The Progress of Neutrino Detection

A visual representation of the technology and capability of neutrino experiments and their evolution.

Neutrino Detection. The beginning. (1950 - 1975)

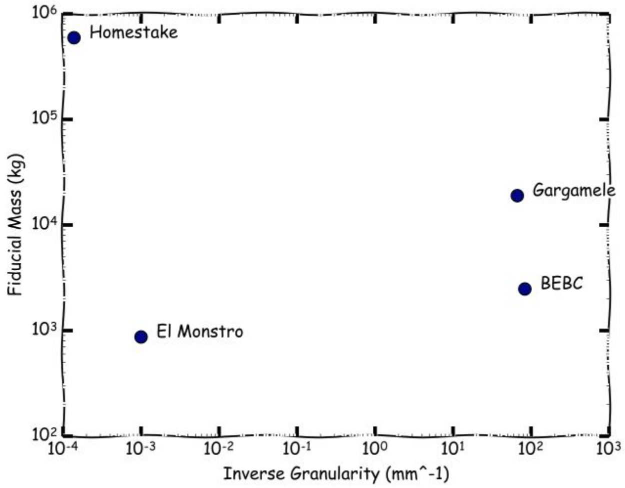
Early Detectors

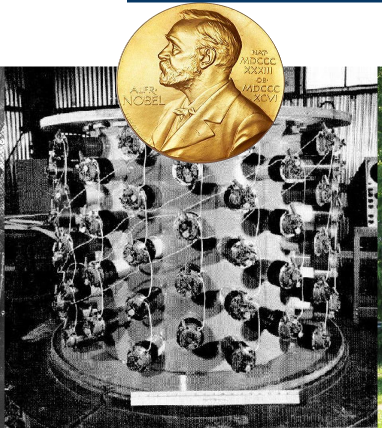
- El Monstro/Hanford
  - Small active volume
  - No spatial reconstruction
  - Liquid Scintillator
- HomeStake
  - No timing information.
  - No spatial reconstruction
  - Large active volume
    RadioChemical detector

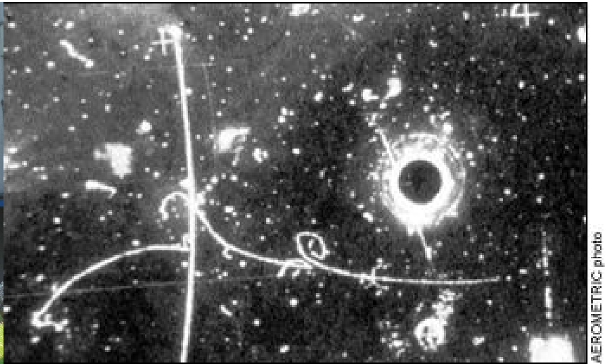
The Bubble Chambers

- Gargamel, BEBC, Fermi/
  Argon Bubble Chamber
  - Great Spatial Resolution
  - Slight risk of explosion.
    - Limited Mass (Liquid Hydrogen has problems).

The Big Questions
Do neutrinos exist?
How do they interact?

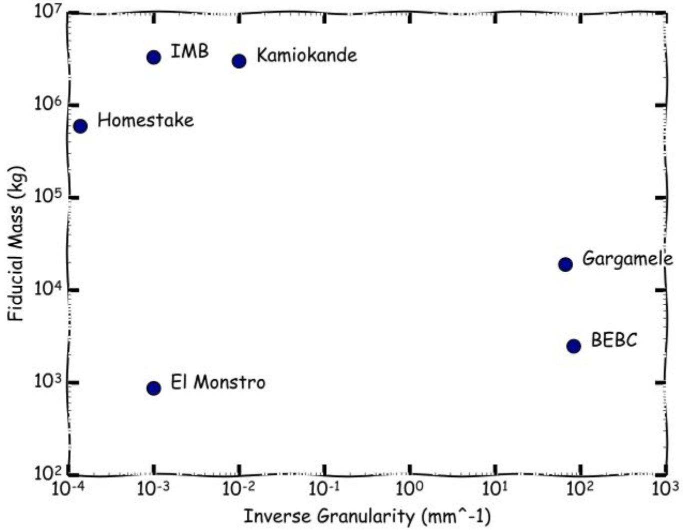






1975 - 1980

The emergence of Water Cherenkov detectors



Baksan:

- BUST - Investigation of cosmic rays including atmospheric neutrino flux variation + neutrino bursts from galactic stars collapses
- GGNT (SAGE) - Measurement of solar neutrino flux - pioneer in use of Ga metal

The first limits on parameters of neutrino oscillations (1985-1990): Dm2 < 6e-3 eV2 (2 types of neutrino)

IMB:

- A pioneer of WC technology, with many components being recycled in later WC experiments

IMB & Kamiokande:

- Designed to search for proton decay
- Neutrinos secondary
- Together with Baksan detected Supernova 1987a through increase of neutrino flux (normal rate of detection 1/week; during Supernova explosion: 8 in a few seconds; Kamiokande - 11 events; Baksan - 5 events)

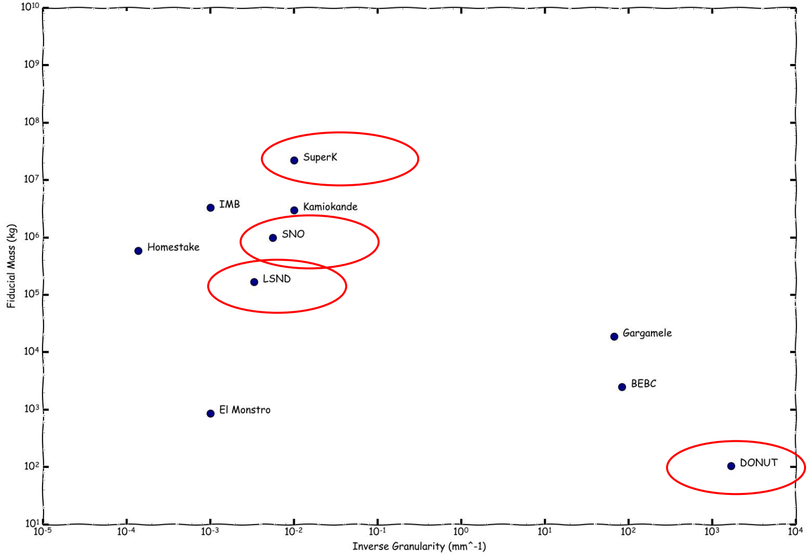
The Big Questions
Solar Neutrino Problem

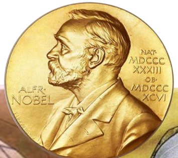
IMB

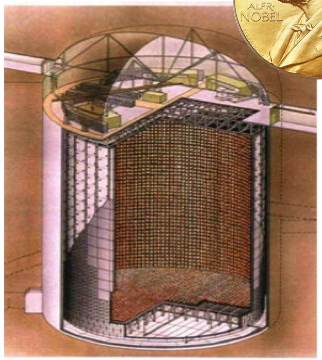
Baksan BUST

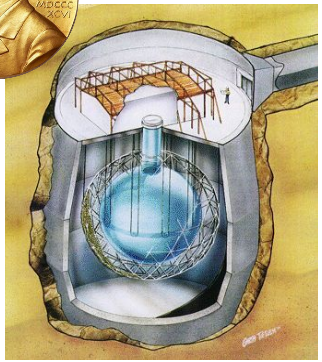
KamiokaNDE model

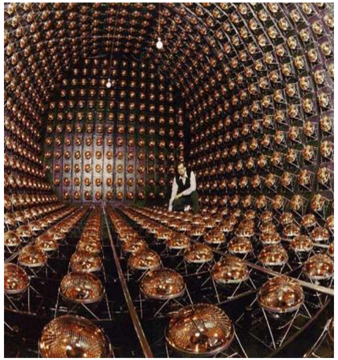
1990 - 2000











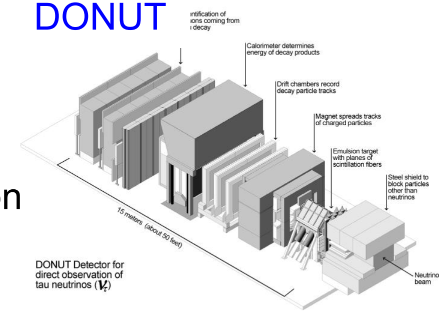
SuperK SNO

- Water Cherenkov detectors
- ~100 mm granularity
- Joint Nobel prize for atmospheric and solar neutrino oscillation

LSND

- Liquid scintillator detector
- Trouble in 3-flavor paradise?

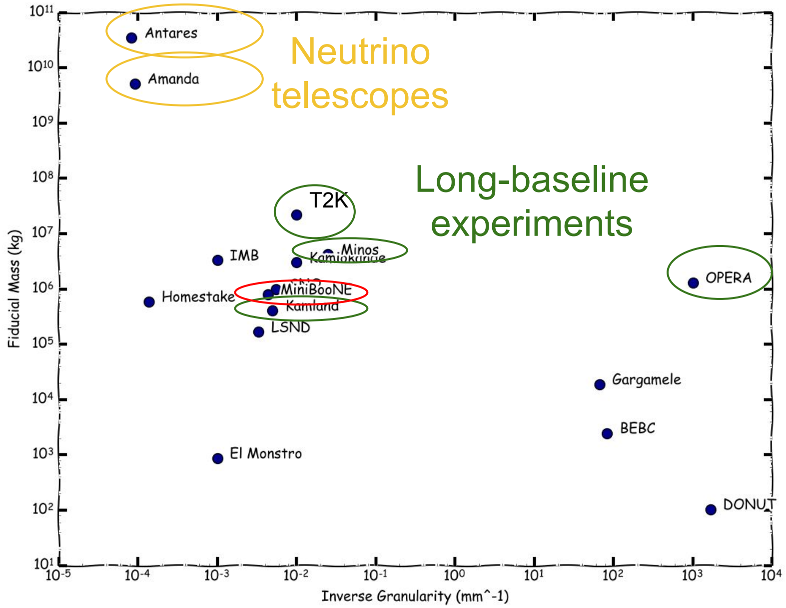
DONUT



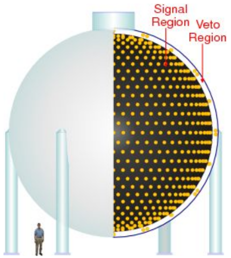
- Nuclear emulsion detector
- Sub-micrometer track resolution
- Direct tau neutrino observation

The Big Questions
Solar Neutrino Flux
Atmospheric Neutrinos
Third generation?

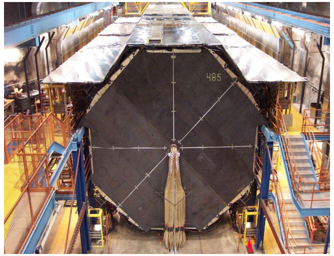
2000-2010



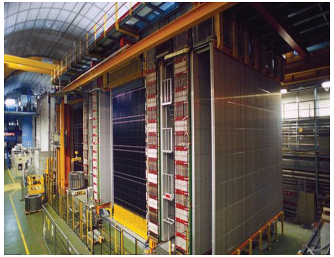
The Big Questions
Oscillation picture
Neutrino astronomy



MiniBooNE



MINOS



OPERA

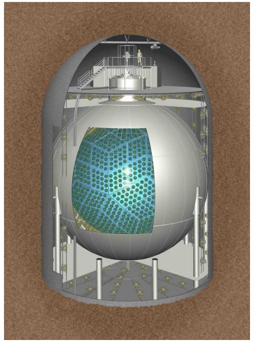
- Muon neutrino beams

MiniBooNE:
- Miniral oil Cherenkov detector
- Electron neutrino appearance

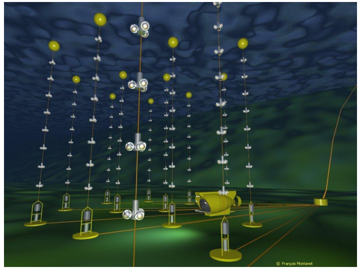
MINOS:
- Iron / scintillator calorimeter (magnetized)
- Three-flavor oscillations and beyond

OPERA:
- Nuclear emulsion + scintillator (magnetized)
- Observed muon to tau neutrino oscillation

KamLAND
- Liquid scintillator detector
- Reactor electron antineutrino beam



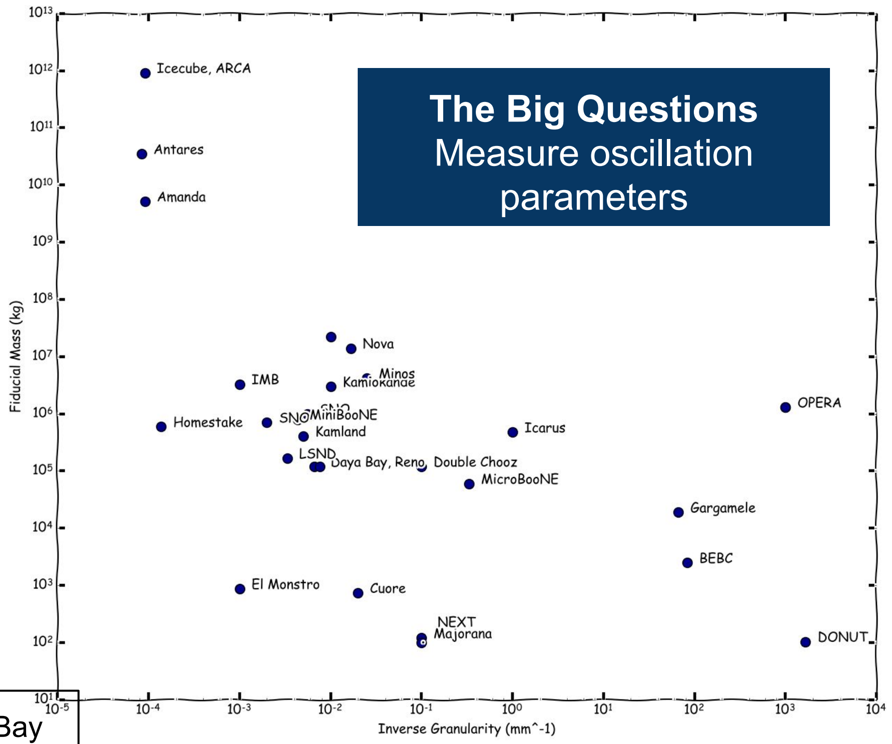
AMANDA, ANTARES



- Water Cherenkov detectors

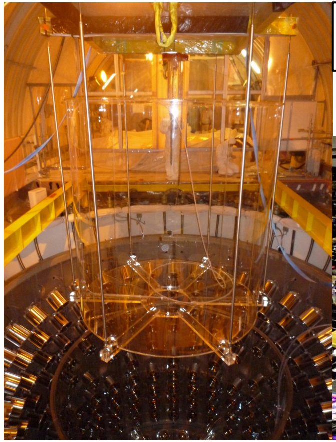
2010 - present

- **IceCube** - First km3-sized detector; WC; detected neutrinos originated outside of Solar System (cost - $279 mln);
- **Daya Bay, Double Chooz** - short baseline reactor neutrino oscillation experiments. Liquid scintillator near and far detectors;
- **NOvA** - long baseline, LS near and far detectors 810 km apart, NuMI beam at Fermilab. Search for both muon neutrino disappearance and electron neutrino appearance due to neutrino oscillations;
- **MicroBooNE** - liquid argon time projection chamber. Studying MiniBooNE low energy excess & low energy neutrino-argon cross sections



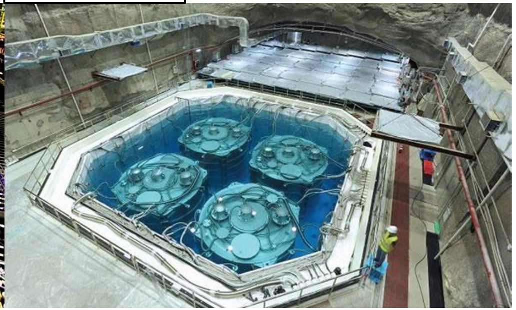
The Big Questions
Measure oscillation parameters

Double Chooz

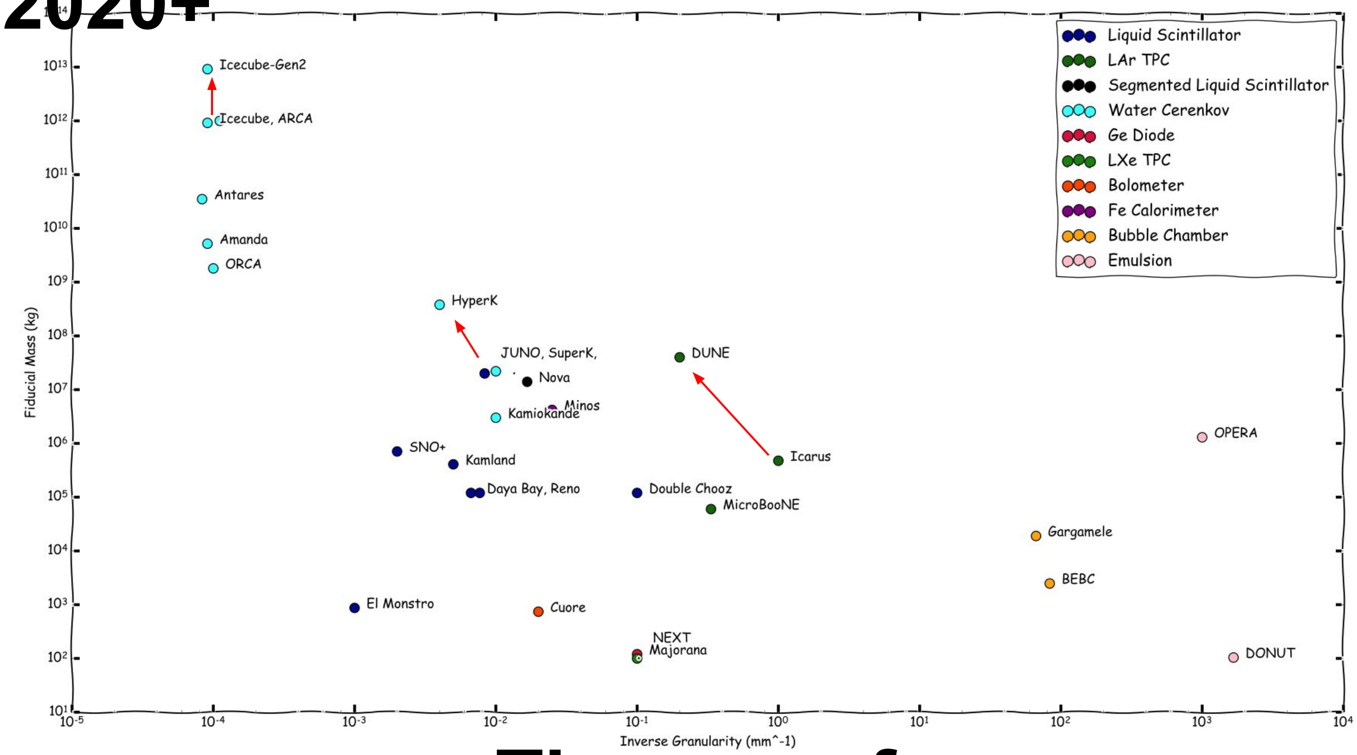


NOvA

Daya Bay



2020+



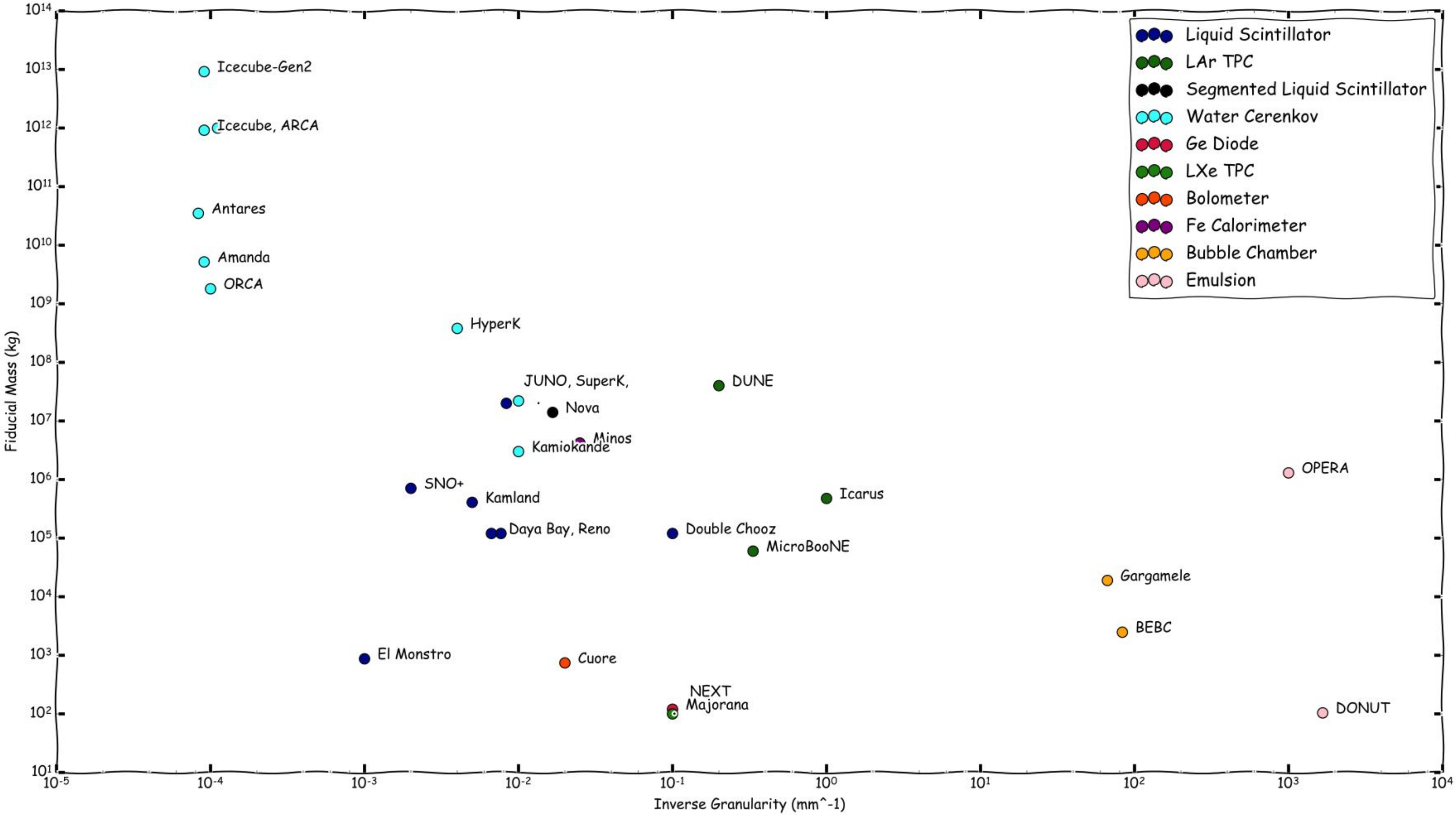
The age of

BIGGER IS BETTER!!

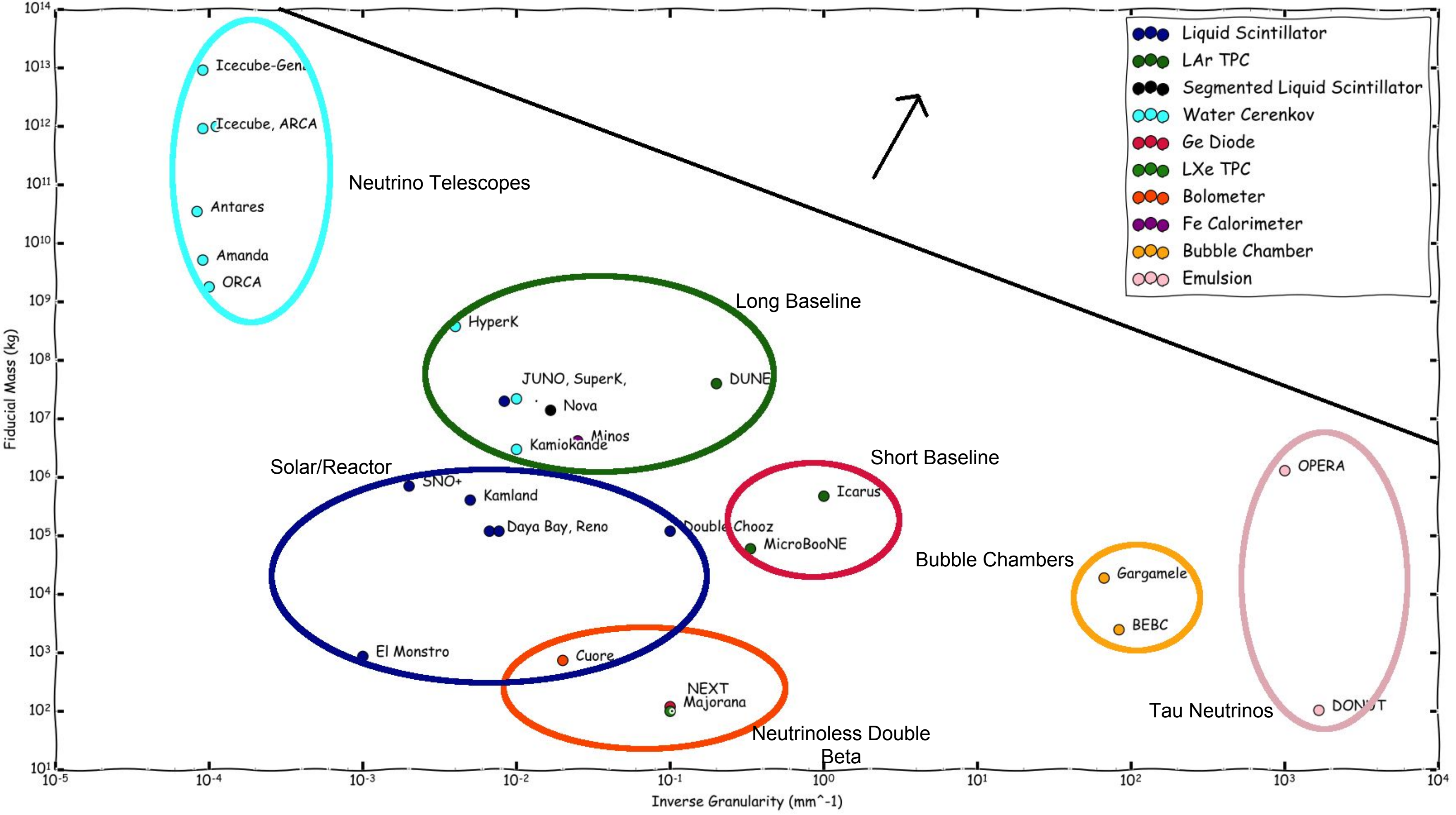
The detector technologies in play are well established, but getting larger and more complex.

With DUNE, HyperK, and ICECUBE-GEN2 we are seeing all 3 major modern neutrino detector designs (Natural WC detectors, Man Made WC Detectors, and LArTPCs) are getting a BIG upscale.

The Big Questions
Precision Oscillations
Mass Hierarchy
CP Violation



Liquid Scintillator
LAr TPC
Segmented Liquid Scintillator
Water Cerenkov
Ge Diode
LXe TPC
Bolometer
Fe Calorimeter
Bubble Chamber
Emulsion
Icecube-Gen2
Icecube, ARCA
Antares
Amanda
ORCA
HyperK
JUNO, SuperK,
Nova
DUNE
Minos
Kamiokande
SNO+
Kamland
Daya Bay, Reno
Double Chooz
MicroBooNE
Icarus
OPERA
Gargamele
BEBC
El Monstro
Cuore
NEXT
Majorana
DONUT
Fiducial Mass (kg)
Inverse Granularity (mm^-1)


Liquid Scintillator
LAr TPC
Segmented Liquid Scintillator
Water Cerenkov
Ge Diode
LXe TPC
Bolometer
Fe Calorimeter
Bubble Chamber
Emulsion
Neutrino Telescopes
Icecube, ARCA
Antares
Amanda
ORCA
Long Baseline
HyperK
JUNO, SuperK,
Nova
DUNE
Minos
Kamiokande
Solar/Reactor
SNO+
Kamland
Daya Bay, Reno
Double Chooz
El Monstro
Short Baseline
Icarus
MicroBooNE
Bubble Chambers
Gargamele
BEBC
OPERA
Tau Neutrinos
Cuore
NEXT
Majorana
Neutrinoless Double Beta
Fiducial Mass (kg)
Inverse Granularity (mm^-1)

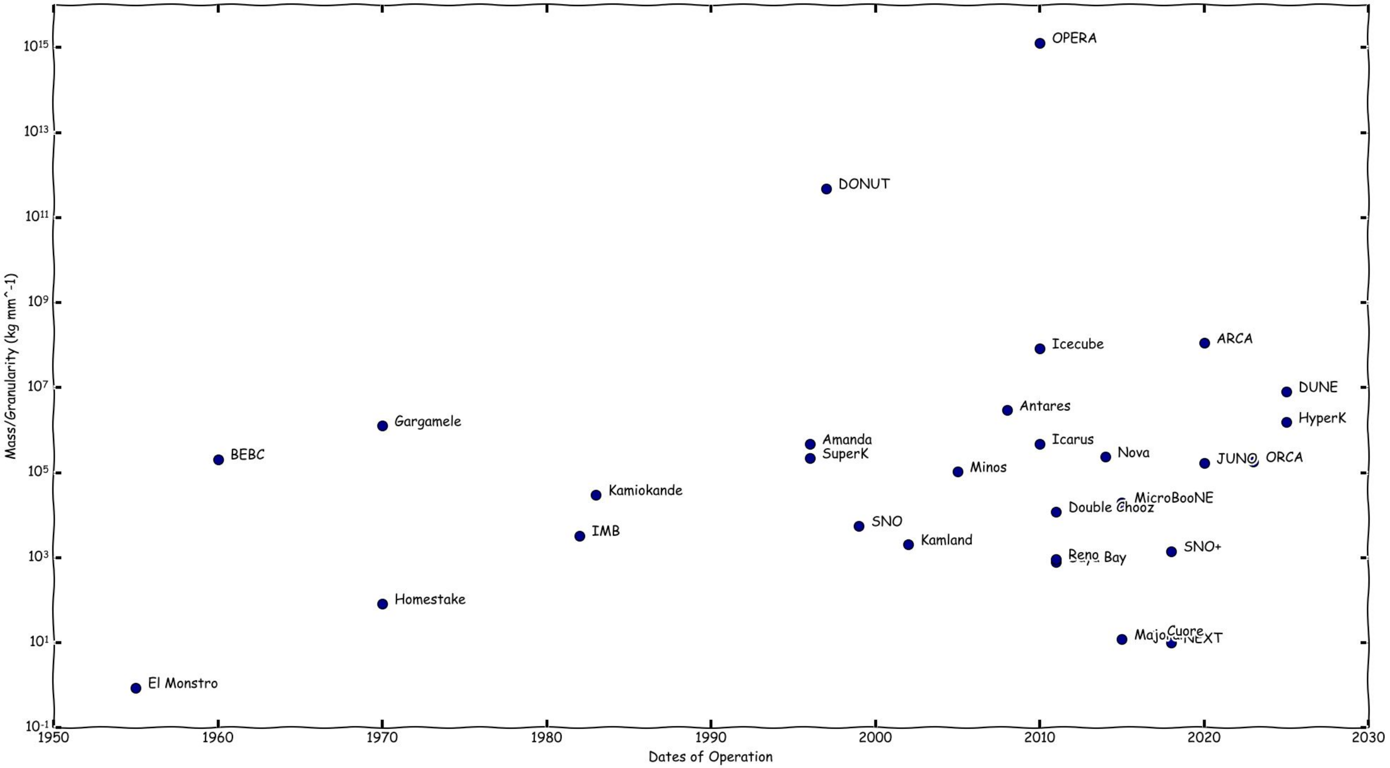
Other Plots

Having tried multiple plots to compare the development of experiments, we find some more apt for various experiment types than others.

The Mass Vs 1/Granularity seems to be the most general, but many others are worth tracking (1/Granularity Vs Energy Resolution, Mass/Granularity Vs Time)

We had many more experiments in our database, but reduced the number of points plotted for presentability.

We hope to make our full database available soon.



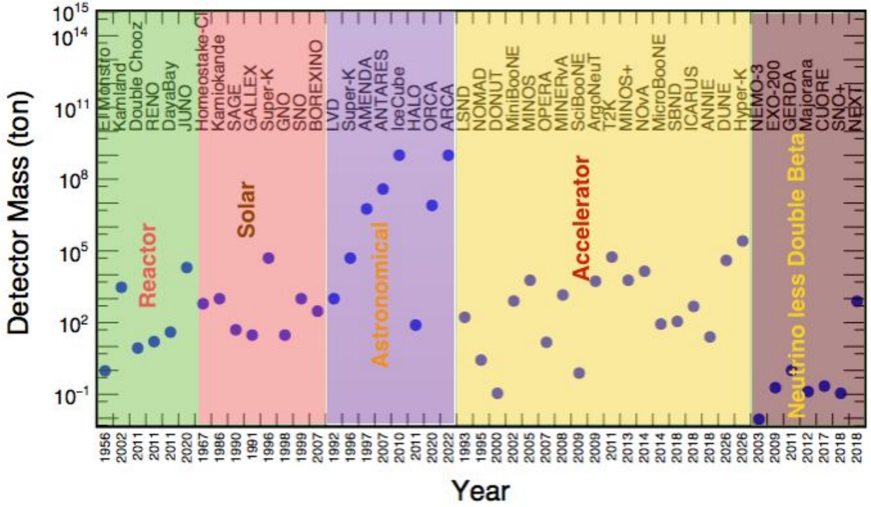
Other Plots

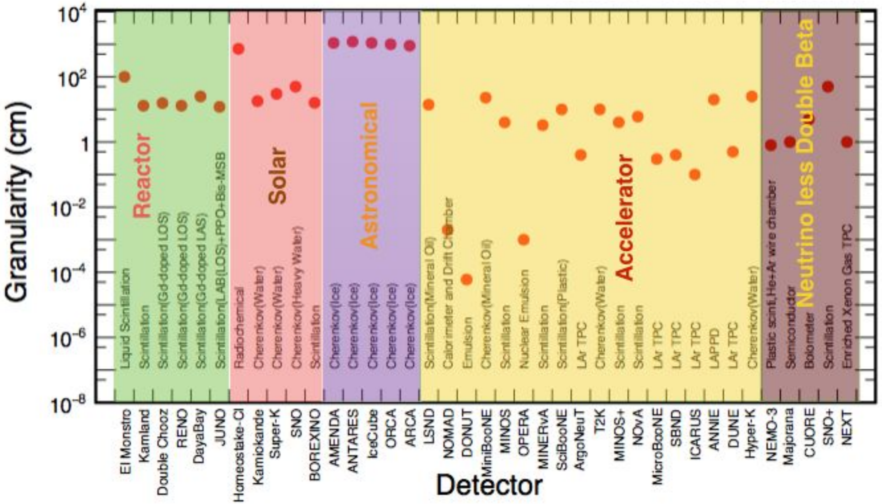
INSS 2017 Fermilab

It bears mentioning that these detectors represent a wide array of different detector technologies, each highlighting different aspects of the physics surrounding neutrinos.

To the left we see figures (courtesy of Biswaranjan Behera) looking at the detectors grouped some aspects of their physics search or technological design. We can see more development in some fields than others.

Energy resolutions would be a very interesting parameter to study in this format.





Conclusions:

- Neutrino physics is a very diverse field which can't be tracked with one parameter.
- Tracking multiple detector properties beyond what we have shown here would be advantageous to gauge the progress of the field. (Energy resolution for example.)
- A shared database would allow experiments to provide their own detector data and make a variety of plots to demonstrate the strengths of the detector