Lepton Flavor Violation (LFV) analysis in $\tau^- \to \mu^- \mu^+ \mu^-$

2024 Belle II Physics week hands-on

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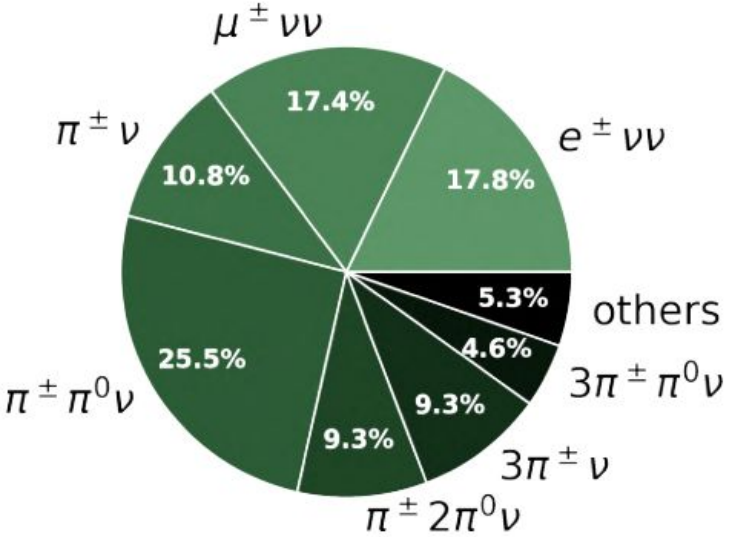
Overview on the reconstruction

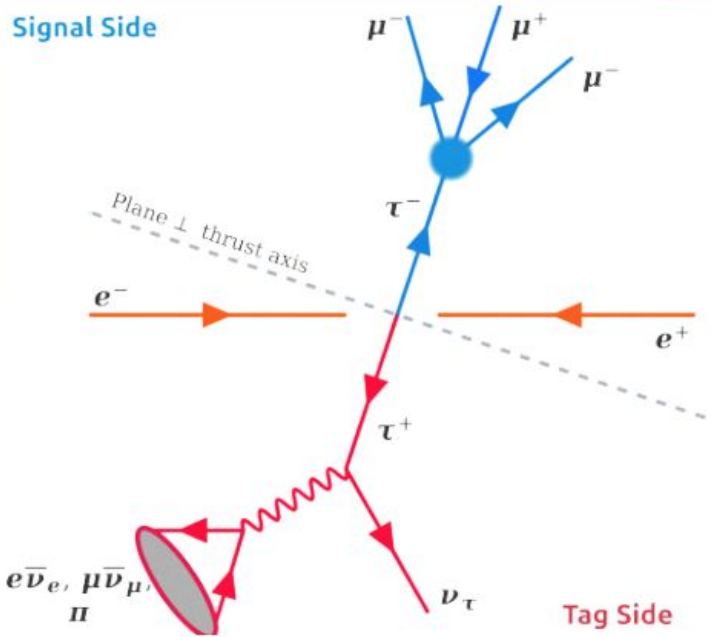
Tagged strategy

Reconstruct τ pair events with a tagged strategy by exploiting back-to-back production:

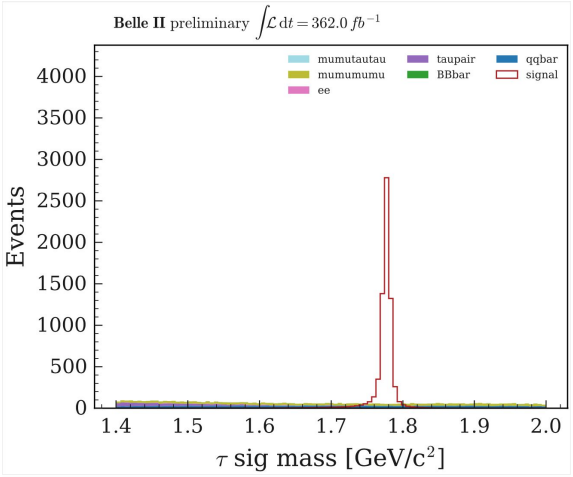
- **Signal hemisphere**: one τ decay into three muons
- **Tag hemisphere**: oppositely charged τ (**tag**) constrained to 1-prong decays

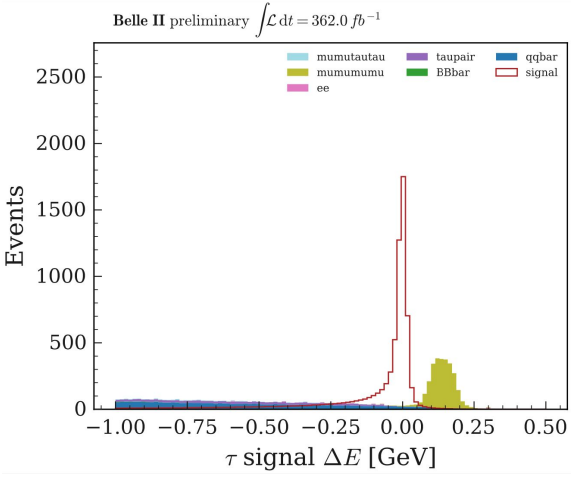
$\Rightarrow$ used at Belle and BaBar





Define the signal region



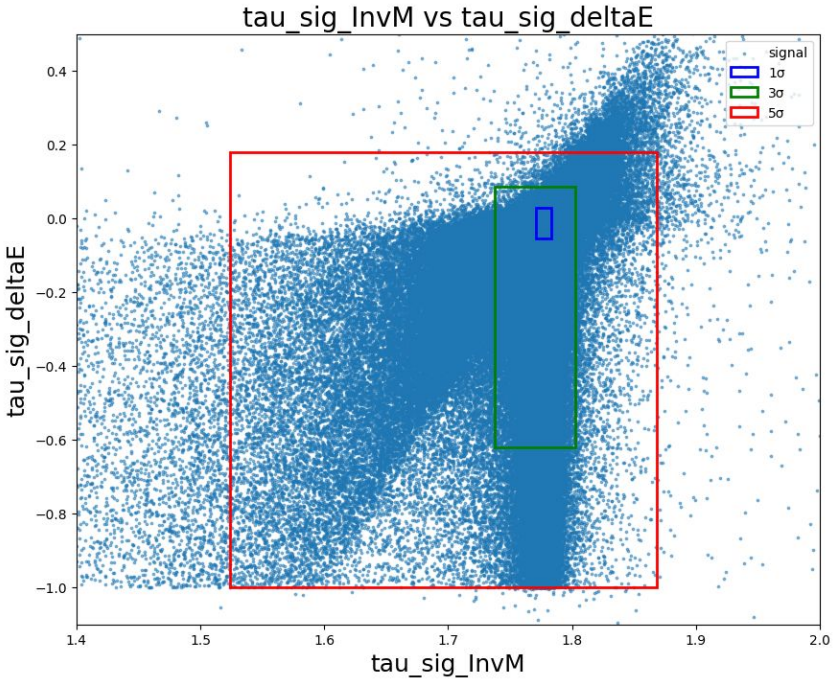


calculated signal yield each axis

1 σ : 68%

3 σ : 95%

5 σ : 99.7%



Find the box cut

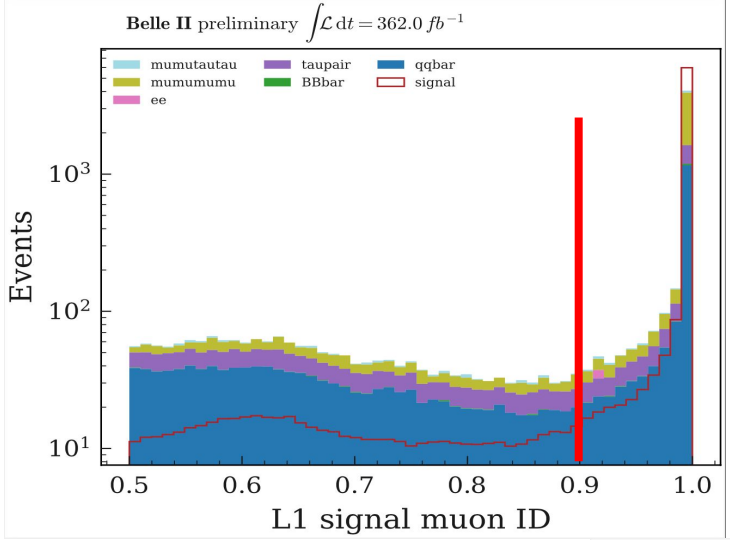
Cut based selection:

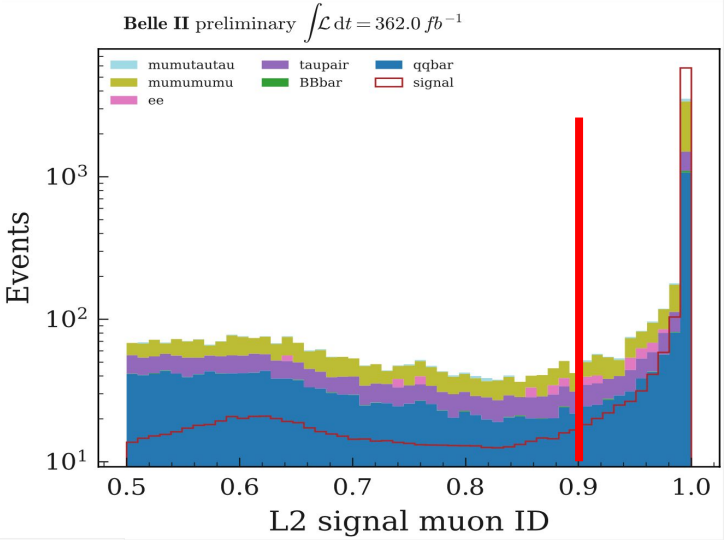
- MuonID of the muons in signal side
- Mass Beam constrained of tag side tau

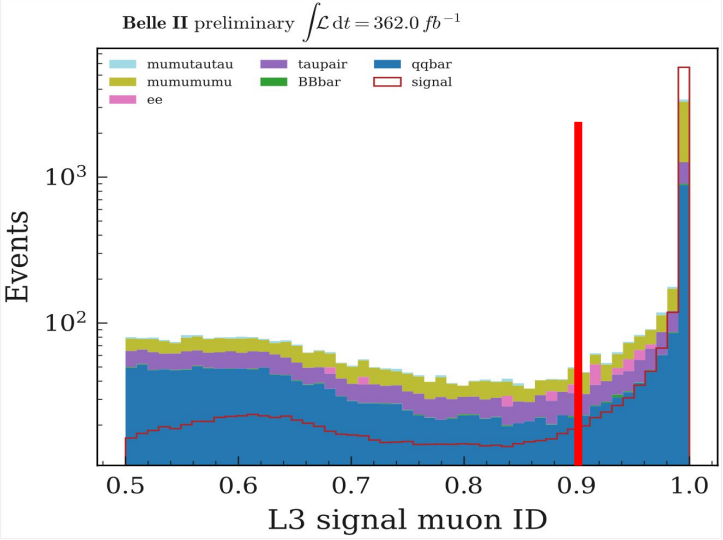
Optimized by Punzi's Figure of merit:

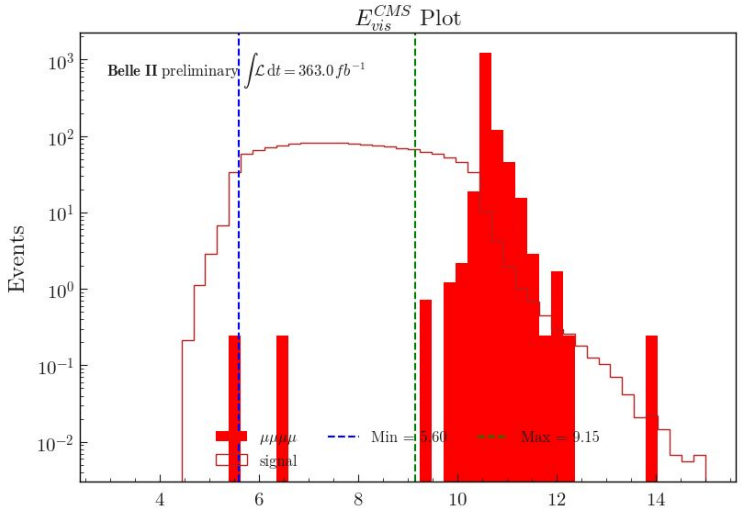
- visible energy
- missing momentum
- thrust

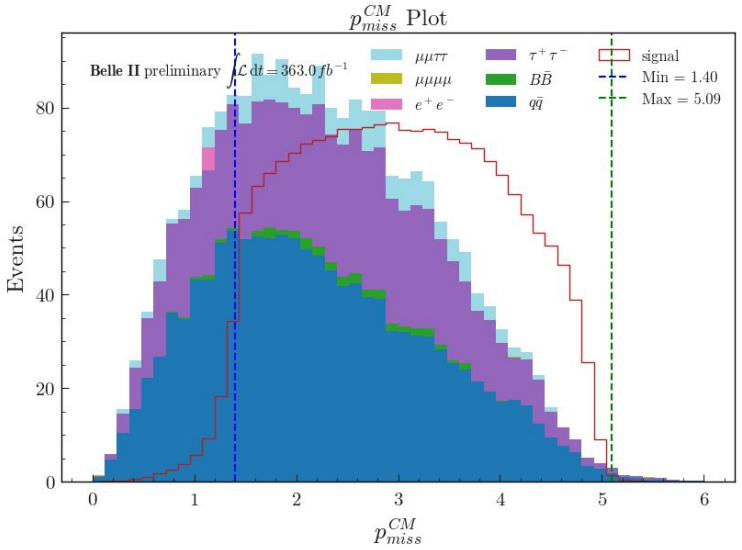
```
'thrust': [0.9, 0.97],
'visibleEnergyOfEventCMS': [5.6, 9.15],
'tau_sig_InvM': [1.7380, 1.8029],
'tau_sig_deltaE': [-0.6195, 0.0872],
# 'missingMass2OfEvent': [-4, 4],
'missingMomentumOfEvent': [1.4, 5.09],
'L1_sig_muonID_noSVD': [0.9, 1],
'L2_sig_muonID_noSVD': [0.9, 1],
'L3_sig_muonID_noSVD': [0.9, 1],
# 'tau_sig_1_CMS_subleadingclusterE': [0, 3],
'tau_tag_Mbc': [2, 6],
```

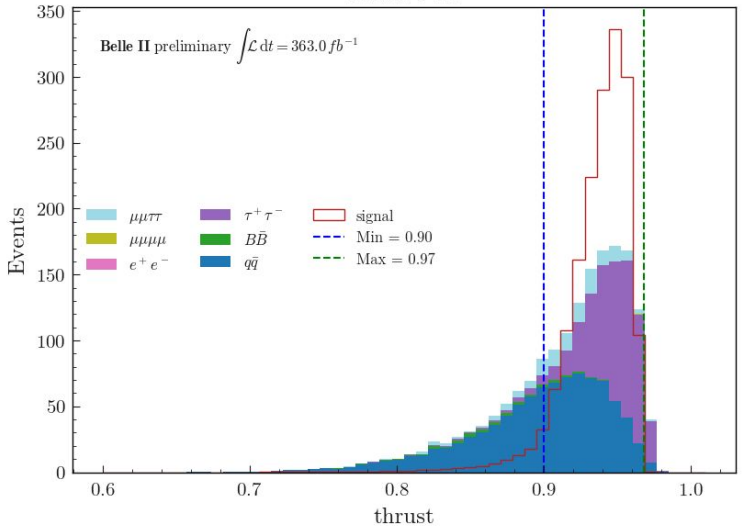

Belle II preliminary $\int \mathcal{L}\,dt = 362.0\ fb^{-1}$
mumutautau
mumumumu
ee
taupair
BBbar
qqbar
signal
Events
10^3
10^2
10^1
0.5
0.6
0.7
0.8
0.9
1.0
L1 signal muon ID

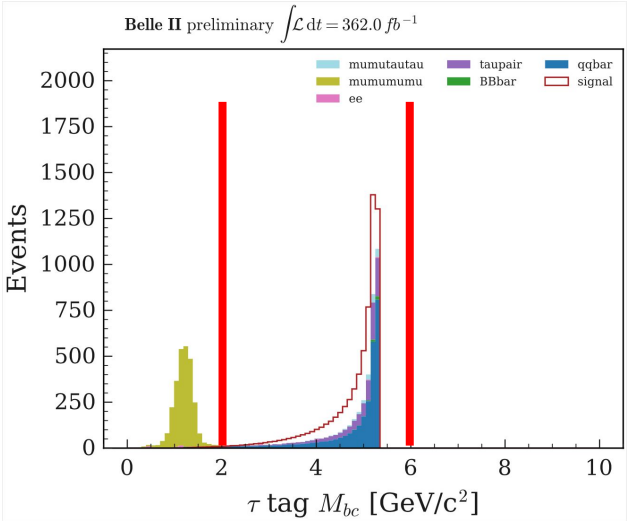

Belle II preliminary $\int \mathcal{L}\,dt = 362.0\ fb^{-1}$
mumutautau
mumumumu
ee
taupair
BBbar
qqbar
signal
Events
10^3
10^2
10^1
0.5
0.6
0.7
0.8
0.9
1.0
L2 signal muon ID


Belle II preliminary $\int \mathcal{L}\,dt = 362.0\ fb^{-1}$
mumutautau
mumumumu
ee
taupair
BBbar
qqbar
signal
Events
10^3
10^2
0.5
0.6
0.7
0.8
0.9
1.0
L3 signal muon ID


E_{vis}^{CMS} Plot
Belle II preliminary $\int \mathcal{L}\,dt = 363.0\,fb^{-1}$
Events
$\mu\mu\mu\mu$
signal
Min = 5.60
Max = 9.15


p_{miss}^{CM} Plot
Belle II preliminary $\int \mathcal{L}\,dt = 363.0\,fb^{-1}$
$\mu\mu\tau\tau$
$\mu\mu\mu\mu$
e^+e^-
$\tau^+\tau^-$
$B\bar{B}$
$q\bar{q}$
signal
Min = 1.40
Max = 5.09
Events
p_{miss}^{CM}


thrust Plot
Belle II preliminary $\int \mathcal{L}\,dt = 363.0\,fb^{-1}$
$\mu\mu\tau\tau$
$\mu\mu\mu\mu$
e^+e^-
$\tau^+\tau^-$
$B\bar{B}$
$q\bar{q}$
signal
Min = 0.90
Max = 0.97
Events
thrust


Belle II preliminary $\int \mathcal{L}\,dt = 362.0\,fb^{-1}$
mumutautau
mumumumu
ee
taupair
BBbar
qqbar
signal
Events
τ tag M_{bc} [GeV/c^2]

Variable/Type	Relative efficiency signal	qqbar	BBbar	taupair	ee	4mu	mumutautau
Initial	1295006	2823.23	36.14	1015.43	72.6	2725.89	196.02
Mu1 muonID	91.48%	1508.69	30.49	566.16	4.84	2424.11	151.01
Mu2 muonID	89.85%	1433.31	31.62	542.75	43.56	2097.9	168.43
Mu3 muonID	88.38%	1264.33	24.04	520.84	43.56	2193.25	144.23
thrust	94%	1877.74	8.23	859.89	0	671.31	140.84
E_vis^CMS	76.83%	1251.68	33.4	765.39	4.84	0.97	160.69
P_miss	73.45%	997.52	31.14	689.7	4.84	2.66	154.4
M_bc^tag	99.33%	2748.03	36.14	1008.35	19.36	17.42	196.02
Delta E_sig	95%	1433.91	2.42	579.11	38.72	232.08	88.09
M_sig^Inv	95%	313.27	5	3.87	0	287.5	22.26
Final	45.22% (8.4%)	3.09	0.16	0.12	0	0	4.36

Summary & Plan

Summary

- We optimized selection cuts for background rejection by Punzi's figure of merit.
- We got the 8.37% signal efficiency with 7.73 remaining background.
- Continuum and mumutautau are dominant backgrounds among the remaining backgrounds.

Plan

- To reduce remaining background, especially continuum and mumutautau, we consider the machine learning classifier.
- The classifier can also replace the cuts on visible energy and missing momentum in order to obtain an higher signal efficiency.