DUSEL Experiment Development and Coordination (DEDC)

NSF Visit

March 19 & 20, 2008

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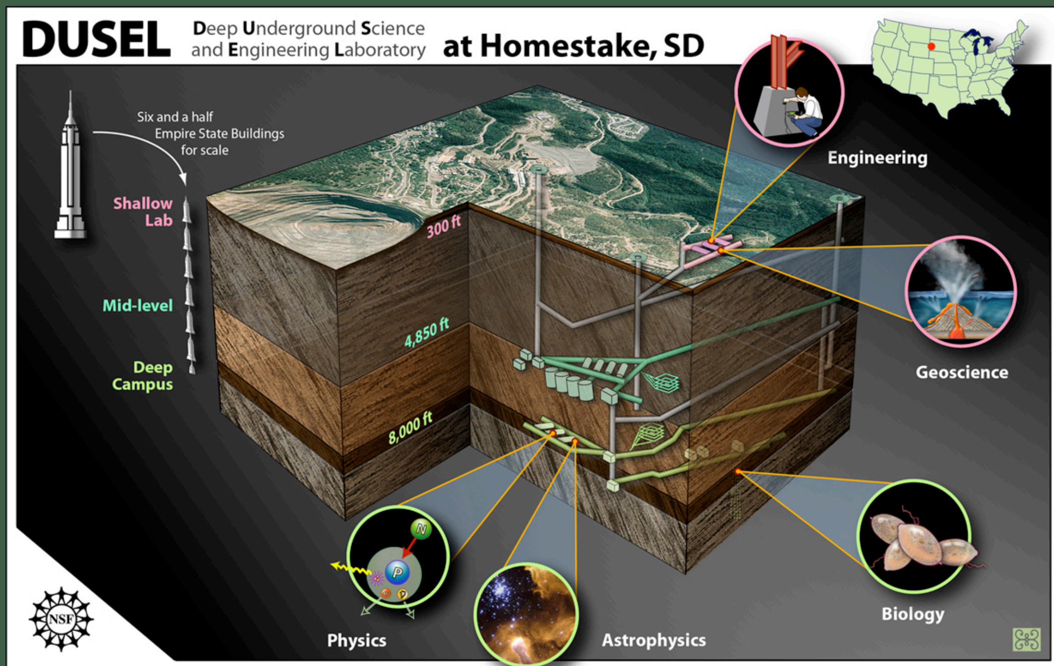


Physics at DUSEL

Steve Elliott

Nuclear Physics
Los Alamos

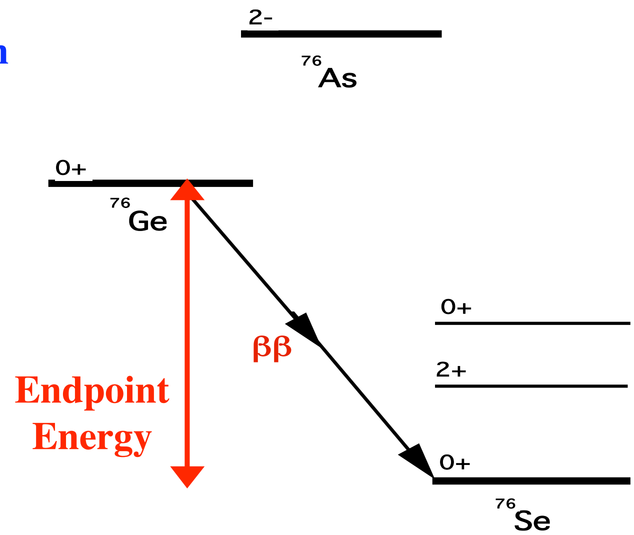
Outline

- **Double beta decay**
- **Solar neutrinos**
- **If Time**
  - Gravity waves
  - Underground accelerators

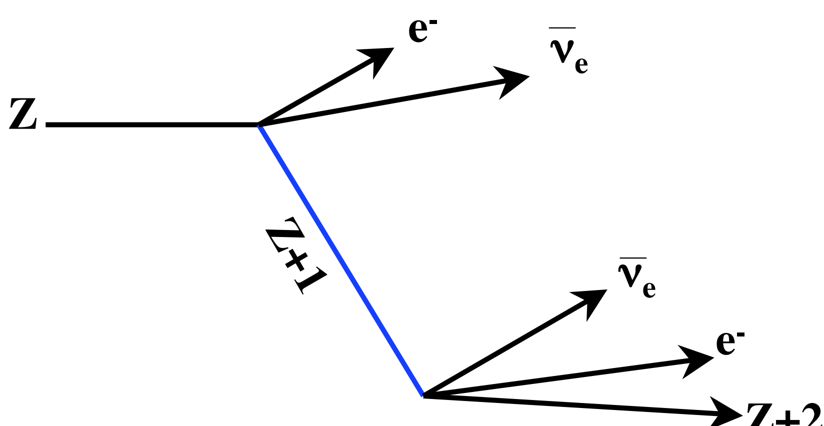
Double Beta Decay

Example ββ Decay Scheme

In many even-even nuclei, β decay is energetically forbidden. This leaves ββ as the allowed decay mode.

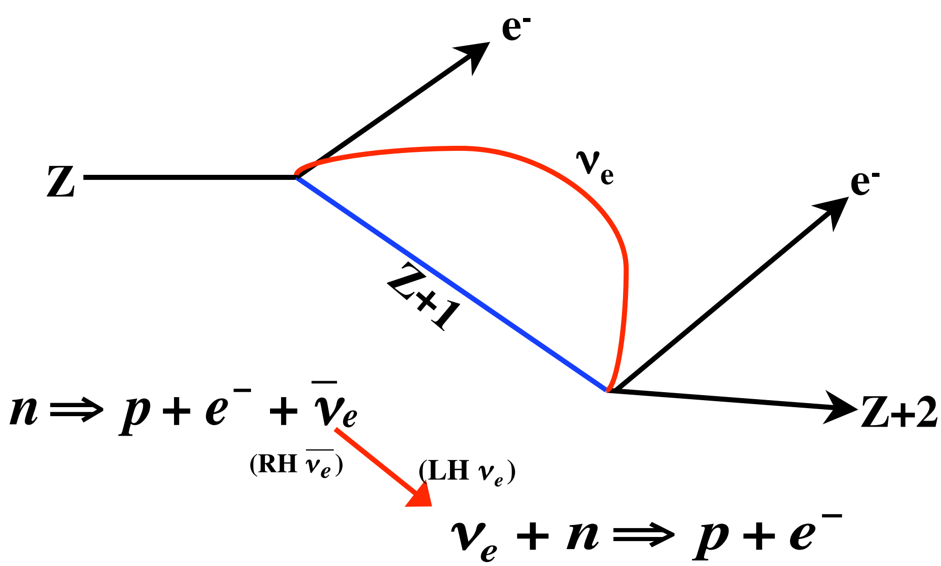


ββ(2ν): Allowed weak decay



$$2n \Rightarrow 2p + 2e^{-} + 2\bar{\nu}_e$$

ββ(0ν): requires massive Majorana ν
Decay rate is proportional to square of mass

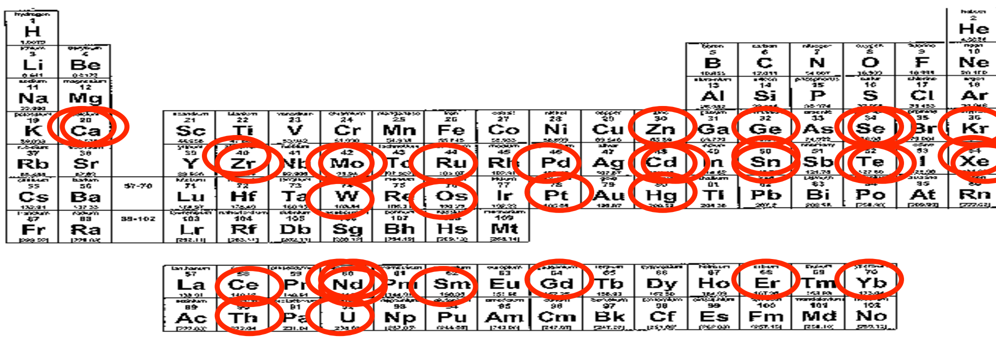


ββ History

- ββ(2ν) rate first calculated by Maria Goeppert-Mayer in 1935.
- First observed directly in 1987.
- Why so long? Background
    - $\tau_{1/2}$(U, Th) ~ $T_{universe}$
    - $\tau_{1/2}(\beta\beta(2\nu))$ ~ 10^{10} $T_{universe}$
- But next we want to look for a process with:
    - $\tau_{1/2}(\beta\beta(0\nu))$ ~ 10^{17} $T_{universe}$

ββ Candidates

There are a lot of them!

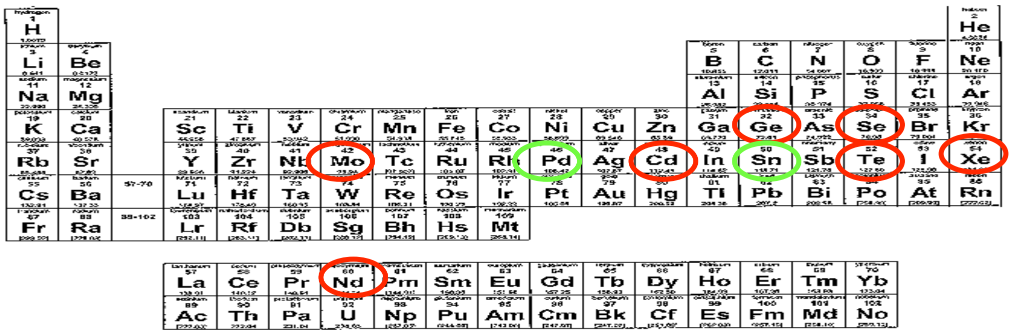


How to choose a ββ isotope?

- Detector technology exists
- High isotopic abundance or an enriched source exists.
- High energy = fast rate
- High energy = above background

ββ Candidates

Abundance > 5%,Trans. Energy > 2 MeV

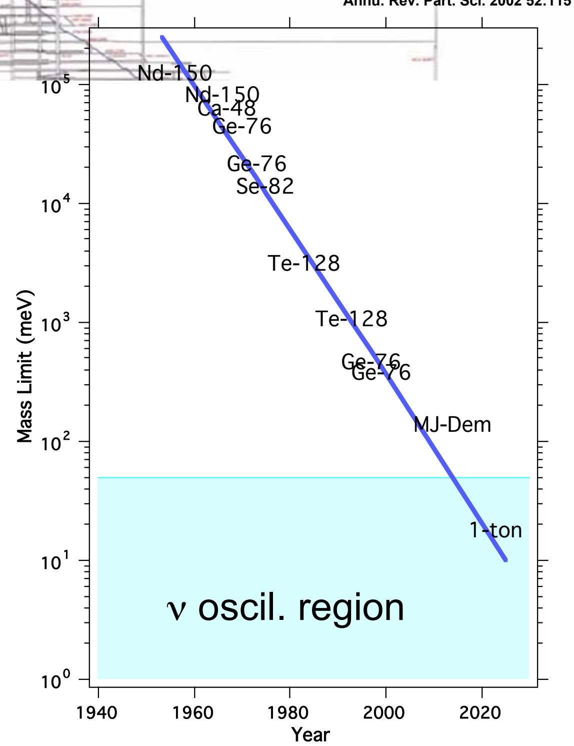


Frequently studied isotope.

Previous Results

^{48}Ca	>1.4x10^{22} y	<(7.2-44.7) eV
^{76}Ge	>1.9x10^{25} y	<0.35 eV
^{76}Ge	>1.6x10^{25} y	<(0.33-1.35) eV
^{76}Ge	=1.2x10^{25} y	=0.44 eV
^{82}Se	>2.1x10^{23} y	<(1.2-3.2) eV
^{100}Mo	>5.8x10^{23} y	<(0.6-2.7) eV
^{116}Cd	>1.7x10^{23} y	<1.7 eV
^{128}Te	>7.7x10^{24} y	<(1.1-1.5) eV
^{130}Te	>3.0x10^{24} y	<(0.41-0.98) eV
^{136}Xe	>4.5x10^{23} y	<(1.8-5.2) eV
^{150}Nd	>1.2x10^{21} y	<3.0 eV

Elliott & Vogel
Annu. Rev. Part. Sci. 2002 52:115



An exciting time for $\beta\beta$!

For at least one neutrino: $$m_i > \sqrt{\delta m^2_{atmos}} \approx 50\,meV$$

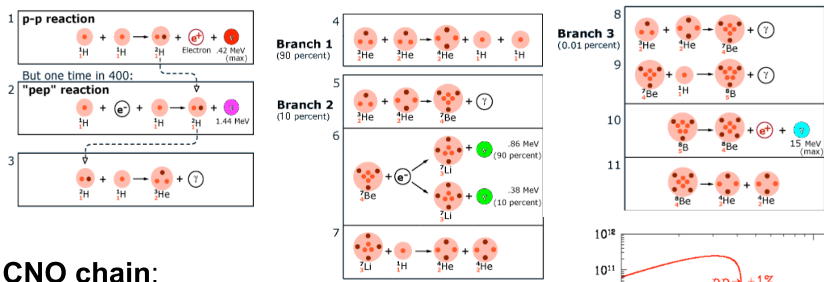
Capability of the technologies: $$\langle m_{\beta\beta} \rangle \leq 50\,meV$$

$< m_{\beta\beta} >$ in the range near 50 meV is very interesting.

Solar Neutrinos

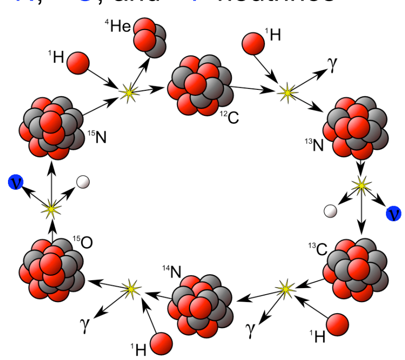
Thanks to Bruce Vogelaar for assistance with content

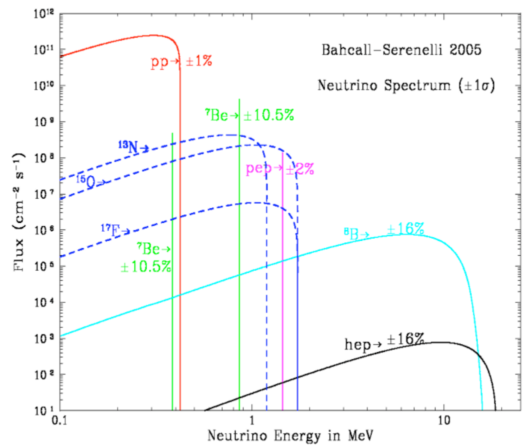
SOLAR NEUTRINO PRODUCTION



pp chain:
pp, *pep*,
^{7}Be, and ^{8}B
neutrinos

CNO chain:
^{13}N, ^{15}O, and ^{17}F neutrinos





SOLAR NEUTRINOS

Extraordinary Neutrino Beam Free of Charge

WELL DEFINED HIGHEST FLUX (~10^{11}cm^{-2}s^{-1})

- **PURE FLAVOR SOURCE - ν_e only**
- **LONGEST BASELINE (10^{8} km)**
- **HIGH DENSITY UP TO 160 g/cm^{3}; ~ 10^{11} g/cm^{2} path**
- **LOWEST ENERGIES (keV to MeV)**
- **PRESENCE OF HIGH MAGNETIC FIELDS**
- **FULL SPECTRUM: ENERGY DEPENDENT EFFECTS**

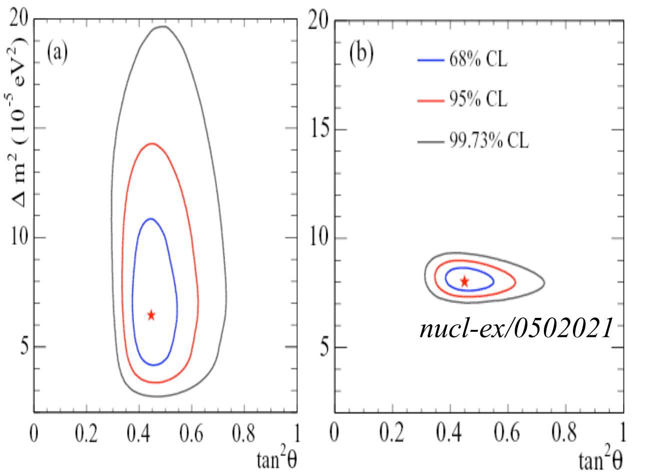
Best tools for investigating neutrino flavor phenomena in Vacuum and in Matter

For ASTROPHYSICS

Best tool for unprecedented look at how a real Star works - in the past, present and future

Neutrino Oscillation Explanation

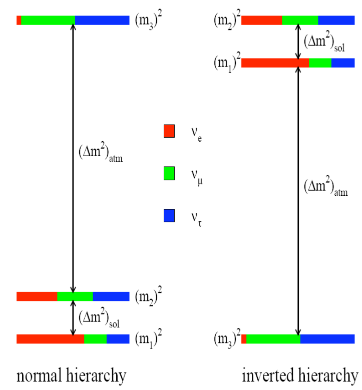
MSW explanation: resonant conversion at ^{8}B energies



Solar data: Δm_{12}^2, θ

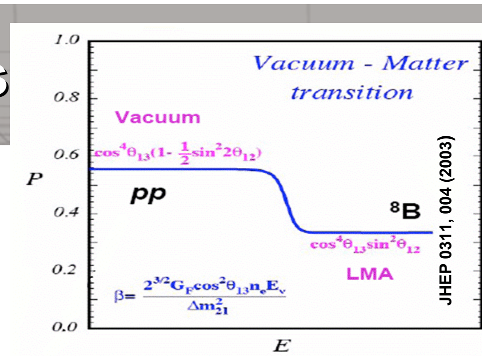
add anti-neutrinos (KamLAND and CPT)

Adding atmospheric neutrino oscillations…



MSW-LMA is based on the *combined* results from many complementary experiments

Neutrino Mixing Studies



Is θ_{13} different from zero?

normalization at low energies $\propto \cos^4(\theta_{13})$

Time dependencies in the Sun's opacity or energy production?

ν's take ~8 min to reach Earth

γ's reflect energy produced ~40,000 yrs ago

Is there a subdominant energy source in the sun?

if θ_{13} measured with reactors, a low pp neutrino flux may indicate other energy sources

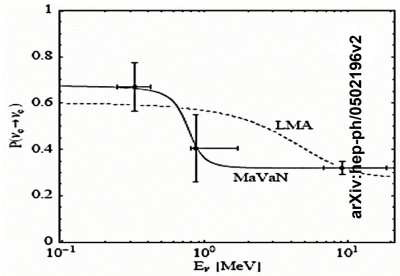
Is the MSW mechanism correct?

- is it really vacuum oscillation at low energies?

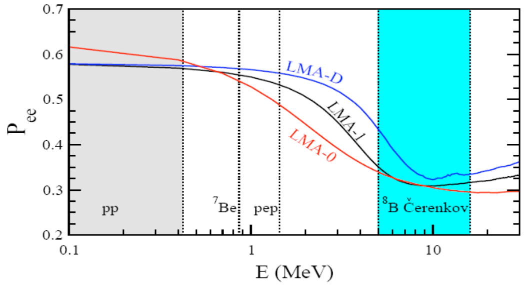
- slight discrepancy with Cl data and ^{8}B spectral upturn & diurnal effect

Do nuclear reactions fully account for the Sun's energy output today?

Are there non-standard ν interactions?



Mass-varying neutrinos



Non-standard interactions

Phys. Lett. B 594, 347 (2004)
arXiv:hep-ph/0406280.

still need pp flux to confirm, since luminosity constraint is built into these predictions

Are there sterile neutrinos?

Is CPT violated in the neutrino sector?

do ν_e and anti-$\bar{\nu}_e$ (from KamLAND) observations agree?

How much CNO? important for opacity

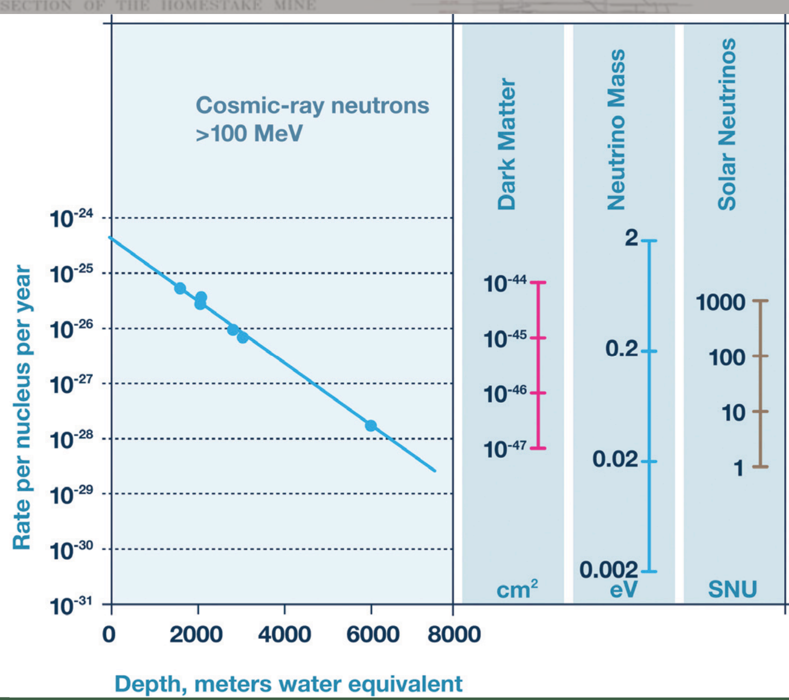
To answer these questions with confidence we need *both* charged current and electron scattering measurements of solar neutrinos at *both* pp and ^{7}Be/pep energies!

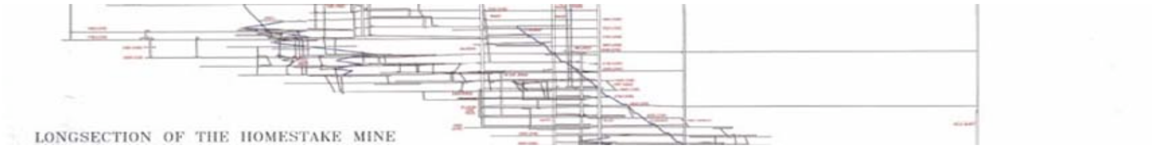
- **any forced re-interpretation of solar result would have a major impact on all neutrino programs**
- **experiments already underway and some in advanced R&D can accomplish these goals**

Some of the Experiments Proposed for DUSEL

- **Double Beta Decay: Both sensitive to key 50-meV range**
  - EXO
    - 1-10 tonnes of liquid Xe
  - MAJORANA-GERDA joint proposal for 1-tonne of Ge detetors
- **Solar Neutrinos**
  - LENS
    - In based metal-loaded liquid scintillator
  - CLEAN
    - Liquid Ne: 50-100 tonnes

These Experiments Need Depth





Nuclear Astrophysics

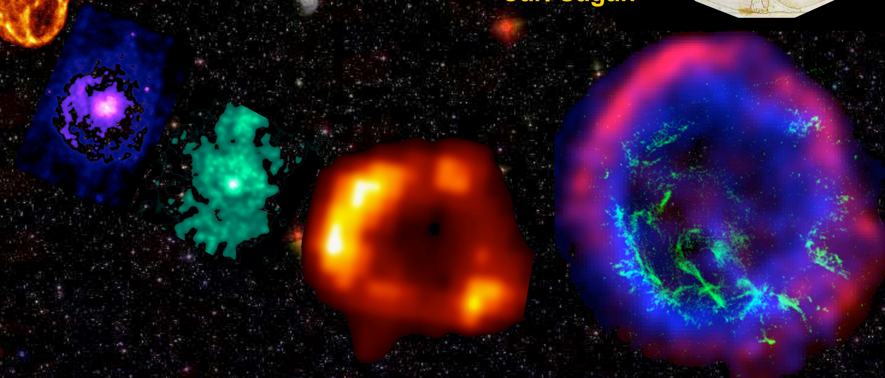
Thanks to Michael Wiescher for assistance with content

The Human Factor

Each heavy atom in our body was built and processed through ~100–1000 star generations since the beginning of time!

We are made of star stuff

Carl Sagan

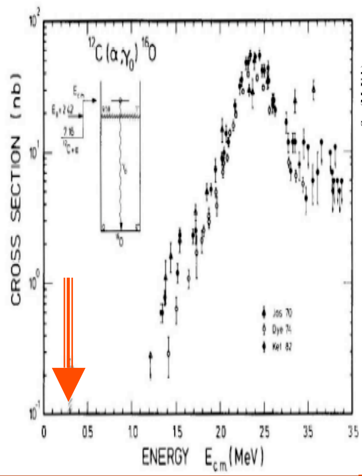


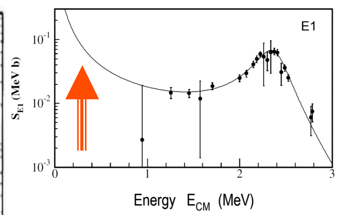
An Important Example

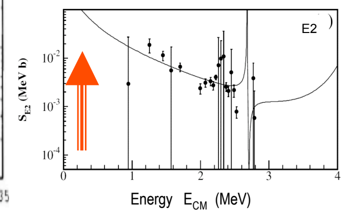
$^{12}C(\alpha,\gamma)^{16}O$ determines the amount

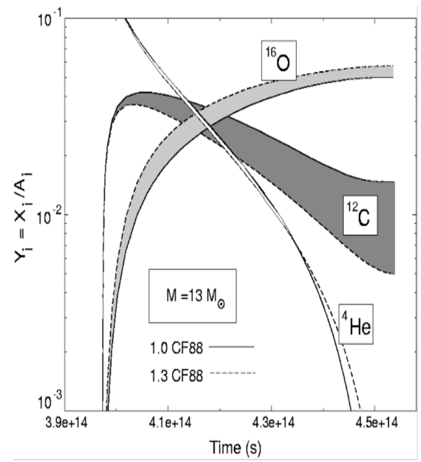
of Carbon which we are made of

and Oxygen which we breathe

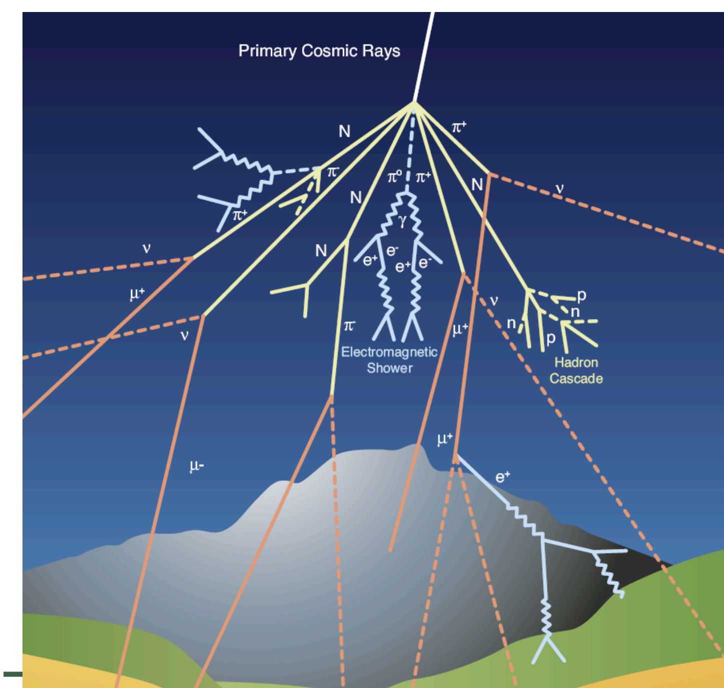


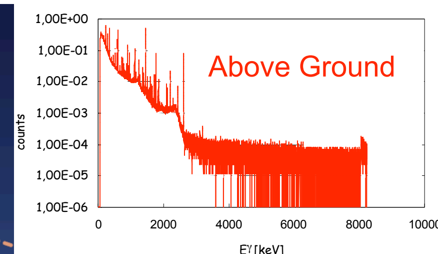


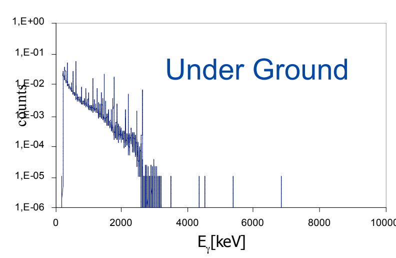




Handicaps: low cross section, high background solution underground!?







10^{-6} reduction of Cosmic Rays by moving under ground

Accelerators Underground

- Low energy cross section extrapolations still carry substantial uncertainties; besides improved experimental techniques (background reduction, detection efficiency) better theoretical tools (R-matrix theory) are required.
- Uncertainties still exist for most of the reactions in stellar H, He, C, … burning. New modeling results, open new questions about reaction flow pattern.
- Underground accelerator approach is promising, but needs to be coupled with event identification techniques (difficult for low energy reactions)
- superior energy stability and resolution are required for an underground accelerator

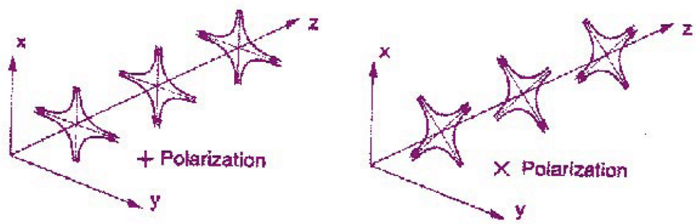
Gravity Waves

Thanks to Vuk Mandic for assistance with content

Gravitational Waves

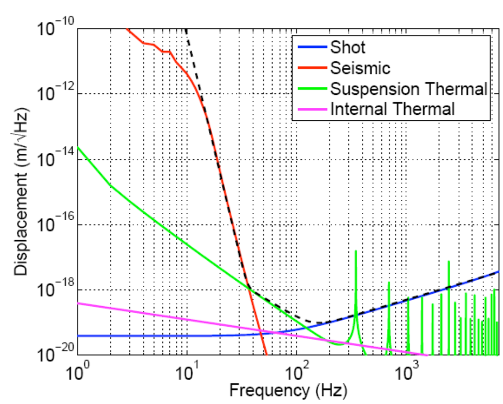
- Newtonian gravity: instantaneous action at a distance.
- General Relativity: the "signal" travels at the speed of light.
- Einstein's field equations reduce to the wave equation.

- Two polarizations:



Why Do GW R&D Underground?

- The scientific motivation for exploring 1-Hz region of gravitational waves is very strong.
  - Many sources: inspiral, periodic, stochastic.
- Seismic noise and gravity gradient noise are among the major obstacles for reaching 1-Hz scale.
  - Both of these should be significantly suppressed underground.



Final Thoughts

The Physics program is very rich and requires a deep underground laboratory.