tau → K_S0 l

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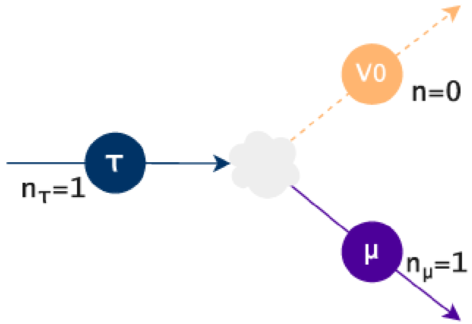
Physics Week Valenica
30.11 2022

Motivation

- **Lepton Flavor Violation (LFV)**

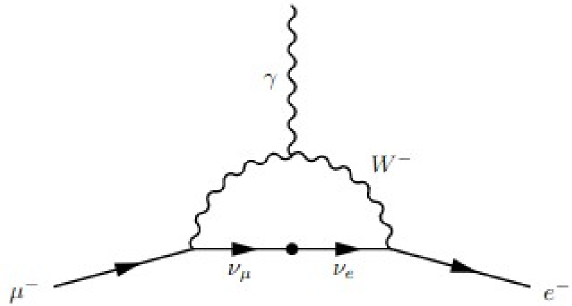


Quantity to be measured

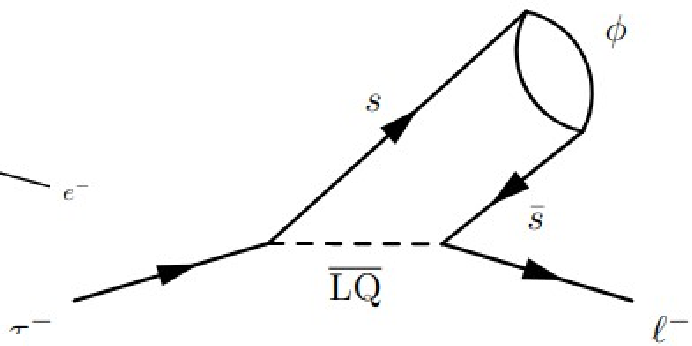
$$\mathcal{B}(\tau \to l K_S^0) = \frac{N_{obs} - N_{exp}}{\mathcal{L} \cdot 2\sigma_{\tau\tau} \cdot \epsilon_{lK_S^0}}$$

- **Forbidden in SM**
  - Only possible due to neutrino oscillation
    BR ~10e-50 → not accessible

Example: LFV decay $\mu^- \to e^- \gamma$ via neutrino oscillations:



- **Extensions to the SM (New Physics) predict such decays via Leptoquarks**
  - Can couple to quarks and leptons and so feature LFV decays



$\tau^- \to \ell^- \phi$ via leptoquark interaction

Motivation: LFV signal (far, far away) → New Physics → some nice prize

Analysis flow

Reconstruction

- Online cuts from next slide
- total_track < 5 (exclusive)

Offline selections

- Optimize some offline cuts with punzi FOM

$$FOM = \frac{\epsilon_{lK_S^0}}{\sigma/2+\sqrt{Bkg}}$$

XGBoost BDT

- ~30 variables taken as initial variable set
- Parameter optimization with *Optuna*
- Remove feature with lowest score and retrain
  accuracy_score metric from *sklearn.metrics* used to find best set of variables
- run BDT 50 times on same, reshuffled samples
- take the one optimizing the Punzi FOM in 3σ SR
- *use _TOP, _KLM, _ECL muonID/pionID variables for BDT (in flight conversion)* → ***is this legal?***

D/MC comparison
Systematics extraction

- Signal channel sidebands comparison
- Reference channel comparison
- List of Systematics
    - ParticleID
    - Tracking efficiency
    - Trigger efficiency
    - BDT efficiency
    - Luminosity
    - Taupair cross section
    - Momentum scale
    - Kshort efficiency depending on 3D distance

Branching Fraction
Upper Limit

- Use pyhf for calculation

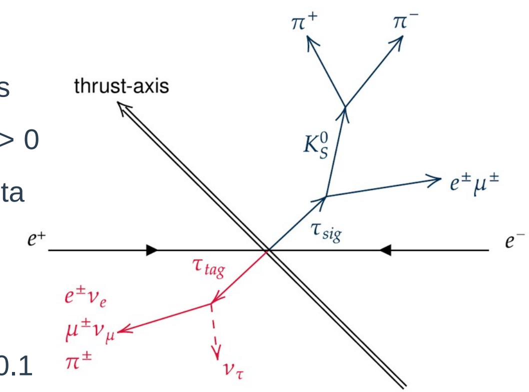
$$\mathcal{B}(\tau \to lK_S^0) = \frac{N_{obs}-N_{exp}}{\mathcal{L}\cdot 2\sigma_{\tau\tau}\cdot\epsilon_{lK_S^0}}$$

Tried out two reconstruction methods

- **Photons**
  - E > 0.02
  - -0.8660 < cosTheta < 0.9563
  - clusterNHits > 1.5
  - isDaughterOfList(pi0:fromLooseGammas) == 0
- **Neutral Pions**
  - E_γ > 0.1
  - -0.8660 < cosTheta < 0.9563
  - clusterNHits > 1.5
  - 0.115 < M < 0.152
-

- **Tracks**
  - pT > 0.1, -3.0 < dz < 3.0, dr < 1.0
  - isDescendantOfList(K S0:FromLoosePions) == 0
- **ParticleID**
  - **e:**
    - electronID noSVD noTOP > 0.9
    - muonID noSVD < 0.95
  - **μ:**
    - muonID noSVD > 0.95
    - electronID noSVD noTOP <= 0.9
  - **π:**
    - muonID noSVD <= 0.95
    - electronID noSVD noTOP <= 0.9

- **K_S**
  - stdV0s.stdKshorts
  - goodBelleKshort > 0
  - significanceOfDistance > 3
- **Event**
  - CorrectBrems: angleThreshold=0.150
  - 20σ signal region around M(τ) and deltaE



Inclusiv: total_tracks < 7

Exclusiv: total_tracks < 5

Calculate branching fraction upper limit with simple poissonian method (also the Belle one). Just needs signal efficiency and background as input. *No systematic errors included.*

Inclusiv

Belle II (Belle)	ε [%]	Background	BR [10^-8]	1-B/B2
e-channel	14.76 (10.2)	2.24 (0.18)	2.3 (2.04)	11 %
mu-channel	11.24 (10.7)	1.47 (0.35)	2.7 (2.09)	23 %

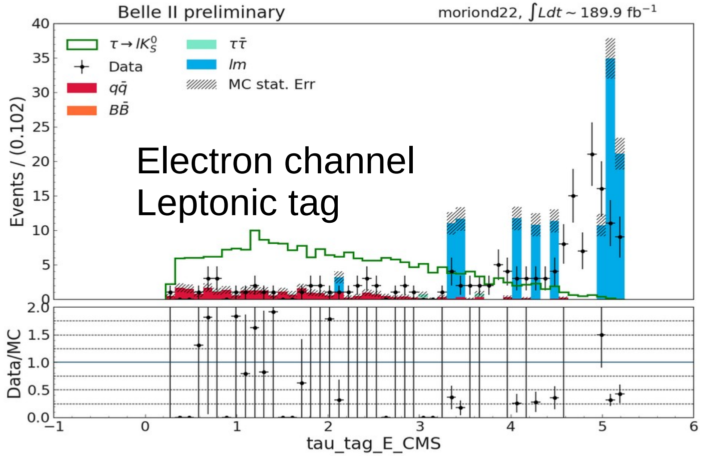
Exclusiv

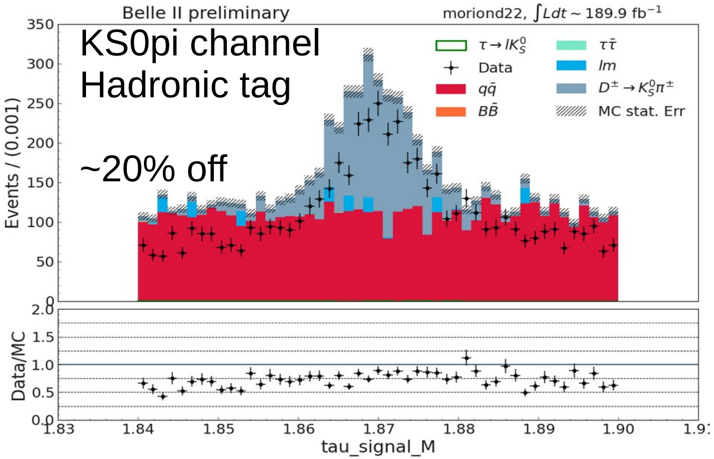
Belle II (Belle)	ε [%]	Background	BR [10^-8]	1-B/B2
e-channel	13.27 (10.2)	0 (0.18)	1.41 (2.04)	44 %
mu-channel	9.41 (10.7)	0 (0.35)	1.99 (2.09)	5 %

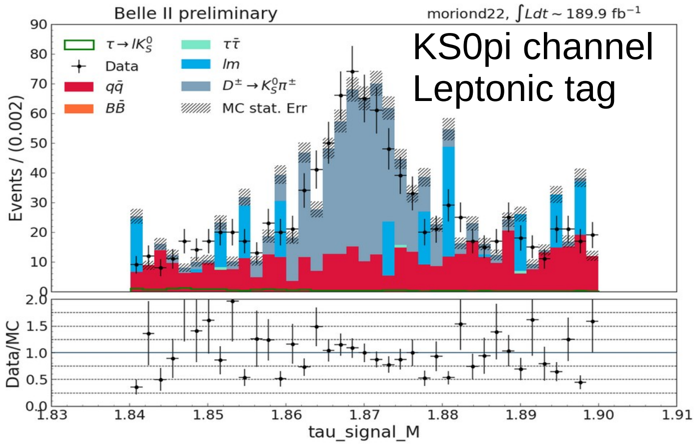
Data/MC comparison

- **Electron channel**
  - Hadronic tag
    - Data/MC before offline cuts: 0.74
    - Data/MC after offline cuts: 0.98
  - Leptonic tag
    - Data/MC before offline cuts: 0.53
    - Data/MC after offline cuts: 0.87
      - BDT_proba > 0.5 : 0.98
      - BUT: shapes are off, **low MC statistics, discrepancy in shapes likely due to missing processes in simulation (ISR)**

- **Muon channel**
  - Hadronic tag
    - Data/MC before offline cuts: 0.65
    - Data/MC after offline cuts: 0.79
      - **good agreement in shape, overall qqbar normalization off by ~20%**
  - Leptonic tag
    - Data/MC before offline cuts: 0.4
    - Data/MC after offline cuts: 0.98



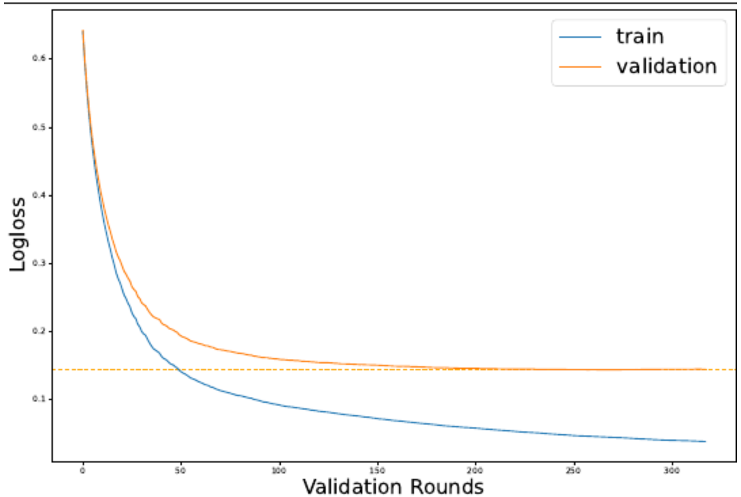


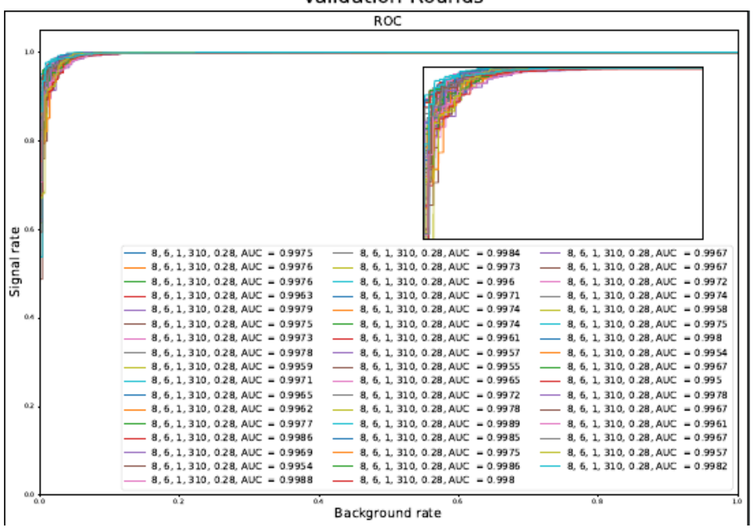


BACKUP

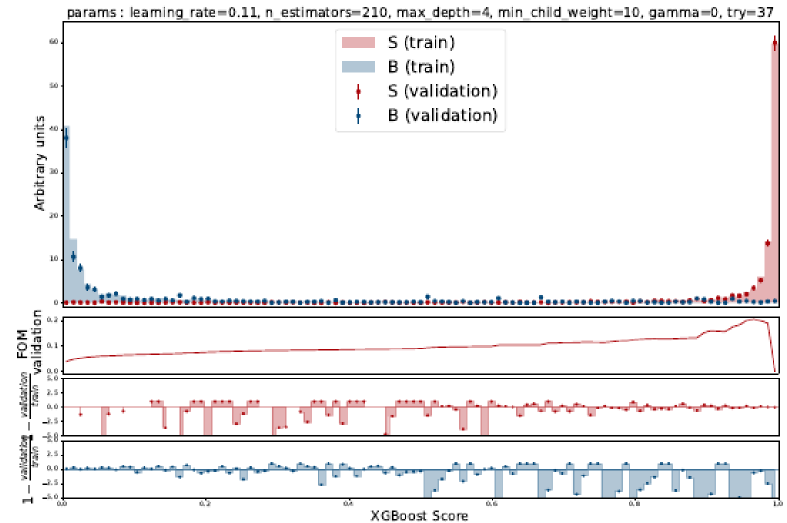
BDT performance

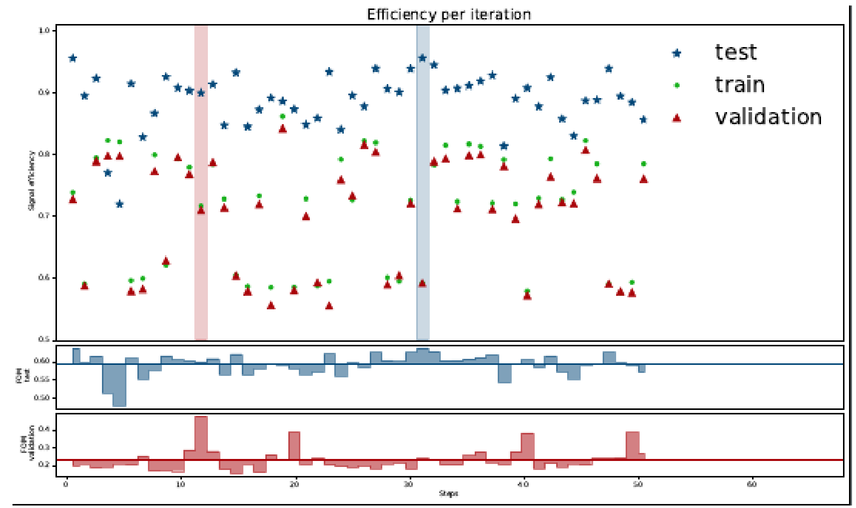
- **Electron channel**





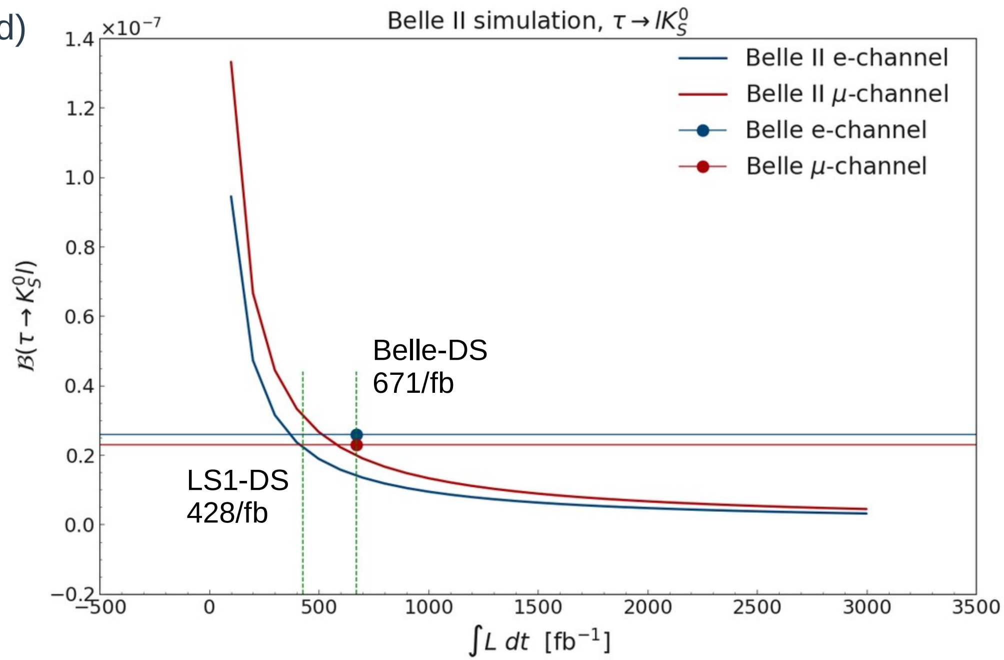
- **Muon channel**





Performance after BDT

- **Results in 3 σ SR on 2/ab test sample**
  - e-channel: ε = 13.07% , bkg = 0, bkg_scaled = 0 (weighted)
  - μ-channel: ε = 9.41 % , bkg = 0, bkg_scaled = 0 (weighted)
  - Stronger cut on pID could bring background to zero → unfortunately this drops signal efficiency to ~5%
  - Sensitivity projection with Poissonian UL calculator (no systematics):
    - Belle numbers computed with the same UL calculator used for projections of Belle II results. Background scaled to 671/fb



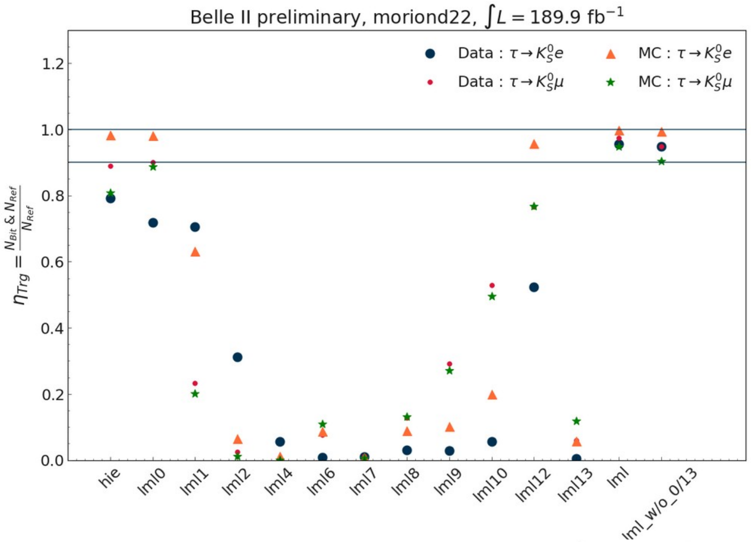
Belle II (Belle)	ε [%]	Background	BR [10^-8]	1-B/B2
e-channel	13.27 (10.2)	0 (0.18)	1.41 (2.04)	44 %
mu-channel	9.41 (10.7)	0 (0.35)	1.99 (2.09)	5 %

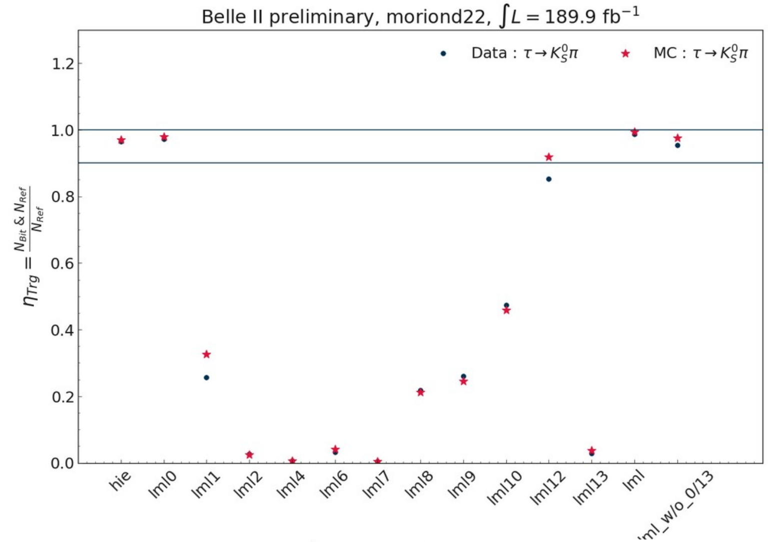
Performance after complete chain better than in semi-inclusive case!

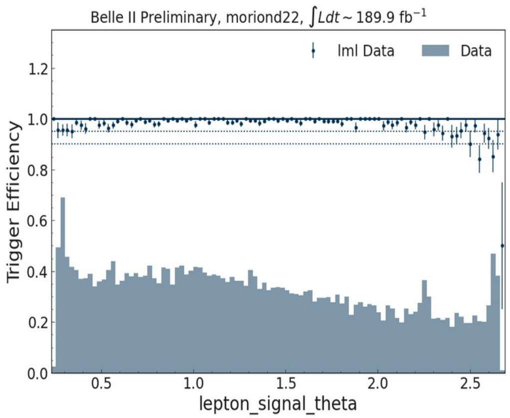
If cutting less strict on the muon BDT, the main Background source is in-flight conversion π → μ

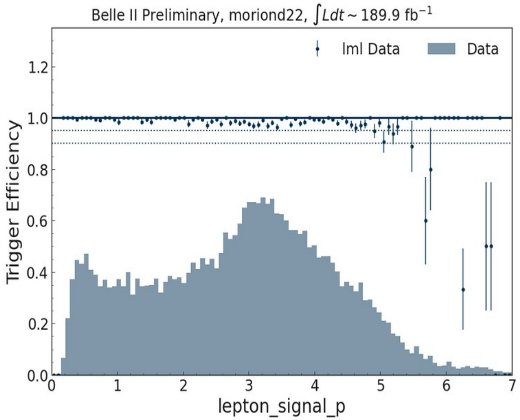
Trigger sudies

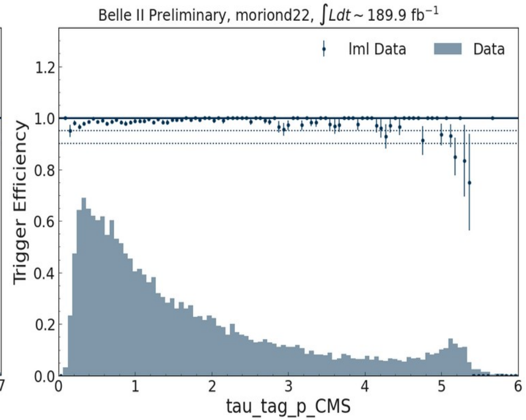
- **Studie trigger efficiency on signal and reference (tau → K_S0 pi) channel**
  - Trigger efficiency: *eff = (N_bit & N_ref)/N_ref*, with *N_ref = fff OR ffs OR ffo OR f30* (CDC lines)

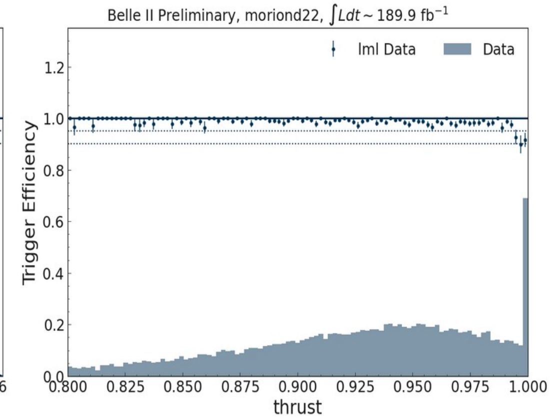












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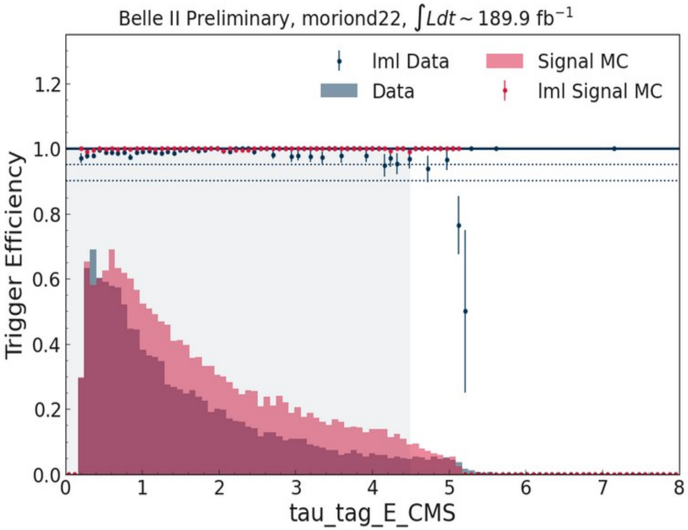
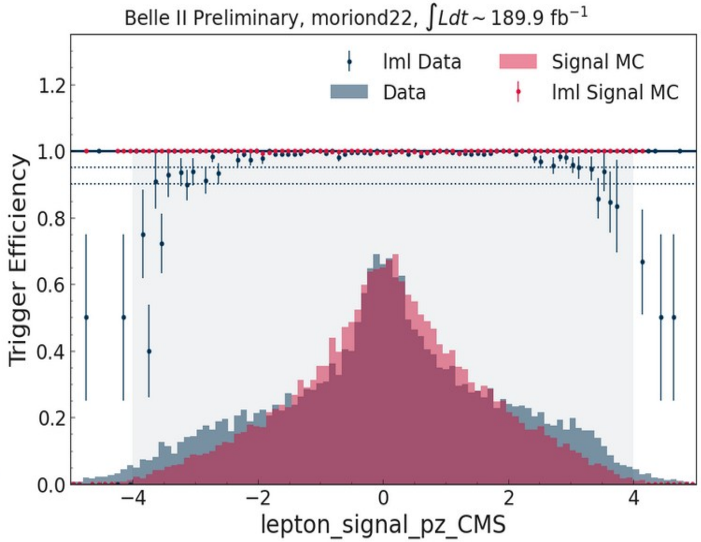
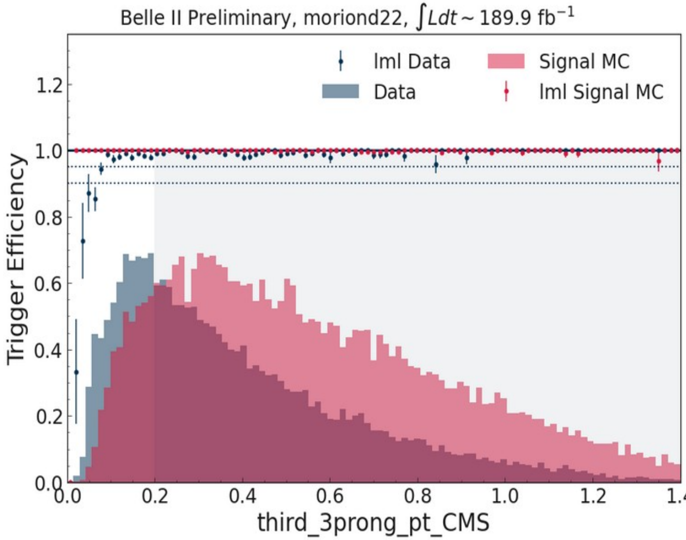
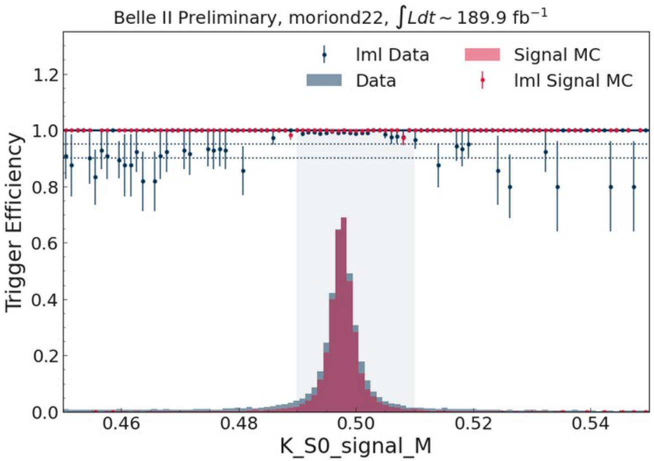
Trigger sudies

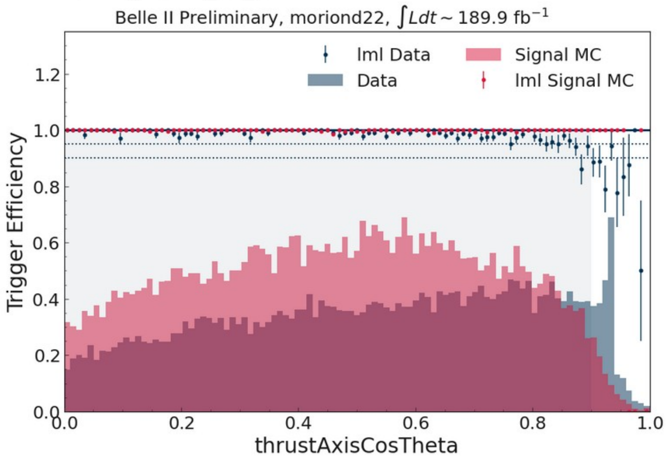
- **Trigger efficiency on pre-selection variables (tau → K_S0 pi reference channel)**





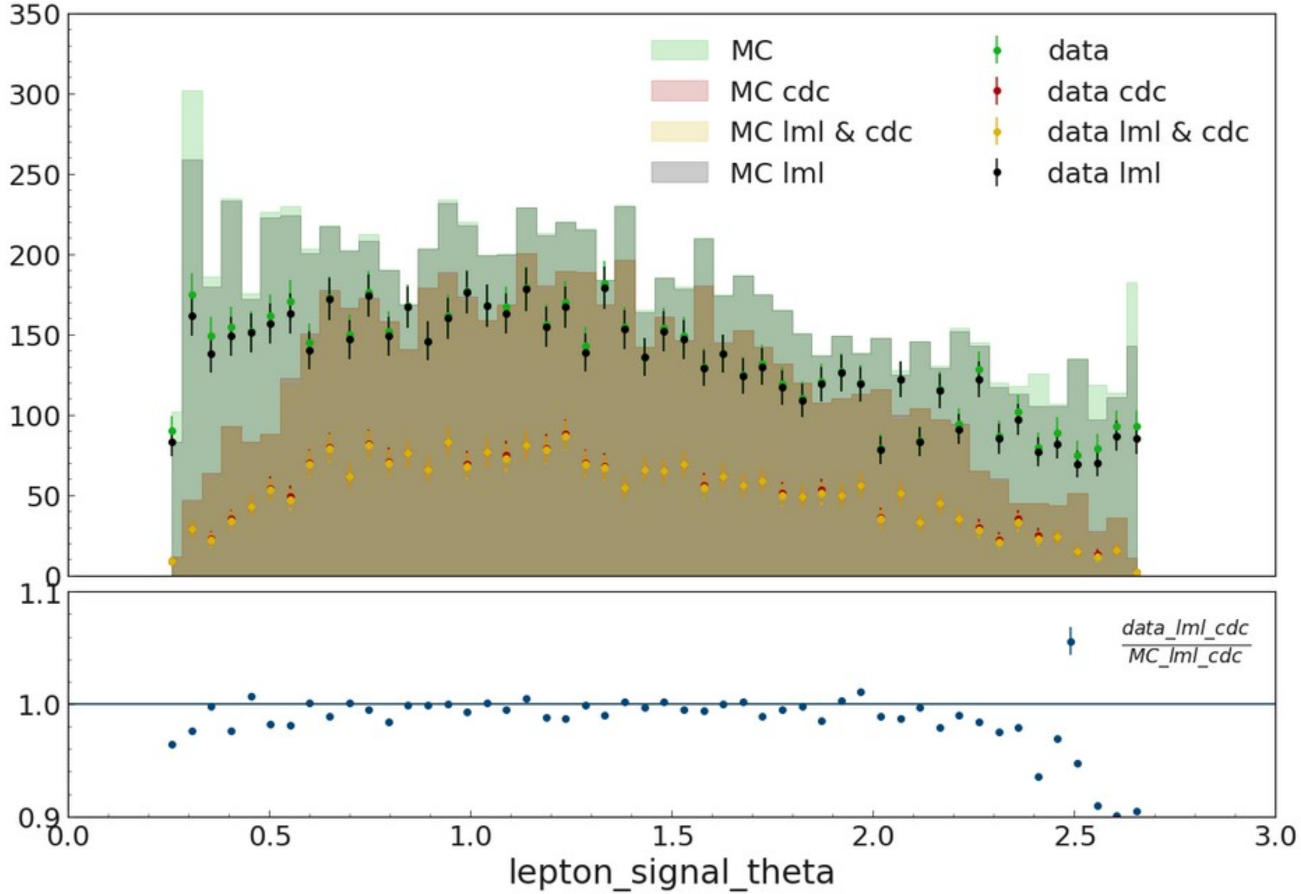






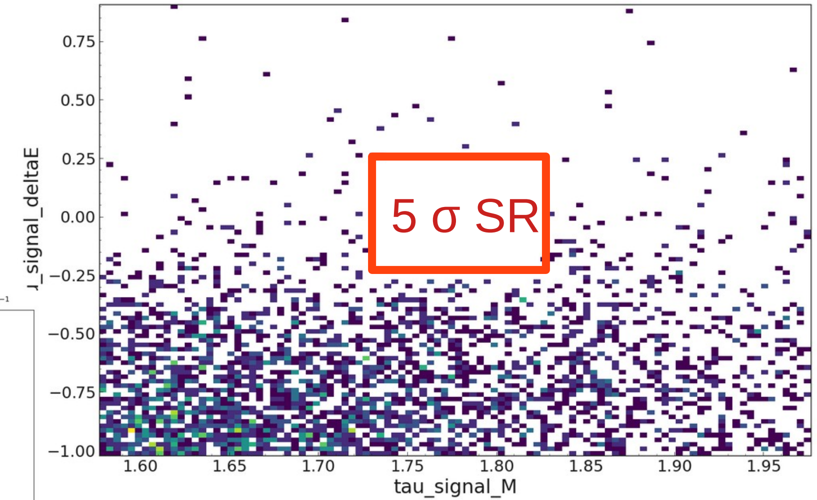
Trigger sudies

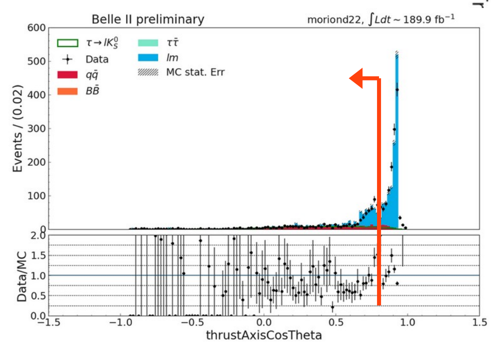
- **Trigger efficiency corrections**
  - Calculate trigger efficiency on data and MC and extract corrections for MC as bin-by-bin ratio
  - For the following data/MC comparison the trigger line selection and the trigger efficiency corrections are applied!

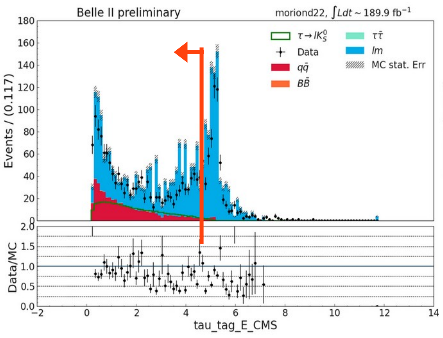


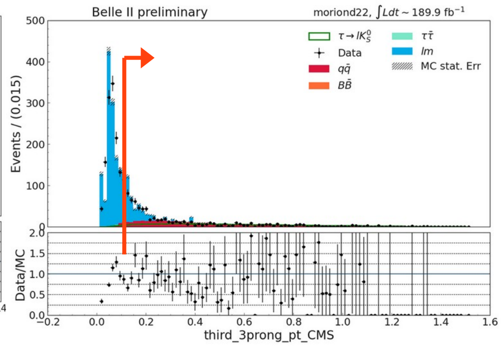
Data/MC comparison in sidebands – e-channel, h-tag

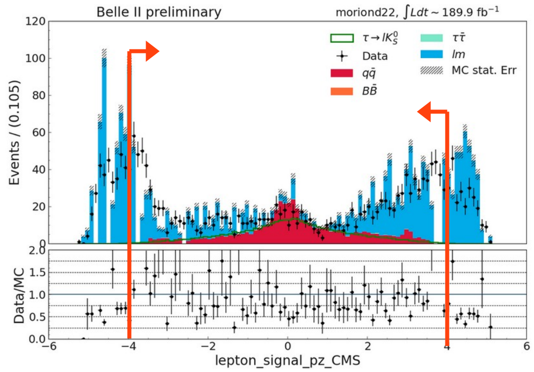
- **Data/MC comparison in the electron channel, hadronic-tag in the 5-20 sigma side-bands**
  - No preselection: D/MC = 0.74
  - Including preselections: D/MC 0.98
  - Preselection variables:
    - tau_tag_E_CMS < 5
    - -4 < lepton_signal_pz_CMS < 4
    - 0.49 < K_S0_signal_M < 0.51
    - third_3prong_pt_CMS > 0.1
    - thrustAxisCosTheta < 0.9

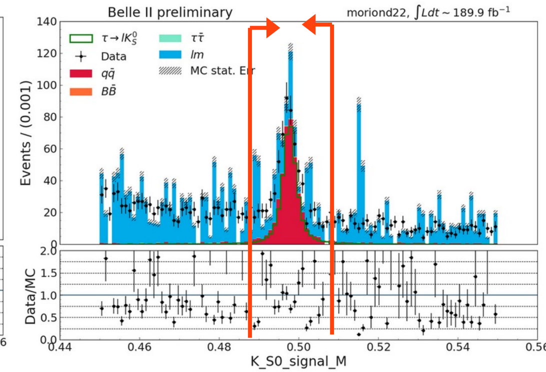












Data/MC comparison in sidebands – μ-channel, l-tag

- **Data/MC comparison in the muon channel, leptonic-tag in the 5-20 sigma side-bands**
  - No preselection: D/MC = 0.4
  - Including preselections: D/MC 0.98
  - Preselection variables: