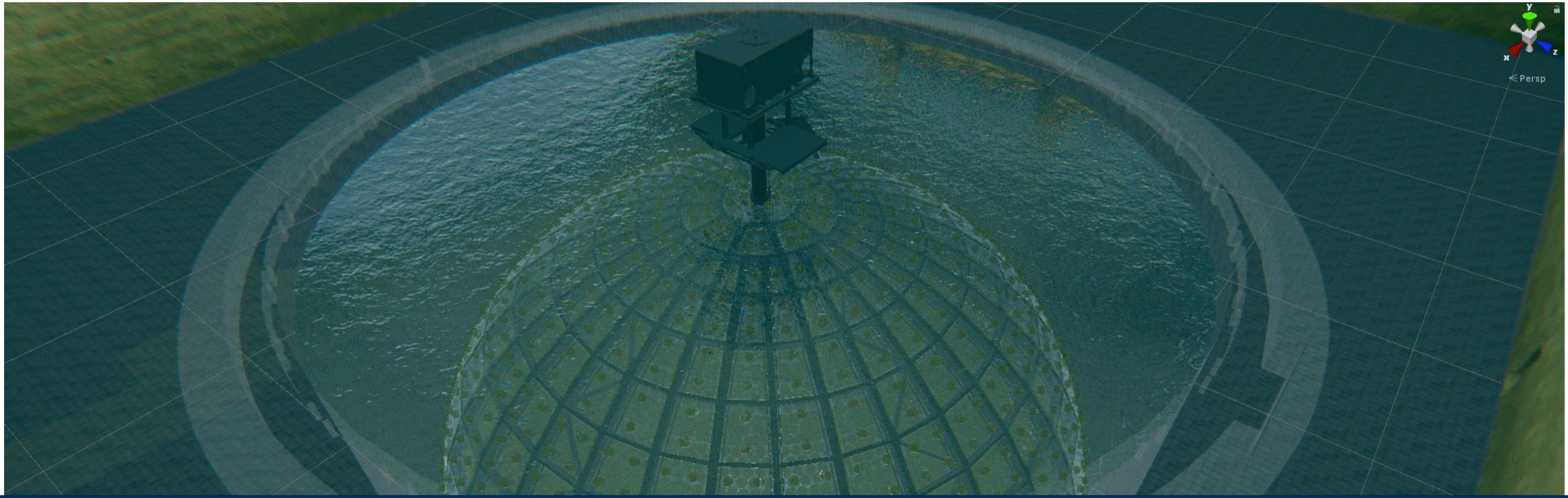


JUNO NON-OSCILLATION PHYSICS

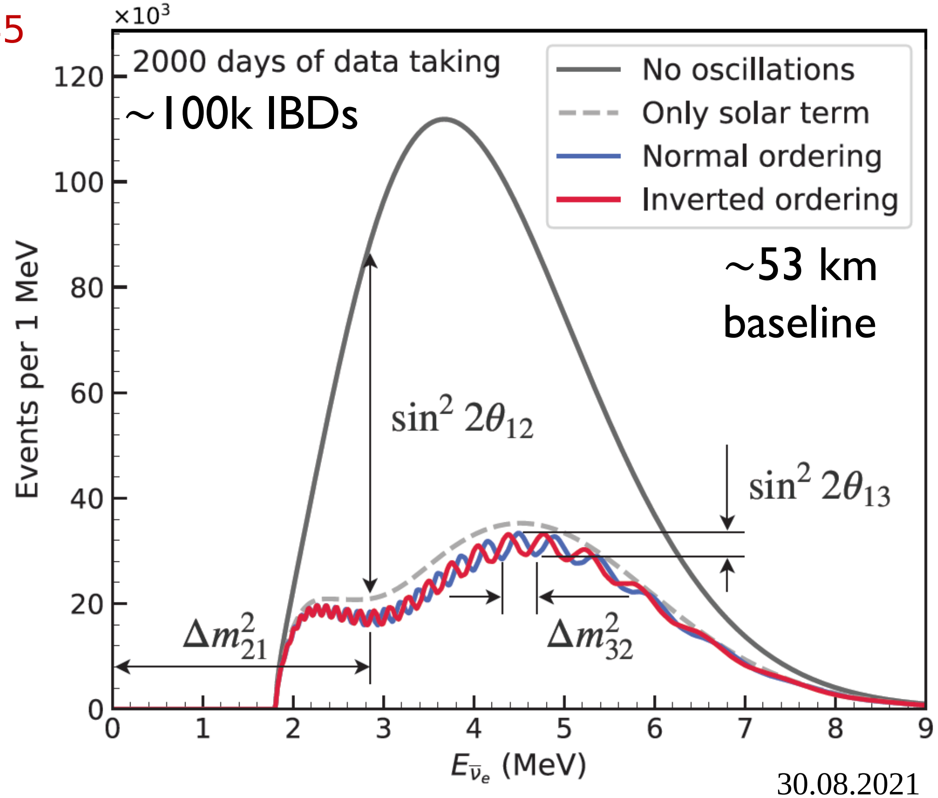
Giulio Settanta, on behalf of the JUNO Collaboration

Institut für Kernphysik, Forschungszentrum Jülich, Germany

TAUP 2021 Conference – Neutrino Physics and Astrophysics

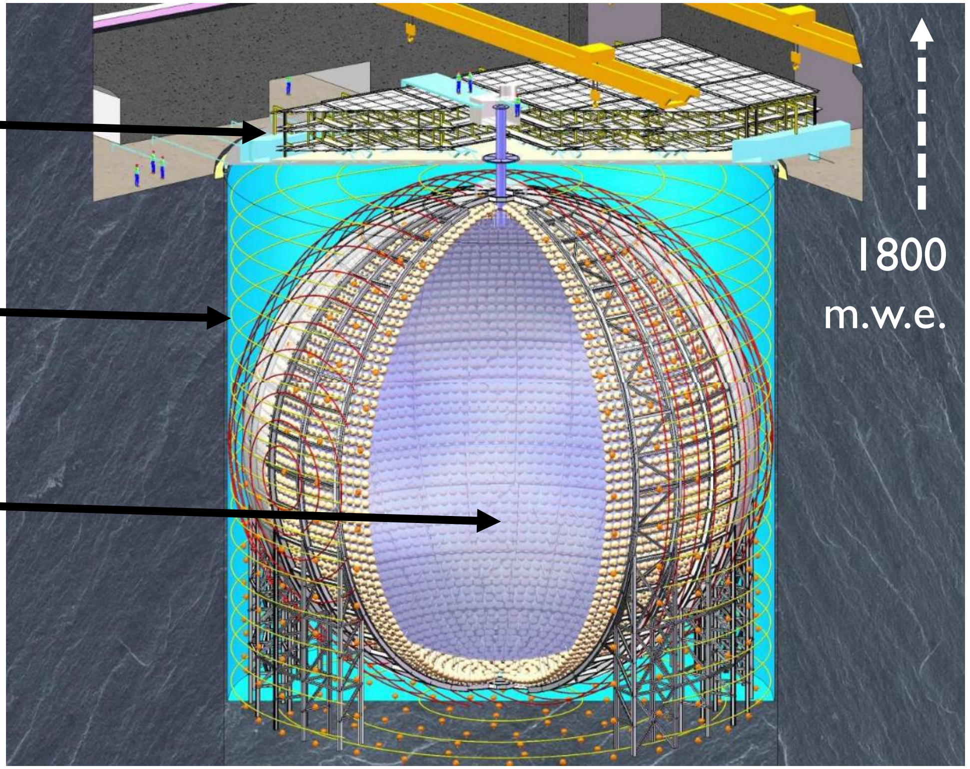
JUNO EXPERIMENT

- JUNO (Jiangmen Underground Neutrino Experiment) will be the largest ever built liquid scintillator (LS) – based experiment
  - 20 kton of LS active volume, cosmic μ flux suppressed down to 4 mHz/m^2
- **The JUNO experiment has been designed as a state-of-art detector for neutrino physics**
  - Primary goal: neutrino mass ordering identification by means of reactor antineutrinos, exploiting oscillation effects in vacuum
  - Location optimized for mass ordering sensitivity, exploiting the interplay between Δm^2_{31} and Δm^2_{32}
  - Reactor flux precisely constrained by JUNO – TAO - arXiv:2005.08745
  - Precise measurement of of solar oscillation parameters
    See J. Zhang talk
  - Strong potential in Astroparticle and BSM Physics → **this talk!**



JUNO DETECTOR

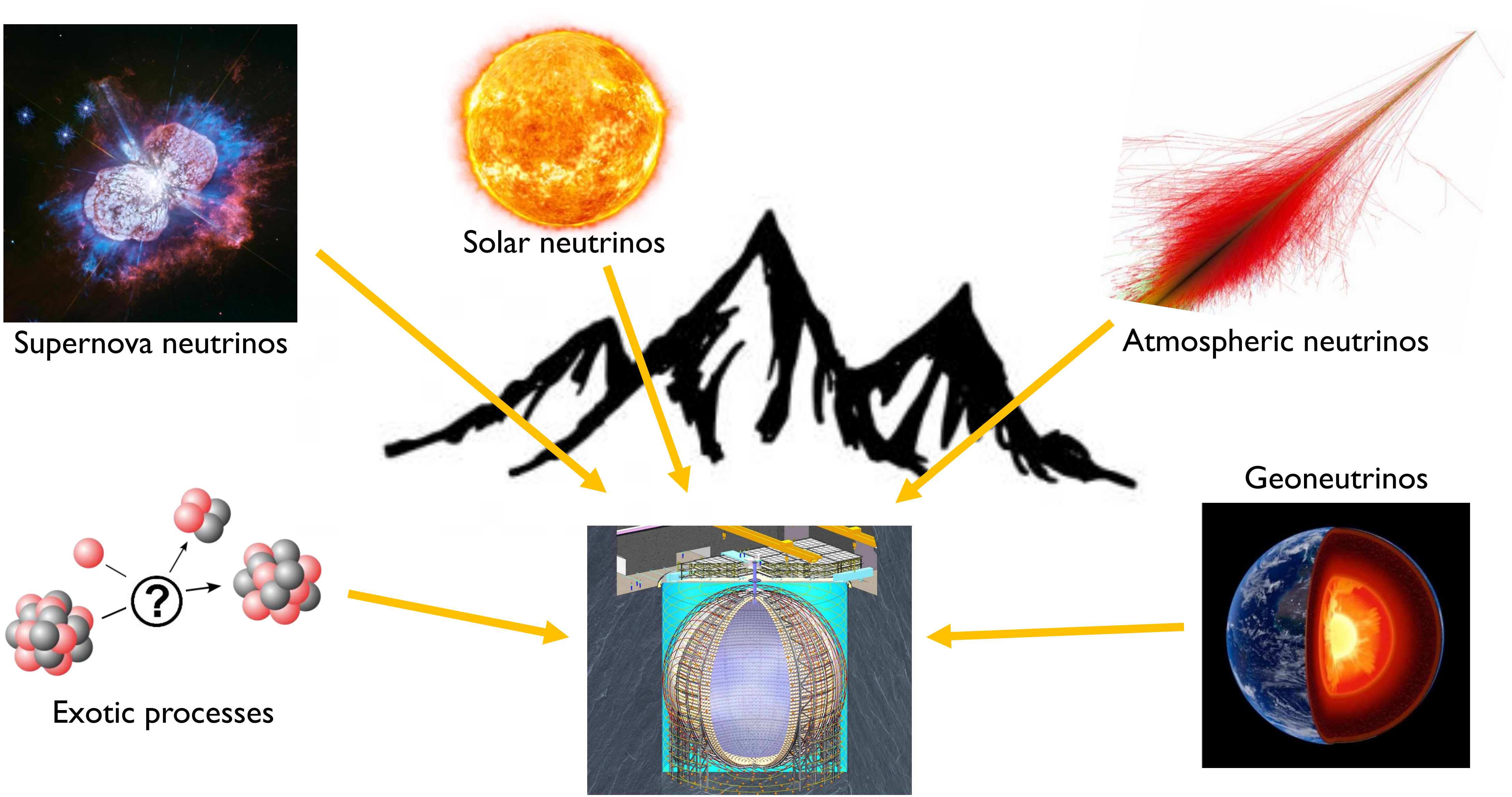
- Top Tracker
  - Plastic scintillator strips
  - Atm. μ median angular resolution ~ 0.2°
- Outer Water Pool (WP)
  - Cherenkov μ veto, 2400 20” PMTs
  - > 99.5% μ detection efficiency
- **Central 20 kt liquid scintillator**
  - ~ 36 m diameter acrylic sphere
  - 17600 20” PMTs
  - 25600 3” PMTs
- High photo – coverage (> 75%), photon yield (10k / MeV) and photon detection efficiency (> 28%) → $\mathbf{3\%/\sqrt{\boldsymbol{E}[\boldsymbol{MeV}]}}$ resolution
- Main detection channel for neutrino mass ordering determination:
  - **Inverse Beta Decay (IBD)**
- Construction complete in 2022
- **Suitable instrument for many measurements in astroparticle field!**



For more details:
- Z. Wang – JUNO Detector Design & Status
- J. Zhang – JUNO Oscillation Physics

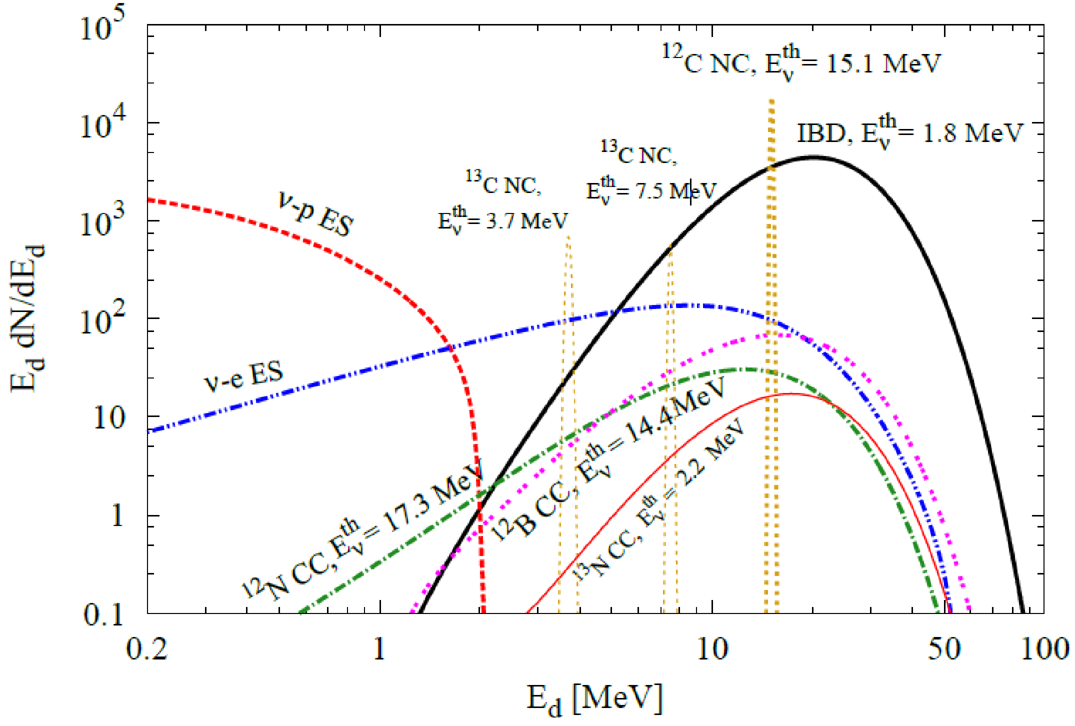
NATURAL SOURCES ACCESSIBLE TO JUNO

NATURAL SOURCES ACCESSIBLE TO JUNO



SUPERNOVA NEUTRINOS

- Before, during and after a supernova (SN) explosion, a high number of neutrinos and antineutrinos of all flavors is produced
  - From days before and for several seconds after the explosion
- JUNO can provide a real – time detection, almost background free
- Typical predictions for a ~10 kpc supernova explosion in JUNO are of ~5000 IBD events, together with other interaction channels
  - Energy range: 0,1 – 100 MeV
  - Sensitivity to all neutrino flavors
- Impressive increase of statistics with respect to SN1987A
- Unique information about explosion mechanism

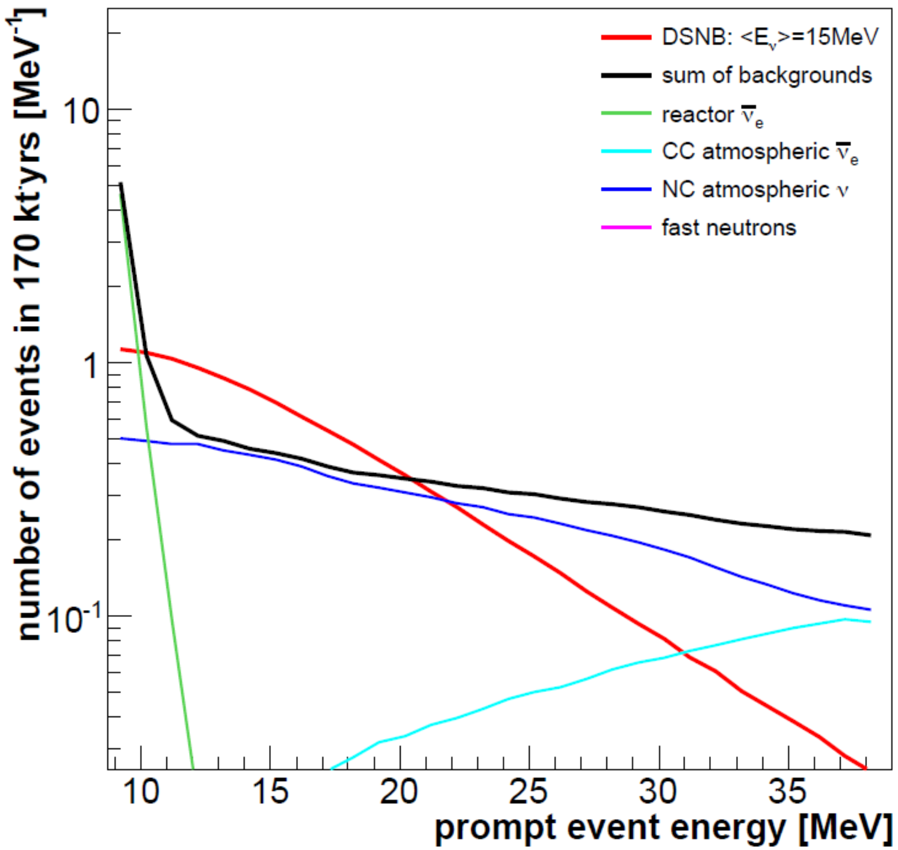


- Detection of pre – supernova neutrinos paves the way to early alerts to optical/X-ray/gamma instruments
  - Pointing limitations because of low energy range (100 keV – 1 MeV) and radioactivity contamination

JCAP05 049 (2020)

DIFFUSE SUPERNOVA NEUTRINO BACKGROUND

- Not only neutrinos from "recent" supernovae, but also the superposition of past explosions
  → *Diffuse Supernova Neutrino Background*
- Many information embedded, such as:
  - Red-shift – dependent SN rate
  - Average SN neutrino spectrum
  - Fraction of black holes formation in core-collapse SNe
- In JUNO, ~3 $\bar{\nu}_e$ IBD events/year above 10 MeV
  - Efficient tagging
- Dominant background consists of atmospheric neutrinos
  - Neutral – current (NC) interactions with ^{12}C atoms
  - Pulse shape – based discrimination is very effective
- Visible signal in the ~(10 – 20) MeV energy range
- Expected 3σ evidence of detection after 10 years, for
  $<E_{\bar{\nu}_e}> \gtrsim$ 15 MeV



MULTI – MESSENGER ASTRONOMY

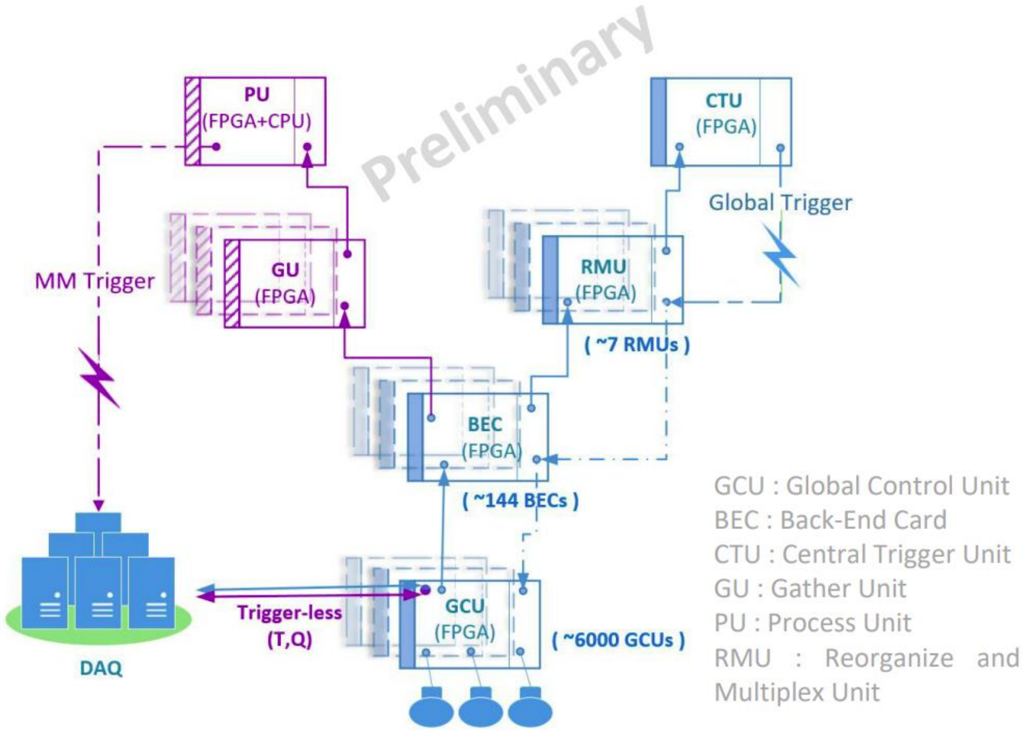
- Global trigger threshold: ~200 keV
- Multi – messenger (MM) trigger threshold: ~10 keV → under development

- Real – time waveform processed by FPGAs (time and charge), sent to DAQ in triggerless mode
- Raw waveforms waiting for global trigger decision

- **Detection threshold lowered by MM trigger**
  - Hardware + firmware + DAQ solution
  - Filter pure dark noise events on FPGAs

- JUNO as a powerful transient machine for MM observations
- **Major role in the next-generation Supernova Early Warning System (SNEWS2.0) for MM astronomy**

  arXiv:2011.00035

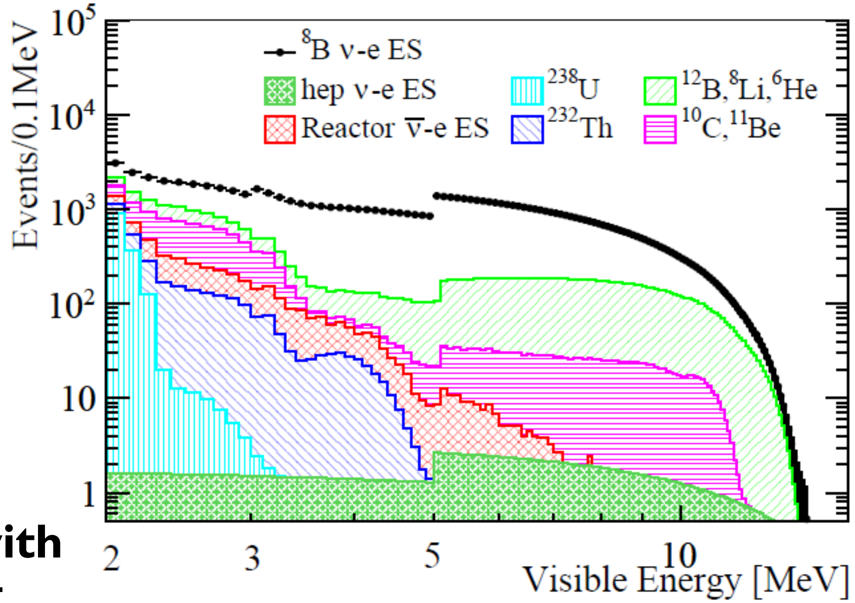


SOLAR NEUTRINOS

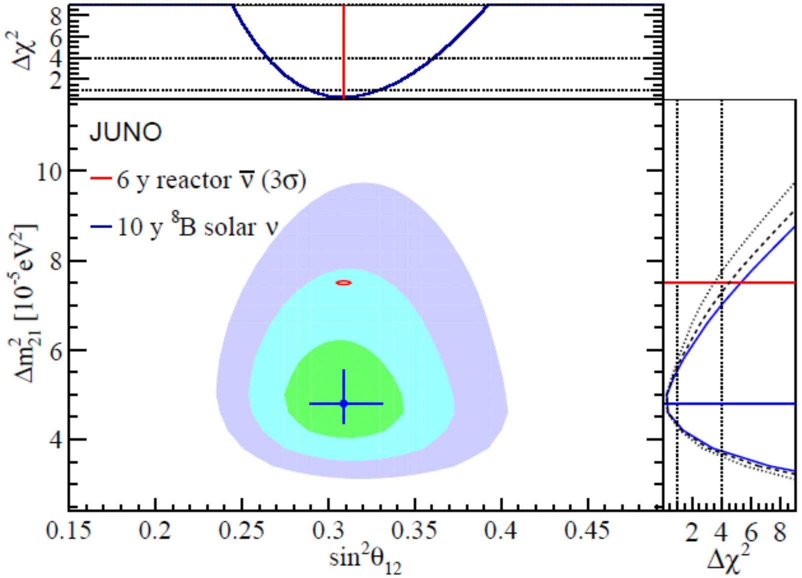
- Main detection channel: ν – *e* elastic scattering

High energy (^{8}B neutrinos) – *Chin. Phys. C* **45** 023004 (2021)

- Unprecedented detection threshold at 2 MeV
- High sensitivity to P_{ee} transition region
- **Simultaneous determination of $\sin^2\theta_{12}$ and Δm^2_{21} with both solar and reactor neutrinos, in one experiment**
- Expected 60k signal and 30k background events in 10 years
- Backgrounds: internal from radioactive chains (^{238}U, ^{232}Th), and cosmogenic (^{10}C, ^{11}C, ^{8}Li, ^{6}He, ...)
- Possibility to use also CC and NC interaction channels



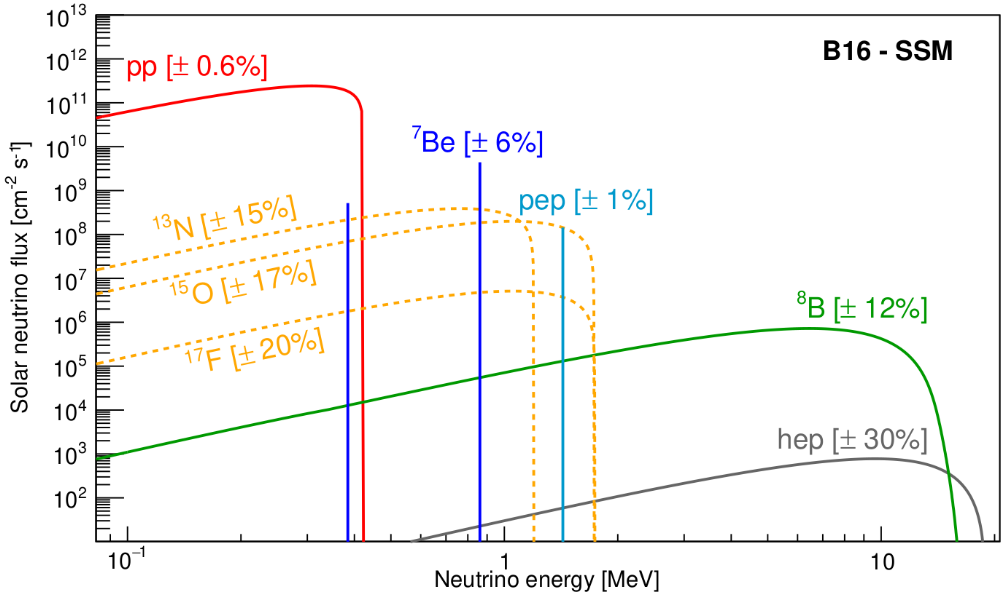
	Type	Reaction	Threshold	Final products	^{8}B	*hep*
1	ES	$\nu + e^- \to \nu + e^-$	0	e^-	3×10^5	640
2	CC	$\nu_e + ^{12}\mathrm{C} \to e^- + ^{12}\mathrm{N}$	16.8 MeV	e^-	0	0.41
3	CC	$\nu_e + ^{13}\mathrm{C} \to e^- + ^{13}\mathrm{N}$	2.2 MeV	e^- and ^{13}N decay	3768	14
4	NC	$\nu + ^{12}\mathrm{C} \to \nu + ^{12}\mathrm{C}^*\ (1^+)$	15.1 MeV	γ	0.2	5
5	NC	$\nu + ^{13}\mathrm{C} \to \nu + ^{13}\mathrm{C}^*\ (\frac{3}{2}^-)$	3.685 MeV	γ	3165	13.5

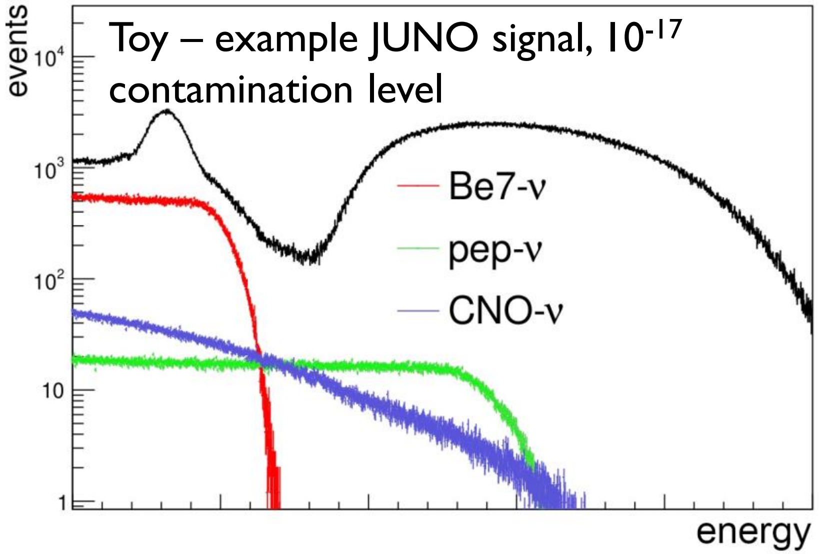


SOLAR NEUTRINOS

Intermediate and low energy (^{7}Be and *pp* neutrinos)

- Given its size, JUNO can benefit of an enormous increase of statistics for intermediate and low energy neutrinos
- ~ 10^4 ^{7}Be and (10^2 - 10^3) *pp* events/day
- CNO neutrinos could benefit of the huge statistics as well
- Additional precision to solve *metallicity puzzle*
- Internal level of radioactivity is a crucial point
- Still, achievable ^{7}Be measurement in a wide range of background levels
- *pp* neutrino flux measurement is challenging

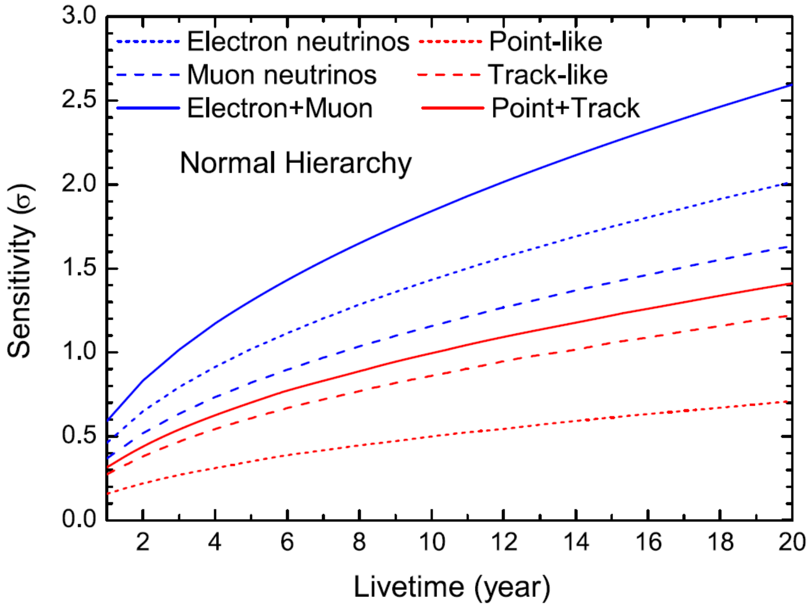




ATMOSPHERIC NEUTRINOS

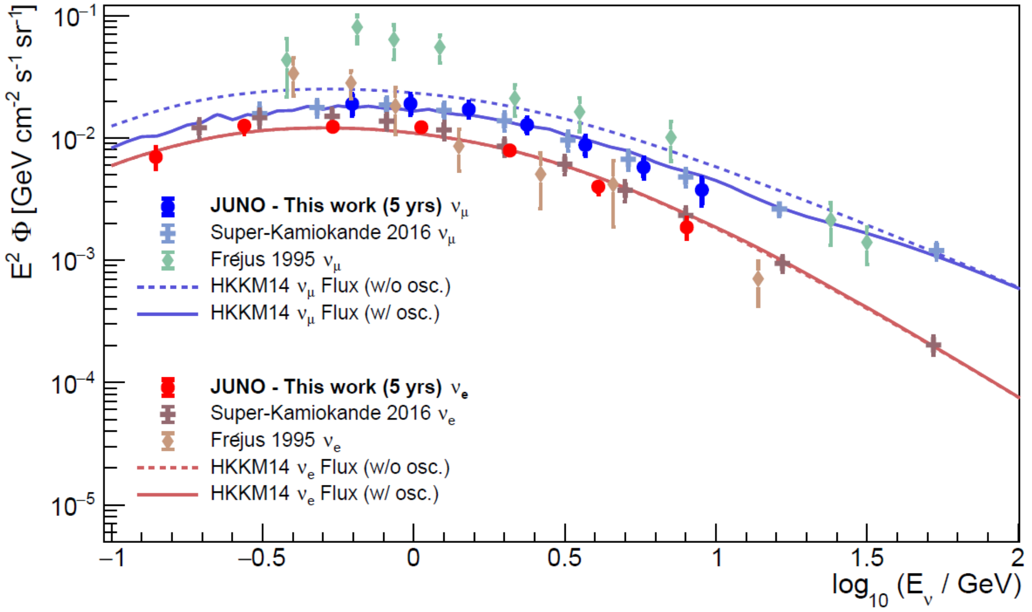
- Optimal sector for neutrino oscillation physics
- Large range in baseline (10 – 10K km) and energy (from MeV to TeV scale)
- **Mass ordering measurement standalone and combined with reactors**
- Exploit matter effects for neutrinos crossing the Earth
- Sensitivity towards $\sin^2\theta_{23}$ and δ_{CP}

  J. Phys. G: Nucl. Part. Phys. 43 030401 (2016)



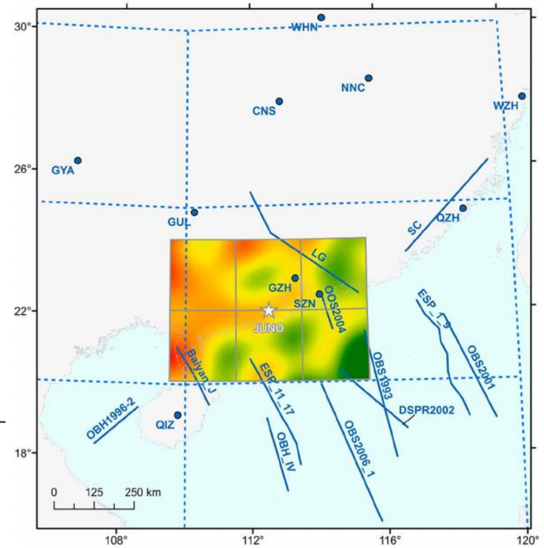
- ν_e/ν_μ discrimination based on time pattern of scintillation light – *EPJ Web of Conf. 209, 01011 (2019)*
- Flavor – dependent energy spectrum accessible in the (0.1 – 10) GeV energy range
- Promising potential towards the low energy range

  arXiv:2103.09908 (2021) – accepted by EPJC for publication

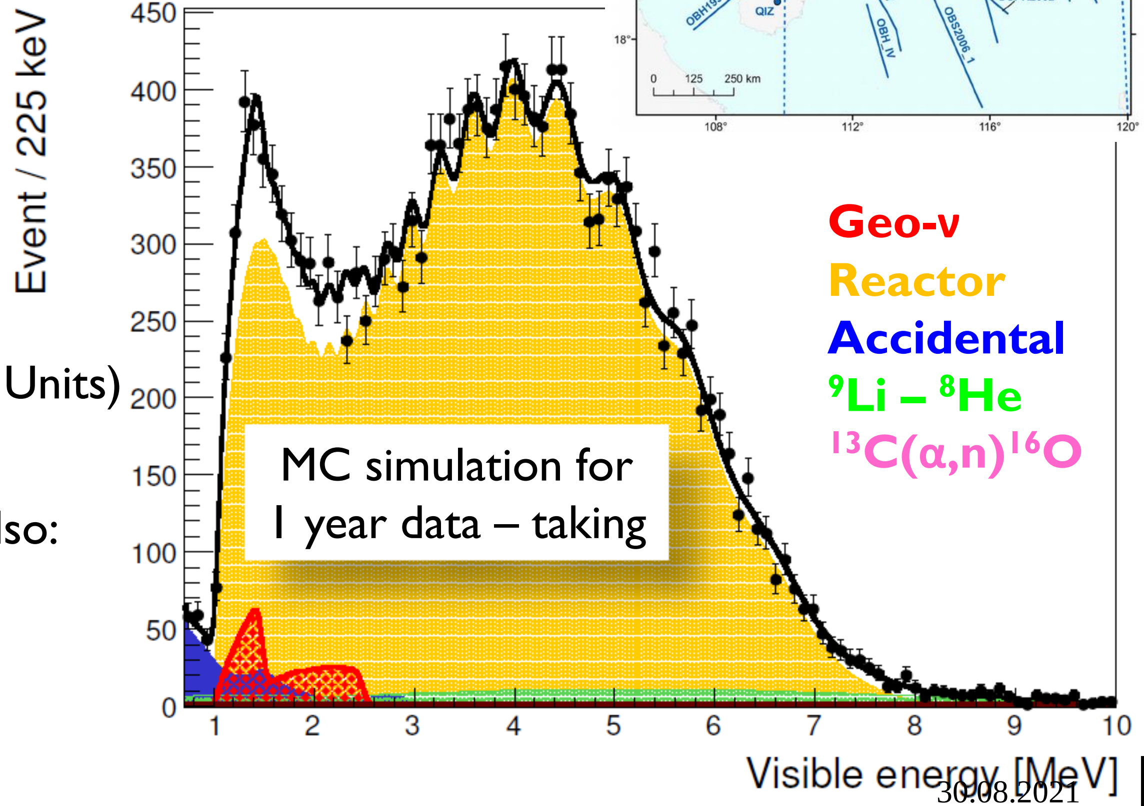


GEONEUTRINOS

- Unique neutrino source to probe the inner structure of Earth, from ^{238}U and ^{232}Th decays in Earth's mantle and crust
- Earth's Th/U ratio still not fully known, nor mantle radiogenic heat
- Again, most benefits come from the huge statistics of JUNO
  - Major improvement with respect to Borexino and KamLAND
- **Signal from local crust is a crucial input for the interpretation of results**
  JGR Solid Earth 124 4 4231 (2019)
- Phys. Earth and Planetary Int. 299 106409 (2020)



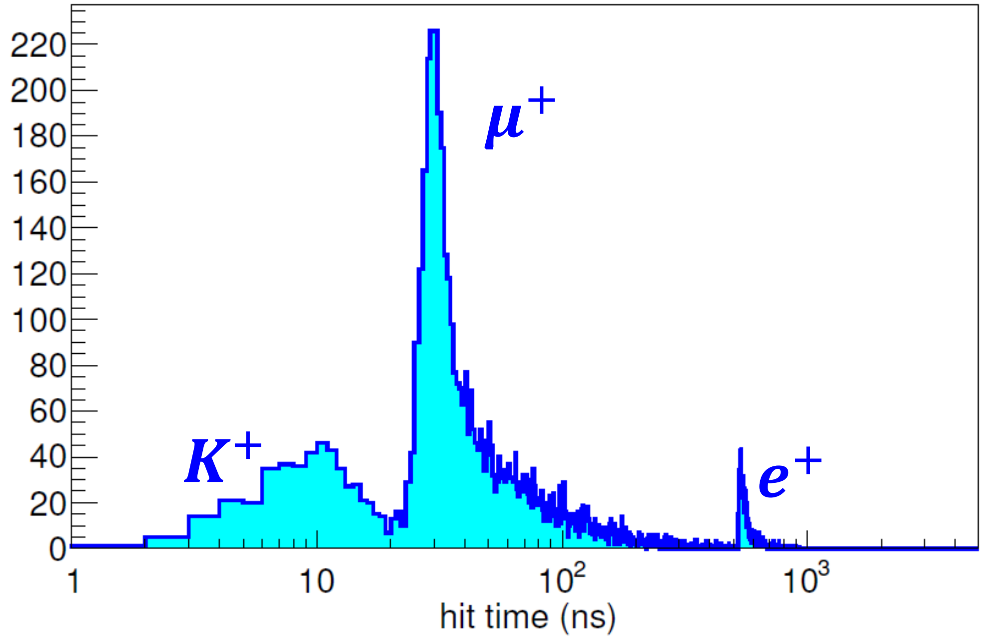
- ~400 events/year are expected (~40 Terrestrial Neutrino Units)
  Chinese Phys. C 40 033003 (2016)
- Main background comes from reactor antineutrinos, but also:
  - Cosmogenic isotopes: ^{9}Li and ^{8}He (β+n) decays
  - Fast neutrons
  - (α+n) interactions
  - Accidentals



EXOTIC PROCESSES AND NEW PHYSICS

Nucleon decay (SUSY – GUT theories)

- Main search channel: $p \rightarrow \bar{\nu} K^+$
  - Constrained by SuperK, but Kaon below Cherenkov threshold
- Clear signature from three – fold coincidence in JUNO
- Main backgound: cosmic muons atmospheric neutrinos
  - Key for removal: differences in time behaviour
- Upper limit sensitivity in 10 years: 8.34 x 10^{33} years (90% C.L.)
  - SuperK: 2,3 x 10^{33} years (90% C.L.) - Phys. Rev. D 72, 052007 (2005)

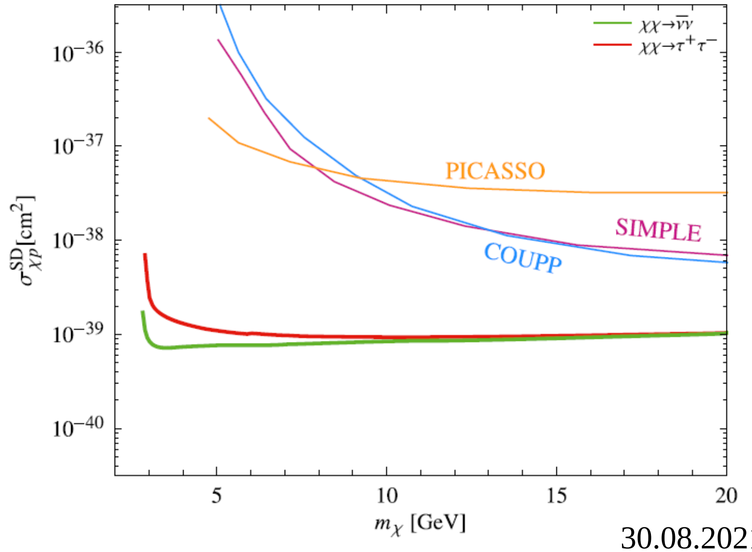


Dark Matter

- Indirect searches of DM particles decay from the Sun
  - Channels: $\bar{\nu}\nu$ and $\tau^+\tau^-$
- Sensitivity to spin – independent cross – section at the (10^{-41} - 10^{-42}) cm^2 level
- (10^{-39} - 10^{-40}) cm^2 for spin – dependent cross – section

JCAP01 039 (2016)

Chinese Phys. C 40 033003 (2016)



EXOTIC PROCESSES AND NEW PHYSICS

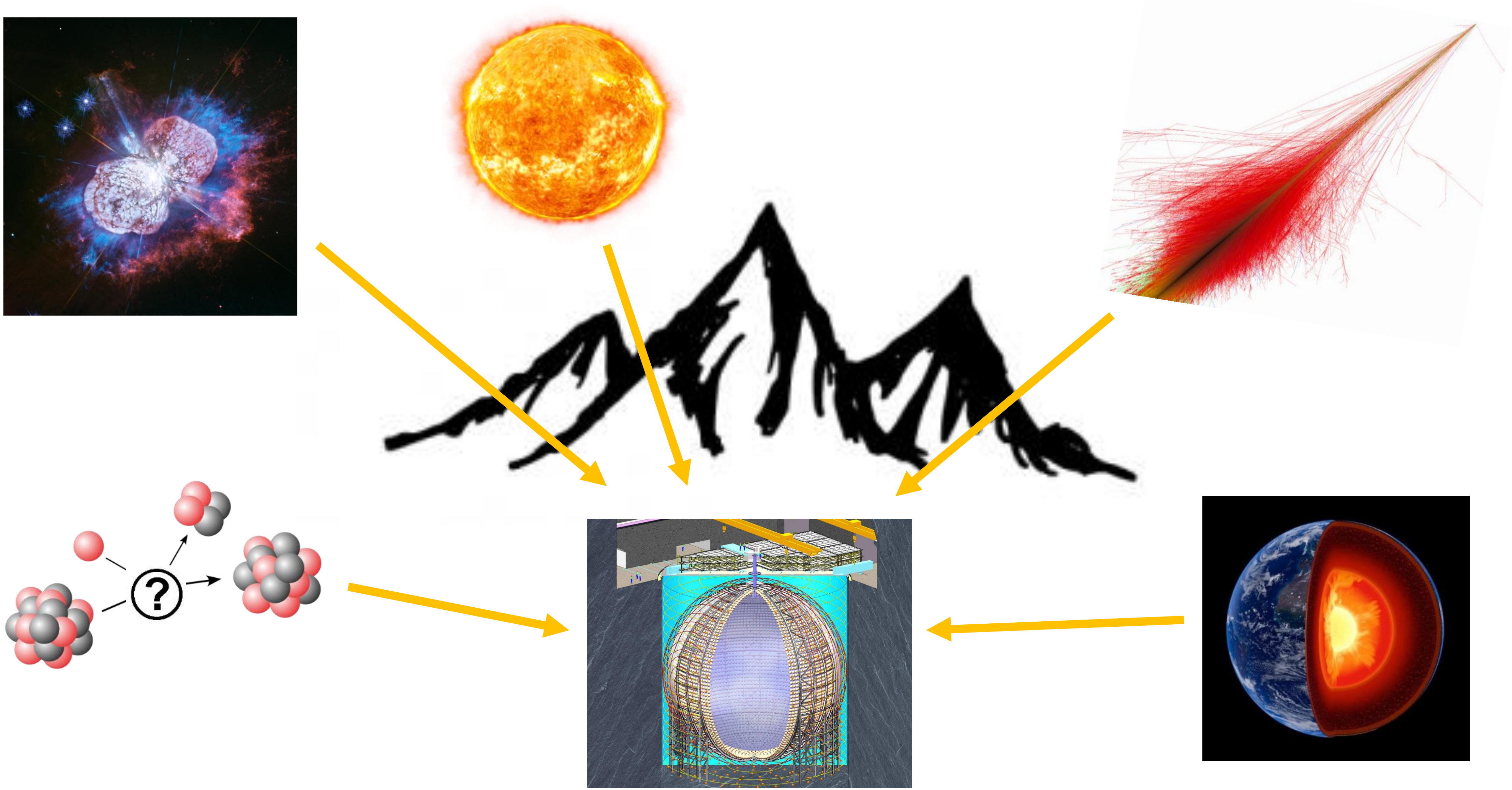
Majorana neutrinos?

- Golden process is the $0\nu\beta\beta$
- Current best limits of $0\nu\beta\beta$ half – life: 10^{25} – 10^{26} years → (60 – 300) meV range for $m_{\beta\beta}$
- Next generation of ton – scale $0\nu\beta\beta$ experiments are expected to reach 10^{27} – 10^{28} years
- JUNO could be used in the future as a $0\nu\beta\beta$ experiment, by loading a sub – volume balloon
  - Preliminary sensitivity studies on $m_{\beta\beta}$ on a 5 years time scale:
  - 50 tons of ^{136}Xe: (5 – 12) meV → *Chinese Phys. C* **41** 053001 (2017)
  - 400 tons of ^{130}Te: (2.3 – 6.0) meV → *Chinese Phys. C* **44** 031001 (2020)

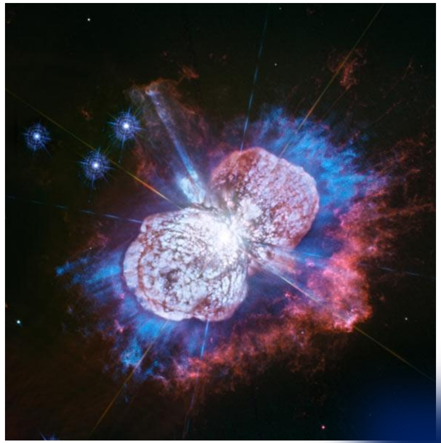
Other processes

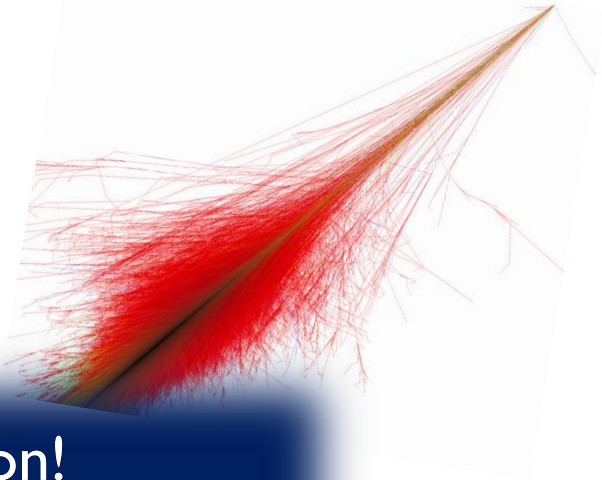
- Light sterile neutrinos with reactor flux: JUNO+ JUNO-TAO
- Magnetic monopoles
- Leptonic unitarity test
- Lorentz Invariance Violation

JUNO – AN INCREDIBLE INSTRUMENT FOR PHYSICS!



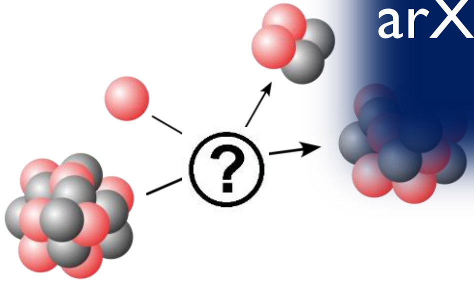
JUNO – AN INCREDIBLE INSTRUMENT FOR PHYSICS!

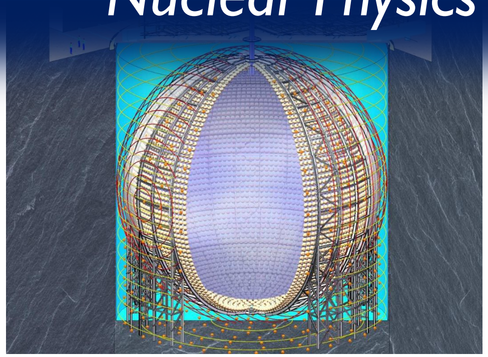


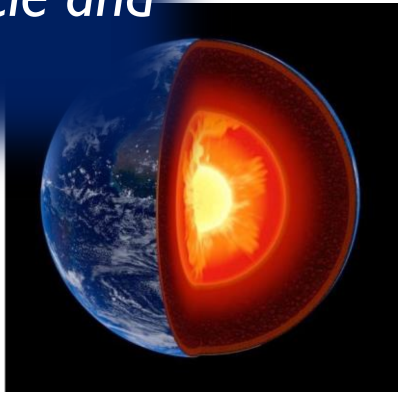


Thank you very much for your attention!

Most of the material I reported is taken from arXiv:2104.02565, soon to appear on *Progress in Particle and Nuclear Physics*

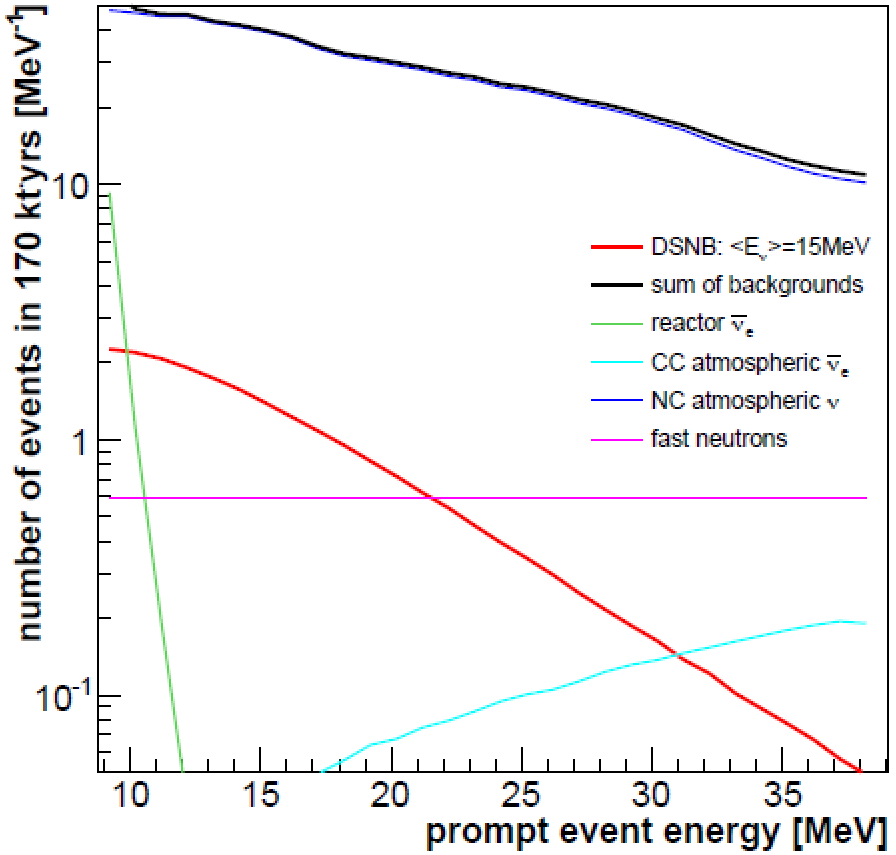


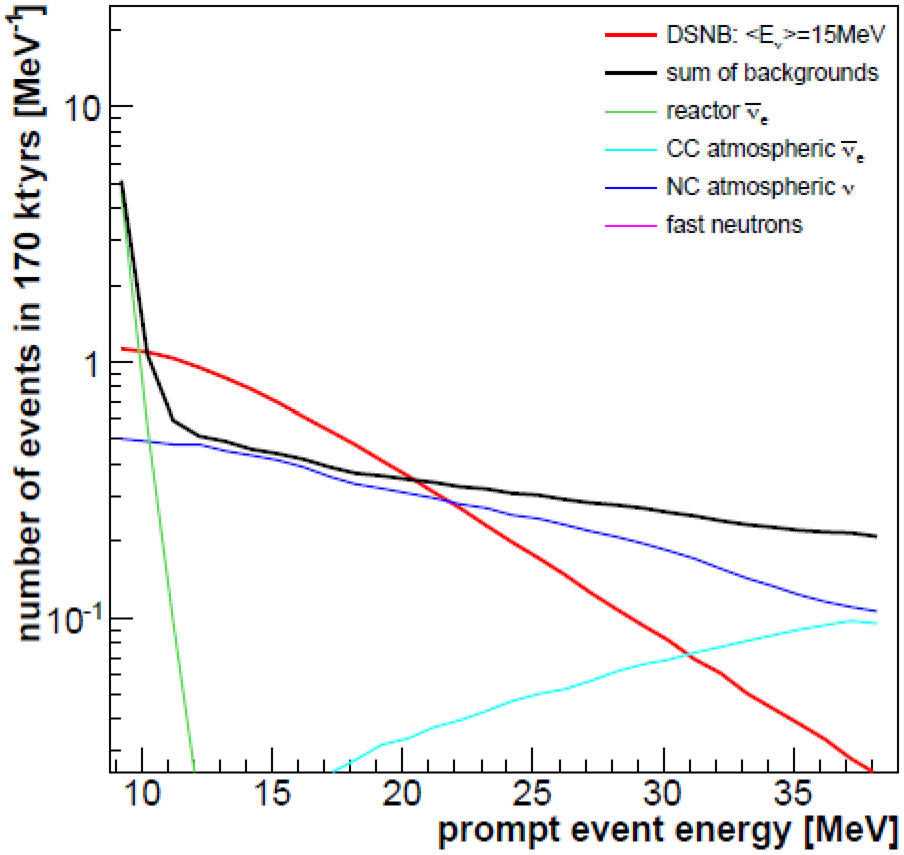




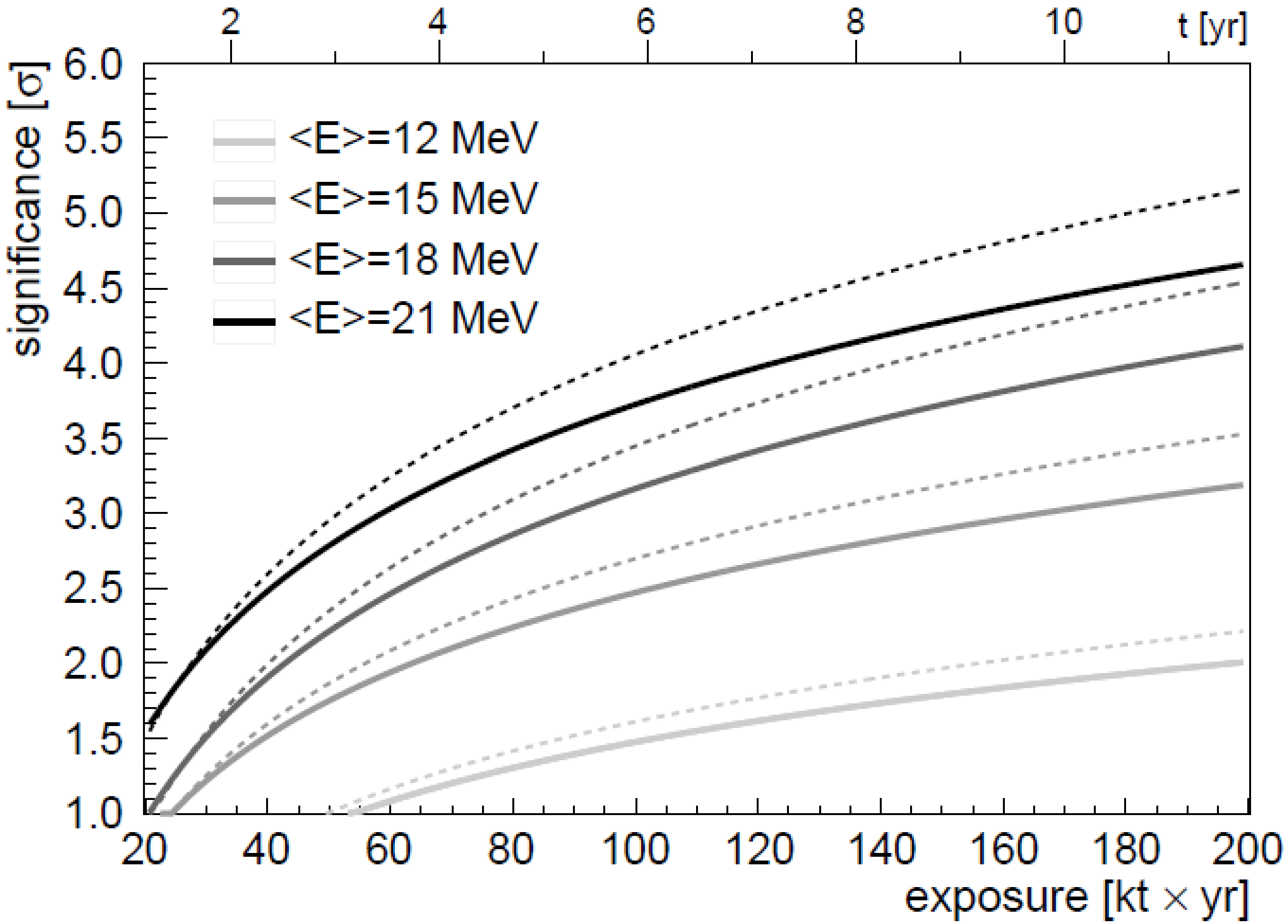
BACKUP

DSNB – SELECTION CUTS

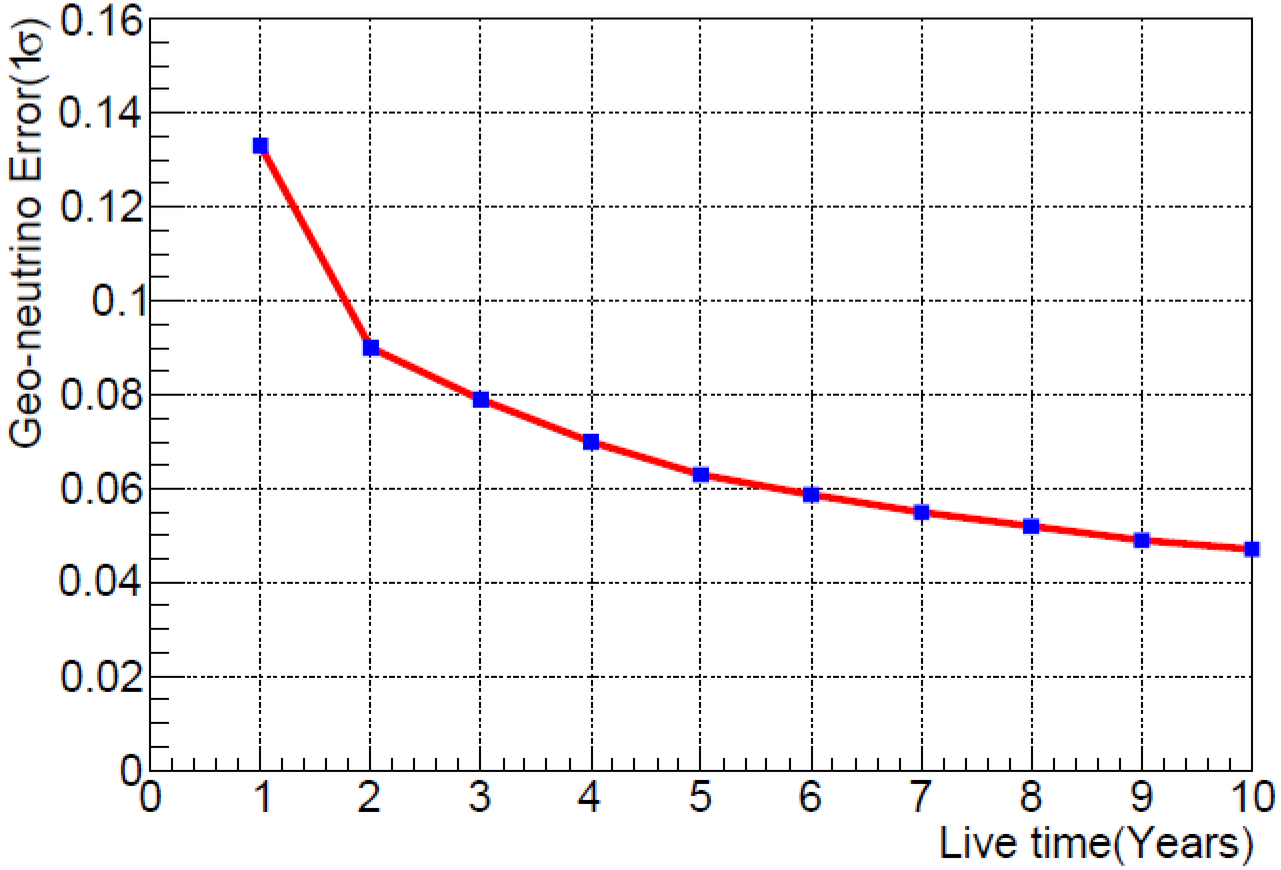




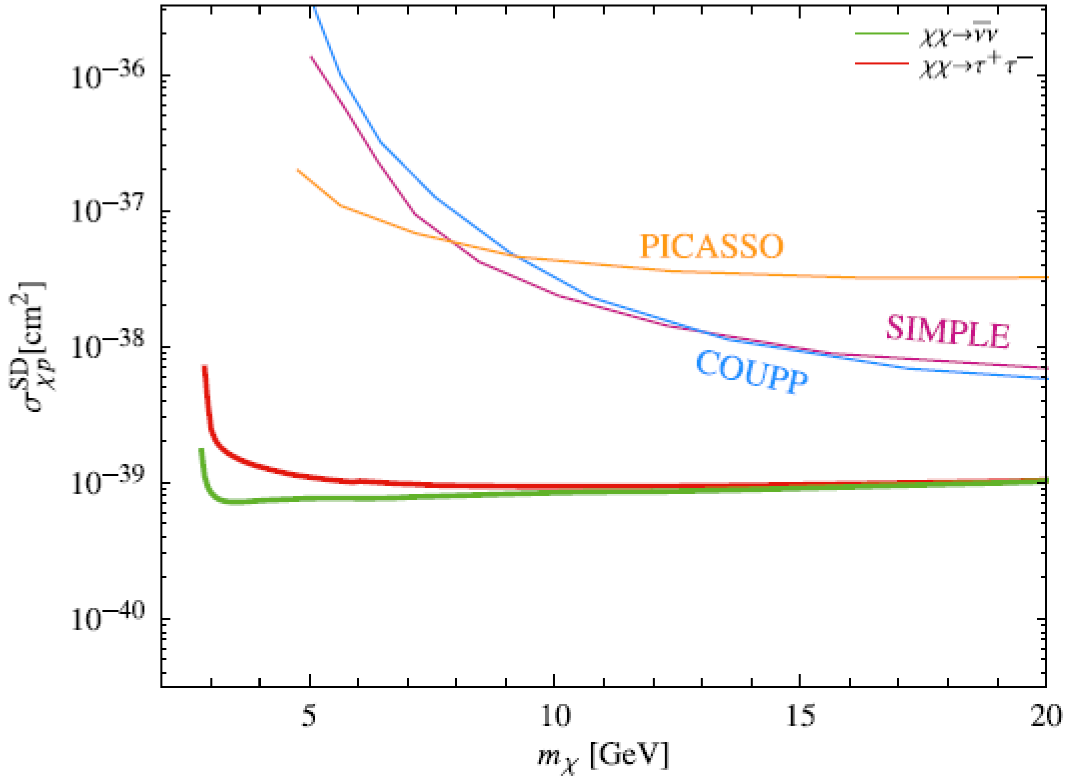
DSNB – SENSITIVITY



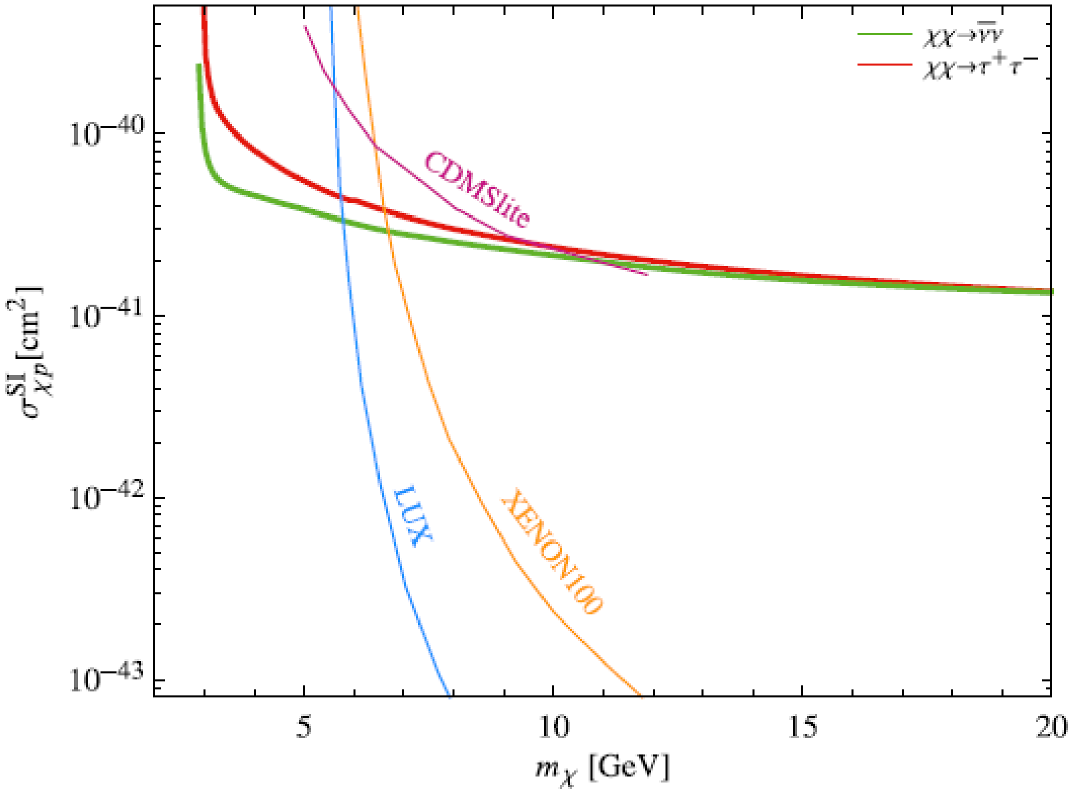
GEONEUTRINOS – SENSITIVITY



DARK MATTER – SENSITIVITY



Spin – dependent (5 years)



Spin – independent (5 years)