The International Conference on
Flavor Physics & *CP* Violation

May 12-16, 2007, Bled, Slovenia

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Belle Hot Topics

BELLE
The Belle Collaboration

The Belle Collaboration

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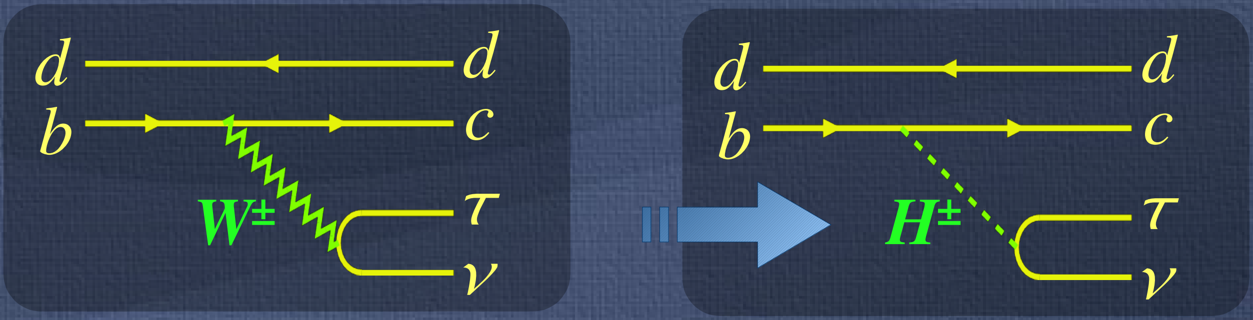
13 countries,
55 institutes,
~400 collaborators

#1: Measurement of $B^0 \to D^{*-} \tau^+ \nu_\tau$

$B \to D^* \tau \nu$: Introduction

"A Missing Piece of $B \to D^* \ell \nu$ Decays"

- $b \to c$ Tree: branching fraction of O(%).
- Tau decays provide the possibility to access more information, e.g. tau polarization.
- Theoretically clean, and is sensitive to the **charged Higgs**:



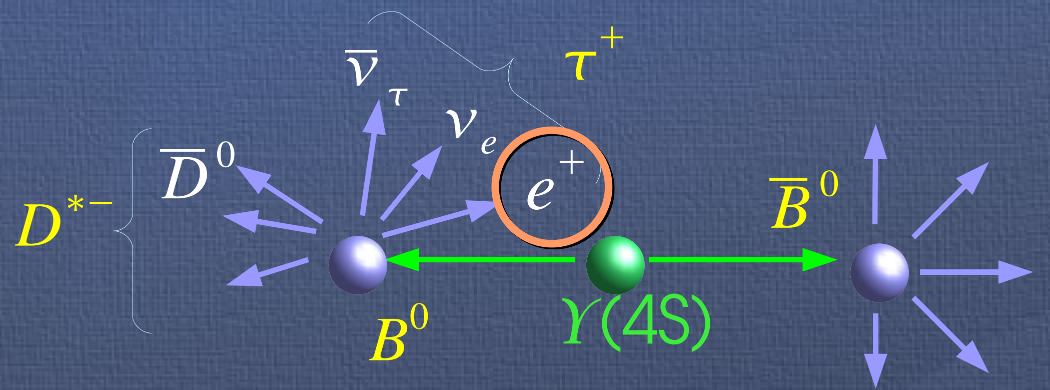
e.g. T.Miki *et. al.*, hep-ph/0210051.

- Less discussed due to the difficulty in the analysis:
  - At least two neutrinos in the final state ➔ **Large missing energy**
  - Reconstruction efficiency is low due to difficulty of reconstructing τ decays.

$B \to D^* \tau \nu$: Reconstruction

Signal Side

"Inclusively" Reconstruct a $D^* \tau \nu$ candidate:

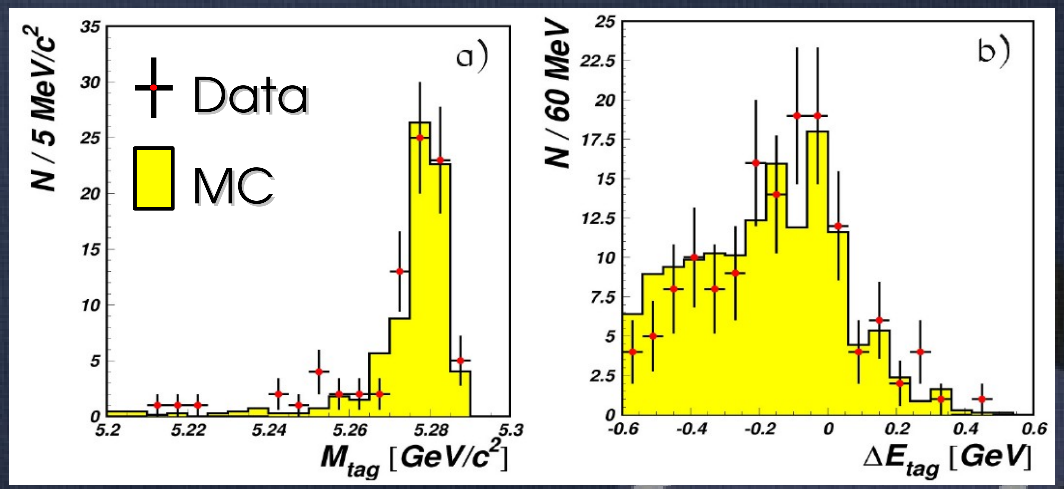


Tag Side

Sum up all the residual objects $\Sigma Q = 0$, no more leptons, etc.

- Select a clear $\boldsymbol{D^{*+}}$ & **eletron**/**positron**/**pion** from τ decays for **signal side**.
- Sub-decay modes: $\boldsymbol{D^0 \to K\pi \;/\; K\pi\pi^0,\ \tau \to e\nu_e\nu_\tau \,/\, \pi\nu_\tau}$
- Look at the recoil system, if it is consistent with a *B* meson:

Check the nominal var. "ΔE" & "M_{bc}" for tag-side (plots from $D^* \pi$ control sample)



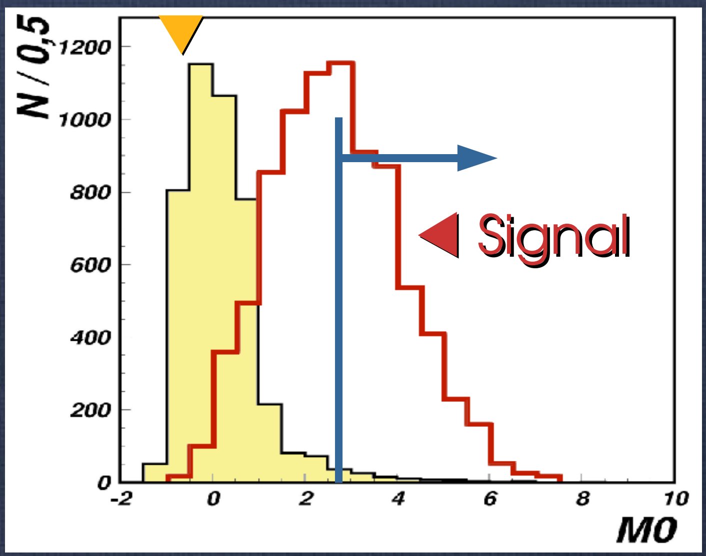
$B \rightarrow D^* \tau \nu$: Background Suppression

- Huge "peaking" background from ***$D^* e\nu$***.
- Suppressed by kinematic variables.
- The most powerful one: ***M0***
  (similar to missing mass)

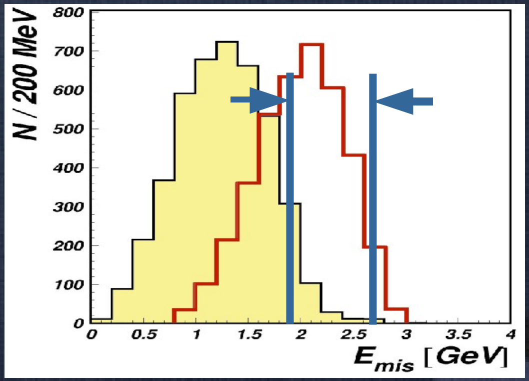
$$M0 = \frac{E_b - E_{D*} - E_{e/\pi} - |\vec{P}_{D*} + \vec{P}_{e/\pi}|}{\sqrt{E_b^2 - M_B^2}}$$

This cut kills almost all $D^* e\nu$ events.

B^0 Sample



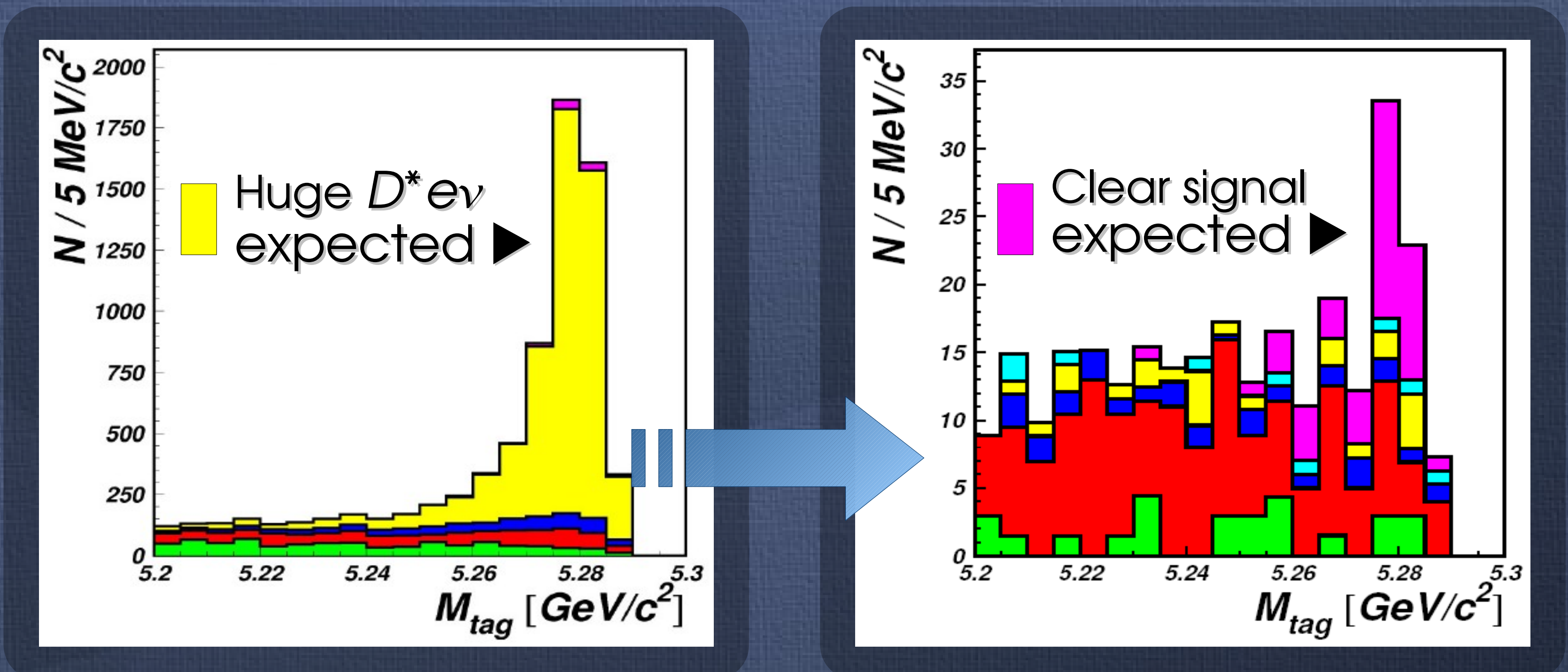
- Plus many others: e.g.
  - Missing energy
  - Visible energy
  - Invariant mass of the virtual *W*
  - Track momentum, etc.



(+ etc...)

$B \to D^* \tau \nu$: Background Suppression

- Expected M_{tag} **(=M_{bc} of tag-side)** distributions from MC:



Before Background Suppression | After Background Suppression

Signal | other τ decays | $D^* e\nu$ | $D^{**} e\nu$

Generic B decays | Continuum

$B \to D^* \tau \nu$: Results

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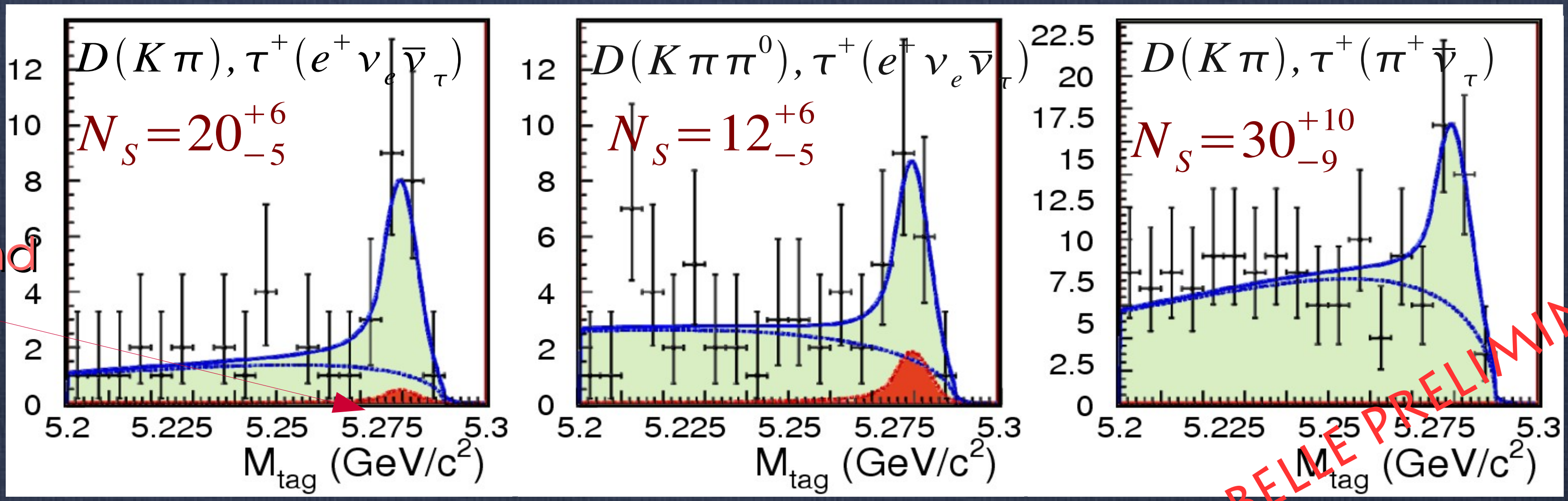
- A combined maximum likelihood fit (w/ a single *Bf*) to 3 M_{tag} distributions:

peaking background $D^* e\nu$



First observation: (3 combined)

$$Bf(B \to D^* \tau \nu) = 2.02^{+0.40}_{-0.37} \pm 0.36\,\%$$

Σ = 6.7σ (stat. only) ➔ 5.8σ (stat.+syst.)

Consistent with existing SM predictions.
More theoretical work needed for beyond SM interpretation.

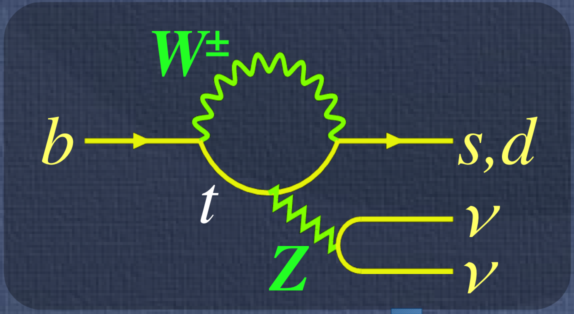
#2: Search for $B \to h^{(*)} \nu \nu$ Decays

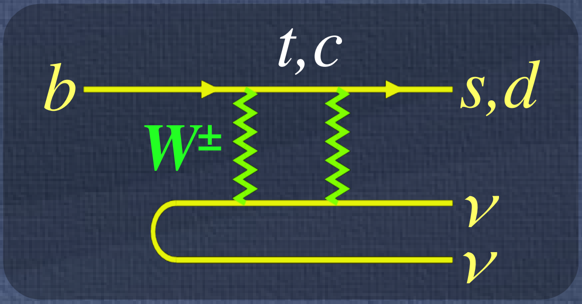
"$h^{(*)}$" stands for one of the light mesons listed below:
$K^{\pm}$, K_S, K^{*0}, $K^{*\pm}$,
$\pi^{\pm}$, π^0, $\rho^{\pm}$, ρ^0, or ϕ.

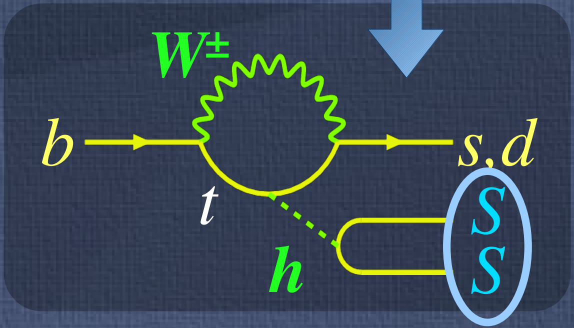
$B \to h^{(*)} \nu\nu$: Introduction

- Proceed through electroweak penguin + box diagram.
- Sensitive to the New Physics in the loop diagram.
- Theoretically clean: no long distance contributions.
- May be sensitive to light dark matter:
  For example: C. Bird, PRL 93, 201803 (2004)

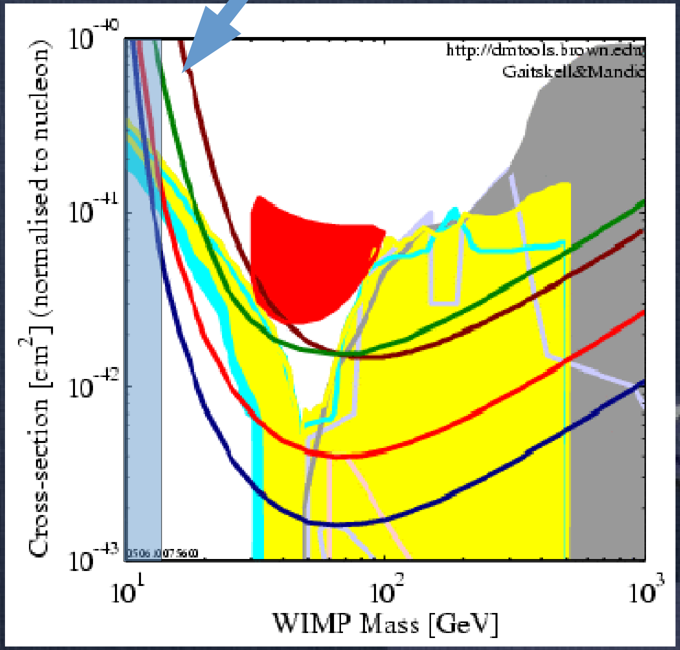
No sensitivity to light dark matter (M<10 GeV) in direct searches





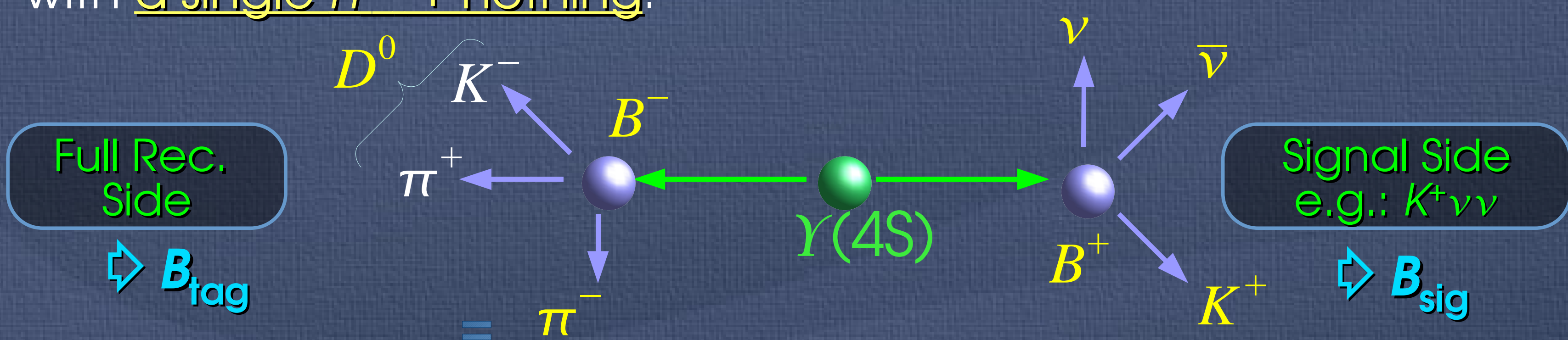


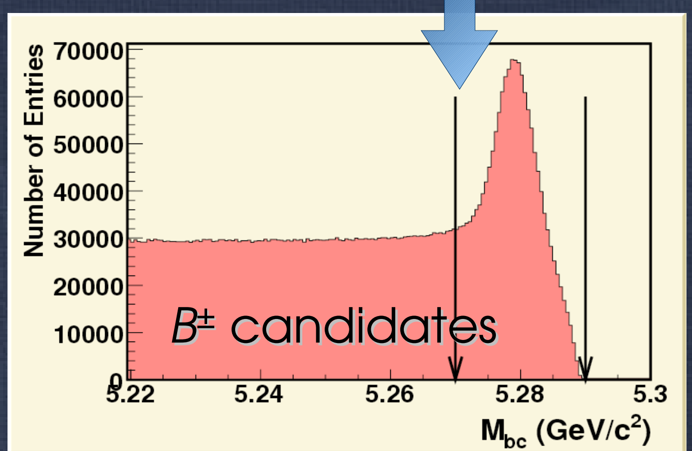
$b \to s(d)$ + Missing E may be enhanced by this extra diagram.



$B \to h^{(*)} \nu \nu$: Reconstruction

- Event signature: fully reconstruct one of the B mesons in one of the hadronic modes: $D^{(*)}\pi$, $D^{(*)}\rho$, $D^{(*)}a_1$, or $D^{(*)}D_s^{(*)}$.
- Check whether the residual energy on the tag side is consistent with a single $h^{(*)}$ + nothing.





A powerful tool for analyzing decays with missing energy/neutrinos

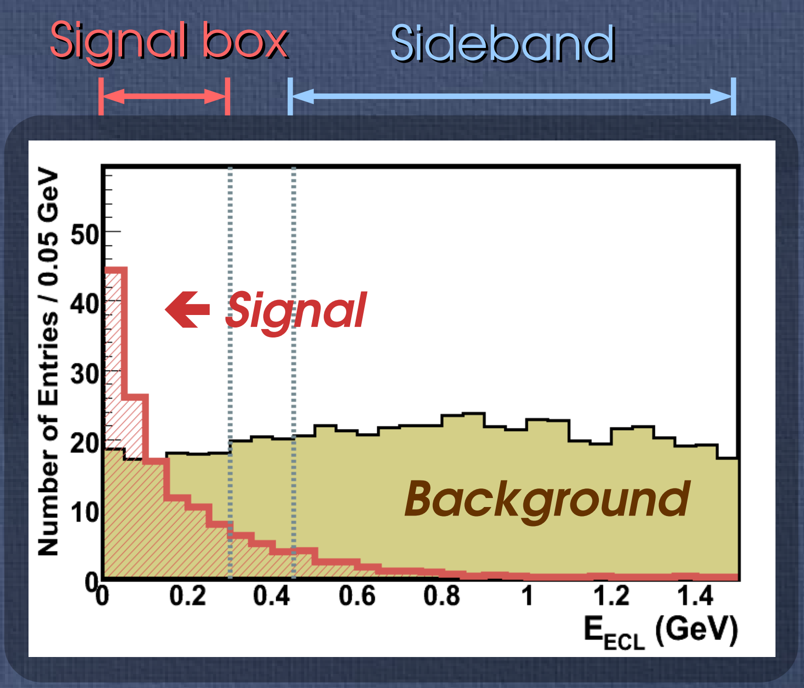
- Typical tagging rate: ~0.1–0.3%.
- B momentum & flavor are well measured.

$B \to h^{(*)}\nu\nu$: Reconstruction

Key Variable: Extra Energy in Calorimeter, E_{ECL}

- The most powerful variable for separating signal & background.
- Summation over neutral clusters that are not associated with the reconstructed B_{tag} and B_{sig}:

$$E_{ECL} = E_{total} - E_{rec.}$$



- **Signal**: zero or small E_{ECL} from beam background.
- **Background**: larger E_{ECL} due to additional neutral clusters.
- Events with any additional track or π^0 are rejected.

$B \to K^* \nu\nu$ Results

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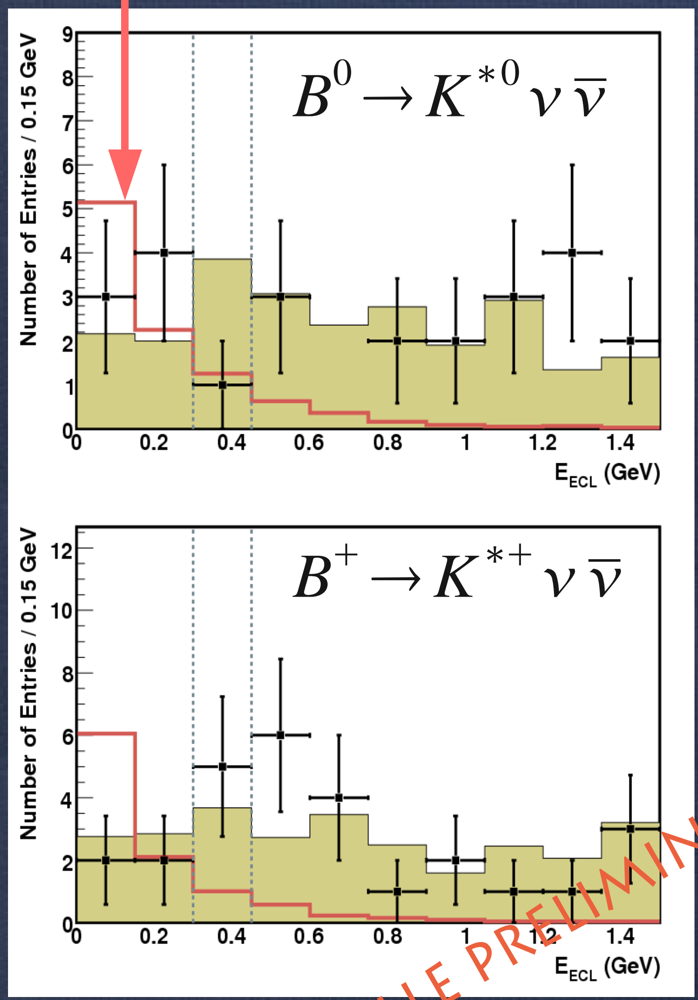
SM Branching fraction x 20



- SM Predictions:

$$Bf(B \to K^* \nu \bar{\nu}) \sim 1.3 \times 10^{-5}$$
$$Bf(B \to K \nu \bar{\nu}) \sim 4 \times 10^{-6}$$

Ref. Buchalla et al. PRD 63, 014015 (2001)

- Reconstructed modes:

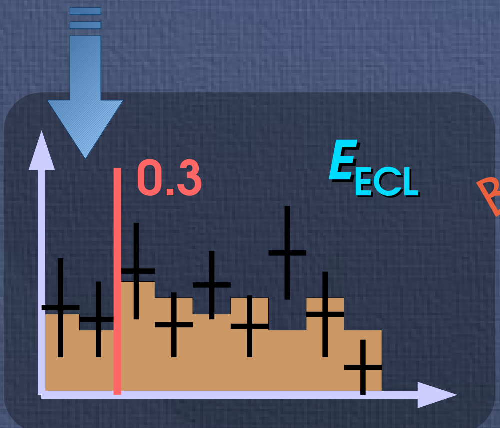
$$K^{*0} \to K^+ \pi^-, K^{*+} \to K^0_S \pi^+ \,\&\, K^+ \pi^0$$

- Supersedes summer 2006 result, with improvements on MC statistics.
- New results (U.L. @ 90% C.L.):

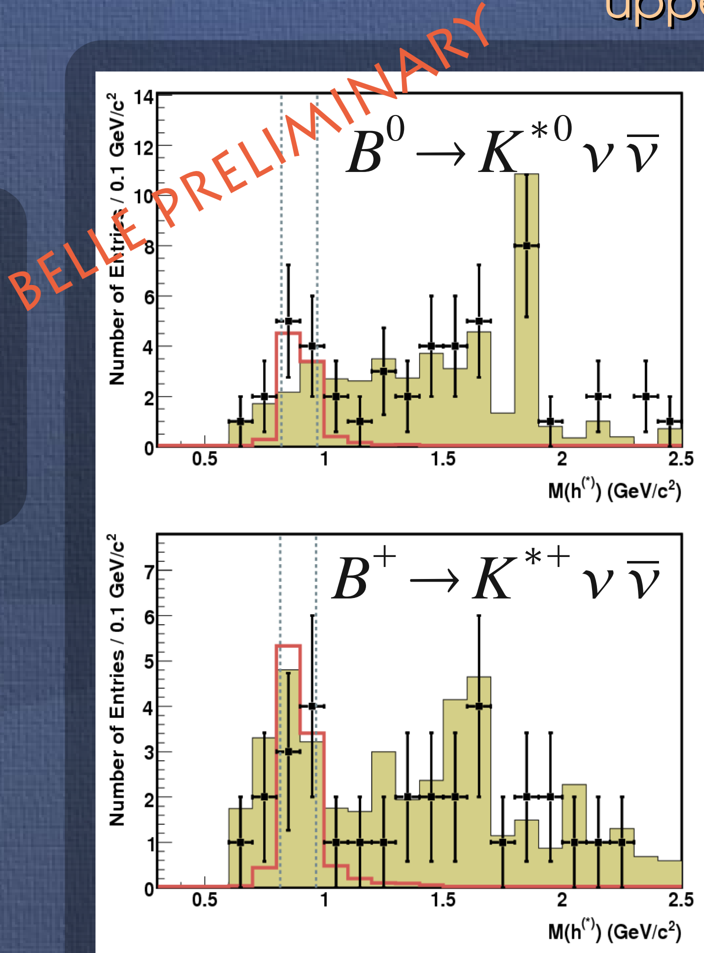
	N_{obs}	N_b	U.L.
$K^{*0} \nu \bar{\nu}$	7	4.2±1.4	< 3.4x10^{-4}
$K^{*+} \nu \bar{\nu}$	4	5.6±1.8	< 1.4x10^{-4}

$B \to K^* \nu\nu$ Results

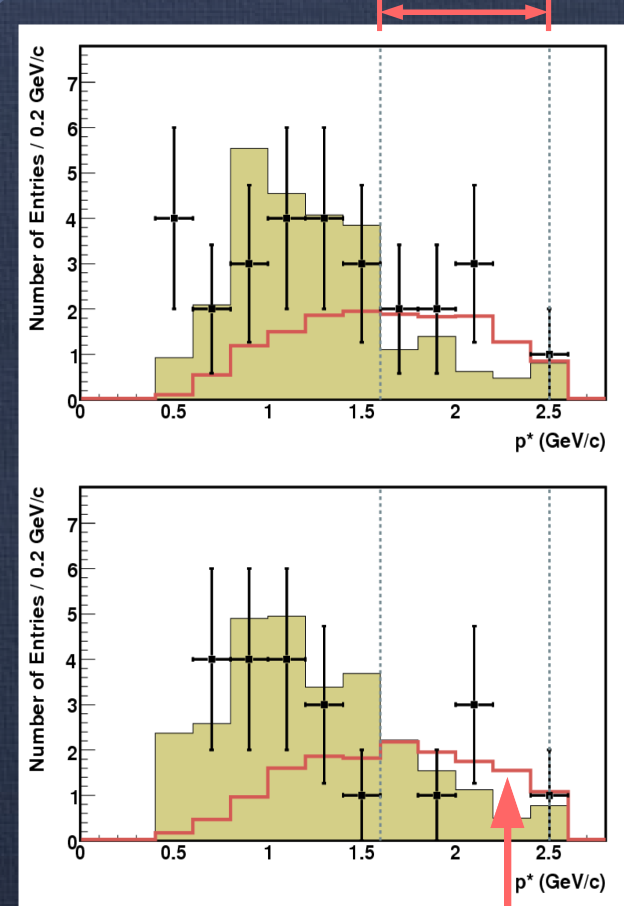
Momentum requirement (1.6-2.5 GeV/*c*)
lower bound: suppresses $b \to c$
upper bound: rejects 2-body (e.g. $K^*\gamma$)



Pickup the events in the signal box (E_{ECL}<0.3) and examine other variables:



M(Kπ)

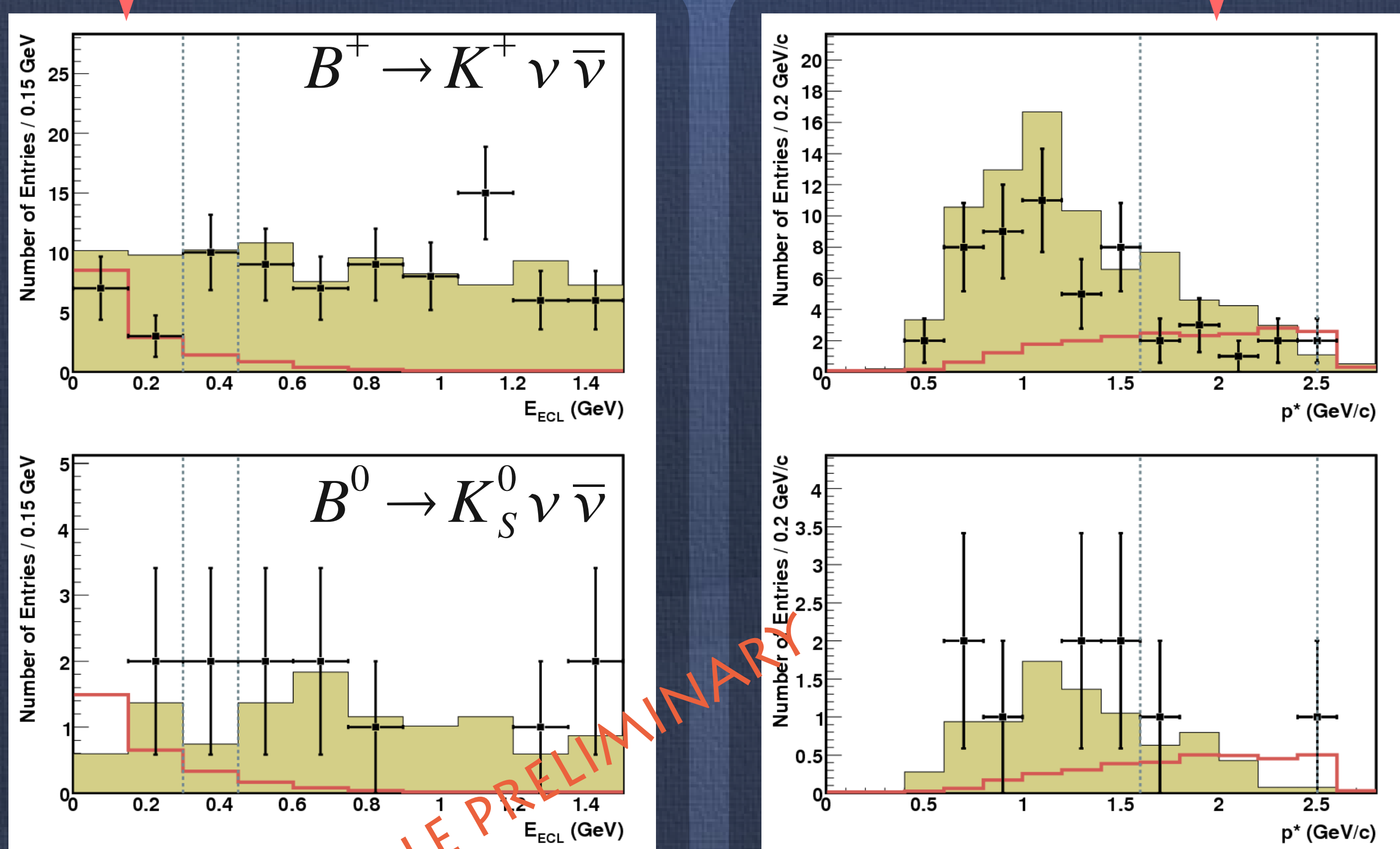


P*(K*)

SM Branching fraction x 20

$B \to K\nu\nu$ Results

Signal box

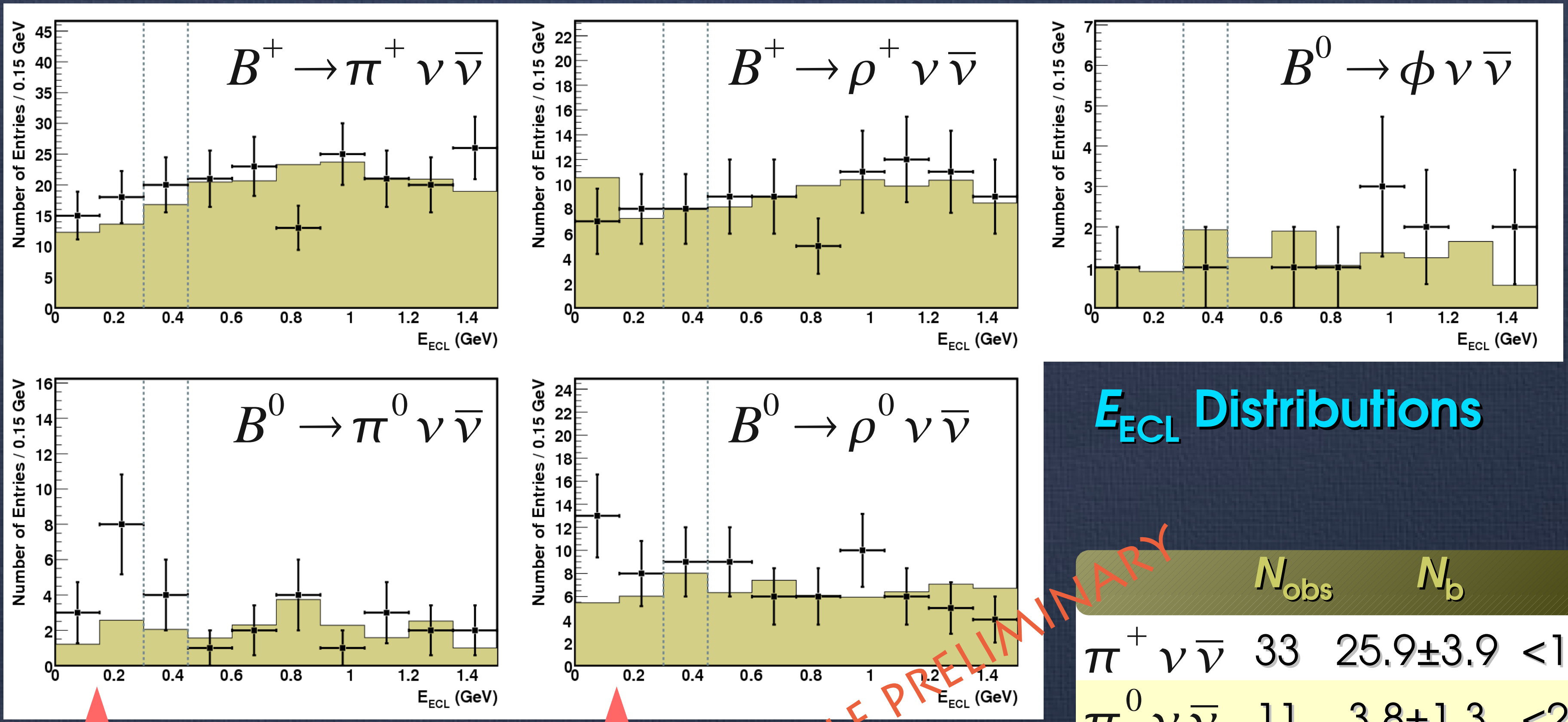


E_{ECL} $P^*(K)$

Most stringent limit, but still 3x larger then the SM branching fraction (4×10^{-6})

	N_{obs}	N_b	U.L.
$K^+ \nu \bar{\nu}$	10	20.0±4.0	**$< 1.4 \times 10^{-5}$**
$K^0 \nu \bar{\nu}$	2	2.0±0.9	$< 1.6 \times 10^{-4}$

Other Results



E_{ECL} Distributions

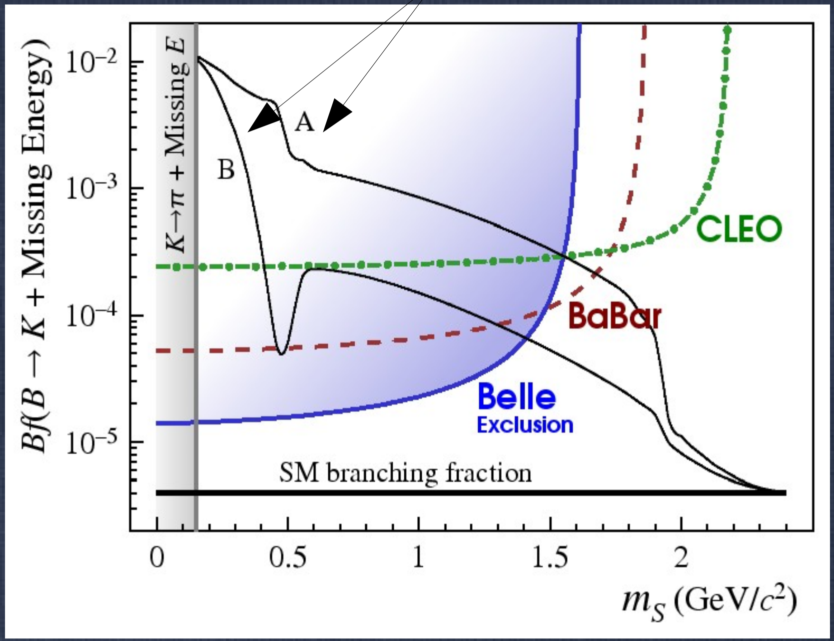
Small excess (<2σ) found, need more data to verify.

	N_{obs}	N_b	U.L.
$\pi^+ \nu \bar{\nu}$	33	25.9±3.9	<1.7x10^{-4}
$\pi^0 \nu \bar{\nu}$	11	3.8±1.3	<2.2x10^{-4}
$\rho^+ \nu \bar{\nu}$	15	17.8±3.2	<1.5x10^{-4}
$\rho^0 \nu \bar{\nu}$	21	11.5±2.3	<4.4x10^{-4}
$\phi \nu \bar{\nu}$	1	1.9±0.9	<5.8x10^{-5}

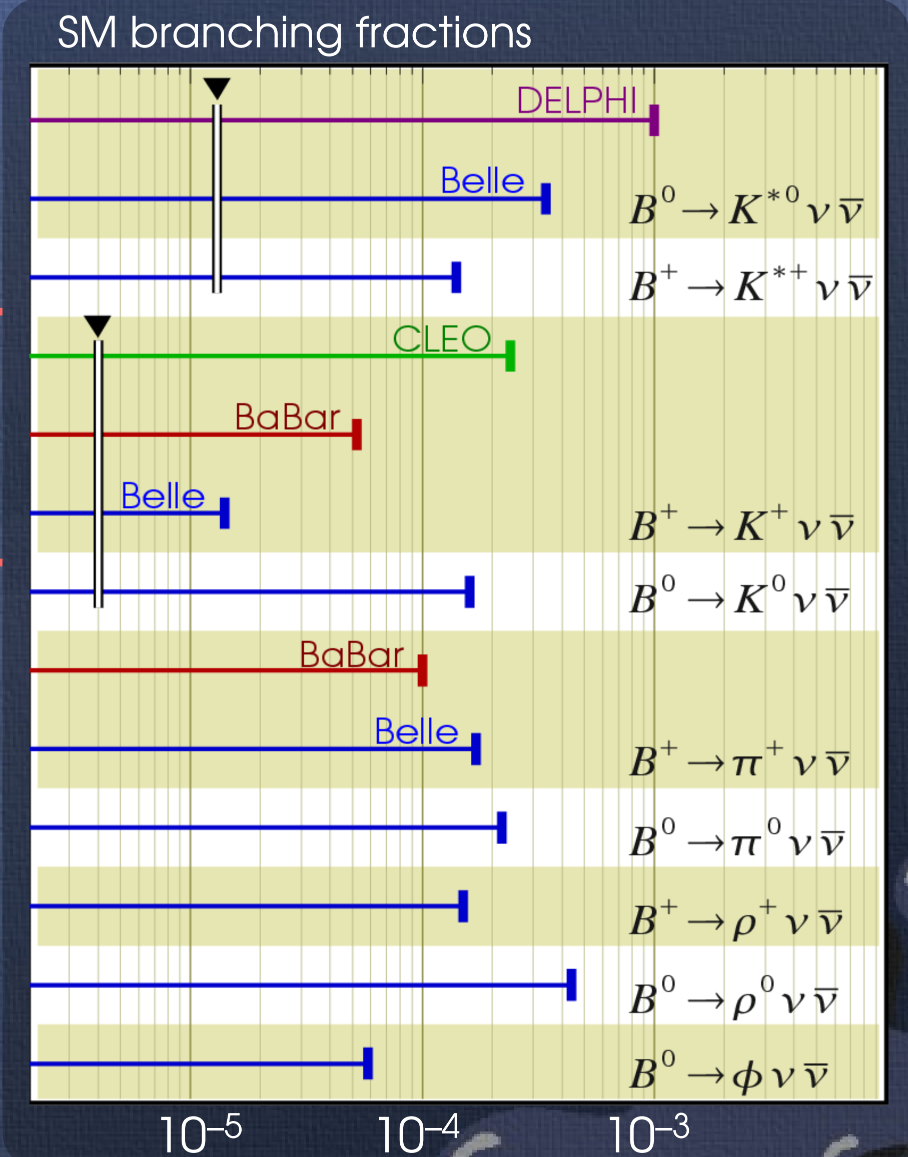
$B \to h^{(*)}\nu\nu$: Summary

- Summary of experimental limits:
- Limit on light dark matter based on $K^{+}\nu\nu$ limits:

Theoretical predictions
Ref. C.. Bird, PRL 93, 201803 (2004)



The curvature is due to the lower bound on P^*(K)



Belle Hot Topics: Summary

Summary

#1: Measurement of $B^0 \to D^{*-} \tau^+ \nu_\tau$

- **FIRST OBSERVATION** of $B \to D^* \tau \nu$ with a significance of **5.8σ**.
- Further theoretical interpretation is necessary.
  (e.g. Precise SM branching fraction & relationship with charged Higgs.)

#1: Search for $B \to h^{(*)} \nu \nu$ Decays

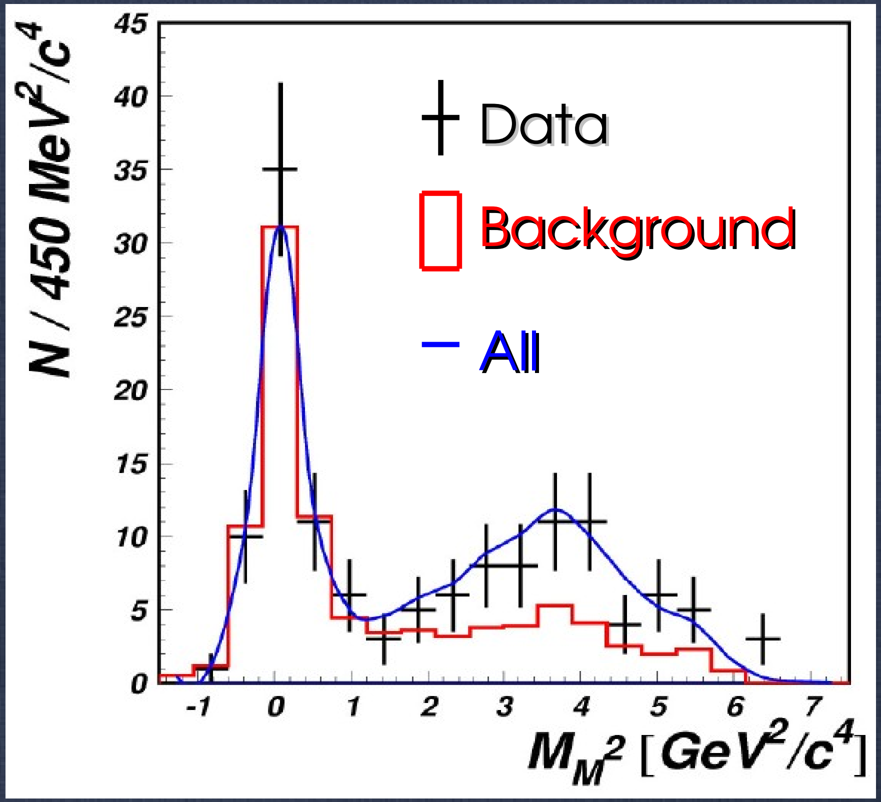
- **6 NEW MEASUREMENTS** ($K^{*+}\nu\nu$, $K_S\nu\nu$, $\pi^0\nu\nu$, $\rho^0\nu\nu$, $\rho^+\nu\nu$, and $\phi\nu\nu$).
- No significant signal found for $h^{(*)}\nu\nu$ decays, upper limits at 90% C.L. are calculated.
- A bound on possible light dark matter is provided by $K^+\nu\nu$ limit.
- A much larger data set is required to probe SM branching fractions.

➔ Look forward to a Super *B* Factory!

... and enjoy the conference!

Backup Slides

$B \to D^* \tau \nu$: Fit to Missing Mass



- Extract the signal yield with the squared missing mass (M_M^2) distribution, instead of Mbc of tag-side (M_{tag}).
- Obtained branching fraction:

$$Bf(B \to D^* \tau \nu) = 1.83 \pm 0.43\ \%$$

Consists with the fits to M_{tag}

$$Bf(B \to D^* \tau \nu) = 2.02^{+0.40}_{-0.37} \pm 0.36\ \%$$

BACKUP SLIDES

$B \to D^* \tau \nu$: Projections

- Check the events in the signal box for other variables: