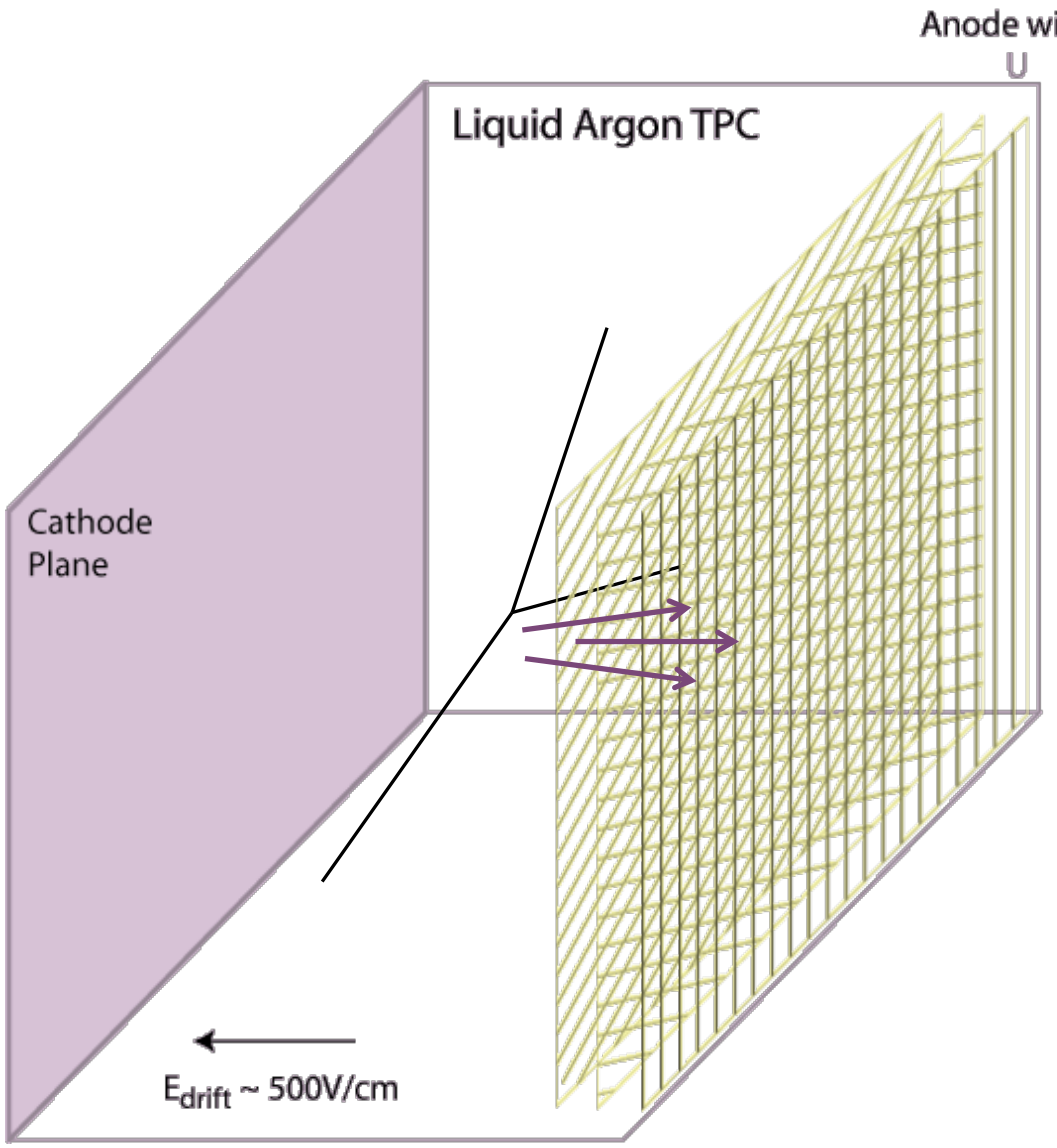
1. LArTPC's:
   Motivation & challenges
   Worldwide effort
   Physics goals
2. Current experiments:
   ICARUS
   MicroBooNE
3. Future experiments:
   LAr1
   2-LAr@CERN-SPS
   LBNE
   100kton@Okinoshima

Current and Future Liquid Argon Experiments

Georgia Karagiorgi
Columbia University
NuInt'12 -- Rio de Janeiro, Brazil

1. LArTPC's: Detector Concept

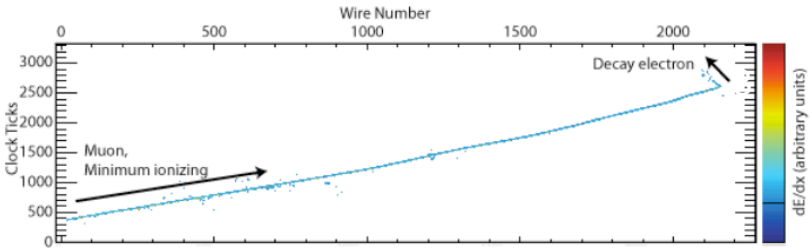


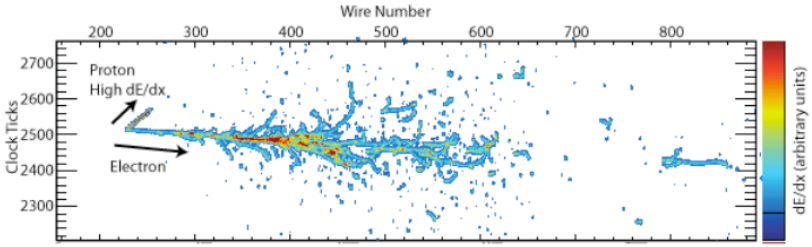
Charged particle tracks ionize argon atoms; Ionization charge drifts to **finely segmented charge collection planes** over ~1-few ms.

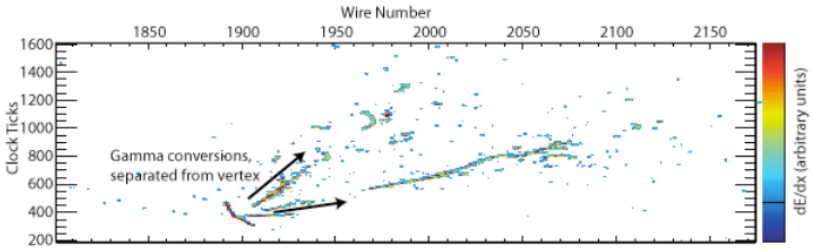
Scintillation light (~few ns) is typically detected by photo-sensitive detectors for event t_0 and triggering

1. LArTPC's: Motivation

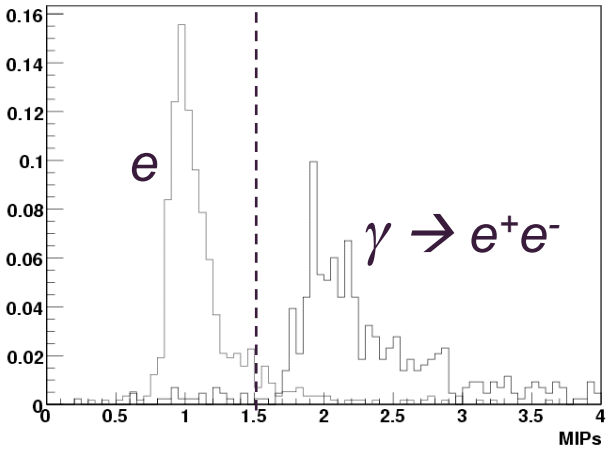
- Liquid argon is ideal for low rate TPCs
  - High-density and relatively cheap medium
  - Factor of ~2 increase in signal detection efficiency and higher background rejection relative to water Cherenkov
    → 1:6 detector mass ratio for comparable oscillation sensitivity
  - Possibility for continuous data taking
  - Homogeneous, fully active neutrino interaction volume
  - High ionization charge yield (MIP, ~1fC/mm), small diffusion (~mm for several meters of drift)
  - High scintillation yield, can be used for T_0, triggering
- Detector performance
  - High-resolution 3D tracking (~mm-scale spatial resolution) with local dE/dx information
  - **Excellent PID (range vs dE/dx) and e/γ separation (~80%)**
  - **Ideal technology for ν_e measurements!**







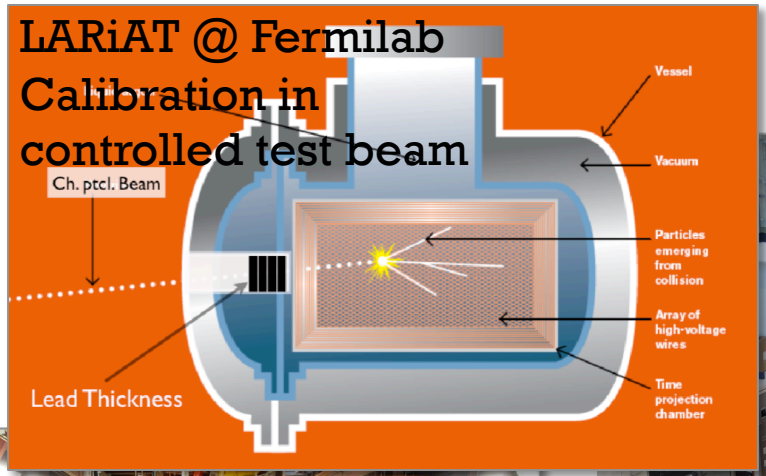
Energy loss in first 24mm of track:
250 MeV electron vs. 250 MeV photon



1. LArTPC's: Technical challenges

[...being addressed by ongoing and planned R&D projects]

- Large cryogenic system
- Long drift distances
  - Requires ultra high purity and evacuation is impractical
  - Implies high voltage on cathode
- Large number of readout channels with high data volume/channel (data storage, data processing, ...)
- Cold electronics
- Reconstruction tools: LArSoft development



1. LArTPC's: Test Facilities & Experiments

United States

Materials Test Stand
ArgoNeuT
LAPD
☆ **MicroBooNE**
☆ **LAr1**
LARiAT
Los Alamos LDRD LArTPC
GLADE
☆ **LBNE**

Europe

50-liter @ CERN
10m^3
☆ **ICARUS**
LArTPC in B-field
ArgonTube @ Bern
UV Laser
☆ **2-LAr @ CERN-SPS**
MODULAr
LAGUNA/LBNO

Japan

Test-Beam (T32) at J-PARC
☆ **100 kton @ Okinoshima island**

☆ Covered in this talk

Updated from M. Soderberg

1. LArTPC's: Test Facilities & Experiments

☆ Covered in this talk
☆ See talks by A. Szelc, K. Partyka, O. Palamara
☆ See talk by A. Szelc
☆ See talk by A. Weber
☆ Backup slides

Updated from M. Soderberg

1. LArTPC's:

Neutrino Physics Goals [unanswered questions] addressed by LArTPC neutrino experiments

Fundamental questions

Pressing experimental questions

CP violation (long-baseline oscillations: $\overset{(-)}{\nu}_e$ appearance)
LBNE LAGUNA/LBNO **100kton@Okinoshima** MODULAr GLADE

Mass hierarchy & Dirac vs. Majorana
(combinations of the above + other expts, in various permutations)

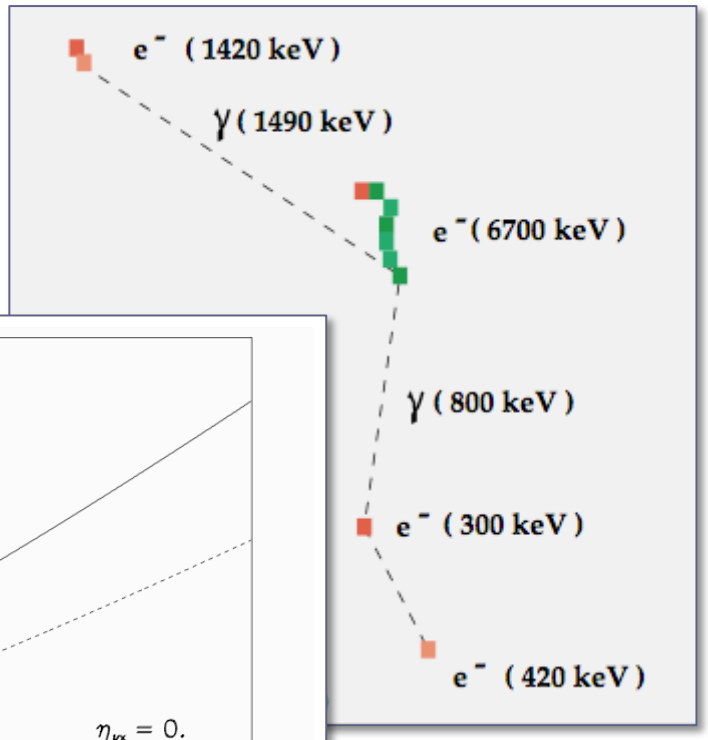
Sterile neutrinos (short-baseline oscillations)
MicroBooNE LAr1 2-LAr@CERN-SPS

Exclusive and inclusive cross section measurements,
Nuclear effects & FSI
MicroBooNE LAr1 2-LAr@CERN-PS ICARUS ArgoNeuT

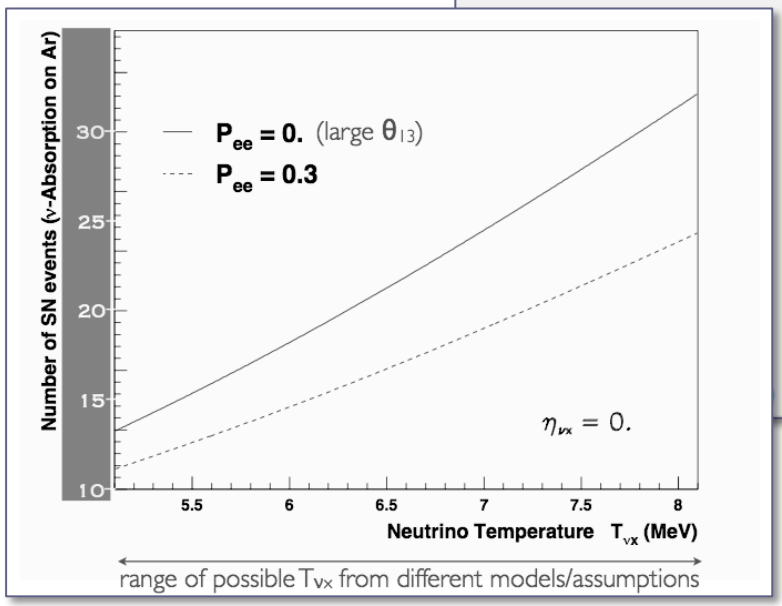
…And more!

- Proton decay & baryon number violating processes
- Supernova core collapse neutrinos
- Atmospheric neutrinos
- Diffuse SN background

Signature of low energy ν_e CC absorption on Ar



SN neutrino event rate predictions for MicroBooNE (60 tons)



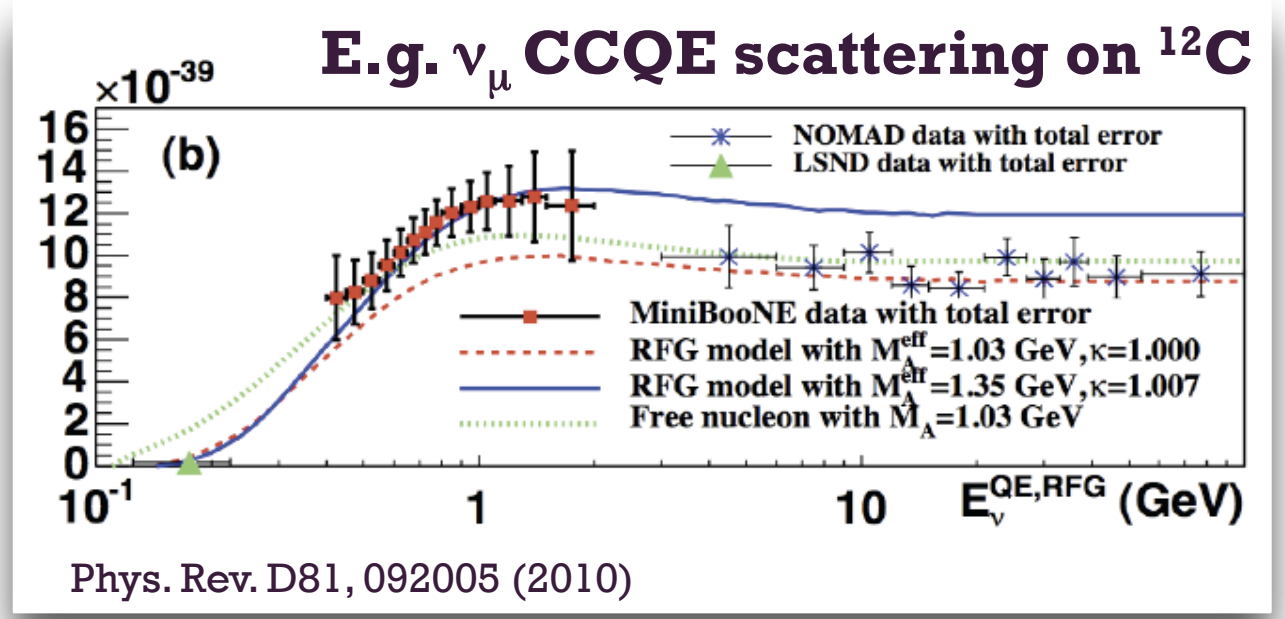
See talk by F. Cavanna

1. LArTPC's: ν Interactions

Goal of next-generation cross-section experiments:
unambiguously measure neutrino cross sections around 1 GeV

- Past cross section measurements (from K2K, MiniBooNE, SciBooNE, MINOS, NOMAD) have revealed limitations in our understanding neutrino interactions from lepton kinematics alone.

Hadronic effects play a critical role and hadronic kinematics should be considered.



- A precise measurement of the hadronic system (**vertex activity, hadronic final state multiplicity and momentum**, etc.) will provide critical information for testing existing models and developing more robust neutrino interaction event generators for oscillation physics.

1. LArTPC's: ν Interactions

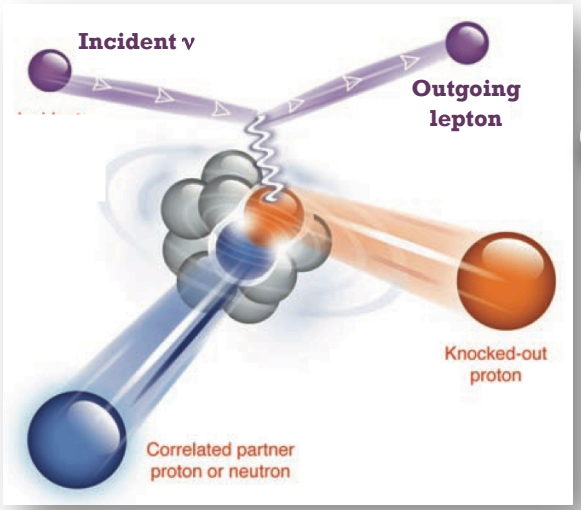
LArTPC's study events **after final state interactions** in exquisite detail

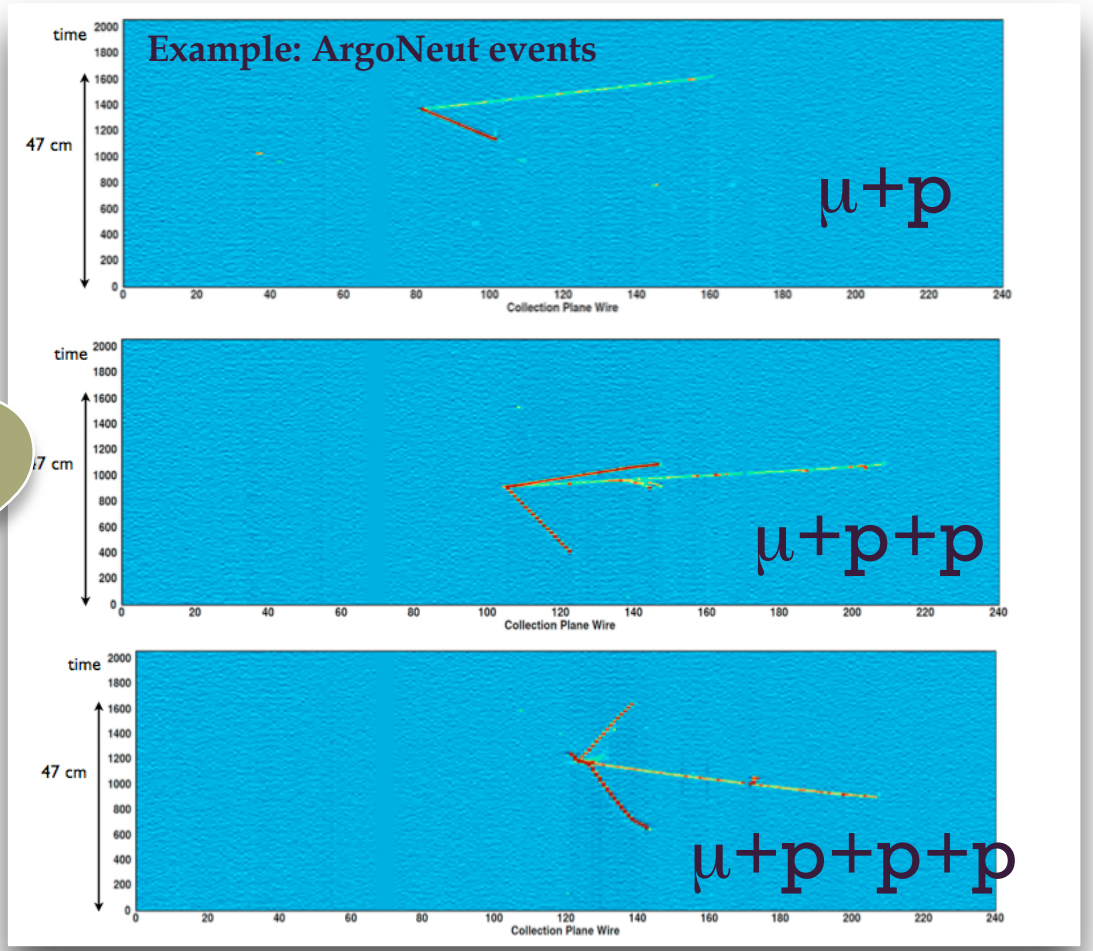
- **Channel of particular interest: Charged Current Quasi-Elastic (CCQE) scattering**

Resolve discrepancy in measured cross section: **nucleon-nucleon correlations? which model?**

Measure channels by **"final states multiplicity"**

E_ν from **lepton kinematics** vs. **momentum balance** vs. **summed total energy**





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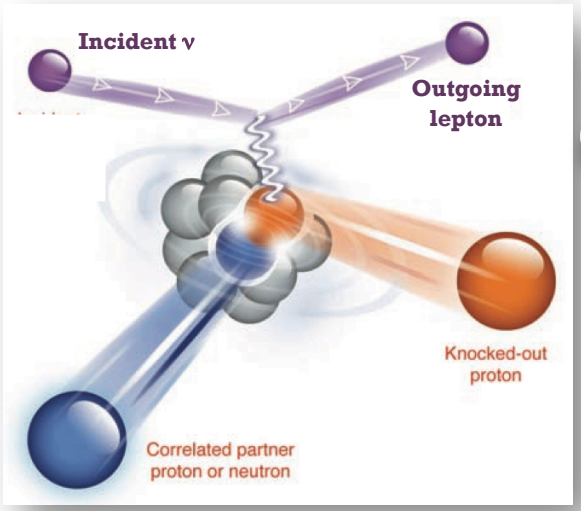
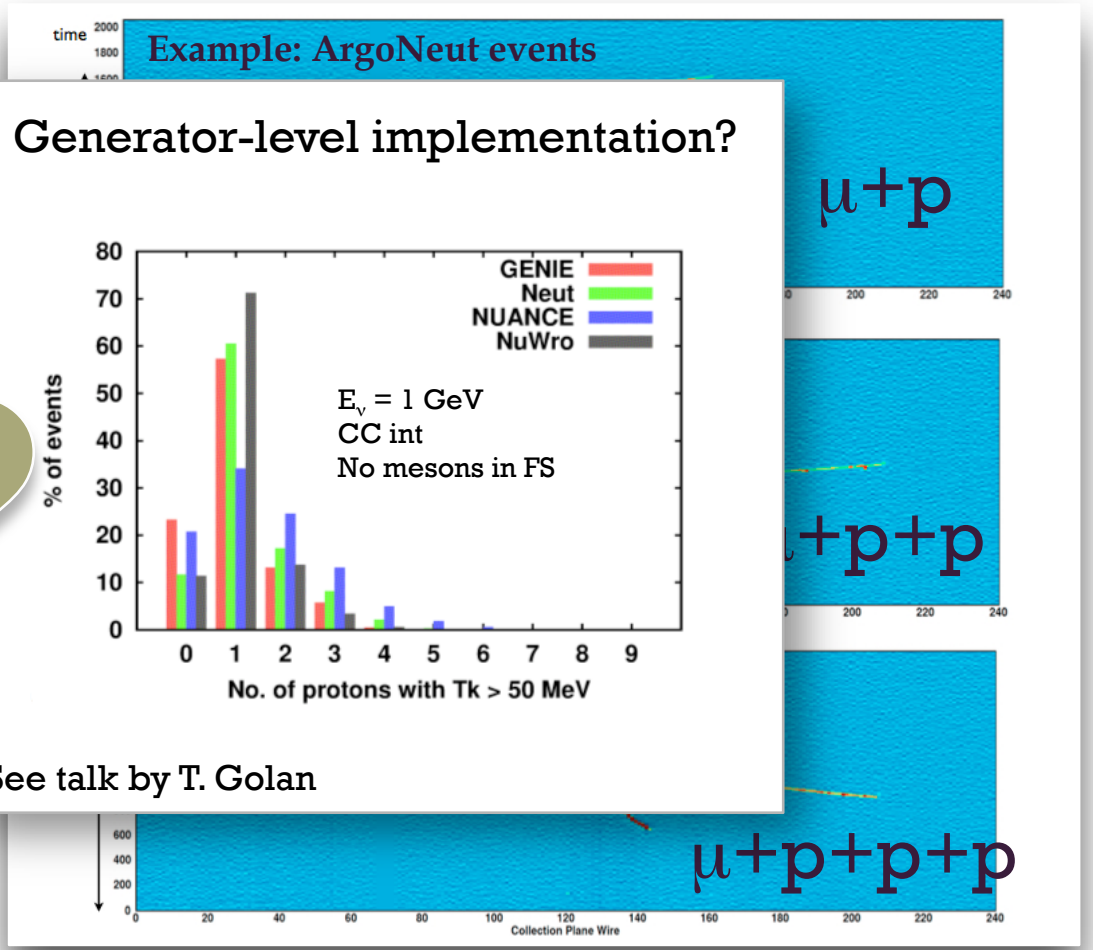
Measure channels by "**final states multiplicity**"

E_ν from **lepton kinematics** vs. **momentum balance** vs. **summed total energy**

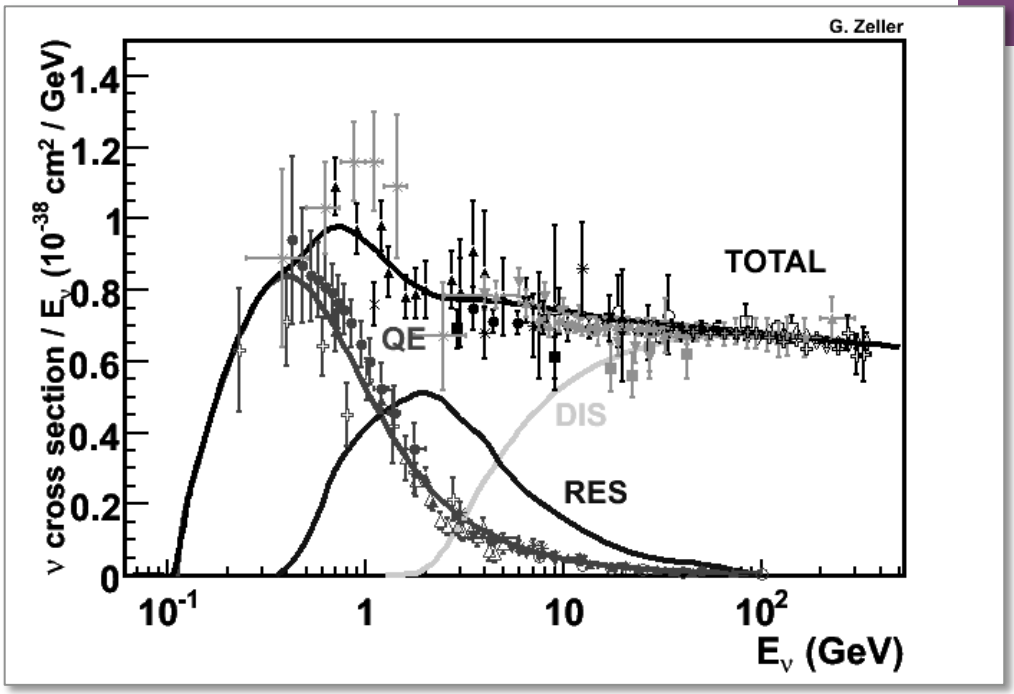




1. LArTPC's: ν Interactions

LArTPC's study events **after final state interactions** in exquisite detail

- **Other channels of interest:**
- **ν-N NC elastic scattering**
  Measure Δs and improve sensitivity of dark matter searches
  $T_{p,min}$ ~ 40 MeV (Q^2 ~ 0.08MeV^2)
- **Kaon production**
  p-decay background constraints
- **Single-π production**
  Resolve theoretical tension?
- **Hyperon production**
- **Single-photon production in low energy scattering**
- **First conclusive ν_e cross-section measurements (~1GeV)**



BNB: MicroBooNE, LAr1

CNGS: ICARUS, MODULAr

NuMI: ArgoNeuT, GLADE

New SPS: 2-LAr@CERN-SPS

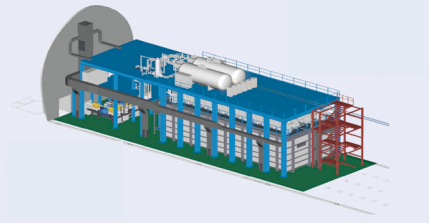
LBNE

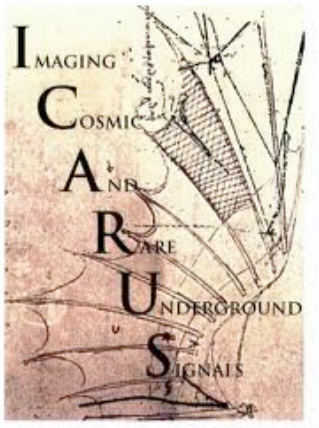
Upgraded T2K: 200kton@Okinoshima

1. LArTPC's: ν Interactions

Limitations

- Only one type of target nucleus (Ar)
- No free protons
- No charge ID on event by event basis
  - Magnetized LArTPC's are challenging
  - Options:
    - High-purity sign-selected beams
    - LArTPC + spectrometer (ArgoNeuT-style) for μ charge ID
    - LArTPC in a magnetic field (LBNE-ND)





2. Current experiments: ICARUS

[running]

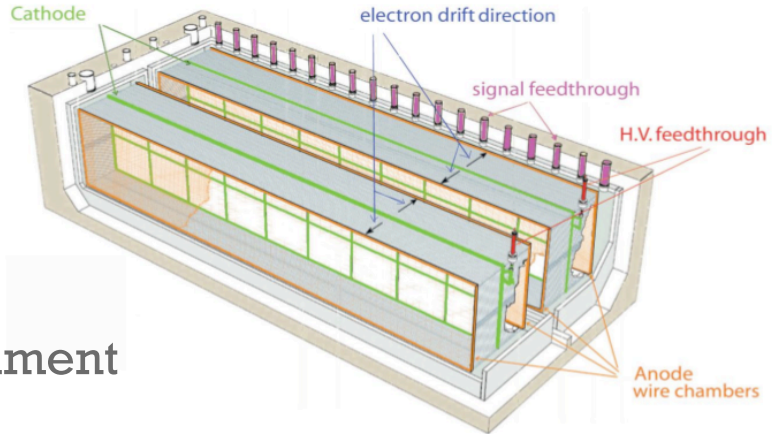
International collaboration:

14 institutions

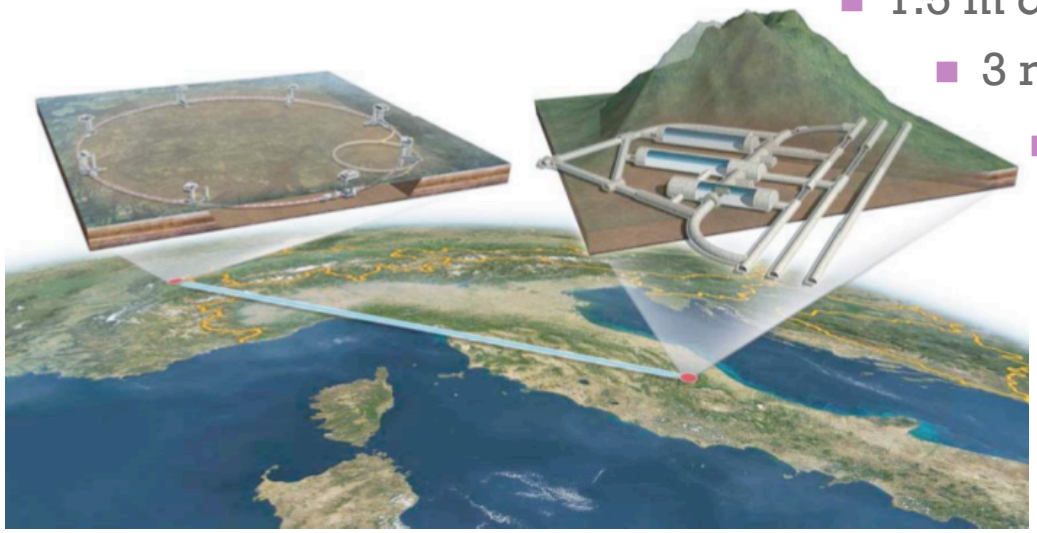
5 countries

ICARUS

Pioneer LArTPC experiment



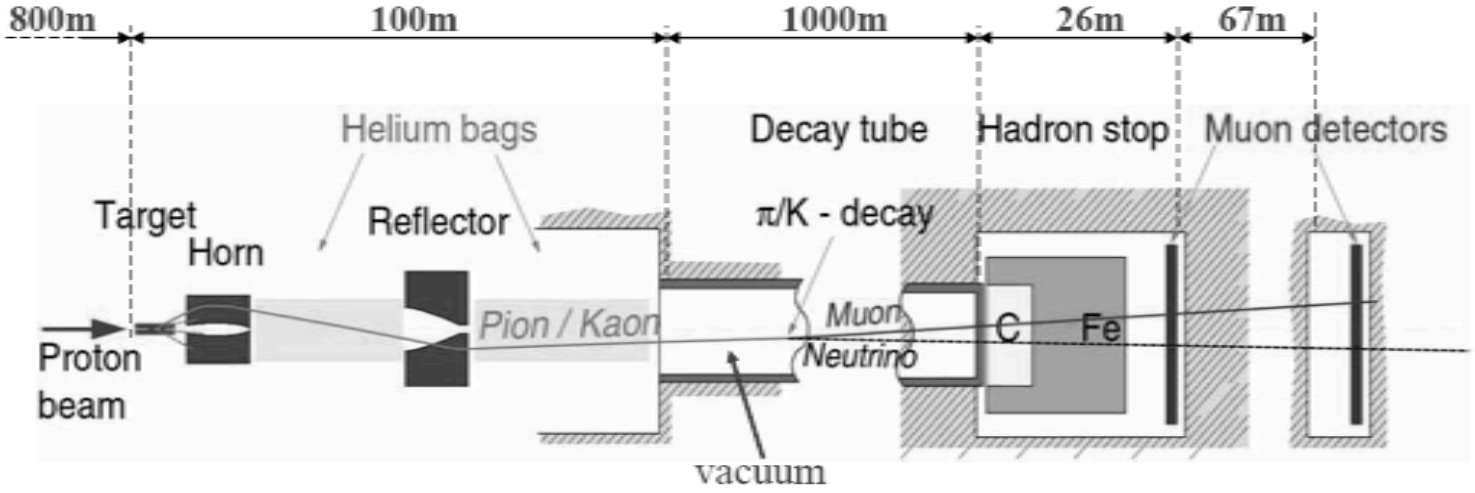
- Largest existing LArTPC neutrino experiment
- Detector located underground at Gran Sasso National Lab, Italy
- Detector parameters:
  - Two identical modules: 3.6x3.9x19.6 ~ 275m^3 each (2 TPC's per module)
    - 600 (476) tons total (active) LAr mass
      - 1.5 m drift length (1ms)
        - 3 mm wire pitch
          - 54k wires
            - PMT's with wavelength shifter for triggering



ICARUS

CNGS beam from CERN

- ν_μ-pure, L=732km, $E_\nu \sim 17$ GeV
- Collecting data since 2010
  (~5E19 POT in 2010-11; 3.3E19 POT analyzed so far)

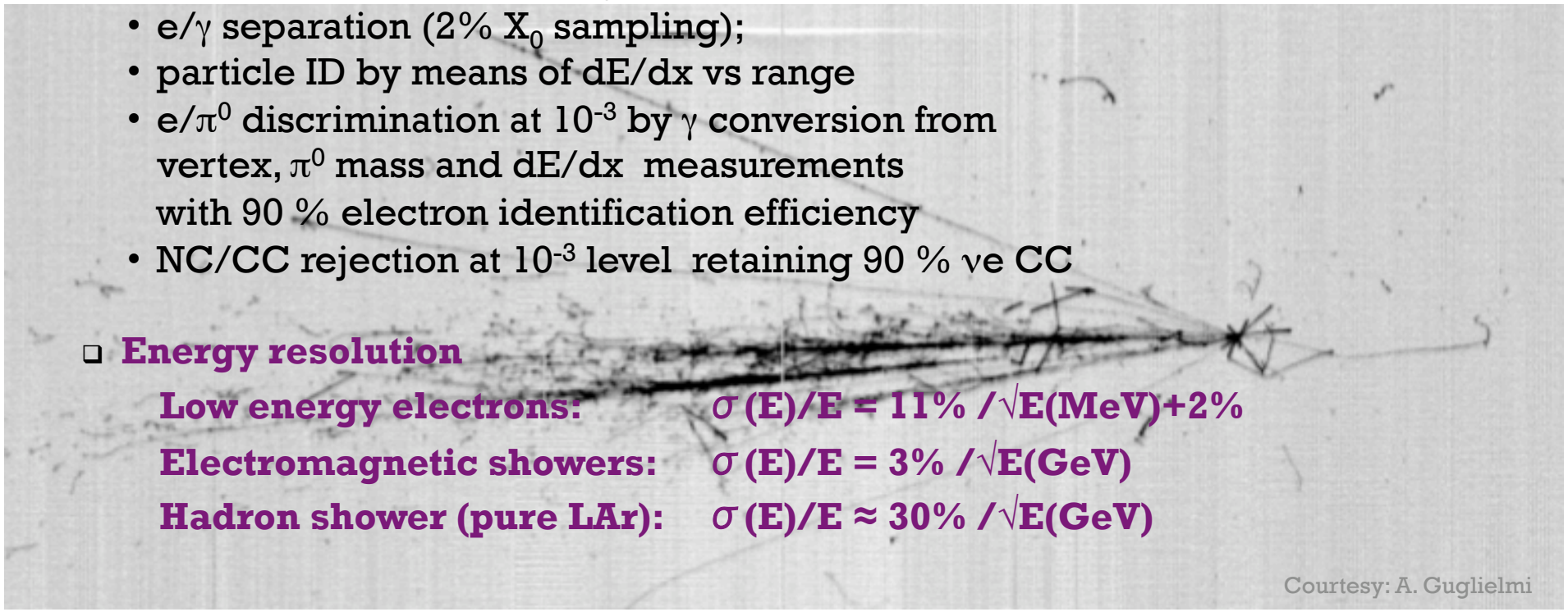


$$p + C \rightarrow \text{(interactions)} \rightarrow \pi^+,\ K^+ \rightarrow \text{(decay in flight)} \rightarrow \mu^+ + \nu_\mu$$

ICARUS

Detector performance

- Fully operational since Oct. 2010
- Tracking device:
  - precise event topology ($\sigma_{x,y} \sim 1$mm, $\sigma_z \sim 0.4$mm)
  - μ momentum measurement via multiple scattering: $\Delta p/p \sim$10-15% depending on track length and p
- Measurement of local energy deposition dE/dx:
  - e/γ separation (2% X_0 sampling);
  - particle ID by means of dE/dx vs range
  - e/π^0 discrimination at 10^{-3} by γ conversion from vertex, π^0 mass and dE/dx measurements with 90 % electron identification efficiency
  - NC/CC rejection at 10^{-3} level retaining 90 % νe CC



- **Energy resolution**

  Low energy electrons: $\sigma(E)/E = 11\%/\sqrt{E(MeV)} + 2\%$

  Electromagnetic showers: $\sigma(E)/E = 3\%/\sqrt{E(GeV)}$

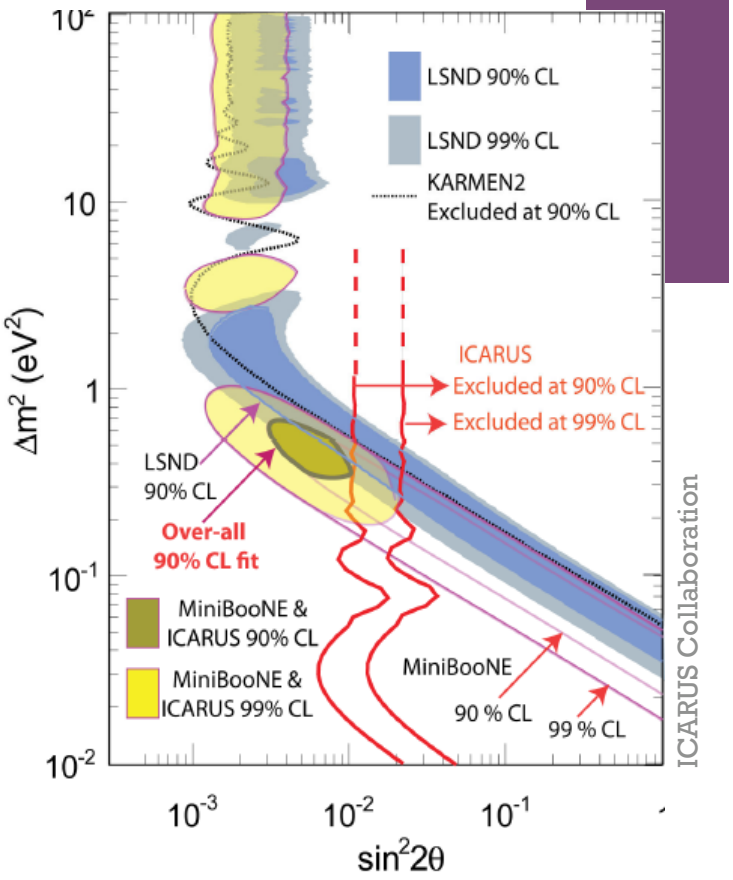
  Hadron shower (pure LAr): $\sigma(E)/E \approx 30\%/\sqrt{E(GeV)}$

Courtesy: A. Guglielmi

ICARUS

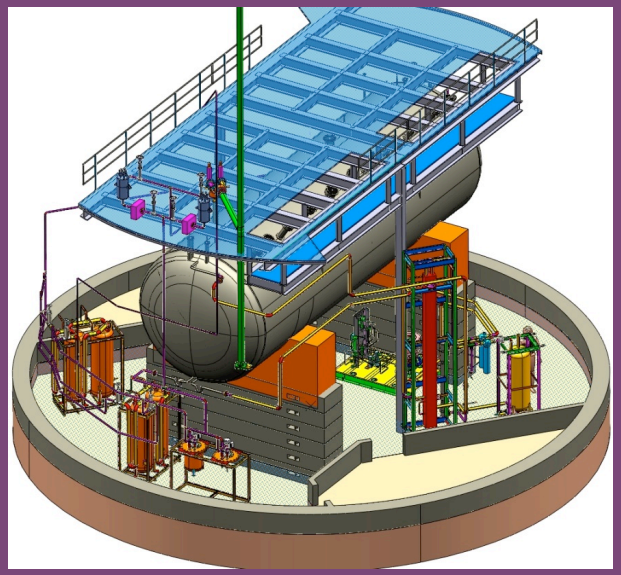
Physics scope

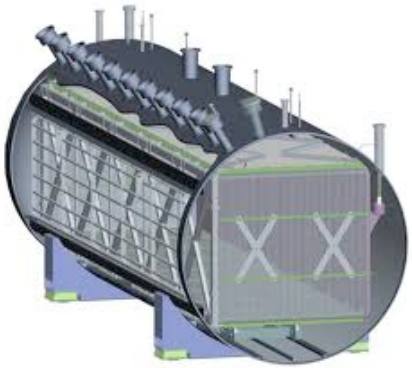
- Multipurpose detector:
  - CNGS neutrinos (5-25 GeV), ~2k evts/yr
  - Solar neutrinos (>8 MeV)
  - SN, expected ~200 evts (10kpc)
  - Atmospheric neutrinos, ~100 evts/yr
  - Nucleon decay searches, 3×10^{32} nucleons



Results with CNGS beam

- CNGS events analysis is ongoing
- Search for sterile neutrinos in LSND parameter space using CNGS: $\nu_\mu \rightarrow \nu_e$ (arXiv:1209.0122)
- Search for the analogue to Cherenkov radiation by high energy CNGS neutrinos at superluminal speeds (Phys. Let. B 711 (3-4): 270-275)
- Precision measurement of the neutrino time-of-flight with the 2011 (Phys. Let. B 713 (1): 17-22) and 2012 (arXiv:1208:2629) CNGS bunched beams





2. Current experiments: MicroBooNE

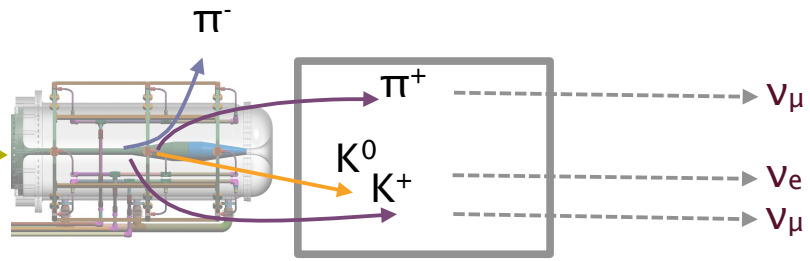
[under construction]

International collaboration:
91 physicists & engineers
16 institutions
3 countries

MicroBooNE

Located in the Fermilab Booster Neutrino Beamline:

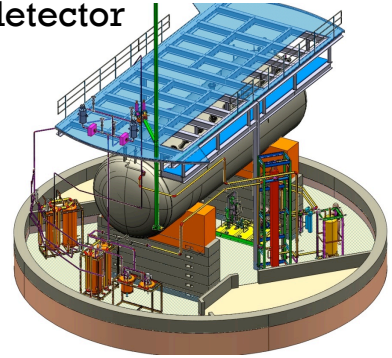
8 GeV protons
(FNAL booster)

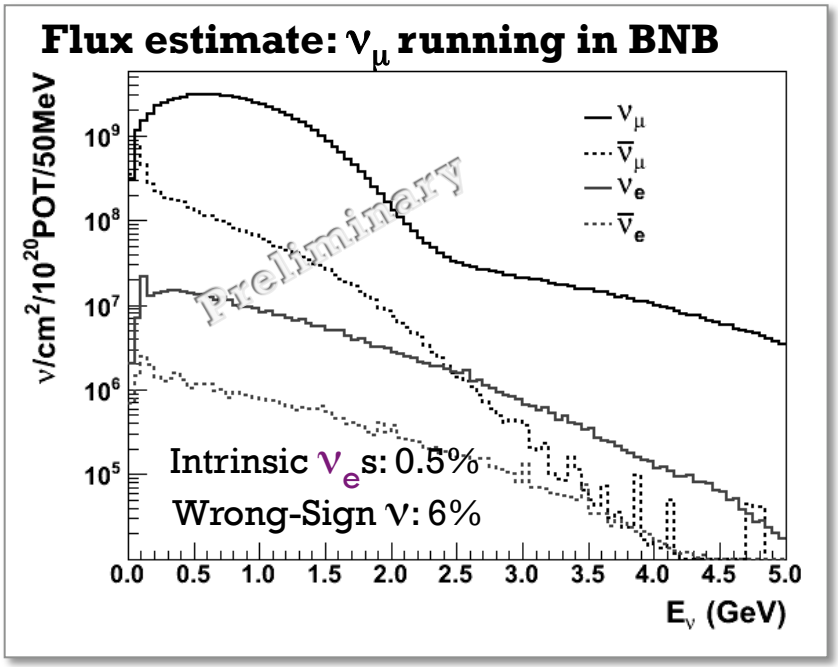


magnetic focusing

L = 470m

MicroBooNE detector





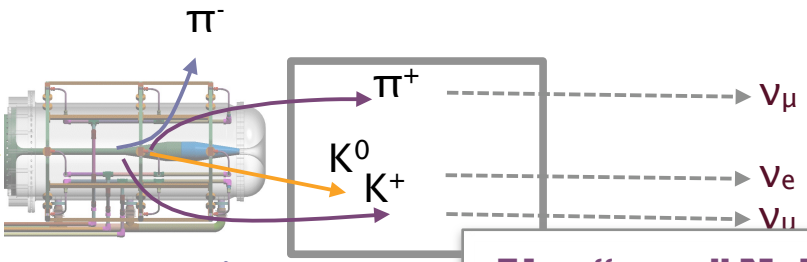
Current run plan (approved):
Neutrino mode running, 6.6e20 POT

Possibility of future antineutrino running (sign-selected beam)

MicroBooNE

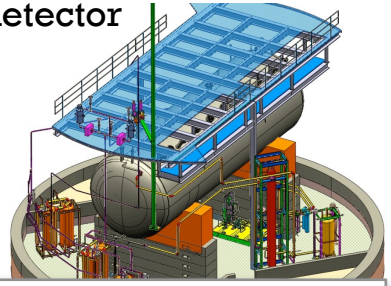
Located in the Fermilab Booster Neutrino Beamline:

8 GeV protons
(FNAL booster)

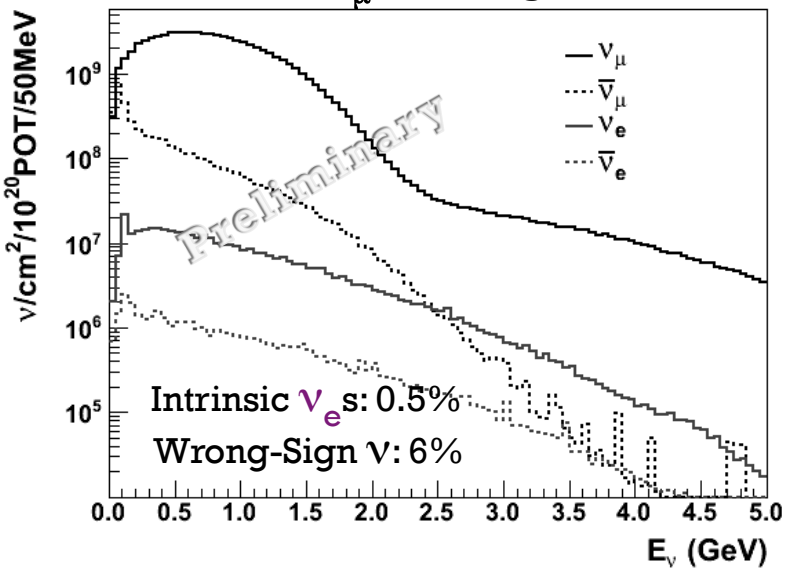


magnetic focusing

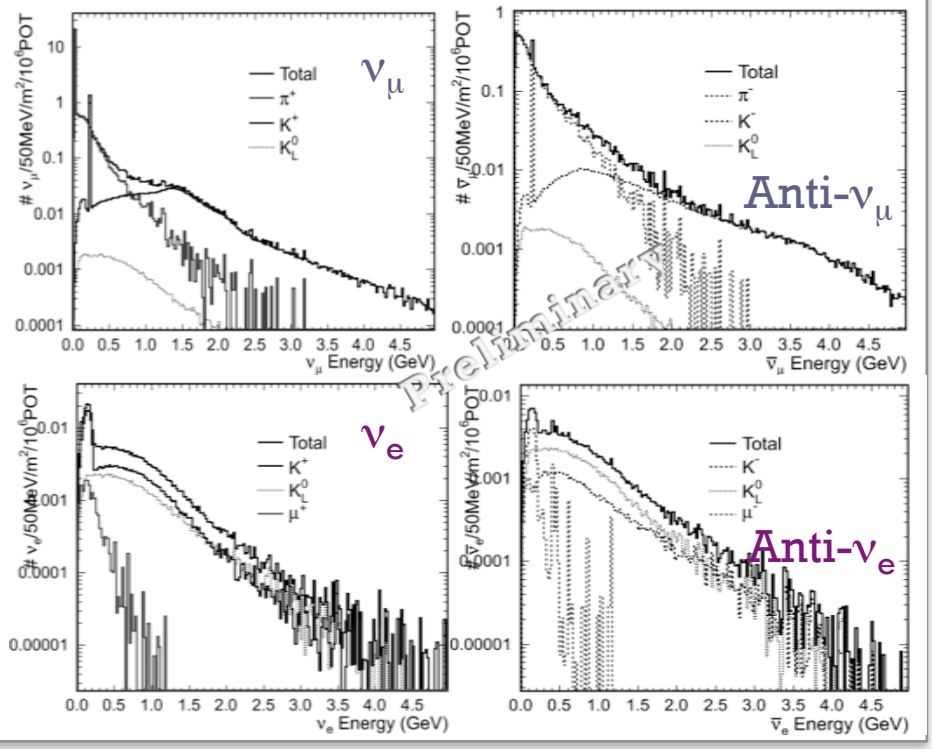
MicroBooNE detector



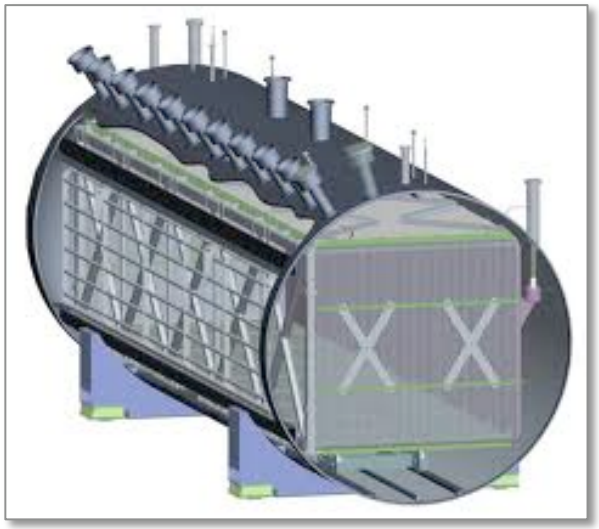
Flux estimate: ν_μ running in BNB



Also "sees" NuMI beam: Off-axis

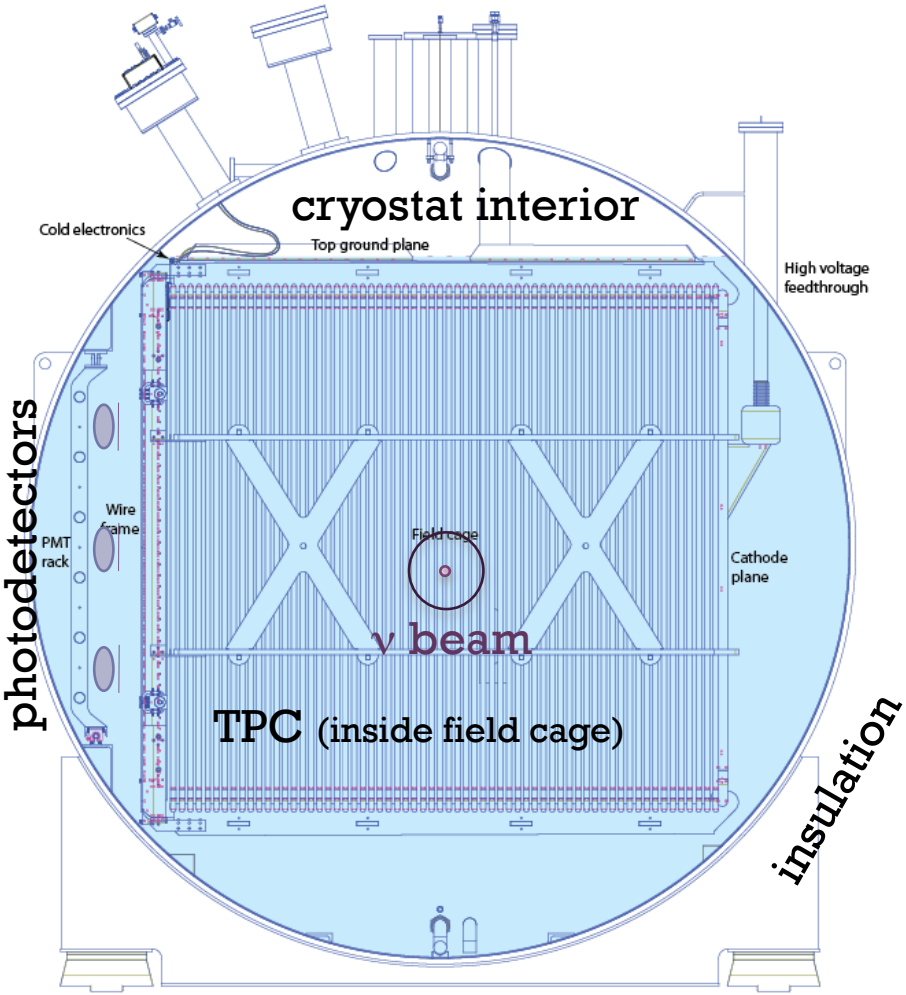


MicroBooNE



- Detector parameters:
  - 2.5 m x 2.3 m x 10.2 m TPC
  - 170 (60) tons total (fiducial) mass
  - 2.5 m drift length
  - 3 wire planes, 0,±60° from vertical
  - 3 mm wire pitch
  - 8256 wires
  - 30 PMT's for T_0 and triggering for empty beam spill rejection

Cross section of detector:

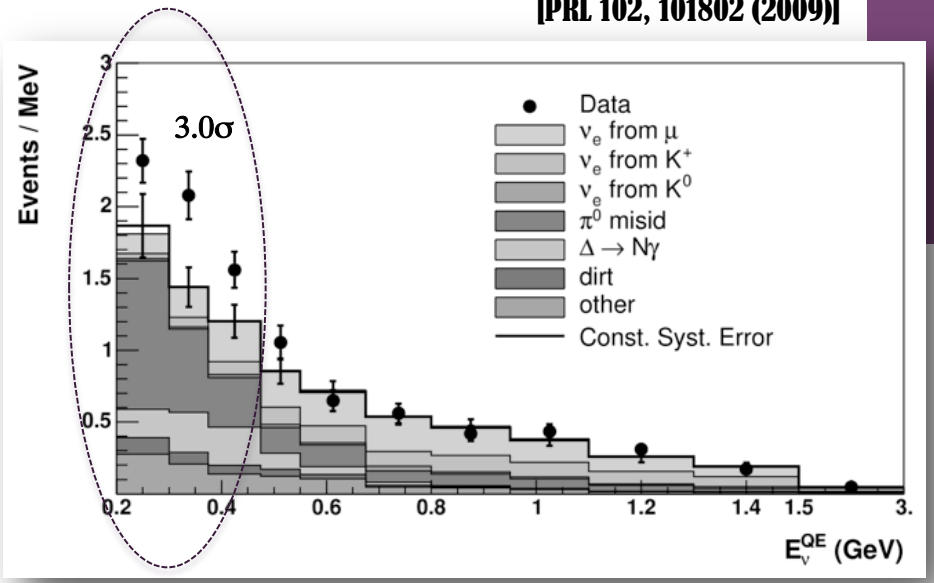


MicroBooNE

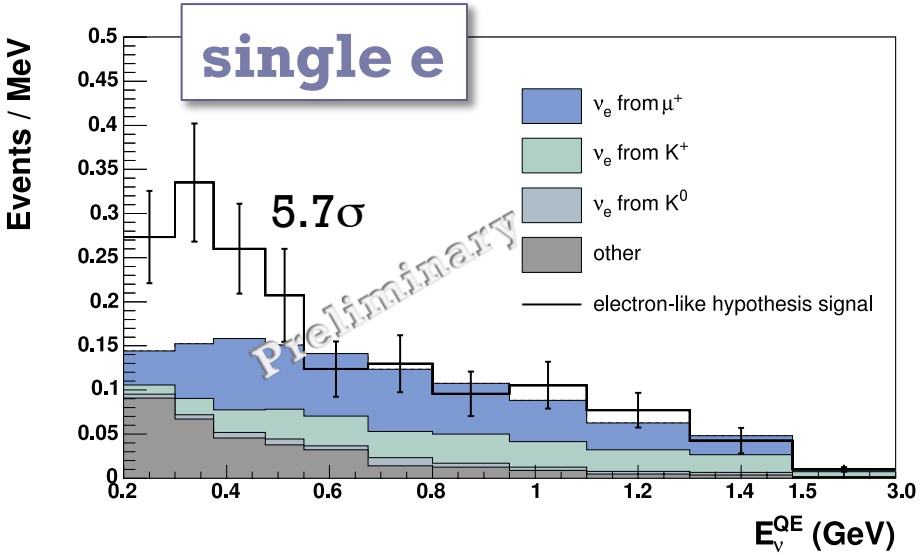
Primary physics goal I

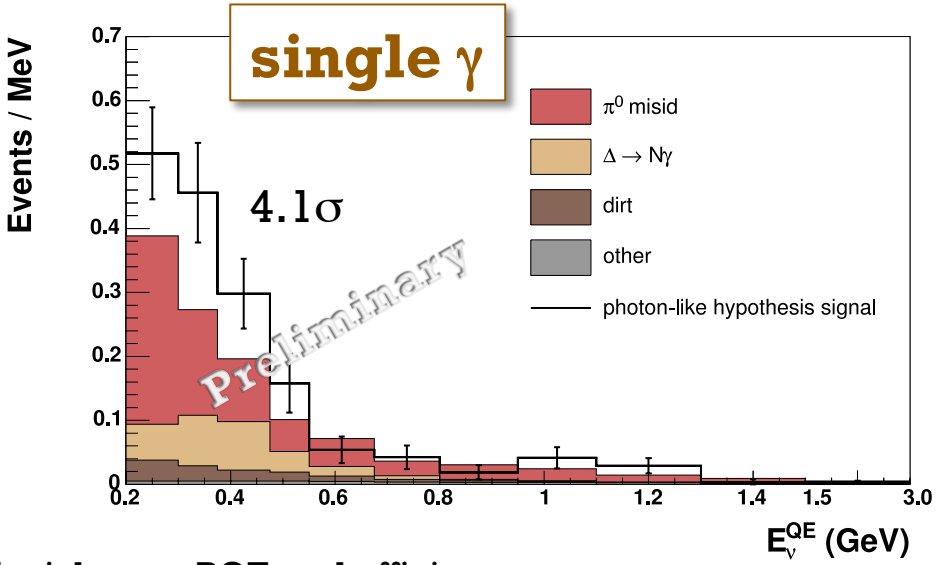
- Investigate the nature of the ν_e-like excess previously observed by MiniBooNE (cherenkov detector)

MiniBooNE unexplained "low energy excess"
[PRL 102, 101802 (2009)]



What MicroBooNE expects to see if excess is due to:

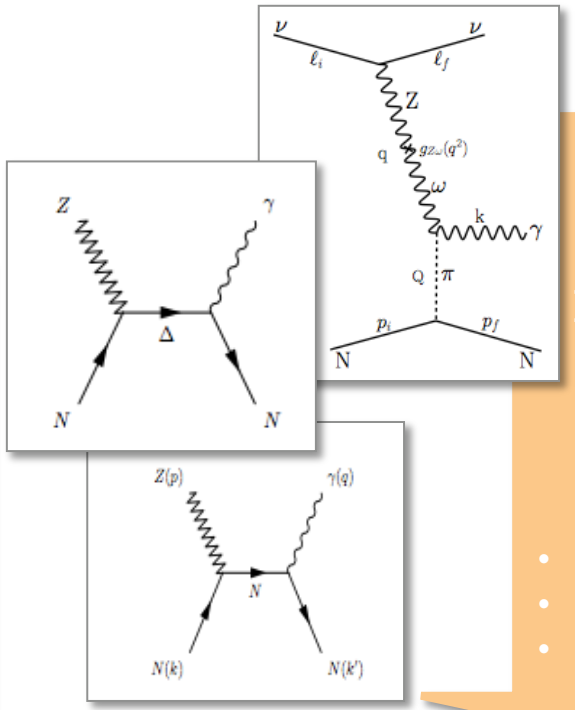




Estimated spectra: scaling from MiniBooNE (^{12}C !) for fiducial mass, POT, and efficiency

MicroBooNE

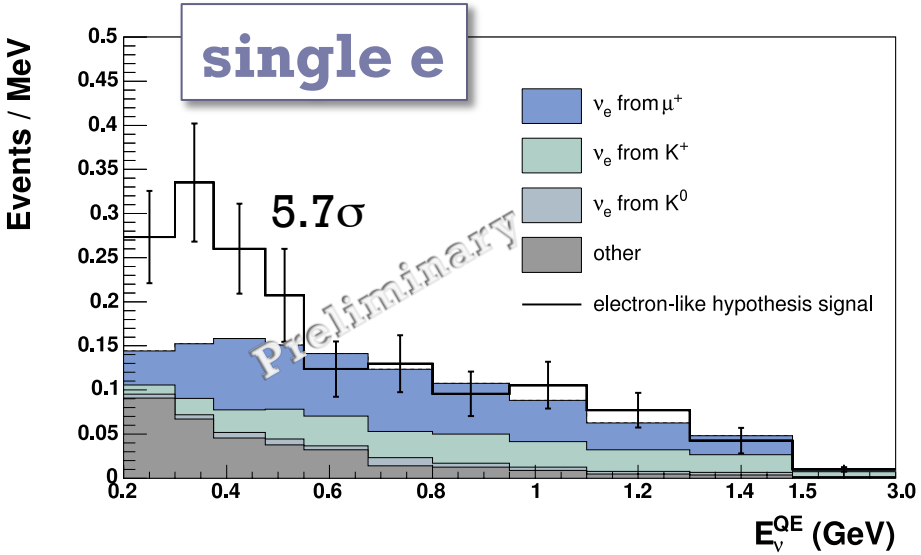
Possible explanation:
$\nu_\mu \rightarrow \nu_e$ nonstandard oscillations
(sterile neutrinos, extra dimensions, NSI,…)

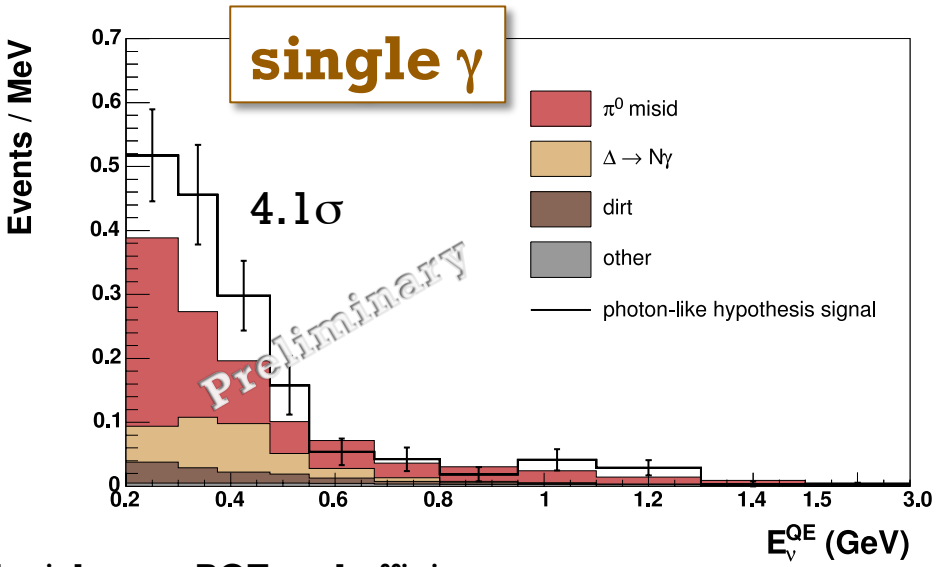


Possible explanation:
background γ or π^0 or "new" single photon production
e.g.

- R. Hill arXiv: 0905.0291
- Jenkins et al arXiv:0906.0984
- Serot et al arXiv: 1011.5913

What MicroBooNE expects to see if excess is due to:





Estimated spectra: scaling from MiniBooNE (^{12}C !) for fiducial mass, POT, and efficiency

MicroBooNE

Primary physics goal II

- First large-statistics neutrino exclusive final states in 1 GeV range and cross section measurements

Expected rates from upgraded NuMI beam (700kW, 6E20POT/yr) 1 yr, 60 ton fiducial volume

Higher energy beam
+ increased ν_e content

40k ν_μ CC
8k anti-ν_μ CC
2k ν_e CC
400 anti-ν_e CC

few 100's of Λ^0s

Preliminary

MicroBooNE Collaboration

Expected event rate for BNB 6.6 x 10^{20} POT 60 ton fiducial volume

production mode	# events
CC QE ($\nu_\mu n \to \mu^- p$)	60,161
NC elastic ($\nu_\mu N \to \nu_\mu N$)	19,409
CC resonant π^+ ($\nu_\mu N \to \mu^- N \pi^+$)	25,149
CC resonant π^0 ($\nu_\mu n \to \mu^- p \pi^0$)	6,994
NC resonant π^0 ($\nu_\mu N \to \nu_\mu N \pi^0$)	7,388
NC resonant $\pi^\pm$ ($\nu_\mu N \to \nu_\mu N' \pi^\pm$)	4,796
CC DIS ($\nu_\mu N \to \mu^- X$, $W > 2$ GeV)	1,229
NC DIS ($\nu_\mu N \to \nu_\mu X$, $W > 2$ GeV)	456
NC coherent π^0 ($\nu_\mu A \to \nu_\mu A \pi^0$)	1,694
CC coherent π^+ ($\nu_\mu A \to \mu^- A \pi^+$)	2,626
NC kaon ($\nu_\mu N \to \nu_\mu K X$)	39
CC kaon ($\nu_\mu N \to \mu^- K X$)	117
other ν_μ	3,678
total ν_μ CC	98,849
total ν_μ NC+CC	133,580
ν_e QE	326
ν_e CC	657

Preliminary

Nuance-generated events on LAr, MicroBooNE Collaboration

MicroBooNE

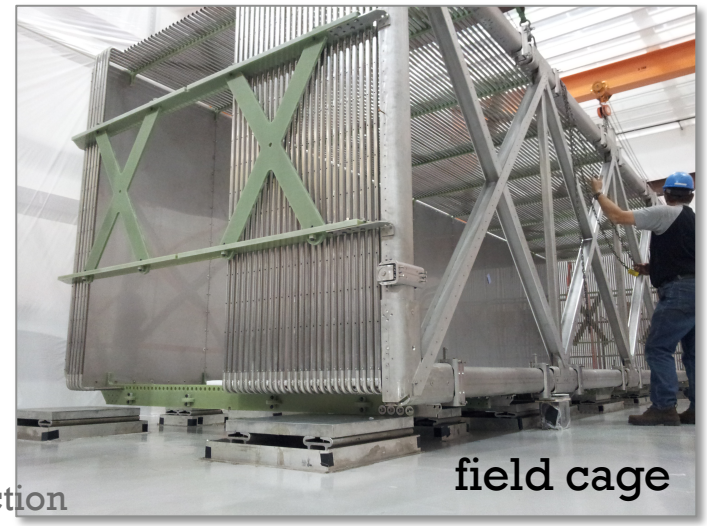
Secondary goals

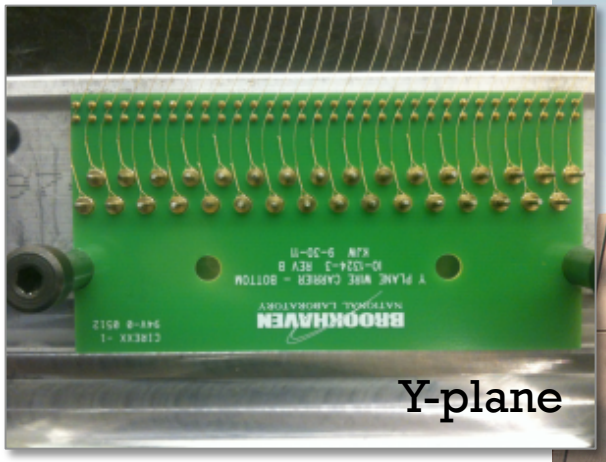
- Physics goals:
  - Backgrounds to p decay for larger (underground) detectors
  - Supernova neutrinos
- R&D goals:
  - Purity without evacuation
  - Foam insulation
  - Cold (in liquid) electronics
  - LArTPC operation on surface
  - Continuous readout for supernova searches
  - Event reconstruction software

MicroBooNE

Current status

- Experiment is well under construction
  - TPC field cage constructed
  - Wire planes constructed
  - Electronics (front end and readout) in production
  - Cryostat to be delivered to Fermilab by March 2013
  - LArTF building nearing completion

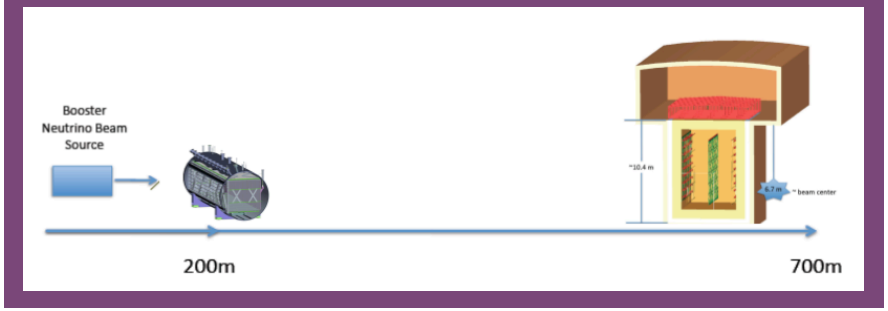

field cage

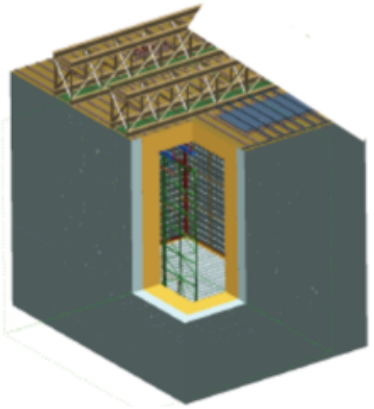


Y-plane


LArTF (Oct. 2012)

- Expected start of data taking:
  early(?) 2014
- Current MicroBooNE run plan:
  neutrino mode running, 6.6e20 POT (2-3 years to complete)





3. Future experiments: LAr1

[proposal]

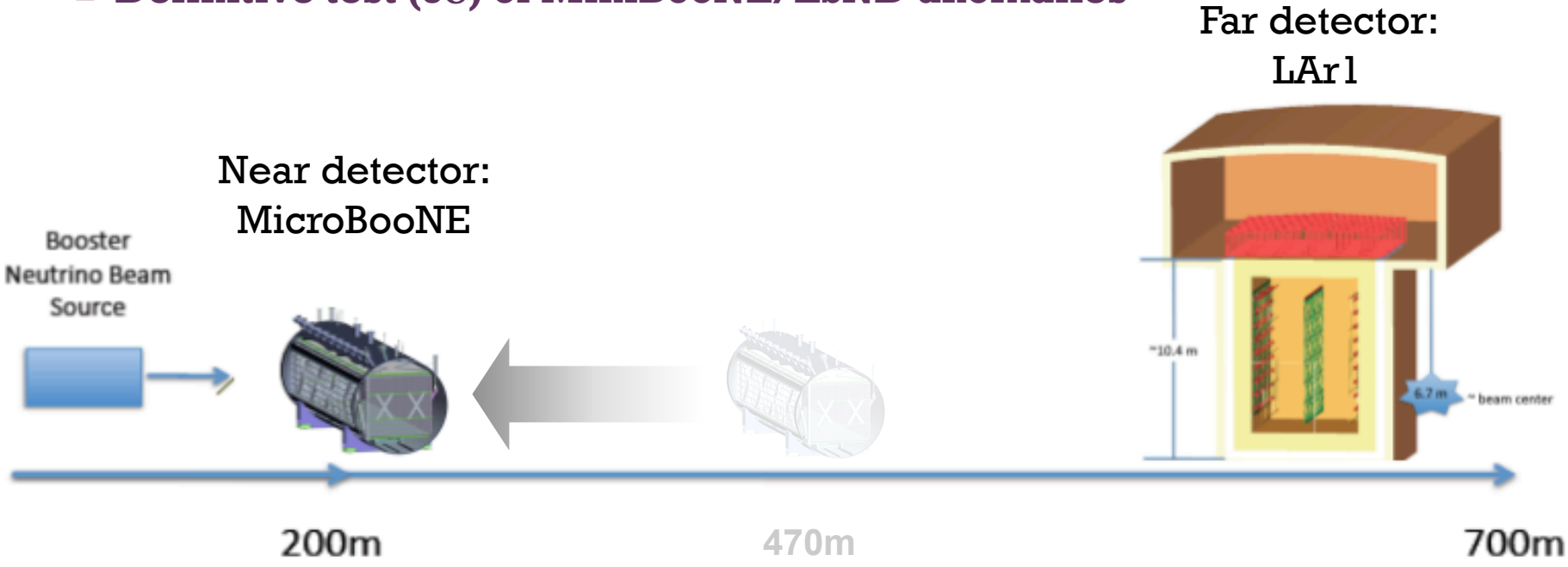
US collaboration:

13 institutions

~50 physicists & engineers

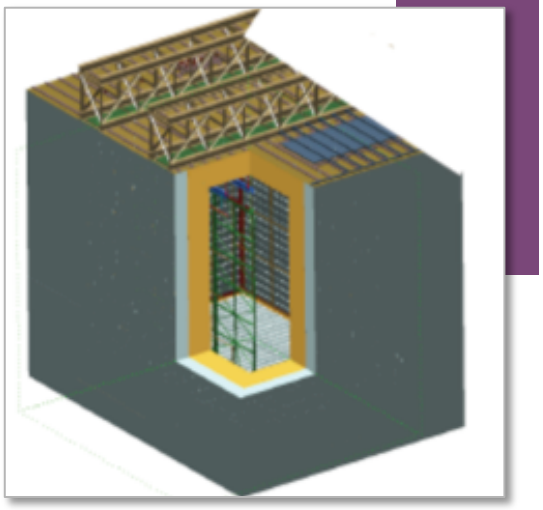
LAr1

- LAr1 concept: developed from 1kton-scale LAr engineering prototype for LBNE
- A second LArTPC placed in the Booster Neutrino Beam at Fermilab, in line with MicroBooNE
- Near/far comparison for short-baseline oscillation search
- **Definitive test (5σ) of MiniBooNE/LSND anomalies**

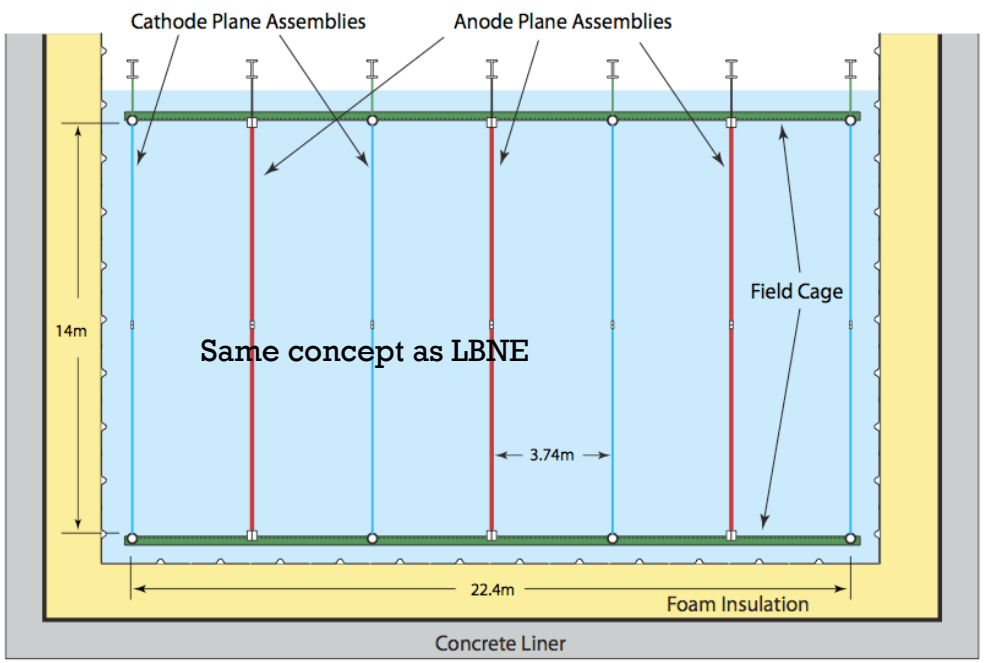


LAr1

Far detector parameters



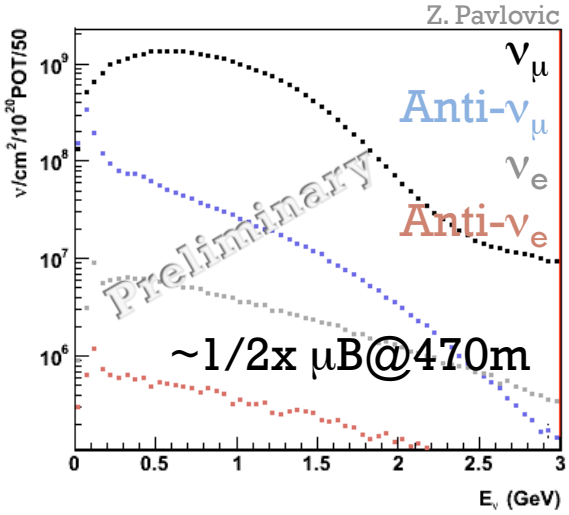
- Conceptual design: same as engineering prototype for LBNE: Membrane cryostat
- Larger mass (1kton fiducial volume) and fully instrumented
- TPC constructed as an array of modular units
  - Anode plane assemblies (2.7m x 7m x 0.10m)
  - Cathode plane assemblies (2.5m x 7m)



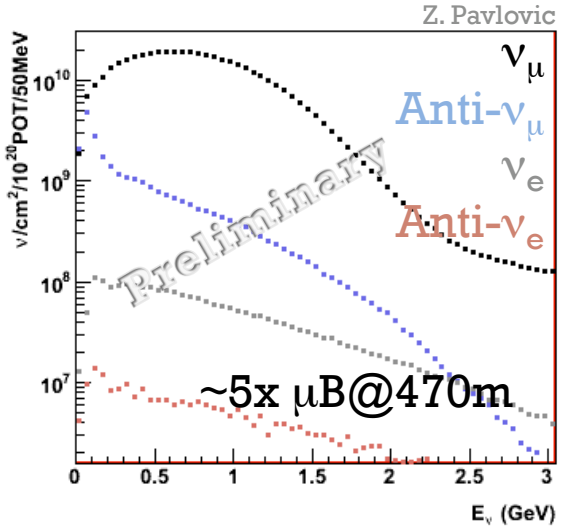
LAr1

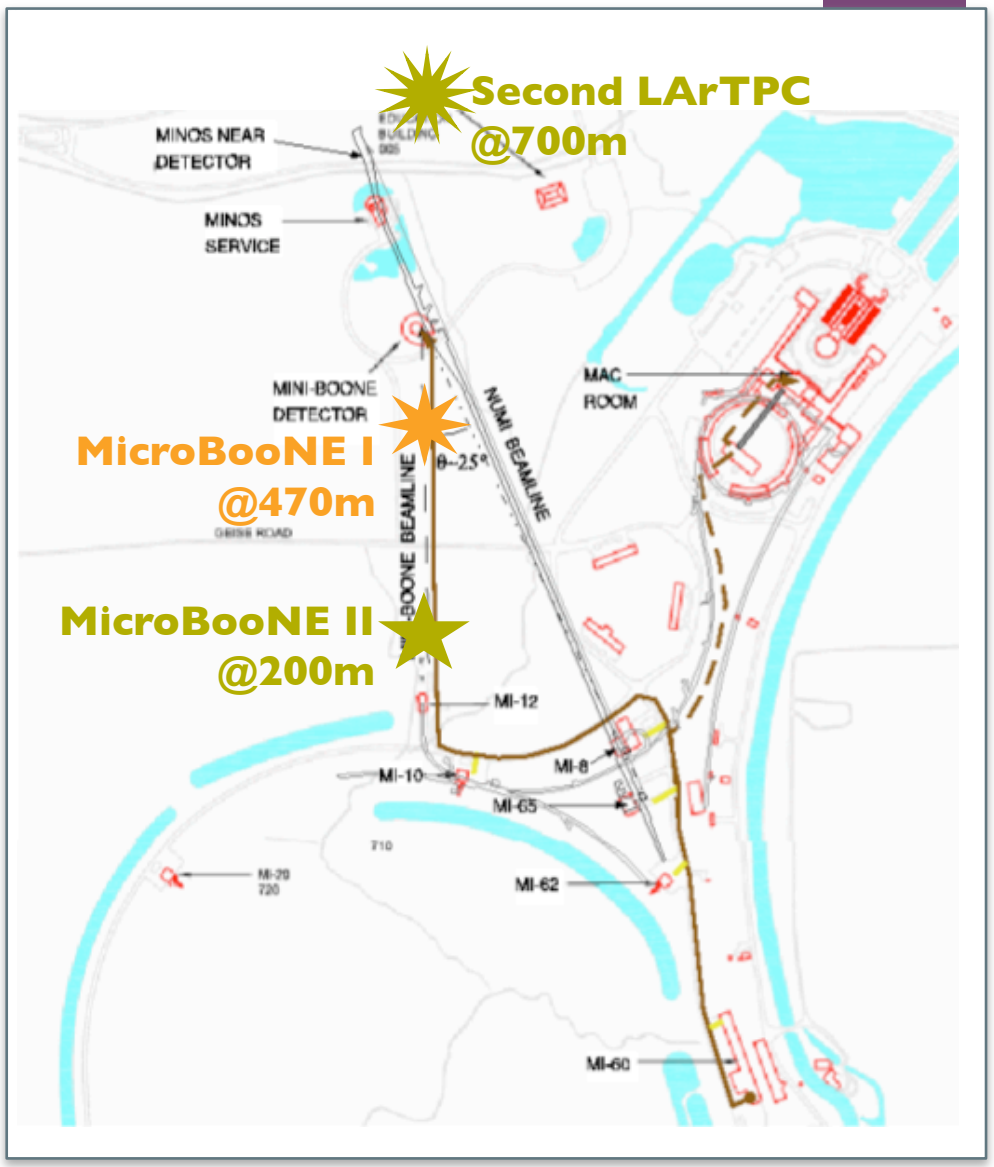
Neutrino flux predictions

LAr1 @ 700m



MicroBooNE @ 200m

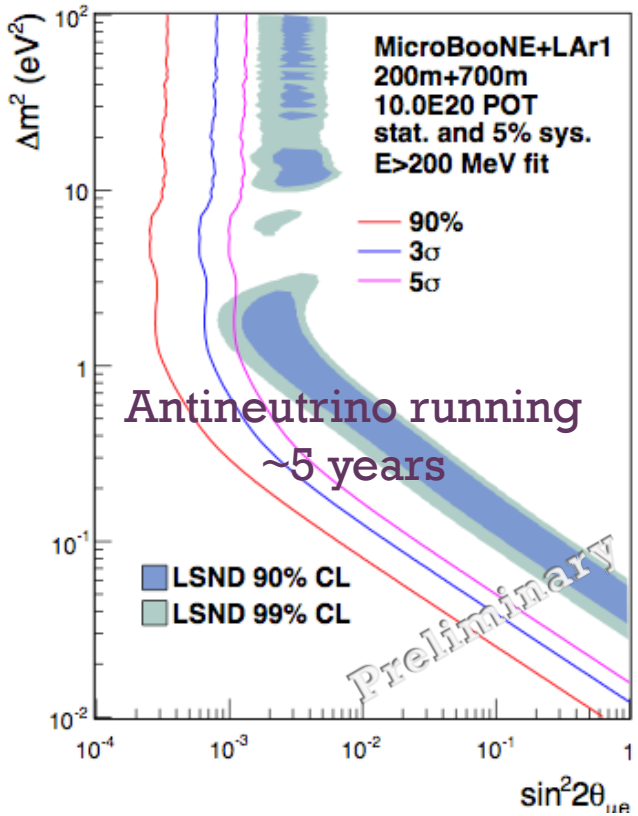


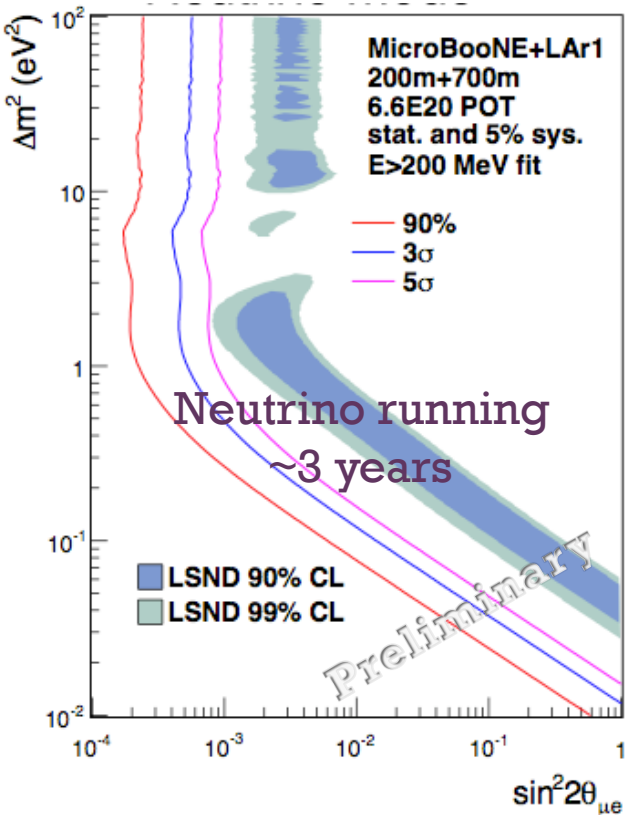


LAr1

Physics reach: Definitive test of LSND and MiniBooNE in both neutrino and antineutrino modes

Assumptions:
- Neutrino events were generated with GENIE from BNB fluxes at 200m, 700m
- Two-neutrino oscillations
- 80% reconstruction efficiency flat in E
- Fiducial volume: 61.4t for MicroBooNE and 1kt for LAr1





- Also $\bar{\nu}_e$ and $\bar{\nu}_\mu$ disappearance!

LAr1

Status

- Letter of Intent submitted to Fermilab Directorate
  - http://www.fnal.gov/directorate/program_planning/June2012Public/Bonnie_LAr1_PAC_2012_Fleming.pdf
- Strong ongoing effort to develop this into a proposal by summer 2013
- Projected start of construction: 2016(?)

A Letter of Intent for a Neutrino Oscillation Experiment on the Booster Neutrino Beamline: LAr1

June 13, 2012

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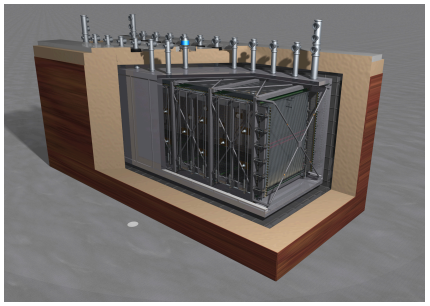
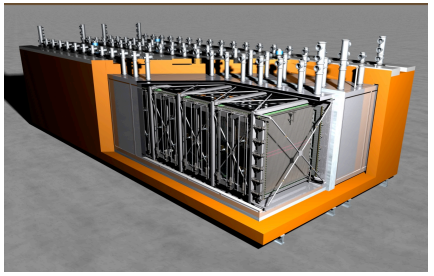




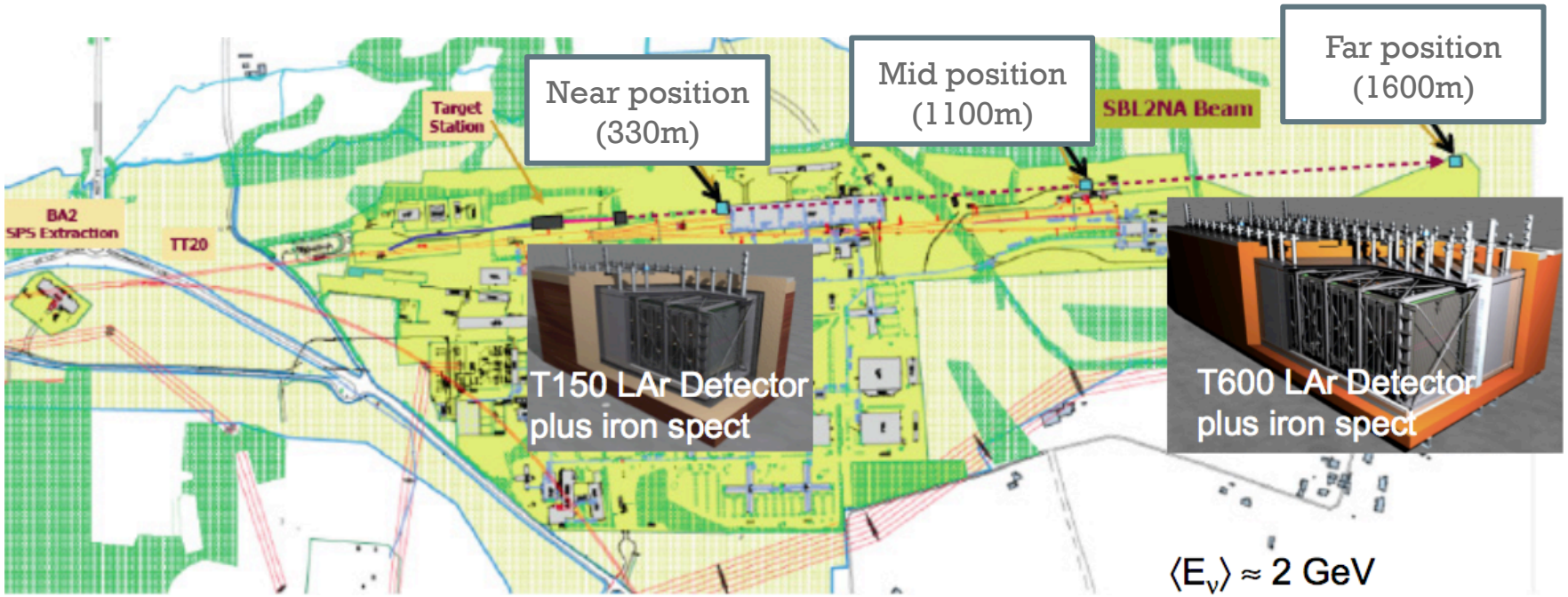
3. Future experiments: 2-LAr @ CERN-SPS

[proposal]

ICARUS+NESSiE collaborations

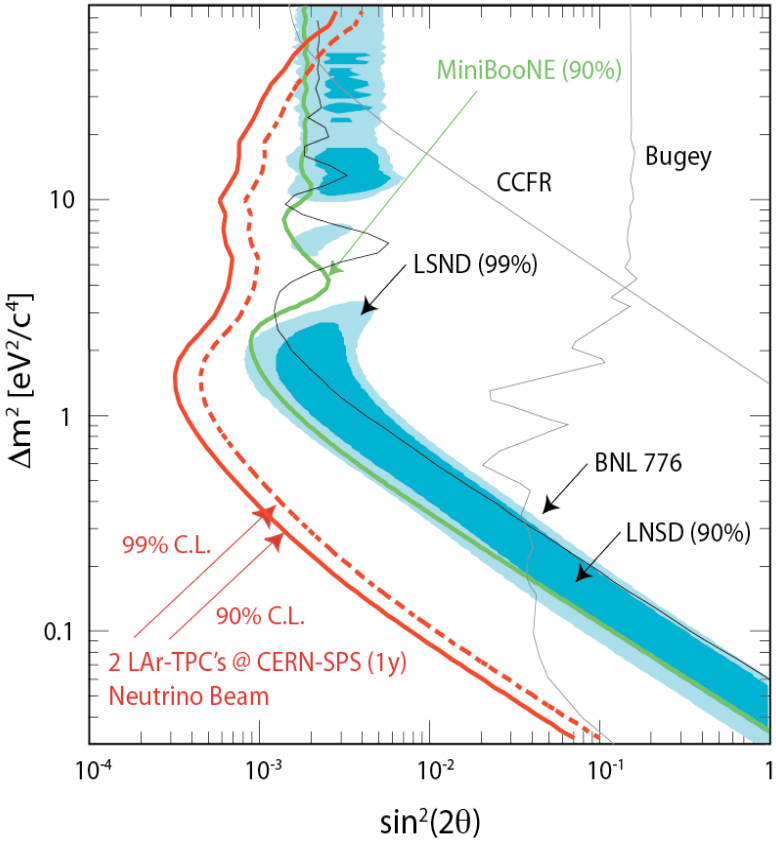
2-LAr @ CERN-SPS

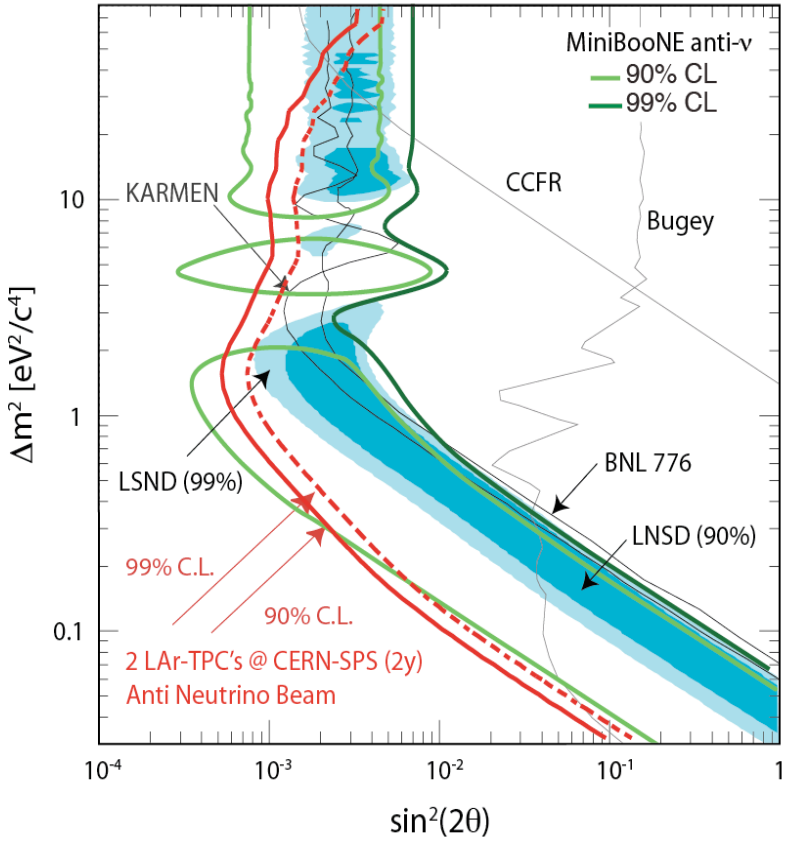
- **New neutrino facility in the CERN North Area**
- New short-baseline neutrino beam: $E_\nu \sim 2$ GeV
- Two (or three) LArTPC's & Iron Spectrometers
  - ICARUS-T600 transported to CERN and exposed to new neutrino beam from SPS at 1600 m from neutrino production
  - Second 150ton LArTPC to serve as a near detector at 330 m



2-LAr @ CERN-SPS

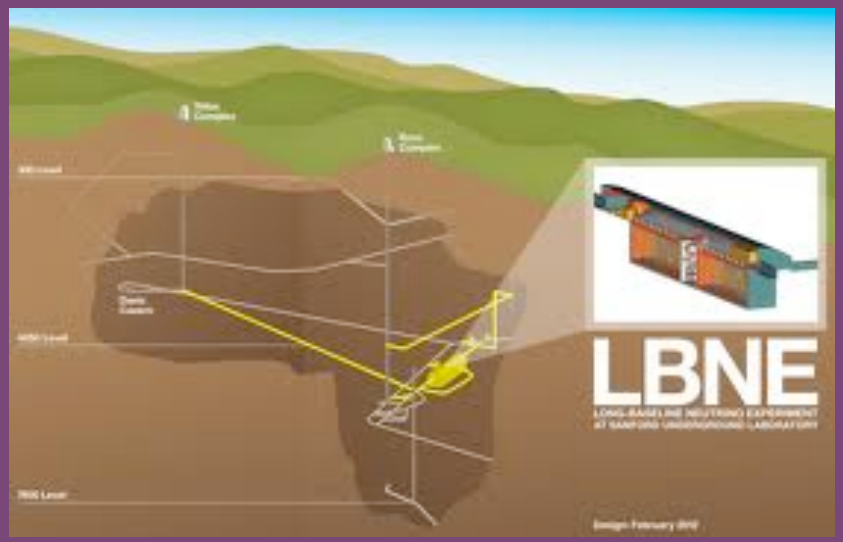
- Expected sensitivity for the proposed experiment: ν_μ beam (left) and anti-ν_μ (right) for 4.5×10^{19} pot (1 year) and 9.0×10^{19} pot (2 years) respectively. LSND allowed region is fully explored in both cases.

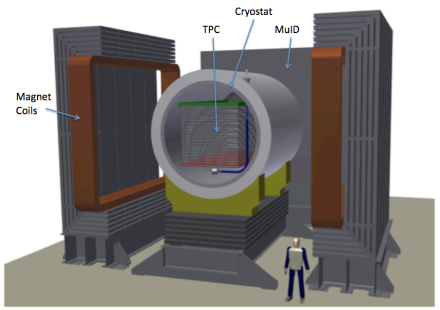


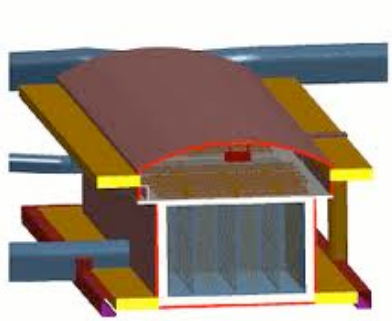


ICARUS/NESSiE collaborations

- Also $\bar{\nu}_e$ and $\bar{\nu}_\mu$ disappearance!







3. Future experiments: LBNE

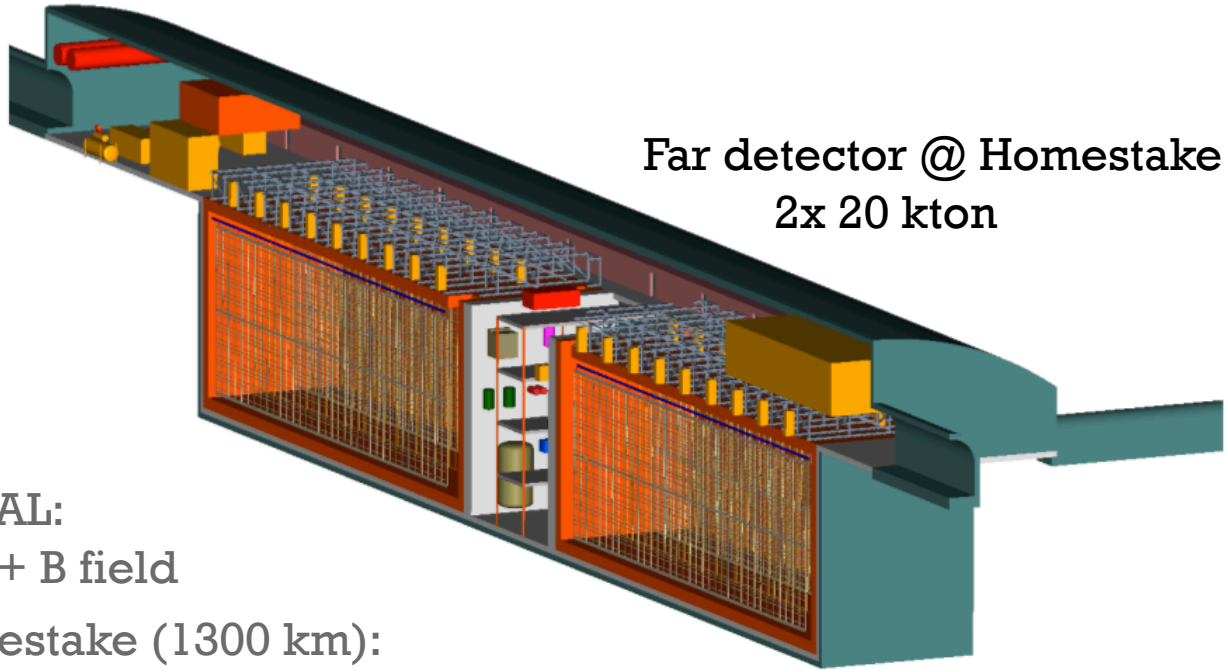
[planned]

US collaboration

500+ physicists and engineers

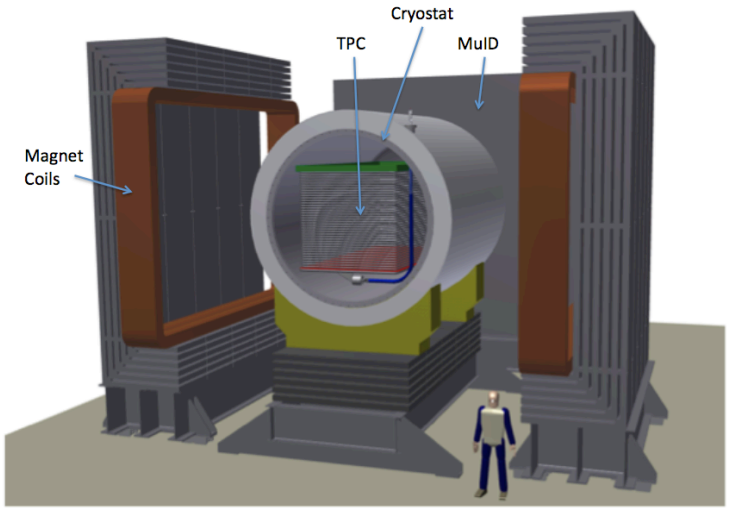
LBNE

Now a LArTPC experiment!



Far detector @ Homestake
2x 20 kton

- Proposed plan:
  - Near detector at FNAL:
    18 tons active mass + B field
  - Far detector at Homestake (1300 km):
    40 ktons active mass, 1.5km underground
  - New high-intensity neutrino beam: 6.5E20POT/yr, E_ν = 0.5-5 GeV



Near detector @ FNAL

Physics goals

- Long baseline oscillation physics through $\nu_\mu \rightarrow \nu_e$ and anti-$\nu_\mu \rightarrow$ anti-ν_e
- Non-accelerator neutrino measurements (atmospheric, SN) and proton decay

LBNE

- LBNE technology decision: January 2012
  (LArTPC over water Cherenkov)
- March 2012: **staged approach** to LBNE in order to maximize scientific output given projected US funding situation
  - **"Reconfiguration"** study
  - Stage I: on-surface operation of 10 kton far detector + new low energy beam from Fermilab
  - http://www.fnal.gov/directorate/lbne_reconfiguration/index.shtml
  - Workshop to establish viability of on-surface operation
- Current stage: CD1 review
- Construction expected to begin in 2020(?)

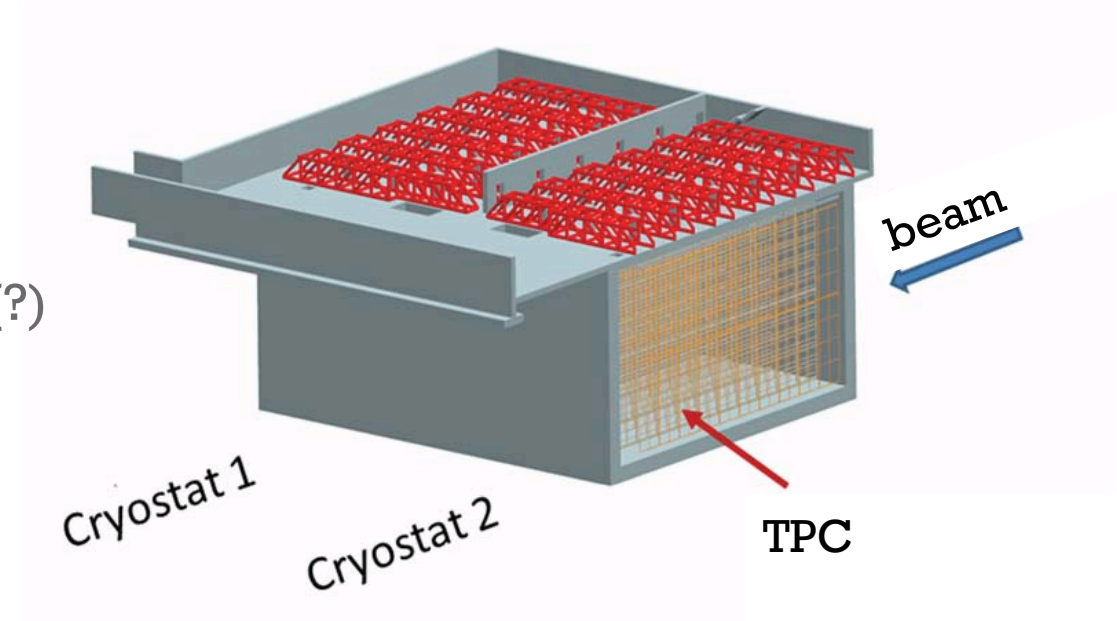
LBNE

LBNE Stage I

- Far Detector Stage I conceptual design (as of Sep. 2012)
  - 10 kton LArTPC in an excavated pit near surface at Sanford Underground Research Facility (SURF)
  - 3m overburden for cosmic ray shielding

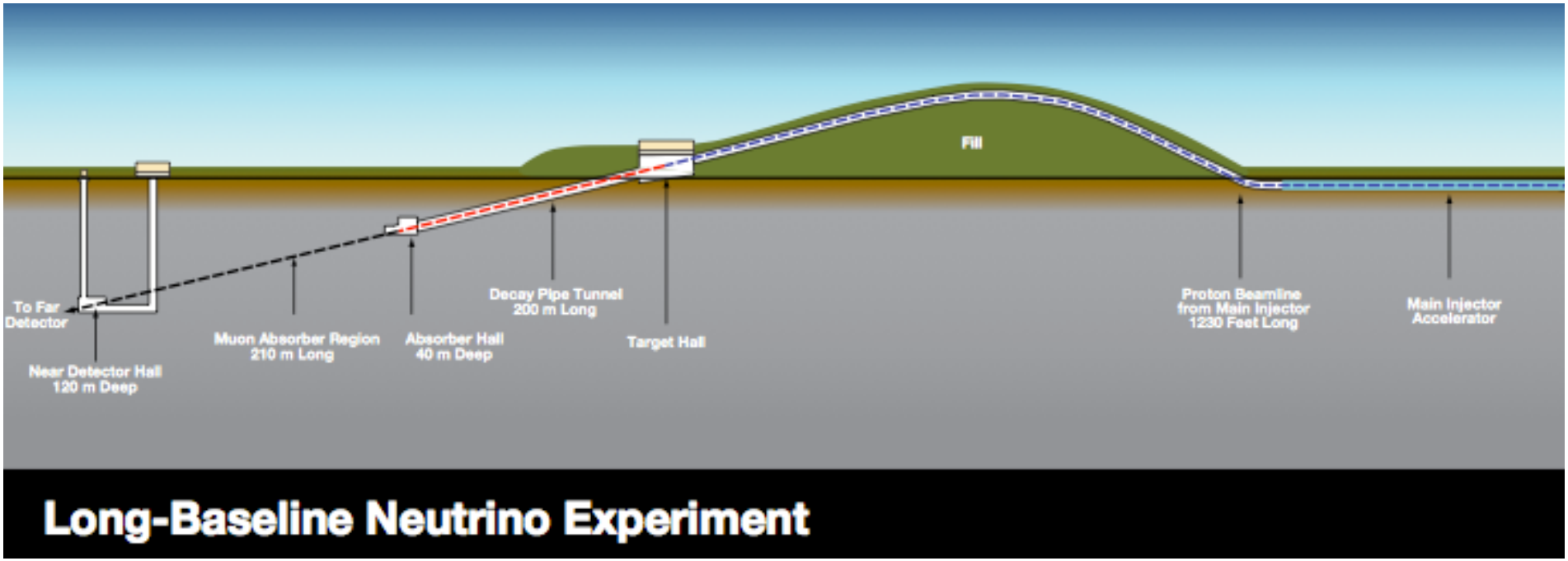
+

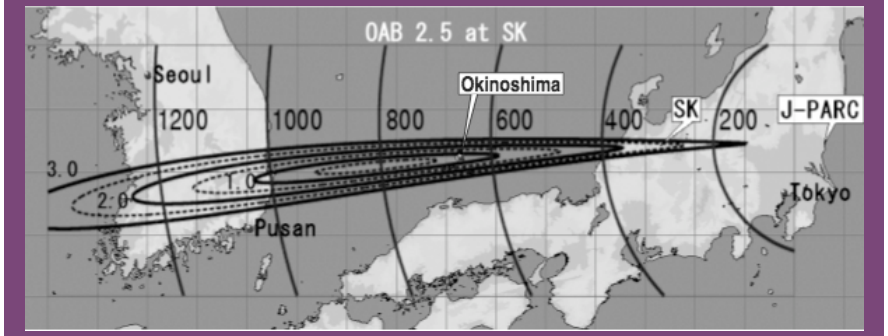
- Low intensity beam
- Realizable in 2015-2020(?)

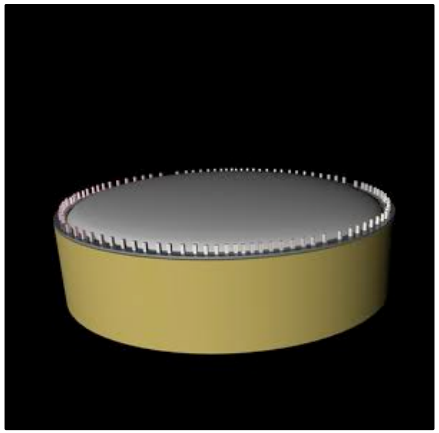


LBNE

- Beam plan:
  - Begin operations with new, low-energy, lower-intensity-than-final beam (LBNE Stage 1); 700kW, 6e20 POT/yr
  - Upgradable in the future to 2 MW (Project X)







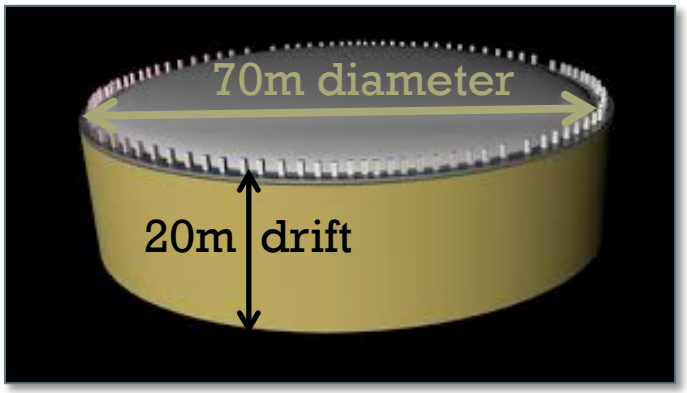
3. Future experiments: 100kton @ Okinoshima

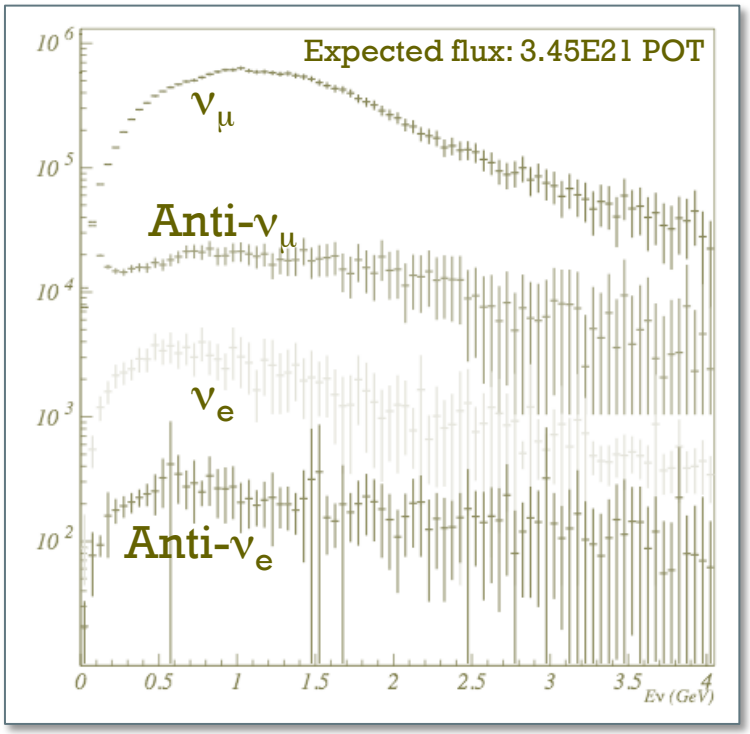
[proposal]

International collaboration:
ETH & KEK
20+ collaborators

100kton @ Okinoshima

- 100kton detector + new (higher intensity) neutrino beam from JPARC (E ~ 1GeV)



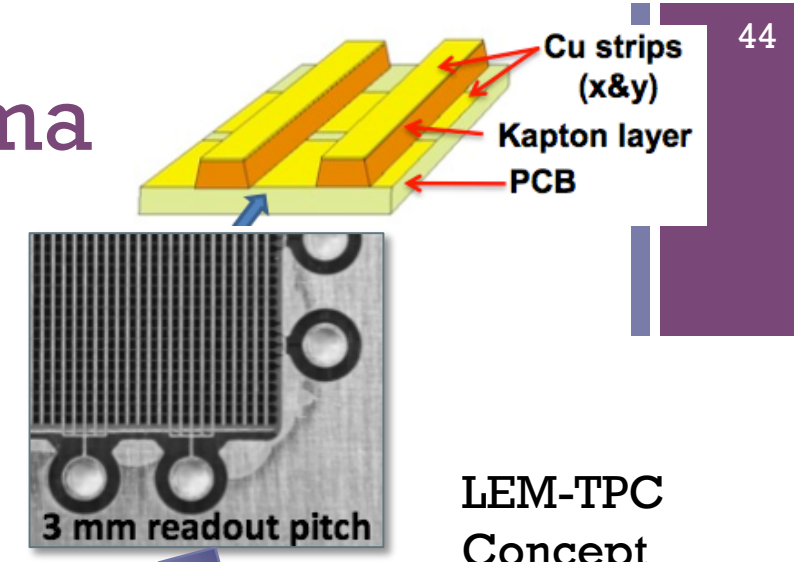


arXiv:0804.2111

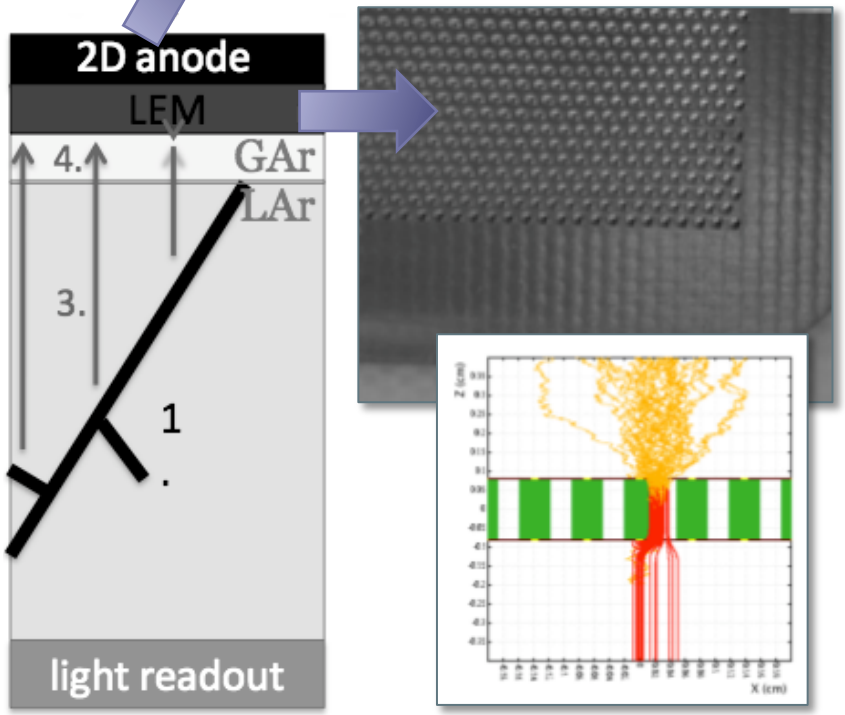
- L=660km, 0.76 deg off-axis
- Upgrade of the J-PARC 30 GeV Main Ring operation from 750 kW to 1.66 MW
- 5 year neutrino running, possibly extended with additional 5 year antineutrino running
- Physics goals:
  - Long-baseline oscillation parameters through (anti-)ν_e appearance and (anti-)ν_μ disappearance
  - Non-accelerator neutrino measurements (supernova, atmospheric) & proton decay

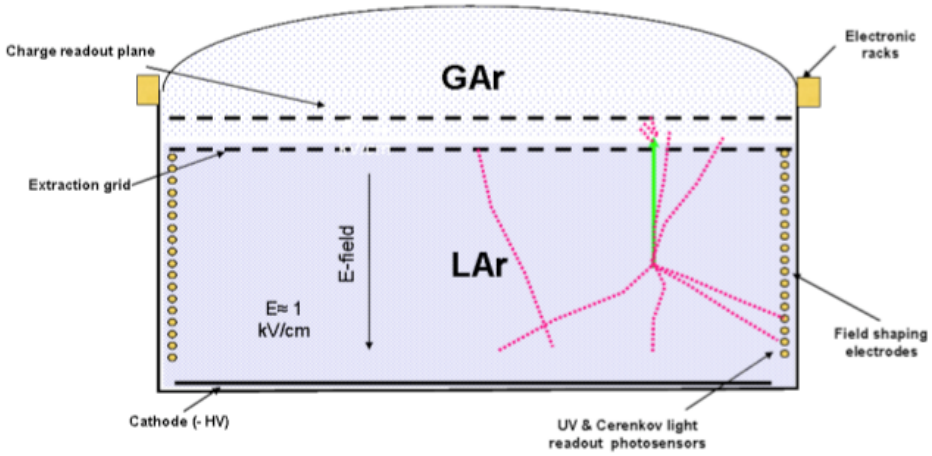
100kton @ Okinoshima

- GLACIER design concept (1x100k, 3x40k, or 4x30k)
  - Much improved S/N (>100) compared to single-phase LArTPC operation (S/N~15-30)
- LEM-TPC
  Double phase: liquid to gas for charge amplification and extraction in gas phase



LEM-TPC Concept





100kton @ Okinoshima

Status

- R&D proposal at J-PARC: EK_J-PARC-PAC2009-1
- ETHZ/KEK MoU for collaboration on LAr R&D

SUBMITTED TO J-PARC PAC

Towards a Long Baseline Neutrino and Nucleon Decay Experiment with a next-generation 100 kton Liquid Argon TPC detector at Okinoshima and an intensity upgraded J-PARC Neutrino beam

A.Badertscher[1], *A.Curioni*[1], *S.DiLuise*[1], *U.Degunda*[1], *L.Epprecht*[1], *L.Esposito*[1], *A.Gendotti*[1], *T.Hasegawa*[2], *S.Horikawa*[1], *L.Knecht*[1], *T.Kobayashi*[2], *C.Lazzaro*[1], *D.Lussi*[1], *A.Marchionni*[1], *A.Meregaglia*[1]*, *T.Maruyama*[2], *G.Natterer*[1], *K.Nishikawa*[2], *F.Resnati*[1], *A.Rubbia*[1]†, *C.Strabel*[1], *M.Tanaka*[2], *and T.Viant*[1]
(1) ETH Zurich, (2) KEK IPNS

December 18, 2009

Conclusions

- **LAr technology is maturing and it is becoming a credible alternative to water cherenkov detectors**
  - The LArTPC can offer **truly unique and superior imaging performance**, in physics measurements where excellent energy resolution and good background rejection power are required
  - Ideal instrument for studying and constraining FSI and nuclear effects in neutrino-nucleus interactions
  - Low-energy neutrino measurements: opportunity for high-statistics SN neutrino data set

- Prepare for a "fun ride":
  - ArgoNeuT and ICARUS results should continue over next 2-3 years
  - MicroBooNE begins data taking in ~1.5 yrs
  - Experiments which may begin construction over the next 5-10 years (if approved): LAr1, 2-LAr@CERN-SPS, GLADE, MODULAr
  - Experiments on a 10+ year timescale: LBNE, LAGUNA/LBNO, 100kton@Okinoshima

Thank you!

Experiment	LAr mass (tons)	Physics goal	Baseline (km)	E_ν (GeV)	Where	Status	Online
ICARUS	600	R&D, Long baseline (single detector)	732	~5-25	Gran Sasso (CNGS beam)	Running	Fully operational in 2010
ArgoNeuT	175L	R&D, Cross sections	1	~0.1-10	NuMI near	Completed	N/A
MicroBooNE	170 (60 fiducial)	R&D, Short baseline (single detector)	0.47	~0.1-3	FNAL (BNB)	Under construction	2014
LAr1	60 + 1000 (fiducial)	Short baseline (2 detectors)	0.2 + 0.7	~0.1-3	FNAL (BNB)	LOI	~5 yrs
2-LAr @ CERN-SPS	150 + 478 (fiducial)	Short baseline (2 detectors)	0.3 + 1.6	~2	CERN (new beam from SPS)	Proposal	~5 yrs
MODULAr	5,000	Long baseline (shallow depth)	730	~5-25	Gran Sasso	Planned	~5-10 yrs
GLADE	5,000	Long baseline (surface)	810	~0.5-2	NuMI off-axis	LOI	~5-10 yrs
LBNE	Start with 10,000	Long baseline (surface FD initially)	1300	~0.5-5	Homestake (new FNAL beam)	Planned (CD-1)	10+ yrs
LAGUNA/ LBNO	Start with 20,000	Long baseline (underground FD)	2300	~few	Finland (new CERN beam)	EOI in preparation	10+ yrs
100kton @ Okinoshima	Up to 100,000	Long baseline (underground FD)	665	~0.5-2	Okinoshima island (new J-PARC beam)	R&D Proposal at J-PARC	10+ yrs

+ various R&D and test experiments:

US: Materials Test Stand, LAPD, LARiAT, Los Alamos LDRD LArTPC
Europe: 50-liter @ CERN, 10m^3, LArTPC in B-field, ArgonTube, UV Laser
Japan: Test-beam T32 @ J-PARC

Future experiments: GLADE

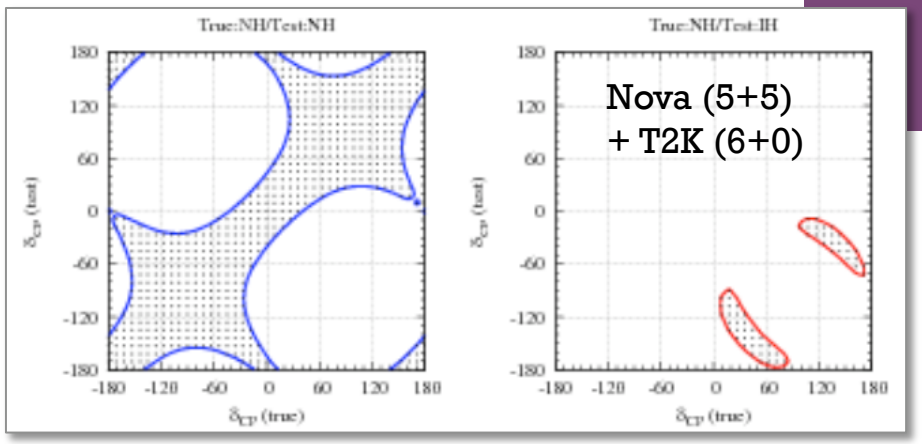
Global Liquid Argon Detector Experiment [US & European Collaboration]

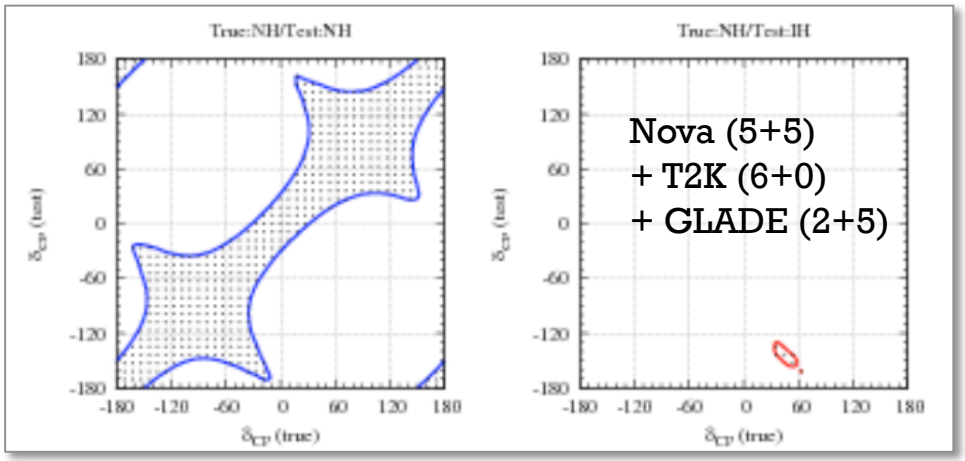
- 5kton LArTPC
- GEM (Gas Electron Multipliers) rather than wire planes, developed at ETH
- Existing (soon-to-be-updated) NuMI beam at Fermilab
- Off-axis, on-surface, at Ash River (Nova far detector site): 810km from neutrino source
- 5-7 years of data taking

Future experiments: GLADE

Primary physics goals:

- CP violation and mass hierarchy
  (in combination with Nova and T2K near-future results)





The incorrect mass hierarchy hypothesis can be ruled out ~90%

Future experiments: GLADE

Current status:

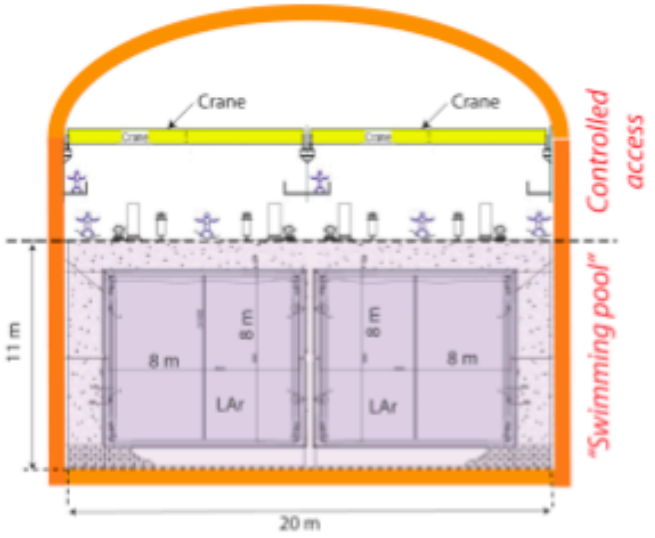
- Support for further studies is being considered by CERN management (rolling CERN R&D program)
- LOI has been submitted to the Fermilab Directorate (May 2012):
  - www.fnal.gov/directorate/program_planning/June2012Public/P-1029_GLADE_LOI.pdf

Future experiments: MODULAr

MODULAr 5kton near LNGS

- Single phase LAr TPC about 10 kt fiducial mass, realised with a modular set of two identical, but independent units, each of about 5 kt, "cloning" the basic design of T600
- Parameters of unit
  - 5370 ton active LAr mass
  - 4 meter drift length
  - 6 mm wire pitch, three wire planes, ≈50kchannels
  - Warm electronics
- Physics goals:
  - off-axis of existing CNGS
  - long baseline neutrino oscillations, cf. Preliminary physics studies by A. Longhin, NUTURN12 workshop, LNGS May 2012
  - proton decay and neutrino astrophysics if underground
- Technology challenges:
  - Linear extrapolation of ICARUS T600 design by factor x2.66 in each dimension for a total unit volume of 8x8m² and 60m long
  - New passive thermal insulation (perlite)
  - Ultra-pure liquid argon without evacuation (R&D needed and proposed with SLICE 8x8x4m³)
  - Cavern stability

Astroparticle Physics 29 (2008) 174–187



◉ LNGS B

- New site (shallow depth 1.2km m.w.e)
- 10 km off-axis present LNGS

A. Rubbia — Future liquid Argon detectors (Neutrino 2012) — 21

Courtesy: A. Rubbia

Future test experiments: LARiAT

LArTPC + controlled testbeam for calibration studies

- Primary goal: study particle interactions in LAr
  - Energy reconstruction, particle identification, detector response, hadronic cross section studies
- (Decommissioned) ArgoNeuT detector placed in a controlled testbeam @ Fermilab: p, π, e, μ Upgrade to larger LArTPC in the future (hadronic shower containment).
- Planned start of data taking: 2013