First 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 6 2019

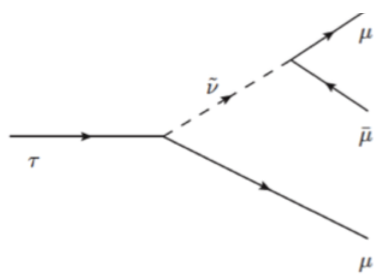
Motivations

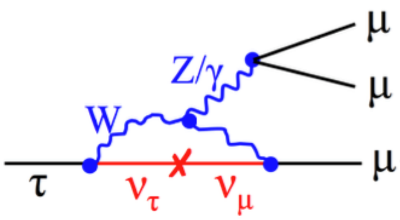
- ❖ $\tau \to 3\mu$ transition
  - ✓ doesn't conserve the lepton family number
  - ✓ doesn't involve neutrinos in the final state
    - ➢ Charged Lepton Flavour Violation (CLFV)

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

- ❖ Suppressed in the Standard Model
  Branching Ratio $\tau \to 3\mu$ (SM) $\sim \mathcal{O}(10^{-14})$
  arXiv:hep-ph/9810484

- ❖ Enhanced BR in SUSY, 2HDM
  $\tau \to 3\mu$ (BSM) $\sim \mathcal{O}(10^{-8})$





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

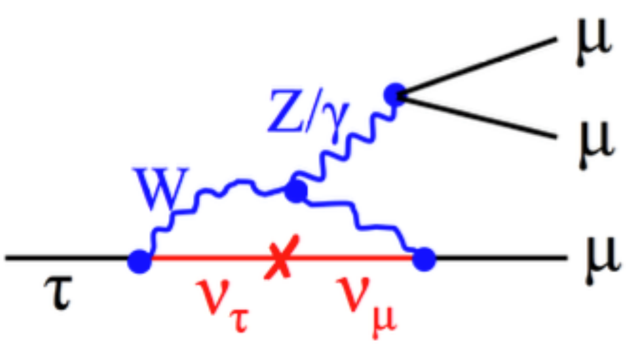
Motivations

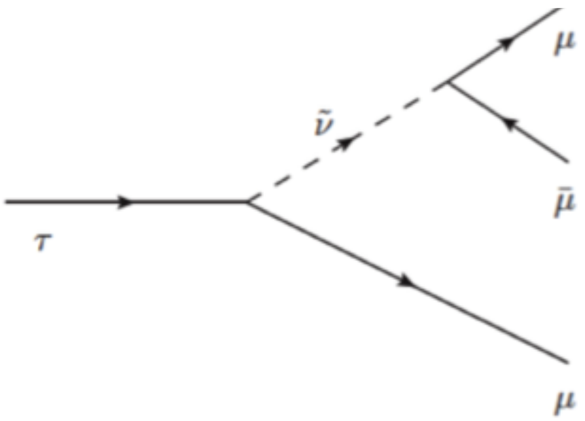
❖Why $\tau \rightarrow 3\mu$ transition?

✓ τ decay can be studied at pp colliders

✓ "background-free" decay mode

✓ enhanced in some BSM theories





State of the art

Search for $\tau \longrightarrow 3\mu$ at **lepton colliders**:

- Belle exp. (KEKB), $BR(\tau \longrightarrow 3\mu) < 2.1 \times 10^{-8}$ at 90% CL
[arXiv:1001.3221]

- BaBar exp. (SLAC), $BR(\tau \longrightarrow 3\mu) < 3.3 \times 10^{-8}$ at 90% CL
[arXiv:1002.4550]

Search for $\tau \longrightarrow 3\mu$ at **hadron colliders**:

- LHCb exp. (LHC), $BR(\tau \longrightarrow 3\mu) < 4.6 \times 10^{-8}$ at 90% CL
[https://doi.org/ 10.1007/JHEP02(2015)121]

- ATLAS exp. (LHC), $BR(\tau \longrightarrow 3\mu) < 3.8 \times 10^{-7}$ at 90% CL
[arXiv:1601.03567]

- CMS exp. (LHC), $BR(\tau \longrightarrow 3\mu) < 8.8 \times 10^{-8}$ at 90% CL
[CMS-PAS-BPH-17-004] 2016 data (Run II, pp @ 13 TeV): $\mathcal{L} = 33 fb^{-1}$

Tau production at CMS

Two channels:

- Heavy Flavour (**HF**) (D ⟶ τν, B ⟶ τν…, B ⟶ D(τν)…)
- **W** boson production (W ⟶ τν)

Expected inclusive production cross section: ~$2\times10^{11} fb$

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

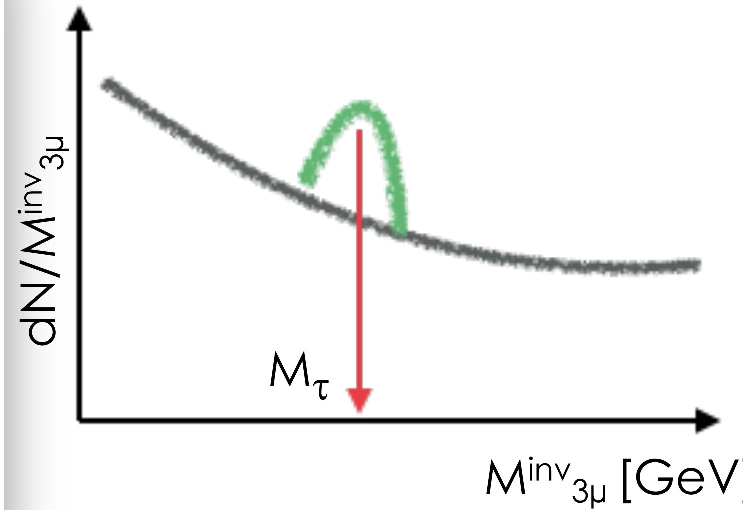
Process 1	Process 2	No. of τ for $\mathcal{L} = 38\ fb^{-1}$
$pp \to c\bar{c} + ...$	$D \to \tau\nu_\tau$ (95% D_s, 5% $D^\pm$)	$4.61 \cdot 10^{12}$
$pp \to b\bar{b} + ...$	$B \to \tau\nu_\tau + ...$ (44% $B^\pm$, 45% B^0, 11% B_s^0)	$1.73 \cdot 10^{12}$
	$B \to D(\tau\nu_\tau) + ...$ (98% D_s, 2% $D^\pm$)	$7.25 \cdot 10^{11}$
$pp \to W + ...$	$W \to \tau\nu_\tau$	$7.72 \cdot 10^{8}$
$pp \to Z + ...$	$Z \to \tau\tau$	$1.50 \cdot 10^{8}$

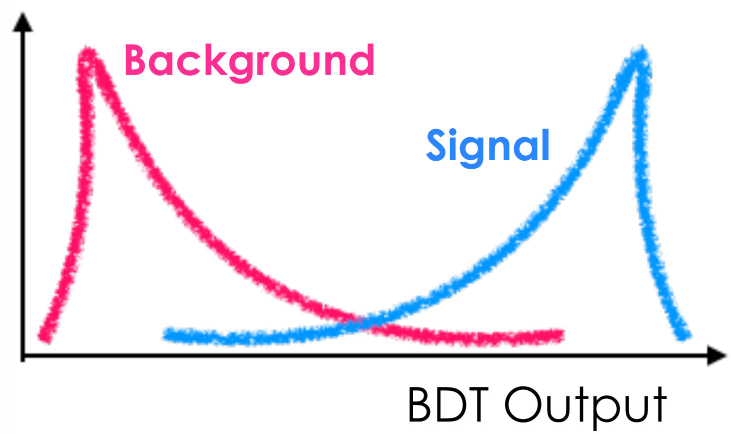
- HF channel: $\mathcal{O}(10^{12})$ produced τ
  ~10^4 τ ⟶ 3μ *events**
  low p_T and low missing transverse energy
- W channel: $\mathcal{O}(10^{9})$ produced τ
  ~10 τ ⟶ 3μ *event* *
  *assuming upper limit by Belle exp.

Analysis strategy

- Search for a **bump at τ mass** in the 3μ invariant mass distribution
  (smoothly distributed background expected)
- Signal from Monte Carlo simulations
- Production rate of D and B mesons obtained from data in $D_s \longrightarrow \phi(\mu\mu)\pi$ **control channel**.

- MVA discriminator for **background rejection**
- **Event categorization** to improve the search sensitivity. Events are binned in
  - 3μ-system mass resolution
  - MVA discriminator
- The $\tau \rightarrow 3\mu$ signal is extracted by a simultaneous **maximum likelihood fit** of the thus-formed six unbinned mass distributions.





Datasets, Trigger and MC simulations

Online data selection: HLT_DoubleMu3_Trk_Tau3mu_v*

seeded by two different triggers at Level 1: DoubleMu/TripleMu

- two collimated muon track with common vertex and $p_T > 3$ GeV
- one track compatible with the 2μ vertex and $p_T > 1.2$ GeV
- invariant mass (2μ+trk) in the range 1.60-2.02 GeV
- vertex (2μ+trk) displaced from beam-spot by >2 sigma

MC signal simulation:

- Events generated with PYTHIA 8 in MinimumBias configuration
  - $D_s \longrightarrow \tau\upsilon_\tau \longrightarrow 3\mu\upsilon_\tau$
  - $B^0 \longrightarrow \tau \ldots \longrightarrow 3\mu$ and $B^\pm \longrightarrow \tau \ldots \longrightarrow 3\mu$
  - $D_s \longrightarrow \phi(\mu\mu)\pi$ (normalization channel)

$\tau \longrightarrow 3\mu$ Event selection

Offline:

- Triplet have at least 2 tracks associated with PV
- 3µ vertex $\chi^2 \in [0, 15]$
- at least 3 globalMuons w/ $p_T > 2$ GeV per event
- dR(2µ) < 0.8 & dz(2µ) < 0.5 cm
- 3µ abs(total charge)=1
- 3µ invariant mass m(3µ): 1.62-2.00 GeV
- exclusion of muon pairs with inv. mass close to ϕ (1020) or ϖ(782)
- Matching trigger "legs" within dR<0.03

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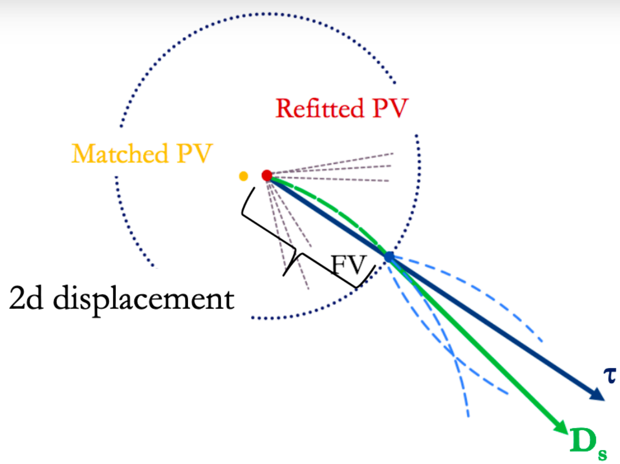
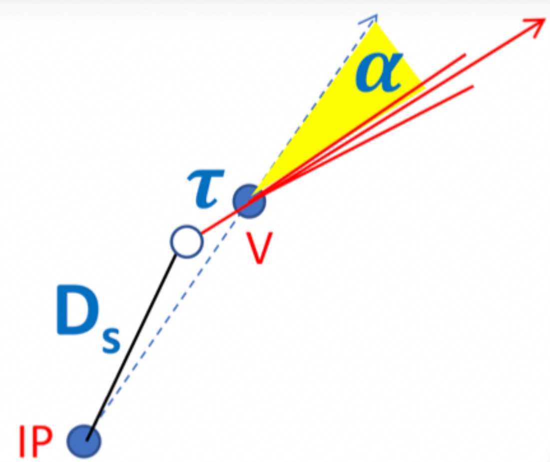
inv. mass signal region [1.75-1.80] GeV
inv. mass sidebands [1.65-1.73] U [1.82-1.90] GeV





$D_s \longrightarrow \phi(\mu\mu)\pi$ Event selection

Offline:

- Triplet have at least 2 tracks associated with PV
- 2μ+1trk vertex $\chi^2 \in [0, 15]$
- at least 2 globalMuons w/ $p_T > 2$ GeV per event
- 2μ have opposite charge and are different from track
- dR(2μ) < 0.8 & dz(2μ) < 0.5 cm
- 3μ abs(total charge)=1
- 2μ invariant mass m(2μ): 1.00-1.04 GeV
- Matching trigger "legs" within dR<0.03

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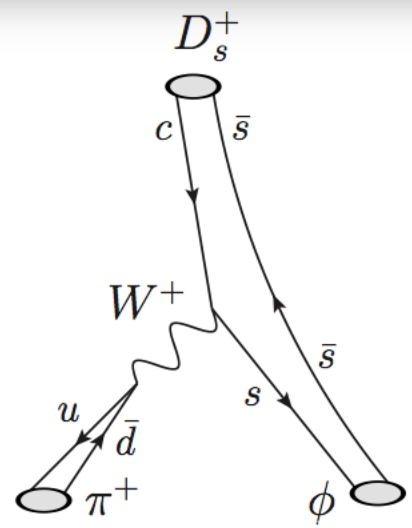
inv. mass signal region [1.93 - 2.01] GeV
inv. mass sideband [1.70 - 1.80] GeV



Signal normalization strategy

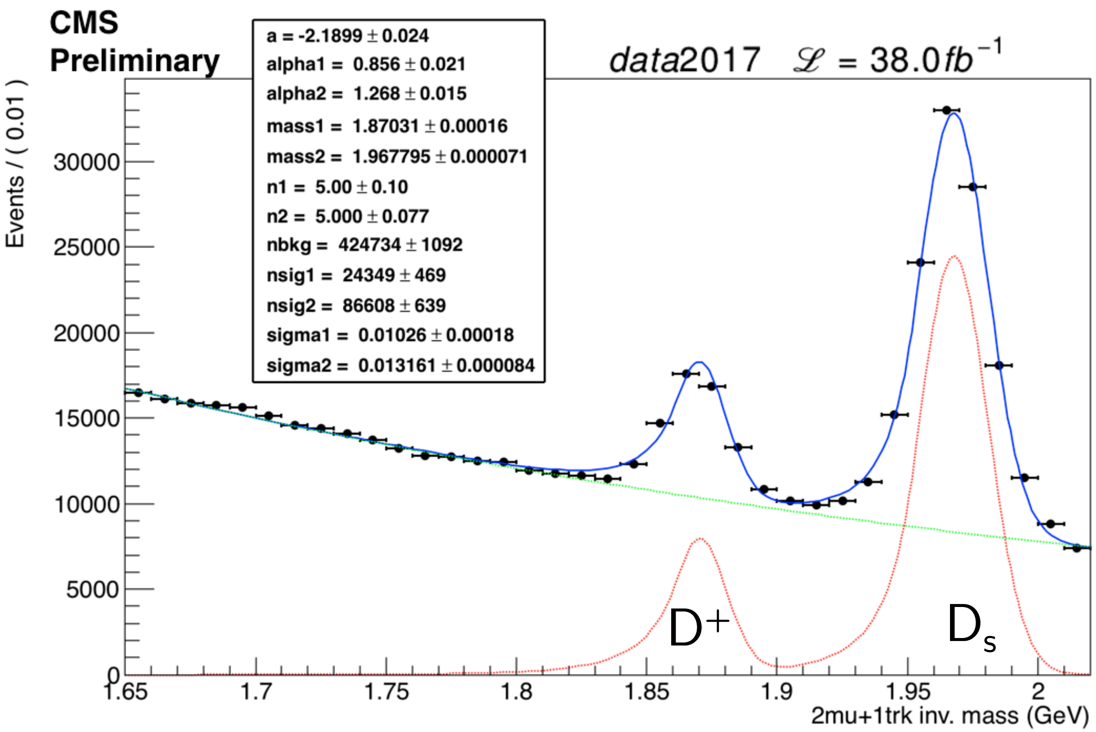
DoubleMu triggered events can be directly normalized by $D_s \longrightarrow \phi(\mu\mu)\pi$

- TripleMu triggered events cannot → DoubleMu/TripleMu ratio measured from data.
- Contribution from B decays scaled to D_s yield using production cross sections
- D_s production is a mixture of prompt D_s and D_s produced in B decays → additional factor derived from MC

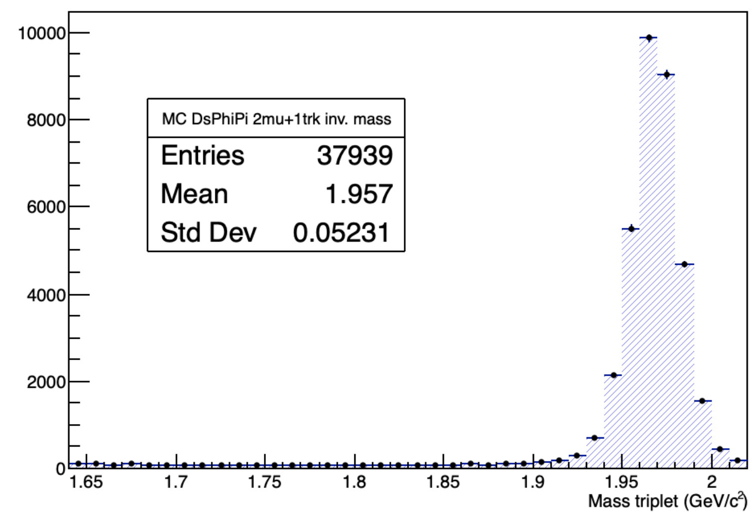
	DoubleMu L1	Exclusive TripleMu L1	
$D_s \longrightarrow \tau$	40% Directly normalized by $D_s \longrightarrow \phi(\mu\mu)\pi$	28%	68%**
$B^0 \longrightarrow \tau$ $B^{\pm} \longrightarrow \tau$	19%	13%	32%**
	59%*	41%*	*estimated from MC **from production BR

Ds yield measurement in $D_s \longrightarrow \phi(\mu\mu)\pi$

Events passing $D_s \longrightarrow \phi(\mu\mu)\pi$ selections:
2μ+1trk invariant mass fitted to compute D_s yield in data triggered by HLT (L1 DoubleMu)

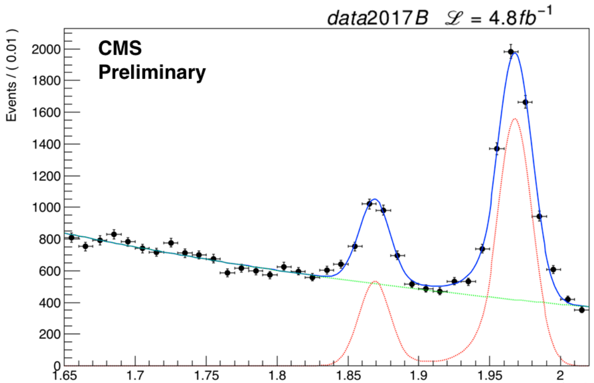


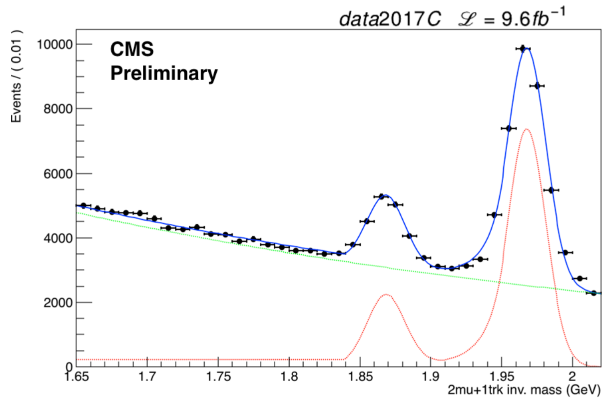
- D^+ peak: crystal ball function in range [1.85, 1.89] GeV
- D_s peak: crystal ball function in range [1.93, 2.0] GeV
- Background: exponential

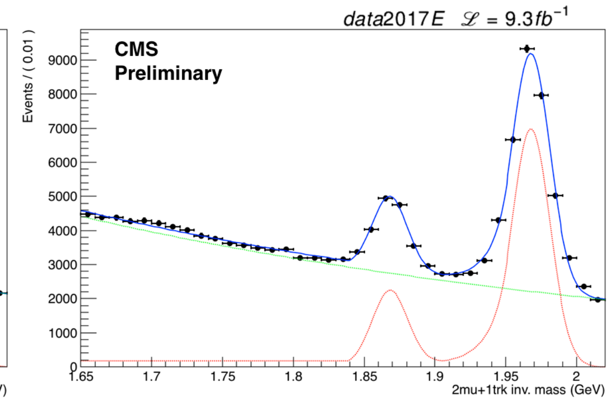


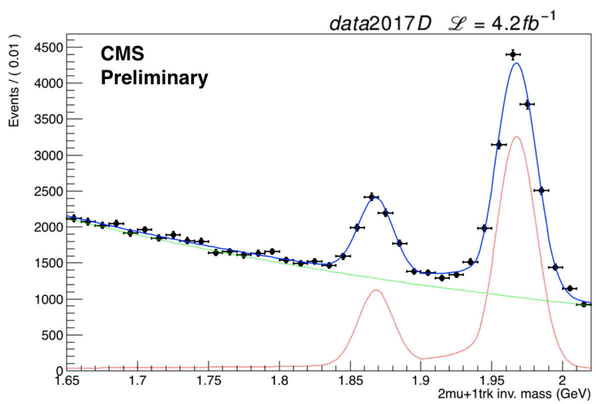
D_s yield in MC = events in [1.93, 2.0] GeV

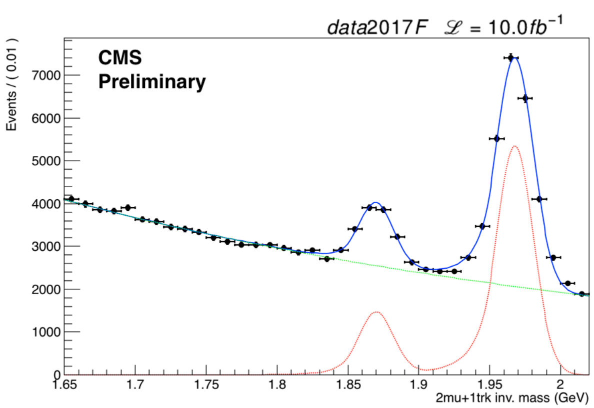
Ds yield measurement in $D_s \longrightarrow \phi(\mu\mu)\pi$









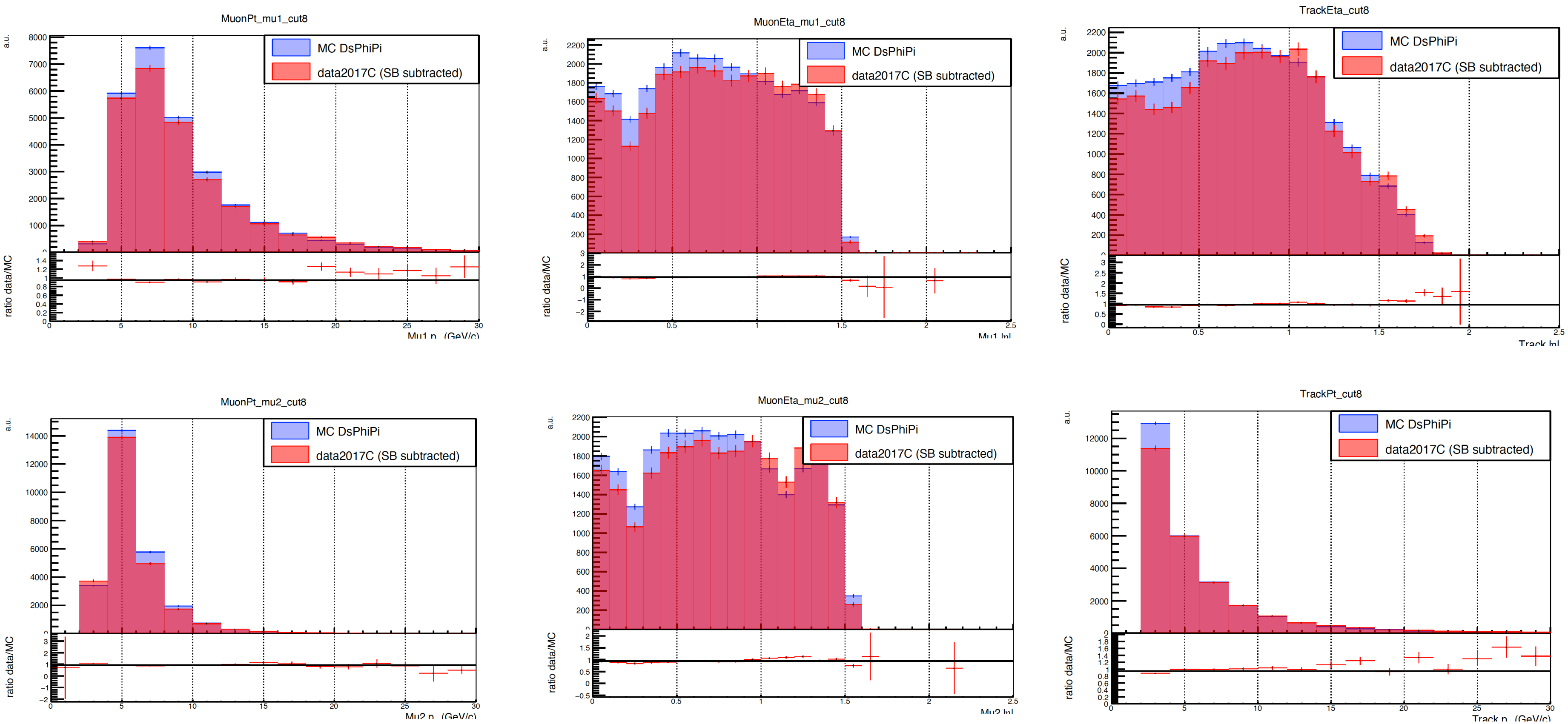


Run	D_s yield per fb^{-1} in data	Data/MC D_s yield
2017 B	1022.0 ± 26.2	0.345 ± 0.009
2017 C	2642.9 ± 74.7	0.892 ± 0.025
2017 D	2724.0 ± 119.6	0.919 ± 0.040
2017 E	2584.5 ± 72.1	0.872 ± 0.024
2017 F	1779.1 ± 26.2	0.600 ± 0.009
Whole 2017	2182.6 ± 15.4	0.737 ± 0.005

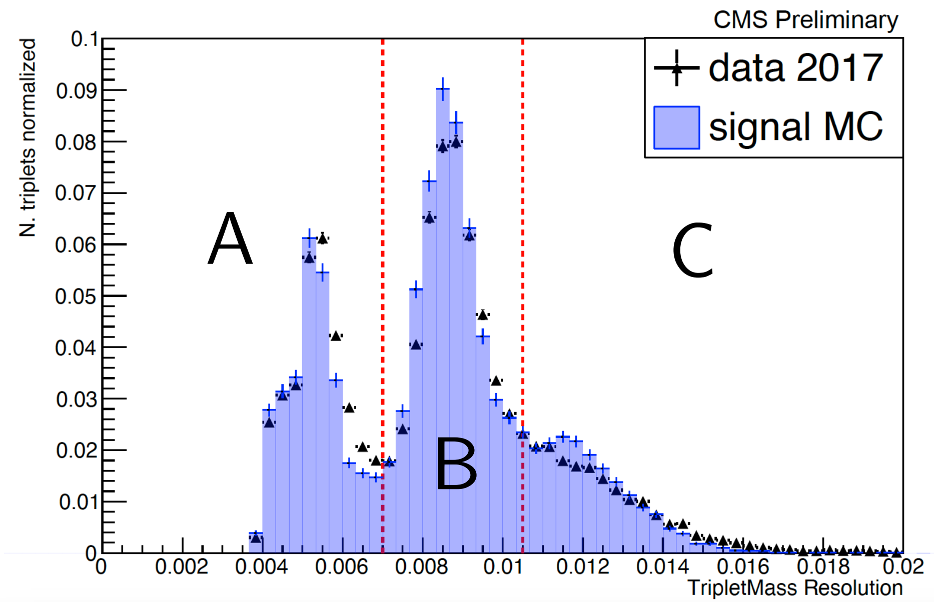
correction factor for signal (MC) normalization

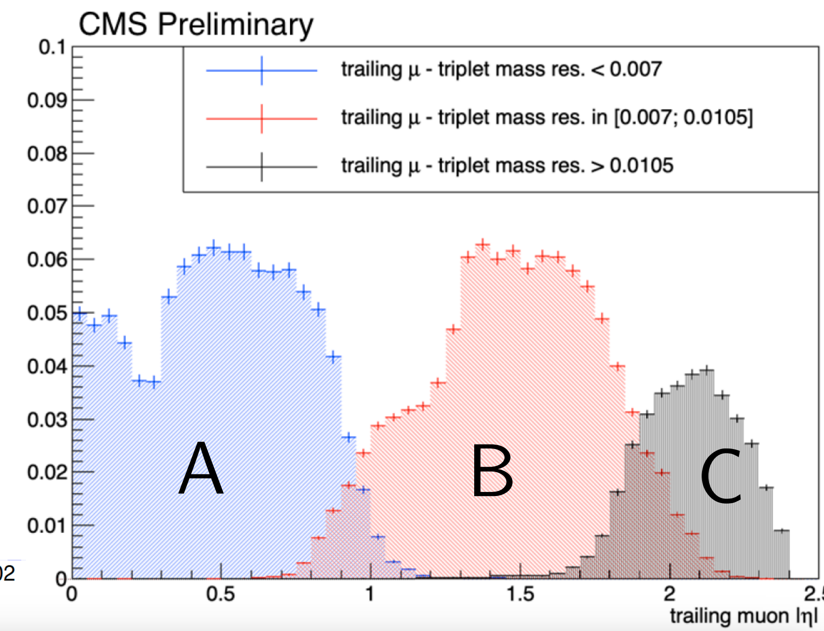
$D_s \longrightarrow \phi(\mu\mu)\pi$ for data-MC validation

$D_s \longrightarrow \phi(\mu\mu)\pi$ used to check simulations comparing relevant distributions;



Event categorization





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

→ "per event" mass resolution: - varies by a factor of 4

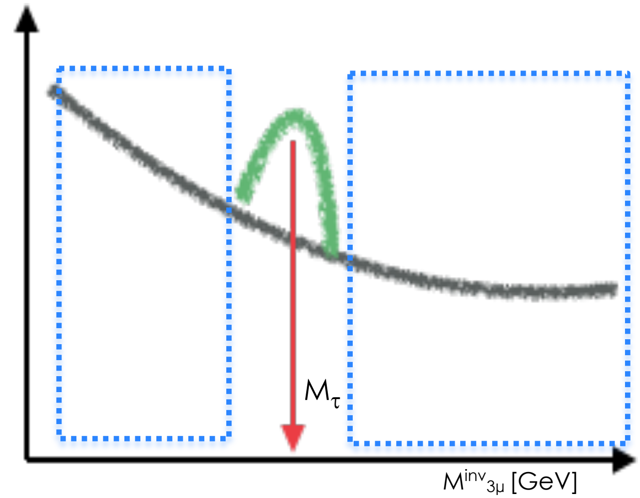
- the observed structure is well understood

The 3μ events are categorized based on the invariant mass resolution ρ:
A: $\rho < 0.0070$, B: $0.0070 < \rho < 0.0105$, C: $\rho > 0.0105$.

MVA for background rejection: BDT

Boosted Decision Tree discriminator trained separately in each event category

Settings: nCuts=20, nTrees = 800, training/test = 50%/50%



- **Signal:** MC events passing selections w/ 3μ inv. mass in tau peak* region
- **Backgroud:** 2017 data events passing selection w/ 3μ inv. mass in SB**

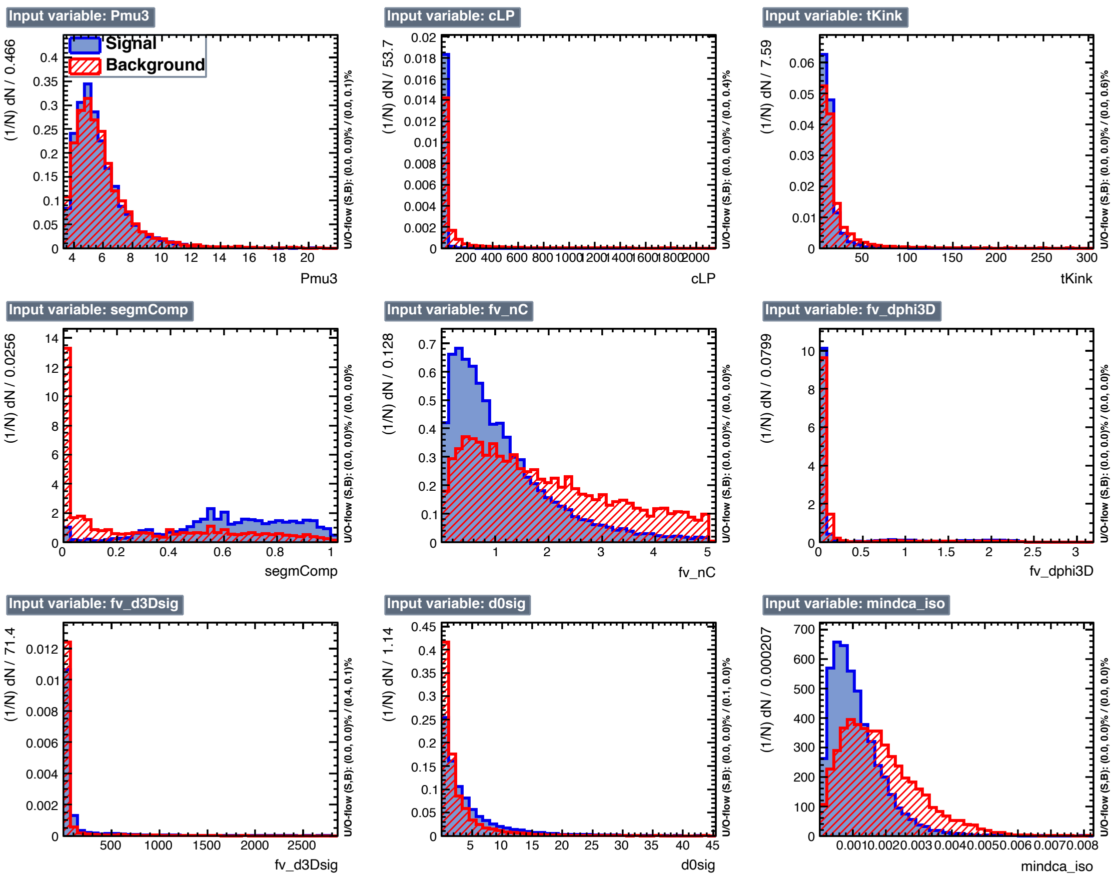
(*)[1.75, 1.80] GeV

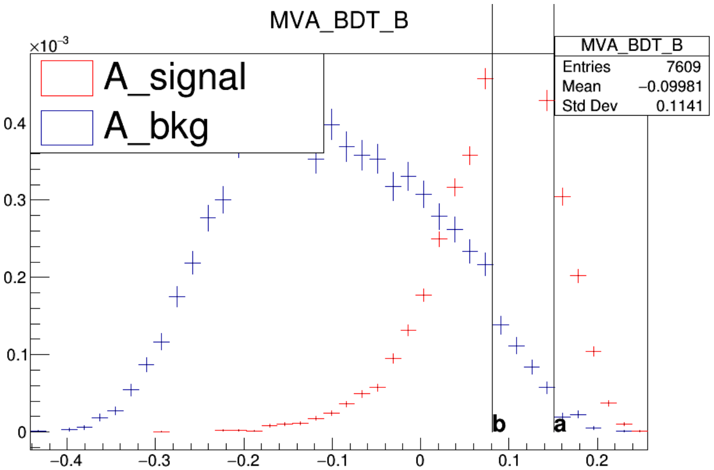
(**)[1.65; 1.73] U [1.82; 1.90] GeV

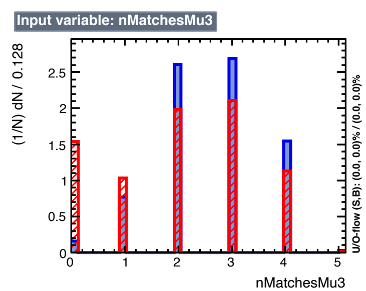
MVA for background rejection: input variables

1. Pmu3 → Momentum of the trailing muon (GeV)
2. cLP → Chi2 value for the STA-TK matching of local momentum (largest of the three)
3. tKink → value of the kink algorithm applied to the global track (largest of the three)
4. segmComp → compatibility between the inner track and the segments in the muon spectrometer (smallest of the three)
5. fv_nC → 3μ vertex Chi2/n.d.f.
6. fv_dphi3D → angle between the 3μ momentum vector and the PV-SV vector
7. fv_d3Dsig → PV-SV Flight distance significance
8. d0sig → Transverse IP significance (|dxy/dxyErr|) (smallest of the three)
9. mindca_iso → Closest distance (min dca) of the 3μ vertex to any other track having pt>1 GeV
10. nMatchesMu3 → Number of segments in muon system matching with mu3 outer track

MVA for background rejection: input variables

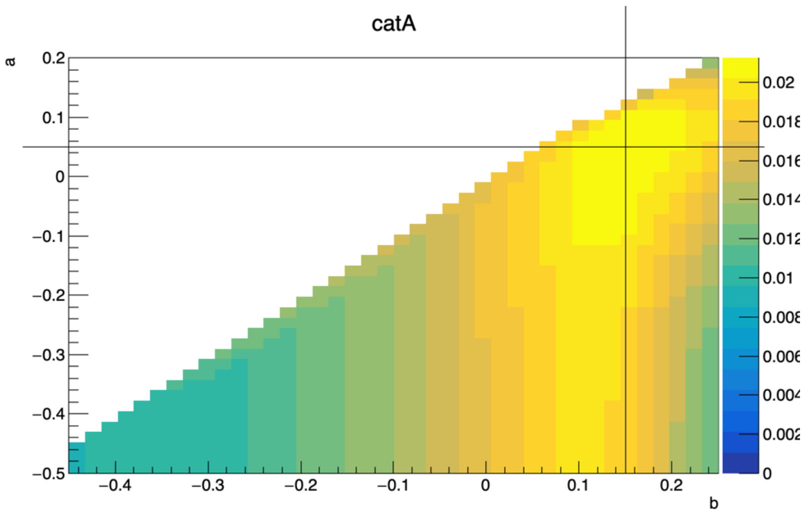


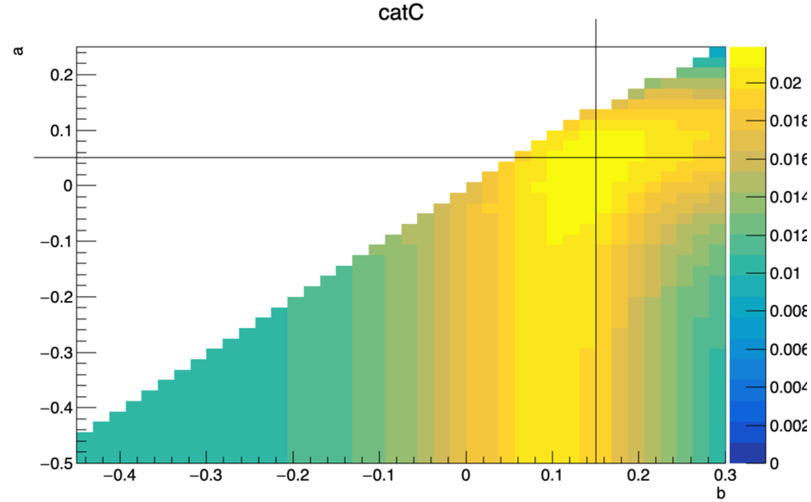


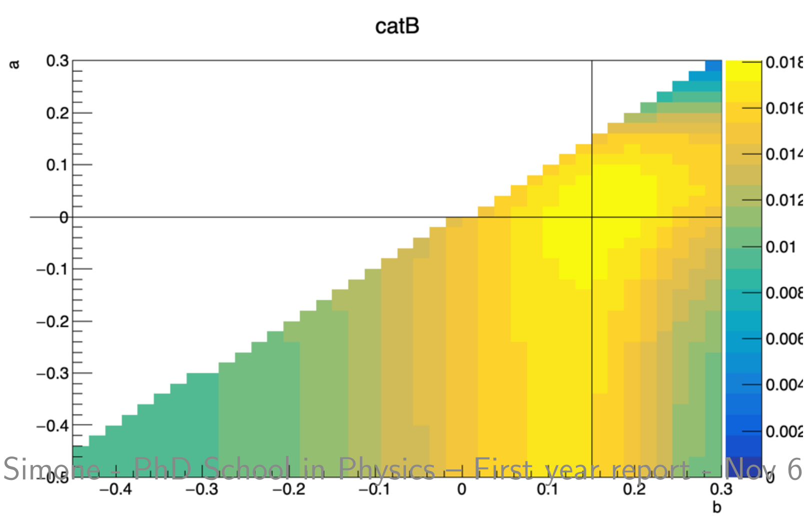


MVA for background rejection: BDT score and categorization

Cuts on BDT score optimized to maximize the combined significance





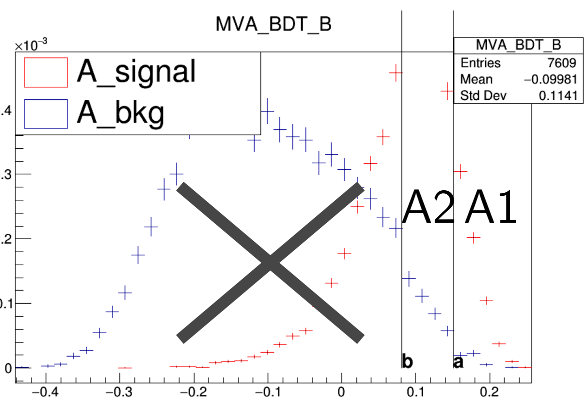


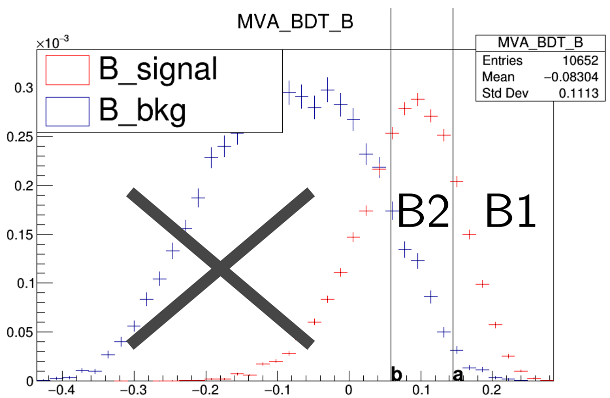
$$S_1 = \frac{n_{S1}}{\sqrt{n_{b1} + n_{S1}}}, S_2 = \frac{n_{S2}}{\sqrt{n_{b2} + n_{S2}}}$$

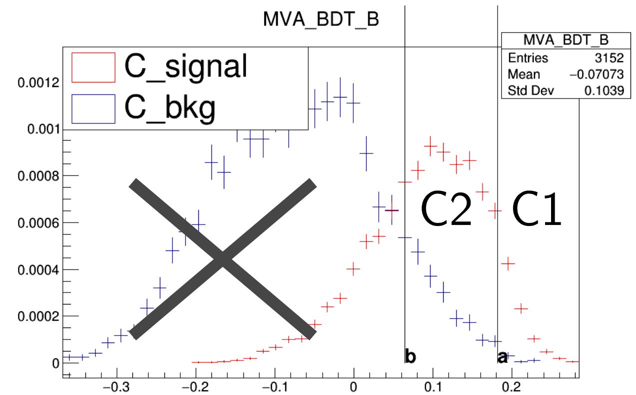
Combined S = sqrt($S_1^2 + S_2^2$)

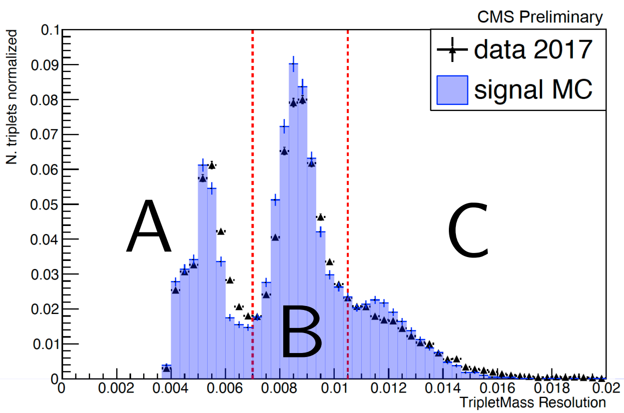
n_S scaled to average normalization factor for the three signal channels

MVA for background rejection: BDT score and categorization





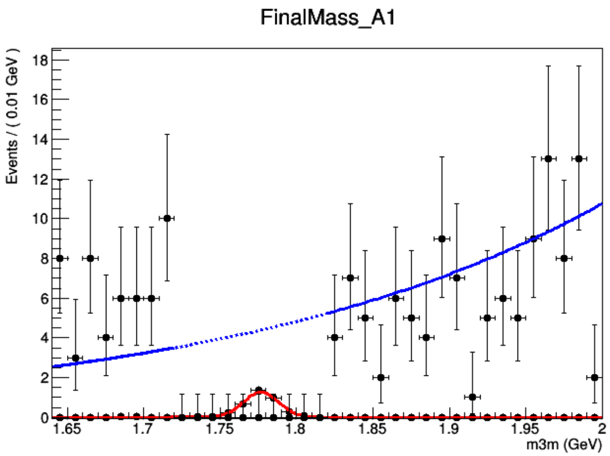


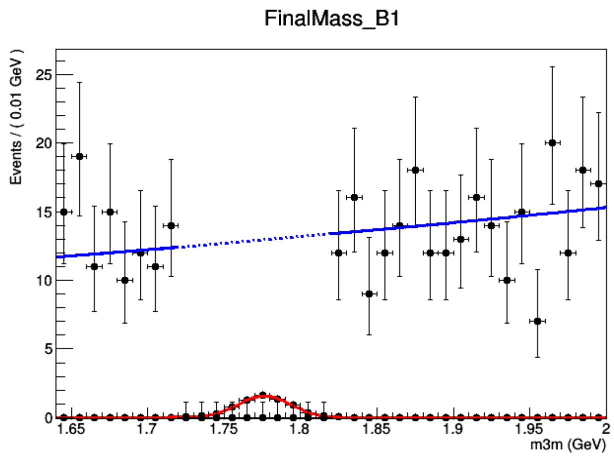


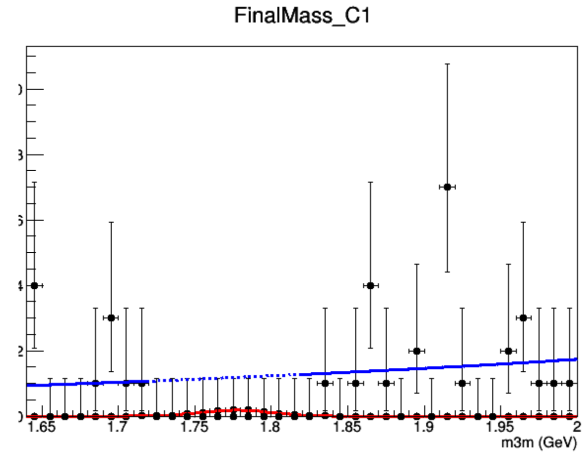
6 categories:

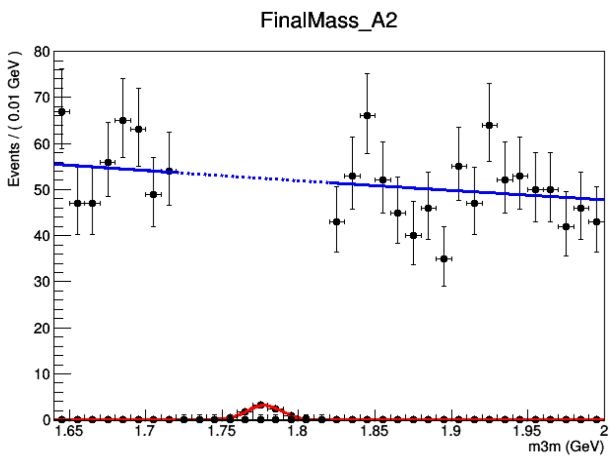
- Used separately for signal (MC) and background (data in sidebands) fit
- signal yields normalized to number of expected events + correction for data-MC Ds yield discrepancy

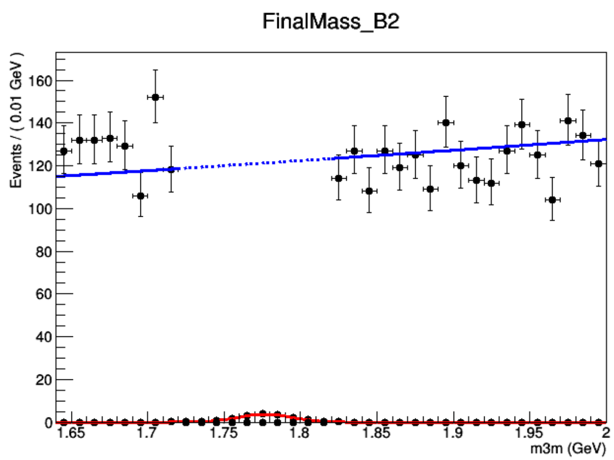
Preliminary results: invariant mass shapes

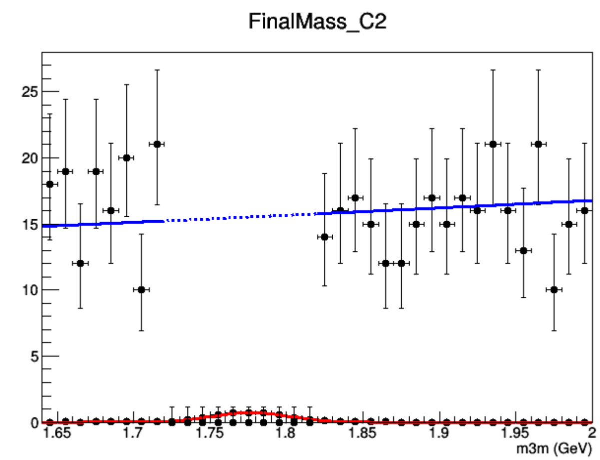












Preliminary results: yields and UL

	Signal		Background	
	BDT-1	BDT-2	BDT-1	BDT-2
Mass-Res A	3.78	9.51	242	1848
Mass-Res B	6.95	17.39	526	4487
Mass-Res C	1.15	4.7	54	621

-- AsymptoticLimits (CLs) --

Expected 2.5%: $r < 0.6325$
Expected 16.0%: $r < 0.8671$
Expected 50.0%: $r < 1.2852$
Expected 84.0%: $r < 1.9688$

2016 Results

	Signal		Background	
	sub-category 1	sub-category 2	sub-category 1	sub-category 2
Category A	6.3	10.4	360(44)	2502(319)
Category B	4.0	19.2	110(27)	2229(440)
Category C	8.9	9.0	389(107)	1549(400)

Expected 50%: $r < 0.88$

Systematic uncertainties

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
Factor *f* for B to D yield normalization	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
Triple Mu to Double Mu Triggered events ratio	1.15	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

Summary

❖ **Work done this year:**

- Performed **preliminary studies** (not covered in this presentation)
  - 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

Summary

Exams taken
- Machine Learning Techniques in High Energy Physics
- Programming with Python
- How to prepare a technical speech in English
- Promozione della Ricerca

Schools and workshops
- Joint 9th IDPASC School and XXXI International Seminar of Nuclear and Subnuclear Physics «Francesco Romano», Otranto, Italy, May 27 - June 4 2019.
- CMS Data Analysis School (CMSDAS) 2019, Pisa, Italy, Jan 28 - Feb 1 2019.

Conference talks
- Ricerca del decadimento tau3mu all'esperimento CMS, 105° National Congress of the Italian Physics Society, L'Aquila, Italy, Sept 23-27 2019.
- Design e prestazioni dei rivelatori a tripla GEM per la stazione GE1/1 dell'esperimento CMS a LHC, 105° National Congress of the Italian Physics Society, L'Aquila, Italy, Sept. 23-27, 2019.
- Upgrade of the CMS Muon System with Triple-GEM detectors, IEEE International Workshop on Advances in Sensors and Interfaces (IWASI), Otranto, Italy, June 13-14 2019.
- Upgrade del Sistema per Muoni dell'esperimento CMS con rivelatori a Tripla GEM, IFAE2019: Incontri di Fisica delle Alte Energie 2019, Napoli, Italy, April 8-10 2019.

Conference posters
- CMS GEM front-end electronics operational experience, 2019 Winter LHCC meeting, CERN, Geneva, Switzerland, Feb 27 2019.

Summary

Publications

1. A. M. Sirunyan *et al.* [CMS Collaboration], "Measurement of properties of $B^0_s \to \mu^+\mu^-$ decays and search for $B^0 \to \mu^+\mu^-$ with the CMS experiment", 2019, arXiv:1910.12127 [hep-ex] (CMS-BPH-16-004, CERN-EP-2019-215). Submitted to JHEP.

2. A. M. Sirunyan *et al.* [CMS Collaboration], "Search for supersymmetry with a compressed mass spectrum in events with a soft τ lepton, a highly energetic jet, and large missing transverse momentum in proton-proton collisions at $\sqrt{s} = 13$ TeV", 2019, arXiv:1910.01185 [hep-ex] (CMS-SUS-19-002, CERN-EP-2019-196). Submitted to PRL.

3. A. M. Sirunyan *et al.* [CMS Collaboration], "Running of the top quark mass from proton-proton collisions at $\sqrt{s} = 13$ TeV", 2019, arXiv:1909.09193 [hep-ex] (CMS-TOP-19-007, CERN-EP-2019-189). Submitted to PLB.

4. A. M. Sirunyan *et al.* [CMS Collaboration], "Search for long-lived particles using delayed photons in proton-proton collisions at $\sqrt{s} = 13$ TeV", 2019, arXiv:1909.06166 [hep-ex] (CMS-EXO-19-005, CERN-EP-2019-185). Submitted to PRD.

5. A. M. Sirunyan *et al.* [CMS Collaboration], "Search for electroweak production of a vector-like T quark using fully hadronic final states", 2019, arXiv:1909.04721 [hep-ex] (CMS-B2G-18-003, CERN-EP-2019-174). Submitted to JHEP.

6. A. M. Sirunyan *et al.* [CMS Collaboration], "Measurements of differential Z boson production cross sections in proton-proton collisions at $\sqrt{s} = 13$ TeV", 2019, arXiv:1909.04133 [hep-ex] (CMS-SMP-17-010, CERN-EP-2019-175). Submitted to JHEP.

7. A. M. Sirunyan *et al.* [CMS Collaboration], "Searches for physics beyond the standard model with the M_{T2} variable in hadronic final states with and without disappearing tracks in proton-proton collisions at $\sqrt{s} = 13$ TeV", 2019, arXiv:1909.03460 [hep-ex] (CMS-SUS-19-005, CERN-EP-2019-180). Submitted to EPJC.

8. A. M. Sirunyan *et al.* [CMS Collaboration], "Search for production of four top quarks in final states with same-sign or multiple leptons in proton-proton collisions at $\sqrt{s} = 13$ TeV", 2019, arXiv:1908.06463 [hep-ex] (CMS-TOP-18-003, CERN-EP-2019-1630. Submitted to EPJC.

Summary

Publications

9. A. M. Sirunyan *et al.* [CMS Collaboration], "Search for supersymmetry in proton-proton collisions at 13 TeV in final states with jets and missing transverse momentum", 2019, arXiv:1908.04722 [hep-ex] (CMS-SUS-19-006, CERN-EP-2019-152). Submitted to JHEP.

10. A. M. Sirunyan *et al.* [CMS Collaboration], "Search for dark photons in decays of Higgs bosons produced in association with Z bosons in proton-proton collisions at $\sqrt{s} = 13$ TeV", JHEP **1910**, 139 (2019) (CMS-EXO-19-007, CERN-EP-2019-159), arXiv:1908.02699 [hep-ex], DOI:10.1007/JHEP10(2019)139.

11. P. Verwilligen et al., "Diamond-Like Carbon for the Fast Timing MPGD", Submitted to Journal of Physics: Conference Series (JPCS) [MPGD 2019]. arXiv:1907.13559 [physics.ins-det].

12. C. Aruta, F. Simone, F. Ivone, B. L. Domey, J. A. Merlin and E. R. Starling, "Tests and investigation towards the final design of the GEM frontend electronics", 2019, DOI:10.1109/IWASI.2019.8791335.

13. F. M. Simone, R. Venditti and E. Soldani, "Upgrade of the CMS Muon system with Triple-GEM detectors", 2019, DOI:10.1109/IWASI.2019.8791422.

14. D. Abbaneo *et al.* [CMS Muon Collaboration], "Layout and Assembly Technique of the GEM Chambers for the Upgrade of the CMS First Muon Endcap Station", Nucl. Instrum. Meth. A **918**, 67 (2019), arXiv:1812.00411 [physics.ins-det], DOI:10.1016/j.nima.2018.11.061.

15. D. Abbaneo *et al.* [CMS Muon Collaboration], "Operational Experience With the GEM Detector Assembly Lines for the CMS Forward Muon Upgrade", IEEE Trans. Nucl. Sci. **65**, no. 11, 2808 (2018). DOI:10.1109/TNS.2018.2871428.

Backup

Datasets and Trigger

2017 Datasets	Run range	Integrated luminosity (fb^{-1})
/DoubleMuonLowMass/Run2017B-17Nov2017-v1/AOD	297046-299329	4.79
/DoubleMuonLowMass/Run2017C-17Nov2017-v1/AOD	299368-302029	9.63
/DoubleMuonLowMass/Run2017D-17Nov2017-v1/AOD	302030-303434	4.24
/DoubleMuonLowMass/Run2017E-17Nov2017-v1/AOD	303824-304797	9.30
/DoubleMuonLowMass/Run2017F-17Nov2017-v1/AOD	305040-306462	10.04
Whole 2017 data	297046-306462	38.00

L1 seeds:

- L1_DoubleMu0er1p5_SQ_OS_dR_Max1p4
  - 2 opposite sign μ with $|\eta| < 1.5$ and $\Delta R \in [0, 1.961]$
- L1_DoubleMu4_SQ_OS_dR_Max1p2 (Runs 306029-306462 → 2018)
- L1_TripleMu_5_3_0_DoubleMu_5_3_OS_Mass_Max17 (Runs 297046–299329)
  - 2 opposite sign μ with inv. mass in $[0, 144.5]$ GeV and $p_{T1} > 5$ GeV and $p_{T2} > 3$ GeV
  - no req. on the third muon
- L1_TripleMu_5SQ_3SQ_0_DoubleMu_5_3_SQ_OS_Mass_Max9 (Runs 299368–305967)
  - 2 opposite sign μ with inv. mass in $[0, 40.5]$ GeV and $p_{T1} > 5$ GeV and $p_{T2} > 3$ GeV
  - no req. on the third muon

HLT:

- HLT_DoubleMu3_Trk_Tau3mu_v*
- HLT_DoubleMu3_TkMu_DsTau3Mu_v* (Runs 306029-306462 → 2018)

json file: /Collisions17/13TeV/ReReco/Cert_294927-306462_13TeV_EOY2017ReReco_Collisions17_JSON_v1.txt

Monte Carlo simulation

Simulated process	MC Dataset name	No. events
$D_s \to \tau\nu_\tau \to 3\mu\nu_\tau$	/DsToTau_To3Mu_MuFilter_TuneCUEP8M1_13TeV-pythia8/RunIIFall17DRPremix-PU2017_94X_mc2017_realistic_v11-v1/AODSIM	$1.2 \cdot 10^6$
$B^0 \to \tau ... \to 3\mu$	/BuToTau_To3Mu_MuFilter_TuneCUEP8M1_13TeV-x pythia8/RunIISummer16DR80Premix- PUMoriond17_80X_mcRun2_asymptotic_2016˙TrancheIV_v6-v1/AODSIM	$2.0 \cdot 10^6$
$B^\pm \to \tau ... \to 3\mu$	/BdToTau_To3Mu_MuFilter_TuneCUEP8M1_13TeV-pythia8/RunIISummer16DR80Premix PUMoriond17_80X_mcRun2˙asymptotic_2016_TrancheIV_v6-v1/AODSIM	$2.9 \cdot 10^6$
$D_s \to \phi\pi \to 2\mu\pi$	/DsToPhiPi_ToMuMu_MuFilter_TuneCUEP8M1_13TeV-pythia8/RunIIFall17DRPremix-PU2017_94X_mc2017_realistic_v11-v2/AODSIM	$1.8 \cdot 10^6$

Process	Branching ratio (BR)	Reference
$D_s \to \tau\nu_\tau$	$(5.48 \pm 0.23) \cdot 10^{-2}$	PDG [1]
$B^+ \to \tau\nu_\tau D_0^*$	$(2.7 \pm 0.3) \cdot 10^{-2}$	PDG [1]
other $B^+ \to \tau\nu_\tau X$	$0.7 \cdot 10^{-2}$	PYTHIA [75]
$B^0 \to \tau\nu_\tau D^{+*}$	$(2.7 \pm 0.3) \cdot 10^{-2}$	PDG [1]
other $B^0 \to \tau\nu_\tau X$	$0.7 \cdot 10^{-2}$	PYTHIA [75]
$B^+ \to D_s X$	$(9.0 \pm 1.5) \cdot 10^{-2}$	PDG [1]
$B^0 \to D_s X$	$(10.3 \pm 2.1) \cdot 10^{-2}$	PDG [1]
$D_s \to \phi\pi \to \mu\mu\pi$	$(1.3 \pm 0.1) \cdot 10^{-5}$	PDG [1]

Events generated with PYTHIA 8 in MinimumBias configuration

- ❖ $D_s \longrightarrow \tau\upsilon_\tau \longrightarrow 3\mu\upsilon_\tau$: Minimum Bias events D_s meson with filter* → D_s forced to decay in $\tau\upsilon_\tau$ → τ set to decay in 3μ (only one D_s per event used)
- ❖ $B^0 \longrightarrow \tau ... \longrightarrow 3\mu$ and $B^\pm \longrightarrow \tau ... \longrightarrow 3\mu$: parton-level b-quark filter on top of the MinimumBias configuration → *B* to τ simulated according to branching fractions → τ set to decay in 3μ
- ❖ $D_s \longrightarrow \phi(\mu\mu)\pi$: Minimum Bias events with D_s meson filter* → decay chain programmed

* D_s come both from prompt production and B decays

- DIGI/RECO performed if 2 gen-level muons with $p_T > 2.7$ GeV and $|\eta| < 2.45$

$\tau \rightarrow 3\mu$ Event selection

Online: HLT_DoubleMu3_Trk_Tau3mu_v*
seeded by DoubleMu L1 or TripleMu L1

- two collimated muon track with common vertex and $p_T > 3$ GeV
- one track compatible with the 2μ vertex and $p_T > 1.2$ GeV
- invariant mass (2μ+trk) in the range 1.60-2.02 GeV
- vertex (2μ+trk) displaced from beam-spot by >2 sigma

Pre-selection and event reconstruction: at least 1 candidate/event:

three muons with: p_T>2 and $|\eta| < 2.4$ and charge!=0
innerTrack().isNonnull
innerTrack().hitPattern().numberOfValidPixelHits()>0
hitPattern().trackerLayersWithMeasurement()>0

candidate must have: mass in (0.5, 10) GeV
abs(total charge)=1

primary vertex refitted removing the 3μ tracks

$D_s \longrightarrow \phi(\mu\mu)\pi$ Event selection

Online: HLT_DoubleMu3_Trk_Tau3mu_v* seeded by DoubleMu L1

- two collimated muon track with common vertex and $p_T > 3$ GeV
- one track compatible with the 2μ vertex and $p_T > 1.2$ GeV
- invariant mass (2μ+trk) in the range 1.60-2.02 GeV
- vertex (2μ+trk) displaced from beam-spot by >2 sigma

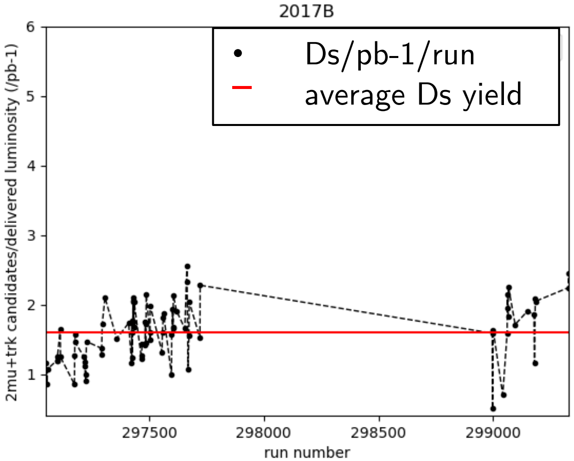
Pre-selection and event reconstruction: at least 1 candidate/event:

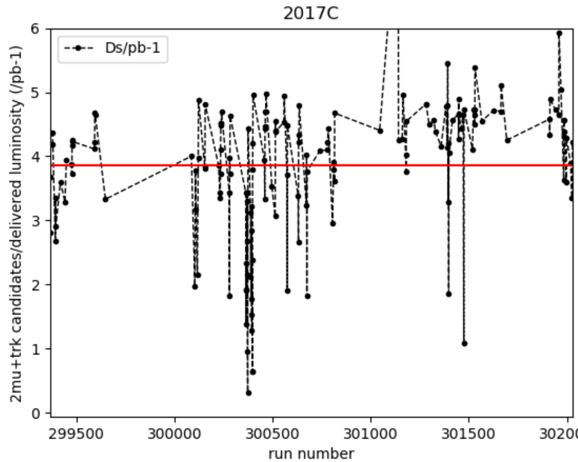
two muons with: $p_T > 2$ and $|\eta| < 2.4$ and charge!=0
innerTrack().isNonnull
innerTrack().hitPattern().numberOfValidPixelHits()>0

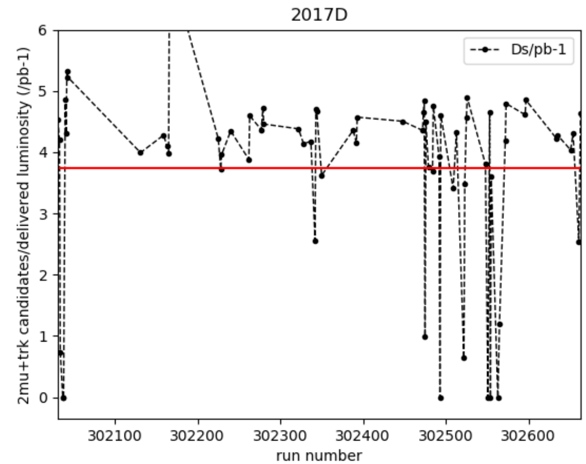
+ 1 track with: $p_T > 2$ and $|\eta| < 2.4$ and charge!=0
hitPattern().trackerLayersWithMeasurement()>5
hitPattern().pixelLayersWithMeasurement()>=1

candidate must have: mass in (0.5, 10) GeV and abs(total charge)=1

Ds yield monitoring during 2017

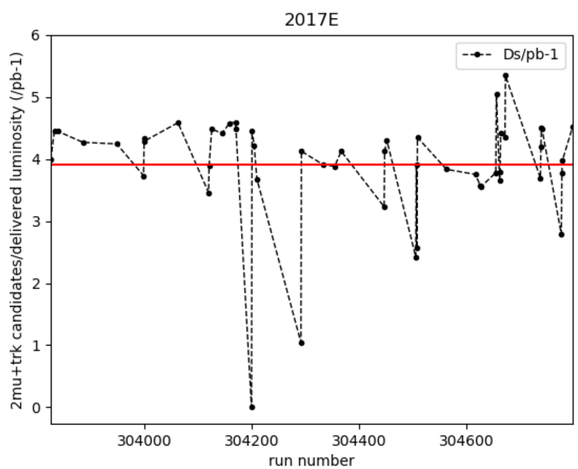


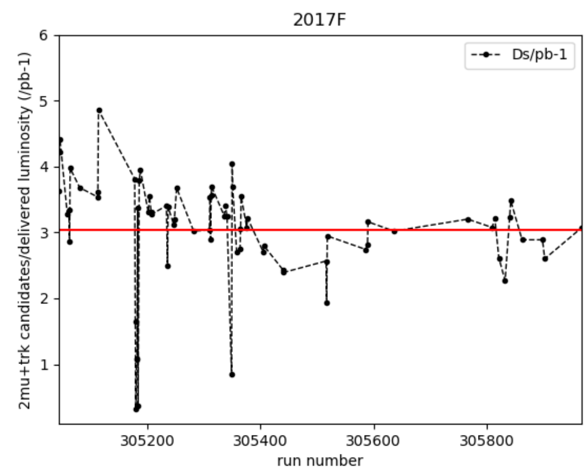




D_s candidates here are number of events passing $D_s \longrightarrow \phi(\mu\mu)\pi$ selections with invariant mass in range: [1.93, 2.0] GeV

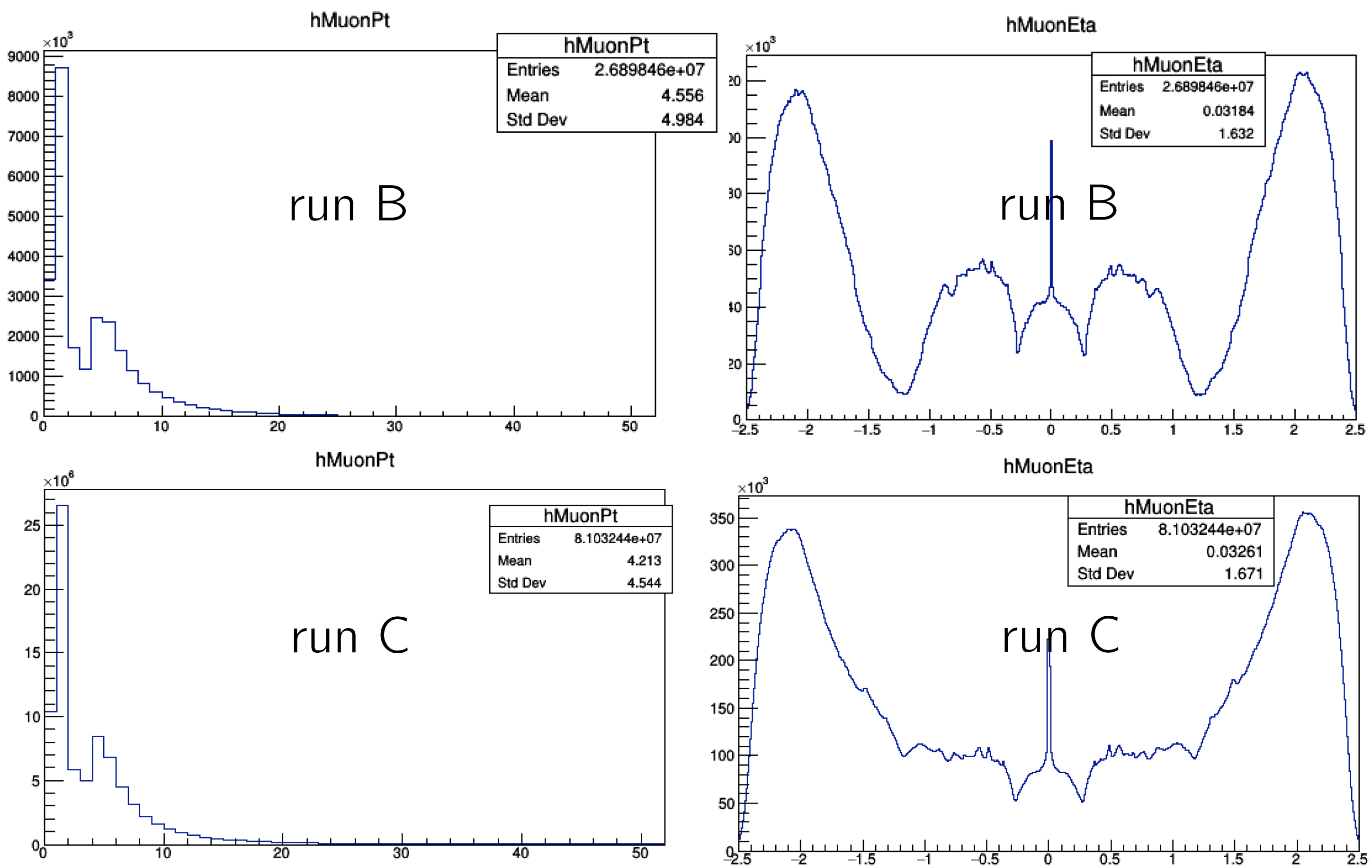
- Compared with delivered luminosity vs run number
- runB has low yield, recovered at beginning of runC
- run F shows gradually decreasing yield





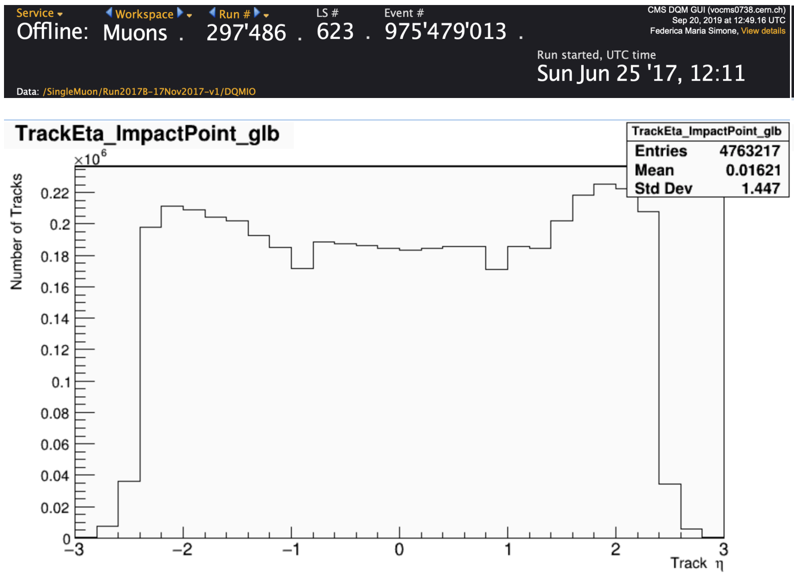
Ds yield issue: run B

all recoMuon distributions in data triggered by HLT before selections:
run B / run C comparison → drop in $1 < |\eta| < 1.5$

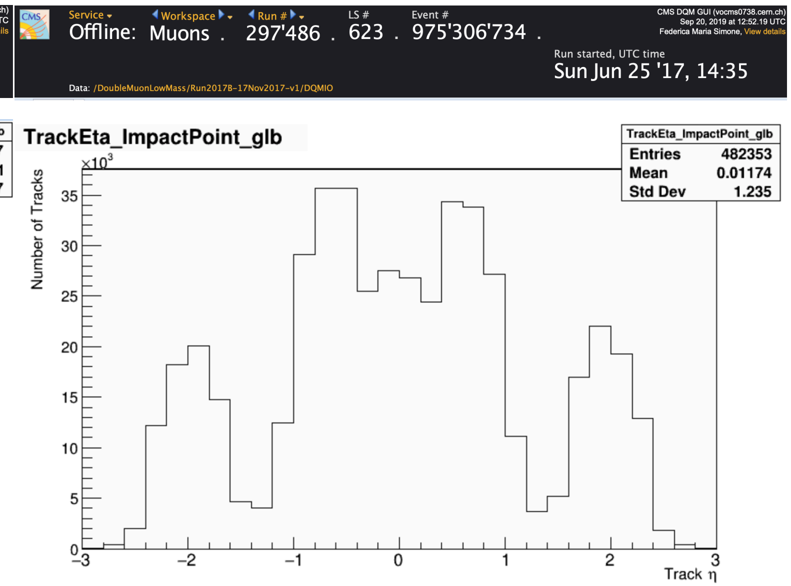


Ds yield issue: run B

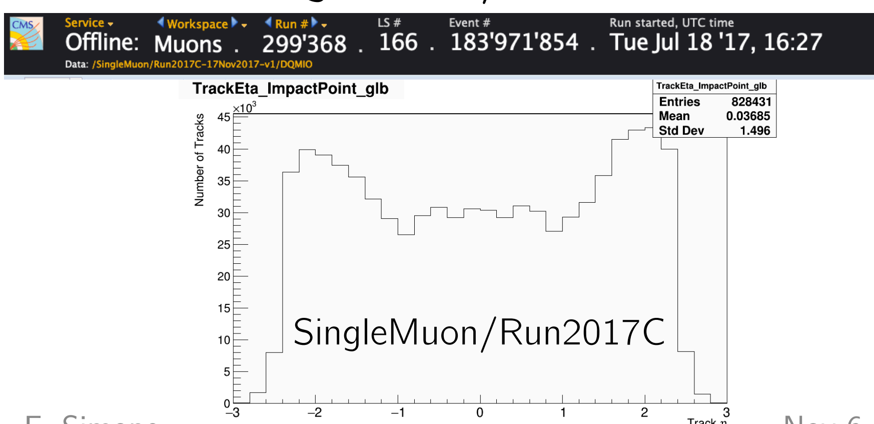
track distributions in data firing SingleMu vs DoubleMu from offline DQM: drop in $1 < |\eta| < 1.5$ affects DoubleMu only



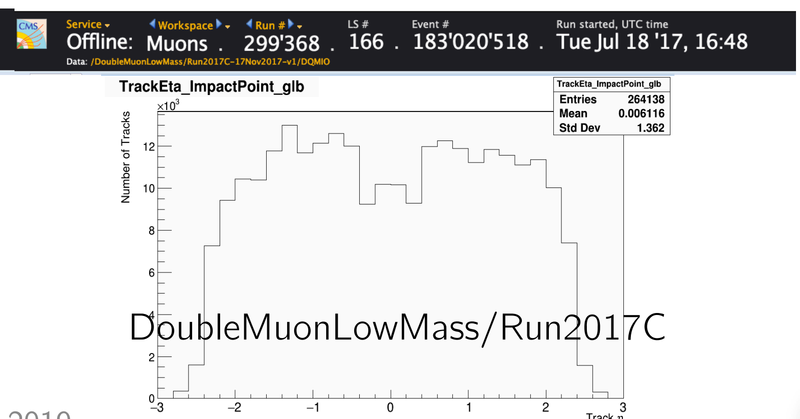
SingleMuon/Run2017B



DoubleMuonLowMass/Run2017B

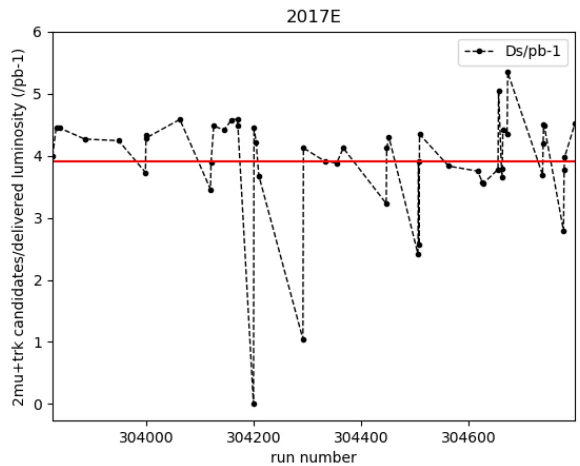


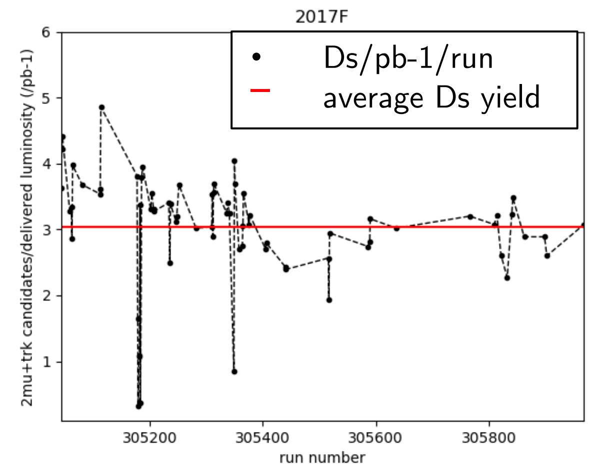
SingleMuon/Run2017C



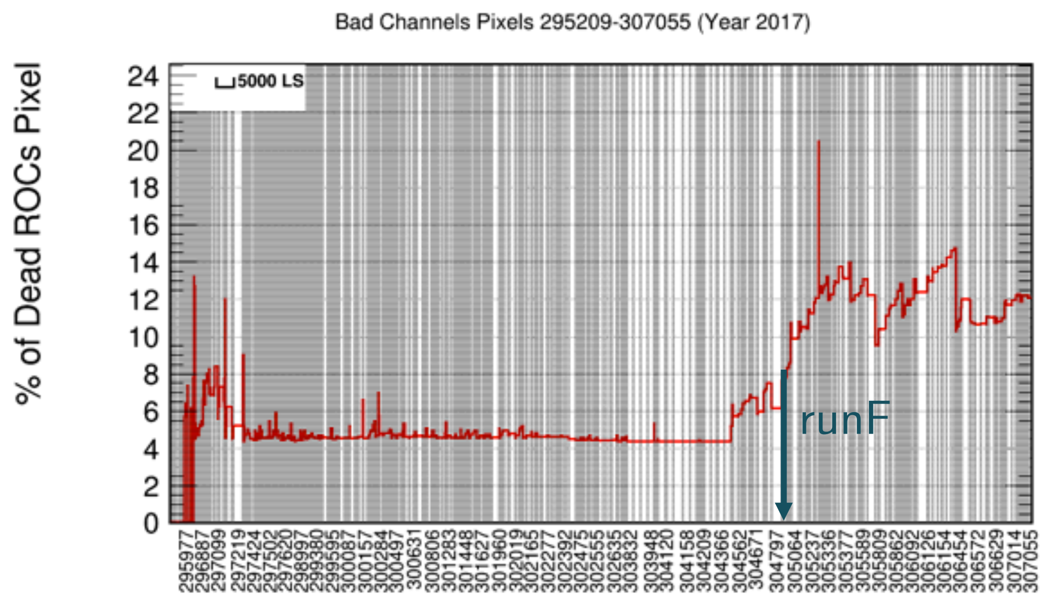
DoubleMuonLowMass/Run2017C

Ds yield issue: run F





- Issue with DCDC converters in pixel detector
- Problem recovered at reconstruction level
- Affects the trigger efficiency
- Need to estimate the impact on run F statistics



https://indico.cern.ch/event/578756/contributions/2807119/attachments/1570048/2476260/PLAN_YETS17-18V2.pdf#search=dcdc%20issue

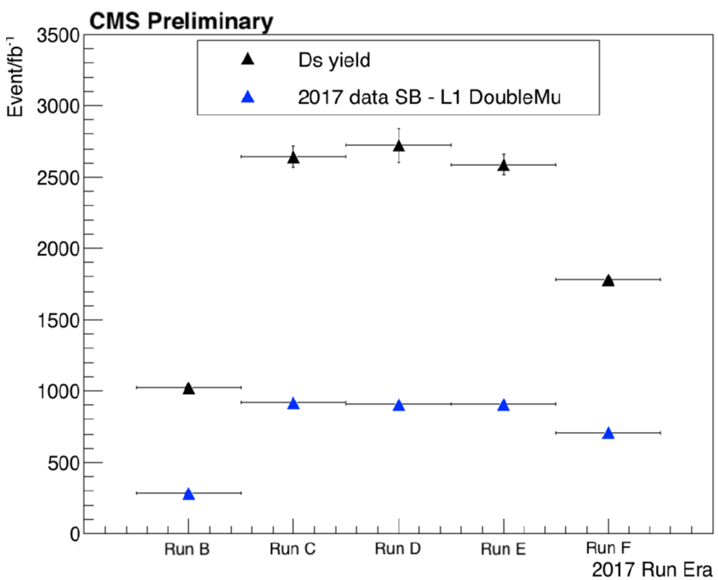
Systematic uncertainty on Ds yield

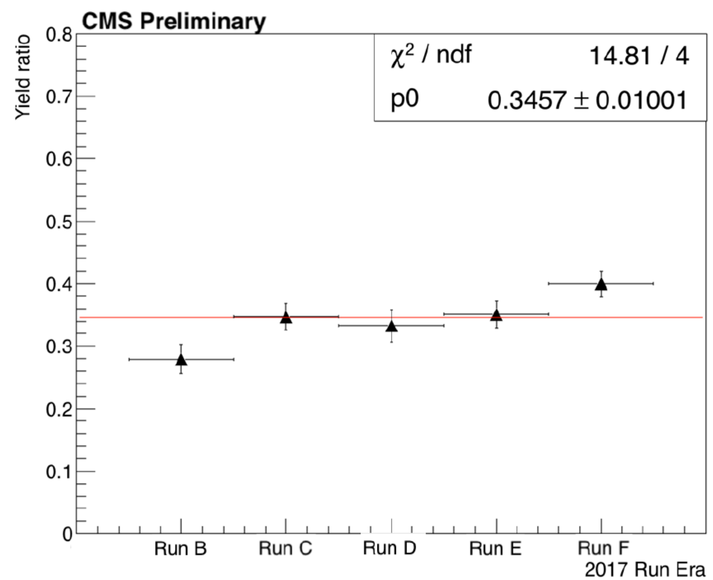
Check if the ratio of three-muons sideband events and Ds→ϕ(2μ)π, both triggered by DoubleMu L1, stays constant over time

Ds yield: signal yield in $2\mu + 1trk$ invariant mass range [1.93; 2.01] GeV
3mu (SB): number of three-muons candidates passing the analysis selections w/ invariant mass in sidebands $[1.65; 1.73]$U$[1.82; 1.90]$ GeV triggered by DoubleMu L1

Stat. error on <yield ratio> $\sigma_\mu = 0.01$
Scale factor $S = \sqrt{\chi^2/(N-1)} = 2.22$

Systematic error $\approx S * \sigma_\mu/\mu = 6.4\%$





Signal normalization

Events from Ds decay:

$$\mathrm{N_{Data}}(D_s \to 3\mu) = \mathrm{N} \cdot \frac{\mathcal{B}(D_s \to \tau\nu_\tau) \cdot \mathcal{B}(\tau \to 3\mu)}{\mathcal{B}(D_s \to \phi\pi \to 2\mu\pi)}$$

N directly measured from $D_s \longrightarrow \phi(\mu\mu)\pi$ decay
$\mathcal{B}(\tau \longrightarrow 3\mu) = 10^{-7}$ assumed for signal normalization

$$\mathrm{N} = \mathrm{N_{Data}}(D_s \to 2\mu\pi)$$

Events from B decays:

$$\mathrm{N_B} = N \cdot f \cdot \frac{\mathcal{B}(B \to \tau + ...)}{\mathcal{B}(D_s \to \phi\pi \to \mu\mu\pi)\ \mathcal{B}(B \to D_s + ...) \cdot \mathcal{B}(\tau \to 3\mu)}$$

where f is fraction of D_s produced by B mesons decays, estimated from MC

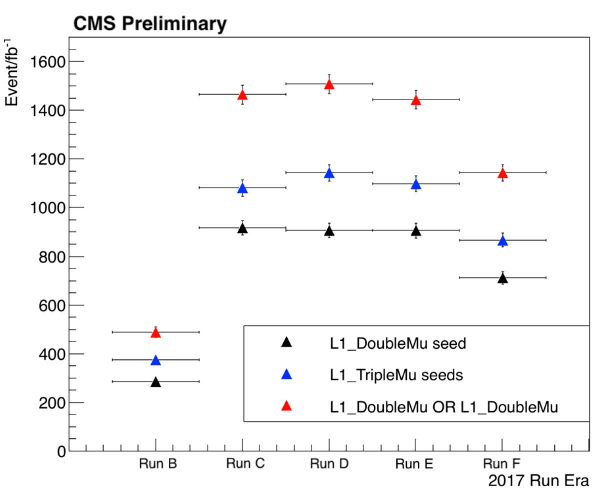
$$f = \frac{\sigma(pp \to B)\ \mathcal{B}(B \to D_s + ...)}{\sigma(pp \to D_s)}$$

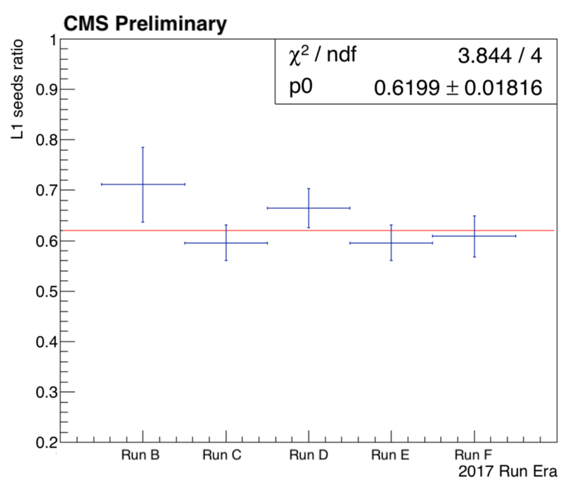
Number of produced Ds from $D_s \longrightarrow \phi(\mu\mu)\pi$ accounts only for events firing DoubleMu L1 seed: contribution from data events triggered by TripleMu L1 measured in data

TripleMu/DoubleMu ratio

Signal normalization can be done using $D_s \longrightarrow \phi(\mu\mu)\pi$ only for events firing DoubleMu L1 seed: ratio between TripleMu and DoubleMu evaluated in data using $\tau \rightarrow 3\mu$ selections to compute a correction factor

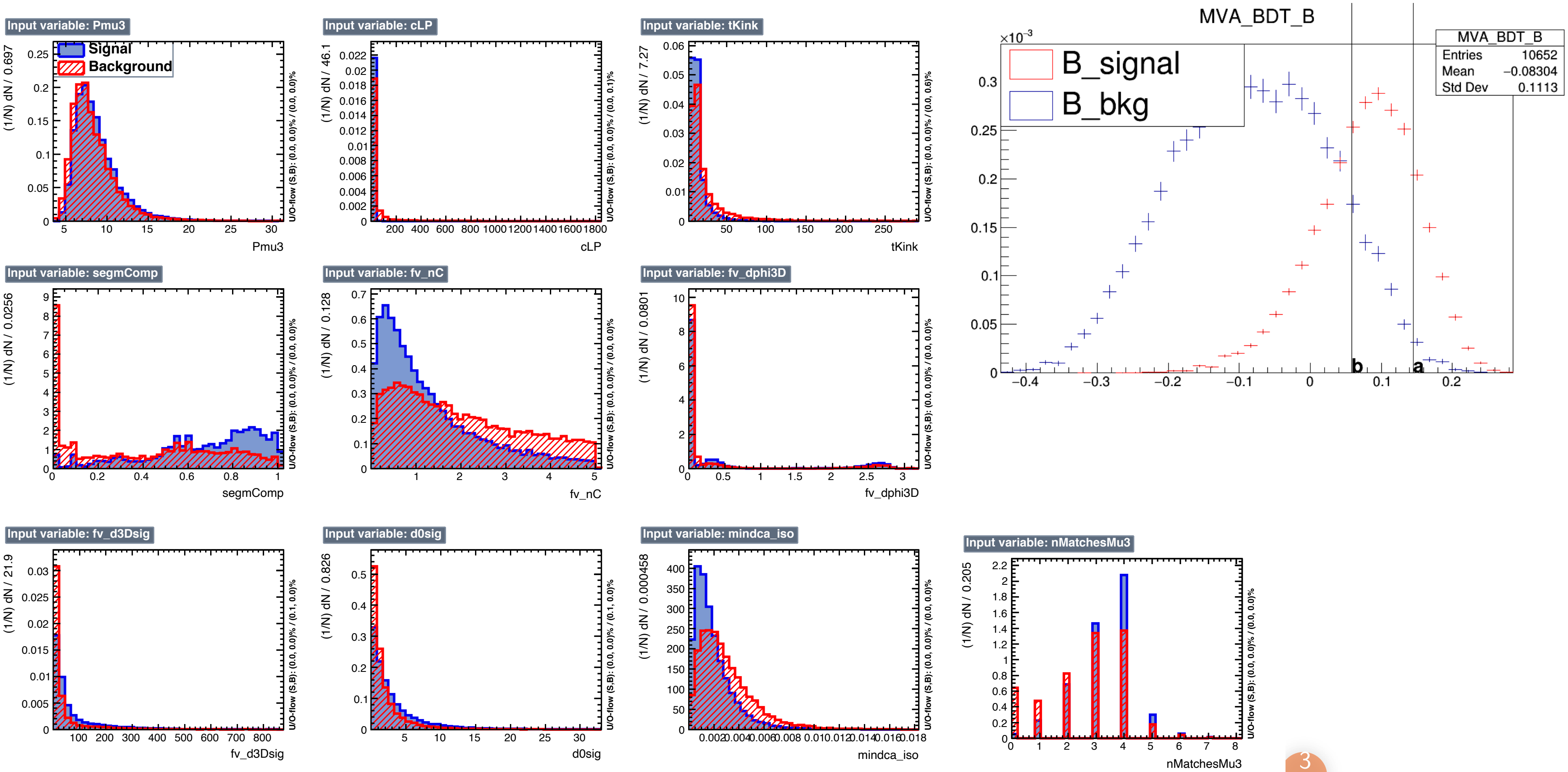
Run	Sidebands data yield per fb^{-1}			
	L1 DoubleMu seed	L1 TripleMu seeds	Only L1 TripleMu seeds	L1 DoubleMu OR TripleMu seeds
2017 B	285.6 ± 16.9	374.3 ± 19.3	203.1 ± 21.2	488.7 ± 22.1
2017 C	917.8 ± 30.3	1081.3 ± 32.9	546.7 ± 32.3	1464.5 ± 38.3
2017 D	905.9 ± 30.1	1143.4 ± 33.8	602.1 ± 35.5	1508.0 ± 38.8
2017 E	905.6 ± 30.1	1097.7 ± 33.1	539.1 ± 32.1	1444.7 ± 38.0
2017 F	711.2 ± 26.7	866.5 ± 29.4	433.0 ± 29.0	1144.1 ± 33.8



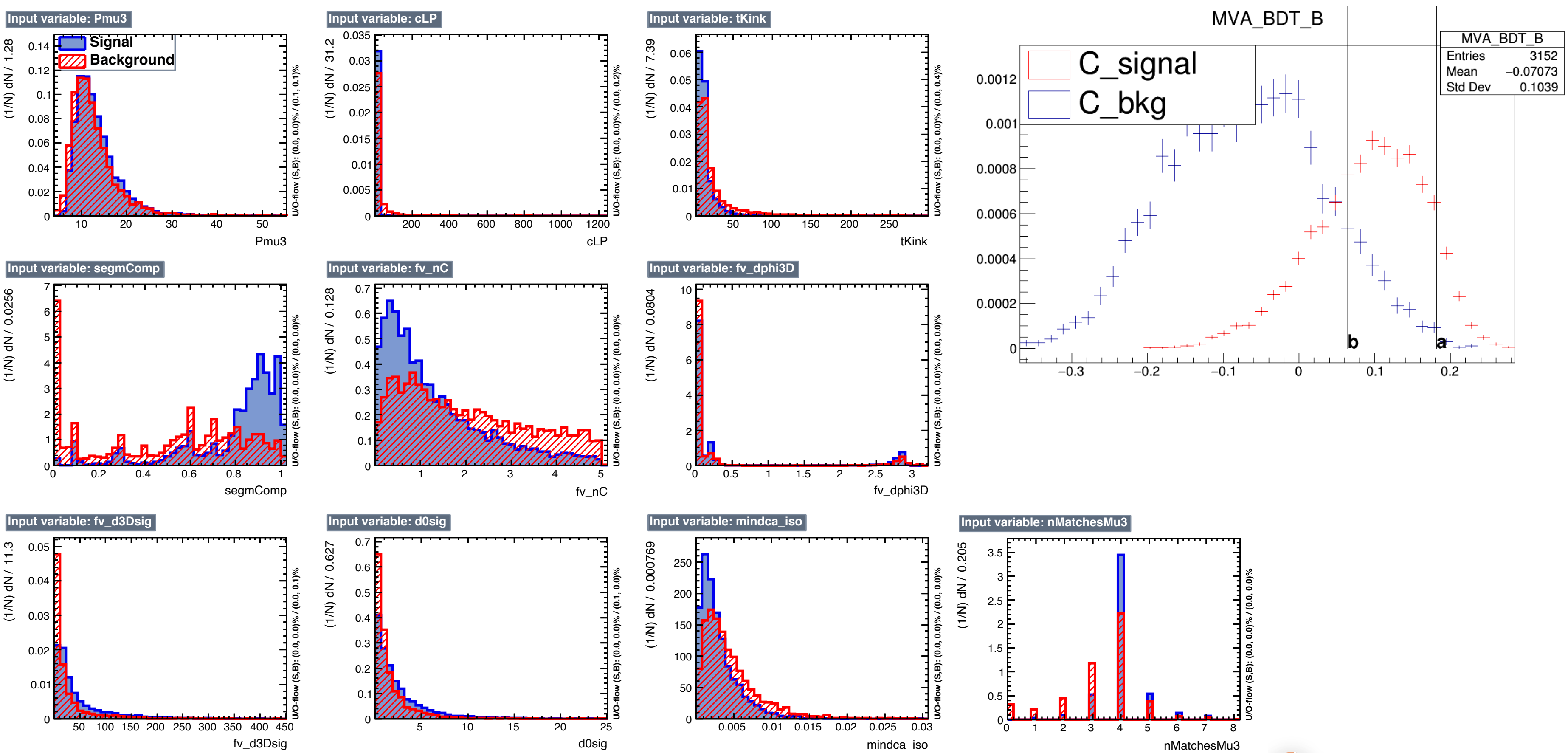


Avg. TripleMu/DoubleMu ratio
in data = 0.51
in MC = 0.70
Discrepancy: 26.7%
Affects 51% events exclusively triggered by L1 TripleMu: 13.6% taken as systematic uncertainty

MVA for background rejection: input variables



MVA for background rejection: input variables



Preliminary results: normalized signal shapes