24th Indian-Summer School
"Understanding Neutrinos"
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Neutrino cross-sections in the wide range of energies relevant for low-background underground experiments

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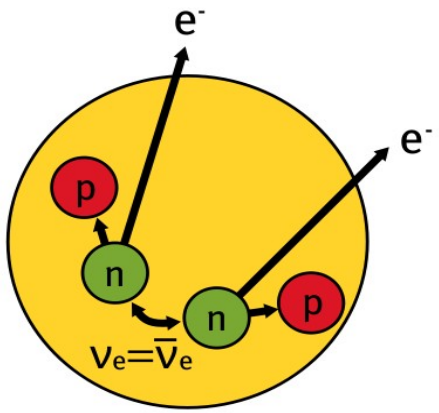
Outline

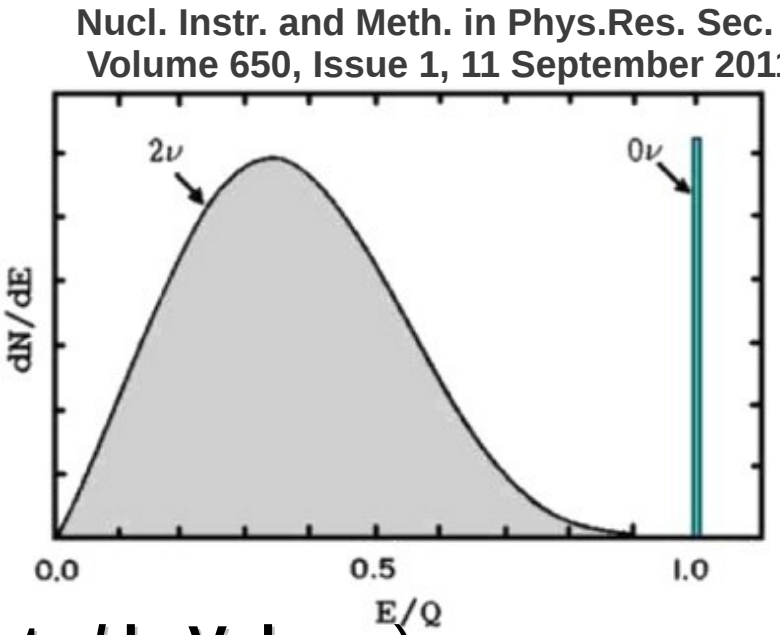
- **Introduction**
  - Low-background experiments
  - Underground facilities
- **Neutrinos**
  - Sources
  - Possible interactions
  - Low and high energy regimes
- **Cross sections**
  - Low energy neutrinos measurement
  - High energy neutrinos measurement
- **Summary**

Low-background experiments

Experiments looking for rare events → low bkg environment

- example: $0\upsilon\beta\beta$ decay for ^{76}Ge
  - expected events: 5 / 100 kg · y





- This generation experiment (10^{-3} events / keV· kg ·y)
  - Lower half life limit $1.9 * 10^{25}$ y (H.M. And IGEX)

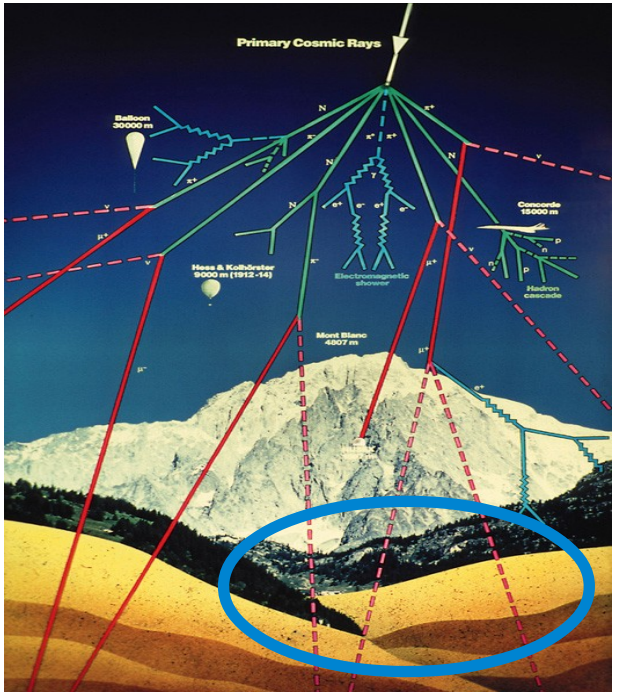
$$T_{\frac{1}{2}}^{0\nu} \propto < m_{\beta\beta} >^{-2} \propto \sqrt{\frac{M \cdot t}{\Delta E \cdot Bkg}}$$

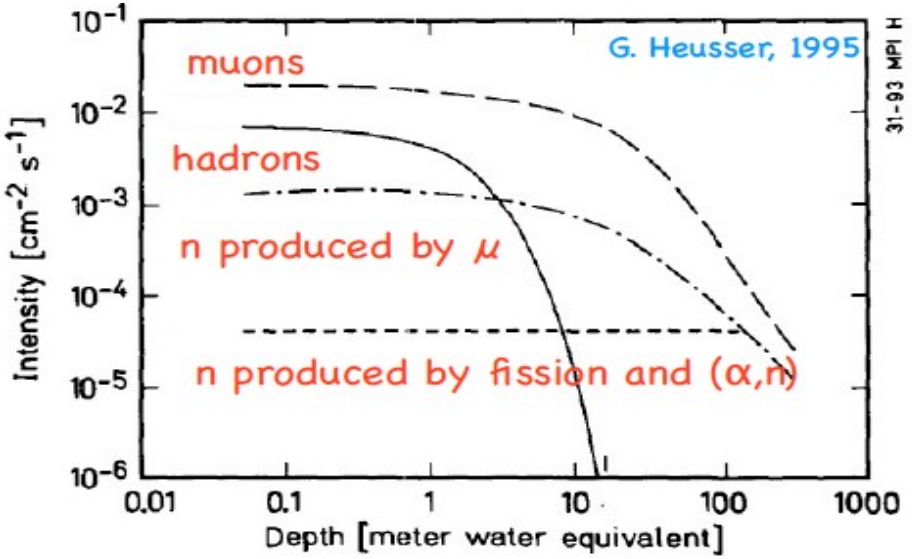
Push the half life limit up -------> increment the mass
-------> lower bkg

Underground Low-background experiments

→ **Main goals:**

A) reduce background ⇒ Go **DEEP** underground





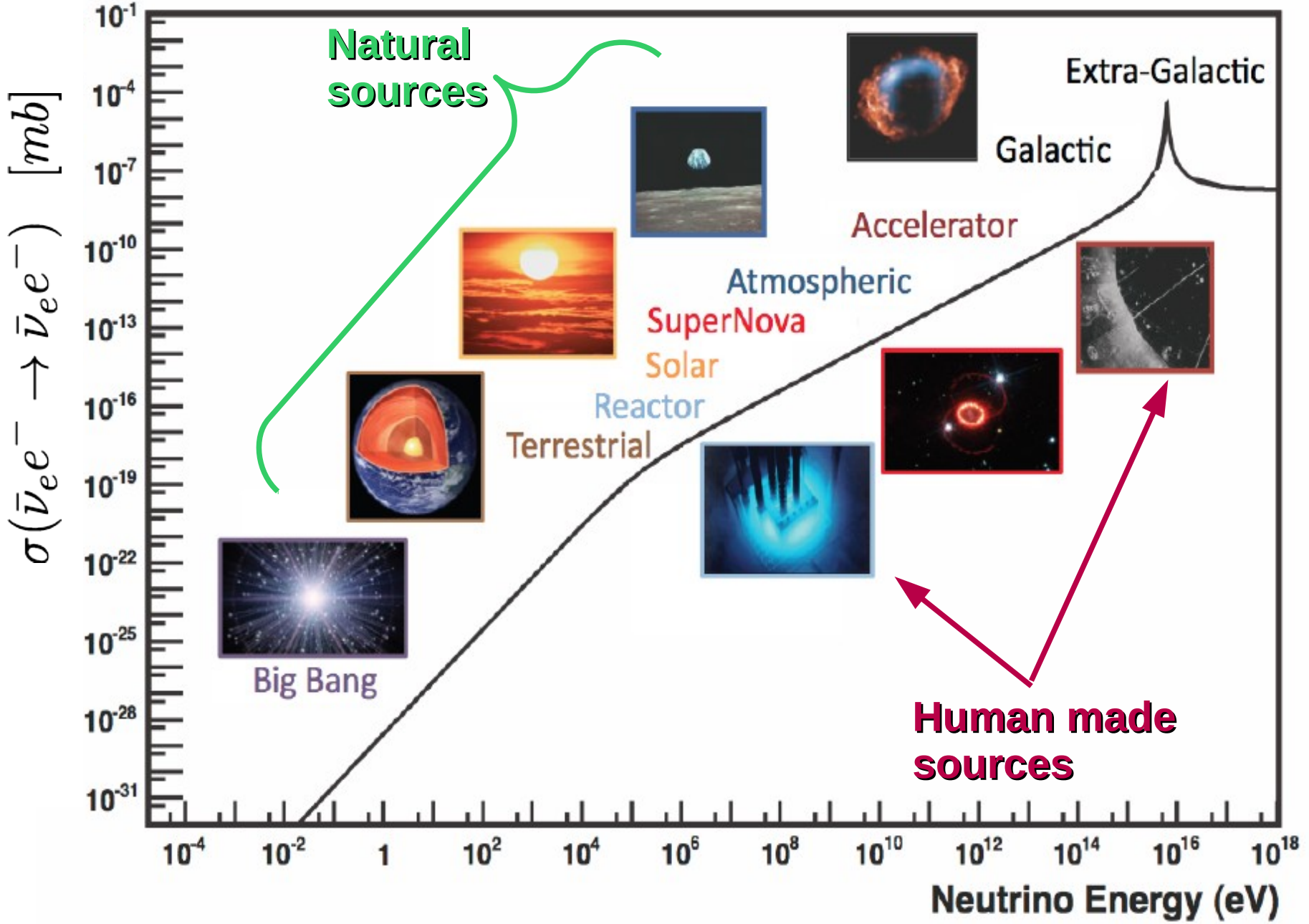
All the components are reduced **BUT neutrinos**

B) know the irreducible bkg sources

cross-sections ⇒ **events** ⇒ **understand data**, **evaluate sensitivity**

FOCUS ON: neutrinos

Neutrinos sources



Private communication: J. Formaggio to be published in Rev. Mod. Phys. (2012)

Neutrino interactions

Weak Interactions:

- Charged current **CC** mediated by W^+ and W^-
- Neutral Current **NC** mediated by Z^0

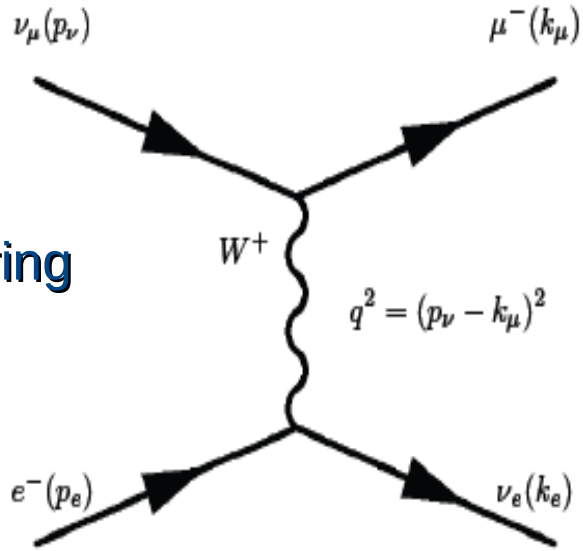
Interaction with matter:

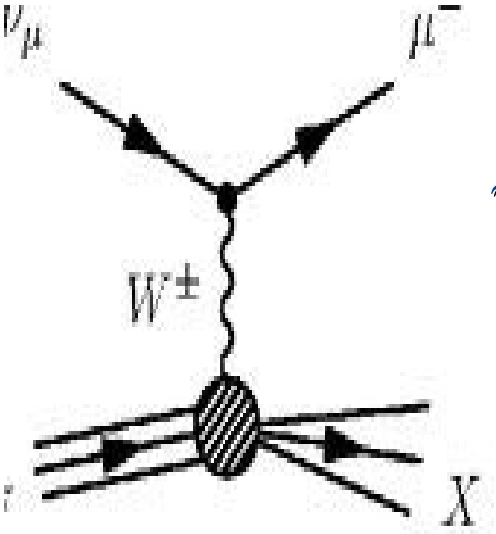
- With **electrons**
- With **nuclei**
  - entire nucleus
  - nucleons
  - partons of the nucleon

Depending on energy!

Examples of Feynman diagrams:

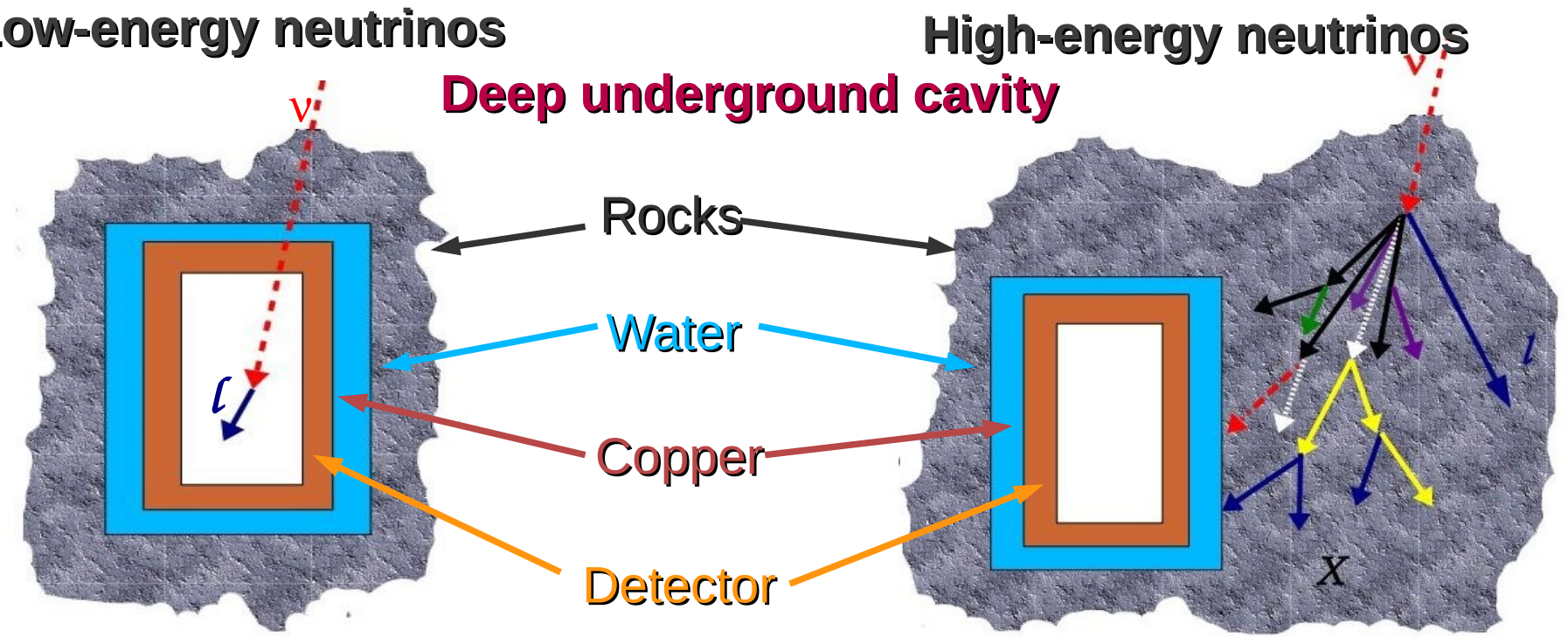
υ_μ –e scattering





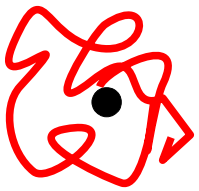
υ_μ Deep Inelastic Scattering

Neutrinos: are they really “dangerous”?

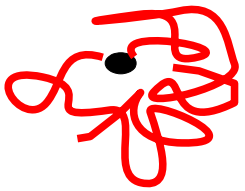


– ν interaction **inside the detector**

- **lepton** → **Energy deposition**



lepton E deposit



ββ decay

– ν interaction **in the rocks**

- **lepton** AND **Hadronic shower**
- Particles can **enter into the detector**

We need to know how probable are these interaction!!

Cross-sections review: Low energies

→ **Threshold less interactions ($0 < E_\nu < 1$ MeV)**

- **coherent scattering**

$$\nu + A_N^Z \rightarrow \nu + A_N^{*Z}$$

  - Initial state = final state
  - Nucleus recoil energy → **small signal + no tag**!

- **neutrino capture on Radioactive Nuclei**

$$\nu + A_N^Z \rightarrow e^- + A_{N-1}^{Z+1}$$

  - exothermic interaction
  - to detect Big Bang neutrinos

→ **Nuclear Processes** **($1 < E_\nu < 100$ MeV)**

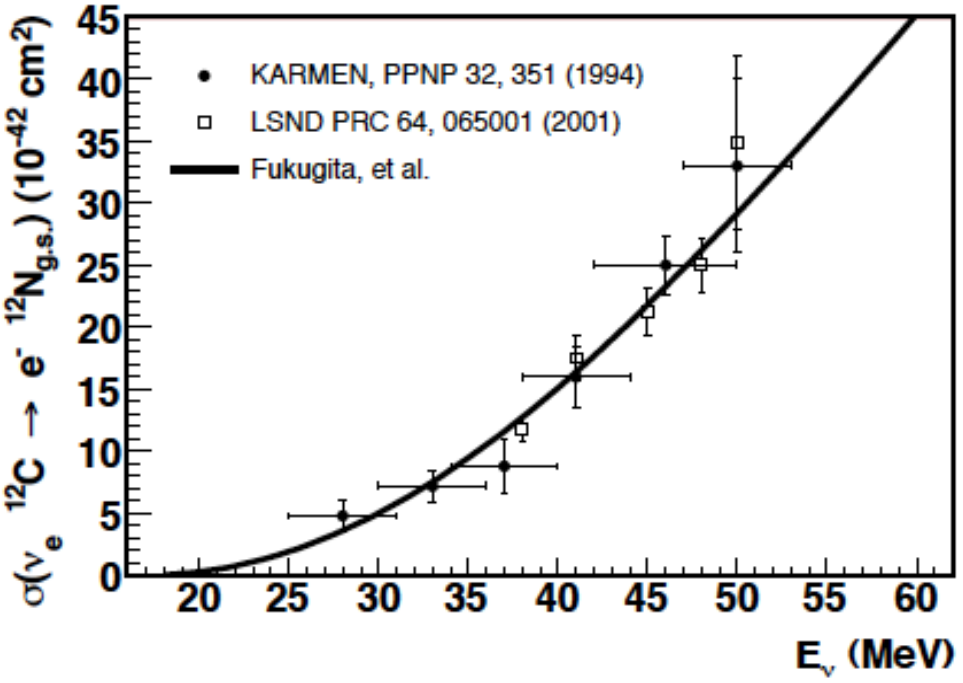
- **Inverse Beta Decay**

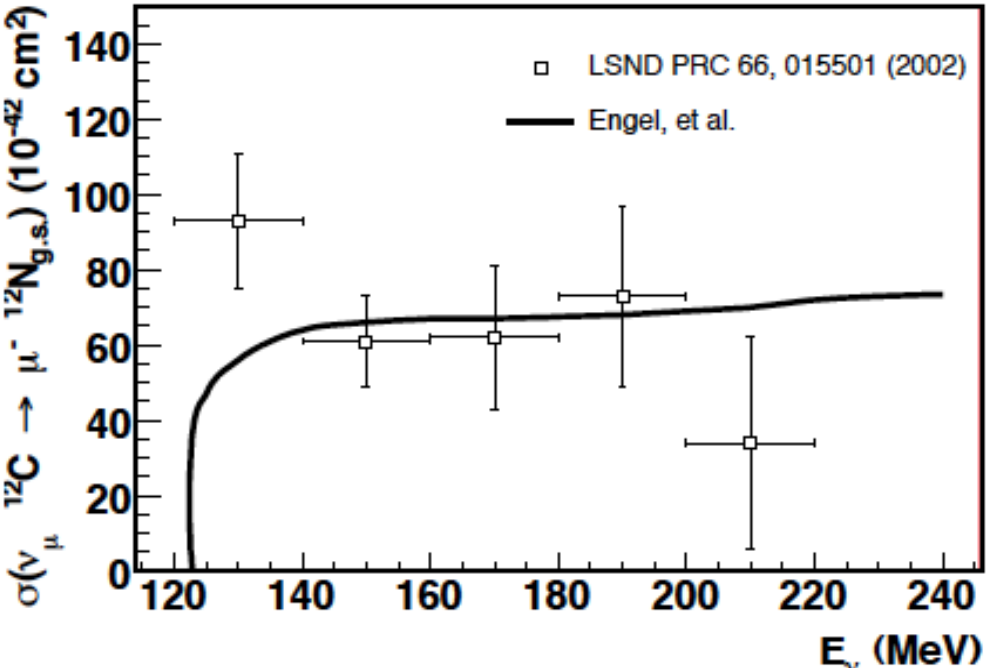
$$\bar{\nu} + p \rightarrow e^+ + n$$

  - threshold at **1.806 MeV**
  - antineutrinos from **reactors**
  - detected for the first time in 1956

Experimental results: inverse beta decay

Inverse beta decay: ^{12}C nuclear target





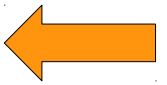
$$\nu_e + C^{12}_{g.s.} \rightarrow e^- + N^{12}_{g.s}$$

- neutrinos from **stopped proton beam**
- detected with the decay of **^{12}N into ^{12}C**: **delayed secondary electron**
- main uncertainty: **neutrino fluxes**

Private communication: J. Formaggio to be published in Rev. Mod. Phys. (2012)

Cross-sections review: High energies

- **Intermediate energies (0.1 < E_υ < 20 GeV)**
  - **elastic and quasi elastic scattering**
    - **CC: nucleon in final state** $\nu_\mu + n \rightarrow \mu^- + p$
    - **NC:** initial = final state $\nu + n \rightarrow \nu + n$



  - **mesons production**
    - **kaon** production
    - resonant and coherent **pion production**

$$\nu_\mu + N \rightarrow \mu^- + N^* \text{ with } N^* \rightarrow \pi + N'$$

      - **bkg** for **oscillation experiments (worst π^0)**

- **High energies (20 < E_υ < 500 GeV)**
  - **deep inelastic scattering**
    - **CC** $\bar{\nu}_\mu + N \rightarrow \mu^+ + X$ **NC** $\nu_\mu + N \rightarrow \nu_\mu + X$

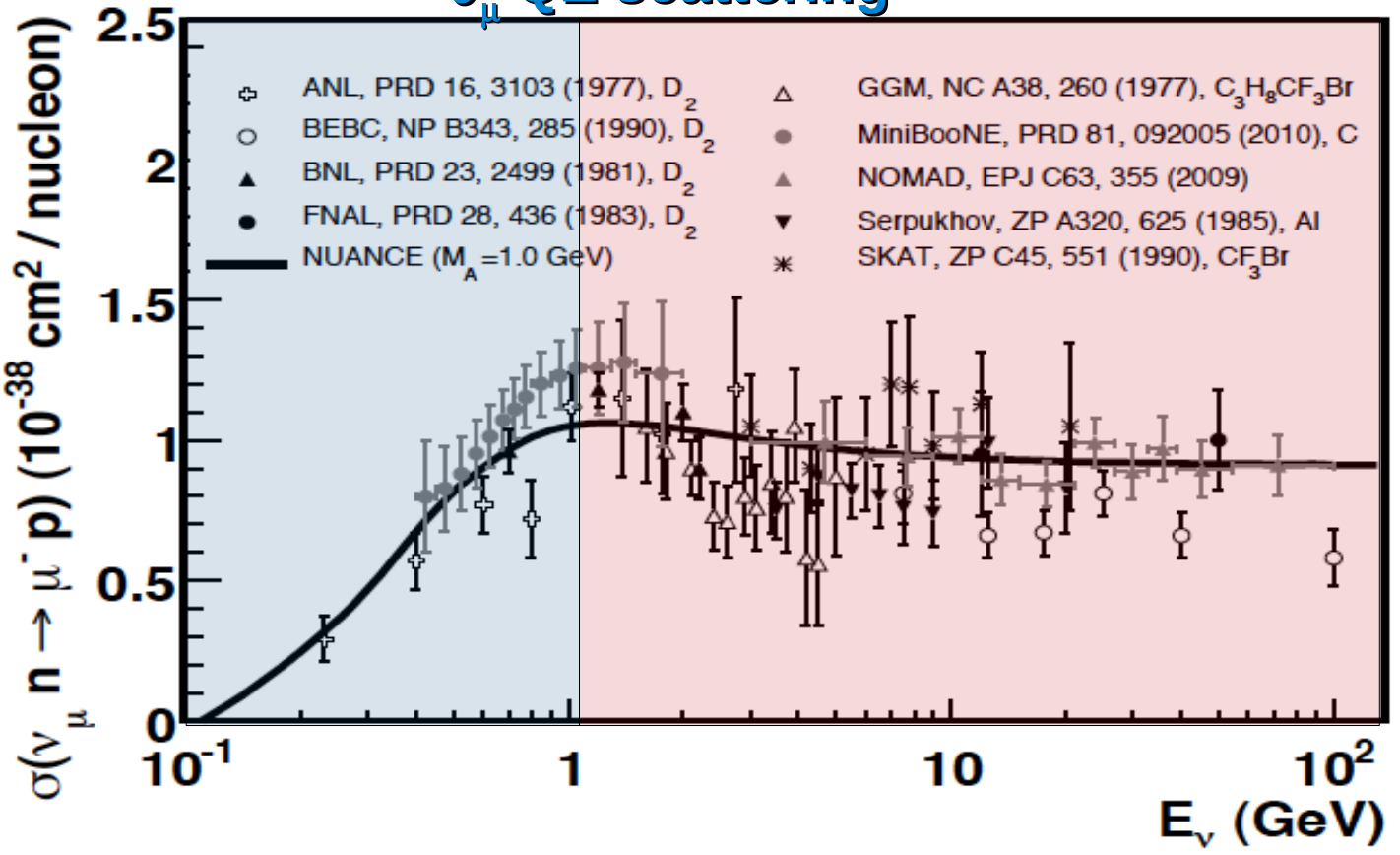
    - **Bjorken scaling**: cross section linear with energy

- **Ultrahigh energies (0.5 TeV < E_υ < 1 EeV)**

  - **IceCube: upper limit** on flux of υ associated with **GRBs**

Experimental results: intermediate energies

υ_μ QE scattering



- **linear rising** for **E < 1 GeV** but **damped** for **E > 1 GeV** ← form factors
- even more modern experiment have **flux normalization uncertainty:**
  - **NOMAD** and **MiniBooNE** curves: **30% difference on normalization**

Private communication: J. Formaggio to be published in Rev. Mod. Phys. (2012)

Summary and outlook

- experiments looking for **rare events**
  - → **reduce the background**
    - → deeper **underground**
  - → **irreducible background** sources => **neutrinos**
    - → we **MUST know** their possible **interaction**

- two **energy regimes** for neutrinos:
  - → **low energy:** interact inside the detector and **mimic the signal**
  - → **high energy**: interact outside the detector and create showers
    - **part of the shower** can **enter** into the detector

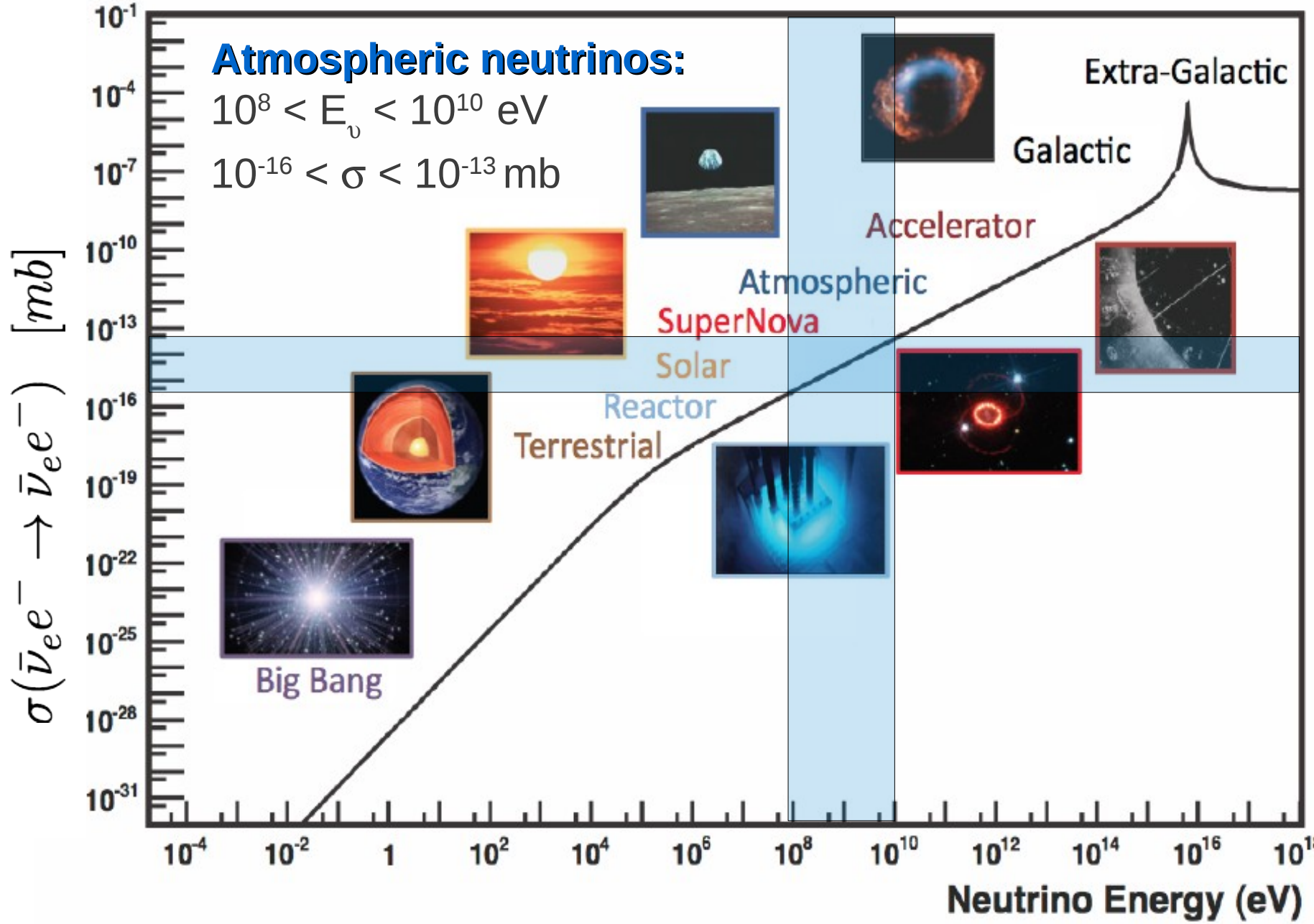
- to **know our bkg** we need:
  - → **cross sections** measurement
    - → evaluate the **sensitivity**
    - → interpretate **data**

Acknowledgment:

J. Formaggio and **G. Zeller** "From eV to EeV: Neutrino Cross-Sections Across Energy Scales" (to be published in **Rev. Mod. Phys. (2012)**)

Back up slides

Neutrinos sources



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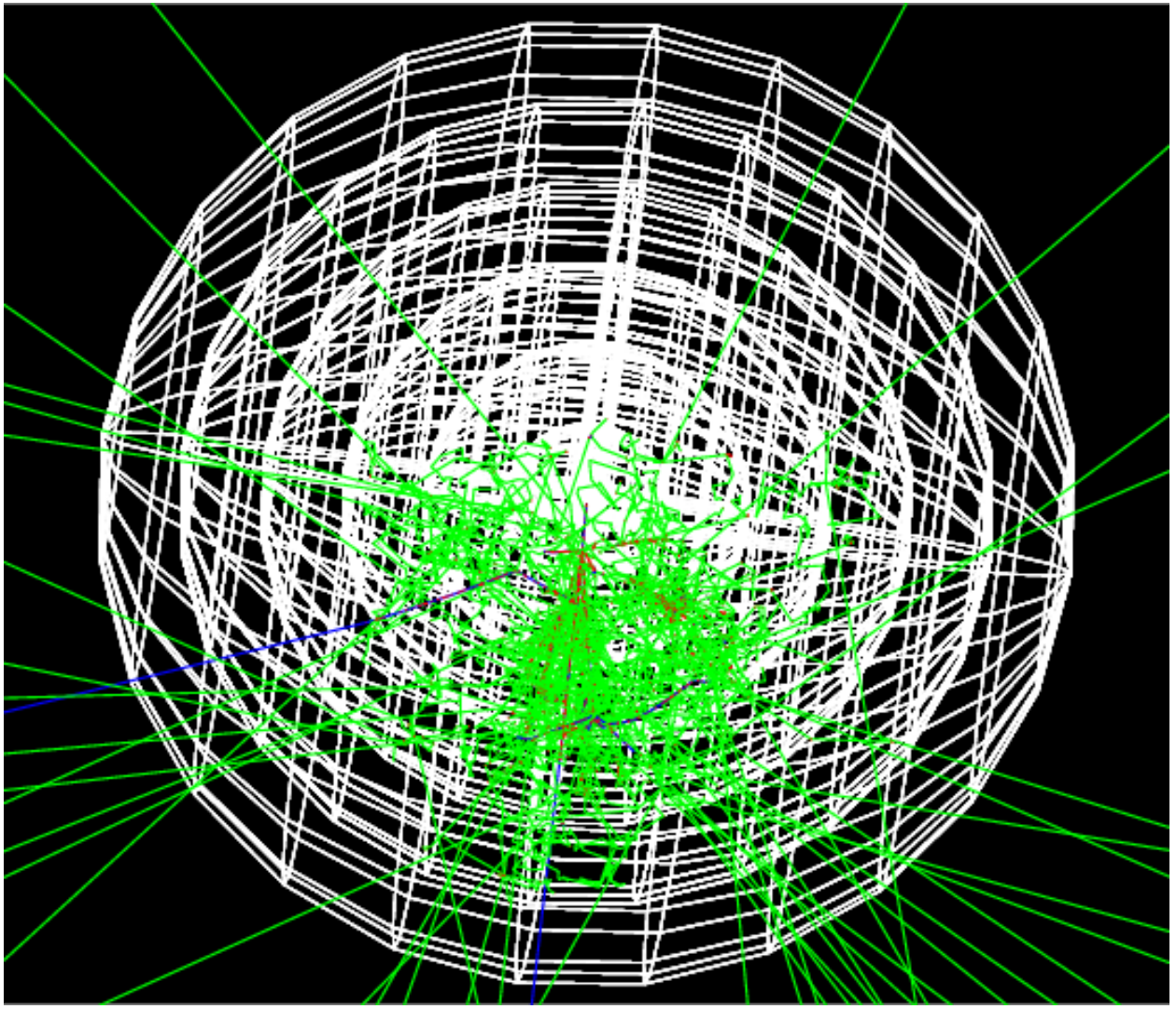
Hadronic Shower: how can it look like?



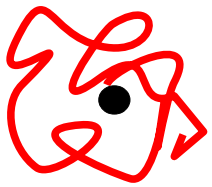
- please see the talk on **Thursday afternoon**
  M. Palermo "Background simulation study for Deep Underground Cavities"

Summary and outlook

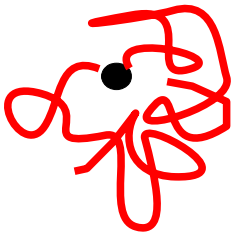
- experiments looking for **rare events** need a **low-background** environment
  → **underground laboratories**

- neutrinos' fluxes underground are **to be taken into account**

- two energy regimes for neutrinos:
  → **low energy:** interact inside the detector and **mimic the signal**



Inverse β decay



ββ decay

- **Not distinguishable**
- Hopefully **tag the nucleus** created

  → **high energy**: interact outside the detector and create showers
  - part of the shower can enter into the detector

- **cross sections** need to be well known → **evaluate the sensitivity**

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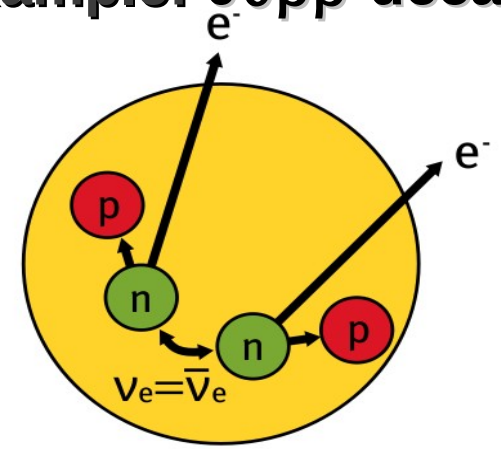
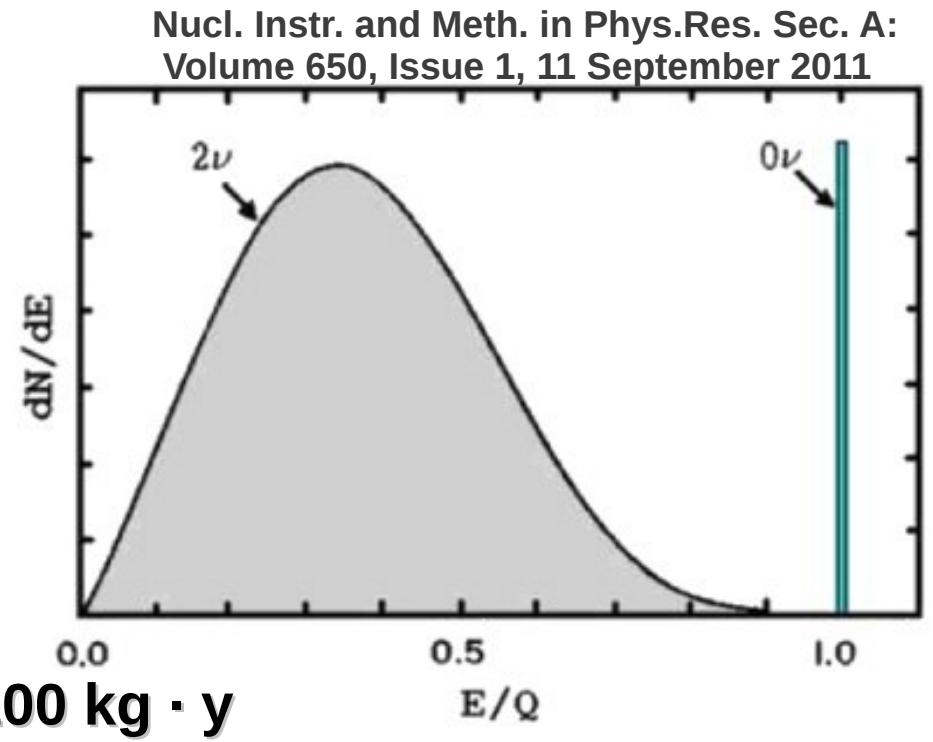
Low-background experiments

→ **Experiments looking for rare events:**

- **example: 0νββ decay**





- **expected events: 5 events / 100 kg · y**
- **Half life lower limit:** 1.9 * 10^{25} y for ^{76}Ge **(H-M and IGEX)**

$$T_{\frac{1}{2}}^{0\nu} \propto < m_{\beta\beta} >^{-2} \propto \sqrt{\frac{M \cdot t}{\Delta E \cdot Bkg}}$$

Push the half life limit up → lower bkg (~ 10^{-3} events / keV· kg ·y)