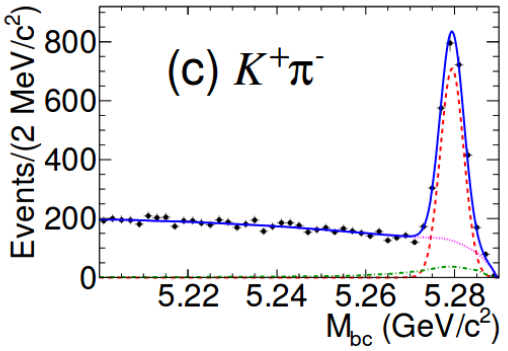
Isospin & ΔA_{CP} asymmetries in B → K*γ

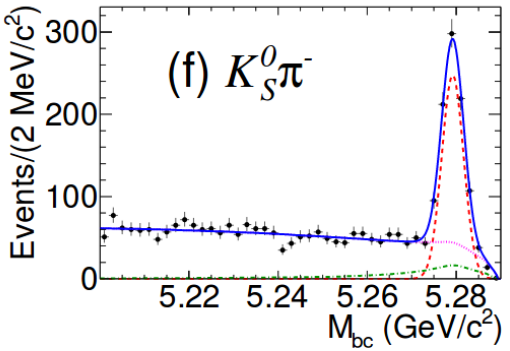


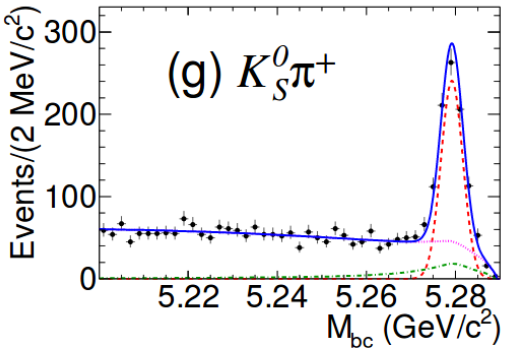












signal
$B\bar{B}$ background
total background

Mode	$N_S^{\bar{B}}$	N_S^B	ϵ [%]
$B^0 \to K^0_S\pi^0\gamma$	$349 \pm 23 \pm 15$		1.16 ± 0.04
$B^0 \to K^+\pi^-\gamma$	$2295 \pm 56 \pm 27$	$2339 \pm 56 \pm 30$	15.61 ± 0.49
$B^+ \to K^+\pi^0\gamma$	$572 \pm 32 \pm 12$	$562 \pm 31 \pm 11$	3.66 ± 0.12
$B^+ \to K^0_S\pi^+\gamma$	$745 \pm 32 \pm 8$	$721 \pm 32 \pm 9$	5.01 ± 0.14

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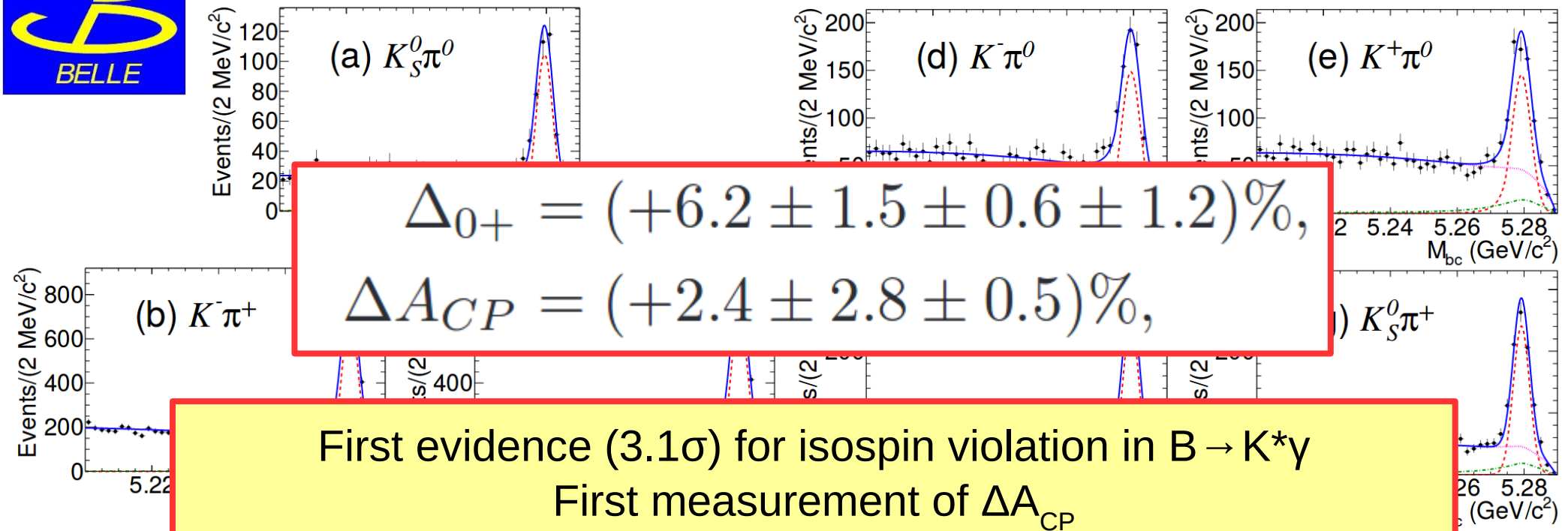
PRL 119 (2017) 191802

Isospin & ΔA_{CP} asymmetries in $B \to K^*\gamma$



$$\Delta_{0+} = (+6.2 \pm 1.5 \pm 0.6 \pm 1.2)\%,$$
$$\Delta A_{CP} = (+2.4 \pm 2.8 \pm 0.5)\%,$$

First evidence (3.1σ) for isospin violation in $B \to K^*\gamma$
First measurement of ΔA_{CP}
(Other results consistent with previous measurements)

$B\bar{B}$ background
total background

Mode	N_S	N_S	$\mathcal{C}$ [%]
$B^0 \to K^0_S\pi^0\gamma$	$349 \pm 23 \pm 15$		1.16 ± 0.04
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arXiv:1807.04236

Isospin & ΔA_{CP} asymmetries in $B \to X_s\gamma$

- Rates and CP asymmetries for $\overline{B}^0 \to X_s^0\gamma$ and $B^- \to X_s^-\gamma$ should be almost identifical in the Standard Model [PRL 106 (2011) 141801]
  - excellent null tests
  - measurement of Δ_{0-} can reduce theory uncertainty on $\mathcal{B}(B \to X_s\gamma)$
- Use "semi-inclusive" (i.e. sum of exclusive) technique
  - many modes studied
    - B+, B^0 and $\overline{B}^0$ flavour-non-specific (fns; *)
    - Expect 56% (74% with $K^0 \to K_S$) of total X_s rate
  - require
    - $m(X_s) < 2.8$ GeV + D veto
    - mode-dependent ΔE requirement
    - MVA to reject $q\overline{q}$ background

Mode ID	Final state	Mode ID	Final state
1	$K^+\pi^-$	20	$K^0_S\pi^+\pi^0\pi^0$
2	$K^0_S\pi^+$	21	$K^+\pi^+\pi^-\pi^0\pi^0$
3	$K^+\pi^0$	22*	$K^0_S\pi^+\pi^-\pi^0\pi^0$
4*	$K^0_S\pi^0$	23	$K^+\eta$
5	$K^+\pi^+\pi^-$	24*	$K^0_S\eta$
6*	$K^0_S\pi^+\pi^-$	25	$K^+\eta\pi^-$
7	$K^+\pi^-\pi^0$	26	$K^0_S\eta\pi^+$
8	$K^0_S\pi^+\pi^0$	27	$K^+\eta\pi^0$
9	$K^+\pi^+\pi^-\pi^-$	28*	$K^0_S\eta\pi^0$
10	$K^0_S\pi^+\pi^+\pi^-$	29	$K^+\eta\pi^+\pi^-$
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*	$K^+K^-K^0_S\pi^0$

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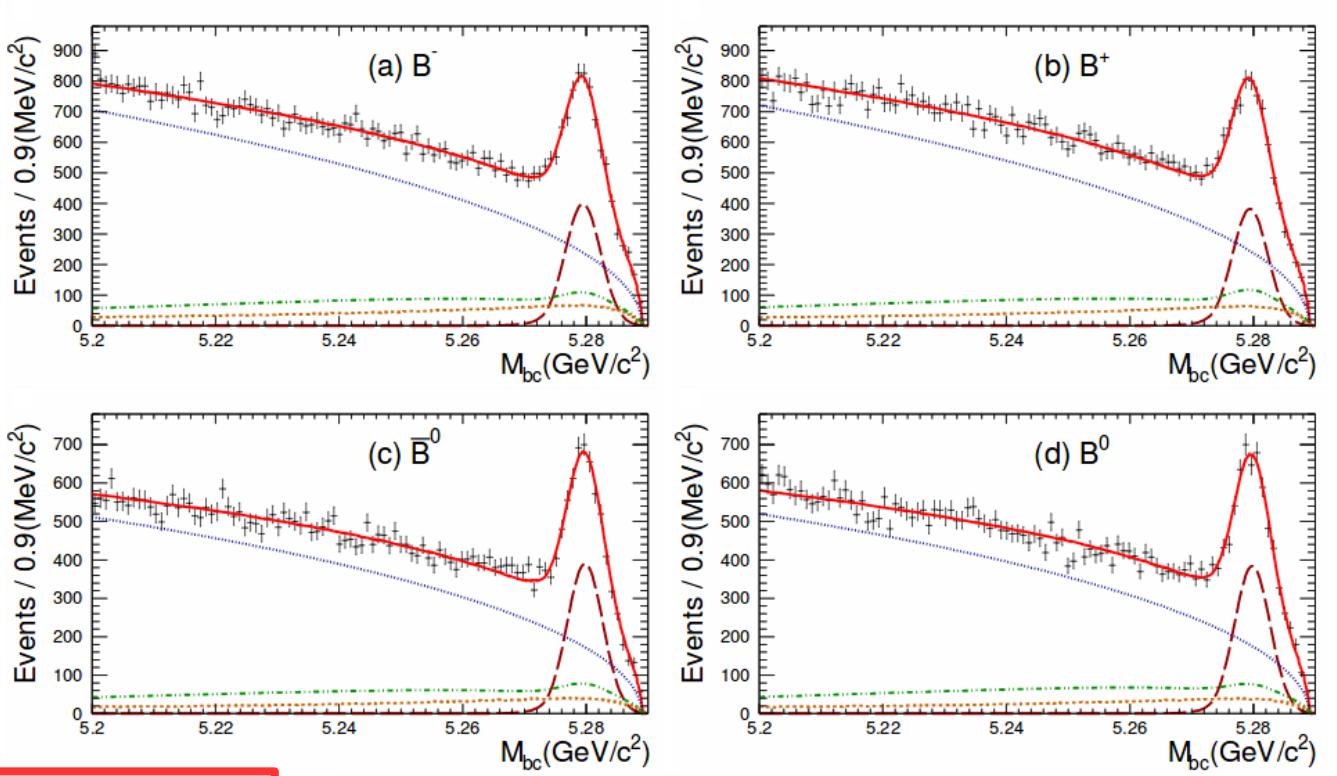
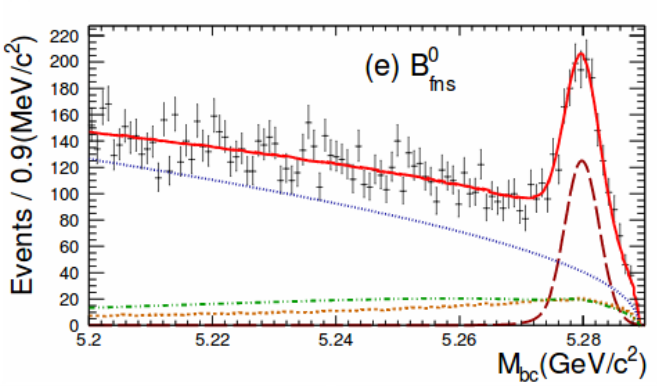
BELLE

arXiv:1807.04236

Isospin & ΔA_{CP} asymmetries in $B \to X_s \gamma$





signal
$q\bar{q}$ continuum
$B\bar{B}$ background
cross-feed

Mode	N_S	ϵ [%]
B^-	3235 ± 82	2.22 ± 0.12
B^+	3105 ± 83	2.22 ± 0.12
$\bar{B}^0$	3165 ± 78	2.44 ± 0.14
B^0	3116 ± 78	2.44 ± 0.14
$B_{\rm fns}$	984 ± 42	0.381 ± 0.023

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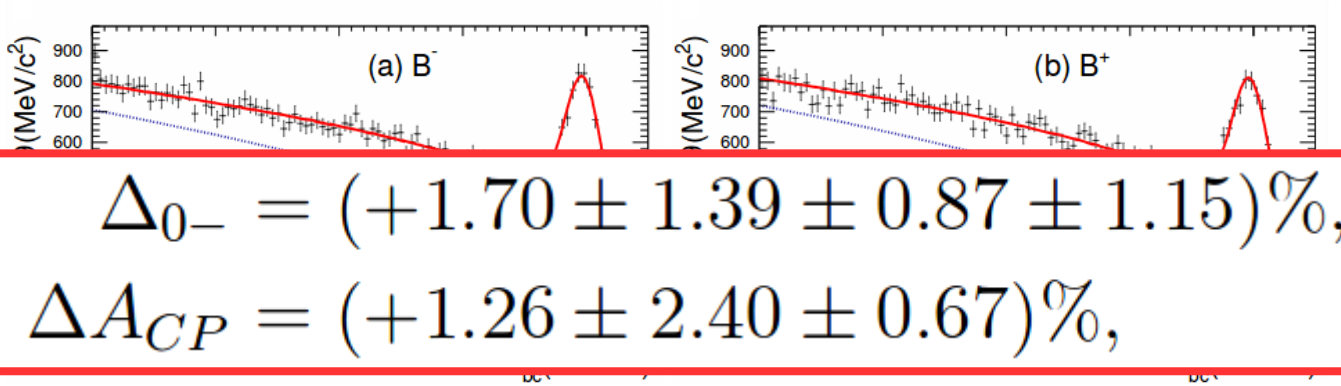
arXiv:1807.04236

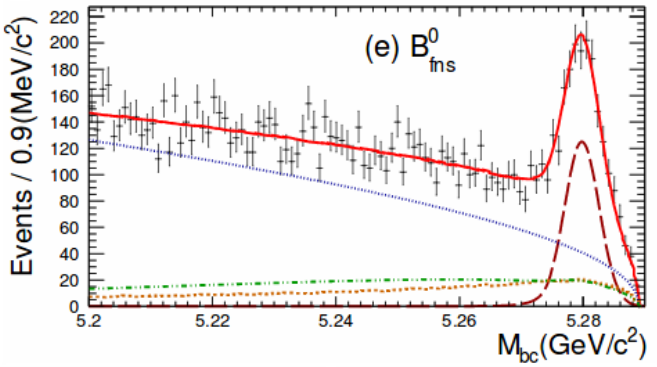
Isospin & ΔA_{CP} asymmetries in $B \to X_s \gamma$



$$\Delta_{0-} = (+1.70 \pm 1.39 \pm 0.87 \pm 1.15)\%,$$
$$\Delta A_{CP} = (+1.26 \pm 2.40 \pm 0.67)\%,$$

Results consistent with zero, with SM, and with previous BaBar results (PR D72 (2005) 052004, PR D90 (2014) 092001)

signal
$q\bar{q}$ continuum
$B\bar{B}$ background
cross-feed



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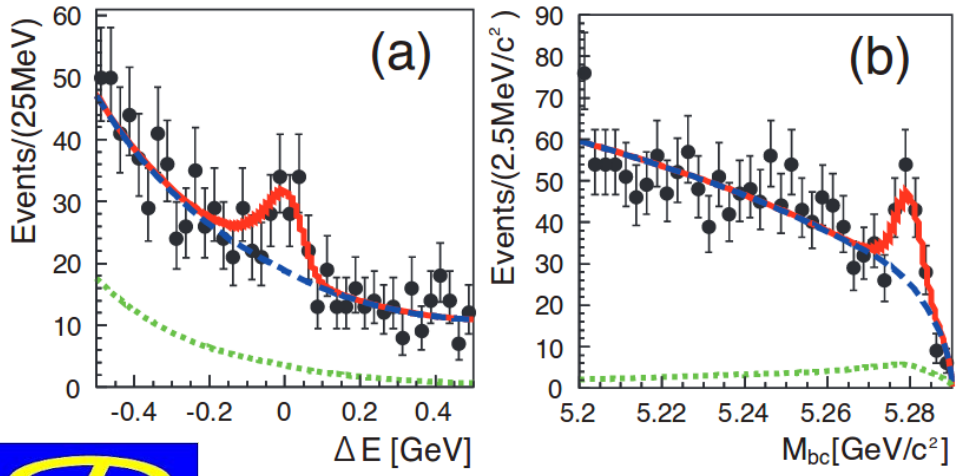
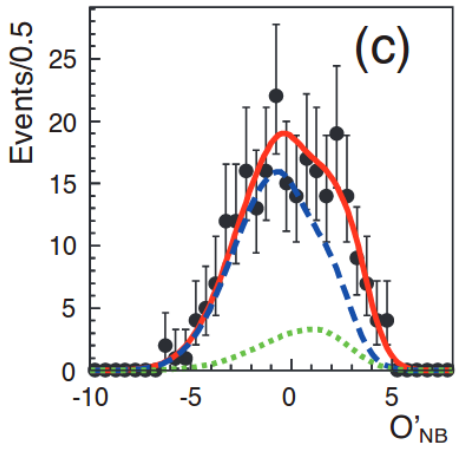
PR D97 (2018) 092003

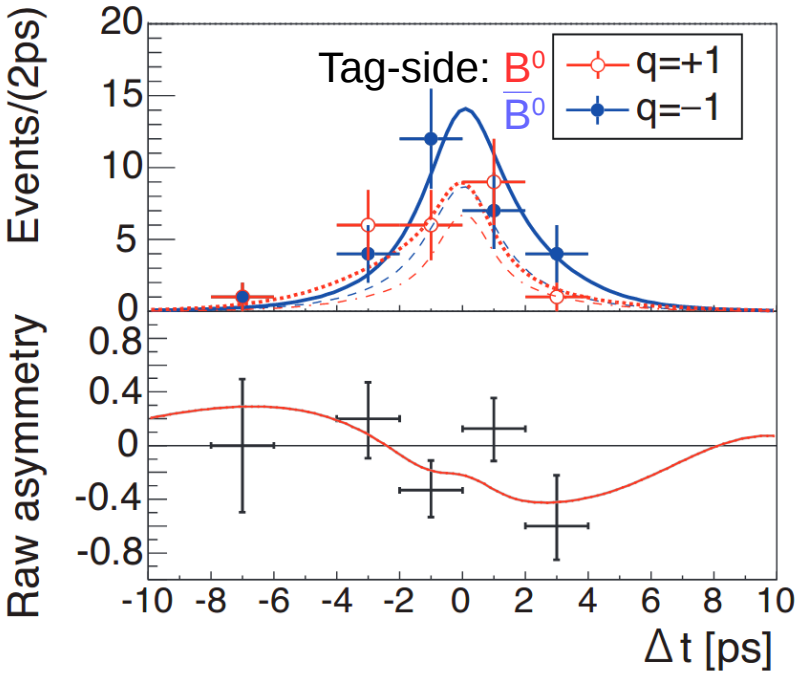
Decay-time-dependent CP asymmetry in $B^0 \to K_S\eta\gamma$

Strong polarisation of emitted γ in Standard Model (V–A weak interaction)
Expect very small decay-time-dependent CP violation (S)

Signal yield: 92 ± 15



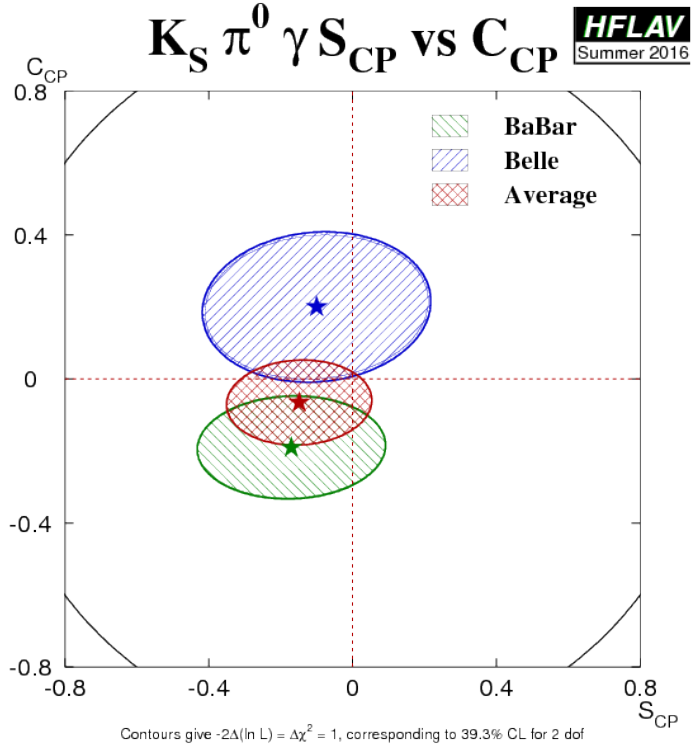


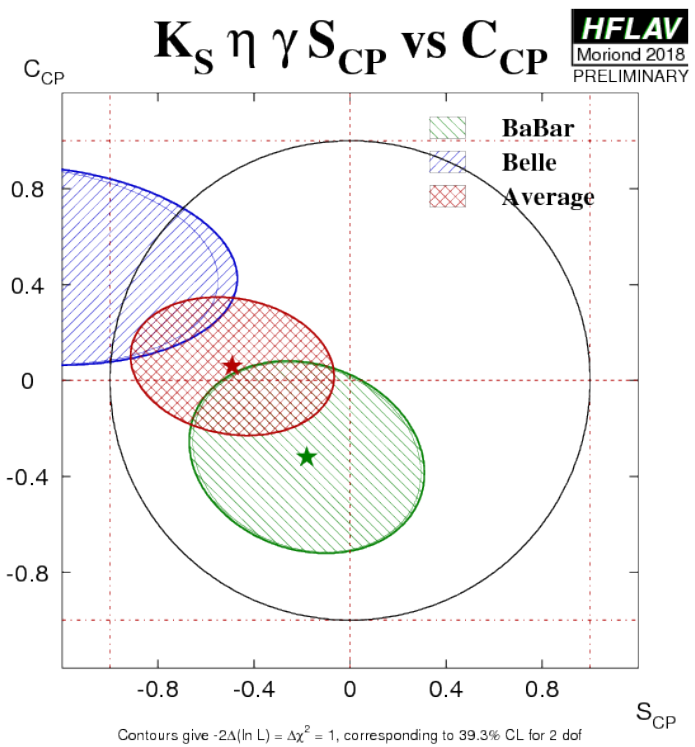


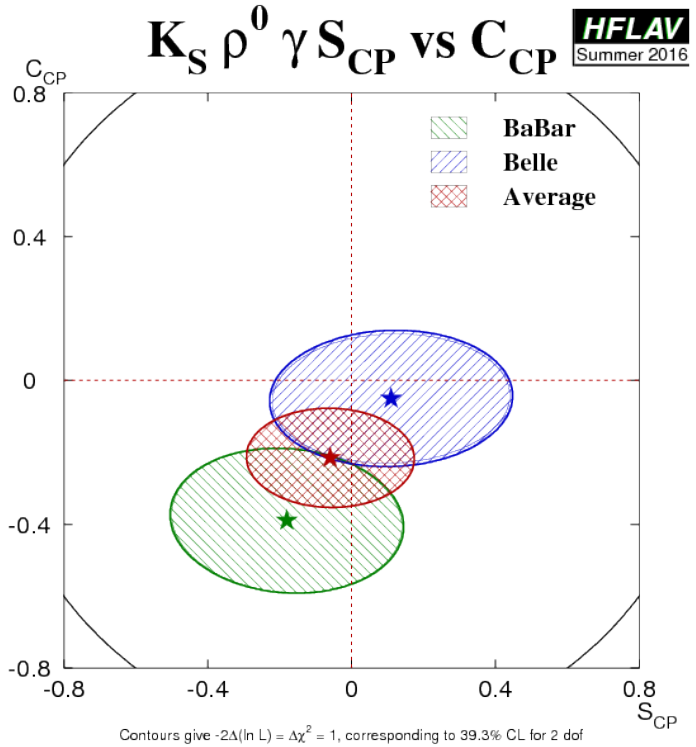
$$\mathcal{S} = -1.32 \pm 0.77(\text{stat.}) \pm 0.36(\text{syst.}),$$
$$\mathcal{A} = -0.48 \pm 0.41(\text{stat.}) \pm 0.07(\text{syst.})$$

$B\bar{B}$ background
total background

Decay-time-dependent CP asymmetry in b→sγ







All results consistent with SM
Still much room for improved sensitivity

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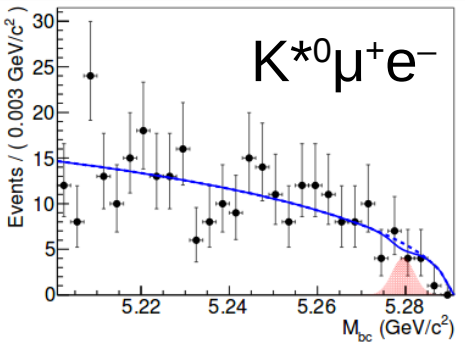
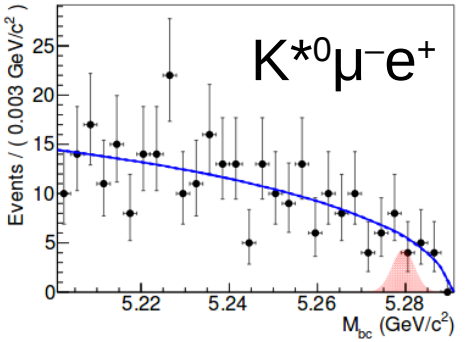
arXiv:1807.03267

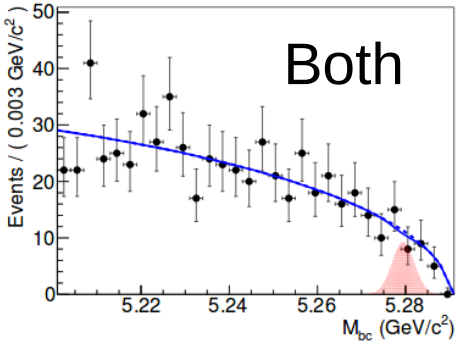
Search for $B^0 \to K^{*0}\mu e$

- Possible signals of lepton universality violation have become a hot topic
  - R(K$^{(*)}$), R(D$^{(*)}$)
- Models predicting LUV generally also predict LFV

- Require
  - → $|m(K\pi)-m_{K^*(892)}| < 0.1$ GeV
  - → $|\Delta E| < 0.025$ GeV
  - → $q\bar{q}$ and $B\bar{B}$ backgrounds suppressed with MVAs
  - → veto misreconstructed $K^{*0}J/\psi$







No signals – most stringent limits to date

Mode	ε (%)	$N_{\rm sig}$	$N_{\rm sig}^{\rm UL}$	$\mathcal{B}^{\rm UL}$ (10^{-7})
$B^0 \to K^{*0}\mu^+e^-$	8.8	$-1.5^{+4.7}_{-4.1}$	5.2	1.2
$B^0 \to K^{*0}\mu^-e^+$	9.3	$0.40^{+4.8}_{-4.5}$	7.4	1.6
$B^0 \to K^{*0}\mu^\pm e^\mp$ (combined)	9.0	$-1.18^{+6.8}_{-6.2}$	8.0	1.8

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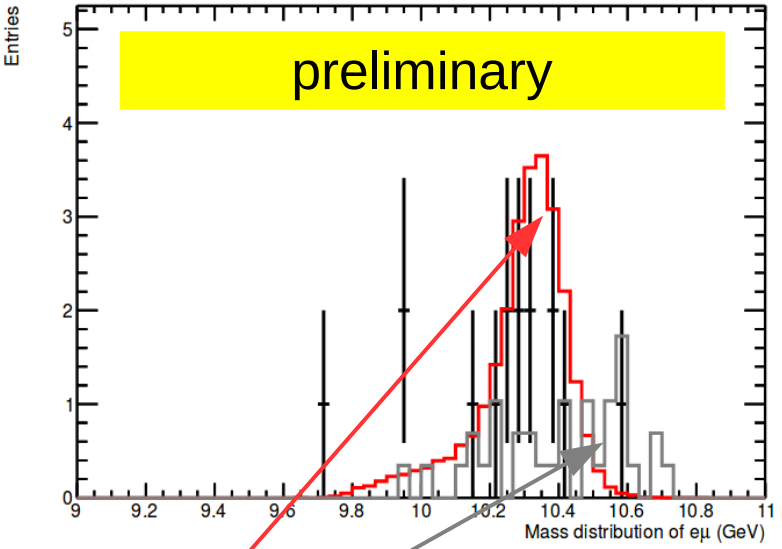
BaBar preliminary

Search for Y(3S)→μe

- Exploit the 27 fb^{-1} data sample collected by BaBar at the Y(3S) resonance
  - corresponds to $(117.7 \pm 1.2) \times 10^6$ Y(3S) produced
- Allows clean search for Y(3S)→μe
  - Two tracks only
    - Must be back-to-back, each with ½ total beam energy
  - Main background from $e^+e^- \to \mu^+\mu^-$ with μ misID or decay in flight

- After all selection criteria, expect 12.2 ± 2.3 background events
  - Estimated from Y(4S) sample
- Observe 15 candidates
- $B(Y(3S) \to \mu e) < 3.6 \times 10^{-7}$ @ 90% CL
  - First result on this decay mode



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arXiv:1808.09680

Observation of $D^0 \to K^-\pi^+e^+e^-$

Also of interest to search for lepton universality violation in charm decays

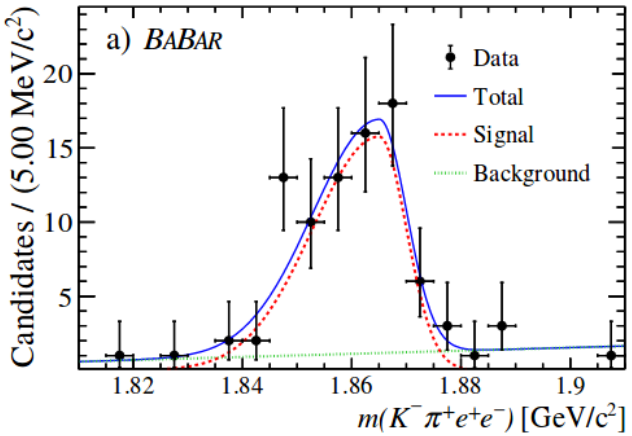
LHCb have recently observed $D^0 \to K^-\pi^+\mu^+\mu^-$ (PL B757 (2016) 558)

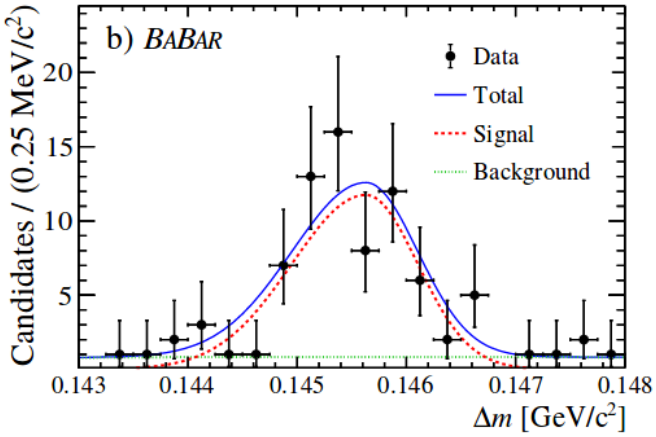
→ look for electron counterpart

- select $D^{*+} \to D^0\pi^+$ to remove background
- use $D^0 \to K^-\pi^+\pi^+\pi^-$ for normalisation
- select ρ-ω region
  - $0.675 < m(e^+e^-) < 0.875$ GeV (expected to be dominant)
- signal yield: 68 ± 9

$B(D^0 \to K^-\pi^+e^+e^-) = (4.0 \pm 0.5 \pm 0.2 \pm 0.1) \times 10^{-6}$

Consistent with LHCb $K^-\pi^+\mu^+\mu^-$ result & SM expectation





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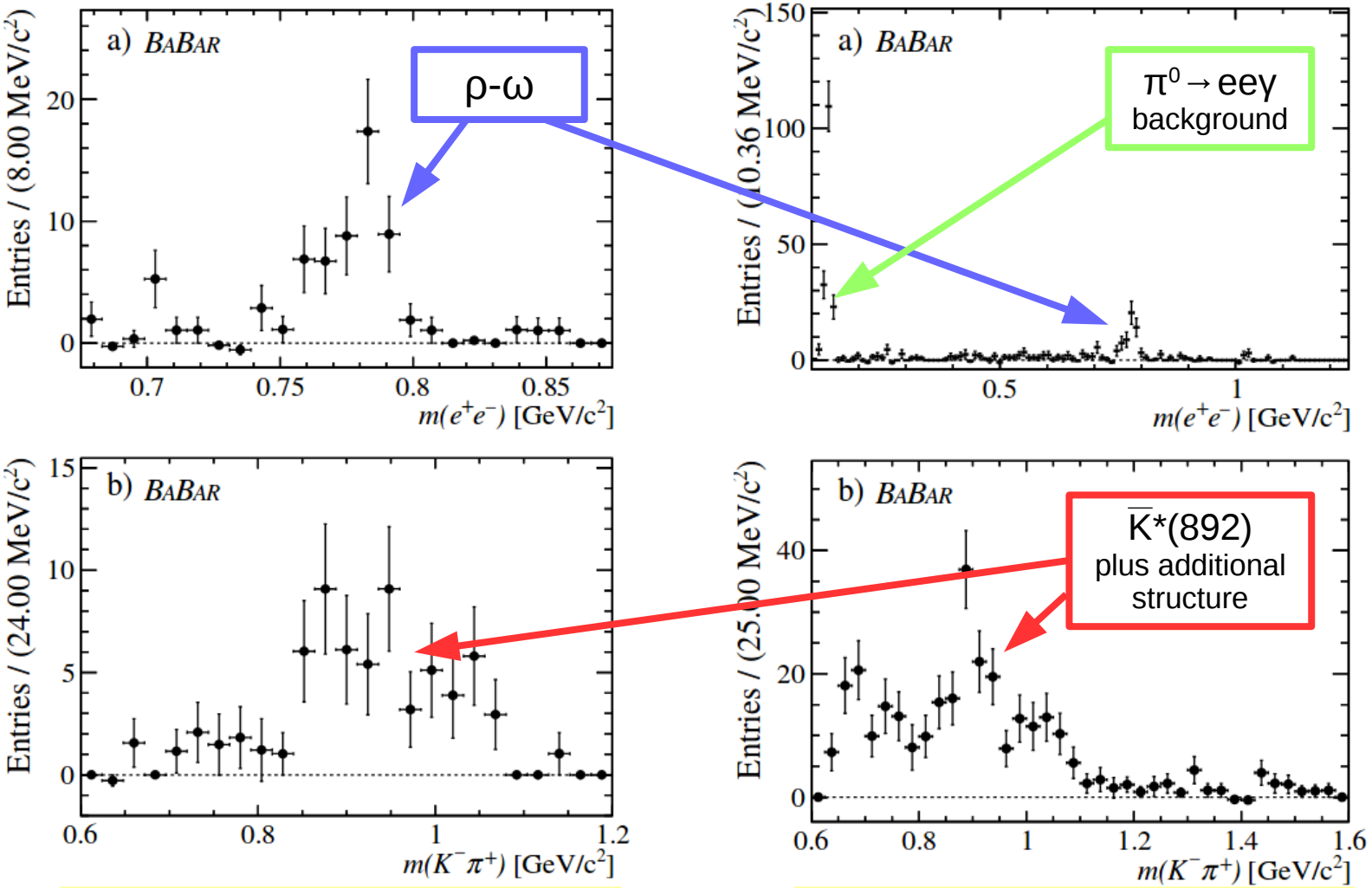
arXiv:1808.09680

Observation of $D^0 \to K^-\pi^+e^+e^-$

Check projections using sPlot background-subtraction technique



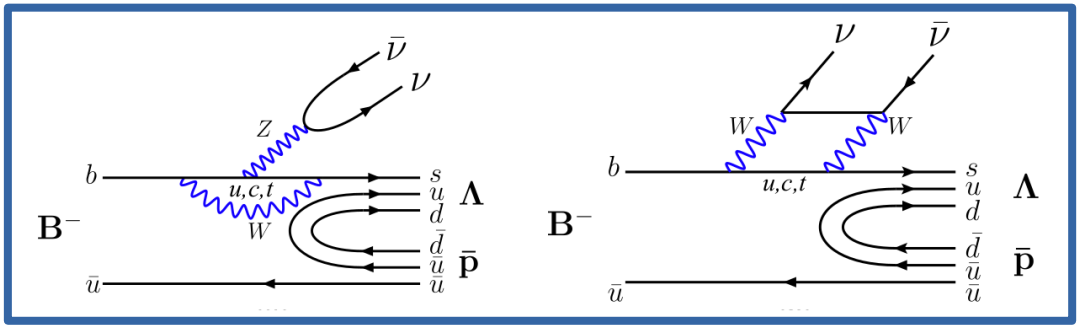
0.675 < m(e⁺e⁻) < 0.875 GeV

0.1 GeV < m(e⁺e⁻)

BaBar preliminary

Search for $B^- \to \Lambda \bar{p} \nu \bar{\nu}$

- FCNC processes with $\nu\bar{\nu}$ pairs theoretically clean
  - only Z penguin and W loop diagrams
  - no γ penguin, no charm loops, no resonances
- Experimentally highly challenging
  - signature of baryons in final state can help reduce background
  - SM prediction: $\mathcal{B}(B^- \to \Lambda \bar{p} \nu \bar{\nu}) = (7.9 \pm 1.9) \times 10^{-7}$ [PR D85 (2012) 094019]
- Exploit $\Upsilon(4S) \to B_{tag} B_{sig}$
  - B_{tag} : hadronic decay modes
  - MVA to reduce $q\bar{q}$ background
  - minimal extra energy
  - residual background level estimated from sidebands + MC



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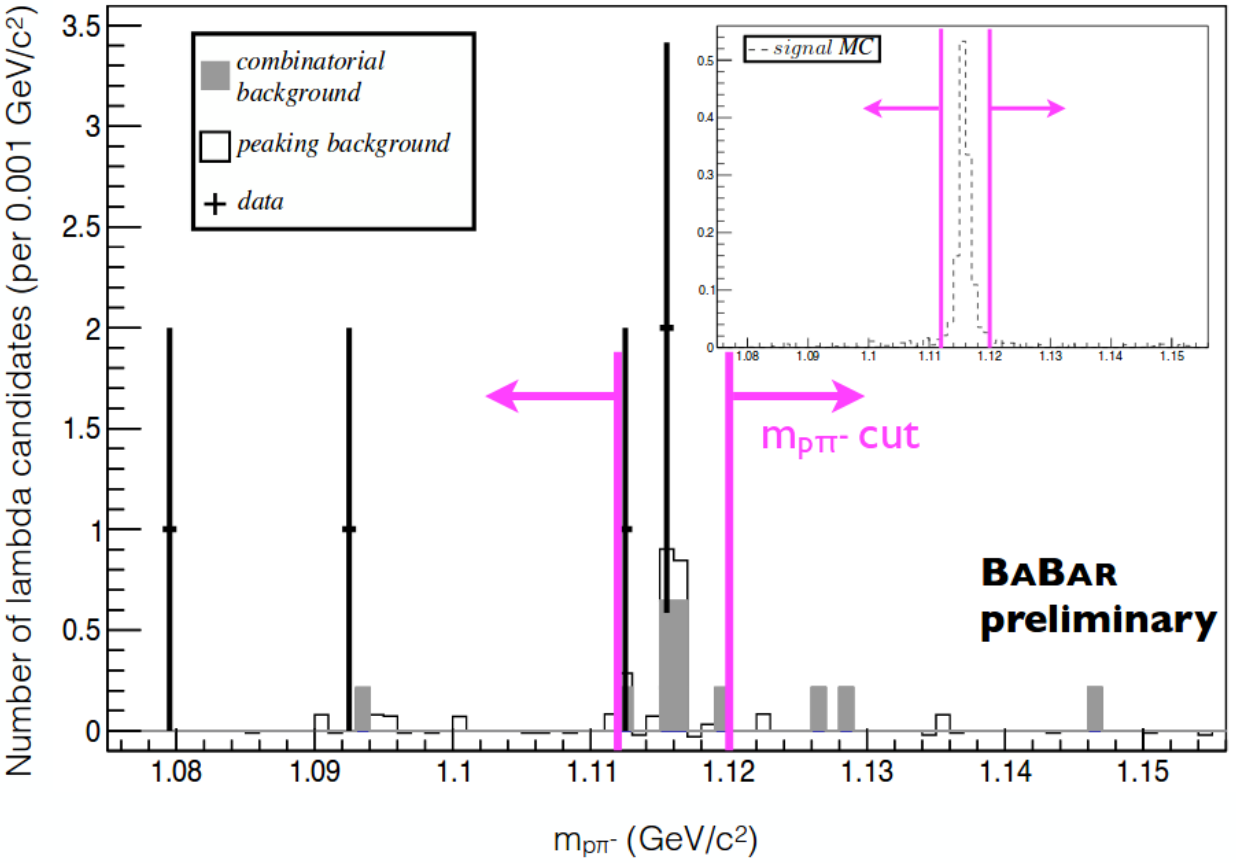
BaBar preliminary

Search for $B^- \to \Lambda \bar{p} \nu \bar{\nu}$

Residual background estimate: 2.3 ± 0.7 ± 0.6
Number of candidates: 3
$\mathcal{B}(B^- \to \Lambda \bar{p} \nu \bar{\nu}) < 3.0 \times 10^{-5}$ @ 90% CL



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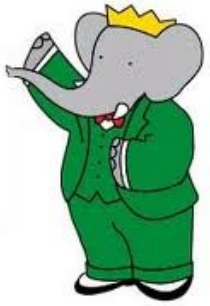

Summary

- Still many interesting new results on rare decays from BaBar and Belle
  - exploiting unique data samples
  - complementing previous measurements and those from other experiments
- All results consistent with the Standard Model
- Excellent prospects for further improvements with Belle II

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BACK UP!

PRL 119 (2017) 191802

Isospin & ΔA_{CP} asymmetries in B → K*γ

$$\mathcal{B}(B^0 \to K^{*0}\gamma) = (3.96 \pm 0.07 \pm 0.14) \times 10^{-5},$$
$$\mathcal{B}(B^+ \to K^{*+}\gamma) = (3.76 \pm 0.10 \pm 0.12) \times 10^{-5},$$
$$A_{CP}(B^0 \to K^{*0}\gamma) = (-1.3 \pm 1.7 \pm 0.4)\%,$$
$$A_{CP}(B^+ \to K^{*+}\gamma) = (+1.1 \pm 2.3 \pm 0.3)\%,$$
$$A_{CP}(B \to K^{*}\gamma) = (-0.4 \pm 1.4 \pm 0.3)\%,$$
$$\Delta_{0+} = (+6.2 \pm 1.5 \pm 0.6 \pm 1.2)\%,$$
$$\Delta A_{CP} = (+2.4 \pm 2.8 \pm 0.5)\%,$$
$$\bar{A}_{CP} = (-0.1 \pm 1.4 \pm 0.3)\%,$$

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PRL 119 (2017) 191802

Isospin & ΔA_{CP} asymmetries in B → K*γ

Source	$K^0_S\pi^0$	$K^+\pi^-$	$K^+\pi^0$	$K^0_S\pi^+$	K^{*0}	K^{*+}	Δ_{0+}
photon reconstruction eff.	2.0	2.0	2.0	2.0	2.0	2.0	–
tracking eff.	0.7	0.7	0.4	1.1	0.7	0.8	0.05
K/π identification eff.	–	1.7	0.8	0.8	1.6	0.8	0.38
π^0 reconstruction eff.	1.6	–	1.6	–	0.1	0.5	0.21
K^0_S reconstruction eff.	0.2	–	–	0.2	<0.1	0.1	0.05
$\mathcal{O}_{\rm NB}$ and π^0/η veto eff.	0.6	0.6	0.6	0.6	0.6	0.6	–
ΔE selection eff.	1.1	<0.1	1.1	0.1	0.1	0.4	0.15
charge asymmetry in eff.	–	<0.1	<0.1	< 0.1	< 0.1	<0.1	<0.01
MC stat.	0.4	0.1	0.3	0.2	0.1	0.2	0.11
number of $B\bar{B}$ pairs	1.4	1.4	1.4	1.4	1.4	1.4	–
f_{+-}/f_{00}	1.2	1.2	1.2	1.2	1.2	1.2	1.16
lifetime ratio	–	–	–	–	–	–	0.19
higher kaonic resonance	0.3	0.3	0.3	0.3	0.3	0.3	–
cross-feed	0.2	0.2	0.3	0.2	0.2	0.2	0.03
peaking backgrounds	1.6	1.2	1.2	1.1	1.2	1.1	0.14
background A_{CP} and Δ_{0+}	0.2	<0.1	<0.1	0.1	<0.1	<0.1	0.03
fixed parameters in fit	3.9	0.1	1.5	<0.1	0.1	0.2	0.10
fitter bias	2.4	0.2	1.3	0.7	0.2	0.2	0.08
total	5.9	3.5	4.2	3.3	3.5	3.3	1.29

PRL 119 (2017) 191802

Isospin & ΔA_{CP} asymmetries in B → K*γ

Source	$K^+\pi^-$	$K^+\pi^0$	$K^0_S\pi^+$	K^{*0}	K^{*+}	K^*	ΔA_{CP}	$\bar{A}_{CP}$
tracking eff.	–	–	–	<0.01	<0.01	<0.01	<0.01	<0.01
K/π identification eff.	–	–	–	<0.01	<0.01	<0.01	<0.01	<0.01
π^0 reconstruction eff.	–	–	–	<0.01	<0.01	<0.01	<0.01	<0.01
K^0_S reconstruction eff.	–	–	–	<0.01	<0.01	<0.01	<0.01	<0.01
charge asymmetry in K/π detection	0.40	0.04	0.41	0.40	0.25	0.28	0.48	0.24
cross-feed	0.02	0.04	0.03	0.02	0.02	0.02	0.02	0.01
peaking backgrounds	0.04	0.06	0.08	0.04	0.06	0.05	0.04	0.05
background A_{CP} and Δ_{0+}	0.10	0.13	0.09	0.10	0.10	0.10	0.05	0.10
fixed parameters in fit	<0.01	0.13	0.02	<0.01	0.02	<0.01	0.02	0.06
fitter bias	0.07	0.16	0.12	0.07	0.09	0.08	0.12	0.06
total	0.42	0.26	0.45	0.42	0.30	0.31	0.50	0.27

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arXiv:1807.04236

Isospin & ΔA_{CP} asymmetries in $B \to X_s \gamma$

Source	Δ_{0-}	ΔA_{CP}	A_{CP}^{C}	A_{CP}^{N}	A_{CP}^{tot}	$\bar{A}_{CP}$
tracking	± 0.02	–	–	–	< 0.01	–
K/π ID	± 0.04	–	–	–	< 0.01	–
π^0/η recon.	± 0.01	–	–	–	< 0.01	–
K_S^0 recon.	± 0.01	–	–	–	< 0.01	–
detection asym.	–	± 0.39	± 0.11	± 0.29	± 0.05	± 0.10
ΔE selection	$^{+0.03}_{-0.06}$	–	–	–	< 0.01	–
f_{+-}/f_{00}	± 1.15	–	–	–	–	–
lifetime ratio	± 0.19	–	–	–	–	–
fragmentation	± 0.58	–	–	–	± 0.01	–
K^*-X_s transition	± 0.12	–	–	–	< 0.01	–
missing fraction	< 0.01	–	–	–	< 0.01	–
background A_{CP}	–	± 0.05	± 0.03	± 0.04	± 0.02	± 0.03
background Δ_{0-}	± 0.01	–	–	–	< 0.01	–
fixed parameters	$^{+0.60}_{-0.47}$	$^{+0.53}_{-0.50}$	$^{+0.27}_{-0.25}$	$^{+0.28}_{-0.29}$	$^{+0.09}_{-0.08}$	$^{+0.08}_{-0.06}$
fitter bias	± 0.08	± 0.11	± 0.02	± 0.09	± 0.02	± 0.03
MC stat.	± 0.03	–	–	–	< 0.01	–
total	$^{+1.44}_{-1.39}$	$^{+0.67}_{-0.64}$	$^{+0.29}_{-0.27}$	$^{+0.41}_{-0.42}$	$^{+0.12}_{-0.10}$	$^{+0.14}_{-0.12}$