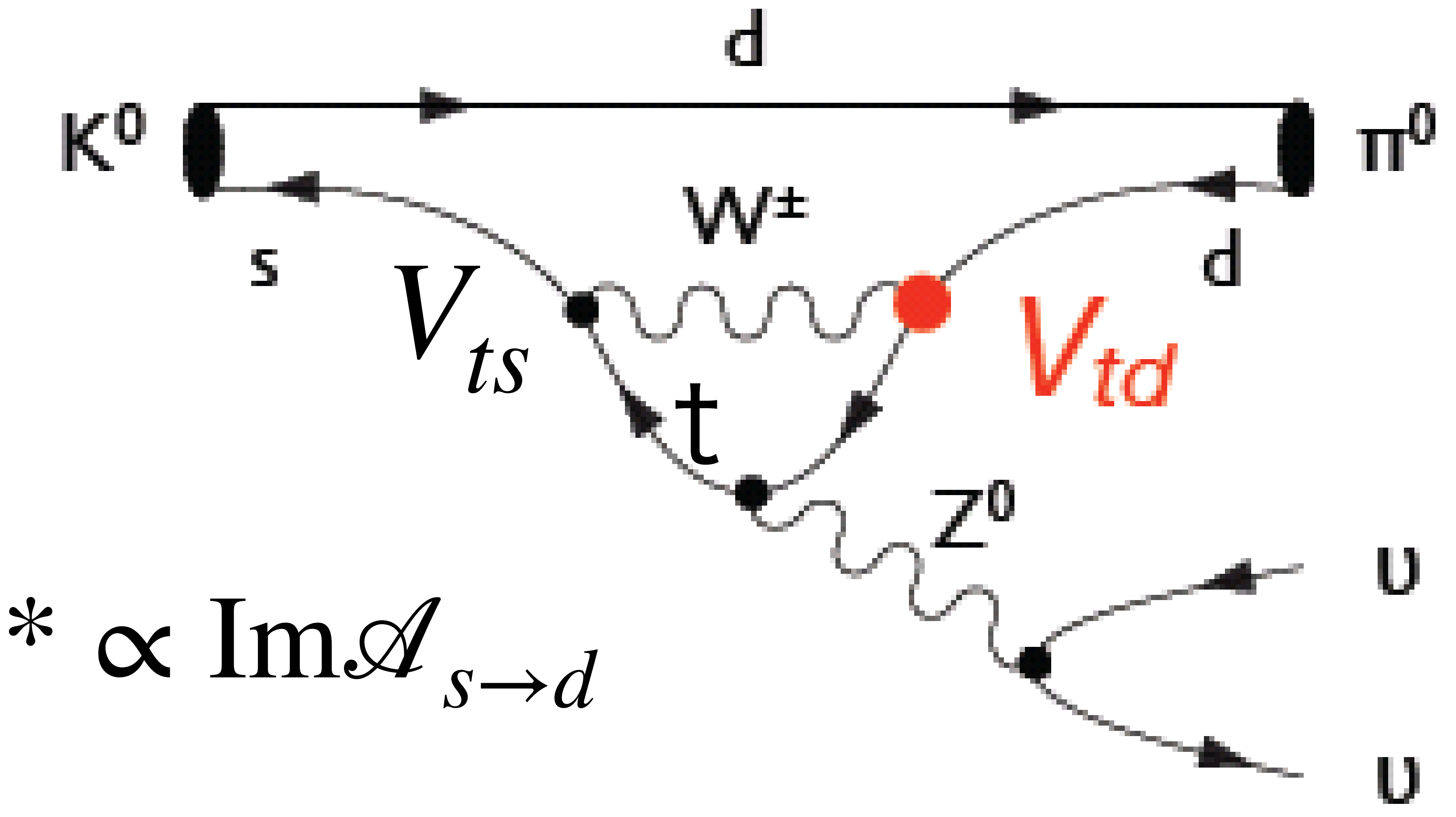
KOTO実験におけるDAQシステム

塩見　公志 (KEK) 2020/11/26 計測システム研究会@J-PARC

Physics on $K_L \to \pi^0 \nu \bar{\nu}$



- Standard Model : FCNC
  - CP-violating:

    $$K_L \propto K^0 - \overline{K^0}$$

    $$\mathscr{A}_{K_L \to \pi^0 \nu\nu} \propto \mathscr{A}_{s \to d} - (\mathscr{A}_{s \to d})^* \propto \mathrm{Im}\mathscr{A}_{s \to d}$$

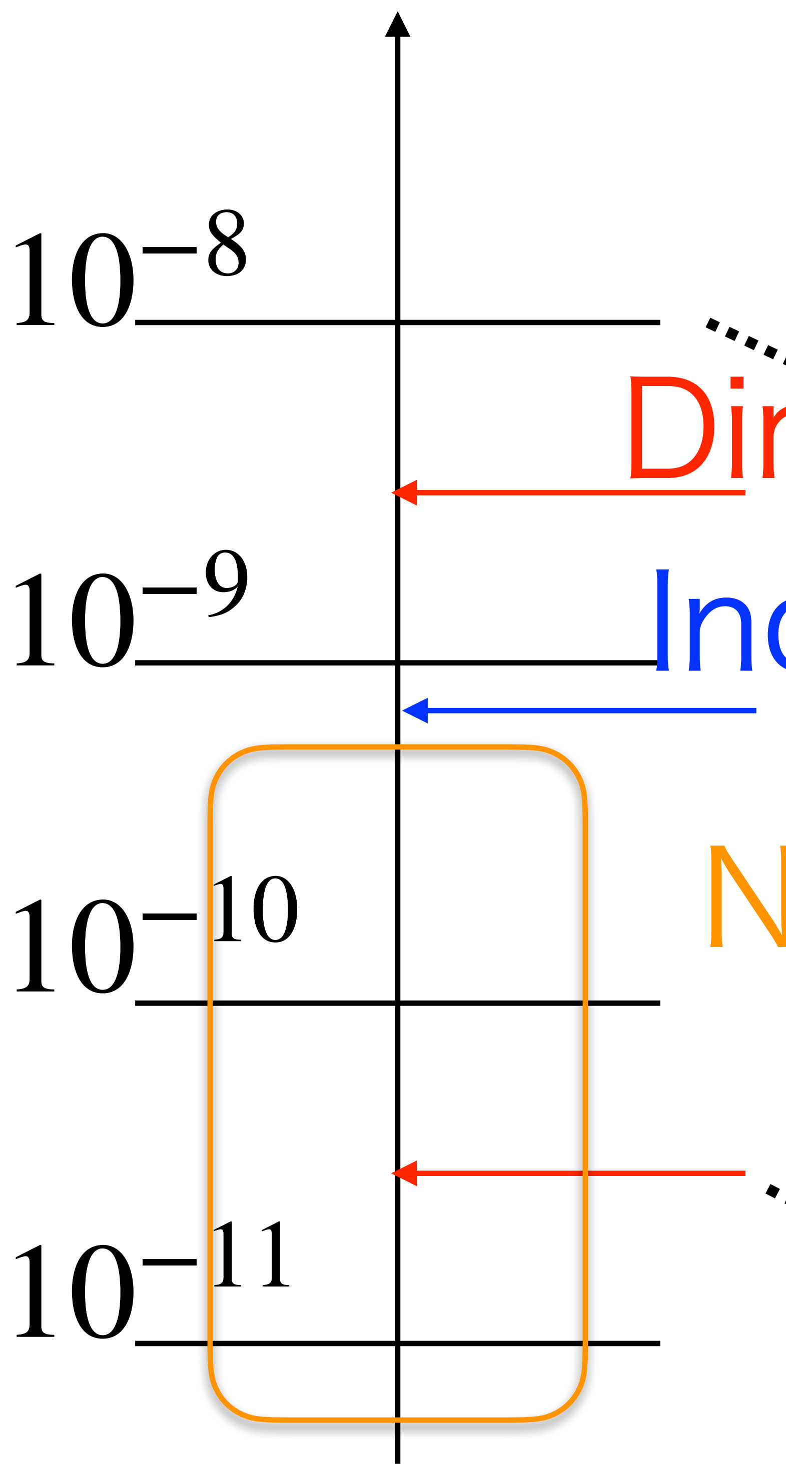
  - Rare:

    $$BR(SM) = 3 \times 10^{-11} \propto \left| V_{ts} V_{td}^* \right|^2$$

  - Accurate:
    - theoretical uncertainty < 2%
- Good probe for New Physics search

Experimental search for $K_L \to \pi^0 \nu \nu$

$BR(K_L \to \pi^0 \nu\nu)$



Open Access

Search for $K_L \to \pi^0 \nu\bar{\nu}$ and $K_L \to \pi^0 X^0$ Decays at the J-PARC KOTO Experiment

J. K. Ahn *et al.* (KOTO Collaboration)

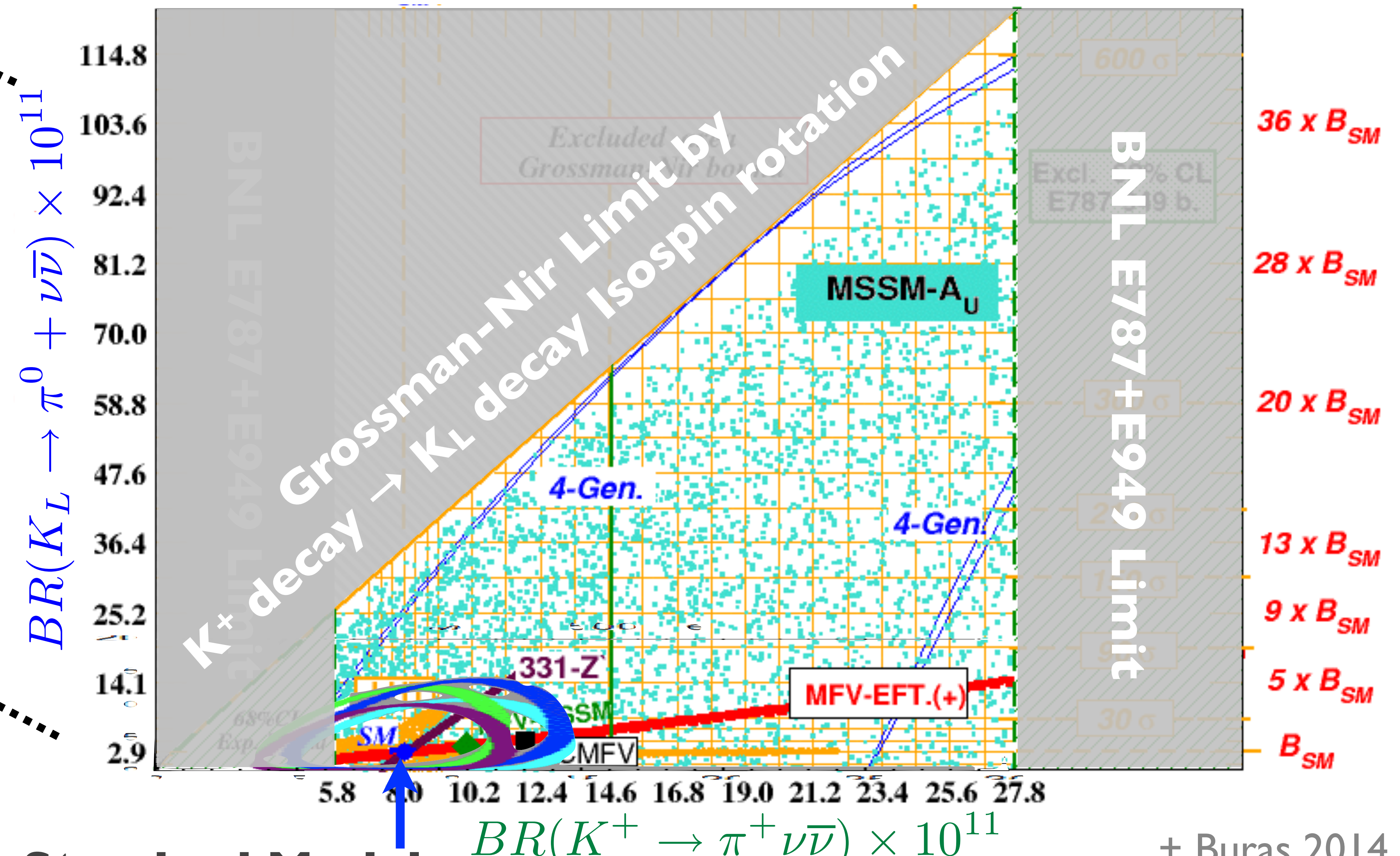
Phys. Rev. Lett. **122**, 021802 – Published 15 January 2019

Direct limit (KOTO 2015) $B_{K_L \to \pi^0 \nu\bar{\nu}} < 3.0 \times 10^{-9} (90\,\%\,\mathrm{CL})$

Indirect limit $B_{K_L \to \pi^0 \nu\nu} < 8.1 \times 10^{-10} (90\,\%\,\mathrm{CL})$

New Physics?

SM



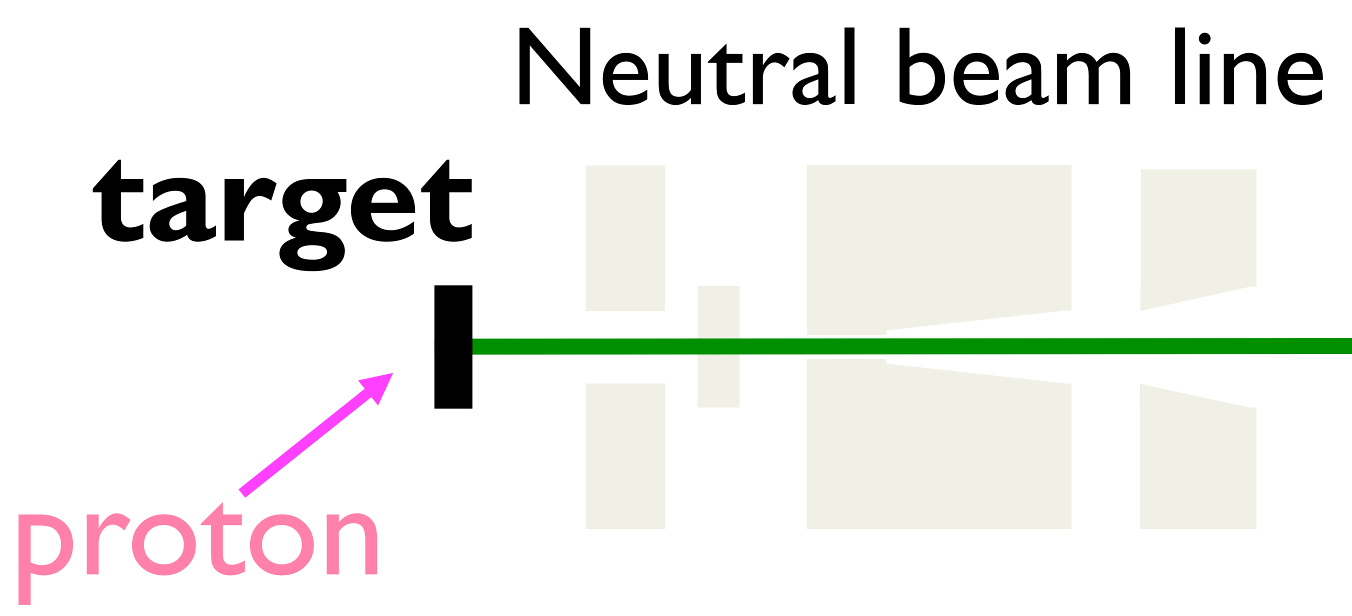
Standard Model

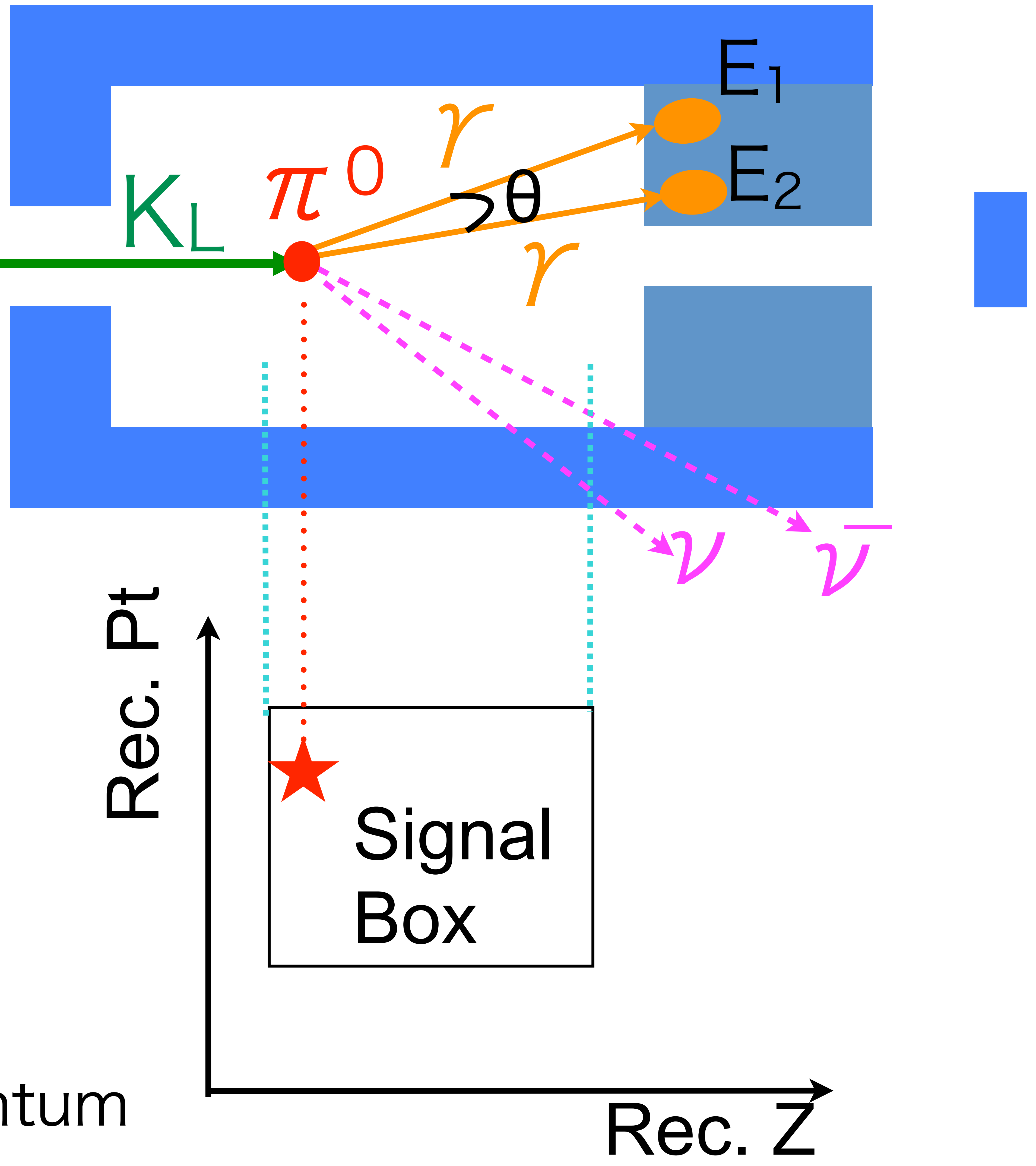
+ Buras 2014

http://www.lnf.infn.it/wg/vus/content/Krare.html

Experimental principle

$K_L \to \pi^0 \nu \bar{\nu}$ decay





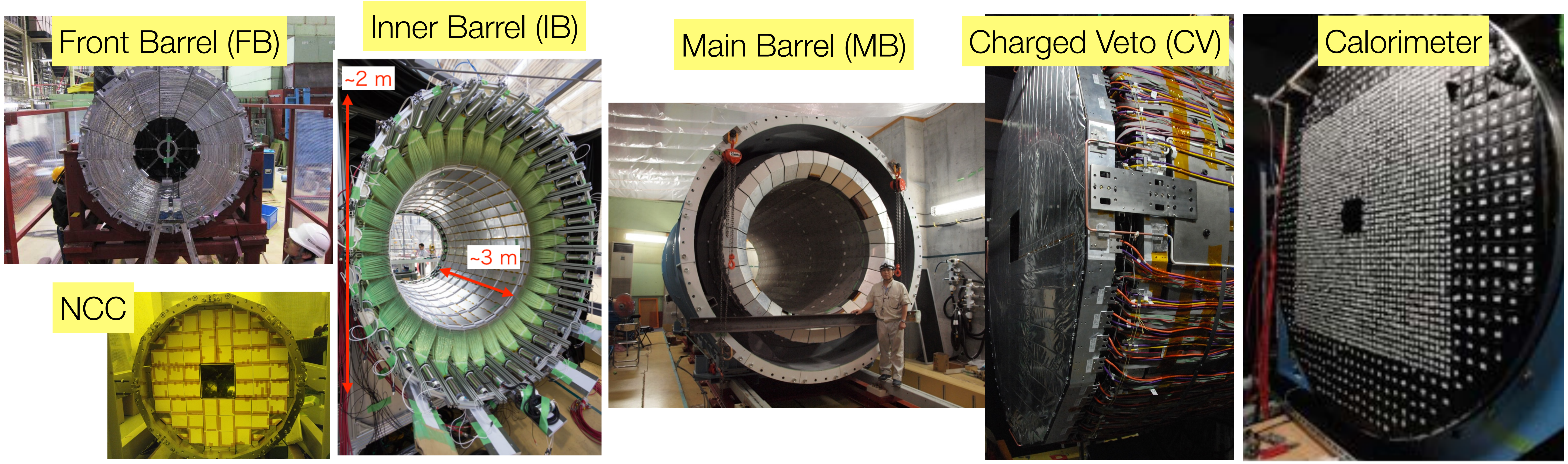
“2γ+Nothing+Pt”

Assuming 2γ from π^0,
Calculate z vertex.

$$M^2(\pi^0)=2E_1E_2(1-\cos\theta)$$

Calculate π^0 transverse momentum

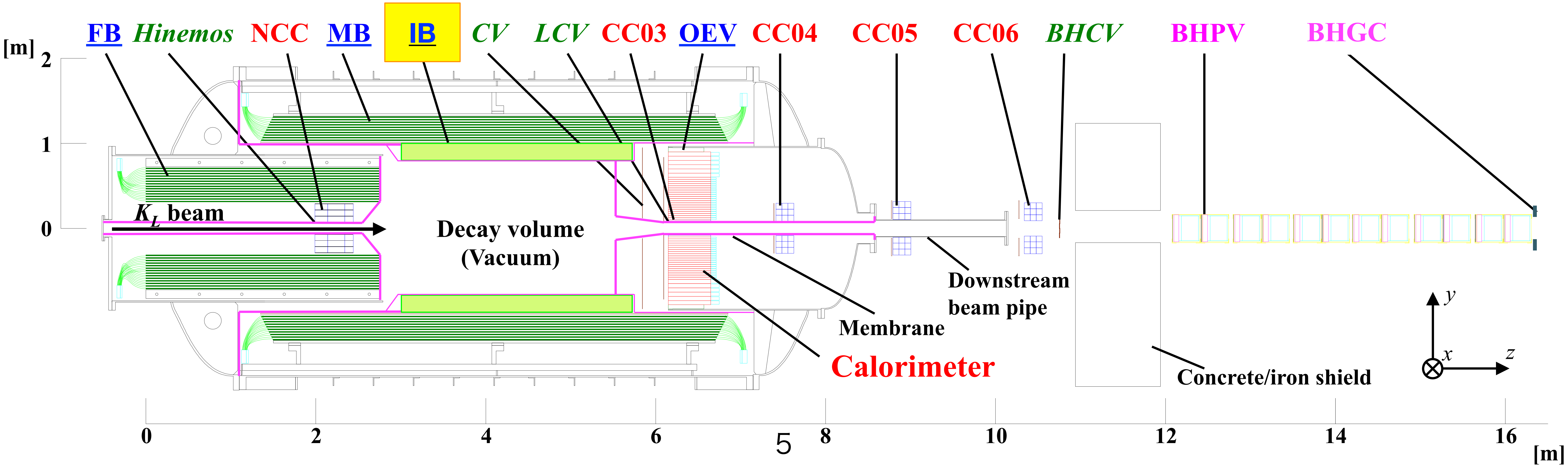
KOTO detector



CsI～3000CH.

他 ～1000CH.

合計～4000CH



1.1e7K_L

@beam exit(/spill)

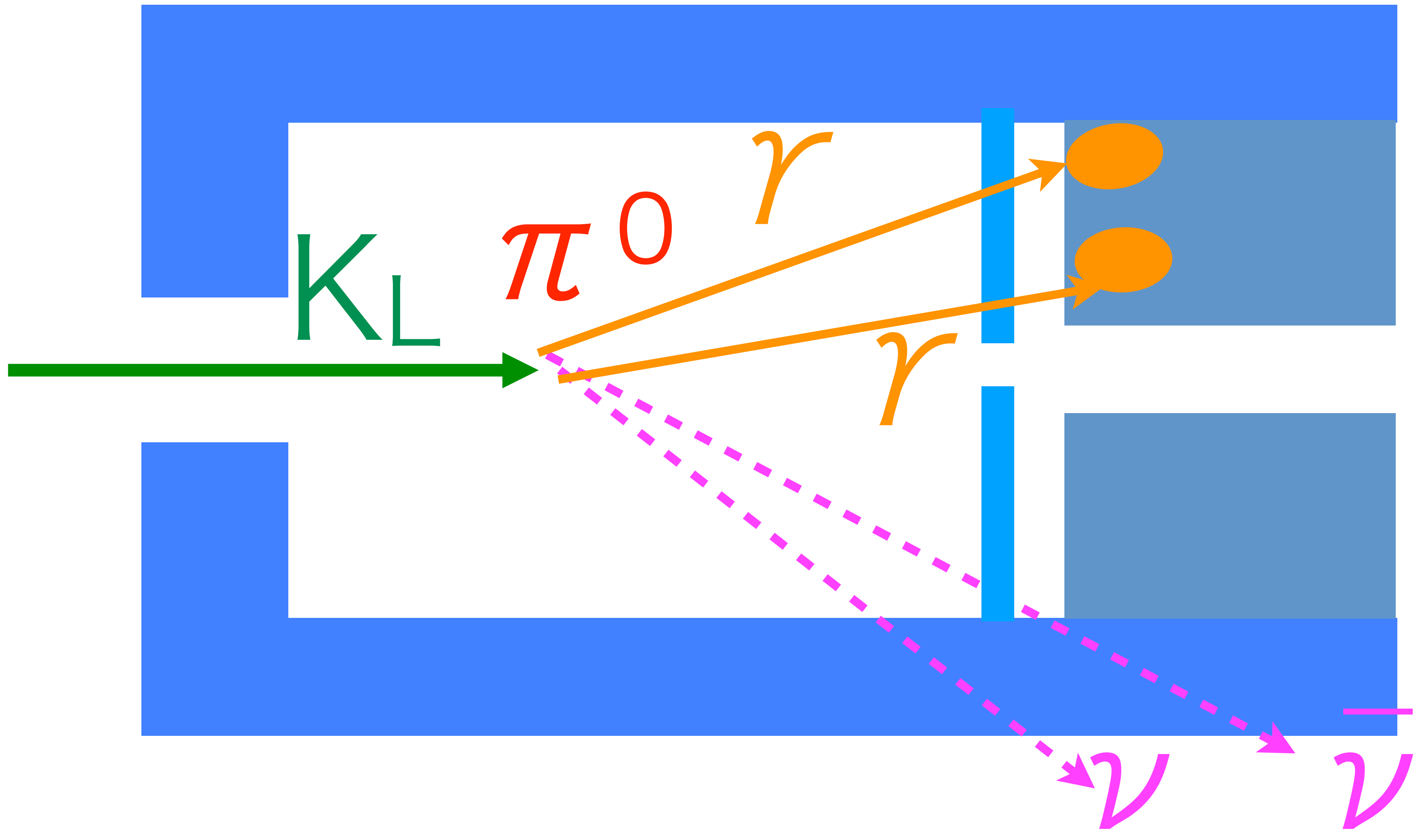
@50kW

5%くらいが

崩壊領域内で崩壊する

KOTO Trigger strategy
(2γ in CsI + Nothing)

$K_L \to \pi^0 \nu \bar{\nu}$ decay

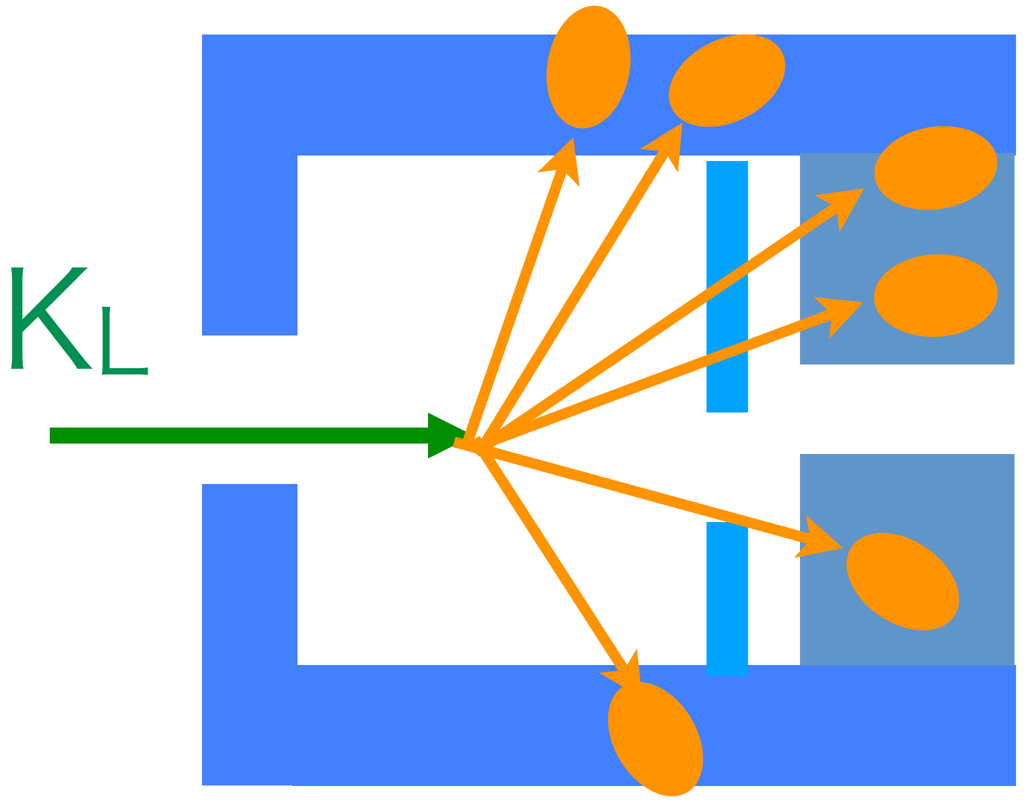


- CsIに大きなエネルギー損失(Et) ： 430K/spill
- Veto検出器にHitがない(Veto) ： 14K/spill
- CsIに2クラスター(Clustering) ： 2K/spill

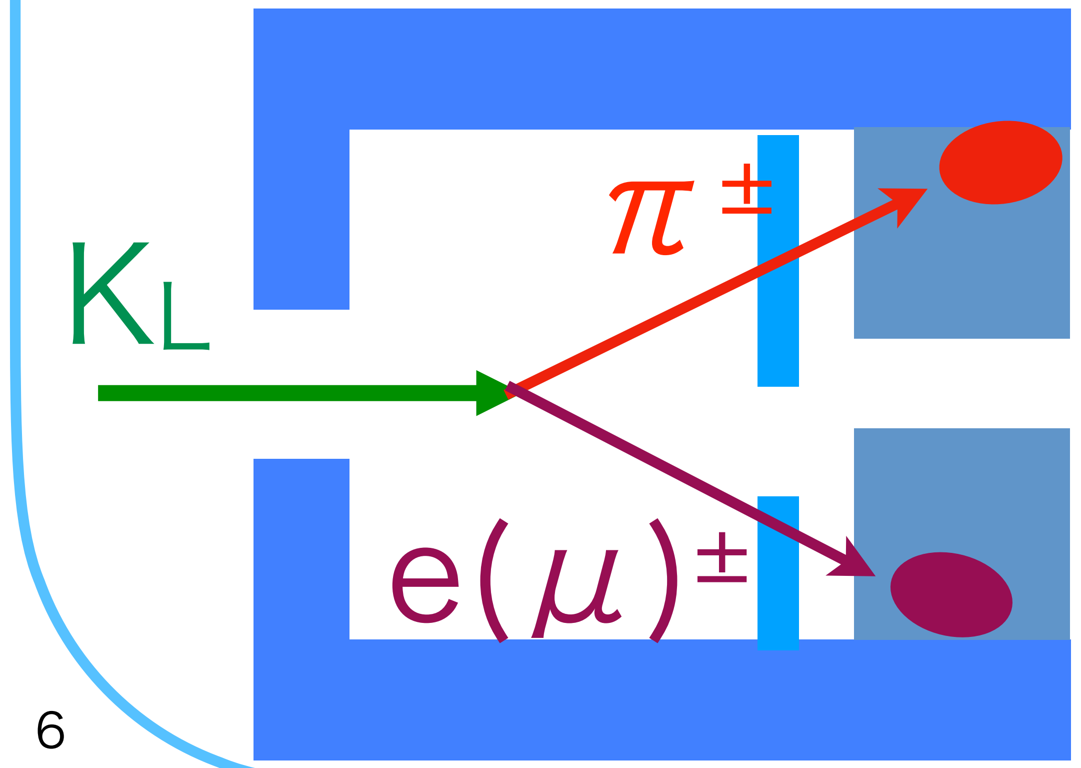
Kのメイン崩壊モード

	分岐比
$K_L \to \pi e \nu$	40.6%
$K_L \to \pi \mu \nu$	27.0%
$K_L \to 3\pi^0$	19.5%
$K_L \to \pi^+ \pi^- \pi^0$	12.5%

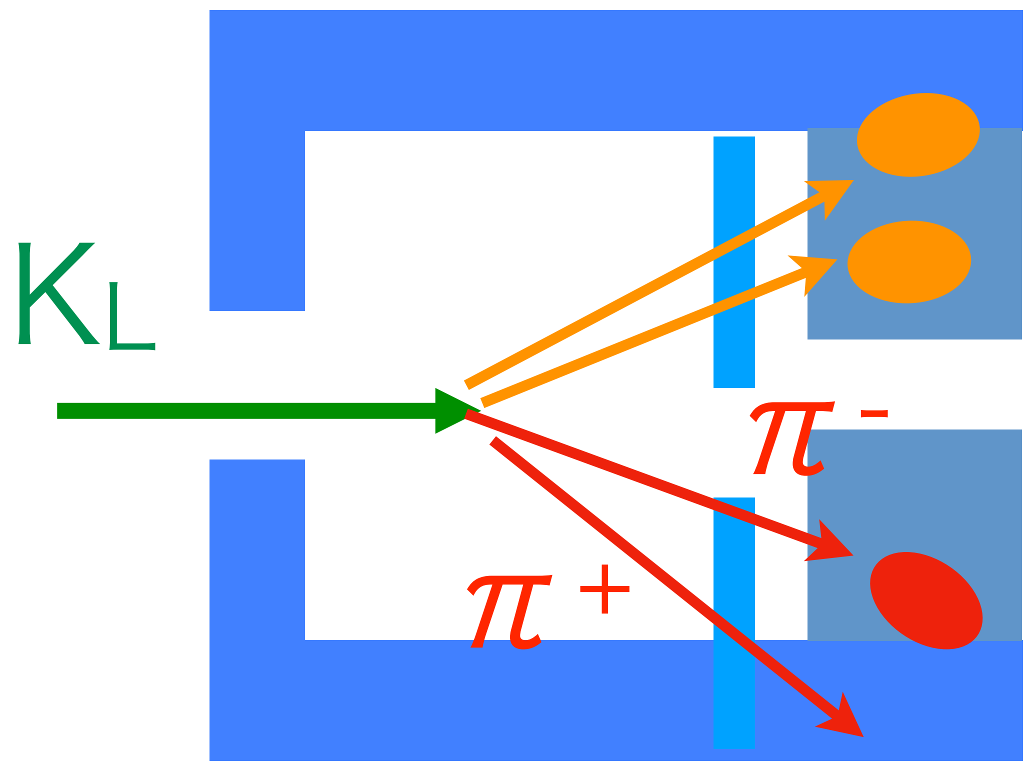
$K_L \to 3\pi^0$



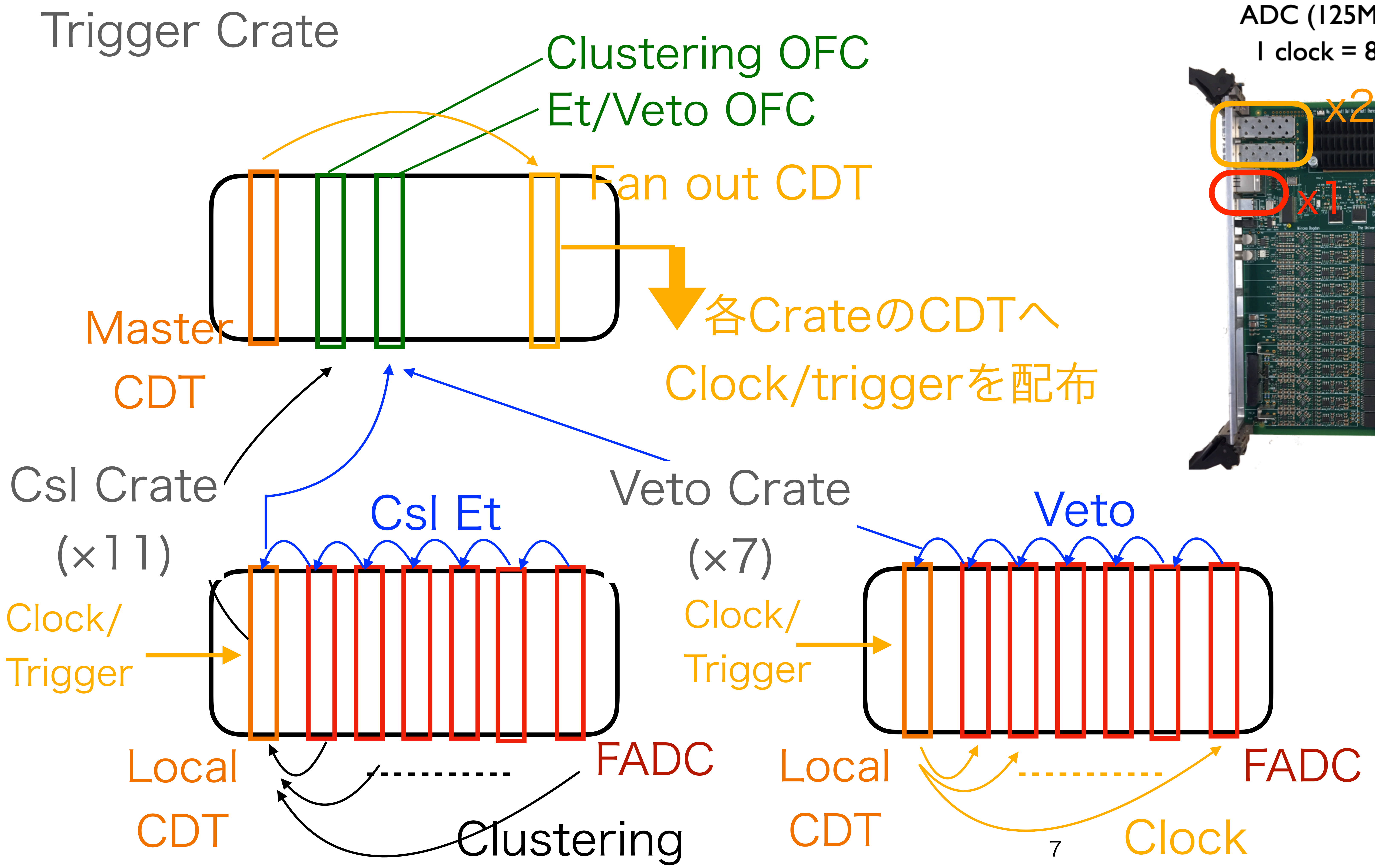
$K_L \to \pi e \nu (\pi \mu \nu)$

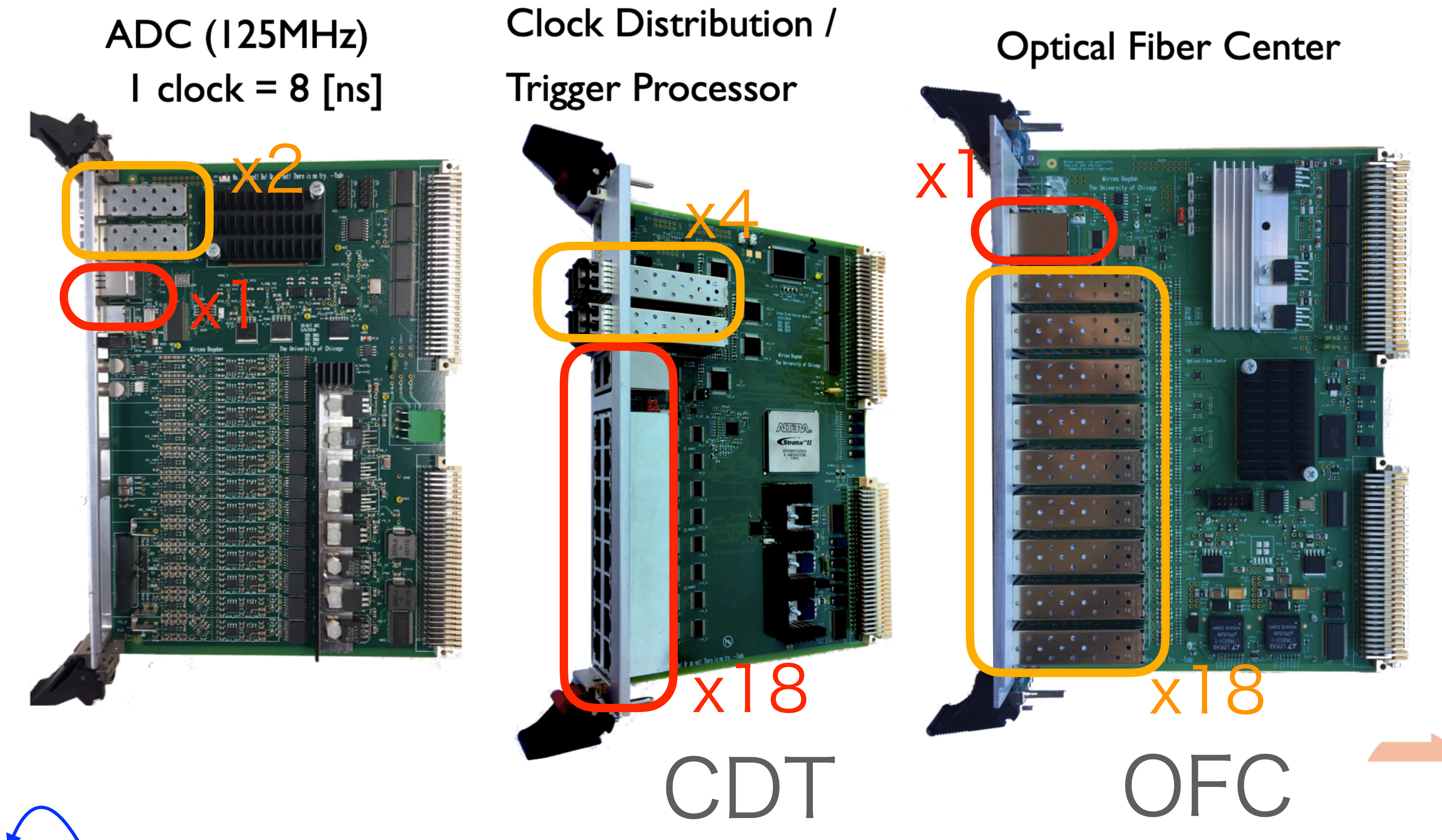


$K_L \to \pi^+ \pi^- \pi^0$



KOTO DAQ 概略図 (Trigger生成部)





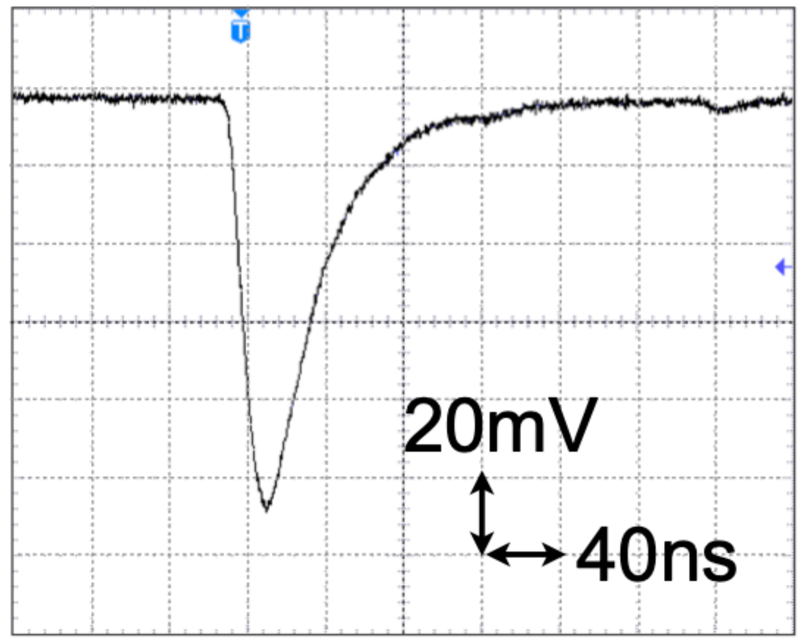
オプティカルリンク (16bit)

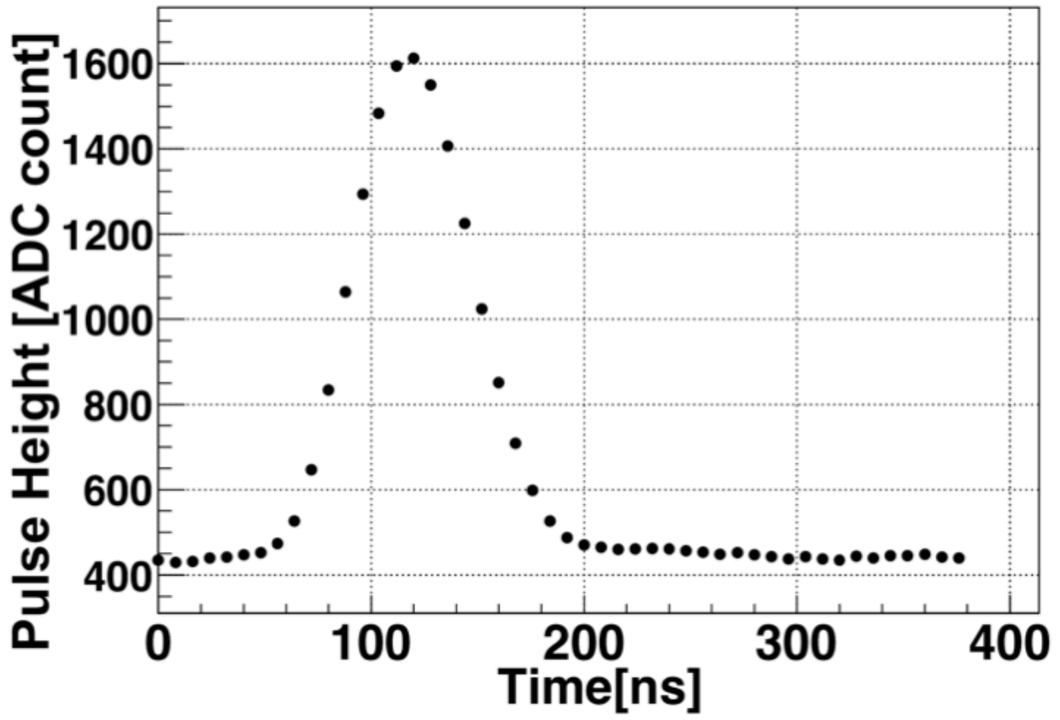
イーサネット(LDVS)
Trigger/Clock/Error/Clustering

KOTO DAQ 概略図 (読み出し部)

KOTO FADCs

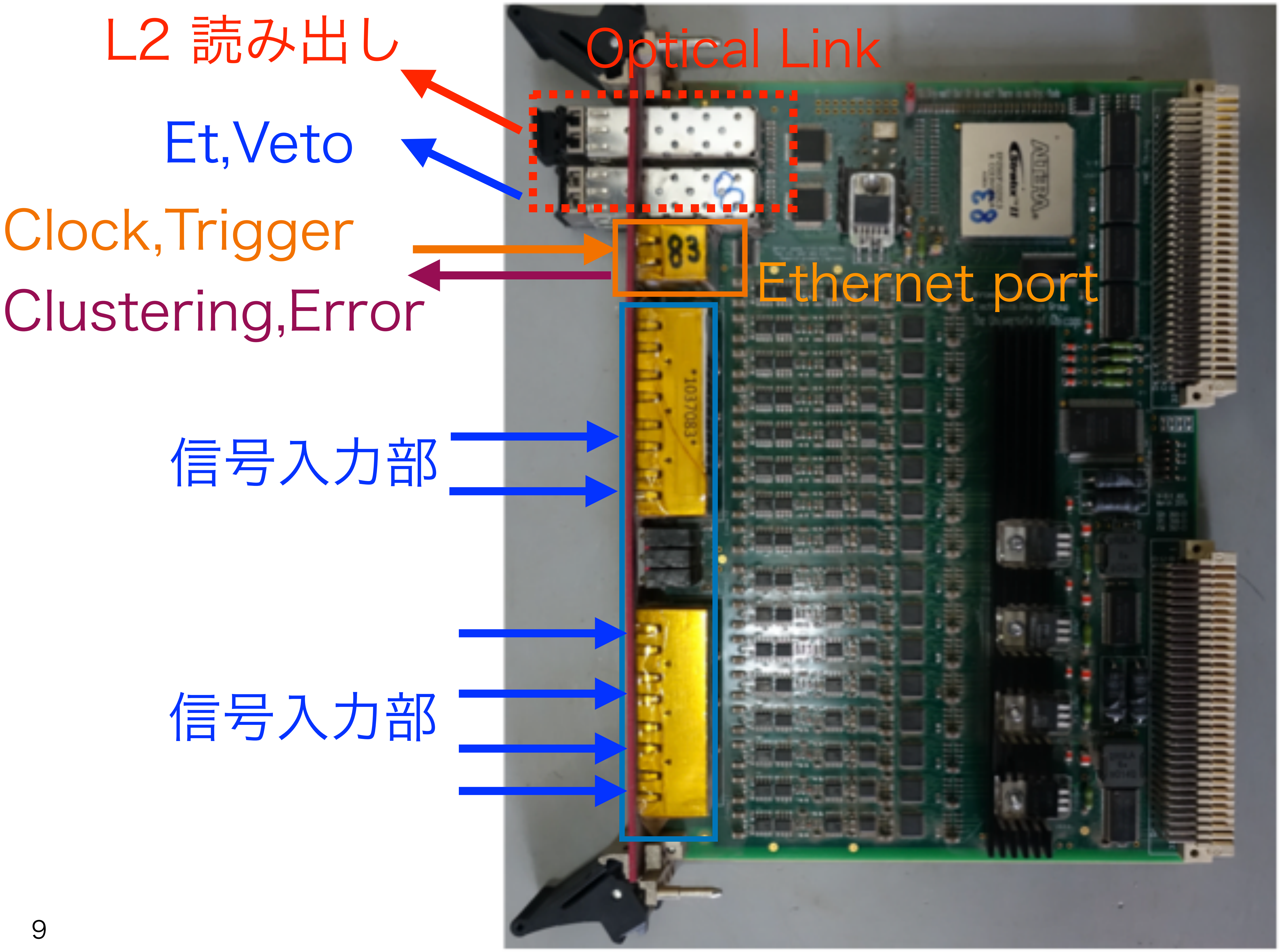
- 16ch 14bit 125MHz FADCs
  - w/ Gaussian filter





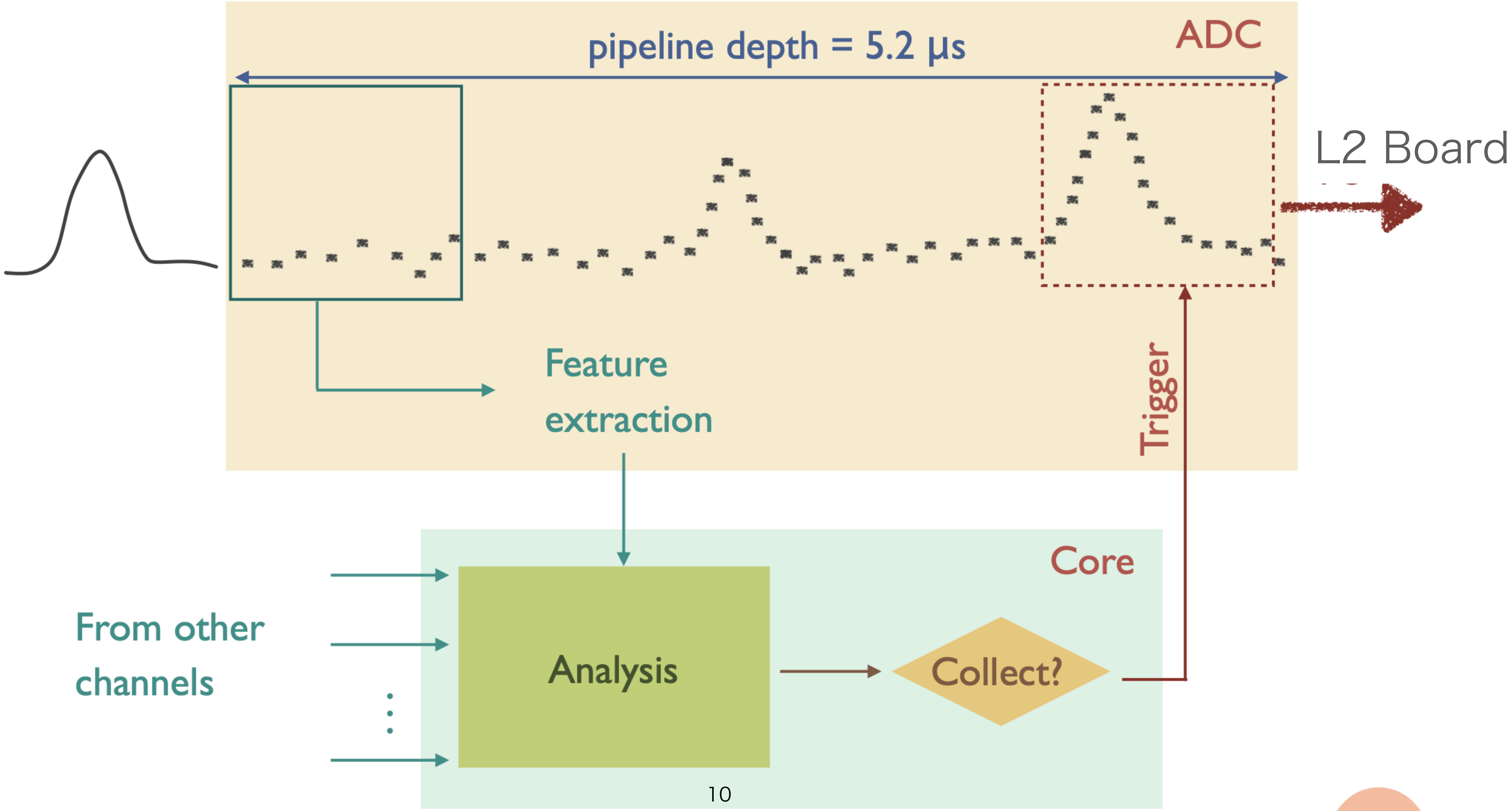
- 4ch 12bit 500MHz FADCs
  - w/o filter
  - 主にBeam中に置かれた検出器に使用

125MHz FADC



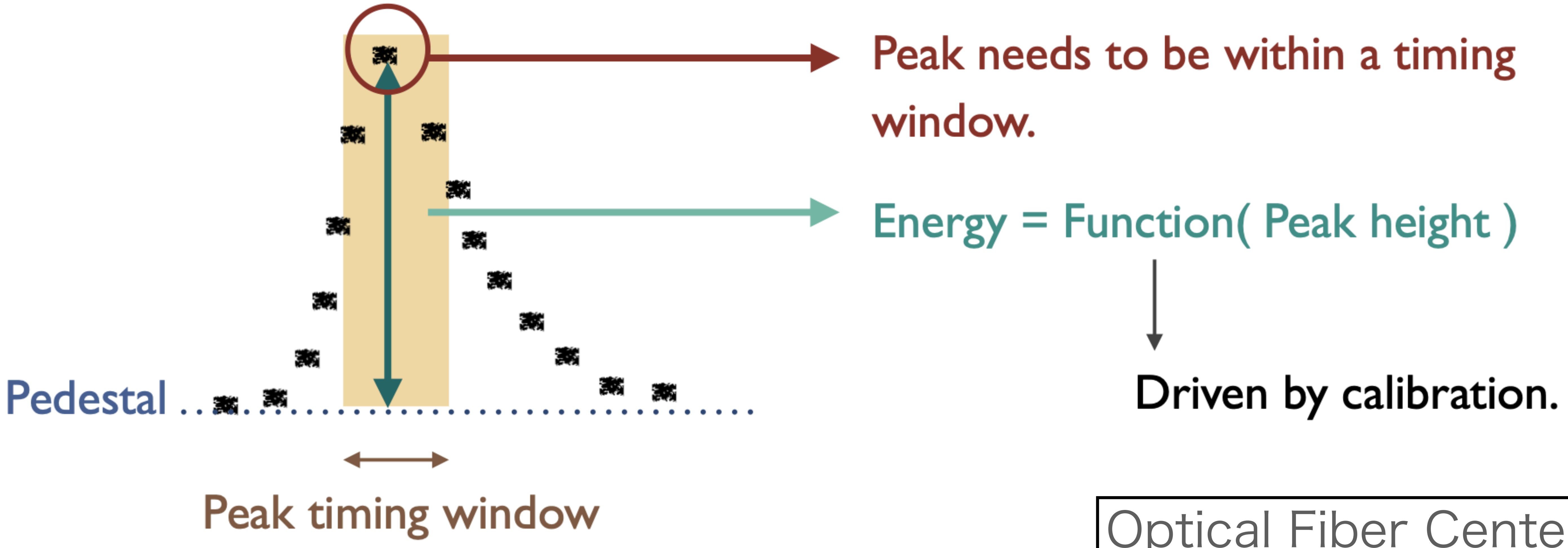
KOTO FADCs

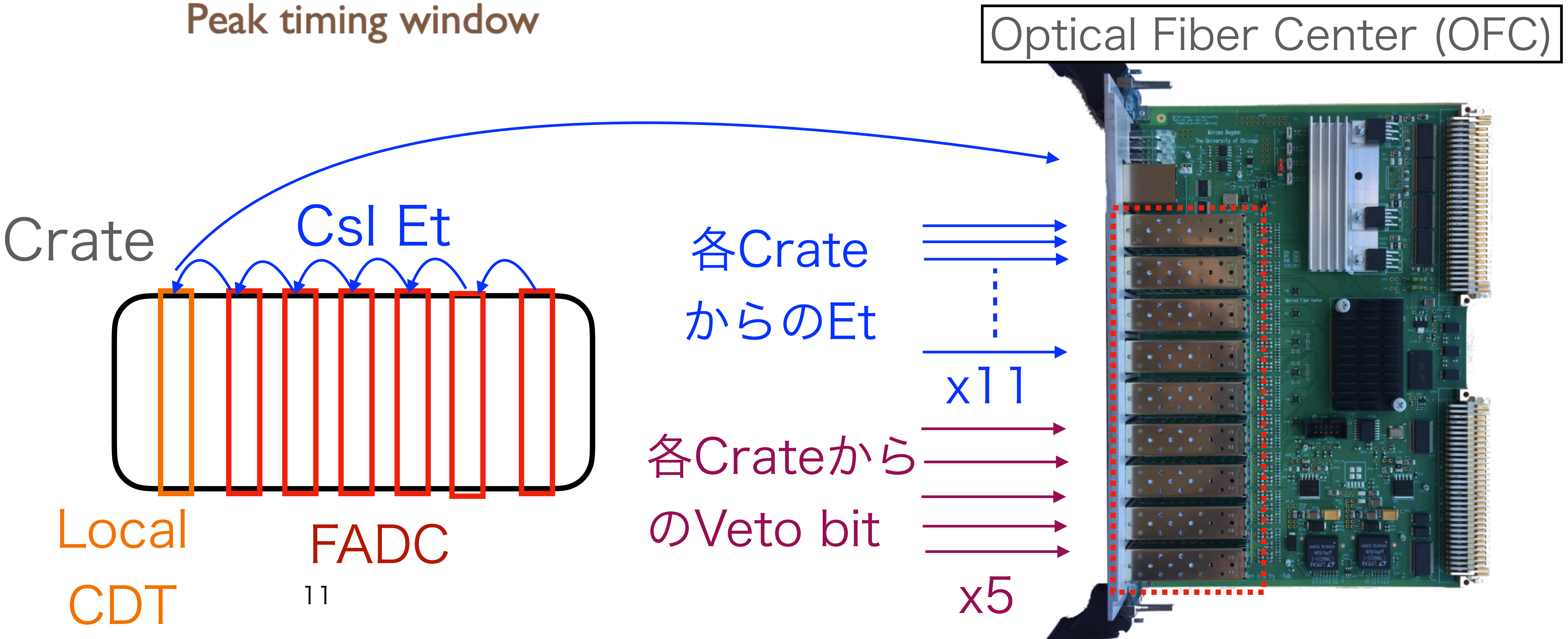
Pipeline読み出し



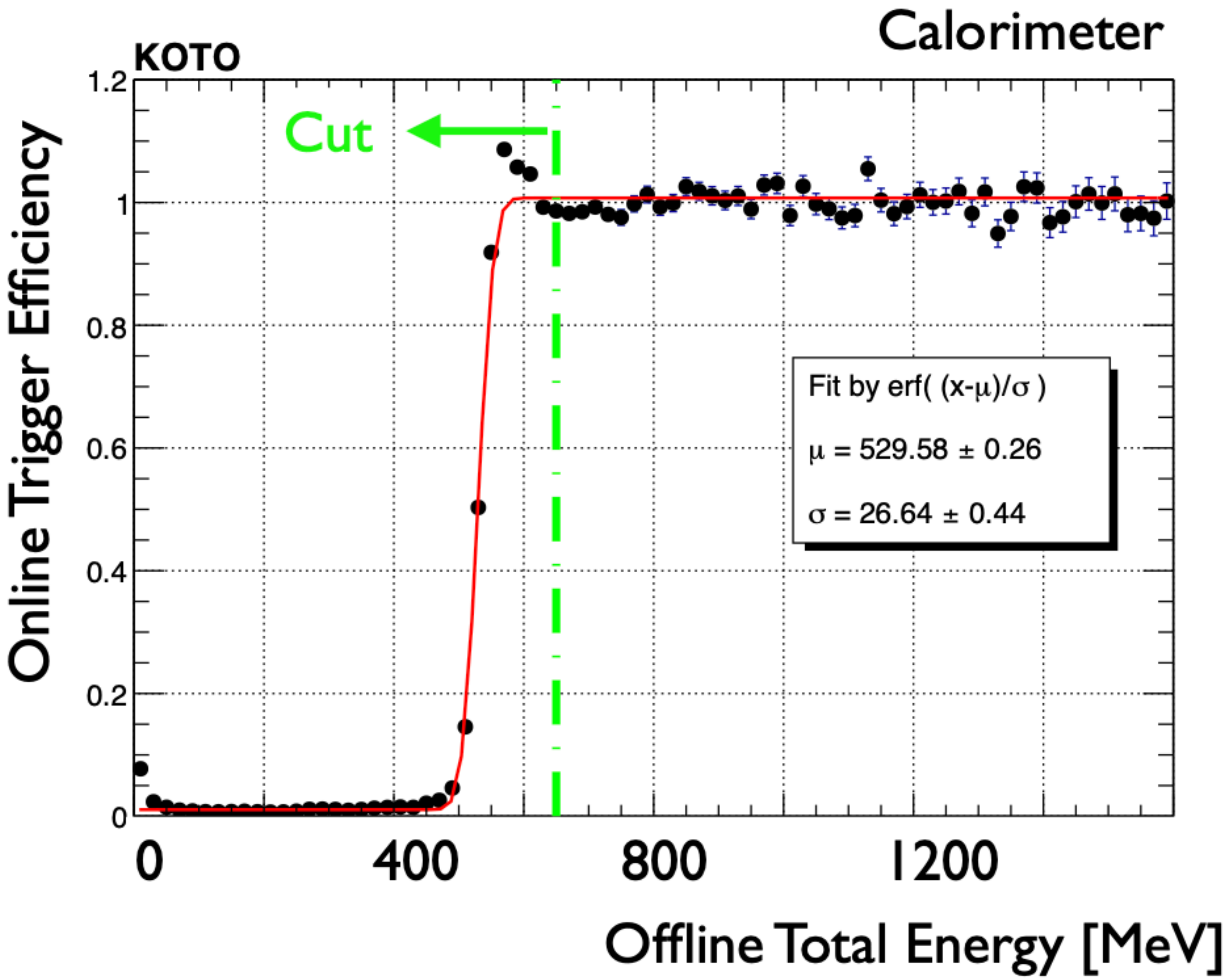
Et/Veto

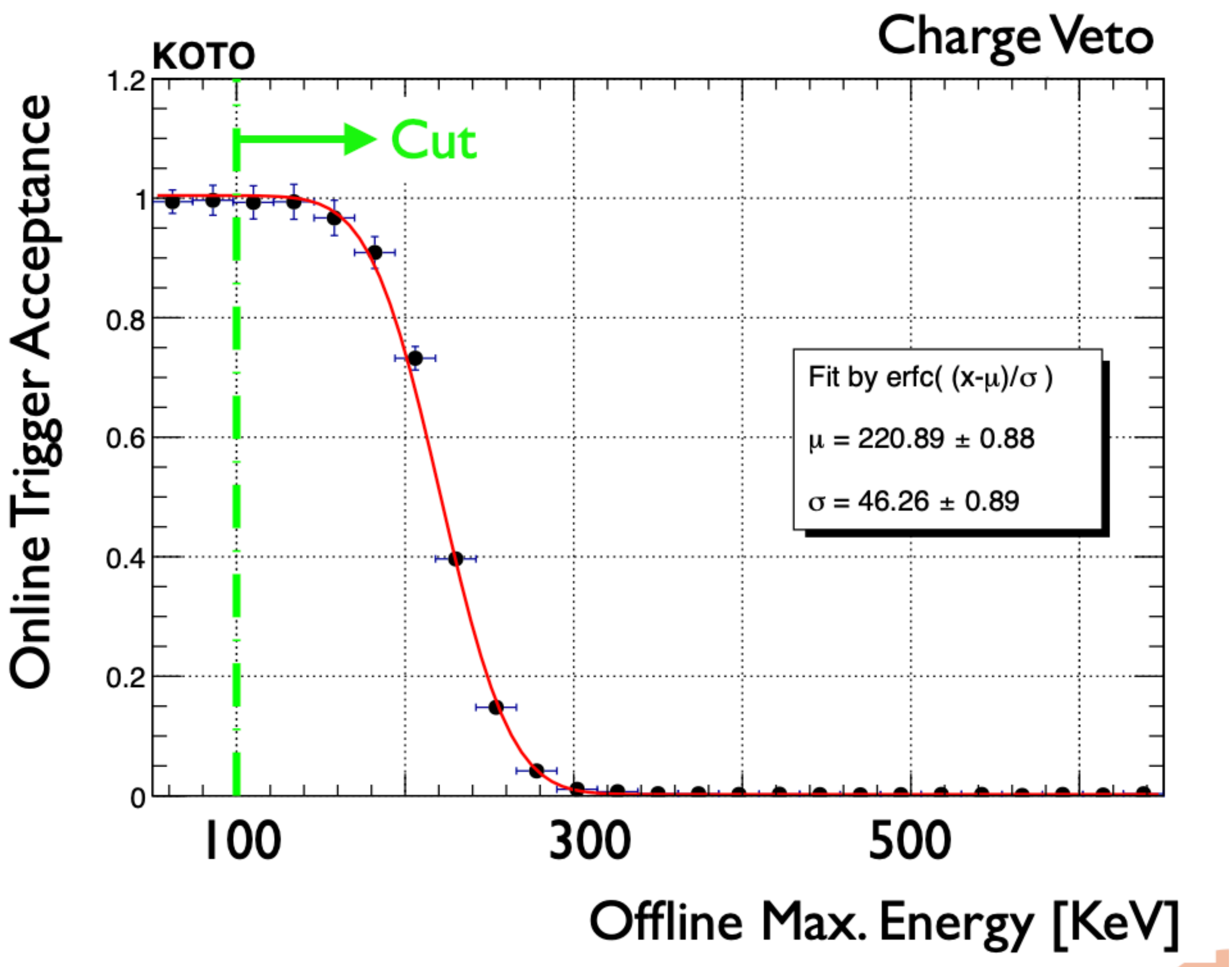
- 8ns毎に計算
    - Et=Σ(Energy)
    - Veto=OR(Energy>閾値)
- Local CDT
    - Crate内の各FADCからの情報をまとめる
- Optical Fiber Center(OFC)
    - 各Crateからの情報をまとめる





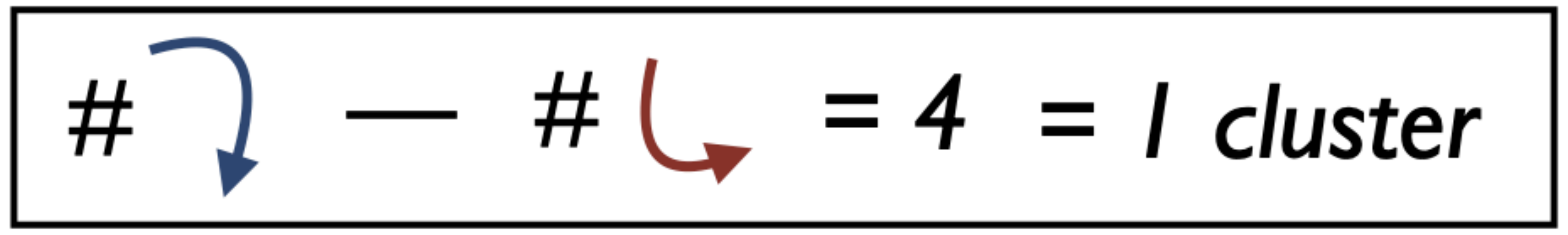
Et/Veto

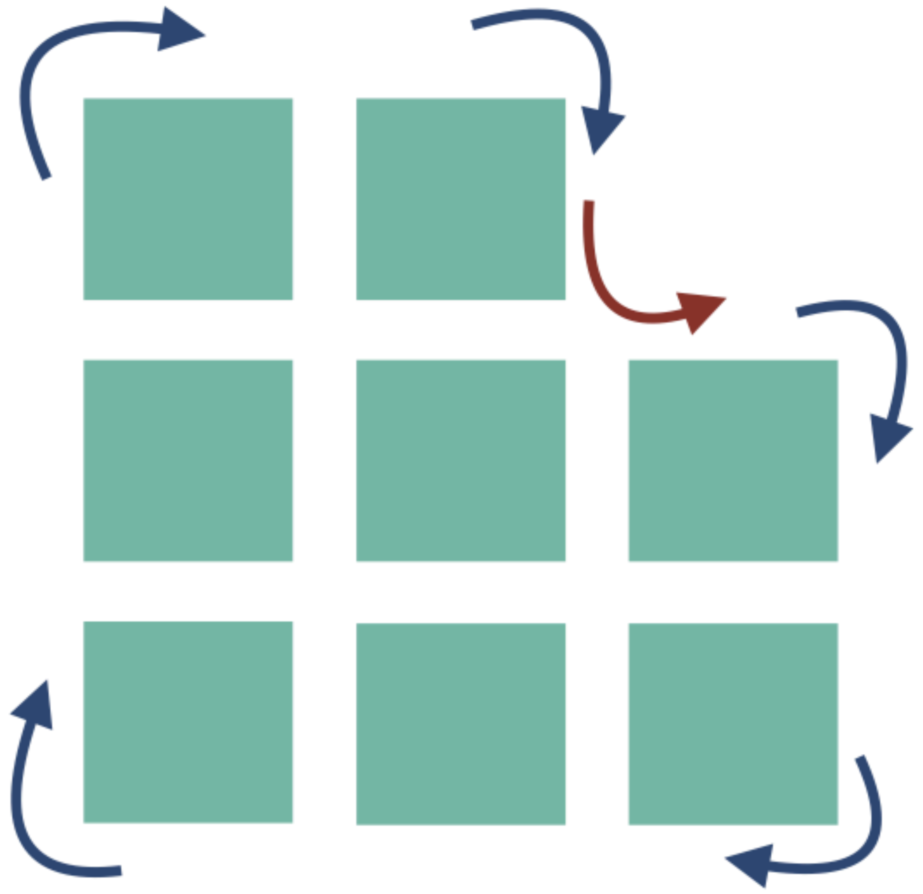


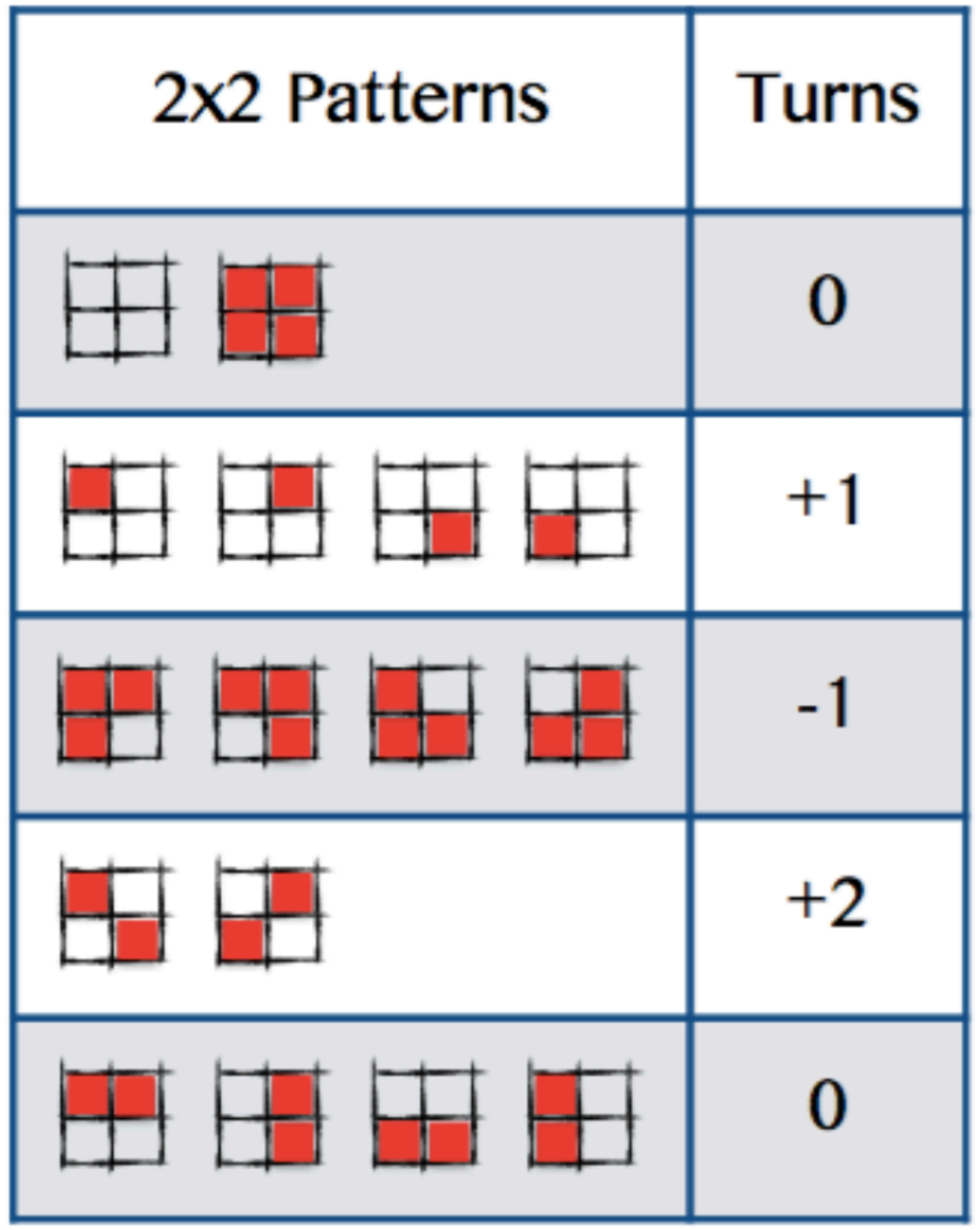


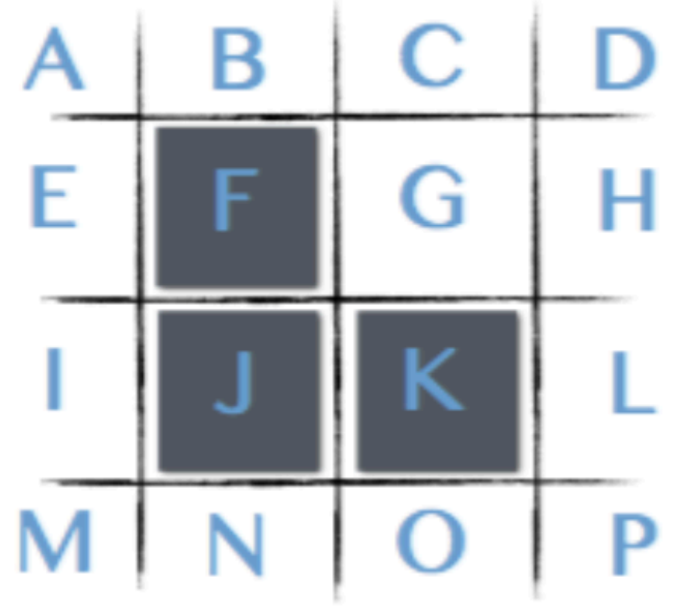
注:CalorimeterのEfficiencyはデータの外挿から求めた点との比

Clustering









=

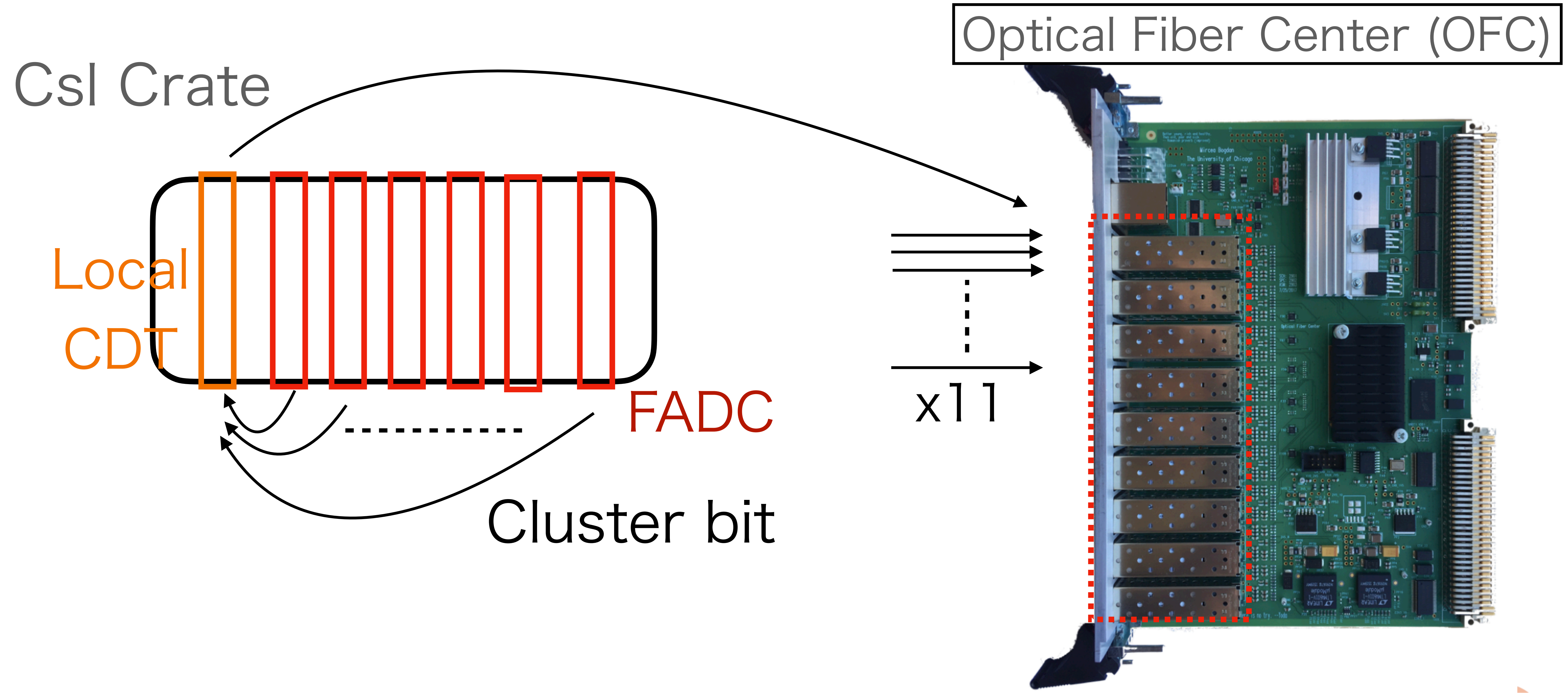
ABEF(1)+BCFG(1)+CDGH(0)
+EFIJ(0)+FGJK(-1)+GHKL(1)
+IJMN(1)+JKNO(0)+KLOP(1)

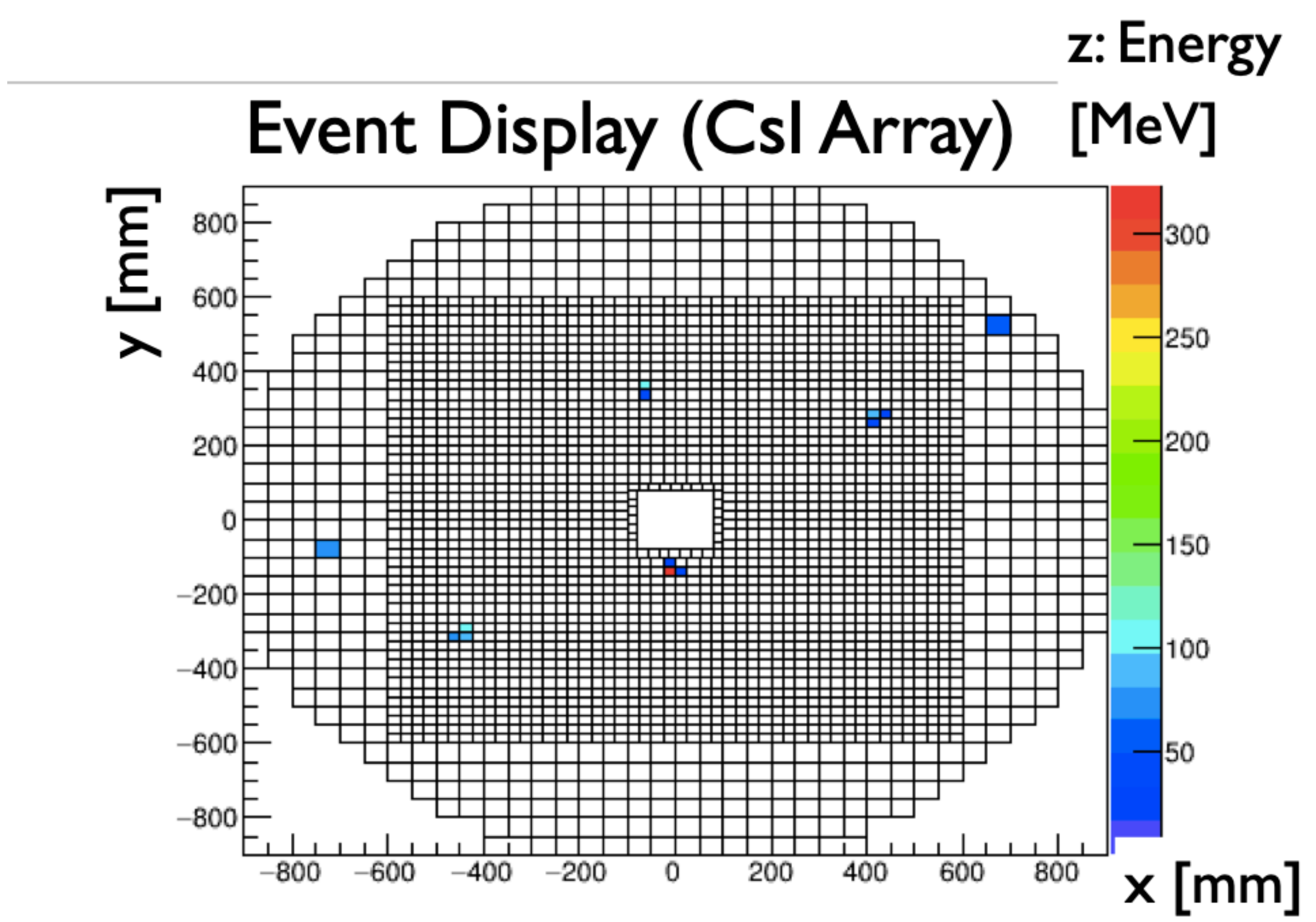
=

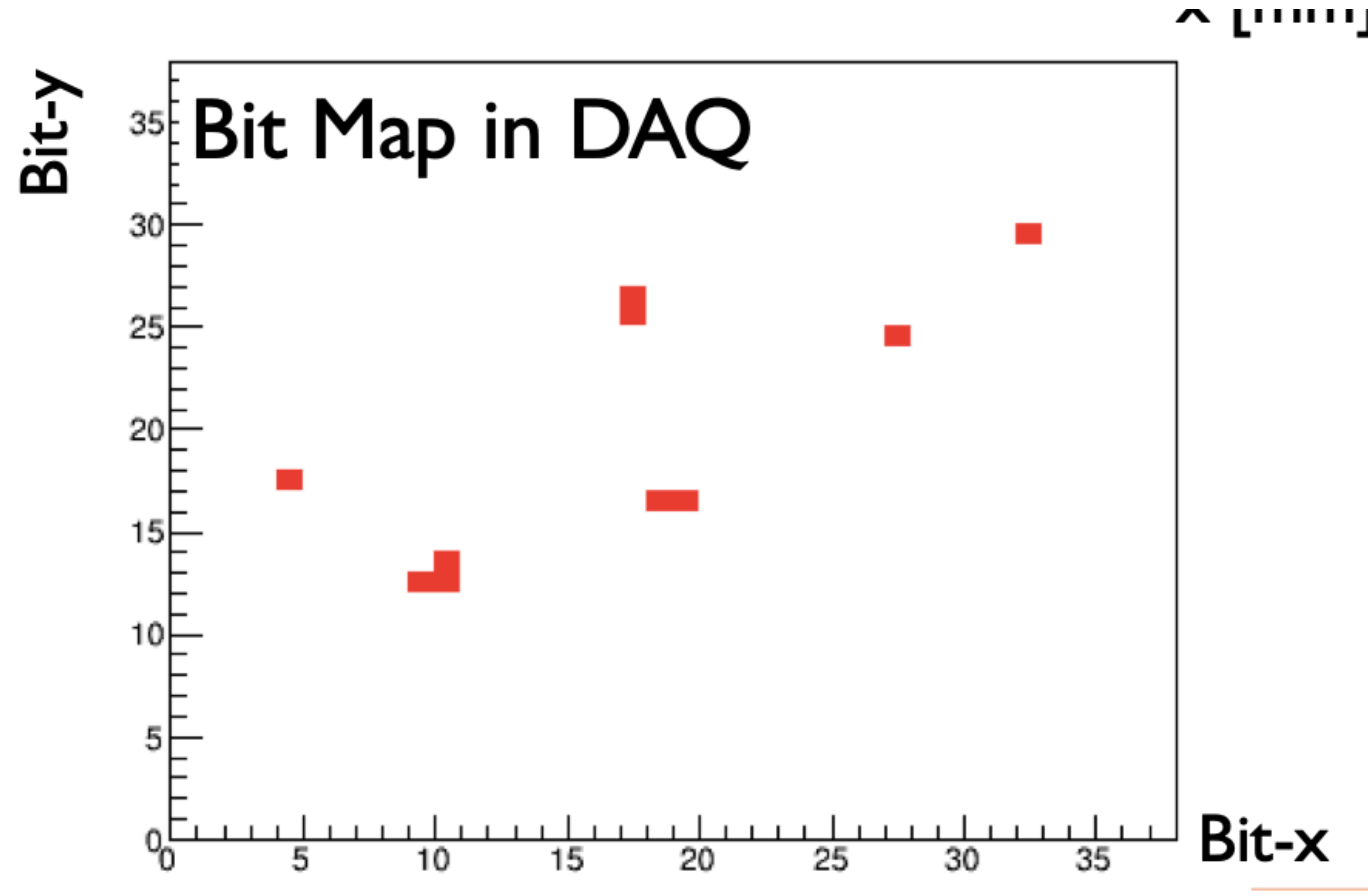
4 turns (one cluster)

Clustering

- Et/Vetoをみたした事象に対して計算
  - 0.16μs(20 clock分)のdead time





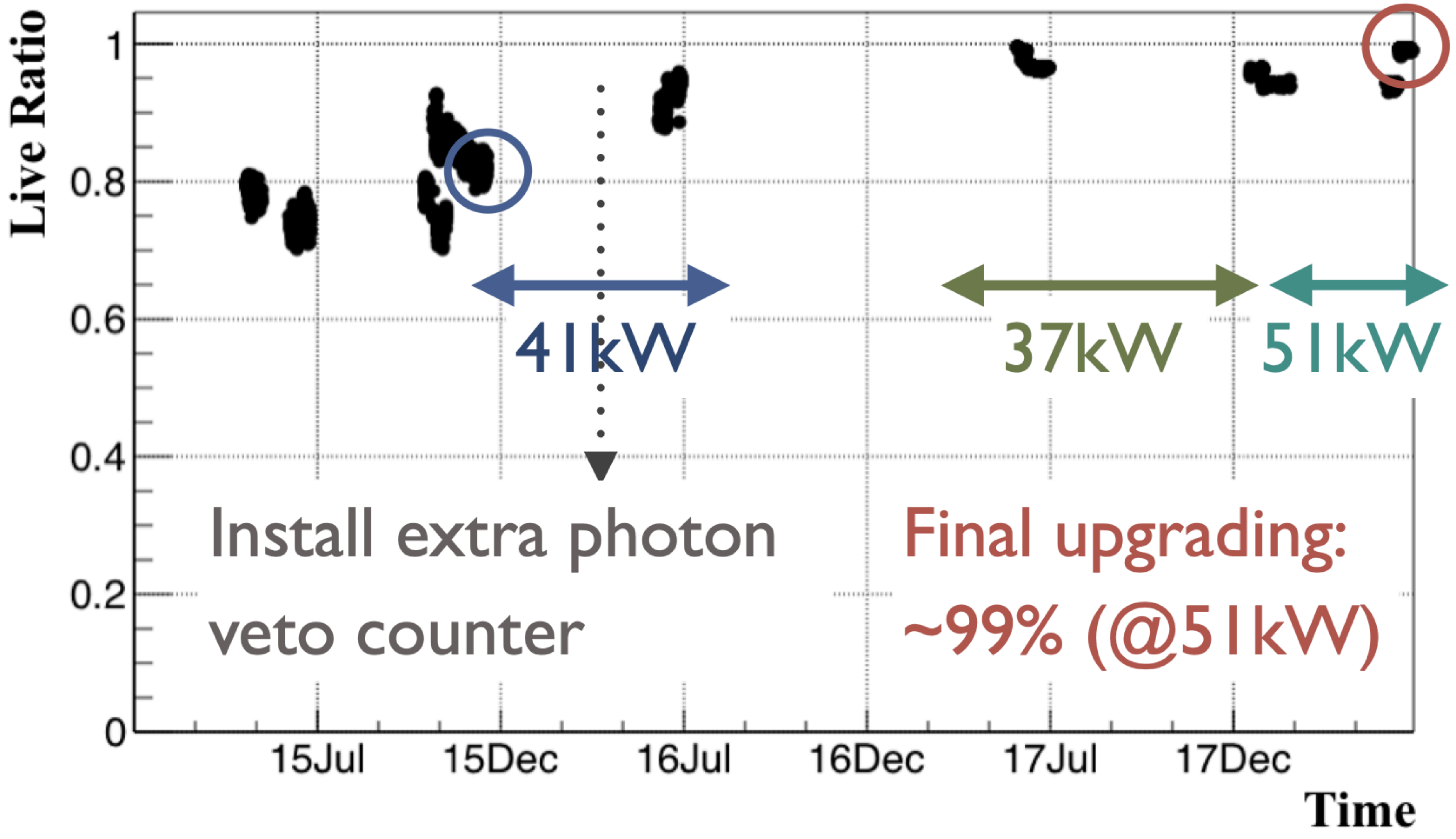


Clustering

Trigger efficiency

Mode	Data	MC
$K \to 2\pi$	96.8%	96.7%
$K \to \gamma\gamma$	99.6%	99.2%
$K \to \pi\nu\nu$	-	99.6%

DAQ performance



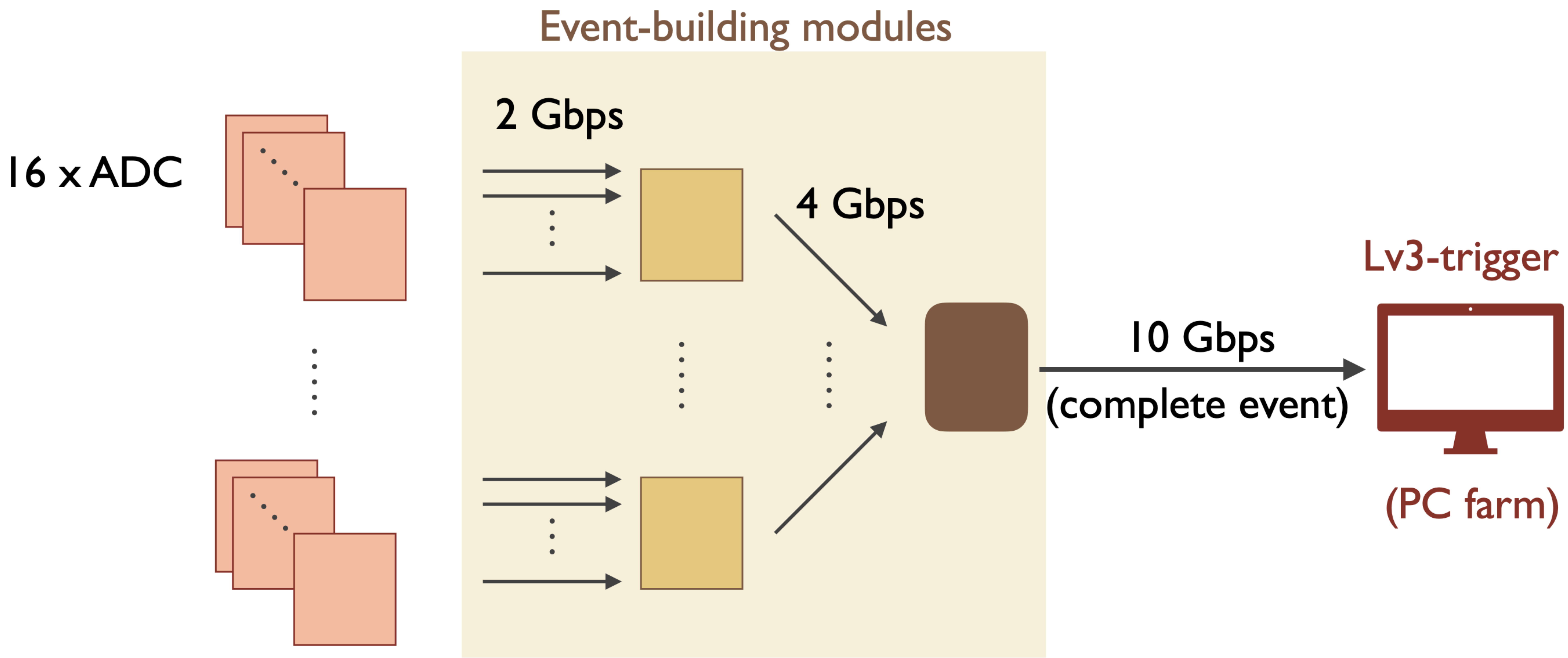
Trigger menuのスナップショット

Run79 (2018年6月) : 51kW

Triggerの種類	Trigger条件	#Trigger/spill
KL→$\pi\nu\nu$ Trigger	Et+Veto+2 cluster	2.0K
Normalization Trigger	Et+Veto	0.7K
Minimumbias trigger	Et	1.5K
4,6 cluster trigger	Et+Veto+ 4 or 6cluster	7.7K
3 cluster trigger	Et+Veto + 3 cluster	1.0K
Sum		13K

Future plan

- Event buildingを上流で行い、PCでより細かな選別を行う。



まとめ

- KOTO実験は$K_L \to \pi^0 \nu \bar{\nu}$崩壊探索を通して新物理の探索を行なっている。
- 大強度のKLビームの中からTriggerの取捨選択をすることが大事
  - 現状は Et + Veto + Cluster countingを基にtriggerを作成し、99%のLive timeを達成している。
- 今後は更なる大強度ビームへの対応、バイプロダクトデータの取得を目指してDAQの更なる改良を進めていく。