Neutrino Detection 1

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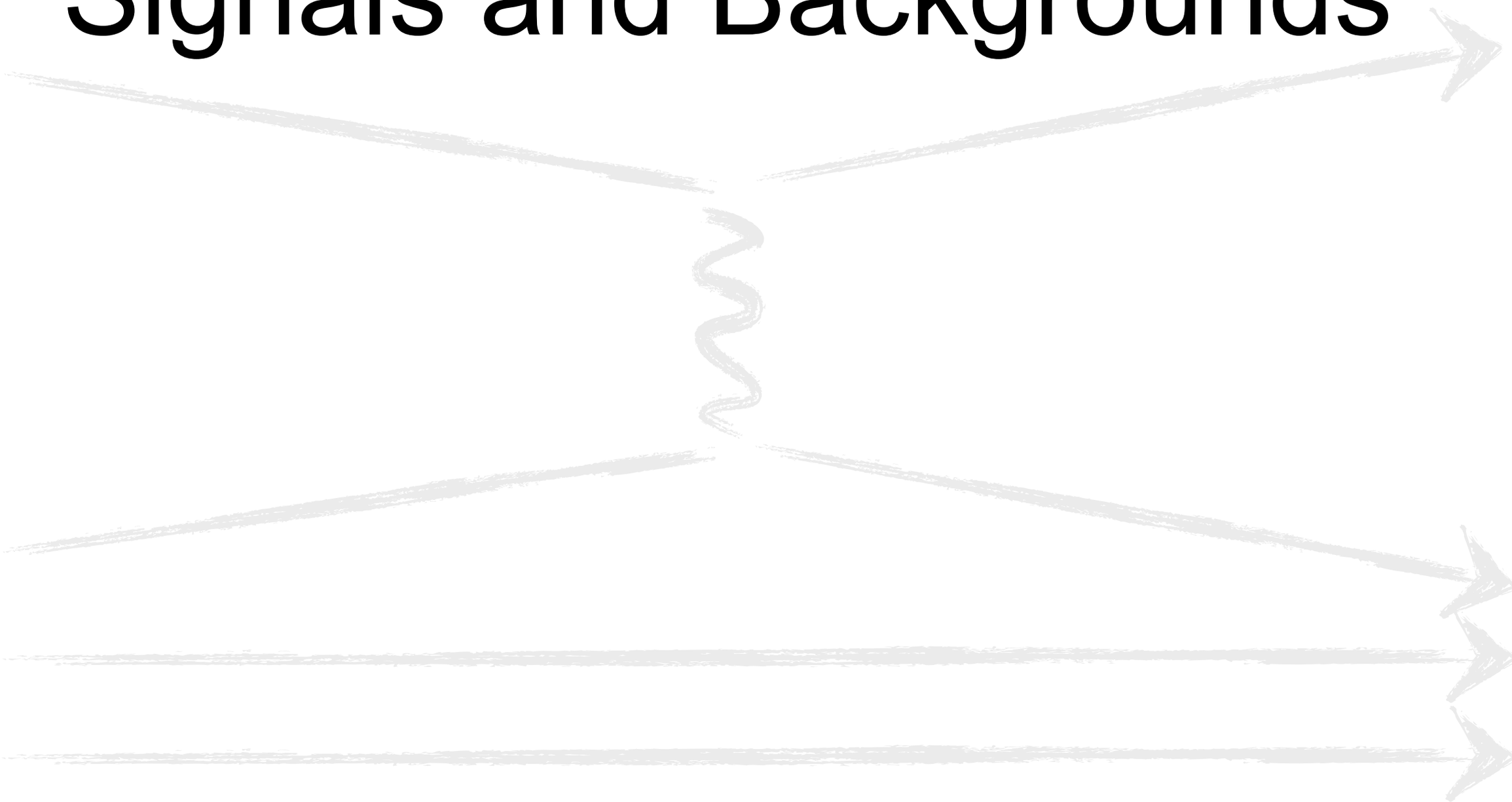
Lecture 1
Signals and Backgrounds



Lecture 1
Signals and Backgrounds

- What is the purpose of a neutrino experiment?

Lecture 1
Signals and Backgrounds

- What is the purpose of a neutrino experiment?

➡ To provide convincing evidence for or against some hypothesis

➡ To make measurements that are accurate enough to be useful

Energy Range

- Need to detect a wide range of neutrino energies
  - Oscillation depends on distance and energy
    - varying E_ν is an important experimental handle
  - ν-scattering probes different regimes of nucleon/ nuclear structure with different E_ν

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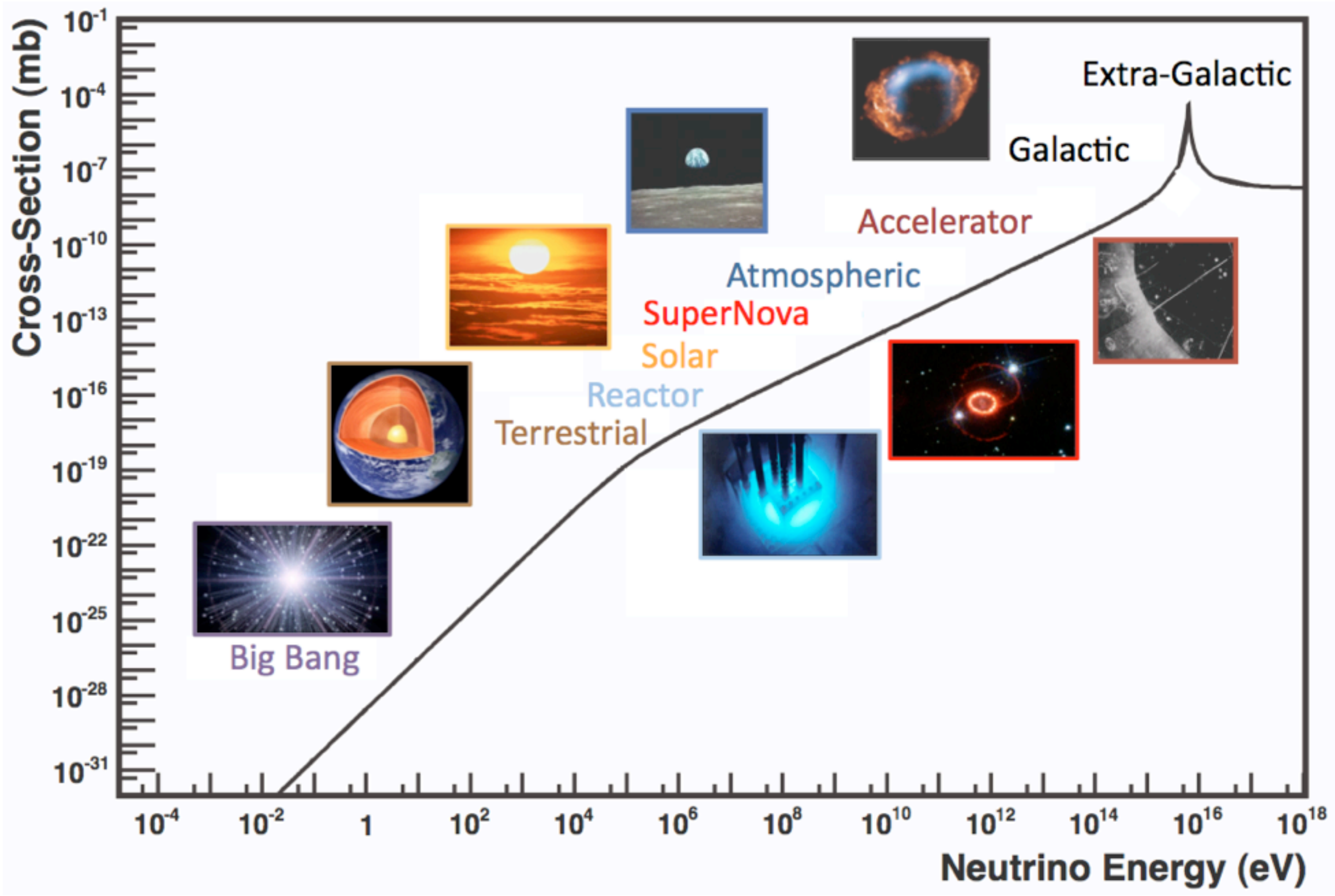
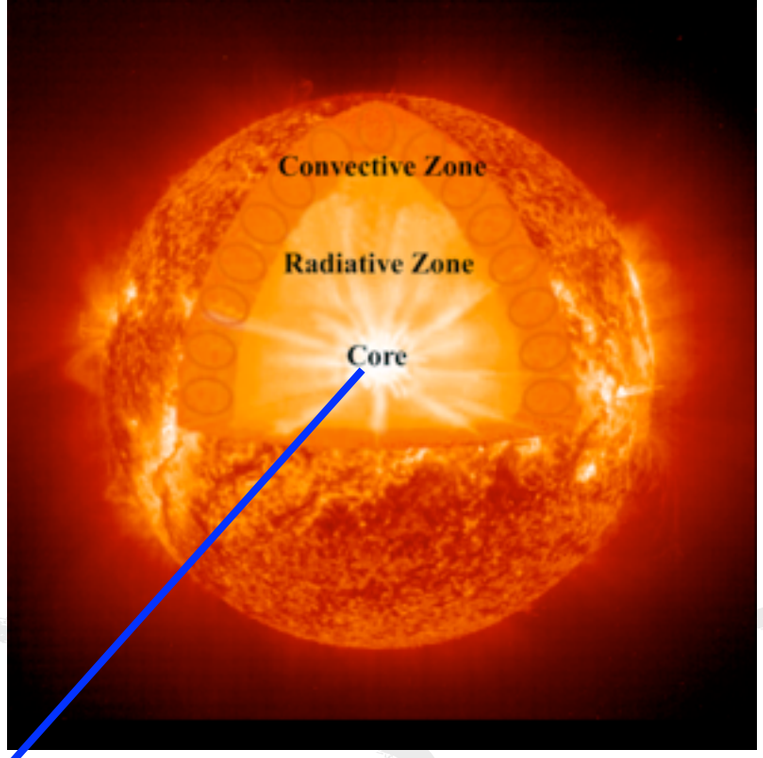
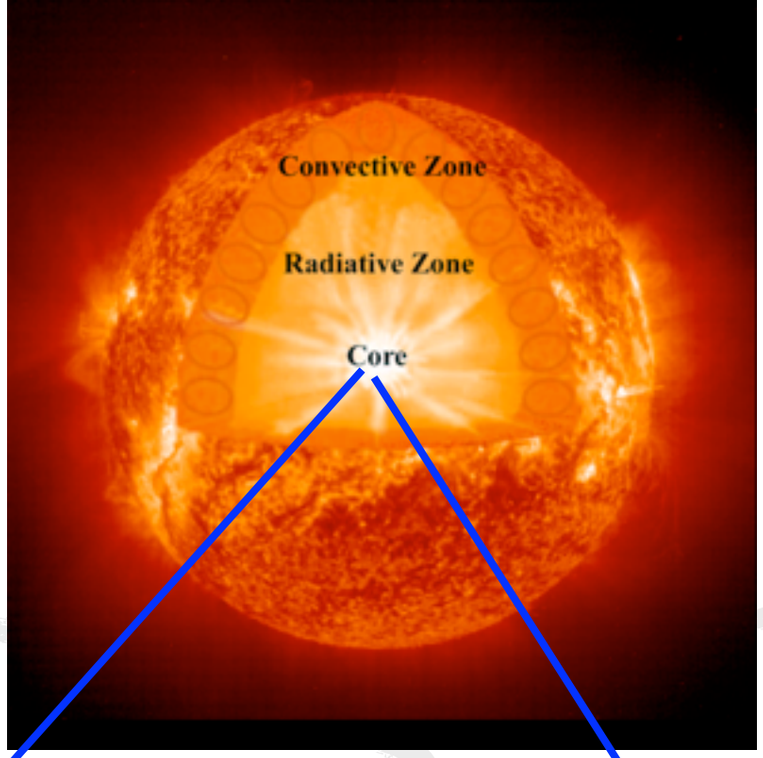



Convective Zone
Radiative Zone
Core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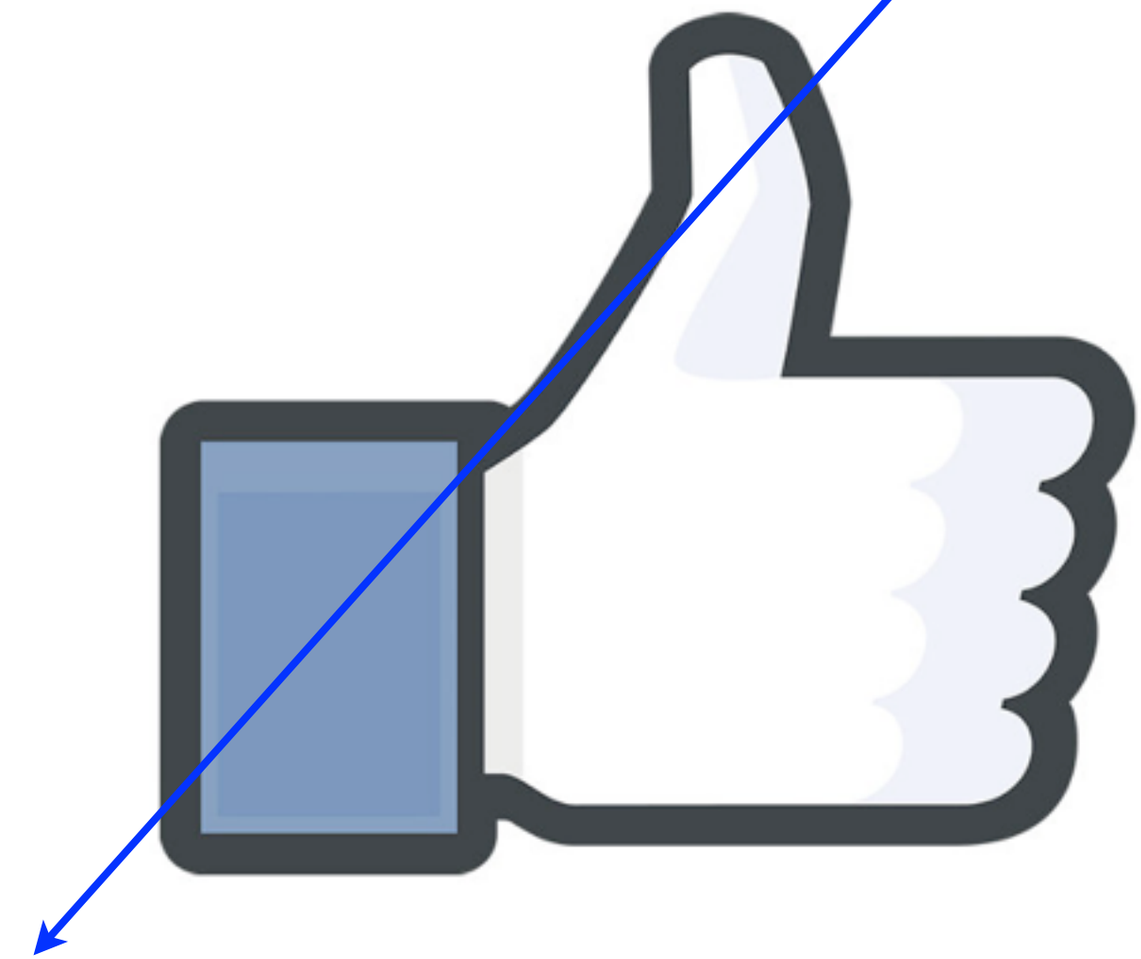
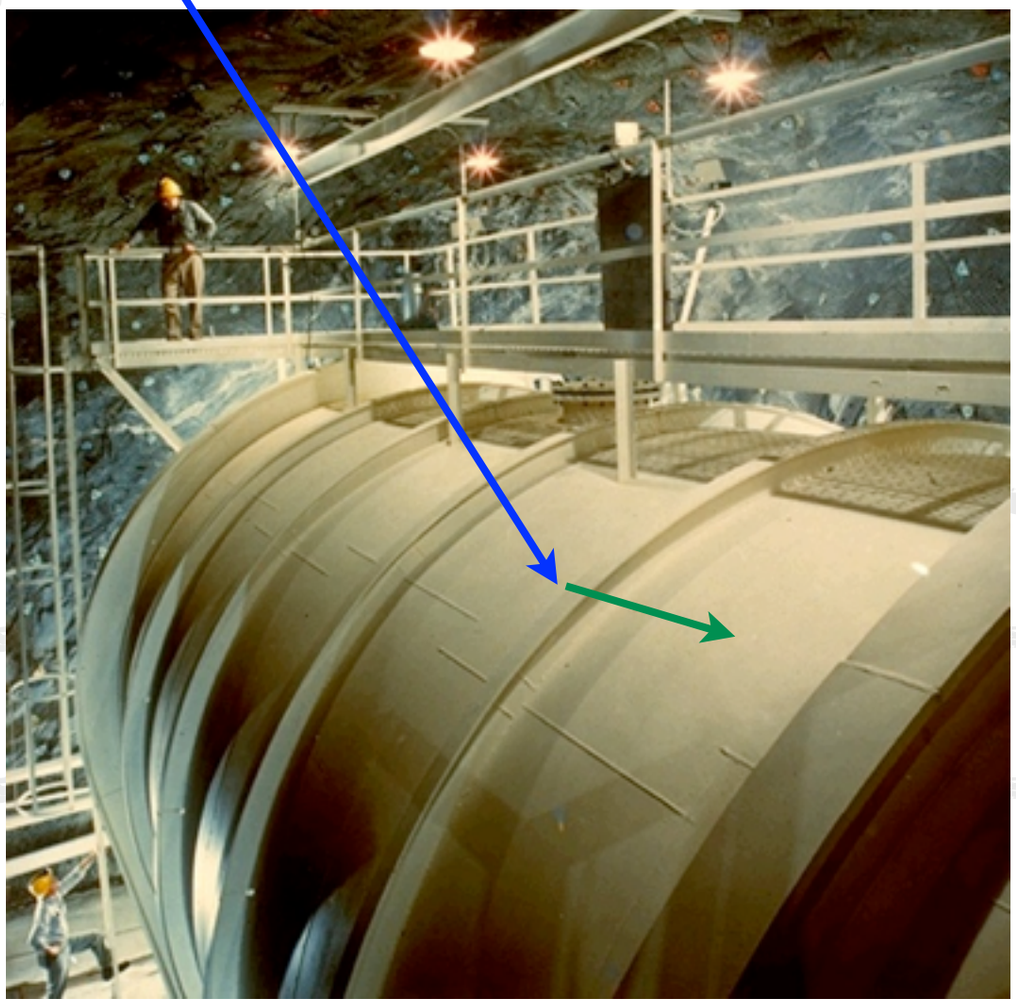




Event rates

$$N_{evt} = \Phi_\nu(E_\nu) \times \sigma_\nu(E_\nu) \times N_{tgt}$$

- (neglected efficiency and backgrounds)
- Written example : reactor neutrinos

- Noteworthy:
  - ✓ Flux is really high!
  - ✓ Detector is really large!
  - ➡ Event rate is still very low!

Signals

Signals

- *What do we actually want to measure?*

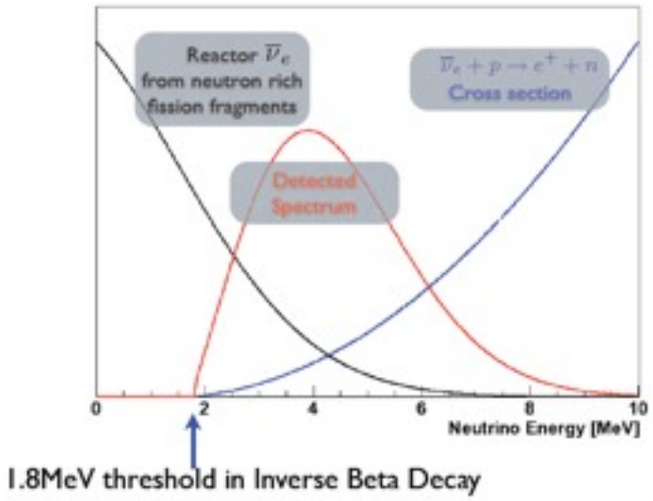
Signals

- *What do we actually want to measure?*
- Go through typical interaction channels in different energy regimes
- Consider final state particles, topologies, energies

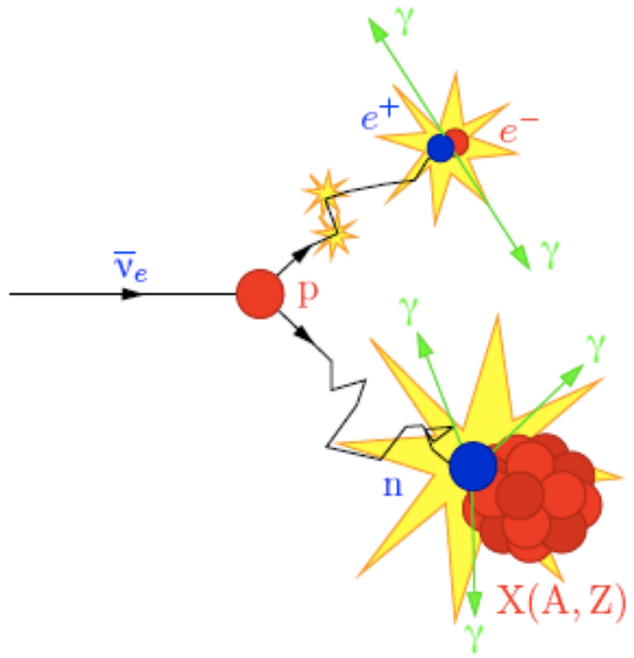
Low energy

- Reactor antineutrinos
- Solar neutrinos
- Geoneutrinos

➡ Want to tag energy of charged lepton (electron) and tag presence of recoil nucleons



$\overline{\nu}_e + p \rightarrow e^+ + n$

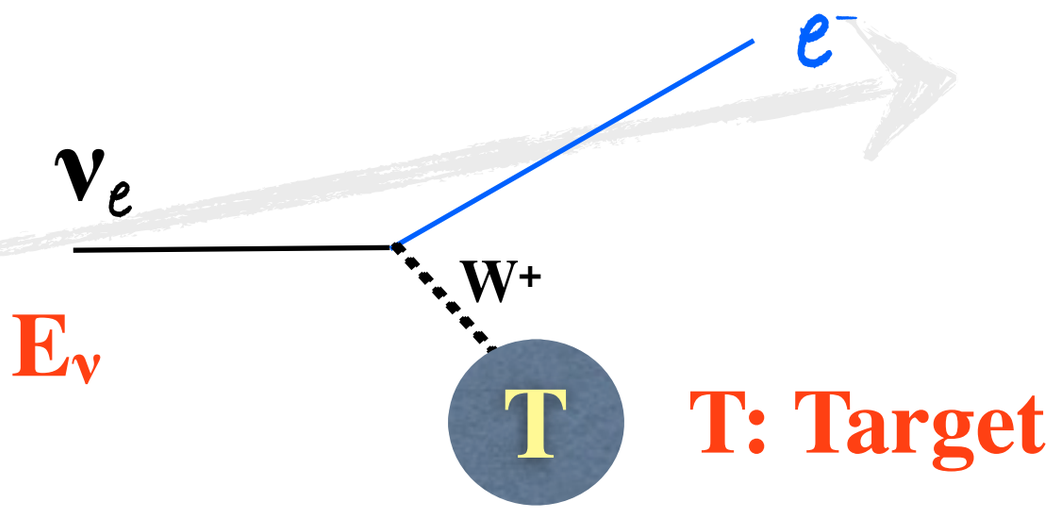


- Inverse beta decay (IBD)
- Delayed coincidence between e^+ and n ,and larger cross section are useful to identify anti-electron-neutrinos.
- “n” is often captured using Gd, Cl, or free protons
  - excited states generate gamma rays O(10~100) μsec after n capture.

➡Tag e+, n

➡Measure energy of e+

Solar neutrinos



- No free neutrons in Nature, so the IBD doesn't work
- Can interact via

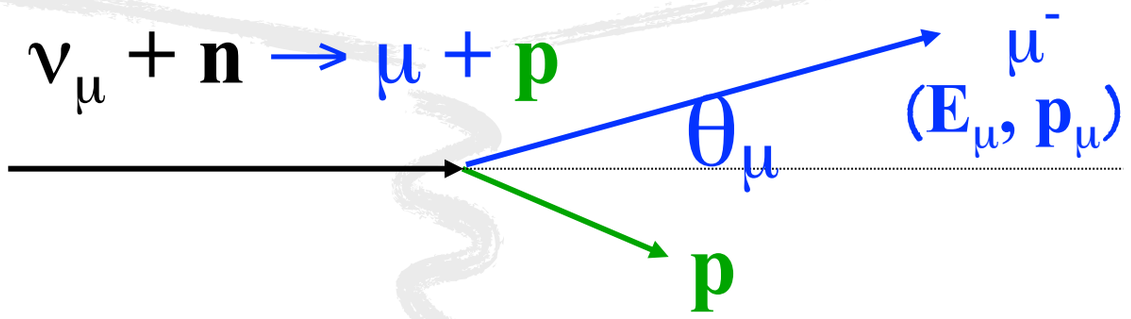
➡ Measure direction and energy of e-

➡ Tag recoil nucleons if possible

Intermediate energies

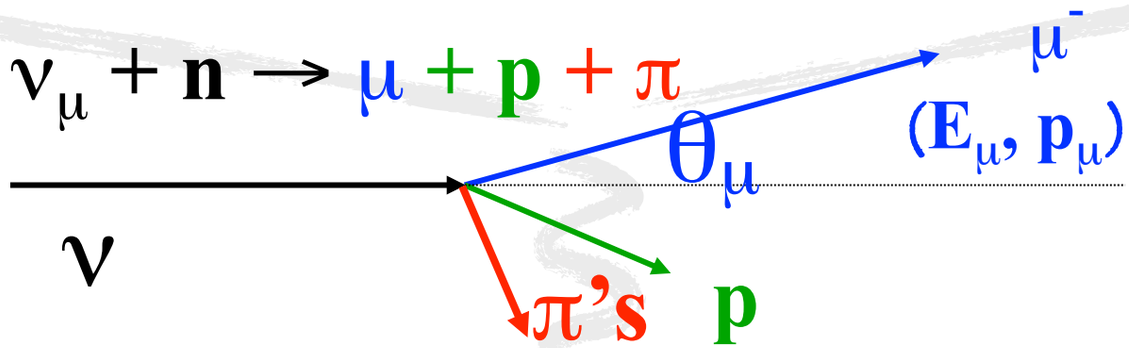
- Recoiling particles have low multiplicities, but now have enough energy to be detected & tracked
- Want to tag lepton flavour, measure El, theta-l
- Tag and track secondary pions, nucleons
- Important also to tag the *sign* of the lepton

Example: CCQE



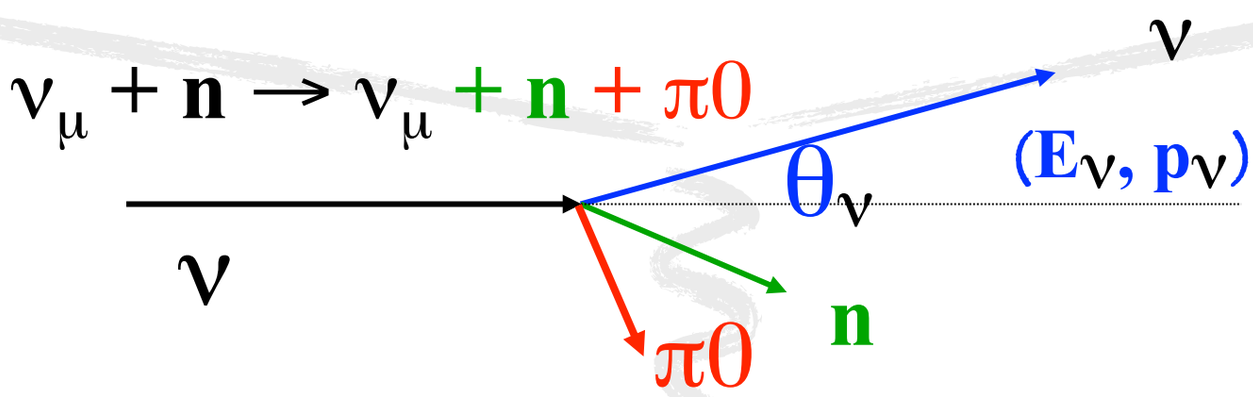
- Tag lepton flavour - crucial for oscillation experiments
- Measure E_μ, θ_μ
  - Can reconstruct neutrino energy with this information
  - HW: derive CCQE energy formula
- Measure proton kinematics, if possible

Example: CC resonant pion production



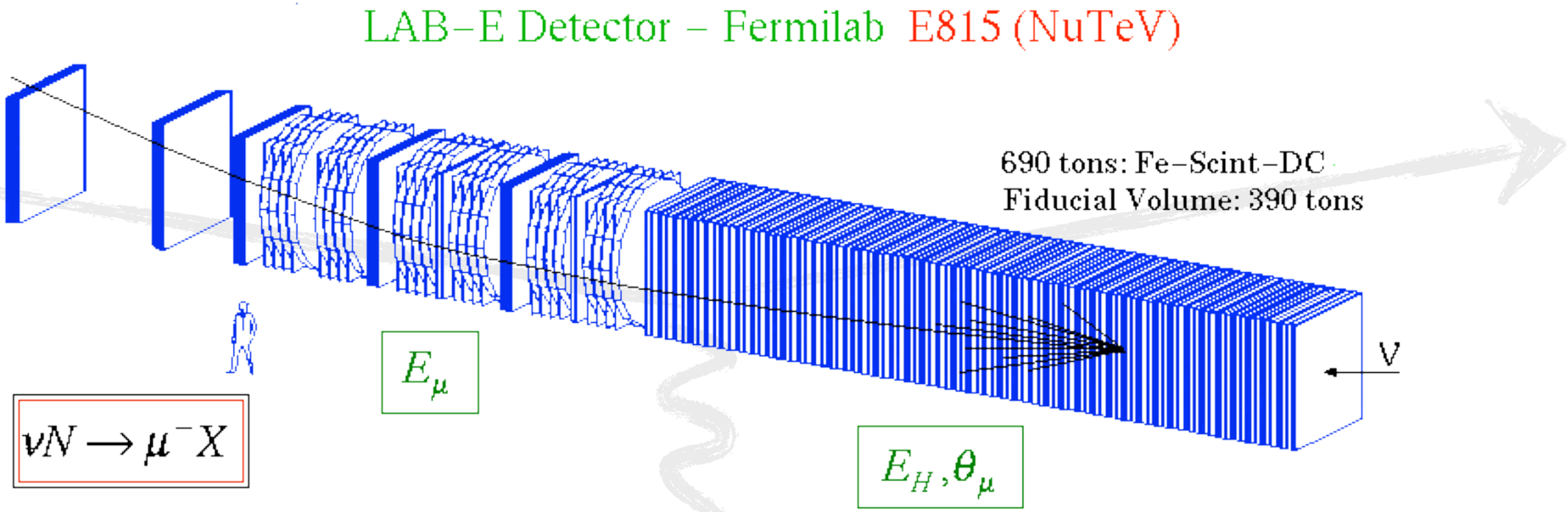
- Tag lepton flavour - crucial for oscillation experiments
- Measure E_μ, θ_μ
  - Can reconstruct energy in this case as well
  - Doesn't work as well. Why?
- Measure pion kinematics, nucleon if possible
  - Allows better reconstruction of neutrino energy
  - HW 2: Derive CC1π energy formula with π kinematics

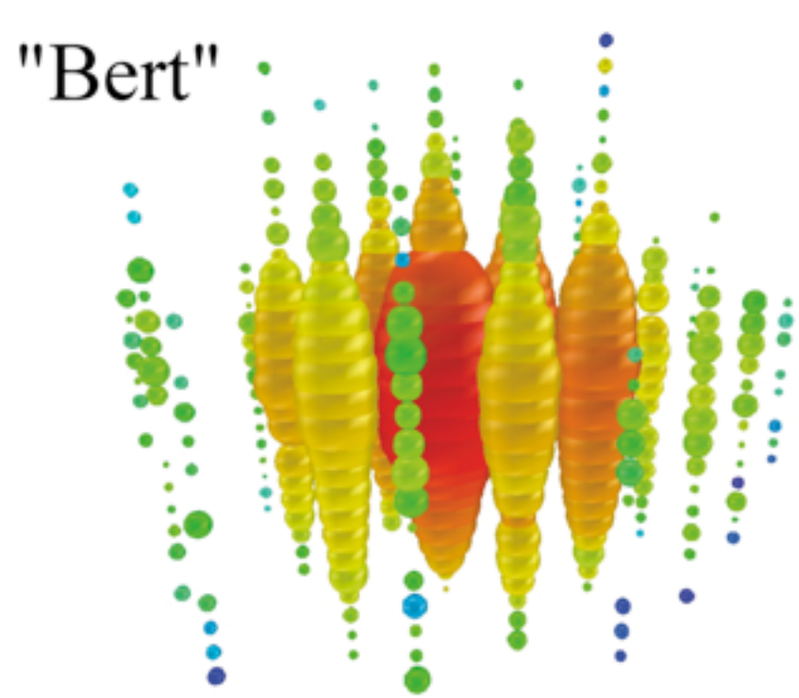
Example: NC resonant pion production

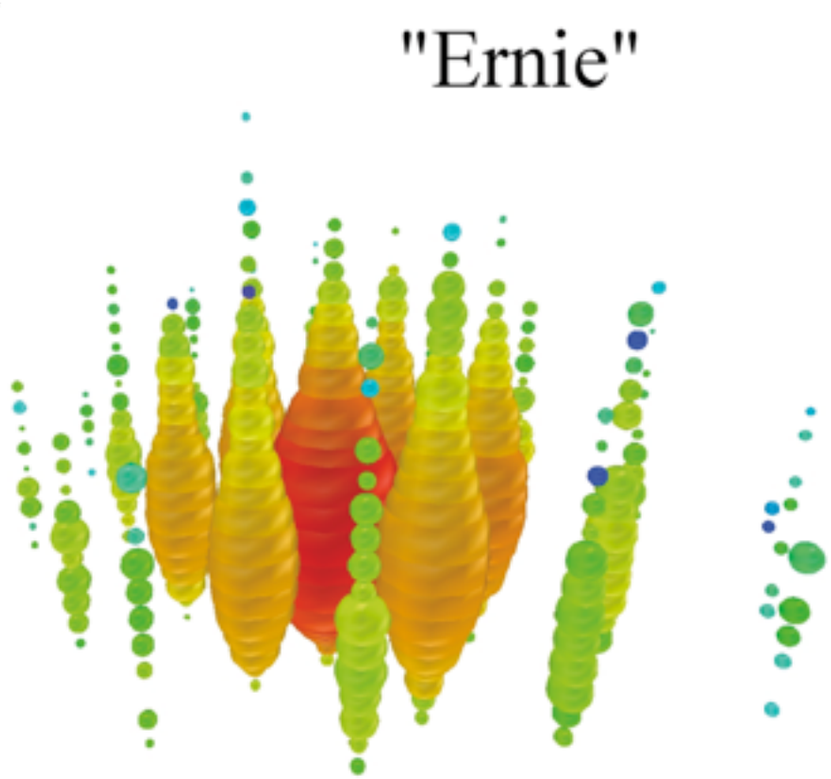


- Tag pi0, measure Epi thetapi
- Can’t reconstruct neutrino energy. Why not?
- Important channel for oscillation experiments

Example: Deep Inelastic Scattering







Backgrounds

- Collect background events as well as signal
  - Inevitable, given low signal rates
  - Anything that shares characteristics with signal interactions is a potential background
  - Degrades statistical precision!

- Backgrounds are different in different energy regimes

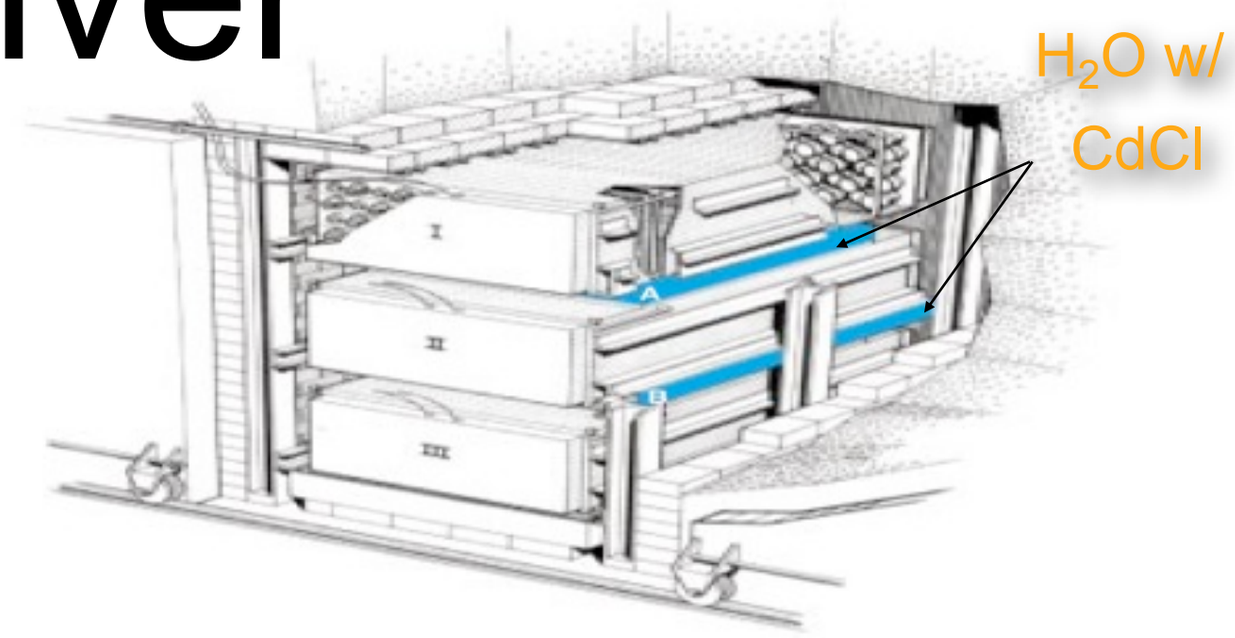
Low energy

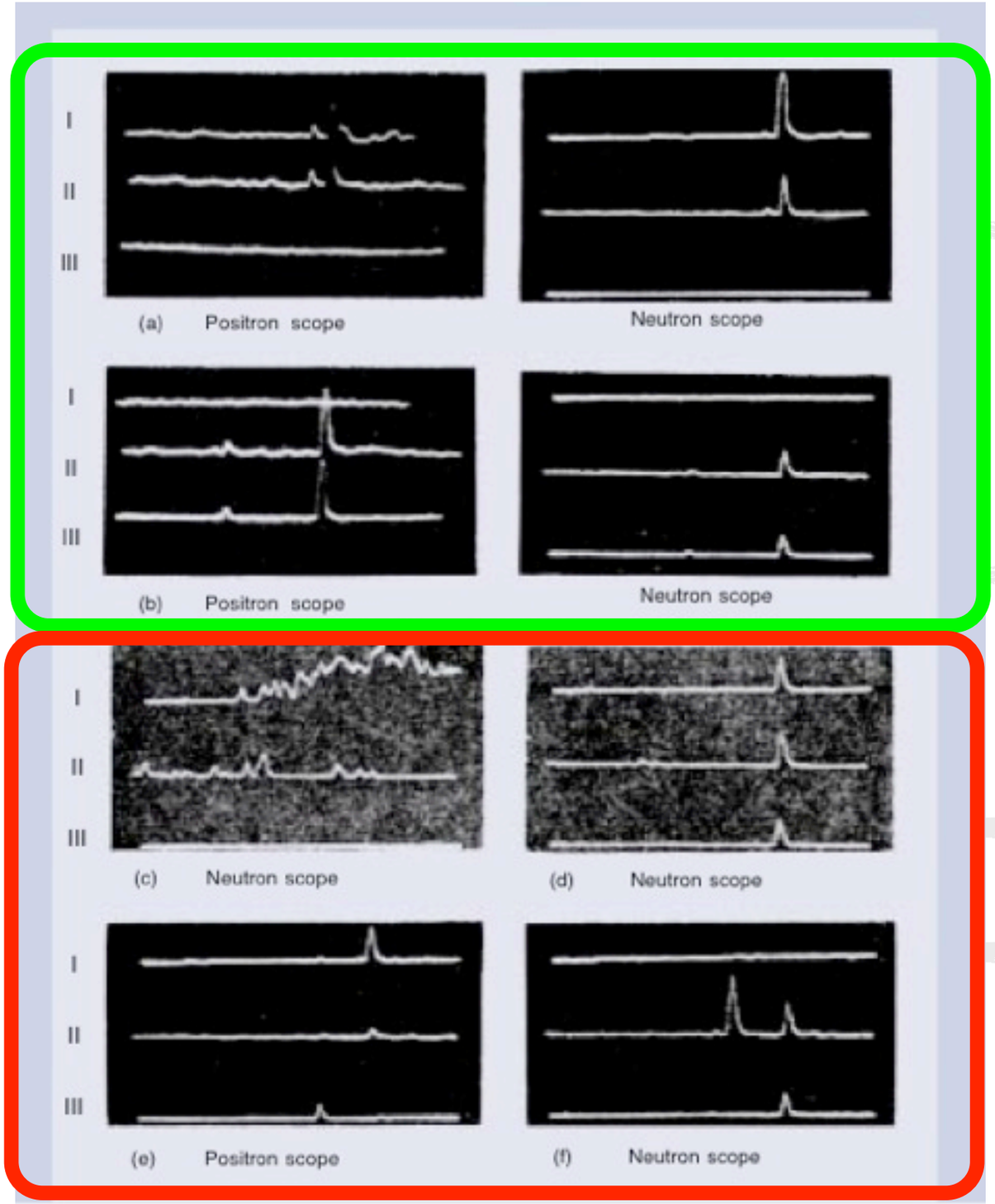
A. Radioactivity in detector materials
B. Cosmogenic neutrinos
C. (Unwanted) neutrinos
   - reactor neutrinos in solar experiments
   - solar, geoneutrinos in reactor and (dark matter) experiments

- Mitigate backgrounds by:

A. Using clean detector materials
B. Going deep underground, analysis/triggering techniques
C. Location and Directionality

Savannah River

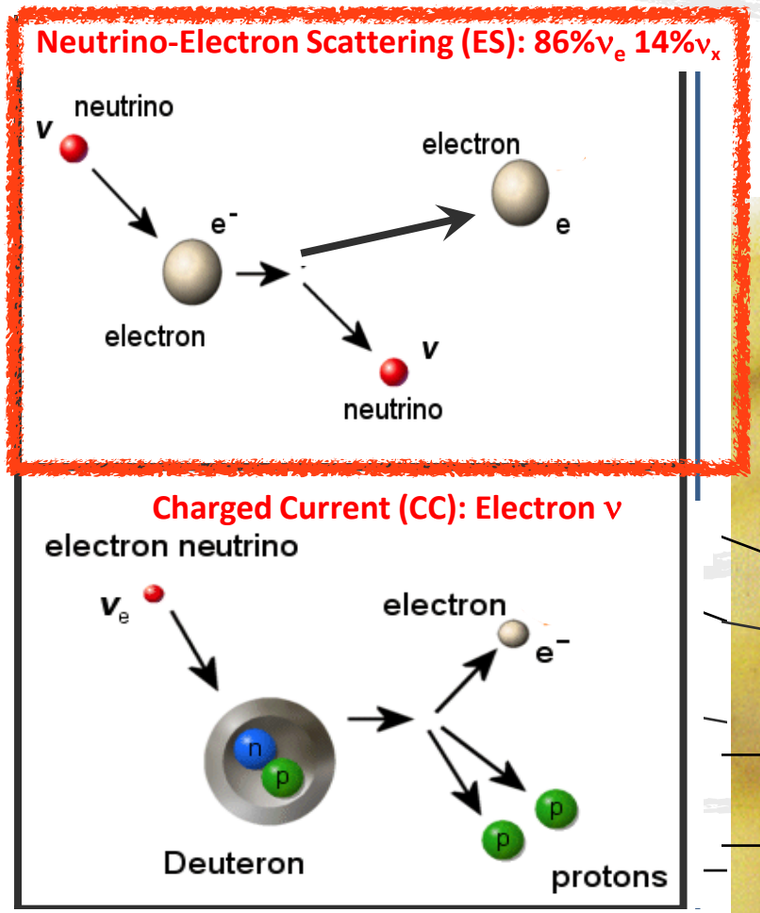




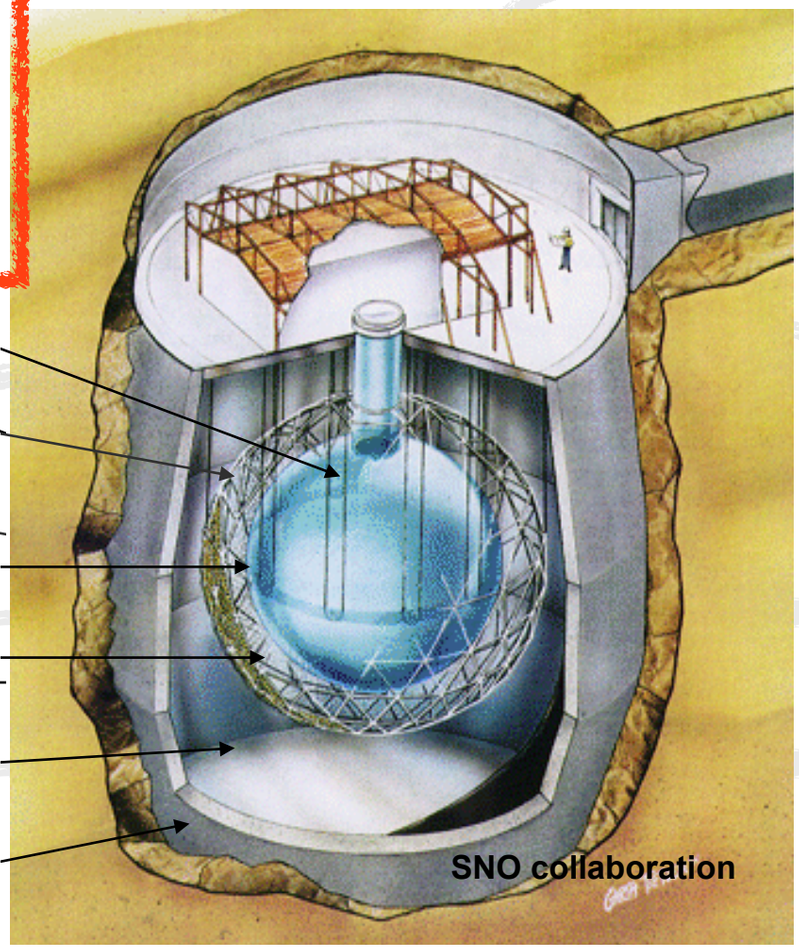
- Coincident signals in multiple subdetectors allows BG discrimination
  - More than 10 tonnes!
- Water serves as target for free antineutrinos
  - Positrons annihilate in surrounding detectors
  - Neutrons capture ~30ms or later on Cd
    - Release gamma rays that leave signals in surrounding scintillator tanks

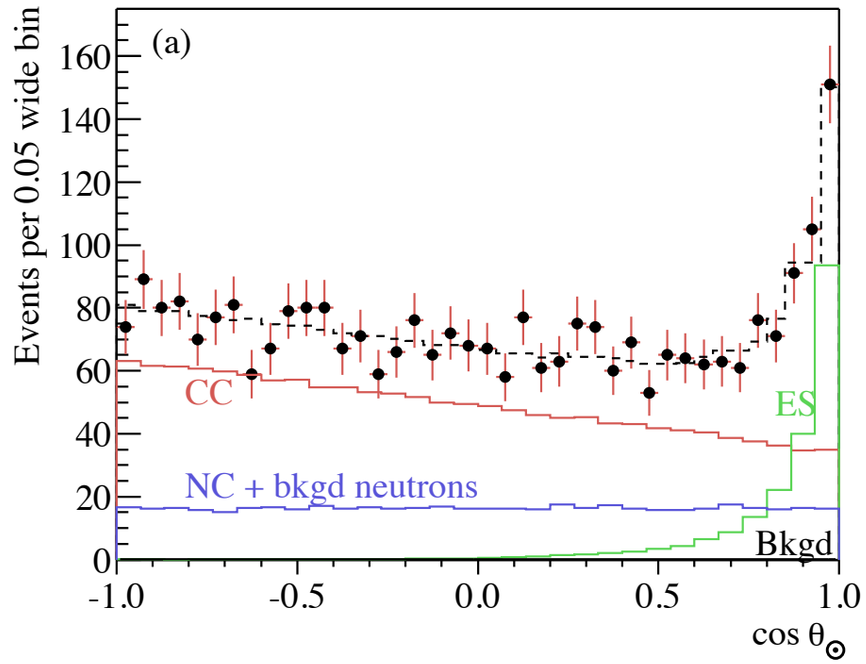
Backgrounds

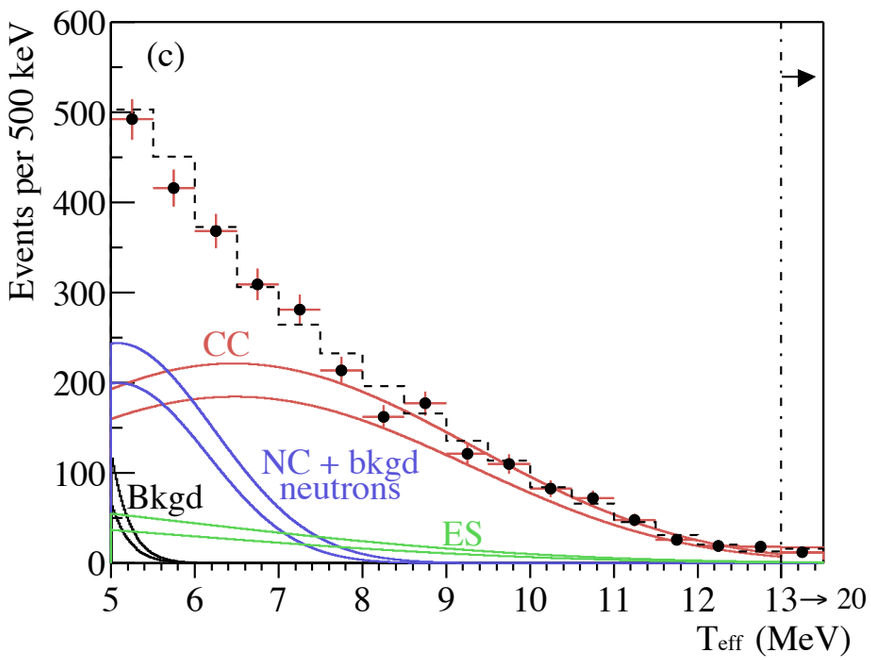
Find ways that signals and backgrounds differ, like other variables



Sudbury Neutrino Observatory

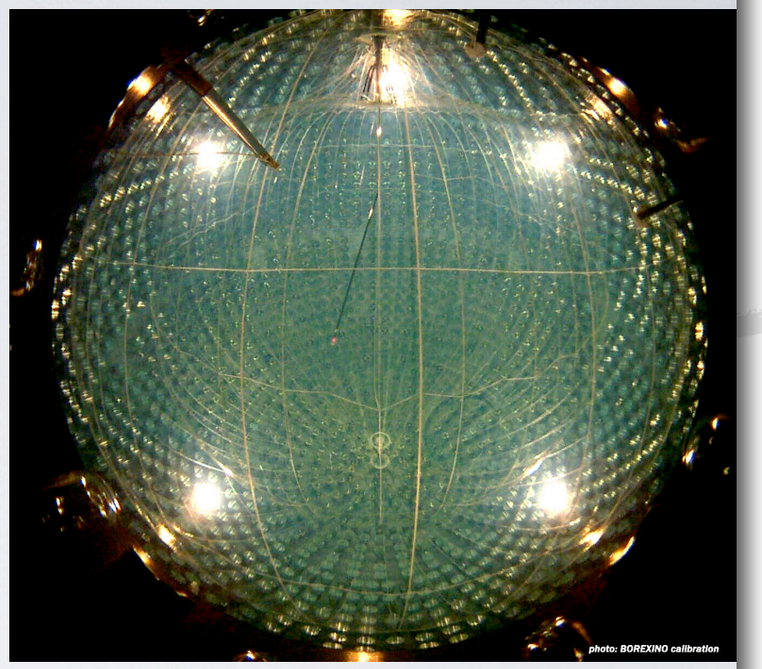


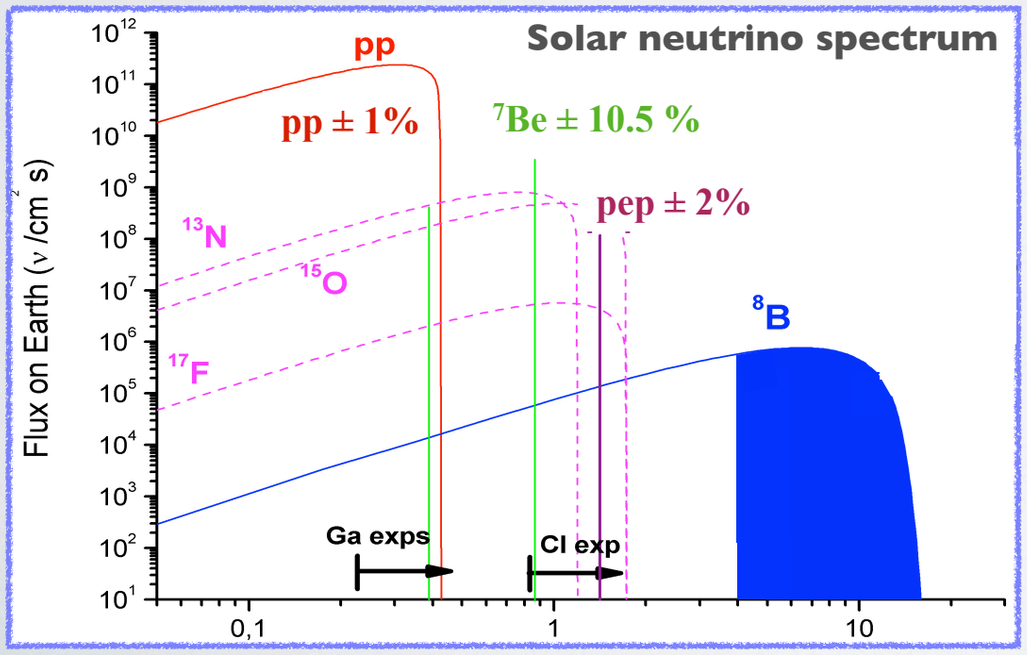


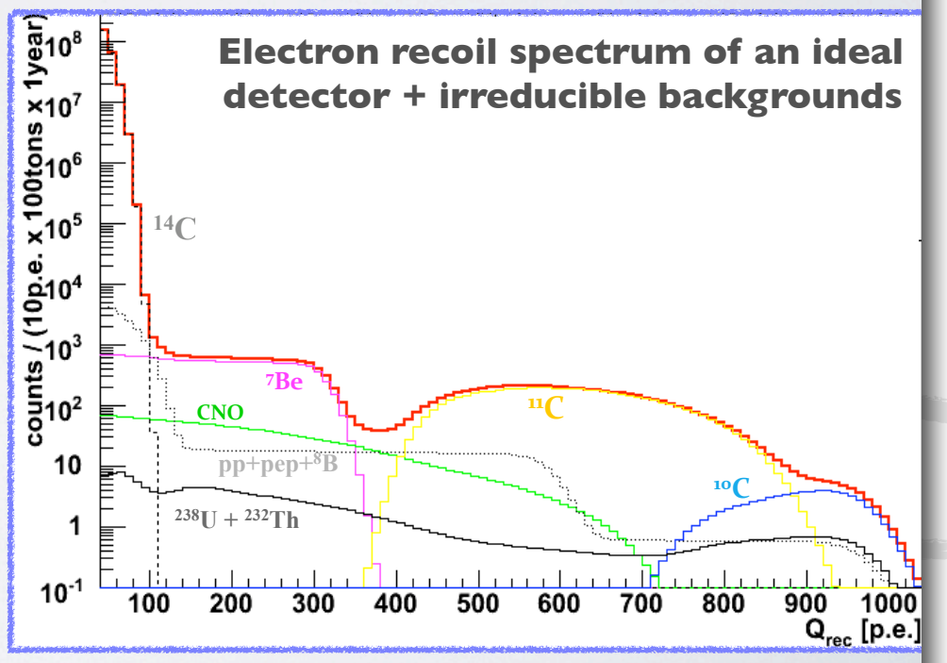


BOREXINO EXPERIMENT

- Mainly, a solar neutrino experiment:
  - $\nu + e^- \rightarrow \nu + e^-$ in an organic liquid scintillator
    - **Ultra-low radioactive background** obtained via **selection, shielding, and purifications**
    - Low energy threshold, good energy resolution, spatial reconstruction, and pulse shape identification
  - But also
    - Geo-neutrinos, search for rare events







Neutrino 2012 - Kyoto M. Pallavicini

Find ways that signals and backgrounds differ, like other variables

Intermediate energy

A. (Unwanted) neutrinos
   - Other interactions processes
   - Interactions outside detector volume

B. Cosmogenic particles

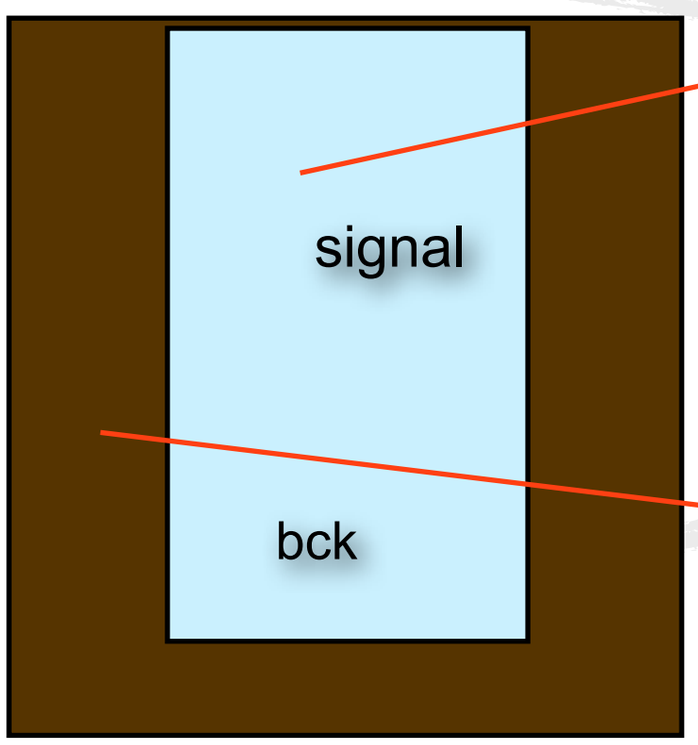
- Mitigate backgrounds by:

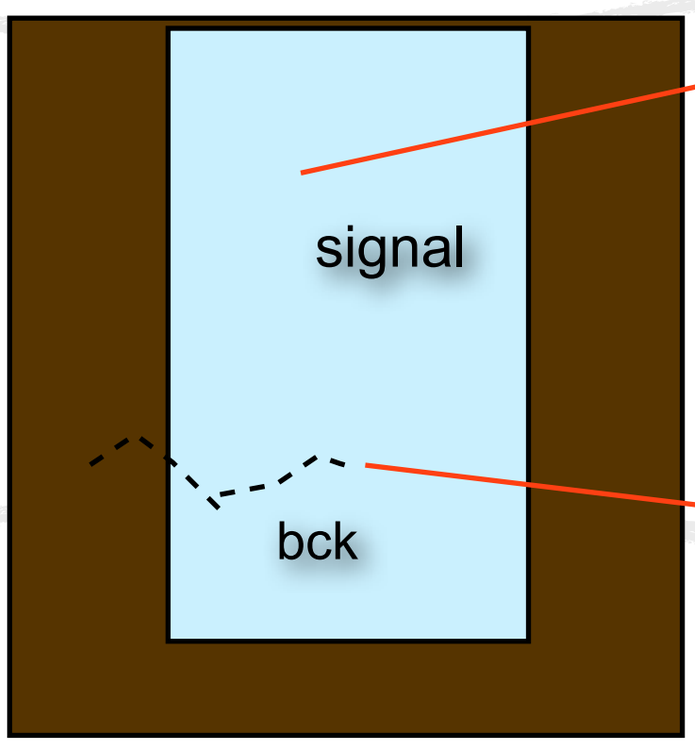
A. Timing, analysis

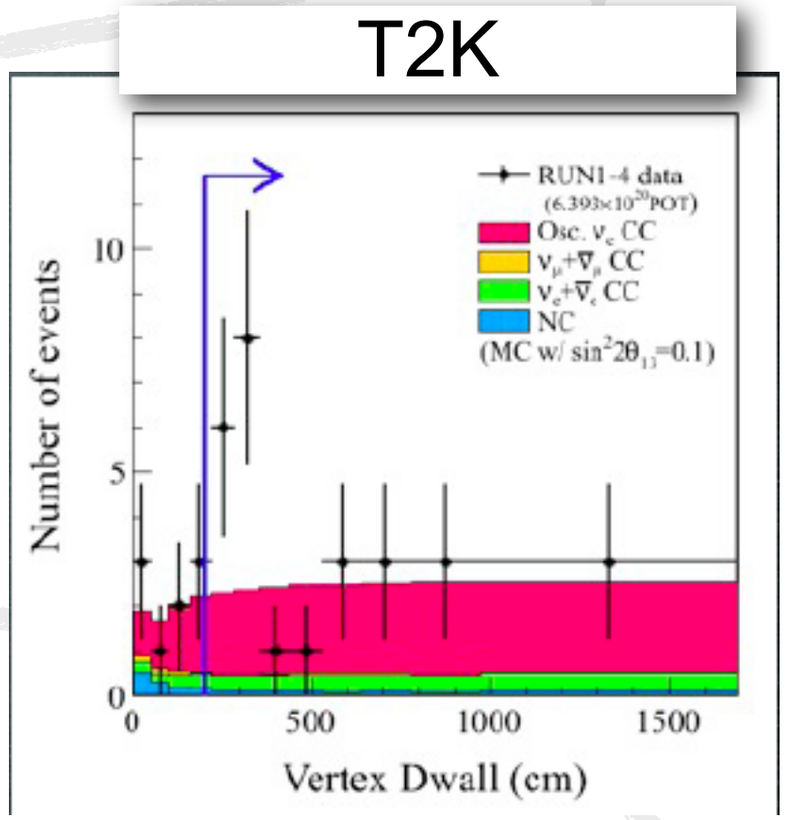
B. Going deep underground, analysis/triggering techniques

Neutrinos outside detecor

Establish “fiducial volume” for signals



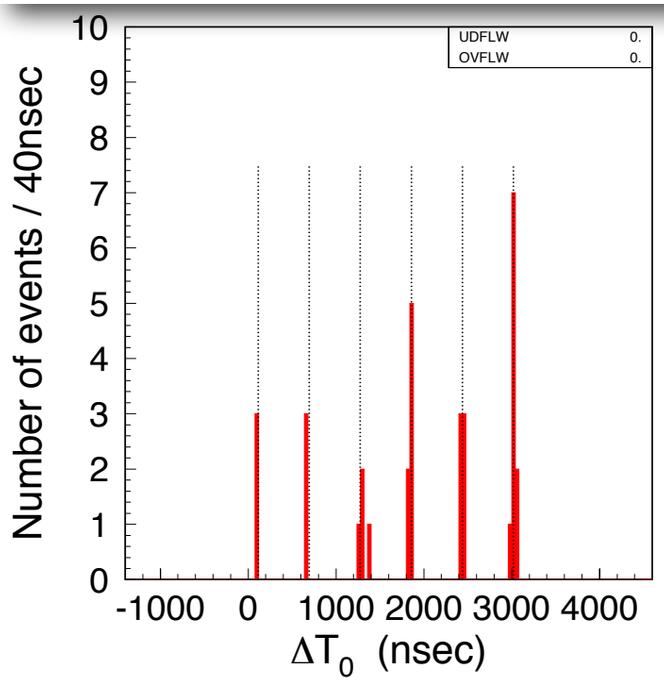




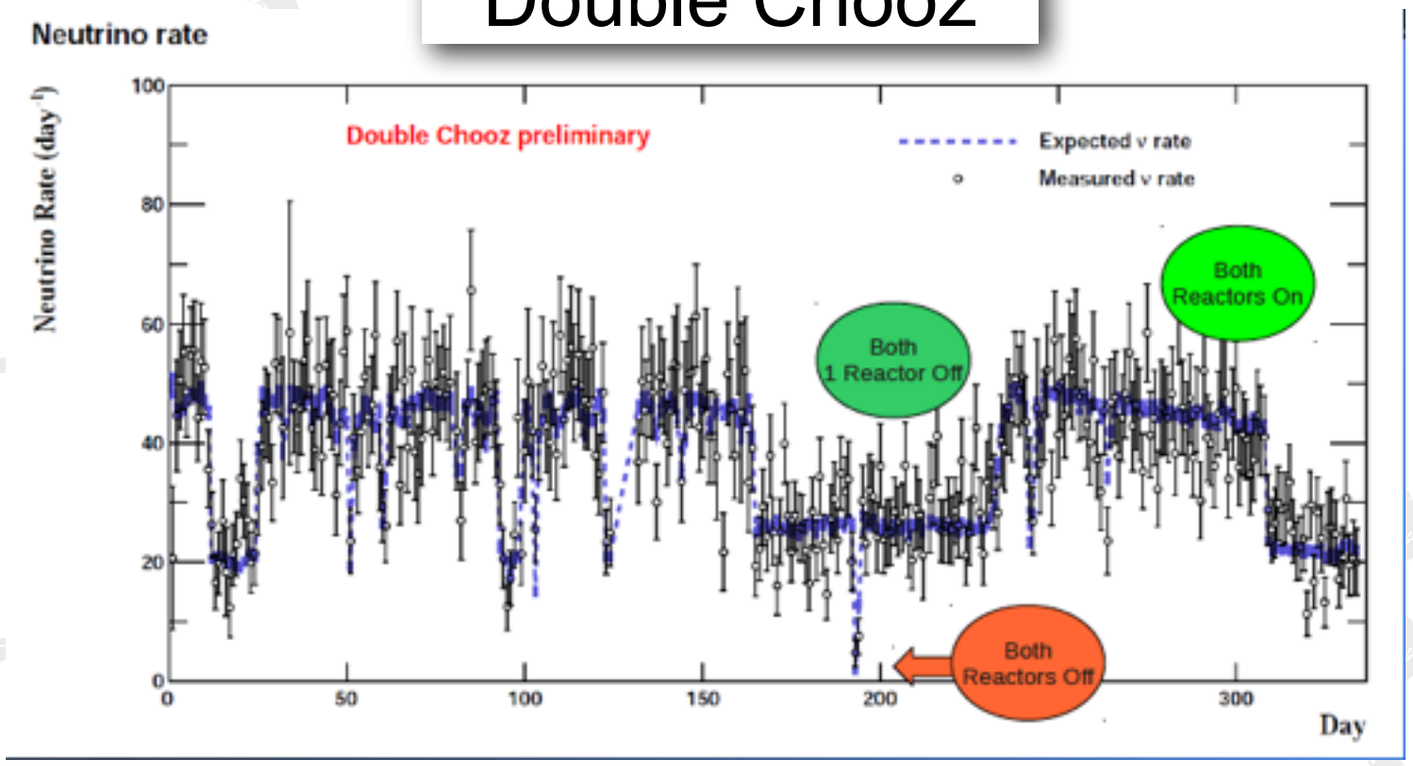
- Timing the measurement:
  - running with beam off might help in measuring the background.

T2K

FC events time distribution at SK



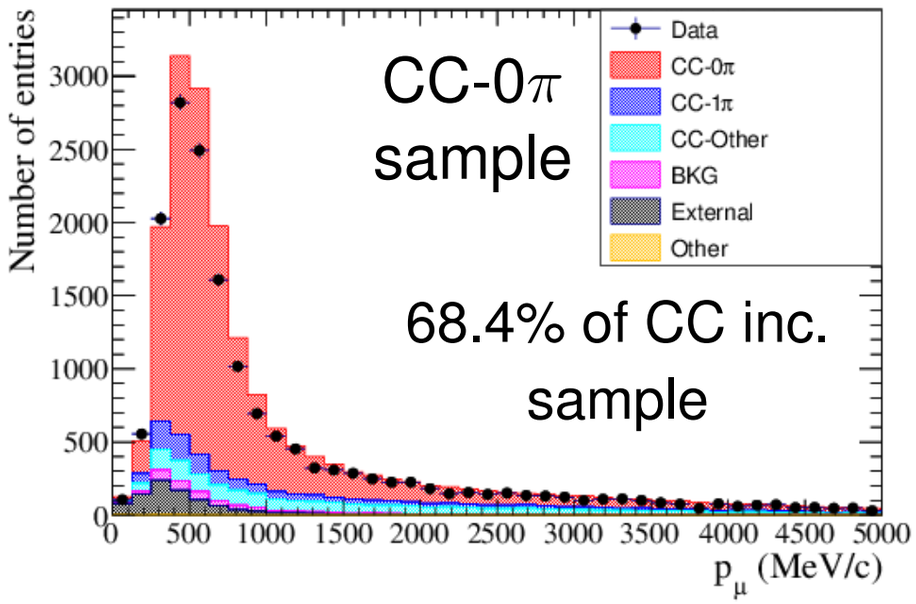
Double Chooz

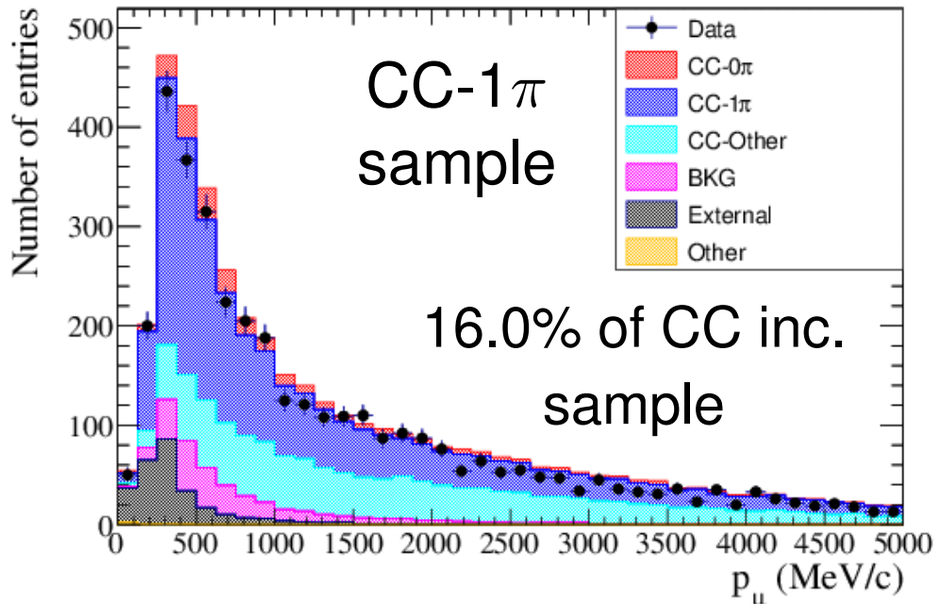


Note the different scales!

Use background enriched data samples

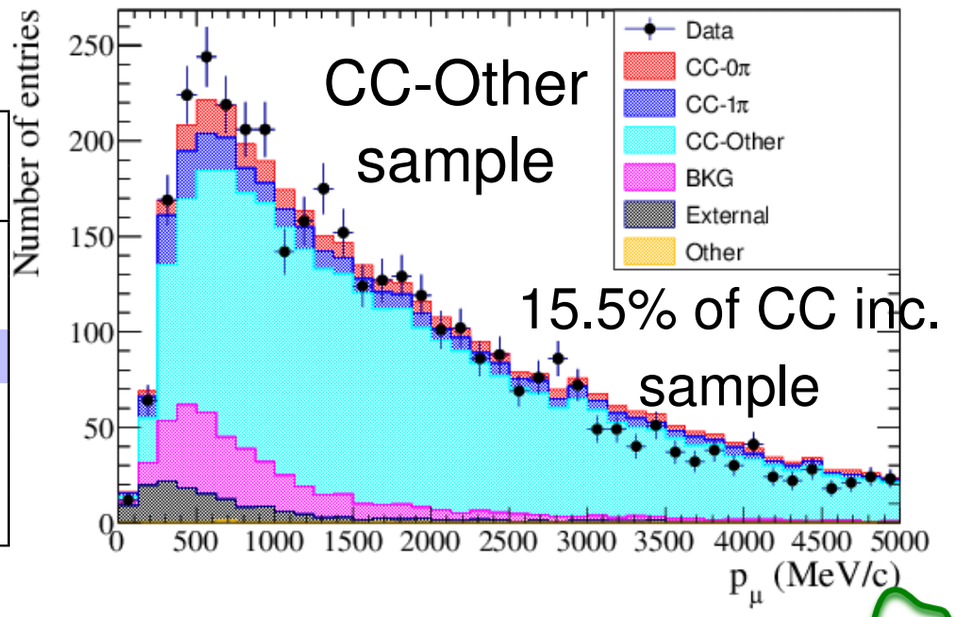
2013 results, 6.30×10^{20} *POT* of ν beam data





Data/MC distributions before any fit

	Purity of each sample		
	CC-0π	CC-1π	CC-Other
CC-0π	72.6%	6.4%	5.8%
CC-1π	8.6%	49.4%	7.8%
CC-Other	11.4%	31.0%	73.8%
Bkg (NC+$\bar{\nu}_\mu$)	2.3%	6.8%	8.7%
Out of fiducial volume	5.1%	6.5%	3.9%



Thank you for your attention!

ご清聴ありがとうございました

水戸の梅の花

Many thanks to:
J Monroe, T Nakaya, F Sanchez for valuable input