Concept of KamLAND2 DAQ system

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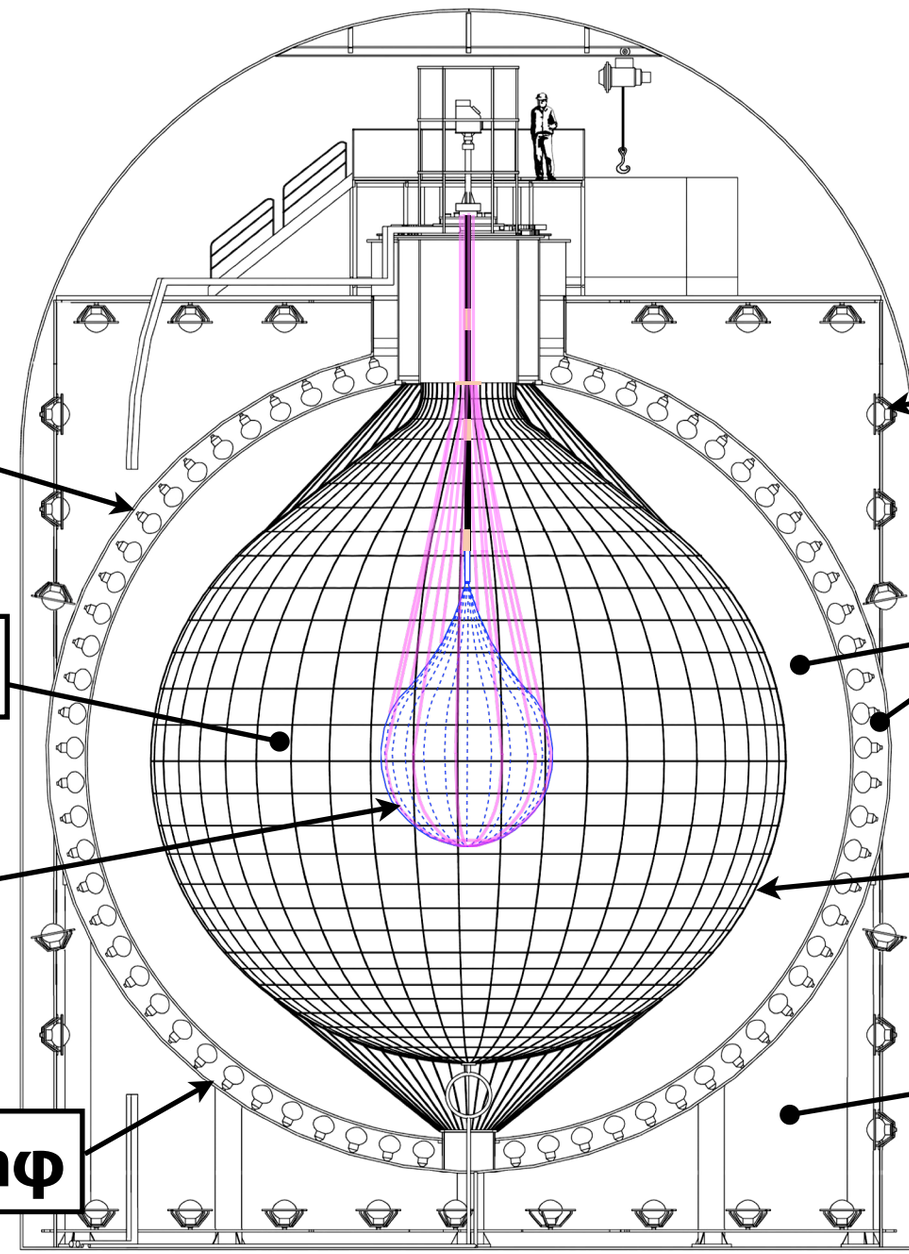
KamLAND

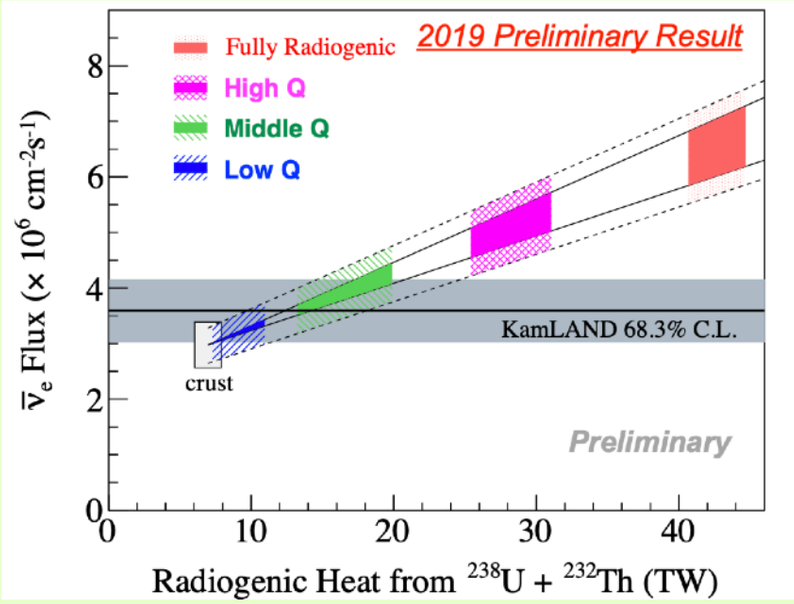
Kamioka **L**iquid scintillator **A**nti-**N**eutrino **D**etector

・KamLAND Zen 800 phase is running since Jan. 2019.

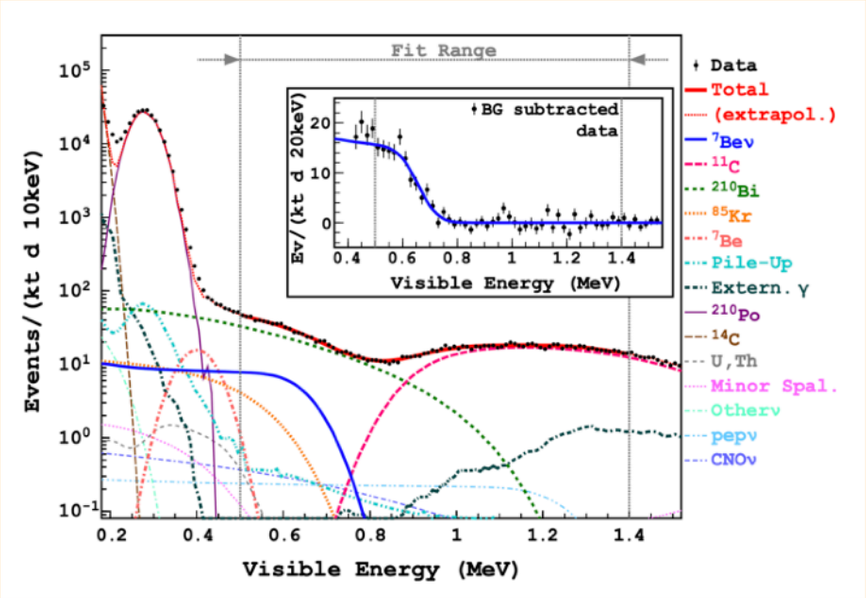


Neutrino physics @ KamLAND

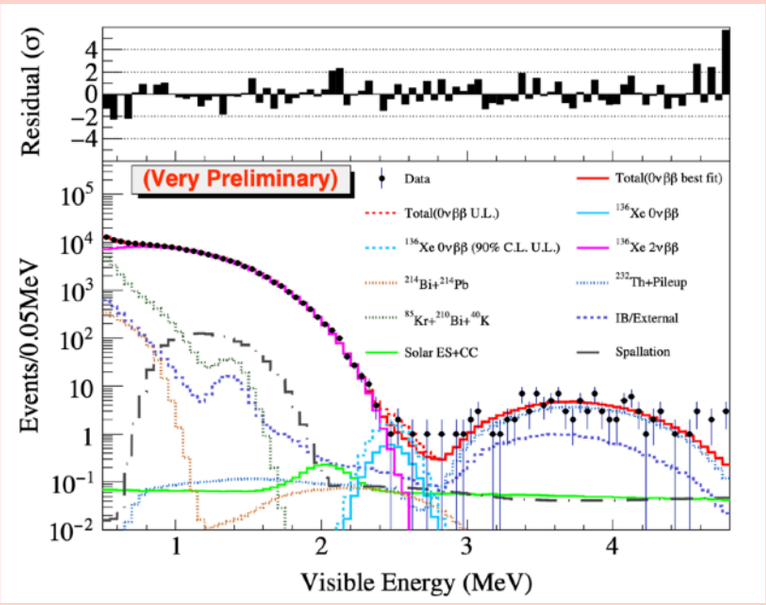
Geo neutrino
(Neutrino Geoscience 2019, H. Watanabe)



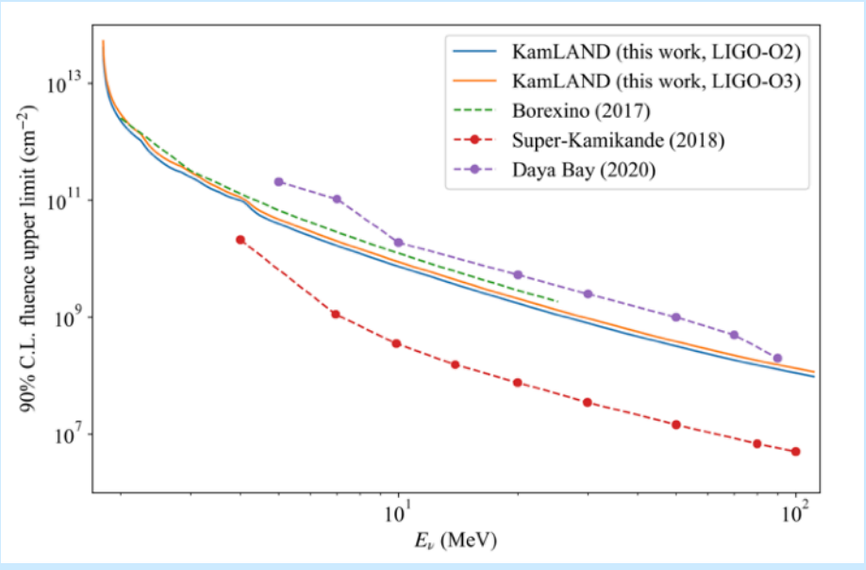
^{7}Be solar neutrino
(PR C **92**, 055808 (2015))



Neutrino-less double β decay
(TAUP2019, Y. Gando)



Gravitational Wave
(Astro. Phys. Journal, **909**;116 (2021))



Neutrino physics @ KamLAND

SNEWS:
SuperNova Early Warning System

International collaboration of experiments

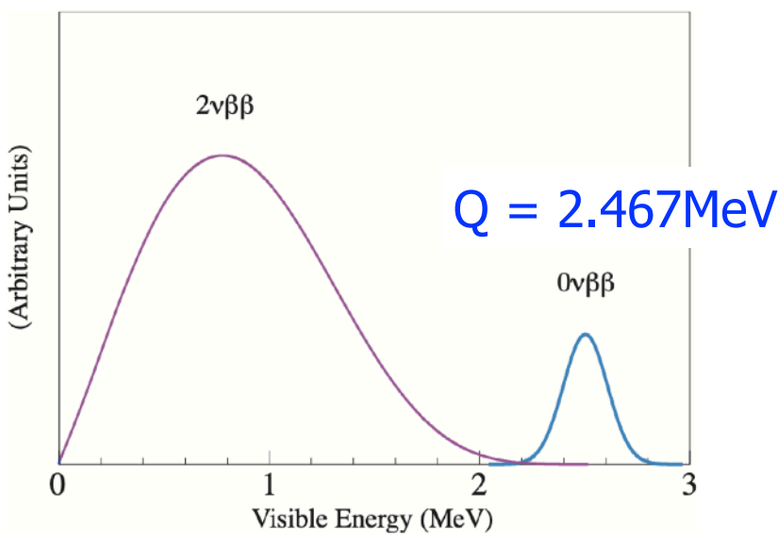
- Super-K (Japan)
- LVD (Italy)
- Ice Cube (South Pole)
- KamLAND (Japan)
- Borexino (Italy)
- Daya Bay (China)
- HALO (Canada)

KamLAND → KamLAND2

Major backgrounds for 0ν2β decay

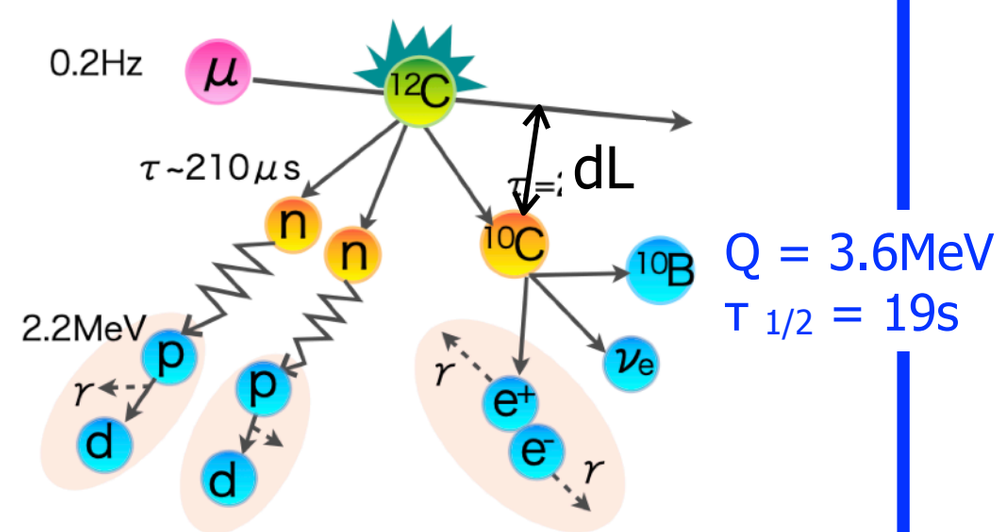
- 2ν2β decay
- Cosmic μ spallation backgrounds

2ν2β decay



To improve energy resolution is the only one solution!

Cosmic μ spallation backgrounds

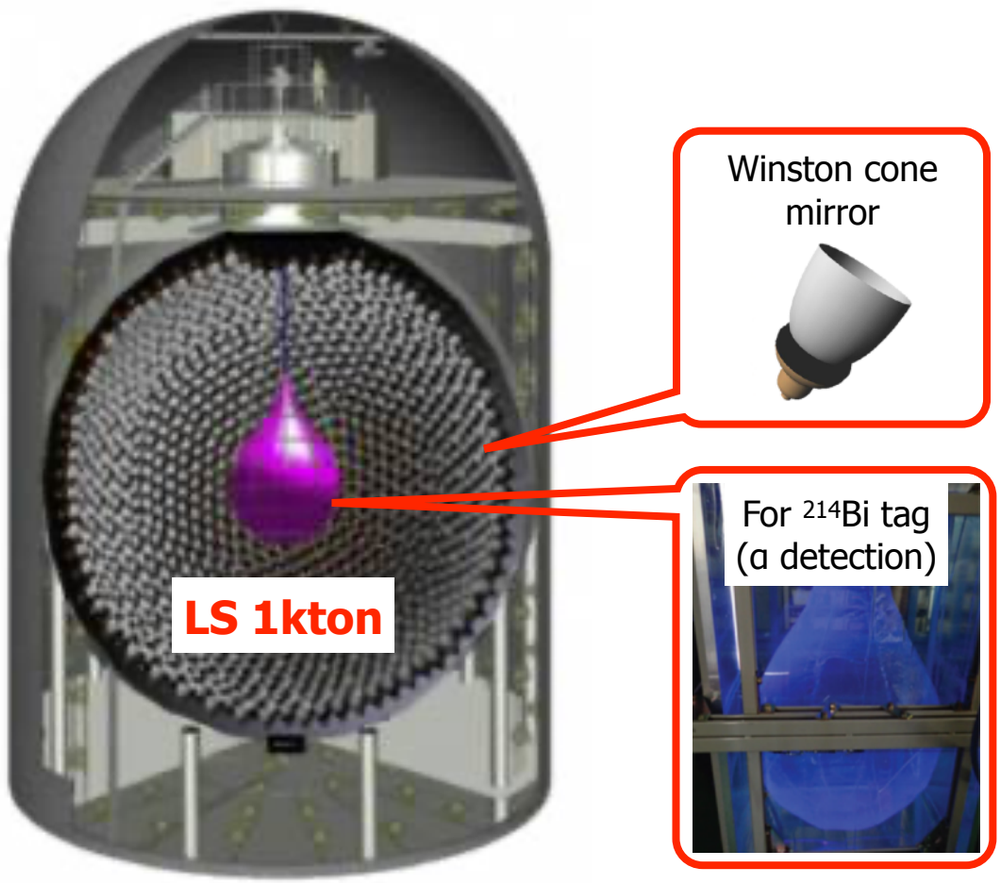


- Likelihood (dE/dX, dL and dT)
- 3-fold tagging (μ, ^{10}C and neutron).

KamLAND → KamLAND2

Major backgrounds for 0ν2β decay

- 2ν2β decay
- Cosmic μ spallation backgrounds



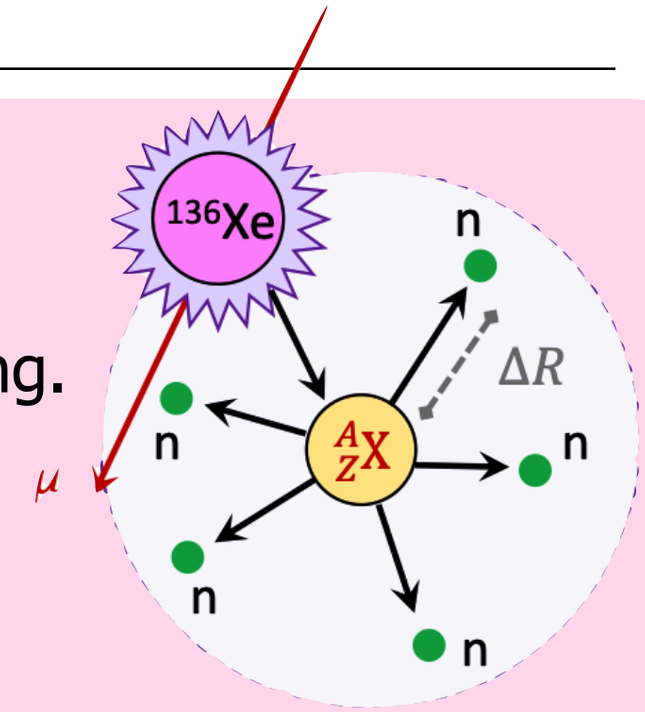
	Gain of light yield
High Q. E. PMT	> 1.9
Light collecting mirror	> 1.8
High light yield LS	> 1.4
Scintillation balloon	-
Total	**> 5**

- **Increase light yield & improve energy resolution!!**
- **Target $\langle m_{\beta\beta} \rangle$ sensitivity ~ 20 meV / 5 years**

Challenges for electronics

- **Cosmic μ spallation backgrounds**
  - Spallation on ^{136}Xe induce serious backgrounds.
  - Number of surrounding neutrons is a key for tagging.

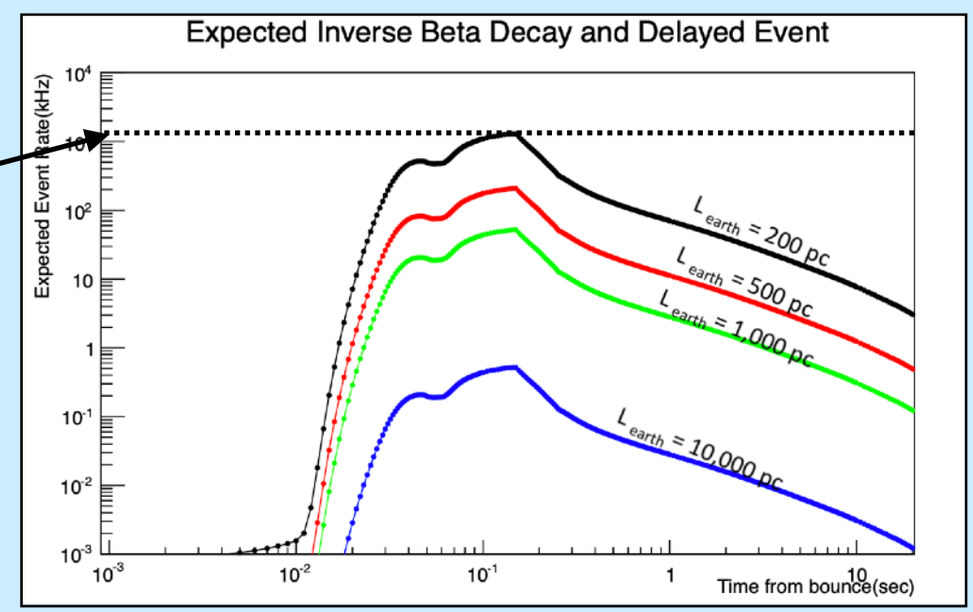
"High neutron detection efficiency"



- **Supernova neutrinos**
  - Time profile of the number of neutrinos is a probe of supernova explosion mechanism.

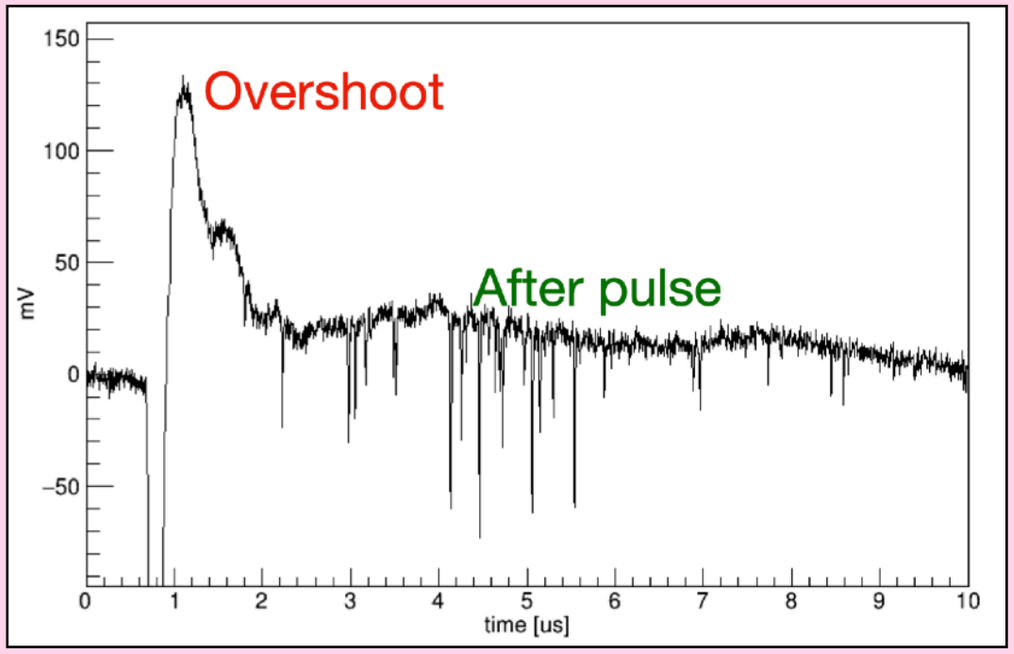
"High event rate tolerance"

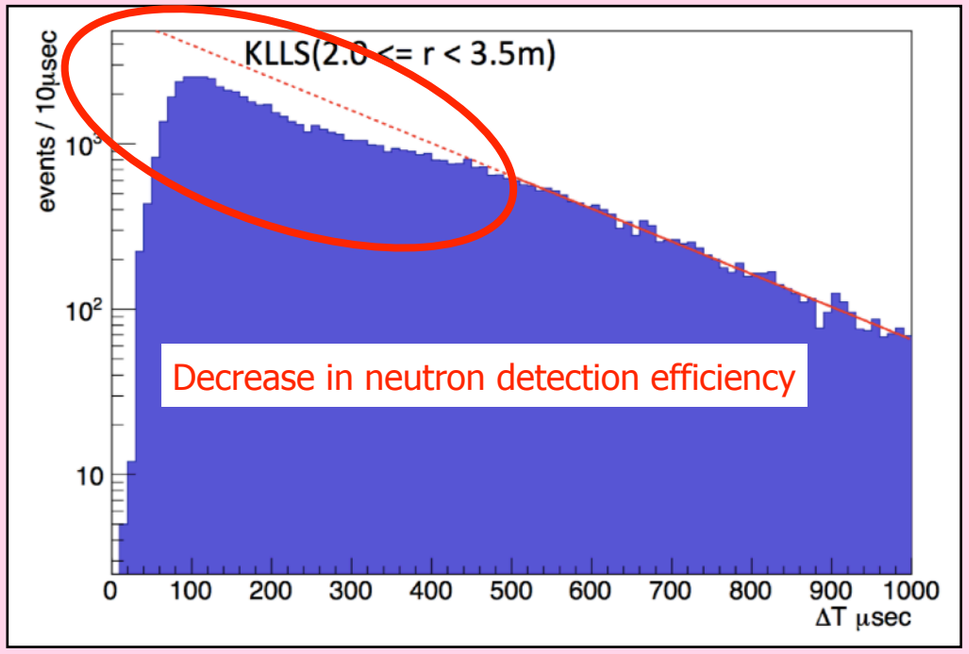
Betelgeuse (200pc)
Maximum instantaneous event rate ~ 1MHz



Current limitation

- **Cosmic μ spallation backgrounds**
  - Trigger decision become difficult under overshoot.



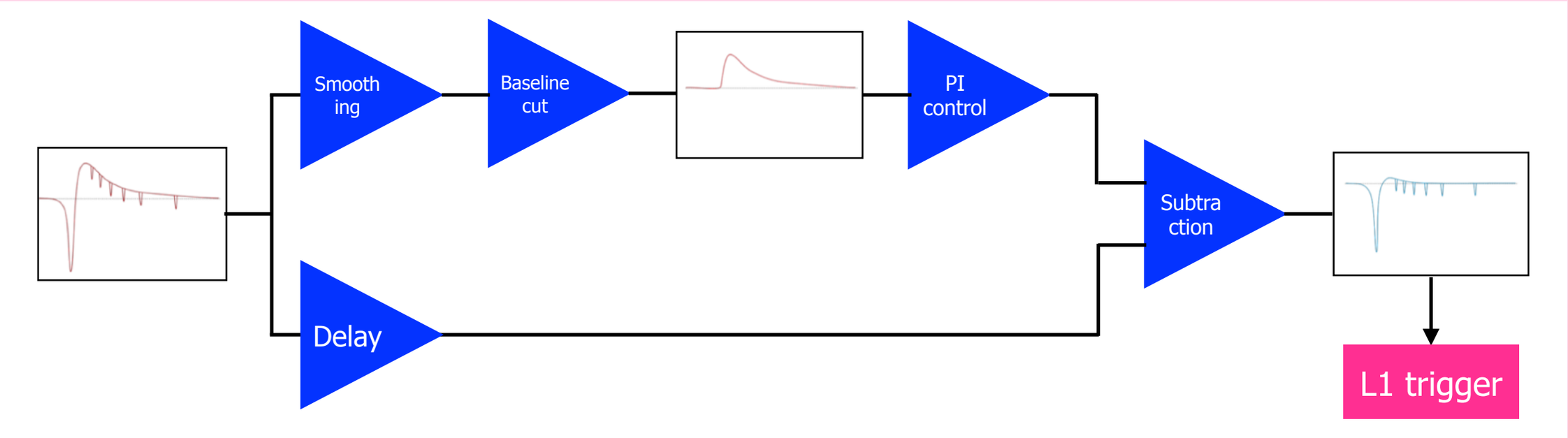


- **Supernova neutrinos**
  - Buffer will be full at around 300μs with event rate of 1MHz.

How to overcome

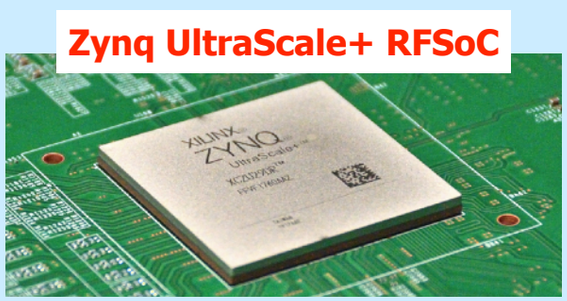
- **Cosmic μ spallation backgrounds**
  - Trigger decision become difficult under overshoot.

"Digital BaseLine Restorer (BLR)"



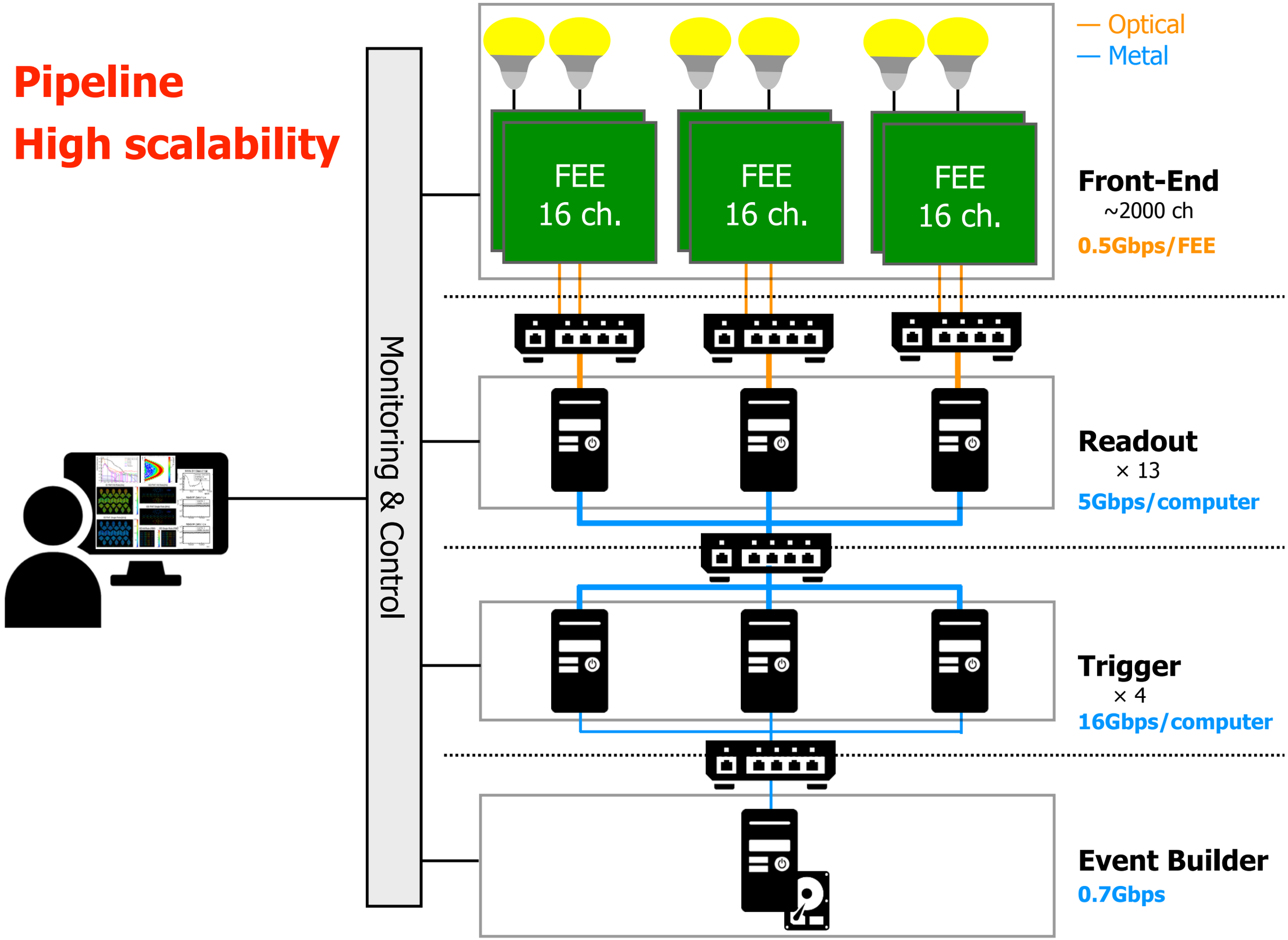
- **Supernova neutrinos**
  - Buffer will be full at around 300μs with event rate of 1MHz.

"RFSoC" transfer speed 76.8 Gbps
"DDR4" on-board buffer 4 GB



DAQ overview

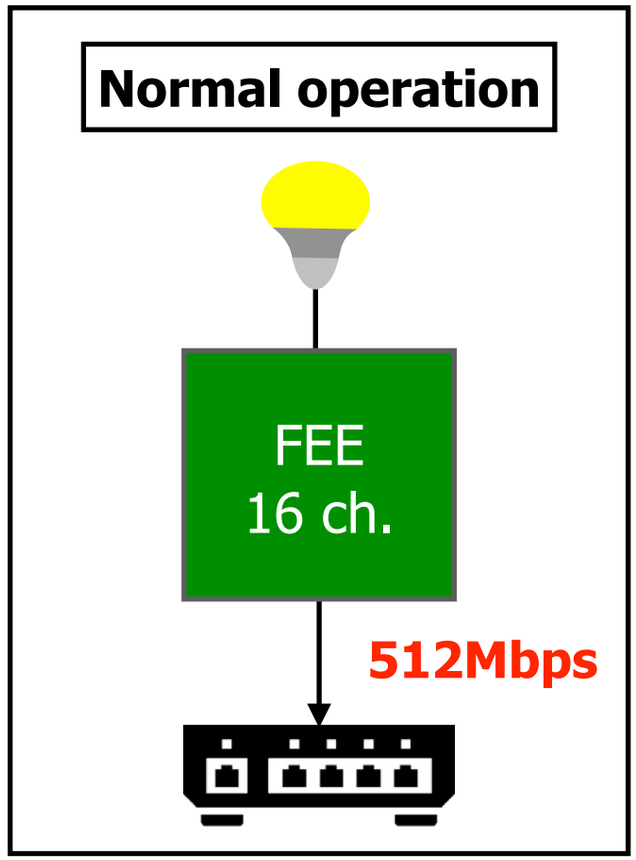
- **Pipeline**
- **High scalability**



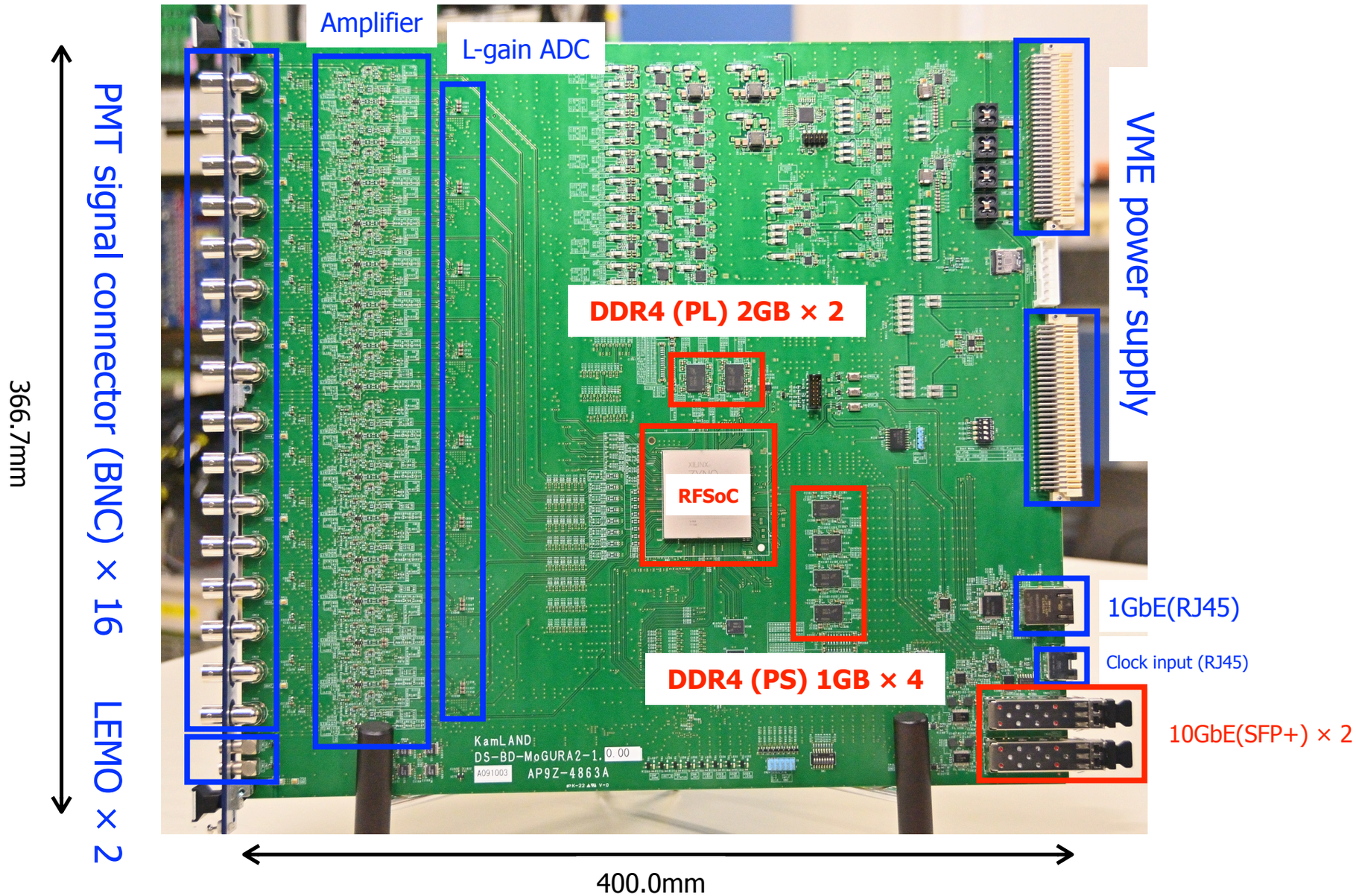
Event rate & Data rate

	Event rate	Data rate
Dark noise	20kHz	32 Mbps/PMT
Cosmic μ	0.3Hz	48 kbps/PMT
Supernovae	1MHz (~1s)	1.6 Gbps/PMT

- **Dark noise**
  1GSPS × 16bit × 100ns × 20kHz = 32 Mbps
- **Cosmic μ**
  1GSPS × 16bit × 10μs × 0.3Hz = 48 kbps
- **Nearby Super novae**
  1GSPS × 16bit × 100ns × 1MHz = 1.6 Gbps



Front-End Electronics



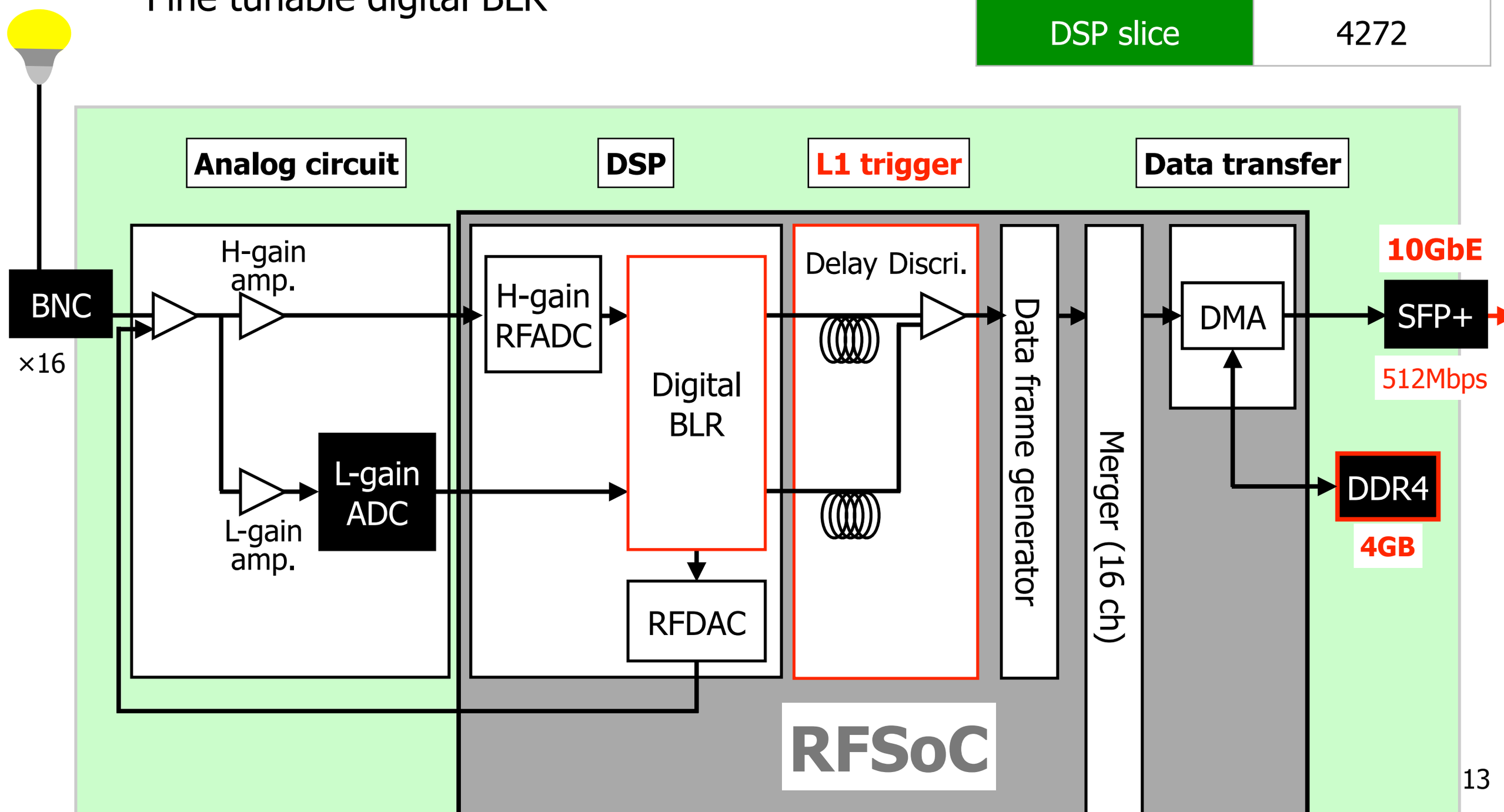
	KamLAND	KamLAND2
On-board buffer	64 MB	4 GB
Transfer speed	12.8 Gbps	76.8 Gbps

Front-End Electronics

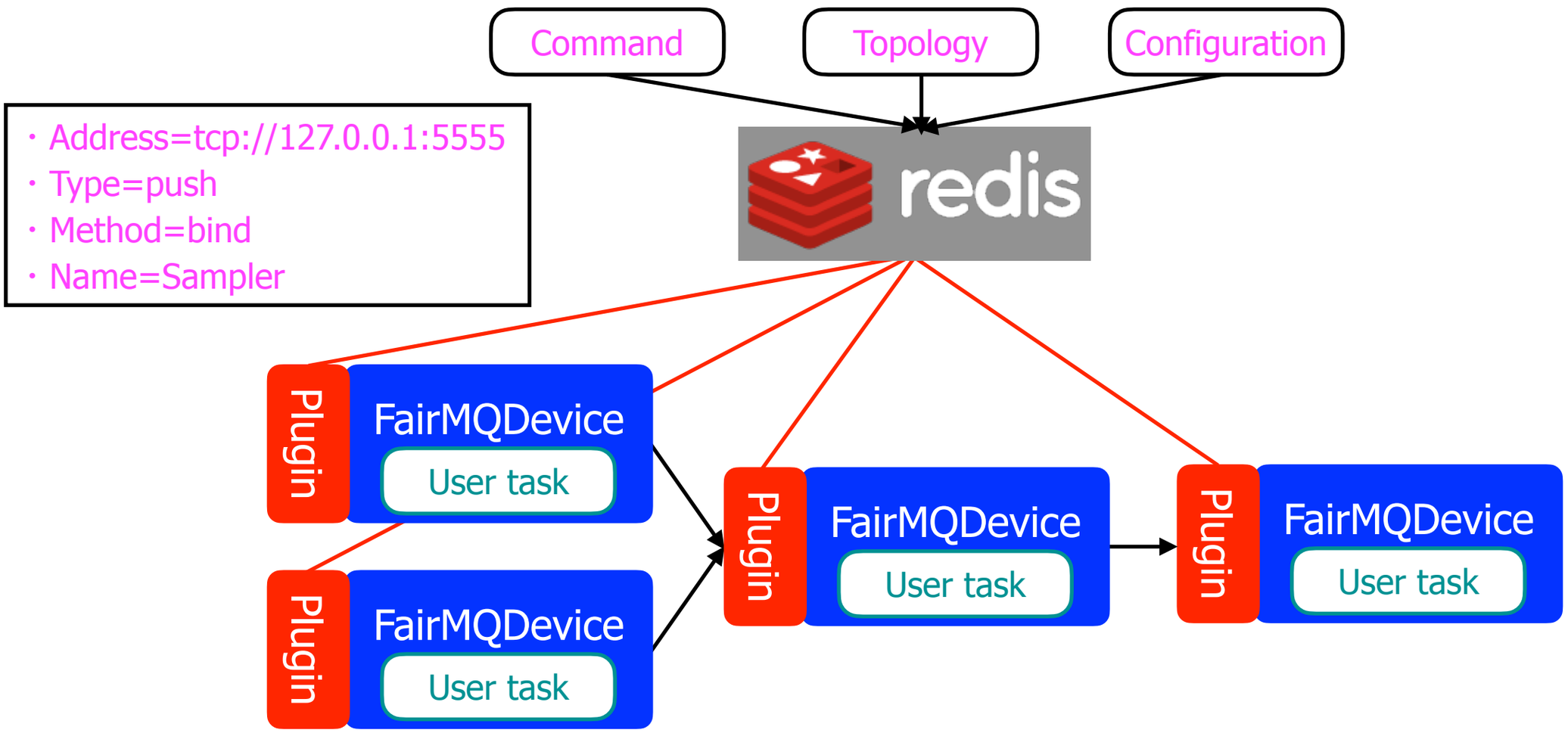
RFSoC (XCZU29DR-1FFVF1760E)

- High speed ADC and DAC
- Large number of Digital Signal Processors (DSP)
- Fine tunable digital BLR

ADC	16 ch
Resolution	12 bit
Max sample speed	2.058 GSPS
Logic cell	930300
DSP slice	4272



DAQ control



Plugin

- Development based on J-PARC E16 experiment
- Redis API
- Key-Value store

https://github.com/redis/redis

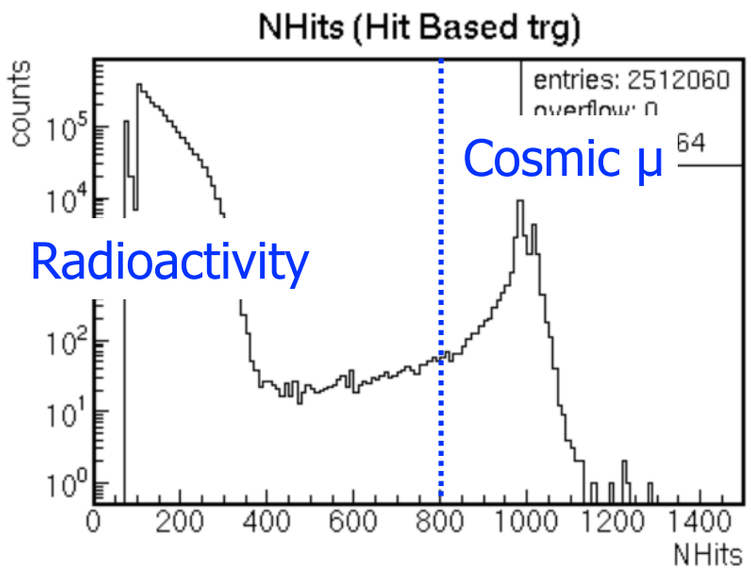
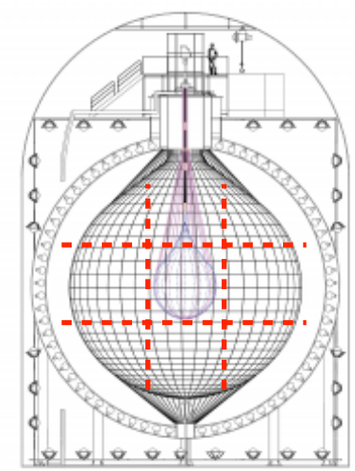
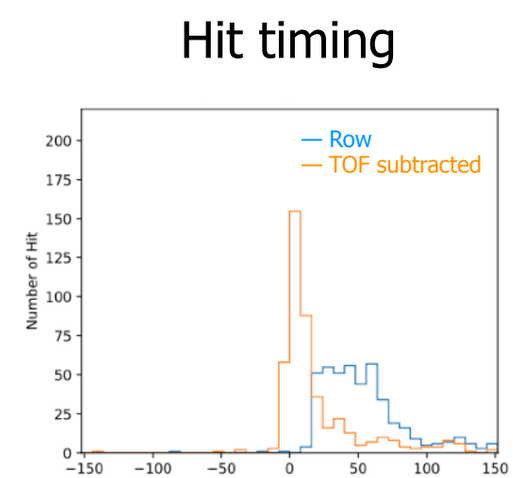
FairMQ

- Asynchronous message processing
- Various transports (TCP/IP, in-process, inter-process)
- Independent process (FairMQDevice)
- StateMachine

https://github.com/FairRootGroup/FairMQ

Trigger

Conceptual study is ongoing based on MC

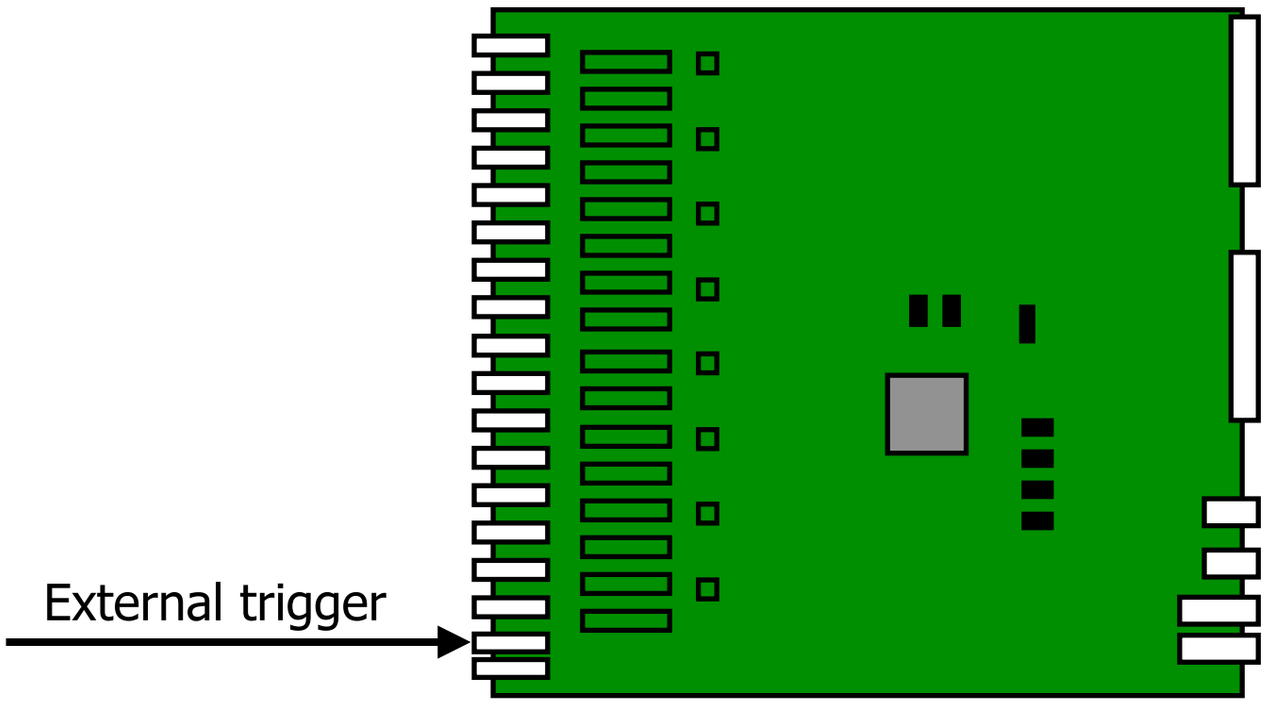
KamLAND	KamLAND2
	 
L1 : 1 p.e. detection (hardware)	L1 : 1 p.e. detection (hardware)
L2 : Hit based hardware trigger	L2 : Time-charge based software trigger ・TOF subtraction ・Vertex depend threshold
Special trigger to detect neutrons after cosmic μ.	Waveform from all of hit channels to be recorded.

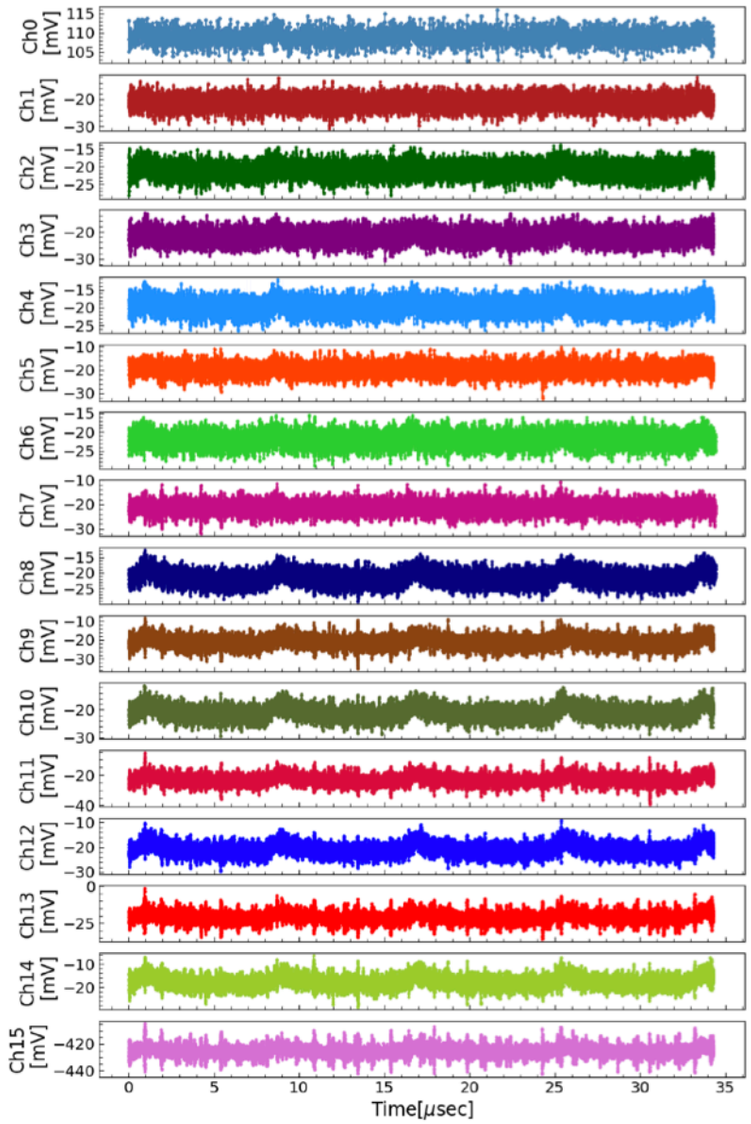
Development status

FEE

☑ Recording waveform with a time window of 34 μs.

Long enough for cosmic μ events!

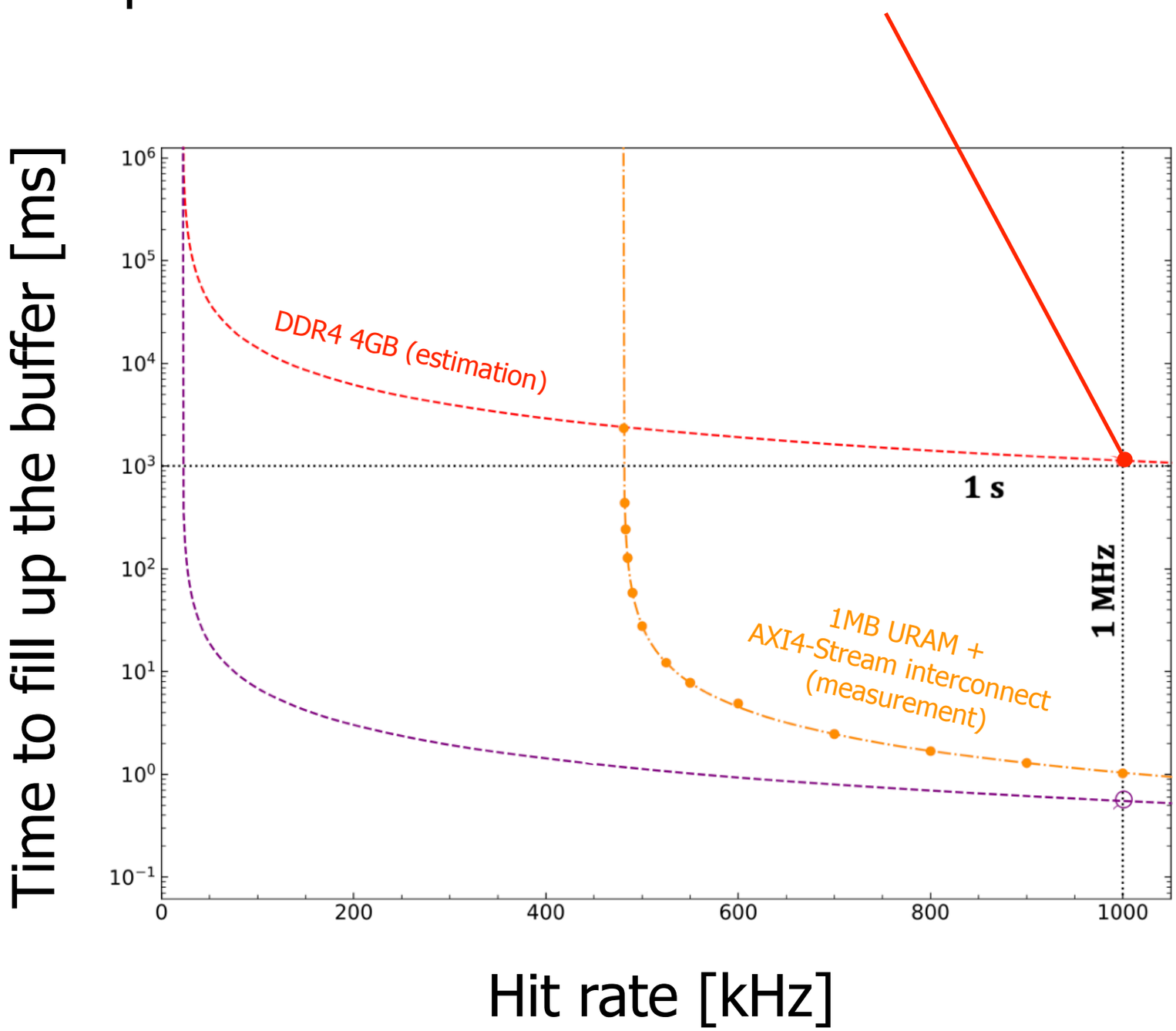




Development status

FEE

- ☑ Recording waveform with a time window of 34 μs.
- ☑ Data acquisition of 1MHz events for 1s.



Summary

- KamLAND2 is planed to improve the energy resolution.

- Challenges for electronics are,
  - to achieve higher rejection efficiency of spallation backgrounds
  - to acquire data of supernova events.

- High speed processing is one of the important subjects.

  Key for implementation
  - RFSoC, DDR4 and 10GbE on FEE
  - Network design and data processing with FairMQ
  - Time-charge based software trigger

Next step

- Operation of KamLAND2 prototype detector around end of this year.