Neutrino interactions in ‘Solid’ hydrogen at the DUNE near site

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Outline

- Introduction to the **'Solid' hydrogen** technique in SAND: obtain a sample of neutrino interactions on hydrogen, **devoid** of **nuclear effect** systematics, by **statistical subtraction**

- Preliminary study of **'Solid' hydrogen** flux measurement in the $\bar{\nu}_\mu$ **CCQE channel** (by G. Ingratta, standalone tools)

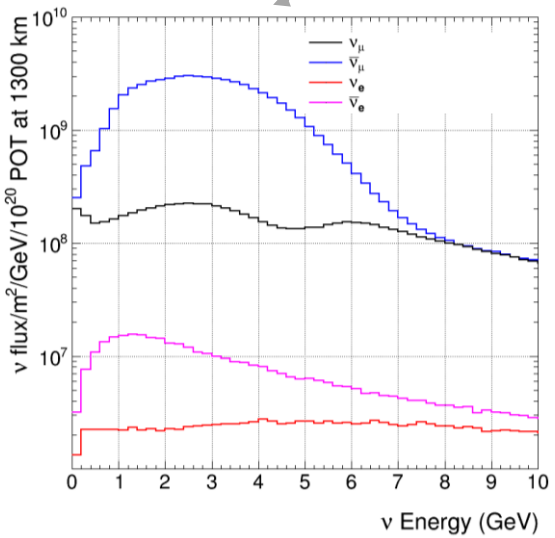
- **New analysis** completely performed inside the sand-reco framework

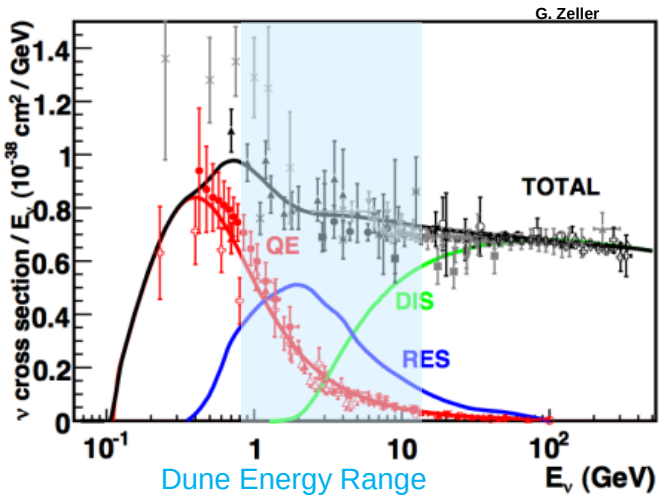
What does DUNE measure?

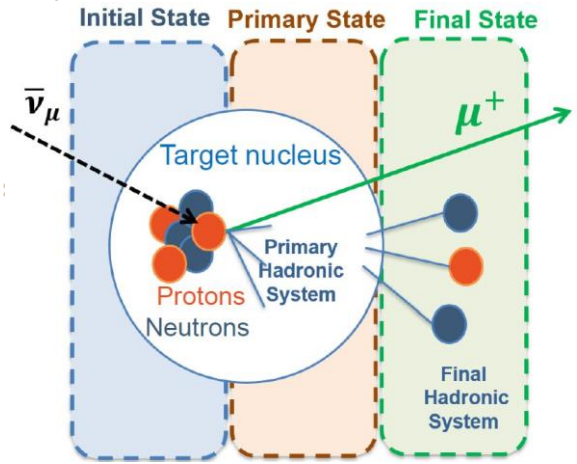
The **number of events** N_x at the Near/Far Detector for a process x is given by:

$$N_x(E_\nu) = \int P_{osc}(E_\nu)\, \Phi_{\overline{\nu}}\, \sigma_x(E_\nu)\, R_{phys}(E_\nu, E_{vis})\, R_{det}(E_{vis}, E_{rec})\, \epsilon_x(E_{rec})\, dE_\nu$$

Neutrino **flux** | **cross section** | **nuclear smearing** | **detector response** | **selection efficiency**







‘Solid’ hydrogen concept

- **Neutrino-hydrogen** interactions are **free from nuclear effects** and thus would be devoid of major source of systematic uncertanties

$$R_{phys}(E_\nu, E_{vis}) \equiv 1$$

- It has been proposed that by using a neutrino detector that **alternates dedicated targets** of graphite (C) and polypropylene (C_3H_6), a sample of interactions on hydrogen can be obtained by **statistical subtraction** [*H. Duyang et al. arXiv.1809.08752*]

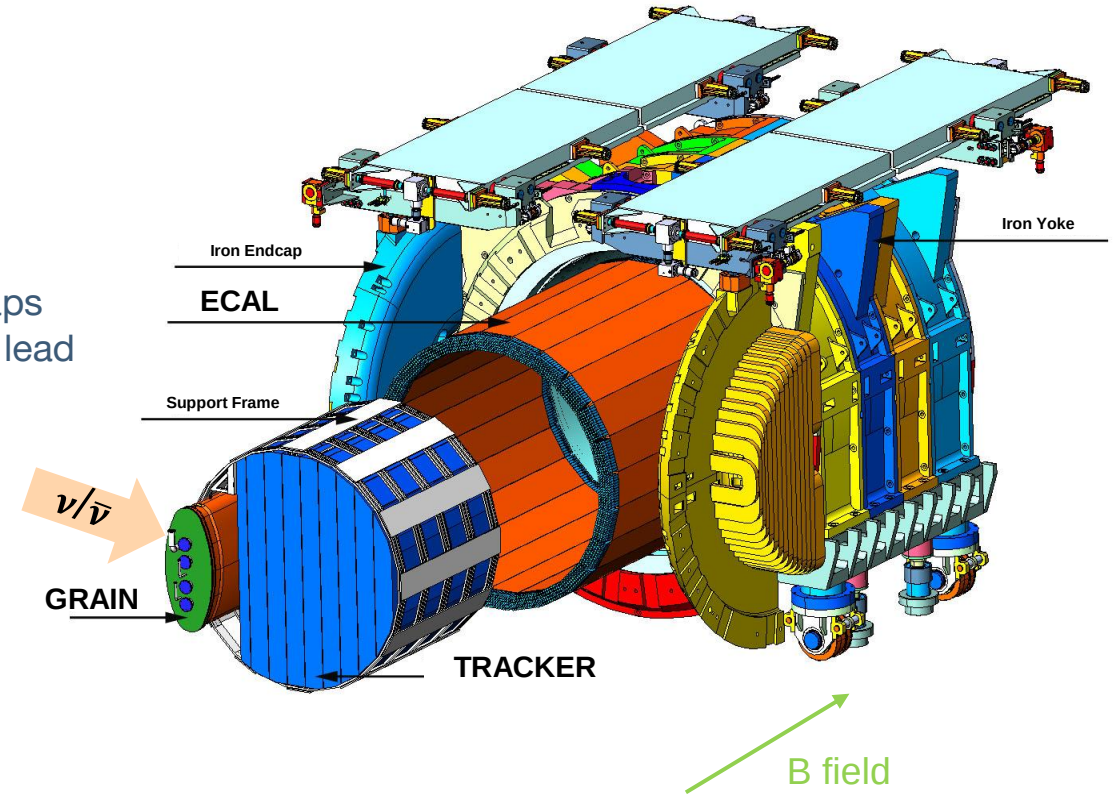
- Selecting for a channel on hydrogen for which the cross section is know, it should be possible to produce a **flux measurement unaffected by nuclear effect systematics**

The SAND detector tracker has been specifically designed to take advantage of this technique

The SAND (System for on-Axis Neutrino Detection)

Design:

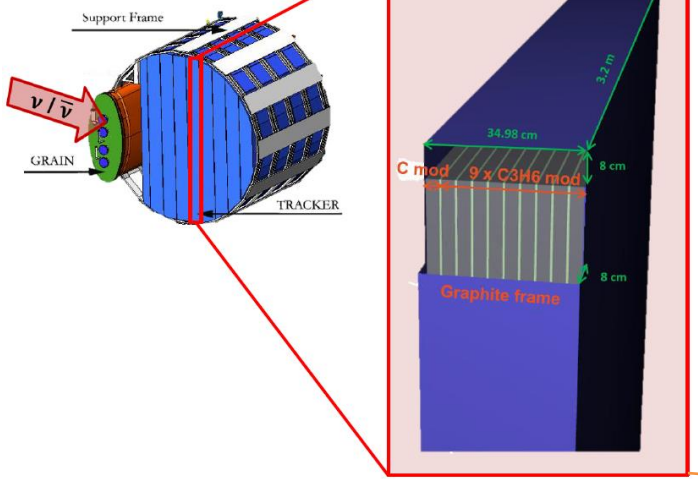
- Solenoidal cryogenic magnet:
  - Yoke of 475 t
  - B field of 0.6 T
- Electromagnetic Calorimeter:
  - 24 barrels modules and 32 end-caps modules of scintillating fibers and lead reused from KLOE
- Tracker:
  - Modular and low density of about 5 t mass with overall 1 radiation length
- GRAIN (GRanular Argon for Interactions of Neutrinos):
  - 1 t liquid argon active target



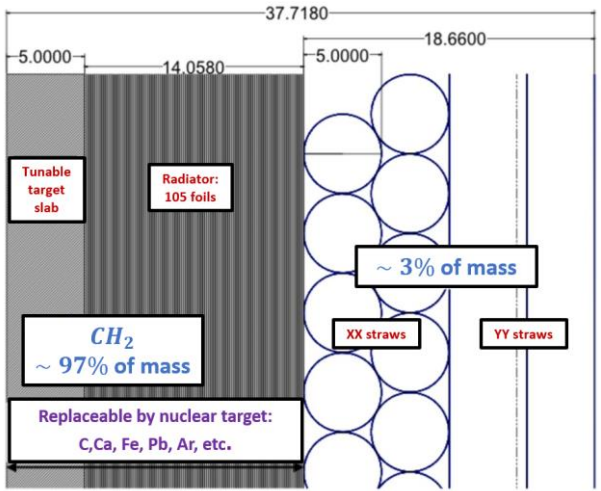
The SAND tracker - Straw Tube Design

Straw Tube Tracker (reference choice) **:**

- composed by a series of **passive target slabs**, and **active straw tube layers**
- 1 graphite target (pure C) for every 9 plastic (C_3H_6) targets
- Overall target mass: **4.7 t** of plastic and **0.7 t** graphite



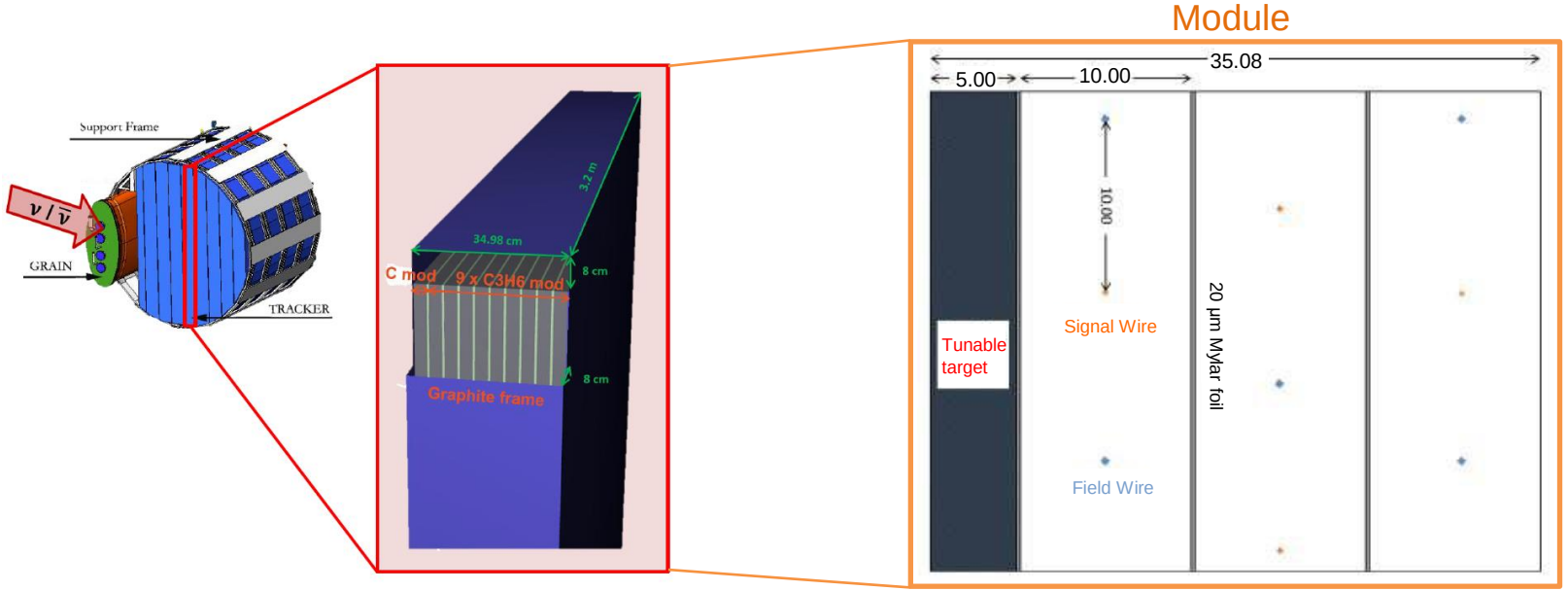
Module



The SAND tracker - Drift Chamber Design

Drift Chamber Tracker (alternative design):

- composed by a series of **passive target slabs**, and **multiwire drift chambers**
- 1 graphite target (pure C) for every 9 plastic (C_3H_6) targets
- Overall target mass: **4.7 t** of plastic and **0.7 t** graphite



‘Solid’ hydrogen study: $\bar{\nu}_\mu + H \rightarrow \mu^+ + n$

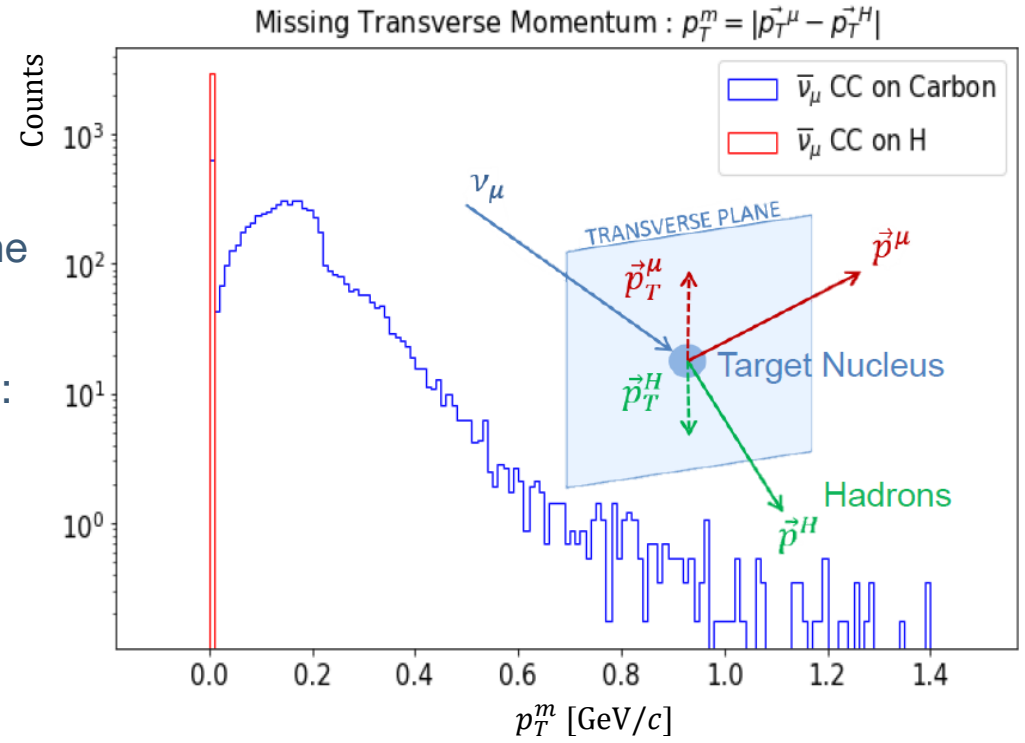
- This is the **simplest reaction** in DUNE energy range for which we have a theoretical parametrization of the cross-section
- ν interactions on H are **perfectly balanced** on a plane transverse to the neutrino direction
- Once μ^+ quantities are reconstructed:

$$E_{\bar{\nu}}^{\text{reco}} = \frac{M_n^2 - m_\mu^2 - M_p^2 + 2M_p E_\mu^{reco}}{2\left(M_p - E_\mu^{reco} + p_\mu^{reco}\cos\theta_\mu^{reco}\right)}$$

$$E_n^{\text{expected}} = E_{\bar{\nu}}^{reco} + M_p - E_\mu^{reco}$$

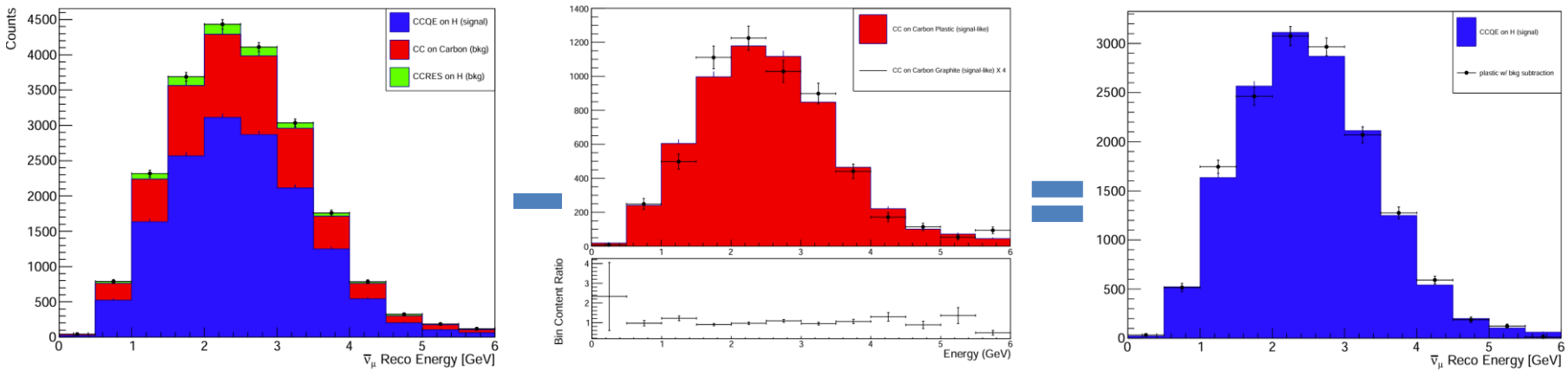
- Neutron will be tagged in ECAL from its time of flight to the calorimeter

- Thesis work by G. Ingratta ‘Study of Neutrino interactions on Hydrogen in the SAND detector of DUNE’



Statistical Subtraction

- **Solid Hydrogen technique**: the **reconstructed signal rate** as function of the **neutrino reconstructed energy**, is obtained from a **statical subtraction** of the measured background giving the (nearly) same detector acceptances



C_3H_6 − C = ‘Solid’ hydrogen

Unfolding of the event rate on Hydrogen

- The **reconstructed signal rate** differs from the **true rate** by the convoluted **effect of the detector** resolution and signal selection efficiency

$$x_{reco} \sim \Phi \otimes \sigma \otimes \epsilon \otimes R$$

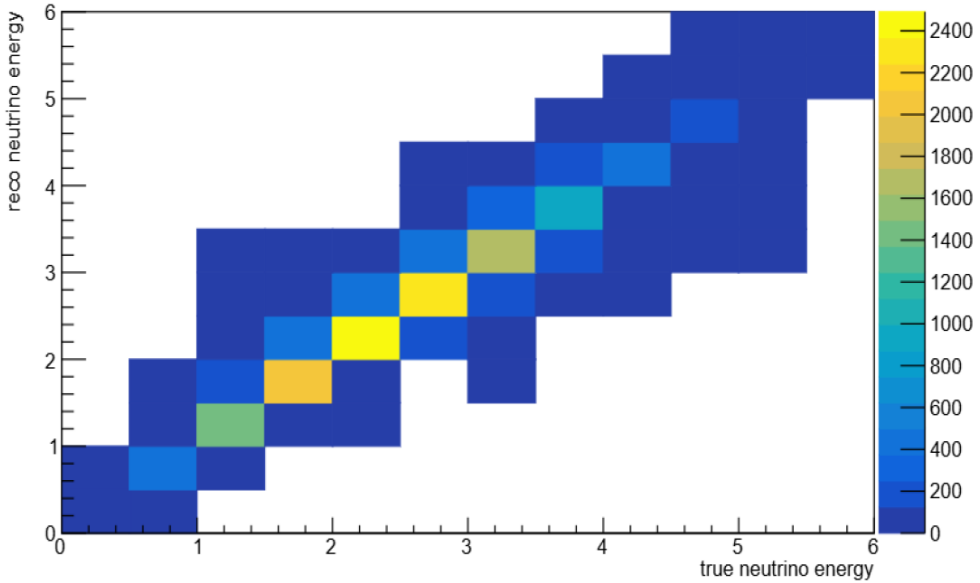
flux · cross section · selection efficiency · detector response

- The unfolding procedure **corrects the reconstructed signal** rate for the effect of the detector response and efficiencies

$$x_{unfolded} \sim R\, x_{reco} \sim \Phi \otimes \sigma$$

Response matrix

Response matrix (true CCQE on H selected)



[from G. Ingratta]

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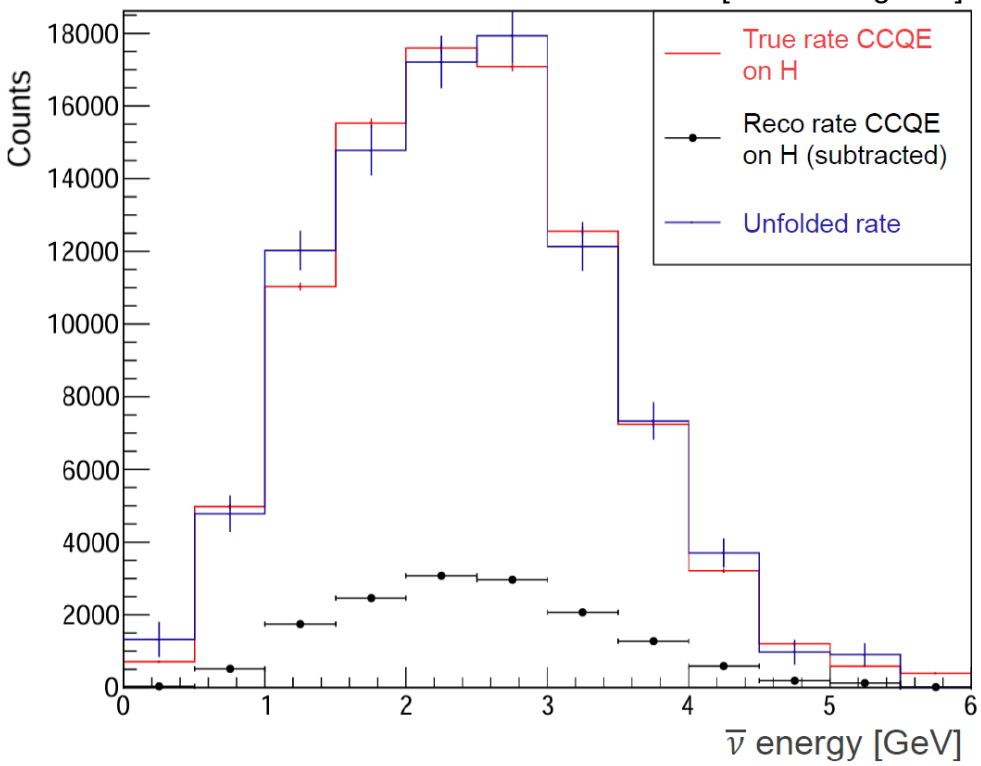
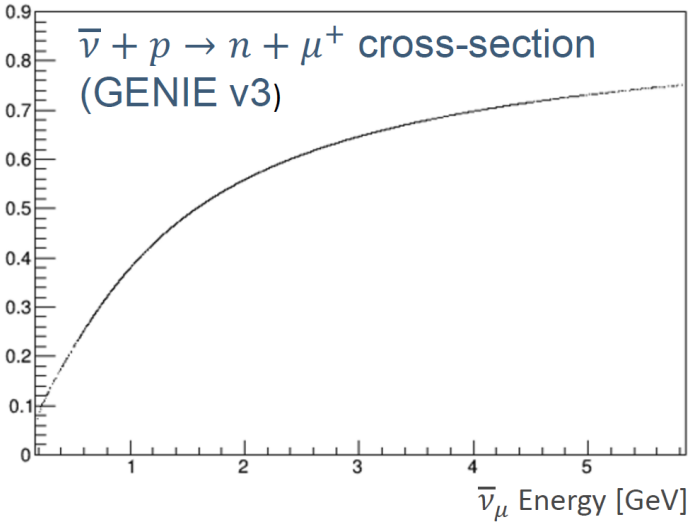


Absolute $\bar{\nu}$ flux

- The **absolute flux** is obtained by dividing the unfolded signal rate by the nominal value of the ν on H cross section



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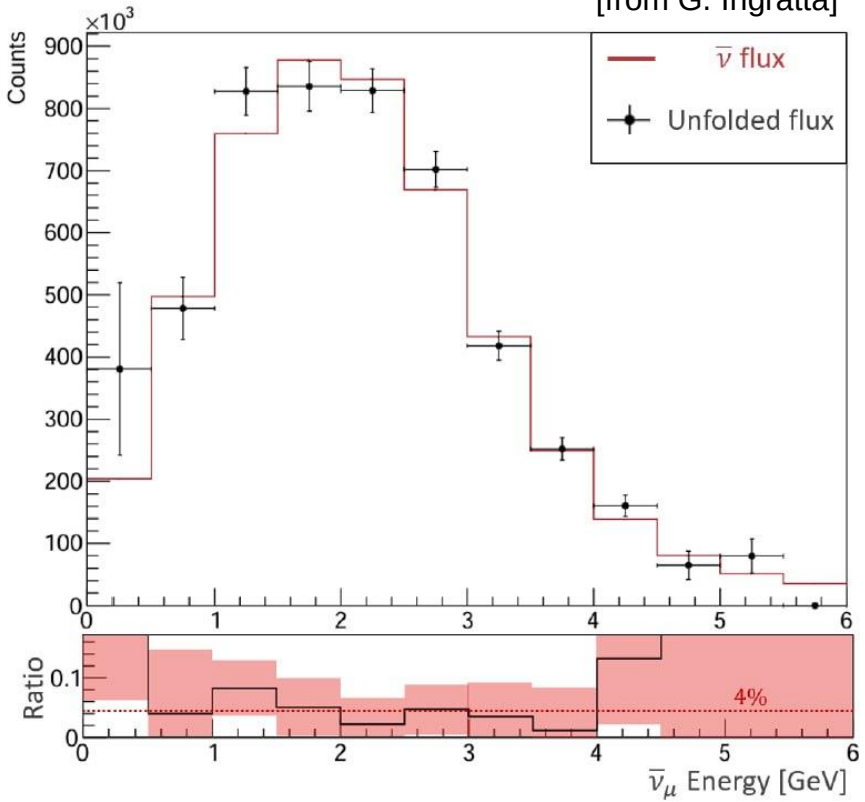


4% systematic uncertanties of the subtraction technique on the **absolute flux**

Solid Hydrogen study

Previous analysis:

- Thesis work by G. Ingratta: ‘Study of Neutrino interactions on Hydrogen in the SAND detector of DUNE’
  presentation: https://indico.fnal.gov/event/62284/timetable/?view=standard
- It is perfomed using the **drift chamber** configuration for the tracker and an **independent reconstruction** with respect to the sand-reco one

Current analysis:

- It is perfomed using **the straw tube** configuration for the tracker and the **official reconstruction** of sand-reco that exploit the Kalman filter

New Analysis Workflow

Production

Event Generation (GENIE) + Propagation in the detector (Edep-sim)

Digitization

ECAL: fired cells
Tracker: fired wires
(Sandreco)

Recostruction

ECAL: Reconstruct hit
Tracker: Reconstruct μ^+
(Sandreco)

ANALYSIS

Get quantities

E_n , $\vec{p}_n$ $\quad E_{ECAL}^{hit}$

E_μ , $\vec{p}_\mu$ $\quad x_{ECAL}^{hit}$

E_ν , $\vec{p}_\nu$ $\quad t_{ECAL}^{hit}$

Organized in a tree.root

Event selection

To **identify signal** events

CCQE on H

$\bar{\nu}_\mu + H \rightarrow \mu^+ + n$

Statistical Subtraction

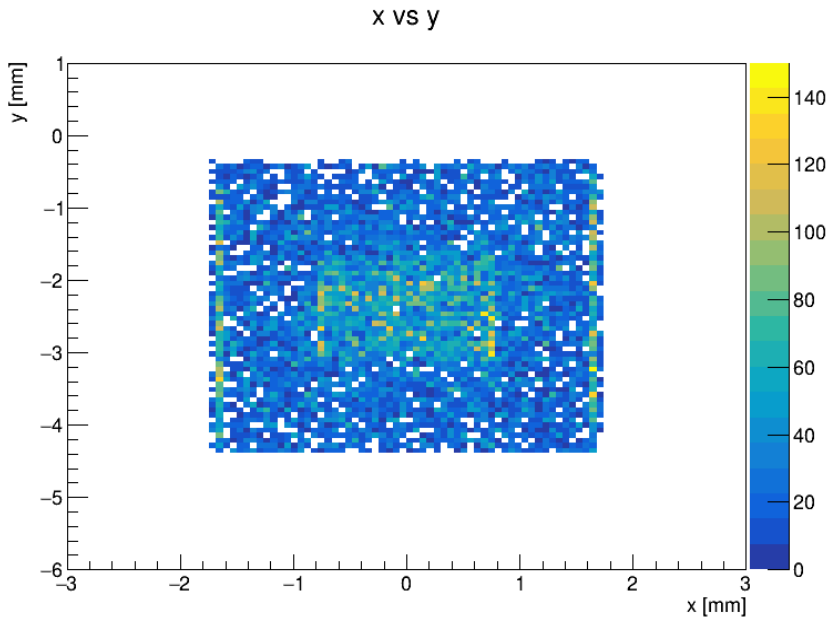
To obtain **reconstructed signal rate** as function of neutrino reconstructed energy

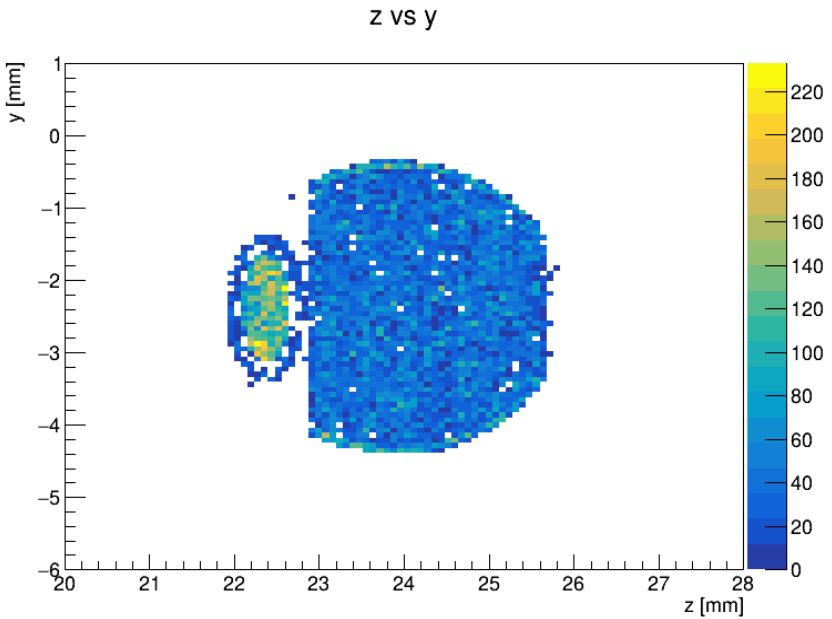
Unfolding

To obtain the **true rate** from the reconstructed signal convoluted with detector effects

New Productions

- Events are produced using: GENIE version 3.06.00, last available SAND geometry (SAND_opt3_STT1) and most complete Dk2nu flux files
- CC antineutrino single events in the **STT** and **GRAIN tracker**

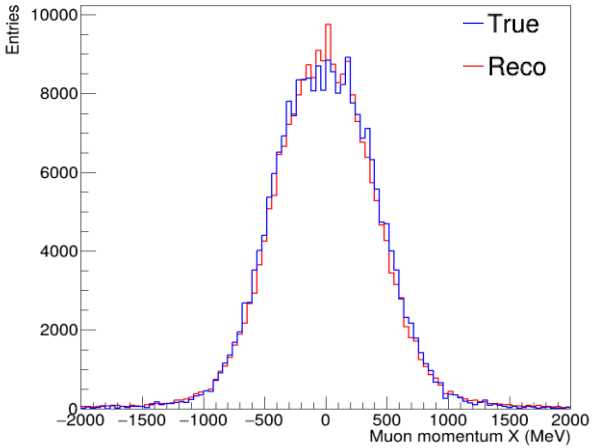




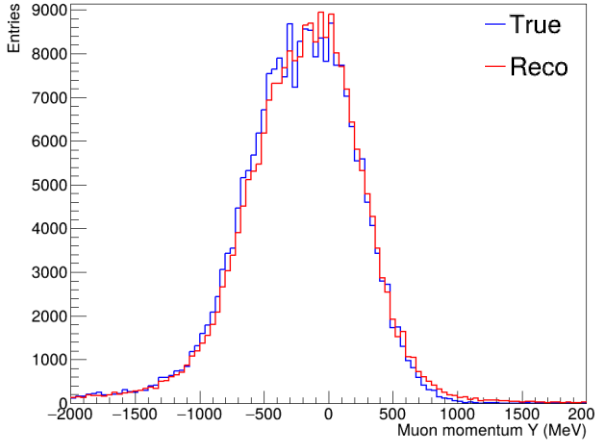
Event selection - Muon momentum

- I select the events with a **successful reconstruction** and with **1 associated muon** track

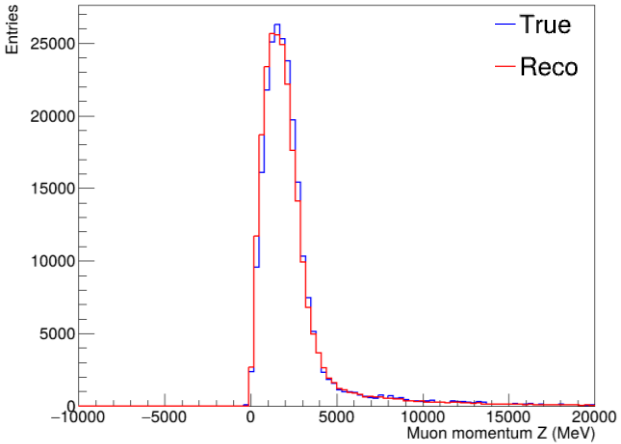
Muon momentum along x



Muon momentum along y



Muon momentum along z



[this analysis, preliminary]

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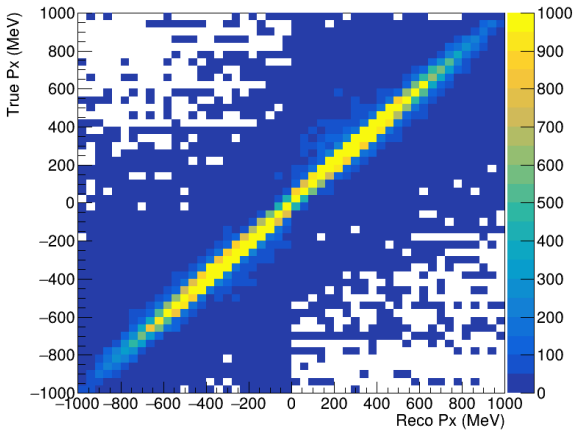
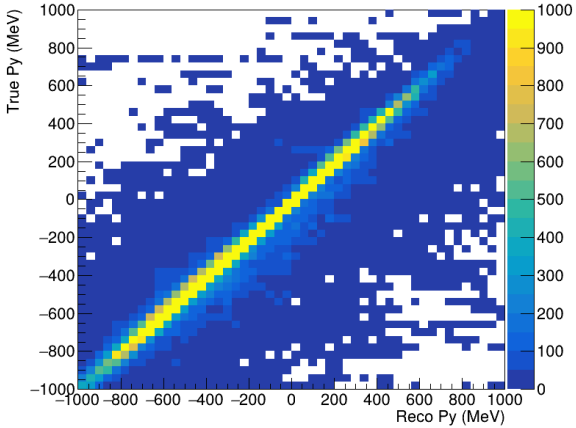
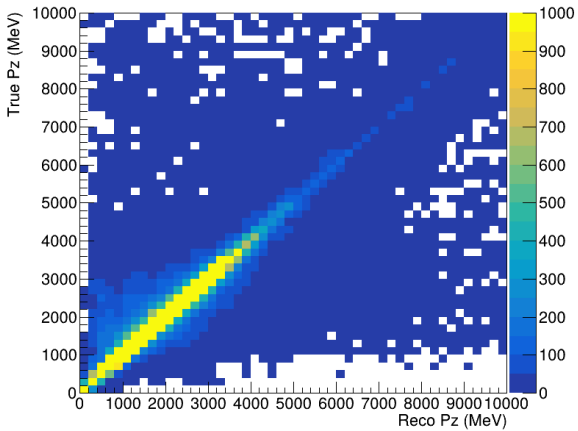
Muon momentum along x



Muon momentum along y



Muon momentum along z



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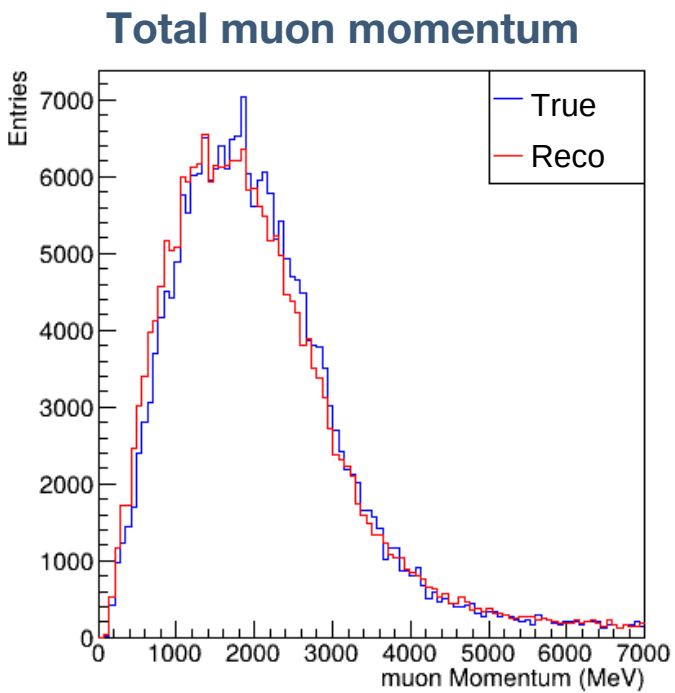
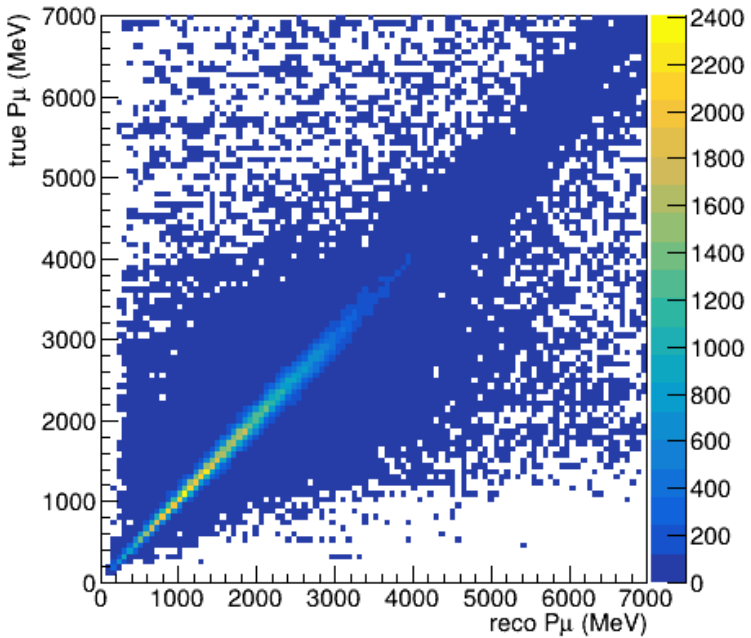
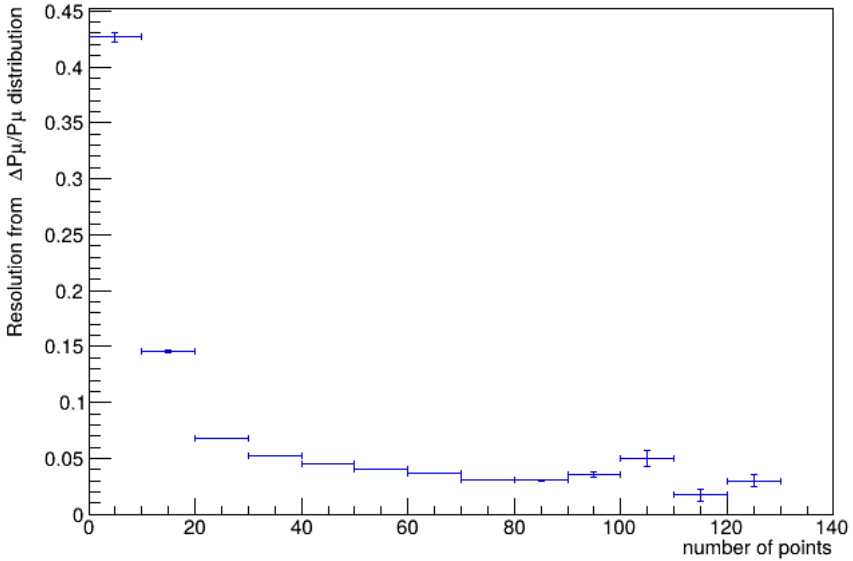


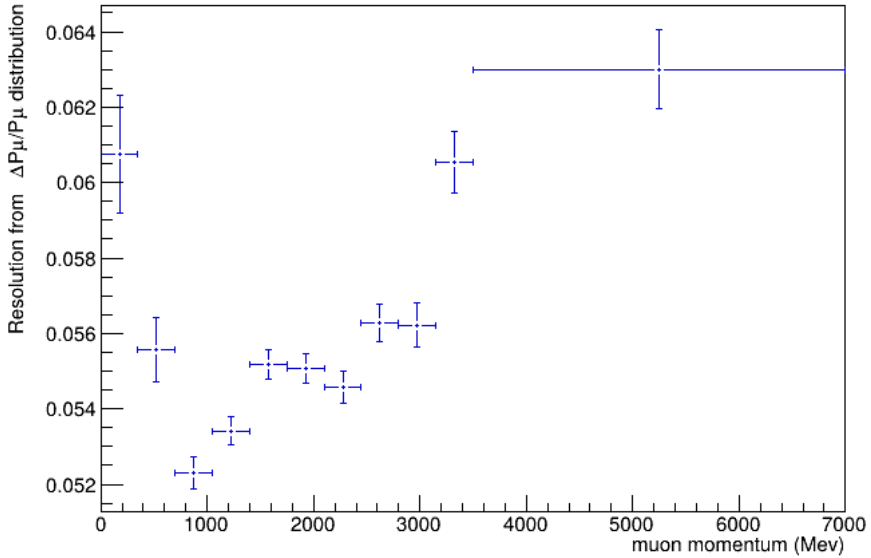


Event selection – Resolution

- **Muon tracks** and their associated **number of points** are considered to obtain the resolution

[this analysis, preliminary]

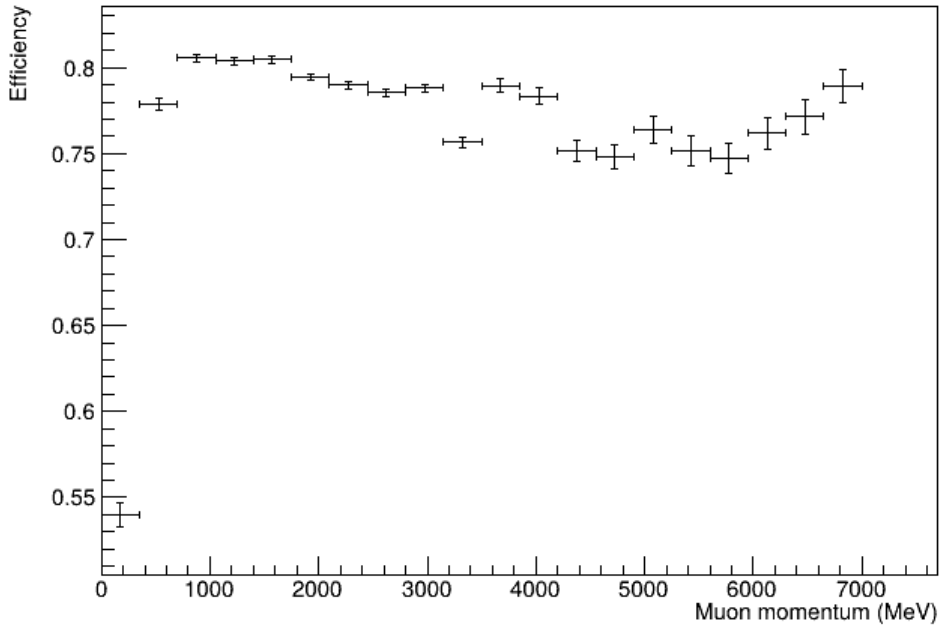




The **resolution** obtained considering the width of the distribution of the muon momentum residulas

Event selection – Efficiency

- **Muon tracks** and their associated **number of points** are considered to obtain the efficiency



[this analysis, preliminary]

The **efficiency** is obtained considering the ratio between the numer of events with an associated muon track and the number of events with a muon

Summary and Outlooks

Summary:

- Preliminary study of **'Solid' hydrogen** technique for the flux measurement in the $\bar{\nu}_\mu$ **CCQE channel** has been presented
- New analysis within sand-reco framework, latest production tools and configuration files is in progress

Next steps for the new analysis:

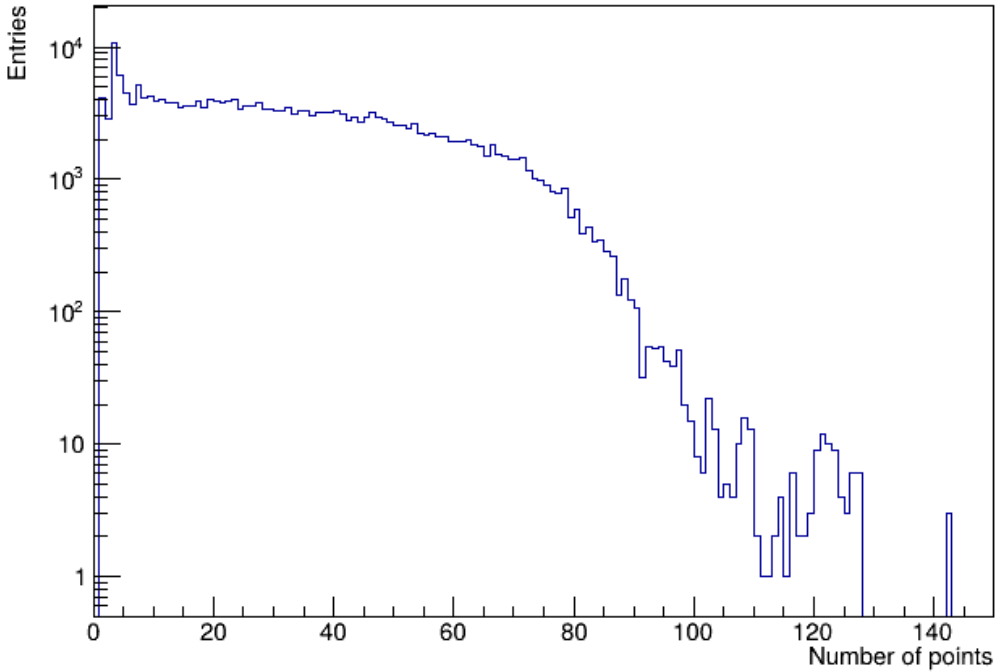
- Consider neutron quantities to fully reconstruct the kinematics of the event and selection cut
- Perfom statistical subtraction and unfoldig to obtain the systematc uncertanties on the antineutrino flux

Thank you!

backup

Event selection – numer of points in the muon track

- Number of points of muon tracks



Event selection – numer of points in the muon track

- $\Delta P_\mu / P_\mu$ distributions for different numbers of points in the muon tracks, from 1 to 9 points