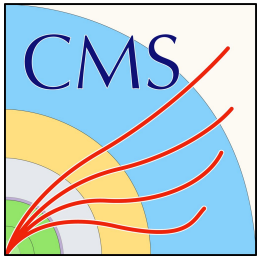

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Muon identification techniques in the CMS experiment

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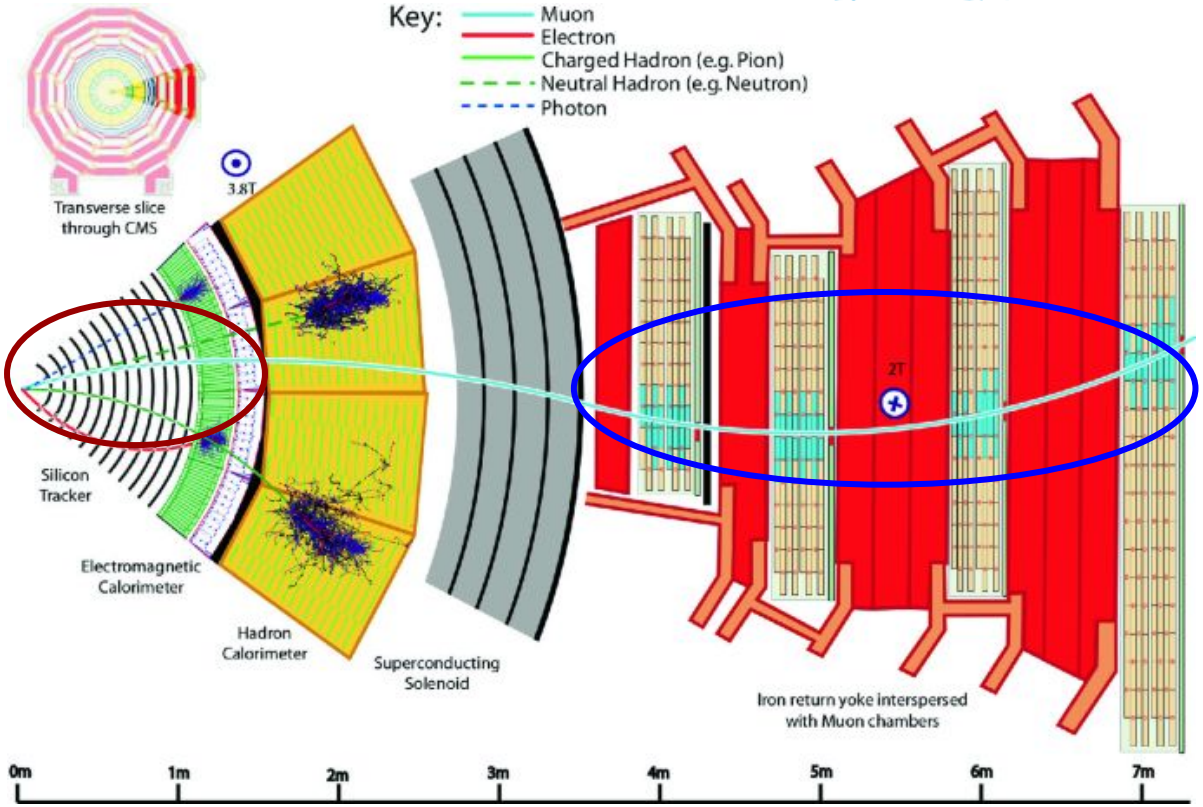
07/05/2024

Jornadas del ICTEA

Introduction



- Types of muons:
  - Tracker muons
  - Standalone muons
  - Global muons

Introduction: Types of muons studied

- Low p_T muons → $p_T < 30$ GeV
  - ★ Cut-based ID
  - ★ Soft Muon ID
- Medium p_T muons → $15\ \text{GeV} < p_T < 200\ \text{GeV}$
  - ★ Cut-based ID
  - ★ Muon MVA ID
  - ★ Prompt MVA ID
- High p_T muons → $p_T > 200$ GeV
  - ★ Cut-based ID

Identification of medium p_T range muons

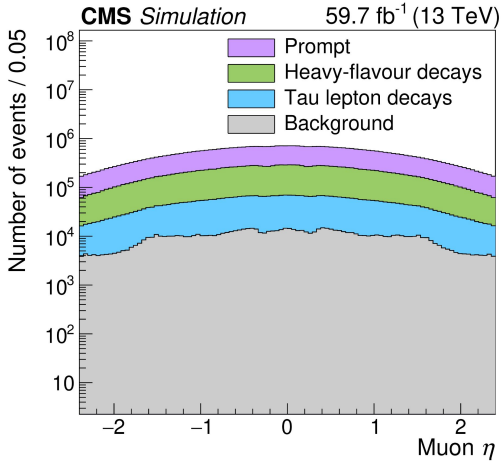
- The identification (ID) of medium p_T range muons has an efficiency larger than 90 % in general:
  - Cut-based ID → Defined as cuts over different variables.
  - Muon MVA ID (MUO-22-001)→ Machine Learning applied to almost the same variables.
- During Run 2, the used ID was the cut-based ID with good performance.
- We show the efficiencies of both the Muon MVA ID and cut-based ID focusing on the MVA ID.

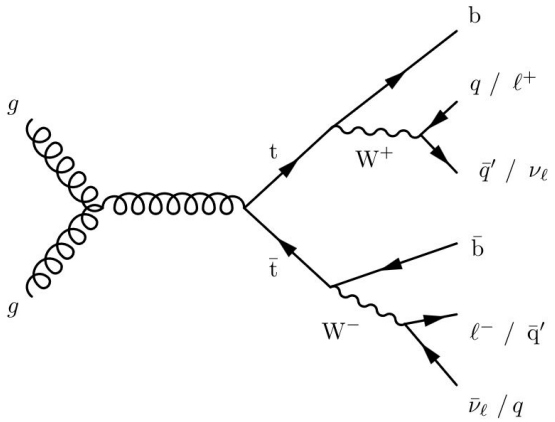
Muon MVA ID

Muon MVA ID: training

- Used 12 input variables to train the MVA (the same of the cut-based ID definition except IP parameters).
- The training sample was semileptonic $t\bar{t}$ to get variate muons depending on the provenance.
  - **Signal muons**: from bosons, tau, B, B decaying in C, and C hadrons.
  - **Bkg muons**: Decays from light hadrons (kaons, pions…), not matched and punchthrough.

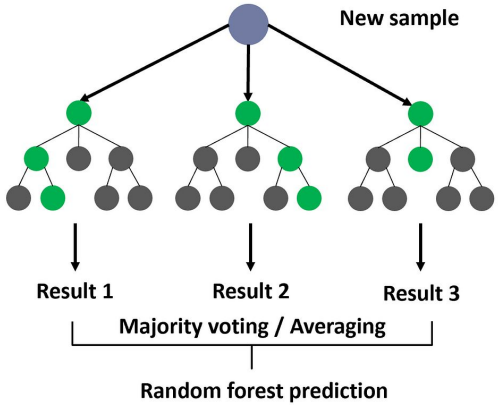
Class imbalance → 98 % of muons are signal.





Muon MVA ID: training

- The algorithm trained was a random forest.
  - Tested other algorithms.
  - 200 trees with a maximum depth of 8.
- Training: 60 % and test: 40 %.
- Validation with another dataset.

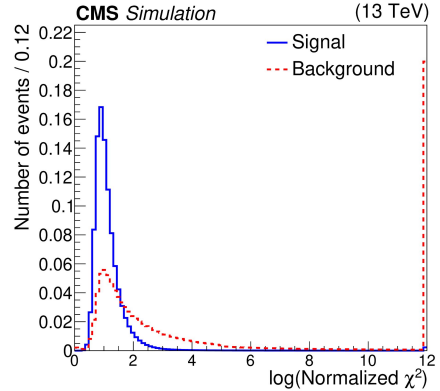


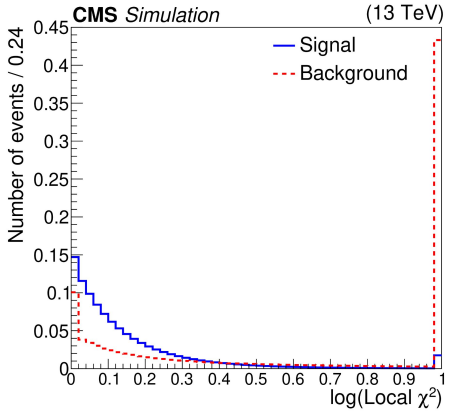
Muon MVA ID: training variables

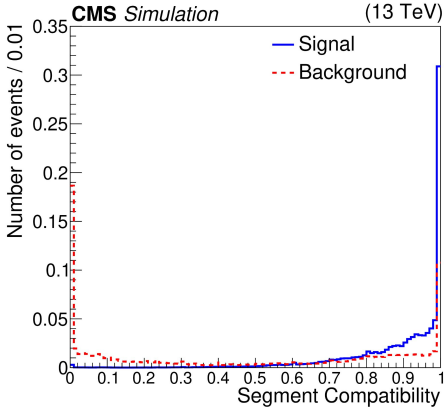
- 12 input variables (definition of cut-based ID)

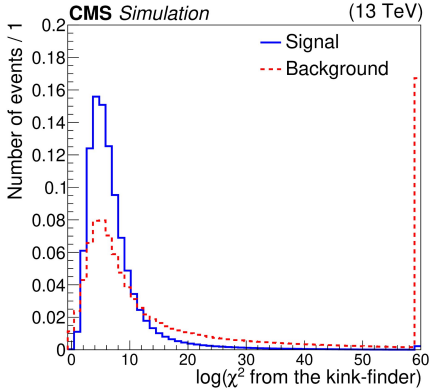
Most relevant

  - Normalized χ^2 of the muon track fit
  - Local χ^2 (inner-SA track)
  - Segment compatibility
  - χ^2 from the kink-finder algorithm on the inner track
  - Number of matched stations with hits
  - Fraction of valid tracker hits
  - Number of valid pixel hits
  - Number of tracker layers with hits
  - Number of valid hits
  - Is Global muon
  - p_T and η from the muons



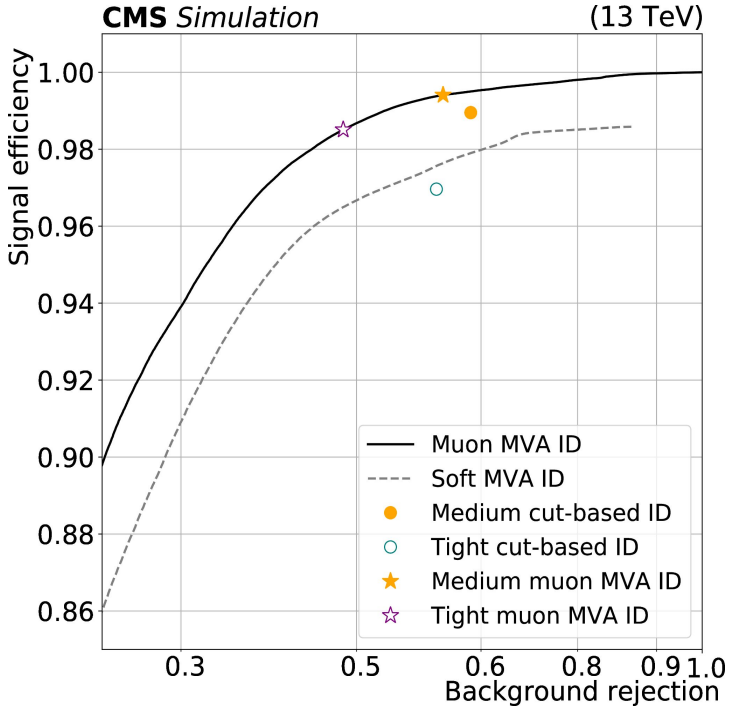






Muon MVA ID: Working points

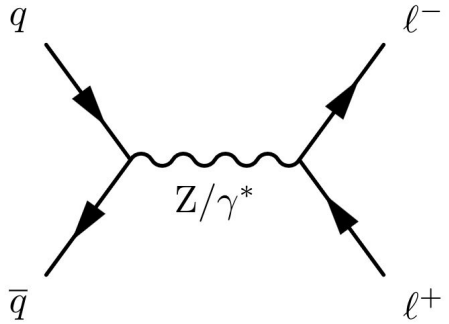
- Defined two WP:
  - Medium WP ⟶ >0.08 (same background rejection as cut-based)
  - Tight WP ⟶ >0.20 (maximize the rejection)
- Efficiency computed with the Tag and Probe (TnP) method.
- Performance tested in 2018 and 2022 data and simulation.



Calculation of efficiency

TnP method:

- Tag muon → pass tight ID and trigger (HLT).
- Probe muon → pass loose ID.

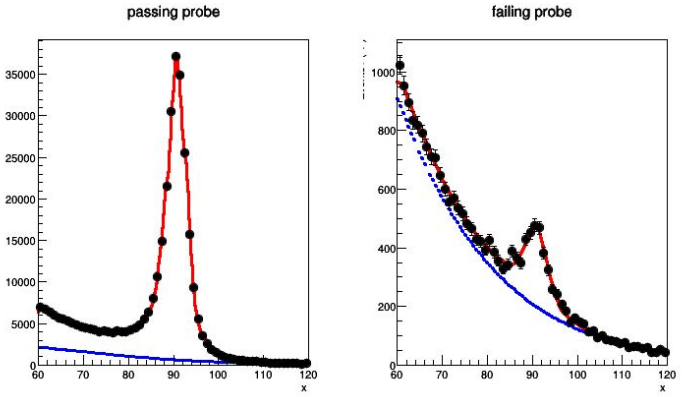


*** fit status pass: 4, fail : 0**

*** eff = 0.9879 ± 0.0007**

--- parmeters

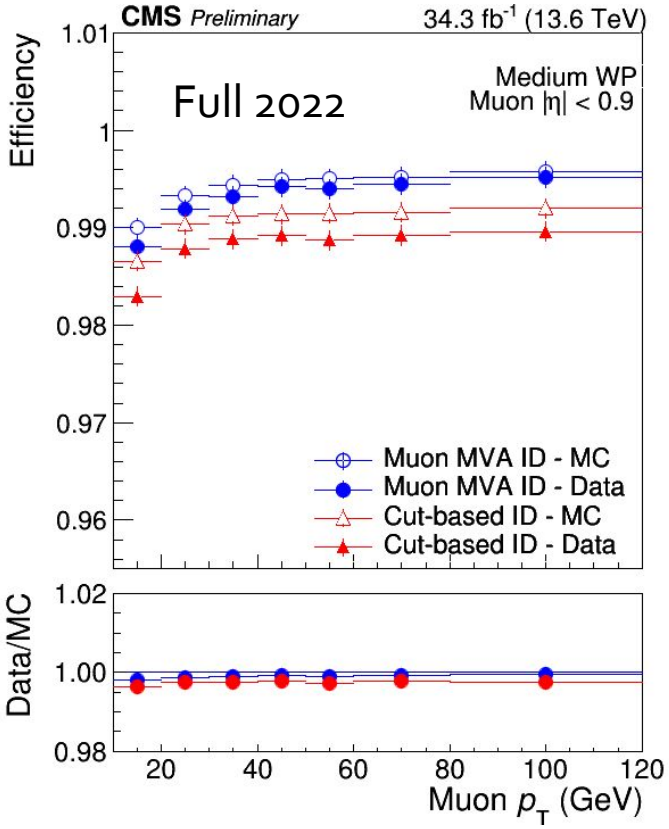
- acmsP = 60.990 ± 10.835
- betaP = 0.033 ± 0.011
- gammaP = 0.061 ± 0.008
- meanP = 0.373 ± 0.006
- nBkgP = 49966.819 ± 654.176
- nSigP = 306111.708 ± 827.092
- sigmaP = 0.500 ± 0.001
- acmsF = 171.198 ± 121.943
- betaF = 0.011 ± 0.002
- gammaF = 0.081 ± 0.019
- meanF = 0.628 ± 0.134
- nBkgF = 17617.830 ± 259.308
- nSigF = 3740.200 ± 230.994
- sigmaF = 1.073 ± 0.420

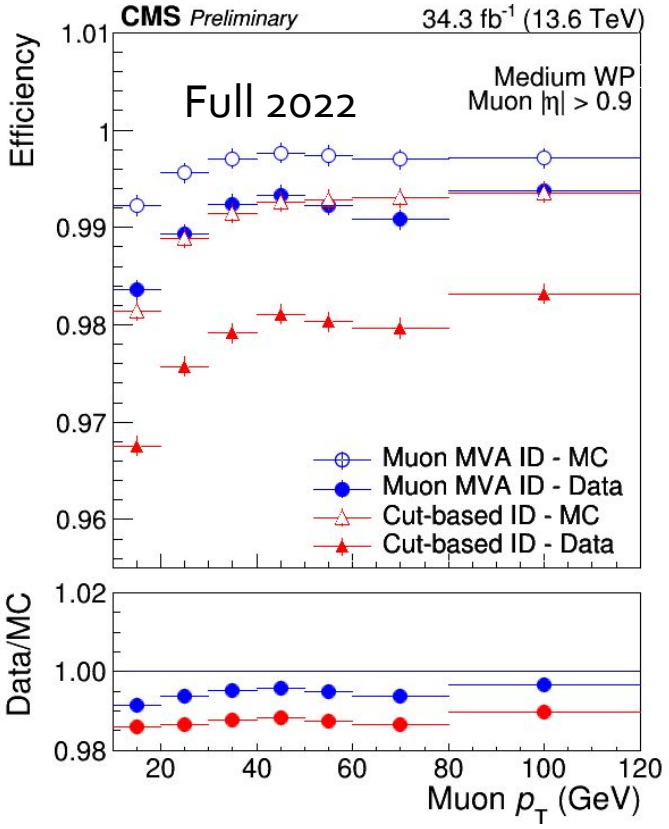


$$Efficiency = \frac{\#Loose\ muons\ passing\ WP\ cut}{\#Loose\ muons}$$

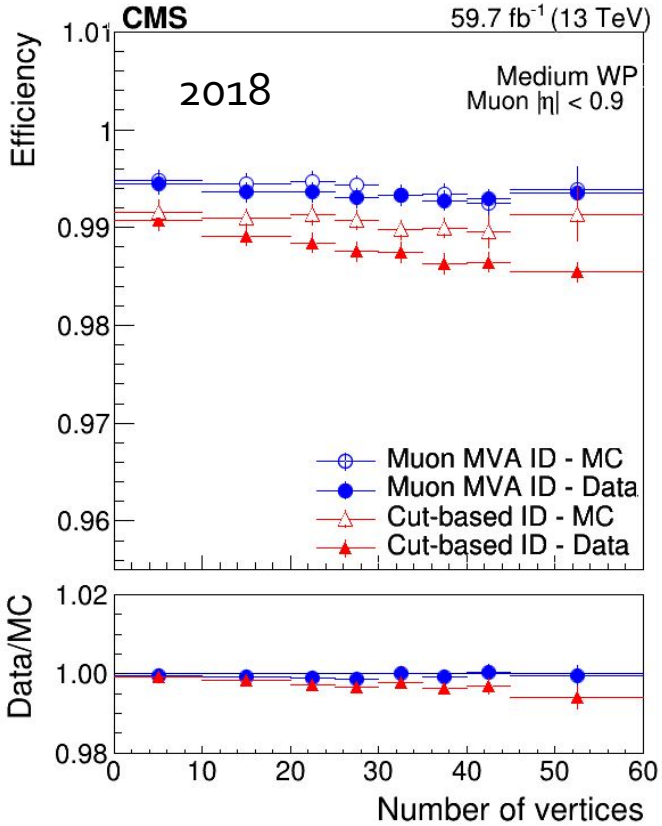
Efficiency measurement

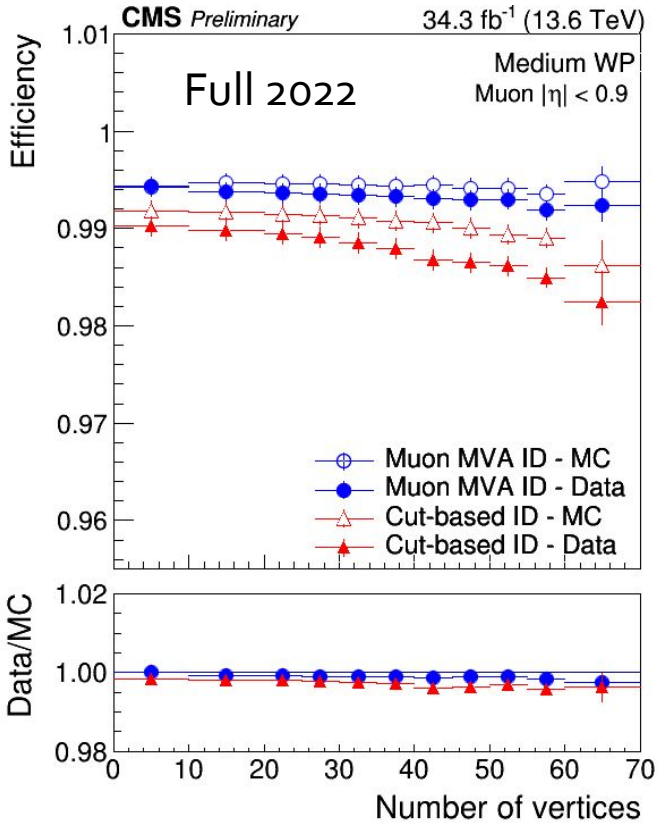
Results of Run 3 in Medium WP



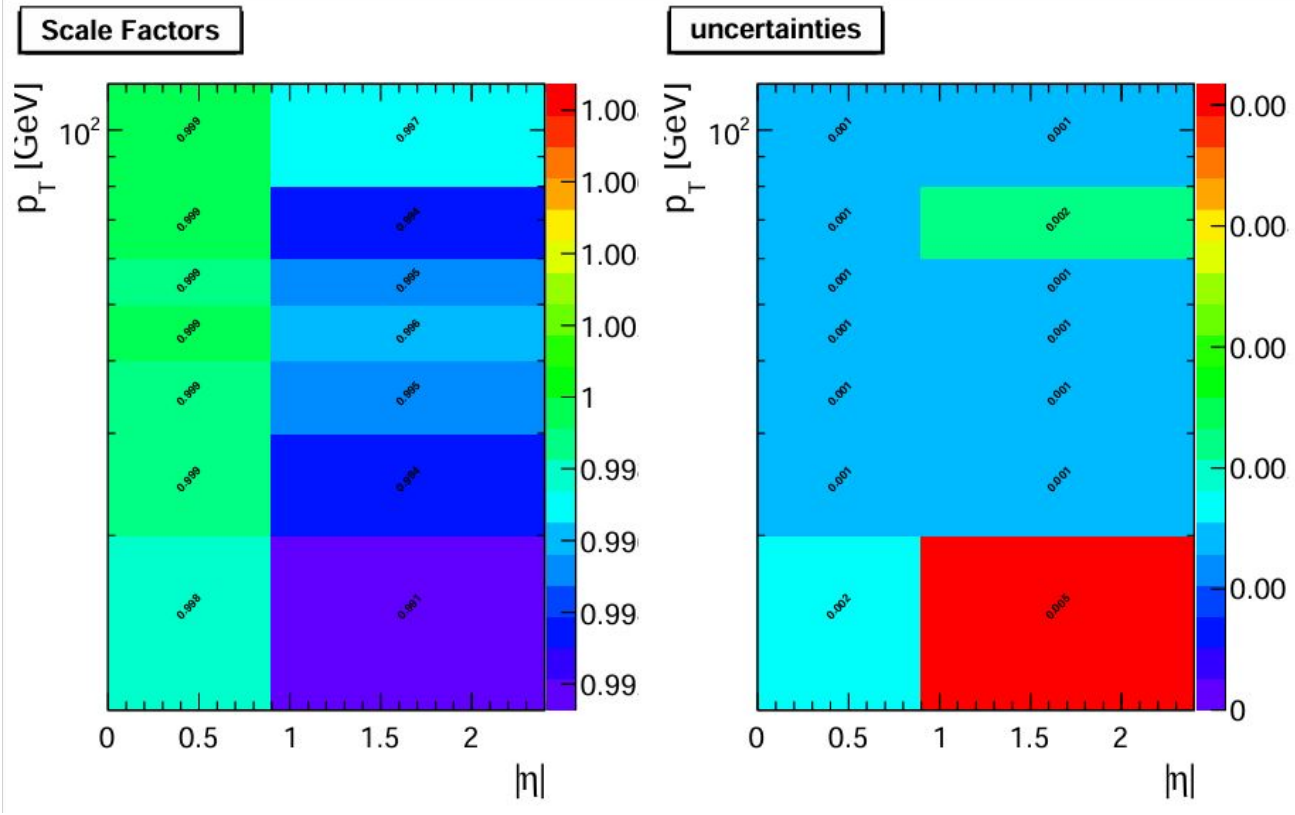


Results of Run 2 and Run 3 in Medium WP



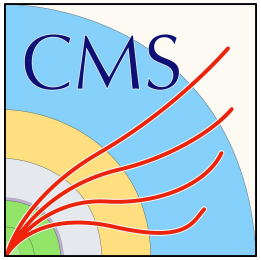


Scale factors



Conclusions

- Several methods to identify muons in CMS.
- For medium p_T range, very high efficiency of cut-based ID and the Muon MVA ID.
- The Run 2 development has a very good performance in Run 3.
- Looking forward to see the behaviour of these ID's with the new data (2023 onwards).



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Thank you!

Backup

Introduction: training of the Muon MVA ID

Data:
/SingleMuon/Run2018X1-UL2018 MiniAODv2 GT36-v1/MINIAOD

DY: /DYJetsToLL M-50 TuneCP5 13TeV amcatnloFXFX-pythia8 RunIISummer20UL18MiniAODv2 106X upgrade2018 realistic v16-L1v1-v2/MINIAODSIM

Sample for training:

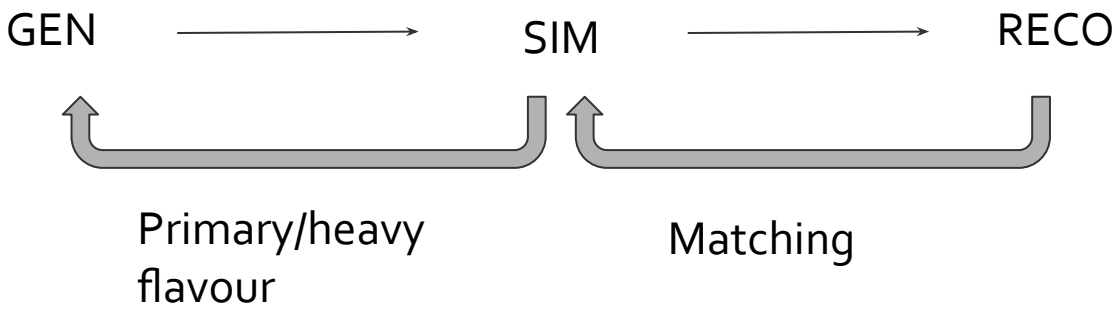
- /TTToSemiLeptonic_TuneCP5_13TeV-powheg-pythia8/RunIIAutumn18MiniAOD-102X_upgrade2018_realistic_v15_ext3-v2/MINIAODSIM

Sample for validation:

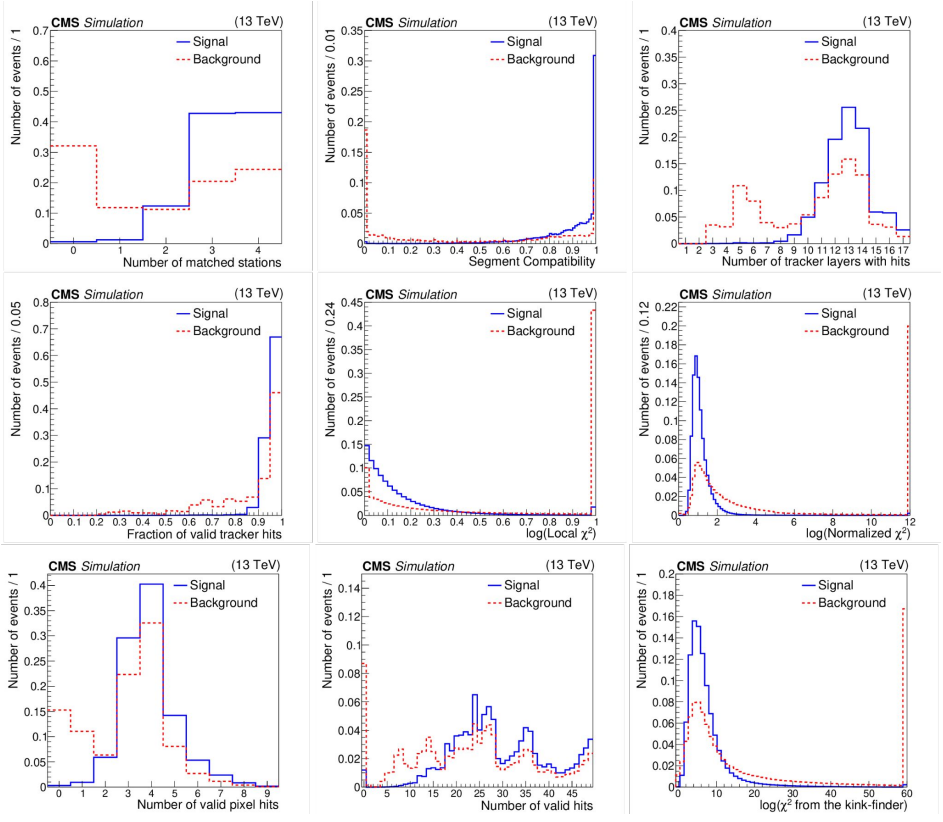
- /TTToSemiLeptonic_TuneCP5_13TeV-powheg-pythia8/RunIISummer20UL18MiniAODv2_PUForMUOVal_106X_upgrade2018_realistic_v16_L1v1_ext1-v2/MINIAODSIM

Background muons

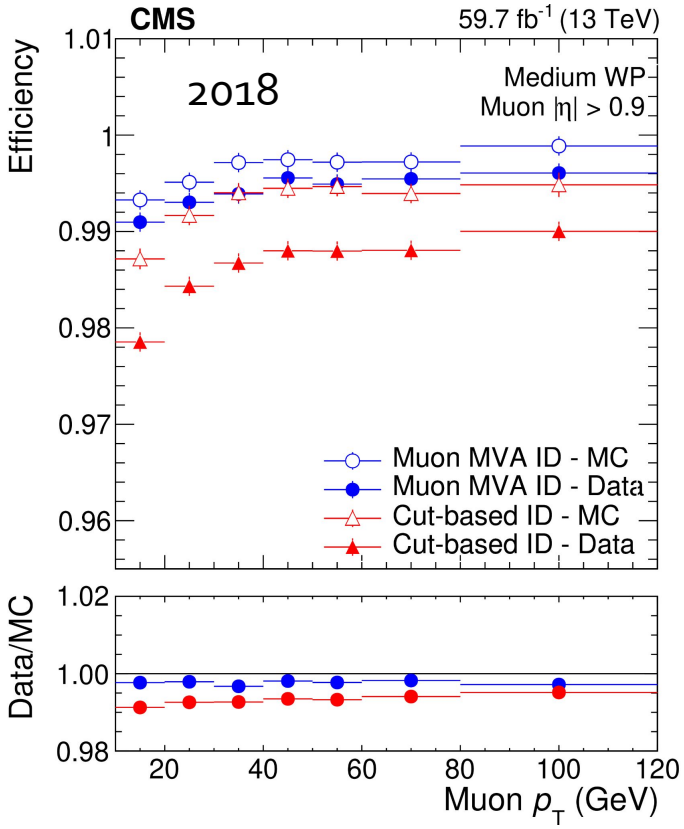
- Decays from kaons and pions → GEN parent light flavour.
- Not matched muons.
- Punchthrough muons → SIM not a muon.

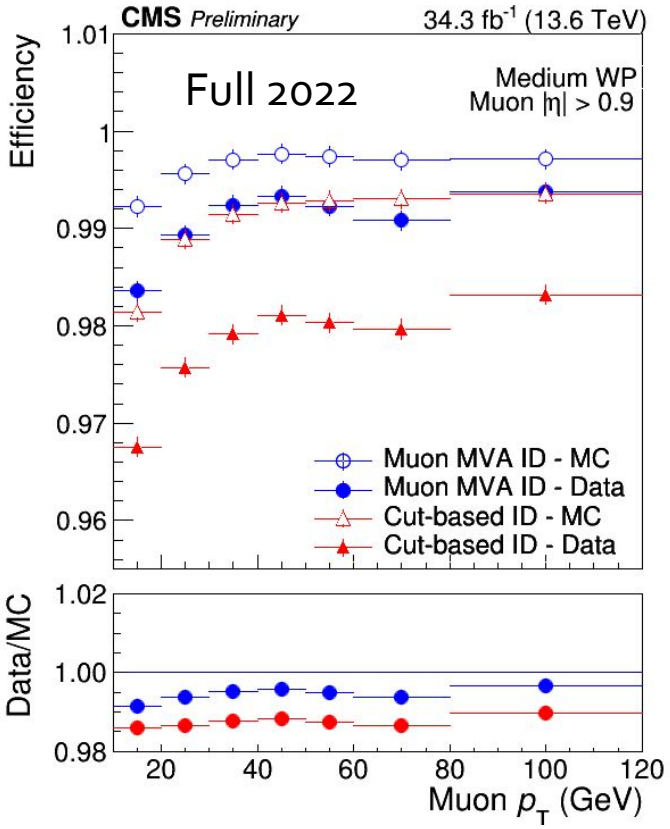


Input variables for training

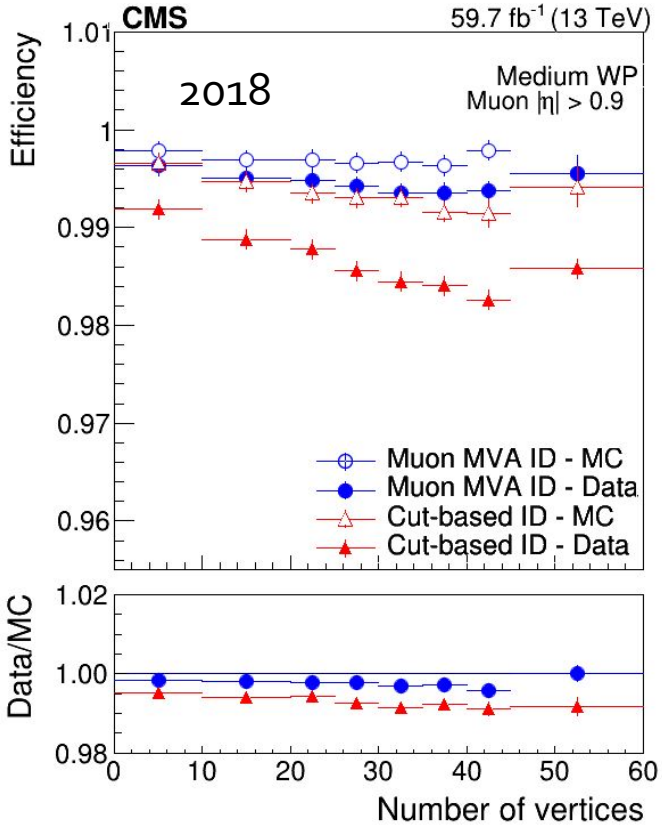


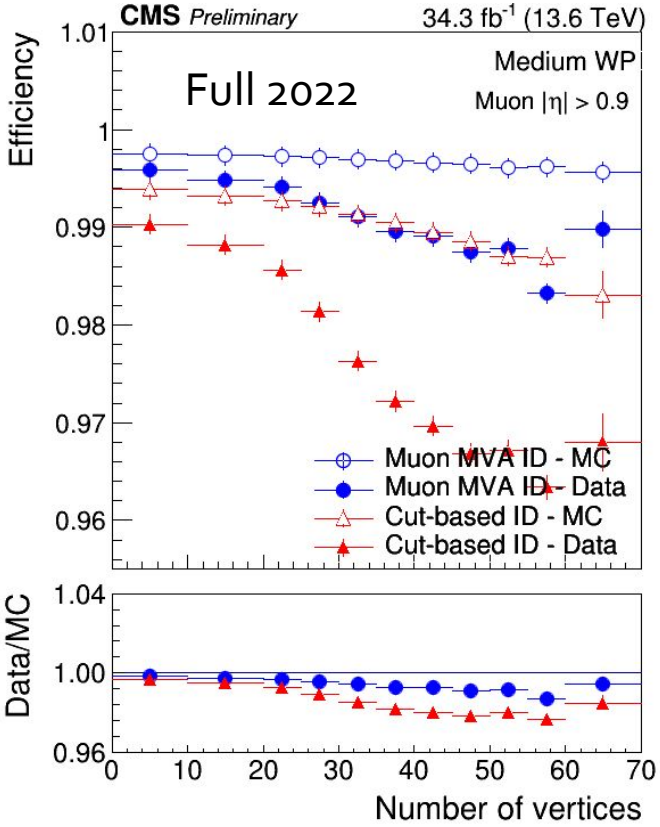
Results of Run 2 and Run 3 in Medium WP



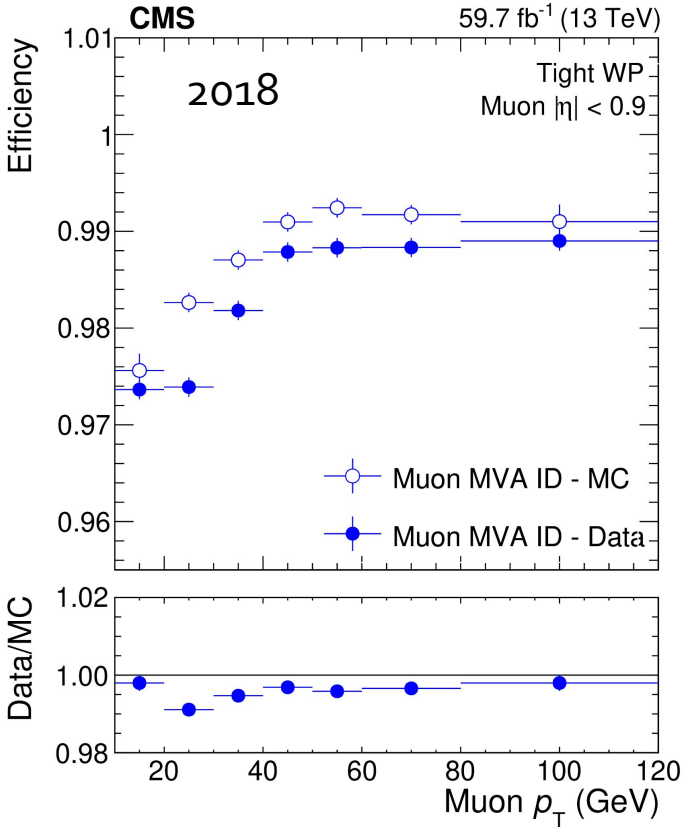


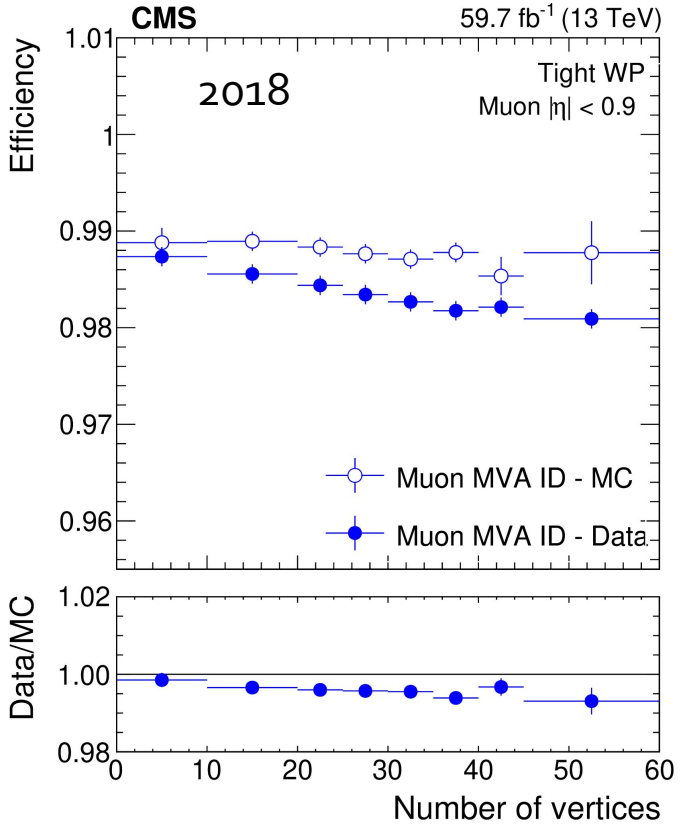
Results of Run 2 and Run 3 in Medium WP



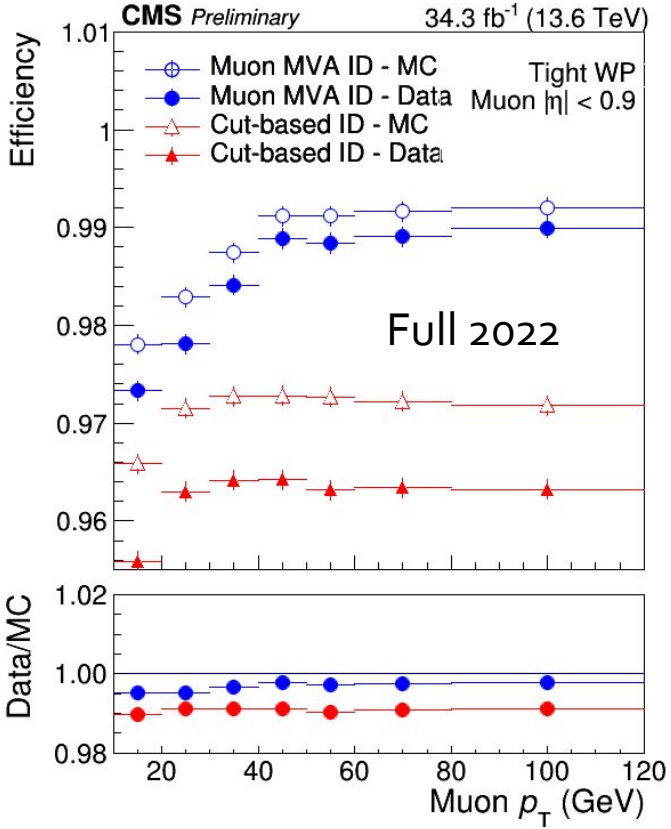


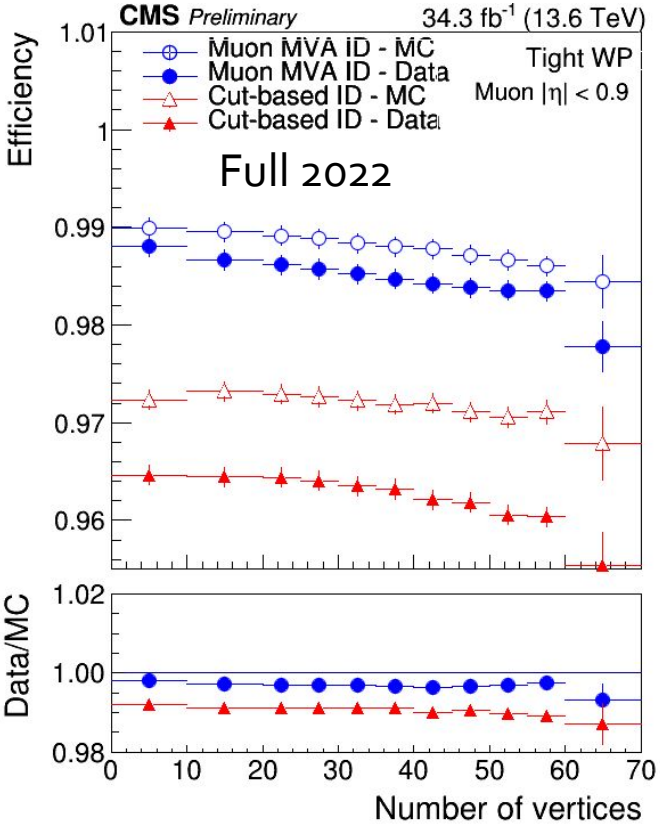
Results of Run 2 in Tight WP





Results of Run 3 in Tight WP





Fits

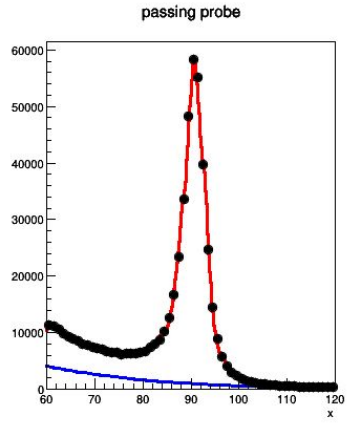
Data

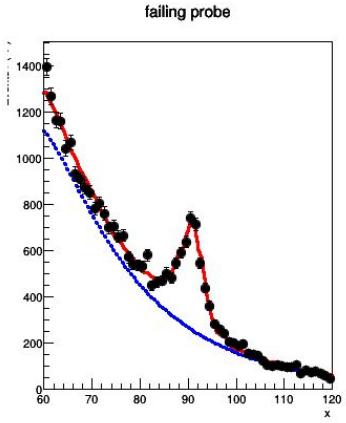
*** fit status pass: 4, fail : 4**

*** eff = 0.9880 ± 0.0004**

--- parmeters

- acmsP = 56.995 ± 16.785
- betaP = 0.020 ± 0.004
- gammaP = 0.062 ± 0.006
- meanP = 0.366 ± 0.005
- nBkgP = 80916.808 ± 694.519
- nSigP = 482214.657 ± 935.132
- sigmaP = 0.500 ± 0.001
- acmsF = 50.119 ± 0.446
- betaF = 0.080 ± 0.007
- gammaF = 0.053 ± 0.001
- meanF = 0.242 ± 0.075
- nBkgF = 22837.004 ± 218.611
- nSigF = 5852.848 ± 175.851
- sigmaF = 0.402 ± 0.021





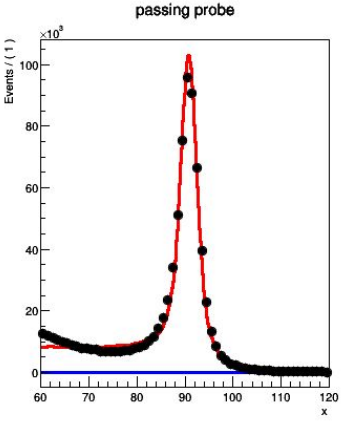
DY

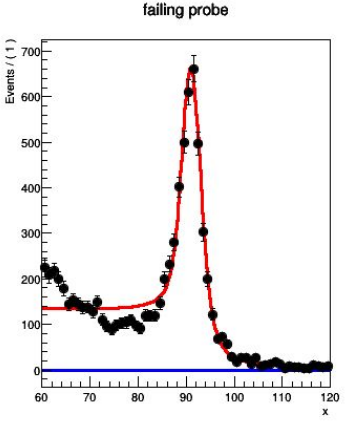
*** fit status pass: 4, fail : 4**

*** eff = 0.9902 ± 0.0001**

--- parmeters

- alphaP = 2.579 ± 0.002
- meanP = 0.025 ± 0.009
- nP = 0.003 ± 0.000
- nSigP = 795291.089 ± 1001.759
- sigmaP = 0.976 ± 369.234
- sigmaP_2 = 0.697 ± 0.707
- alphaF = 2.075 ± 0.015
- meanF = 0.194 ± 0.055
- nF = 0.001 ± 0.145
- nSigF = 7858.574 ± 100.357
- sigmaF = 1.444 ± 0.045
- sigmaF_2 = 0.979 ± 2.436





Other fits:

2022EE