T2K – The Next Generation

S. Boyd

WARWICK

Precis

- T2K in context
- The T2K Experiment
  - Introduction, Physics goals and sensitivity
  - JPARC and the neutrino beam
  - Near Detector
  - Far Detector
  - Schedule
- Conclusion

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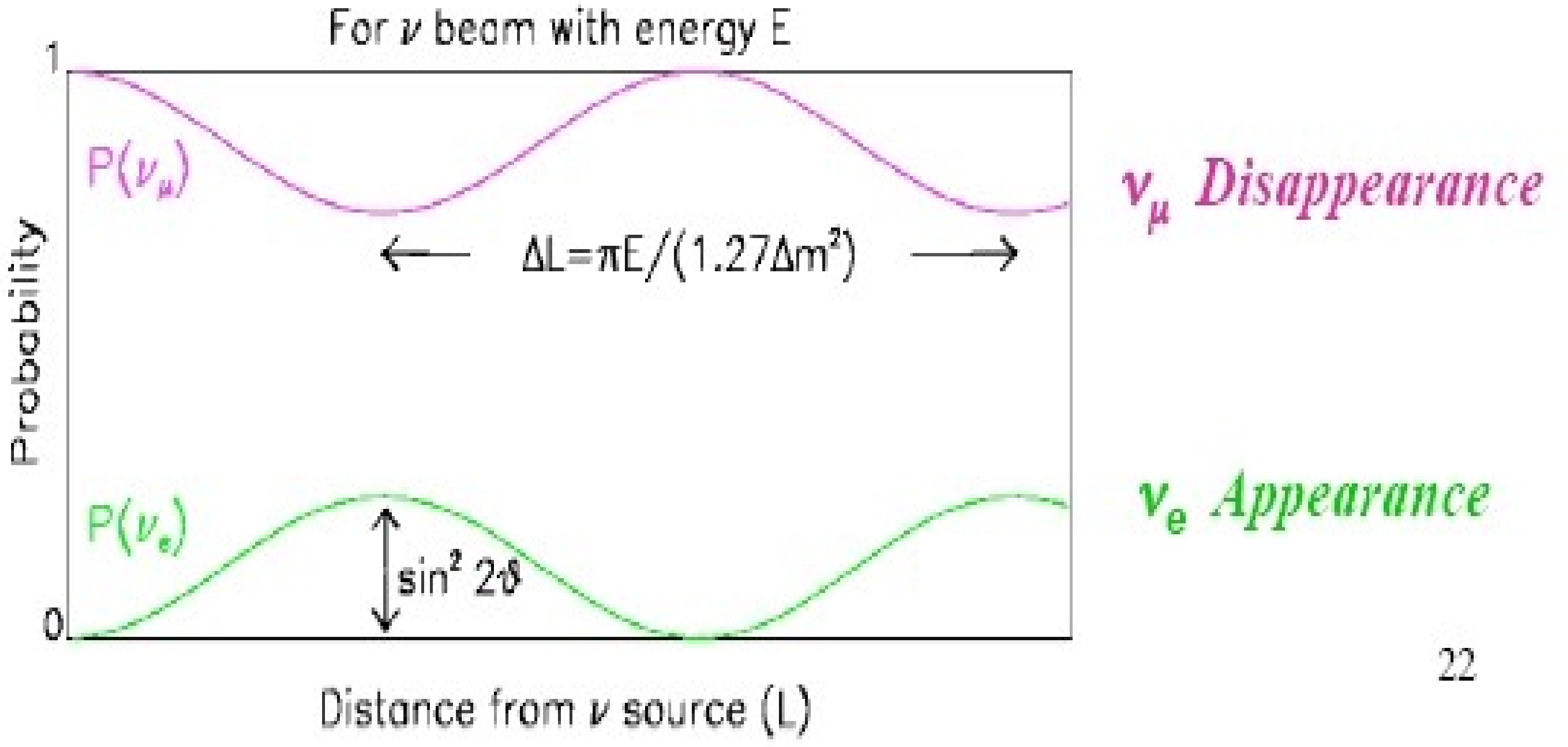
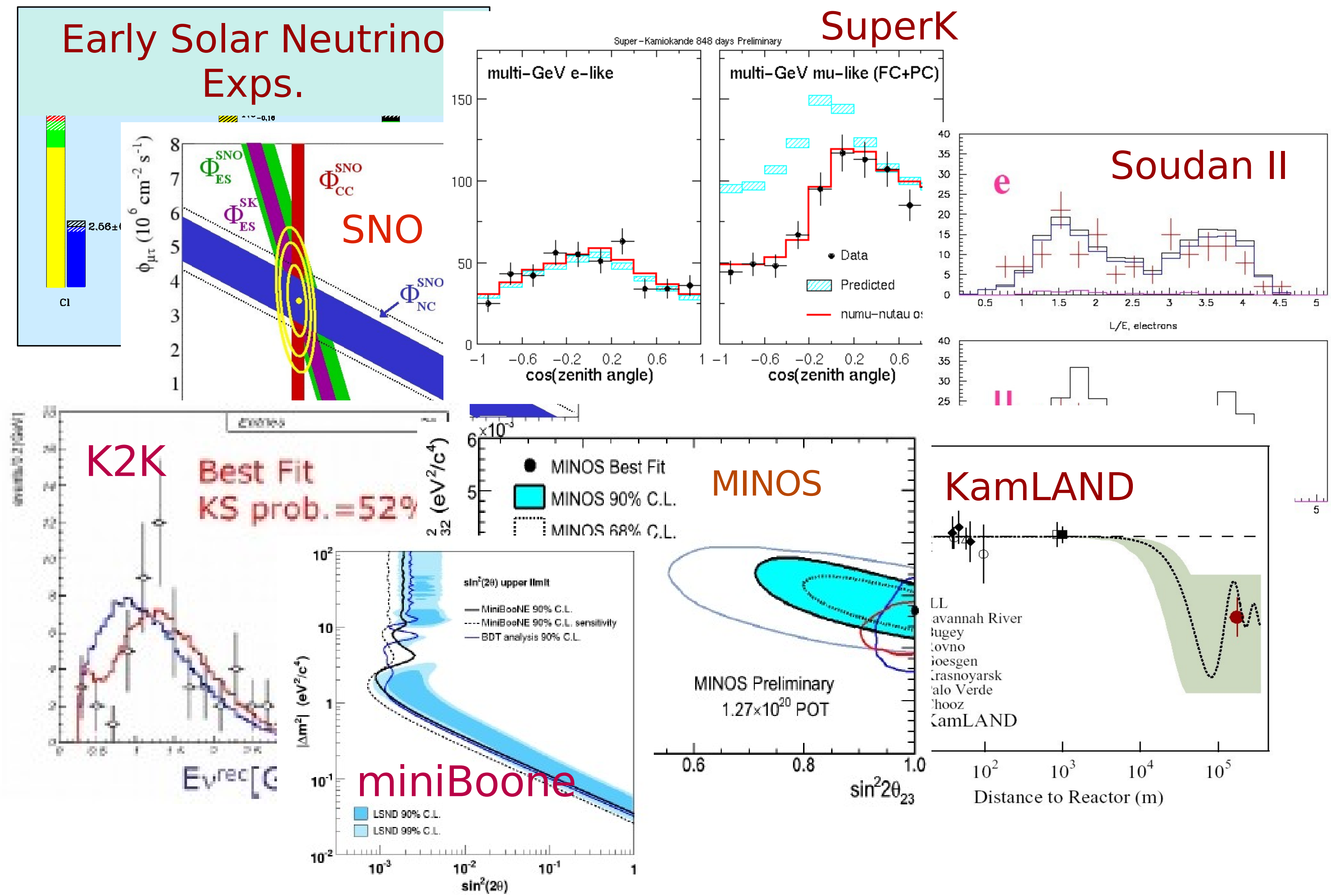
ν Oscillations

A quantum mechanical effect whereby a beam of neutrinos of one flavour can change to other flavours in flight.



This can only happen if neutrinos have mass

ν Oscillations



ν oscillations for Dummies

If neutrinos have mass then

$$l \in e, \mu, \tau \quad |\nu_l> = \sum_i U_{li} |\nu_i> \quad i \in 1,2,3$$

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = U \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix} \Leftrightarrow U = \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13} e^{i\delta} \\ 0 & 1 & 0 \\ -s_{13} e^{i\delta} & 0 & c_{13} \end{pmatrix}$$

$$c_{ij} = \cos\theta_{ij}; \; s_{ij} = \sin\theta_{ij}$$

$$P(\nu_\alpha \rightarrow \nu_\beta) = \sin^2(2\theta) \sin^2(1.27 \Delta m_{ij}^2 \frac{L}{E})$$

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Three angles

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$$c_{ij} = \cos\theta_{ij};\ s_{ij} = \sin\theta_{ij}$$

Two independent mass splittings – each with a sign

$$P(\nu_\alpha \rightarrow \nu_\beta) = \sin^2(2\theta) \sin^2(1.27 \Delta m_{ij}^2 \frac{L}{E})$$

ν oscillations for Dummies

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A CP violating term

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$$P(\nu_\alpha \to \nu_\beta) = \sin^2(2\theta) \sin^2(1.27\, \Delta m_{ij}^2 \frac{L}{E})$$

What do we know?

$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix}=U\begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}\Leftrightarrow U=\begin{pmatrix}c_{12} & s_{12} & 0\\ -s_{12} & c_{12} & 0\\ 0 & 0 & 1\end{pmatrix}\begin{pmatrix}1 & 0 & 0\\ 0 & c_{23} & s_{23}\\ 0 & -s_{23} & c_{23}\end{pmatrix}\begin{pmatrix}c_{13} & 0 & s_{13}e^{i\delta}\\ 0 & 1 & 0\\ -s_{13}e^{i\delta} & 0 & c_{13}\end{pmatrix}$$

$$\theta_{12}=32.5^\circ\pm 2.4^\circ$$
$$\Delta m^2_{12}=+7.1\times 10^{-5}\, eV^2$$
$$\nu_e\rightarrow\nu_\mu$$

Solar

$$\theta_{23}=45^\circ\pm 10^\circ$$
$$\Delta m^2_{23}=\left|2.1\times 10^{-3}\right| eV^2$$
$$\nu_\mu\rightarrow\nu_\tau$$

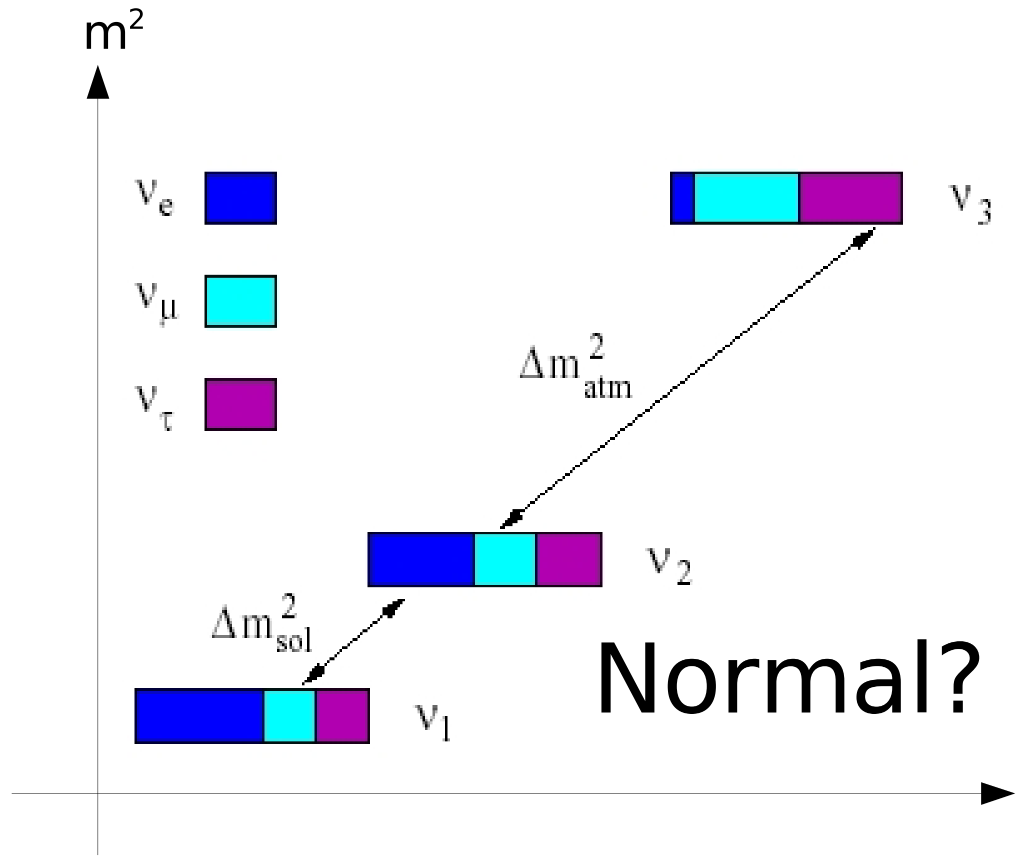
Atmospheric

$$\theta_{13}<10^\circ$$
$$0<\delta_{CP}<2\pi$$

Reactor

What we still have to do...

- Better measurements of known parameters
- Is $\theta_{23} = 45^o$?
- Value of θ_{13}?
- Value of δ_{CP}?
- Mass heirarchy?
- Absolute mass scale
- Dirac vs Majorana
- LSND anomaly



$$U_{MNSP} = \begin{pmatrix} 0.8 & 0.5 & \epsilon \\ 0.4 & 0.6 & 0.7 \\ 0.4 & 0.6 & 0.7 \end{pmatrix} \Leftrightarrow U_{CKM} = \begin{pmatrix} 0.975 & 0.222 & 0.004 \\ 0.221 & 0.97 & 0.04 \\ 0.01 & 0.04 & 0.999 \end{pmatrix}$$

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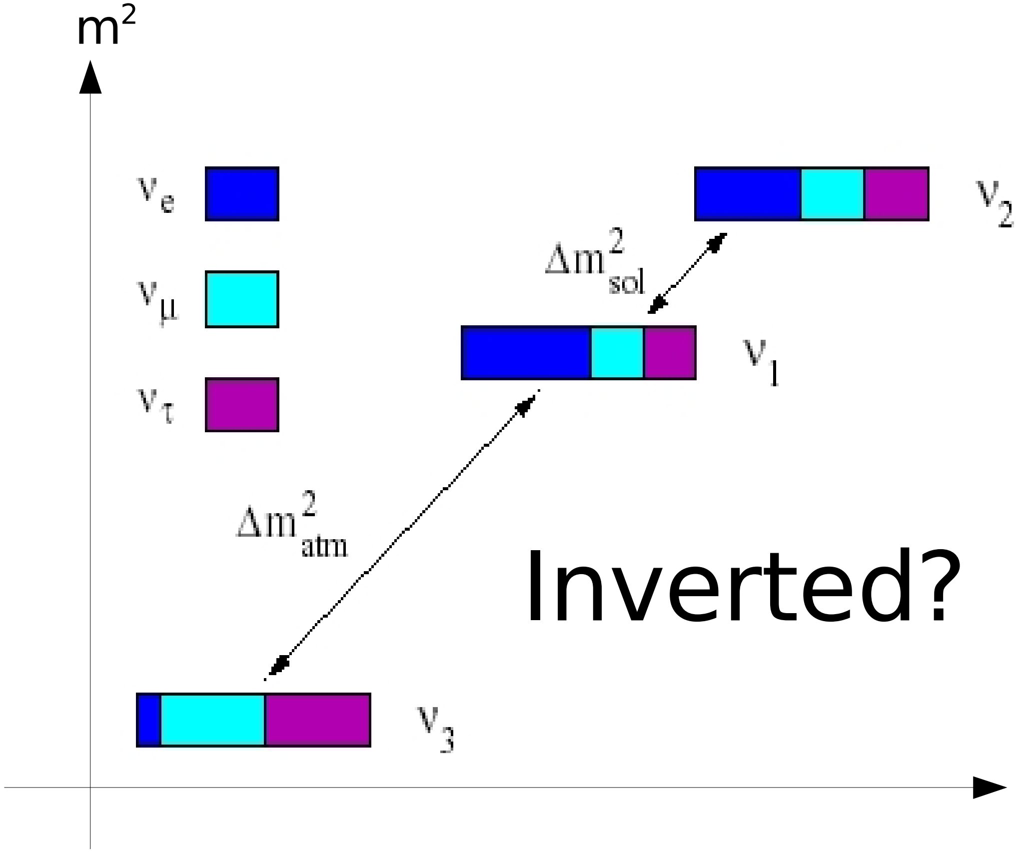

Inverted?

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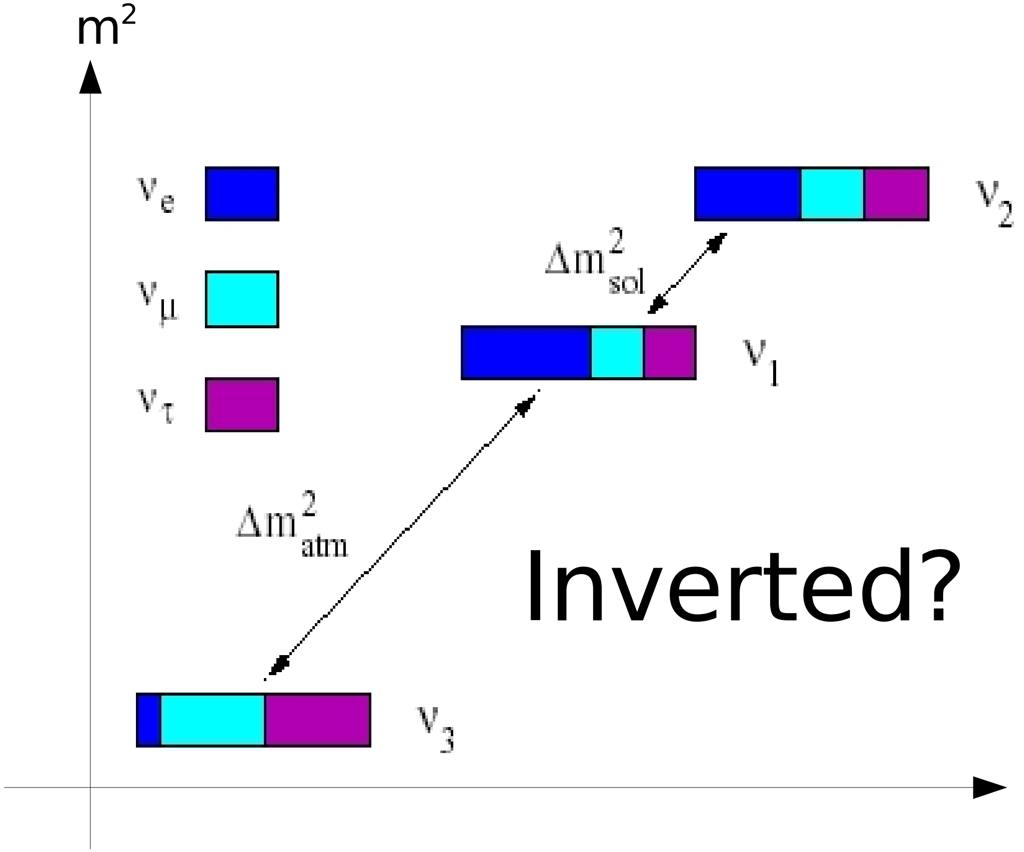

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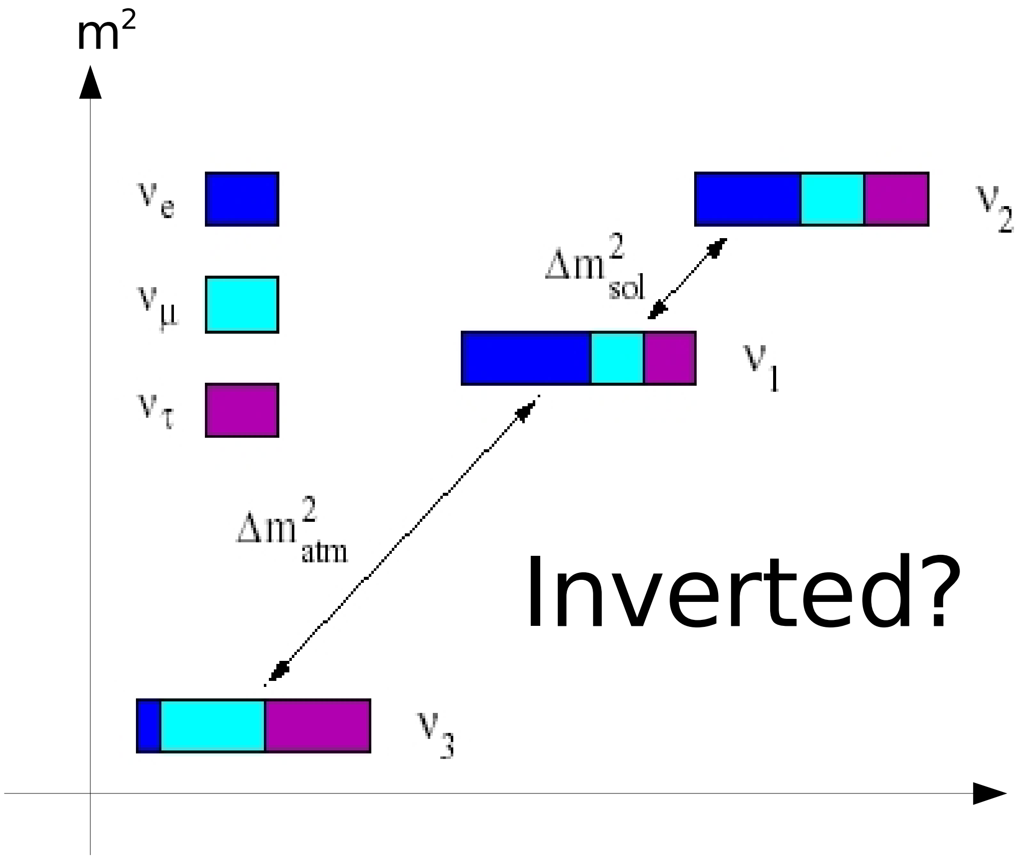

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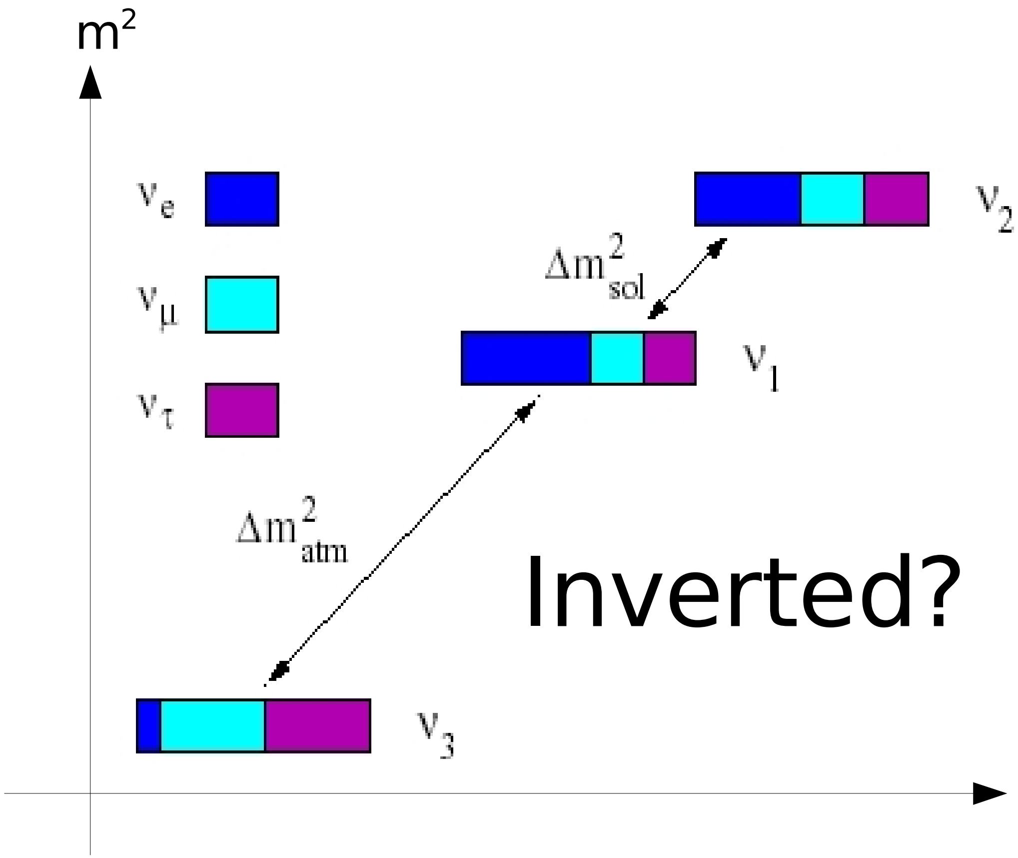

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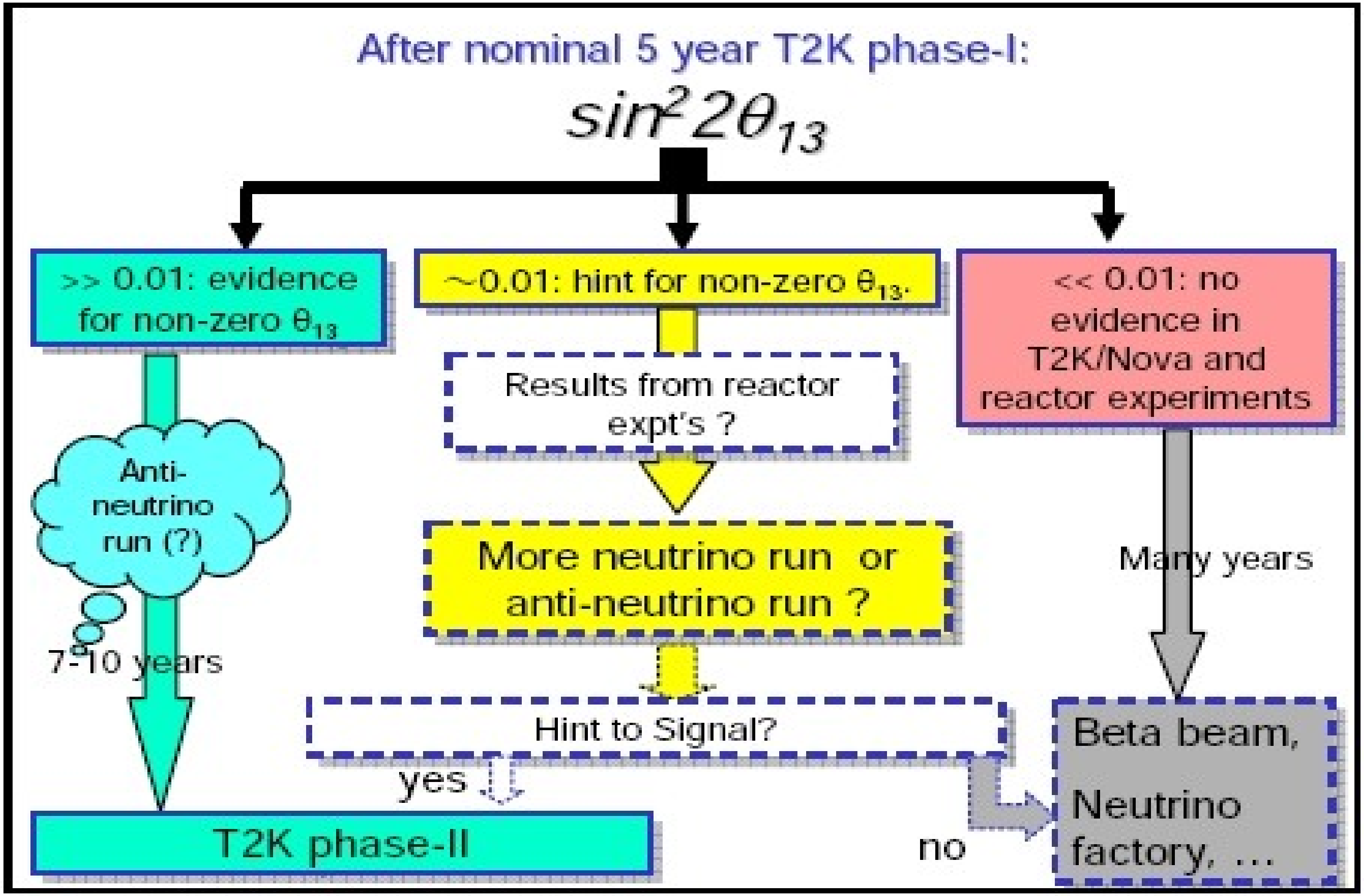
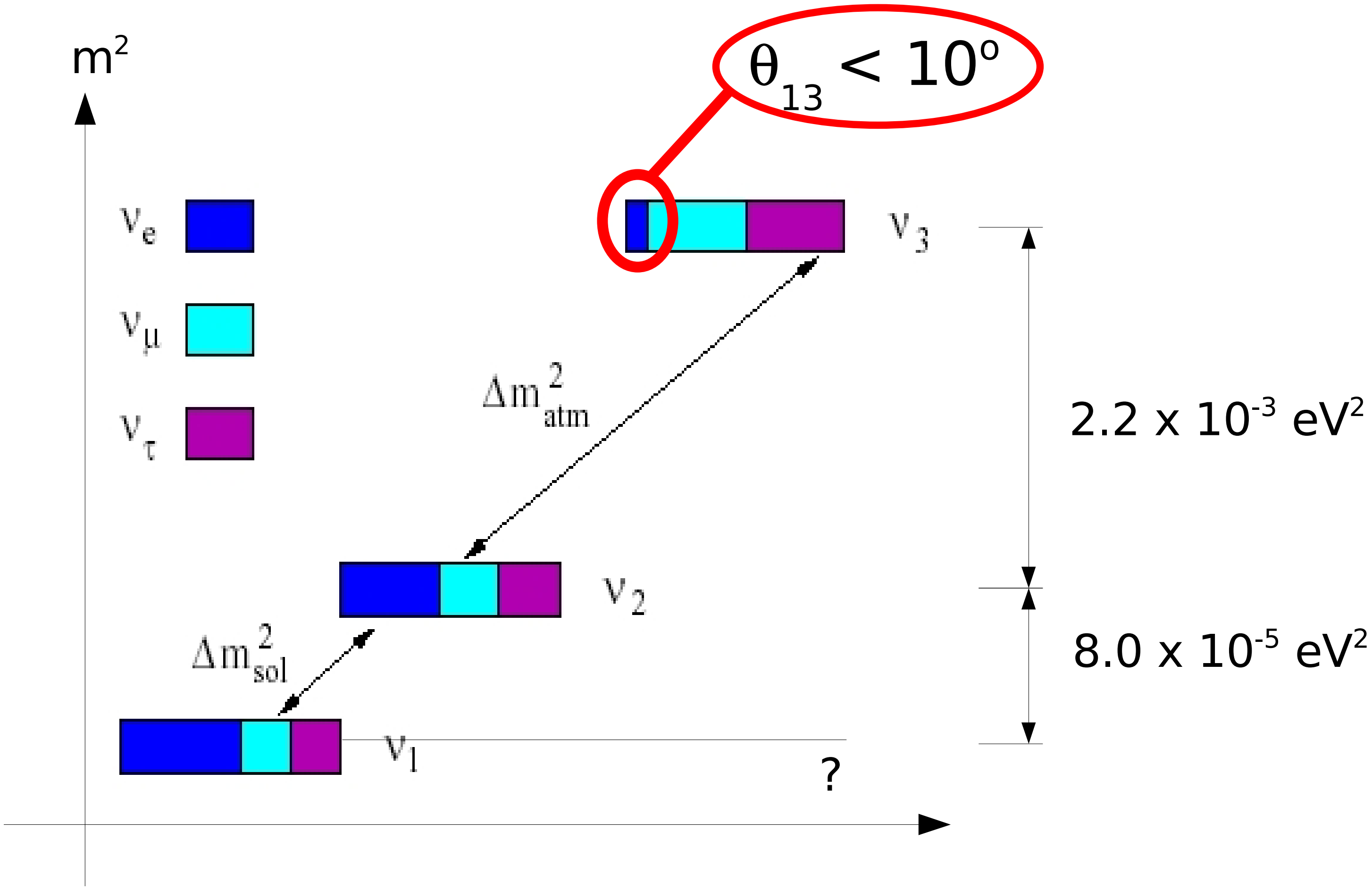
The Master Plan



θ_{13} determines the next 15-30 years or so of the field

What do we know about θ_{13}?



Easiest (!) path to study is the oscillation of ν_μ to ν_e at the atmospheric Δm^2

In all it's naked glory

$$P(\nu_\mu(\overline{\nu_\mu})\rightarrow\nu_e(\overline{\nu_e}))=s_{13}^2 s_{23}^2\sin^2(\frac{\Delta m_{31}^2 L}{4E})-\frac{1}{2}s_{12}^2 s_{13}^2 s_{23}^2(\frac{\Delta m_{21}^2 L}{2E})\sin(\frac{\Delta m_{31}^2 L}{2E})$$

$$+2J_r\cos\delta(\frac{\Delta m_{21}^2 L}{2E})\sin^2(\frac{\Delta m_{31}^2 L}{2E})\mp4J_r\sin\delta(\frac{\Delta m_{21}^2 L}{2E})\sin^2(\frac{\Delta m_{31}^2 L}{4E})$$

$$\pm c_{13}s_{13}^2 s_{23}^2(\frac{4Ea(x)}{\Delta m_{31}^2})\sin^2(\frac{\Delta m_{31}^2 L}{4E})$$

$$\mp\frac{a(x)L}{2}s_{13}^2 c_{13}s_{23}^2\sin(\frac{\Delta m_{31}^2 L}{2E})$$

$$+c_{23}^2 s_{12}^2\sin^2(\frac{\Delta m_{12}^2 L}{4E})$$

$$a=\pm2\sqrt{2}G_F n_e E_\nu$$

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$$\mp \frac{a(x) L}{2} s_{13}^2 c_{13} s_{23}^2 \sin(\frac{\Delta m_{31}^2 L}{2E})$$

$$+ c_{23}^2 s_{12}^2 \sin^2(\frac{\Delta m_{12}^2 L}{4E})$$

- Θ_{13}

$$J_r \equiv c_{12} s_{12} c_{23} s_{23} c_{13}^2 s_{13}$$

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- Θ_{13}
- $\Theta_{23}>45$ or $\Theta_{23}<45$

$$J_r\equiv c_{12}s_{12}c_{23}s_{23}c_{13}^2 s_{13}$$

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$$P(\nu_\mu(\overline{\nu}_\mu)\rightarrow\nu_e(\overline{\nu}_e))=s_{13}^2 s_{23}^2 \sin^2\left(\frac{\Delta m_{31}^2 L}{4E}\right)-\frac{1}{2}s_{12}^2 s_{13}^2 s_{23}^2\left(\frac{\Delta m_{21}^2 L}{2E}\right)\sin\left(\frac{\Delta m_{31}^2 L}{2E}\right)$$

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- Θ_{13}
- $\Theta_{23}>45$ or $\Theta_{23}<45$
- Sign(Δm_{23}^2)

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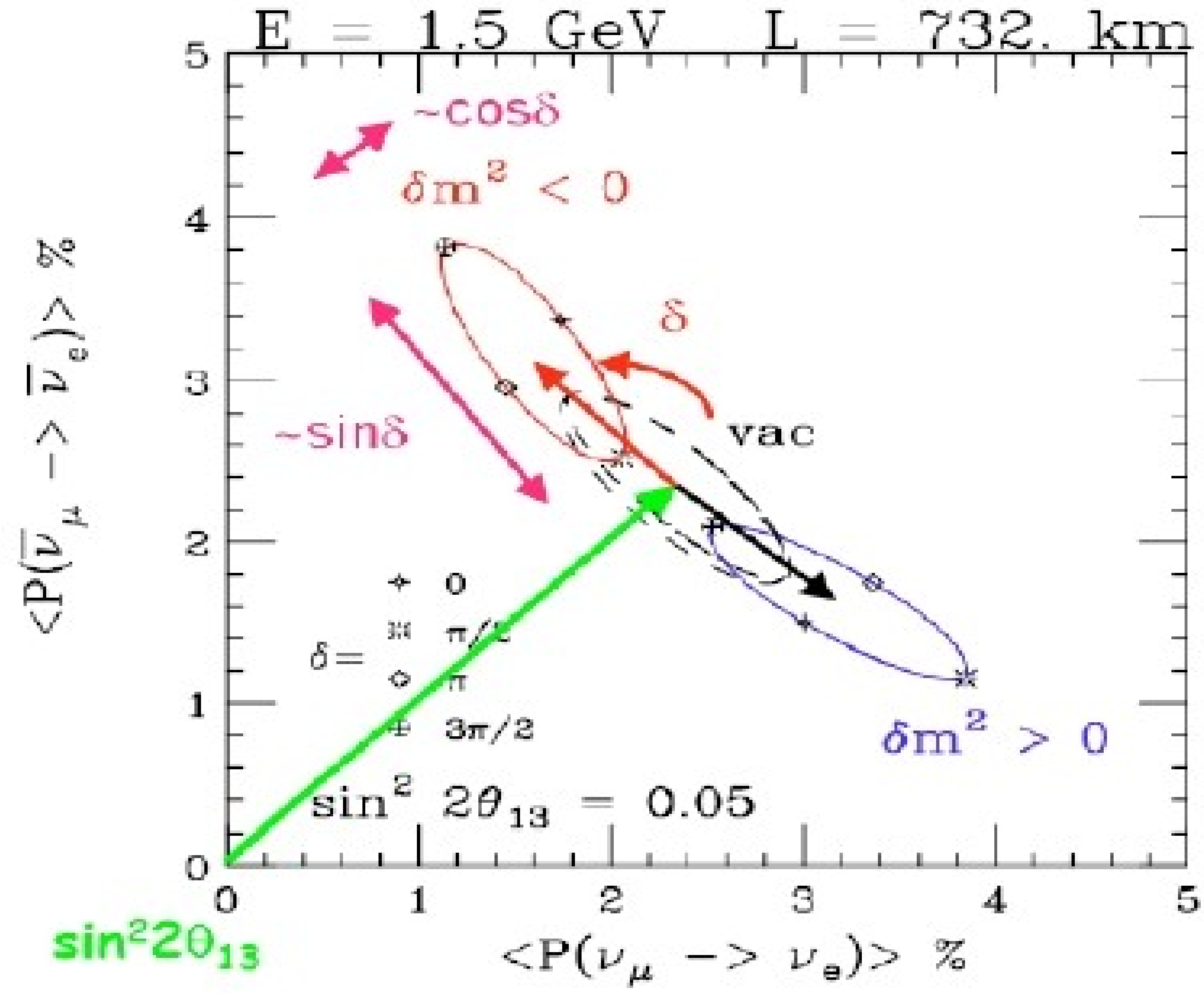
- δ

Ambiguities



Good news : $P(\nu_\mu \rightarrow \nu_e)$ depends on θ_{13},δ,mass heirarchy

NuSAG Report Mar '06

Good news : $P(\nu_\mu \rightarrow \nu_e)$ depends on θ_{13},δ,mass heirarchy

Bad news : $P(\nu_\mu \rightarrow \nu_e)$ depends on θ_{13},δ,mass heirarchy

NuSAG Report Mar '06

T2K,NOνA,Reactors...oh my!

Experiment	θ_{13}	CP δ	Mass Heirarchy
Reactor	✓	✗	✗
T2K	✓	✓	✗
NovA	✓	✓	✓

Not only combination, but generally agreed that a reactor plus two long baseline measurements at different L/E will be required to fully disentangle all the effects.

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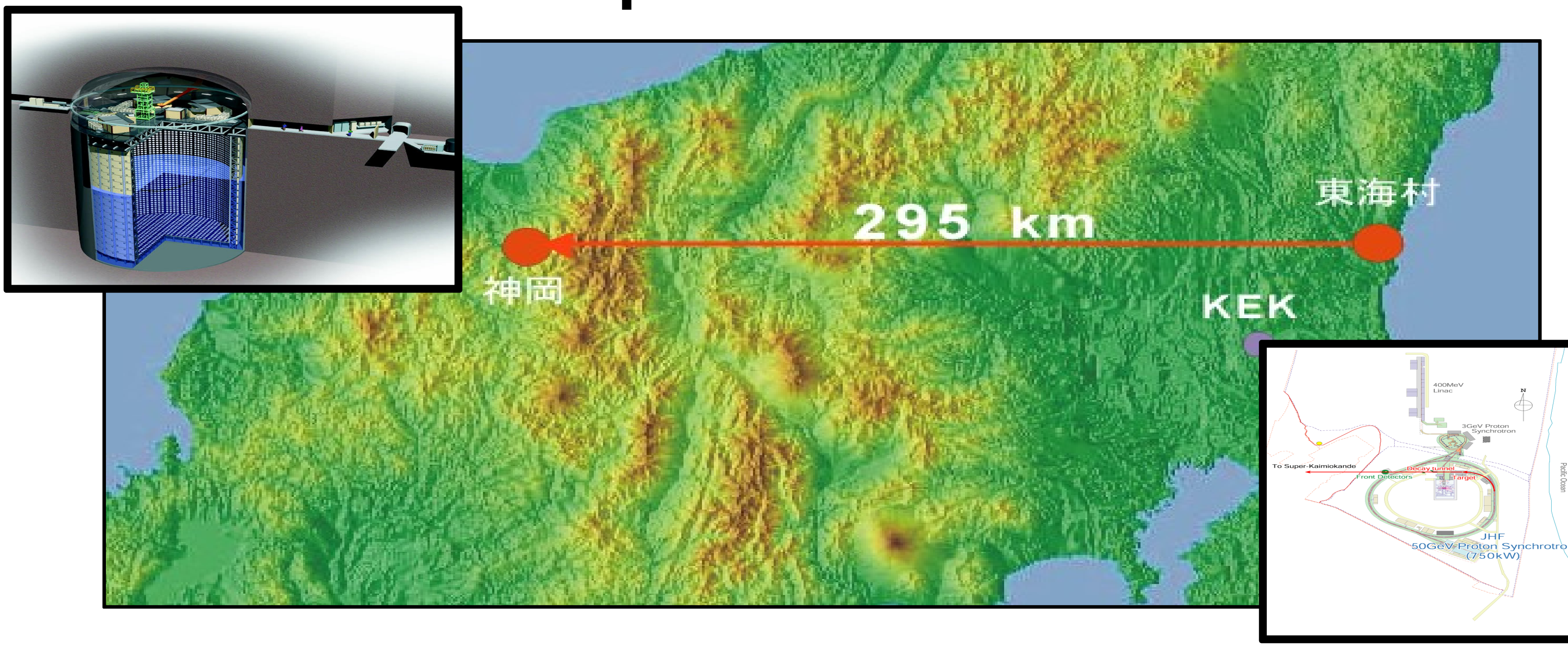
The T2K (Tokai-2-Kamioka) Experiment

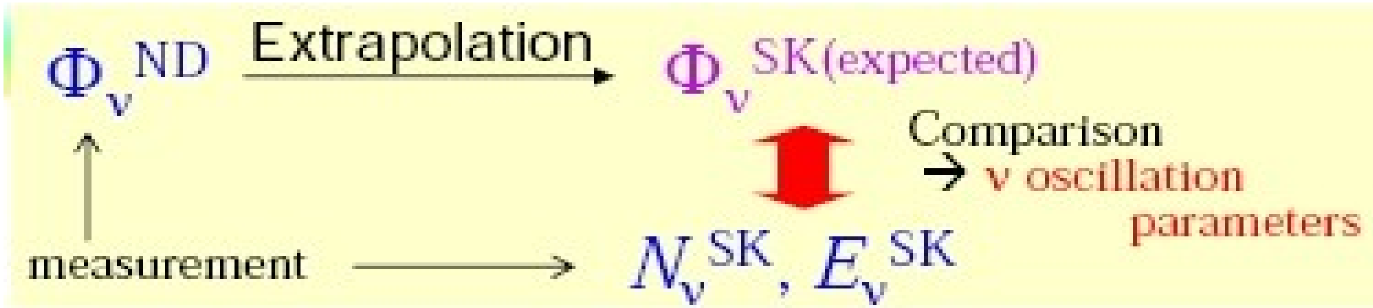


- Phase 1 : 2007-201x(?)
  - ~ 1 MW 50 GeV PS → 22.5 kton SuperK
  - $\nu_\mu \rightarrow \nu_x$ disappearance, $\nu_\mu \rightarrow \nu_e$ appearance
- Phase 2 : 201x(?)-202x(?)
  - ~4 MW 50 GeV PS → 1 Mton detector (HK, or Korea)

Who we are...

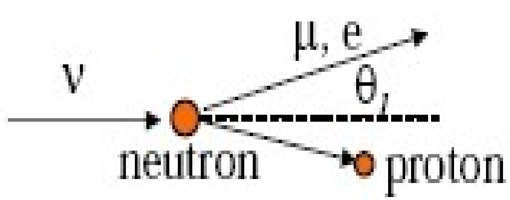
11 countries, 58 institutions, 190 (and rising) physicists

How to do an oscillation experiment



Δm^2_{23} ~2.5 x 10^{-3} eV^2, L = 295 km ⇒ osc. Max @ 0.6 GeV

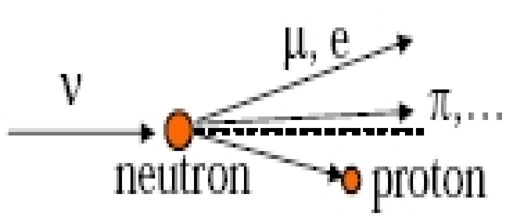
- CC-QE is dominant interaction mode

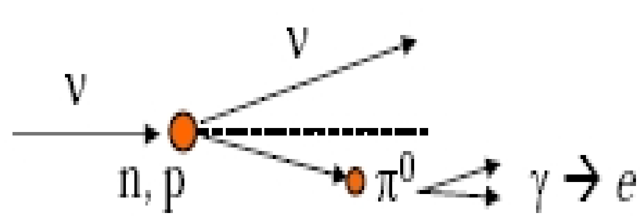


$$E_\nu = \frac{m_N E_l - m_l^2/2}{m_N - E_l + p_l \cos\theta_l}$$

$$\frac{\Delta E}{E} \sim 0.1$$

- Non CC-QE modes important for background issues





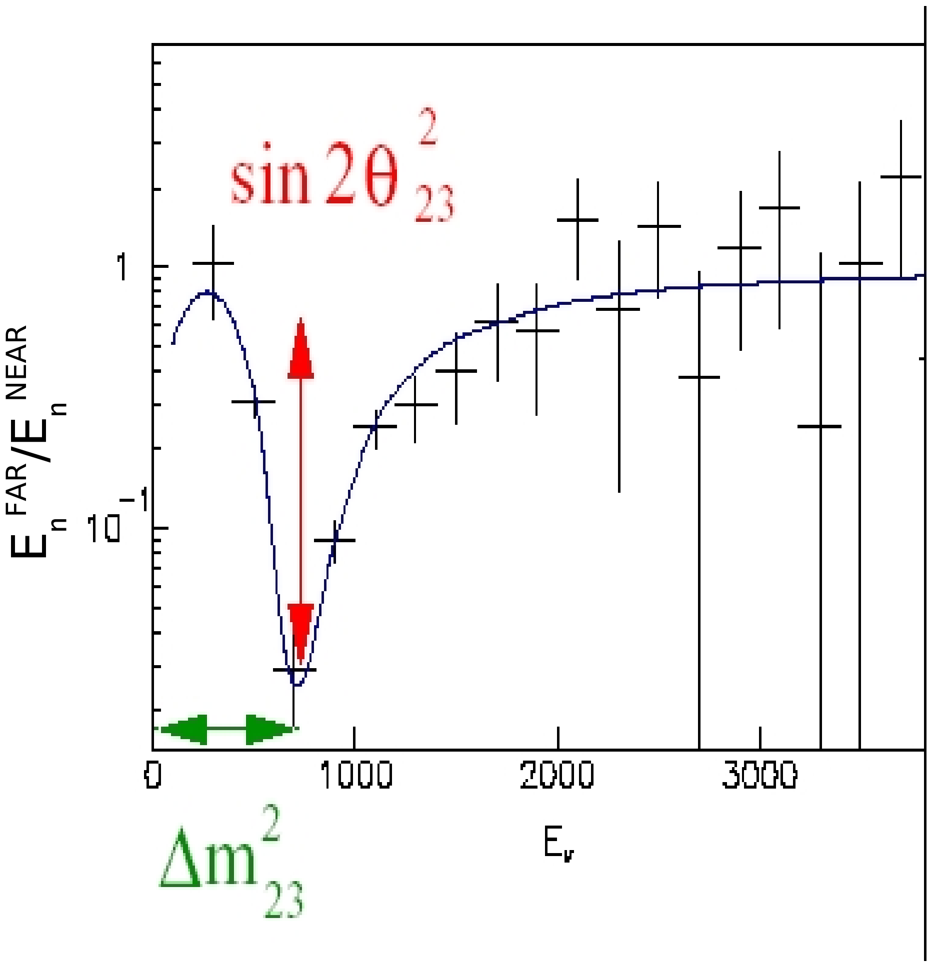
Disappearance Measurement

$$P\left(\nu_\mu \rightarrow \nu_x\right) \sim \sin^2 2\theta_{23} \sin^2\left(1.27\,\Delta m_{23}^2 \frac{L}{E}\right)$$

We want to measure

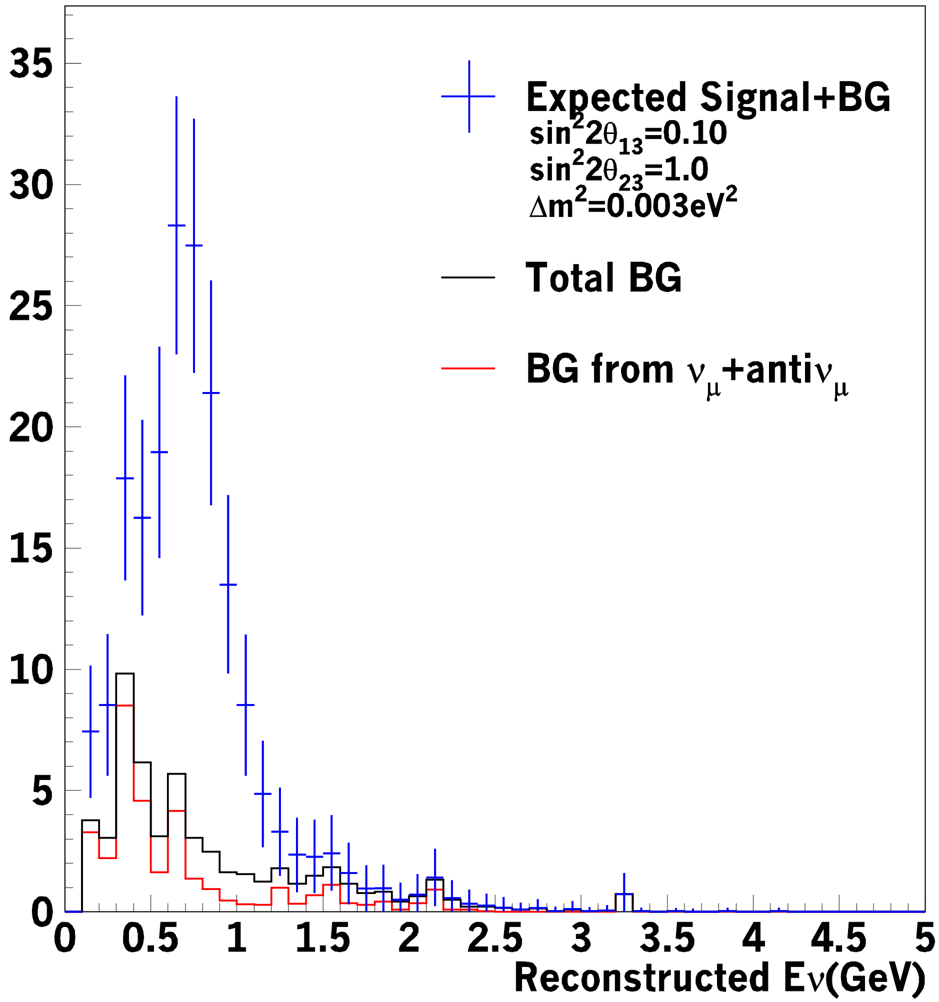
$$\frac{\Phi(E_\nu)(@SK)}{\Phi(E_\nu)(no\,oscillations)}$$

- Measure Φ times σ, not Φ
- Detector has efficiencies
- Backgrounds exist



Appearance Measurement

$$P\left(\nu_\mu \rightarrow \nu_e\right) \sim \sin^2(\theta_{23})\sin^2(2\theta_{13})\sin^2\left(1.27\,\Delta m_{23}^2 \frac{L}{E_\nu}\right)$$



- Look for an excess of ν_e in the far detector
- Understanding the background is the crucial issue

Conventional beams are never 100% pure

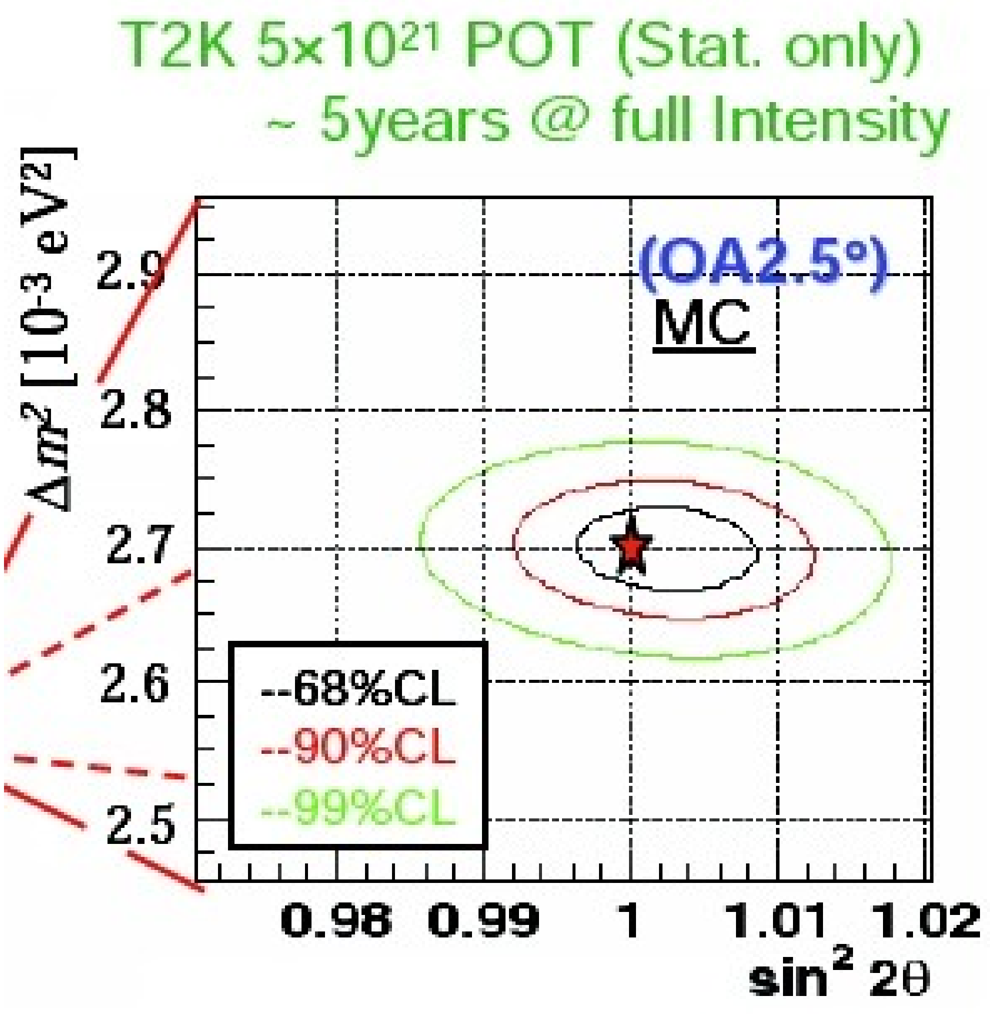
Always some background in the analysis of far detector data

T2K-I Physics Goals

- ν_μ disappearance : $P(\nu_\mu \rightarrow \nu_\mu) = 1 - \sin^2 2\theta_{23} \sin^2(1.27\Delta m^2_{23} L/E)$

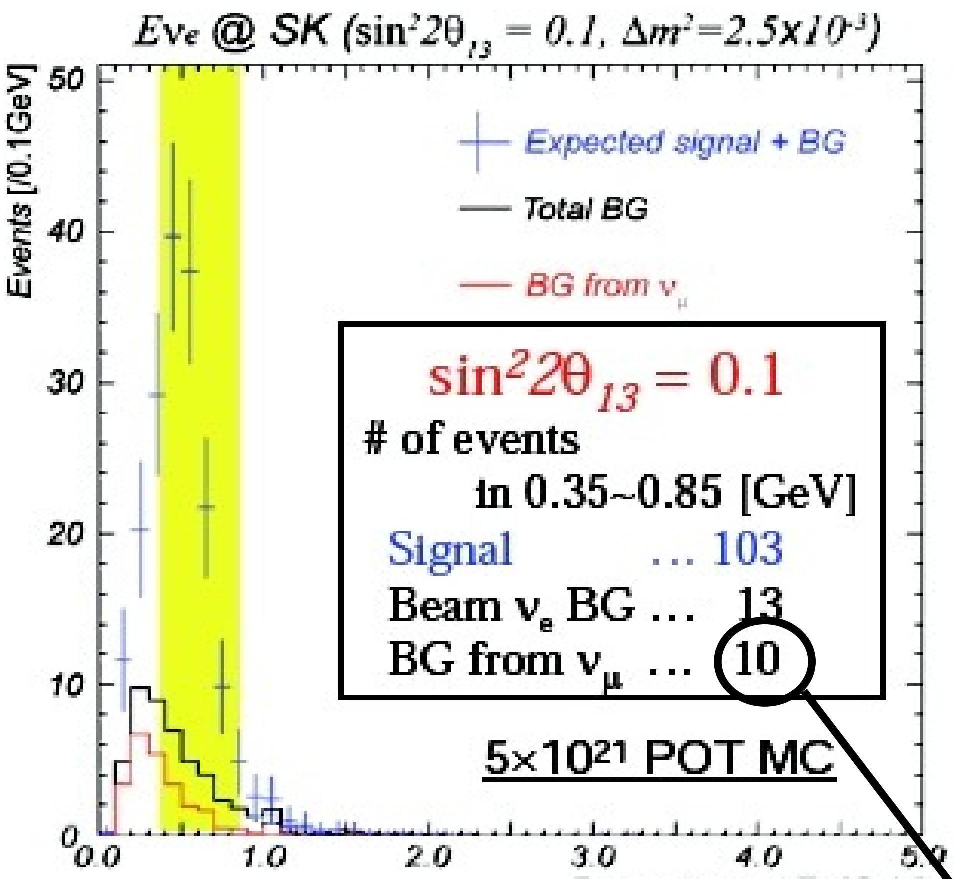
Δm^2 (eV^2)	CC-QE	CC-nonQE	NC	All ν_μ
No oscillation	3,620	1,089	96	4,805
2.0×10^{-3}	933	607	96	1,636
2.3×10^{-3}	723	525	96	1,344
2.7×10^{-3}	681	446	96	1,223
3.0×10^{-3}	800	414	96	1,310

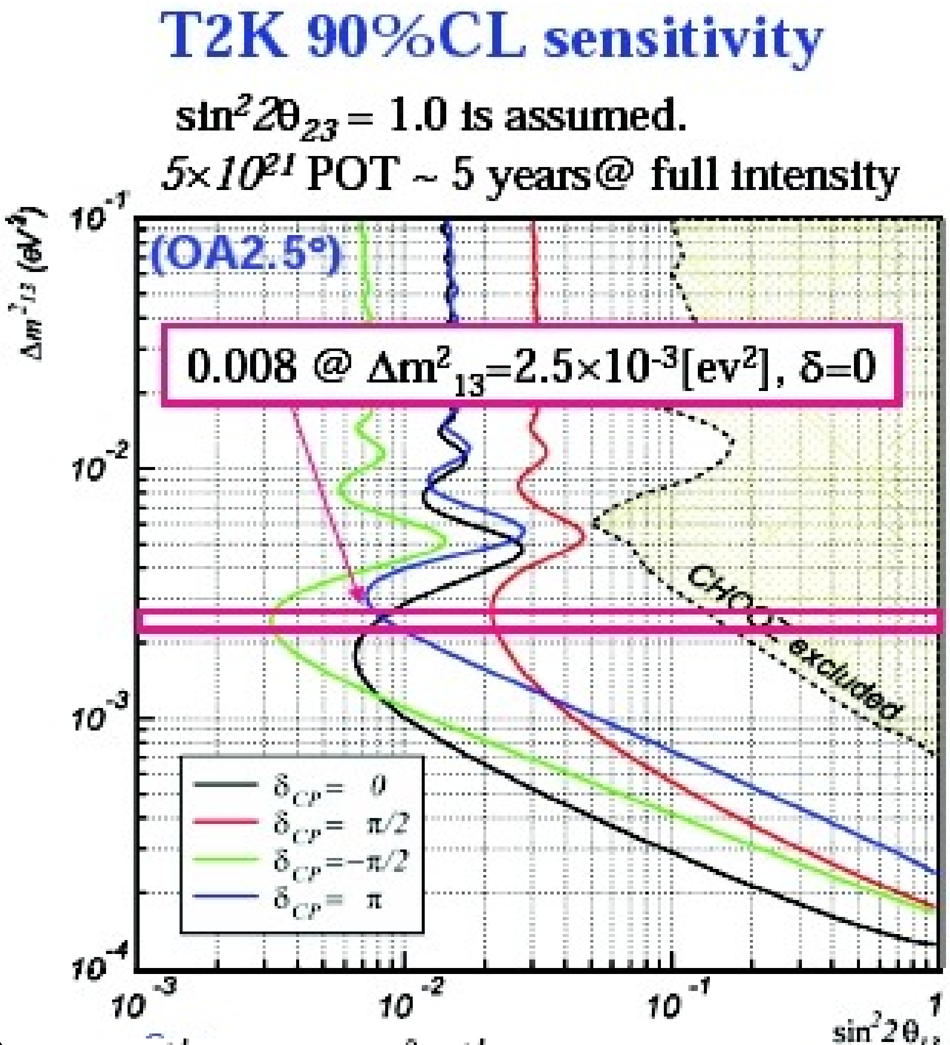
	MINOS	T2K-1
$\delta(\sin^2(2\theta_{23}))$	0.06	0.01
$\delta(\Delta m^2_{23})$	$2*10^{-4}$ eV^2	$1*10^{-4}$ eV^2

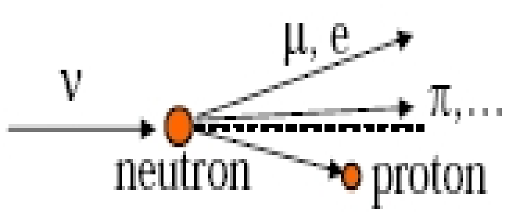


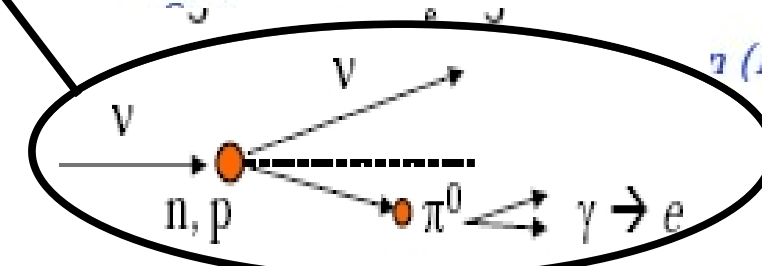
T2K-I Physics Goals

- ν_e appearance

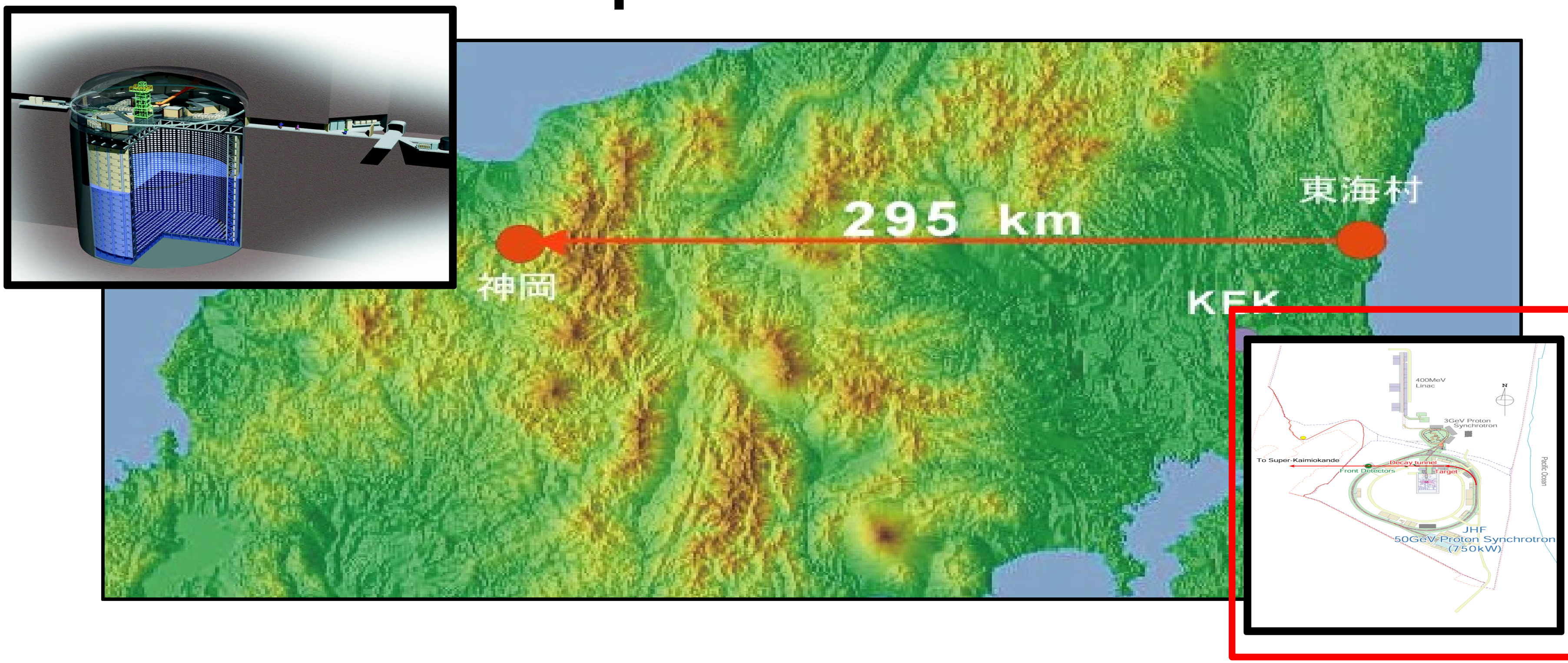




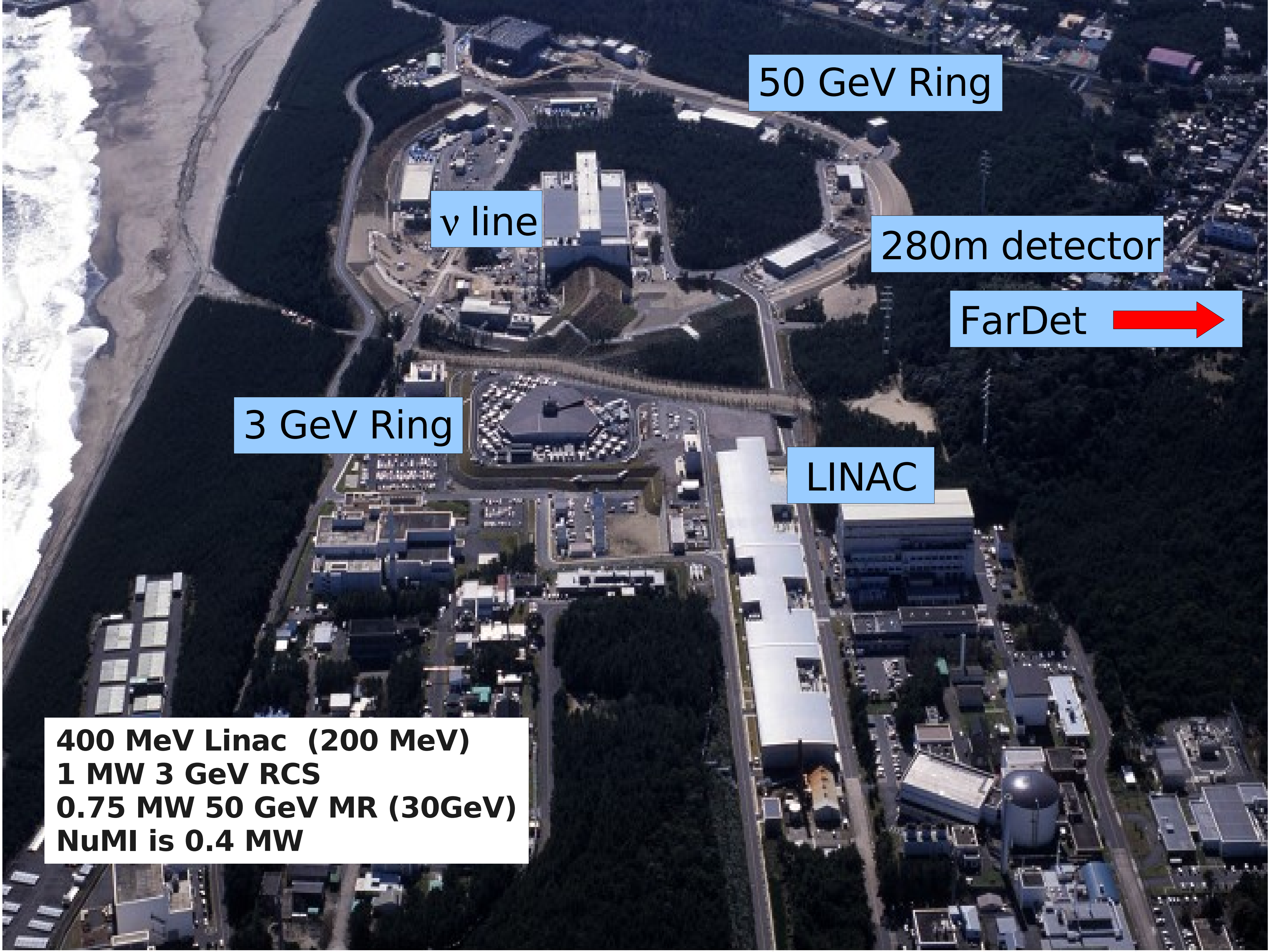




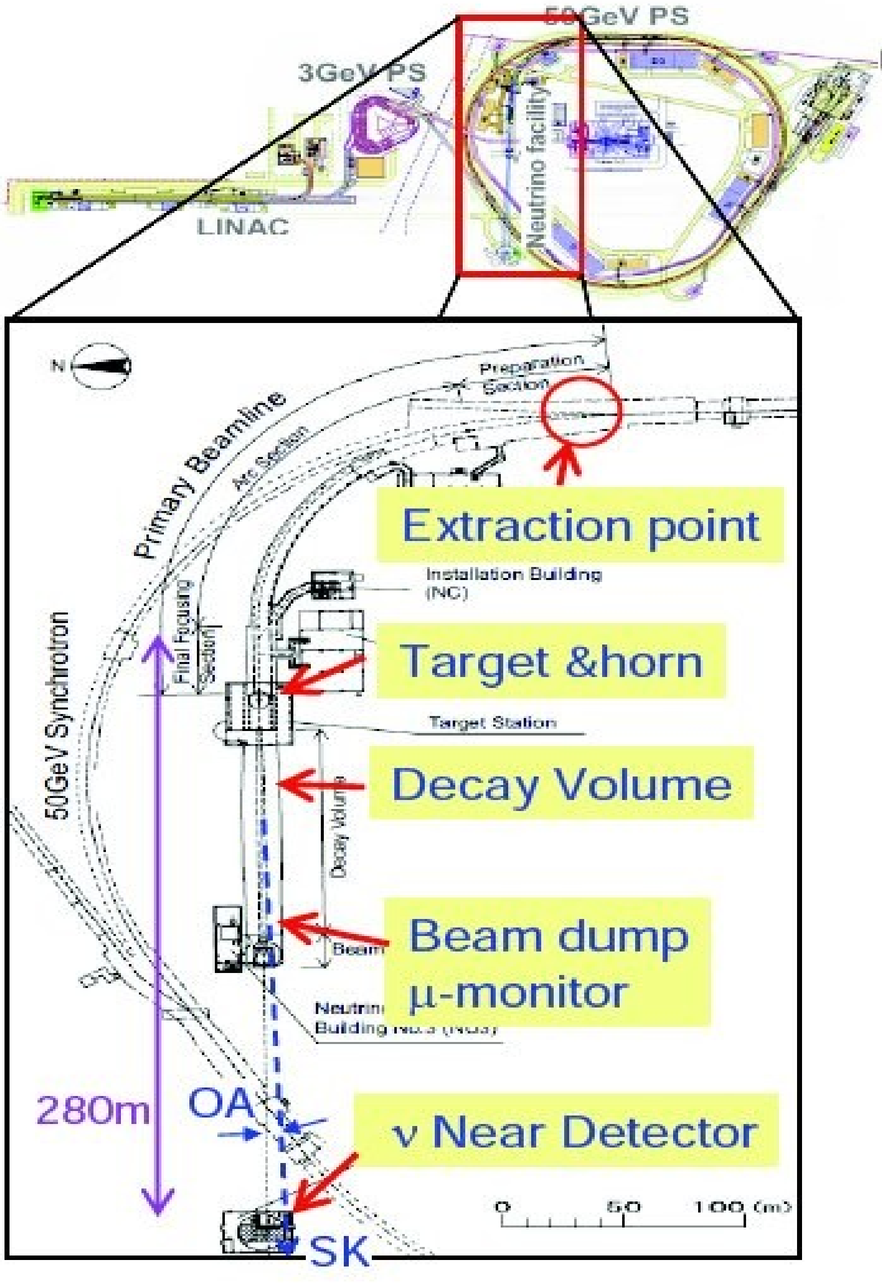
The T2K (Tokai-2-Kamioka) Experiment



- Phase 1 : 2007-201x(?)
  - ~ 1 MW 50 GeV PS → 22.5 kton SuperK
  - $\nu_\mu \rightarrow \nu_x$ disappearance, $\nu_\mu \rightarrow \nu_e$ appearance
- Phase 2 : 201x(?)-202x(?)
  - ~4 MW 50 GeV PS → 1 Mton detector (HK, or Korea)


50 GeV Ring
ν line
280m detector
FarDet
3 GeV Ring
LINAC
400 MeV Linac (200 MeV)
1 MW 3 GeV RCS
0.75 MW 50 GeV MR (30GeV)
NuMI is 0.4 MW

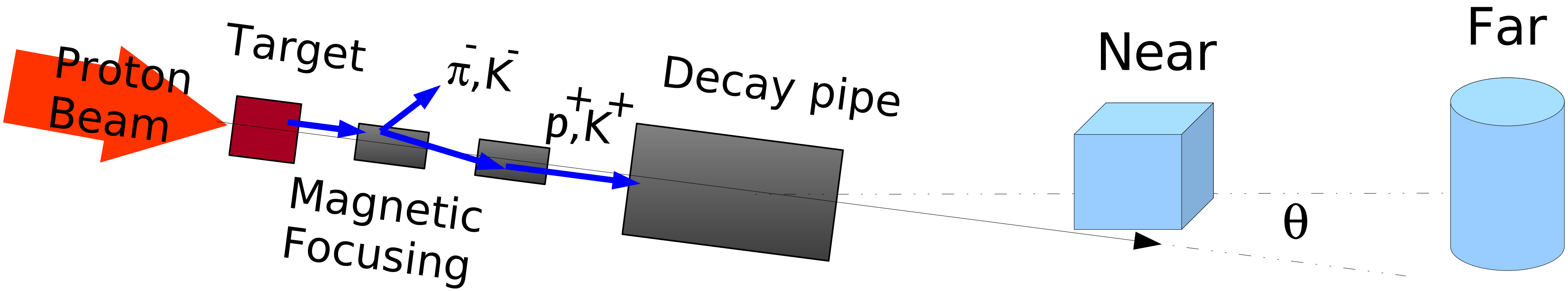
JPARC Neutrino beam

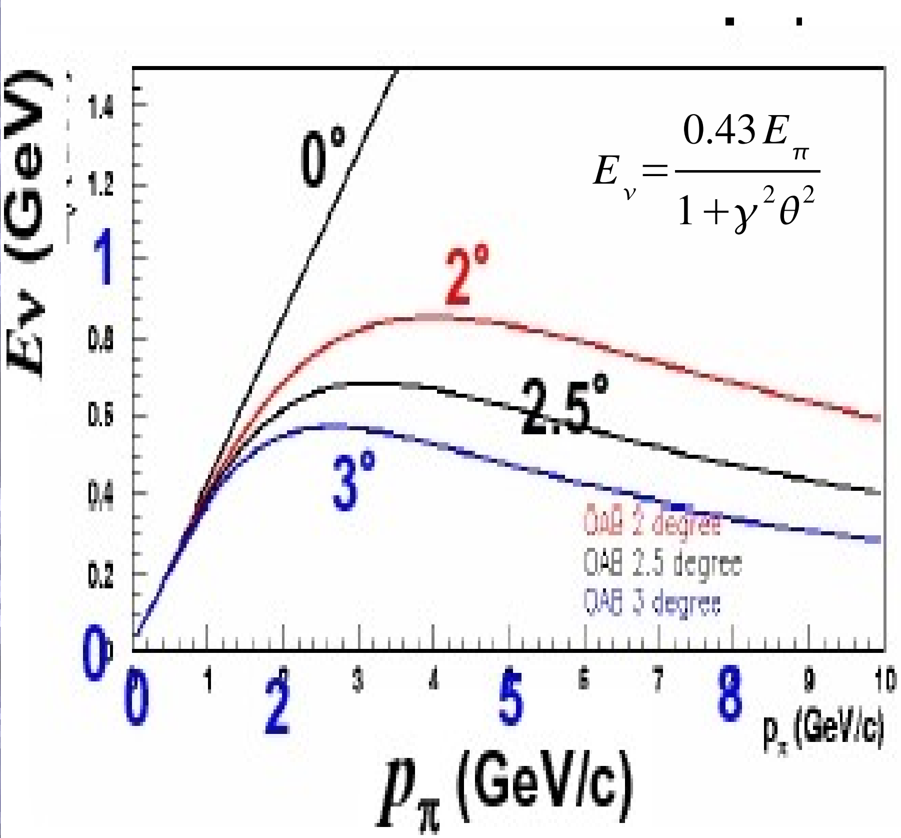


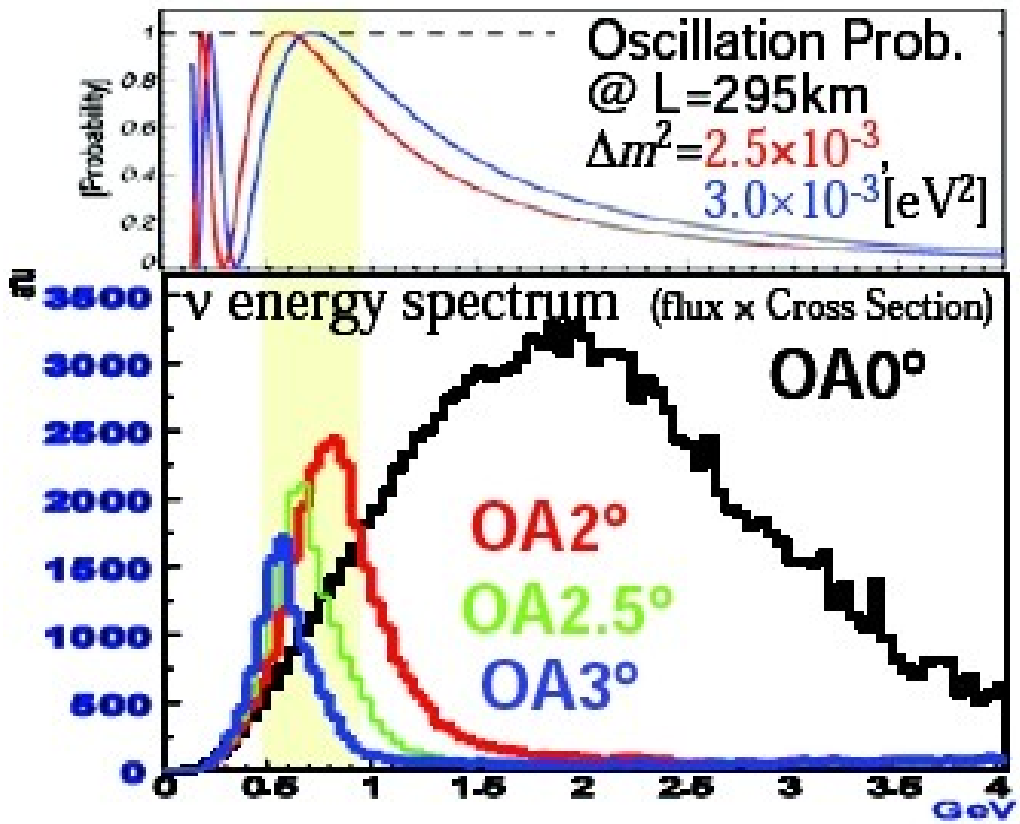
- Phase 1 : 0.75 MW 50 GeV (30 GeV @ T=0)
  - 3.3×10^{14} protons/pulse
  - 0.3 Hz, 15 bunches per spill
- Phase 2 : increase to 4 MW
- Fast extraction must bend proton beam inside the ring!

- One pulse @ 0.75 W can crack an iron block (ambient to 1100° K in 5 ms)!

Off-axis Neutrino Beam

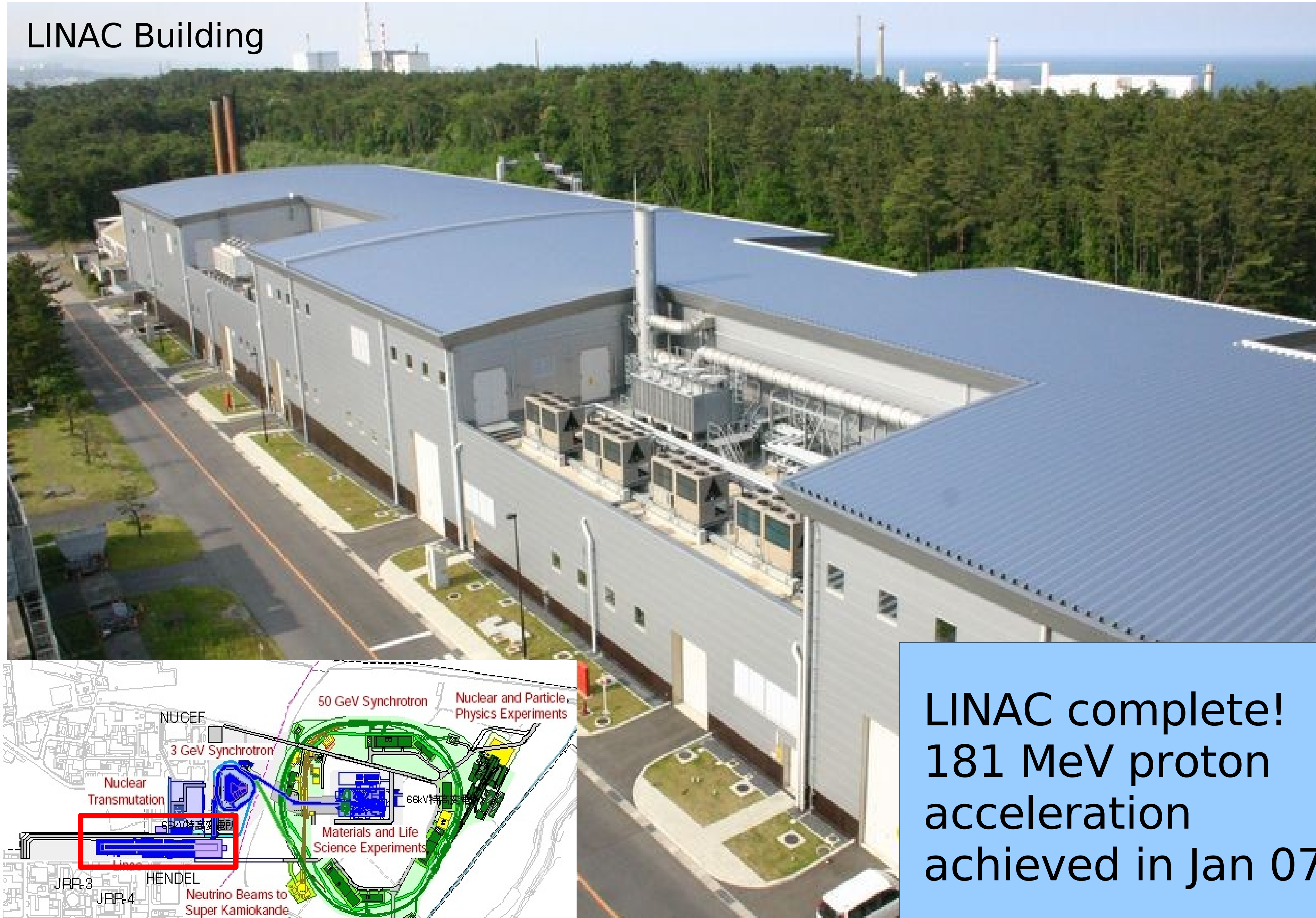






Energy tuned to oscillation max.

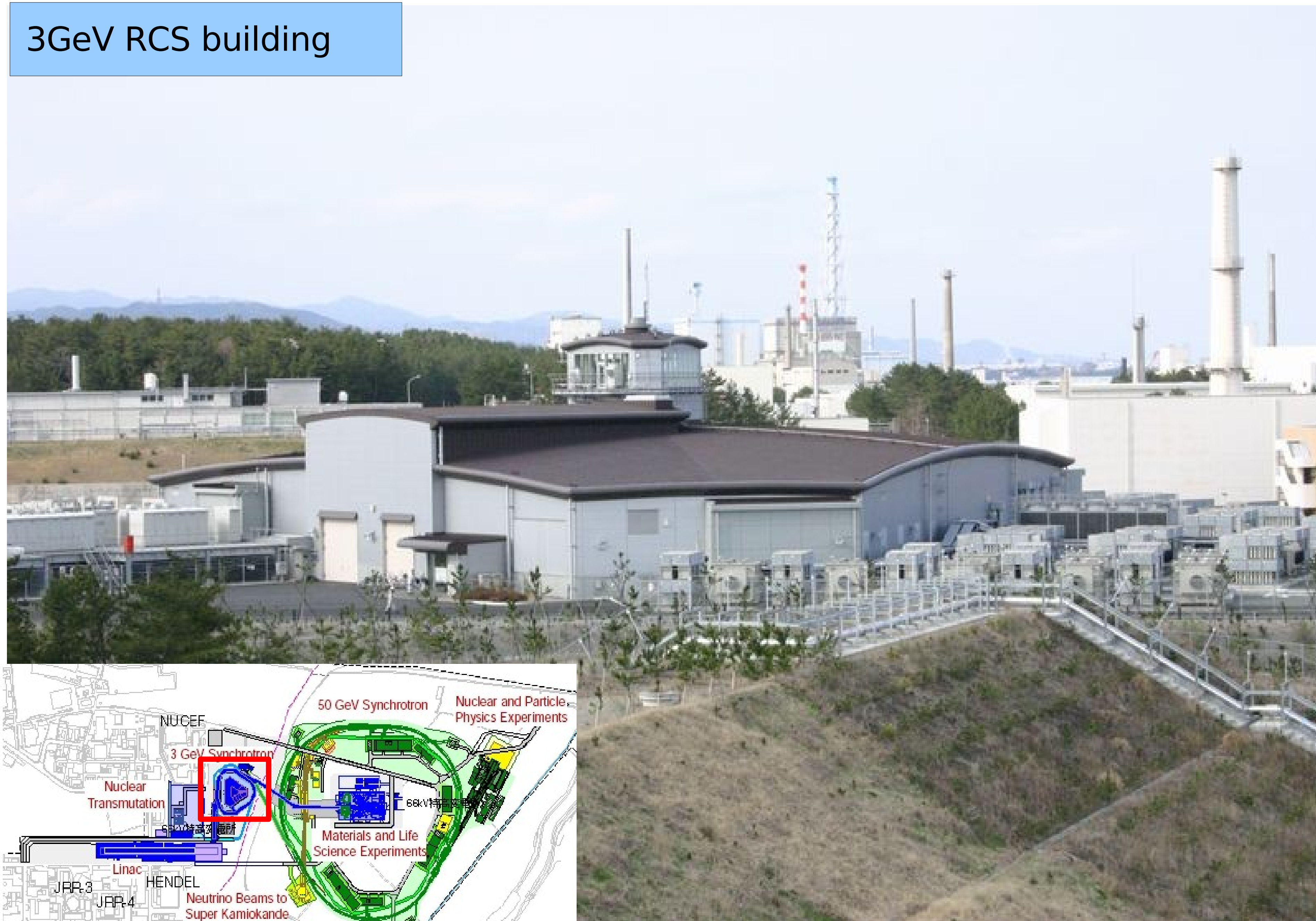
Accelerator Construction Status



LINAC complete!
181 MeV proton acceleration achieved in Jan 07

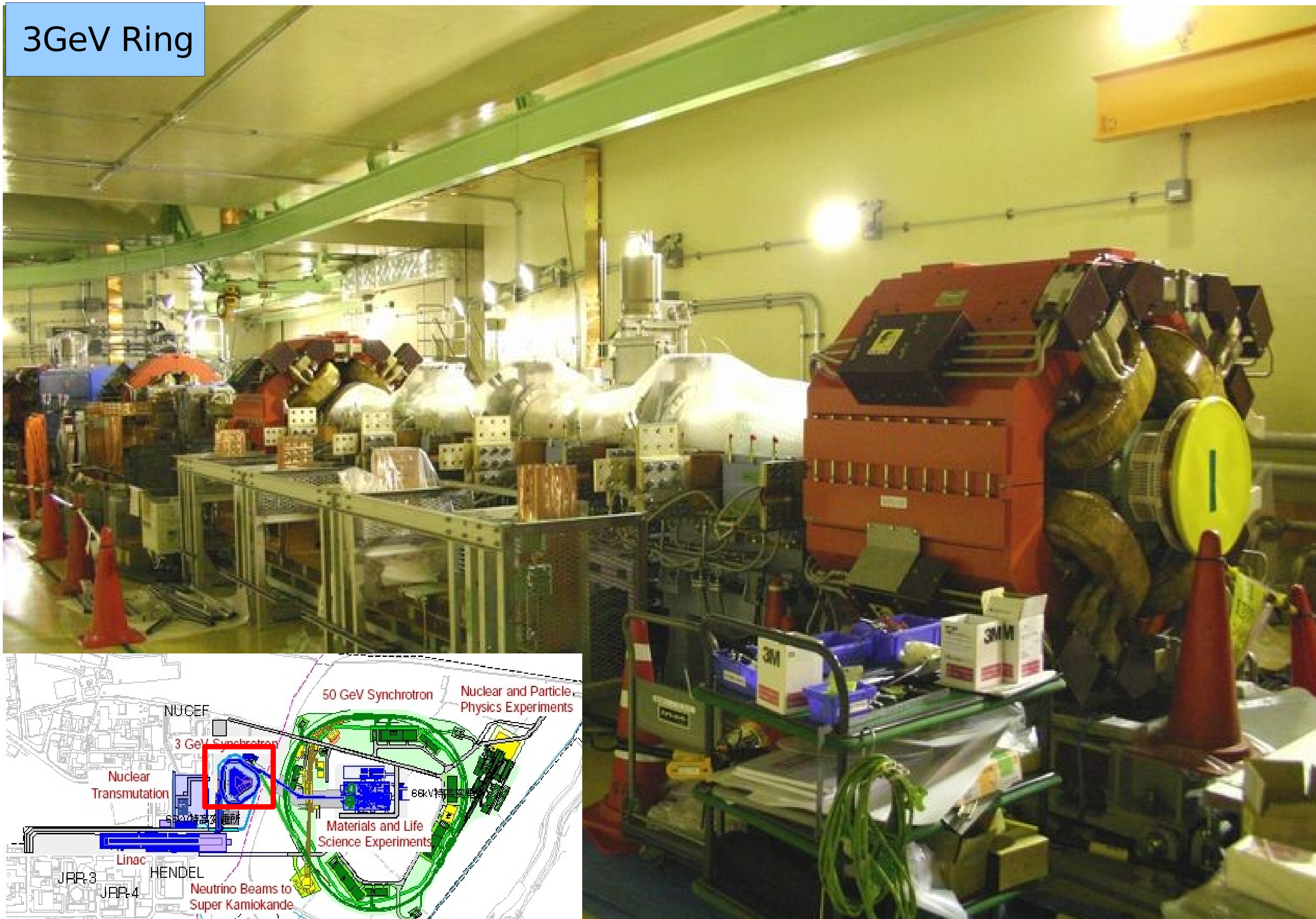
Accelerator Construction Status

3GeV RCS building



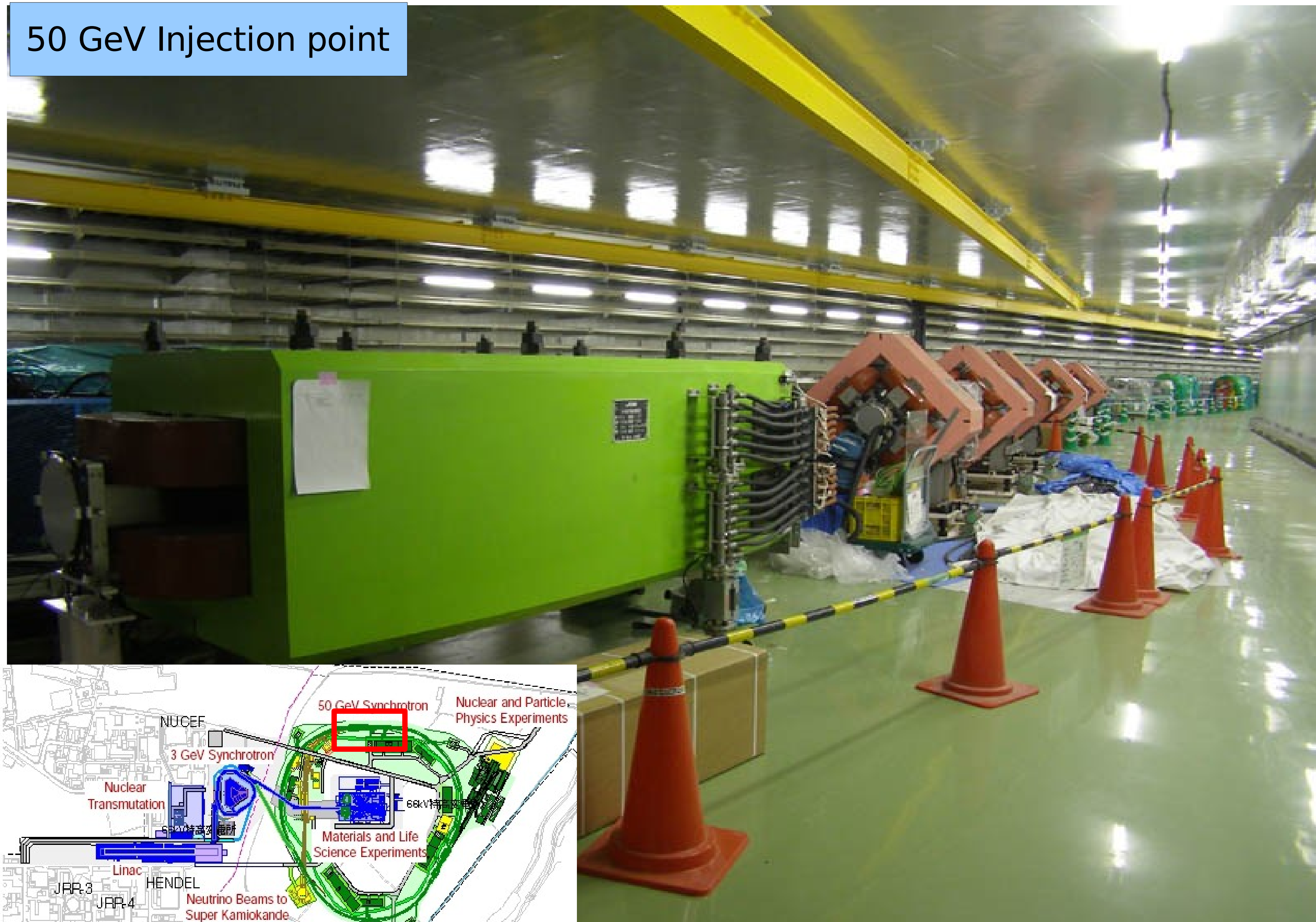
Accelerator Construction Status

3GeV Ring



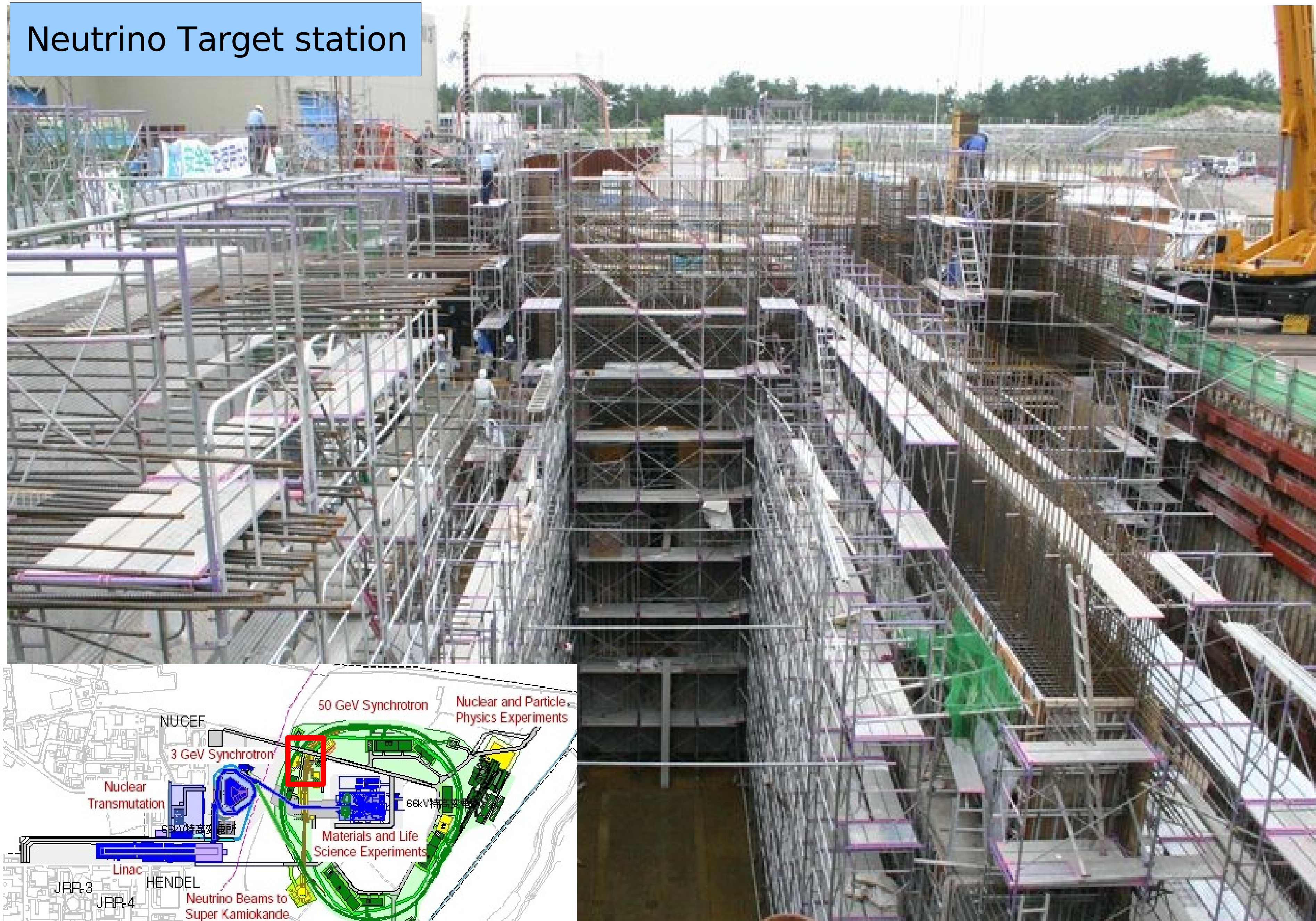
Accelerator Construction Status

50 GeV Injection point

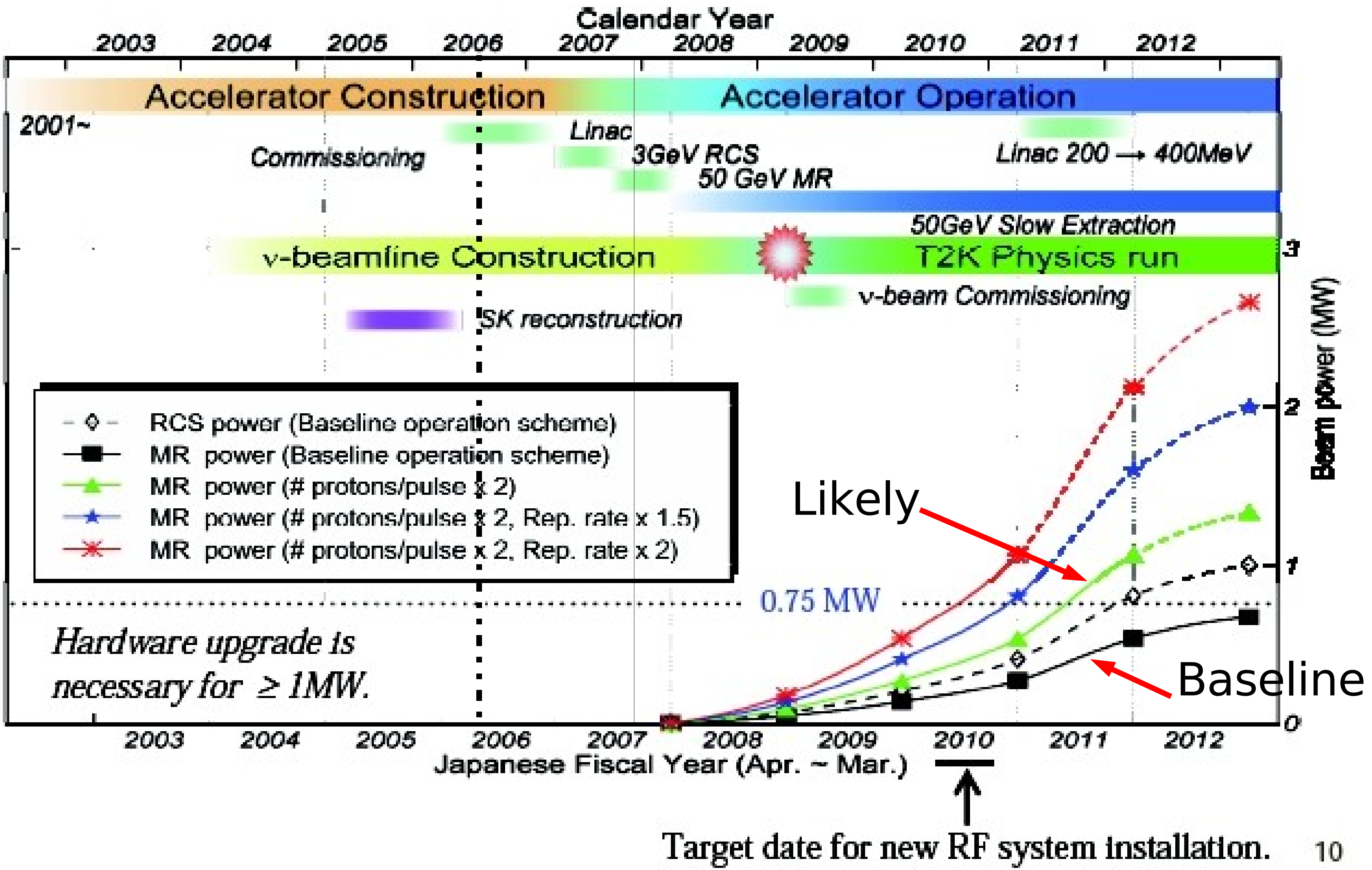


Accelerator Construction Status

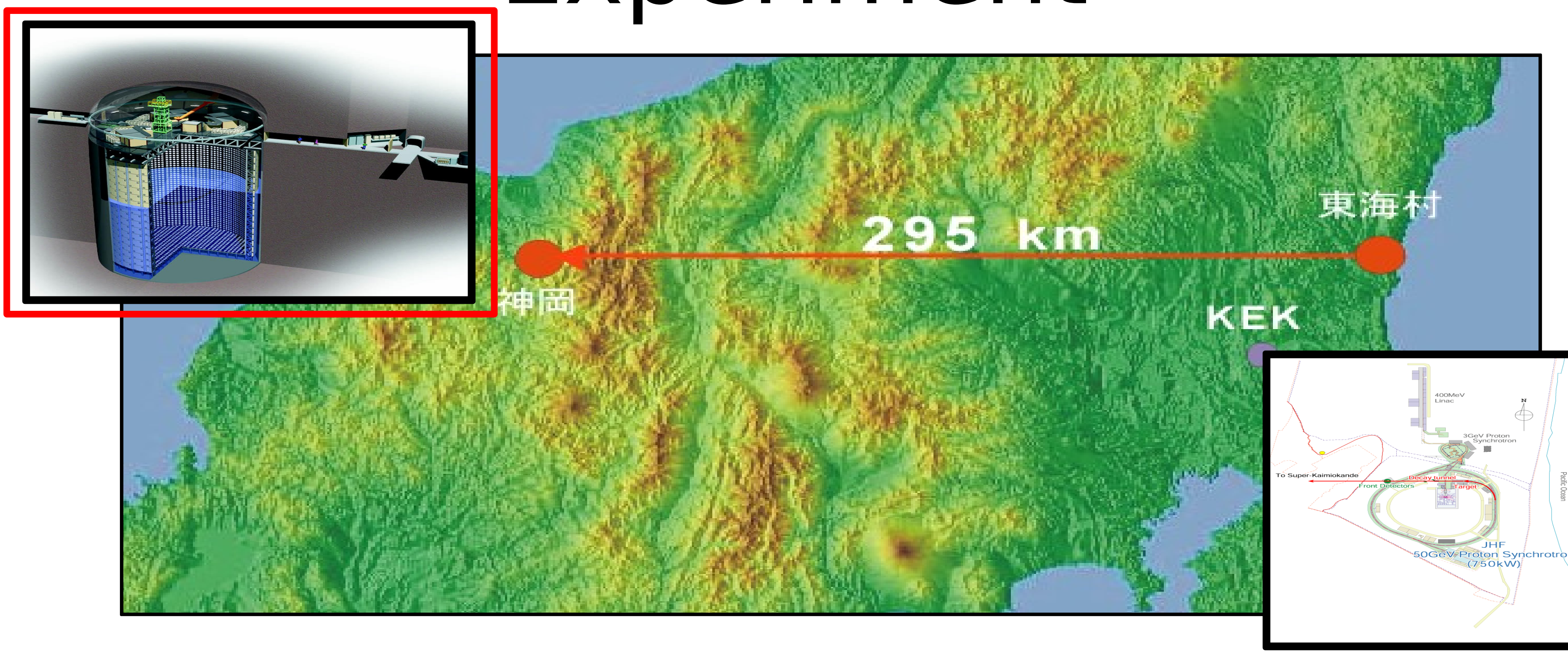
Neutrino Target station



JPARC Schedule



The T2K (Tokai-2-Kamioka) Experiment



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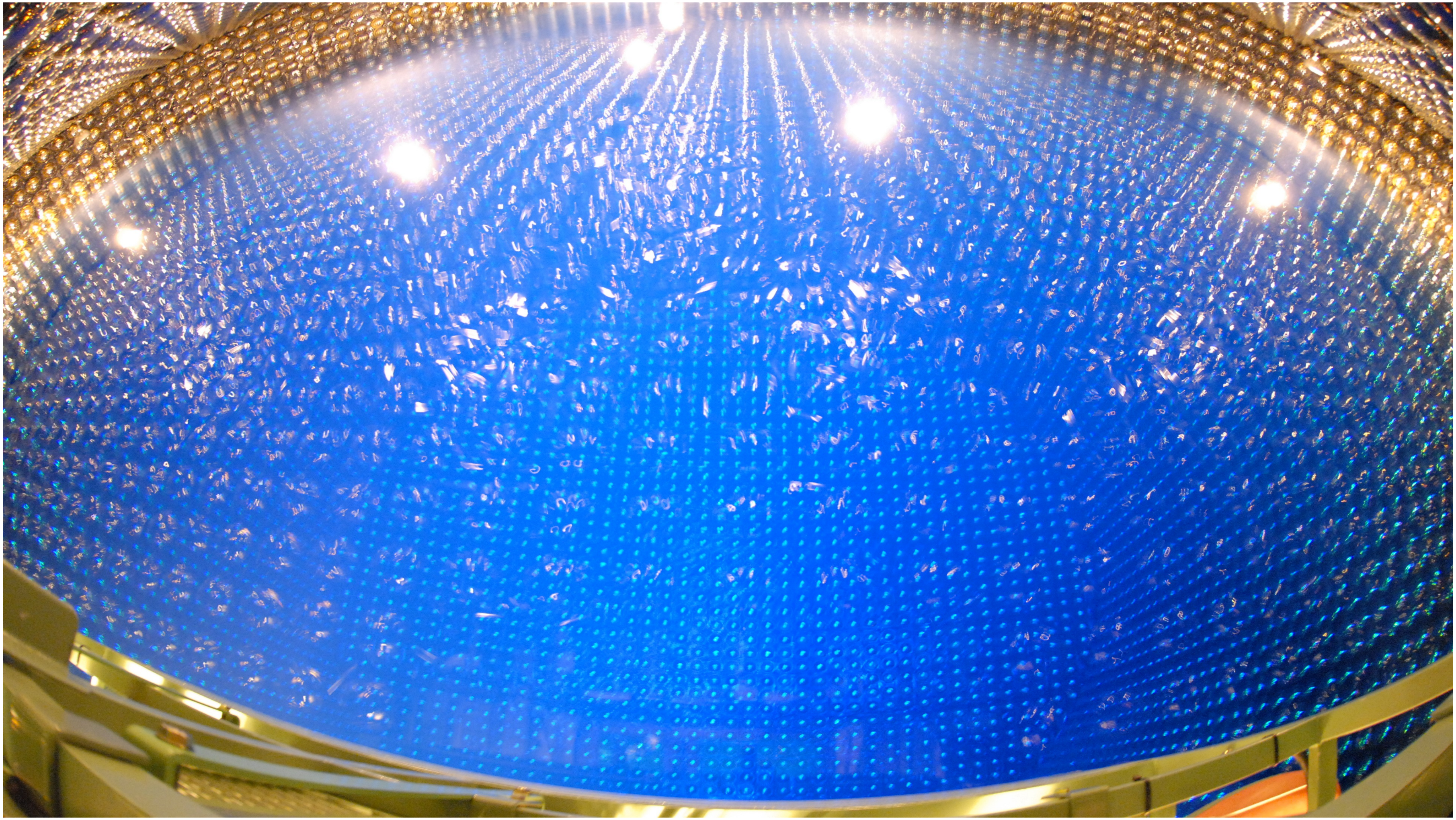
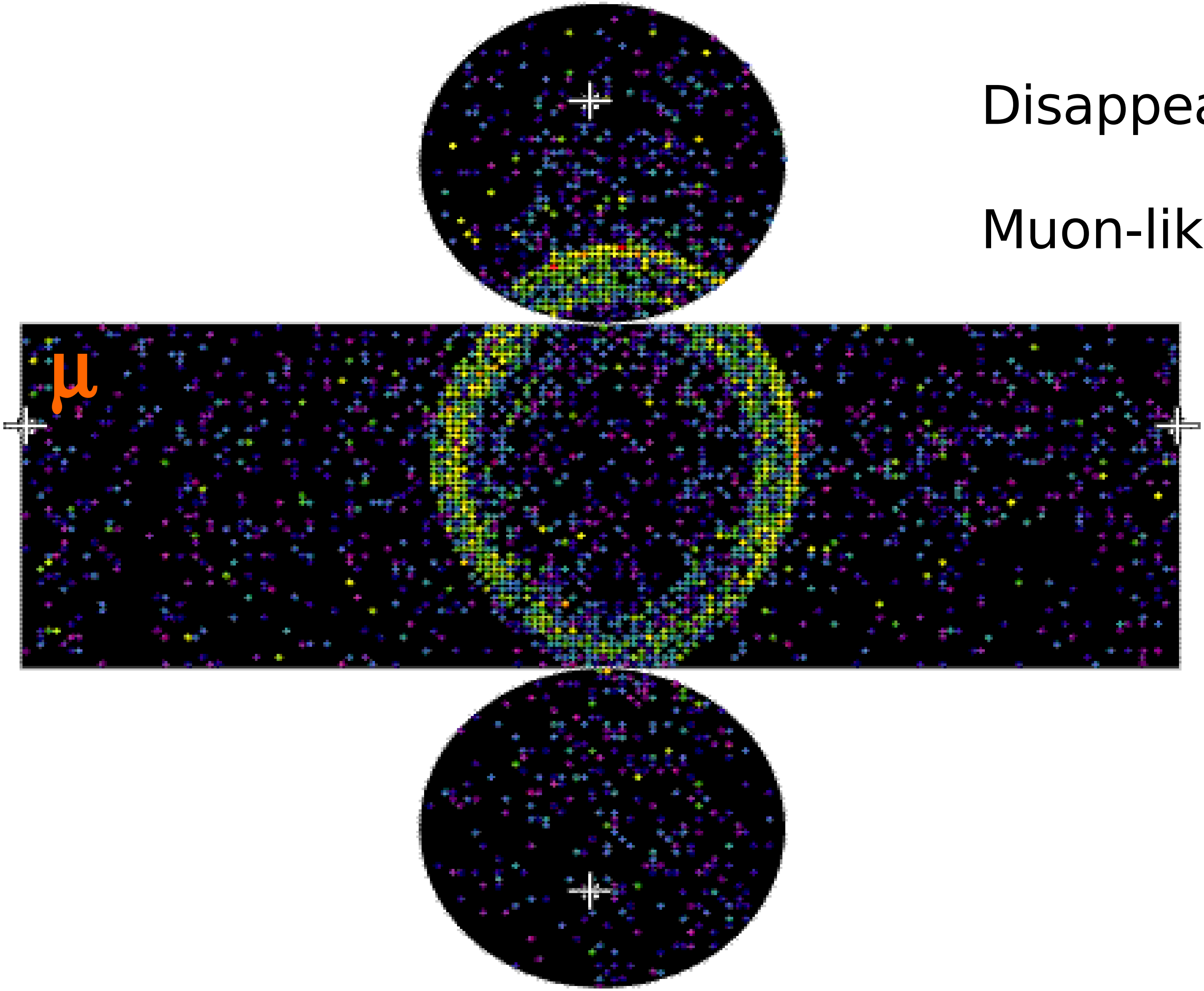
Super-Kamiokande III



50 kton Water Cerenkov detector
Reconstruction completed in April 2006 – *Ready for T2K*

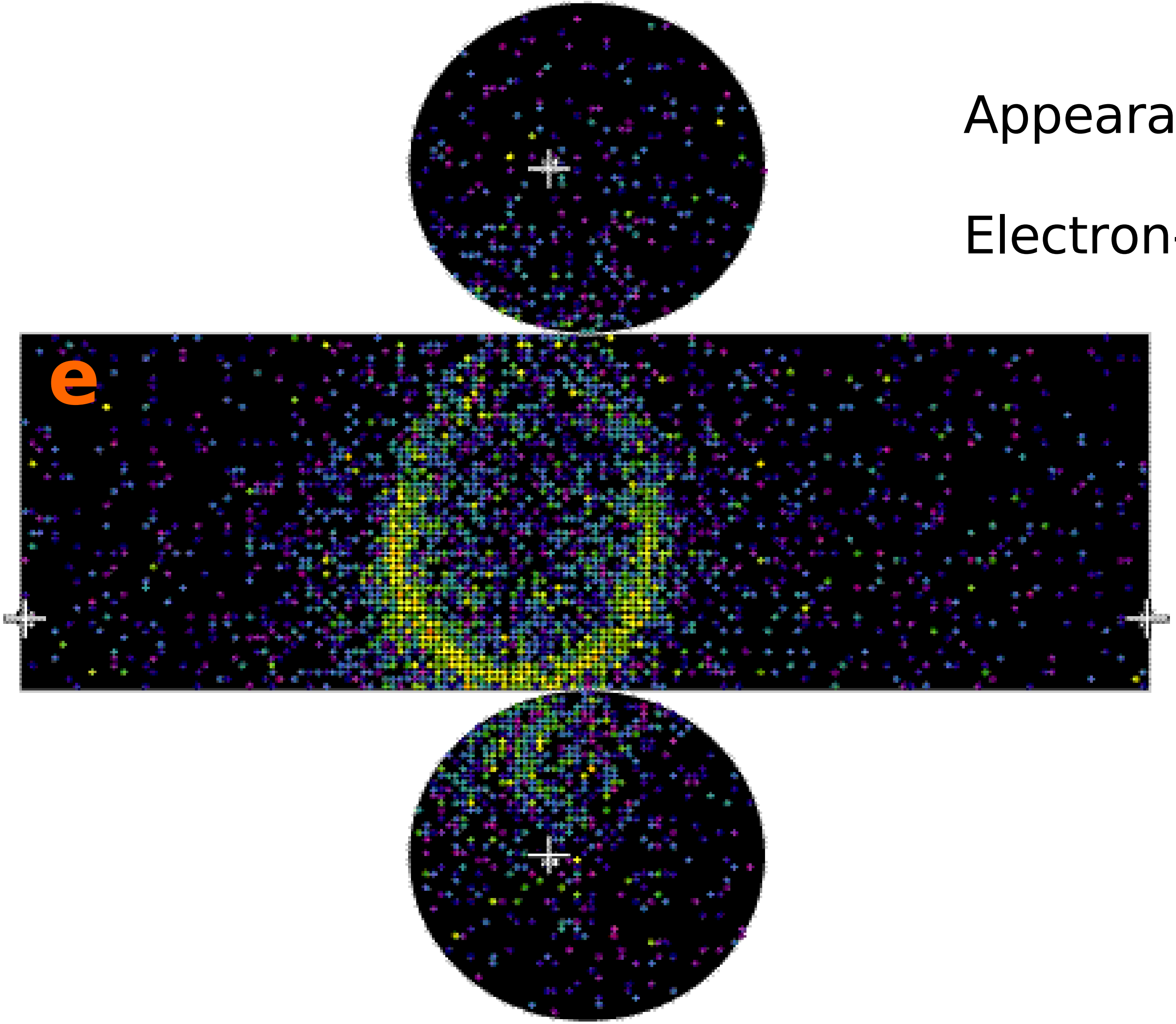
Super-K signals



Disappearance Mode

Muon-like ring

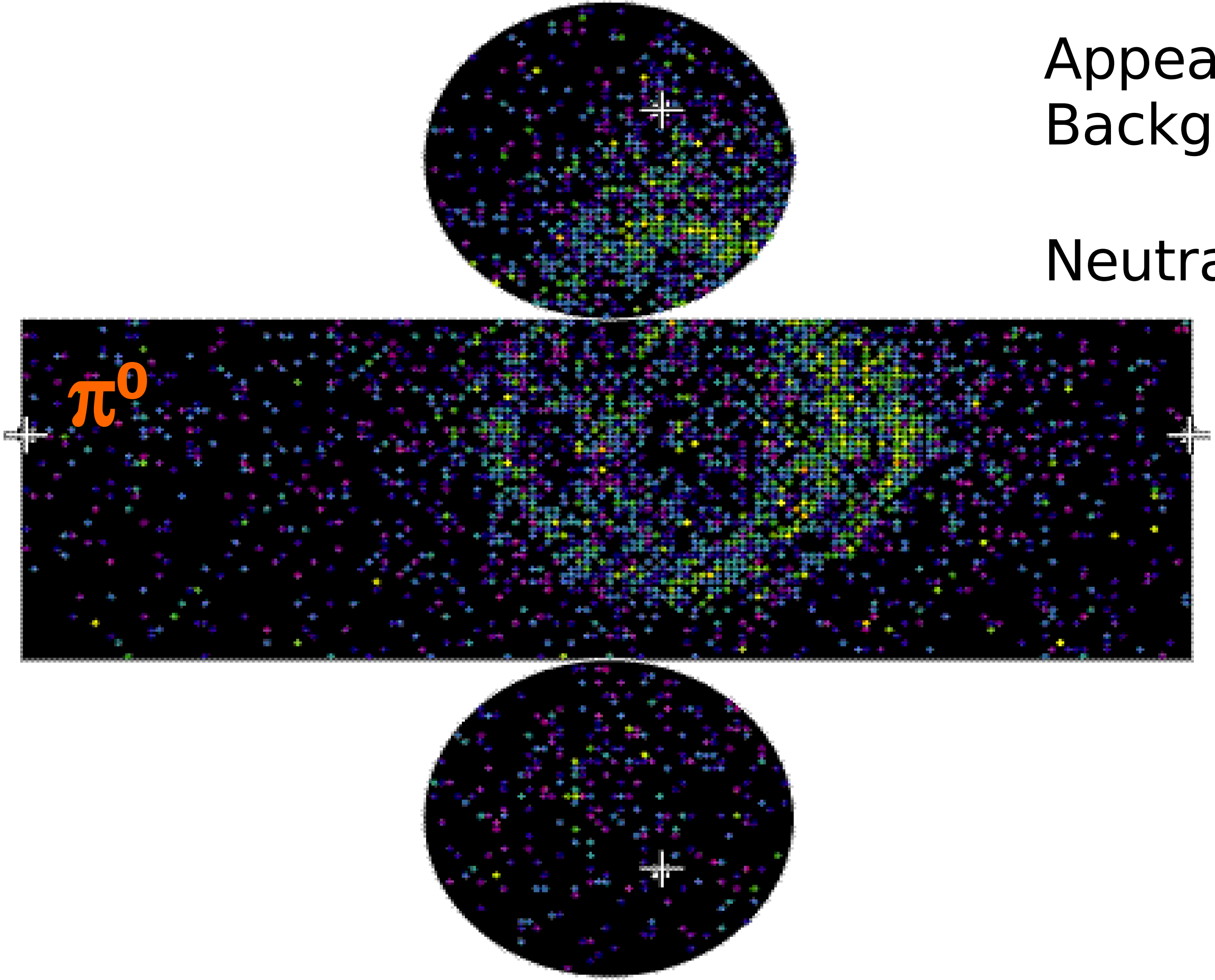
Super-K signals



Appearance Mode

Electron-like ring

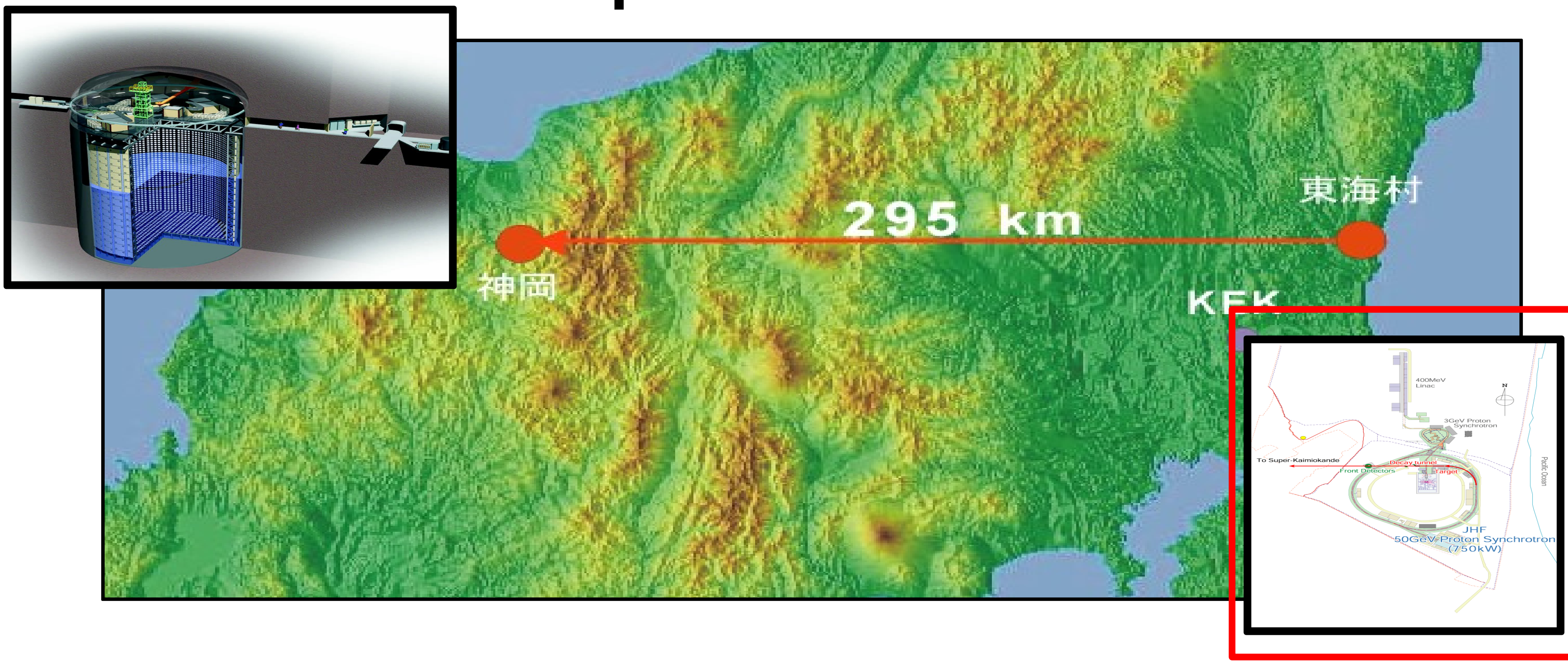
Super-K signals



Appearance Mode Background

Neutral Current π^0

The T2K (Tokai-2-Kamioka) Experiment



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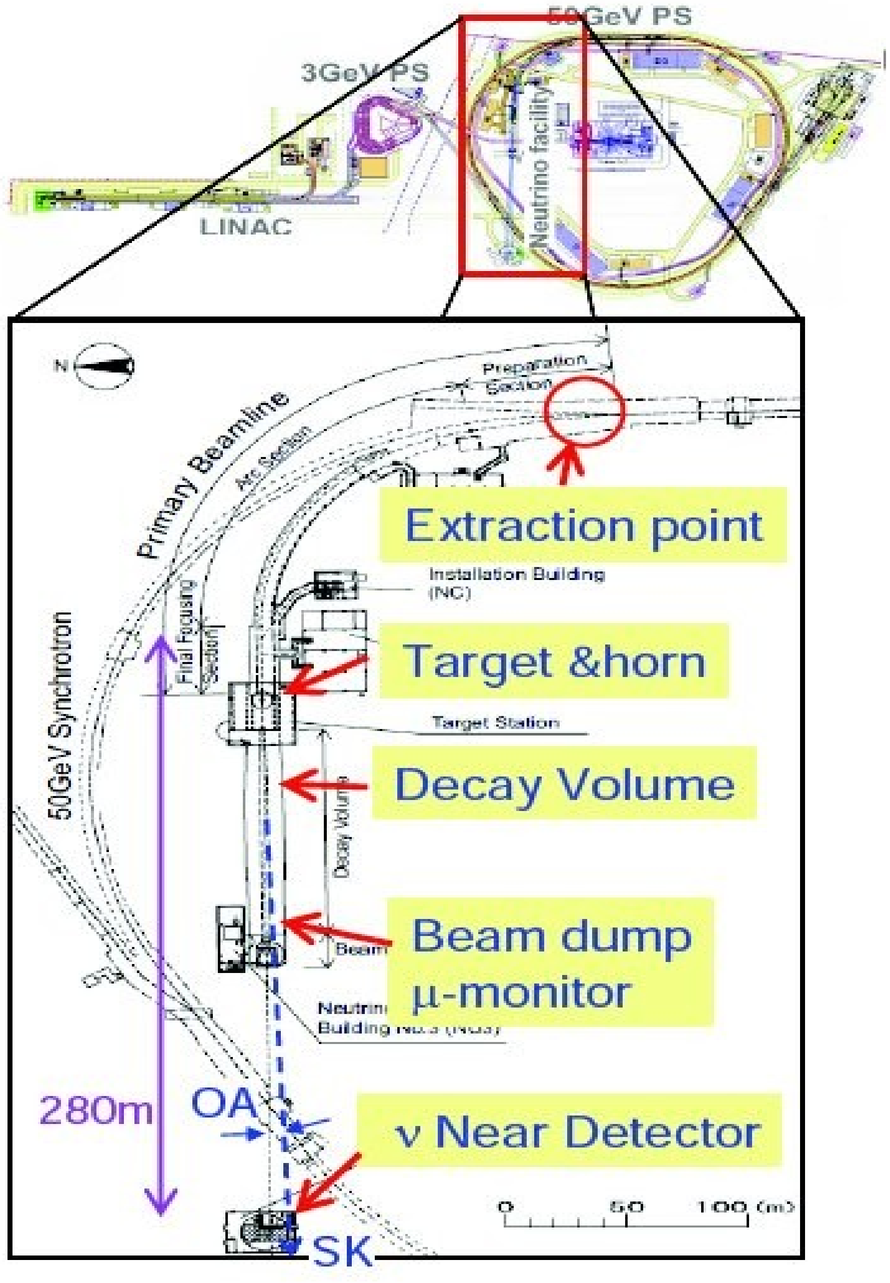
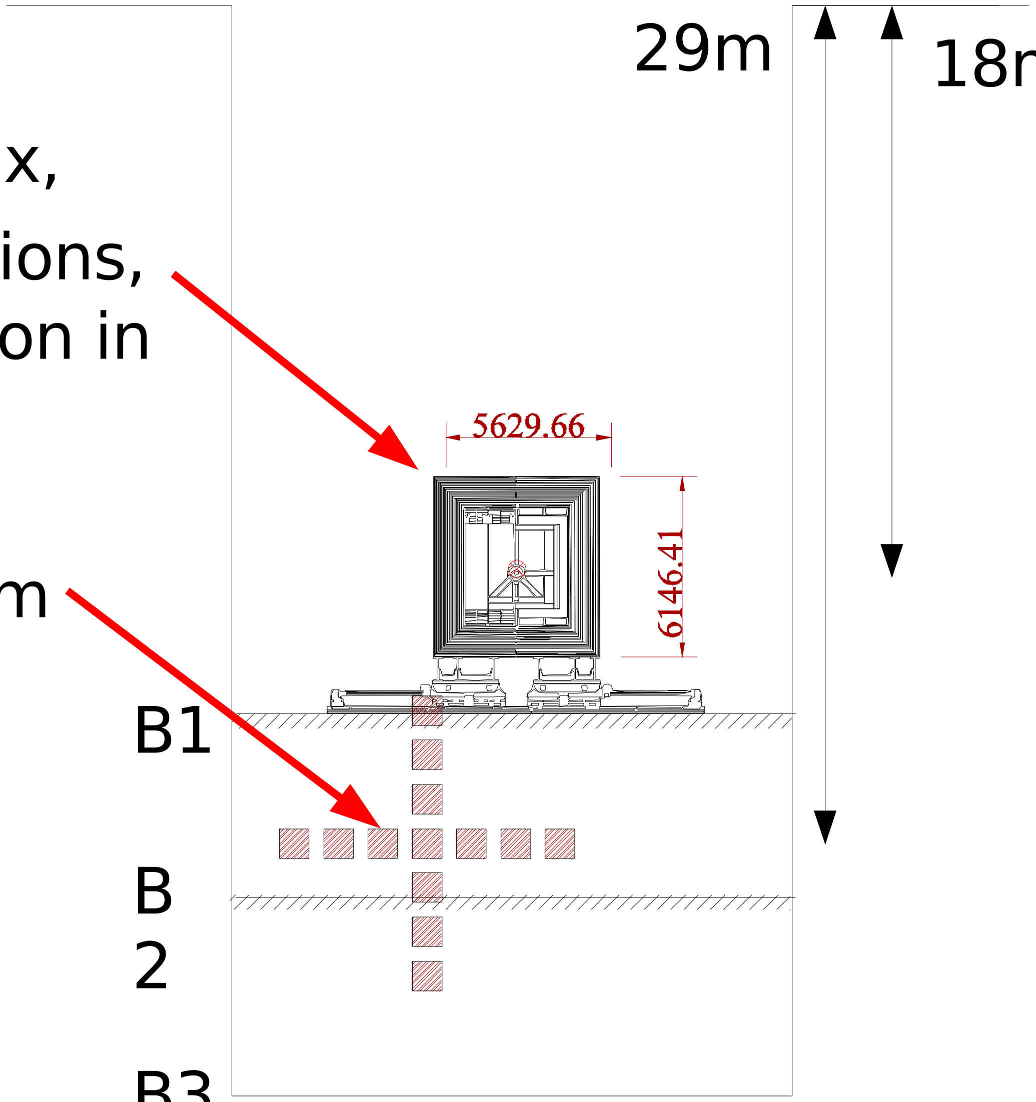
The Near Detectors



Near Detector Suite

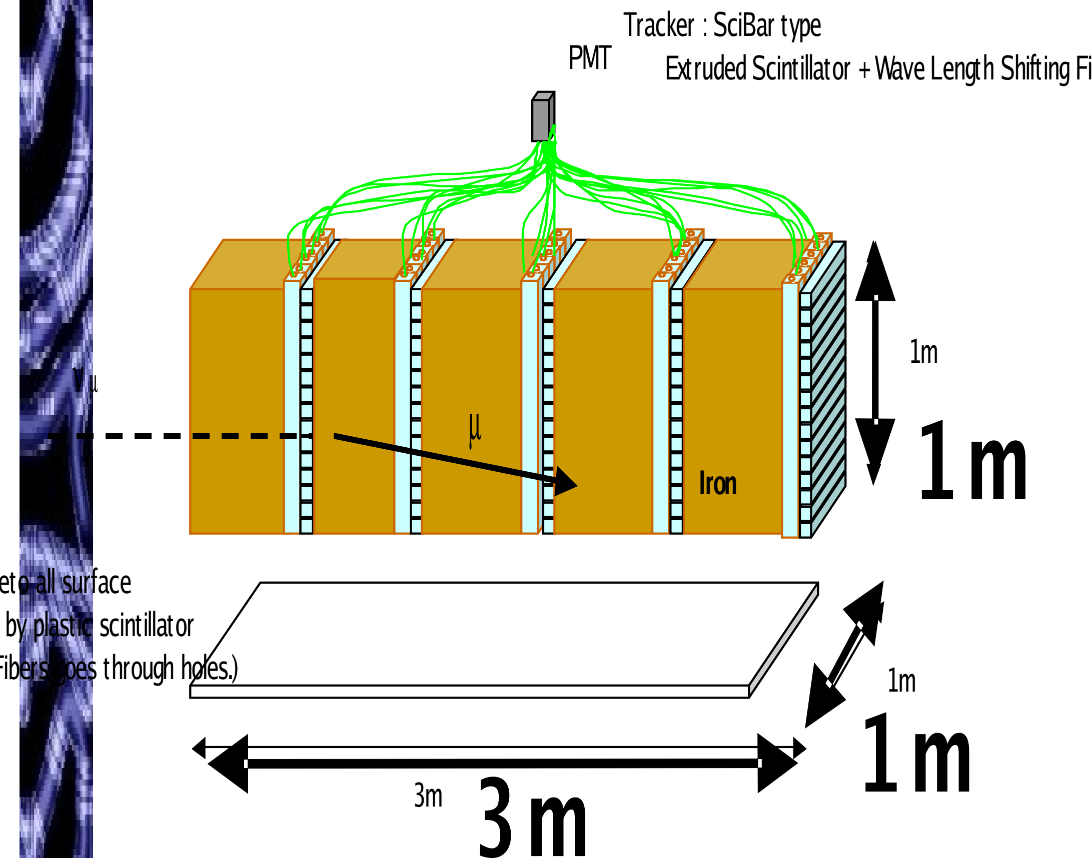
ND280 – Off-axis ν_μ,ν_e flux, charged current interactions, π^0 production cross section in water for ν_e background

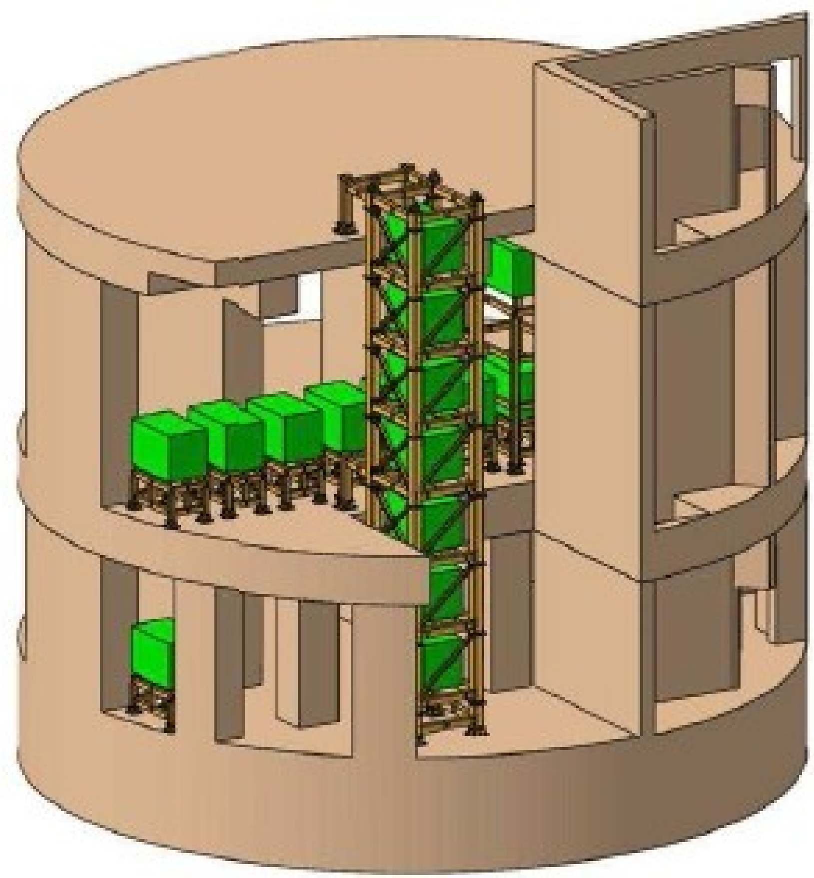
INGRID – Profile of ν beam



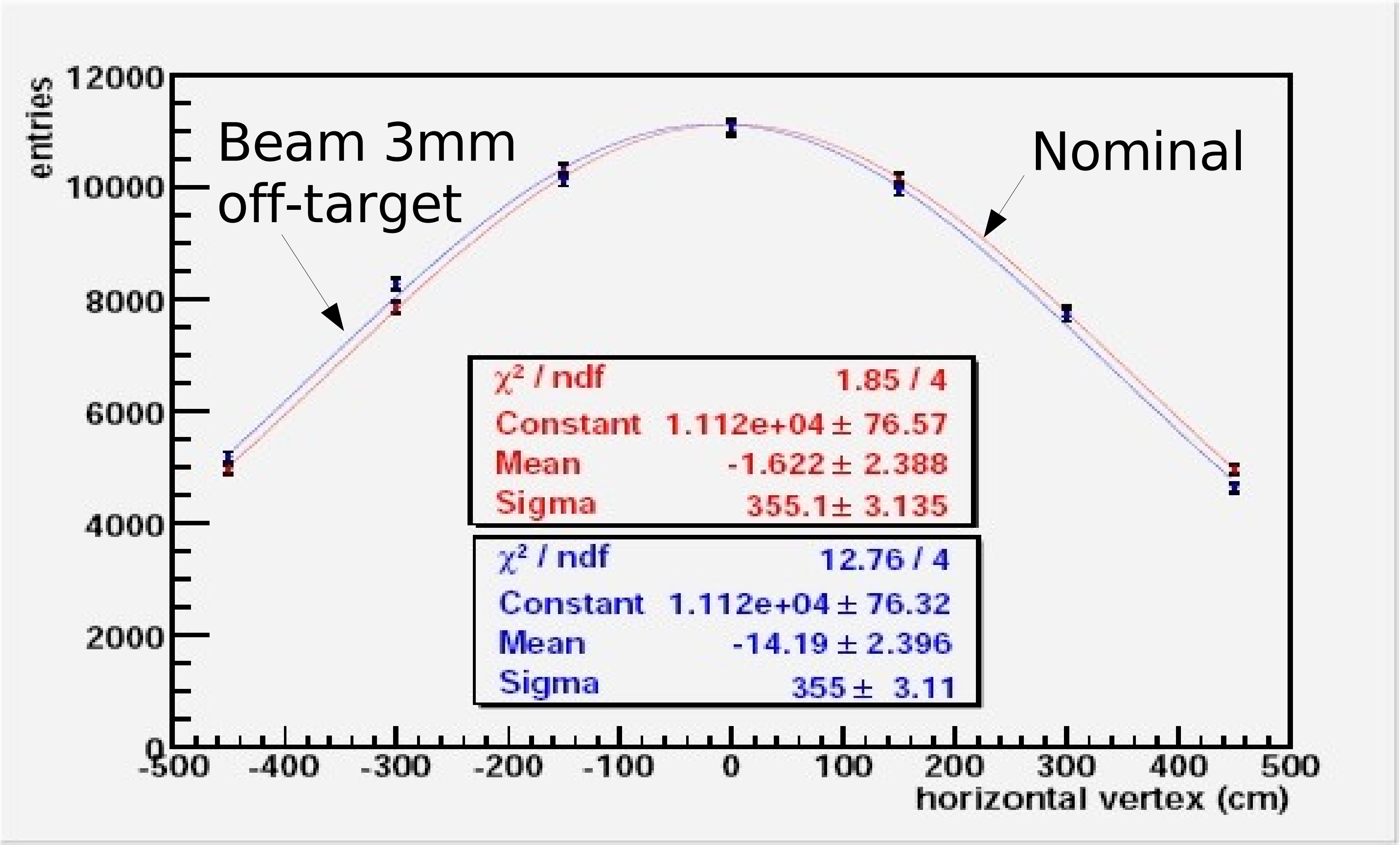
On Axis - INGRID

Array of “simple” iron/scintillator stacks to determine neutrino flux and direction to about 1 mrad
10cm wide strips on 10 cm thick iron





INGRID



Challenge is to understand the relative efficiencies of each component in the INGRID array.

Explicit requirements for ND280

- Muon momentum scale uncertainty – 2%
- Muon momentum resolution – 10%
- μ^+/μ^- identification
- Detection of recoil protons for CCQE measurement
- Charged pion measurement
  - Background for flux measurement
- Neutral pion measurement
  - Background for ν_e measurement
- Measurement of ν_e contamination in beam to 10% accuracy

Explicit requirements for ND280

- Muon momentum scale uncertainty – 2%
- Muon momentum resolution – 10%

→ Good tracking

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→ Good tracking

→ Magnetic field

Explicit requirements for ND280

- Muon momentum scale uncertainty – 2%
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→ Good tracking

- μ^+/μ^- identification

→ Magnetic field

- Detection of recoil protons for CCQE measurement

→ Fine granularity
Calorimetry

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→ Particle ID

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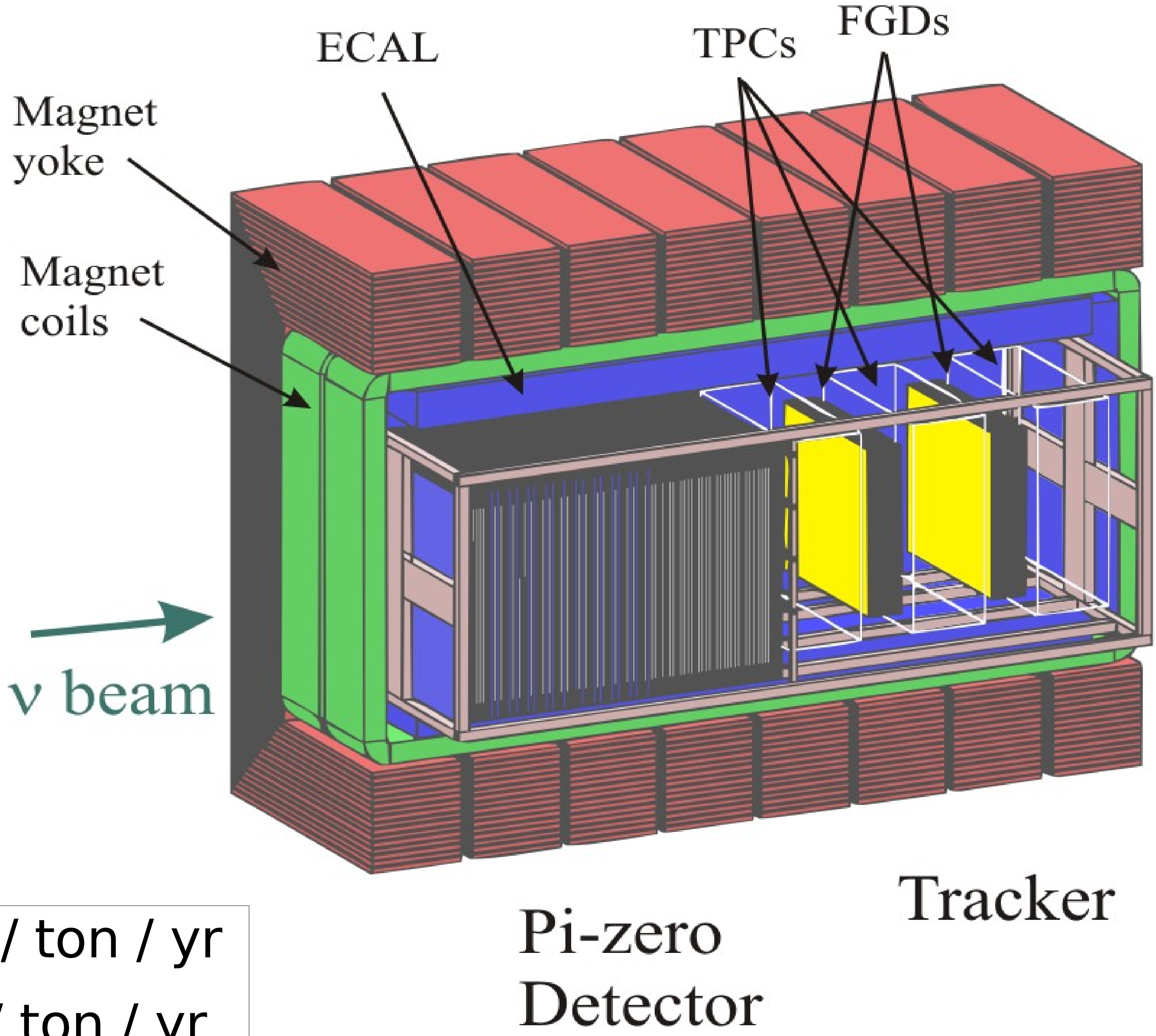
- Charged pion measurement → Particle ID
  - Background for flux measurement
- Neutral pion measurement → Photon ID
  - Background for ν_e measurement
- Measurement of ν_e contamination in beam to 10% accuracy → Tracking Calorimetry

All on a water target w/o Cerenkov technique

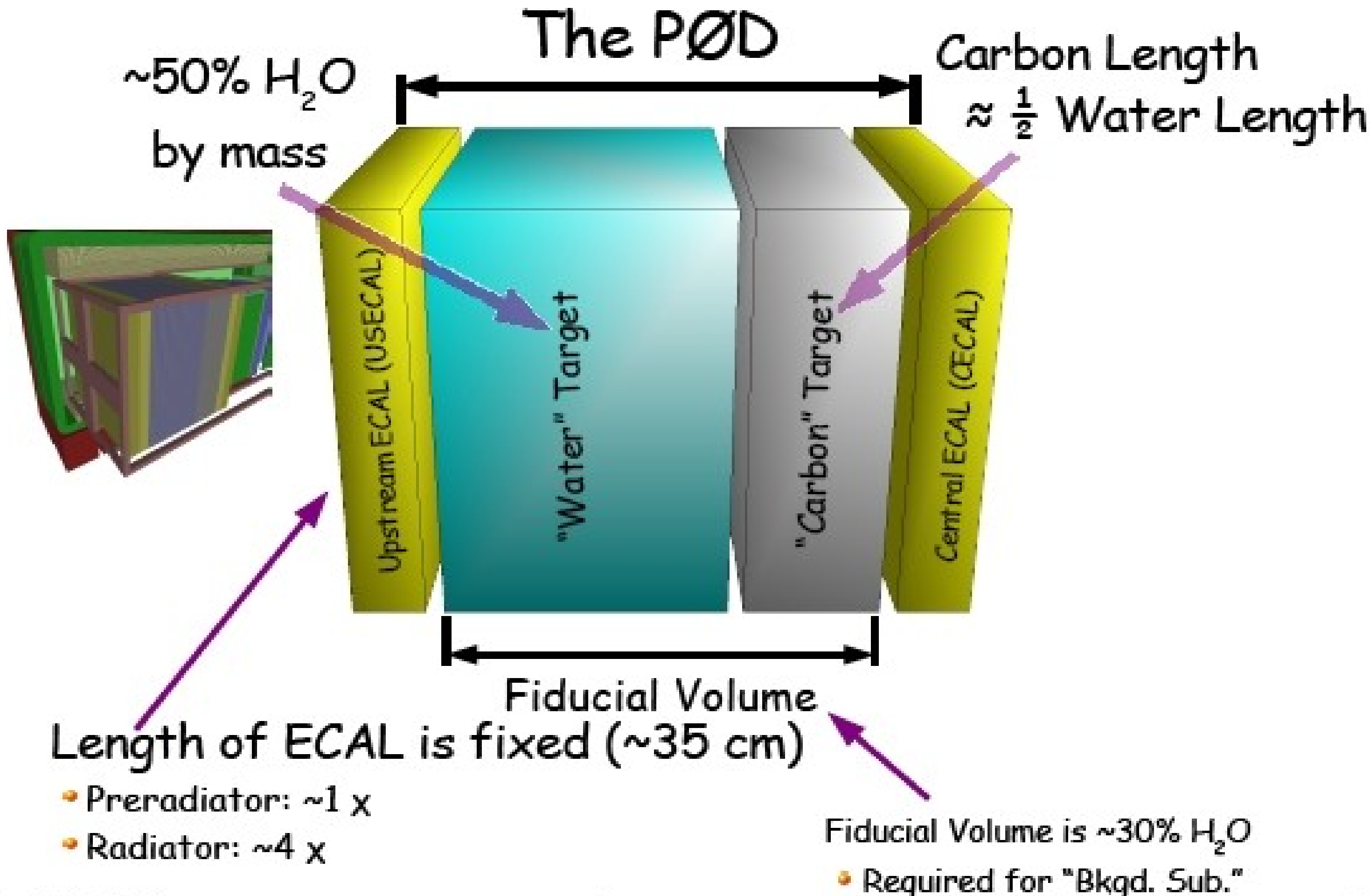
Off Axis - ND280



170k ν_μ / ton / yr

3.3k ν_e / ton / yr

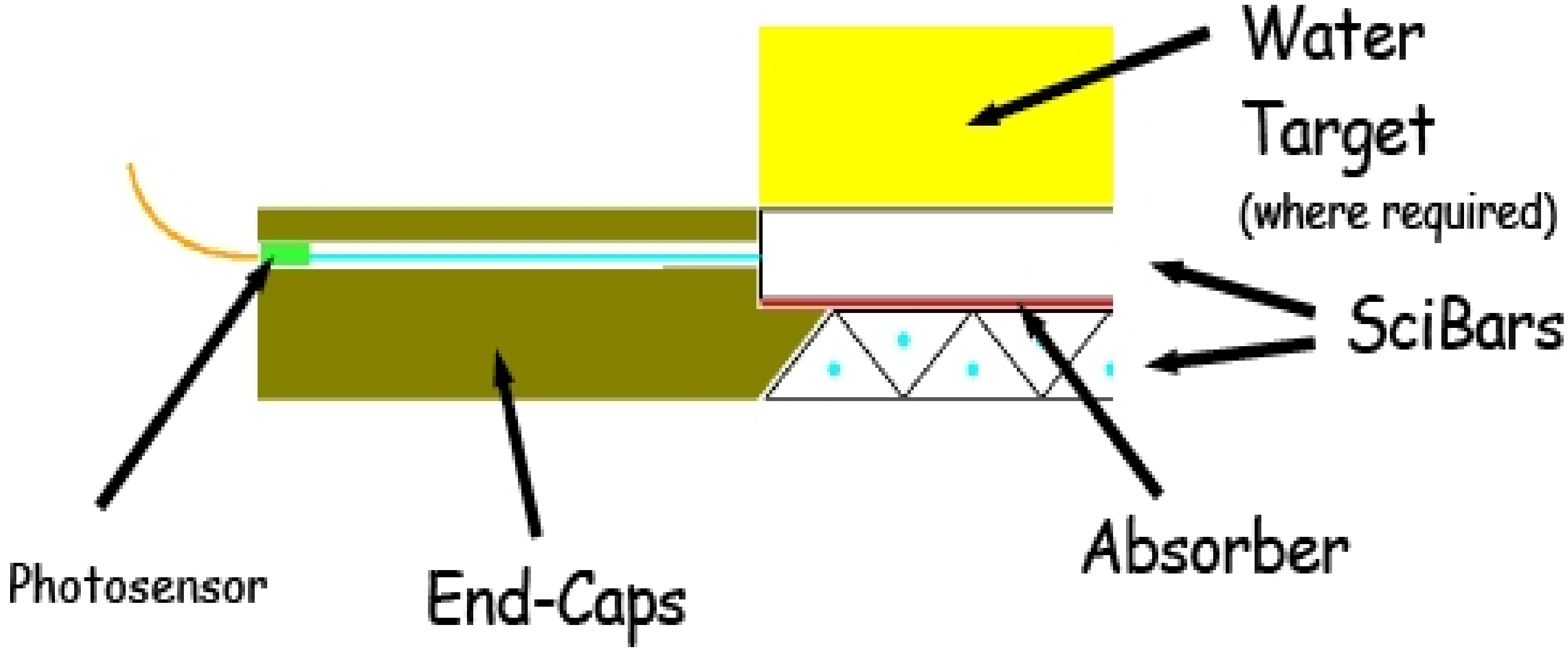
π0d (P0D)



- NC Interaction
- CC π^0 production
- Intrinsic ν_e

17k NC π^0 /year
π^0 Rec Eff ~ 60%

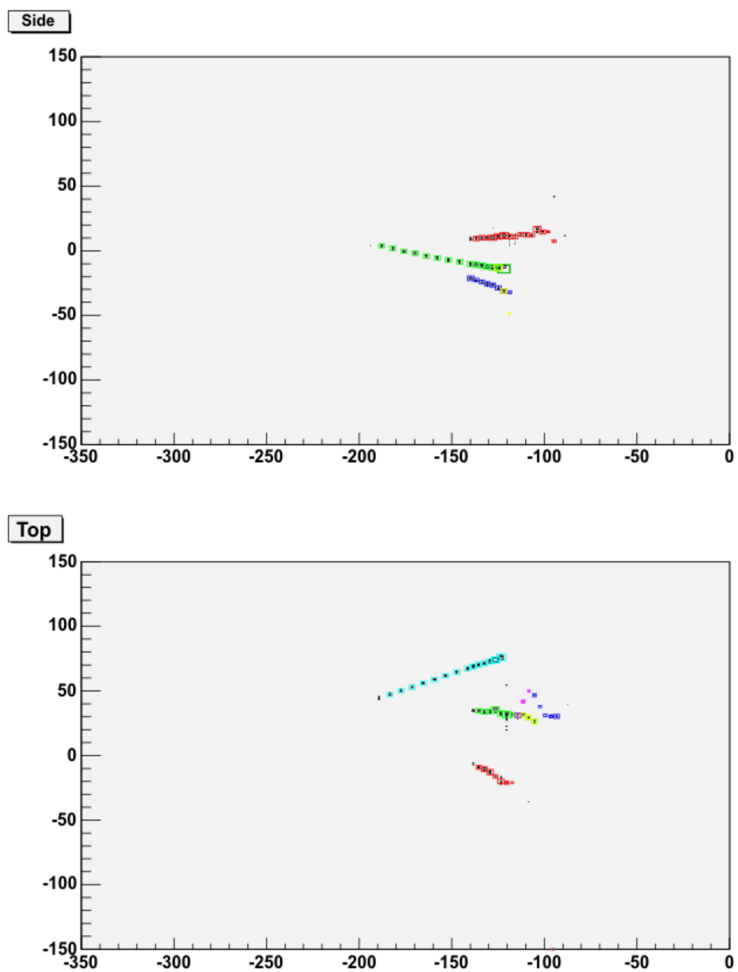
π0d (POD)



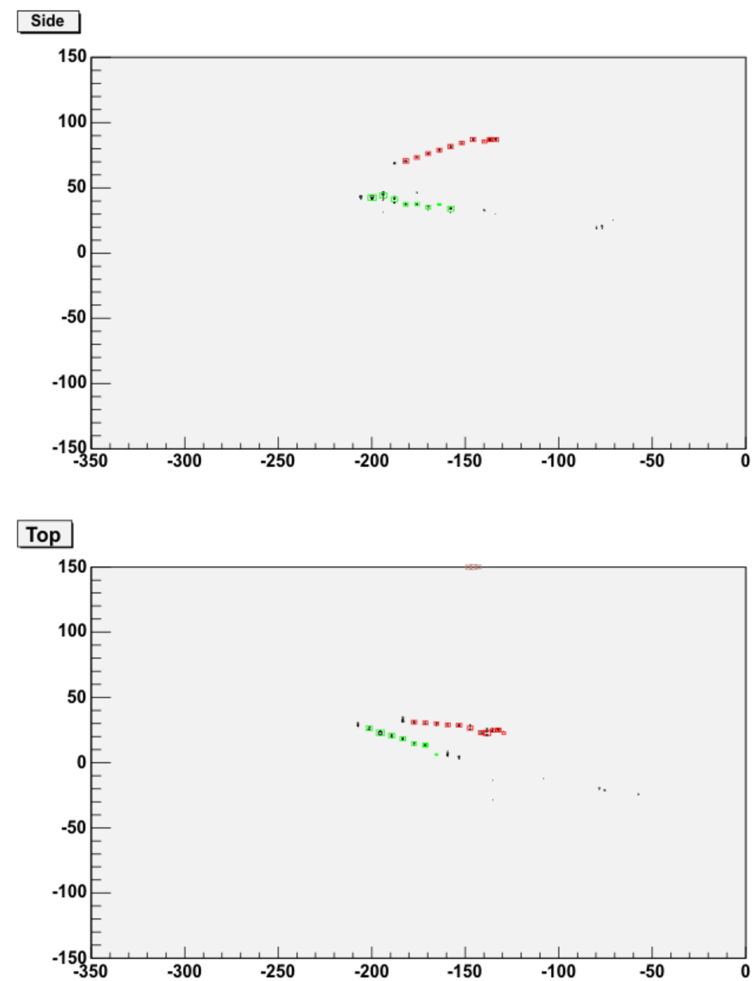
- Triangular scintillator bars
- Readout by WLS fiber inserted into central hole
- Each scintillator plane separated by 0.6mm thick lead foil to enhance probability of photon conversion.
- Lead+coarse segmentation makes precise tracking difficult.

π0d (POD)

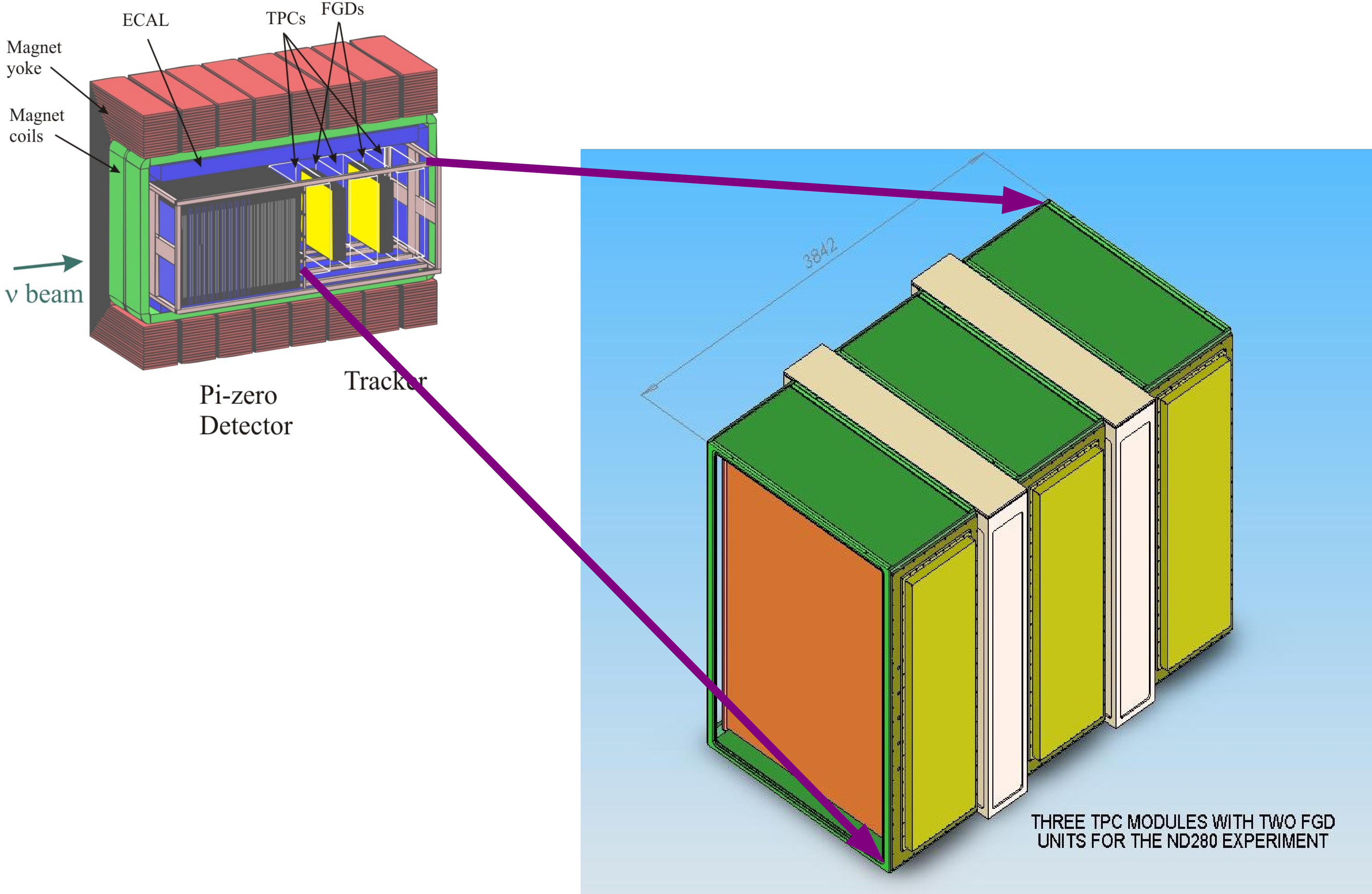
0.5 GeV/c π^0 + 1 GeV/c proton



0.5 GeV/c π^0 + undetected neutron

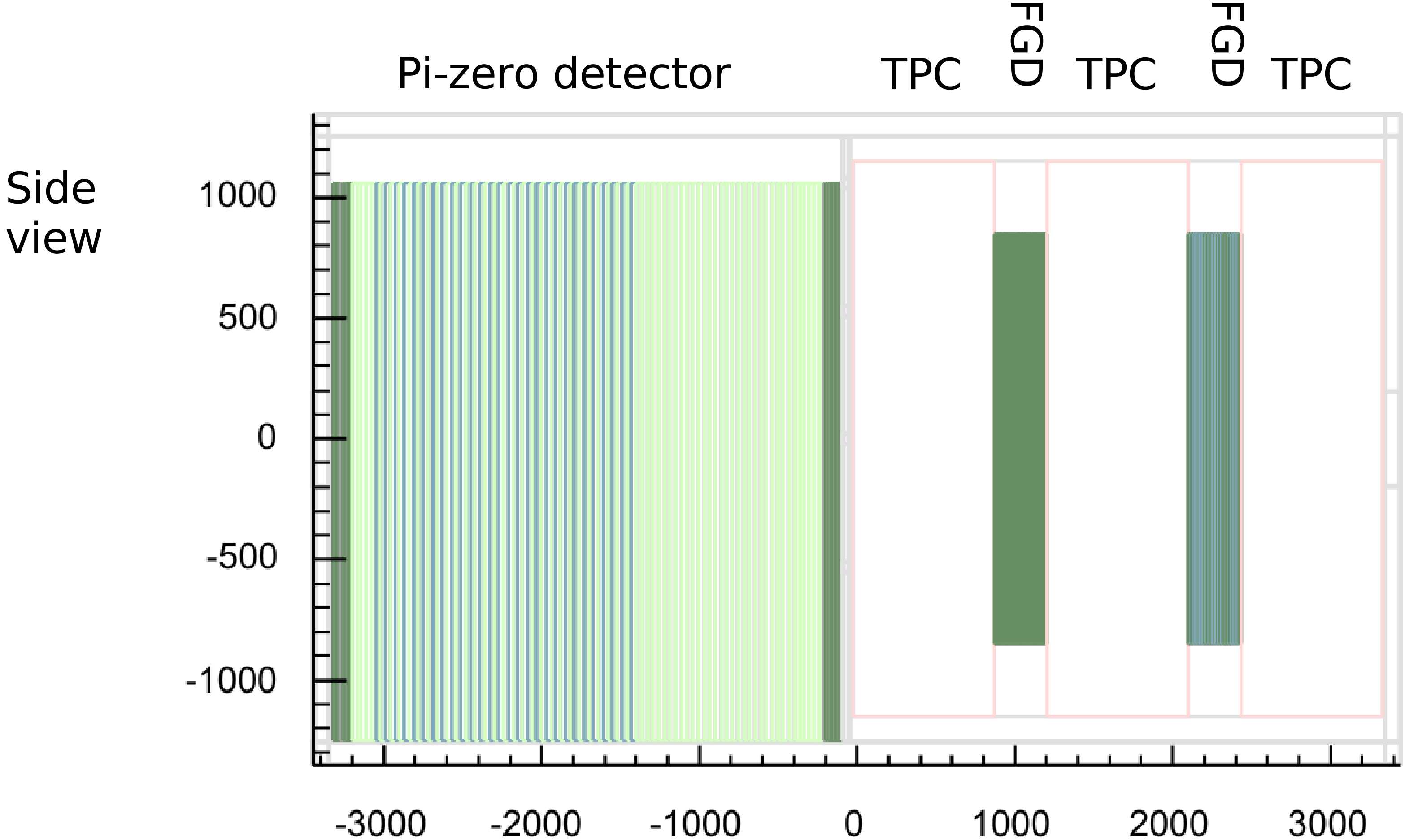


FGD+Tracker

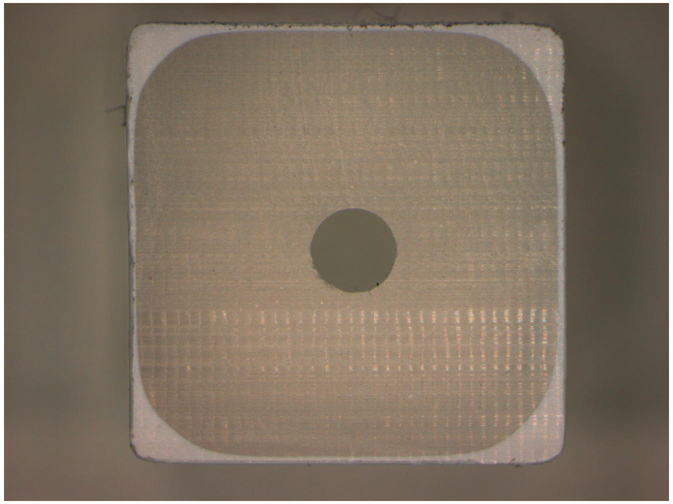

ECAL
TPCs
FGDs
Magnet yoke
Magnet coils
ν beam
Pi-zero Detector
Tracker
3842
THREE TPC MODULES WITH TWO FGD UNITS FOR THE ND280 EXPERIMENT

FGD+Tracker

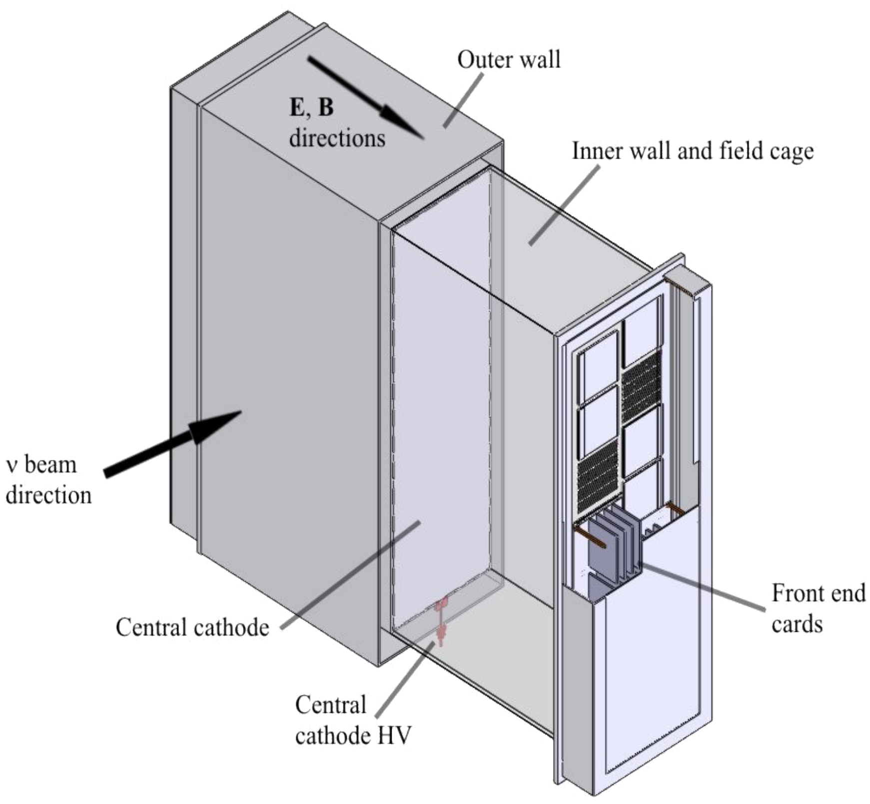
- Consists of solid active modules (FGD) separated by gas time projection chambers (TPC)
- Designed to study 2 and 3 prong interactions in finer detail than the P0D can.



FGD+Tracker



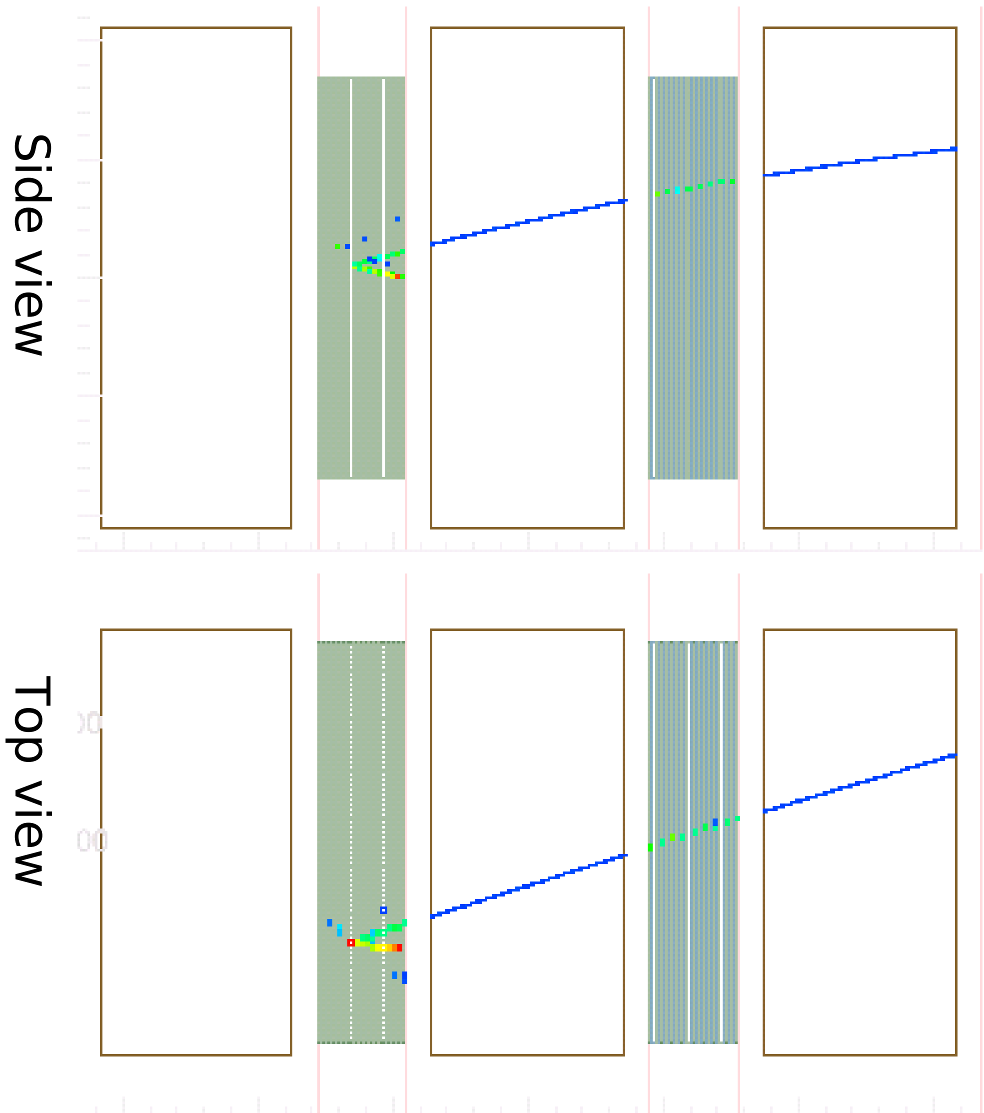
- 2 FGDs – one containing passive water targets in 3cm wide tubes
- Instrumented with 1cmx1cm square scintillator bars
- 30 cm thick to provide good proton reconstruction and minimal material between TPC tracker
- 4 x 10^5 events / year in FGD modules



$$\frac{\sigma_p}{p} \sim 0.1\ \mathrm{for}\ p < 1\ \mathrm{GeV/c}\hat{}\{2\}$$

- Dedx capability for particle id
- Gas amplification microMEGAS readout
- 2000 events purely on gas

Tracker – ν_μ CC event



Event No.: 24 Reaction code: 1 Position in File: 24

Primary Vertex [mm]: (-423, 53, 808)

Located in

Basket_0/TRK_0/Active_1/ScintX1_136/bar_37278

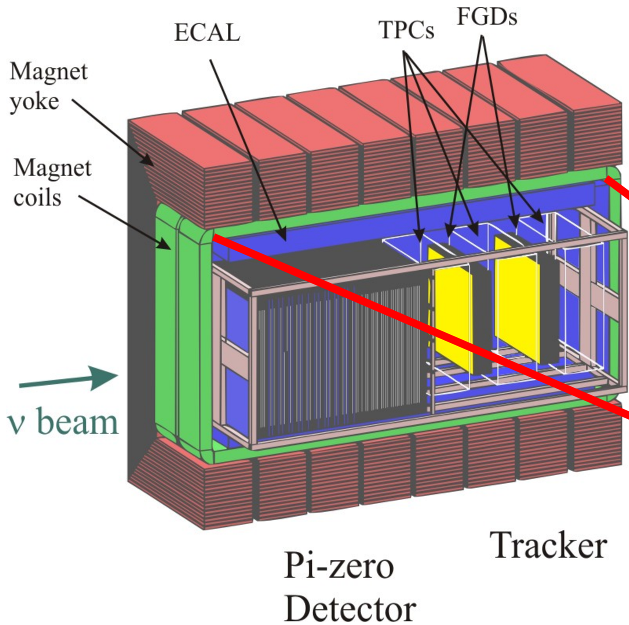
Informational particles

ν_μ (14)	Trk -1,	KE= 1340 MeV
n (2112)	Trk -1,	KE= 0 MeV

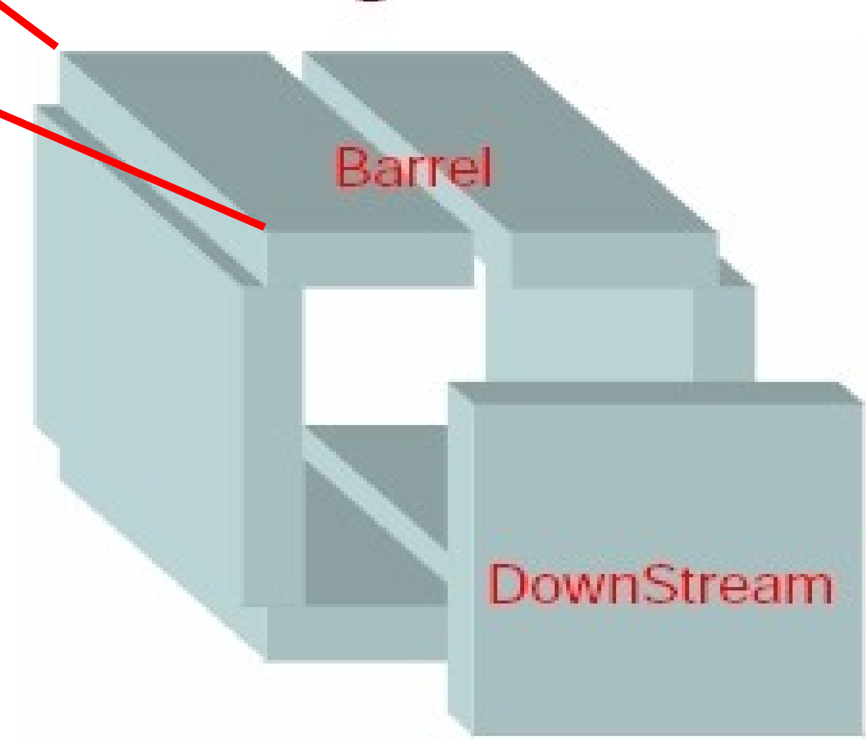
Primary particles

μ^- (13)	Trk 1,	KE= 938 MeV
p (2212)	Trk 2,	KE= 170 MeV
n (2112)	Trk 3,	KE= 72 MeV
p (2212)	Trk 4,	KE= 12 MeV
p (2212)	Trk 5,	KE= 3 MeV
p (2212)	Trk 6,	KE= 3 MeV
γ (22)	Trk 7,	KE= 6 MeV

ECAL



- P0 reconstruction around tracker
- Charged particle identification
- ν_e tagging (downstream)
- Veto for magnet events
- Energy catcher for π0d

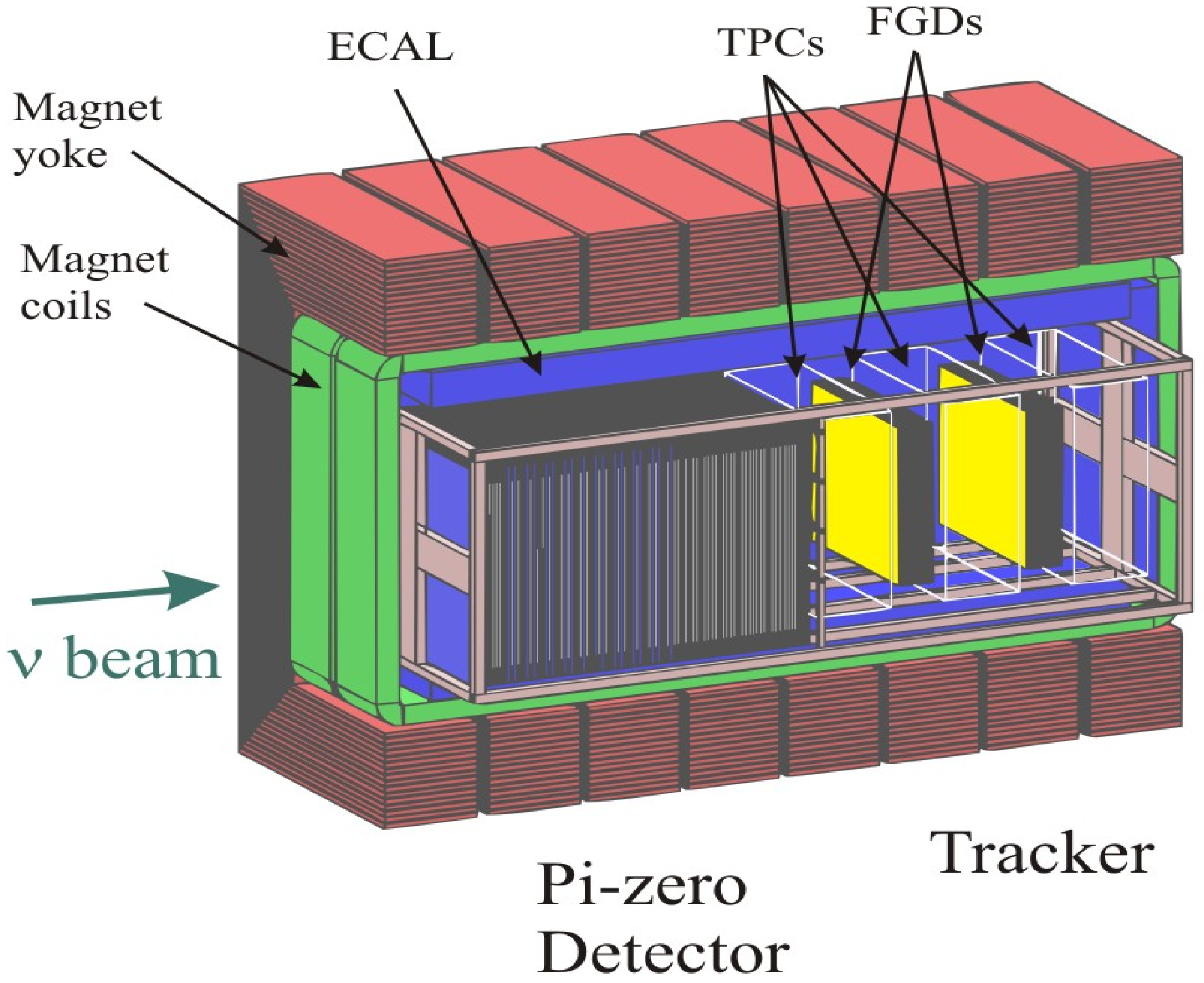


- Pb-scint sampling calorimeter
- Readout via WLS
- ΔE/E ~ 10-15%/√E
- 10 X_0 thick
- 4cm wide bars
- 21,000 channels

SMuRF (SMRD)

- 17 mm gaps between plates in magnet C's.
- Instrumented to catch muons exiting at 90 degrees to beam
- veto magnet events
- Forms basis for cosmic trigger

There's always a problem



How do we extract the fibres from magnet to photosensors?

Choice of Photosensor

In ND280 there are ~ 10^5 WLS fibers. There is no space to route them out of the magnet, so photosensor must live inside the magnet, must be compact and cheap(ish)

Pixellated Photodiodes (PPD)

Arrays of photodiodes working in Geiger mode.

Each APD is a digital device

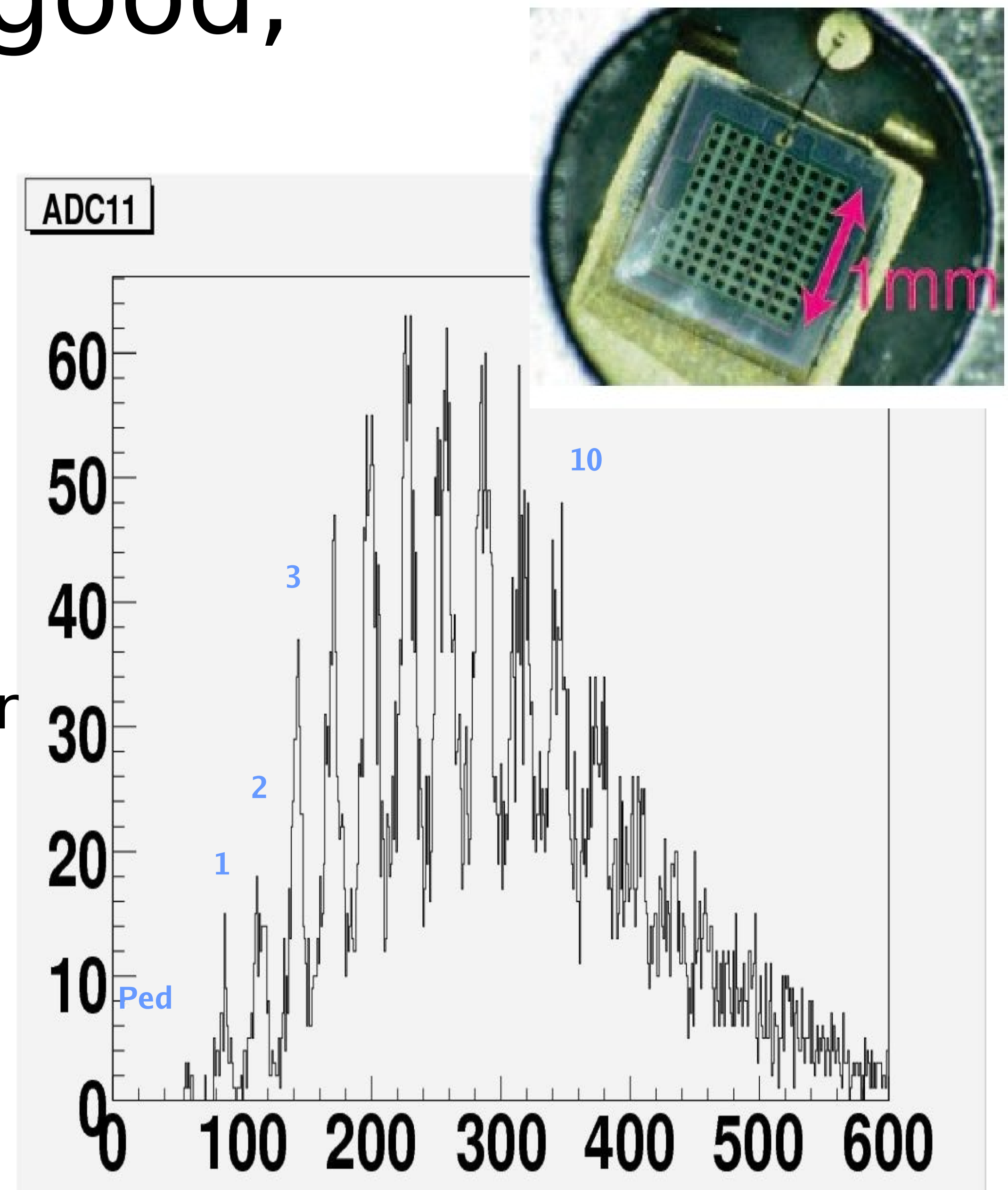
Total signal is the sum over all elements of the array.

Currently under development in Russia, Japan and UK

arXiv:physics/0605241

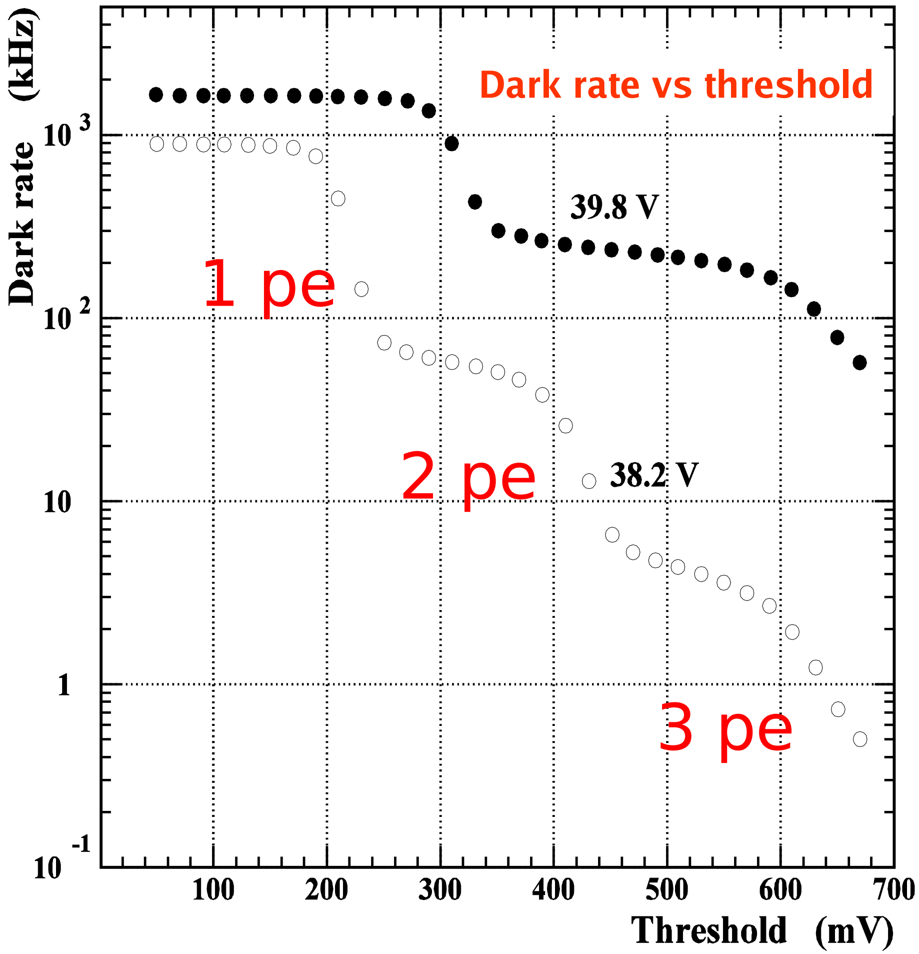
The good,

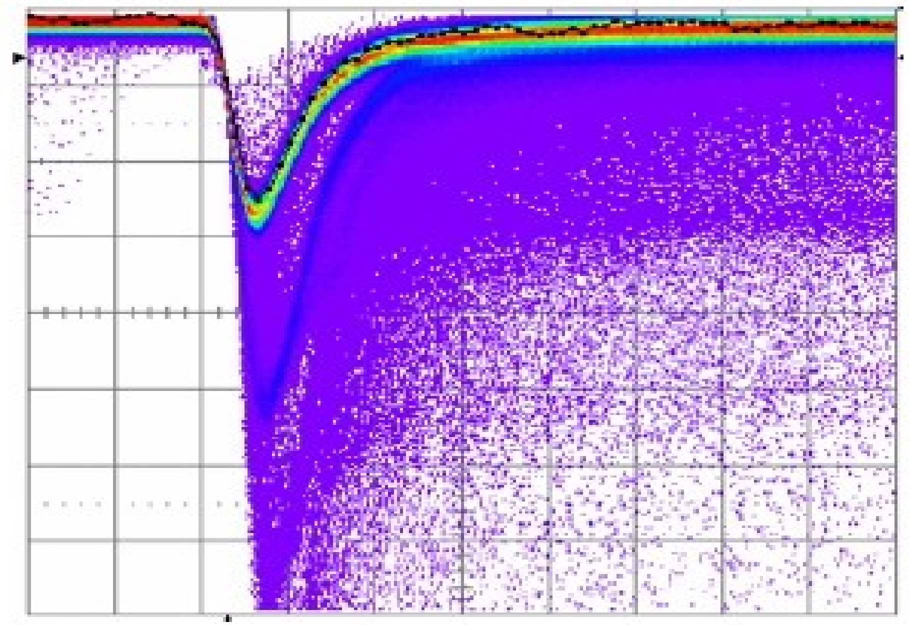
- Active area ~ 1.0-2.0 mm^2
- Gain ~ 10^6
- Fast (<1ns pulses possible)
- PDE ~ 10-15%
- Bias voltage ~ 25-70 V
- Digital device
- Roughly $10-$20 / device
- No damage if exposed under bias
- Mechanically robust
- Sensitivity in the blue
- Gain can be determined from single pe peaks
- One per fibre



The bad,

The ugly



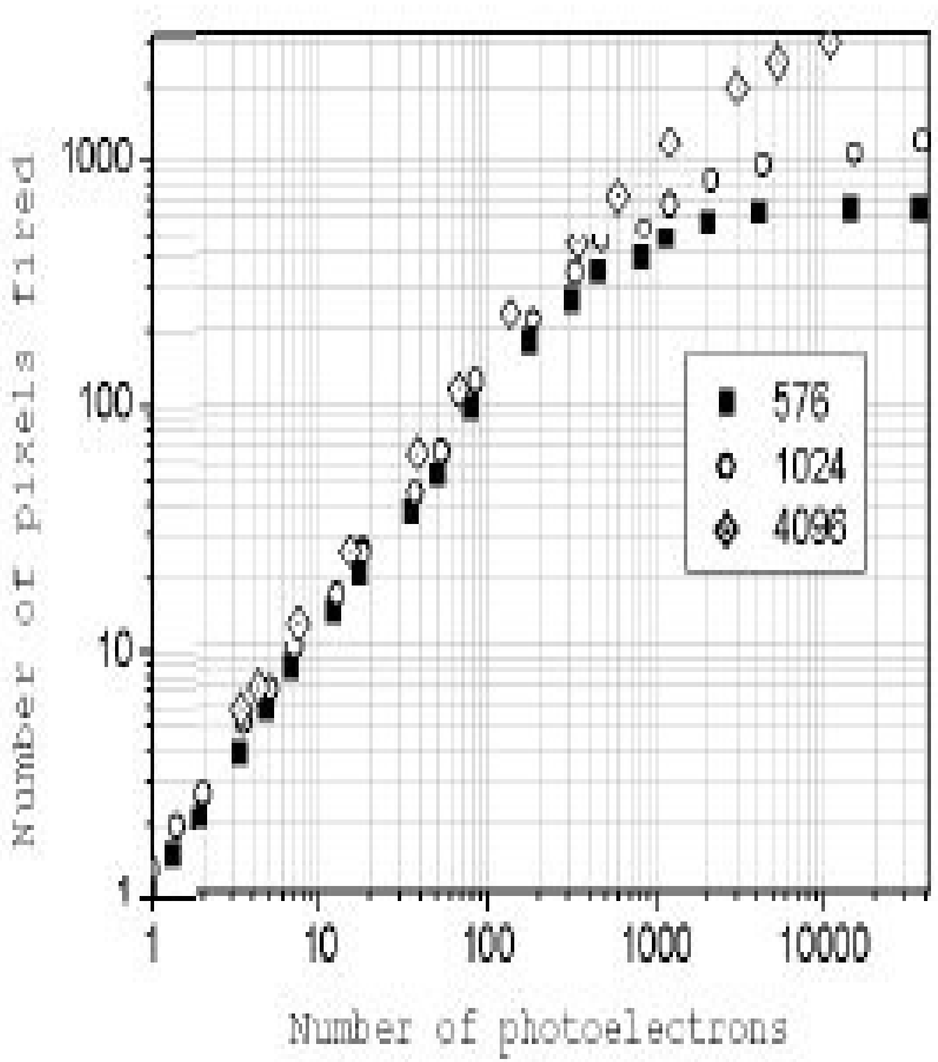


5-10% optical crosstalk. Photon from one cell starts avalanche in a neighbour

High dark noise rate highly dependent on temperature

Afterpulsing effect which is not yet understood.

The Ugly (2)



Intrinsically non-linear device

Linearity governed by the number of pixels.

If a photon hits an already active pixel, or the field gate between pixels, it will not produce a signal.

In principle this is calculable and depends on the probability of one photon triggering an avalanche and the geometric active coverage.

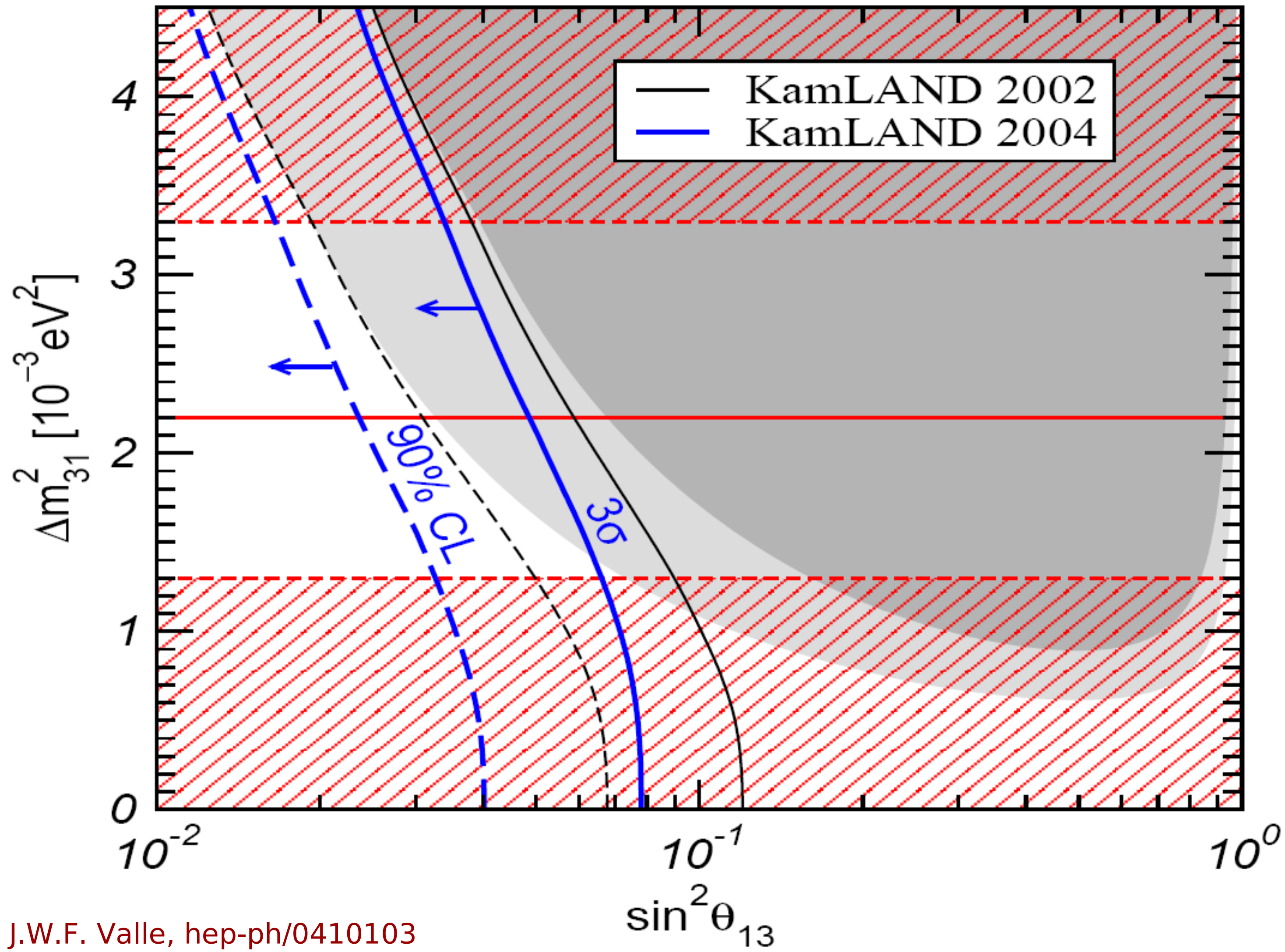
Precis

- Neutrino Oscillations – Present and Future
- The T2K Experiment
  - Introduction, Physics goals and sensitivity
  - JPARC and the neutrino beam
  - Near Detector
  - Far Detector
  - Schedule
- Conclusion

Conclusion

- T2K will be the first operating Superbeam in the next generation of long baseline neutrino oscillation experiments.
- Ambiguities make these measurements difficult so this should be viewed as part of a global strategy.
- Focus of T2K-Phase 1 is a measurement, if possible, of θ_{13} to above 3^{o}
- Beamline is almost finished, Far detector exists. We have 3 years to build the Near Detector.
- Will (MUST) switch on in August 2009.

What about θ_{13}?



J.W.F. Valle, hep-ph/0410103

A few assumptions later…

$$P_{e\mu} \approx \sin^2 2\theta_{13} \sin^2 2\theta_{23}$$ θ_{13}

$$\mp \alpha \sin 2\theta_{13} \sin\delta \cos\theta_{13} \sin 2\theta_{12} \sin 2\theta_{23} \sin^2\delta$$ CP-odd

$$+\alpha^2 \cos 2\theta_{23} \sin 2\theta_{12}$$ Solar

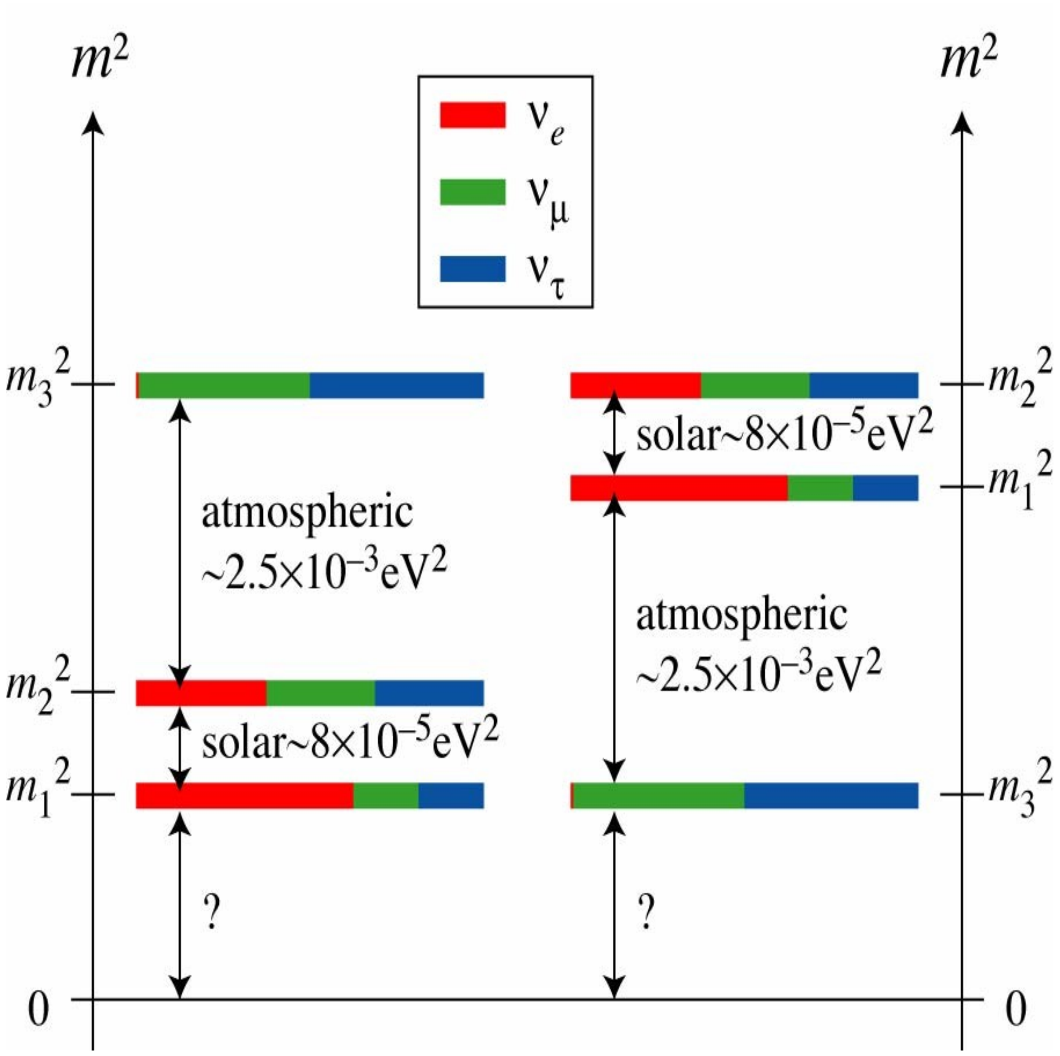
with $\alpha = \frac{\Delta m^2_{21}}{\Delta m^2_{31}} \sim 0.03$ $\quad \Delta = \Delta m^2_{31} \frac{L}{4E} \sim \frac{\pi}{2}$

@Osc max

And ignoring matter effects

- *if θ_{13} = 0 then no measurement can be made of δ*
- *if we see anything at all then θ_{13} > 0 regardless of δ*
- *need precise measurements of 23 parameters*

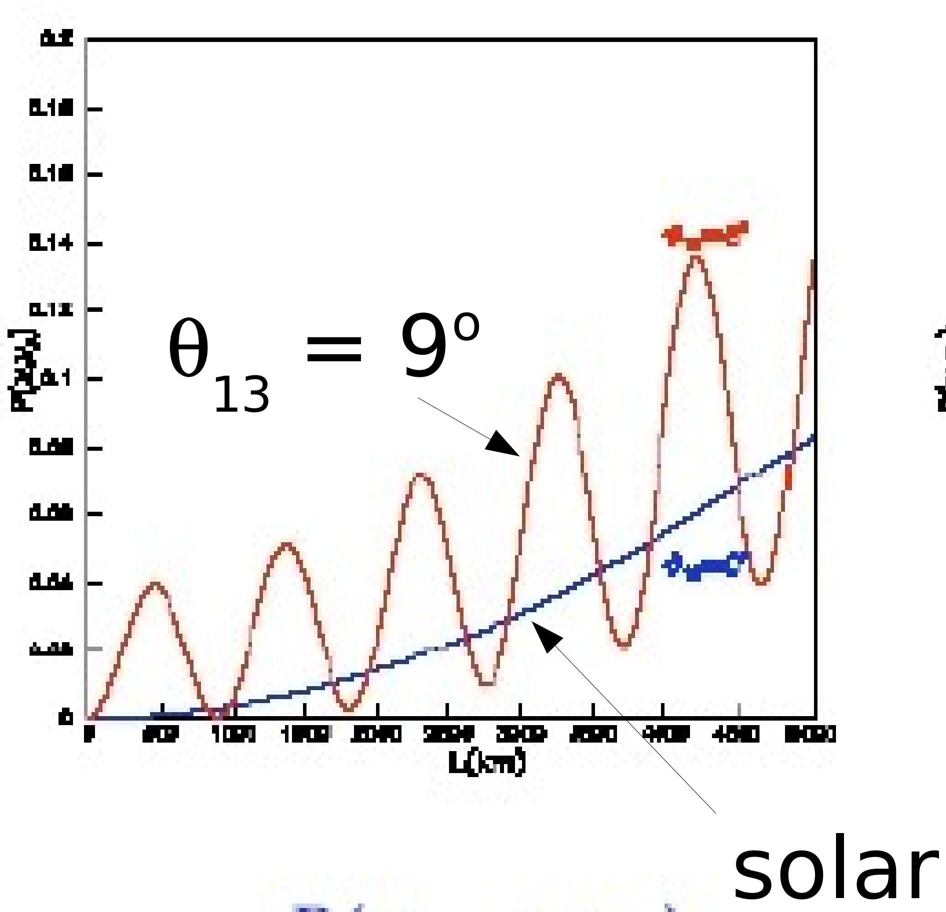
A word on mass heirarchy



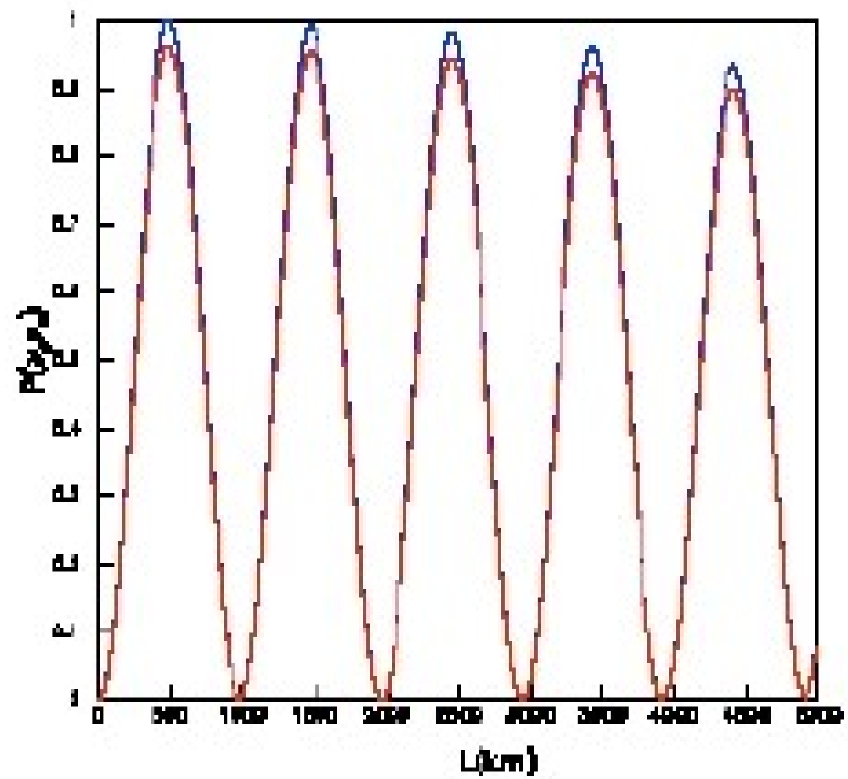
Sign of Δm^2_{32} can be determined by looking at how oscillations are affected as the neutrinos pass through matter

Size of the matter effect is proportional to the amount of matter (baseline distance)

Measuring θ_{13} II



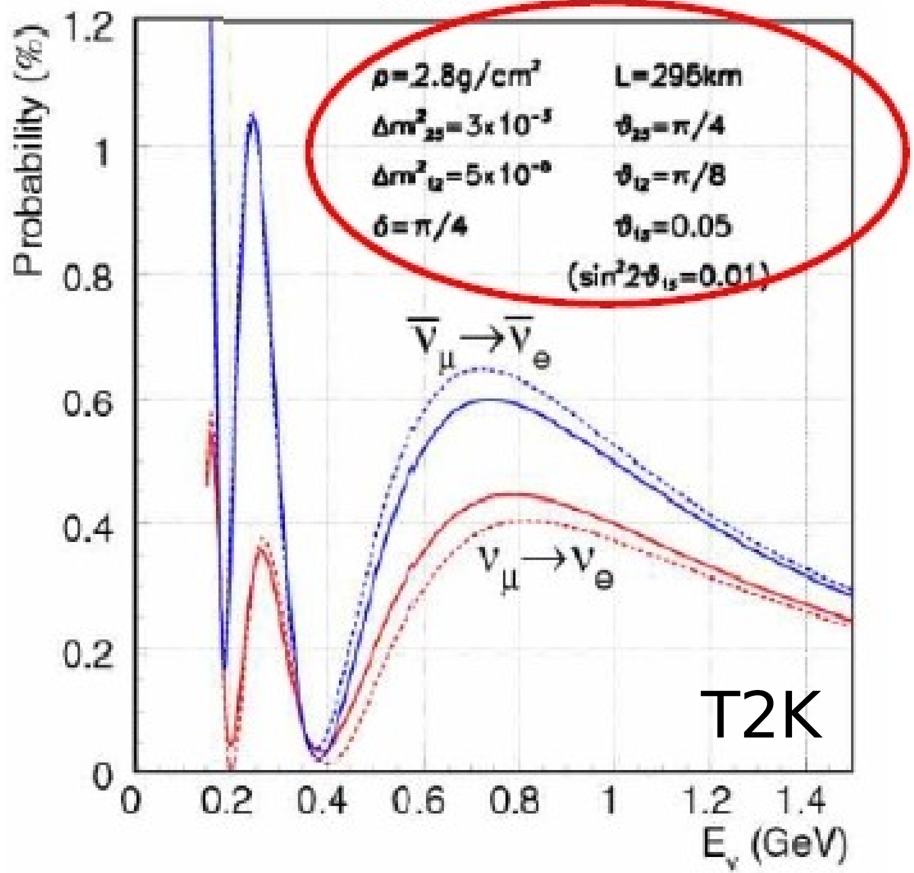
$P(\nu_e \to \nu_\mu)$



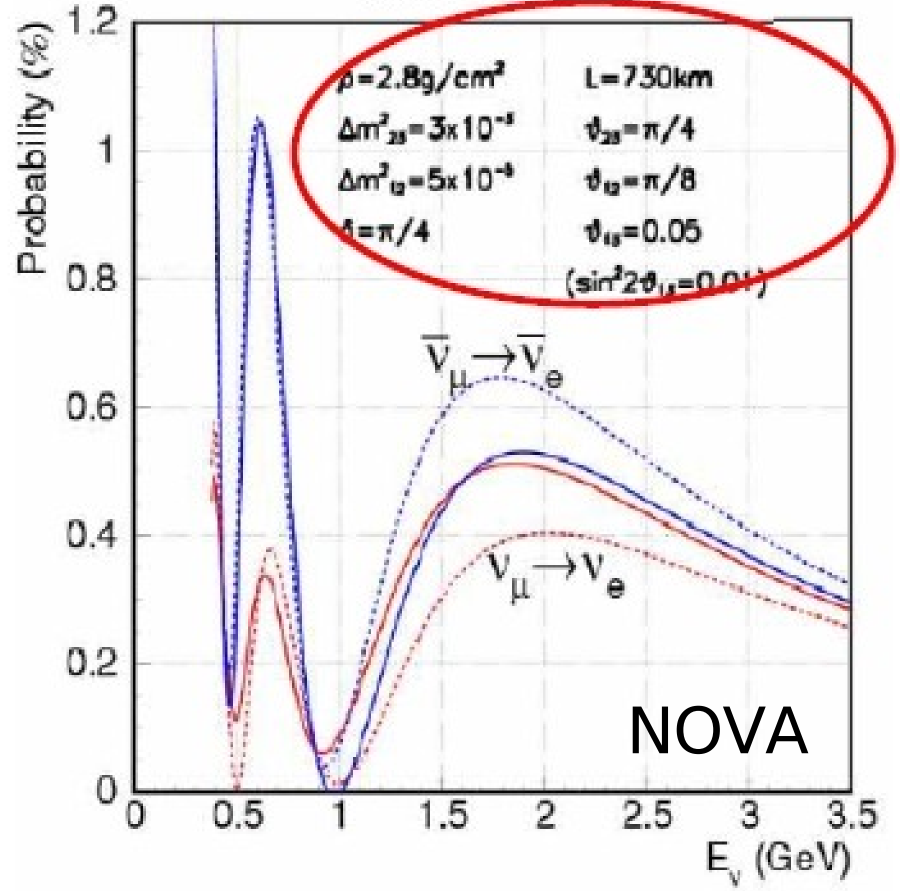
$P(\nu_\mu \to \nu_\tau)$

Matter Effects in T2K

295 km

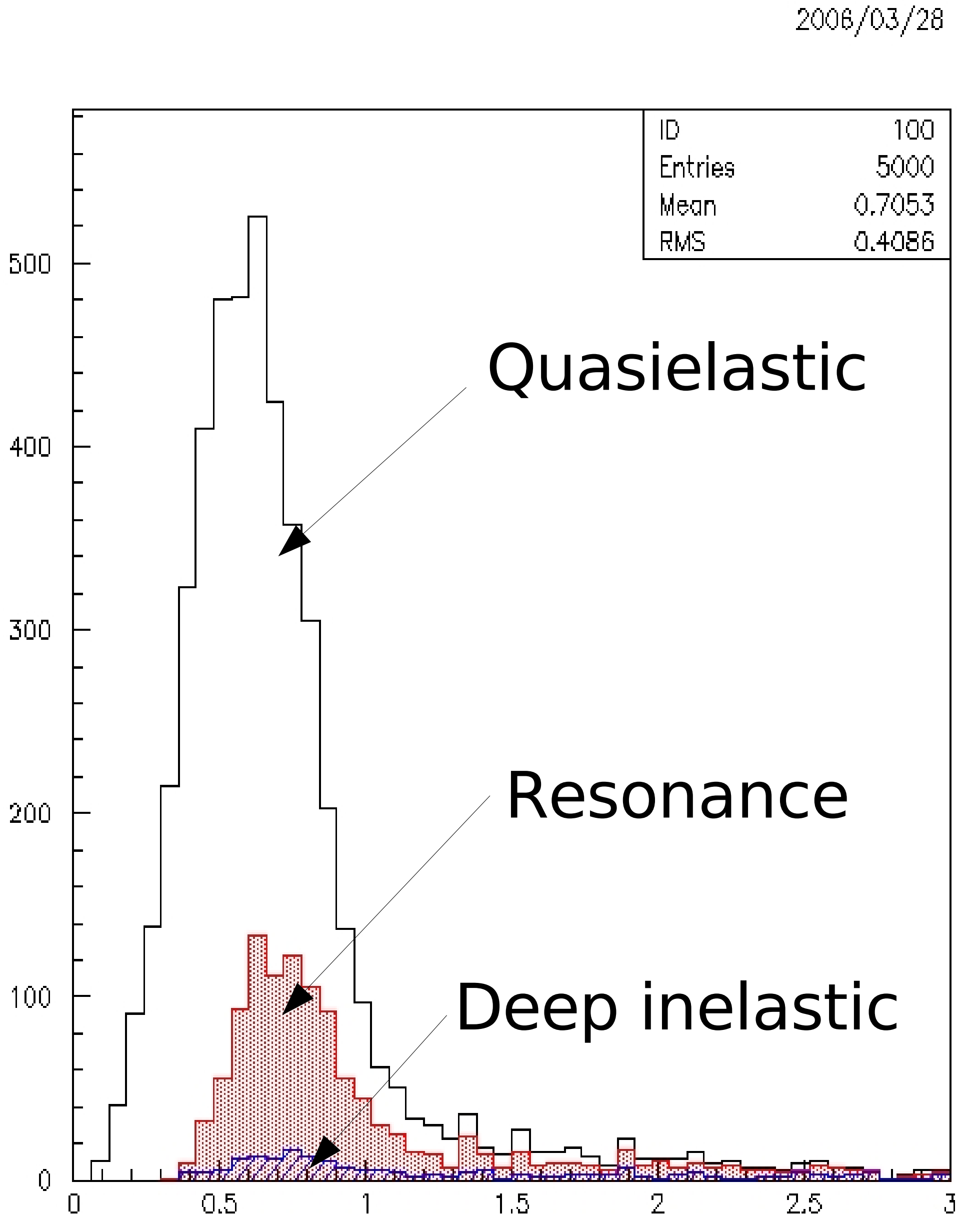


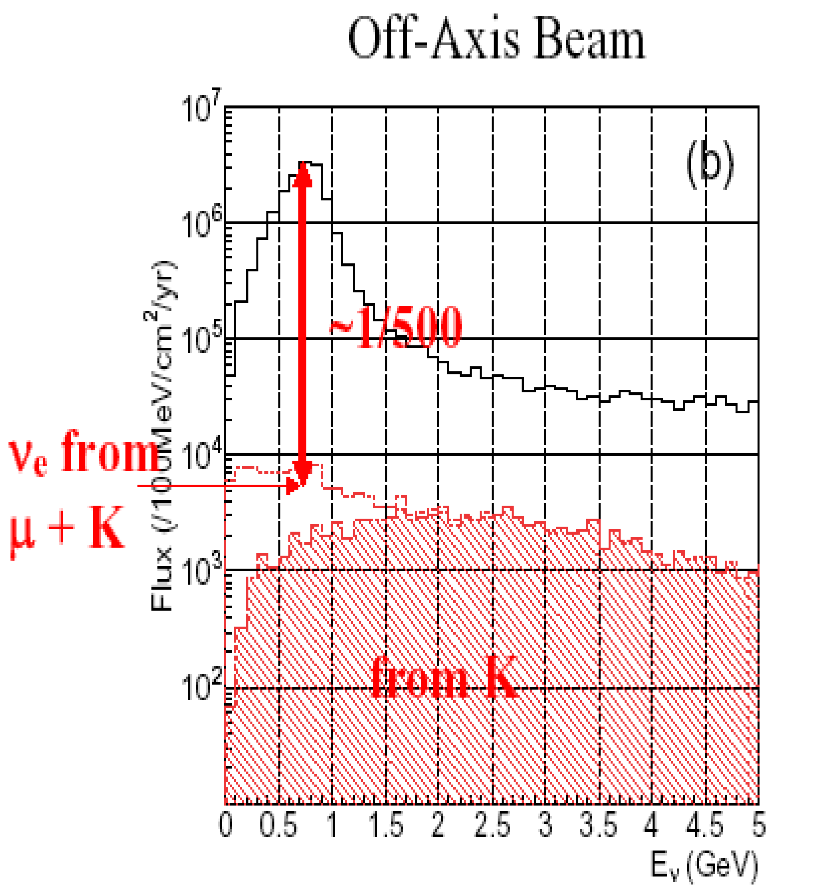
730 km



Solid line : with matter effects
Dashed line : w/out matter effects

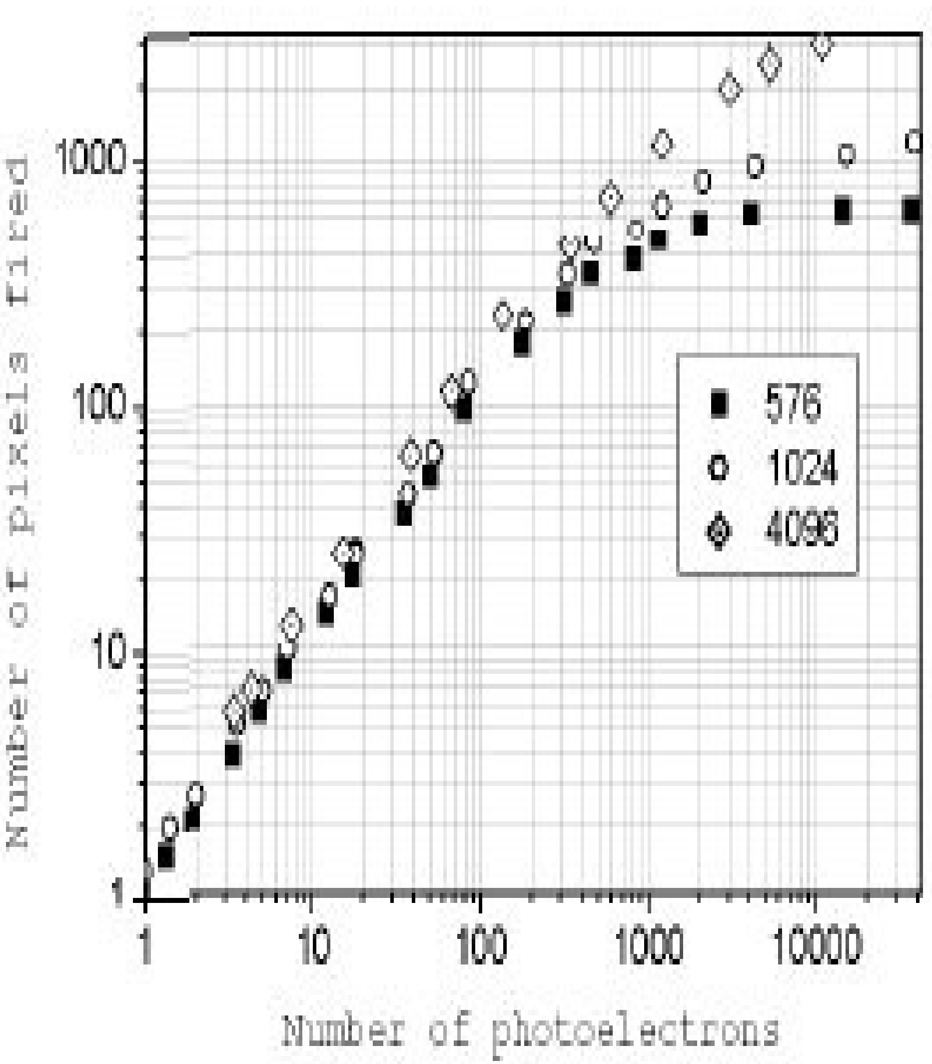
T2K Spectrum





Intrinsic background: ν_e / ν_μ (peak) ~ 0.002

Dynamic range

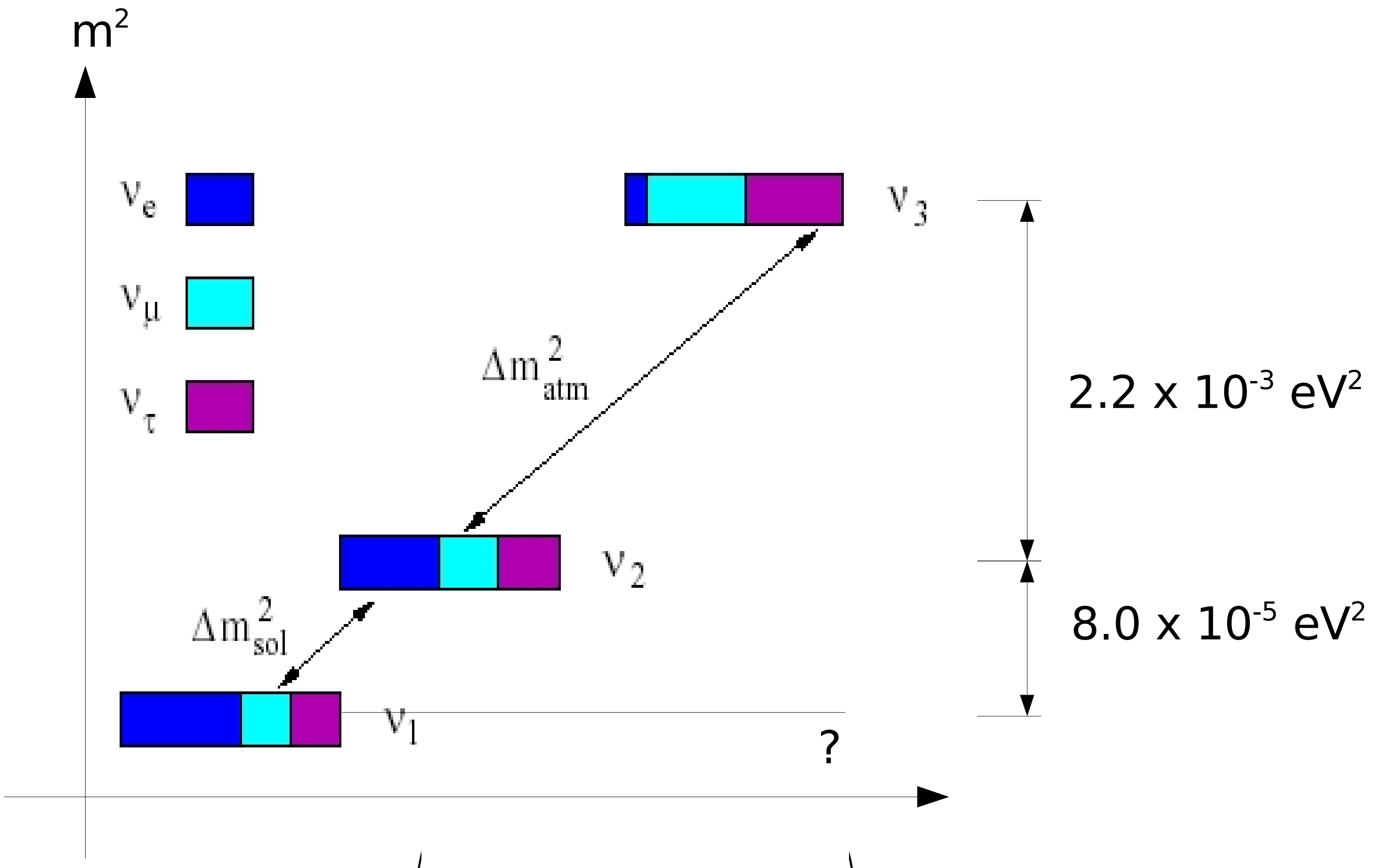


Linearity governed by the number of pixels.

If a photon hits an already active pixel, it will not produce a signal.

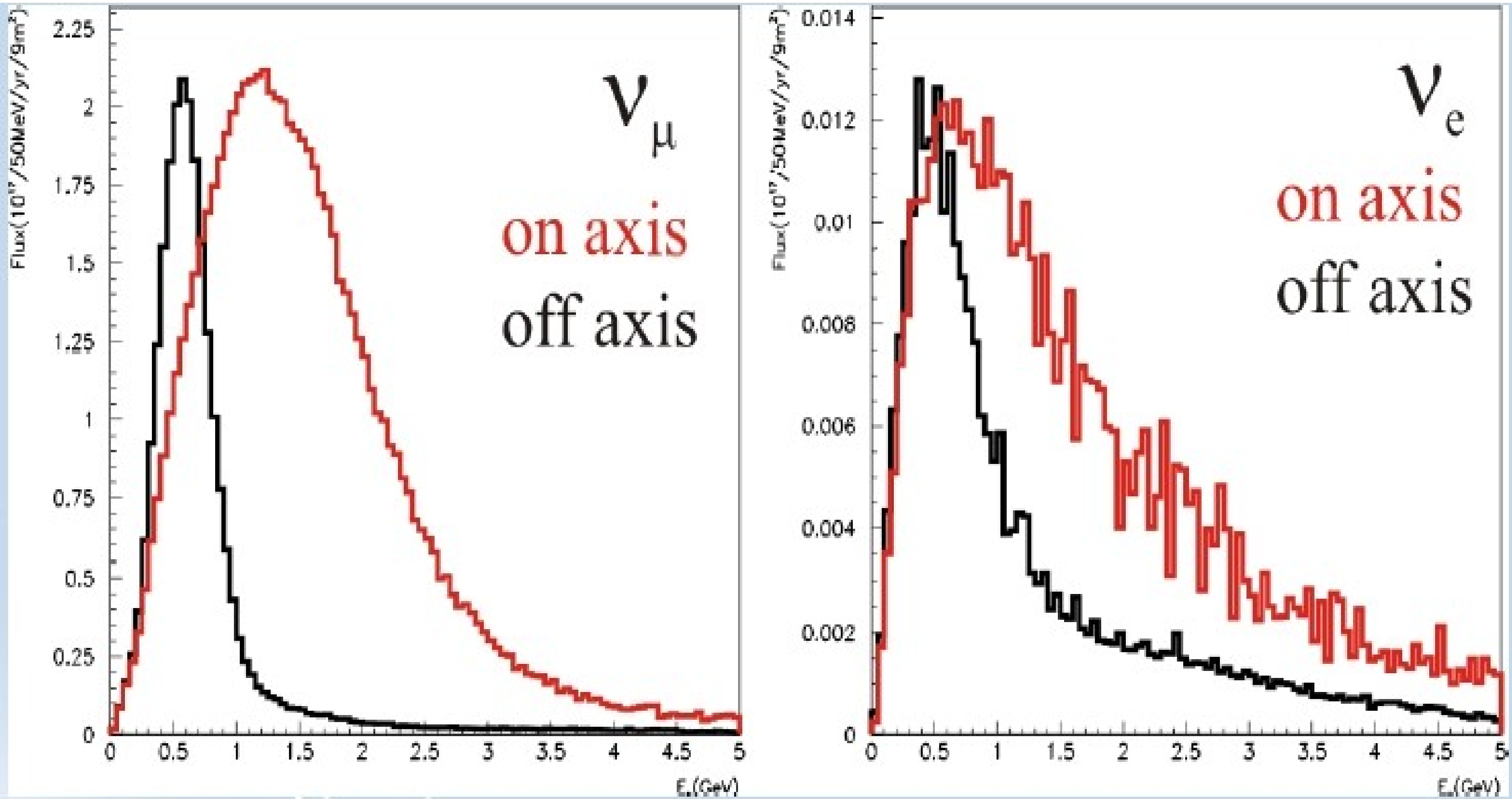
In principle this is calculable and depends on the probability of one photon triggering an avalanche.

What do we know?

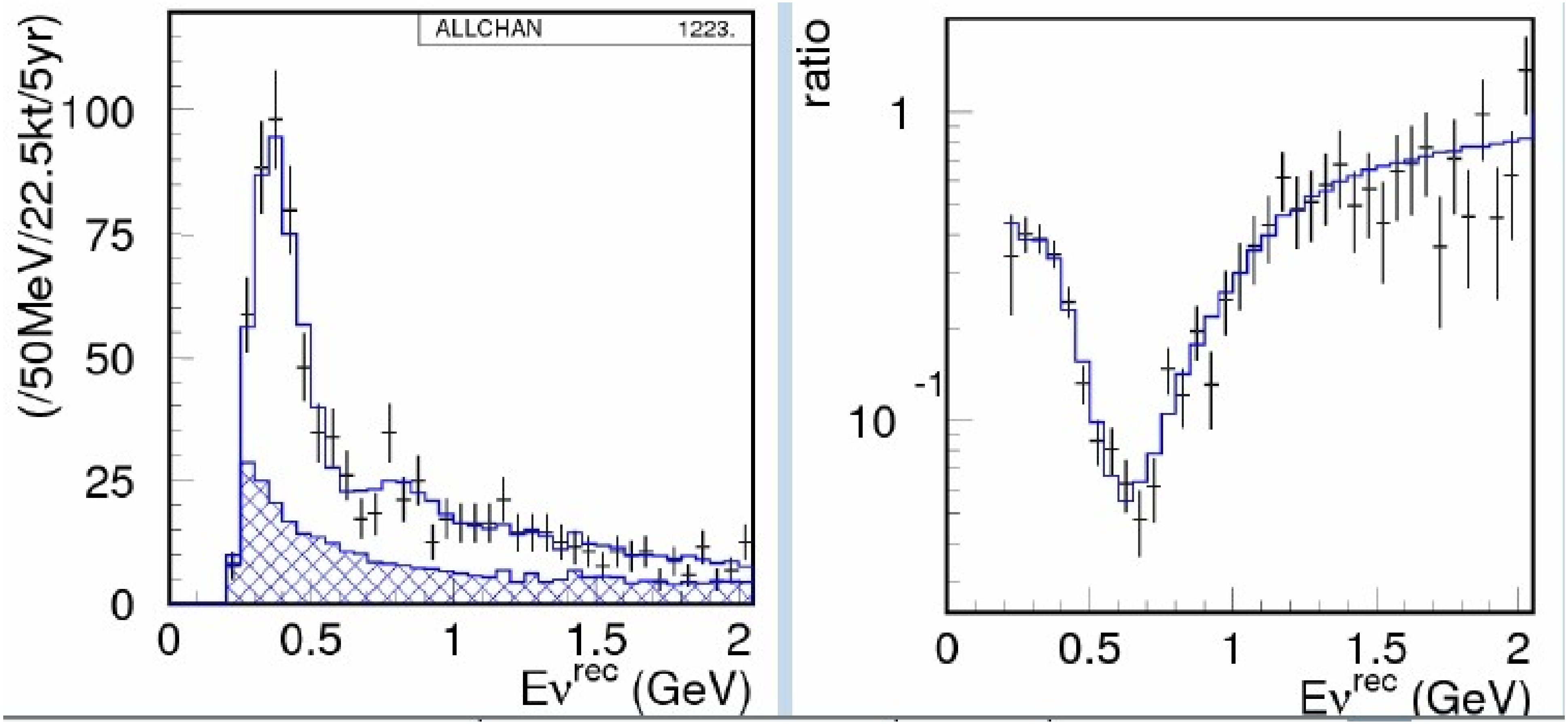


$$U_{MNSP} = \begin{pmatrix} 0.8 & 0.5 & \epsilon \\ 0.4 & 0.6 & 0.7 \\ 0.4 & 0.6 & 0.7 \end{pmatrix}$$

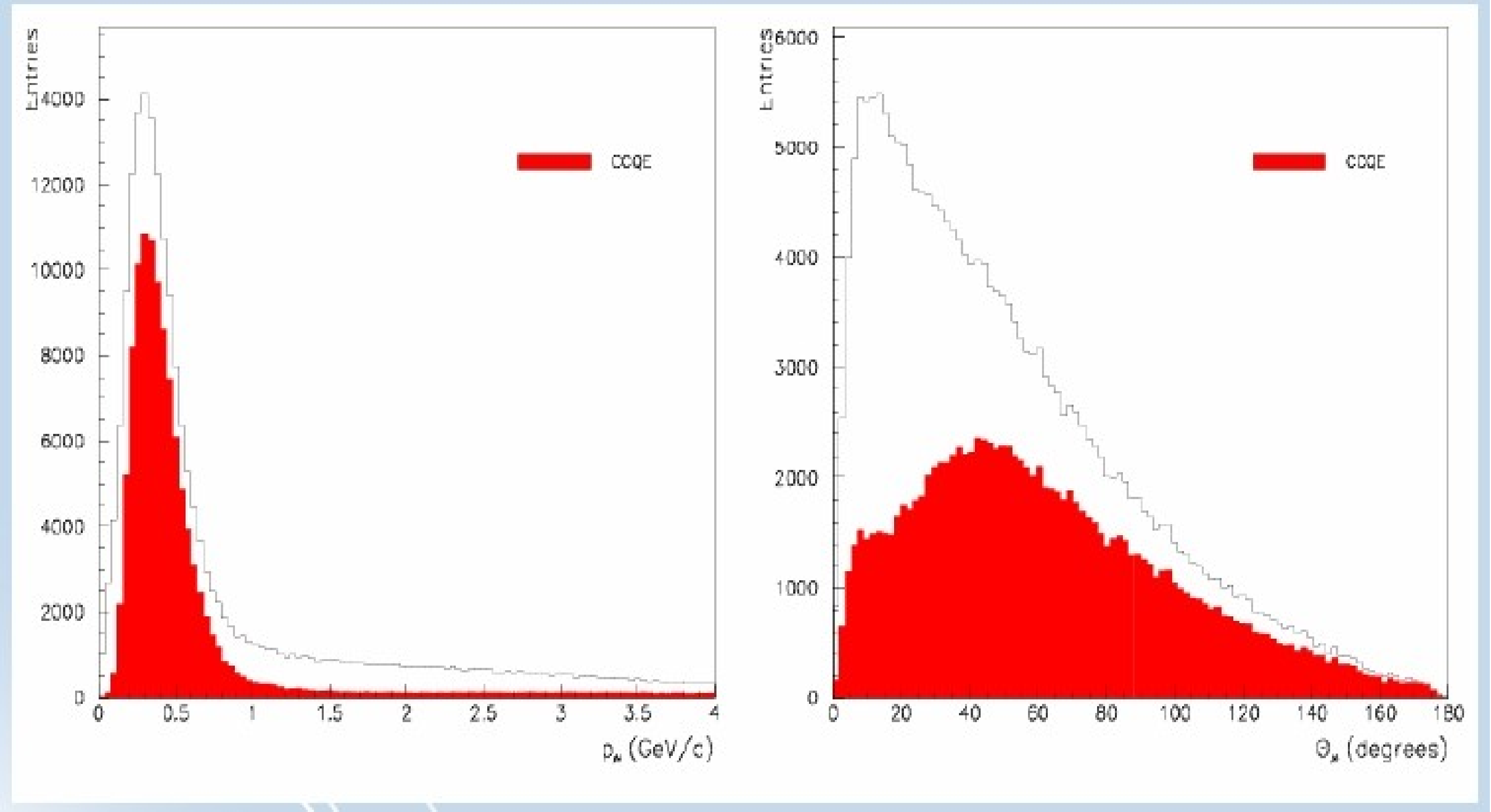
Neutrino Spectra



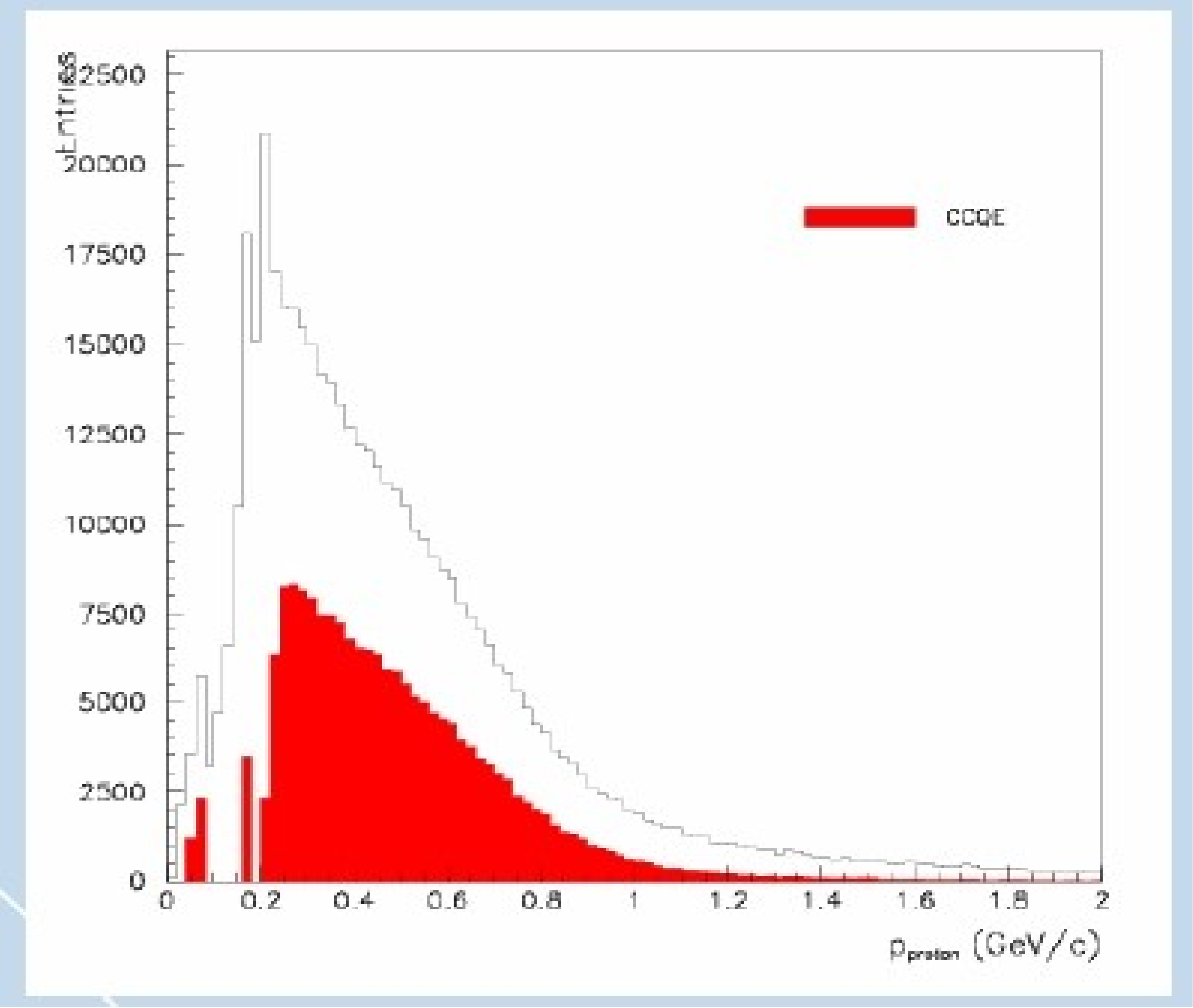
Muon disappearance



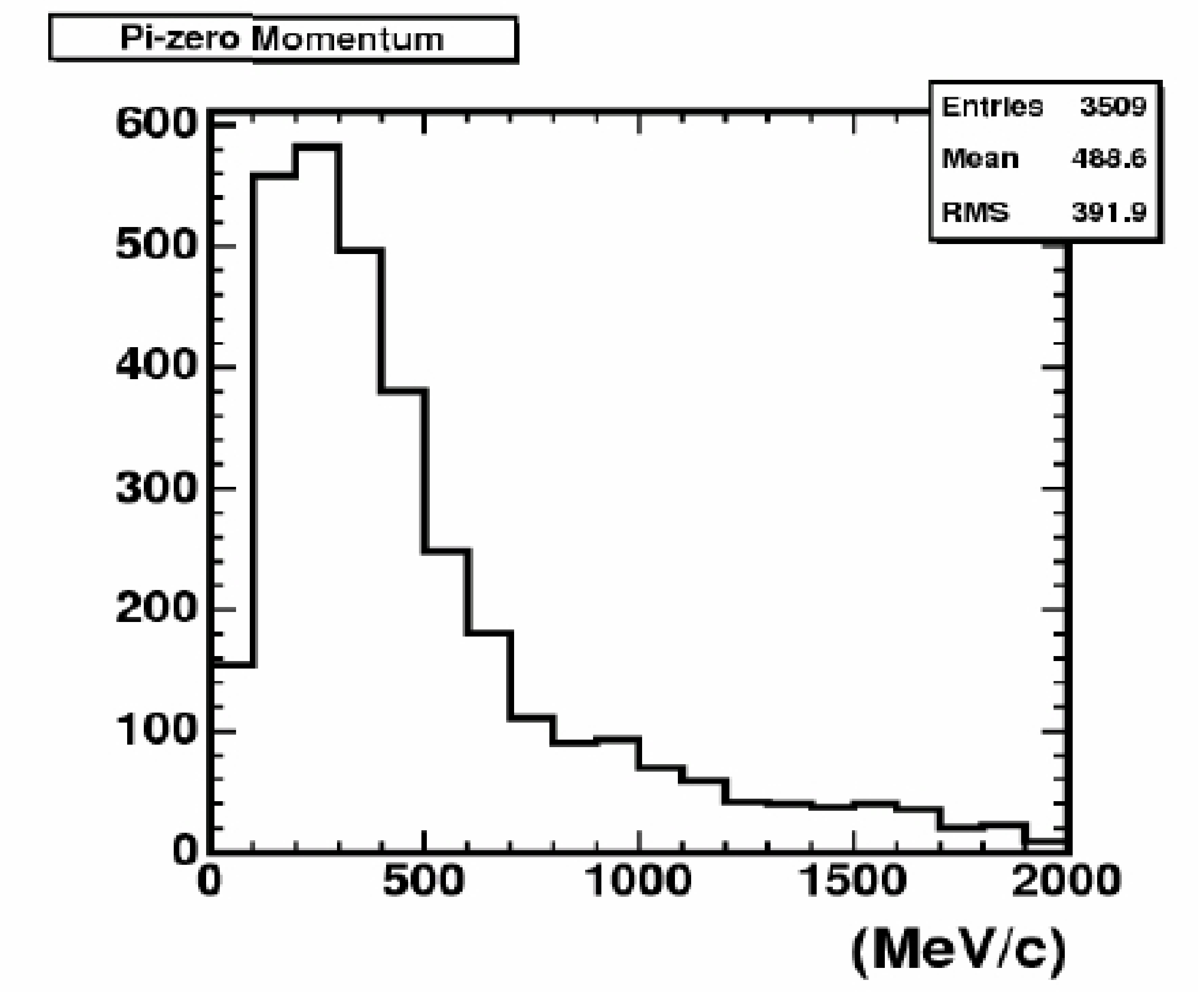
Muon properties @ 280m



Proton momentum at 280m

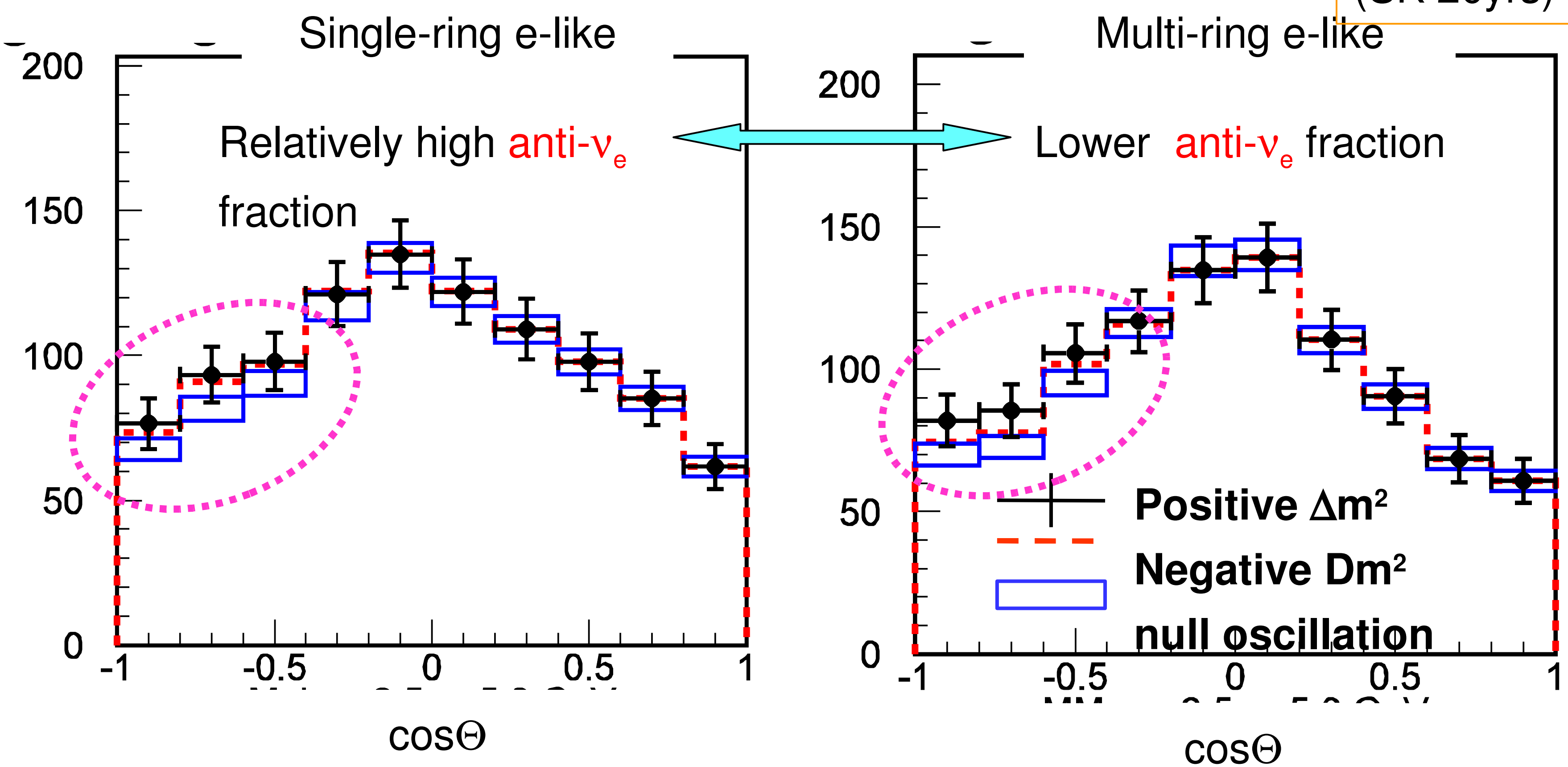


Pizero Momentum @ 280m

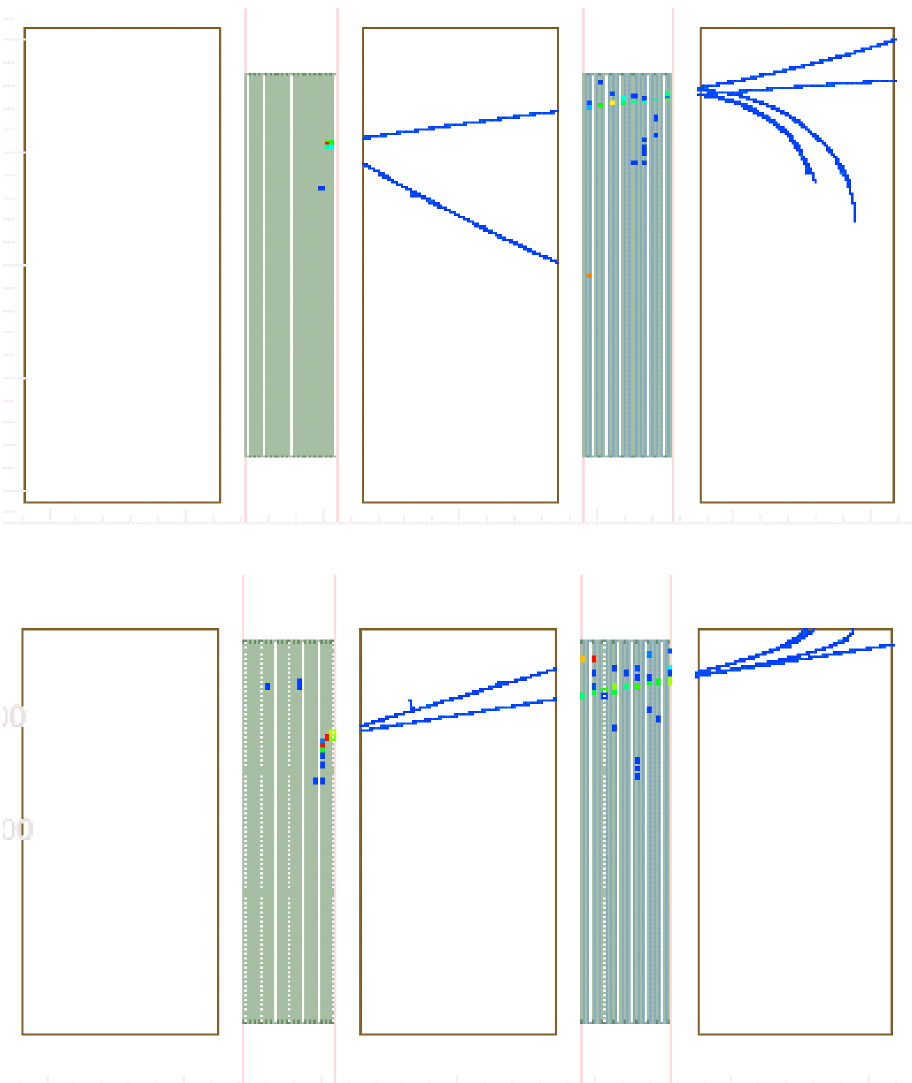


Heirarchy Sensitivity

Δm^2=0.002eV^2
$s^2\theta_{23}$ = 0.5
$s^2\theta_{13}$ = 0.05
(SK 20yrs)



Tracker – ν_e CC event



Event No.: 13 Reaction code: 1 Position in File: 13

Primary Vertex [mm]: (423, 543, 985)

Located in

Basket_0/TRK_0/Active_1/ScintX1_145/bar_39527

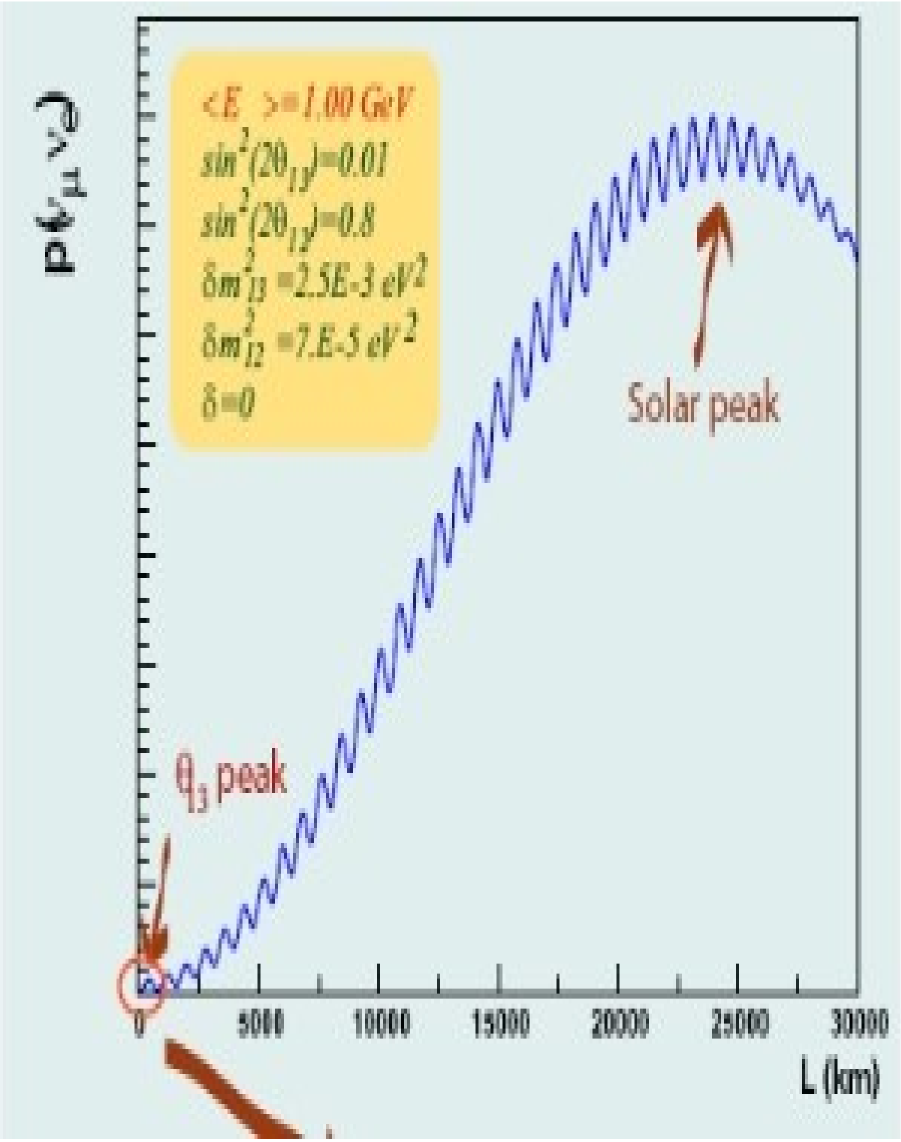
Informational particles

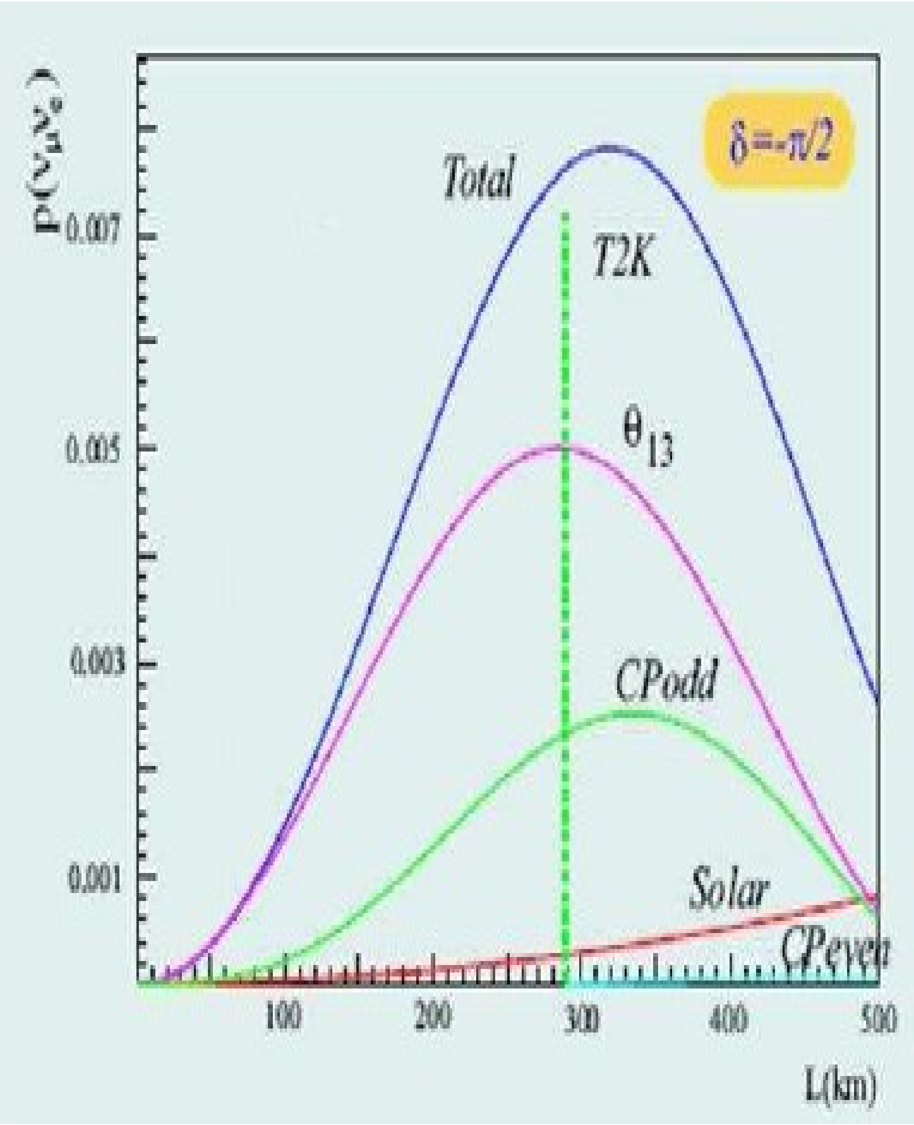
ν_e	(12)	Trk -1,	KE= 2893 MeV
n	(2112)	Trk -1,	KE= 0 MeV

Primary particles

e^-	(11)	Trk 1,	KE= 2578 MeV
n	(2112)	Trk 2,	KE= 46 MeV
p	(2212)	Trk 3,	KE= 15 MeV
p	(2212)	Trk 4,	KE= 117 MeV
p	(2212)	Trk 5,	KE= 86 MeV
p	(2212)	Trk 6,	KE= 14 MeV
γ	(22)	Trk 7,	KE= 4 MeV

Measuring θ_{13}



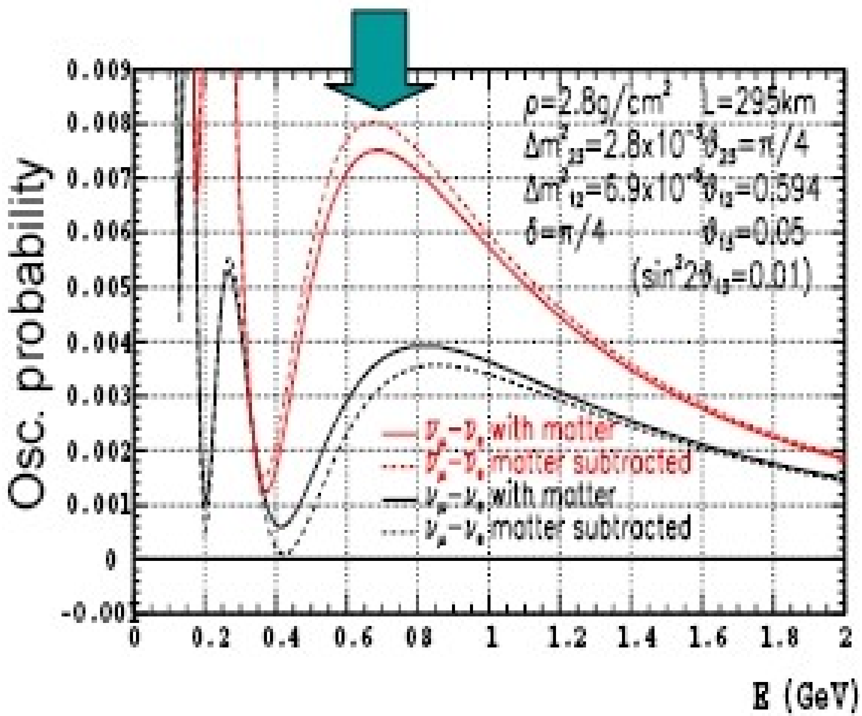


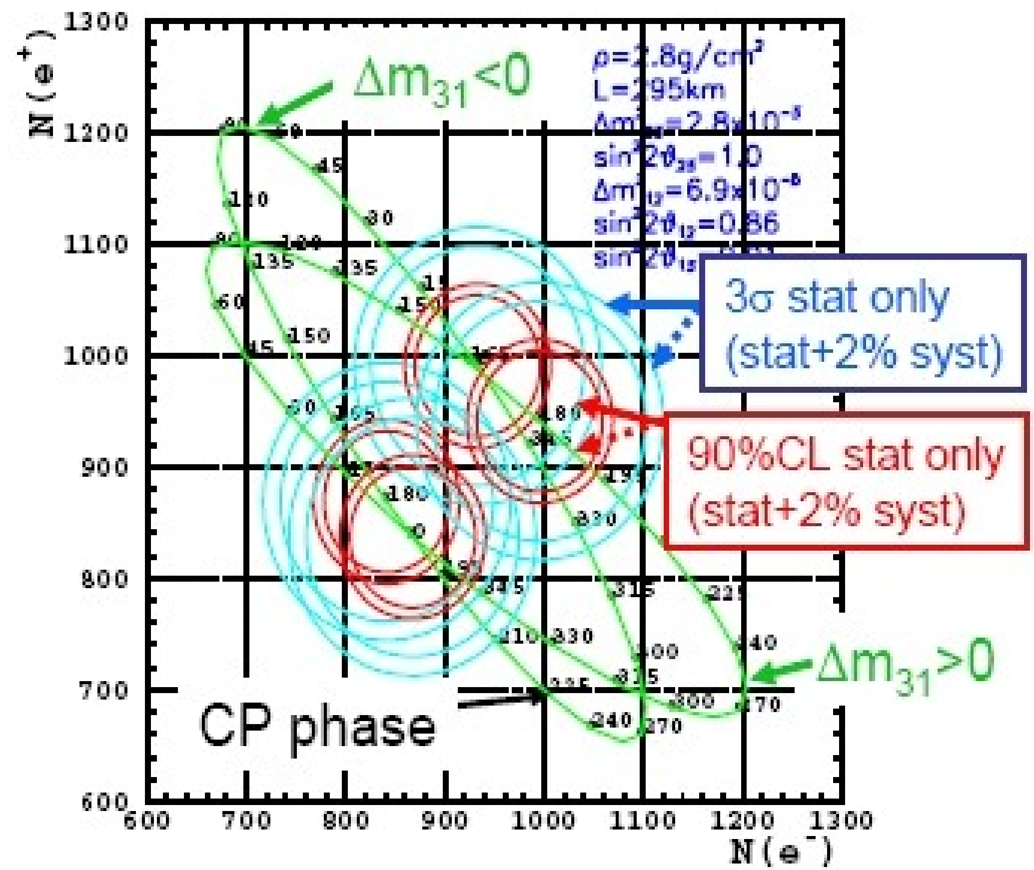
Oscillation Probabilities

$\sin^2 2\theta_{13} = 0.01$

Neutrino run=2years,
anti-neutrino run=6.8years,
4MW, 0.54Mton fid. Vol.

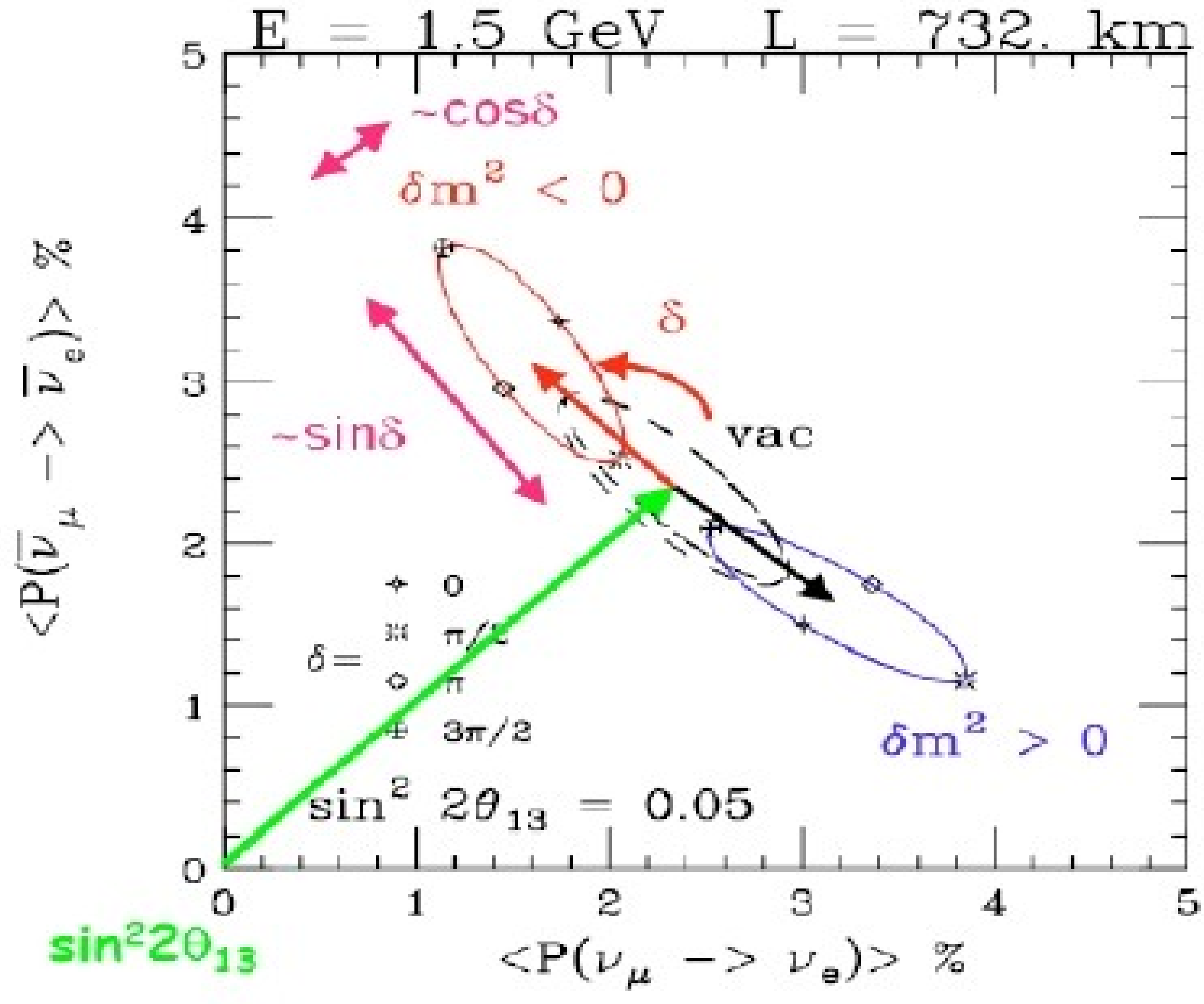
Peak energy of the T2K beam



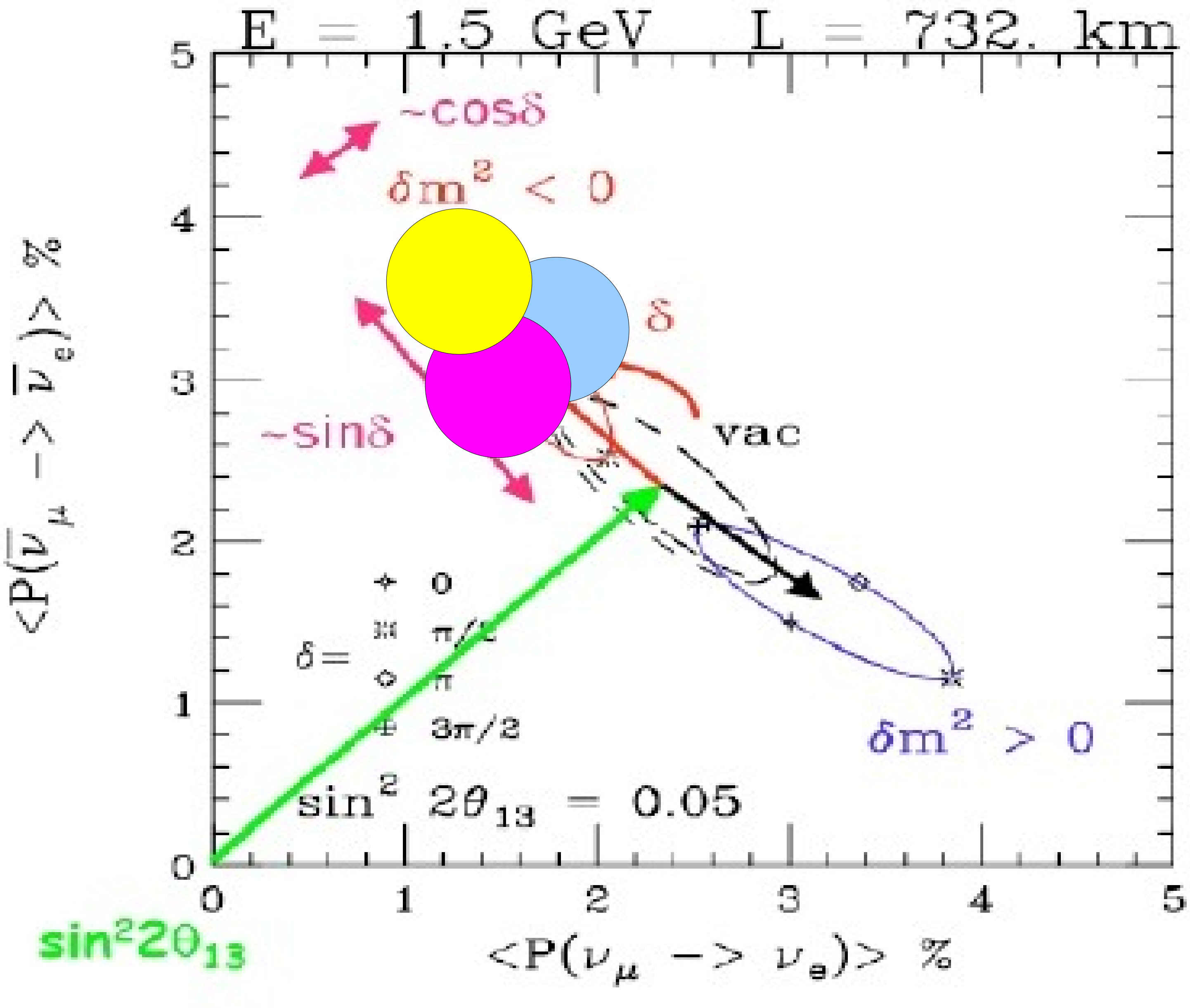


Solid line: w/ matter
Dashed line: w/o matter

Ambiguities

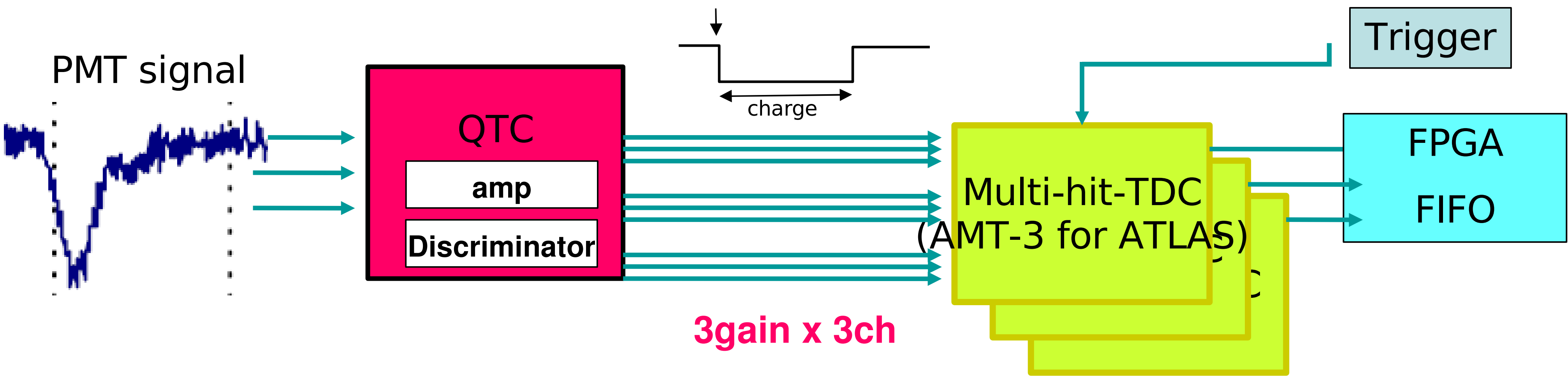


Ambiguities



New DAQ System

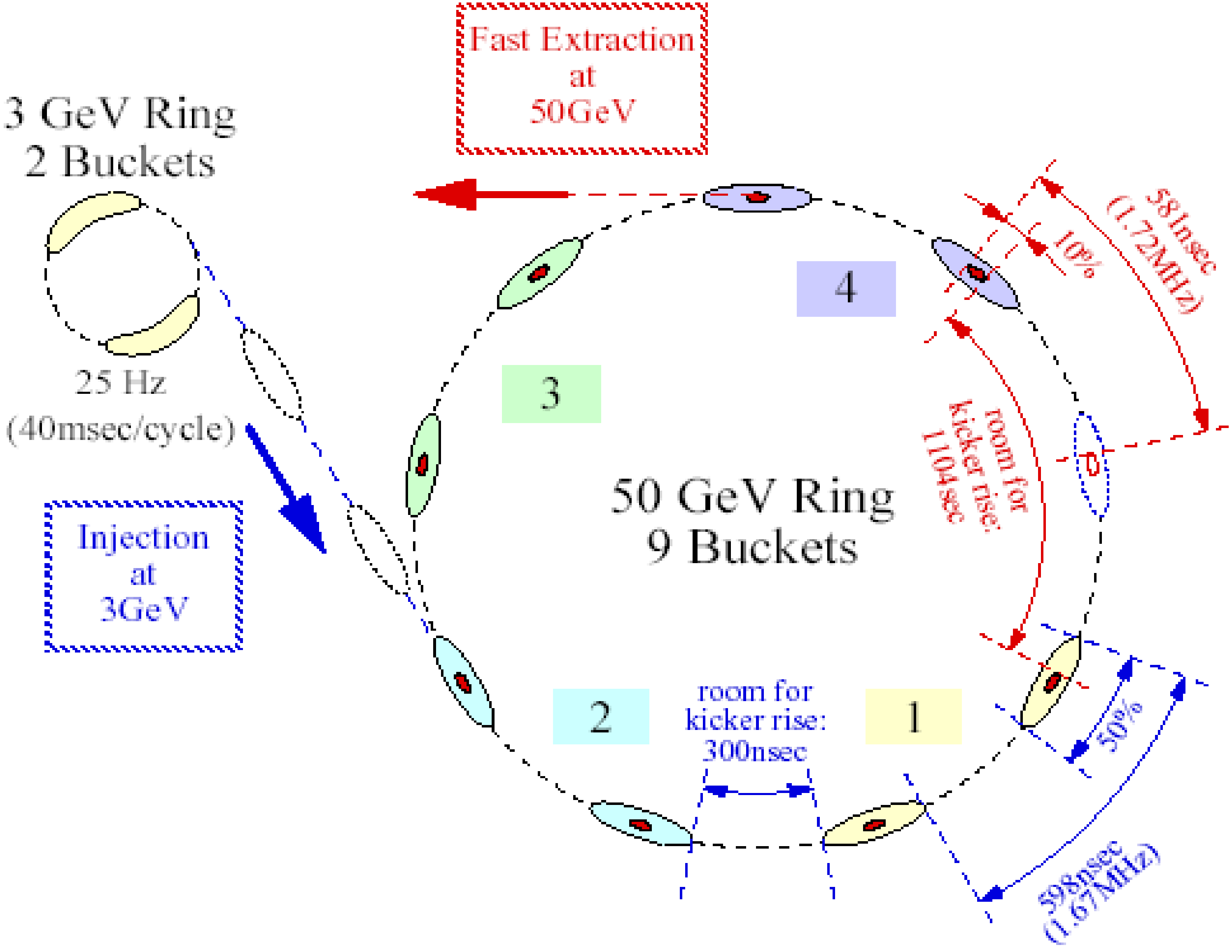
Current SK DAQ is over 10 years old



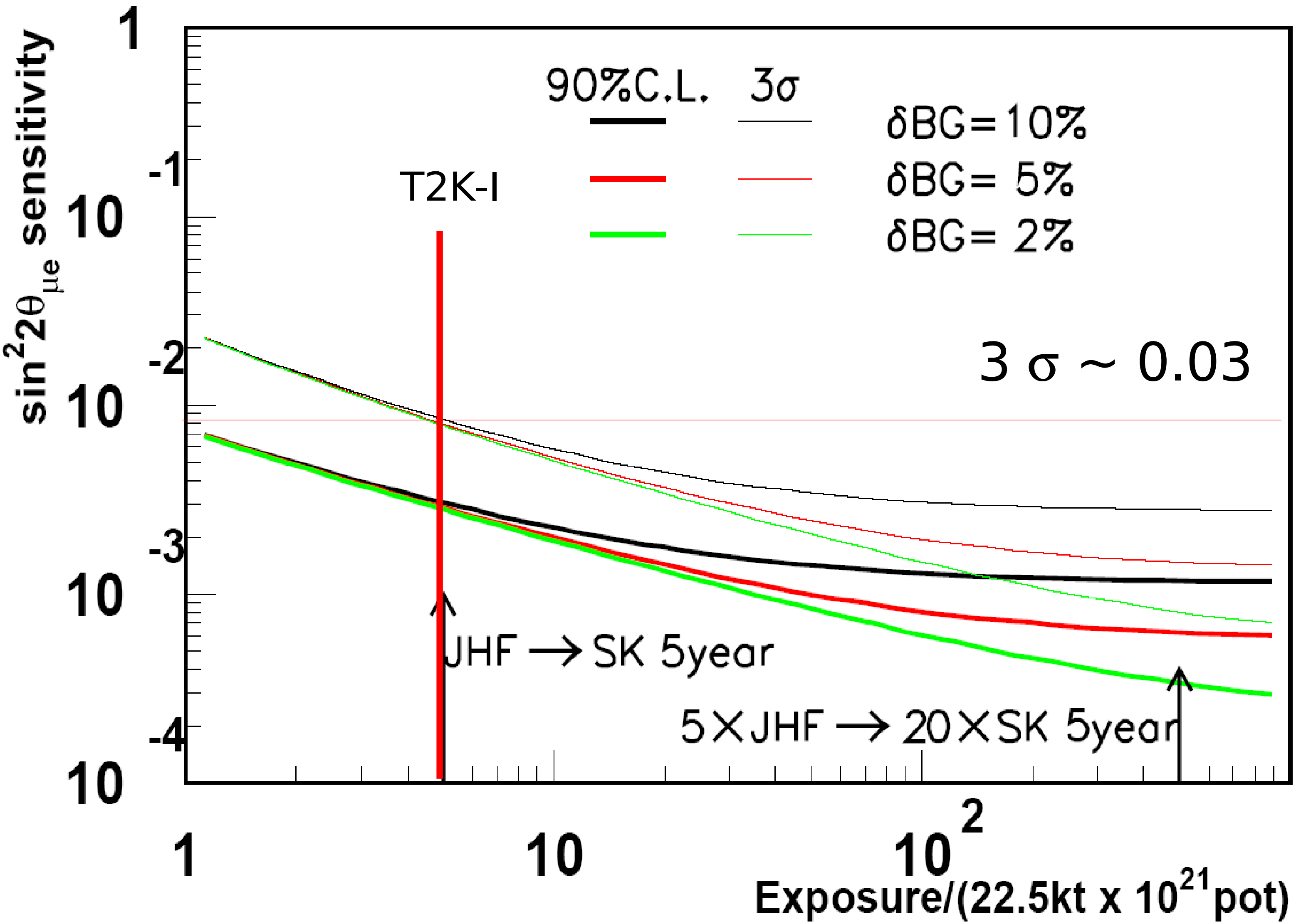
- Better T/Q resolution
- Dynamic range : 250pe->1250pe
- Smaller electronic crosstalk
- Smaller signal reflection
- Better temp. compensation

2004 – Began custom ASIC development
2005 – Began design of FEB
2006 – First FEB prototype
2007-2008 – Full installation in SK

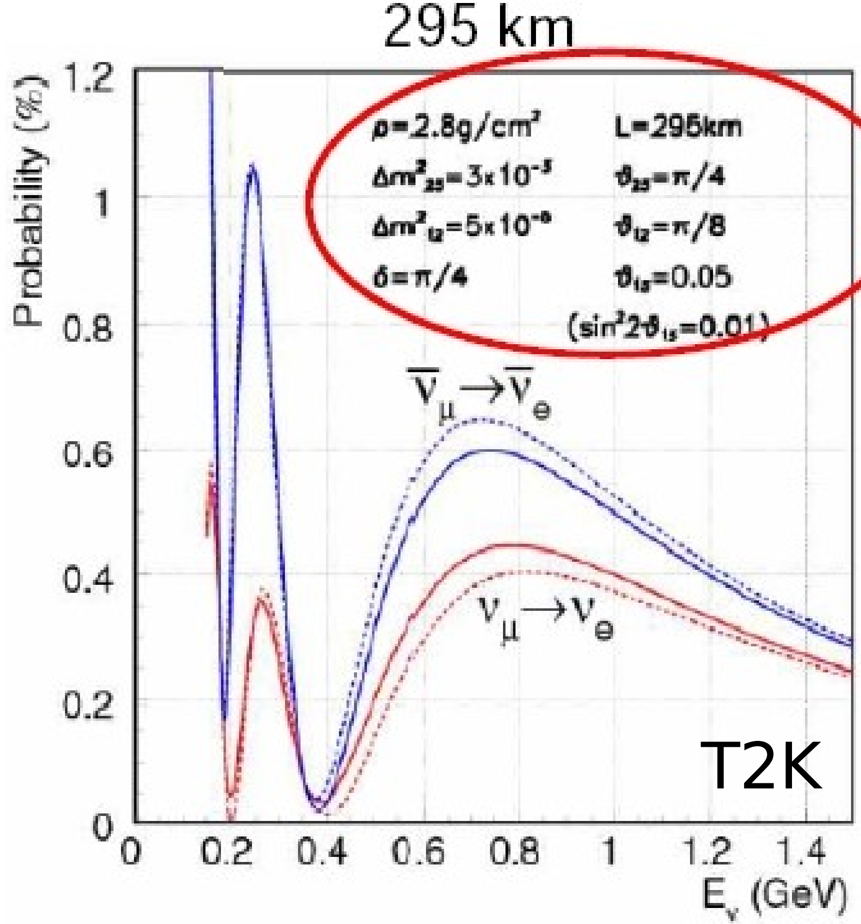
Beam structure

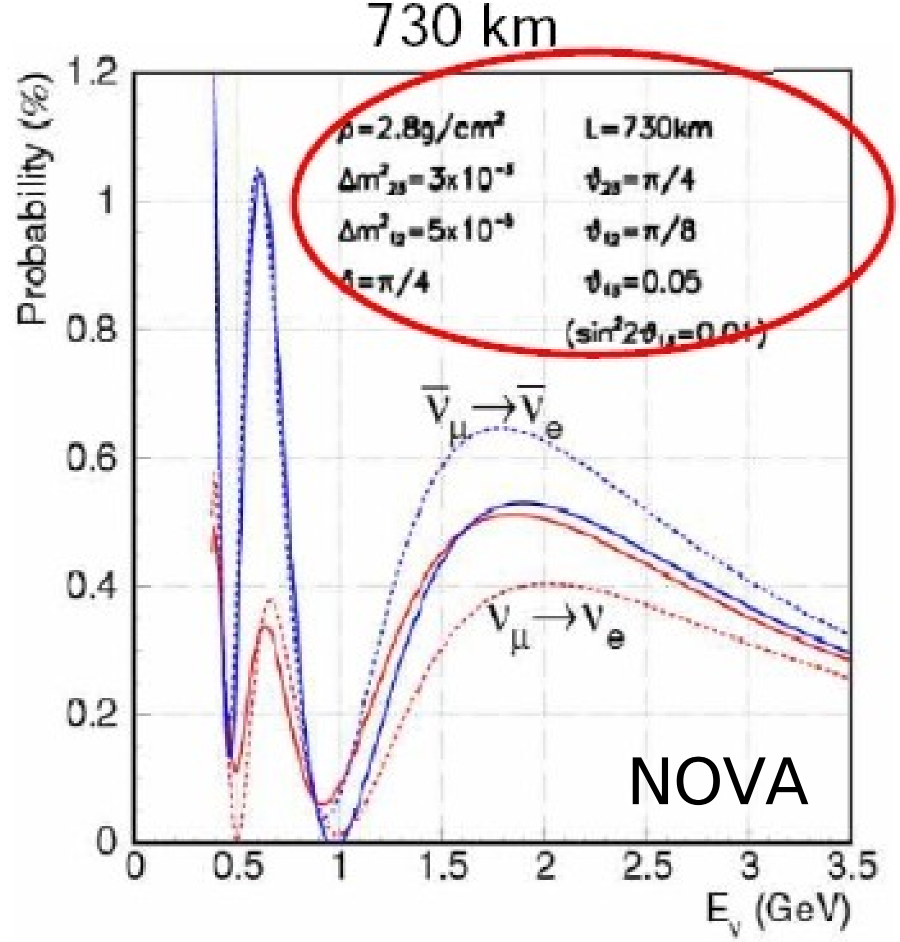


How well do we need to know the background?



Mass Heirarchy - T2K-I





Solid line : with matter effects
Dashed line : w/out matter effects

Baseline is just too short

Another Sensitivity plot

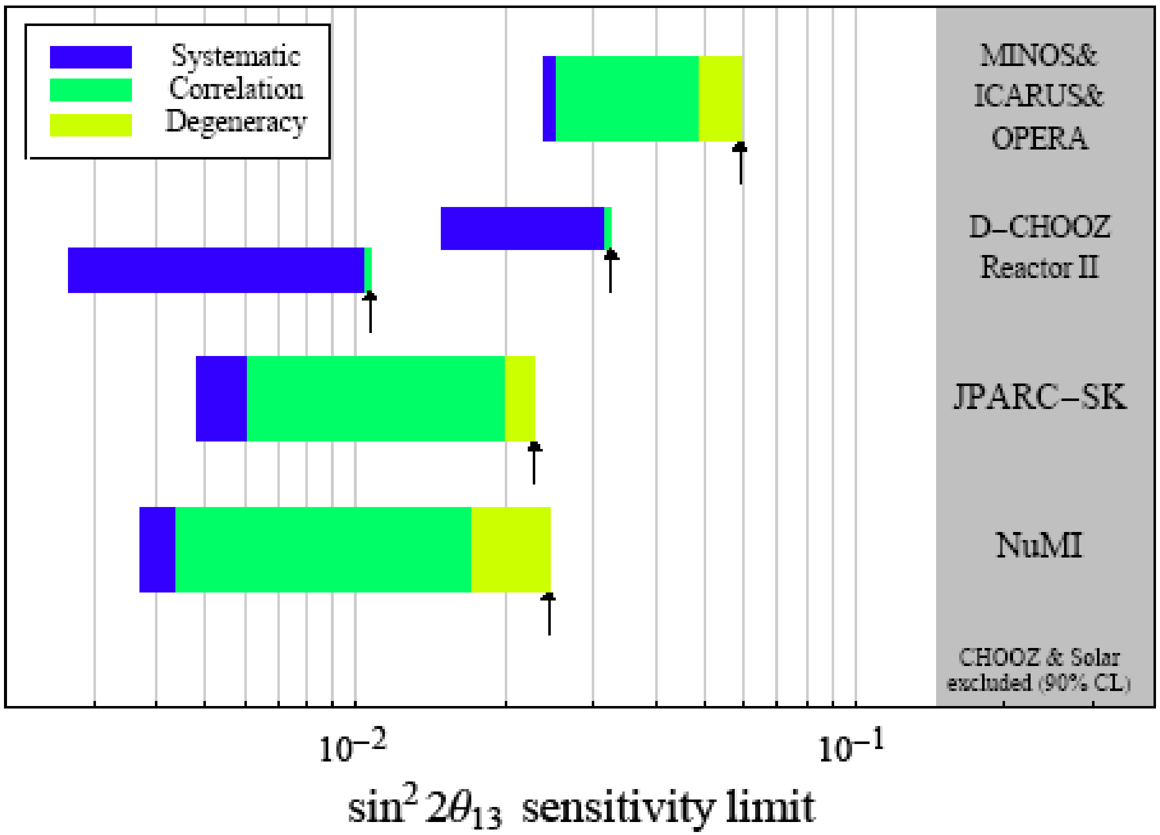
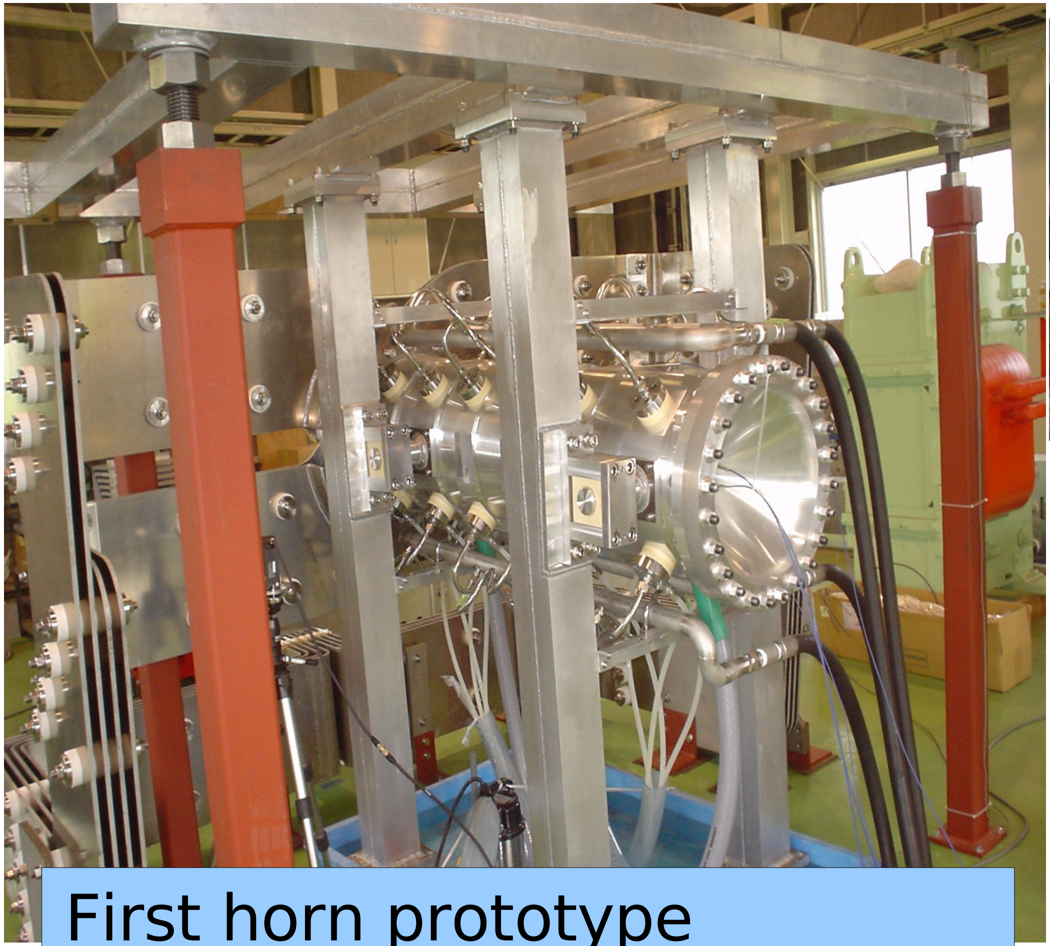


Figure 2. Sensitivity to $\sin^2 2\theta_{13}$ at 90% CL for the true values $\Delta m^2_{31} = 2 \times 10^{-3}$ eV^2, $\Delta m^2_{21} = 7 \times 10^{-5}$ eV^2.

Huber et al., hep-ph/0412133

Target and Horn Status

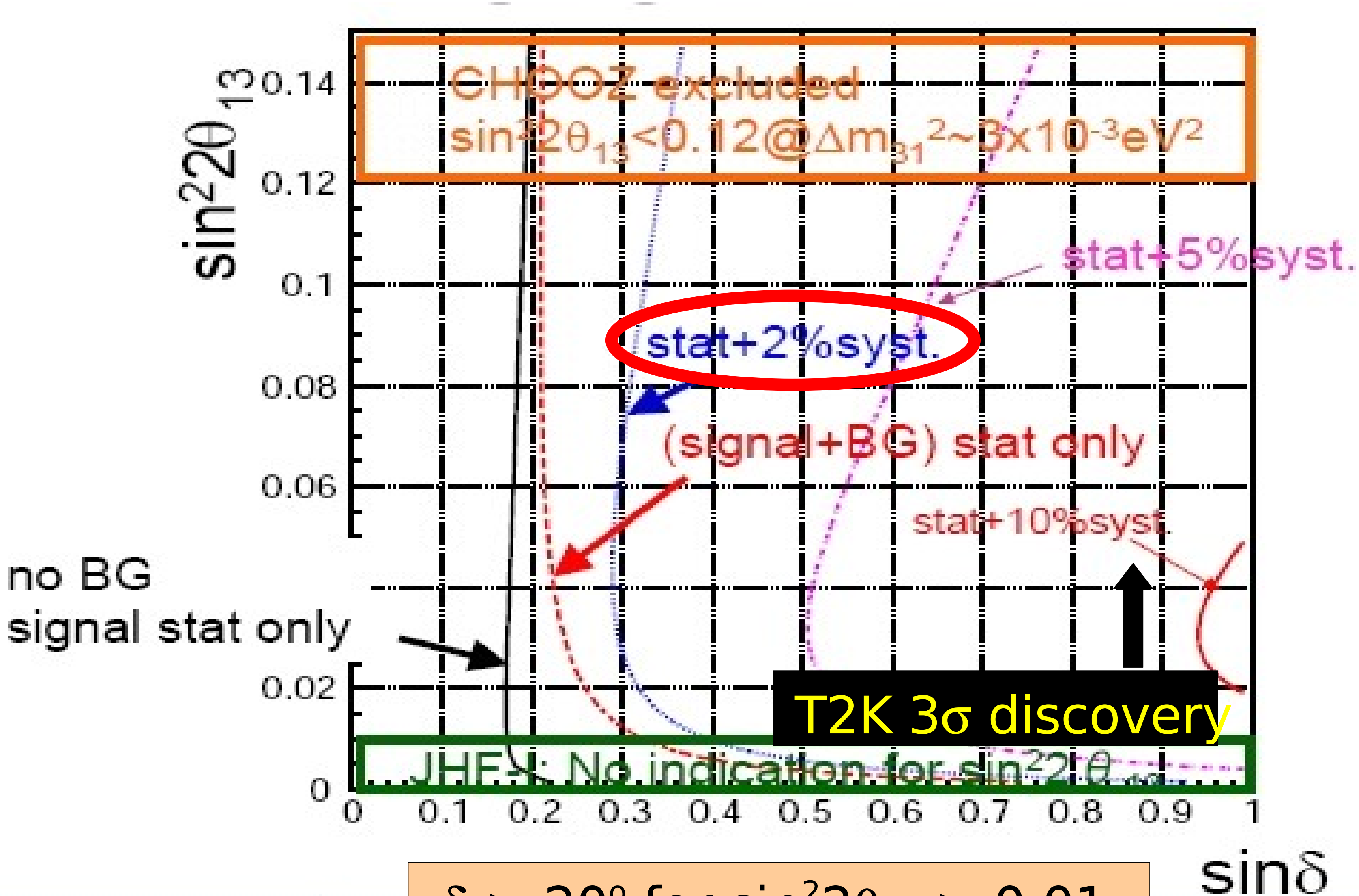
3 horn (320 kA) focussing system with Graphite target embedded in first horn



First horn prototype
Successfully pulsed @ 320 kA

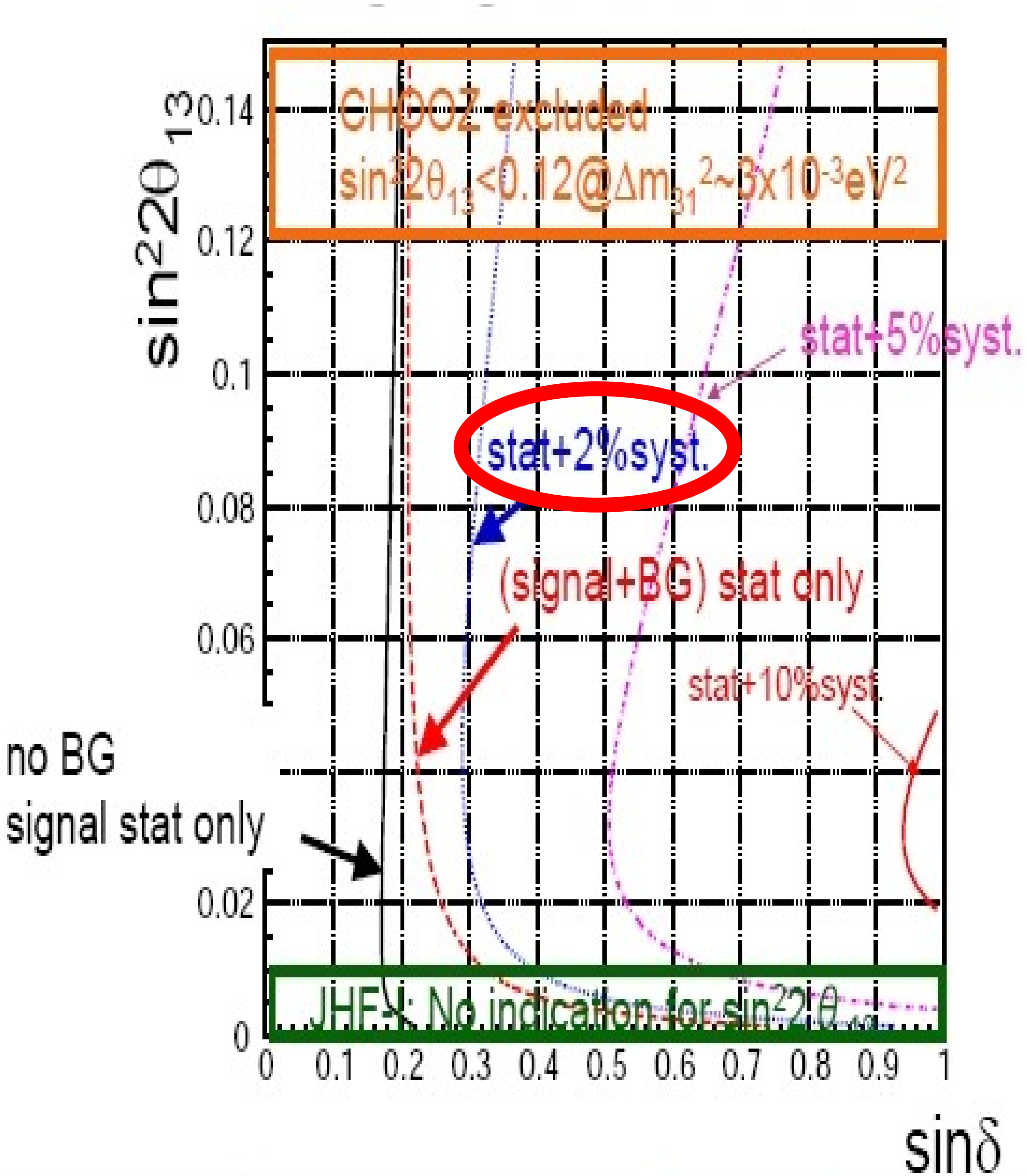
Thermal shock resistant at 0.75 MW
He gas cooling system

CP Sensitivity assuming $sign(\Delta m^2_{32})$ is known



$\delta > 20^o$ for $\sin^2 2\theta_{13} > 0.01$

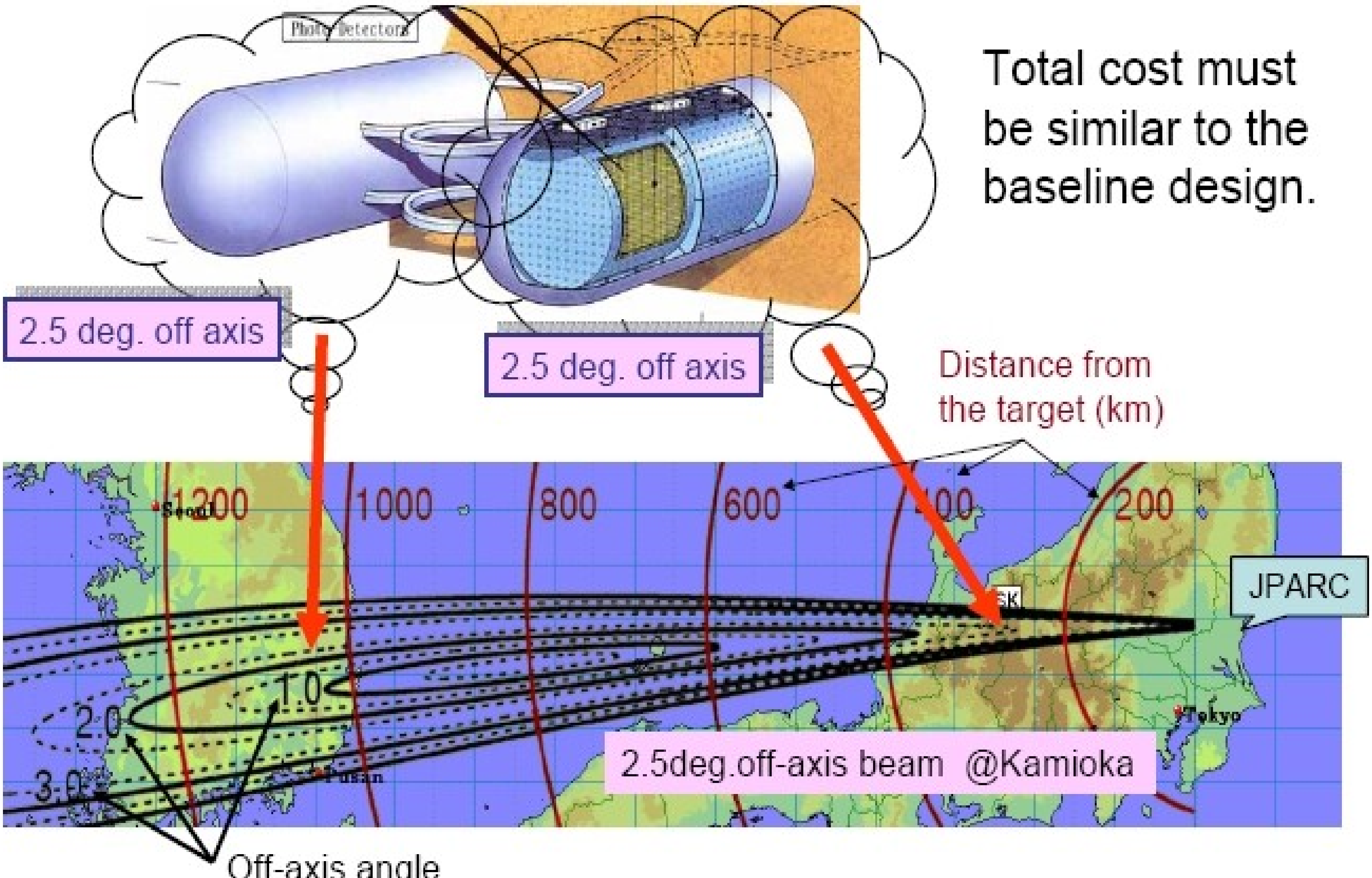
CP Sensitivity assuming sign(Δm^2_{32}) is known



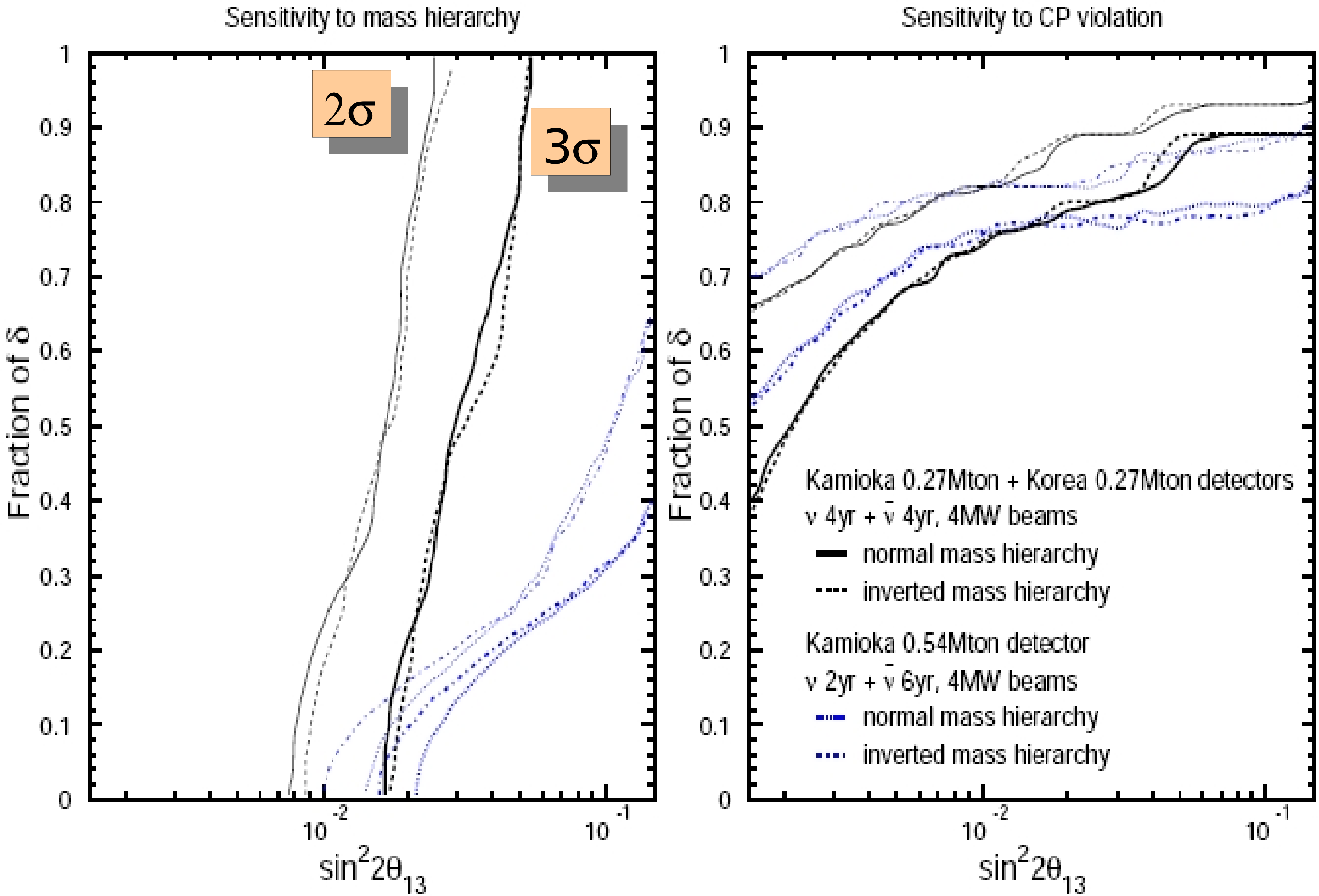
- Is 2% realistic or even needed? Are there better ways to do this?
- This still assumes that the mass heirarchy is measured elsewhere. Can we do this with the JPARC beam ourselves?
- Mass heirarchy measured using matter effects which increase with increasing L

T2KK - VLBL

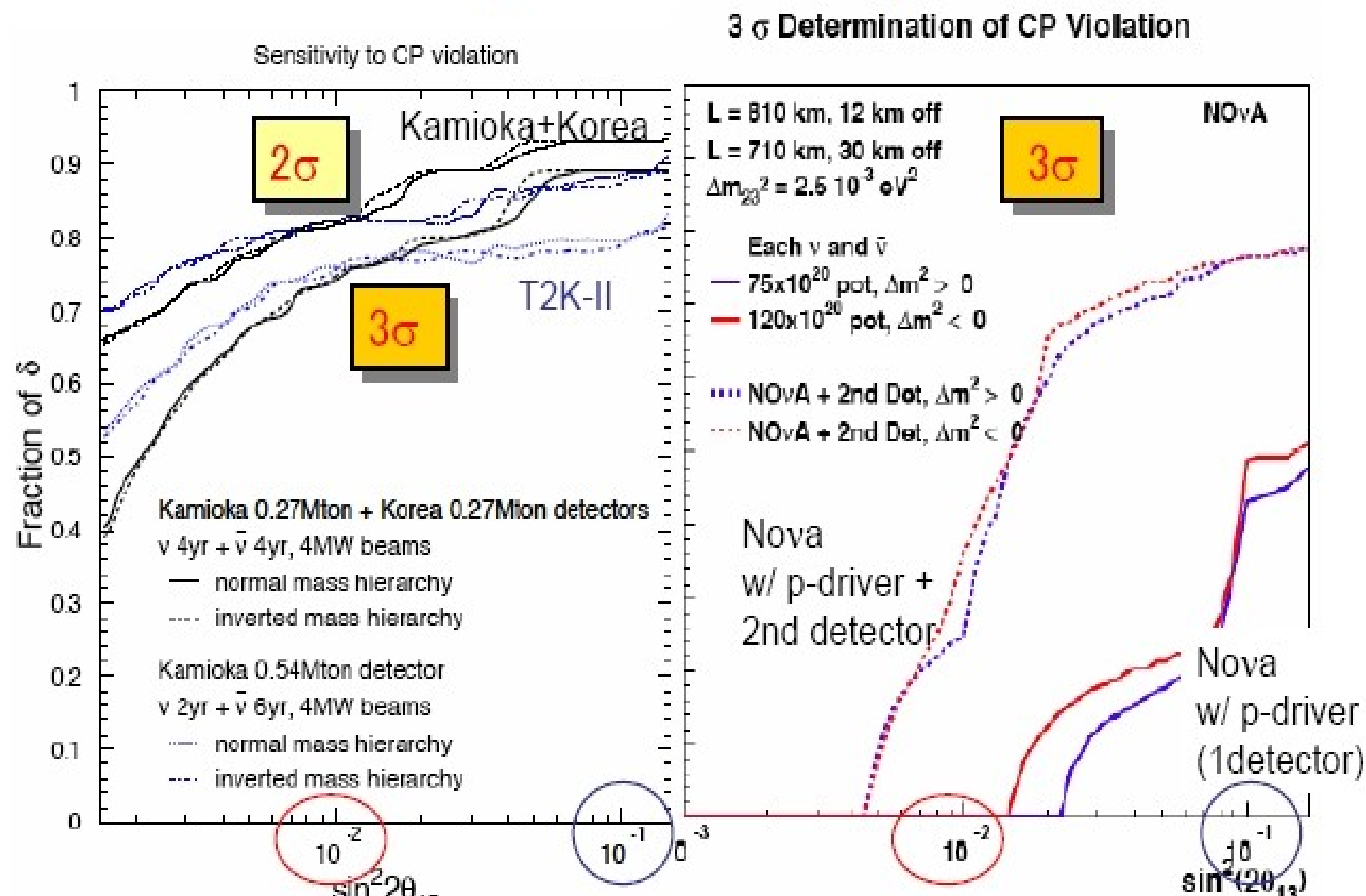
Total cost must be similar to the baseline design.



Sensitivity

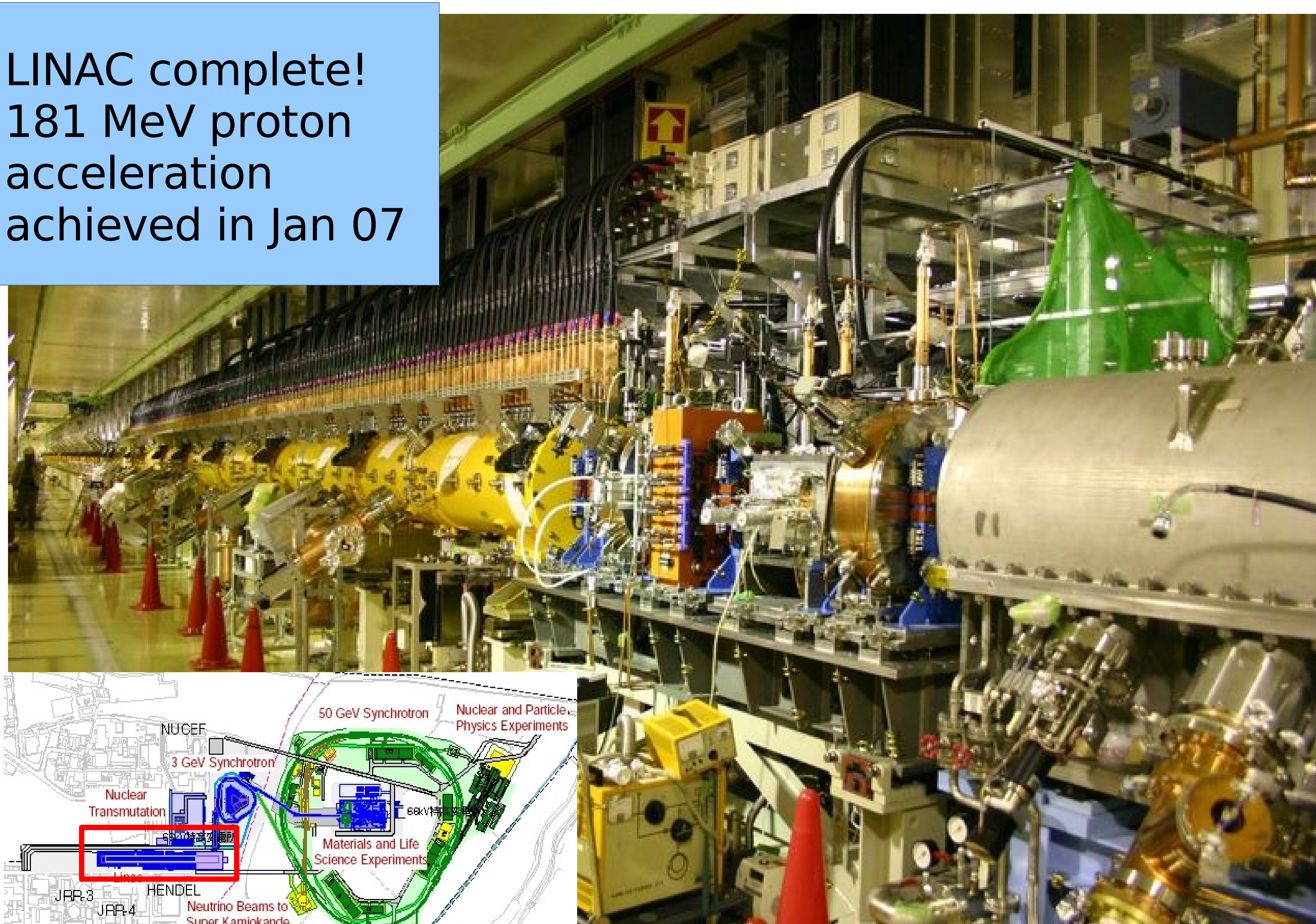


T2K-II vs. (Kam+Korea) vs. Nova

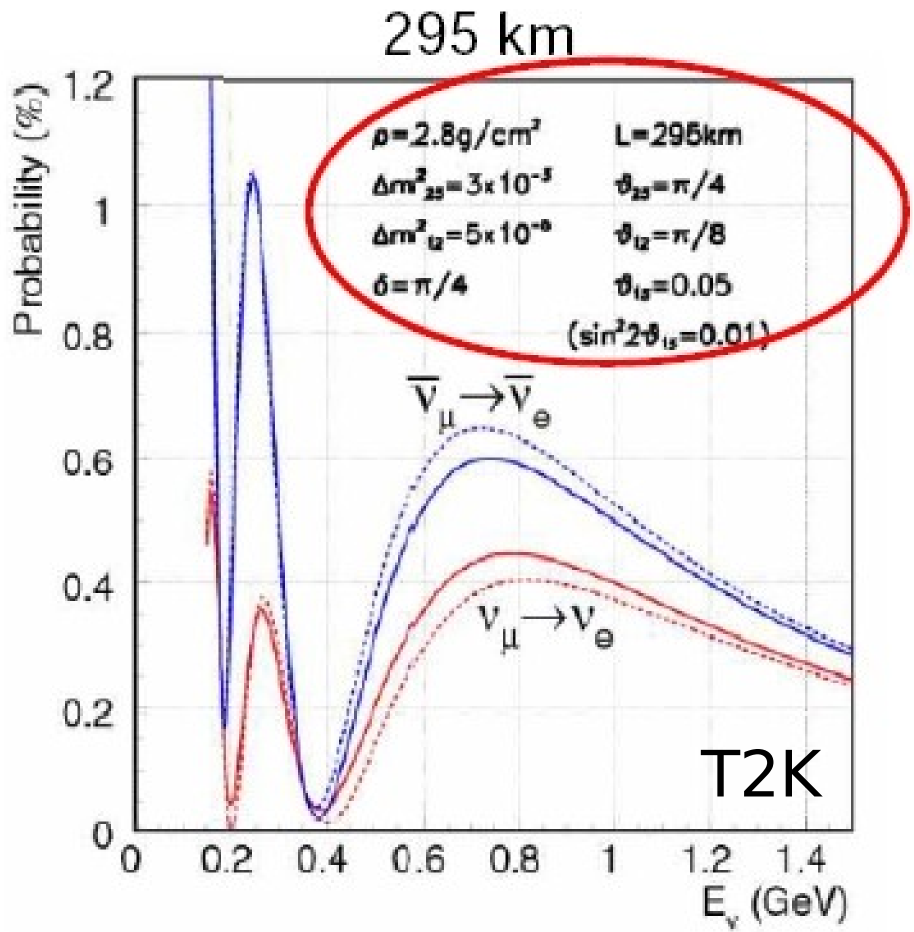


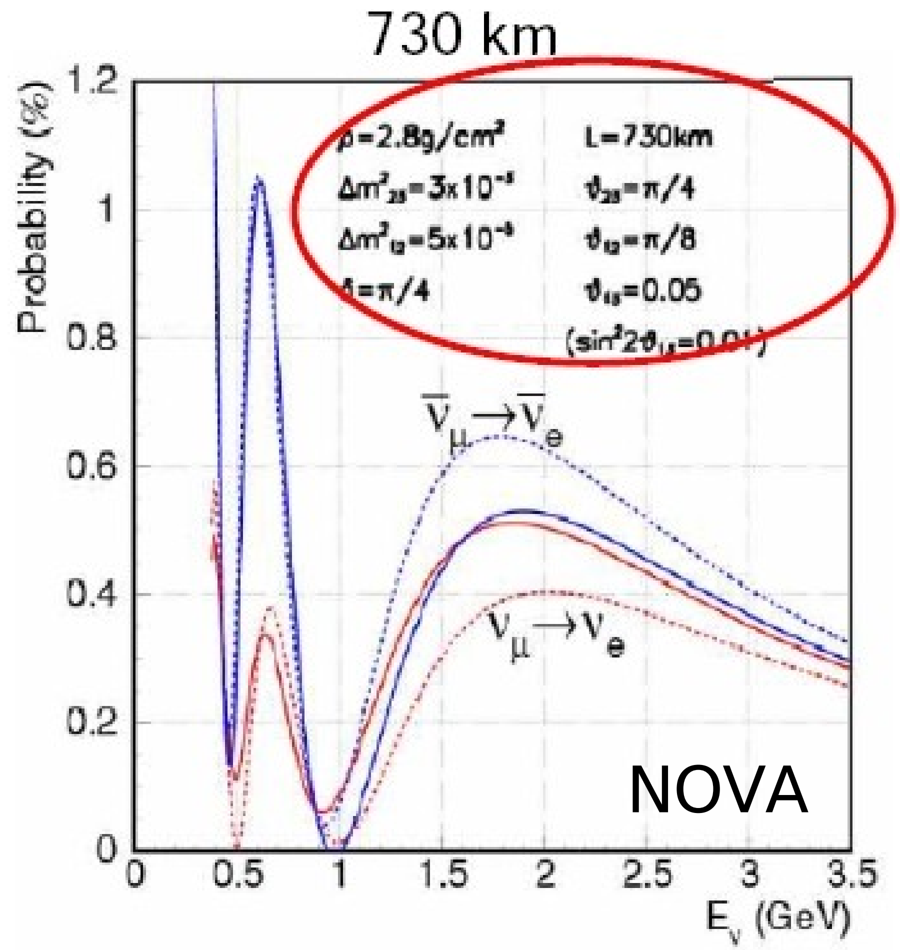
Accelerator Construction Status

LINAC complete!
181 MeV proton acceleration achieved in Jan 07



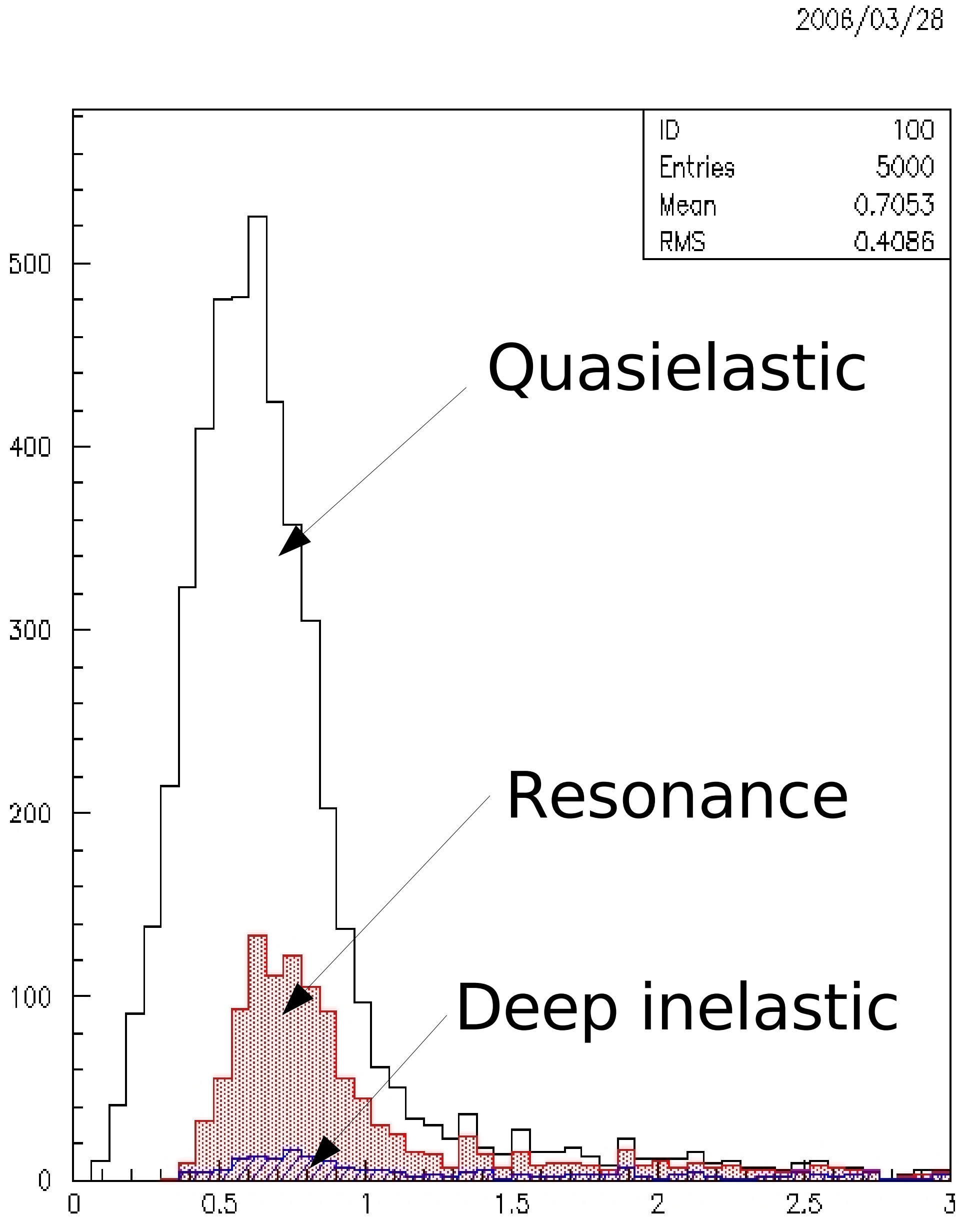
Mass Heirarchy - T2K-I

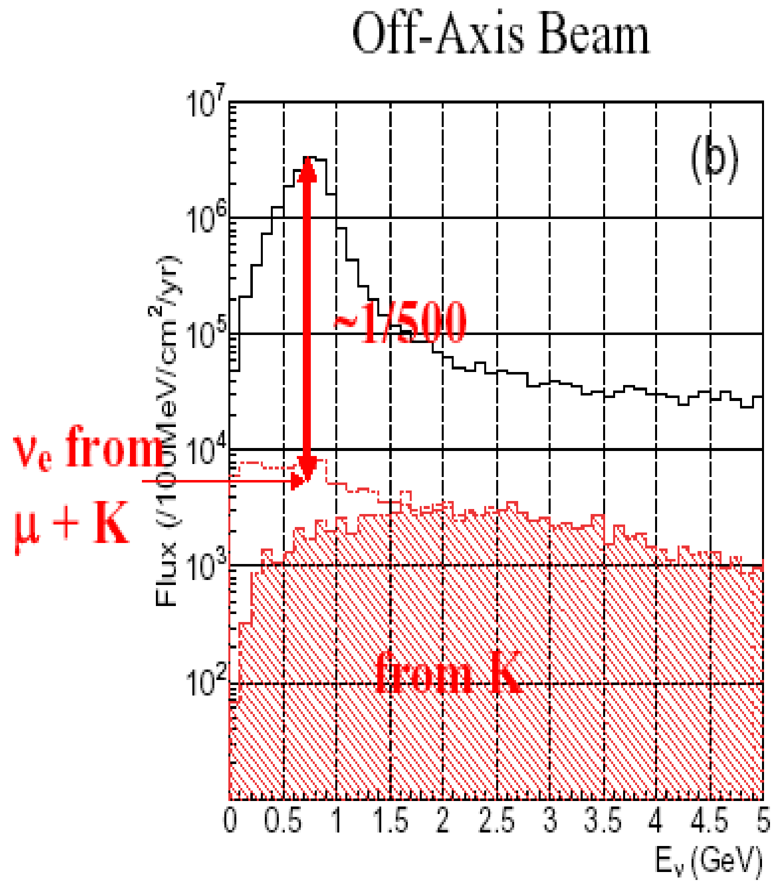




Solid line : with matter effects
Dashed line : w/out matter effects

T2K Spectrum





Intrinsic background: ν_e / ν_μ (peak) ~ 0.002

How well do we need to know the background?