Data-Acquisition System Upgrade at the KOTO Experiment

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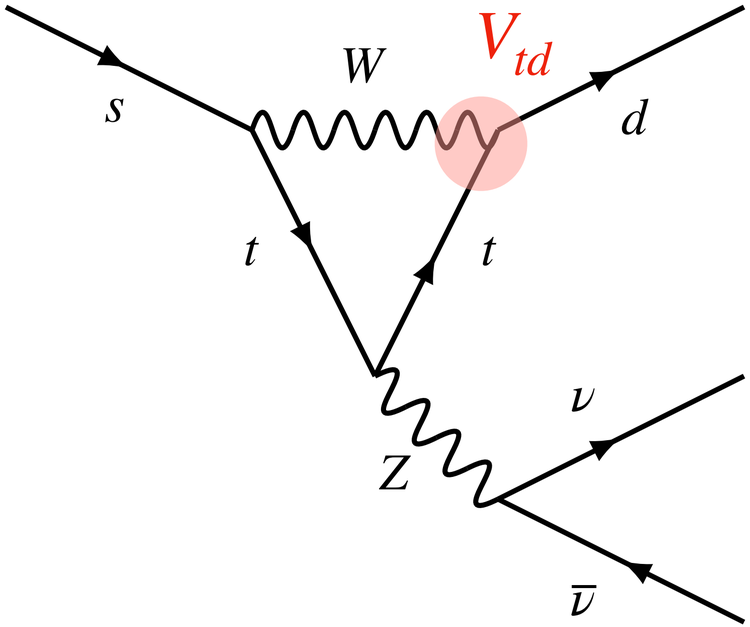
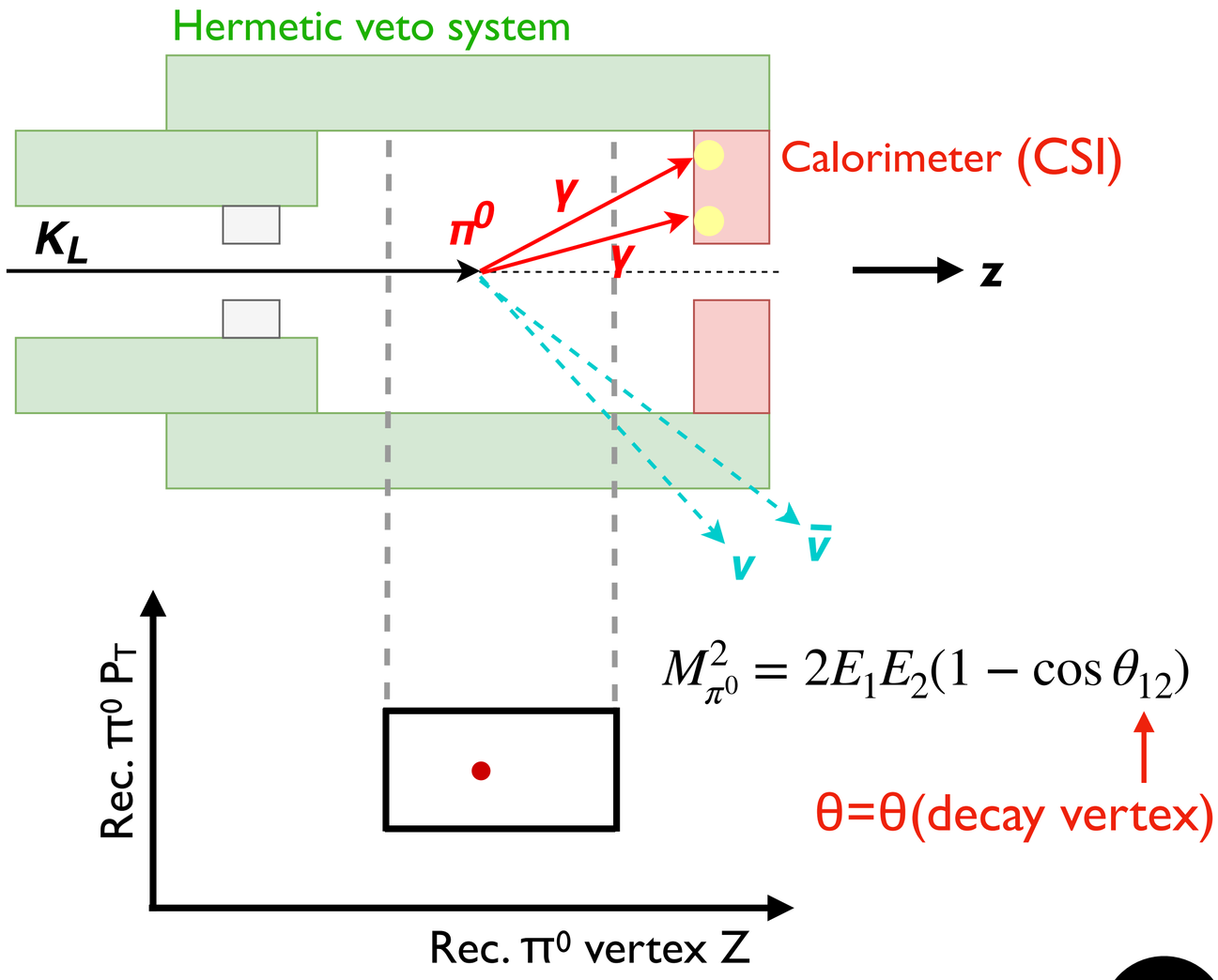
KOTO: Search for New Physics via $K_L^0 \to \pi^0 \nu \bar{\nu}$

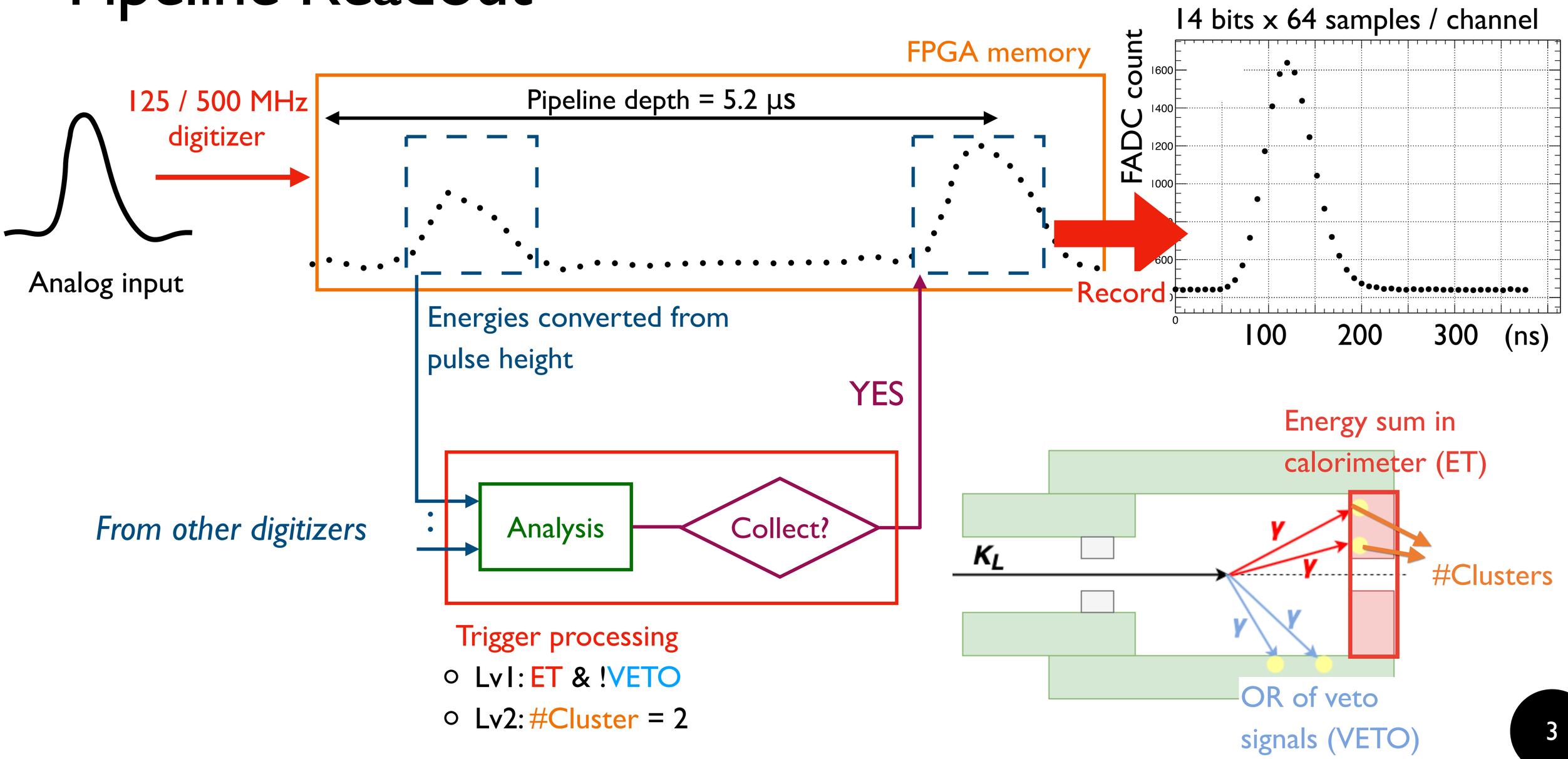
Clean & **Rare** $\Longrightarrow$ Sensitive to New Physics:

$$BR(K_L^0 \to \pi^0 \nu \bar{\nu}) = (3.0 \pm 0.3) \times 10^{-11}$$



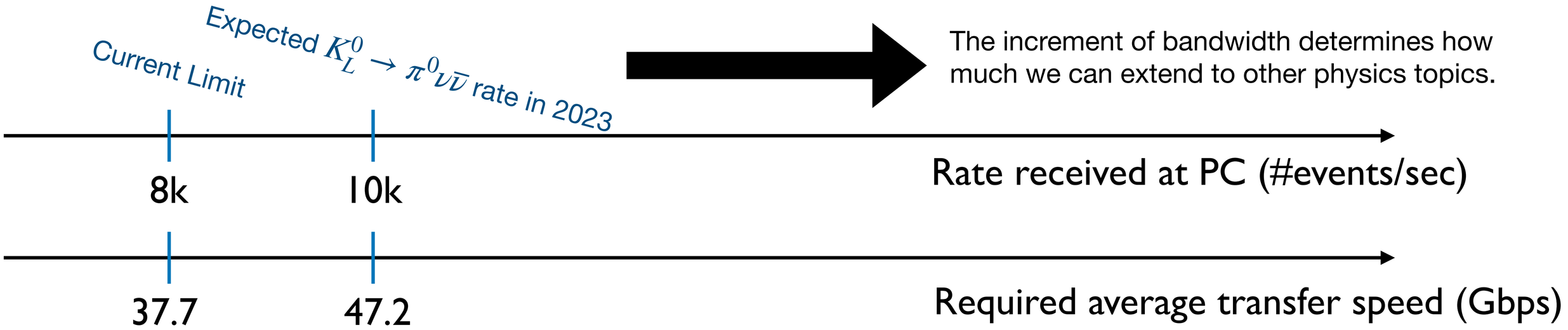


Pipeline Readout



Target of the KOTO DAQ Upgrade

- KOTO beam power will be increased from 64 kW to 100 kW.
- Introduce more triggers for other physics topics (dark particle search, more rare kaon decays, etc).
  - Perform Lv3 trigger at PC.



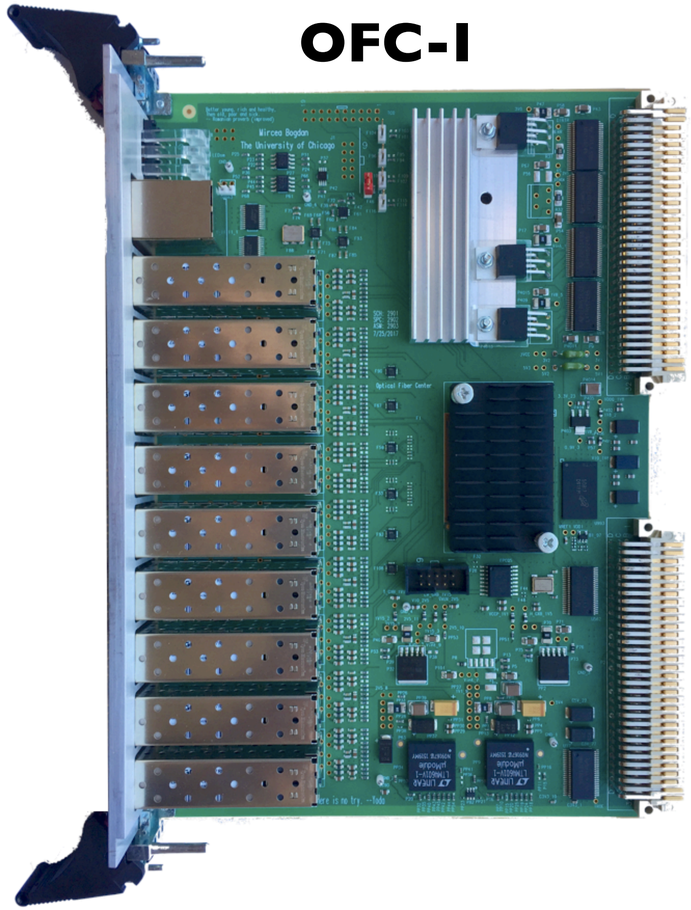
* *One event has size of 4.7 Mb.*

Modules with Large Throughput for Data Transfer

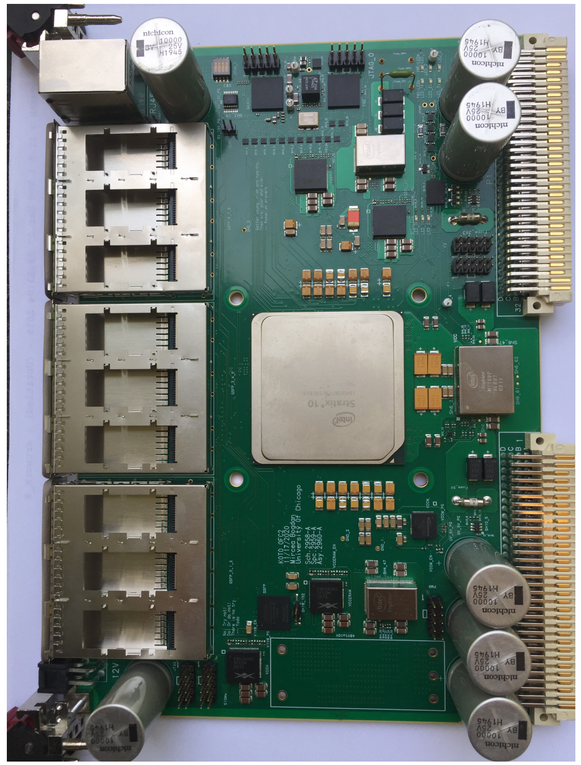
Optical Fiber Center (OFC) is designed to transfer data between ADC and PC.

	OFC-I	OFC-II
Upstream	16 x ADC data	18 x OFC-I data
Downstream	OFC-II	PC (ethernet protocol)
Input/Ouput	18 x 4 Gbps (18 SFP)	36 x 10 Gbps (9 QSFP)
FPGA type	Arria V	Stratix X
Memory buffer	~50 events	~20 events

OFC-I



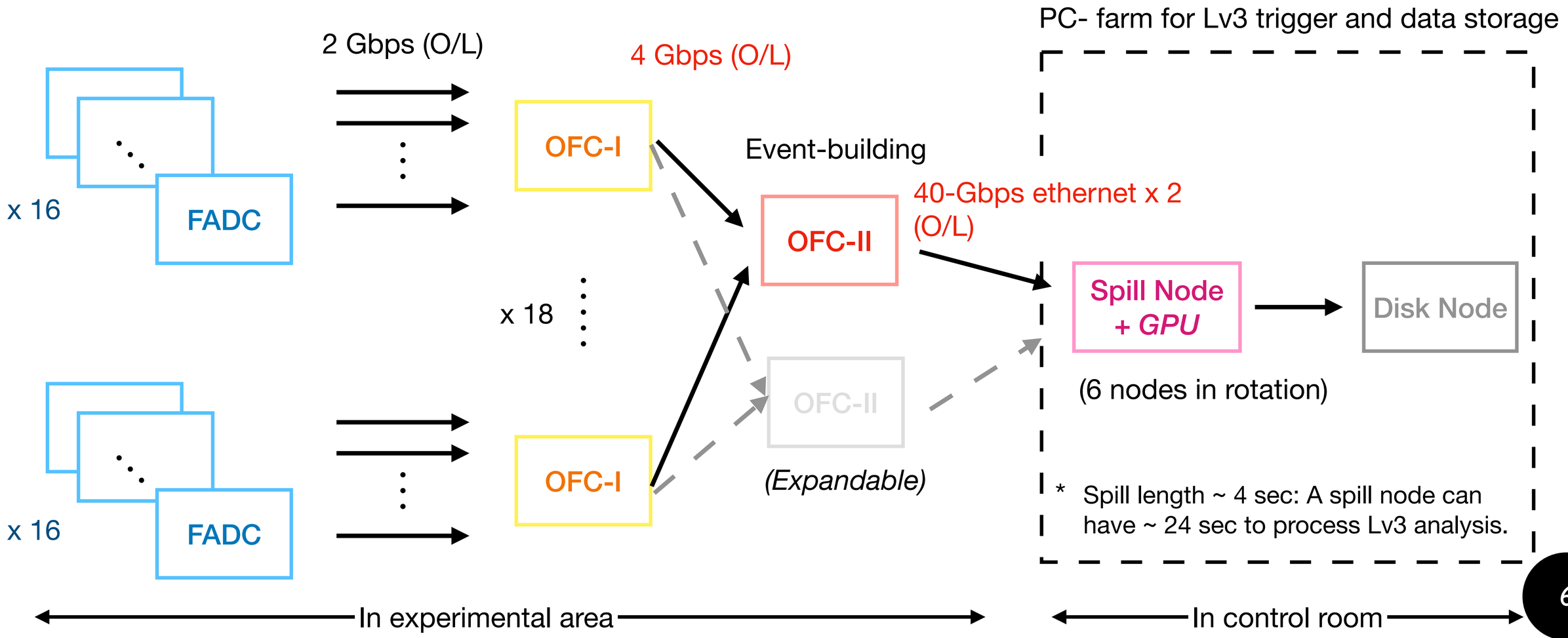
OFC-II



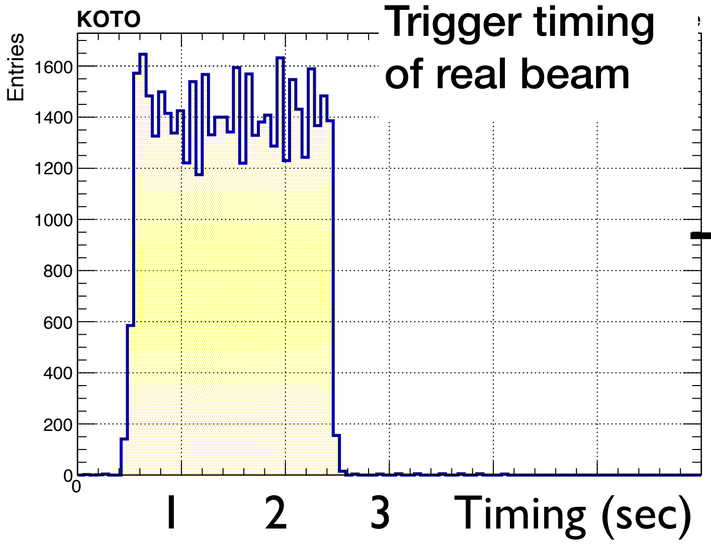
* *Memory can be read / written simultaneously.*

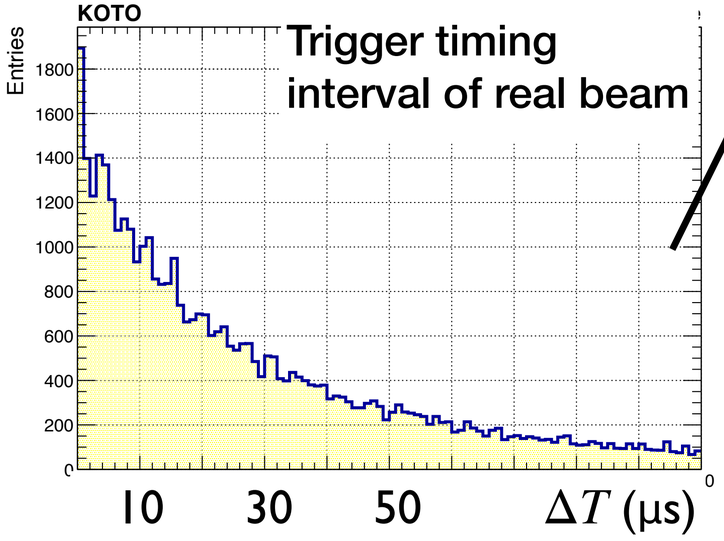
Pyramid Structure for Data Transfer

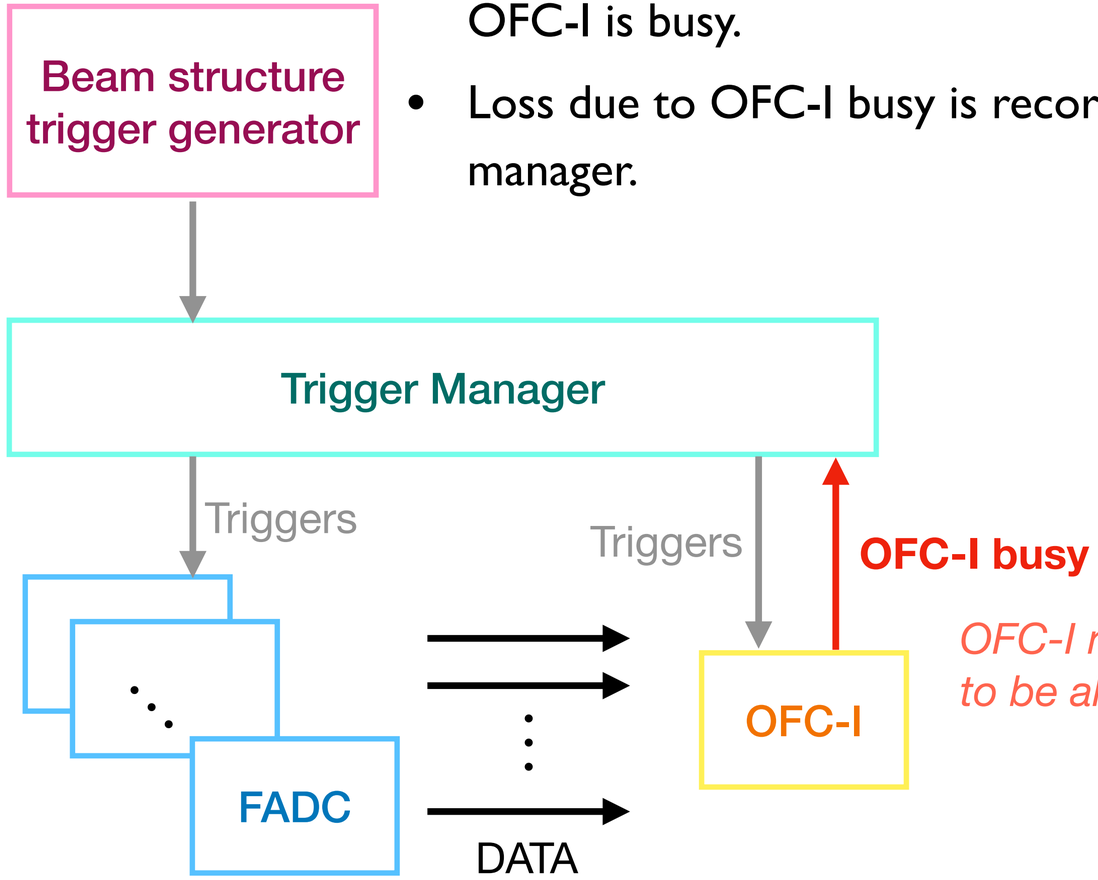
- Throughput between ADC and PC and can be horizontally expanded if needed.
- Bottleneck is expected to happen at OFC-I.



Setup for the Event Rate Study



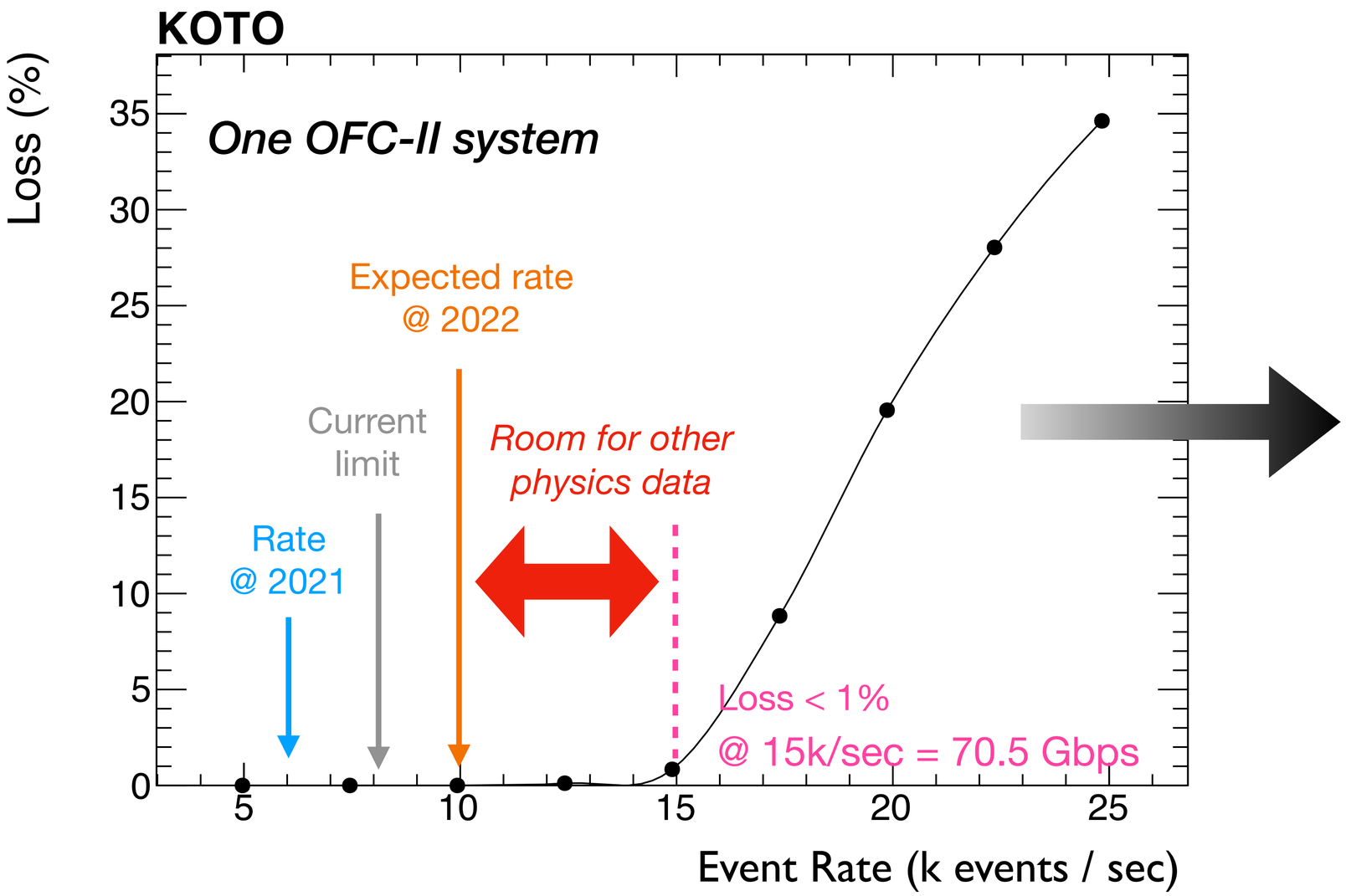




- Trigger manager refrains from issuing triggers if OFC-I is busy.
- Loss due to OFC-I busy is recorded by trigger manager.

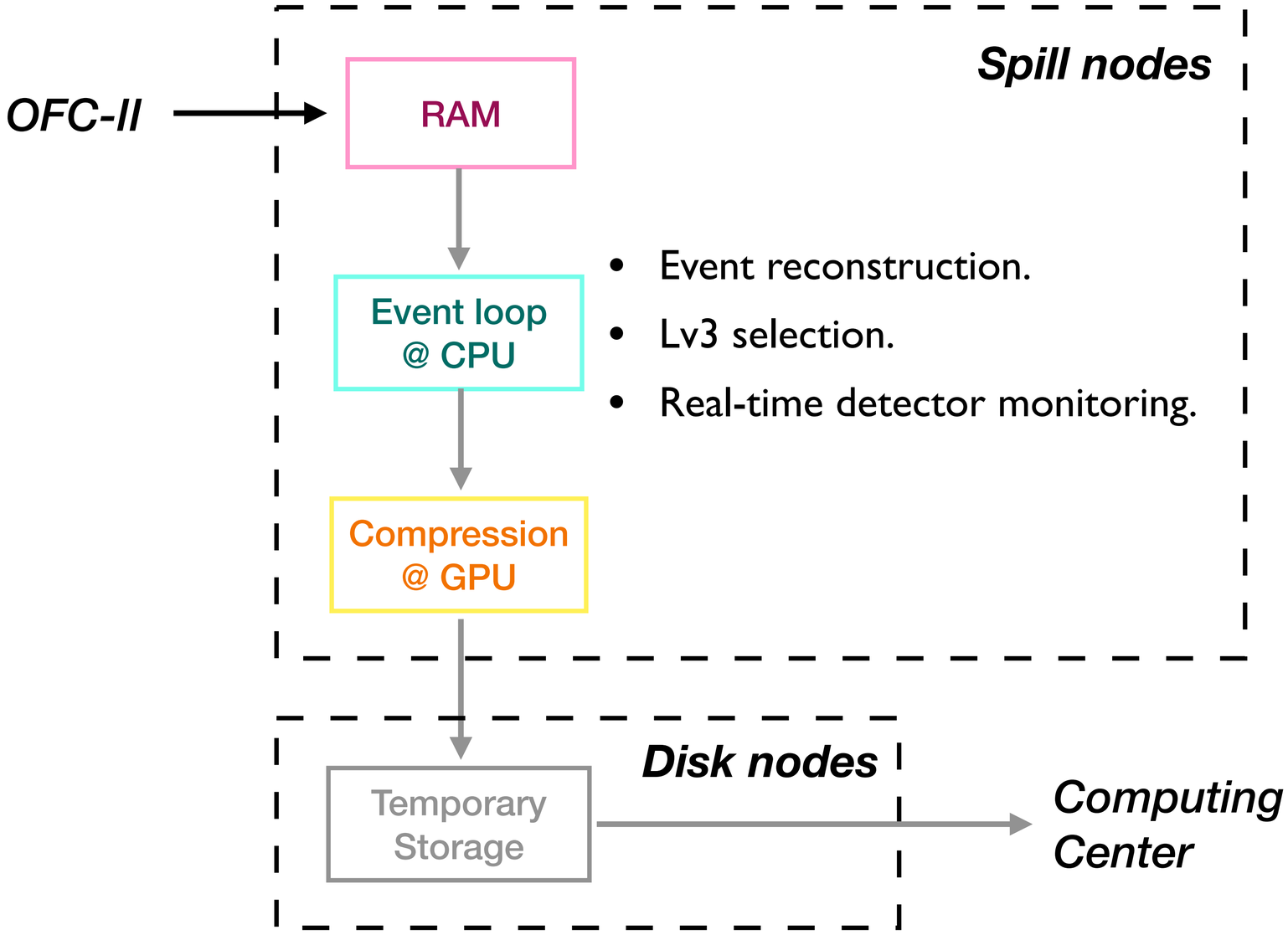
OFC-I memory is expected to be almost full.

Measurement of the Loss versus Event Rate



The turning point can be pushed forward by introducing more OFC-II modules.

Level-3 Trigger at PC Farm



- Event reconstruction.
- Lv3 selection.
- Real-time detector monitoring.

Summary

- New modules with multiple optical links and large memory size in FPGA are introduced to increase the data throughput.
  - The event rate of 15k/sec = 70.5 Gbps can be achieved with loss less than 1%. It can be further improved by simply connecting to more downstream modules.
- PC receives a complete event with the pyramid architecture.
  - An advanced trigger evaluation (Lv3) can be directly performed.

Trigger Table for 2021 Run

Two additional triggers are introduced for the background estimation.

$\Longrightarrow$ Expect the trigger rate to be ~19 k/spill @ 100kW beam.

$K_L \to \pi^0 \nu\nu$ Background Table

Source		Number of events
K_L	$K_L \to 3\pi^0$	0.01 ± 0.01
2nd	$K_L \to 2\gamma$ (beam halo)	0.26 ± 0.07^a
	Other K_L decays	0.005 ± 0.005
$K^\pm$	1st	0.87 ± 0.25^a
Neutron	Hadron cluster	0.017 ± 0.002
	CV η	0.03 ± 0.01
	Upstream π^0	0.03 ± 0.03
Total		1.22 ± 0.26

[a]Background sources studied after looking inside the blind region.

[PRL 126, 121801 (2021)]

Trigger rate in 2021 June run (~60kW)

Primary Trigger	Rate
$K_L \to \pi^0 \nu\nu$ physics	1.8k/spill
$K_L \to 3\pi^0$ (Halo K_L measurement)	2.0k/spill
K^+ measurement	5.0k/spill
Total Rate	11.2k/spill

Spill length ~ 2 sec

Current DAQ Architecture for Data Transfer

Trigger rate limit ~ 16k / (spill = 2 s) caused by 1-Gbps data transfer to PC farm.