
Target Studies for Pion Production

Large Scale Simulations

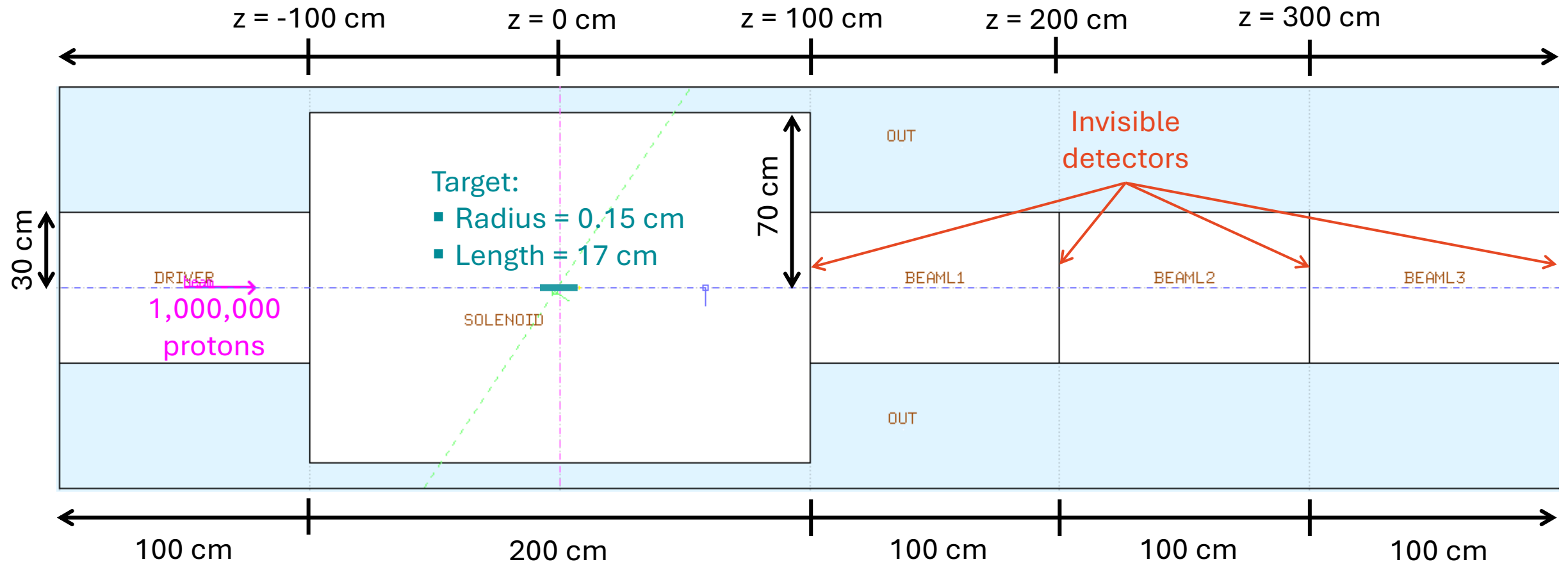


9/14/2026

Ruaa Alharthy

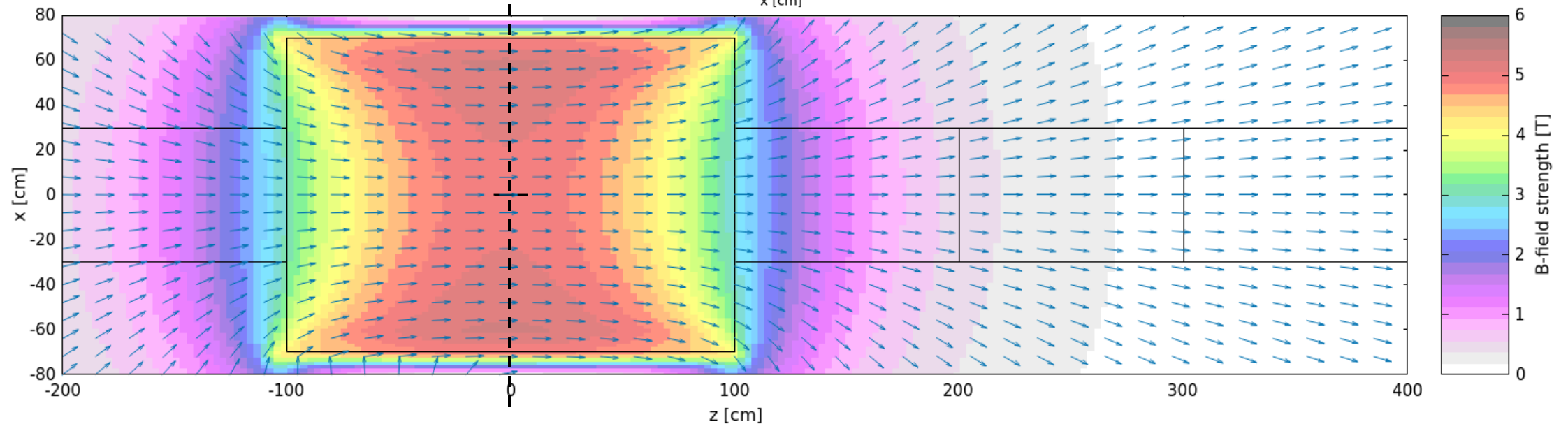
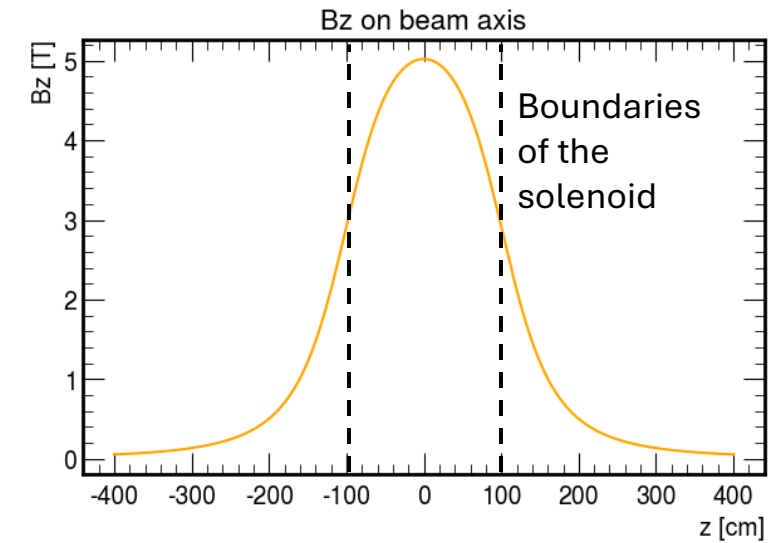
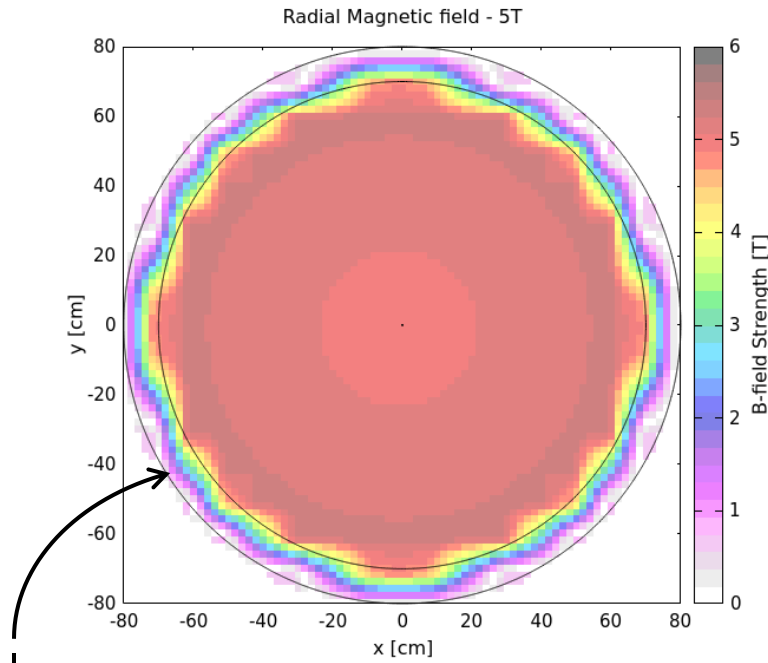
Shielding Module.
To protect heads

Geometry Setup



Magnetic Field Topology

- Magnetic fieldmaps for 0T & 3T – 10T were created.



Large-Scale Simulations

- Successfully completed nine simulations (0T, 3-10T), each using 1,000,000 primary protons, an increase from the previous 100,000 primary simulations.
- Since the full-scale simulations cannot be run in a single job, each simulation was divided into 10 spawns. This took a very long time to complete.
- Each spawn has a distinct random seed. The same set of random seeds was used for 3-10T simulations, and a different set of random seeds was used for the 0T simulation. This is because the 0T simulation crashes if I used the same random seeds. → *This needs to be further investigated.*
- All simulation output files have been stored in /nfs_scratch/. The total size of all output files is 10GB.
- Implemented a variable to identify the mother of the particle currently being tracked. The variable appears to be working well.

**How were the
pions
produced?**

π^+ production sorted by mother particle

B(T)	Total
0	850027
3	901513
4	902996
5	902703
6	904074
7	904256
8	904128
9	904052
10	902273

- The **Total** column shows the total number of π^+ produced inside the Inconel target. Note that 1,000,000 primaries were used in these simulations.
- Simulations for 3-10T have a similar amount of π^+ produced while the 0T simulation seems to have a lower count for π^+ production in the target.
- This is because I used the same random seeds for simulations 3-10T and different random seeds for the 0T simulation. For some reason, using the same set of random seeds for the 0T simulation produced lots of errors, therefore, I ended up just using different random seeds.

π^+ production sorted by mother particle

B(T)	Total	Proton
0	850027	0.957450
3	901513	0.957200
4	902996	0.957352
5	902703	0.957199
6	904074	0.957426
7	904256	0.956962
8	904128	0.957263
9	904052	0.956791
10	902273	0.956631

- The entries in the **Proton** column represent the ratio of π^+ that was produced by protons in the target.
- Recording ratios made more sense here since they are not affected by the fluctuations in π^+ production values.
- The ratios of π^+ produced by protons are similar across all simulations, which matches my expectations.
- The last row in the table shows the average ratio of the ratios obtained from all simulations.

π^+ production sorted by mother particle

B(T)	Total	Proton	Neutron
0	850027	0.957450	0.011088
3	901513	0.957200	0.011186
4	902996	0.957352	0.011269
5	902703	0.957199	0.011368
6	904074	0.957426	0.011140
7	904256	0.956962	0.011331
8	904128	0.957263	0.011159
9	904052	0.956791	0.011388
10	902273	0.956631	0.011178
Average		0.957142	0.011234

- Same thing applies for other columns.

π^+ production sorted by mother particle

B(T)	Total	Proton	Neutron	Pi+
0	850027	0.957450	0.011088	0.023742
3	901513	0.957200	0.011186	0.023851
4	902996	0.957352	0.011269	0.023682
5	902703	0.957199	0.011368	0.023662
6	904074	0.957426	0.011140	0.023664
7	904256	0.956962	0.011331	0.023908
8	904128	0.957263	0.011159	0.023798
9	904052	0.956791	0.011388	0.024050
10	902273	0.956631	0.011178	0.024353
Average		0.957142	0.011234	0.023857

- Same thing applies for other columns.

π^+ production sorted by mother particle

B(T)	Total	Proton	Neutron	Pi+	Pi-
0	850027	0.957450	0.011088	0.023742	0.004233
3	901513	0.957200	0.011186	0.023851	0.004212
4	902996	0.957352	0.011269	0.023682	0.004175
5	902703	0.957199	0.011368	0.023662	0.004148
6	904074	0.957426	0.011140	0.023664	0.004126
7	904256	0.956962	0.011331	0.023908	0.004252
8	904128	0.957263	0.011159	0.023798	0.004243
9	904052	0.956791	0.011388	0.024050	0.004152
10	902273	0.956631	0.011178	0.024353	0.004175
Average		0.957142	0.011234	0.023857	0.004191

- Same thing applies for other columns.

π^+ production sorted by mother particle

Mother particle type: The entries in these columns are the ratio of pions that were produced by the corresponding mother.

B(T)	Total	Proton	Neutron	Pi+	Pi-	Kaon+	Kaon-	K-zero	AK-zero	Lambda	Sigma+	Sigma-
0	850027	0.957450	0.011088	0.023742	0.004233	0.000340	0.000042	0.001219	0.000321	0.000384	0.000038	0.001134
3	901513	0.957200	0.011186	0.023851	0.004212	0.000334	0.000040	0.001228	0.000356	0.000368	0.000044	0.001177
4	902996	0.957352	0.011269	0.023682	0.004175	0.000374	0.000047	0.001203	0.000318	0.000391	0.000051	0.001132
5	902703	0.957199	0.011368	0.023662	0.004148	0.000389	0.000063	0.001226	0.000321	0.000443	0.000029	0.001149
6	904074	0.957426	0.011140	0.023664	0.004126	0.000387	0.000052	0.001236	0.000316	0.000416	0.000029	0.001202
7	904256	0.956962	0.011331	0.023908	0.004252	0.000365	0.000071	0.001186	0.000318	0.000364	0.000041	0.001195
8	904128	0.957263	0.011159	0.023798	0.004243	0.000393	0.000043	0.001158	0.000325	0.000373	0.000043	0.001197
9	904052	0.956791	0.011388	0.024050	0.004152	0.000413	0.000046	0.001187	0.000333	0.000414	0.000034	0.001186
10	902273	0.956631	0.011178	0.024353	0.004175	0.000393	0.000048	0.001257	0.000323	0.000393	0.000039	0.001204
Average		0.957142	0.011234	0.023857	0.004191	0.000376	0.000050	0.001211	0.000326	0.000394	0.000039	0.001175

π - production sorted by mother particle

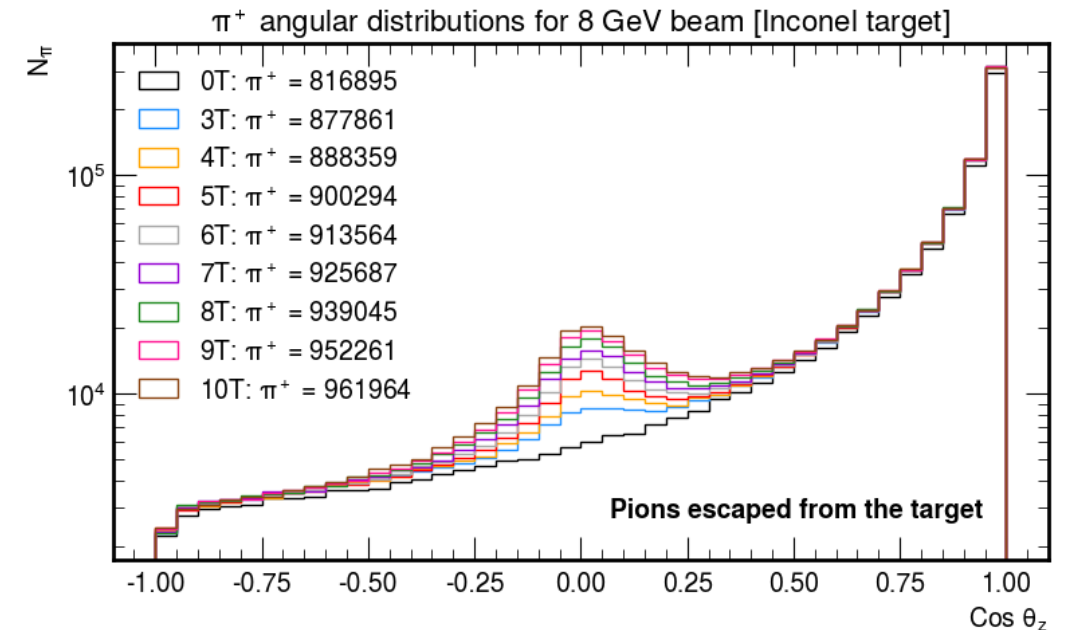
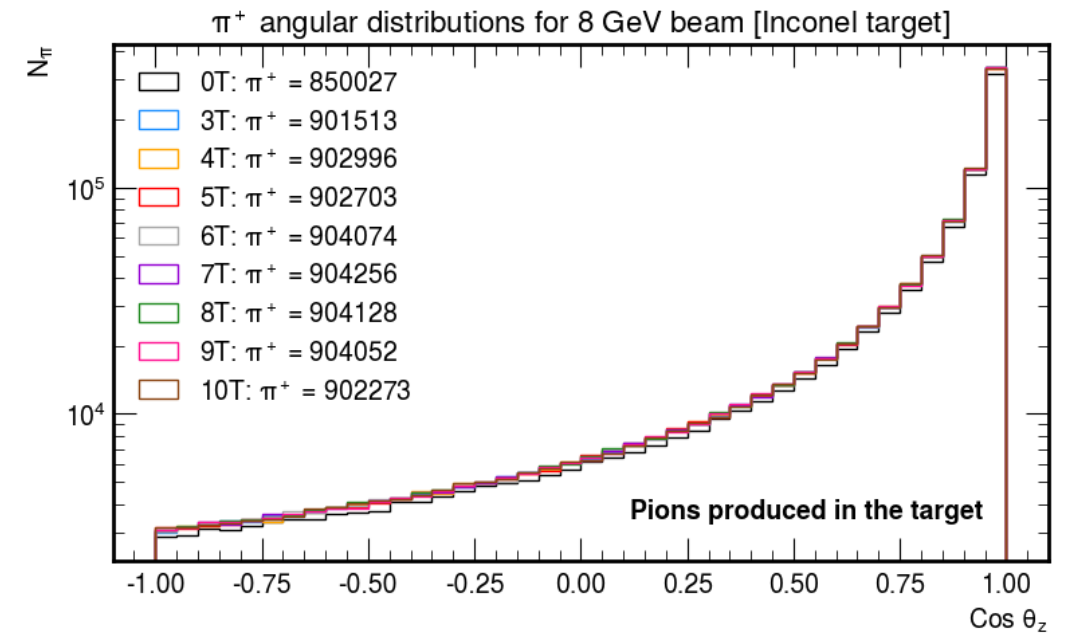
Mother particle type: The entries in these columns are the ratio of pions that were produced by the corresponding mother.

B(T)	Total	Proton	Neutron	Pi+	Pi-	Kaon+	Kaon-	K-zero	AK-zero	Lambda	Sigma-	Sigma+
0	691347	0.940437	0.022424	0.009369	0.021407	0.000171	0.000146	0.001626	0.000363	0.002504	0.001391	0.00014
3	734269	0.939925	0.022662	0.009408	0.021581	0.000169	0.000163	0.001591	0.000391	0.002679	0.001329	0.000095
4	735442	0.94057	0.022529	0.009223	0.021346	0.000203	0.000126	0.001575	0.000334	0.002486	0.001471	0.000114
5	733079	0.940211	0.022998	0.009041	0.021291	0.000192	0.000154	0.001621	0.000336	0.002569	0.001475	0.000108
6	736050	0.940671	0.022391	0.008855	0.021572	0.000194	0.000164	0.001643	0.000353	0.002622	0.001388	0.000137
7	735055	0.940472	0.02268	0.009152	0.021319	0.000188	0.000165	0.001573	0.000343	0.002607	0.00139	0.000102
8	735071	0.940456	0.022459	0.009111	0.021531	0.000159	0.000127	0.001556	0.000344	0.002668	0.001468	0.000112
9	734199	0.939881	0.022792	0.009188	0.021685	0.000174	0.000151	0.001606	0.00036	0.002631	0.001396	0.000118
10	734193	0.939512	0.022652	0.009184	0.021966	0.000206	0.000157	0.001681	0.000361	0.002709	0.001434	0.000127
Average		0.940237	0.022621	0.009170	0.021522	0.000184	0.000150	0.001608	0.000354	0.002608	0.001416	0.000117

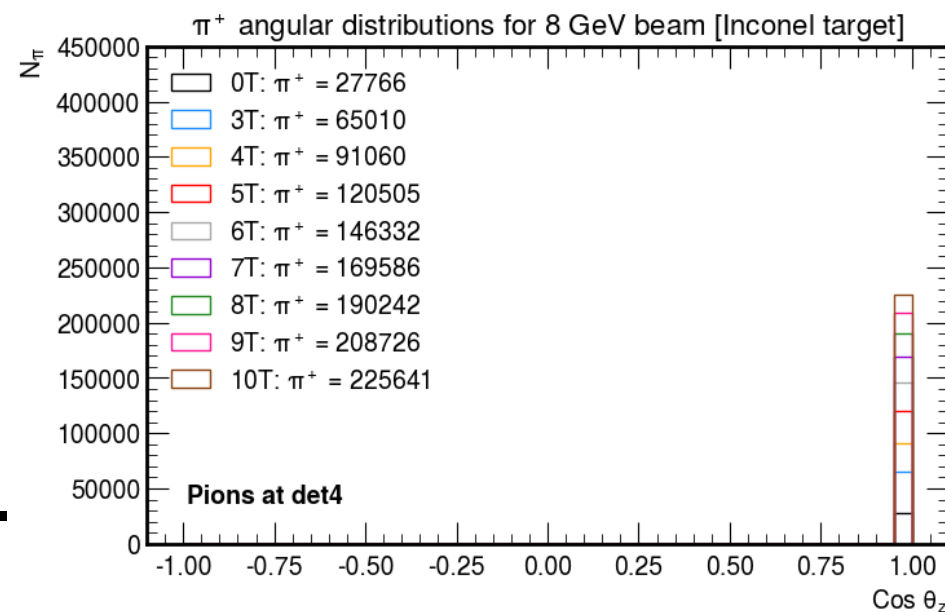
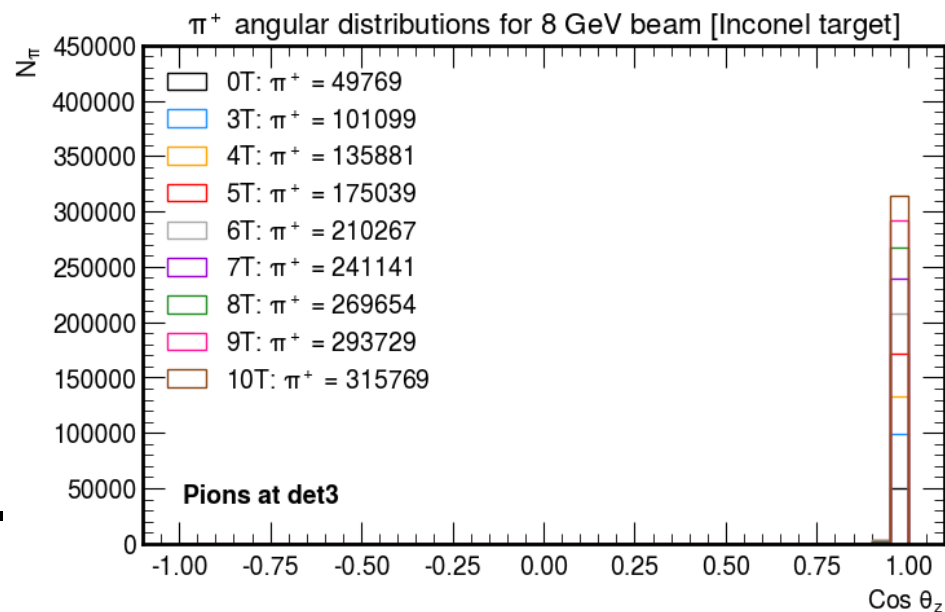
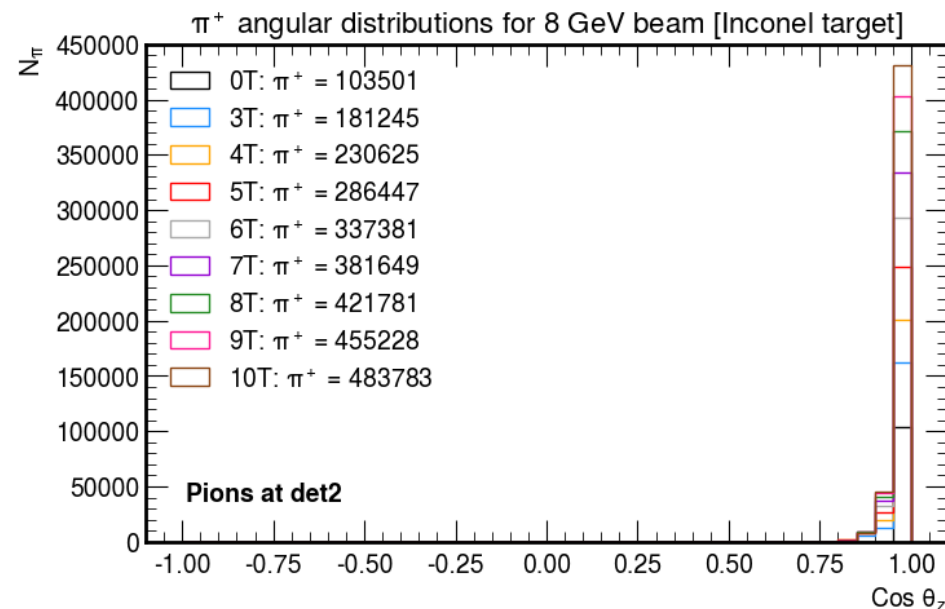
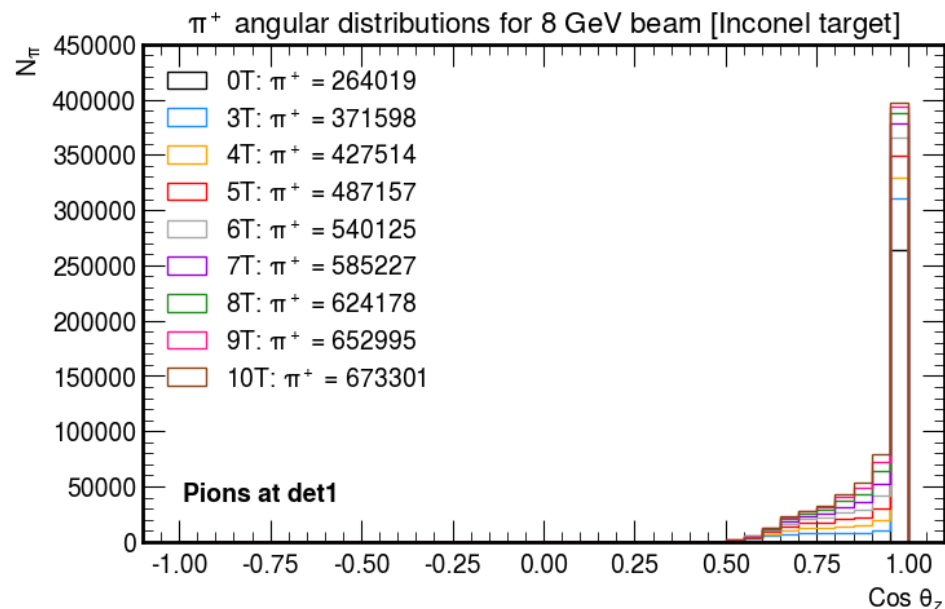
Kinematic distributions of the pions

Angular distribution

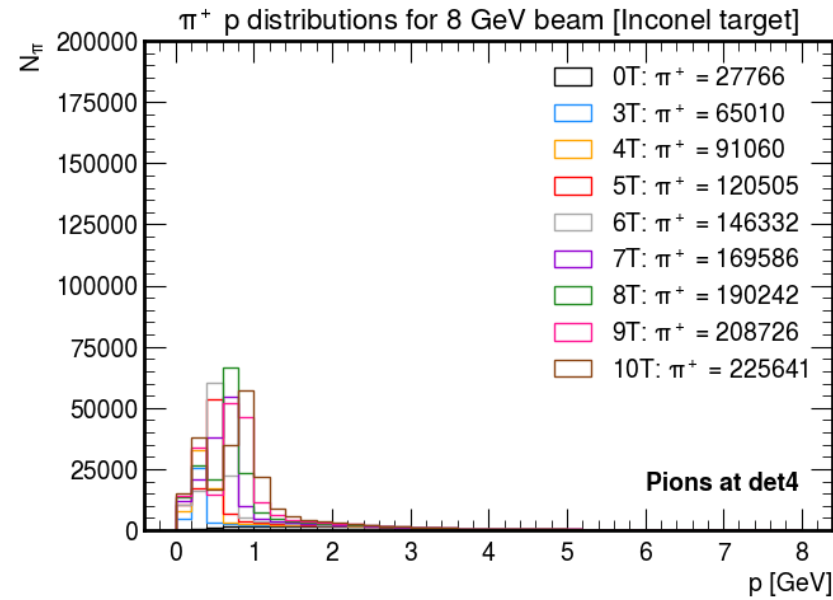
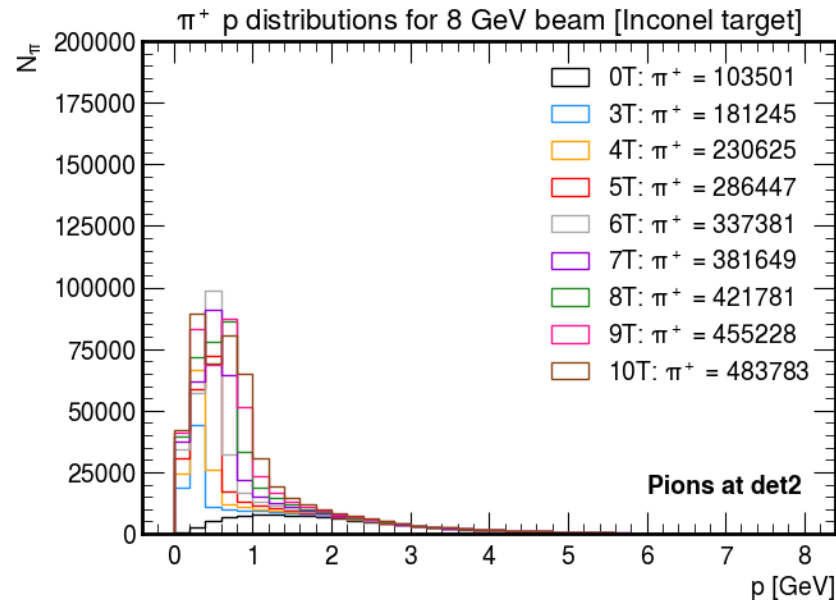
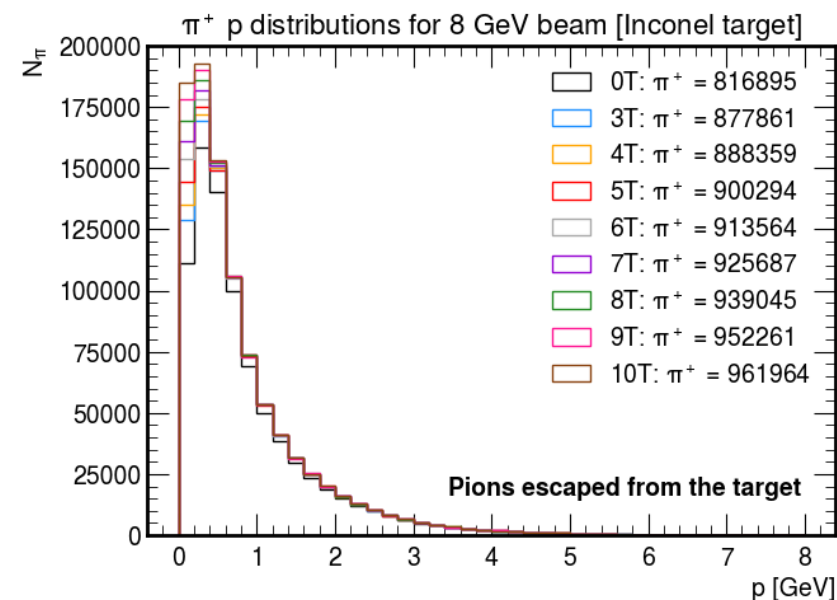
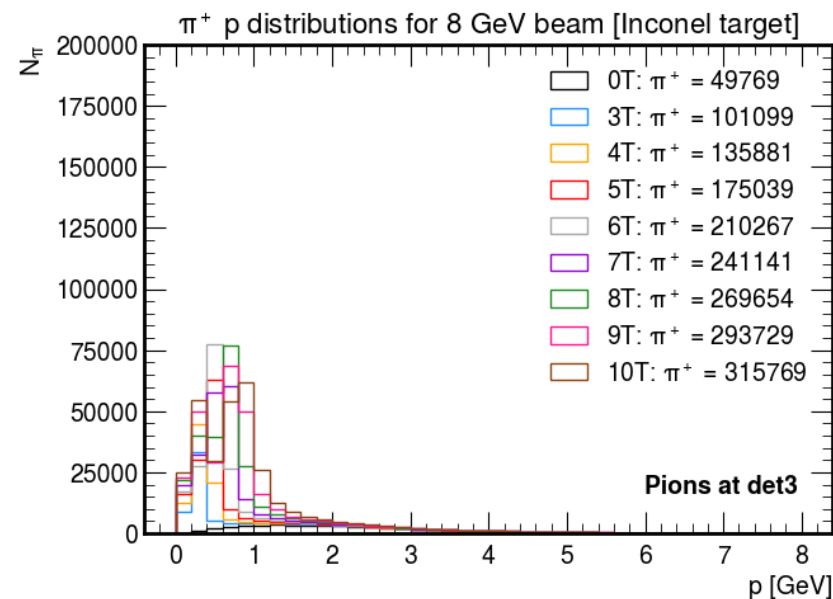
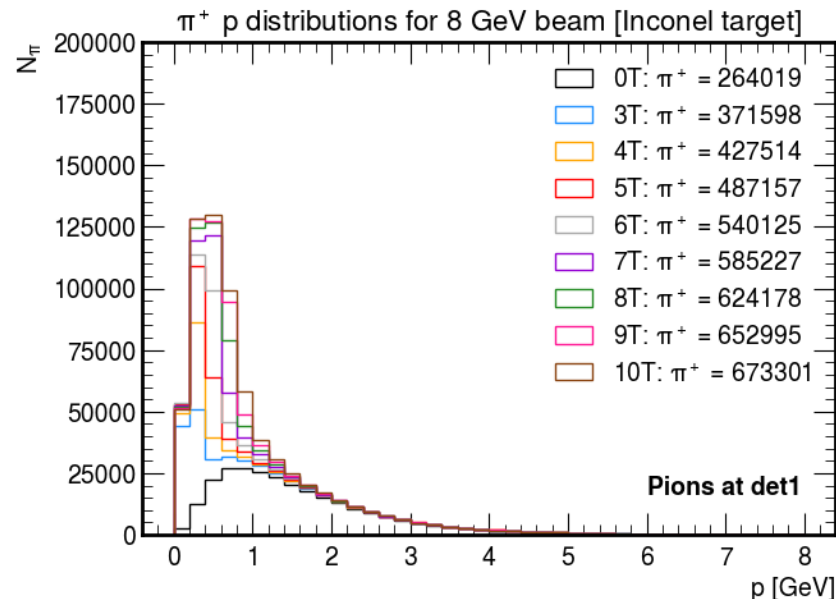
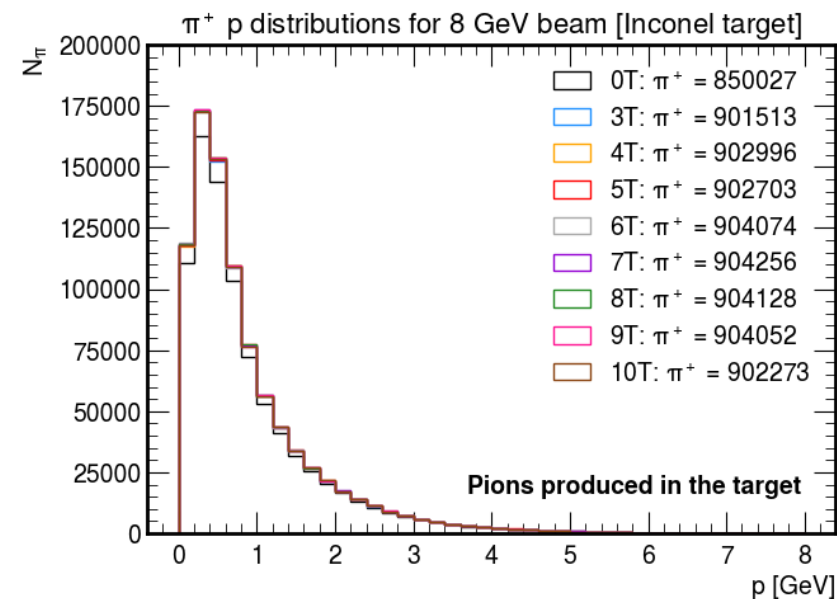
- The following are angular distributions of pions that are produced inside the target and those that have escaped the target.
- Θ_z is the angle of the momentum of the particle w.r.t the beam axis.
- $\cos \Theta_z = 1$ means that the pion's momentum is completely along the beam axis.
- $\cos \Theta_z = 0$ means that the pion's momentum is perpendicular to the beam axis.



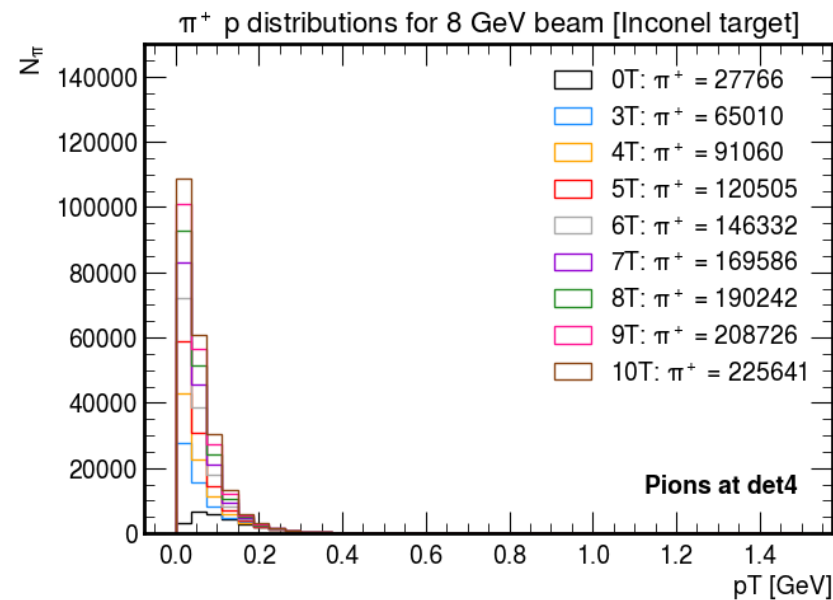
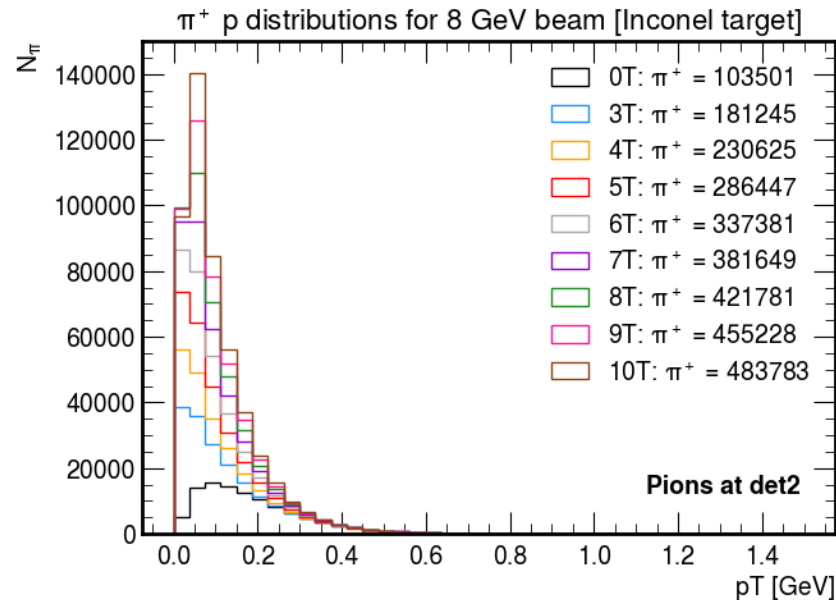
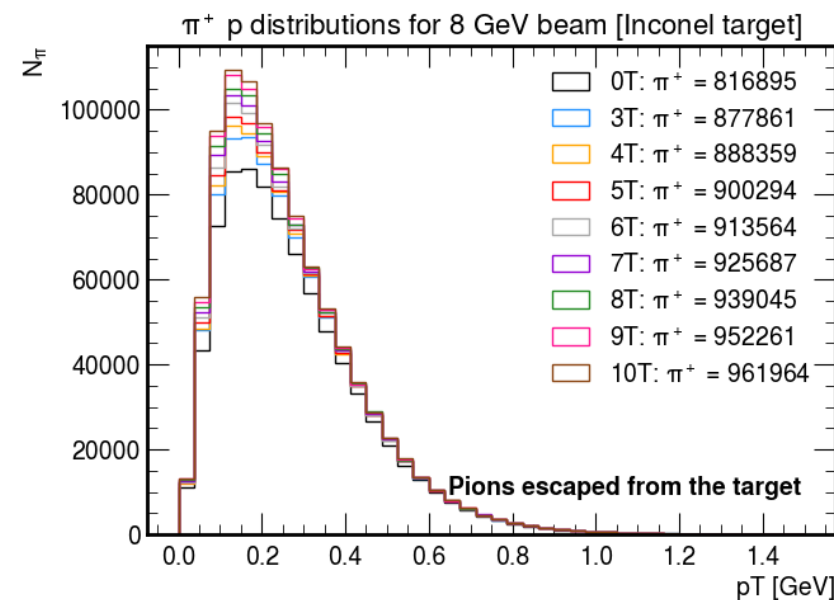
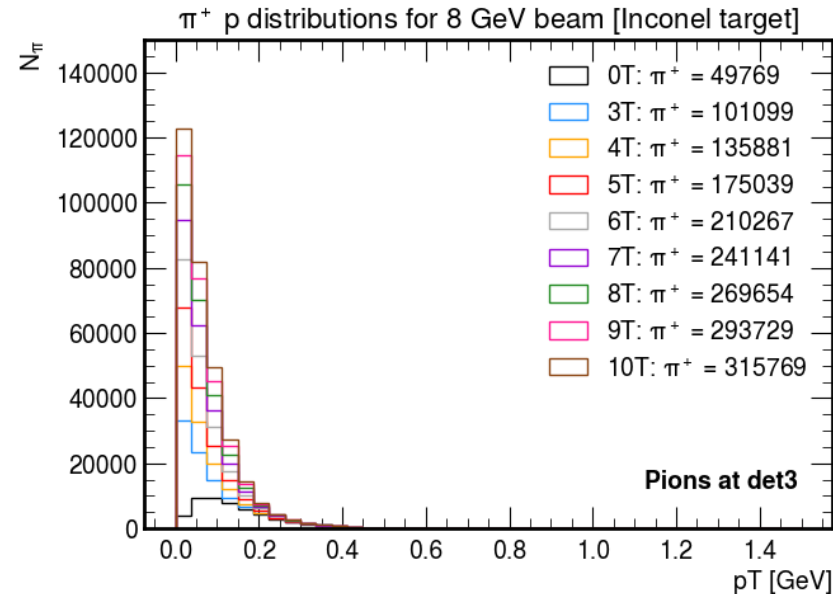
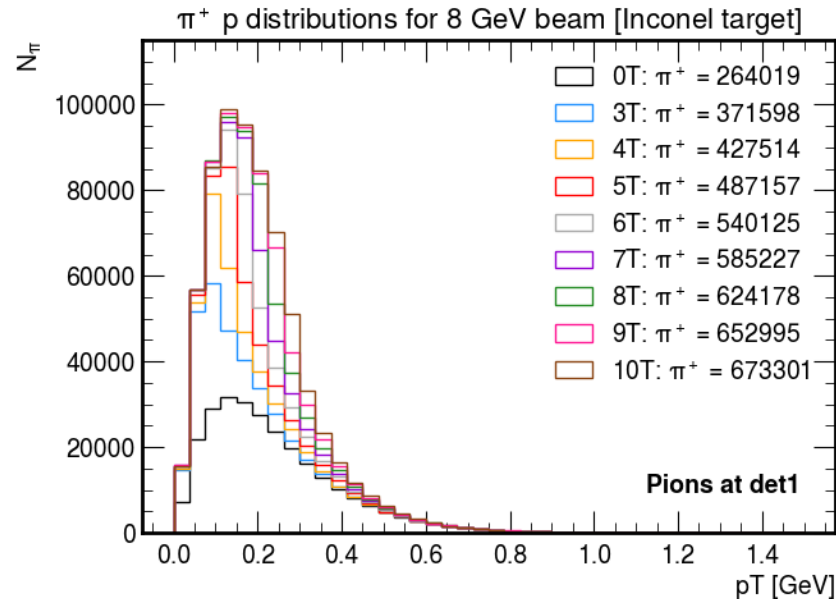
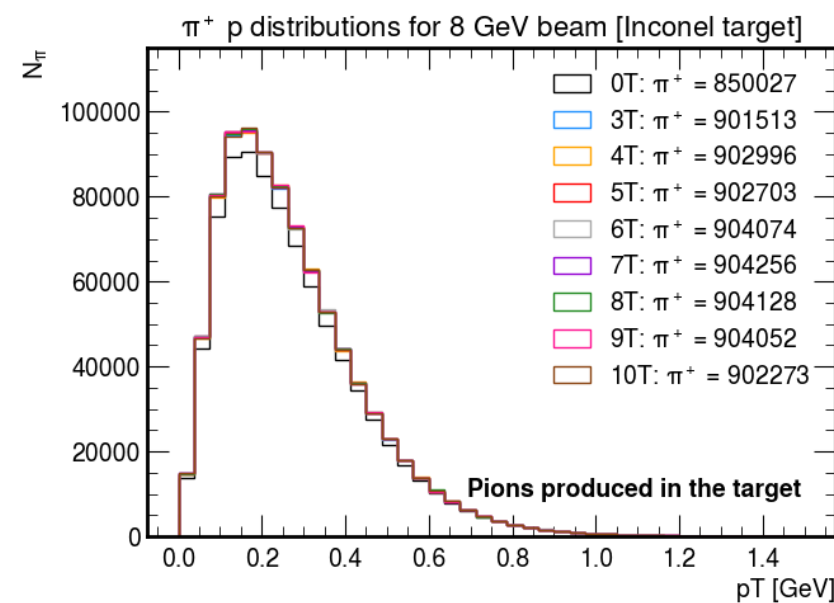
Angular distribution



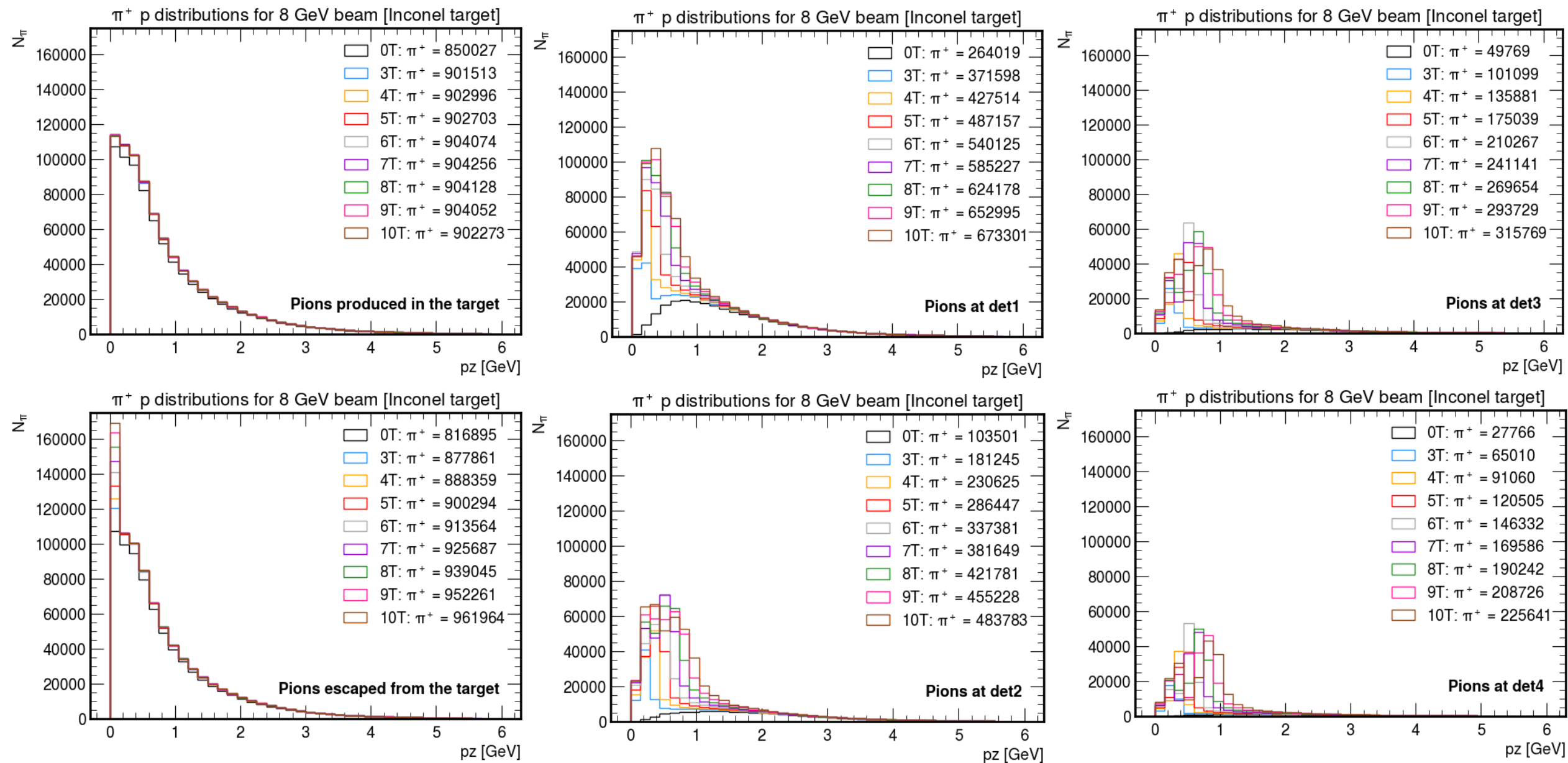
Momentum distributions



pT distributions



pz distributions



Summary

→ I will continue to work on my project for the rest of the summer.

→ My project has two aspects:

→ *Nuclear interactions that produce the pions inside the target:* This was encouraged by Katsuya. The goal is to identify the dominant pion-production processes and use these insights to inform the target geometry design.

→ *Maximizing the number of pions that enter the next stage:* Explore the effect of the solenoid volume and width on the pion beam upstream, with the goal of optimizing pion transmission into the next stage.

