R($D^{(*)}$) MEASUREMENT AT THE BELLE II DETECTOR

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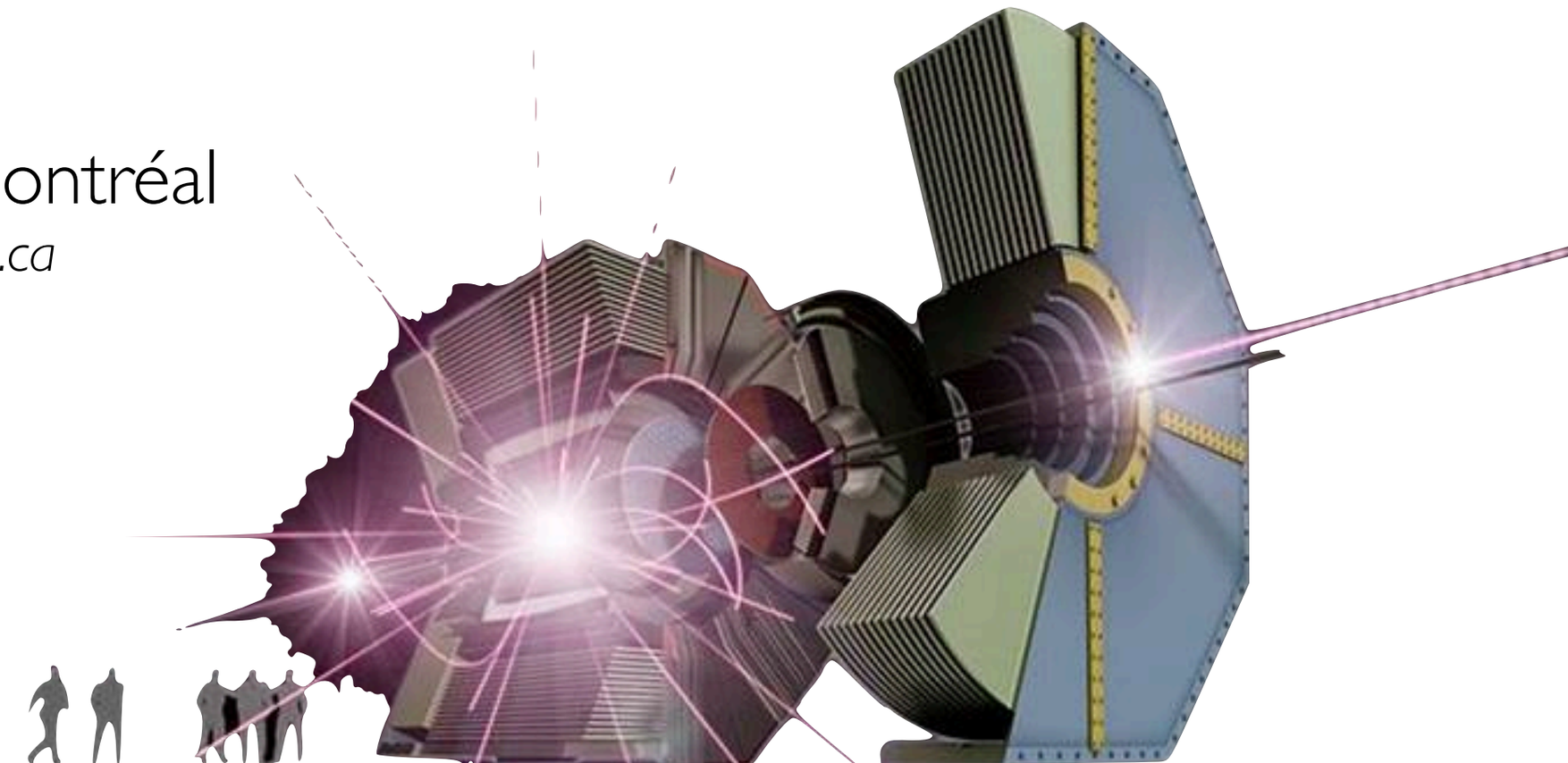
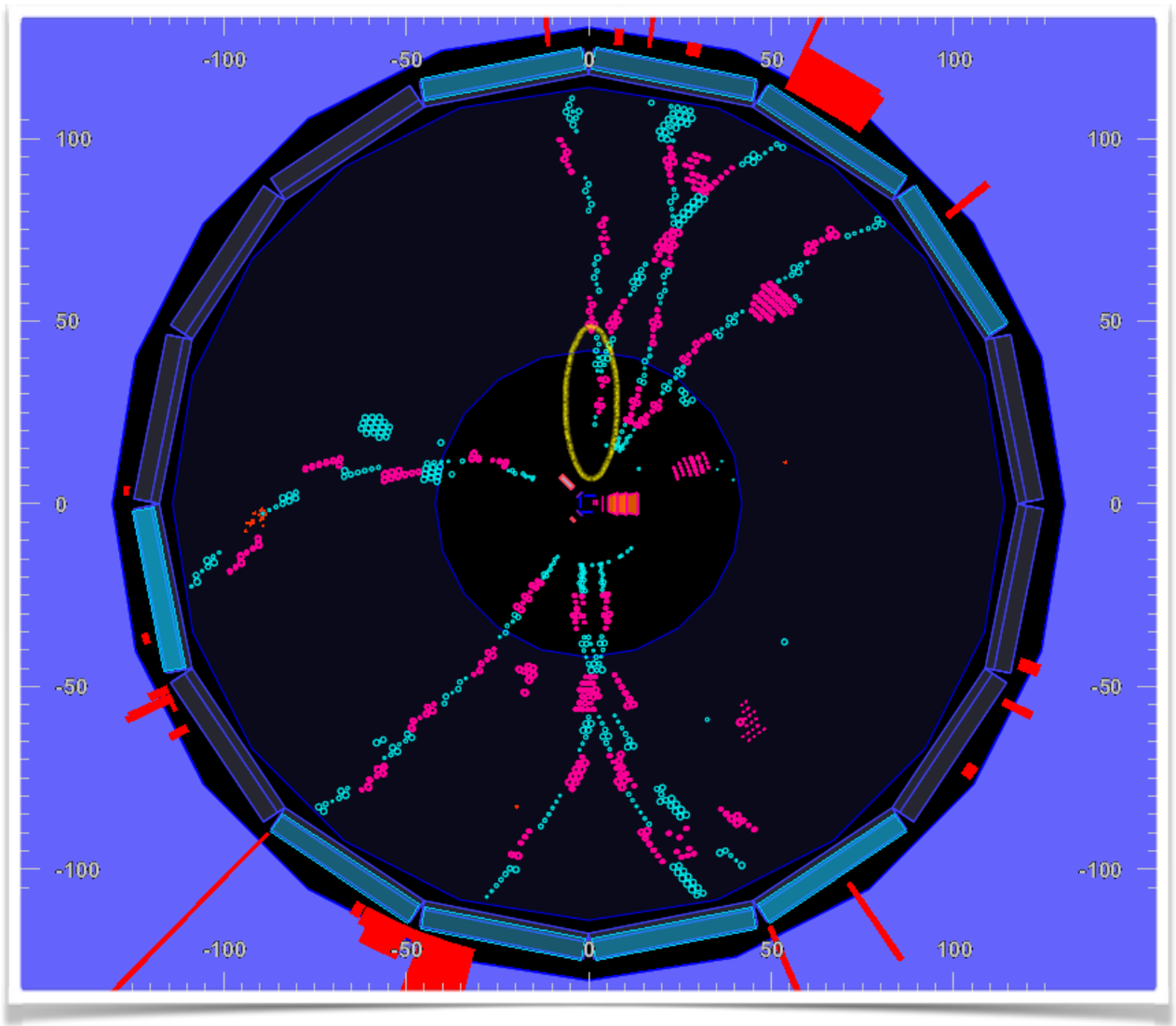


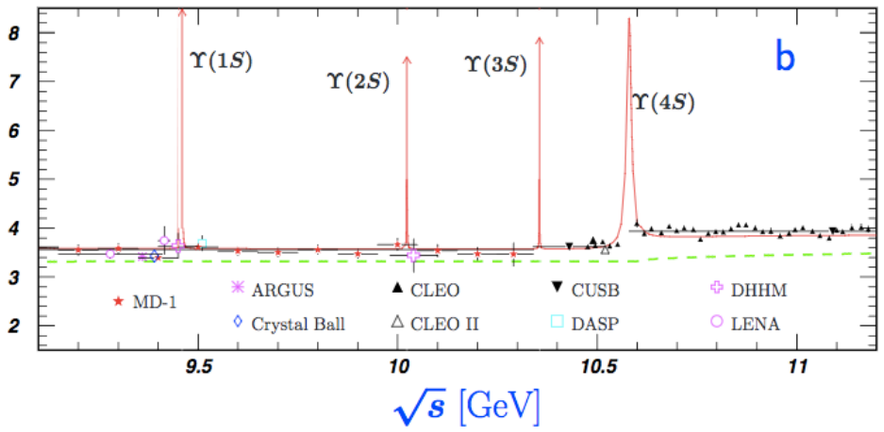
CONTENT

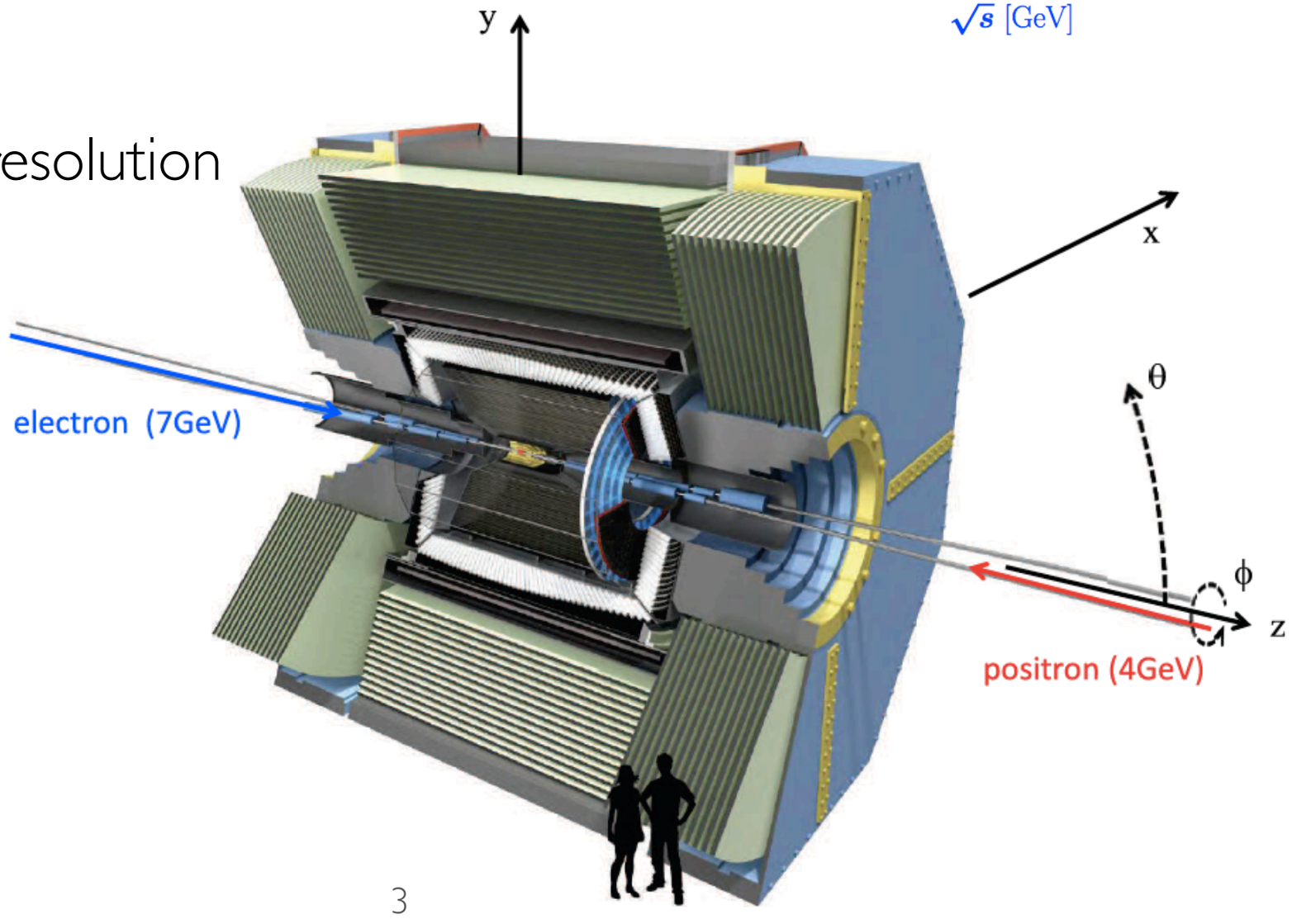
- The Belle II Experiment
- Semi-Leptonic Decays
- Reconstruction
- $B \rightarrow D^{(*)}\tau\nu, B \rightarrow D^{(*)}\ell\nu$
- $\boldsymbol{R}(D^{(*)})$
- Analysis Procedure
- Summary



BELLE II

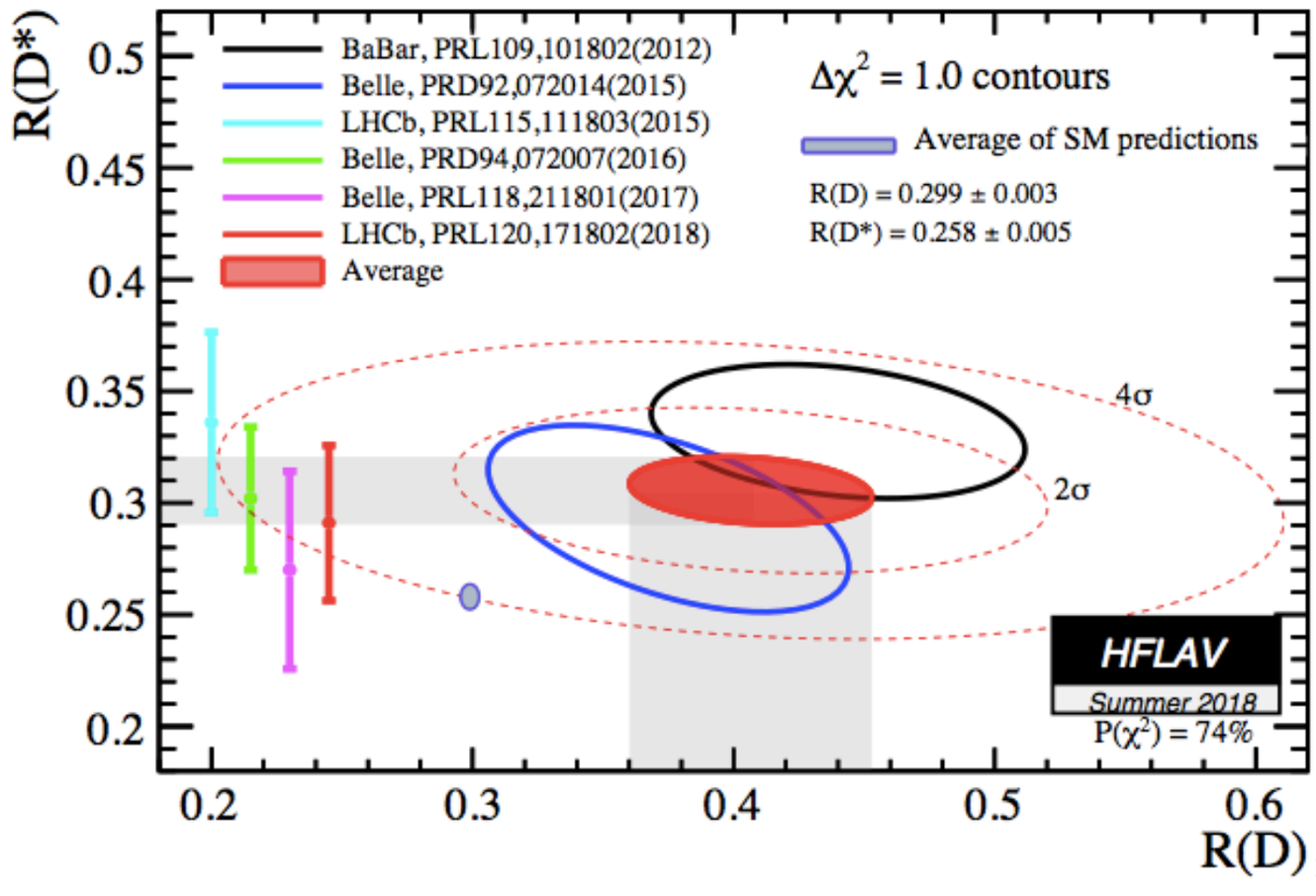
- Ideal environment for measuring rare decays with missing energy i.e. neutrinos!
  - Hermeticity of Belle II better than Belle and Babar
  - Improved vertex resolution
  - Higher statistics





SEMI-LEPTONIC DECAYS

- Tree level decays with 1 or more hadrons, 1 lepton and corresponding ν; mediated by the W boson.
- Anomalies observed in data, weird! → New Physics should be swamped by tree level physics!
- Sensitive to New Physics (Large branching fraction $\mathcal{B}$ in the Standard Model: ~1%).

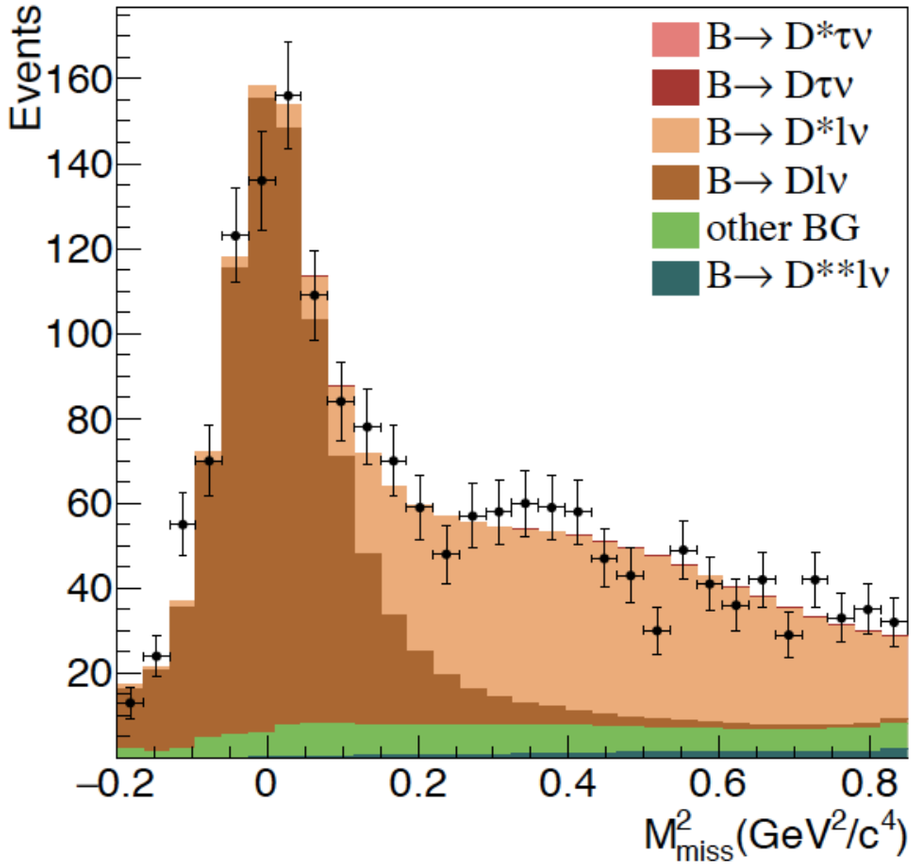


E. Kou et al., "The Belle II physics book", arXiv:1808.10567

SEMI-LEPTONIC DECAYS

- Decays involving τs are sensitive to additional amplitudes (i.e. those involving an intermediate charged boson).

- The luminosity at Belle II significantly improves the precision on measurements of B, D and τ decays and should be able to resolve these observed anomalies!

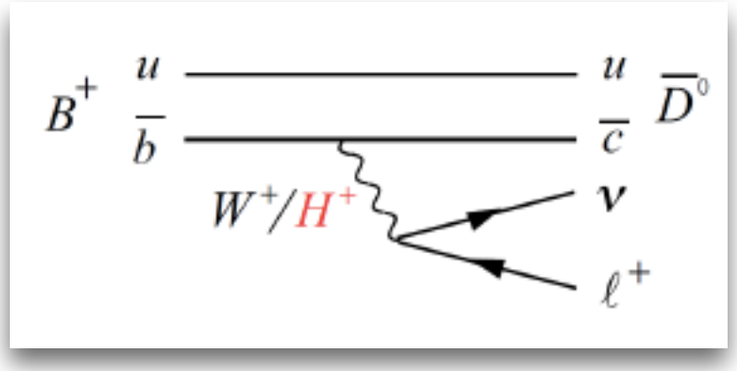


- Hints of possible lepton flavour universality violation.

- Missing energy (i.e. νs) allows us to probe for signs of physics beyond the Standard Model.

- Decays with only 1 single missing neutrino peak sharply at 0, while the signal is spread out to positive values

$B \rightarrow D(^*)\tau\nu$

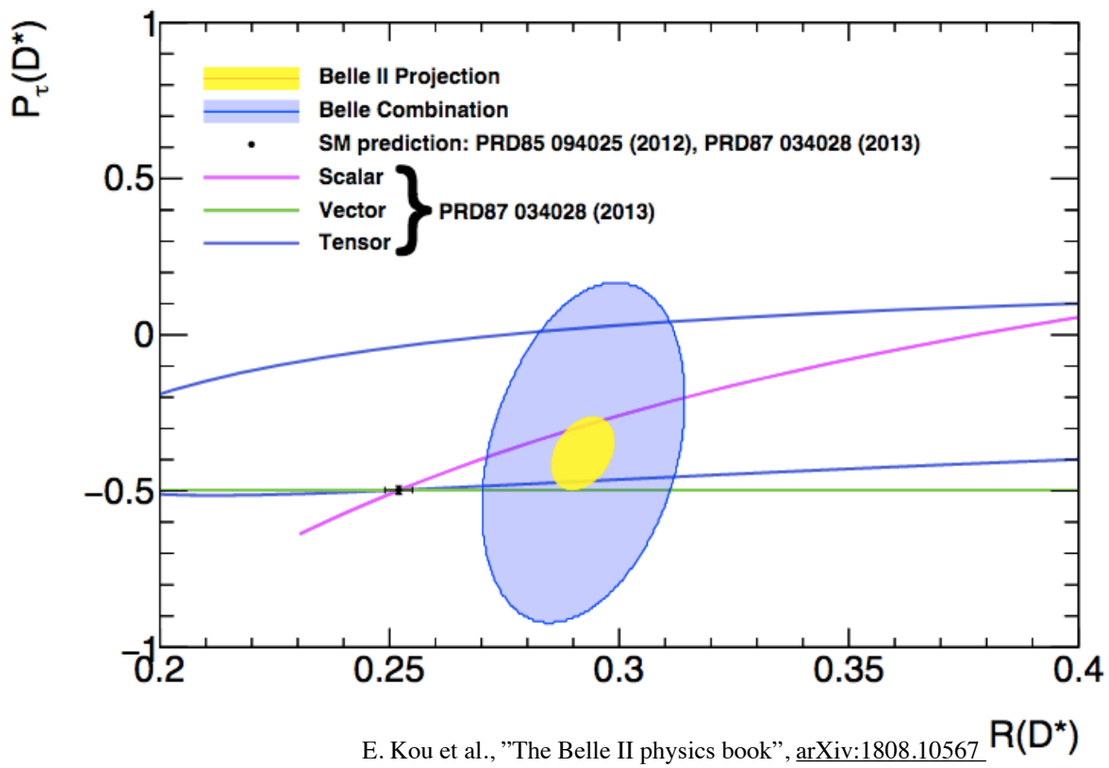


- Rare decay with missing energy!
- $B \rightarrow D^*\tau\nu$ BABAR observed 2007
- $B \rightarrow D\tau\nu$ evidence from Belle and Babar
- In the Standard Model, the rate is $\propto |V_{cb}|^2$
- Branching fractions of $B \rightarrow D^{(*)}\tau\nu$ and $B \rightarrow D^{(*)}\ell\nu$ are expected to differ due to the m_τ.

$\boldsymbol{R}(D^{(*)})$

$$\mathcal{R}(\mathcal{D}^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau\nu_\tau)}{\mathcal{B}(B \to D^{(*)}\ell\nu_\ell)}$$

- The ratio $\boldsymbol{R}(\boldsymbol{D}^{(*)})$ of the branching ratio decays cancels various sources of uncertainty! ($|V_{cb}|$ & Hadronic Form Factors)
- A very well defined value in SM, so allows sensitivity to New Physics (2HDMII, leptoquarks,…)
- Other observables:
  - Momentum transfer squared (q^2) distribution
  - Measurements of the $\boldsymbol{\tau}$ polarisation $P_\tau(D^*)$ could be combined with $\boldsymbol{R}(\boldsymbol{D}^{(*)})$



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PROJECTION FOR BELLE II

- 5σ confirmation of $\boldsymbol{R}(\boldsymbol{D}^{(*)})$ anomalies at 5 ab^{-1}
- Using FEI:

Total Uncertainty	Belle 0.7ab^{-1}	Belle II 5ab^{-1} (2021)	Belle II 50ab^{-1} (2025)
R(D)	16%	6%	3%
R(D*)	7%	3%	2%

- Systematic uncertainty is dominated by D** and missed soft πs.

SM prediction:

- $\boldsymbol{R}(\boldsymbol{D})_{SM}$ = 0.299 ± 0.003
- $\boldsymbol{R}(\boldsymbol{D}^*)_{SM}$ = 0.252 ± 0.003

Averaged B-tagged measurements:

- $\boldsymbol{R}(\boldsymbol{D})_{meas}$ = 0.407 ± 0.039 ± 0.024
- $\boldsymbol{R}(\boldsymbol{D}^*)_{meas}$ = 0.304±0.013±0.007

- In tension with SM by 2.3σ and 3.4σ (combined 4.1σ)

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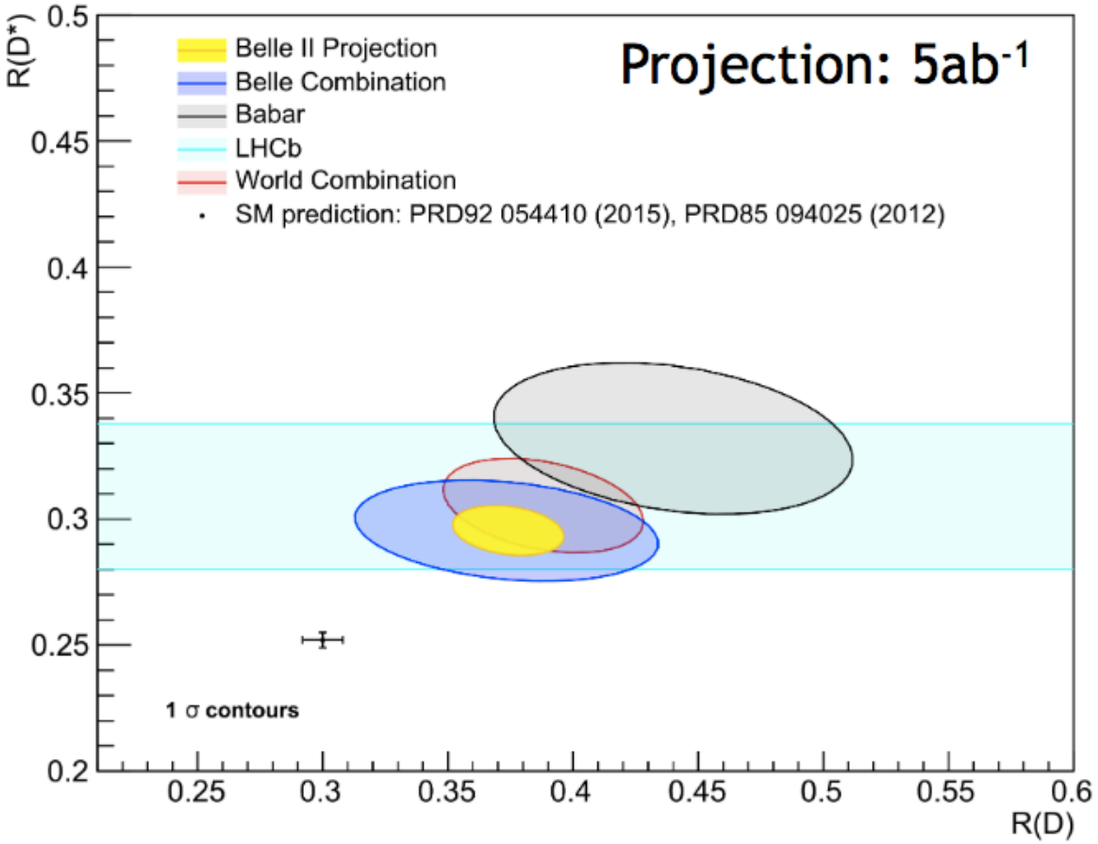

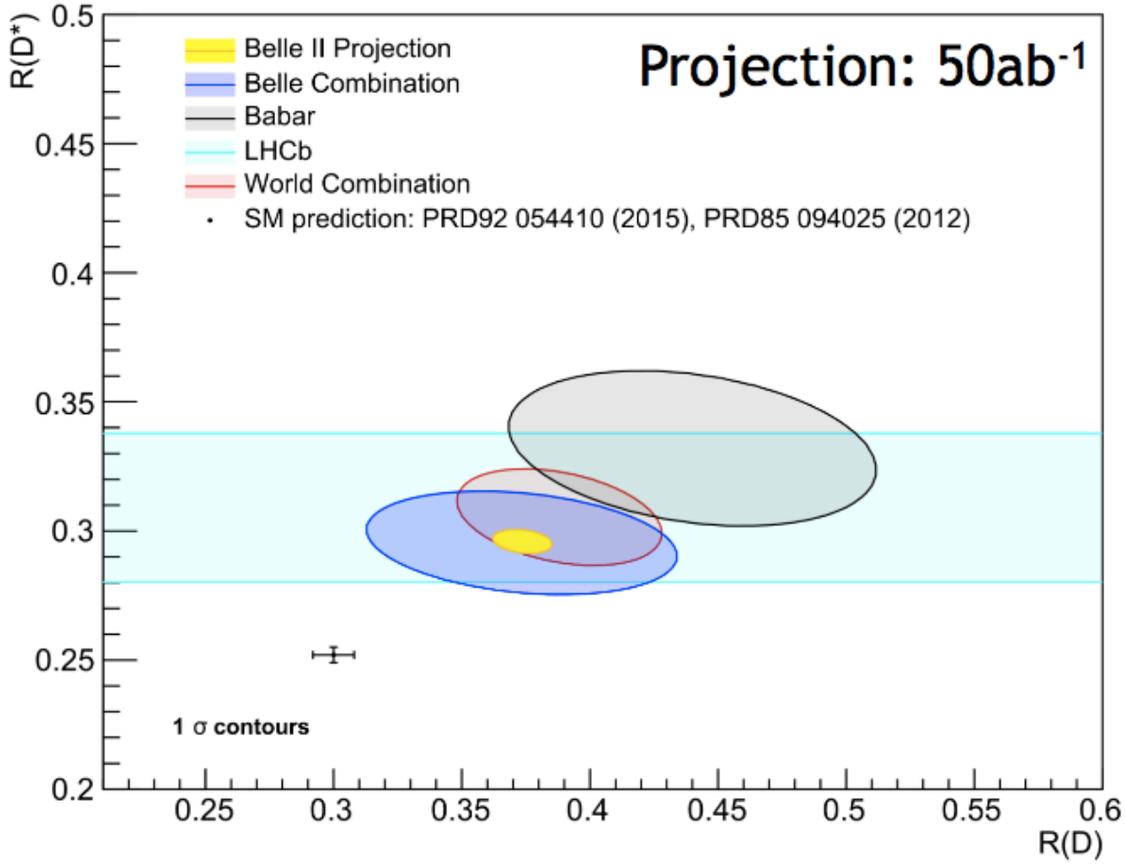

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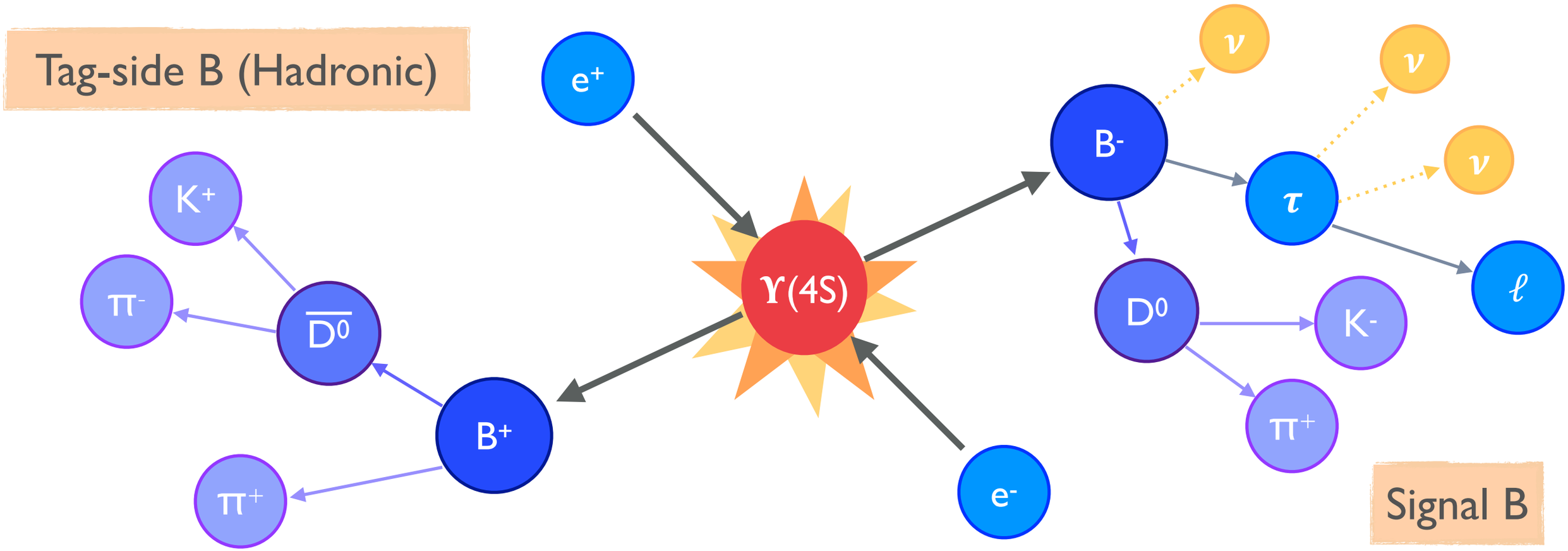
RECONSTRUCTION

B decays with missing energy are limited in their available kinematic information.



- Hadronic tagging: well known kinematics, and tagged sample is pure BUT only possible for a small fraction of the dataset

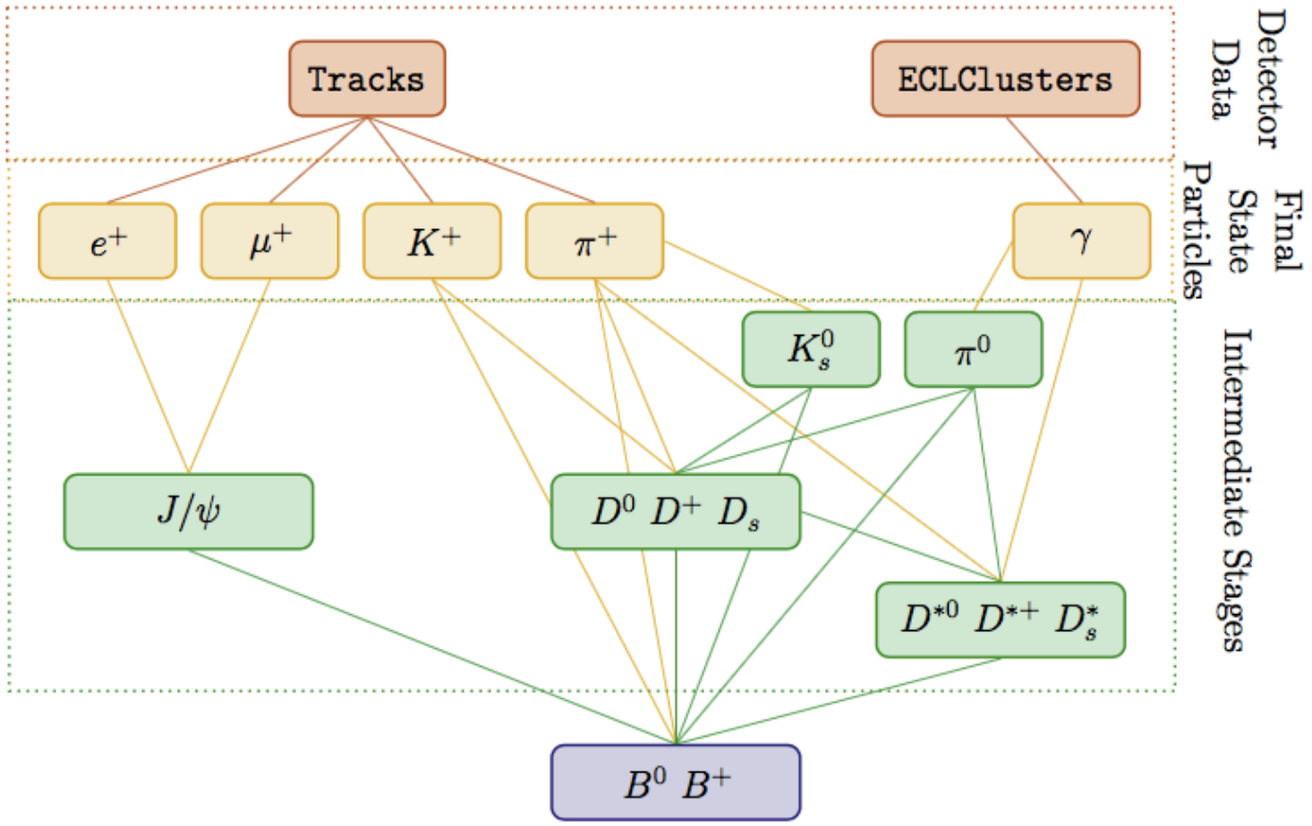
- Semi-leptonic tagging: Higher branching fraction of S-L decays so higher tagging efficiency BUT missing kinematic energy so not so pure

FULL EVENT INTERPRETATION

How do we detect missing kinematic information at Belle II?

- FEI is a Fast Boosted Decision Tree Multi Variate Analysis

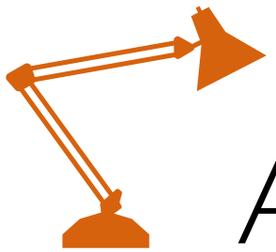
- Unifies the hadronic and semi-leptonic tagging into a *single* algorithm



- Partially recovers missing information and infers strong constraints on the signal candidates by reconstructing the Rest of Event (ROE) in thousands of exclusive decay channels

- Combines all information into single signal probability value

The Full Event Interpretation for Belle II - Keck, Thomas IEKP-KA-2014-18



ANALYSIS PROCEDURE

- Using FEI: Hadronic tagged exclusive analysis on $B \rightarrow D^{*}\tau\nu$

$B^+ \rightarrow D^0\tau\nu$

1. $K^-\ \pi^+$
2. $K^0_S\ \pi^0$
3. $K^-\ \pi^+\ \pi^0$
4. $K^-\ \pi^+\ \pi^-\pi^+$
5. $K^0_S\ \pi^+\ \pi^-$
6. $K^0_S\ \pi^+\ \pi^-\ \pi^0$

$B^0 \rightarrow D^+\tau\nu$

1. $K^-\ \pi^+\ \pi^+$
2. $K^-\ \pi^+\ \pi^+\ \pi^0$
3. $K^0_S\ \pi^+$
4. $K^0_S\ \pi^+\ \pi^-\ \pi^+$
5. $K^0_S\ \pi^+\ \pi^0$
6. $K^0_S\ K^+$

$B^+ \rightarrow D^{*0}\tau\nu$

1. $D^0\ \pi^0$
2. $D^0\ \gamma$

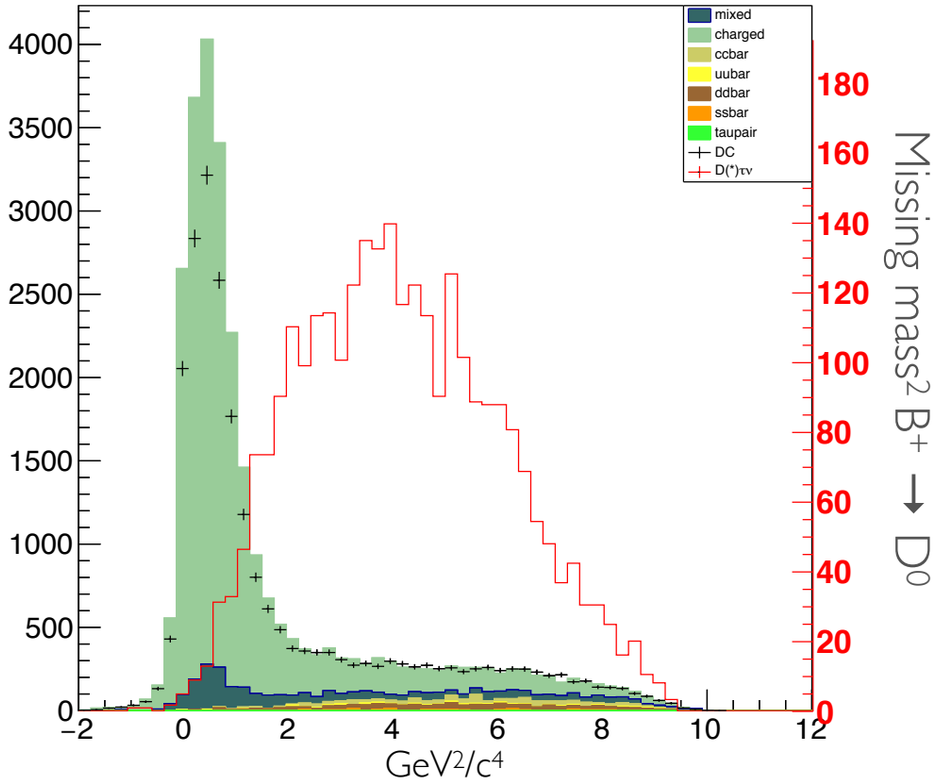
$B^0 \rightarrow D^{*+}\tau\nu$

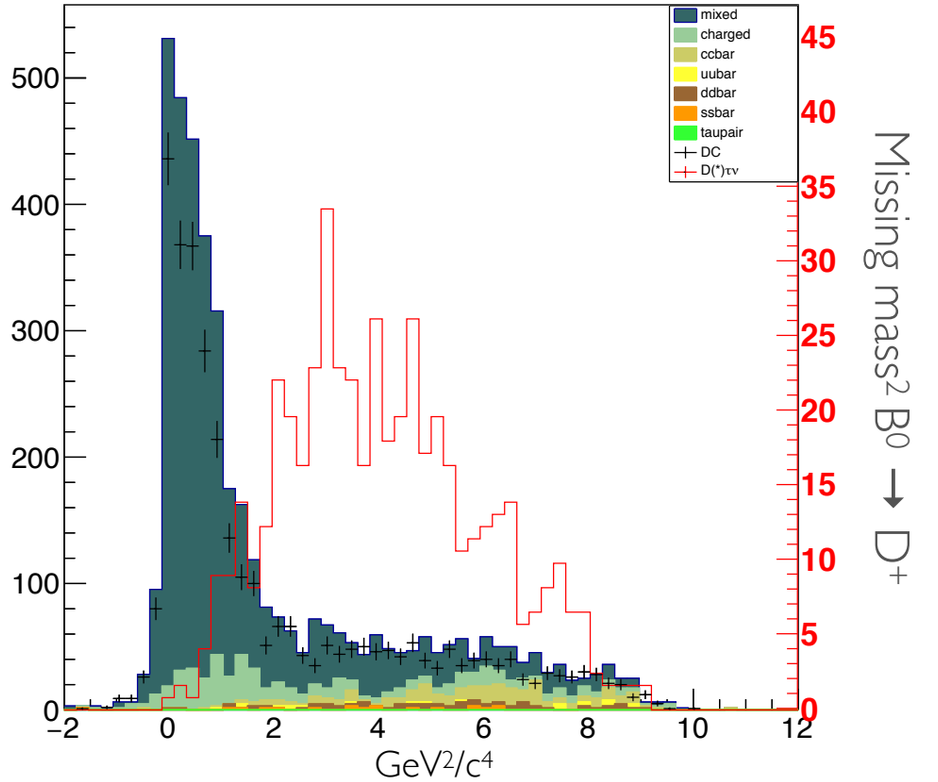
1. $D^0\ \pi^+$
2. $D^+\ \pi^0$

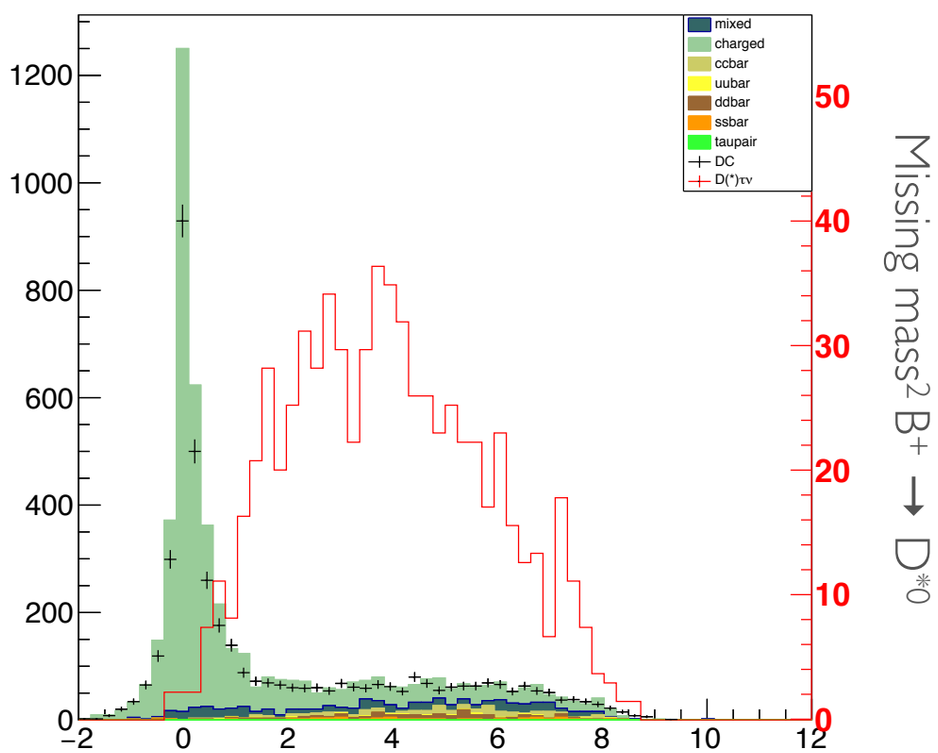
- Currently working on:
  - Best candidate selection for D^*
  - Need improved selection of π^0s

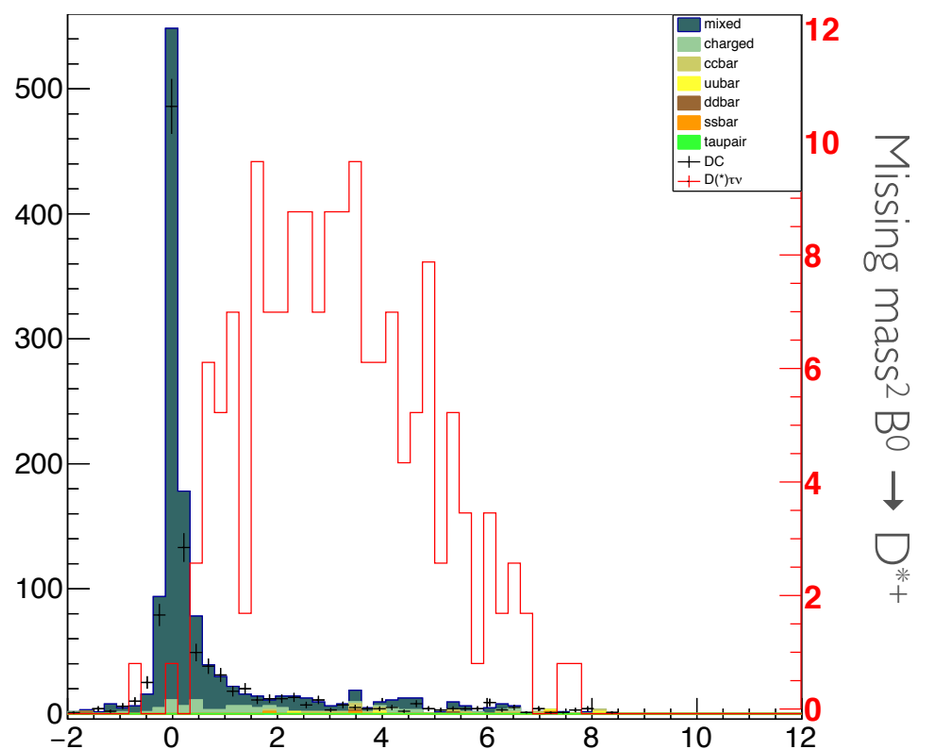
MONTE CARLO STUDIES

Neutrino mass squared i.e. missing mass squared









SUMMARY

- Belle II is a very competitive and unique environment to study B decays with missing energy
- Potentially sensitive to indirect NP effects!
- The improvements in analysis strategy (FEI) and a large data sample will allow us to probe further these possible effects
- Investigating the deviation from/consistency with the Standard Model of $B \rightarrow D^{(*)}\tau\nu$ and $\boldsymbol{R}(D^{(*)})$. Could be resolved with just a few ab^{-1} of data!

By 2021 we should have a significant data sample with potential for a competitive result.