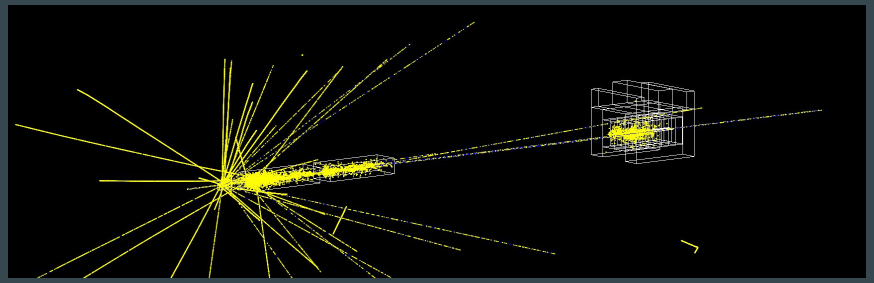


ProtoDUNE GEANT4 simulation

•••

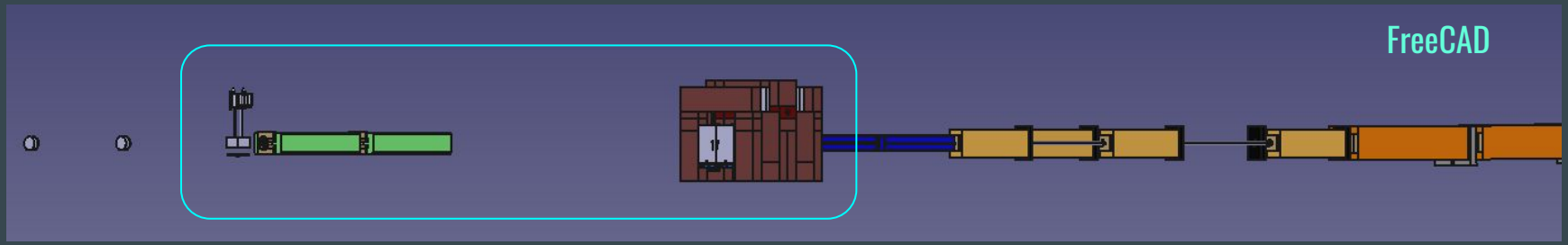
Update on background simulation from T2 and TAX

H. Sieber, L. Molina Bueno, J. Martin-Albo Simon

11.04.2024

Overview of the work

Implementation of a **GEANT4-based simulation** framework for the study of **background events** from meson decays to final-state neutrinos



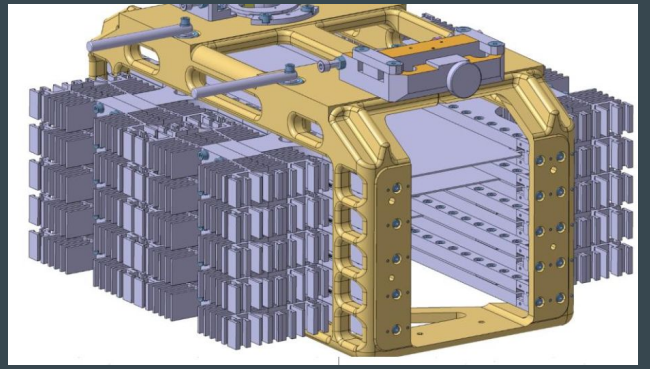
REMINDER

T2 Target

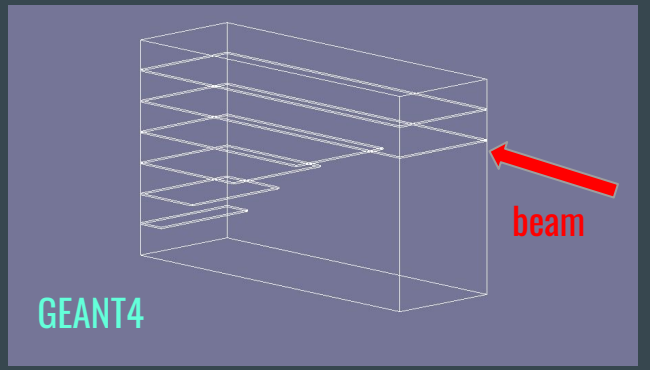
REMINDER

EDMS no. 1267311

- Simplified implementation of T2 target geometry (**only Be plates**, no Al cooling fins)
- Different Be **plates geometry** (5) + one “empty” configuration



Position	Material	Length (mm)	Height (mm)	Width (mm)
0	*Air/OUT*	-	-	-
1	Be	500	2	160
2	Be	300	2	160
3	Be	180	2	160
4	Be	100	2	160
5	Be	40	2	160
		5x plates, 40 mm inter-plate distance		



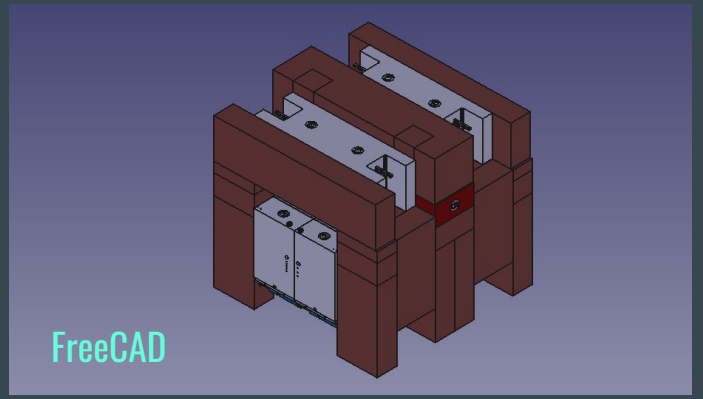
TAX and shielding blocks

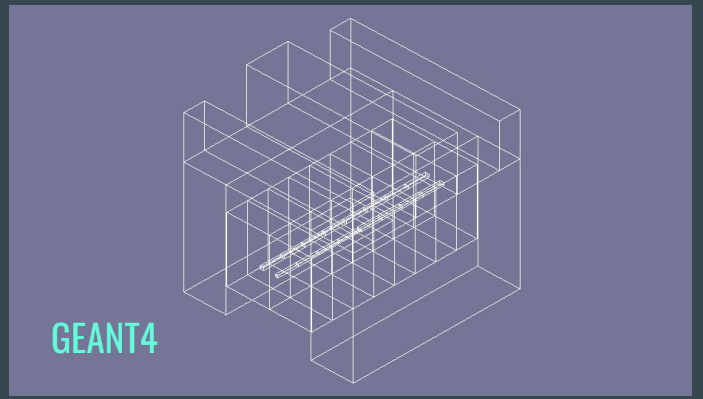
REMINDER

EDMS no. 2593676

- Implementation of both TAX for **H4 and H2 beam lines** and enclosing Fe shield structures
- TAX block structures: (i) **Al-Cu-Cu-Fe** and (ii) **Cu-Cu-Fe-Fe** with hole within the individual blocks

Name	Beam	Taxmot	Reference	Y-position	Hole size	Insert position				TAX range	Composition	Comments
						Block1	Block2	Block3	Block4			
T2 (checked 26/04/2023)	H2	1	XTAX0210023	143,5	dump					small	Al-Cu-Cu-Fe	Negative range limits:
				100	120 cm Be (Ø=12)	■	■	■		small		Small: +85
				-20	60x40					medium		Medium: -35
				-140	48x40					large		Large: -142 mm
		2	XTAX0210025	142	dump					small	Cu-Cu-Fe-Fe	**<12 mm holes have W inserts**
				80	80 cm Be (Ø=12)	■	■			small		
				20	Ø=4 (W insert)					small		Negative range limits:
				-60	Ø=12					medium		Small: +5
				-140	80x40					large		Medium: -75
												Large: -142 mm
	H4	3	XTAX0220023	142	dump					small	Al-Cu-Cu-Fe	Negative range limits:
				60	160 cm Be (Ø=12)	■	■	■	■	small		Small: +45
				-20	Ø=12					medium		Medium: -35
				-140	64x50					large		Large: -142 mm
		4	XTAX0220025	143	dump					small	Cu-Cu-Fe-Fe	**<10 mm holes have W inserts**
				100	Ø=4.2 (W insert)	■	■			small		
				60	Ø=6.0 (W insert)	■	■			small		Negative range limits:
				20	Ø=5.0 (W insert)	■	■			medium		Small: +45
				-20	Ø=7.2 (W insert)	■	■			medium		Medium: -35
				-60	Ø=16.0					large		Large: -142 mm
				-140	64x50					large		

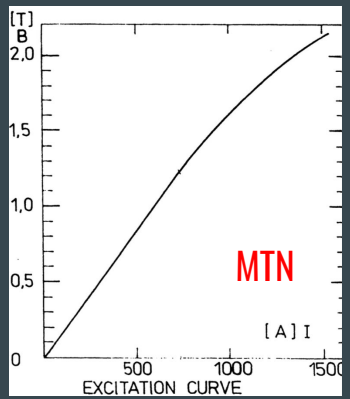




Implementation details for MTN bending magnets

- Simplified implementation of MTN magnets **without epoxy coil** structure
- **Uniform magnetic field** within the magnet aperture (no fringe effects)
- Field value tunable depending on the **wobbling configuration**

REMINDER



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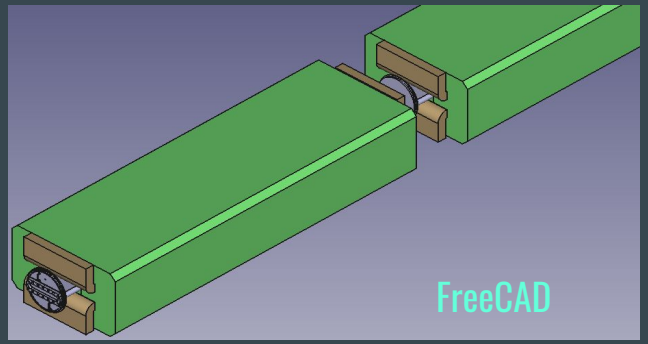
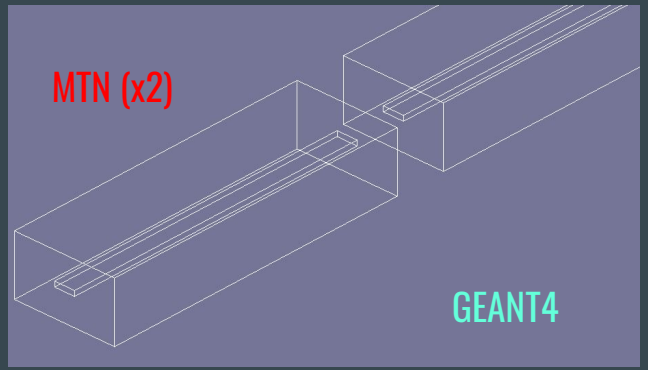
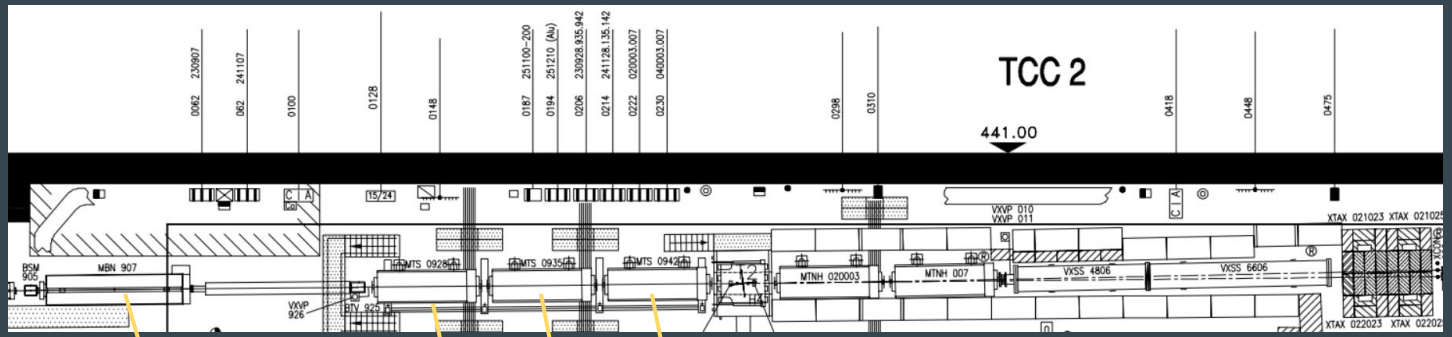




Simulation geometry extension: implementation of the MBN and MTR(S) magnets

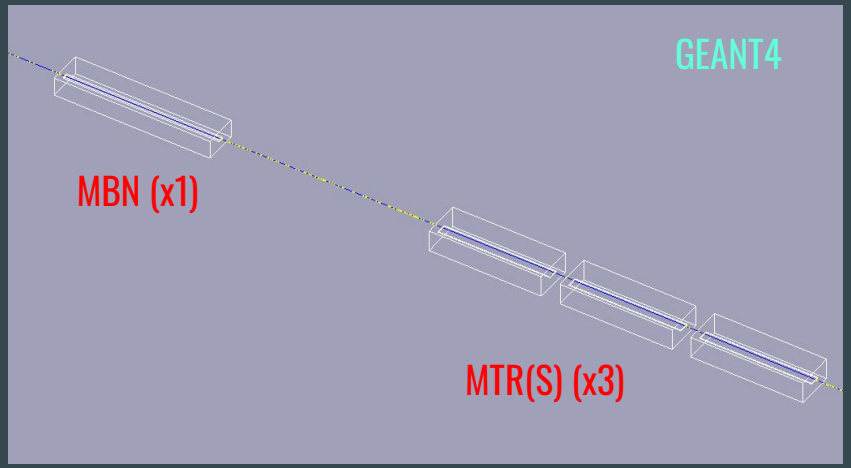
Simulation framework further expanded to test the different **wobbling configurations**, given magnetic deflection before and after the T2 target

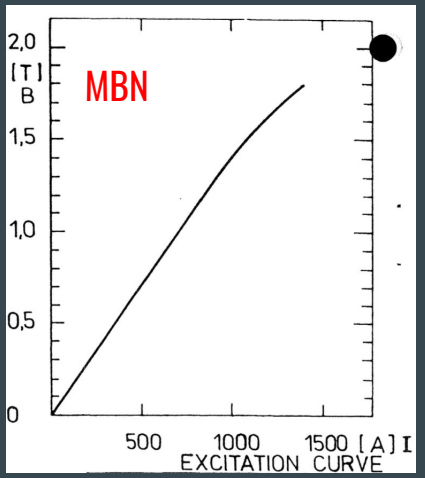


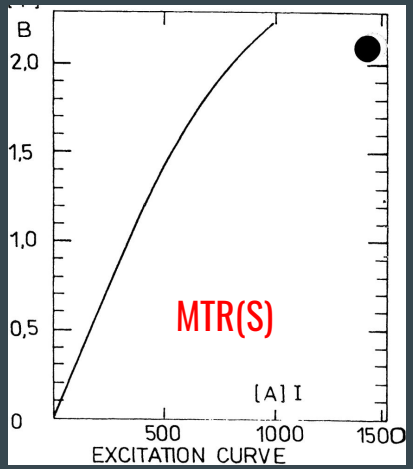
CERN-OPEN-2004-003

Implementation details for MBN and MTR(S) bending magnets

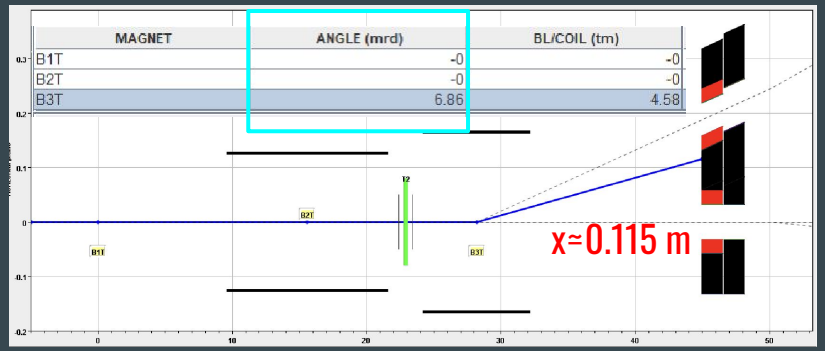
- Simplified implementation of bending magnets without epoxy coil structure
- Uniform magnetic field within the magnet aperture (no fringe effects)
- Field tunable depending on the **wobbling configuration**

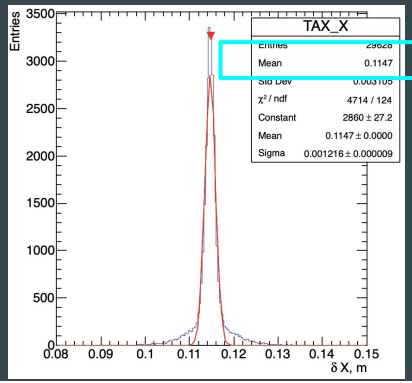


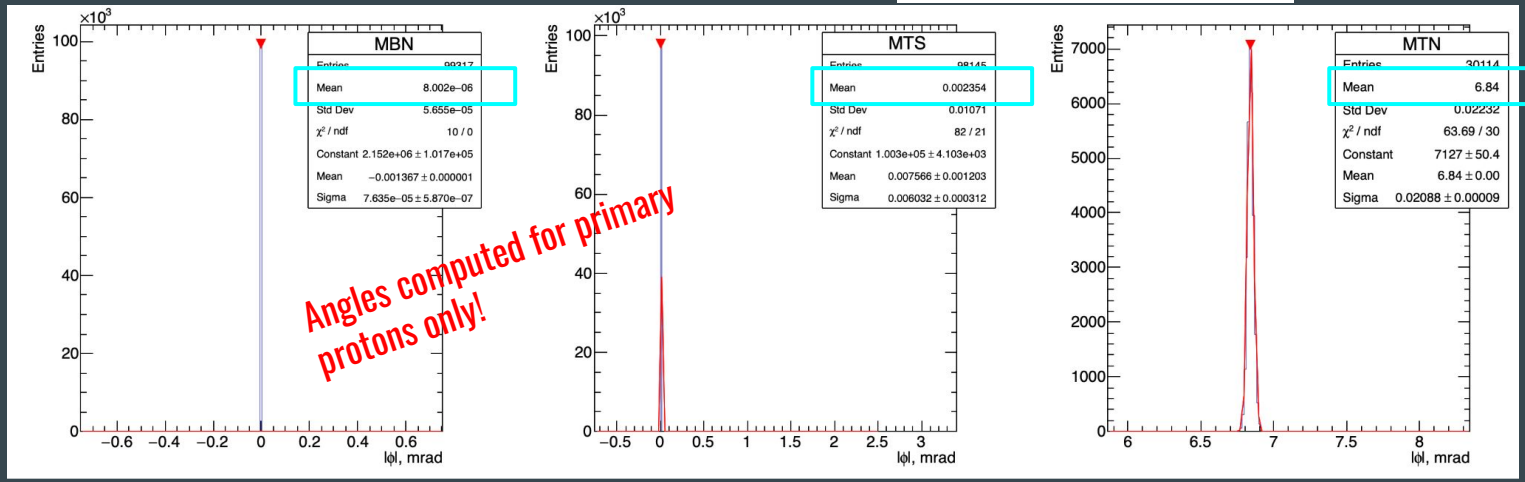




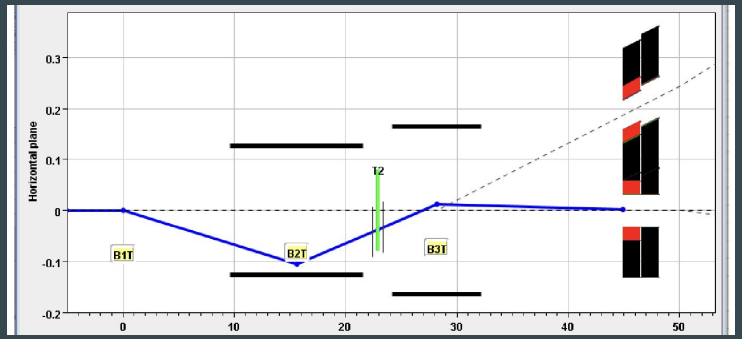
Validation of the field implementation: testing of the wobbling configuration **133**



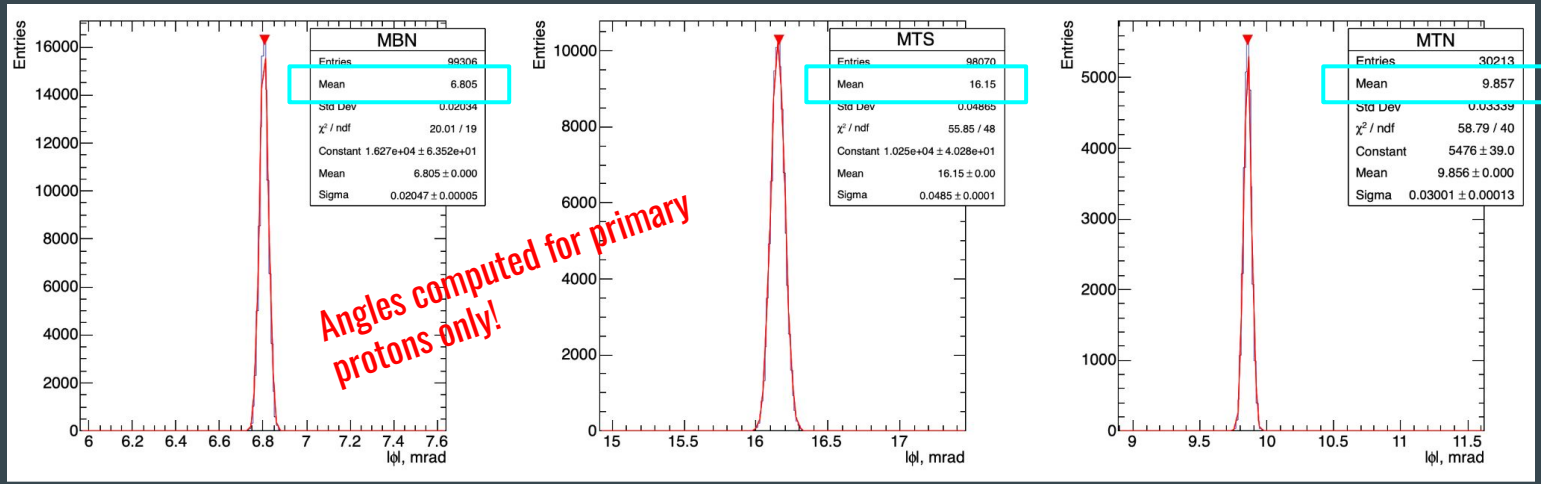




Validation of the field implementation: testing of the wobbling configuration **153**

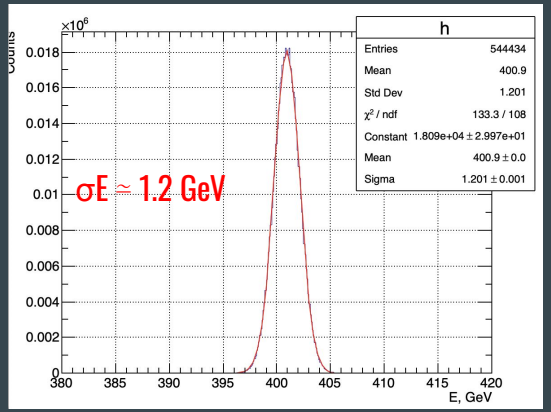


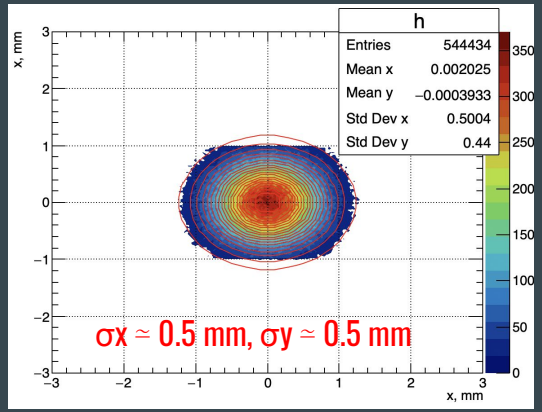
MAGNET	ANGLE (mrd)	BL/COIL (tm)	CURRENT (amps)
B1T	-6.81	-9.09	1,300
B2T	16.15	7.19	-787
B3T	-9.87	-6.59	1,140

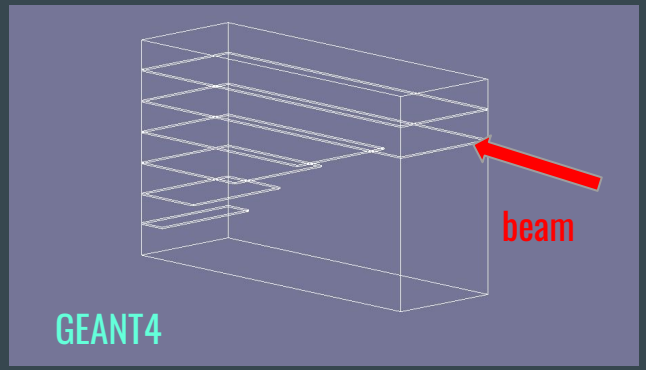


Refining the primary interaction comparison between GEANT4 and Pythia8

Investigation of mesons production → **Fast simulation** within the full GEANT4 geometry: event abortion after the first primary **proton inelastic** / **hadronic elastic** interaction within the T2 target (handled through the G4VUserSteppingAction), **list of secondaries** saved at this step (only primary track processed in the stack)







Light *I=0,1* mesons production

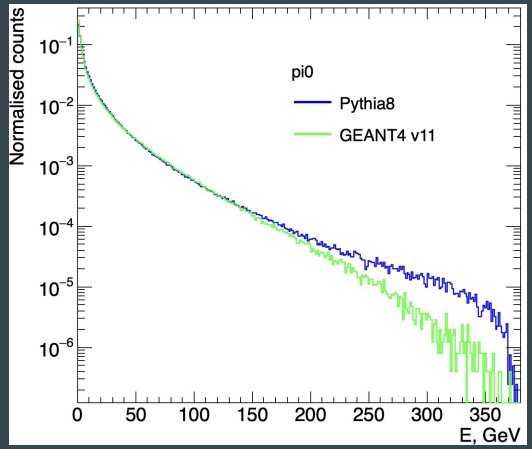
Normalised to account for the 70% proton interaction rate in T2

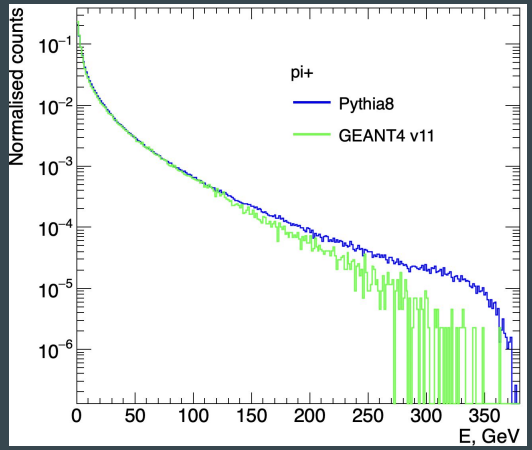
/	GEANT4v11	Pythia8	Ratio
η	0.28	0.32	0.88

Table 3: Light $I = 0$ mesons production from primary proton first interaction with `GEANT4` in the reaction $p + \mathrm{Be} \rightarrow$ anything and `Pythia` with $p + p \rightarrow$ anything. The `SoftQCD:all` flag is used. The maximum uncertainty is $\sim \mathcal{O}(10\%)$.

/	GEANT4v11	Pythia8	Ratio
π^0	2.5	2.8	0.89
π^+	2.4	2.7	0.89
π^-	2.2	2.3	0.97

Table 1: Light $I = 1$ mesons production from primary proton first interaction with `GEANT4` in the reaction $p + \mathrm{Be} \rightarrow$ anything and `Pythia` with $p + p \rightarrow$ anything. The `SoftQCD:all` flag is used. The maximum uncertainty is $\sim \mathcal{O}(10\%)$.

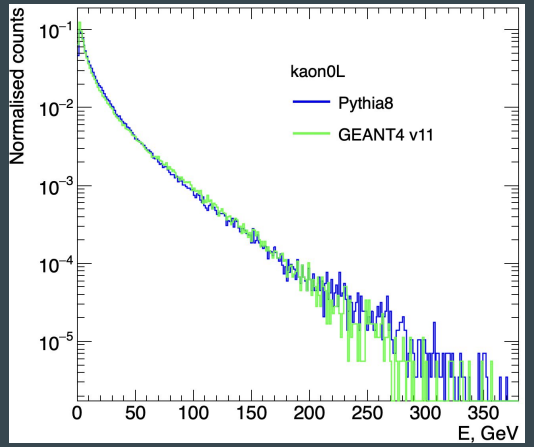


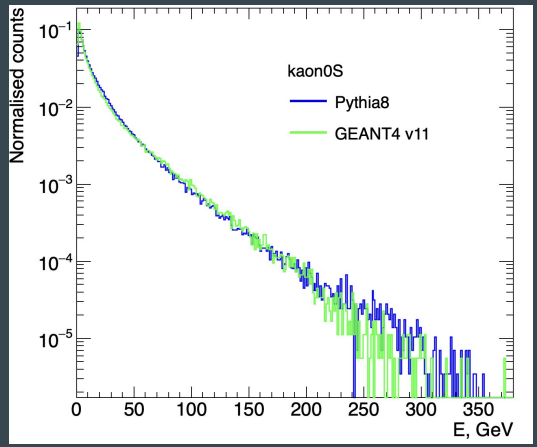


Strange mesons production

/	GEANT4v11	Pythia8	Ratio
K_L^0	0.18	0.20	0.90
K_S^0	0.18	0.20	0.90
K^+	0.21	0.25	0.84
K^-	0.16	0.18	0.89

Table 2: Strange mesons production from primary proton first interaction with `GEANT4` in the reaction $p + \mathrm{Be} \rightarrow$ anything and `Pythia` with $p + p \rightarrow$ anything. The `SoftQCD:all` flag is used. The maximum uncertainty is $\sim \mathcal{O}(15\%)$.





Charmed and bottom mesons

/	GEANT4v11	Pythia8	Ratio
D^0	$6.6 \cdot 10^{-5}$	$6.3 \cdot 10^{-4}$	0.10
D^+	$6.7 \cdot 10^{-5}$	$3.3 \cdot 10^{-4}$	0.20
D^-	$1.1 \cdot 10^{-4}$	$4.0 \cdot 10^{-4}$	0.28
D_s^+	$1.1 \cdot 10^{-5}$	$9.7 \cdot 10^{-5}$	0.11
D_s^-	$1.3 \cdot 10^{-5}$	$1.1 \cdot 10^{-4}$	0.12

Table 4: Charmed mesons production from primary proton first interaction with `GEANT4` in the reaction $p + \text{Be} \rightarrow$ anything and `Pythia` with $p + p \rightarrow$ anything. The `HardQCD:all` flag is used.

/	GEANT4v11	Pythia8	Ratio
B^0	$5.0 \cdot 10^{-6}$	$1.4 \cdot 10^{-7}$	> 10
B^+	$6.2 \cdot 10^{-6}$	-	-
B^-	$2.4 \cdot 10^{-6}$	-	-

to be simulated

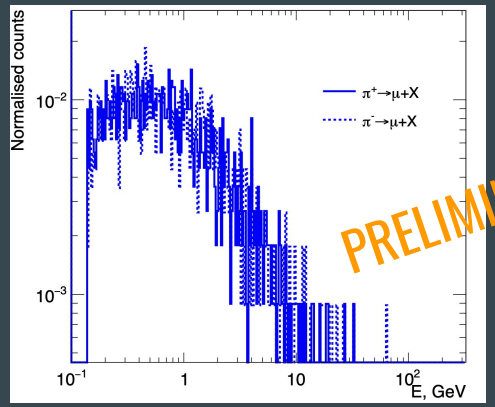
Table 5: Bottom mesons production from primary proton first interaction with `GEANT4` in the reaction $p + \text{Be} \rightarrow$ anything and `Pythia` with $p + p \rightarrow$ anything.

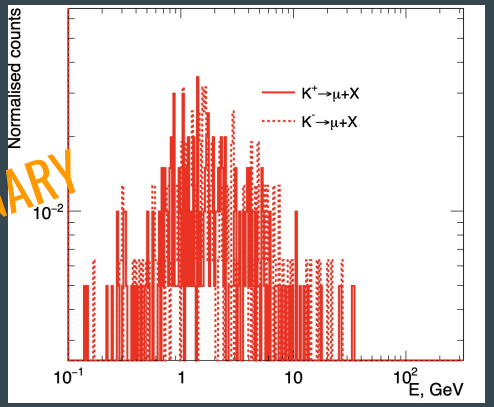
Discrepancies in charm and bottom mesons production rate! → input from SHiP would be most welcome.

First look at mesons within the set-up

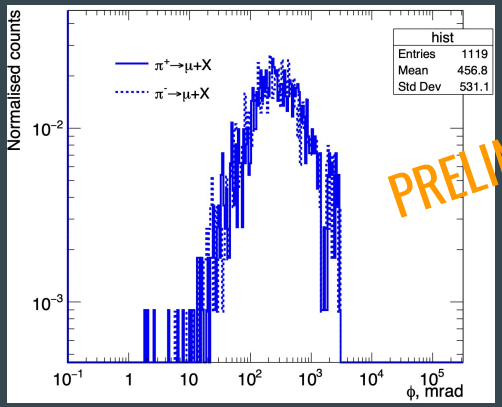
- Small sample (1e7 POT) of events generated to study the s**ignature of mesons decaying** to final-states with neutrinos within the geometry (fiducial volume **from T2 to TAX**) for wobbling configuration **133**.

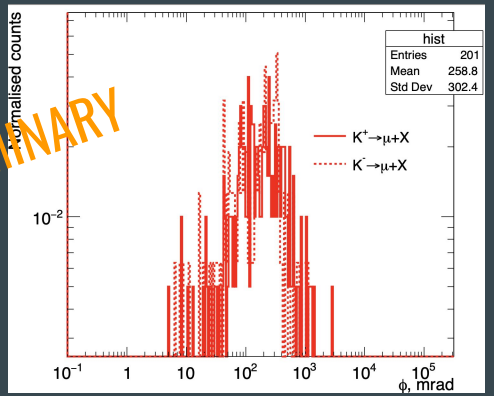
- Need to generate larger statistics and study to study also **neutral mesons** (not affected by the magnetic fields).





PRELIMINARY





PRELIMINARY

Summary and outlook

- **Full geometry** implemented for study of both (i) **wobbling configuration** and (ii) **particle production and propagation** within the set-up
- Good agreement between **GEANT4 v11 and Pythia v8** in meson production, except for **heavier D and B flavours**
- On-going study of the **mesons distribution** after the **T2** target and **TAX** (provided Josu with small sample of events with decays containing **final-state neutrinos**)