Muon plume beam studies and simulations

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AD, External Beamlines

NOvA Test Beam Parallel Session

05/08/2020

Beam studies

- Fix primary target back-scatter monitor, re-tune position/angle on target for maximum secondary yield. No noticeable effect on experiment.
- Implement two-scintillator coincidence between upstream end of MC7 and just before NOvA target: F:MC7SC2. Tuning to improve secondary throughput.
- Got NOvA target MWPC functioning consistently and remotely-viewable. Tune up position and spot size on target. No noticeable effect on experiment. Secondary beamline trims do not move the plume.
- Scan secondary beam momentum-selection collimator vertical opening to see if plume goes away; plume dissipates continuously as opening closes.
- Scan MC6D momentum selection dipole string with rest of beamline off; plume dissipates but does not appear to move.
- Run at negative polarity -64 GeV/c mode. Plume is gone, but secondary yield too low to be useful.
- Mike and Andrew slide MWPC in MC7 upstream end up and down to see if they could identify the plume; they could not.
- Ran with maximum primary yield allowed with MC2 pinhole collimator in; data consistent with very low rate on target.
- Carol and Adam accessed MC6 and MC7 to do a radiation survey and better understand the geometry of the shielding and line-of-sight to the plume. No obvious holes in shielding identified.
- MC2 pinhole collimator put in beam, tuned up for maximum rate on MC6 target (~5E6 ppp): unclear if detector data is significantly different from background
- Running at 8mm momentum collimator opening since studies showed this may have an improved secondary yield to plume intensity. Data analysis says reduced halo rate not worth reduced tertiary yield.
- Took experimental runs (~10 spills or so each) for beam to Meson absorber, beam only to Mtest, and no beam at all. All consistent with no hits on NOvA detector; plume is not coming from absorber shine or Mtest scraping.

Summary of effects on the plume

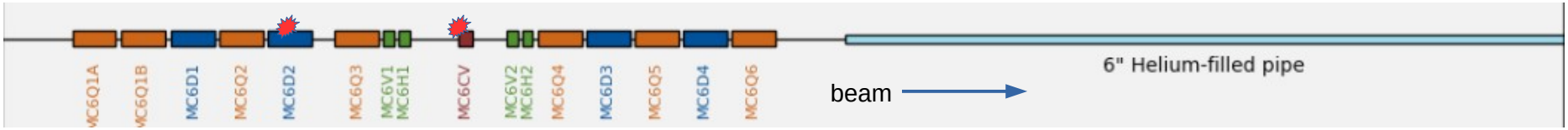
Does affect plume:

- MC6CV momentum-selection collimator opening gap changes apparent intensity of the plume.
- Scanning MC6D with all other magnets (trims and quads) off does not appear to move the plume, but does change its intensity.
- Running 64 GeV/c negative polarity makes plume go away, but secondary yield is too low to be useful to the experiment.
- Increased beam intensity appears to increase plume intensity
- Turning off the beam removes the plume.
- Pinhole collimator in MC2 makes plume go away, but rate is so low that it may just be an intensity effect.

Does not affect plume:

- Changing position/angle on the primary target
- Secondary beamline dipole trims do not appear to move the plume.
- Changing position and spot size on secondary (NOvA TB) target

Hot spots in MC6 secondary beamline



MC6 secondary beamline plan (top) view

- Asymmetric hot spots verified on West side, upstream ¼ of MC6D2, as well as West and ~1cm high on MC6CV upstream face.
- Same spots were identified before target position/angle scan, appear unchanged.
- May suggest horizontal alignment issue, consistent with target angle scan results.
- Data from Metrology group is incomplete (no primary target, no momentum collimator), but so far does not show obvious mis-alignments. Waiting on the rest of the data we need to verify.

Simulation work during quarantine

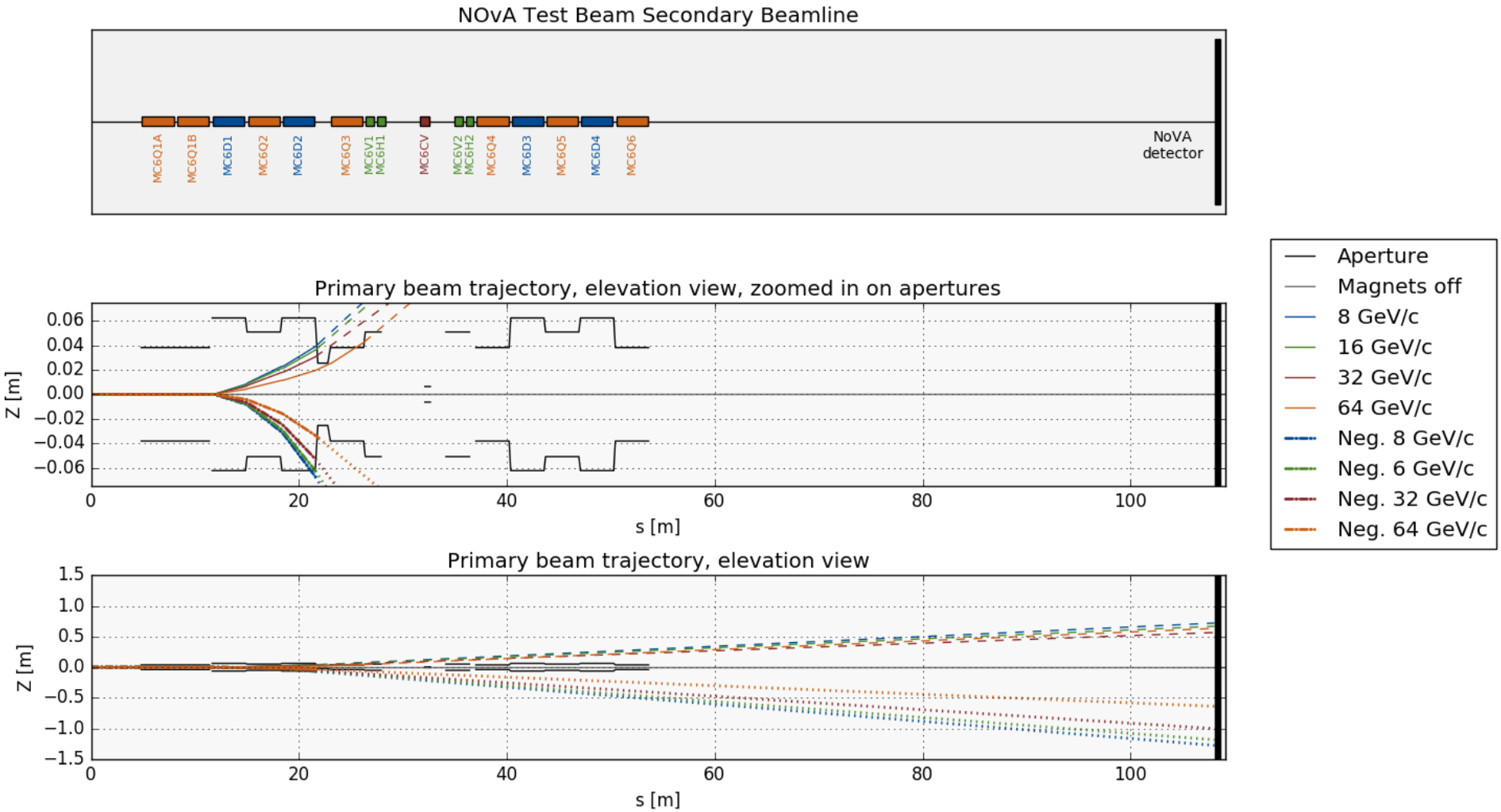
During quarantine, my work has focused on cross-checking beamline simulation models with respect to each other and alignment data, as well as making improvements to the Monte Carlo model to try and fine the source of the plume.

Models used are simple beam optics (TRANSPORT/MADX) and G4Beamline (GEANT4 Monte Carlo).

Early G4Beamline results were with sparse model that only included the secondary beamline. Significant work has been put into adding real-world details to the model, such as vacuum pipe and windows, shielding blocks, enclosure floor and walls, experimental equipment, etc.

If plume is re-created with G4Beamline, model can be adjusted to investigate possible mitigation methods, such as a longer/thicker primary target, different beamline tunes, muon spoiler coils outside the beam pipe, etc.

TRANSPORT, primary beam dump

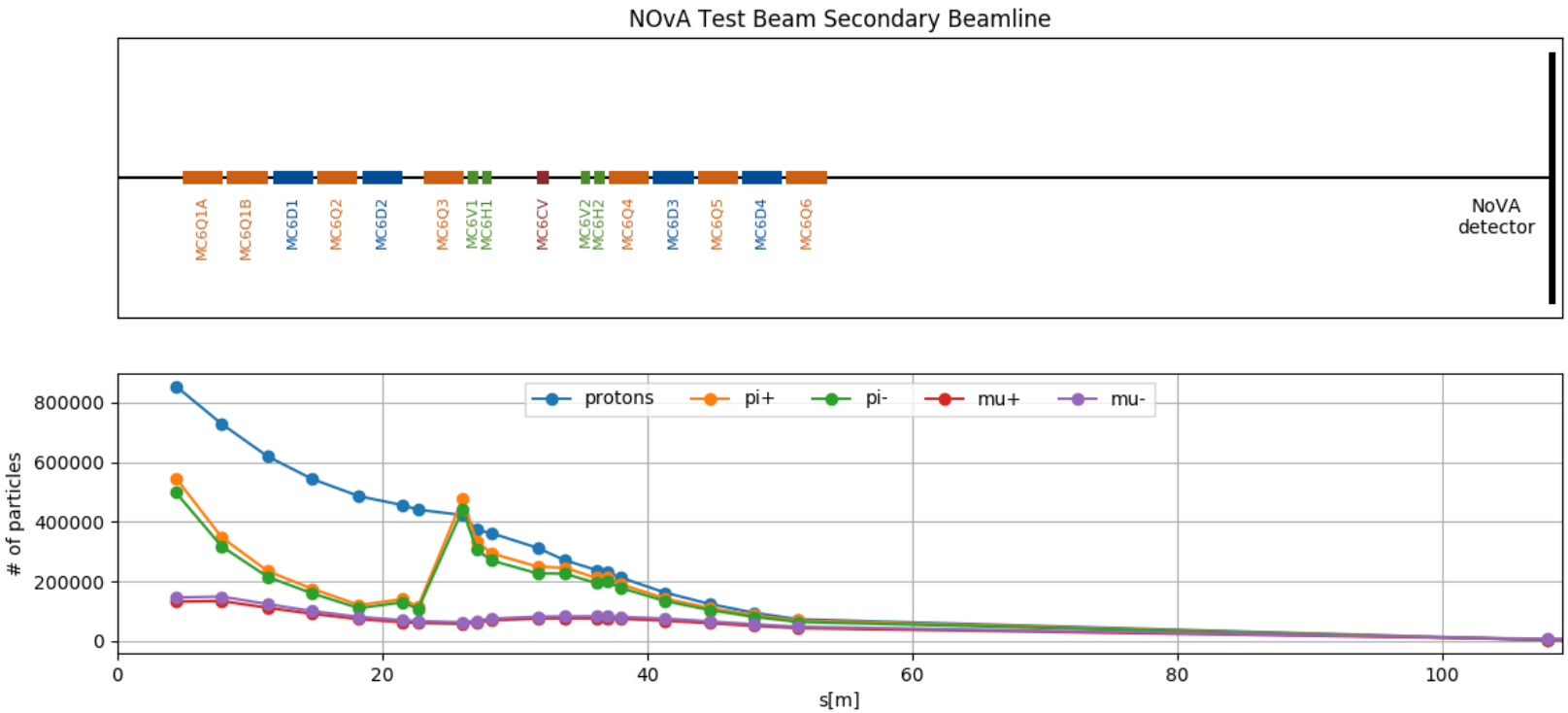


Using TRANSPORT, determined that 120 GeV/c beam dumps into Q3 aperture after passing through or around primary target. Beamline tune has little effect, but polarity does.

NoVA detector

G4BL output, 1E6 on target

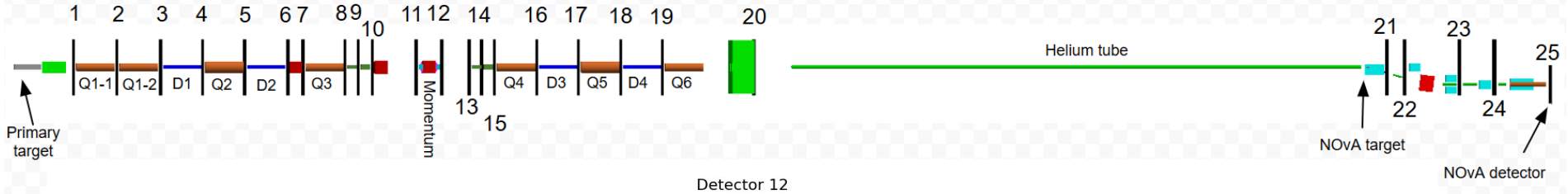
trackcuts keep=proton,mu+,pi+,pi0,kaon+



Early Monte Carlo results appear to agree with primary beam dump location predicted by TRANSPORT, indicated by spike in proton/pion count after Q3.

G4BL output, 1E8 on target

The following plots show data from an early version of the G4Beamline model that does not include shielding blocks and enclosure walls in the secondary beamline. 1E8 protons on primary target, keeping only secondaries > 1 GeV/c and only protons, pi+/-, mu+/-, k+/- to reduce computational intensity and data file size.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Q1-1
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Q3
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Q4
D3
Q5
D4
Q6
Helium tube
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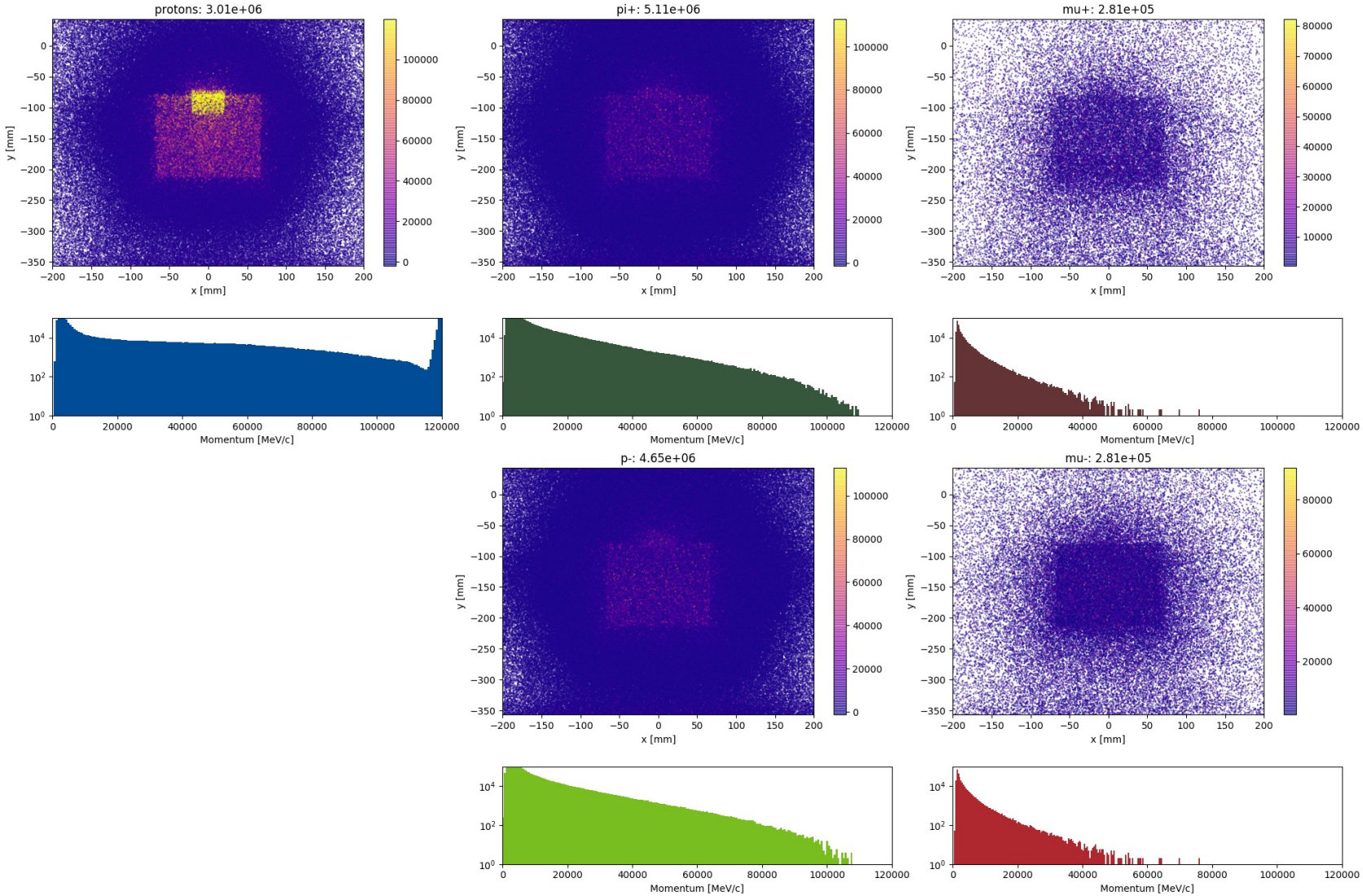
Primary target
NOvA target
NOvA detector

Detector 12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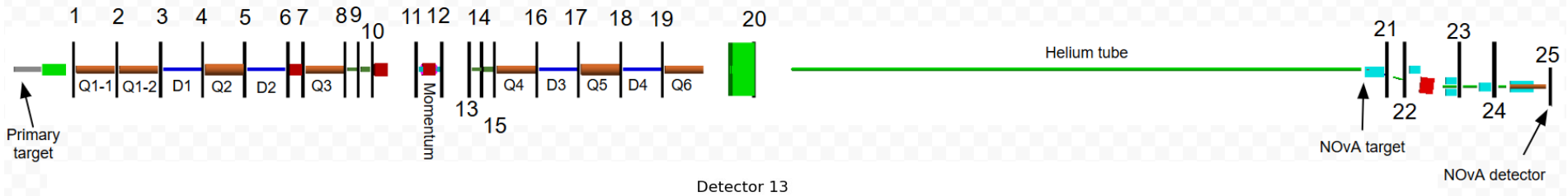
pi+: 5.11e+06
mu+: 2.81e+05
p-: 4.65e+06
mu-: 2.81e+05
x [mm]
y [mm]
Momentum [MeV/c]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Q1-1
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Q5
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Helium tube
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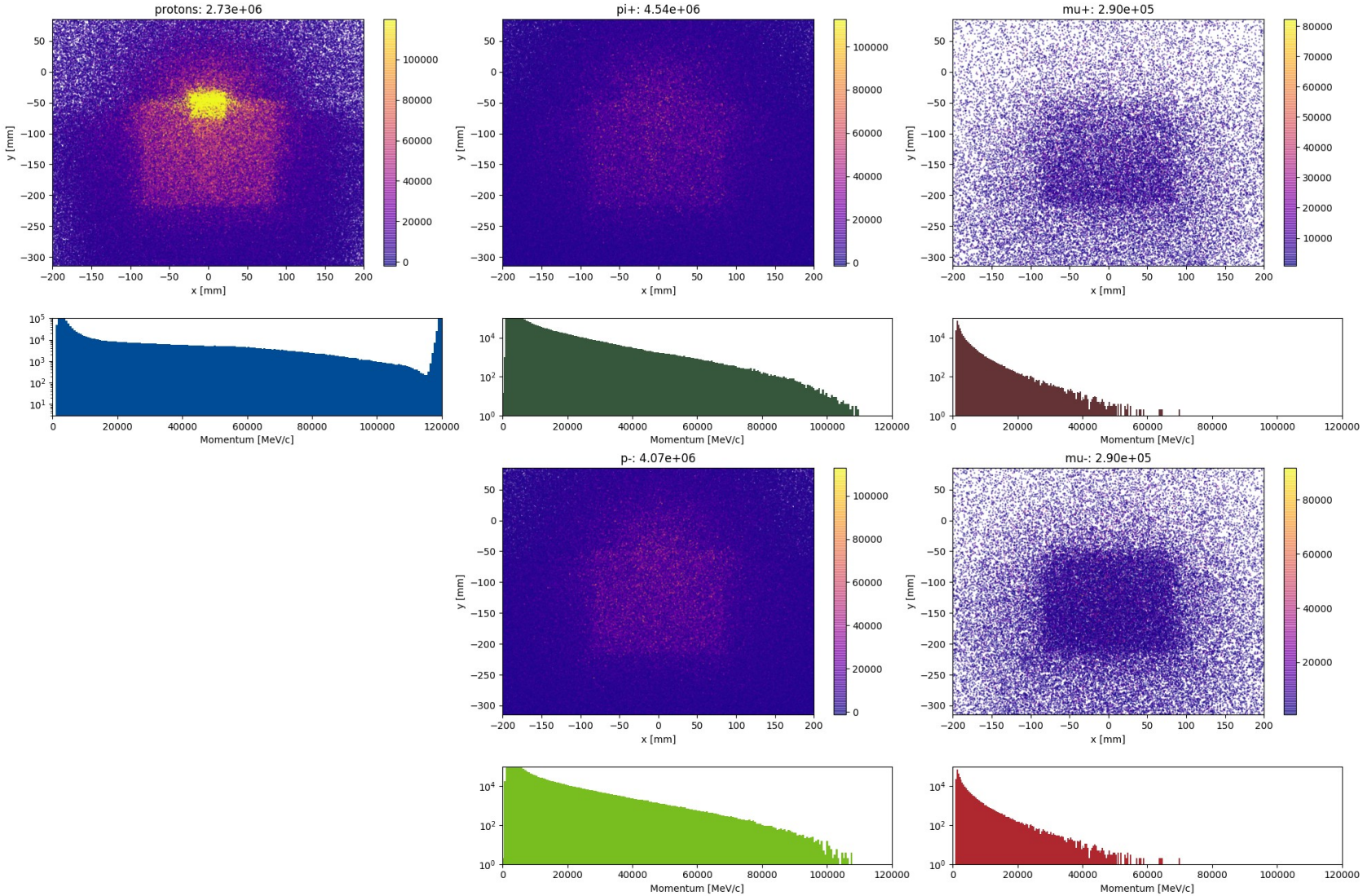
Primary target
NOvA target
NOvA detector

Detector 13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pi+: 4.54e+06
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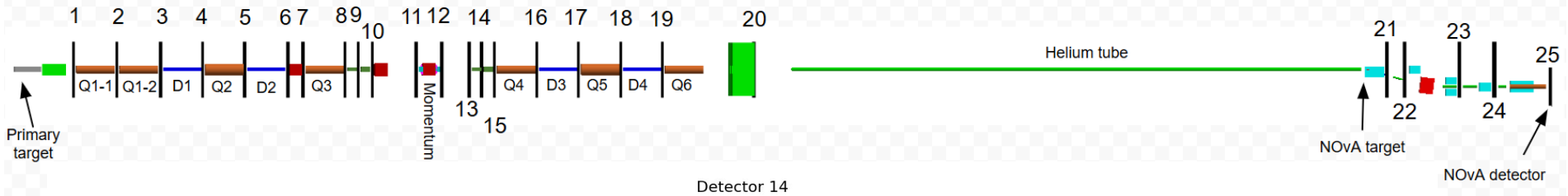
p-: 4.07e+06
mu-: 2.90e+05
x [mm]
y [mm]
Momentum [MeV/c]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Helium tube
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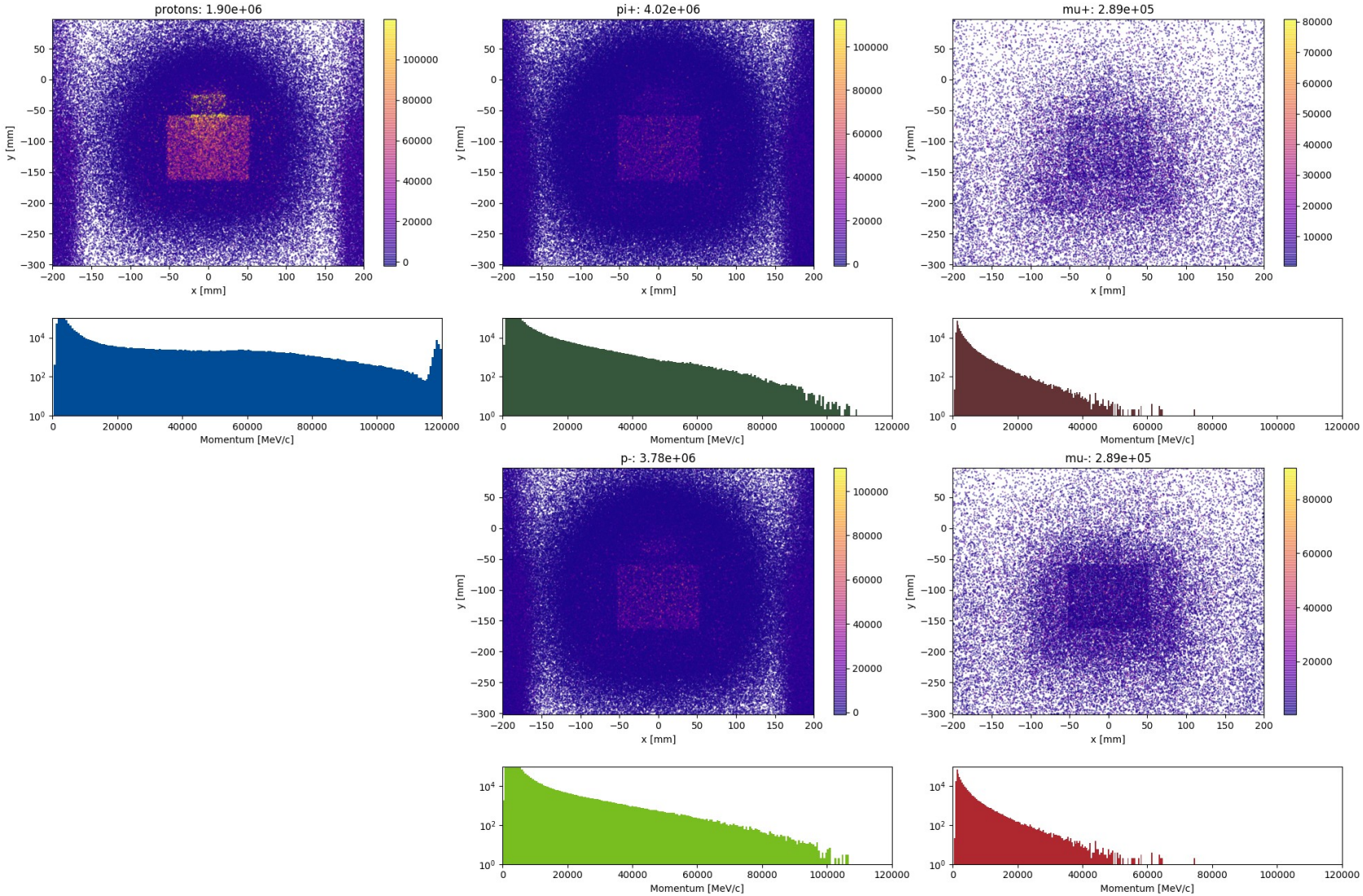
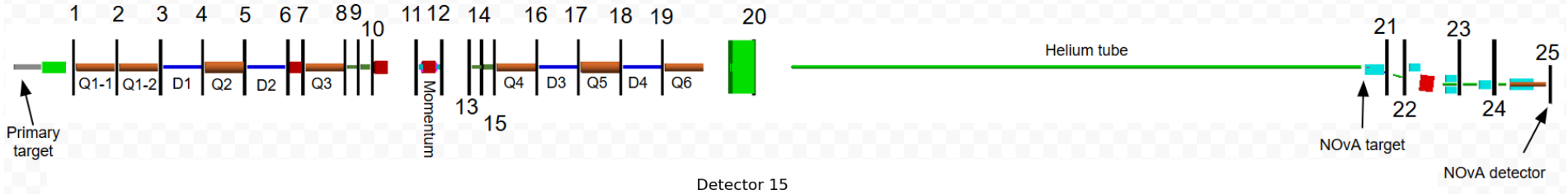
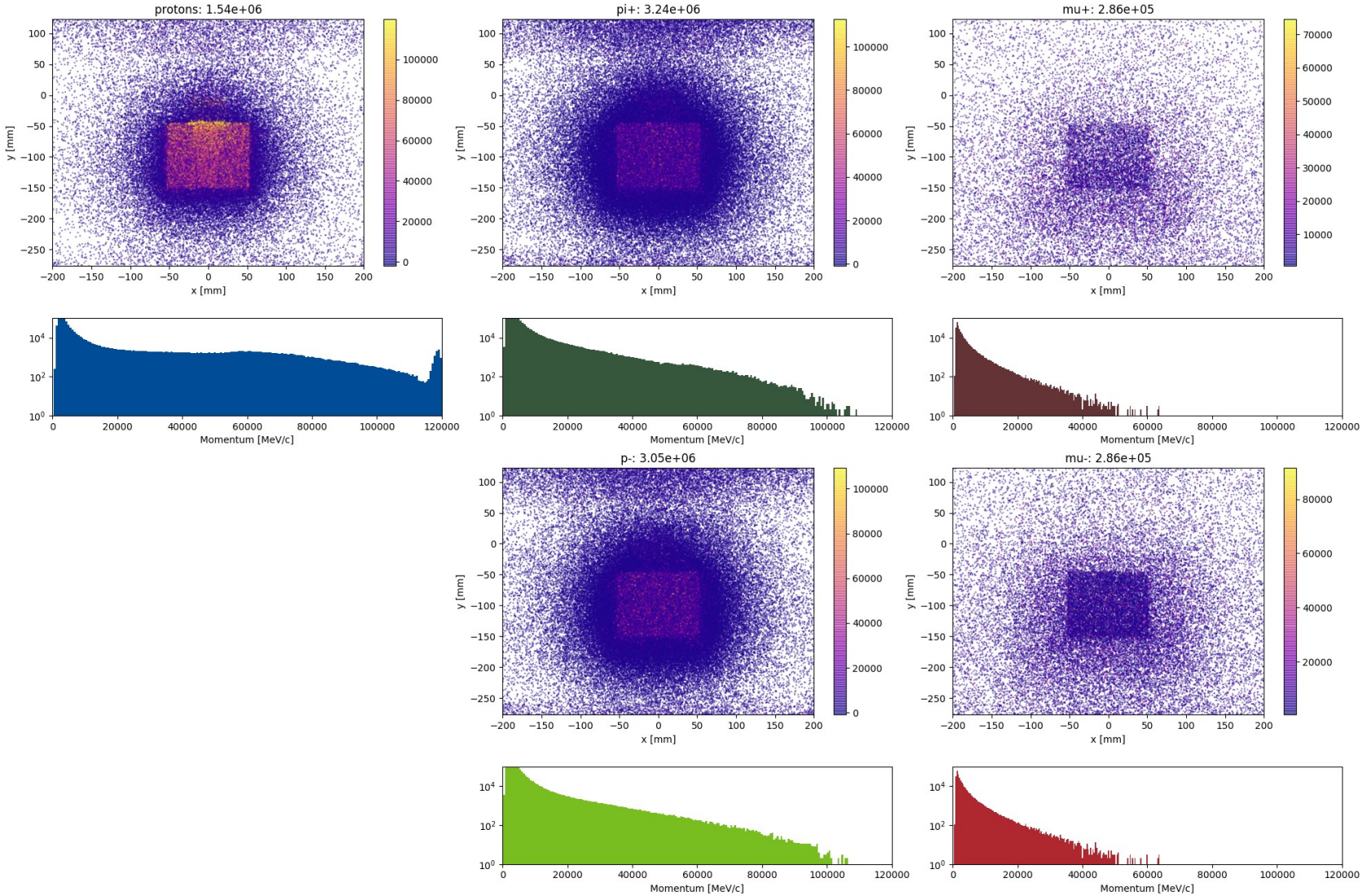
Primary target
NOvA target
NOvA detector

Detector 14


protons: 1.90e+06
pi+: 4.02e+06
mu+: 2.89e+05
p-: 3.78e+06
mu-: 2.89e+05
x [mm]
y [mm]
Momentum [MeV/c]



Detector 15



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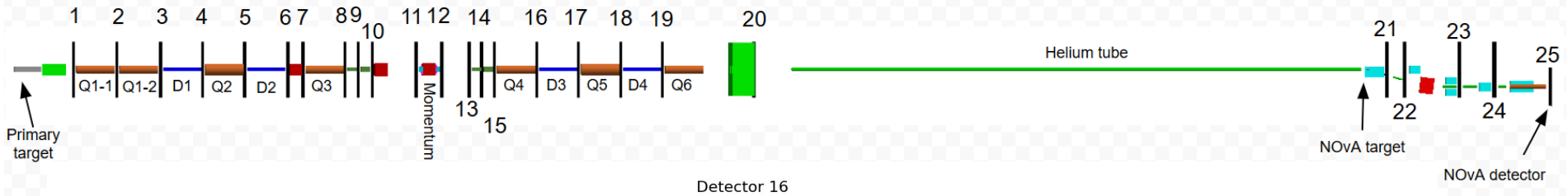
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Q6
Helium tube
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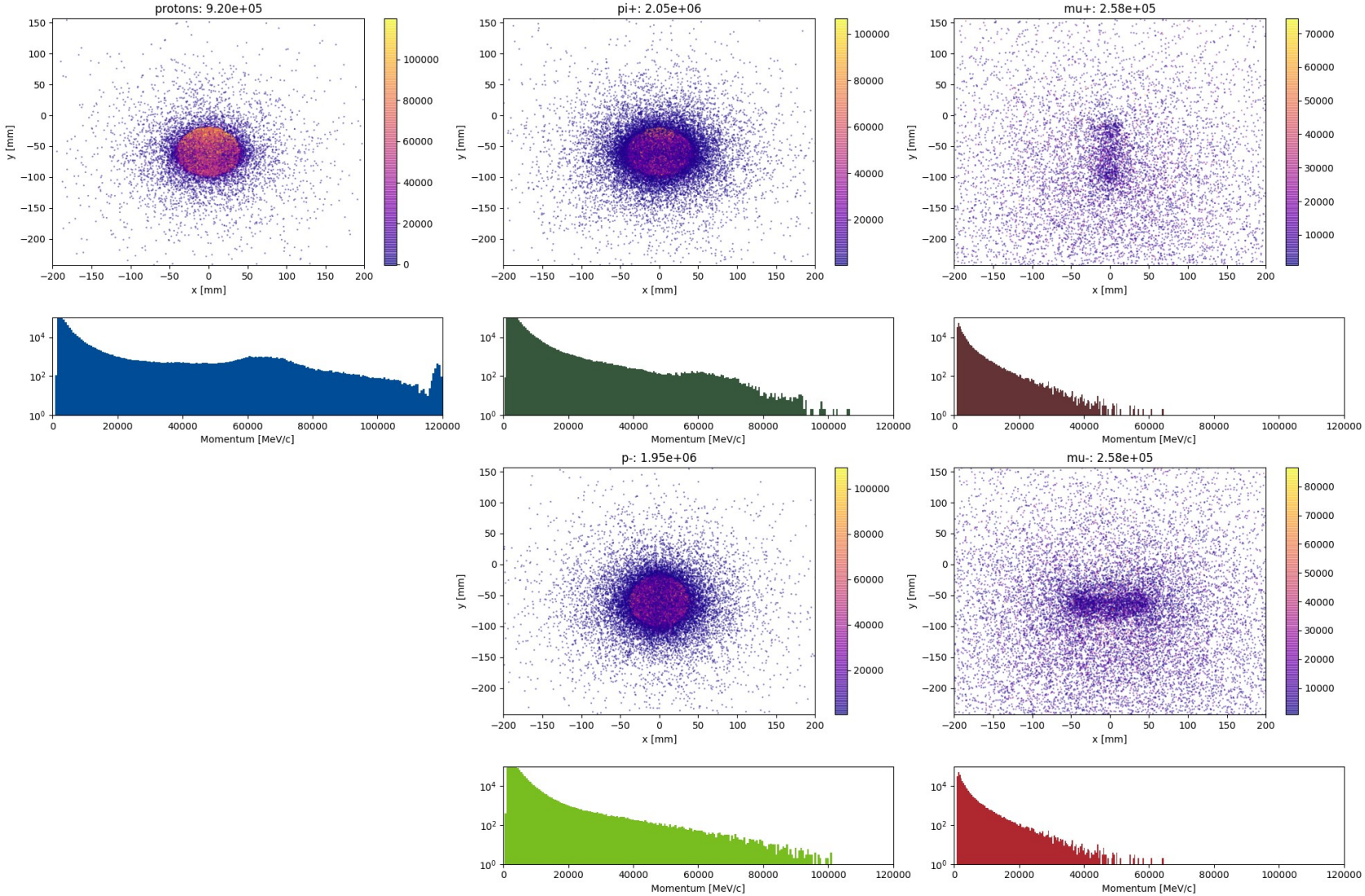
Primary target
NOvA target
NOvA detector

Detector 16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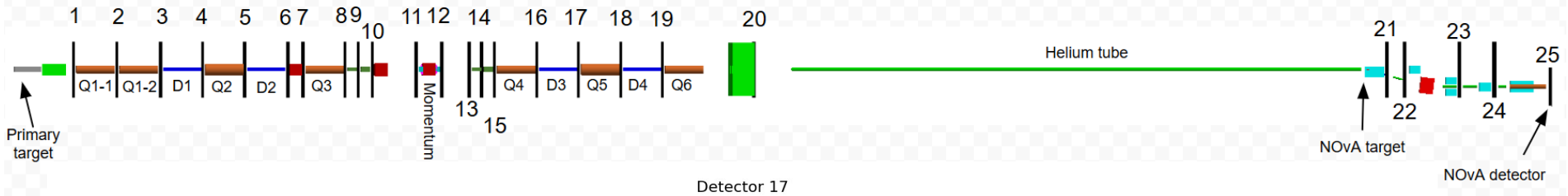
pi+: 2.05e+06
mu+: 2.58e+05
p-: 1.95e+06
mu-: 2.58e+05
x [mm]
y [mm]
Momentum [MeV/c]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Helium tube
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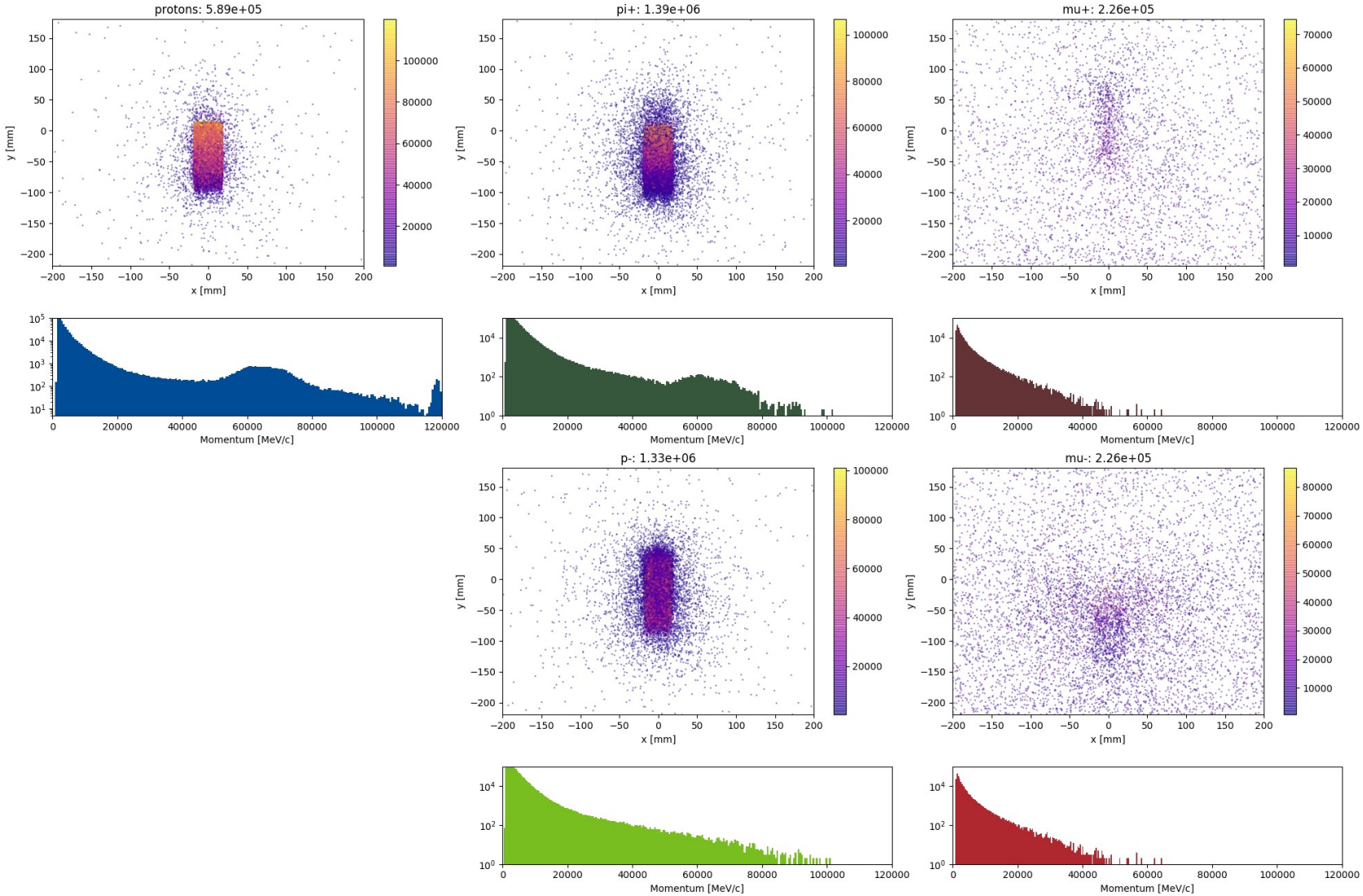
Primary target
NOvA target
NOvA detector

Detector 17


protons: 5.89e+05
pi+: 1.39e+06
mu+: 2.26e+05
p-: 1.33e+06
mu-: 2.26e+05
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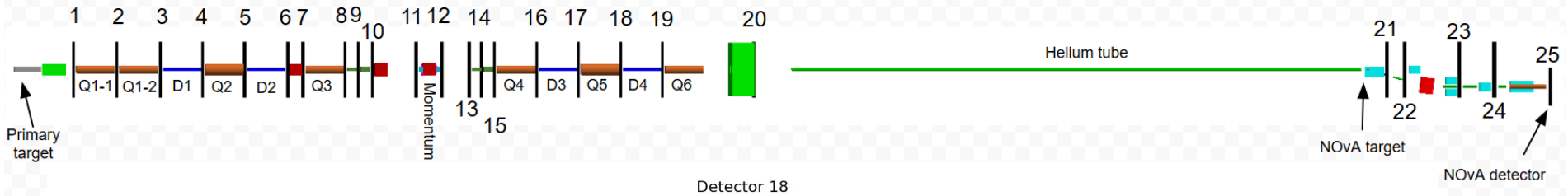
Momentum [MeV/c]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Helium tube
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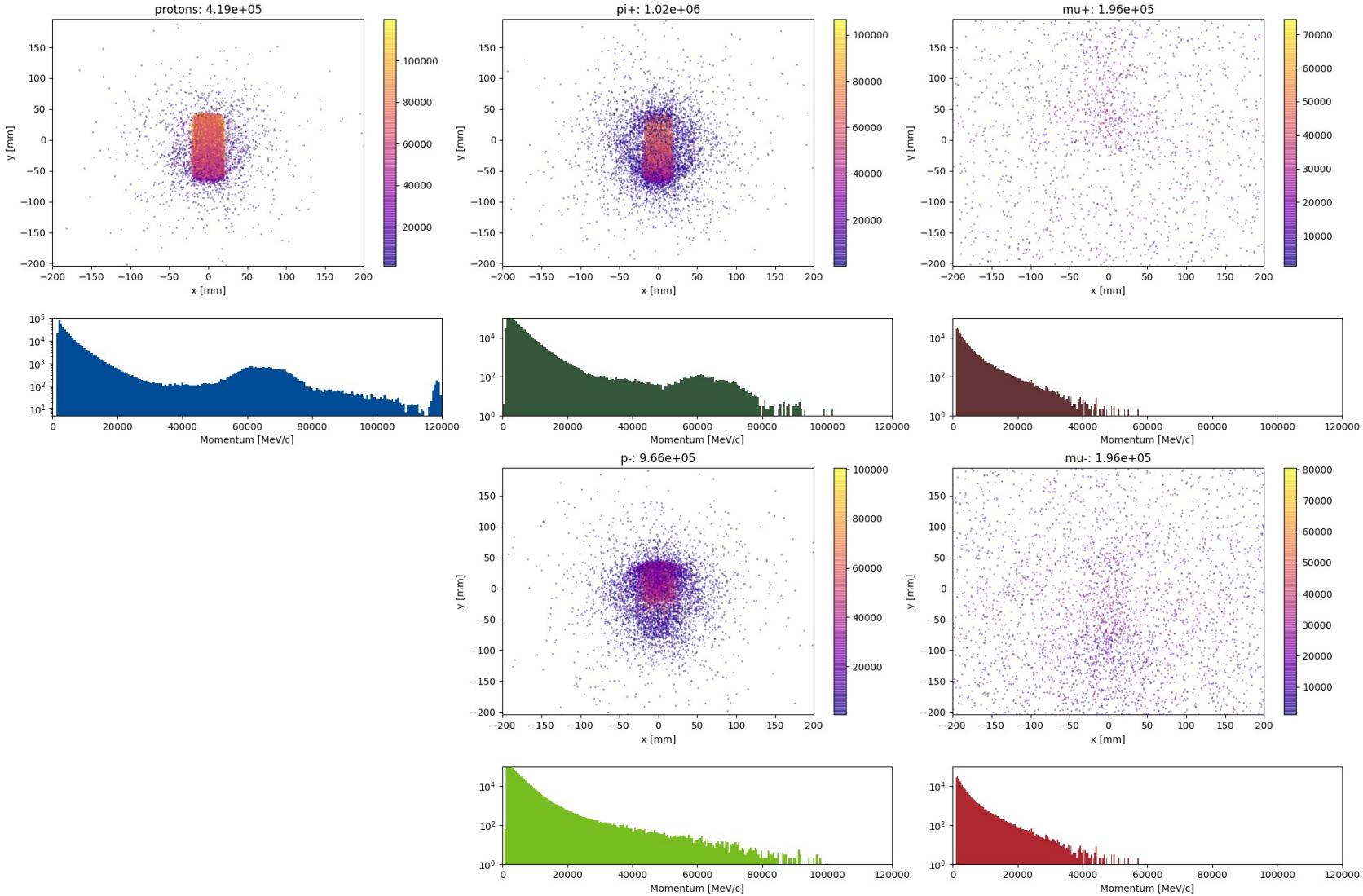
Primary target
NOvA target
NOvA detector

Detector 18


protons: 4.19e+05
pi+: 1.02e+06
mu+: 1.96e+05
p-: 9.66e+05
mu-: 1.96e+05
x [mm]
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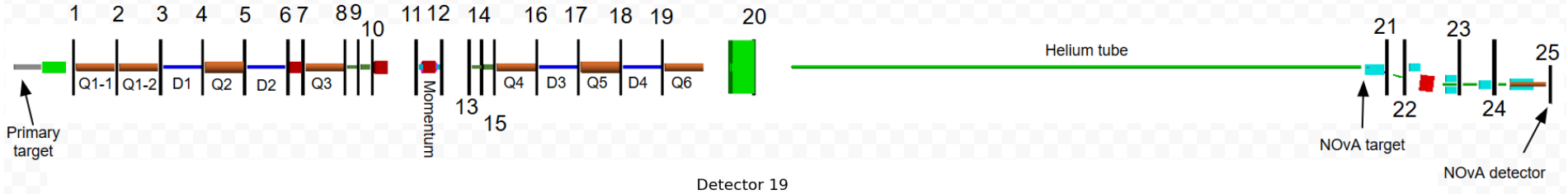
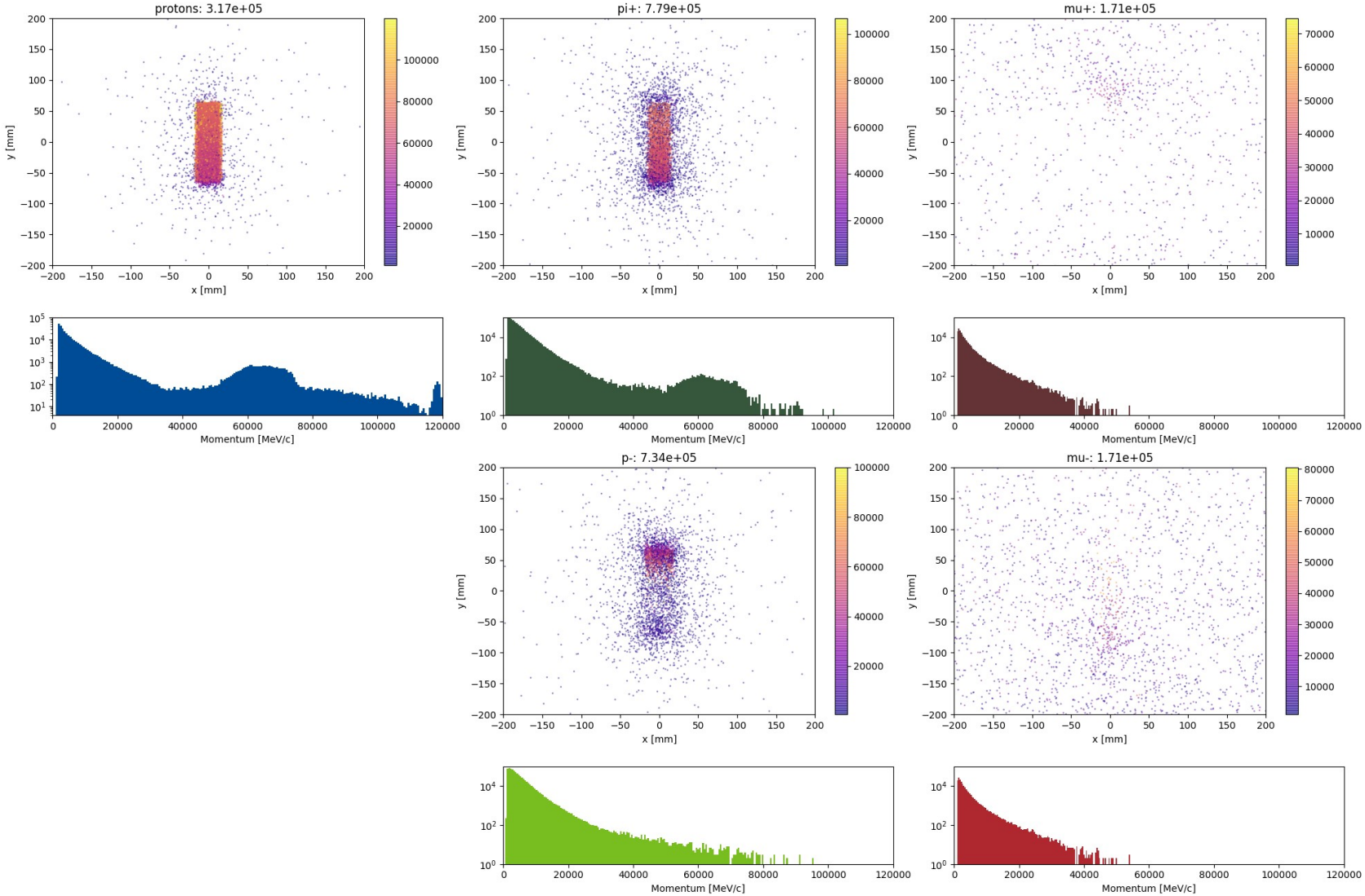
Momentum [MeV/c]



Detector 19



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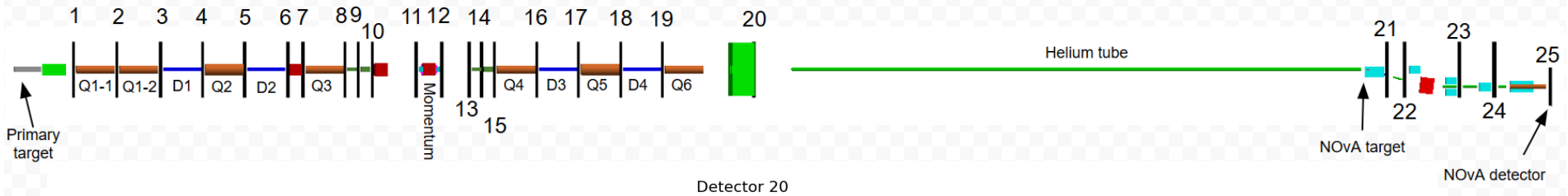
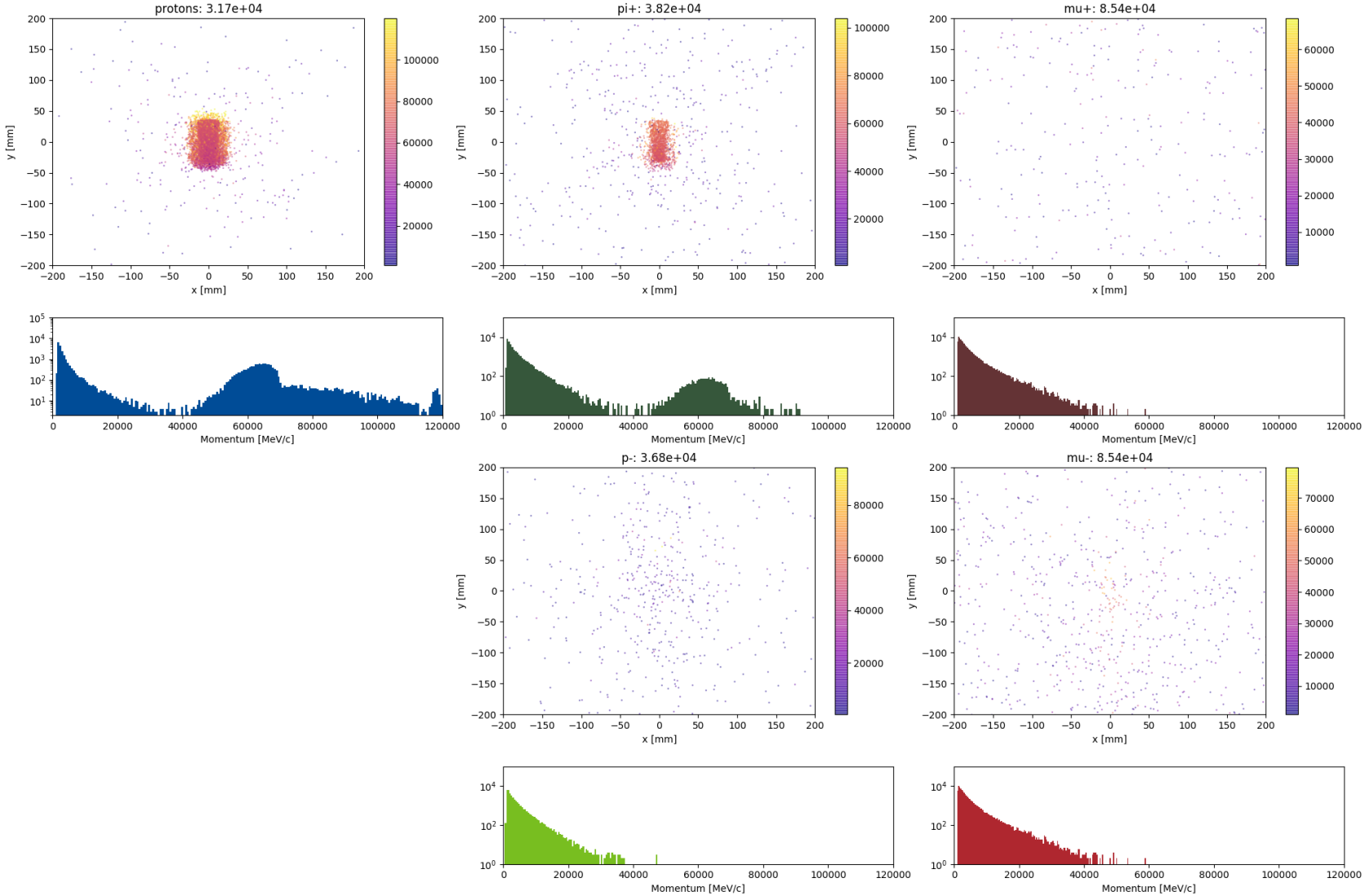


Detector 20



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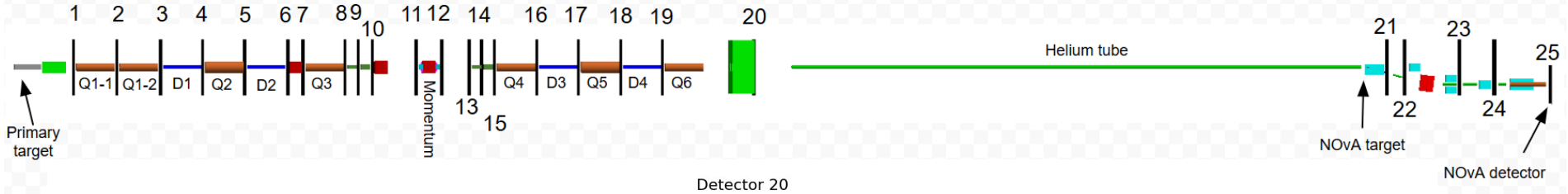
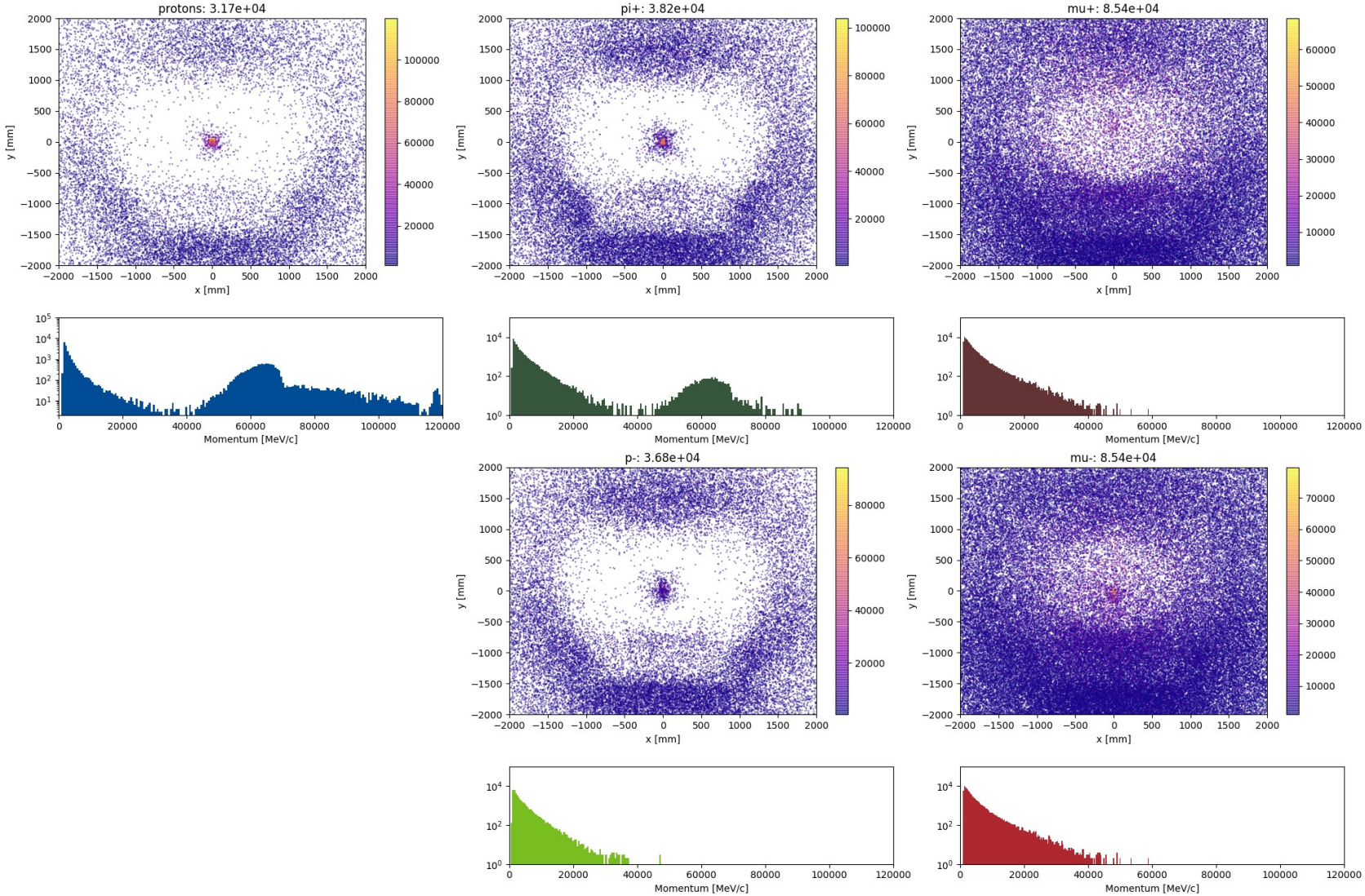
G4BL output, 1E8 on target

The next several plots are from the same G4Beamline model and data run, but the plot limits have been widened by a factor of 10 to look for hints of plume downstream of the secondary beamline.



Detector 20



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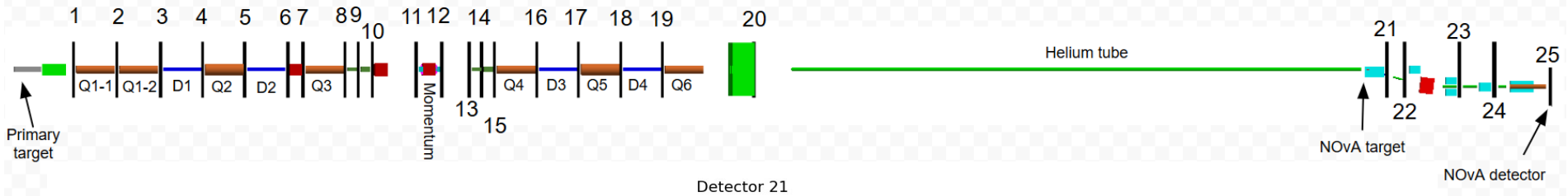
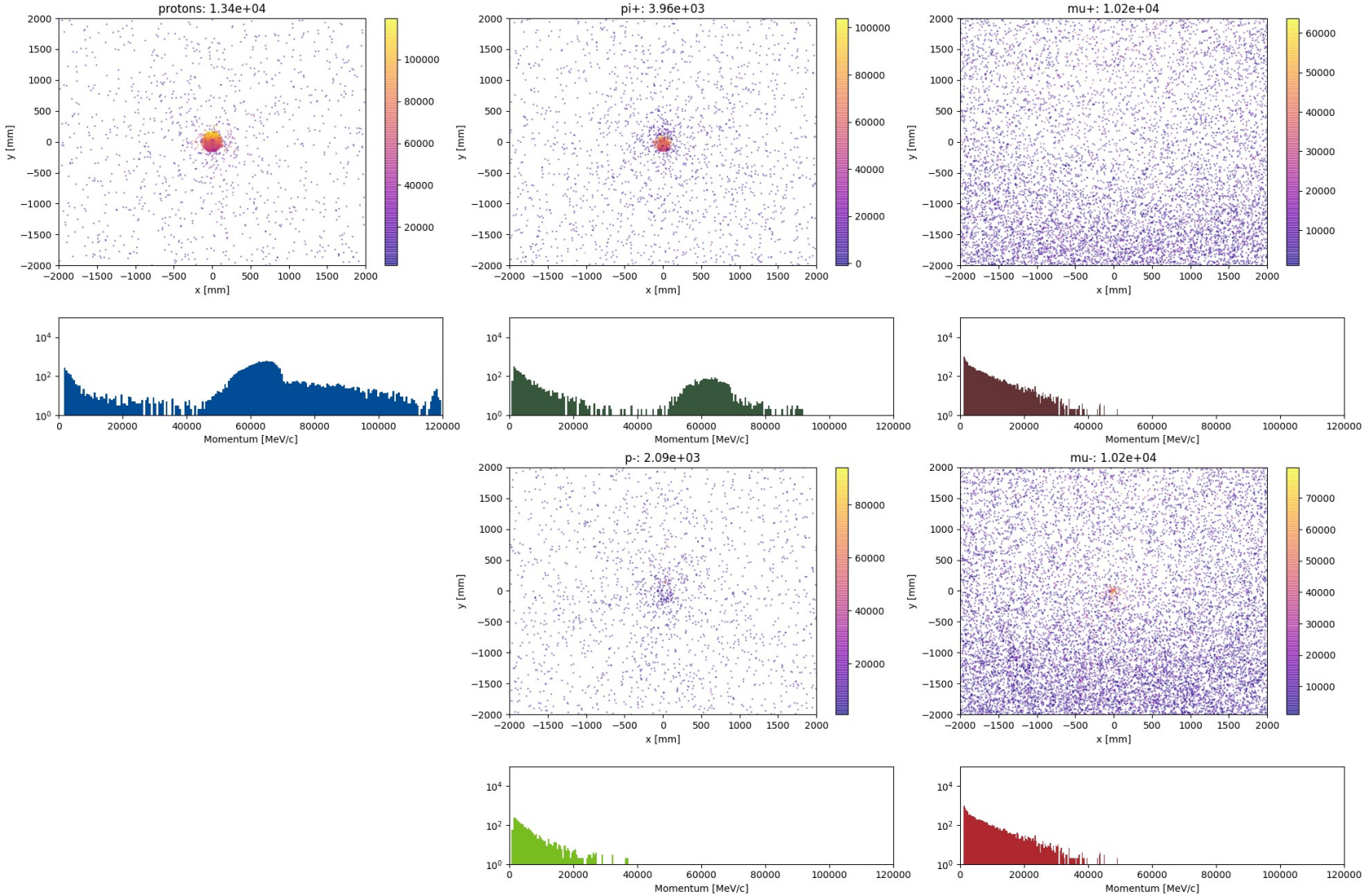


Detector 21



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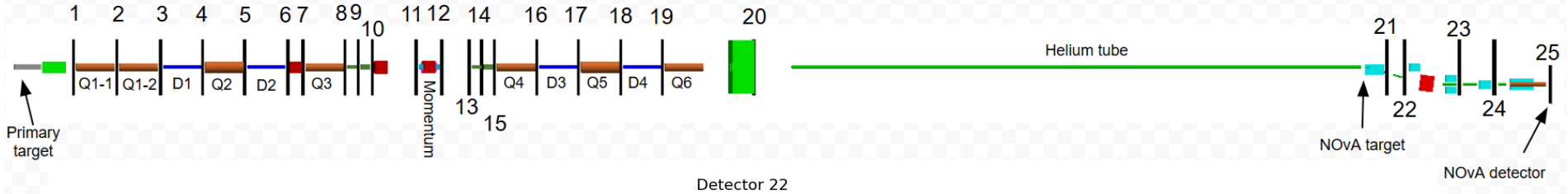
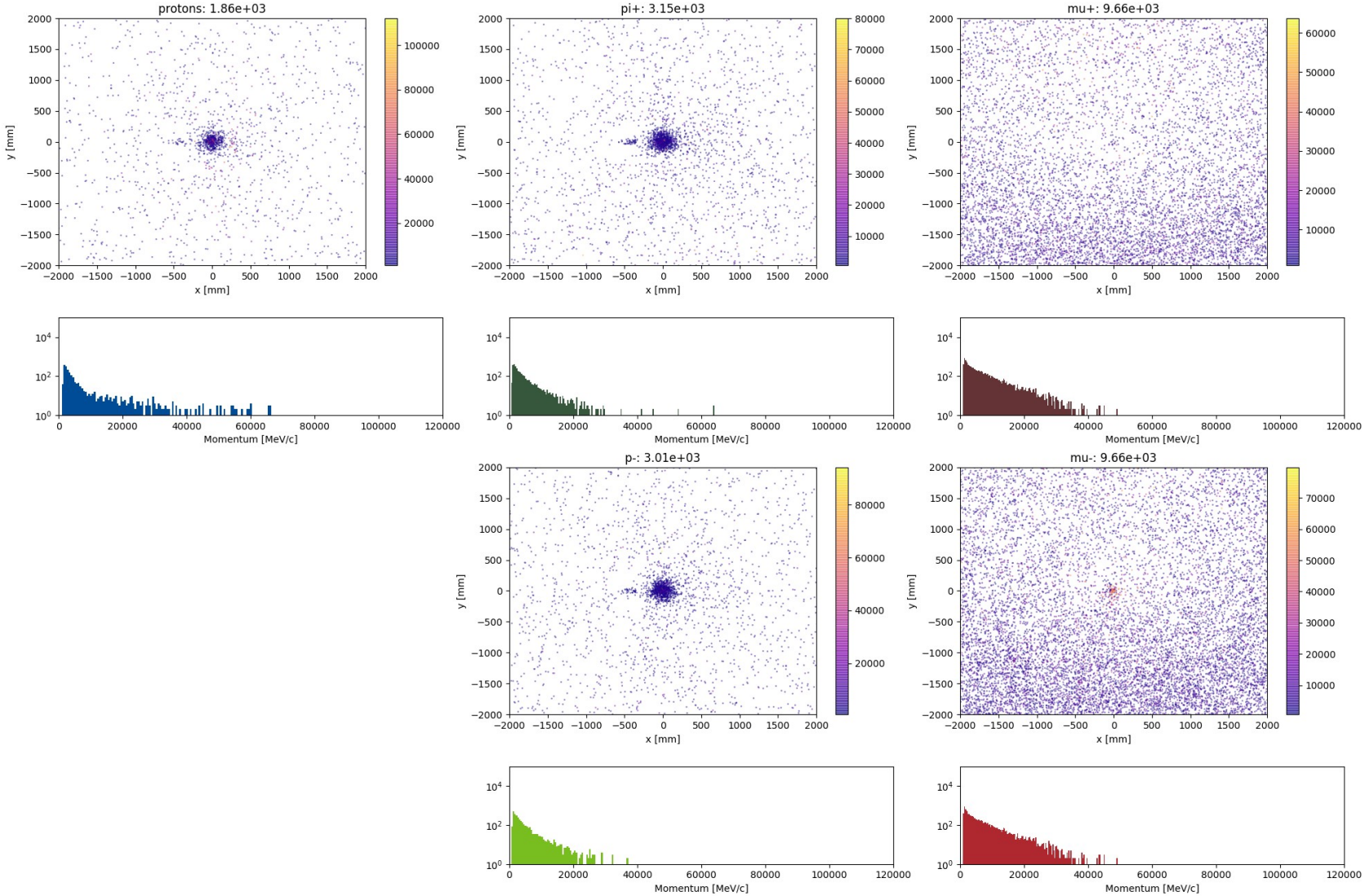


Detector 22



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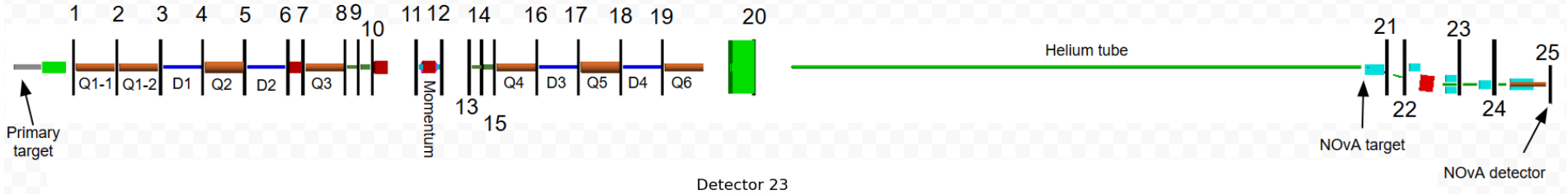
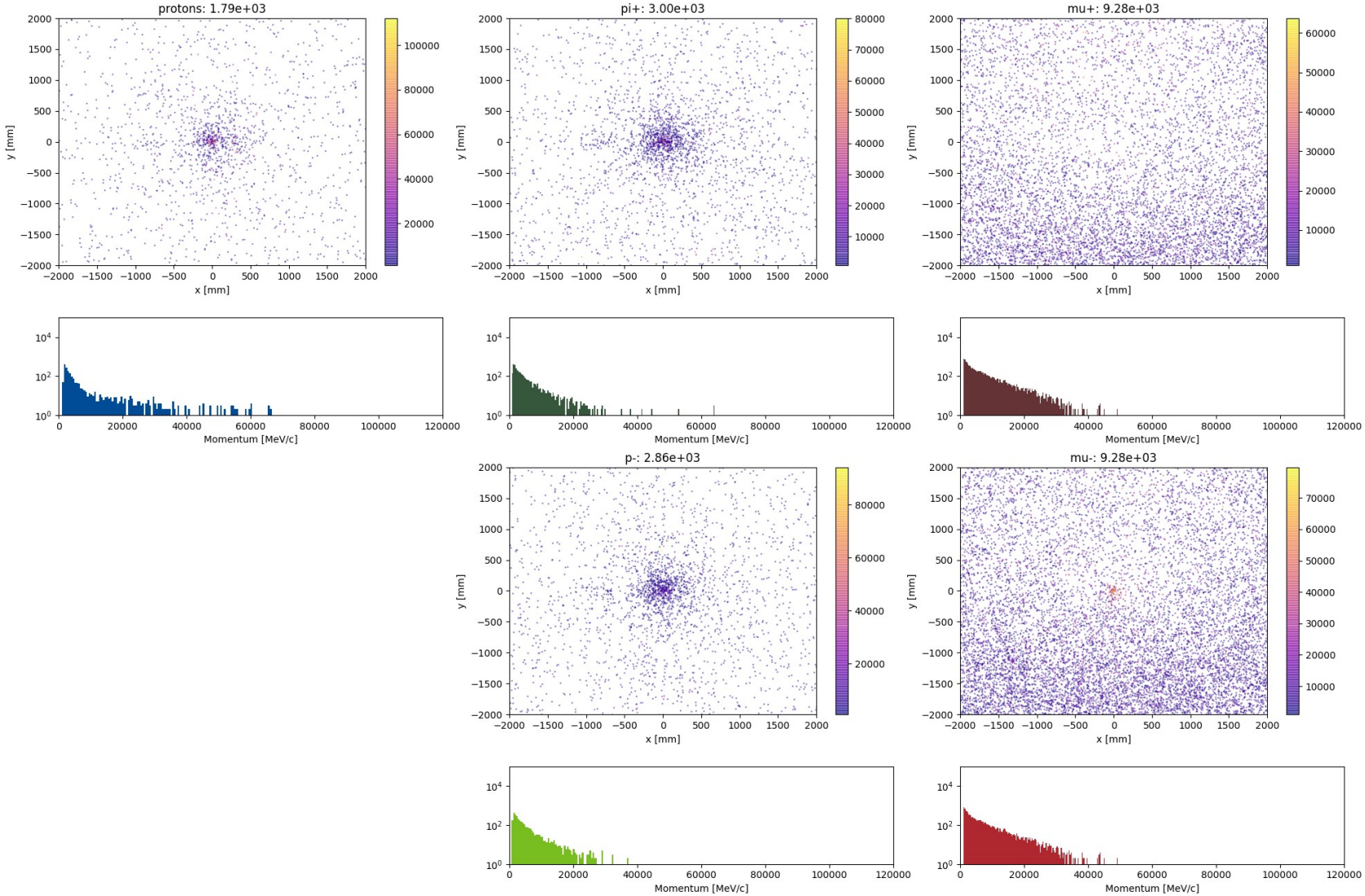


Detector 23



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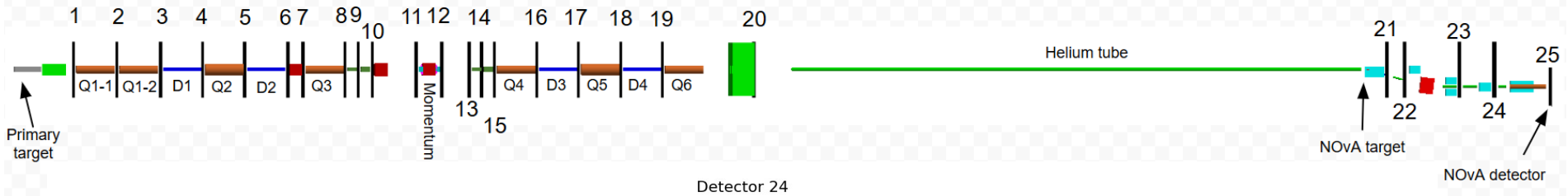
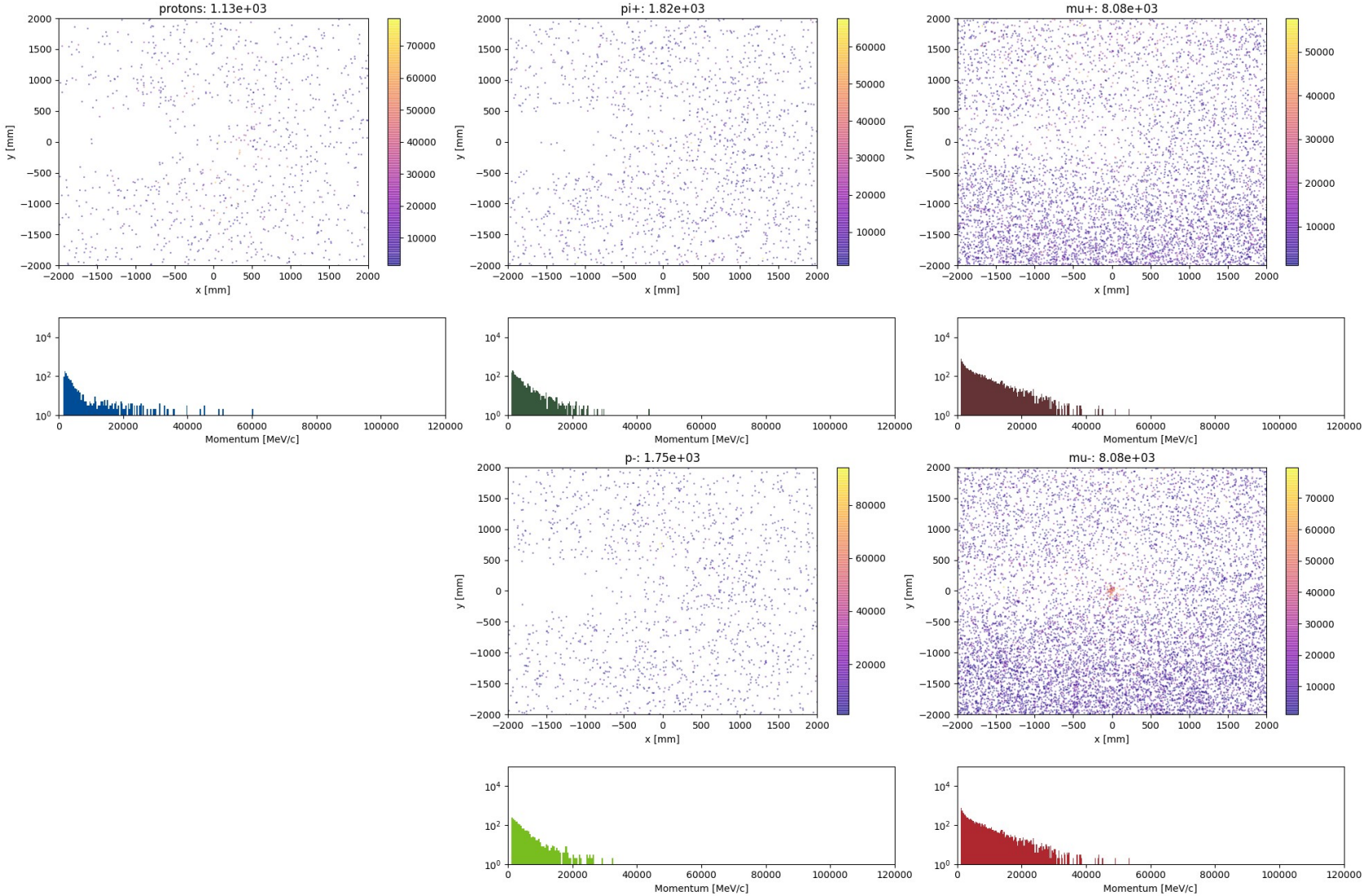


Detector 24



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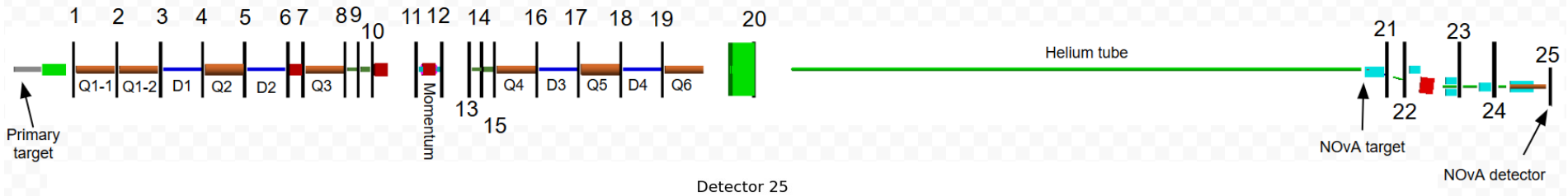
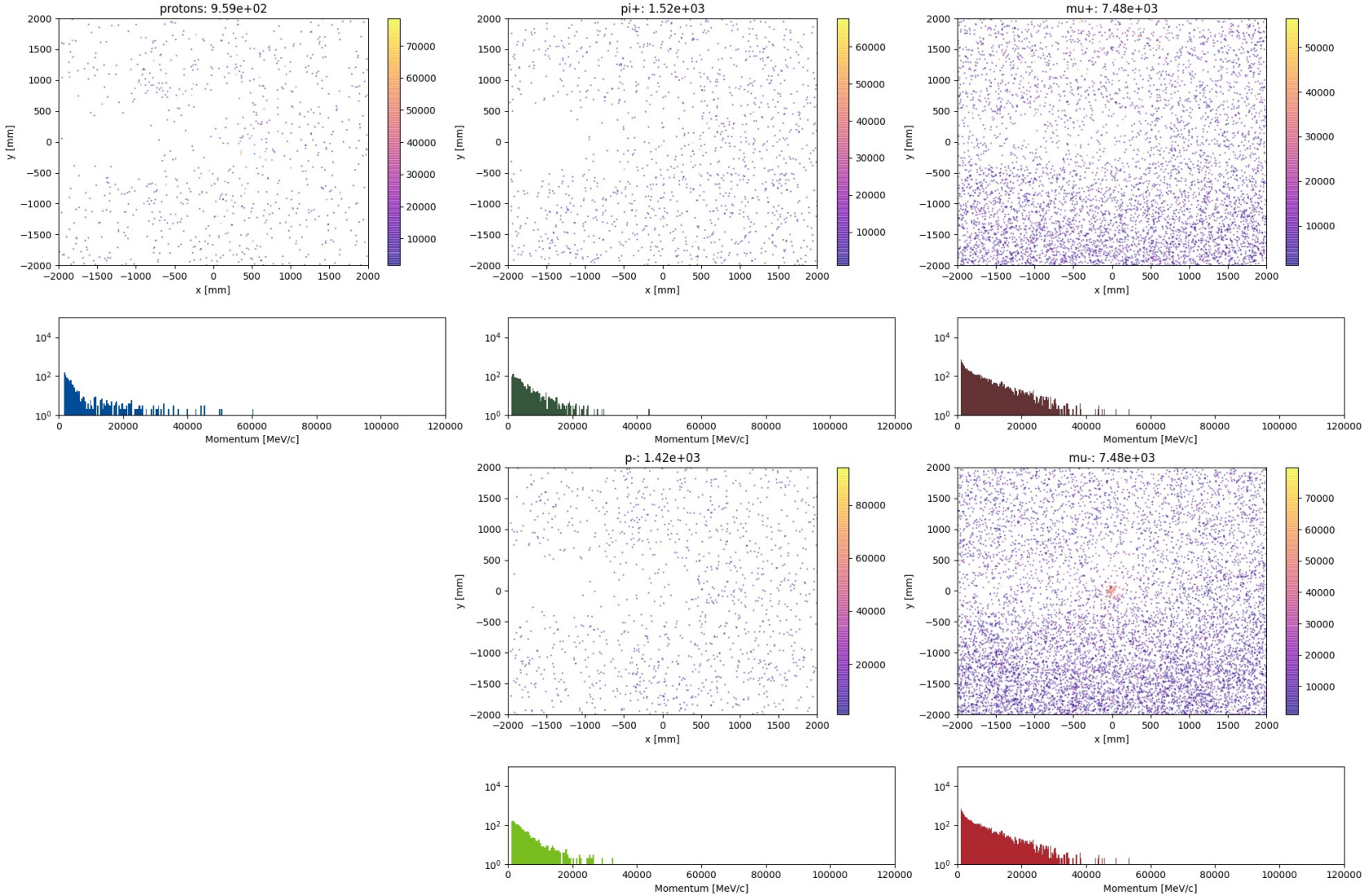


Detector 25



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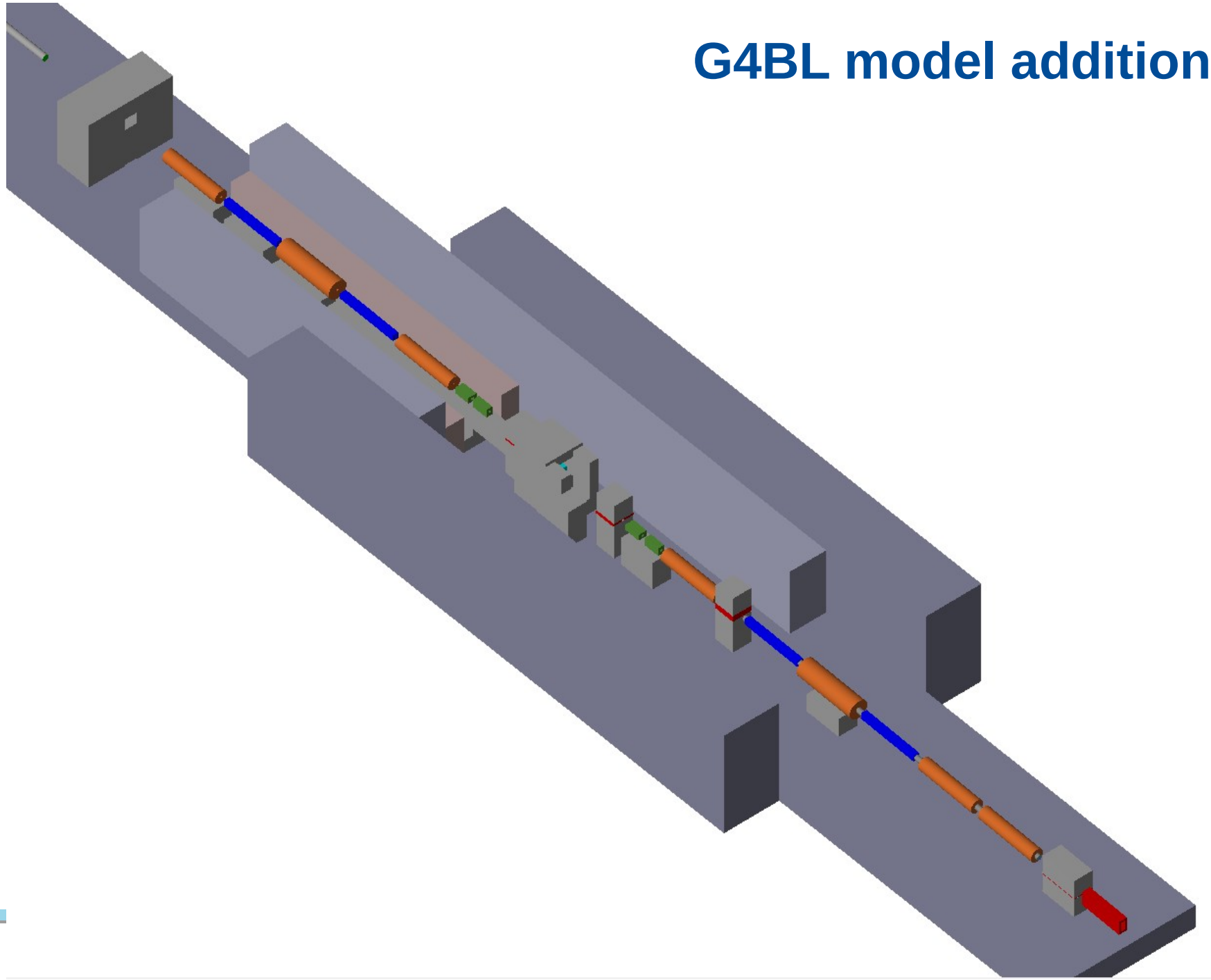
G4BL model additions

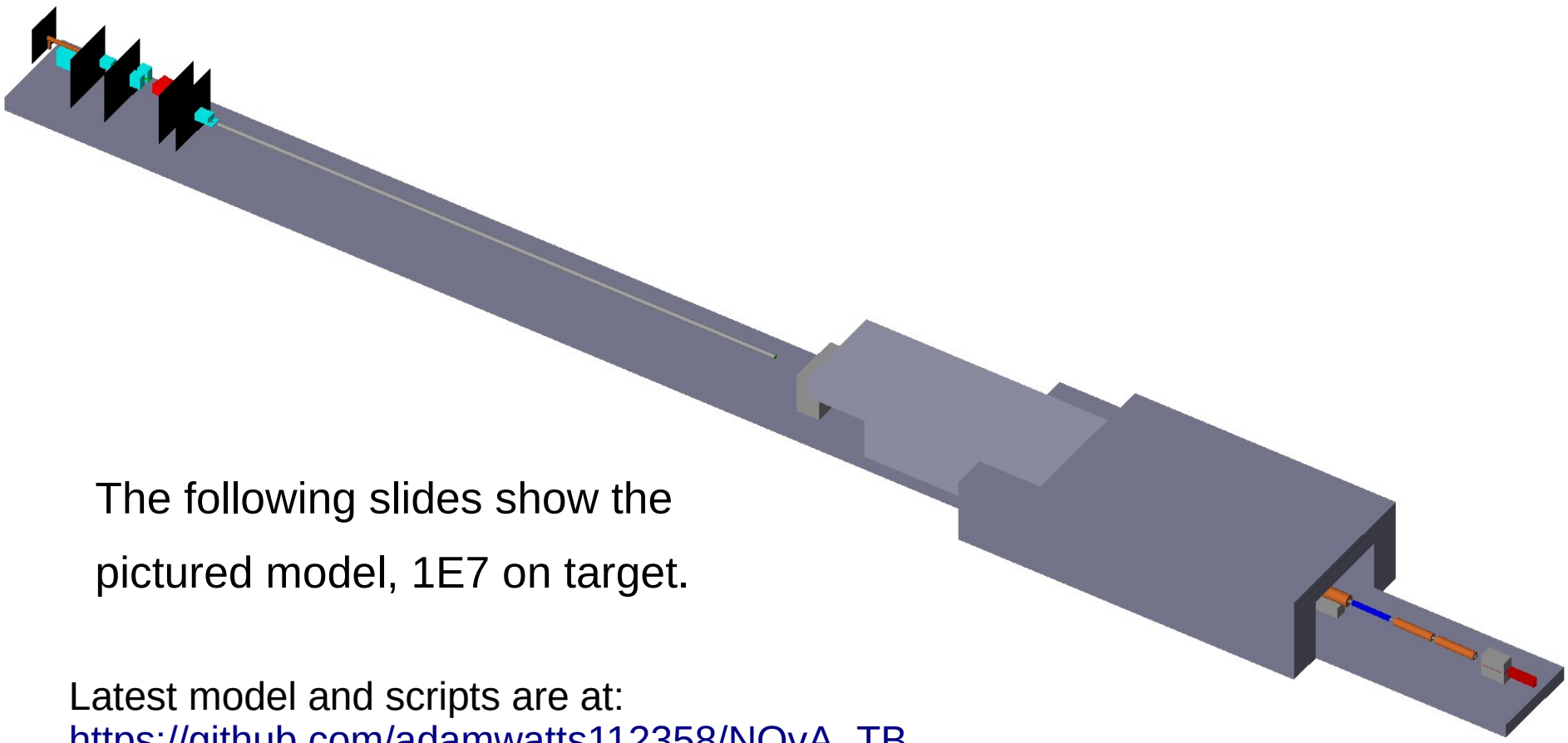
Currently working on adding the following to the G4BL model:

- MC6 shielding, enclosure walls/floor (complete, see next two slides)
- Remove any geometry collision errors that could skew data picked up by virtual detectors (complete)
- MC7 shielding blocks and equipment; thanks for Yagmur, Mike, and Dave for local measurements during their walk-through this week
- Magnetic fields in the magnet yoke iron.

G4BL model additions



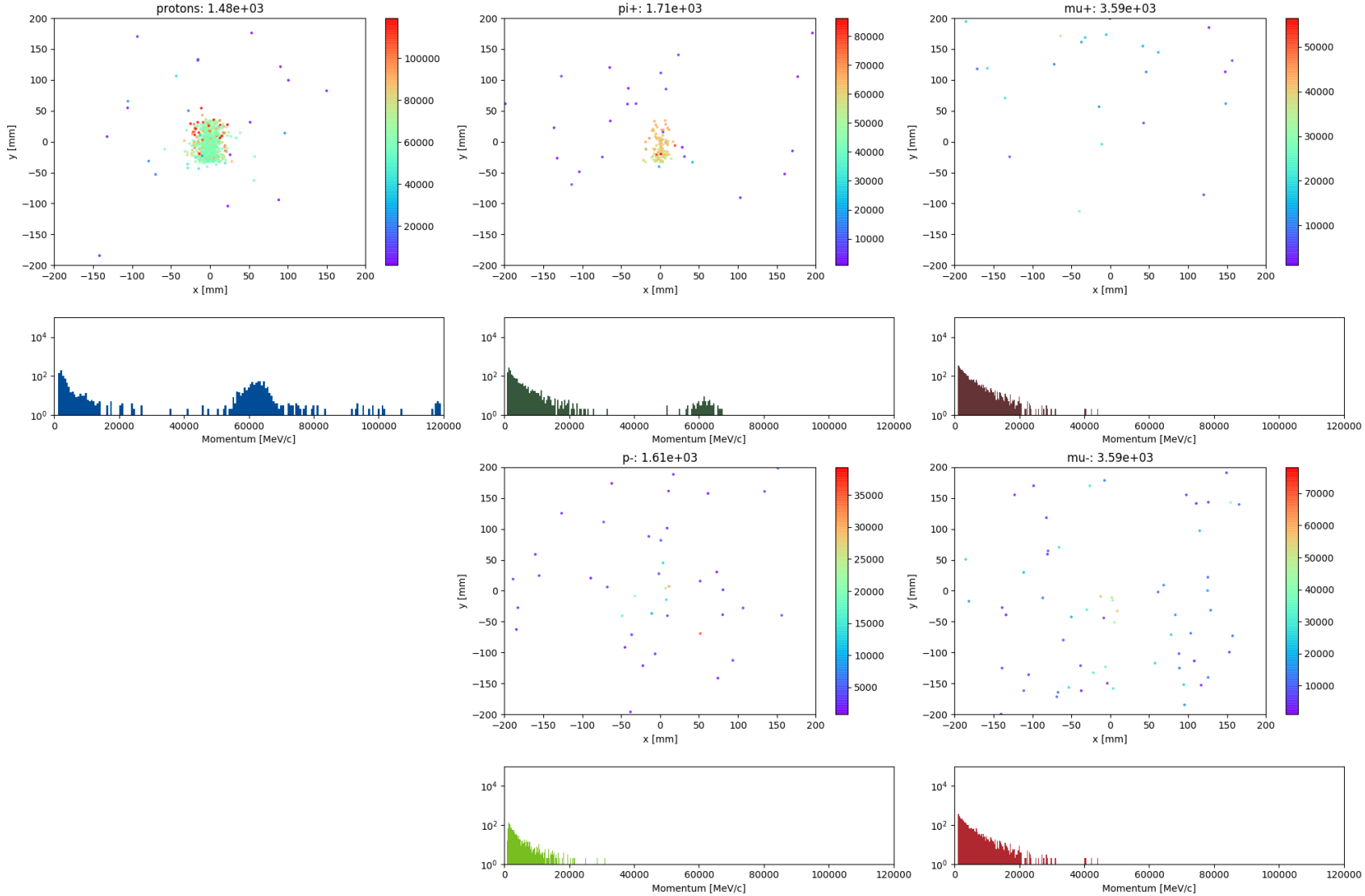
G4BL model additions



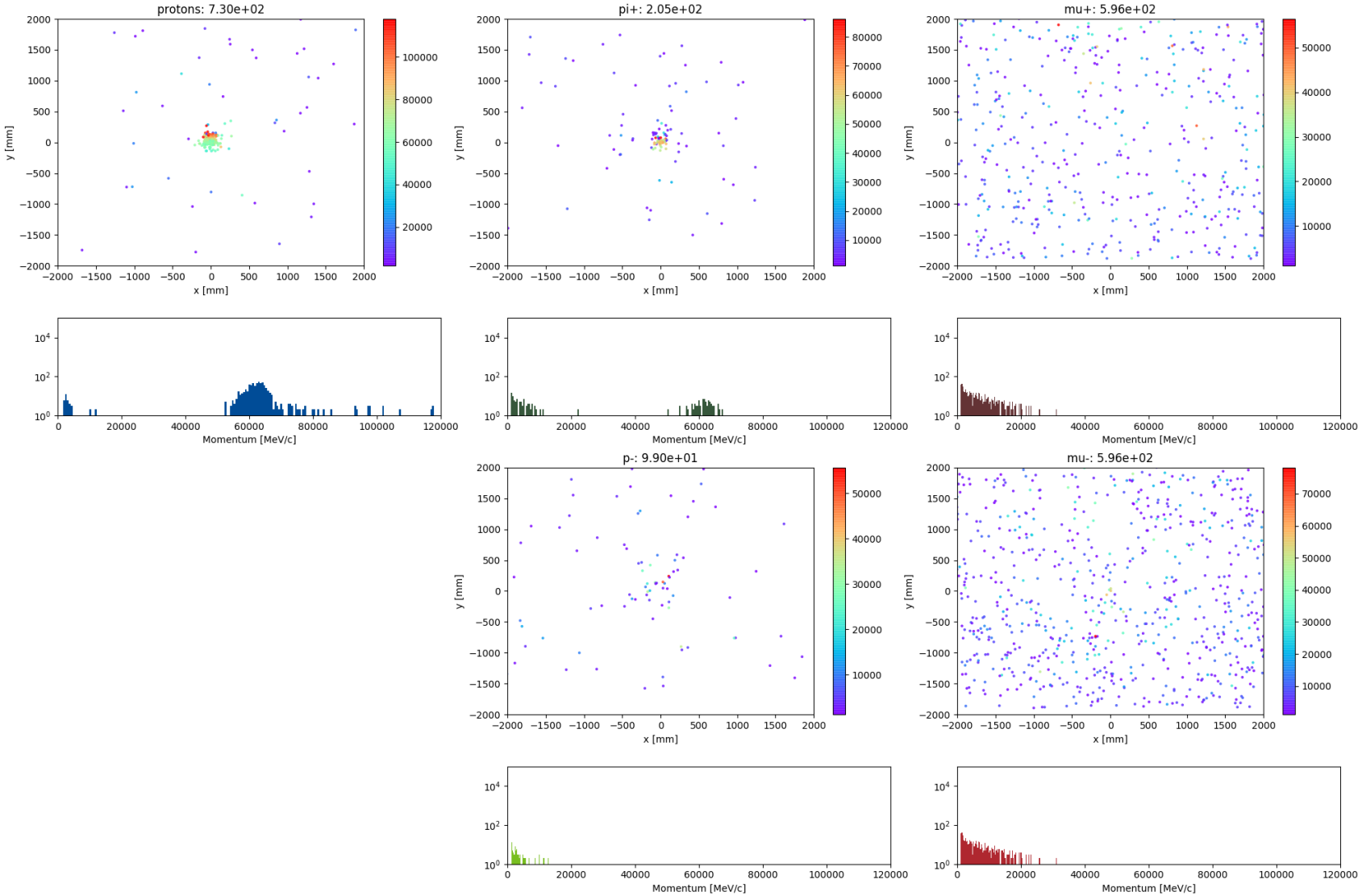
The following slides show the pictured model, 1E7 on target.

Latest model and scripts are at:
https://github.com/adamwatts112358/NOvA_TB

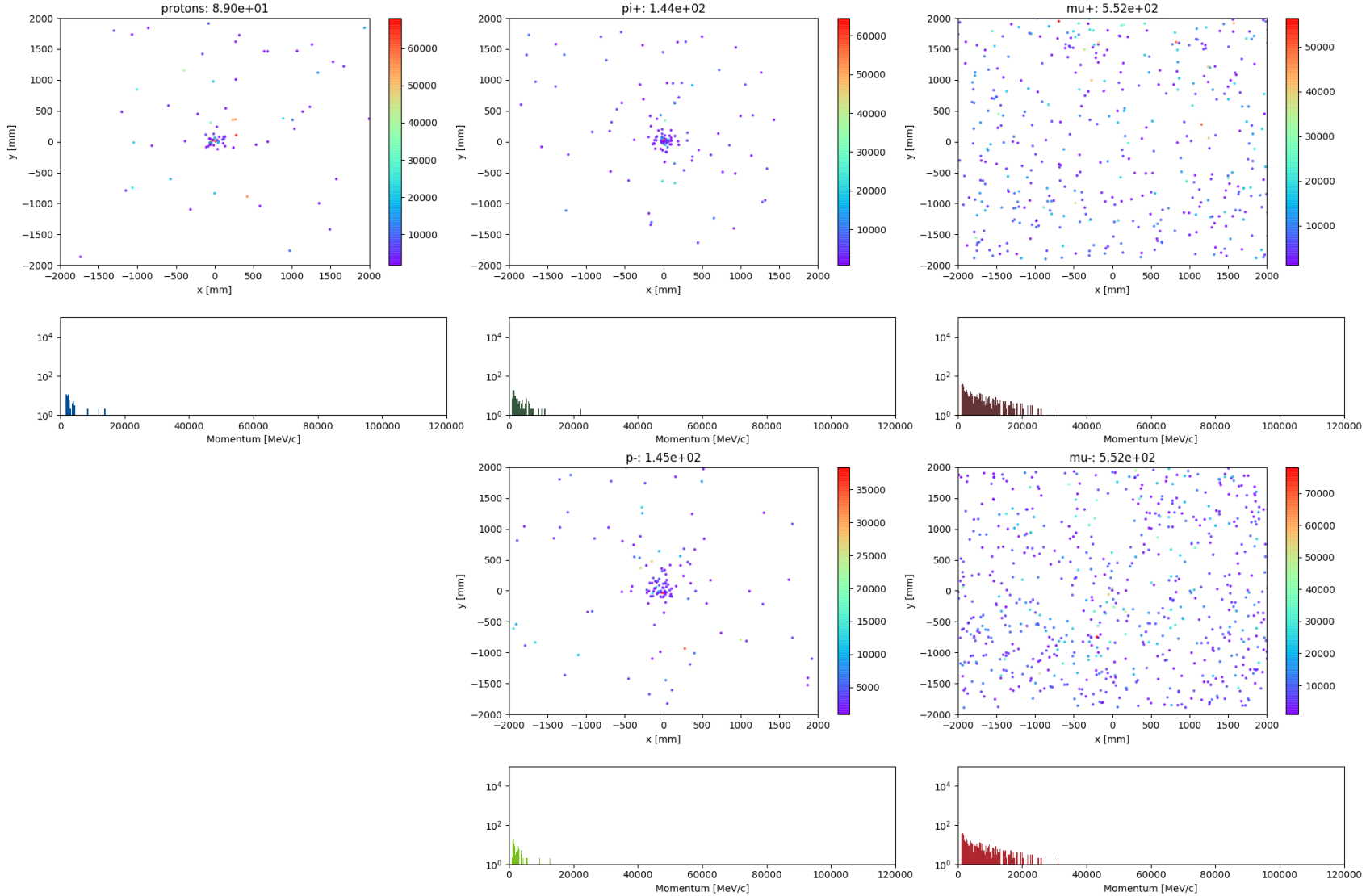
Detector 20_0



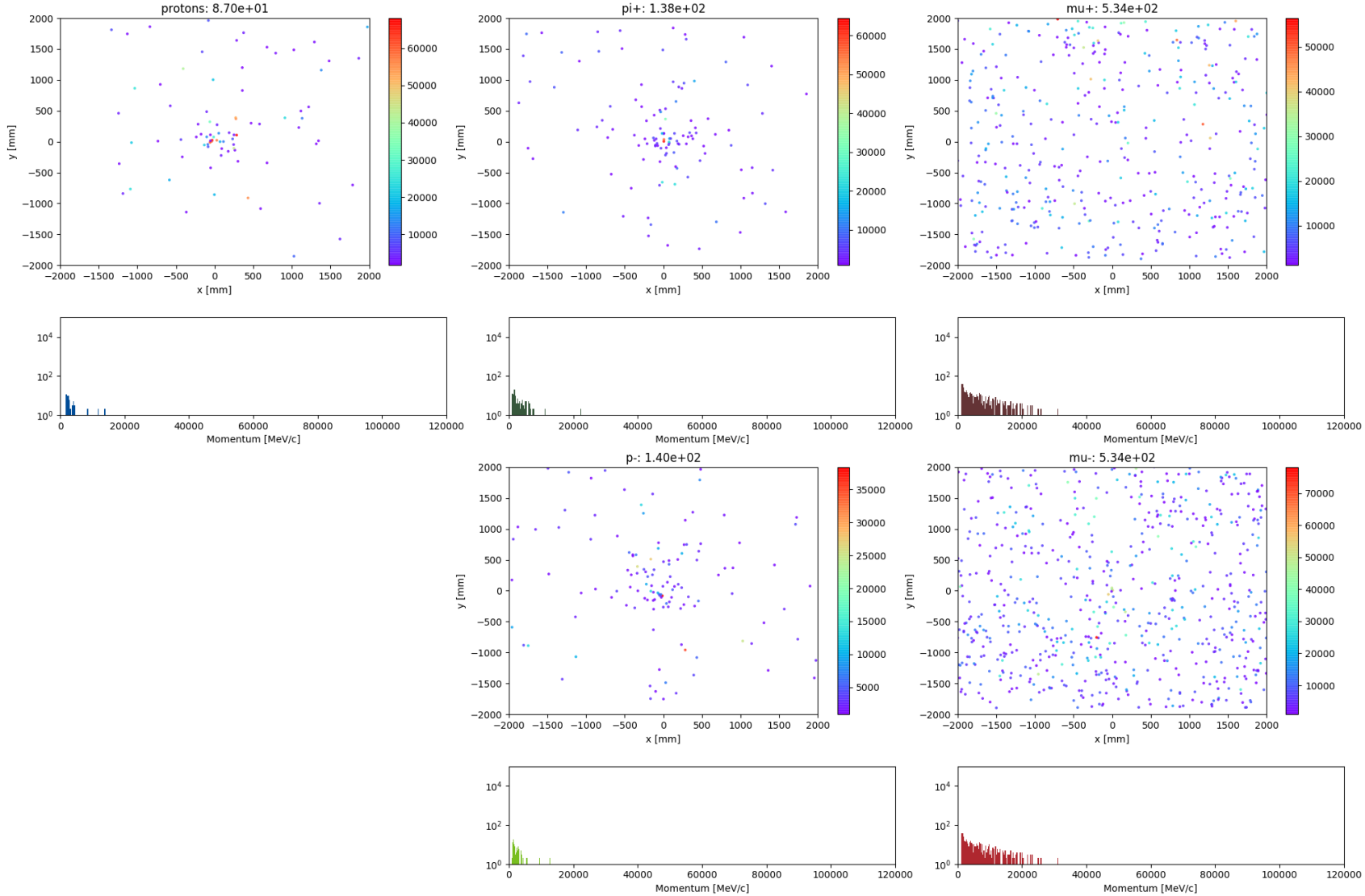
Detector 21_0



Detector 22_0



Detector 23_0

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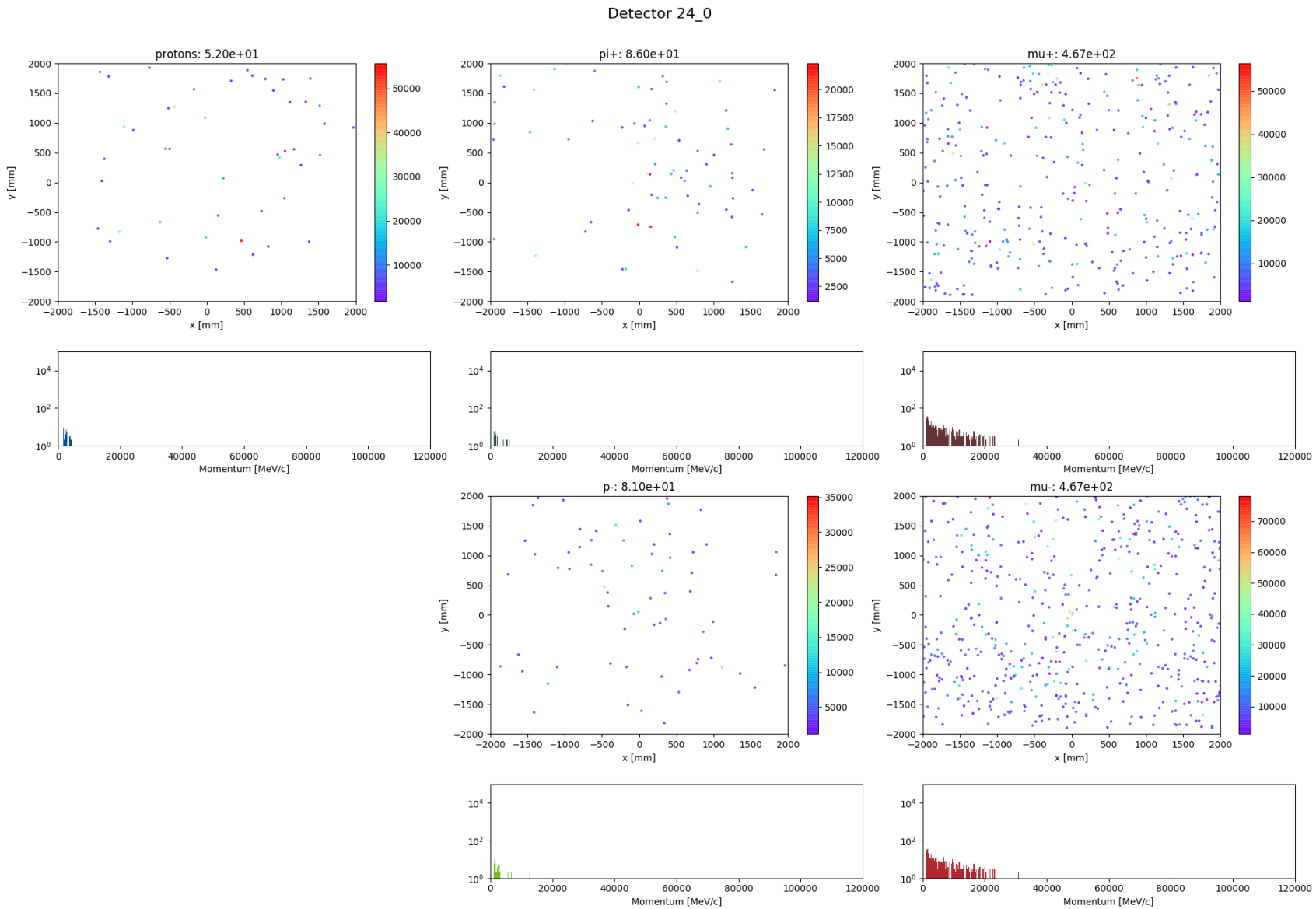
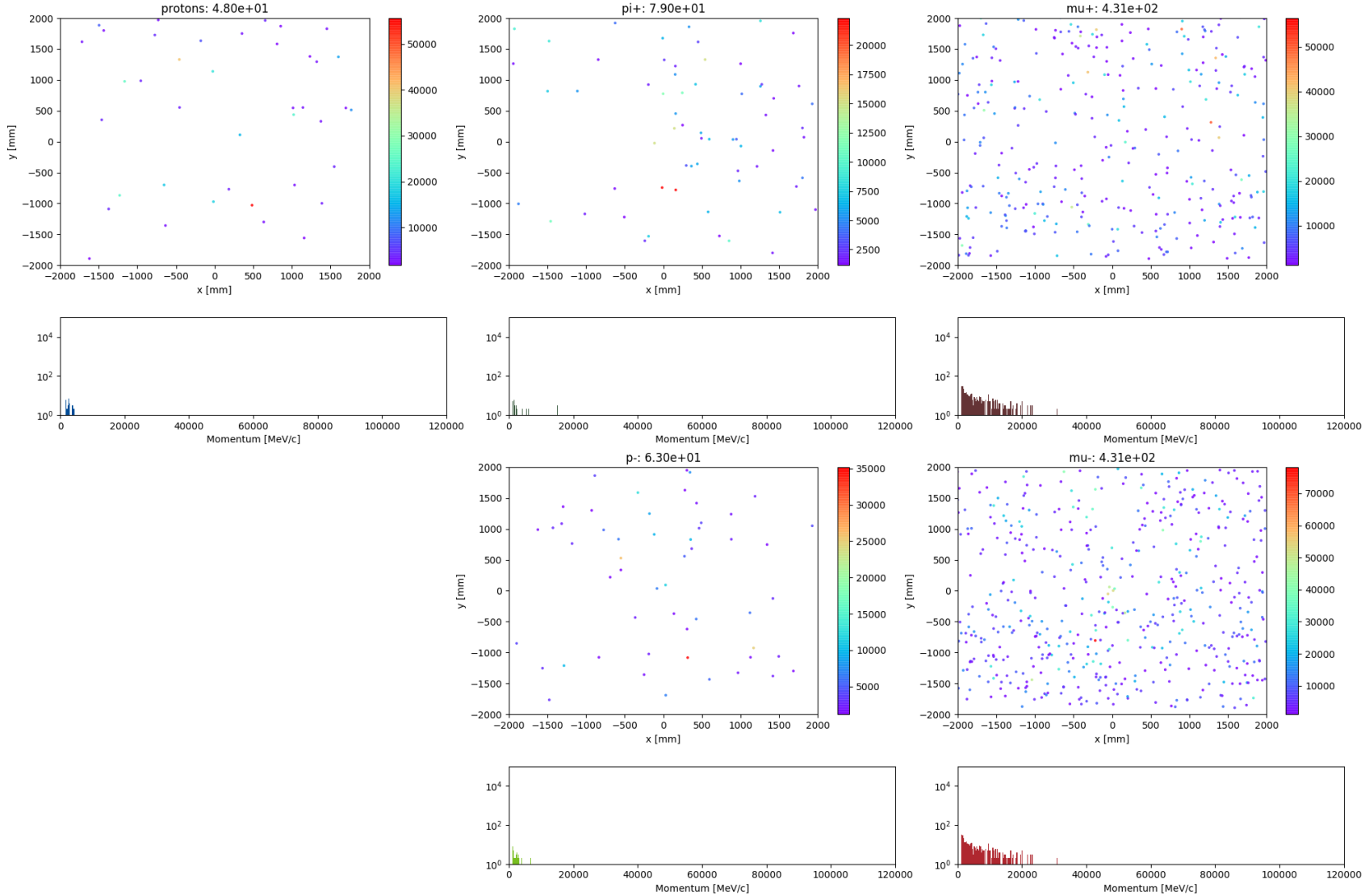

Detector 24_0
protons: 5.20e+01
pi+: 8.60e+01
mu+: 4.67e+02
p-: 8.10e+01
mu-: 4.67e+02
x [mm]
y [mm]
Momentum [MeV/c]

Detector 25_0




20
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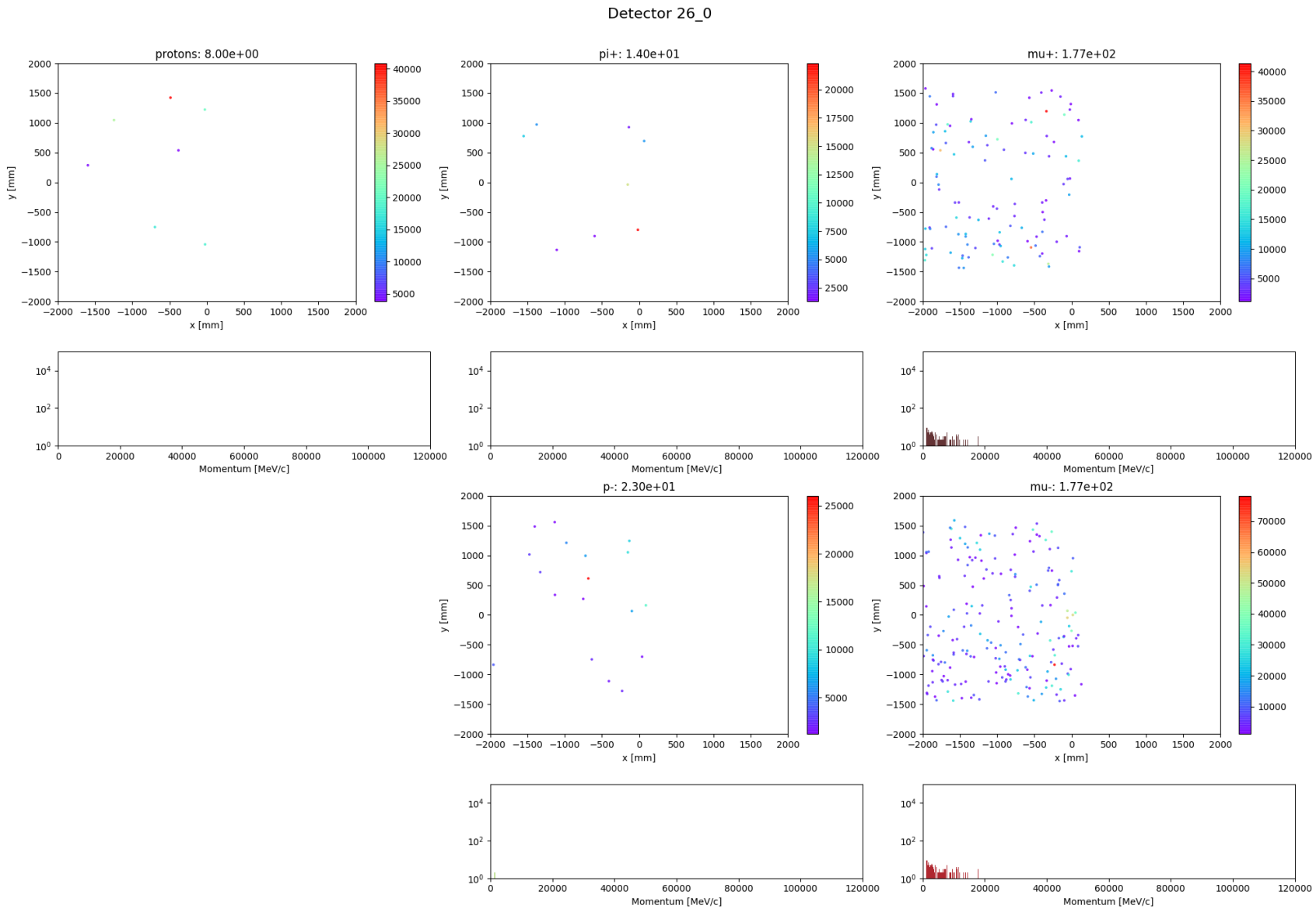
Detector 26_0
protons: 8.00e+00
pi+: 1.40e+01
mu+: 1.77e+02
p-: 2.30e+01
mu-: 1.77e+02
x [mm]
y [mm]
Momentum [MeV/c]

Takeaway, next steps

Takeaway:

- Plume not yet recreated in simulation
- Seeing vertical primary/secondary separation in G4BL output
- Beam very clearly hitting Q3 magnet aperture and scraper as predicted by TRANSPORT
- No obvious plume at +60cm on NOvA detector without shielding or yoke fields
- Noticeable mu- punch-through on NOvA detector

Next steps:

- Finish adding dense material to model (shielding blocks, LArIAT range stack and target assembly, MIPP analyzing magnets, etc.)
- Re-define beamline magnets to have realistic yoke shapes and fields
- Run batch jobs for 1E9 on target, using only the last 5 detectors
- If halo is recreated in simulation
  - Track plume particles back to determine origin; try extra shielding or spoiler coil at origin
  - Close down momentum-selection collimator in MC6 to see if plume goes away in agreement with beam studies
  - Try thicker/wider primary targets

Short and Long Term Possibilities

Impossible to determine correct long-term mitigation effort without understanding the cause of the plume.

However, these are potential ideas:

Short-term:

- Movable scintillator array to pinpoint plume origin (NOvA TB)
- Check magnet polarities (AD)
- Check magnet inductances to look for coil-to-coil shorts (AD)
- Run with no primary target to see if plume persists

Long term potential steps:

- 120 GeV/c primary protons all the way to NOvA test beam target.
  - Requires interlocked pinhole collimators, shielding assessment required (addendum?)
- Longer target in MC6
- Move primary target upstream to M02 enclosure
  - How much longer is the baseline?
  - Additional optics needed?
  - Shielding assessment required (addendum?)
- Send < 120 GeV/c beam from Main Injector
  - Affects all other Switchyard experiments (MTest, SpinQuest)
  - Requires re-tuning of MI slow extraction and all beamlines

Thank you.