First Measurement of the τ Lepton Polarization in the Decay $\bar{B} \to D^* \tau^- \bar{\nu}_\tau$ at Belle

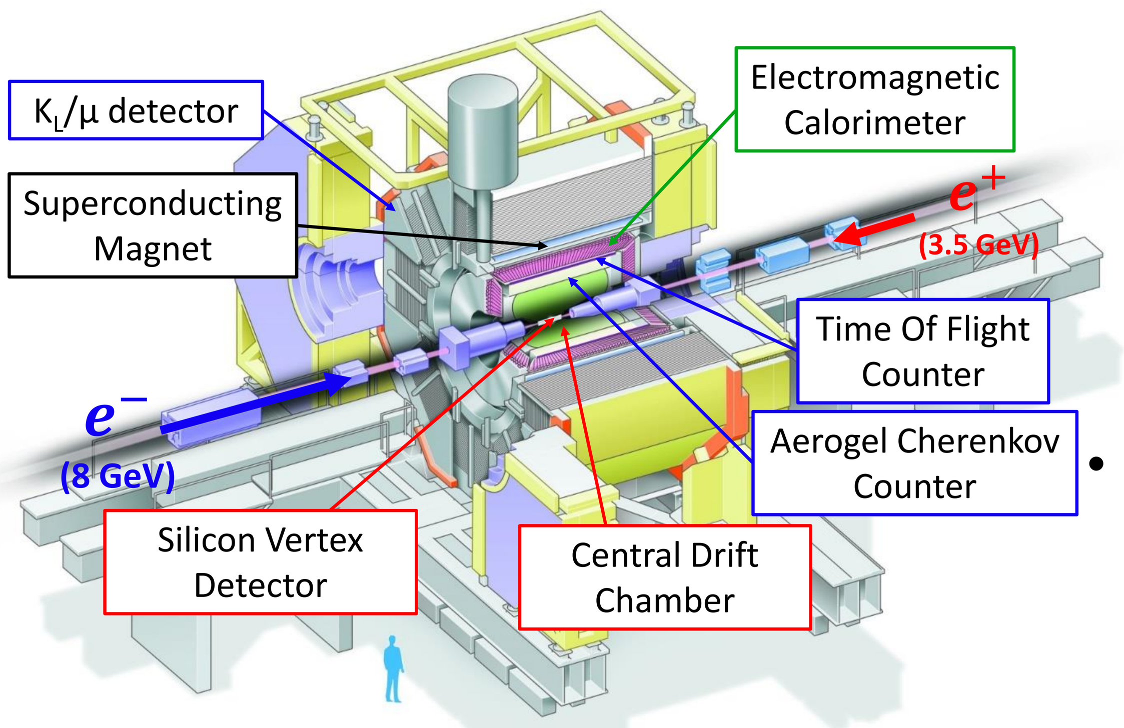
S. Hirose et al. (Belle Collaboration), arXiv:1612.00529 (submitted to Phys. Rev. Lett.)

The decay $\bar{B} \to D^* \tau^- \bar{\nu}_\tau$ is predicted to be sensitive to new physics including a non-universal coupling over the three generation. We report the first measurement of the τ polarization $P_\tau(D^*)$ and a new measurement of the ratio of the branching fractions $R(D^*) = BF(\bar{B} \to D^* \tau^- \bar{\nu}_\tau)/BF(\bar{B} \to D^* l^- \bar{\nu}_l)$ using the full data sample containing $(7.72 \pm 0.11) \times 10^8\ B\bar{B}$ pairs accumulated at the Belle experiment. We reconstruct signal events from $\tau^- \to \pi^- \nu_\tau$ and $\rho^- \nu_\tau$. Our measurement results in $P_\tau(D^*) = -0.38 \pm 0.51(\text{stat.})\ ^{+0.21}_{-0.16}(\text{syst.})$ and $R(D^*) = 0.270 \pm 0.035(\text{stat.})\ ^{+0.028}_{-0.025}(\text{syst.})$. These are consistent with the SM prediction.

Shigeki Hirose (Nagoya University, Japan), Toru Iijima (Nagoya U.) and the Belle Collaboration

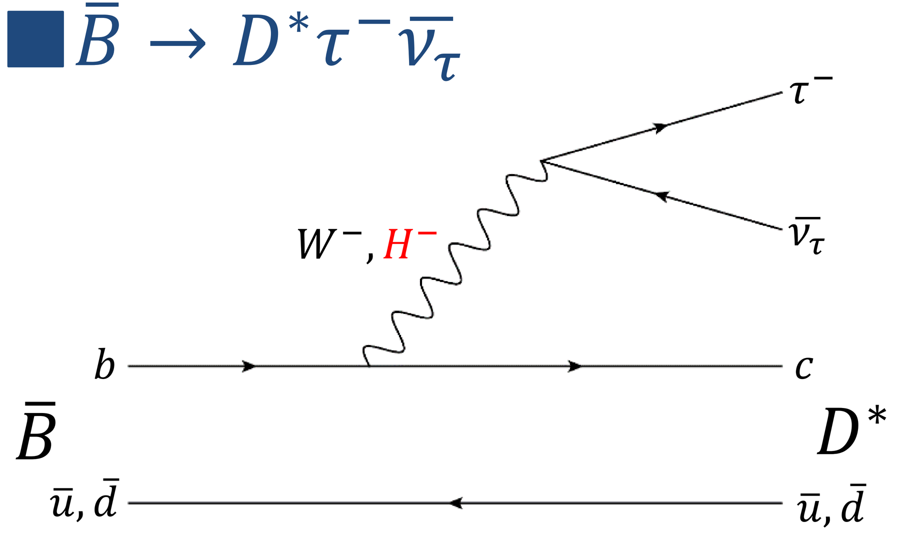
Belle Experiment

B-factory at the e^+e^- Collider KEKB

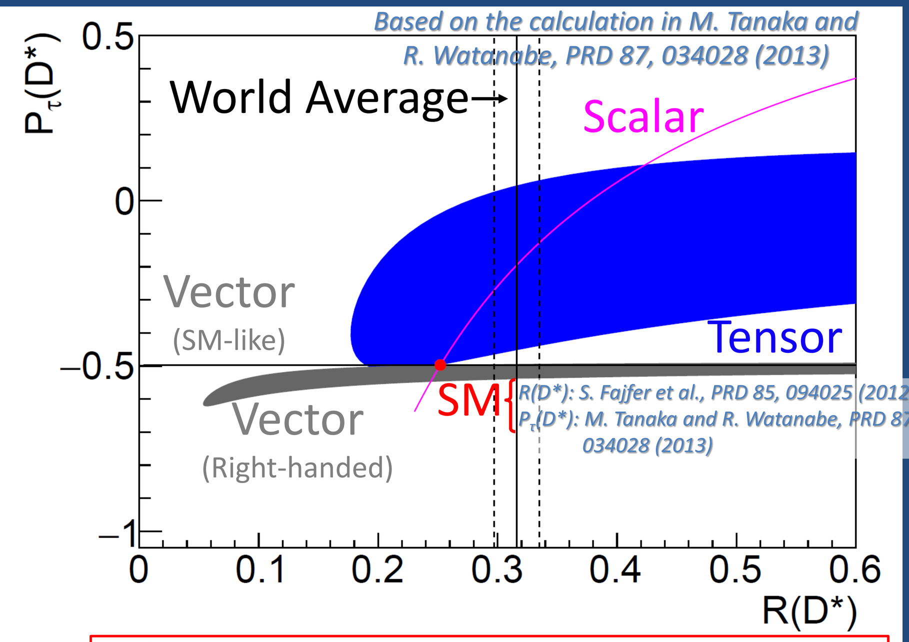


- e^+e^- collision at 10.58 GeV, where B mesons are produced through $\Upsilon(4S) \to B\bar{B}$
  → Clean environment as there is no particle except for two B mesons
- KEKB holds a world-record peak luminosity of $2 \times 10^{34}/\text{cm}^2/\text{s}$
  → Belle has recorded data containing $(7.72 \pm 0.11) \times 10^8\ B\bar{B}$

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



- Sensitive to new physics (NP) having an enhanced coupling to the third-generation fermions
- 3.3σ deviation from the standard model (SM) prediction has been observed
- Belle has measured this mode with leptonic τ decays



Definition

$$P_\tau(D^*) = \frac{\Gamma_R - \Gamma_L}{\Gamma_R + \Gamma_L} \qquad R(D^*) = \frac{BF(\bar{B} \to D^* \tau^- \bar{\nu}_\tau)}{BF(\bar{B} \to D^* l^- \bar{\nu}_l)}$$

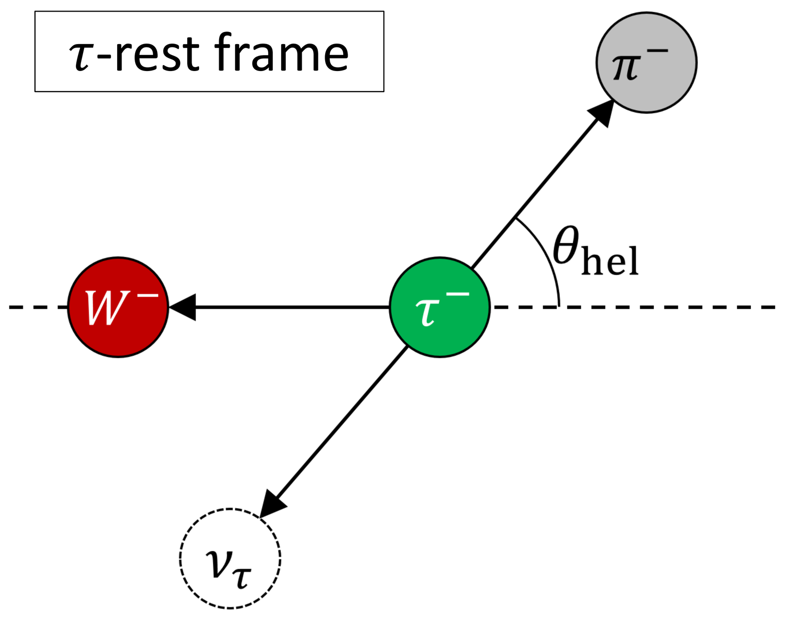
Using $\tau^- \to \pi^- \nu_\tau$ and $\rho^- \nu_\tau$,
- Measurement of $P_\tau(D^*)$
- Measurement of $R(D^*)$ independent of the past meas.

are possible!

Belle Collaboration, PRD 92, 072014 (2015)
Belle Collaboration, PRD 94, 072007 (2016)

τ Polarization Analysis Method

Principle of the Measurement



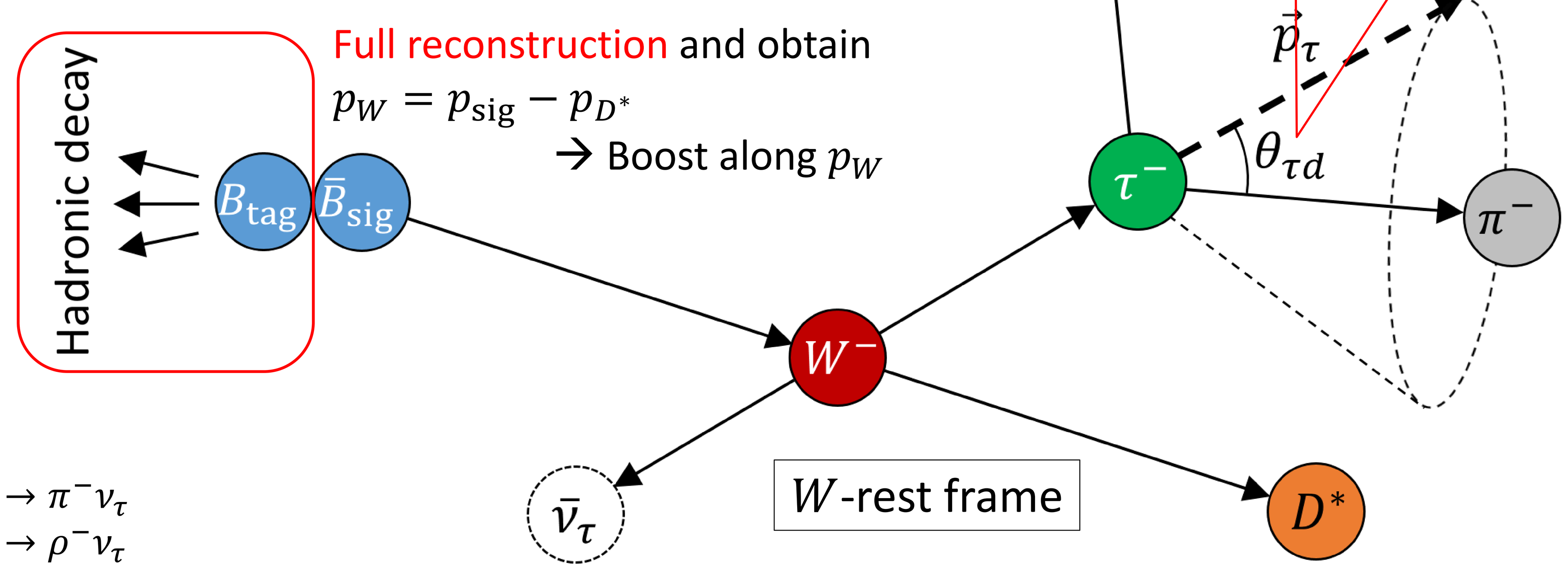
$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_{\text{hel}}} = \frac{1}{2}[1 + \alpha P_\tau(D^*)\cos\theta_{\text{hel}}]$$

$$\alpha = \begin{cases} 1 & \text{for } \tau^- \to \pi^- \nu_\tau \\ (m_\tau^2 - m_\rho^2)/(m_\tau^2 + m_\rho^2) & \text{for } \tau^- \to \rho^- \nu_\tau \end{cases}$$

We need to measure $\cos\theta_{\text{hel}}$, but cannot obtain the complete τ momentum due to insufficient constraint
→ Use W rest frame

We can obtain this value experimentally

$$\cos\theta_{\tau d} = \frac{2E_\tau E_d - m_\tau^2 - m_d^2}{2|\boldsymbol{p}_\tau||\boldsymbol{p}_d|}$$



By the rotation symmetry, the frame can be boosted along any direction to
→ Obtain a correct $\cos\theta_{\text{hel}}$

Parameterization

- Use two bins of $\cos\theta_{\text{hel}}$
- Signal yields in [0, 1] and [-1, 0] are, respectively,

$$N_F = \frac{N}{2}\left[1 + \frac{\alpha}{2}P_\tau(D^*)\cos\theta_{\text{hel}}\right]$$

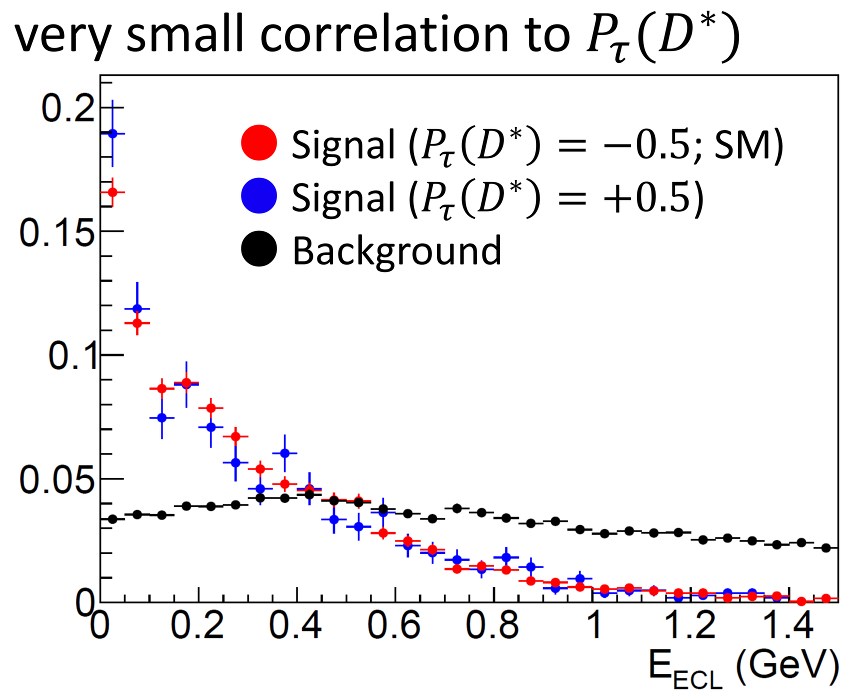
$$N_B = \frac{N}{2}\left[1 - \frac{\alpha}{2}P_\tau(D^*)\cos\theta_{\text{hel}}\right]$$

- $P_\tau(D^*)$ is parameterized as

$$P_\tau(D^*) = \frac{2}{\alpha}\frac{N_F - N_B}{N_F + N_B}$$

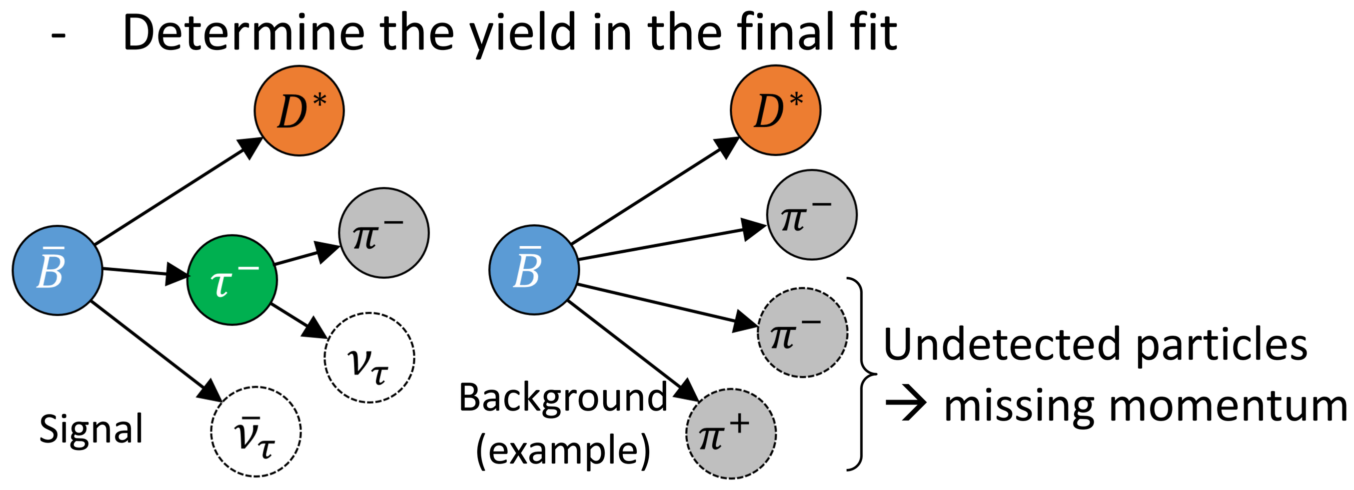
Signal Extraction

- E_{ECL} is a linear energy sum of the remaining clusters in ECL
- This is the best variable in terms of
  - good background discrimination
  - very small correlation to $P_\tau(D^*)$



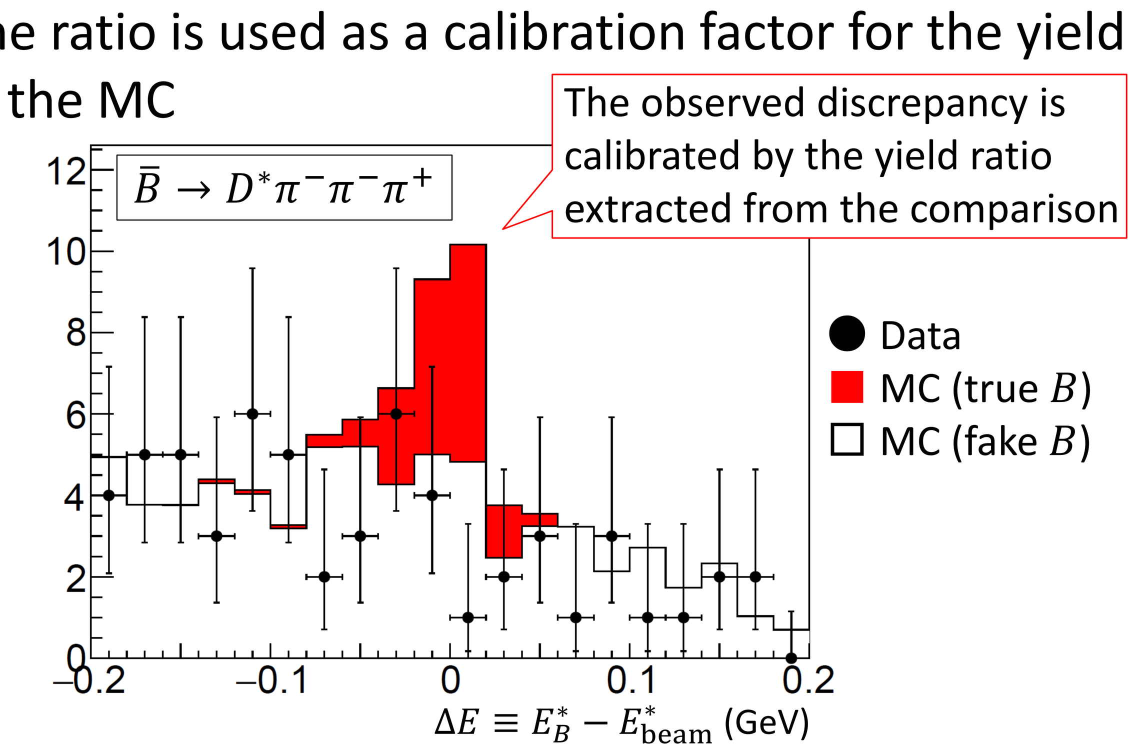
Hadronic B Background Calibration

- Important background component:
  - similar event topology to the signal
  - huge uncertainty due to low energy hadronization process
- Strategy for the yield determination
  - Calibrate composition of hadronic B decays modes using data
  - Determine the yield in the final fit

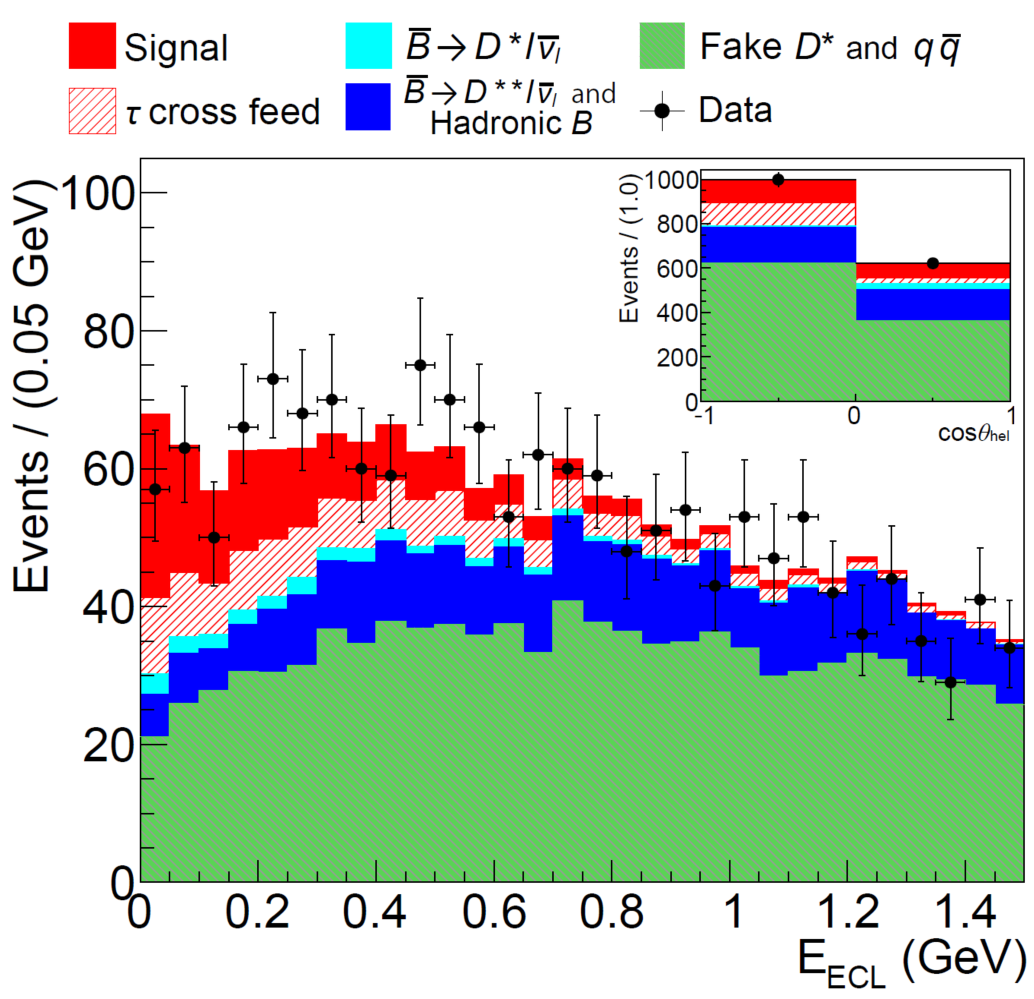


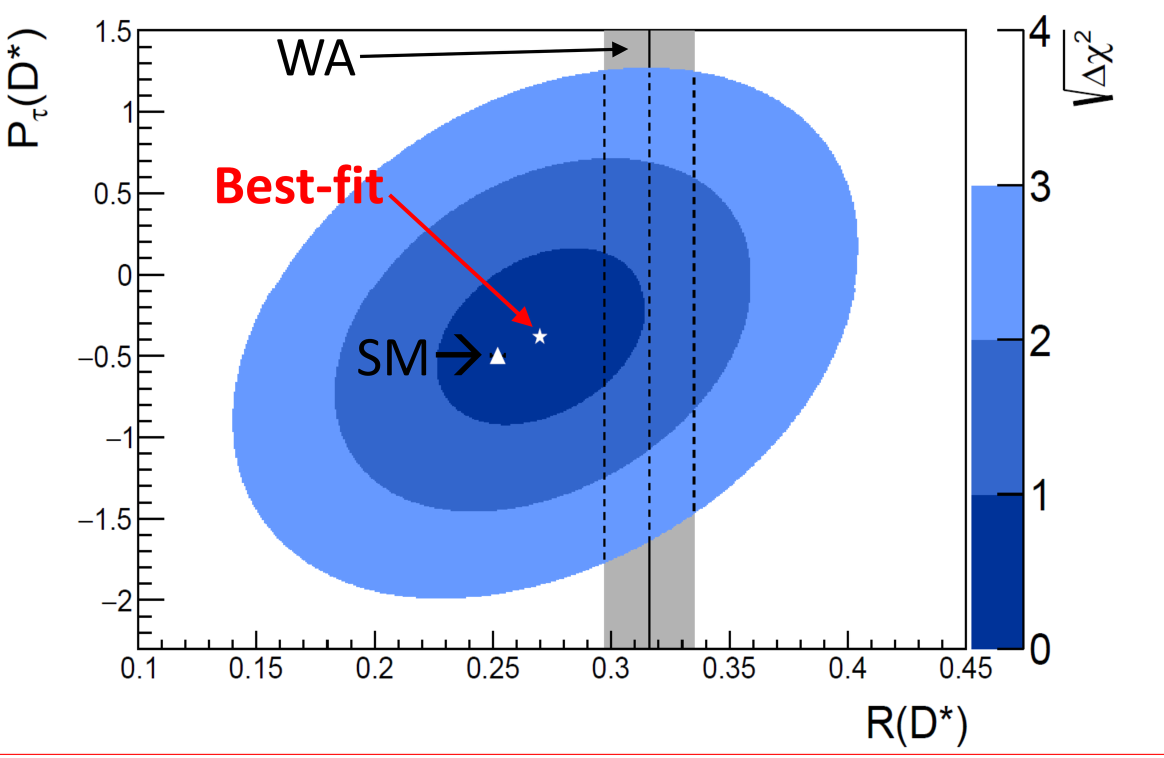
Calibration Method

- Fully reconstruct seven specific B decay modes
- Compare the yields between the MC and the data
  → Take the yield ratio
- The ratio is used as a calibration factor for the yield in the MC



Result





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

First $P_\tau(D^*)$ measurement!
→Results consistent with the SM

Summary

Using hadronic τ decays $\tau^- \to \pi^- \nu_\tau$ and $\rho^- \nu_\tau$, we measured $P_\tau(D^*)$ as well as $R(D^*)$. One of the difficulties in the $P_\tau(D^*)$ measurement was that the full τ momentum could not be obtained. We have established the $P_\tau(D^*)$ measurement method using the rest frame of W and the symmetry in the decay kinematics. To cope with background from hadronic B decays, we have calibrated the composition of the decay modes using the calibration data samples. Our measurement results in

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

consistent with the SM prediction. Our study has demonstrated the polarization measurement in $\bar{B} \to D^* \tau^- \bar{\nu}_\tau$, that gives an additional dimension in the NP searches with the semitauonic B meson decays.