NanoAODs production packages comparison for $B^0 \to K^{*0} \mu^+\mu^-$ decay channel

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BPHNano

- CMS framework designed for the production of custom NanoAODs for B-physics analyses
- Developed to avoid each analysis reinventing the same reconstruction code
- Supports multiple decay channels simultaneously, all within the same output file
- New channels and variables can be added with minimal code changes
- Produces NanoAODs that contain standard NanoAOD content + BPH additional branches

Validation

- Our objective is to check whether BPHNano-produced NTuples (**BPH**) are equivalent to the standard private NTuple production in CMSSW (**Nano**)

- Since both methods of production apply pre-selection cuts in order to generate the NanoAOD outputs, we need to:

    - Identify, through both package codes, the equivalent branch names of NanoAOD outputs
    - Use them to apply the same cuts to both outputs
    - Compare plots of different physical variables after the cuts are equalized

Identification

- Embedded pre-selections, applied during generation, that cannot be removed (e.g. isLooseMuon)

- Not all variables from one package have a direct equivalent in the other (e.g. mumuDCA, svip2d)
    - Some of these are also used as pre-selection criteria for the final outputs

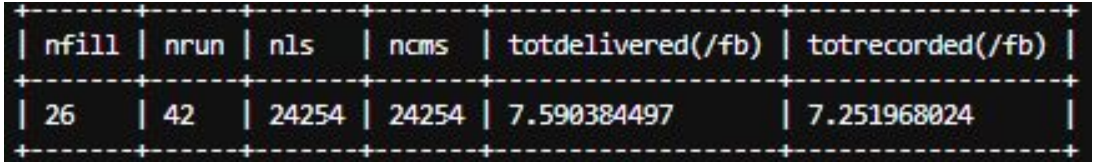
- Some branches represent the same physical concept, but are derived differently (e.g., muon pT)

- This means we can’t fully equalize all pre-selections using only cuts on the available output branches, so some differences are expected

Dataset

0,1,…,7

Dataset: /ParkingDoubleMuonLowMass0/Run2024C-PromptReco-v1/MINIAOD
Dataset size: 4156631421735 (4.2TB) Number of blocks: 38 Number of events: 75262728 Number of files: 1288 Creation time: 2024-04-16 20:14:39
Release, Blocks, Files, Runs, Configs, Parents, Children, Sites, Physics Groups XSDB Sources: dbs3 show



```
+-------+------+-------+-------+-------------------+------------------+
| nfill | nrun | nls   | ncms  | totdelivered(/fb) | totrecorded(/fb) |
+-------+------+-------+-------+-------------------+------------------+
| 26    | 42   | 24254 | 24254 | 7.590384497       | 7.251968024      |
+-------+------+-------+-------+-------------------+------------------+
```

Integrated Luminosity for our dataset: ≈ 0.9 fb^{-1}

CMSSW version: CMSSW_15_0_13_patch2
Nano github link
BPHNano github link

Dataset

CMSSW version: CMSSW_15_0_13_patch2
Nano: link BPHNano: link

Dataset: /ParkingDoubleMuonLowMass0/Run2024C-PromptReco-v1/MINIAOD
Dataset size: 4156631421735 (4.2TB) Number of blocks: 38 Number of events: 75262728 Number of files: 1288 Creation time: 2024-04-16 20:14:3
Release, Blocks, Files, Runs, Configs, Parents, Children, Sites, Physics Groups XSDB Sources: dbs3 show

BPH cuts

4.5 < “B_chosen_mass” < 6.5	BToTrkTrkMuMu_fit_trk1_pt, trk2_pt > 0.72
BPHMuon_pt1, pt2 > 3.96	0.99 < BToTrkTrkMuMu_mll_fullfit < 4.848
|BPHMuon_eta1|, |BPHMuon_eta2| < 2.4	MuMu_svprob > 0.1
Track_DCASig > 0.8	MuMu_l_xy / MuMu_l_xy_unc > 3.0
MuMu_pt > 6.831	MuMu_fit_cos2D > 0.9

Nano cuts

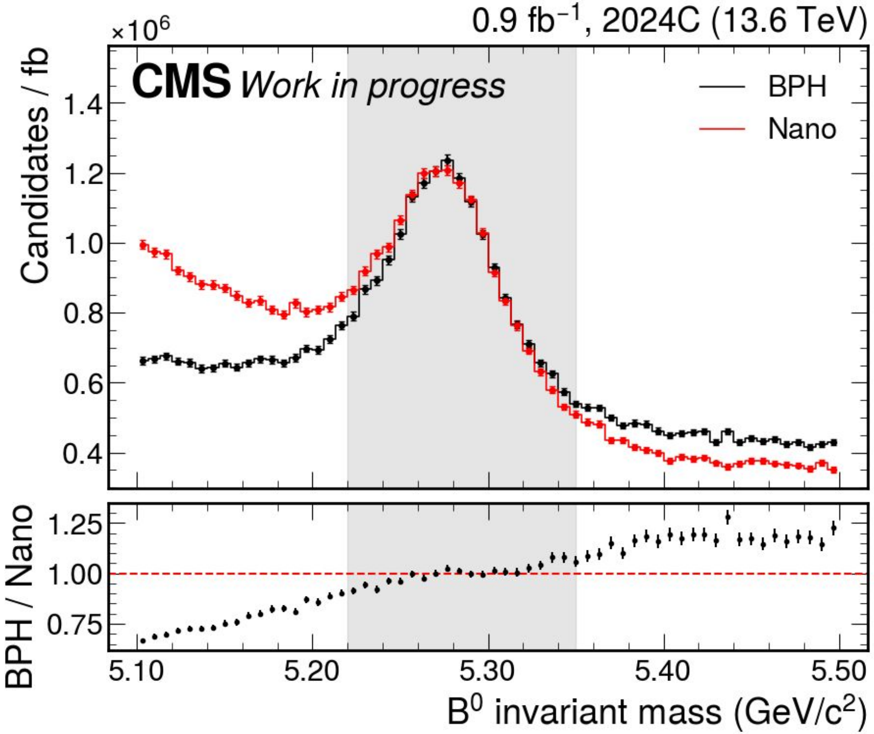
4.5 < “B_chosen_mass” < 6.5	mumuCosAlphaBS > 0.9
|rawkstTrkmEta|, |rawkstTrkpEta|< 2.4	|rawmumEta|, |rawmupEta| < 2.4

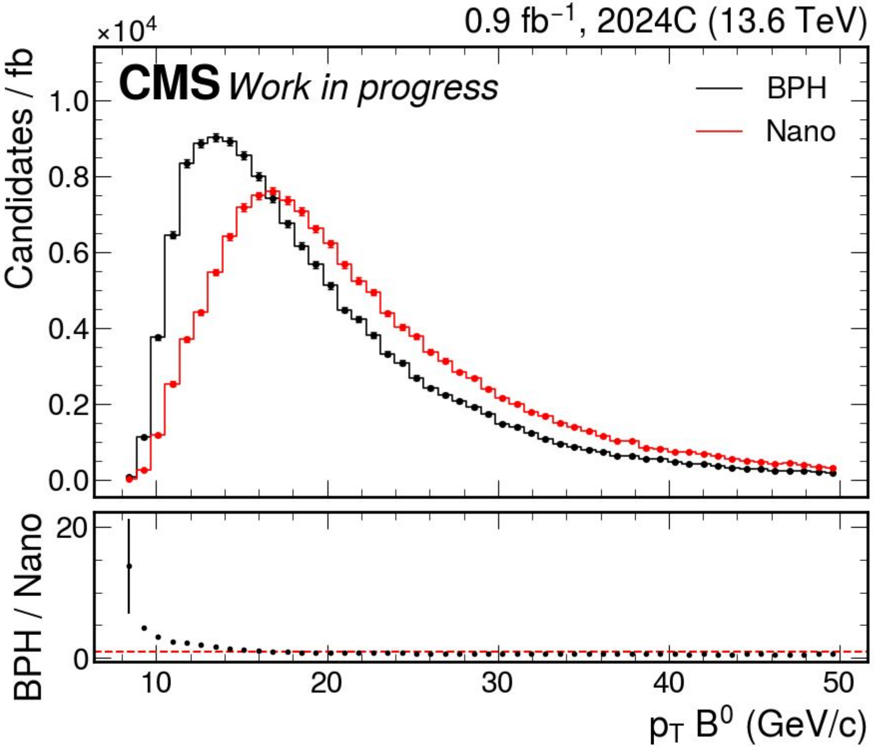
BPH: 31.083.532 candidates (295.3 GB) → 942.827 after cuts (3.03% efficiency), 49.1 GB
Nano: 1.910.666 candidates (12.1 GB) → 1.662.114 after cuts (86.99% efficiency), 11.3 GB

Plots

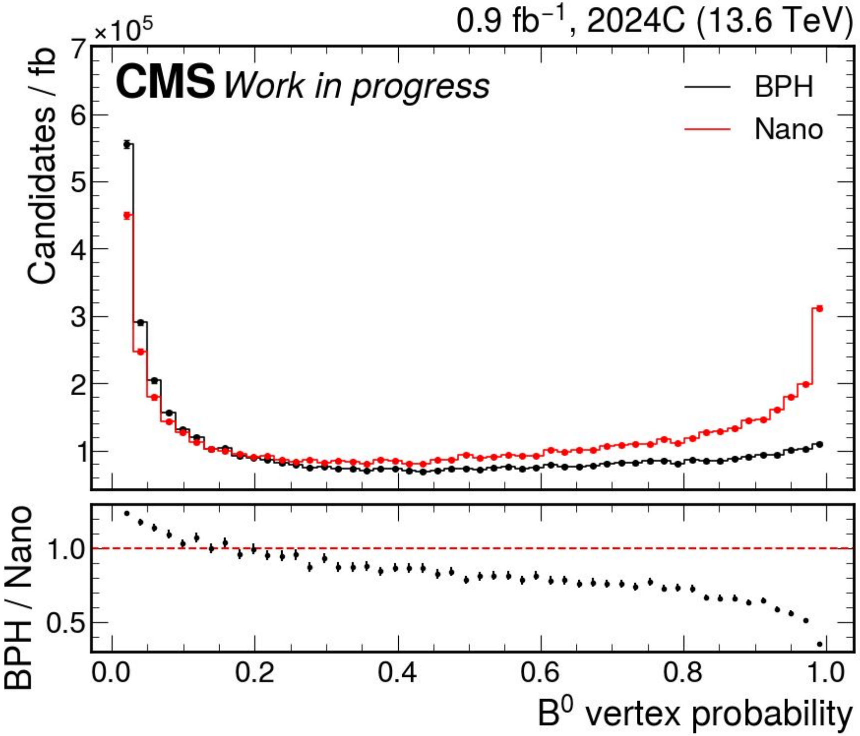
* All normalized by integrated luminosity

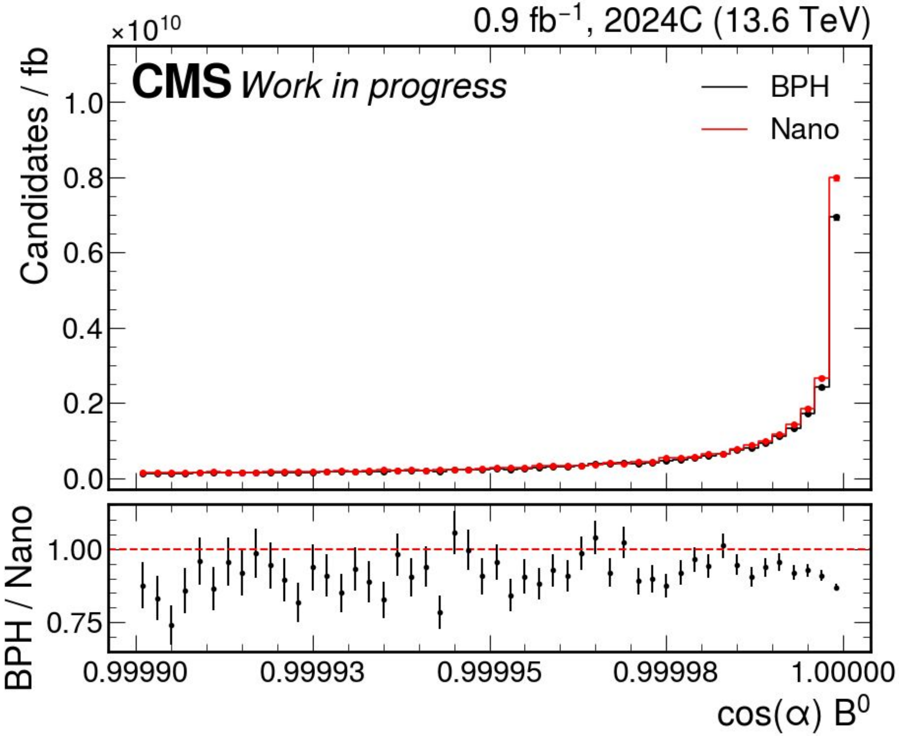
* No resonances removed



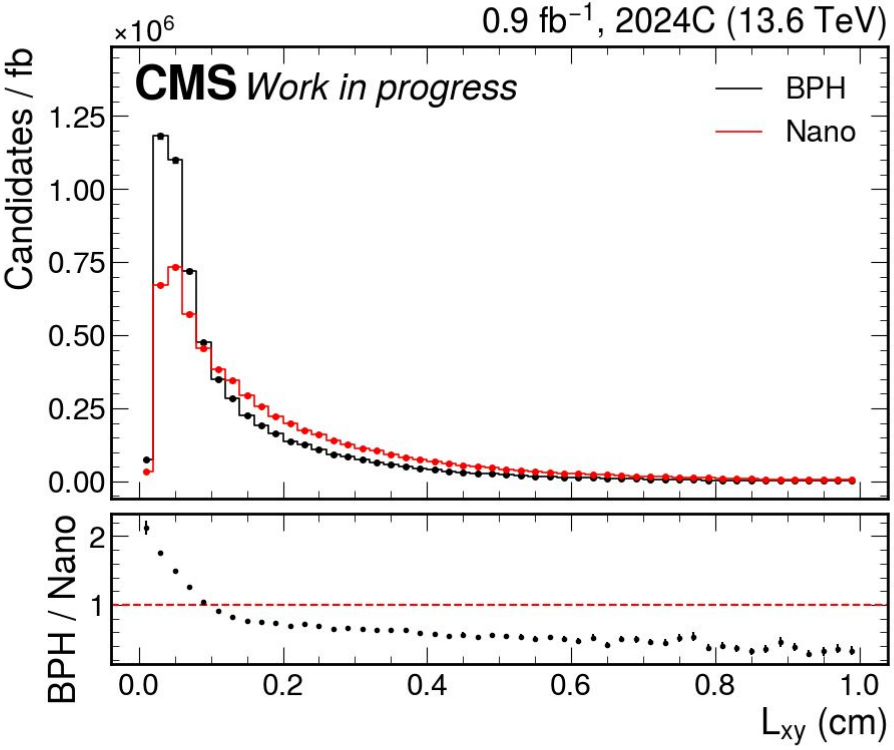


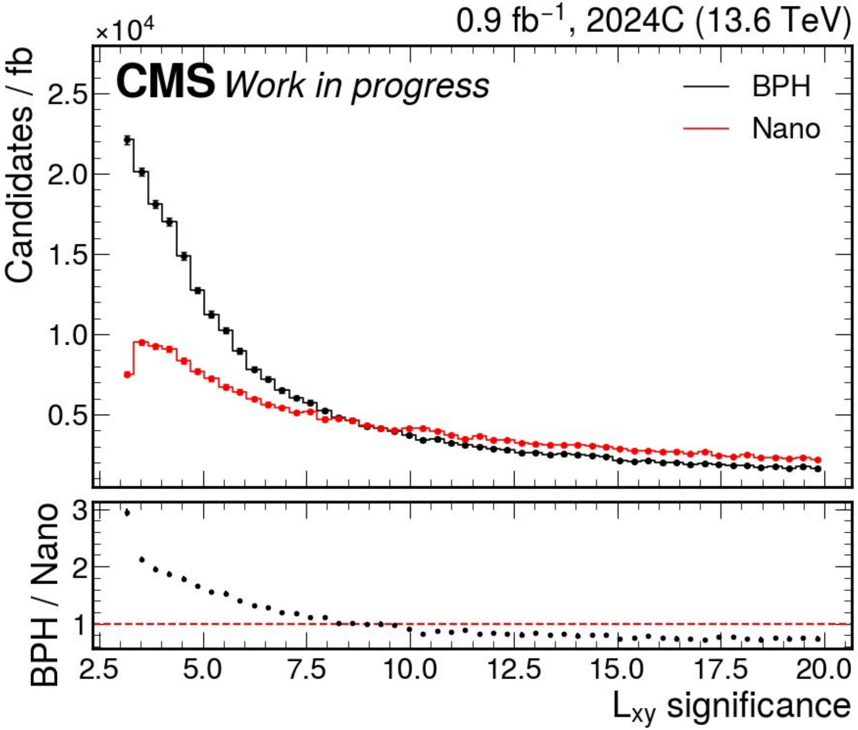
Plots


0.9 fb^{-1}, 2024C (13.6 TeV)
×10^5
CMS Work in progress
BPH
Nano
Candidates / fb
7
6
5
4
3
2
1
BPH / Nano
1.0
0.5
0.0
0.2
0.4
0.6
0.8
1.0
B^0 vertex probability

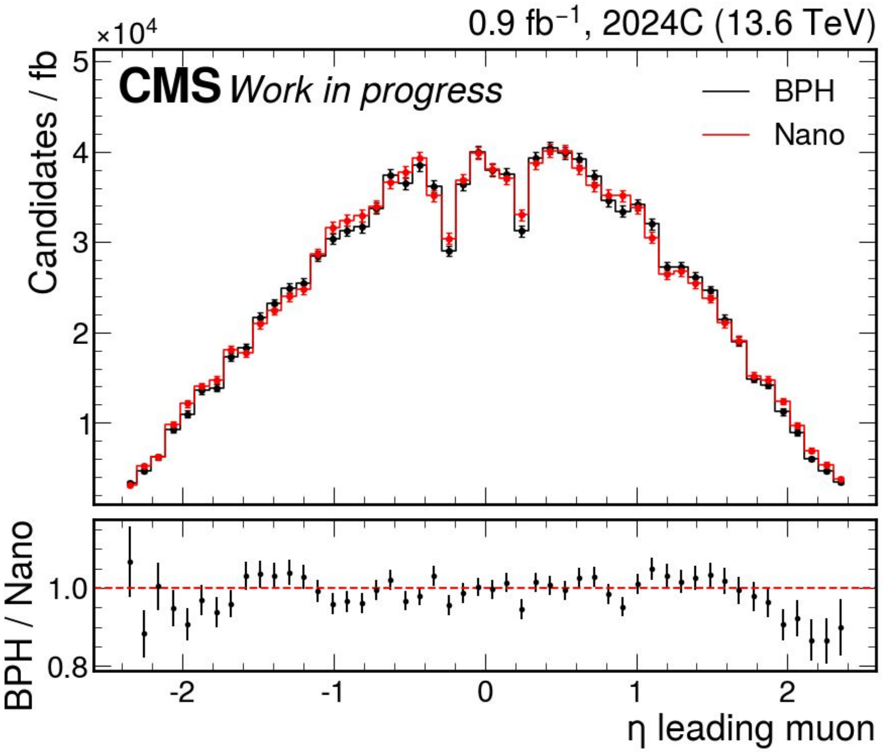

0.9 fb^{-1}, 2024C (13.6 TeV)
×10^{10}
CMS Work in progress
BPH
Nano
Candidates / fb
1.0
0.8
0.6
0.4
0.2
0.0
BPH / Nano
1.00
0.75
0.99990
0.99993
0.99995
0.99998
1.00000
cos(α) B^0

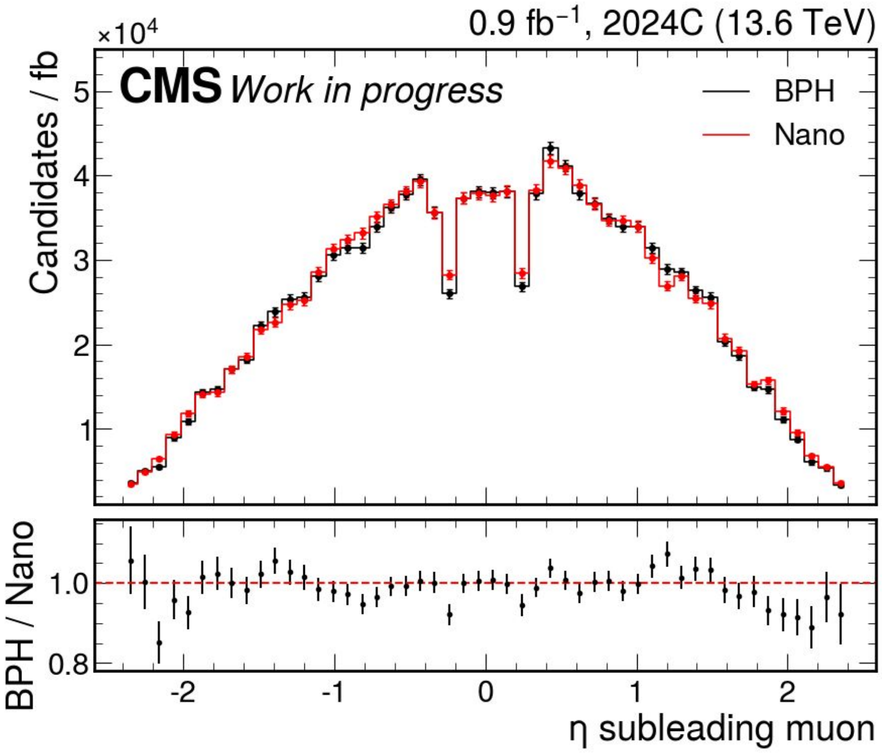
Plots


×10^6
0.9 fb^−1, 2024C (13.6 TeV)
CMS Work in progress
BPH
Nano
Candidates / fb
1.25
1.00
0.75
0.50
0.25
0.00
BPH / Nano
2
1
0.0
0.2
0.4
0.6
0.8
1.0
Lxy (cm)

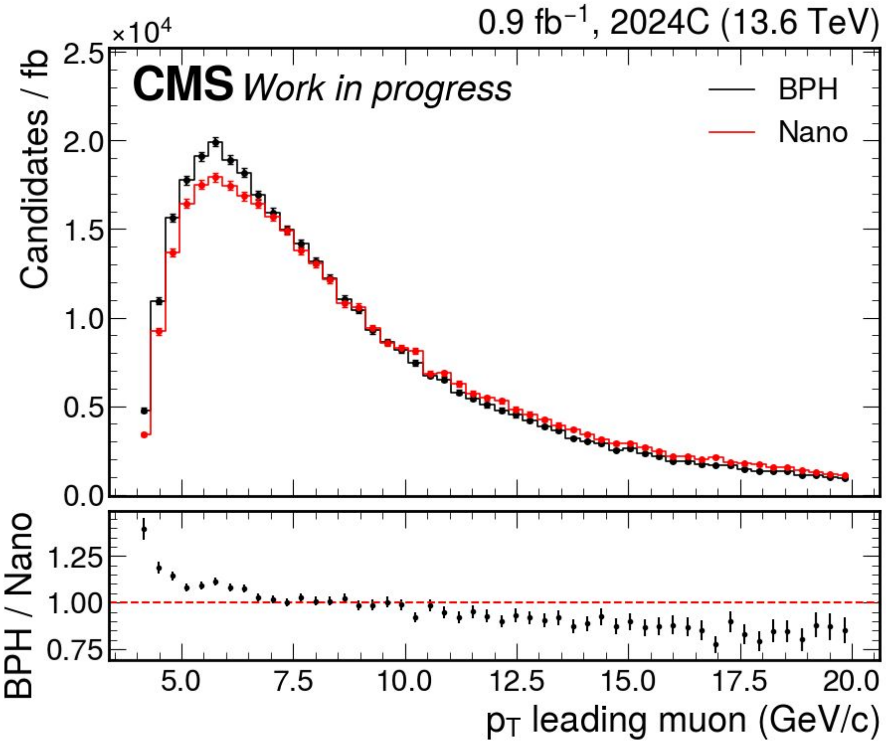

×10^4
0.9 fb^−1, 2024C (13.6 TeV)
CMS Work in progress
BPH
Nano
Candidates / fb
2.5
2.0
1.5
1.0
0.5
BPH / Nano
3
2
1
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
Lxy significance

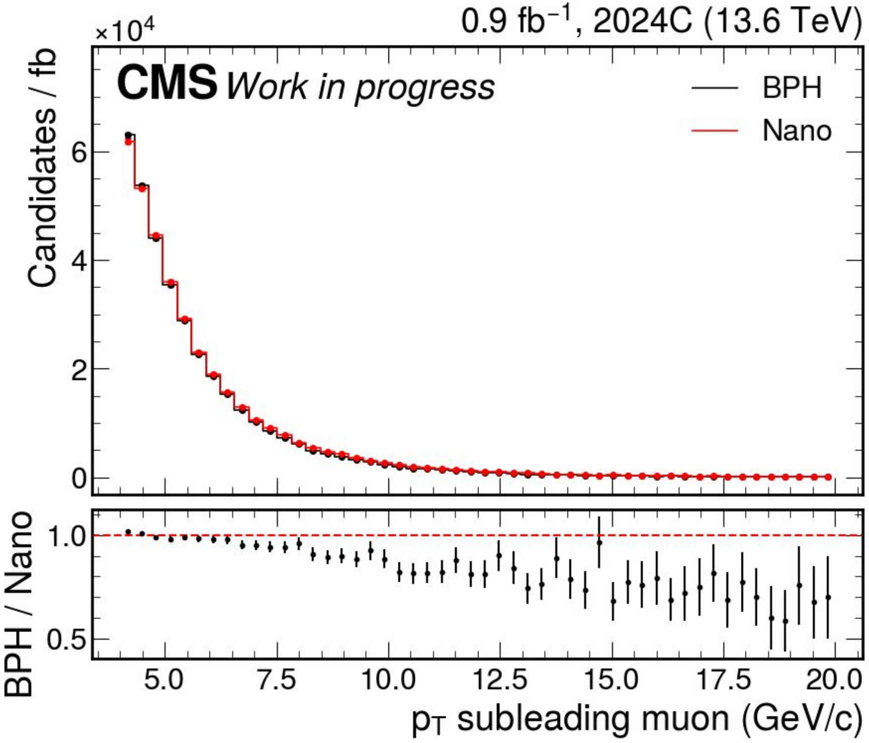
Plots


0.9 fb^{-1}, 2024C (13.6 TeV)
×10^4
CMS *Work in progress*
BPH
Nano
Candidates / fb
5
4
3
2
1
BPH / Nano
1.0
0.8
-2
-1
0
1
2
η leading muon

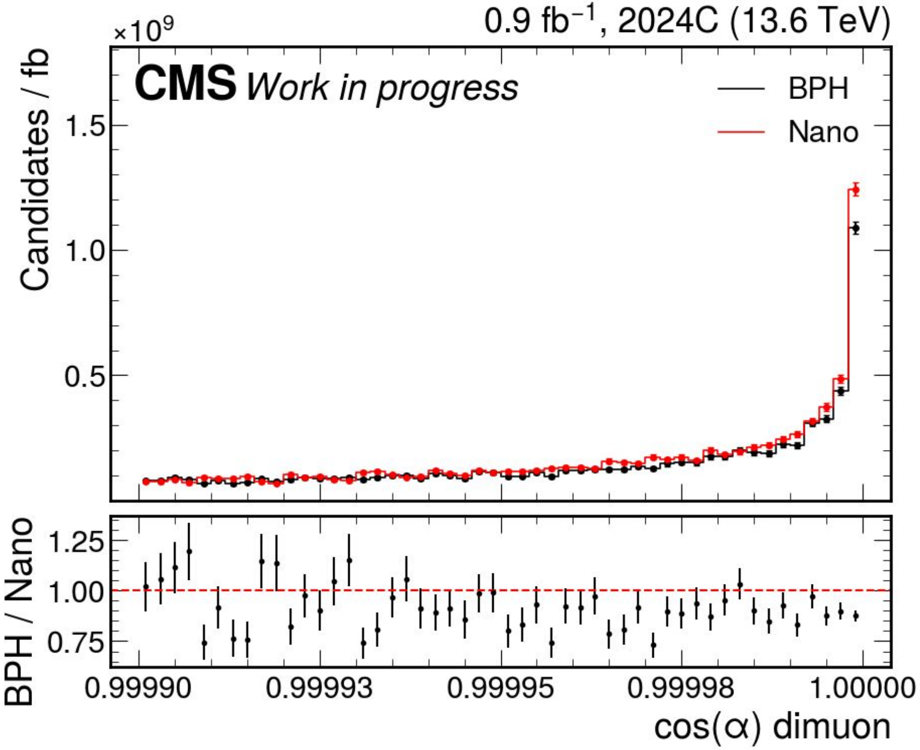

0.9 fb^{-1}, 2024C (13.6 TeV)
×10^4
CMS *Work in progress*
BPH
Nano
Candidates / fb
5
4
3
2
1
BPH / Nano
1.0
0.8
-2
-1
0
1
2
η subleading muon

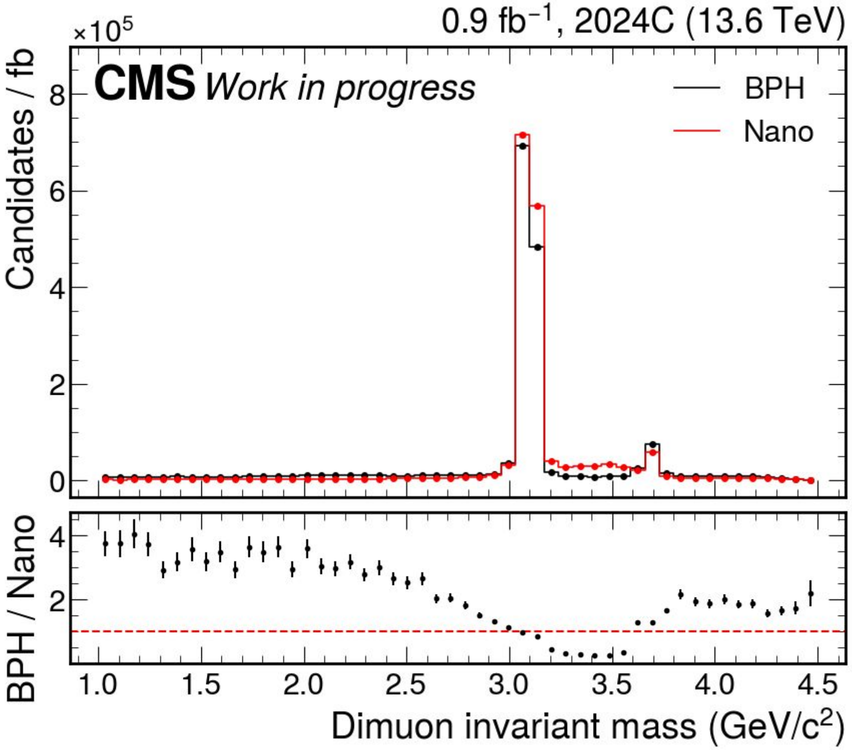
Plots


0.9 fb^{-1}, 2024C (13.6 TeV)
×10^4
CMS Work in progress
BPH
Nano
Candidates / fb
2.5
2.0
1.5
1.0
0.5
0.0
BPH / Nano
1.25
1.00
0.75
5.0
7.5
10.0
12.5
15.0
17.5
20.0
p$_T$ leading muon (GeV/c)

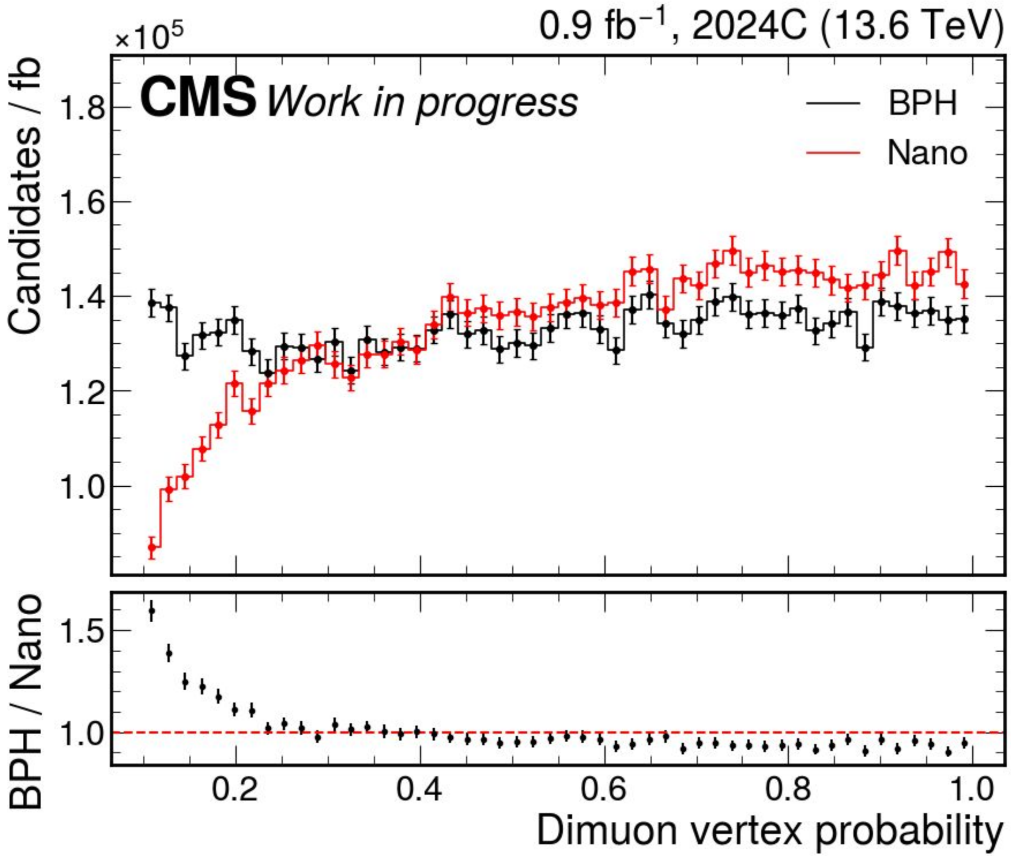

0.9 fb^{-1}, 2024C (13.6 TeV)
×10^4
CMS Work in progress
BPH
Nano
Candidates / fb
6
4
2
0
BPH / Nano
1.0
0.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
p$_T$ subleading muon (GeV/c)

Plots

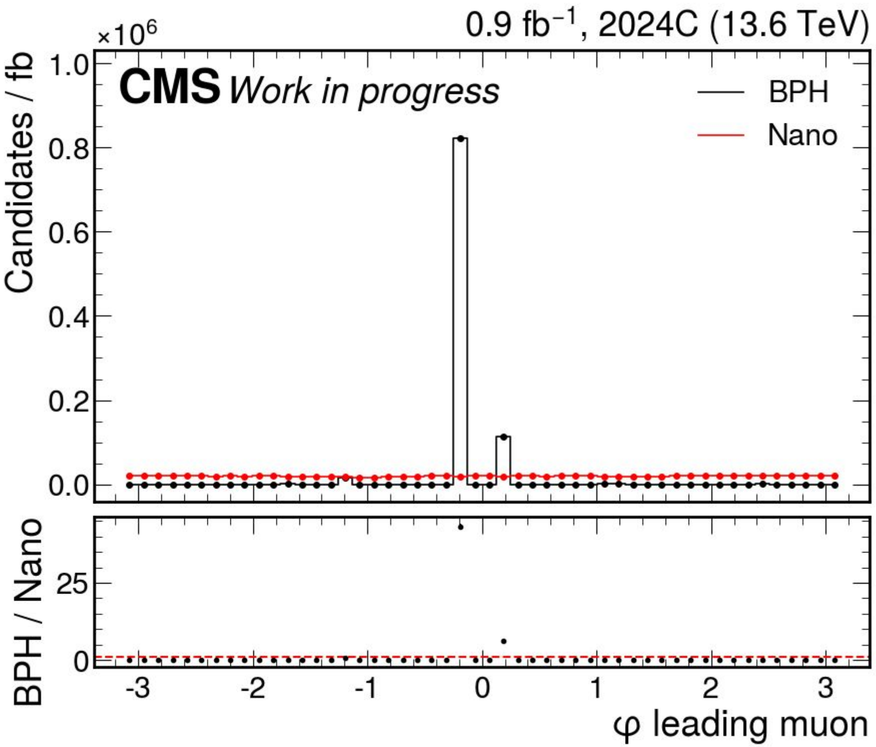

×10^9
0.9 fb^-1, 2024C (13.6 TeV)
CMS Work in progress
BPH
Nano
Candidates / fb
1.5
1.0
0.5
BPH / Nano
1.25
1.00
0.75
0.99990
0.99993
0.99995
0.99998
1.00000
cos(α) dimuon

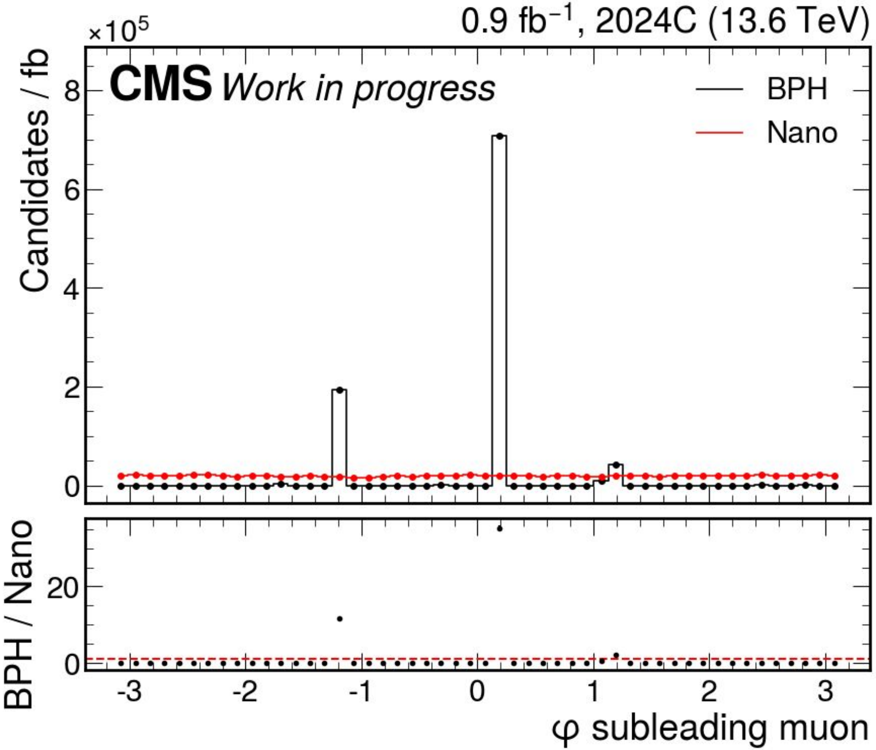

×10^5
0.9 fb^-1, 2024C (13.6 TeV)
CMS Work in progress
BPH
Nano
Candidates / fb
8
6
4
2
0
BPH / Nano
4
2
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Dimuon invariant mass (GeV/c^2)

Plots

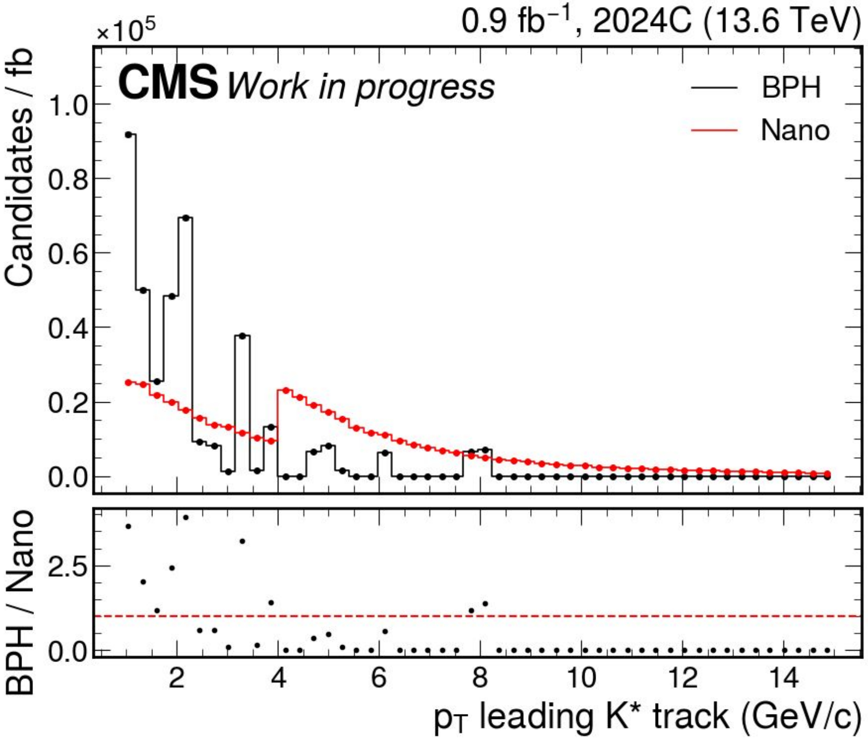

0.9 fb^{-1}, 2024C (13.6 TeV)
×10^5
CMS Work in progress
BPH
Nano
Candidates / fb
1.0
1.2
1.4
1.6
1.8
BPH / Nano
1.0
1.5
0.2
0.4
0.6
0.8
1.0
Dimuon vertex probability

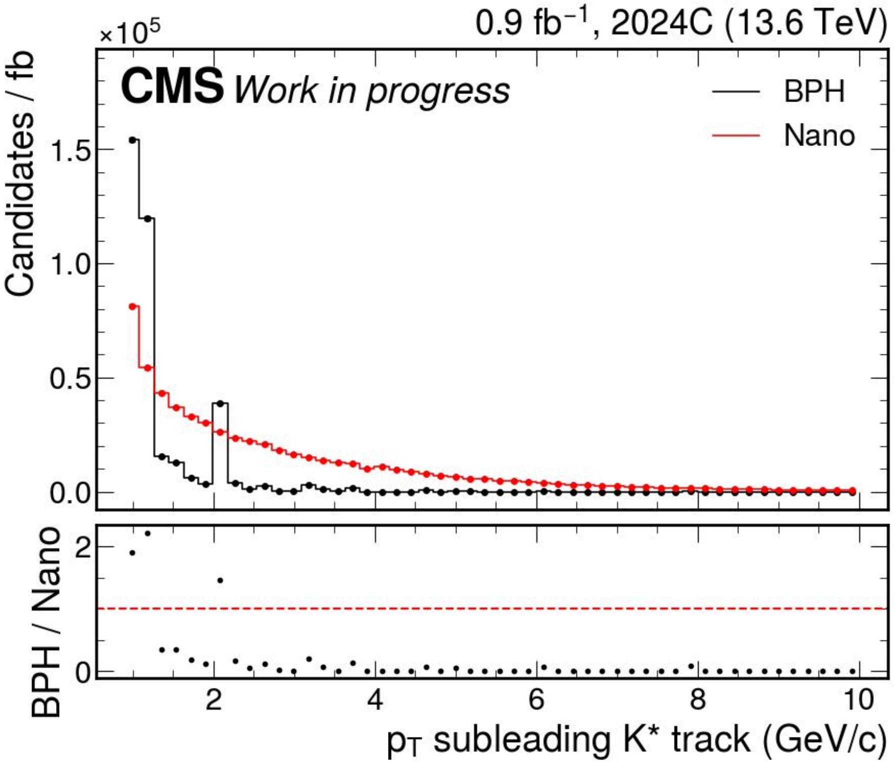
Plots


0.9 fb^{-1}, 2024C (13.6 TeV)
×10^6
CMS Work in progress
BPH
Nano
Candidates / fb
1.0
0.8
0.6
0.4
0.2
0.0
BPH / Nano
25
0
-3
-2
-1
0
1
2
3
φ leading muon

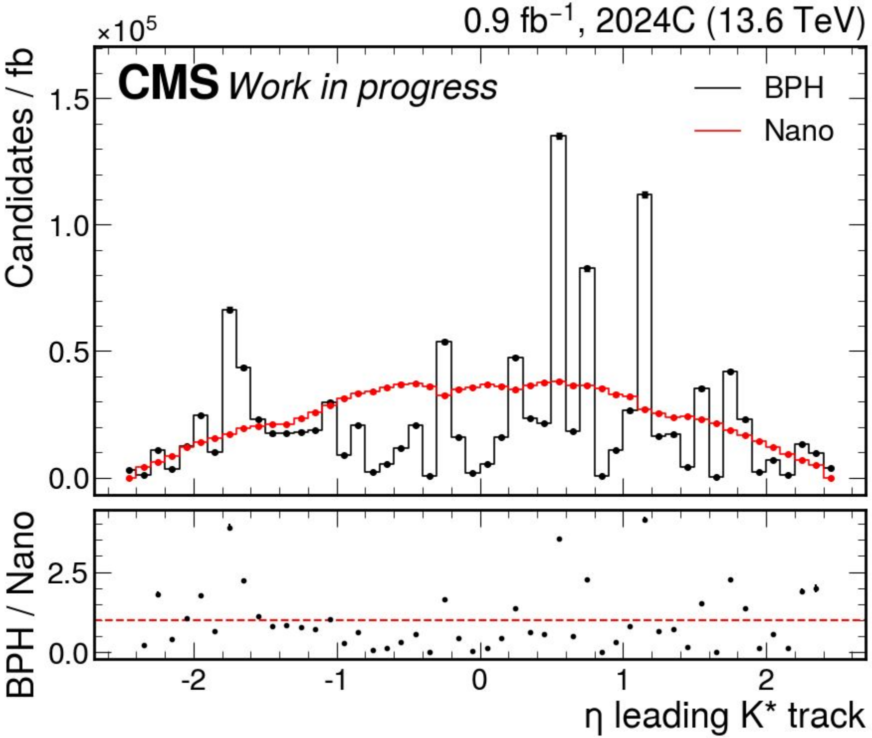

0.9 fb^{-1}, 2024C (13.6 TeV)
×10^5
CMS Work in progress
BPH
Nano
Candidates / fb
8
6
4
2
0
BPH / Nano
20
0
-3
-2
-1
0
1
2
3
φ subleading muon

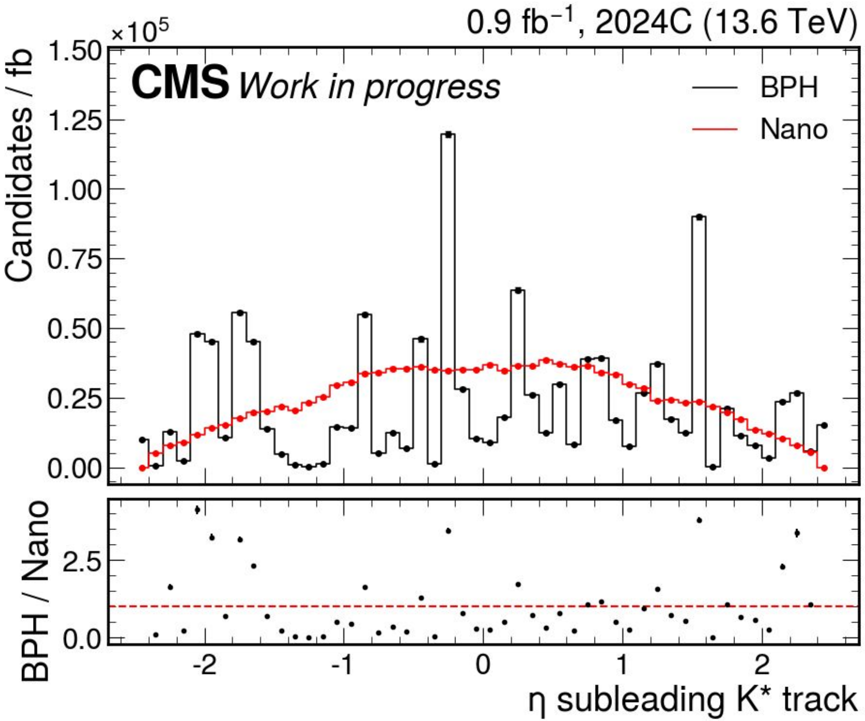
Plots


×10^5
0.9 fb^-1, 2024C (13.6 TeV)
CMS Work in progress
BPH
Nano
Candidates / fb
1.0
0.8
0.6
0.4
0.2
0.0
BPH / Nano
2.5
0.0
2
4
6
8
10
12
14
pT leading K* track (GeV/c)

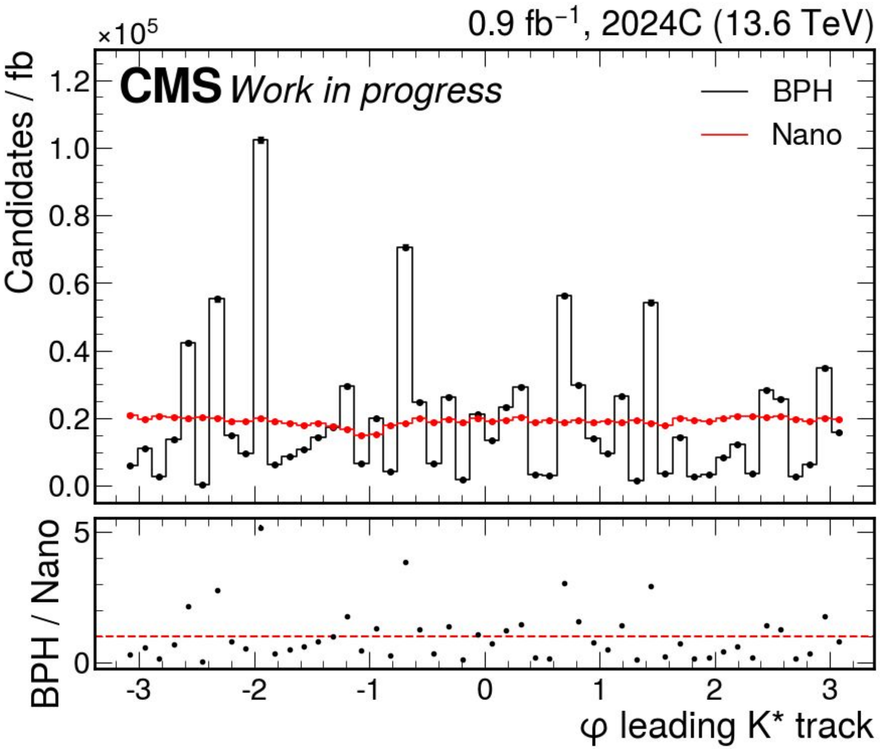

×10^5
0.9 fb^-1, 2024C (13.6 TeV)
CMS Work in progress
BPH
Nano
Candidates / fb
1.5
1.0
0.5
0.0
BPH / Nano
2
0
2
4
6
8
10
pT subleading K* track (GeV/c)

Plots

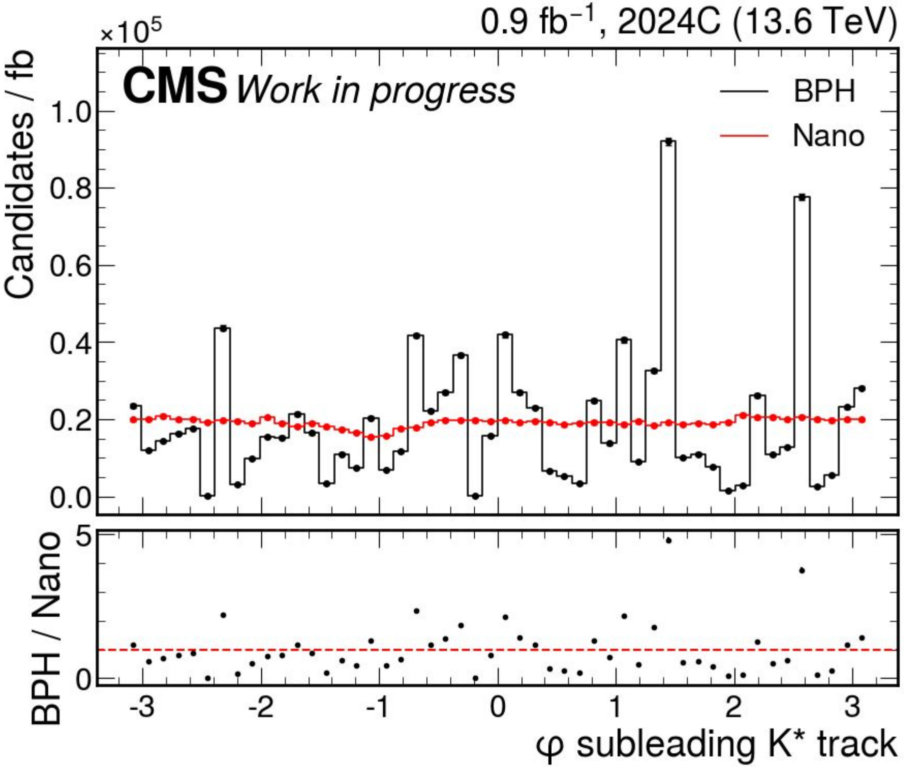

×10^5
0.9 fb^-1, 2024C (13.6 TeV)
CMS Work in progress
BPH
Nano
Candidates / fb
0.0
0.5
1.0
1.5
BPH / Nano
0.0
2.5
-2
-1
0
1
2
η leading K* track


×10^5
0.9 fb^-1, 2024C (13.6 TeV)
CMS Work in progress
BPH
Nano
Candidates / fb
0.00
0.25
0.50
0.75
1.00
1.25
1.50
BPH / Nano
0.0
2.5
-2
-1
0
1
2
η subleading K* track

Plots



0.9 fb^{-1}, 2024C (13.6 TeV)
$\times10^5$
CMS *Work in progress*
BPH
Nano
Candidates / fb
0.0
0.2
0.4
0.6
0.8
1.0
1.2
BPH / Nano
0
5
-3
-2
-1
0
1
2
3
φ leading K* track



0.9 fb^{-1}, 2024C (13.6 TeV)
$\times10^5$
CMS *Work in progress*
BPH
Nano
Candidates / fb
0.0
0.2
0.4
0.6
0.8
1.0
BPH / Nano
0
5
-3
-2
-1
0
1
2
3
φ subleading K* track

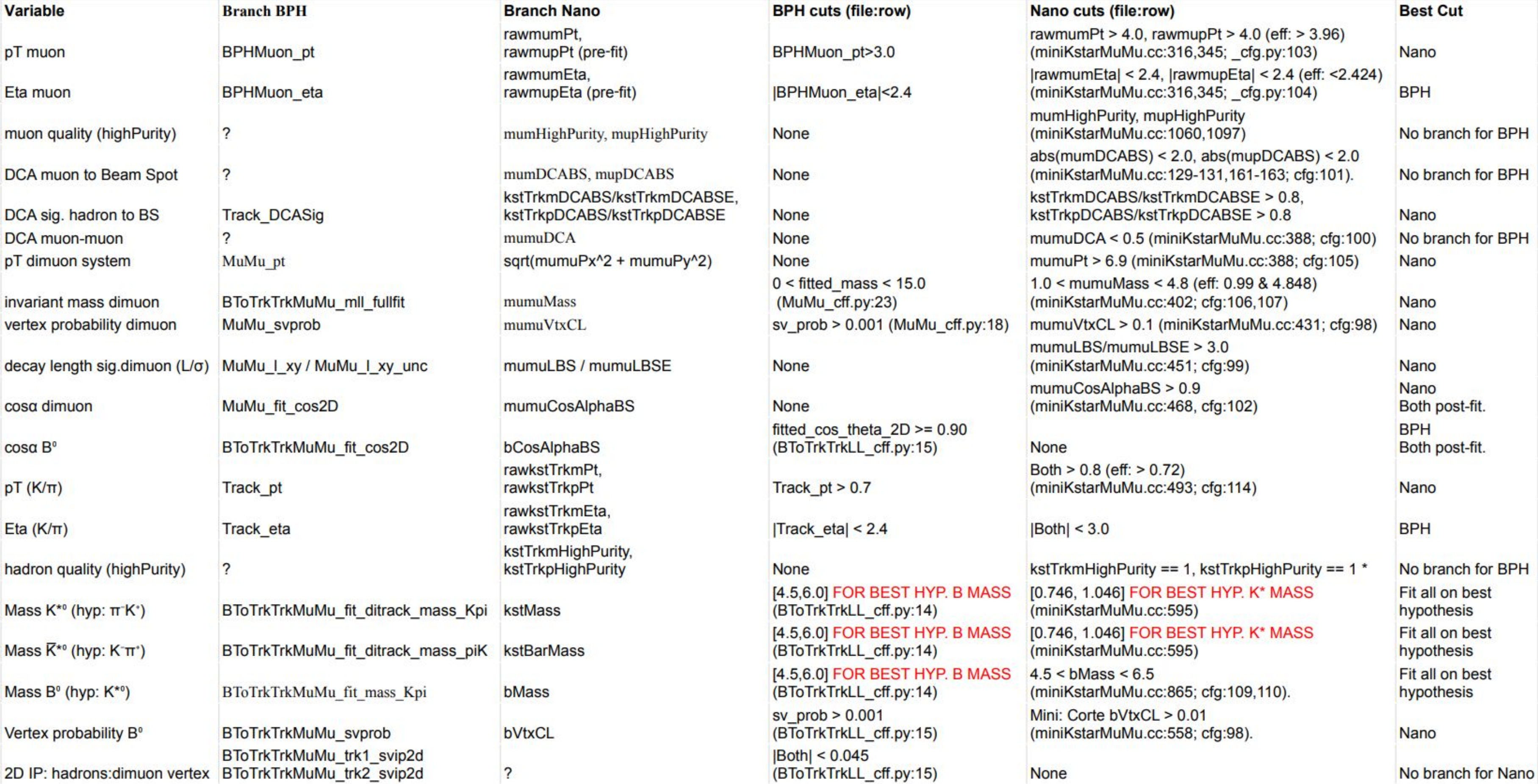
Conclusion

- Since the BPH and Nano do not yet share the same preselection, some differences were already expected. This is evident by the different number of candidates after cuts (BPH: 942.827, Nano: 1.662.114)
- Despite the difference in preselections, many of these variables show reasonable agreement, validating the comparison strategy
- Some anomalies are probably caused by the reordering of tracks by transverse momentum (BPH) instead of charge (Nano) and/or by the incorrect flattening of these variables

- Next steps include the correction of track variables and a better alignment of the preselection cuts

Thank you

Backup



Variable	Branch BPH	Branch Nano	BPH cuts (file:row)	Nano cuts (file:row)	Best Cut
pT muon	BPHMuon_pt	rawmumPt, rawmupPt (pre-fit)	BPHMuon_pt>3.0	rawmumPt > 4.0, rawmupPt > 4.0 (eff: > 3.96) (miniKstarMuMu.cc:316,345; _cfg.py:103)	Nano
Eta muon	BPHMuon_eta	rawmumEta, rawmupEta (pre-fit)	|BPHMuon_eta|<2.4	|rawmumEta| < 2.4, |rawmupEta| < 2.4 (eff: <2.424) (miniKstarMuMu.cc:316,345; _cfg.py:104)	BPH
muon quality (highPurity)	?	mumHighPurity, mupHighPurity	None	mumHighPurity, mupHighPurity (miniKstarMuMu.cc:1060,1097)	No branch for BPH
DCA muon to Beam Spot	?	mumDCABS, mupDCABS	None	abs(mumDCABS) < 2.0, abs(mupDCABS) < 2.0 (miniKstarMuMu.cc:129-131,161-163; cfg:101).	No branch for BPH
DCA sig. hadron to BS	Track_DCASig	kstTrkmDCABS/kstTrkmDCABSE, kstTrkpDCABS/kstTrkpDCABSE	None	kstTrkmDCABS/kstTrkmDCABSE > 0.8, kstTrkpDCABS/kstTrkpDCABSE > 0.8	Nano
DCA muon-muon	?	mumuDCA	None	mumuDCA < 0.5 (miniKstarMuMu.cc:388; cfg:100)	No branch for BPH
pT dimuon system	MuMu_pt	sqrt(mumuPx^2 + mumuPy^2)	None	mumuPt > 6.9 (miniKstarMuMu.cc:388; cfg:105)	Nano
invariant mass dimuon	BToTrkTrkMuMu_mll_fullfit	mumuMass	0 < fitted_mass < 15.0 (MuMu_cff.py:23)	1.0 < mumuMass < 4.8 (eff: 0.99 & 4.848) (miniKstarMuMu.cc:402; cfg:106,107)	Nano
vertex probability dimuon	MuMu_svprob	mumuVtxCL	sv_prob > 0.001 (MuMu_cff.py:18)	mumuVtxCL > 0.1 (miniKstarMuMu.cc:431; cfg:98)	Nano
decay length sig.dimuon (L/σ)	MuMu_l_xy / MuMu_l_xy_unc	mumuLBS / mumuLBSE	None	mumuLBS/mumuLBSE > 3.0 (miniKstarMuMu.cc:451; cfg:99)	Nano
cosα dimuon	MuMu_fit_cos2D	mumuCosAlphaBS	None	mumuCosAlphaBS > 0.9 (miniKstarMuMu.cc:468, cfg:102)	Nano Both post-fit.
cosα B^0	BToTrkTrkMuMu_fit_cos2D	bCosAlphaBS	fitted_cos_theta_2D >= 0.90 (BToTrkTrkLL_cff.py:15)	None	BPH Both post-fit.
pT (K/π)	Track_pt	rawkstTrkmPt, rawkstTrkpPt	Track_pt > 0.7	Both > 0.8 (eff: > 0.72) (miniKstarMuMu.cc:493; cfg:114)	Nano
Eta (K/π)	Track_eta	rawkstTrkmEta, rawkstTrkpEta	|Track_eta| < 2.4	|Both| < 3.0	BPH
hadron quality (highPurity)	?	kstTrkmHighPurity, kstTrkpHighPurity	None	kstTrkmHighPurity == 1, kstTrkpHighPurity == 1 *	No branch for BPH
Mass K^{*0} (hyp: π^-K^+)	BToTrkTrkMuMu_fit_ditrack_mass_Kpi	kstMass	[4.5,6.0] FOR BEST HYP. B MASS (BToTrkTrkLL_cff.py:14)	[0.746, 1.046] FOR BEST HYP. K* MASS (miniKstarMuMu.cc:595)	Fit all on best hypothesis
Mass $\overline{K}^{*0}$ (hyp: $K^-\pi^+$)	BToTrkTrkMuMu_fit_ditrack_mass_piK	kstBarMass	[4.5,6.0] FOR BEST HYP. B MASS (BToTrkTrkLL_cff.py:14)	[0.746, 1.046] FOR BEST HYP. K* MASS (miniKstarMuMu.cc:595)	Fit all on best hypothesis
Mass B^0 (hyp: K^{*0})	BToTrkTrkMuMu_fit_mass_Kpi	bMass	[4.5,6.0] FOR BEST HYP. B MASS (BToTrkTrkLL_cff.py:14)	4.5 < bMass < 6.5 (miniKstarMuMu.cc:865; cfg:109,110).	Fit all on best hypothesis
Vertex probability B^0	BToTrkTrkMuMu_svprob	bVtxCL	sv_prob > 0.001 (BToTrkTrkLL_cff.py:15)	Mini: Corte bVtxCL > 0.01 (miniKstarMuMu.cc:558; cfg:98).	Nano
2D IP: hadrons:dimuon vertex	BToTrkTrkMuMu_trk1_svip2d BToTrkTrkMuMu_trk2_svip2d	?	|Both| < 0.045 (BToTrkTrkLL_cff.py:15)	None	No branch for Nano

Definitions

- B invariant mass reconstruction (“B_chosen_mass”):
  1- Evaluates the ditrack masses from both hypothesis ($K^+\pi^-$ and $K^-\pi^+$ hypothesis)
  2- Select the hypothesis whose ditrack mass is closest to K* mass
  3- Define “B_chosen_mass” as either bMass ($K^+\pi^-$) or bBarMass ($K^-\pi^+$)

- Flattening

  The entire analysis was carried out in a Python + uproot environment
  Data processing relies on columnar analysis and multiprocessing
  Arrays must have the same length to be used together, but many arrays are jagged — different events contain a different number of entries (e.g., muons, tracks).
  Flattening is the process of converting these jagged arrays into flat, one-dimensional arrays of equal length, so they can be combined with other variables.