Semitauonic B meson decays

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outline

- Introduction
- Measurements at B factories
- Prospects at Belle2
- Summary

Why study $B \to X\tau\nu$

- Babar, Belle and LHCb measured:
  $R(D^{(*)}) = \frac{BR(B\to D^{(*)}\tau\nu)}{BR(B\to D^{(*)}\ell\nu)}$ with $\ell = \mu, e$
- many systematic uncertainties cancel (theory and experiment)
- theoretical very "clean" as it is a tree level process
  - $\sigma(R(D^*))_{theory} \approx 2\%$
- good statistics $BR(B \to D^*\tau\nu) = 1.24\%$
- sensitive to new physics
- different channels to reconstruct for X and τ: $\tau \to \ell\nu_\ell\bar{\nu}_\tau$; $\tau \to \bar{\nu}_\tau + hadrons$

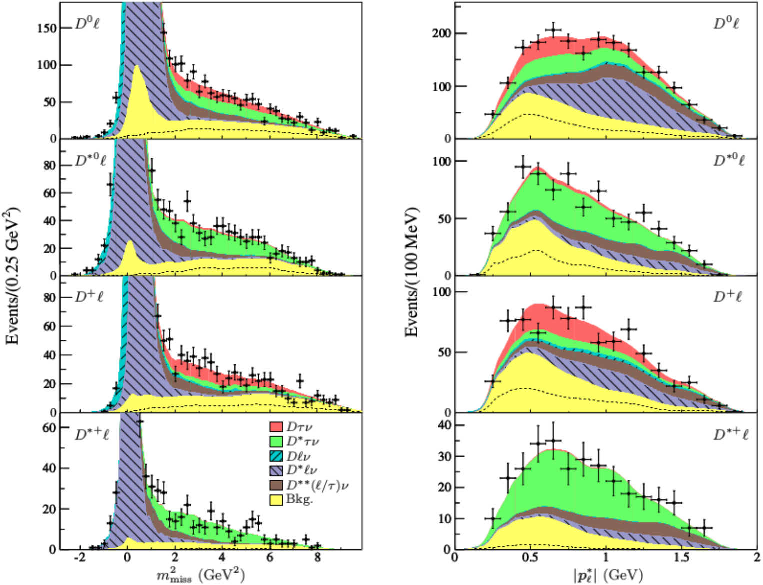
Experimentally challenging

- depending on channel 2-3 neutrinos in the event
- large backgrounds from $B \to D^{*,**}\ell\nu$ and secondaries
- signal is flat

Babar measurement

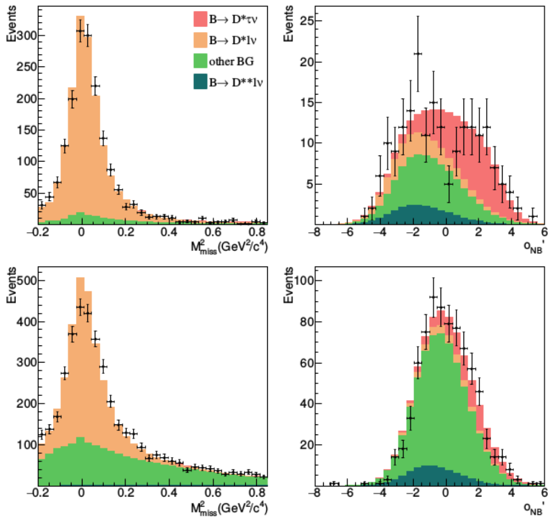
- fully reconstruct the tag side B meson in a hadronic decay mode (had. tag)
- require a lepton for the signal side μ or e
- require that $E_{extra} = \sum_{unmatched} E_{cal} < 0.5 GeV$
- define signal region with $q^2 > 4 GeV^2$
- no additional charged tracks in the event
- background rejection by 2 BDT:
  - reject continuum events
  - reject $B \to D^{**} \ell \nu$
- use control samples to constrain backgrounds from $B \to D^{**} \ell \nu$

- signal yields are extracted in a 2D maximum likelyhood fit in $m^2_{miss} = (p_{ee} - p_{tagB} - p_{D^{(*)}} - p_\ell)^2$ and lepton momentum p_ℓ



- similar analysis from Belle (i.e. hadronic tag, leptonic tau decay)
- simultanious fit in M^2_{miss} and neural network output O_{NB}

Fit result for $B \to D^*\tau\nu$ channels ($D^{*\pm}$ top; D^{*0} bottom)



Belle measurement semileptonic tag

- use semileptonic $B \to D^{(*)}\ell\nu$ decays to tag the other B meson:
  - large statistics: $BR(B \to D^{(*)}\ell\nu) \approx 25\%$
  - more difficult due to additional neutrino on tag side
- reconstruct events with two leptons (e, μ)
- use $\cos\theta_{BY} = \frac{2E_{beam}E_{D^{(*)}\ell} - m_B^2 - M_{D^{(*)}\ell}^2}{2|\vec{p}_B||\vec{p}_{D^{(*)}\ell}|}$ to distinguish signal $B \to D^{(*)}\tau\nu$ and normalization $B \to D^{(*)}\ell\nu$
- select lower $\cos\theta_{BY}$ as signal

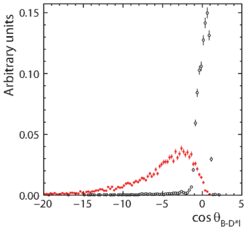
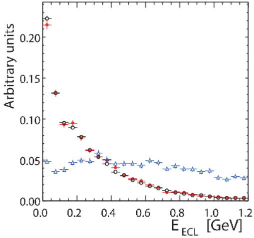
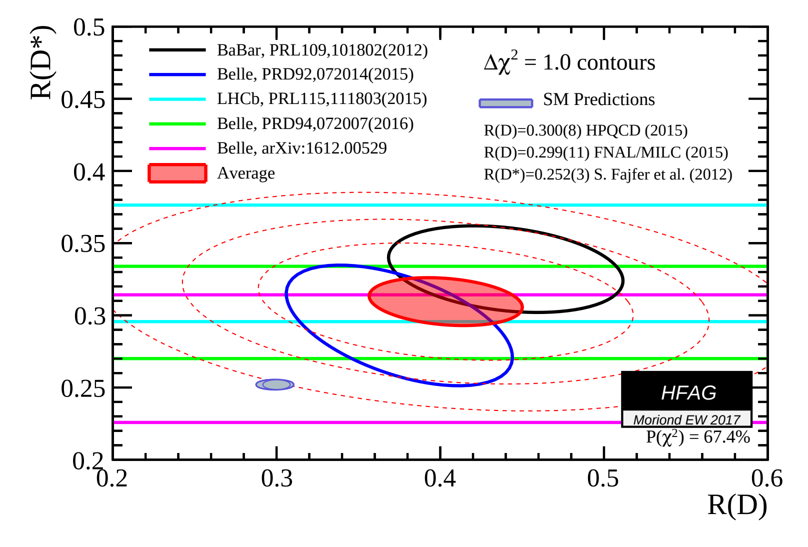


FIG. 1. The $\cos\theta_{B\text{-}D^*\ell}$ distributions for $\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau$ (solid red circles) and $\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}_\ell$ (open black circles) taken from MC simulation.



Current world of average for $D(D)$ vs. $R(D^*)$

- current world average is 3.9 σ away from SM prediction



(dashed curves correspond to 2-3-4 σ contours)

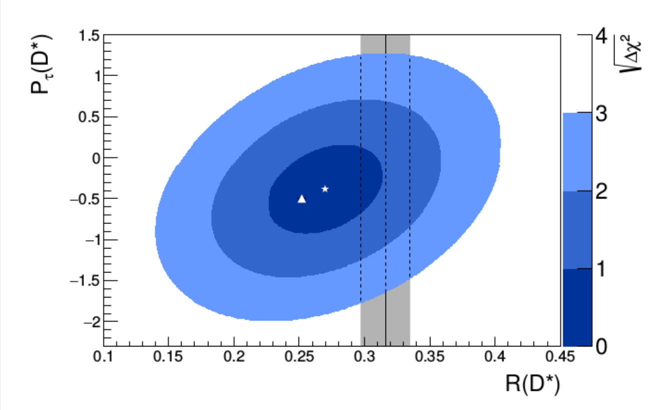
- discrepancy to SM consistent over different experiments and different channels
  - hadronic tag: fully reconstruct one B meson in a $B\bar{B}$ event
  - semileptonic tag: reconstruct a lepton (μ, e) on the tag side (not signal) for $B\bar{B}$ events
  - reconstruct the τ in leptonic channel $\tau \to \ell\nu_\ell\nu_\tau$
  - reconstruct the τ in hadronic channel e.g. $\tau \to \pi\nu_\tau$; $\tau \to \rho\nu_\tau$
- $\Rightarrow$ different systematic effects:
- not easy to pick up systematic bias

Measurements used by HFAG

Experim.	R(D*)	R(D)	corr. c.	Remarks
BaBar	$0.332 \pm 0.024 \pm 0.018$	$0.440 \pm 0.058 \pm 0.042$	-0.27	had. tag, lep. τ
BELLE	$0.293 \pm 0.038 \pm 0.015$	$0.375 \pm 0.064 \pm 0.026$	-0.49	had. tag, lep. τ
BELLE	$0.302 \pm 0.030 \pm 0.011$	-	-	semilep. tag, lep. τ
LHCb	$0.336 \pm 0.027 \pm 0.030$	-	-	hadron machine
BELLE	$0.270 \pm 0.035^{+0.028}_{-0.025}$	-	-	had. tag, had. τ
Average	$0.310 \pm 0.015 \pm 0.008$	$0.403 \pm 0.040 \pm 0.024$	-0.23	$\chi^2/\mathrm{dof} = 3.17/5$ (CL $= 0.67$)

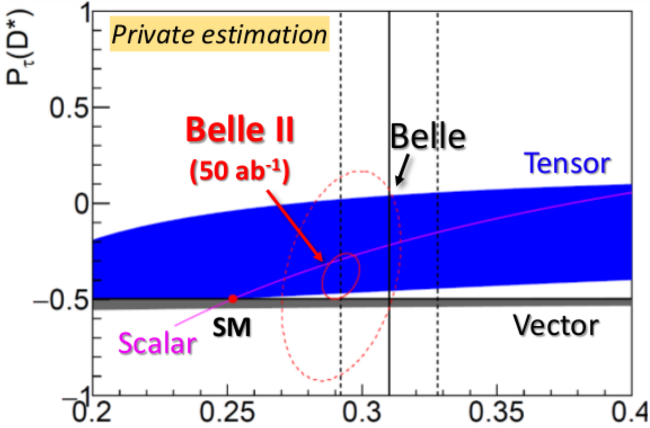
Measured polarization of the τ (arXiv:1612.00529)

- investigate the polarization of the τ
- sensitive to new physics
- Belle first measured the polarization of the τ in $B \to D^*\tau\nu$; with had. tag and $\tau \to \pi\nu$; $\tau \to \rho\nu$
- suffers from low statistics $\Rightarrow$ can be improved by Belle2



- presented by P. Urquijo at the Tau mini workshop in Nagoya, March 2017

$$R(D^*) = 0.270 \pm 0.035(\text{stat.})\,^{+0.028}_{-0.025}(\text{syst.})$$
$$P_\tau(D^*) = -0.38 \pm 0.51(\text{stat.})\,^{+0.21}_{-0.16}(\text{syst.})$$



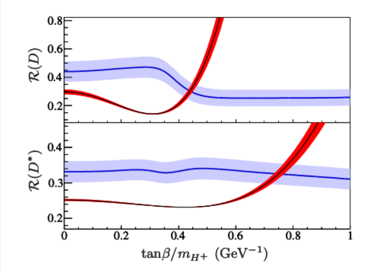
Theoretical calculation based on M. Tanaka and R. Watanabe, Phys. Rev. D 87, 034028 (2013)

Constraint on NP models

- the measurement of $R(D^{(*)})$ can be used to constrain NP models
- e.g. charged Higgs (2HDM type II) input parameter $\tan\beta/m_{Higgs}$
- deduce from the measurement:
  - from $R(D^*)$: $\tan\beta/m_{Higgs} = 0.75 \pm 0.04$
  - from $R(D)$: $\tan\beta/m_{Higgs} = 0.44 \pm 0.02$
- excludes 2HDM type II with $P > 99.8\%$ for $m_{Higgs} > 15 GeV$

Babar measurement (similar for Belle)

- efficiency corrected measurement of $R(D^{(*)})$ (blue)
- prediction of $R(D^{(*)})$ from 2HDM model as function of $\tan\beta/m_{Higgs}$



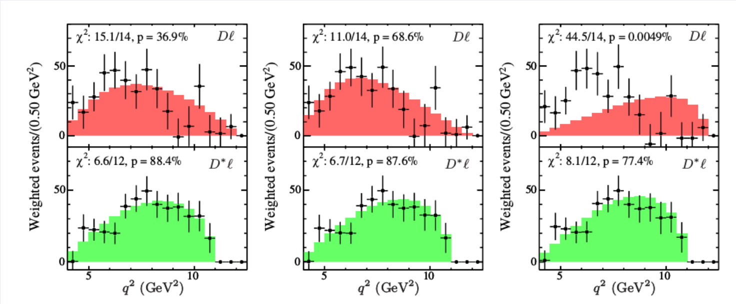
Constraints on new physics models

- distributions of $q^2 = (p_B - p_{D^{(*)}})^2$, p_{lep}, $p_{D^{(*)}}$ are sensitive to new physics contributions
- by measuring them one can constrain NP models

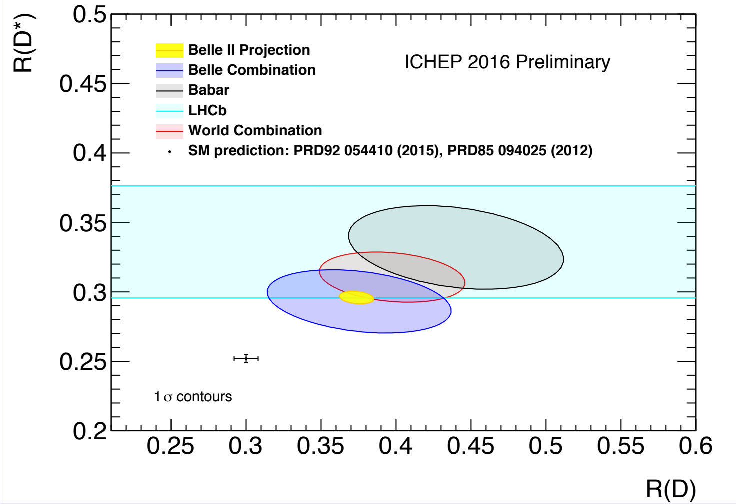
Example from Babar (but similar studies from Belle)

- background subtracted measured q^2 distribution compared to the 2HDM model for different values of $\tan\beta/m_{Higgs}$

$\tan\beta/m_{Higgs} = 0.0$ $\tan\beta/m_{Higgs} = 0.3 GeV^{-1}$ $\tan\beta/m_{Higgs} = 0.45 GeV^{-1}$



Prospects at Belle2 for $R(D)$ and $R(D^*)$



at $50ab^{-1}$ expected rel. uncertainty on $R(D) \approx 3\%$ and on $R(D^*)$ $\approx 2\%$

Prospects at Belle2 continued

- high statistics allows to look into other channels e.g. R(pi) R(D**)
- one of the biggest bkg contributions from $B \to D^{**}\ell\nu$
  - currently not well measured
  - new measurements at Belle2 can help to constrain those further
- difference between sum of measured BR for exclusive modes $\sum_i BR(B \to X_i\ell\nu)$ and the also measure inclusive BR: $BR(B \to X\ell\nu)$:
  $\Delta = BR(B \to X\ell\nu) - \sum BR(B \to X_i\ell\nu) \approx 0.7\%$
- unknown decays could pose further background to $B \to D^{(*)}\tau\nu$ analyses
- $\Rightarrow$ needs further measurements

Semitauonic analysis group

- subgroup of semi leptonic B decays analysis group
- goal to measure R(X), dN/dq^2, dN/dp_{lep}, dN/dp_D, $P(\tau)$
- channels:
  - $B \to D\tau\nu$
  - $B \to D^*\tau\nu$
  - $B \to \pi\tau\nu$; $B \to \rho\tau\nu \Rightarrow R(\pi)$; $R(\rho)$
  - inclusive $B \to X\tau\nu$ decays
  - $B \to D^{(*)}\pi\tau\nu$
  - $B \to D^{**}\tau\nu$
- around 20 collaborators expressed interest in contributing

Idea for doing the analyses

- do the analyses as group effort
- have a common skimmed dataset
- have a common analyses framework

summary

- semitauonic B decays good proving ground for testing the SM
- currently several measurement of $R(D^{(*)})$ available
- tension to the SM (need further measurements)
- several aspects where Belle2 can improve
- the next years will be exciting

BACKUP

Slide presented at the Feb. 2017 B2GM by Shigeki Hirose

BSemiTauonicDecay Model

- Implemented both in the Belle and the Belle II libraries
- Effects from NP currents can be included based on the model-independent theoretical study

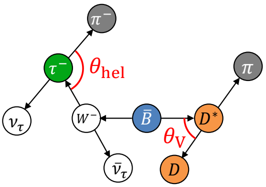
$$\mathcal{L}_{\rm eff} = -2\sqrt{2}G_F V_{cb}\left[\mathcal{O}_{V_1} + \sum_{i=V_1,V_2,S_1,S_2,T} C_i \mathcal{O}_i\right]$$

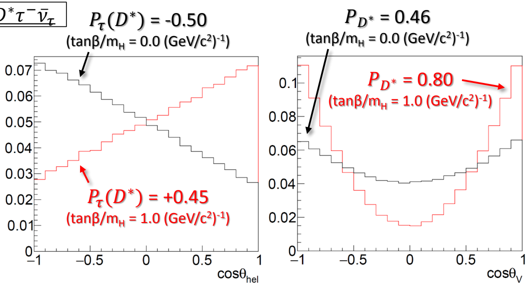
For type-II 2HDM:

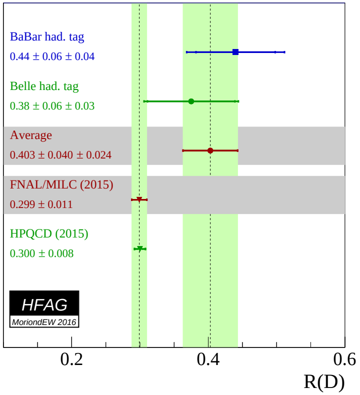
$$C_{S_1} = -m_b m_\tau \left(\frac{\tan\beta}{m_{H^\pm}}\right)^2$$

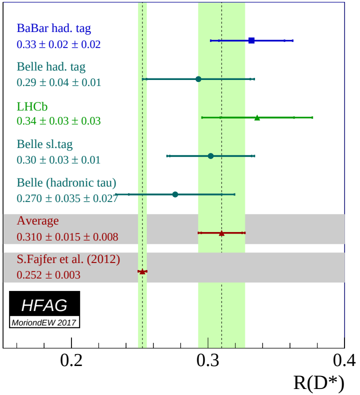
M. Tanaka and R. Watanabe, Phys. Rev. D 87, 034028 (2013)

Angular distributions for $\bar{B} \to D^* \tau^- \bar{\nu}_\tau$

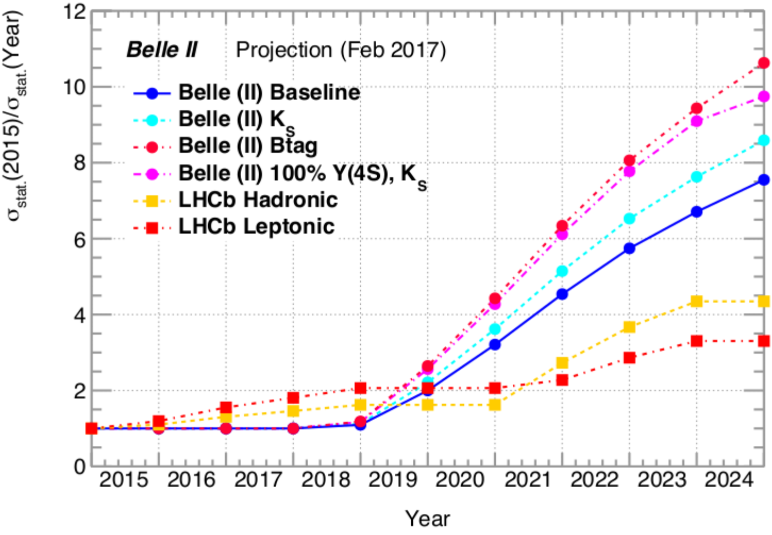





BaBar had. tag
0.44 ± 0.06 ± 0.04
Belle had. tag
0.38 ± 0.06 ± 0.03
Average
0.403 ± 0.040 ± 0.024
FNAL/MILC (2015)
0.299 ± 0.011
HPQCD (2015)
0.300 ± 0.008
HFAG
MoriondEW 2016
0.2
0.4
0.6
R(D)

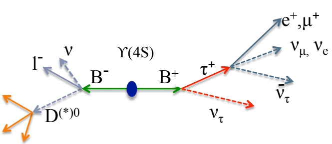

BaBar had. tag
0.33 ± 0.02 ± 0.02
Belle had. tag
0.29 ± 0.04 ± 0.01
LHCb
0.34 ± 0.03 ± 0.03
Belle sl.tag
0.30 ± 0.03 ± 0.01
Belle (hadronic tau)
0.270 ± 0.035 ± 0.027
Average
0.310 ± 0.015 ± 0.008
S.Fajfer et al. (2012)
0.252 ± 0.003
HFAG
MoriondEW 2017
0.2
0.3
0.4
R(D*)

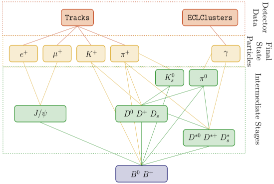
Phillip Urquijo, Tau mini workshop, Nagoya 2017



presented by Guglielmo De Nardo, Tau mini workshop, Nagoya, Japan, 27-28 March 2017

Belle II : Full event Interpretation





- Input variables used to train the multivariate classifiers:
  - PID, tracks momenta, impact parameters (charged FS particles);
  - cluster info, energy and direction (photons);
  - invariant mass, angle between photons, energy and direction (π^0);
  - released energy, invariant mass, daughter momenta and vertex quality ($D^{(*)}_{(s)}$, J/ψ);
  - the same as previous step plus vertex position, ΔE (B);
  - additionally, for each particle the classifier output of the daughters are also used as discriminating variables.

presented by Robert Kowalewski, Tau mini workshop, Nagoya, Japan, 27-28 March 2017

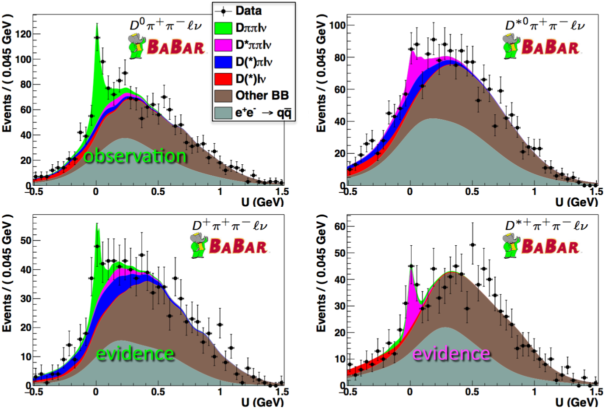
University of Victoria

VISPA – Victoria Subatomic Physics

B → $D^{(*)}\pi^+\pi^- l^- \nu$ yields

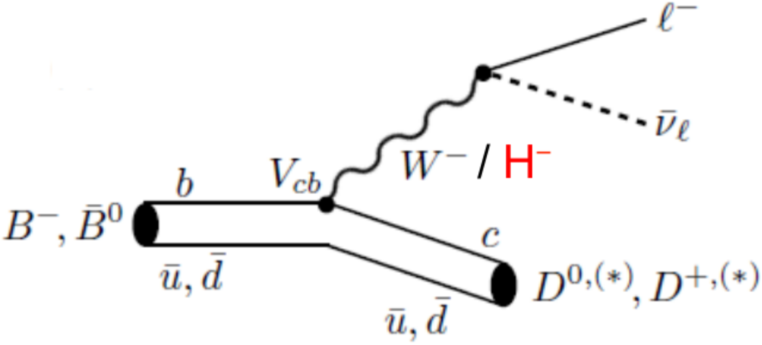
Channel	Yield	$\epsilon \times 10^4$	$\mathcal{S}$	$\mathcal{S}_{tot}$
$D^0\pi^+\pi^-\ell^-\overline{\nu}$	171 ± 30	1.18 ± 0.03	5.4	5.0
$D^+\pi^+\pi^-\ell^-\overline{\nu}$	56 ± 17	0.51 ± 0.02	3.5	3.0
$D^{*0}\pi^+\pi^-\ell^-\overline{\nu}$	74 ± 36	1.11 ± 0.02	1.8	1.6
$D^{*+}\pi^+\pi^-\ell^-\overline{\nu}$	65 ± 18	0.49 ± 0.02	3.3	3.0

BaBar PRL 116, 041801 (2016)



S = statistical significance

S_{tot} = significance with systematics



ℓ^-
$\bar{\nu}_\ell$
W^- / H^-
V_{cb}
b
$B^-, \bar{B}^0$
$\bar{u}, \bar{d}$
c
$D^{0,(*)}, D^{+,(*)}$
$\bar{u}, \bar{d}$