Search for the rare decay $\tau \rightarrow 3\mu$ at the CMS experiment

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END OF THE YEAR REPORT
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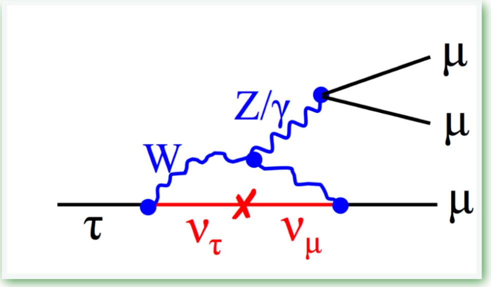
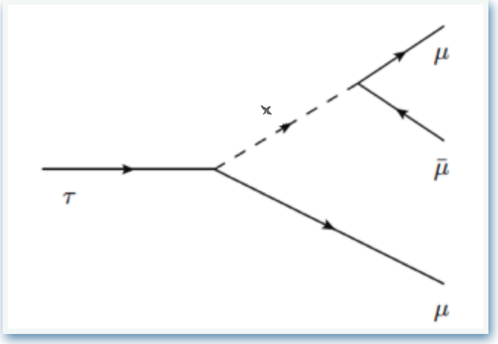
The physics case

Lepton Flavour Violation (LFV) is suppressed within the Standard Model (SM)

- neutrino oscillations has been observed
  - this induces LFV
  - *Branching Ratio* MS (BR) $\tau \rightarrow 3\mu \sim \mathcal{O}(10^{-55})$ [arXiv:1912.09862]



LFV decays can be a good test for beyond SM physics



τ → 3μ decay

- *pp* collisions are a rich source of τ leptons
- 3μ channel has a clear signature due to the presence of three muons in the final state
- some BSM models predict enhanced coupling to the third family

State of the art

$\tau \longrightarrow 3\mu$ search at **lepton colliders**

- **Belle** (KEKB), BR($\tau \longrightarrow 3\mu$) < 2.1 x 10^{-8} @ 90% di Confidence Level (CL) [arXiv:1001.3221]
    - best upper limit today
- **BaBar** (SLAC), BR($\tau \longrightarrow 3\mu$) < 3.3 x 10^{-8} @ 90% di CL [arXiv:1002.4550]

$\tau \longrightarrow 3\mu$ search at **hadron colliders**

- **LHCb** (LHC), BR($\tau \longrightarrow 3\mu$) < 4.6 x 10^{-8} @ 90% di CL [https://doi.org/10.1007/JHEP02(2015)121]
- **ATLAS** (LHC), BR($\tau \longrightarrow 3\mu$) < 3.8 x 10^{-7} @ 90% di CL [https://doi.org/10.1140/epjc/s10052-016-4041-9]
- **CMS** (LHC), BR($\tau \longrightarrow 3\mu$) < 8.0 x 10^{-8} @ 90% di CL [arXiv:2007.05658]

Search at CMS

Both **Heavy Flavour** (HF) ($D \longrightarrow \tau\nu$..., $B \longrightarrow \tau\nu$..., $B \longrightarrow D(\tau\nu)$...) and **W** ($W \longrightarrow \tau\nu$) production channels can be investigated

CMS Run2 (pp @ 13 TeV): integrated luminosity **~140 fb^{-1}**

- **HF channel**: $\mathcal{O}(10^{12})$ τ leptons produced
  - ~$\mathbf{10^4 \div 10^5}$ $\tau \longrightarrow 3\mu$ events (assuming Belle's limit)
  - low transverse momenta, low missing energy
- **W channel**: $\mathcal{O}(10^{9})$ τ leptons produced
  - ~**10 ÷ 100** $\tau \longrightarrow 3\mu$ events (assuming Belle's limit)
  - stronger final state signature

Prima analisi $\tau \longrightarrow 3\mu$ a CMS su dati 2016

- Journal (JHEP) publication under review
- available on the CDS, arxiv

Analysis strategy

Online: dedicated High Level Trigger (HLT)

- selecting two muons and one tracker muon coming from the same vertex
- implementing tau object reconstruction + isolation cut at HLT
- updated for the 2017-2018 data taking specifically for the W channel

Offline: selecting $\tau \longrightarrow 3\mu$ events within offline reconstructed objects

- identification of three muons coming from a common vertex
  - kinematic acceptance: $p_T > 1$ GeV, $|\eta| < 2.4$

Signal/background discrimination

- S/B discrimination is done with MVA techniques (BDT) exploiting the full information of the event (no hard cuts)
- BDT trained on simulated signal samples and data from the signal-mass sidebands
- Using two categories: barrel ($|\eta| < 1.6$) and endcap ($|\eta| \geq 1.6$)

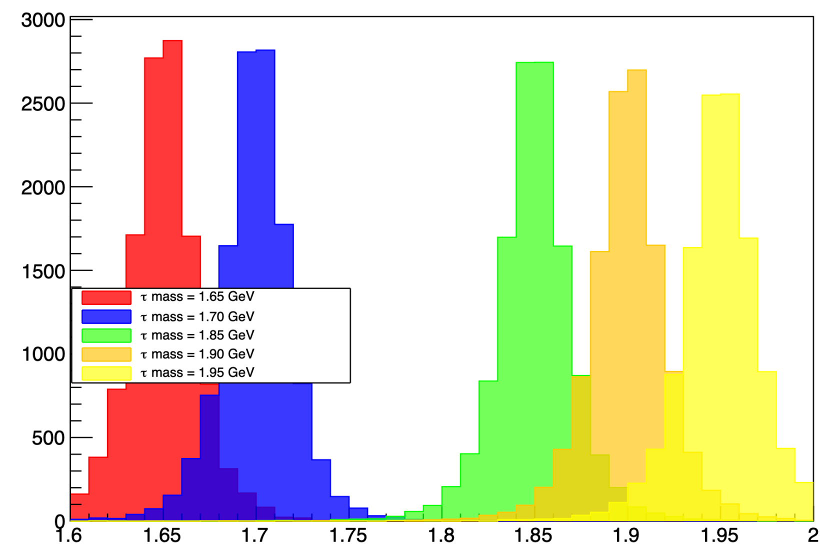
BDT discriminator

BDT rejection of background events

BDT discriminator trained with the **XGBoost** package, using a five-fold approach

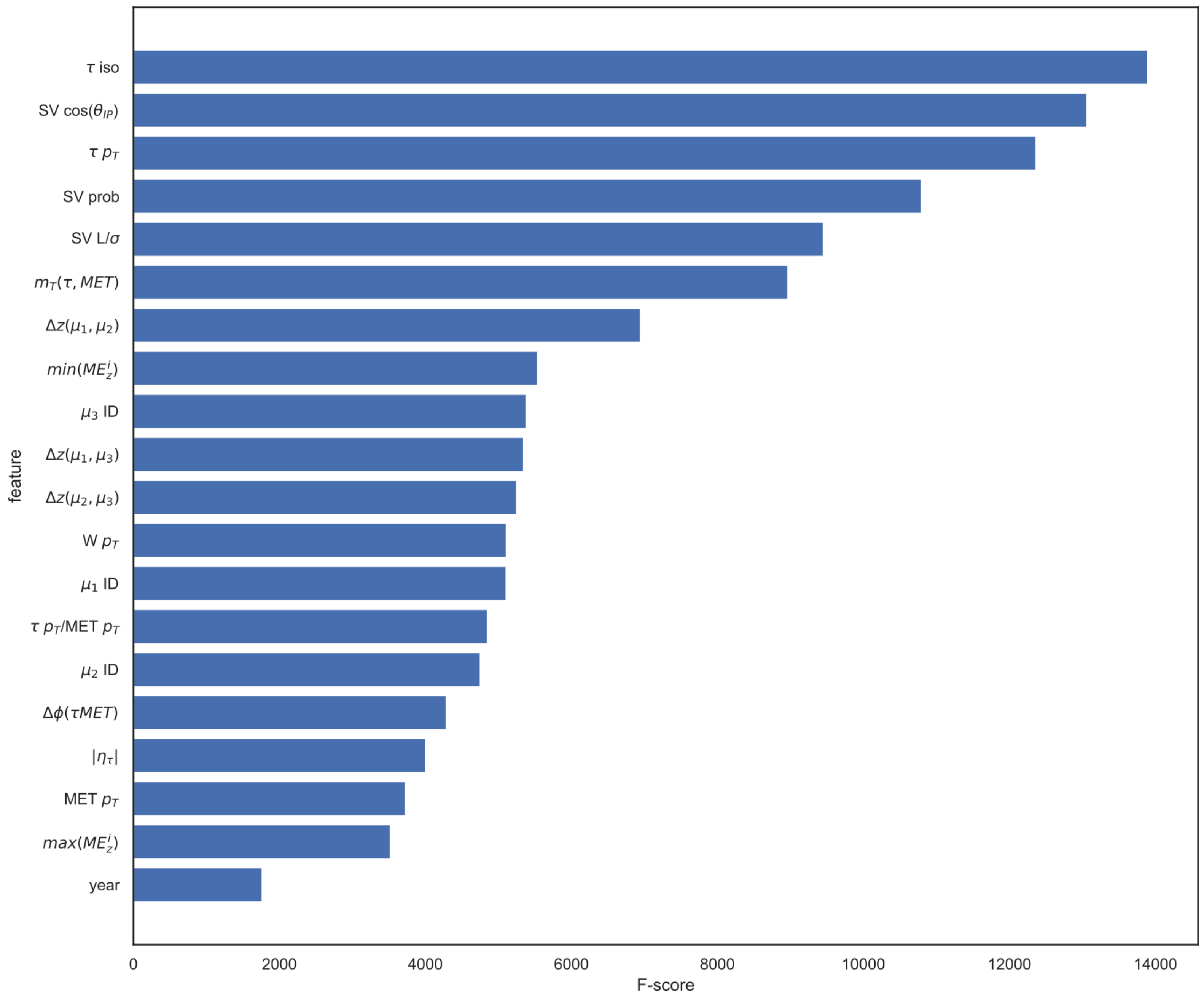
- Trained on 2017-2018 dataset (data SB + MC)

- signal MC (private Pythia production)
  - 390k events for 2017
  - 380k events for 2018
- added shifted-tau-mass samples to the training
  - 5 samples per year, 50k events per sample
  - 1.65, 1.70, 1.85, 1.90 and 1.95 GeV
- data corresponding to 90 fb-1 (2017+2018)



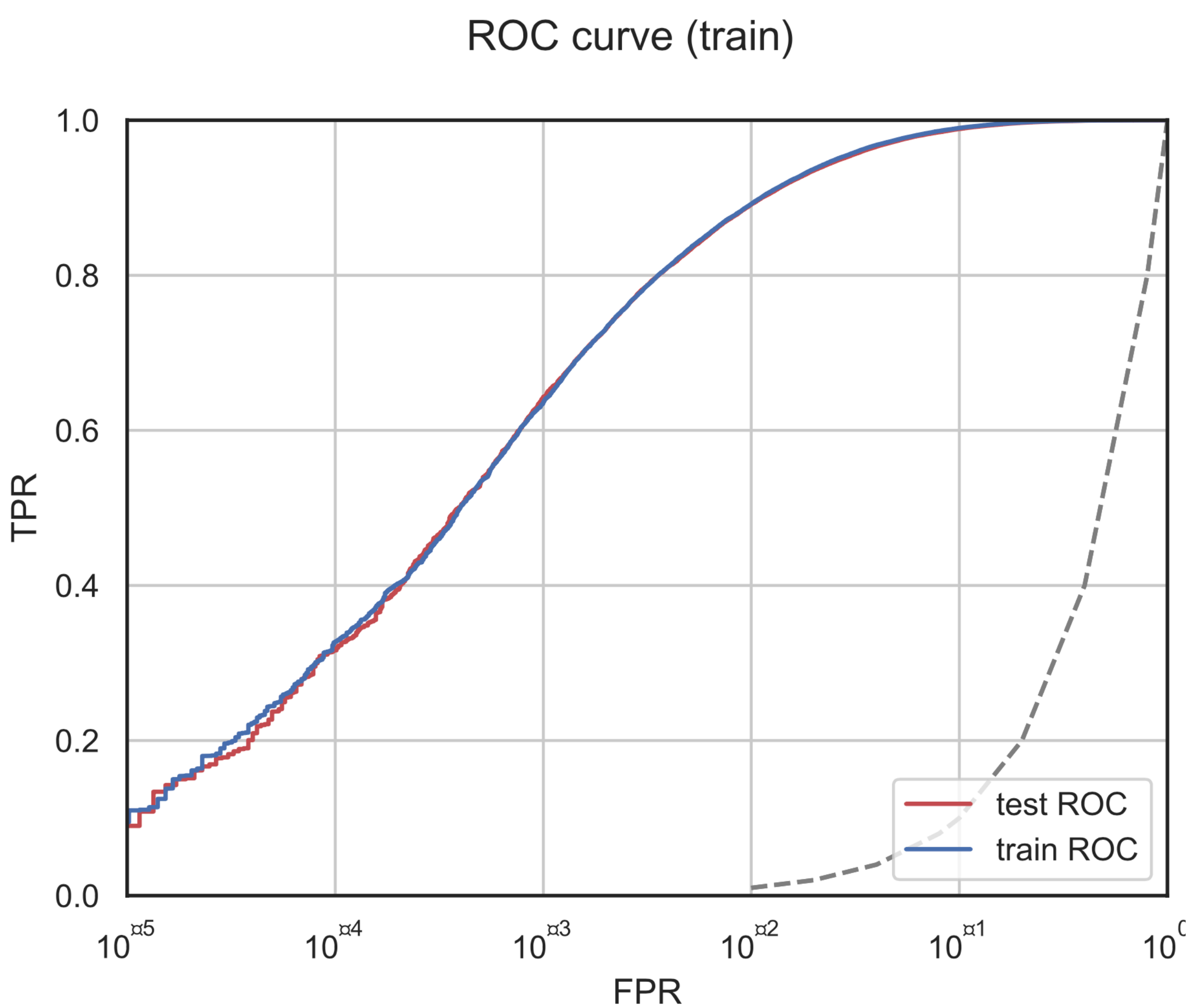
3mu mass

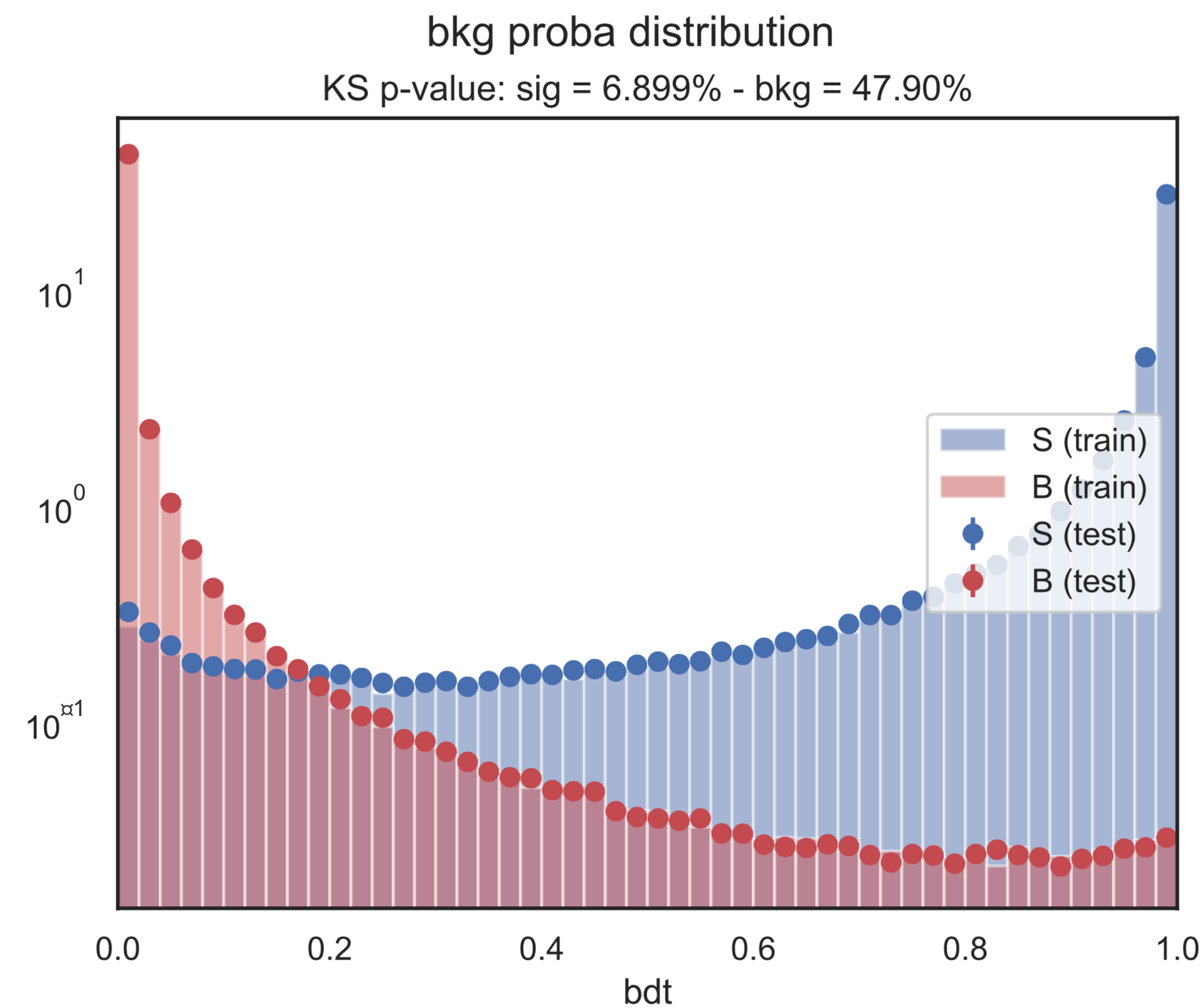
BDT discriminator
Feature importance



BDT DISCRIMINATOR

PERFORMANCE

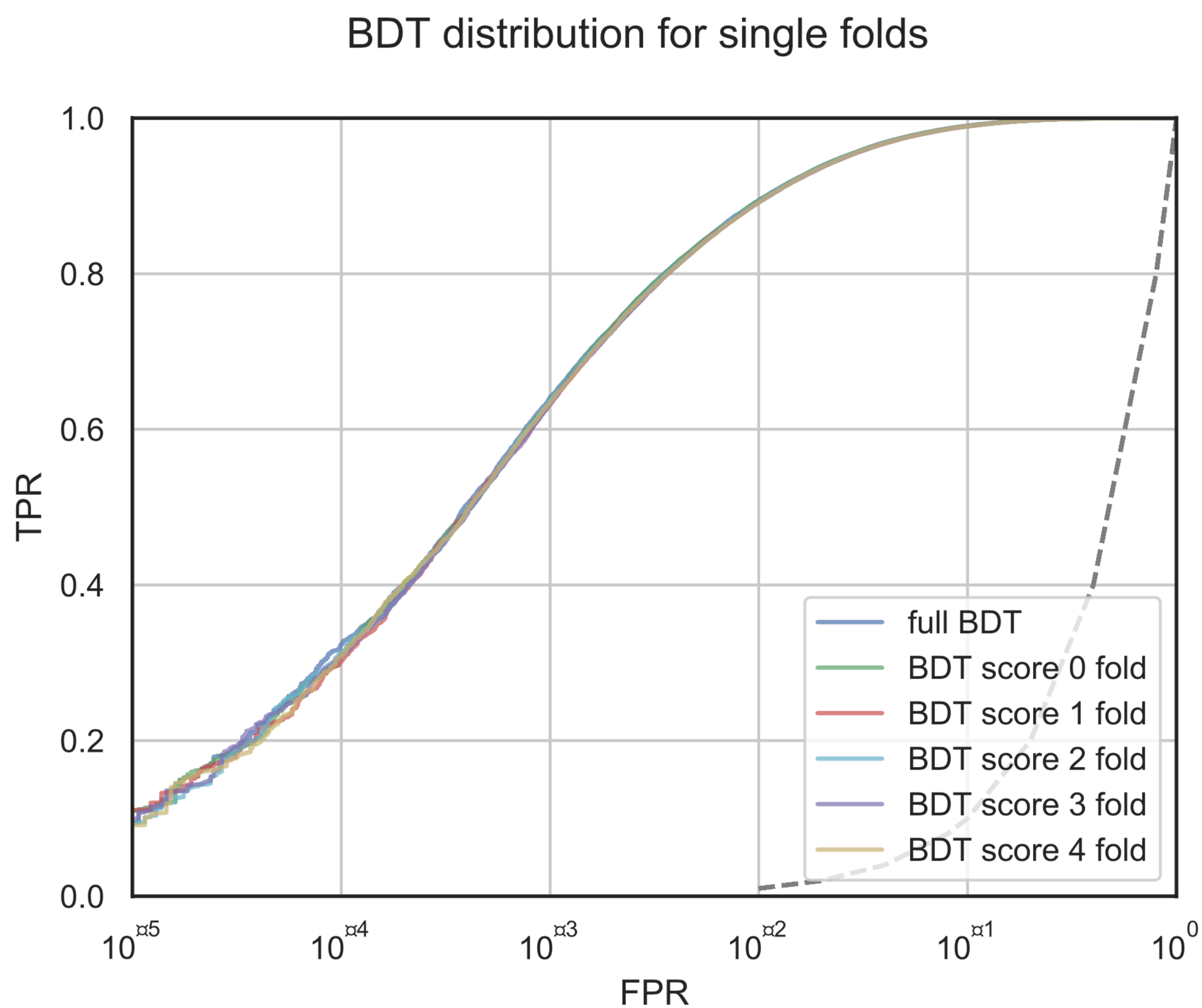




Overtraining checks ok

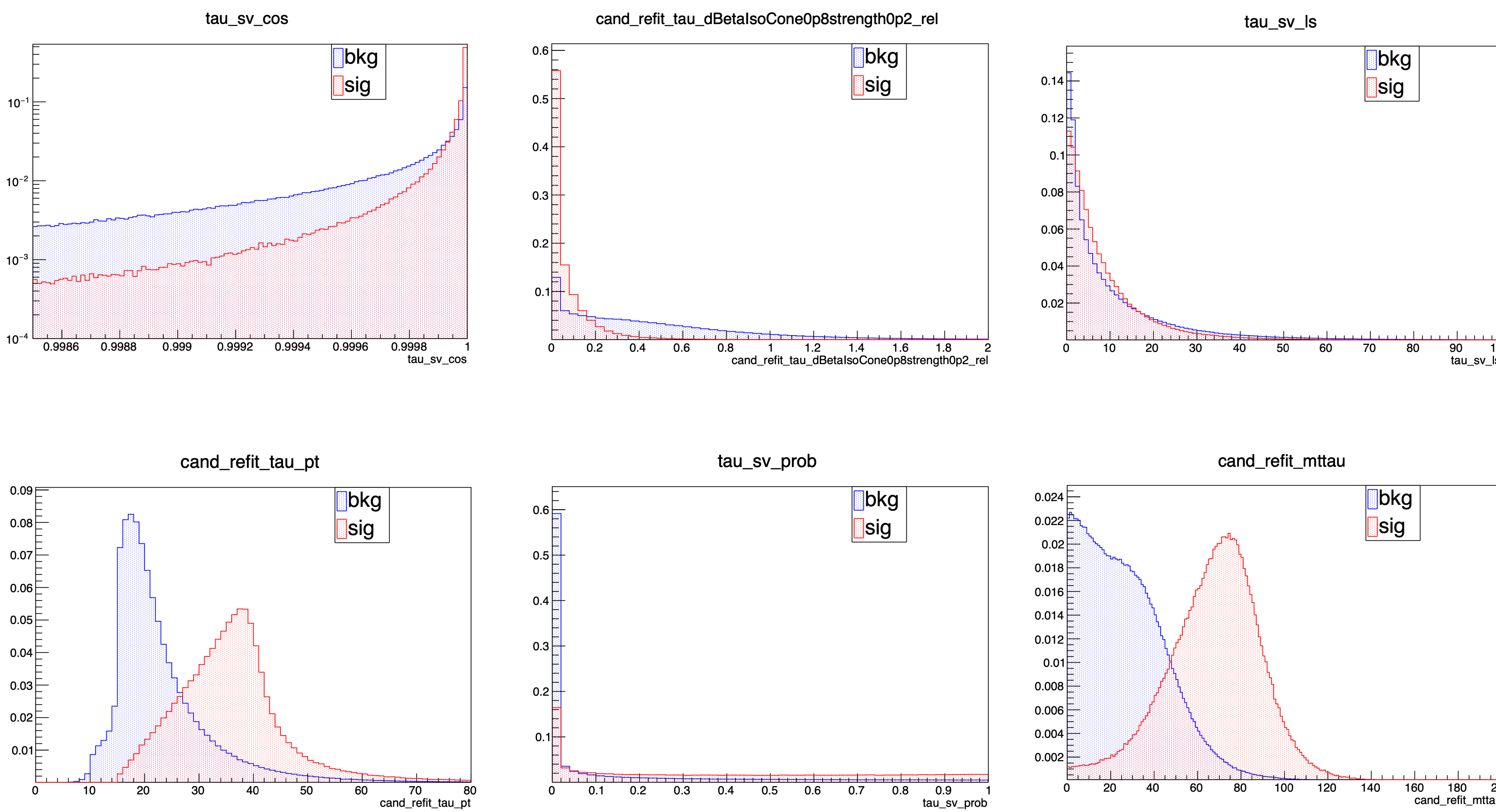
BDT DISCRIMINATOR

PERFORMANCE



BDT DISCRIMINATOR

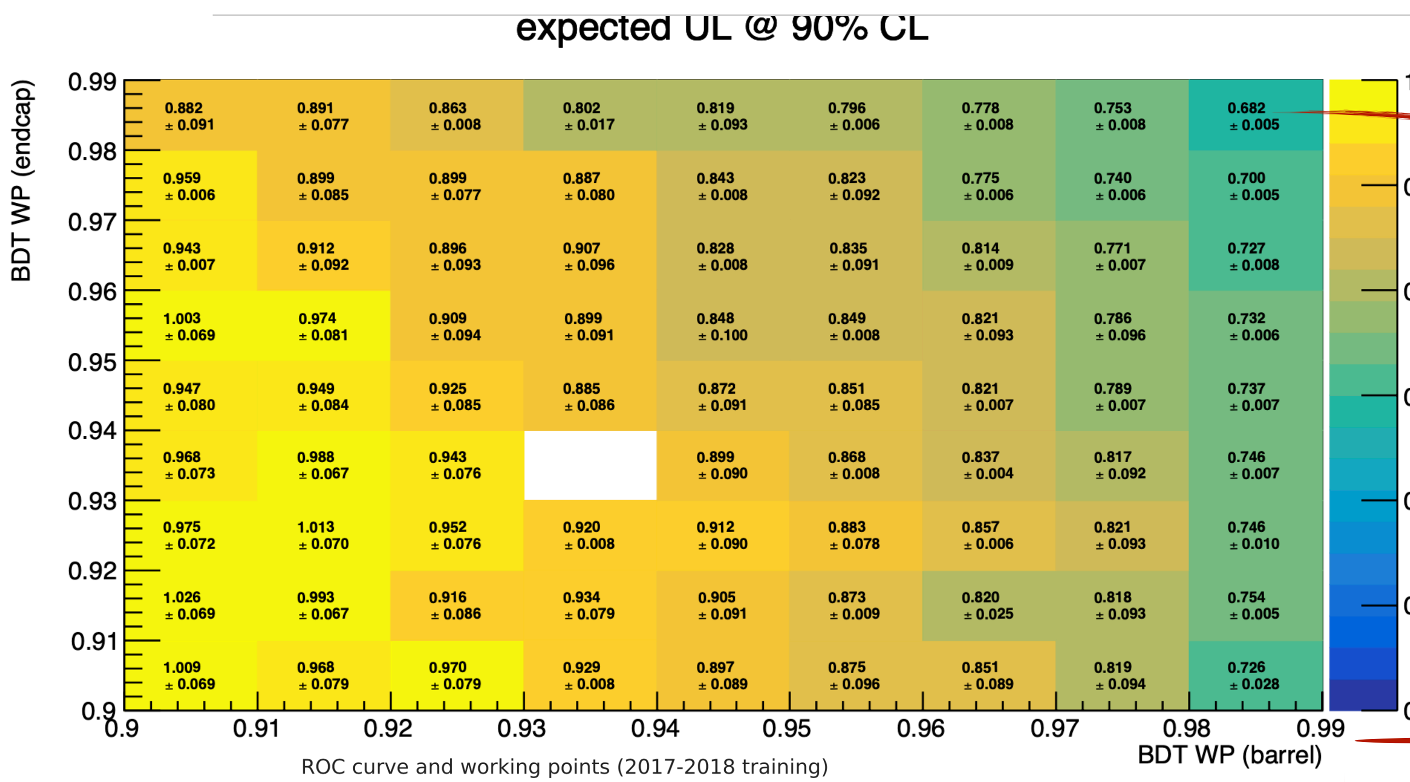
VARIABLES



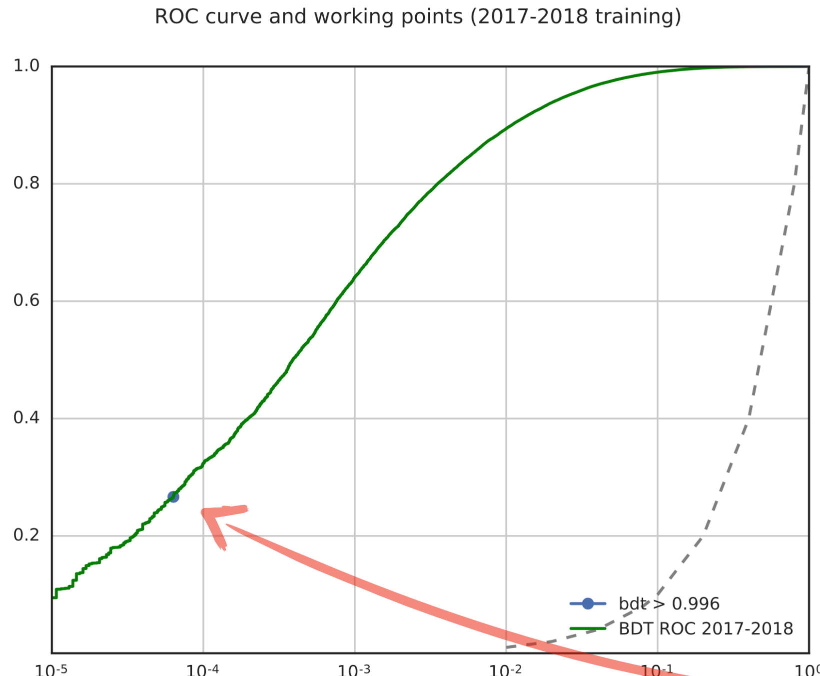
more in backup

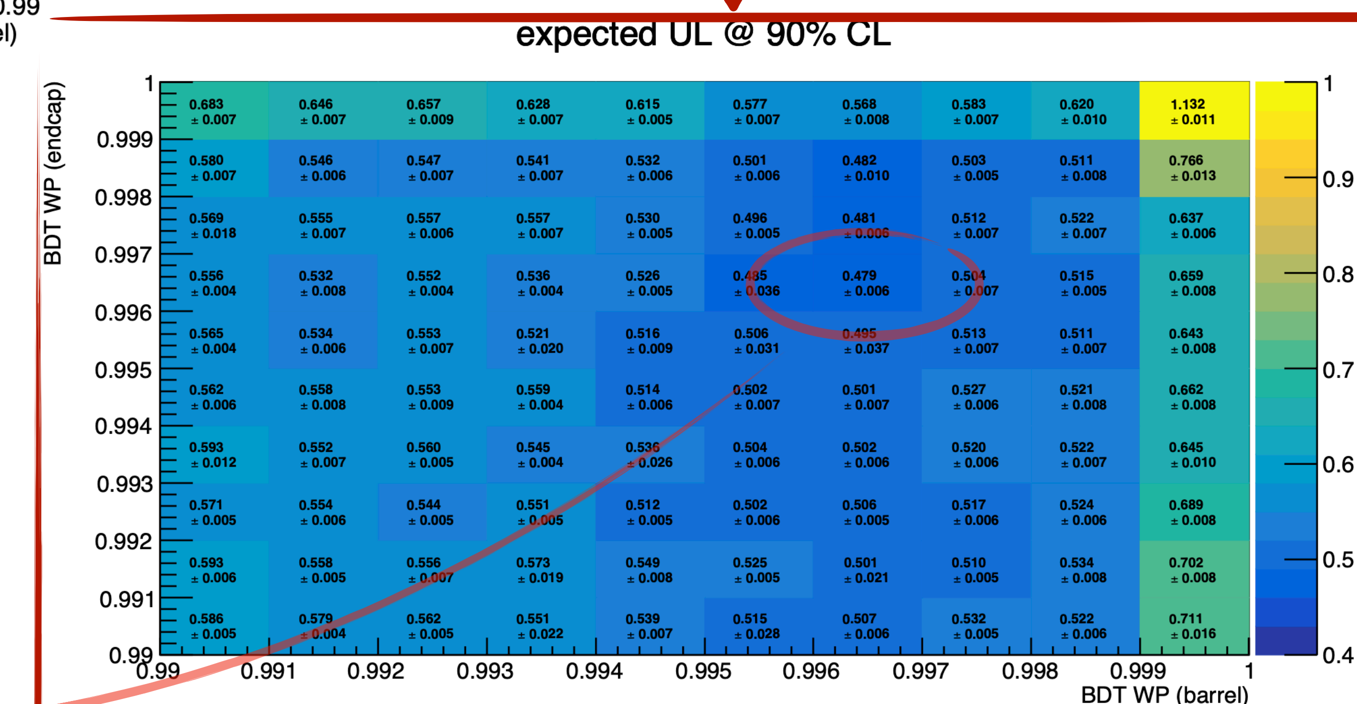
BDT DISCRIMINATOR

WORKING POINT OPTIMIZATION



WP is (0.996, 0.996)





BACKGROUND STUDIES

Possible background sources from di-muon resonance + muon/fake channels:

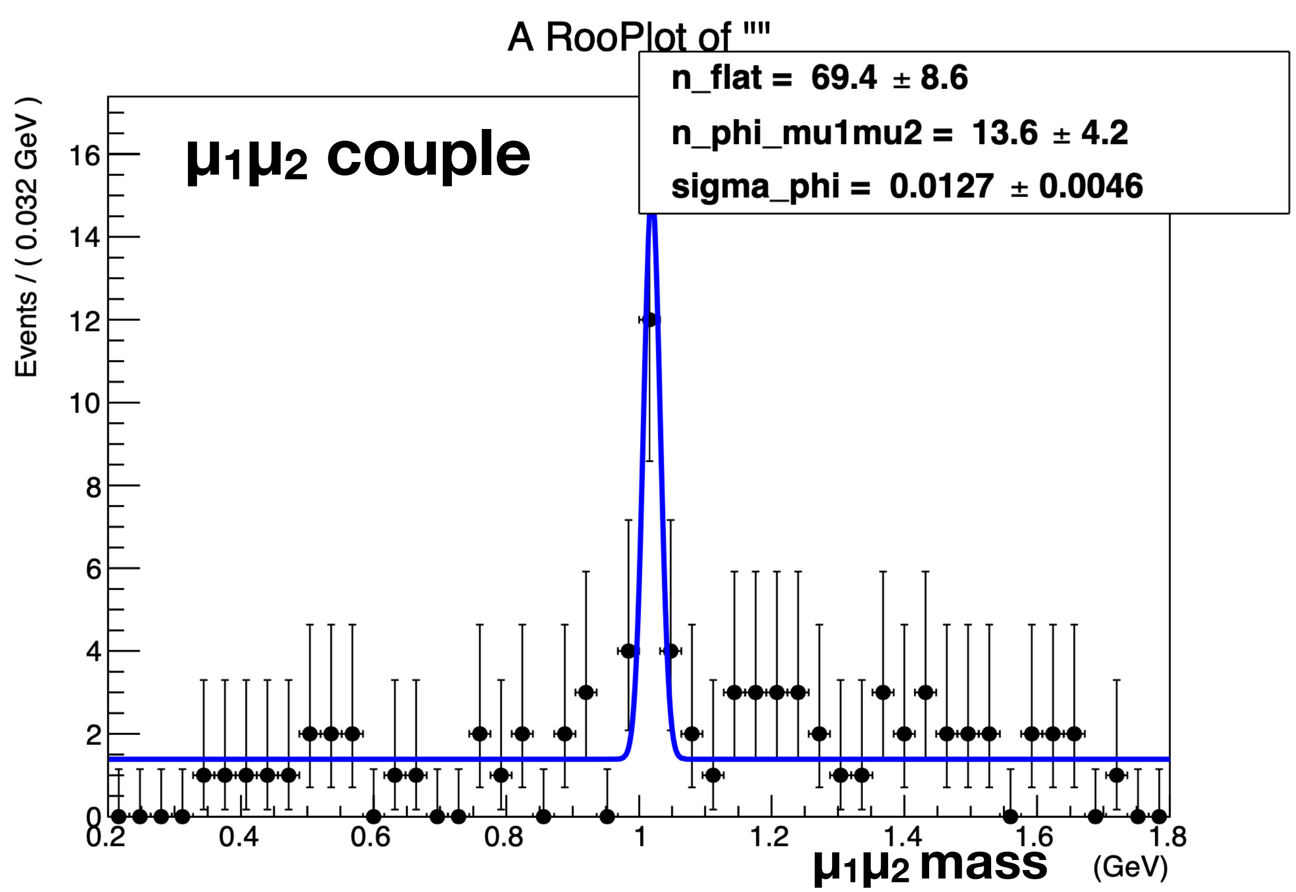
- di-muon resonant + random track
- from D^+ and Ds decays with a di-muon resonance + fake muon final state
  - e.g. $D^+(s) \rightarrow \phi(\mu\mu)\ \pi$
- from D → three-real-muons + undetected (through di-muon resonances)
  - $D^+(s) \rightarrow \phi(\mu\mu)\ \mu\nu$

Possible background sources are D → three-fake decays

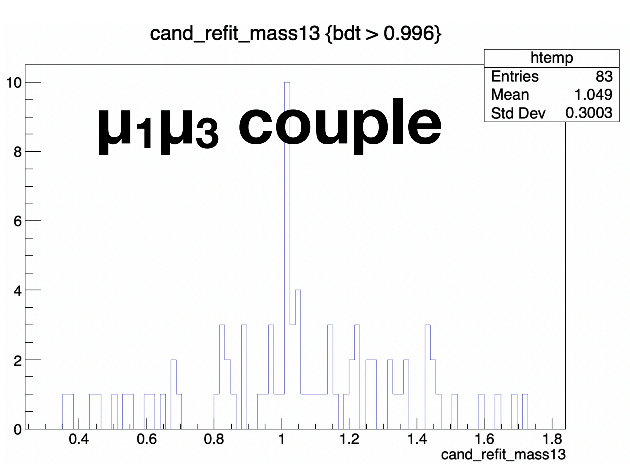
- e.g. $D \rightarrow KK\pi$

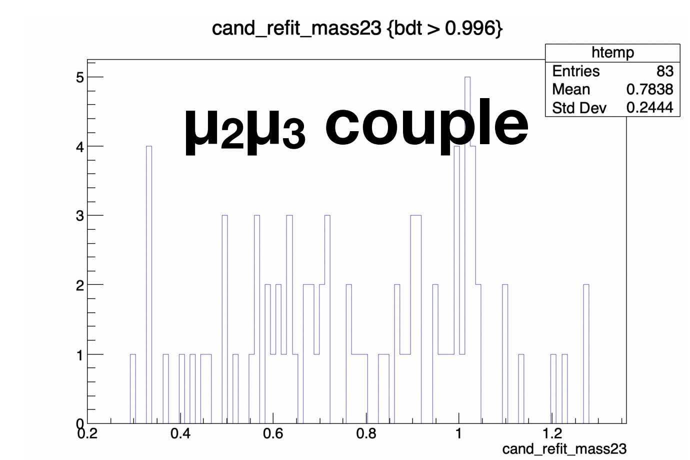
DI-MUON BACKGROUND

- Phi survives the BDT selections, need to veto the phi resonance
  - could be related to ϕ + random track, or $D^+(s)$ decays
  - 13 MeV width, can veto with a 20 MeV cut
  - expected limit improves with the phi meson veto



Expected limit ($\times 10^{-7}$) @ 90% CL
No veto: 0.56
ϕ veto: 0.48



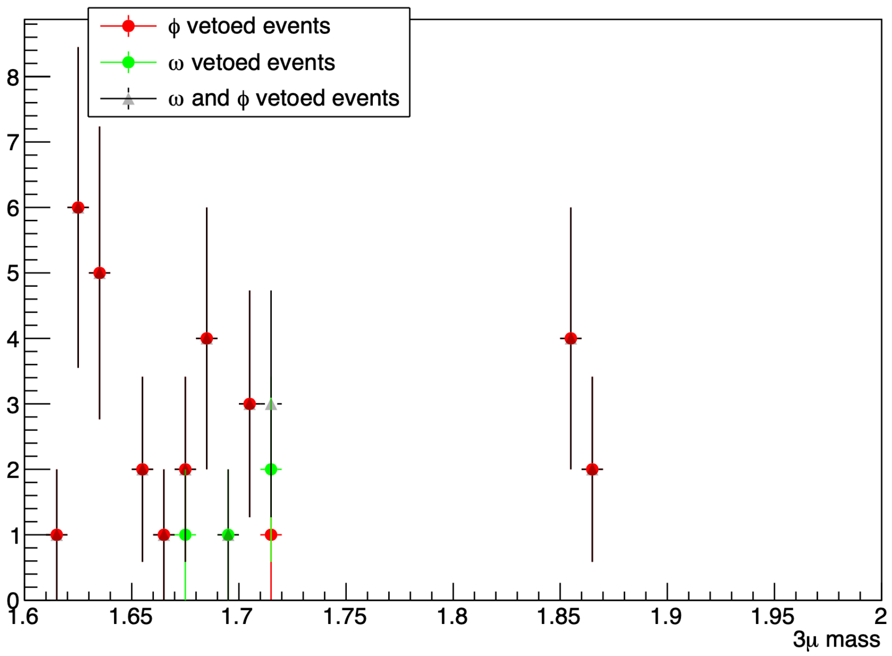


Expected D events in 90 fb^{-1}

fit to data

channel	After TM
Ds → ϕπ	4651
Ds → ωπ	248
Ds → ηπ	1757
D+ → ϕπ	1017
D+ → ωπ	62
D+ → ηπ	672

barrel - ϕ vetoed events



Branching ratios (from PDG)

- D+ → ϕπ 5.6 x 10^{-3}
- D+ → ωπ 3.4 x 10^{-4}
- D+ → ηπ 3.7 x 10^{-3}

- Ds → ϕπ 4.5 x 10^{-2}
- Ds → ωπ 2.4 x 10^{-3}
- Ds → ηπ 1.7 x 10^{-2}

No Ds → ϕπ in the final mass spectrum after the BDT selection

- Should not expect other channels too (comparable BDT efficiency)

THREE-FAKE BACKGROUND

Rough (over)estimation of Ds → three-fake background

- About 5000 Ds → $\phi(\mu\mu)$ π events in 90 fb^{-1} (trigger matched)
    - all events are most likely $\phi(\mu\mu)$ events, since the ϕ → KK is about 3 orders of magnitude more likely, but 10^{-5} suppressed by the mis-id
- About 5000 / 3 x 10^{-4} ($\phi \rightarrow \mu\mu$) / 4.5 x 10^{-2} (Ds → $\phi\pi$) Ds events in 90 fb^{-1} with one mis-id'ed track (trigger matched)
    - Less than 4 x 10^{+8} Ds → three-fake events in 90 fb^{-1} with one mis-id'ed track
- Additional 10^{-5} factor from the other two mis-id'ed tracks
- less than 2000 Ds → three-fake events trigger matched
    - assuming a BR for Ds → three-fake of order 50%
    - **less than Ds → $\phi\pi$ events**
    - same calculation on D^+ gives less than 3000 D^+ → three-fake events

D SEMILEPTONIC DECAYS

Leptonic decays

http://cds.cern.ch/record/2002363/files/CERN-THESIS-2015-021.pdf

D decay	$\mathcal{B}_1^{(*)}$	Secondary decay	$\mathcal{B}_2$	$\mathcal{B}_1 \times \mathcal{B}_2$	$\sigma(3\mu X)$
$\mathbf{D_s}$					
$\eta\mu\nu_\mu$	2.67×10^{-2}	$\eta \to \mu\mu$	5.8×10^{-6}	1.5×10^{-7}	0.03 nb
$\eta\mu\nu_\mu$	2.67×10^{-2}	$\eta \to \mu\mu\gamma$	3.1×10^{-4}	8.2×10^{-6}	1.5 nb
$\eta\mu\nu_\mu$	2.67×10^{-2}	$\eta \to \pi^0\mu\mu\gamma$	$< 3 \times 10^{-6}$	$< 8.0 \times 10^{-8}$	< 0.02 nb
$\eta'\mu\nu_\mu$	9.9×10^{-3}	$\eta' \to \mu\mu\gamma$	1.09×10^{-4}	1.1×10^{-6}	0.20 nb
$\phi\mu\nu_\mu$	2.49×10^{-2}	$\phi \to \mu\mu$	2.87×10^{-4}	7.1×10^{-6}	1.3 nb
$\phi\mu\nu_\mu$	2.49×10^{-2}	$\phi \to \mu\mu\gamma$	1.4×10^{-5}	3.5×10^{-7}	0.06 nb
$\phi\mu\nu_\mu$	2.49×10^{-2}	$\phi \to \mu\mu\pi^0$	$1.12 \times 10^{-5}(\dagger)$	2.8×10^{-7}	0.05 nb
$\mathbf{D^+}$					
$\eta\mu\nu_\mu$	1.14×10^{-3}	$\eta \to \mu\mu$	5.8×10^{-6}	6.6×10^{-9}	< 0.01 nb
$\eta\mu\nu_\mu$	1.14×10^{-3}	$\eta \to \mu\mu\gamma$	3.1×10^{-4}	3.5×10^{-7}	0.20 nb
$\eta\mu\nu_\mu$	1.14×10^{-3}	$\eta \to \pi^0\mu\mu\gamma$	$< 3 \times 10^{-6}$	$< 3.4 \times 10^{-9}$	< 0.0[illegible] nb
$\eta'\mu\nu_\mu$	2.2×10^{-4}	$\eta' \to \mu\mu\gamma$	1.09×10^{-4}	2.4×10^{-8}	0.01 nb
$\omega\mu\nu_\mu$	1.6×10^{-3}	$\omega \to \mu\mu$	9.0×10^{-5}	1.4×10^{-7}	0.09 nb
$\omega\mu\nu_\mu$	1.6×10^{-3}	$\omega \to \mu\mu\pi^0$	1.3×10^{-4}	2.1×10^{-7}	0.13 nb
$\rho^0\mu\nu_\mu$	2.4×10^{-3}	$\rho^0 \to \mu\mu$	4.55×10^{-5}	1.1×10^{-7}	0.07 nb
$\phi\mu\nu_\mu$	$< 9 \times 10^{-5}$	$\phi \to \mu\mu$	2.87×10^{-4}	2.6×10^{-8}	0.02 nb

$(*)$: given branching ratios are from corresponding $e\nu_e$ decays

$(\dagger)$: given branching ratio is from $\phi \to e^+e^-\pi^0$ decays

LHCb numbers

- as in previous slide none of these is resonant, due to neutrinos → non peaking

Cannot make quantitative consideration as done for Ds → ϕπ

All the decays driven by pure di-muon resonances can be excluded (no di-muon resonances after the BDT but for ϕ meson -veoted-)

Anyway, the presence of one or more undetected particles makes the 3μ mass spectrum non-peaking

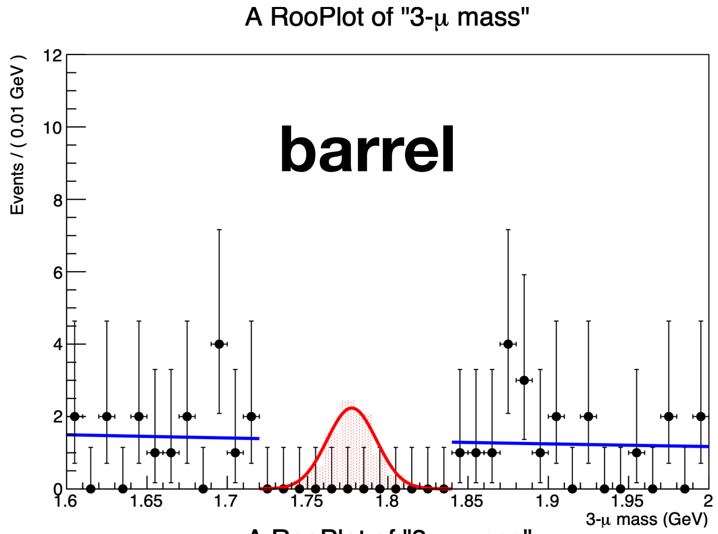
EXPECTED LIMIT

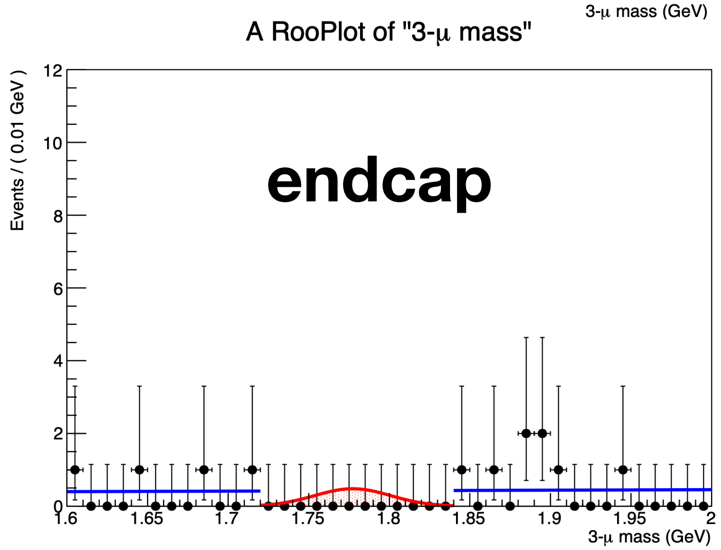
- Extracted with unbinned ML fit to the 3μ mass distribution
- using combine tool (HybridNew with LHC statistics)
- signal region is blinded (1.72-1.84 GeV)

exp. 0.16 BR(Tau3Mu) < 0.35 x 10^{-7} @ 90% CL
exp. 0.50 BR(Tau3Mu) < 0.48 x 10^{-7} @ 90% CL
exp. 0.84 BR(Tau3Mu) < 0.73 x 10^{-7} @ 90% CL

Expected from 2016 (lumi scaled without SFs):
1.3 x 0.81 / sqrt(3) = 0.61 x 10^{-7} @ 90% CL

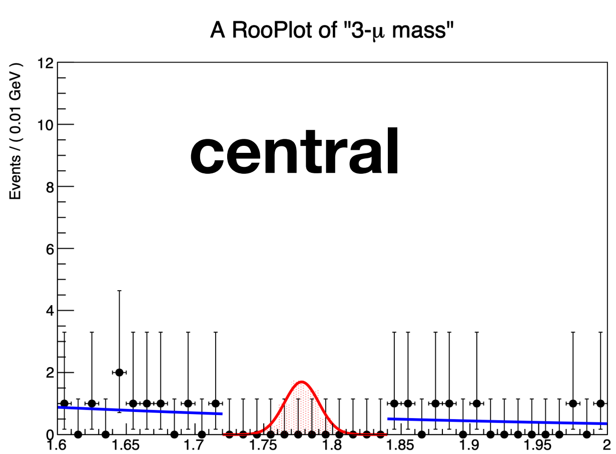
2016 expected limit
2016 average scale factor
luminosity factor

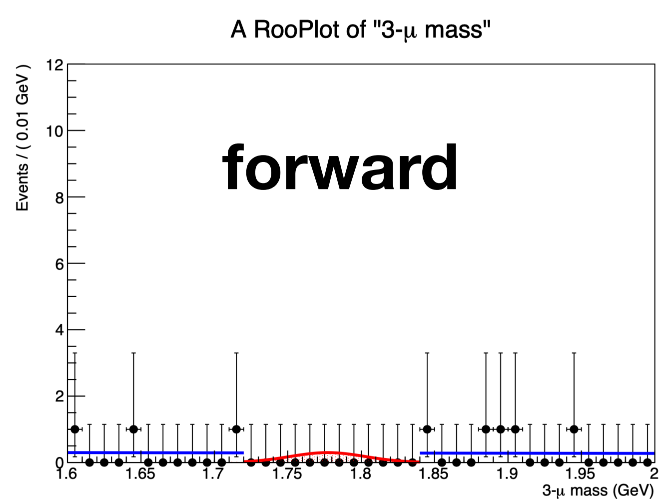


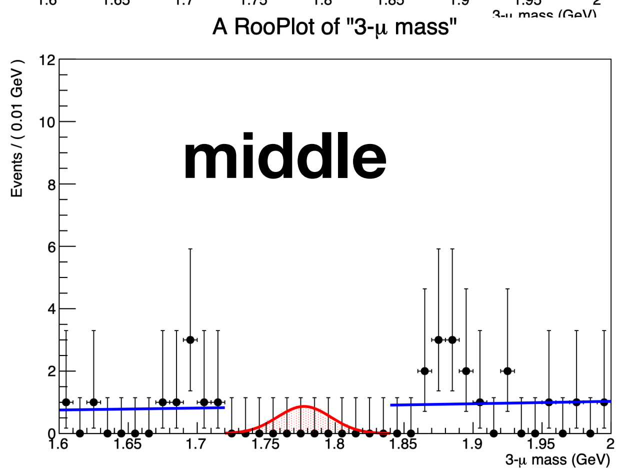


New event categories

- So far events have been categorized as barrel or endcap (cut at eta 1.6).
- Could find a better definition, based on the mass resolution
  - mass resolution seems to have a change point at eta = 1, eta 1.8
  - three categories are defined (not yet optimized): central, middle, forward

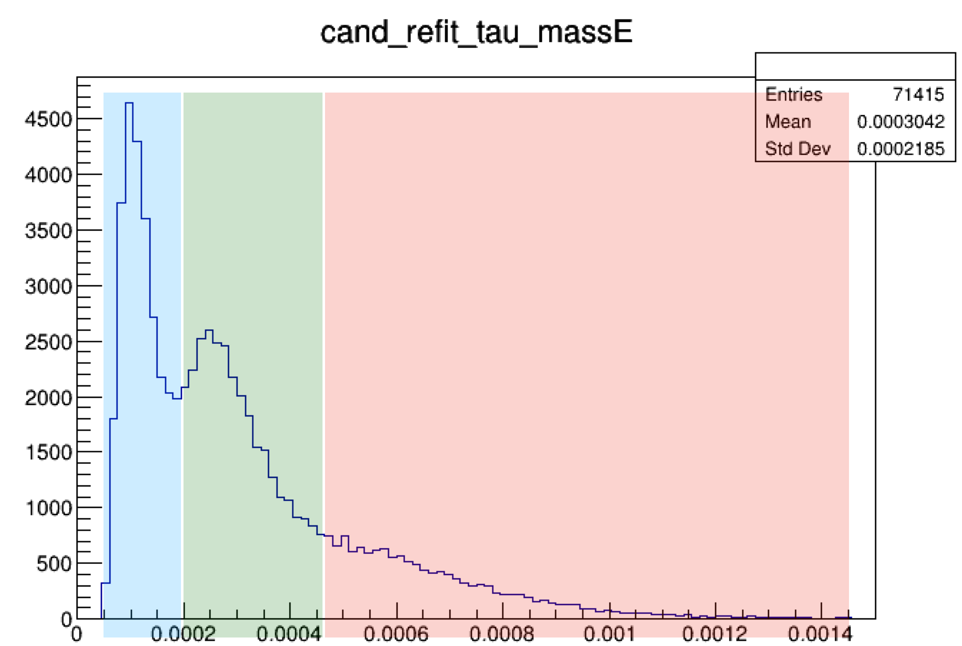






BR < 0.44
@ 90%CL
(+10% sensitivity)

|η| < 1
1 < |η| <1.8
|η| > 1.8



Coordination between the W and D/B channels

- Analysis is carried out in two different channels ($W \to \tau\nu$ and $D/B \to \tau\nu X$) by two different analysis groups
- Full potentiality of CMS is exploited by the statistical combination of the two
- This is done through the *combine* tool, efforts are being made in this direction
- The synchronization of the analysis has started to ensure:
  - common reco dataset
  - analysis milestones (AN, pre-approvals, etc.)
  - combination as done in 2016 (combine)
- Ideally: aim to Moriond 2021
- $\tau \to 3\mu$ analysis is a flagship for Belle II, this period is a window of opportunity for CMS to obtain a competitive result

TODO and conclusions

Ongoing studies

- study of the BDT efficiency vs. the tau mass
- MC Ultra Legacy performance study

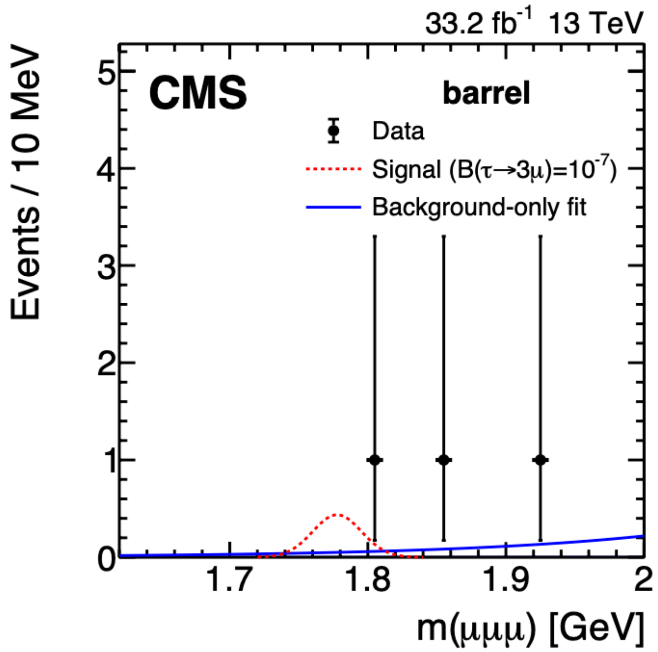
TODO

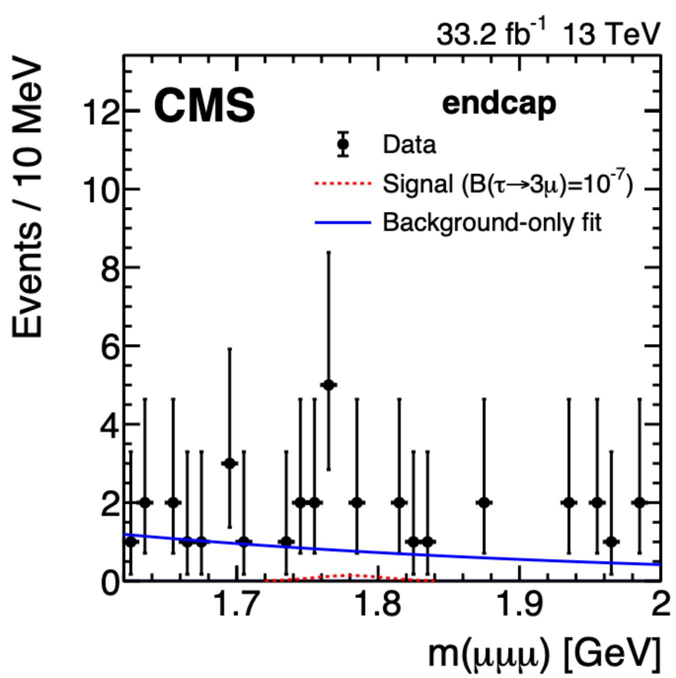
- trigger and offline muon ID efficiencies and scale factors

Results on 2016 dataset (W channel)

No evidence of τ → 3μ signal was found, an upper limit was set

- the observed (expected) upper limit at 90% CL is BR(τ → 3μ) < 2.0 (1.4) · 10^{-7}





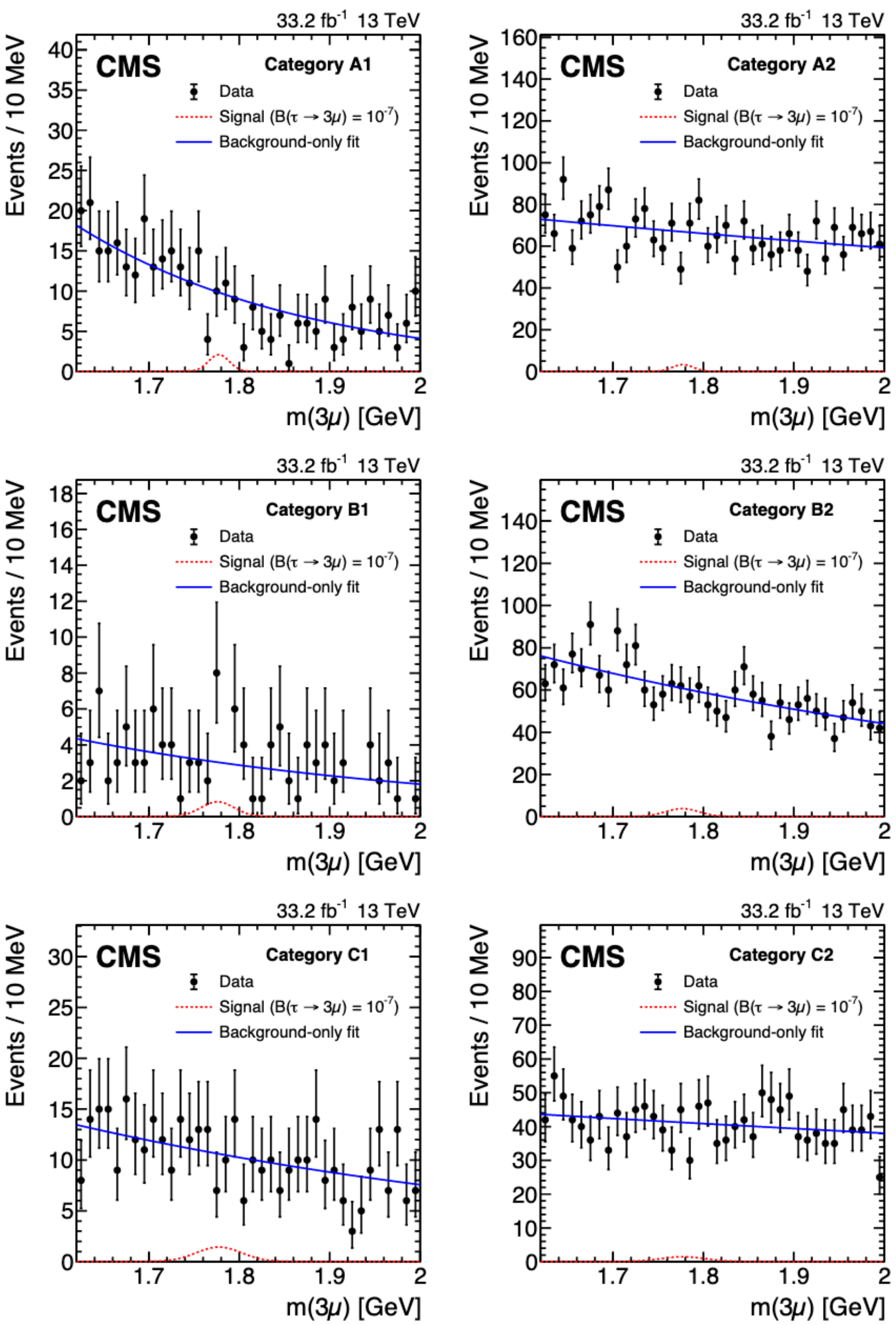
Expected	Prefit $\mathcal{B}(\tau \to 3\mu) = 10^{-7}$		B only Fit		S+B Fit	
	barrel	endcap	barrel	endcap	barrel	endcap
Signal	2.0 ± 0.2	0.9 ± 0.1	-	-	0.6 ± 1.1	0.3 ± 0.6
Background	3.1	30.6	3.0 ± 1.8	37.0 ± 6.5	2.6 ± 1.8	36.5 ± 6.3

Observed	barrel	endcap
	3	37

Results on 2016 dataset (D/B channel)

No evidence of τ → 3μ signal was found, an upper limit was set

- the observed (expected) upper limit at 90% CL is BR(τ → 3μ) < 9.2 (10.0) · 10^{-8}



Combined result

- the observed (expected) upper limit at 90% CL is BR(τ → 3μ) < 8.0 (6.9) · 10^{-8}

Other tasks and CFU

Conferences

- selected for the talk *Search for τ→3μ decay in CMS with the 2016 dataset and combining tau leptons produced in B, D and W decays* at the YSF section of Moriond 2020 (cancelled due to covid-19 pandemic)

Schools in 2019-20

- PRecision Electroweak Field Theory (PREFIT) school at DESY

Work for the CMS collaboration

- Beamspot online monitoring (Ultra Legacy 2017)
- Maintenance and updating of tau reconstruction/identification software in CMSSW

Obtained 8 CFU in total

- CMS DAS school (Pisa) report (2 CFU) (2018-19)
- Introduction to statistics with R (part I): data description and basic inference (2 CFU) (2018-19)
- Machine learning course (1 CFU) (2018-19)
- Introduction to C++ (2 CFU) (2019-20)
- Introduction to python programming (1 CFU) (2019-20)

Backup

THREE-FAKE BACKGROUND

Rough (over)estimation of Ds → three-fake background

- About 5000 Ds → $\phi(\mu\mu)\,\pi$ events in 90 fb^{-1} (trigger matched)
  - all events are most likely $\phi(\mu\mu)$ events, since the $\phi \to KK$ is about 3 orders of magnitude more likely, but 10^{-5} suppressed by the mis-id
- About 5000 / 3 x 10^{-4} ($\phi \to \mu\mu$) / 4.5 x 10^{-2} (Ds → $\phi\pi$) Ds events in 90 fb^{-1} with one mis-id'ed track (trigger matched)
  - Less than 4 x 10^{+8} Ds → three-fake events in 90 fb^{-1} with one mis-id'ed track
- Additional 10^{-5} factor from the other two mis-id'ed tracks
- less than 2000 Ds → three-fake events trigger matched
  - assuming a BR for Ds → three-fake of order 50%
  - **less than Ds → $\phi\pi$ events**
  - same calculation on D^+ gives less than 3000 D^+ → three-fake events

D semileptonic decays

Leptonic decays

http://cds.cern.ch/record/2002363/files/CERN-THESIS-2015-021.pdf

D decay	$\mathcal{B}_1^{(*)}$	Secondary decay	$\mathcal{B}_2$	$\mathcal{B}_1 \times \mathcal{B}_2$	$\sigma(3\mu X)$
$\mathbf{D_s}$					
$\eta\mu\nu_\mu$	2.67×10^{-2}	$\eta \to \mu\mu$	5.8×10^{-6}	1.5×10^{-7}	0.03 nb
$\eta\mu\nu_\mu$	2.67×10^{-2}	$\eta \to \mu\mu\gamma$	3.1×10^{-4}	8.2×10^{-6}	1.5 nb
$\eta\mu\nu_\mu$	2.67×10^{-2}	$\eta \to \pi^0\mu\mu\gamma$	$< 3 \times 10^{-6}$	$< 8.0 \times 10^{-8}$	< 0.02 nb
$\eta'\mu\nu_\mu$	9.9×10^{-3}	$\eta' \to \mu\mu\gamma$	1.09×10^{-4}	1.1×10^{-6}	0.20 nb
$\phi\mu\nu_\mu$	2.49×10^{-2}	$\phi \to \mu\mu$	2.87×10^{-4}	7.1×10^{-6}	1.3 nb
$\phi\mu\nu_\mu$	2.49×10^{-2}	$\phi \to \mu\mu\gamma$	1.4×10^{-5}	3.5×10^{-7}	0.06 nb
$\phi\mu\nu_\mu$	2.49×10^{-2}	$\phi \to \mu\mu\pi^0$	$1.12 \times 10^{-5}(\dagger)$	2.8×10^{-7}	0.05 nb
$\mathbf{D^+}$					
$\eta\mu\nu_\mu$	1.14×10^{-3}	$\eta \to \mu\mu$	5.8×10^{-6}	6.6×10^{-9}	< 0.01 nb
$\eta\mu\nu_\mu$	1.14×10^{-3}	$\eta \to \mu\mu\gamma$	3.1×10^{-4}	3.5×10^{-7}	0.20 nb
$\eta\mu\nu_\mu$	1.14×10^{-3}	$\eta \to \pi^0\mu\mu\gamma$	$< 3 \times 10^{-6}$	$< 3.4 \times 10^{-9}$	< 0.0[illegible] nb
$\eta'\mu\nu_\mu$	2.2×10^{-4}	$\eta' \to \mu\mu\gamma$	1.09×10^{-4}	2.4×10^{-8}	0.01 nb
$\omega\mu\nu_\mu$	1.6×10^{-3}	$\omega \to \mu\mu$	9.0×10^{-5}	1.4×10^{-7}	0.09 nb
$\omega\mu\nu_\mu$	1.6×10^{-3}	$\omega \to \mu\mu\pi^0$	1.3×10^{-4}	2.1×10^{-7}	0.13 nb
$\rho^0\mu\nu_\mu$	2.4×10^{-3}	$\rho^0 \to \mu\mu$	4.55×10^{-5}	1.1×10^{-7}	0.07 nb
$\phi\mu\nu_\mu$	$< 9 \times 10^{-5}$	$\phi \to \mu\mu$	2.87×10^{-4}	2.6×10^{-8}	0.02 nb

$(*)$: given branching ratios are from corresponding $e\nu_e$ decays

$(\dagger)$: given branching ratio is from $\phi \to e^+e^-\pi^0$ decays

LHCb numbers

- as in previous slide none of these is resonant, due to neutrinos → non peaking

Cannot make quantitative consideration as done for Ds → ϕπ

All the decays driven by pure di-muon resonances can be excluded (no di-muon resonances after the BDT but for ϕ meson -veoted-)

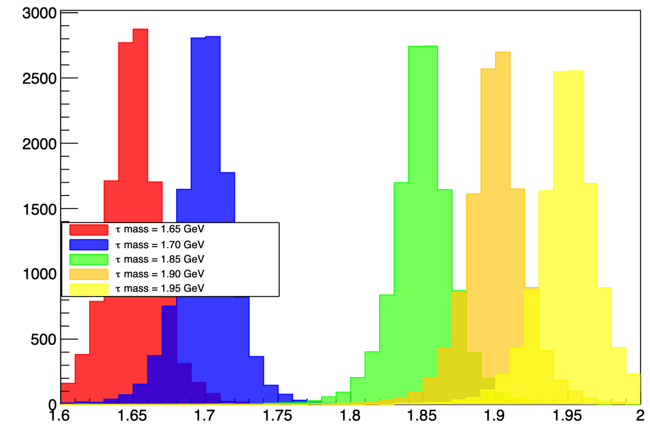
Anyway, the presence of one or more undetected particles makes the 3μ mass spectrum non-peaking

Riccardo Manzoni - ETHZ

MC production 2017-2018

MC is used to train the BDT

- **2016**: 20k events produced via MadGraph (2HDM)
- **2017-2018**: 800k events produced con Pythia (phase space), private production
    - asked a central production of 1 M events under the Ultra Legacy conditions (phase space)
- asked the central production of 1M events under the 2HDM model
    - compare phase space of the two montecarlo samples
- also producing 500k events with a shifted tau lepton mass value for BDT training purpose

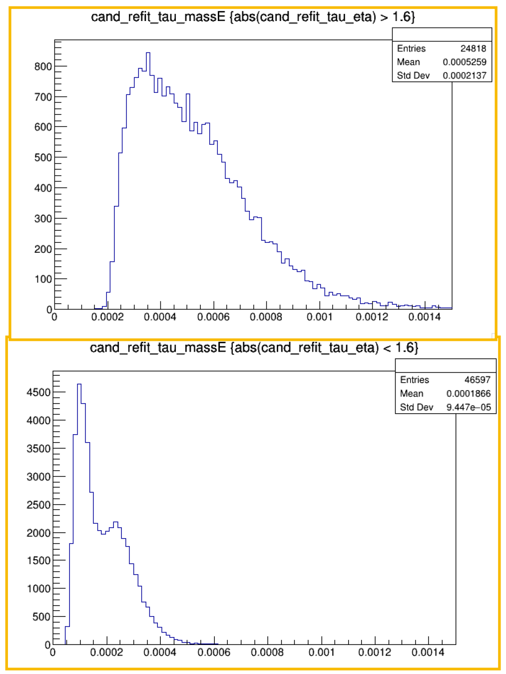


SYSTEMATICS (W CHANNEL, 2016)

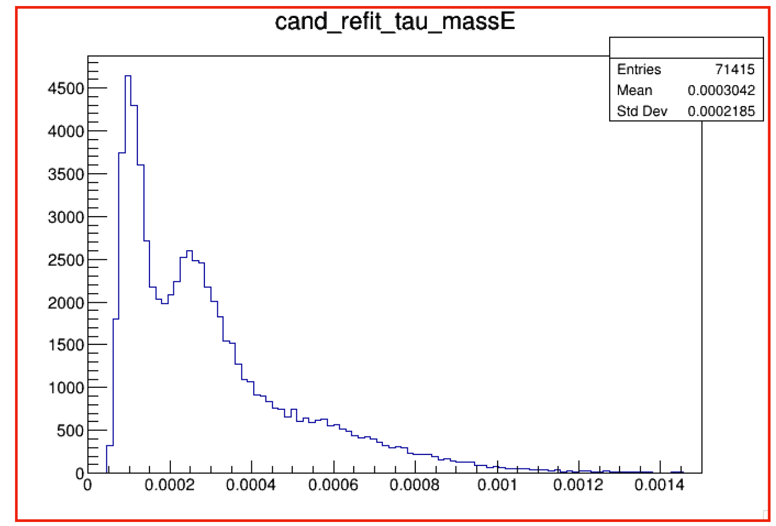
	Uncertainty (%)	
Source	Barrel	Endcap
Signal efficiency	7.9	32
Limited size of simulated samples	4.3	6.2
Integrated luminosity	2.5	2.5
$pp \to W$ cross section	2.9	2.9
$\mathcal{B}(W \to \mu\nu)$	0.2	0.2
$\mathcal{B}(W \to \tau\nu)$	0.2	0.2

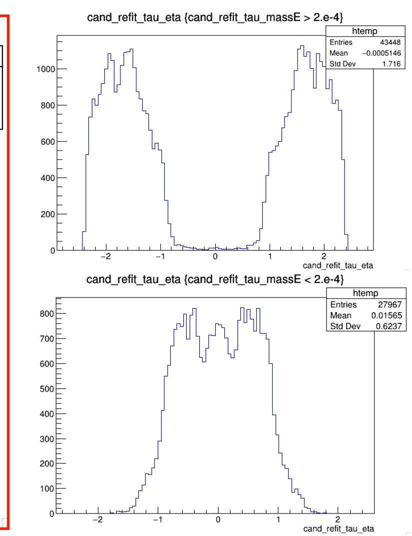
EXPECTED LIMIT - NEW BARREL-ENDCAP DEFINITION

barrel definition |eta| < 1.6



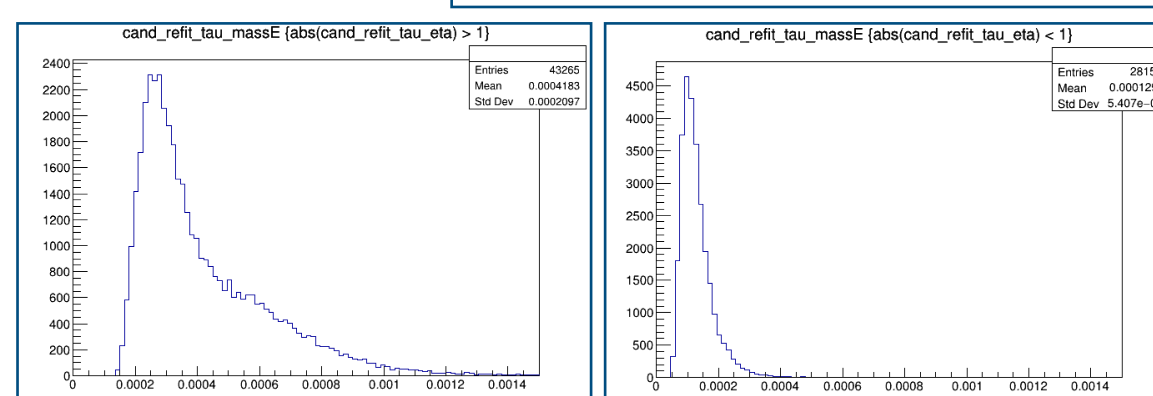
- Currently splitting barrel-endcap at |η| = 1.6
- Mass resolution can be used to define a better event categorization
- |η| = 1 seems a better slitting point





mass resolution after refit

barrel definition |eta| < 1.0



Data samples

Dataset DoubleMuLowMass MINIAOD

2017 data (30.45 fb^{-1})

- /DoubleMuonLowMass/Run2017#-31Mar2018-v*/MINIAOD
  - # = C, D, E, F
  - *Collisions17/13TeV/ReReco/Cert_294927-306462_13TeV_EOY2017ReReco_Collisions17_JSON_v1.txt*
  - trigger attivo da run 301046
  - possibile recuperare run B e C con trigger 2016 (~ 11 fb^{-1})

2018 data (59.71 fb^{-1})

- /DoubleMuonLowMass/Run2018#-17Sep2018-v*/MINIAOD
  - # = A, B, C
- /DoubleMuonLowMass/Run2018D-PromptReco-v2/MINIAOD
- *Collisions18/13TeV/PromptReco/Cert_314472-325175_13TeV_PromptReco_Collisions18_JSON.txt*

High Level Trigger

HLT 2016

HLT_DoubleMu3_Track_Tau3Mu

two muons

- $pT(\mu) > 3$ GeV, $pT(\mu\mu) > 6$ GeV
- $|\eta| < 2.5$
- massa invariante in (0.5, 1.7) GeV
- CL vertice > 0.01
- $\Delta R(\mu 1,\mu 2) < 0.6$
- $L/\sigma > 1$
- $\cos(\alpha) > 0$

one track

- $pT > 1.2$ GeV
- $|\eta| < 2.5$
- χ^2 vertice < 8

muons + track

- $pT > 8$ GeV
- $L/\sigma > 2$,
- $\cos(\alpha) > 0.9$
- massa invariante in (1.6, 2.02) GeV

L1_DoubleMu0er1p5_SQ_OS_dR_Max1p4

L1_TripleMu_5_3_0_DoubleMu_5_3_OS_Mass_Max17

HLT 2017-2018 (W)

HLT_Tau3Mu_Mu7_Mu1_TkMu1_IsoTau15

Tre muoni

- $pT(\mu_1) > 7$ GeV, $pT(\mu_{2,3}) > 1$GeV
- massa invariante τ in (0.5, 1.7) GeV
- $|\eta|_\tau < 2.5$
- **$pT_\tau > 15$ GeV**
- $\Delta R_{3\mu} < 0.3$
- **$Iso_\tau^{REL} < 0.2$**

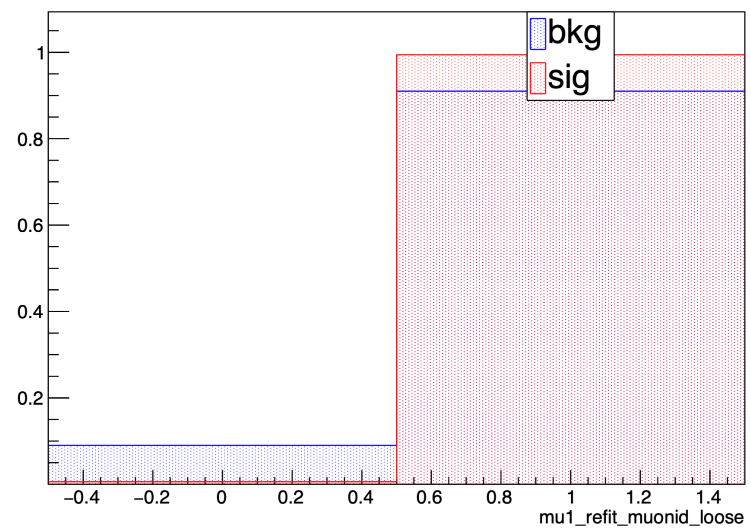
L1_DoubleMu_10_1_Q12_maxMass4p0

$$I^{abs} = \sum p^{charged}(d_z < 0.2\text{ cm}) + \max(0, \sum p^{\gamma} - \Delta\beta \sum p^{charged}(d_z > 0.2\text{ cm}))$$

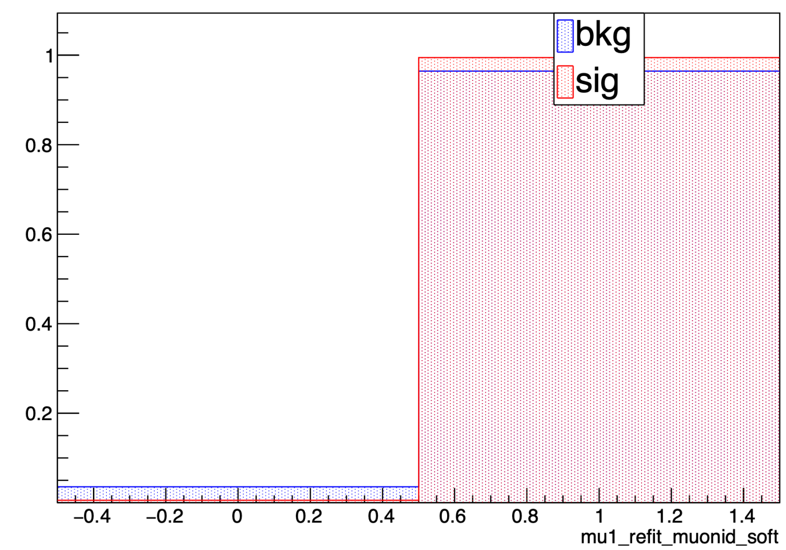
$$I^{rel} = I^{abs}/p_T^{\tau}$$

BDT VARIABLES

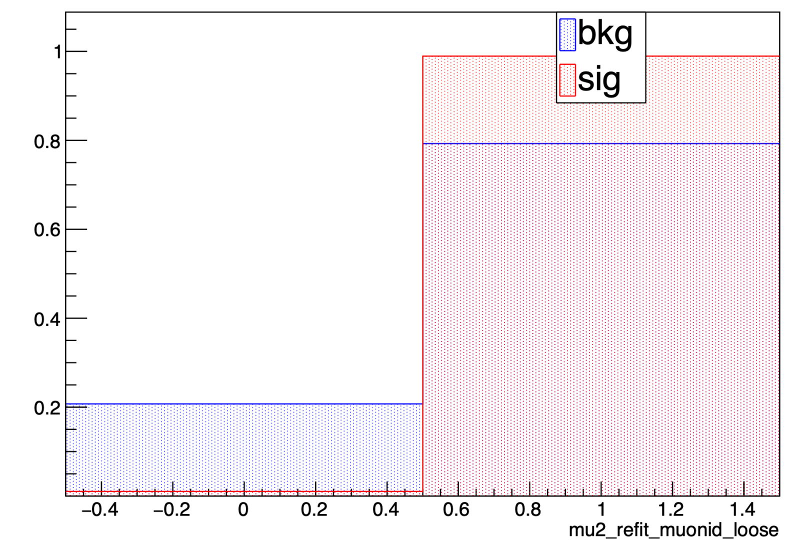
mu1_refit_muonid_loose



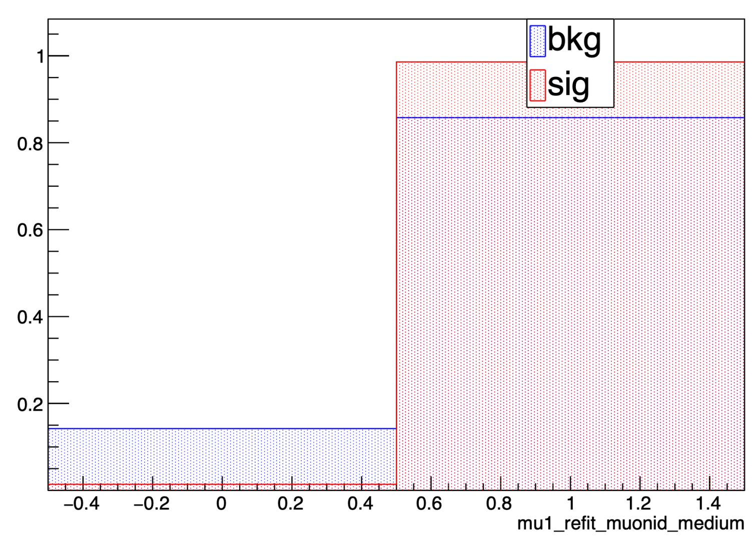
mu1_refit_muonid_soft



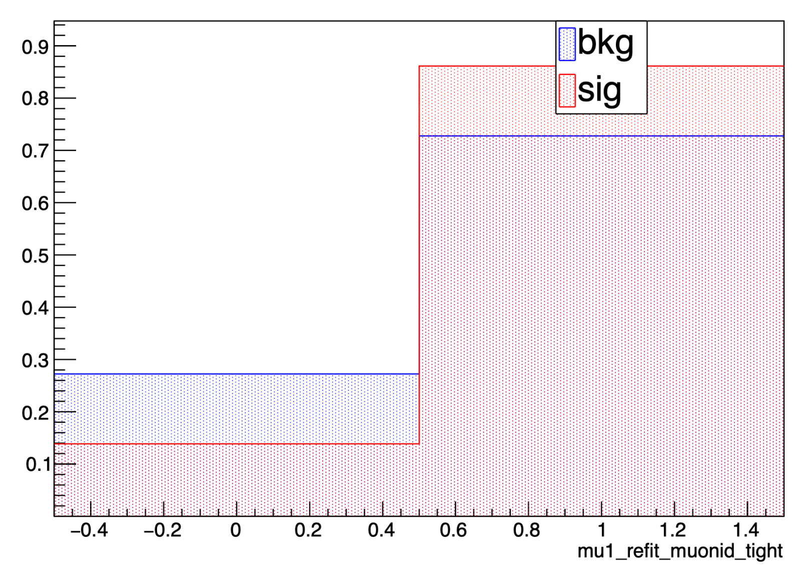
mu2_refit_muonid_loose



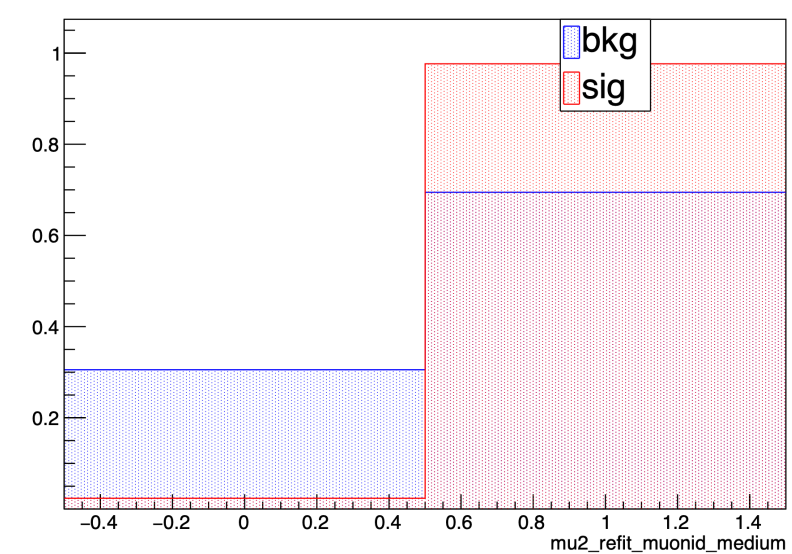
mu1_refit_muonid_medium



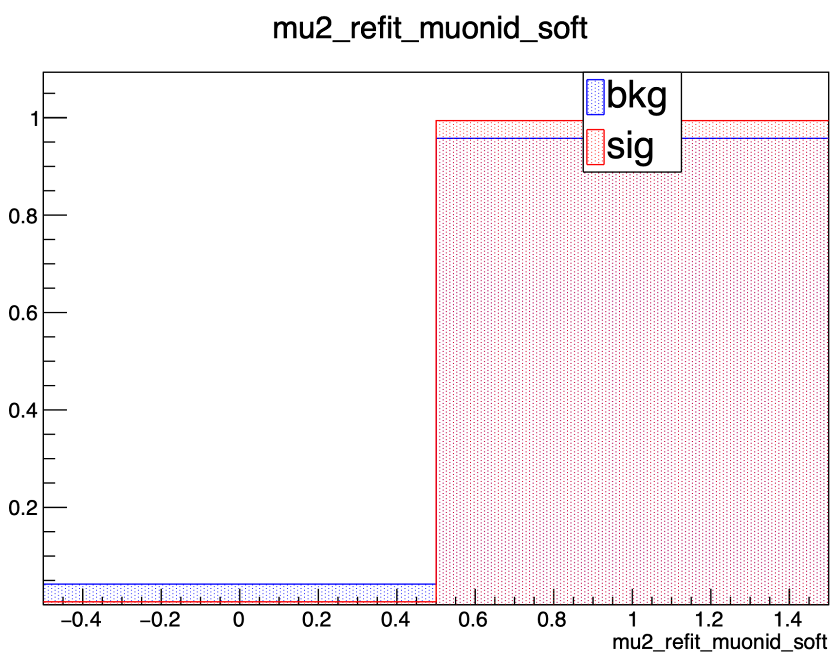
mu1_refit_muonid_tight

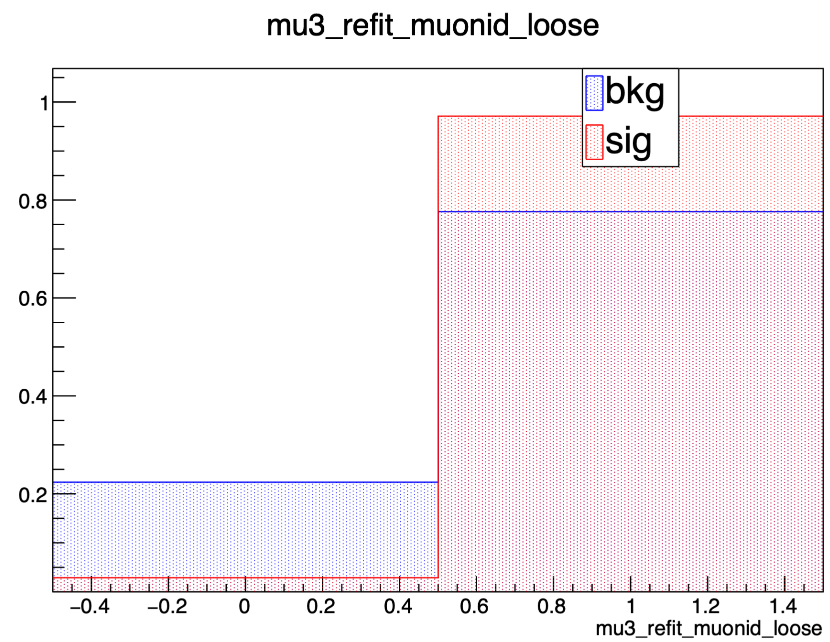


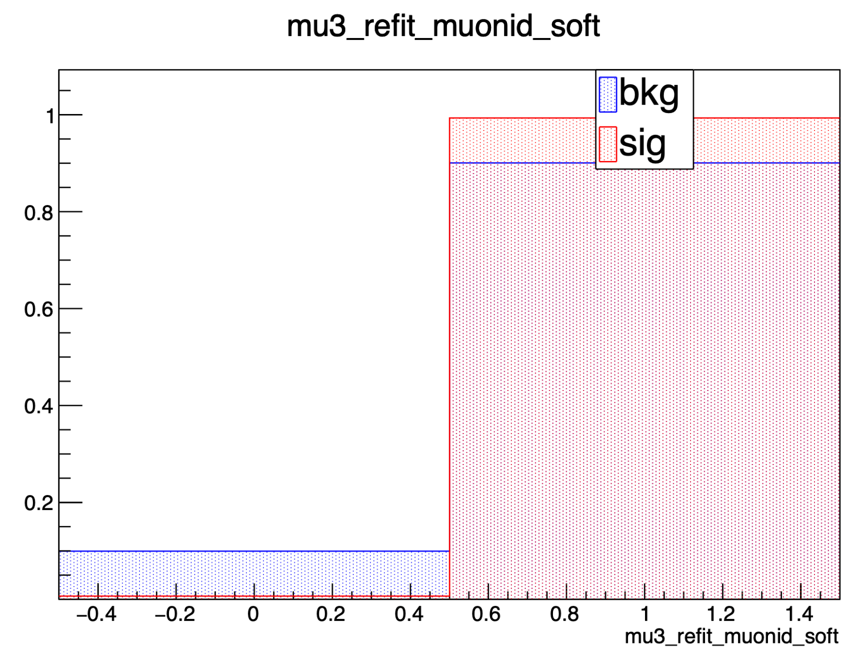
mu2_refit_muonid_medium

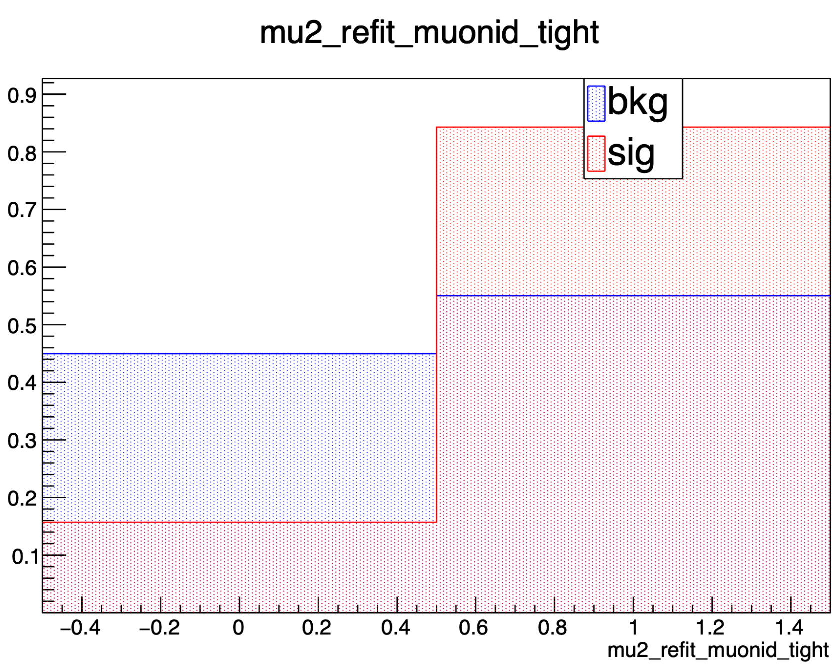


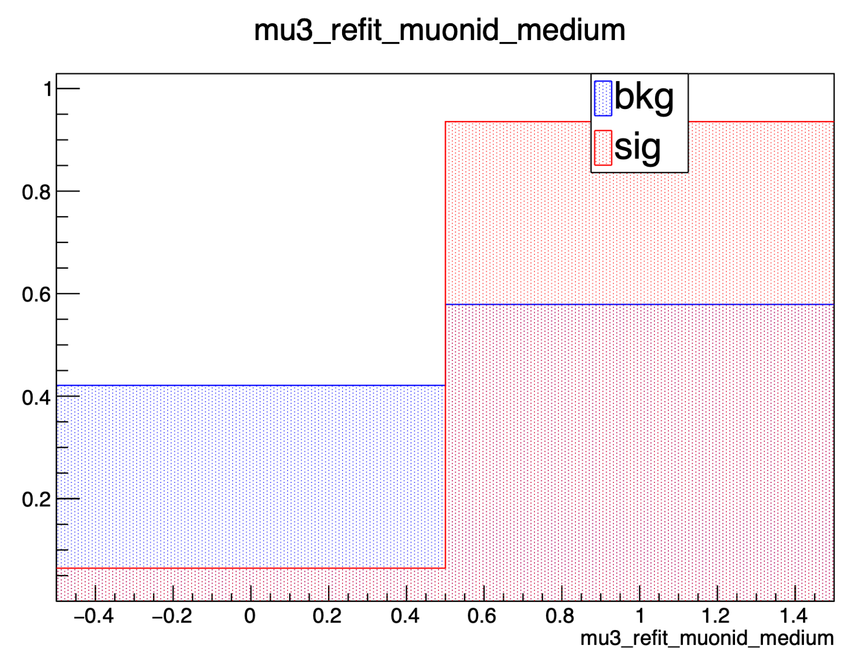
BDT variables

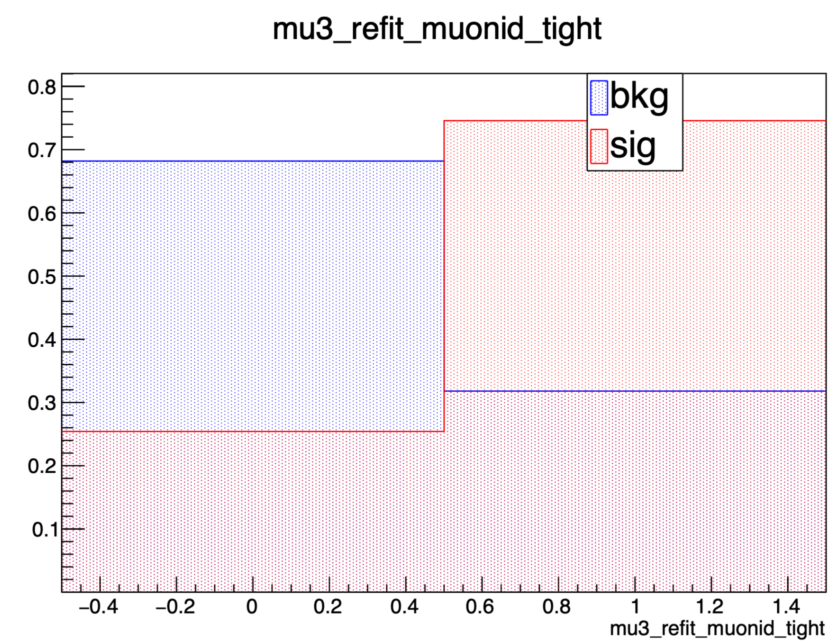




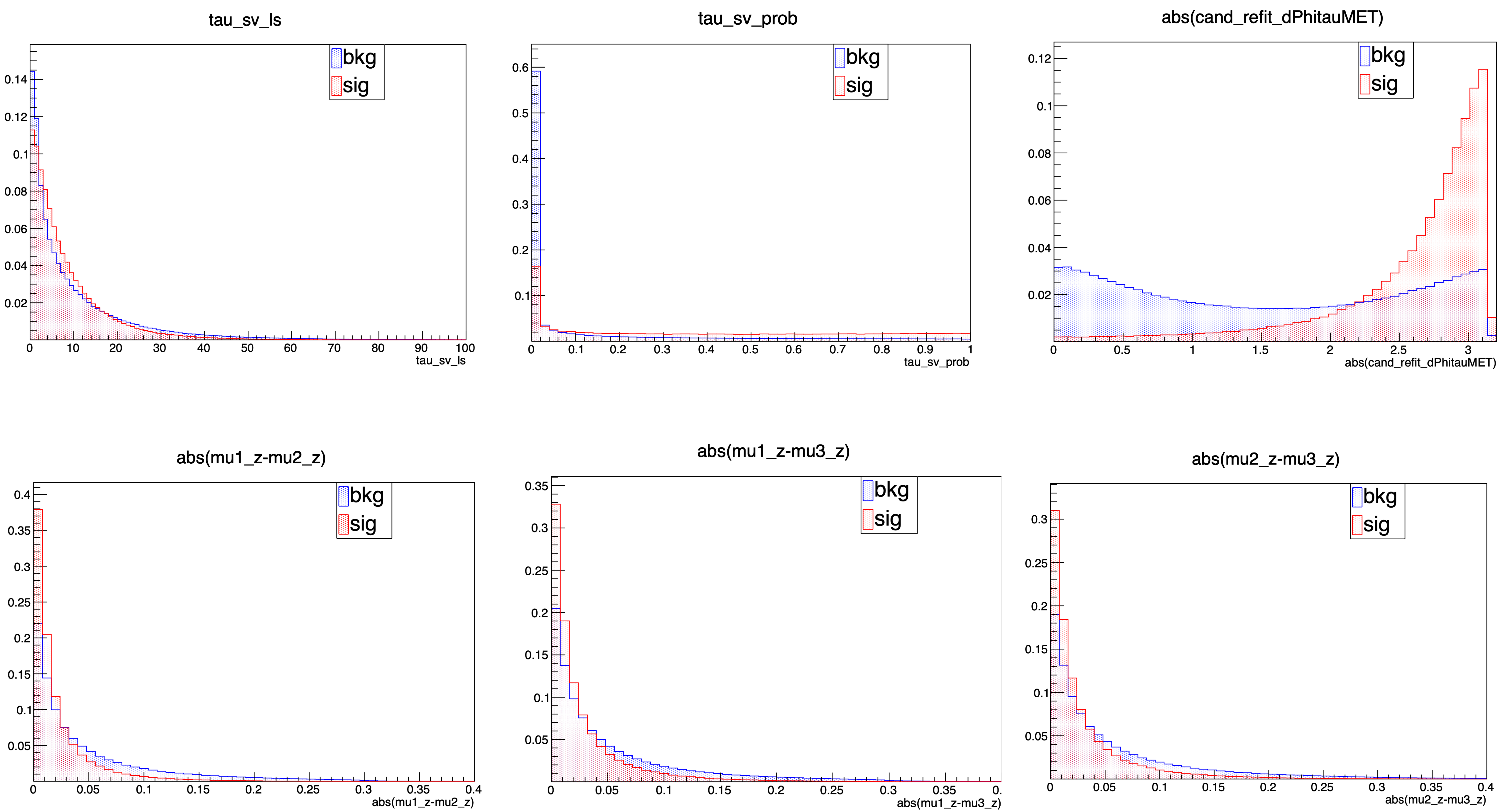




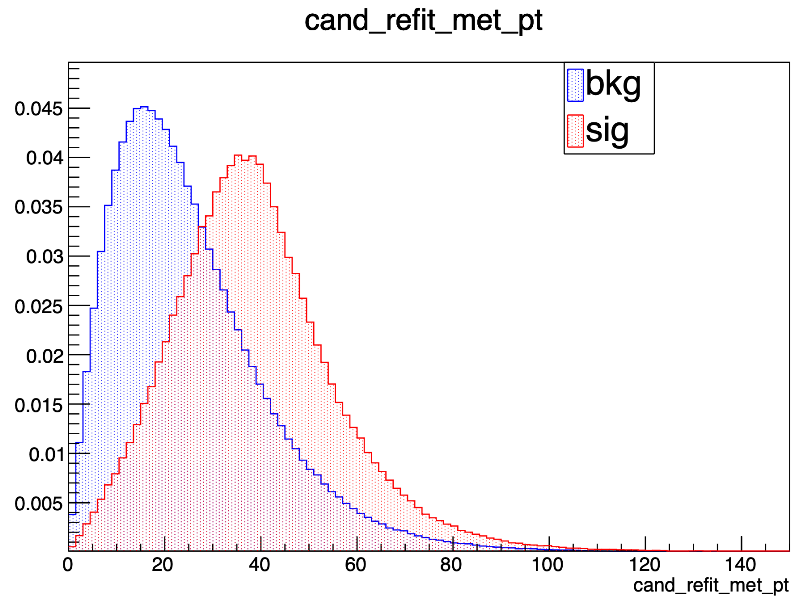


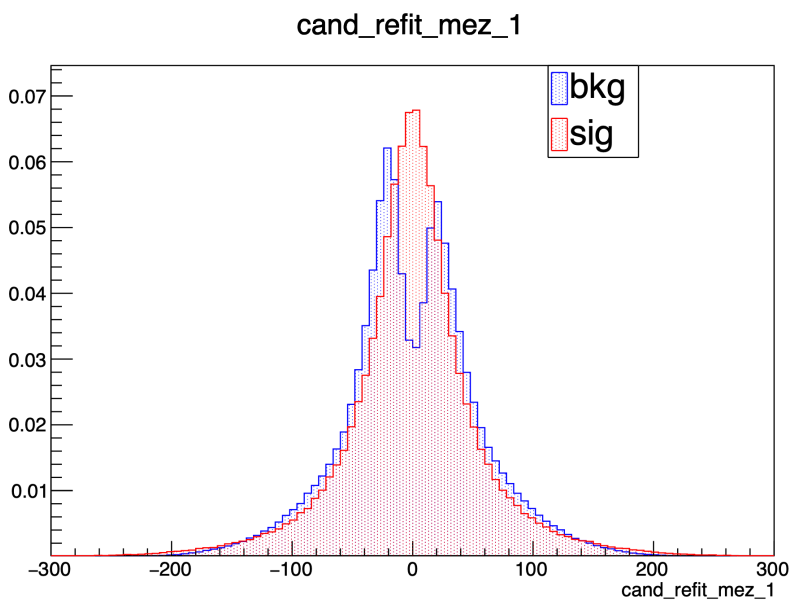


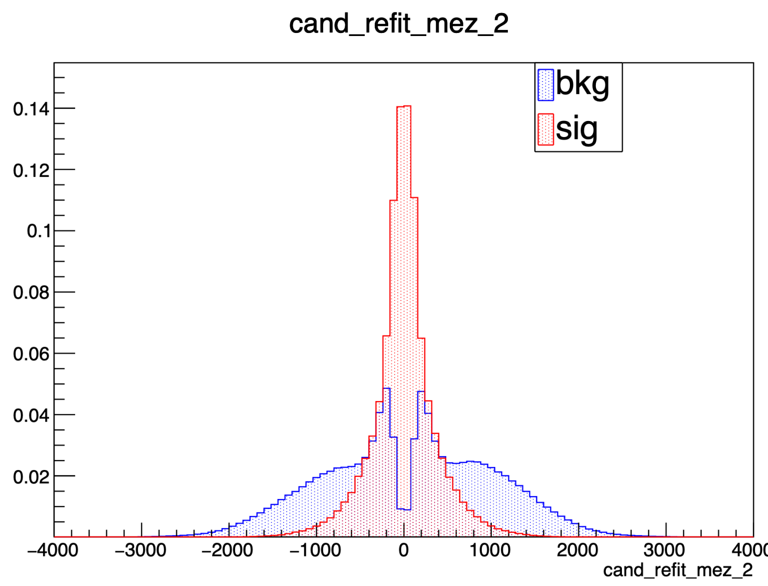
BDT VARIABLES

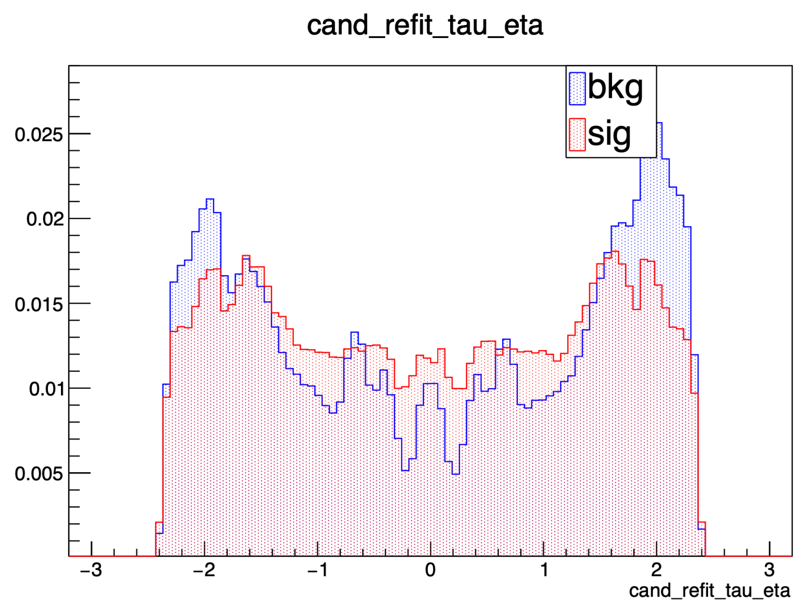


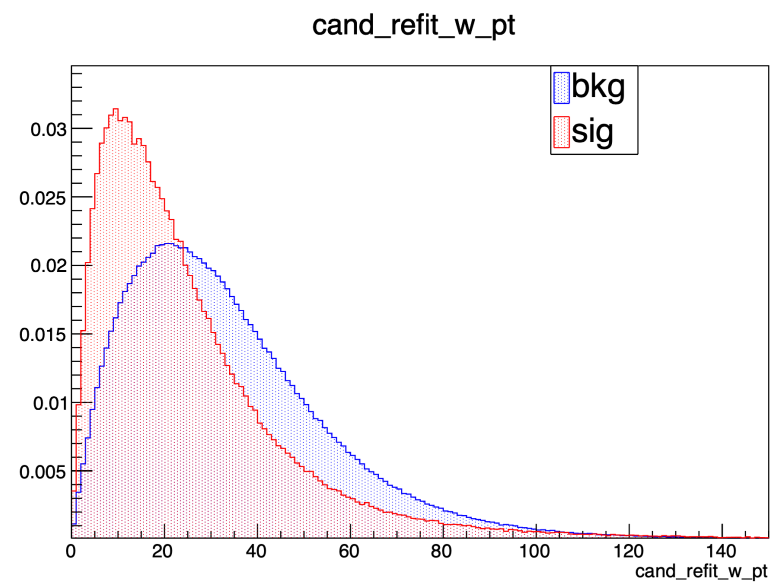
BDT variables

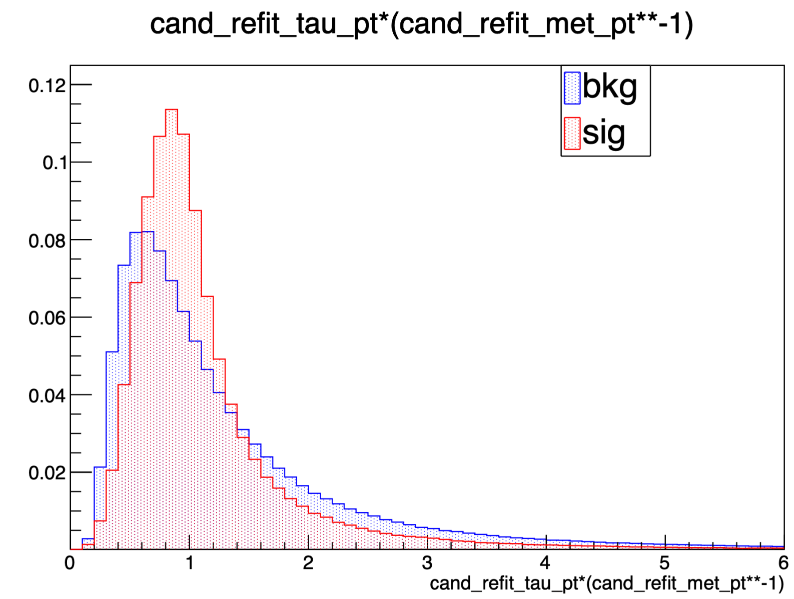




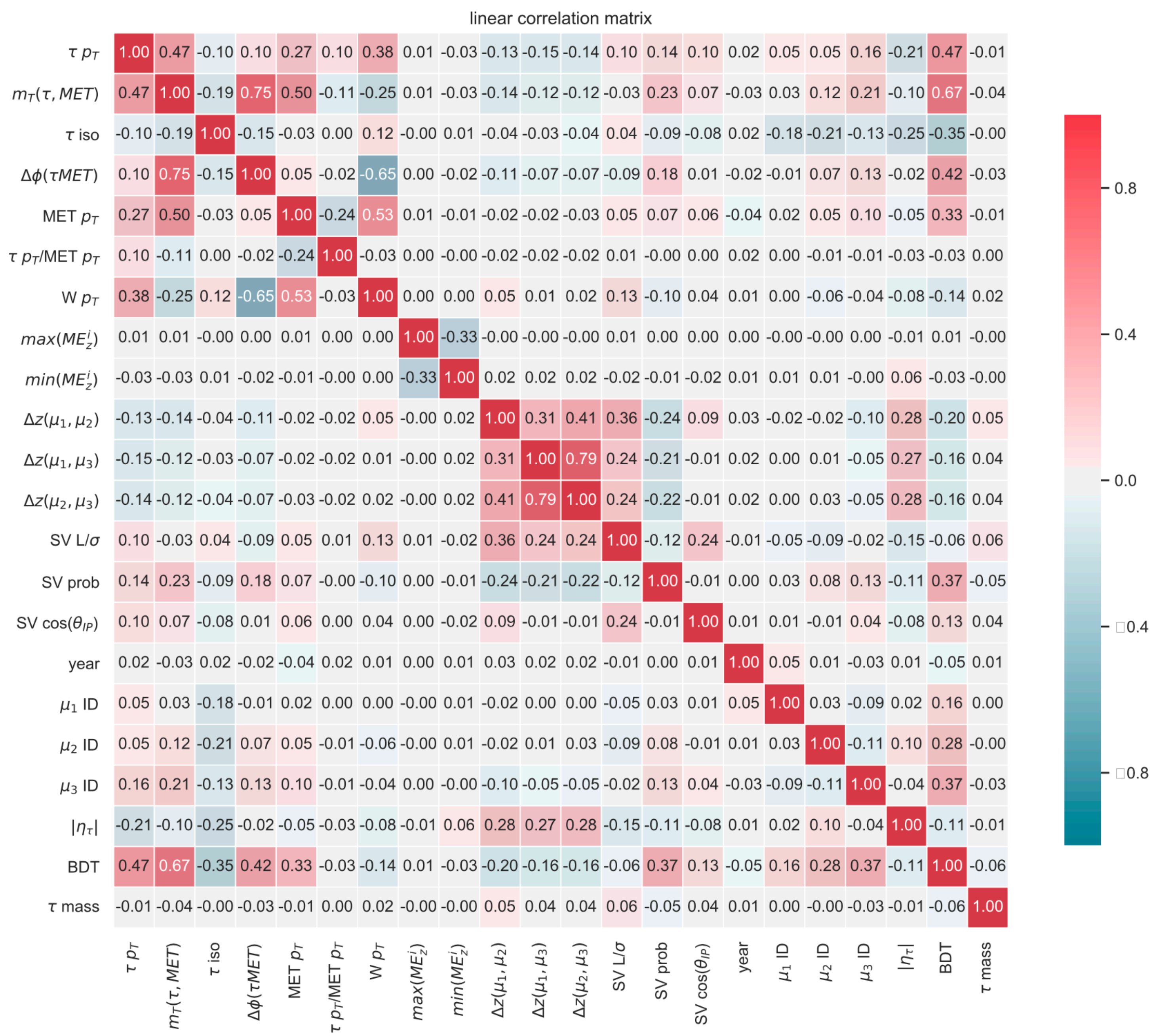








BDT correlation matrix



Trigger gain

Trigger efficiencies evaluated on $\tau \longrightarrow 3\mu$ MC (2016 and 2017)

#Events_firing_the_trigger / #GEN
2016 4288 / 20000 = 0.21
2017 8938 / 40600 = 0.22

Preselection efficiency (#Offline_Trigger_matched / #Events_firing_the_trigger)
2016 3073/4288 = 0.72
2017 8585/8938 = 0.96
ratio 1.33

- event loss in 2016 due to HLT request (two muons and a track)
  - the track could fail muon reconstruction
- this happens less for 2017-18, which selects three muons at HLT

Global efficiency (#Offline_Trigger_matched / #GEN)
2016 3073/20000 = 0.15
2017 8585/40600 = 0.21
ratio 1.40

	Data 2016 RunG	Data 2017 RunD
luminosità [fb^{-1}]	7.57	4.25
eventi	251803	68074
ev / fb^{-1} sidebands	33263	16017
ev in the signal region / fb^{-1} (extrapolated)	14600	6900

EXPECTED D EVENTS IN 90 FB^{-1}

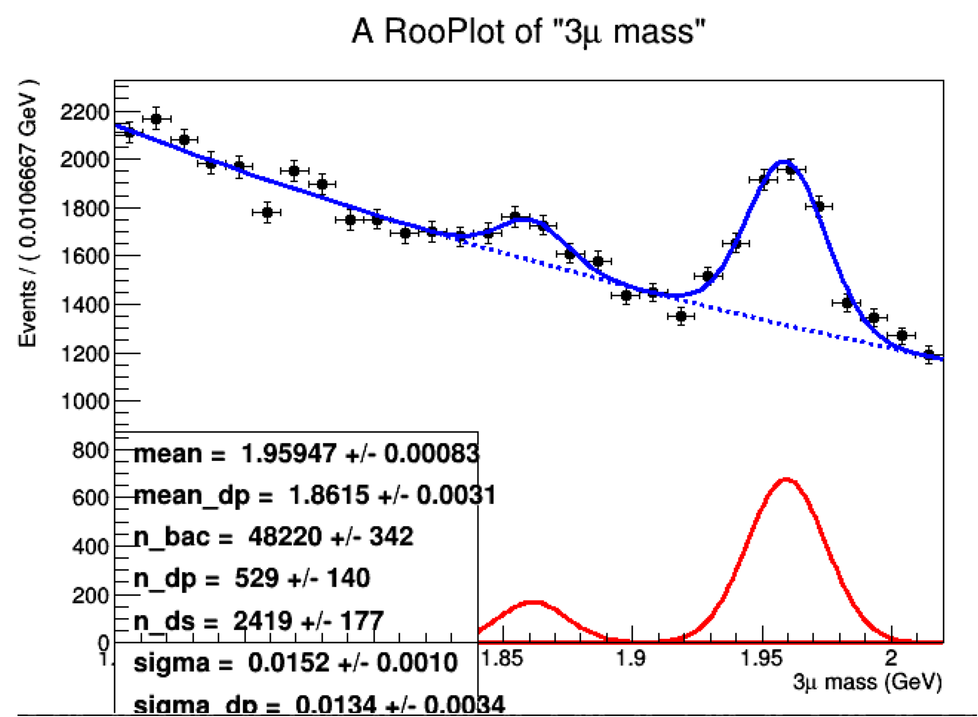
- Expected number of trigger matched D^{+}(s) → ϕπ events obtained from a fit to the data (2017+2018)
- Likely all the events are ϕ → μμ, since the ϕ → KK channels are suppressed by a mis-id factor 10^{-5}
- Sample selection:

```
trigger_selection = '(HLT_Tau3Mu_Mu7_Mu1_TkMu1_IsoTau15_matched || HLT_Tau3Mu_Mu5_Mu1_TkMu1_IsoTau10_Charge1_matched)'
```

```
phi_selection = '(  (abs(cand_mass12 - 1.019) < 0.05 & cand_charge12 == 0) || \
                    (abs(cand_mass13 - 1.019) < 0.05 & cand_charge13 == 0) || \
                    (abs(cand_mass23 - 1.019) < 0.05 & cand_charge23 == 0) )'
```

```
tau_selection  = '(tau_sv_prob > 0.01 & tau_sv_ls > 5)'
```

- **SV selection efficiency** is evaluated on Ds → ϕπ MC to be 52%
- Trigger matched Ds → ϕπ: 2419 / 0.52 = **4651**
- Trigger matched D^{+} → ϕπ: 529 / 0.52 = **1017**
- other channels (ω and η) obtained scaling the branching ratios



THREE-FAKE BACKGROUND

Rough (over)estimation of Ds → three-fake background

- About 5000 Ds → ϕ(μμ) π events in 90 fb^{-1} (trigger matched)
  - all events are most likely ϕ(μμ) events, since the ϕ → KK is about 3 orders of magnitude more likely, but 10^{-5} suppressed by the mis-id
- About 5000 / 3 x 10^{-4} (ϕ → μμ) / 4.5 x 10^{-2} (Ds → ϕπ) Ds events in 90 fb^{-1} with one mis-id'ed track (trigger matched)
  - Less than 4 x 10^{+8} Ds → three-fake events in 90 fb^{-1} with one mis-id'ed track
- Additional 10^{-5} factor from the other two mis-id'ed tracks
- less than 2000 Ds → three-fake events trigger matched
  - assuming a BR for Ds → three-fake of order 50%
  - **less than Ds → ϕπ events**
  - same calculation on D^+ gives less than 3000 D^+ → three-fake events

D semileptonic decays

Leptonic decays

http://cds.cern.ch/record/2002363/files/CERN-THESIS-2015-021.pdf

D decay	$\mathcal{B}_1^{(*)}$	Secondary decay	$\mathcal{B}_2$	$\mathcal{B}_1 \times \mathcal{B}_2$	$\sigma(3\mu X)$
$\mathbf{D_s}$					
$\eta\mu\nu_\mu$	2.67×10^{-2}	$\eta \to \mu\mu$	5.8×10^{-6}	1.5×10^{-7}	0.03 nb
$\eta\mu\nu_\mu$	2.67×10^{-2}	$\eta \to \mu\mu\gamma$	3.1×10^{-4}	8.2×10^{-6}	1.5 nb
$\eta\mu\nu_\mu$	2.67×10^{-2}	$\eta \to \pi^0\mu\mu\gamma$	$< 3 \times 10^{-6}$	$< 8.0 \times 10^{-8}$	< 0.02 nb
$\eta'\mu\nu_\mu$	9.9×10^{-3}	$\eta' \to \mu\mu\gamma$	1.09×10^{-4}	1.1×10^{-6}	0.20 [illegible]
$\phi\mu\nu_\mu$	2.49×10^{-2}	$\phi \to \mu\mu$	2.87×10^{-4}	7.1×10^{-6}	1.3 [illegible]
$\phi\mu\nu_\mu$	2.49×10^{-2}	$\phi \to \mu\mu\gamma$	1.4×10^{-5}	3.5×10^{-7}	0.06 [illegible]
$\phi\mu\nu_\mu$	2.49×10^{-2}	$\phi \to \mu\mu\pi^0$	$1.12 \times 10^{-5}(\dagger)$	2.8×10^{-7}	0.05 [illegible]
$\mathbf{D^+}$					
$\eta\mu\nu_\mu$	1.14×10^{-3}	$\eta \to \mu\mu$	5.8×10^{-6}	6.6×10^{-9}	< 0.0[illegible]
$\eta\mu\nu_\mu$	1.14×10^{-3}	$\eta \to \mu\mu\gamma$	3.1×10^{-4}	3.5×10^{-7}	0.20 [illegible]
$\eta\mu\nu_\mu$	1.14×10^{-3}	$\eta \to \pi^0\mu\mu\gamma$	$< 3 \times 10^{-6}$	$< 3.4 \times 10^{-9}$	< 0.0[illegible]
$\eta'\mu\nu_\mu$	2.2×10^{-4}	$\eta' \to \mu\mu\gamma$	1.09×10^{-4}	2.4×10^{-8}	0.01 [illegible]
$\omega\mu\nu_\mu$	1.6×10^{-3}	$\omega \to \mu\mu$	9.0×10^{-5}	1.4×10^{-7}	0.09 [illegible]
$\omega\mu\nu_\mu$	1.6×10^{-3}	$\omega \to \mu\mu\pi^0$	1.3×10^{-4}	2.1×10^{-7}	0.13 nb
$\rho^0\mu\nu_\mu$	2.4×10^{-3}	$\rho^0 \to \mu\mu$	4.55×10^{-5}	1.1×10^{-7}	0.07 nb
$\phi\mu\nu_\mu$	$< 9 \times 10^{-5}$	$\phi \to \mu\mu$	2.87×10^{-4}	2.6×10^{-8}	0.02 nb

$(*)$: given branching ratios are from corresponding $e\nu_e$ decays

$(\dagger)$: given branching ratio is from $\phi \to e^+e^-\pi^0$ decays

LHCb numbers

- as in previous slide none of these is resonant, due to neutrinos → non peaking

Cannot make quantitative consideration as done for Ds → ϕπ

All the decays driven by pure di-muon resonances can be excluded (no di-muon resonances after the BDT but for ϕ meson -veoted-)

Anyway, the presence of one or more undetected particles makes the 3μ mass spectrum non-peaking