LAGUNA-LBNO

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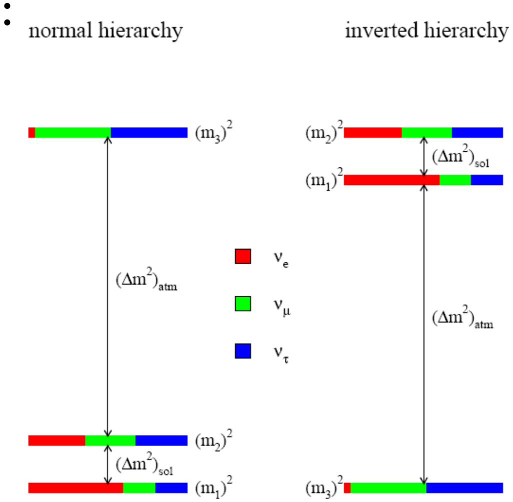
IOP Half Day Meeting Queen Mary, Nov 2012

Neutrino Mixing

- Neutrino mixing is characterised by the PMNS matrix.

$$\mathbf{U}_{PMNS} = \underbrace{\begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}}_{\text{Solar}} \underbrace{\begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -\sin\theta_{13}e^{i\delta} & 0 & \cos\theta_{13} \end{pmatrix}}_{\text{1-3 Sector}} \underbrace{\begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix}}_{\text{Atmospheric}}$$

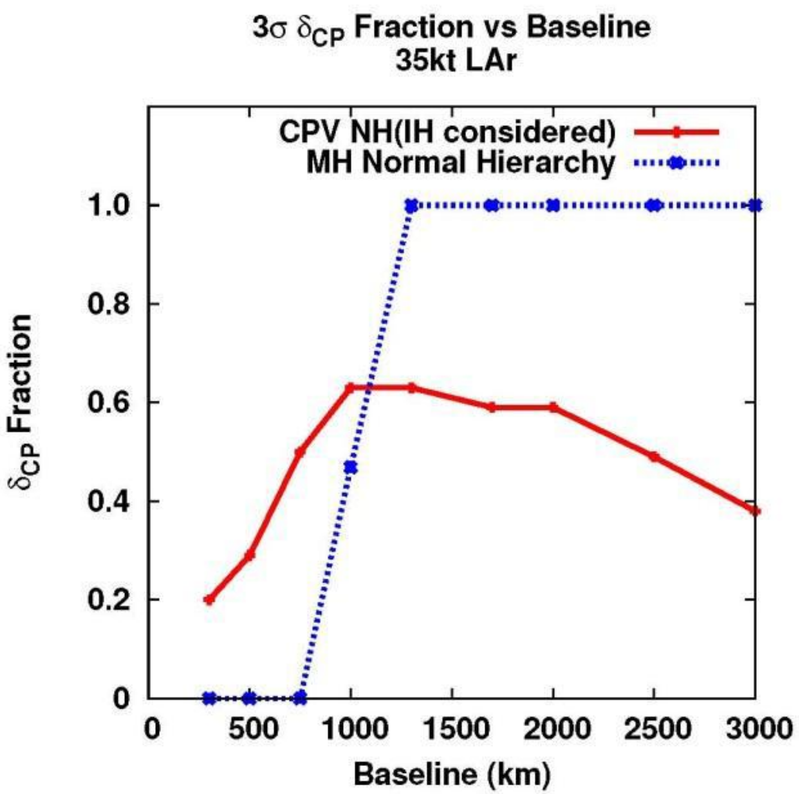
- Fundamental parameters of nature just like CKM
- Open questions for long baseline experiments:
  - Mass Hierarchy
    - Either/Or Question
    - Appears though matter effect.
  - CP Violating Phase δ
  - Questions on θ_{23}
    - Is θ_{23} maximal
    - Which octant?



Measuring the mass hierarchy and CP violation

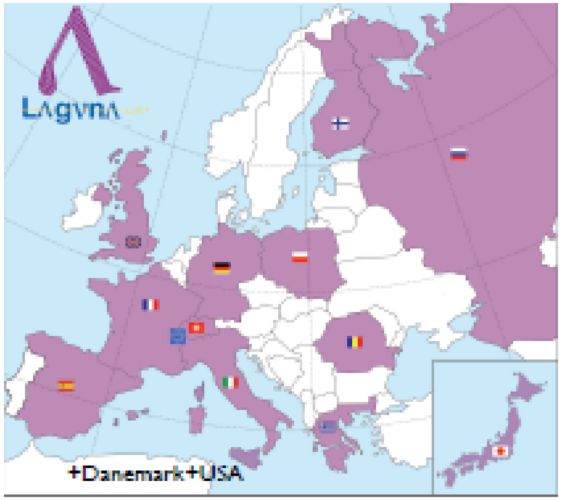
- Several ways to approach this
  - Measure appearance probabilities for neutrinos and anti-neutrinos
  - Compare first and second oscillation maxima
  - Increased distance to give increased matter effect.

- Increased distance required higher energy neutrinos
  - Increased cross section
  - Rate does not drop as $1/r^2$.



Plot from LBNE

LAGUNA-LBNO consortium



14 countries, 47 institutions, ~300 members

Switzerland
University Bern
University Geneva
ETH Zürich (*coordinator*)
Lombardi Engineering*

Finland
University Jyväskylä
University Helsinki
University Oulu
Rockplan Oy Ltd*

CERN

France
CEA
CNRS-IN2P3
Sofregaz*

Germany
TU Munich
University Hamburg
Max-Planck-Gesellschaft
Aachen
University Tübingen

Poland
IFJ PAN
IPJ
University Silesia
Wroklaw UT
KGHM CUPRUM*

Greece
Demokritos

Spain
LSC
UA Madrid
CSIC/IFIC
ACCIONA*

United Kingdom
Imperial College London
Durham
Oxford
QMUL
Liverpool
Sheffield
Sussex
RAL
Warwick
Technodyne Ltd*
Alan Auld Ltd*
Ryhal Engineering*

Romania
IFIN-HH
University Bucharest

Denmark
Aahrus

Italy
AGT*

Russia
INR
PNPI

Japan
KEK

USA
Virginia Tech

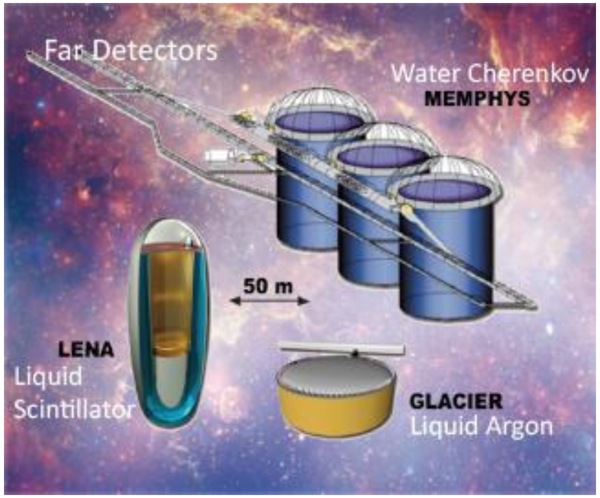
(*=industrial partners)

The LAGUNA study

- European design study to investigate future long baseline experiments and large underground facilities.
- The study ran from 2008-2011.
  - Detailed investiagtion and engineering of 7 sites across Europe
  - Detector technologies and capabilities assessed
  - > 1000 pages of documentation produced.

LAGUNA - LBNO

- Design study to continue LAGUNA for long baseline neutrino experiments
- Focus on 3 sites
  - Pyhäsalmi, Finland
    - 2300 km baseline
    - Currently under detailed study
  - Frejus Tunnel
    - 130 km baseline
  - Further exploitation of CNGS
    - 665 km baseline
    - No option for near detector



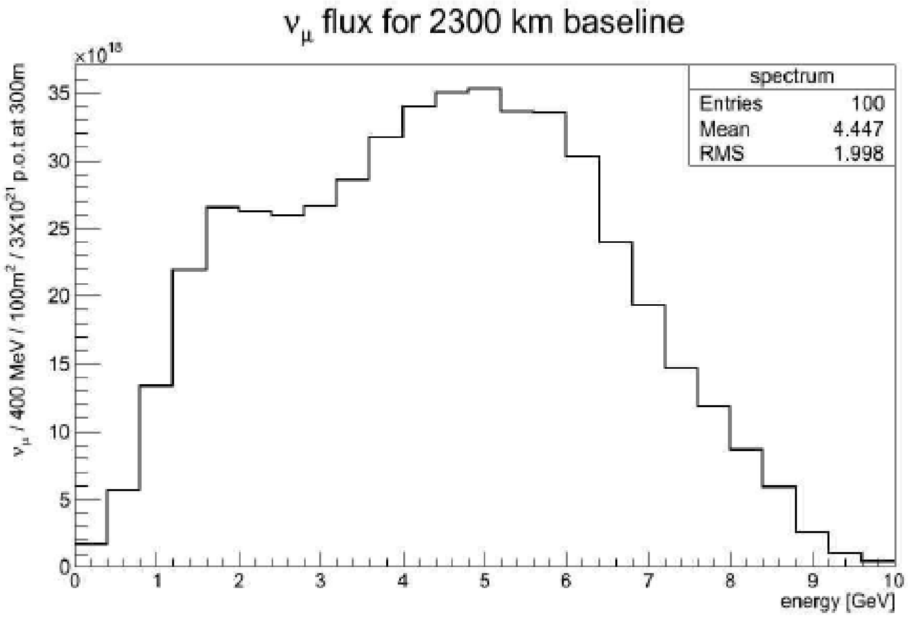
CERN to Pyhäsalmi

- Baseline design:
  - Neutrino beam from SPS
    - 500 -700 kW operation
  - Farsite to host
    - 20 kT double phase liquid argon TPC
    - 50 kT magnetised iron calorimeter
    - Possible large liquid scintilator detector
- Resolve first and second oscillation maxima
  - Increases CP sensitivity
  - Test Oscillations
- Large distance
  - Spectacular matter effect!

2100 km from RAL, 1500 km from DESY, and 1160 km from Protvino.

The Beamline

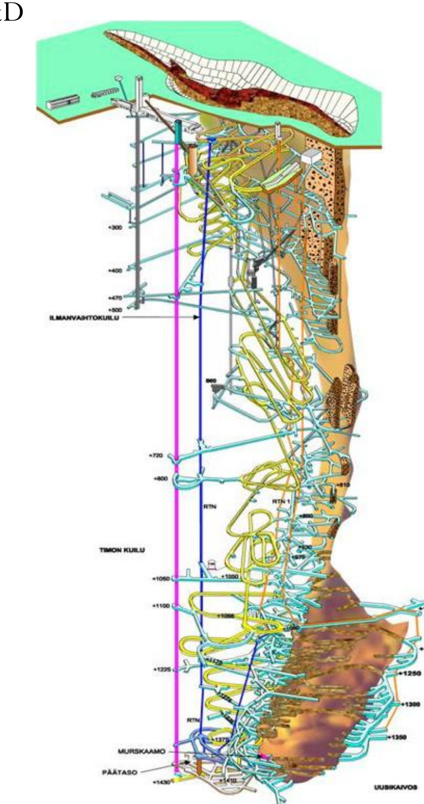
- CERN already has the most powerful neutrino beam
  - CNGS 500kW
  - Natural starting point for design
- Relatively short tunnel (300m) but 10º dip angle.
  - Target station and tunnel in NA.
- Potential improvements with upgrades for HL-LHC
  - Studies on going at CERN.
- Number of upgrade paths
  - SPS upgrades – 700 kW
  - New accelerator HP-PS 2MW



The mine at Pyhäsalmi

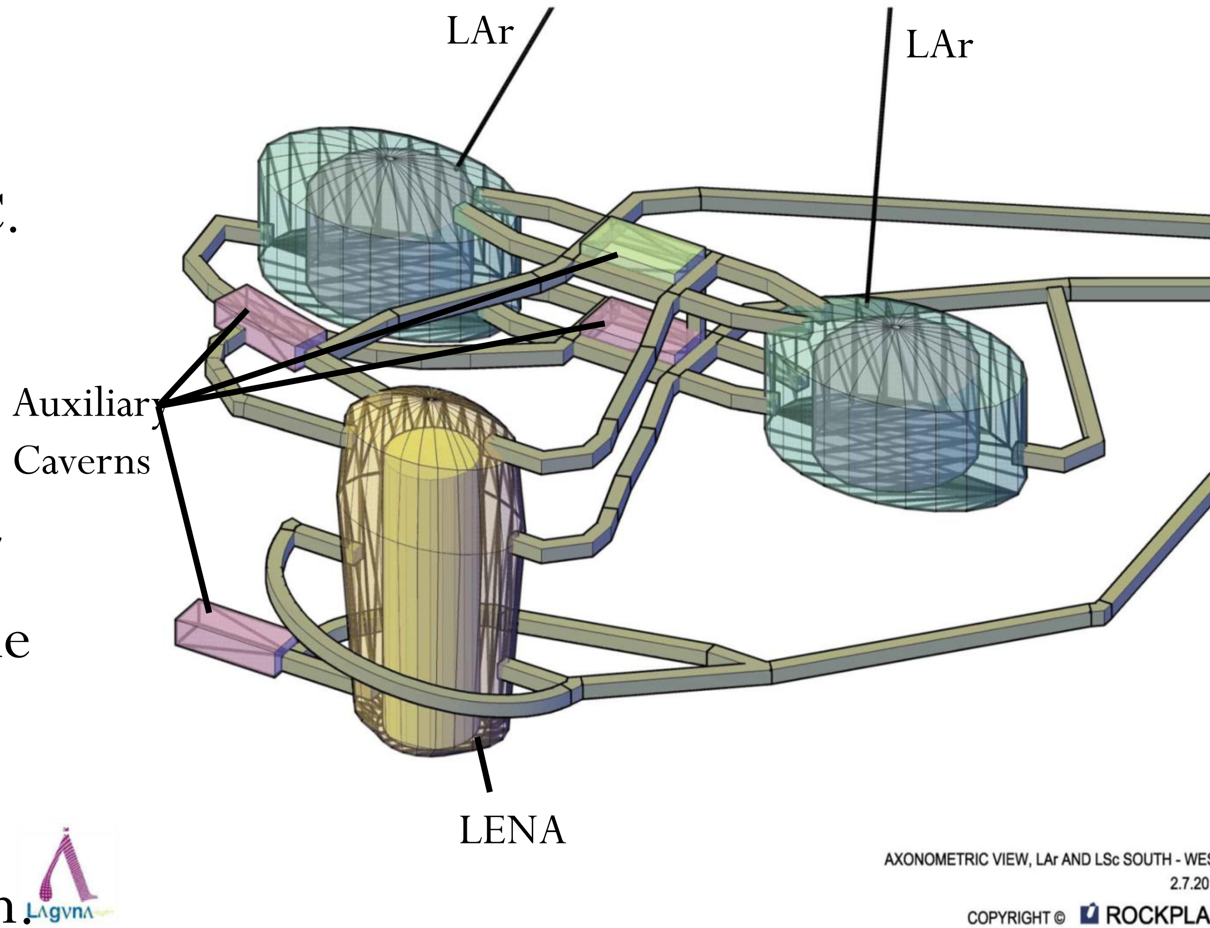
- Deepest mine in Europe
  - Depths to 1400 m possible
  - Produces Cu, Zn and FeS_2
- Currently a working mine
  - Reserves until 2018
  - Chance to take over this infrastructure
- Access underground via 11km tunnel and via shaft.
- Distance via road
  - Oulu – 165 km
  - Jyväaskylä – 180 km
  - Helsinki 450 km
- Strong support from Finland
  - €1.6 m for site investigation

250 m long tunnel and a cavern at 1400 m excavated for LAGUNA R&D



Possible Underground Layout

- Space for
  - 2x50 kton LAr TPC.
  - 50 kton magnetised iron calorimeter
  - 50 kton liquid scintillator detector
- Proposed site in mine at 1400m depth
- Area now under detailed investigation.

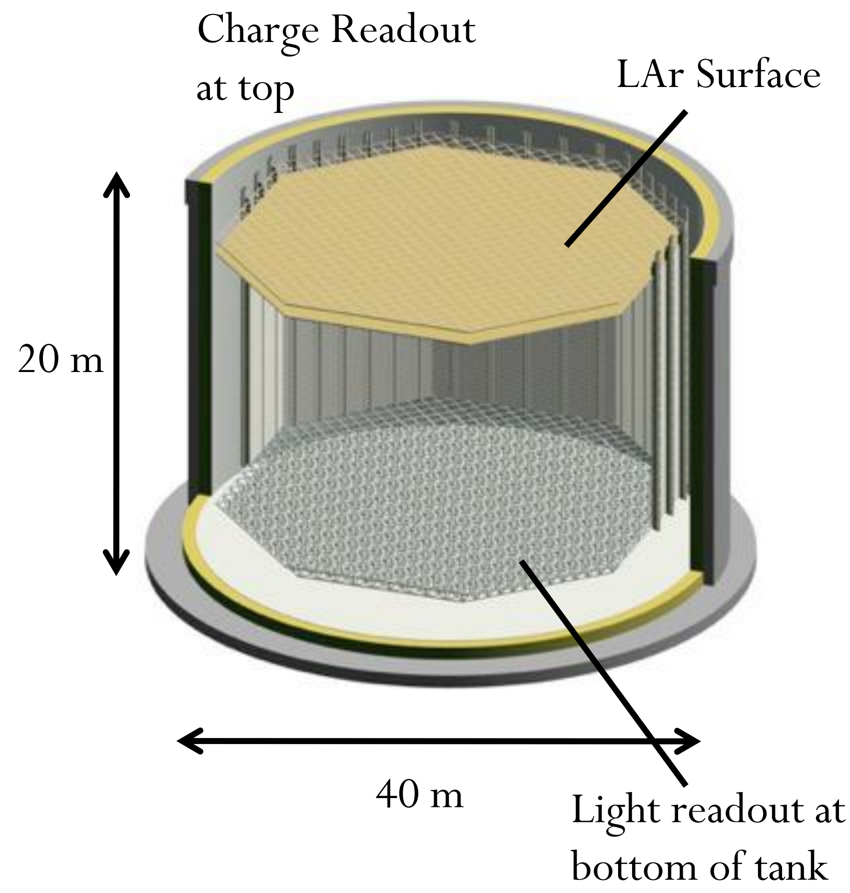


Far Detector Options

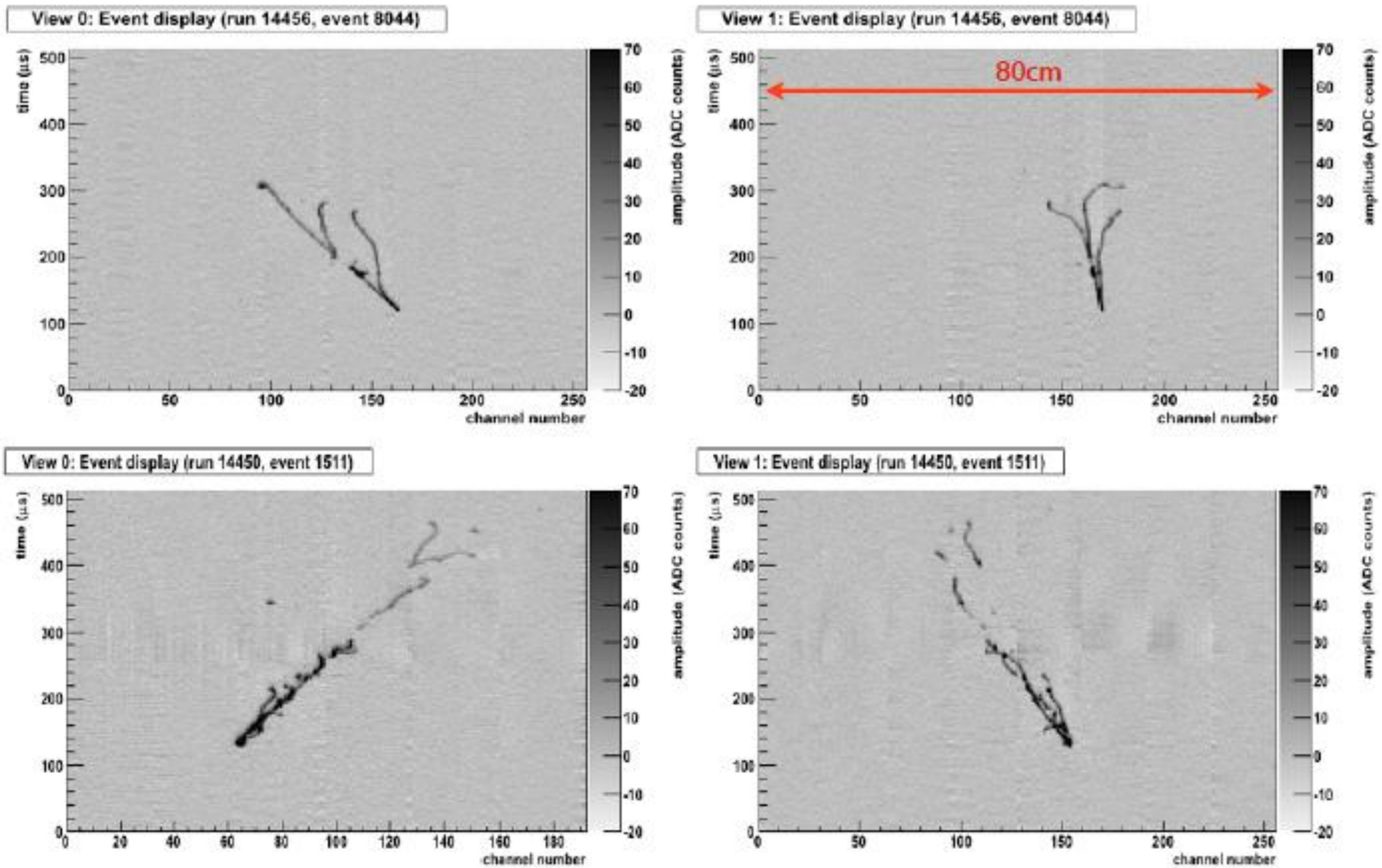
- To fully exploit the beamline the far detector must have the following capabilities:
  - Must be scalable to the large masses required.
  - Must be able to distinguish electrons and muons
  - Must be able to reconstruct many tracks at once
  - Should have excellent energy resolution.
- To achieve this we study as many possible technologies as possible
  - Combinations of detectors to give best results?
- Note water Cherenkov does not meet these criteria.

Glacier

- 20 kton double phase LAr LEM TPC.
  - Very fine grained tracking calorimeter
- Best detector for
  - Electron appearance
  - Reconstruction of multiple tracks from high multiplicity events.
- Excellent ν energy reconstruction.
- Low energy threshold for all particles



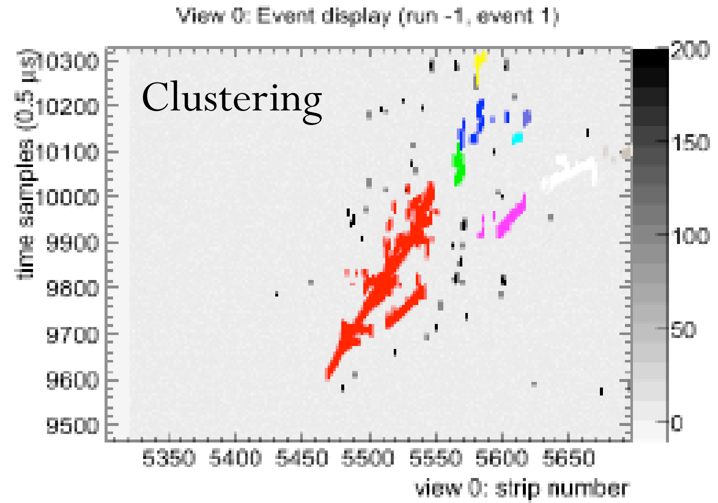
Events in LAr

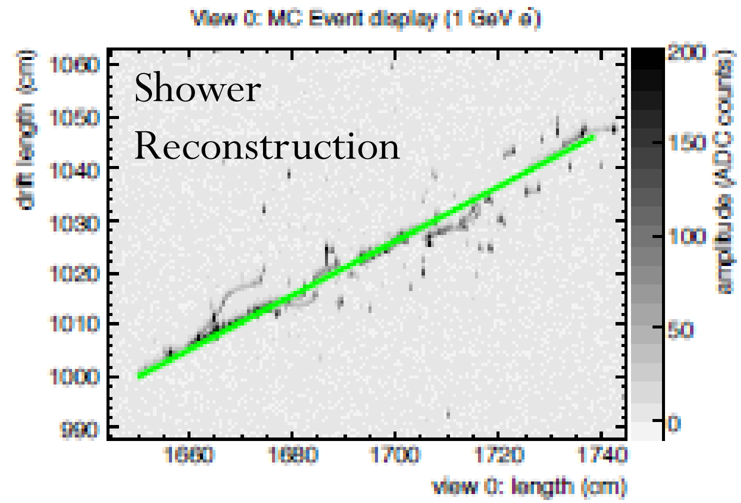


Cosmic track in 80 cm X 40 cm double phase test detector MIP S:N >100

Reconstruction in Liquid Argon

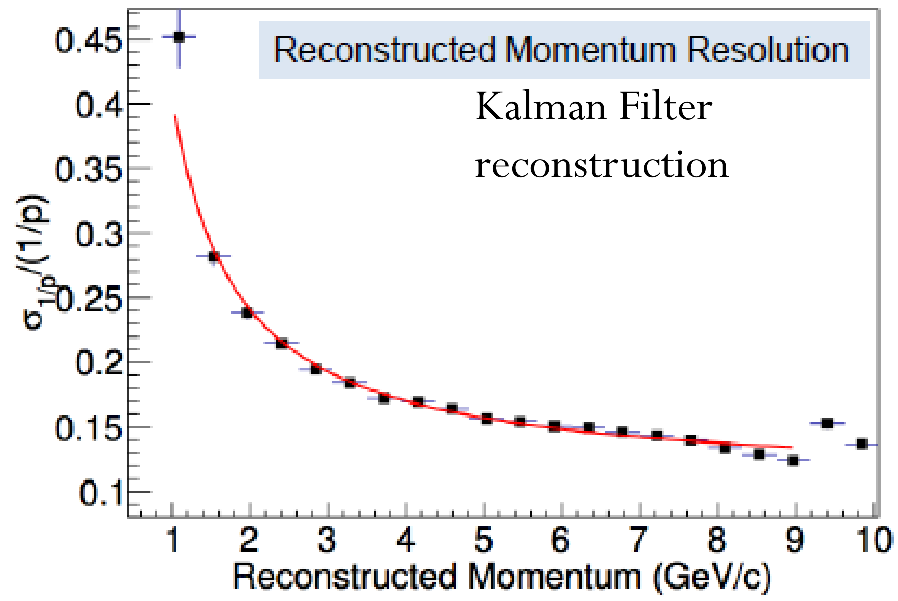
- Studies underway to simulate LAr TPC and to reconstruct the events.
- QSCAN software provides testbed for simulation and reconstruction tools.

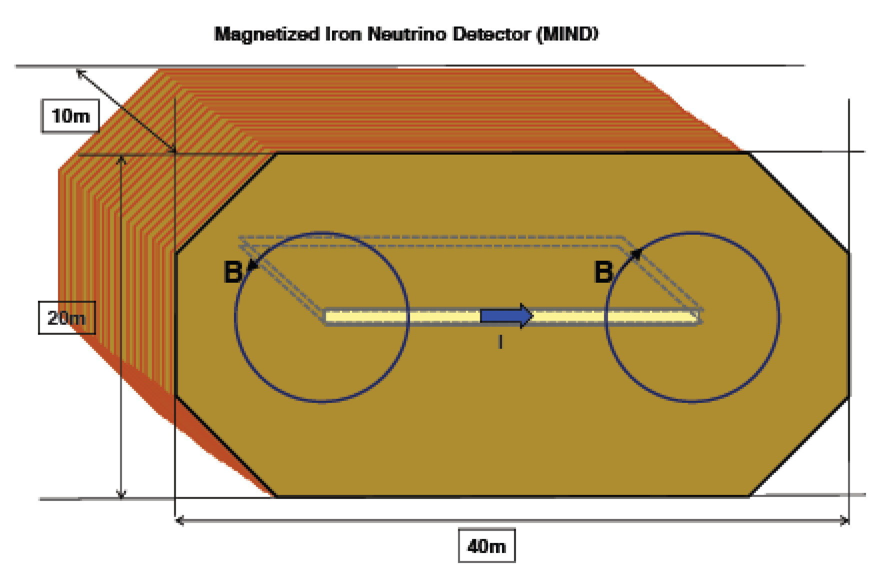




MIND

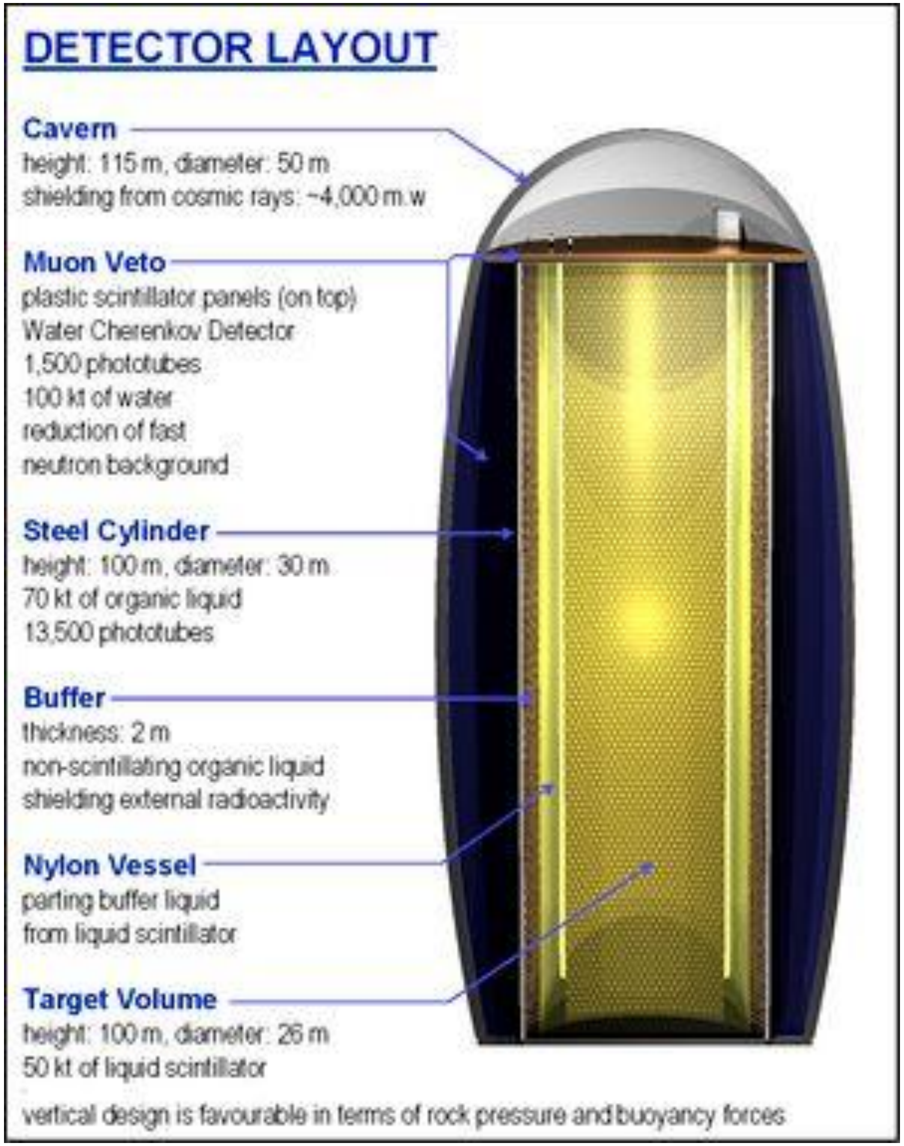
- Magnetised Iron Calorimeter
  - Similar to MINOS
  - Well proven technology
- 3cm Fe Plates, 1cm Scintillator Bars
- B= 1.5-2.5 T
- Measurement of muon momentum distribution and total neutrino energy.
- Excellent Charge determination
  - Ideal far detector for future neutrino factory.



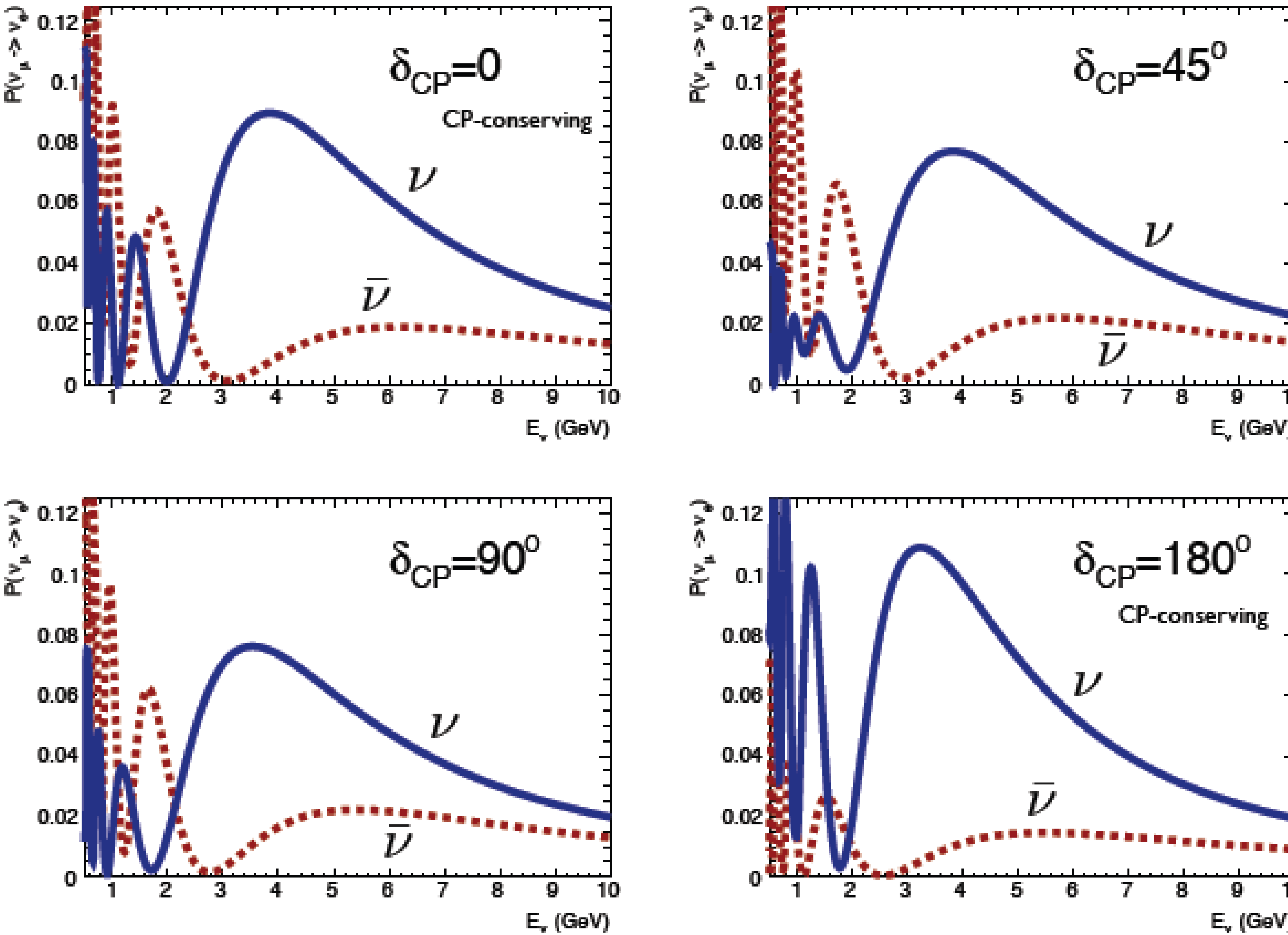


LENA

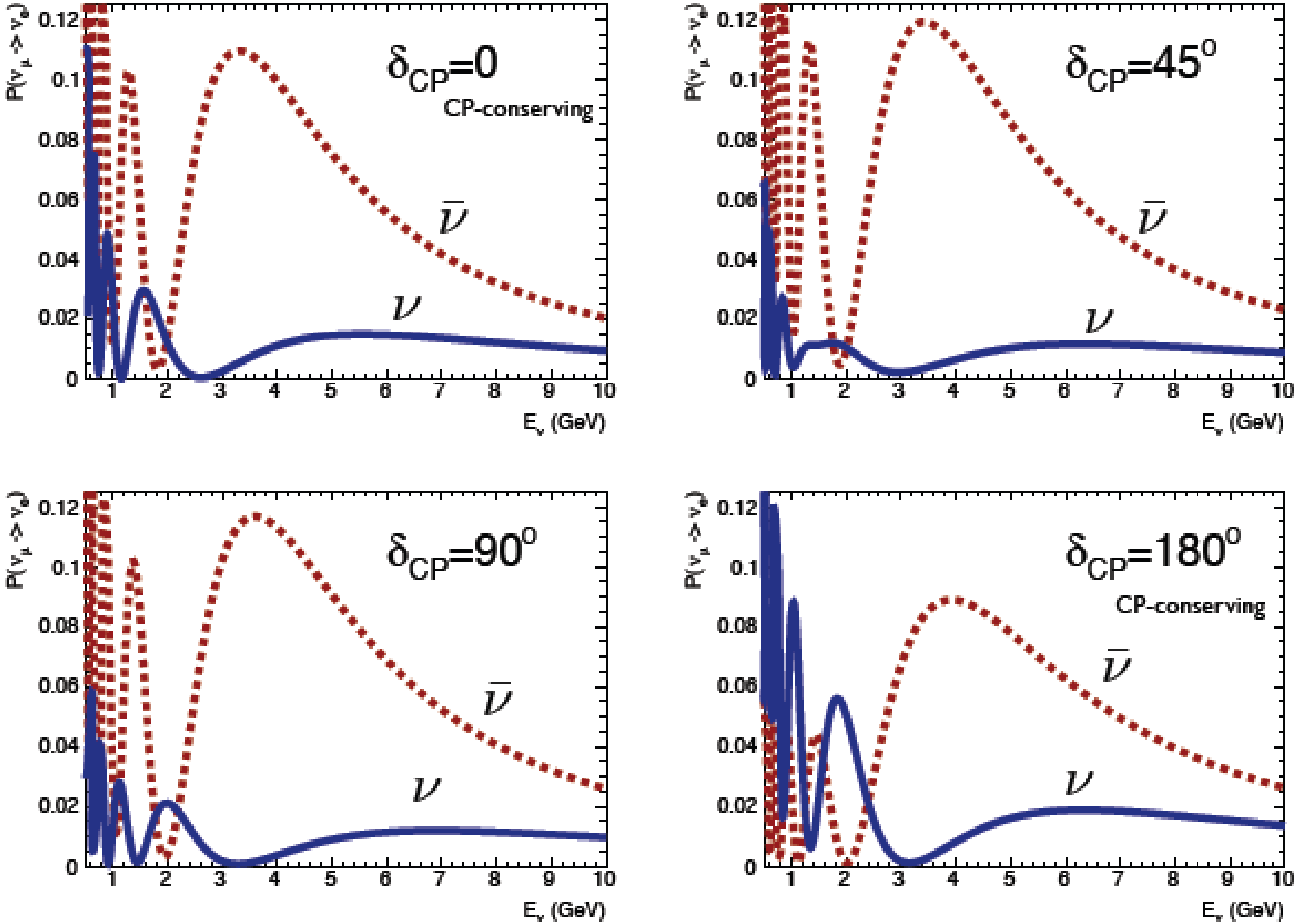
- Liquid Scintillator detector
  - Proven technology, scaled up.
- As well as beam measurements rich physics program
  - Solar neutrinos
  - Supernova neutrinos
  - Atmospheric neutrinos
  - Proton Decay
- Target : 100m high x 26m diameter
  - 50 kton
- 45000 8" PMTs



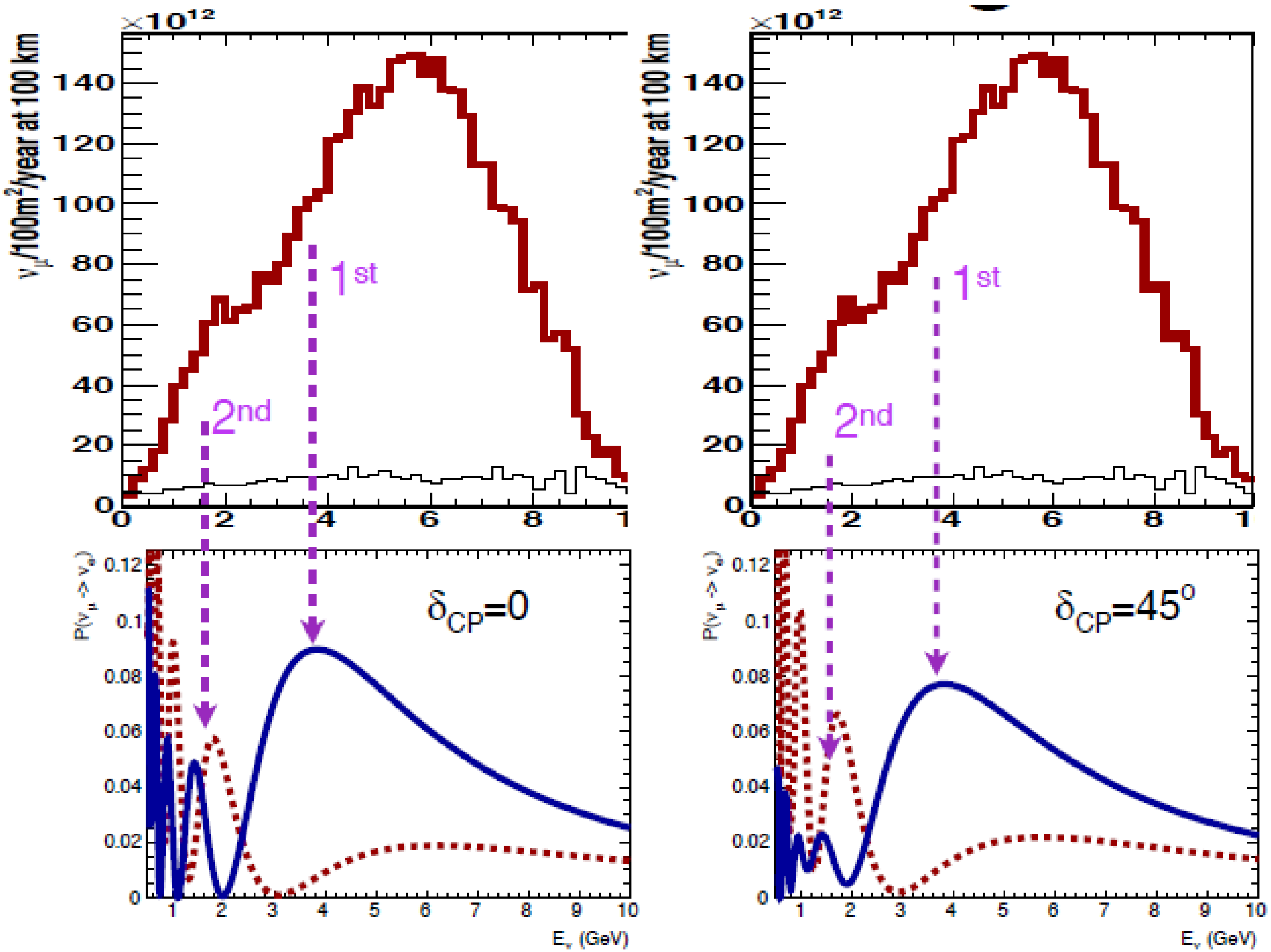
Signals at Pyhäsalmi : Normal Hierarchy



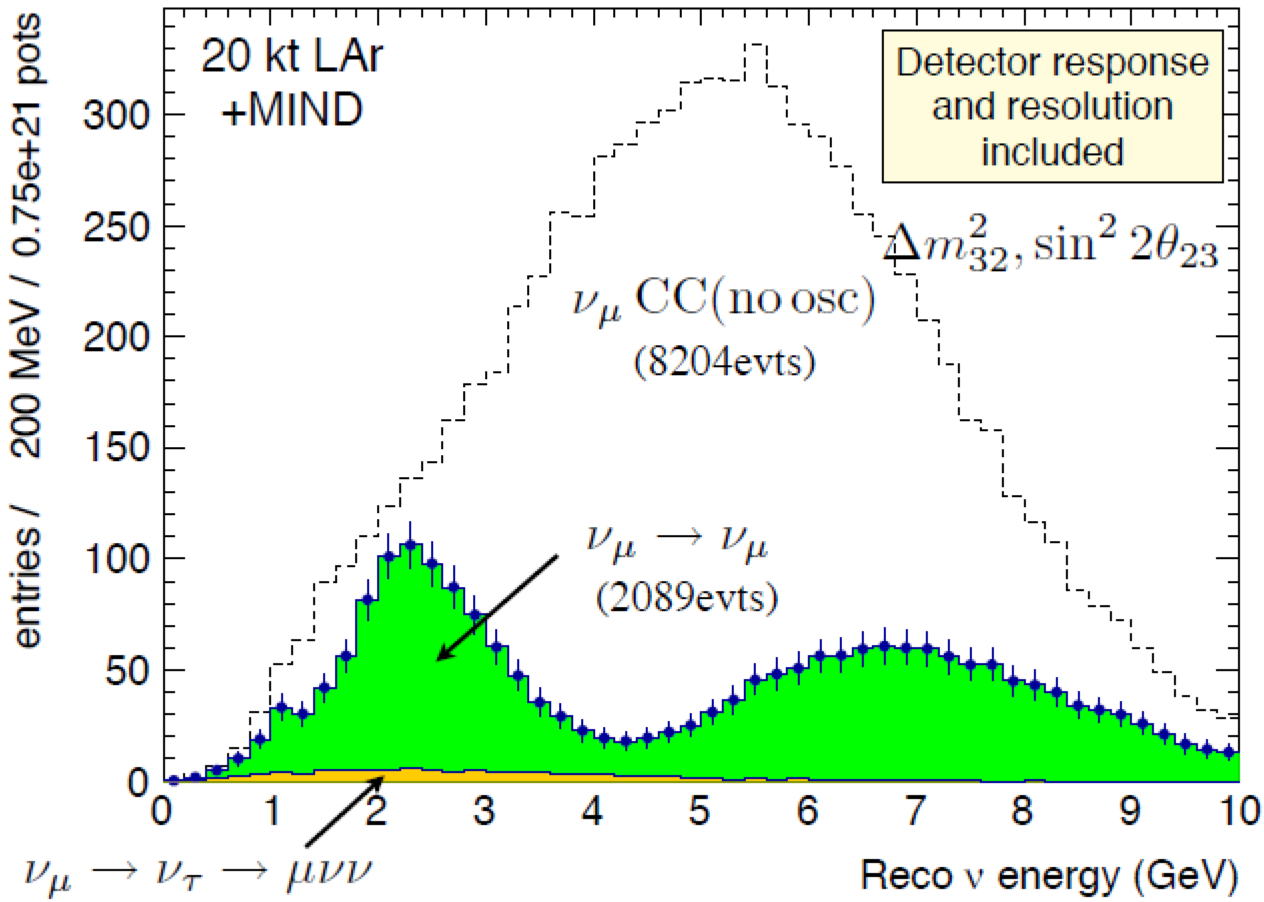
Signals at Pyhäsalmi : Inverted Hierarchy



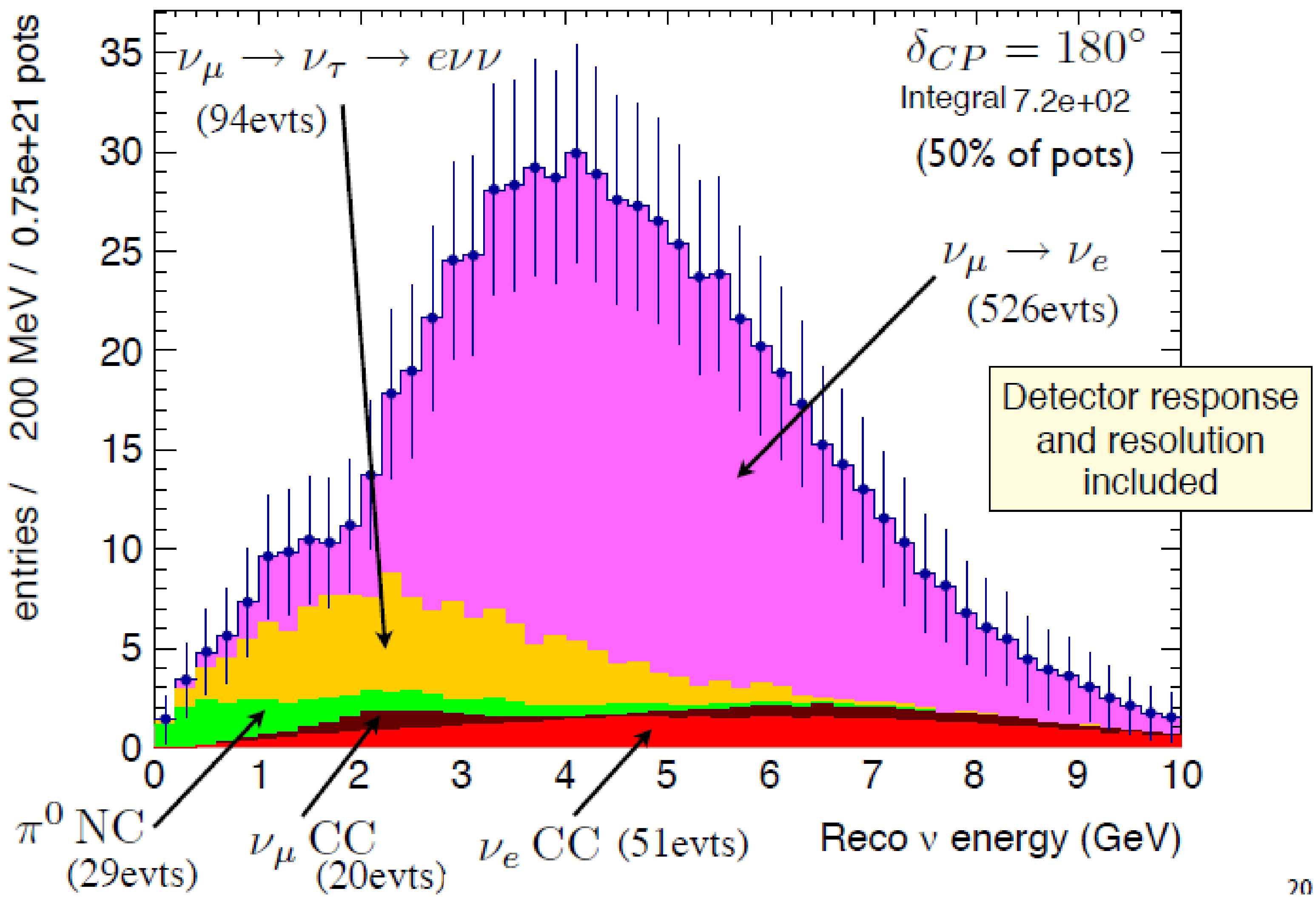
Flux Matching



Expected ν_μ sample



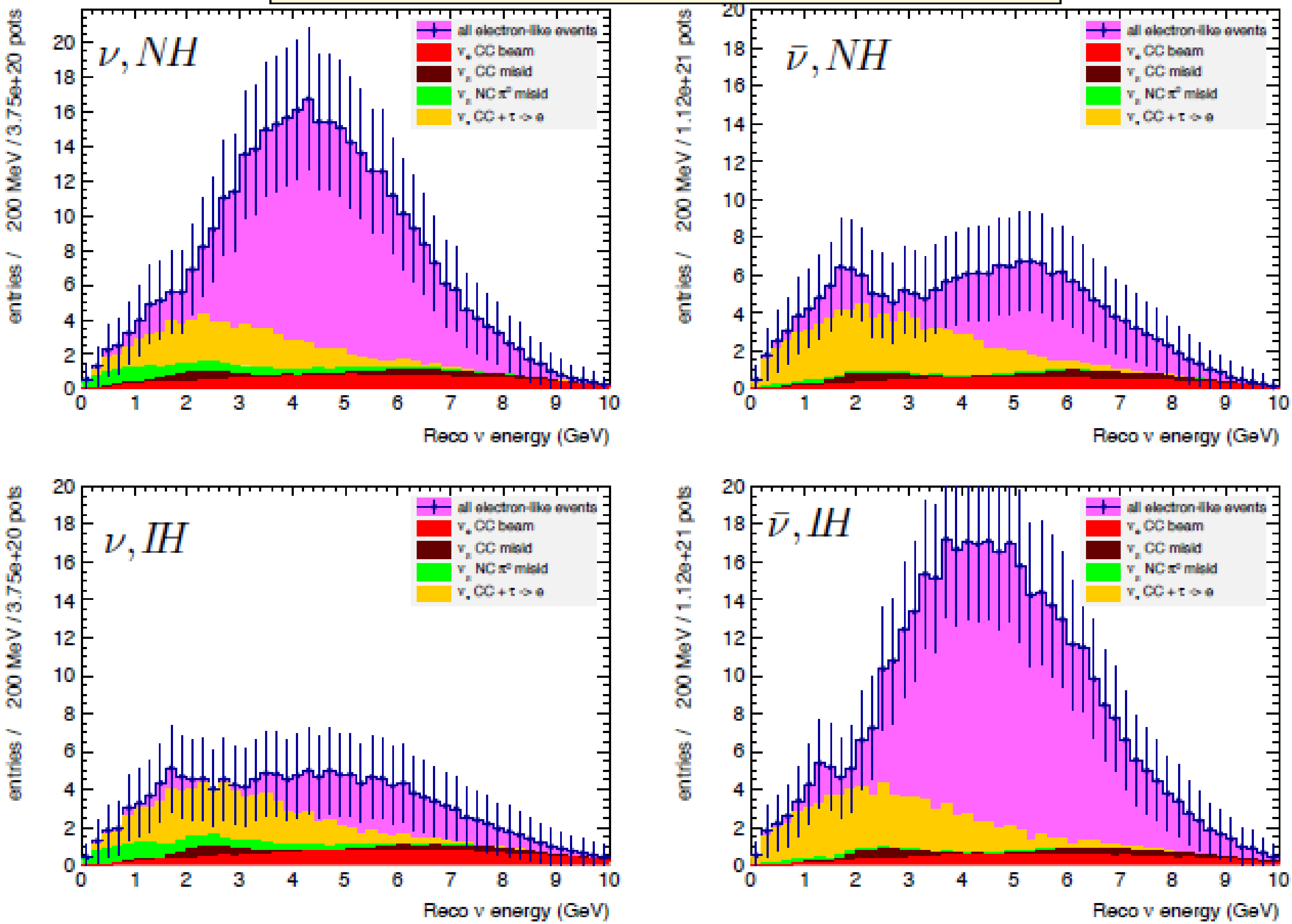
Expected ν_e sample



Determining oscillation parameters

Detector response and resolution included

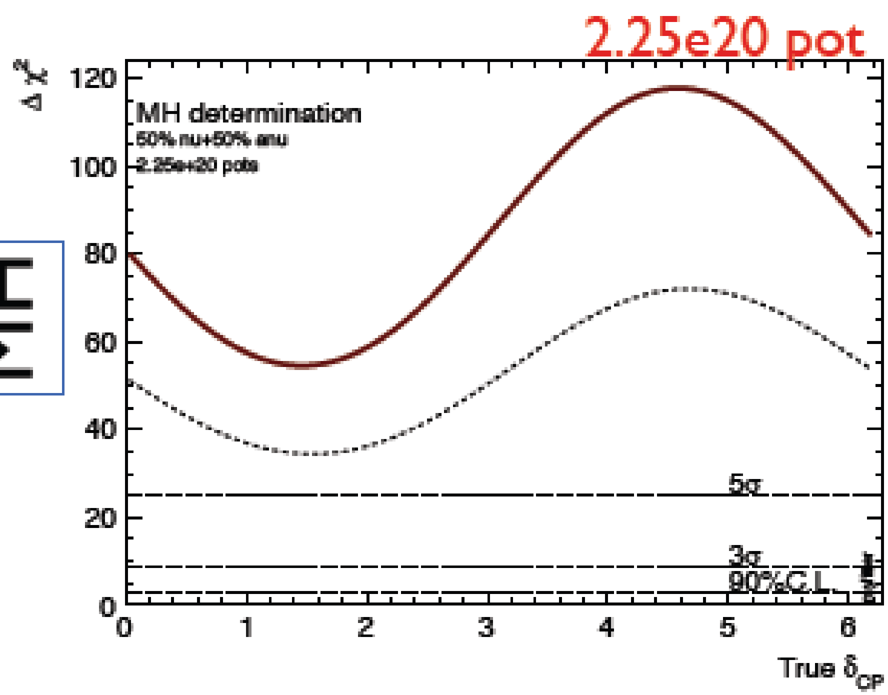
Running mode:
ν/anti-ν:25%/75%

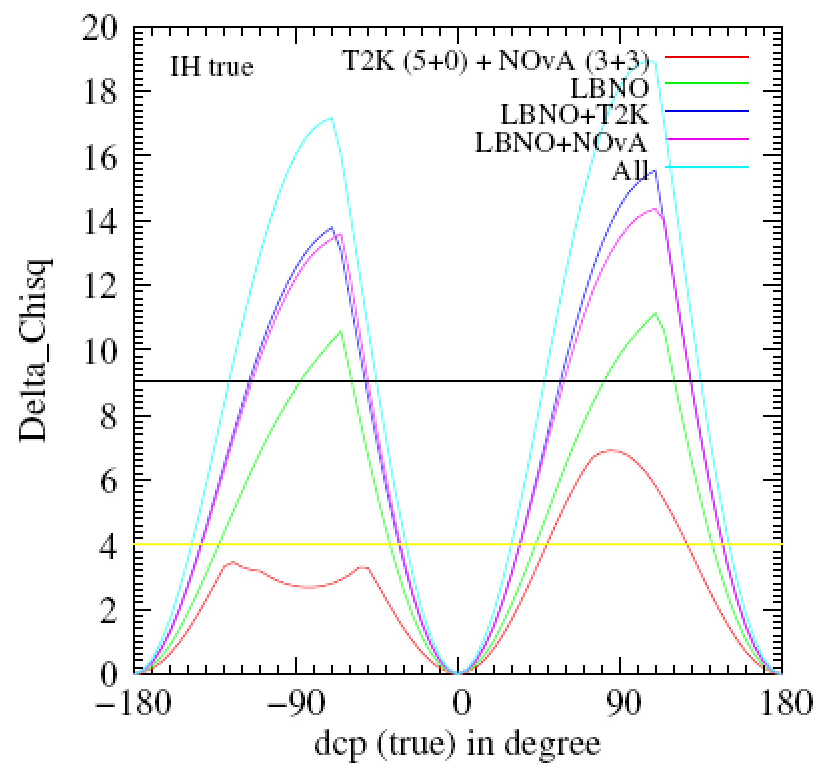


Physics reach of CERN- Pyhäsalmi

- After 10 years:
  - Full coverage of matter effect at 5σ.
  - 71% (44%) coverage of CPV at 90% (3σ).

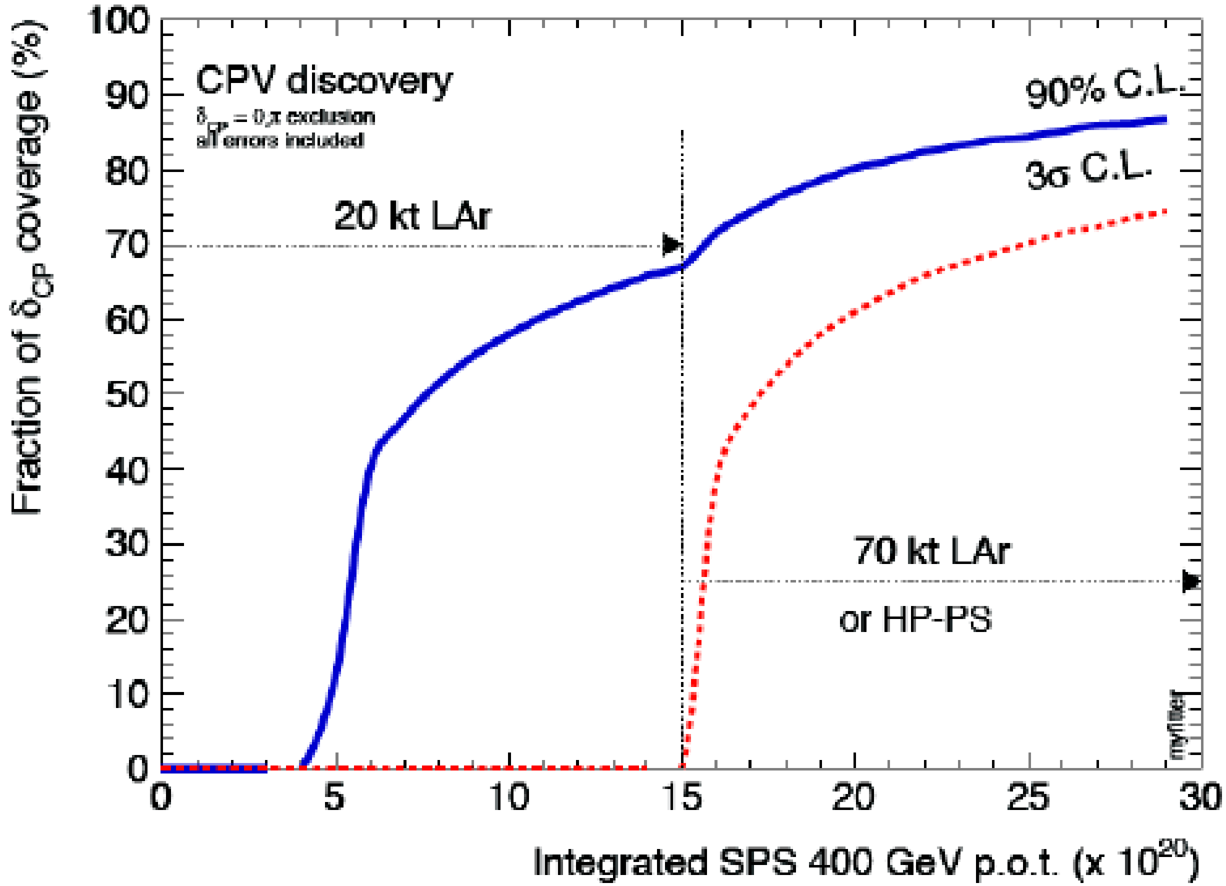
MH





CP Coverage

Incremental approach with conventional beams

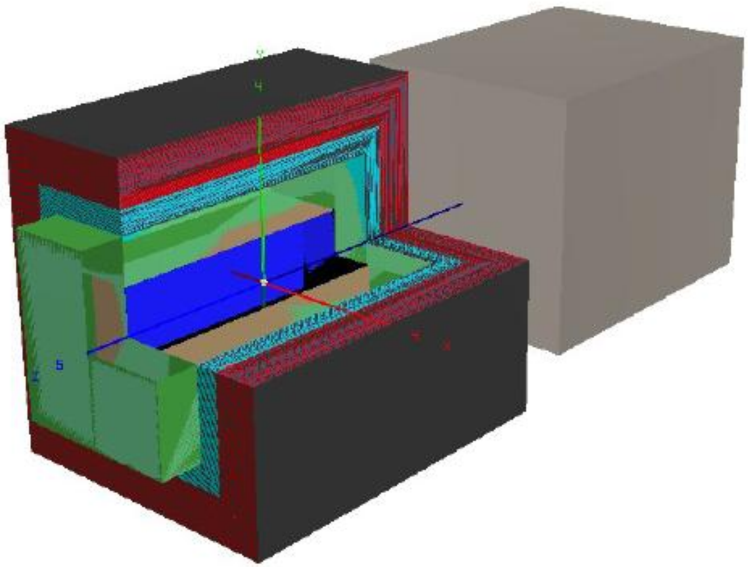


Limits to sensitivity

- Number of systematics that will need dedicated experiments to reduce
- Beam systematics
  - Target experiments ala NA61
  - Near detector
- Cross sections
  - T2K ND280, Minerva, MINOS
  - Near Detector
  - ν-storm
- Detector systematics
  - Test beam program.

Near Detector Options

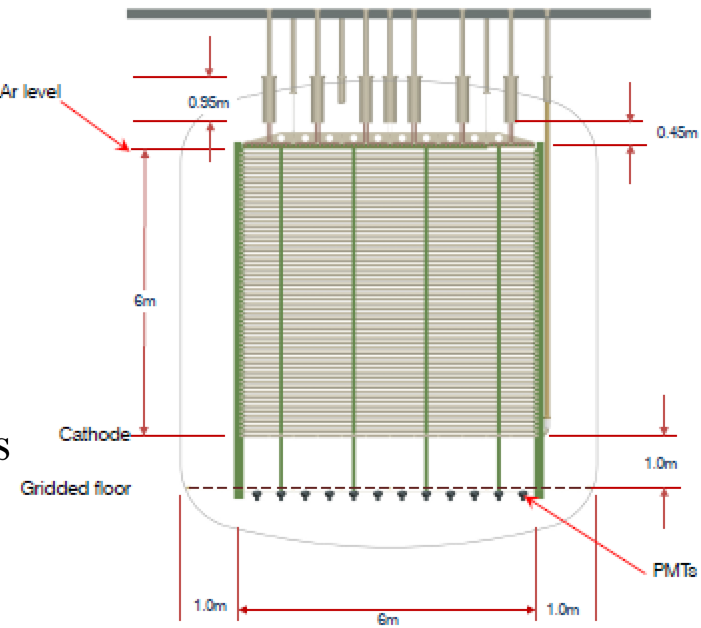
- A near detector will be required to control beam systematics and measure required cross sections.
- Can place the detector between 300m and 800m from target.
- Challenges:
  - Fully reconstruct DIS events
  - Match target materials
  - Detector Speed
- There is now a dedicated working group looking at the near detector design.



Possible Option:
High Pressure Ar TPC surrounded by scintillator with magnetic field
Followed by a magnetised iron calorimeter

The LAr testbeam program at CERN

- CERN is now planning and will start construction on a testbeam facility for liquid Argon detectors
  - Extension of existing beams in the north area
  - LAr infrastructure and detector pit provided
- Will provide
  - Charged particles from the test beam facility
  - Neutrinos from the potential short baseline program.
- Laguna liquid argon prototype will exploit this facility
  - 6x6x6 m detector
  - 300 tons of liquid Argon.
  - 5m drift
  - Ability to swap out readout
  - Full test of technology for Glacier.



side view

Timeline

- LAGUNA design study 2008-2011
- Start of LAGUNA – LBNO 2011
- Submission of EOI to CERN SPSC summer 2012
- EOI discussed at SPSC and invitation to submit TDR 2 weeks ago
- Extended site investigations 2013
- End of LAGUNA LBNO 2014
- LAGUNA LAr prototype at CERN begins 2014-2016
- Critical decision 2015?
- Construction from 2016?
- Start of physics running 2023?

Additional Option

- 2 beam approach
  - Second beam from Protovino (Russia)
  - 1160 km baseline
  - 350-500 kW

- Can run concurrently with beam from CERN
- Significantly enhanced CP coverage
- Physics studies underway in LAGUNA, to conclude next year.

2100 km from RAL, 1500 km from DESY, and 1160 km from Protvino.

Summary

- CERN – Pyhäsalmi program offer a rich physics program to fully explore the neutrino oscillation sector
  - 5 sigma discovery of mass hierarchy.
  - Good coverage of CP phase space.
  - Wide astrophysical neutrino program also possible.

- CERN SPSC has invited the submission of a TDR.

- Liquid Argon Testbeam program moving forward
  - Expect LAGUNA LAr prototype ~2017