Neutrino Working Group Summary (Experiment)

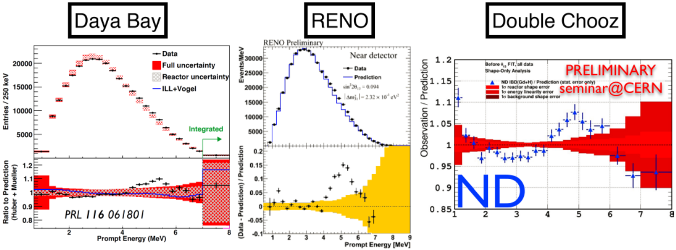
WIN2017, UC Irvine, CA, June 19-24

Mary Bishai, Brookhaven National Laboratory

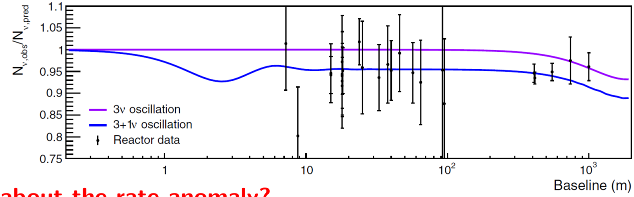
June 23, 2017

Reactor Anomalies: Dead? and New?

Reactor Anomalies



Shape anomaly most likely due to ^{238}U fission yield underestimated in previous estimates.

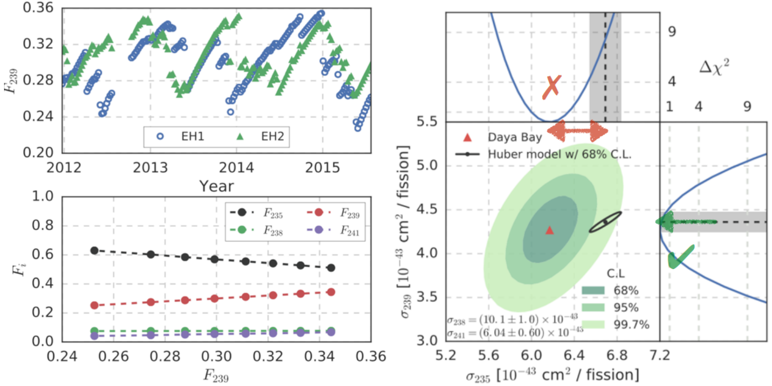


What about the rate anomaly?

Reactor Anomalies: Dead? and New?

Daya Bay: $\bar{\nu}_e$ rate with different fuel - D. Martinez

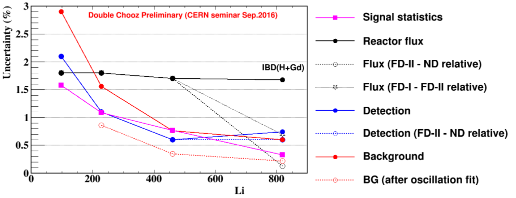
Look at time dependent flux, using known % ^{235}U, ^{239}Pu, ^{238}U, ^{241}Pu from power station to separate flux from different isotopes.

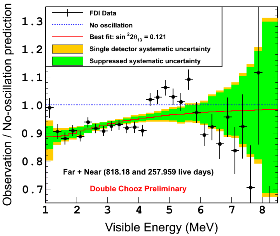


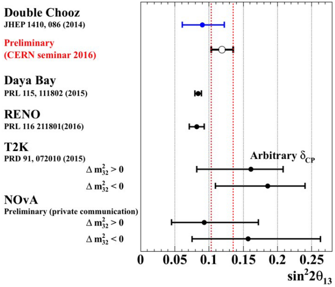
Rate anomaly ALSO due to mismodeling of U fission chain?

Reactor Anomalies: Dead? and New?

Double Chooz : New θ_{13} Measurement - T. Sogo Bezerra







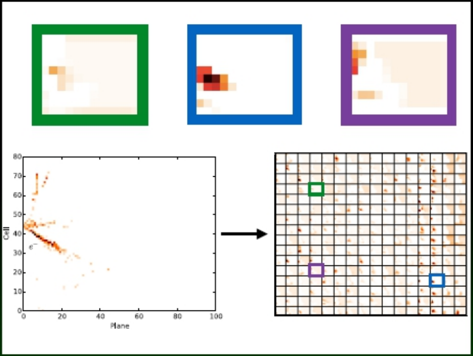
Why is D. Chooz θ_{13} 2.2 σ higher?

Latest from Long Baseline: NoVA

Improved Event Selection

This analysis features a new event selection technique based on ideas from computer vision and deep learning

- Calibrated hit maps are inputs to Convolutional Visual Network (CVN)
- Series of image processing transformations applied to extract abstract features
- Extracted features used as inputs to a conventional neural network to classify the event



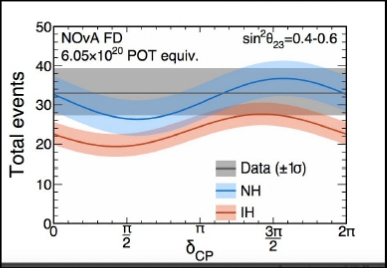
Latest from Long Baseline: NoVA

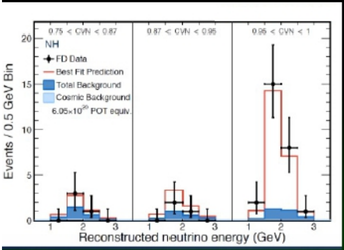
Appearance Results

Prediction (signal + bkgd)

NH, $3\pi/2$	IH, $\pi/2$
36.4	19.4

Observed in far detector: 33





- 10% excess in selected ν_e events (in ND) over simulation
- Data-driven methods used to estimate fractions of NC, beam ν_e, and CC ν_μ backgrounds

Hmm.. what if θ_{13} higher than world average?

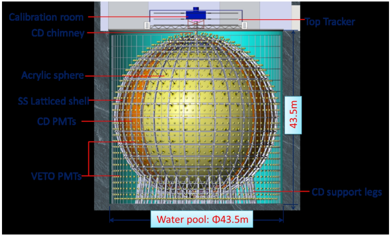
Future Long Baseline

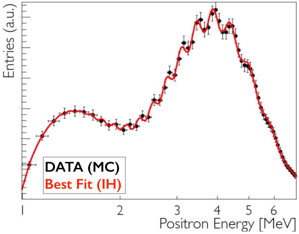
JUNO - N. Cabrera

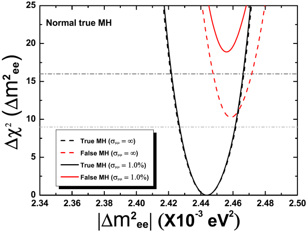
Baseline: $\sim$ 60km, Beam: 1-6 MeV $\bar{\nu}_e$ Taishan (18.4 GW) and Yangjiang (17.4 GW) reactors

Detector: 20 kton LS with 20" PMTs (80% photocoverage) AND 3"PMTs for double calorimetery. Highest light yield 1.2 kPE/MeV

Status: LS attenuation length achieved 25m. 26,000 PMT's ordered from HZC-Photonics. Civil construction delay under control

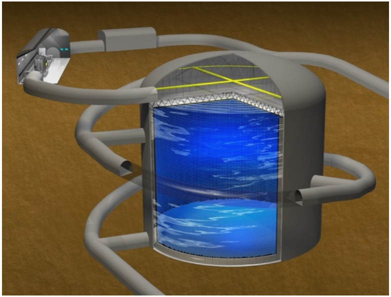






Future Long Baseline

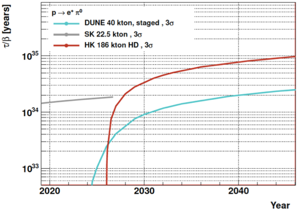
HyperKamiokande - S. Nakayama

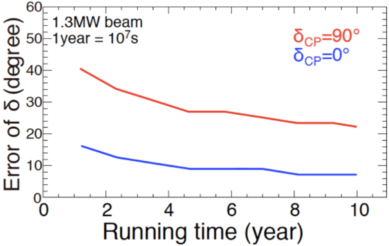


Baseline: 295km, Beam: JPARC 0.6 GeV $\nu_\mu/\bar{\nu}_\mu$ 1.3MW by 2026

Detector: 260 kton (186 fiducial) Water Cerenkov with **new 50 cm photosensors with 2x photon detection eff.**

Status: **Budget request submitted to start construction in FY18.** MEXT (funding agency) to release "Roadmap 2017"

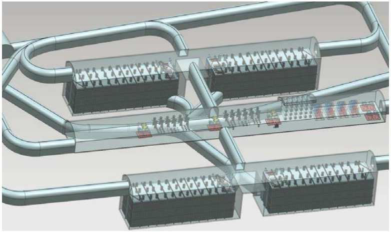


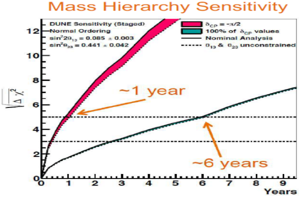


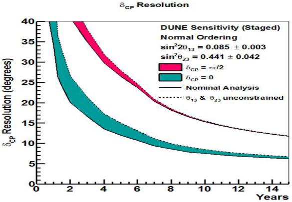
Future Long Baseline

DUNE CP and Mass Hierarchy- J. Bian

Baseline: 1300km, Beam: Fermilab PIP II 0.5-8 GeV $\nu_\mu/\bar{\nu}_\mu$ 1.2MW by 2026, PIP III 2.4 MW by 2032 (?)
Detector: 70 kton (40 fiducial) LArTPC with cold electronics readout (single phase) and gas-multiplication (dual phase)
Status: Groundbreaking for far site civil in July 2017. Two full scale prototypes under contstruction at CERN with test beam in 2018.







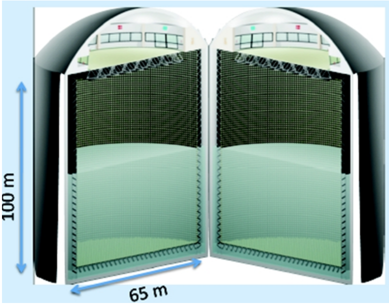
Future Long Baseline

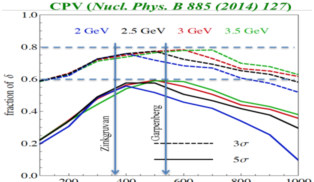
ESSνSB - M. Dracos

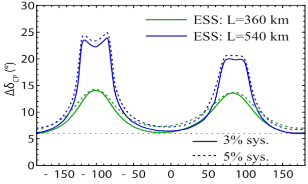
Baseline: 360 or 540km, **Beam:** ESS Proton Linac with $E_p = 2.5 - 3.5$ 5MW by 2023. 0.2-0.6 GeV $\nu_\mu/\bar{\nu}_\mu$

Detector: 500 kton fiducial Water Cerenkov with 240k 8" PMTS and 30% optical coverage.

Status: A H2020 EU Design Study has been submitted end of March 2017. COST application for networking support has succeeded. Construction 2023-2030 if approved.



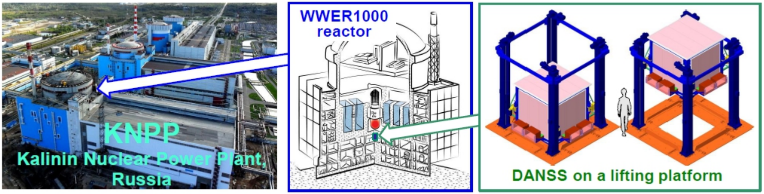


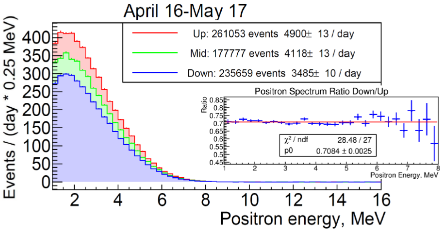


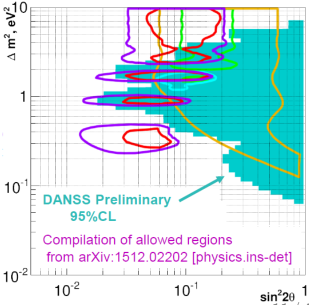
Steriles and Reactor SBL: Latest Results

DANSS - D. Svirida

Detector of reactor AntiNeutrino based on Solid Scintillator





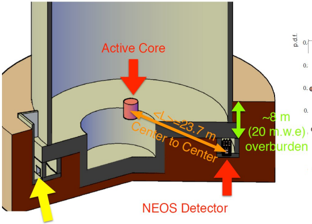


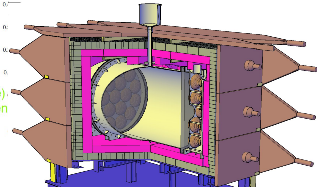
Steriles and Reactor SBL: Latest Results

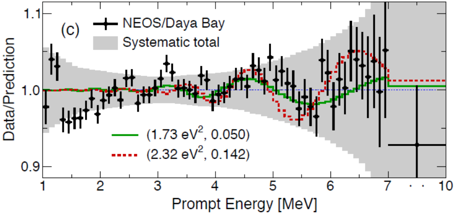
NEOS - Y. Oh

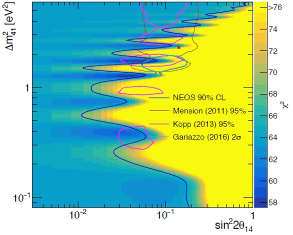
Site: At Hanbit Nuclear Power Plant reactor 5. Same as RENO.

Detector: Homogeneous 1008L of Gd loaded LS target





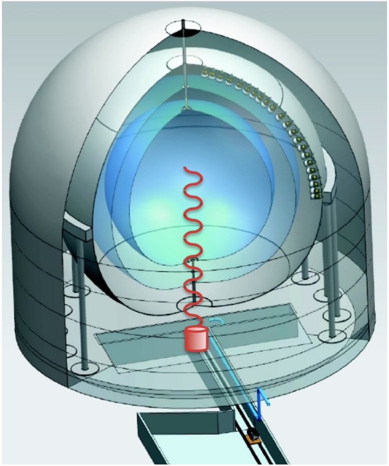


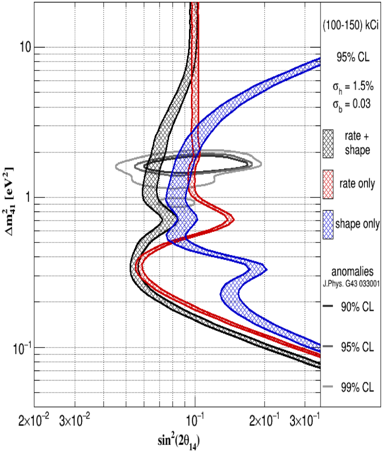


arXiv:1610.05134 / Phys. Rev. Lett. **118**, 121802 (2017)

Future Reactor SBL

SOX - M. Nielsony



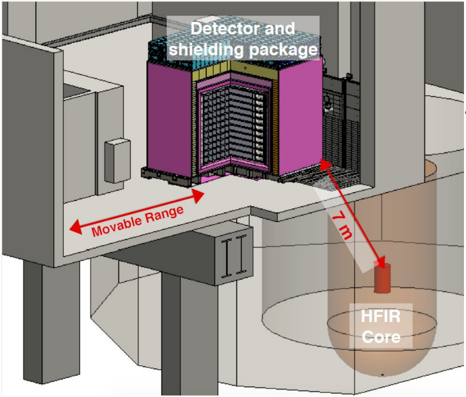


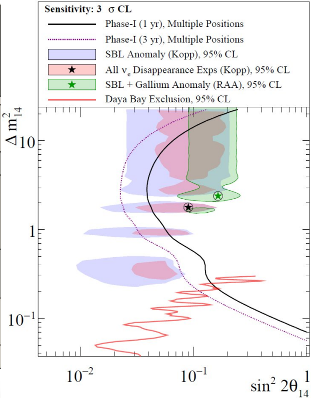
Status: Transportation of source from Mayak to LNGS planned in detail. Source arrival early 2018.

Future Reactor SBL

PROSPECT

Site: At HFIR reactor in Oakridge Natl. Lab.
Detector:$\sim$ 4ton ^{6}Li-loaded LS detector. Optically divided into 14x11 identical segments = 154 detectors with double ended readout.



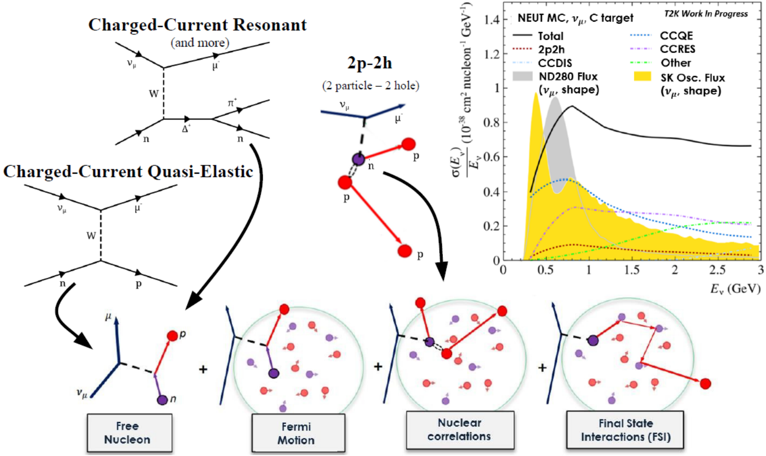


Status: Detector construction is proceeding, deployment and first data taking will begin before the end of 2017

Neutrino Scattering Expts

Cross-sections and Oscillations

Cross-section modeling contributes the largest systematic uncertainty to the oscillation analysis

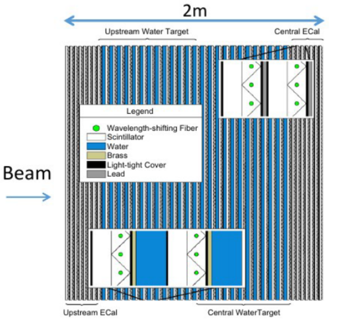


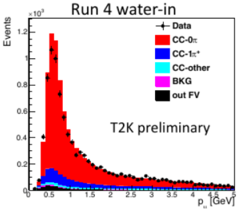
une 20, 2017 McGrew for T2K @ WIN 2017

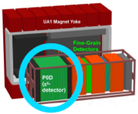
Neutrino Scattering Expts

Latest from T2K - C. McGrew

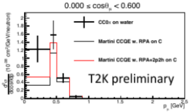
Inclusive CC ν_μ on Water

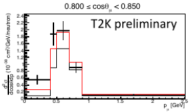


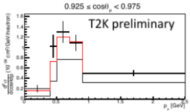


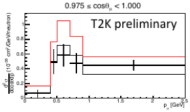


- Measure p_μ and $\cos(\theta_\mu)$
- Bayesian unfolding to remove detector response
  - Unfold water-in and water-out separately
- Statistical subtraction to get cross section on water.









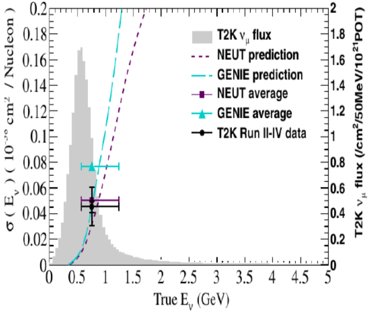
arxiv:1611.03536

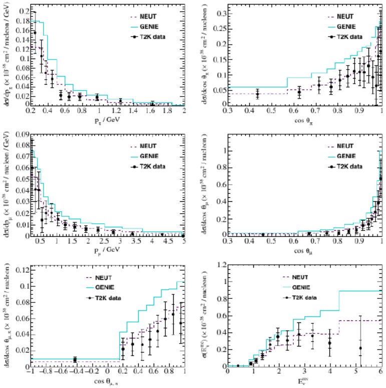
Neutrino Scattering Expts

Latest from T2K - C. McGrew

CC ν_μ Single π^+ Production on Water

- First differential cross section for CC π^+ on water
  - Statistical subtraction of
    - FGD2 (water+scintillator)
    - FGD1 (scintillator)
- Bayesian unfolding with background subtraction



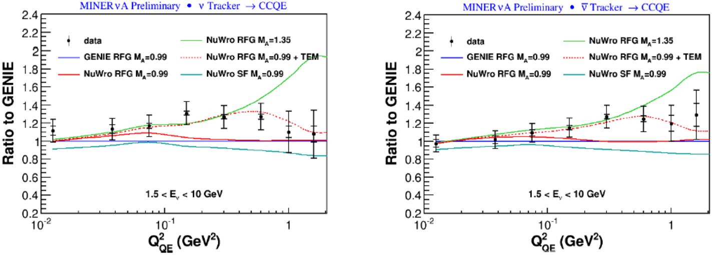


PRD 95, 012010

Neutrino Scattering Expts

Survey of Minerva Results - V. Paolone

CCQE ν_μ $\qquad Q^2_{QE} = -m_l^2 + 2E_\nu^{QE}(E_l - \sqrt{E_l^2 - m_l^2}cos\theta_l)$ $\qquad$ CCQE $\bar{\nu}_\mu$



Both results prefer models with interactions involving multi-nucleon clusters → More later

M_A = 1.35: Fit to MiniBooNE data
TEM(dotted): Transverse Enhancement Model
→ Empirical model based on electron scattering data
GENIE: Independent nucleons in mean field
SF: More realistic nucleon momentum-energy relation

NuWro: Golal, Jusczak, Sobczyk arXiv:1202.4197

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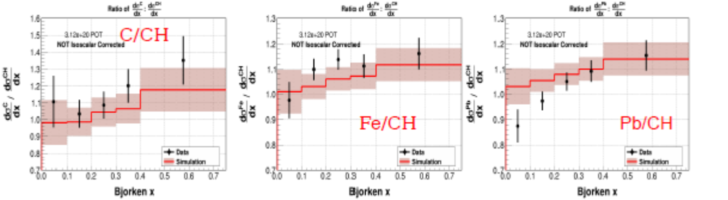
Neutrino Scattering Expts

Survey of Minerva Results - V. Paolone

CC DIS Inclusive:

- *Divide C, Fe, Pb cross sections by scintillator (CH) cross section*
  - Each nucleus divided by a statistically independent scintillator measurements
  - Scintillator measurement is specific for each target type: use the same transverse area
    - The ratio of cross sections reduces errors by factor of 2 (~5%):

Mousseau et al., PRD93 (2016) 071101



- Deficit at low x in Pb indicates additional nuclear shadowing than presently in models (Genie 2.6.2) needed
- As function of E_ν (@LE): No tension between MINERvA data and GENIE simulations

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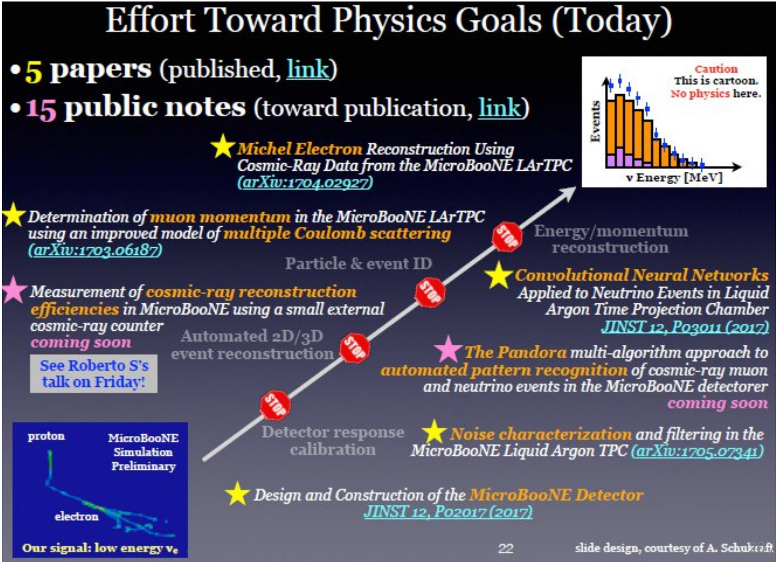
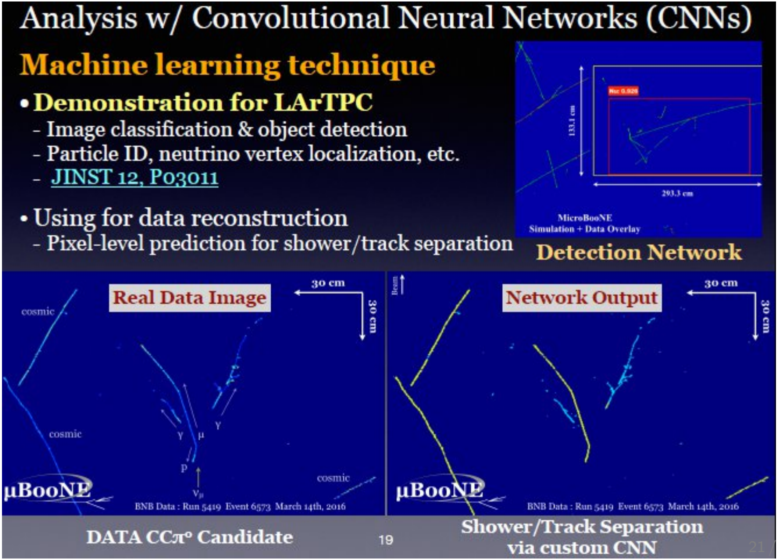
Neutrino Scattering Expts

Status of MicroBooNE - K. Terao



Neutrino Scattering Expts

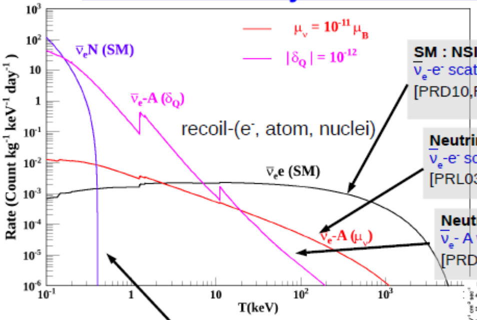
Status of MicroBooNE - K. Terao



Neutrino Scattering Expts

Neutrino Properties at Kuo-Cheng - H. Li

TEXONO Physics Program : interactions by neutrino at reactor

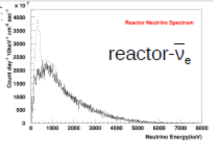


SM : NSI/BSM
$\bar{\nu}_e$-e⁻ scattering with 200 kg CsI
[PRD10,PRD10,PRD12]

Neutrino Magnetic Moment
$\bar{\nu}_e$-e⁻ scattering with 1 kg HPGe
[PRL03,PRD05,PRD07,PRD15]

Neutrino milli-charge
$\bar{\nu}_e$- A with sub-keV ULEGe, PCGe
[PRD14,PRD15]

ν-Nuclei Coherent Scattering [goal] [PRD2016]
sub-keV ULGe, PCGe
Dark Matter Searches at KSNL [PRD09,PRL13,AP14]
at CDEX(CJPL) [PRD13,PRD14,PRD14,PRD16]
Axion at CJPL [PRD17]



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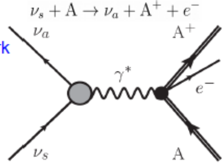
Neutrino Scattering Expts

Neutrino Properties at Kuo-Cheng - H. Li

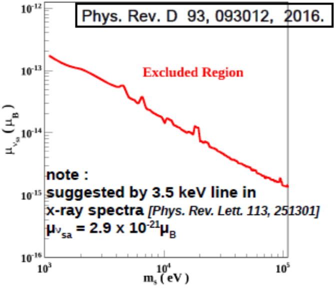
Sterile Neutrino Magnetic Moment

In Radiative Decay $\nu_a, \nu_s \rightarrow \nu_a + \gamma$

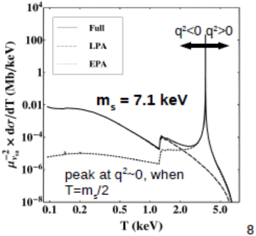


Under the assumption of sterile neutrino as cold dark matter, following parameters are adopted,

- Dark matter density = 0.4 GeVcm^{-3},
- Maxwellian velocity distribution with
- mean velocity = 220.0 km/s and V_{esc} = 533 km/s



$q^2>0$: forward scattering ν_s+A→ν_a+A^++e^-, T>m_s/2
$q^2<0$: ν_s+A→ν_a+A^++e^-, for all T



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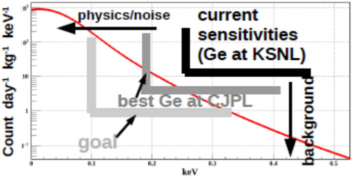
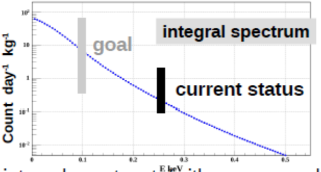
Neutrino Scattering Expts

Neutrino Properties at Kuo-Cheng - H. Li

νN coherent scattering

estimated events rate at KSNL

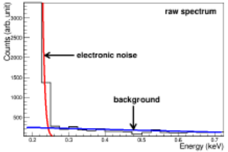




integral events rate (with energy resolution) :
6.6 count day^{-1} kg^{-1} at 100 eV threshold
0.59 count day^{-1} kg^{-1} at 200 eV threshold

improvements (plan) :

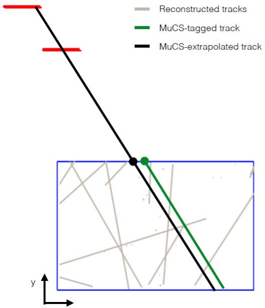
- <u>**background**</u> : **cosmic correction, B/S correction, known sources, understanding (simulation).**
- <u>**phys/noise**</u> : **hardware improvement : cooling, electronic. PSD, noise-simulation.**

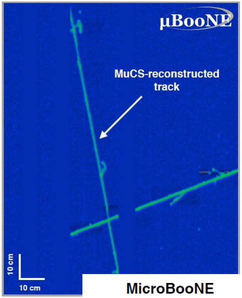


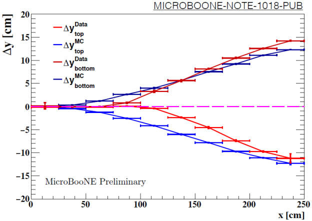
11

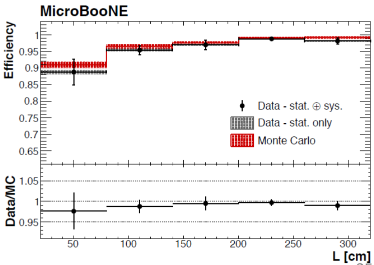
Detector R&D - Nobel Liquid

MicroBooNE Performance with Cosmics -S. Soleti



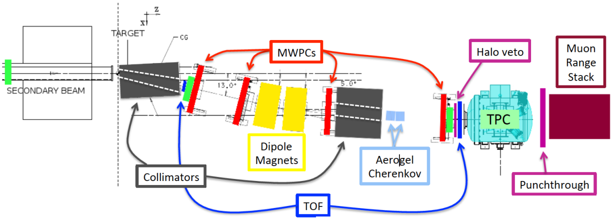


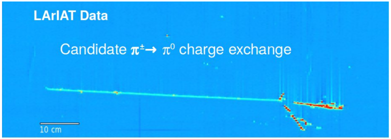


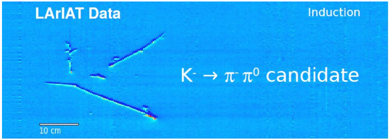


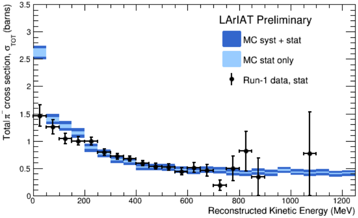
Detector R&D - Nobel Liquid

Liquid Argon in a Testbeam -A. Falcone







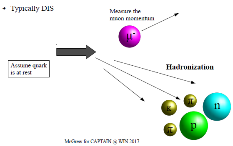


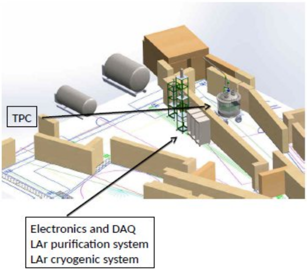
Kaon cross-sections coming SOON!

Detector R&D - Nobel Liquid

Liquid Argon for Neutron and Stopped Pion - C. McGrew

CAPTAIN (1m drift) and miniCAPTAIN (32cm) detectors at the LANL Neutron Science Center WNR facility. Measurement of neutrons in LAr up to 800 MeV. Results from engineering run presented.





mini-CAPTAIN installed in the WNR 15R beam line

Status: Physics run with miniCAPTAIN starts July 11, 2017

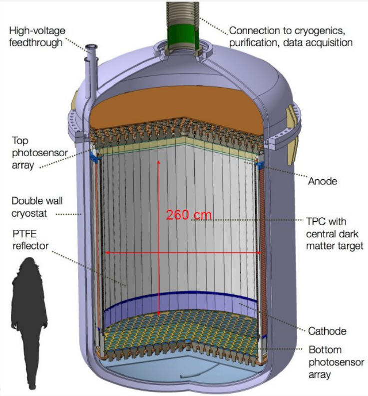
Considering possible measurements at SNS for Supernova neutrino calibrations.

Detector R&D - Nobel Liquid

Liquid Xenon for Neutrino and Dark Matter - K. Ni

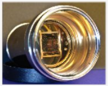
Generation-3: DARWIN the Ultimate WIMP Detector

JCAP 11, 017 (2016)



Baseline scenario
~30 t fiducial mass (baseline)
~40 t LXe TPC
~50 t total LXe mass
~1000 photosensors

Multi-purpose detector:
- sensitivity of a few 10^{-49} cm² for WIMPs
- reach the sensitivity to detect CNNS
- solar and supernova neutrinos
- 0v2b



3-inch PMT, R11410-21

4-inch PMT

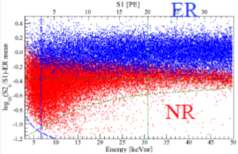
Kaixuan Ni (UCSD) – DARWIN

other proposed G3 LXe experiment: PandaX-30T

Detector R&D - Nobel Liquid

Liquid Xenon for Neutrino and Dark Matter - K. Ni

DARWIN: not only the WIMP Detector



- WIMP searches (NR)
  - Spin-independent
  - Spin-dependent and inelastic interactions
- Coherent neutrino-nucleus scattering (NR)
  - Predicted by SM, not yet observed
- Supernova neutrinos (NR)
  - Sensitive to all neutrino flavors (CNNS)
  - Complementarity to large-scale neutrino detectors
- Low-energy solar neutrinos: pp, ^{7}Be (ER)
  - Test/improve solar model, test neutrino models
- Solar axions and galactic axion-like particles (ER)
  - Alternative dark matter candidates
  - Coupling to electrons via axio-electric effect
- Neutrinoless double beta decay (ER)
  - Lepton number violating process, effective Majorana mass
  - No enrichment in ^{136}Xe required

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Detector R&D - Liquid Scintillators

Double Calorimetery in LS - M. Grassi

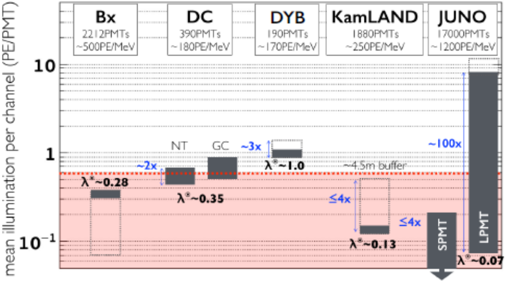
Double Calorimetry in JUNO

Large PMTs (LPMT)
75% photocoverage
1200 PE/MeV
PE = charge / gain

CALIBRATION

Small PMTs (SPMT)
3% photocoverage
50 PE/MeV
PE = hits

SPMT in **photon counting regime** across all dynamic range (energy & position)



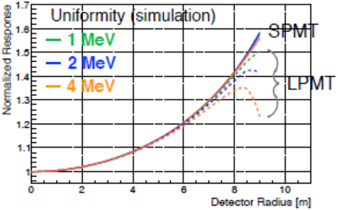
Detector R&D - Liquid Scintillators

Double Calorimetery in LS - M. Grassi

Summary & Conclusions

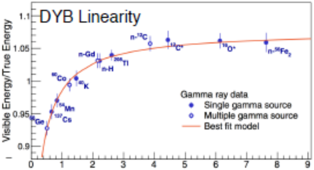
Three **examples** of Double Calorimetry in action

Detector **uniformity map** valid at different energies



Reliable measurement of detector **light non-linearity** (LS quenching)

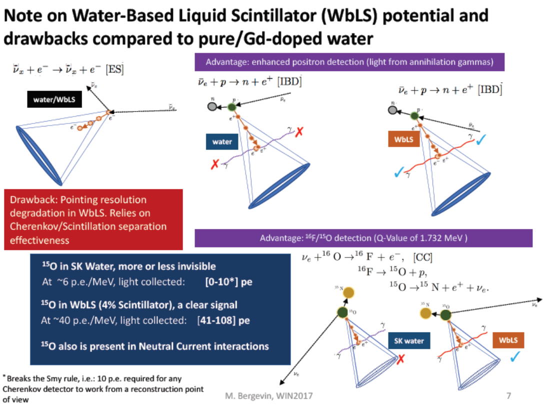
Break correlation among calibration terms



Redundancy: key ingredient to achieve high-precision calorimetry

Detector R&D - Liquid Scintillators

Supernova Detection in Water Based LS - M. Bergevin

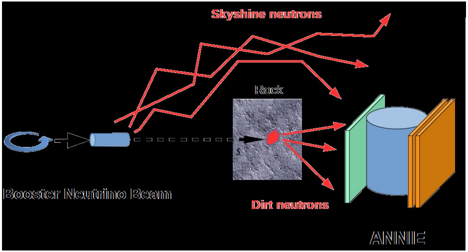


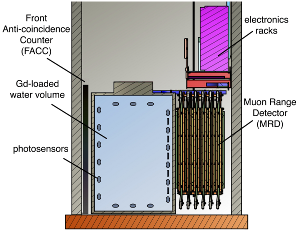
WBLS allows the observation of the ^{16}F chain allowing to identify that a CC or NC interactions. Also is more efficient at tagging Supernova anti-neutrino originating ^{16}N events.

Detector R&D - New Photodetectors for WCD

The ANNIE Experiment - V. Fischer

Accelerator Neutrino-Neutron Interaction Experiment with GD-loaded Water Cerenkov detector (26 tons) placed in Fermilab Booster Beam.



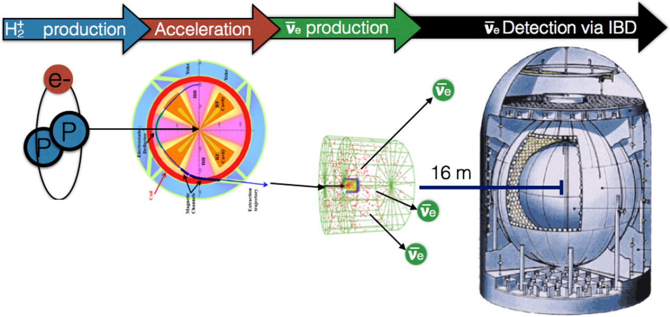


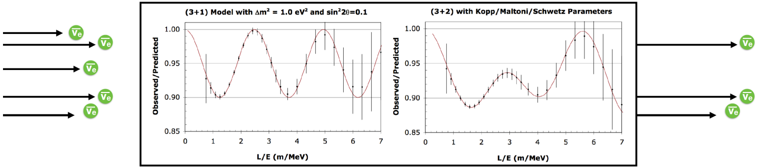
Goal: proof of concept of a novel kind of photosensor: Large Area Picosecond Photo Detectors (LAPPD):

Currently taking background data in Phase I. LAPPD's ready for PhaseII. Taking physics data in 2018

R&D for π DAR Experiments

The IsoDAR Experiment - S. Axani





Report on R&D advances in source, injection and acceleration

0νββ: Half-Life and Neutrino Mass

$$[T^{0\nu}_{1/2}]^{-1} = G^{0\nu}|M_{0\nu}|^2\langle m_{\beta\beta}\rangle^2$$

$T^{0\nu}_{1/2}$ 0νββ half-life. Best current result: > 3.0 x 10^{25} years [5]

$G^{0\nu}(Q_{\beta\beta}, Z)$ phase space factor: kinematics of emission of two electrons

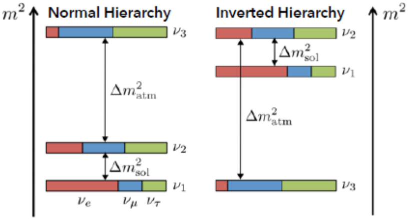
$M_{0\nu}$ nuclear matrix elements: govern transition probabilities

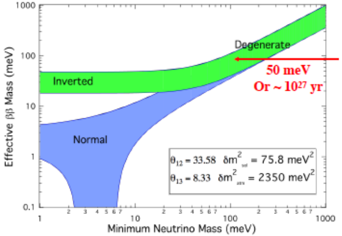
$$\langle m_{\beta\beta}\rangle \equiv \left|\sum_k m_k U^2_{ek}\right|$$

Effective Majorana mass of electron neutrino

Contributions from electron terms in mixing matrix U

Measurements constrain the minimum mass eigenstate





SR Elliott et al. [4]

Latest from $0\nu\beta\beta$

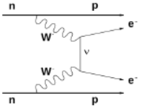
Experimental search for $0\nu\beta\beta$

WHAT WE ARE LOOKING FOR

2νββ: $(A,Z) \to (A,Z+2) + 2e^- + 2\bar{\nu}_e$

- allowed in the SM and already observed with $T_{1/2} > 10^{18}$ y

0νββ: $(A,Z) \to (A,Z+2) + 2e^-$



- not allowed in the SM
- expected with $T_{1/2} > 10^{25}$ y

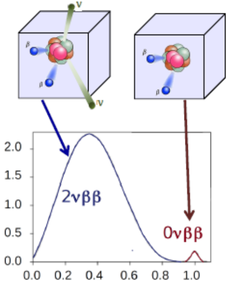
If observed:

- lepton number violation
- neutrinos are Majorana particles
- measures effective electron neutrino mass

$$m_{\beta\beta} \equiv |e^{i\alpha_1}|U_{e1}^2|m_1 + e^{i\alpha_2}|U_{e2}^2|m_2 + |U_{e3}^2|m_3|$$

EXPERIMENTAL SIGNATURE

Approach:
SOURCE = DETECTOR



Main signature:
Peak at Q-value over 2νββ tail enlarged only by detector resolution

EXPERIMENTAL SENSITIVITY

Lifetime corresponding to the minimum detectable number of events over background at a given C.L.:

$$S^{0\nu} \propto \epsilon\, i.a. \sqrt{\frac{MT}{b\Delta E}} \qquad b \neq 0$$

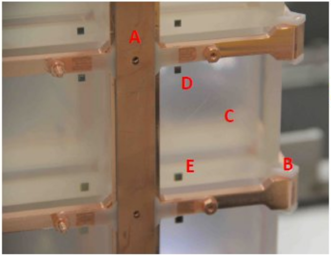
$$S^{0\nu} \propto \epsilon\, i.a.\, MT \qquad b = 0$$

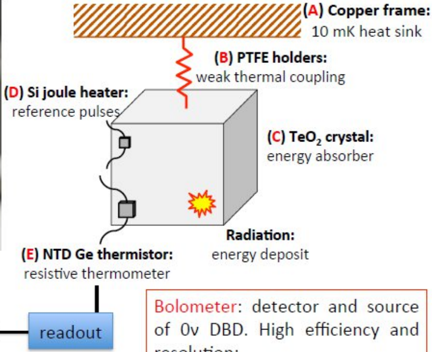
- ***M*:** Total active mass in kg
- ***ε*:** Detector efficiency
- ***i. a.*:** Isotopic abundance
- ***b*:** Background in c/keV/kg/y
- **ΔE:** Detector resolution @ ROI in keV
- ***T*:** Exposure time in y

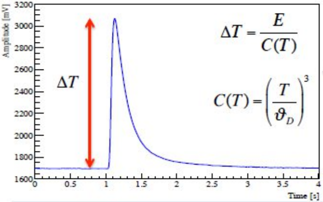
Latest from $0\nu\beta\beta$

CUORE -A. Branca

INFN Bolometric technique in CUORE







Bolometer: detector and source of 0ν DBD. High efficiency and resolution;

Low temperature needed:

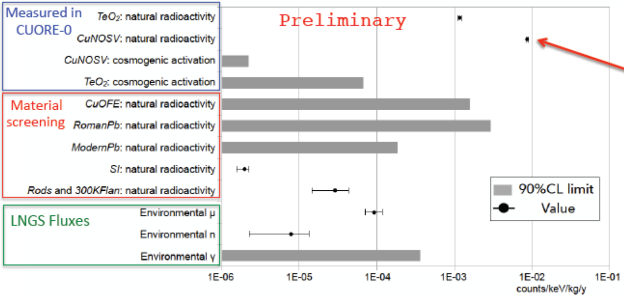
$$@T = 10mK \Rightarrow \quad C \sim 10^{-9}\frac{J}{K}; \quad \Delta T = 0.1\frac{mK}{MeV}; \quad \tau \sim 1s;$$

Latest from $0\nu\beta\beta$

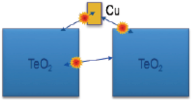
CUORE -A. Branca

INFN CUORE background projection

Main background index in the 0v DBD region expected for the various components of CUORE



expected dominant contribution from the Cu of the towers structure



Projected total BI in the 0v DBD region is consistent with CUORE background goal (10^{-2} counts/(keV•kg•yr)):

$$BI = (1.02 \pm 0.03(stat.)^{+0.23}_{-0.10}(syst.)) \cdot 10^{-2} \frac{counts}{kev \cdot kg \cdot yr}$$ (Preliminary)

Latest from $0\nu\beta\beta$

CUPID -M. Martinez

Beyond CUORE: CUPID

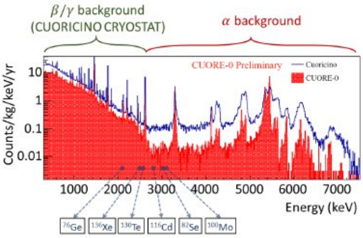
CUORE UPGRAGE WITH PARTICLE IDENTIFICATION

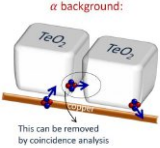
CUPID goal: ~0 bkg at ton scale

- CUORE infrastructure
- Isotope enrichment
- Improved material selection
- Particle identification

CUPID Interest Group: 32 institutions

White papers:
arXiv:1504.03599
arXiv:1504.03612





To reduce background we need active α discrimination

CUPID -M. Martinez

Summary

- Completely exploring the inverted hierarchy region of neutrino masses will require a detector with ~1 ton isotopic mass and background level at the order of 0.1 counts/ton/yr.
- CUPID (Cuore Upgrade with Particle Identificiation) is pursuing this goal through several strategies, one of them being using scintillating bolometers.
- ZnSe crystals and Ge-light detectors fulfill the project requirements both in terms of α background rejection and energy resolution.
- CUPID-0, the first CUPID demonstrator with $Zn^{82}Se$ is taking data at LNGS since March 2017. We expect to release the first data in Summer 2017

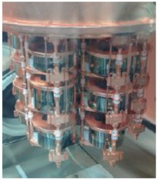
Latest from $0\nu\beta\beta$

Majorana Demonstrator -W. Xu

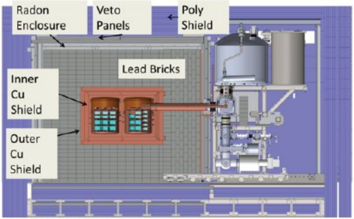
The MAJORANA DEMONSTRATOR

Funded by DOE Office of Nuclear Physics, NSF Particle Astrophysics, NSF Nuclear Physics with additional contributions from international collaborators.

Goals: — **Demonstrate backgrounds low enough to justify building a tonne scale expt.**
— **Establish feasibility to construct & field modular arrays of Ge detectors.**
— **Search for additional physics beyond the standard model.**



- **Operating underground** at 4850′ level of Sanford Underground Research Facility
- **Background Goal** in the $0\nu\beta\beta$ peak region of interest (4 keV at 2039 keV) :
  - 3 counts/ROI/t/y (after analysis cuts). Assay UL currently ≤ 3.5
- **44.1 kg of Ge detectors**
  - 29.7 kg of 88% enriched ^{76}Ge crystals
  - 14.4 kg of ^{nat}Ge
  - Detectors: P-type, point-contact (PPC)
- **2 independent cryostats**
  - Ultra-clean, electroformed Cu
  - 22 kg of detectors per cryostat
  - Naturally scalable
- **Ultra low-activity components and construction**
- **Compact Shield**
  - Low-background passive Cu and Pb shield with active muon veto



N. Abgrall et al., Adv. High Ener. Phys. 2014, 365432 (2013); arXiv:1308.1633

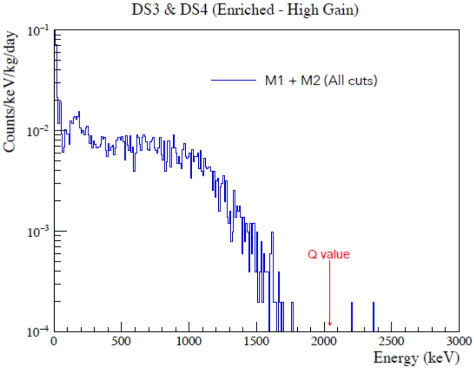
Latest from $0\nu\beta\beta$

Majorana Demonstrator -W. Xu

Estimated 0νββ-decay ROI background, DS-3&4

Lowest background configuration, with both modules in shield.

(Previous data presented at Neutrino 16 was from Module 1, DS-0 and DS-1)



- Exposure: 1.39 kg y
- After cuts, 1 count in 400 keV window centered at 2039 keV (0νββ peak)
- Projected background rate is $5.1^{+8.9}_{-3.2}$ c /(ROI t y) for a 2.9 (Module1-DS3) & 2.6 (Module2 - DS4) keV ROI, (68% CL).
- Background index of 1.8×10^{-3} c/(keV kg y)
- Analysis cuts are still being optimized.
- Through mid-May, have 10x more exposure in hand. Analysis is in progress.

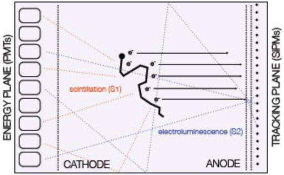
Initial results and status of the MAJORANA DEMONSTRATOR. Wenqin Xu WIN2017 Jun-23-2017 12

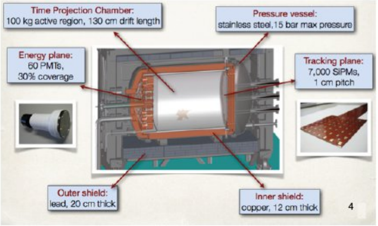
Latest from $0\nu\beta\beta$

NEXT -G. Martinez Lema

NEXT: **N**eutrino **E**xperiment with a **X**enon **TPC**

- High Pressure Xenon (HPXe) TPC to search for the neutrinoless double beta decay.
- 100 kg of xenon at 15 bar enriched to 90% ^{136}Xe.
- Asymmetric detector:
  - PMTs for calorimetry and t_0.
  - SiPMs for tracking.
- Ionization signals are amplified with electroluminescence (EL).





4

Mary Bishai, Brookhaven National Laboratory

Latest from $0\nu\beta\beta$

NEXT-WHITE (NEW) 1:2 scale detector

Status and future plans for NEW

- The detector is operational since October 2016.
- ^{136}Xe-depleted xenon in use.
- Commissioning run: June - September 2016.
- Calibration run: October 2016 - present.
  - Energy resolution & topology.
- Physics run (background model & $\beta\beta^{2\nu}$): October 2017-2018.

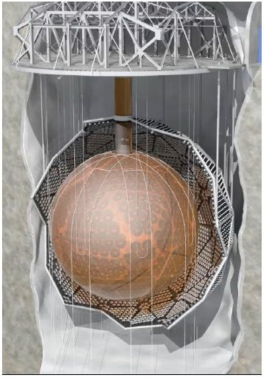
Latest from $0\nu\beta\beta$

SNO+ -R. Bonventre

The SNO detector → SNO+ detector

SNO+ detector upgraded to look for neutrinoless double beta decay

- Target material changing from heavy water to liquid scintillator
  - Lower energy threshold and higher resolution
  - Load with ^{130}Te for $0\nu\beta\beta$ measurement
- Hold-down ropes: compensate for buoyancy of scintillator
- Upgraded electronics: handle higher event rates (>1kHz)
- Repaired PMTs
- Installed new LED calibration system



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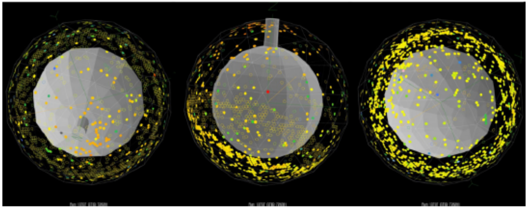
Latest from $0\nu\beta\beta$

SNO+ -R. Bonventre

Conclusion



Candidate atmospheric neutrino event

- SNO+ is currently filled with water and taking physics data
  - In 6 months of running it will provide the strongest limit on invisible nucleon decay
- Scintillator purification system being commissioned
- Tellurium systems under construction
- Neutrinoless double beta decay phase will begin in 2018
  - In 5 years will reach the top of the inverted hierarchy

My Conclusions

- **In 2017 more results from reactor experiments are strengthening the case that reactor anomaly is due to imperfect modeling of the uranium fission chain NOT a sterile neutrino.**
- **Data from the very short baseline reactor neutrino experiments DANSS and NEOS** ***find no evidence*** **of $\bar{\nu}_e$ disappearance in most of the region covered by the appearance anomalies. Exclusion is at the 95% CL**
- **Next generation long baseline experiments searching for the mass hierarchy and neutrino CP violation are now** ***facts on the ground*****. JUNO and DUNE are in the construction phase and a 2017 decision on proceeding with HyperKamiokande is soon**
- **A very active theoretical effort on modeling neutrino cross-section using the rich datasets now available from T2K, NOνA and MinerνA is starting to yield significant improvements**
- **A very active and** ***diverse*** **program of ν detector R&D is providing a lot of fun and exciting experiments!**
- **The current R&D and demonstrators for $0\nu\beta\beta$ experiments are** ***meeting background requirements*** **for the current and next generation of experiments**