$B \to \tau\nu$ Branching Ratio with Hadronic tagging

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Riunione Gruppo 1 INFN Napoli – Jan 12th 2023

Scuola Superiore Meridionale

Istituto Nazionale di Fisica Nucleare
Sezione di Napoli

Belle II

Status of data taking

Integrated Luminosity: 424 fb^{-1} (2019-2022):

- 363 fb^{-1} at $\sqrt{s}$=10.58 GeV = $M(\Upsilon(4S))$
- 42 fb^{-1} at $\sqrt{s}$=10.52 GeV
- 19 fb^{-1} at $\sqrt{s}$=10.75 GeV for exotic hadron searches

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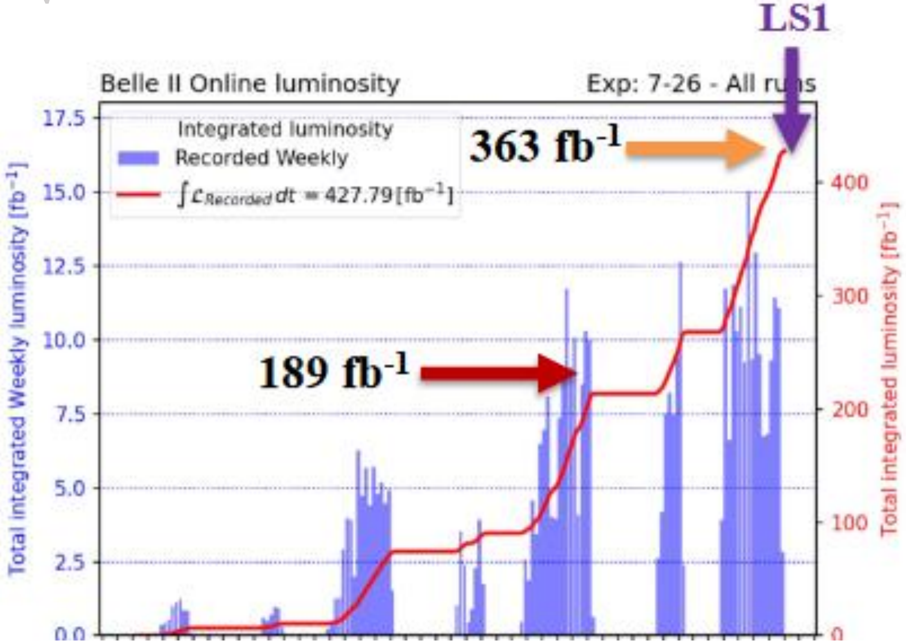
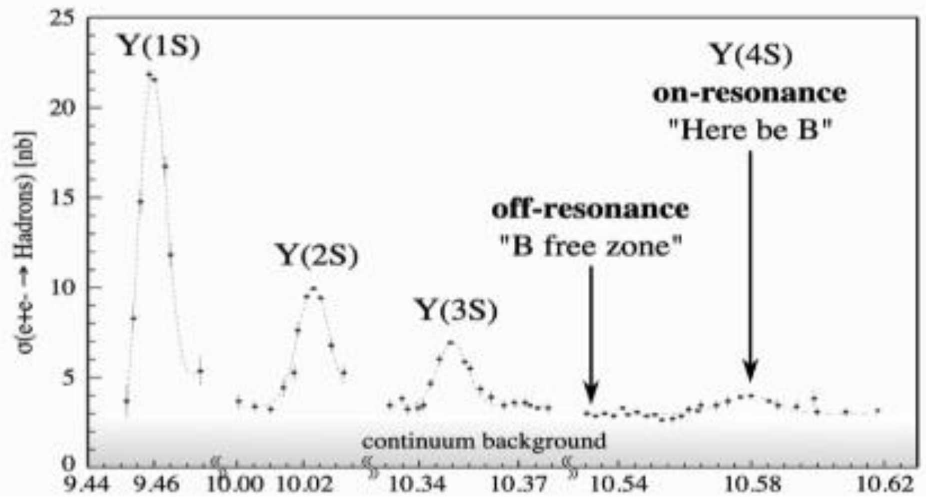
On resonance data

Off resonance data



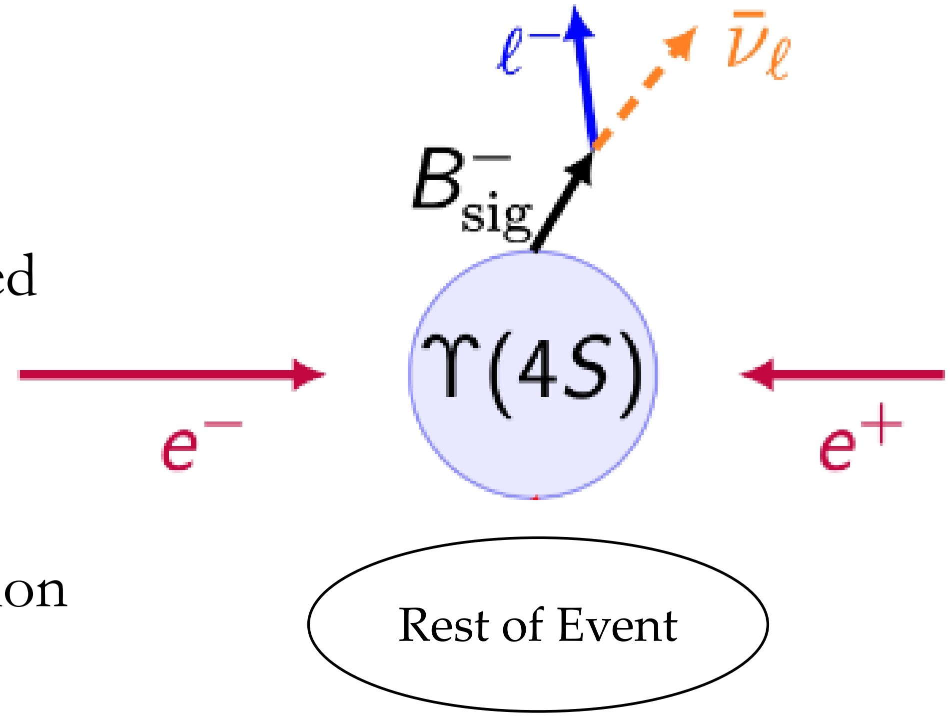


Currently: Long Shutdown 1 (15 mos.) for detector upgrades and beam-pipe improvement

(Semi)Leptonic decays approach: Untagged vs Tagged

Untagged:
Only B_{sig} is reconstructed

High signal yield
High background
Poor neutrino reconstruction



Tagged:
B_{sig} and B_{tag} are reconstructed

Signal Yield 1000 times lower
Low backgrounds
Good neutrino reconstruction
Tag Calibration

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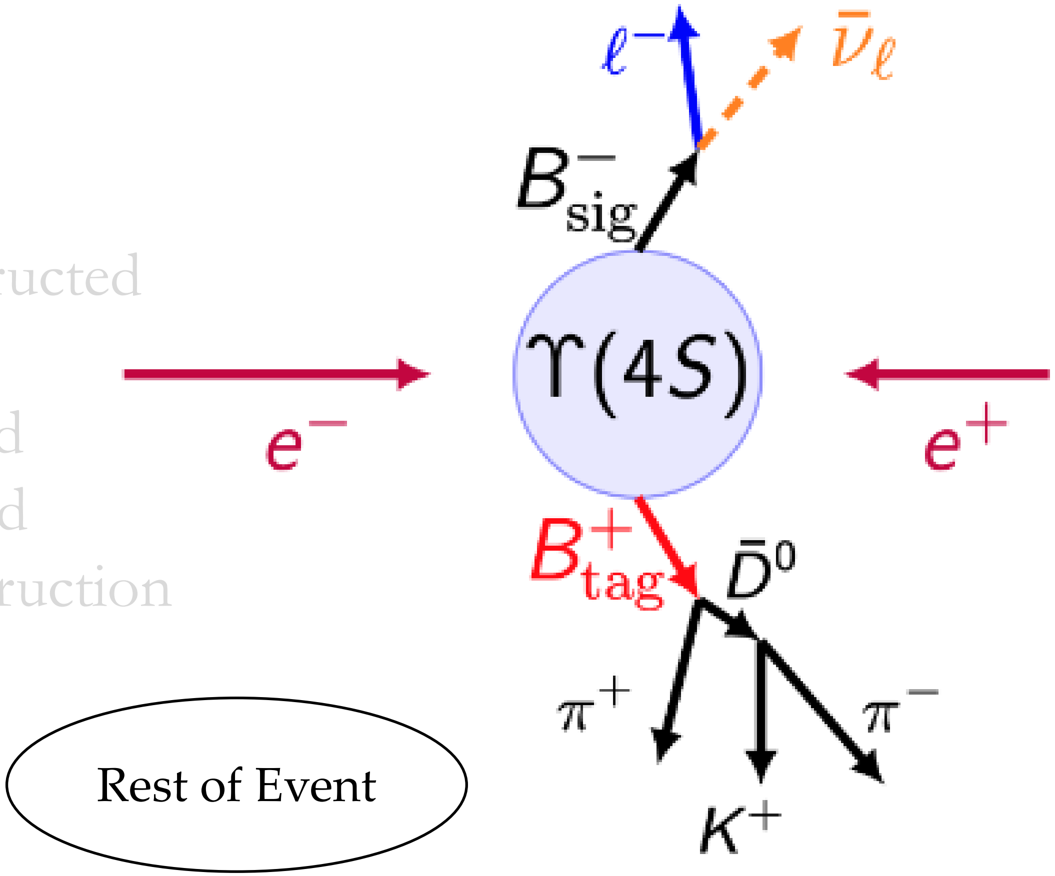

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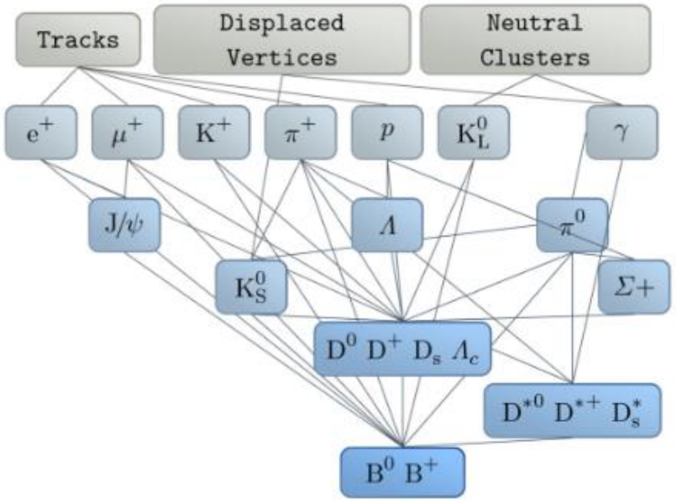
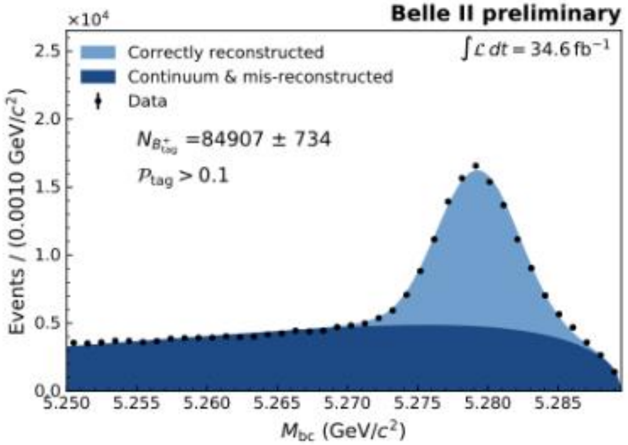
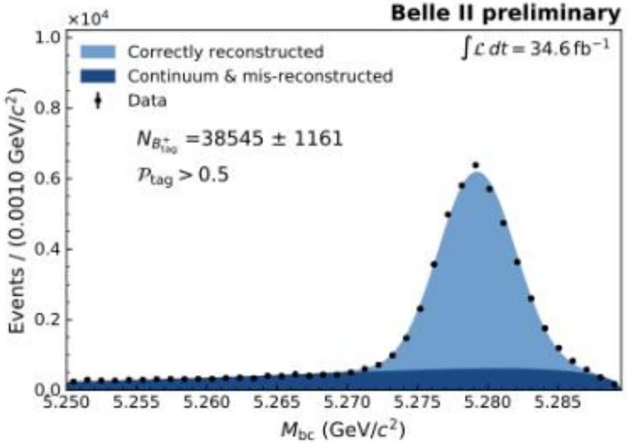
Hadronic tagging at Belle II

Comput Softw Big Sci (2019) 3: 6.







$$M_{bc} = \sqrt{E_{beam}^2/4 - (p_{B_{\mathrm{tag}}}^{\mathrm{cm}})^2} > 5.27\ \mathrm{GeV}/c^2$$

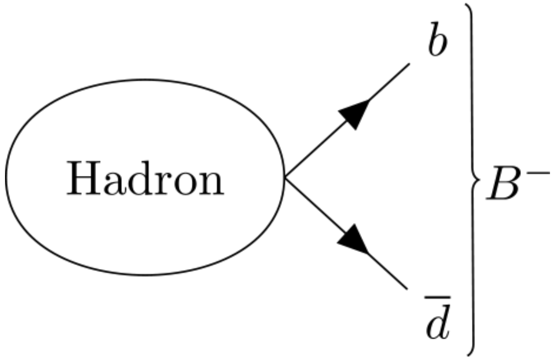
The Hadronic FEI employs over 200 boosted decision trees to reconstruct 10000 B decay chains:

$\epsilon_{B^+} \approx 0{,}5\ \%, \epsilon_{B^0} \approx 0{,}3\ \%$ at low purity (about 50% increase with respect to the Belle tag)

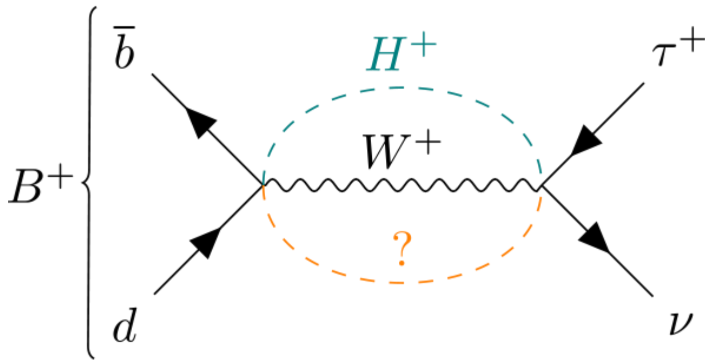
$B \to \tau\nu$ decay with Hadronic FEI

Hadronic FEI Skim

- TagProb > 0.001
- $|\Delta E| < 0.2$ GeV
- $M_{bc} > 5.24$ GeV



- 0 Extra Tracks (from IP)
- Extra Energy in ECL must be 0 in signal events and larger in background.



$$\mathcal{BR}(B \to \ell\nu) = \frac{G_F^2 m_B m_\ell^2}{8\pi}\left[1 - \frac{m_\ell^2}{m_B^2}\right] f_B^2 |V_{ub}|^2 \tau_B \alpha\beta$$

Very clean theoretically, hard experimentally
Standard Model is helicity suppressed

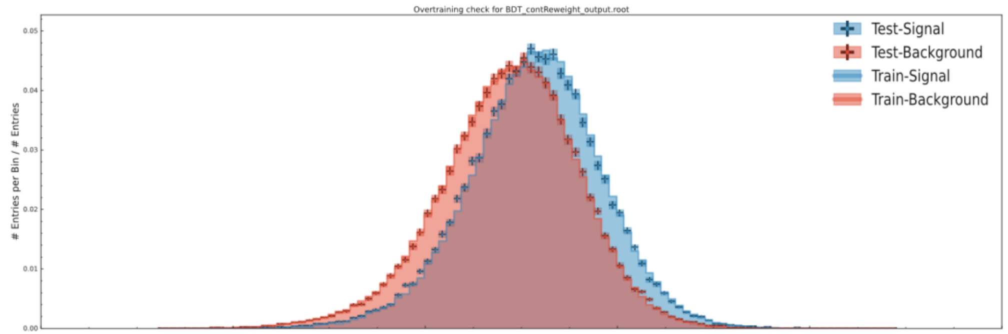
- 1 track with PID request $(e, \mu \text{ or } \pi)$ with $p_t > 0.5$ GeV
- π^0 for $\tau \to \rho\nu \to \pi\pi^0\nu$ decay

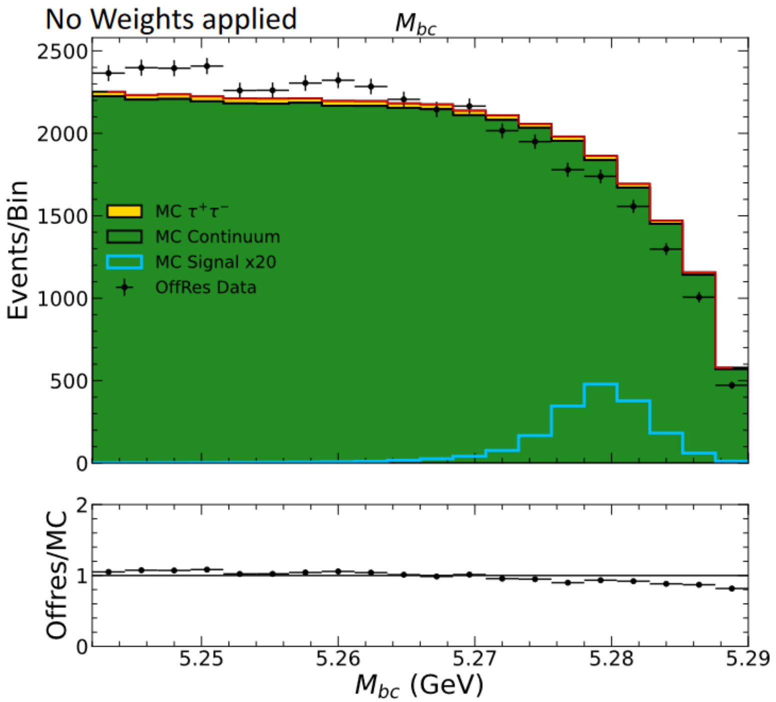
Dataset: 189/fb on res – 14/fb off res – 1000/fb MC

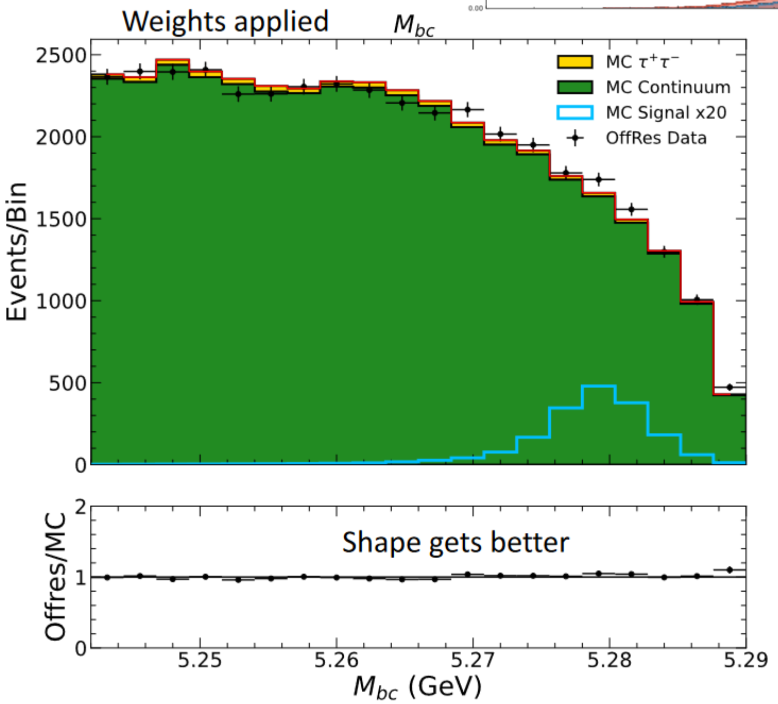
Analysis workflow: continuum background treatment

The $q\overline{q}$ MC background is

1. Reweighted with a BDT-weight ($q\overline{q}$ vs offres data)
2. Normalized to off peak yield



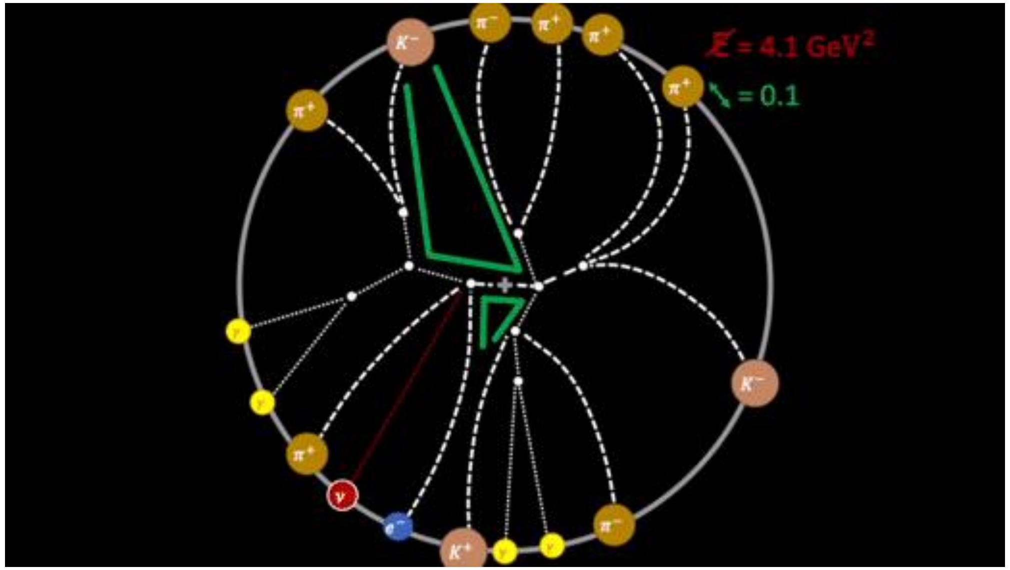




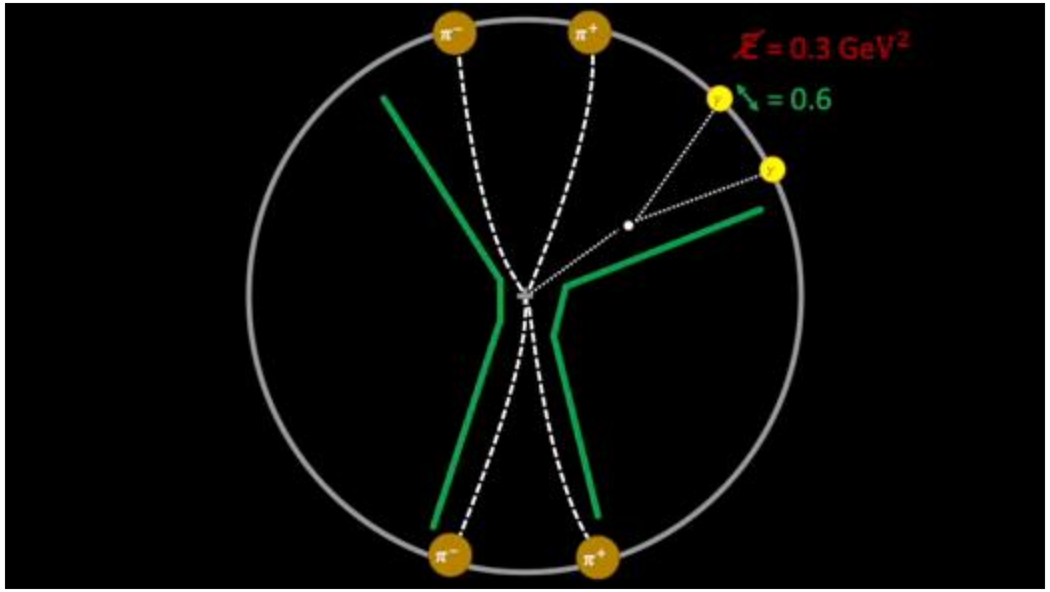
$$w_{contReweight} = \frac{BDT_{output}}{1 - BDT_{output}}$$

Analysis workflow: enhancement of the signal

The $q\overline{q}$ background rejection is obtained with a BDT ($q\overline{q}$ vs $B \to \tau\nu$). It is trained with all the event shape variables.



Example of $e^+e^- \to BB$ event



Example of $e^+e^- \to u\overline{u}$ event

Analysis workflow: enhancement of the signal

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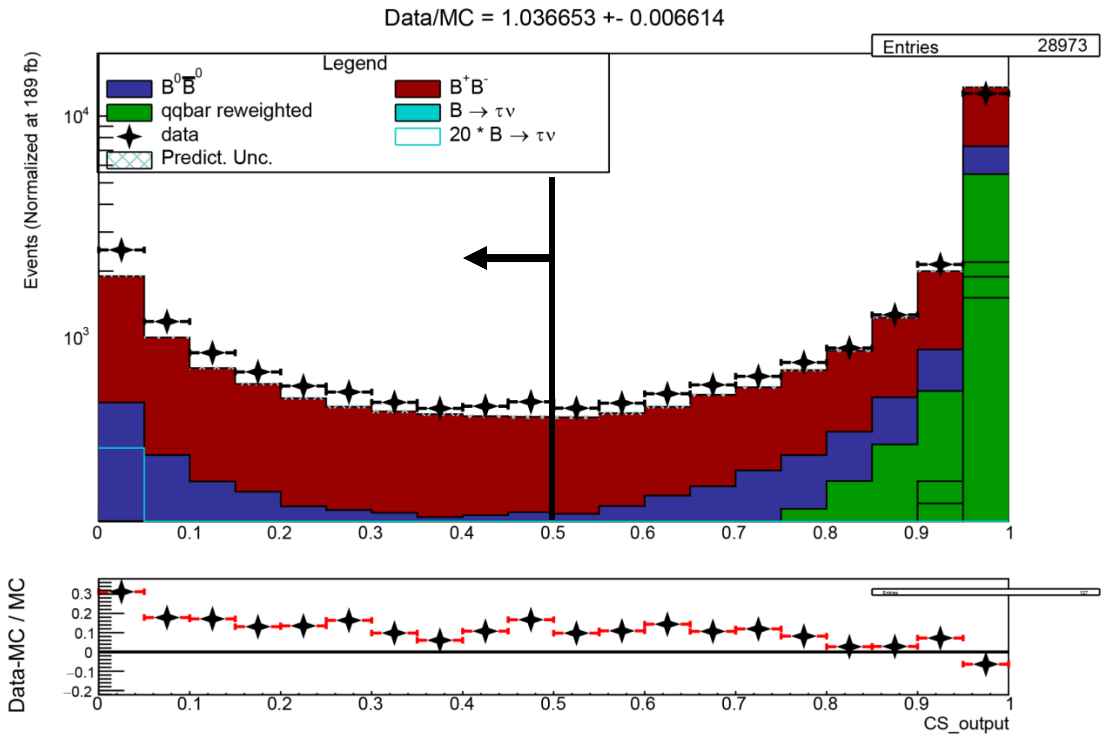
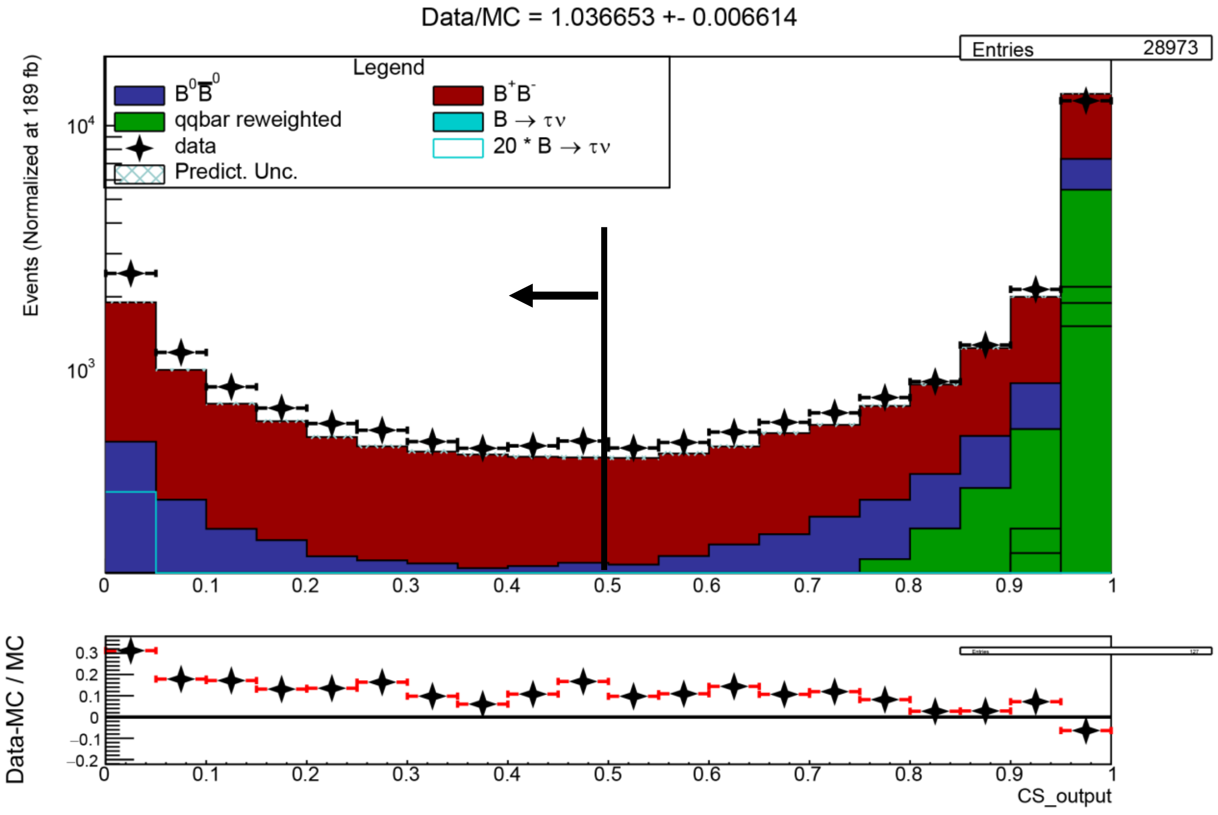


CS output

Analysis workflow: enhancement of the signal



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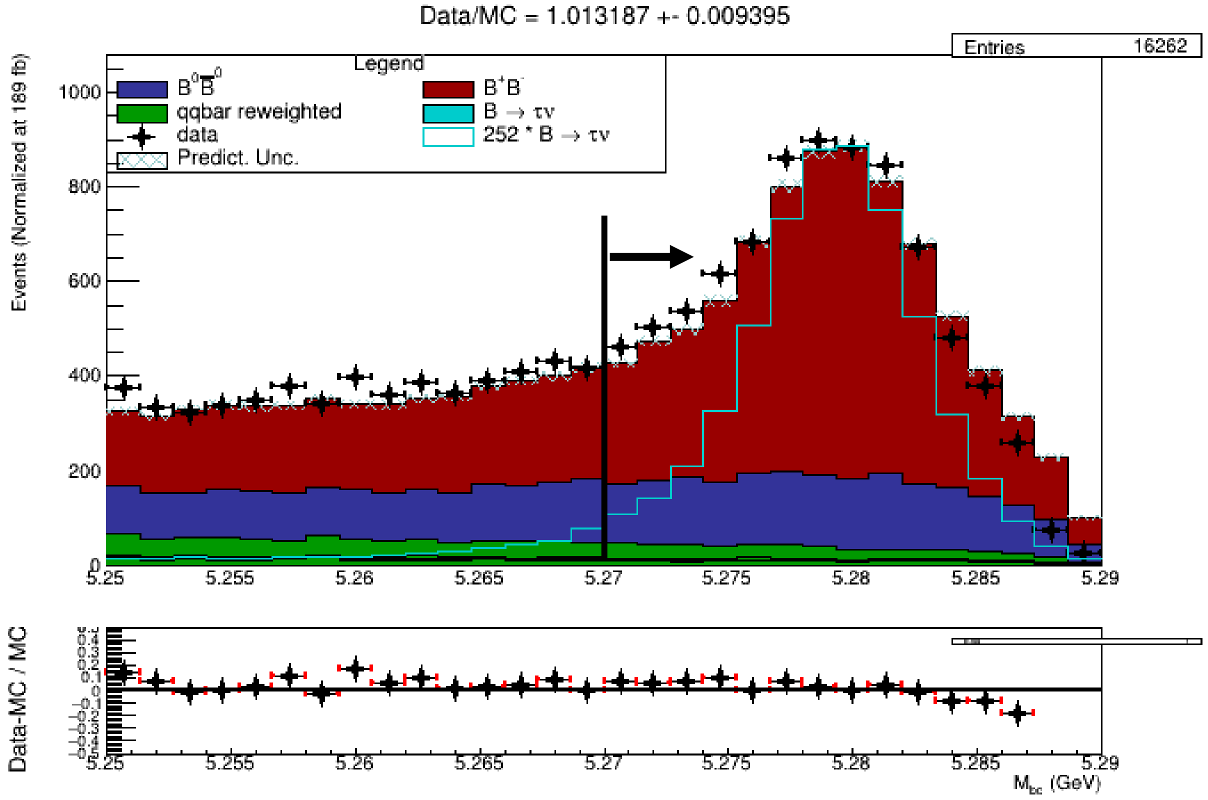
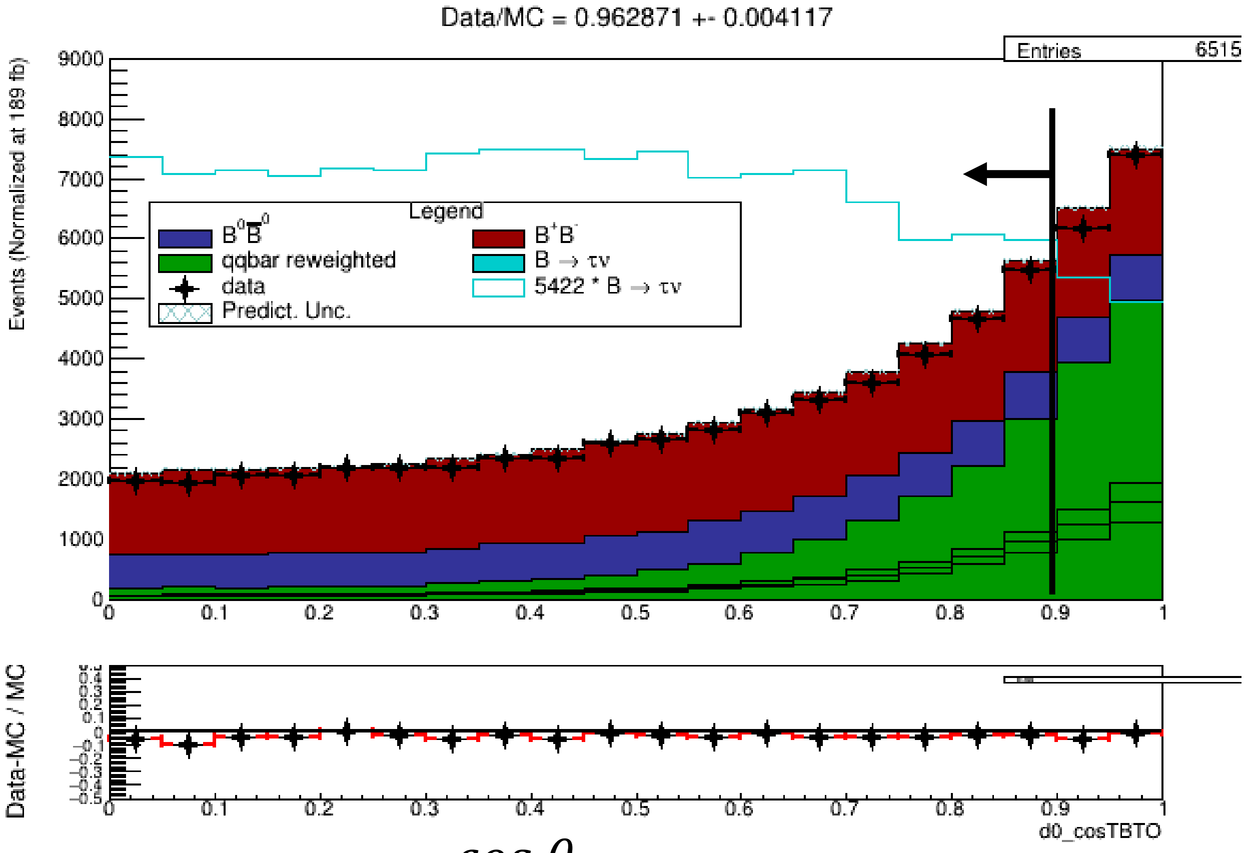


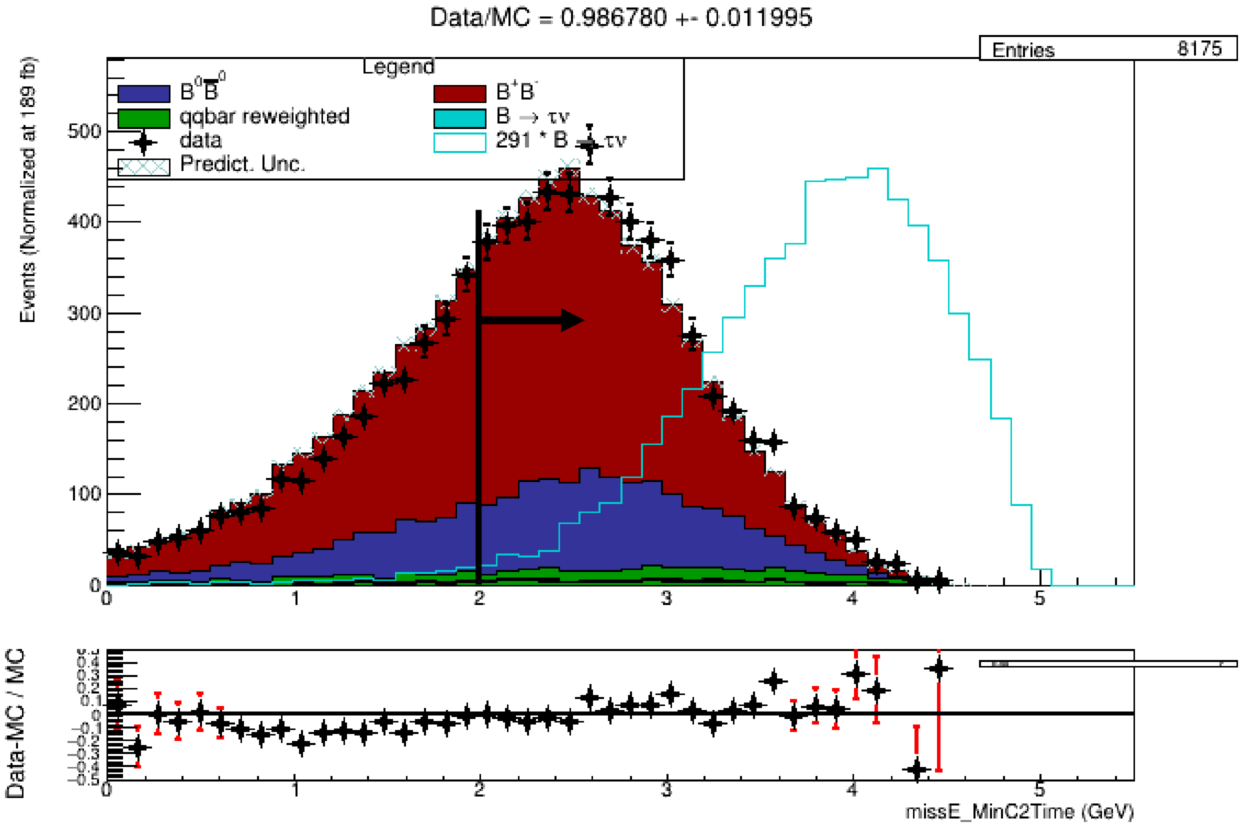
M_{bc}

Analysis workflow: enhancement of the signal



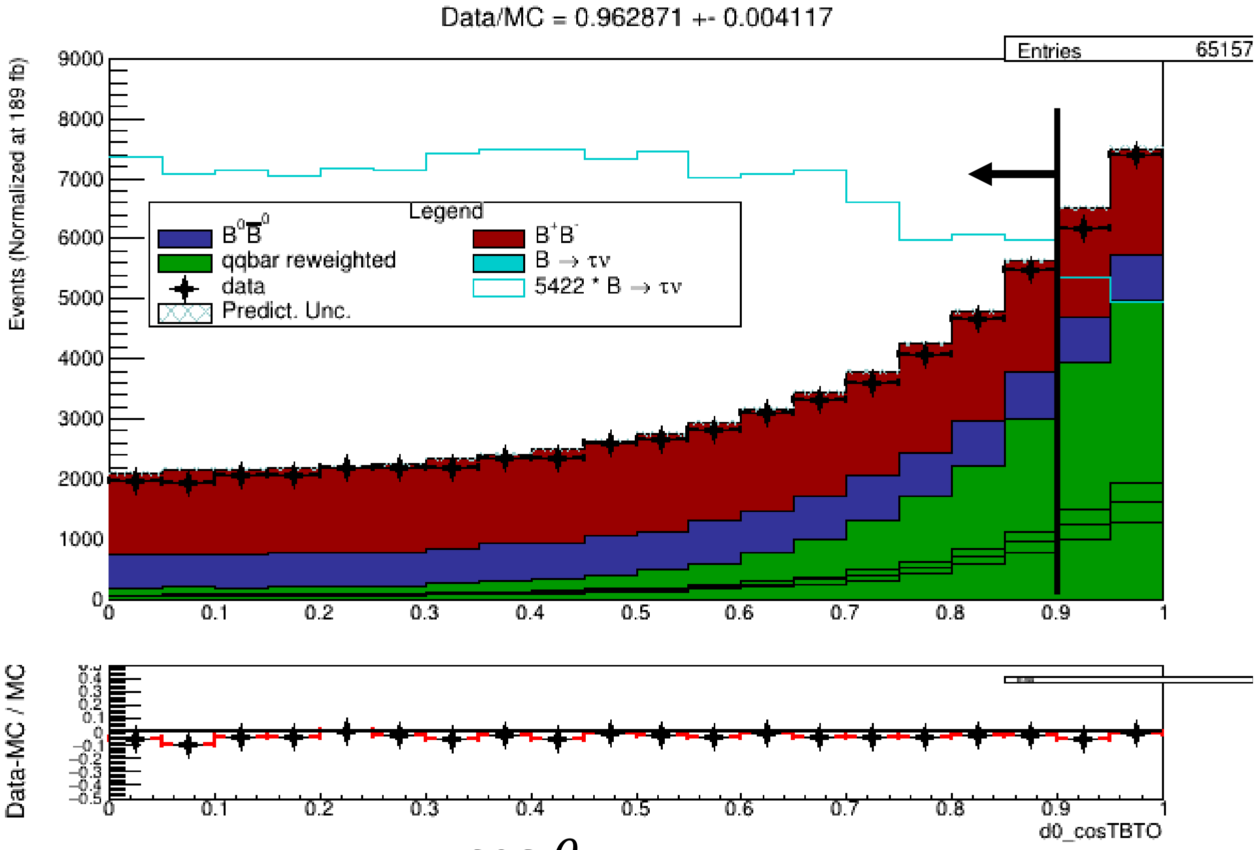
$cos\ \theta_{TBTO}$

In lepton channels



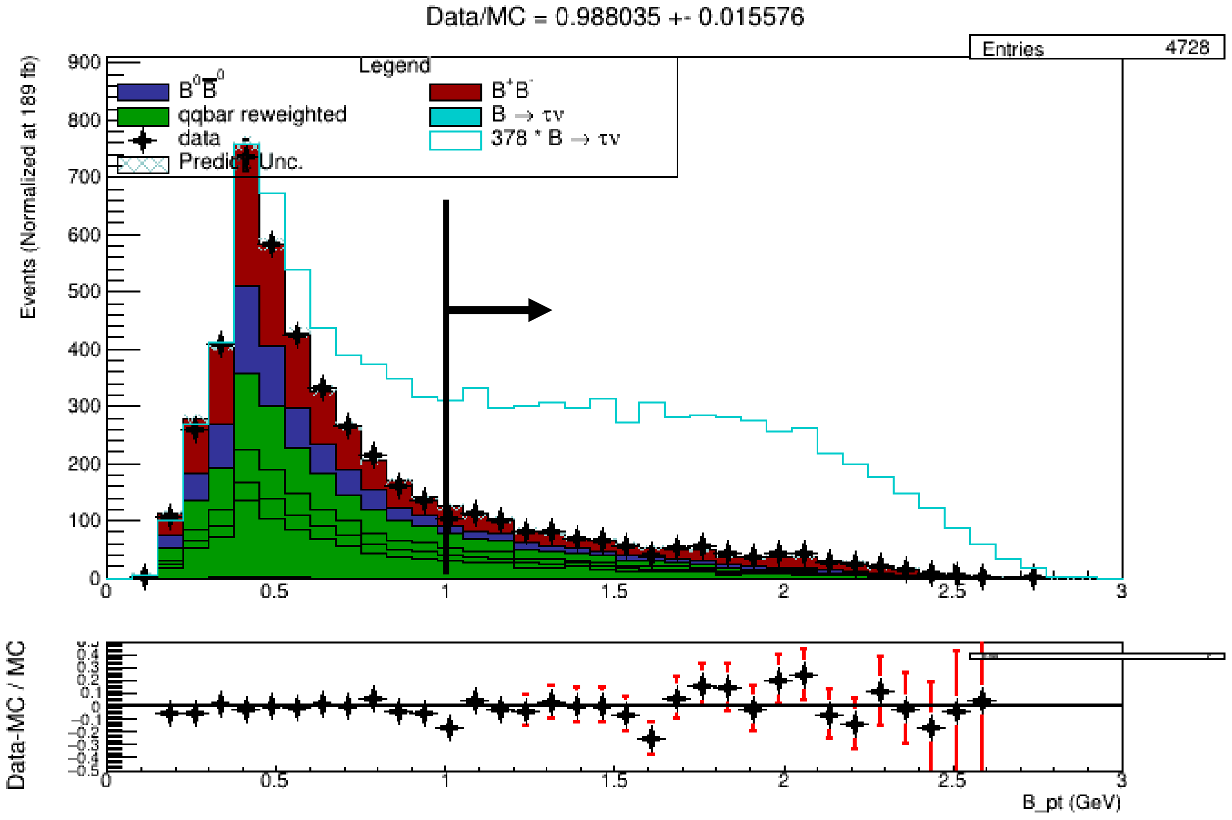
E_{miss}

Analysis workflow: enhancement of the signal



$cos\ \theta_{TBTO}$

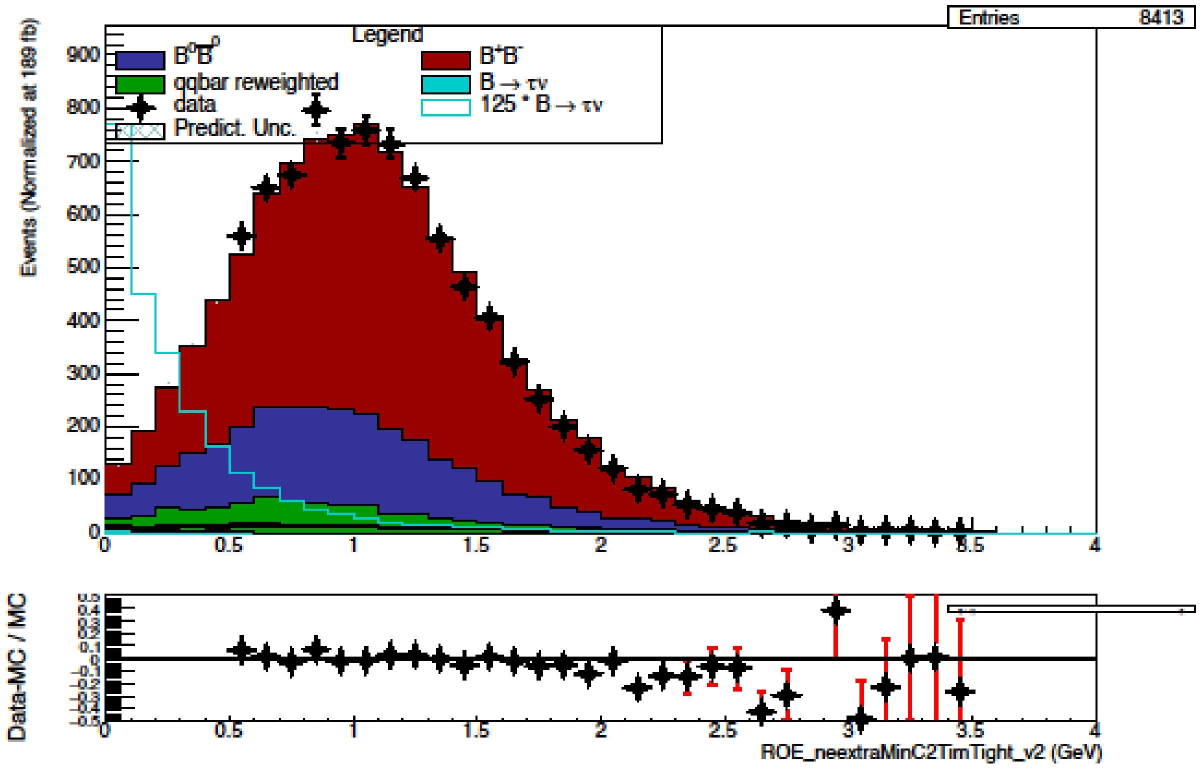
In hadron channels



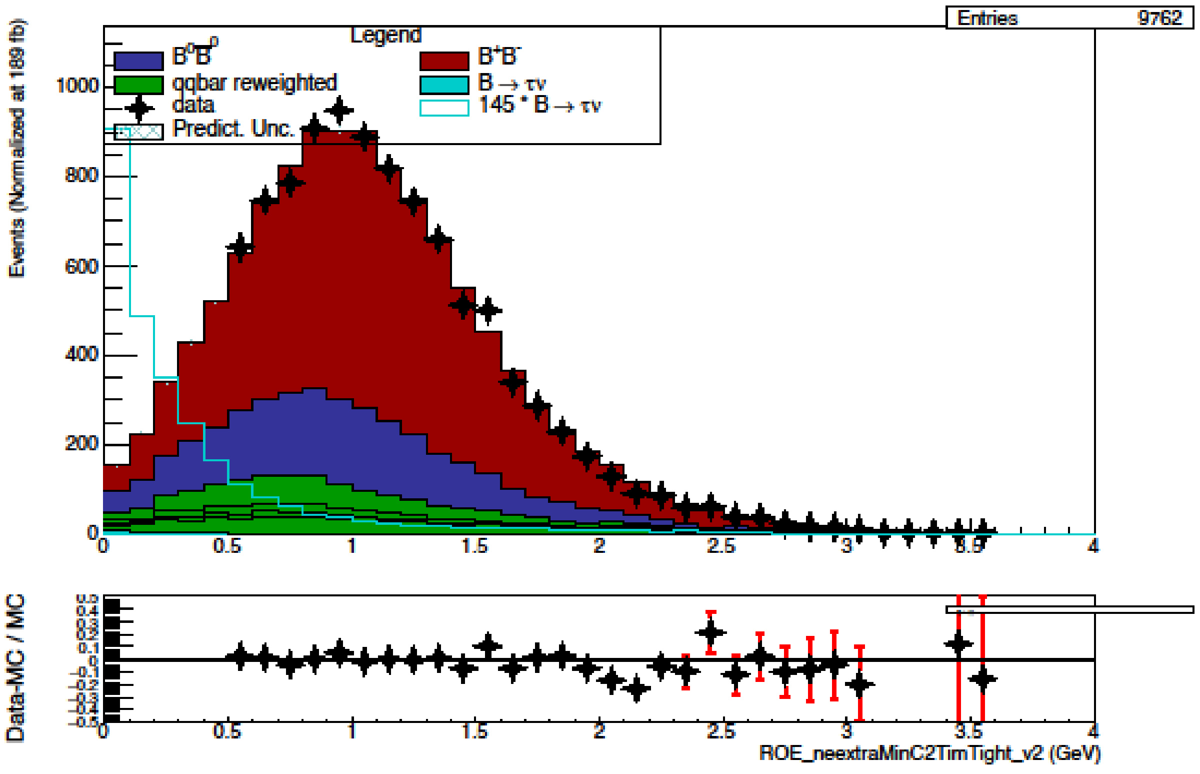
Candidate p_t

E_{ECL} distributions

The Branching Ratio measurement will be done with a ECL energy fit. This is the energy released in the calorimeter with no tracks or cluser associated.

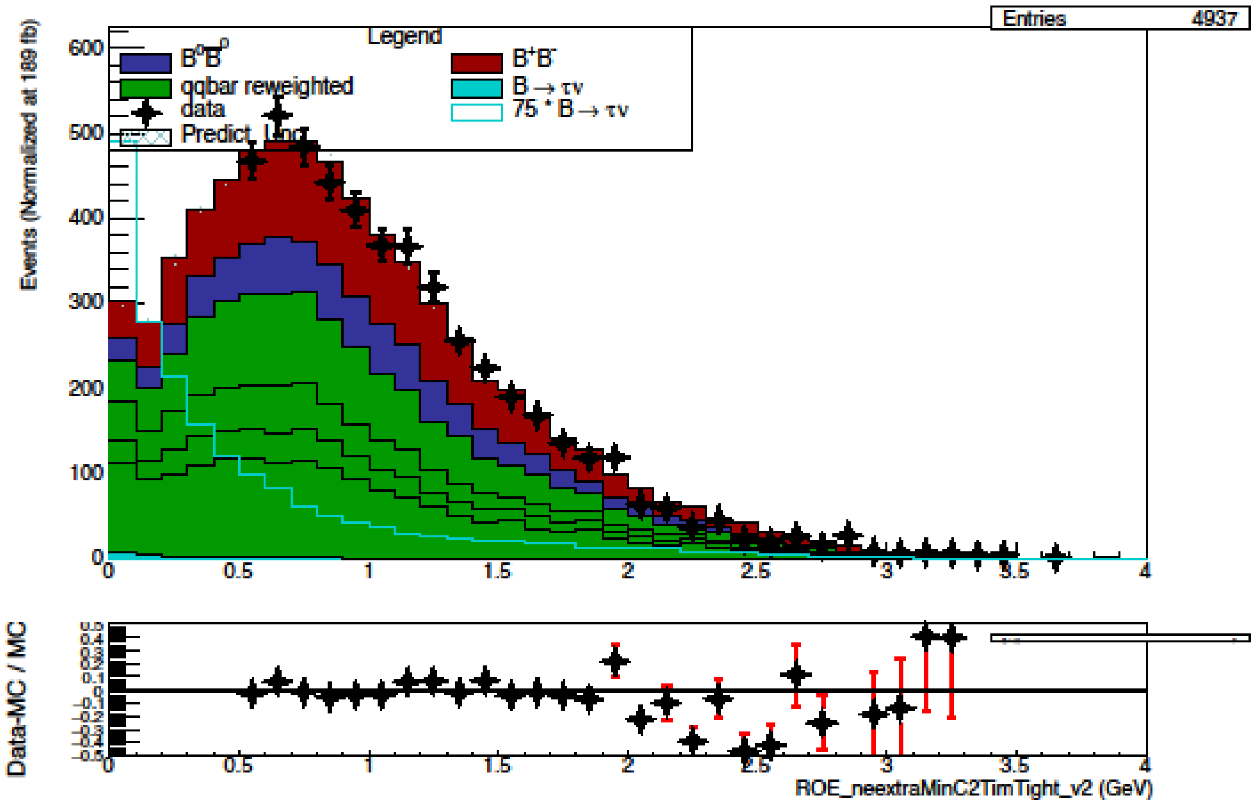


$\tau \to e\nu\nu$

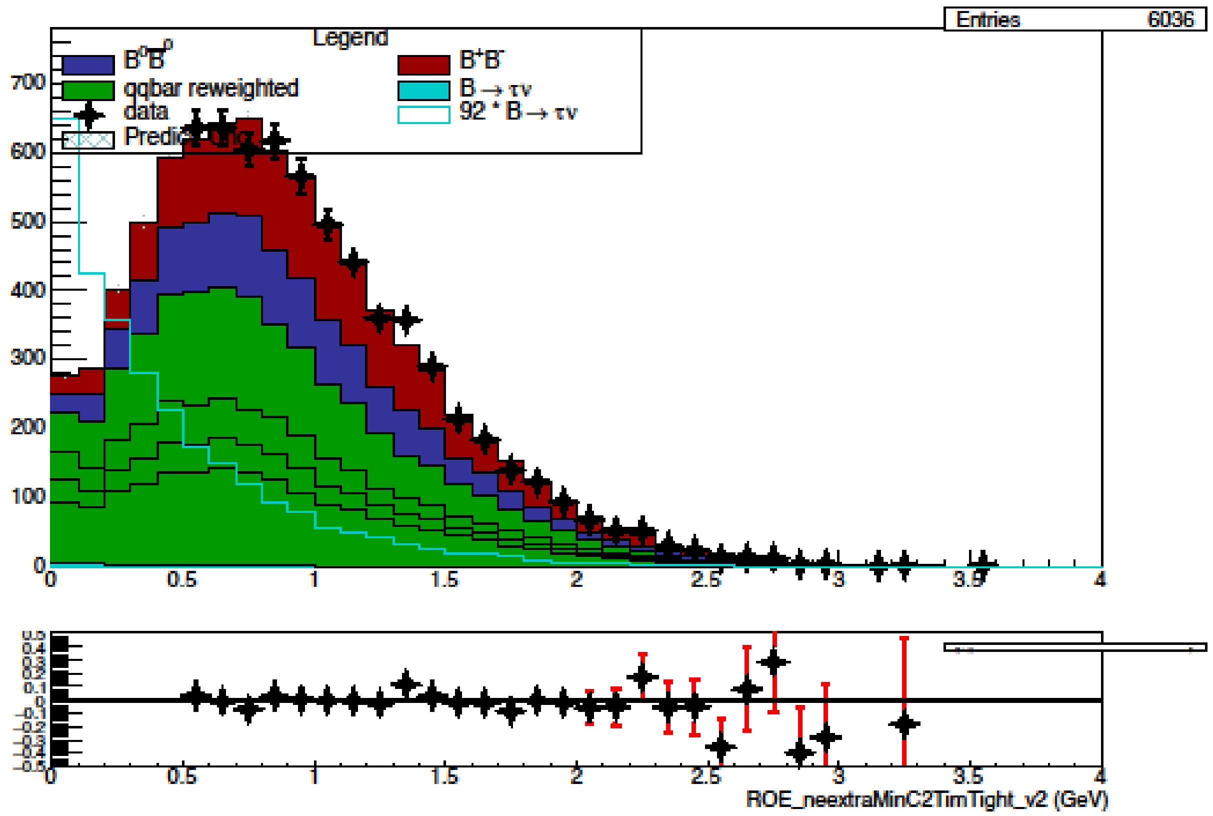


$\tau \to \mu\nu\nu$

E_{ECL} distributions



$\tau \rightarrow \pi\nu$



$\tau \rightarrow \rho\nu$

Sensitivity study on Branching Ratio measurement

$$\mathcal{L}_k = \frac{e^{-(n_{s,k}+n_{b,k})}}{N_k!}\prod_{i=1}^{N_k}\left\{n_{s,k}\mathcal{P}_k^s(E_{i,k}) + n_{b,k}\mathcal{P}_k^b(E_{i,k})\right\}$$

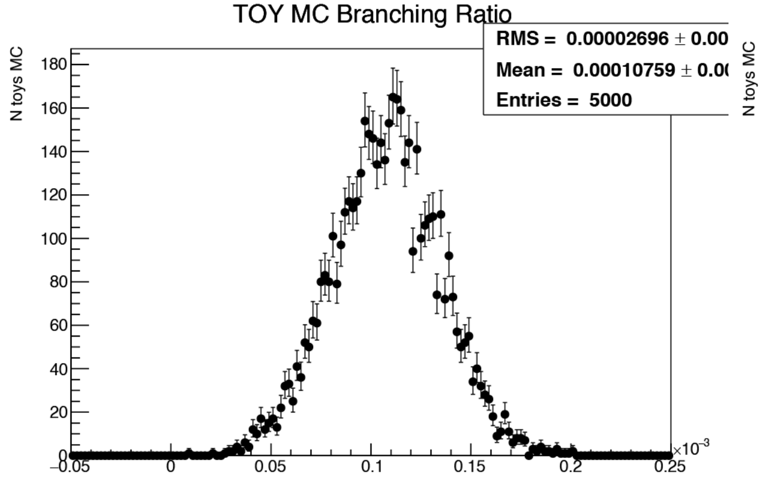
$$n_{s,k} = 2L_{\rm int}\sigma_{B^+B^-}\varepsilon_k \mathcal{BR}(B\to\tau\nu) = 2L_{\rm int}\sigma_{B^+B^-}\frac{N^{\rm reco}(\tau\to k)}{N^{\rm gen}(B\to\tau\nu)}\mathcal{BR}(B\to\tau\nu)$$

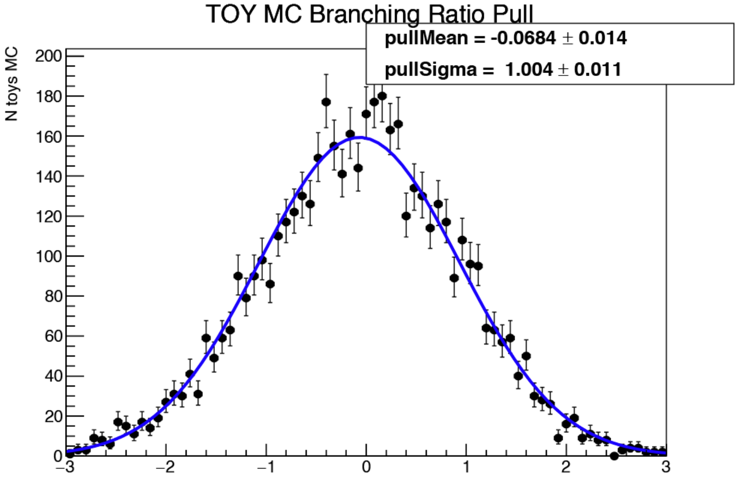
$\tau \rightarrow$	P_{min}(GeV)	TagProb	E_{miss}(GeV)	BDT
$e\nu\nu$	0.4	0.01	2.5	0.5
$\mu\nu$	0.4	0.01	2.5	0.5
$\pi\nu$	1.2	0.01	2	0.5
$\rho\nu$	1.3	0.01	2	0.5

Optimal cut configuration by minimizing relative uncertanty on the Branching Ratio with TOY MC

The fit will be performed on «the best» E_{ECL} distribution: that is the one that gives the best relative error

Branching Ratio prediction in a simultaneous fit @ 364 /fb
$BR = 1.08 \pm 0.29$
Relative Error = 0.2677





Conclusion

The next step of this analysis are:

1. We use MC to get signal and B background shapes: we need to validate MC modelling of E_{ECL} we need control samples, one for signal and another for BB background
2. Improve and consolidate the most important steps of the analysis
3. Start evaluating largest systematic uncertainties

We aim to publish the measurement in an article in summer 2023.

Thanks for your attention