CORE-COLLAPSE SUPERNOVA SIGNAL DETECTION WITH BOREXINO AND FRIENDS

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on behalf of the Borexino collaboration(1,2) and GWNU working group

JULY 4 2018 I WORKSHOP ON CORE-COLLAPSE SUPERNOVA NEUTRINO DETECTION, ORSAY, FRANCE

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Mitglied der Helmholtz-Gemeinschaft

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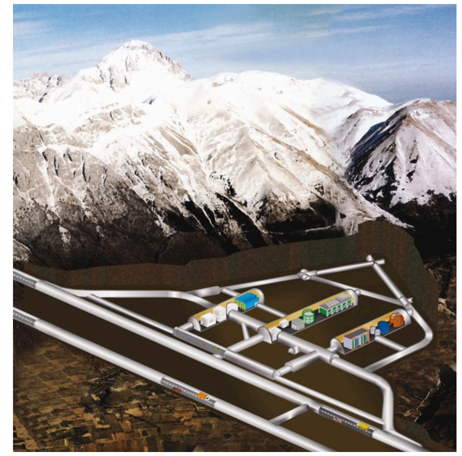
Say Hi to Borexino



Laboratori Nazionali
del Gran Sasso (LNGS)

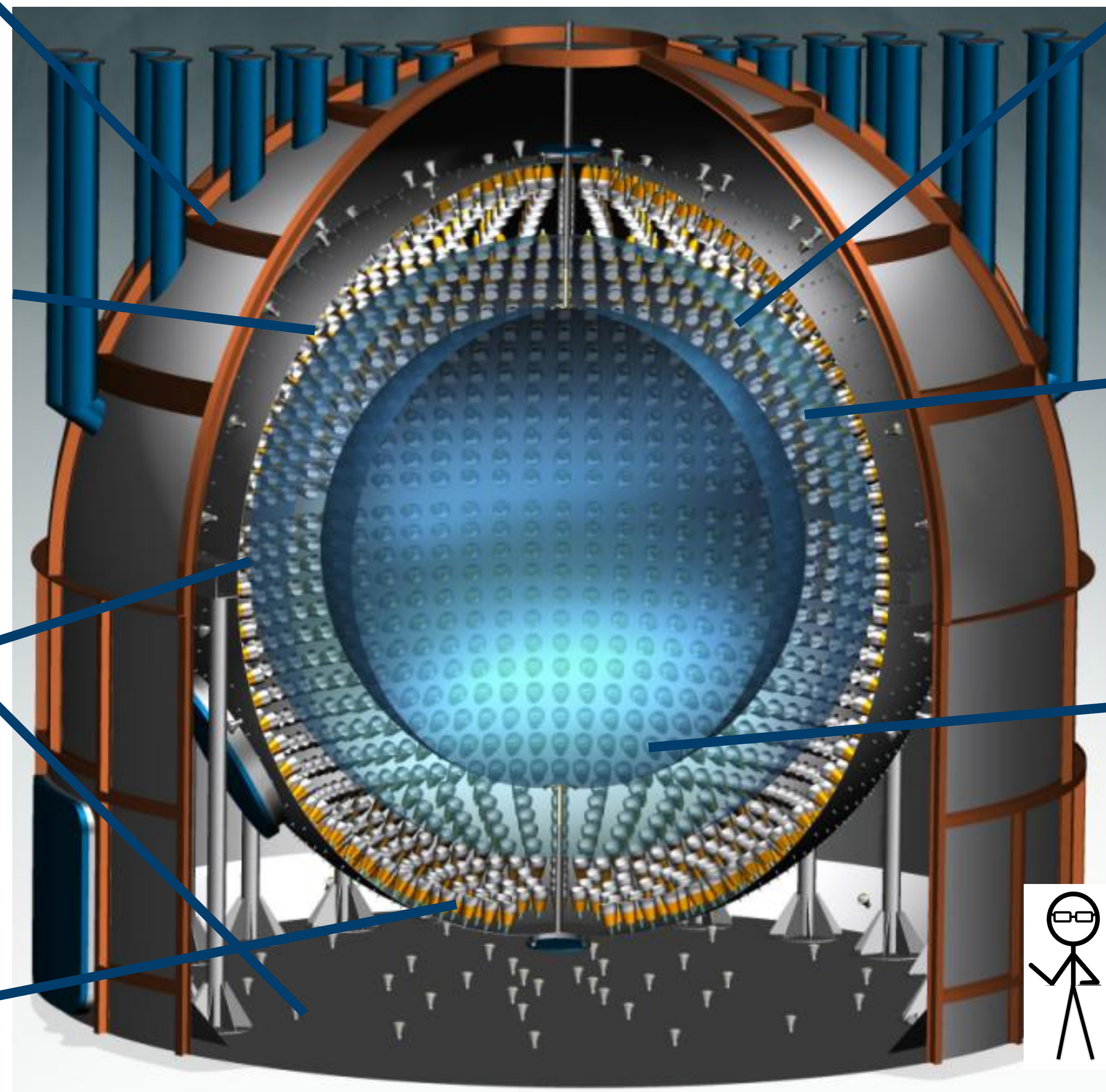
3800 m.w.e shielding against cosmic rays

Water tank
R = 9 m, 2.1 kt water
Shielding
Cherenkov muon veto

Stainless Steel Sphere
R = 6.85 m
PMTs support
Buffer + scint. container

208 Outer Detector PMTs

2212 Inward-facing PMTs



Nylon Outer Vessel
R = 5.5 m
Barrier for ^{222}Rn
from steel, PMTs etc.

Buffer
Pseudocumene (PC) +
DMP quencher

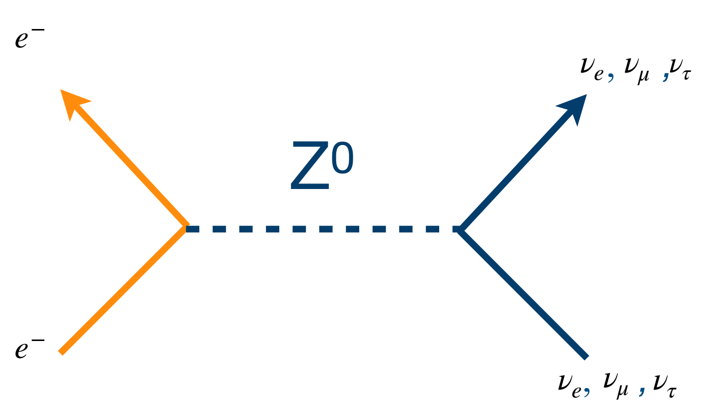
Nylon Inner Vessel
R = 4.25 m
~ 300 tons of
liquid scintillator
(PC/PPO solution)

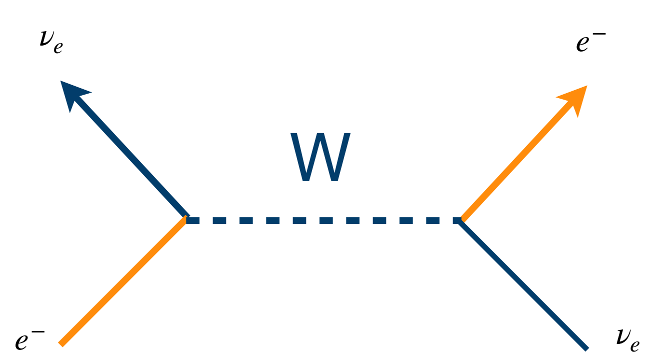
Say Hi to Borexino: Detection Channels

Most radiopure scintillator core, lowest threshold on real-time measurements

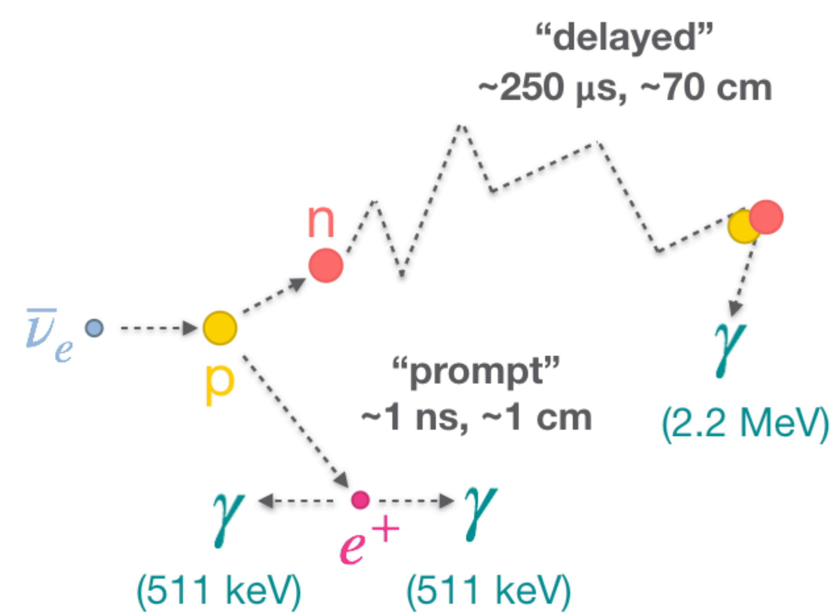
Low-energy threshold
High Light Yield
Good energy and position resolution
No directionality

Neutrinos detection:
Elastic scattering on electrons

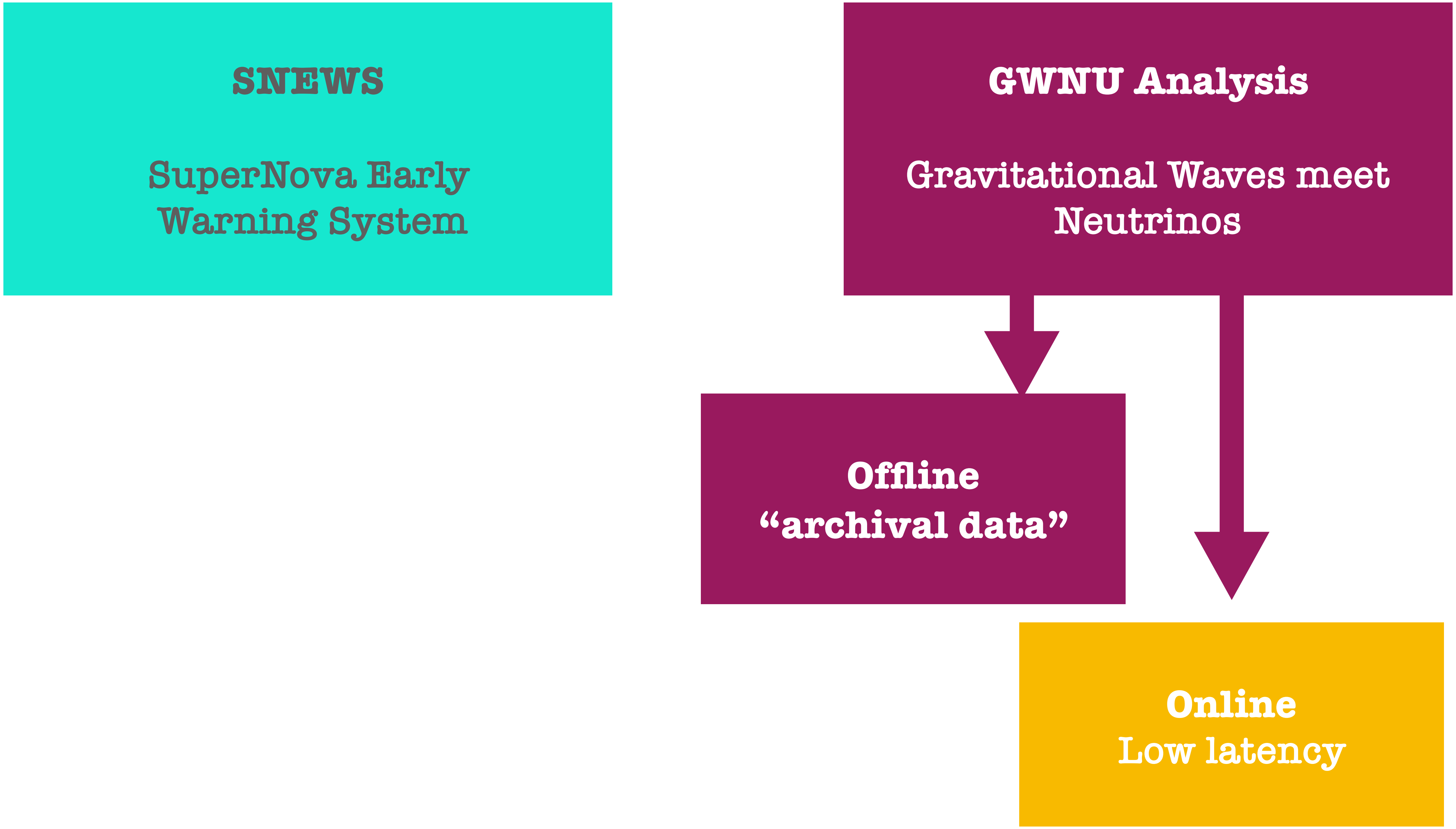




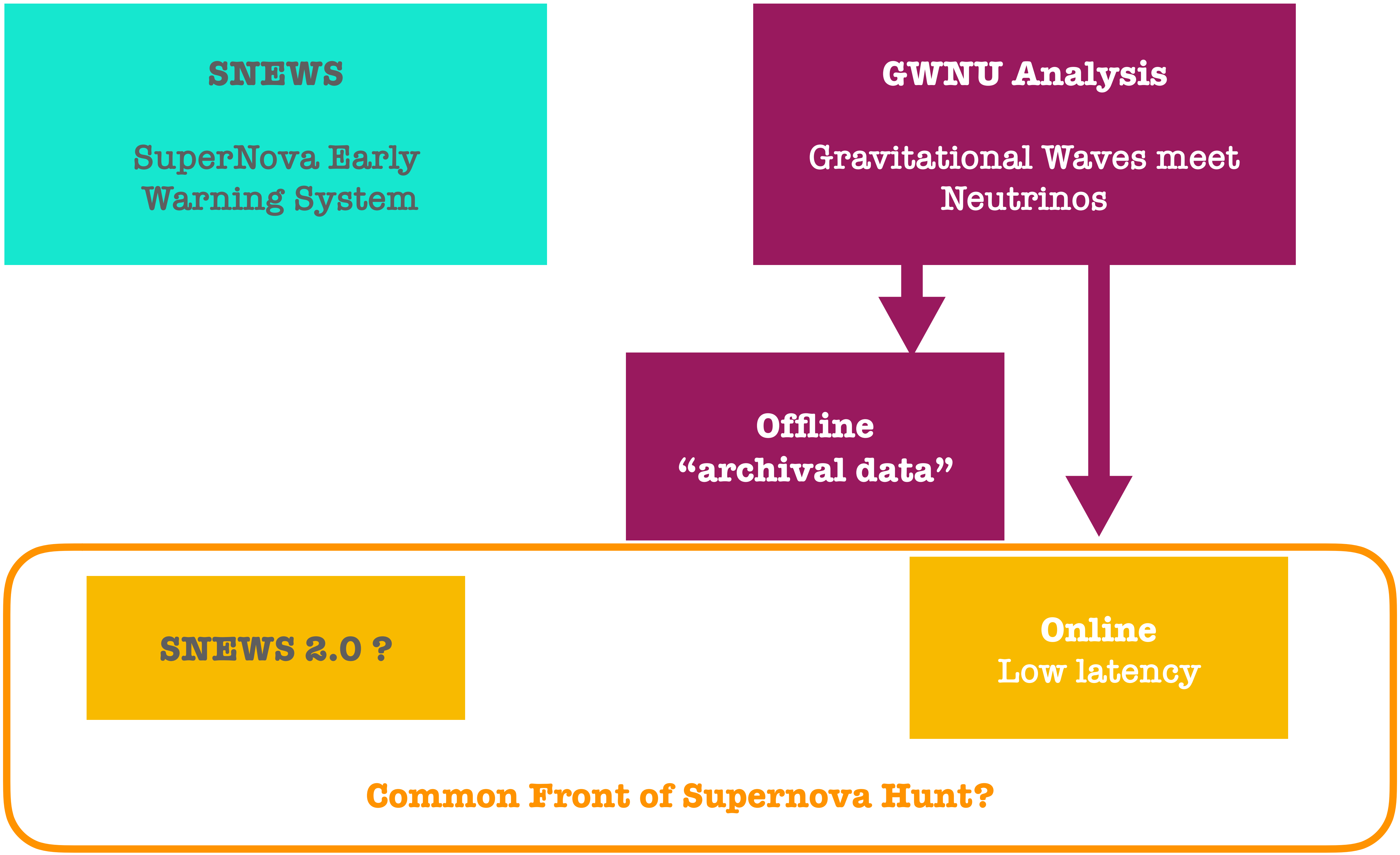
Antineutrinos detection:
Inverse Beta Decay (IBD)



Core Collapse Supernova Search Activities @ Borexino



Core Collapse Supernova Search Activities @ Borexino



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Borexino @ SNEWS

- Current **NU** experiments in **SNEWS**:
  - LVD
  - IceCube
  - KamLAND
  - **Borexino**
  - Super-K
  - Daya Bay
  - HALO
- Prospective experiments in **SNEWS:**
  - NOVA
  - SNO+
  - KM3NeT?

Running in automated mode since 2005

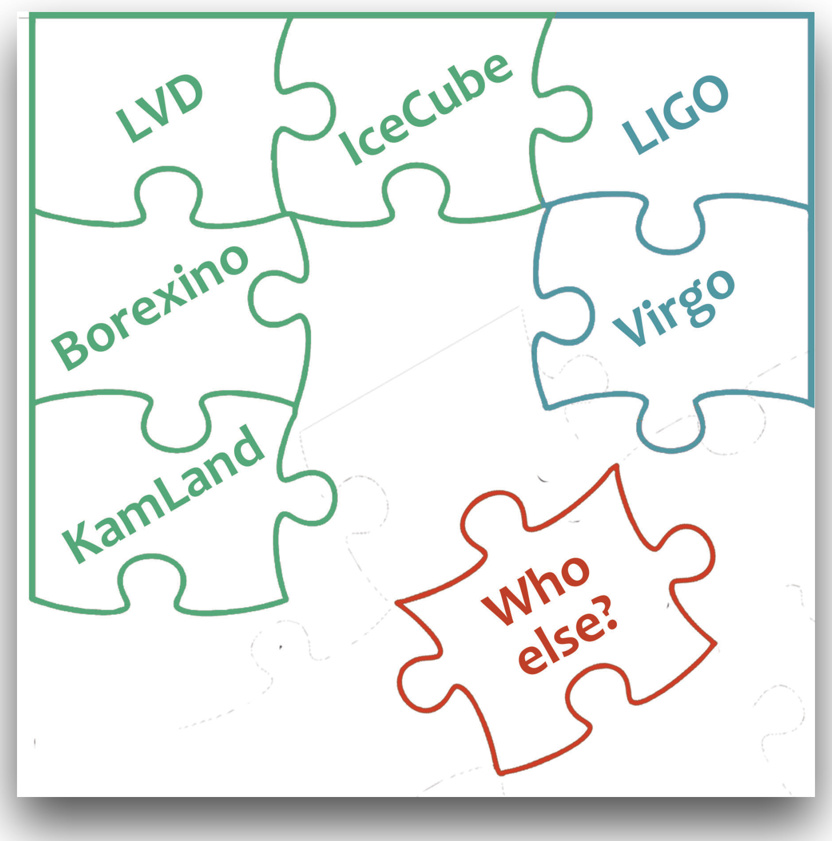
Borexino joined in July 2009

SNEWS & GWNU

- Current **NU** experiments in **SNEWS**:
  - LVD
  - IceCube
  - KamLAND
  - **Borexino**
  - Super-K
  - Daya Bay
  - HALO
- **GW**
  - LIGO
  - VIRGO

GWNU

- Prospective experiments in **SNEWS**/**GWNU**:
  - NOVA
  - SNO+
  - KM3NeT?
  - MicroBooNE
  - XENON1T



GWNU Overview

- Current **NU** experiments in **SNEWS**:
  - LVD
  - IceCube
  - KamLAND
  - **Borexino**

GWNU

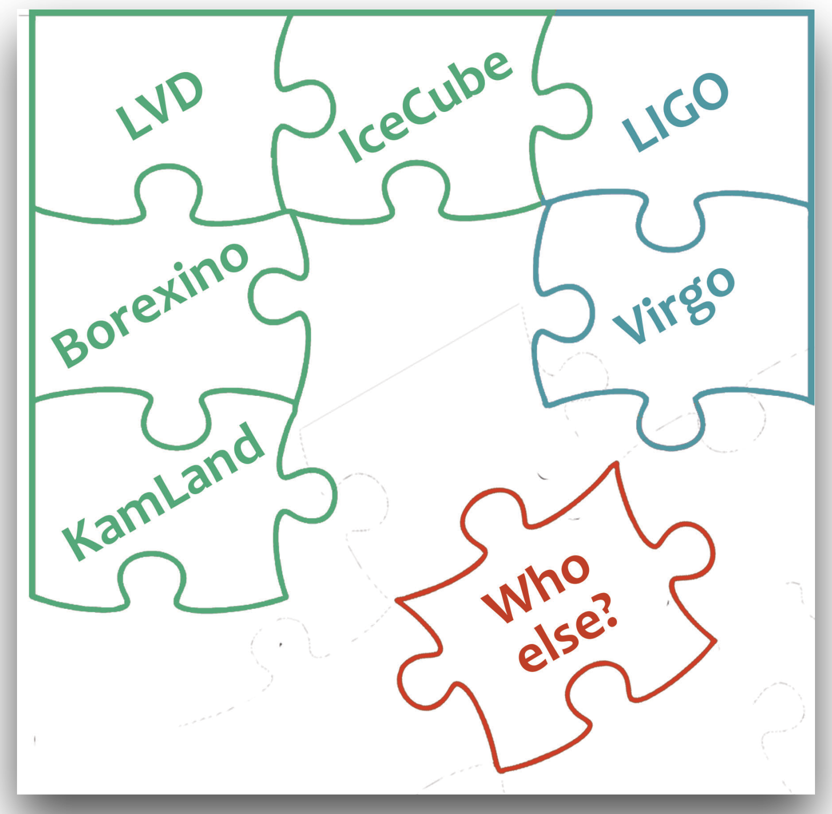
- **GW**
  - LIGO
  - VIRGO

GWNU Global network

Proposed in 2010/2013, MoU since 2015

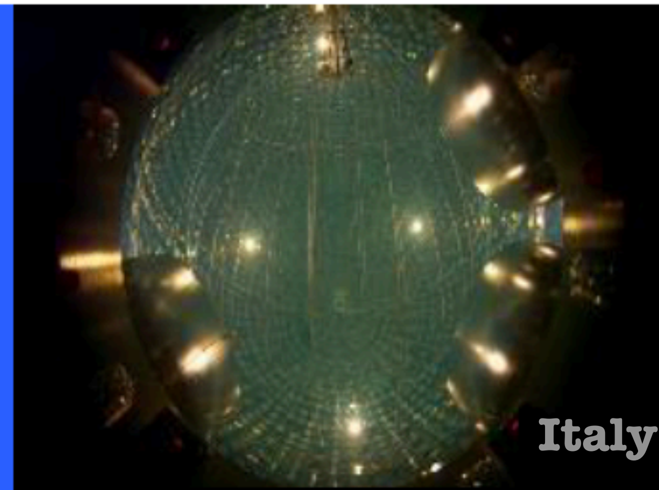
Main Goal: Search and Investigation of Core-Collapse Supernova signals from the Local Group

Conservative approach: t_coin = ± 10 s
Galactic events -> Smaller time window



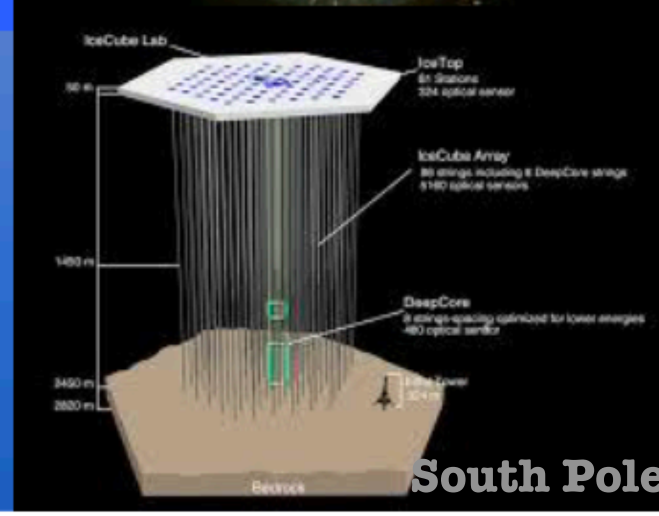
Borexino's friends in GWNU

Borexino
- Liquid Scintillator
- Energy & NC
- M= 0.3 kton



Italy

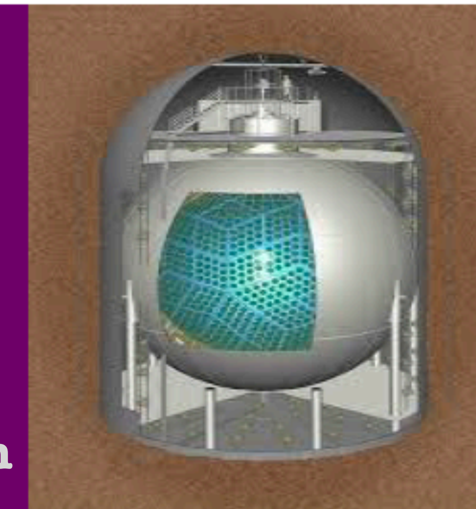
IceCUBE
- Ice Cerenkov
- Statistics
- M≈ 0.4kton/PMT



South Pole

Kamland
- Liquid Scintillator
- Energy & NC
- M= 1 kton

Japan



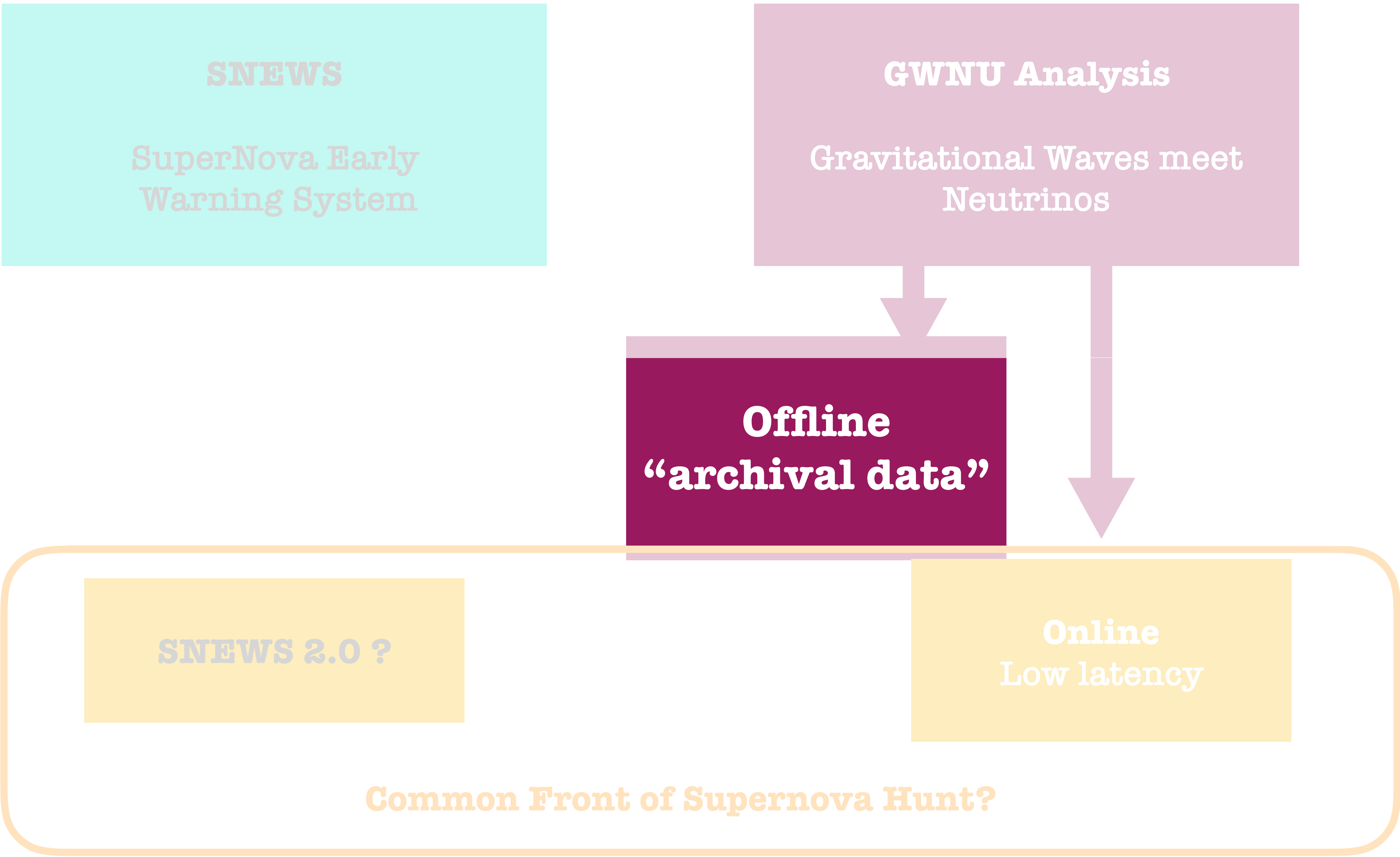
LVD
- Liquid Scintillator
- Energy & NC
- M= 1 kton

Italy

Hartford, Livinston, USA

Italy

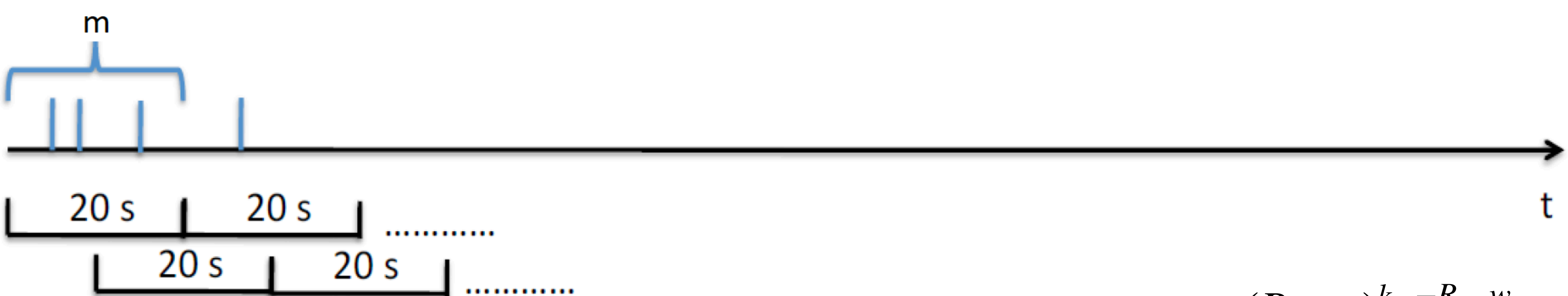
Core Collapse Supernova Search Activities @ Borexino



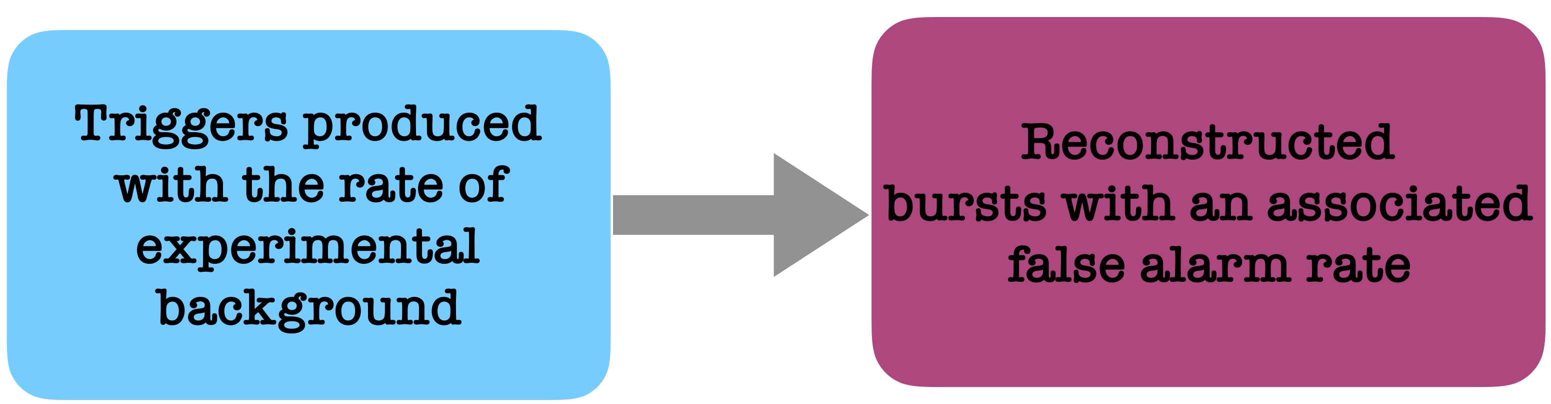
Methodology

Background and False Alarm Rate

- 10 years of simulated background per experiment
- The number of triggers (m) in overlapped time window (w=20s)
- Algorithm following LVD paper Astroparticle Physics 28 (2008) 516-522



$$R_{FA} = 8640 \sum_{k=m_i}^{\infty} \frac{(R_{bkg}w)^k e^{-R_{bkg}w}}{k!}$$



R_{FA} - false alarm rate

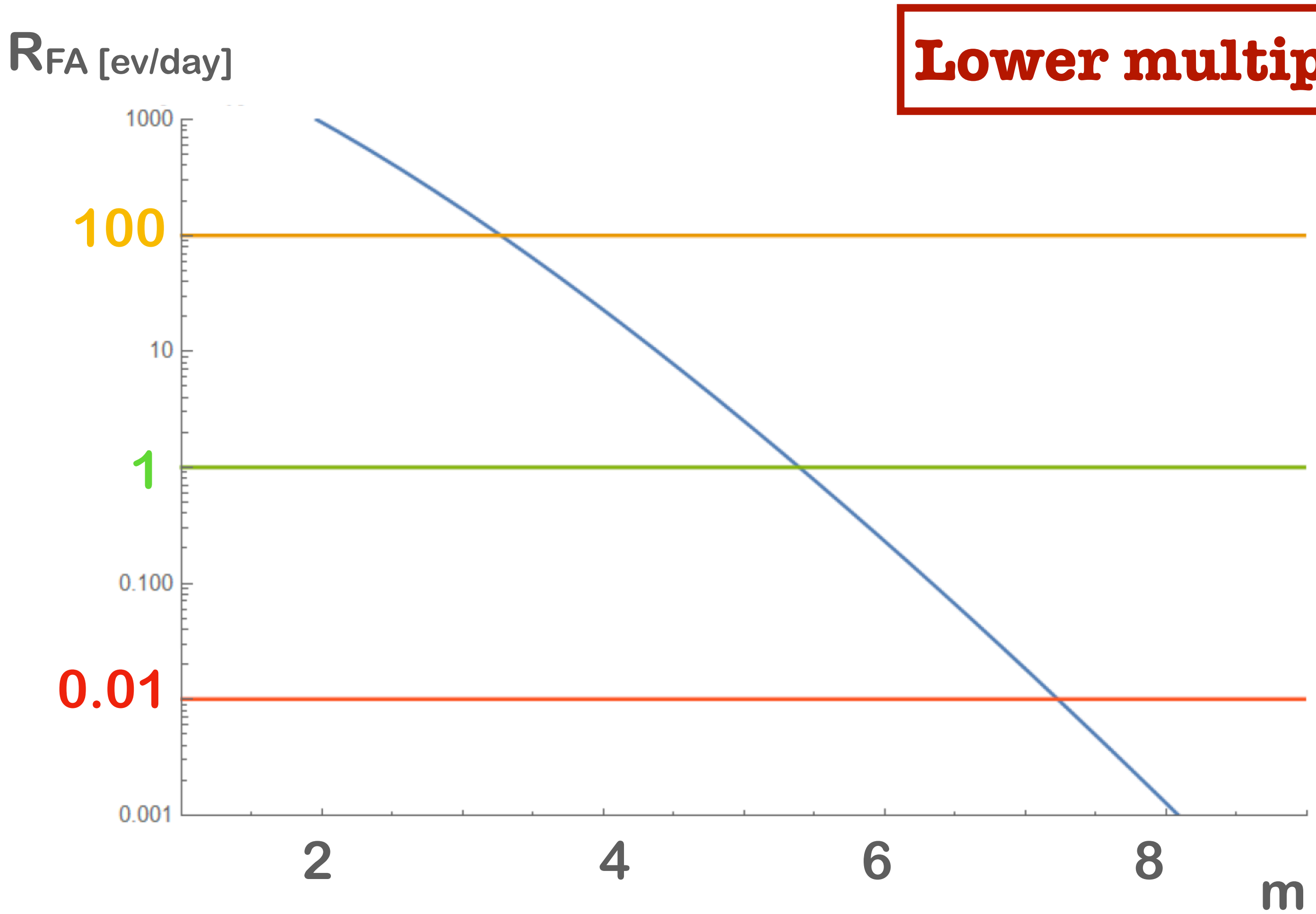
R_{bkg} - rate of experimental background

Background and False Alarm Rate

$$R_{FA} = 8640 \sum_{k=m_i}^{\infty} \frac{(R_{bkg}w)^k e^{-R_{bkg}w}}{k!}$$

- R_{FA} - False alarm rate, aka imitation frequency
- R_{bkg} - background rate of the given detector
- m_i - multiplicity, the number of triggers in overlapped time window (w=20s)
- 8640 - number of 20s windows in 1 day (overlapped every 10 sec)

Lower multiplicity m -> higher false alarm rate R_{FA}



The thresholds on false alarm rate R_{FA} for the LVD detector

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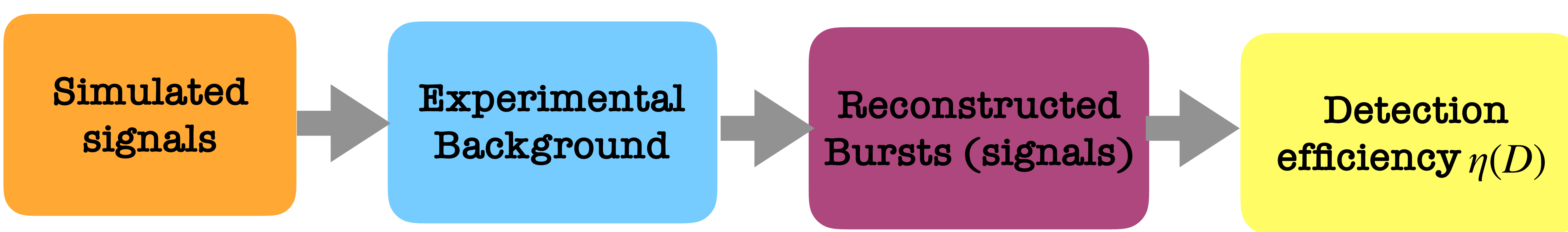
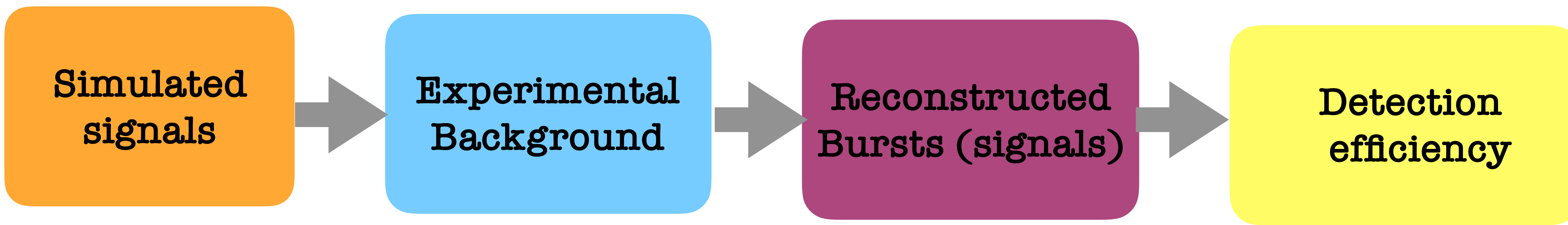
Signal Injection

- Injection of simulated signals at the given distance with a rate of 1/day inside previously produced unclustered background events time series
- 3652 signals for each distance
- Burst definition and reduction procedure -> detection efficiency η (D)



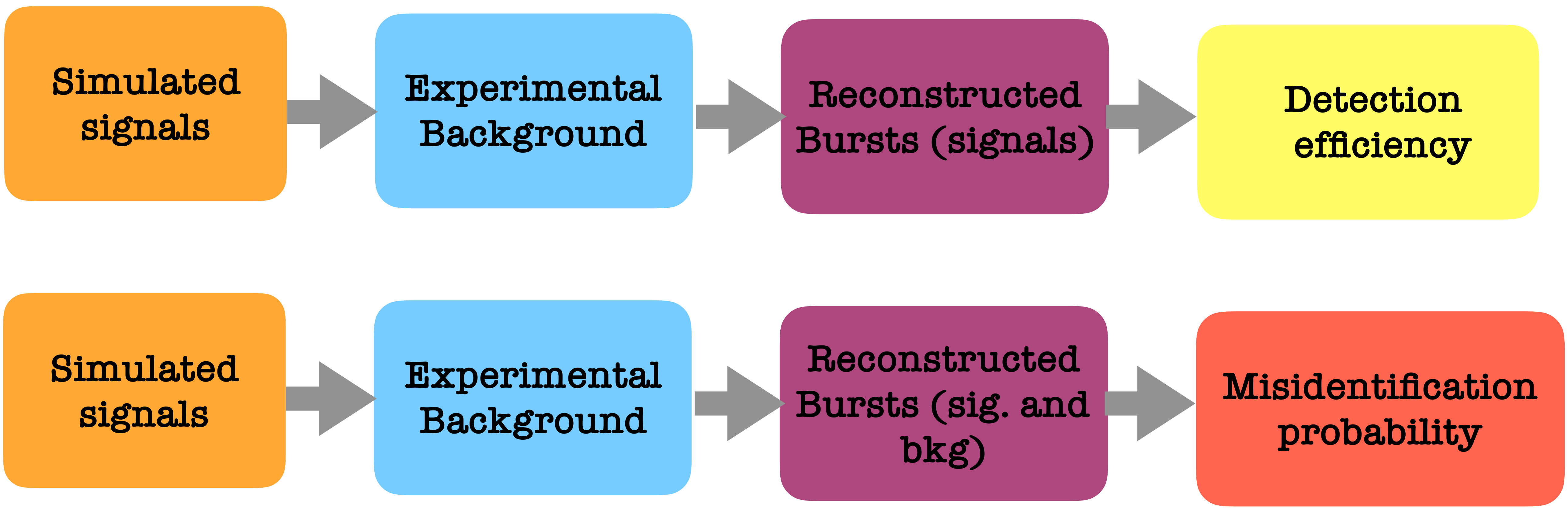
Detection efficiency & Misidentification probability



Detection efficiency

$$\eta(D) = \frac{N_{rec,s}}{N_{inj,s}}$$

Detection efficiency & Misidentification probability



Detection efficiency

$$\eta(D) = \frac{N_{rec,s}}{N_{inj,s}}$$

Misidentification probability

$$\zeta(D) = \frac{N_{rec,b}}{N_{rec,b} + N_{rec,s}}$$

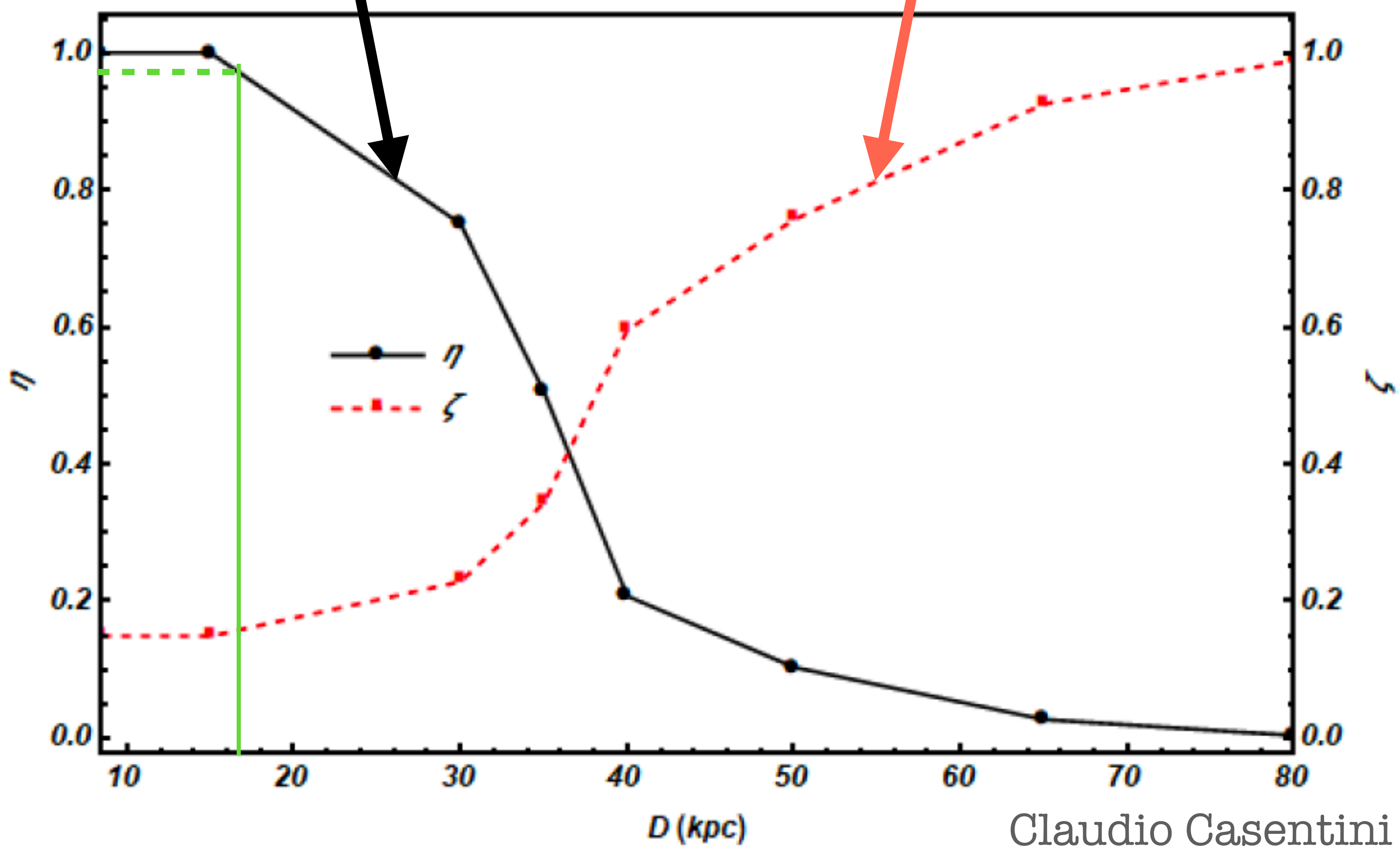
Detection efficiency & Misidentification probability

Detection efficiency

$$\eta(D) = \frac{N_{rec,s}}{N_{inj,s}}$$

Misidentification probability

$$\zeta(D) = \frac{N_{rec,b}}{N_{rec,b} + N_{rec,s}}$$

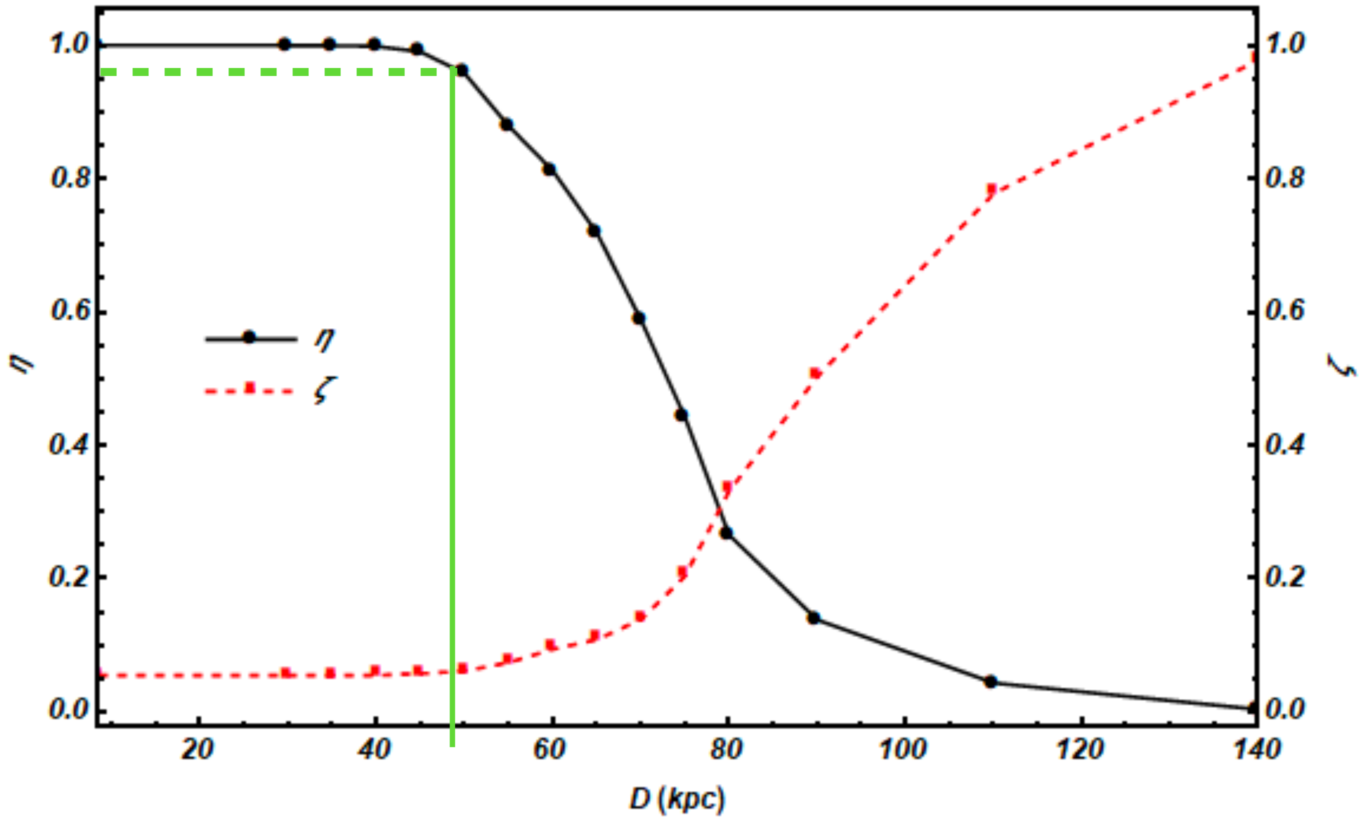


Borexino

Claudio Casentini PhD Thesis 2017

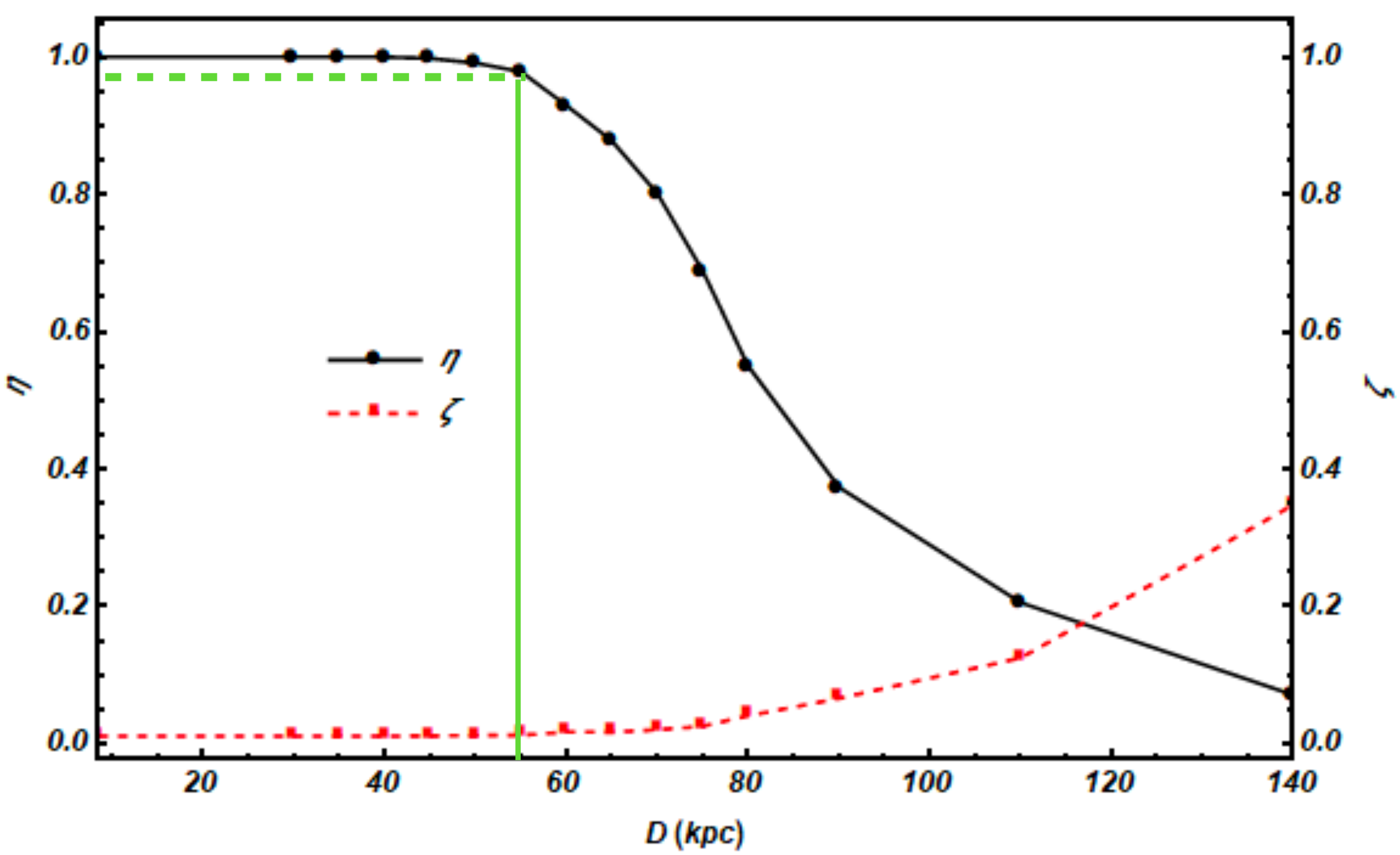
Borexino detector working alone at a background level R_{FA} = 1 ev/day.

Detection efficiency & Misidentification probability



LVD

Each detector working alone
at a background level R_{FA} = 1 ev/day.



KamLAND

Claudio Casentini PhD Thesis 2017

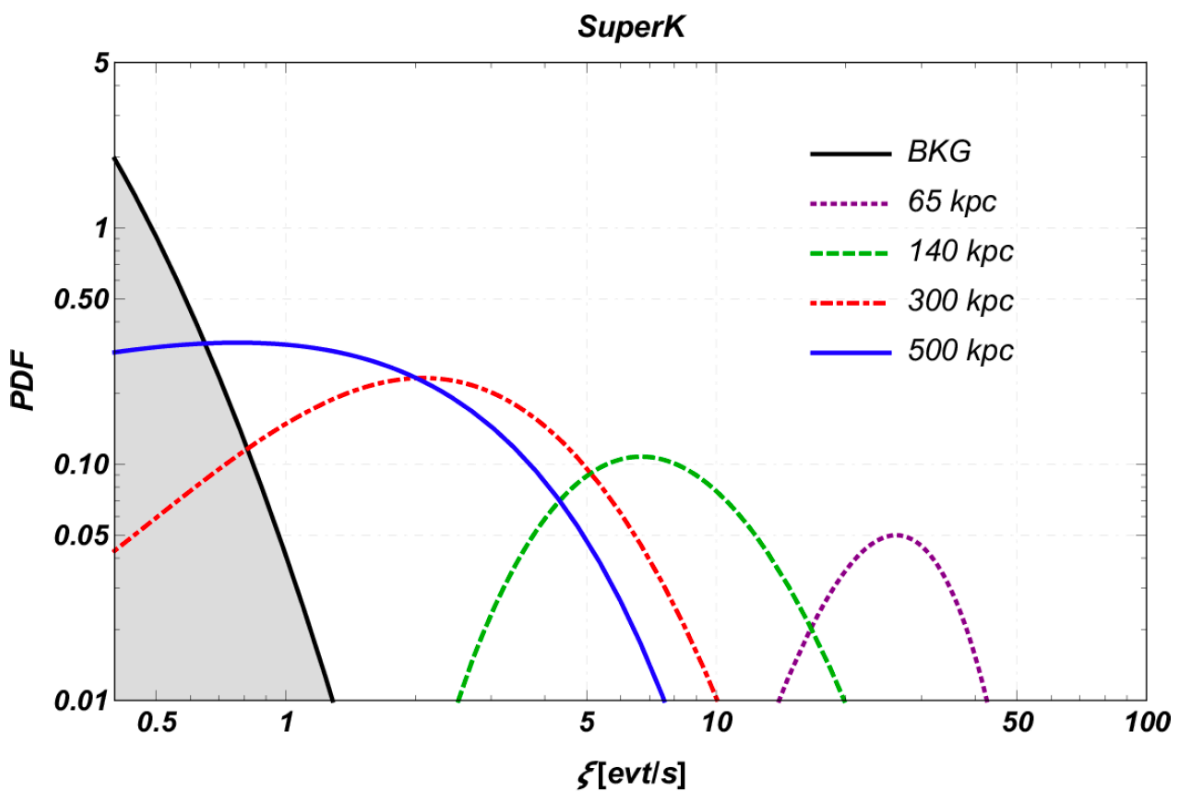
Burst discrimination - ξ parameter

$$\xi = \frac{m}{\Delta t}$$

m - burst (aka cluster) multiplicity, i.e. number of events in the coincidence window
Δt - burst duration (time difference between the last and first trigger of each burst)

$$\Xi[\xi]_X = \int_0^{\bar{\xi}_X} \mathrm{PDF}_X^{bkg}\, d\xi + \int_{\bar{\xi}_X}^{\infty} \mathrm{PDF}_X^{sig+bkg}(D)\, d\xi$$

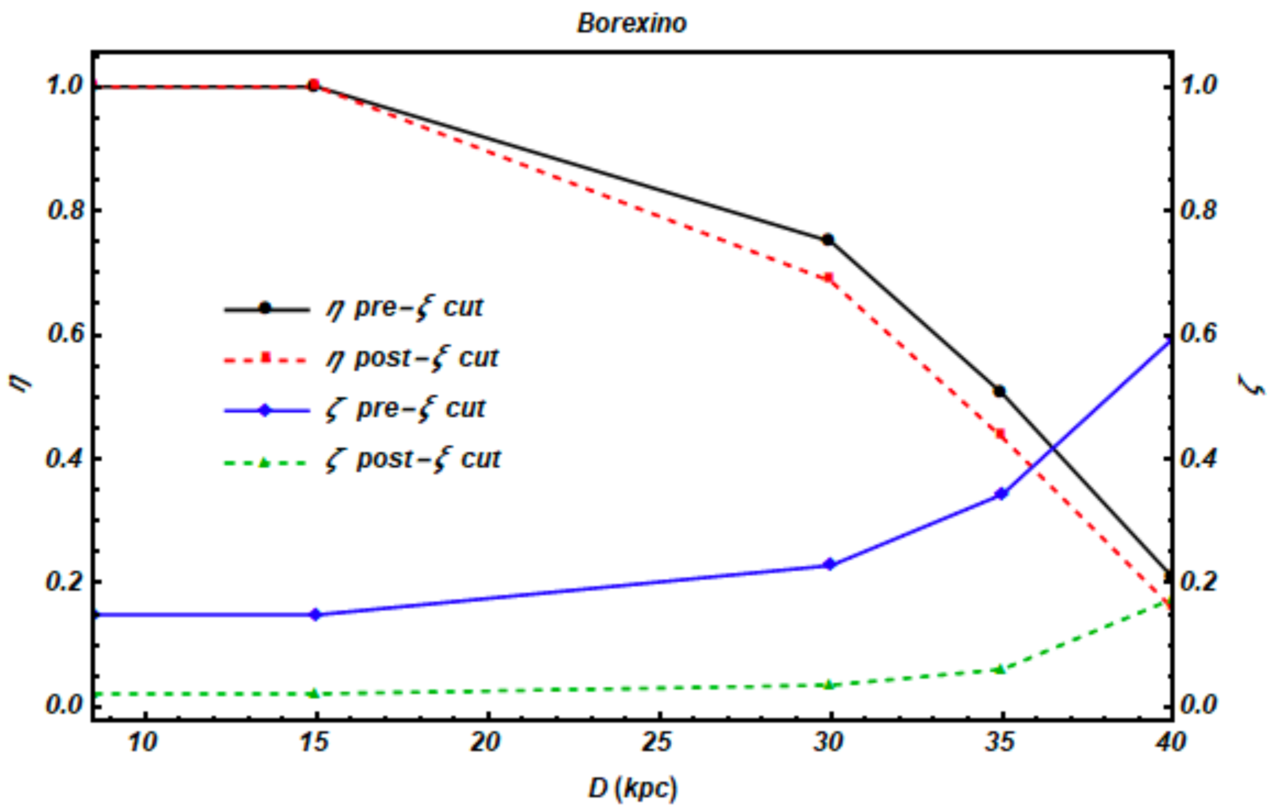
Distributions of pure background and background plus signal clusters in terms of Probability Density Functions (PDFs)

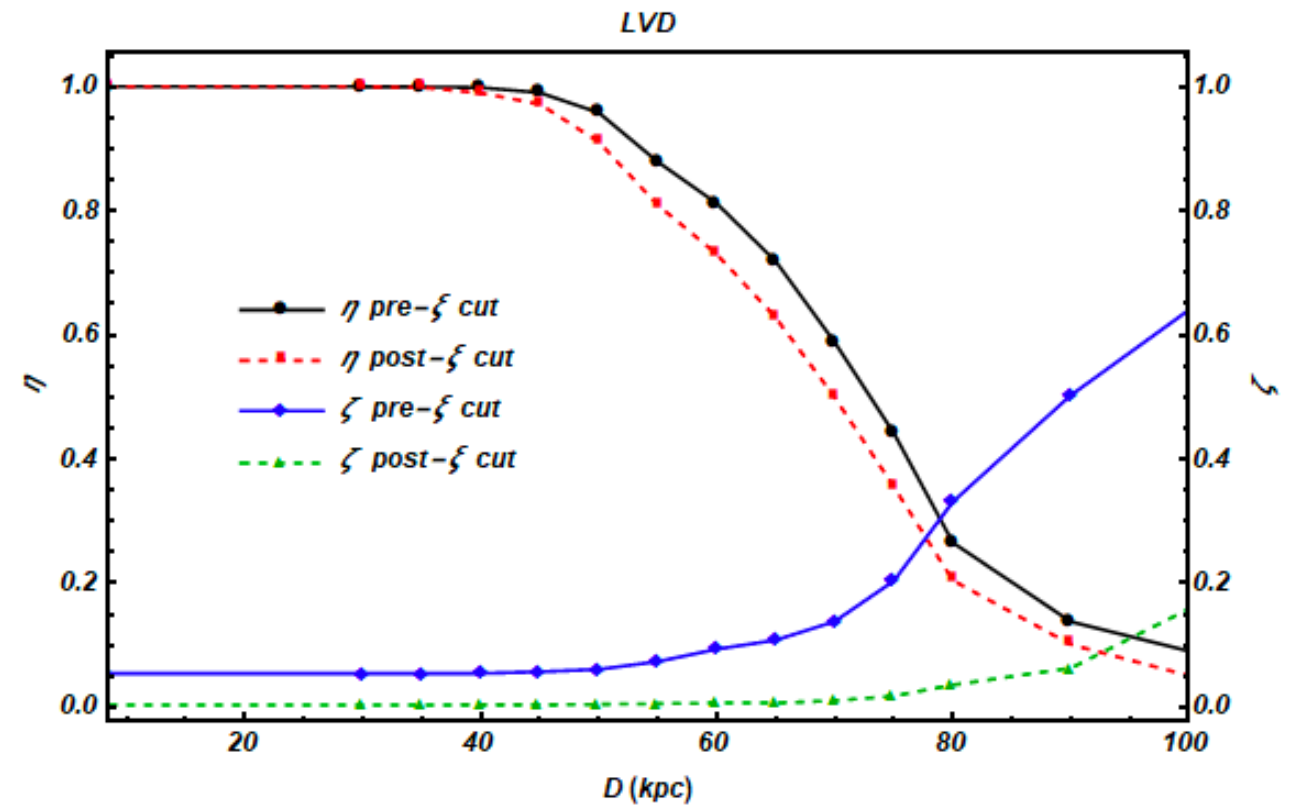


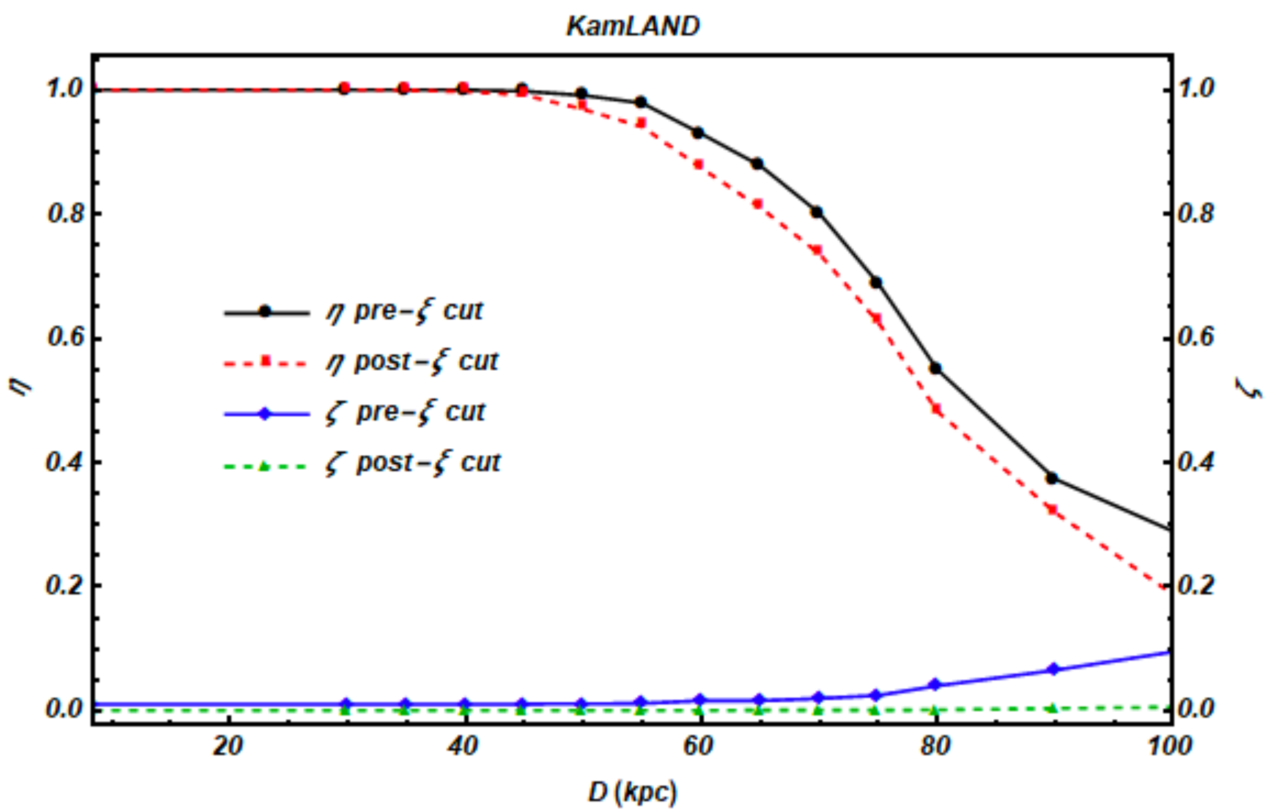
Closer source -> increased multiplicity -> better separation of signals and backgrounds

Casentini et. al (2017) arXiv:1801.09062

Improvements due to ξ parameter cut







No big loss in detection efficiencies η
Big improvement in misidentification probability ζ
at galactic distances (Large Magelanic Cloud)

Claudio Casentini PhD Thesis 2017

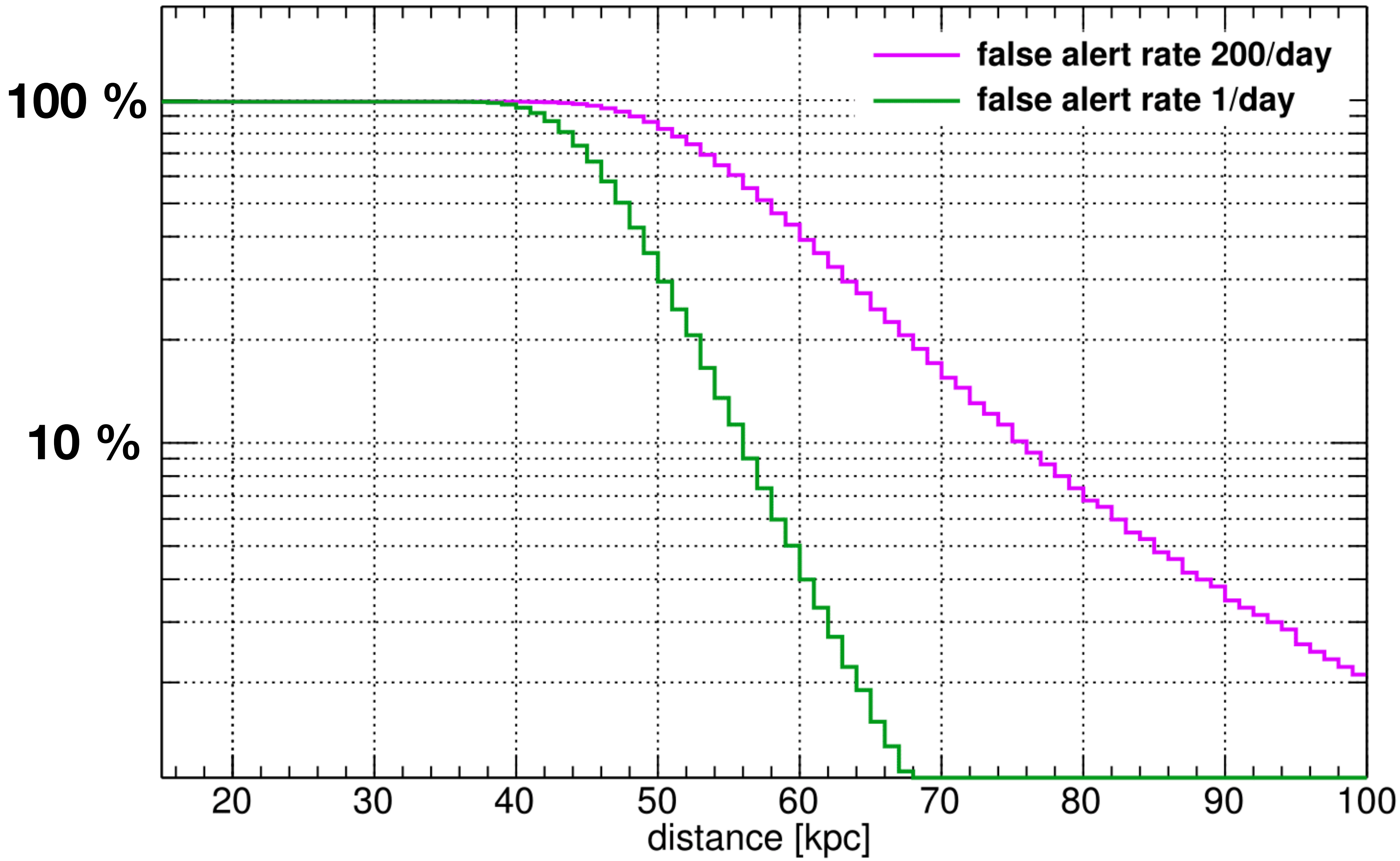
Improvements due to ξ parameter cut

Detector	M [kton]	E_{thr} [MeV]	ξ cut [Hz]	Gain	D [kpc]
Borexino	0.3	1	0.65	6.9	20
LVD	1	10	0.72	14.0	40
KamLAND	1	1	0.77	13.4	50

Claudio Casentini PhD Thesis 2017

IceCube Sensitivity

Trigger efficiency



IceCube in the network of 3

IceCube alone

Lutz Köpke, Alexander Fritz

Network Sensitivity

False Alarm Rate for detector networks

$$R_{joint} = \prod_{i=1}^{N} R_i (2t_{coin})^{N-1}$$

R_{joint} **- the joint False Alarm Rate , a number of accidental coincidence of detector signals in the network**

$$R_{joint} = R_{joint}^{GW} \times R_{joint}^{\nu} \times (2t_{coin})$$

Guidelines: $\frac{1\ ev}{1000\ years}$ $\frac{1\ ev}{month}$ $\frac{1\ ev}{day}$

$$R_{joint}^{GW} = R_{LG} \times R_{VG} \times 2t_{coin} \qquad R_{joint}^{\nu} = R_{BX} \times R_{IC} \times R_{LVD} \times R_{KL} \times (2t_{coin})^3$$

False Alarm Rate for neutrino detector networks

$$R_{joint} = \prod_{i=1}^{N} R_i (2t_{coin})^{N-1}$$

$$R_{joint} = R_{joint}^{GW} \times R_{joint}^{\nu} \times (2t_{coin})$$

R_{joint}^{ν}: $\frac{1\ ev}{day}$

$$R_{joint}^{\nu} = R_{BX} \times R_{IC} \times R_{LVD} \times R_{KL} \times (2t_{coin})^3$$

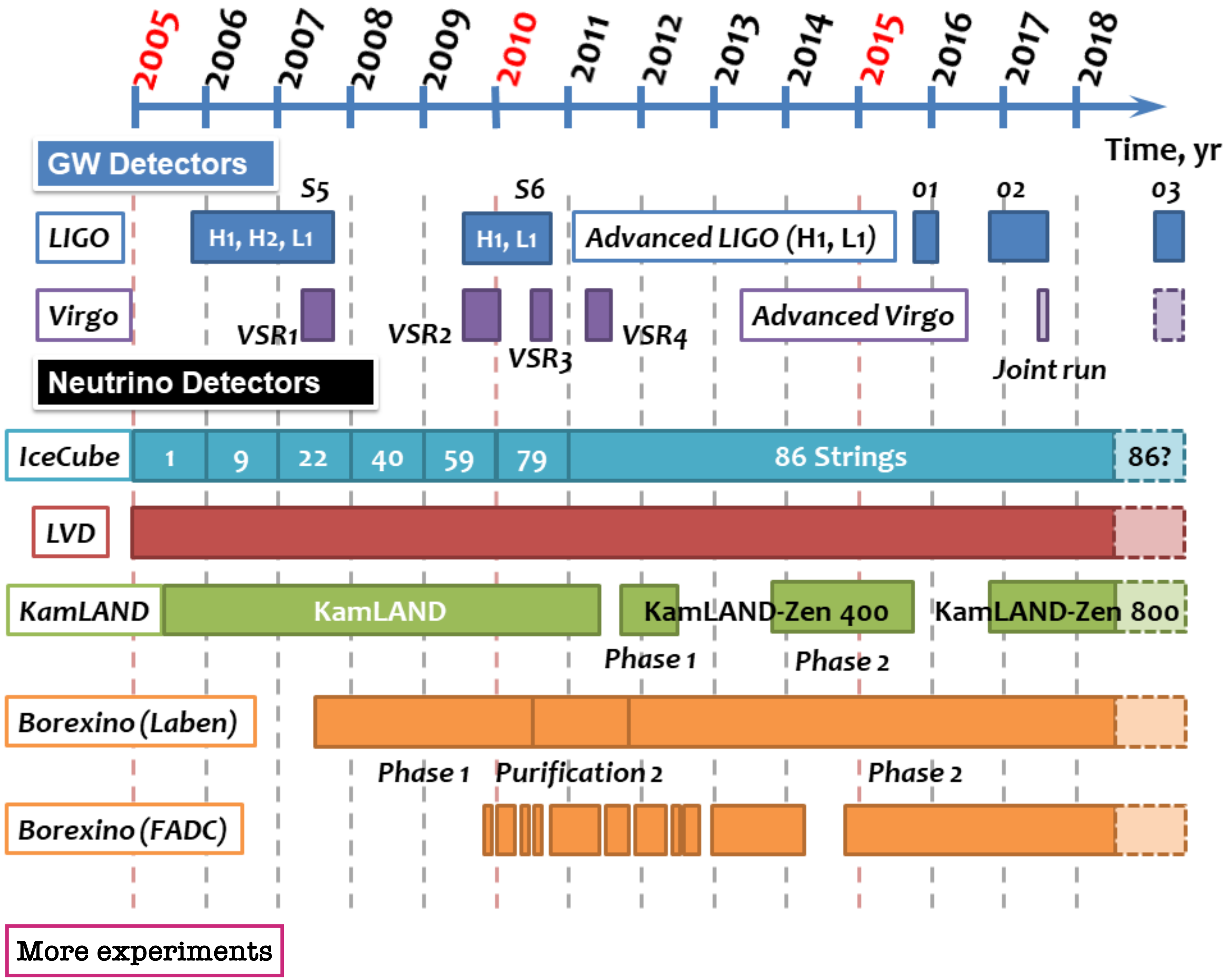
False Alarm Rate requirement on the individual detector in the neutrino network:

a) Network of 1 detector: R_i^{ν} = 1 ev/day
b) Network of 2 detectors: R_i^{ν} = 66 ev/day
c) Network of 3 detectors: R_i^{ν} = 265 ev/day
d) Network of 4 detectors: R_i^{ν} = 525 ev/day

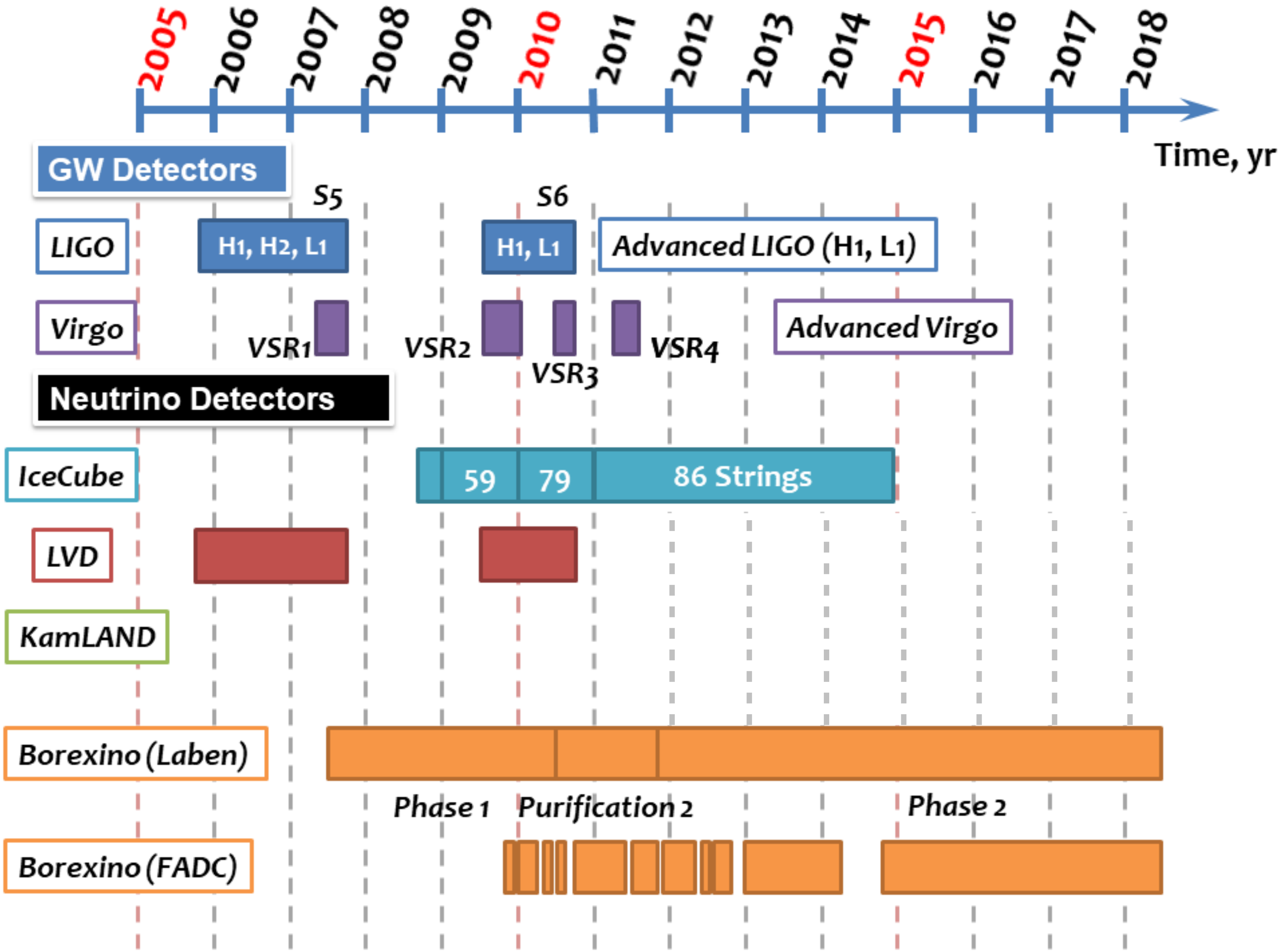
$$R_{joint}^{\nu} \approx \frac{1\ ev}{day}$$

More detectors -> lower detection threshold

Data overlap: What data may we have in general?



Shared Data: What data have we analysed?



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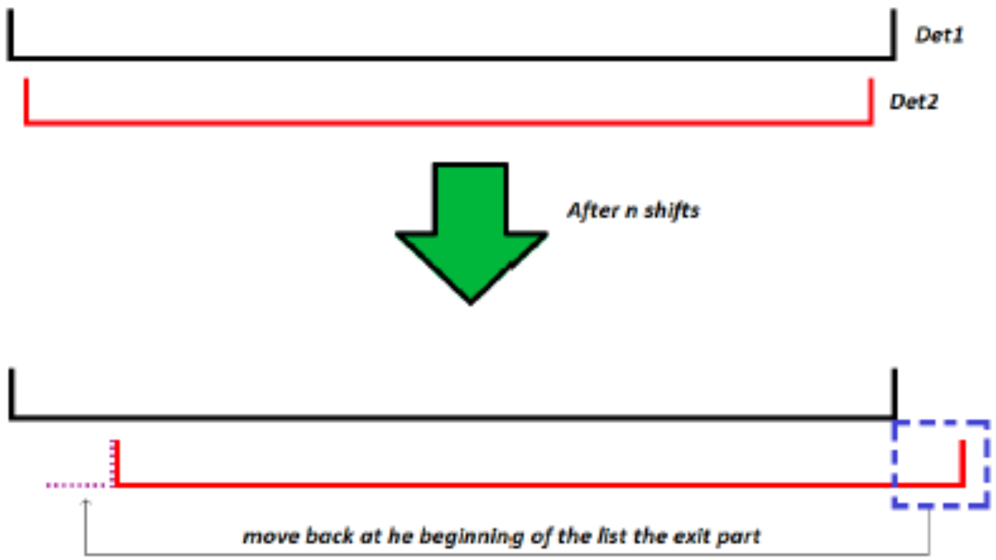
Background analysis

~ 4000 Time shifts allow to simulate 100-1000 years of background



Expected number of coincidences:

$$\lambda_{coin} = N_{exp}\left(\frac{\tau_{coin}^{N_{exp}-1}}{T_{common}^{N_{exp}}}\right)\prod_{i=1}^{N_{exp}} n_i$$

N_{shifts}	$lifetime_{background}$	Expected N_{coin}	Found N_{coin}
3999	317yr	6 ± 2	4
3999	88yr	8 ± 3	9
3999	491yr	9 ± 3	7
3999	40yr	5 ± 2	7

TABLE 6.3: Background results of LVD-Borexino network.

The results obtained agree with the expectation->the goodness of the procedure

Coincidence search in networks

Expected number of coincidences:

$$\lambda_{coin} = N_{exp}\left(\frac{\tau_{coin}^{N_{exp}-1}}{T_{common}^{N_{exp}}}\right)\prod_{i=1}^{N_{exp}} n_i$$

Network composition	$FAR_{joint}^{\nu-net}$	BKG coinc. exp.	BKG coinc. found	BKG livetime
LVD+IceCube	1/24years	374 ± 19	390	5331 years
LVD+Borexino	1/24years	28 ± 6	27	656 years
Borexino+IceCube	1/24years	4116± 64	4147	7133 years

Coincidence search (GW +NU)

GW network + LVD:

Background study coincidences as expected

No real coincidences as expected

GW network + Borexino:

Background study coincidences as expected

No real coincidences as expected

GW network + IceCube:

Background study coincidences as expected

One real coincidence (due to a noisy behaviour in Virgo detector)

To further improve the sensitivity:

Lower the threshold
Increase the common lifetime

CONCLUSIONS AND OUTLOOK

- Proof of Principle and methodology of the offline analysis - Done ✅
- Successful exchange of data and its analysis - Done ✅
- Redo the analysis with lower thresholds and more common life time in the new data format - Coming up
- Low latency analysis - Coming up
- Get ready for the new scientific run of GW detectors

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OPEN COMMUNITY:
THE MORE THE MERRIER!

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