Inclusive B-meson tagging for an $R(D^*)$ measurement at Belle II

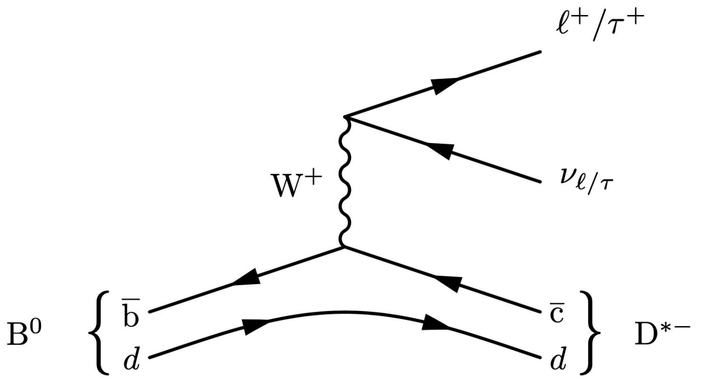
IMPRS Interview

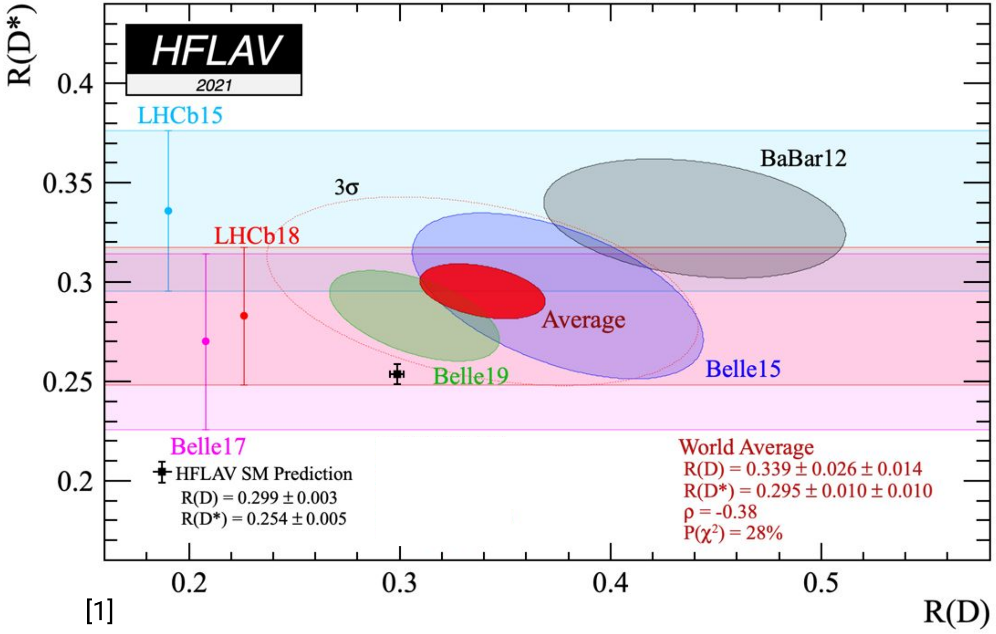
Sofia Palacios Schweitzer
LMU München

18. July 2022

A Road to New Physics

$$R(D^*) = \frac{\mathcal{B}(B \to D^* \tau \nu_\tau)}{\mathcal{B}(B \to D^* l \nu_l)} \quad l = \mu, e$$





[1]

→ Measured values in 3.3σ tension with SM prediction

How to get a B-Meson

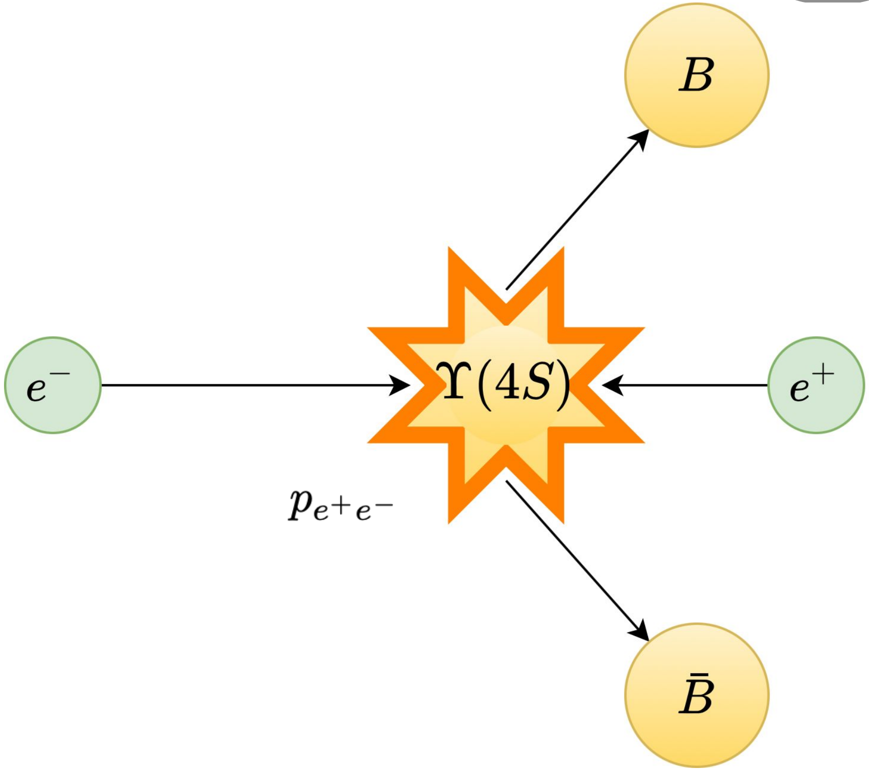
In the Belle II Experiment at SuperKEKB :

1. Collision of electron & positron ($\sqrt{s}$=10.58 GeV) (precisely known)

2. Production of Υ(4S)

3. Decay into B-Meson pair

→ in 8 years : $5 \cdot 10^{10}$ B-Meson pairs

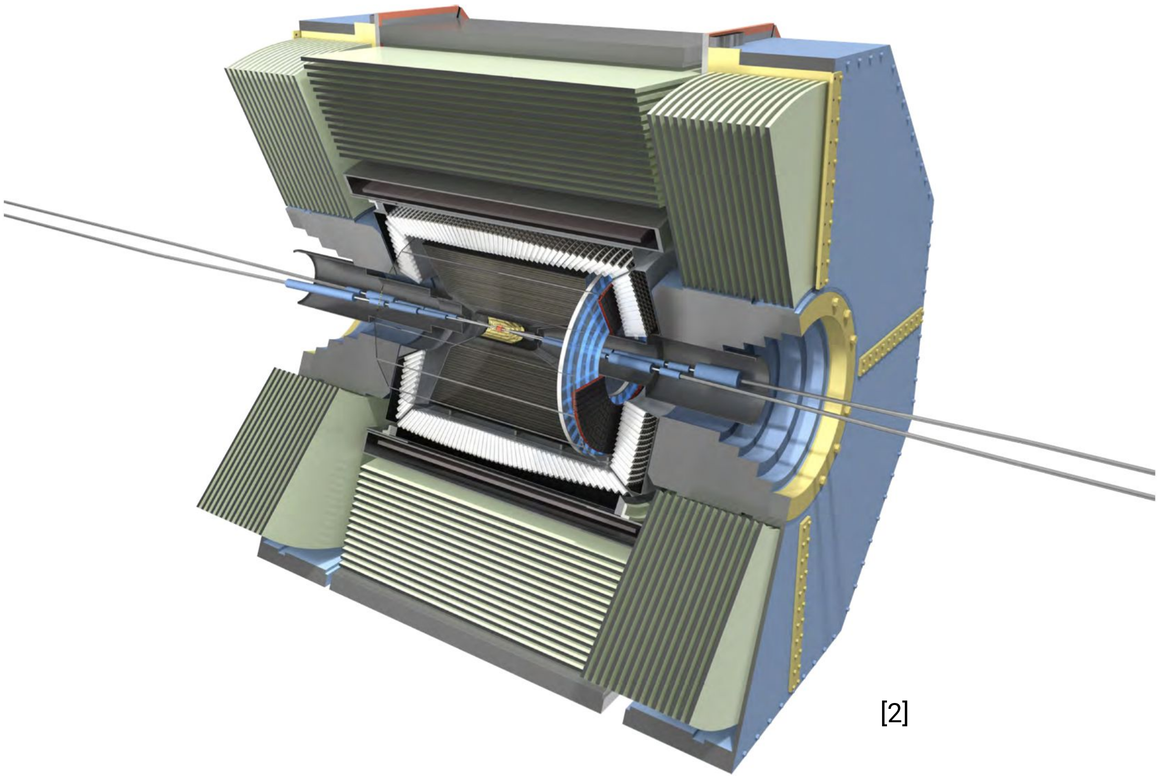


How to detect

Belle II Detector

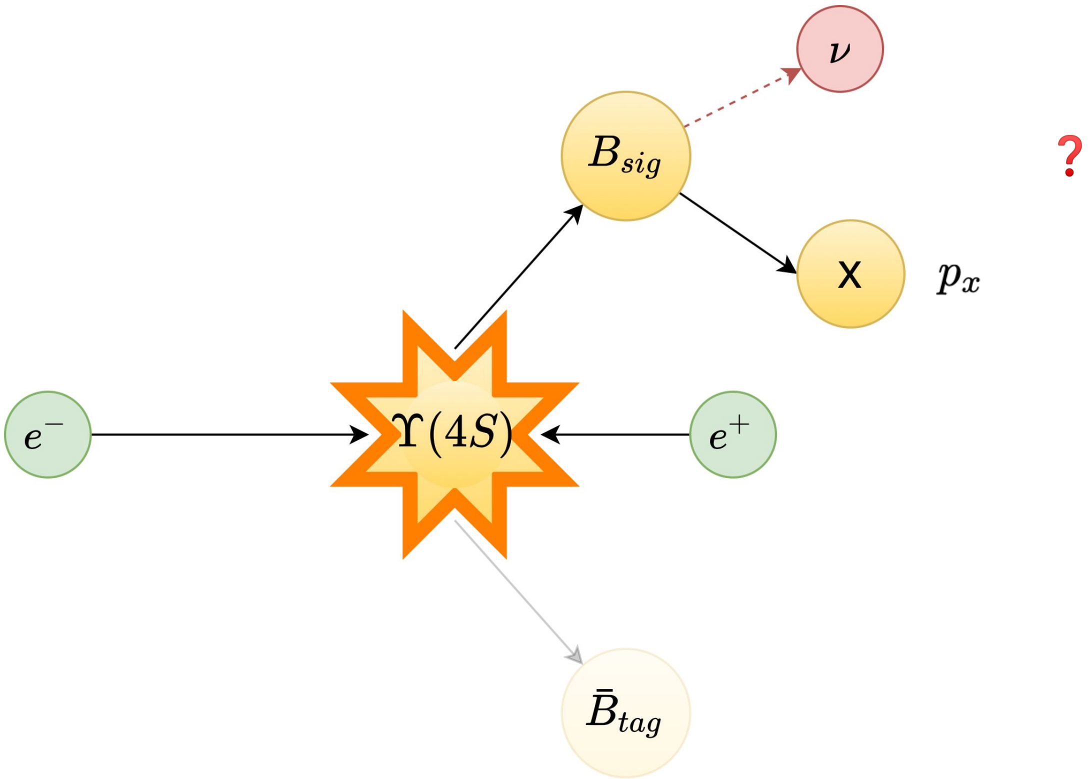
1. Vertex detector
2. Central Drift Chamber
3. Particle identification detectors
4. EM Calorimeter inside solenoid
5. K_L & μ detector

→ Neutrinos?

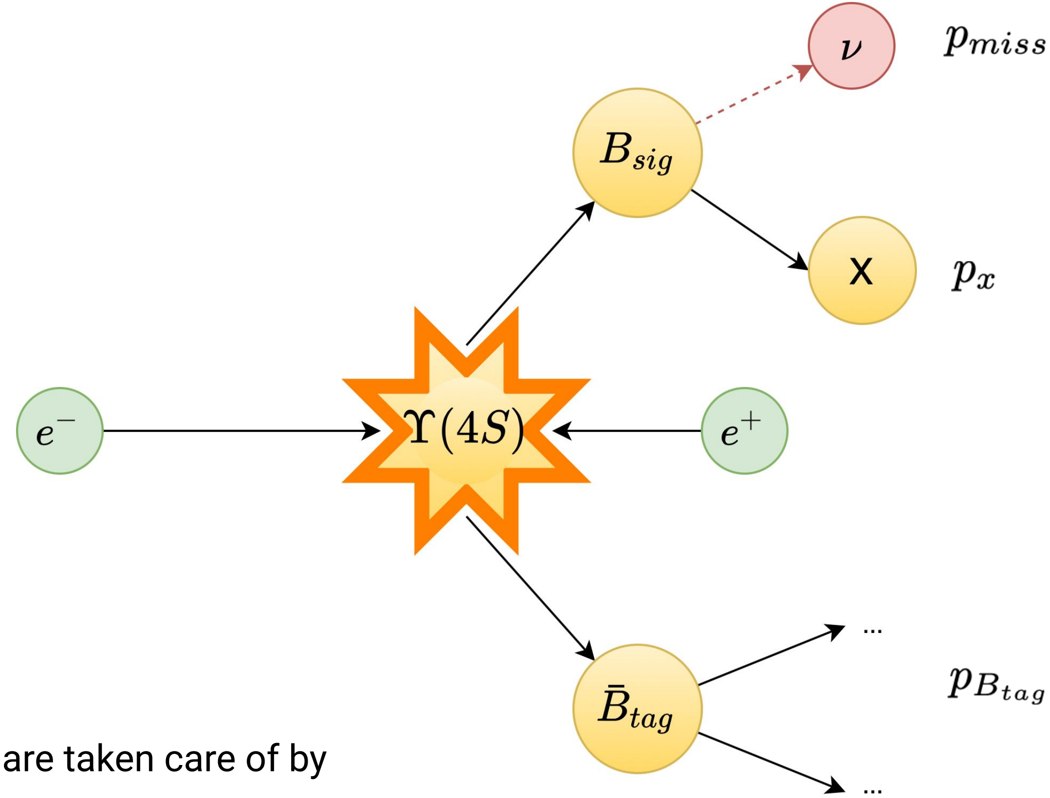


[2]

What about Neutrinos?



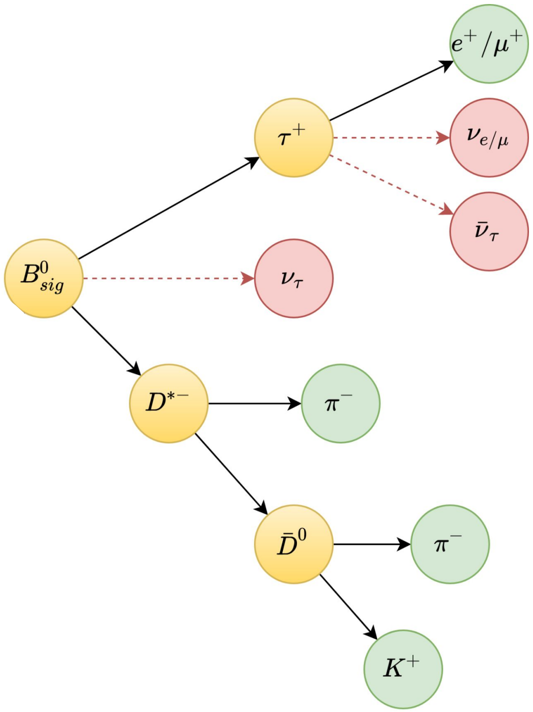
Let's just tag it



→ Neutrinos are taken care of by

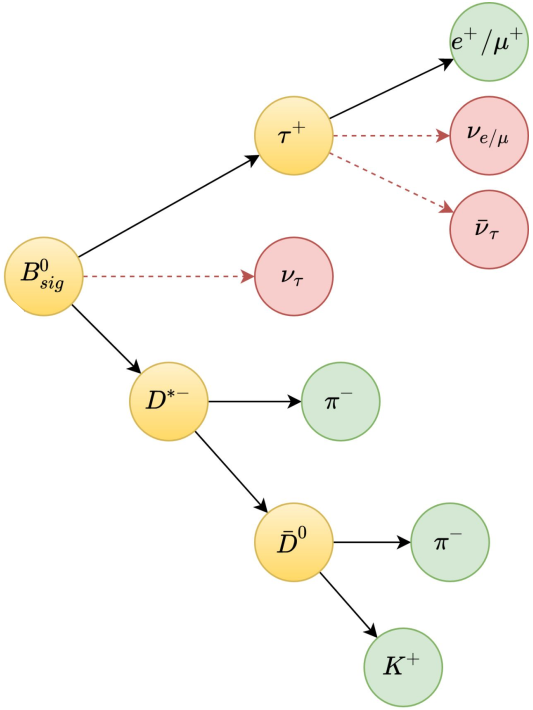
$$p_{miss} = p_{e^+e^-} - p_{B_{tag}} - p_x$$

Reconstruction Strategy



1. Reconstruct signal side exclusively

Reconstruction Strategy



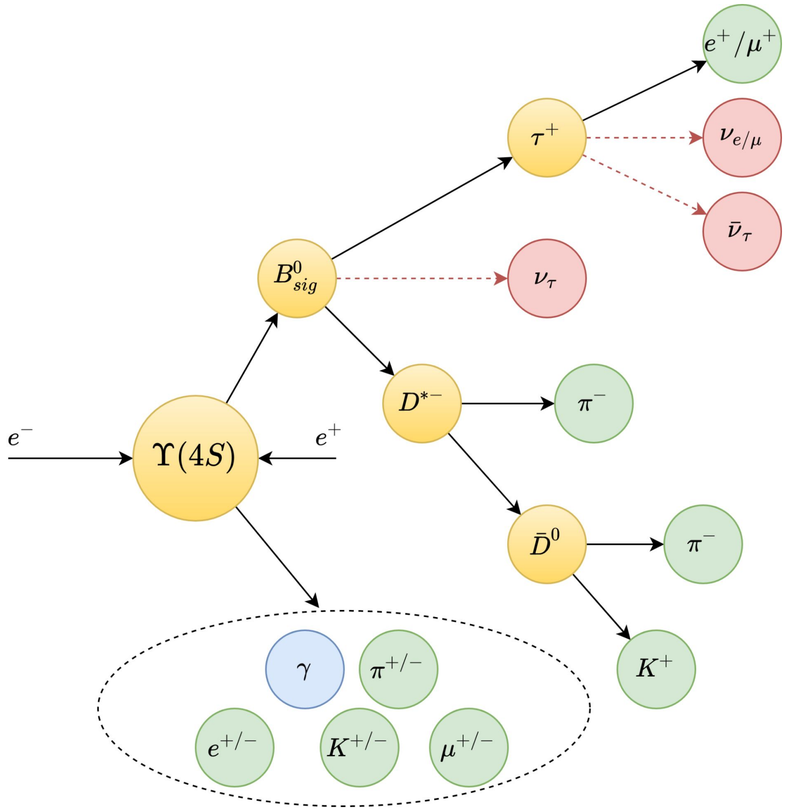
For tag side reconstruction:

- iterating over multiple exclusive decay modes (default)

vs

- inclusively

Reconstruction Strategy

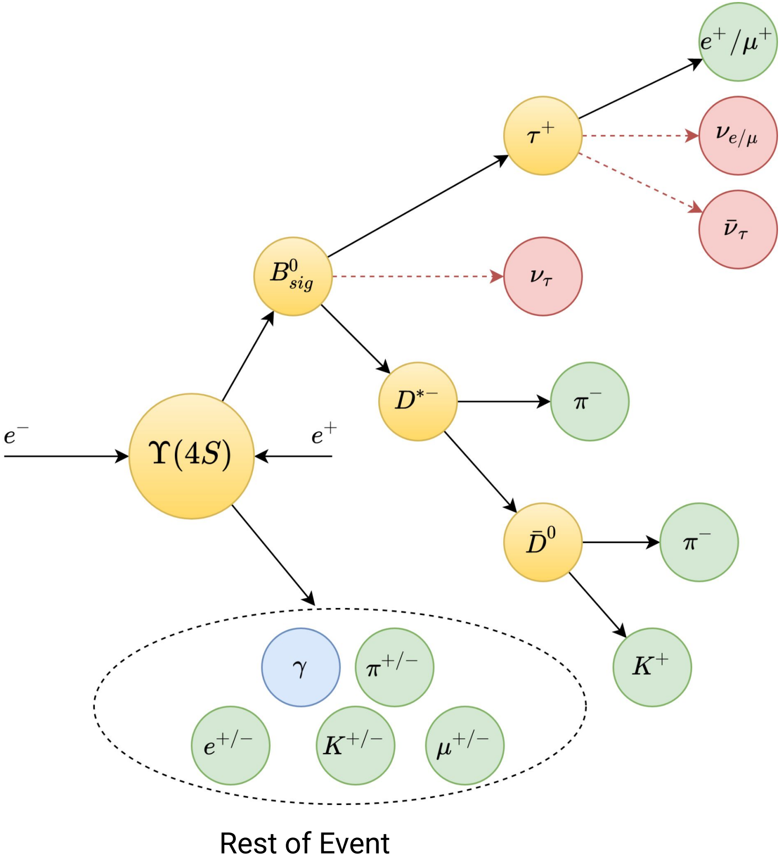


Rest of Event

2. Reconstruct tag side inclusively (hadronically)

  - no intermediate daughters are reconstructed

Reconstruction Strategy



Belle II exclusive tagging algorithm

Tags	Decay Modes covered	Tag Side Efficiency
Semileptonic	4.0%	2.04%
Hadronic	1.1%	0.46%

[3],[4]

→ fully inclusive promises higher tag side efficiency

BUT: Very high background levels

Workflow

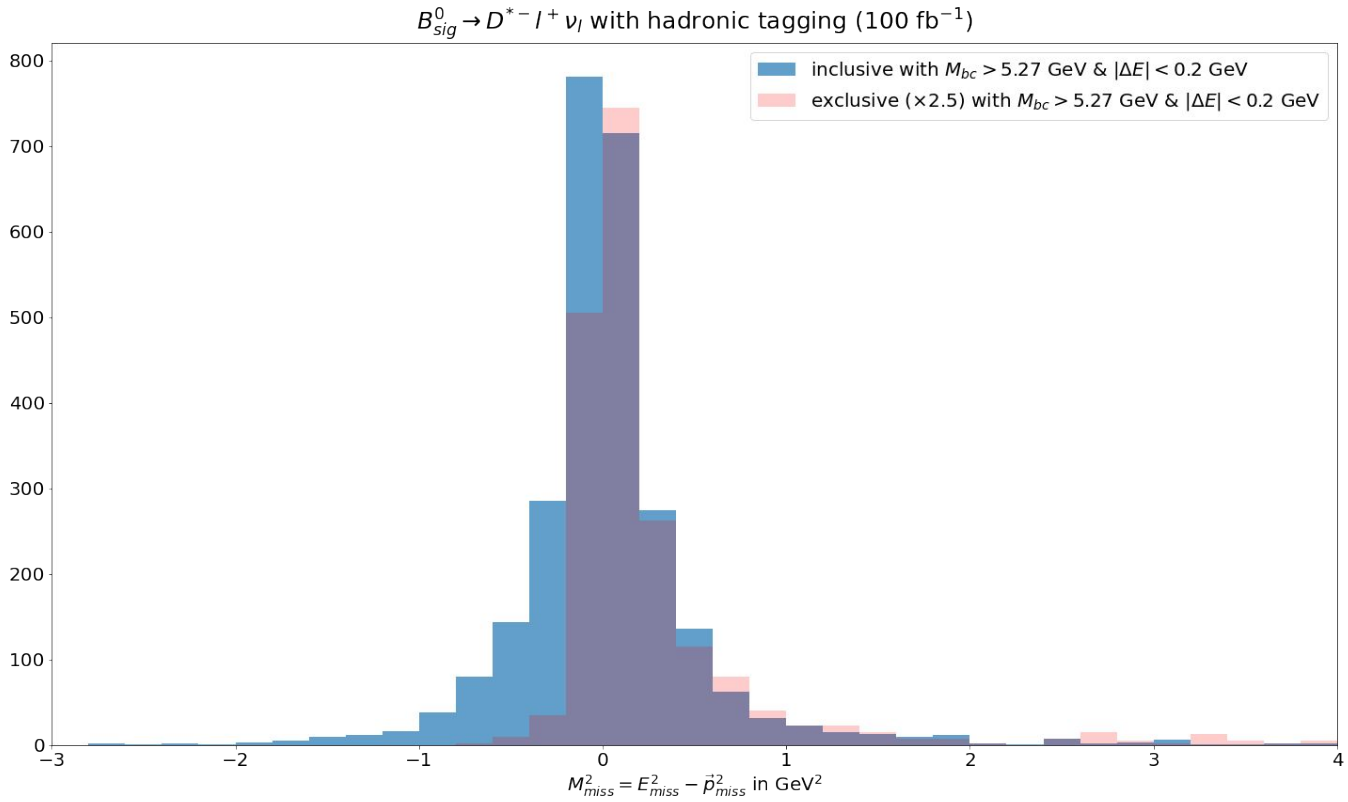
1. Reconstruction
    a. optimize signal & tag side selection

2. Background Analysis
    a. categorize background modes
    b. build MVAs

3. Fit
    a. 2D Fit in M^2_{miss} and lepton momentum

4. Estimate Systematic Uncertainties

1. Reconstruction

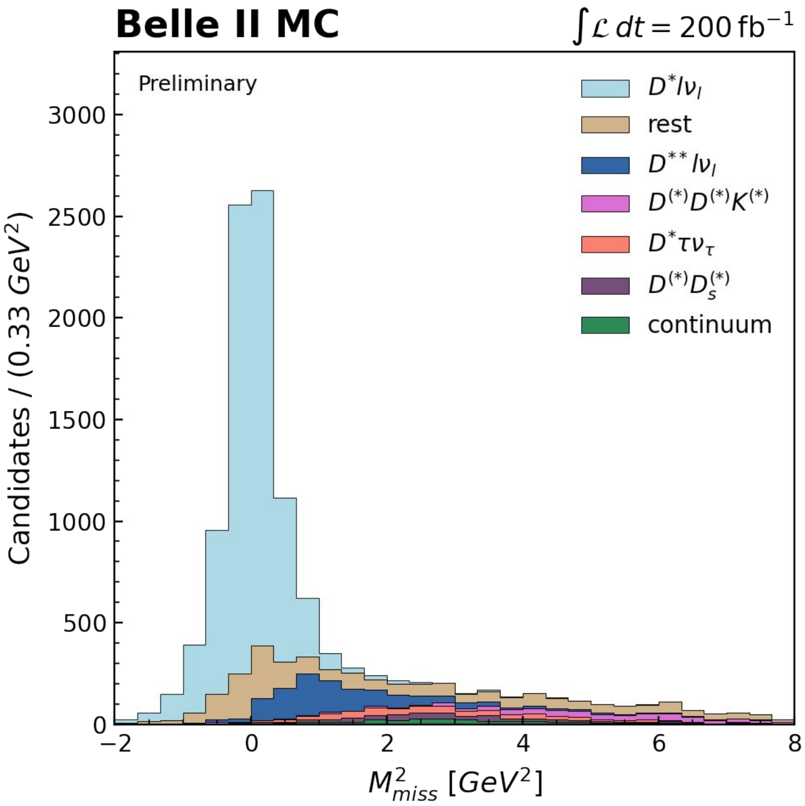


→ Reconstruction strategy works

2. Background Analysis

Reconstruction Modes:

- 62% normalization mode
- 3.5% signal mode
- 2.6% continuum background
- 32% combinatorial background



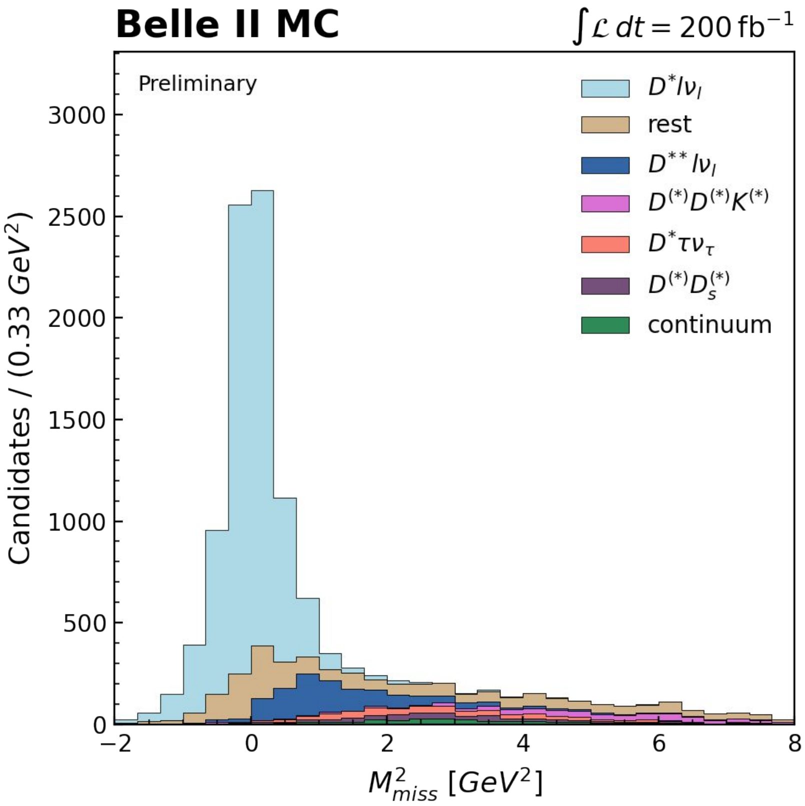
2. Background Analysis

For M^2_{miss} < 1 GeV^2:

Normalization Channel with purity of 82%

For M^2_{miss} > 1 GeV^2:

Signal Channel with purity of 12%

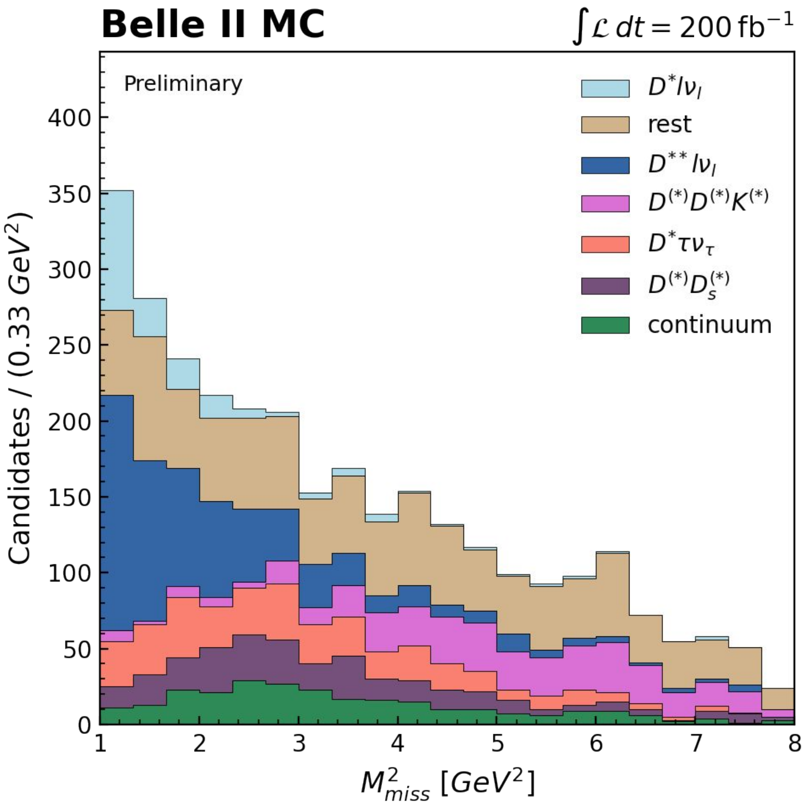


2. Background Analysis

Sideband Components

Background:

- 20% D** l ν (higher excited D states)
  - ↪ D* π
- 13% $D^{(*)}$ $D^{(*)}$ $K^{(*)}$
- 10% $D_s^{(*)}$ $D^{(*)}$
  - ↪ τ ν
- 8.6% continuum
- 38% rest



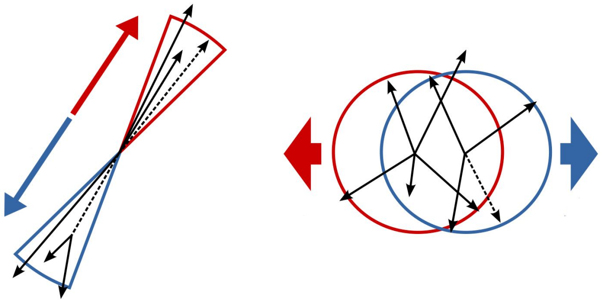
2. Background Analysis

Suppression

Idea: Build MVAs to suppress different background components

1. Continuum Background: Event Shape Variables

2. Combinatorial Background: ?



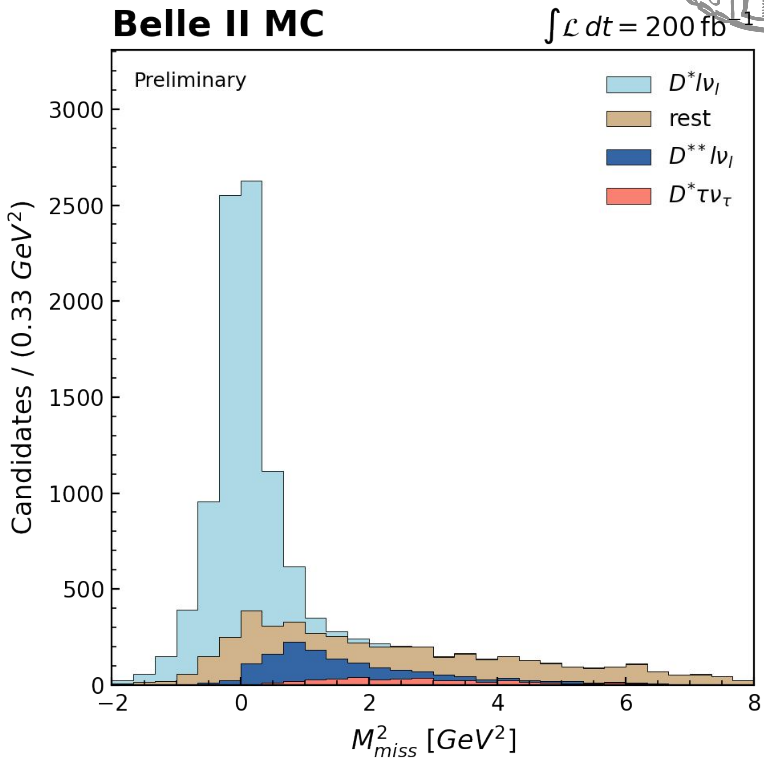
→ Suppression not optimal yet

3. Fit

- unbinned maximum likelihood fit
- pdfs: kernel density estimation from MC
- 2D: M^2_{miss} & lepton momentum

Fit Components:

1. normalization mode
2. signal mode
3. D** background
4. remaining background

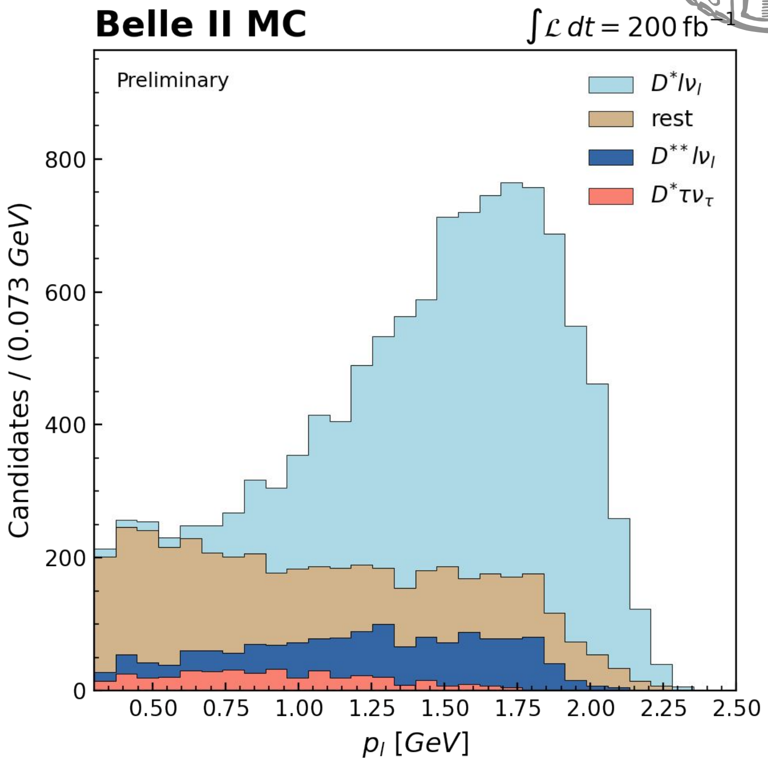


3. Fit

- unbinned maximum likelihood fit
- pdfs: kernel density estimation from MC
- 2D: M^2_{miss} & lepton momentum

Fit Components:

1. normalization mode
2. signal mode
3. D** background
4. remaining background



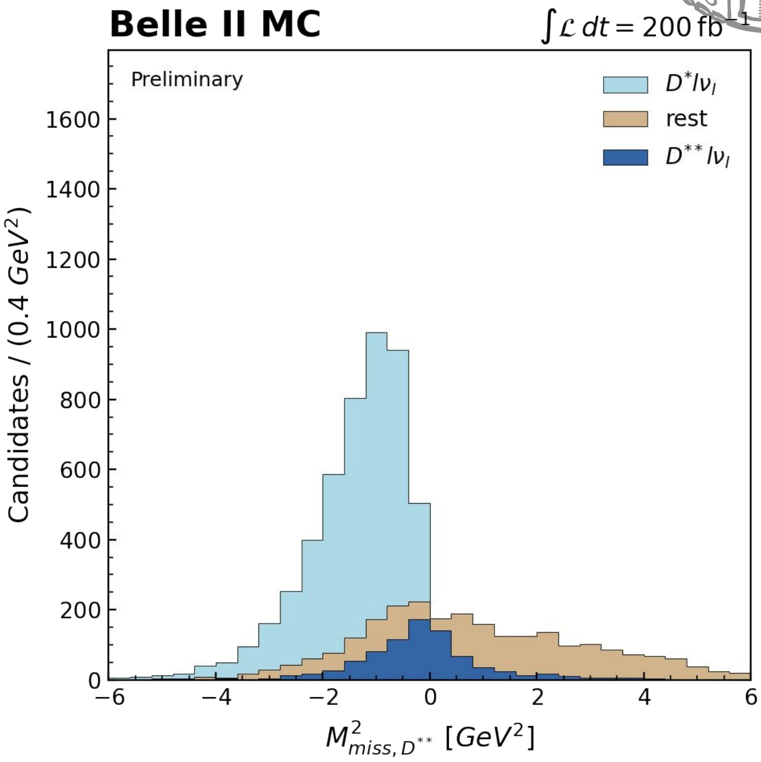
3. Fit

Investigate way to fix D** Background:

- Reconstruct D** in $B \rightarrow D^* \pi l \nu$
- Fit of M^2_{miss} of D**
- Reconstruction efficiency

→ Use fit result to constrain D** component in signal fit

→ Sequential fit: 1d + 2d



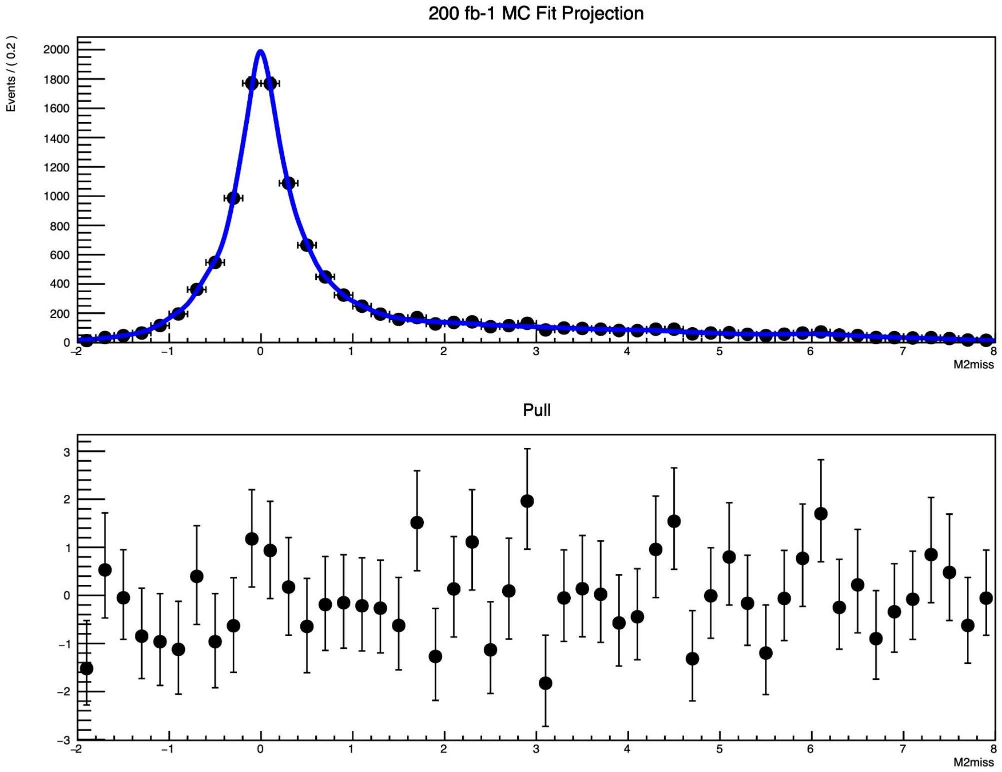
3. Fit

Test fit to MC sample:

$$R(D^*) = \frac{n_{sig}}{n_{norm}} \frac{\epsilon_{norm}}{\epsilon_{sig}} = 0.28 \pm 0.03$$

in MC: $R(D^*) = 0.258$

- toy test show unbiased fit with well described uncertainties



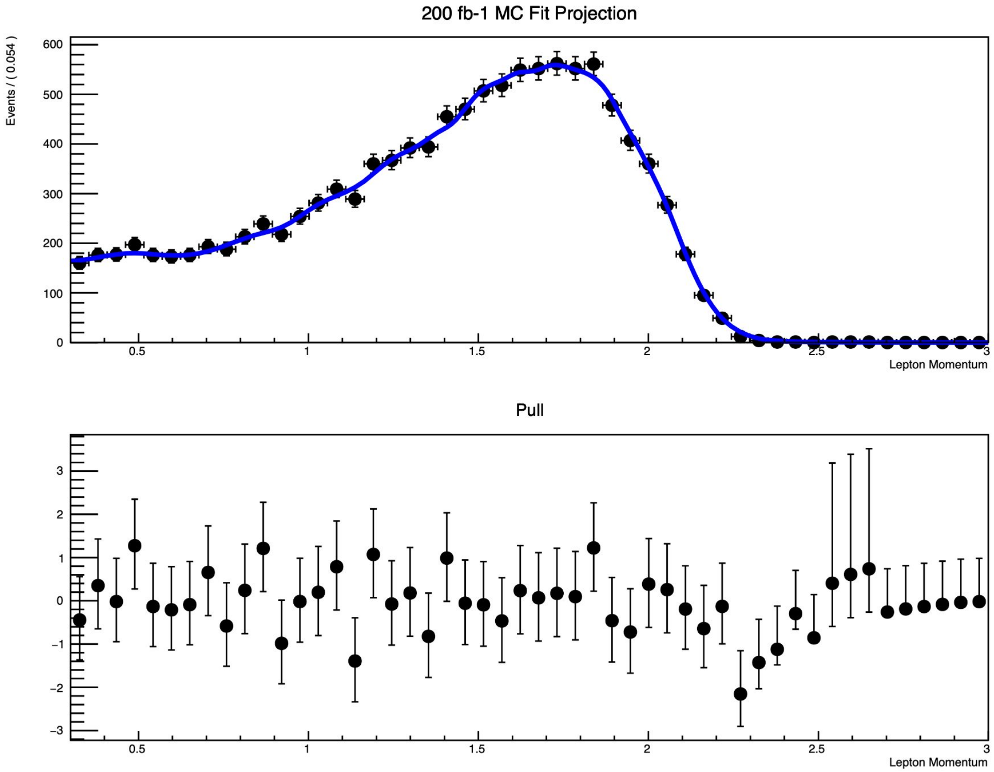
3. Fit

Test fit to MC sample:

$$R(D^*) = \frac{n_{sig}}{n_{norm}} \frac{\epsilon_{norm}}{\epsilon_{sig}} = 0.28 \pm 0.03$$

in MC: $R(D^*) = 0.258$

- toy test show unbiased fit with well described uncertainties



What now?

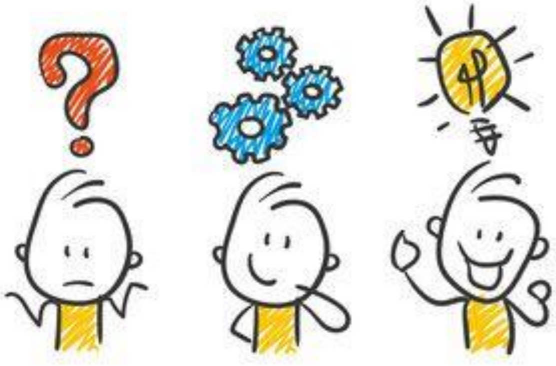
Is this approach compatible with exclusive tagging?

For now **yes**, available data statistically limited (currentently ~200 fb-1)

BUT: statistical limit will be overcome eventually

To stay compatible:

- Optimize training
- Estimate systematic uncertainties



[5]

Sources

[1] https://hflav-eos.web.cern.ch/hflav-eos/semi/spring21/r_dtaunu/rdrds_2021.png

[2] https://www.belle2.org/e21595/e21770/infoboxContent25428/BelleII3D.pdf

[3] T.Keck, “The Full Event Interpretation for Belle II” (2014), KIT Karlsruhe

[4] T.Keck et al. “The Full Event Interpretation” (2019), arXiv:1807.08680

[5] https://stock.adobe.com/de/contributor/205527442/strichfiguren-de