Conventional Neutrino Beam Experiments: Present and Future Generations

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Fermilab

NuFact10

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The Banjo Lesson by Henry Ossawa Tanner

Outline

- Current Generation:
  - MiniBooNE
  - MINOS
  - OPERA
  - MINERvA
  - T2K
  - ICARUS
- Almost Current Generation
  - NOvA
- Next Generation(s)
  - Building on existing beams: MicroBooNE, T2KK
  - New beams, new detectors: LBNE, CERN-Frejus,…
- What legacies are being handed down from one generation to the next?

Goals and Strategies: From one generation to the next

- Current Generation: building foundations
  - Pinning down atmospheric mass splitting
    - Muon neutrino disappearance
  - Figuring out what "LSND signal" means
    - Electron Neutrino appearance at short baseline
  - First hopes of seeing $\sin^2 2\theta_{13}$ above zero
    - Electron neutrino appearance at ~1% level
  - Pinning down neutrino interactions in preparation for the goals of measuring $\sin^2 2\theta_{13}$ and beyond

Current Generation

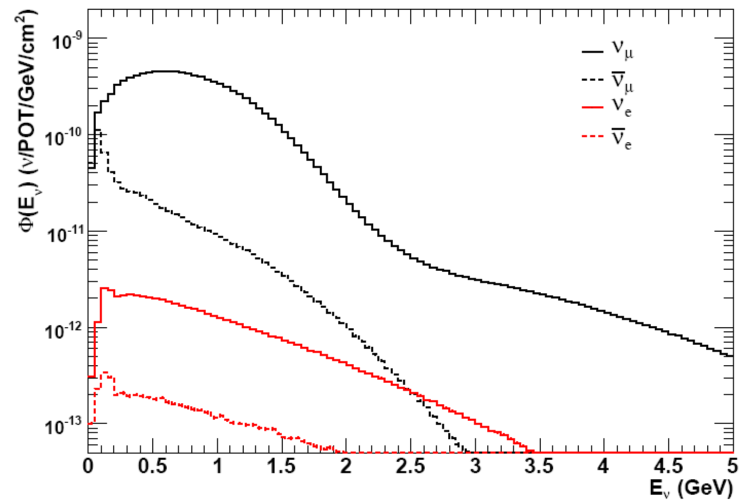
	Moti-vattion	Beam Power (kW)	Detector	Base-line (km)	ν Ener gy (GeV)	Experi-mental Method	Integrated POT so far
Mini-BooNE	ν_e appr.	30 (max)	Oil Cerenkov	0.5	0.7 (Wide)	1st max	15e20
MINOS	ν_μ dis-appr.	350	Steel-Scint.	734	3.5 (Wide)	1st max	11e20
OPERA	ν_τ appr.	500	Lead-Emulsion	730	25 (Wide)	Before the 1st max	8e19
ICARUS			LAr TPC				2e19
MINERvA	ν inter-actions	350	Fine-Grained Scint.	1.0	3.5 ++ (Wide)	Nucl. Targets	12e19
T2K	ν_e appr.	750 (50 so far)	Water Cerenkov+ ND280	295	0.700 (Narrow)	Off-Axis	3.4e19

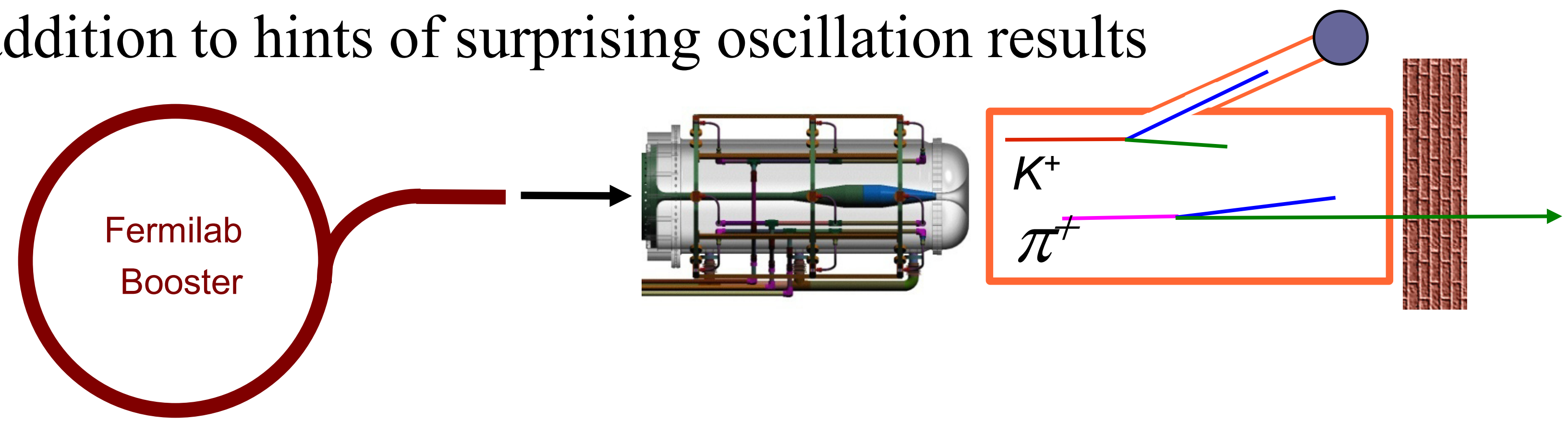
Ingredients for Conventional Neutrino beams

- Ingredients
  - As many protons as you can get…
  - Target
  - Horns (at least one, at most three)
  - Decay Volume
  - Hadron Absorber
  - Beamline Monitoring
- "Tales from the Front Lines"

Booster Neutrino Beam

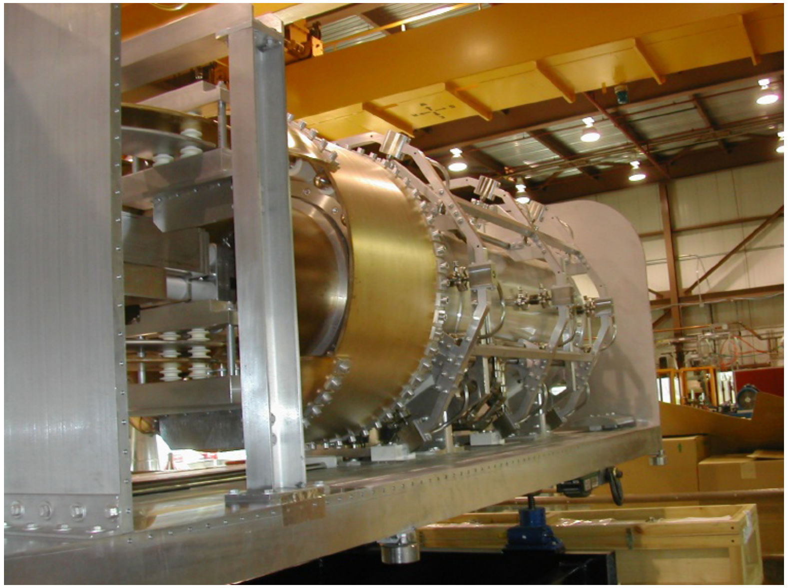
- 8 GeV protons, Beryllium target, one horn, short decay pipe
  - Enclosures for SciBooNE and MiniBooNE detectors
- Produces broad band of ν_μ events centered at ~1.4GeV
- Designed for $\nu_\mu \rightarrow \nu_e$ oscillations, has found many surprising cross section results in addition to hints of surprising oscillation results



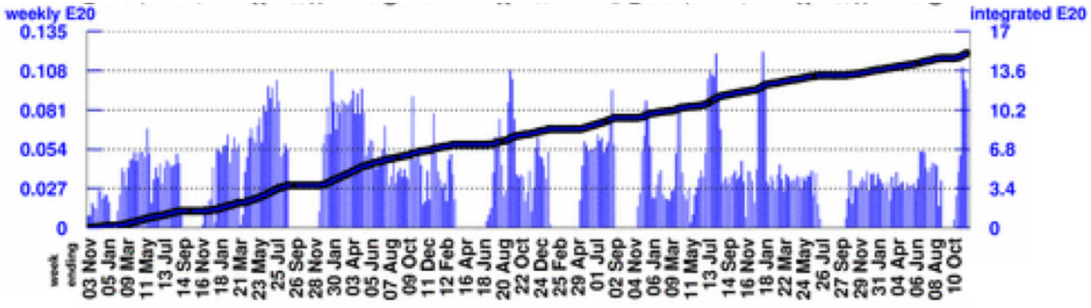


BNB: Tales from the front line

- In operation the longest of current neutrino beamlines
- 15e20 POT as of 10/11/10
- Current horn has worked 6 years, 275M pulses
- First horn survived 100M pulses
- Showing water leak and ground faults, may need to be repaired/replaced soon
- Have to replace horn with target at same time

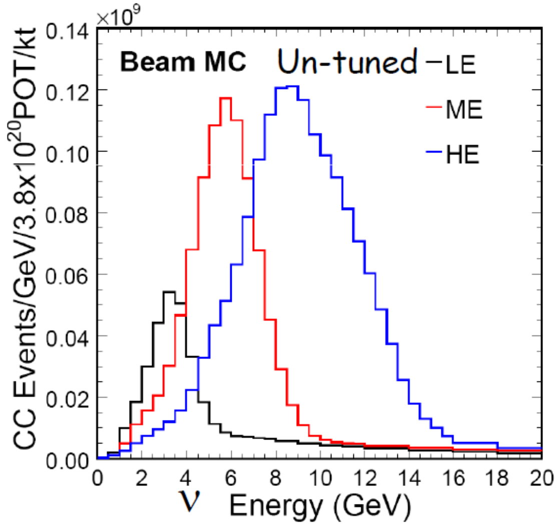


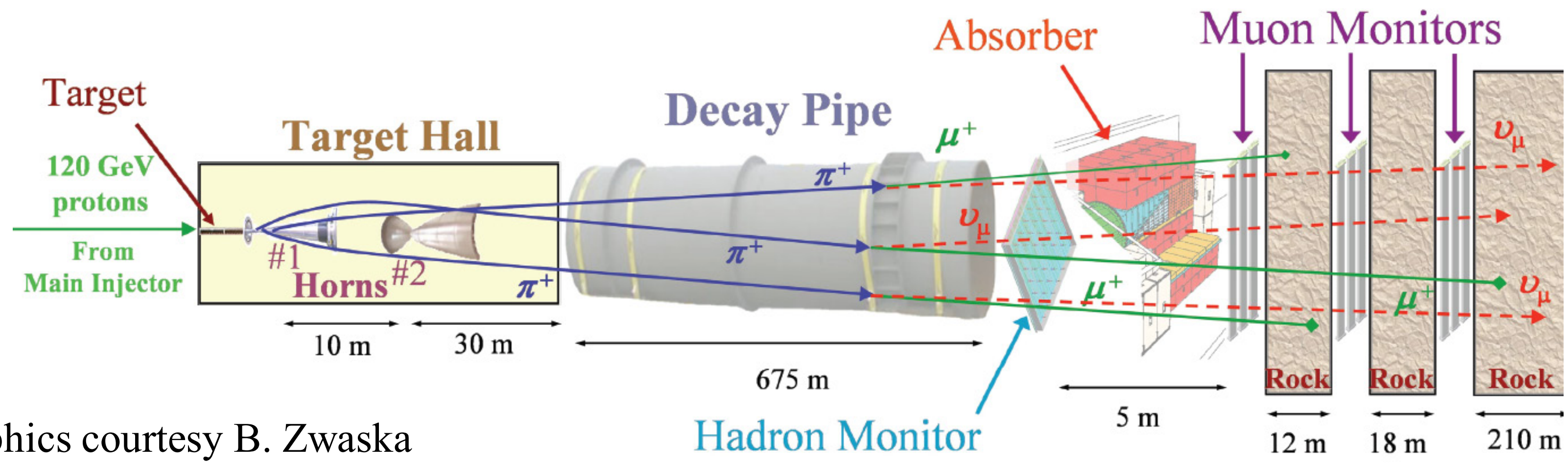
W. Huelsnitz, FNAL AEM, 10/11/10



Neutrinos at the Main Injector Beamline

- 120GeV protons, Graphite target, two horns
- Operating since 2005, over 1e21 POT
- Flexible enough to produce peak energies from 3.5 to 10GeV
- Three planes of μ monitors, one hadron monitor at downstream end of decay pipe

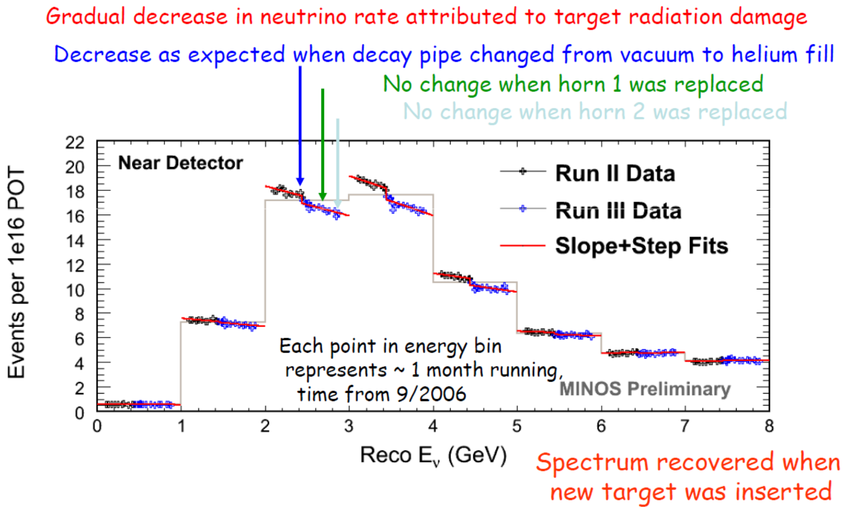


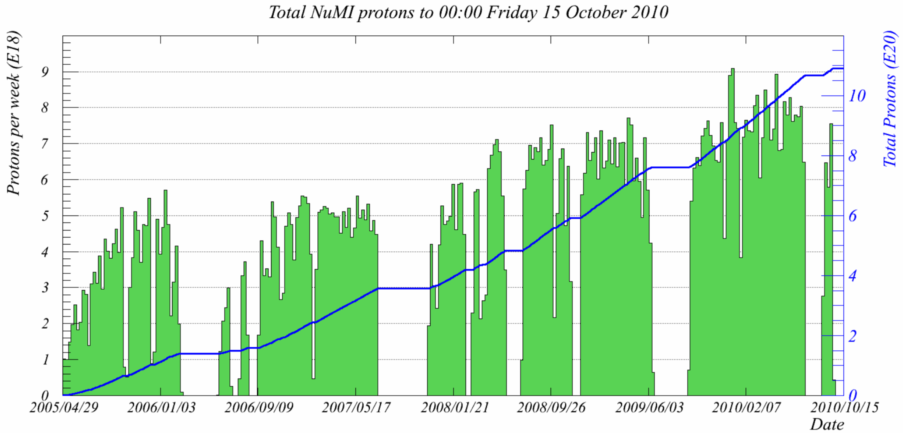


Graphics courtesy B. Zwaska

NuMI: Tales from the Front Line

- In 5 years, replaced both horns once, replaced target 4 times
- 3 target replacements linked to problems braising graphite to stainless steel water cooling tubes
- Extensive monitoring system provides ways to evaluate beamline conditions as problems arise

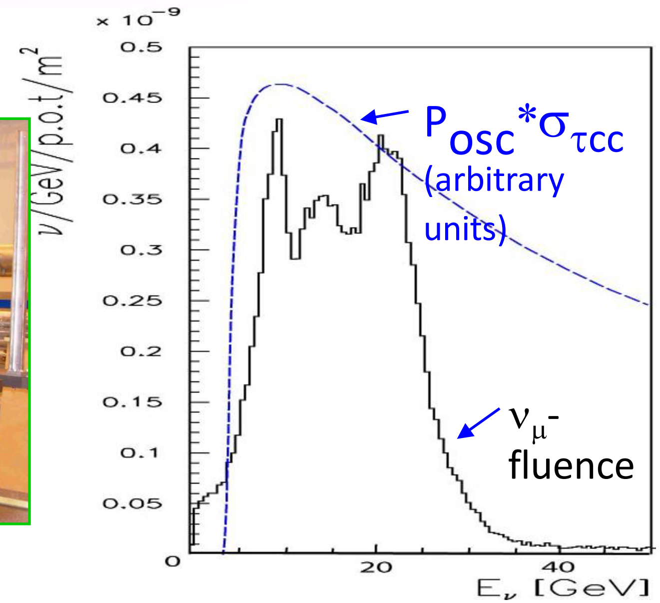




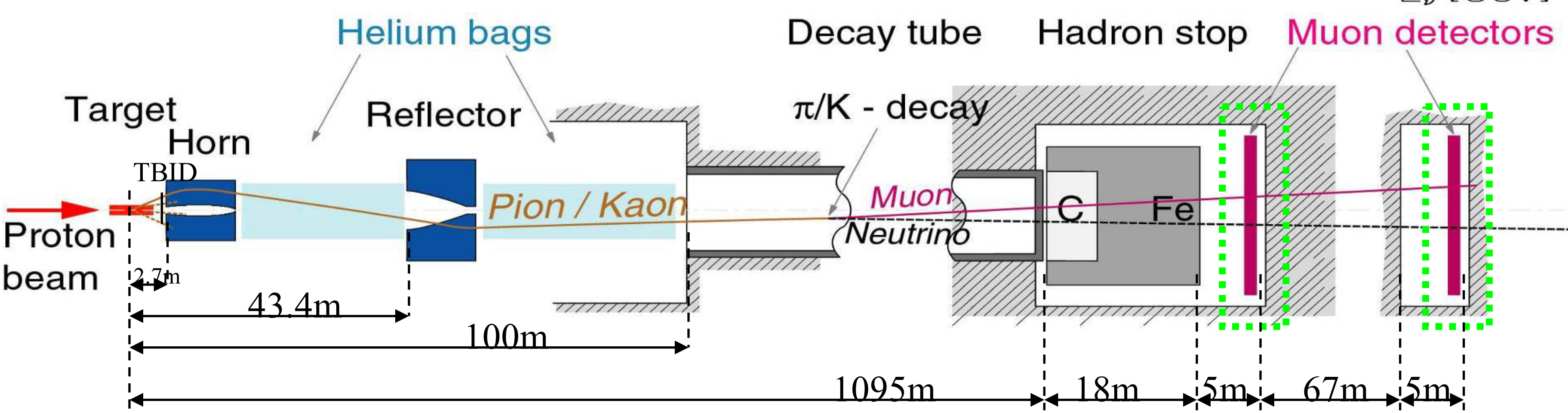
Plots and chart: J. Hylen, P. Adamson

CERN to Gran Sasso Beamline

- 400GeV protons, air cooled graphite target, 2 horns
- design power of 500kW
- 8E19 protons on target
- 2 stations of muon monitors



Figures courtesy E. Gschwendtner, NBI2010

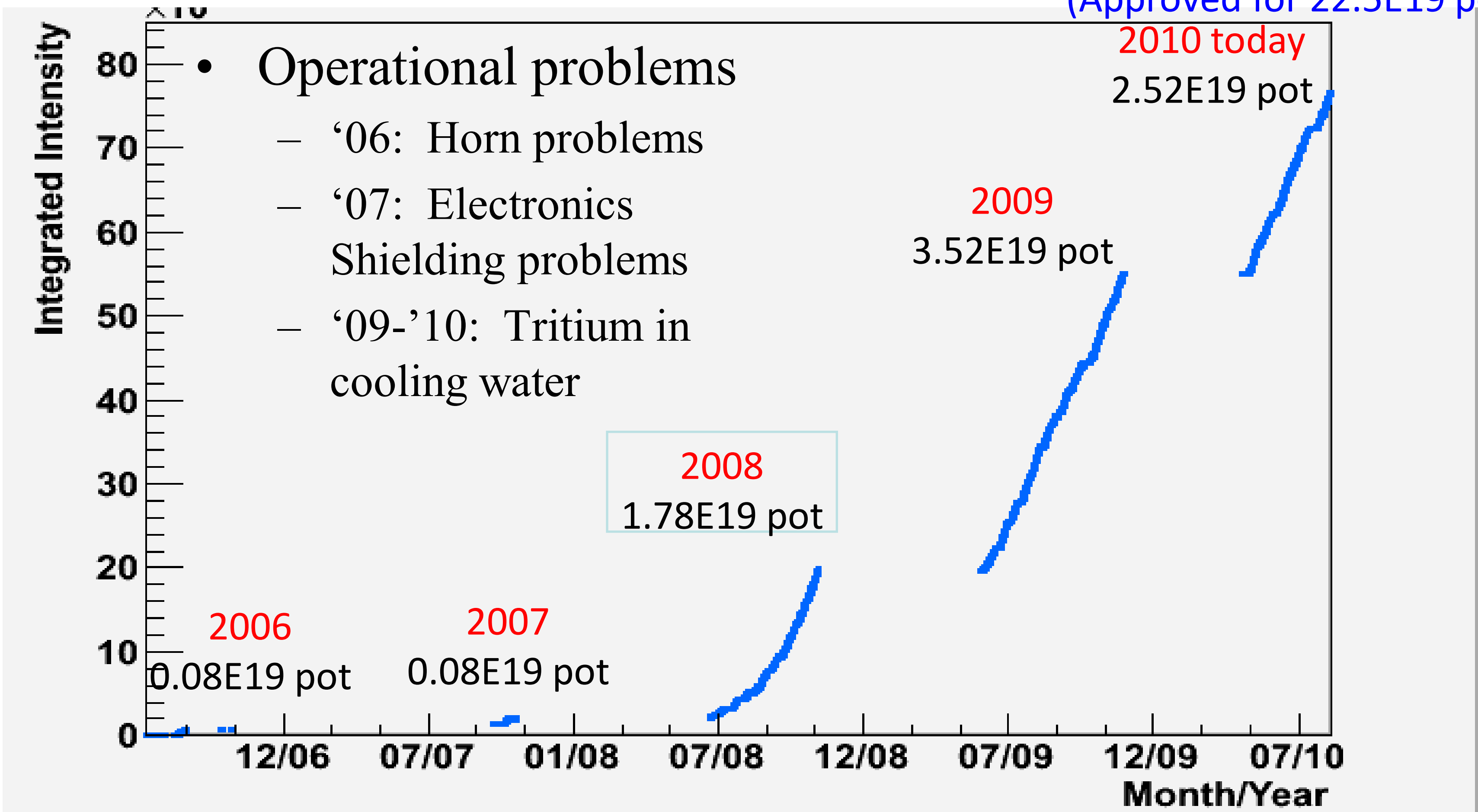


Tales from the front line: CNGS

Total today: 8E19 pot

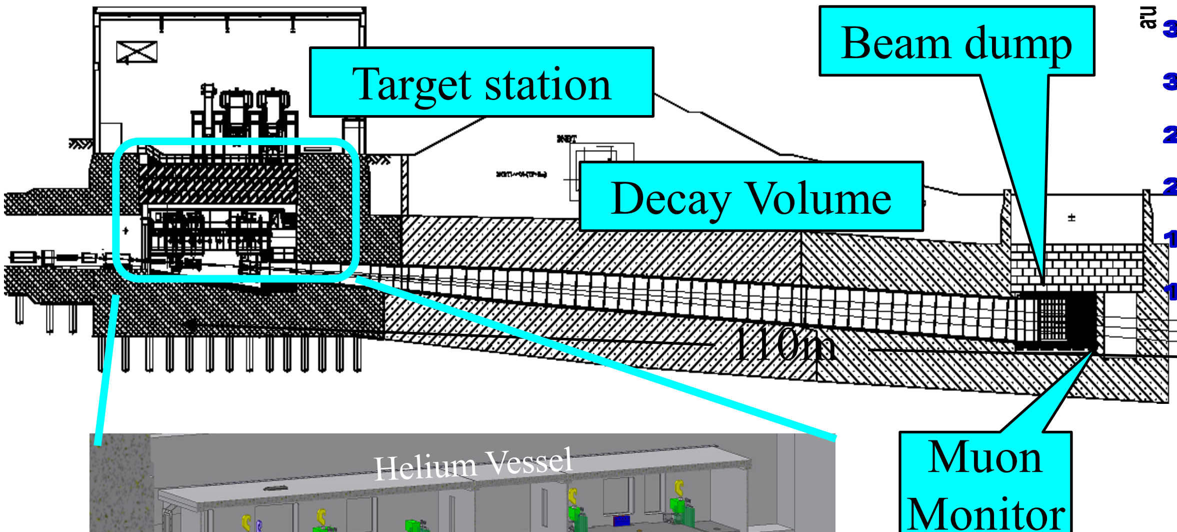
(Approved for 22.5E19 pot)

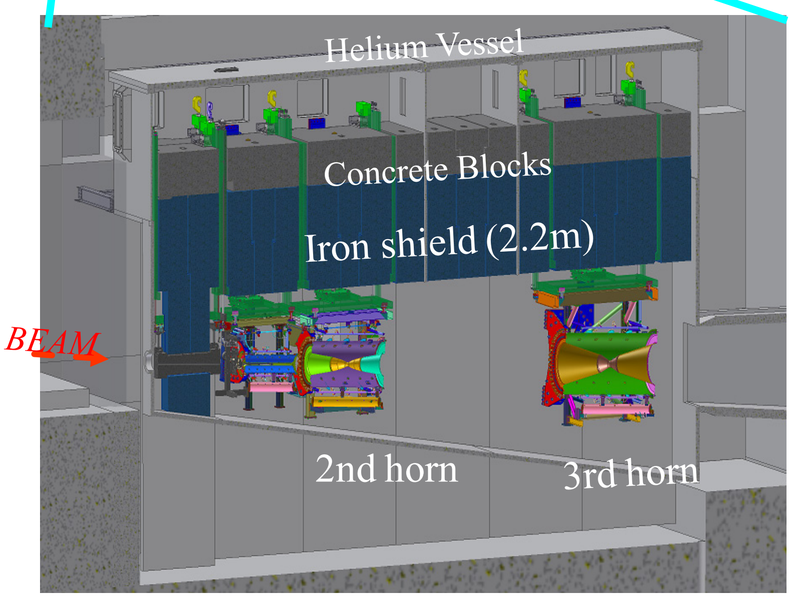
- Operational problems
  - '06: Horn problems
  - '07: Electronics Shielding problems
  - '09-'10: Tritium in cooling water



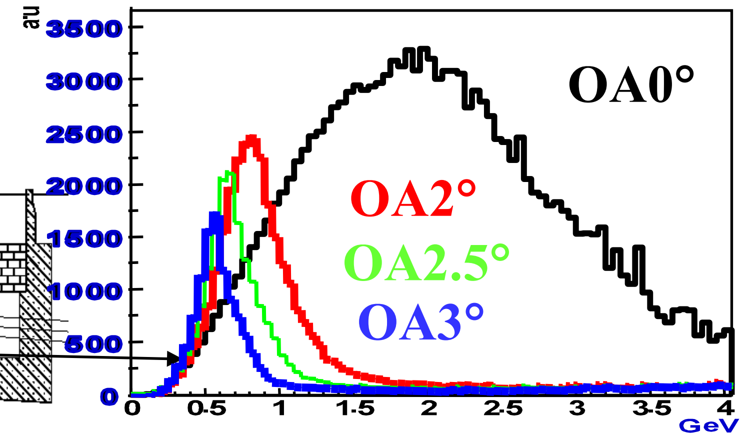
E. Gschwendtner, NBI2010

J-PARC ν Beamline





ν energy spectrum (flux × Cross Section)

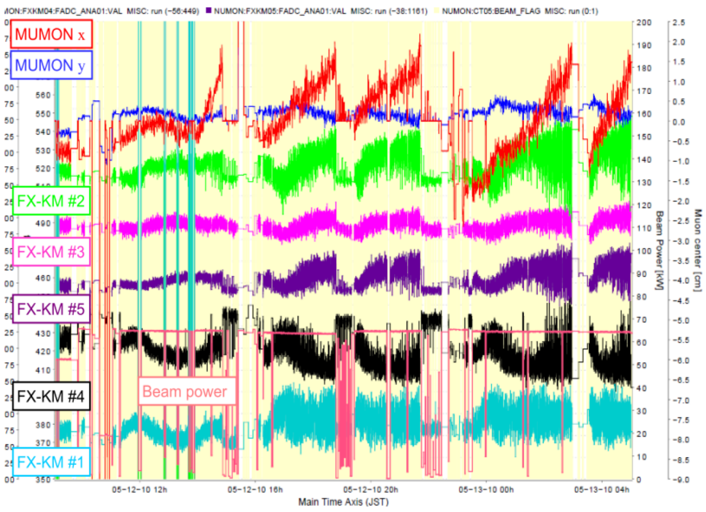


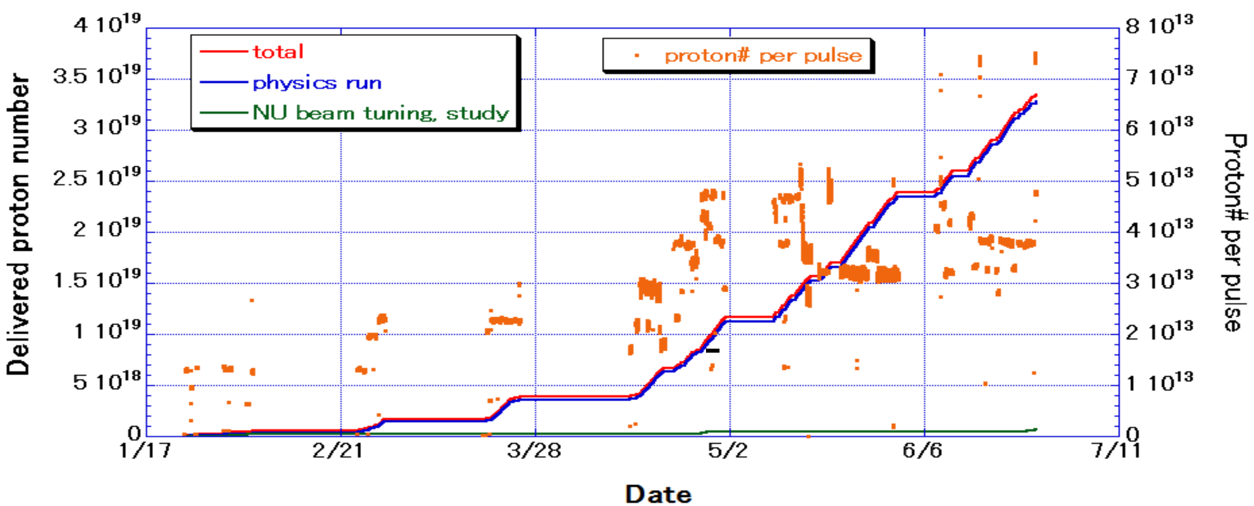
H. Kakuno NBI2010

- 40-50GeV protons, He-cooled target, 3 horns, secondaries all in helium
- Highest design power (770kW upgradable to 1.66MW)
- 2 technologies of muon monoitoring at one shielding depth

T2K: Tales from the front line

- Accumulated 3.35×10^{19} protons (3.28×10^{19} for physics data analysis) from 1/10 to 6/10
- Continuous operation ~50kW
- Short (few minutes) trials up to 100kW
- Problems with kicker magnets leading to beam center drift, all replaced this summer, minimum functionality tests successful





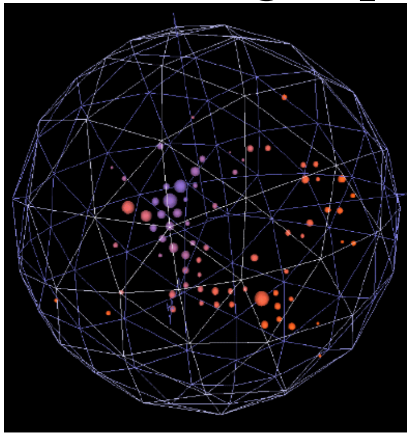
Slow extraction started in mid-October
Neutrino beam expected to return November 15 or16
Plots:H. Kakuno NBI2010, schedule from T. Kobayashi

Neutrino Detectors

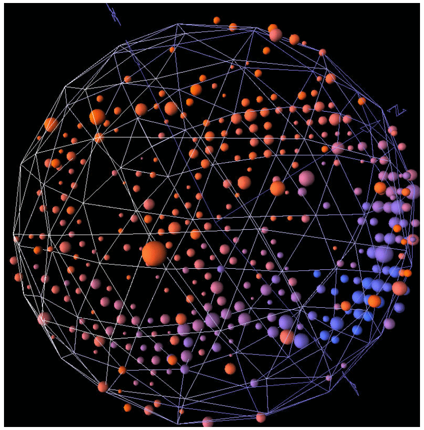
- Brief reminder of detector technologies in use
- Detector performance
- Milestones reached since NuFact09
  - Note: I am not going to talk about the neutrino oscillation or neutrino interaction surprises, that's the subject of a later talk…
    - see Sacha Kopp in the voice and appearance of Maury Goodman for oscillation results
    - See Kevin McFarland for Interaction Experiments
  - This still leaves me plenty to talk about

MiniBooNE Detector

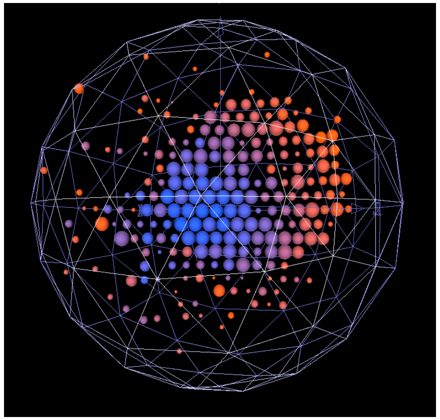
- Pure mineral oil
  - Cherenkov:Scintillator ~ 3:1
  - Total volume: 800 tons (6 m radius)
  - Fiducial volume: 500 tons (5m radius)
- New Reconstruction techniques not previously predicted:
  - Three ring events (for charged current pi0 analysis)
  - Charged pion tag (look for pi->mu->e chain)



e candidate



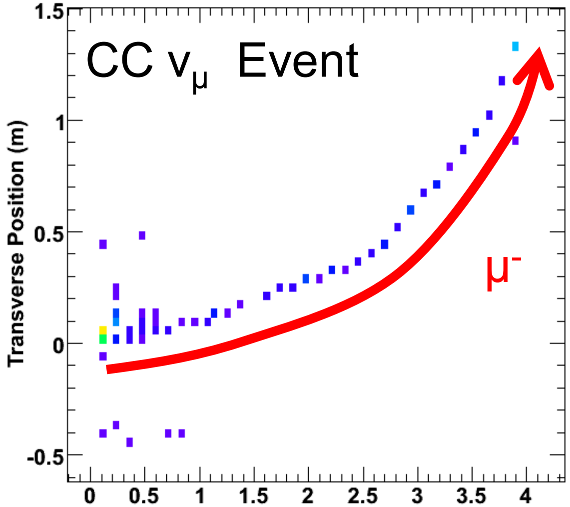
π^0 candidate

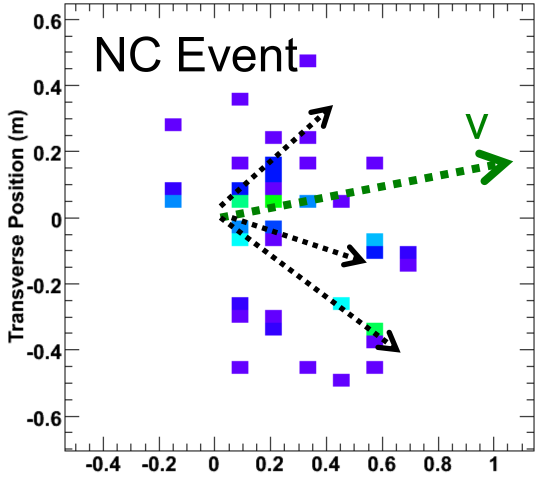


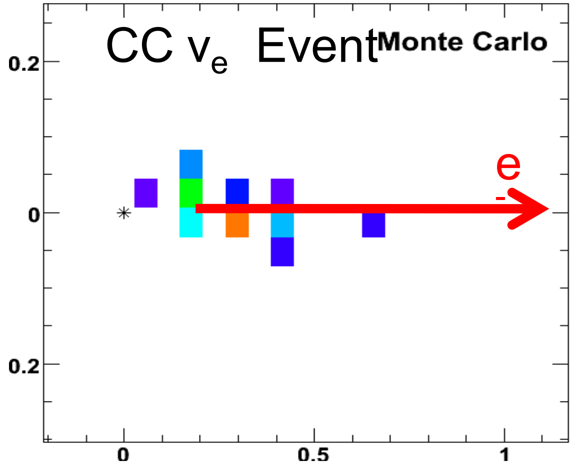
μ candidate

MINOS

- ν_μ disappearance and ν_e appearance with $7.2x10^{20}$ POT in neutrino running
- Anti-ν_μ appearance with $1.7x10^{20}$ POT in anti-neutrino running

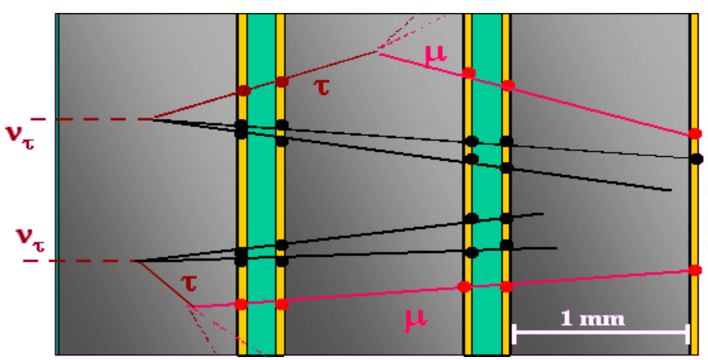


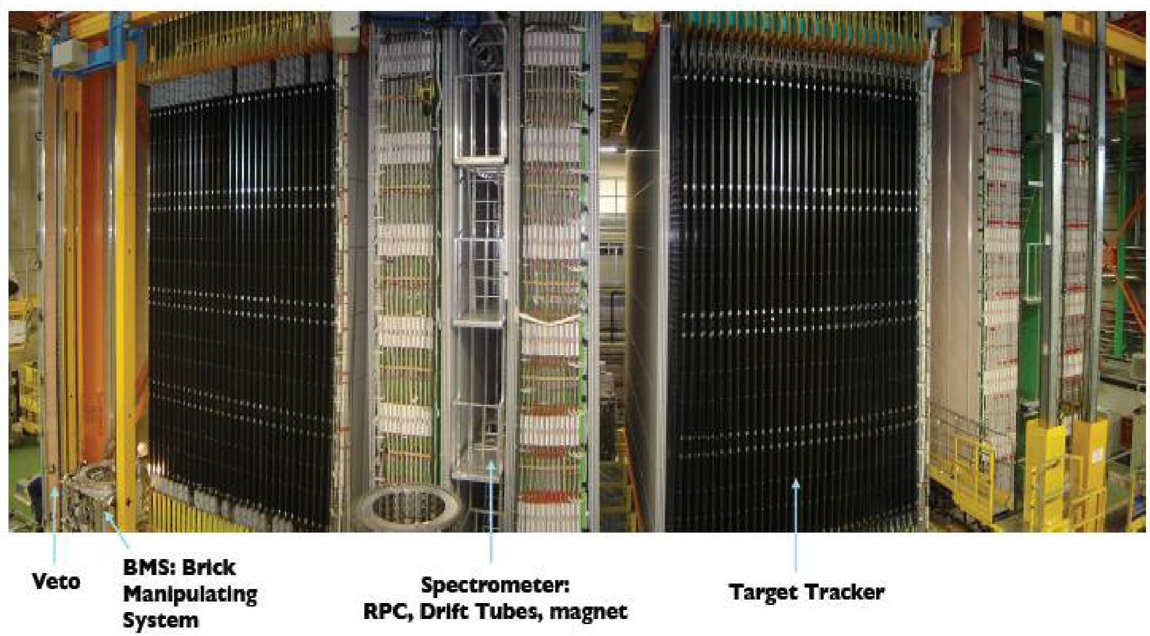




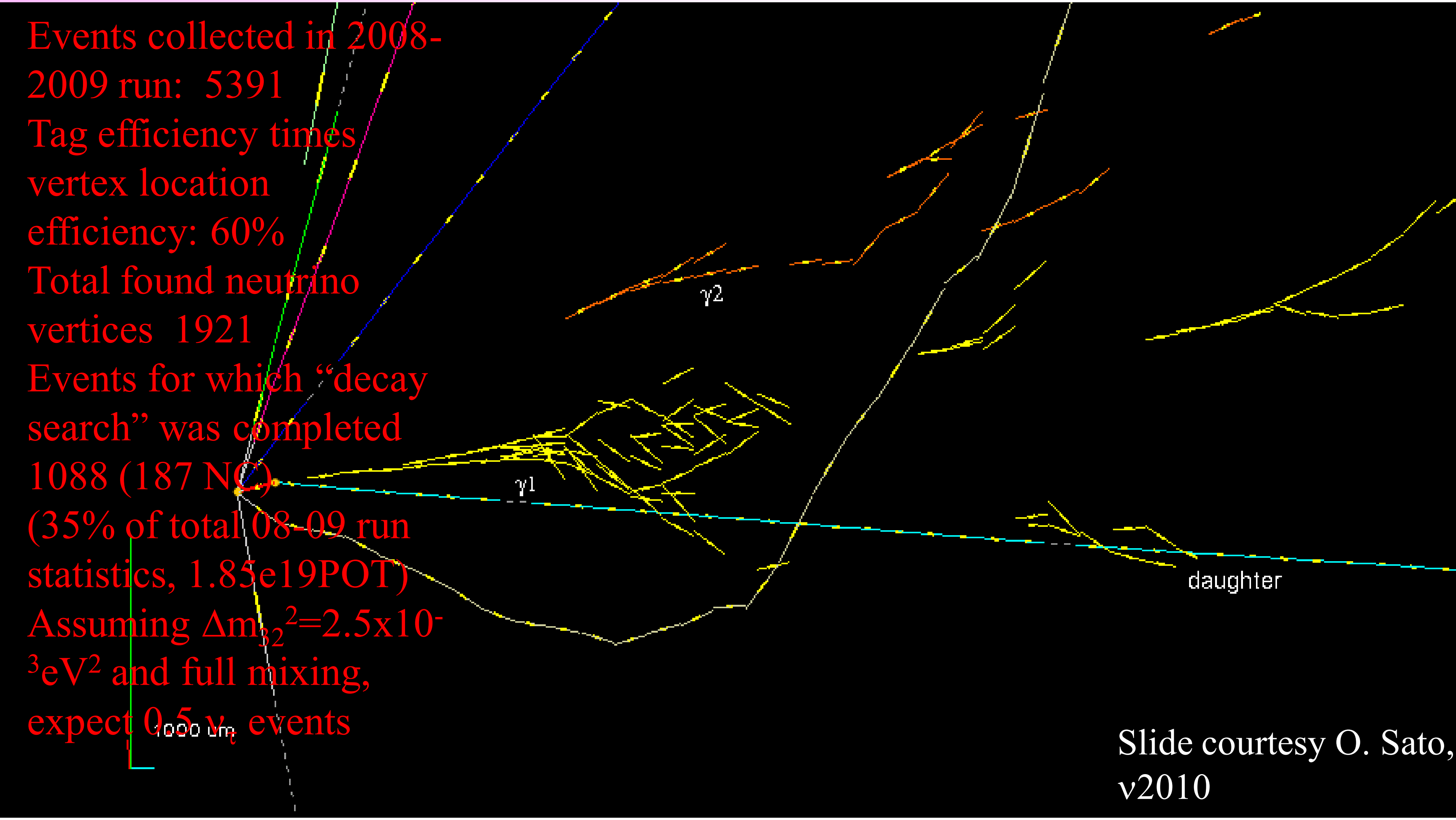
OPERA

- 1.2kT emulsion detector
  - 146621 bricks, each 8.3kg
  - 56 (1mm) Pb sheets
  - 57 (300mm) FUJI emulsion layers
  - 2 (300mm) changeable sheets (CS)





First Tau Neutrino Detected

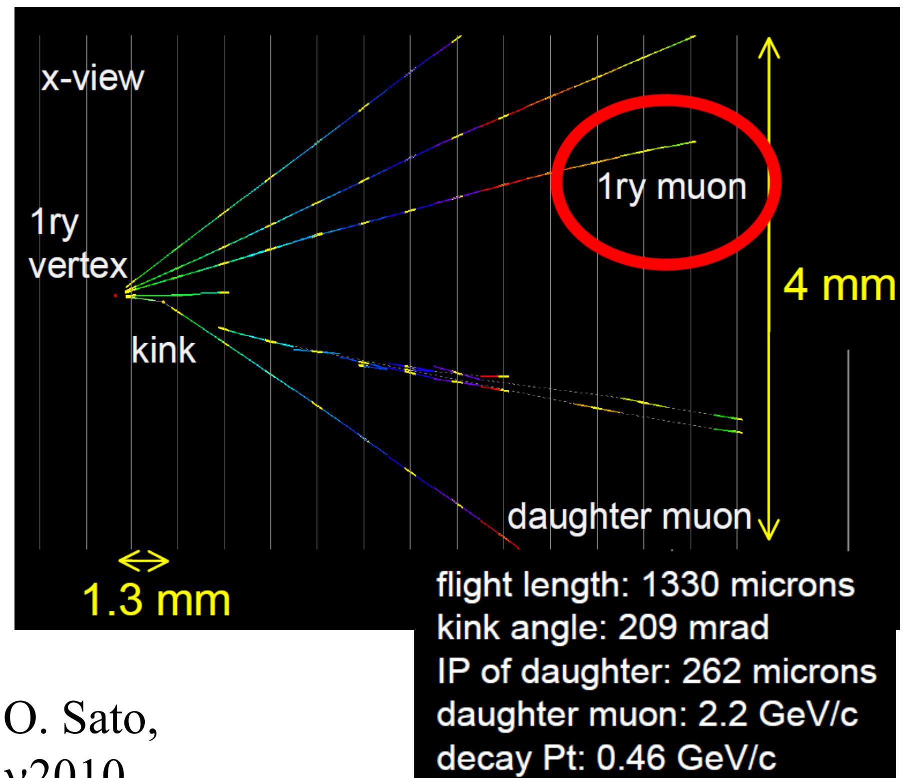


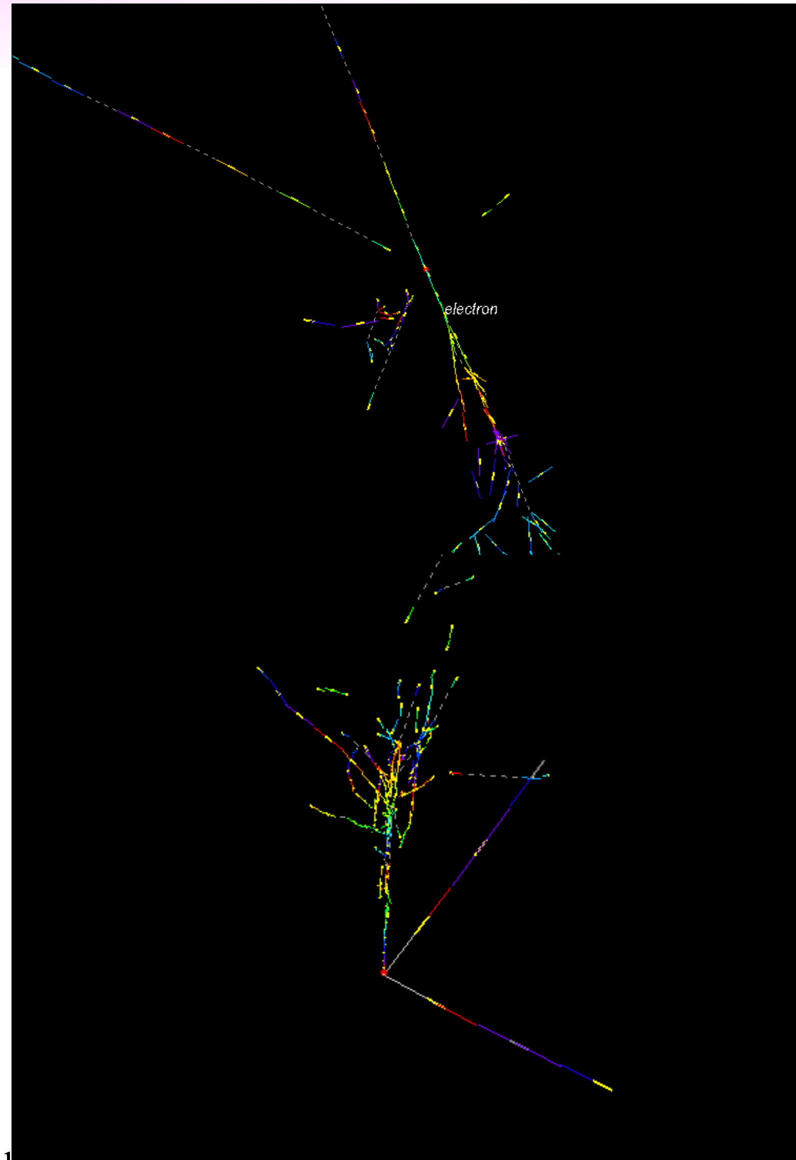
- Events collected in 2008-2009 run: 5391
- Tag efficiency times vertex location efficiency: 60%
- Total found neutrino vertices 1921
- Events for which "decay search" was completed 1088 (187 NC) (35% of total 08-09 run statistics, 1.85e19POT)
- Assuming $\Delta m_{32}^2=2.5\times10^{-3}\,eV^2$ and full mixing, expect 0.5 ν_τ events

Slide courtesy O. Sato, ν2010

Other interesting events from OPERA

- Charm candidates, and 6 electron neutrino candidates out of 800 located vertices (2 at right)

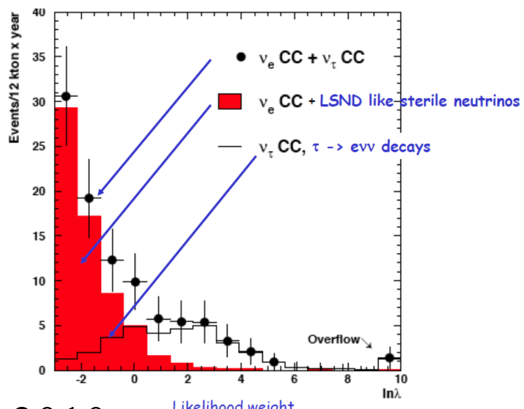




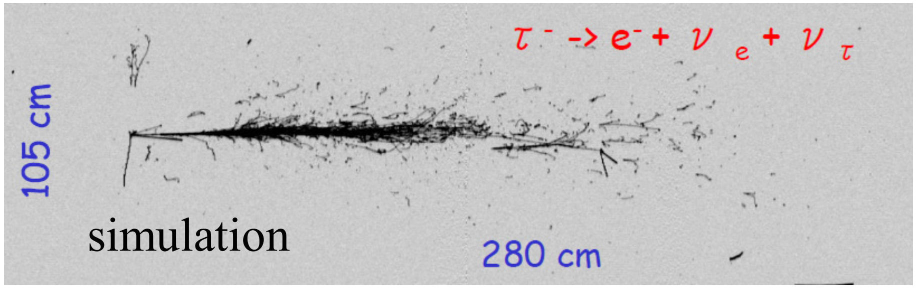
O. Sato, ν2010

ICARUS

- Liquid Argon TPC
- Active mass: 475x2 tons
- Fiducial mass: 600 tons
- Wire spacing: 3mm
- Electron drift distance: 1.5m
- 54000 wires, 3 stereo angles
- 74 PMT's for scintillation light
- Statistical measurement of ν_τ appearance

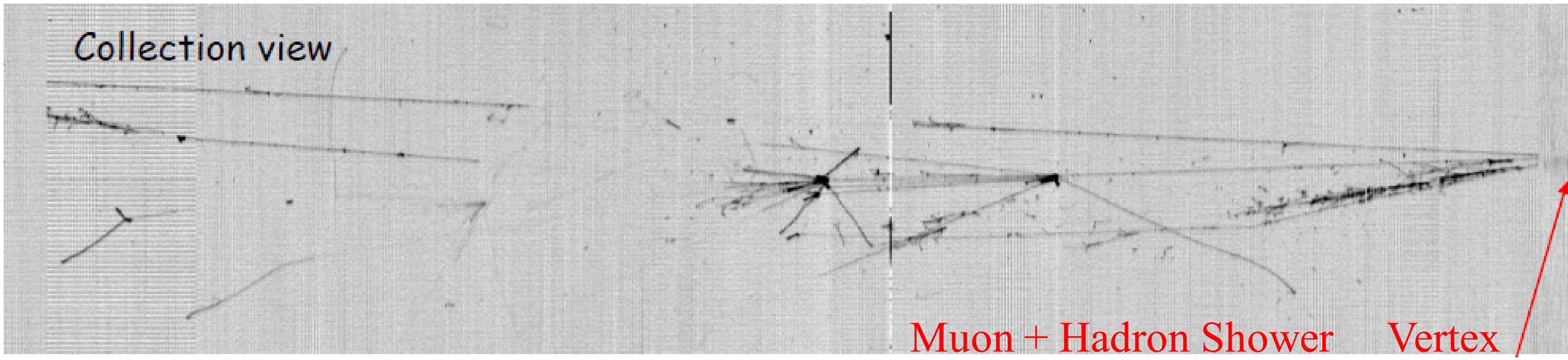


A. Guglielmi, ν2010

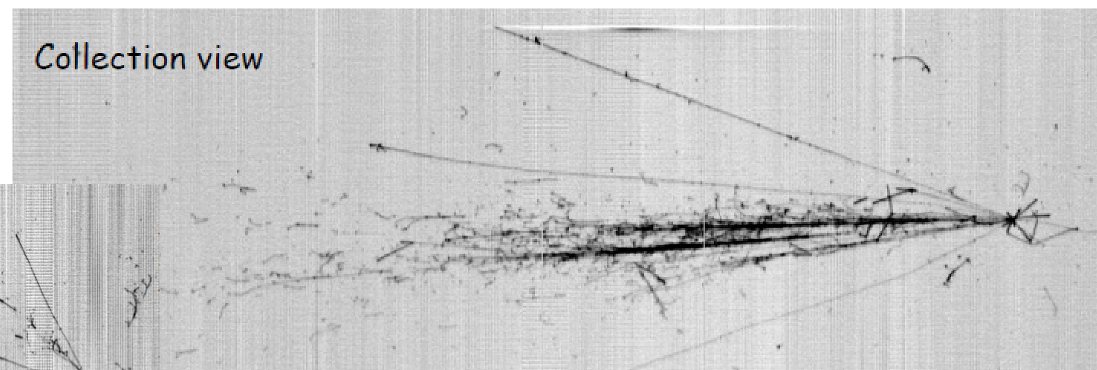


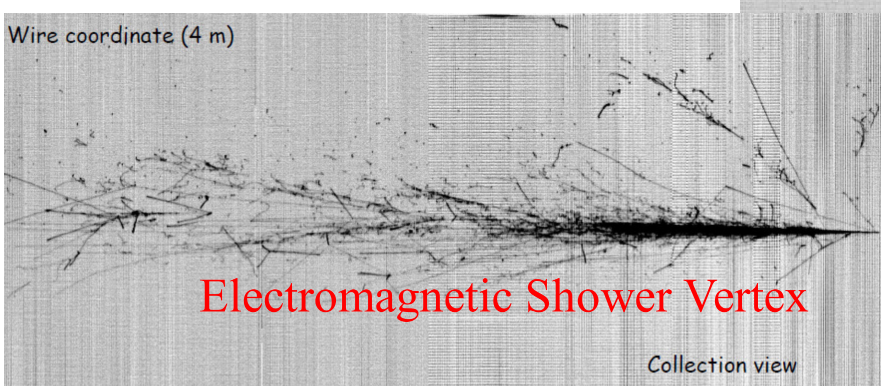
Expect 6 beam ν_e's, expect 12 ν_τ's

CNGS Beam events in ICARUS



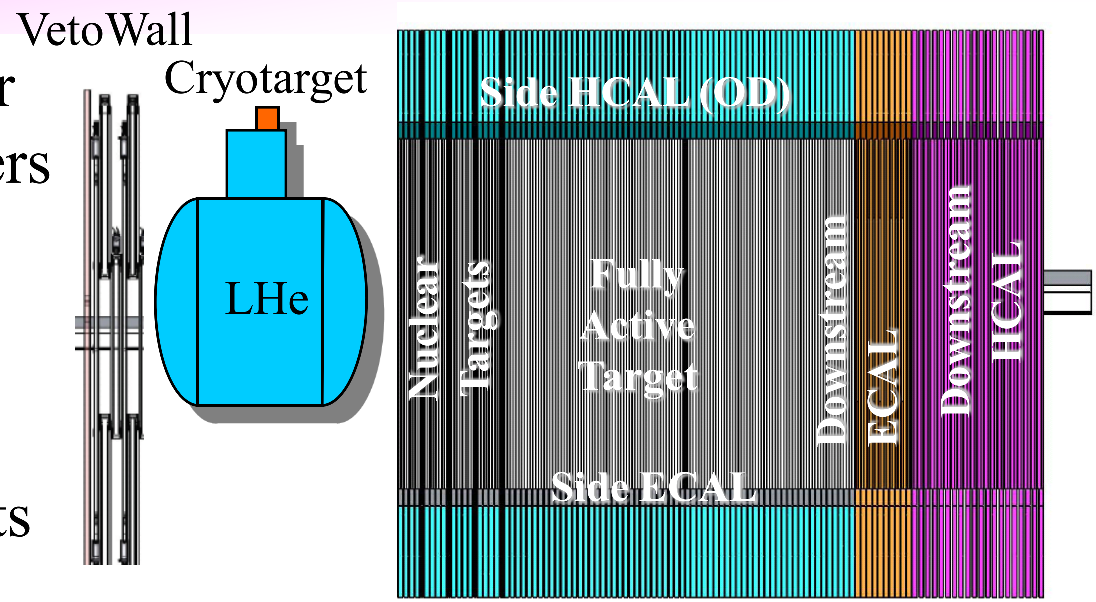
A. Guglielmi, ν2010

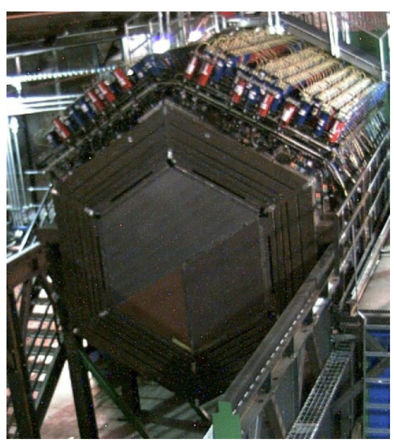


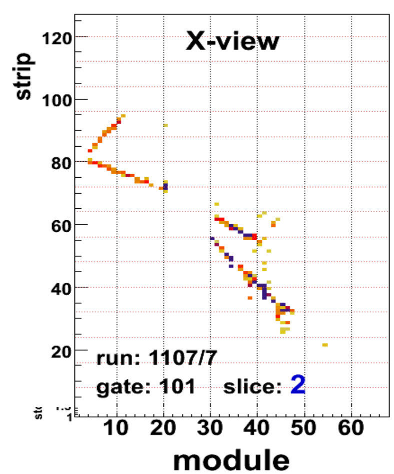


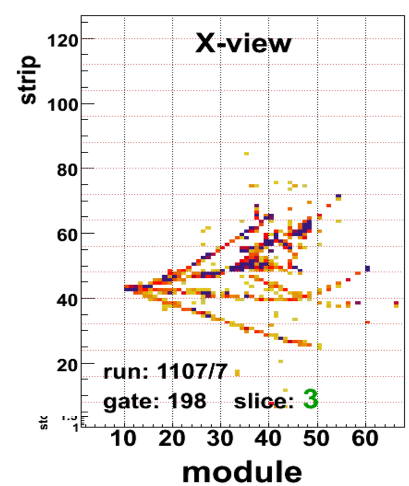
MINERνA Detector

- Finely segmented scintillator planes read out by WLS fibers
- Side and downstream calorimetry, 3-5 ton fiducial
- Signals to 64-anode PMT's
- Several ~1ton Nuclear targets of C, Fe, Pb, in now
- Helium and water targets soon
- MINOS Detector as muon spectrometer
- See K. McFarland's talk



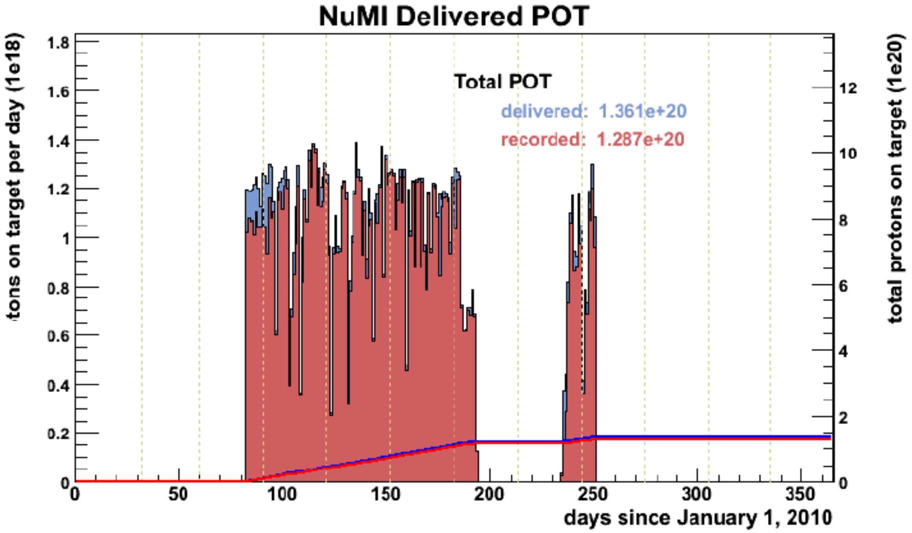




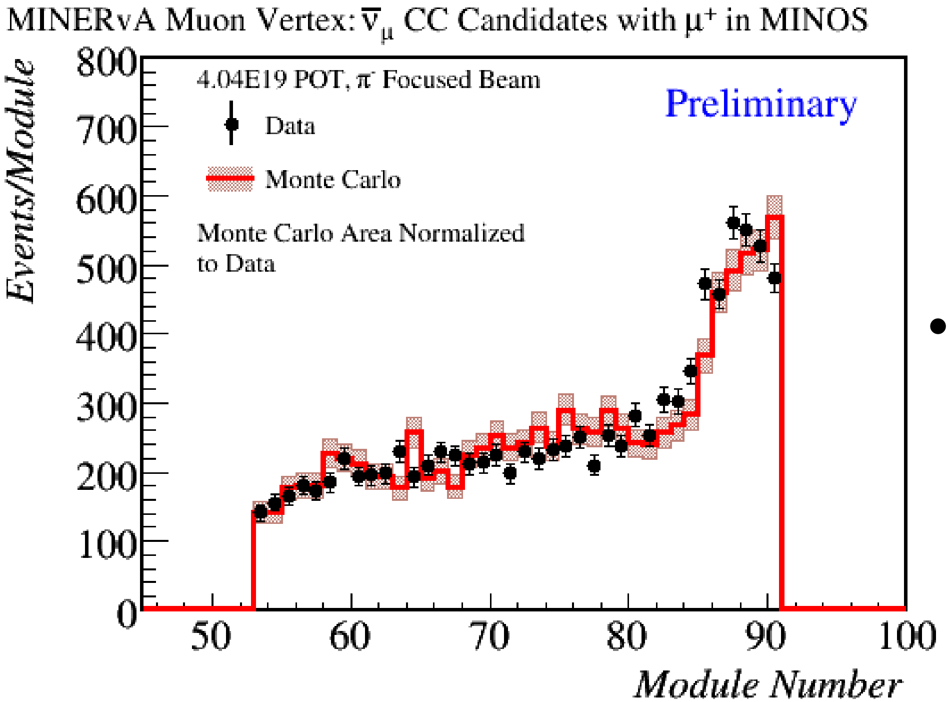


MINERvA run has started

- Recorded 1.3e20, of that 1.4e19 in special runs to understand neutrino flux



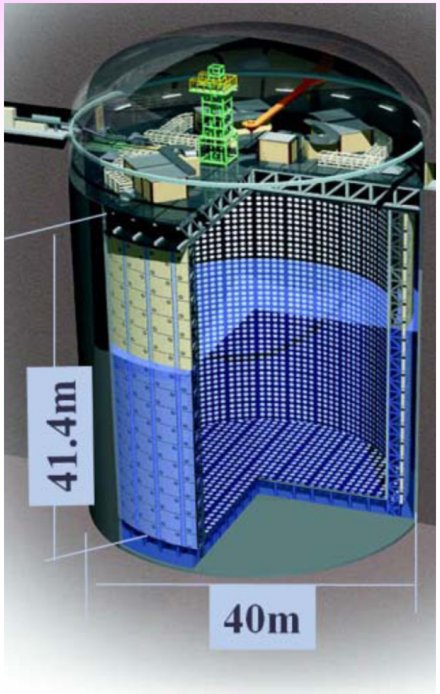
H. Budd, FNAL AEM 9/13/10



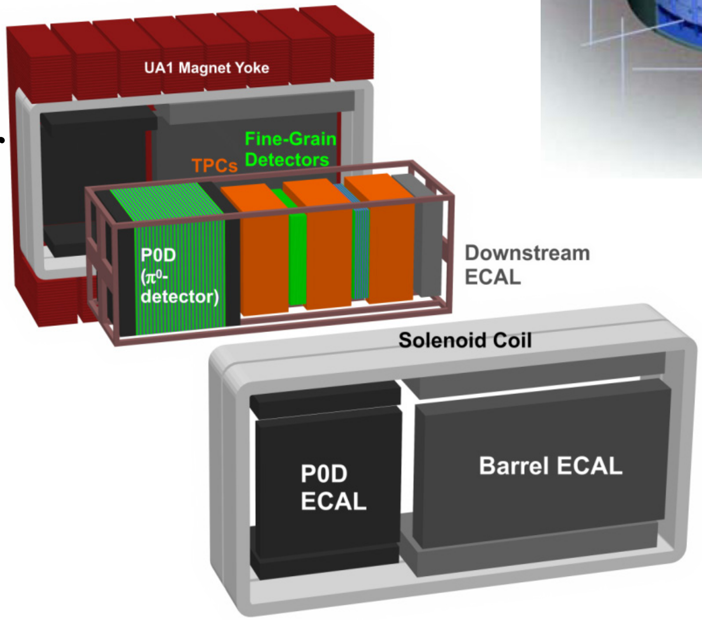
- Anti-ν CC candidate vertex distribution
  - GENIE 2.6.0
  - Geant4 Detector model

G. Perdue, ICHEP10

T2K Detectors

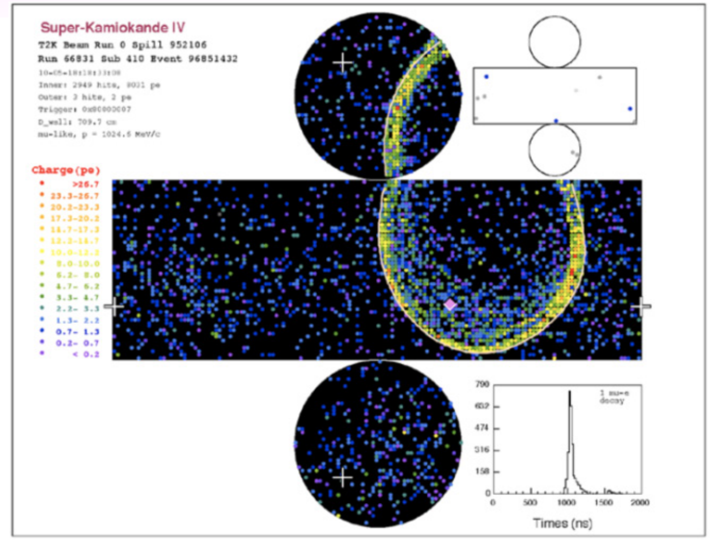


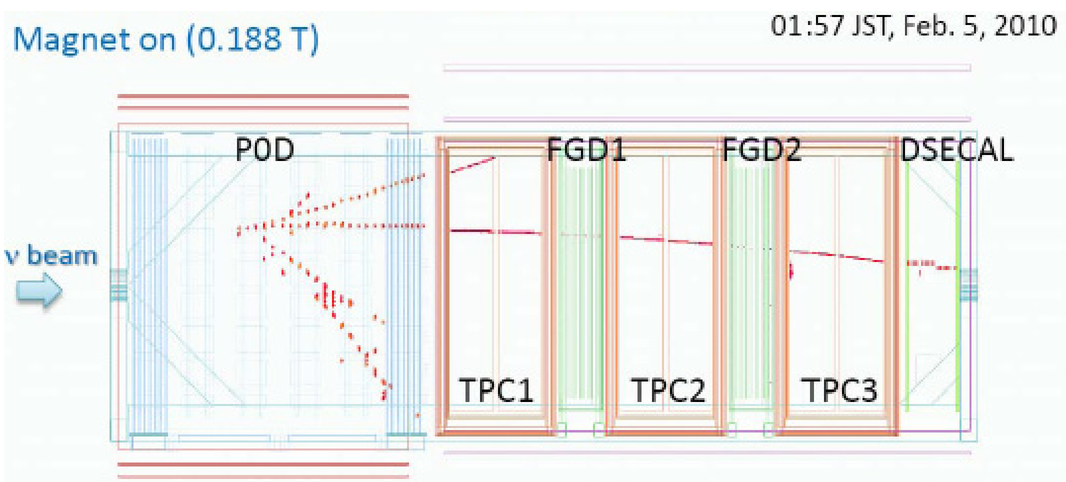
- Far Detector: Super-Kamiokande
- Near Detectors at 280m
- P0D: optimized to study electromagnetic final states in water and scintillator
- TPC: precise tracking and momentum, plus particle identification
- FGD: water and scintillator targets
- Side electromagnetic and hadronic calorimetry, 0.2T B field

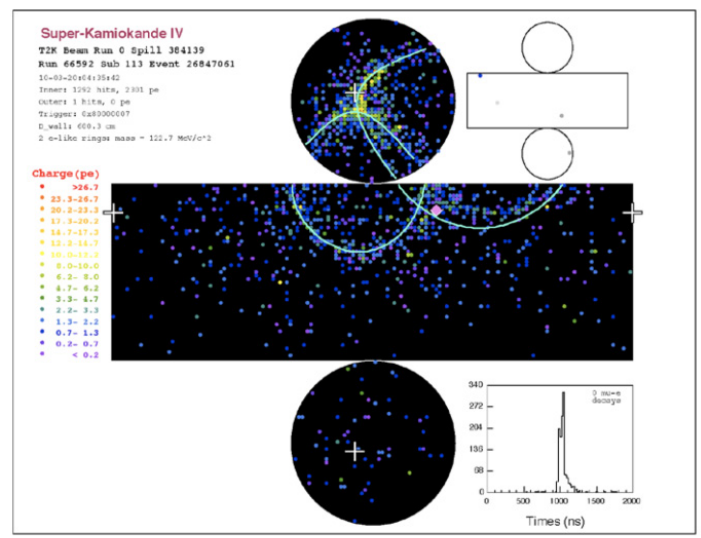


T2K Highlights

- First neutrino events from J-PARC beam seen at Far detector (22 so far)
- Near Detector complex commissioned and operating, events in all neutrino targets so far







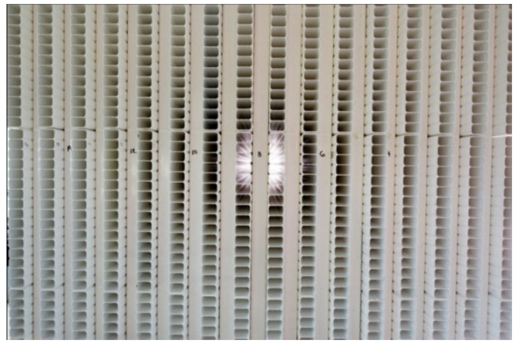
T. Kobayashi, v2010

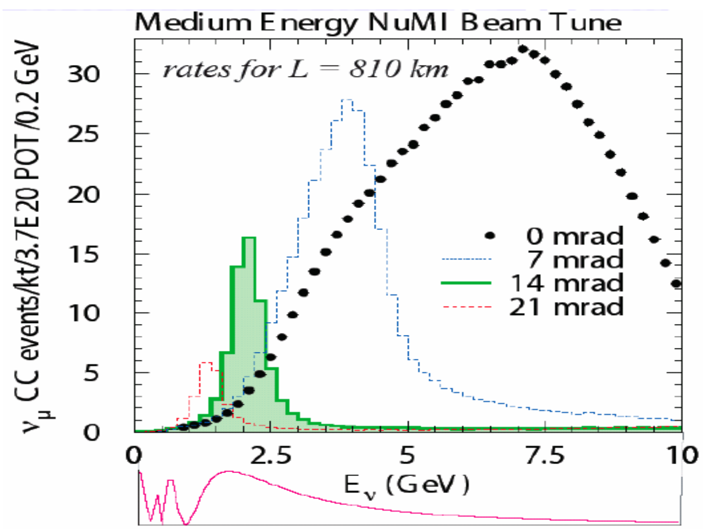
Next Generation(s)

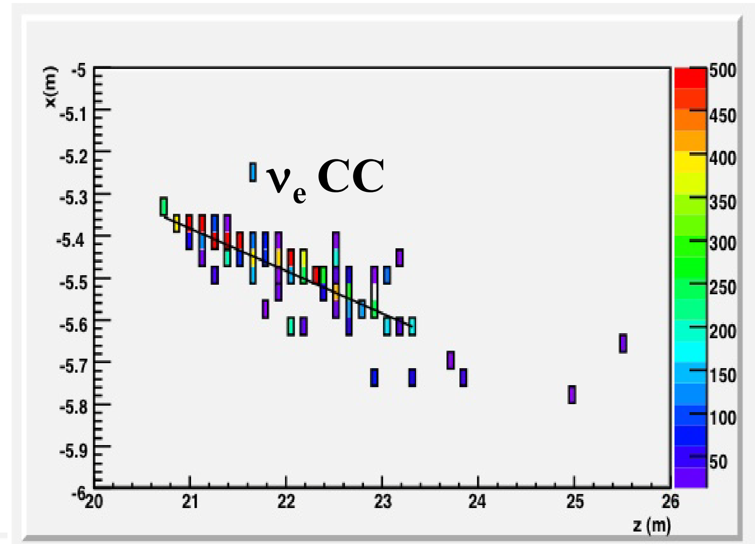
	Moti-vattion	Beam Power (kW)	Detector	Base-line (km)	ν Ener gy (GeV)	Experi-mental Method	Integrated POT so far
MINERvA	ν inter-actions	350	Fine-Grained Scint.	1.0	3.5 ++ (Wide)	Nucl. Targets	11e19
T2K	ν_e appr.	750 (50 so far)	Water Cerenkov+ ND280	295	0.700 (Narrow)	Off-Axis	3.4e19
NOvA	ν_e appr.	700	Liquid Scint.	810	2.2 (Narrow)	Off-axis	-
Micro-BooNE	ν_e appr. And LAr R&D	30	Liquid Argon TPC	≤1km	0.7 (Wide)	1st Max	-

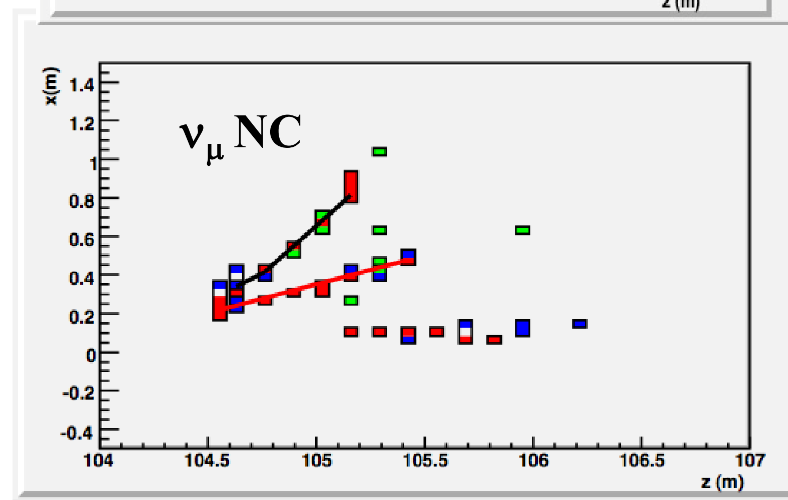
NOvA

- Off-axis NuMI neutrino beam, 2GeV peak energy
- 14kton liquid scintillator totally active detector







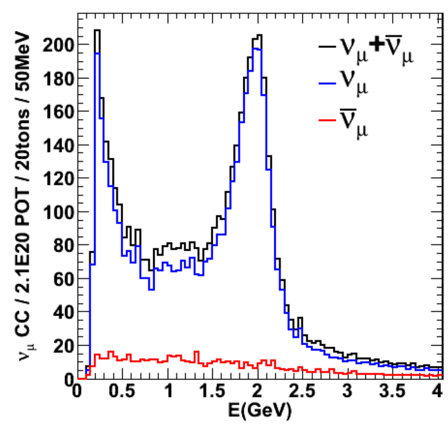


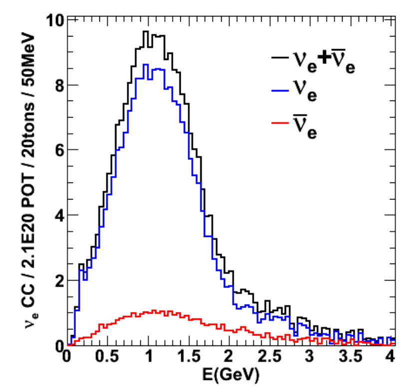
P. Shanahan, FNAL W&C 9/24/10

z (cm)

NOvA Progress since last NuFact

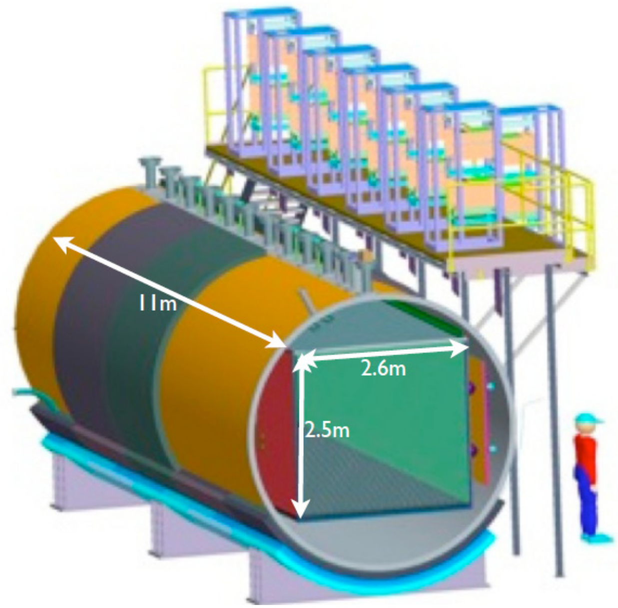
- Far detector site construction
- Full scale proto-type tests
- Near Detector on Surface starting operations





P. Shanahan, FNAL W&C 9/24/10

MicroBooNE



- Goals: put LAr TPC in Booster Neutrino beam
  - Examine MiniBooNE excesses
  - Meaure Performance of LAr TPC in low energy neutrino beam at high statistics
  - Try to use tricks you will want for >>kton devices
    - Long drift lengths
    - Ar Purity without pumping cryostat down to vacuum

Cryostat Volume	150 Tons
TPC Volume	90 Tons
# Electronic Channels	~9000
Wire Pitch	3 mm
Electronics Style (Temp.)	JFET (120 K)
Max. Drift Length (Time)	2.5m (1.5ms)
Light Collection	~30 8" Hamamatsu PMTs

M. Soderberg v2010

Next to Next Generation Technique: Electron Neutrino Appearance

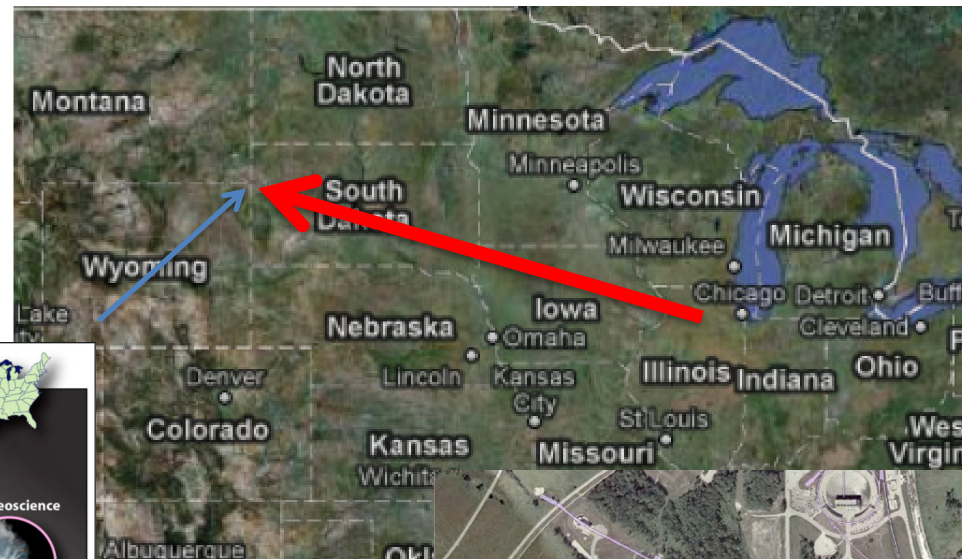
- Goals: searching for CP violation, determining the neutrino mass hierarchy
- Overall, two strategies
  - Narrow Band Beam to focus on first oscillation maximum
  - Wide band beam to see first and second max
- Strategies vary, depend on
  - Geography and existing "natural" resources
  - Status of planning for LAr TPC

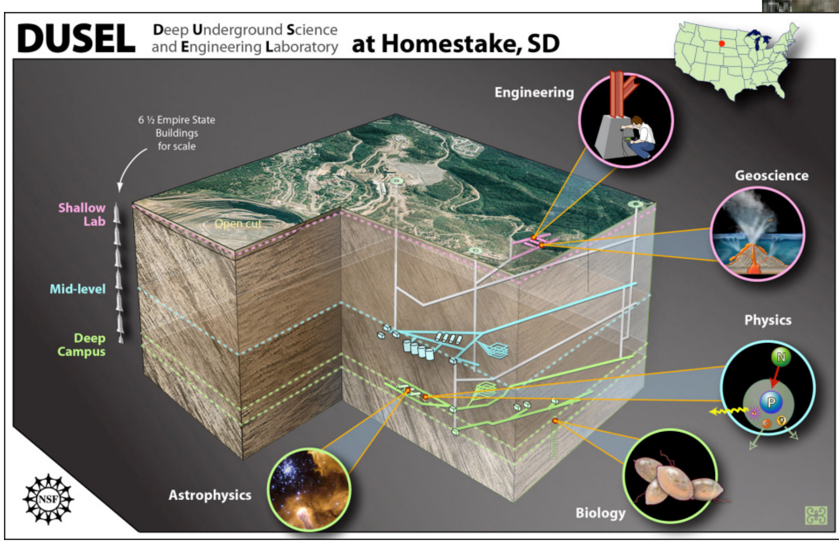
Next Generation and beyond…

- LBNE: Fermilab to Homestake (1290km)
  - Considering both LAr TPC and Water Cerenkov
  - Synergy with Deep Underground Science
    - detector charged with searching for proton decay as well
- T2K++: use existing J-PARC beamline, upgrade, and use second far detectors,
  - Okinoshima Island to see both maxima
  - Second very large detector at Kamioka to focus on 1^{st} max
- CERN to Frejus or elsewhere in Europe
  - Different baselines call for different far detector technologies

LBNE: Fermilab to Homestake

- Progress this year in planning the development of a large undertaking:
  - New Beamline
  - New Detector





Is there Life after CNGS?

- Several ideas exist for CERN-based long baseline neutrino experiments

  100kton LArTPC x 1.6MW (HP-PS2)
  ν run x 5year + $\bar{\nu}$ run x 5year
- Far detectors of Water Cerenkov or Liquid Argon TPC
- Focus on low energy beams, shorter distances: CP Violation

	PS+SPS	SpS RF upgrade	SPL+PS2+ SPS new RF	SPL + PS2	New HP-PS	Booster + RCS 4 MW
Machine param.		[33]		[35]	this paper	[37]
Proton energy E_p		400 GeV			50 GeV	30 GeV
$ppp(\times 10^{13})$	4.8	7	10	12.5	25	10
T_c (s)	6	7.2	4.8	2.4	1.2	$(8.33\text{Hz})^{-1}$
Beam power (MW)	0.5	0.6	1.3	0.4	1.6	4
Global efficiency	0.8	0.8	0.8	1.0	1.0	1.0
Beam sharing	0.85	0.85	0.85	0.85	0.85	1.0
Running (d/y)	200	200	200	200	200	200
N_{pot}/yr $(\times 10^{19})$	**9.4**	**11.4**	**24.5**	**77**	**300**	**1437**
$E_{tot} \equiv E_p \times N_{pot}$ $(\times 10^{22}$ GeV·pot/yr)	4	4.5	10	4	15	43
E_{tot} increase compared to CNGS	×2	×2	×4	×2	×5	×16

AR, arXiv:1003.1921

Slide courtesy K Sakashita, v2010

Summary of Future Long Baseline Experiments

already existing or upgrade existing acc/beam-line | construct new one

	motivation	Beam Power [MW]	ν beam facility	detector	baseline [km]	ν energy (peak E_ν)	experimental method
JPARC-Okinoshima	**CPV, θ_{13} (hierarchy)**	1.66	existing	100kton LArTPC	658	WBB (1.2GeV)	1st, 2nd max
JPARC-Kamioka	**CPV, θ_{13}**	1.66	existing	540kton W.C.	295	NBB (0.7GeV)	ratio of ν and $\bar{\nu}$
FNAL-DUSEL	**CPV, θ_{13}, hierarchy**	0.7 / 2.1	need new one	~300kton WC. and/or ~50kton LArTPC	1300	WBB (3GeV)	1st, 2nd max
CERN-Frejus	**CPV, θ_{13}**	4 (HP-SPL)	need new one	~440kton W.C.	130	on-axis low energy (0.2GeV)	ratio of ν and $\bar{\nu}$
CERN-Pyhasalmi	**CPV, θ_{13}, hierarchy**	1.6 (HP-PS2)	need new one	100kton LArTPC	2300	WBB (3GeV)	1st, 2nd max

Slide courtesy K. Sakashita, v2010

Lessons from Current Generation

- Getting to design power takes time and experience
  - MINOS example: 1st 2 years at ~ ½ intensity of 2nd 2 years
  - CNGS Example: 2 years at low intensity, high intensity now
- The fluxes you assumed aren't necessarily right
  - NuMI High Energy tail 50% higher than predicted
  - MINOS Near Det. ν_e background prediction 20% high
- The cross sections you assumed aren't necessarily right
  - MiniBooNE is seeing 20% higher σ(QE) than expected
- Radiation shielding is harder than you imagined

Conclusions

- This has been an exciting year for conventional ν beam experiment operations
  - First beam on full detector:
    - T2K, ICARUS, MINERvA
  - First ν_τ event shown by OPERA
  - NOvA Near Detector assembled, ready for data
- Oscillation and cross section results have been exciting too, to be covered in later talks
- Many lessons to take away for future plans