Studies of the nu_tau/LDM target with and without magnetic field

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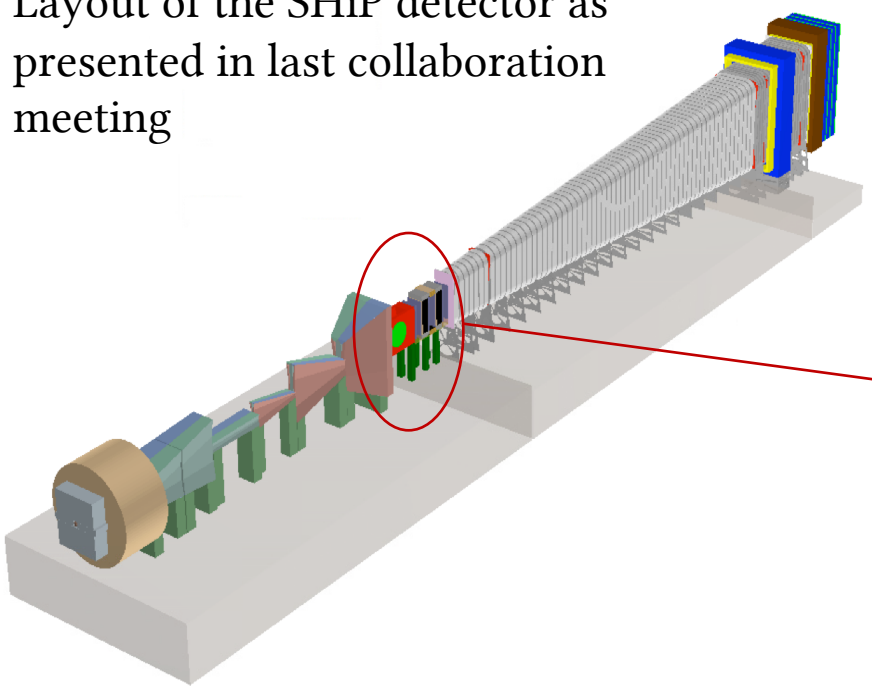
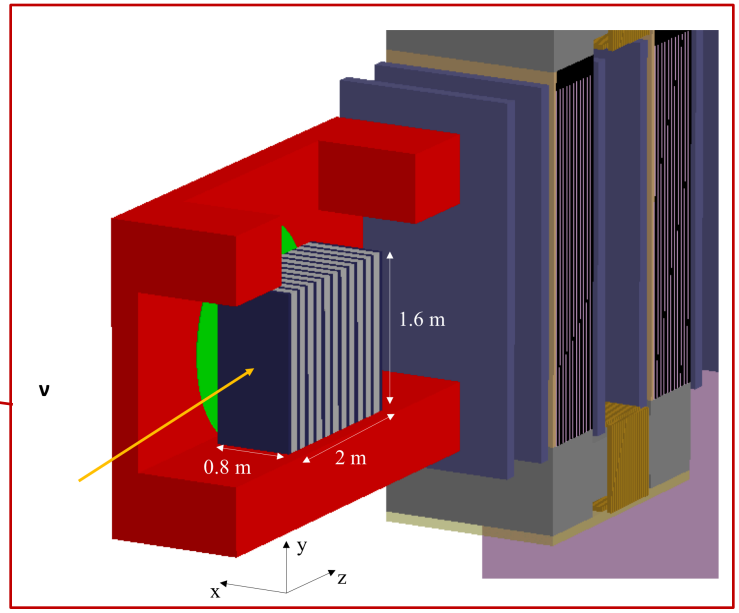
A short summary

Layout of the SHiP detector as presented in last collaboration meeting





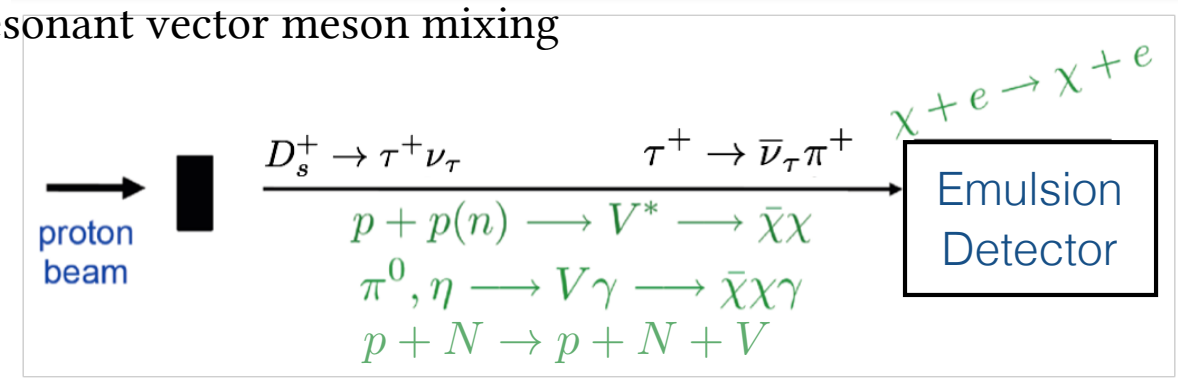
Neutrino/LDM Target

- Dimensions: 0.8 x 2 x 1.6 m^3
- Number of ECC bricks: 924
- Total mass: ~7 tons
- Horizontal magnetic field

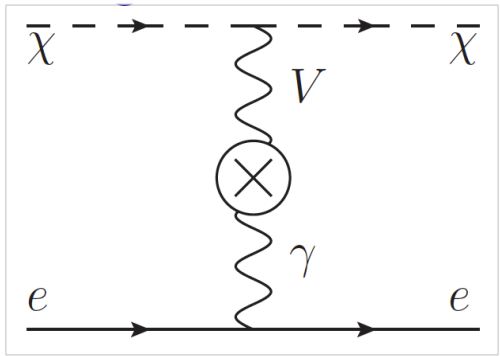
Optimisation still ongoing

Light DM searches

- Generated in the beam-dump, e.g. via light dark photon mediators **(V)**
- Main production modes:
  1) direct production
  2) decay in flight
  3) resonant vector meson mixing



- Detected when scattering on atomic electrons of the target



Detector optimization for Light DM searches

- Improvement of SHiP sensitivity in LDM search requires a dedicated optimization of the emulsion detector, concerning:

1) **Data analysis tools:**
   - electromagnetic shower identification
   - electron energy measurement

2) **Detector layout:**
   - increase the detector mass ⇒ Remove the magnet surrounding the neutrino detector ?
   - structure and material of ECC

⇓

   - Explore different segmentations of passive material
   - Explore use of W rather than Pb

Detector optimization for Light DM searches

MASS INCREASE

Pros

1) increase in the LDM sensitivity
2) increase in neutrino statistics
3) CES not needed anymore: simplification of the target, further increase in target mass
4) Avoid multiple scattering in magnet iron

Contra

1) CES not needed anymore: charge measurement of hadrons not possible
2) only muonic tau channel (Br 17%) used for ν_τ/anti-ν_τ separation
3) momentum measurement for hadron rely only on MCS in the brick

TARGET MAGNETIZATION

Pros

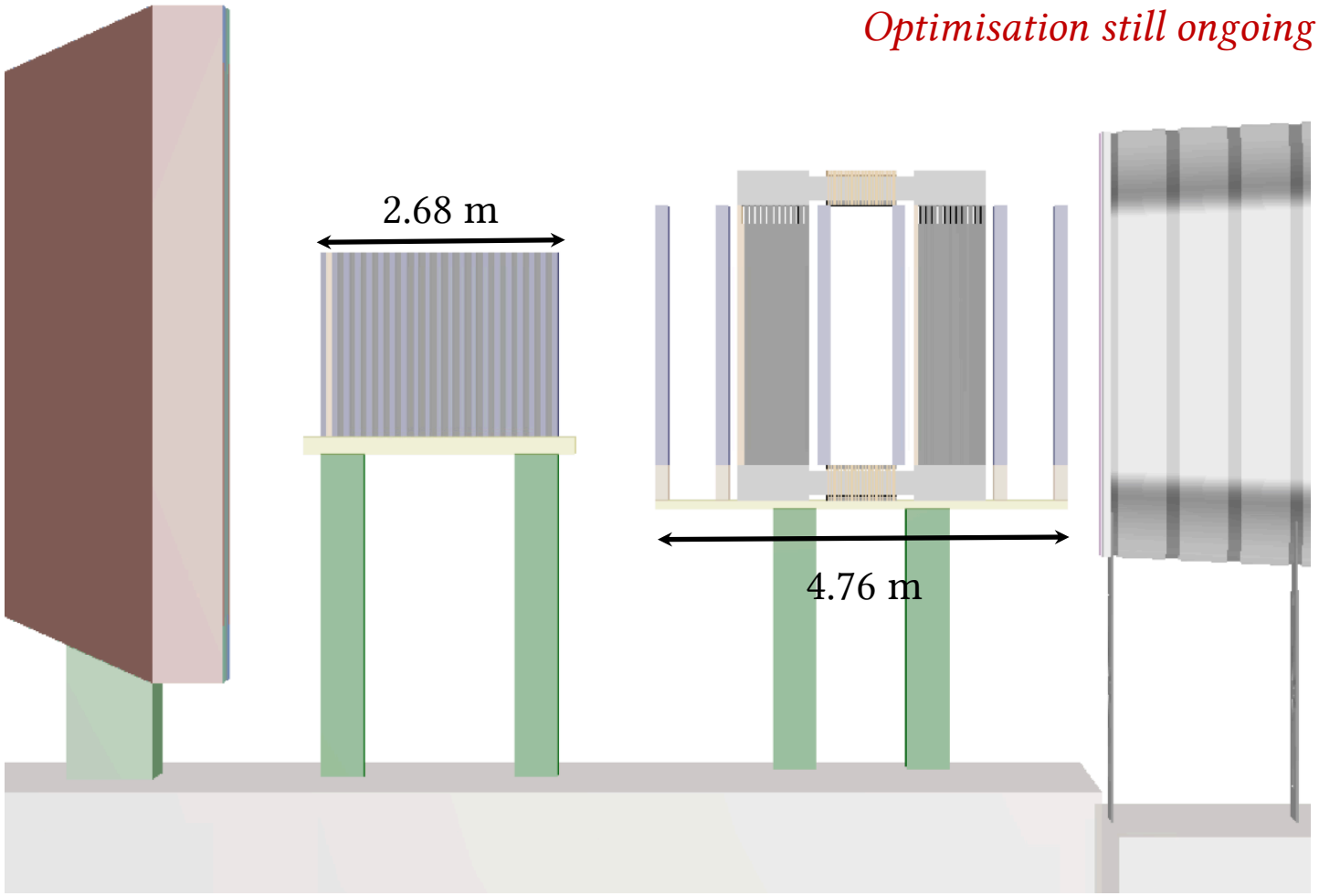
1) hadronic (Br 65%) and muonic (Br 17%) tau decay channels used for ν_τ/anti-ν_τ separation
2) momentum measurement for hadrons per formed with MCS algo in the brick and with sagitta method in CES

Contra

1) lower sensitivity in LDM search
2) target volume limited by the magnetized region
3) Multiple scattering in magnet iron

New neutrino/LDM target layout implemented

Optimisation still ongoing



New neutrino/LDM target layout

Optimisation still ongoing

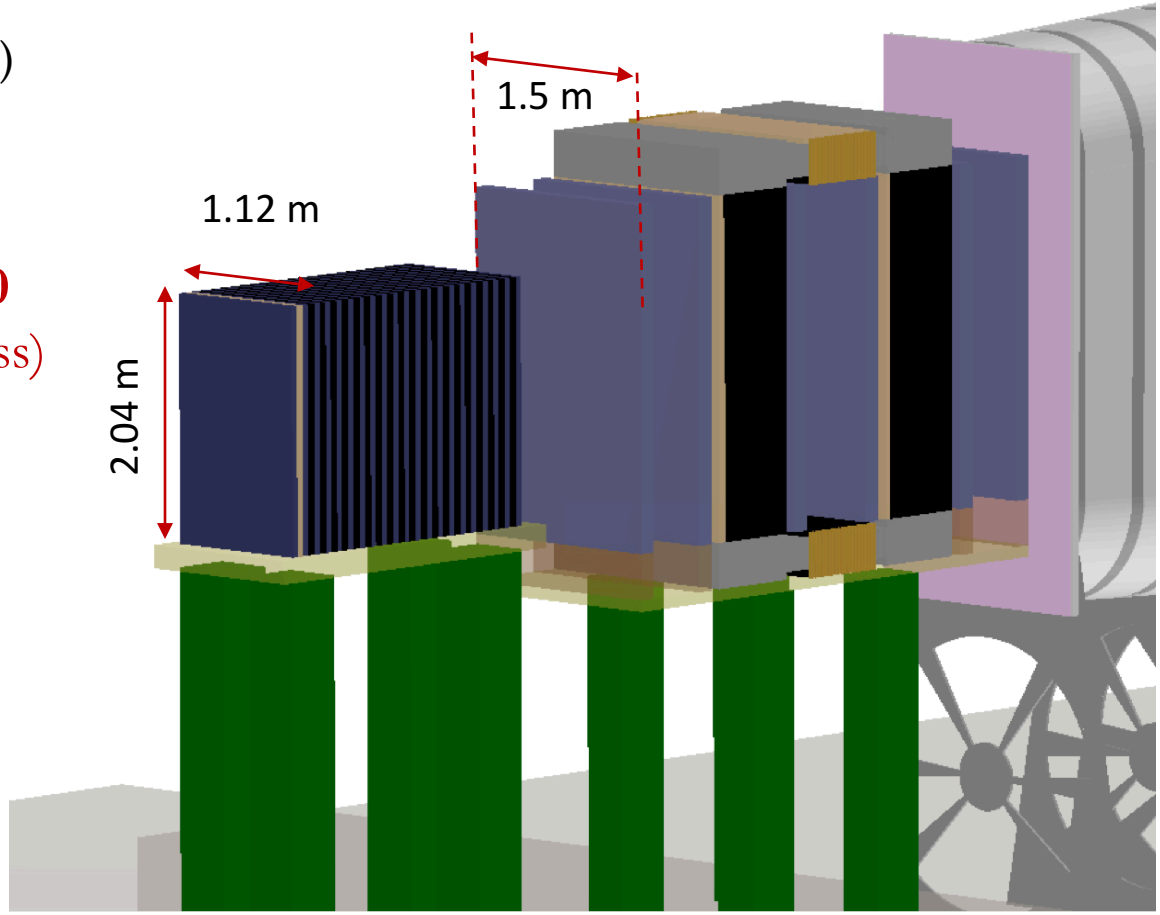
Neutrino Target

- 9 columns (along x direction)
- 20 rows (along y direction)
- 20 walls (along z direction)

Total number of bricks: 3600
(increase ≈ x4 in the target mass)

Magnetic Spectrometer

- Reduced transversal dimension so to completely fit in the free muon background region



Expected CC Neutrino Interactions

WITH MAGNET

	Flux	<E> (GeV)
ν_μ	2.3×10^6	31
ν_e	6.3×10^5	50
ν_τ	2.6×10^4	45
ν_μ-bar	8.6×10^5	26
ν_e-bar	2.2×10^5	38
ν_τ-bar	1.9×10^4	58

WITHOUT MAGNET

	Flux	<E> (GeV)
ν_μ	6.9×10^6	28
ν_e	1.7×10^5	45
ν_τ	7.5×10^4	43
ν_μ-bar	2.9×10^6	24
ν_e-bar	6.5×10^5	36
ν_τ-bar	4.7×10^4	54

Expected Neutrino-induced charm events

WITH MAGNET

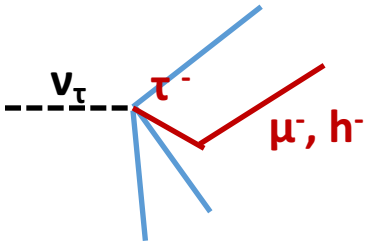
	Flux	<E> (GeV)	charm/CC (%)
ν_μ	1.0×10^5	48	4.3
ν_e	3.9×10^4	59	6.3
ν_μ-bar	3.6×10^4	41	3.8
ν_e-bar	1.2×10^4	49	5.3

WITHOUT MAGNET

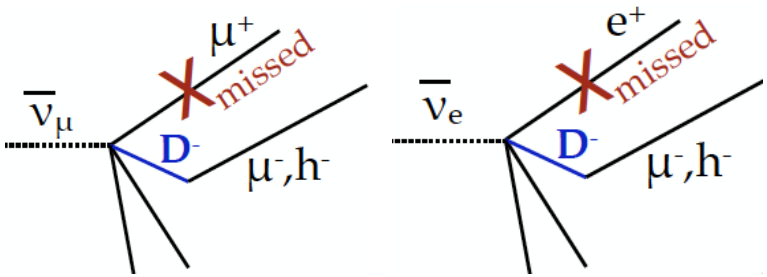
	Flux	<E> (GeV)	charm/CC (%)
ν_μ	2.7×10^5	45	3.9
ν_e	$9{,}7\times10^4$	56	5.7
ν_μ-bar	1.0×10^5	39	3.6
ν_e-bar	3.2×10^4	46	4.9

Main background source in ν_τ and anti-ν_τ searches is the charm production in anti-ν_μCC (ν_μ CC) and anti-ν_e CC (ν_e CC) interactions, when the primary lepton is not identified.

SIGNAL

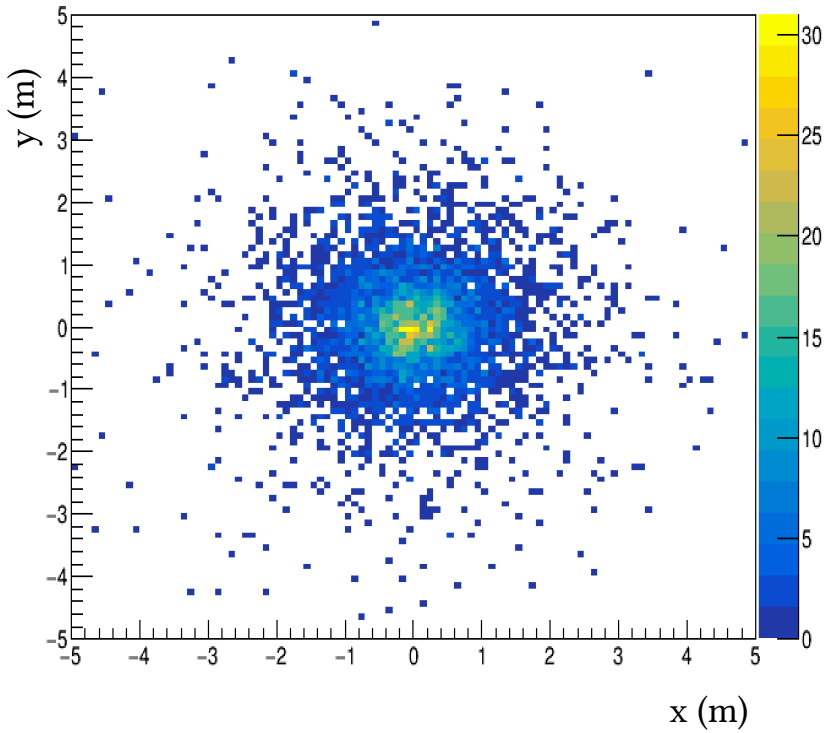


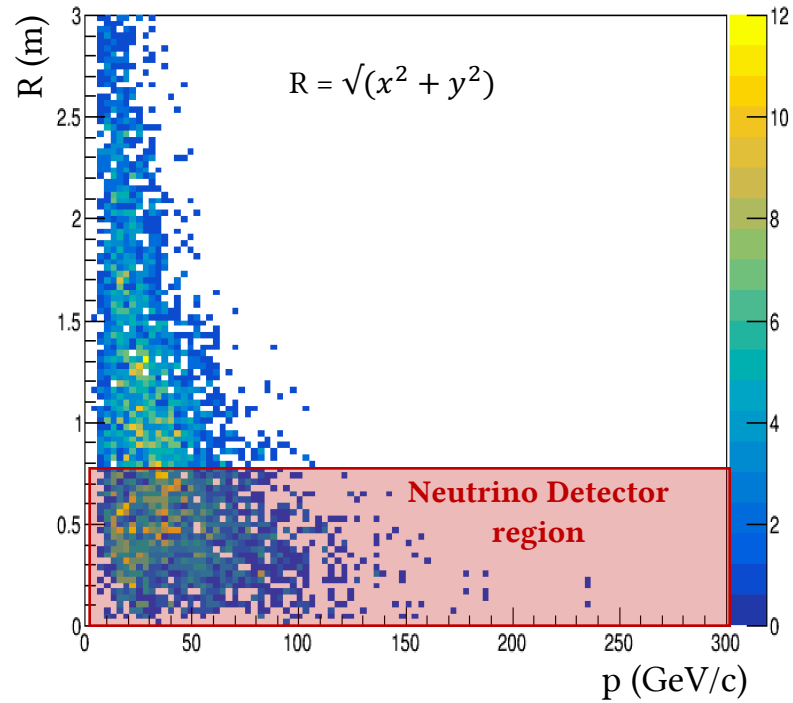
BACKGROUND



Implementation of neutrino interactions with Genie

- Neutrino interactions generated in Genie on Pb (1.4% ^{204}Pb, 24.1% ^{206}Pb, 22.1% ^{207}Pb, 52.4% ^{208}Pb)



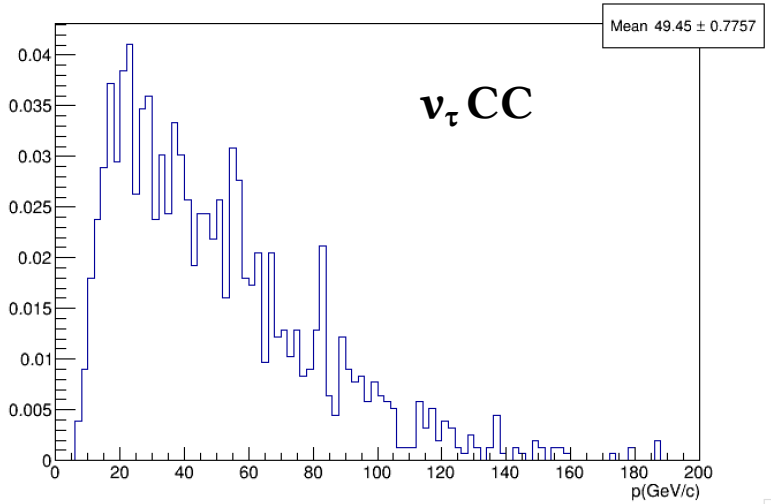


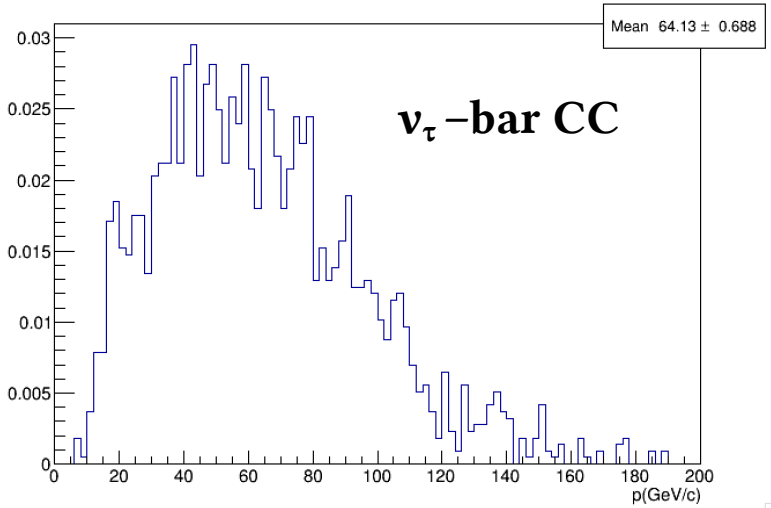
NB: Interactions not scaled to one spill!

Example with ν_τ CC in config. with magnet

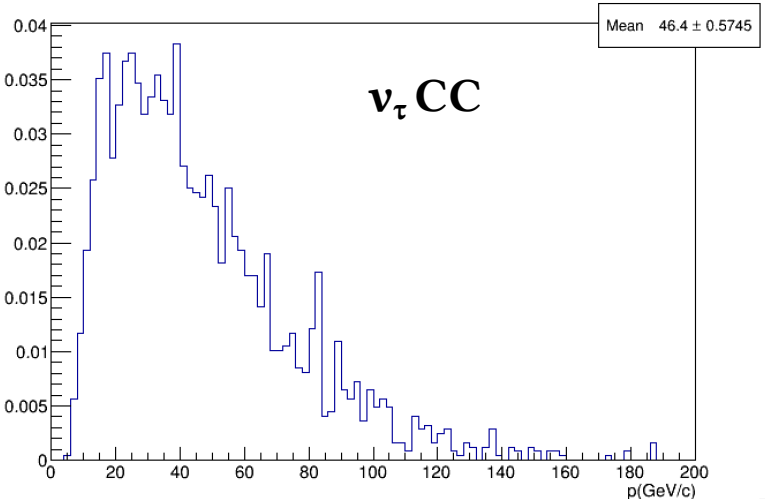
Spectra of generated neutrino interactions

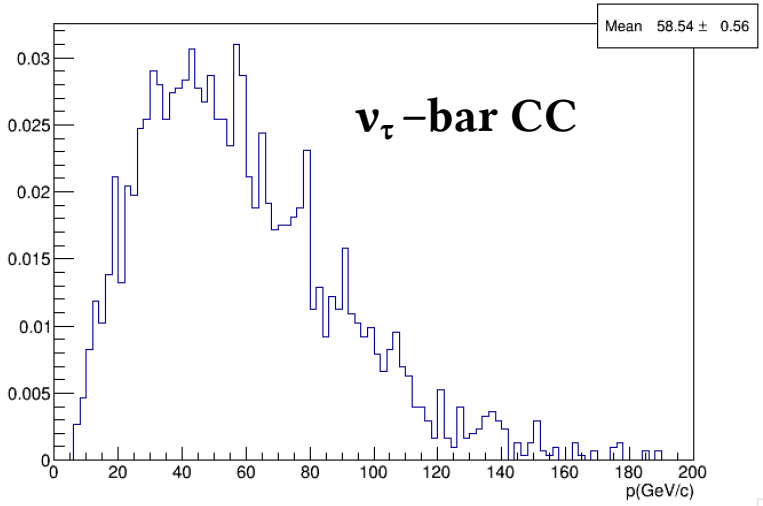
WITH MAGNET





WITHOUT MAGNET





Location and Decay Search efficiencies (signal)

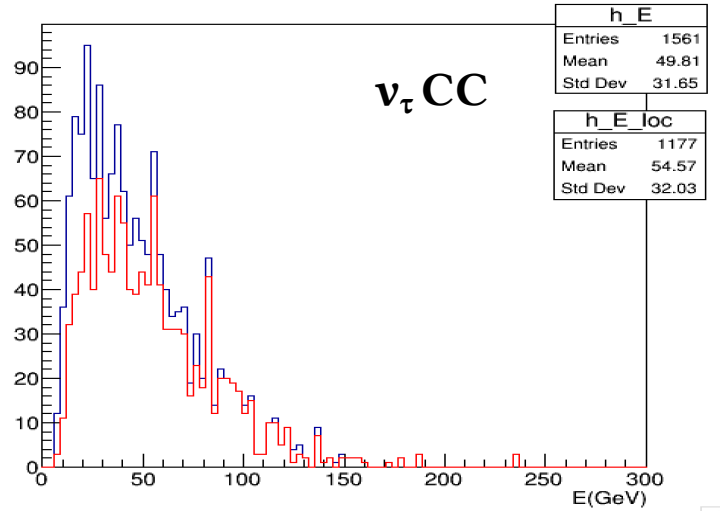
	WITH MAGNET		WITHOUT MAGNET	
	ε_{LOC} (%)	ε_{DS} (%)	ε_{LOC} (%)	ε_{DS} (%)
$\tau \rightarrow \mu$	78	79	75	78
$\tau \rightarrow e$	76	73	75	75
$\tau \rightarrow h$	74	75	76	74
$\tau \rightarrow 3h$	77	86	76	88

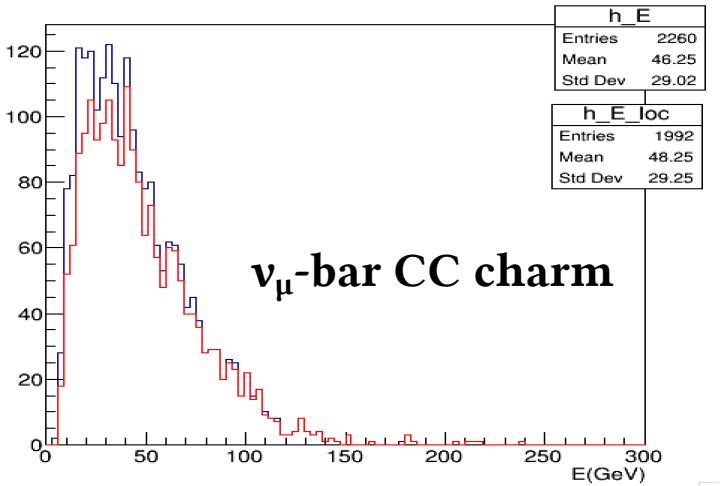
- To locate a neutrino interaction:
  - at least 2 visible tracks at ν interaction vtx
  - at least one track of ν interaction vtx with p>1GeV
- Criteria used to select τ candidates (Decay Search):
  - kink angle>20 mrad
  - IP daugther w.r.t ν interaction vtx >10 μm

Visible tracks
- charged
- p>100 MeV/c
- tg θ_x and tg θ_y< 1 rad

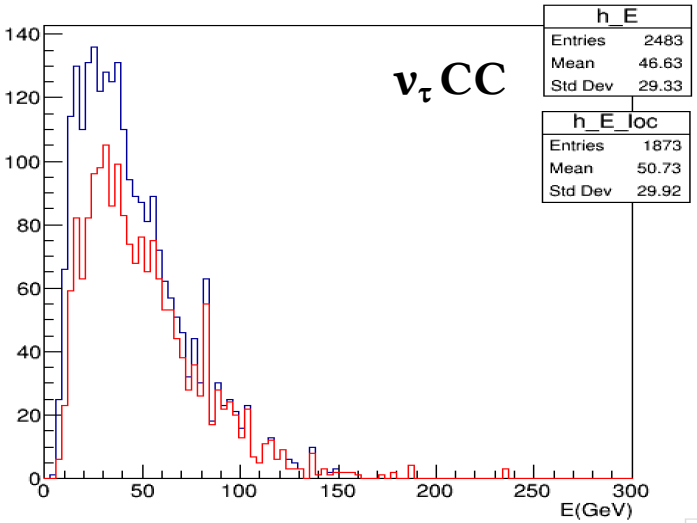
Energy spectra of located events

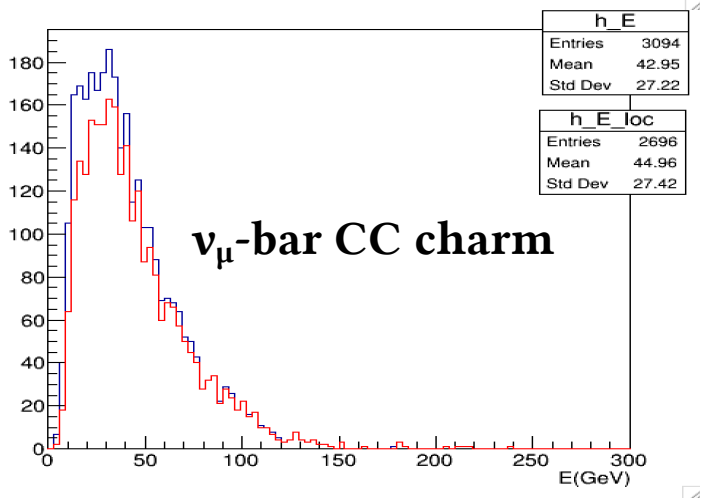
WITH MAGNET





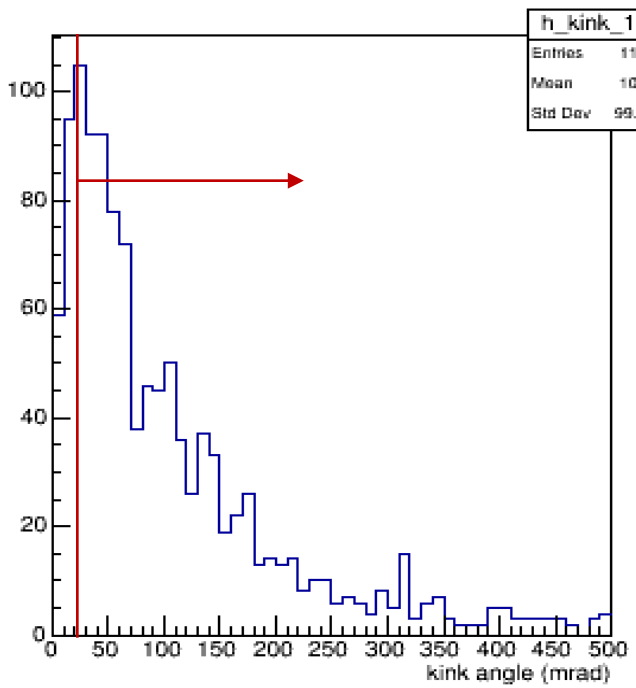
WITHOUT MAGNET

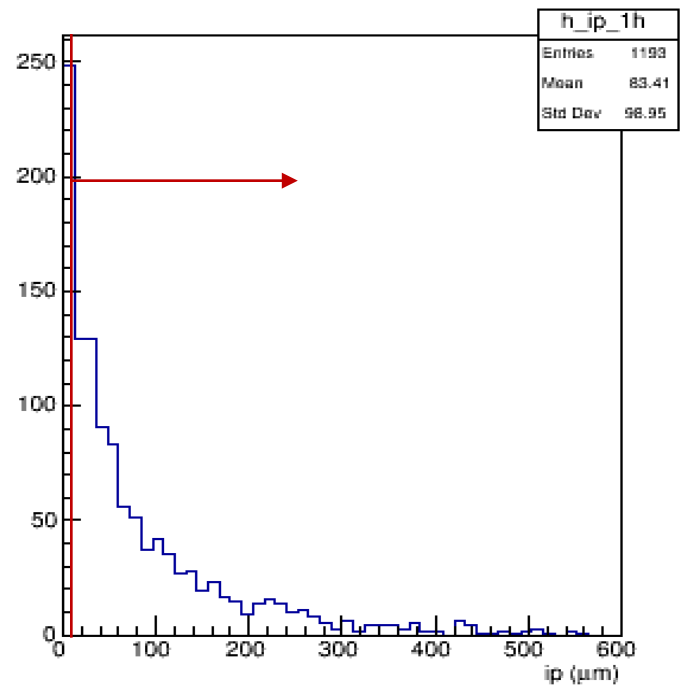




Impact parameter and kink angle distributions

$\tau \longrightarrow h$





Kinematical Variables

- Help in discriminating τ vs Charm events
- Different according to the different decay channel
- For TP used loose cuts:

τ⟶e

- p_e>1 GeV
- p_T>100 MeV

τ⟶μ

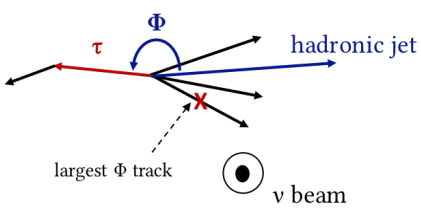
- p_μ>1 GeV
- p_T>250 MeV

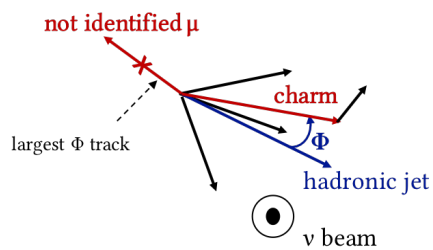
τ⟶1h

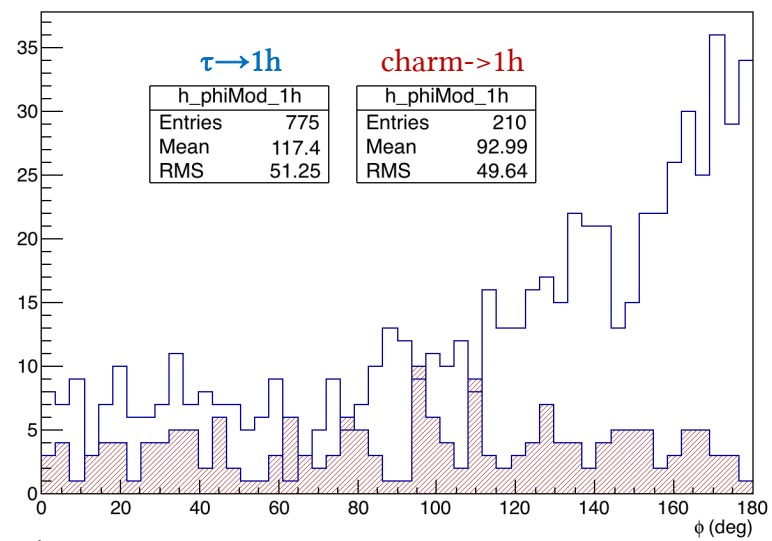
- p_h>1 GeV
- p_T>100 MeV
- $\Phi^{mod}>\pi/2$

τ⟶3h

- p_{3h}>3 GeV
- $\Phi^{mod}>\pi/2$







- **Next step:** MVA to perform optimal S vs B discrimination

Muon Identification Efficiency - 1

Required at least 3 hits in the RPCs of the downstream Muon Magnetic Spectrometer

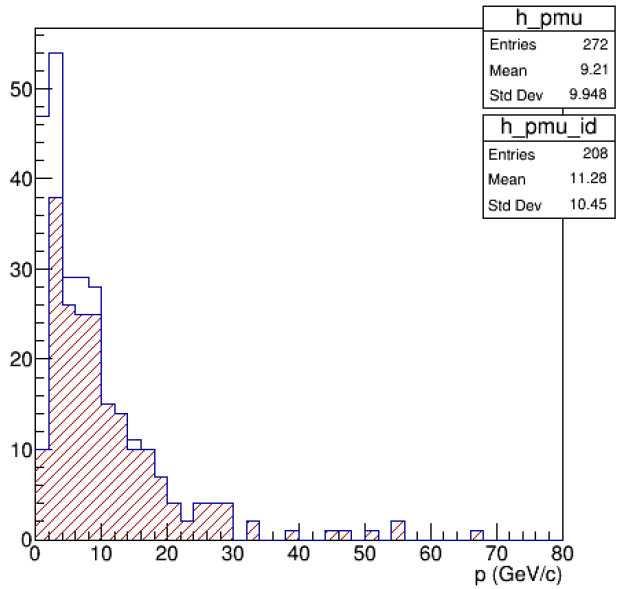
WITH MAGNET

	$\varepsilon\ \mu_{ID}$ (%)
ν_τ	76
ν_μ-bar charm	64
ν_τ-bar	91
ν_μ charm	63

- Differences between charm and τ due to:
  - Lower mean energy of muon produced from charm decay
  - Wider angular distribution of muon produced from charm decay

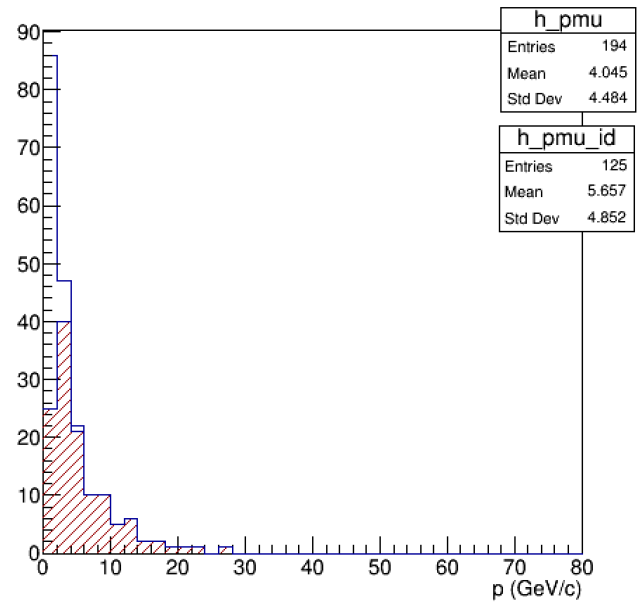
Checks on Muon Identification Efficiency (τ/charm)

τ→μ



- Average energy of muons from τ: **9.2 GeV**
- Average energy identified muons 11.3 GeV
- Average energy not identified muons: 2.5 GeV

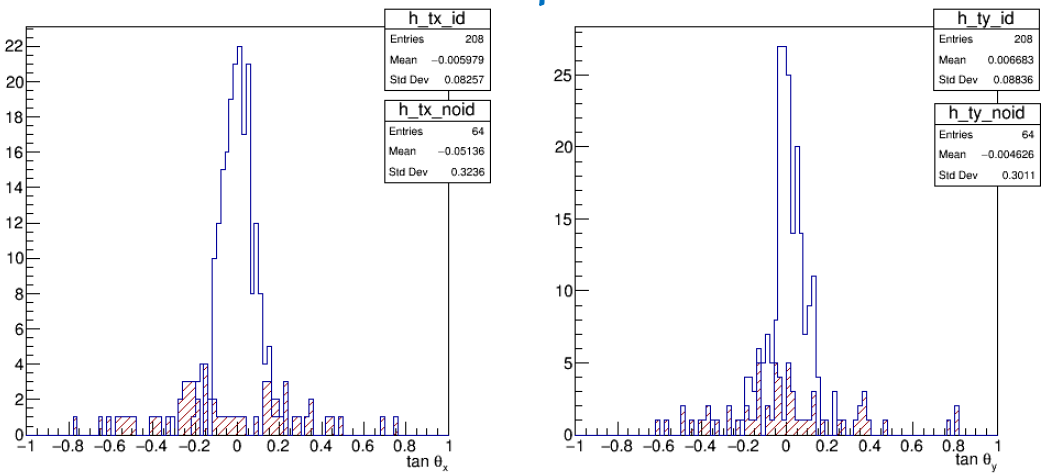
Charm→μ



- Average energy of muons from charm: 4 GeV
- Average energy identified muons 5.5 GeV
- Average energy not identified muons: 1.1 GeV

Checks on Muon Identification Efficiency (τ/charm)

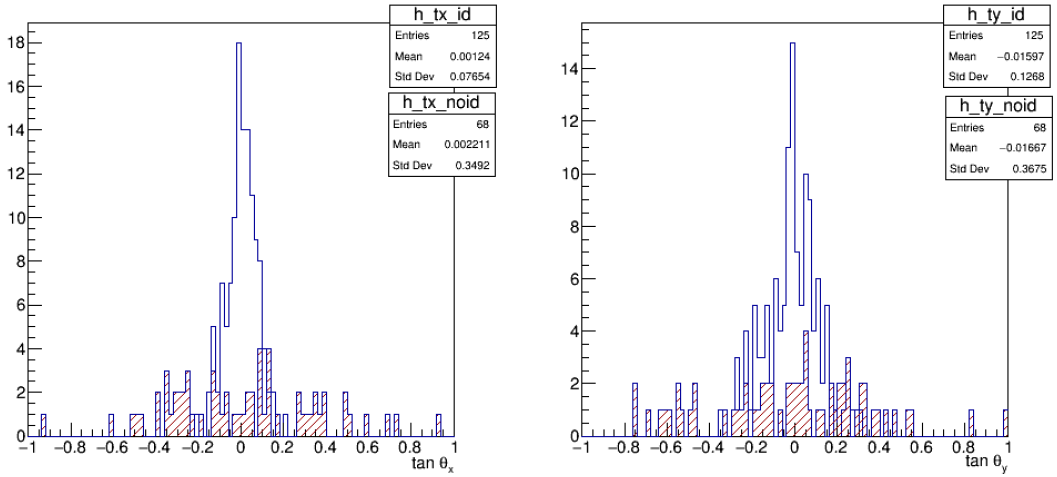
τ→μ



- RMS of slope distribution for identified muons ~85mrad
- RMS of slope distribution for not identified muons ~300 mrad

Charm→μ

- RMS of slope distribution for identified muons ~85mrad
- RMS of slope distribution for not identified muons ~350 mrad



Muon Identification Efficiency

Required at least 3 hits in the RPCs of the downstream Muon Magnetic Spectrometer

WITH MAGNET

	$\varepsilon\ \mu_{ID}$ (%)
ν_τ	76
ν_μ-bar charm	64
ν_τ-bar	91
ν_μ charm	63

WITHOUT MAGNET

	$\varepsilon\ \mu_{ID}$ (%)
ν_τ	76
ν_μ-bar charm	59
ν_τ-bar	83
ν_μ charm	51

- Differences between the two configurations given by:
  - Lower mean energy of anti-ν_τ in no magnet configuration option
  - Slightly lower energy of ν-charm events in no magnet configuration option -> slightly lower average energy of muon from charm
  - NB: Statistics still very limited

Conclusions

- Evaluation of the performances of the emulsion detector in the two options: with/without magnet
  - Neutrino interactions produced with Genie
  - Used GenieGenerator for propagation in the detector
  - Evaluation of location and decay search efficiencies for ν_τ interactions
  - Evaluation of muon identification efficiency for signal and charm background

- Next steps:
  - Further optimisation of the two configurations
  - Reproduce all TP studies in both configurations

- Results of these studies will be the subject of a paper