Rare *B* Decays with Missing Energy at Belle

Leo Piilonen, Virginia Tech
representing the Belle Collaboration

$B \to \tau\nu$

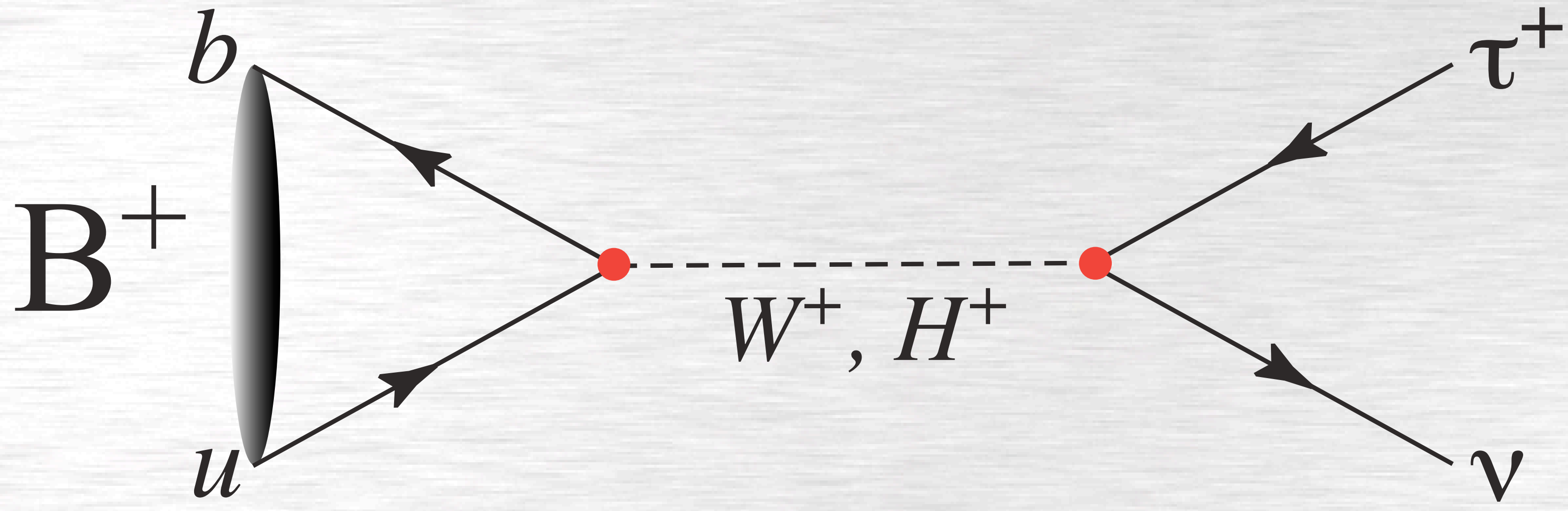
$B \to K^{*}\nu\bar{\nu}$

Joint Meeting of Pacific Region Particle Physics Communities
November 1, 2006

$$B^+ \to \tau^+ \nu_\tau$$

hep-ex/0604018v2

$B \to \tau\nu$ is sensitive to a charged Higgs boson (if the B decay constant f_B is known)

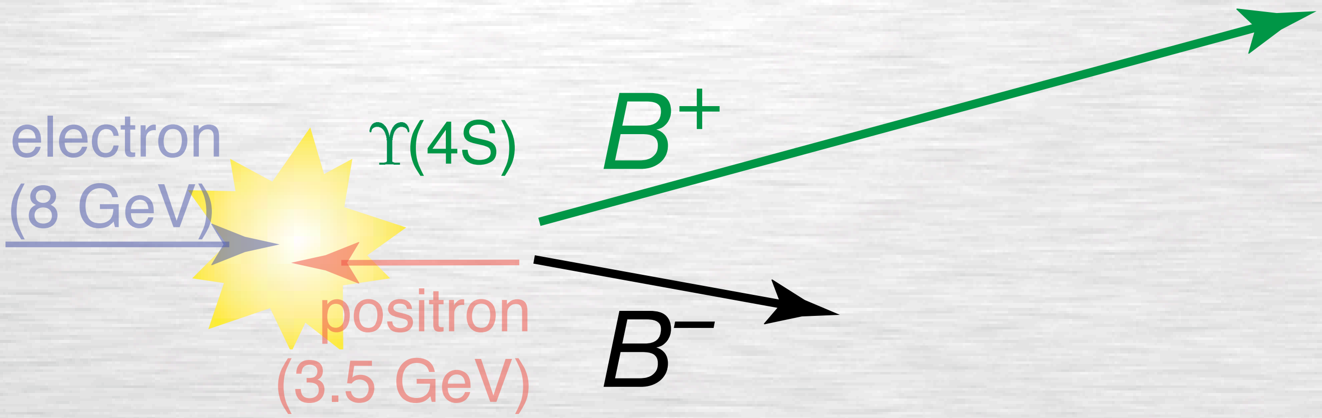


$$\mathcal{B}(B^+ \to \tau^+ \nu_\tau) = \frac{G_F^2 m_B}{8\pi} m_\tau^2 \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 {f_B}^2 \left|V_{ub}\right|^2 \tau_B$$

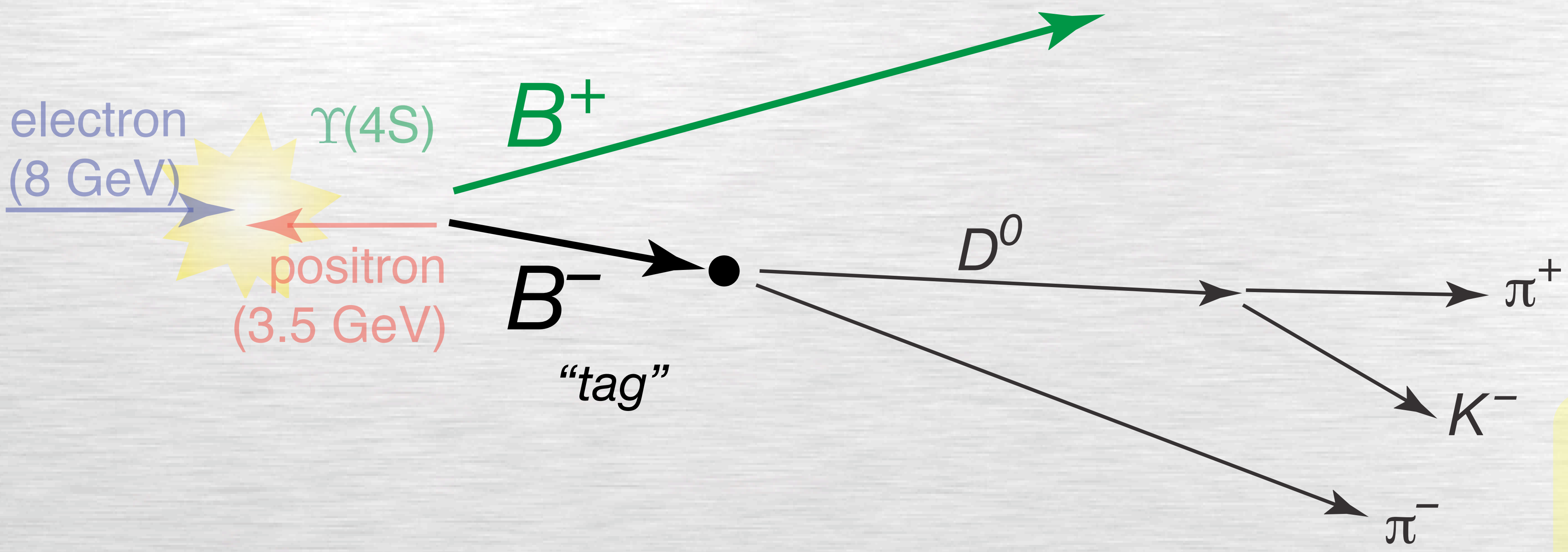
$$\mathcal{B}(B \to \tau\nu) < 2.6 \times 10^{-4} \ (90\% \text{ C.L.})$$

B. Aubert *et al.*, PRD **73**, 057101 (2006)

$B \to \tau\nu$ is hard to measure because the B meson decays (usually) to one charged track + missing energy

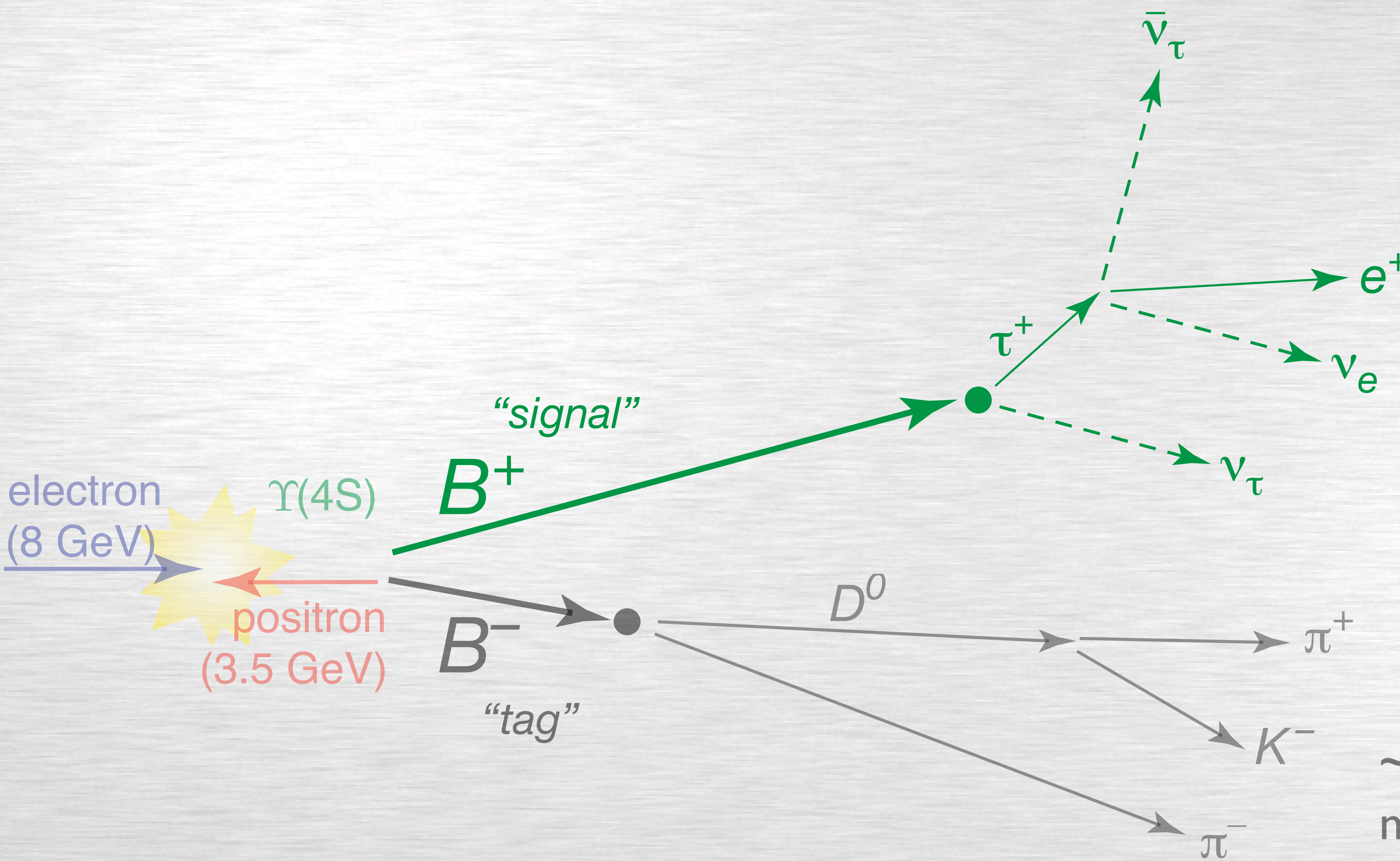


$B \to \tau\nu$ is hard to measure because the B meson decays (usually) to one charged track + missing energy



~180 hadronic decay modes reconstructed on tag side; signal region is $-0.08 < \Delta E < 0.06$ GeV & $M_{bc} > 5.27$ GeV/c^2

$B \to \tau\nu$ is hard to measure because the B meson decays (usually) to one charged track + missing energy



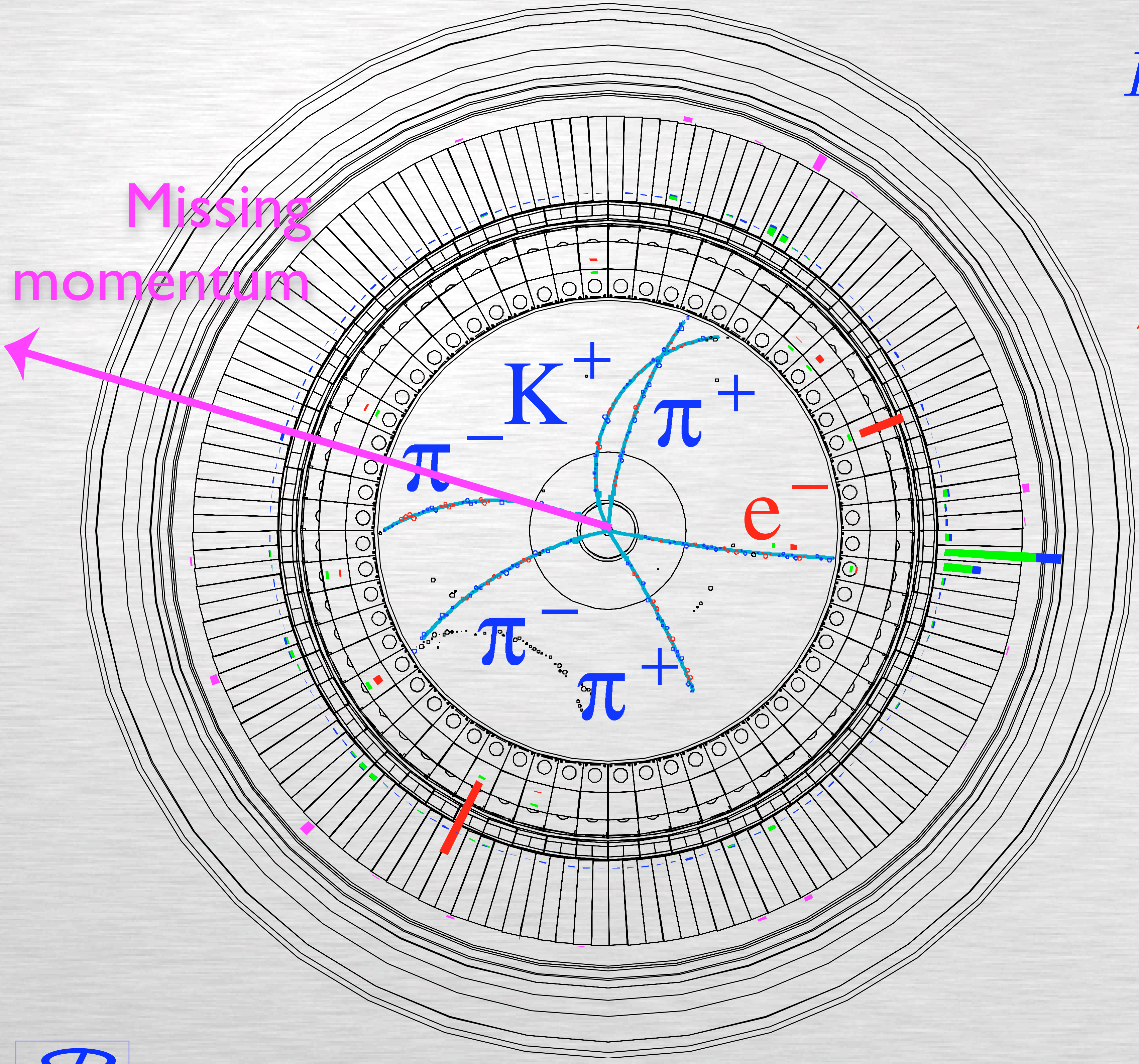
τ^+ decay modes used:

$e^+\nu\bar{\nu}$	(17.8%)
$\mu^+\nu\bar{\nu}$	(17.4%)
$\pi^-\nu$	(10.9%)
$\pi^-\pi^0\nu$	(25.5%)
$\pi^-\pi^+\pi^-\nu$	(9.3%)
	80.9%

Signal-side efficiency is (15.81 ± 0.05)%, including τ BFs.

~180 hadronic decay modes reconstructed on tag side

$B \to \tau\nu$ candidate event

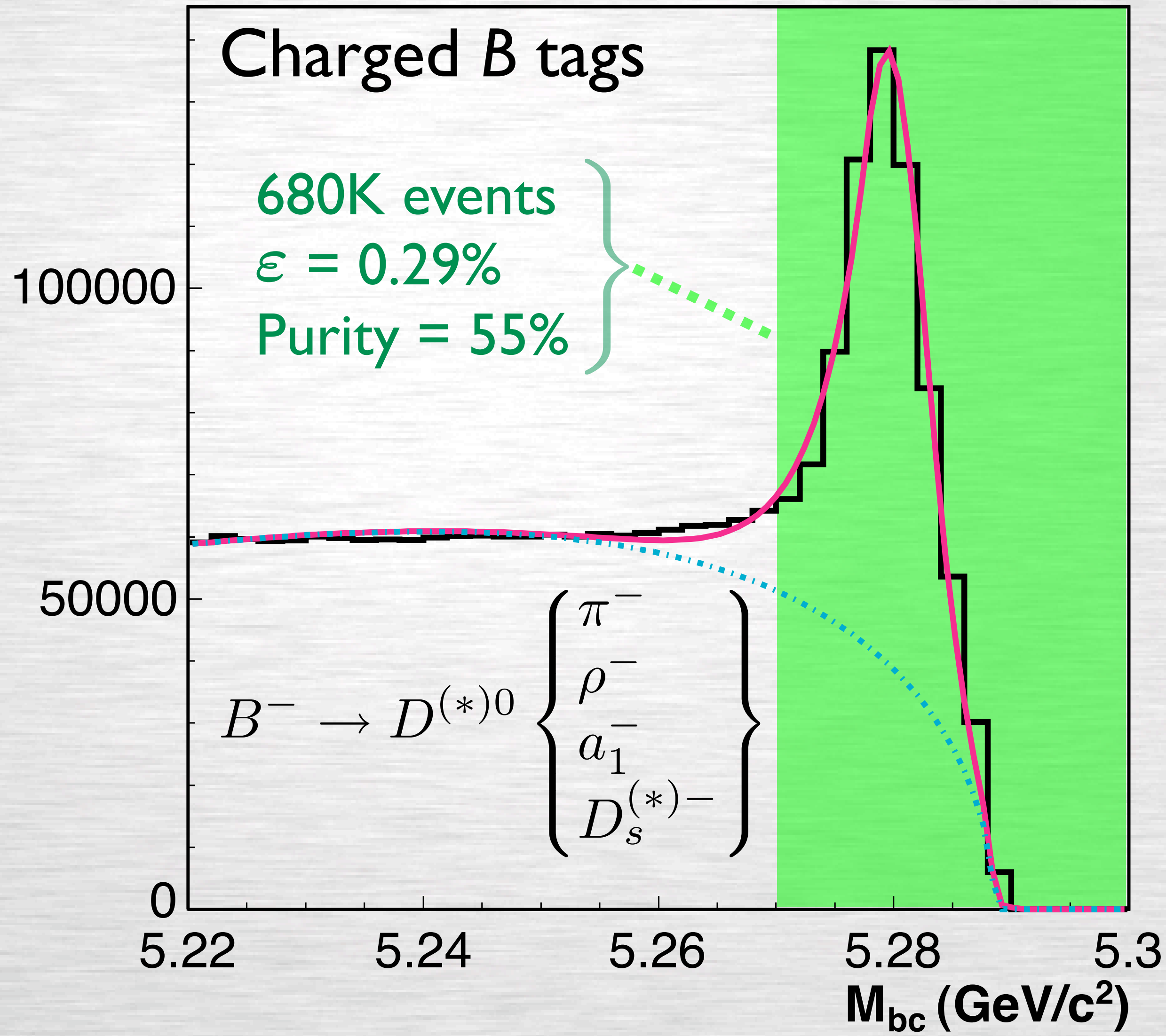


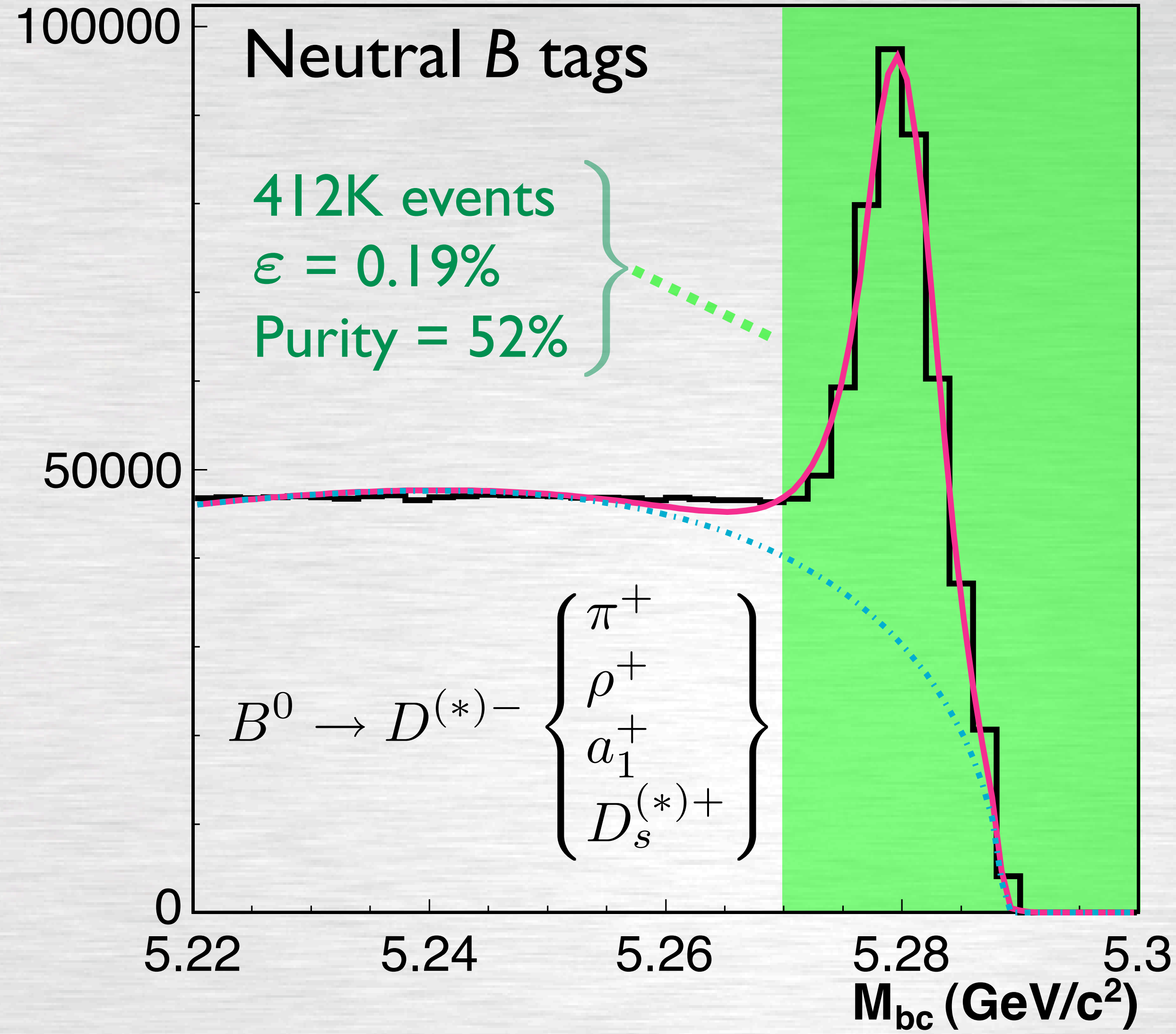
$B^+ \to \bar{D}^0 \pi^+$

$\hookrightarrow K^+ \pi^- \pi^+ \pi^-$

$\tau^- \to e^- \bar{\nu}_e \nu_\tau$

Reconstruct 1.1 x 10^6 charged and neutral B tags in 449 x 10^6 $B\overline{B}$ events ($\int \mathcal{L} dt$ = 414 fb^{-1})





where $D^{*0} \to \{D^0\pi^0 \,|\, D^0\gamma\}$

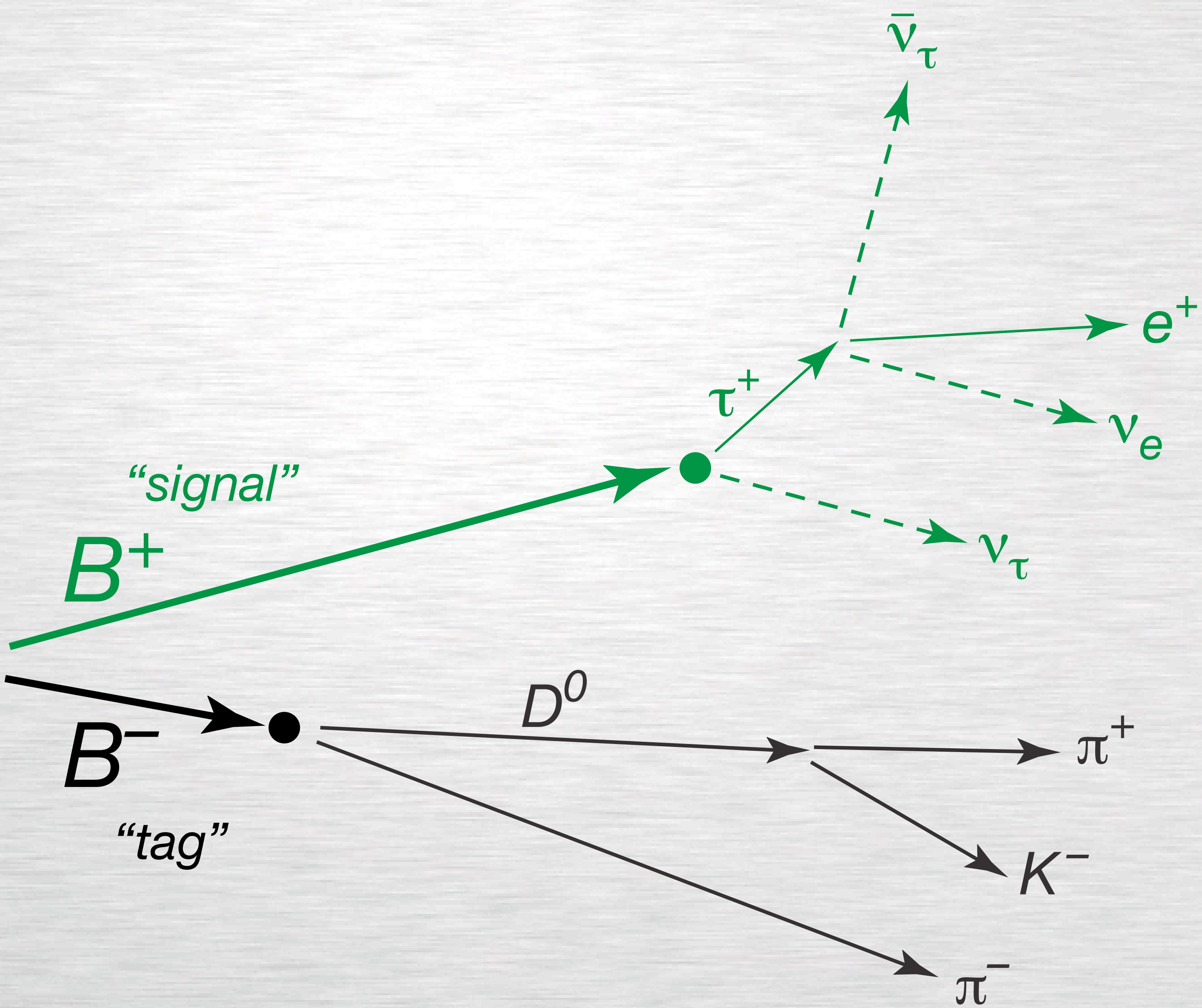
$D^{*-} \to \{\bar{D}^0\pi^- \,|\, D^-\pi^0\}$

$D_s^{*-} \to D_s^-\gamma$

and $D^0 \to 7$ modes, $D^- \to 6$ modes, $D_s \to 2$ modes

~180 hadronic decay modes reconstructed

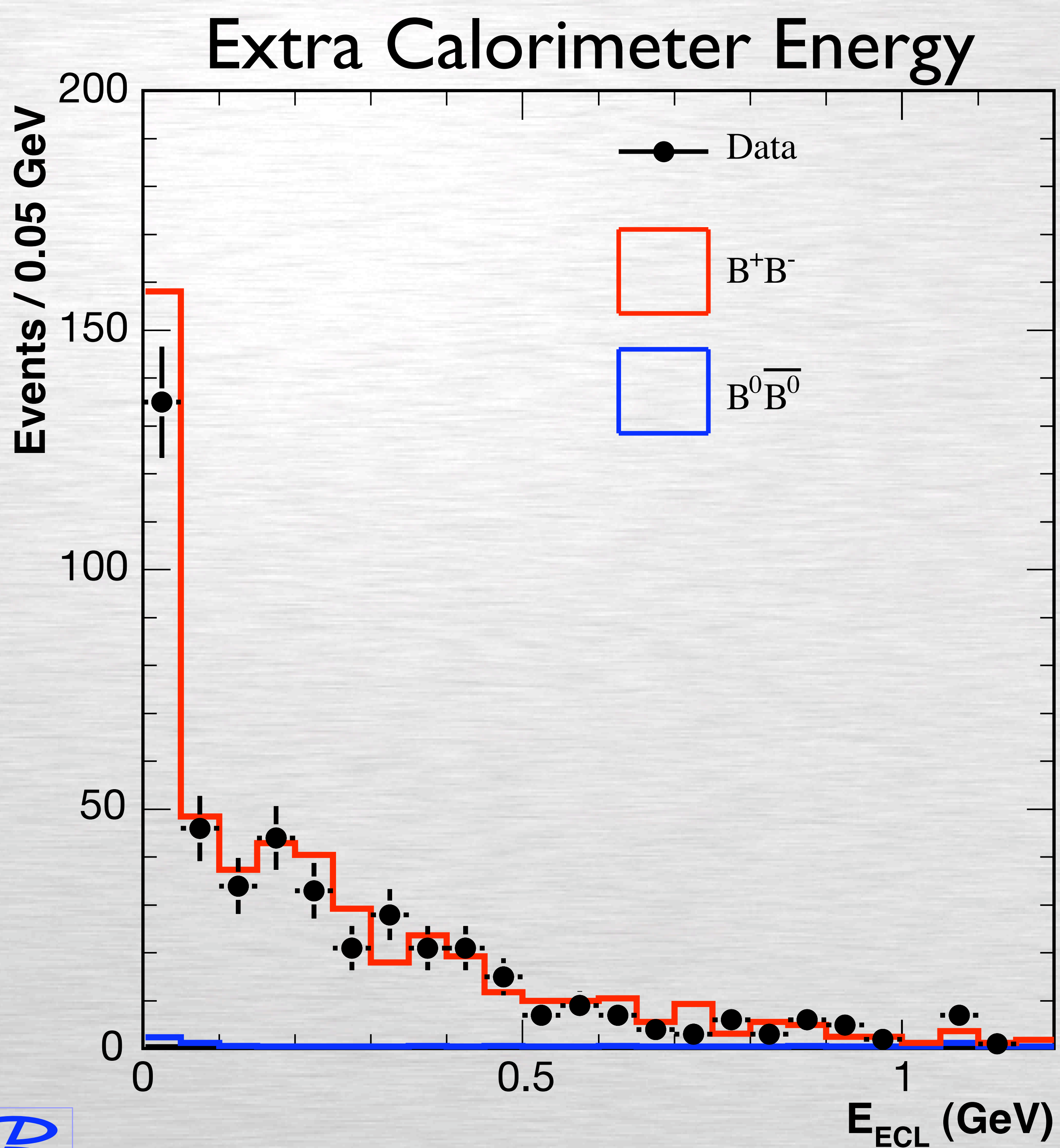
Reconstruct B_{tag} in purely hadronic mode and $B \to \tau\nu$ from the remaining detected particles



All selection criteria were optimized in MC before examining the data ("blind analysis")

- Signal side has 1 or 3 charged tracks, with charge opposite that of B_{tag}
- Reject event with π^0 on signal side (except for $\tau \to \pi^-\pi^0\nu$ mode)
- In CM frame,
  - apply mode-dependent threshold on p_{miss}: 0.2 GeV/c for $\ell\nu\bar{\nu}$
    1.0 GeV/c for $\pi\nu$
    1.2 GeV/c for $\pi\pi^0\nu$
    1.8 GeV/c for $\pi\pi\pi\nu$
  - require $-0.86 < \cos\theta_{miss} < 0.95$
- Ignore low energy calorimeter clusters *(contaminated by beam background)*:
  E < 0.05 GeV (barrel)
  E < 0.10 GeV (forward endcap)
  E < 0.15 GeV (backward endcap)
- **Fit extra calorimeter energy E_{ECL}**

Validate the E_{ECL} simulation using double-tagged events (with $B \rightarrow D^* \ell \nu$ on the "signal" side)



"Signal" reconstruction (purity ~ 90%):

$B^- \rightarrow D^{*0} \ell^- \nu$

$\hookrightarrow D^0 \pi^0$

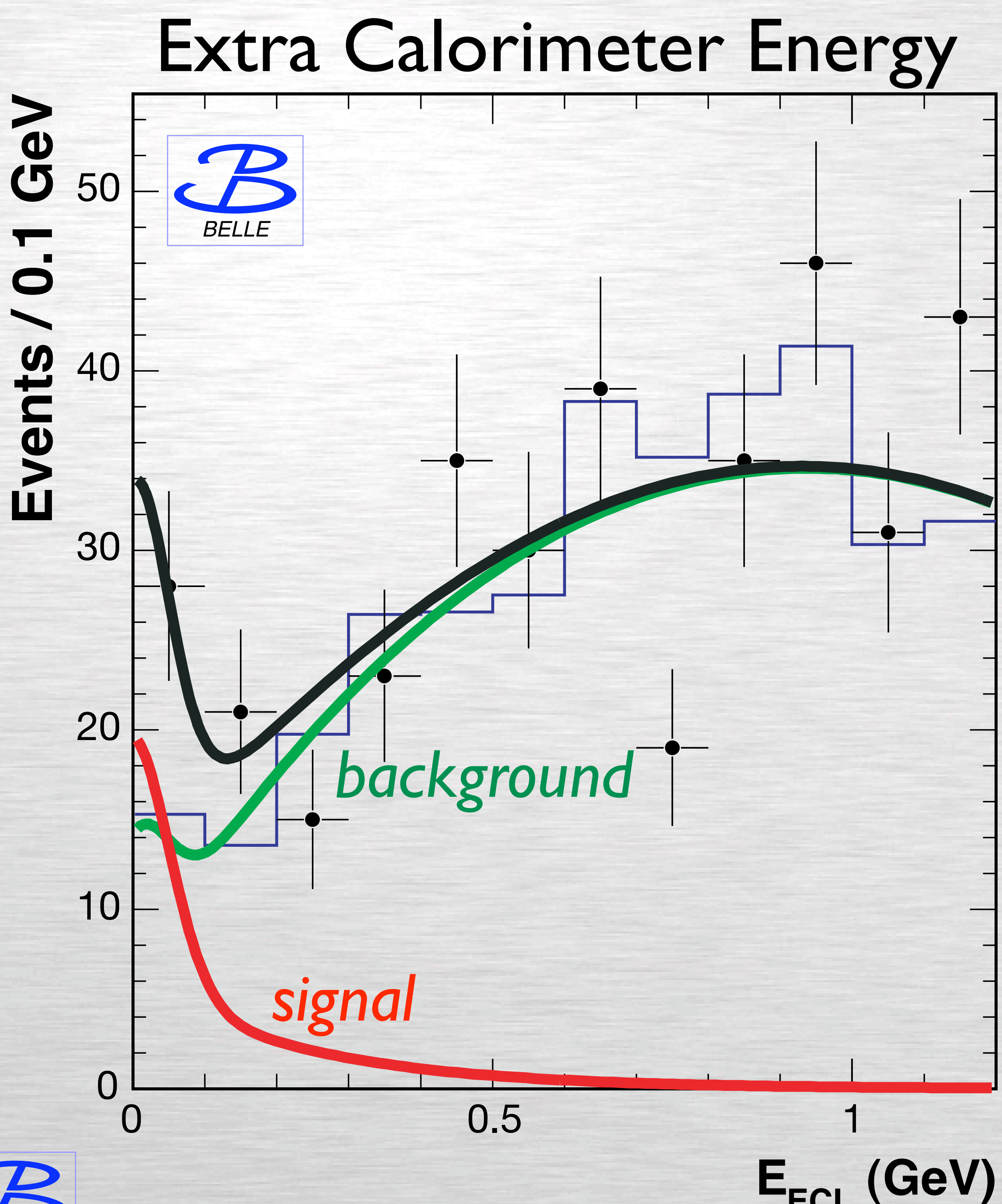
$\hookrightarrow K^- \pi^+$

$\hookrightarrow K^- \pi^+ \pi^- \pi^+$

MC:

B^+B^-:	494 ± 18
$B^0\overline{B}^0$:	8 ± 2
Combined:	**502 ± 18**
Data:	**458**

We find evidence for $B^+ \to \tau^+\nu$ by examining the distribution of extra calorimeter energy E_{ECL}



449 x 10^6 $B\bar{B}$ pairs

680 x 10^3 $B^\pm$ tags (55% purity)

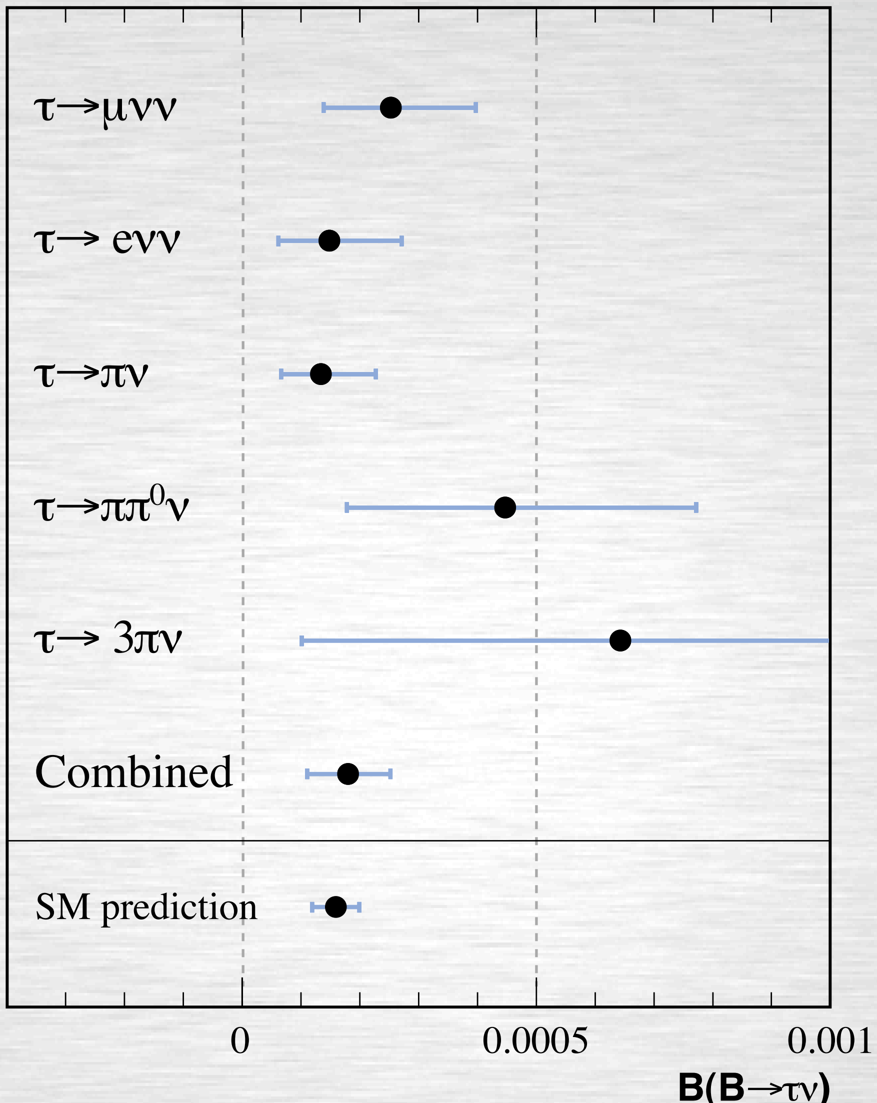
54 $\tau\nu$ candidates in signal region:

- E_{ECL} < 0.2 GeV $[\ell\nu\nu,\ \pi\nu]$
- E_{ECL} < 0.3 GeV $[\pi\pi(\pi)\nu]$

$17.2 \pm^{5.3}_{4.7}$ events in signal region

We find evidence for $B^+ \to \tau^+ \nu$ by examining the distribution of extra calorimeter energy E_{ECL}

	N_{obs}	N_{sig}	$\mathcal{B}\,(10^{-4})$	Σ
$\mu^- \bar{\nu}_\mu \nu_\tau$	13	$5.6 \pm ^{3.1}_{2.8}$	$2.57 \pm ^{1.38}_{1.27}$	2.2σ
$e^- \bar{\nu}_e \nu_\tau$	12	$4.1 \pm ^{3.3}_{2.6}$	$1.50 \pm ^{1.20}_{0.95}$	1.4σ
$\pi^- \nu_\tau$	9	$3.8 \pm ^{2.7}_{2.1}$	$1.30 \pm ^{0.89}_{0.70}$	2.0σ
$\pi^- \pi^0 \nu_\tau$	11	$5.4 \pm ^{3.9}_{3.3}$	$4.54 \pm ^{3.26}_{2.74}$	1.5σ
$\pi^- \pi^+ \pi^- \nu_\tau$	9	$3.0 \pm ^{3.5}_{2.5}$	$6.42 \pm ^{7.58}_{5.42}$	1.0σ



$$\mathcal{B}(B^+ \to \tau^+ \nu) = (1.79 \pm ^{0.56}_{0.49} \pm ^{0.46}_{0.51}) \times 10^{-4}$$

Significance: $\Sigma = 3.5\sigma$ (statistical & systematic)

We extract the B decay constant from our branching fraction measurement

$$\mathcal{B}(B^+ \to \tau^+\nu) = (1.79 \pm ^{0.56}_{0.49} \pm ^{0.46}_{0.51}) \times 10^{-4}$$

$$\Rightarrow \quad f_B \cdot |V_{ub}| = (10.1 \pm ^{1.6}_{1.4} \pm ^{1.3}_{1.4}) \text{ GeV}$$

Preliminary

$$\Rightarrow \boxed{f_B = (229 \pm ^{36}_{31} \pm ^{34}_{37}) \text{ MeV}}$$

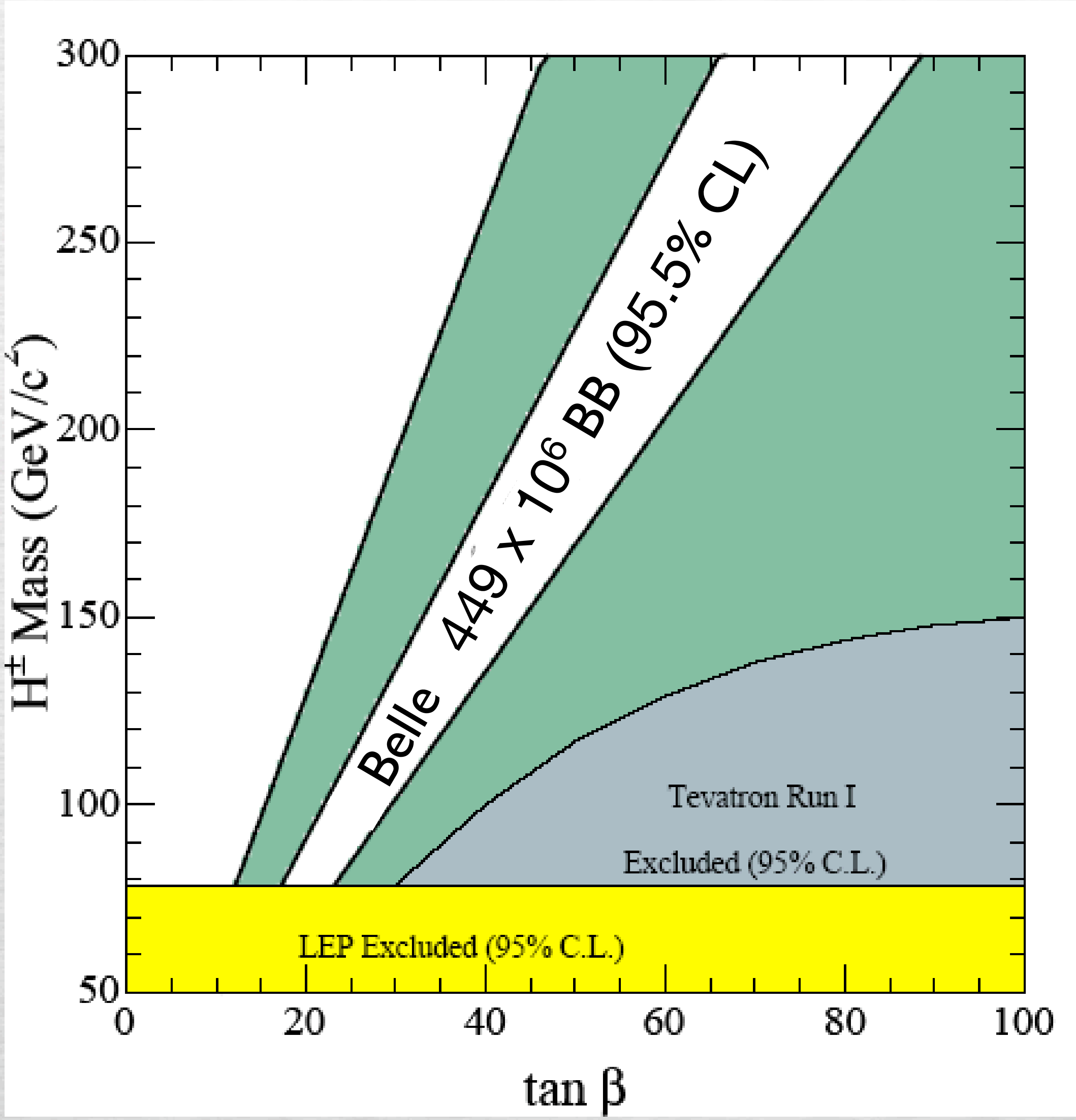
using $|V_{ub}| = (4.39 \pm 0.33) \times 10^{-3}$ from HFAG

*Compare with f_B = 216 ± 22 MeV from HPQCD unquenched lattice calculation in PRL **95**, 212001 (2005)*

We determine constraints on the charged Higgs boson assuming f_B and $|V_{ub}|$ are known

$$\mathcal{B}(B^+ \to \tau^+\nu) = (1.79 \pm^{0.56}_{0.49} \pm^{0.46}_{0.51}) \times 10^{-4}$$

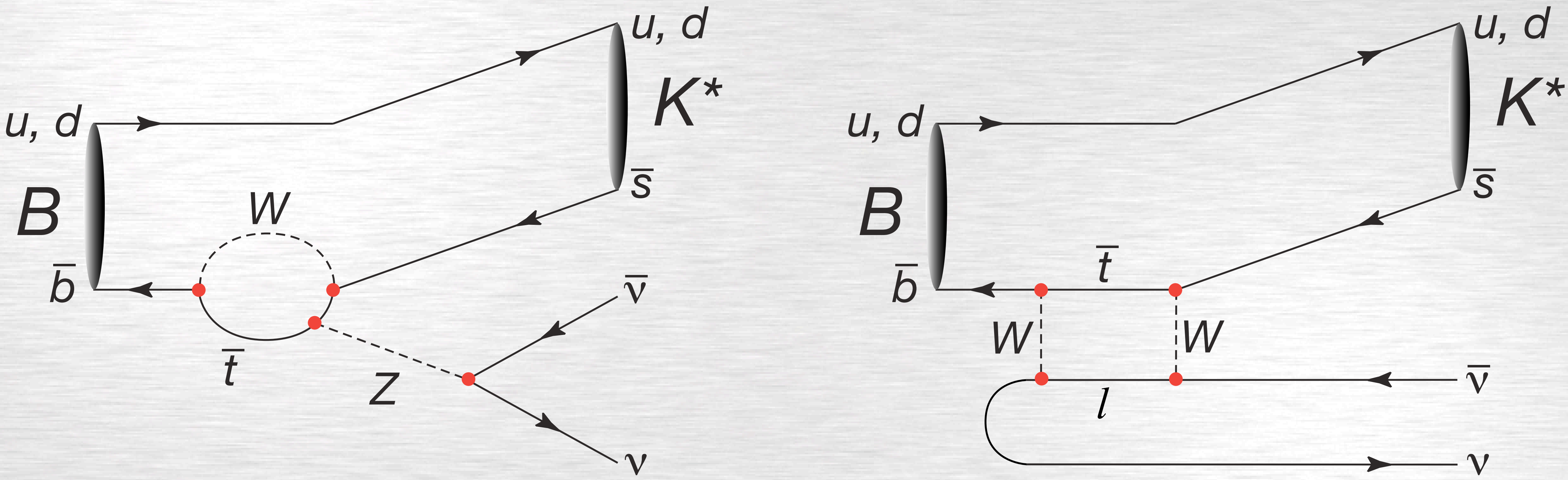
$$r_H = \frac{\mathcal{B}_{\rm meas}}{\mathcal{B}_{\rm SM}} = \left(1 - \frac{m_B^2}{m_H^2}\tan^2\beta\right)^2 = 1.13 \pm 0.51$$



$B \to K^* \nu \bar{\nu}$

hep-ex/0608047

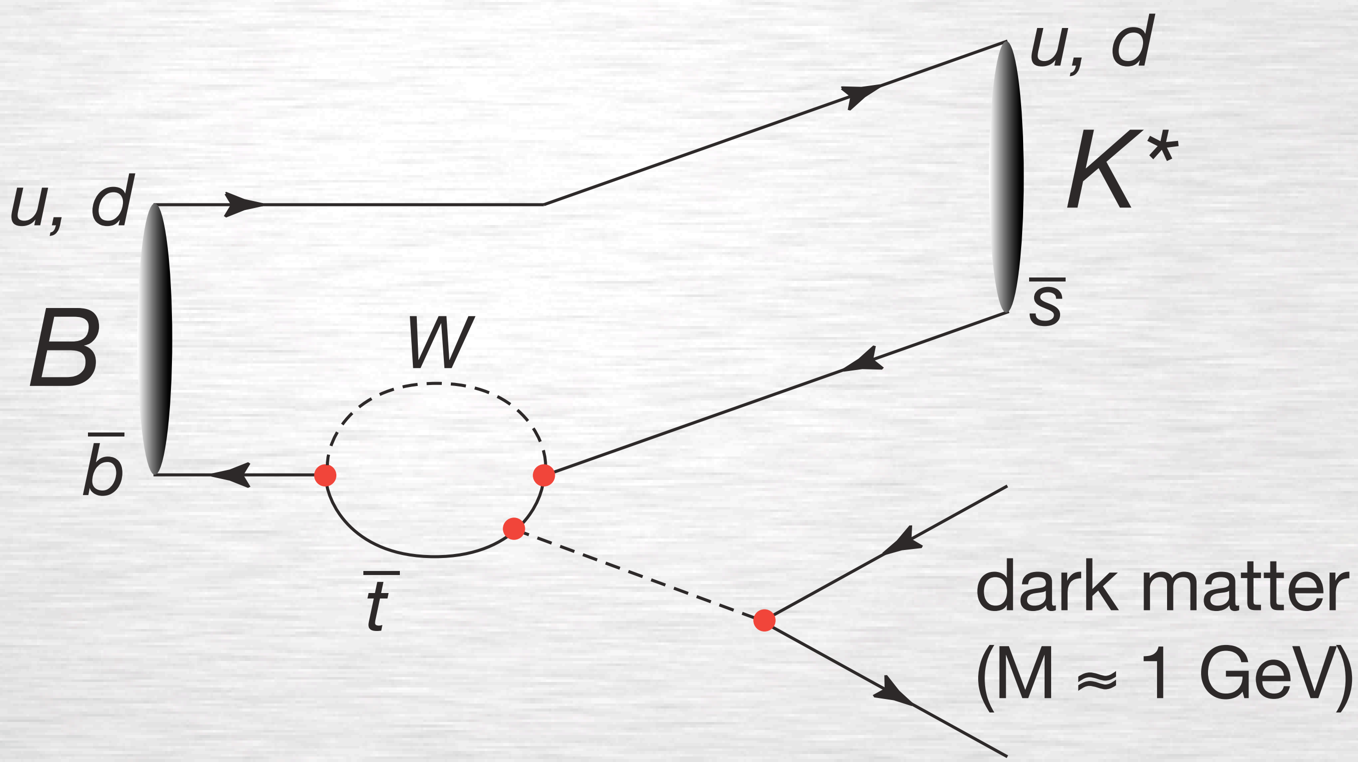
$B \to K^* \nu\bar{\nu}$ is sensitive to new heavy particles in the penguin loop or box (e.g., supersymmetric)

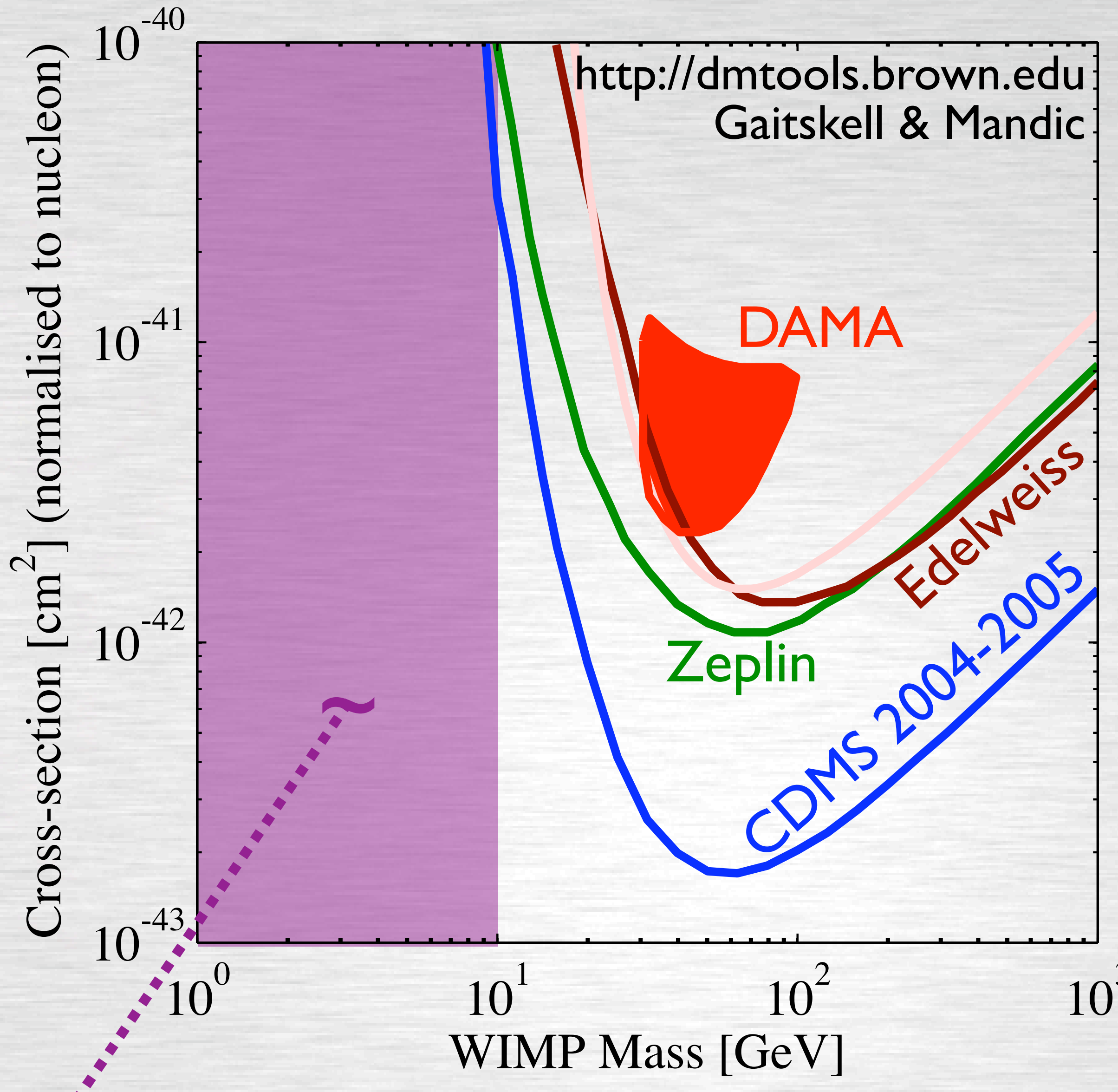


$$\mathrm{SM}: \quad \mathcal{B}(B \to K^* \nu\bar{\nu}) \simeq 1.3 \times 10^{-5}$$

Buchalla, Hiller and Isidori, PRD **63**, 014015 (2001)

$B \to K^* + \text{nothing}$ can pair-produce scalar WIMPs with mass below 10 GeV

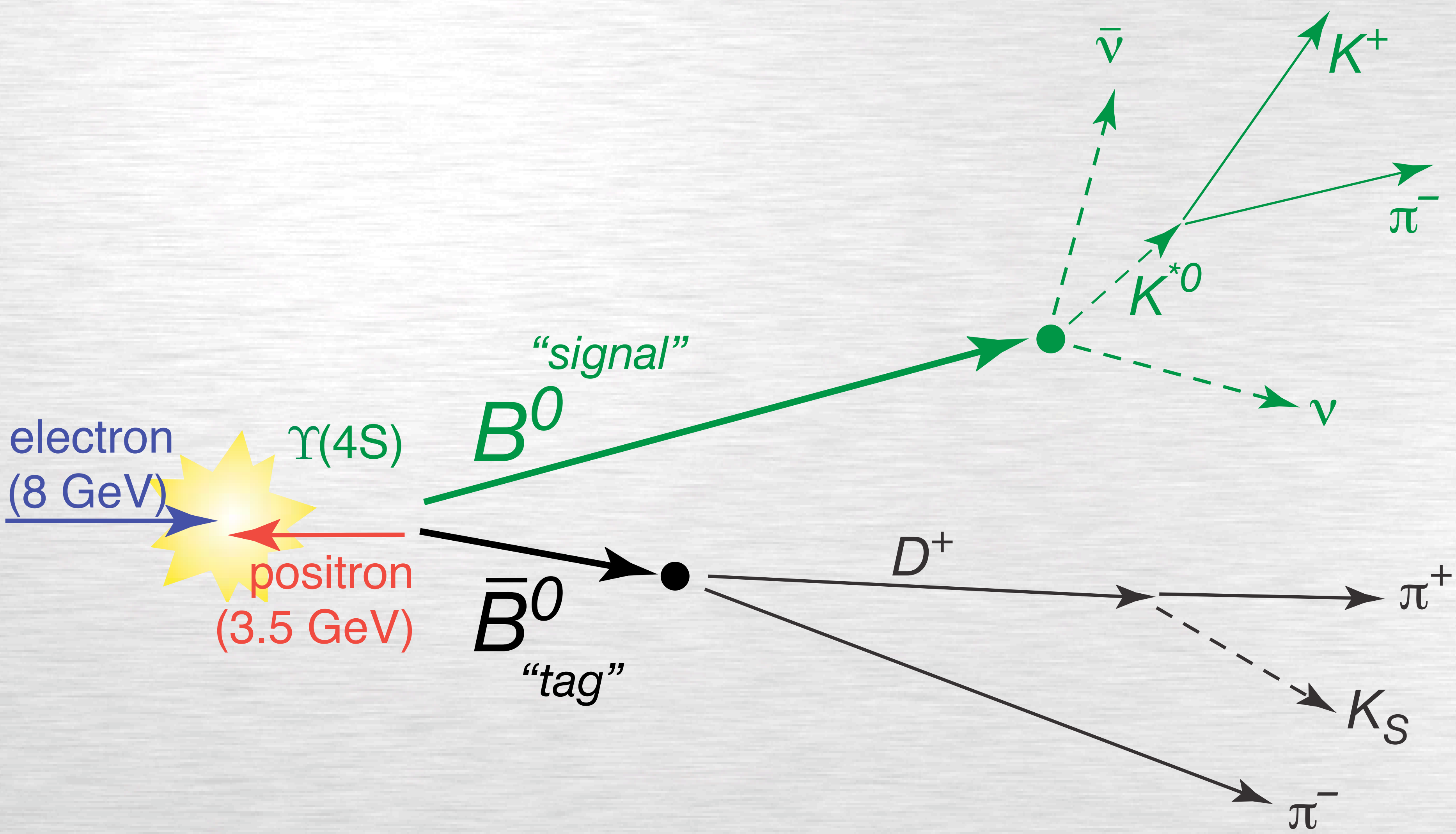




Unexplored in direct searches

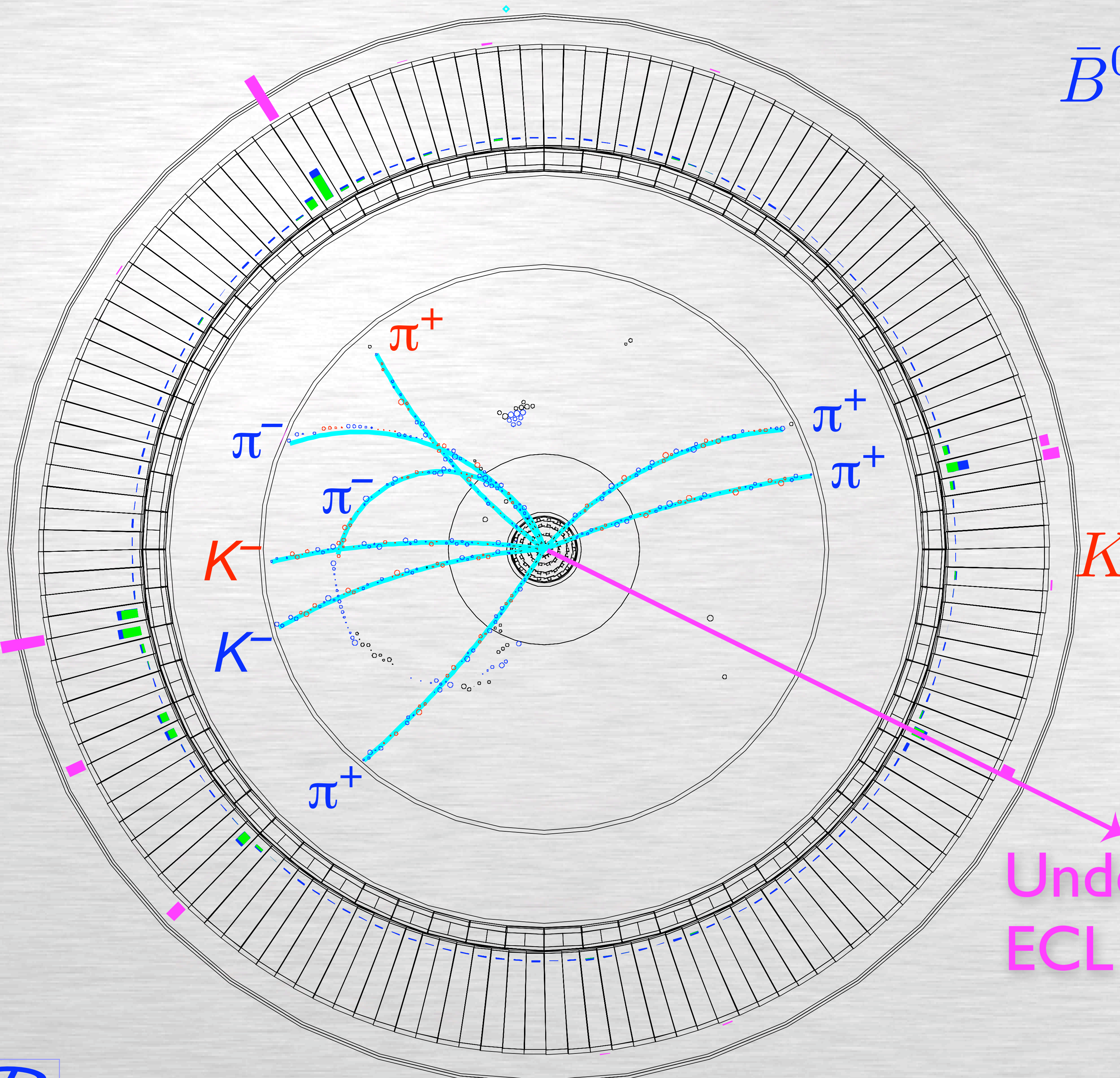
Bird *et al.*, PRL **93**, 201803 (2004)
Dedes *et al.*, PRD **65**, 015001 (2002)
Adams *et al.*, PRL **87**, 041801 (2001)

$B \to K^* \nu\bar{\nu}$ is reconstructed in a manner similar to $B \to \tau\nu$ (but with $K^{*0} \to K^+\pi^-$ signal)



~80 hadronic decay modes reconstructed on tag side

$B \to K^*\nu\bar{\nu}$ candidate event (actually, $B \to K^*\gamma$)



$\bar{B}^0 \to D^+ a_1^-$

$a_1^- \to \rho^0 \pi^-$

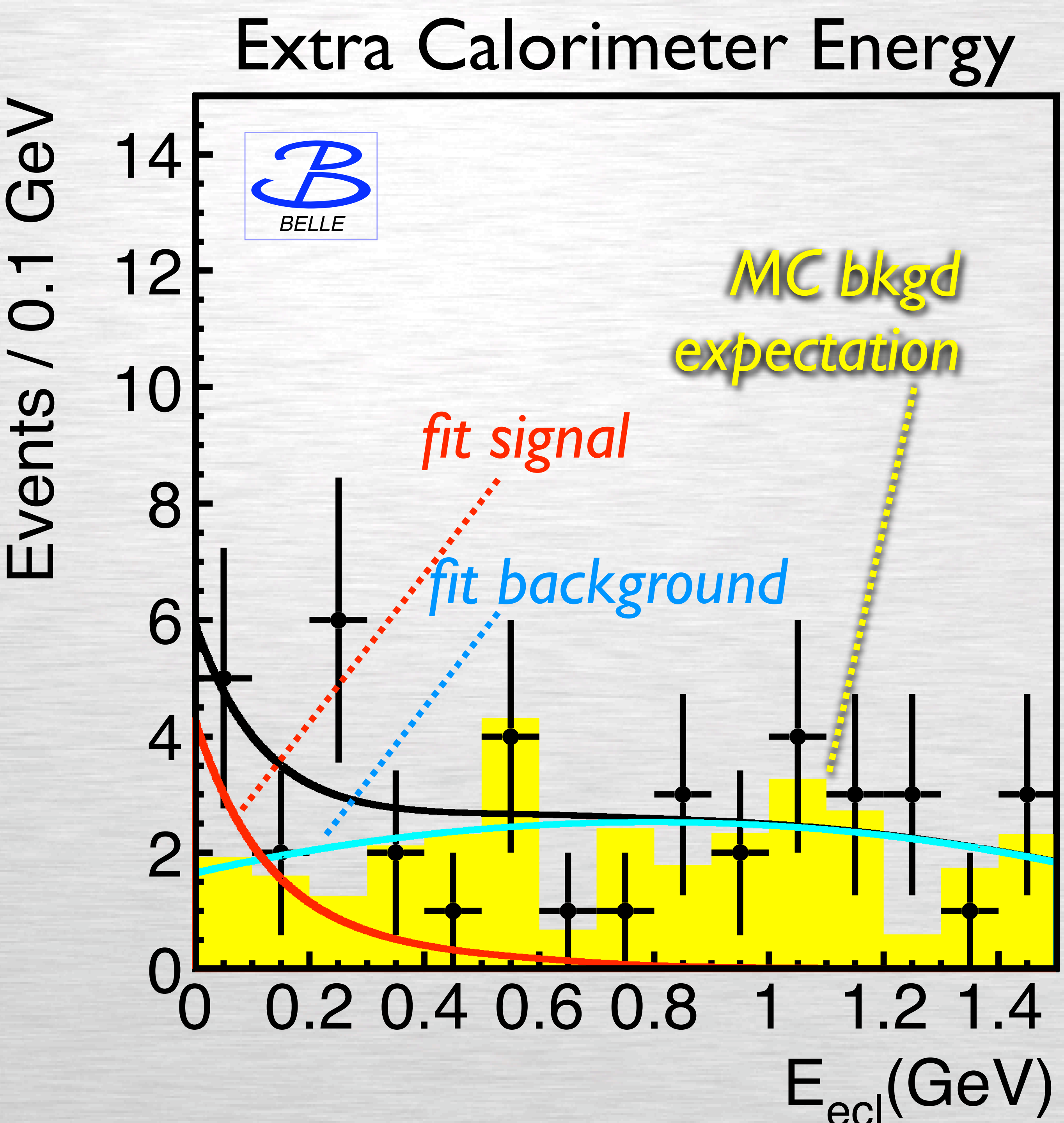
$\rho^0 \to \pi^+ \pi^-$

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

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

Undetected photon in ECL barrel-endcap gap

We find no evidence for $B \to K^* \nu\bar{\nu}$ by examining the distribution of extra calorimeter energy E_{ECL}



535 x 10^6 $B\bar{B}$ pairs
13 $K^*\nu\nu$ candidates in signal region (E_{ECL} < 0.3 GeV)
4.7 $\pm^{3.1}_{2.6}$ signal events from fit

$$\mathcal{B}(B^0 \to K^{*0}\nu\bar{\nu}) < 3.4 \times 10^{-4}$$

at 90% C.L.

cf. SM expectation of 1.3 x 10^{-5} by Buchalla, Hiller & Isidori

Preliminary

Conclusions

- Belle has found evidence for $B \to \tau\nu$ and has used this to determine the *B* decay constant f_B:

$$\mathcal{B}(B^+ \to \tau^+\nu) = (1.79 \pm^{0.56}_{0.49} \pm^{0.46}_{0.51}) \times 10^{-4}$$

$$f_B = (229 \pm^{36}_{31} \pm^{34}_{37})\ \mathrm{MeV}$$

Preliminary

using $|V_{ub}| = (4.39 \pm 0.33) \times 10^{-3}$ from HFAG

- Belle has searched for $B \to K^*\nu\bar{\nu}$:

$$\mathcal{B}(B^0 \to K^{*0}\nu\bar{\nu}) < 3.4 \times 10^{-4}\ @\ 90\%\ \mathrm{C.L.}$$

... still 10x above SM expectation

Preliminary

- Further progress will require **Super B Factory** luminosity