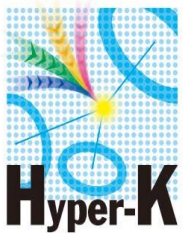
Updates on the GNN for PID and energy/vertex reconstruction

Christine QUACH - Laboratoire Leprince-Ringuet



Outline.

1. **Status** of the GNN
2. **e/pi0** on a spectrum of energy
3. **Energy reconstruction** for e & mu
4. **3D Vertex reconstruction** for e

1 Status of the GNN.

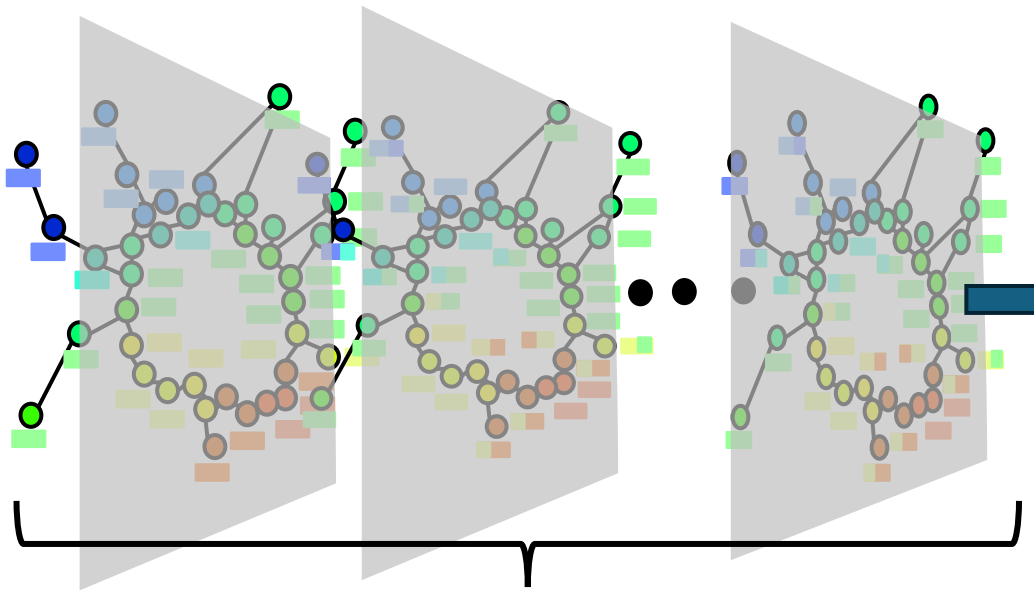
a) Architecture

b) Recap on the results so far

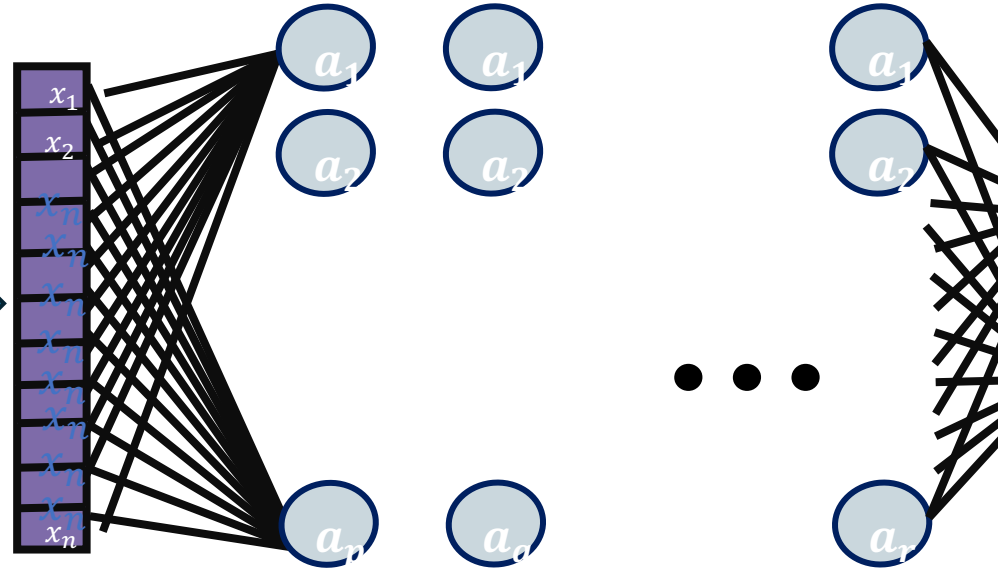
1 Status of the GNN

a) Architecture

Graph architecture



# of convolutional layers



INPUT
(Graph representation as 1D vector)

NEURONS **NEURONS**

NEURONS

# of hidden layers

OUTPUT

b) Recap on the results so far

Loss function :

$$\frac{1}{n}\Sigma(y_i - \hat{y}_i)^2$$

$\hat{y}_1$	μ^-
0.9	1
$\hat{y}_2$	e^-
0.2	0

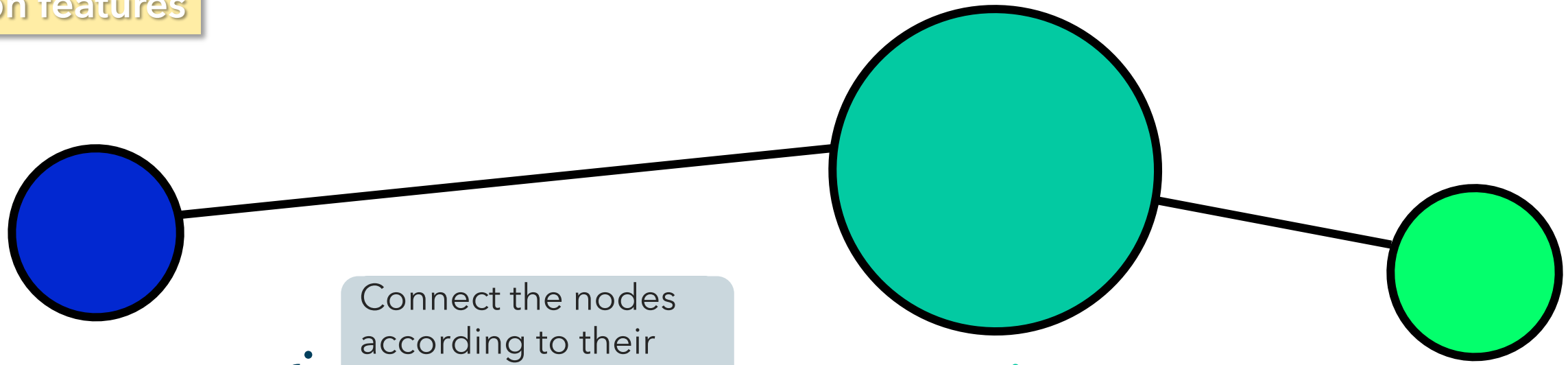
Minimization of the loss function !

1 Status of the GNN

a) Architecture

b) Recap on the results so far

Graph features



Edge.

Connect the nodes according to their proximity in **Charge, time, spatial coordinates**.

Node : **Hit PMT**

Features.

- Charge (Q)
- Hit time (t)
- Position (x,y,z)

1 Status of the GNN

a) Architecture

b) Recap on the results so far

	GNN	FitQun
e/mu		
e/pi0		
e/gamma		
Energy reconstruction for e & mu (1D)		
Vertex reconstruction for e & mu (1D)		

Classification

1 Status of the GNN

a) Architecture

b) Recap on the results so far

	GNN	FitQun
e/mu		
e/pi0		
e/gamma		
Energy reconstruction for e & mu (1D)		
Vertex reconstruction for e & mu (1D)		

Regression.

1 Status of the GNN

a) Architecture

b) Recap on the results so far

	GNN	FitQun
e/mu	**99% electron efficiency** at 5% muon bg acceptance, Dwall, towall analysis: After 2 m, efficiency above 99.4% !	**99% electron efficiency** at 5% muon bg acceptance,
e/pi0		
e/gamma		
Energy reconstruction for e & mu (1D)		
Vertex reconstruction for e & mu (1D)		

1 Status of the GNN

a) Architecture

b) Recap on the results so far

	GNN	FitQun
e/mu	**99% electron efficiency** at 5% muon bg acceptance, Dwall, towall analysis: After 2 m, efficiency above 99.4% !	**99% electron efficiency** at 5% muon bg acceptance,
e/pi0	**78% electron efficiency** at 25% pi0 bg acceptance [Spectrum of energy]	**94% electron efficiency** at 25% pi0 bg acceptance
e/gamma		
Energy reconstruction for e & mu (1D)		
Vertex reconstruction for e & mu (1D)		

1 Status of the GNN

a) Architecture

b) Recap on the results so far

	GNN	FitQun
e/mu	**99% electron efficiency** at 5% muon bg acceptance, Dwall, towall analysis: After 2 m, efficiency above 99.4% !	**99% electron efficiency** at 5% muon bg acceptance,
e/pi0	**78% electron efficiency** at 25% pi0 bg acceptance [Spectrum of energy]	**94% electron efficiency** at 25% pi0 bg acceptance
e/gamma	**58% efficiency** at 50% bg acceptance... **[Fixed energy]**	None
Energy reconstruction for e & mu (1D)		
Vertex reconstruction for e & mu (1D)		

1 Status of the GNN

a) Architecture

b) Recap on the results so far

	GNN	FitQun
e/mu	**99% electron efficiency** at 5% muon bg acceptance, Dwall, towall analysis: After 2 m, efficiency above 99.4% !	**99% electron efficiency** at 5% muon bg acceptance,
e/pi0	**78% electron efficiency at 25% pi0 bg acceptance [Spectrum of energy]**	**94% electron efficiency** at 25% pi0 bg acceptance
e/gamma	**58% efficiency** at 50% bg acceptance… **[Fixed energy]**	None
Energy reconstruction for e & mu (1D)	**Electron : 5% resolution at 500 MeV, energy bias at ~4%** **Muon : 7% resolution at 500 MeV, energy bias at ~7%**	**Electron : 7% resolution at 500 MeV** **Muon : 6% resolution at 500 MeV**
Vertex reconstruction for e & mu (1D)		

1 Status of the GNN

a) Architecture

b) Recap on the results so far

	GNN	FitQun
e/mu	**99% electron efficiency** at 5% muon bg acceptance, Dwall, towall analysis: After 2 m, efficiency above 99.4% !	**99% electron efficiency** at 5% muon bg acceptance,
e/pi0	**78% electron efficiency** at 25% pi0 bg acceptance [Spectrum of energy]	**94% electron efficiency** at 25% pi0 bg acceptance
e/gamma	**58% efficiency** at 50% bg acceptance... **[Fixed energy]**	None
Energy reconstruction for e & mu (1D)	**Electron : 5% resolution at 500 MeV, energy bias at ~4%** **Muon : 7% resolution at 500 MeV, energy bias at ~7%**	**Electron : 7% resolution at 500 MeV** **Muon : 6% resolution at 500 MeV**
Vertex reconstruction for e & mu (1D)	**Electron : 91,7 cm longitudinal resolution, 153 cm transversal resolution,** **Muon : 103 cm longitudinal resolution, 181 cm transversal resolution,**	**Electron : 91,7 cm longitudinal resolution, 153 cm transversal resolution,** **Muon : 103 cm longitudinal resolution, 181 cm transversal resolution,**

2 Particle Identification e/pi0.

a) Architecture

b) Results

2 Particle Identification e/pi0

a) Architecture

b) Results

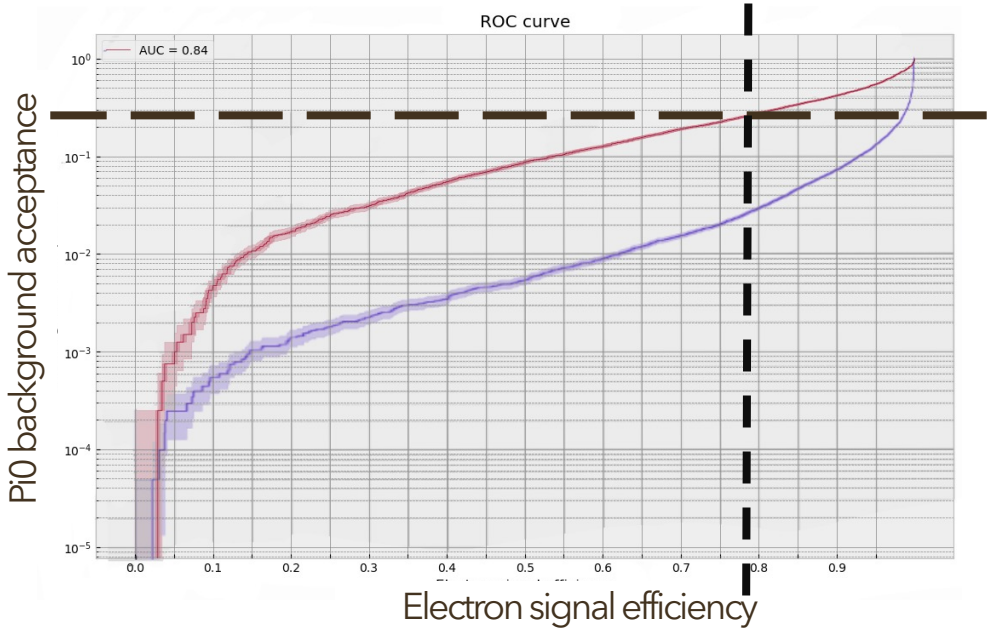
Dataset

ROC Curve

Previous results

Sub-GeV region

- Number of events : 20k e, 20k pi0
- Energy : 100 MeV to 1 GeV
- Direction and position : Uniform & isotropic
- Signal : e, Background : pi0
- 80% train, 20% evaluation



78% efficiency!! at 25% bg acceptance. (FitQun : 94% at 25% bg acceptance)

Small dataset

2 Particle Identification e/pi0

a) Architecture

b) Results

Dataset

Big dataset

Sub-GeV region

- Number of events : 200k e, 200k pi0
- Energy : 100 MeV to 1 GeV
- Direction and position : Uniform & isotropic
- Signal : e, Background : pi0
- 80% train, 20% evaluation

Optimisation of hyper parameters

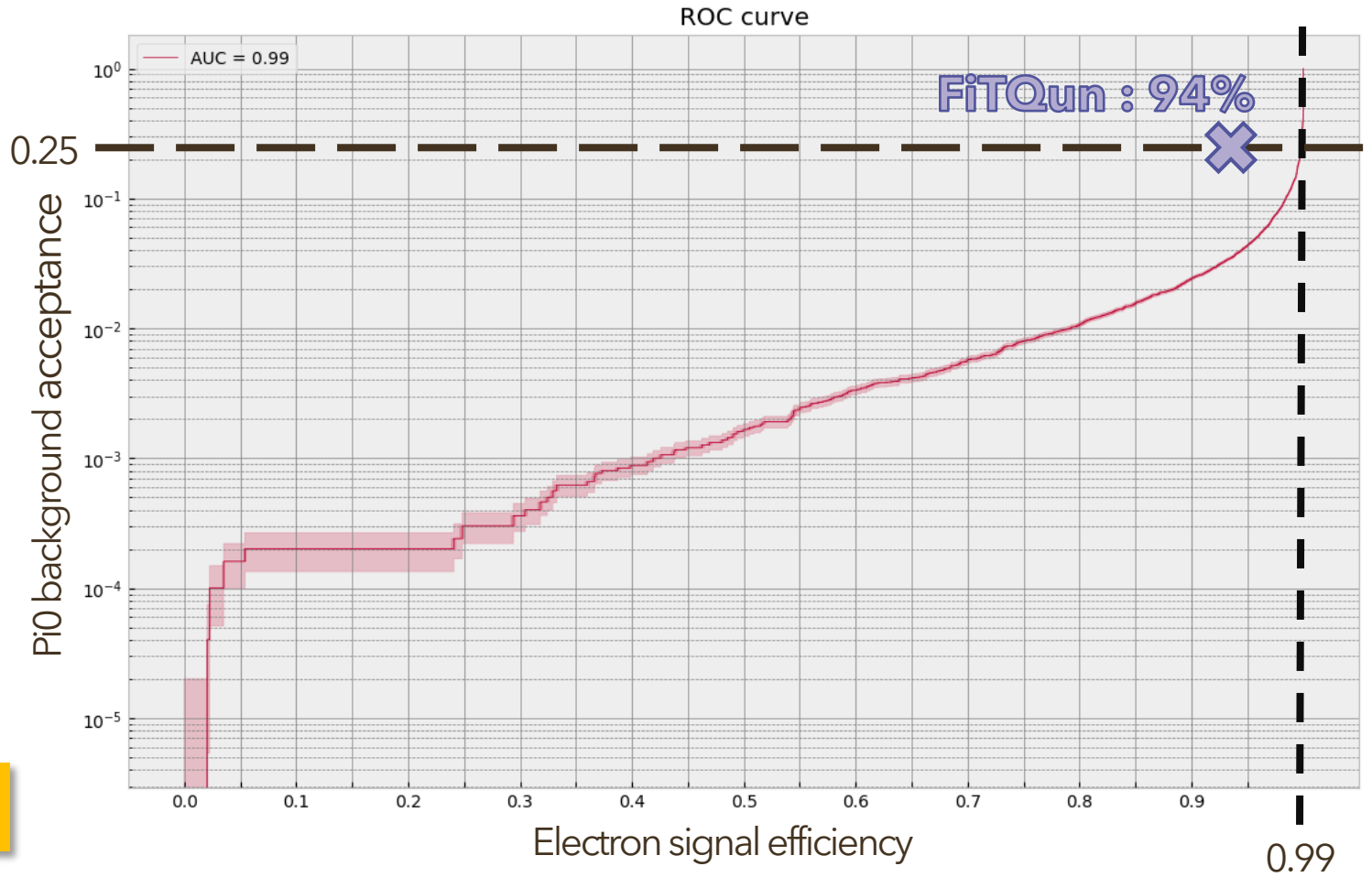
- Neighbours = 30
- Convolutionnal layers = 6
- Batch size = 16
- Learning rate = e-5
- Hidden layers = 7
- Neurons = 128

2 Particle Identification e/pi0

a) Architecture

b) Results

Roc curve **Results on Spectrum of Energy.**



GNN :
99% efficiency at
25% bg acceptance

FiTQun :
94% efficiency at
25% bg acceptance

0.1 s per event (GNN)
1min30 (fiTQun)

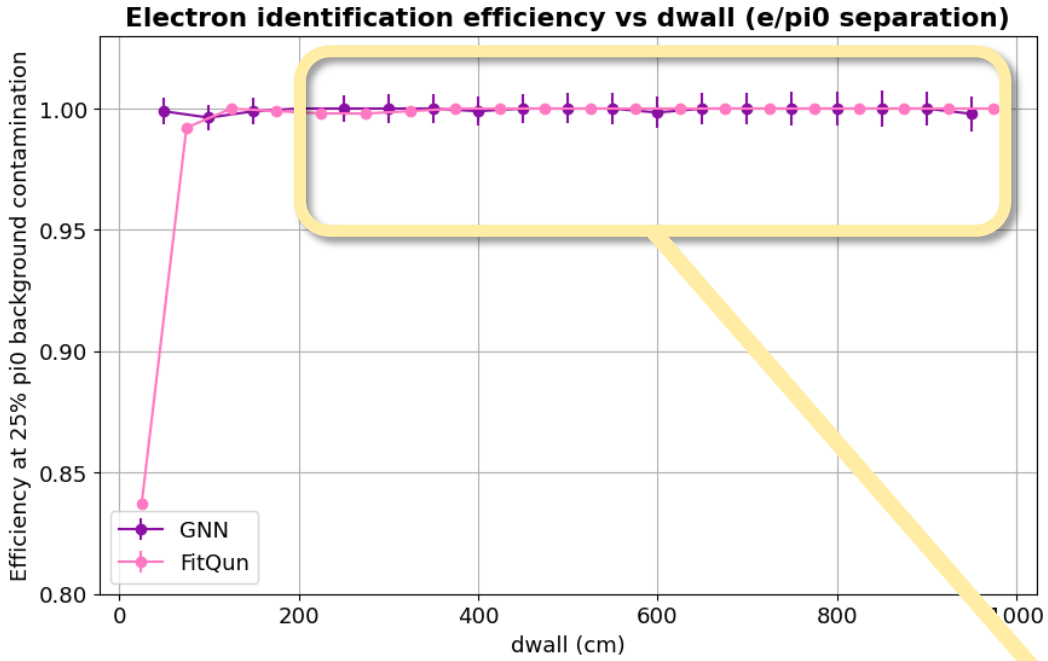
2 Particle Identification e/pi0

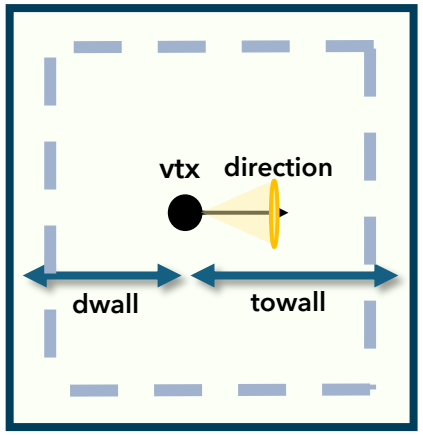
a) Architecture

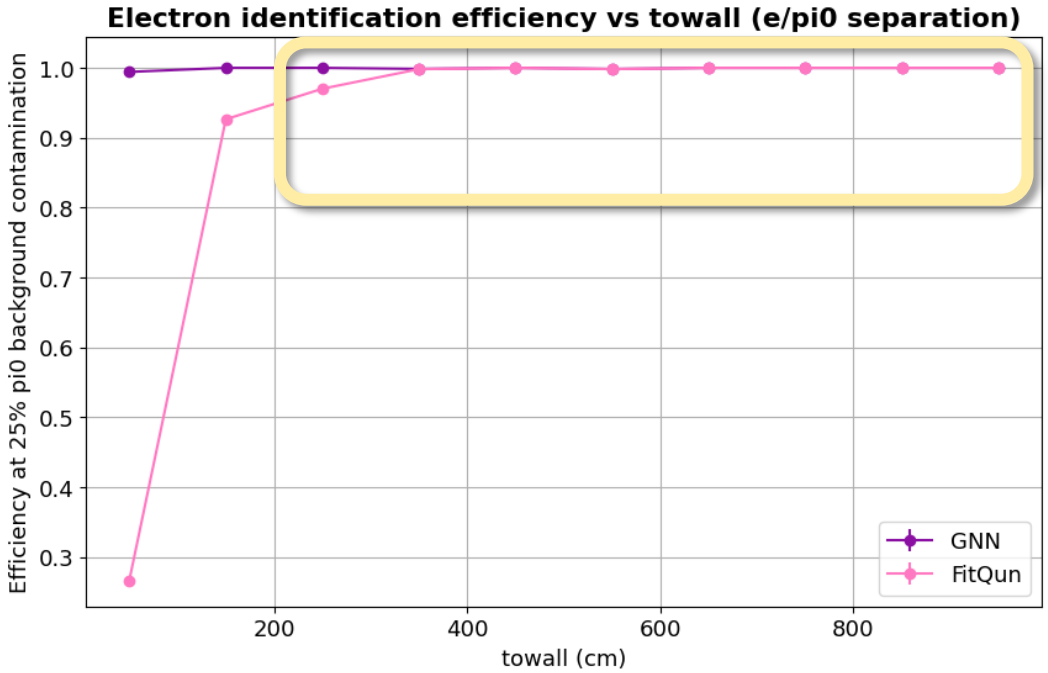
b) Results

dwall

towall







After 2 m, efficiency above 99% !

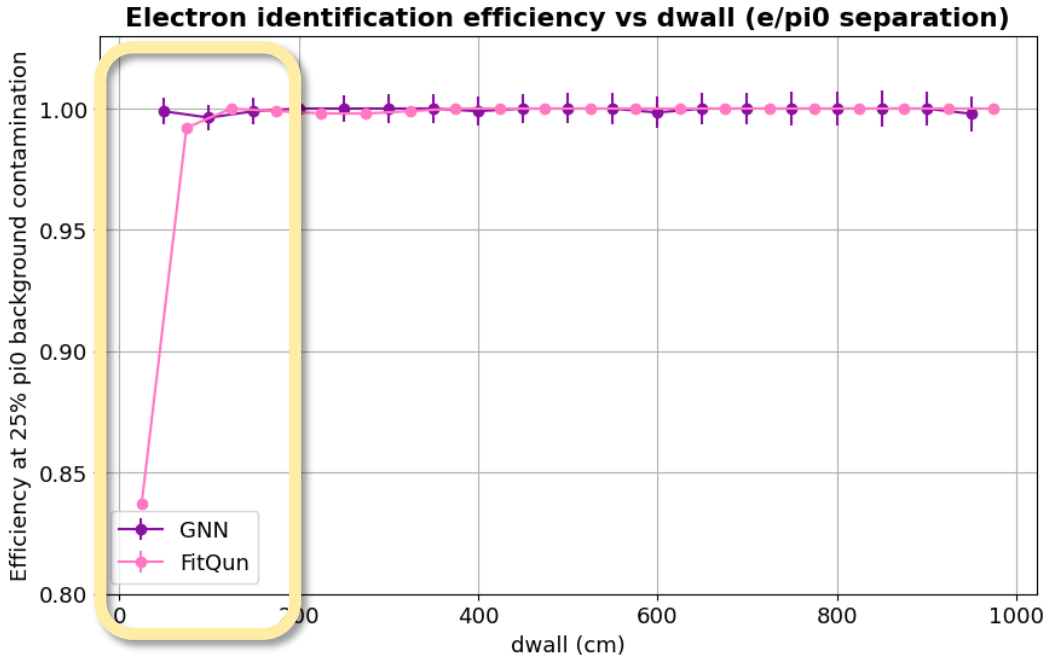
2 Particle Identification e/pi0

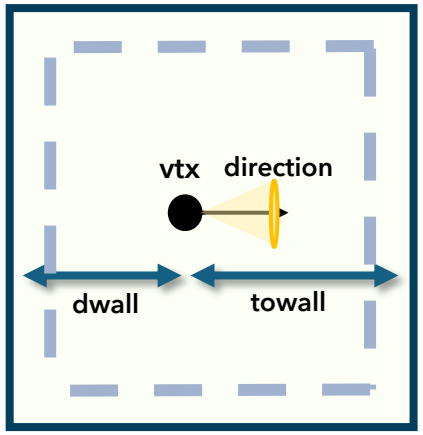
a) Architecture

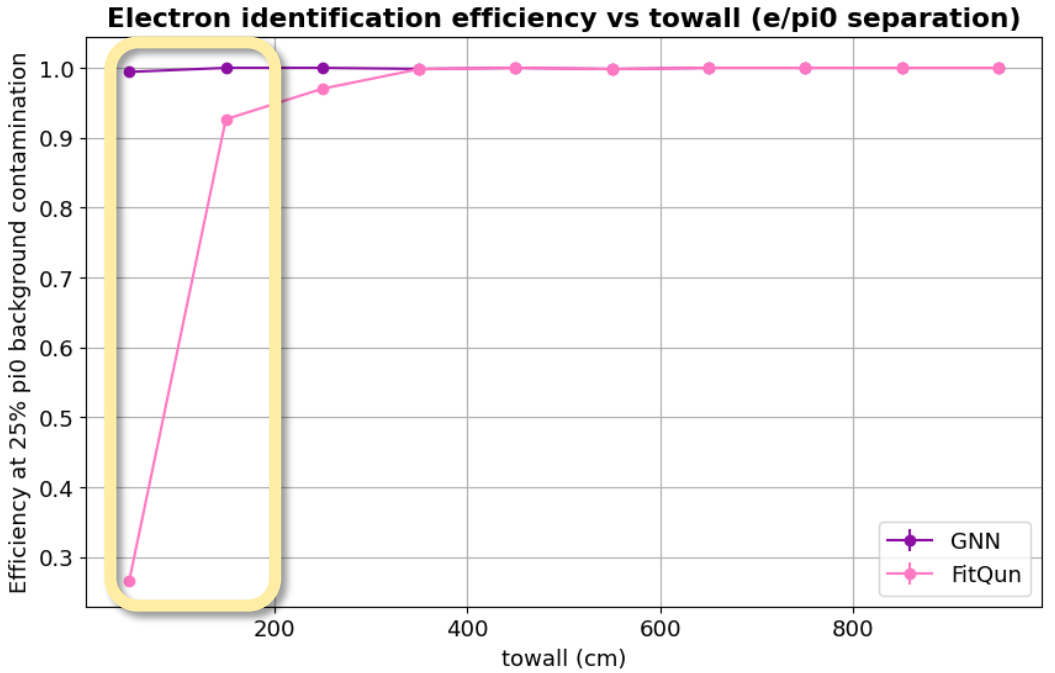
b) Results

dwall

towall







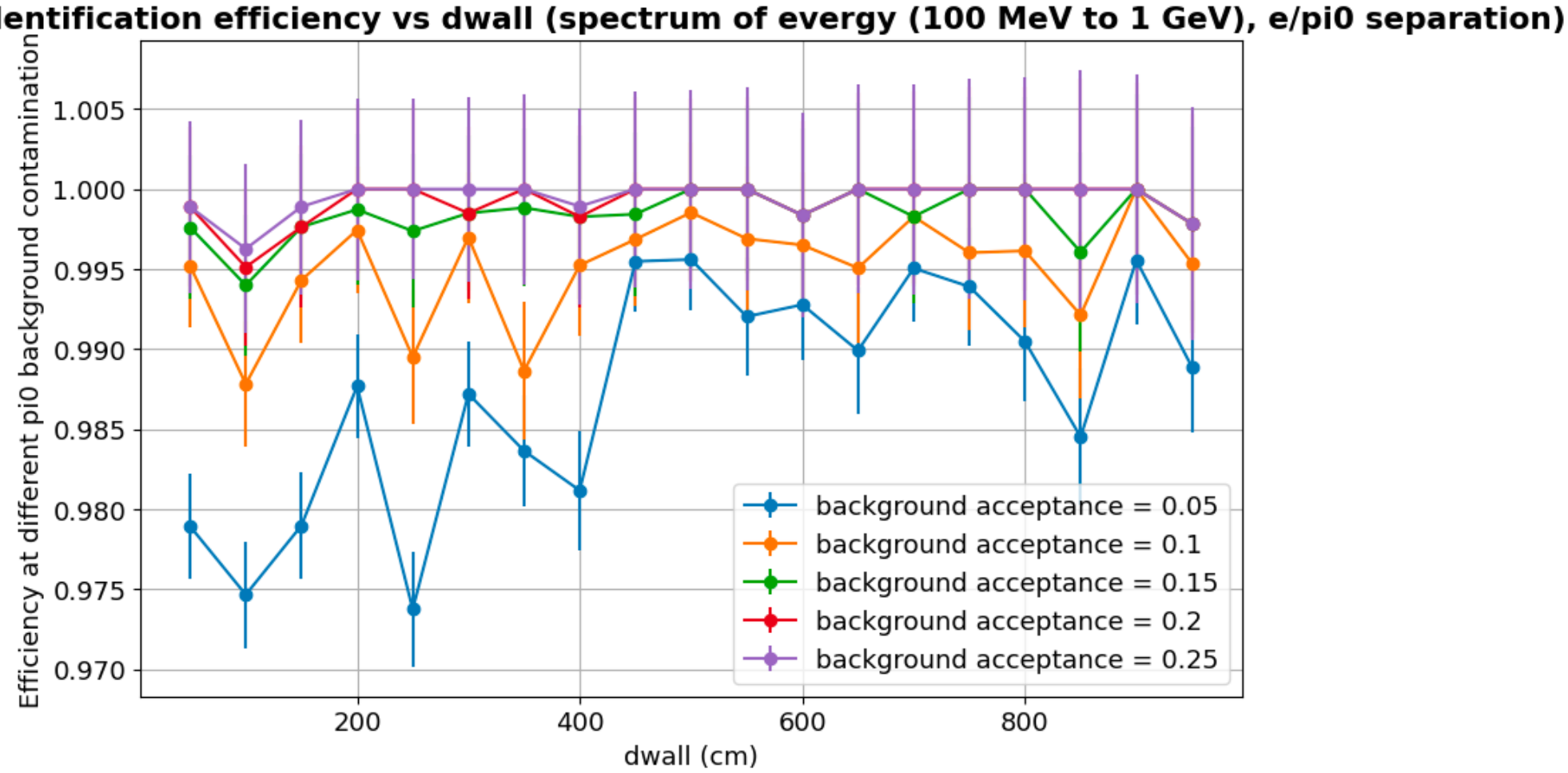
For events close to the wall : GNN > FiTQun => potentially increase FV

2 Particle Identification e/pi0

a) Architecture

b) Results

dwall



3 Energy reconstruction for e & mu.

a) Architecture

b) Results

3 Energy reconstruction for e & mu.

Sub-GeV region

a) Architecture

Dataset

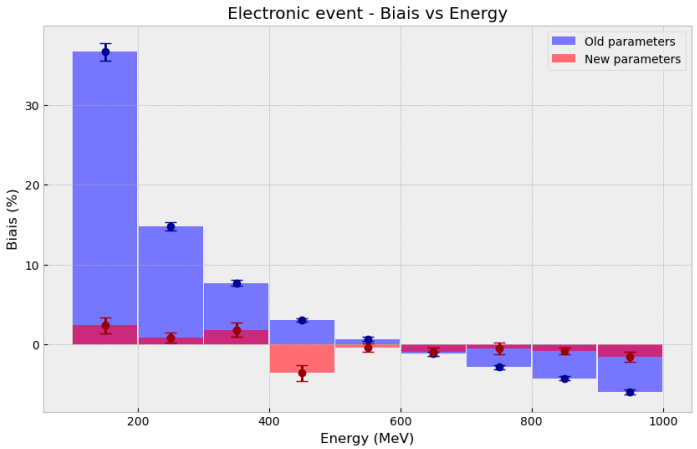
Previous results

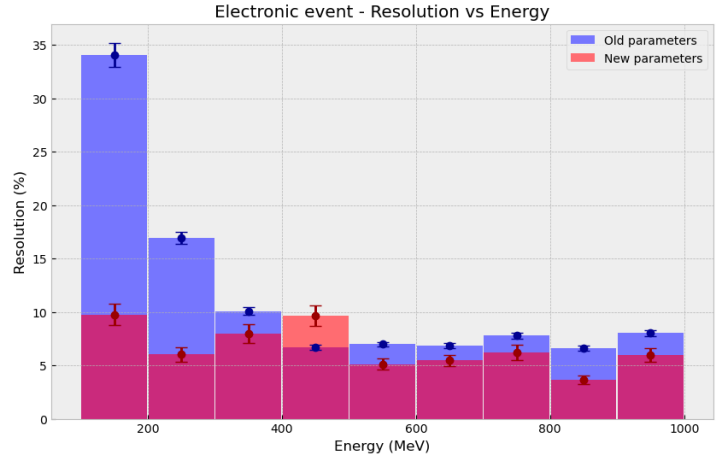
- Number of events : 20k e, 20k mu
- Energy : 100 MeV to 1000 MeV
- Direction and position : Uniform & isotropic

- 80% train, 20% evaluation

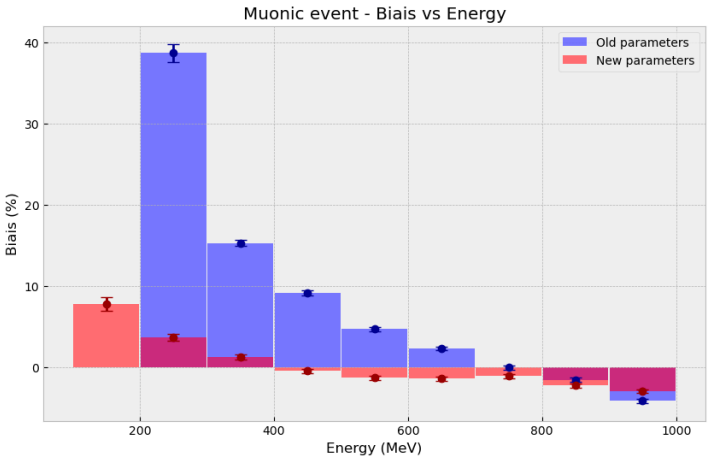
b) Results

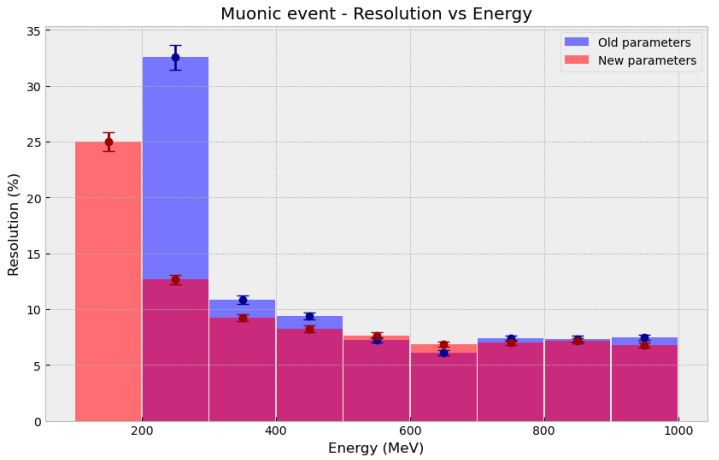
Electron





Muon





3 Energy reconstruction for e & mu.

Sub-GeV region

a) Architecture

Dataset

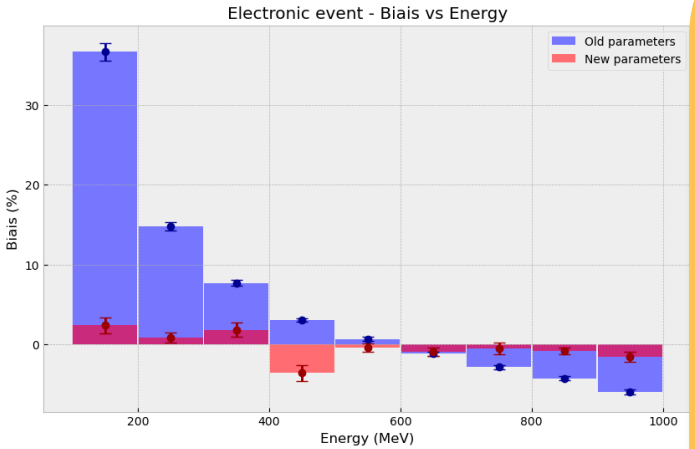
Previous results

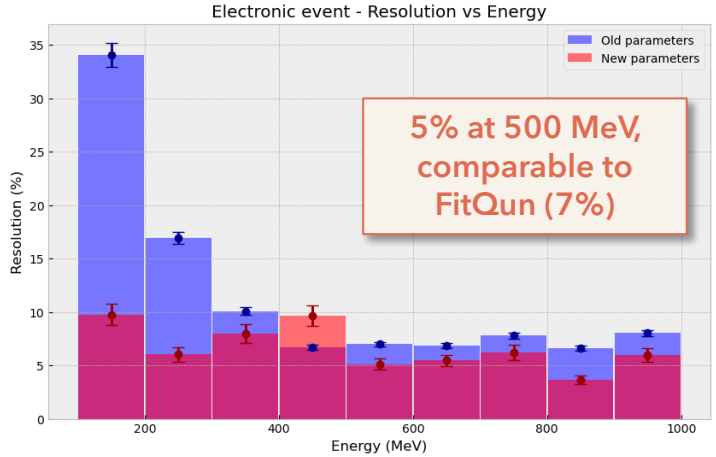
- Number of events : 20k e, 20k mu
- Energy : 100 MeV to 1000 MeV
- Direction and position : Uniform & isotropic

- 80% train, 20% evaluation

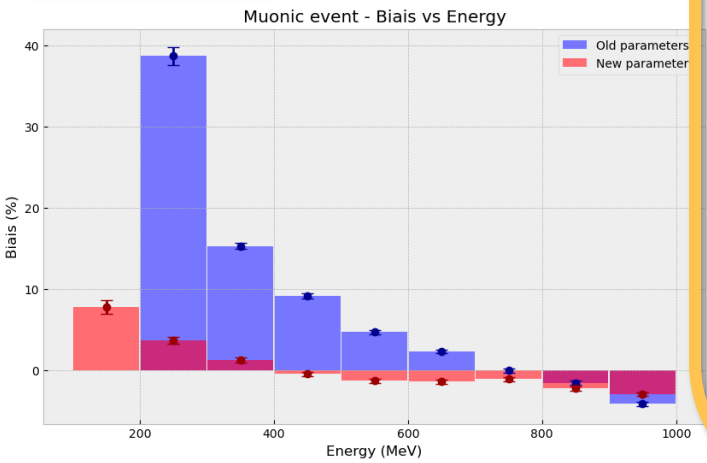
b) Results

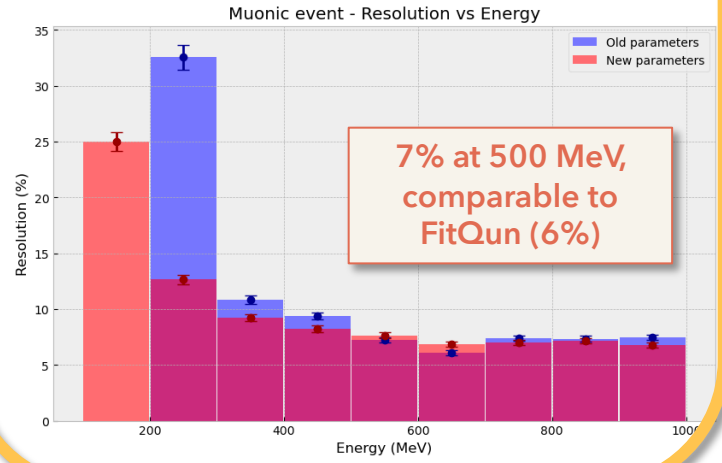
Electron





Muon





3 Energy reconstruction for e & mu.

Sub-GeV region

a) Architecture

Dataset

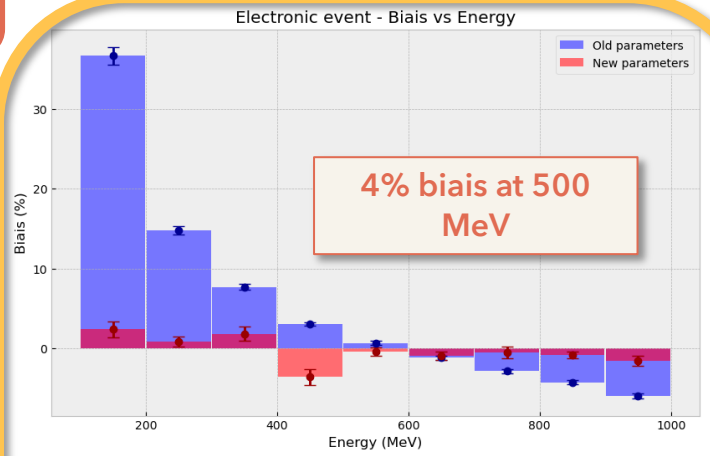
Previous results

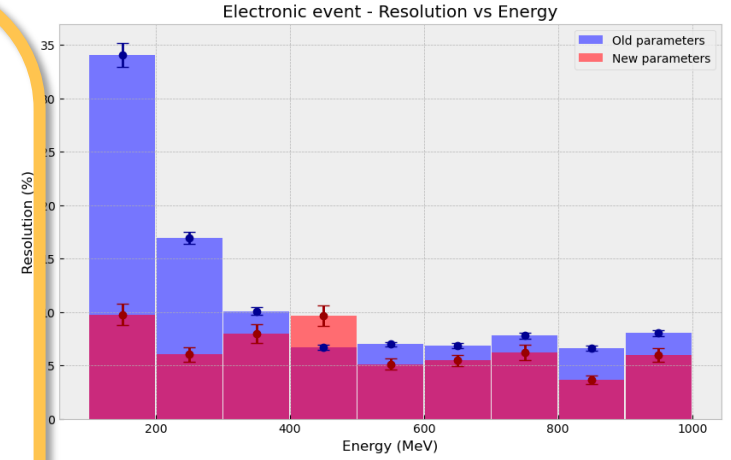
- Number of events : 20k e, 20k mu
- Energy : 100 MeV to 1000 MeV
- Direction and position : Uniform & isotropic

- 80% train, 20% evaluation

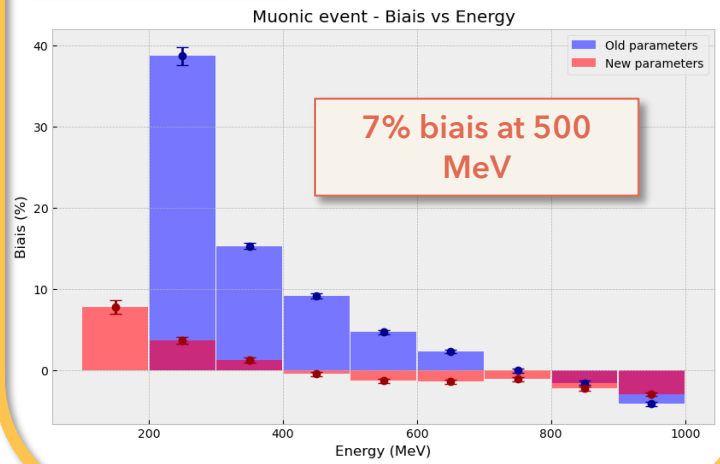
b) Results

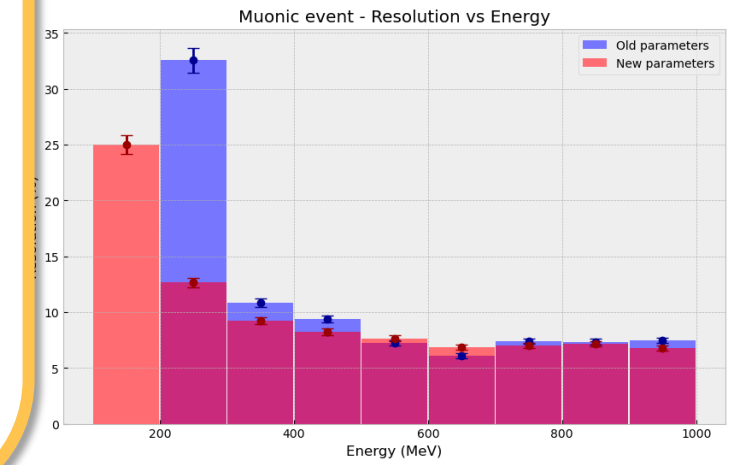
Electron





Muon





3 Energy reconstruction for e & mu.

Sub-GeV region

a) Architecture

Dataset

- Number of events : 200k e, 200k mu
- Energy : 100 MeV to 1000 MeV
- Direction and position : Uniform & isotropic

- 80% train, 20% evaluation

Bigger dataset

b) Results

Optimisation of hyper parameters

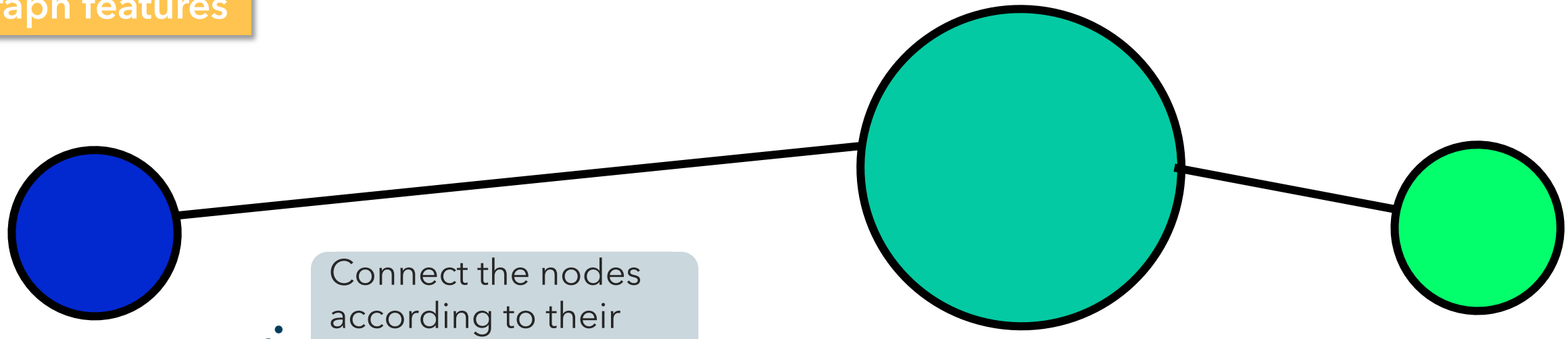
- Neighbours = 32
- Convolutionnal layers = 6
- Batch size = 64
- Learning rate = e-3
- Hidden layers = 2
- Neurones = 32

3 Energy reconstruction for e & mu.

a) Architecture

b) Results

Graph features



Edge.

Connect the nodes according to their **spatial (x, y, z) and Charge (Q), Time (t) proximity.**

Node : **Hit PMT**

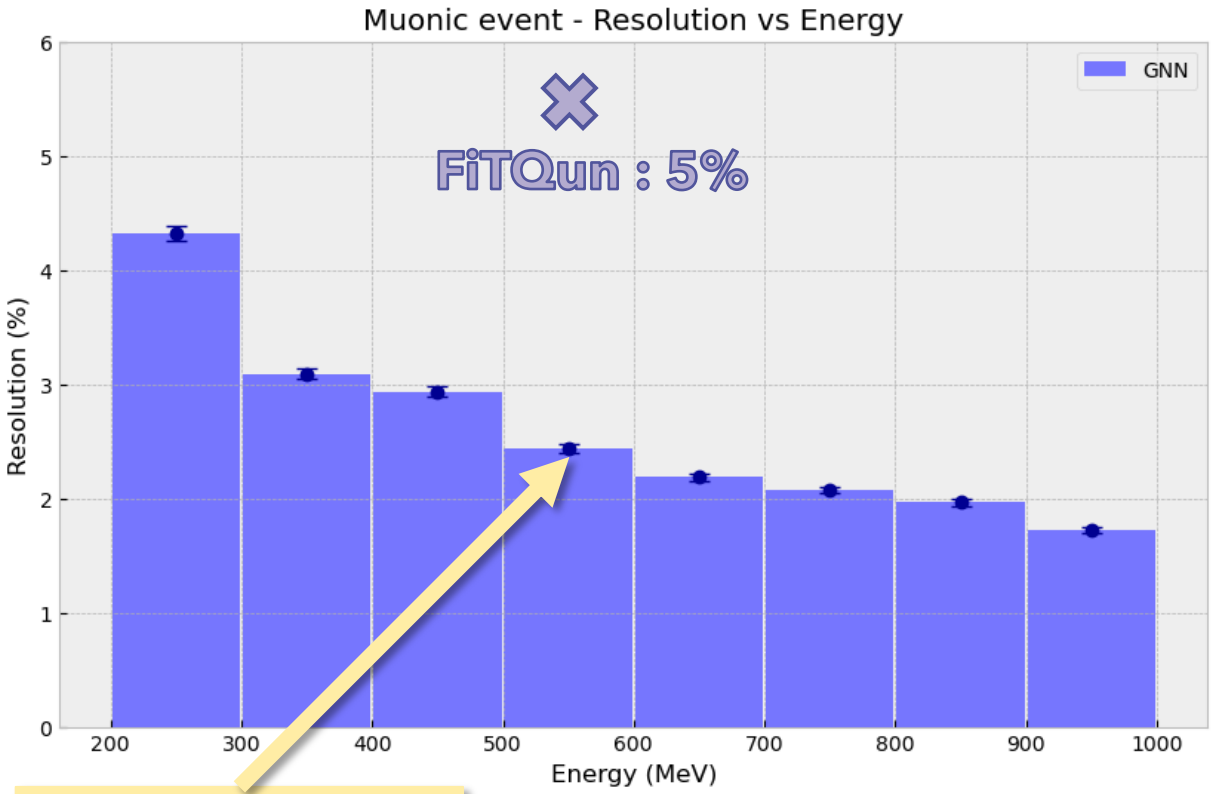
Features.

- Charge (Q)
- Hit time (t)
- Position (x,y,z)

3 Performance comparison : fiTQun vs GRANT

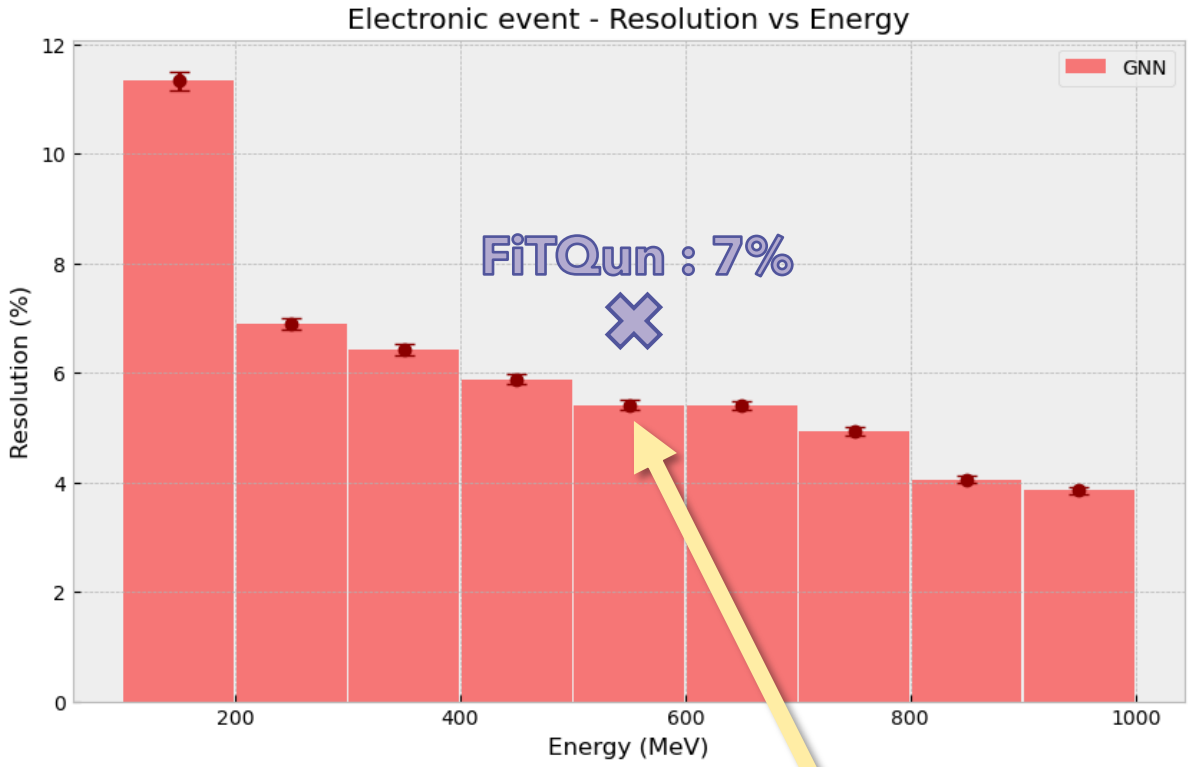
a) e/mu b) e/pi0 **c) Energy** d) Vertex e) Direction

Resolution



GNN : 2.5% at 500 MeV,

0.06 s per event (GNN)
1min30 (fiTQun)



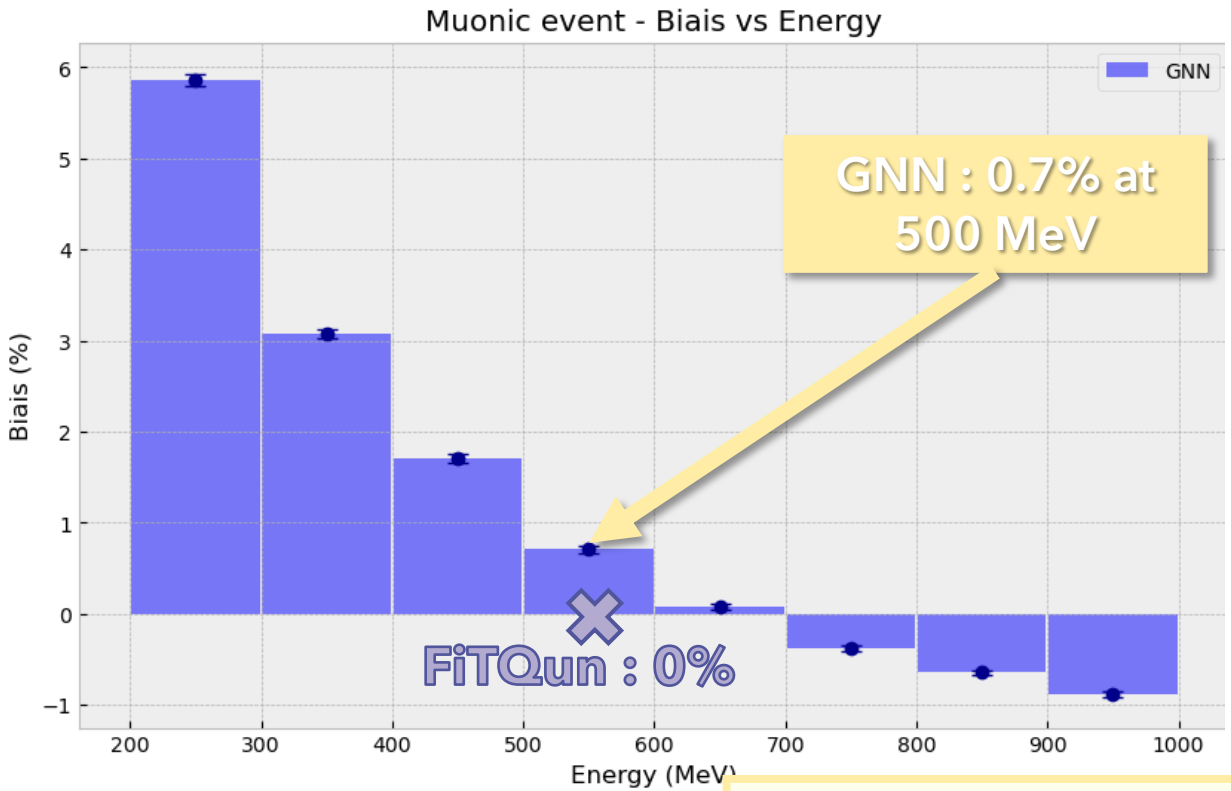
GNN : 5.5% at 500 MeV,

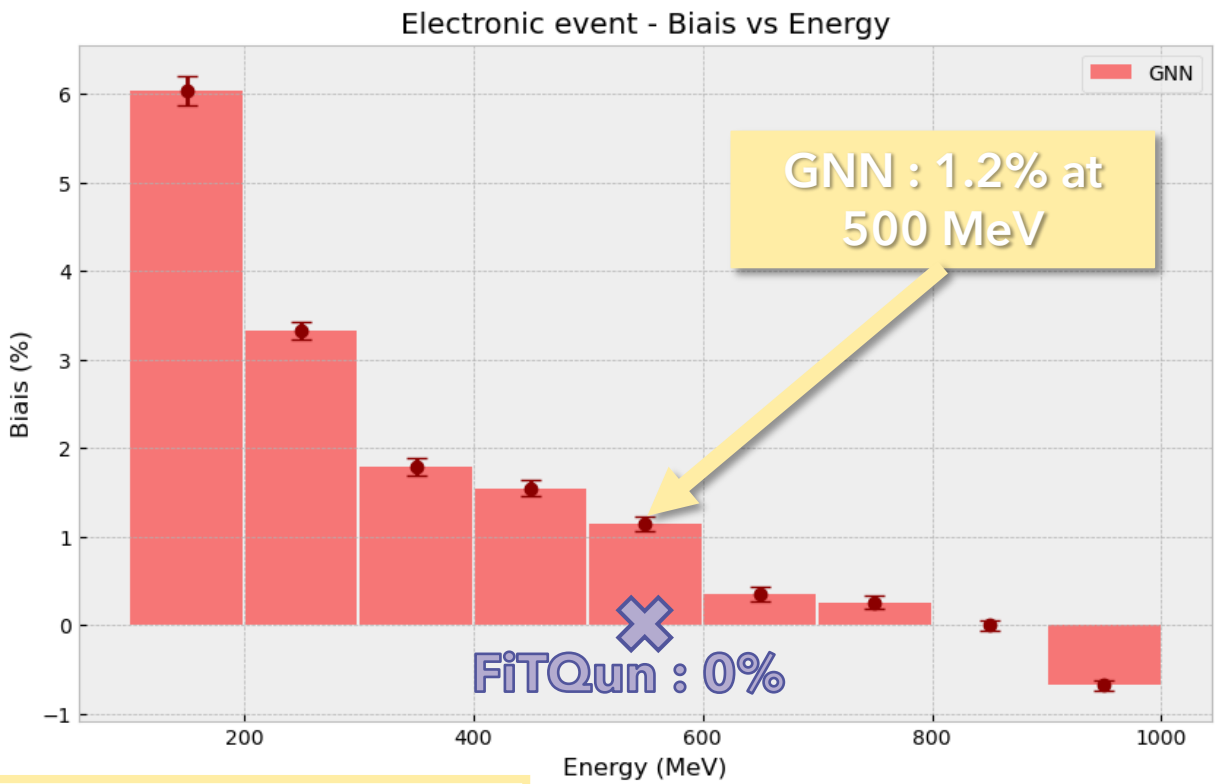
3 Energy reconstruction for e & mu.

a) Architecture

b) Results

Biais





BUT : the GNN has a biais ☹
(1.5% electron, 0.5% muon at 500 MeV)

FiTQun : 0% biais !

4 Vertex reconstruction 3D.

a) Architecture

b) Results

4 Vertex reconstruction 3D.

a) Architecture

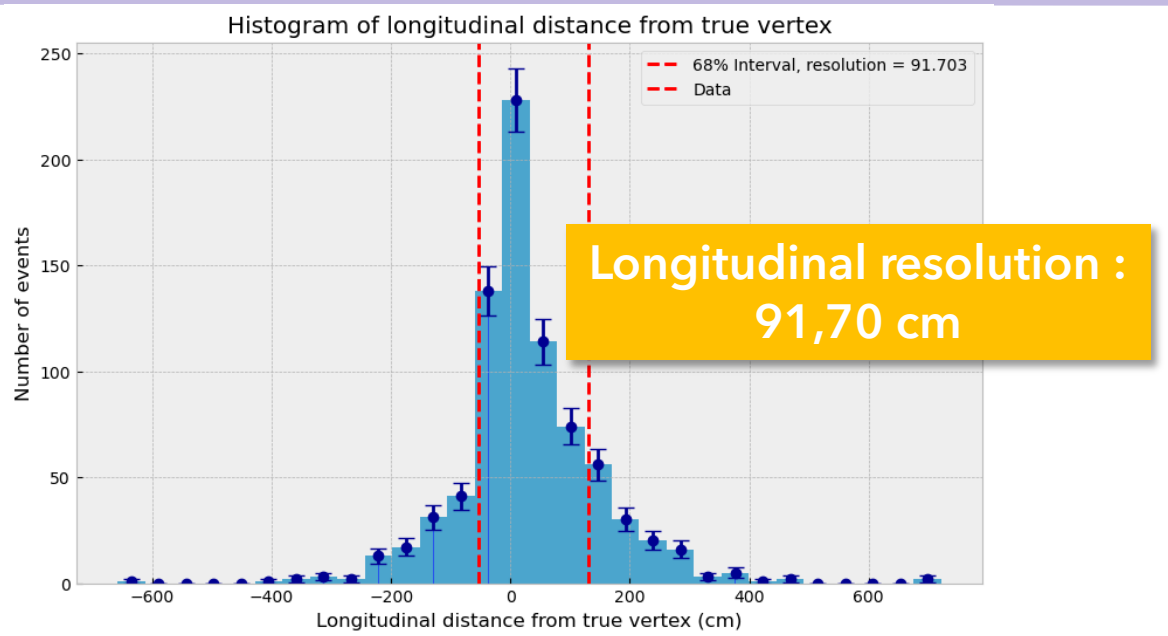
b) Results

Dataset

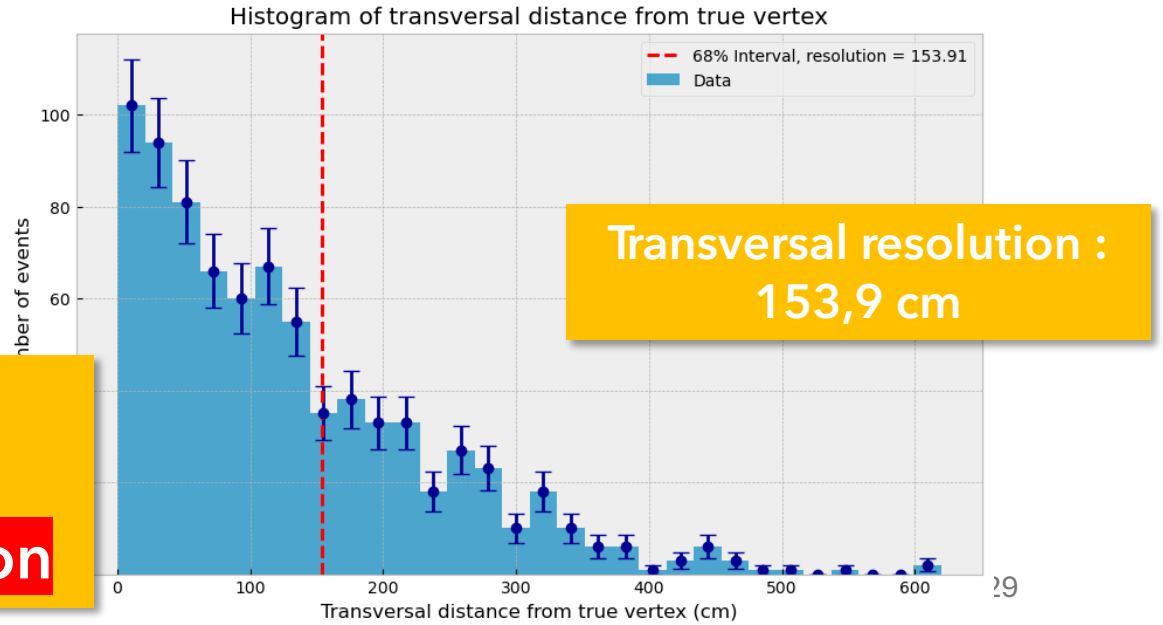
Previous results

- Number of events : 4k e, 4k mu
- Energy : 500 MeV
- Direction and position : Uniform & isotropic
- 80% train, 20% evaluation

- Fixed energy
- Small dataset
- 1D reconstruction



Longitudinal resolution : 91,70 cm



Transversal resolution : 153,9 cm

4 Vertex reconstruction 3D.

a) Architecture

Dataset

- Number of events : 200k e
- Energy : 100 MeV to 1 GeV
- Direction and position : Uniform & isotropic
- 80% train, 20% evaluation

b) Results

Optimisation of hyper parameters

- Neighbours = 32
- Convolutionnal layers = 6
- Batch size = 64
- Learning rate = e-3
- Hidden layers = 2
- Neurons = 32

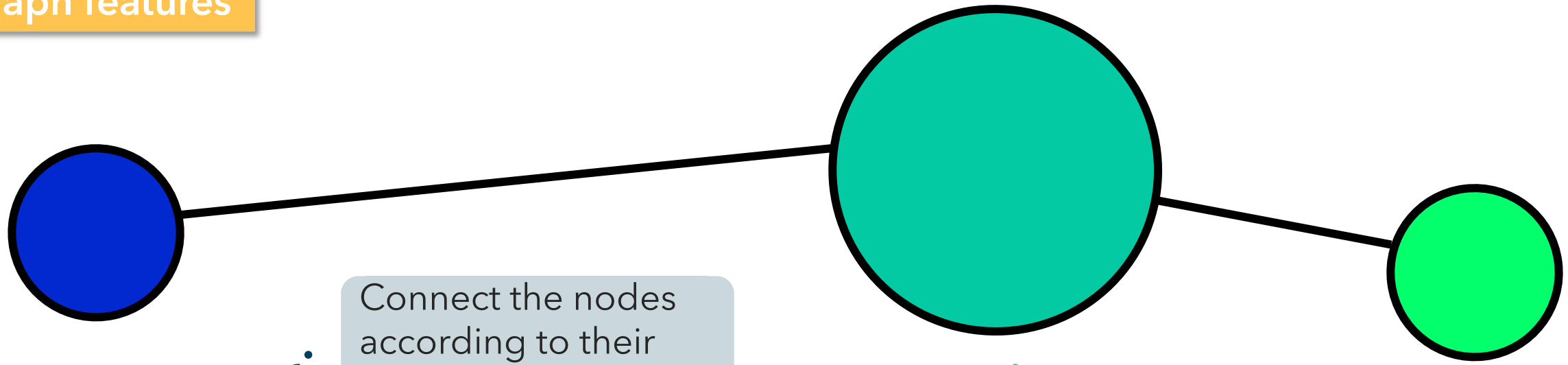
- Spectrum of energy
- Bigger dataset
- 3D reconstruction

4 Vertex reconstruction 3D.

a) Architecture

b) Results

Graph features



Edge.

Connect the nodes according to their proximity in **Charge, time, spatial coordinates**.

Node : **Hit PMT**

Features.

- Charge (Q)
- Hit time (t)
- Position (x,y,z)

Output.

Vertex coordinate x (3D)

!!!!!

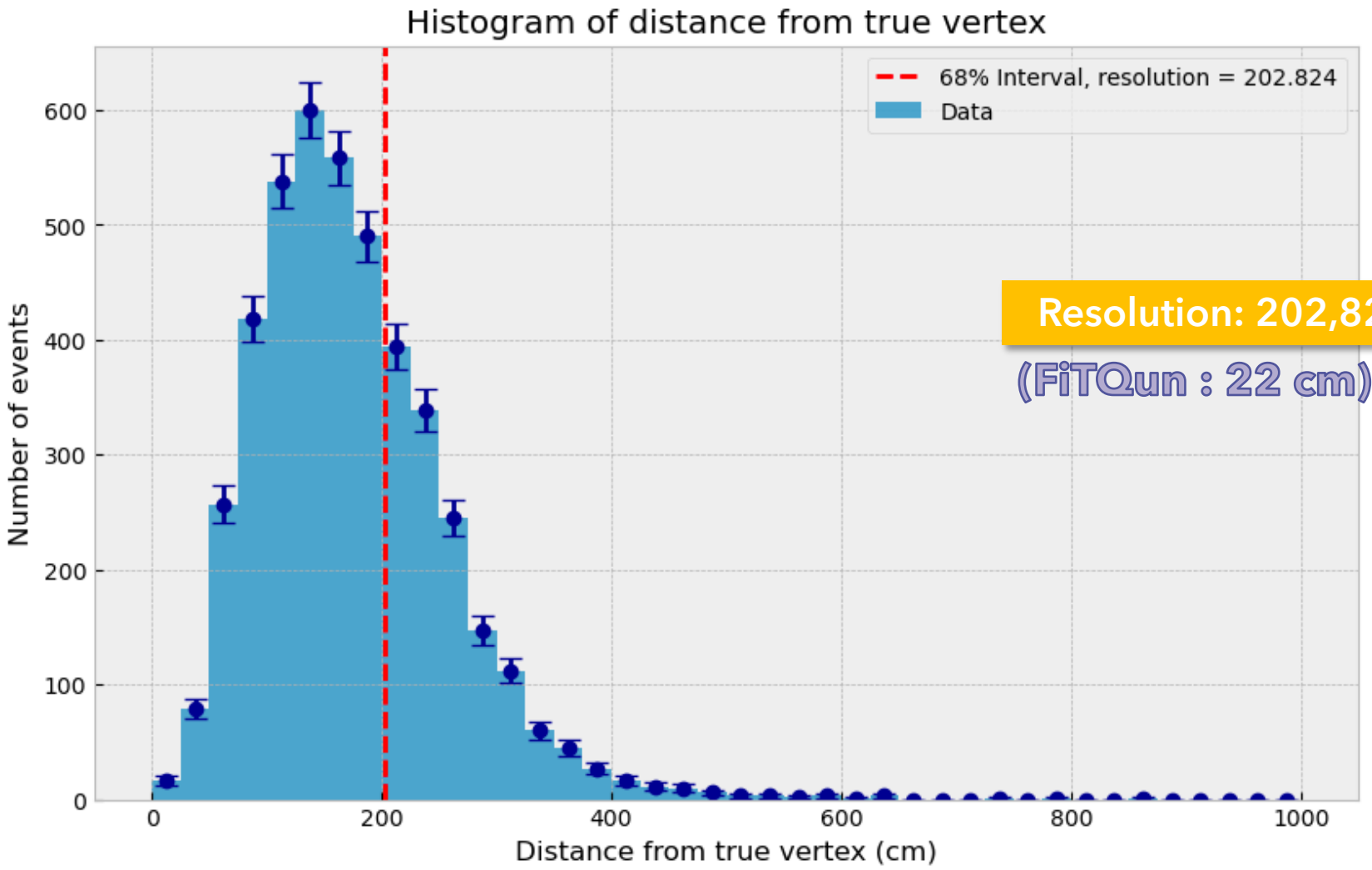
4 Vertex reconstruction 3D.

a) Architecture

b) Results

Electron

0.07 s per event (GNN)
1min30 (fiTQun)



Resolution: 202,82 cm

(FiTQun : 22 cm)

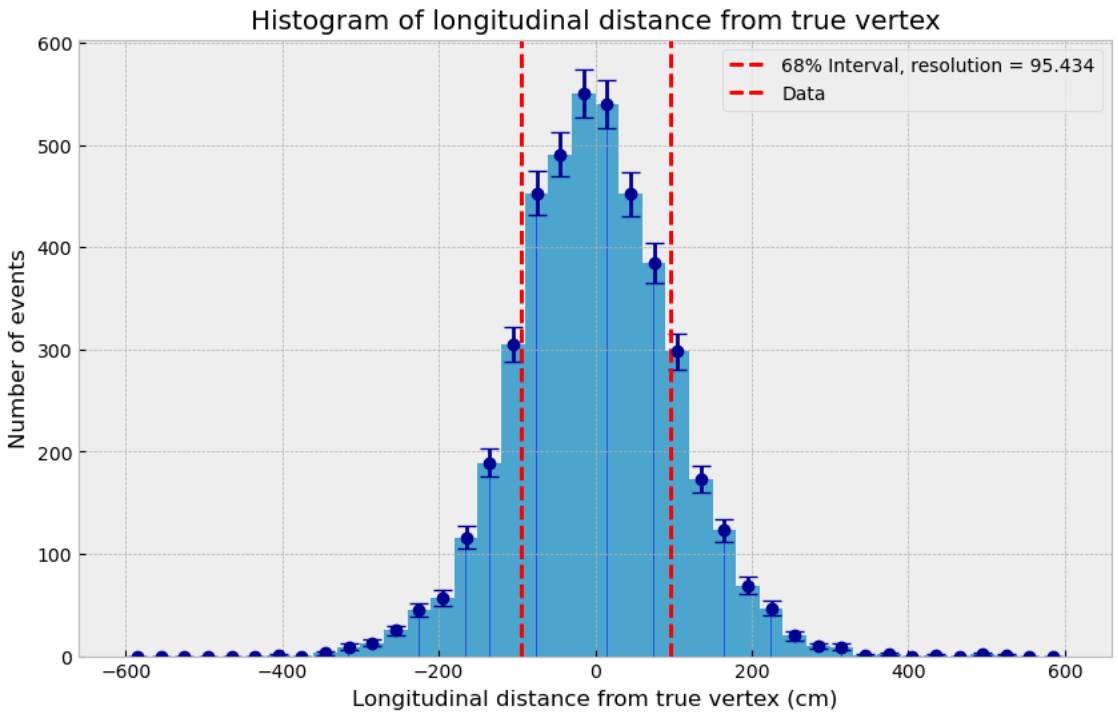
4 Vertex reconstruction 3D.

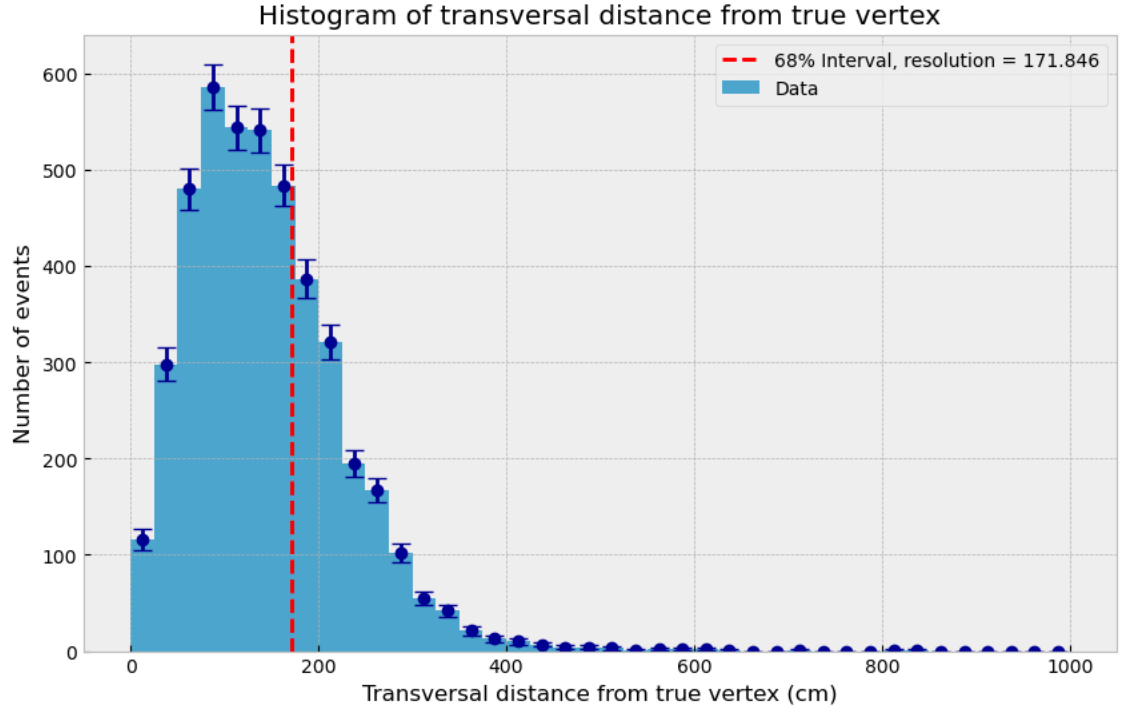
a) Architecture

b) Results

Electron

0.07 s per event (GNN)
1min30 (fiTQun)





Longitudinal resolution : 95,43 cm

Transversal resolution : 171,8 cm

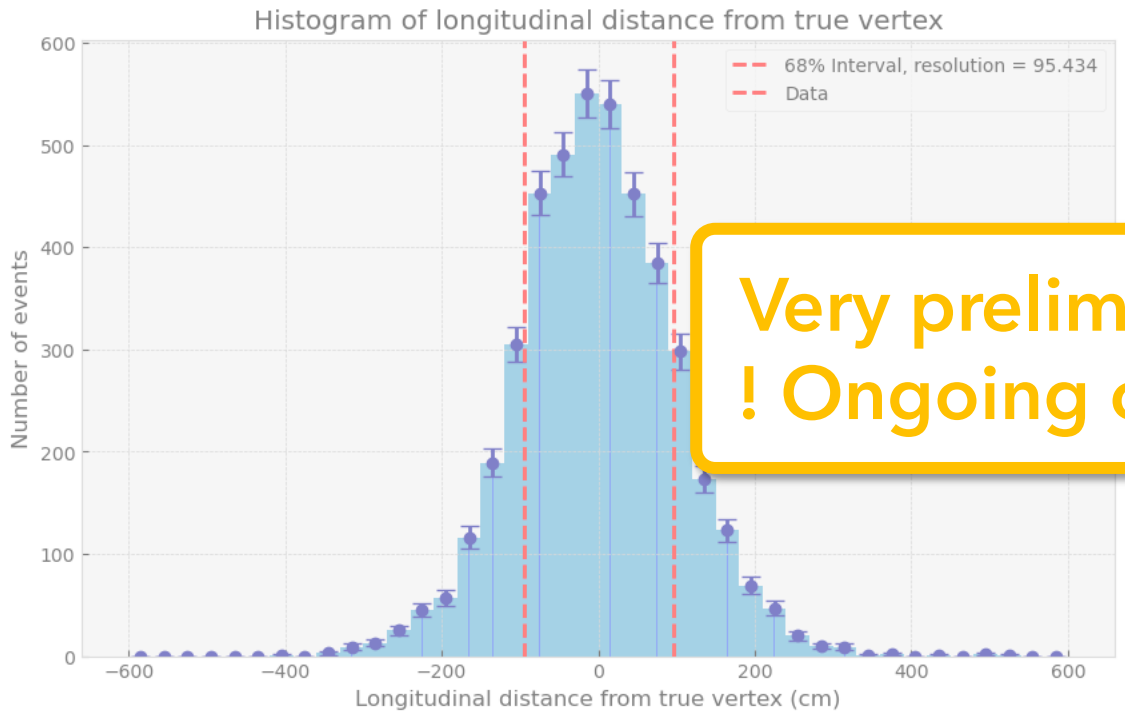
4 Vertex reconstruction 3D.

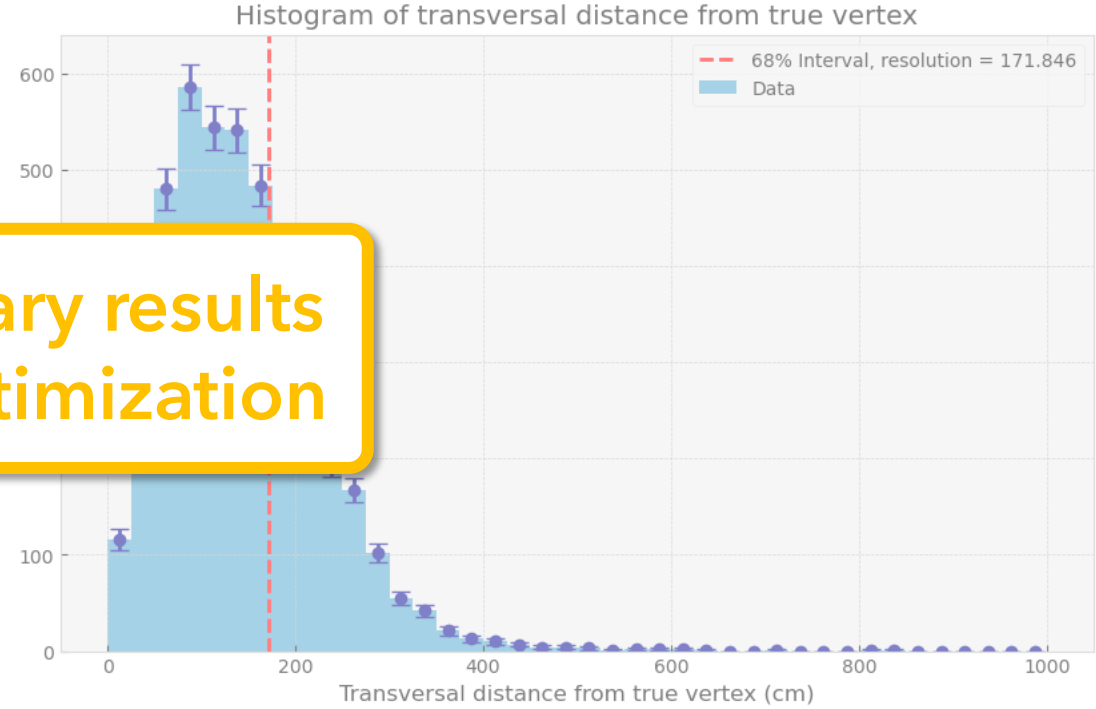
a) Architecture

b) Results

Electron

0.07 s per event (GNN)
1min30 (fiTQun)





Very preliminary results
! Ongoing optimization

Longitudinal resolution :
95,43 cm

Transversal resolution :
171,8 cm

Conclusion.

Conclusion.

	GNN	FitQun
e/mu	**99% electron efficiency** at 5% muon bg acceptance,	**99% electron efficiency** at 5% muon bg acceptance,
e/pi0	**99% electron efficiency at 25% pi0 bg acceptance [Spectrum of energy]**	**94% electron efficiency** at 25% pi0 bg acceptance
e/gamma	**58% efficiency** at 50% bg acceptance... **[Fixed energy]**	None
Energy reconstruction for e & mu (1D)	**Electron : 5.5% resolution** at 500 MeV, **energy bias at ~1.5%** **Muon : 2.5% resolution** at 500 MeV, **energy bias at ~0.5%**	**Electron : 7% resolution** at 500 MeV, **energy bias at ~0%** **Muon : 6% resolution** at 500 MeV, **energy bias at ~0%**
Vertex reconstruction for e & mu (1D)	**Electron :** 203 cm **Muon:** to do	**Electron :** 22 cm **Muon :** 28 cm

Conclusion.

	GNN	FitQun
e/mu	99% electron efficiency at 5% muon bg acceptance,	99% electron efficiency at 5% muon bg acceptance,
e/pi0	99% electron efficiency at 25% pi0 bg acceptance [Spectrum of energy]	94% electron efficiency at 25% pi0 bg acceptance
e/gamma	58% efficiency at 50% bg acceptance... [Fixed energy]	None
Energy reconstruction for e & mu (1D)	Electron : 5.5% resolution at 500 MeV, energy bias at ~1.5% Muon : 2.5% resolution at 500 MeV, energy bias at ~0.5%	Electron : 7% resolution at 500 MeV, energy bias at ~0% Muon : 6% resolution at 500 MeV, energy bias at ~0%
Vertex reconstruction for e & mu (1D)	Electron : 203 cm Muon: to do	Electron : 22 cm Muon : 28 cm

Conclusion.

	GNN	FitQun
e/mu	99% electron efficiency at 5% muon bg acceptance,	99% electron efficiency at 5% muon bg acceptance,
e/pi0	99% electron efficiency at 25% pi0 bg acceptance [Spectrum of energy]	94% electron efficiency at 25% pi0 bg acceptance
e/gamma	58% efficiency at 50% bg acceptance... [Fixed energy]	None
Energy reconstruction for e & mu (1D)	Electron : 5.5% resolution at 500 MeV, energy bias at ~1.5% Muon : 2.5% resolution at 500 MeV, energy bias at ~0.5%	Electron : 7% resolution at 500 MeV, energy bias at ~0% Muon : 6% resolution at 500 MeV, energy bias at ~0%
Vertex reconstruction for e & mu (3D)	Electron : 95,45 cm longitudinal resolution, 171,8 cm transversal resolution, Muon: NaN	Electron : 22 cm Muon : 28 cm

Conclusion.

GRANT: A tool to continue developing. ☺

- **Graph neural network** (Machine learning) based algorithm: introduces an intriguing approach to particle identification and energy and vertex reconstruction.
- It provides **promising and quicker results efficiency (0.1s per event per task),** demonstrating superior performances compared to FiTQun in PID for e/mu, e/pi0, and energy reconstruction
- It is **still under development**, with ongoing work by the LLR (Anna Ershova, Erwan Le Blévec, Christine Quach, Benjamin Quilain)

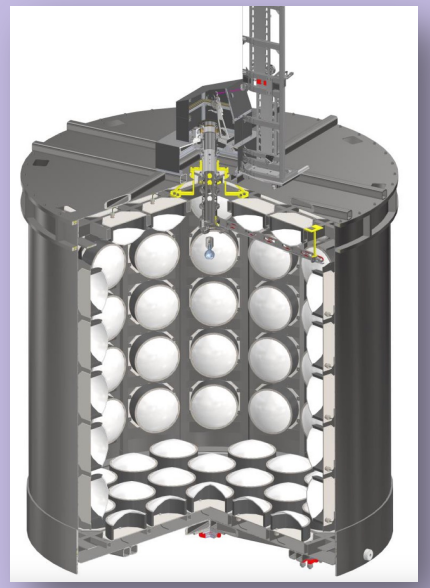
Prospects.

The next steps to come :

GRANT: A tool to continue developing. ☺

- Continuing the effort for **multidimensional reconstruction**
  - Optimizing for 3D vertex reconstruction,
  - Simultaneous **vertex and direction reconstruction**
- Enhancing **e/gamma** separation
- **Ring counting** (to be developed)

- **Test the algorithm performances on WCTE** by the LLR (Anna Ershova)



Bonus.

I did a little drawing of HK hihi :)