Real data run 32 and MC comparison

General information

Data run 32:

- Muon Beam intensity: high
- Analysis performed on Single muon interaction
- Files from directory:
- /eos/experiment/mu-e/reco/2025/32/single_muon_interaction_0/
- /eos/experiment/mu-e/reco/2025/32/single_muon_interaction_1/
- Trigger Settings: Single muon int. trigger has incoming muon cut loosened from <= 7 hits to <= 9 hits

Reconstruction

- FairMUonE version: v1.0.1
- triggerVersion: 3
- maxNumberOfSharedHits: 0

MC data:

FairMUonE version: v1.1.x

- **Production** of signal events without pileup and bkg
- Interaction can be forced on either target0 or target1
- detectorConfiguration: TR2025_geometry.yaml
- vertexGenerator: Mesmer
- beamProfile: beamProfile_11_11_2025
- mode: weighted
- ord: alpha2 - NNLO
- nwarmup: 100000
- triggerVersion: 3
- maxNumberOfSharedHits: 0
- alignmentFile: alignment_2025_misalignedSimulation_1Mevts_startidealGeom_it10_MFit3.yaml

Target 0

- Tot requested - 600K events -> Output file (after the trigger) - 190 884 -- 32%

Target 1

- Tot requested - 1M events -> Output file (after the trigger) - 309 478 –-31%

Skim v2								
			Station_i-1			Station_i		
	NHits S_i-1	NHits S_i	First X and Y	U and V	Last X and Y	First X and Y	U and V	Last X and Y
Single muon interaction	5 <= N <=7	8 < N	Each module fired	At least 1 of modules fired	Each module fired	All 4 xy modules fired and at least one uv fired		
			At least 5 hits			At least 2 multifired xy module and at least 2 uv hits or At least 3 multifired xy modules and at least 1 uv hit		
			No more than 1 of modules multifired (2 hits)			At least 1 module multifired		At least 1 module multifired

Single muon int. trigger has incoming muon cut loosened from <= 7 hits to <= 9

Definitions and useful information

- `//calculate the` **`distance between outgoing tracks`** `before vertex fitting at the target Z`
  `double z_t = target.z(); // <-- use the correct accessor if it's named differently`
  `m_distanceBetweenOutgoingTracksAtTargetZ = std::hypot(m_firstOutgoingTrack.x(z_t) - m_secondOutgoingTrack.x(z_t), m_firstOutgoingTrack.y(z_t) - m_secondOutgoingTrack.y(z_t)); //`
  `std::hypot is more numerically stable than sqrt(a2 +b2) -before vertex`

- `maxNumberOfSharedHits -- integer, max number of hits that two tracks can share`
  `This is used in clone track removal, where the tracks are first sorted from best to worst by quality and the tracks which share more than this set number of hits with a better one are removed.`
- MUonE/MUonEReconstruction/MUonERecoVertex.h: for(int `i = 0; i < maxNumberOfSharedHits && i < hitsPerModule.size(); ++i)`

Positions of modules (in cm) taken from geometry file
X modules, **Y modules**, **U** and **V modules**
Stat 0 = **566.6227**, **570.4722**, **603.8635**, **605.0965**, **638.5227**, **642.3722**,
Stat 1 = **683.9227**, **687.7722**, **721.1635**, **722.3965**, **755.8227**, **759.6722**,
Stat 2 = **801.2227**, **805.0722**, **838.4635**, **839.6965**, **873.1227**, **876.9722**,
Target positions = **664.6, 780.7.**

List of cuts

Fiducial cuts:

1. N tracks before target (incoming muon) == 1
2. |X1 hits| < 1.5 cm (reconstructedHits() -> hits[i].positionPerpendicular())
3. |Y1 hits| < 1.5 cm
4. z vertex outside the detector (posFit < 540 || ZposFit > 890)

Selection cuts:

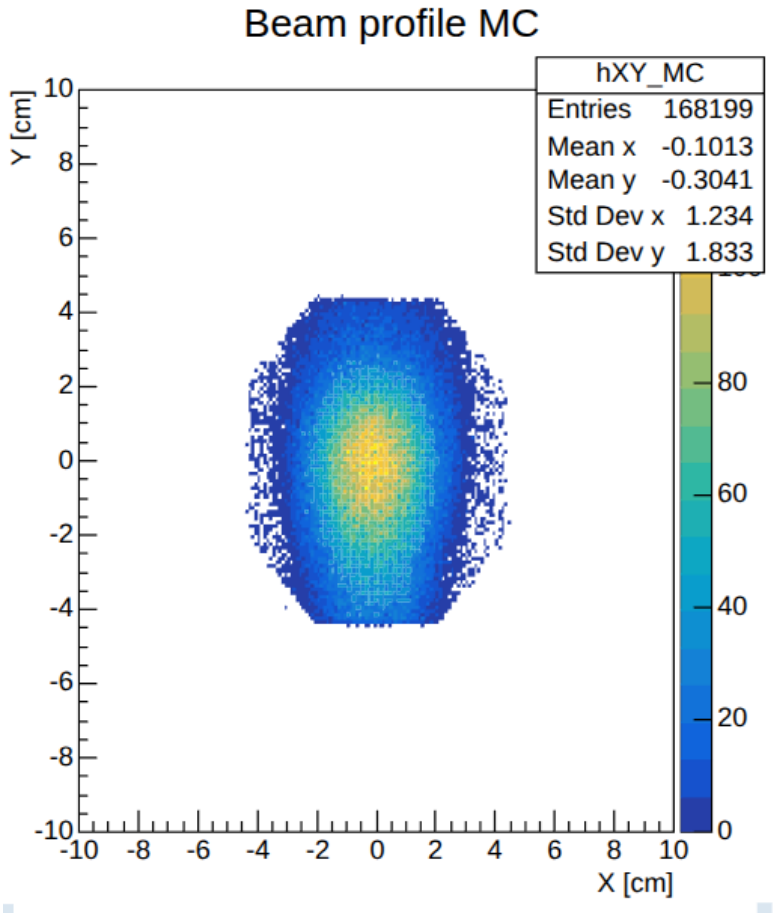
1. thetaE_max < 32 mrad && thetaMu_min >= 0.2 mrad
2. Distance between the two tracks at target < 0.2
3. N hits in Station after the target < 15
4. |Acoplanarity| < 0.4
5. chi2_vertex (KF) <= 20
6. |z_vertex - z_target| <= 2 cm

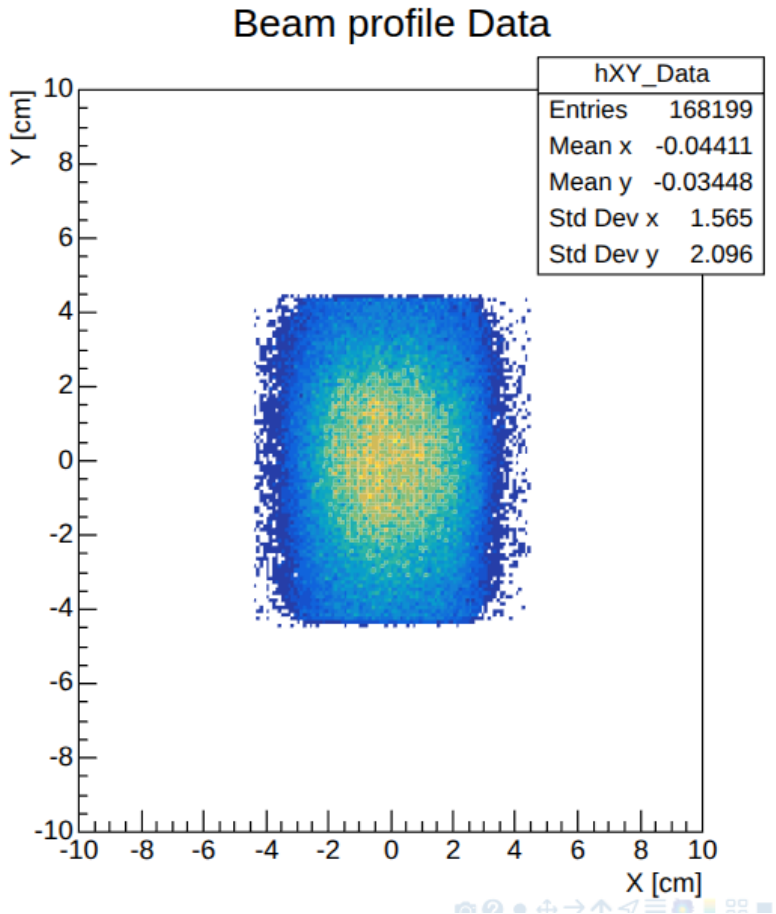
* TargetID == 0 && fabs(ZposFit - 664.6) <= 2.0) || (TargetID == 1 && fabs(ZposFit - 781.2) <= 2.0

Target 0 – First target

FIRST TARGET (TARGET 0)				
Number of events	MESMER – NNLO		REAL DATA RUN 32	
Total	190 884		28 722 471	
Reconstructed	168 199	88.1 %	5 458 338	19.0 %
After Fiducial cuts - Single-track incoming muon, X1, Y1 < 1.5 cm, z vertex outside the detector (posFit < 540 || ZposFit > 890)	99.9 % * of reco		56.5 % * of reco	
Events left after the cuts (applied separately) - considering reconstructed				
Angle cut- theta min >= 0.0002 && theta max < 0.032	20.8 %		11.6 %	
Distance between the two tracks at target < 0.2	69.5 %		6.7 %	
N hits in Station after the target < 15	96.9 %		48.0 %	
|M. acop.| < 0.4	62.5 %		11.4 %	
Chi2 of the vertex <= 20	92.1 %		28.8 %	
Target - |ZposFit - 664.6| <= 2.0	64.8 %		5.1 %	
After all cuts - nAfterCuts/nReco	49 852	29.6 %	43 870	0.80 %
After all cuts - nAfterCuts/nTot	49 852	26.1 %	43 870	0.15 %

Beam profile – First target



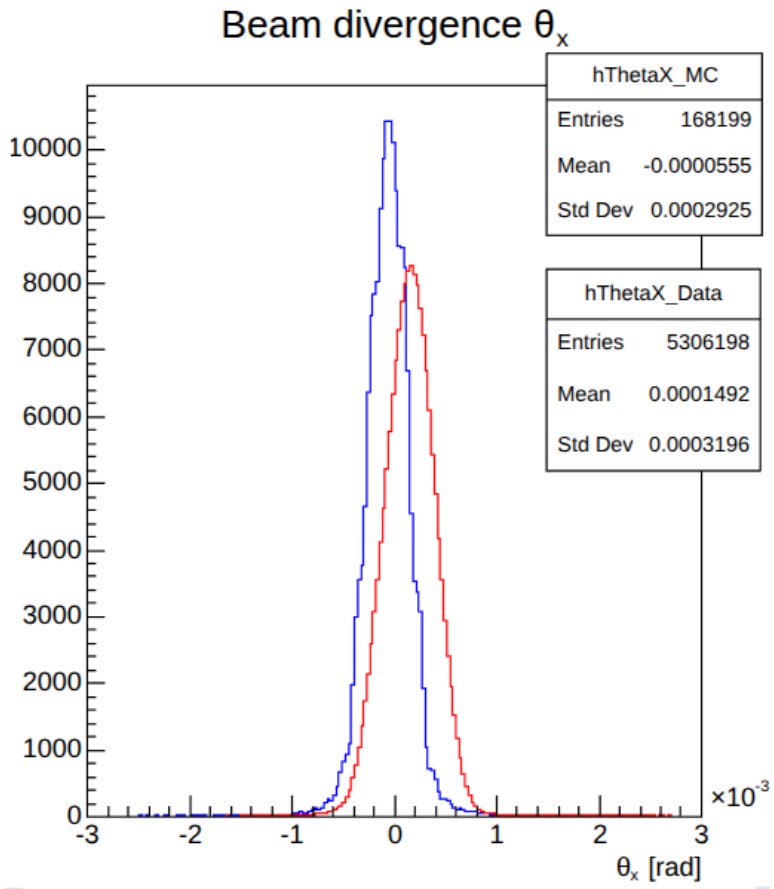


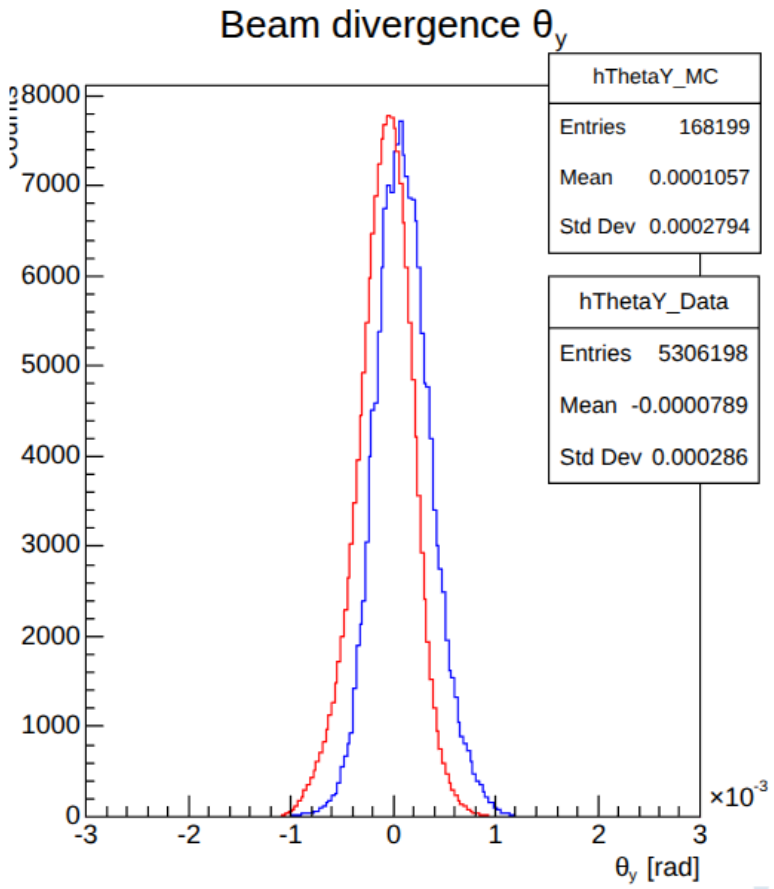
- If we have interaction in the **first target** (given by the trigger labeling) - We take x and y hits coordinates from the first 2 modules in the first station reconstructedHits() -> hits[i].positionPerpendicular()

- If we have interaction in the **second target** (given by the trigger labeling) - We take x and y coordinates from the first 2 modules in the second station

- **Profiles were taken considering events/hits passing the trigger and without using any additional selection**
- Real data beam profile is wider and more centered than in MC (checked for the same statistics)

Beam divergence





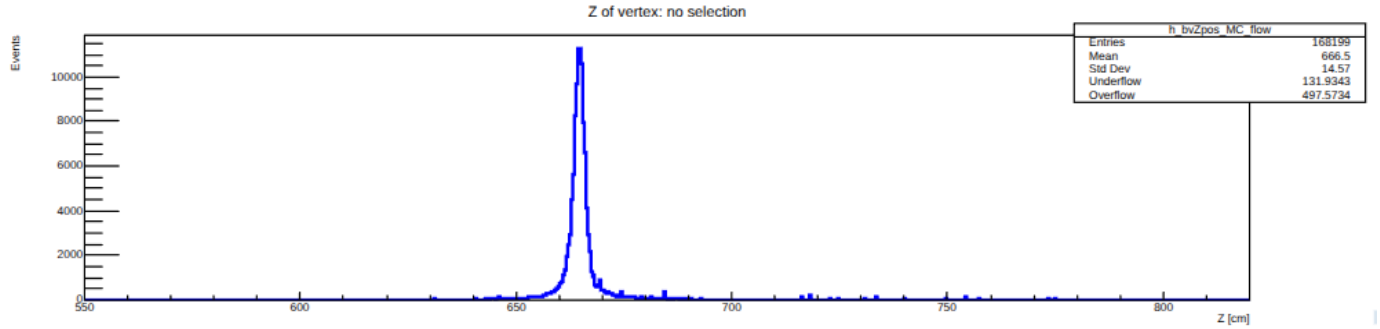
Real Data
MC

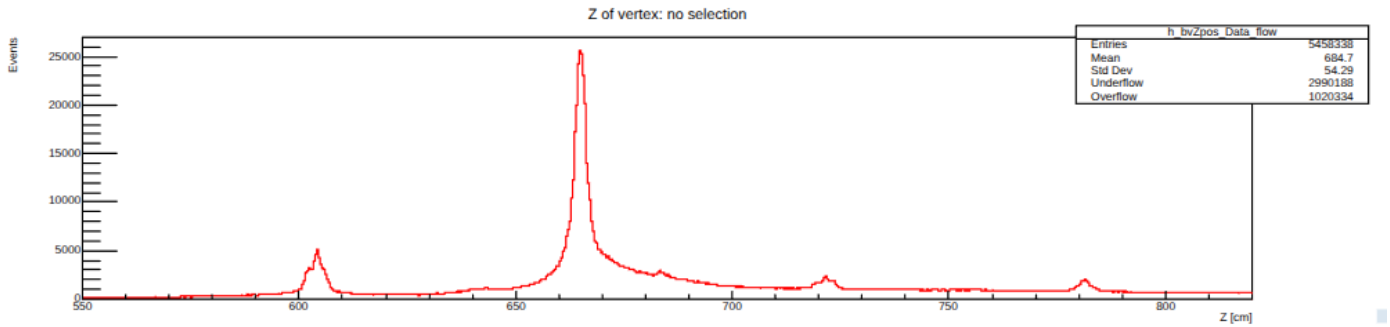
Angles from reconstructedTracks slopes
thetaX = atan(trk.xSlope())
thetaY = atan(trk.YSlope(

In the MC the direction of muons is more parallel with the tracking system and the spread is more narrow in the x direction compared to Real data
In the y direction, MC and Real data are more similar

Real Data

MC





Z position of the vertex without any selection

- MC forces interaction in target and produces only signal events
- Real data – peaks on U and V modules

Positions of modules (in cm) taken from geometry file

X modules, **Y modules**, **U** and **V modules**

Stat 0 = **566.6227**, **570.4722**, **603.8635**, **605.0965**, **638.5227**, **642.3722**,

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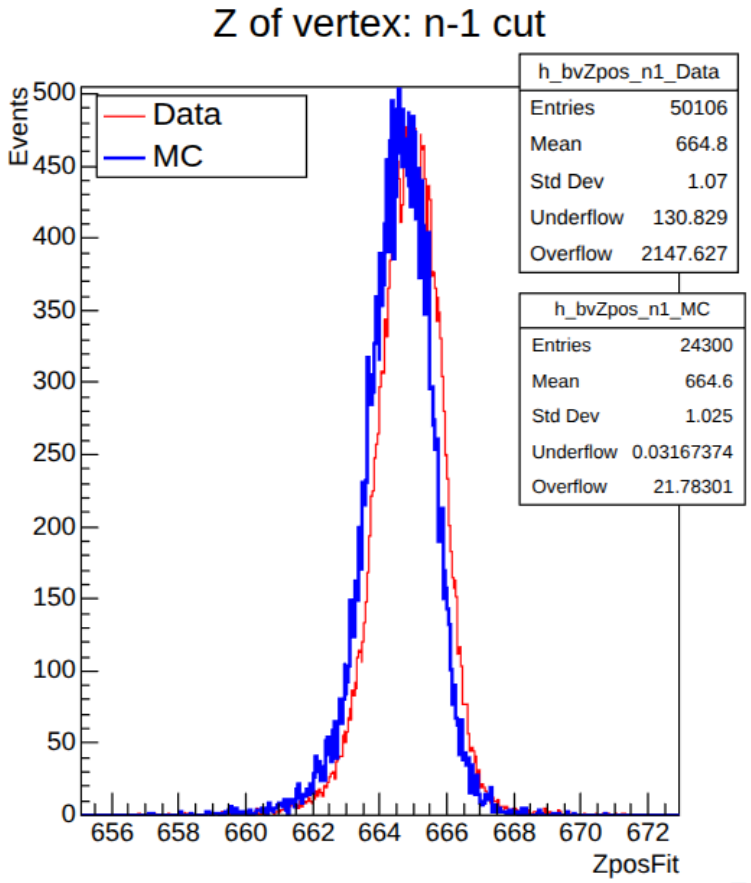
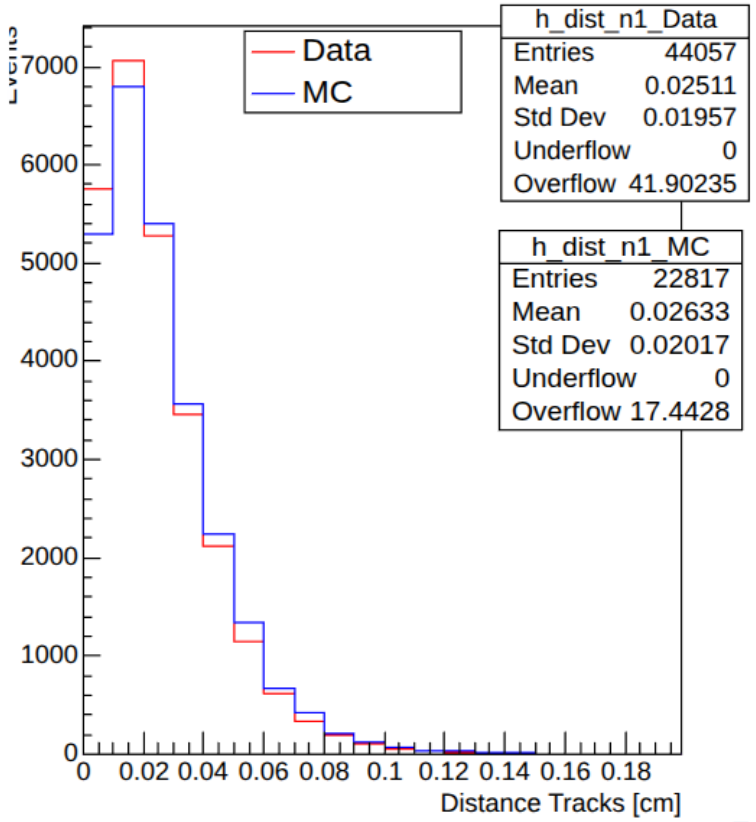
Stat 2 = **801.2227**, **805.0722**, **838.4635**, **839.6965**, **873.1227**, **876.9722**,

Target positions = **664.6, 780.7**

N-1 study

Real Data
MC

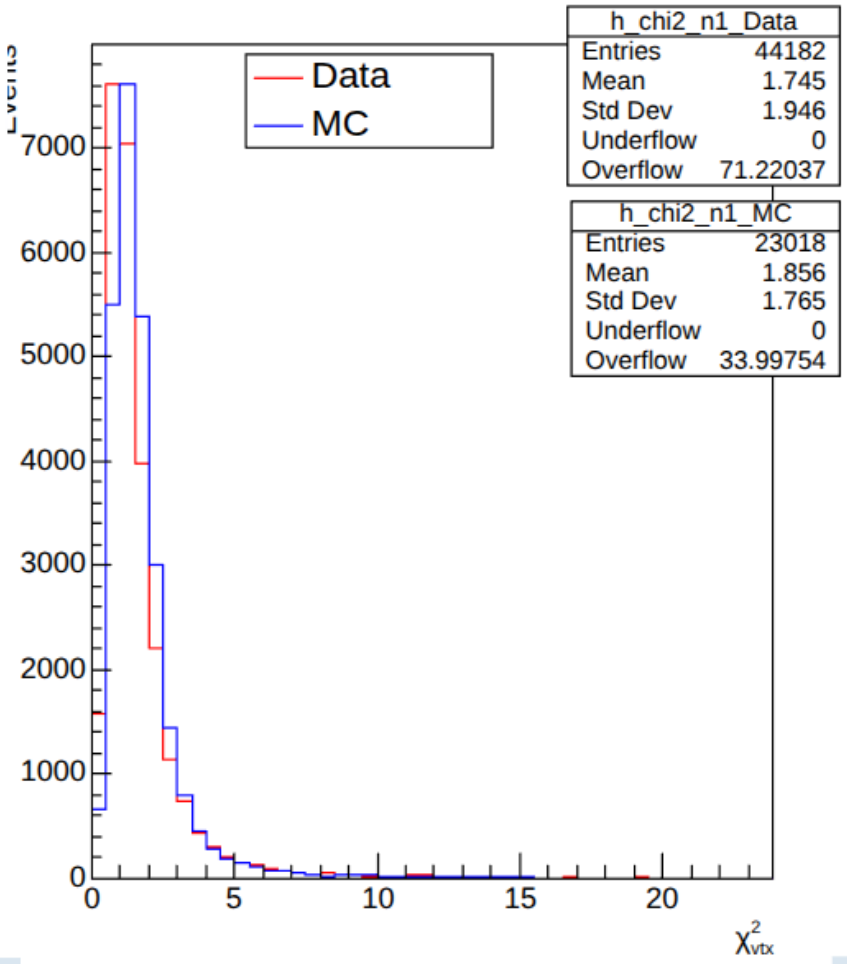


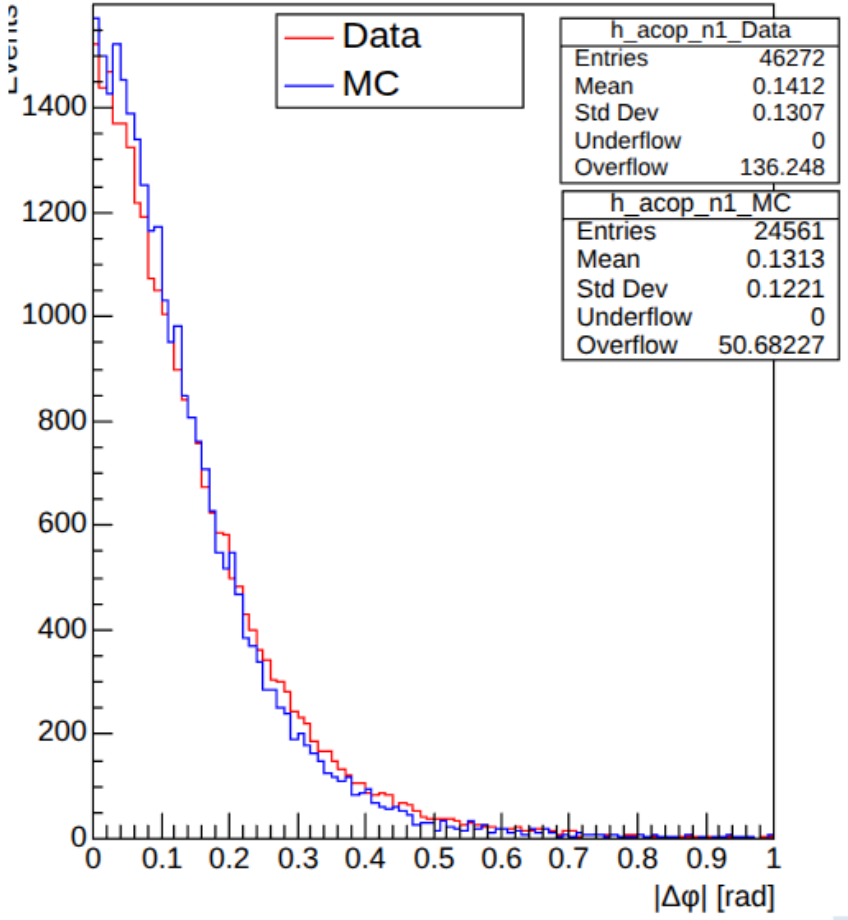


- Applying all the cuts except the cut of one variable and looking how it behaves
- Z of the target in MC shifted in the respect with Real data for 2 mm and having more narrow tail
- Distance between the tracks is good described by MC

Real Data

MC

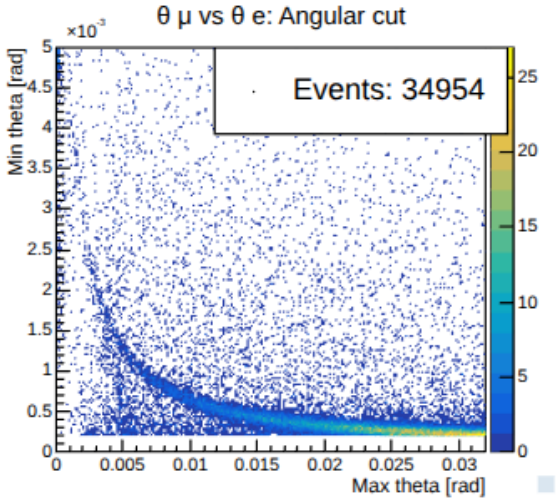


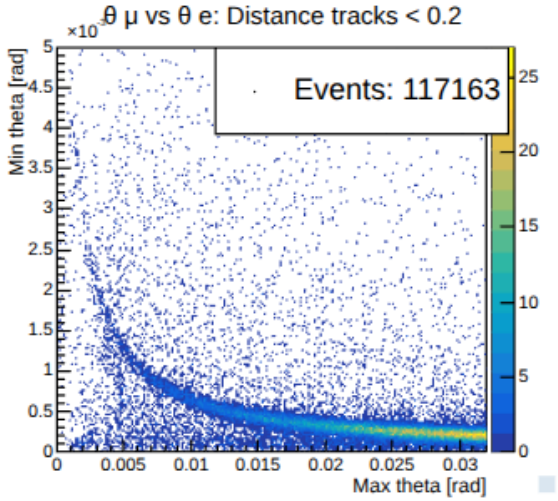


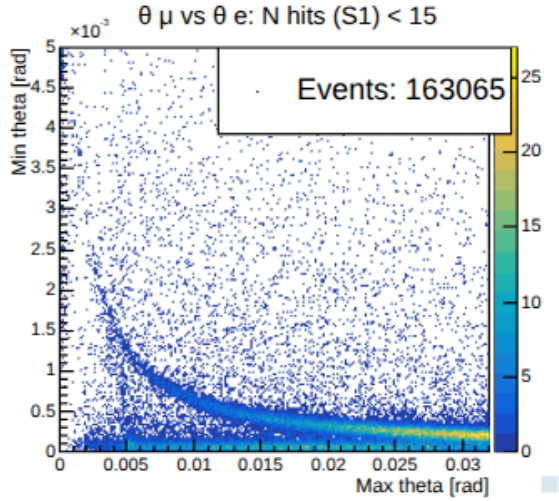
Chi2 of the vertex and acoplanarity aligned

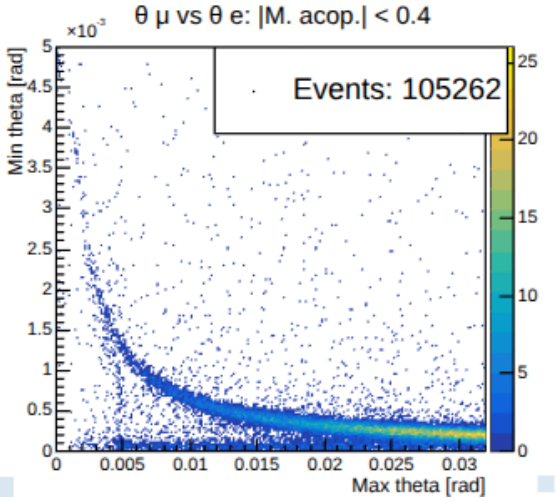
Cut analysis – separate cuts

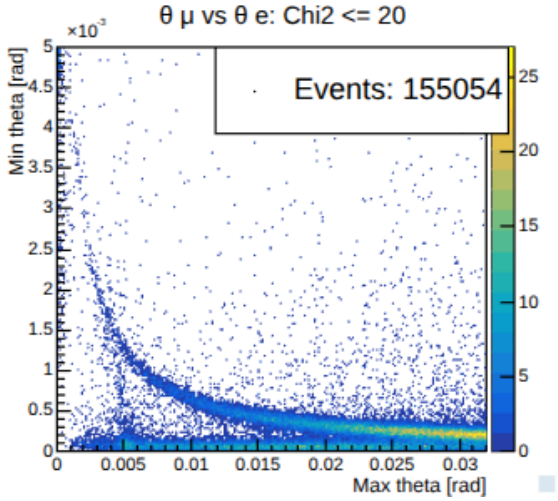
MC

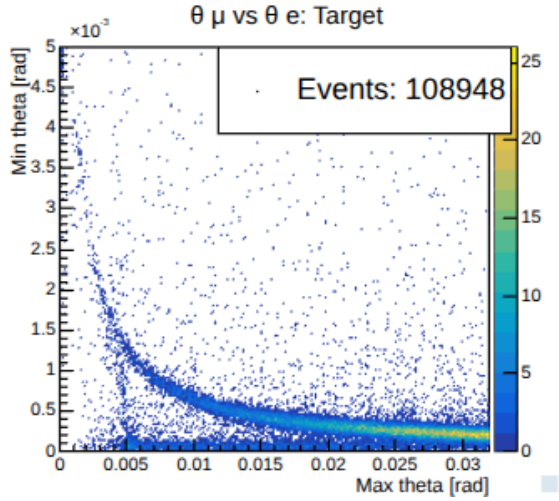




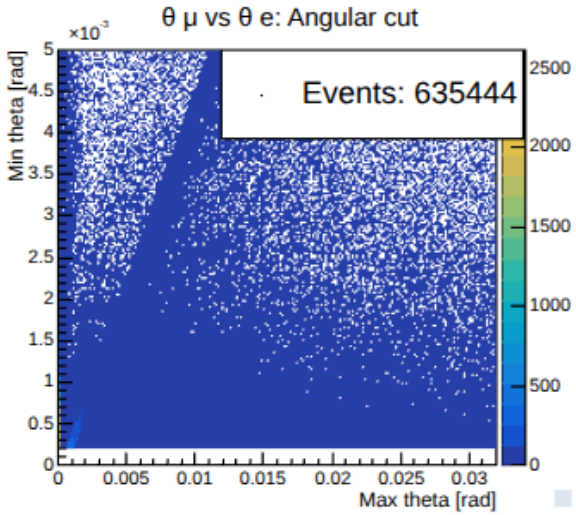


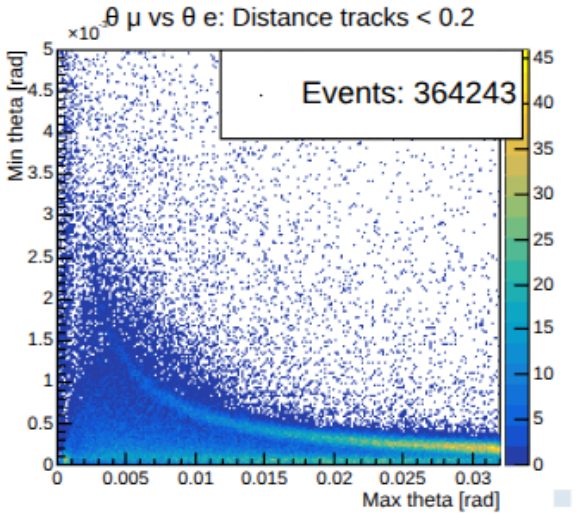


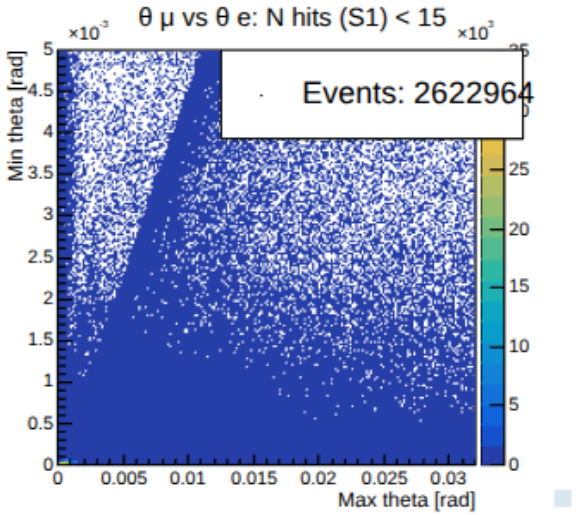


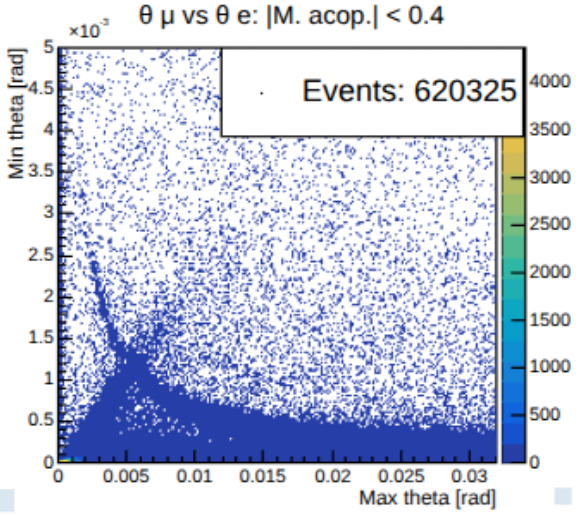


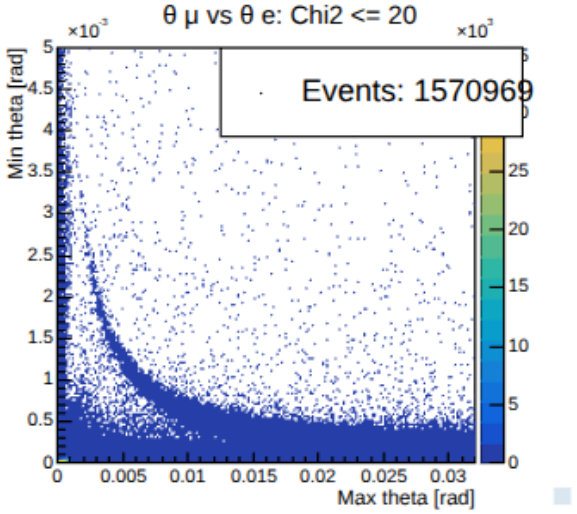
Real Data

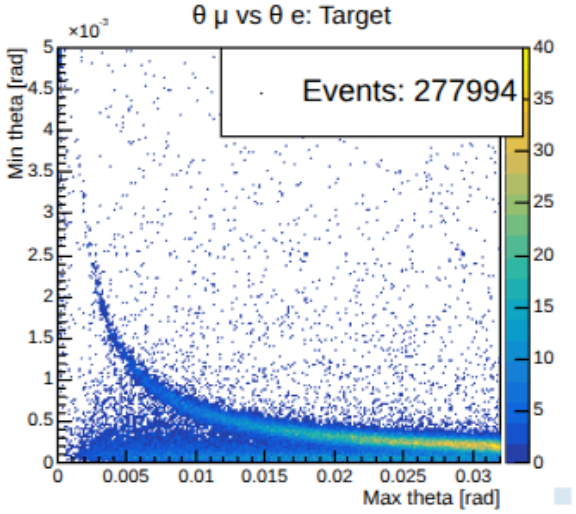






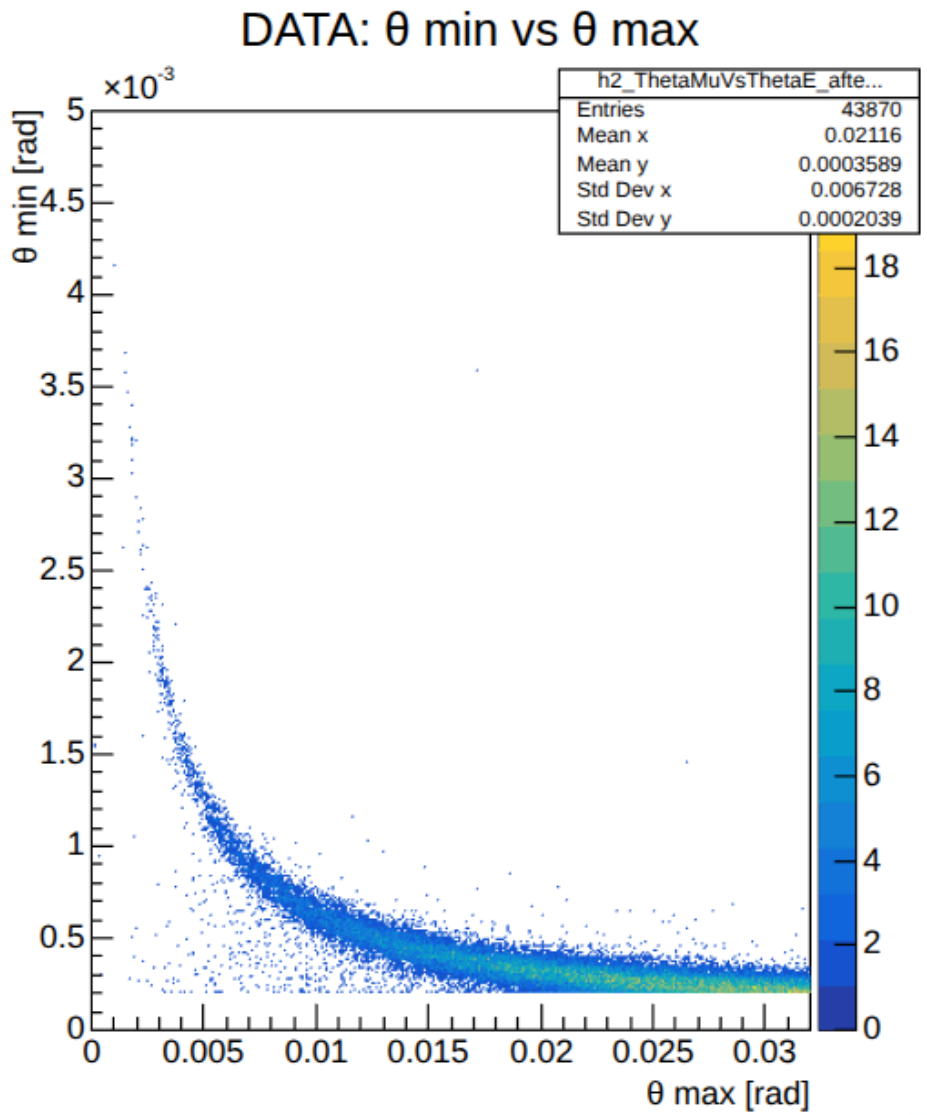


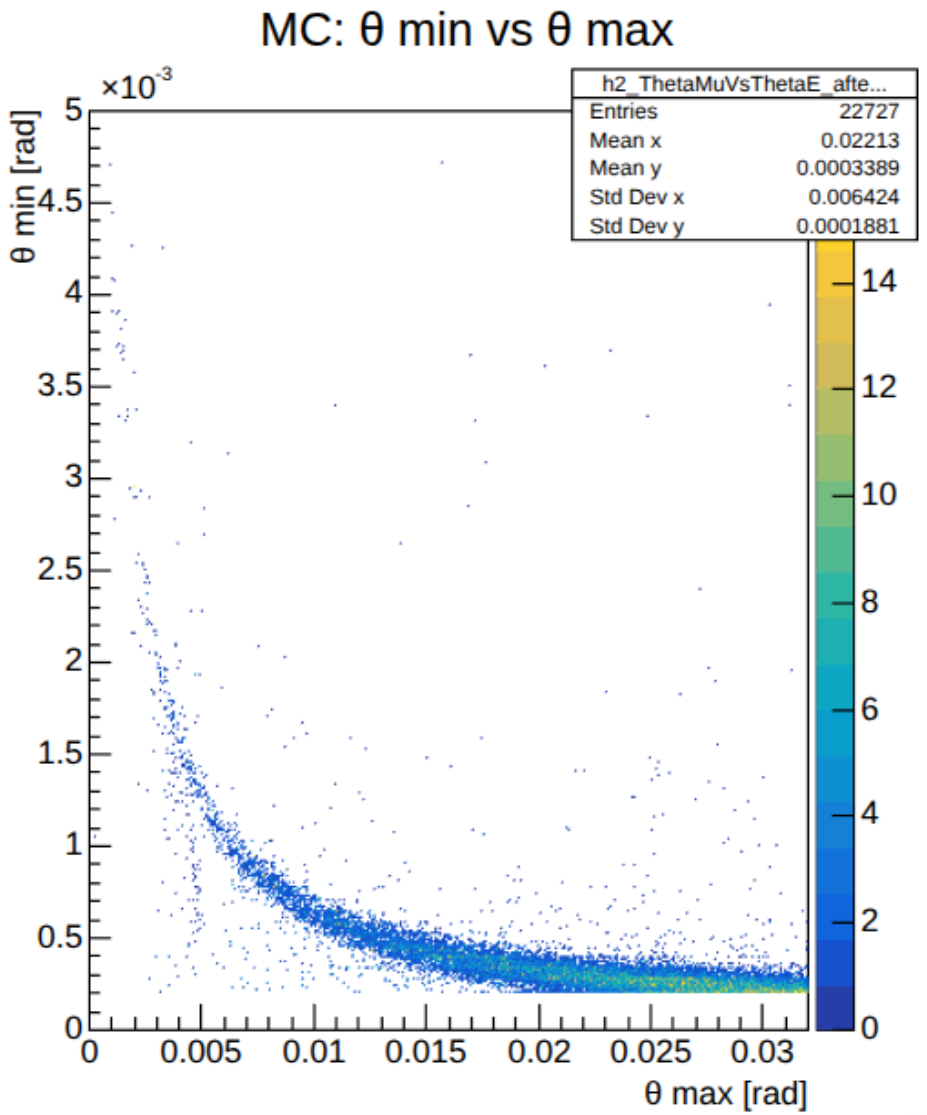




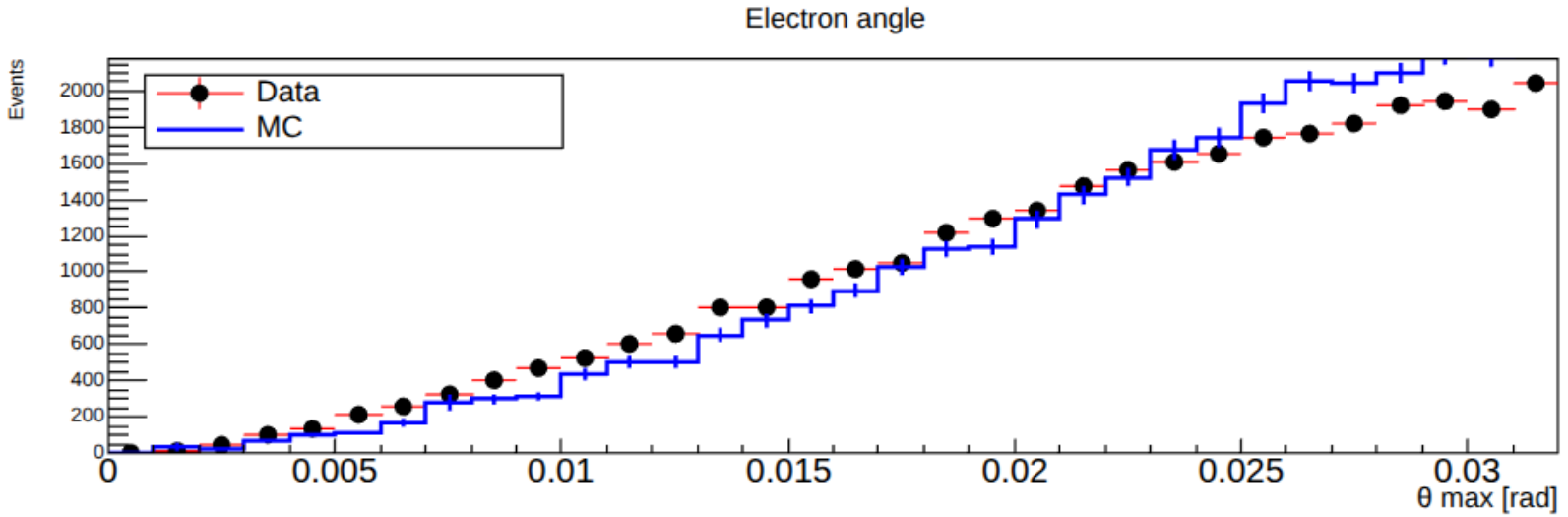
Target cut removes the most of the bkg

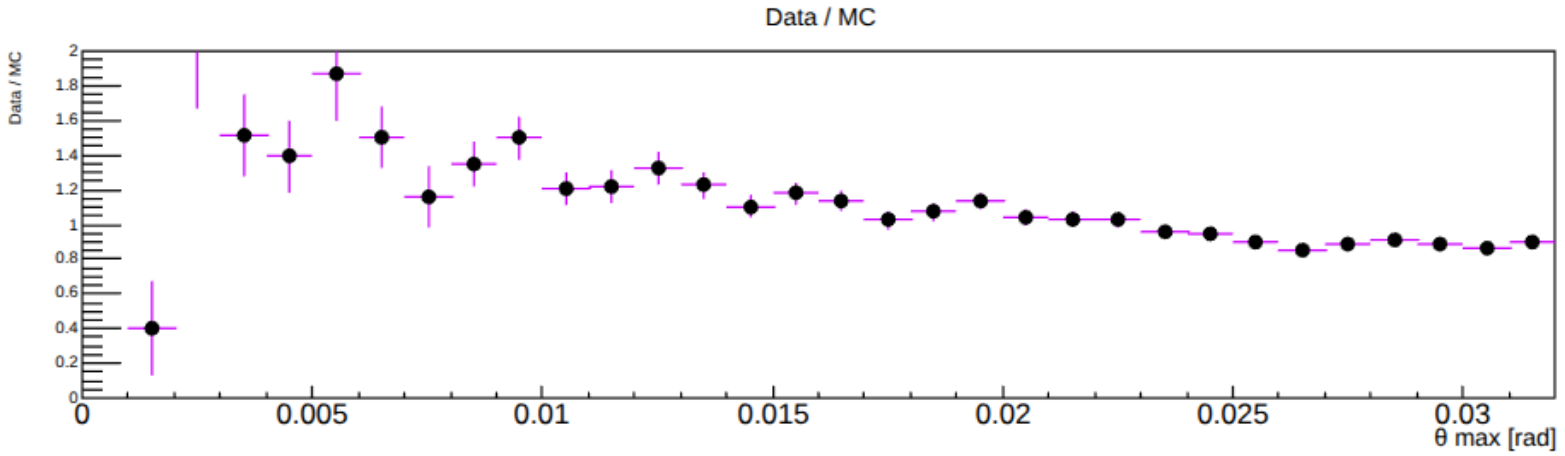
Angular distribution after applying all cuts





MC and Real data comparison in angular distributions

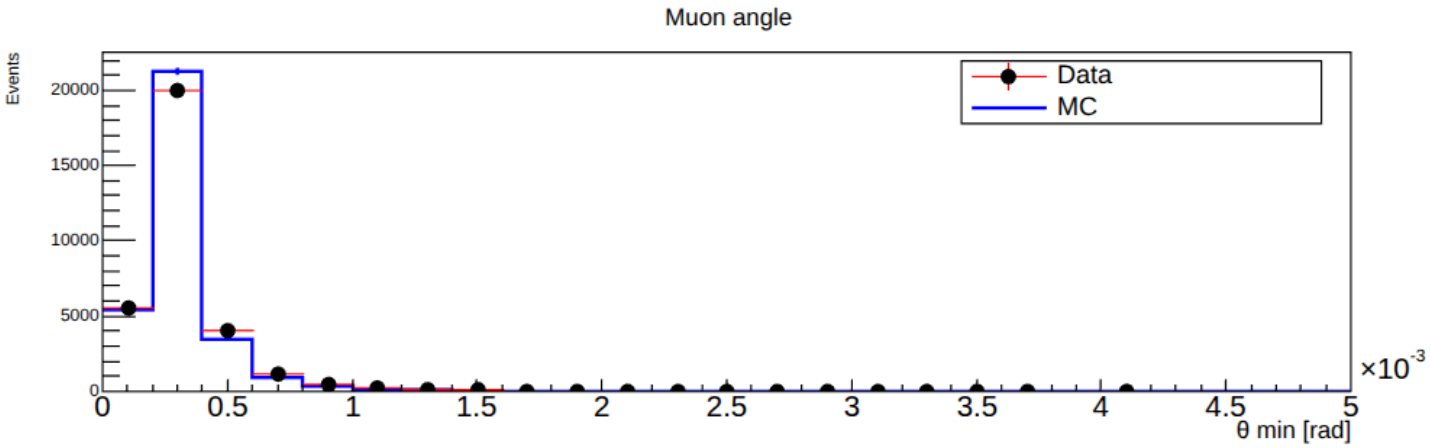


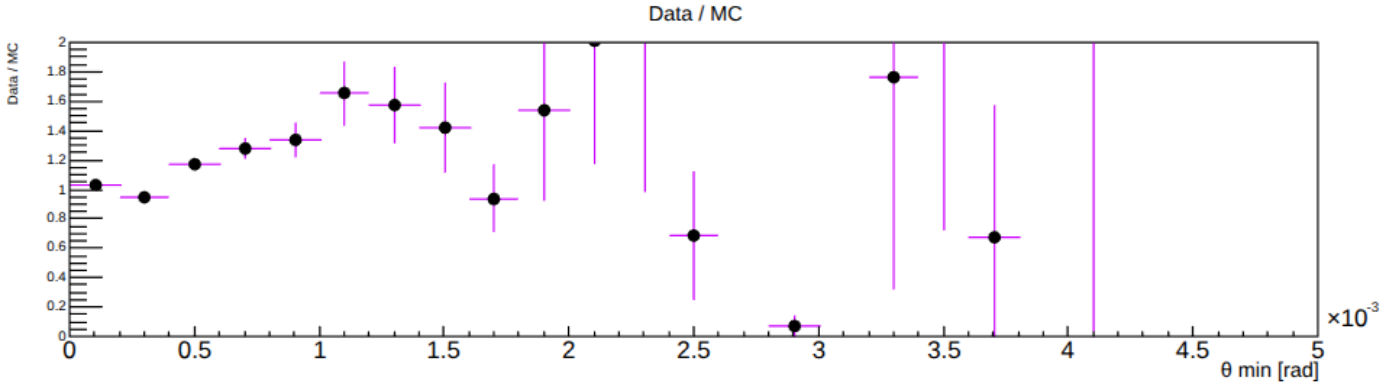


Using events passing all selection cuts except the cut on theta min angle

In data event number linearly grows with the angle

Data / MC ratio is getting more flat after 0.01 rad

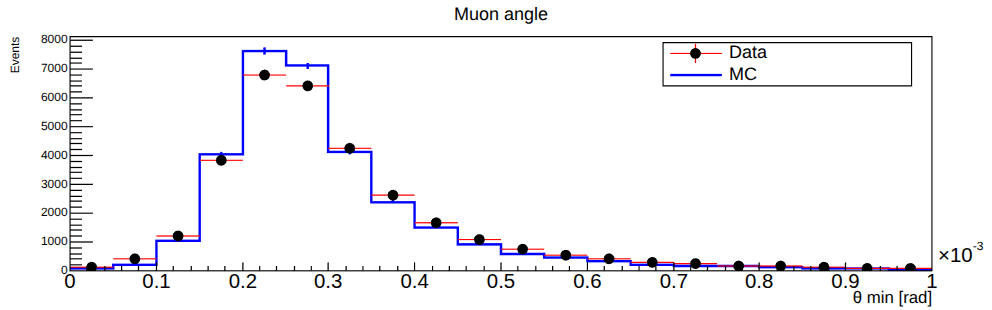


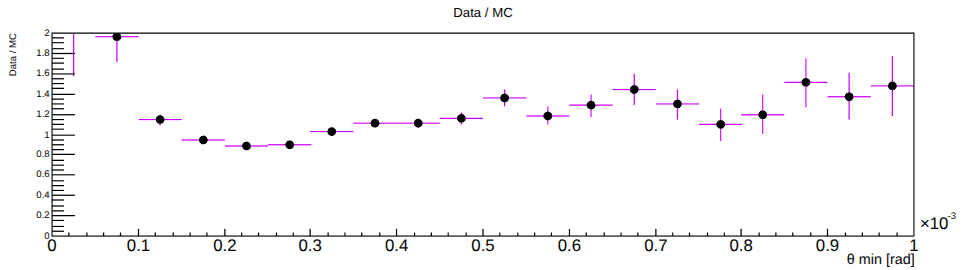


Number of events is having a maximum between 0.2 and 0.3 rad

MC up to1.5 mrad follows the real data distribution

Data / MC ratio after 1.5 mrad is dispersed

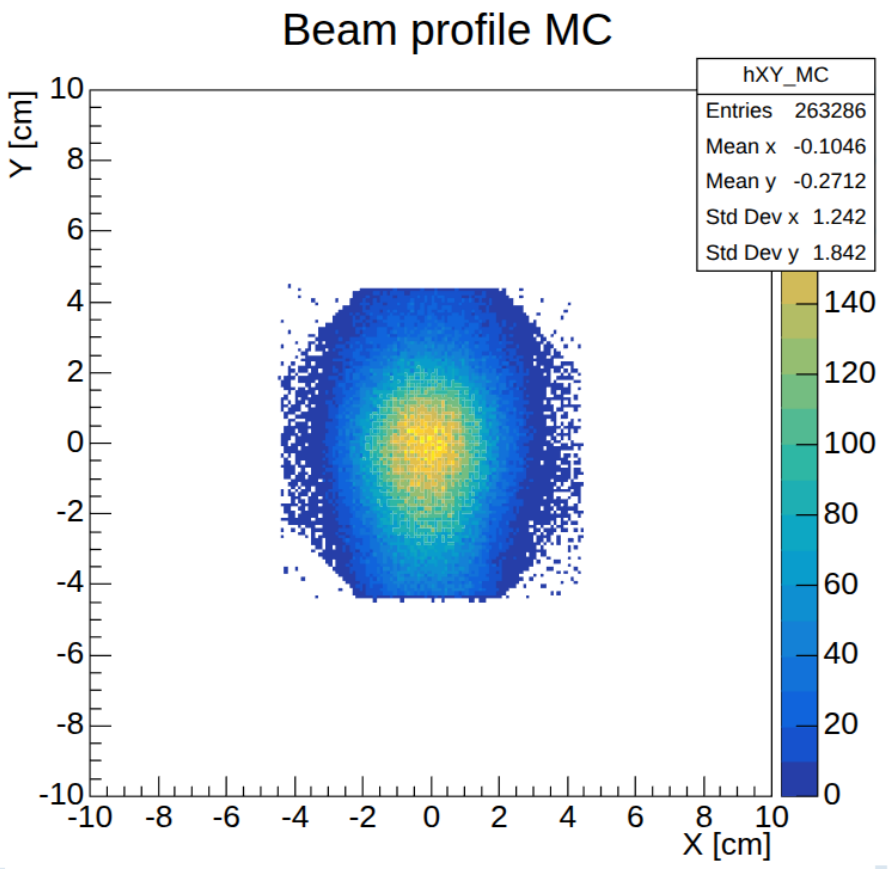


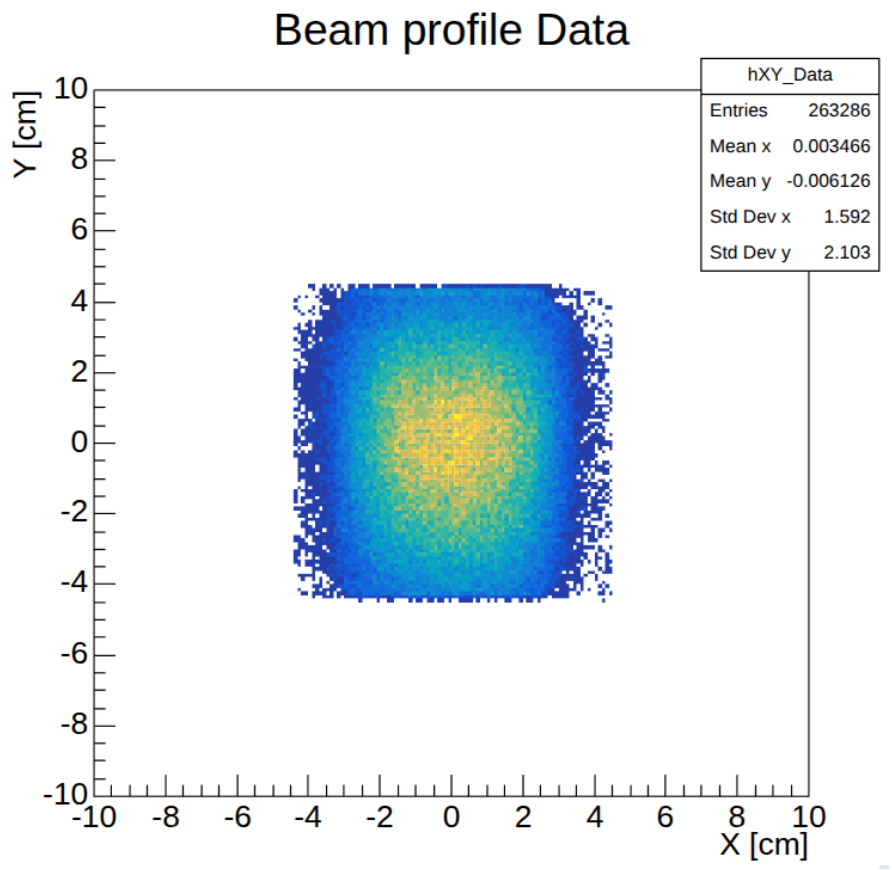


Target 1 – Second target

SECOND TARGET (TARGET 1)				
Number of events	MESMER – NNLO		REAL DATA RUN 32	
Total	309478		46896815	
Reconstructed	**263286**	85.1 %	3423557	7.3 %
Fiducial cuts - Single-track incoming muon, X1, Y1 < 1.5 cm, z vertex outside the detector (posFit < 540 || ZposFit > 890)	99.98 % * of reco		70.3 % * of reco	
Events left after the cuts (applied separately) - considering reconstructed				
Angle cut- theta min >= 0.0002 && theta max < 0.032	32.0 %		14.4 %	
Distance between the two tracks at target < 0.2	84 .2%		17.9 %	
N hits in Station 2 < 15	97.0 %		49.7 %	
|M. acop.| < 0.4	67.9 %		19.0 %	
Chi2 of the vertex <= 20	90.4 %		34.6 %	
Target	74.0 %		13.6 %	
After all cuts - nAfterCuts/nReco	120649	45.8 %	94124	2.7 %
After all cuts - nAfterCuts/nTot	120649	39.0 %	94124	0.2 %

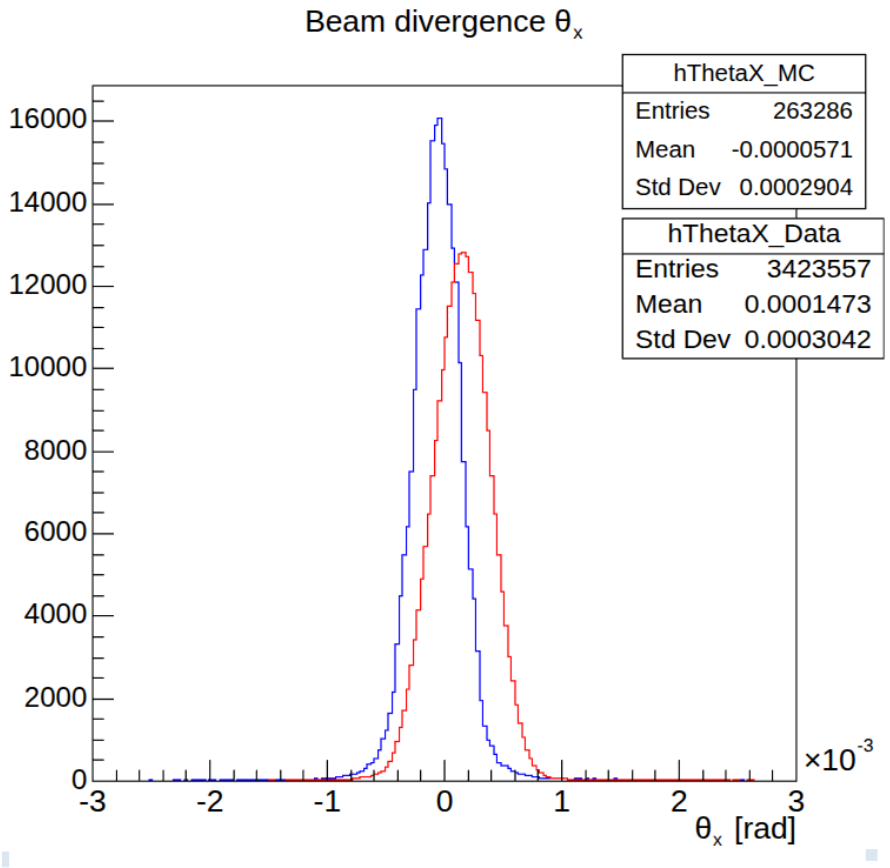
Beam profile – First target

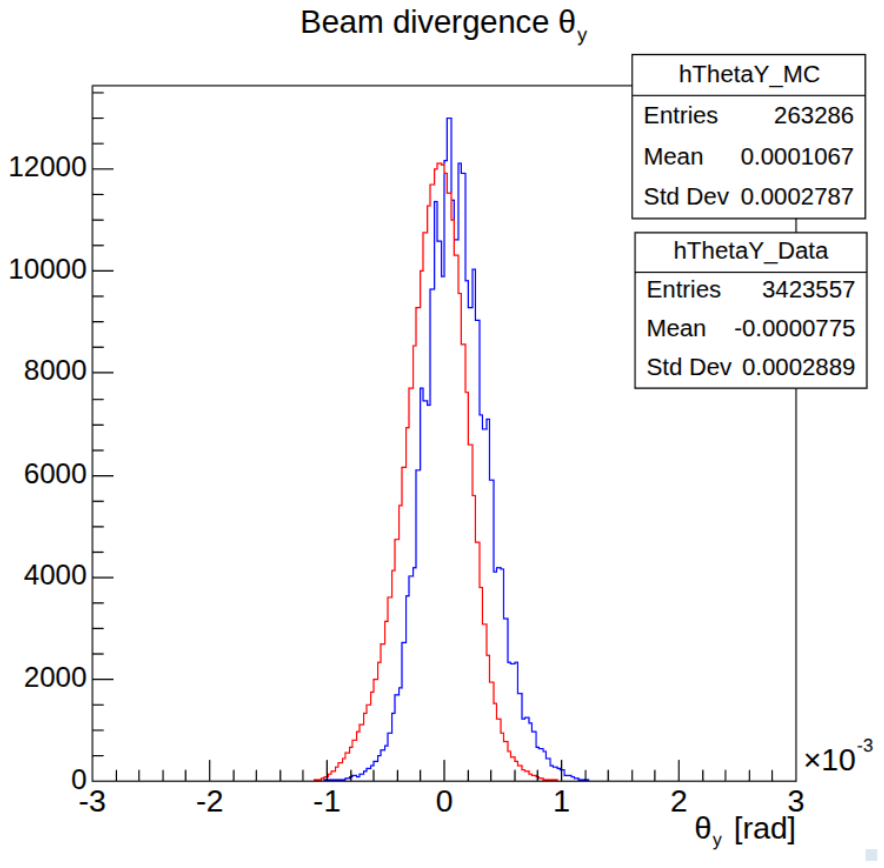




- Profiles were taken considering events/hits passing the trigger and without using any additional selection
- Real data beam profile is wider and more centered than in MC (checked for the same statistics)

Beam divergence

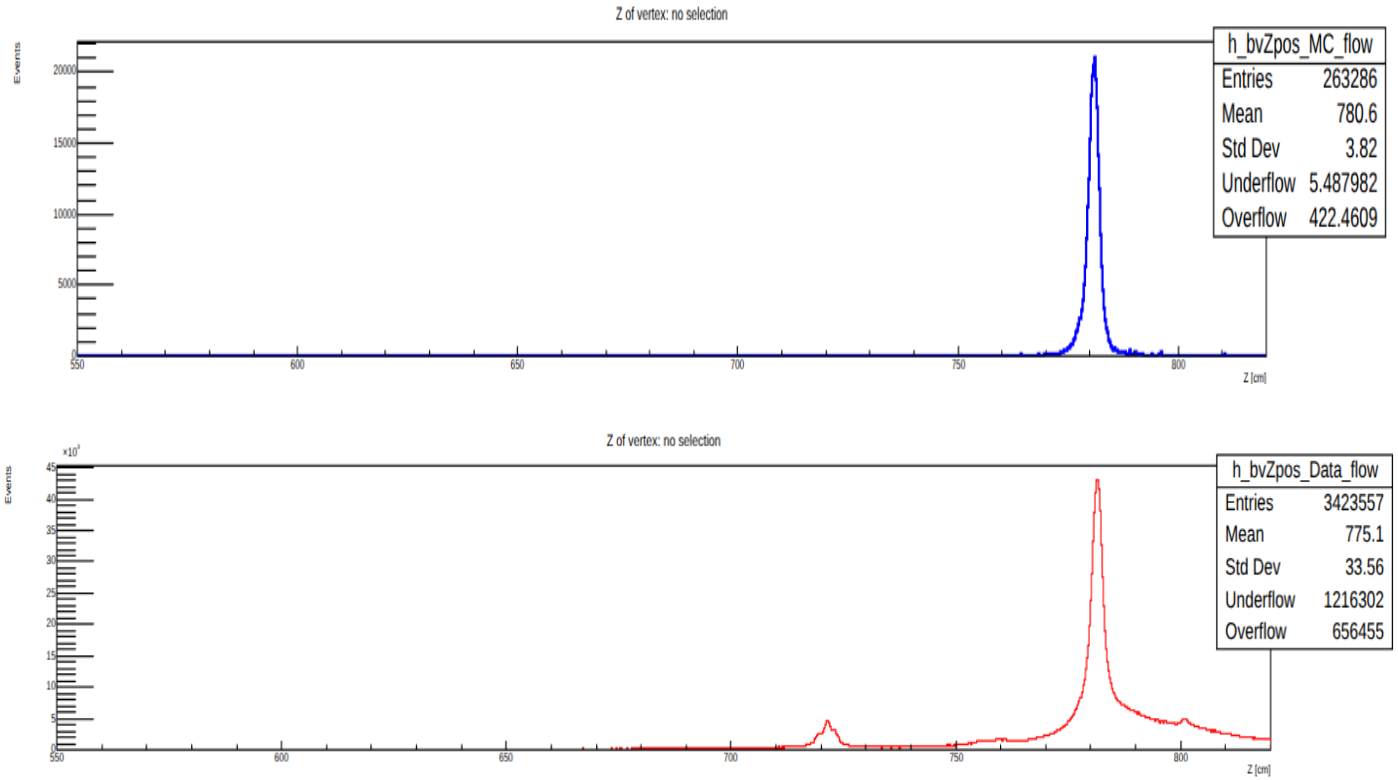




- **x direction -** in the MC, the direction of muons is more parallel with the tracking system and the spread is more narrow compared to Real data
- **y direction -** MC and real data have similar spread – data peak closer to the center

Real Data

MC



Z position of the vertex without any selection

- MC forces interaction in target and produces only signal events
- Real data – peaks on U and V modules

Positions of modules (in cm) taken from geometry file

X modules, **Y modules**, **U** and **V modules**

Stat 0 = **566.6227**, **570.4722**, **603.8635**, **605.0965**, **638.5227**, **642.3722**,

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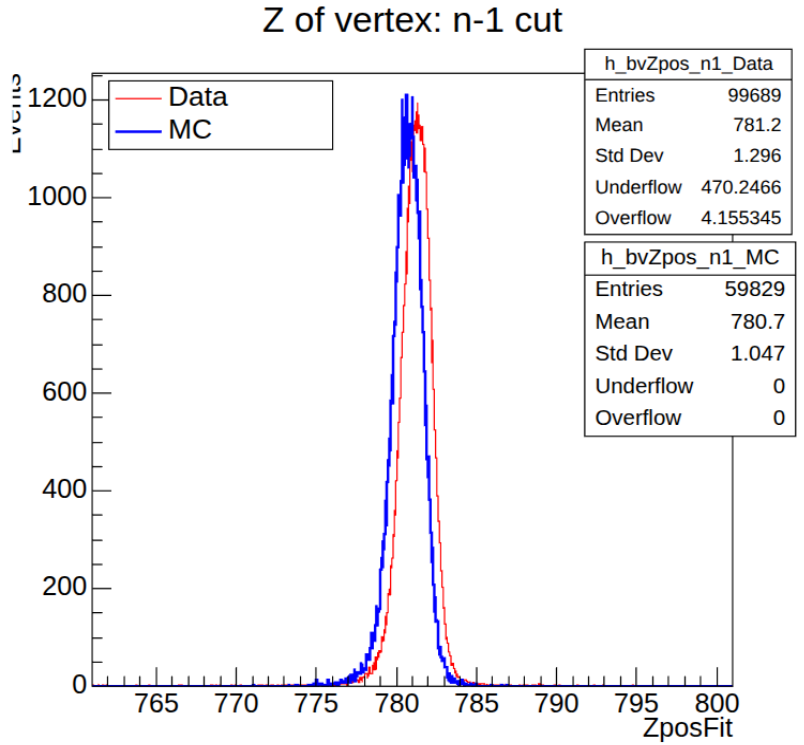
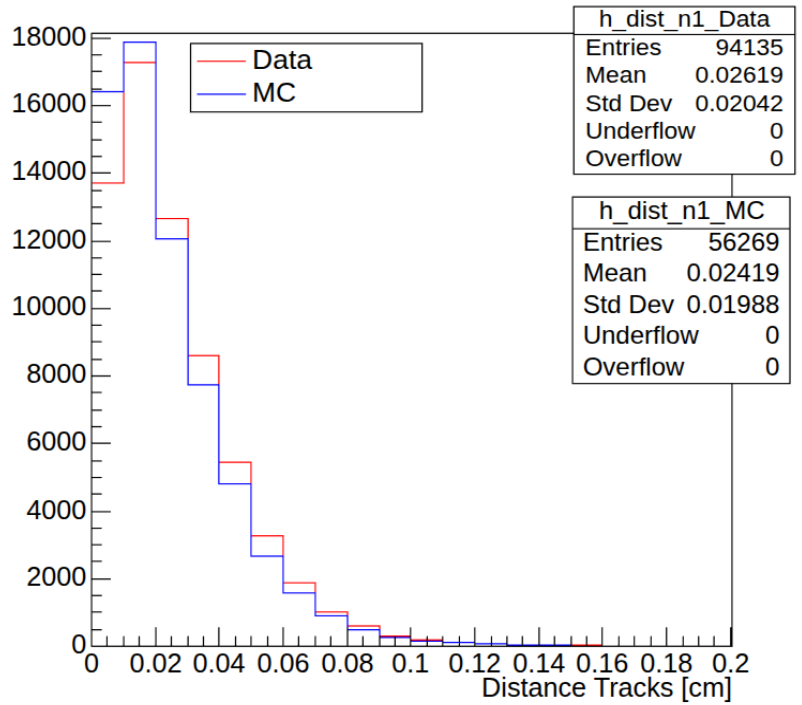
Stat 2 = **801.2227**, **805.0722**, **838.4635**, **839.6965**, **873.1227**, **876.9722**,

Target positions = **664.6, 780.7**

N-1 study

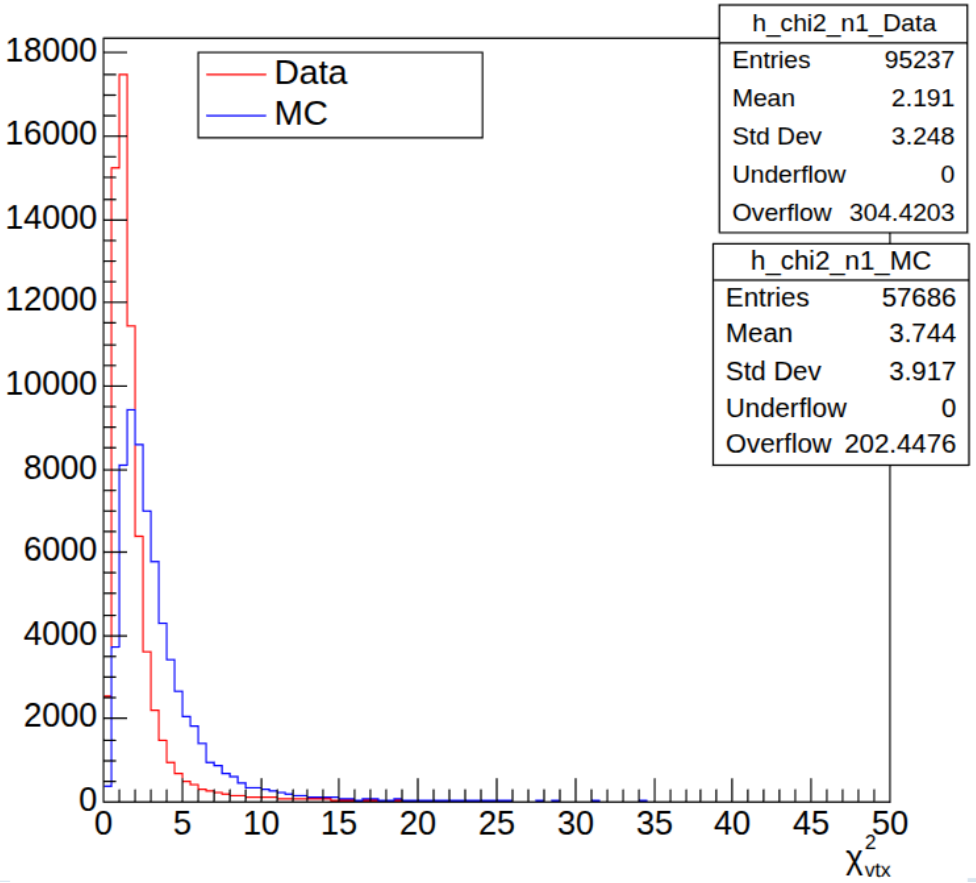
Real Data
MC

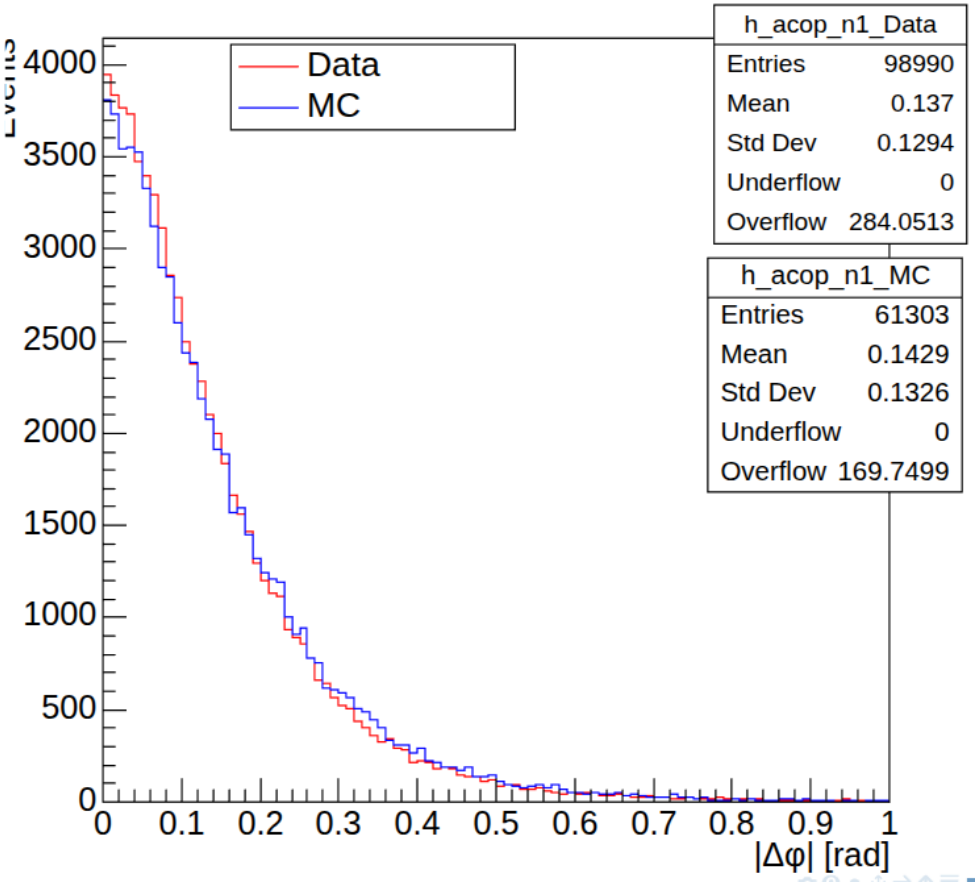




Applying all the cuts except the cut of one variable and looking how it behaves

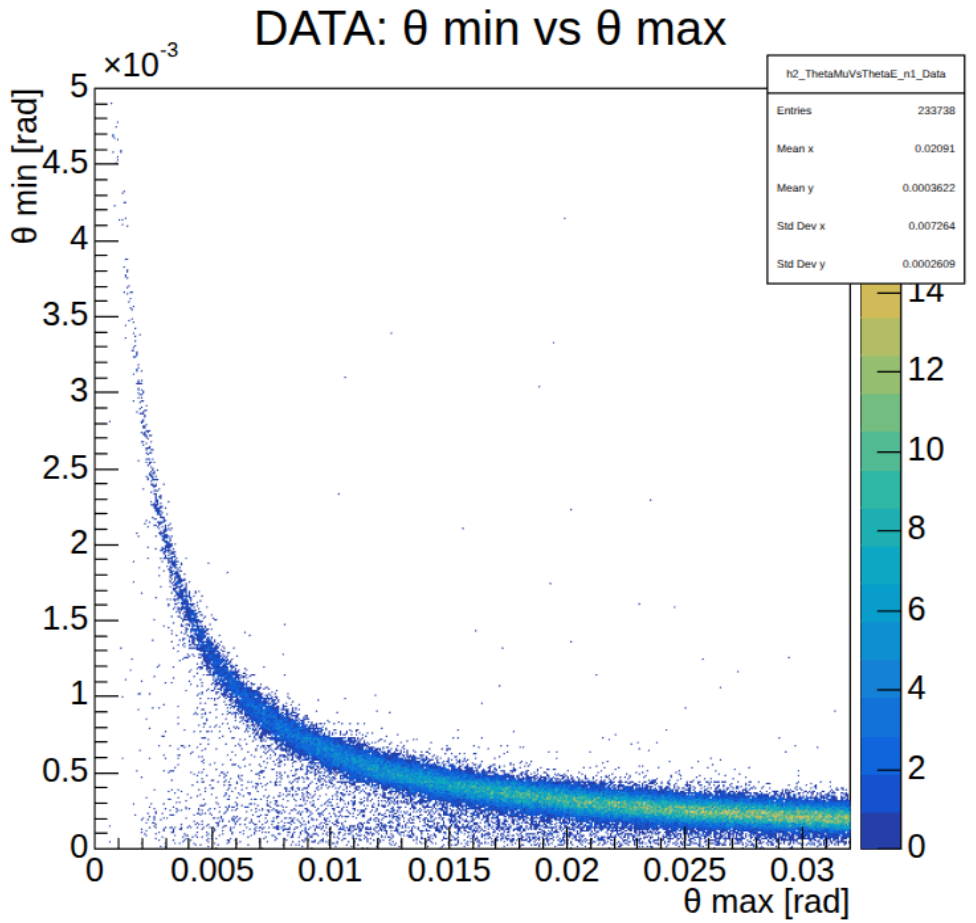
- Z of the target in MC shifted in the respect with Real data for 5 mm and having more narrow tail
- Distance between the tracks is good described by MC

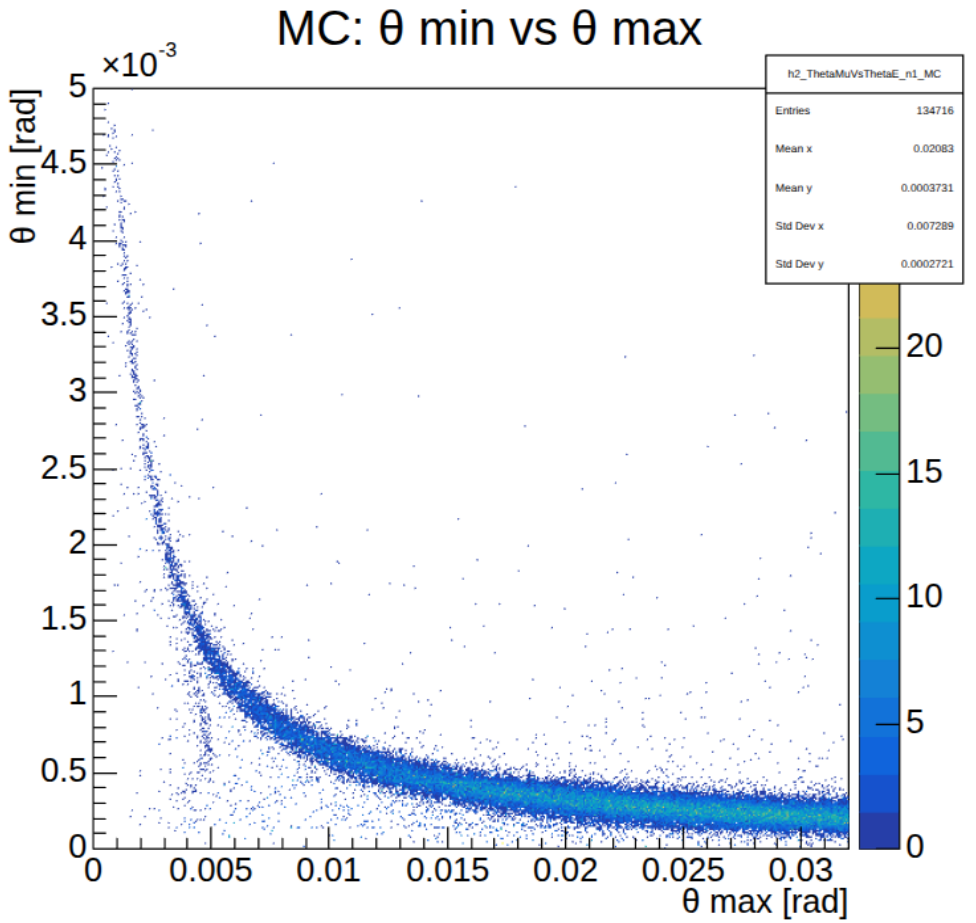




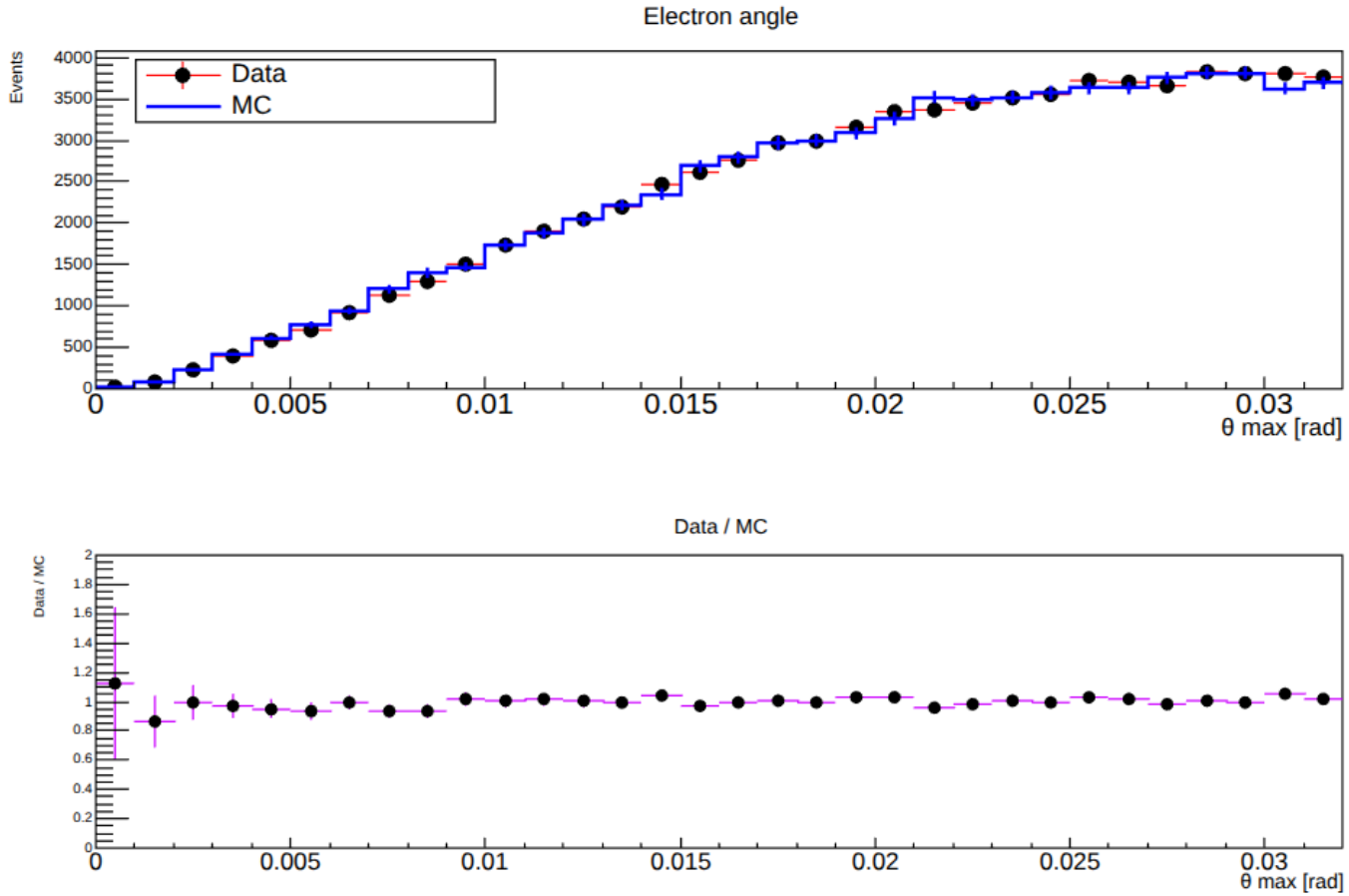
- Chi2 of the vertex peaks closer to 0 and is more narrow than in MC
- Acoplanarity of the data and MC aligned

Angular distribution after applying all cuts





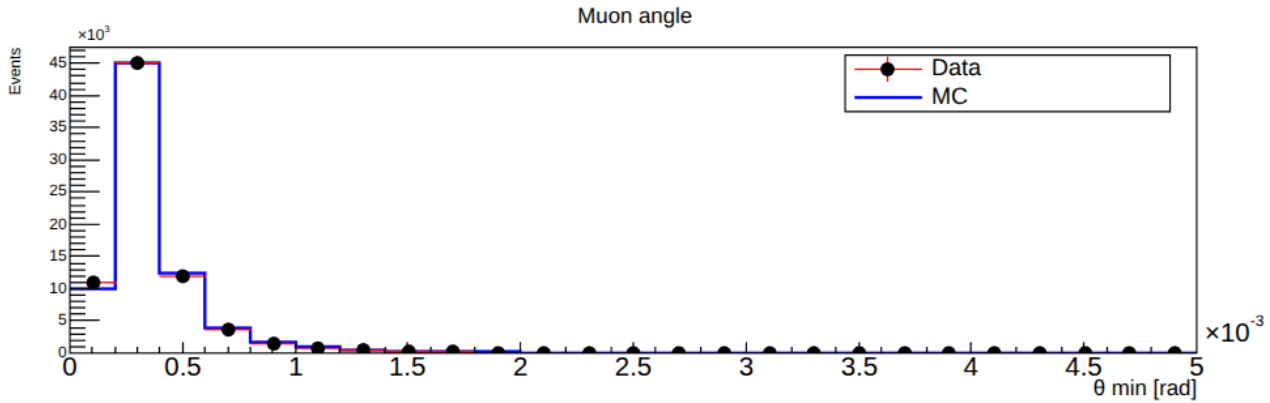
MC and Real data comparison in angular distributions

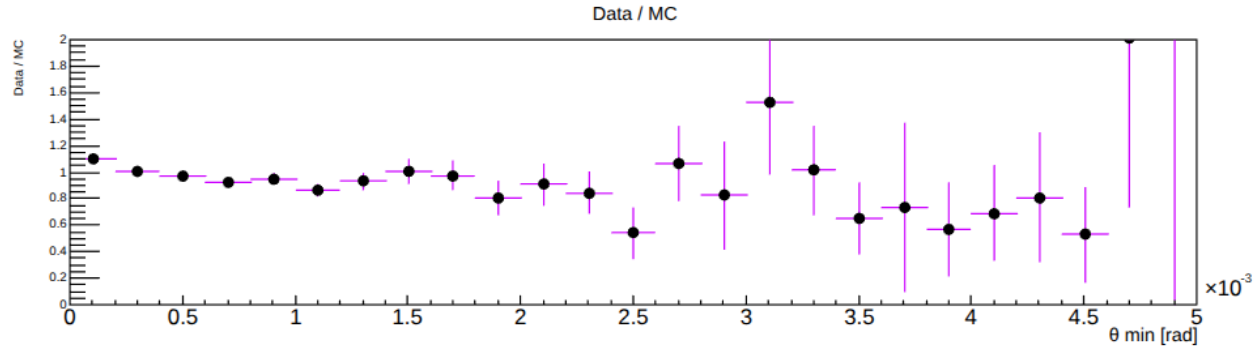


Using events passing all selection cuts except the cut on theta min angle

In data event number linearly grows with the angle

Data / MC ratio relatively flat along all the range

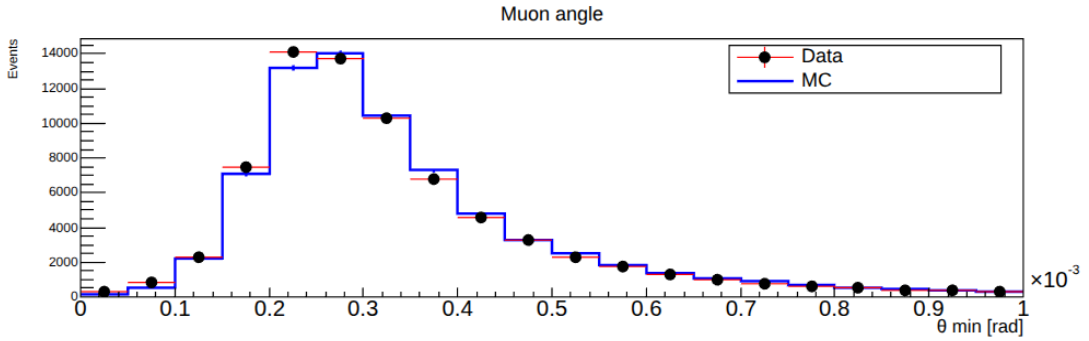


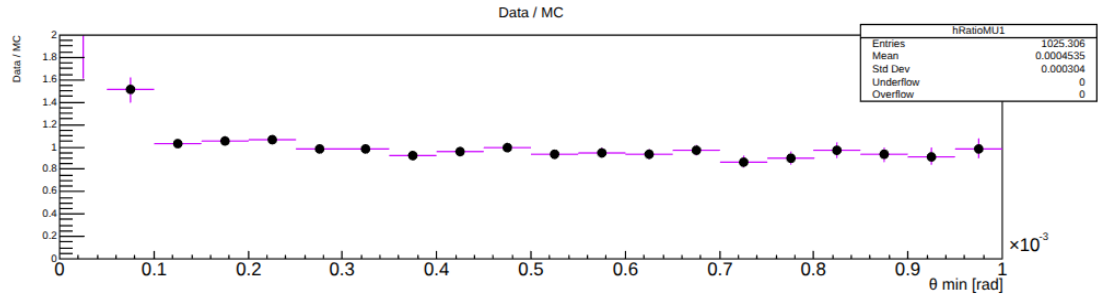


Number of events is having a maximum between 0.2 and 0.3 rad

MC up to 2 mrad follows the real data distribution

Data / MC ratio after 2 mrad has more fluctuations





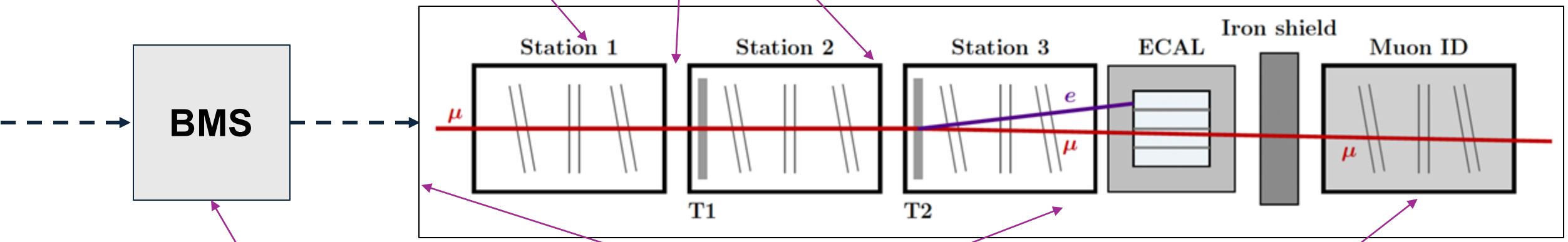
FIRST TARGET (TARGET 0)			SECOND TARGET (TARGET 1)	
Number of events	MESMER – NNLO	REAL DATA RUN 32	MESMER – NNLO	REAL DATA RUN 32
Reconstructed	88.1 %	19.0 %	85.1 %	7.3 %
After Fiducial cuts of reco	99.9 %	56.5 %	99.98 %	70.3 %
After all cuts - nAfterCuts/nReco	29.6 %	0.80 %	45.8 %	2.7 %
After all cuts - nAfterCuts/nTot	26.1 %	0.15 %	39.0 %	0.2 %

Backup

3x tracking stations each equipped with 6 pre-production 2S modules

2x C targets 2cm thick

ECAL for PID and (E_e) measurement: achieved synchronisation with tracker for first time



Measure incoming (p_\mu): 2x tracking stations each equipped with 4 prototype 2S modules

Timing Detector to measure arrival time of muons: 2x plastic scintillator

Muon PID: tracking station equipped with 4 prototype 2S modules

			Skim v2					
			Station_i-1			Station_i		
	NHits S_i-1	NHits S_i	First X and Y	U and V	Last X and Y	First X and Y	U and V	Last X and Y
Single mu int	5<= N <8	8< N	Each module fired	At least 1 of modules fired	Each module fired	All 4 xy modules fired and at least one uv fired		
			At least 5 hits			At least 2 multifired xy module and at least 2 uv hits or At least 3 multifired xy modules and at least 1 uv hit		
			No more than 1 of modules multifired (2 hits)			At least 1 module multifired		At least 1 module multifired
Pileup 2mu int	10 <= N < 13	13 < N	Each module multifired	Total number of hits on both modules at least 2	Each module multifired	All 4 xy modules are multifired		
			At most one of the modules threefired			At least 2 xy modules are threefired and UV has at least 3 hits or At least 3 xy modules are threefired and UV has at least 2 hits		
			Not more than 13 hits in total			At least 1 module threefired		At least 1 module threefired
Pileup 3mu int	-	-						
Pileup 4mu int	-	-						
Passing mu (golden)	6	6	1 hit each module			1 hit each module		
Passing 2mu (golden)	12	12	2 hit each module			2 hit each module		
Passing 3mu (golden)	18	18	3 hit each module			3 hit each module		