BEAM MONITORING FOR THE DUNE EXPERIMENT WITH THE SAND DETECTOR

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NEUTRINO OSCILLATIONS

questo è falso. Il mixing dei neutrini non implica che siano massivi. Ti deve essere chiaro. Ne parliamo se non lo è

and not degenerate mass eigenstates

- Neutrino oscillation: in flight flavour change due to neutrino mixing
- Neutrino mixing ~~implies non-zero neutrino rest mass:~~ three flavour eigenstates are connected to 3 mass eigenstates by unitary mixing matrix U

(nu_alpha)

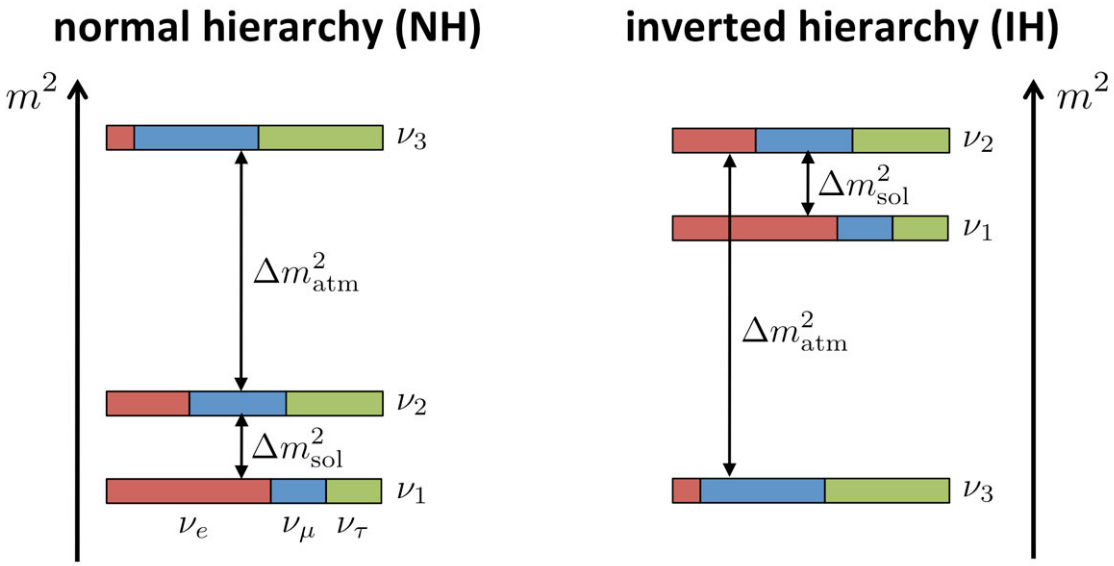
(nu_i) così fai riferimento alle formule

- ~~Non-zero~~ neutrino masses ~~are not allowed by the Standard Model~~

$$|\nu_\alpha\rangle = \sum_i U_{\alpha i}\,|\nu_i\rangle$$

$$|\nu_i\rangle = \sum_\alpha U^*_{\alpha i}\,|\nu_\alpha\rangle$$

io metterei: No right-handed neutrino in SM -> impossible to construct a neutrino Dirac mass term



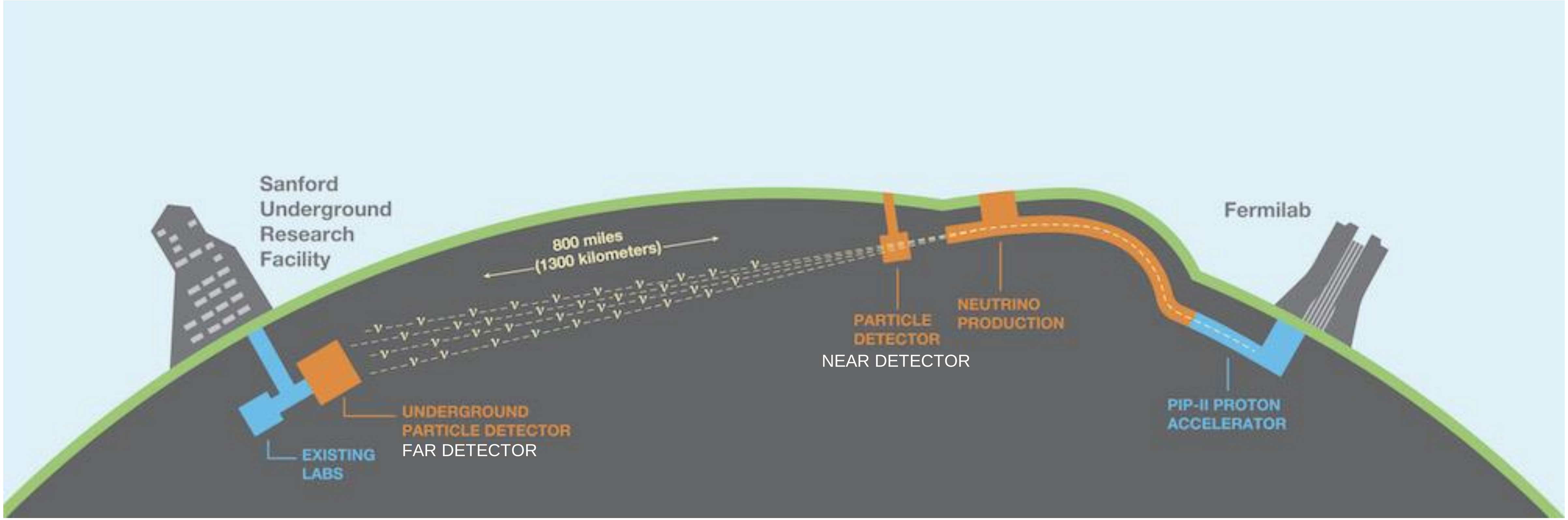
Existence of CP symmetry violation in neutrino sector (delta_CP)

Still major unknowns:

- CP violation: δ_{CP}
- Neutrino mass ordering: $sign(\Delta m^2_{23})$

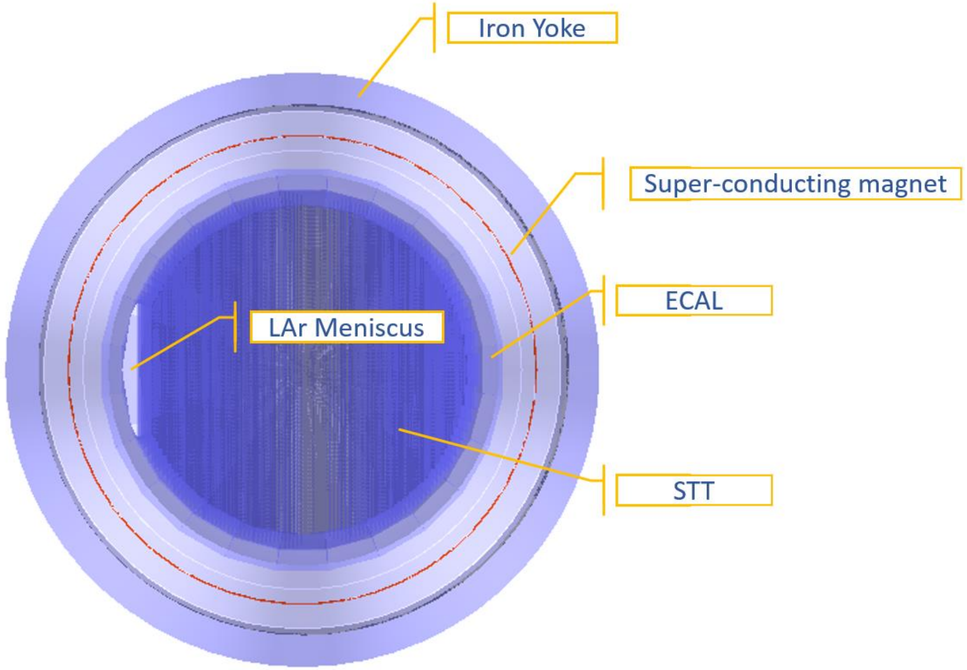
di solito il primo numero è maggiore del secondo: dm^2_31 oppure dm^2_32

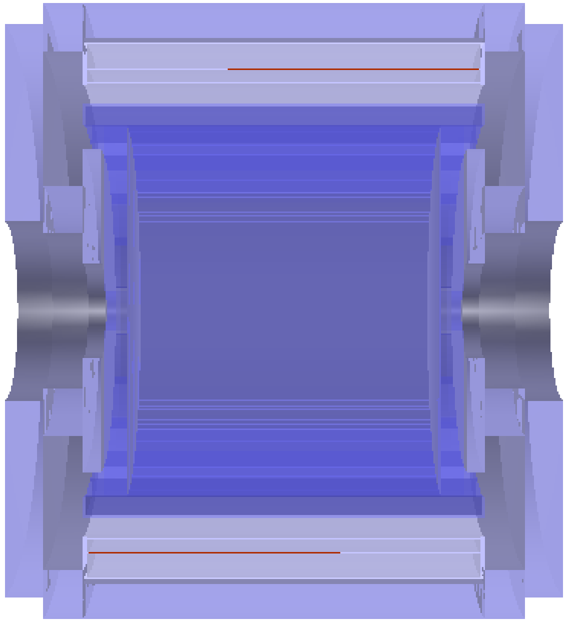
DUNE: DEEP UNDERGROUND NEUTRINO EXPERIMENT



- DUNE will be a long baseline accelerator neutrino experiment capable of measuring both CP violation and mass ordering

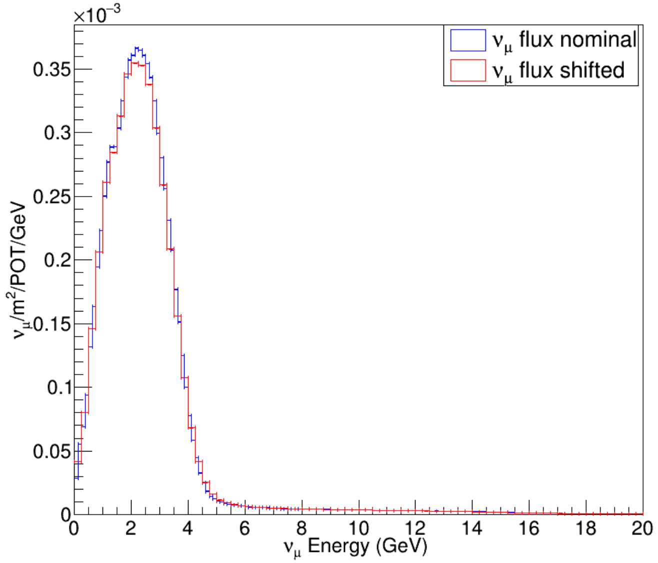
SAND: SYSTEM FOR ON-AXIS NEUTRINO DETECTION





$$\frac{\frac{dN^{far}_{\nu_e}}{dE_{rec}}}{\frac{dN^{near}_{\nu_\mu}}{dE_{rec}}} = \frac{\int P_{\nu_\mu\to\nu_e}(E_\nu)\times \phi^{near}_{\nu_\mu}(E_\nu)\times F_{far/near}(E_\nu)\times \sigma^{Ar}_{\nu_e}(E_\nu)\times D^{far}_{\nu_e}(E_\nu,E_{rec})dE_\nu}{\int \phi^{near}_{\nu_\mu}(E_\nu)\times\sigma^{Ar}_{\nu_\mu}(E_\nu)\times D^{near}_{\nu_\mu}(E_\nu,E_{rec})dE_\nu}$$

BEAM MONITORING

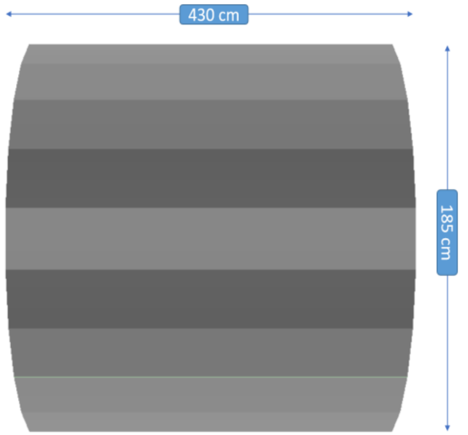


- My thesis studied the beam monitoring capabilities of the SAND detector, via the comparison od the distribution of an observable sensitive to beam anomalies
- **Observable:** reconstructed muon momentum
- **~~First~~ systematic:** horn-1 0.5 mm Y shift
- **Test statistic:** χ^2

We used interaction on the front ....

under study

on a temporal week basis (o qualcosa del genere)

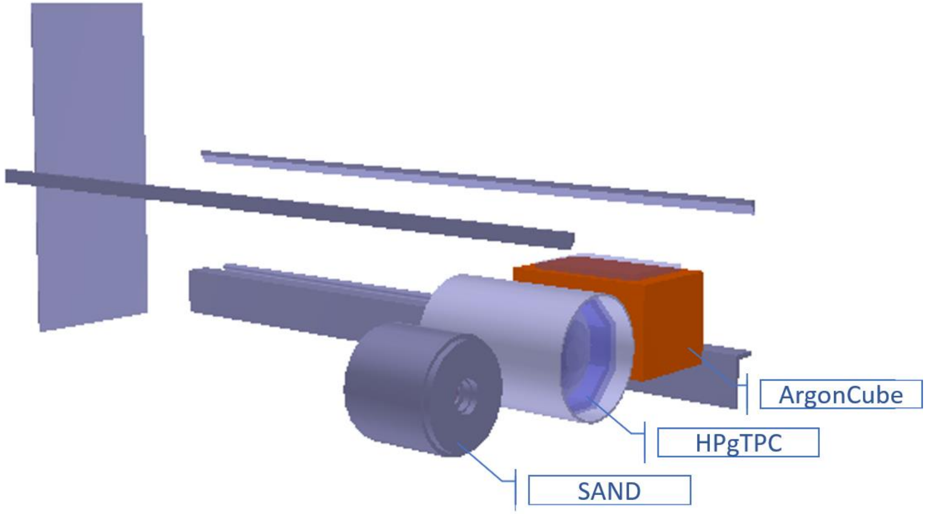


$$N_{week} = r_{CC} \times f_{CC}^{-1} \times m_{mod} \times n_{mod} \simeq 1.75 \times 10^6$$

One week's worth of statistics on front calorimeter modules

upstream

GEOMETRY AND INTERACTION SIMULATION

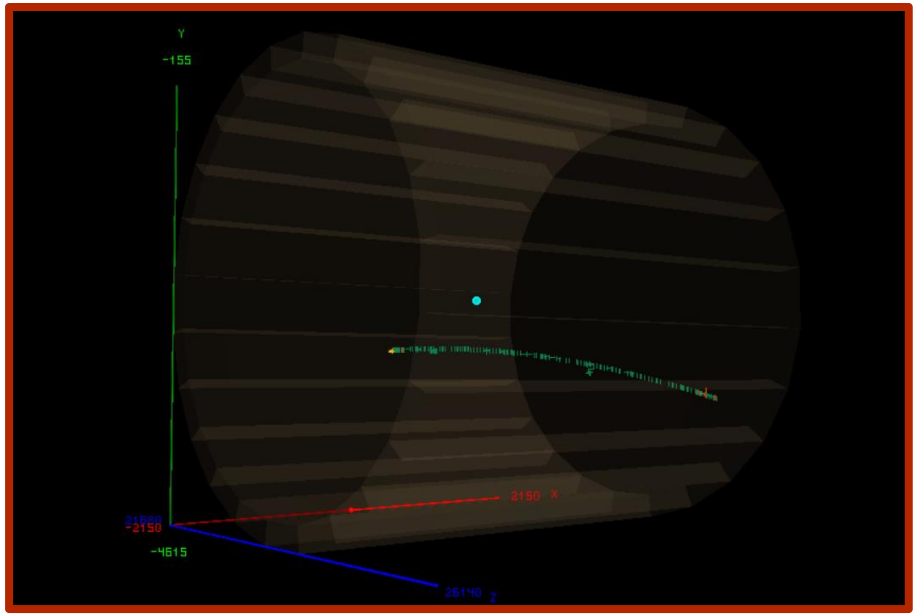


- **Geometry:** *dunendggd* (ND-group specific software based on Geant4)

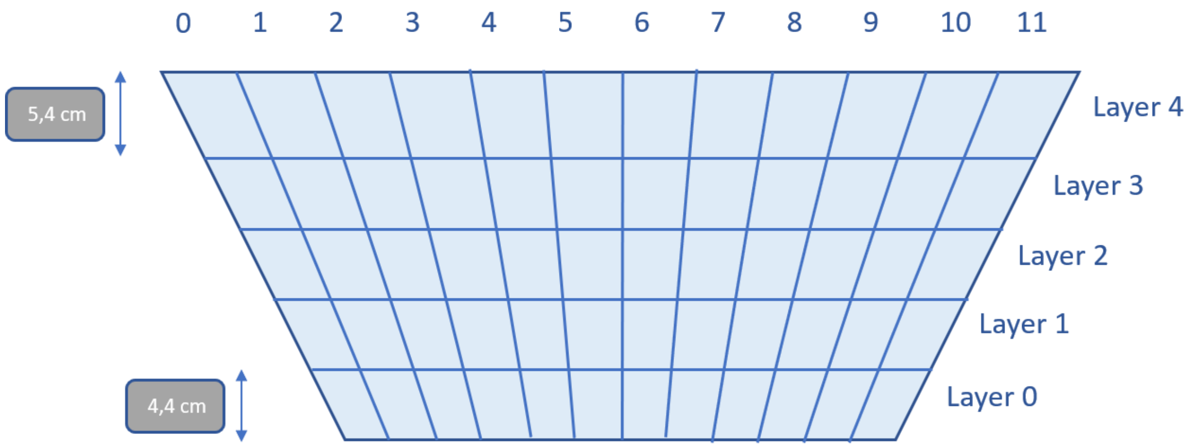
(*ND hall geometry simulation*)

- **Neutrino interactions:** *GENIE* (neutrino Monte Carlo generator)
- **Particle propagation:** *edep-sim*

(*Propagation of a CC event on the front ECAL barrel modules*)



ECAL: DIGITIZATION AND RECONSTRUCTION



DIGITIZATION

- We assign the hits to the calorimeter cells and evaluate, based on time and energy deposition:

$$N_{p.e.} = 25 \times E_A \times dE$$

$$t_{p.e.} = t_{part} + t_{decay} + d \cdot u_{ph} + Gauss(1\text{ns})$$

RECONSTRUCTION

- Cells hit by particles that were the primary in at least one cell are grouped into clusters.
- For each cell in the cluster we evaluate position (y and z are just the centre point of the cell) and time:

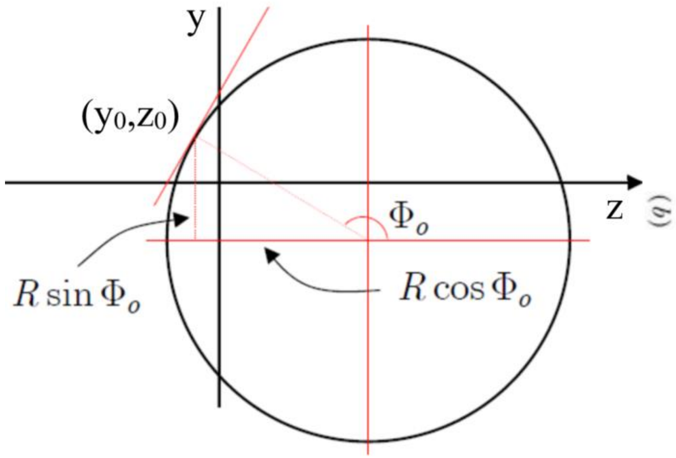
$$x = \frac{t_{TDC1} - t_{TDC2}}{2u_{p.e.}} + x_{cell}; \qquad t = (t_{TDC1} + t_{TDC2} - u_{p.e.} \times L);$$

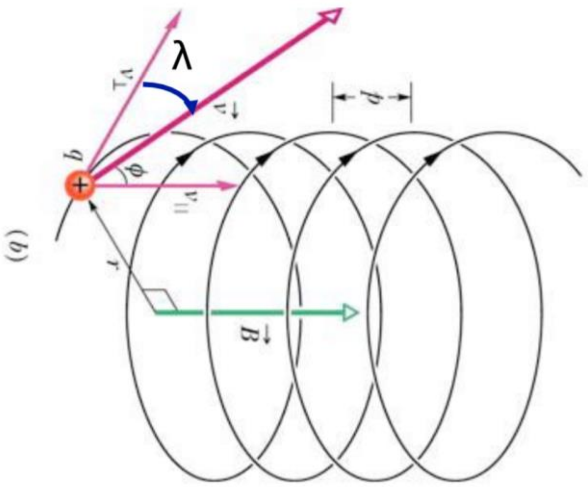
- Average cluster (x,y,z,t,) are calculated to estimate the components of the direction versor of the particle in the calorimeter

STT: DIGITIZATION AND RECONSTRUCTION

DIGITIZATION

- Active component of the STT: two double straw layers (XX and YY)
- Divide hits into clusters: one for each straw
- Save straw name,(x,y,z,t), energy deposition, hit map





RECONSTRUCTION

- Elicoidal motion in the STT due to B on the x axis
- Circular fit on the yz plane and find radius R and angle Φ_0 :

$$(y - y_0 + R\cos\Phi_0)^2 + (z - z_0 + R\sin\Phi_0)^2 = R^2$$

- Linear fit on $x\rho$ plane to find dip angle λ:

$$x = x_0 + \rho\tan\lambda$$

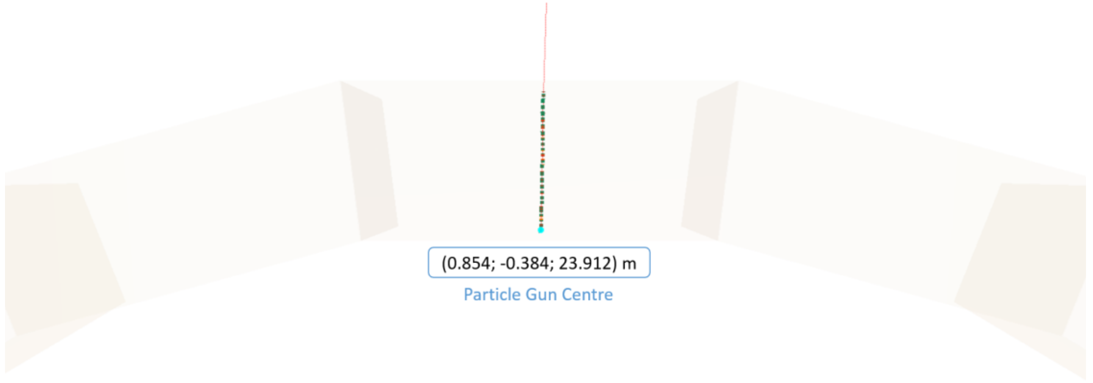
- Find transverse momentum:

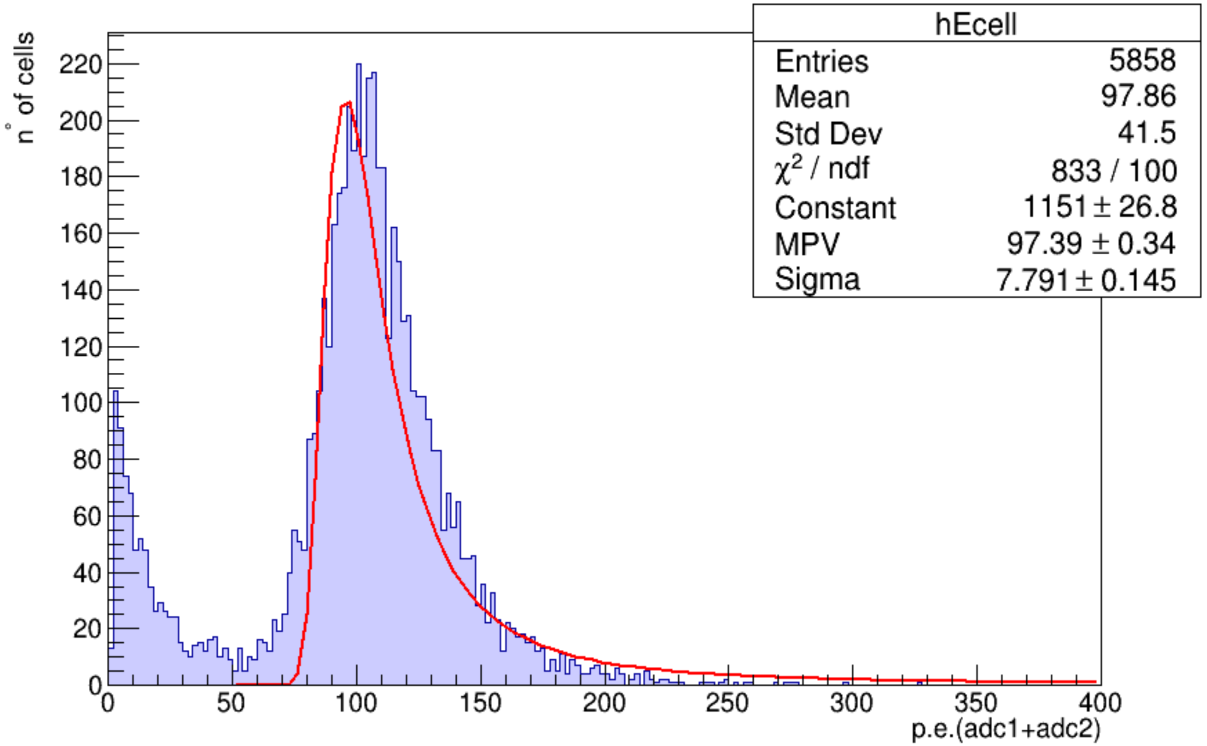
$$p_T[\text{GeV}] = 0.3B[\text{T}]R[\text{m}]$$

- Find momentum components:

$$p_x = p_T\tan\lambda$$
$$p_y = p_T\cos\Phi_0$$
$$p_z = p_T\sin\Phi_0$$

PRELIMINARY MEASUREMENT: LIGHT YIELD





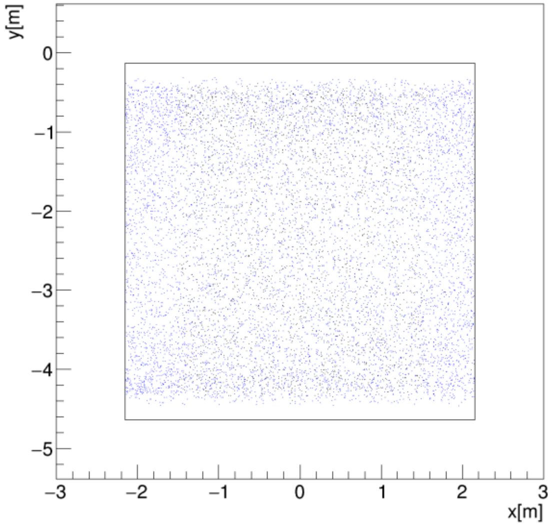
- Simulated 1000 muons at 10 GeV passing through an ECAL barrel module

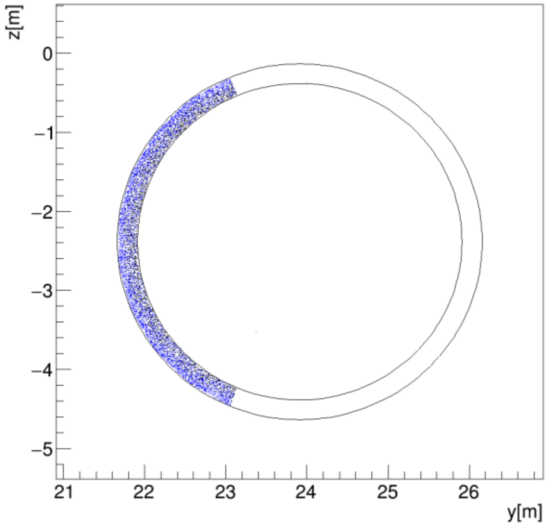
$$\Delta E_{cell} \simeq \left(\frac{dE}{dx}\right)^{MIP} \rho_{Pb}\Delta x_{Pb} + \left(\frac{dE}{dx}\right)^{MIP} \rho_{Sc}\Delta x_{Sc} \simeq 42.22 \text{ MeV}$$

$$N^{cell}_{p.e.} = (97.4 \pm 0.3) \text{ p.e.}$$

$$c = \frac{N^{cell}_{p.e.}}{\Delta E_{cell}} \simeq 2.31 \; [\text{p.e./MeV}]$$

FIDUCIAL CUT





- Threshold on the energy deposition on the outer layer (E < 15MeV):

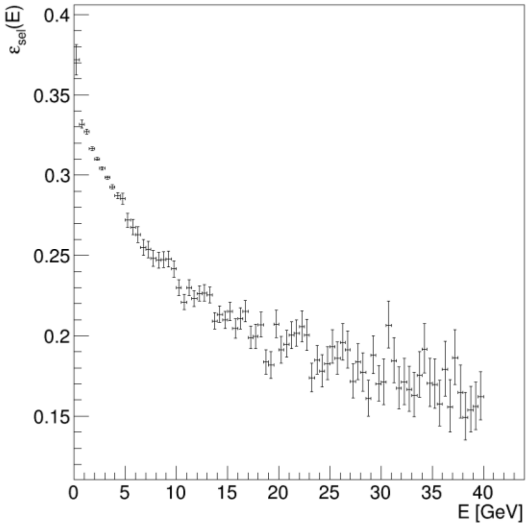
$$N_{p.e.}^{th} = c \times \Delta E_{th} \simeq 35 \text{ p.e.}$$

- X vertex, estimated as a weighted average on the energy deposition on the cells, is selected as:

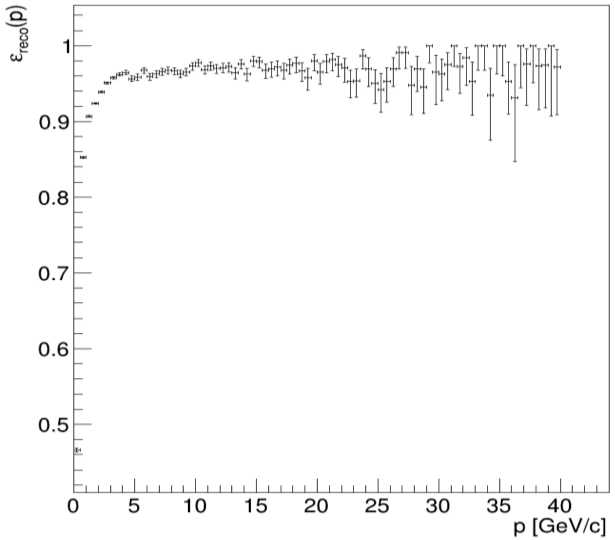
$$|x_V| \leq 1.5 \text{ m}$$

$$\boxed{\varepsilon_{cut} = \frac{N_{fid}}{N_{CC}} = 0.2905 \pm 0.0004}$$

Note: efficiency decreases at higher energy; might be due to nuclei fragmentation in DIS



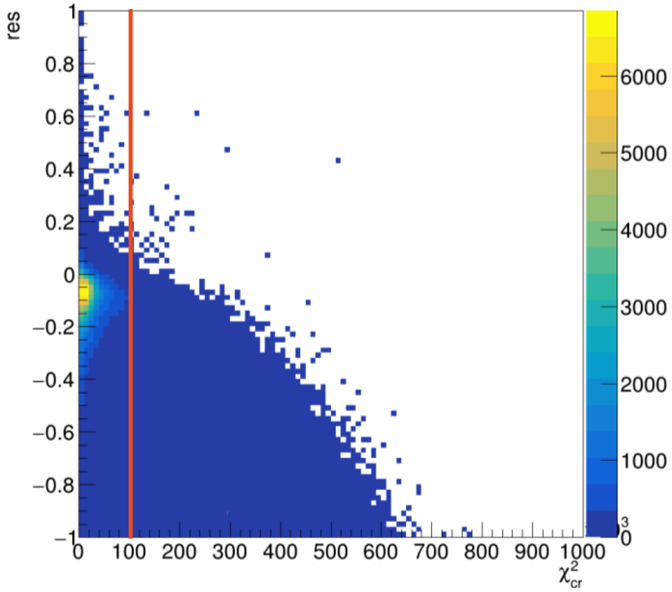
MOMENTUM RECONSTRUCTION SELECTION



~~EFFICACY~~ Efficiency

- Momentum reconstruction efficiency:

$$\varepsilon_{reco} = \frac{N_{reco}}{N_{fid}} = 0.9168 \pm 0.0004$$



QUALITY

$$\chi^2_{cr} = \frac{1}{N_{hits}} \sum_{i=1}^{N_{hits}} |(y_i - y_C)^2 + (z_i - z_C)^2 - R^2|$$

$$res = 1 - p_\mu^{true}/p_\mu^{reco}$$

$$\chi^2_{cr} < 10^5$$

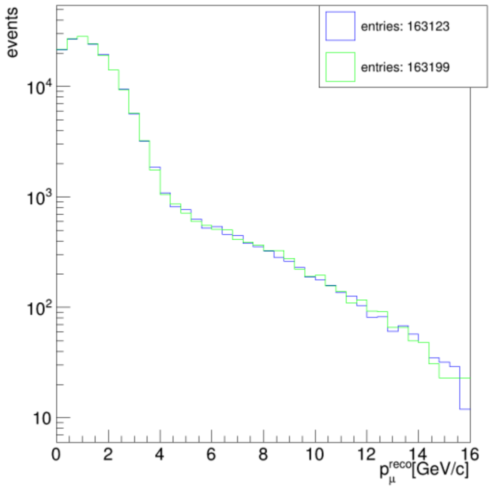
$$\boxed{\varepsilon_{qual} = \frac{N_{qual}}{N_{reco}} = 0.9290 \pm 0.0004}$$

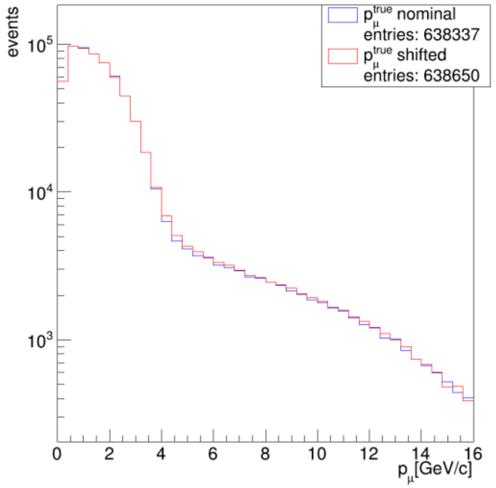
CHI-SQUARED TWO-SAMPLE TEST STATISTICS

$$\boxed{T = \sum_{i=1}^{k} \frac{(u_i - v_i)^2}{u_i + v_i}}$$

- Where k is the number of bins in the histograms and u_i and v_i are their contents
- T approximately follows a chi-squared distribution

CONTROL ANALYSIS





- We apply the T to the reconstructed momenta from ~~two nominal samples.~~ We expect to obtain a p-value that is close to 1:

two equal-size samples obtained from nominal beam

$$p_{control} = 0.527; \qquad \sigma_{control} = 0.633 \ (\chi^2)$$

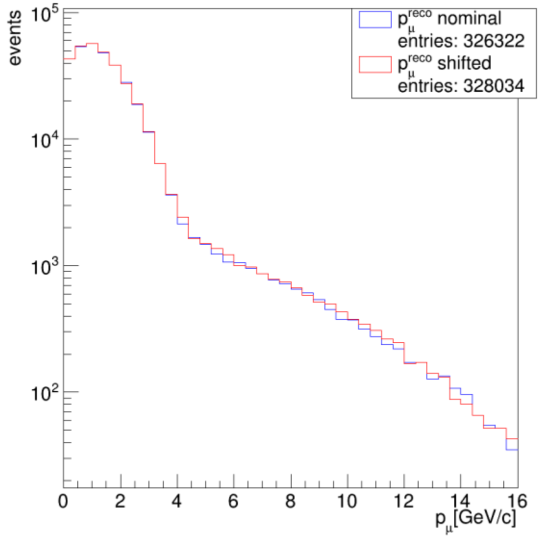
Definirli prima di utilizzarli

- We applied the test T to the true Monte Carlo momenta from the nominal and shifted samples in order to gauge what the best possible p-value might be:

$$p_{truth} = 5.15 \times 10^{-7}; \qquad \sigma_{truth} = 5.02 \ (\chi^2)$$

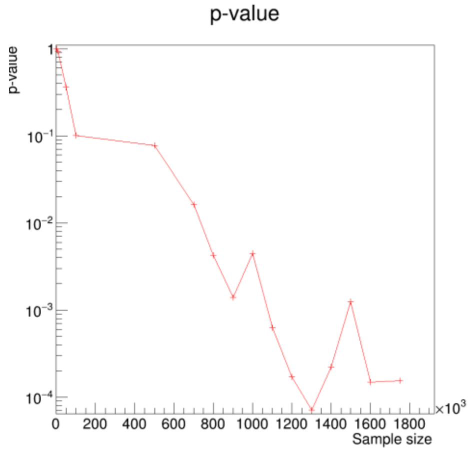
Note: in principle no p-value should be smaller than p_{truth}

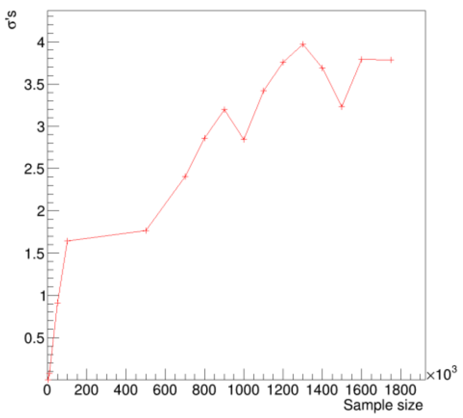
RESULTS

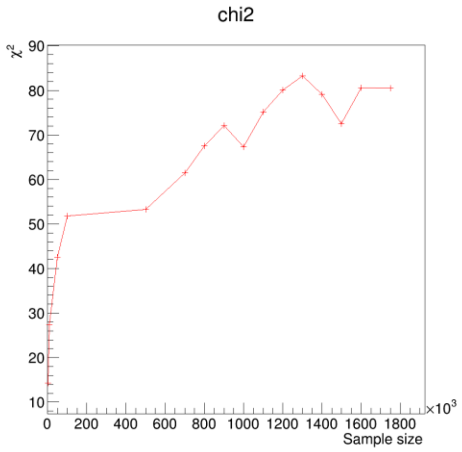


- We apply the T test to the two muon momenta samples after all cuts are applied:

$$\boxed{\begin{aligned} p_{reco} &= 1.55 \times 10^{-4}; \\ \sigma_{reco} &= 3.78 \end{aligned}}$$







- We study the evolution of p-value with the sample: as the samples become larger the χ^2 and number of σ's increase, while the p-value decreases.

inserire anche qui una conclusione
in cui diciamo che con una statistica
superiore a ... raggiungiamo i ...
di livello di confidenza

CONCLUSIONS

- We observed that in the case of a perfect detector with a perfect reconstruction, (i.e. using the Monte Carlo “truth”), the significance of the difference among the nominal and shifted samples does not exceed 5σ
- After a detailed analysis, we found that we are able to distinguish the two reconstructed samples at 3.8σ confidence level
- The result can be improved: for example include neutrinos with interactions in the STT, or consider the reconstructed position on the *xy* plane of the interaction vertexes, both in the front calorimeters and the STT.