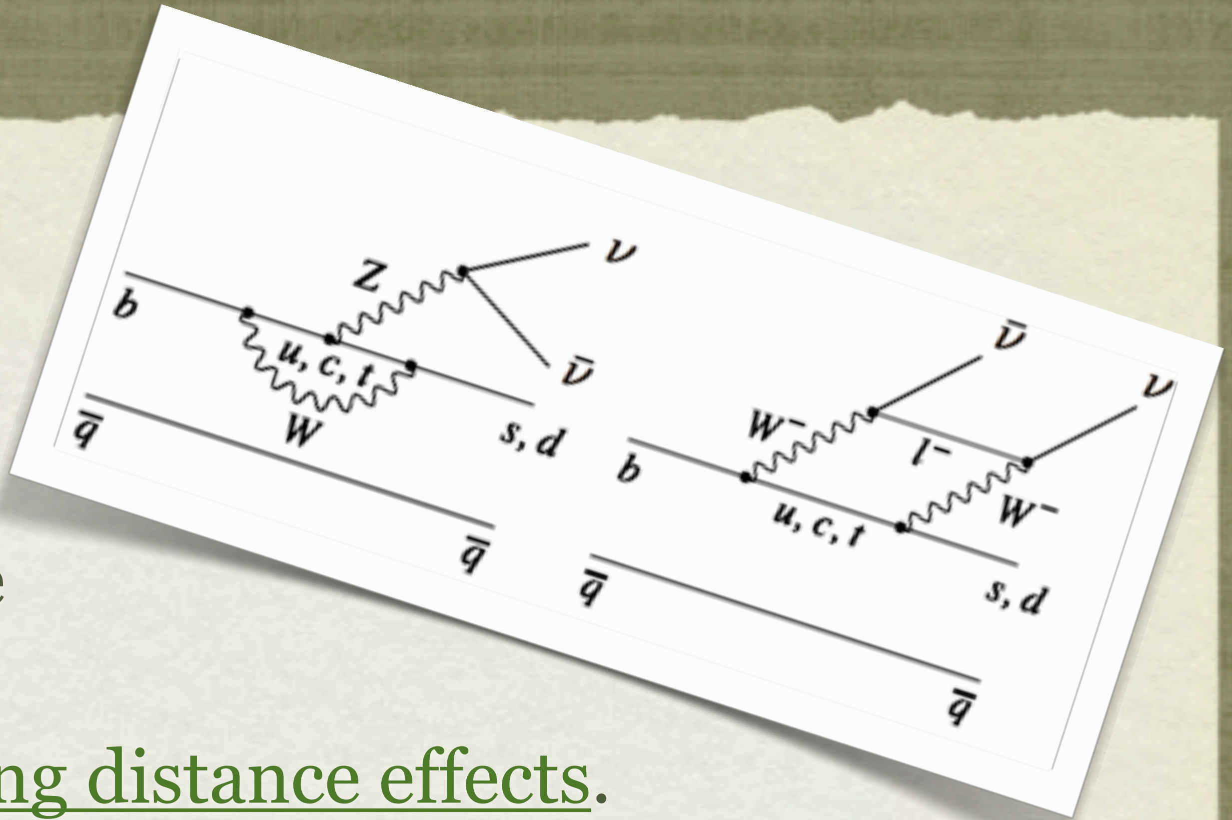
$b \to s,d\nu\bar{\nu}$ FROM B-FACTORIES

KAI-FENG CHEN
NATIONAL TAIWAN UNIVERSITY

INTRODUCTION & MOTIVATION



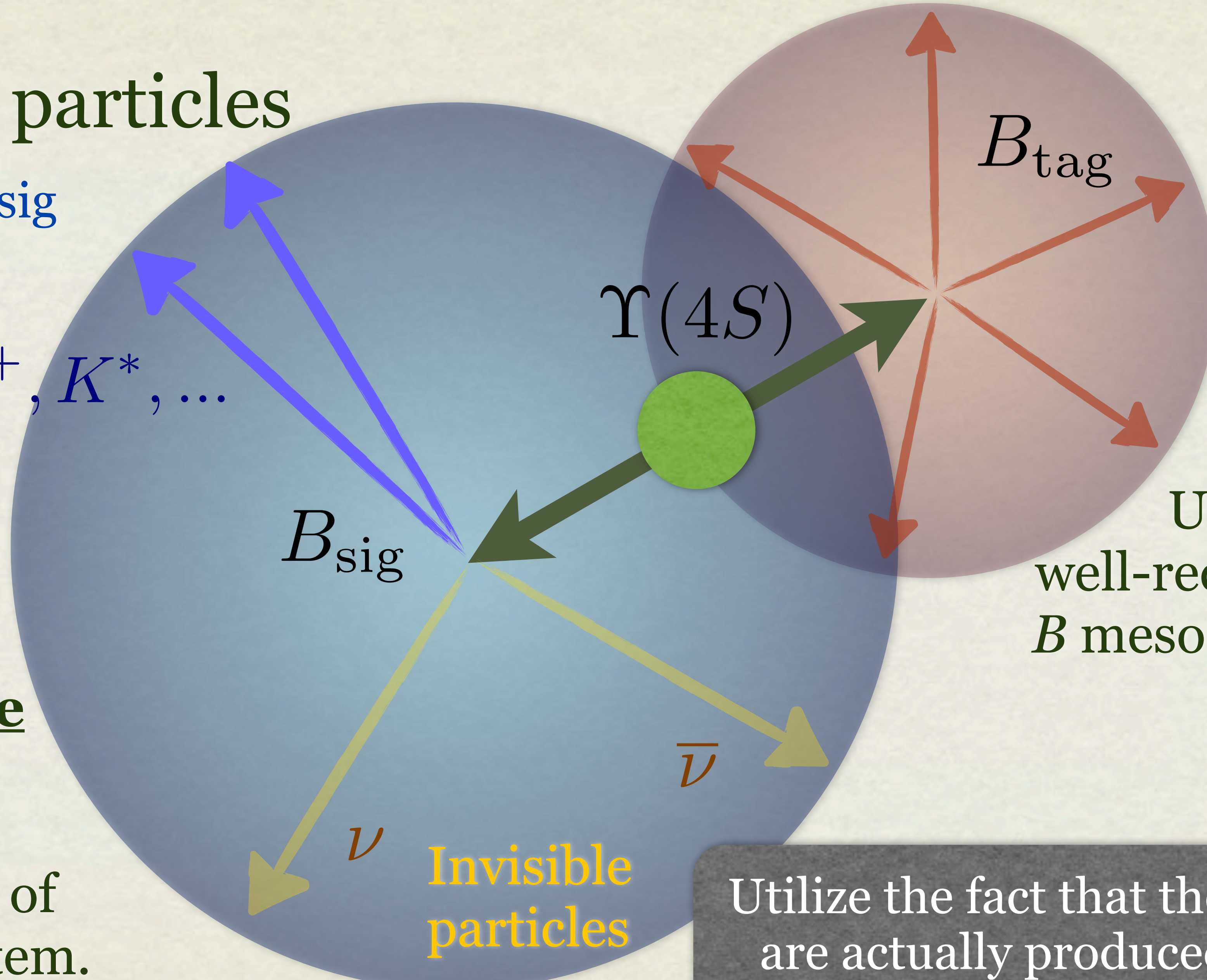
- The FCNC $b \to s(d)\nu\nu$ processes only occur via *Z*-penguin or *W*-box diagrams.
- The decay branching fractions in the Standard Model are small, but:
  - Theoretically clean: absence of long distance effects.
  - Loop processes are ideal places to look for new physics, e.g.
    - Light scaler dark matter;
    - MSSM through chargino or charged Higgs;
    - Extra dimensions;
    - Unparticle;
    - etc.

If any of these NP exists, we should observe a large boost on the $b \to s(d)\nu\nu$ branching fractions!


WANTED
B mesons decaying into a kaon or a pion together with invisible neutrinos

EXPERIMENTAL TECHNIQUE

Visible particles from B_{sig}



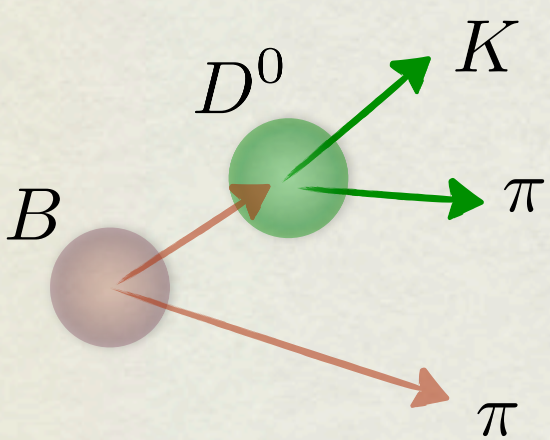
Using a well-reconstructed B meson as a "**tag**"

Require **no particle** and **no energy** left after removing B_{tag} and visible particles of B_{sig} in the recoil system.

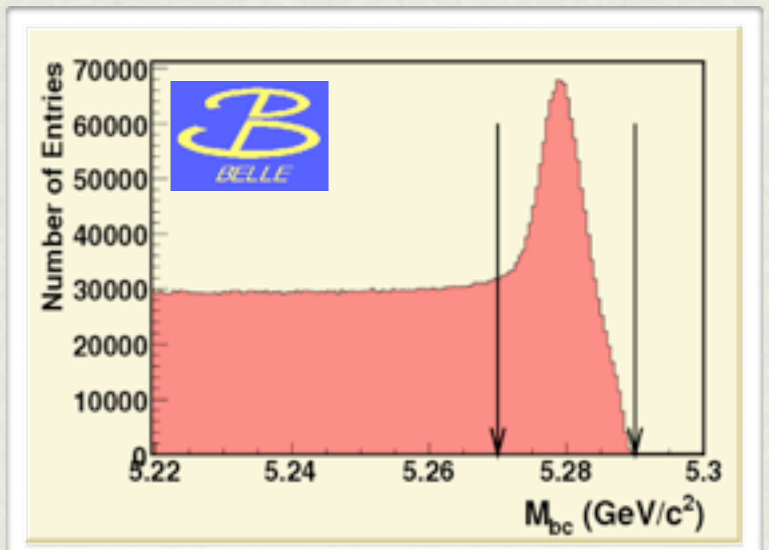
Utilize the fact that the B mesons are actually produced through Υ(4S) at B-factories.

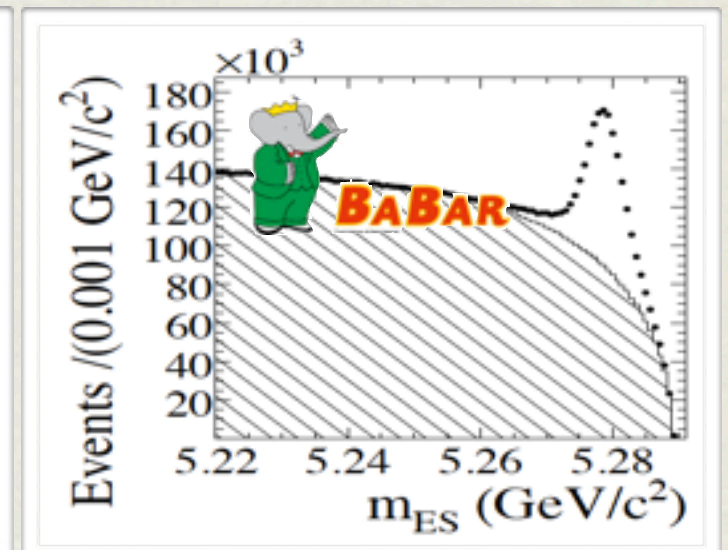
TAG B MESONS IN HADRONIC CHANNELS

- Belle: Fully reconstruct B mesons in one of the hadronic channels, e.g. $D^{(*)}\pi$, $D^{(*)}\rho$, $D^{(*)}a_1$, $D^{(*)}D_s^{(*)}$, etc.
- BaBar: Full reconstruction with $D^{(*)}$ + many light hadrons (include hadrons up to 5 K^+/π^+, up to 2 K_S, and up to 2 π^0)



Identify the signal with ΔE and M_{bc} / M_{ES}

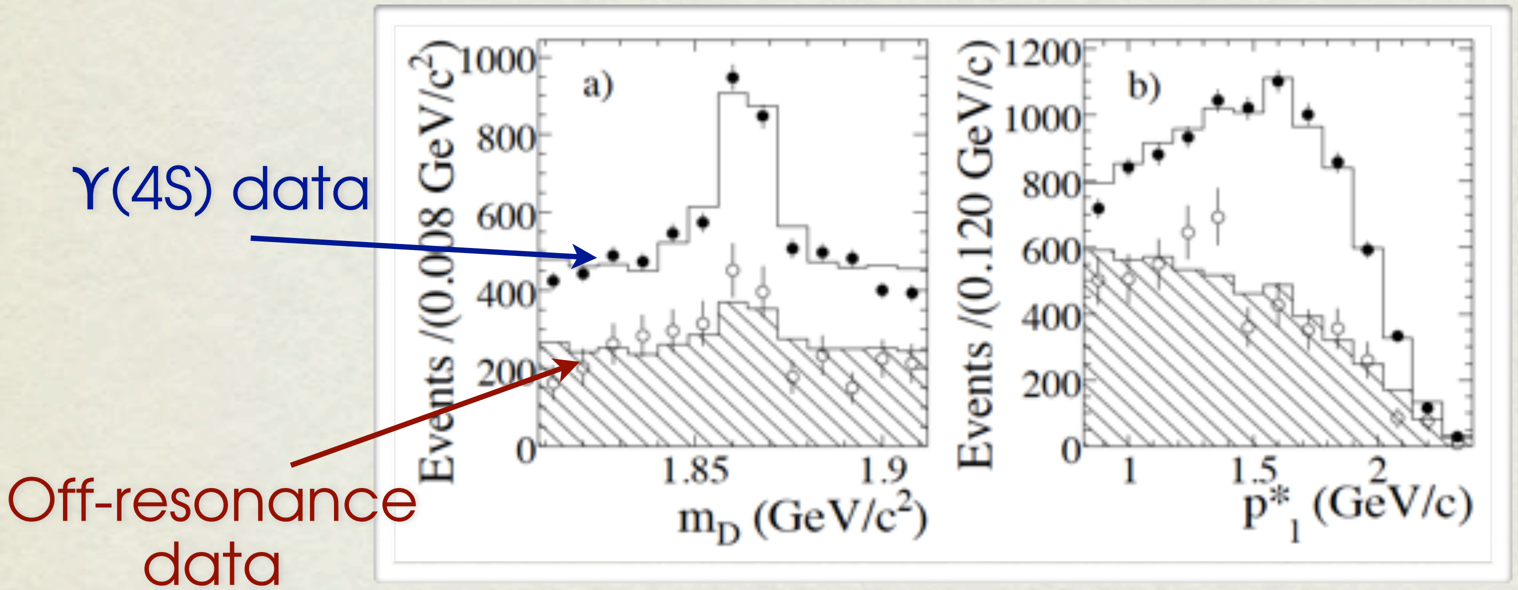




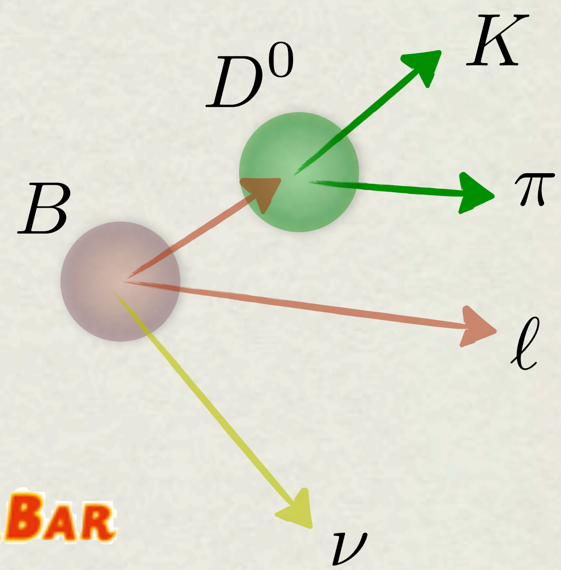
Pro: Higher purity, good resolution, full kinematics can be examined.
Con: Lower efficiency (can be as low as 0.1~<1%)

TAG B MESONS IN SEMILEPTONIC CHANNELS

- BaBar: Reconstruct a $B \to D^{(*)} l\nu$ decay with a clean $D^{(*)}$ meson plus a high momentum charged lepton.
- Belle: Not implemented for this analysis yet.



histograms are the MC distributions.



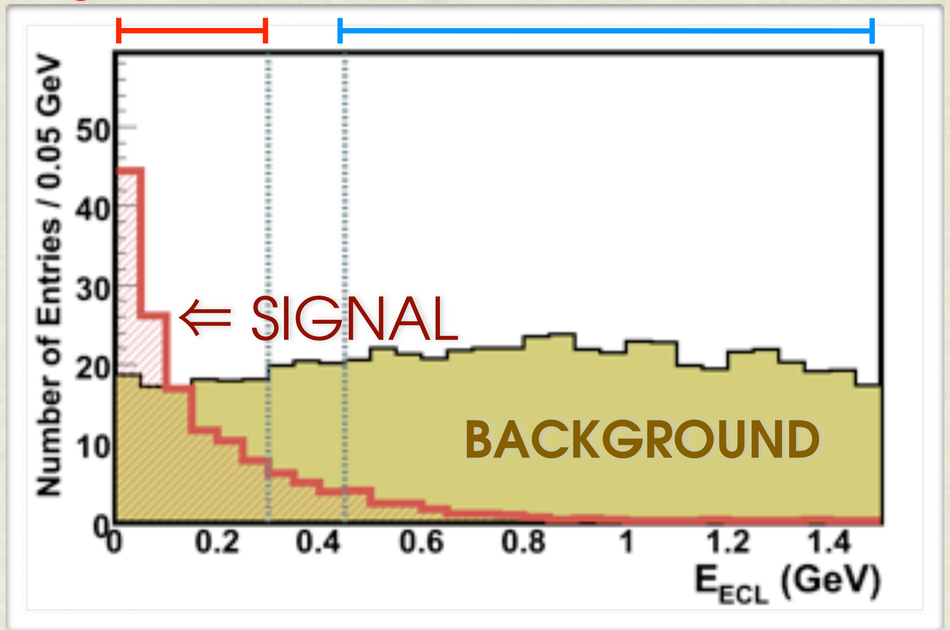
Pro: Higher efficiency

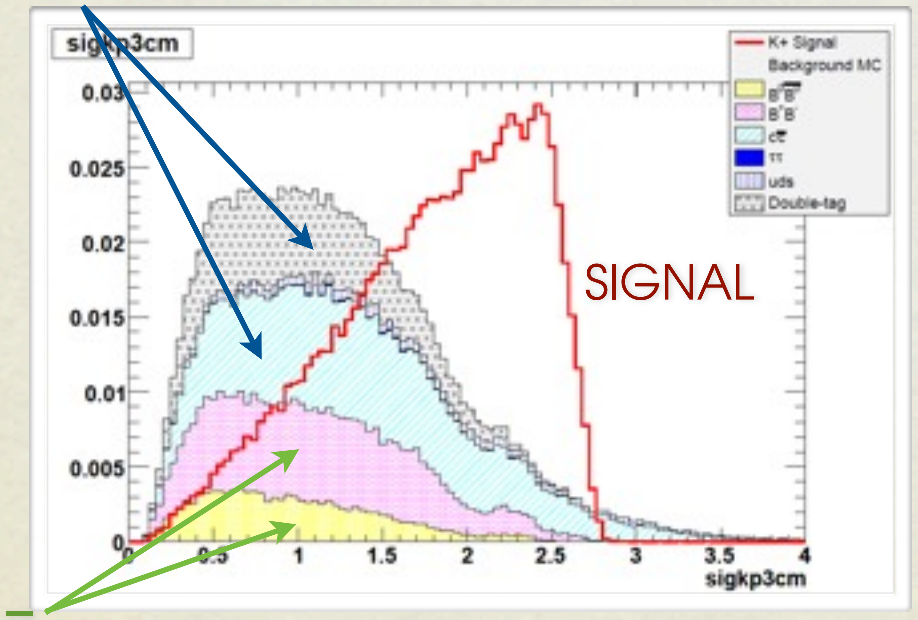
Con: Lower purity, bad resolution, additional neutrino

KEY KINEMATICAL VARIABLES

Extra energy in calorimeter

- The most powerful variable for separating signal and background.
- Sum up neutral clusters that are not associated with B_{tag} and B_{sig}.
- Signal: zero or tiny extra energy from beam background.



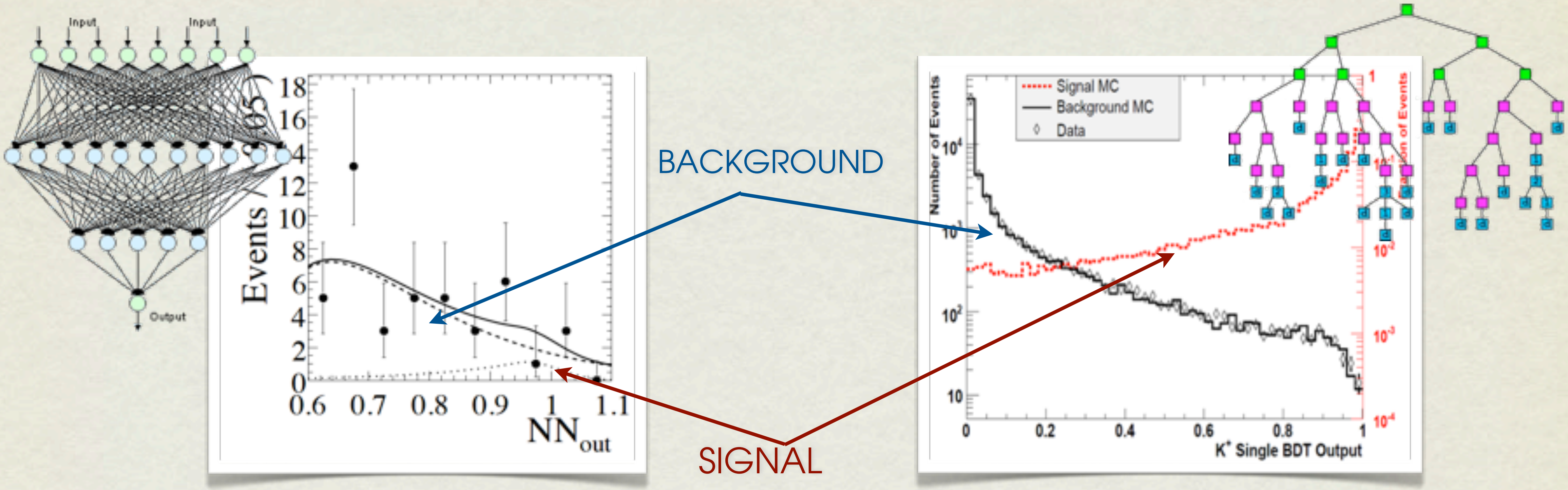


Momentum of visible B_{sig} daughter(s)

- Signal: large momentum according to the kinematic constraint of $b \to s(d)\nu\nu$.
- However, tight selection also reduces the sensitivity to the heaver invisible NP particles, e.g. dark matters.

MULTI-VARIANT ANALYSIS

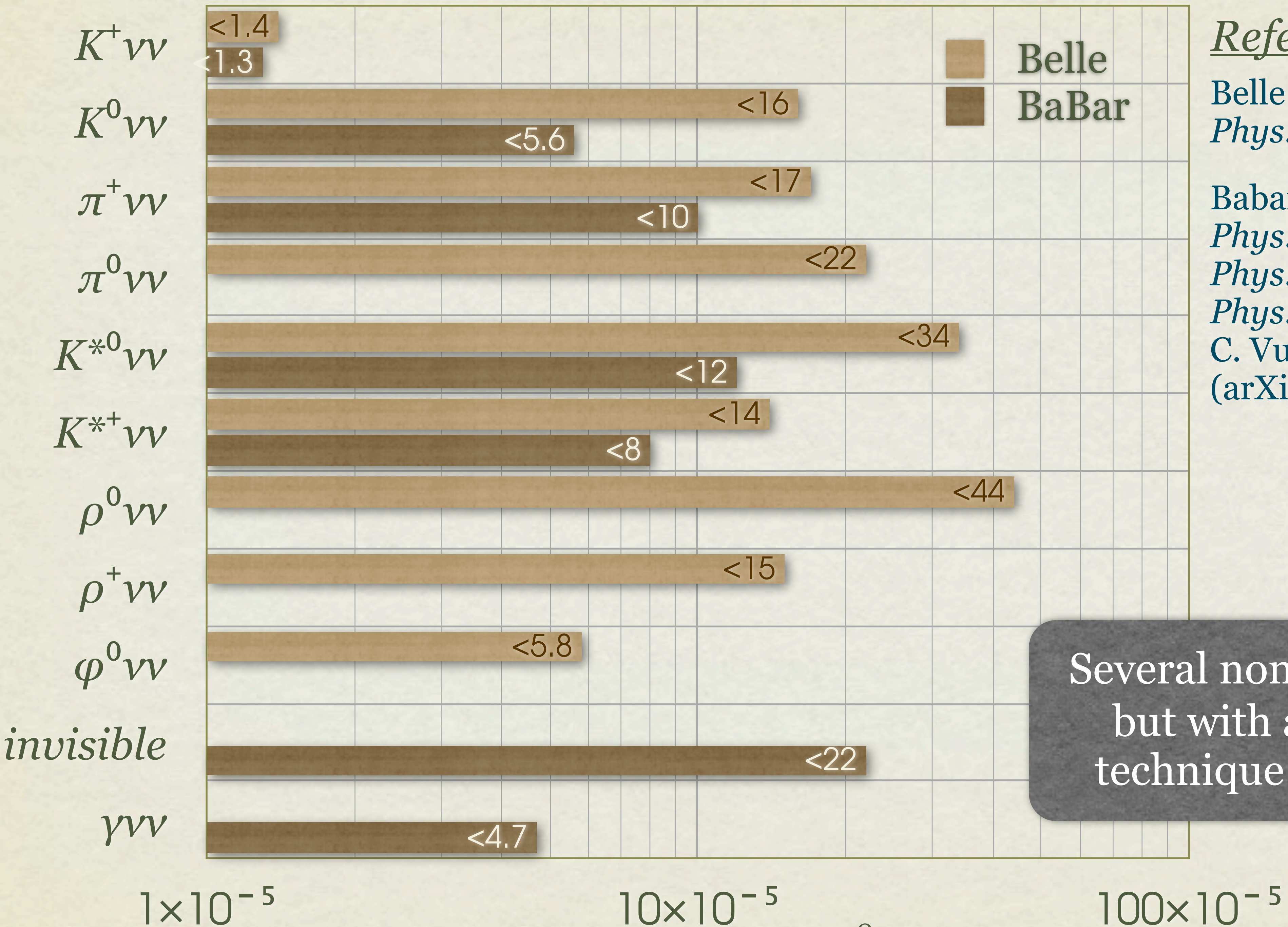
- BaBar has adopt some multi-variant analysis tools in order to improve the sensitivity for $K^+\nu\nu$ and $K^*\nu\nu$.



Neutral network is used in BaBar's $B \to K^*\nu\nu$ hadronic tag analysis. These variables are included: R2, $\cos\theta^*(B_{tag},T)$, $E_{miss} + P_{miss}$, $\cos\theta_{miss}$, M_{K^*}, M_{Ks}, E_{Extra}

Bagged decision tree is introduced in $B \to K^+\nu\nu$ and $K^0\nu\nu$, total 26/38 variables included for K^+/K^0 leptonic tag analysis: Signal kinematics, tag qualities, missing qualities, event qualities, e.g. E_{Extra}, P^*_K, $\cos\theta^*_K$, E_{miss}, P_{miss}, ...

RESULTS TO BE SHOWN IN THIS PRESENTATION



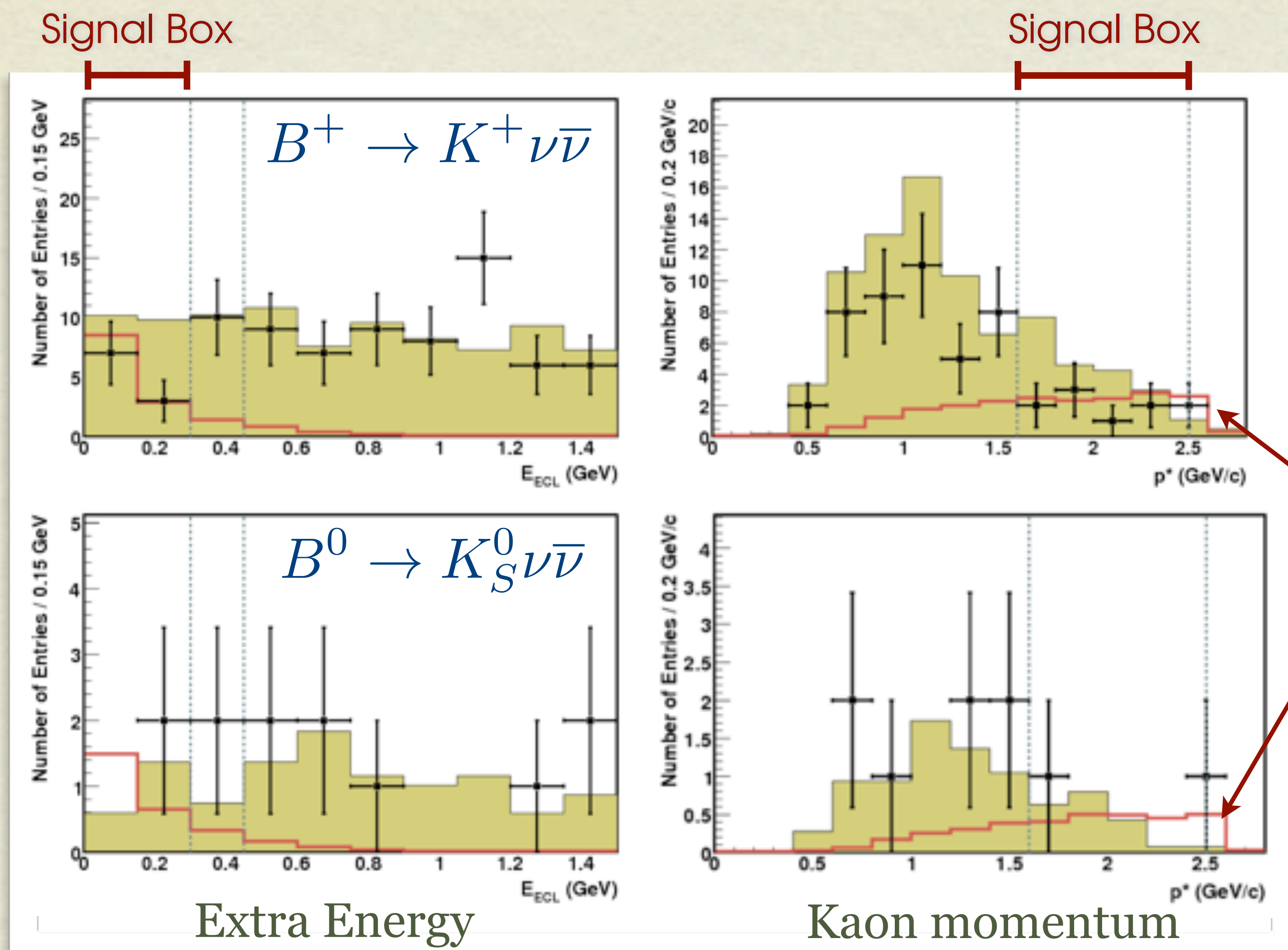
References

Belle Collaboration
Phys. Rev. Lett. 99, 221802 (2007)

Babar Collaboration
Phys. Rev. Lett. 93, 091802(2004)
Phys. Rev. Lett. 94, 101801 (2005)
Phys. Rev. D78, 072007 (2008)
C. Vuosalo's talk at LLWI'10
(arXiv:0911.1988)

Several non-b→*s,d$\nu\nu$* channels but with a similar analysis technique are also included.

$B \to K^+\nu\nu$ & $K^0\nu\nu$



Belle
535M

Phys. Rev. Lett. 99, 221802

Expected signal x 20
(with SM BF ~ 4×10^{-6} x 20)

- Belle hadronic tag analysis with a robust cut-and-count method:

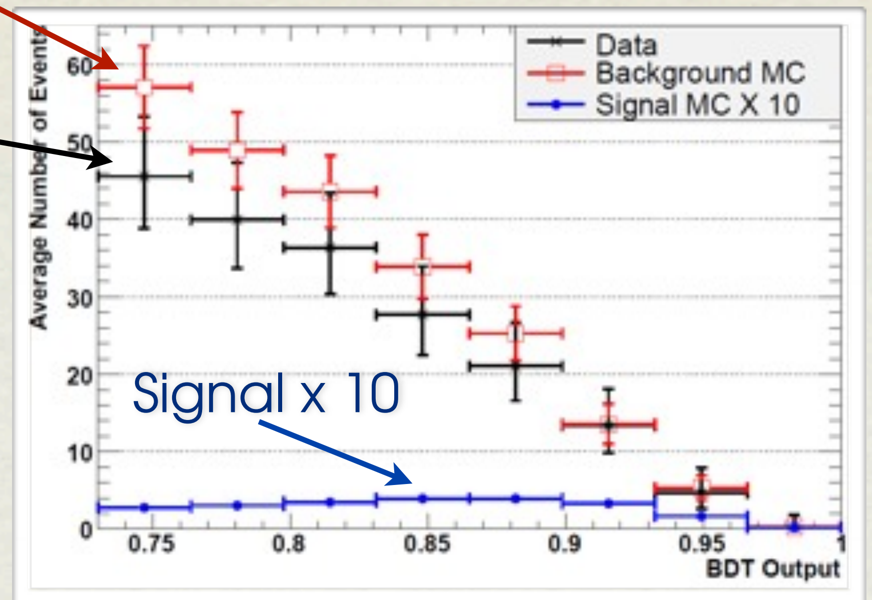
	N_{obs}	N_b	U.L.
$K^+\nu\nu$	10	20.0±4.0	< 1.4×10^{-5}
$K^0\nu\nu$	2	2.0±0.9	< 1.6×10^{-4}

$B \to K^+\nu\nu$ & $K^0\nu\nu$

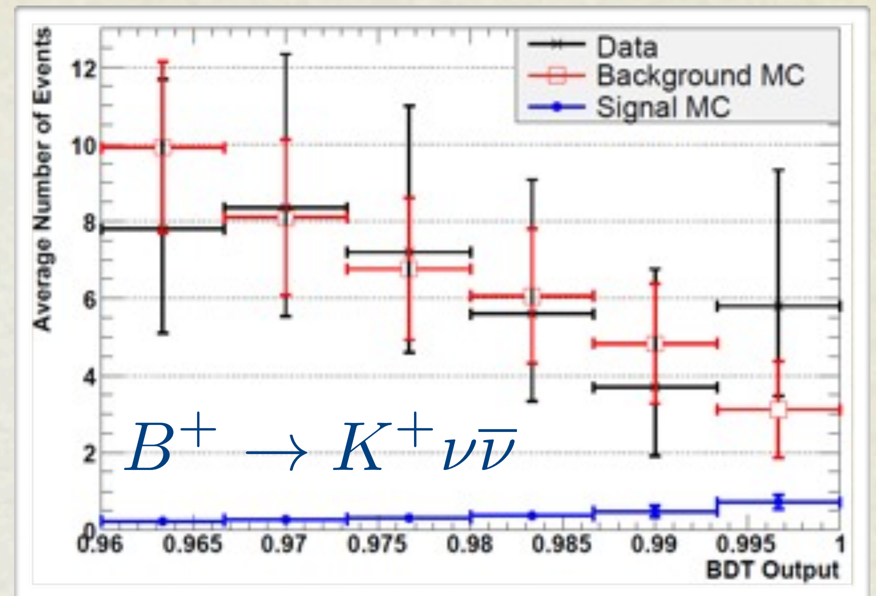
BaBar 459M

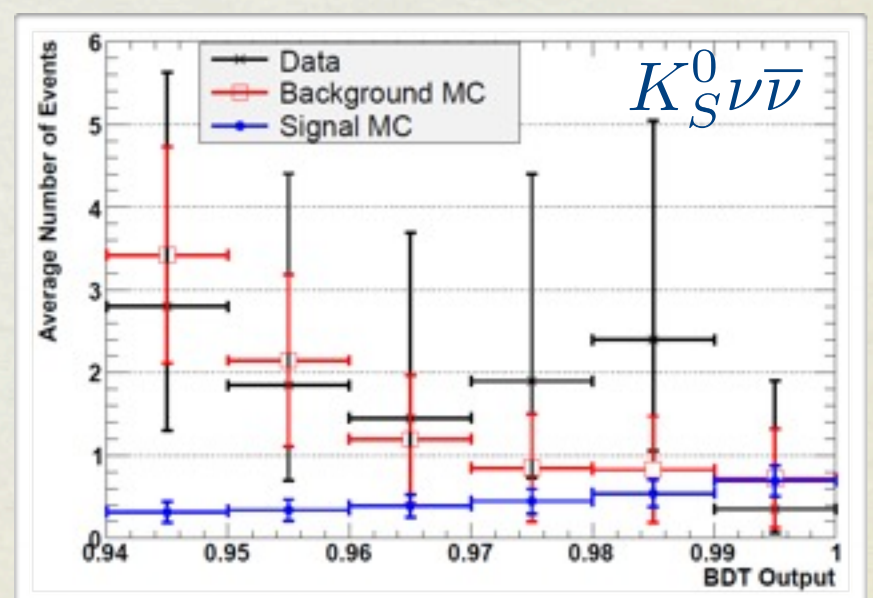
- BaBar semi-leptonic tag analysis with Bagged Decision Tree classifier:

$P^*_K < 1.5$ GeV/c



$P^*_K > 1.5$ GeV/c



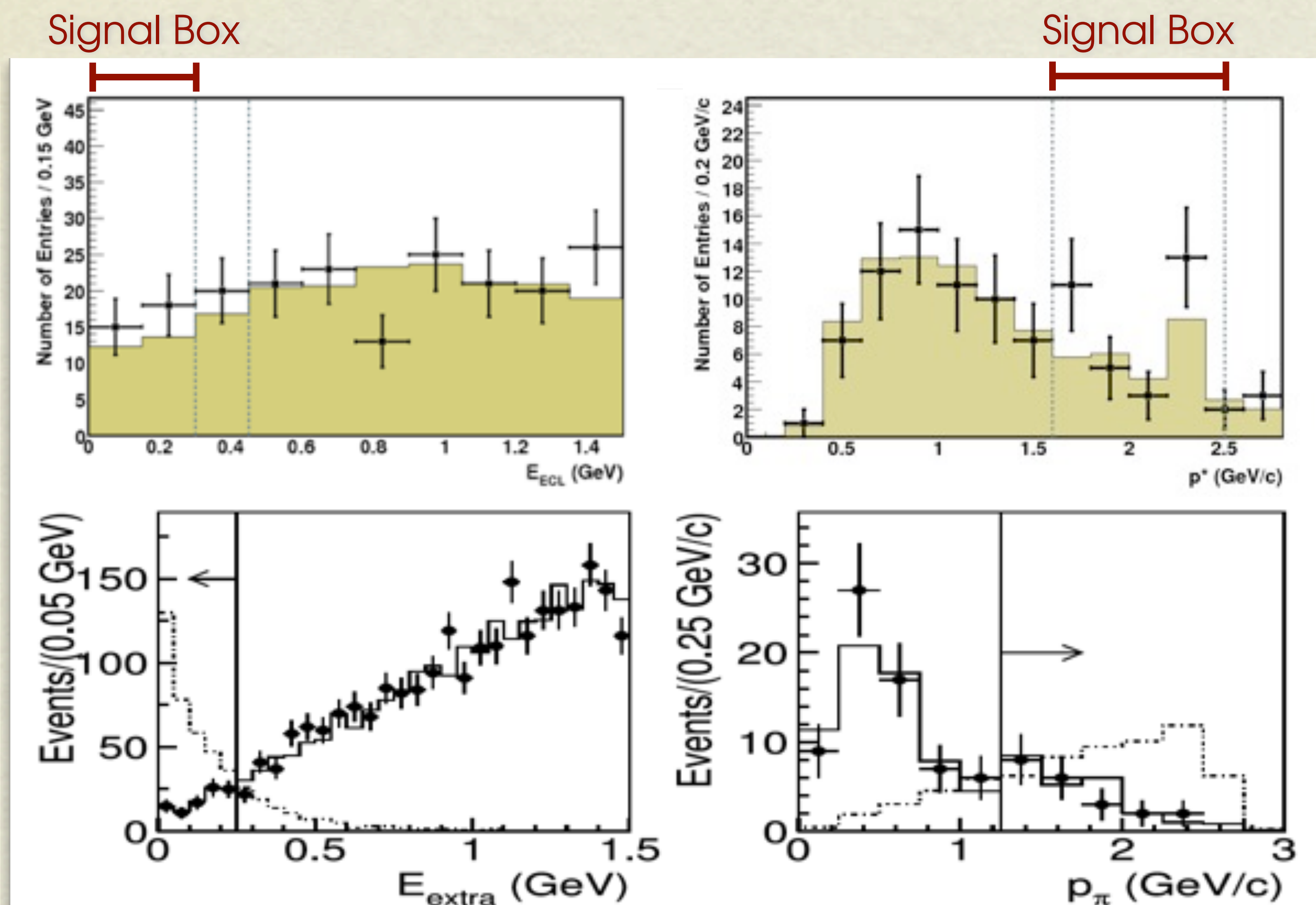


The most stringent limit to date, but it's still 3x larger then the SM branching fraction.

	N_{obs}	N_b	U.L.
$K^+\nu\nu$ (high P^*_K)	19.4±4.4	17.6±2.8	$< 1.3 \times 10^{-5}$
$K^+\nu\nu$ (low P^*_K)	164±13	187±47	
$K^0\nu\nu$	$6.1^{+4.0}_{-2.2}$	3.9±1.4	$< 5.6 \times 10^{-5}$

Ref. C. Vuosalo's talk at LLWI'10

$B \rightarrow \pi^+ \nu \nu$



Extra Energy

Pion momentum

Belle
535M
Phys. Rev. Lett. 99, 221802

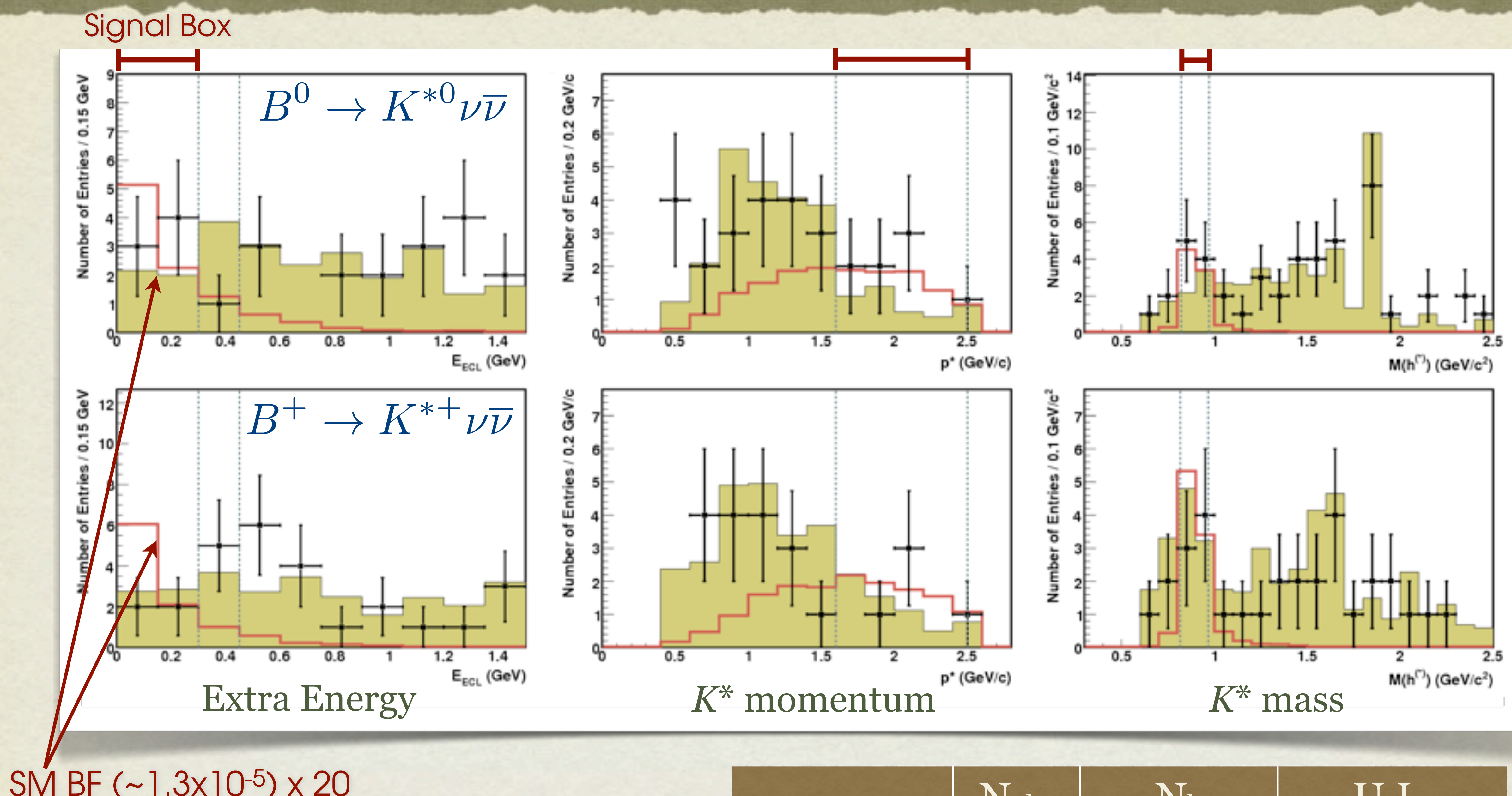
BaBar
89M
Phys. Rev. Lett. 94, 101801

- Belle/BaBar hadronic tag analysis:

	N_{obs}	N_b	U.L.
Belle	33	25.9±3.9	< 1.7 x 10^{-4}
BaBar	21	24.1±3.6	< 1.0 x 10^{-4}

$B \to K^{*+}\nu\nu$ & $K^{*0}\nu\nu$

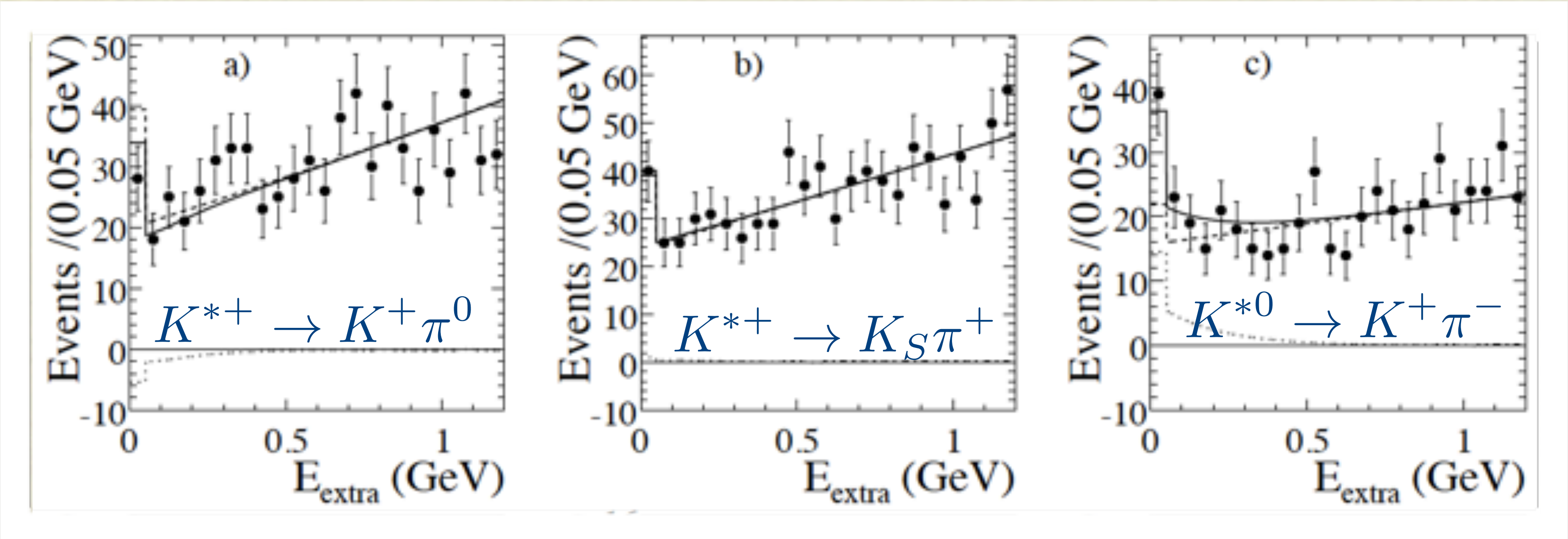
Belle
535M



- Belle hadronic tag analysis:

	N_{obs}	N_b	U.L.
$K^{*0}\nu\nu$	7	4.2±1.4	< 3.4 x 10^{-4}
$K^{*+}\nu\nu$	4	5.6±1.8	< 1.4 x 10^{-4}

$B \to K^{*+}\nu\nu$ & $K^{*0}\nu\nu$

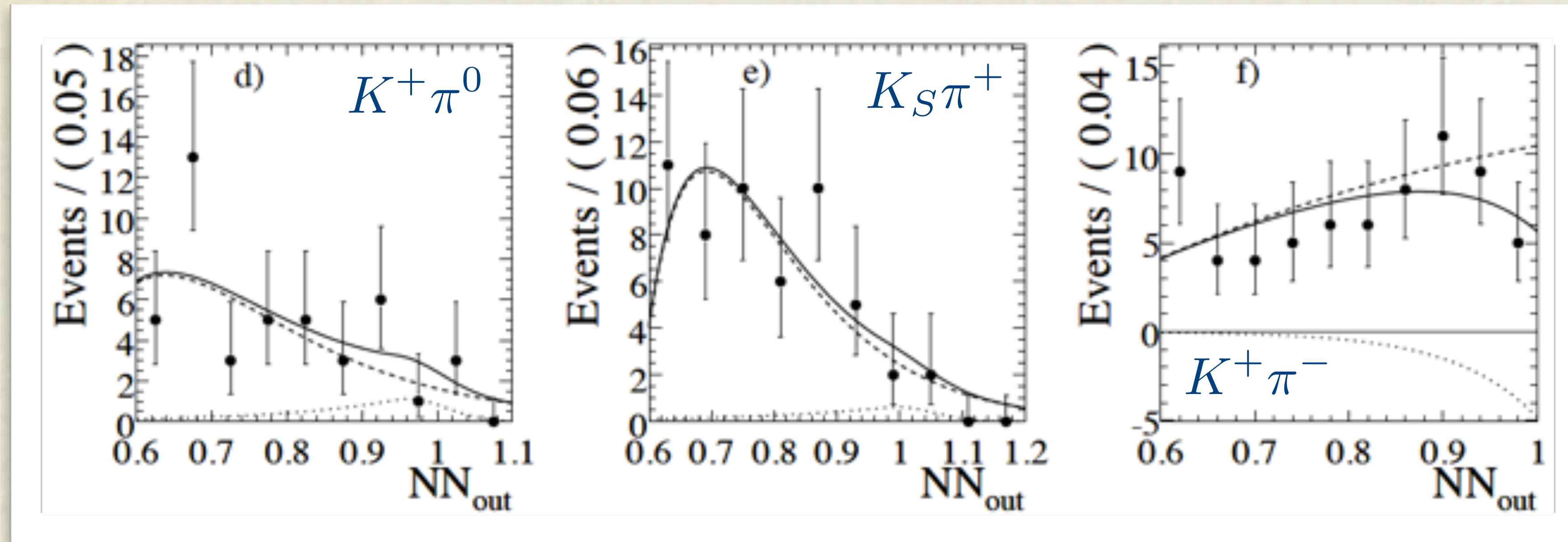


BaBar
454M
Phys. Rev. D78, 072007

- BaBar semi-leptonic tag analysis:

	Expected Yields		Fitted Yields		Semileptonic
	N_s	N_b	N_s	N_b	U.L.
$K^{*+}(\to K^+\pi^0)\nu\nu$	3.31	697	-22 ±16 ±14	754 ±32	$< 9 \times 10^{-5}$
$K^{*+}(\to K_S\pi^+)\nu\nu$	2.54	827	3 ±17 ±15	869 ±34	
$K^{*0}(\to K^+\pi^-)\nu\nu$	4.07	468	35 ±13 ±9	476 ±25	$< 18 \times 10^{-5}$

$B \to K^{*+}\nu\nu$ & $K^{*0}\nu\nu$



BaBar 454M

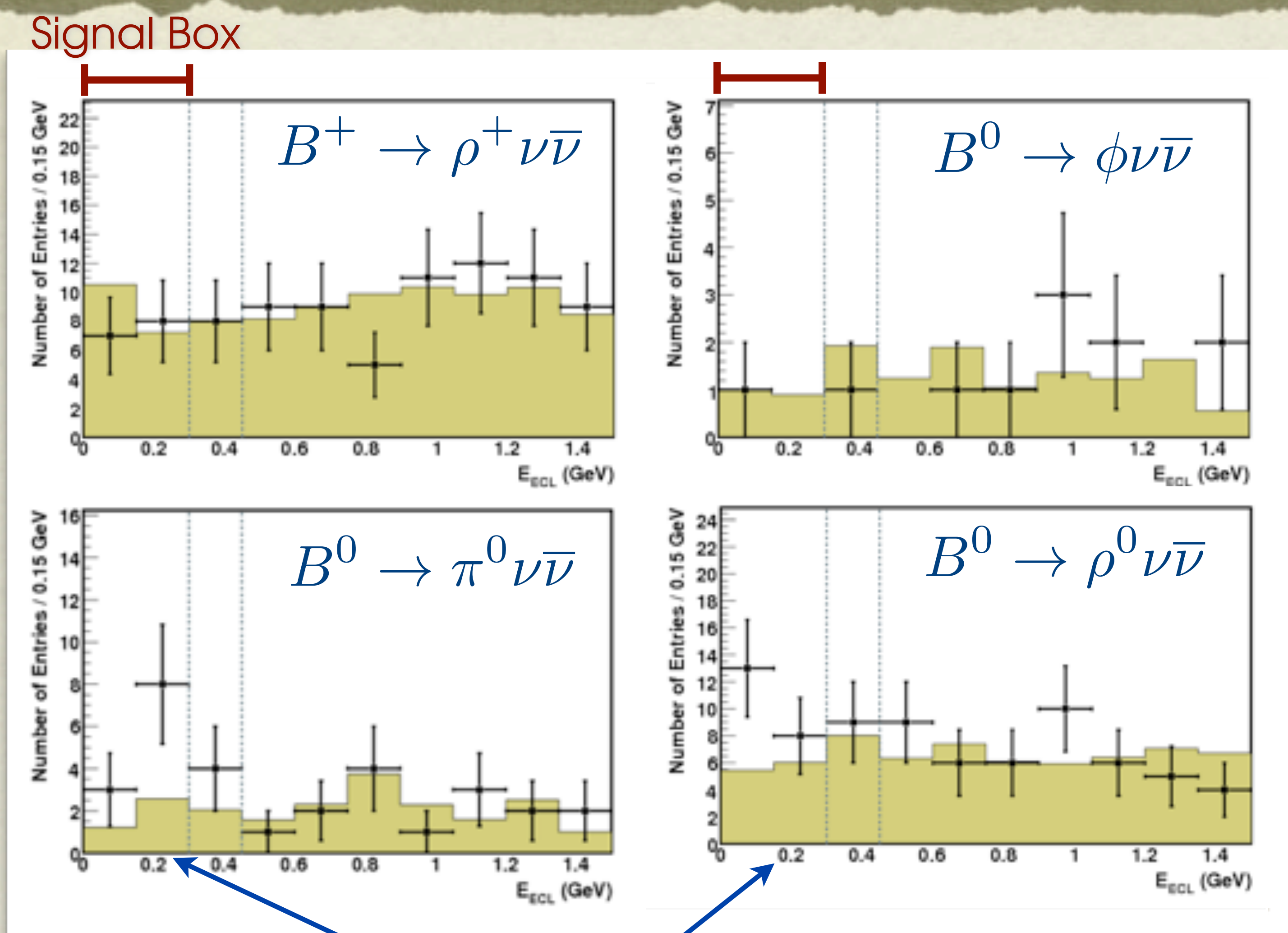
Phys. Rev. D78, 072007

Hadronic tags + semi-leptonic tags

- BaBar hadronic tag analysis with neural network:

	Expected Yields		Fitted Yields		Hadronic	Combined
	N_s	N_b	N_s	N_b	U.L.	U.L.
$K^{*+}(\to K^+\pi^0)\nu\nu$	0.87	46	5 ±6 ±4	39 ±9	$< 21 \times 10^{-5}$	$< 8 \times 10^{-5}$
$K^{*+}(\to K_S\pi^+)\nu\nu$	0.77	35	3 ±7 ±4	51 ±10		
$K^{*0}(\to K^+\pi^-)\nu\nu$	1.64	73	-10 ±9 ±6	77 ±13	$< 11 \times 10^{-5}$	$< 12 \times 10^{-5}$

OTHER CHANNELS



Small excess found (<2σ);
Need more data to verify.

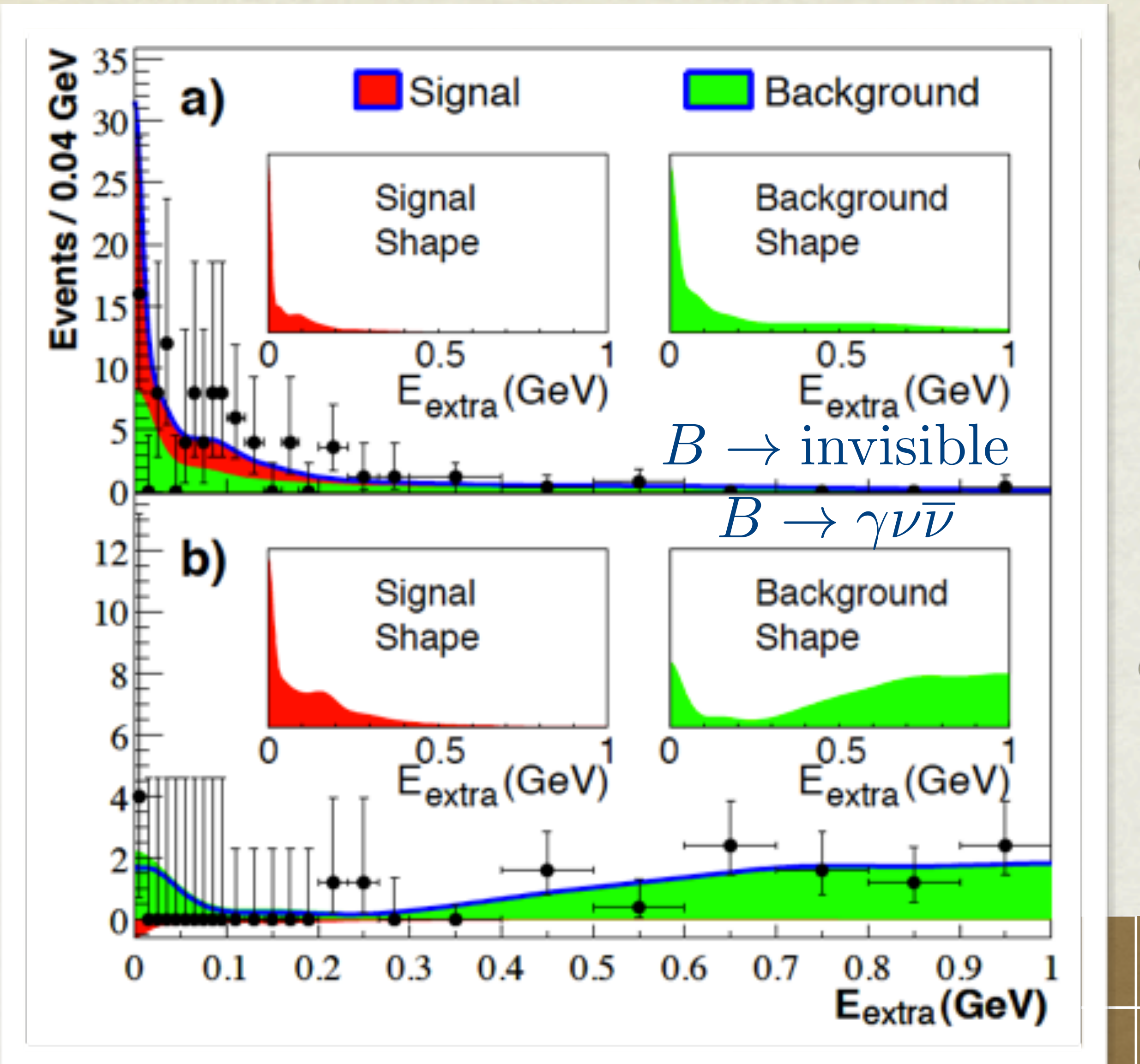
Belle
535M

Phys. Rev. Lett. 99, 221802

- Belle hadronic tag analysis:

	N_{obs}	N_b	U.L.
$\rho^+\nu\nu$	15	17.8±3.2	< 1.5 x 10^{-4}
$\rho^0\nu\nu$	21	11.5±2.3	< 4.4 x 10^{-4}
$\pi^0\nu\nu$	11	3.8±1.3	< 2.2 x 10^{-4}
$\varphi\nu\nu$	1	1.9±0.9	< 5.8 x 10^{-5}

OTHER CHANNELS



- BaBar semi-leptonic tag analysis.
- SM $B \to \nu\nu$ is predicted to be strongly suppressed by the factor of $(m_\nu/m_B)^2$, but NP may contribute to the final state of $B \to$invisible.
- BF($B \to \gamma\nu\nu$) is predicted to be around 10^{-9}.

	Fitted Yields		
	N_s	N_b	U.L.
$B \to$invisible	17±9	19^{+10}_{-8}	$< 2.2 \times 10^{-4}$
$B \to \gamma\nu\nu$	$-1.1^{+2.4}_{-1.9}$	28^{+6}_{-5}	$< 4.7 \times 10^{-5}$

BABAR

89M

Phys. Rev. Lett. 93, 091802

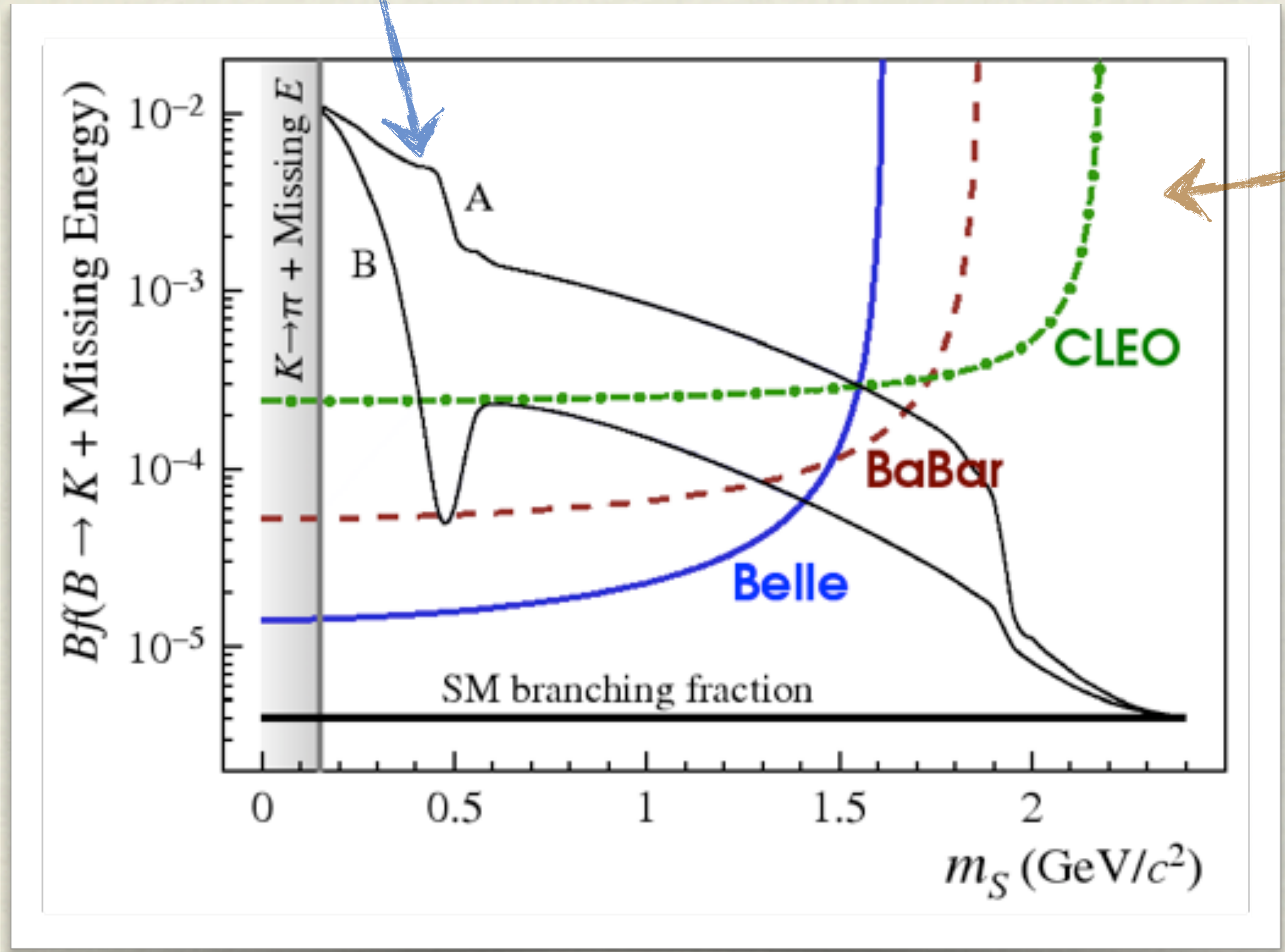
SUMMARY

- The best experimental limits from B-factories for $b \to s\nu\nu$, $d\nu\nu$, and other similar decay channels are summarized.
- Limits of $10^{-4} \sim 10^{-5}$ are approached based large data sets with hadronic tags and/or semi-leptonic tags.
- The current sensitivity is still below the expected SM branching fractions; but they can be probed with the upcoming super B factory experiment(s).
- Any deviations from the prediction could provide a hint to the physics beyond the SM, e.g. unparticle, dark matter, etc.

	Target Channel	Best B-factories Exp. Limits
$b \to s\nu\nu$	$B \to K^{+}\nu\nu$	$< 1.3 \times 10^{-5}$
	$B \to K^{0}\nu\nu$	$< 5.6 \times 10^{-5}$
	$B \to K^{*0}\nu\nu$	$< 12 \times 10^{-5}$
	$B \to K^{*+}\nu\nu$	$< 8 \times 10^{-5}$
$b \to d\nu\nu$	$B \to \pi^{+}\nu\nu$	$< 1.0 \times 10^{-4}$
	$B \to \rho^{+}\nu\nu$	$< 1.5 \times 10^{-4}$
	$B \to \rho^{0}\nu\nu$	$< 4.4 \times 10^{-4}$
	$B \to \pi^{0}\nu\nu$	$< 2.2 \times 10^{-4}$
others	$B \to \varphi\nu\nu$	$< 5.8 \times 10^{-5}$
	$B \to$ invisible	$< 2.2 \times 10^{-4}$
	$B \to \gamma\nu\nu$	$< 4.7 \times 10^{-5}$

SENSITIVITY TO LIGHT DARK MATTERS

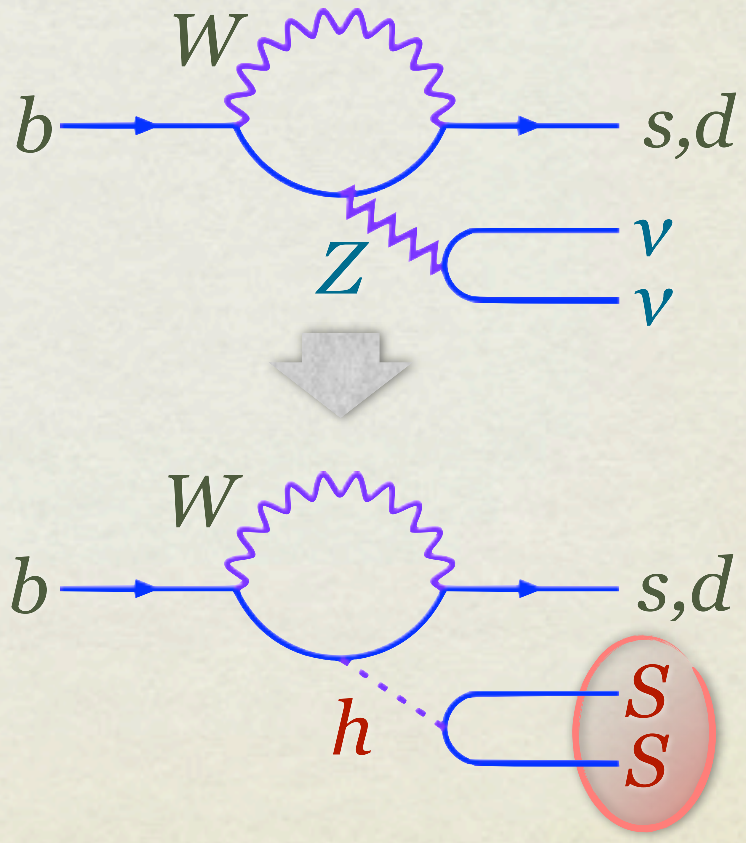
TH Predictions from C.Bird, PRL 93, 201803 (2004)



Note: the BaBar 2010 limit is not shown since $P^*(K^+)$ is included in the bagged decision tree classifier.

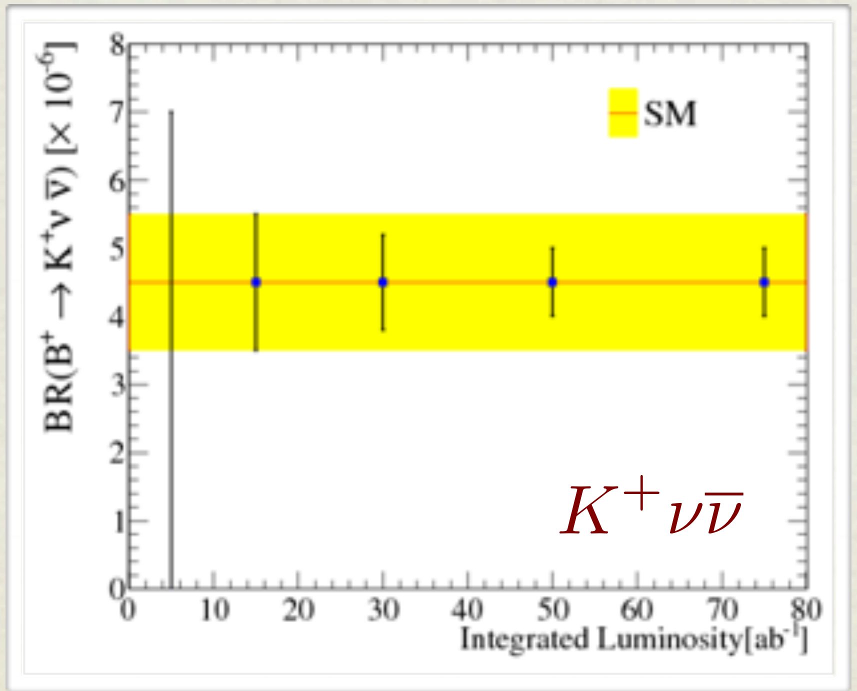
The curvature is due to the lower bound on $P^*(K^+)$.

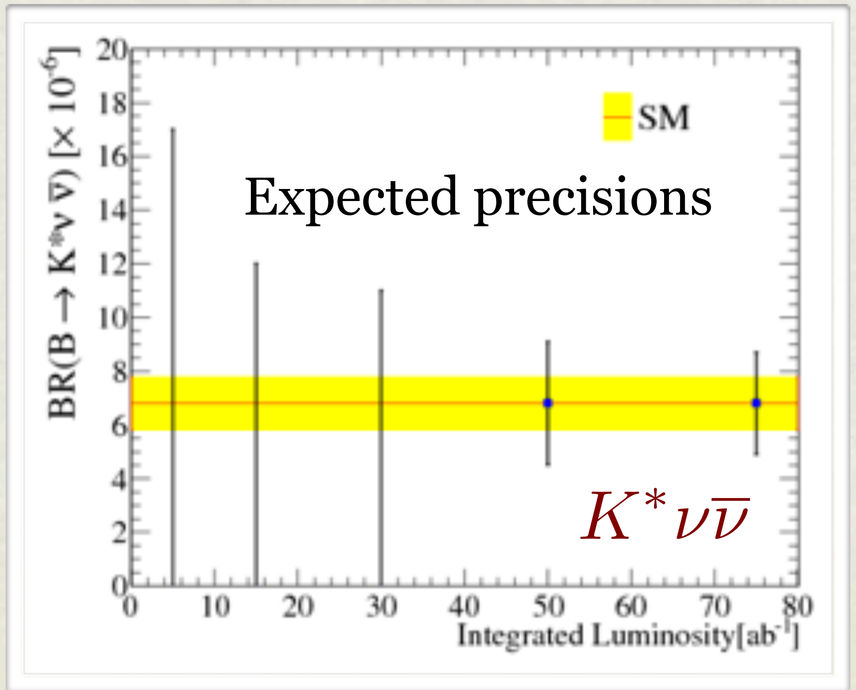
$B\to K^+\nu\nu$ limits included	
Belle	< 1.4 x 10^{-5}
BaBar (2005)	< 5.2 x 10^{-5}
CLEO	< 2.4 x 10^{-4}



PROSPECTS OF SUPER B • BELLE II

- Key factors for such searches for the future super *B*-factories:
  - Large statistics, since the reconstruction efficiency of B_{tag} is not high.
  - Detector acceptance: as high as possible (smaller CM boost will also help) - this improves both B_{tag} efficiency and background suppression.
  - Lower beam background will improve the resolution, but higher luminosity is accompanied by large beam backgrounds.



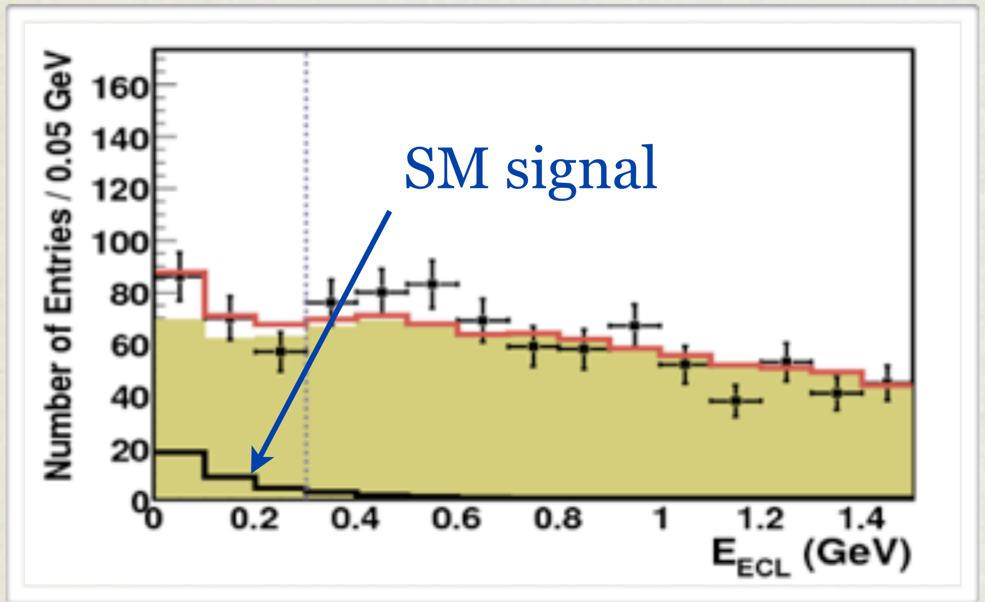


Ref. arXiv:1008.1541

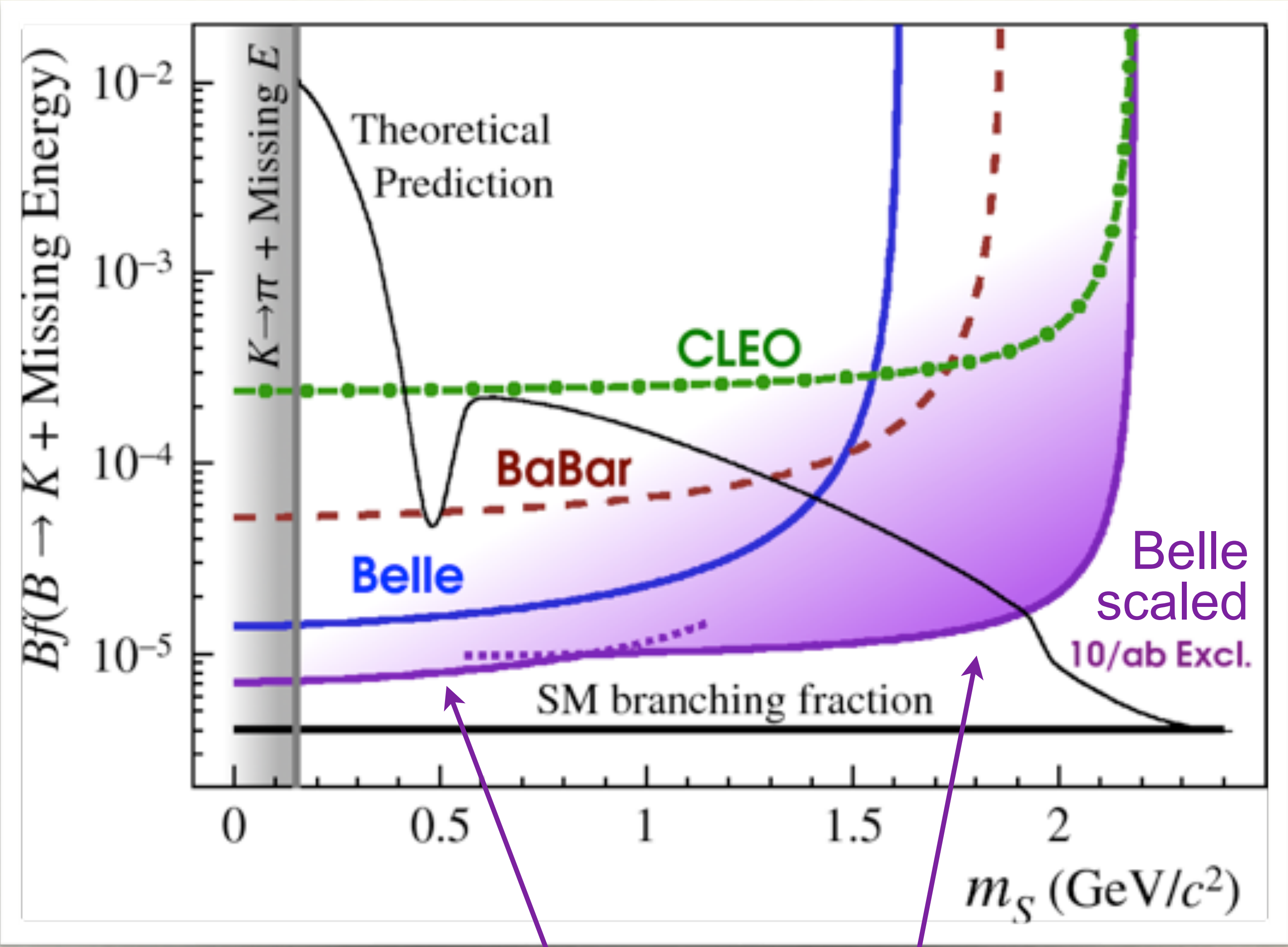
Prospects for the Super B project (assuming 20-30% improvement on eff.)

PROSPECTS OF SUPER B • BELLE II

- We can easily improve the limits on the light dark matter by simply adding more data.



Extra energy scaled to 10/ab data. Assuming the same performance of Belle detector.



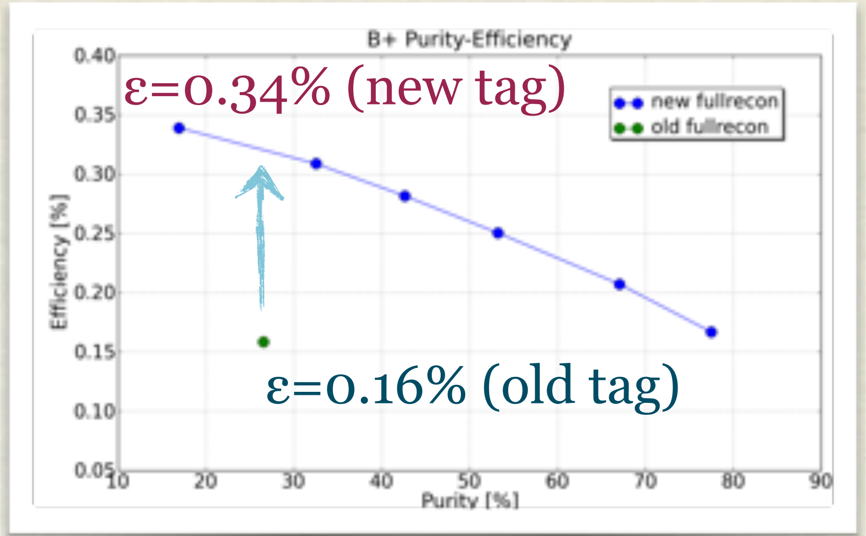
Limit with $P^*_K > 1.6$ GeV/c

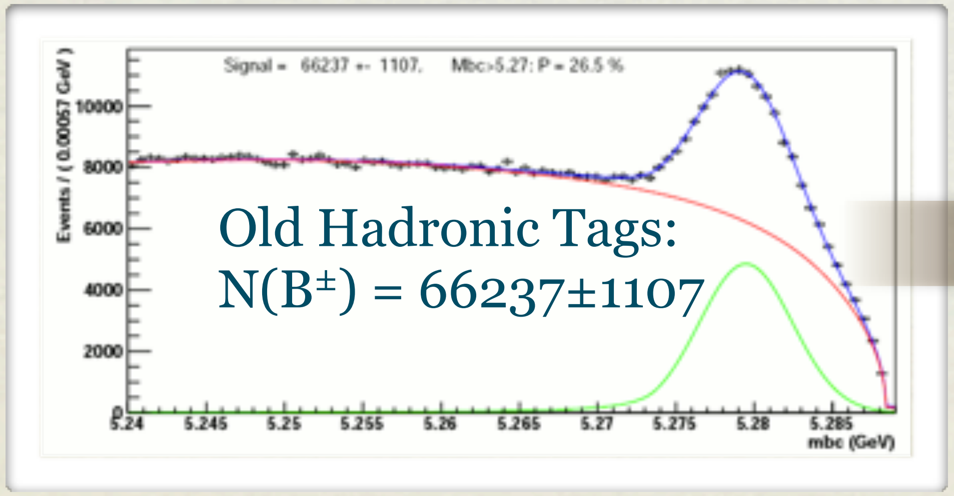
Limit with $P^*_K > 0.7$ GeV/c

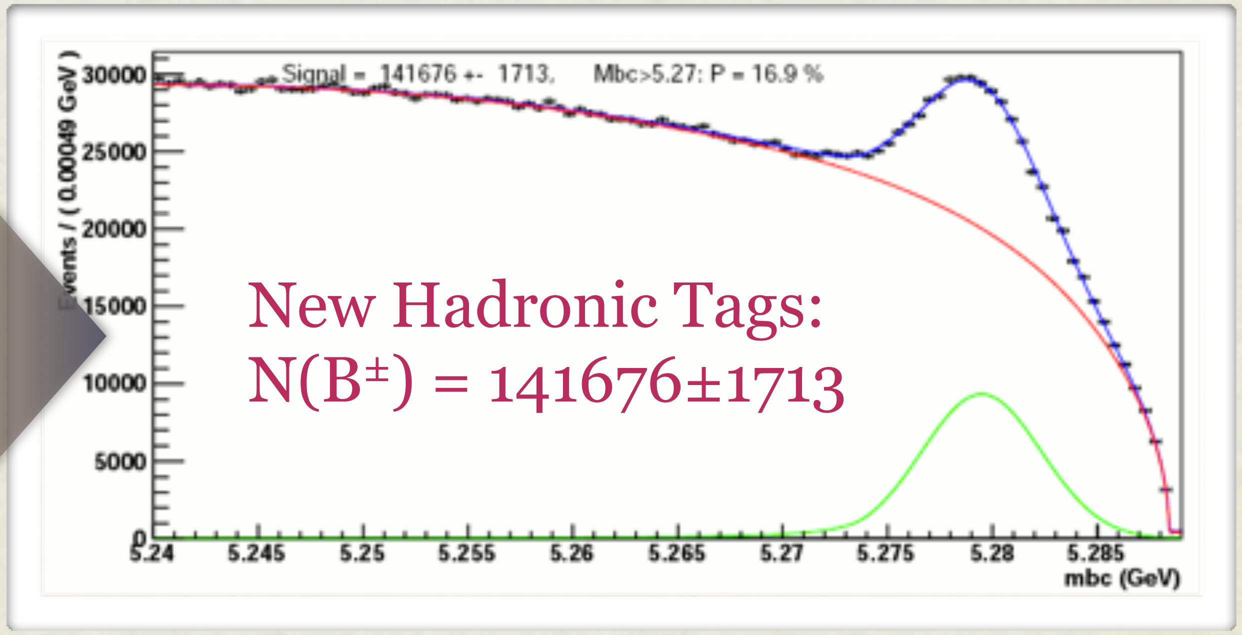
FINAL REMARK

- Significant analysis improvement is foreseeable even **BEFORE** Super *B*-factories era:
  - We are only reconstructing <1% of the total *B* decays at this moment - a large room for improvement is still there.
  - Not all of the analyses utilize the full power of hadronic+semi-leptonic tags.
  - For example – new Belle hadronic tags:

Efficiency versus Purity





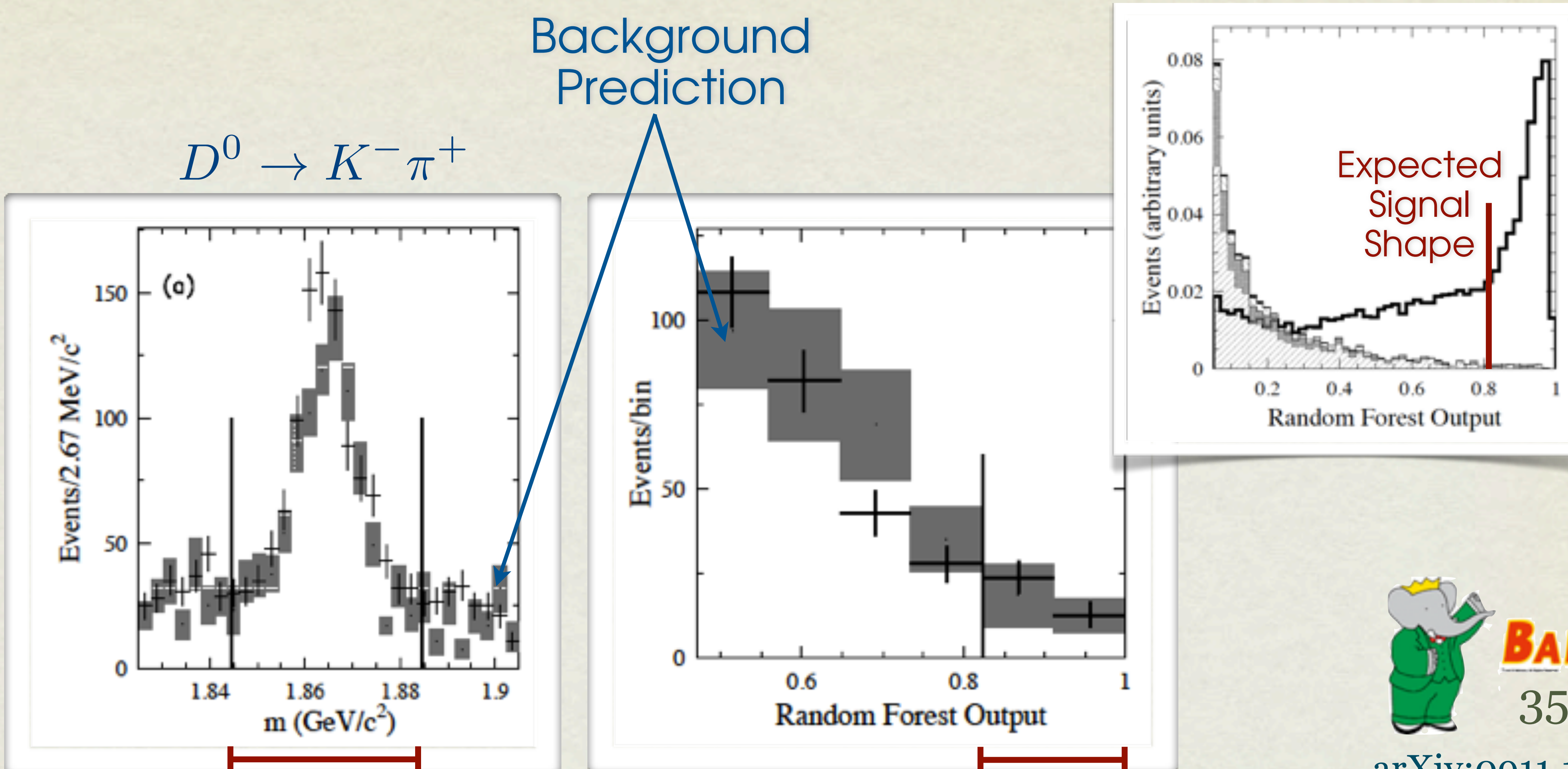


BACKUP SLIDES

$B \to K^+\nu\nu$ & $K^0\nu\nu$

Background Prediction

$D^0 \to K^-\pi^+$



Signal Box

Signal Box

351M

arXiv:0911.1988

- BaBar semi-leptonic tag analysis with random forest:

	N_{obs}	N_b	U.L.
$K^+\nu\nu$	38	31±12	$< 4.5 \times 10^{-5}$