

TKI Event Selection

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ProtoDUNE analysis meeting
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Outline

Purpose of this talk:

To summarize TKI selection and examine reconstruction performance

1. Beam cut
2. Particle definition
3. Selected particles
4. Event selection

Samples by Jake:

data: pionana_5387_6_15_20.root
MC: pionana_mc_1GeV_6_15_20.root

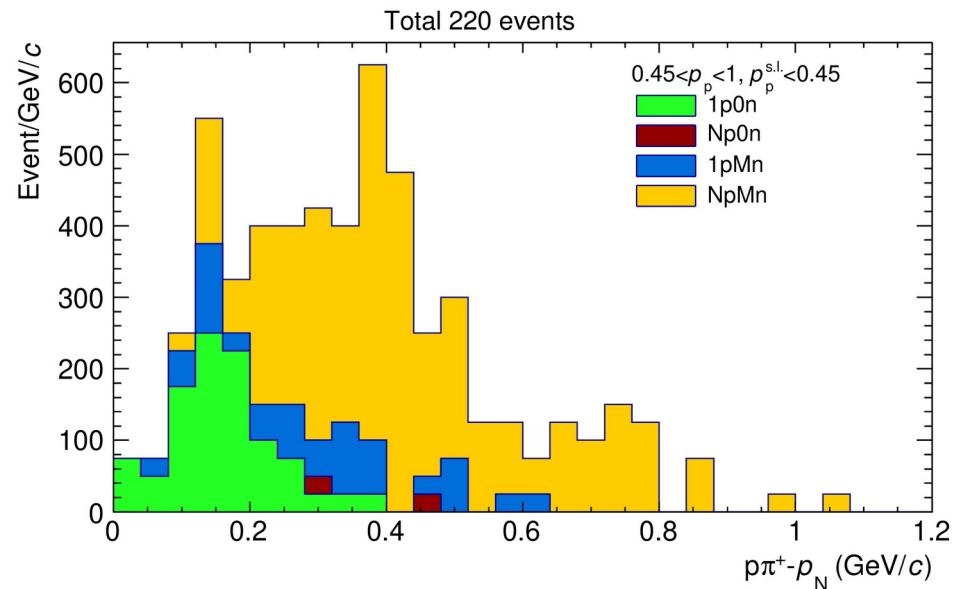
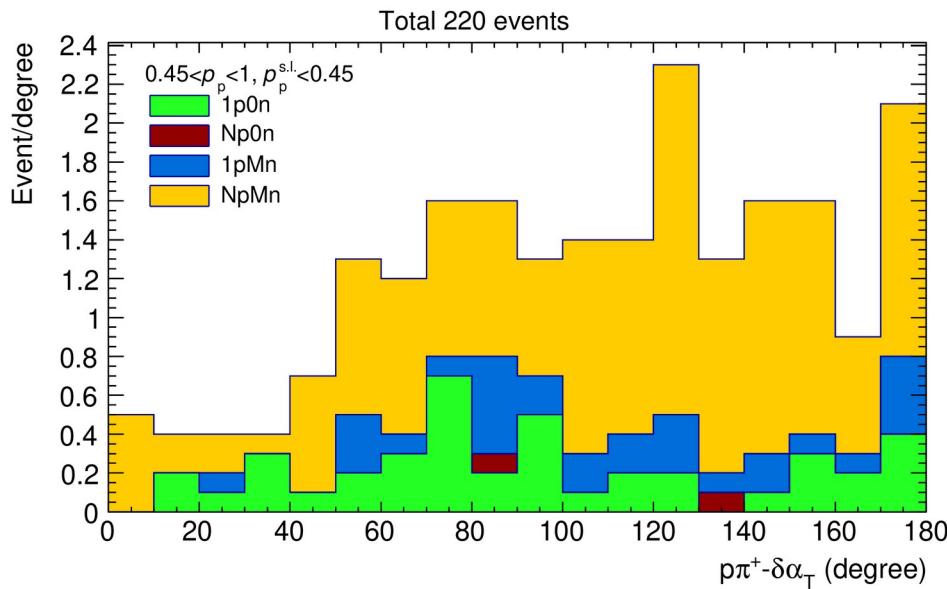
Past presentations

Physics motivation and signal definitions
([DUNE Physics Week June 2020](#))

Reconstruction performance of protons
and pions, and refined signal definitions
([Analysis Meeting 18 June 2020](#))

Refined signal definition

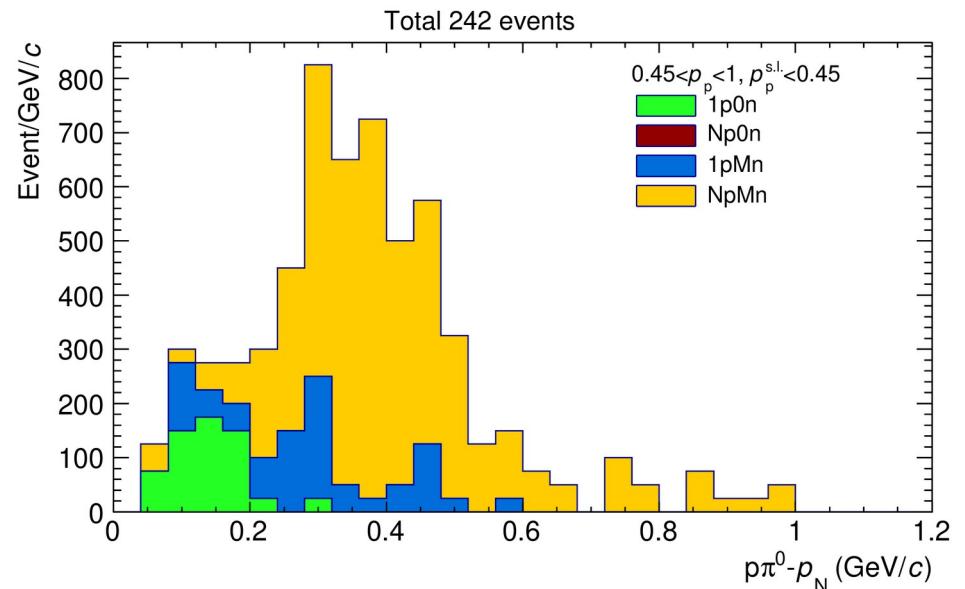
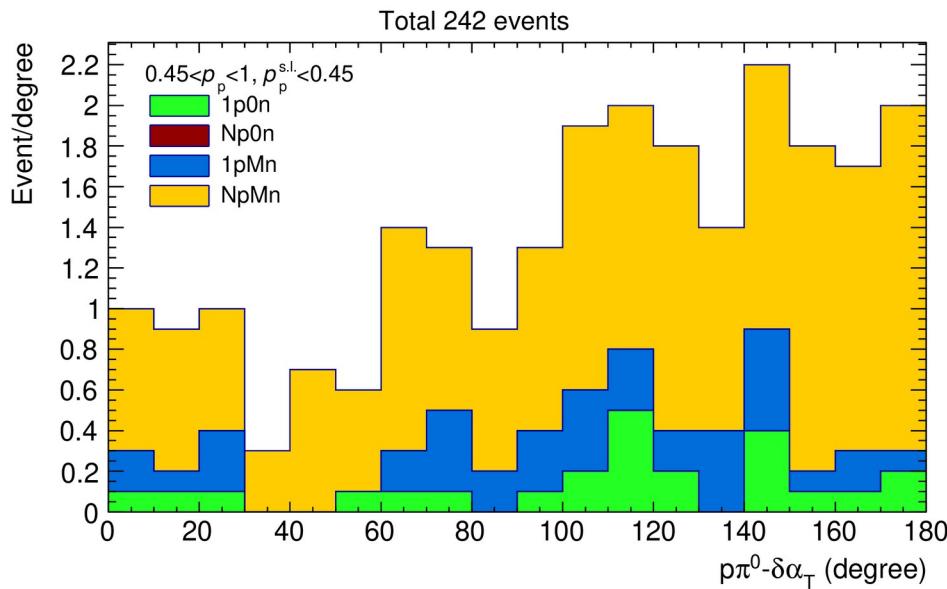
Recap



1. Pi+ beam
 2. At least 1 proton (leading proton kinematics used in calculation)
 3. Exactly 1 pi+, no other pions
(Don't care about neutron, gamma, nucleus)
 4. Phase space restriction (NEW):
 - 1) Leading proton momentum in 0.45 – 1 GeV/c
 - 2) Sub-leading proton below 0.45 GeV/c
(No phase space restriction on pi+)
- 220 pπ+ signal in 3263 1-GeV pi+ beam events
 - 224 in new data sample

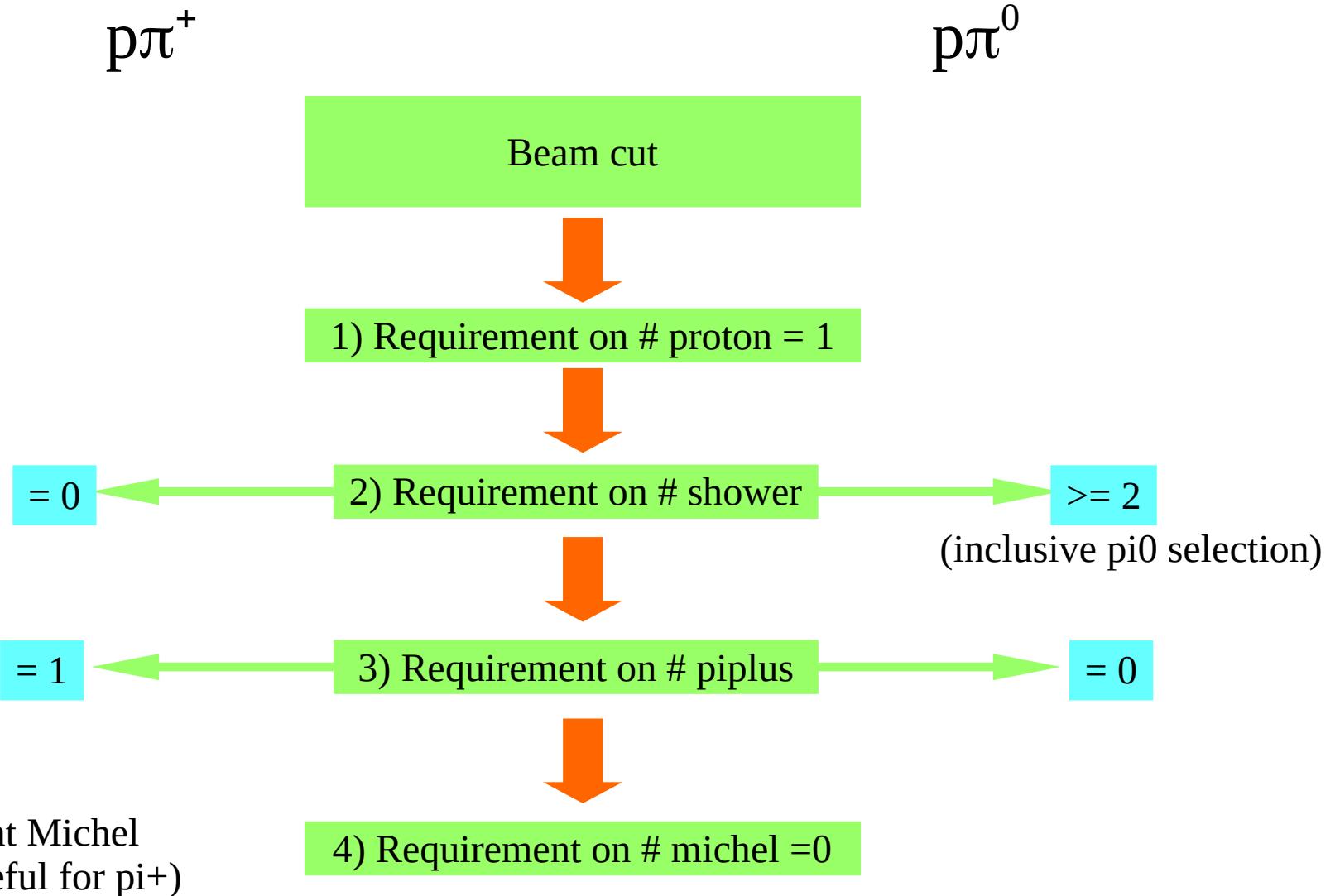
Refined signal definition

Recap

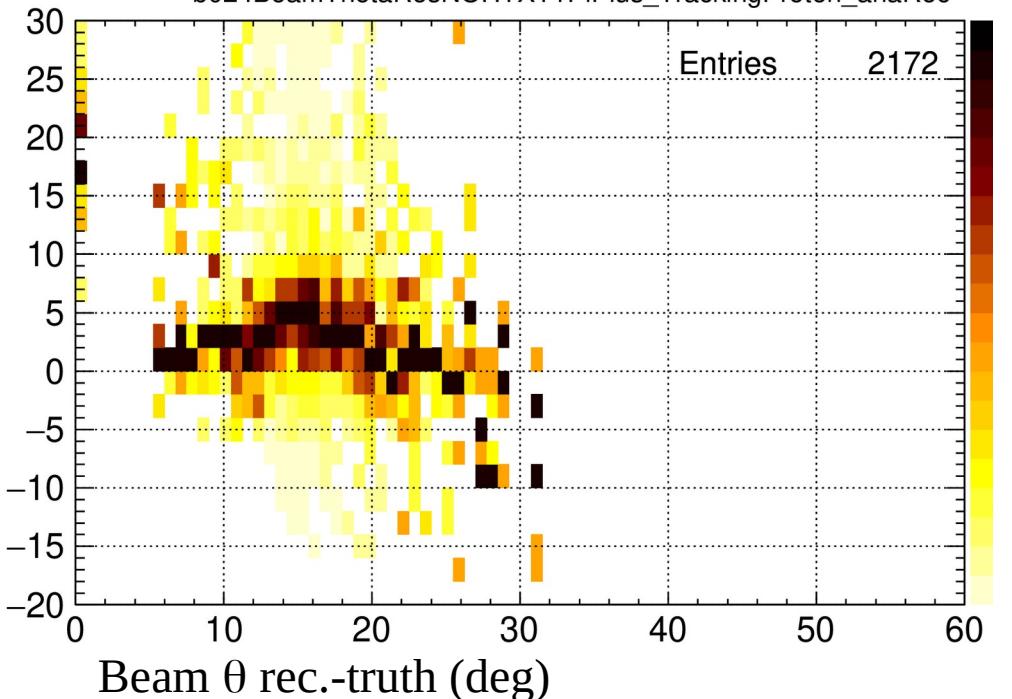


1. Pi+ beam
 2. At least 1 proton (leading proton kinematics used in calculation)
 3. At least 1 pi0, no other pions
(Don't care about neutron, gamma, nucleus)
 4. Phase space restriction (NEW):
 - 1) Leading proton momentum in 0.45 – 1 GeV/c
 - 2) Sub-leading proton below 0.45 GeV/c
(No phase space restriction on pi0)
- 242 pπ0 signals in 3263 1-GeV pi+ beam events
246 in new data sample

Event selection



Beam cuts follow pion abs/cex analyses (details in BACKUP)
• All MC normalized to data by event count after beam cut
scale factor = $4859/2256 = 2.15$



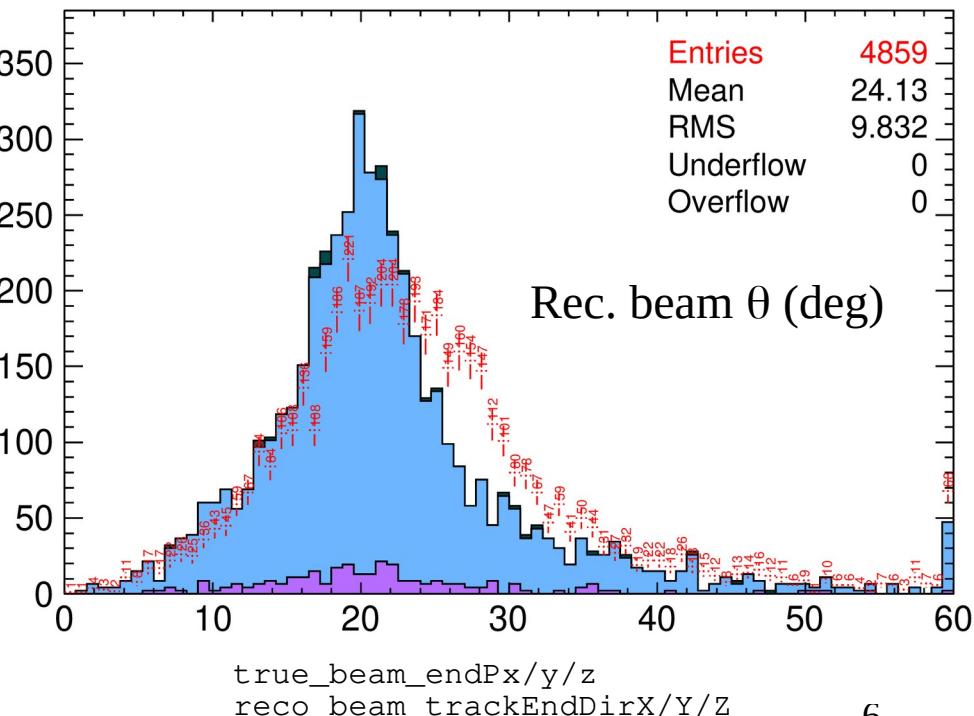
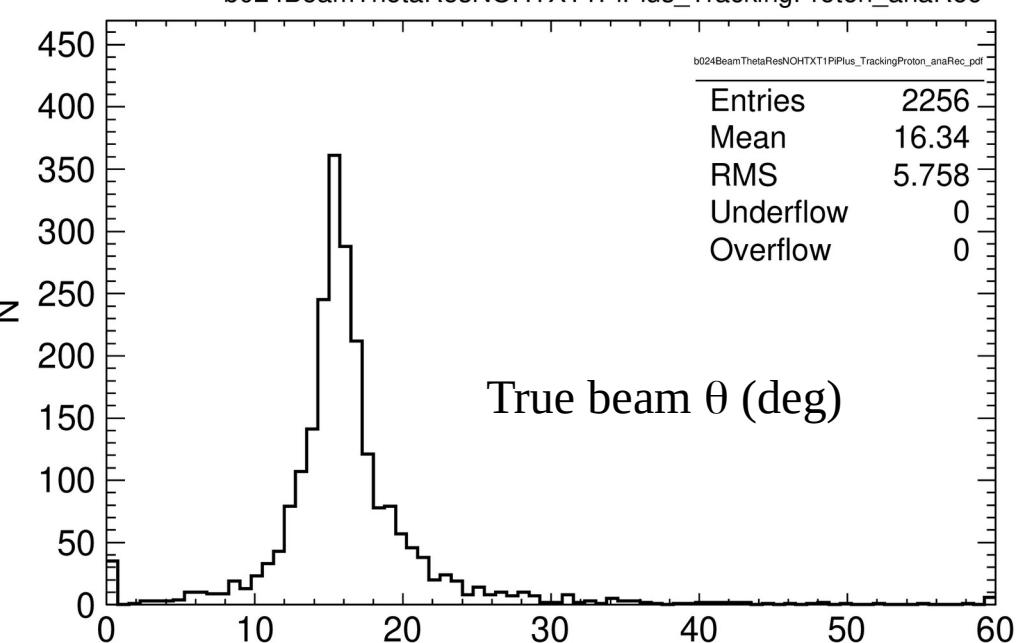
vs
True beam θ (deg)

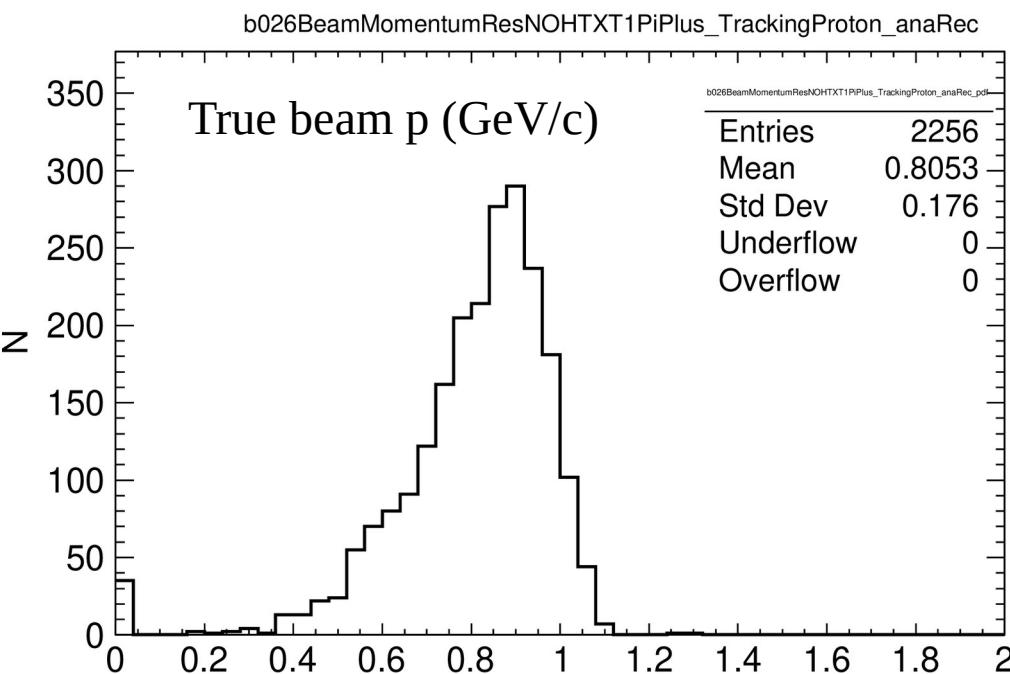
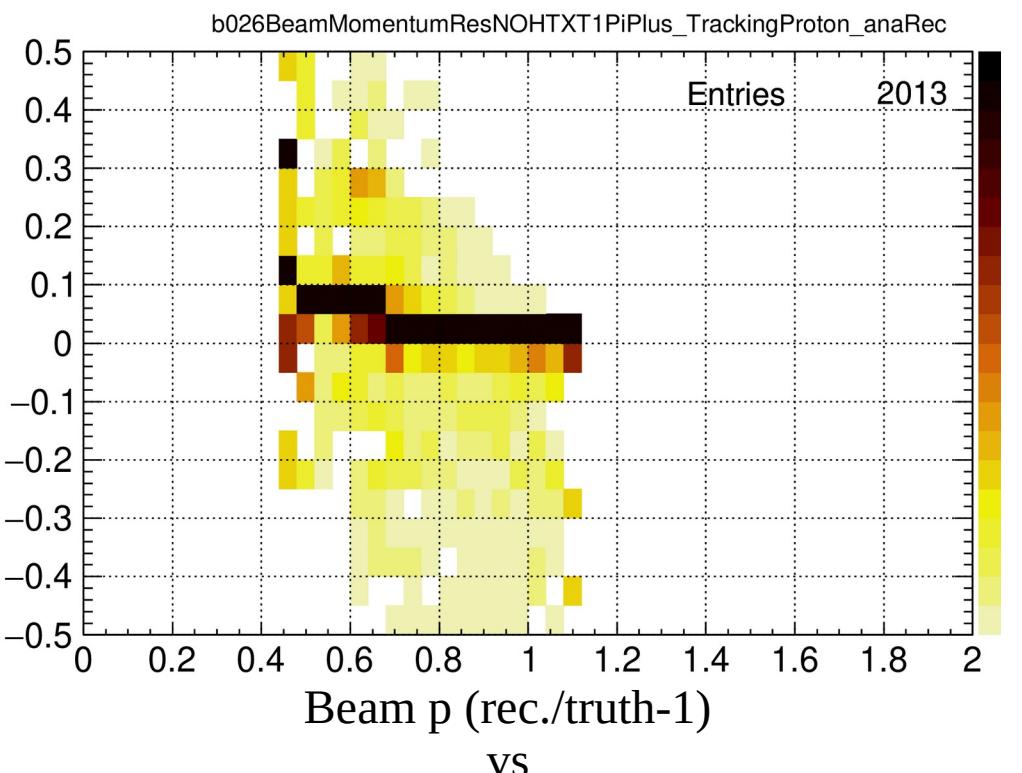
signal
background
non- π^+ beam
data



- Beam θ reconstruction: mostly +5 deg bias
- Large data-MC discrepancy → more tests in BACKUP

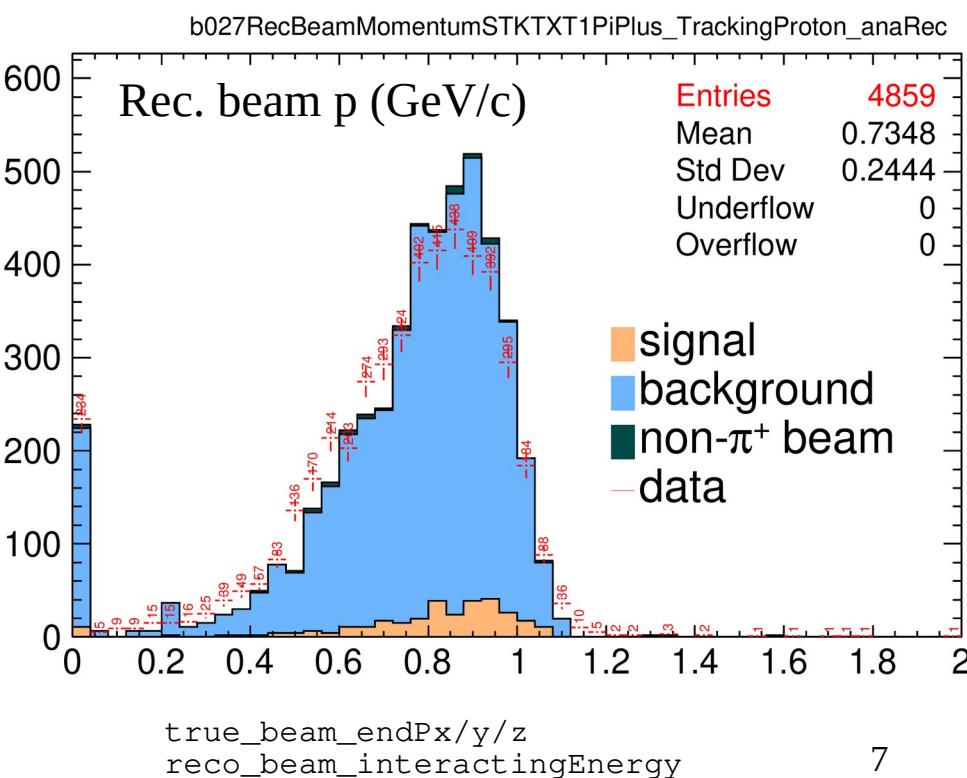
– After beam cut



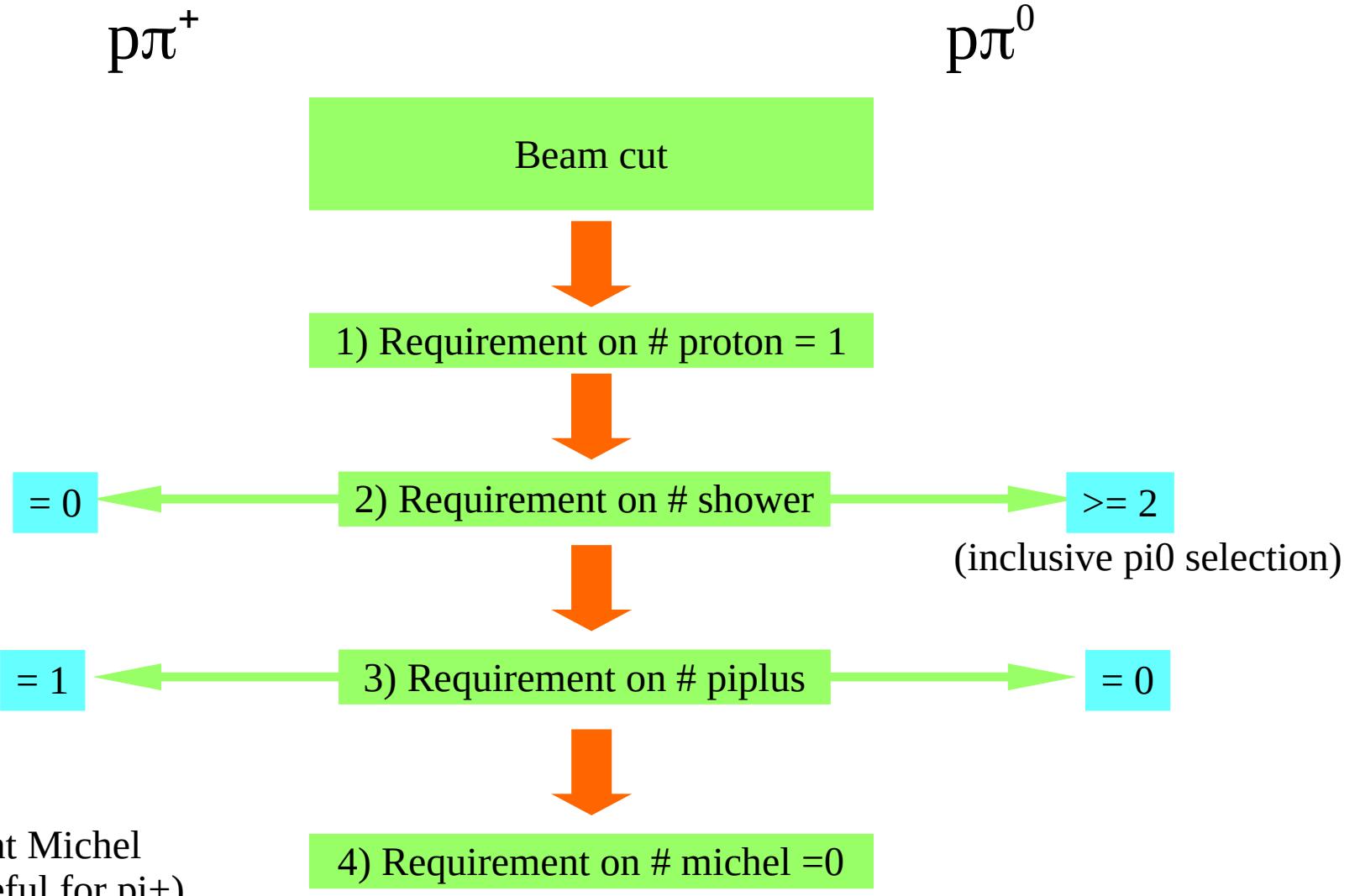


Beam momentum at interaction vertex

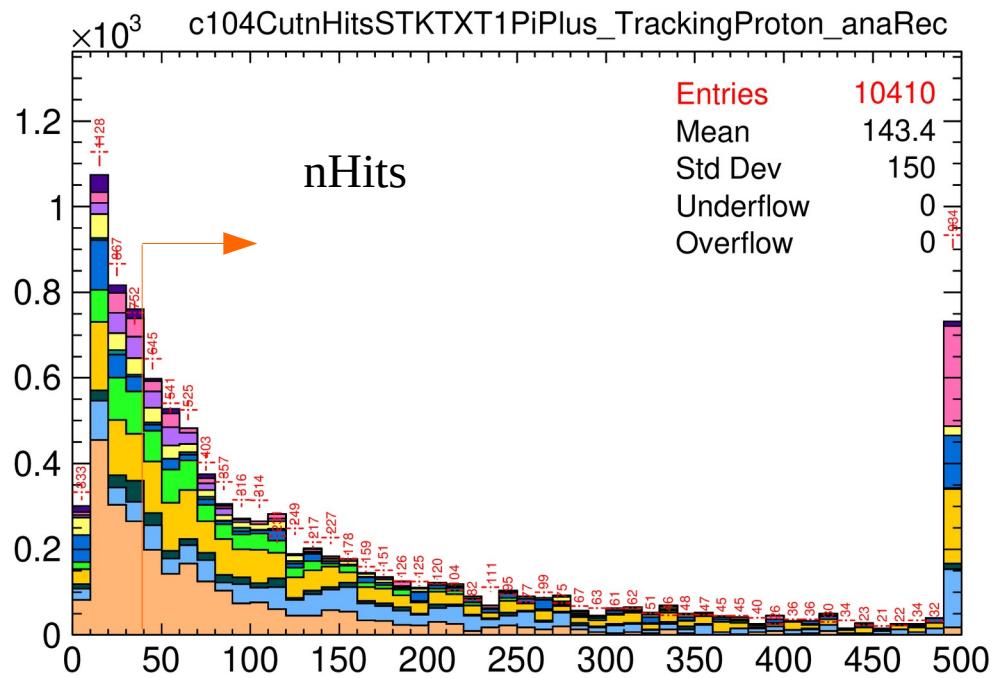
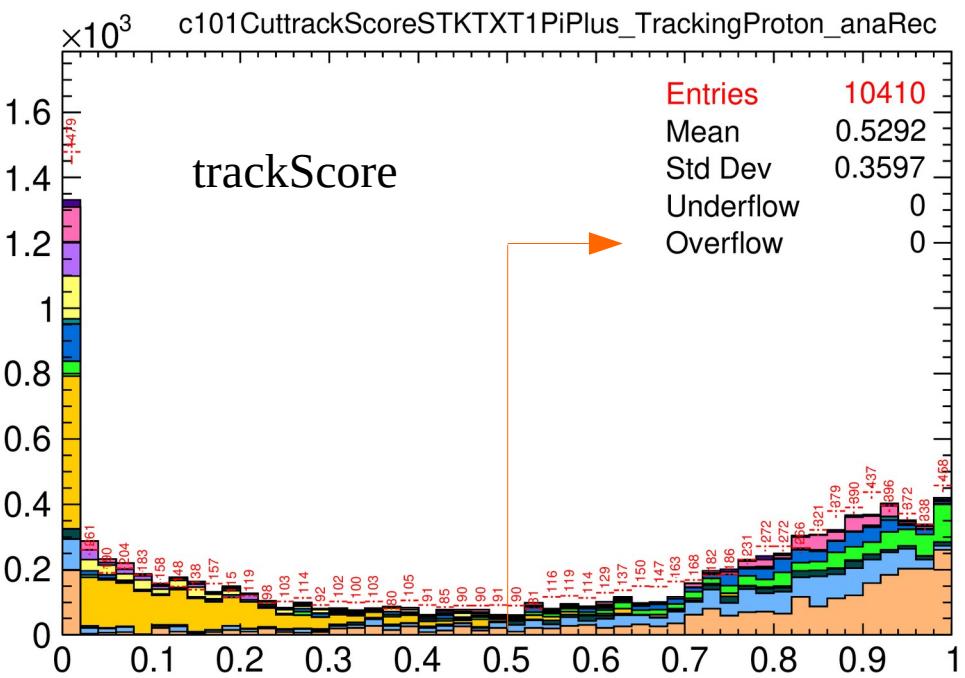
- ~ +5% bias, resolution with long tails
- Data-MC consistent
→ OK-ish, might need to find a cut to remove bad resolution → but probably will improve automatically after requiring p-pi final state due to better vertex determination.



Event selection

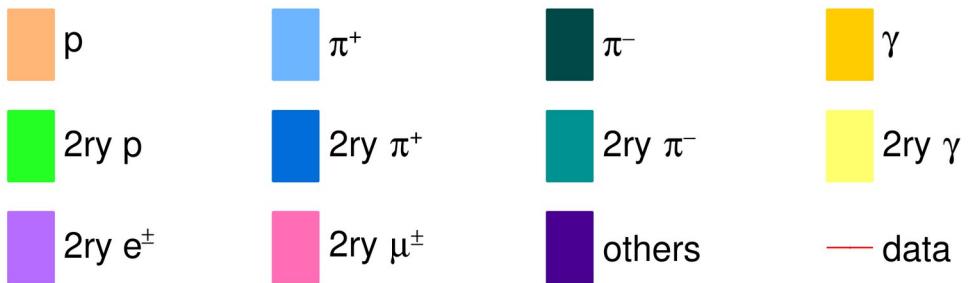


- $\#\text{proton}$, $\#\text{shower}$, $\#\text{piplus}$, and $\#\text{michel}$ all depends on particle definitions using reconstructed variables discussed in the following slides

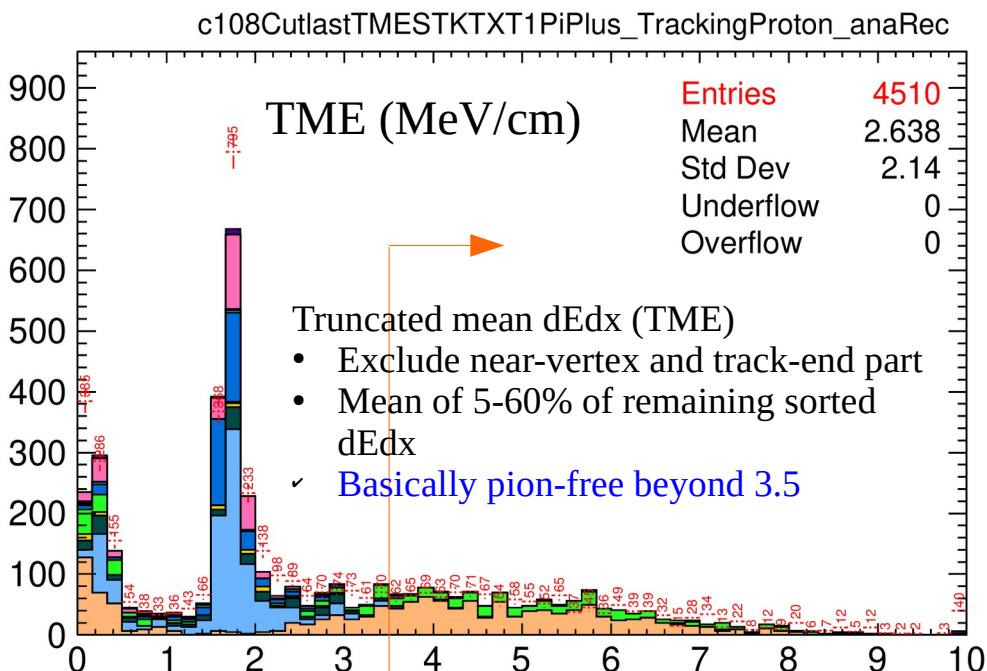
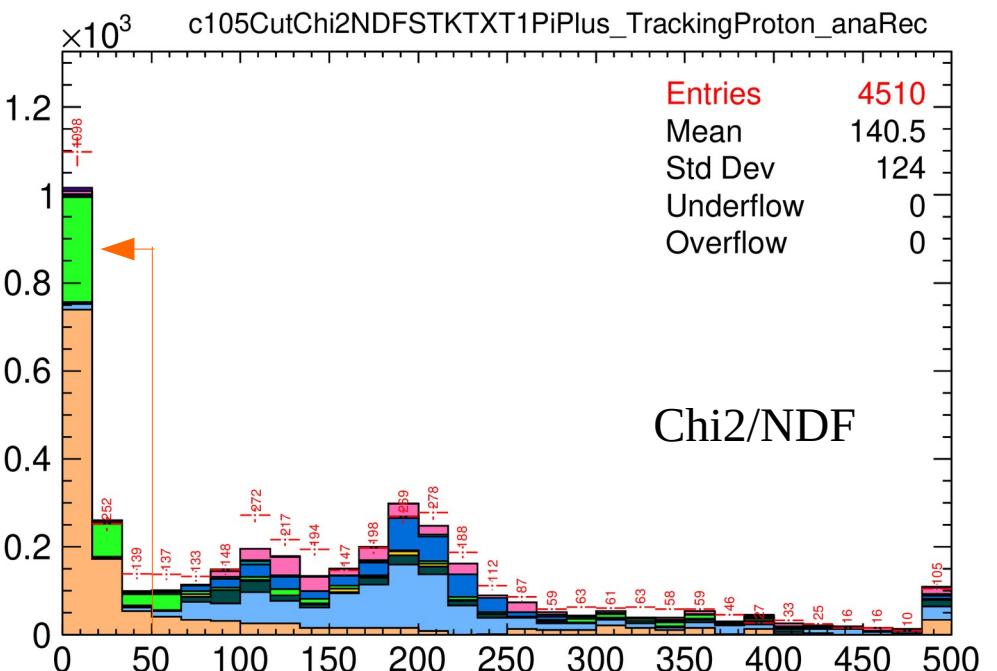


Counted as **track** if

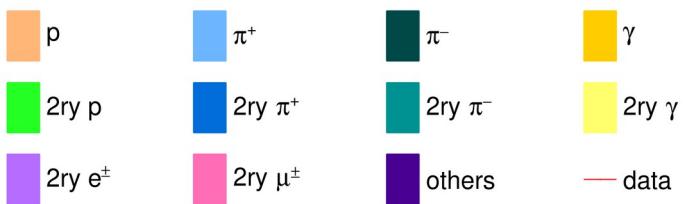
- allTrack_ID != -1
- TrackScore > 0.5
- nHits > 40



– After beam cut



- Track candidates

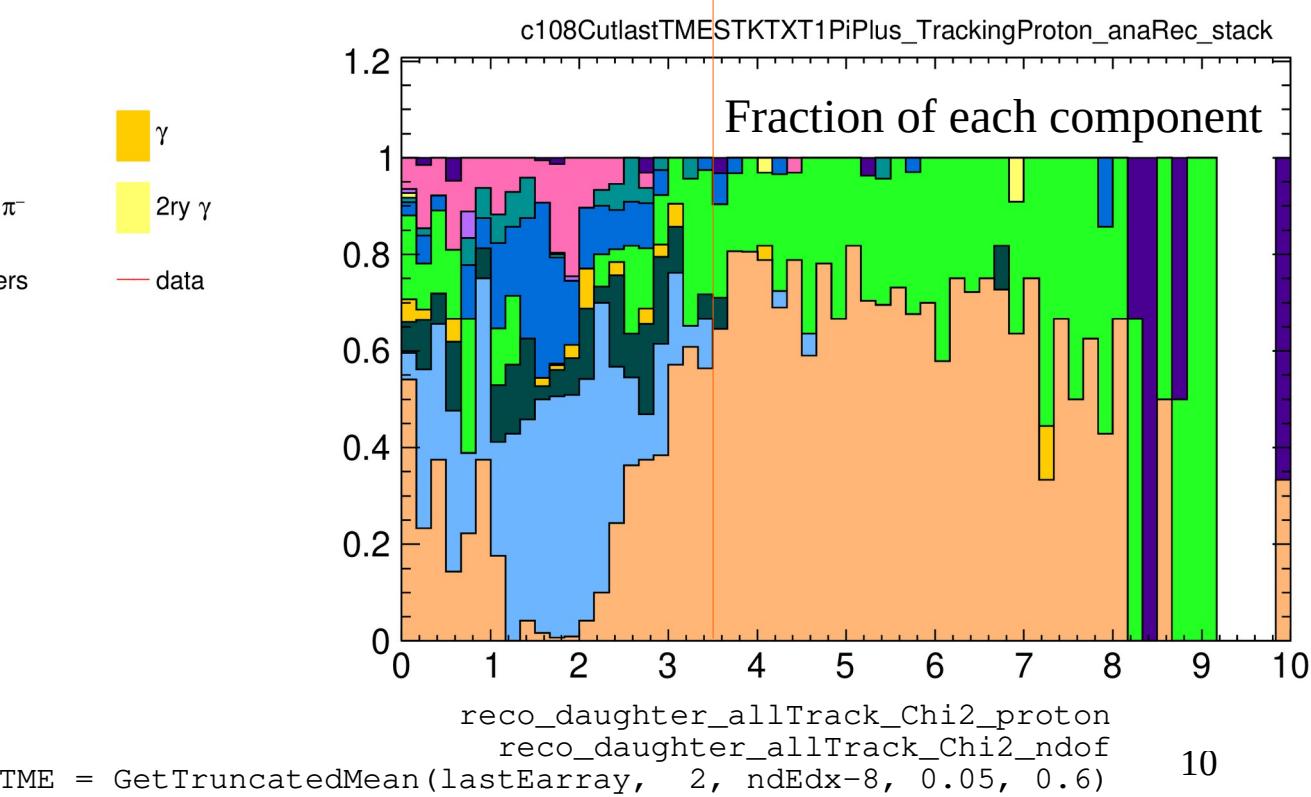


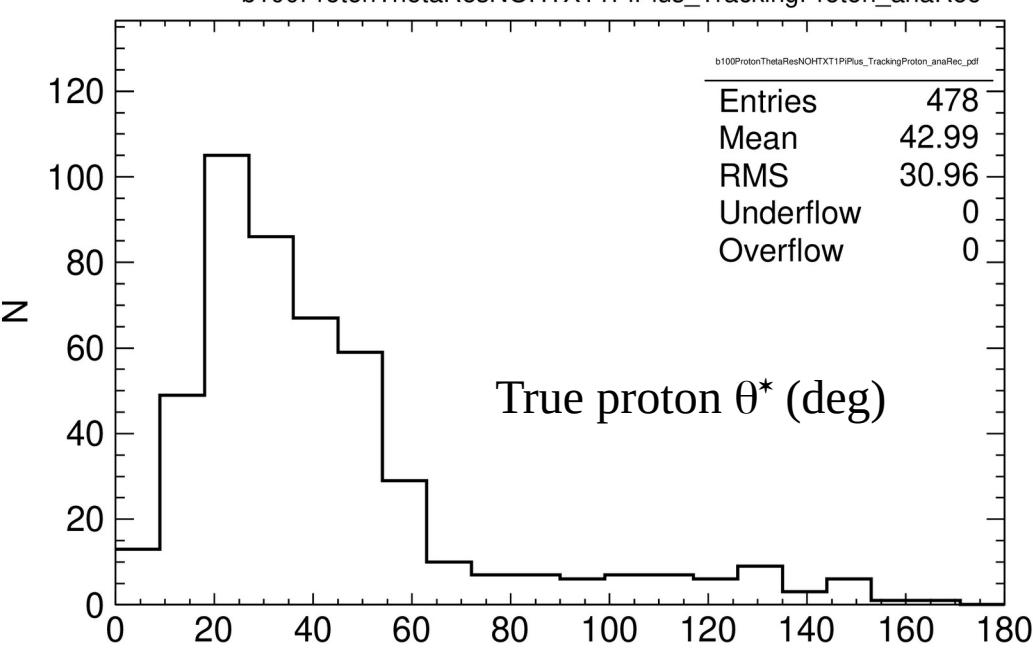
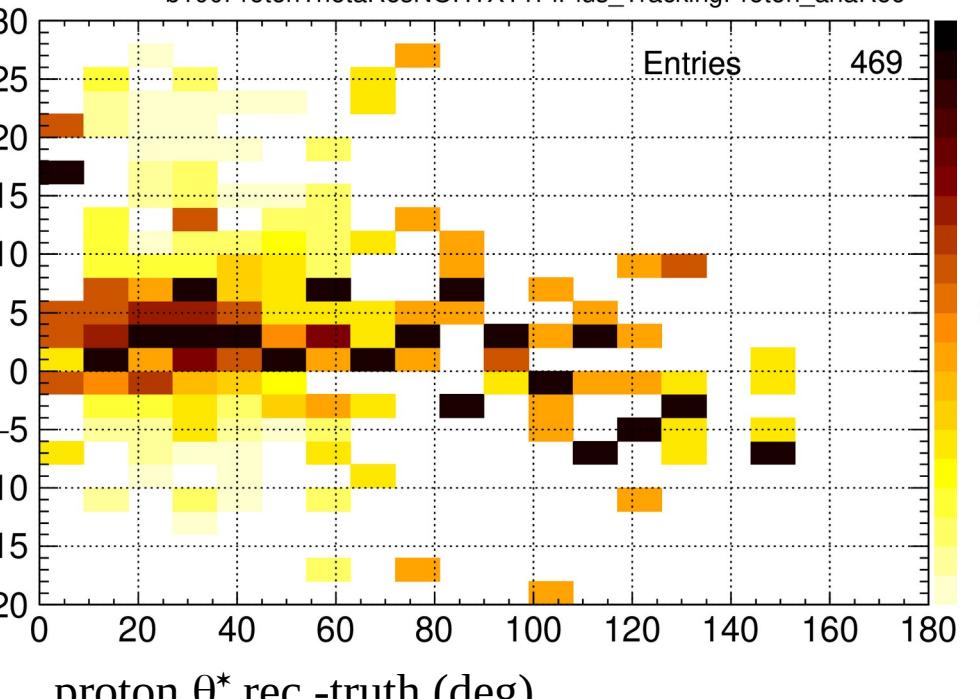
Counted as proton if

- Counted as track
- $\text{Chi2/NDF} < 50$ or $\text{TME} > 3.5$

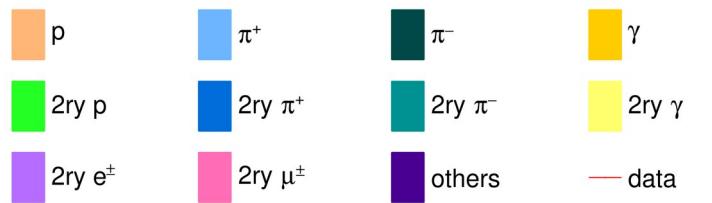
As pi⁺ if

- Counted as track
- Not counted as proton





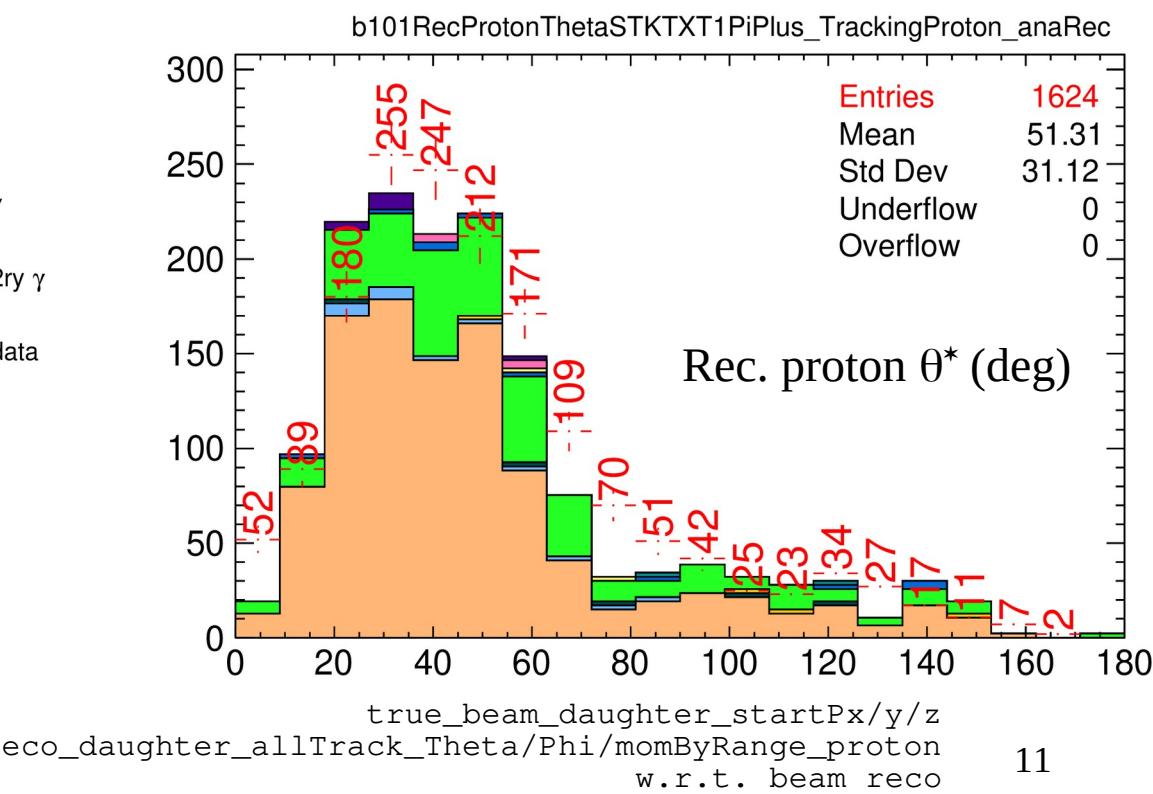
vs
True proton θ^* (deg)

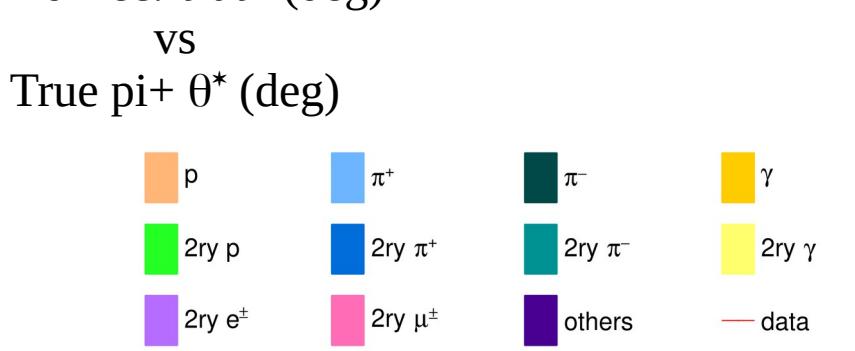
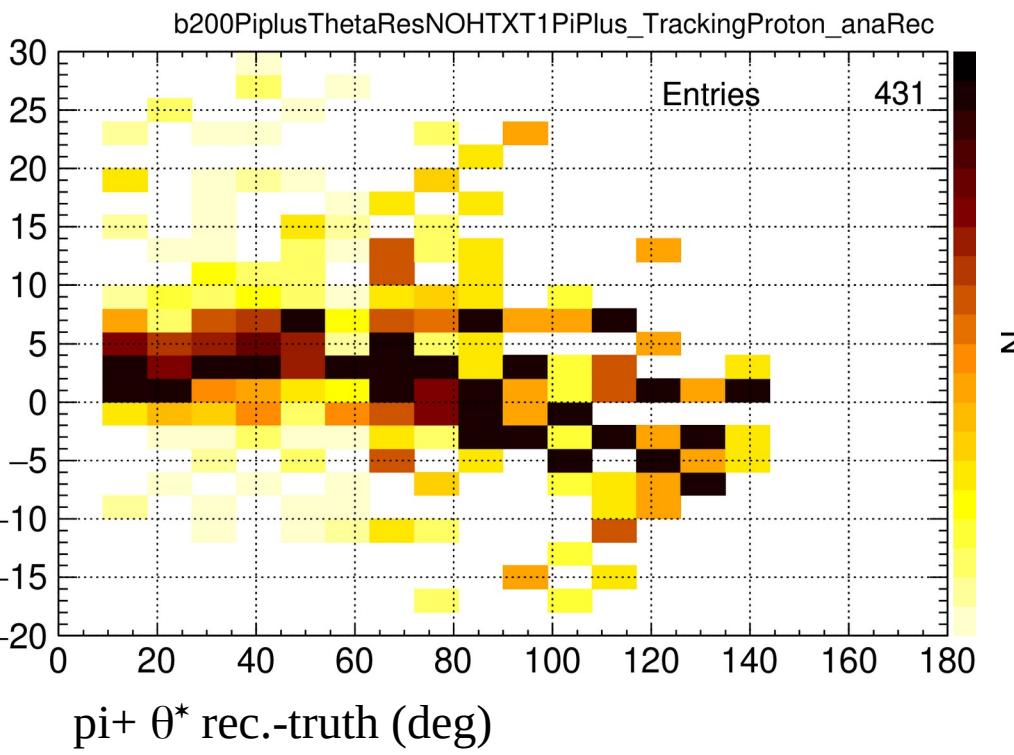


Selected proton theta wrt beam

- +2-3 deg bias
- Data-MC agree

Contamination from 2ry protons

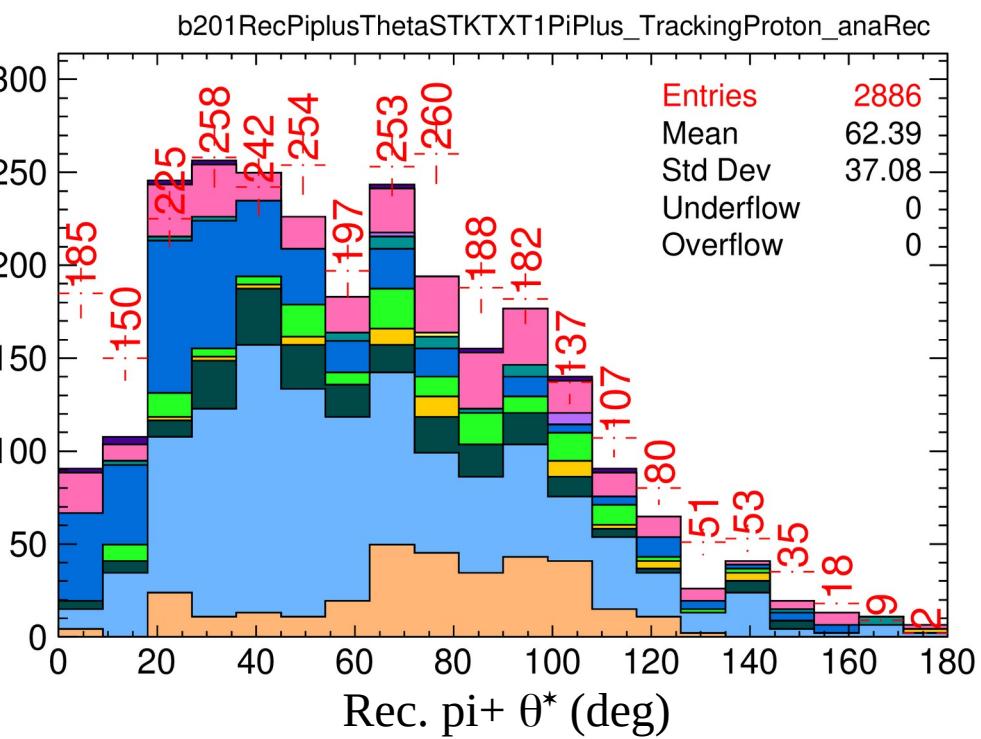
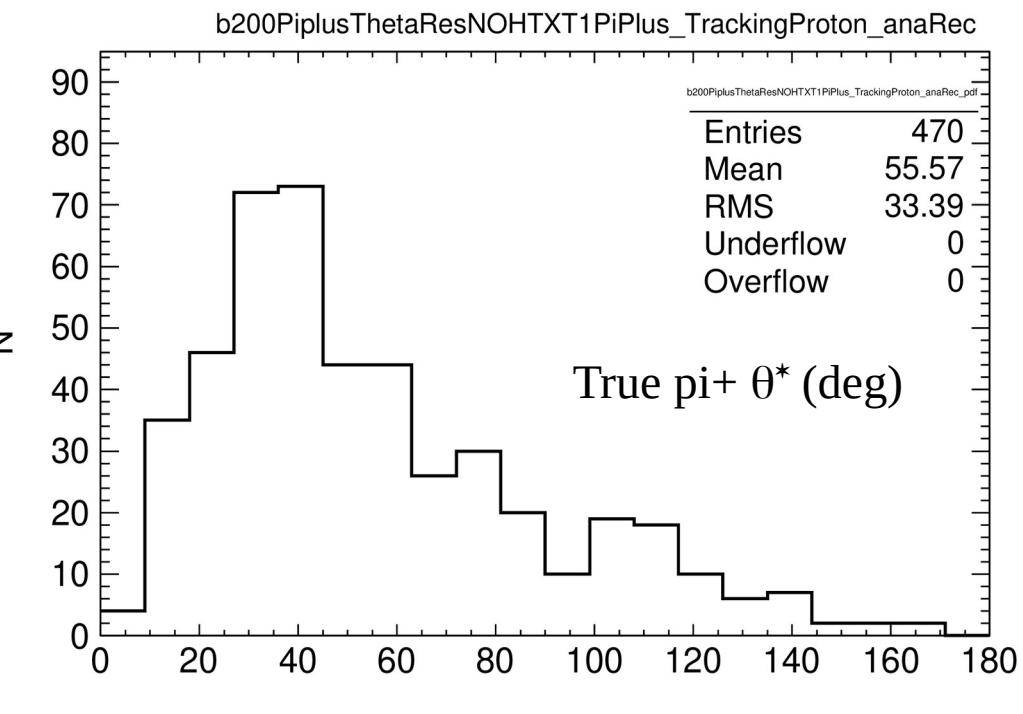


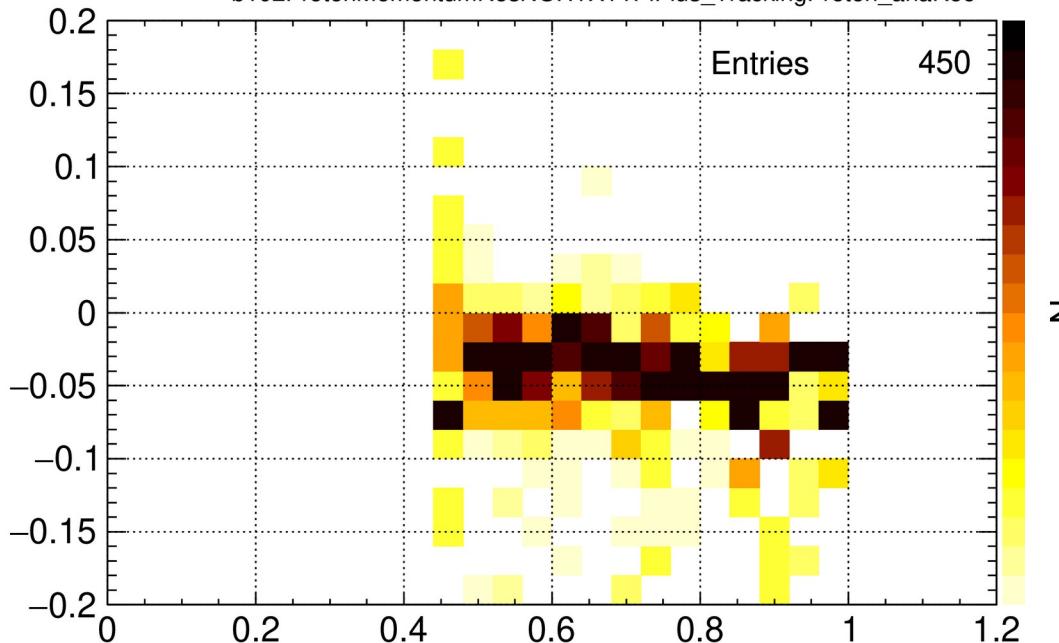


Selected π^+ theta wrt beam

- +2-3 deg bias
- Data-MC agree (except at 0 deg)

Contamination from proton, pi-, 2ry pi+, and muons

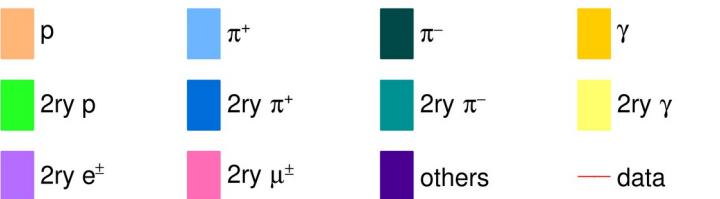




Proton p rec./truth-1

vs

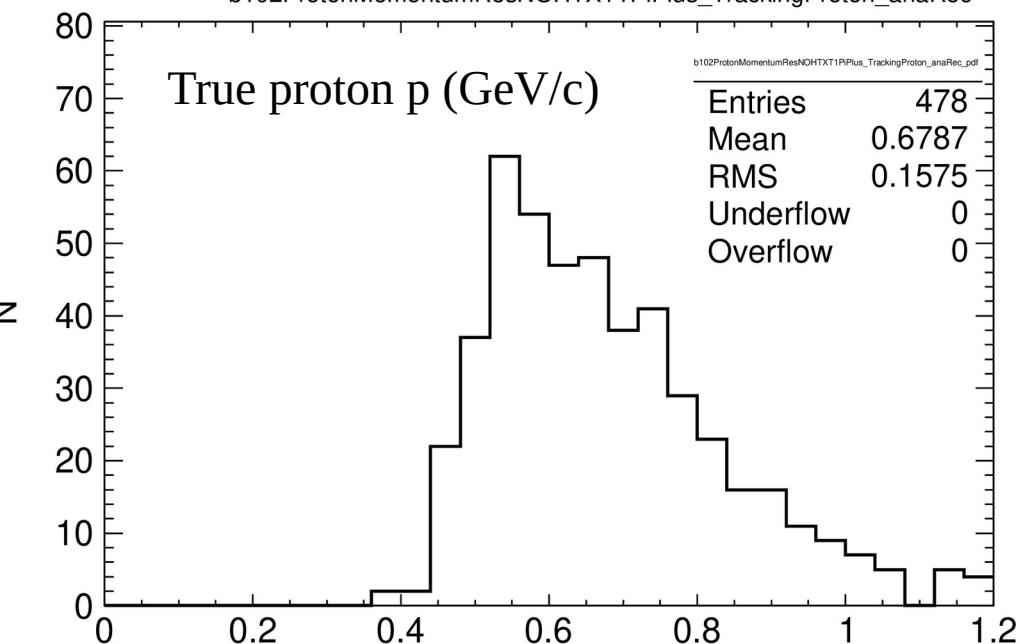
True proton p (GeV/c)



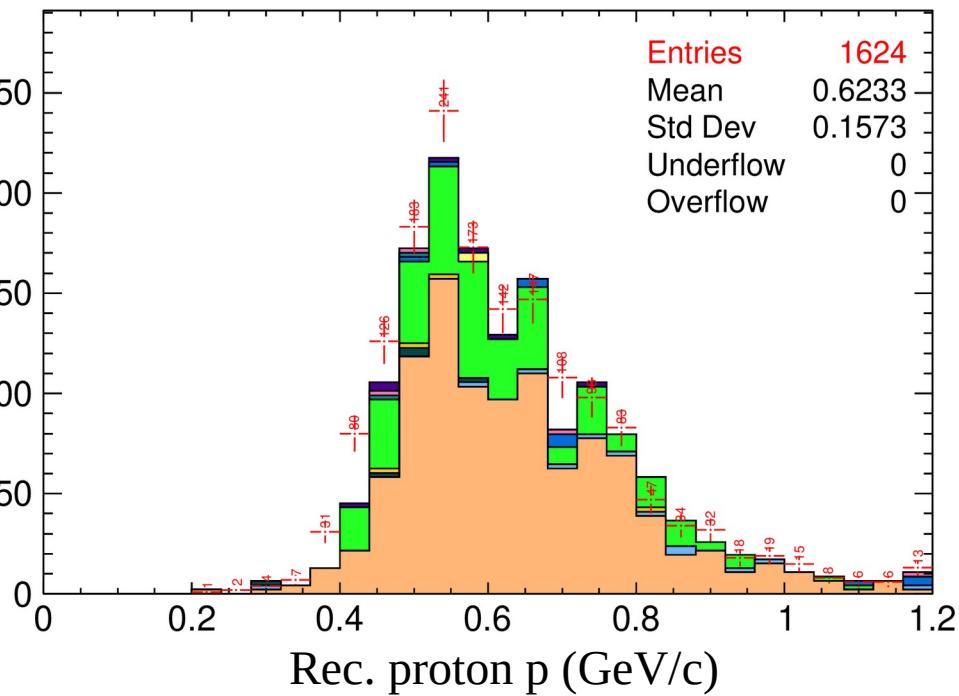
Selected proton momentum

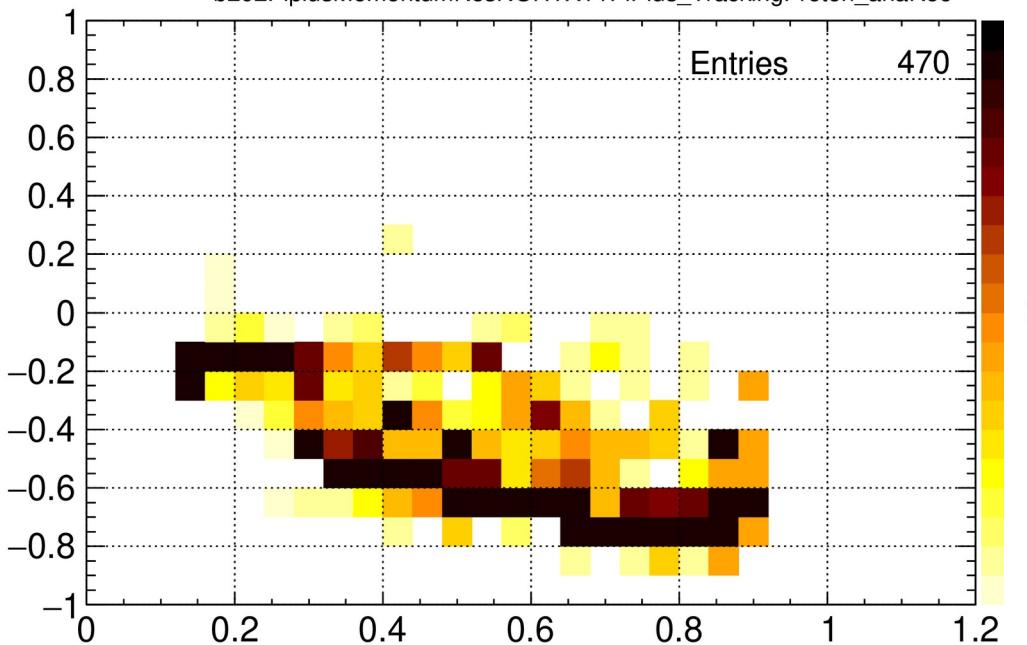
- -3% bias
- Data-MC agree

– Proton candidates



b103RecProtonMomentumSTKTXT1PiPlus_TrackingProton_anaRec

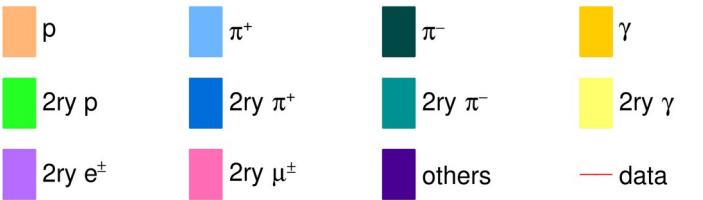




pi⁺ p rec./truth-1

vs

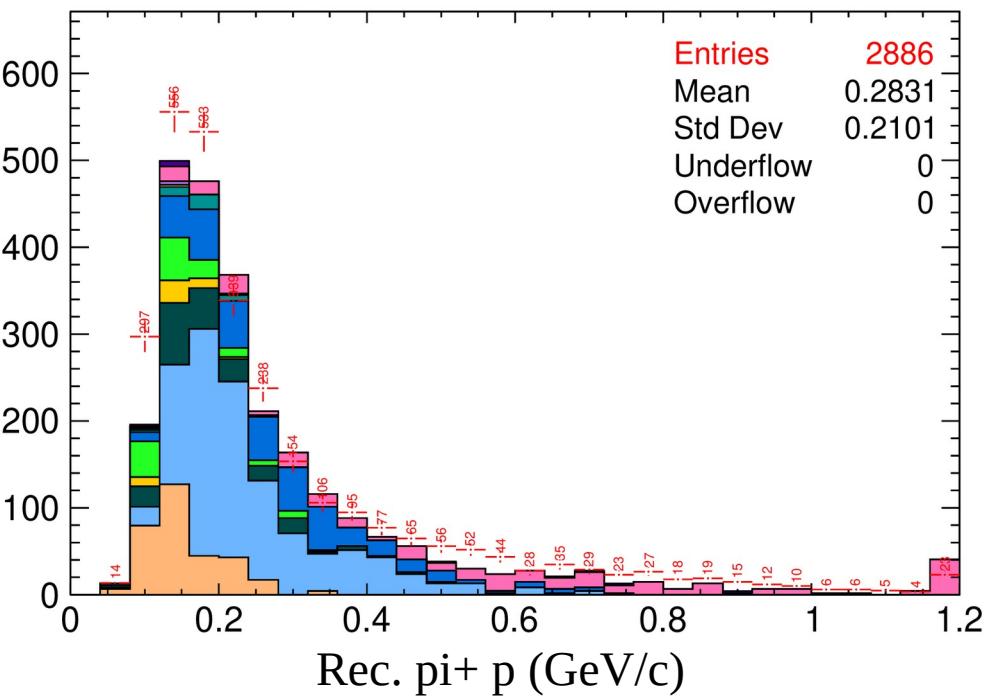
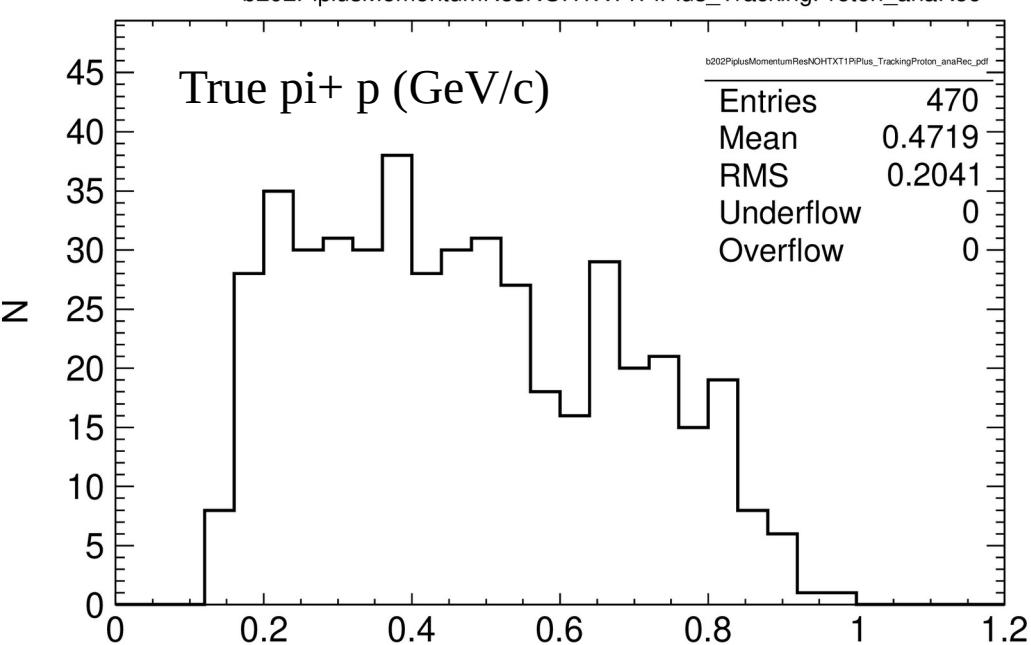
True pi⁺ p (GeV/c)

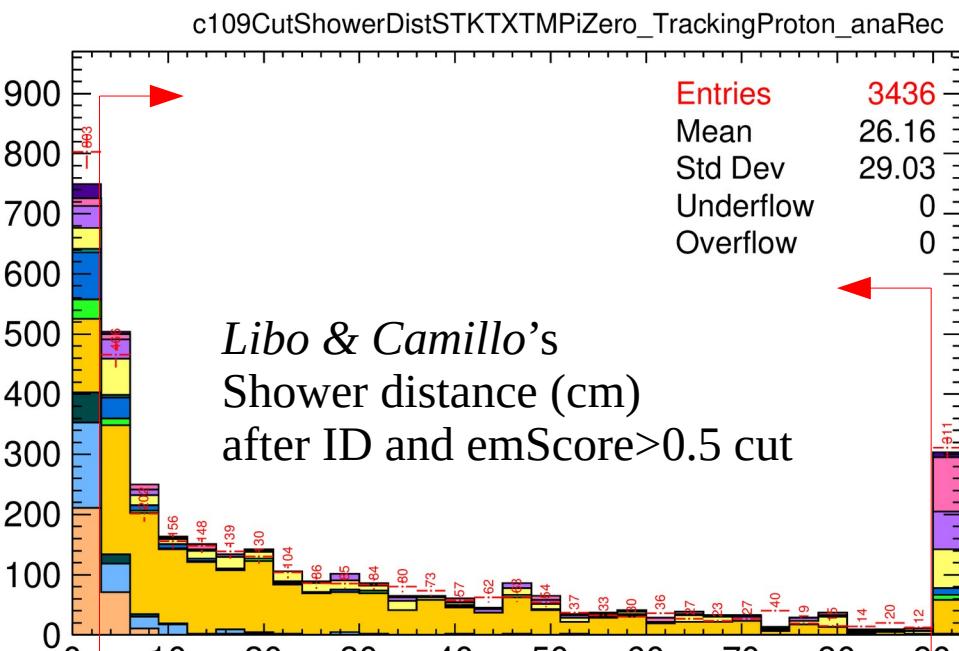
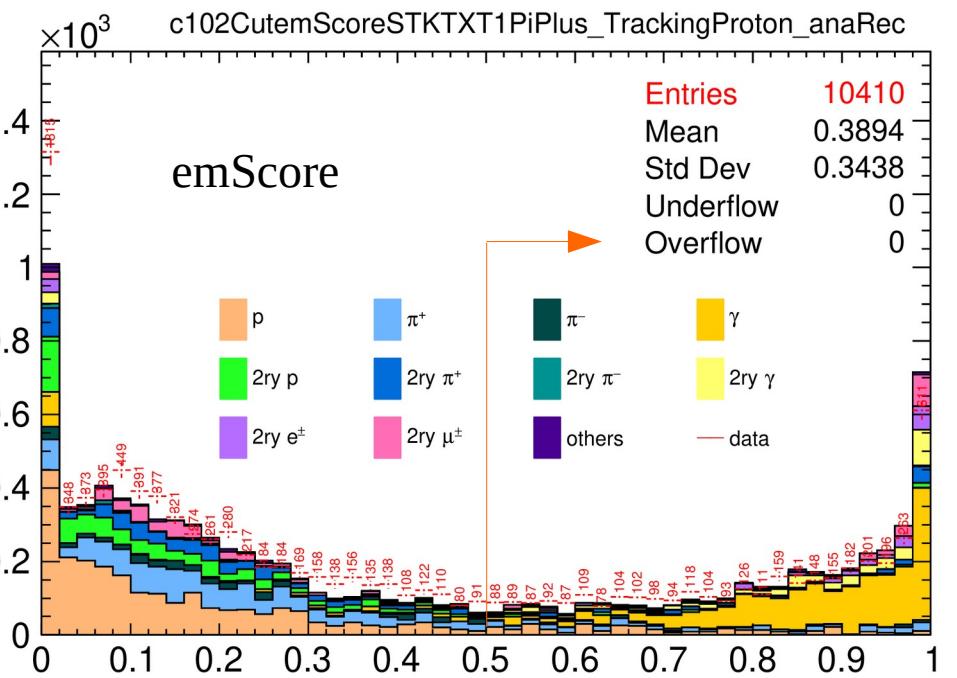


Selected pi⁺ momentum

- Most get reconstructed at ~0.2 GeV/c

– pi⁺ candidates



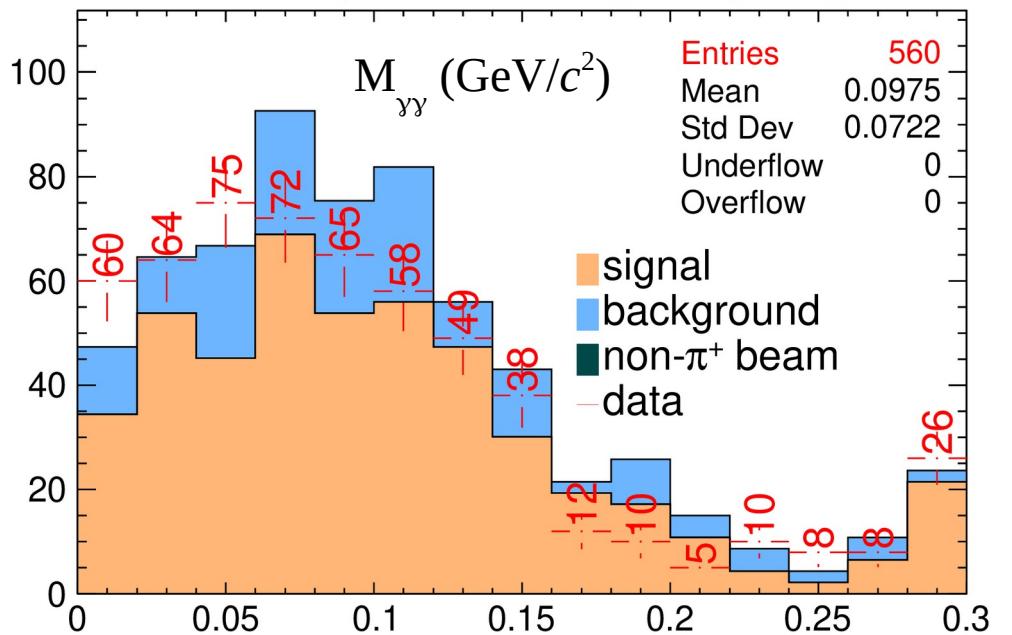


Counted as **EM shower** if

- allShower_ID != -1
- emScore > 0.5
- Applied for $p\pi^0$ channel only:
shower distance 3-90 cm (tuned to have maximal signal event eff*purity)

reco_daughter_allShower_ID
reco_daughter_PFP_emScore_collection

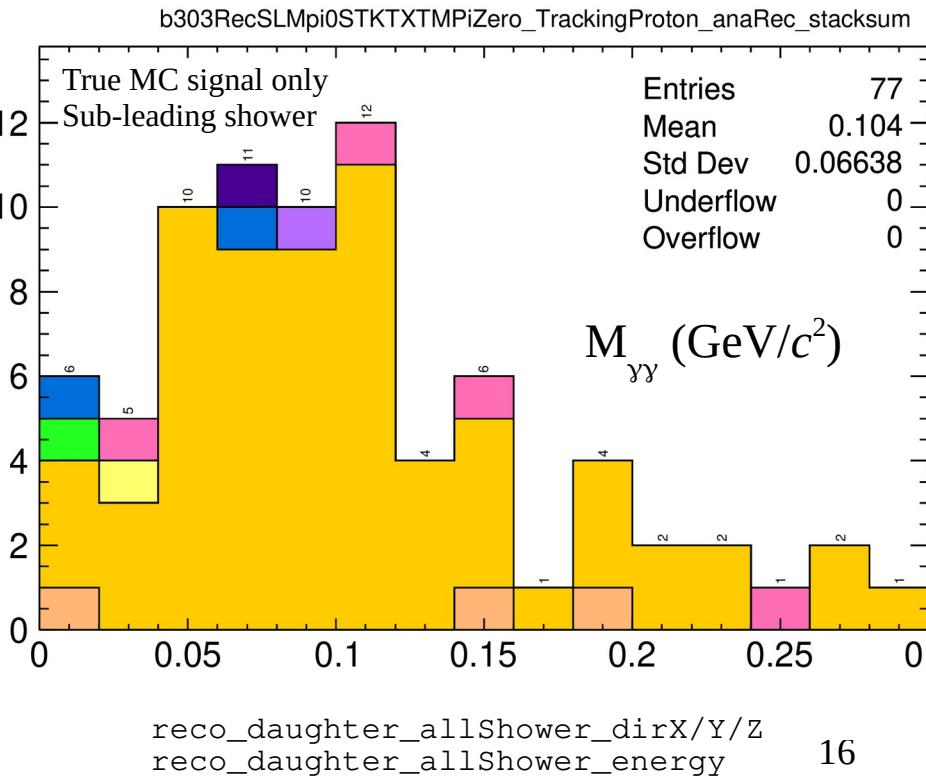
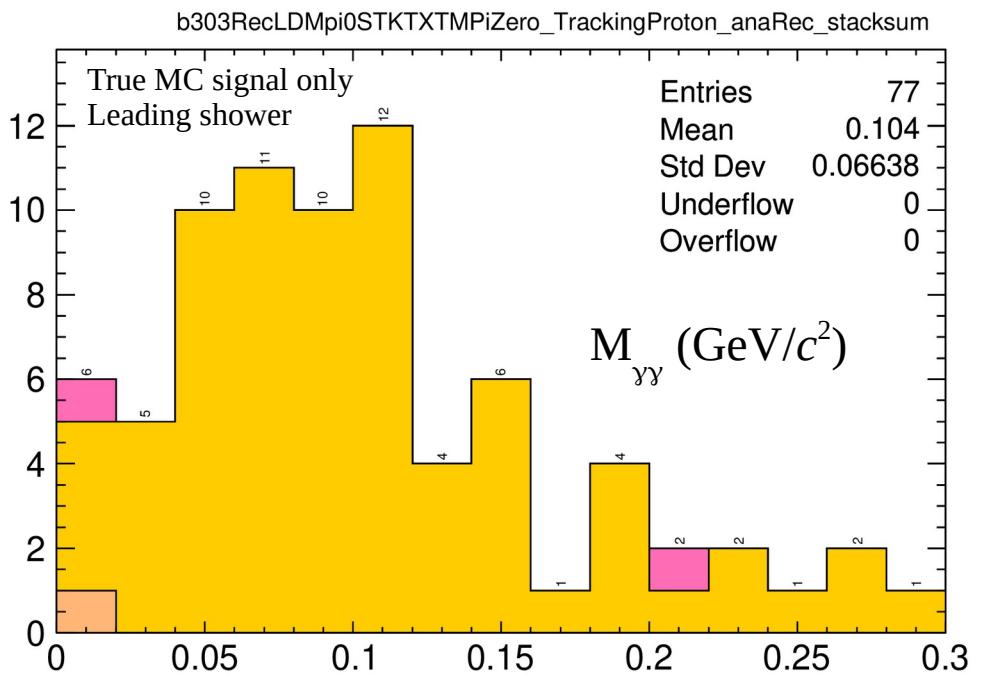
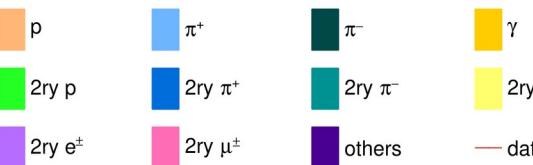
– After beam cut

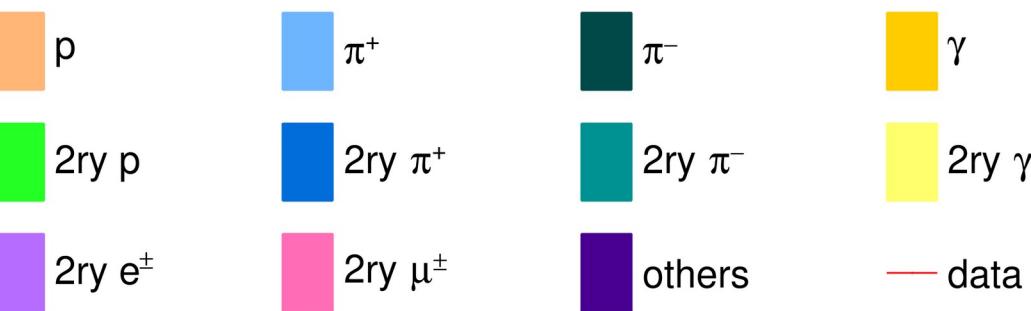
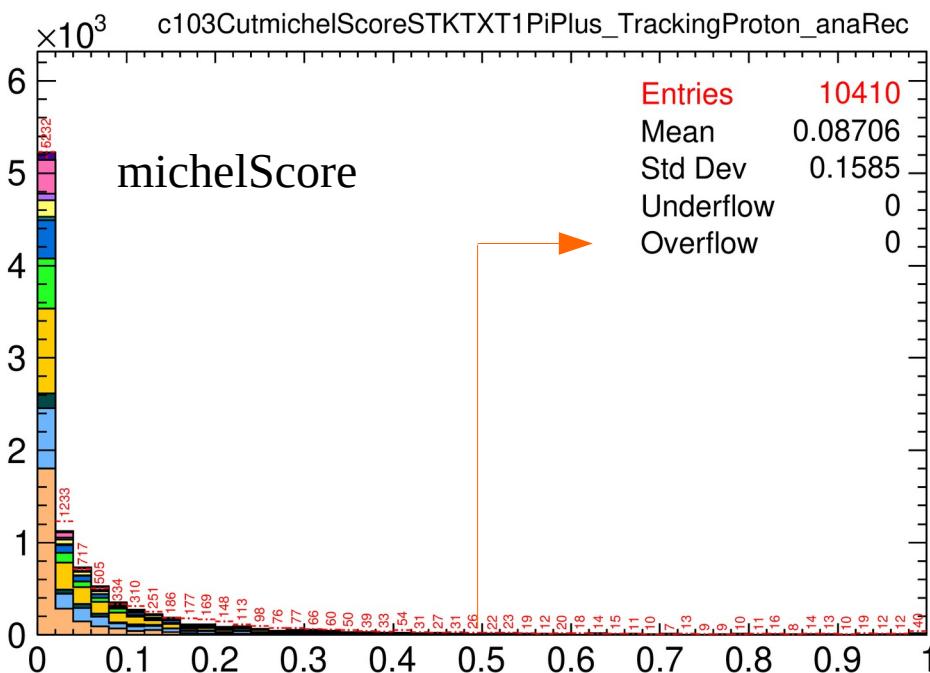


– pi0 candidates
from leading showers = leading pi0

Reconstructed pi0 mass

- peak in wrong position
- The MC signal distributions below show the pi0 is indeed reconstructed from gamma.





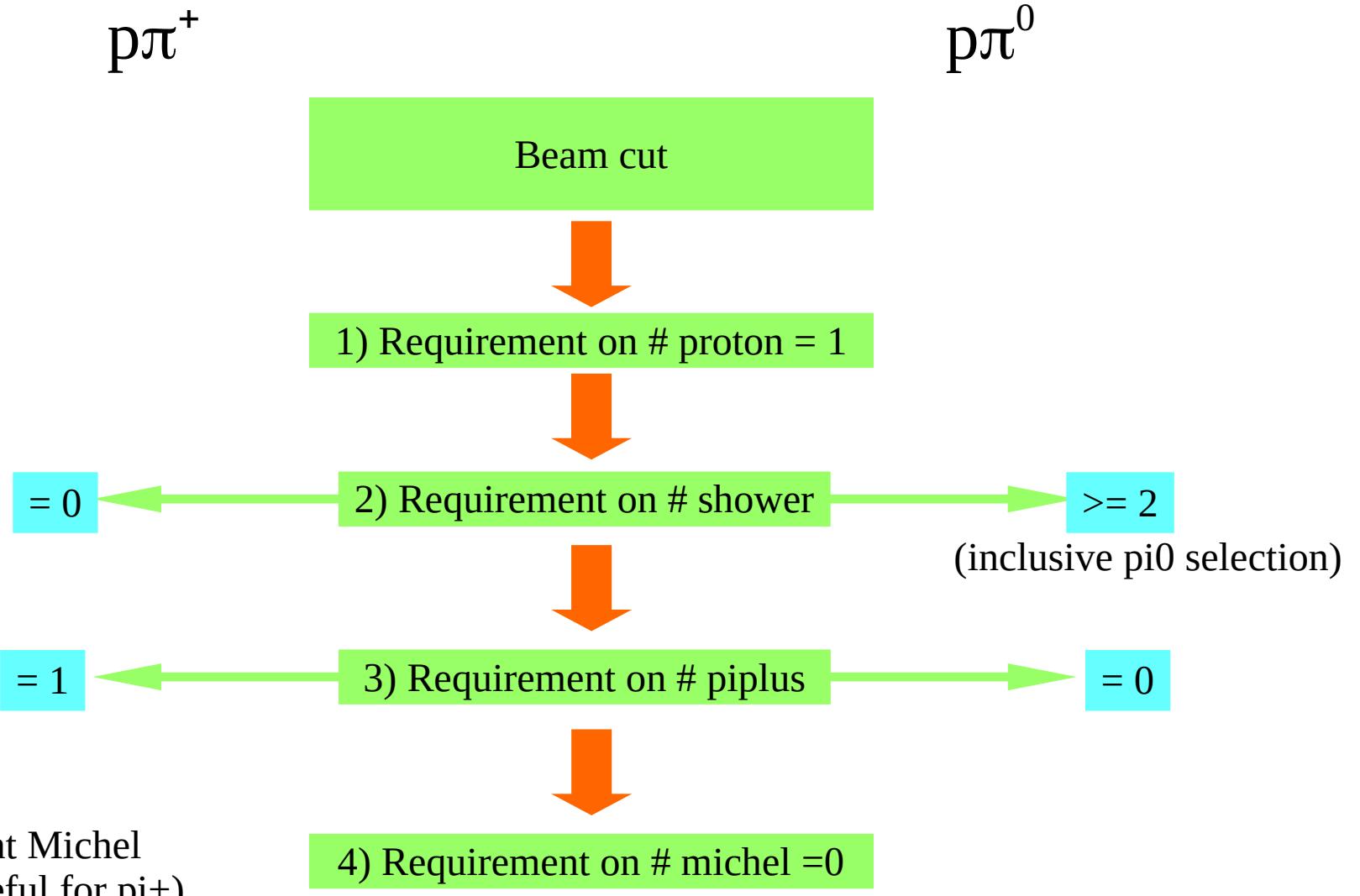
As Michel if

- MichelScore > 0.5

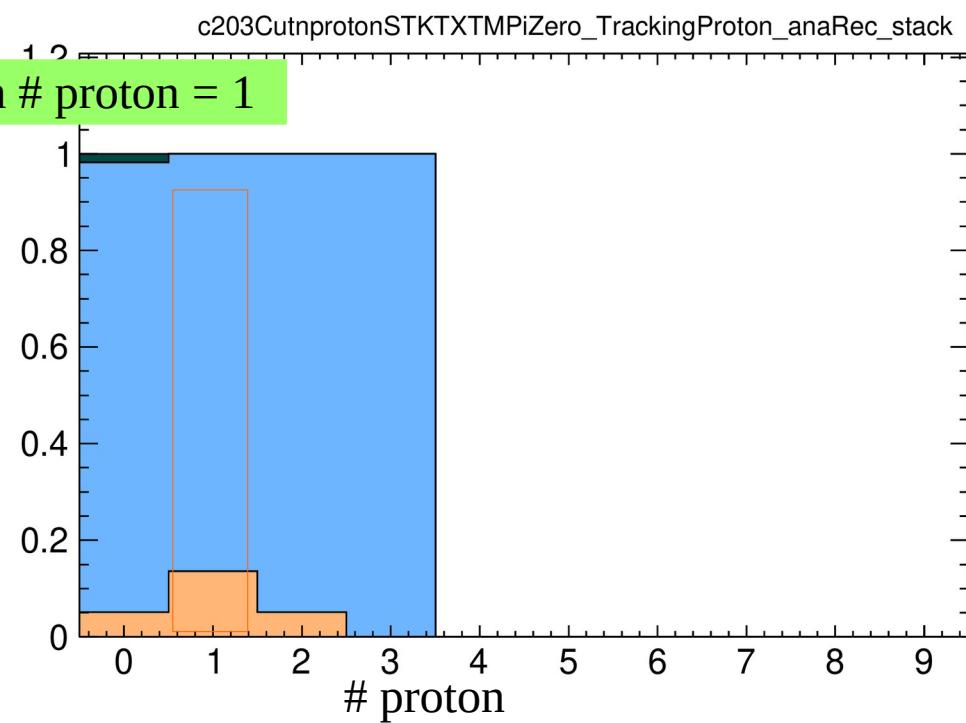
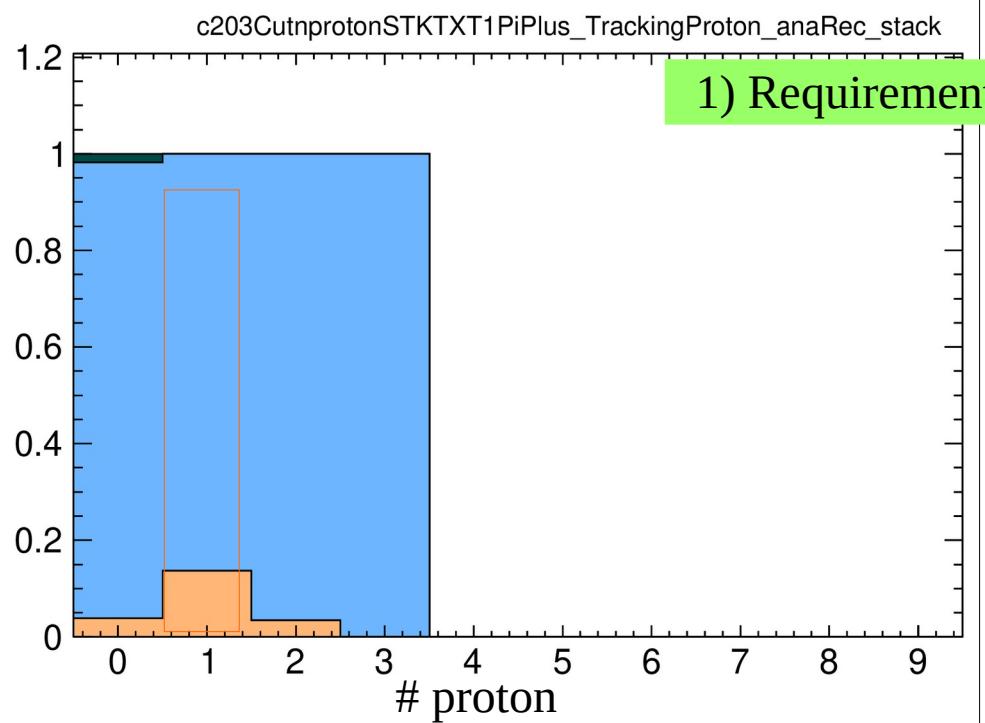
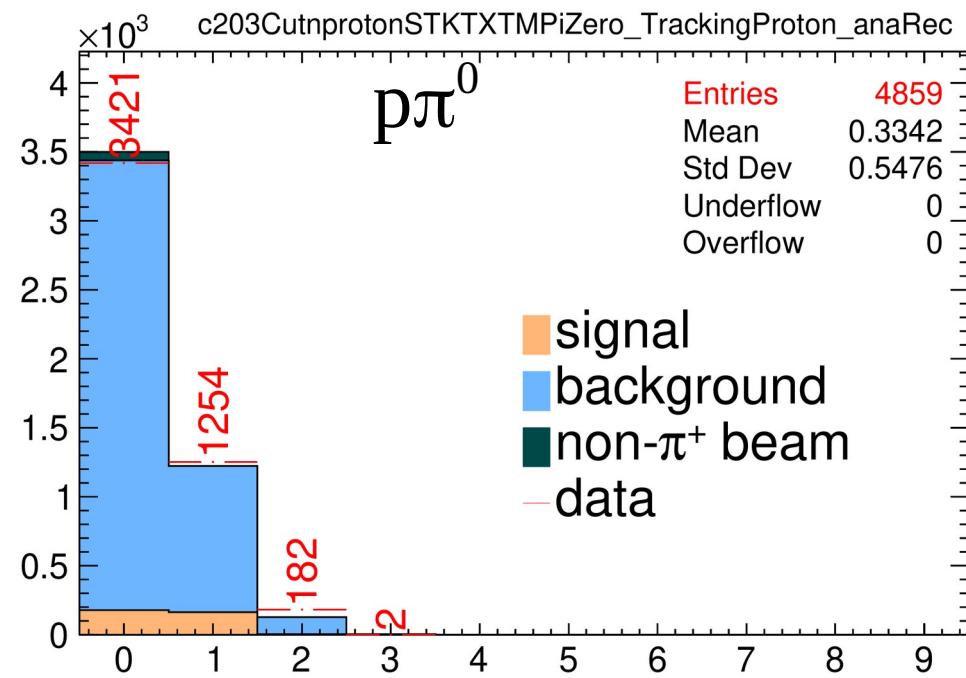
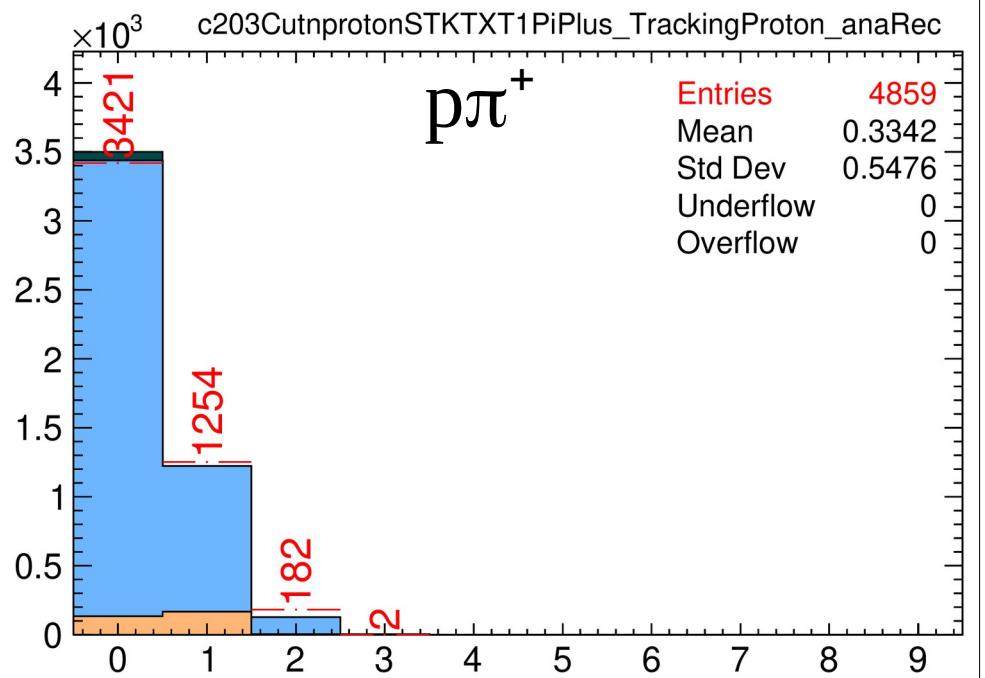
reco_daughter_PFP_michelScore_collection

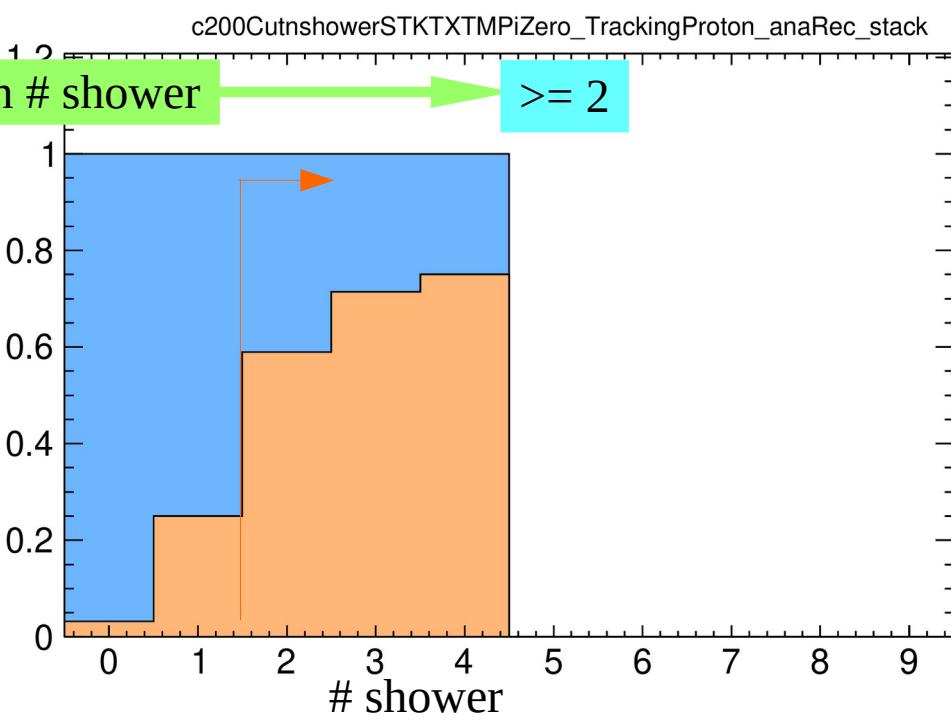
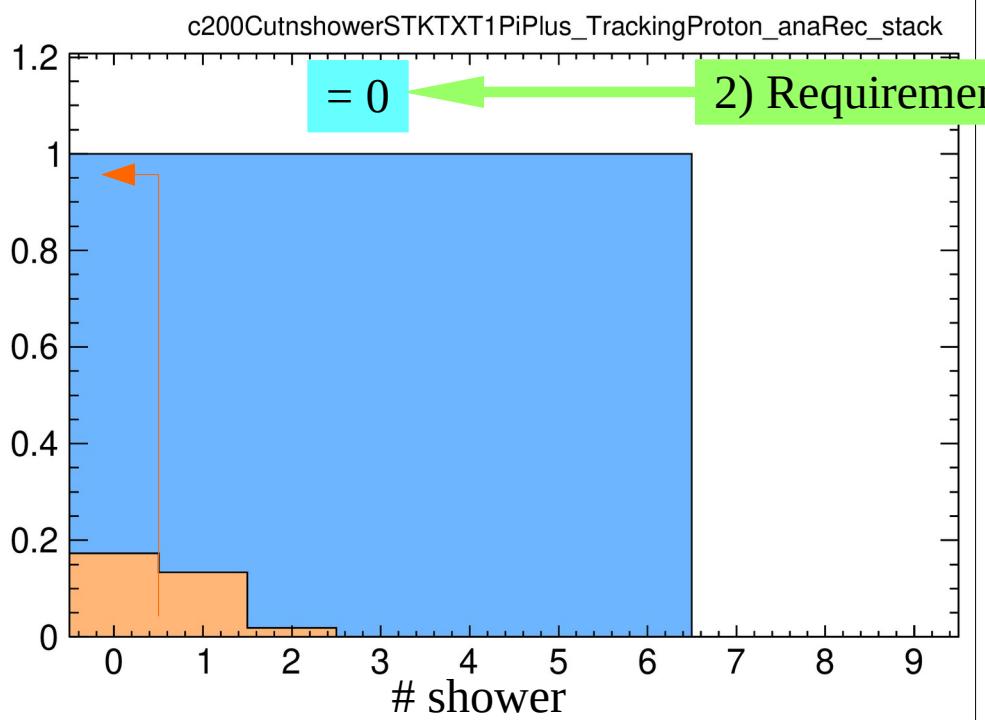
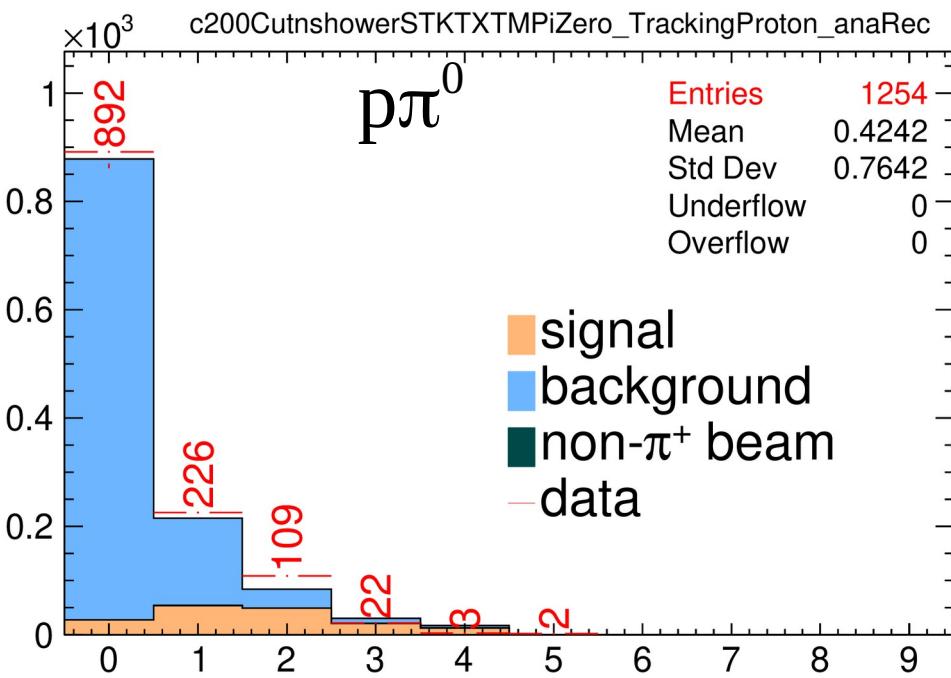
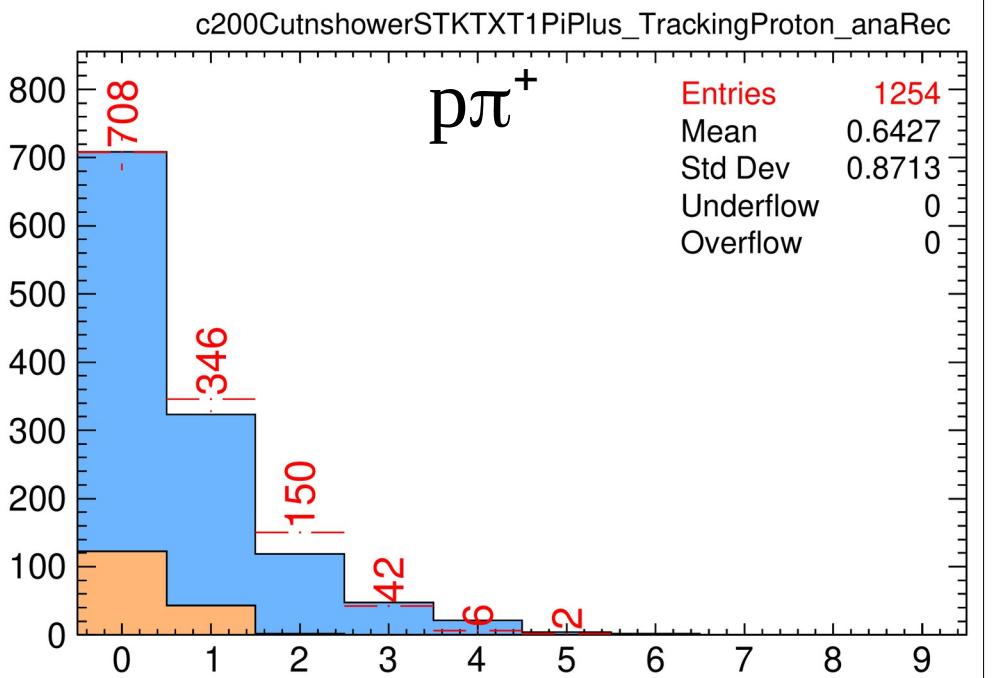
– After beam cut

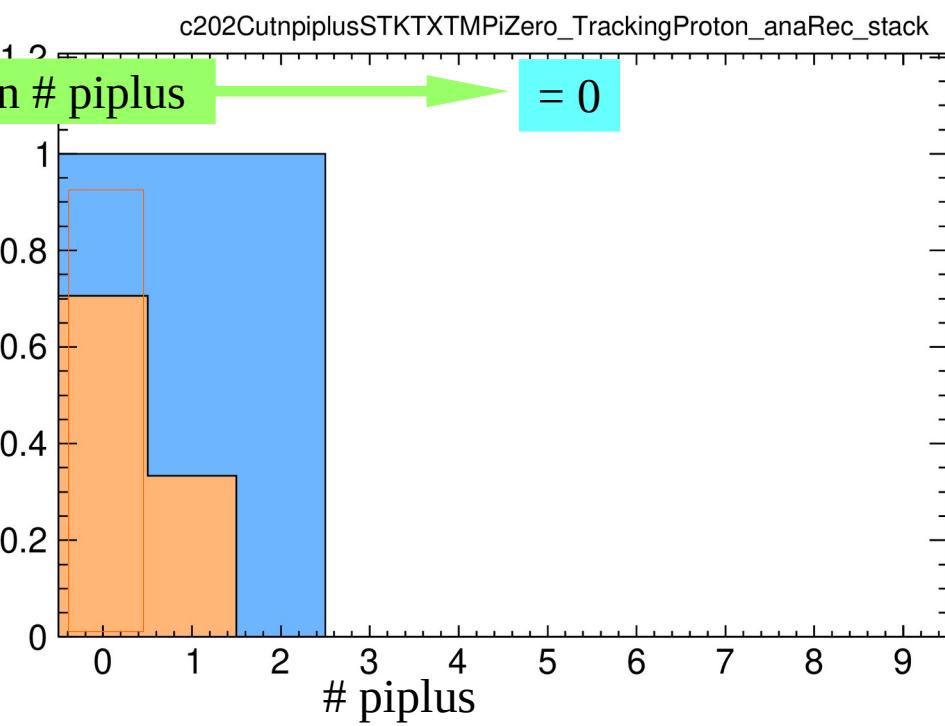
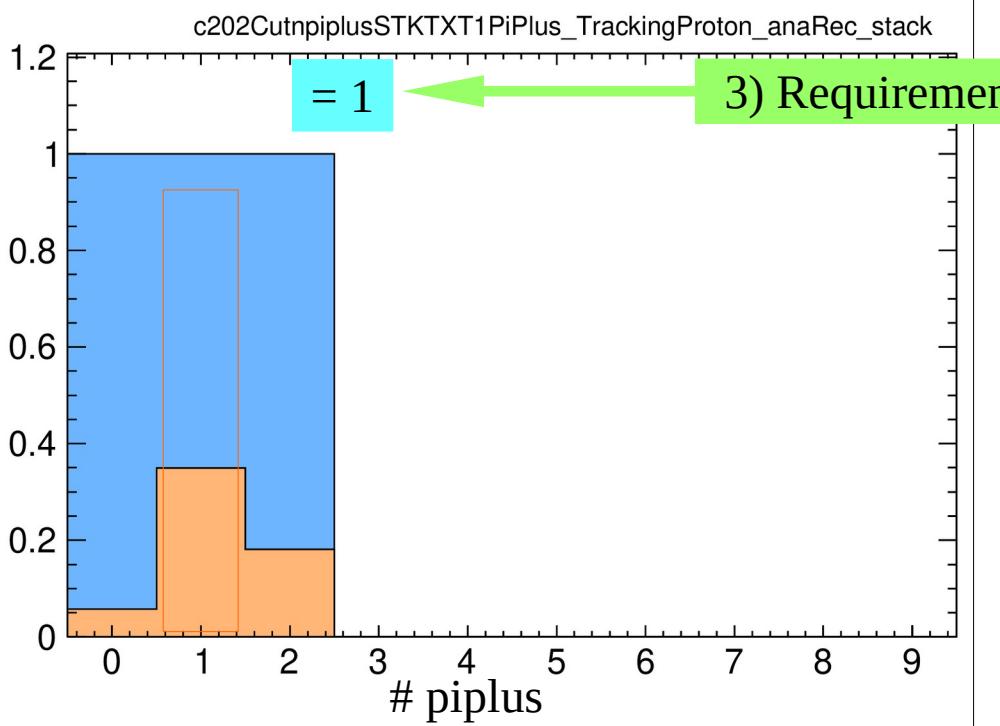
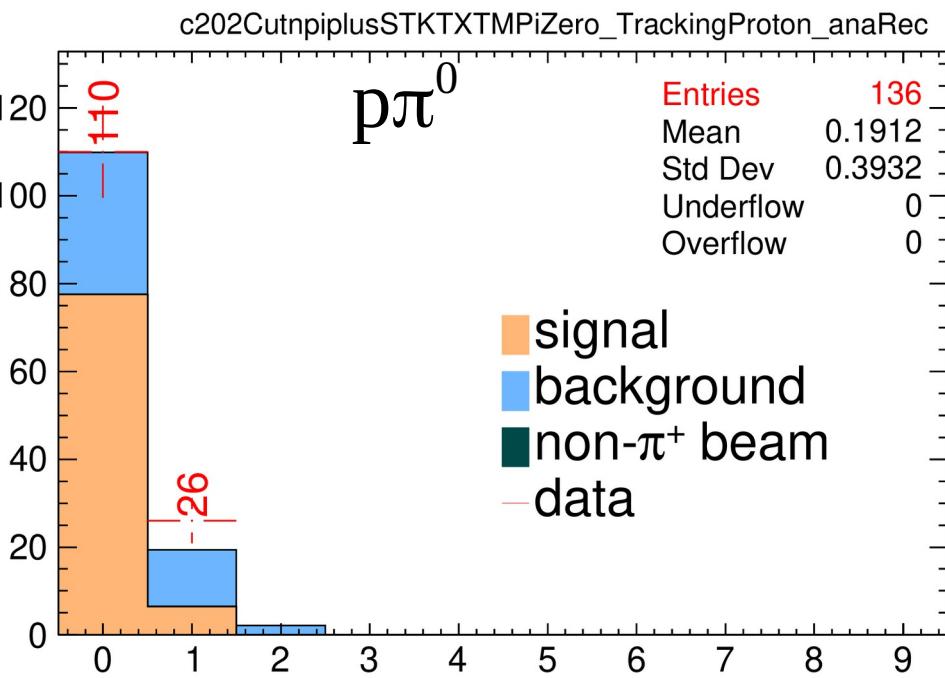
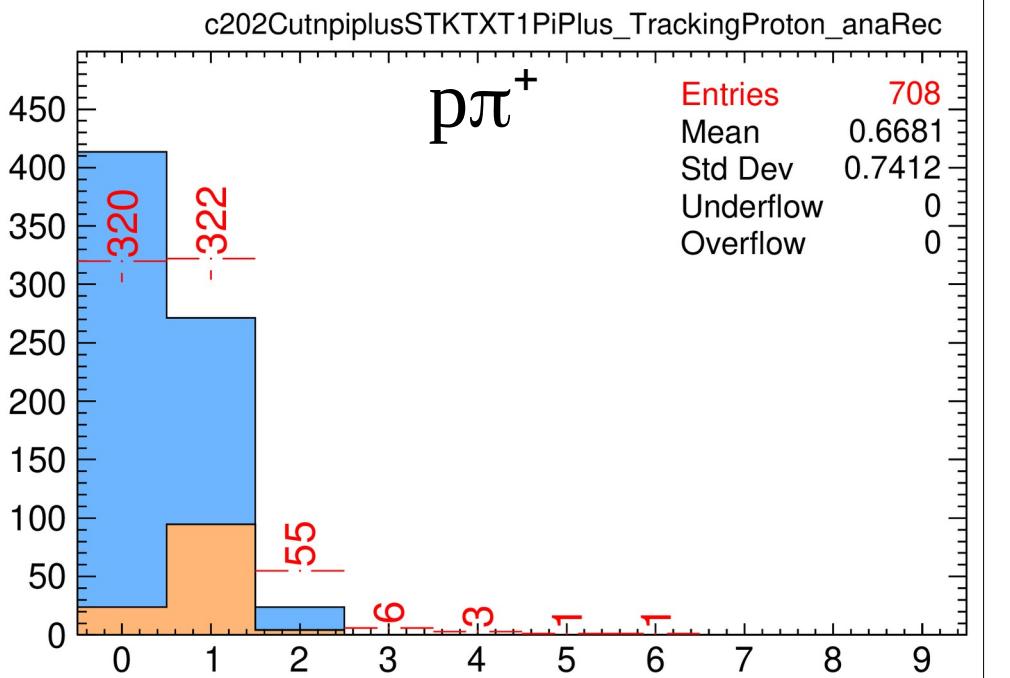
Event selection



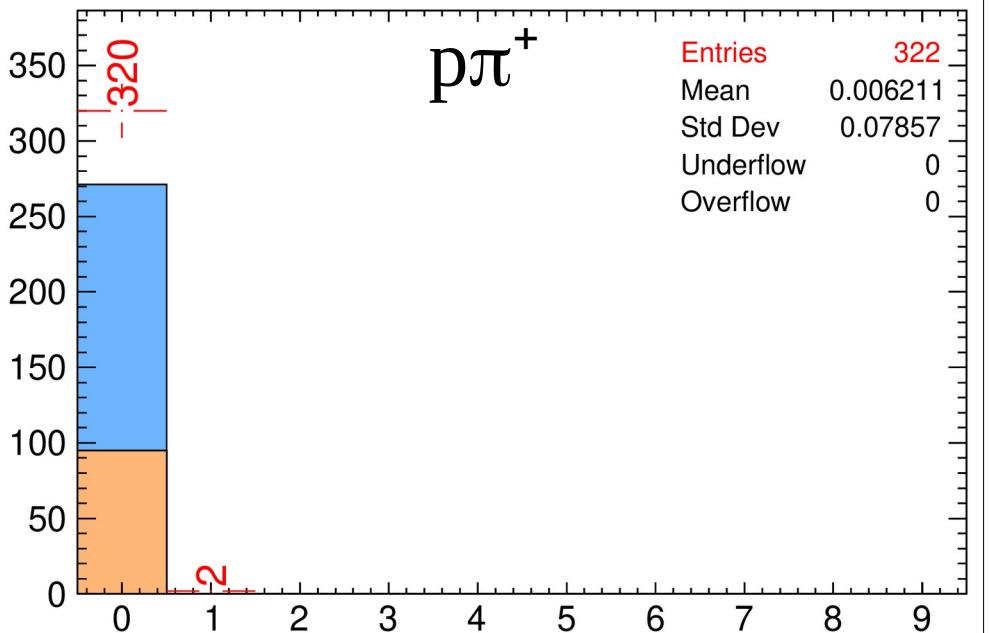
- #proton, #shower, #piplus, and #michel all depends on particle definitions using reconstructed variables discussed in previous slides



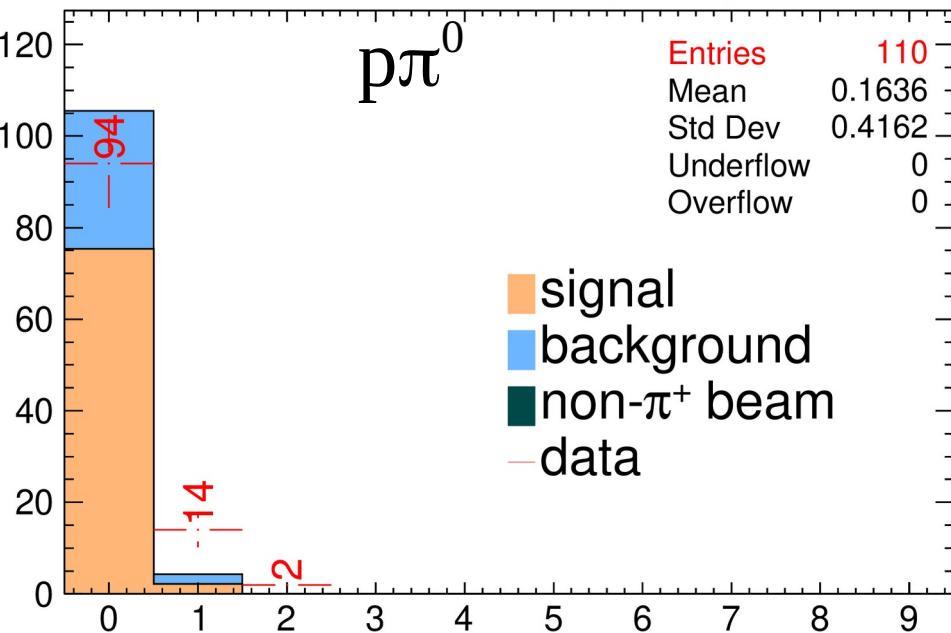




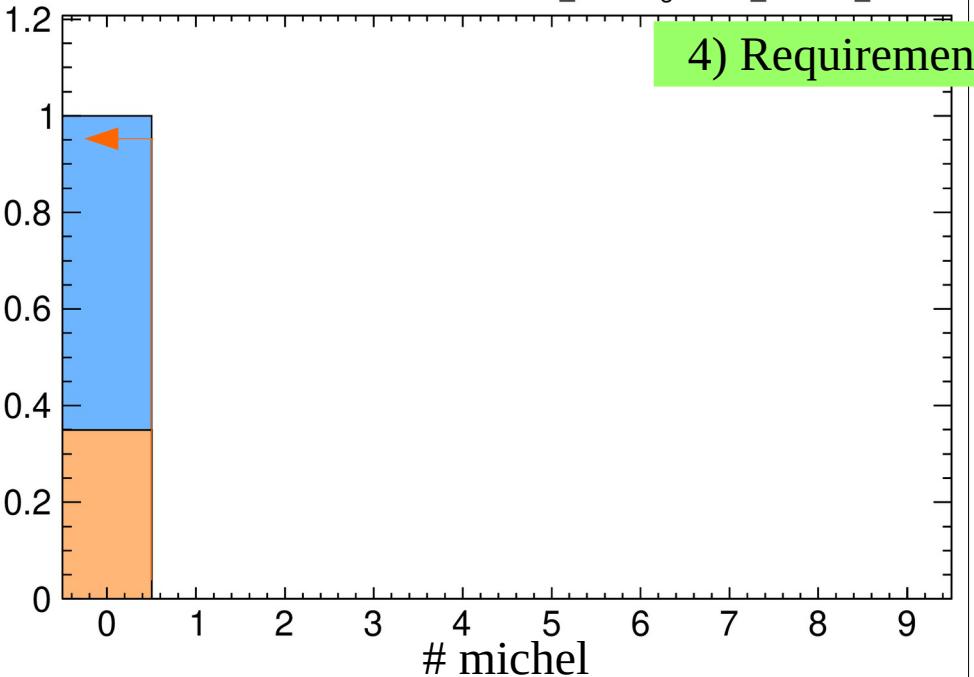
c201CutnichelSTKTXT1PiPlus_TrackingProton_anaRec



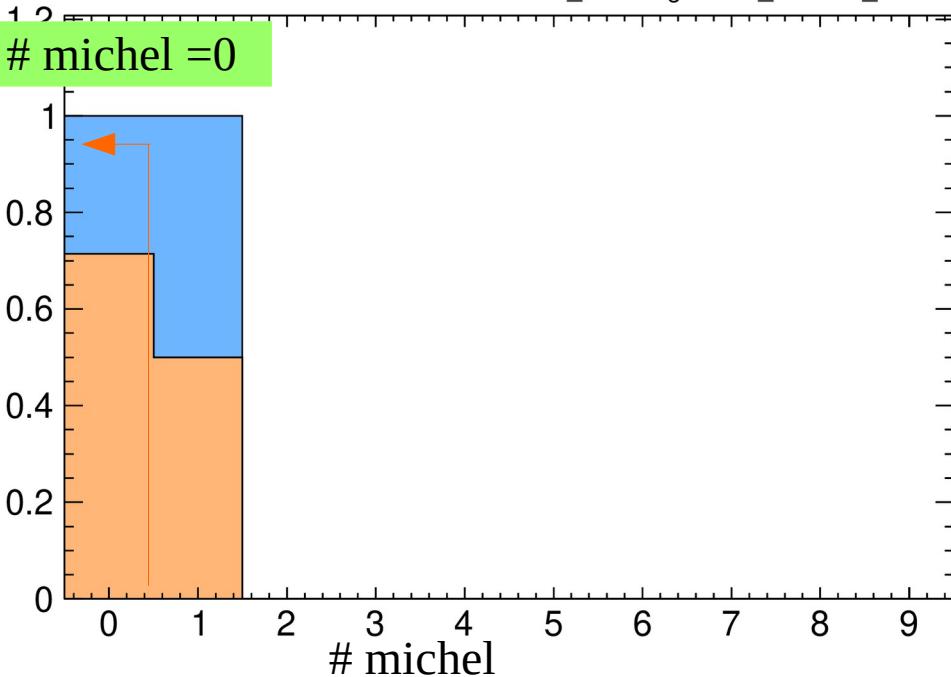
c201CutnichelSTKXTMPiZero_TrackingProton_anaRec



c201CutnichelSTKTXT1PiPlus_TrackingProton_anaRec_stack



c201CutnichelSTKXTMPiZero_TrackingProton_anaRec_stack



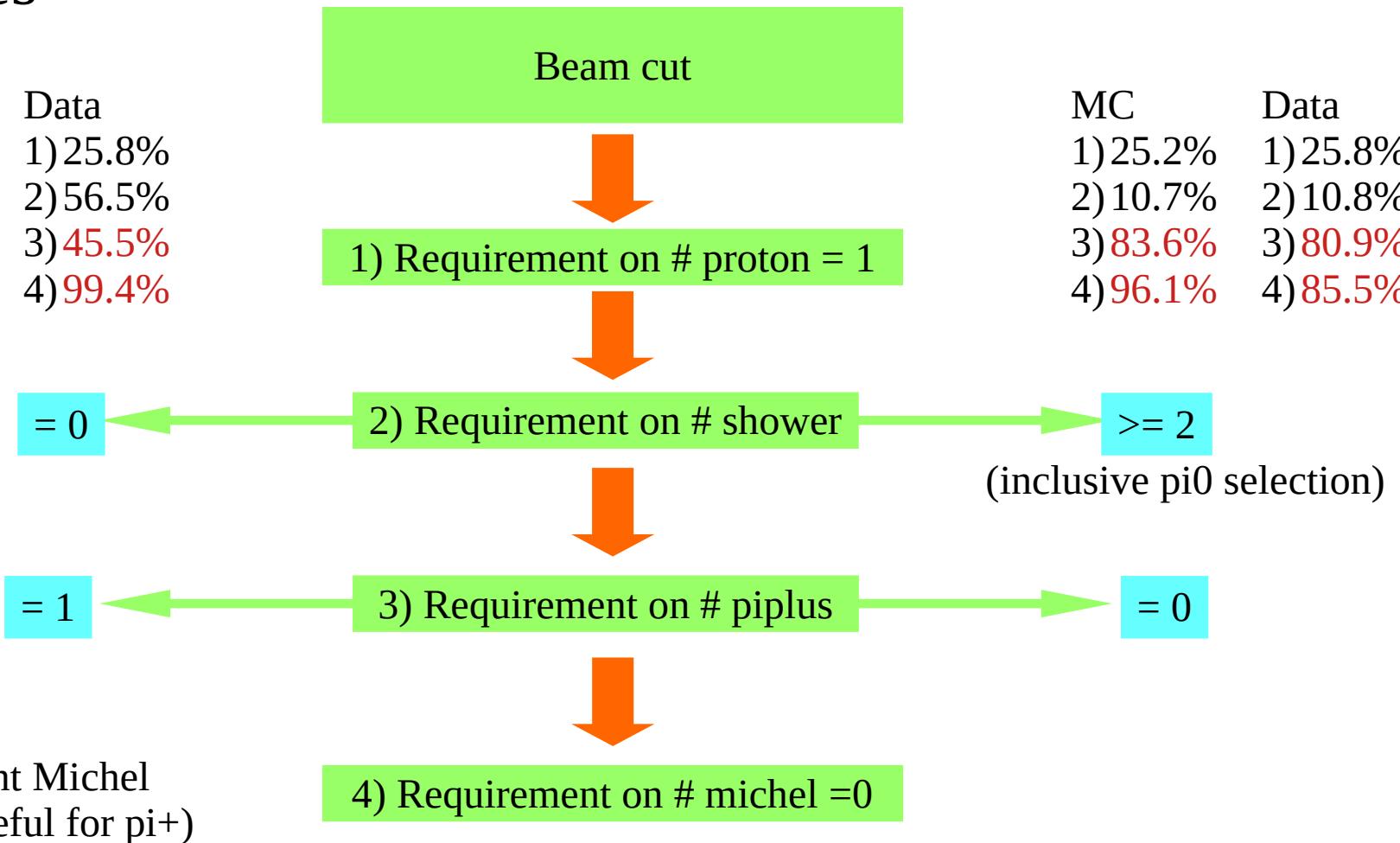
Cut efficiencies

$p\pi^+$

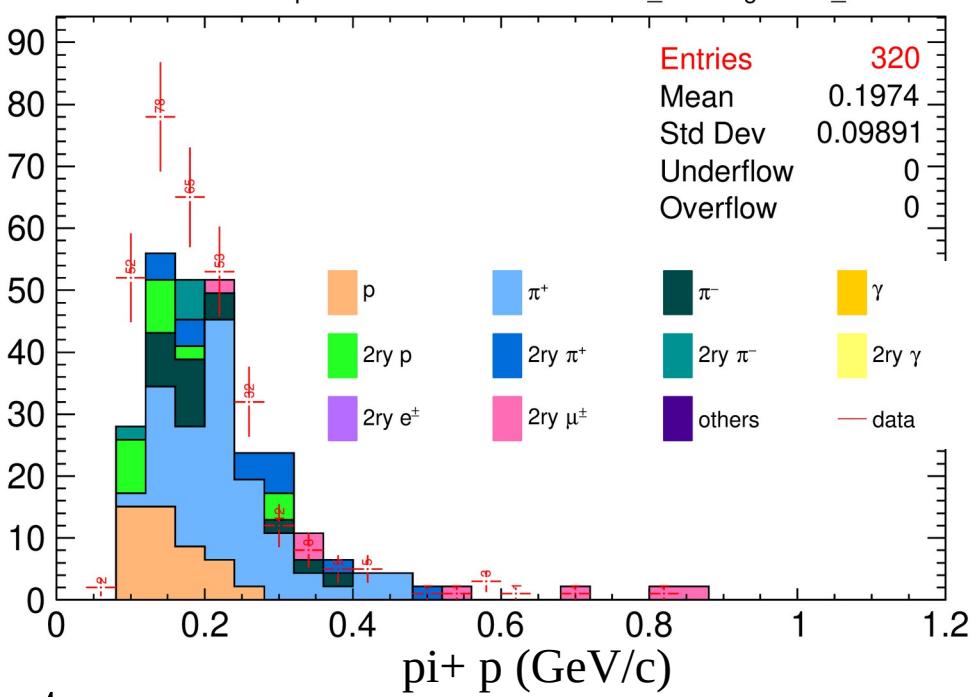
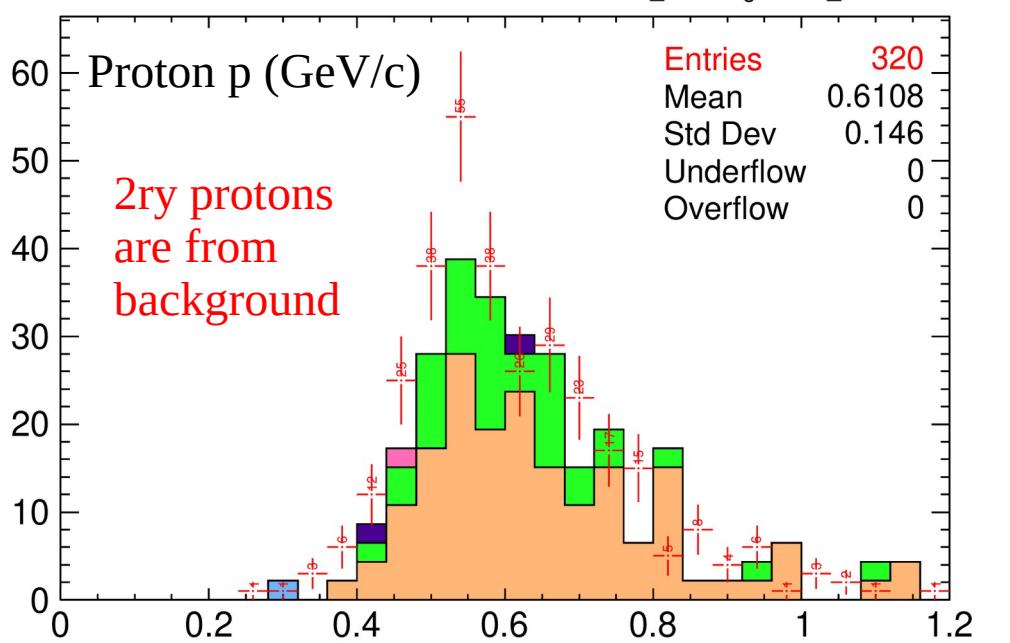
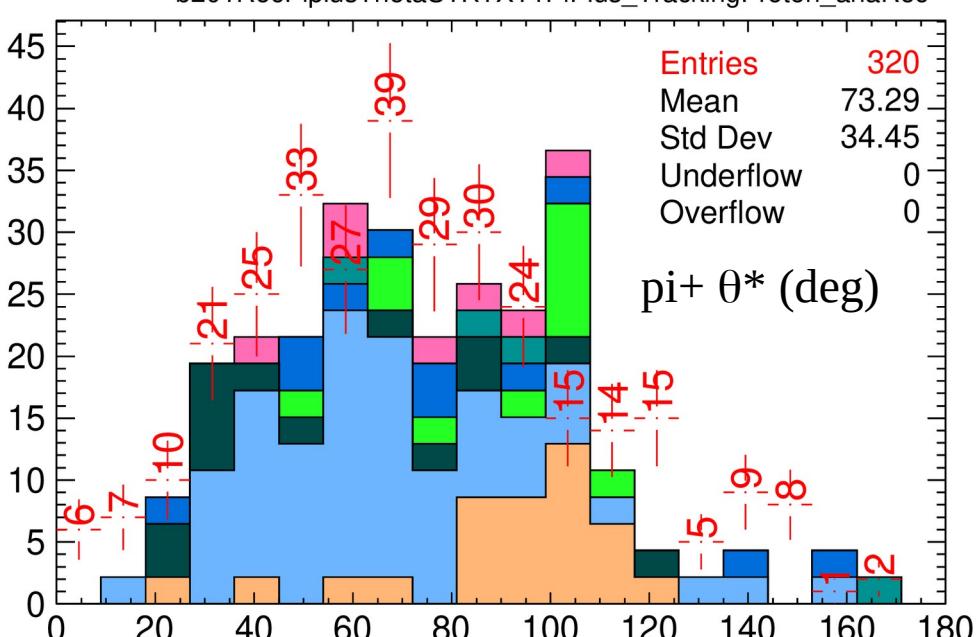
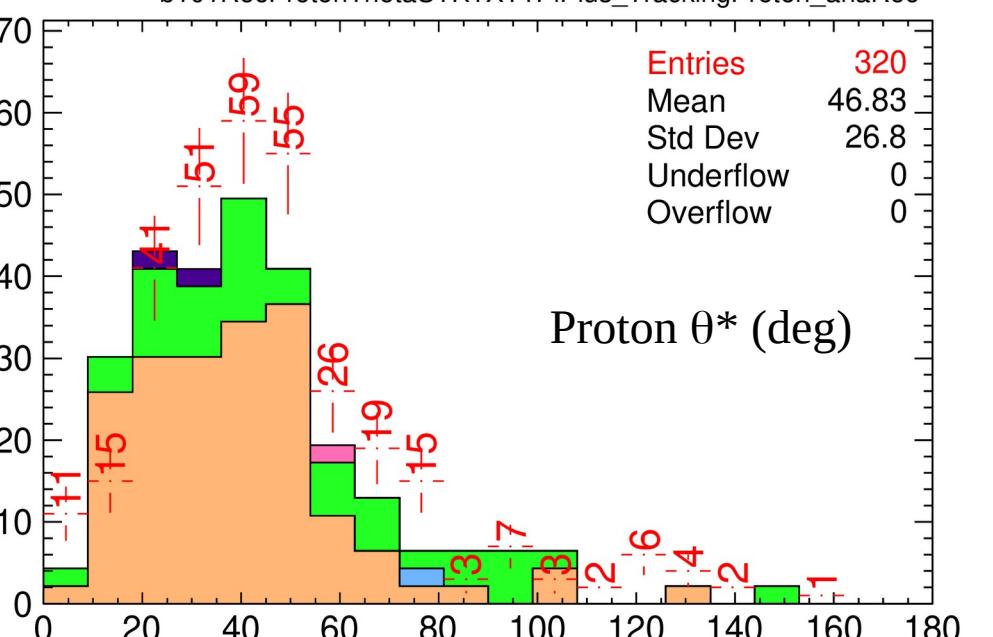
MC	Data
1) 25.2%	1) 25.8%
2) 57.8%	2) 56.5%
3) 38.3%	3) 45.5%
4) 100.0%	4) 99.4%

$p\pi^0$

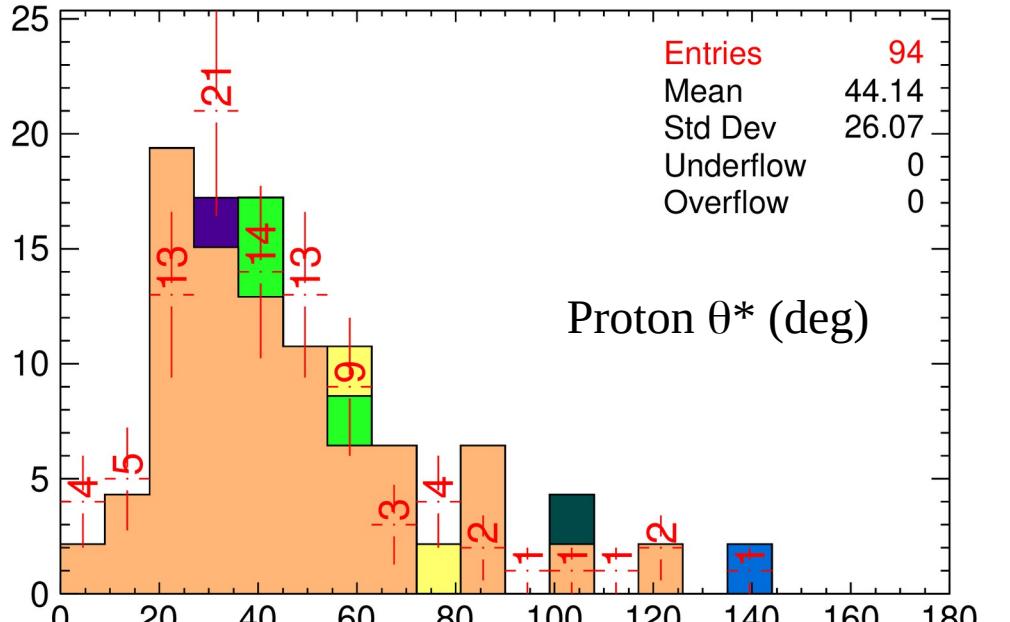
MC	Data
1) 25.2%	1) 25.8%
2) 10.7%	2) 10.8%
3) 83.6%	3) 80.9%
4) 96.1%	4) 85.5%



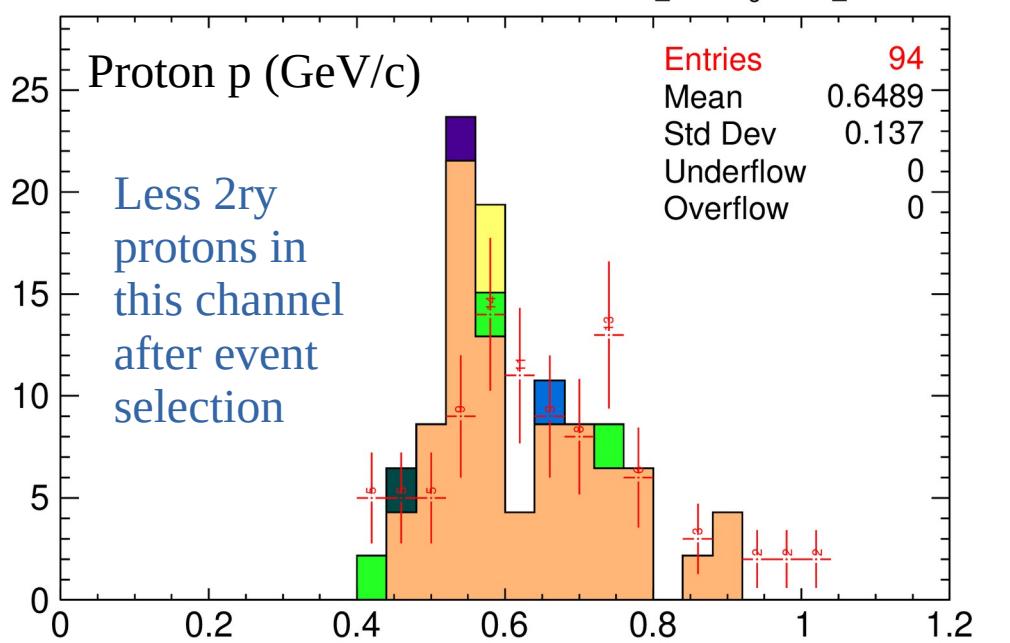
- Cut efficiency consistent between data and MC for proton and shower selections
- Pi+ and michel counting needs to be improved



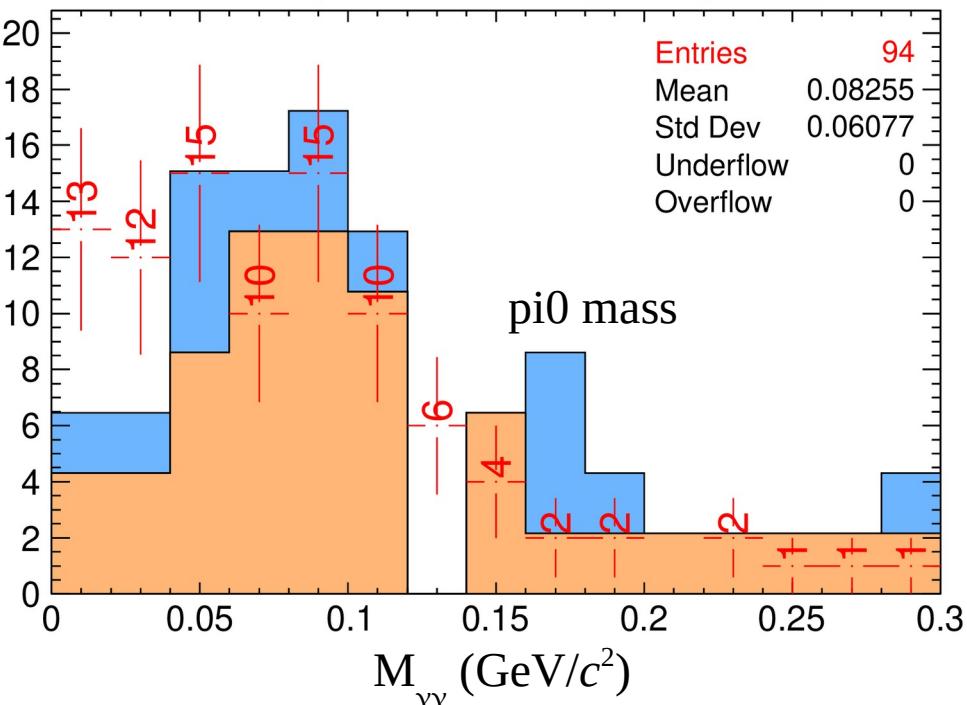
b101RecProtonThetaSTKXTMPiZero_TrackingProton_anaRec



b103RecProtonMomentumSTKXTMPiZero_TrackingProton_anaRec



b301RecMp0STKXTMPiZero_TrackingProton_anaRec



- signal
- background
- non- π^+ beam
- data

Pi0 mass peak in wrong position

p	π^+	π^-	γ
2ry p	2ry π^+	2ry π^-	2ry γ
2ry e^\pm	2ry μ^\pm	others	data

Summary and discussions

Looked at beam, proton, pi+, and shower selection and reconstruction

1. Beam
 - 1) Angle has issues (p6)
 - 2) Energy at interaction vertex OK (p7)
2. Proton
 - 1) Angle (p11) and momentum (p13) reconstruction is OK
 - 2) Has physics background from secondary protons (p11, 13, 24), check if reconstruction can handle them – after event selection, pπ0 channel is less affected (p25)
3. Shower
 - 1) Reconstructed π0 mass (p16, p25) is not physical
4. Pi+
 - 1) Forward angle (p12) has large data excess due to intrinsic difficulty when beam and final state are the same particle
 - Require very precise vertexing (FS proton helps)
 - 2) Momentum-by-range (p14) start to fail at 0.3 GeV/c due to onset of inelastic scattering
 - See previous detailed discussions ([Analysis Meeting 18 June 2020](#))
 - 3) Contamination from proton, pi-, (physics bkg) 2ry pi+, and muons (p12, 14, 24).

MC	All Signal	Selected signal	Selected sample	purity	efficiency	efficiency*purity
pπ+	224.0	44.0	126.0	34.9%	19.6%	6.9%
pπ0	246.0	35.0	49.0	71.4%	14.2%	10.2%

BACKUP

Running anaRec kMC 1 kPiZero 0 TrackingProton 1

```

myEntries 0
AnaUtils::GetRecBeamFull using version -1
All entries 26330
1PiPlus_TrackingProton_anaRec 0. Beam ID : all 26330.0 selected 3636.0 fraction 13.8%
c000CutBeamIDTXT1PiPlus_TrackingProton_anaRec : all 3636.0 selected 3203.0 fraction 88.1%
1PiPlus_TrackingProton_anaRec 1. Pandora beam type : all 3203.0 selected 2657.0 fraction 83.0%
c001CutBeamTypeSTKTXT1PiPlus_TrackingProton_anaRec : all 2657.0 selected 2256.0 fraction 84.9%
1PiPlus_TrackingProton_anaRec 2. Beam Pos : all 2256.0 selected 569.0 fraction 25.2%
c002CutBeamPosPassSTKTXT1PiPlus_TrackingProton_anaRec : all 569.0 selected 329.0 fraction 57.8%
1PiPlus_TrackingProton_anaRec 3. APA3 : all 329.0 selected 126.0 fraction 38.3%
c004CutBeamEndZPassSTKTXT1PiPlus_TrackingProton_anaRec : all 126.0 selected 126.0 fraction 100.0%
1PiPlus_TrackingProton_anaRec 4. Nproton : all 126.0 selected
c203CutnprotonSTKTXT1PiPlus_TrackingProton_anaRec : all
1PiPlus_TrackingProton_anaRec 5. Nshower : all 126.0 selected
c200CutnshowerSTKTXT1PiPlus_TrackingProton_anaRec : all
1PiPlus_TrackingProton_anaRec 6. Npiplus : all 126.0 selected
c202CutnpiplusSTKTXT1PiPlus_TrackingProton_anaRec : all
1PiPlus_TrackingProton_anaRec 7. Nmichel : all 126.0 selected
c201CutnmichelSTKTXT1PiPlus_TrackingProton_anaRec : all
End of 8 cuts: 126.0 selected
kPiZero 0 fullsig 224.0 signal 44.0 all 126.0 purity 34.9% eff 19.6% ep 6.9%

```

Running anaRec kMC 0 kPiZero 0 TrackingProton 1

```

myEntries 0
All entries 32600
1PiPlus_TrackingProton_anaRec 0. Beam ID : all 32600.0 selected 17708.0 fraction 54.3%
c000CutBeamIDTXT1PiPlus_TrackingProton_anaRec : all 17708.0 selected 14862.0 fraction 83.9%
1PiPlus_TrackingProton_anaRec 1. Pandora beam type : all 14862.0 selected 6365.0 fraction 42.8%
c001CutBeamTypeSTKTXT1PiPlus_TrackingProton_anaRec : all 6365.0 selected 4859.0 fraction 76.3%
1PiPlus_TrackingProton_anaRec 2. Beam Pos : all 4859.0 selected 1254.0 fraction 25.8%
c002CutBeamPosPassSTKTXT1PiPlus_TrackingProton_anaRec : all 1254.0 selected 708.0 fraction 56.5%
1PiPlus_TrackingProton_anaRec 3. APA3 : all 708.0 selected 322.0 fraction 45.5%
c004CutBeamEndZPassSTKTXT1PiPlus_TrackingProton_anaRec : all 322.0 selected 320.0 fraction 99.4%
1PiPlus_TrackingProton_anaRec 4. Nproton : all 320.0 selected
c203CutnprotonSTKTXT1PiPlus_TrackingProton_anaRec : all
1PiPlus_TrackingProton_anaRec 5. Nshower : all 320.0 selected
c200CutnshowerSTKTXT1PiPlus_TrackingProton_anaRec : all
1PiPlus_TrackingProton_anaRec 6. Npiplus : all 320.0 selected
c202CutnpiplusSTKTXT1PiPlus_TrackingProton_anaRec : all
1PiPlus_TrackingProton_anaRec 7. Nmichel : all 320.0 selected
c201CutnmichelSTKTXT1PiPlus_TrackingProton_anaRec : all
End of 8 cuts: 320.0 selected
anaRec beamcount data: 4859 mc: 2256 plotscale 2.153812

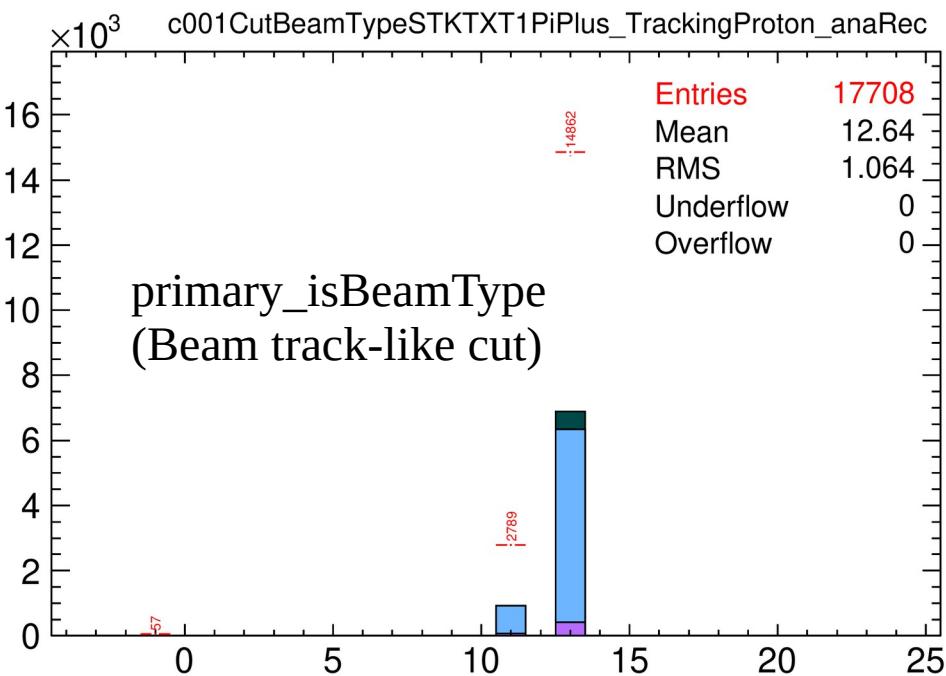
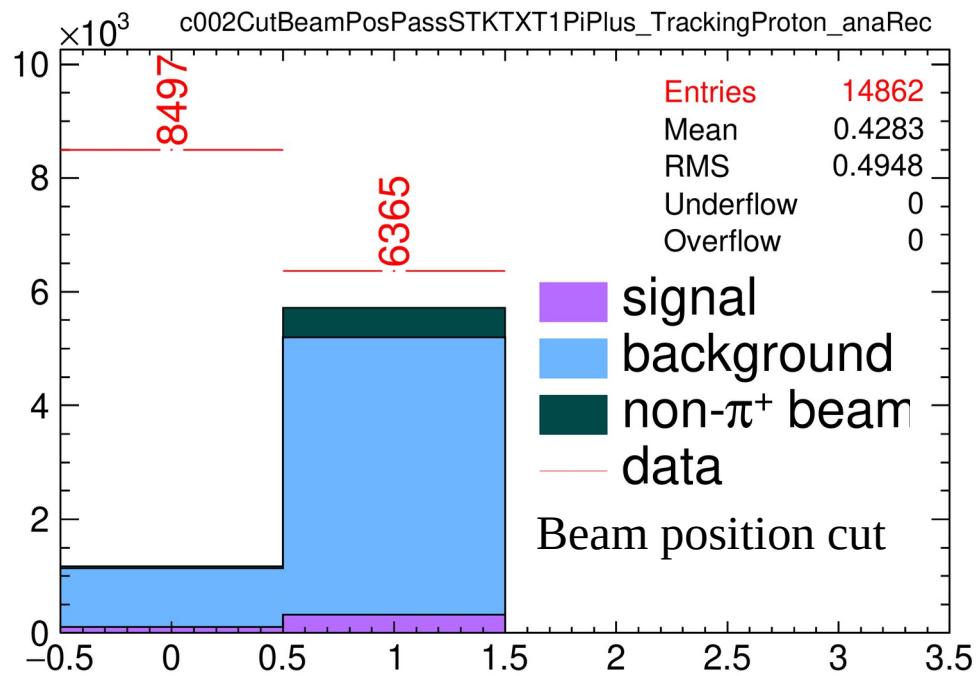
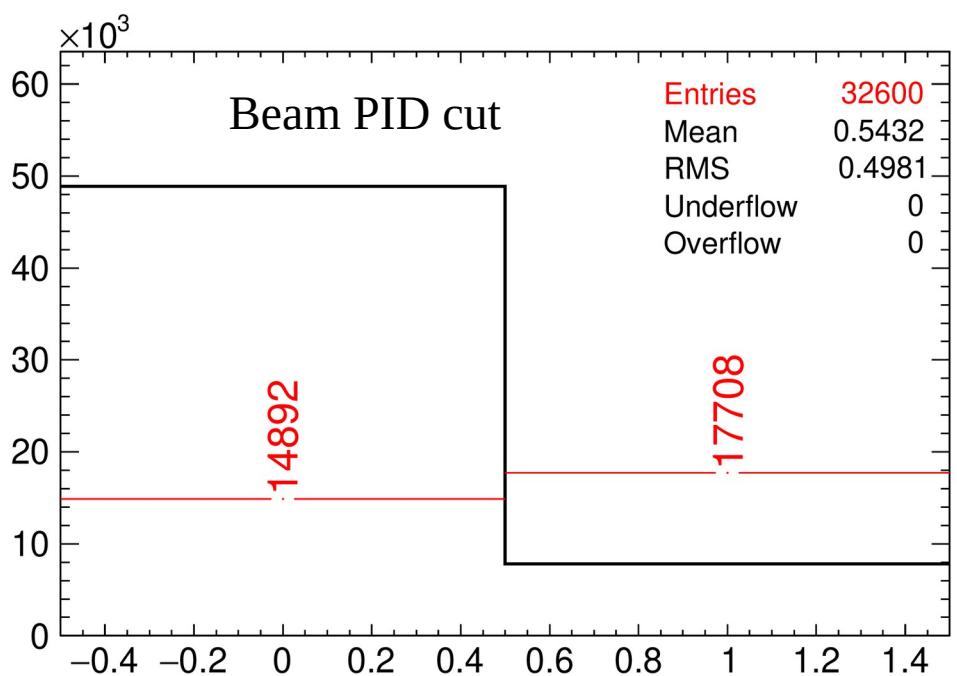
```

Running anaRec kMC 1 kPiZero 1 TrackingProton 1

```
myEntries 0
AnaUtils::GetRecBeamFull using version -1
All entries 26330
MPiZero_TrackingProton_anaRec 0. Beam ID : all 26330.0 selected 3636.0 fraction 13.8%
c000CutBeamIDTXTMPiZero_TrackingProton_anaRec : all 3636.0 selected 3203.0 fraction 88.1%
MPiZero_TrackingProton_anaRec 1. Pandora beam type : all 3203.0 selected 2657.0 fraction 83.0%
c001CutBeamTypeSTKXTMPiZero_TrackingProton_anaRec : all 2657.0 selected 2256.0 fraction 84.9%
MPiZero_TrackingProton_anaRec 2. Beam Pos : all 2256.0 selected 569.0 fraction 25.2%
c002CutBeamPosPassSTKXTMPiZero_TrackingProton_anaRec : all 569.0 selected 61.0 fraction 10.7%
MPiZero_TrackingProton_anaRec 3. APA3 : all 61.0 selected 51.0 fraction 83.6%
c004CutBeamEndZPassSTKXTMPiZero_TrackingProton_anaRec : all 51.0 selected 49.0 fraction 96.1%
MPiZero_TrackingProton_anaRec 4. Nproton : all 569.0 selected 61.0 fraction 10.7%
c203CutnprotonSTKXTMPiZero_TrackingProton_anaRec : all 51.0 selected
MPiZero_TrackingProton_anaRec 5. Nshower : all 49.0 selected
c200CutnshowerSTKXTMPiZero_TrackingProton_anaRec : all 49.0 selected
MPiZero_TrackingProton_anaRec 6. Npiplus : all 49.0 selected
c202CutnpiplusSTKXTMPiZero_TrackingProton_anaRec : all 49.0 selected
MPiZero_TrackingProton_anaRec 7. Nmichel : all 49.0 selected
c201CutnmichelSTKXTMPiZero_TrackingProton_anaRec : all 49.0 selected
End of 8 cuts: 49.0 selected
kPiZero 1 fullsig 246.0 signal 35.0 all 49.0 purity 71.4% eff 14.2% ep 10.2%
```

Running anaRec kMC 0 kPiZero 1 TrackingProton 1

```
myEntries 0
All entries 32600
MPiZero_TrackingProton_anaRec 0. Beam ID : all 32600.0 selected 17708.0 fraction 54.3%
c000CutBeamIDTXTMPiZero_TrackingProton_anaRec : all 17708.0 selected 14862.0 fraction 83.9%
MPiZero_TrackingProton_anaRec 1. Pandora beam type : all 14862.0 selected 6365.0 fraction 42.8%
c001CutBeamTypeSTKXTMPiZero_TrackingProton_anaRec : all 6365.0 selected 4859.0 fraction 76.3%
MPiZero_TrackingProton_anaRec 2. Beam Pos : all 4859.0 selected 1254.0 fraction 25.8%
c002CutBeamPosPassSTKXTMPiZero_TrackingProton_anaRec : all 1254.0 selected 136.0 fraction 10.8%
MPiZero_TrackingProton_anaRec 3. APA3 : all 136.0 selected 110.0 fraction 80.9%
c004CutBeamEndZPassSTKXTMPiZero_TrackingProton_anaRec : all 110.0 selected 94.0 fraction 85.5%
MPiZero_TrackingProton_anaRec 4. Nproton : all 136.0 selected 110.0 fraction 85.5%
c203CutnprotonSTKXTMPiZero_TrackingProton_anaRec : all 110.0 selected
MPiZero_TrackingProton_anaRec 5. Nshower : all 94.0 selected
c200CutnshowerSTKXTMPiZero_TrackingProton_anaRec : all 94.0 selected
MPiZero_TrackingProton_anaRec 6. Npiplus : all 94.0 selected
c202CutnpiplusSTKXTMPiZero_TrackingProton_anaRec : all 94.0 selected
MPiZero_TrackingProton_anaRec 7. Nmichel : all 94.0 selected
c201CutnmichelSTKXTMPiZero_TrackingProton_anaRec : all 94.0 selected
End of 8 cuts: 94.0 selected
anaRec beamcount data: 4859 mc: 2256 plotscale 2.153812
```



primary_isBeamType
(Beam track-like cut)

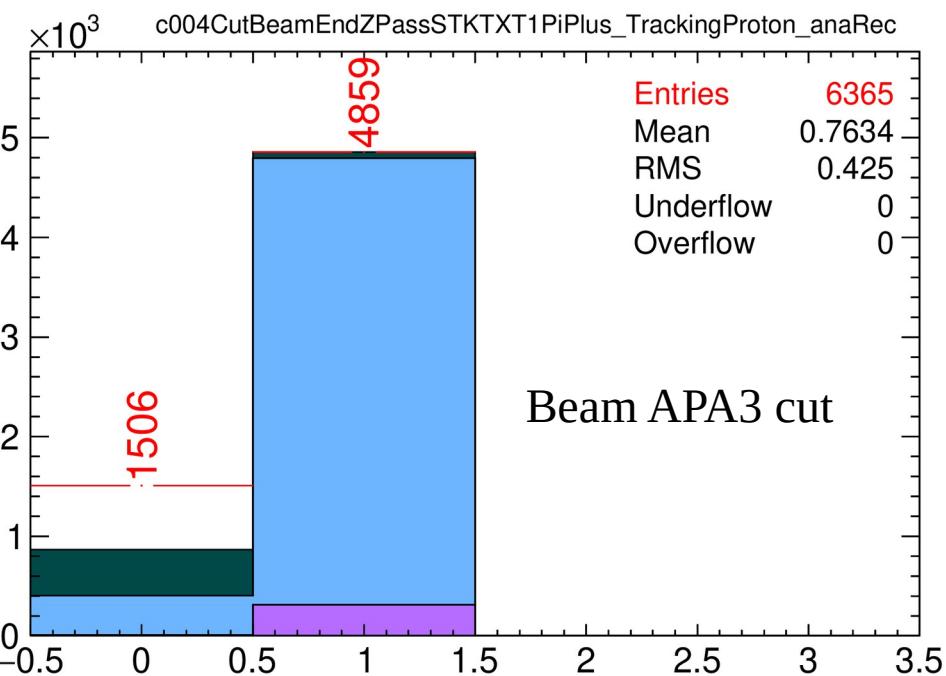
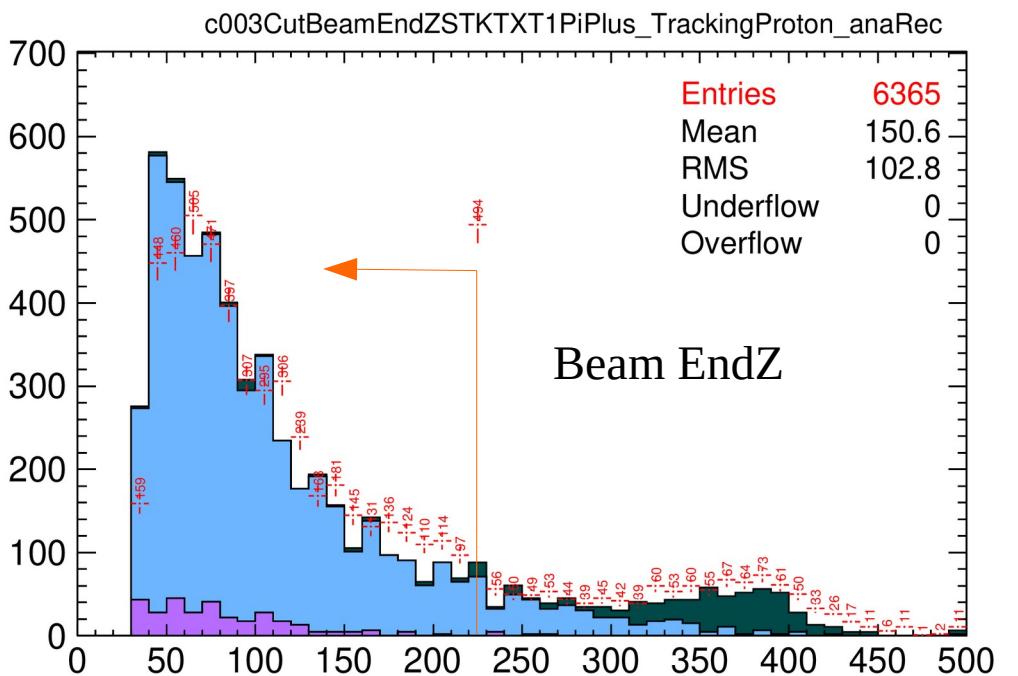
[follows pion analyses]

Beam cuts (data stat. vs. MC):

1. PID 32600 → 17708 (54.3%) vs. (13.8%)
2. Track-like 17708 → 14862 (83.9%) vs. (88.1%)
3. Beam position 14862 → 6365 (42.8%) vs. (83.0%)
4. APA3 (next page) 6365 → 4859 (76.3%) vs. (84.9%)

- Data and MC have very different cut efficiency

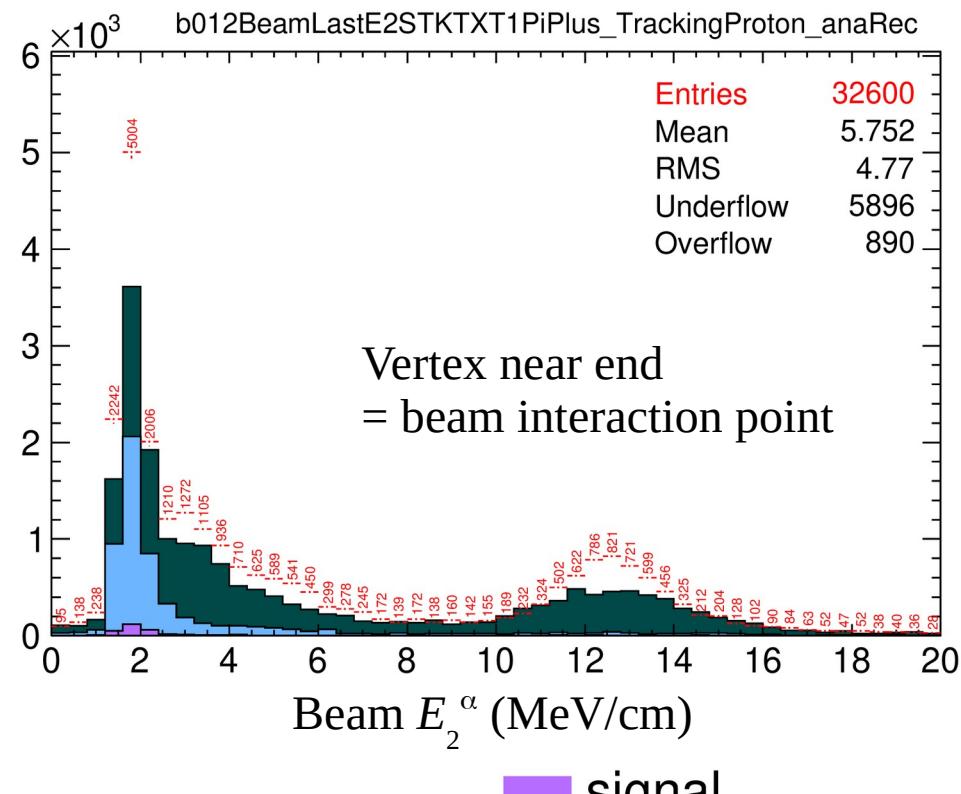
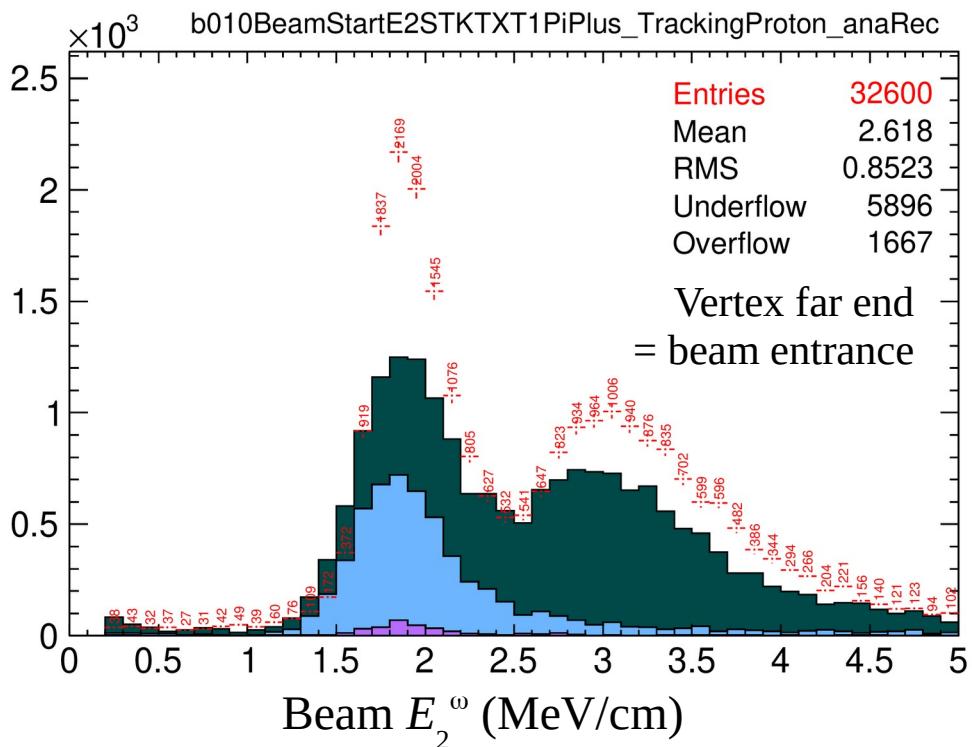
– Beam cut



- signal
- background
- non- π^+ beam
- data

- All MC normalized to data by event count after beam cut
scale factor = $4859/2256 = 2.15$

– Beam cut



- signal
- background
- non- π^+ beam
- data

Before beam cut

- Seen two Bethe-Bloch at beam entrance
- Seen Bragg peak
- Data MC not agree – expected

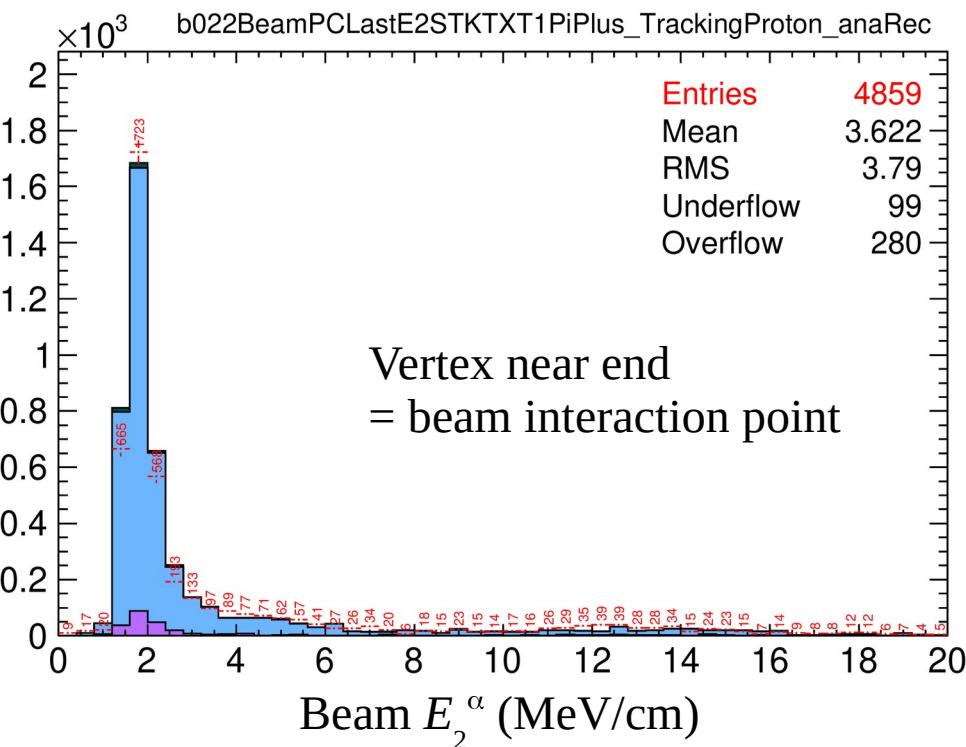
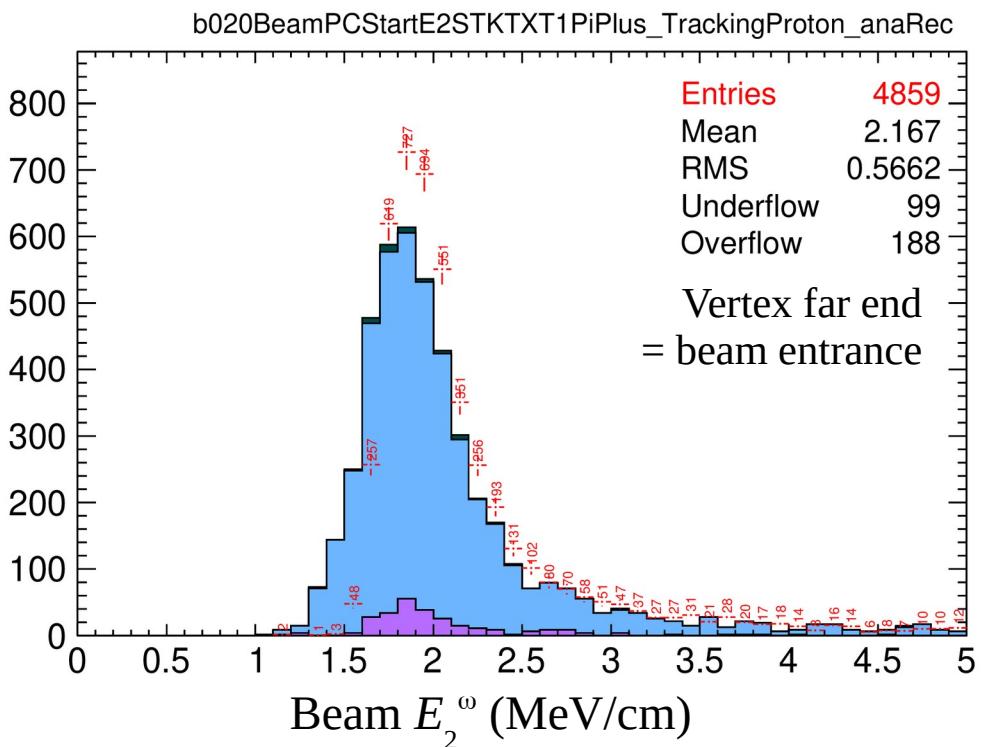
reco_beam_calibrated_dEdX ($\omega2:[2], \alpha2:[n-1-2]$)

(This has SCE correction)

Xianguo Lu, Oxford

– Before beam cut

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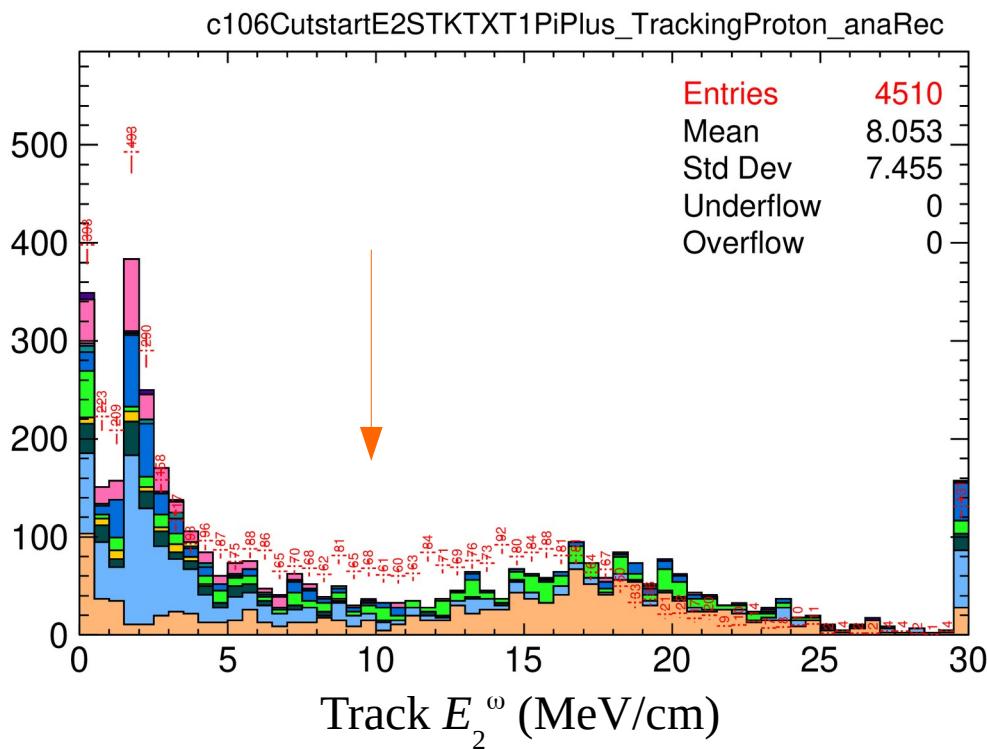
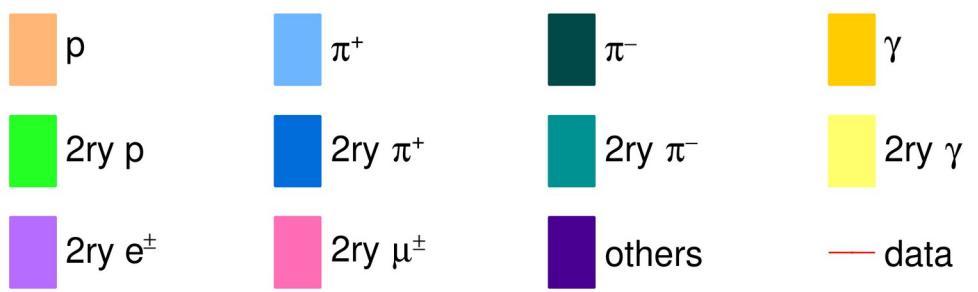


- █ signal
- █ background
- █ non- π^+ beam
- data

After beam cut

- Seen only pion-like dEdx
- Data and MC consistent, neither show unexpected dEdx
- Peak shape not perfect in either ends → is it just understanding of dEdx or contamination?
- Proton Bragg peak might still hide in long tail of near vertex, but should be cleaned up by requiring interaction.

– After beam cut

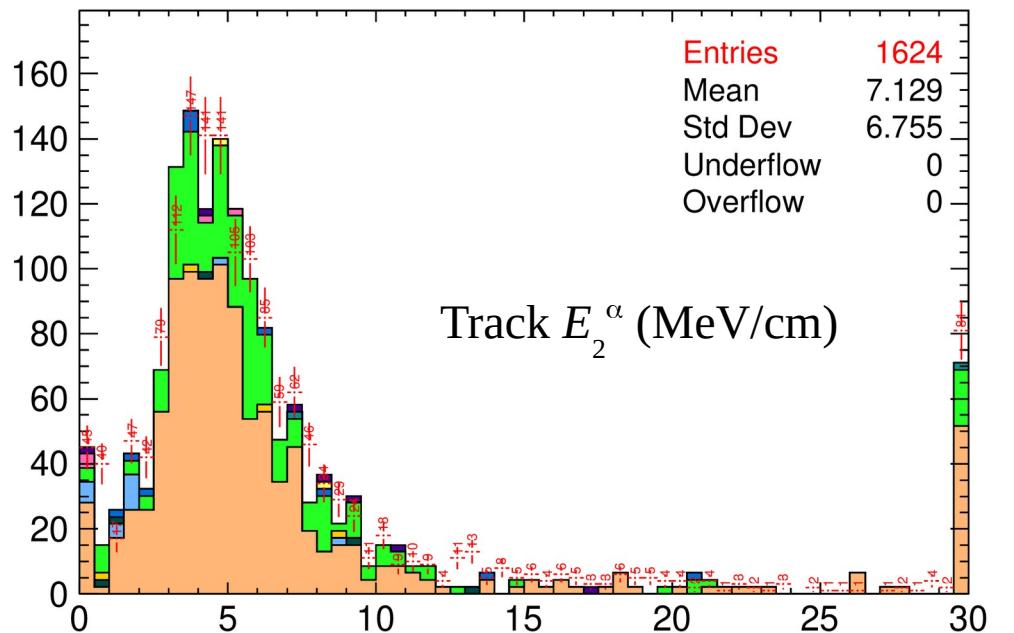


dEdx near track end has large data-MC discrepancy around proposed cut value at 10
 → not to use for the moment

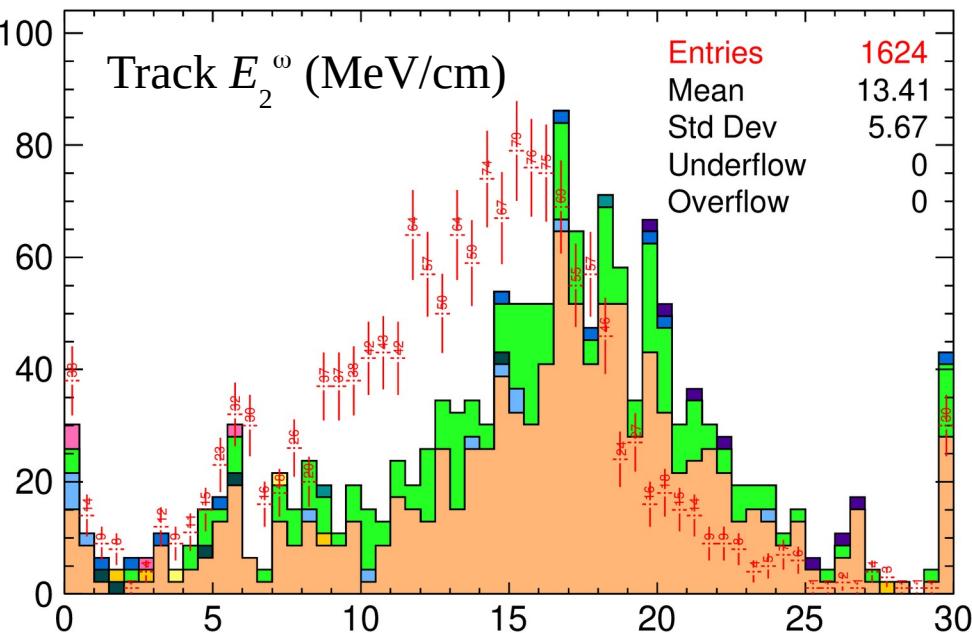
reco_daughter_allTrack_calibrated_dEdX_SCE [2]

– Track candidates

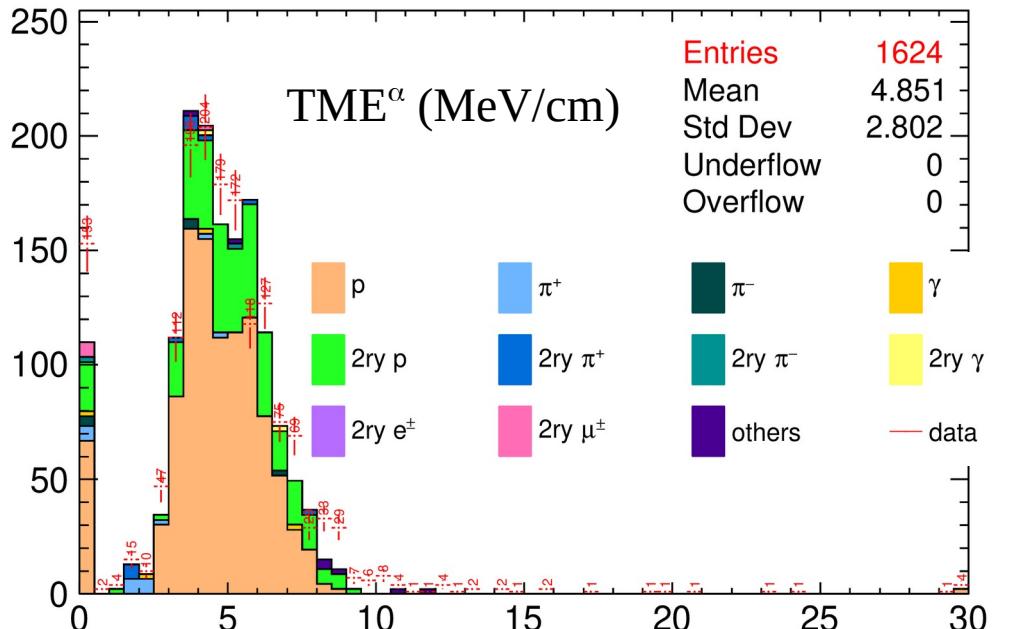
b104RecProtonLastE2STKTXT1PiPlus_TrackingProton_anaRec



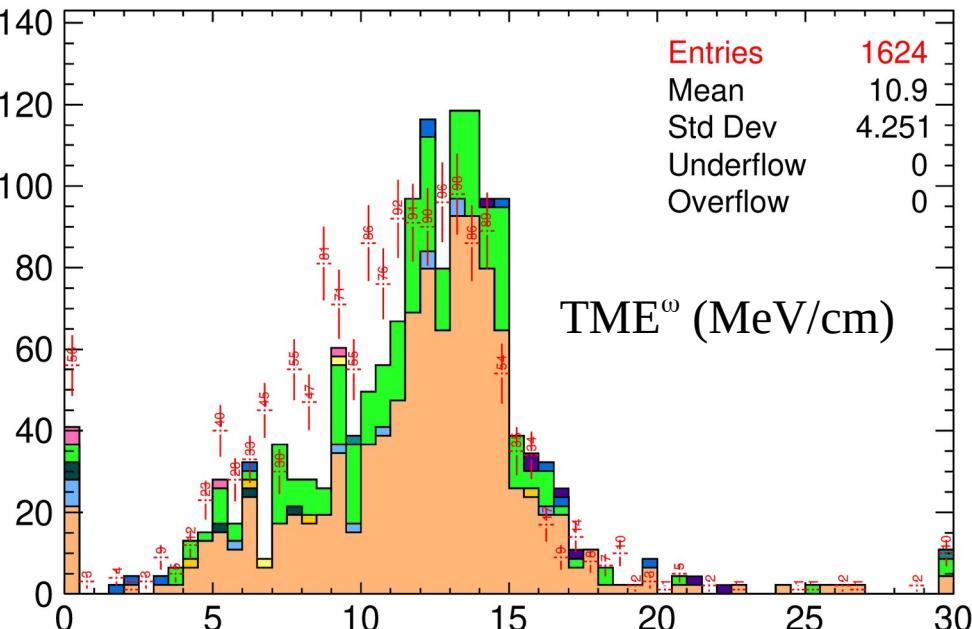
b106RecProtonStartE2STKTXT1PiPlus_TrackingProton_anaRec

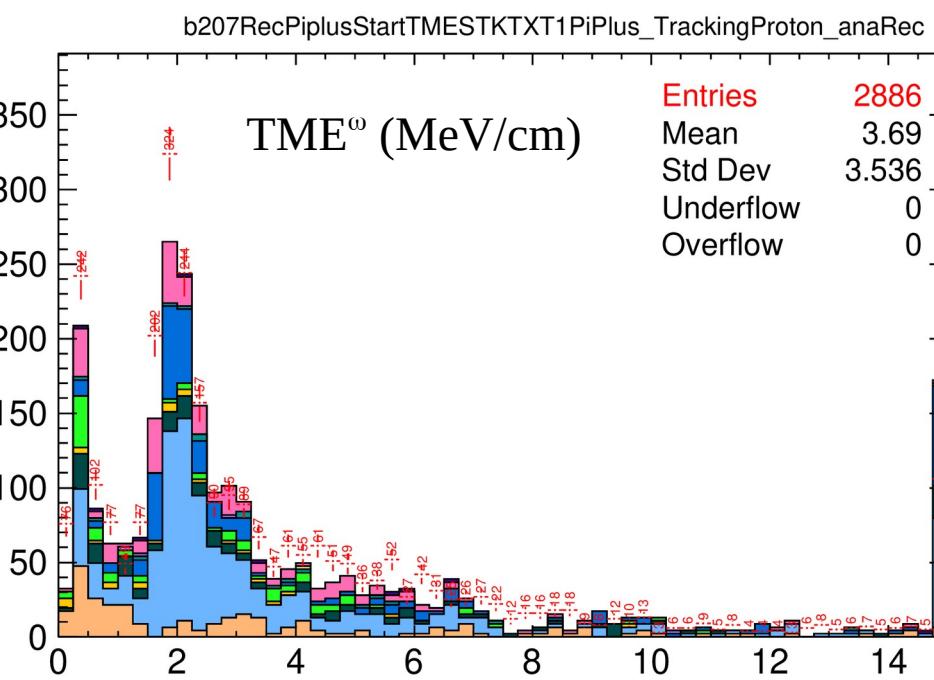
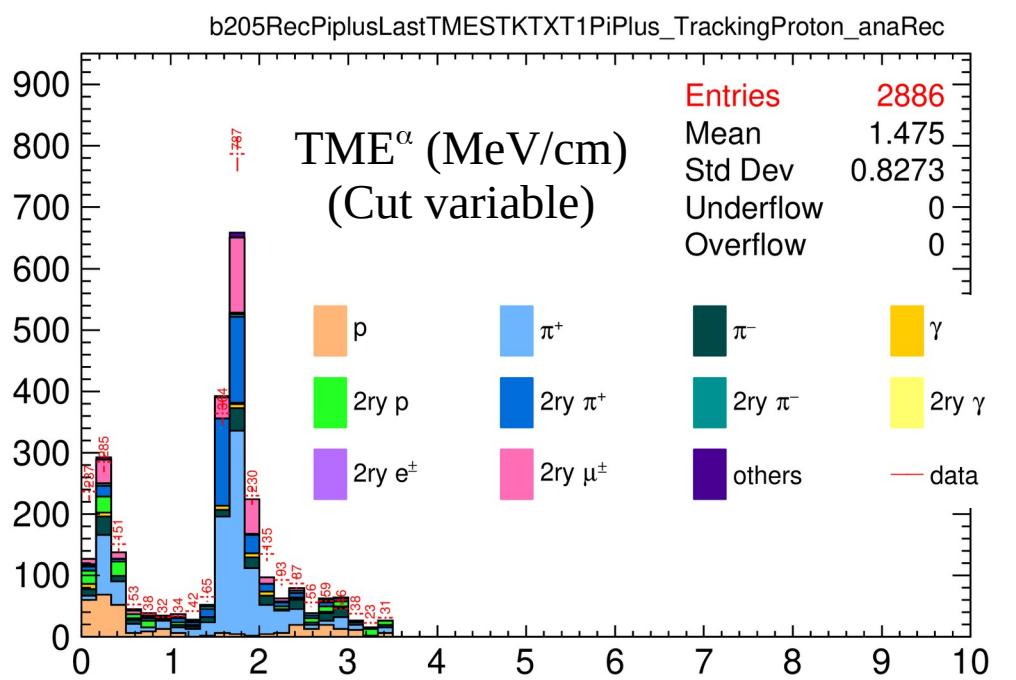
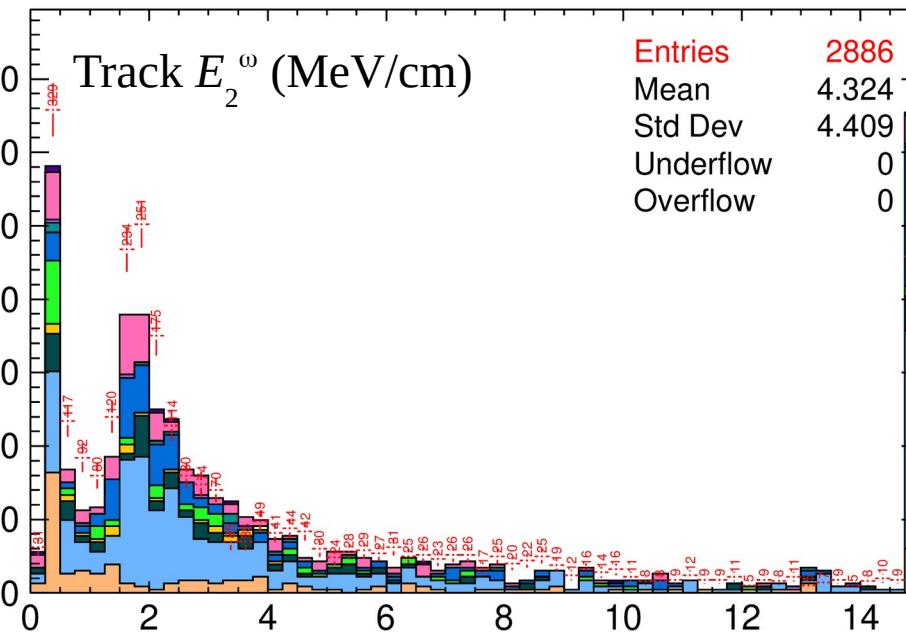
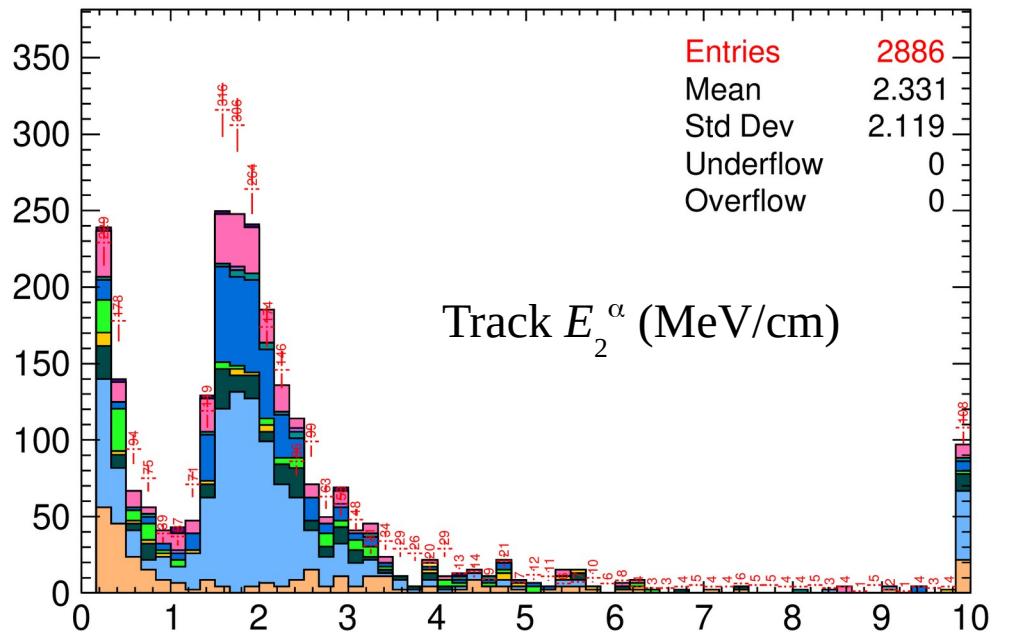


b105RecProtonLastTMESTKTXT1PiPlus_TrackingProton_anaRec



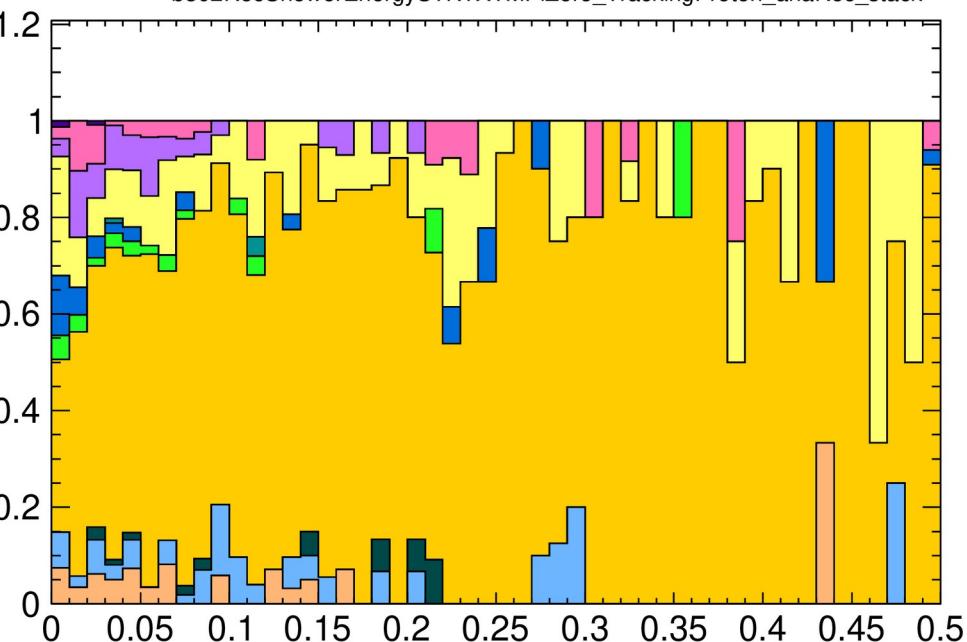
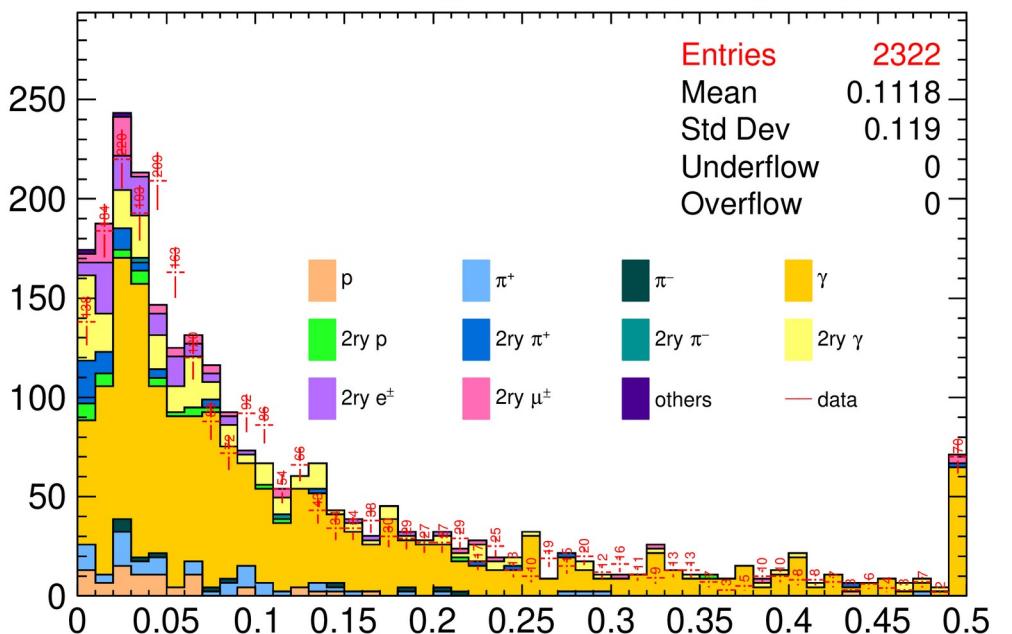
b107RecProtonStartTMESTKTXT1PiPlus_TrackingProton_anaRec





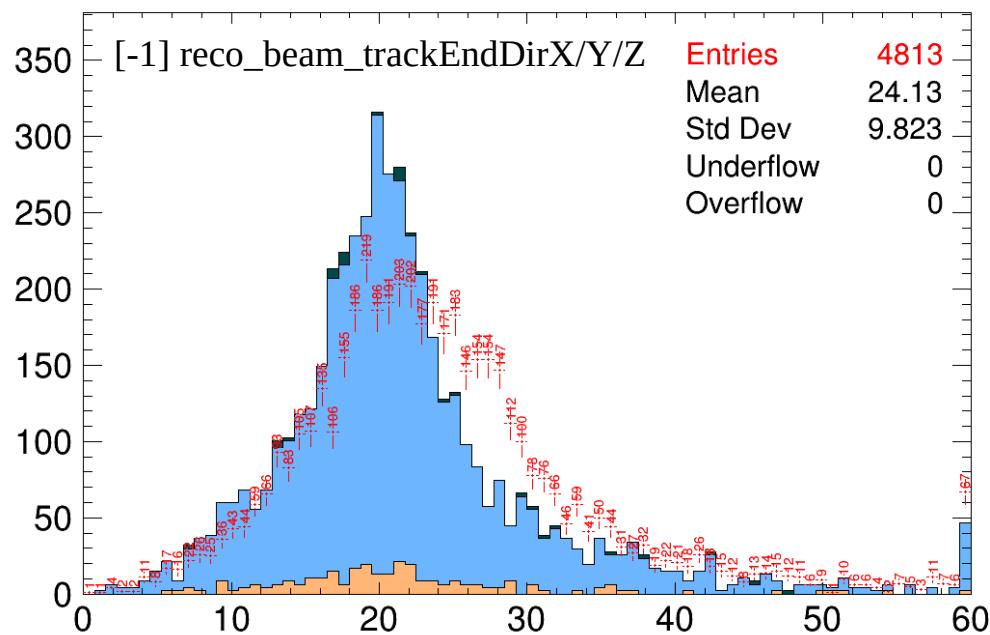
TME $^\omega$ = GetTruncatedMean(startArray, 2, 6, 0.4, 0.95)

TME $^\alpha$ = GetTruncatedMean(lastArray, 2, ndEdx-8, 0.05, 0.6) 36

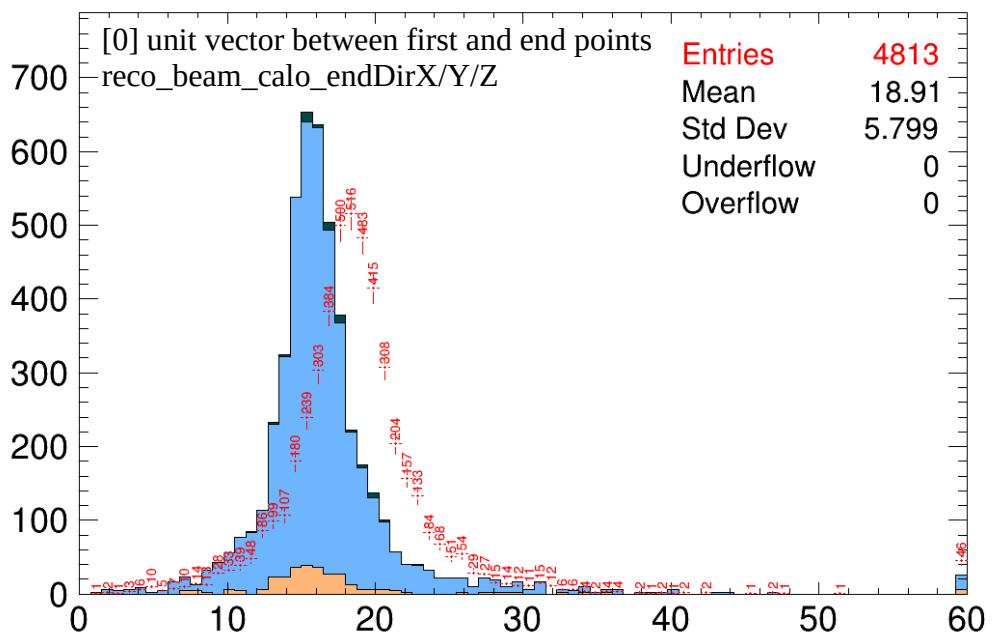


- No cut on shower energy
- Only use leading and subleading showers to reconstruct π^0
= leading π^0 in all shower combinations

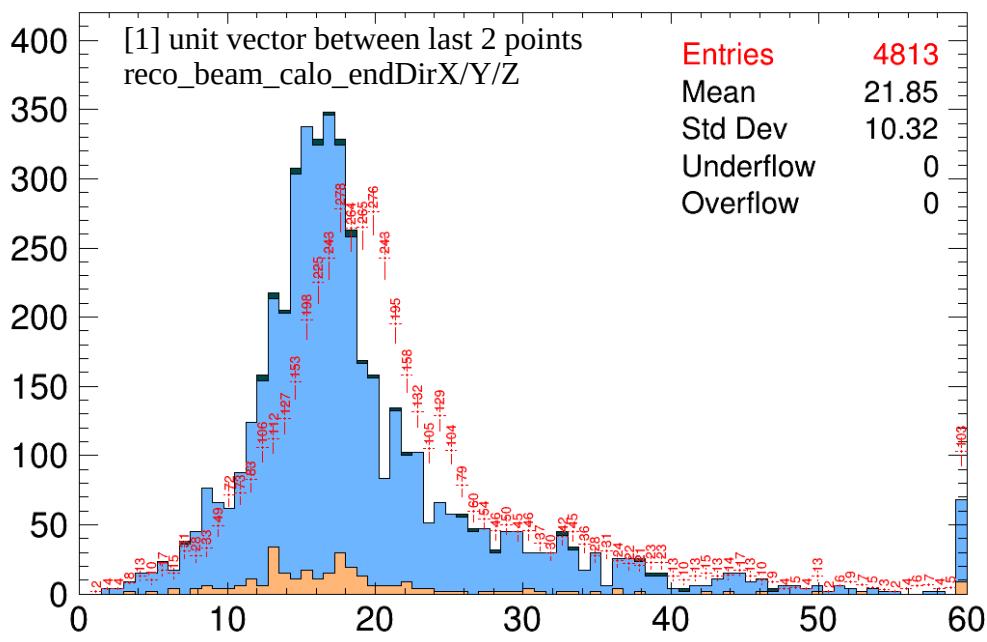
Shower candidates in $p\pi^0$ channel



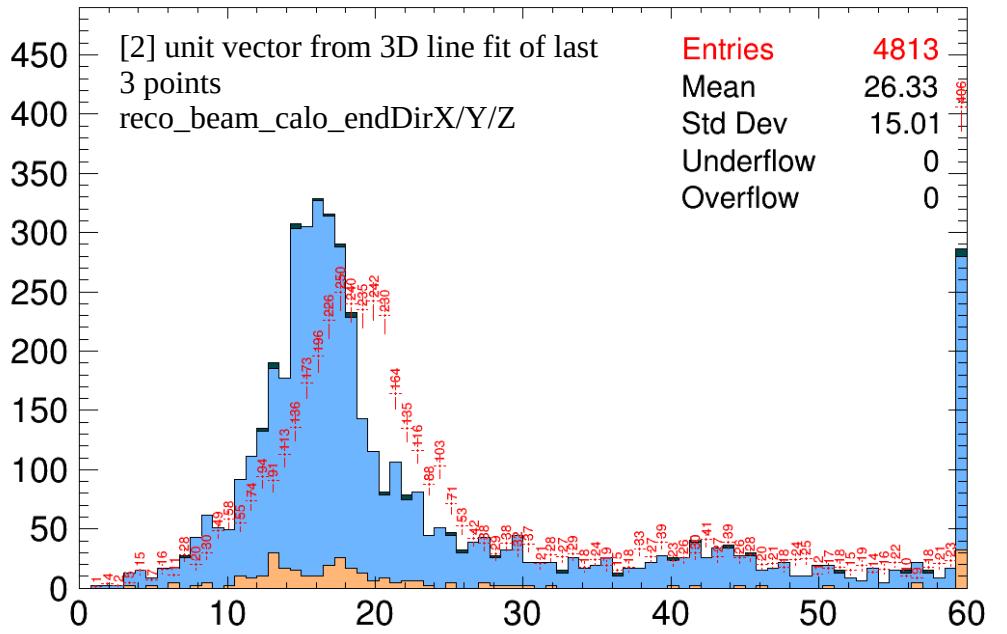
b025RecBeamThetaSTKTXT1PiPlus_TrackingProton_anaRec



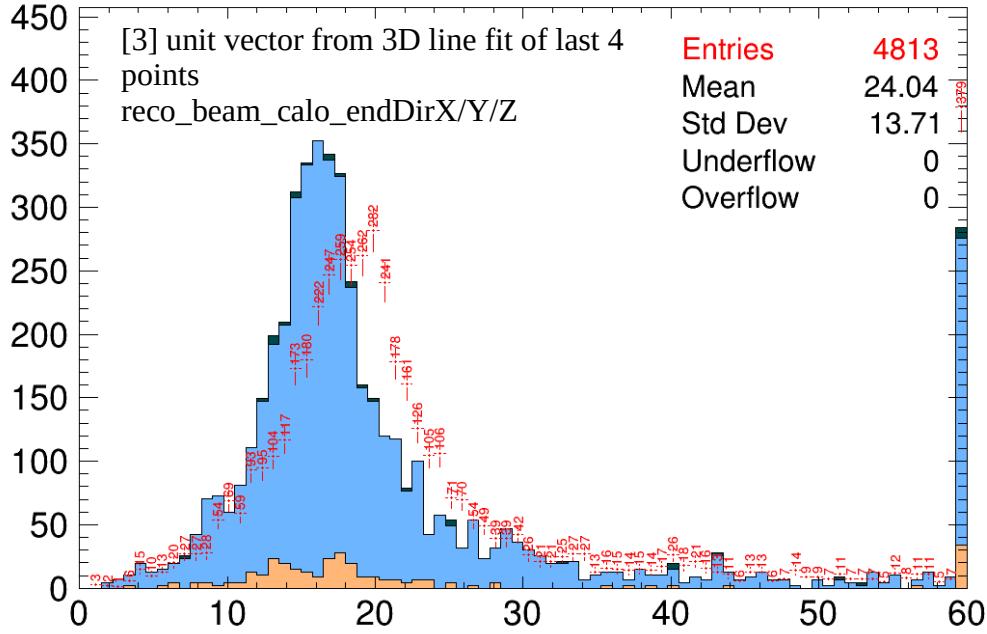
b025RecBeamThetaSTKTXT1PiPlus_TrackingProton_anaRec



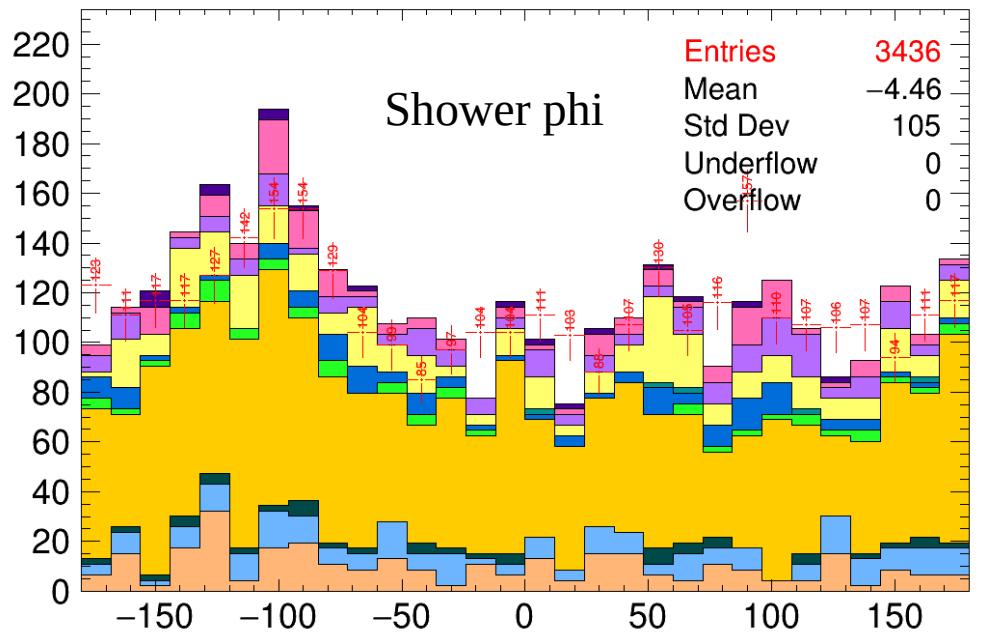
b025RecBeamThetaSTKTXT1PiPlus_TrackingProton_anaRec



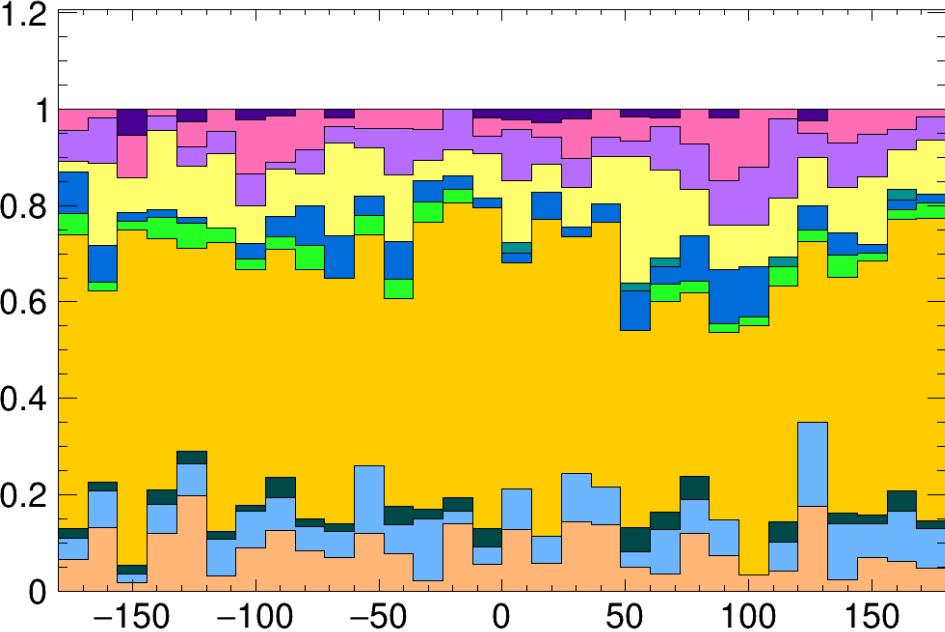
b025RecBeamThetaSTKTXT1PiPlus_TrackingProton_anaRec



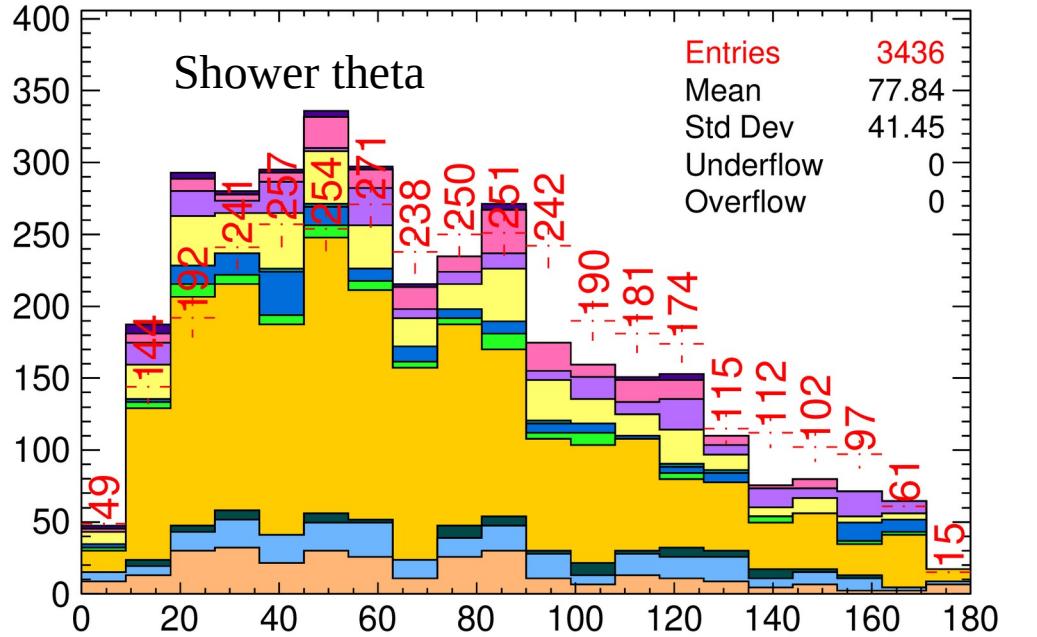
c109CutShowerPhiSTKXTMPiZero_TrackingProton_anaRec



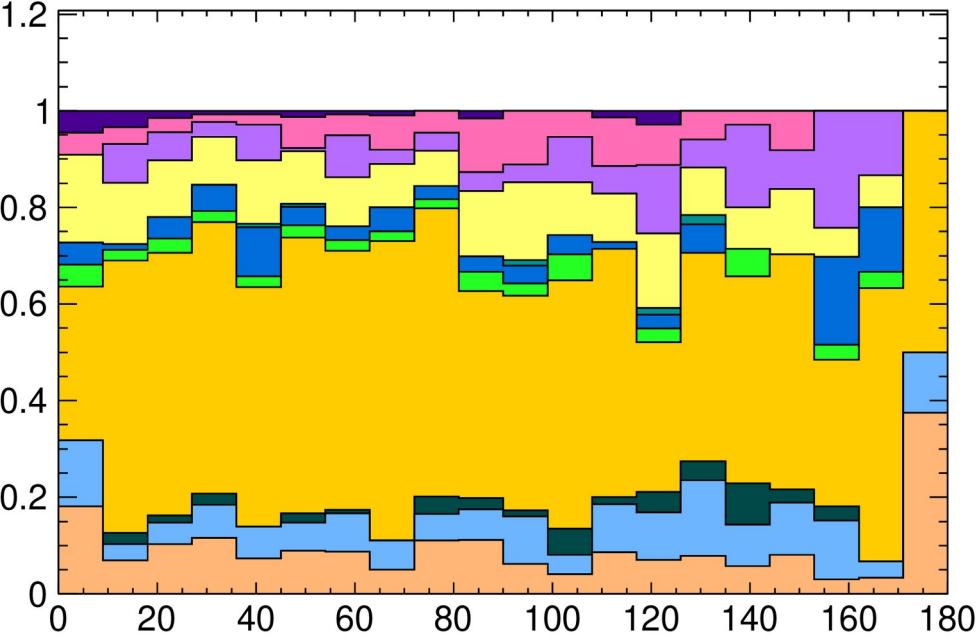
c109CutShowerPhiSTKXTMPiZero_TrackingProton_anaRec_stack



c109CutShowerThetaSTKXTMPiZero_TrackingProton_anaRec

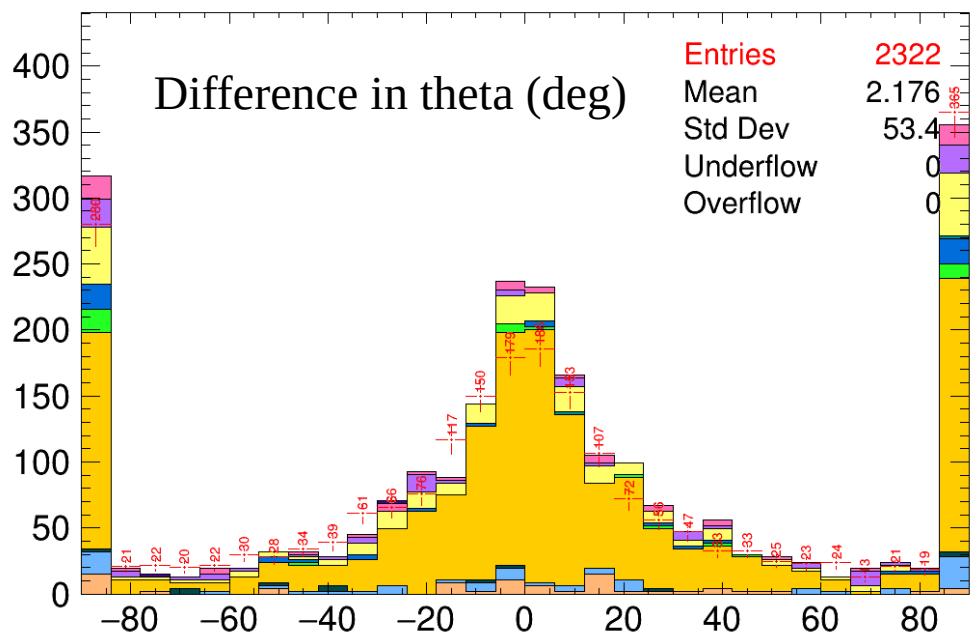


c109CutShowerThetaSTKXTMPiZero_TrackingProton_anaRec_stack

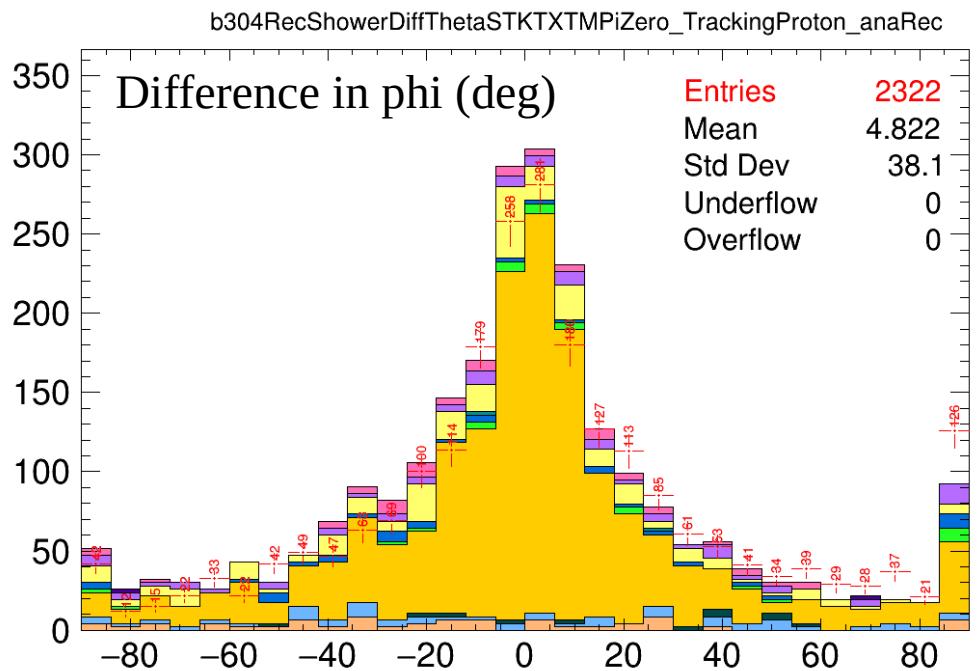


reco_daughter_allShower_startX/Y/Z - reco_beam_endX/Y/Z

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Difference between
 $\text{reco_daughter_allShower_startX/Y/Z} - \text{reco_beam_endX/Y/Z}$
and
 $\text{reco_daughter_allShower_dirX/Y/Z}$



END