Classification of ν_{tau} events in the Scattering and Neutrino Detector (SND) using kinematic information

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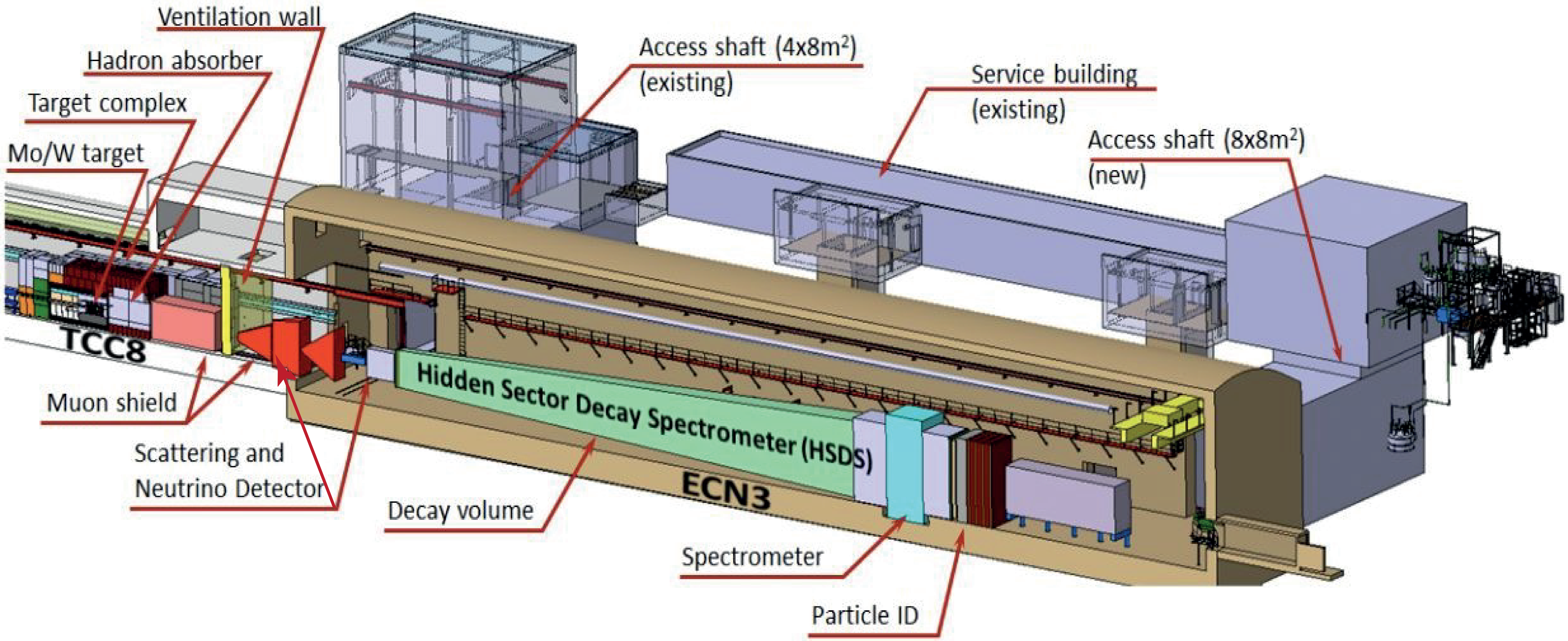
Introduction

- The main goal of the experiment is to provide sensitivity to FIPs models not accessible to colliders



General Purpose experiment for Hidden Particles in the forward region

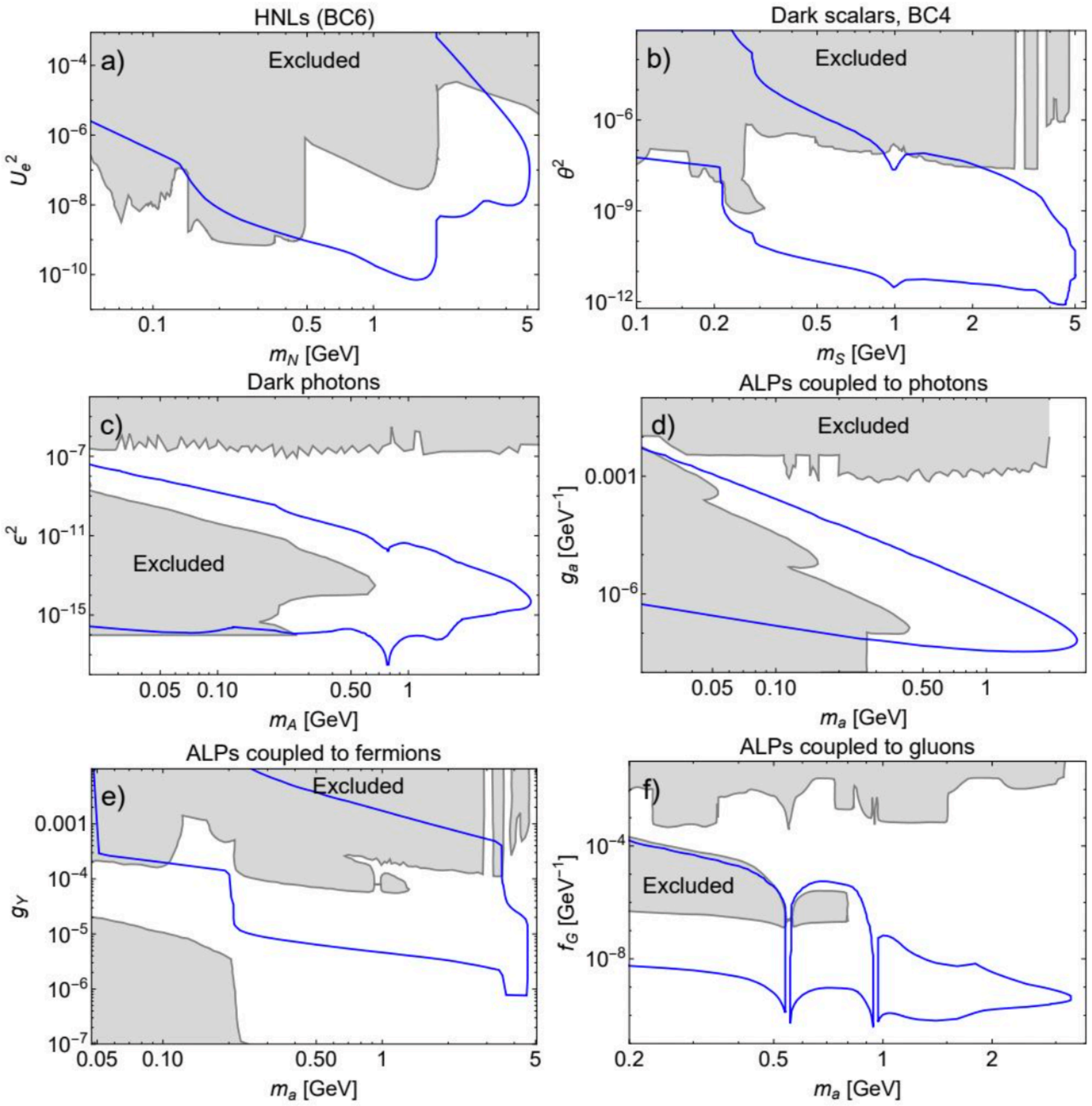
Introduction

- ➡Measurement of the **cross section** (including the least studied τ neutrinos **ν_τ**).
- ➡Lepton flavour universality test in neutrino interactions.
- ➡Direct search for feebly interacting particles (FIPs) through their scattering.
- ➡Neutrino DIS cross section measurement: F4 and F5.

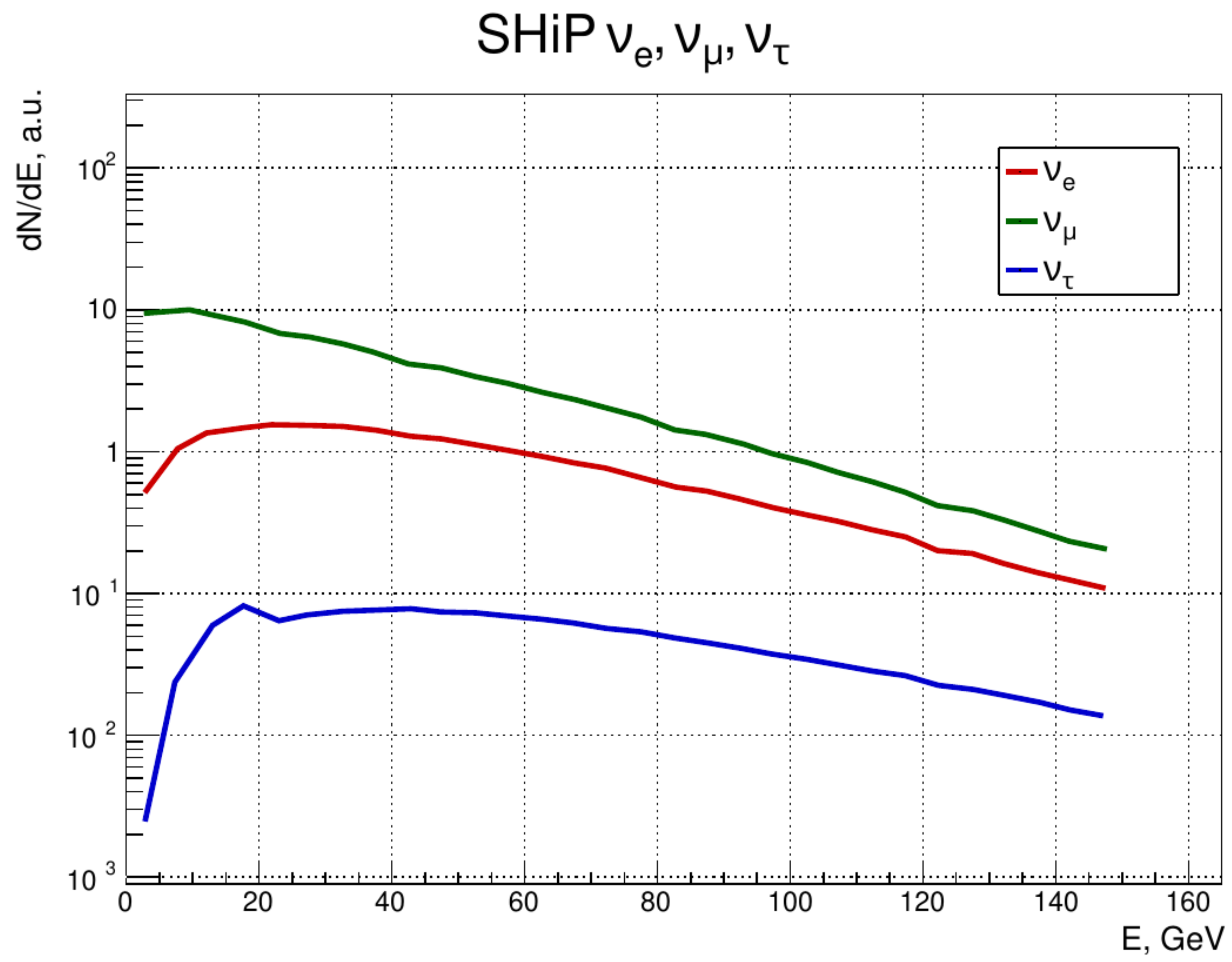
$$\frac{d^2\sigma^{\nu(\overline{\nu})}}{dxdy} = \frac{G_F^2 M E_\nu}{\pi(1+Q^2/M_W^2)^2}\Bigg((y^2x + \frac{m_\tau^2 y}{2E_\nu M})F_1 + \left[(1-\frac{m_\tau^2}{4E_\nu^2}) - (1+\frac{Mx}{2E_\nu})\right]F_2 \pm \left[xy(1-\frac{y}{2}) - \frac{m_\tau^2 y}{4E_\nu M}\right]F_3 + \frac{m_\tau^2(m_\tau^2+Q^2)}{4E_\nu^2 M^2 x}F_4 - \frac{m_\tau^2}{E_\nu M}F_5\Bigg),$$

✓ Final states and models evaluated for sensitivity studies

	Physics model	Final state
HSDS	SUSY neutralino	$\ell^\pm\pi^\mp$, $\ell^\pm K^\mp$, $\ell^\pm\rho^\mp$, $\ell^+\ell^-\nu$
	Dark photons	$\ell^+\ell^-, 2\pi, 3\pi, 4\pi, KK, q\bar{q}, D\bar{D}$
	Dark scalars	$\ell\ell, \pi\pi, KK, q\bar{q}, D\bar{D}, GG$
	ALP (fermion coupling)	$\ell^+\ell^-, 3\pi, \eta\pi\pi, q\bar{q}$
	ALP (gluon coupling)	$\pi\pi\gamma, 3\pi, \eta\pi\pi, \gamma\gamma$
	HNL	$\ell^+\ell'^-\nu, \pi l, \rho l, \pi^0\nu, q\bar{q}'l$
	Axino	$\ell^+\ell^-\nu$
	ALP (photon coupling)	$\gamma\gamma$
	SUSY sgoldstino	$\gamma\gamma, \ell^+\ell^-, 2\pi, 2K$
SND	LDM	electron, proton, hadronic shower
	ν_τ, $\overline{\nu}_\tau$ measurements	$\tau^\pm$
	Neutrino-induced charm production $(\nu_e, \nu_\mu, \nu_\tau)$	$D_s^\pm$, $D^\pm$, D^0, $\overline{D^0}$, Λ_c^+, $\overline{\Lambda_c}^-$



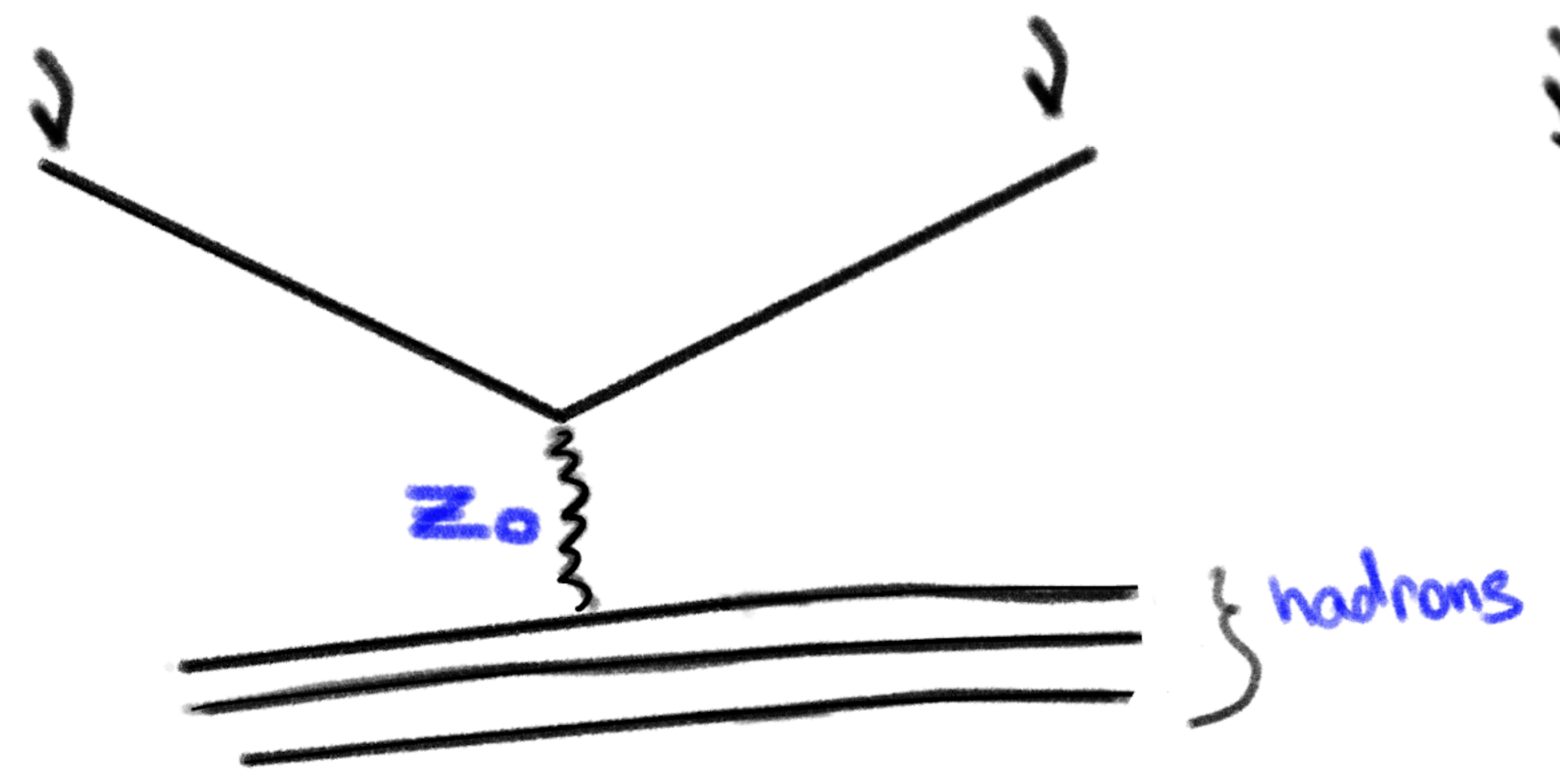
Introduction

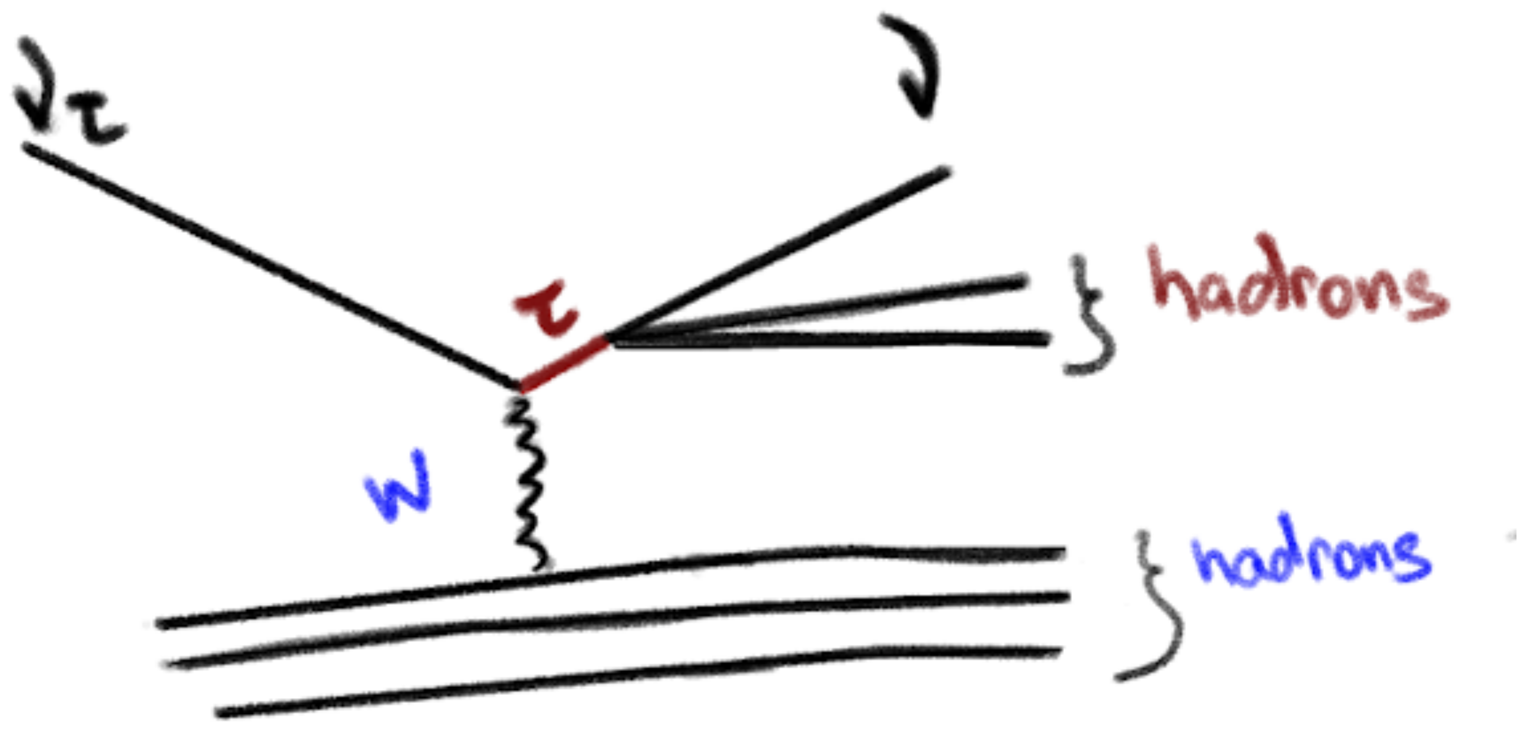


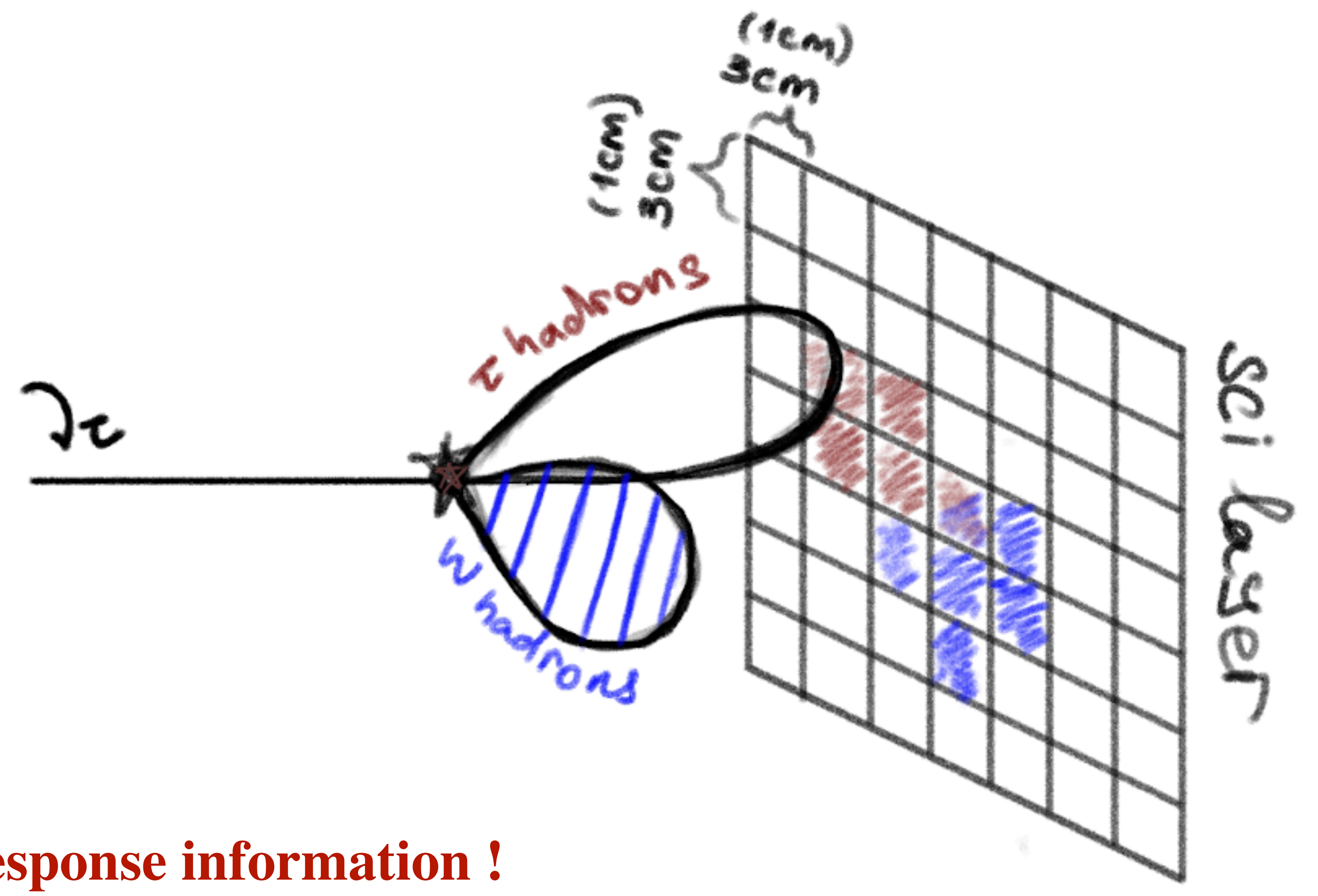
1. We need to classify the signal from these 2 processes:
   - NCDIS $\nu_\mu \rightarrow hadrons$
   - CCDIS$\nu_\tau \rightarrow \tau + hadrons$ (and hadronic τ decay mode)

2. Neutrino spectra were taken from the SHiP experiment and used as a GENIE input.

3. Detector response were performed using Geant4.







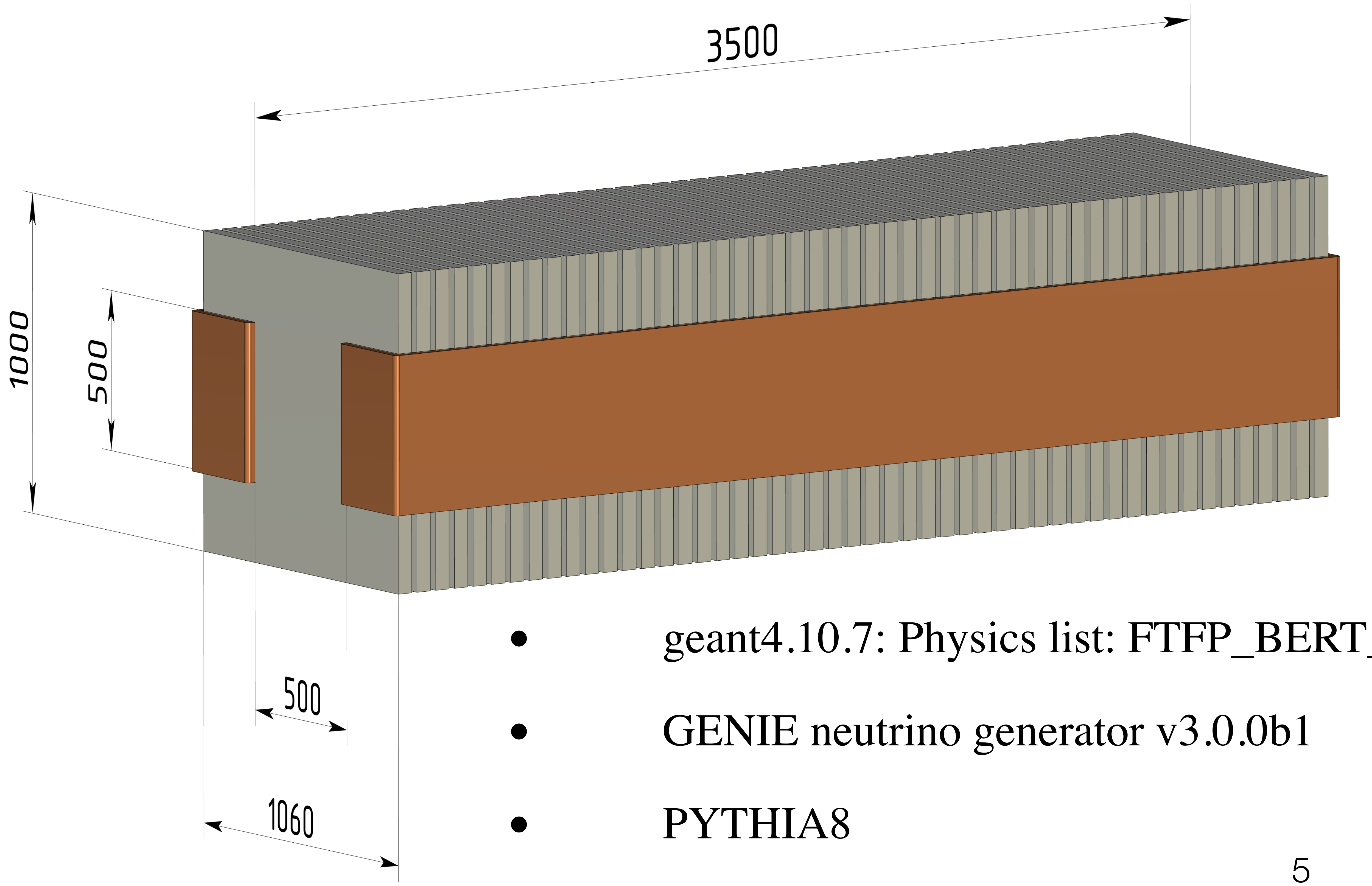
Goal: to separate CCDISν_τ and NCDISν_μ using detector response information !

Detector concept

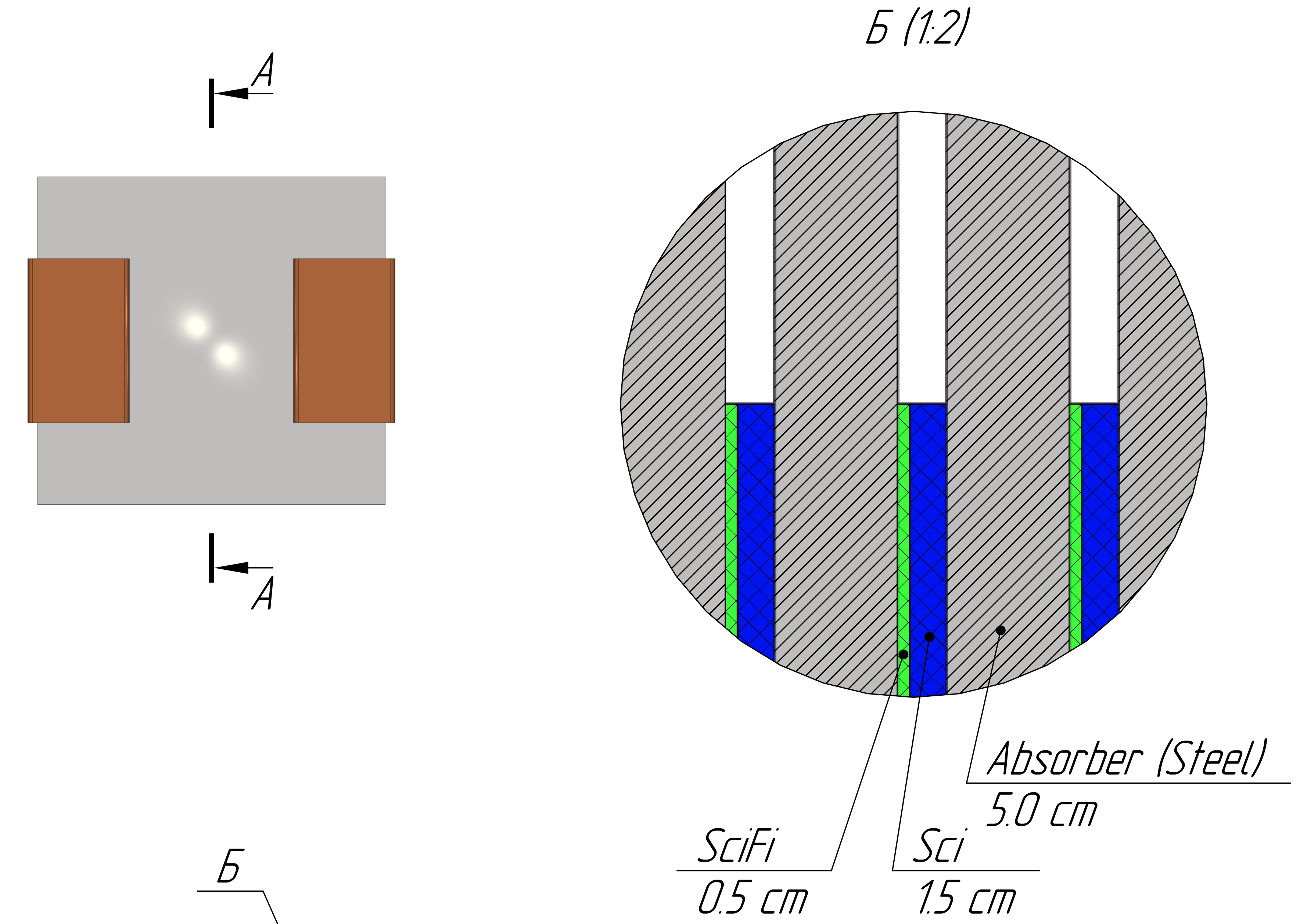
Absorber:
material: Fe (~**5cm**, 2cm)— 1.7 Tesla along y axis

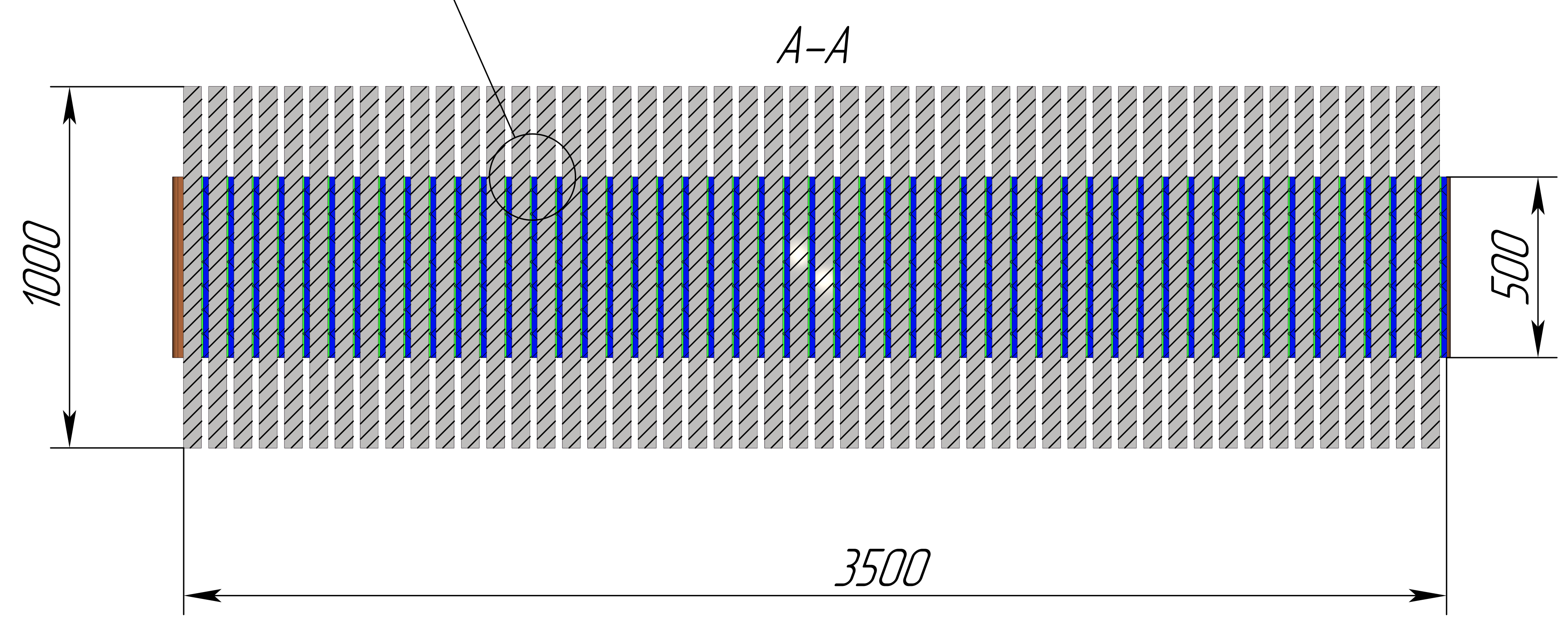
Tracker:
Fibres: 250 μm (diameter) SciFi (Poly)

Scintillator:
Edep Sci layers— 1 (3) cm x 1 (3) cm x 1.5 cm (xyz) (Poly)



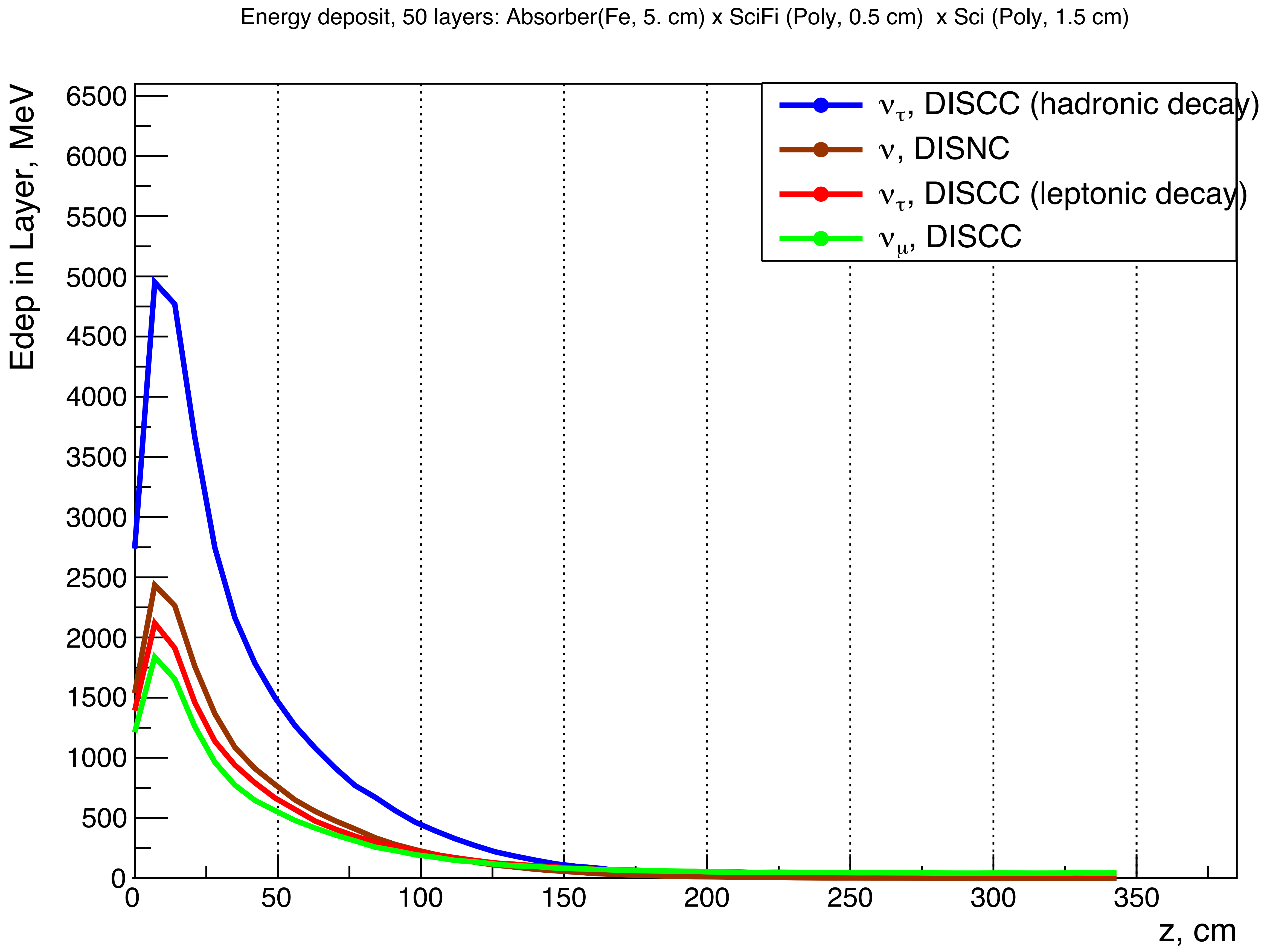
- geant4.10.7: Physics list: FTFP_BERT_HP
- GENIE neutrino generator v3.0.0b1
- PYTHIA8

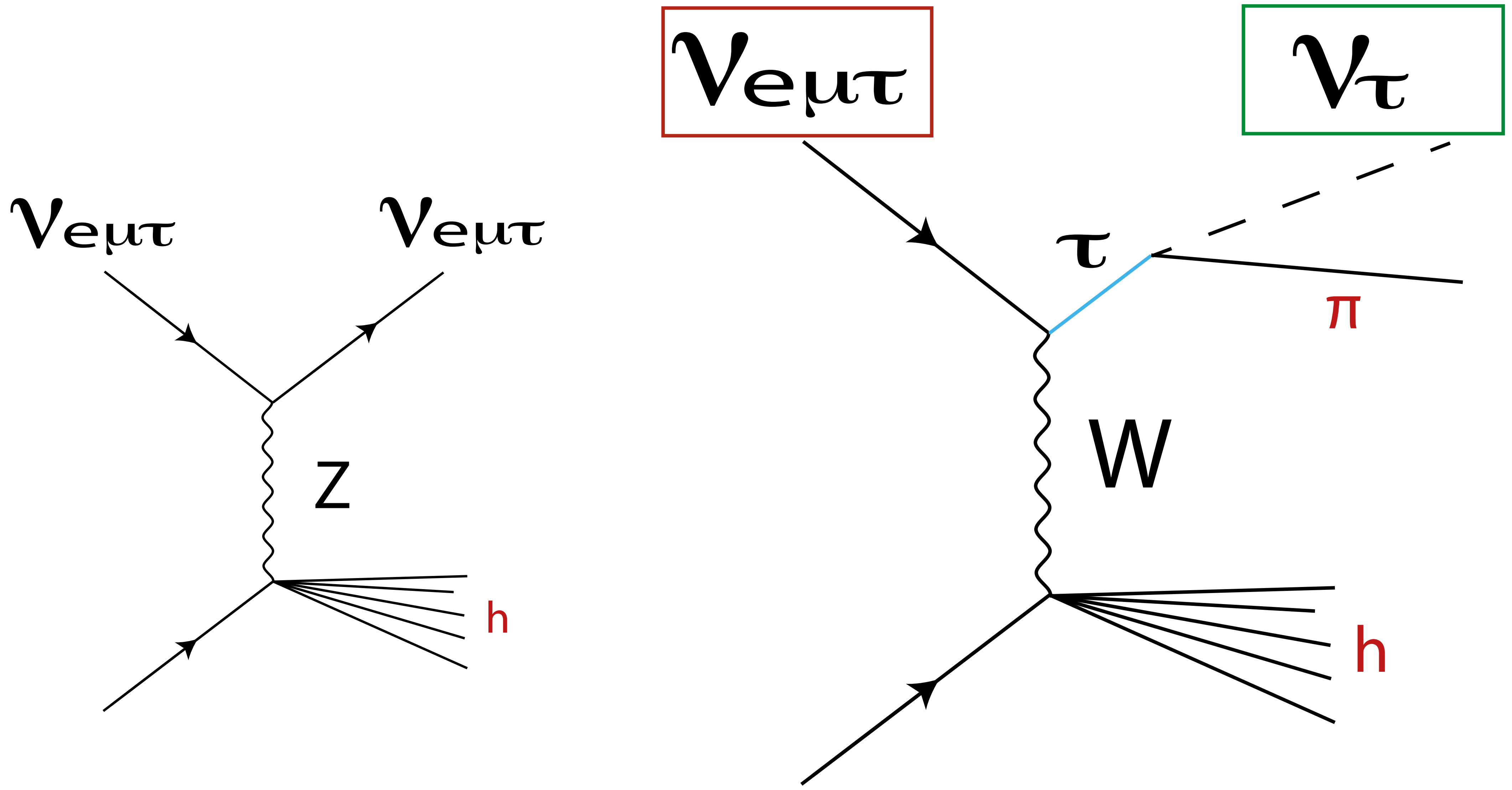


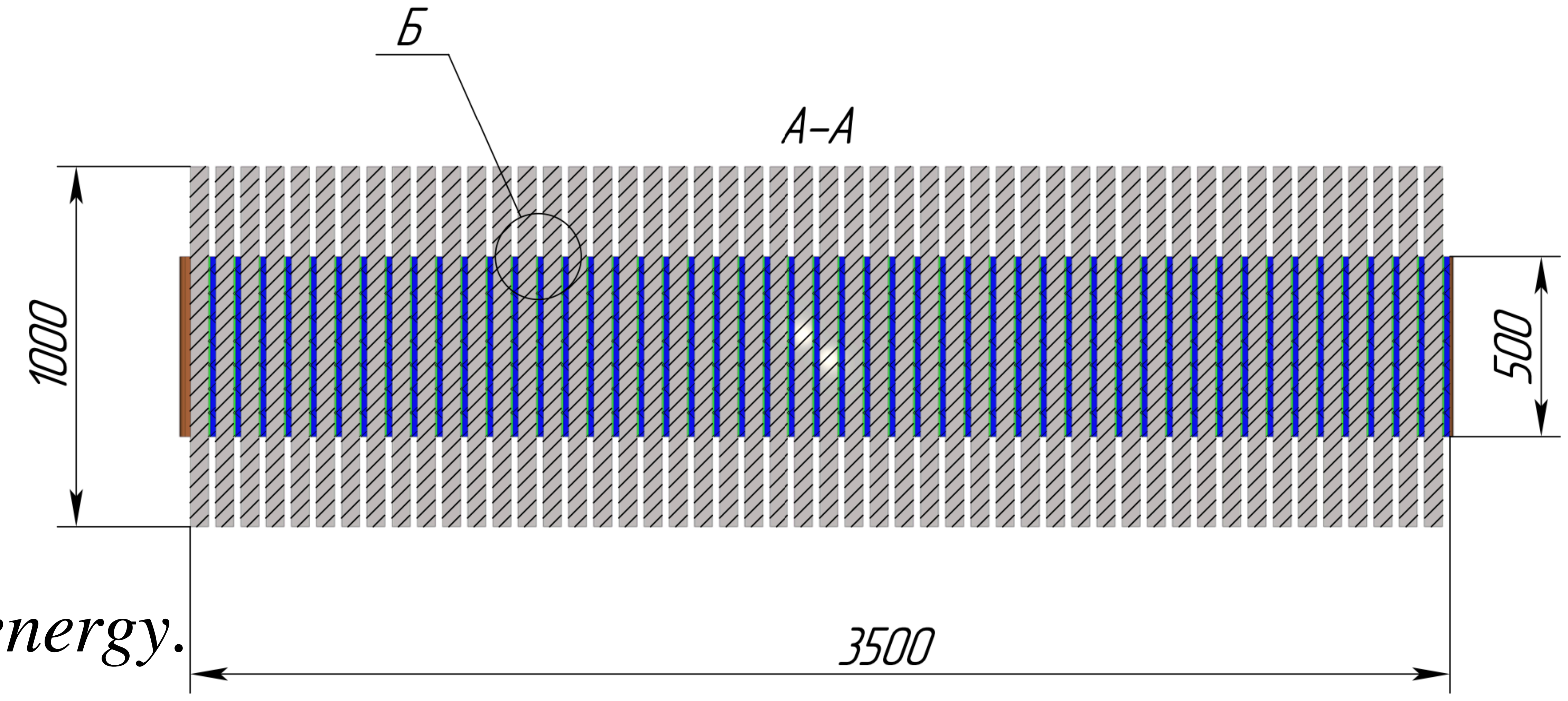


#	Name	Quantity
1	Magnetic absorber (GO Steel)	50
2	Sci	50
3	SciFi	50
4	Current Coil	2

Longitudinal shower profile for CCDIS ν_τ & NCDIS ν_μ







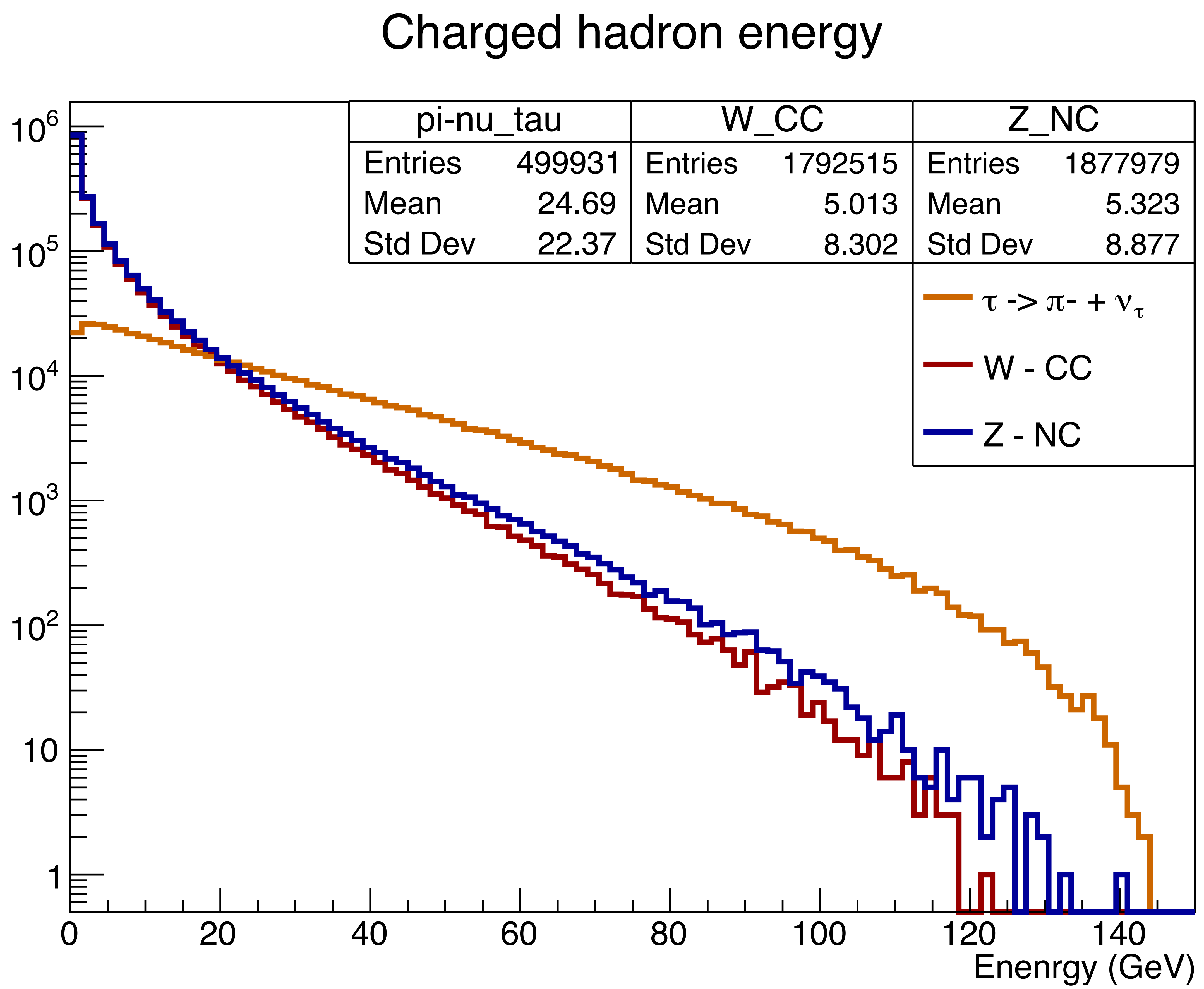
Charged current (τ hadronic decay):

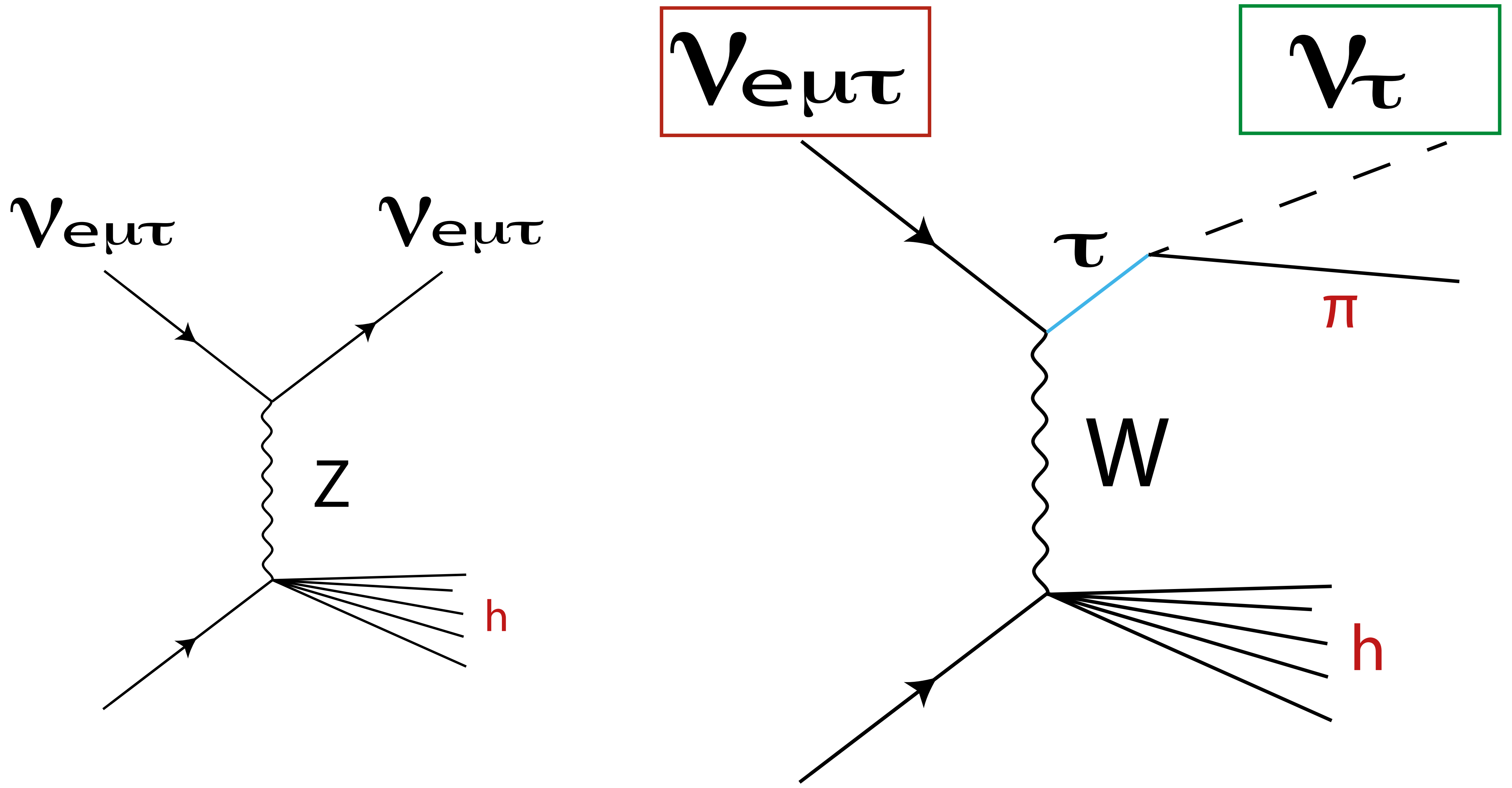
Hadrons from τ decay more energetic.

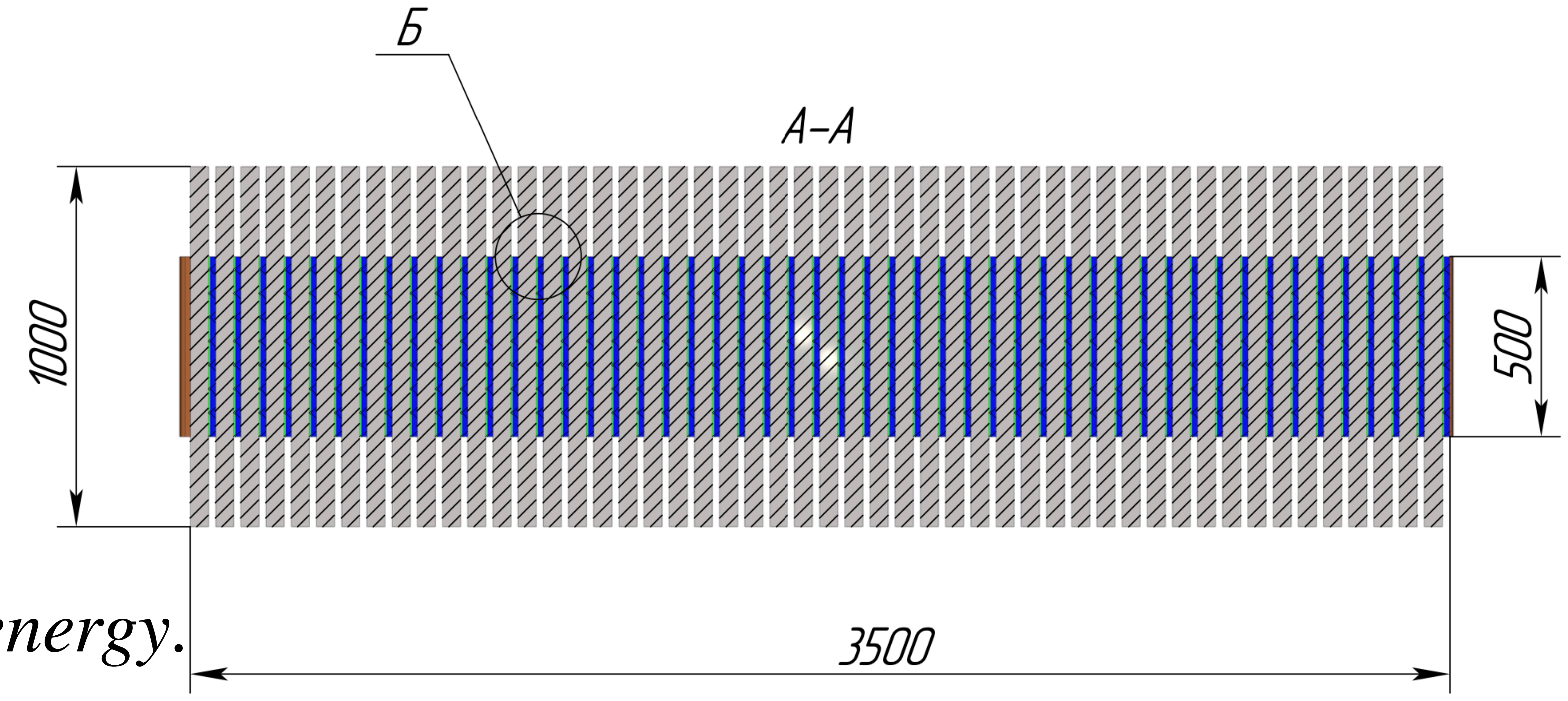
Neutral current and CC (τ leptonic decay):

Hadrons initiated by W or Z_0 (hadron cluster) have a same energy.

Longitudinal shower profile for CCDIS ν_τ & NCDIS ν_μ







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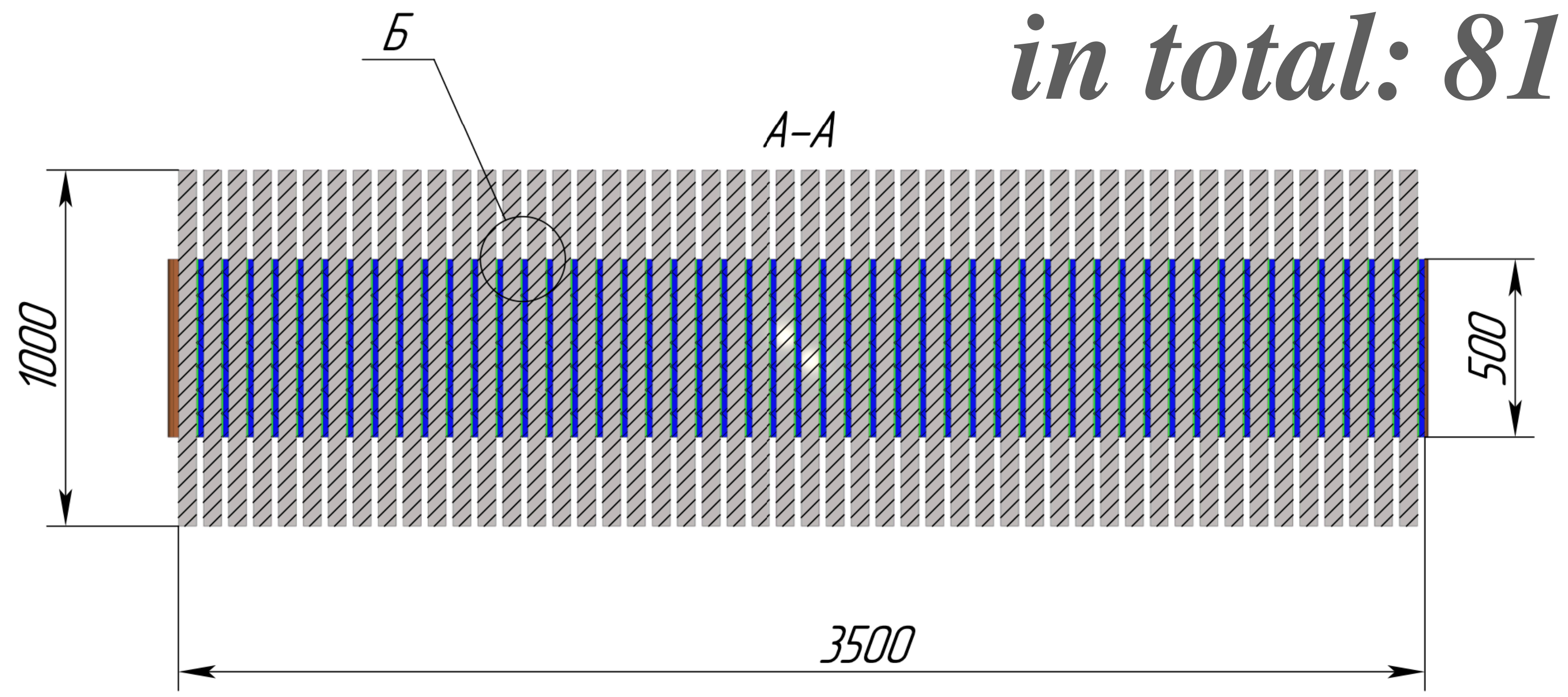
Parameters correlation

Parameters:

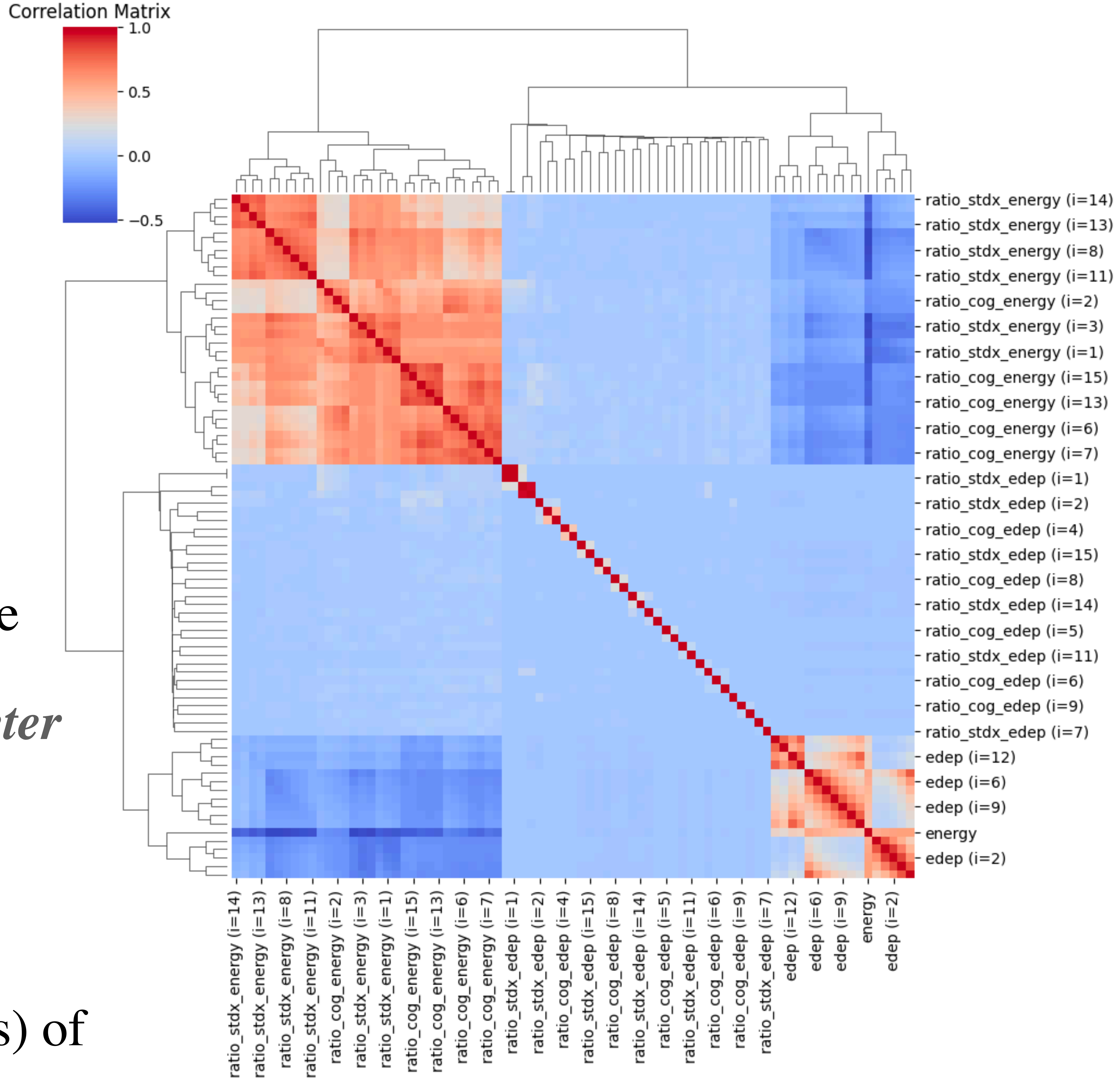
16 sensitive layers (out of 50 layers)

- Energy deposition
- Energy of hadron cluster
- Shower CoG in XY plane
- Shower standard deviation in XY plane



in total: 81 parameter

Parameters describing close parts (layers) of the detector are correlated



Parameters (example):

Pipeline of the classifier

Dataset generation

- ✳ GENIE simulation 500k $CC\nu_{tau}$ & $NC\nu$
- ✳ Geant4 detector response simulation
- ✳ Weighting the events according SHiP spectrum

→

Preprocessing

- ✳ Preparing / selecting parameters
- ✳ Removing NaN

→

Boosted Decision Tree

- ✳ Training on the simulated data

→

Checking perfomance

- ✳ Cross-validation
- ✳ Confusion matrix
- ✳ Explainability

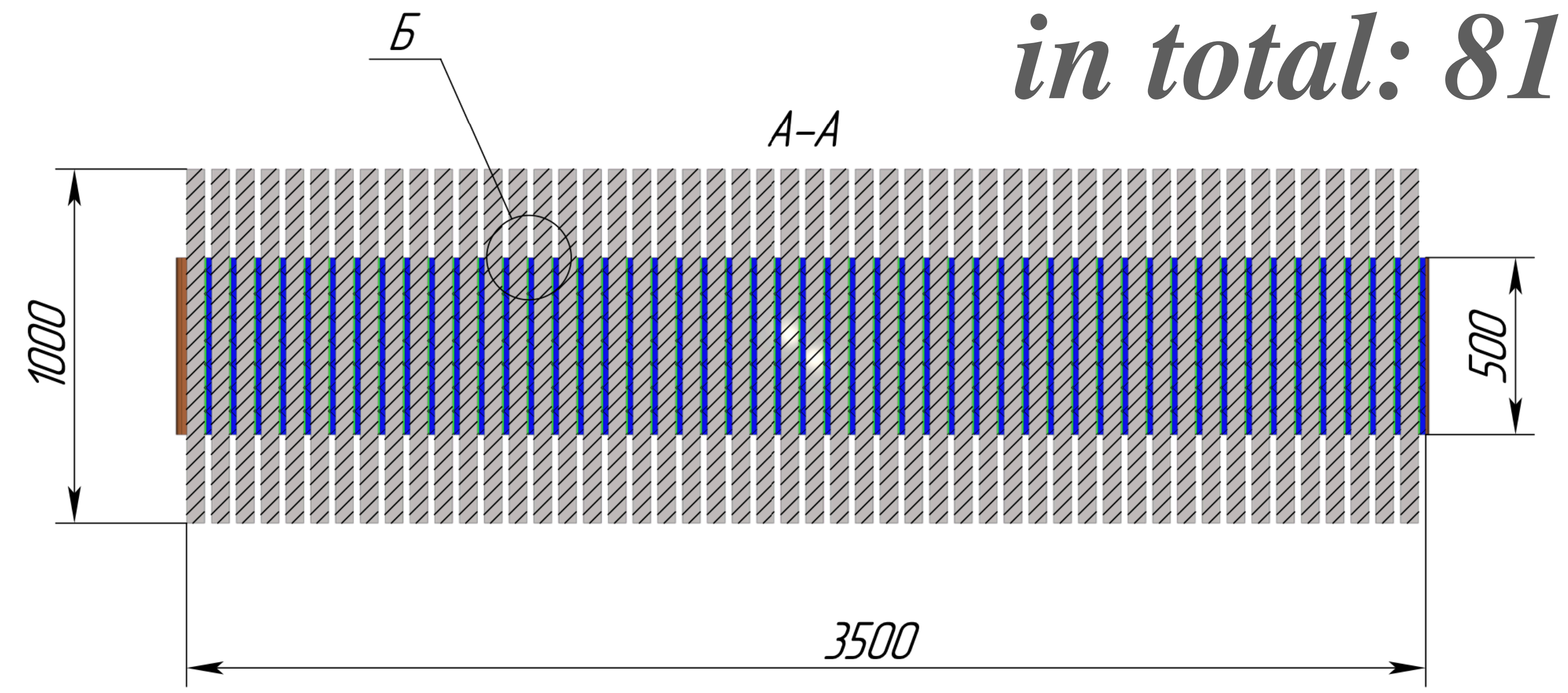
Results

The less diagonal the matrix,
the better the classification

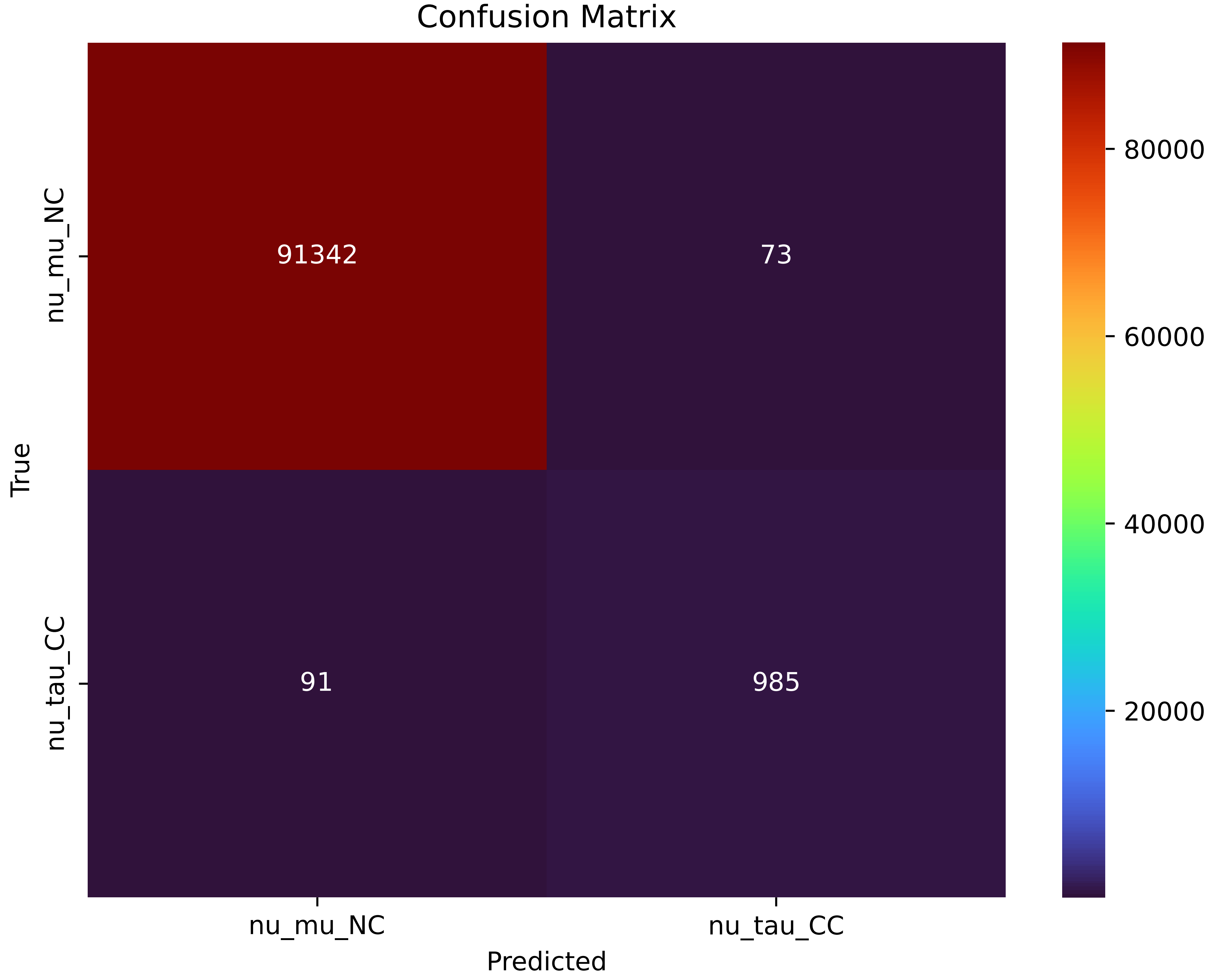
16 sensitive layers (out of 50 layers)

- Energy deposition
- Energy of hadron cluster
- Shower CoG in XY plane
- Shower standard deviation in XY plane

in total: 81 parameter



Parameters describing close parts (layers) of the detector are correlated

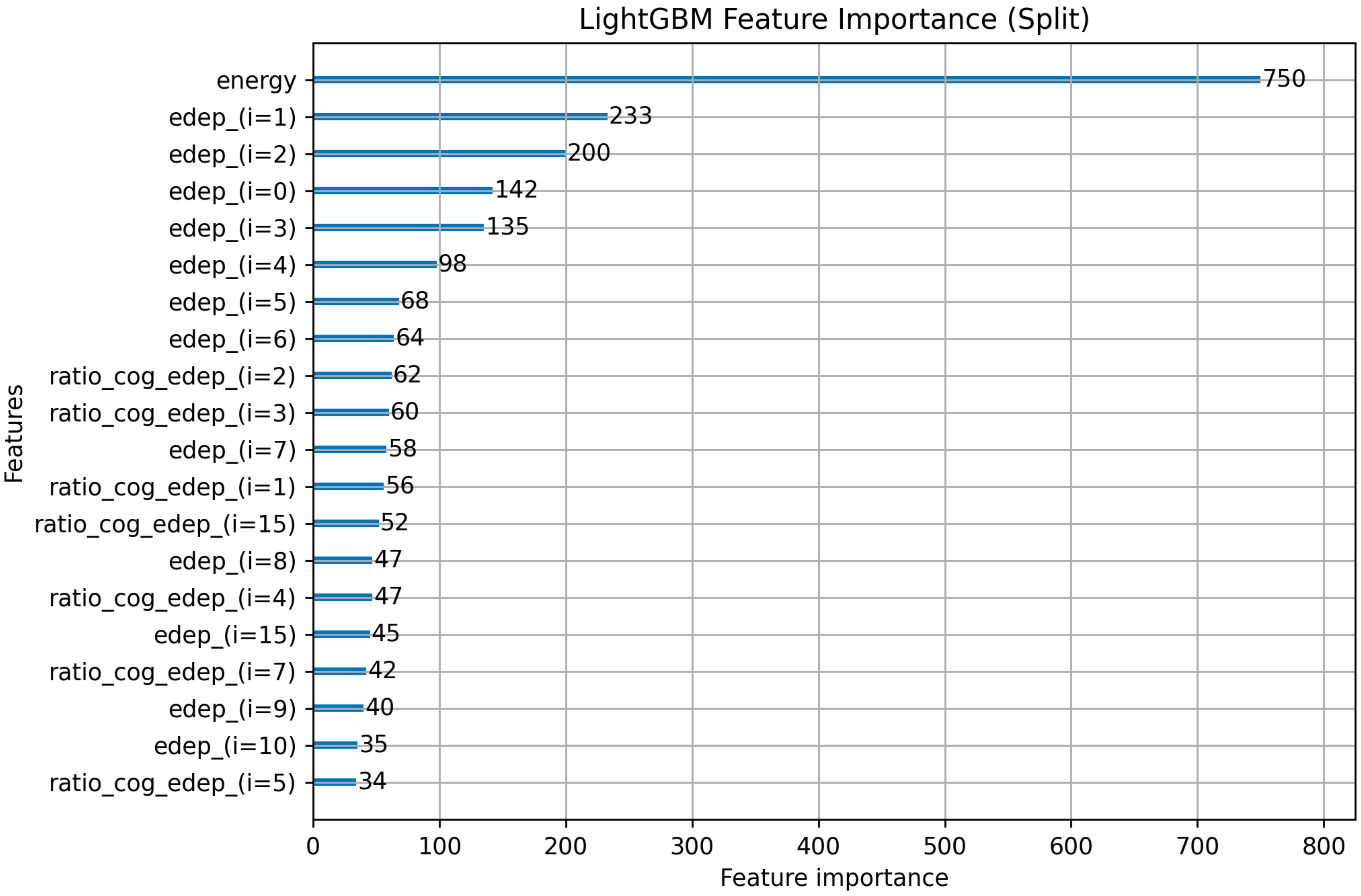


Predicted

Actual	0	1
0	TN	FP
1	FN	TP

Importance of parameters

- Most valuable: energy of hadron cluster, energy deposit in layers;
- Split measures how often a feature is used to split the data in decision trees during training, which helps assess the feature's importance in making decisions.



Summary

- At this stage, we have only considered a specific branching scenario.
- Despite CCDISν_τ flux being ~100 times lower than NCDIS ν_μ, the results are promising.
- We will explore other configurations of the tracking system in SND detector (to retrieve information about Impact Parameter (IP)):

  This is particularly important for classifying the signal from signals from CCDISν_τ (τ leptonic decay) & CCDISν_μ.

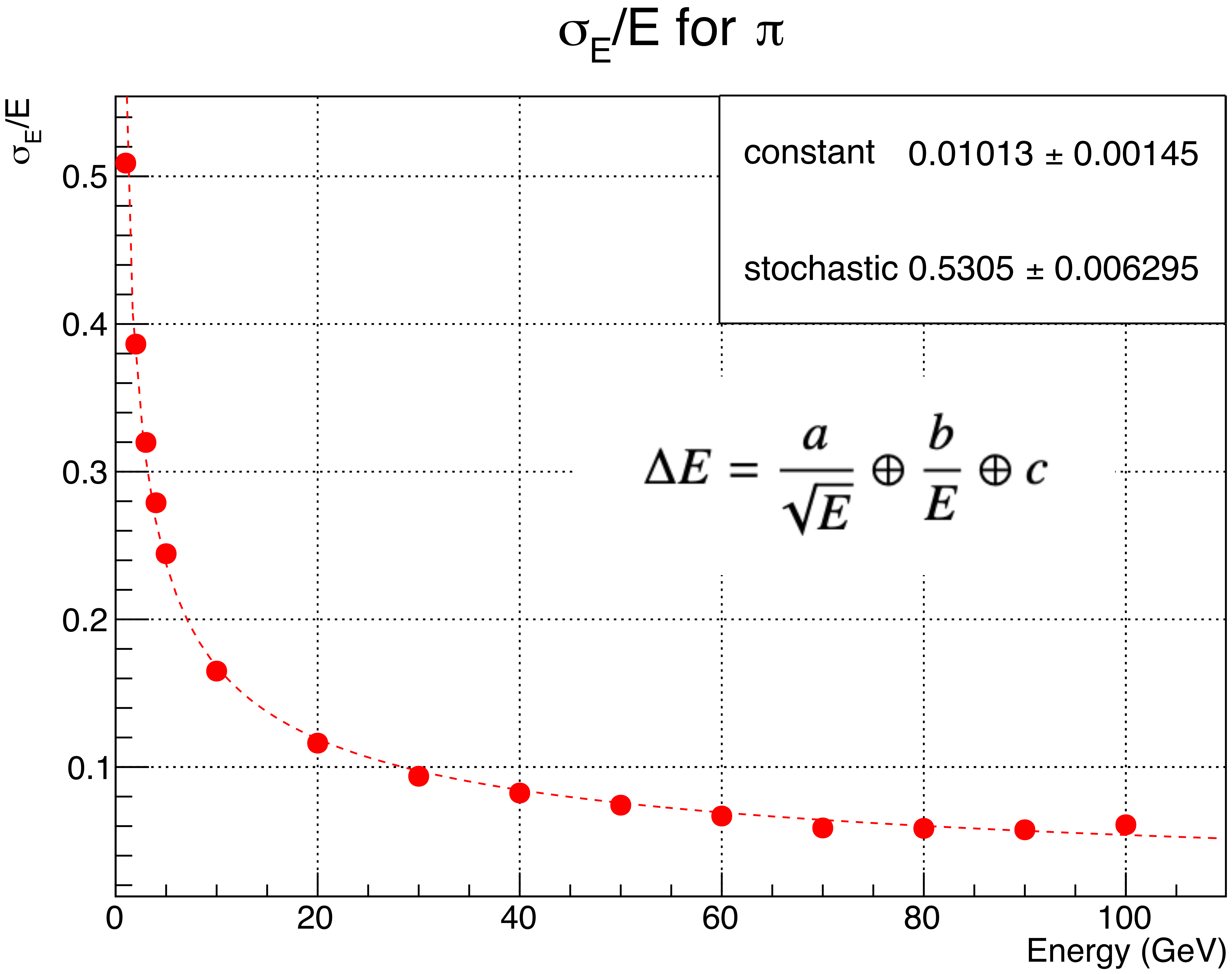
Thank you for your attention!

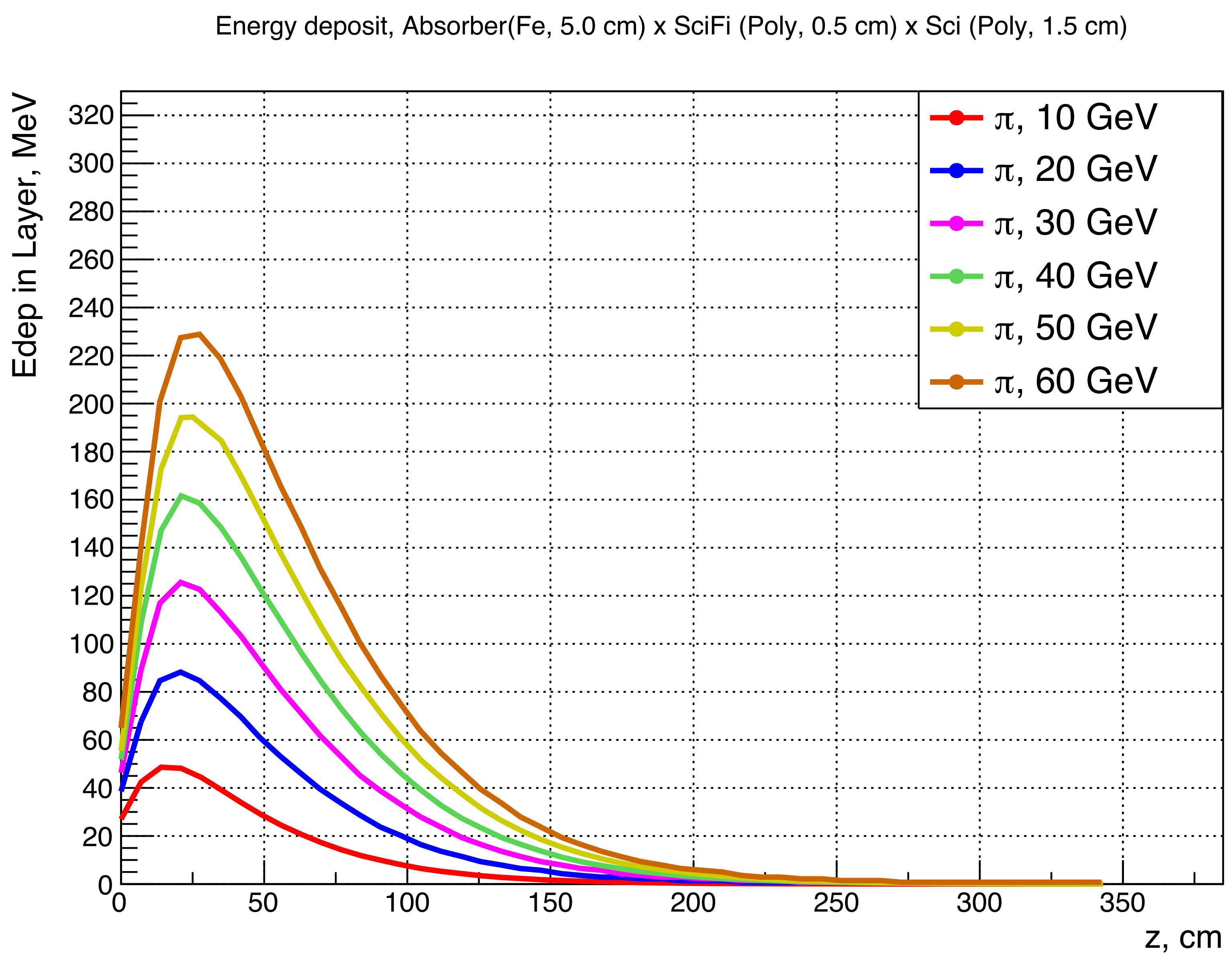
back up slides

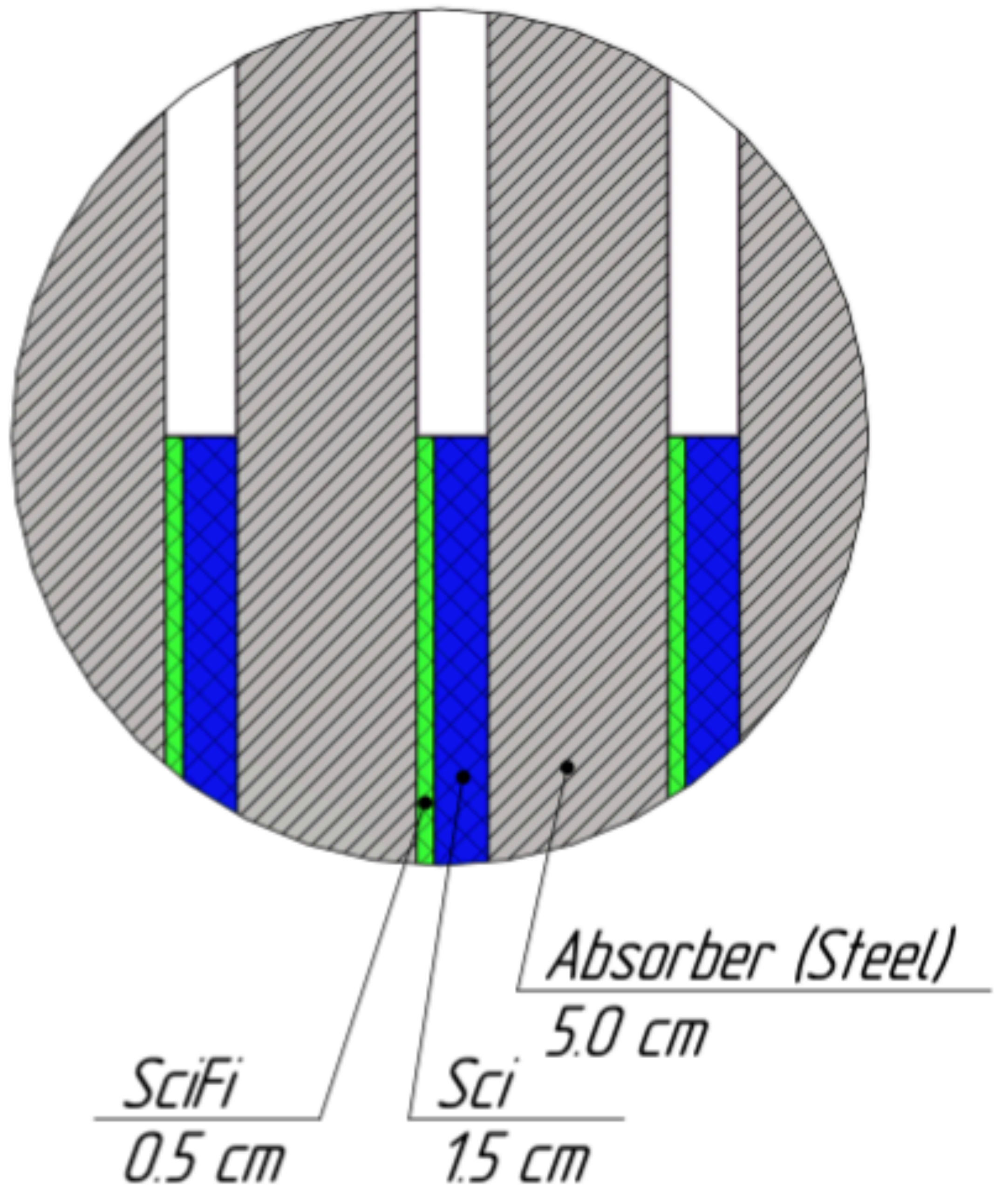
Energy resolution (for pi)

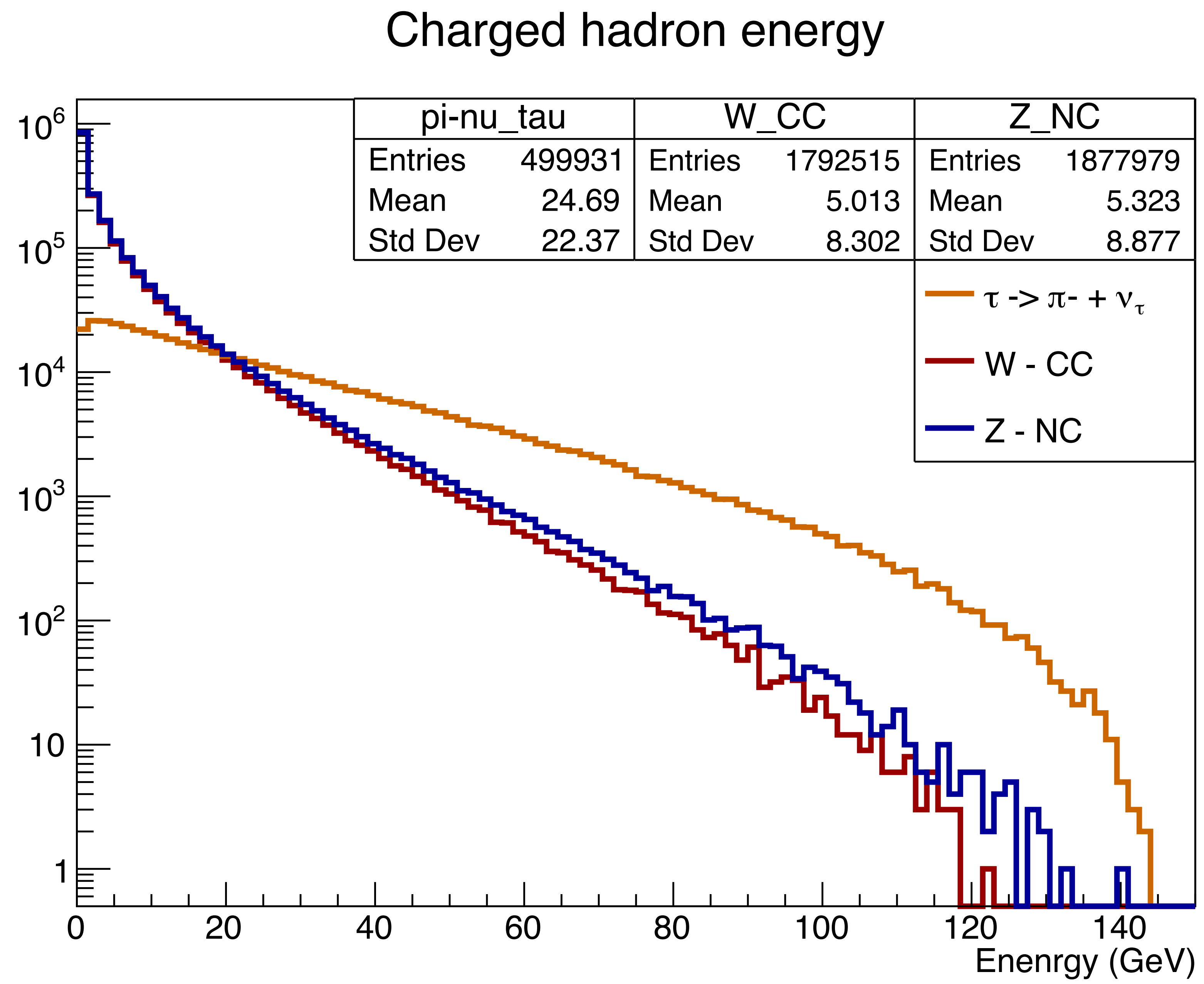
Incoming particles: pion

Particle momentum range: 1-100 GeV/c

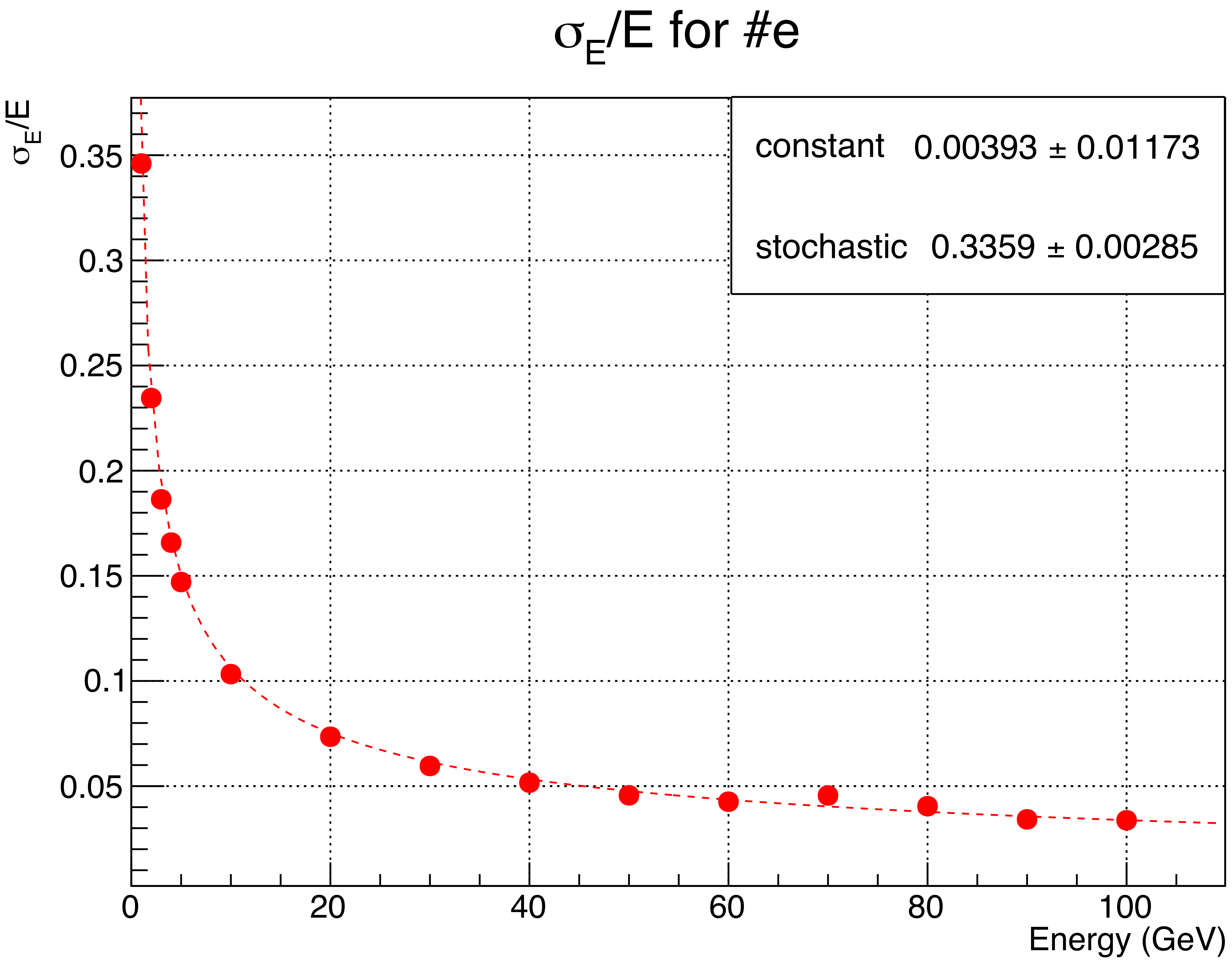


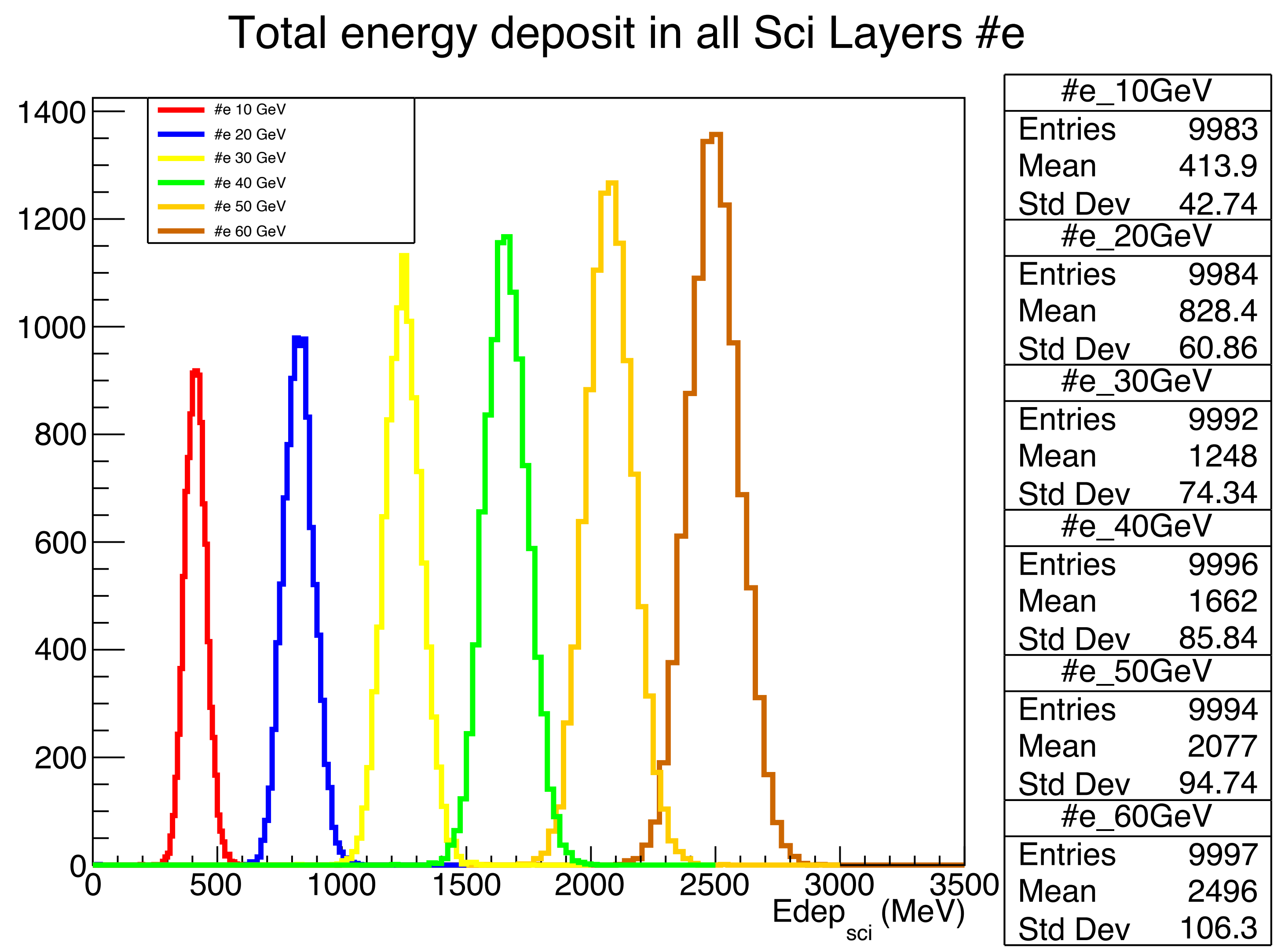


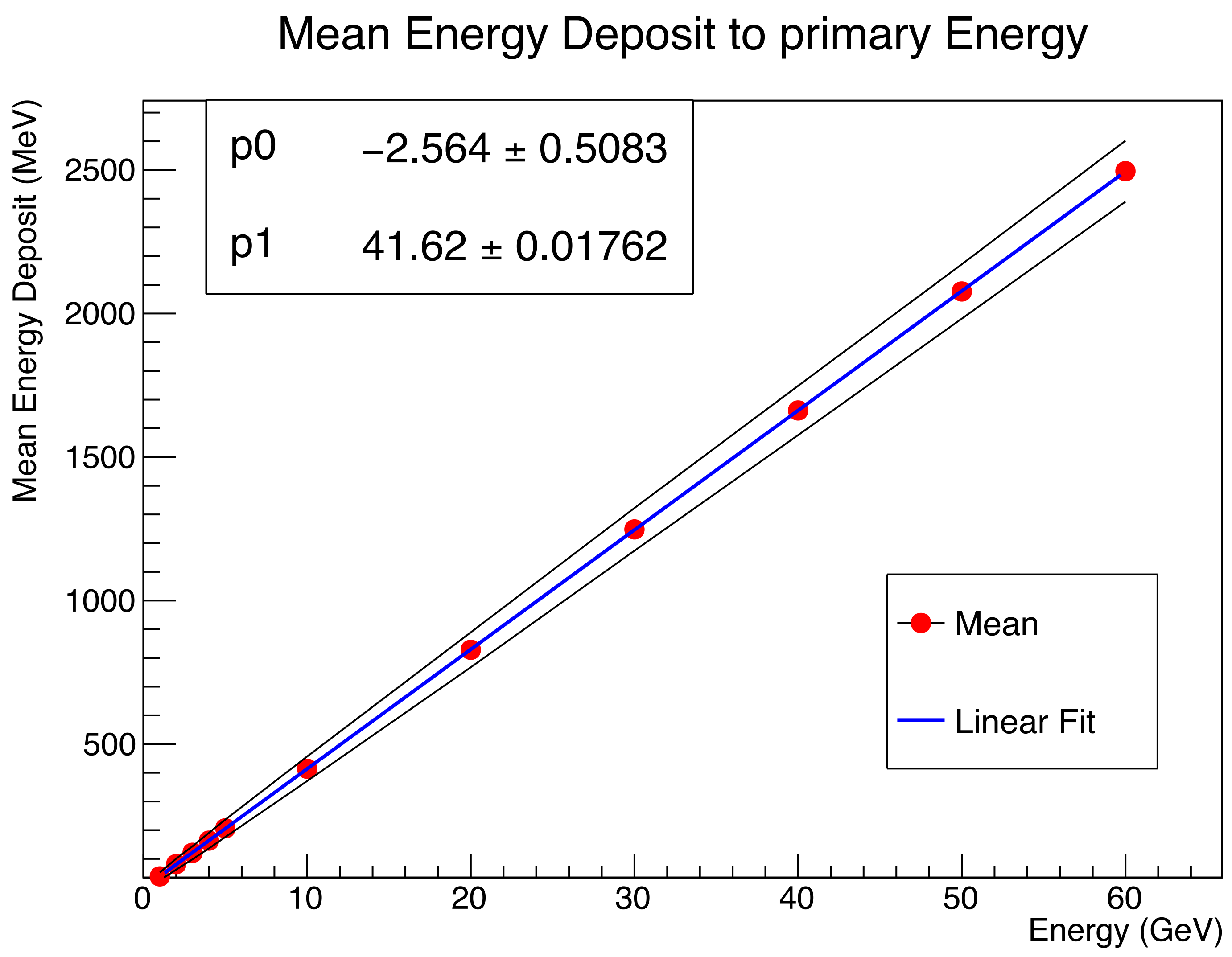




Energy resolution (for e)







parameters that was used in BDT

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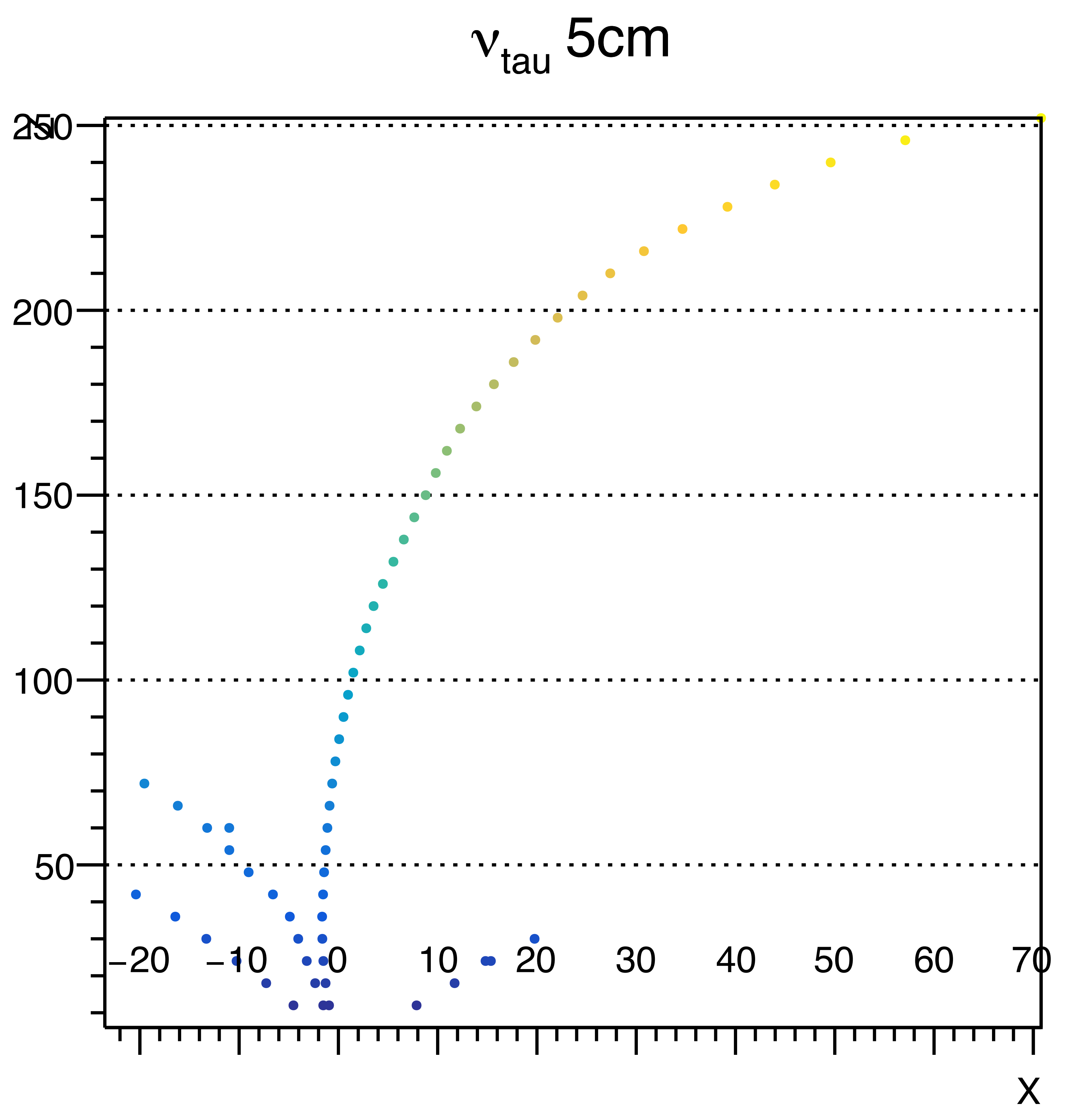
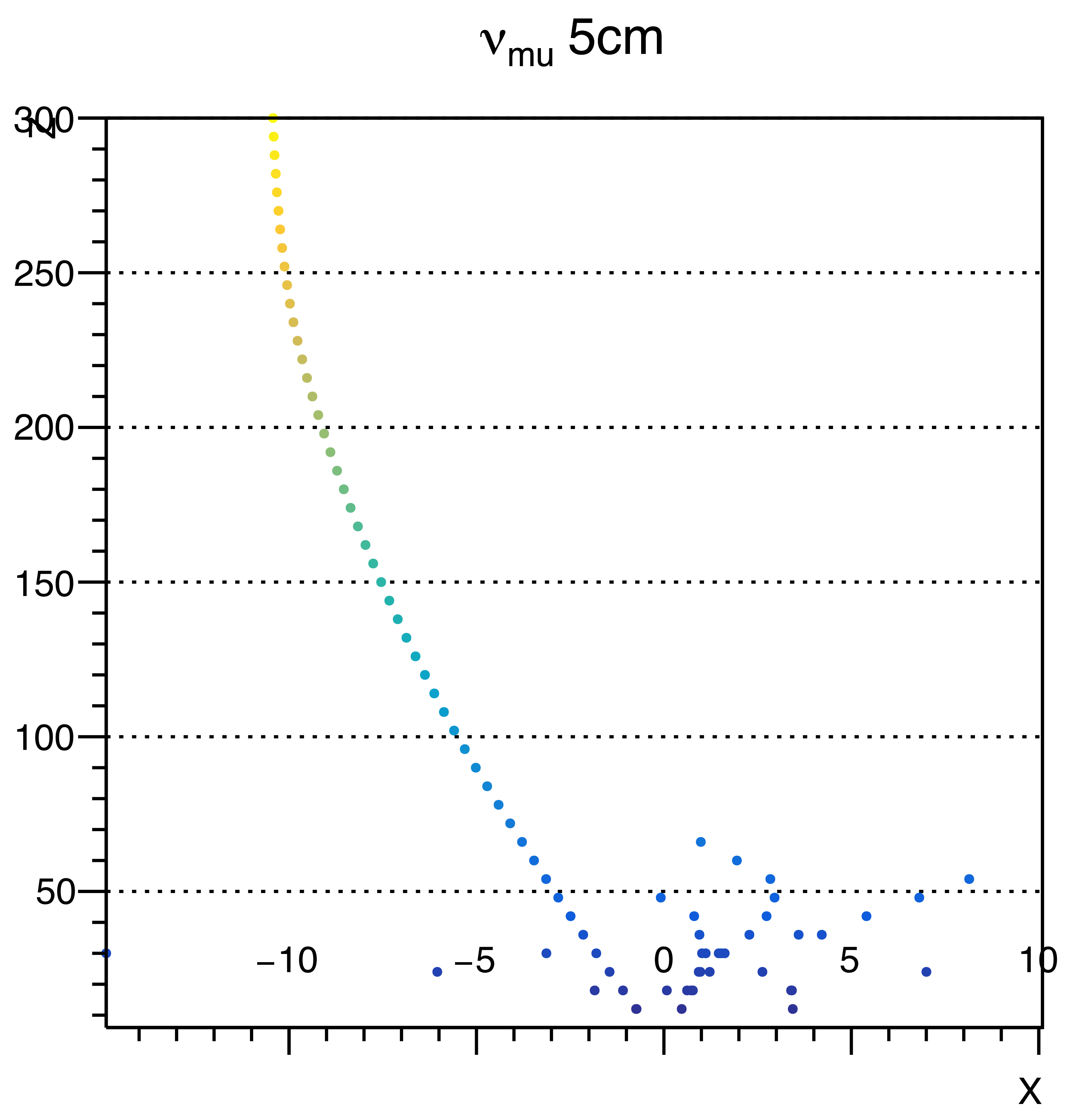
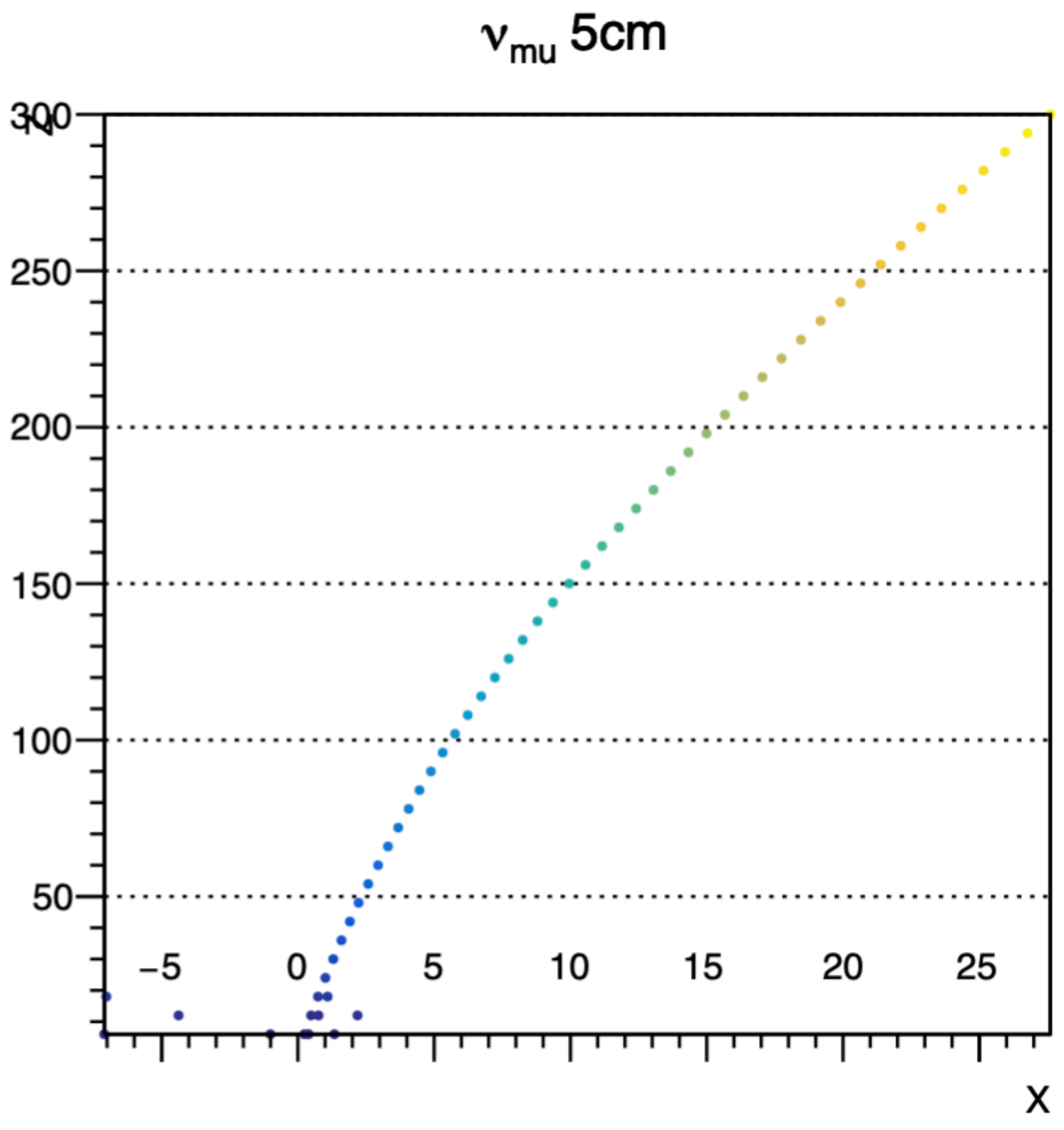
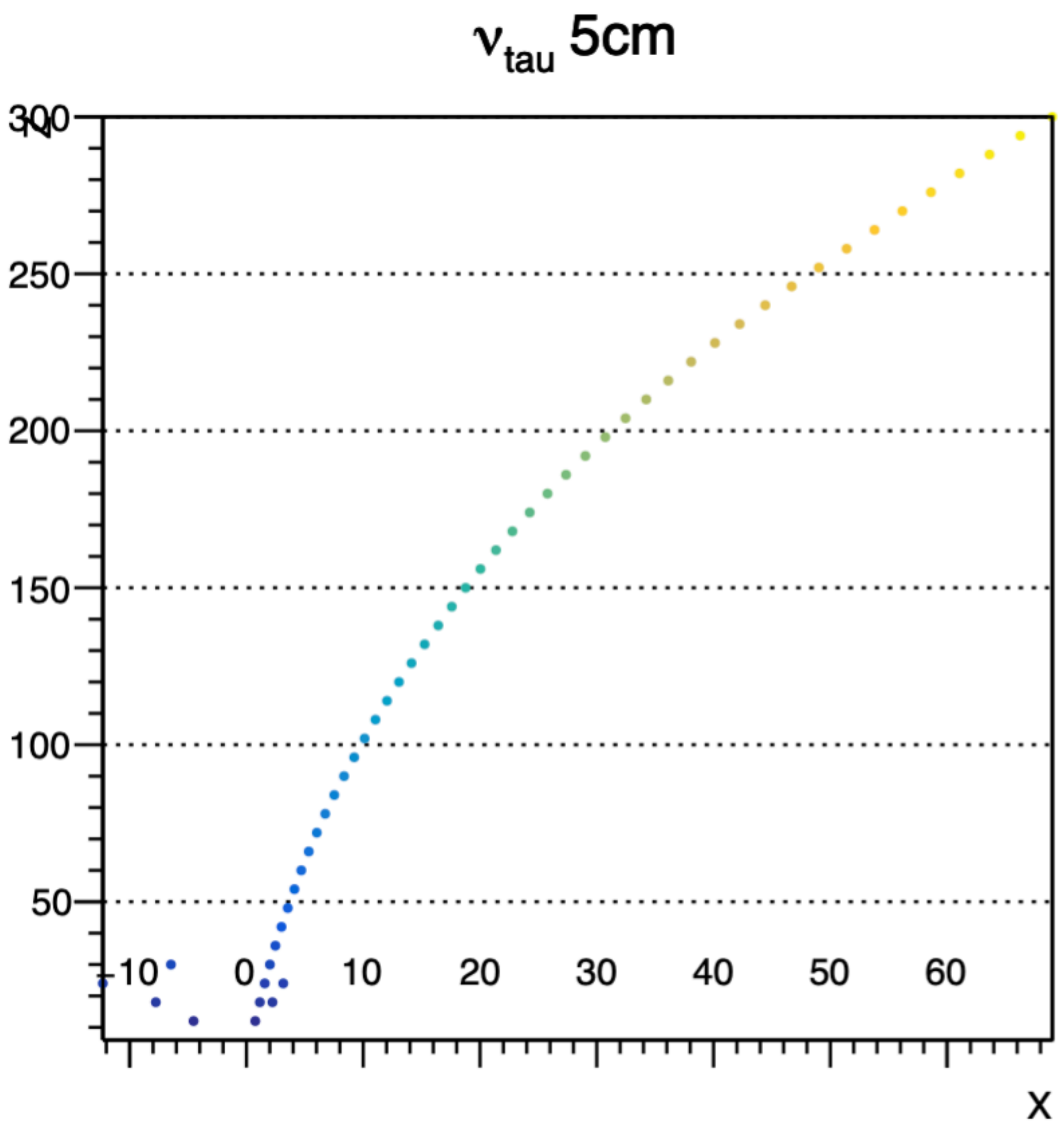


ν_{tau} 5cm
250
200
150
100
50
−20
−10
0
10
20
30
40
50
60
70
X



ν_{mu} 5cm
300
250
200
150
100
50
−10
−5
0
5
10
X


ν_{mu} 5cm
N
300
250
200
150
100
50
−5
0
5
10
15
20
25
X


ν_{tau} 5cm
N
300
250
200
150
100
50
−10
0
10
20
30
40
50
60
X