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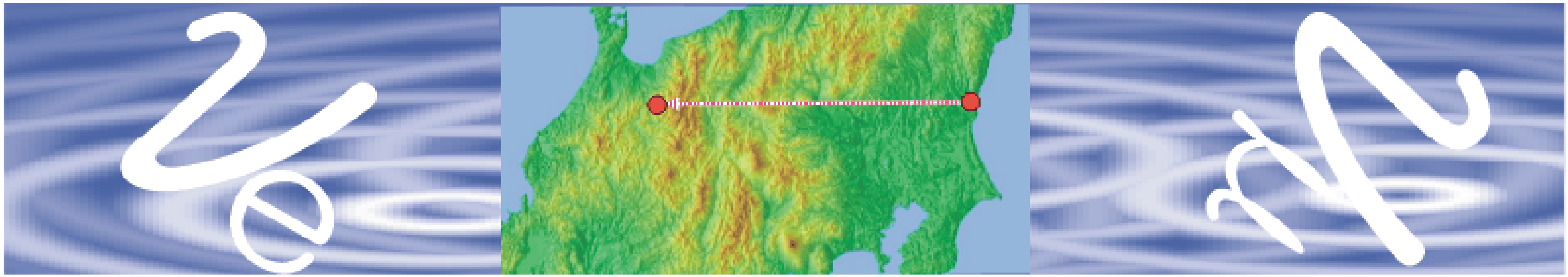
T2K oscillation experiment: Getting the neutrino out of the bottle.



James Dobson - 1st year project presentation.

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Outline of presentation.

•Neutrino oscillations: A brief overview.

•T2K: Experimental setup.

•Neutrino event generators: What are they and why are they needed.

•GENIE:An overview. Re-weighting and T2K specific flux driver.

•Plan of attack and general direction of project.

Neutrino oscillations.

$$|\nu_i\rangle = U_{ij}\,|\nu_j\rangle$$

where,

$$U_{ij} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Have introduced seven new parameters

$$\theta_{12}, \theta_{23}, \theta_{13}, \delta$$

$$\left.\begin{matrix} m_1 \\ m_2 \\ m_3 \end{matrix}\right\} \begin{matrix} |\Delta m^2_{12}| \\ |\Delta m^2_{23}| \end{matrix}$$

Improve on current (θ_{23}, $|\Delta m^2_{23}|$)

Make new measurement or improve limit (θ_{13})

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Disappearance and appearance measurement.

$$|\nu_j(\tau)\rangle = e^{-im_j\tau}\,|\nu_j(0)\rangle$$

↓

Oscillation formulae

$$P(\nu_\mu \rightarrow \nu_\mu) \simeq 1 - cos^4\theta_{13} sin^2 2\theta_{23} sin^2\left[\frac{1.27\Delta m^2_{23}(eV^2)L(km)}{E_\nu(GeV)}\right]$$

$$P(\nu_\mu \rightarrow \nu_e) \simeq sin^2\theta_{23} sin^2 2\theta_{13} sin^2\left[\frac{1.27\Delta m^2_{23}(eV^2)L(km)}{E_\nu(GeV)}\right]$$

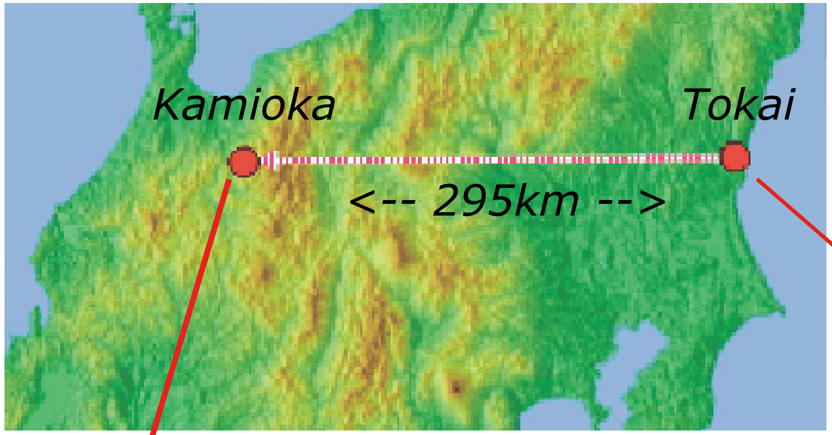
For both measurements need to characterise neutrino flux both before and after oscillation.

Tokai to Kamioka (T2K) experimental setup.

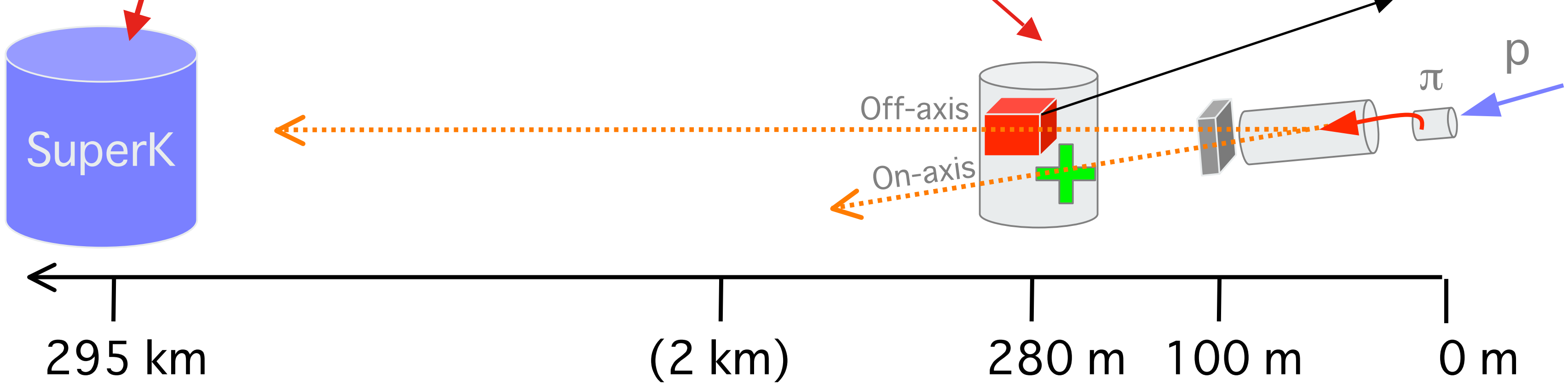
T2K long-baseline setup.

Off-axis design:
Narrower energy
distribution

Highest intensity
neutrino beam to
date -> Higher
statistics.



Near Detector at
280m (ND280)

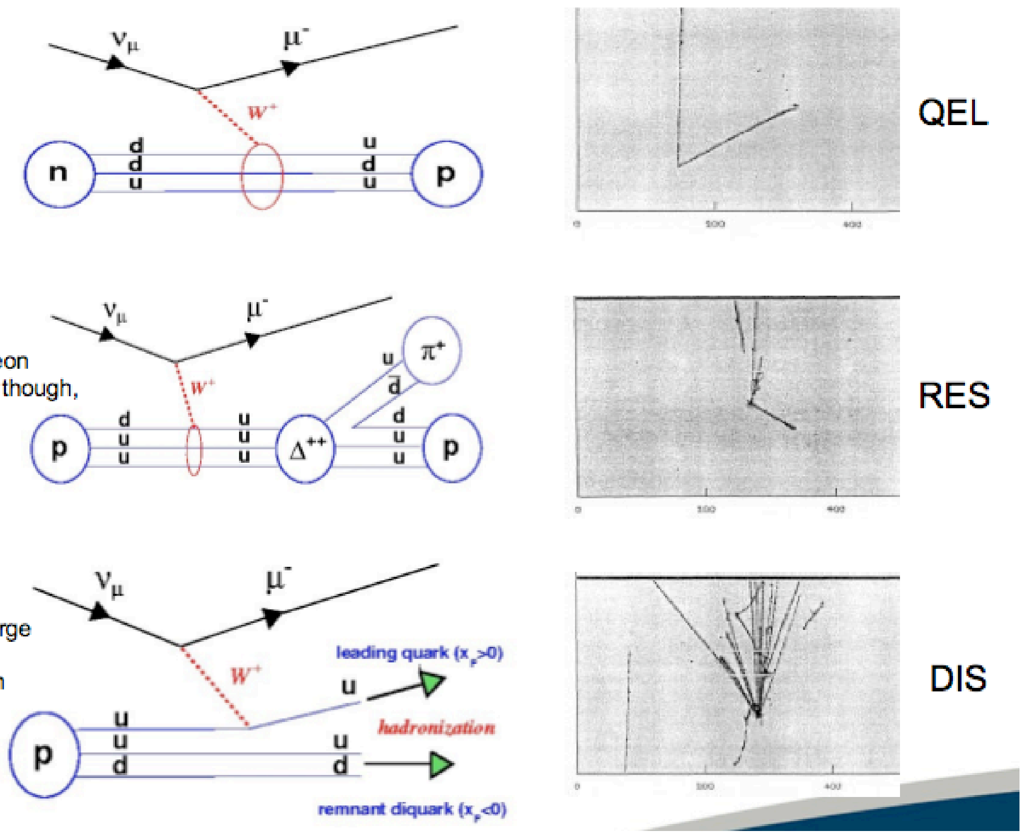


Neutrino interaction generator.

Need to understand the neutrino interactions in detectors at ~1GeV scale. So require a generator that models interaction of neutrinos with detector nuclei.

Neutrino interactions

QEL, RES, DIS dominant in different kinematical regimes



Usually single pion + nucleon
Other final states possible though,
eg Delta -> N + gamma

q, qq materialize to give large number of f/s.
At low masses though can look like RES

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Neutrino interaction generator (cont).

Why is it difficult:

- Hadronic interactions at the ~GeV scale. Physics very difficult to describe/unknown and often no theoretical models exist.
- Have to deal with hadronisation, re-hadronisation.
- Relies heavily on parametric models. Leads to re-weighting
- When and where to apply what model. A lot of choice and often not clear.

The generator simulates the primary interaction and outputs result to the rest of the detector simulation software.

GENIE (Generates Events for Neutrino Interaction Exp).

T2K is generator-agnostic. Can use a number of different generators including NUANCE, NEUT and GENIE.

GENIE is already official generator for MINOS, NOvA experiments.

Co-supervised by one of the creators of GENIE.

Plus points of GENIE:

- Re-weighting
- Well designed C++ code
- T2K specific flux generator
- Much effort gone into validation using external data

T2K specific flux driver.

Specific flux driver. Using ND280 as an example.

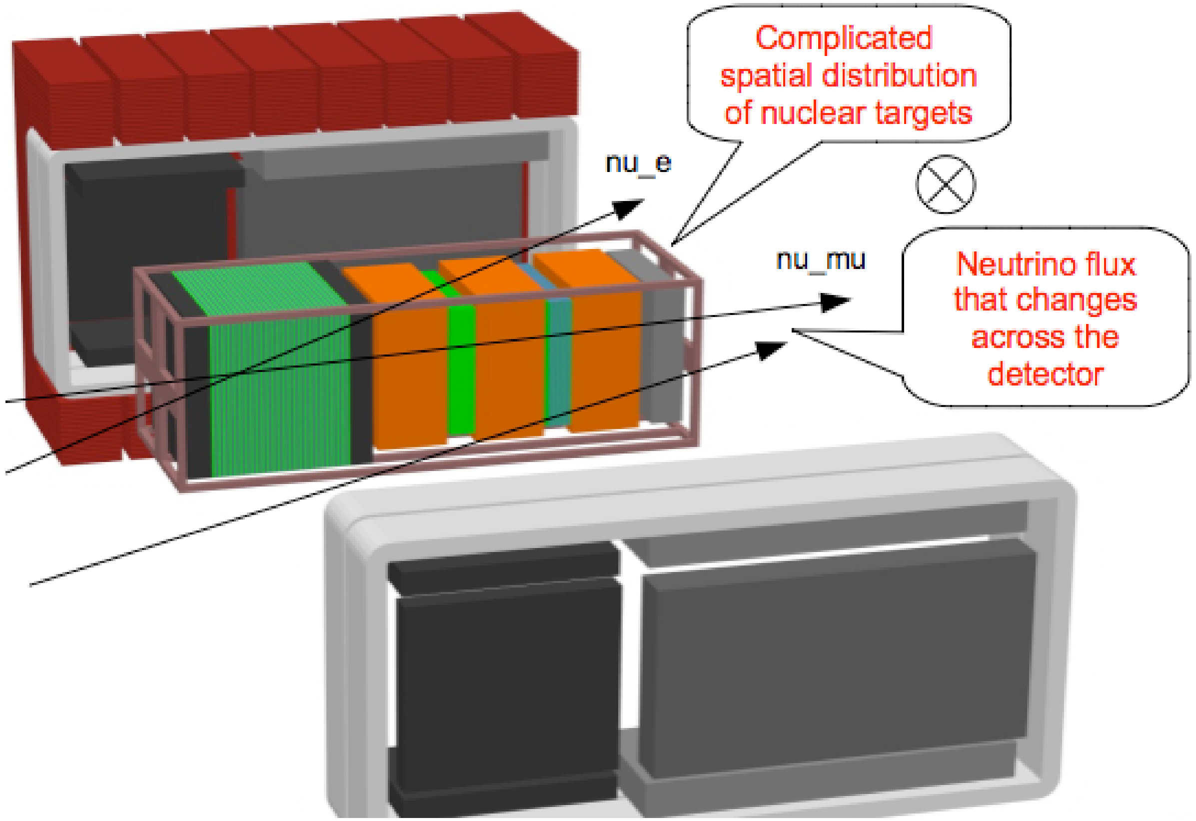
Throws an event by calculating interaction probability.

Interaction probability for ith section of path.

$$P_i \sim \frac{\sigma_i L_i \rho_i}{A_i}$$

Cross section for given neutrino and target, at E.

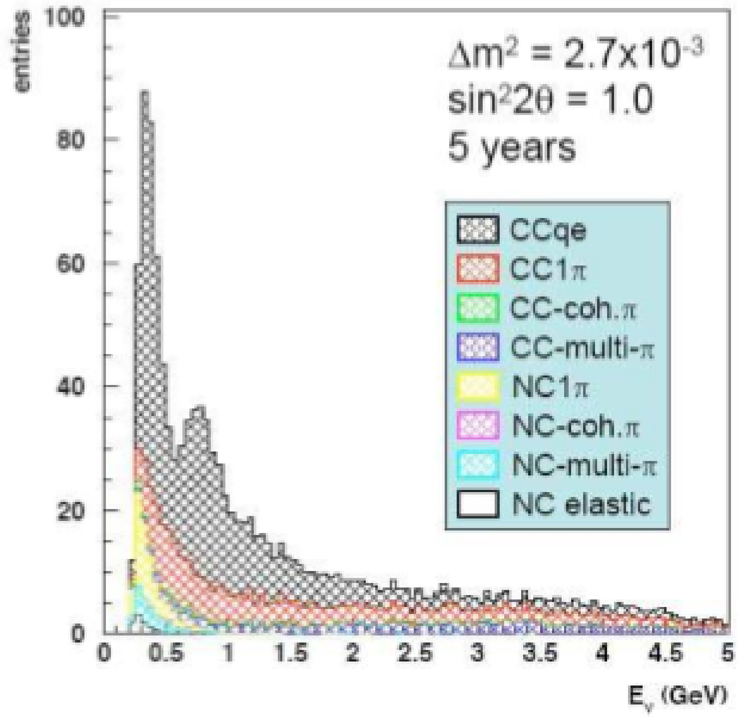
Density weighted path length.

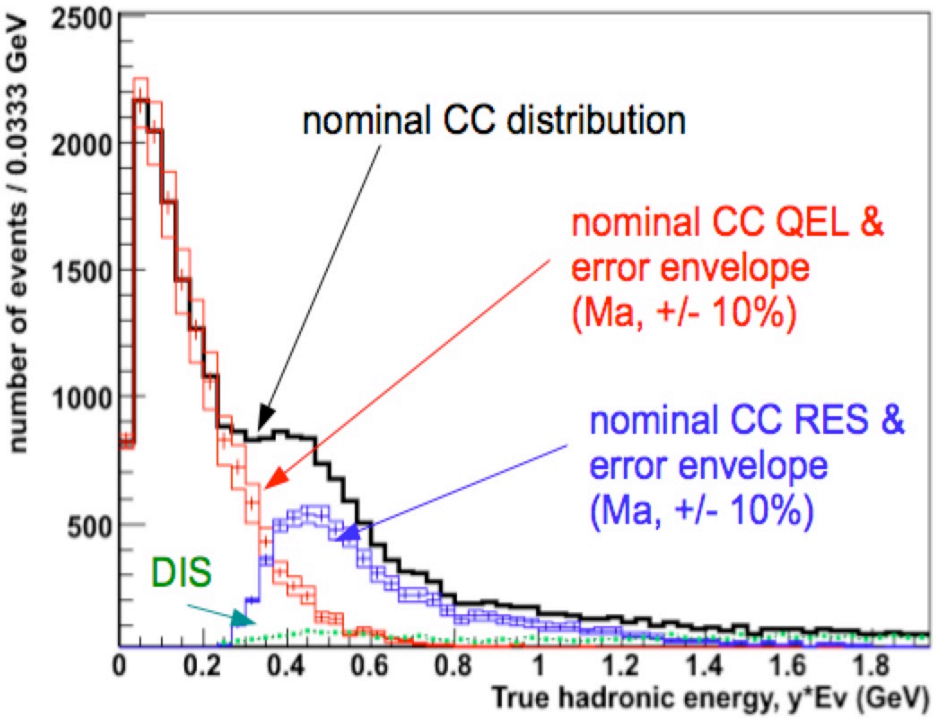


Re-weighting and error envelopes.

Cross-section re-weighting exist at present.

Future re-weighting schemes. Hadronisation and Intra-nuclear transport models. Much harder.





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Ways of using GENIE.

1) As a tool for the experiment. For monte-carlo studies. Re-weighting, calculating error envelopes due to dependency on parametric models.

2) Using data from experiment to fine tune parametric models. As a tool for testing new hadronic/intra-nuclear models. Deciding what models describe the physics over what range.

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Plan of attack.

Immediate plan of attack:

- Validating T2K specific flux driver.
- Re-weighting for cross sections. Then developing other re-weighting schemes.
- Working with Antonin Vacheret on MPPC's

General direction of project:

- Assisting Costas Andreopolous, one of the creators, in the development of generator.
- Using GENIE for physics studies of neutrino nucleus interactions.
- Acting as mediator / interface between Imperial T2K group and GENIE creators.

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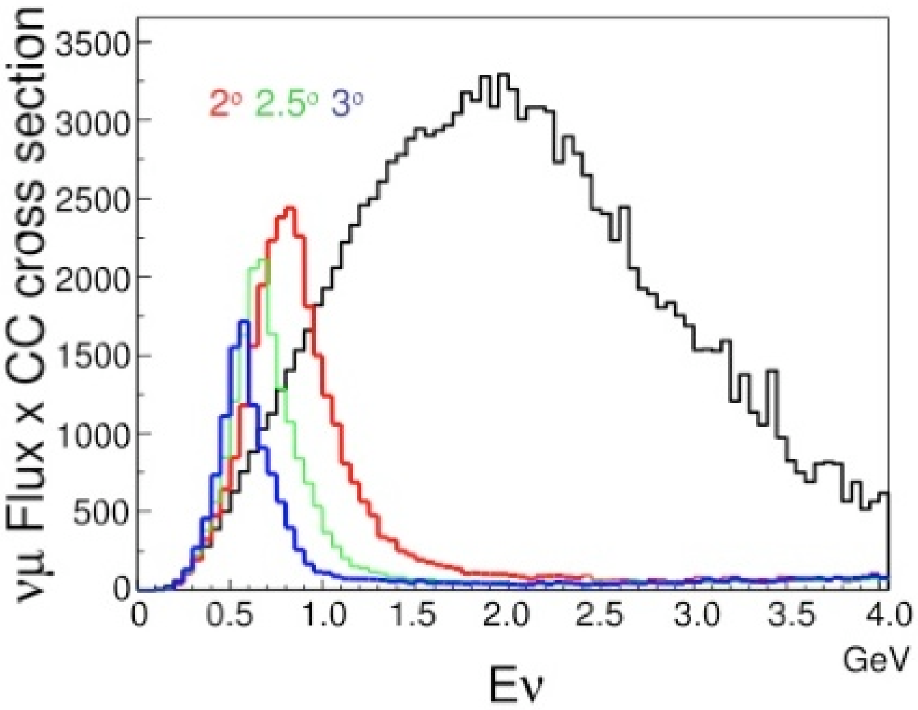
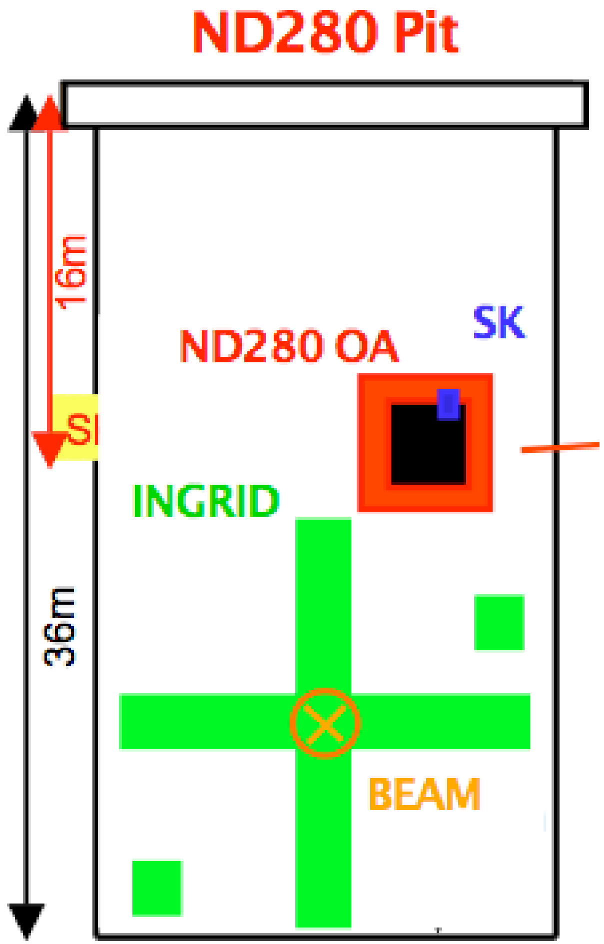
The End.


2° 2.5° 3°
vμ Flux x CC cross section
Eν
GeV
0
500
1000
1500
2000
2500
3000
3500
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0


ND280 Pit
16m
36m
ND280 OA
SK
INGRID
BEAM

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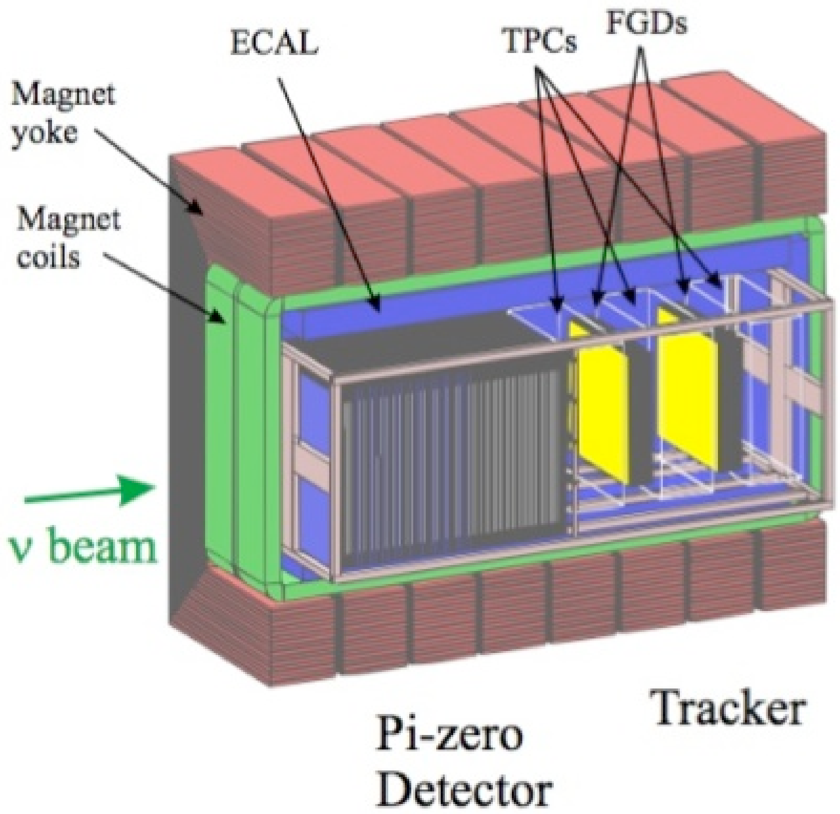
ND280

Why ND280? Need to characterise flux before oscillations. Electron neutrino contamination.

Imperial's role. Heavily involved in the software for the ND280 detector: Detector simulation, Reconstruction, Analysis.

Working on characterising MPPC's. Now moving into a stage of testing >>1000 of them.



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BACKUP.

Physics in latest production version (2.2.*)

- **Cross section model**
  - QEL: Llewellyn-Smith with any of Sachs/BBA03/BBA05 elastic f/f
  - RES: Rein-Sehgal
  - COH pi production: Rein-Sehgal / includes updated PCAC
  - DIS: latest Bodek-Yang
    - Including parametrization of the longitudinal structure function FL
    - Including NuTeV parameterization of nuclear effects
  - Many other more rare channels: DIS & QEL charm / ve- elastic / inv.mu-decay/...
- **Nuclear model**
  - Relativistic Fermi Gas model
  - Including high momentum tail due to N-N correlations modelled from eN data
  - "Standard" FG prescription for off-shell kinematics...

Fairly standard at all ν MCs

Careful implementation as MINOS spans a huge kinematical region (E ~ <1 to >100 GeV)

- **Transition region cross section modelling**
  - Non resonance background modelled from DIS & AGKY hadronization
  - Tuned to the world exclusive multi-pion cross section data
- **Neutrino-induced primary hadronic shower modelling**
  - AGKY
  - Effective KNO-based hadronization at low-W
  - Switching gradually to PYTHIA/JETSET at high-W
  - SKAT-type formation zone parametrization / improvements in progress
- **Intranuclear hadron transport**
  - INTRANUKE hA model
  - Anchored to a set of hadron+Fe56
  - Scaled to all nuclei

Unique to GENIE

'State of the art'

Costas Andreopoulos, *Rutherford Appleton Lab.*

Science & Technology Facilities Council