The XV International Conference
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Rare decays at Belle and BaBar

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On behalf of the Belle and BaBar collaborations

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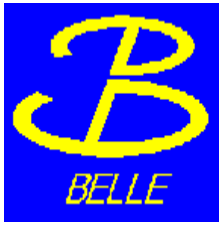


- Introduction
- ΔA_{cp} and Δ_{0-} in inclusive decay $b \to s\gamma$
- R_K^* from $B \to K^* \ell^+ \ell^-$
- Search for $B^0 \to K^{*0} \tau^+ \tau^-$
- Search for $B^+ \to K^+ \tau^+ \tau^-$
- Search for $B^- \to \Lambda \bar{p} \nu \bar{\nu}$

B-factory: KEKB and PEPII

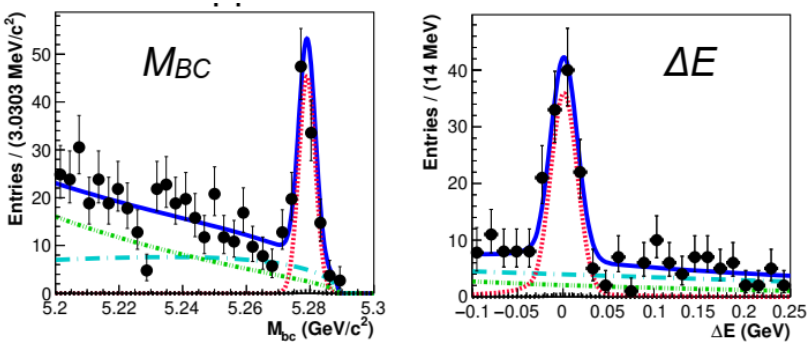
$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$ **at** √s = 10.58 GeV

- Energy of the B-mesons are know.

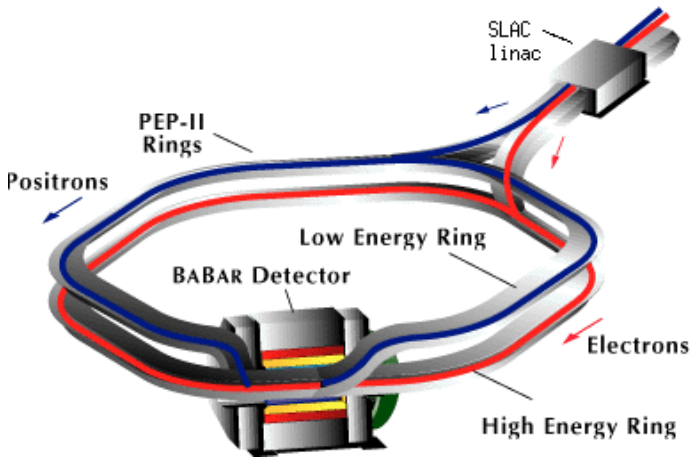
Beam-constrained mass:

$$M_{bc/ES} = \sqrt{(E_{beam}/2)^2 - \vec{p}_B^{\,2}}$$

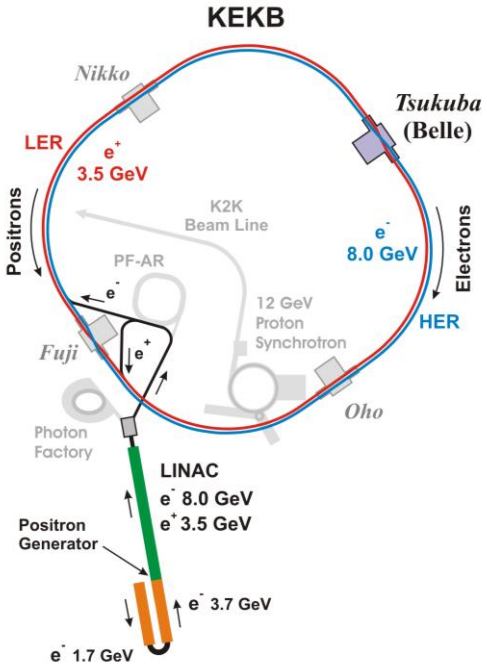
Energy difference: $\Delta E = E_B - E_{beam}/2$



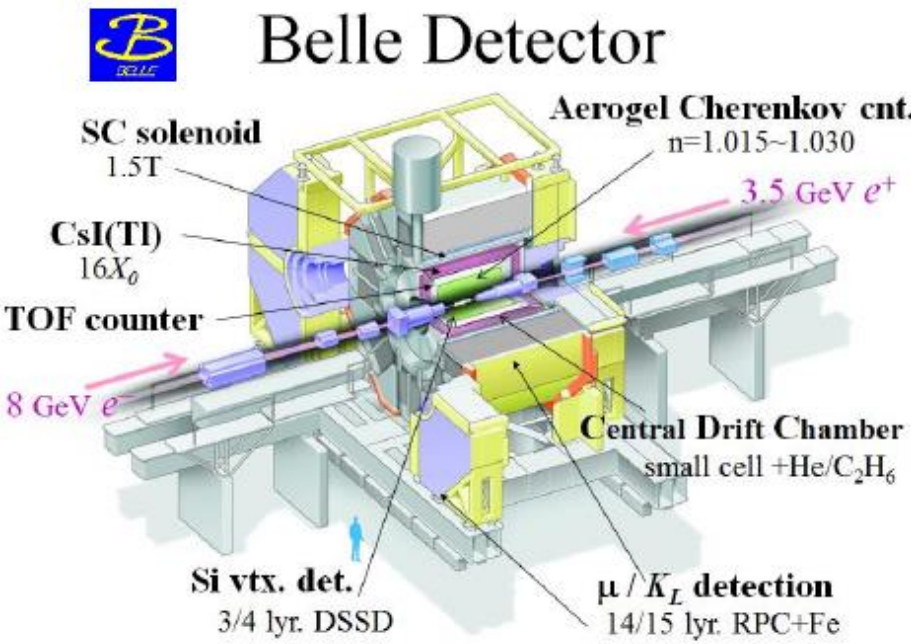
PEPII at SLAC
Energy: e^-/e^+ = 9/3.1 GeV

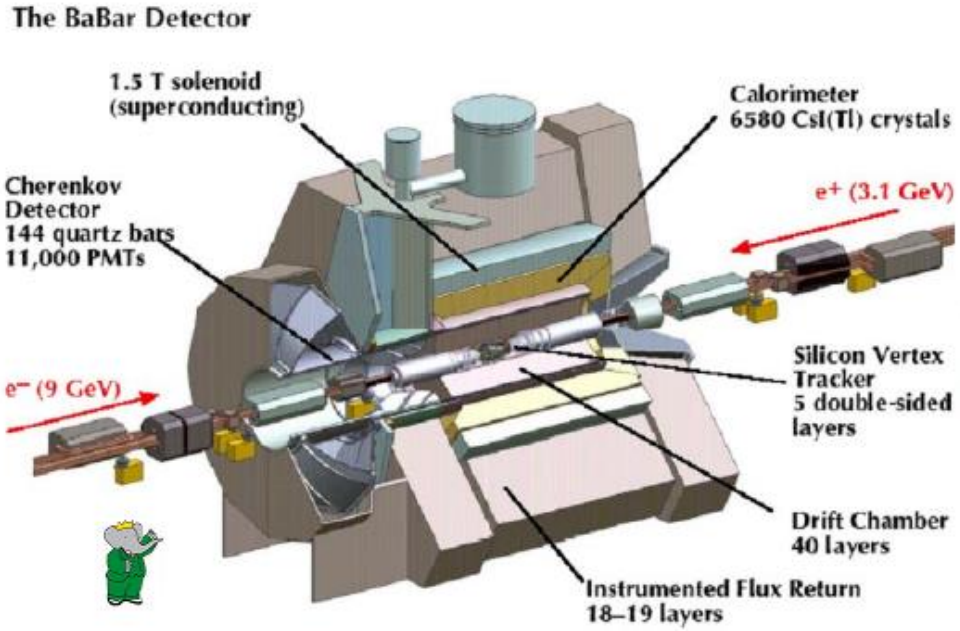


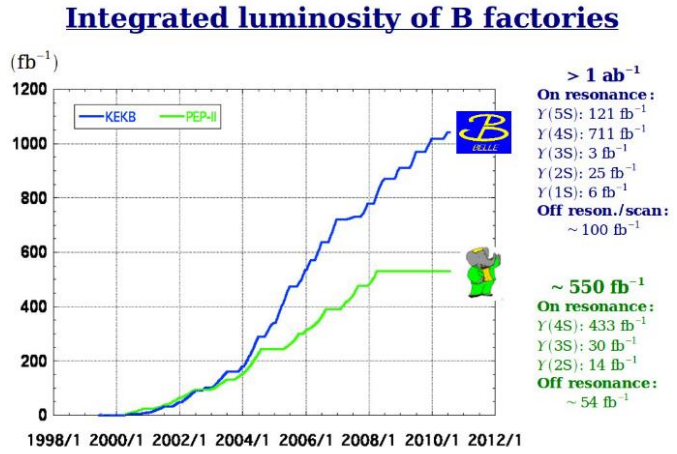
KEKB at KEK
Energy: e^-/e^+ = 8/3.5 GeV



Belle and Babar detectors



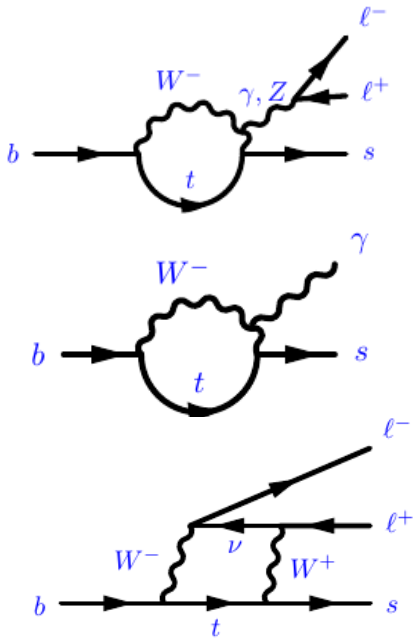




- Belle and Babar collected data of 711 + 433 fb^{-1} at $\Upsilon(4S)$
- → more than 1 Billions BB pairs, ➔ high statistics for rare decay searches

Radiative and Electroweak Penguin decays

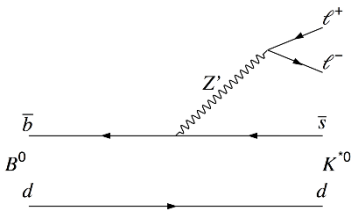
- In the SM:
  - fobidden at tree level.
  - only process via box and loop diagrams.
  - branching fractions are very small, e.g $<10^{-5}$



==> sensitive to search for NP beyond the SM.

- New particle might appear in the loop
- Can also decay via tree diagram for some of the new particles.

  ➔ the branching fraction can be different with the SM prediction.



- Provide many observables to probe for new physics: angular, asymmetries, q^2

PRD 99 032012 (2019)

ΔA_{cp} and Δ_{0-} in inclusive decay $b \to s\gamma$

- ΔA_{CP} is good quantity for testing the SM, the ratio will cancel the systematic errors.

$$\Delta A_{cp} = A_{cp}(B^+ \to X_s^+\gamma) - A_{cp}(B^0 \to X_s^0\gamma)$$
$$\approx 0.12 \left(\frac{\widetilde{\Lambda}_{78}}{100\ MeV}\right) Im\left(\frac{C_8}{C_7}\right) \begin{cases} = 0\ in\ SM \\ \neq 0, \Rightarrow NP \end{cases}$$

PRL106, 141801

- The measured $\mathcal{B}(b \to s\gamma)$ is consistent with the SM. However, the uncertainty of the theory is larger ~7%.

=> Reduce the theoretical uncertainty is crucial to tighten contrain the NP.

- The dominance source of theoreitcal uncertainty is due to resolved photon and depend on spectator quark => relate to isospin asymmetry

$$\frac{\mathcal{B}_{RP}^{78}}{\mathcal{B}} \approx \frac{1}{3}\Delta_{0-}$$

➔ measurement of Δ_{0-} help to reduce the theory uncertainty.

PRD 99 032012 (2019)

Reconstruction and background suppression

- Data: 711 fb^{-1} at $\Upsilon(4S)$
- Reconstruct of Xs with 38 exclusive modes, modes with asterisk which that is non-specific-flavor are only used for Δ_{0-} measurement

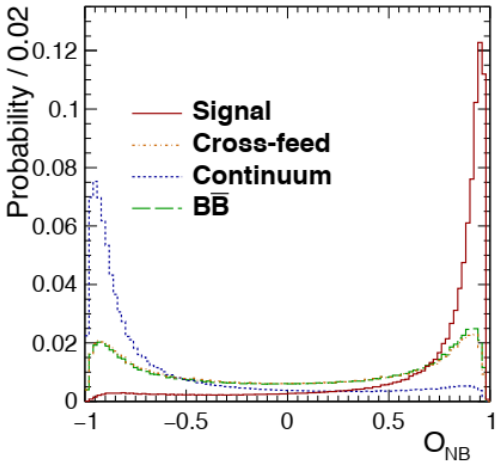
Mode ID	Final state	Mode ID	Final state
1	$K^+\pi^-$	20	$K^0_S\pi^+\pi^0\pi^0$
2	$K^0_S\pi^+$	21	$K^+\pi^+\pi^-\pi^0\pi^0$
3	$K^+\pi^0$	22*	$K^0_S\pi^+\pi^-\pi^0\pi^0$
4*	$K^0_S\pi^0$	23	$K^+\eta$
5	$K^+\pi^+\pi^-$	24*	$K^0_S\eta$
6*	$K^0_S\pi^+\pi^-$	25	$K^+\eta\pi^-$
7	$K^+\pi^-\pi^0$	26	$K^0_S\eta\pi^+$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

Mode ID	Final state	Mode ID	Final state
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*	$K^+K^-K^0_S\pi^0$

Backgrounds:

+ Continuum (qq) ➔suppressed by Neural network

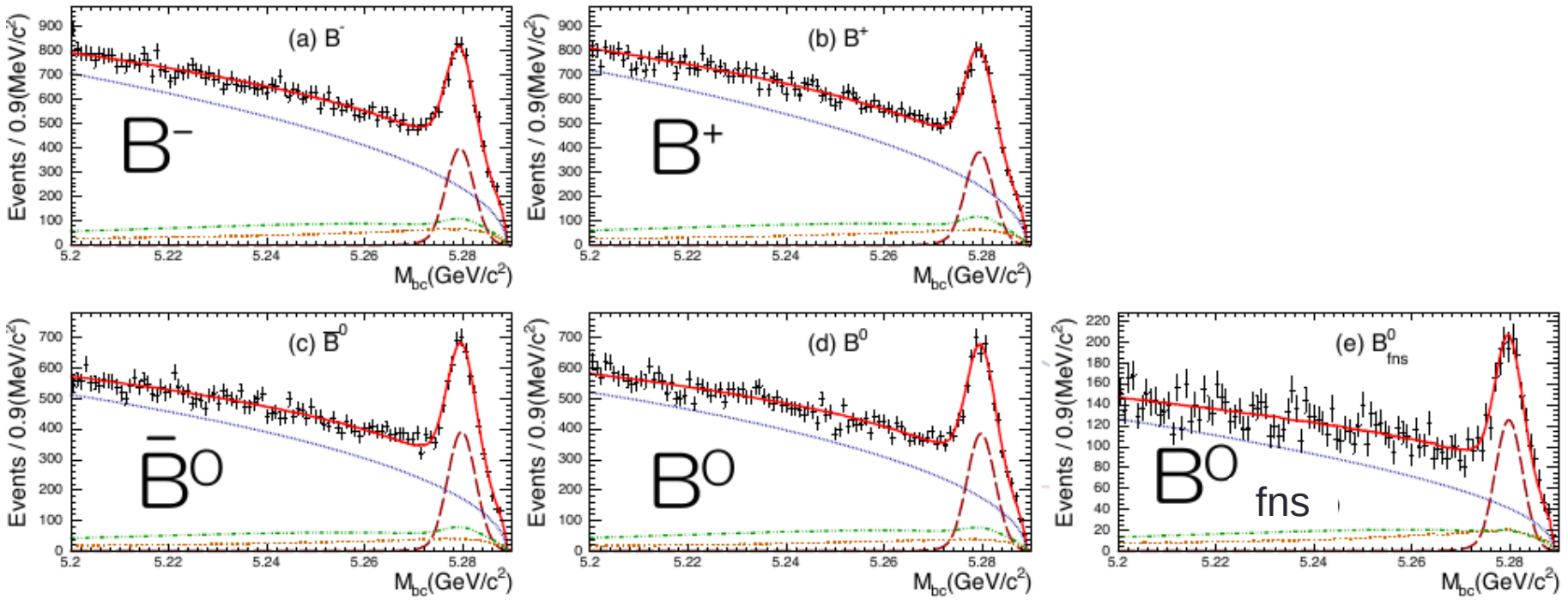
+ B→D(*)ρ ➔ suppressed by D veto



PRD 99 032012 (2019)

Results

Signal is extracted by fit to M_{bc} distributions



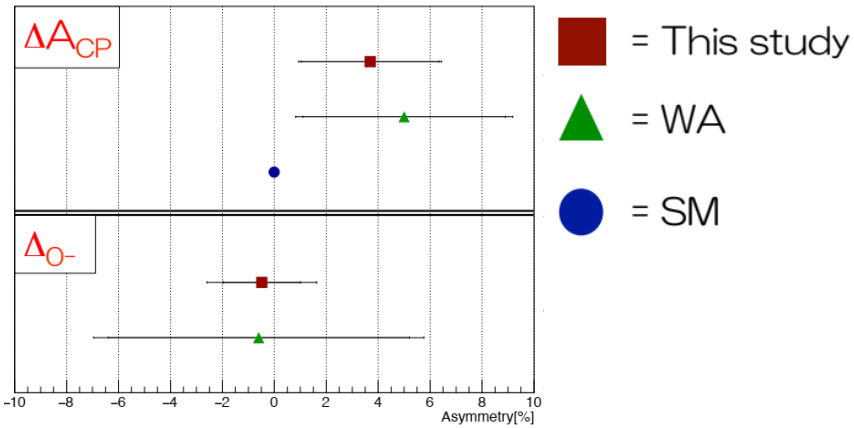
B_{fns} = flavor-non-specific neutral B

PRD 99 032012 (2019)

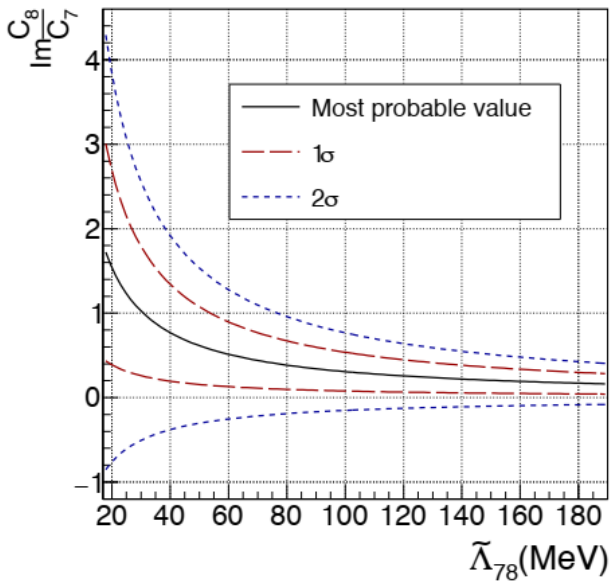
Results

$$\Delta_{0-} = (-0.48 \pm 1.49 \pm 0.97 \pm 1.15)\%,$$
$$\Delta A_{CP} = (+3.69 \pm 2.65 \pm 0.76)\%,$$
$$A_{CP}^{\mathrm{C}} = (+2.75 \pm 1.84 \pm 0.32)\%,$$
$$A_{CP}^{\mathrm{N}} = (-0.94 \pm 1.74 \pm 0.47)\%,$$
$$A_{CP}^{\mathrm{tot}} = (+1.44 \pm 1.28 \pm 0.11)\%,$$
$$\bar{A}_{CP} = (+0.91 \pm 1.21 \pm 0.13)\%,$$

$$\frac{\mathcal{B}_{\mathrm{RP}}^{78}}{\mathcal{B}} \simeq (+0.16 \pm 0.50 \pm 0.32 \pm 0.38 \pm 0.05)\%$$



- Measurement of ΔA_{CP} consistent with zero as expected by the SM. The improvement in uncertainty help to constrain NP tighten
- Measurement of Δ_{0-} is also consistent with zero, constrain the contribution of resolved photon in $B \to X_s\gamma$ decays, ~1.45% by taken 2sigma.

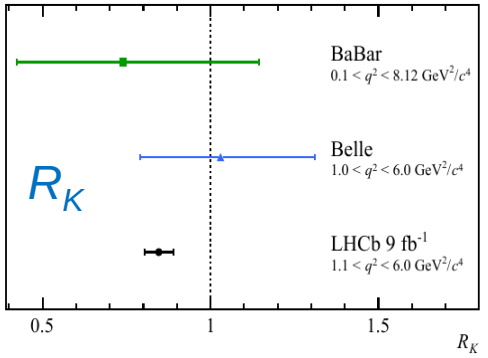


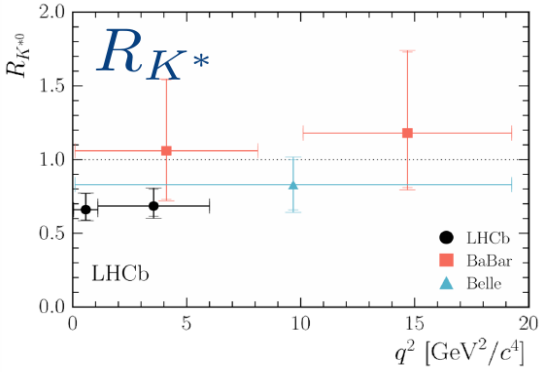
PRL126, 161801 (2021)

Measurement R_K* from $B \to K^* \ell^+ \ell^-$

$$R_{K^{(*)}} = \frac{\mathcal{B}(B \to K^{(*)} \mu^+ \mu^-)}{\mathcal{B}(B \to K^{(*)} e^+ e^-)} \approx 1 \text{ in the SM}$$

arXiv:2103.11769



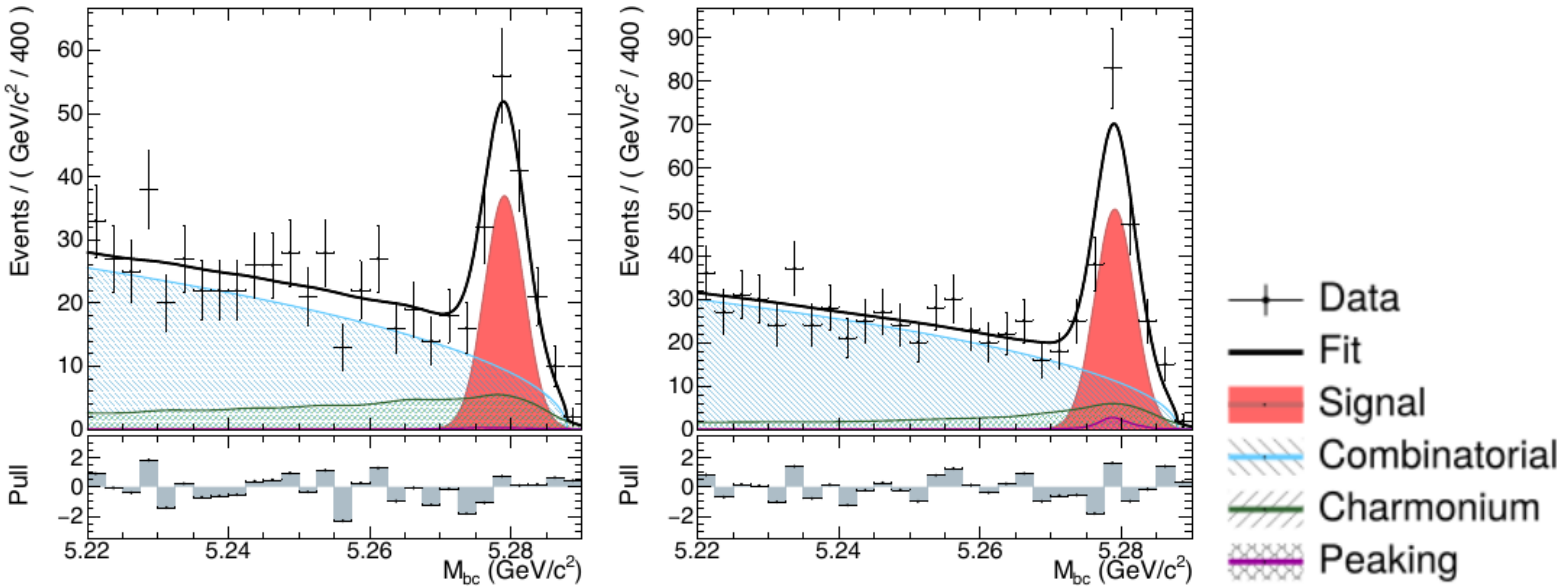


- Belle and Babar results are consistent with the SM.
- LHCb observed a deviation from SM for both R_K and R_{K^*} ~2.5sigma (2018). The latest result of R_K is 3.1σ (2021)
- Data: 711 fb^{-1} at $\Upsilon(4S)$
- Study for both B^0 and B^+.
  - K* modes: $K_S^0\pi^0, K^+\pi^-, K^+\pi^0, K_S^0\pi^+$
- vetos $M_{\ell\ell}$ ~ $M_{J/\Psi}$, $M_{\Psi(2S)}$.
- Employed neural network for reconstruction and background suppression.

Measurement R_K^* from $B \to K^* \ell^+ \ell^-$

- Signal extraction by fitting M_{bc} for q^2 regions.
  - Signal: Crystal Ball, shape is determined from control sample.
  - Background: combinatoric(ARGUS) + peaking (MC)+ charm(MC)

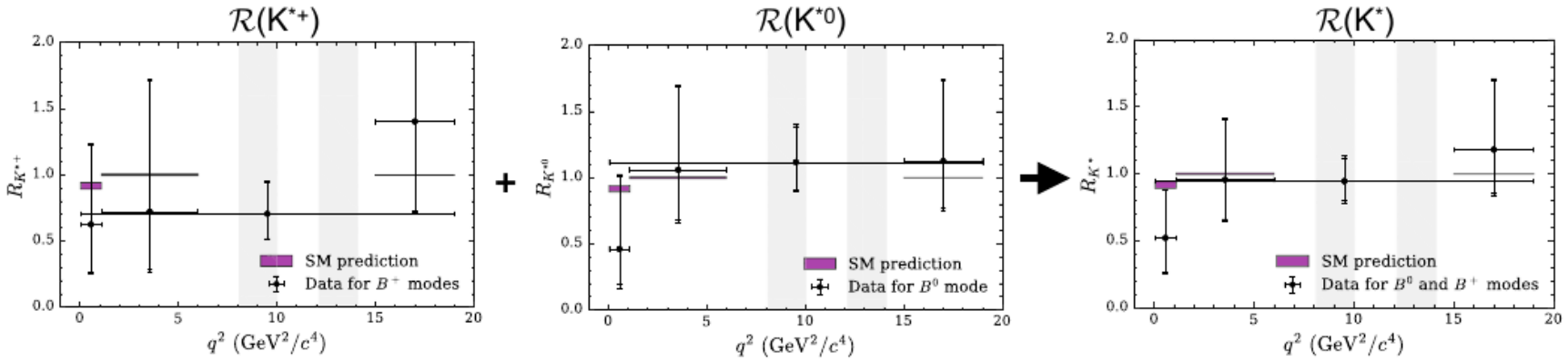
e-mode μ-mode

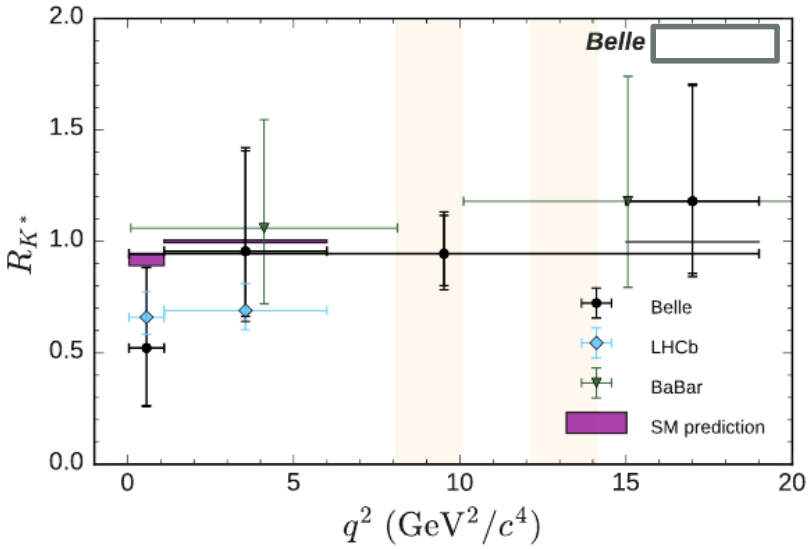


Example fit: $0.045 < q^2 < 19$GeV (full range)

PRL126, 161801 (2021)

Measurement R_K^* from $B \to K^* \ell^+ \ell^-$



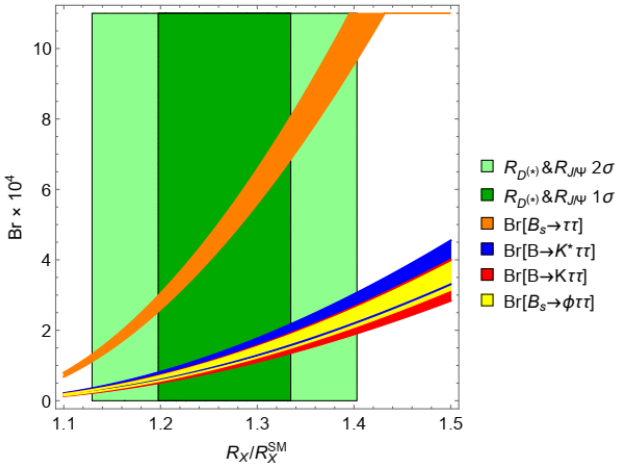


- The results are consistent with the SM, and previous measurement,
- This is the first measurement of $R_{K^{*+}}$

Preliminary

Search for the decay $B^0 \to K^{*0}\tau^+\tau^-$

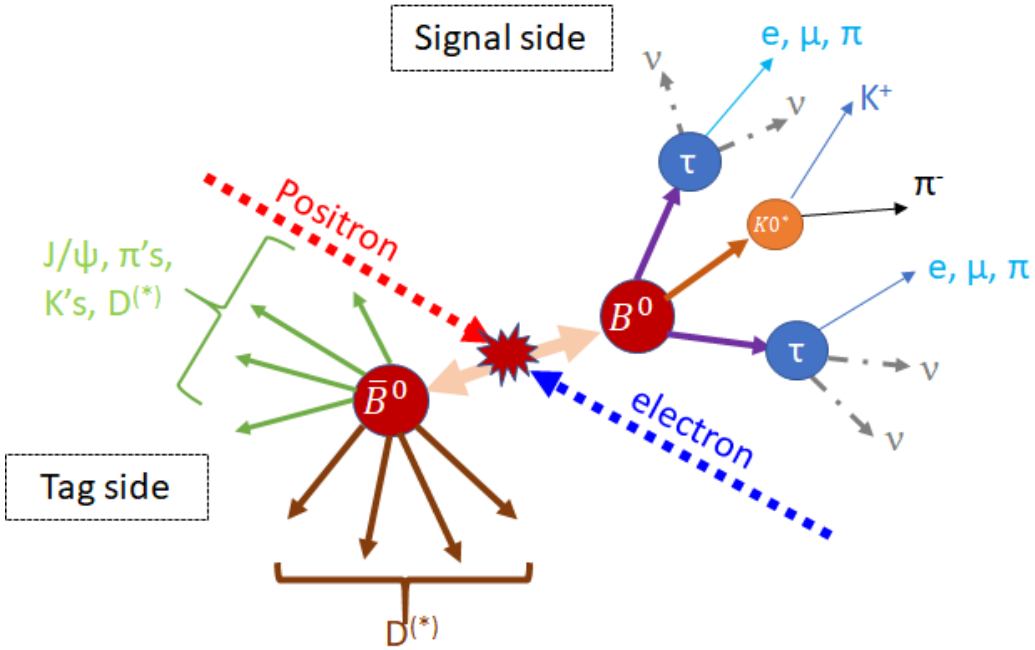
- The decay is third family equivalent of the $B \to K^*\ell^+\ell^-$ decay, hence expected to be more sensitive to NP due to the large mas of τ lepton.
- In the SM the branching fraction Br ~10^{-7}.
- When including NP effect to explain the R_D, R_{D^*}, $R_{J/\psi}$ and R_K anomalies Br($B^0 \to K^{*0}\tau^+\tau^-$) ~ 10^{-4} *PRL 120, 181802 (2018)*.
- Currently, no limit is set for this decay mode (due to the presence of 2-4 neutrino in final state)



Preliminary

Analysis strategy

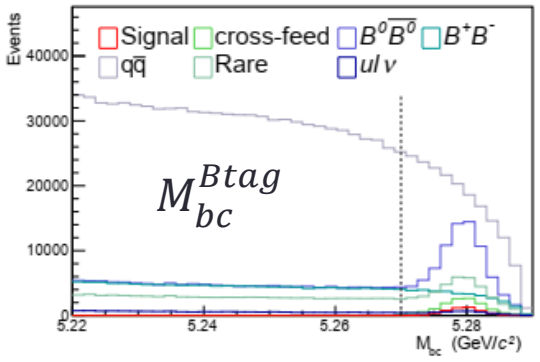
- Data: 711 fb^{-1} at $\Upsilon(4S)$.
- Tag side (Btag) is reconstructed with the hadronic decays using hierarchal neural networks based algorithm. Signal is searched for in the Rest of Event.
  - continuum suppression is enabled and employed event shape variables.



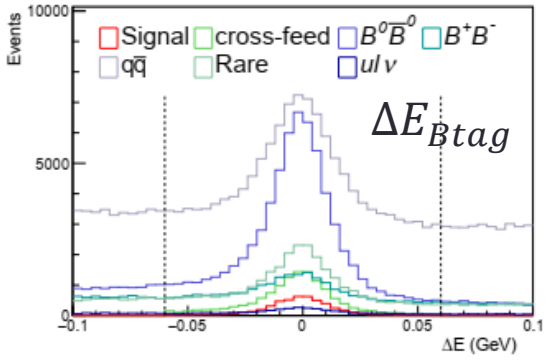
Preliminary

Search for the decay $B^0 \to K^{*0}\tau^+\tau^-$

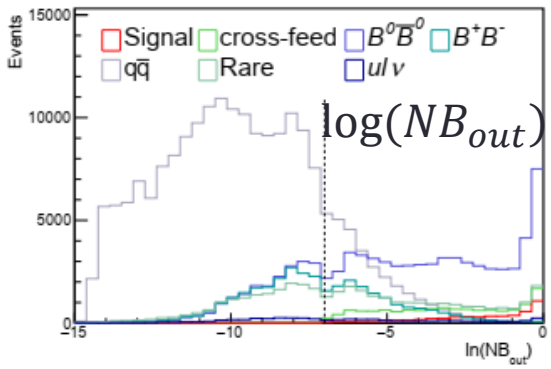
- Select B-tag using M_{bc}, ΔE and the Neural network ouput



(a) Cut: $M_{bc} > 5.27$

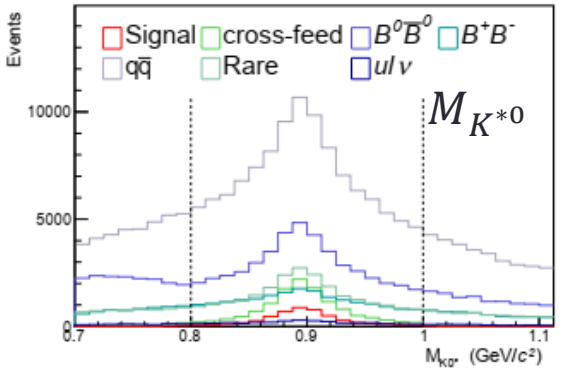


(b) Cut: $|\Delta E| < 0.06$



Require 4 charged tracks in RoE and net charge = 0

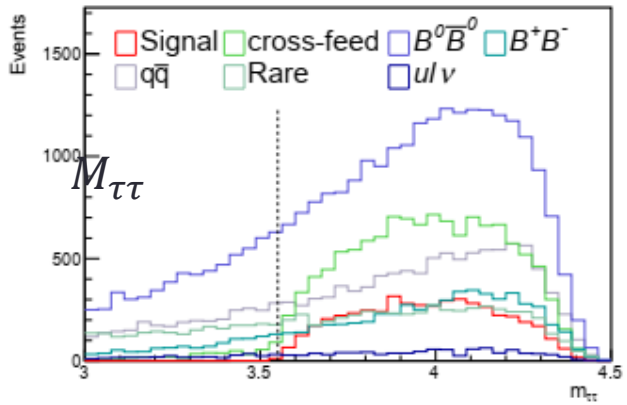
(after cleaning up the duplicated tracks)

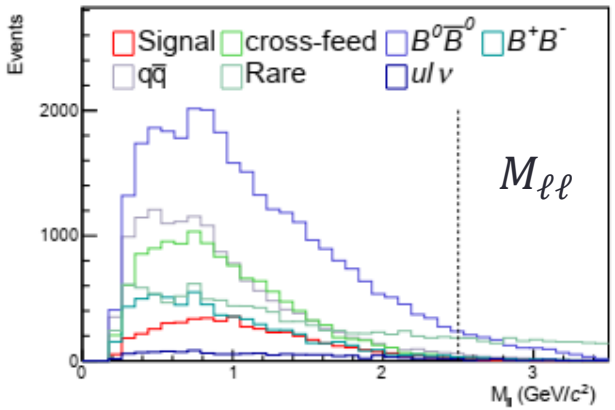


Preliminary

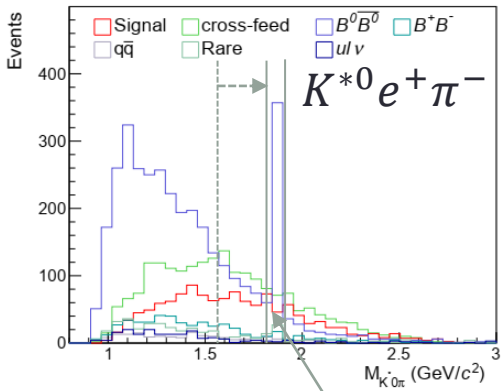
Search for the decay $B^0 \to K^{*0}\tau^+\tau^-$

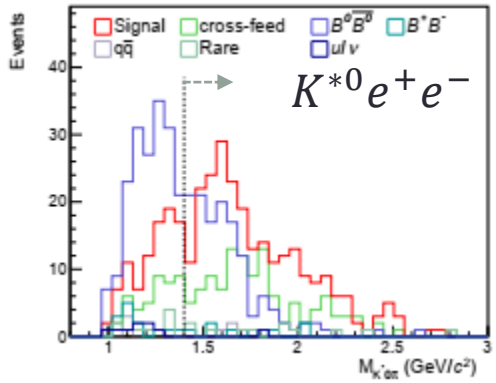
- Reject background by cut on $M_{\ell\ell}$, $M_{\tau\tau}$, Veto K_S^0, π^0, and at most K_L.

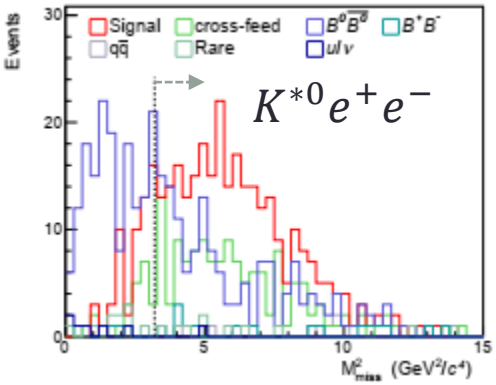




- Final background suppression is done for mode-by-mode depend on final state particles, using M^2_{miss} and $M_{K^{*0}\pi}$ variables.





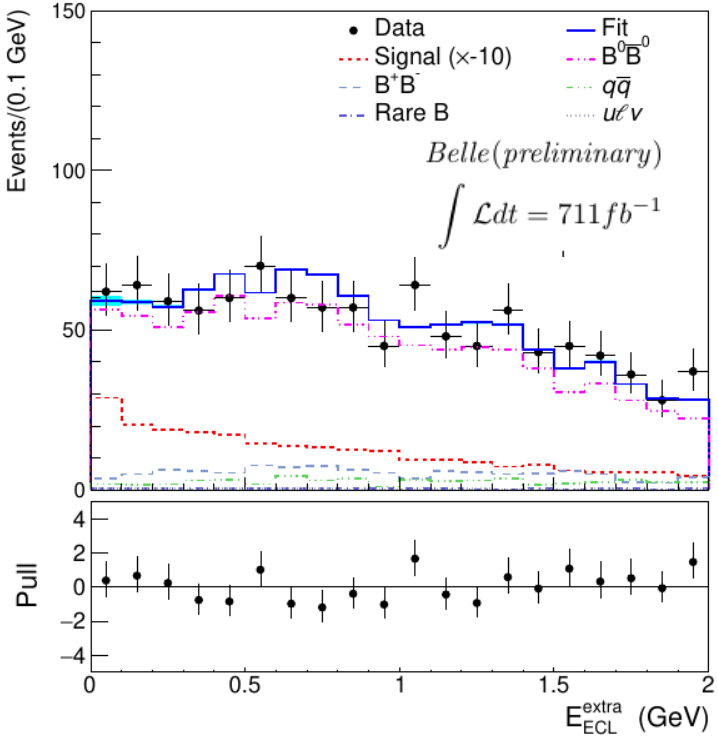


Veto D for $K^{*0}l^+\pi^-$ and $K^{*0}\pi^+\pi^-$ modes

Preliminary

Search for the decay $B^0 \to K^{*0}\tau^+\tau^-$

- Signal is obtained by fitting to E_{ecl}^{extra}, the sum of cluster energy which are not associated in either B-tag or B-sig reconstruction.
- Validate procedure and fitting model using $B^0 \to D^- l^+ \nu$ with $D \to K^{*0}\pi$



- N_{sig} = -4.9 Events

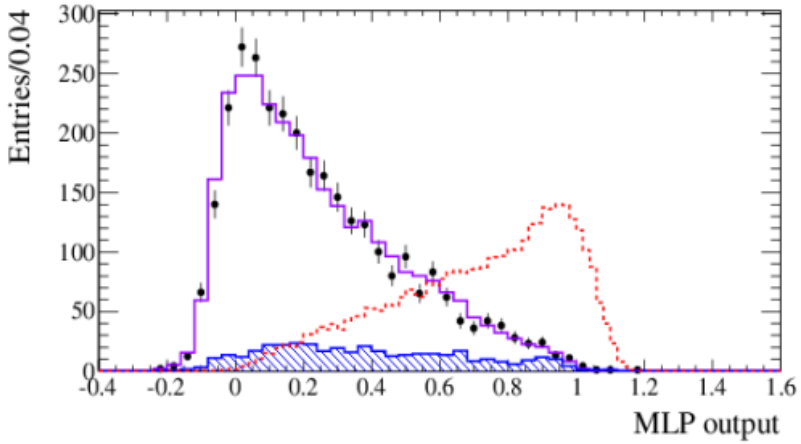
$\Rightarrow$ Setting the upper limit using CLs method.

- $\mathcal{B}(B^0 \to K^*\tau^+\tau^-) < 2.0 \times 10^{-3}$ at 90% C.L
- This is the first experimental limit for $B^0 \to K^*\tau^+\tau^-$.

PRL118, 031802 (2017)

Search for the decay $B^+ \to K^+\tau^+\tau^-$ at Babar

- Data: 424 fb^{-1} at $\Upsilon(4S)$
- B_{tag} is reconstructed with hadronic B decays and search for signal in the Rest of Event (RoE)
- Select B-tag by ΔE and M_{ES}
- Continuum suppression with multivariate likelihood selector with event shape variables
- Veto D, J/ψ.
- Using A multi-layer perceptron (MLP) to suppress $B^+ \to D^* l^+ \nu$
- Signal efficiency and expected peaking bkg event are obtained from MC after corrected to reproduce B_{tag} data yield.
- Expected combinatorial bkg events are determined using data m_{ES} side band
- No signal is found

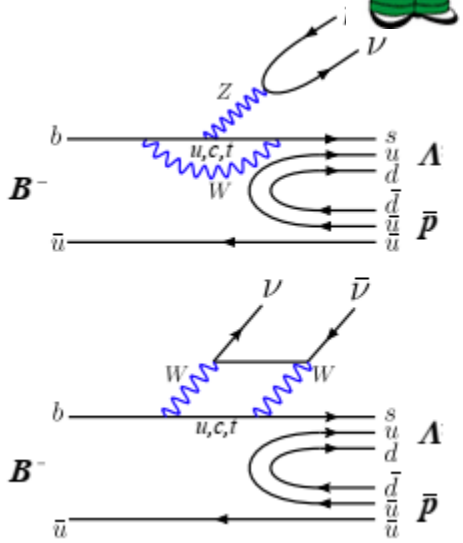


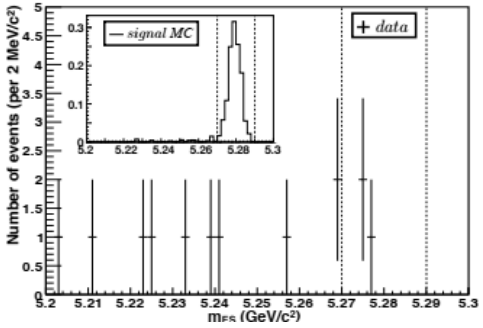
$\mathcal{B}(B^0 \to K^+\tau^+\tau^-) < 2.25 \times 10^{-3}$ at 90% C.L

•*PRD* 100 (2019) 11, 111101

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

- FCNC processes with vv pairs theoretically clean
  – only Z penguin and W loop diagrams
  – no γ penguin, no charm loops, no resonances
  – SM prediction: $\mathcal{B}(B^- \to \Lambda\bar{p}\nu\nu)$ = (7.9 ± 1.9) × 10^{-7}
- Data: 424 fb^{-1} at $\Upsilon(4S)$
- Using Hadron tag method.
- Reduce background by MVA and cut on residual energy
- Remaining background is estimated using MC and side-band region.
- No significant is found,
  $\mathcal{B}(B^- \to \Lambda\bar{p}\nu\bar{\nu}) < 3.0 \times 10^{-5}$ @ 90% CL





Summary

- With the huge data sample taken at B-factories, Belle and Babar obtained many interesting result on rare decays.
  - Results are consistent with SM, and previous measurement.
  - Improve the precision of the previous measurement

  ➔help to constrain NP parameter more tighten.
  - The first result of $B^0 \to K^{*0}\tau^+\tau^-$ search at Belle was presented. No signal is found, upper limit on branching fraction is
    $$\mathcal{B}(B^0 \to K^*\tau^+\tau^-) < 2.0 \times 10^{-3} \text{ at 90\% C.L}$$
- For a long term, we can expect the contribution from Belle II with x50 of data and the improvement of detector performance.