Second year report on progress

Search for $\tau \longrightarrow 3\mu$ decay at the CMS experiment in Run-II

PhD School in Physics, XXXIV Cycle

Federica Simone

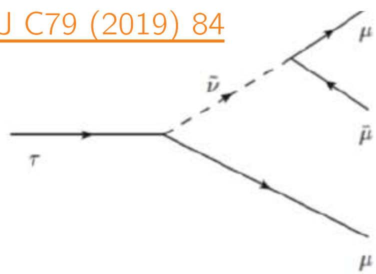
University of Bari, Nov 2 2020

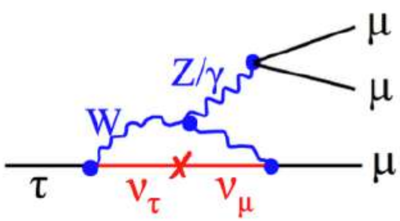
Motivations

- $\tau \to 3\mu$ transition
  - ✓ doesn't conserve the lepton family number
  - ✓ doesn't involve neutrinos in the final state
    - ➢ Charged Lepton Flavour Violation (CLFV)

Neutrino flavor violation → CLFV (e.g. $\tau \to 3\mu$) also allowed

- Suppressed in the Standard Model:
  Branching Ratio $\tau \to 3\mu$ (SM) $\sim \mathcal{O}(10^{-54})$
  from the most recent calculations, EPJ C79 (2019) 84





- Enhanced BR in SUSY, 2HDM
  $\tau \to 3\mu$ (BSM) $\sim \mathcal{O}(10^{-7} \div 10^{-9})$
  https://arxiv.org/pdf/hep-ph/061

The rates for CLFV processes are expected to provide information regarding the **nature of new physics**

State of the art

Date	Experiment	Exp. [*]	Obs [*]		
2010	Belle	-	2.1	$ee \longrightarrow \tau\tau$	[arXiv:1001.3221]
2010	BaBar	4.0	3.3	$ee \longrightarrow \tau\tau$	[arXiv:1002.4550]
2014	LHCb	5.0	4.6	*HF channel - Run I*	[https://doi.org/10.1007/JHEP02(2015)121]
2016	ATLAS	39	38	*W channel - Run I*	[arXiv:1601.03567]
2020	**CMS**	**6.9**	**8.0**	***HF + W - 2016***	[CMS-PAS-BPH-17-004]

[*] x 10^{-8} at 90% CL

In this talk:

2017 Data (Run II, pp @ 13 TeV): integrated luminosity of 38 fb^{-1}
2018 Data (Run II, pp @ 13 TeV): integrated luminosity of 59.7 fb^{-1}

Heavy Flavour (HF) ($D \longrightarrow \tau\nu$, $B \longrightarrow \tau\nu$..., $B \longrightarrow D(\tau\nu)$...)
$\mathcal{O}(10^{13})$ τ produced (2018) → $\sim\mathbf{10^5}$ $\tau \longrightarrow 3\mu$ *events**
*assuming upper limit by Belle

Analysis strategy

Workflow:

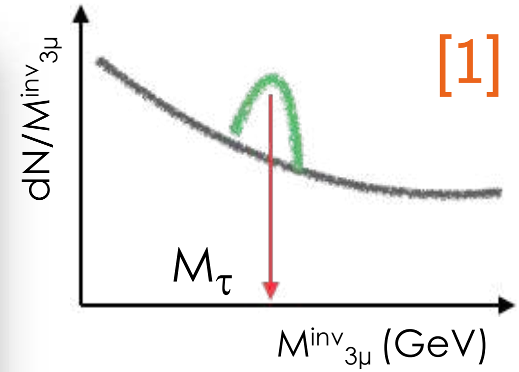
- search for a bump at nominal **tau mass peak** in the invariant mass distribution of the 3μ-system [1]
  - smoothly distributed background expected
  - signal from Monte Carlo simulations
- MVA discriminator for **background rejection**
- Event **categorization** to improve search sensitivity:
  - 3 X 3μ-system mass resolution [2]
  - 2 X MVA discriminator output [3]
- The $\tau \rightarrow 3\mu$ signal is extracted by a simultaneous **maximum likelihood fit** of the thus-formed six unbinned mass distributions.

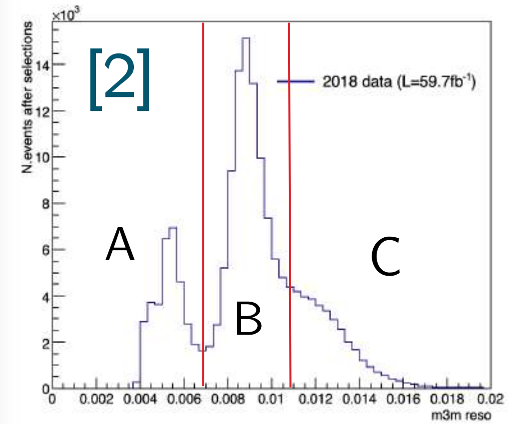
Data online selection: High Level Trigger (HLT)

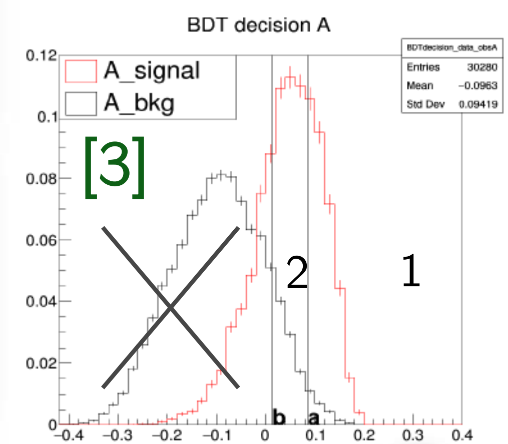
HLT used in 2017 (2018) requires 2 muons with pT > 3.0 GeV and one additional track (tracker muon) with pT > 1.2 GeV in the final state

$D_s \longrightarrow \phi(\mu\mu)\pi$ control channel:

- used to measure D meson production rate in data
  - normalise the signal MC
  - monitor data taking
- check data/MC agreement for quantities relevant for the analysis







$\tau \to 3\mu$ Event selection

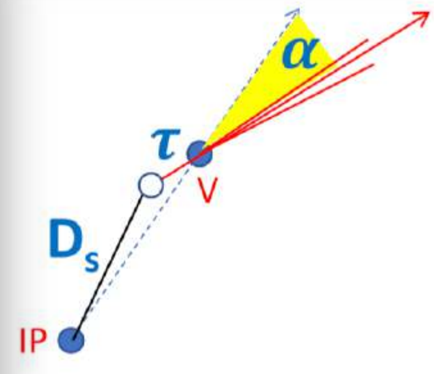
Online

2017: HLT_DoubleMu3_Trk_Tau3Mu_v*,
2018: HLT_DoubleMu3_TkMu_DsTau3Mu_v*

seeded by DoubleMu L1 or TripleMu L1

Offline:

- Displacement of the 3μ vertex (Secondary Vertex, SV):
  - SV-BeamSpot displacement on transverse plane > 2σ
- Muon identification (p_T > 2 GeV and $|\eta| < 2.4$):
  - all three muons must pass the «ParticleFlow» reconstruction
  - the two muons with higher p_T are «global muon»
  - two exclusive categories *[*]* of events based on reco of lowest-p_T μ_3:
    - μ_3 is «global muon»
    - μ_3 is not «global muon» but is a «tracker muon»
- Conditions on muon pairs:
  - Collimation: $\Delta R(2\mu) < 0.8$ & $\Delta z(2\mu) < 0.5$ cm
  - Eclusion of o.s. 2μ compatible with ϕ (1020) resonance
- $\tau \to 3\mu$ candidate and matching with HLT:
  - abs(total charge)=1 and 3μ invariant mass m(3μ): 1.62-2.00 GeV
  - Matching trigger "legs" within $\Delta R<0.03$ and $\Delta p_T/p_T<0.1$
    - If more than one 3μ candidate in the event -> best vertex χ^2



[*] analysis done independently on those two exclusive category of 3mu candidates.

Combination of results is performed after extraction of final yields

$D_s \longrightarrow \phi(\mu\mu)\pi$ normalisation channel

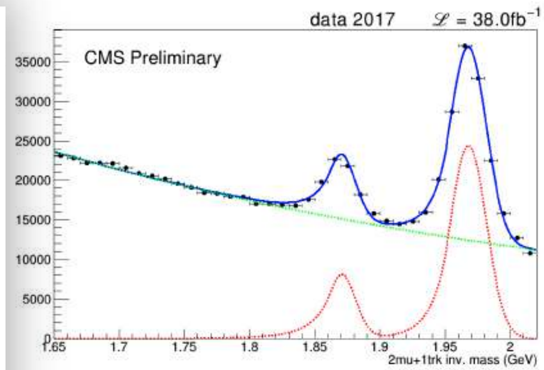
Online selection:
HLT_DoubleMu3_Trk_Tau3mu
(prescaled by 20 over 2018)

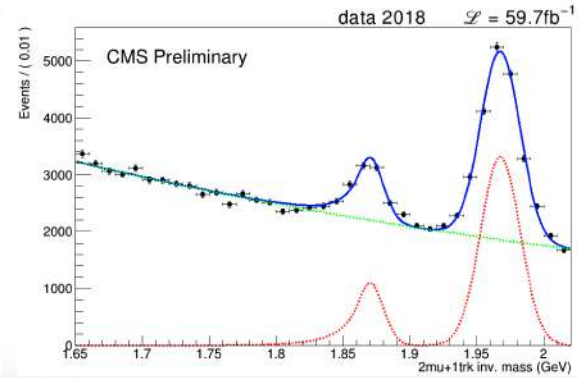
2mu+1trk offline selection:

- HLT and L1 DoubleMu fired
- valid PV with at least 2 associated tracks
- reco μ don't coincide with the track
- 2 reco μ are Global+ParticleFlow
- 2 μ have opposite charge and mass within 1..1.04 GeV
- cut on track I.P. (dz<20 and dxy<0.3)
- muons and track match with trigger legs within dR<0.03 and dP/P<0.1

Analysis:

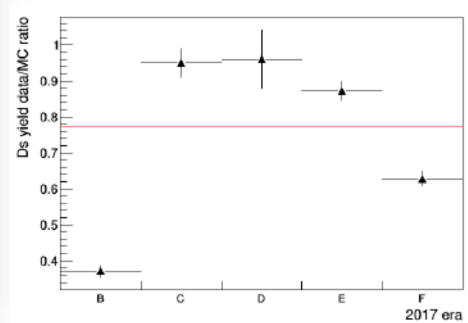
- 2μ+1trk mass fitted with exponential + CB functions to extract **Ds yield in data**
- yield used to evaluate correction to MC Ds production → used for **signal normalisation**





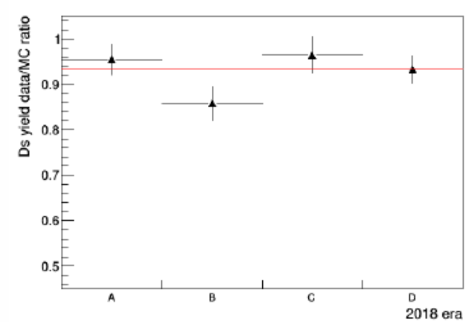
2017 Ds yield:

- overall ratio of D_s yields in 2017 data and MC is 0.775±0.015
- drop of Ds yields during eras B and F



2018 Ds yield:

- overall ratio of D_s yields in data and MC is found to be 0.93±0.03
- yield stability over 2018 checked

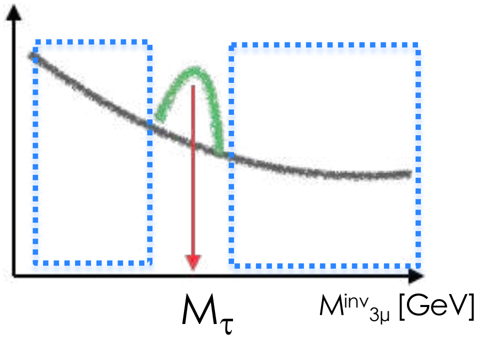


MVA for background rejection: Boosted Decision Tree

- Using adaptive boosting algorithm implemented in ROOT TMVA
- between 11 and 18 input variables

optimised depending on category and number of events available for training

- BDT **training done separately** for each event category
  - Signal: MC events passing selections
    - Different samples (Ds, Bu, Bd) weighted accordingly to branching ratios and normalization factors
  - Backgroud: events passing selection w/ 3μ inv. mass in sidebands*



(*)[1.62; 1.75] U [1.80; 2.0] GeV

"baseline" set of BDT input variables

Muon-related

1. Momentum of the trailing muon (GeV)
2. Chi2 value for the STA-TK matching of local position (largest of the three)
3. value of the kink algorithm applied to the inner track (largest of the three)
4. compatibility between the inner track and the segments in the muon spectrometer (smallest of the three)
5. N. of segments in muon system matching with mu3 inner track extrapolation

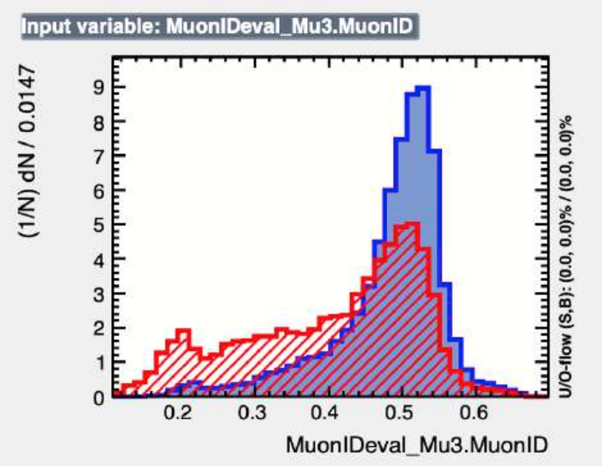
Triplet-related

6. 3μ vertex Chi2/n.d.f.
7. angle between the 3μ momentum vector and the PV-SV vector
8. PV-SV Flight distance significance
9. Transverse IP significance (|dxy/dxyErr|) (smallest of the three)
10. Closest distance (min dca) of the 3μ vertex to any other track having pt>1 GeV
11. The ratio of the pT of surrounding tracks having pt>1 GeV, deltaR <0.3, dca<1mm (largest value from the three muons)

Additional BDT variables (MVA muon quality)

GlobalMuonID (see next slide)

- **MVA-based muon discriminator** build on top of the global muon reconstruction. Aimed to extend SoftMVA to endcap + pt<4GeV
- Returns the BDT score evaluated on a set of 15 muon-related variables (related to global track, inner track, outer track quality)
- BDT trained on:
  - global muons from $\tau \to 3\mu$ MC sample as signal,
  - pions and kaons reconstructed as global muons from $B \to \pi\pi$, $B \to \pi K$, $B \to KK$ MC samples as bkg
- NEW **Training done separately for 2017 and 2018 using different MC simulations**

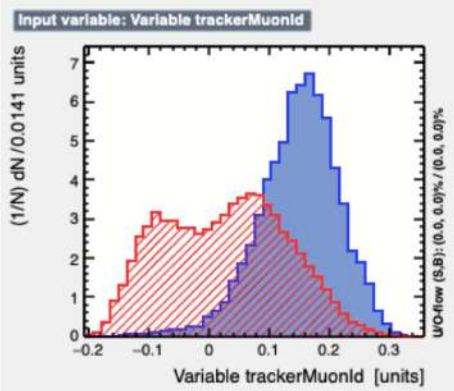


example: GlobalMuonID used in the per-event BDT - mu3 cat.C

TrackerMuonID

- **MVA-based muon discriminator** build on top of the tracker muon reconstruction
- Returns the BDT score evaluated on a set of 12 muon-related variables (related to inner track quality, energy deposits in ECAL/HCAL, pt resolution)
- BDT trained on:
  - tracker* muons from $\tau \to 3\mu$ MC sample as signal,
  - pions reconstructed as tracker* muons from $Ds \to \varphi\,(\mu\mu)\pi$ MC samples as background

*muons reconstructed as tracker but NOT global

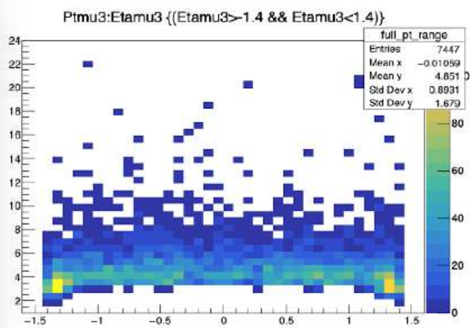


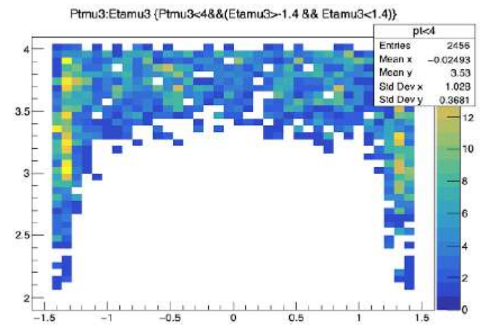
example: TrackerMuonID used in the per-event BDT - cat B

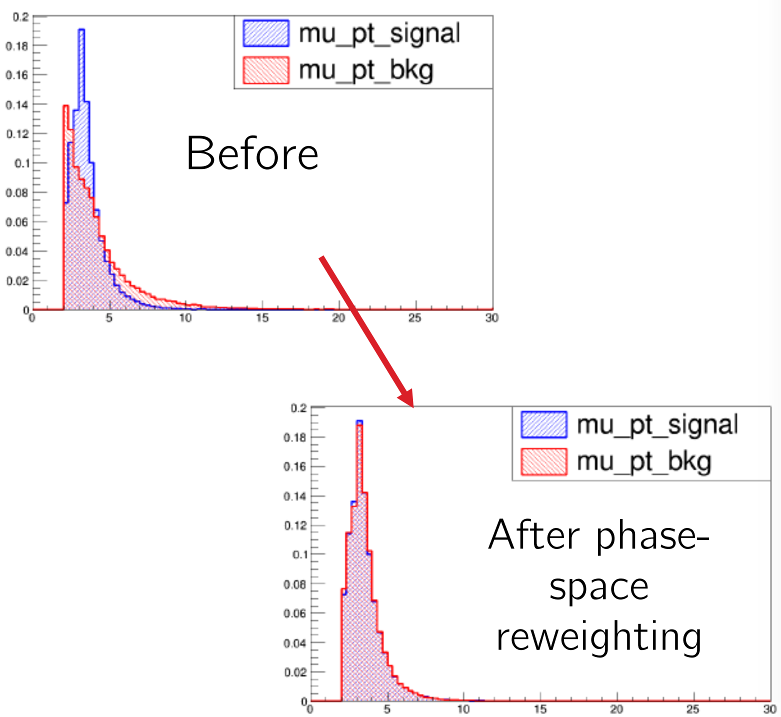
Development of MVA-based μ identification for global muons (1)

Motivation

Existing flags for low-pt muon reco quality (*softMVA*) is not optimized for our phase-space of interest. We deal with very soft muons: in ~30% of signal we find a muon with $p_T < 4GeV$







Selecting signal and background muons:

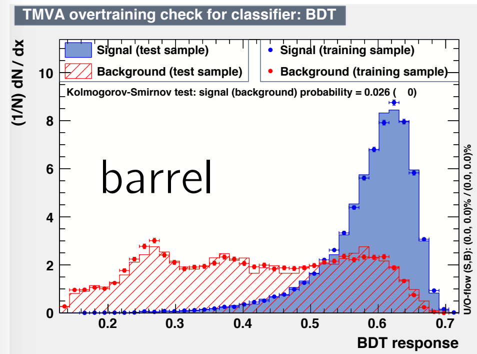
- Simulated event has 1 <u>global muon</u>, $p_T > 2GeV$, $|\eta| < 2.4$, attached simulation-level info.
  - **Signal** ($D_s \to \tau \to 3\mu$): Lowest-p_T muon from τ decay. Event must fire HLT used $\tau \to 3\mu$ analysis.
  - **Background** ($B_{d/s} \to KK/\pi\pi/K\pi$): muon matches at simulation level a π, K or with a muon produced from π or K decay

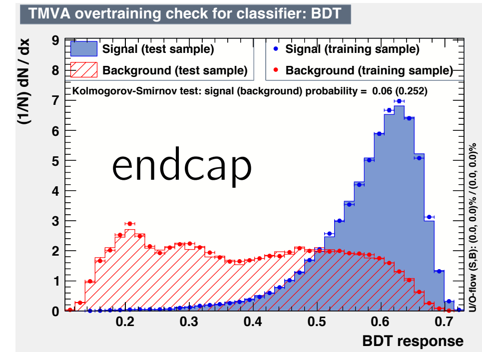
Phase-space reweighing applied to background muons (separately for barrel and endcap)

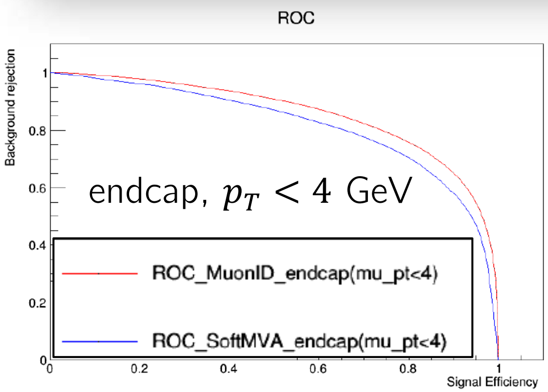
Development of MVA-based μ identification for global muons (2)

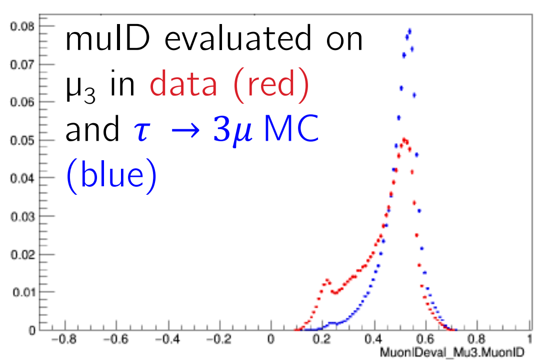
BDT training

- Long list of variables (>20) related with muon reconstruction studied
- Sorted by ranking, different lists tested, final pruned list in backup
- BDT trained on bkg/signal muons separately for endcap and barrel









Performance

- Comparison of ROC curve to compare signal/bkg discrimination wrt existing variable softMVA
- Evaluation of BDT score on data and MC used in the analysis: peak related to μ from decay in flight, still good variable to be used in per-event BDT

Summary of BDT implementations

2017 – 3 global muon

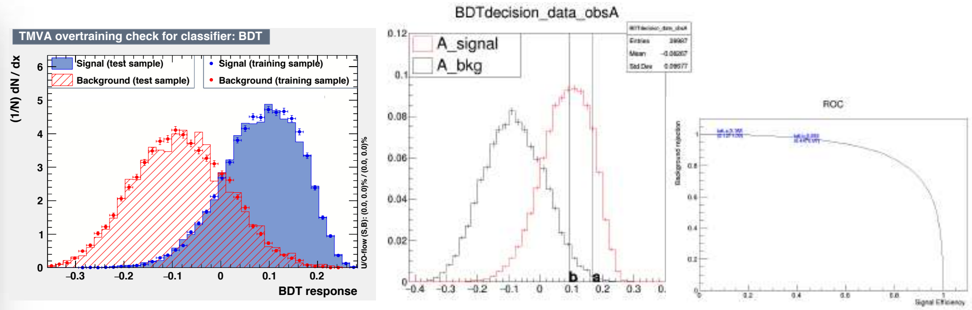
- **"extended"** set of variables used
    - globalMuonID for all the 3 mu
    - additional muon-related variables
    - **optimization still needed**

2018 – 3 global muon

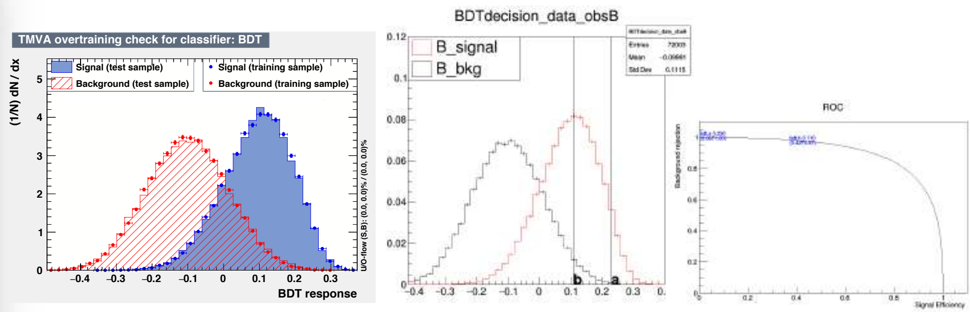
- **"optimised"** set of variables used
    - globalMuonID for all the 3 mu
    - additional muon-related variables in categories B and C (higher eta)
    - additional vtx variables in cat.A
- fine tuning of BDT settings

2017 and 2018 – 2 glb + 1 trkMu exclusive category

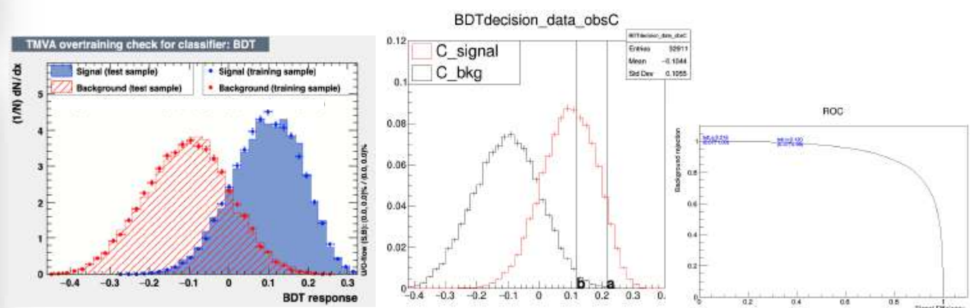
- **"baseline"** set of variables used + dedicated trackerMuonID



2018 catA-3glb: K-S test signal (bkg) = 0.55(0.41)



2018 catB-3glb: K-S test signal (bkg) = 0.65(0.37)



2018 catC-3glb: K-S test signal (bkg) = 0.56(0.44)

Preliminary results: yields and expected U.L.

Statistical analysis:

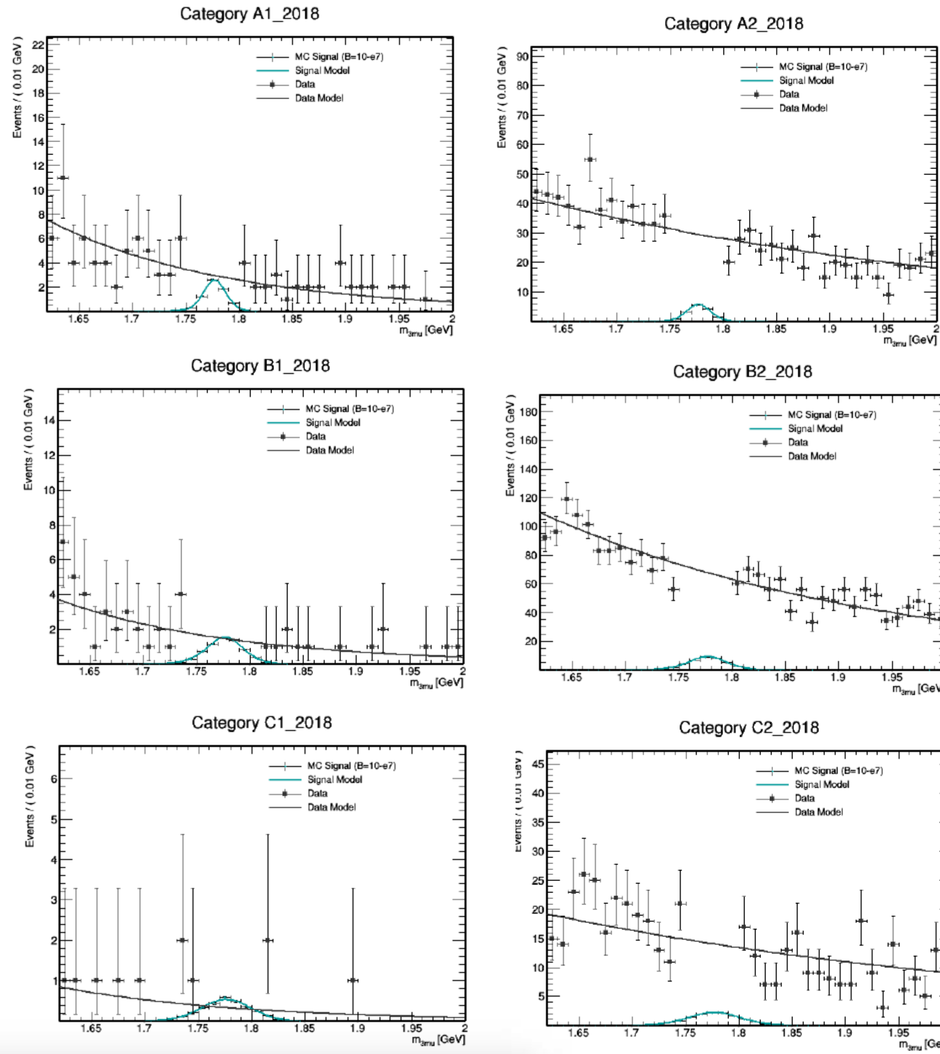
- done using CMS Higgs CombinedLimit tool
- Unbinned max likelihood fits
- Systematic uncertainties as nuisance parameters

2017 – 3 global muon
«extended» BDT
$\mathcal{B}(\tau \to 3\mu) < 0.71 \times 10^{-7}$

2018 – 3 global muon
«optimised» BDT
$\mathcal{B}(\tau \to 3\mu) < 0.46 \times 10^{-7}$

2017 – 2 glb + 1 trkMu
(exclusive category)
baseline BDT + muonID
$\mathcal{B}(\tau \to 3\mu) < 1.66 \times 10^{-7}$

2018 – 2 glb + 1 trkMu
(exclusive category)
baseline BDT + muonID
$\mathcal{B}(\tau \to 3\mu) < 1.47 \times 10^{-7}$



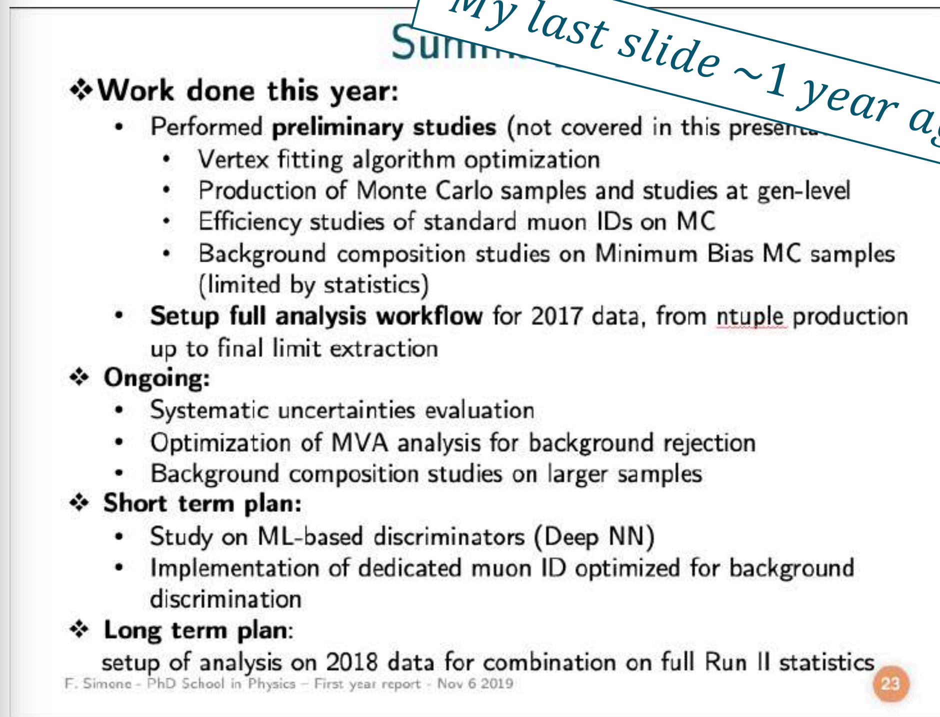
2017+2018 combined result – HF

$$\mathcal{B}(\tau \to 3\mu) < 0.35 \times 10^{-7} \text{ @90\% C.L.}$$

Summary – work done so far

- **Analysis performed on full statistics**
  - Extracted upper limit for 2017+2018 datasets
  - Preliminary combined result produced
- **Analysis workflow**
  - Implemented exclusive event category based on reconstruction of lowest-p_T μ_3
- **MVA optimization**
  - optimized BDT variables and settings
  - implemented dedicated MVA-based muon identification to discriminate μ from mis-identified tracks

My last slide ~1 year ago


Summ

❖ **Work done this year:**

- Performed **preliminary studies** (not covered in this presenta
  - Vertex fitting algorithm optimization
  - Production of Monte Carlo samples and studies at gen-level
  - Efficiency studies of standard muon IDs on MC
  - Background composition studies on Minimum Bias MC samples (limited by statistics)
- **Setup full analysis workflow** for 2017 data, from ntuple production up to final limit extraction

❖ **Ongoing:**

- Systematic uncertainties evaluation
- Optimization of MVA analysis for background rejection
- Background composition studies on larger samples

❖ **Short term plan:**

- Study on ML-based discriminators (Deep NN)
- Implementation of dedicated muon ID optimized for background discrimination

❖ **Long term plan:**

setup of analysis on 2018 data for combination on full Run II statistics

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Summary – work done so far

Special INFN Associate Programme in the Framework of the LHC at CERN:

12 months contract as Cooperation Associate (COAS) (so called «simil-fellow»)

Jan 2020 – Jan 2021

Project: «Search for $\tau \rightarrow 3\mu$ decay at the CMS experiment using full Run-II data and preparation for Run-III»

1 year at CERN: additional work on site

- Responsible for the final validation of the GE1/1 detectors at the cosmic stand (QC8)
- Work at P5: contributing to the commissioning of the installed GE1/1 station as detector expert

Schools and workshops

- ISOTDAQ - International School of Trigger and Data Acquisition, University of Valencia, Spain, 13-22 January 2020.

Conference talks

- "Recent CMS heavy flavour physics results", 9th International Conference on New Frontiers in Physics, Creta, Greece, Sept 4 - Oct 2 2020 (virtual).

Summary – work ongoing and to-do list

- Ongoing:
  - investigation on **vertexing mismodelling** which affects 2017 simulation. Assess impact on analysis by studying BDT cut efficiency on control channel
  - **background studies**:
    - optimization of vetos on 2μ resonances
    - characterization of processes contributing to continuous background
    - isolation studies to cut out background events from specific processes
  - **Muon ID scale factors** computation with Tag&Probe for ID "global muon and ParticleFlow muon" (almost finalized)
  - filling **analysis documentation** (AN-2020/102)
  - machinery for **combining HF + W** results in place
  - Plan is to finalise the analysis **targeting winter conferences** (Moriond)

- To do:
  - Assess contribution from non-prompt D mesons in data and MC (for both 2017 and 2018) and related uncertainty
  - Update **uncertainty on BDT cut** efficiency
  - Evaluate performance of unique training of the BDT on the full 2017+2018 dataset

Backup

In this talk:

2017 Data (Run II, pp @ 13 TeV): integrated luminosity of 38 fb^{-1}
2018 Data (Run II, pp @ 13 TeV): integrated luminosity of 59.7 fb^{-1}

2017 trigger HLT_DoubleMu3_Trk_Tau3mu_v*
L1_TripleMu_5_3_0_DoubleMu_5_3_OS_Mass_Max17 (Runs 297046–299329)
L1_TripleMu_5SQ_3SQ_0_DoubleMu_5_3_SQ_OS_Mass_Max9 (Runs 299368–305967)
L1_DoubleMu0er1p5_SQ_OS_dR_Max1p4

2018 trigger HLT_DoubleMu3_TkMu_DsTau3Mu_v*
L1_TripleMu_5SQ_3SQ_0_DoubleMu_5_3_SQ_OS_Mass_Max9
L1_DoubleMu0er1p5_SQ_OS_dR_Max1p4 (never prescaled)
L1_DoubleMu4_SQ_OS_dR_Max1p2 (prescaled from run 315973(A) to 319579(C))

Note: 2016/2017 trigger *HLT_DoubleMu3_Trk_Tau3mu* was prescaled by 20 over 2018

MC samples

2017: Centrally produced MC samples:

DsToTau_TauTo3Mu	3.6 M evts
BdToTau_TauTo3Mu	2.0 M evts
BuToTau_TauTo3Mu	2.9 M evts
DsToPhiMuMuPi	1.8 M evts

campaign: RunIIFall17DRPremix-PU2017_94X_mc2017_realistic_v11-v1

2018: Privately produced MC samples:

DsToTau_TauTo3Mu	4.6 M evts
BdToTau_TauTo3Mu	3.5 M evts
BuToTau_TauTo3Mu	1.3 M evts
DsToPhiMuMuPi	0.9 M evts

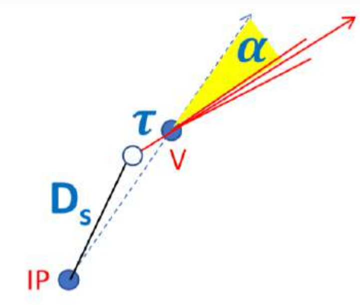
conditions: 102X_upgrade2018_realistic_v20
cmssw_version: CMSSW_10_2_X

$\tau\to3\mu$ Event selection

Online
2017: HLT_DoubleMu3_Trk_Tau3Mu_v*,
2018: HLT_DoubleMu3_TkMu_DsTau3Mu_v*
seeded by DoubleMu L1 or TripleMu L1

Offline:

- SV-BS displacement on transverse plane > 2 std dev
- Muon ID (p_T > 2 GeV and $|\eta| < 2.4$)
  - 3PF & 3glbMu
  - 3PF & (2glbMu + 1trkMu)[*] NEW
- $\Delta R(2\mu) < 0.8$ & $\Delta z(2\mu) < 0.5$ cm
- 3μ abs(total charge)=1 and 3μ invariant mass m(3μ): 1.62-2.00 GeV
- exclusion of os 2μ with inv. mass close to ϕ (1020) within 2σ
- *exclusion of os 2μ with inv. mass close to ω (782) within 2σ*
- Matching trigger "legs" within $\Delta R<0.03$ and $\Delta p_T/p_T<0.1$
  - **If more than one 3μ candidate in the event -> best vertex χ^2**



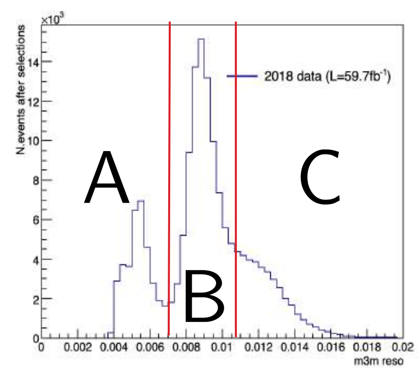
[*] exclusive category of 3mu candidates made of 2global+1tracker implemented on 2018 analysis

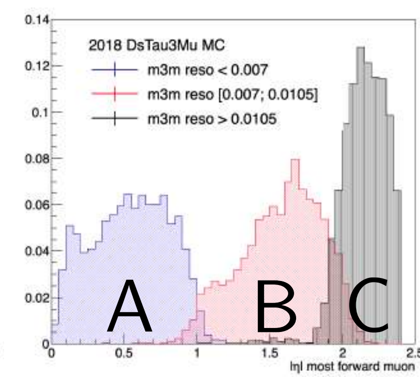
Event categorization

Events categorized based on the relative invariant mass resolution ρ:

A: $\rho < 0.0070$
B: $0.0070 < \rho < 0.0105$
C: $\rho > 0.0105$

ρ is calculated by propagating the muon momentum uncertainty to 3mu mass





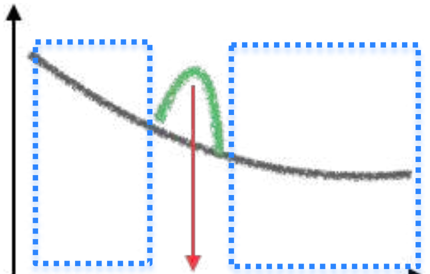
Per-muon momentum resolution: varies considerably, mostly depends on η

MVA for background rejection: Boosted Decision Tree

- Using adaptive boosting algorithm implemented in ROOT TMVA
- between 11 and 18 input variables

NEW **optimised depending on category and number of events available for training**

- 3 X BDT **trained separately** for each event category
  - Signal: MC events passing selections
    - Different samples (Ds, Bu, Bd) weighted accordingly to branching ratios and normalization factors
  - Backgroud: events passing selection w/ 3μ inv. mass in sidebands*



(*)[1.62; 1.75] U [1.80; 2.0] GeV

"baseline" set of BDT input variables

Muon-related

1. Momentum of the trailing muon (GeV)
2. Chi2 value for the STA-TK matching of local position (largest of the three)
3. value of the kink algorithm applied to the inner track (largest of the three)
4. compatibility between the inner track and the segments in the muon spectrometer (smallest of the three)
5. N. of segments in muon system matching with mu3 inner track extrapolation

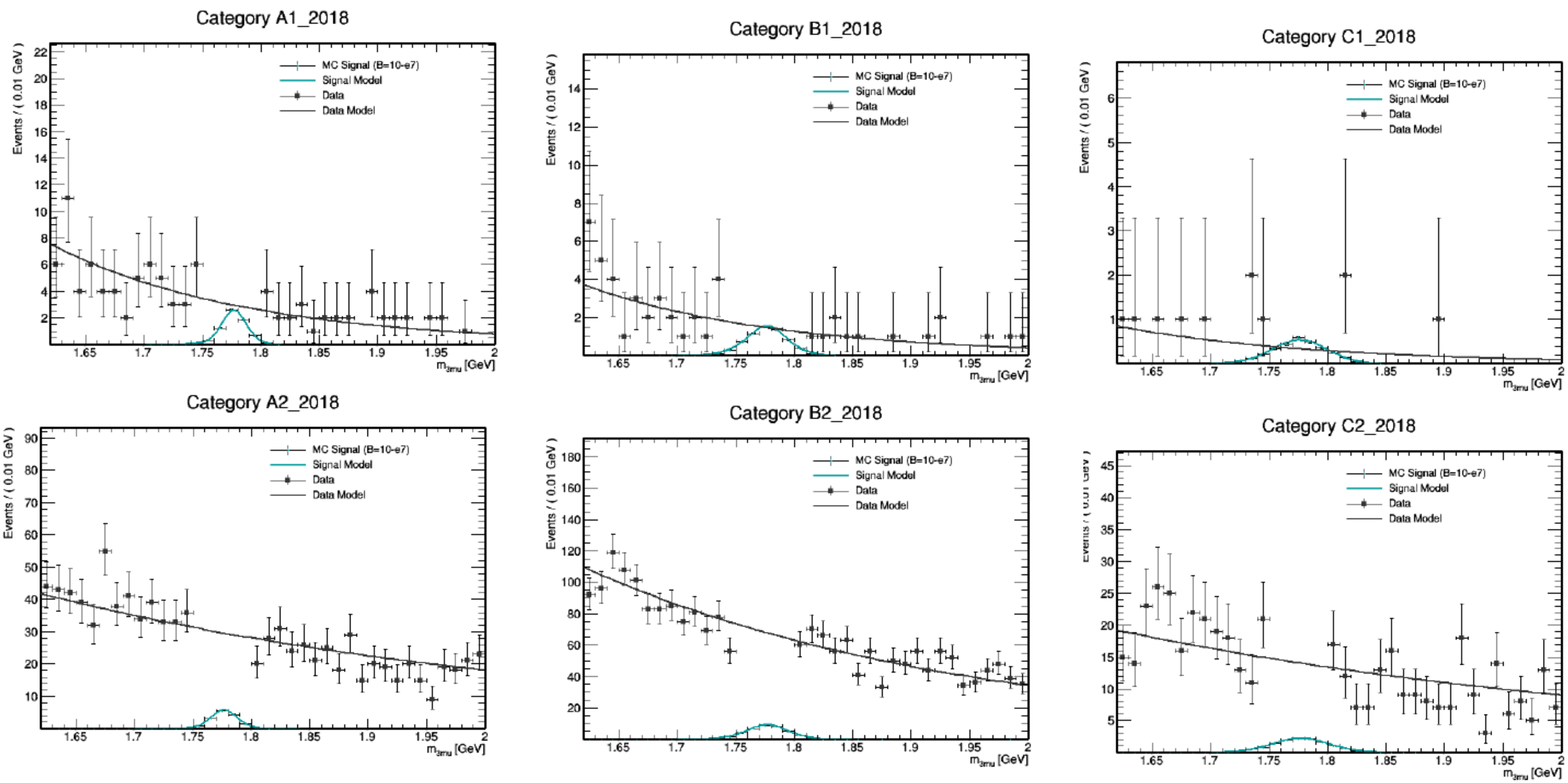
Triplet-related

6. 3μ vertex Chi2/n.d.f.
7. angle between the 3μ momentum vector and the PV-SV vector
8. PV-SV Flight distance significance
9. Transverse IP significance (|dxy/dxyErr|) (smallest of the three)
10. Closest distance (min dca) of the 3μ vertex to any other track having pt>1 GeV
11. The ratio of the pT of surrounding tracks having pt>1 GeV, deltaR <0.3, dca<1mm (largest value from the three muons)

2018 (3glb mu) results:

Fit model:

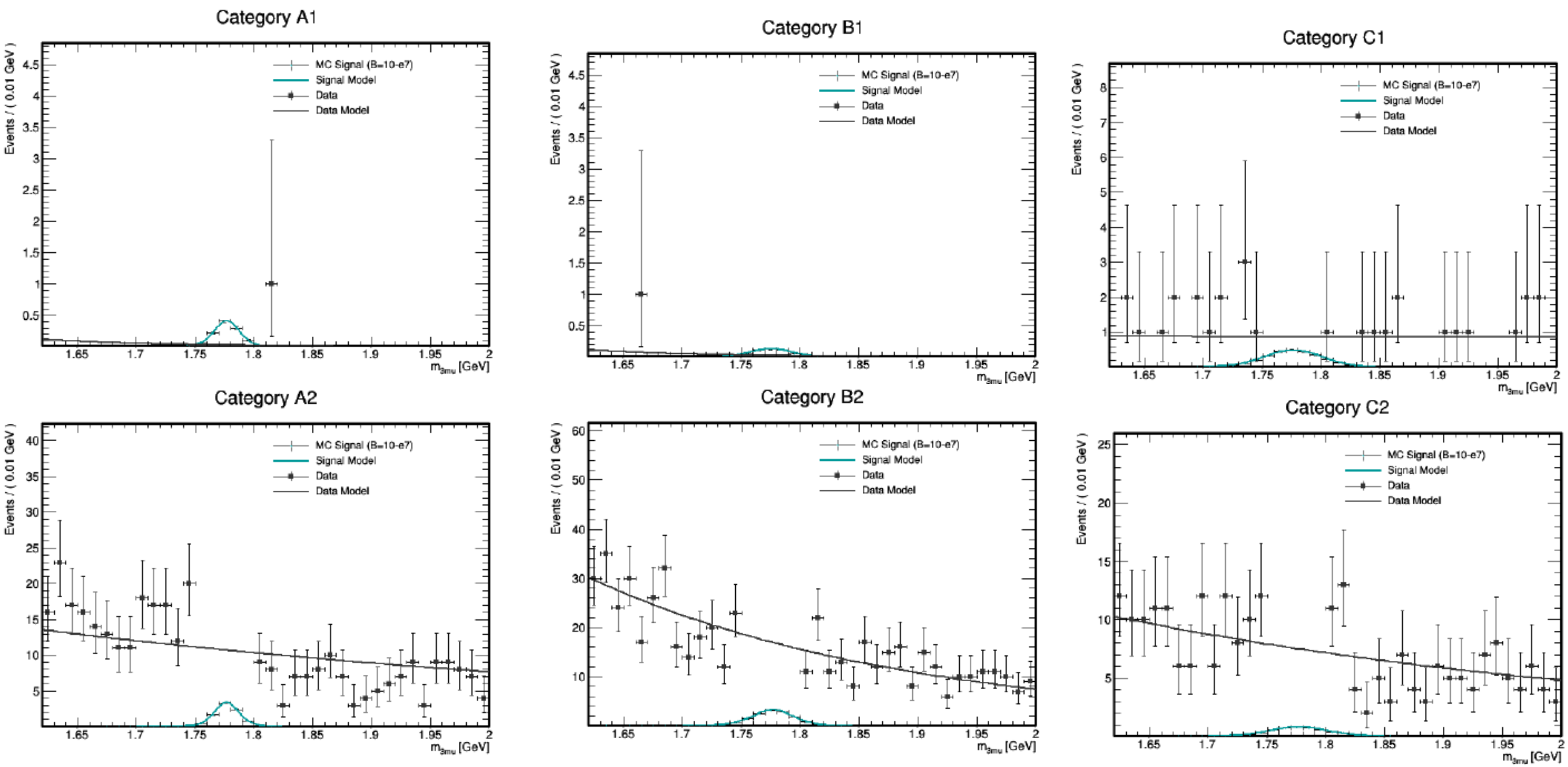
- Signal: gaussian + crystal ball function with mean fixed at tau mass,
  normalised to pp → B/D → τν branching ratios, assuming $\mathcal{B}(\tau \rightarrow 3\mu) = 10^{-7}$
- **Background** (data in sidebands): falling exponential



2017 (3glb mu) results:

Fit model:

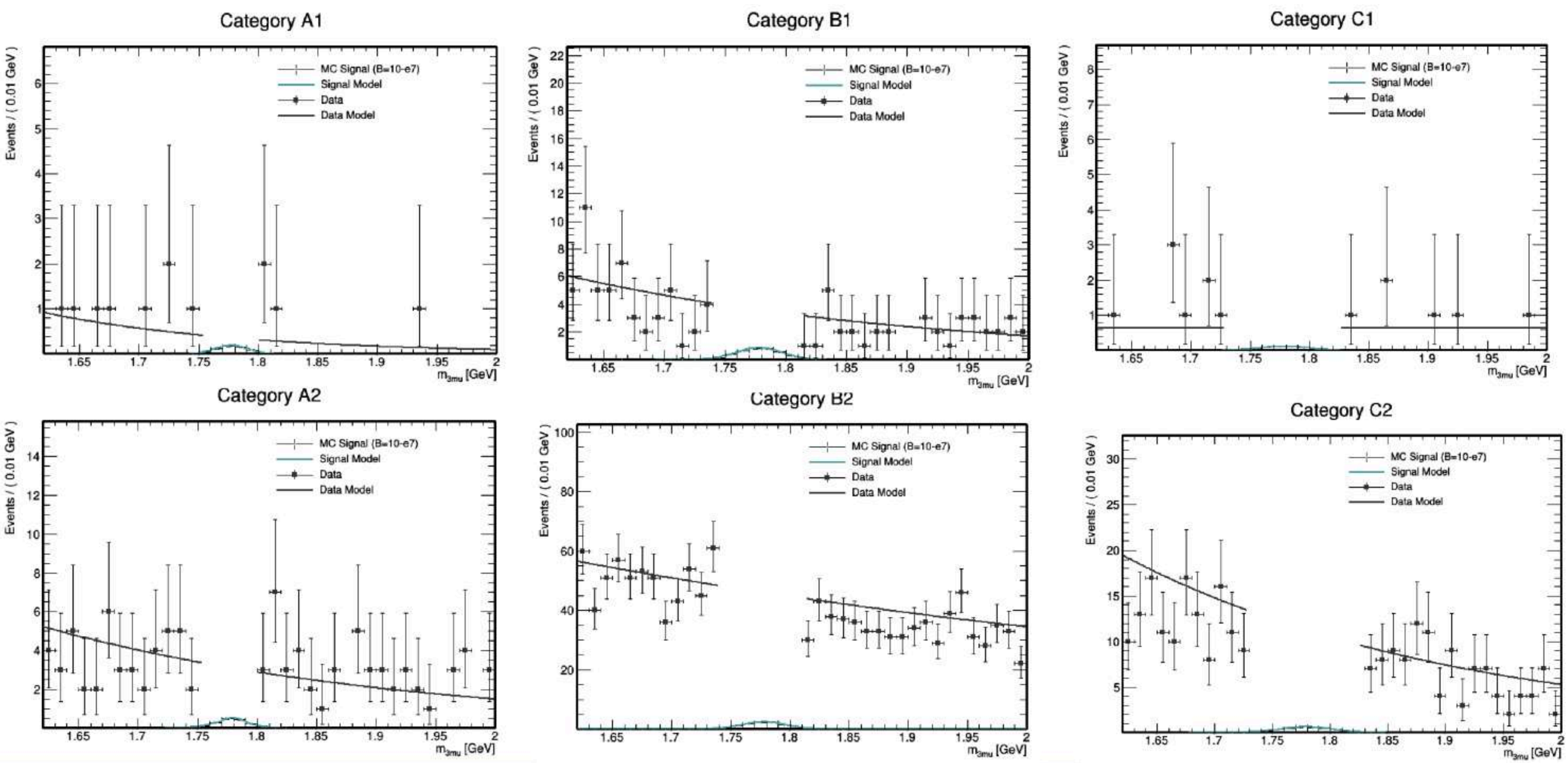
- **Signal:** gaussian + crystal ball function with mean fixed at tau mass, normalised to pp → B/D → τν branching ratios, assuming $\mathcal{B}(\tau \rightarrow 3\mu) = 10^{-7}$
- **Background** (data in sidebands): falling exponential



2018 (2 gbl+1trk mu) results:

Fit model:

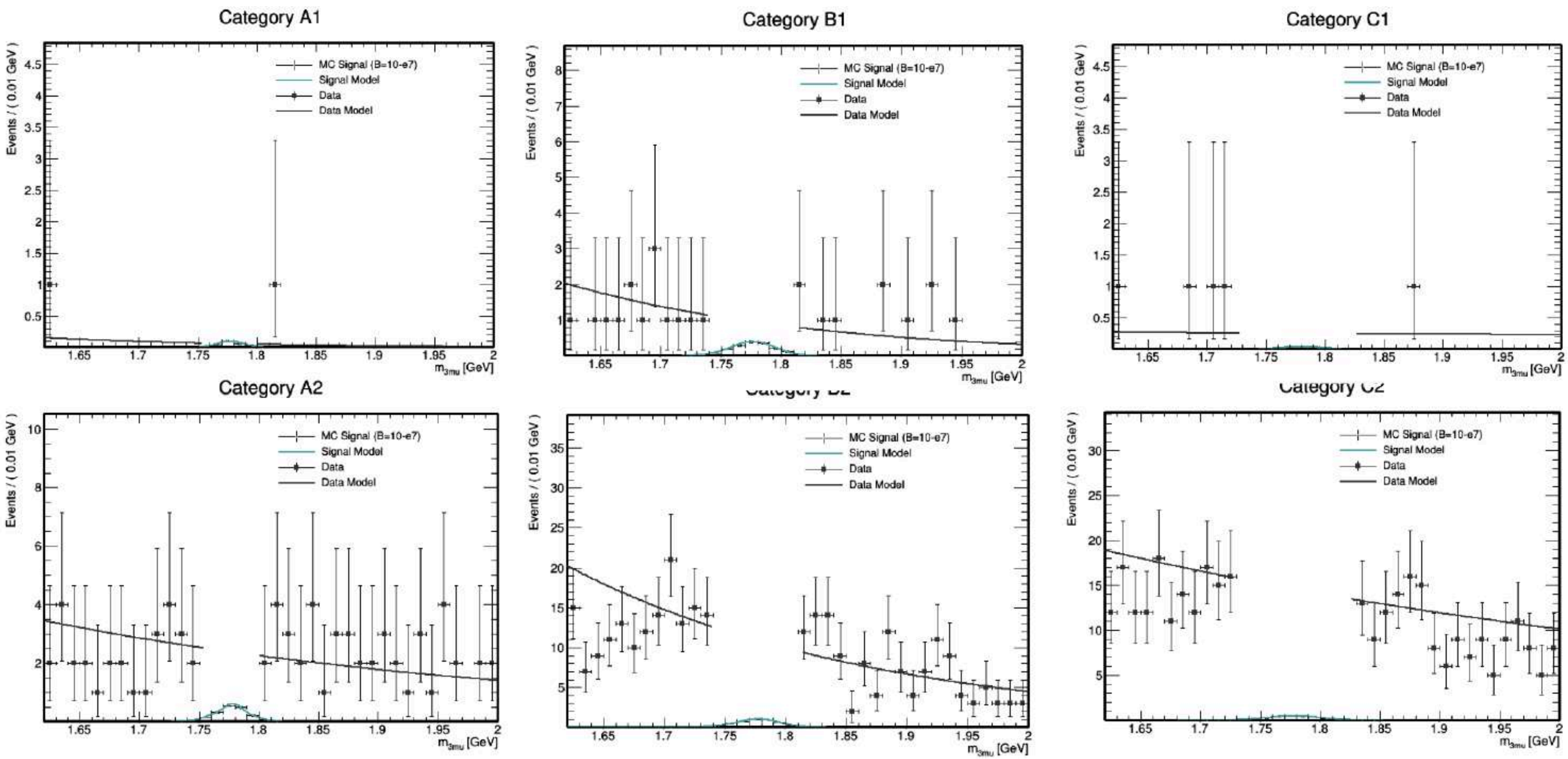
- Signal: gaussian + crystal ball function with mean fixed at tau mass,
  normalised to pp → B/D → τν branching ratios, assuming $\mathcal{B}(\tau \to 3\mu) = 10^{-7}$
- **Background** (data in sidebands): falling exponential



2017 (2 gbl+1trk mu) results:

Fit model:

- Signal: gaussian + crystal ball function with mean fixed at tau mass, normalised to pp → B/D → τν branching ratios, assuming $\mathcal{B}(\tau \to 3\mu) = 10^{-7}$
- **Background** (data in sidebands): falling exponential



Systematic uncertainties 2017

Systematics	Value	Notes
Ds Normalization	1.06	Computed in 2017 data
BR D→Tau	1.03	From PDG
BR Ds→PhiPi	1.08	From PDG
BR B→D	1.05	From PDG
BR B→Tau	1.03	From PDG
Uncertainty of measuring factor *f* (B/D ratio)	1.03	From 2016 AN, to be recomputed
$D^{\pm}$ Scaling	1.03	From PDG, scaled for the expected yield
B_s Scaling	1.04	From PDG, scaled for the expected yield
TripleMu to DoubleMu Triggered events ratio	1.14	Computed in 2017 data, as the difference of DM/TM triggered events in data and MC, scaled for the TM yield
BDT Cut	1.05	From 2016 AN, to be recomputed
Ratio Acceptances	1.01	From 2016 AN, to be recomputed
Muon ID Efficiencies	1.015	From 2016 AN, to be recomputed

Systematic uncertainties 2018

Systematics	Value	Notes
Ds Normalization	1.03	Stable yield in 2018, assigned uncertaintly on Ds yield from fit
BR D→Tau	1.03	From PDG
BR Ds→PhiPi	1.08	From PDG
BR B→D	1.05	From PDG
BR B→Tau	1.03	From PDG
Uncertainty of measuring factor *f* (B/D ratio)	1.03	From 2016 AN, to be recomputed
$D^{\pm}$ Scaling	1.03	From PDG, scaled for the expected yield
B_s Scaling	1.04	From PDG, scaled for the expected yield
TripleMu to DoubleMu Triggered events ratio	1.05	Takes into account correction for L1_TripleMu* and L1_DoubleMu4_* seeds in 2018
BDT Cut	1.05	From 2016 AN, to be recomputed
Ratio Acceptances	1.01	From 2016 AN, to be recomputed
Muon ID Efficiencies	1.015	From 2016 AN, to be recomputed

2017 Signal normalization

Events from Ds decay:

$$\text{w\_MC\_Ds} =$$

$$\frac{(\text{Initialprod\_XSection\_MC}) * \mathcal{B}(D_s \longrightarrow \tau\upsilon) * \mathcal{B}(\tau \longrightarrow 3\mu) * \mathcal{L}}{N_{initial_{MC}}} =$$

$$= 1.242 * 10^{-3} \times 1.05 \text{ (D+ correction)}$$

- $\mathcal{B}(\tau \longrightarrow 3\mu) = 10^{-7}$ assumed
- $\mathcal{B}(D_s \longrightarrow \tau\upsilon) = 0.055$ (PDG)
- $\mathcal{L}_{2017} = 38\ fb^{-1}$
- Initialprod_XSection_MC $= 2.18 * 10^{10} fb$ (GenXsecAnalyzer)
- $N_{initial_{MC}} = 3665610$

2017 Signal normalization

Events from B decays:

$$\text{w\_MC\_B} =$$

$$\frac{(\text{Initialprod\_XSection\_MC}) * \mathcal{B}(\tau \longrightarrow 3\mu) * [\mathcal{B}(B \longrightarrow \tau) + \mathcal{B}(B \longrightarrow D_s + ..) * \mathcal{B}(D_s \longrightarrow \tau v)] * \mathcal{L}}{N_{initial_{MC}}} =$$

$$= 4.160 * 10^{-4}\ (\text{B0}) \times 1.12\ (\text{Bs correction})$$
$$= 6.203 * 10^{-4}\ (\text{Bp}) \times 1.12\ (\text{Bs correction})$$

- $\mathcal{B}(\tau \longrightarrow 3\mu) = 10^{-7}$ assumed
- $\mathcal{B}(D_s \longrightarrow \tau v) = 0.055$ (PDG)
- $\mathcal{B}(B \longrightarrow \tau) = 0.03$ (PDG)
- $\mathcal{B}(B0 \longrightarrow D_s + ..)$ = 0.103 (PDG)
- $\mathcal{B}(Bp \longrightarrow D_s + ..)$ = 0.09 (PDG)
- $\mathcal{L}_{2017} = 38\ fb^{-1}$
- Initialprod_XSection_MC($B0$) $= 9.22 * 10^9 fb$ (GenXsecAnalyzer)
- Initialprod_XSection_MC(Bp) $= 9.37 * 10^9 fb$ (GenXsecAnalyzer)
- $N_{initial_{MC}}$ (B0) = 3 002 410, $N_{initial_{MC}}$ (Bp) = 2 005 360

2018 Signal normalization

Events from Ds decay:

$$\text{w\_MC\_Ds} = \frac{(\text{Initialprod\_XSection\_MC}) * \mathcal{B}(D_s \longrightarrow \tau \upsilon) * \mathcal{B}(\tau \longrightarrow 3\mu) * \mathcal{L}}{N_{initial_{MC}}} =$$

$$= 1.32 * 10^{-3} \times 1.05 \text{ (D+ correction)} \times 0.93 \text{ (Ds scale factor)}$$

- $\mathcal{B}(\tau \longrightarrow 3\mu) = 10^{-7}$ assumed
- $\mathcal{B}(D_s \longrightarrow \tau\upsilon) = 0.055$ (PDG)
- $\mathcal{L}_{2018} = 59.7\ fb^{-1}$
- Initialprod_XSection_MC $= 1.85 * 10^{10} fb$ (GenXsecAnalyzer)
- $N_{initial_{MC}} = 4.60 \cdot 10^{6}$

2018 Signal normalization

Events from B decays:

$$w\_MC\_B = \frac{(\text{Initialprod\_XSection\_MC}) * \mathcal{B}(\tau \longrightarrow 3\mu) * [\mathcal{B}(B \longrightarrow \tau) + \mathcal{B}(B \longrightarrow D_s+..) * \mathcal{B}(D_s \longrightarrow \tau v)] * \mathcal{L}}{N_{initial_{MC}}} =$$

$$= 4.78 * 10^{-4}\ (\text{B0}) \times 1.12\ (\text{Bs correction}) \times 0.93\ (\text{Ds scale factor})$$
$$= 1.44 * 10^{-3}\ (\text{Bp}) \times 1.12\ (\text{Bs correction}) \times 0.93\ (\text{Ds scale factor})$$

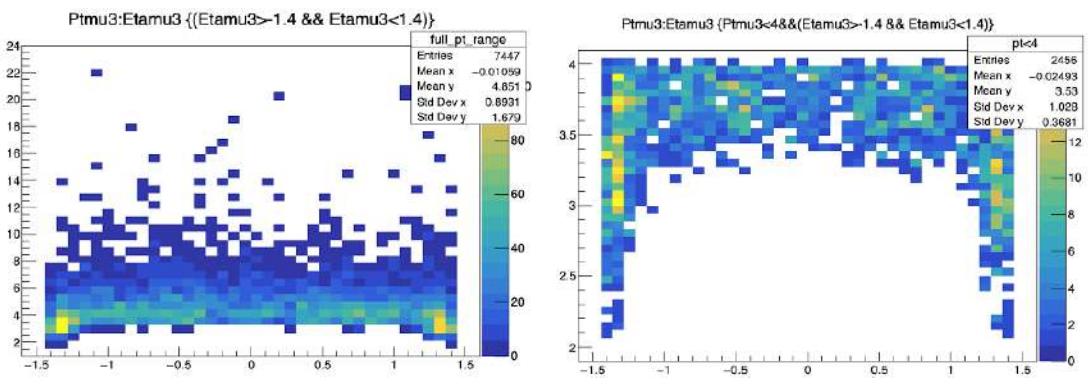
- $\mathcal{B}(\tau \longrightarrow 3\mu) = 10^{-7}$ assumed
- $\mathcal{B}(D_s \longrightarrow \tau v) = 0.055$ (PDG)
- $\mathcal{B}(B \longrightarrow \tau) = 0.03$ (PDG)
- $\mathcal{B}(B0 \longrightarrow D_s+..)$ = 0.103 (PDG)
- $\mathcal{B}(Bp \longrightarrow D_s+..)$ = 0.09 (PDG)
- $\mathcal{L}_{2018} = 59.7\ fb^{-1}$
- Initialprod_XSection_MC($B0$) $= 7.85 * 10^9 fb$ (GenXsecAnalyzer)
- Initialprod_XSection_MC(Bp) $= 9.17 * 10^9 fb$ (GenXsecAnalyzer)
- $N_{initial_{MC}}$ (B0) $= 3.49 \cdot 10^6$, $N_{initial_{MC}}$ (Bp) $= 1.33 \cdot 10^6$

“custom” globalMuonID - motivations

Bsmumu team developed the SoftMVA muon ID (ref: CMS AN-2016/178)

the BDT training and test was done on mu, pi, k with pT>4GeV and |eta|<1.4

- in DsTau3Mu, asking mu3_pt>4 GeV cuts 30% of signal
- moreover, an extension of such SoftMVA would be necessary to cover |eta|>1.4



globalMuonID: vars used in BDT, preselections and settings

1. mu_combinedQuality_chi2LocalMomentum < 5000
2. mu_combinedQuality_chi2LocalPosition < 1000
3. mu_combinedQuality_staRelChi2
4. mu_combinedQuality_trkRelChi2 < 20
5. mu_combinedQuality_globalDeltaEtaPhi
6. mu_combinedQuality_trkKink < 900 (log used)
7. log_mu_combinedQuality_glbKink
8. mu_combinedQuality_glbTrackProbability
9. **mu_trackerLayersWithMeasurement**
10. mu_Numberofvalidpixelhits > 0
11. mu_validMuonHitComb
12. mu_numberOfMatchedStations
13. mu_segmentCompatibility
14. mu_timeAtIpInOutErr < 10
15. mu_GLnormChi2 < 6000
16. mu_innerTrack_normalizedChi2 < 40
17. mu_outerTrack_normalizedChi2
18. mu_innerTrack_validFraction > 0.5

BDT settings:

```
NTrees=1000
MinNodeSize=1.5%
MaxDepth=8
BoostType=RealAdaBoost
AdaBoostBeta=0.3
UseBaggedBoos
BaggedSampleFraction=0.05
SeparationType=GiniIndex
nCuts=-1
```

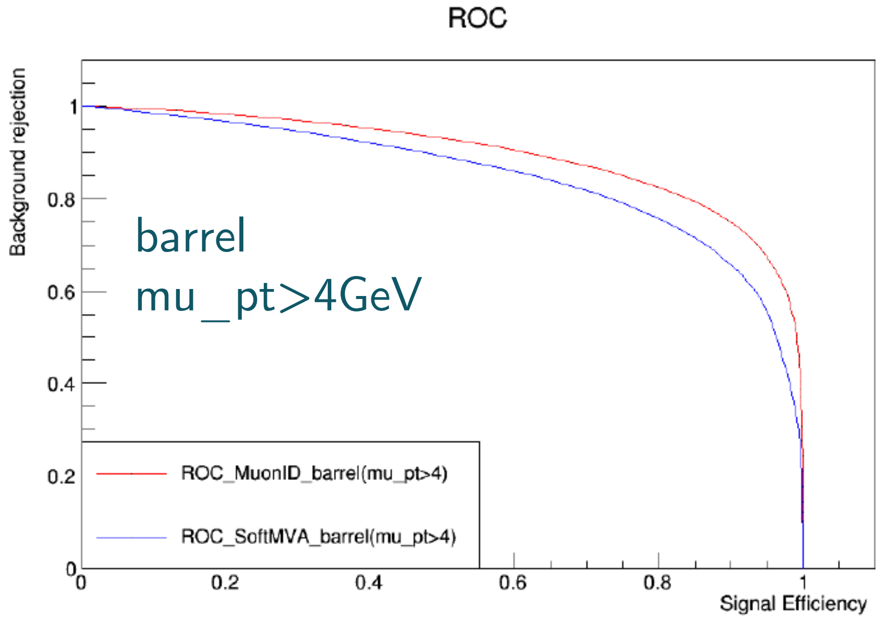
Training/test splitting:

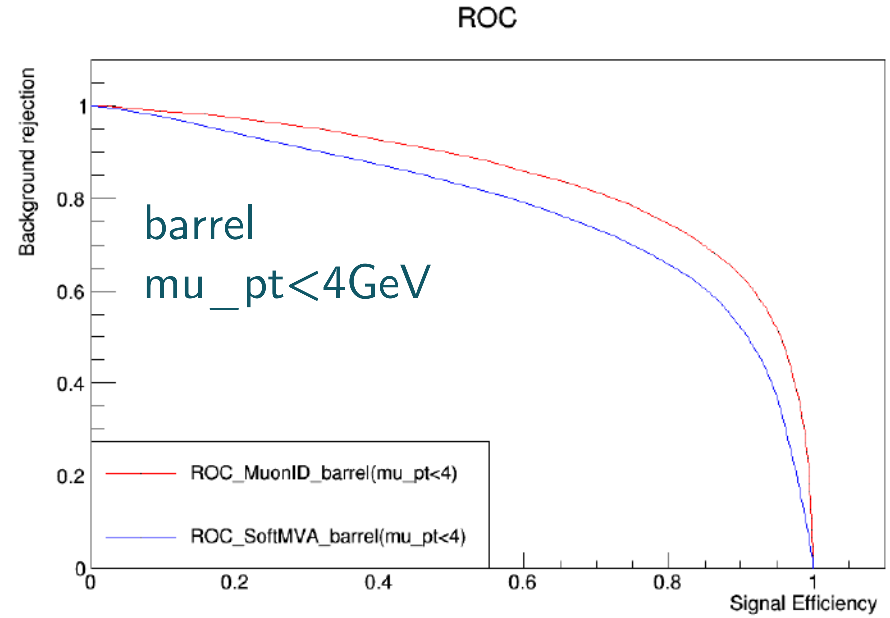
- Random
- 70/30 proportion

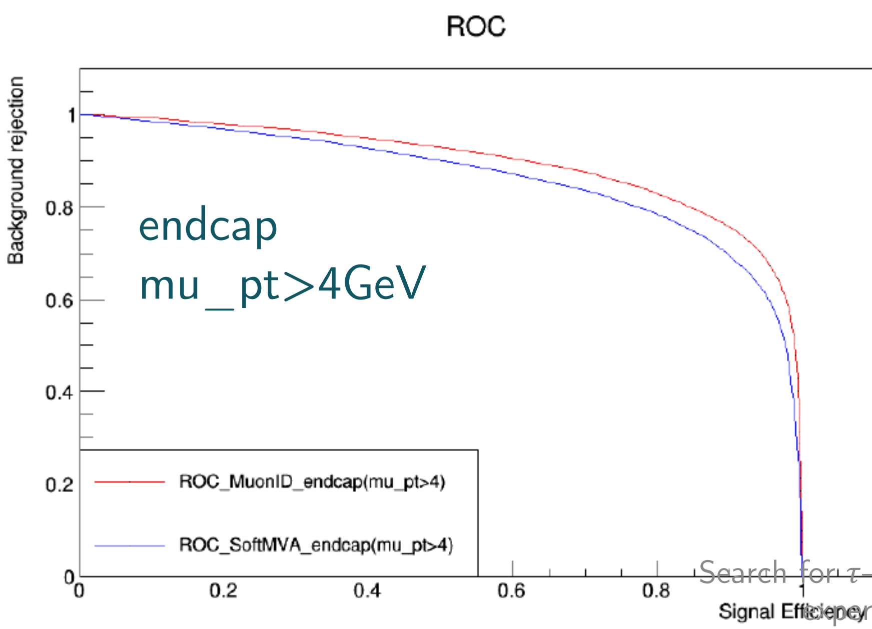
```
BARREL
: Signal     -- train : 51150
: Signal     -- test  : 22000
: Signal     -- total : 73150
: Background -- train : 29391
: Background -- test  : 13000
: Background -- total : 42391
```

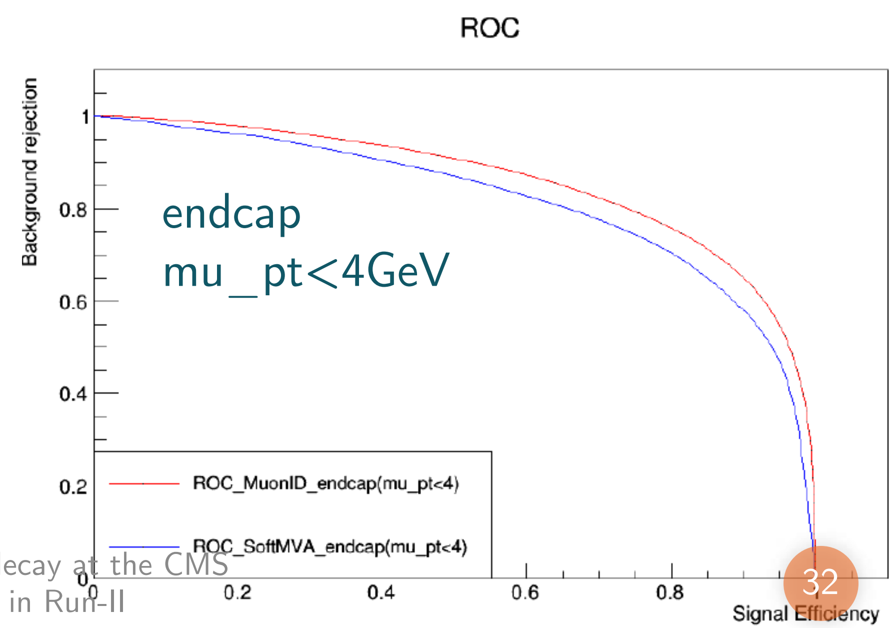
```
ENDCAP
: Signal     -- train : 81405
: Signal     -- test  : 35000
: Signal     -- total : 116405
: Background -- train : 50030
: Background -- test  : 21500
: Background -- total : 71530
```

SoftMVA – «custom»glbMuonID ROC comparison

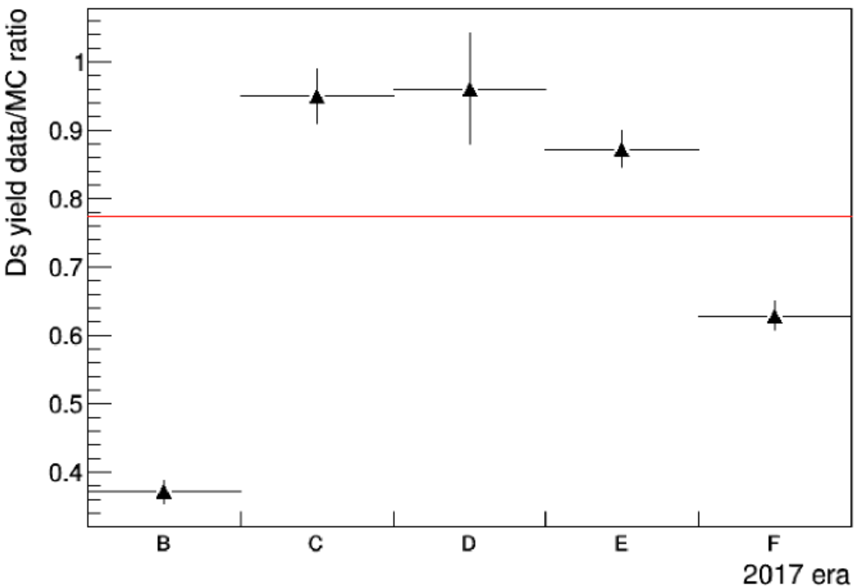


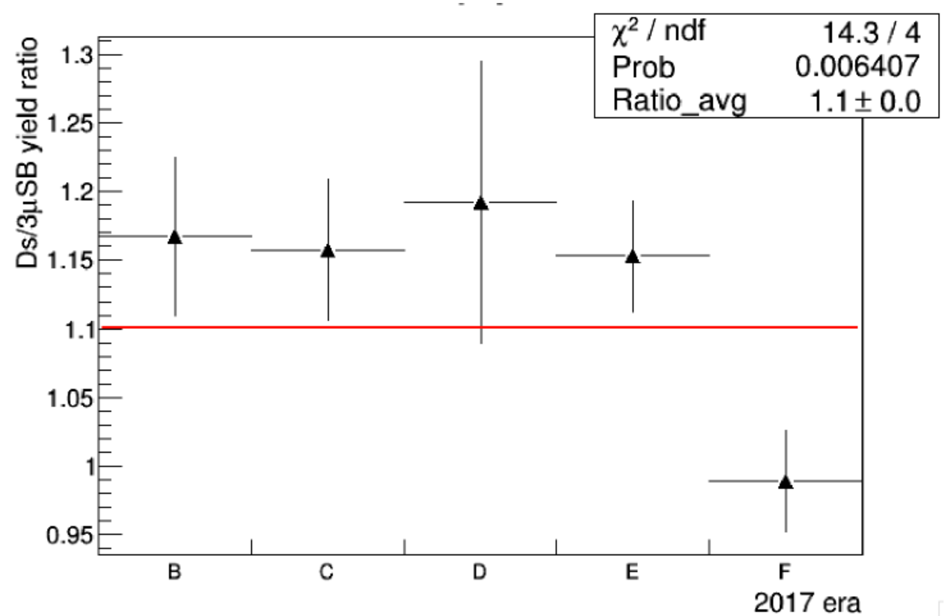


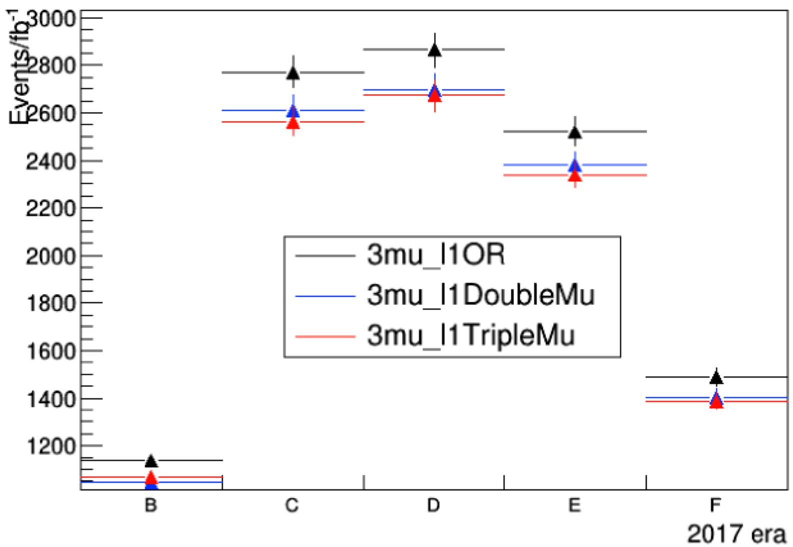




checks on Ds and trigger yields 2017







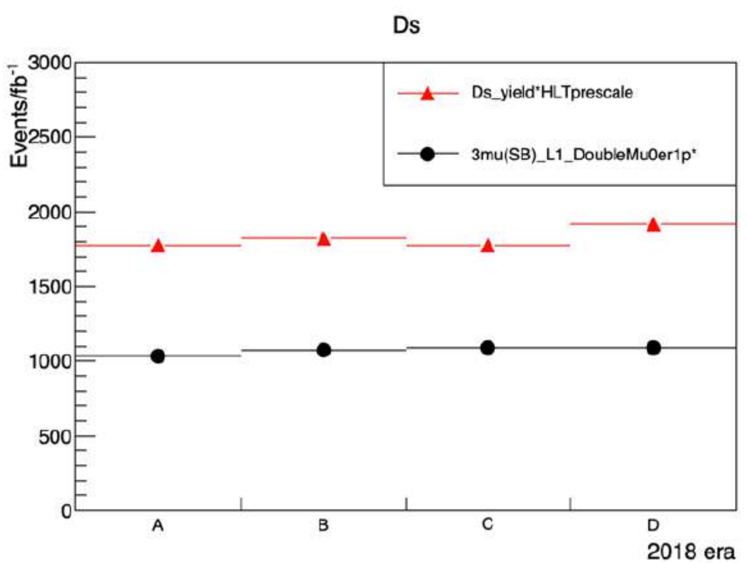
2018 Ds yield stability

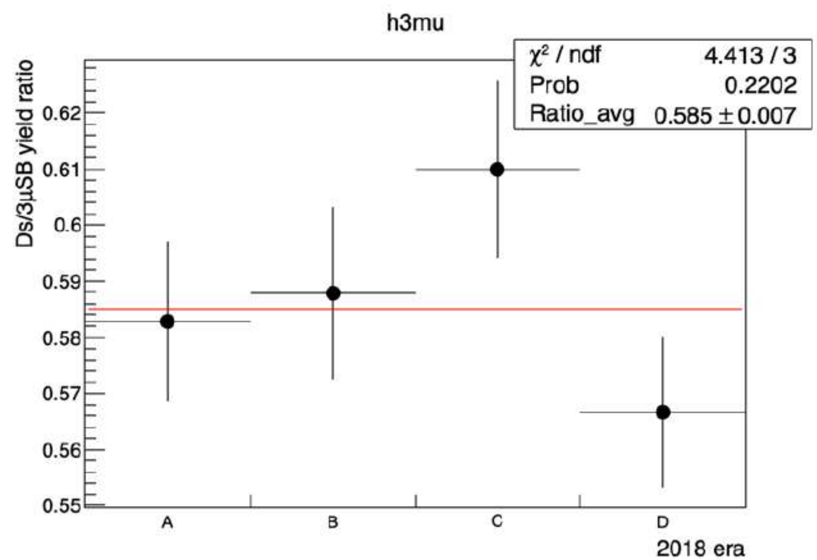
Check if the ratio of three-muons sideband events and Ds→ϕ(2μ)π, both triggered by L1_DoubleMu0er1p*, stays constant over time

Ds yield: signal yield from $2\mu + 1trk$ invariant mass fit
3mu (SB): number of three-muons candidates passing the analysis selections in mass sidebands triggered by L1_DoubleMu0er1p5_SQ_OS_dR_Max1p4

Stat. error on <yield ratio> $\sigma_\mu = 0.007$
Scale factor $S = \sqrt{\chi^2/(N-1)} = 1.2$

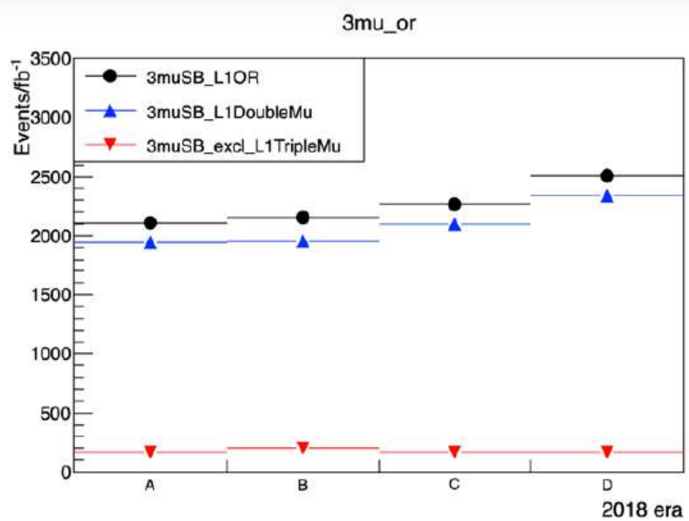
Systematic error $\approx S * \sigma_\mu/\mu = 1.4\%$

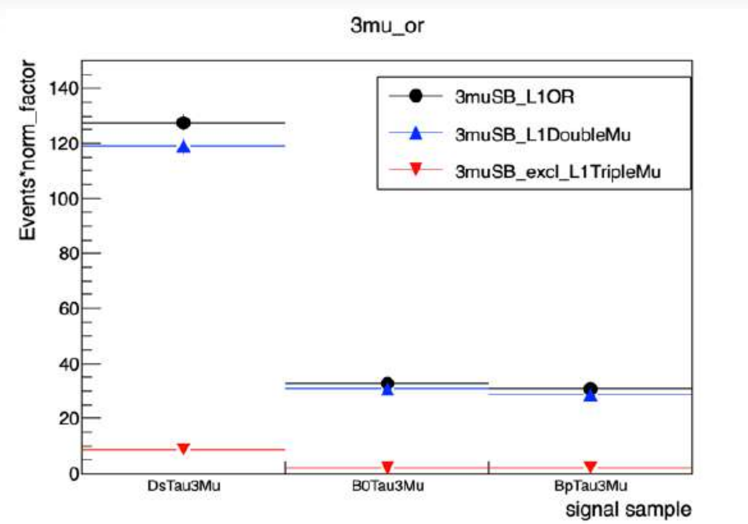




2018 - L1seeds other than DoubleMu0

Ds yield stability has been checked using L1_DoubleMu0er1p* (always on).
Here we account for contributions from L1_TripleMu*





Average TripleMu*/DoubleMu ratio:

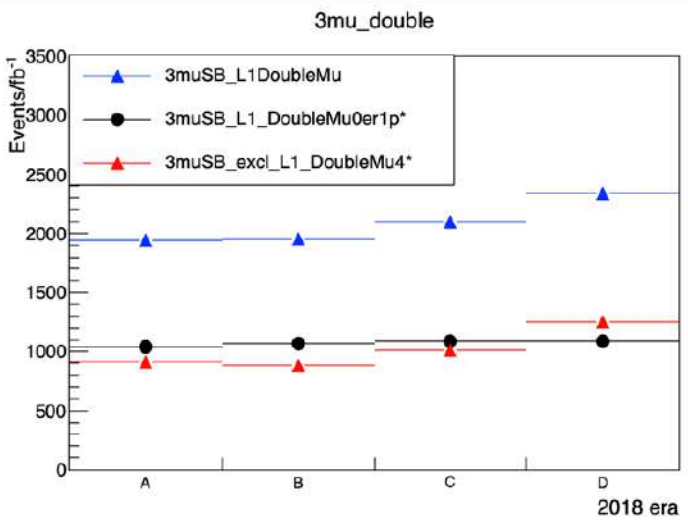
- in data = 0.080
- in MC = 0.069

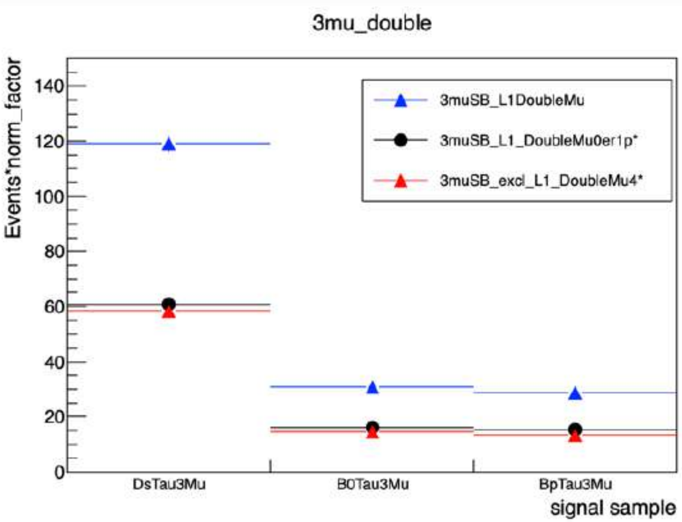
Discrepancy: 10%, only affects ~7% of events* → < **1%**

*events exclusively triggered by L1_TripleMu

2018 - L1seeds other than DoubleMu0

Ds yield stability has been checked using L1_DoubleMu0er1p* (always on).
Here we account for contributions from **L1_DoubleMu4_***





Average **DoubleMu4***/DoubleMu ratio:

- in data = 0.50
- in MC = 0.47

Discrepancy: 7%, affects ~47% of events* → **4%** systematic uncertainty

*events exclusively triggered by L1DoubleMu4_*

2018 3 global BDT input variables – without PS-SV distance

cat A

0 - cLP - cLP>30?30:cLP
1 - tKink - tKink>80?80:tKink
2 - segmComp - segmComp<0.2?0.2:segmComp
3 - fv_nC - fv_nC>25?25:fv_nC
4 - fv_dphi3D - fv_dphi3D>0.15?0.15:fv_dphi3D
5 - fv_d3Dsig - fv_d3Dsig>100?100:fv_d3Dsig
6 - d0sig - d0sig>15?15:d0sig
7 - mindca_iso - mindca_iso>0.5?0.5:mindca_iso
8 - trkRel - trkRel>10?10:trkRel
9 - MuonID_Mu1
10 - MuonID_Mu2
11 - MuonID_Mu3
12 - TreeMu3.mu_nTracks03
13 - Pt_tripl - Pt_tripl
14 - abs(dxy3/dxyErr3)
~~15 - PS_SV_dxy = sqrt((RefVx1-SVx)*(RefVx1-SVx)+(RefVy1-SVy)*(RefVy1-SVy))~~

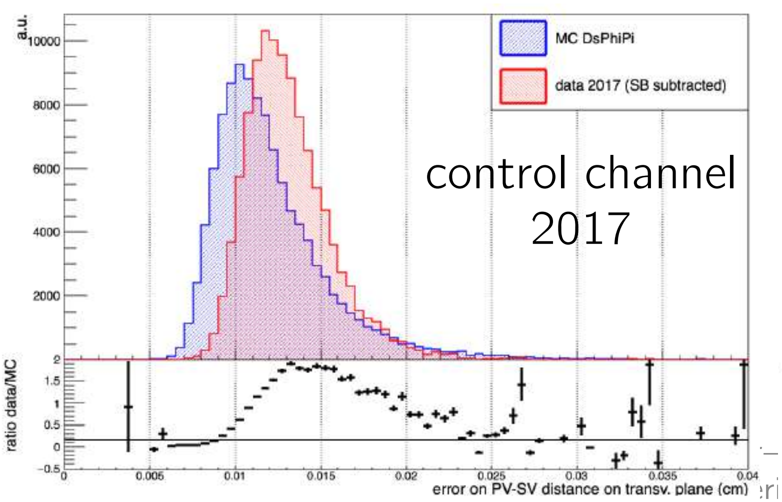
Var 0..8 are same as 2016 analysis

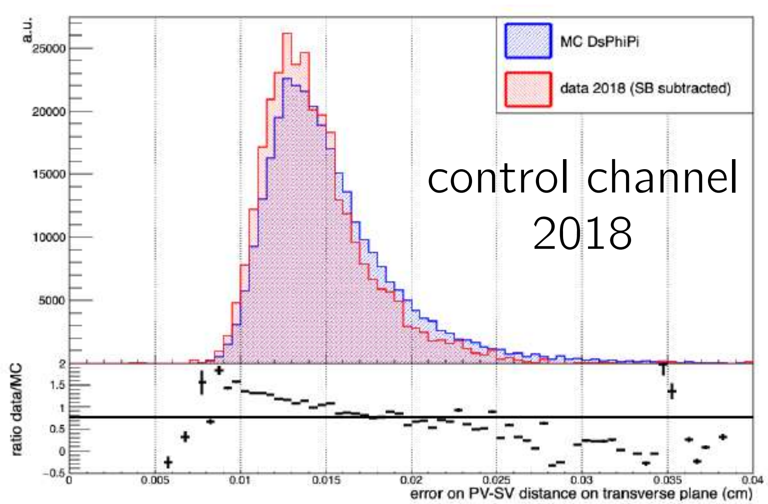
cat B - C

0 - cLP - cLP>30?30:cLP
1 - tKink - tKink>80?80:tKink
2 - fv_nC - fv_nC>25?25:fv_nC
3 - fv_dphi3D - fv_dphi3D>0.15?0.15:fv_dphi3D
4 - fv_d3Dsig - fv_d3Dsig>100?100:fv_d3Dsig
5 - d0sig - d0sig>15?15:d0sig
6 - mindca_iso - mindca_iso>0.5?0.5:mindca_iso
7 - trkRel - trkRel>10?10:trkRel
8 - MuonIDeval_Mu1.MuonID
9 - MuonIDeval_Mu2.MuonID
10 - MuonIDeval_Mu3.MuonID
11 - TreeMu3.mu_segmentCompatibility
12 - TreeMu2.mu_segmentCompatibility
13 - TreeMu1.mu_segmentCompatibility
14 - Pt_tripl - Pt_tripl
~~15 - PS_SV_dz = abs(RefVz1-SVz)~~

Study on vertexing variables mismodelled in 2017 MC

1. Mismodelling of some vertexing variable in 2017 simulation has been reported in the past by other analises. It is know that the **mismodelling is still there also in the UL samples**.
2. In our analysis, we observed that the usage of pure PV-SV distances (both 3d and dxy) gave an artificially good BDT (biased by the mismodelling)
3. We studied all quantities related to the distance between the two vertices: positions, errors, distance projections. The outcome apparently is that the **mismodelling mostly affects the errors on the vertex positions**. The major contribution in distance error computation comes from SV covariance matrix:
   - 2018: decent data/MC agreement for all elements of SV cov. matrix
   - 2017: strong differences between data and MC
4. As our HLT has a cut on the BS-PV distance significance, we performed the following additional exercise:
   - Dropped HLT filter for 2017 MC,
   - put veto on trigger matching
   - looked at triplets made of muons which didn't match with the trigger legs:
     - ➢ the mismodelling is still there, so **does not come from the trigger**



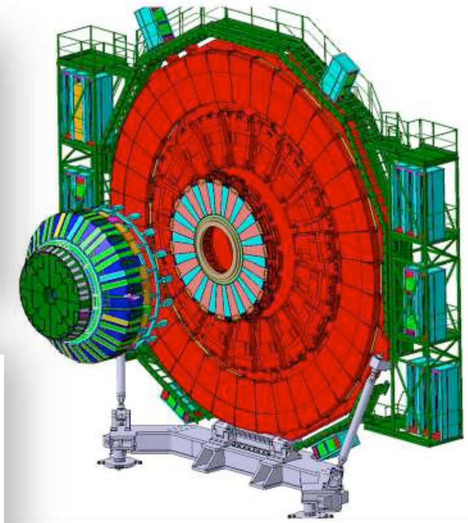


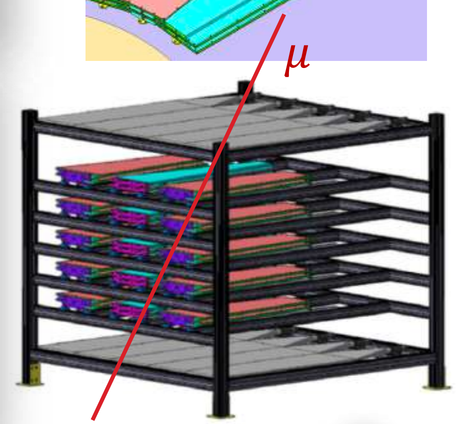
Preparation for Run-III:

Trigger:
- Dedicated trigger will be needed for Run III data taking
- Will benefit from upgraded Muon System (CSC+GE11 trigger)

GE11 upgrade: final validation, installation, commissioning
- Installation of positive endcap started in July 2020
- Validation of detectors at the cosmic stand for the positive endcap finalised in Oct. 2020
- Both stations have been fully installed, negative endcap has 100% of services in place
- GEM joined the last 2 MWGRs

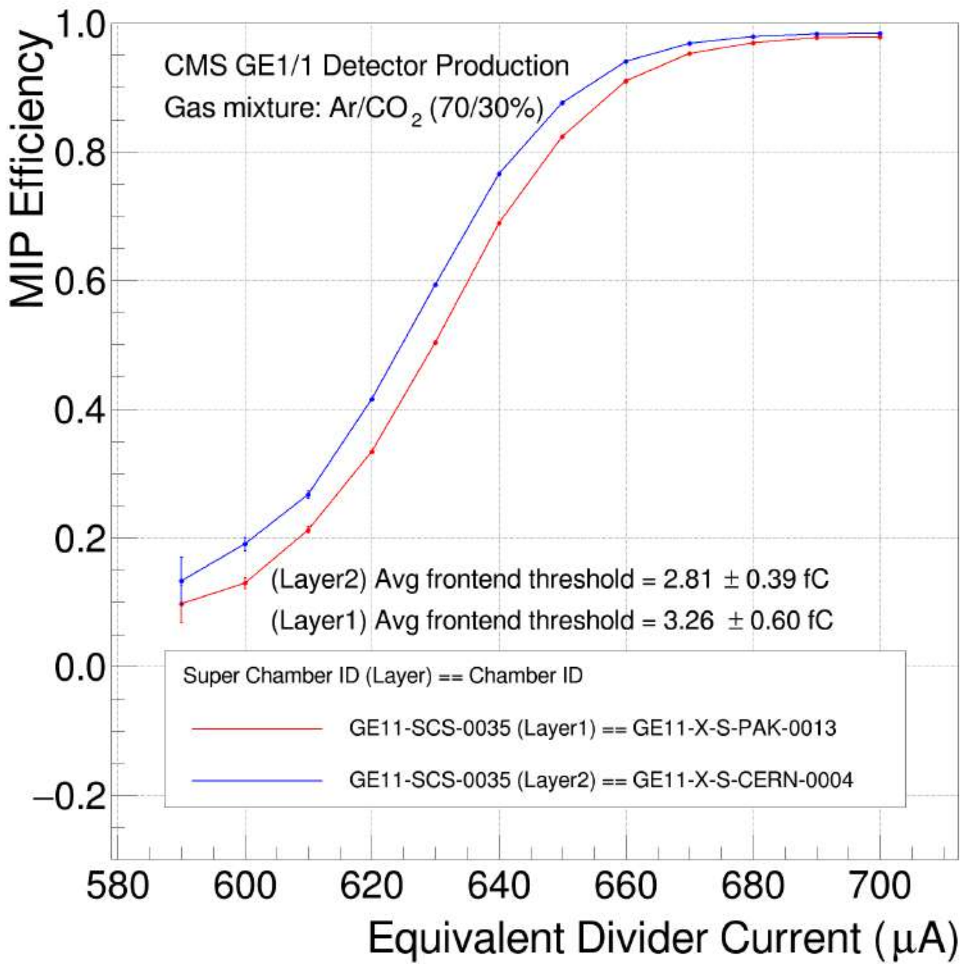
My work on-site
- Performed final validation of the GE1/1 detectors at the cosmic stand (QC8) for the finalisation of the positive endcap. Recently validated additional spare detectors.
- Now contributing to the commissioning of the installed GE1/1 station (DOC shifts)



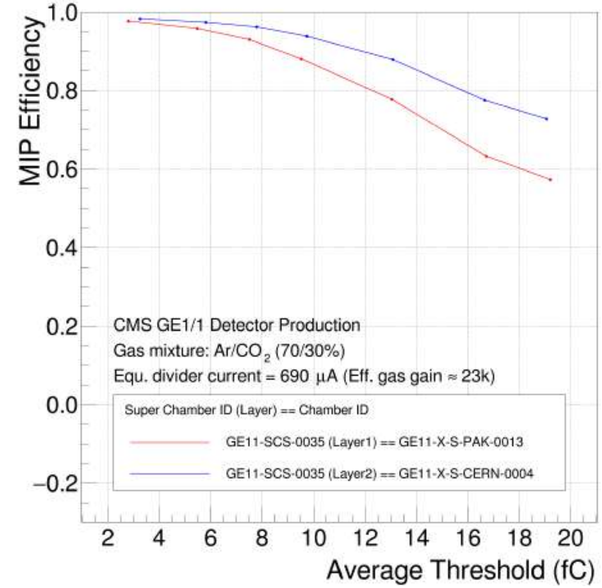


GE11 Final quality controls: QC8 results

Example of efficiency vs HV scan



Efficiency vs thresh. scan



Spatial resolution