

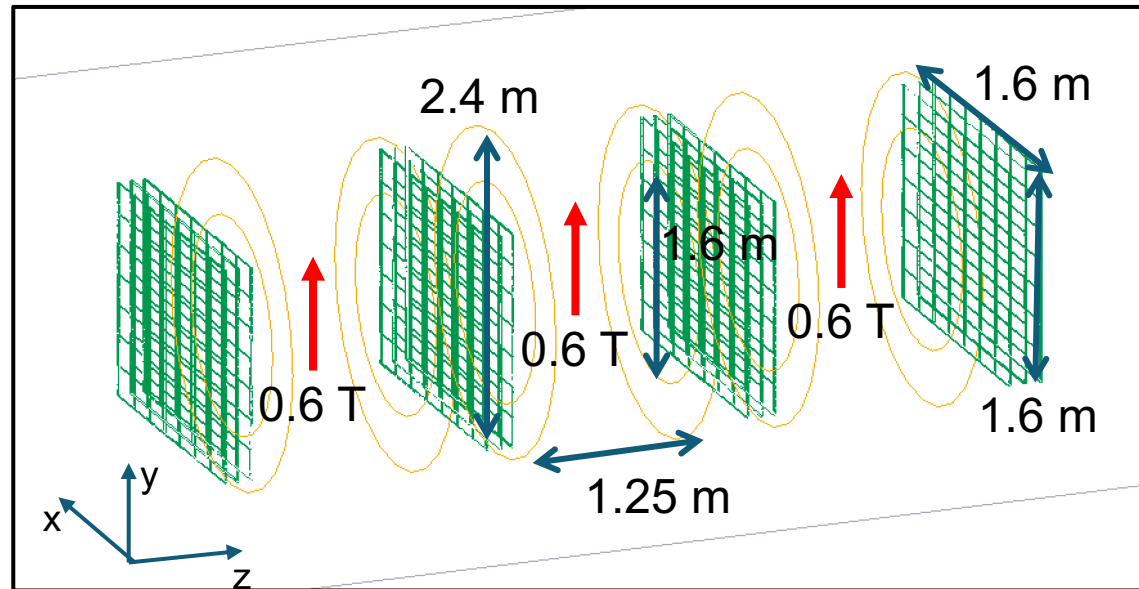
Muon acceptance into FASER2 for different FPF options

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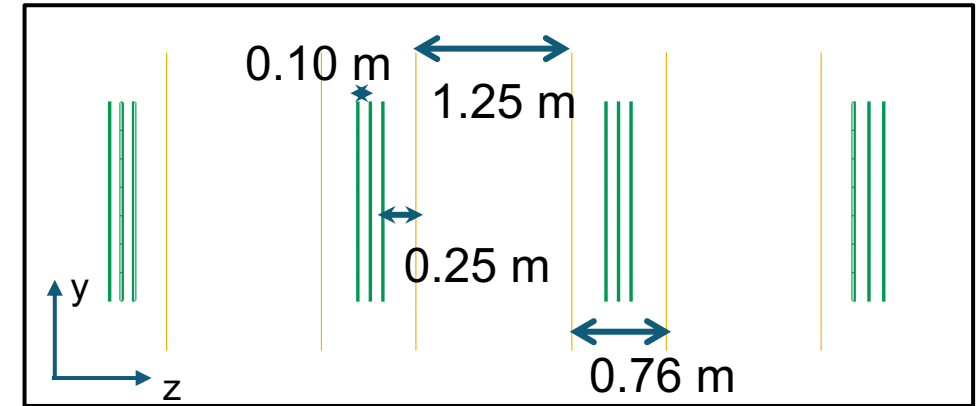
November 28th, 2023

FLArE Technical Meeting

Magnet: CrystalPulling



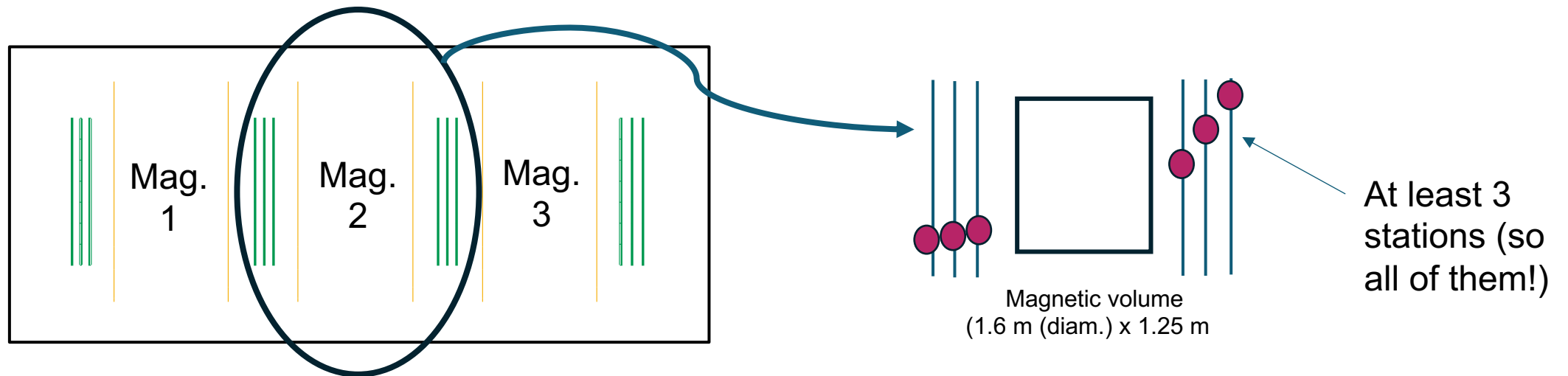
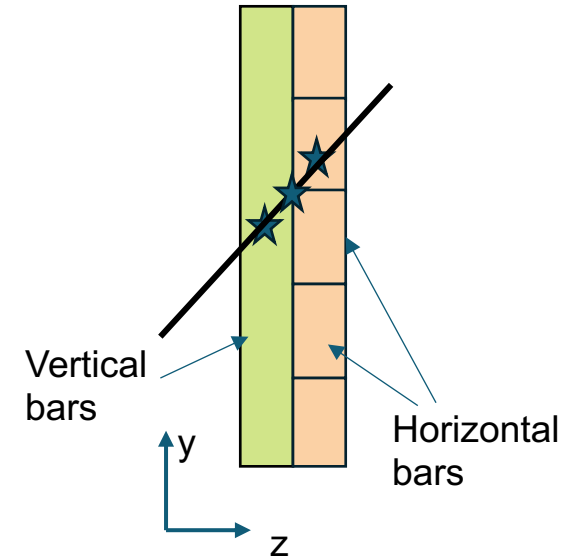
3 Crystal-Pulling Magnets: 1.6 m (diameter) x 1.25 m
Inner radius: 0.8 m; Outer radius: 1.2 m
3 tracking stations in-between, 0.25 m gap
 $B = 0.6$ T (vertical & uniform, for now)



3 tracking stations (10cm apart)
1.6 m x 1.6 m x 0.02 m
0.25 m gap to magnets
Total magnet spacing: ~ 0.76 m

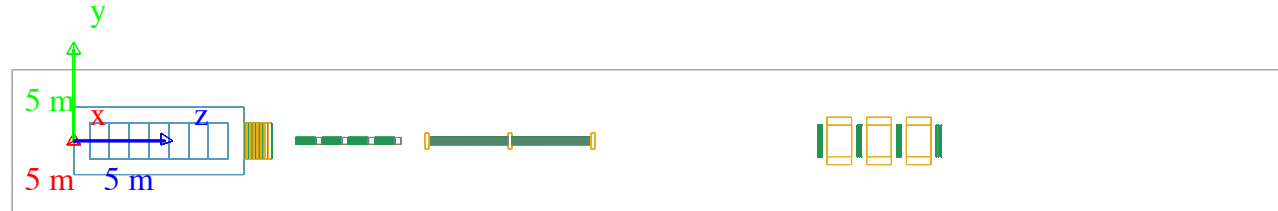
Acceptance requirements

- Each magnet is considered independently, looking at the tracking stations immediately before/after.
- >0 digits in the pre-magnet tracking stations AND >2 digits in the post-magnet tracking stations
- Given the geometry, a muon accepted into Mag. 3 is also accepted in Mag. 2 and Mag. 1.



Options

Option 0:
Reference hall



FLArE to FASER2:
(center to center)

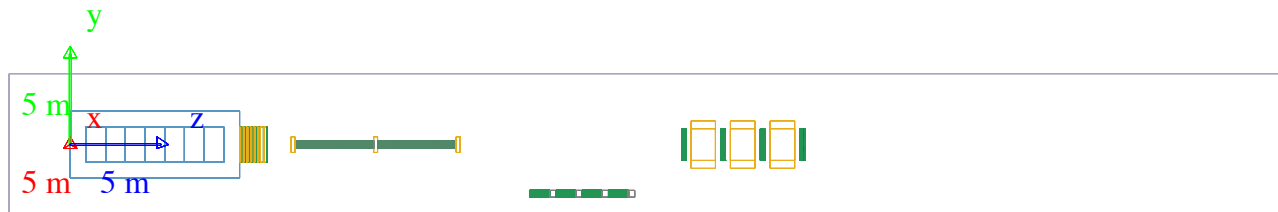
D = 36361 mm

Option 1a:
FORMOSA last



D = 29841 mm

Option 1b:
FORMOSA under



y = -2.5m

Option 2:
FASERnu2 first



y = -2.5m

D = 20055 mm

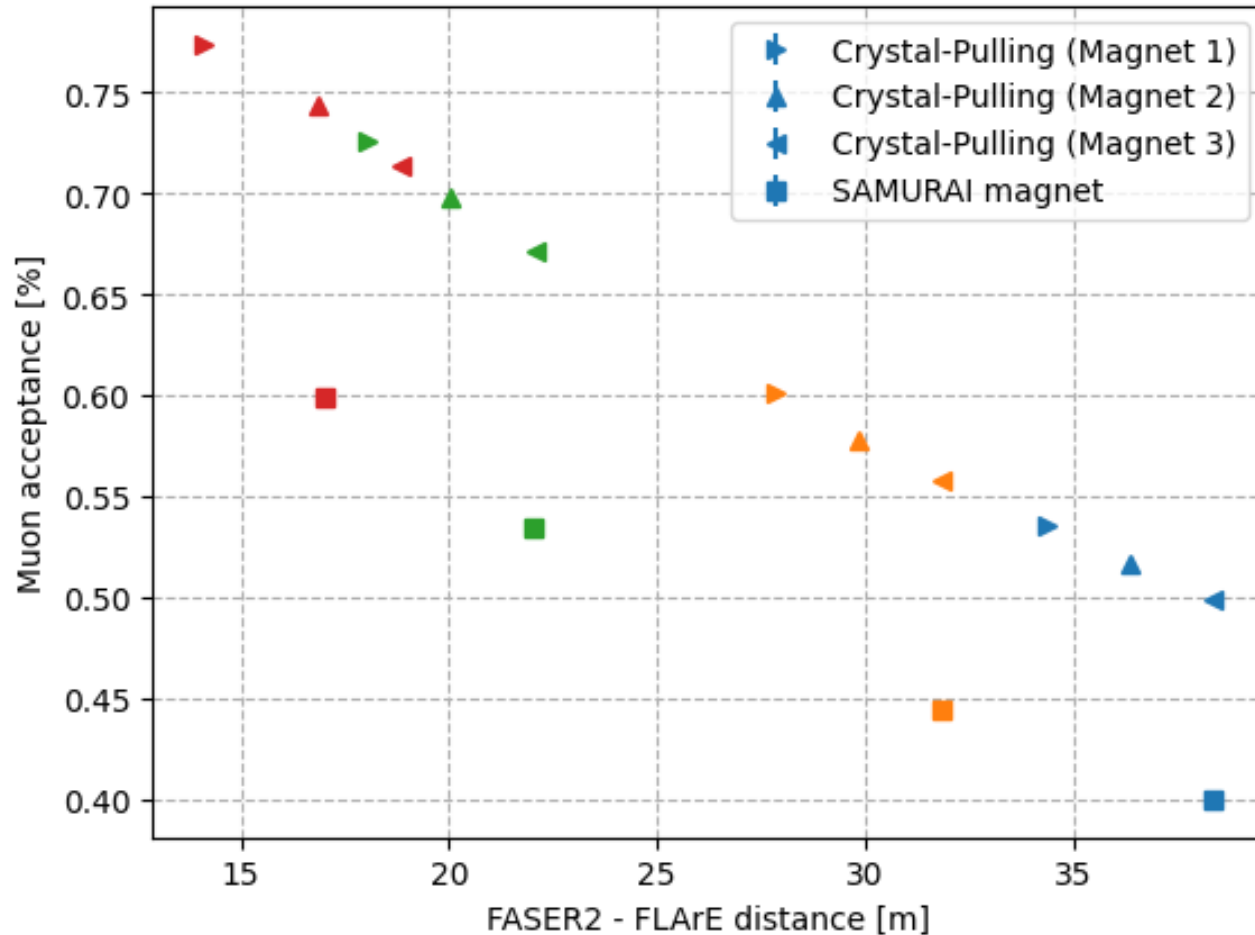
+ "squeezed"
version (D = 17m)

Muon acceptance

Muons from a sample of 100k ν_μ CC interactions in FLArE.
B-field @ FLArE: 1 T; FLArE fiducial is: 1m x 1m x 7m.

OPTION	Distance to FASER2	TOT	FASER2 Mag. 1	FASER2 Mag. 2	FASER2 Mag. 3
Option 0: Reference hall	36.4 m	76699	41048 (53.5%)	39645 (51.7%)	38281 (49.9%)
Option 1a: FORMOSA last	29.8 m	76699	46077 (60.1%)	44360 (57.8%)	42764 (55.7%)
Option 1b: FORMOSA under		76699	46077 (60.1%)	44360 (57.8%)	42764 (55.7%)
Option 2: FASERnu2 first	20.0 m	76699	55689 (72.6%)	53514 (69.8%)	51502 (67.1%)
Option 2 "squeezed"	16.8 m	76699	59351 (77.4%)	57001 (74.3%)	54749 (71.4%)

Acceptance vs distance



Each color represents a different option (Reference, Option 1(a,b), Option 2, Option 2 (squeezed)).

Crystal-Pulling magnets appear always better:

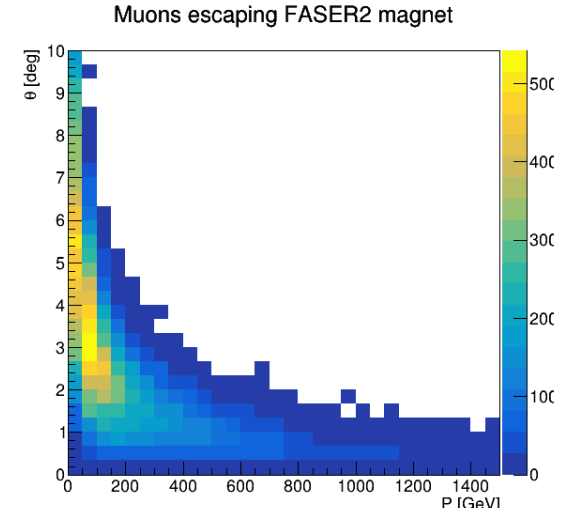
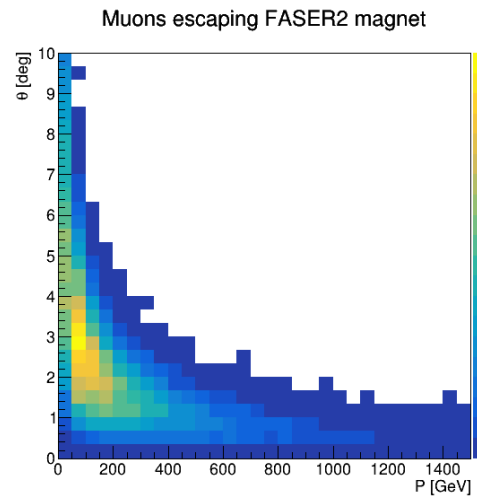
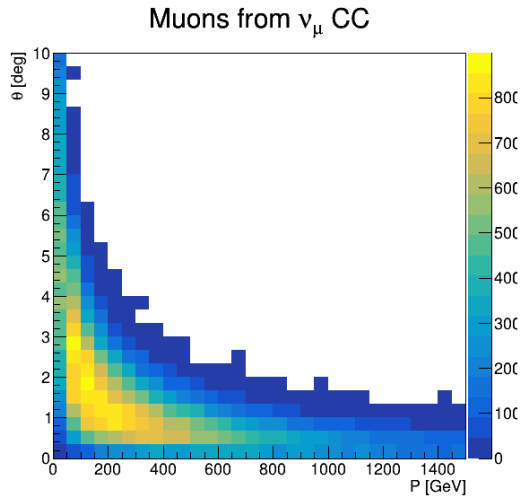
- Magnet window area is a bit less (2m^2 vs 3m^2) but more symmetric?
- Shorter distance (tracking stations are more compact).

Phase space

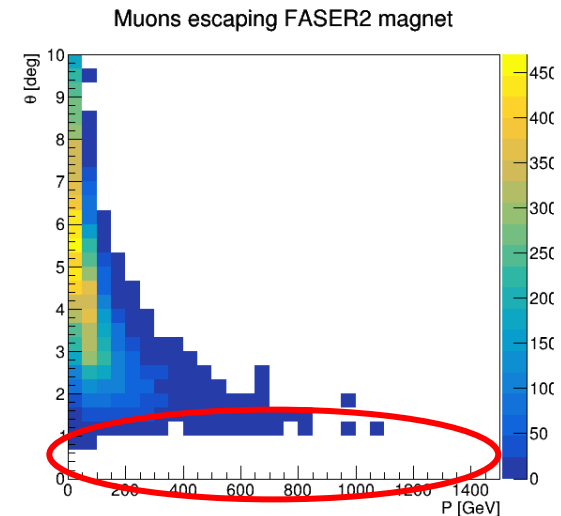
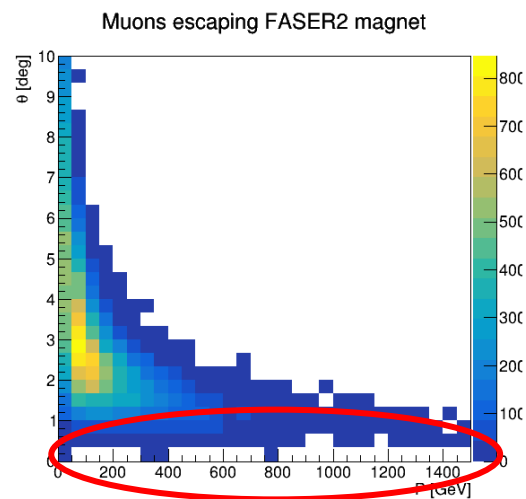
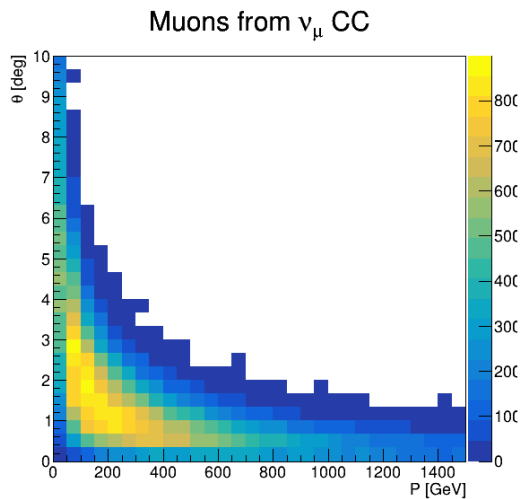
Option 0:
reference

Option 2:
“squeezed”

SAMURAI-style
magnet



Crystal-Pulling
magnet



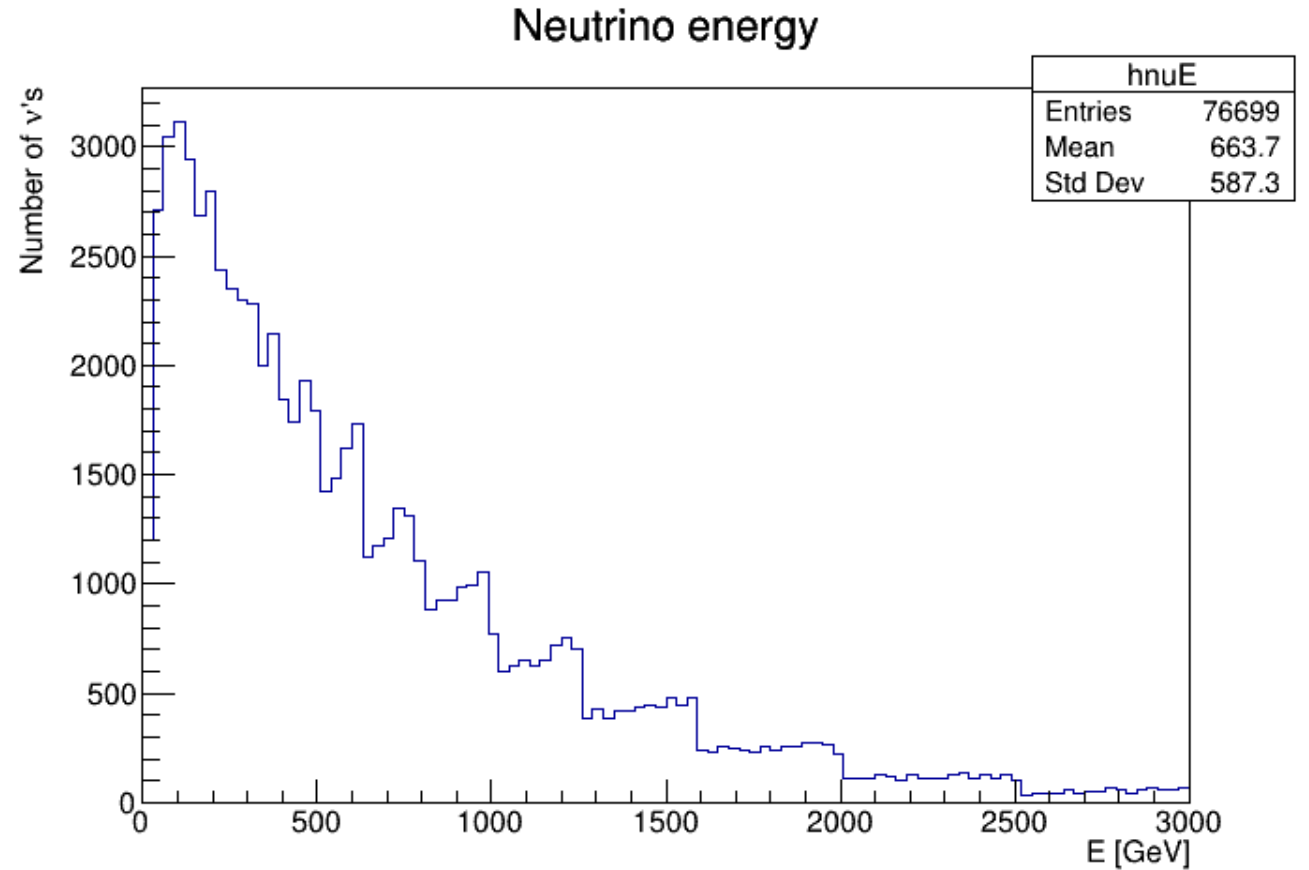
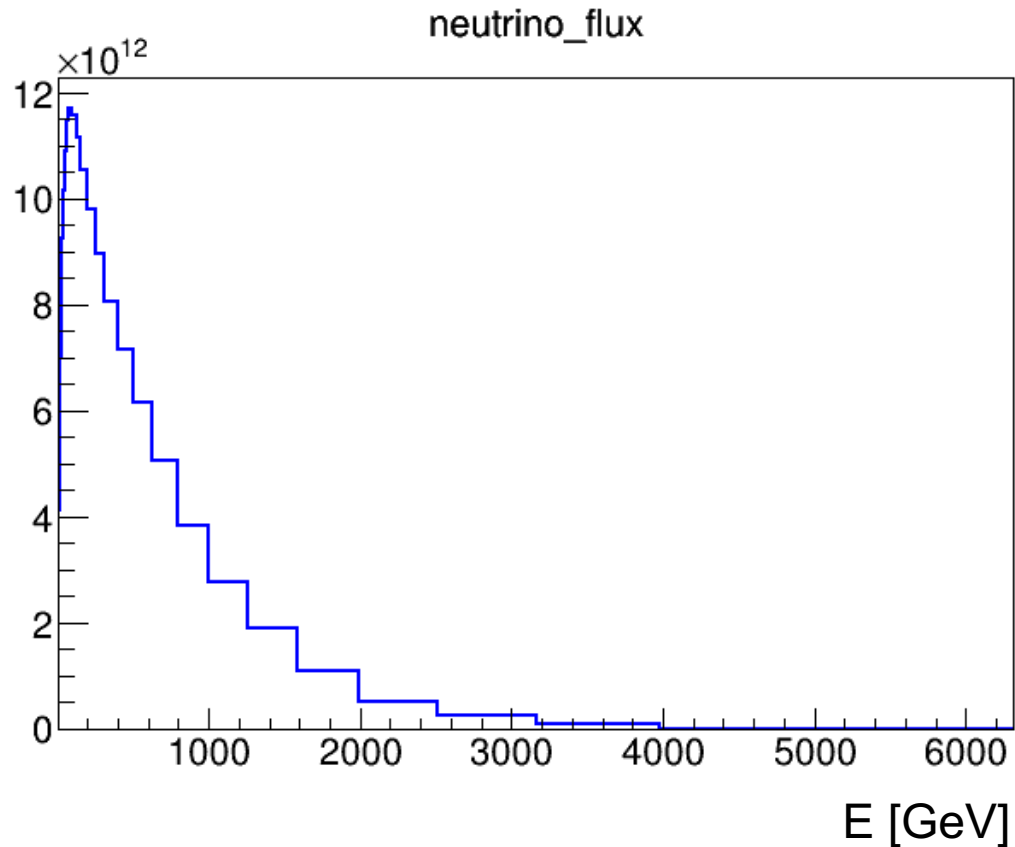
Complete
recovering
straight-going
muons
→ larger y-size
of the window

Next steps

- Try SAMURAI with larger pole gap (2m) + non-uniform field.
- Revisiting muon momentum reconstruction performance (both magnets).
- Optimize FLArE HadCat+MF for muons escaping FASER2
 - Targeting 20% resolution for ~10 GeV muons
- Summarize these results in the tech note.

Back-up

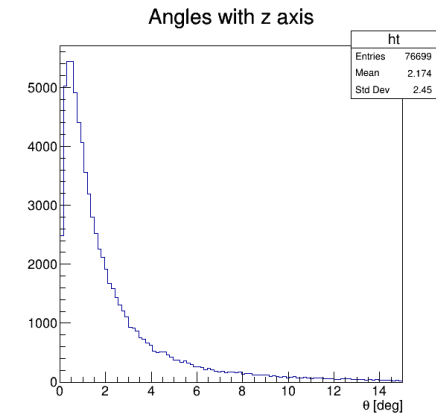
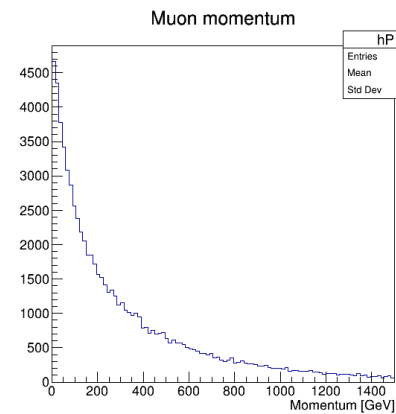
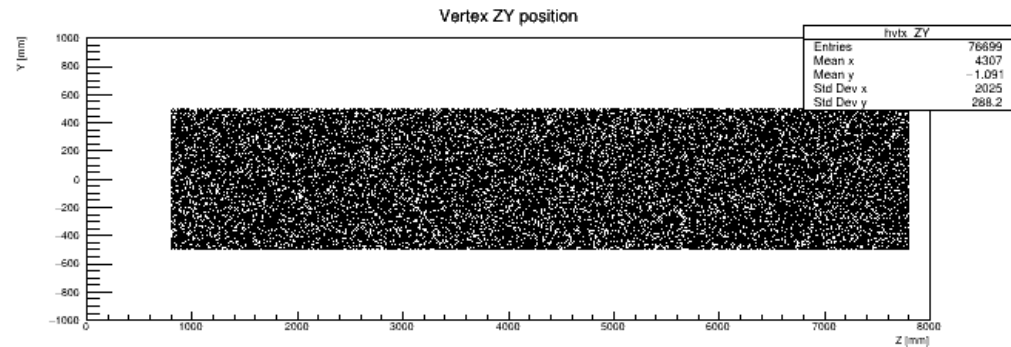
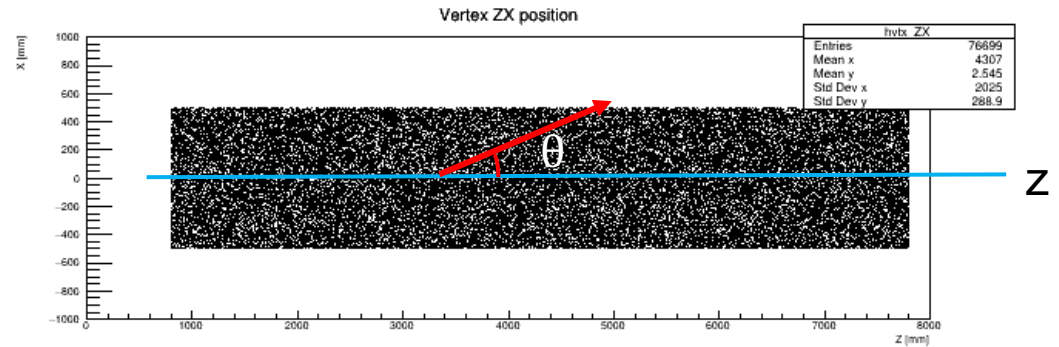
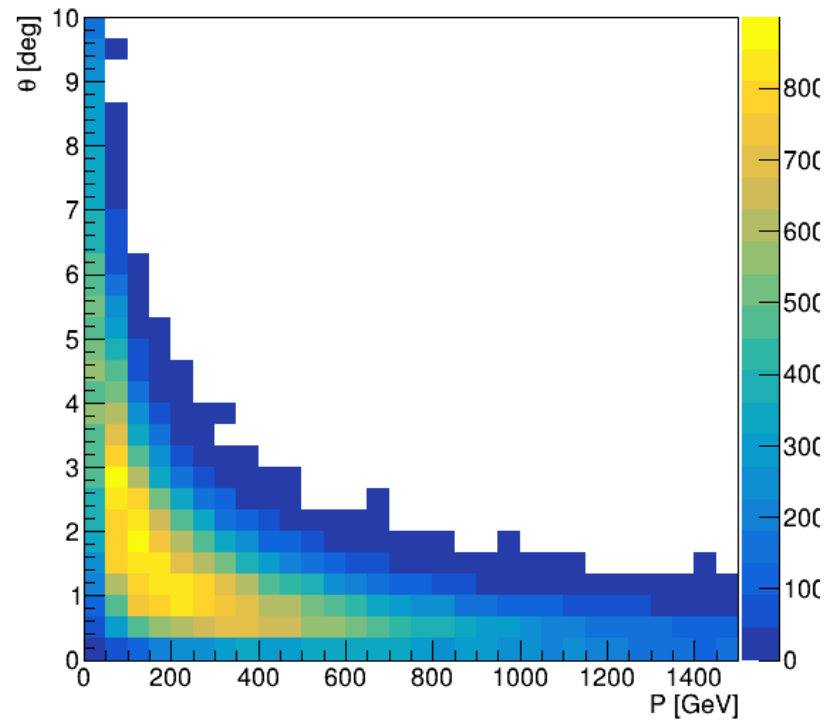
Input ν_μ flux



Muons from ν_μ

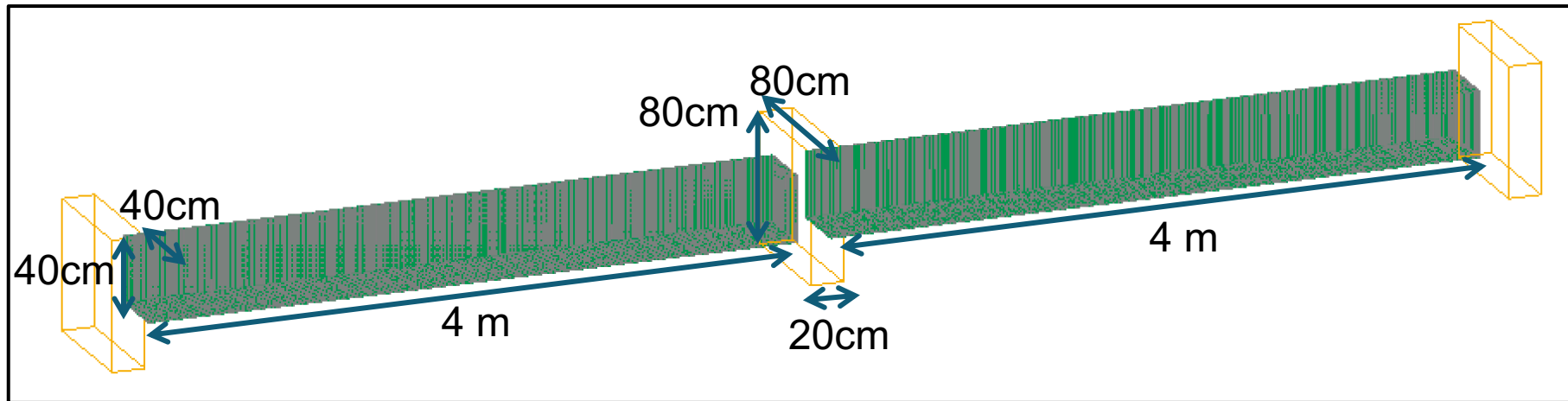
- Picking out muons from ν_μ interactions, uniformly distributed in FLArE. [ref]
- 100k ν_μ sample \rightarrow 76.7k μ (77%)

Muons from ν_μ CC



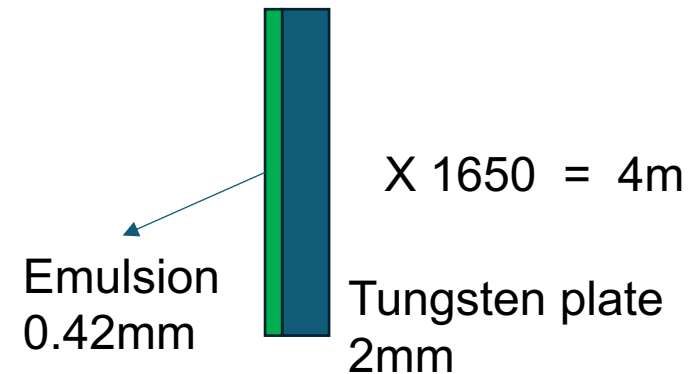
FASERnu2

FASERnu2 geometry according to [\[ref\]](#)



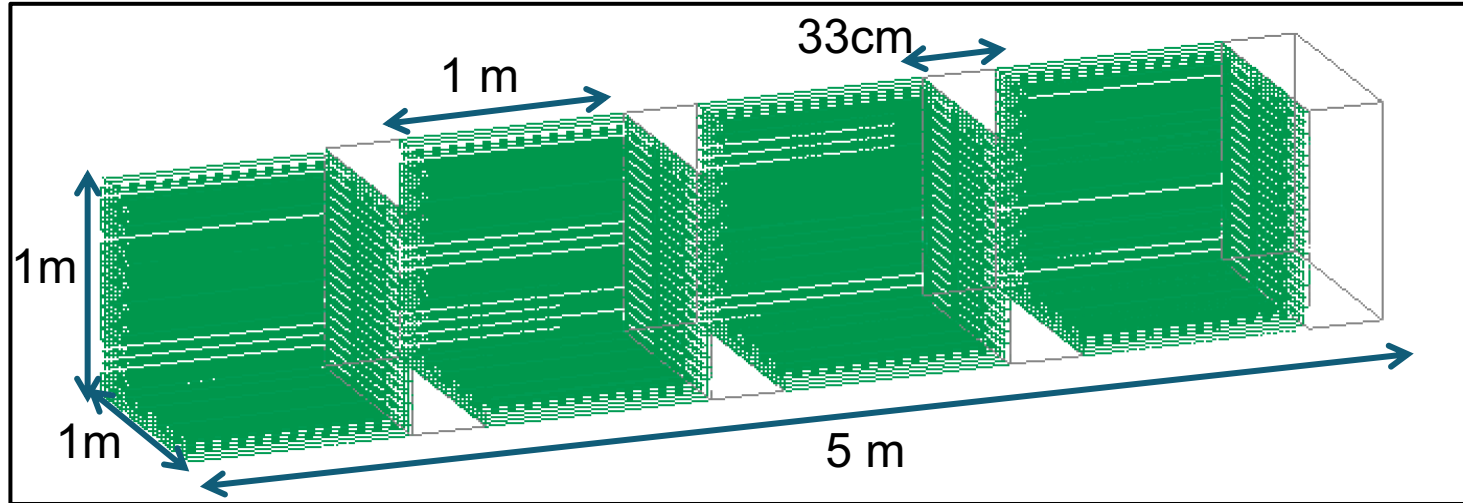
2 emulsion-tungsten modules, 40cm x 40cm x 4m
3300 tungsten plates, 2mm thick
3 veto/interface detectors, 80cm x 80cm x 20cm
(no cooling box for now)

Total length: 8.6m



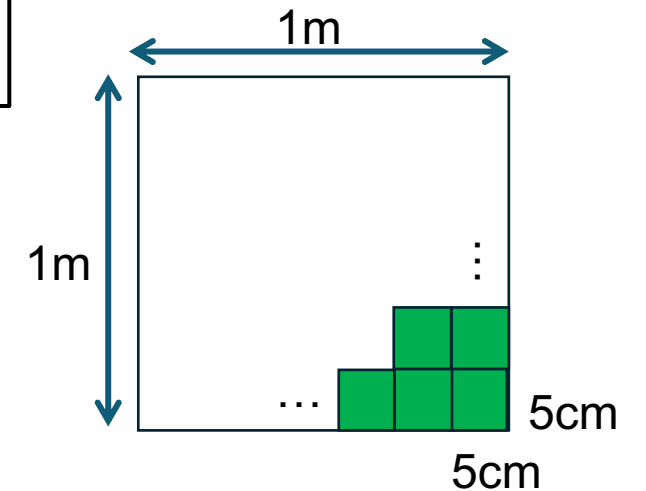
FORMOSA

FORMOSA geometry from FPF P5 paper [[ref](#)]

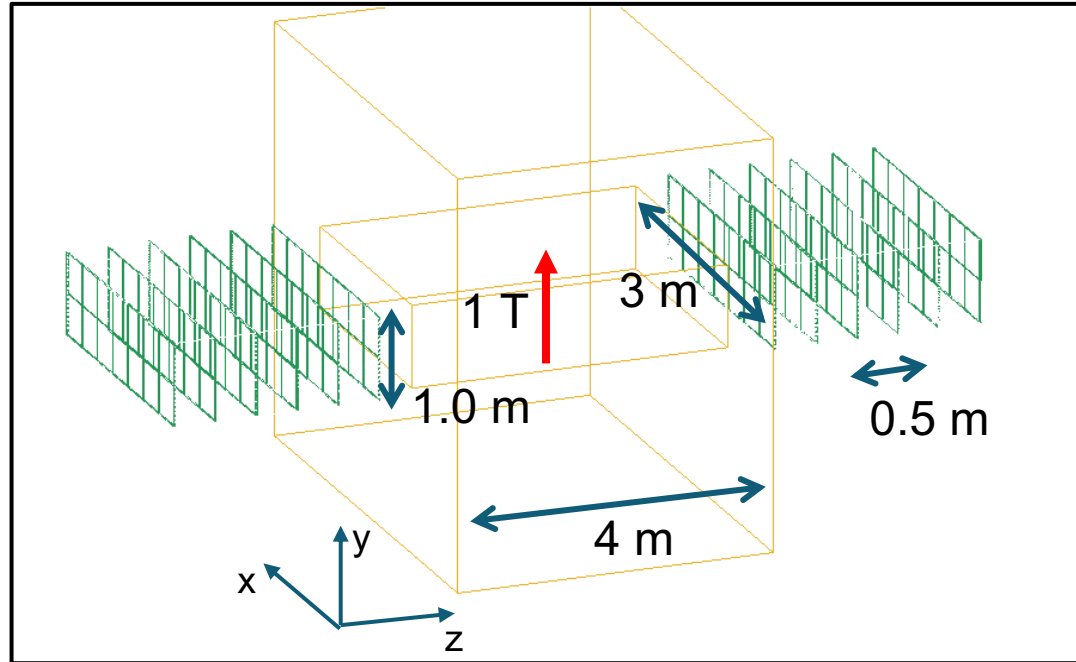


4 scintillator modules, 1m x 1m x 1m
Each made of 400 bars, 20 x 20
Single bar: 5cm x 5cm x 1m
2 veto detectors (not added yet)

Total length: ~5m

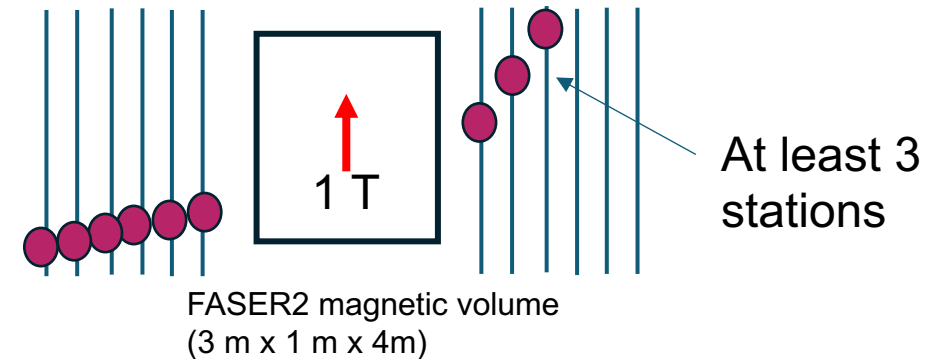


Magnet: SAMURAI



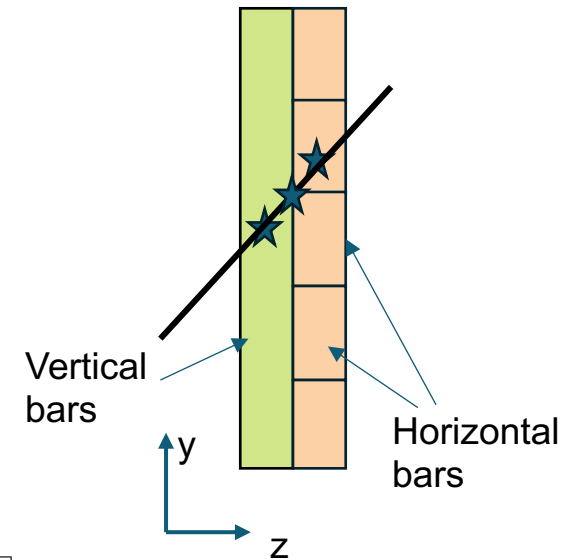
Rectangular window: 3 m x 1 m (4 Tm)
6 tracking stations, 50 cm apart
 $B = 1$ T (fixed)
Yoke X-thickness: 1.5m
Yoke Y-thickness: 2m

- Simple acceptance requirements:
 - **>0 digits** in the pre-magnet tracking stations
 - **>2 digits** in the post-magnet tracking stations

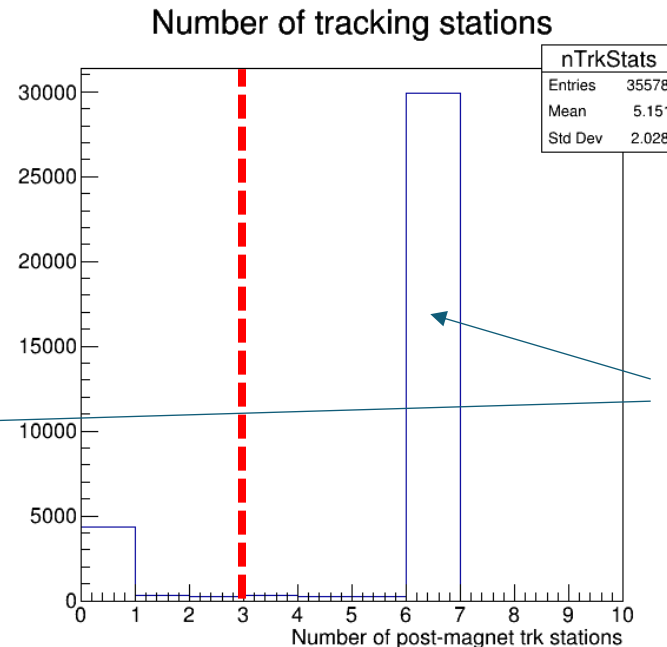
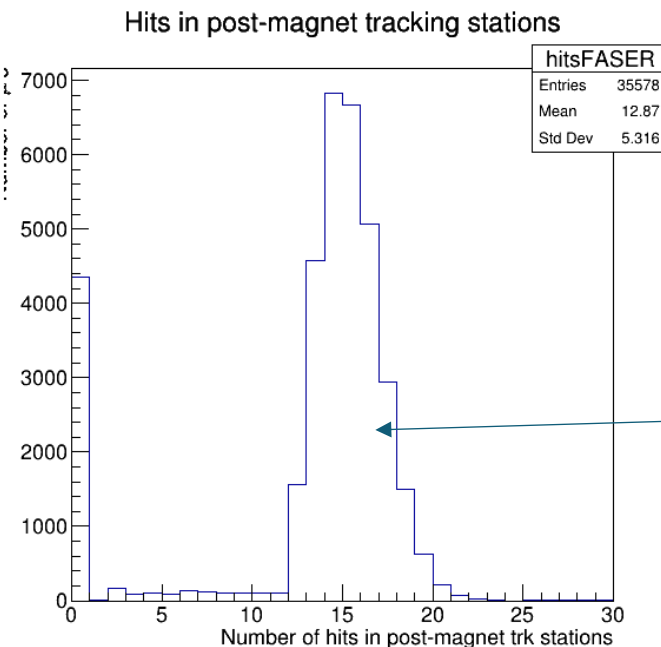


Segmentation

- The segmentation/digitization of the tracking stations is currently ignored.
- In the past studies, I was requesting **>5 hits** assuming each station was yielding only 2 hits (which is not always true).
- Now I'm setting a requirement on the number of tracking station crossed (1 digit = 1 tracking station), rather than the number of hits.



Distributions of hits for the muons that touched the pre-magnet tracking stations:



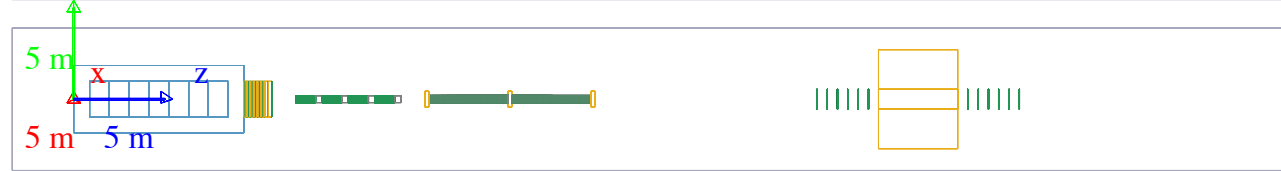
Crossing all 6 stations:
number of hits is not fixed, due to the stepping of the simulation

Options

FLArE +
FASER2 only



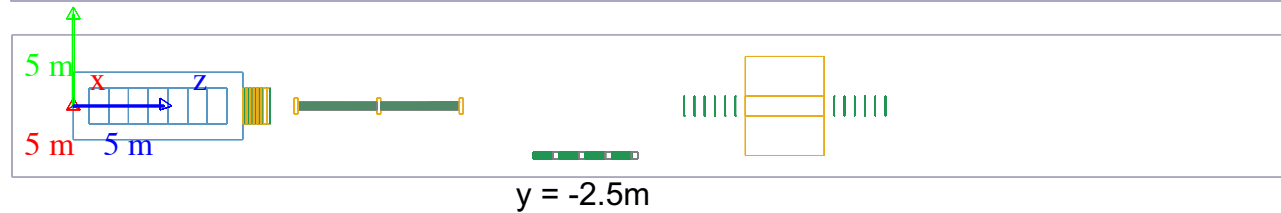
Option 0:
Reference hall



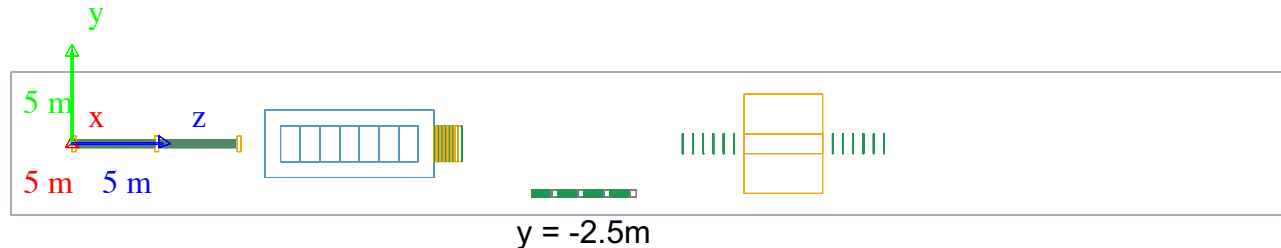
Option 1a:
FORMOSA last



Option 1b:
FORMOSA under



Option 2:
FASERnu2 first



FLArE to FASER2:
(center to center)

D = 38336 mm

D = 31816 mm

D = 22030 mm

Muon acceptance

Muons from a sample of 100k ν_μ CC interactions in FLArE.
B-field @ FLArE: 1 T; FLArE fiducial is: 1m x 1m x 7m.

OPTION	Distance to FASER2	FLArE volume	TOT	HadCat + MF	FASER2
FLArE + FASER2 only	38.3 m	All	76699	66899 (87.2%)	23760 (31.0%)
		Fiducial	76699	73486 (95.8%)	30808 (40.2%)
Option 0: Reference hall		Fiducial	76699	73486 (95.8%)	30668 (40.0%)
Option 1a: FORMOSA last	31.6 m	Fiducial	76699	73486 (95.8%)	34118 (44.5%)
Option 1b: FORMOSA under			76699	73486 (95.8%)	34118 (44.5%)
Option 2: FASERnu2 first	22 m	Fiducial	76699	73461 (95.8%)	41027 (53.5%)
Option 2 "squeezed"	17 m	Fiducial	76699	73309 (95.6%)	45952 (59.9%)

Fiducial volume

- In the past I reported a 32.8% acceptance using the FLArE fiducial volume.

OPTION	D [m]	FLArE volume	TOT	HadCat + MF	FASER2
FLArE + FASER2 (OLD)	~37	All	15407	13580 (88.1%)	4905 (31.8%)
		1m x 1.8m x 7m	8519	7843 (92.0%)	2793 (32.8%)

Old study [REF]:
Fiducial only with $|x| < 0.5\text{m}$

*past study used >5 hits requirement

- Now I'm getting ~40% in the "same" conditions. This is due to a **difference in the definition of the fiducial volume**: cut along Y dominates the acceptance (due to y-size of magnet window)

OPTION	D [m]	FLArE volume	TOT	HadCat + MF	FASER2
FLArE + FASER2	38.3	All	76699	66898 (87.2%)	23760 (31.0%)
		1m x 1m x 7m	76699	73486 (95.8%)	30808 (40.2%)
		1m x 1.8m x 7m	42554	38885 (91.4%)	13364 (31.4%)
		1.8m x 1m x 7m	42799	39061 (91.3%)	16917 (39.5%)

New study:
Comparing fiducial volumes:

$|x| < 0.5\text{m} \ \&\& \ |y| < 0.5\text{m}$

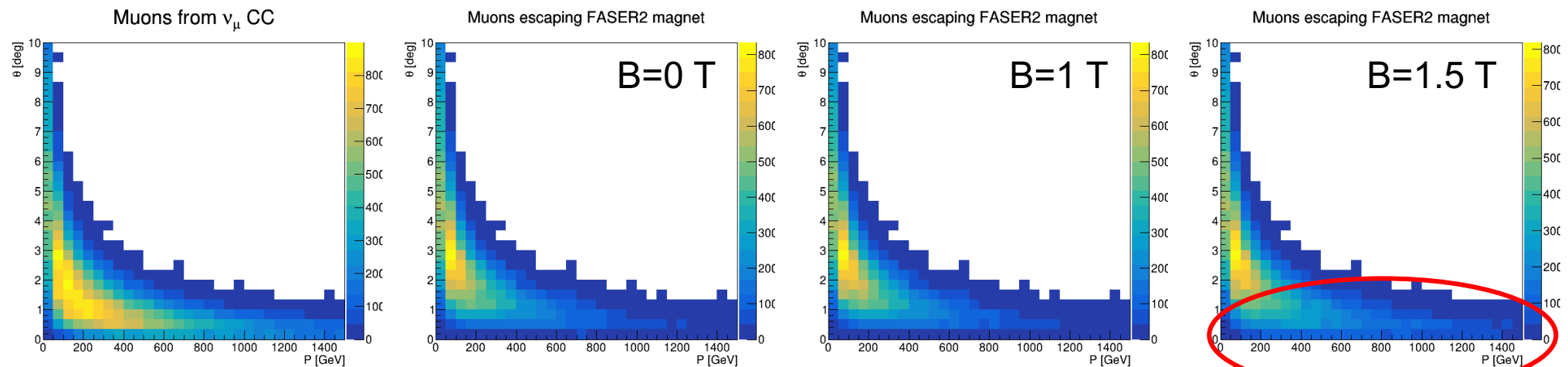
$|x| < 0.5\text{m}$ (only)

$|y| < 0.5\text{m}$ (only)

Dependence on FLArE B-field

- In the past study, the effect of FLArE B-field on the FASER2 acceptance appeared negligible. This is no longer the case, possibly given then newer fiducial volume definition.

OPTION	D [m]	B [T]	FLArE volume	TOT	HadCat + MF	FASER2
FLArE + FASER2 only	38.3	0	Fiducial	76699	73284 (95.5%)	30680 (40.0%)
		1	Fiducial	76699	73486 (95.8%)	30808 (40.2%)
		1.5	Fiducial	76699	69440 (90.5%)	26381 (34.4%)



Acceptance vs digits requirement

- The nominal requirement is at least 3 tracking stations. Minimum requirement for momentum reconstruction is 2 tracking stations.

OPTION	Req.	TOT	FASER2
Option 0: Reference hall	>1	76699	30924 (40.3%)
	>2	76699	30668 (40.0%)
	>3	76699	30383 (39.6%)
	>4	76699	30143 (39.3%)
	>6	76699	29879 (38.9%)

