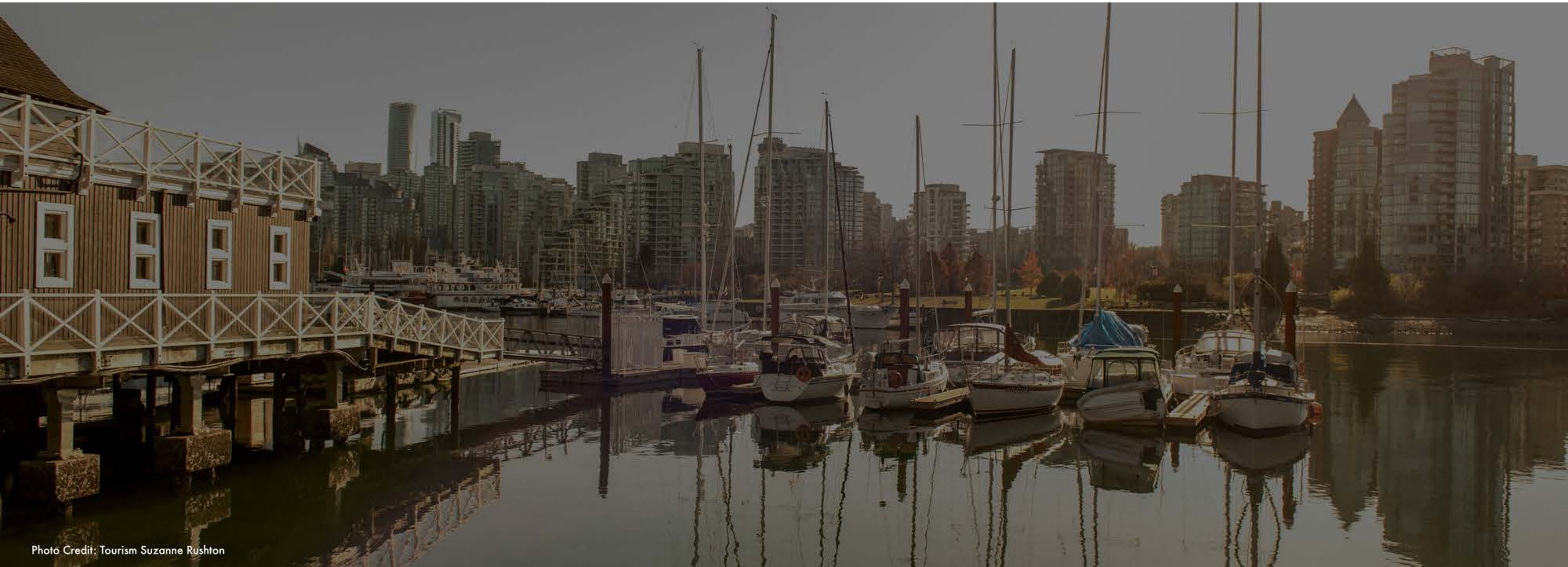
NNN2018 Summary

M. Nakahata

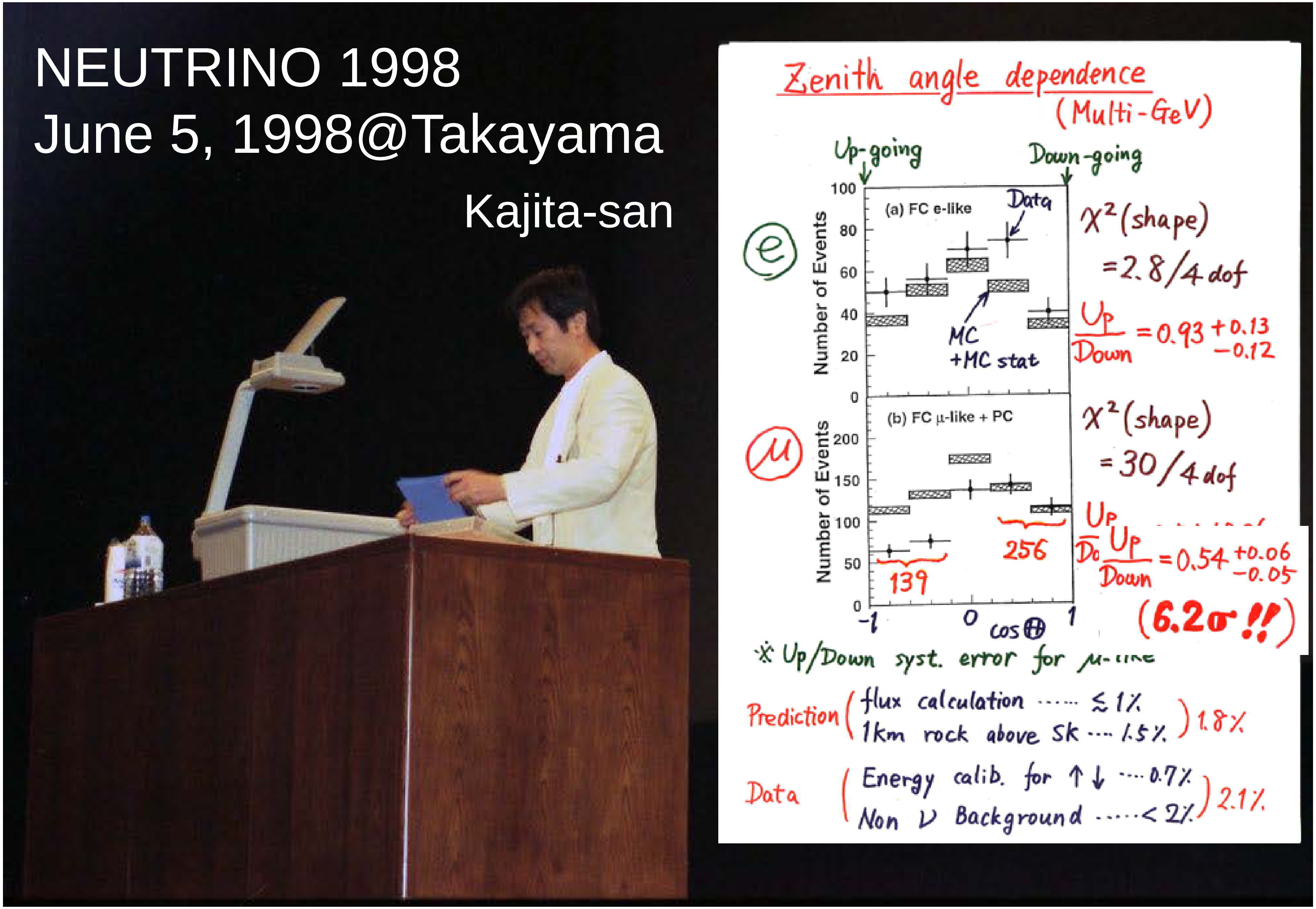
Kamioka Observatory, ICRR,
Kavli IPMU, Univ. of Tokyo

Disclaimer: Impossible to summarize all wonderful talks in short time given to me.
Apologies for skipping many brilliant talks.



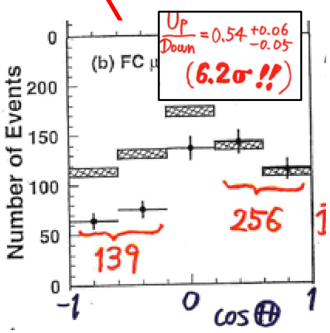
This year is the

20th Anniversary of Neutrino Oscillations

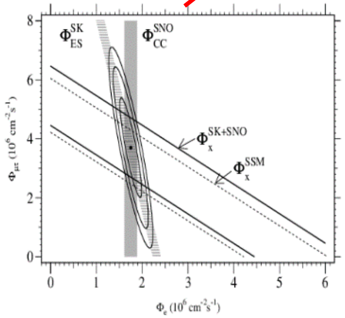


Discoveries in last 20 years

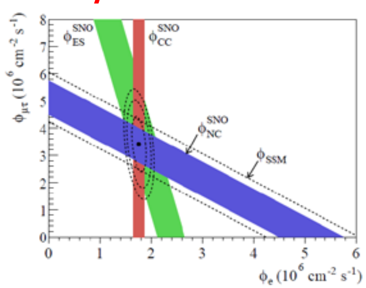
1998	1999	2000	2001	2002	2003	2004	2005	2006	2007



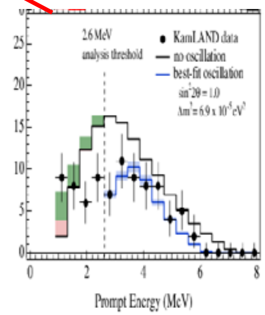
Evidence for atmospheric ν osc. (SK)



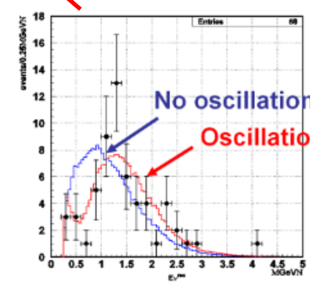
Evidence for solar ν osc. (SK vs. SNO CC)



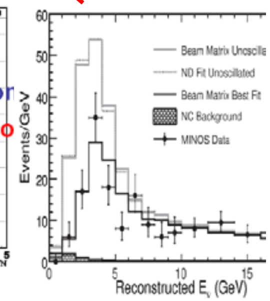
Evidence for solar ν osc. (SNO CC vs. NC)



Evidence for reactor ν osc. (KamLAND)



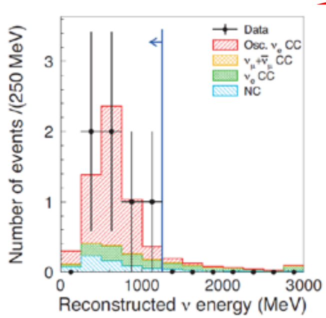
(K2K)



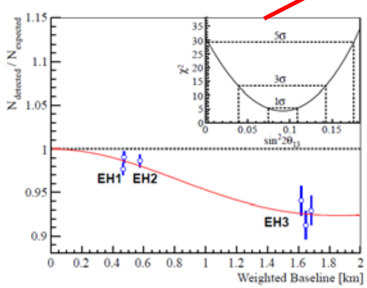
(MINOS)

Evidence for ν_μ disappearance by artificial ν

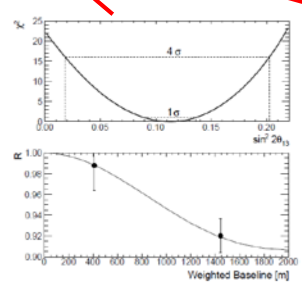
2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018



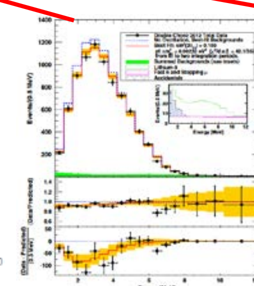
Indication of ν_e appearance (T2K)



(Daya Bay)

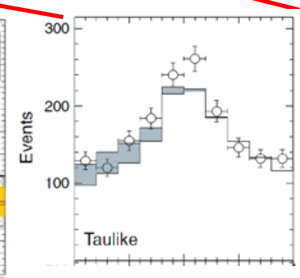


(RENO)

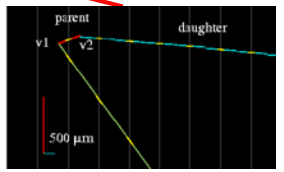


(Double Chooz)

Observation of $\bar{\nu}_e$ disappearance in reactor



(SK, 3.8σ)



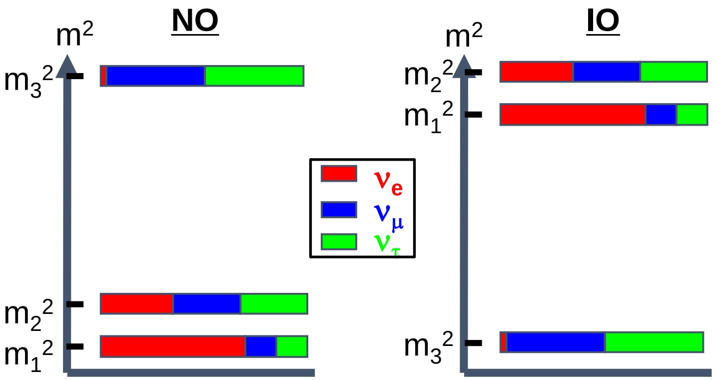
(OPERA, 5.1σ)

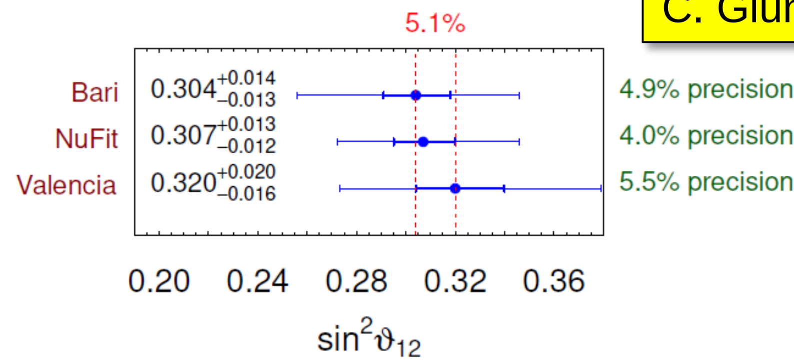
ν_τ appearance

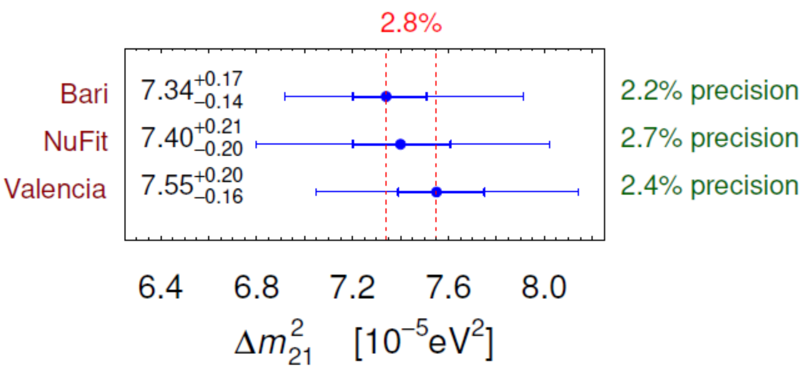

Workshop for the
Next Generation Nucleon Decay and Neutrino Detector (NNN99)
September 23 - 25, 1999
SUNY at Stony Brook, NY, USA
Working Groups:
Nucleon Decay
Neutrino Oscillations
Neutrino Astrophysics
NNN99 International Advisory Committee
J. Bahcall, IAS
R. Cowsik, IIAP
L. DiLella, CERN
G. Feldman, Harvard
T. Gaisser, Bartol
M. Goldhaber, BNL
F. Halzen, Wisconsin
W. Haxton, Washington
P. Langacker, Penn
W. Marciano, BNL
L. Moscoso, CEA/Saclay
K. Nakamura, KEK
J. Peoples, Fermilab
F. Sciulli, Columbia
H. Sobel, UCI (Chair, IAC)
C. Spiering, DESY/Zeuthen
P. Strolin, Napoli/CERN
Y. Totsuka, ICRR
F. Wilczek, IAS
S. Wojcicki, Stanford
C.N. Yang, StonyBrook
NNN99 Organizing Committee
D. Casper, UCI
M. Diwan, BNL (Co-chair)
R.I. Hahn, BNL
C.K. Jung, Stony Brook (Co-chair)
T. Kajita, ICRR
R. McCarthy, Stony Brook
C. Mcgrew, Stony Brook
K.K. Ng, Stony Brook
A. Rubbia, ETH/Zurich
D. Schamberger, Stony Brook
R. Shrock, Stony Brook
H. Sobel, Chair, International Advisory Committee
B. Svoboda, LSU (Chair, Program Committee)
C. Yanagisawa, Stony Brook
For more information, please contact:
Joan Napolitano, Conference Secretary
HEP group, Dept. of Physics and Astronomy
SUNY at Stonybrook, NY 11794-3800, USA
PHONE: 516-632-8095
FAX: 516-632-8101
EMAIL: nnn99@superk.physics.sunysb.edu
Further information and registration:
http://superk.physics.sunysb.edu/NNN99/

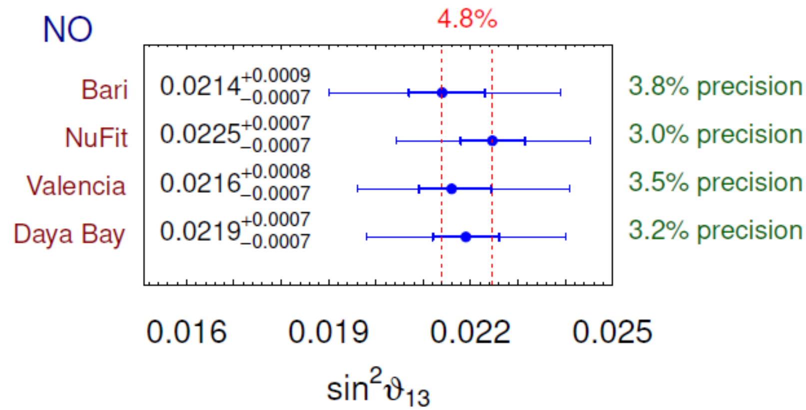
What we know now after the 20 years

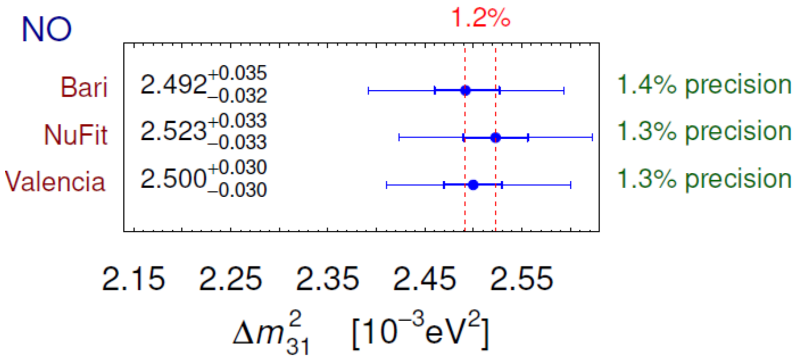
C. Giunti

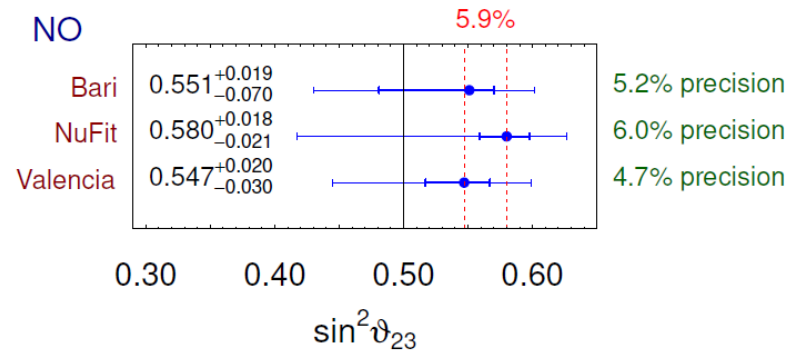












Note: differences between global fit groups should be resolved.

Next Questions in Neutrino Physics

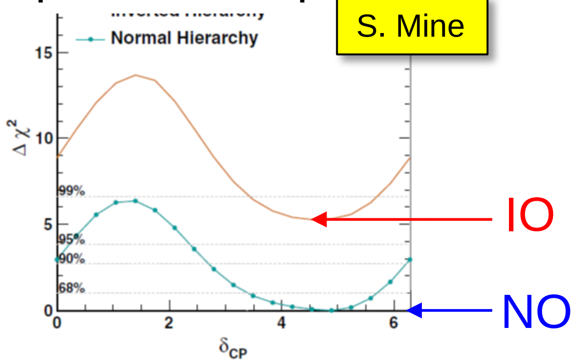
M. Messier

S. Zhou

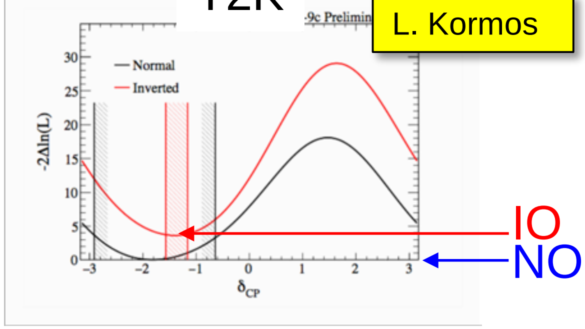
- Which mass ordering? Normal or Inverted?
- Is CP violated?
- θ23 octant or full mixing?
- What is the absolute mass of neutrinos?
- Is neutrino mass Dirac or Majorana?
- Is there sterile neutrinos?

Mass ordering at present

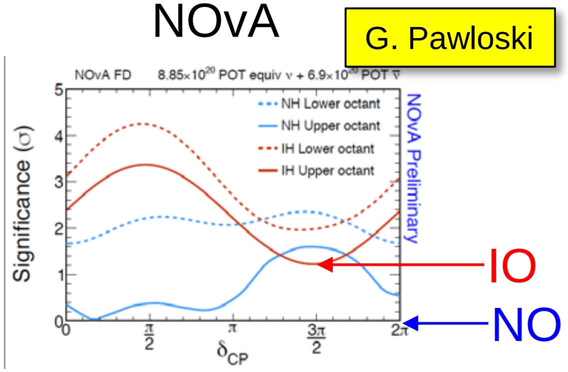
Super-K atmospheric ν



T2K



NOvA



Global analyses

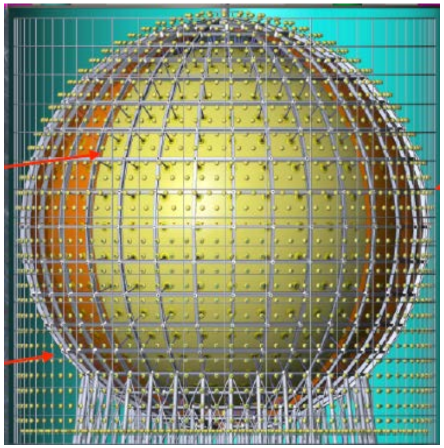
C. Giunti

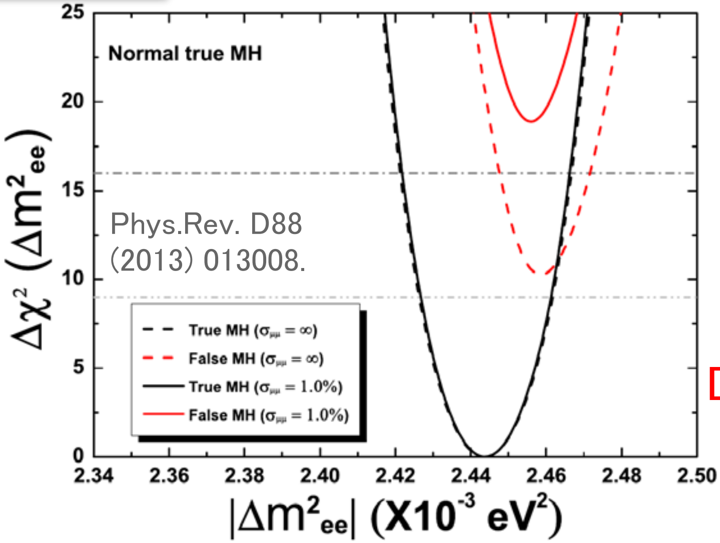
Bari:	$\chi^2_{IO} - \chi^2_{NO} = 9.5$	$(\approx 3.1\sigma)$
NuFit:	$\chi^2_{IO} - \chi^2_{NO} = 9.1$	$(\approx 3.0\sigma)$
Valencia:	$\chi^2_{IO} - \chi^2_{NO} = 11.7$	$(\approx 3.4\sigma)$

NO is favored over IO at ~3σ level.

Mass Ordering in near future

JUNO A. Garfagnini



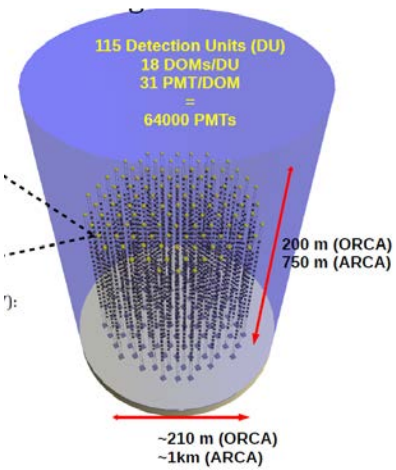


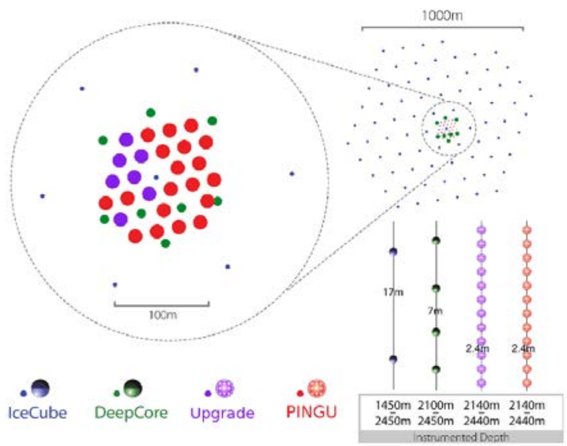
$\Delta\chi^2$ ~10 JUNO only

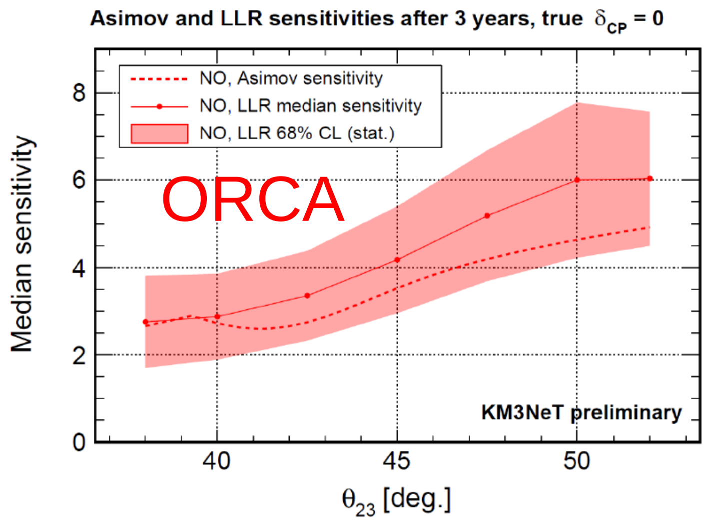
$\Delta\chi^2$ ~14
(if accuracy of $\Delta m^2_{\mu\mu}$ is constraint to be 1% by long baseline exp.)

Data taking will start in 2021.

KM3NeT(ORCA)/PING







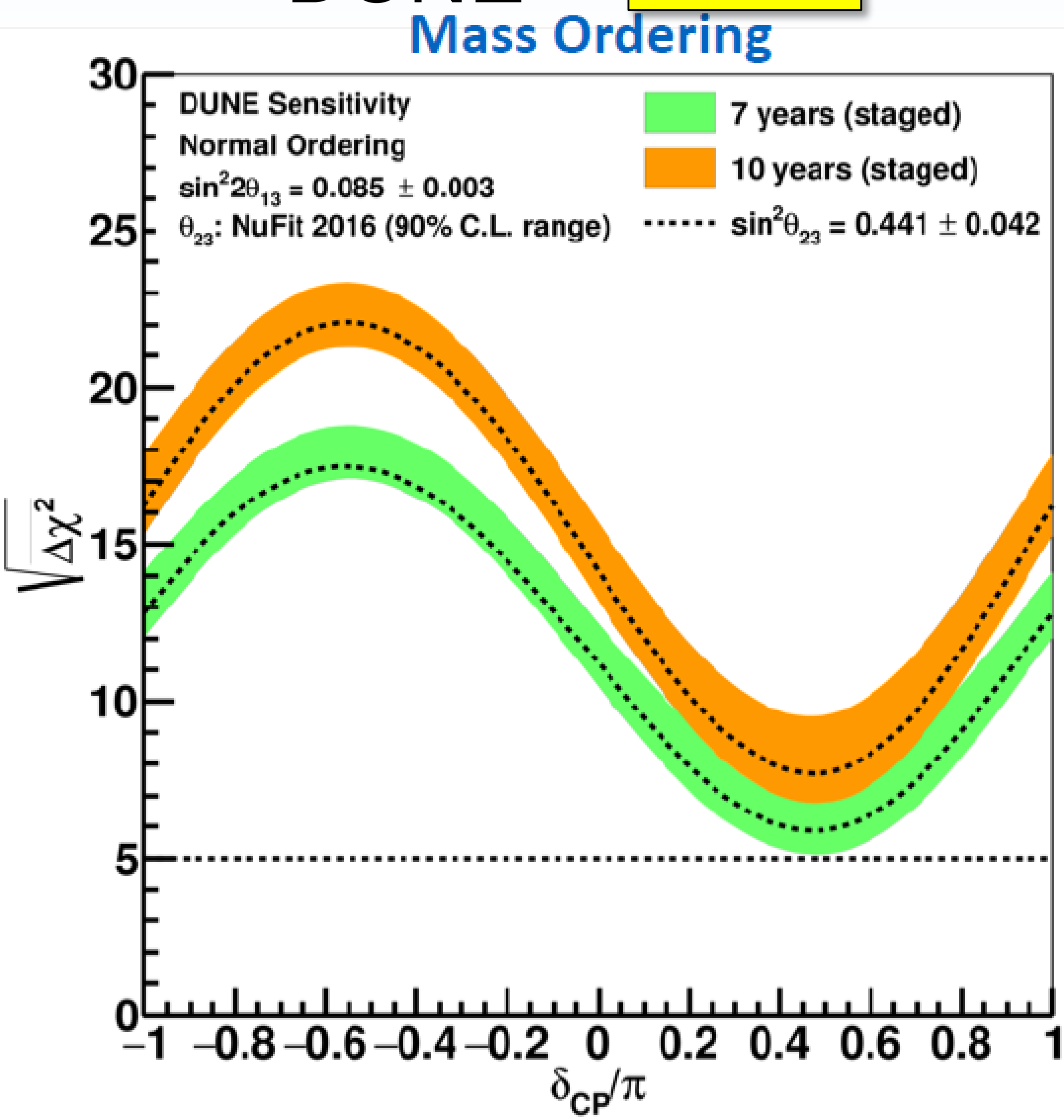
C. Nielsen J. Hignight

~4σ level for full mixing.

Mass Ordering, eventually

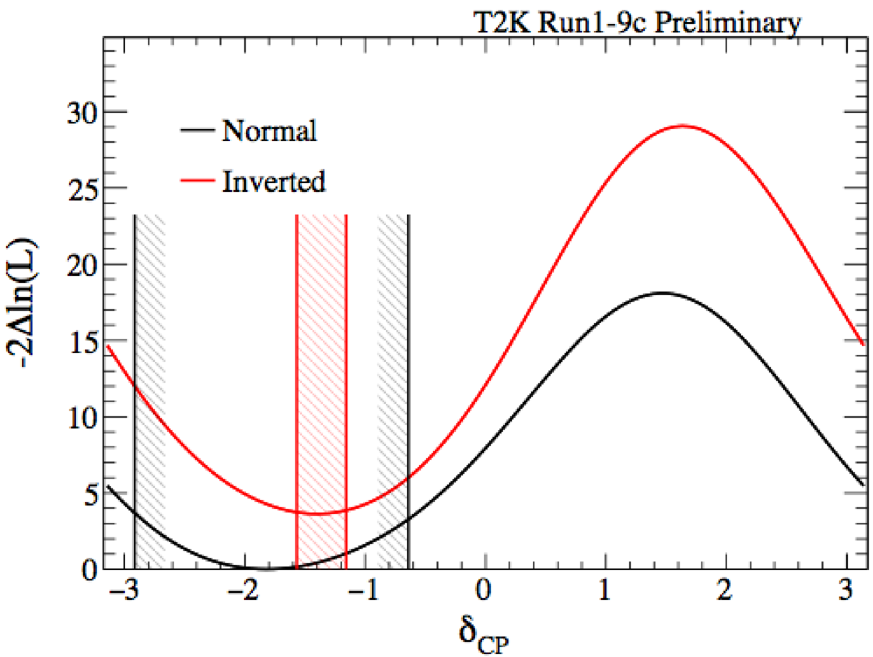
DUNE

A. Sousa

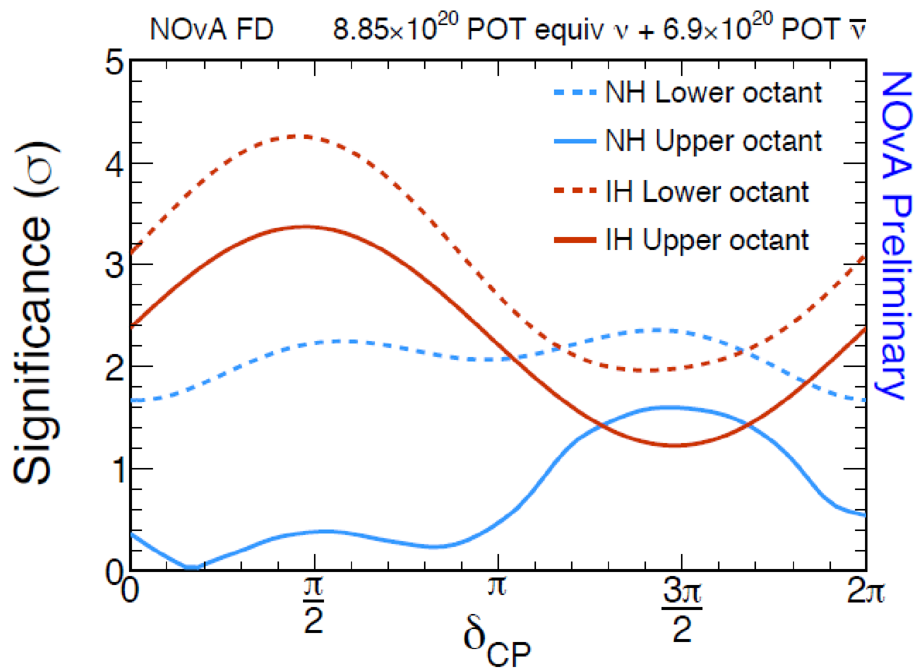


CP violation now

T2K L. Kormos



NOvA G. Pawloski

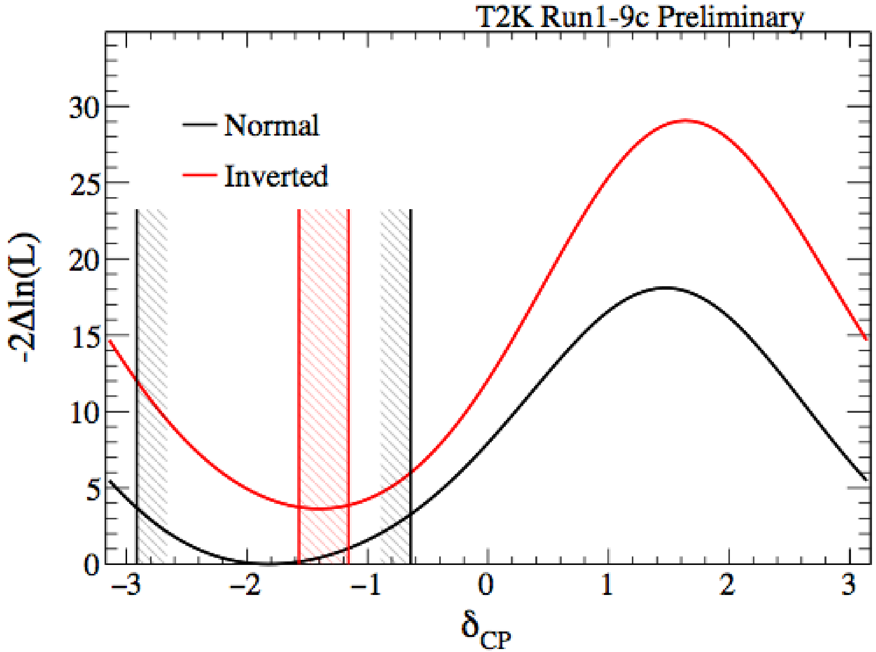


CP conserving values of δCP lie outside 2σ region.

Excludes δCP=π/2 of IO at >3σ but CP conserving values still allowed.

CP violation now

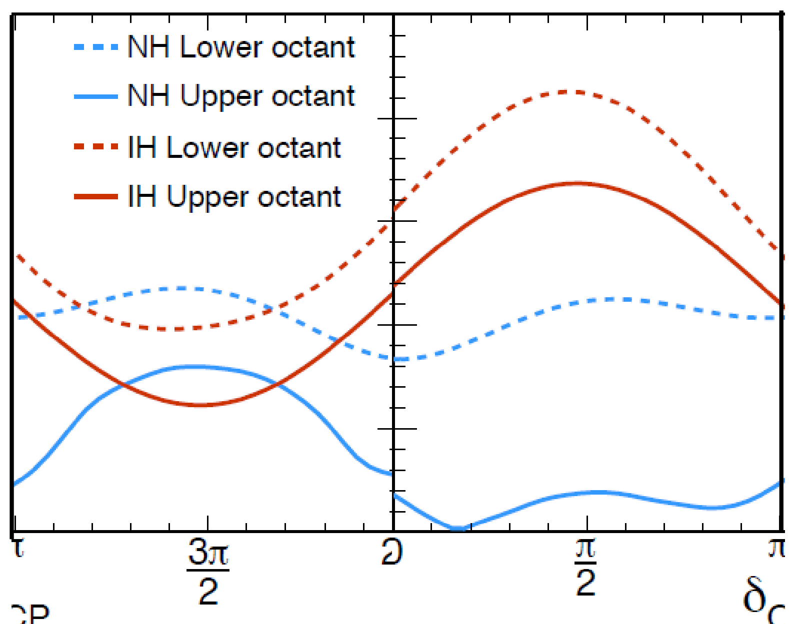
T2K



With same horizontal axis

Similar shape for IO.
More statistics are necessary to discuss further.

NOvA

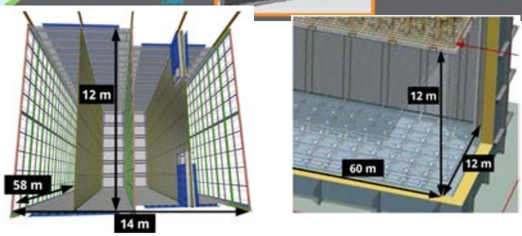


Future δCP measurement

DUNE

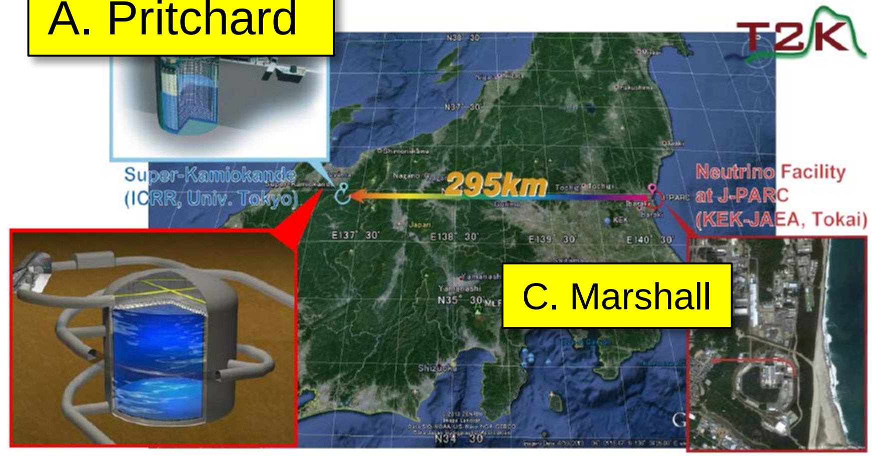
A. Sousa

J. Walker



Hyper-Kamiokande

A. Pritchard



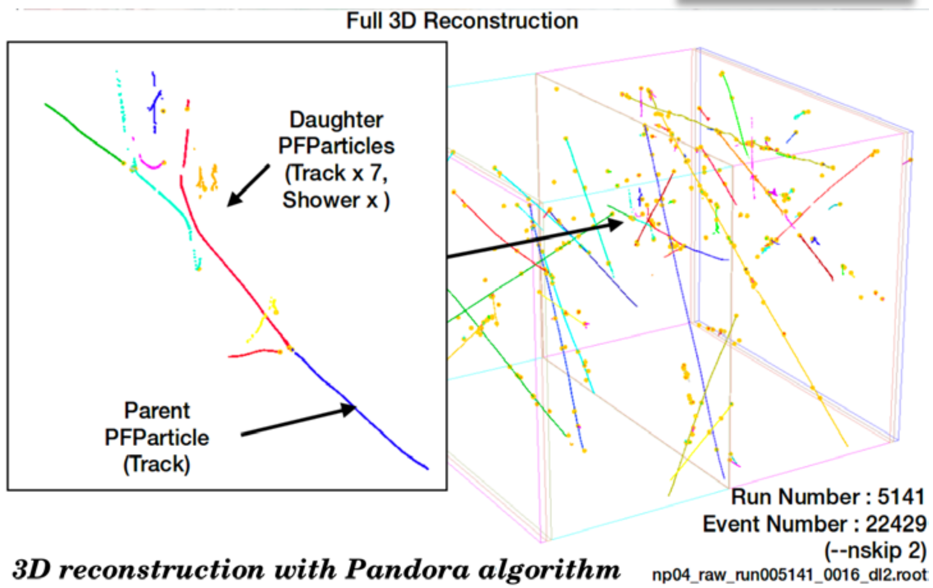
C. Marshall

	DUNE	Hyper-K
Baseline	1300 km	295 km
Beam energy	Several GeV	~0.6 GeV
Earth Matter effect	Large (sensitive to mass ordering)	Small (less effect from mass ordering)
Detector	40 kton Liquid Ar TPC	190 kton water Cherenkov

Complementary measurements.

Hot news from DUNE and Hyper-K

A. Sousa



The protoDUNE SP at CERN taking beam and cosmic-ray data.

A. Pritchard

HYPER-KAMIOKANDE EXPERIMENT TO BEGIN CONSTRUCTION IN APRIL 2020

Posted on SEPTEMBER 19, 2018 5:01 PM by ADMIN

Last week at the 7th Hyper-Kamiokande proto-collaboration meeting, a statement was issued by the University of Tokyo recognizing the significant scientific discoveries which the planned Hyper-Kamiokande experiment would enable.

It states that, based on these exciting prospects, the University of Tokyo will ensure that construction of the experiment will begin in 2020. Hyper-Kamiokande now moves from planning to a real experiment.

The Hyper-Kamiokande proto-collaboration welcomes this exciting endorsement of the project and the boost it will give to increasing even further the international contributions and participation in the experiment. Introducing the statement, Professor Takaaki Kajita, Director of the Institute for Cosmic Ray Research at the University of Tokyo and 2015 Nobel Laureate in Physics, pointed out that the Japanese funding agency MEXT has included seed funding for Hyper-Kamiokande in its JFY 2019 budget request. He illustrated with many examples that it is standard in Japan for large projects to begin with a year of seed funding, and said that in any case the University of Tokyo commitment meant that Hyper-Kamiokande construction will begin in April 2020.

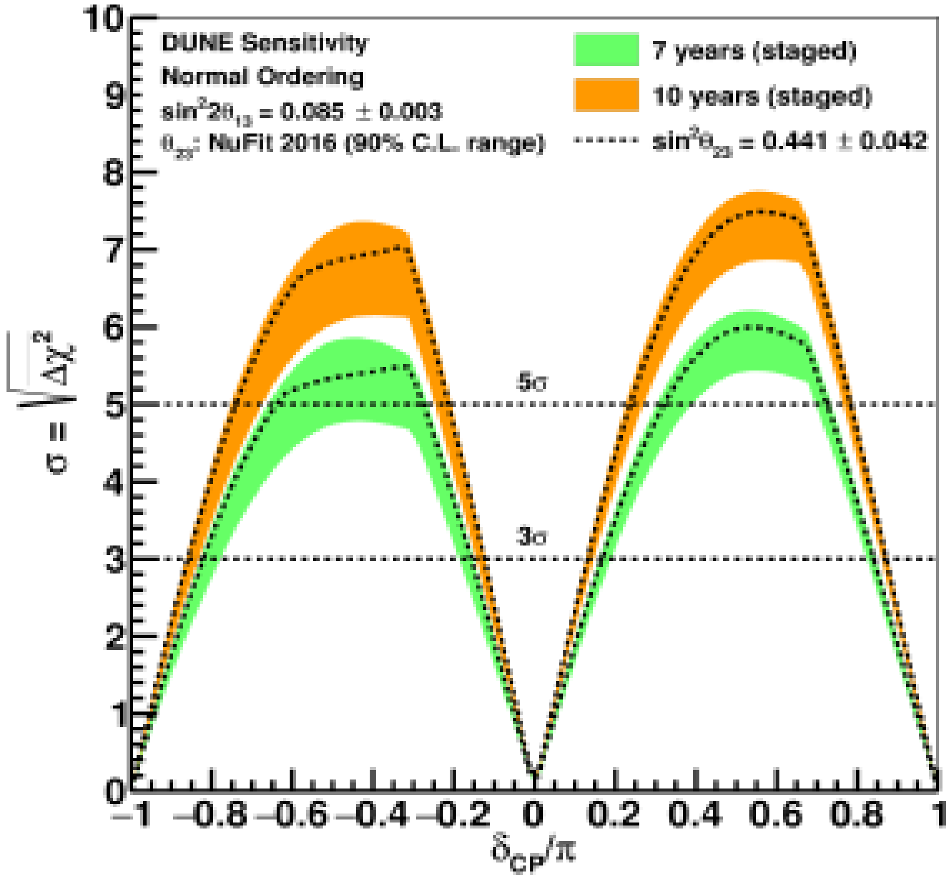
The Hyper-Kamiokande Proto-Collaboration will now work to finalize designs, and is very open to more international partners to join in this far-reaching new experiment.

Hyper-K construction will begin in April 2020.

Future δCP measurement

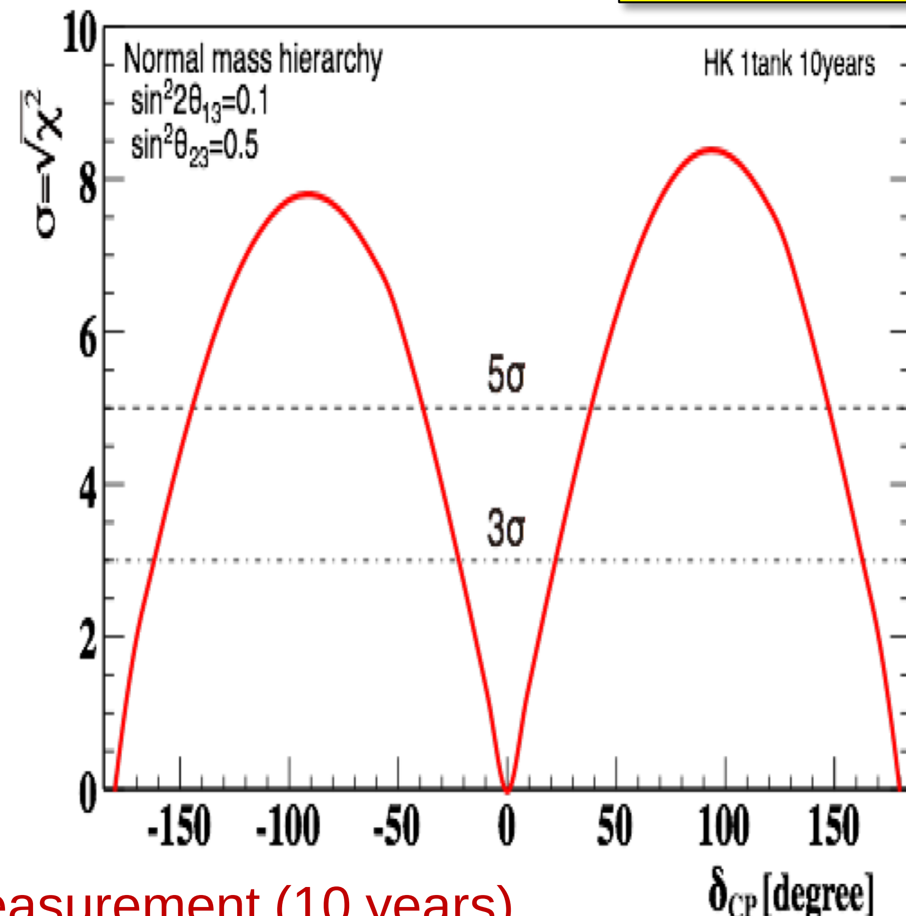
DUNE

A. Sousa



Hyper-Kamiokande

A. Pritchard



Precision of δCP measurement (10 years)

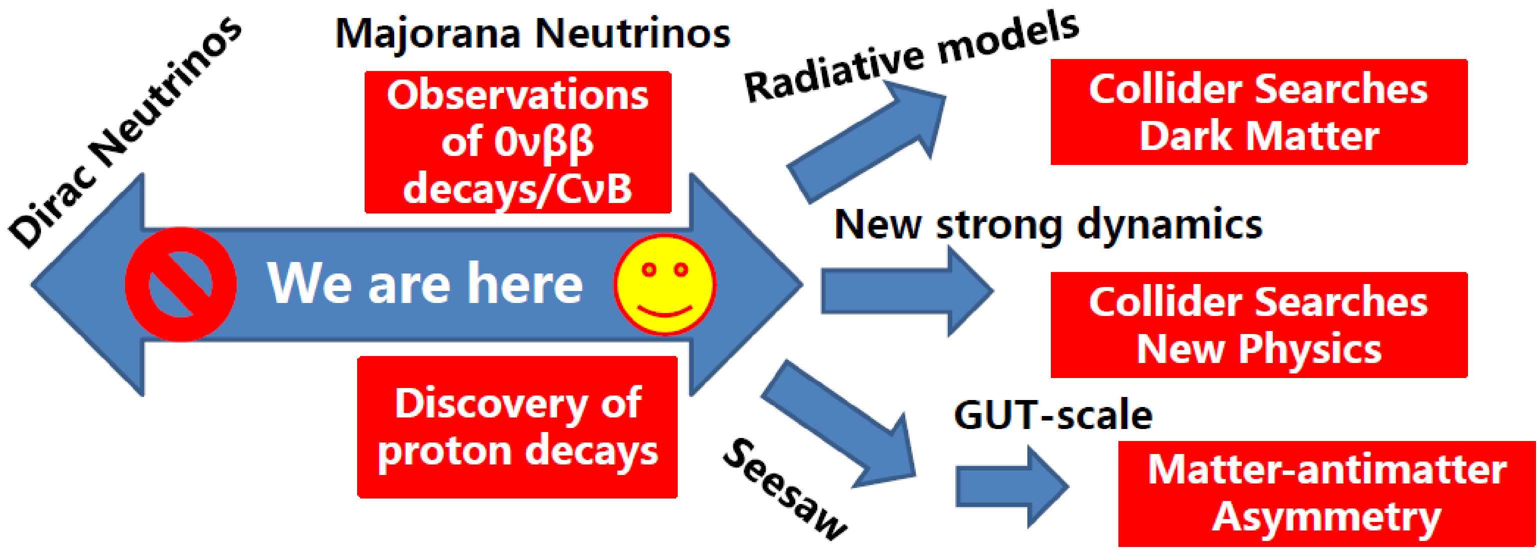
~16° (~7°) for δCP=±90° (0°)

~22° (~7°) for δCP=±90° (0°)

S. Zhou

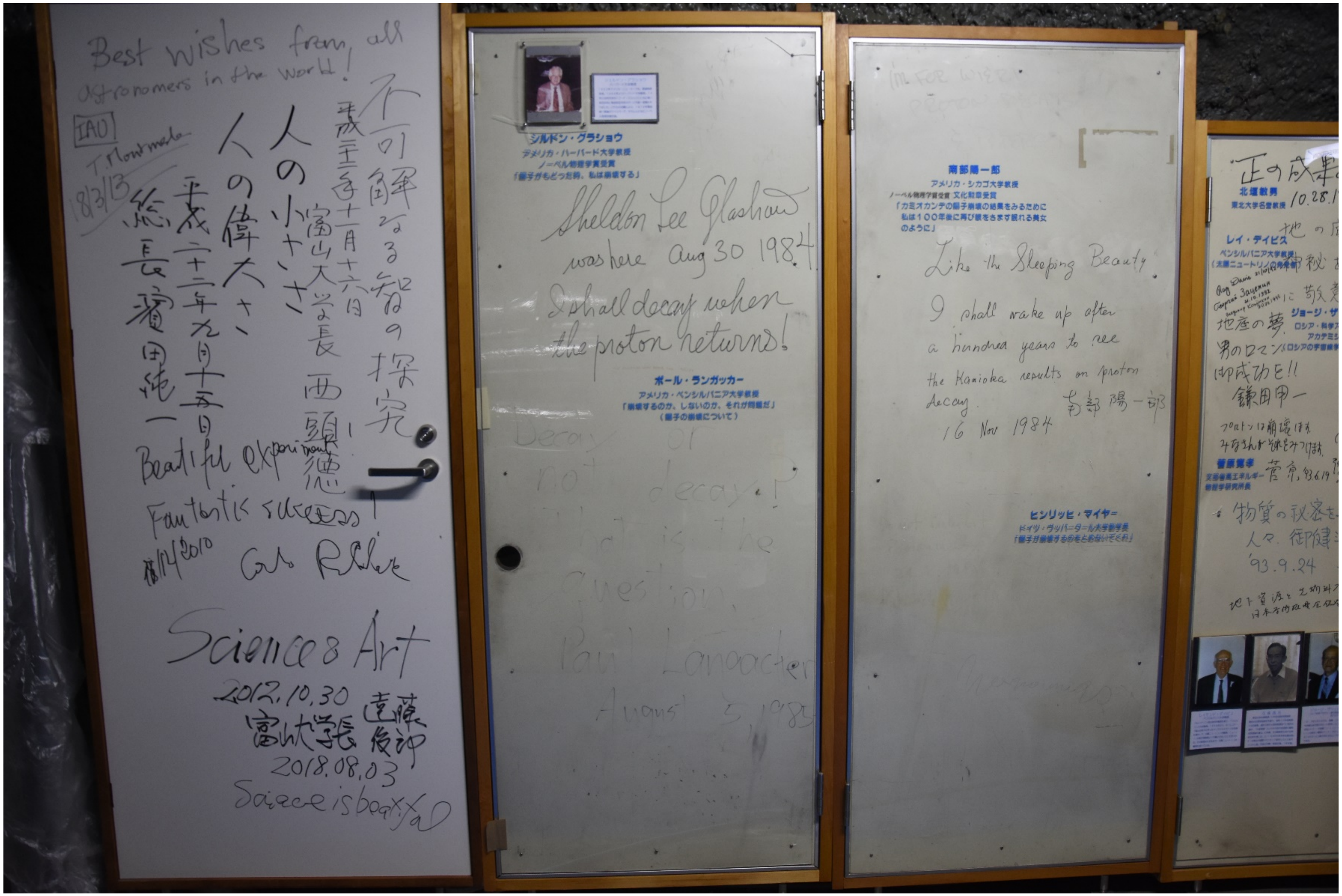
Exploring the Origin of Neutrino Masses

16

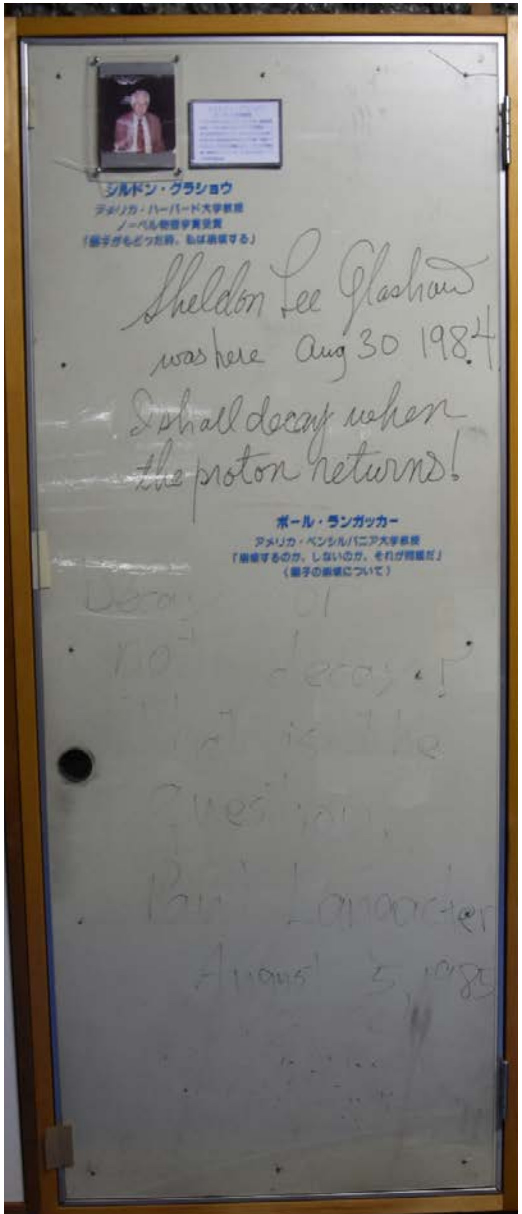


- A long way to go before we understand the origin of neutrino masses
- A decisive signal will be the discovery of B and L number violation (e.g., nucleon decays & 0νββ decays)
- Try different ideas, such as the detection of CνB and atomic/molecular systems

Sign doors at Kamioka



The first door at Kamiokande



Sheldon Lee Glashow
Aug.30, 1984

I shall decay when

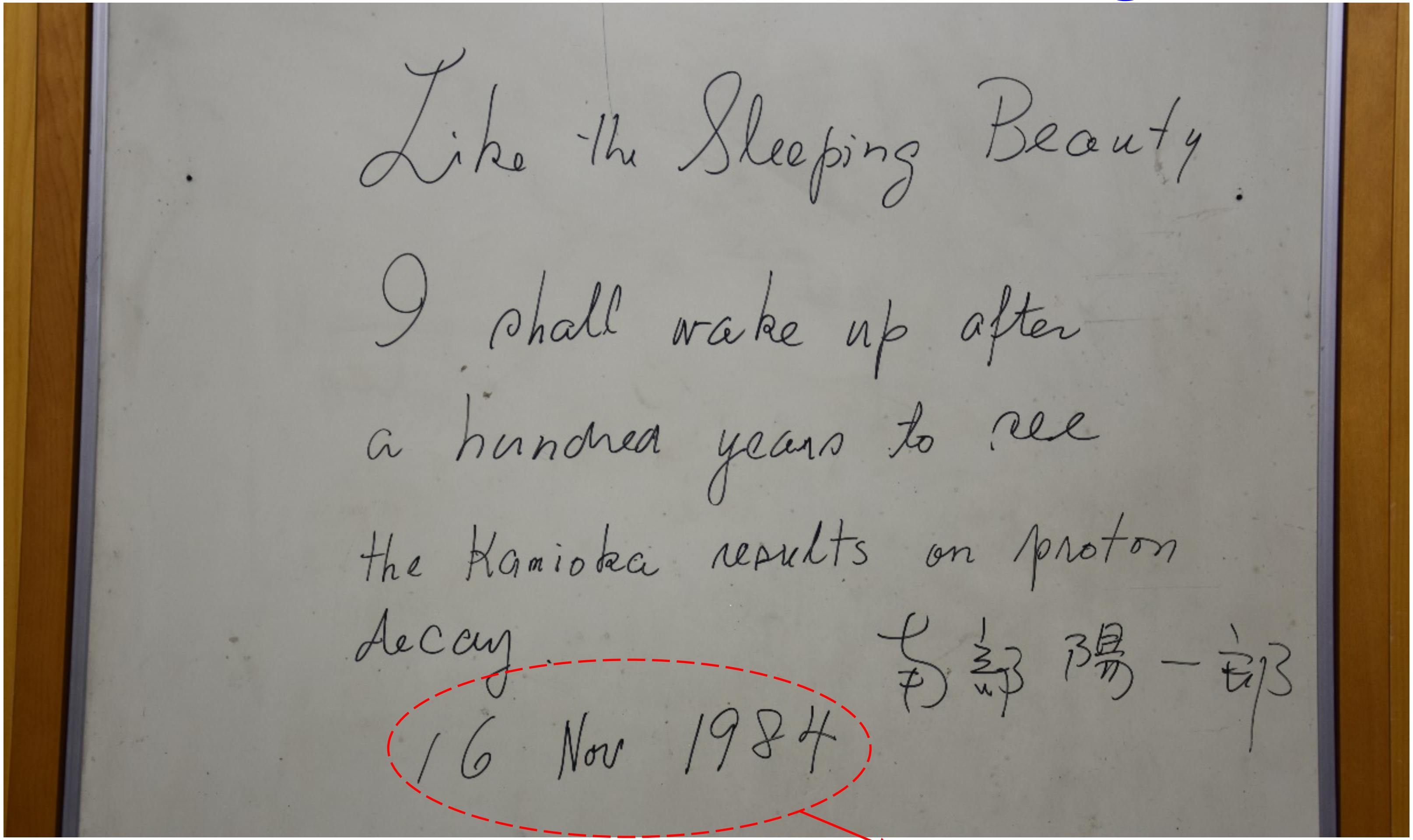
the proton returns!

Paul Langacker
August 5, 1985

Decay or not decay?

That is the question.

Yoichiro Nambu's sign



Kamiokande era

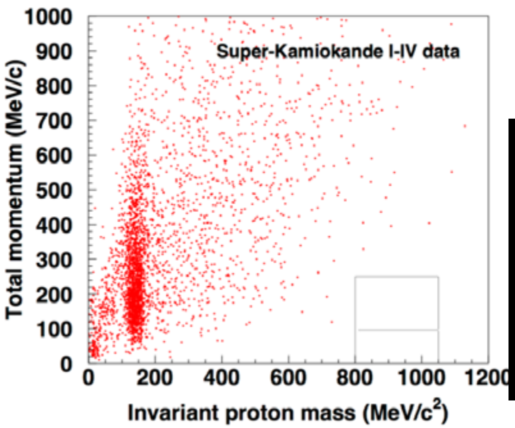
My interpretation

It would take a hundred years to discover proton decay, if you keep taking data with Kamiokande. You must make a much bigger detector.

A hundred years at Kamiokande = a few years at Hyper-Kamiokande

Proton decay current results

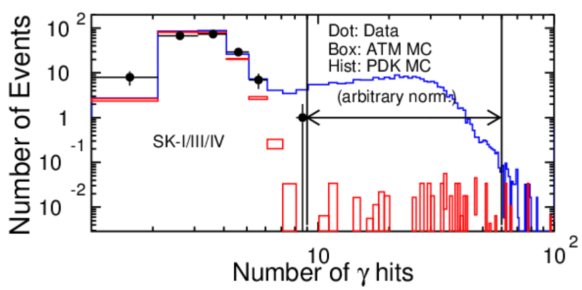
S. Mine

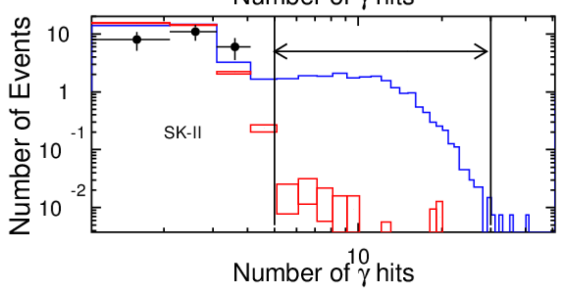


$p \rightarrow e^+\pi^0$ search result

$p \rightarrow e^+\pi^0$	Eff. (%)	BKG	OBS
Low P_{tot}	18.7	0.05	0
High P_{tot}	19.9	0.58	0
Total	38.6	0.63	0

- Total expected #BKG (SK I-IV) < 1:
  - confirmed with K2K ν beam data; PRD 77, 032003 (2008)
- No data candidate (SK I-IV 0.37 Mt·yrs)
  - $\tau/B_{p \rightarrow e\pi} > 2.0 \times 10^{34}$ years (90% CL)





$p \rightarrow \nu K^+$ search result

SK preliminary exposure (megaton·years): 0.09, 0.05, 0.03, 0.19

	SK1			SK2			SK3			SK4		
	Eff (%)	BG (ev)	Obs (ev)	Eff (%)	BG (ev)	Obs (ev)	Eff (%)	BG (ev)	Obs (ev)	Eff (%)	BG (ev)	Obs (ev)
Pr.γ	7.9 ±0.1	0.078	0	6.5± 0.1	0.082	0	7.5 ±0.1	0.018	0	9.4 ±0.1	0.12	0
$\pi^+\pi^0$	7.8 ±0.1	0.21	0	6.5± 0.1	0.19	0	8.3± 0.1	0.07	0	9.6 ±0.1	0.14	0

- No data candidate (SK I-IV 0.37 Mt·yrs)
  - $\tau/B_{p \rightarrow \nu K+} > 8.2 \times 10^{33}$ years (90% CL)

Mode	SNO+ Limits (years)	Current Limits
n	2.49×10^{29}	5.8×10^{29} [KamLAND]
p	3.56×10^{29}	2.1×10^{29} [SNO]
pp	4.68×10^{28}	5.0×10^{25} [Borexino]
pn	2.57×10^{28}	2.1×10^{25} [Tretyak et. al.]
nn	1.25×10^{28}	1.4×10^{30} [KamLAND]

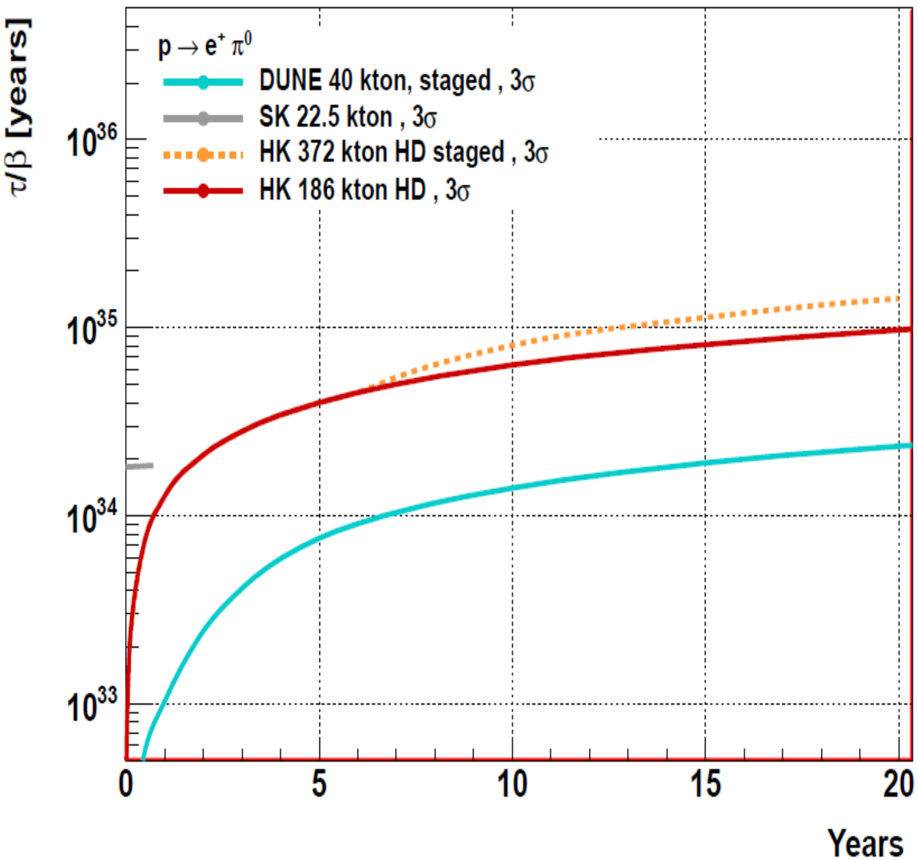
SNO+ limit on 3ν decay mode

M. Askins

Proton decay sensitivity of HK

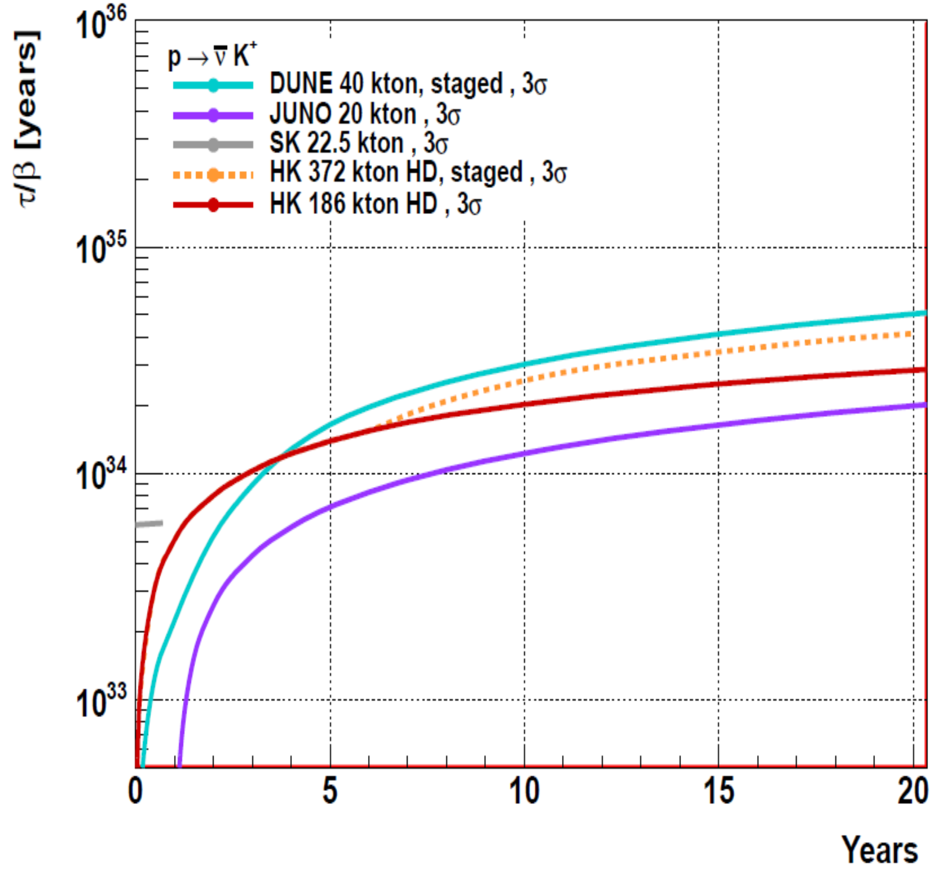
A. Pritchard

$p \rightarrow e^+\pi^0$



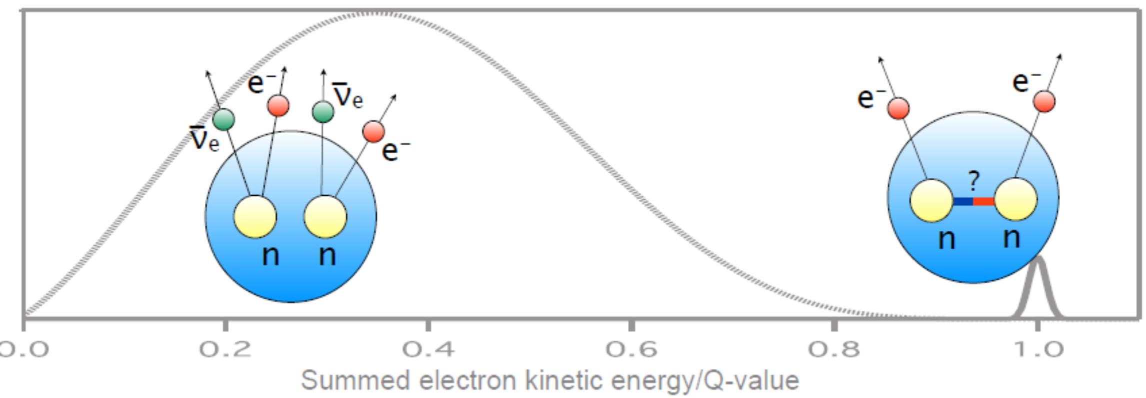
3σ discovery sensitivity:
τ/BR=10^{35} years

$p \rightarrow \nu K^+$

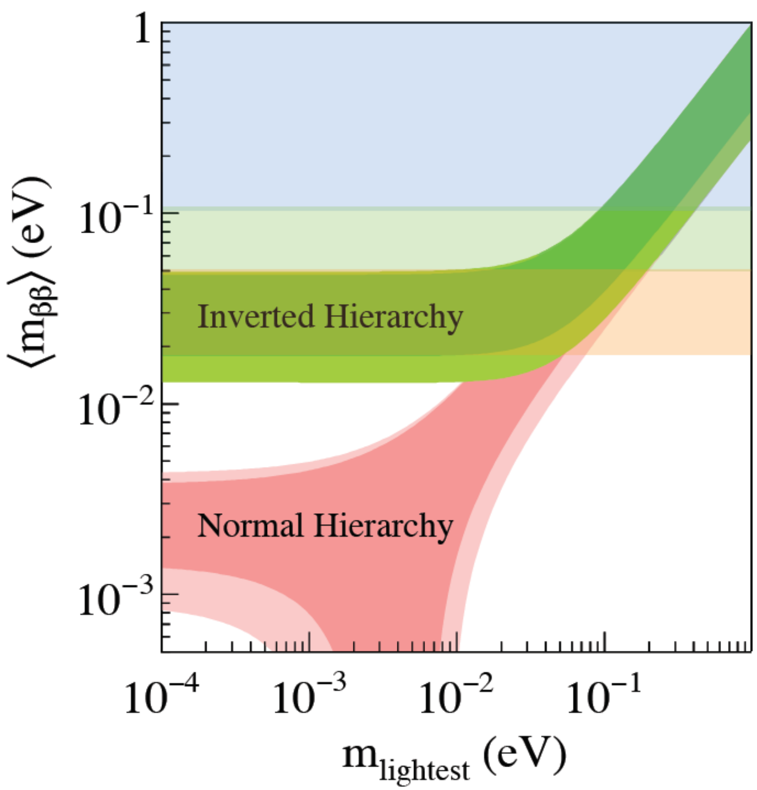


3σ discovery sensitivity:
τ/BR=3x10^{34} years

Double beta decay



Unique method to investigate Majorana feature of neutrino mass.



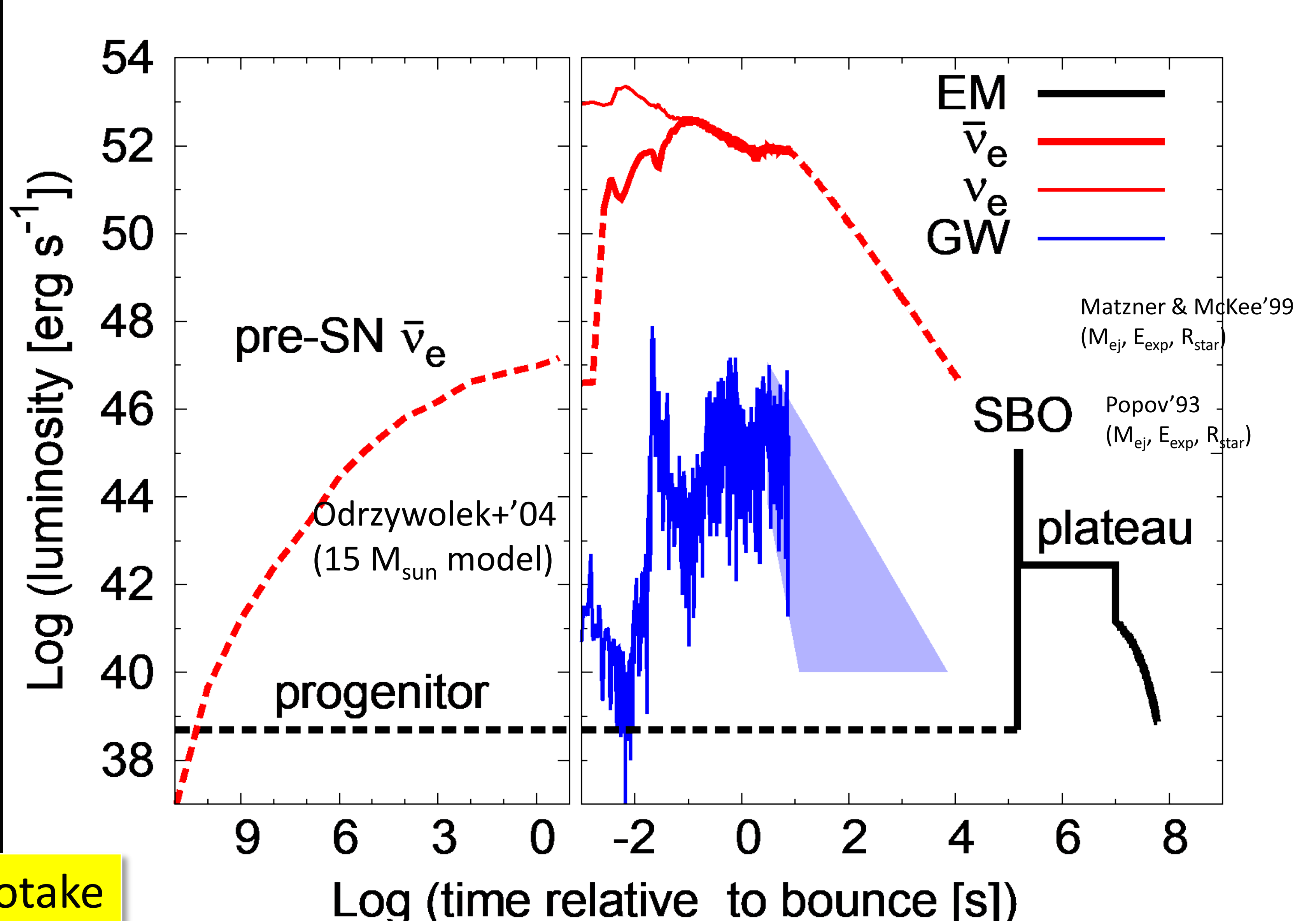
	Half life	Mass of isotopes
Past & present ~100meV →	10^{25}~10^{26}y	10~10^2kg
Near future ~50meV →	10^{26}~10^{27}y	10^2~10^3kg
Future ~20meV →	10^{27}~10^{28}y	10^3 kg~

A. Gando

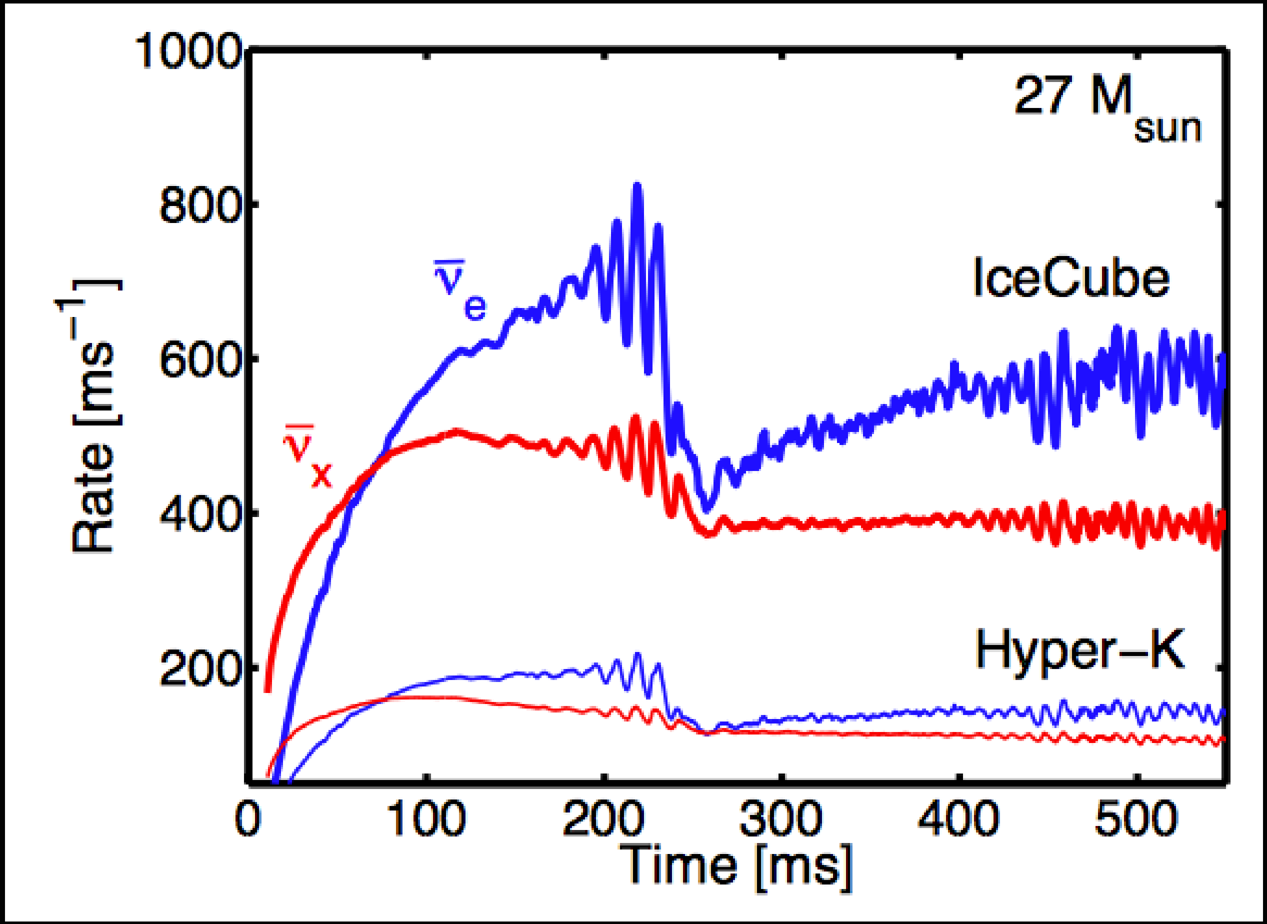
Summary of "multi-messenger signals" from exploding 17 M_{sun} star

Nakamura, Horiuchi, Tanaka, Hayama, Takiwaki, KK (MNRAS) 2016

Energetics: $E_{neutrino}$ ~10^{53} erg, $E_{kinetic}$ ~10^{51}erg, E_{photon} ~ 10^{49} erg, E_{GW} ~ 10^{46} erg



K. Kotake

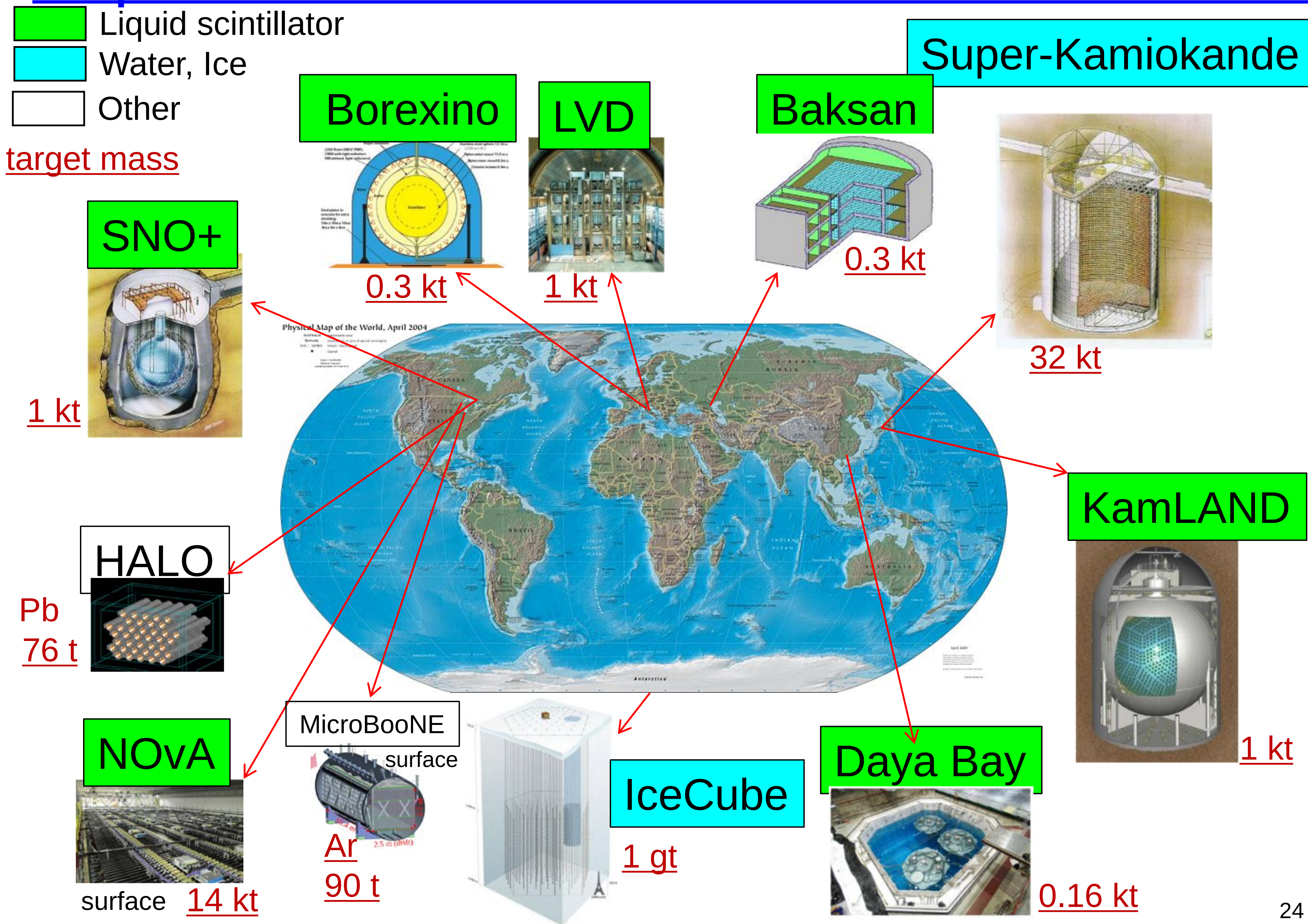


High frequency variation by SASI might be observed.

K. Kotake

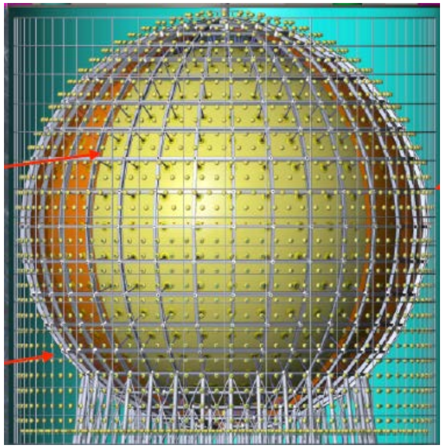
E. O'Sullivan

Supernova burst detectors in the world now



Supernova in Future Large Volume Detectors

JUNO(China)
(20kton Liq. Sci.)

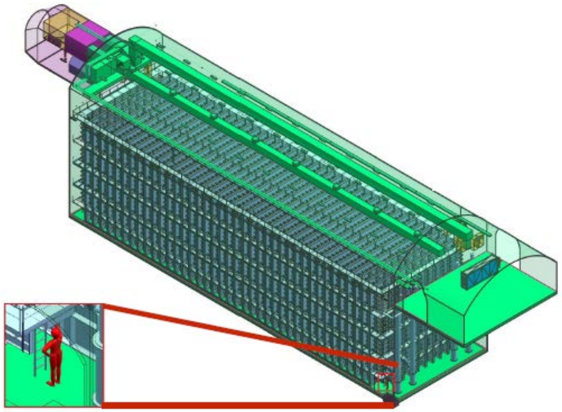


Precise measurement of average energy and luminosity for all neutrino flavors.

~1% for <E> for $\bar{\nu}_e$
~10% for <E> for ν_e
~5% for <E> for ν_x

A. Garfagnini

DUNE/LBNF (US)
(40 kton Liq. Ar)

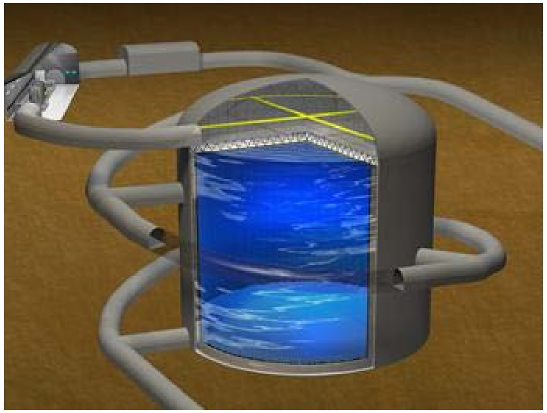


$\nu_e + {}^{40}Ar \rightarrow e^- + {}^{40}K^*$ is the dominant interaction.

~4000 events for 10kpc SN. ~60 events from neutronization burst for IO case (~0 for NO).

A. Sousa

Hyper-Kamiokande
(220 kton Water)



50~80k $\bar{\nu}_e p$ for 10 kpc SN.
2~3k events for LMC,
~10 events for M31.

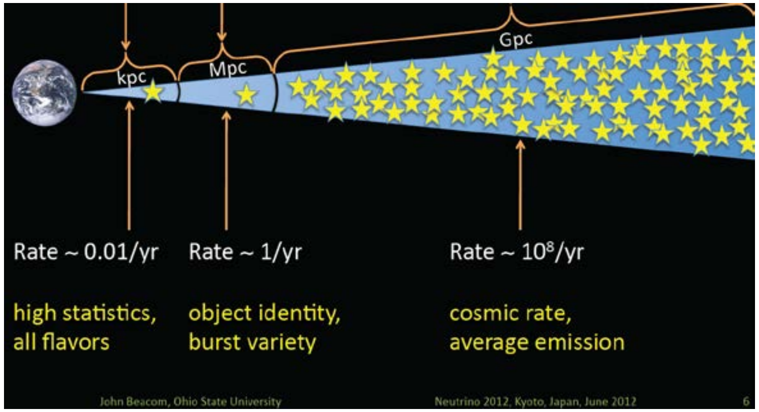
Precise measurement of time variation (e.g. SASI).

3~4k ν+e gives ~1 deg. pointing accuracy.

A. Pritchard
E. O'Sullivan

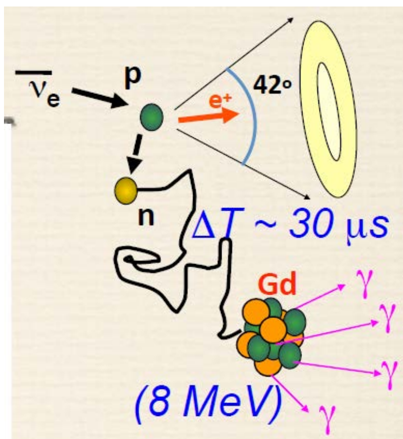
Diffuse supernova ν in SK-Gd

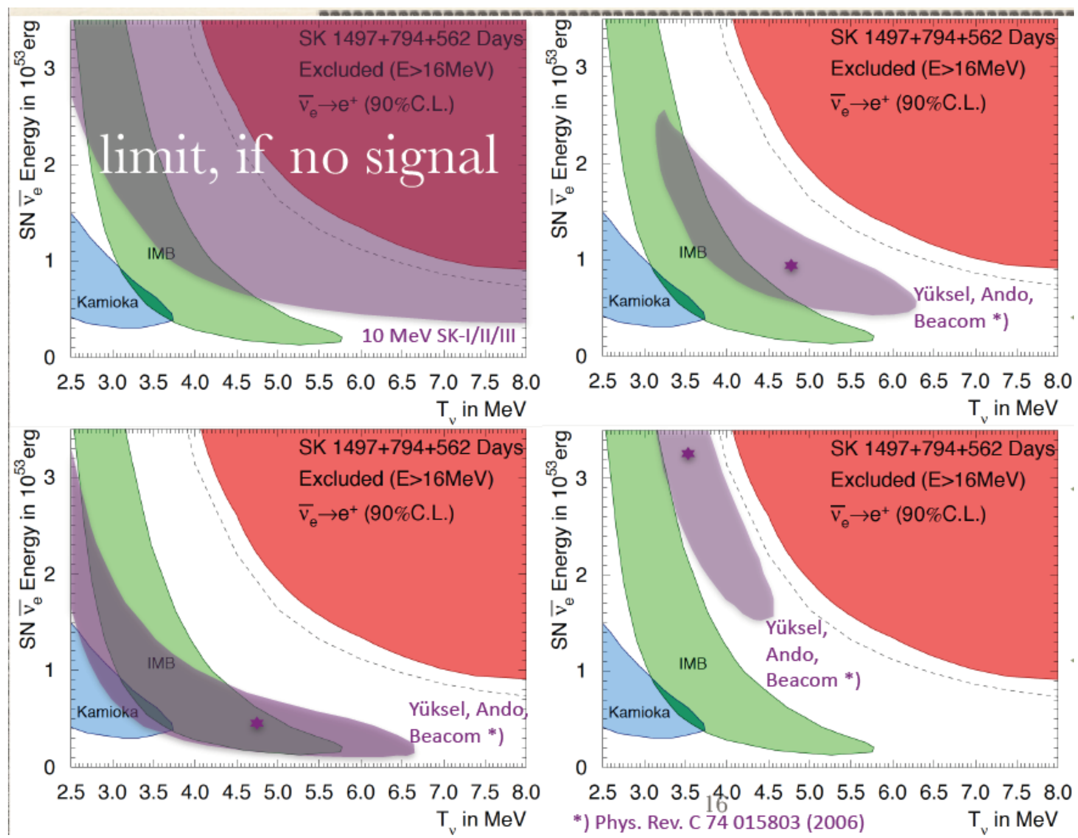
M. Smy



↓Expected # of signals and backgrounds through SK-Gd 10 years observation

HBD model	10–16 MeV	16–28 MeV	Total	significance
T_{eff} = 8 MeV	11.3	19.9	31.2	5.3 σ
T_{eff} = 6 MeV	11.3	13.5	24.8	4.3 σ
T_{eff} = 4 MeV	7.7	4.8	12.5	2.5 σ
T_{eff} = SN1987A	5.1	6.8	11.9	2.1 σ
BG	10	24	34	–



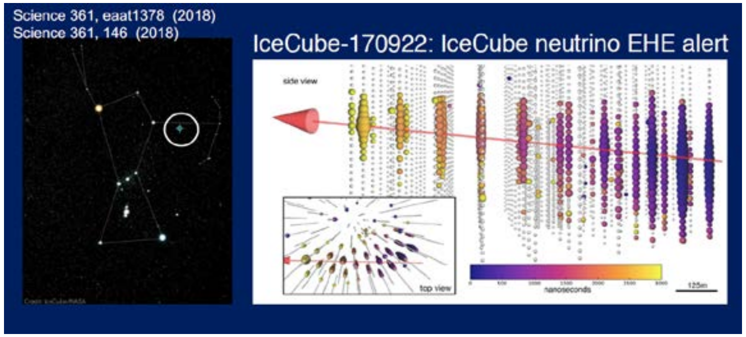


Similar sensitivity
expected at JUNO too.

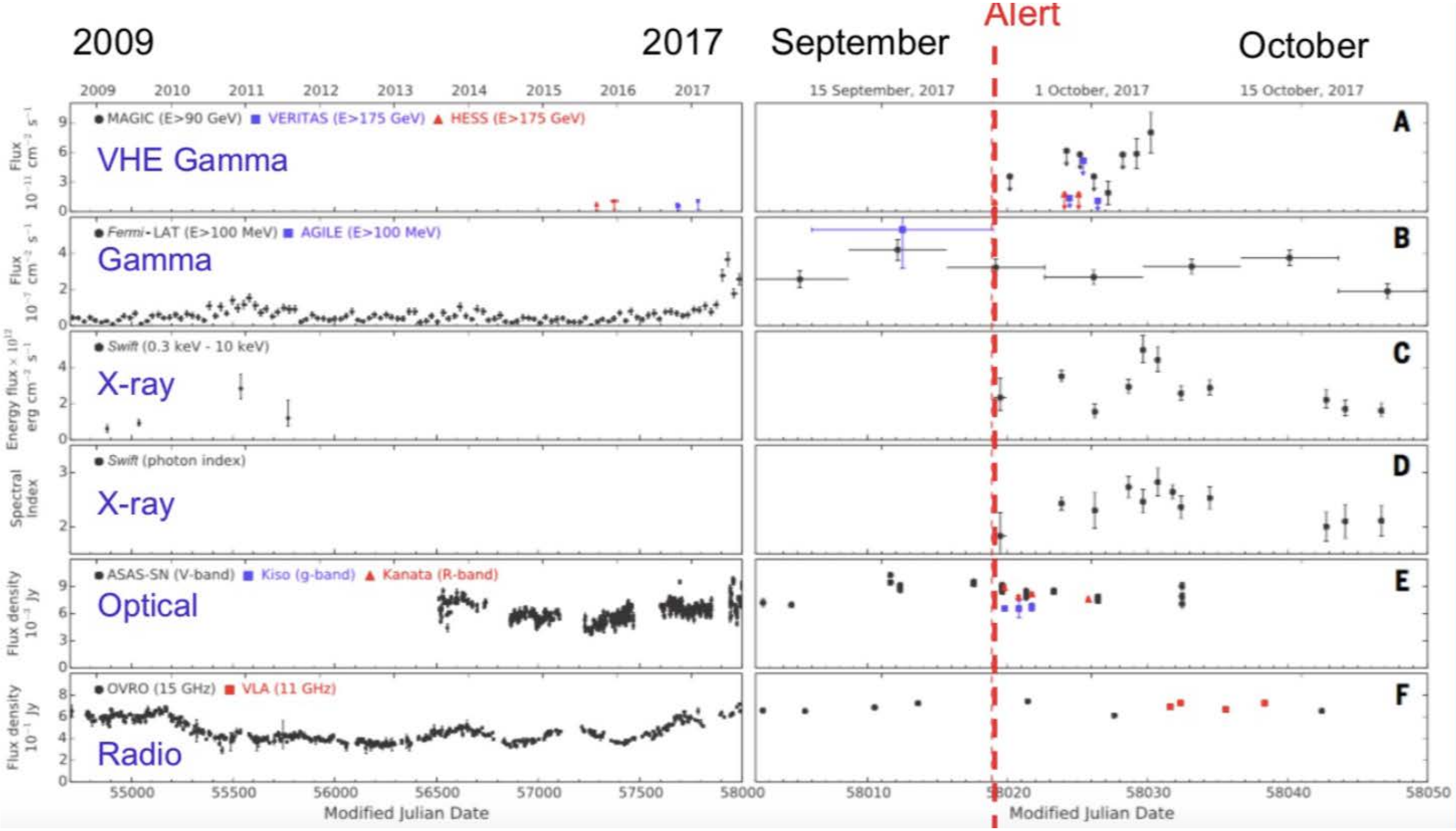
Multi-messenger Astronomy

Opening a new window

J. Kiryluk

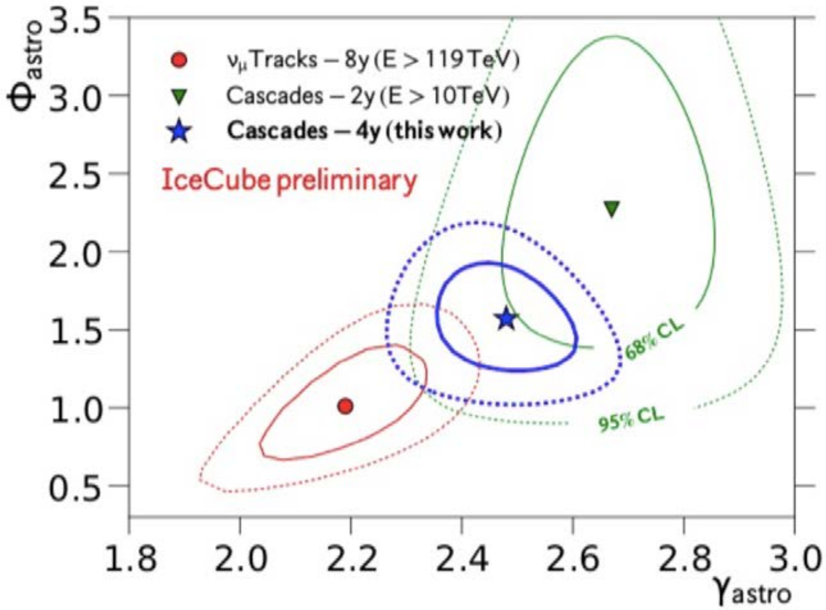


On 22 September 2017 IceCube detected a ~290-TeV neutrino from a direction , as reported by Fermi-LAT on September 28 2017, consistent with the flaring g-ray blazar TXS 0506+056.



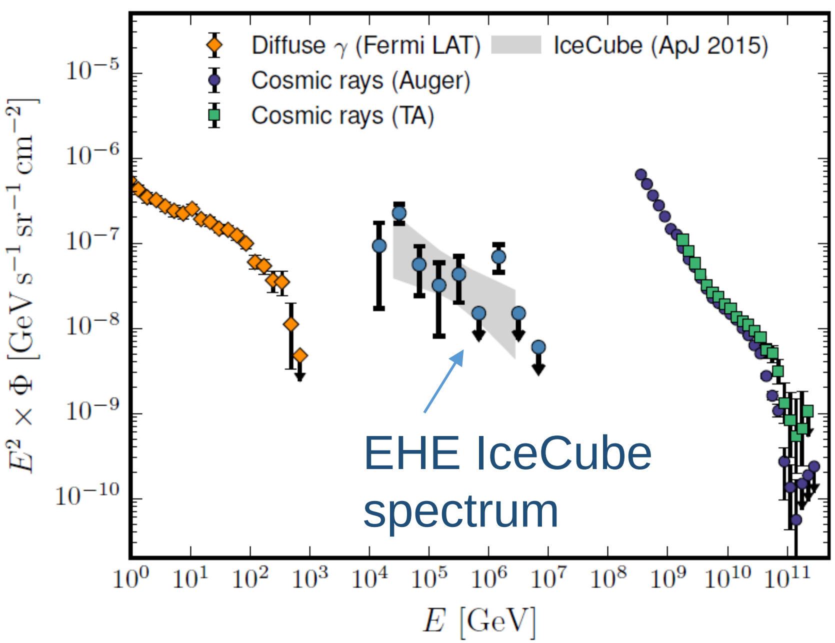
High energy neutrino astronomy by IceCube

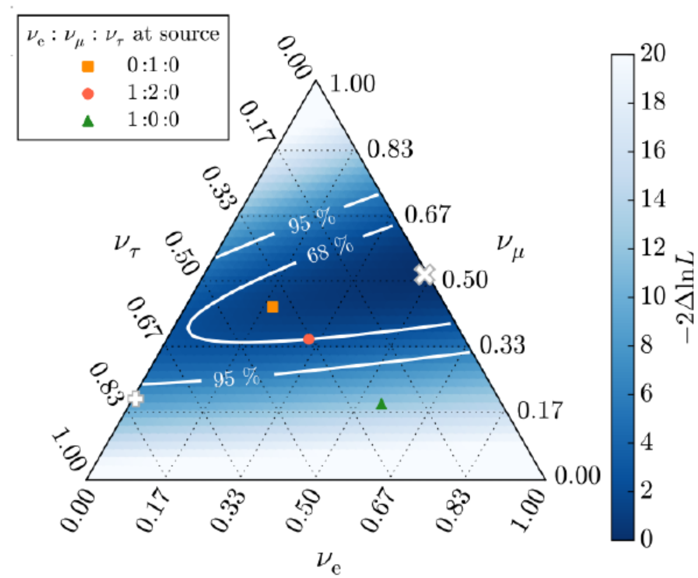
J. Kiryluk



Spectrum index depends on event type.

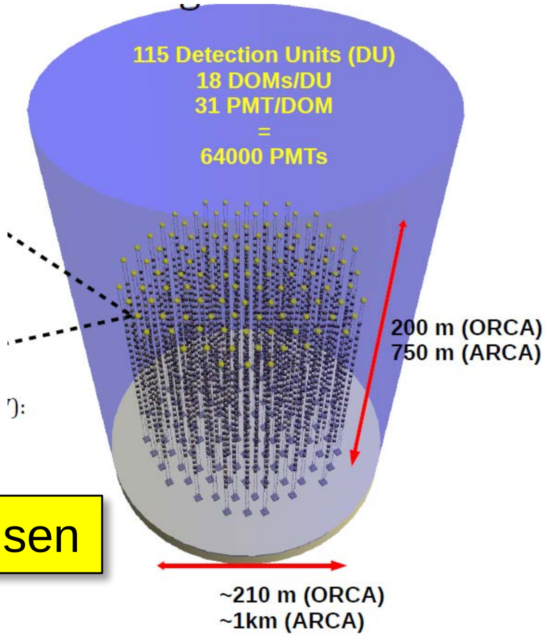
J. Hignight





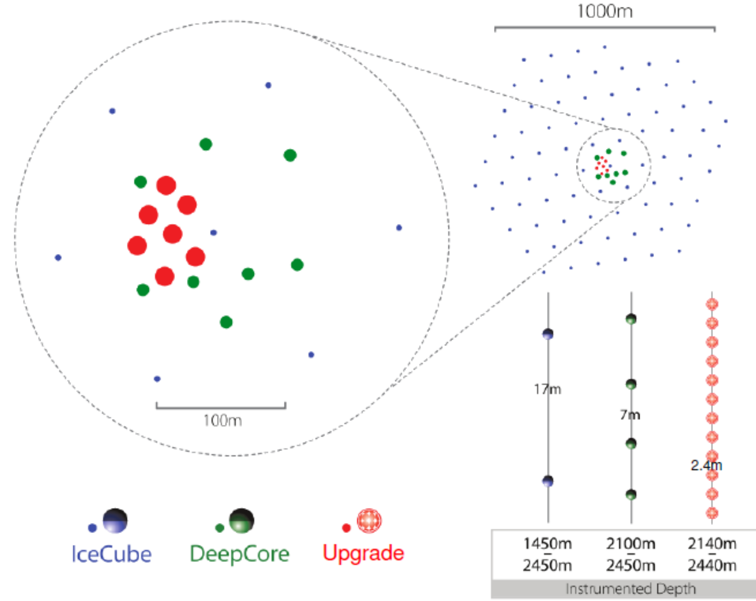
High Energy Neutrino Astrophysics: Future

KM3NeT/ARCA

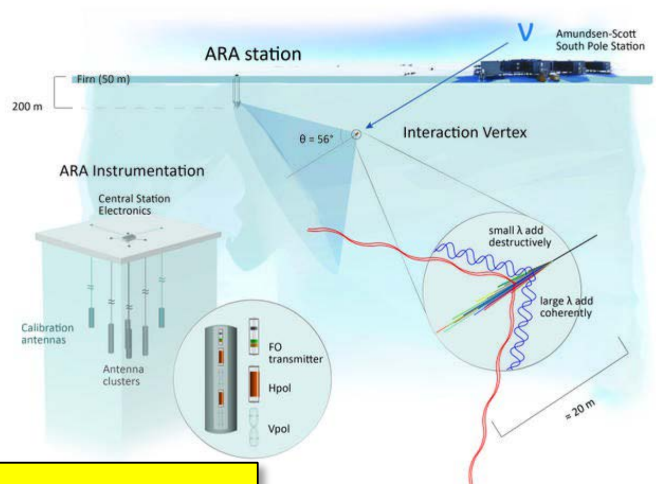


C. Nielsen

IceCube Upgrade

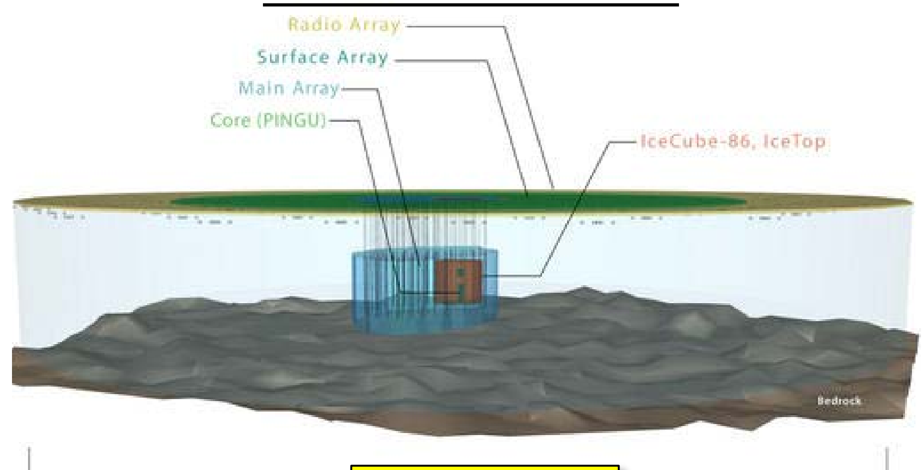


ARA



N. Whitehorn

IceCube-Gen2



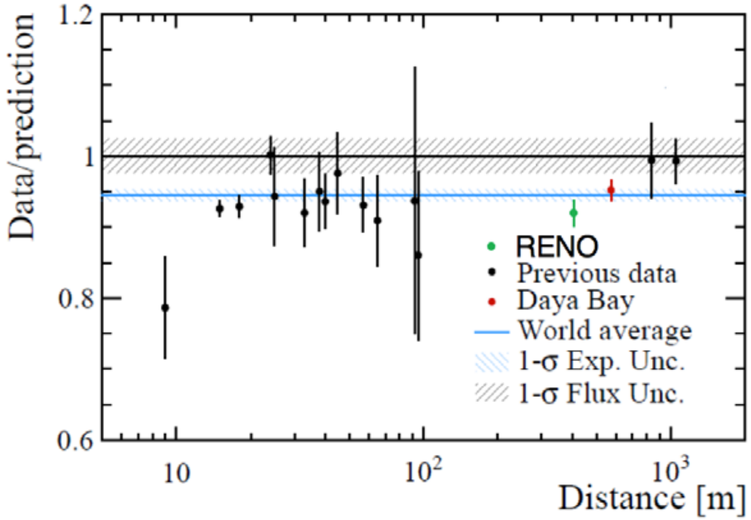
J. Hignight

Anomalies

Anomalies (problems) are important for future discoveries, e.g. "solar neutrino problem" in the Homestake experiment and atmospheric ν anomaly in Kamiokande.

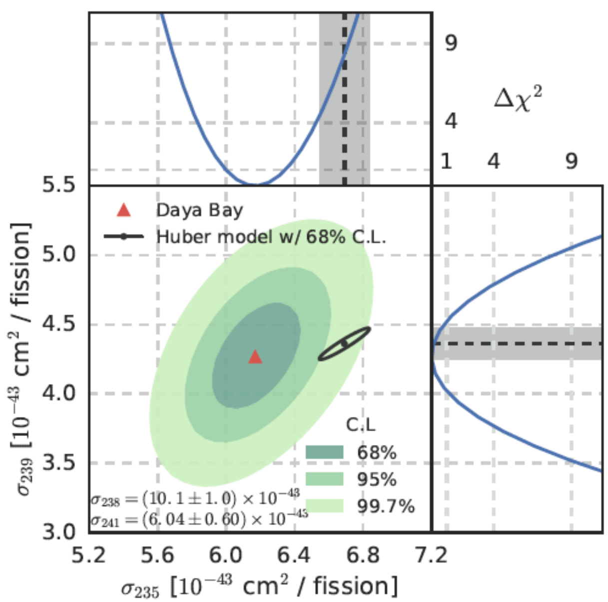
Reactor Anomaly

H. Band

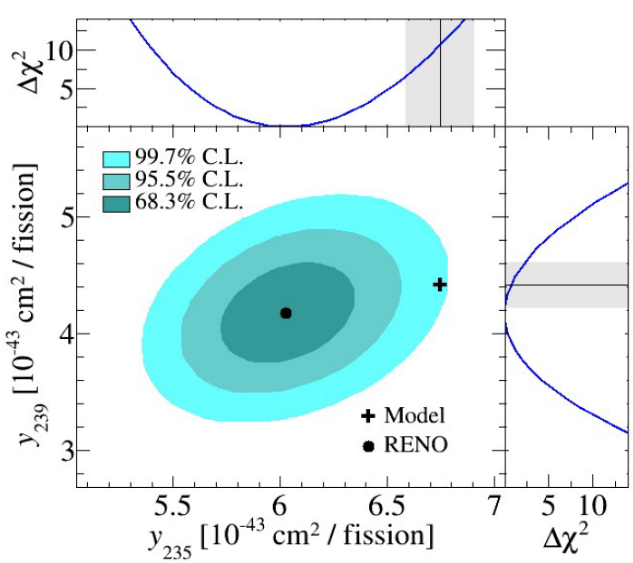


Composition of the reactor core change with time.
^{239}Pu yield is consistent with model.
^{235}U yield disagree with the model at ~3σ level.
This result suggests that this isotope may be the primary source of the anomaly.

Daya Bay

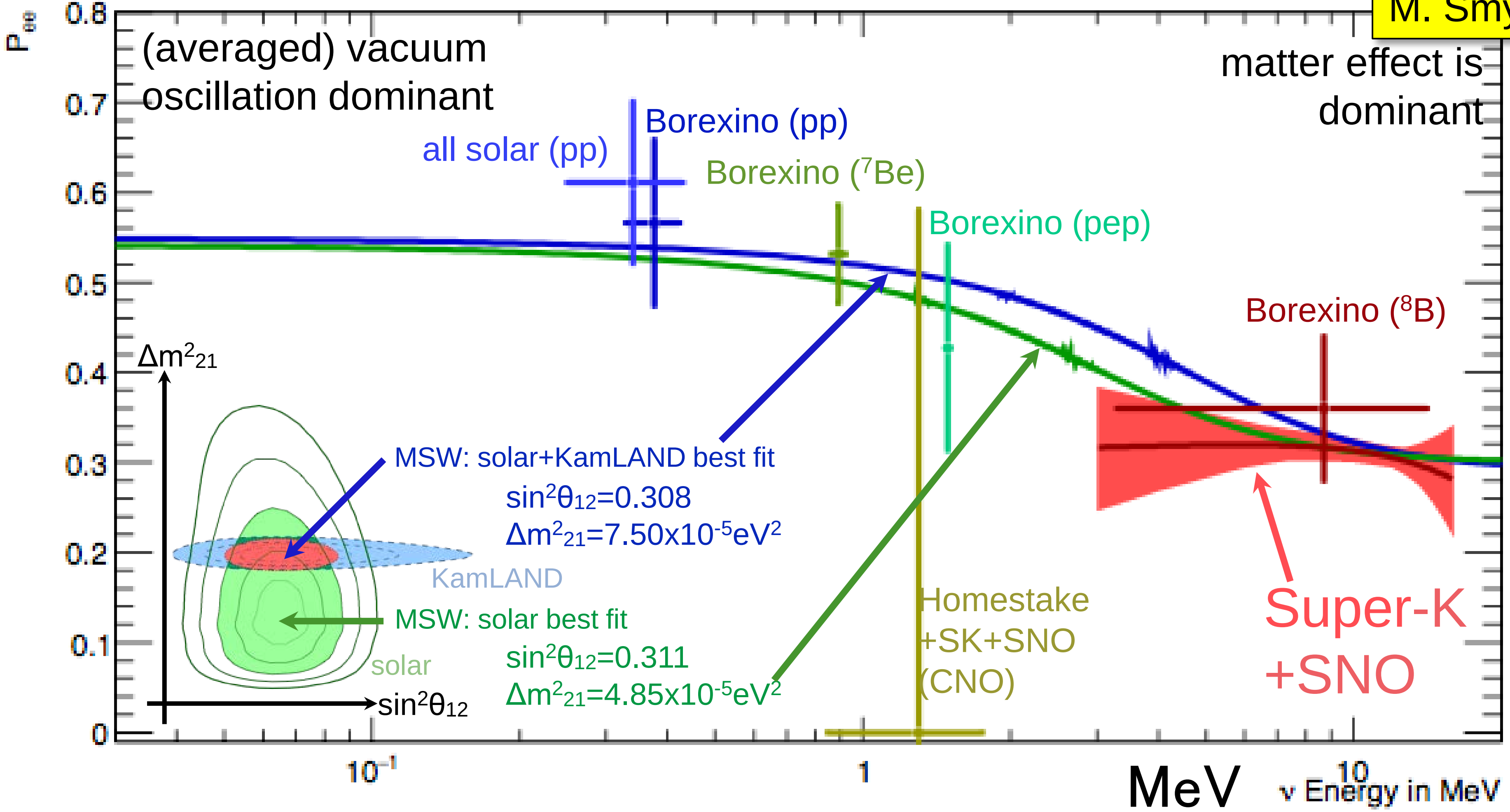


RENO



New Solar Neutrino Problem?

M. Smy



Tension in Δm^2_{21} between reactor and solar neutrinos.
In future, spectrum and day/night measurements by Hyper-K and JUNO should solve the issue.

A. Garfagnini

E. O'Sullivan

SNO+ and Borexino has potential to measure CNO neutrinos.

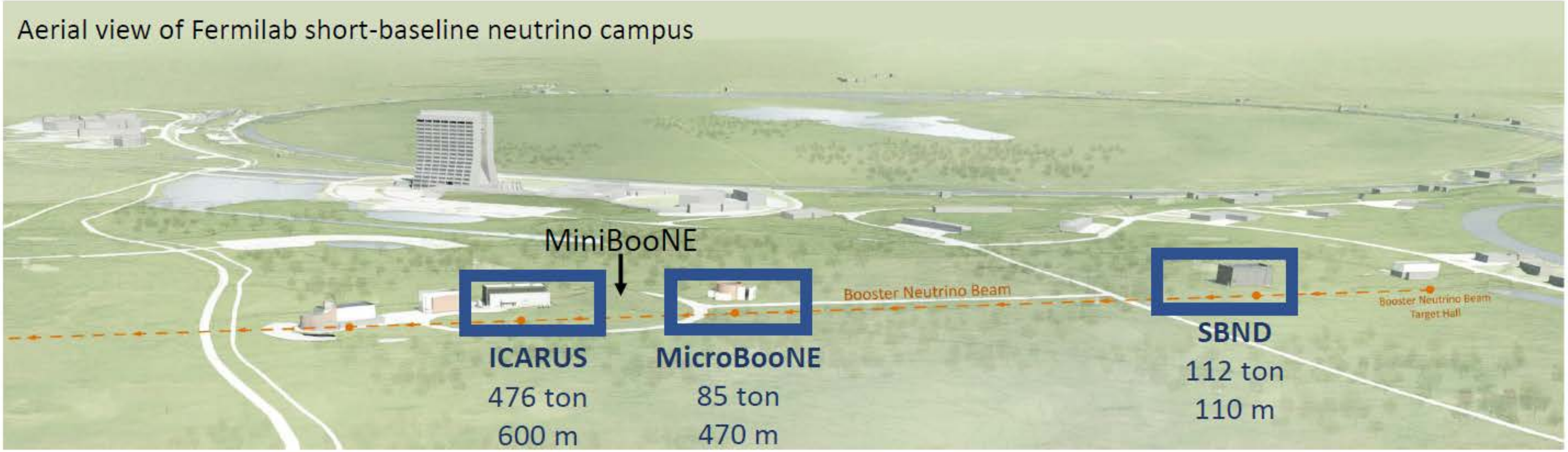
E. O'Sullivan

LSND/MiniBooNE anomaly

Fermilab SBN program

B. Russell

Staged approach to address short baseline anomalies
Phase 1: MicroBooNE – definitive test of the MiniBooNE low energy excess
Phase 2: SBND + MicroBooNE + ICARUS – ν_e appearance and ν_μ disappearance searches



Analysis of MicroBooNE data is on-going. We hope to see phase 1 results in near future.

SBND: Detector construction on-going.
Plan to begin taking data in 2020

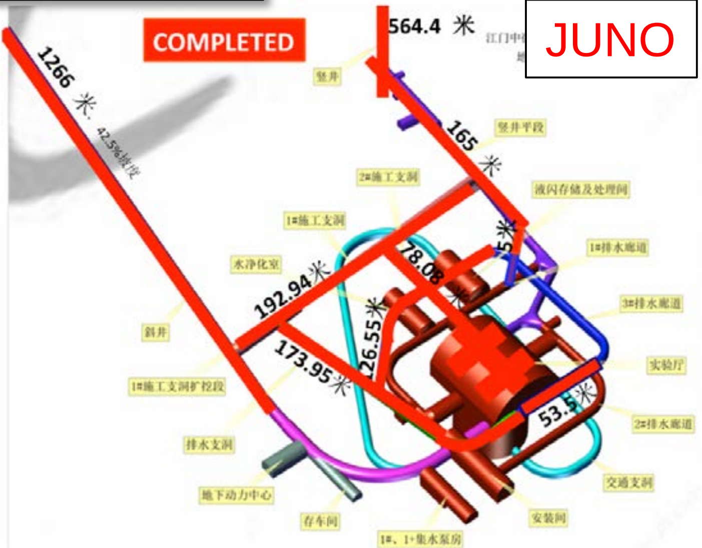
ICARUS: Currently instrumenting and commissioning the detector
Plan to begin taking data in 2019

New underground sites

A. Garfagnini

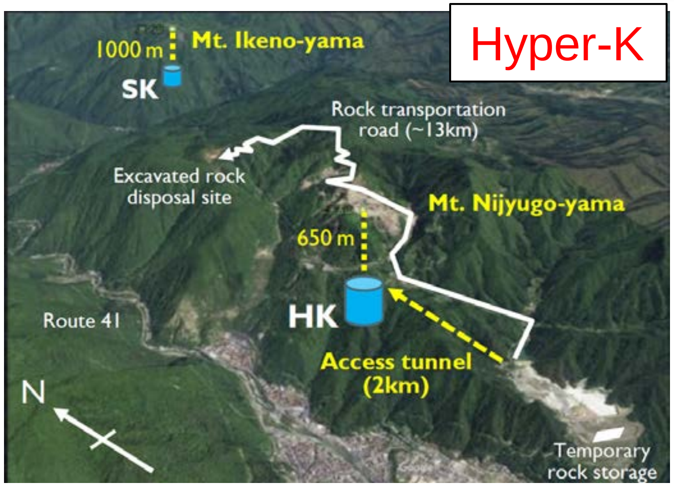
S. Nakayama

JUNO



~700 m underground

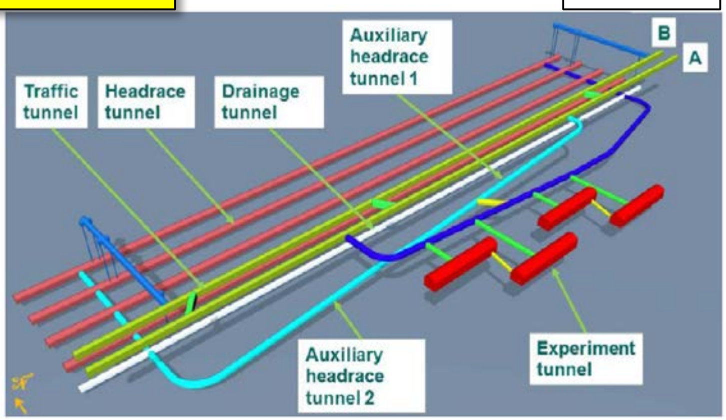
Hyper-K



650 m underground

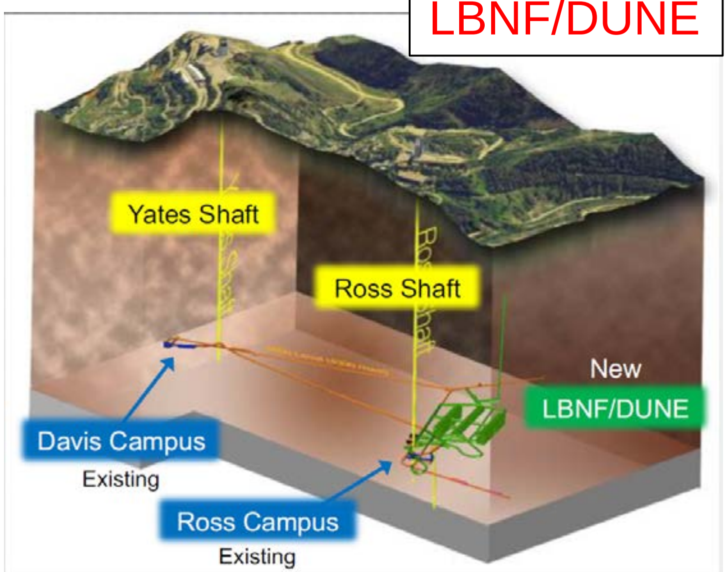
J. Tang

CJPL



2400 m underground

LBNF/DUNE



1475 m underground

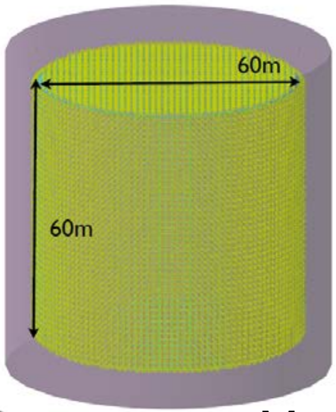
Development for possible future large volume detectors

G. D. Orebi Gann

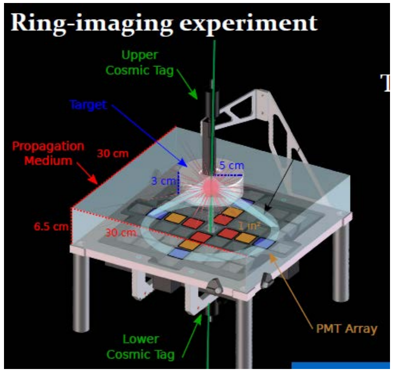
Theia

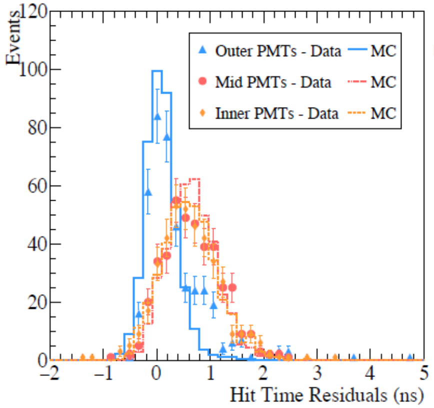
- Large-scale detector (50-100 kton)
- Water-based LS target
- Fast, high-efficiency photon detection with high coverage
- Deep underground (e.g. Homestake)
- Isotope loading (Gd, Te, Li...)
- *Flexible*! Target, loading, configuration

➡ **Broad physics program!**



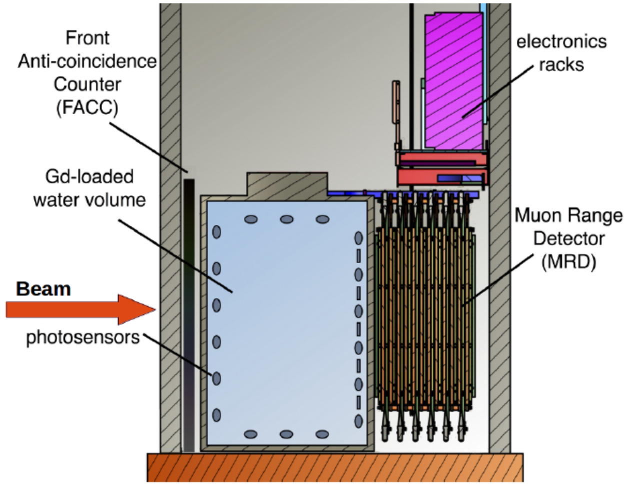
Development of water-based LS





More interesting plots. See Dr. Gann's presentation

ANNI



V. Fischer

Pure water fill
Spring 2019
→ **Commissioning**

Gadolinium loading
Spring 2019 - Summer 2020
→ **Physics data taking**
→ Neutron yield measurement
→ CC cross section measurement
→ CC0π cross section measurement

Additional LAPPDs
Fall 2020
→ More detailed reconstruction of multi-track final states and pions
→ Possible NC cross section measurement

Phase III
~2021
→ **Testbed for new technologies**

Conclusion

- Fantastic neutrino physics in last 20 years.
- We expect another interesting ~20 years.
- Let's continue to enjoy neutrino physics.
- Hope to discover proton decays and double beta decays sometime in future.