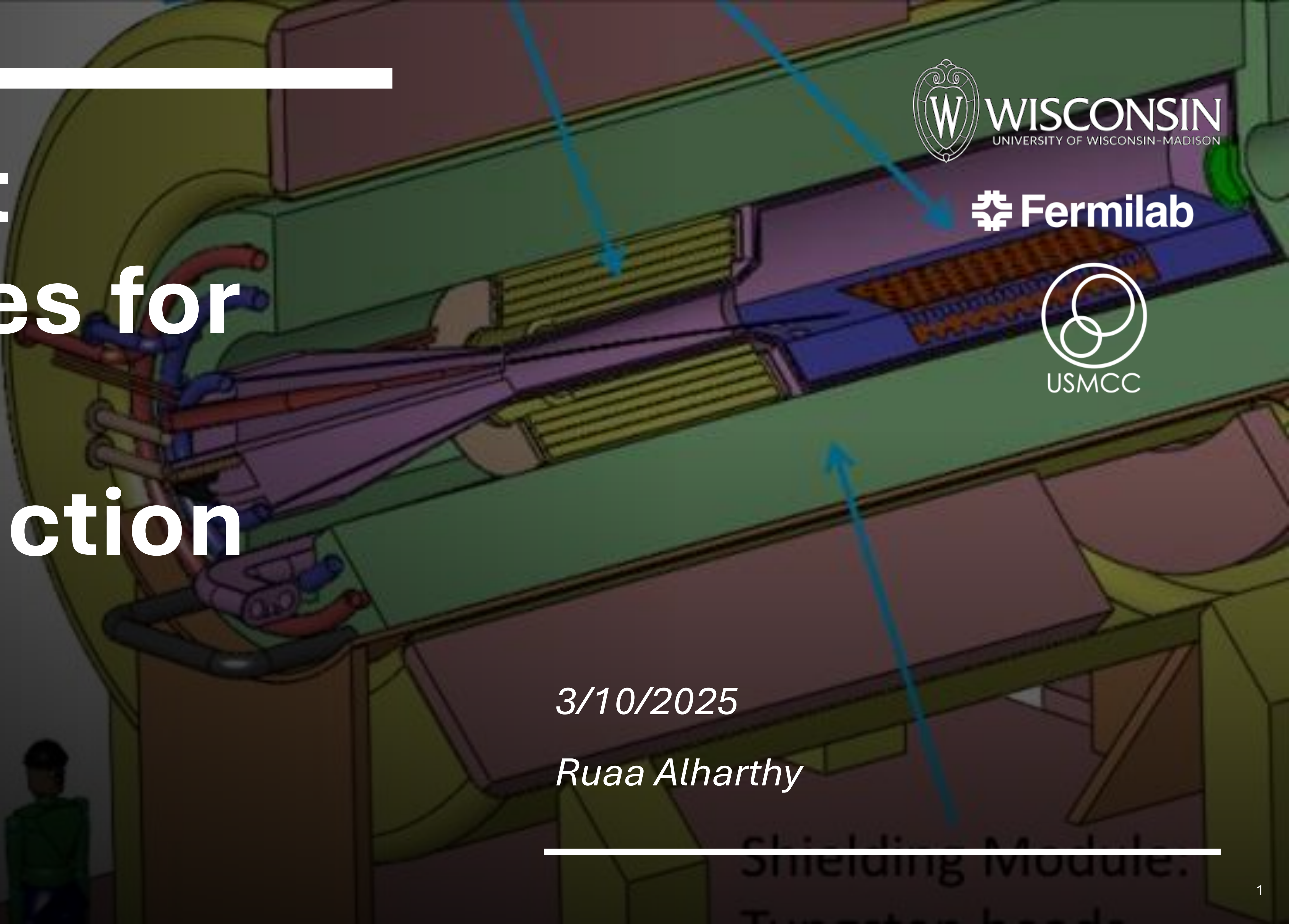
Target Studies for Muon Production



WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

Fermilab

USMCC

3/10/2025

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Simulation setup

→Material = *Graphite* and *Tungsten*

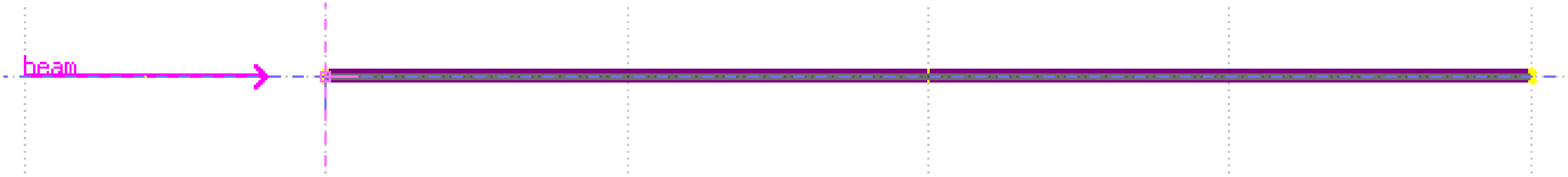
→Length = *40* / *10* cm (one interaction length)

→Radius = 0.15 cm

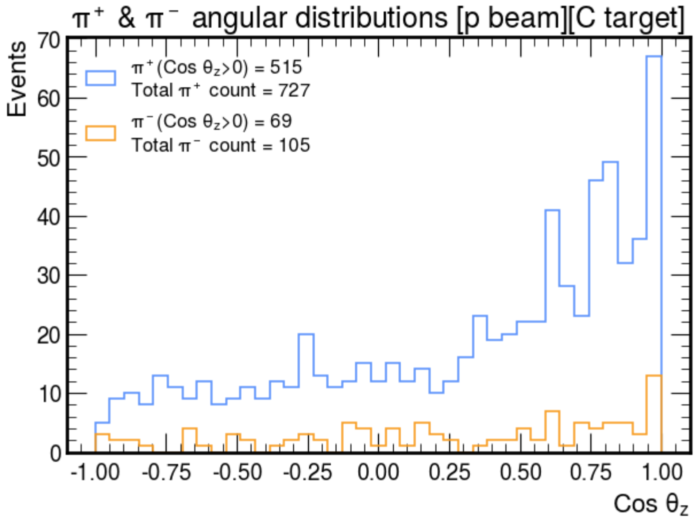
→No magnetic field

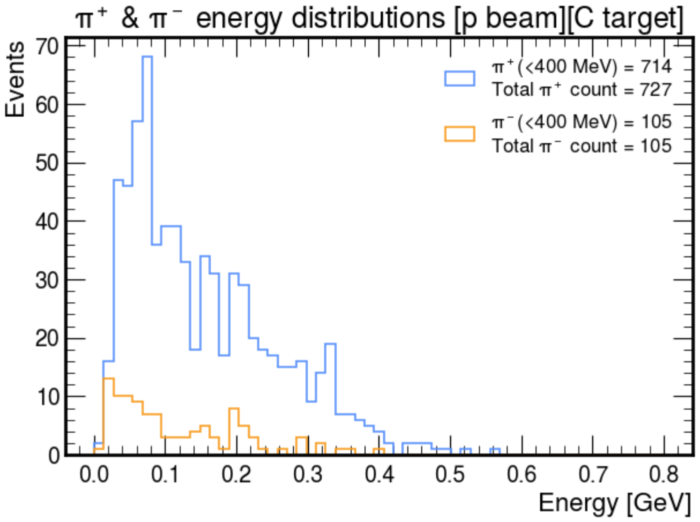
→10,000 primaries

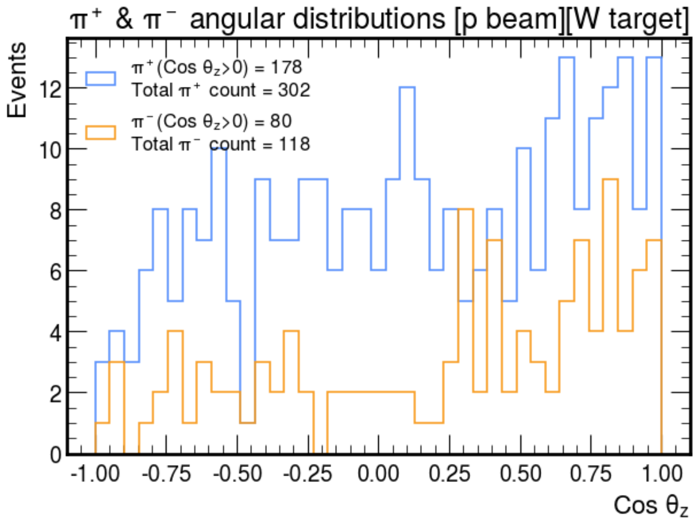
→0.8 GeV/proton beams

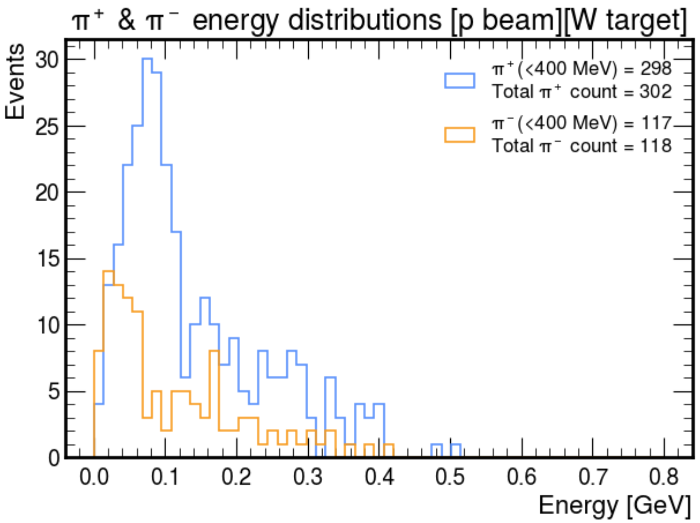


Proton beam, K = 0.8 GeV





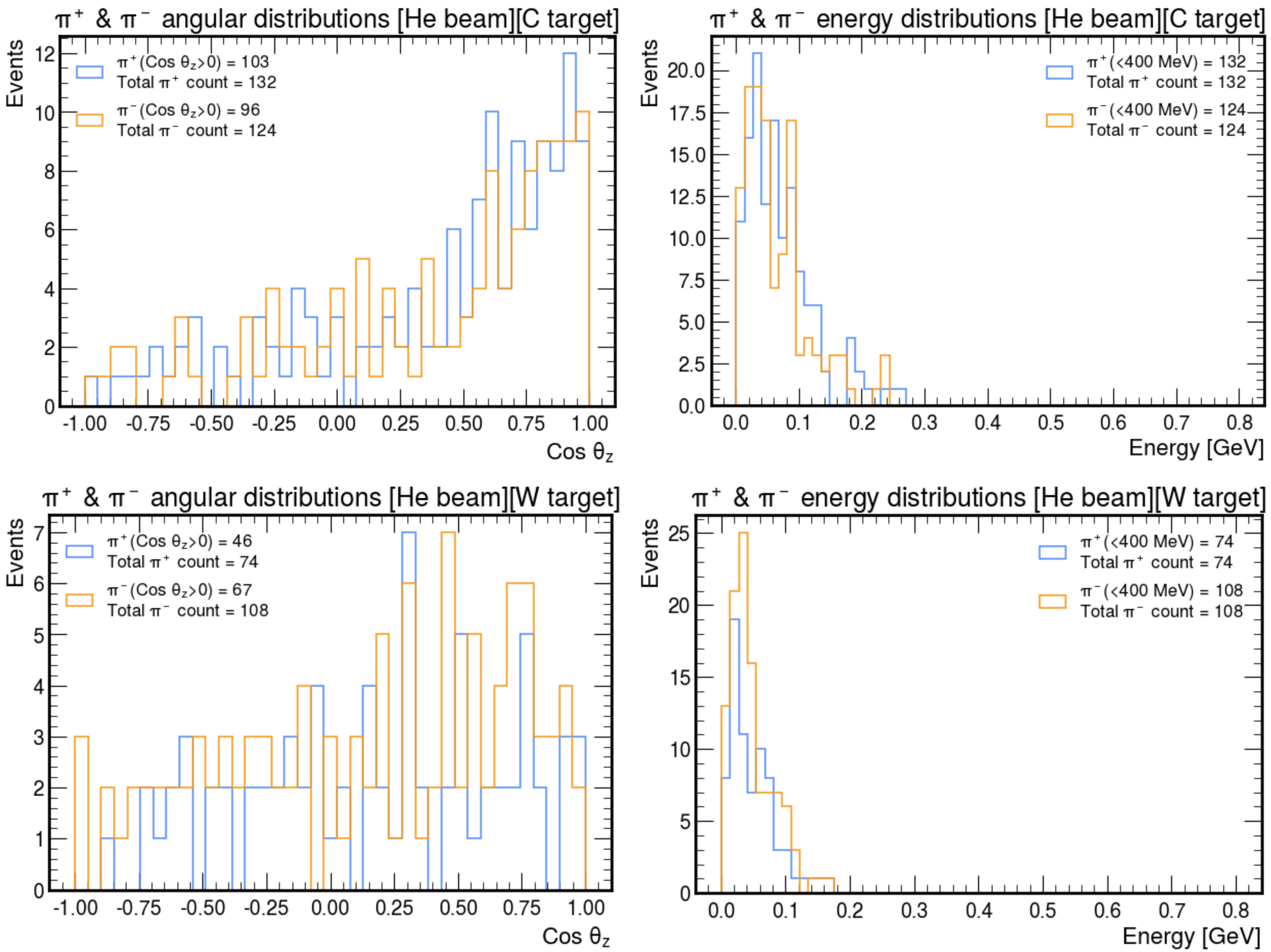




Target	π^+/π^-	Accept π^+	Accept π^-
C	6.9	502	69
W	2.6	174	74

→ Ratio = total pi+/ total pi-
→ Pion yield is higher with the graphite target
→ For both targets, pi+ yield is higher than pi- yield

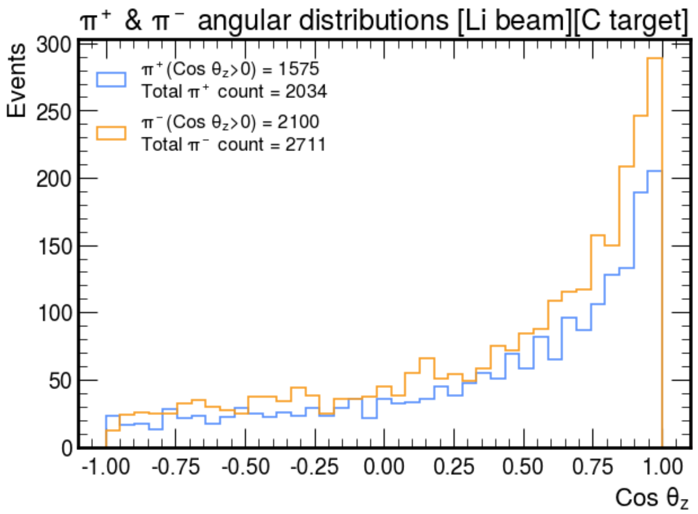
Helium beam, K = 1.6 GeV

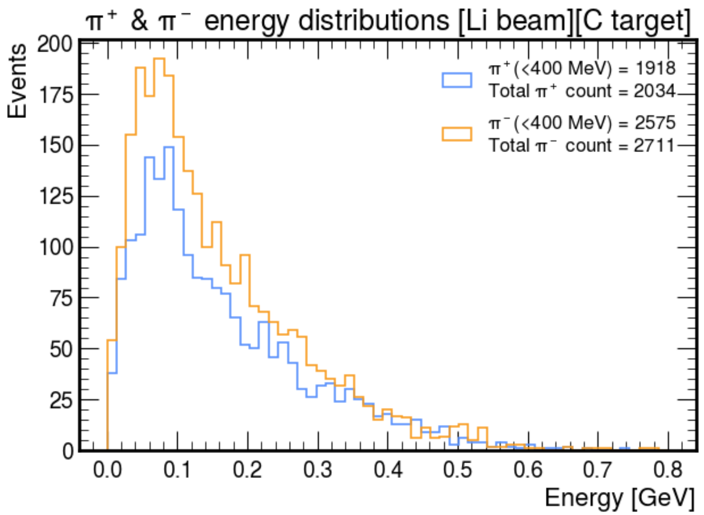


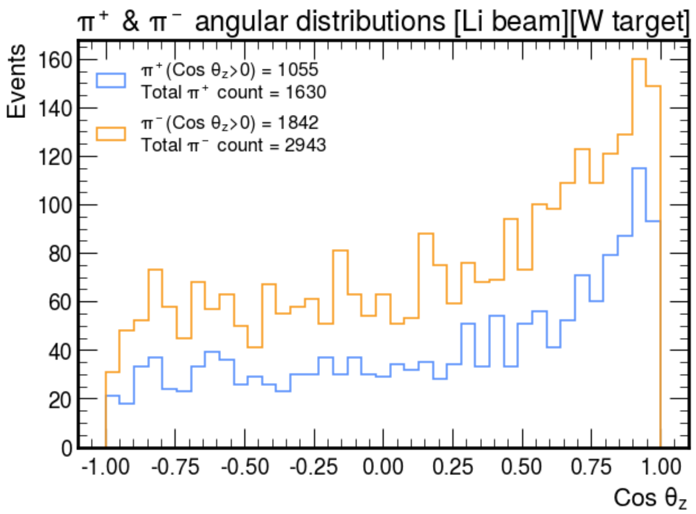
Target	π^+/π^-	Accept π^+	Accept π^-
C	1.1	103	96
W	0.69	46	67

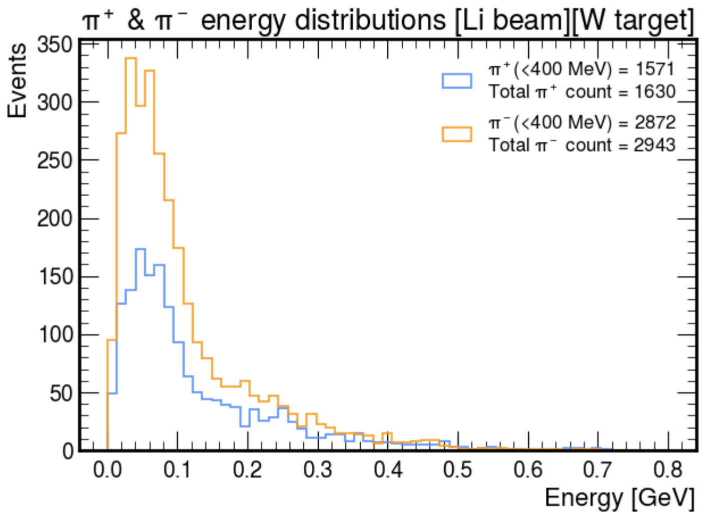
→ Ratio = total pi+/ total pi-
→ Pion yield is higher with the graphite target
→ In the carbon target, yields of pi+ = pi-, and in the tungsten target, pi- yield is higher
→ Expectation: pi+ = pi-

Lithium beam, K = 2.4 GeV









Target	π^+/π^-	**Accept** π^+	**Accept** π^-
C	0.75	1459	1964
W	0.55	996	1771

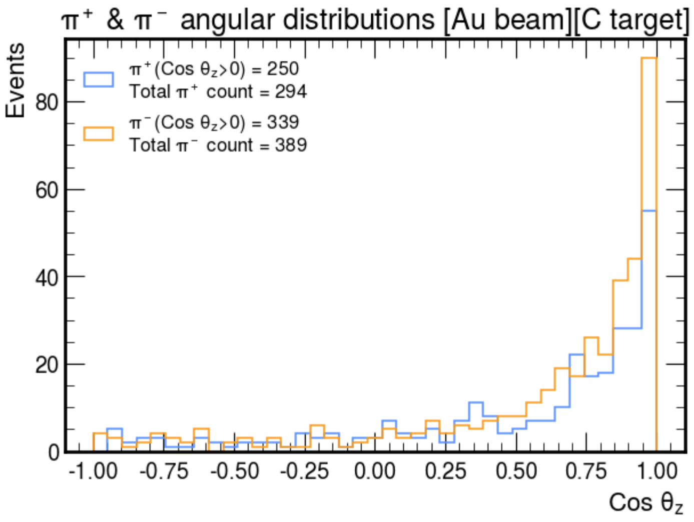
→ Ratio = total pi+/ total pi-

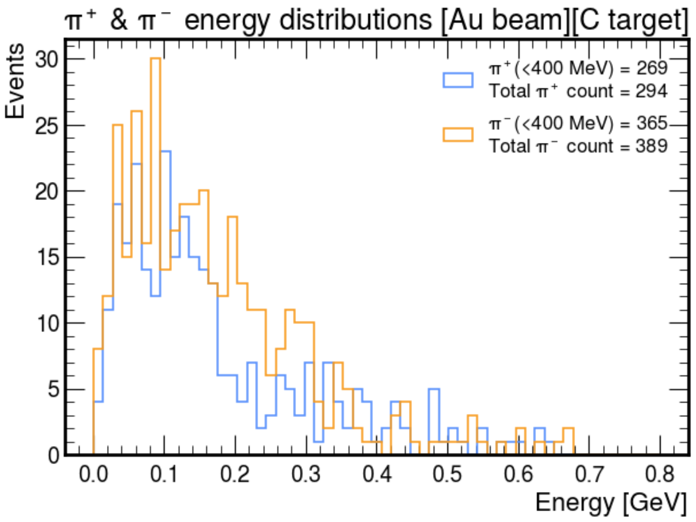
→ Pion yield is higher with the graphite target

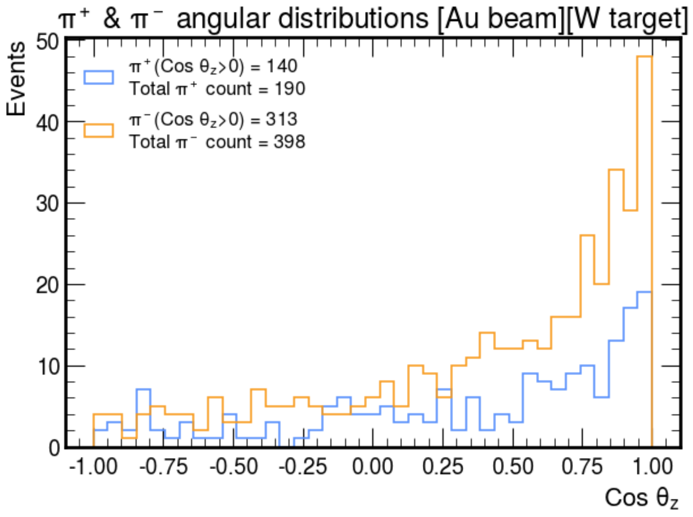
→ For both targets, pi- yield is higher than pi+ yield

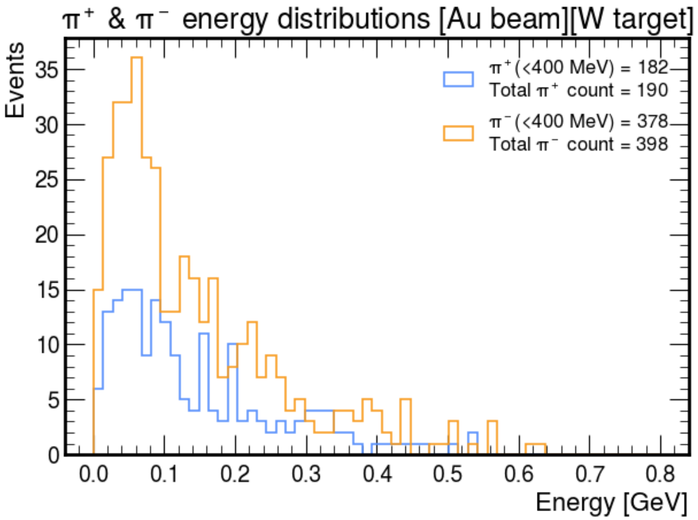
1000 primaries

Gold beam, K = 63.2 GeV









Target	π^+/π^-	Accept π^+	Accept π^-
C	0.76	225	315
W	0.48	132	293

→ Ratio = total pi+/ total pi-

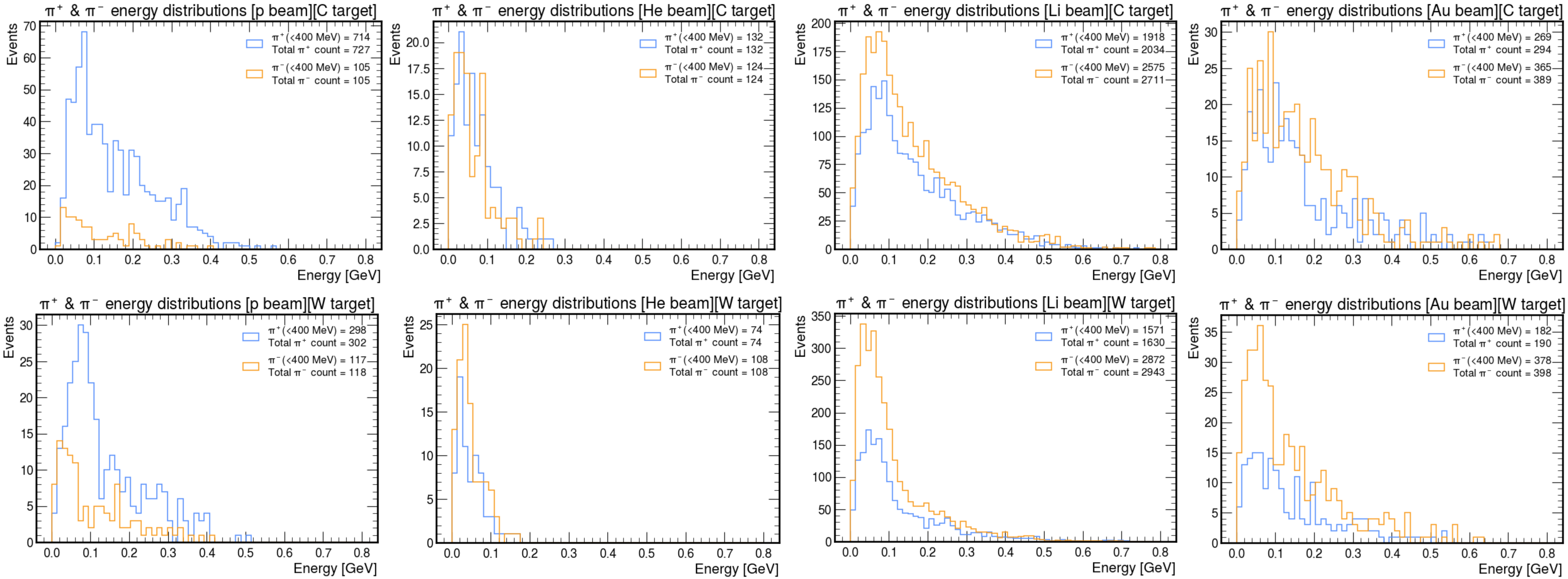
→ Pion yield is higher with the graphite target

→ For both targets, pi- yield is higher than pi+ yield

→ ***Pattern:*** *Au and Li have more neutrons than protons, could this justify the discrepancy in the charged pion yields?*

Closer look at energy plots…

→ It's easier to see pi+ and pi- production yield patters form energy plots



My attempt to justify the charged pion production pattern…

Beam	Energy [GeV]	Energy/nucleon
p	0.8	0.8
4-He	1.6	0.4
Li	2.4	0.34
Au	63.2	0.32

→ I am planning to run simulations with various energies for next week to see the effect of Energy/nucleon on the charged pion yield.

Element	Protons	Neutrons	Ratio p/n
Carbon	6	6	1
4-He	2	2	1
Lithium	3	4	0.75
Tungsten	74	110	0.67
Gold	79	118	0.67

Beam	Target	Most common interaction
P	C	p-p
	W	p-n
4-He	C	p-p, p-n, n-n
	W	p-n, n-n
Li	C	p-n, n-n
	W	n-n
Au	C	p-n, n-n
	W	n-n

→ I thought of listing all the interactions and compute the cross-sections for producing pi+ vs pi-, but prof. Herndon investigated it and didn't find anything

Isospin:

$$I_3 = \frac{n_u - n_d}{2} = \frac{Z - N}{2}$$

Particle	I_3
p	+1/2
n	-1/2
4-He	0
Li	-1/2
Au	-19.5
C	0
W	-18

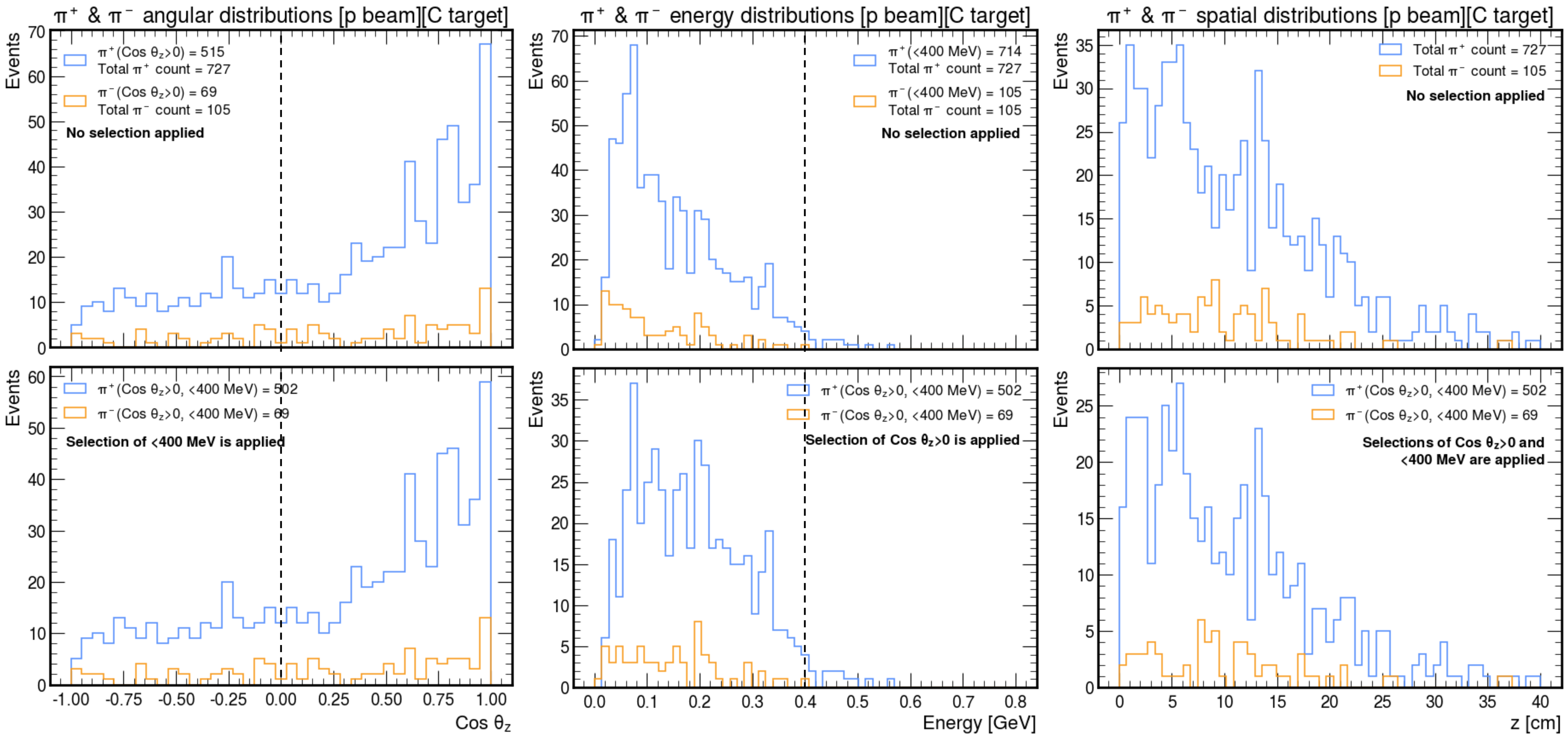
The following are detailed plots for pion production

- → I won’t go through these slides in the meeting for the interest of time, but I would appreciate if anybody could go through them and give me feedback on them.
- → Thanks!

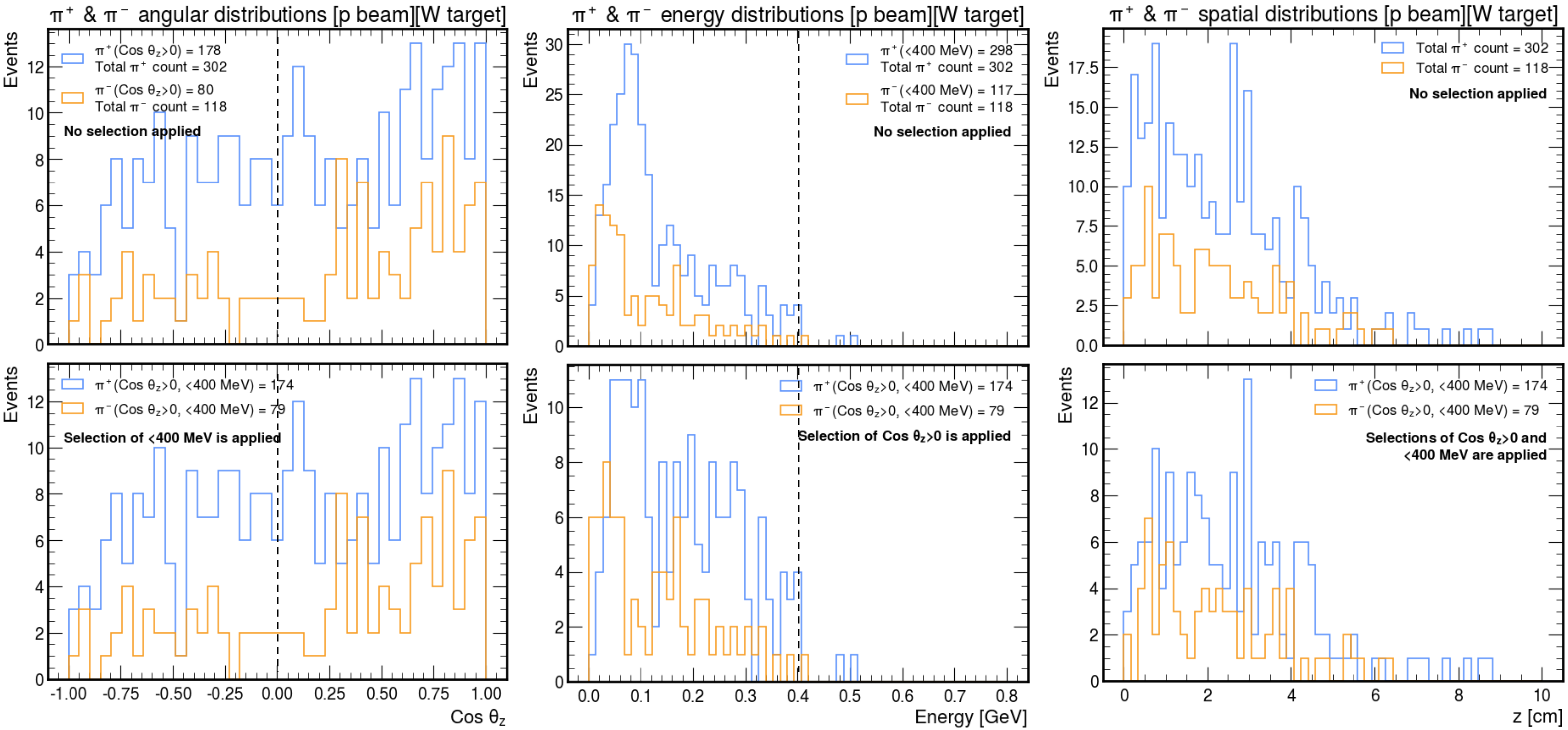
Note that I used 10,000 primaries for all simulations except for gold beam simulations where I have only used 1,000 primaries

10,000 primaries

Proton beam, K = 0.8 GeV [Graphite]

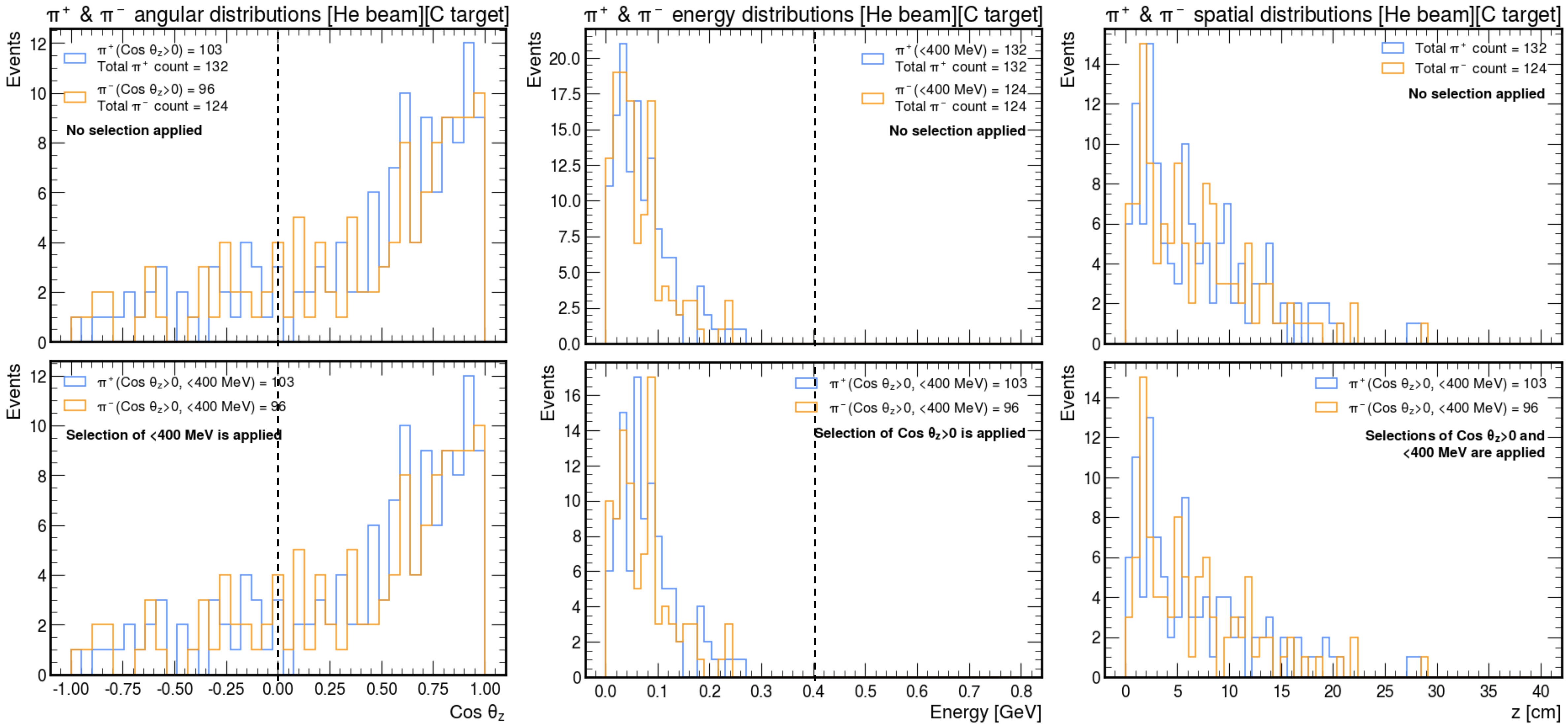


Proton beam, K = 0.8 GeV [Tungsten]



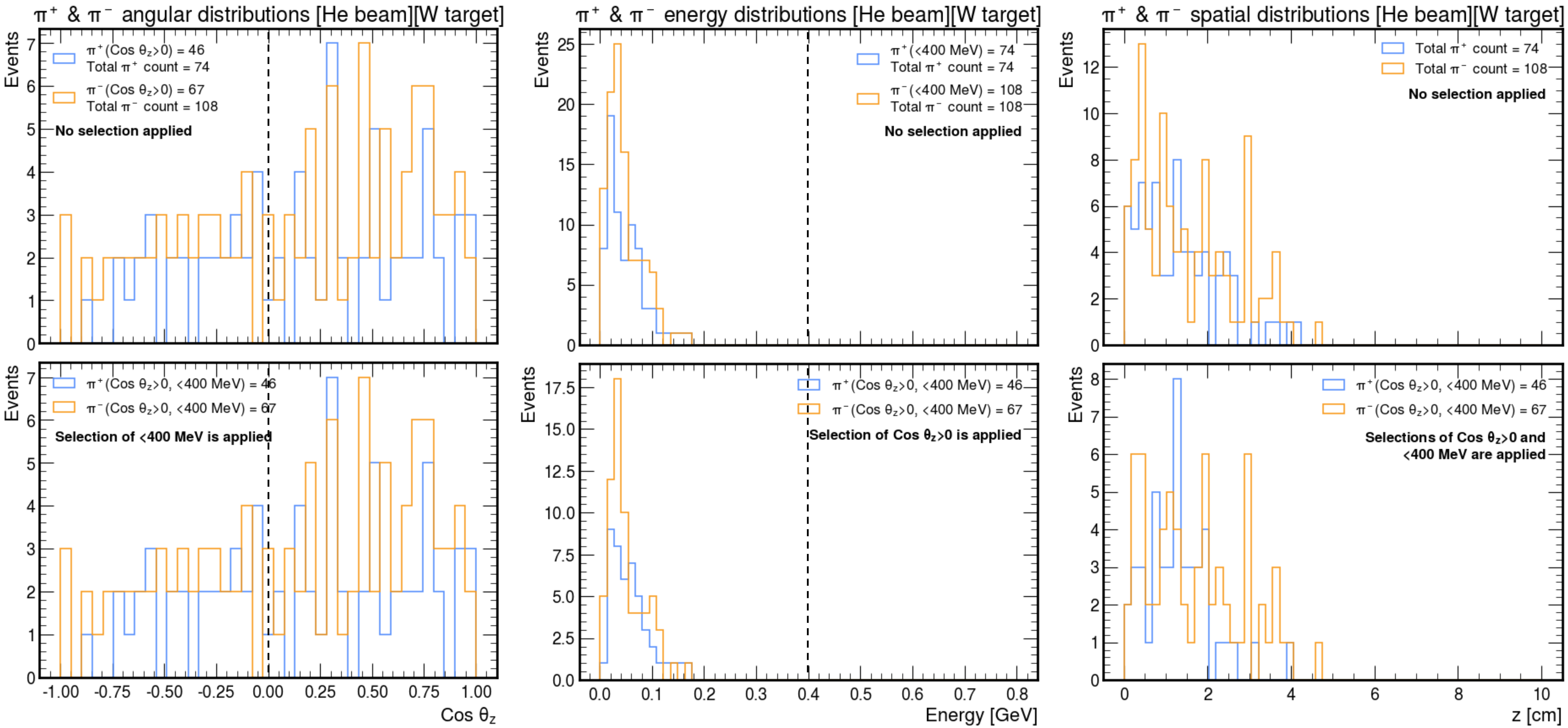
10,000 primaries

4-Helium beam, K = 1.6 GeV [Graphite]



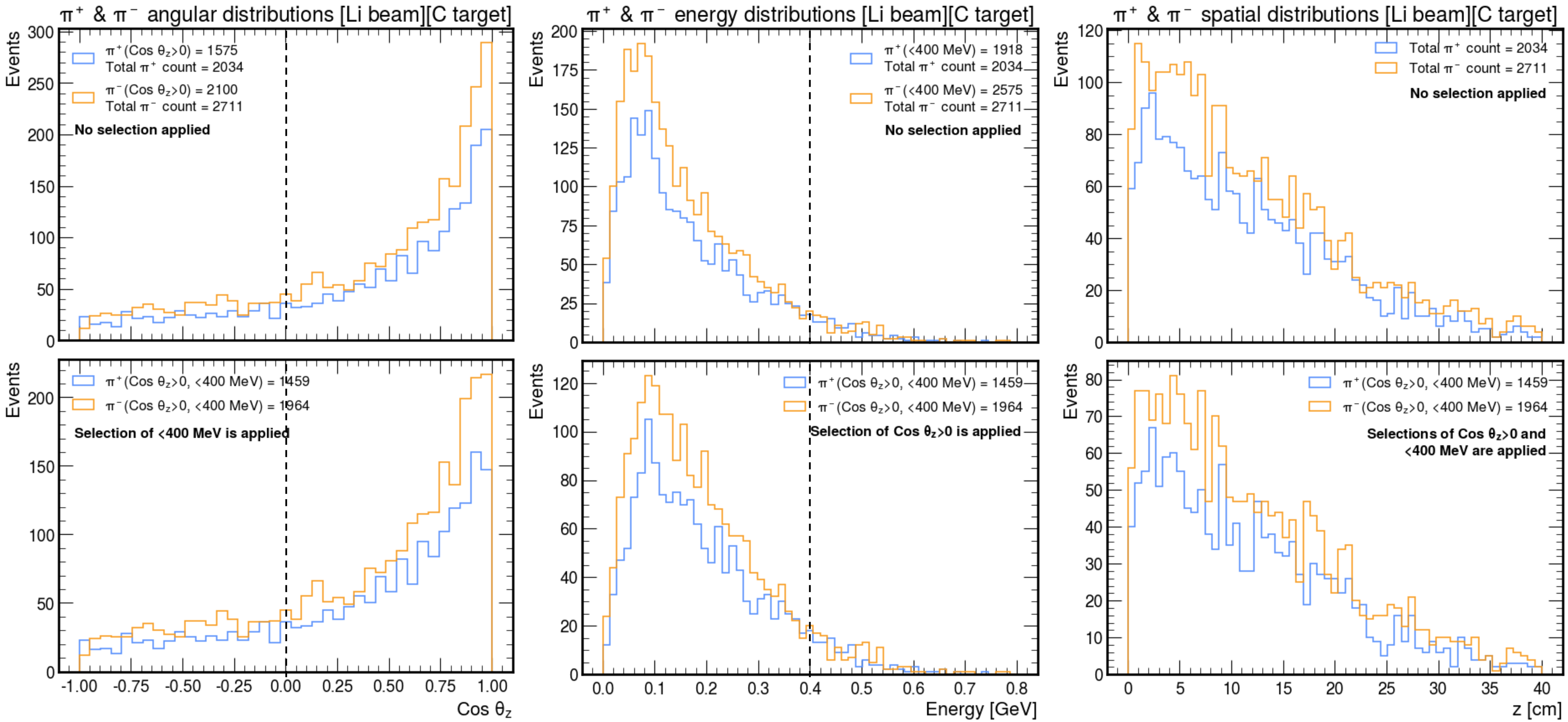
10,000 primaries

4-Helium beam, K = 1.6 GeV [Tungsten]



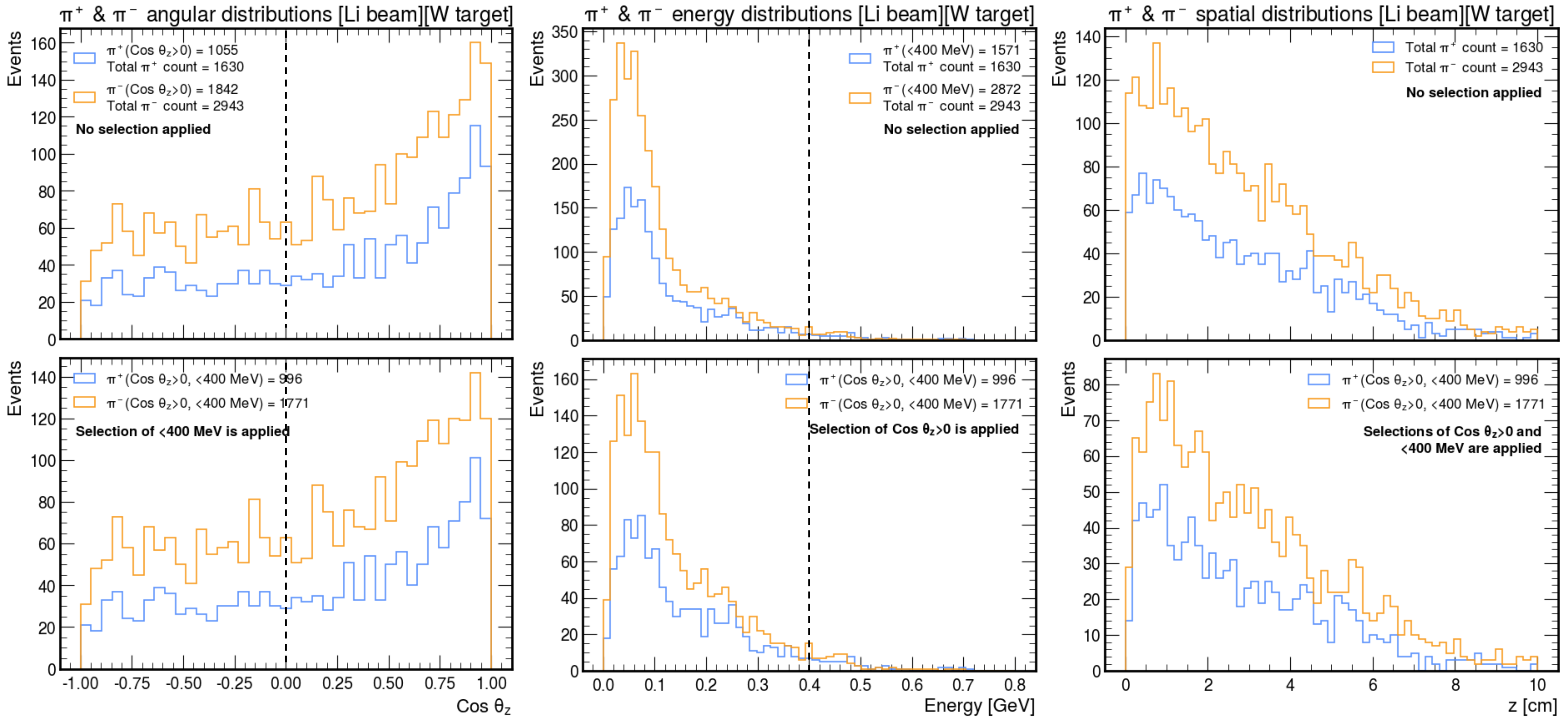
10,000 primaries

Lithium beam, K = 2.4 GeV [Graphite]



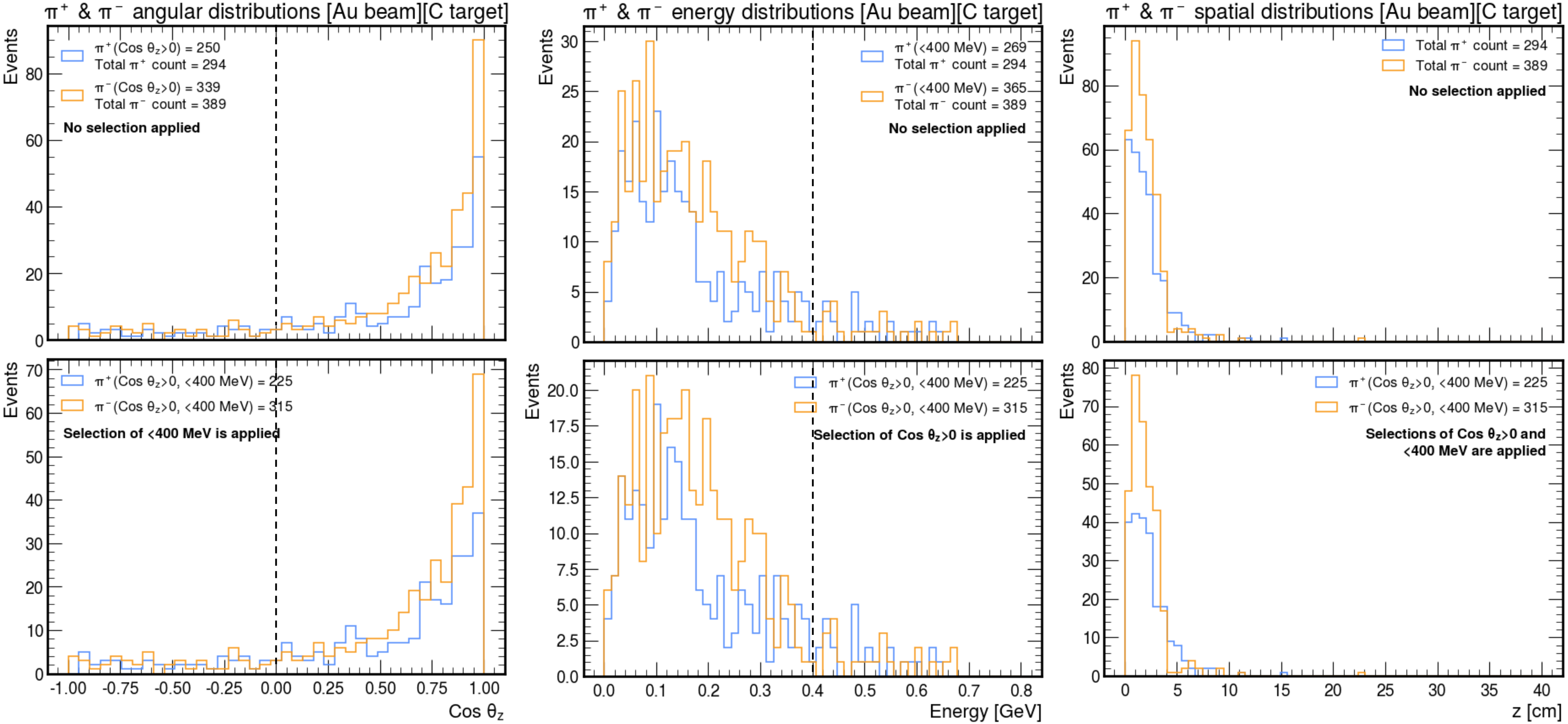
10,000 primaries

Lithium beam, K = 2.4 GeV [Tungsten]

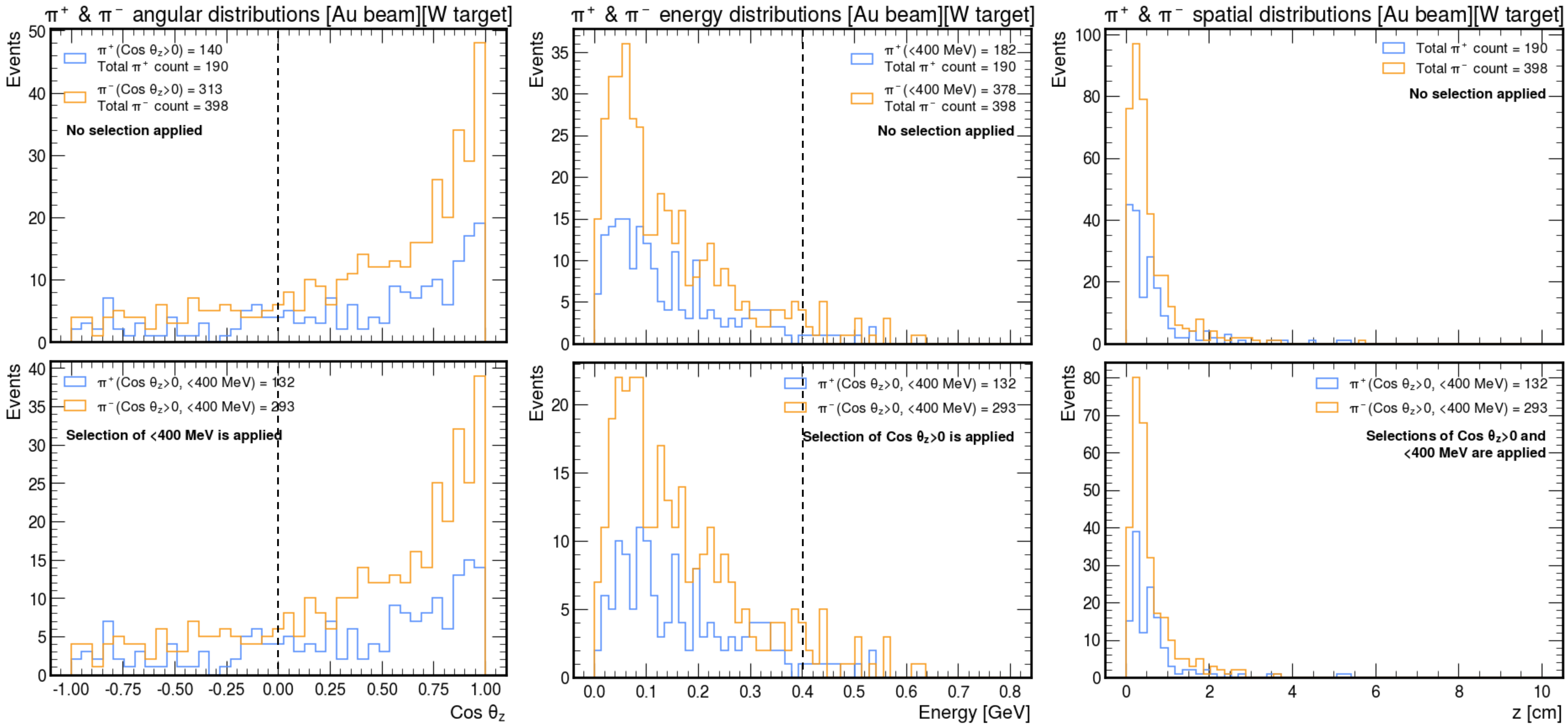


1000 primaries

Gold beam, K = 63.2 GeV [Graphite]



Gold beam, K = 63.2 GeV [Tungsten]



Summary

Beam	Energy [GeV]	Target	Total π^+	Total π^-	π^+/π^-	<400 MeV π^+	<400 MeV π^-	π^+ $(\cos\theta_z > 0)$	π^- $(\cos\theta_z > 0)$	Accept π^+	Accept π^-
P	0.8	C	727	105	6.9	714	105	515	69	502	69
		W	302	118	2.6	298	117	178	80	174	74
4-He	1.6	C	132	124	1.1	132	124	103	96	103	96
		W	74	108	0.69	74	108	46	67	46	67
Li	2.4	C	2034	2711	0.75	1918	2575	1575	2100	1459	1964
		W	1630	2943	0.55	1571	2872	1055	1842	996	1771
Au	63.2	C	294	389	0.76	269	365	250	339	225	315
		W	190	398	0.48	182	378	140	313	132	293

Summary

→The result for the proton beam simulation match our expectations as the π+ count is higher than the π- count. This is primarily since π- gets trapped inside the material by the attraction force created by atom nuclei.

→In the helium beam simulation, we see that the total number of π+ and π- detected around the target is similar, but why is this the case?

→Interestingly, we see far more π- detected in the lithium beam simulation than π+. This was completely unexpected.

→Look into p-p, p-n, n-n interactions and try to understand the reason of why we see more π- as the number of neutrons increase.

→Try using a one-interaction length target and simulate even shorter targets to see what happens