Borexino Supernova Alarm System 2.0

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on behalf of the Borexino collaboration

SNEWS 2.0 Workshop
16.06.2019

Borexino Experiment

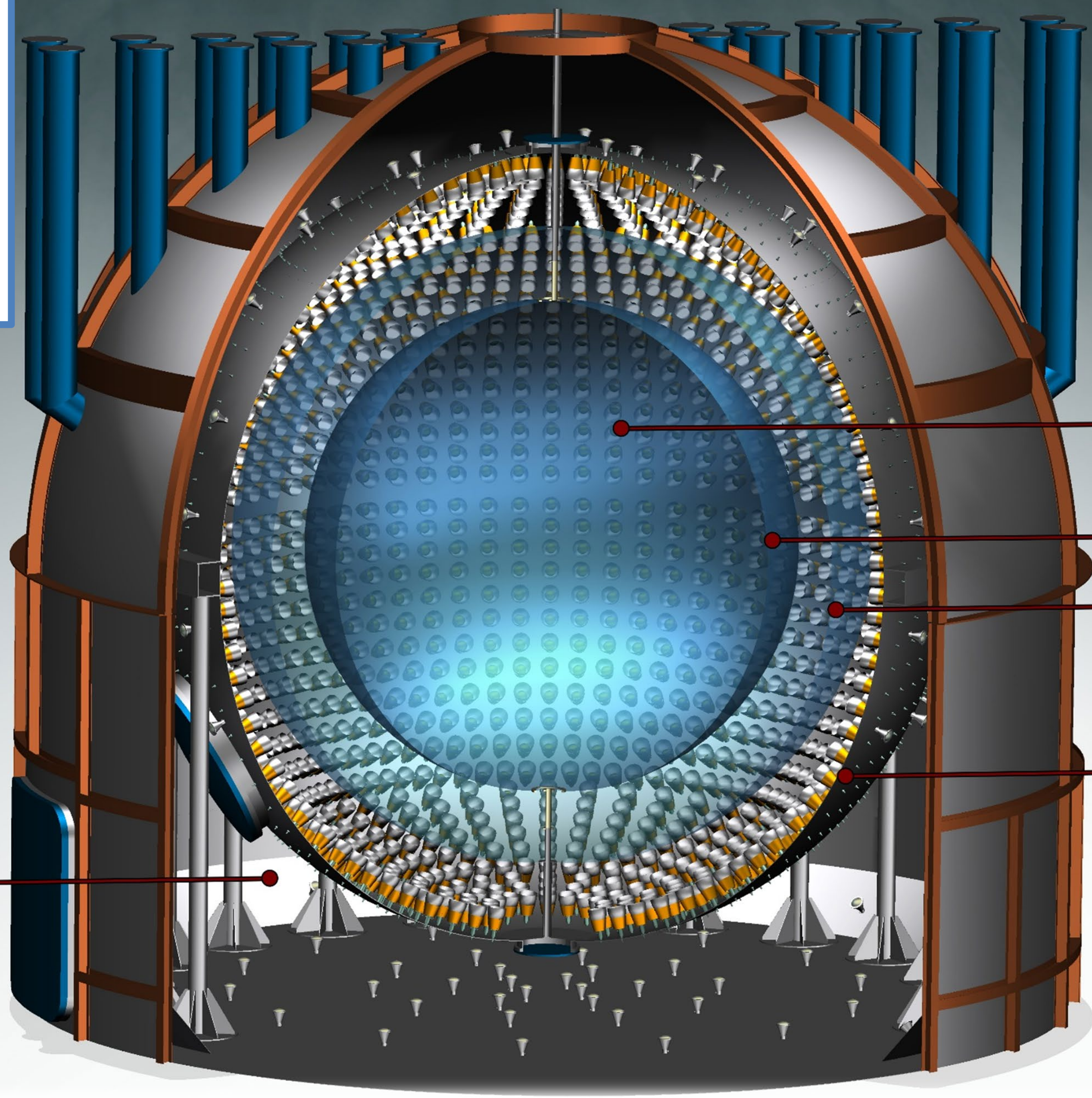
Laboratori Nazionali del Gran Sasso

Laben DAQ
Energy range:
200 keV – 20 MeV
+ PSD
+ position reco
Made for solar ν

FADC DAQ
Energy range:
1 – 50 MeV
+ PSD
+ position reco
Made for SN-ν

Energy:
5% @ 1 MeV

Position :
10 cm @ 1 MeV



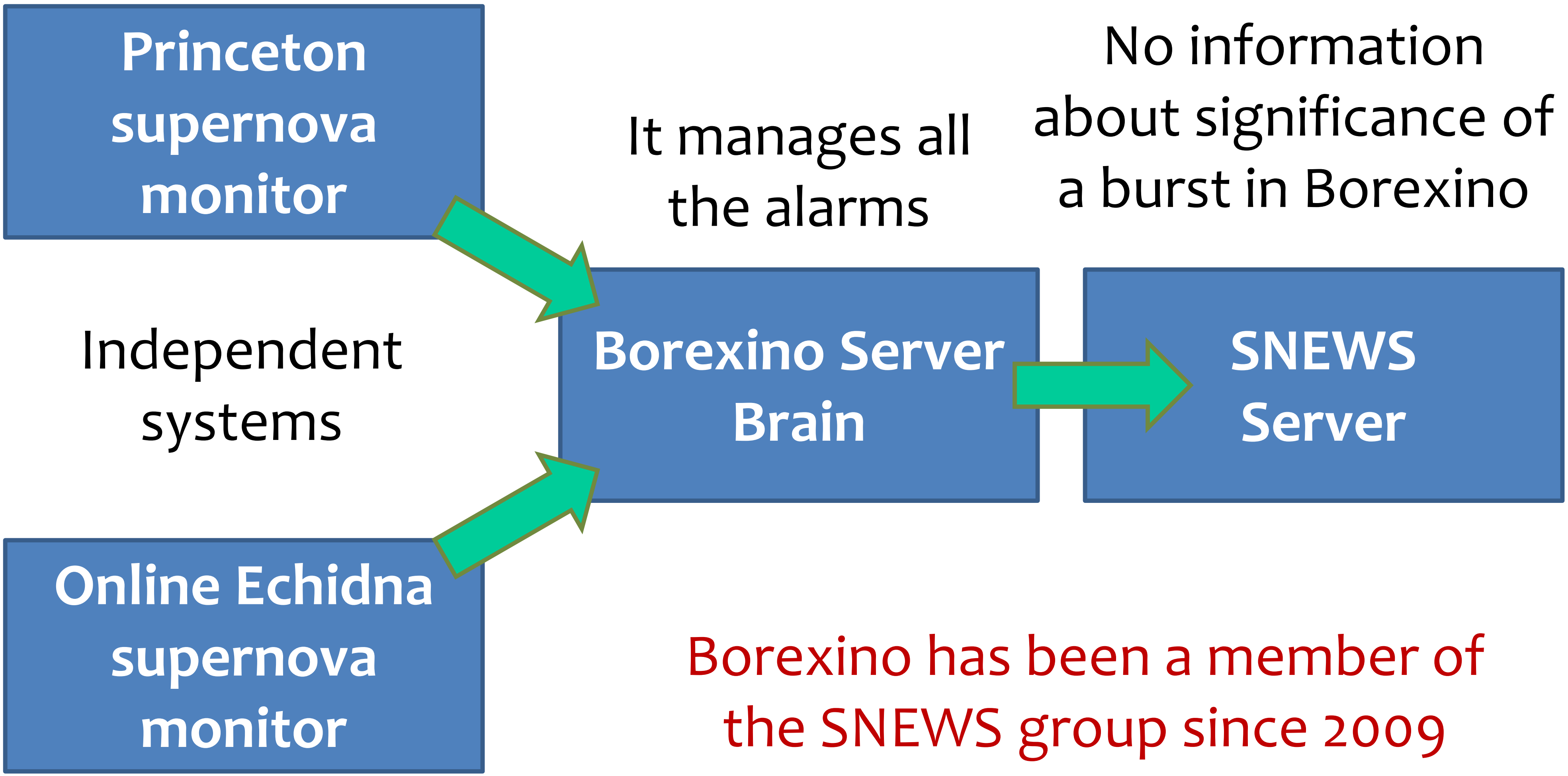
Scintillator:
278 t PC+PPO (1.5 g/l)

Nylon vessels:
(125 μm thick)
Inner: 4.25 m
Outer: 5.50 m
(radon barrier)

Stainless Steel Sphere
6.85 m, 1340 m³
- 2212 8” (ETL 9351) PMTs
- ~1000 m³ buffer of PC+DMP (light quenching)

Water tank:
γ and n shield
μ water Cherenkov detector
2100 m³
208 PMTs in water

Borexino SNEWS history
Original design (2009)



Borexino has been a member of the SNEWS group since 2009

Borexino SNEWS history
Original design and status

Princeton SN monitor

Based on hardware independent from the Laben and FADC DAQs

- Searching for bursts of neutrons
- Input: analog sum of all ID PMTs
- Active while the PMTs are on
- Multiplicity ≥ **6**
- Δt (subsequent pulses) < 10 s
- Real burst duration ≥ 2 ms
- Noise cut
- Working up to now

Online Echidna SN monitor

Online Echidna is a lightweight version of the reconstruction framework

- Searching for bursts of events
- In 30 s window
- Multiplicity ≥ **15**
- Energy threshold 500 keV
- Reject muons and neutrons
- Partly tested (offline mode)
- Not commissioned

Borexino SNEWS history
Current status (2019)

FADC DAQ

Online Echidna
for
monitoring
detector stability

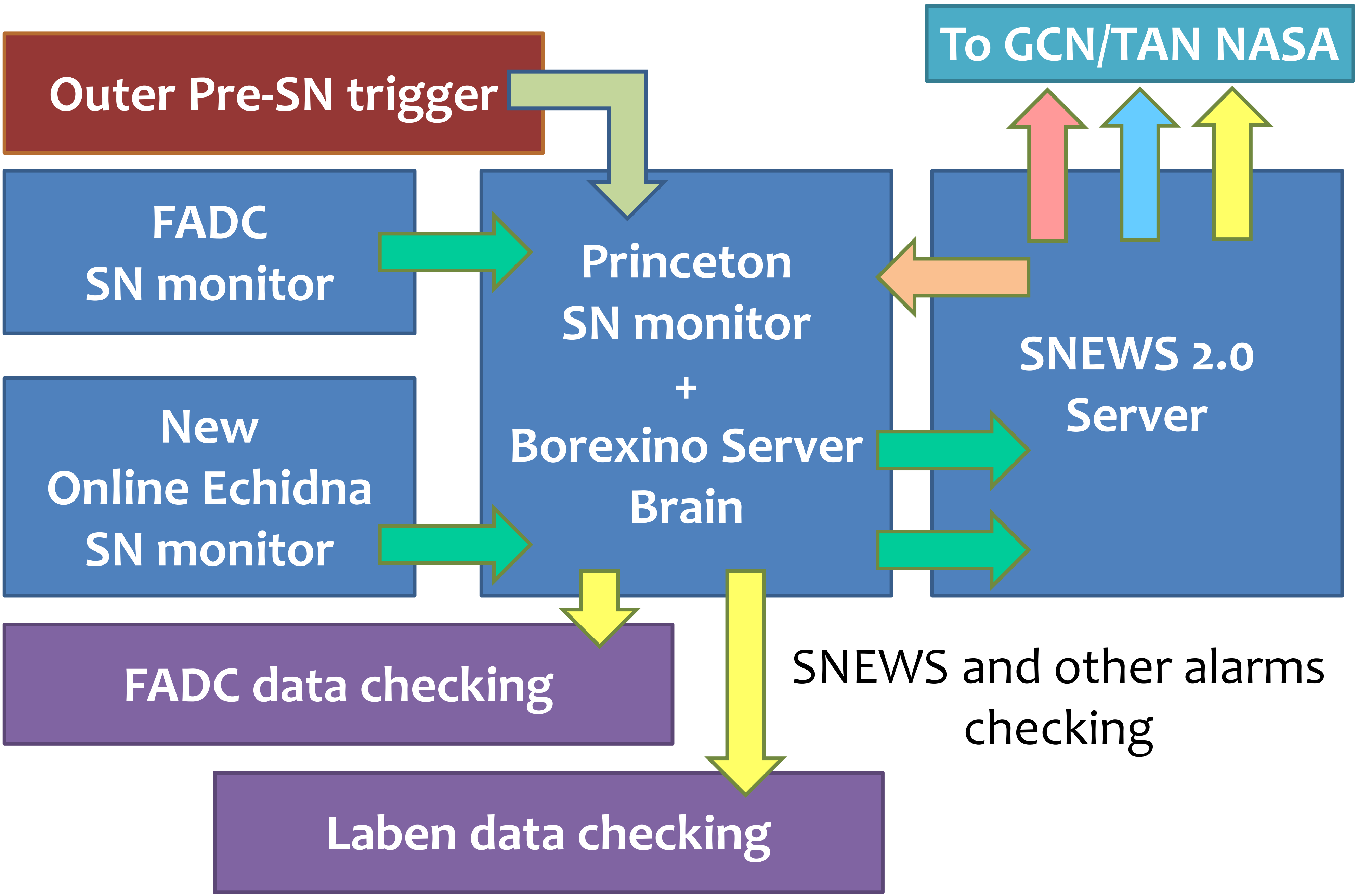
Princeton
SN monitor
+
Borexino Server
Brain

No information
about significance of
a burst in Borexino

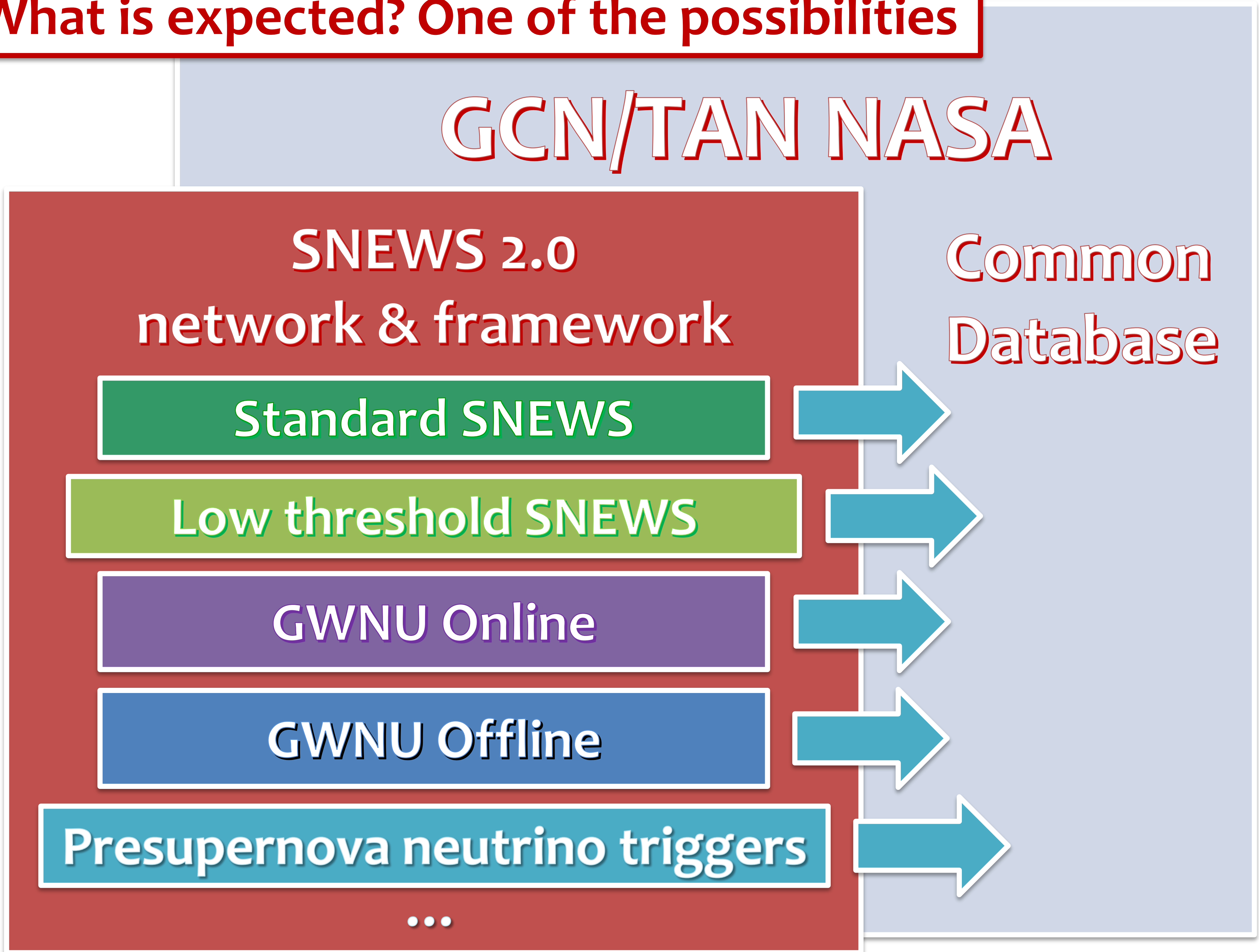
SNEWS
Server

Only one SN monitor (Princeton) is alive

Borexino SNEWS 2.0 (2019)



What is expected? One of the possibilities



Adding the burst significance False Alarm Rate

- **The False Alarm Rate (FAR or the Imitation Frequency)**

  is a number of accidental background fluctuation above the SN detection threshold per year

- **The joint FAR is a number of accidental coincidence of detector signals in the network**

$$FAR_{joint} = \prod_{i=1}^{N} FAR_i \times (2t_{coin})^{N-1},$$

where t_{coin} is a coincidence window between GW and neutrino signals in which the correlation is looked for
Conservative approach: t_{coin} = 10 s, whereas in some paper it's in order of tens ms [1].
The factor "2" is due to unknown time order of signals.

[1] G. Pagliaroli et al., Phys.Rev.Lett.103:031102,2009; arXiv:0903.1191v1

FAR: a powerful parameter for accidental background rejection

Let's choose the joint FAR of 1 cluster/1000 yr and

the GW subnetwork FAR of 1 cl/1 month

$$FAR_{joint} = \frac{1\ \text{CL}}{1000\ \text{YR}} =$$

$$= FAR_{GW} \times FAR_{LVD} \times FAR_{IceCube} \times FAR_{BX} \times (2t_{coin})^3$$

Assuming the same FAR per each neutrino detector:

$$FAR_{\nu} \sim 2 \times 10^{-3}\ \text{Hz} \sim \frac{1\ \text{CL}}{10\ \text{MIN}}$$

If there is only one detector it's necessary to stay at very low value of FAR_i in order to be statistically significant

➡ The value equals 1 cl/100 yr in the LVD paper [2]

[2] Agafonova N Y et al. (LVD Collaboration) 2015 ApJ 802 47 (Preprint 1411.1709v2)

Parameters of ν bursts selection

In case of counting detectors like Borexino, LVD, KamLAND, JUNO

Type of the event bursts:
- a) burst consisting of single events
- b) burst of the IBD events

Type of the burst window:
- a) fixed (static) time window
- b) fixed time windows with shifts (duration - 20 s, start shift - 10 s)
- c) dynamic (every event is a starting point)

Multiplicity:
- a) based on the signal/background ratio
- b) based on the significance (FAR)

Well-developed approaches:

[2] Agafonova N Y et al. (LVD Collaboration) 2015 ApJ 802 47 (Preprint 1411.1709v2)

[3] Agafonova N Y et al. (LVD Collaboration) 2008 Astropart. Phys. 28 516–22 (Preprint 0710.0259v1)

BX SNEWS: ν event bursts selection

According to the LVD article [3]

the technique implies for JUNO-like detectors:

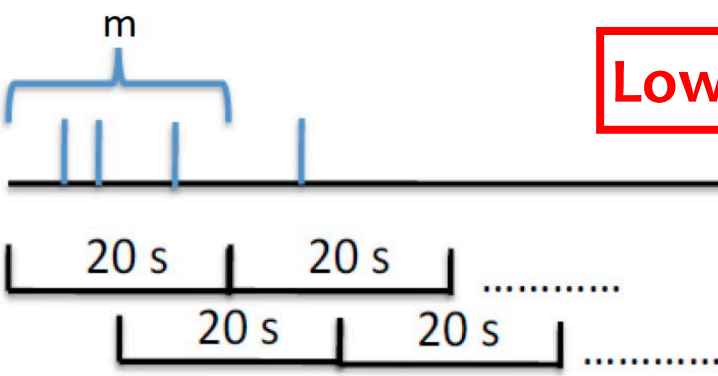
- **the search for a burst of events within a fixed-duration time window** $\Delta t = 20$ s
- **each burst is characterized by duration** Δt **and multiplicity** m_i
- **each data period** T **is divided into** $N = 2\,T/\Delta t - 1$ **intervals, each one starting in the middle of the previous one**
- **as a result the unbiased time window is 10 s**
- **calculation of average background** f_{bk} **for each period of measurements under constant conditions (trigger levels, purity,...)**

  Note: Every ν - candidate is considered as a background event
- **each burst is associated with** ***FAR*** **which is based on the Poisson distribution:**

$$FAR(m, f_{bk}, 20\,\mathbf{s}) = 8640 \cdot \sum_{k \geqslant m}^{\infty} P\left(k; 20 \cdot \frac{f_{bk}}{s^{-1}}\right) \frac{ev}{day}$$

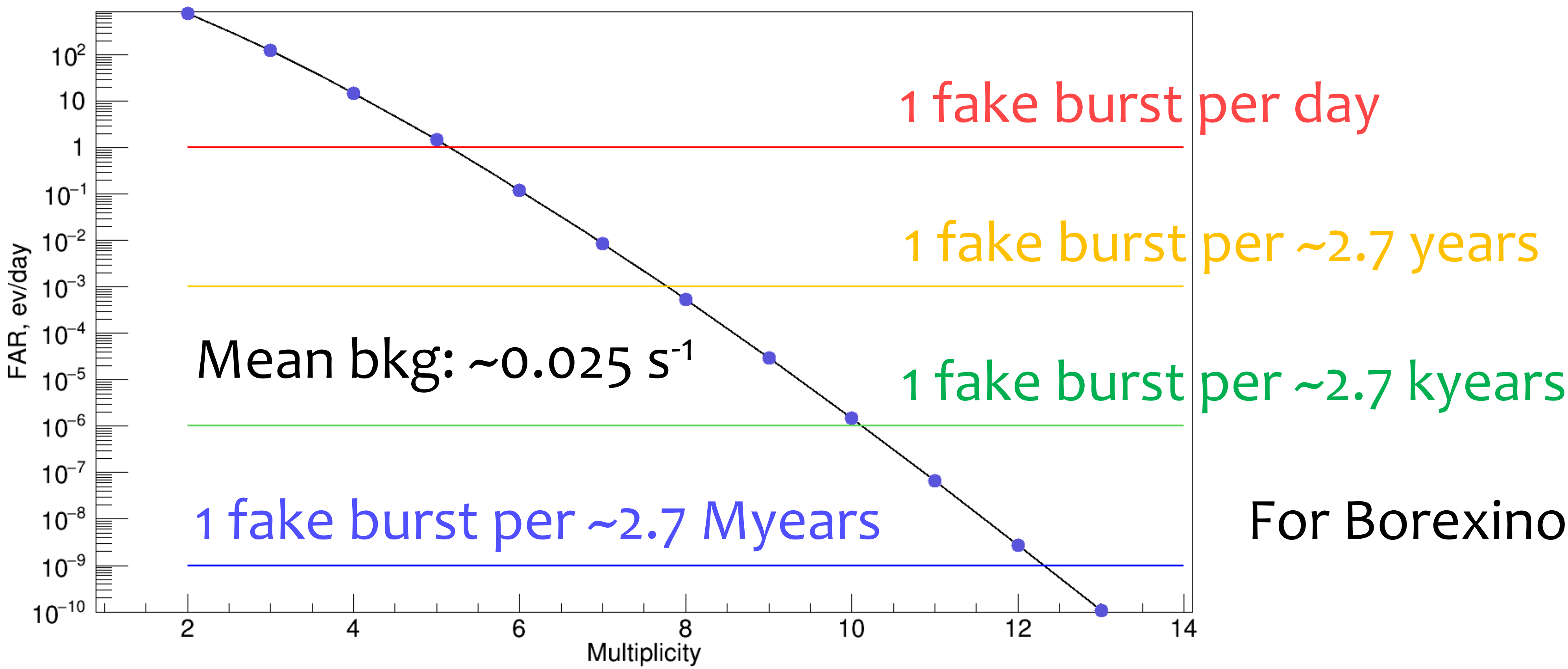
[3] Agafonova N Y et al. (LVD Collaboration) 2008 Astropart. Phys. 28 516–22 (Preprint 0710.0259v1)

BX SNEWS: ν event bursts selection



Lower multiplicity m ➡ higher False Alarm Rate

$$FAR = 8640 \sum_{k=m}^{\infty} \frac{(f_{bk}\Delta t)^k e^{-f_{bk}\Delta t}}{k!}$$



For Borexino

Simulation

Goals:

- Verification techniques and tools
- The efficiency of the coincidence search depending on the distance to the supernova and the number of detectors in the network

How? By inserting the generated signals into real data

SN models (penalty: model-dependent efficiency):

1) Pagliaroli's approach: reproduce SN1987A signal, taking the main parameters from the analysis Astroparticle Physics 31 (2009) 163–176; arXiv:0810.0466v1
2) Lawrence Livermore model (characteristics similar to SN1987A) Astrophys. J. 496 (1998) 216-225; arXiv:astro-ph/9710203v1
3) One of the most conservative assumptions producing the lowest flux Phys. Rev. Lett. 104: 251101, 2010; arXiv:0912.0260v3
4) "Optimistic assumption": lots of neutrinos with rising energy Astrophys.J.667:382-394,2007; arXiv:0706.3762v1

Possible data format

Two types of data lists for each detector

➡ The first type: for the coincidence search itself

GPS time of the burst start, seconds, precision 1 s	FAR, events/day
562392268	2199.78
562392288	652.72
562392308	5377.14
…	…

Possible data format

Two types of data lists for each detector

The second type: for further investigation
in case of LVD, Borexino, KamLAND, JUNO

multiplicity	FAR, events/day	GPS start time, seconds	GPS start time, nanoseconds	duration, seconds (20 s)	Real duration, seconds	Parameter ξ, events/second	mean energy, MeV	after muon event	energy, MeV	time, us
3	652.71	562389708	226221964	20.000	18.436148	0.16	1.49	0	0.94	504194.836
								1	1.17	14113123.037
								1	2.26	14563833.635
								0	1.59	18940342.891

See also the GWNU poster

Conclusions and proposals

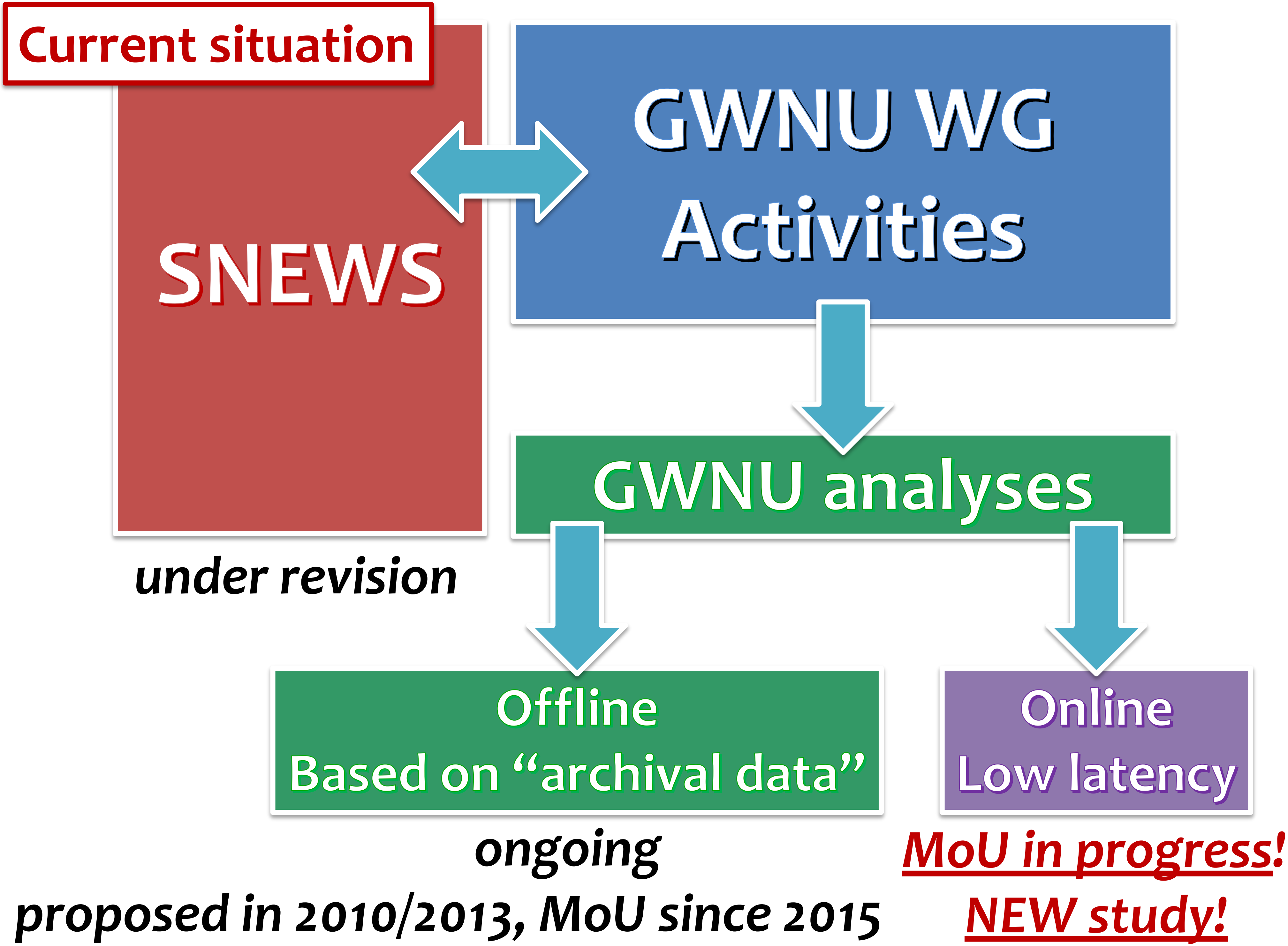
- Borexino SN Alarm System 2.0 is in progress
- The new design is quite flexible and independent from the design of the SNEWS server
- Looking for manpower for simulations

Next milestones:

- SNEWS 2.0:
  general framework and network
  uniting various experiments
- SNEWS 2.0 and/or GWNU MoU
- The low threshold analysis and sky localization

Thank you for your attention!

Backup slides


Current situation
SNEWS
GWNU WG Activities
GWNU analyses
under revision
Offline
Based on "archival data"
Online
Low latency
ongoing
proposed in 2010/2013, MoU since 2015
MoU in progress!
NEW study!

SNEWS and GWNU

Current NU experiments in SNEWS:

- LVD
- IceCube
- KamLAND
- Borexino
- Super-K
- Daya Bay
- HALO

GW experiments:

- LIGO
- VIRGO

GWNU

Other experiments in GWNU:

NOνA JUNO

Perspective experiments in GWNU:

KM3NET XENON1T MicroBooNE

Detection efficiency study (simplified)
By Claudio Casentini and Giulia Pagliaroli

Simulation of background for Borexino, KamLAND and LVD; staticsics – 1 month
Simulation and injection 50 signals per distance using the Pagliaroli model [4]
Energy thresholds: Borexino, KamLAND – 1 MeV, LVD – 10 MeV
Detection channel: IBD
After clusterization three cases were considred: 1, 2 and 3 detectors in the neutrino network with the Joint False Alarm Rate R_{Joint} at 1 ev/day:

- a) Network of one detector: R = 1 ev/day
- b) Network of two detectors: R = 66 ev/day
- c) Network of three detectors: R = 265 ev/day

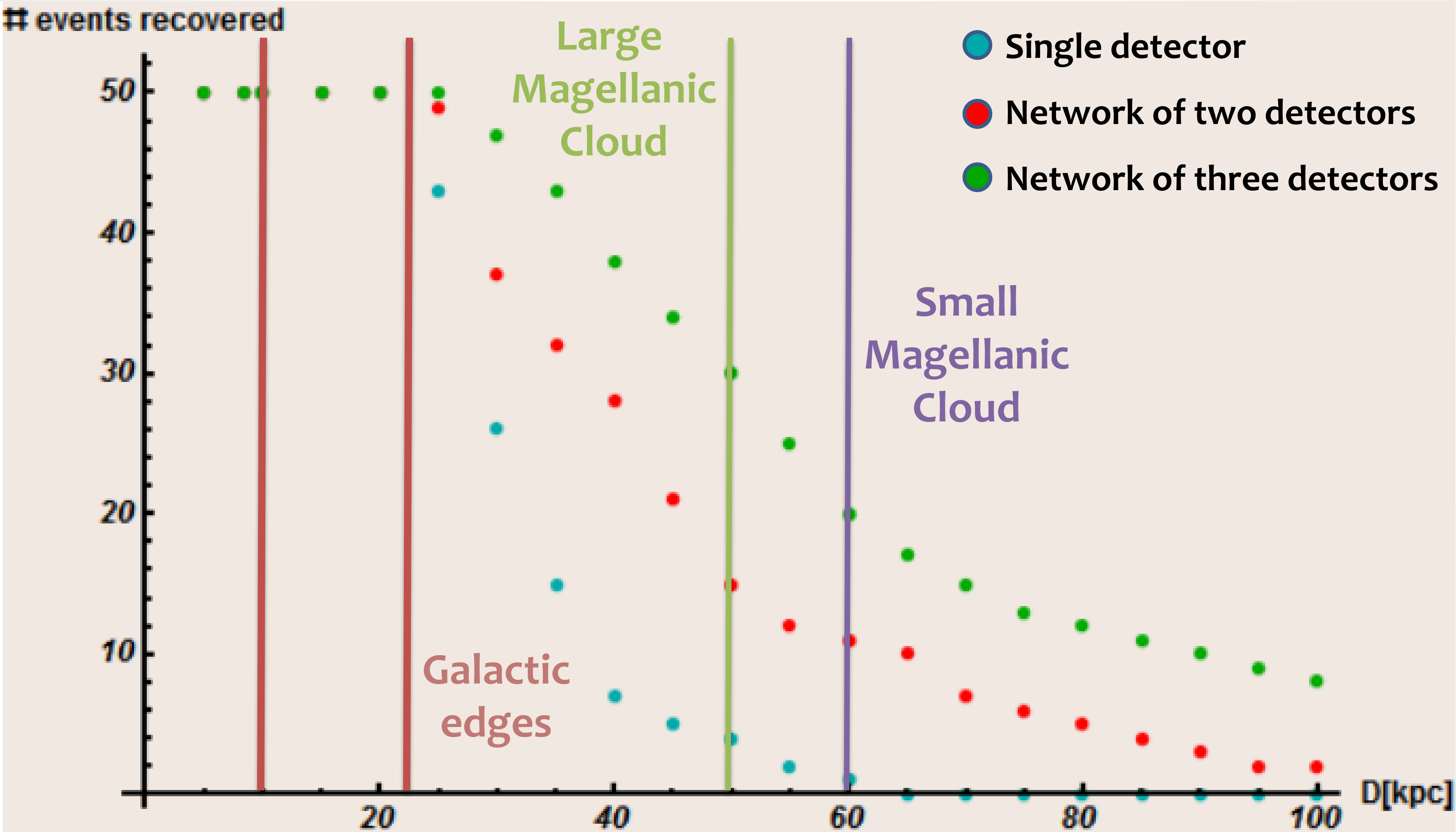
Burst selection according to the required FAR
Simplified mode: no coincidence search was made
For each distance the average efficiency of any detector in the network:

$$< \eta > = \frac{1}{10000} \sum_{i=1}^{10000} \frac{the\ number\ of\ recovered\ signals\ (i)}{the\ number\ of\ injected\ signals\ (i)}$$

[4] G. Pagliaroli et al., Astroparticle Physics 31 (2009) 163–176; arXiv:0810.0466v1

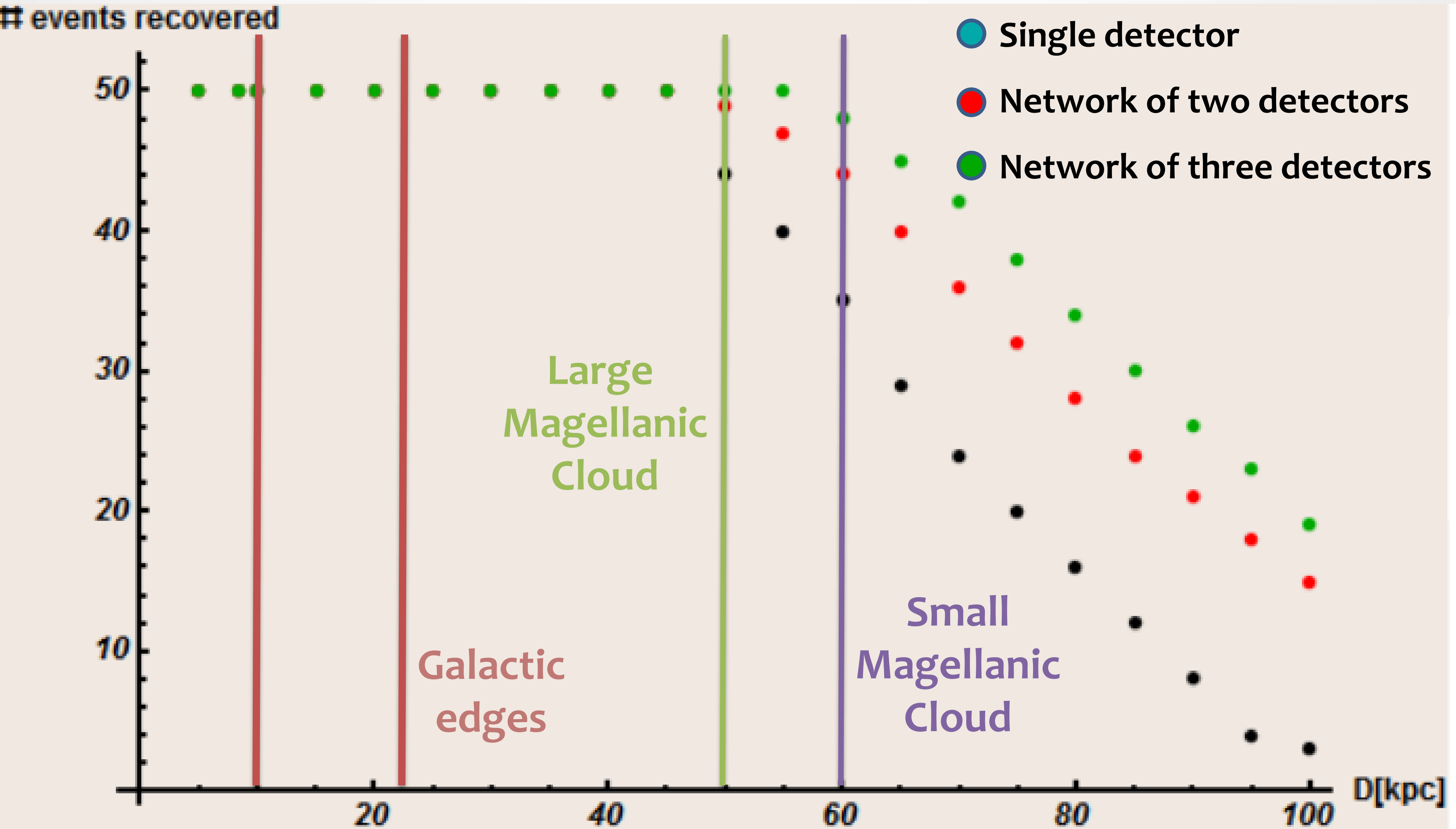
Borexino efficiency

By Claudio Casentini and Giulia Pagliaroli



LVD efficiency

By Claudio Casentini and Giulia Pagliaroli



KamLAND efficiency

By Claudio Casentini and Giulia Pagliaroli