A search for correlation of neutrino events in the Borexino detector with transient astrophysical phenomena

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Transient astrophysical phenomena

- Transient events are short-lived, energetic phenomena observed across the universe.
- Examples include **Fast Radio Bursts (FRBs), Gravitational Waves (GWs),** and **Gamma-Ray Bursts (GRBs).**
- These events offer unique insights into extreme astrophysical environments and high-energy processes, helping us understand the universe's most violent occurrences.

Transient astrophysical phenomena

- Fast Radio Bursts (FRBs): Millisecond bursts of radio waves from unknown cosmic origins, possibly linked to neutron stars or magnetars.

Importance: Provide clues to the intergalactic medium and exotic astrophysical processes.

- Gravitational Waves (GWs): Spacetime distortions caused by events like black hole mergers, detected by LIGO and Virgo observatories.

Importance: Revolutionized our ability to observe cosmic events beyond electromagnetic radiation.

- Gamma-Ray Bursts (GRBs): Sudden flashes of gamma rays, often associated with supernovae or neutron star collisions.

Importance: Among the brightest electromagnetic events, GRBs offer insights into stellar evolution and the formation of black holes.

Multimessenger Astophysics and Transient Phenomena

Multimessenger astrophysics involves observing cosmic events using different "messengers" like electromagnetic radiation, gravitational waves, neutrinos, and cosmic rays.

Transient phenomena such as FRBs, GWs, and GRBs are prime targets for multimessenger studies, providing a more complete understanding of these energetic processes.

Multimessenger Astophysics and Transient Phenomena

Examples of Multimessenger Observations:

Gravitational Waves + Electromagnetic Counterpart: The detection of GWs from a neutron star merger (GW170817) was followed by gamma rays and other electromagnetic signals, confirming the event as a kilonova and revealing the origins of heavy elements.

Gamma-Ray Bursts and Neutrinos: Simultaneous detection of GRBs and high-energy neutrinos helps probe the environments of these explosions and the processes powering them

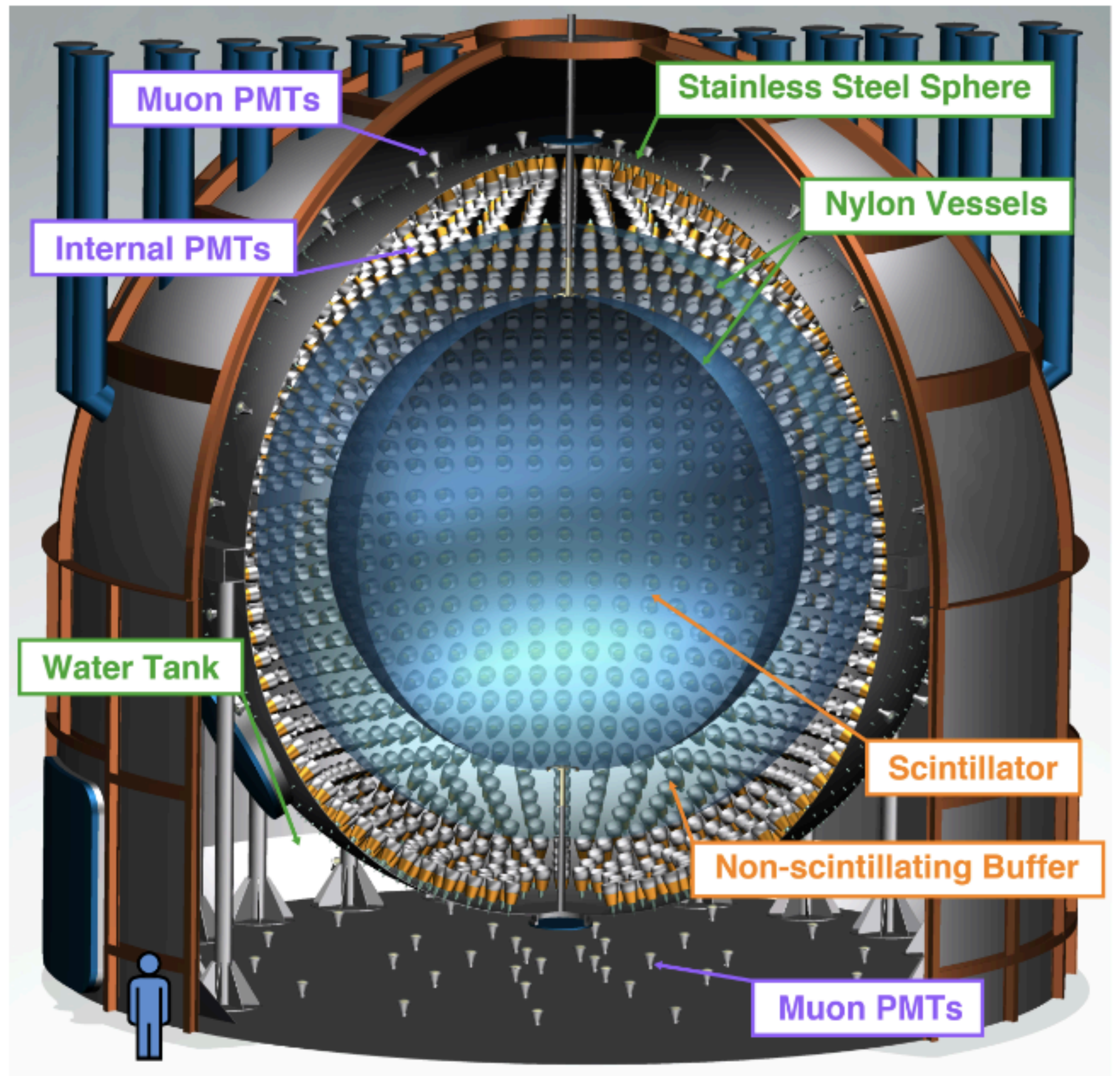
Importance:

Cross-verification: Multiple messengers allow for confirmation and deeper insights into transient events.

Expanded knowledge: Unlocks new physics and improves understanding of the most extreme and distant cosmic events.

Borexino detector

Detector located in the Gran Sasso Laboratory



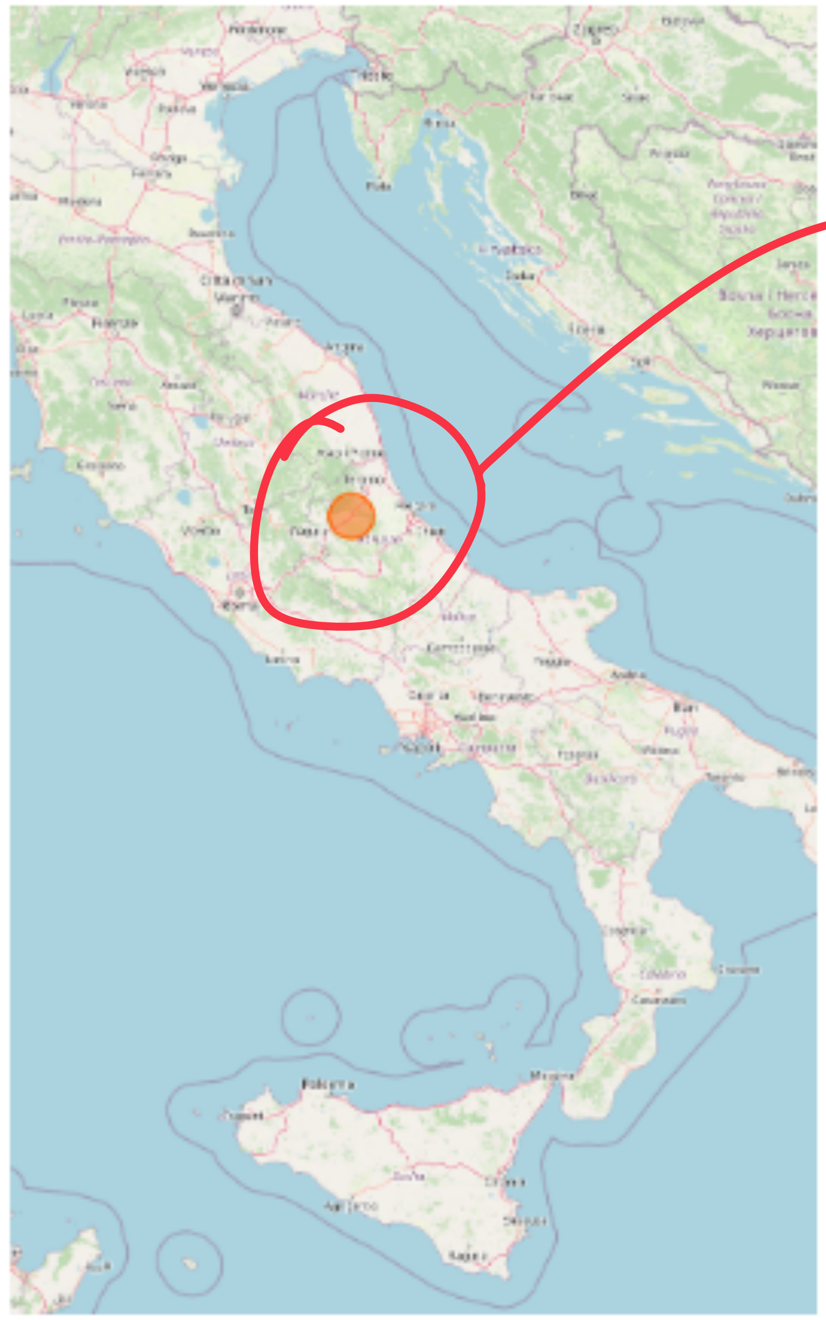
Water tank:
2.1 kt of water
Radiation shielding
Muon veto

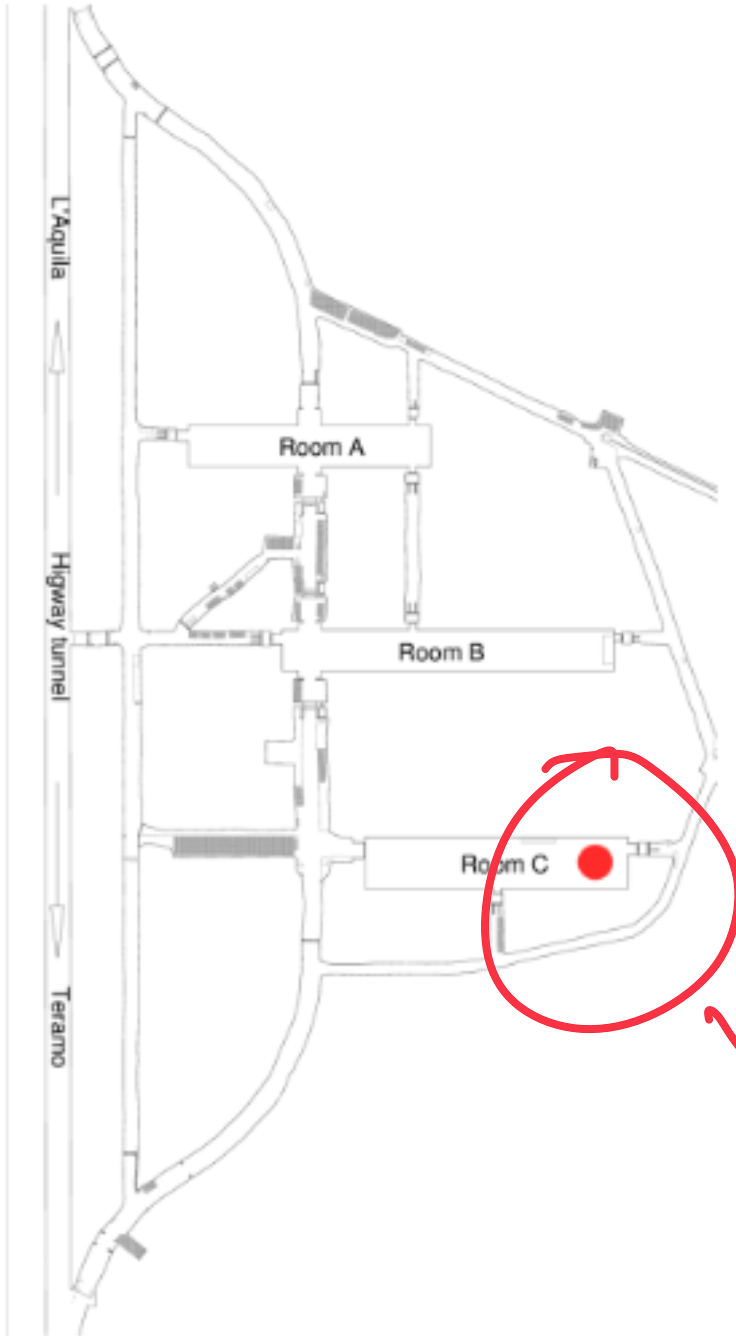
Stainless Steel Sphere:
R = 6.85 m
Sustaining structure + scintillator volume

Nylon vessel (OV – outer, IV – inner):
(OV) R = 5.5 m, barrier for Rn from steel
(IV) R = 4.25 m, filled by ~300 t of liquid organic scintillator (pseudocumene/PPO)

Muon PMT's: 208 8"

Internal PMT's: 2212 8"





Neutrino registration method: Elastic scattering on electrons
Construction benefits: high light yield (~500 p.e./MeV)
High radio purity: < 5 10^{-9} Bq/kg (on ^{238}U isotope)

Primary electronics: optimized for < 1 MeV (solar neutrino spectroscopy)

Flash ADC system: for energies >1 MeV

Borexino detector: data selection

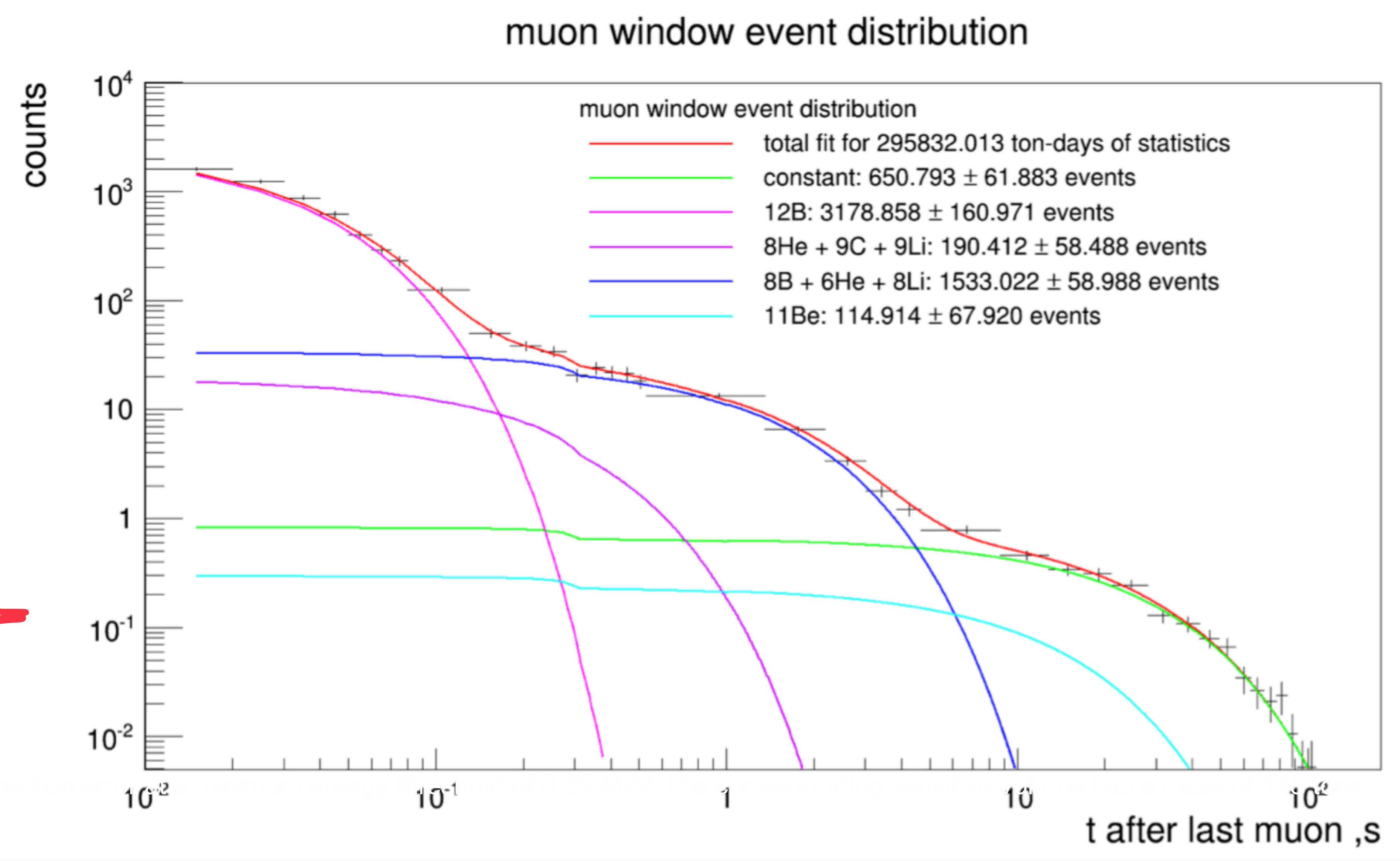
Background sources:

Cosmogenic:

External: ^{8}B, ^{8}He, ^{9}C, ^{9}Li $\tau \lesssim 1c$

Internal: ^{11}Be, ^{10}C, ^{11}C $\tau \gtrsim 1c$

Muon veto in 0.3 s after muons passing through detector volume

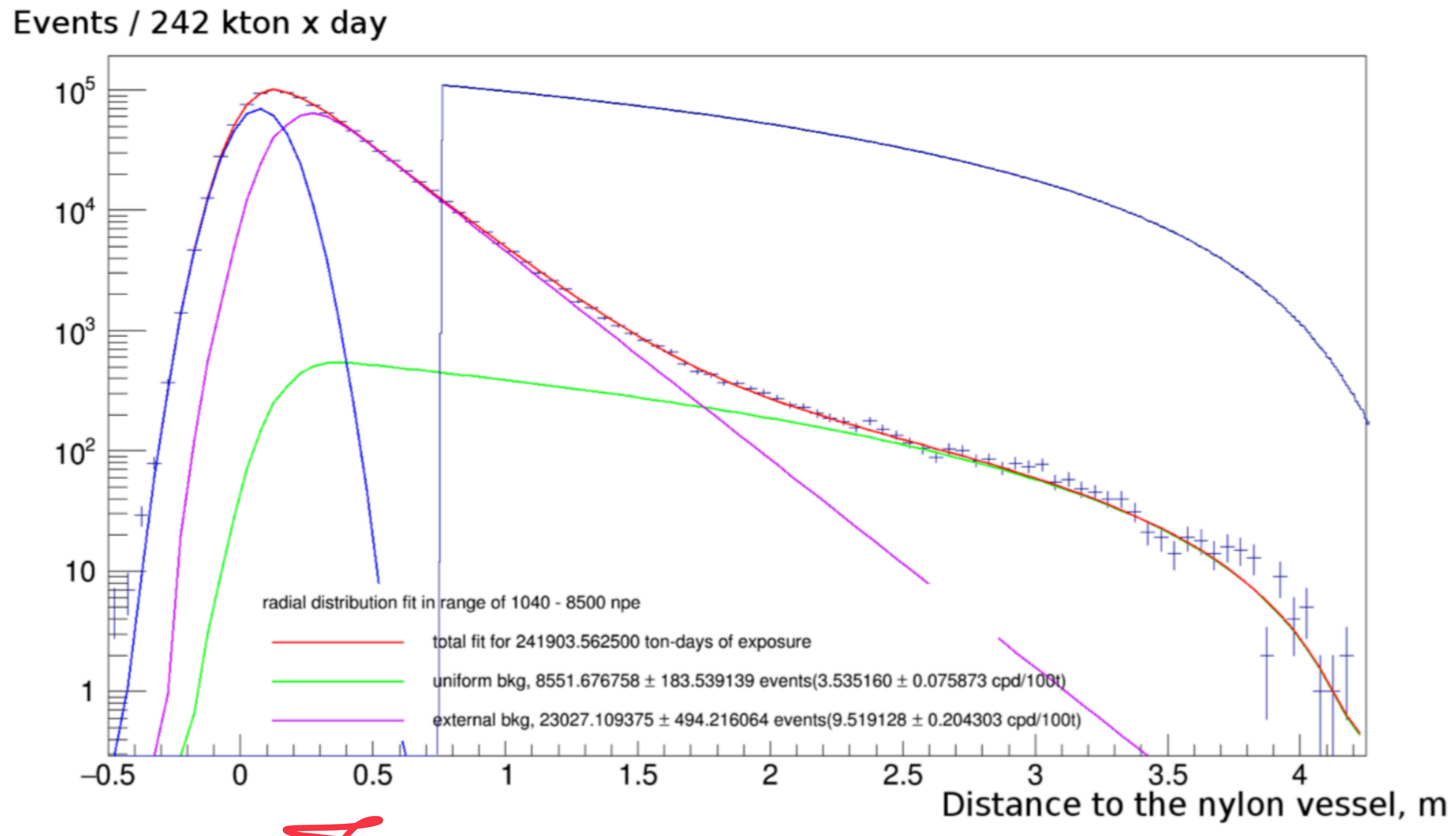


External γ:

Structural materials + PMTs

Nylon vessel surface contamination: ^{210}Po, and U/Th chains

The sensitive volume is defined to retain all events within and beyond 75 cm from the nylon shell. This distance corresponds to three standard deviations of the position reconstruction error at a minimum energy threshold of 0.25 MeV. The corresponding sensitive volume has a mass of 145 tons.



Borexino detector and GW

- Extremely energetic events
- (~ 10^{54} erg from merging black holes or neutron stars)
- All-sky rate: ≈ 1 event/month (for binary black hole mergers)
- Duration: From milliseconds to several seconds depending on the mass and system

Possible sources:

- Mergers of neutron stars (NS) or black holes (BH)
- Core collapse of massive stars (supernovae)
- Rapidly spinning neutron stars (magnetars)

Types:

- Continuous
- Spiral
- Stochastic

GW data selection

Event	Type	M1	M2	R	M^{rad}
GW17071	NSNS	1.46	1.27	40	< 0.04
GW19042	NSNS	2.0	1.40	160	—
GW19042	NSBH	5.7	1.5	370	—
GW19121	NSBH	31.1	1.17	550	0.1
70 GW	BHBH	36.7	23.0	2130	2.4

O1/O2

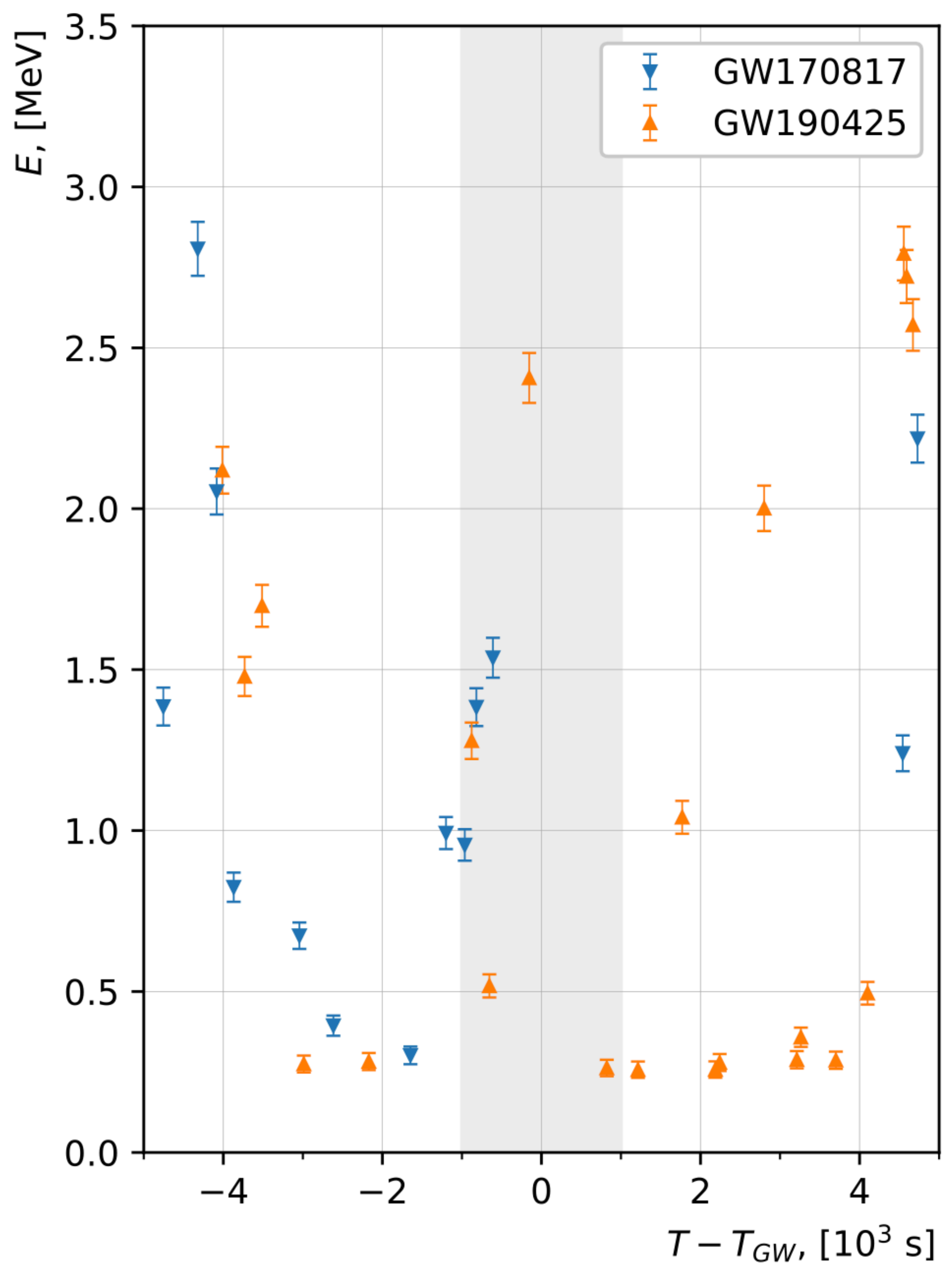
11 events
mostly black hole - black hole (BB) and 1 event of neutron-neutron star (NN) (GW170817)

O3 (included GWTC-3)

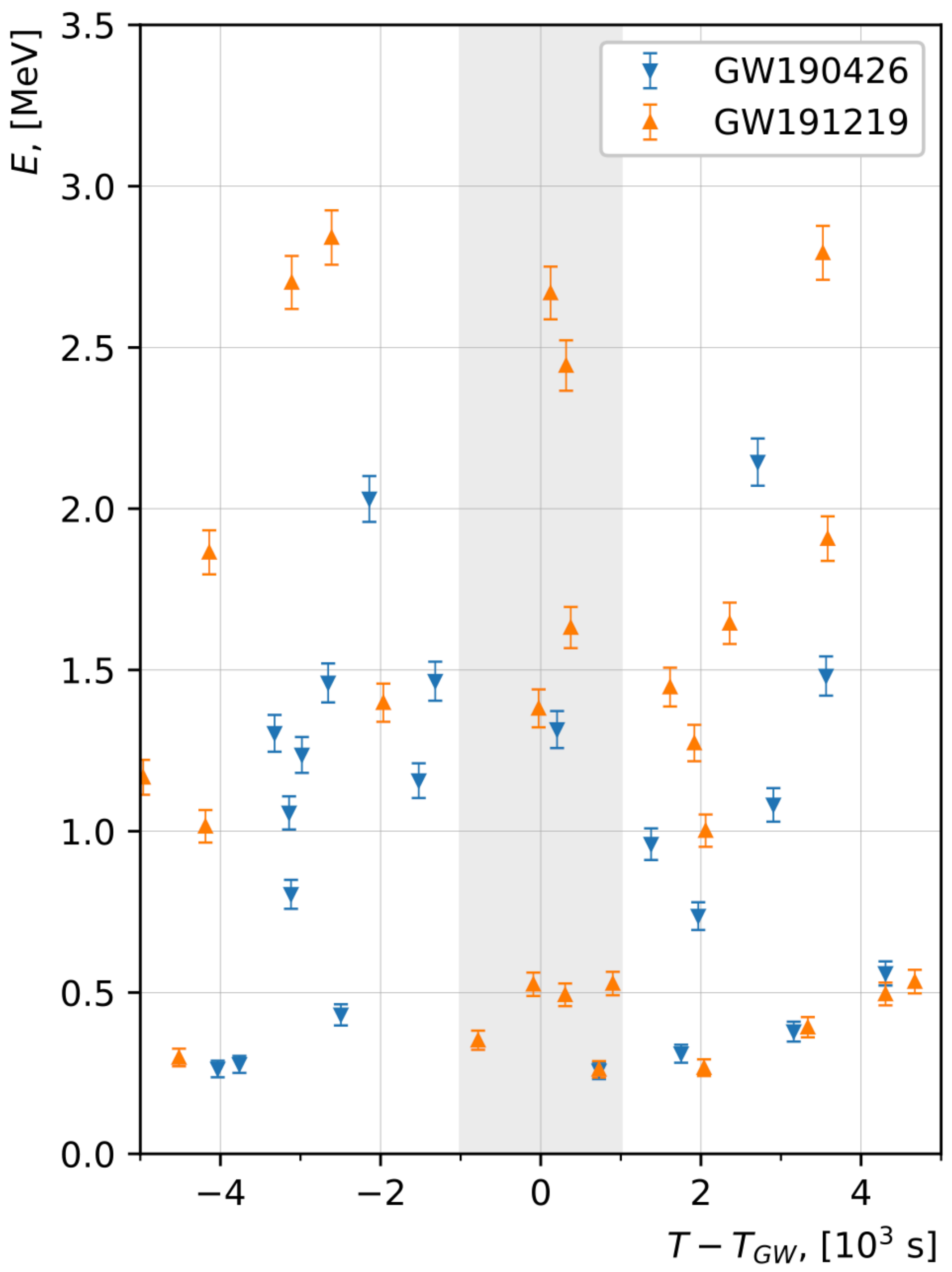
74 (of 93) events
(all data collection time)

70 (of 87) black hole - black hole (BB)
2 events of neutron-neutron star (NN)
And 3 (of 4) events neutron star - black hole (NB)

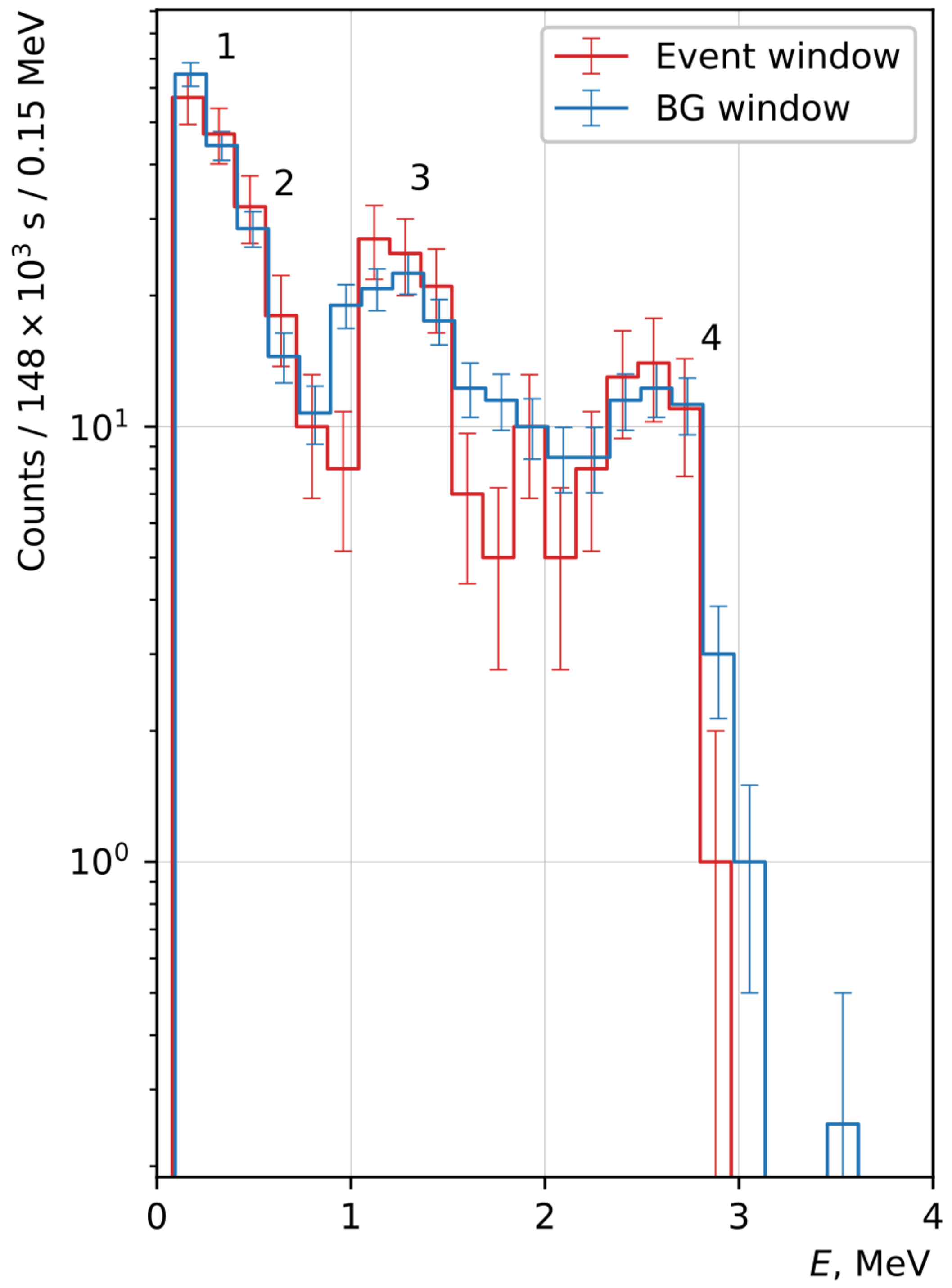
GW data selection



Borexino events with energies above 0.25 MeV observed within a ±5000 second window around the neutron star merger events GW170817 and GW190425.



The Borexino events for GW190426 and GW191219, with energies above 0.25 MeV, were observed in a ±5000 second window around the neutron star–black hole mergers.



The visible energy spectrum of single Borexino events in correlation with 70 BH events within a < 1000 second time window. The blue line represents the normalized background spectrum measured in the intervals [-5000...-1000] s and [1000...5000] s.

1 - α-peak from ^{210}Po,

2 - recoil electrons from solar ^{7}Be neutrinos,

3 - β^+ decay of ^{11}C,

4 - external background (^{208}Tl)

All events are consistent with the expected solar neutrino rates and background events.

Data analysis

$$\sigma(E_{th}, E_\nu) = \int \frac{d\sigma(E_\nu, E_e)}{dE_e} dE_e$$ → Full cross-section

$$\sigma(E_1, E_2) = \int\int \frac{d\sigma(E_\nu, E_e)}{dE_e} \phi(E_\nu) dE_e dE_\nu$$ → Cross-section for continious spectrum

From Fieldman-Cosins

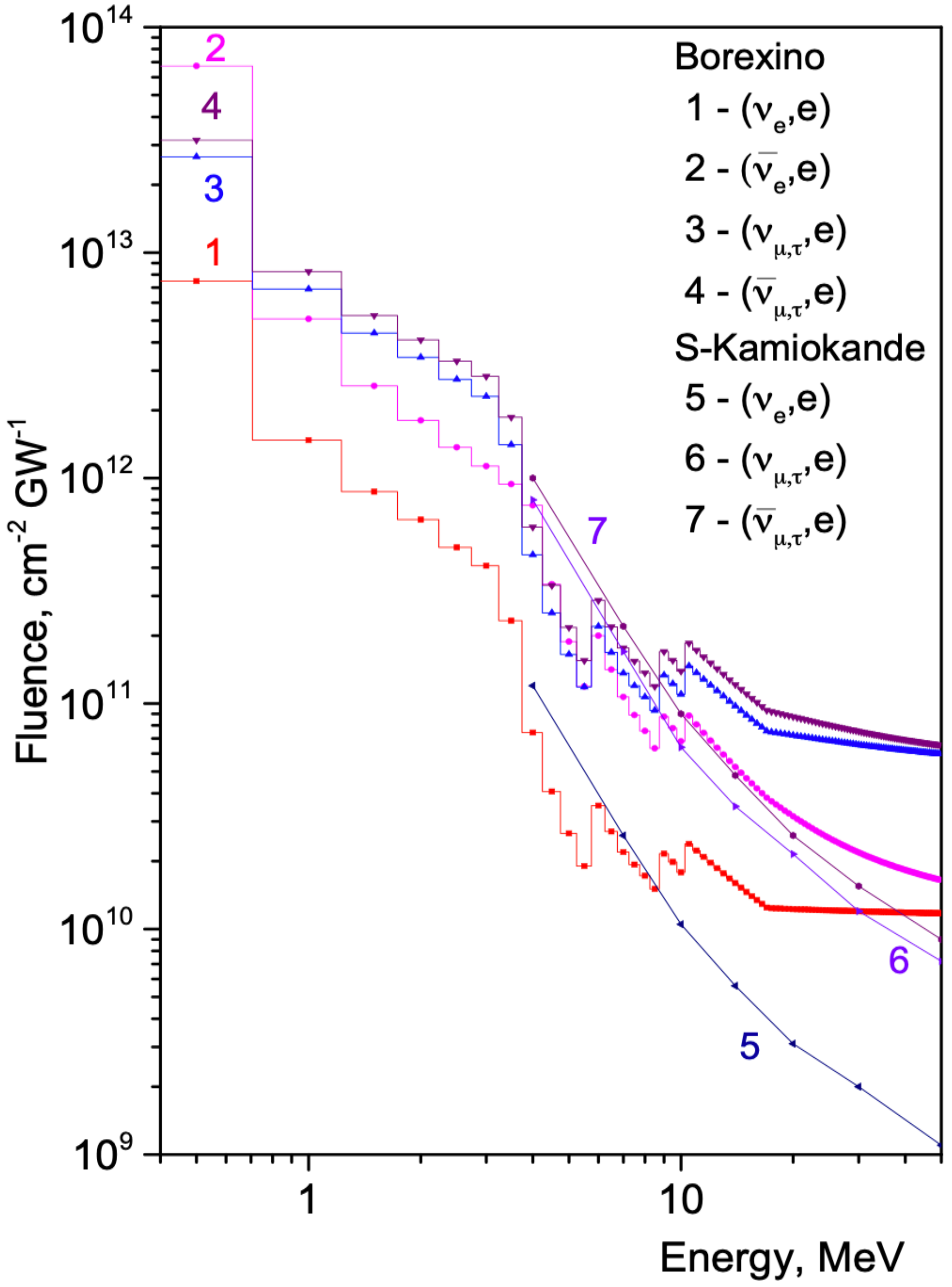
$$\Phi_{lim} = \frac{N_{90}(E_\nu, n_{obs}, n_{bkg})}{r N_e \sigma(E_{th}, E_{e_{max}})}$$

r = 1 - recoil electrons detection efficiency

N_e: amount of e^- in 145t scintillator

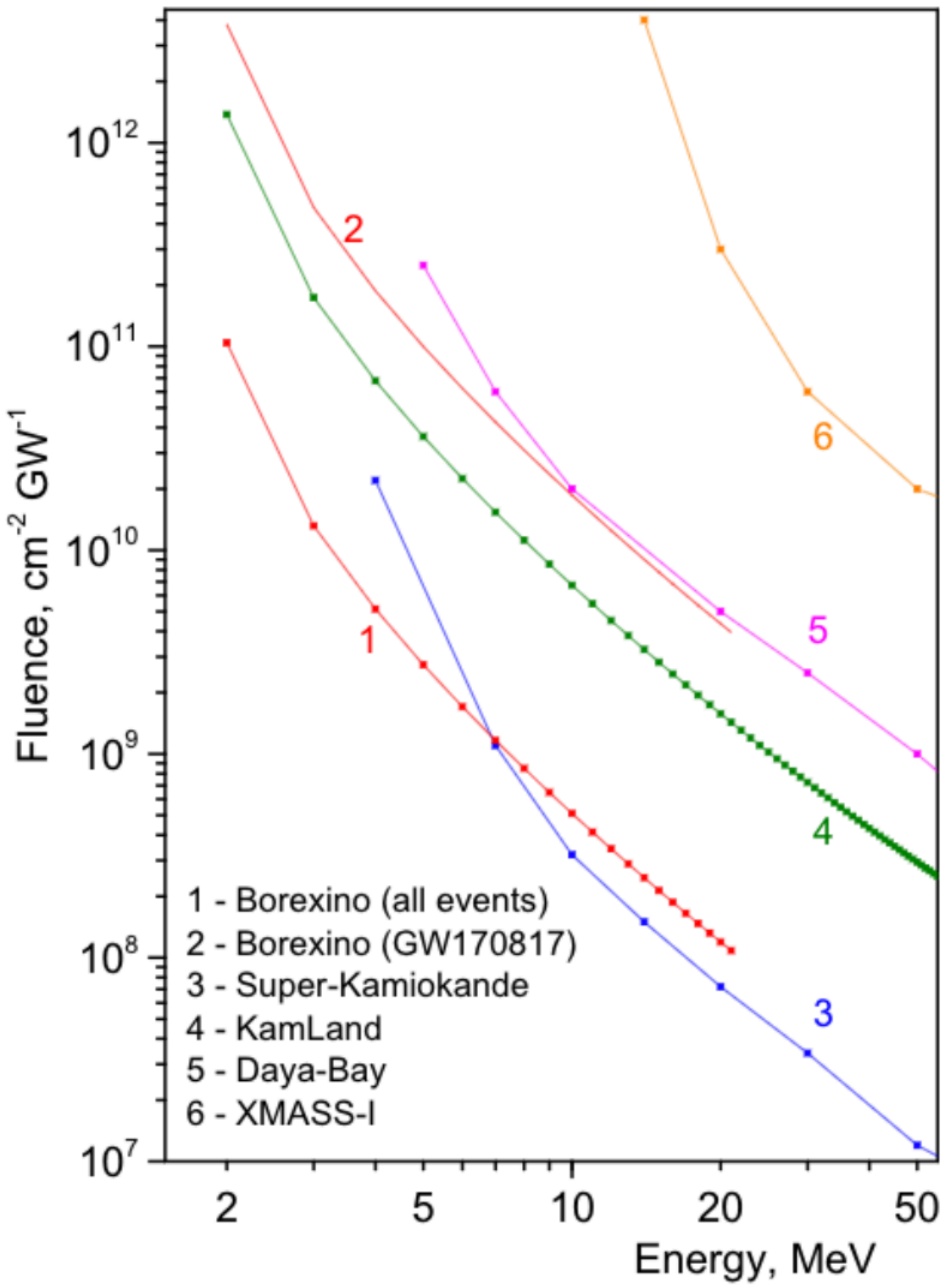
E_{th}: threshold energy

GW Limits from (ν_e, e^-) scattering and from IBD



Upper limits for monoenergetic neutrinos obtained through the elastic scattering reaction (ν, e) via temporal correlation analysis for 74 GW events (90% C.L.)

Also shown are the limits 5, 6, and 7 from Super-Kamiokande, obtained for the single GW170817 event from the (ν, e) scattering reaction.



Upper limits on the flux of monoenergetic electron antineutrinos obtained through the OB reaction:

1 - Borexino (74 GW events, normalized to one GW),

2 - Borexino (GW170817 neutron star merger),

3 - Super-Kamiokande (GW170817),

4 - KamLand (GW170817),

5 - DayaBay,

6 - XMASS-I.

(All for 90% C.L.).

Borexino detector and FRB

- Extremely energetic events
- (~ 10^{38} - 10^{40} erg)
- All-sky rate: ≈ 1000 events/day
- Duration: Milliseconds, with occasional repeating bursts

Possible sources:

- Highly magnetized neutron stars (magnetars)
- Mergers of neutron stars (NS)
- Exotic phenomena like cosmic strings or pulsar collapses

Borexino detector and FRB

FRB dadasets:

chime-frb.ca, database by CHIME Radio Telescope,

frbcat.org database:

Parkes, Arecibo, Green Bank, UTMOST, ASKAP, FAST, Apertif, VLA. DSA-19, Pushchino.

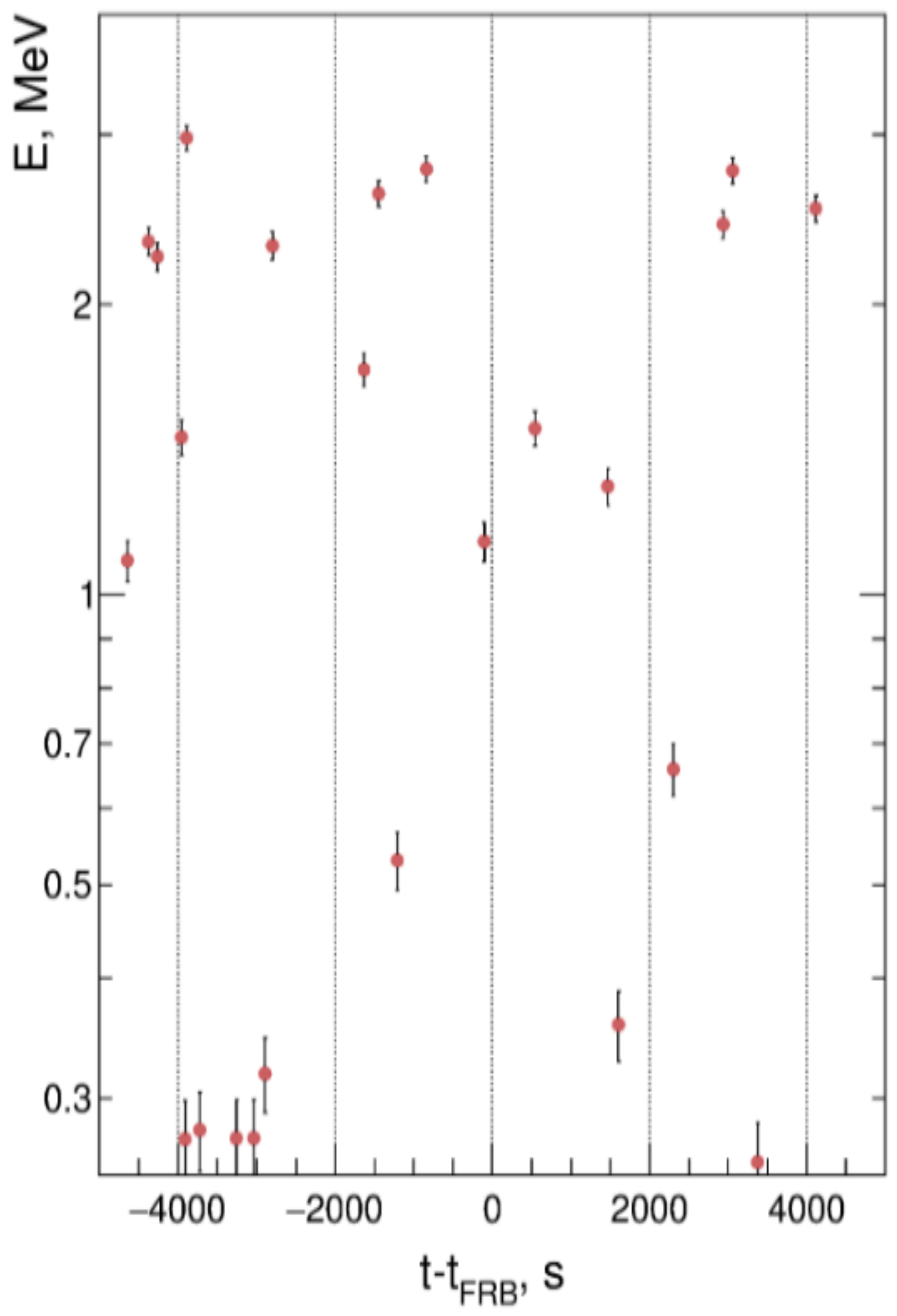
42 FRBs with ΦFRBi > 40 Jy ms for temporal correlation search.

$F_{all} = \Phi_{all} N_{all} / T s^{-1}$

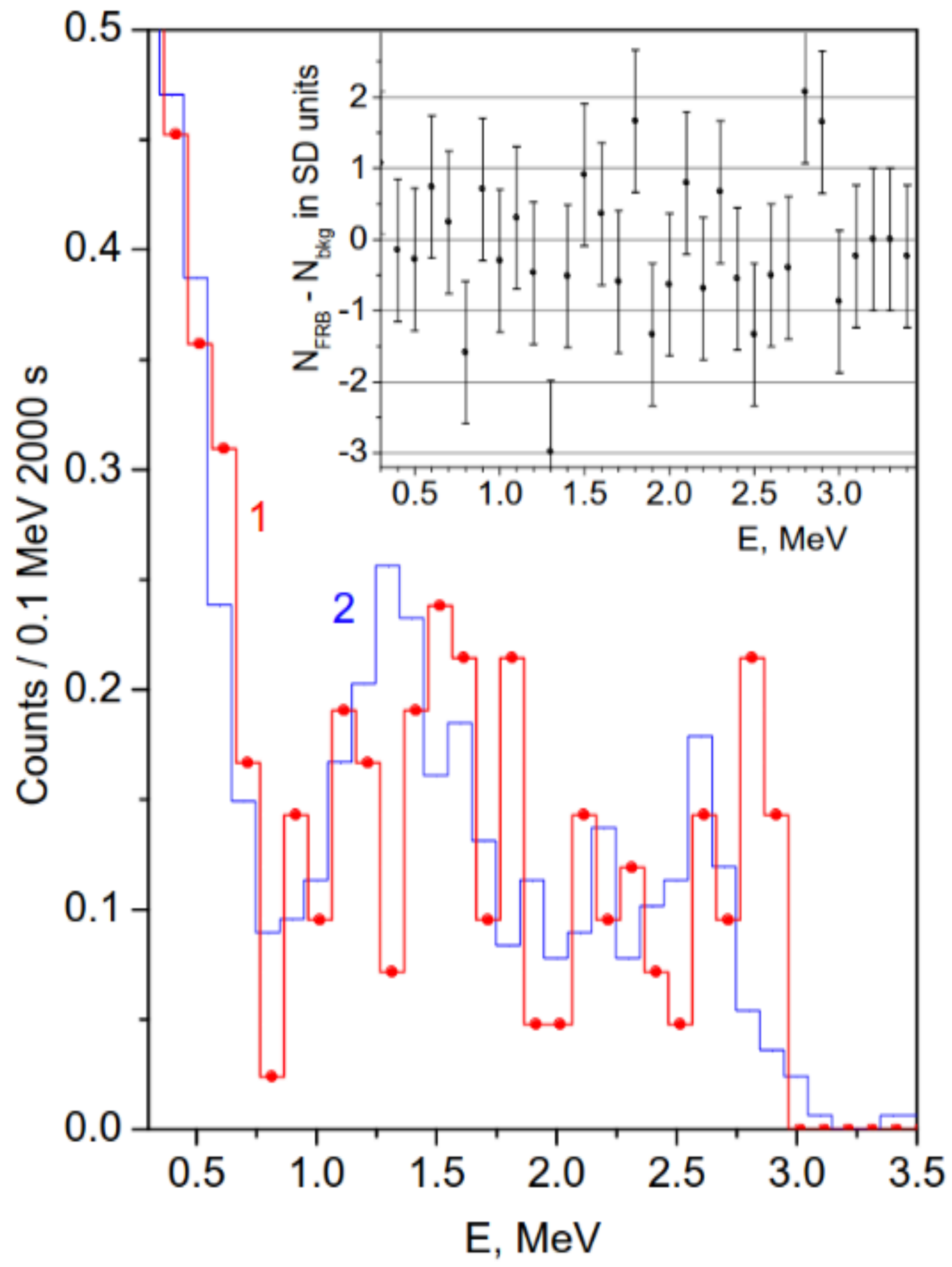
Excess neutrino events ratio:

$r = \Phi_{40}/(\Delta t\ F_{all})$ $\Phi_{all} = 7.0$ (Jy ms) per FRB ⇒ $r = 0.2$ for time window $\Delta t = 2000$ s

FRB data selection

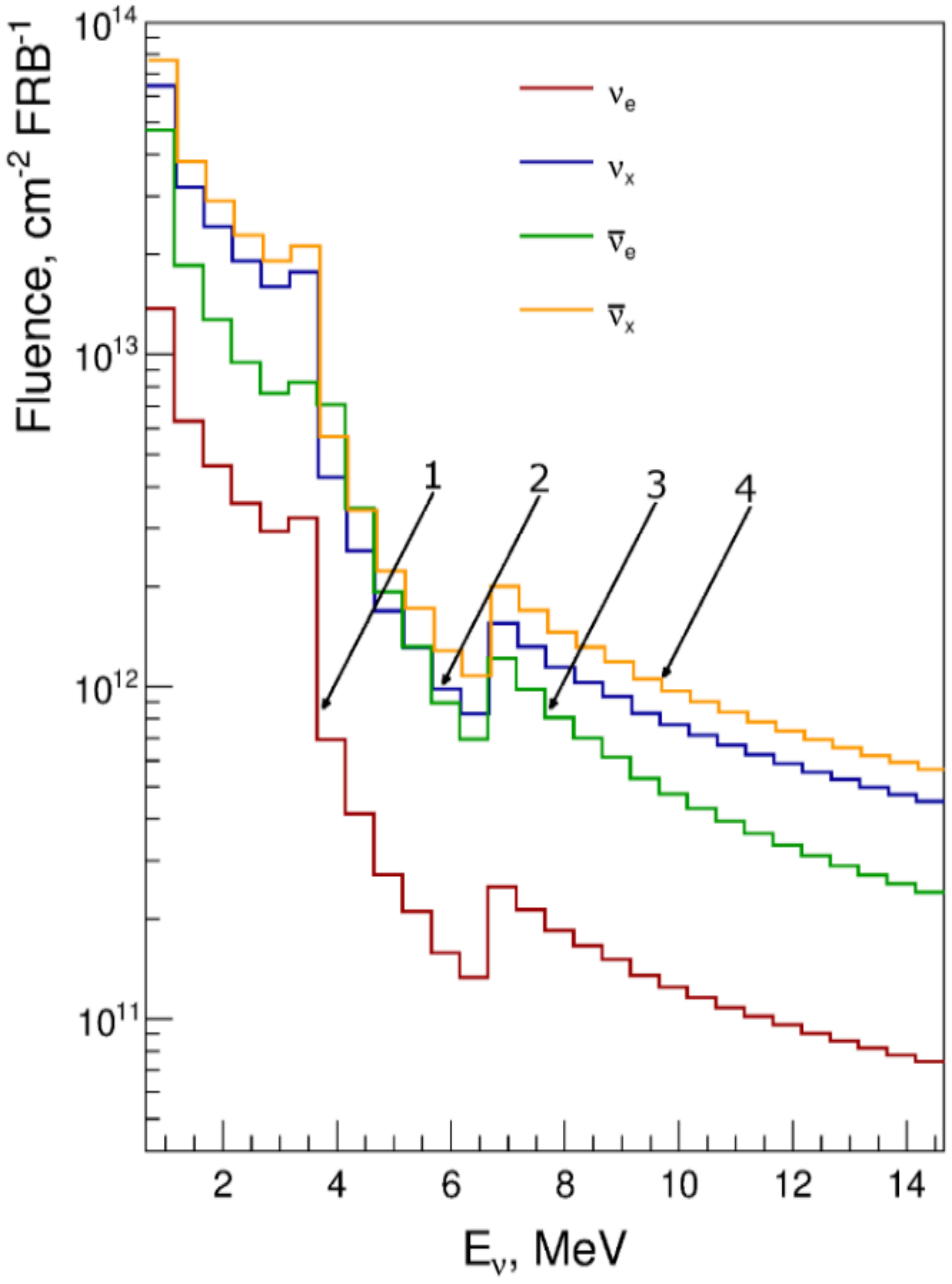


BX events (E > 0.25 MeV) within ± 5000 s of FRB 200428 detection time



BX events within ± 1000 s time window Normalized BG[−5000. . .−1000]∪[1000. . .5000] s

FRB data selection



90% C.L. upper limits on mono-energetic neutrino fluences for 42 FRBs with $\Phi_{FRB} \geq 40$ Jy ms

Total electron neutrino fluence per single FRB: $\Phi(ve) \leq 3.69 \times 10^{10}$ cm^{-2}

Summary

GW: searched for temporal correlation. 74 GW events from 2015 - 2020 data. No statistically significant excess of events ⇒ set new limits on vx fluences in 0.5–50 MeV range.

FRB: searched for temporal correlation. FRB data 2007 - 2021, including 42 with $\Phi FRBi > 40$ Jy ms. No statistically significant excess of events ⇒ new limits on vx fluences in 0.5–15 MeV energy range from temporal correlation + new limits in 0.5–50 MeV from spectral shape approach.

Thank you for your attention!!!