
Target Studies for Pion Production

IPAC review &
2D kinematic plots



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Shielding Module.
Target heads

IPAC review

I received the following comments from one of my reviewers:

- The proton beam size is not specified, and it is unclear whether a pencil beam is assumed. As IMCC studies show, beam size is a relevant parameter for the muon yield.
- The magnetic field is a key factor influencing muon (and pion) yield, even prior to the capture system. In addition, the current approach does not preserve the production kinematics, as pion interactions within the target are simulated. In this context, the sentence “To preserve the intrinsic production kinematics, no magnetic field is included in the simulation” should be rephrased. For future works, I strongly suggest considering realistic magnetic field conditions.
- If only pion production within the target is considered, the contribution of kaons to both muon and pion production is neglected; it should be clarified whether this omission is justified and whether it could have a non-negligible impact.

IPAC review

To address the three points, I included the following paragraph in the “Simulation setup” section:

→The proton beam is modeled using the default FLUKA beam definition, corresponding to a pencil beam with zero transverse extent. While beam size is known to influence pion and muon yields in realistic target systems, it is not varied in the present study, which focuses on characterizing pion production within the target for proton beams of different energies. Contributions from secondary hadrons such as kaons, and their subsequent decay chains, are not explicitly separated in the current analysis. No magnetic field is included in the simulation in order to isolate the effects of pion production and hadronic interactions within the target from those associated with magnetic capture and transport. The inclusion of realistic magnetic field configurations will be considered in future studies.

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Comment:

- The statement “To address this, a custom user routine was developed to register only the first occurrence of each particle” is unclear: does this refer to scoring particle production? Moreover, since target optimization is not addressed, it is not evident why the analysis does not simply consider pions exiting the target.

To address this point, I included the following paragraph in the “Simulation setup” section:

→A comparison is made between pions produced within the target and those that escape it. A custom user routine was developed to record pion information within the target at their creation point and at target–vacuum boundary crossing. This enables a direct comparison between the pion production distributions and the distributions of pions that successfully exit the target. Such a comparison provides insight into the effects of pion reabsorption within the target on the final pion yield and kinematic distributions.

IPAC review

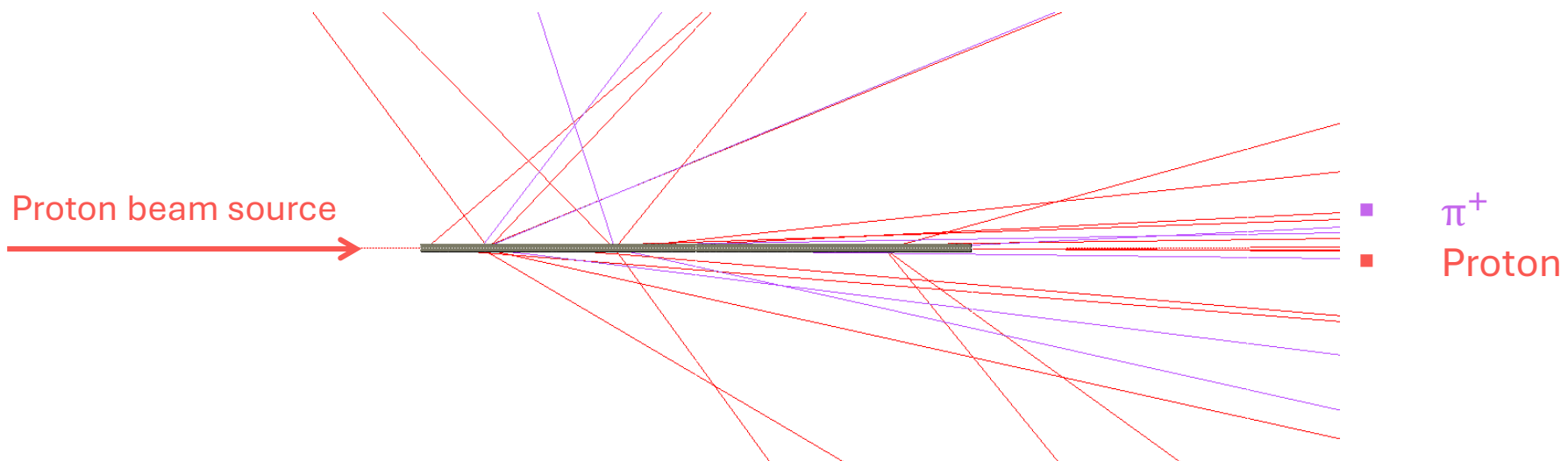
- The writer states that luminosity is proportional to multiplication of μ^+ and μ^- which states the muon collider is a $\mu^+ \mu^-$ collider. While the reviewer doesn't have a lot of knowledge about muon colliders the lower energy proton could be better for a $\mu^+ \mu^+$ machine considering the charge asymmetry.

My new conclusion:

- These results show that optimization of a target system for a muon collider depends not only on pion yield, but also on beam intensity and downstream acceptance. Although higher-energy proton beams produce more pions per interaction, Fermilab can provide roughly two orders of magnitude more 0.8 GeV protons than 8 GeV/c protons. Consequently, the lower-energy beam can produce a larger overall yield of useful positive pions at lower operational cost, despite its lower per-event production rate.
- Since the primary goal of the demonstrator is to validate ionization cooling, demonstrating the concept with π^+ -derived muons is sufficient, as the cooling performance is expected to be symmetric for positive and negative muons. In addition, previous studies on the influence of target geometry on pion and muon production *\cite{ruaa}* further emphasize the importance of jointly optimizing beam and target parameters for the demonstrator.

FLUKA setup

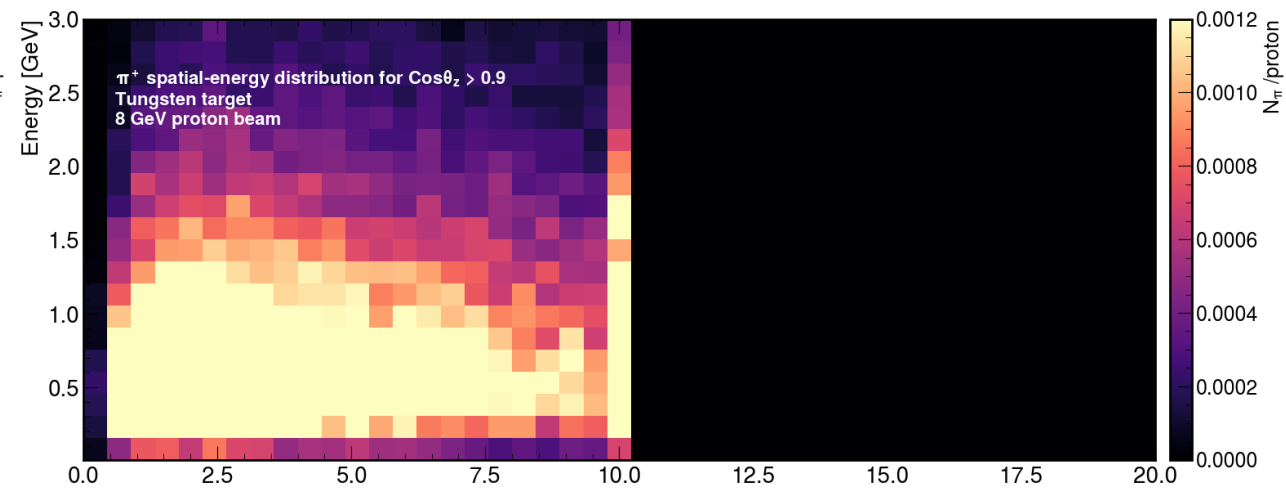
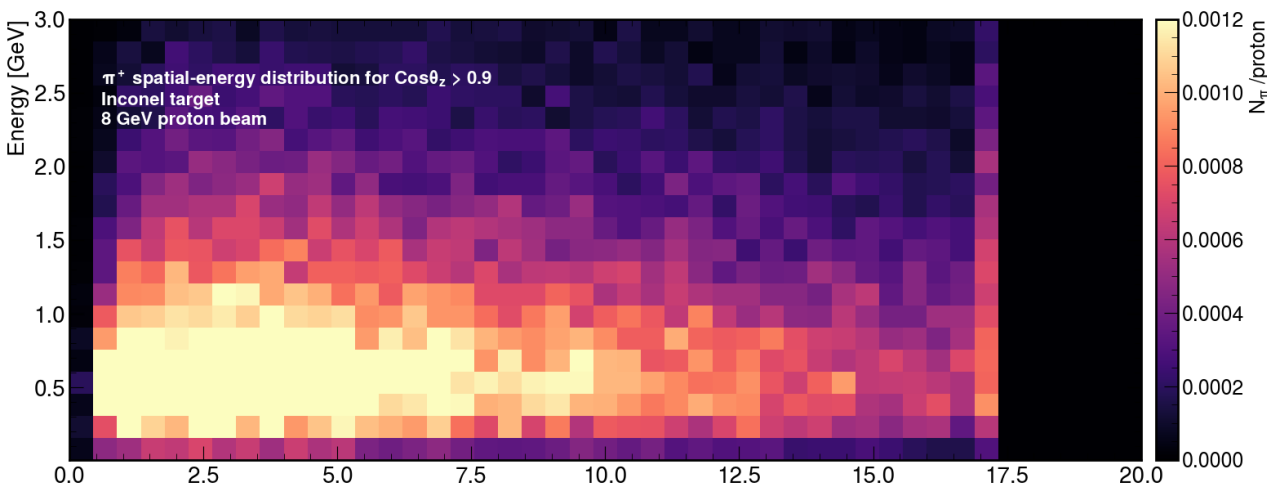
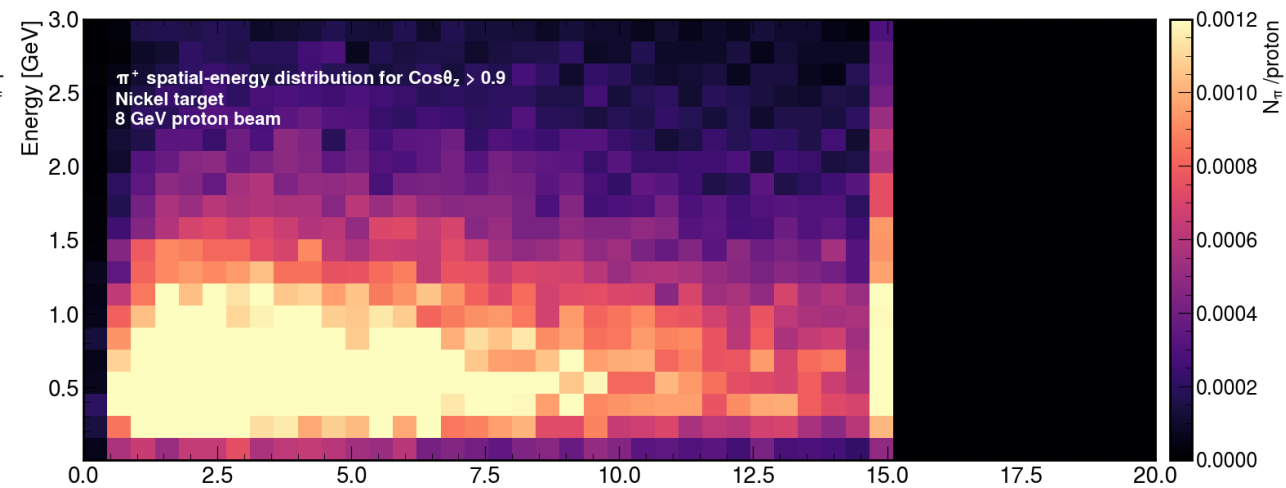
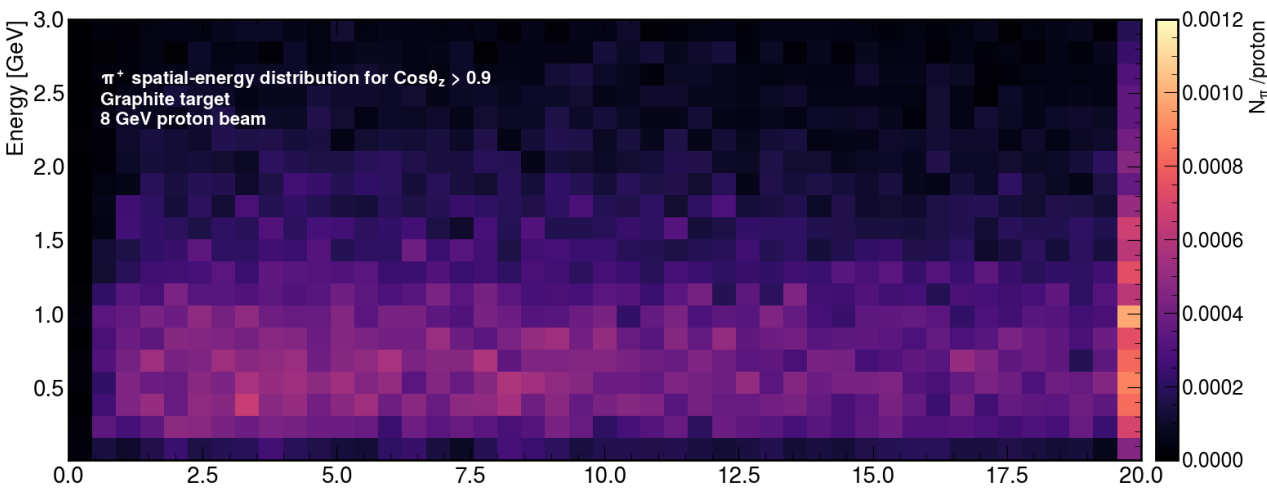
Beam	Energy	8 GeV
	Primaries	100,000
Target	Length	one interaction length
	Radius	0.15 cm
	Material	Different materials



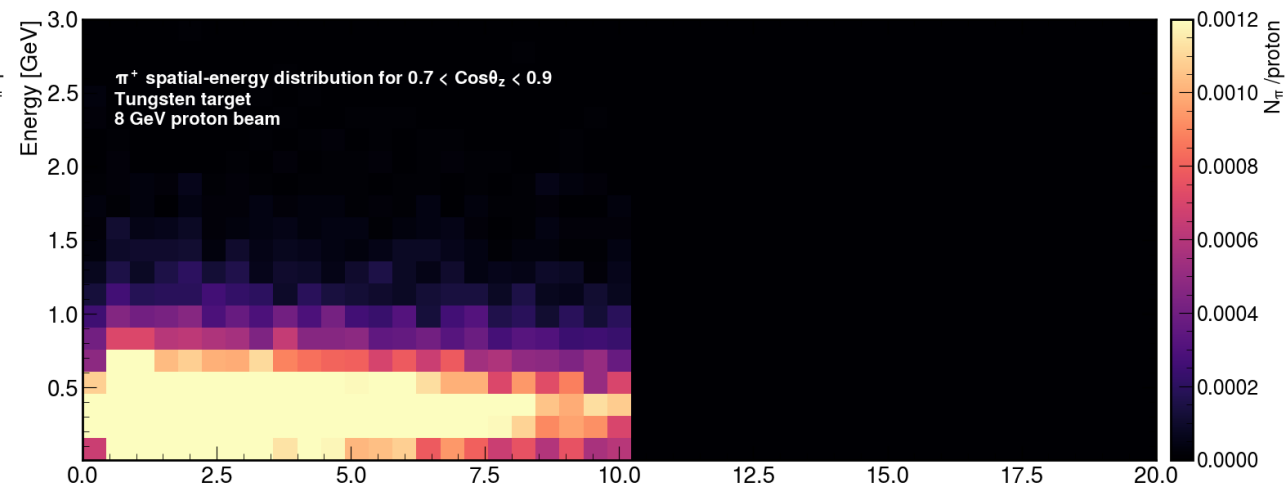
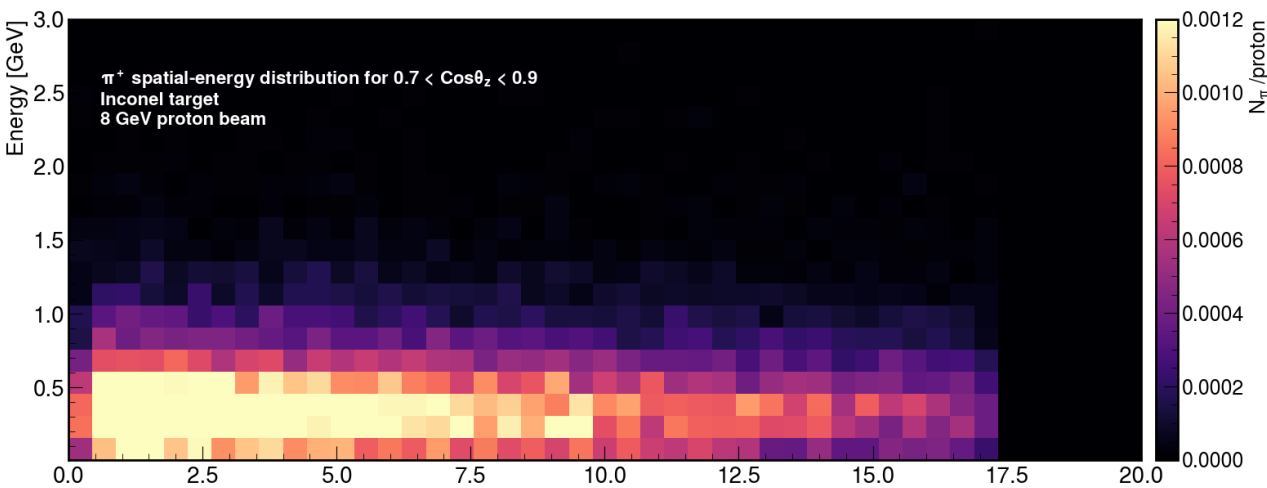
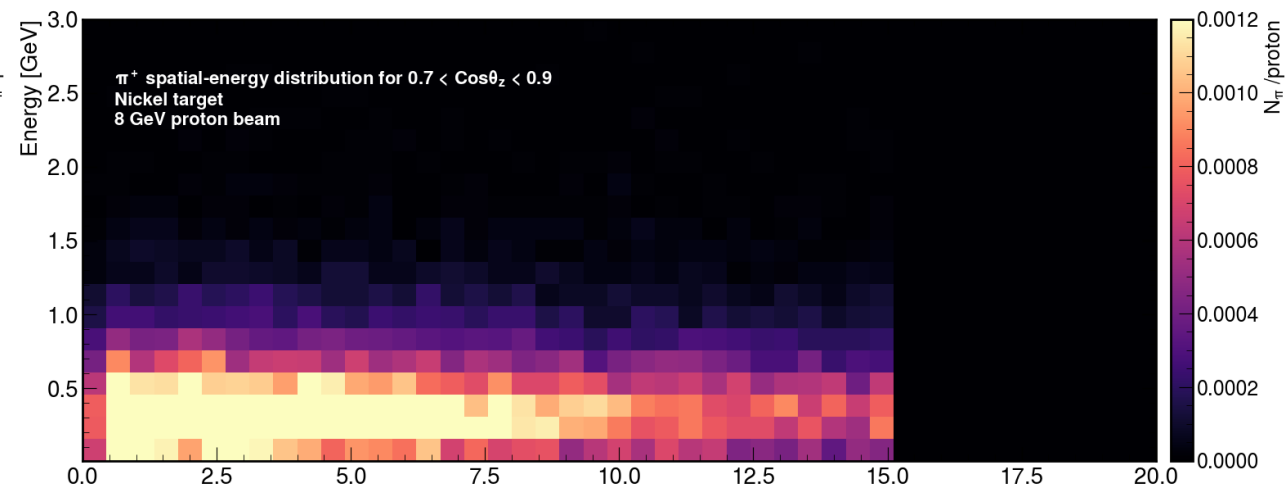
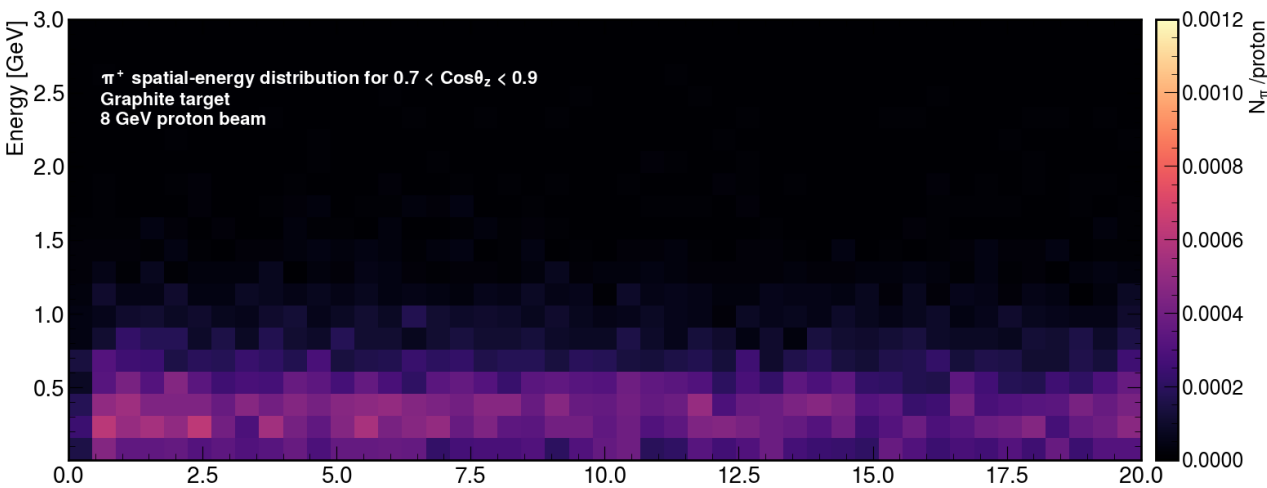
Summary of Pion production in different targets

Material (one λ_{int} length)	π^+ produced per p^+	π^- produced per p^+	π^+ escaped per p^+	π^- escaped per p^+
Graphite (20 cm)	0.40	0.30	0.39	0.29
Nickel (15 cm)	0.87	0.70	0.84	0.71
Inconel (17 cm)	0.91	0.73	0.88	0.70
Tungsten (10 cm)	0.84	0.80	0.79	0.74

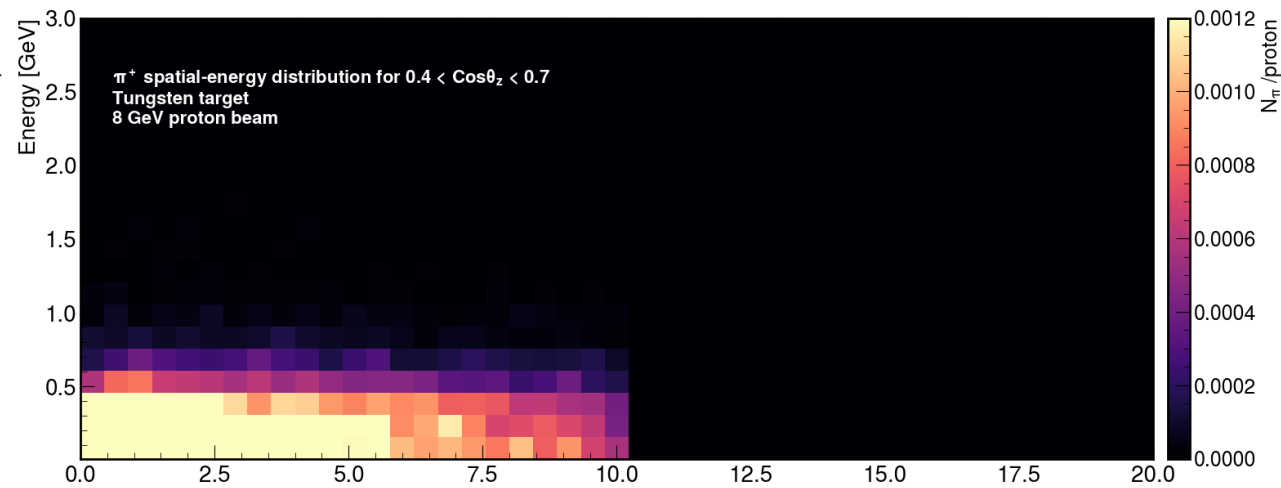
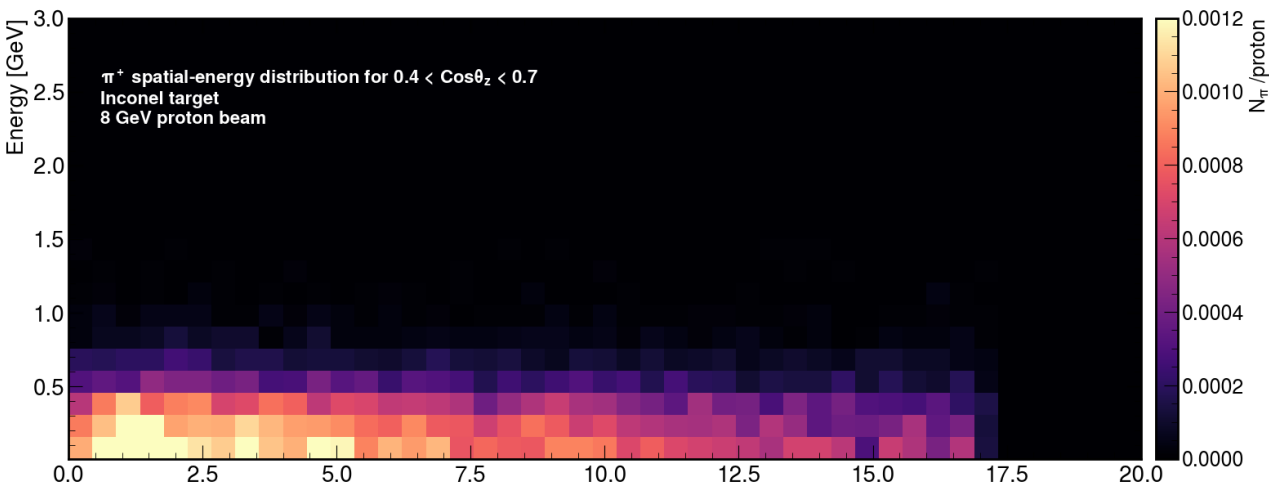
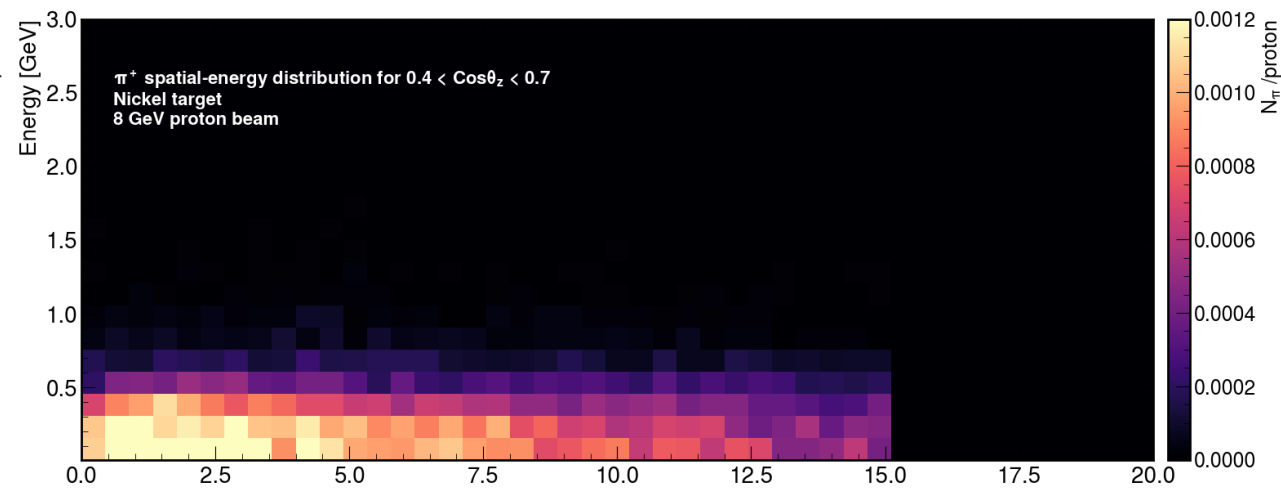
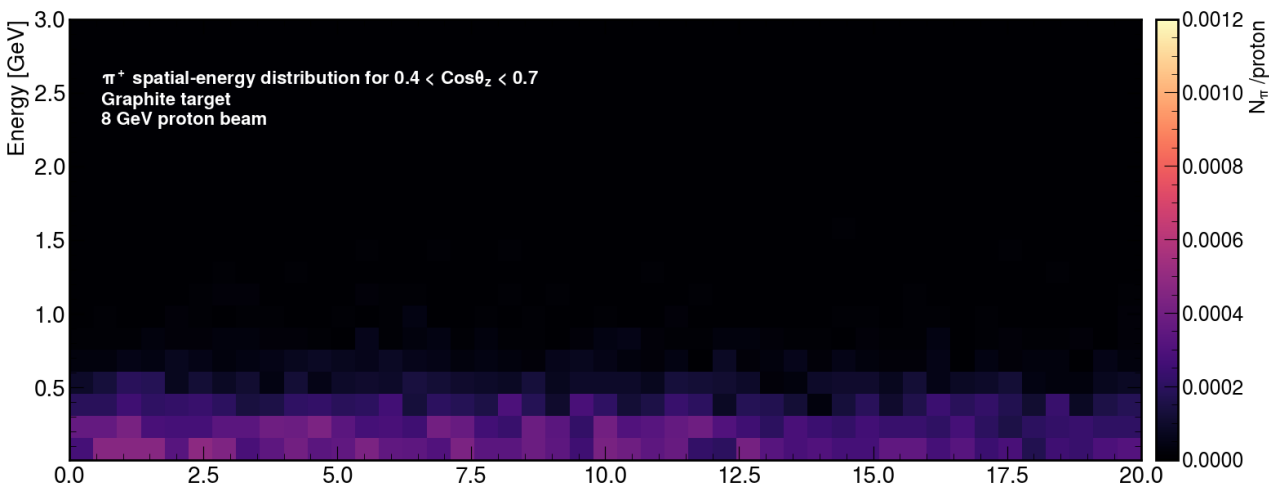
For $\text{Cos } \theta_z > 0.9$



For $0.7 < \text{Cos } \theta_z < 0.9$



For $0.4 < \text{Cos } \theta_z < 0.7$



For $0 < \text{Cos } \theta_z < 0.4$

