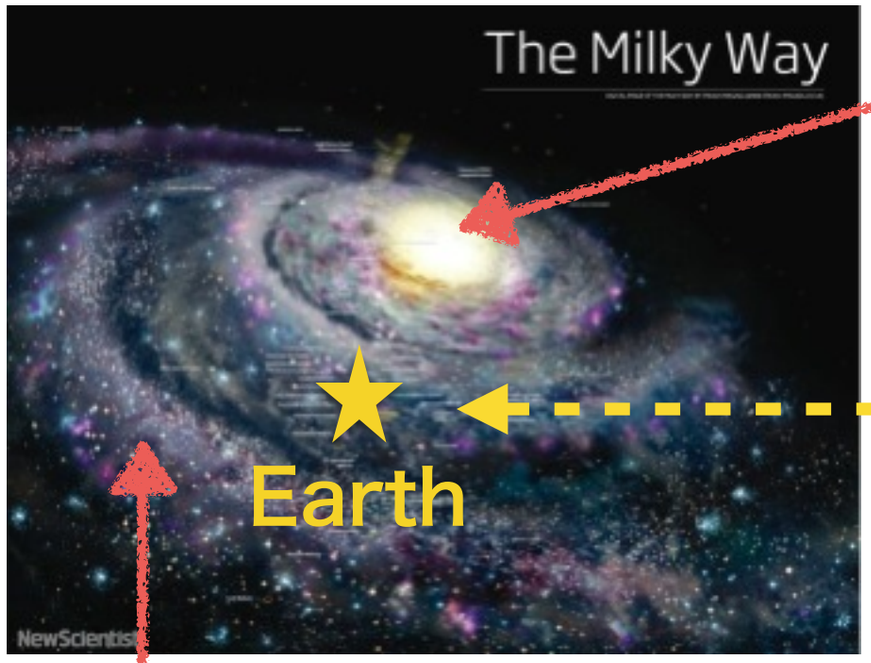
# Development of a High-Speed Data Acquisition System for the Large-Sized Telescopes of CTA

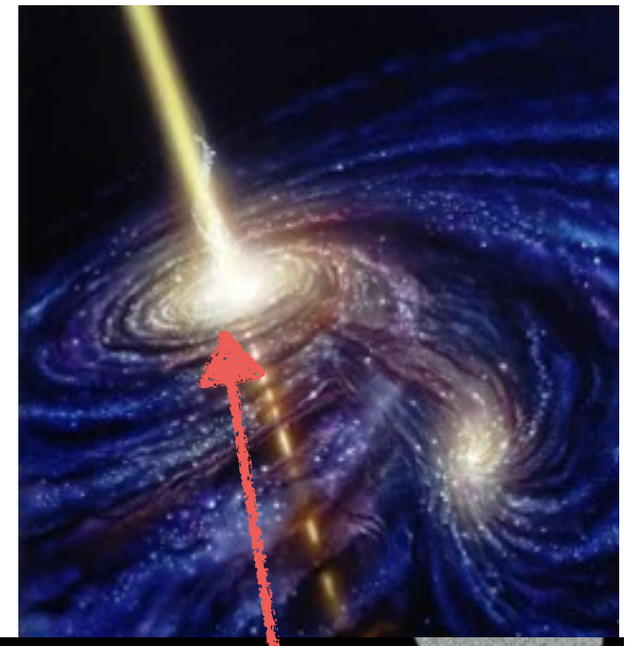
Kazuma Ishio
University of Tokyo

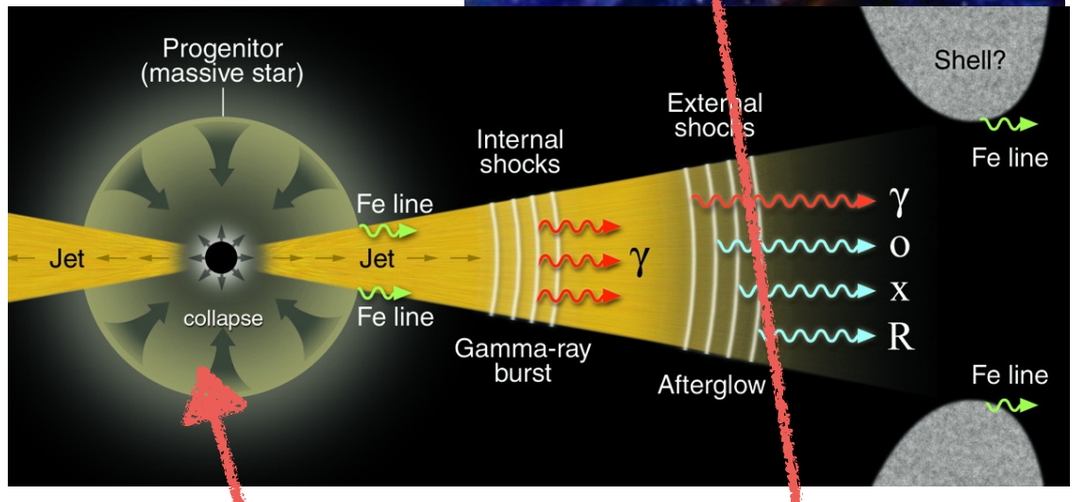
# Gamma-ray astrophysics

Attempts to solve extreme universe




- Galactic center
- Dark matter

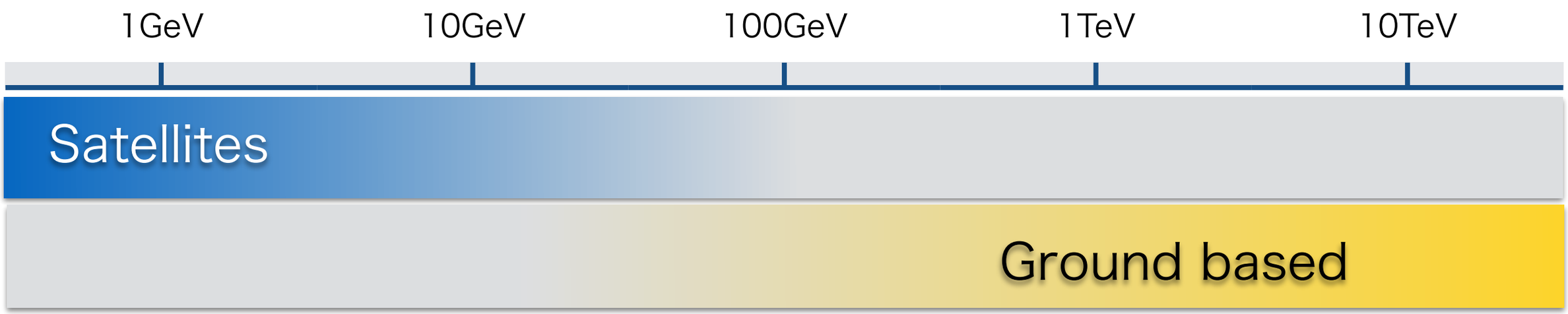


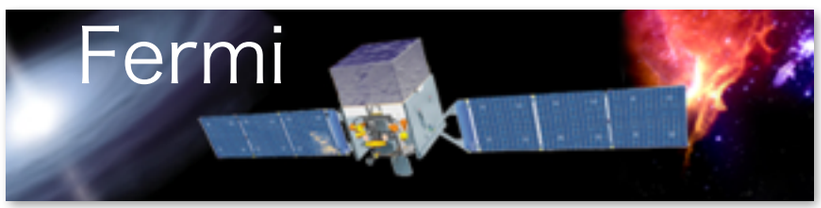


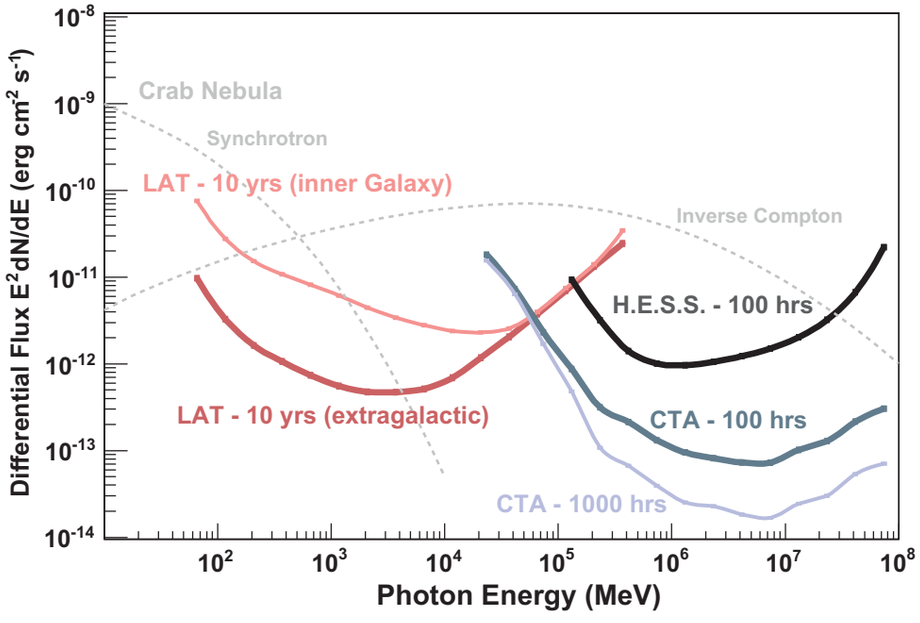

- Super Nova Remnants and pulsars
- Star formation history and Inter Galactic Magnetic Field by EBL absorption
- Gamma Ray Bursts
- Active Galactic Nuclei

**TeV scale universe is a space laboratory and a hint for Cosmic Ray origin**

# Energy range and detectors




IACT( Imaging Atmospheric Cherenkov Telescope)

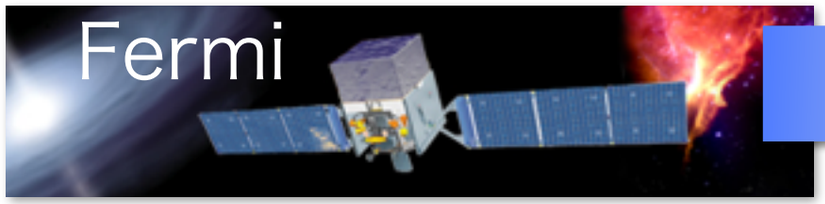


# Energy range and detectors

1GeV　10GeV　100GeV　1TeV　10TeV

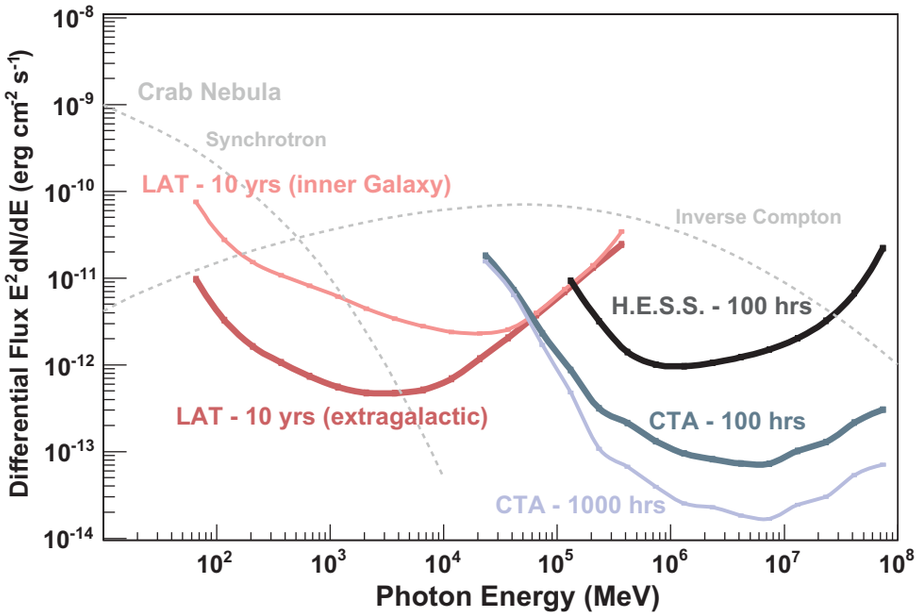
Satellites

Ground based

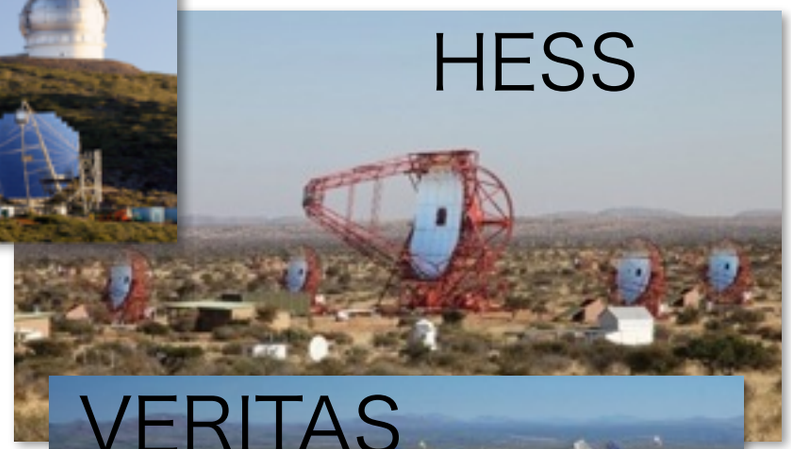



High E
→ Less flux

**Limited by photon statistics**




IACT( Imaging Atmospheric Cherenkov Telescope)

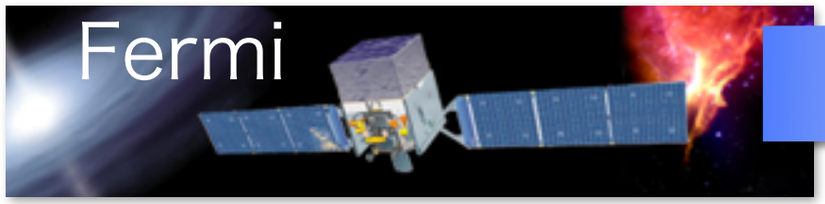




# Energy range and detectors

1GeV 10GeV 100GeV 1TeV 10TeV

Satellites

Ground based

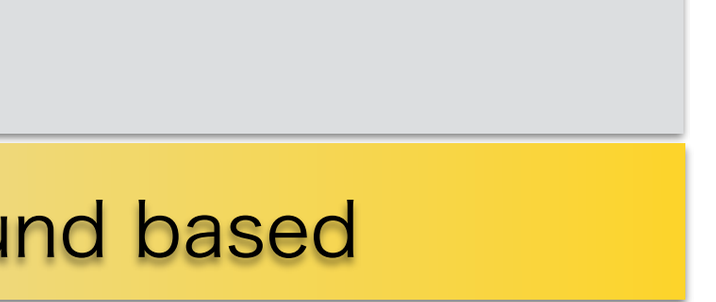



High E
→ Less flux

Limited by photon statistics

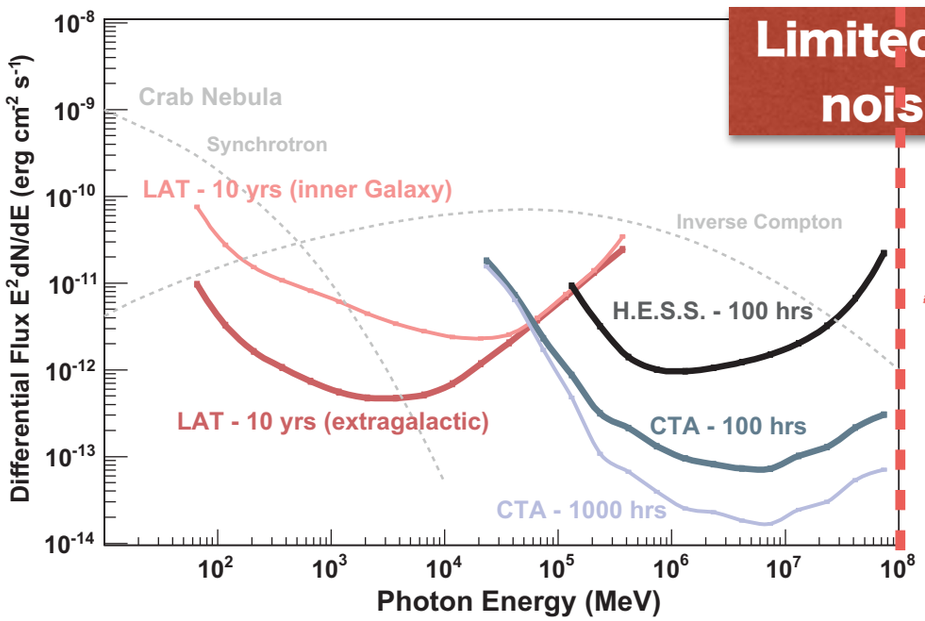
IACT( Imaging Atmospheric Cherenkov Telescope)






Low E
→ dim shower

Limited by noise

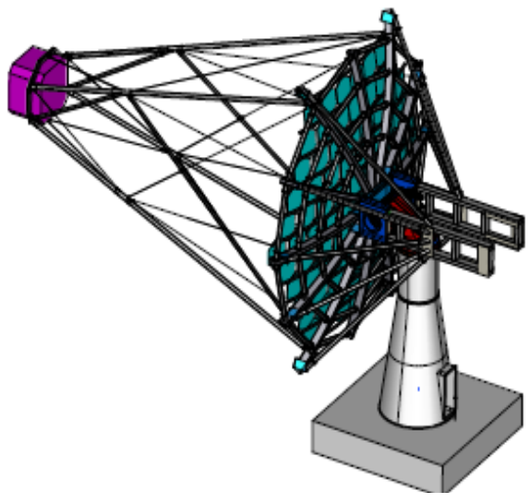



"valley"

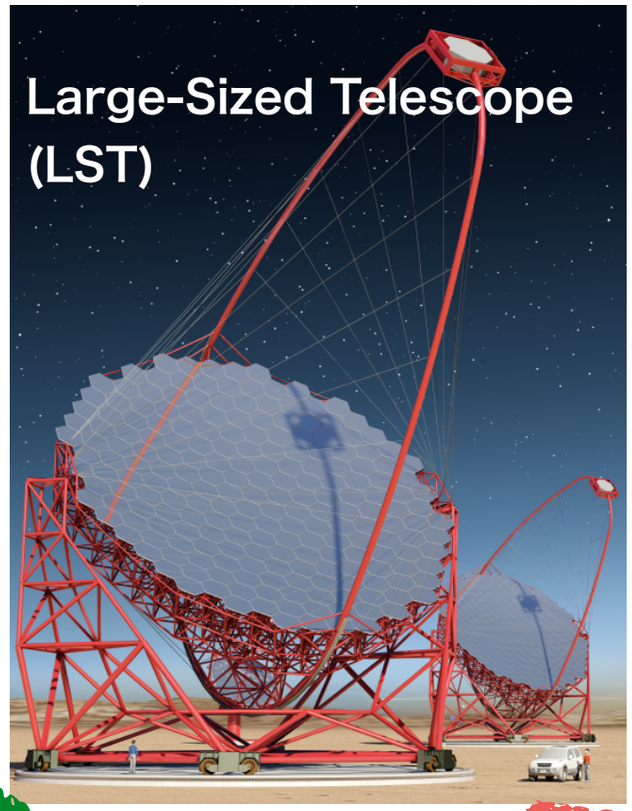
but, important range for high redshift sources…

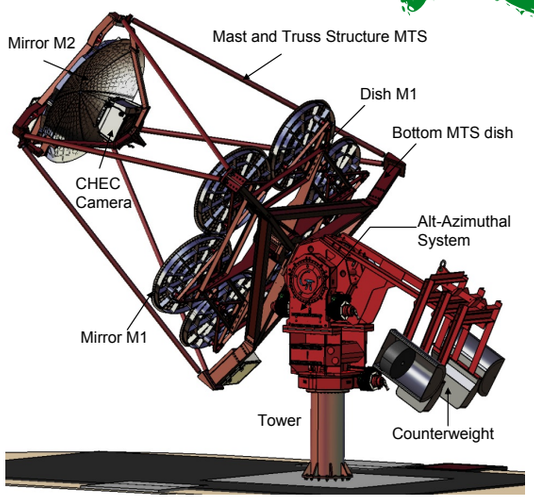
# CTA project — next generation IACT

## x10 sensitivity in 4 decades of E range

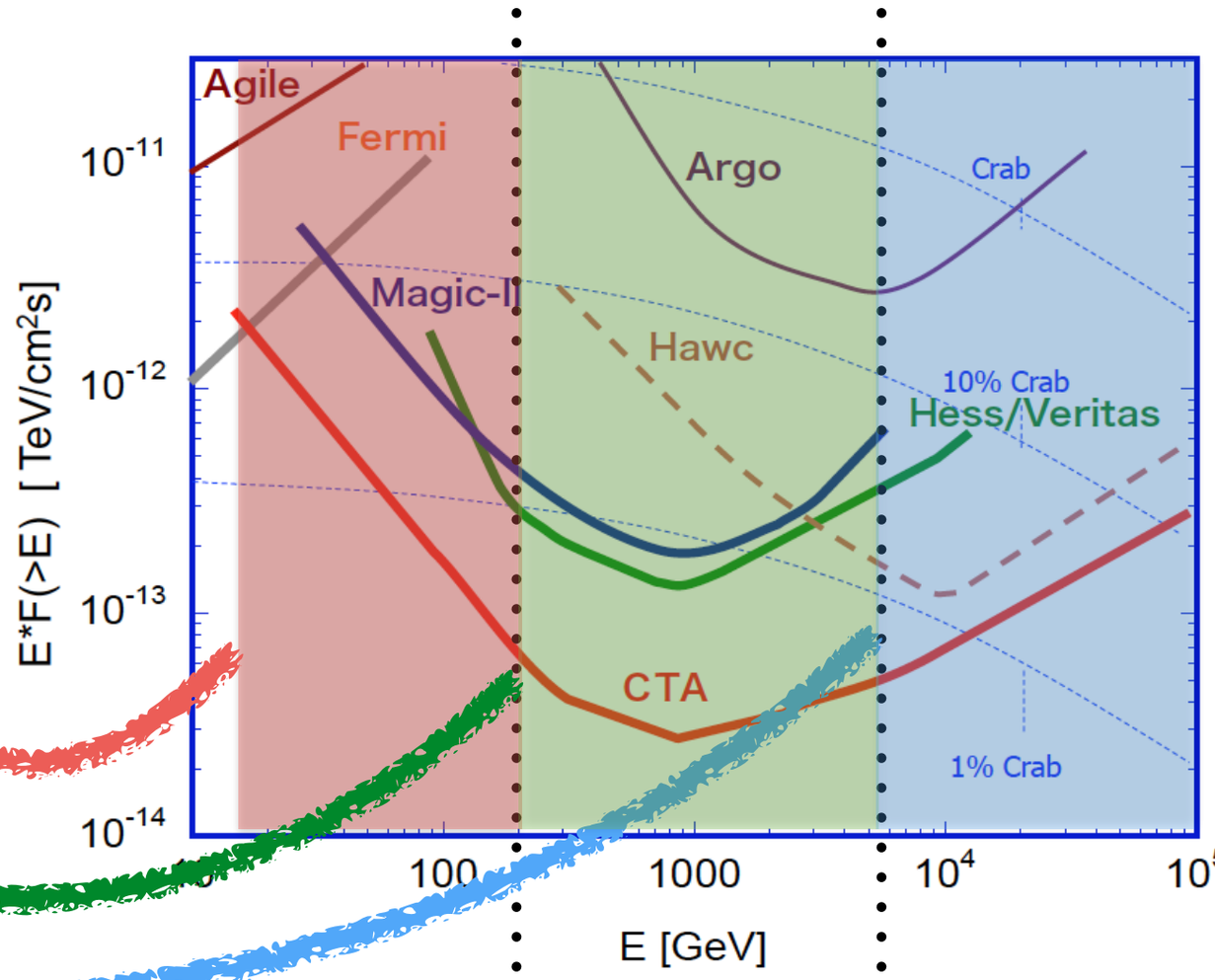


Mid-Sized Telescope (MST)




Small-Sized Telescope (SST)



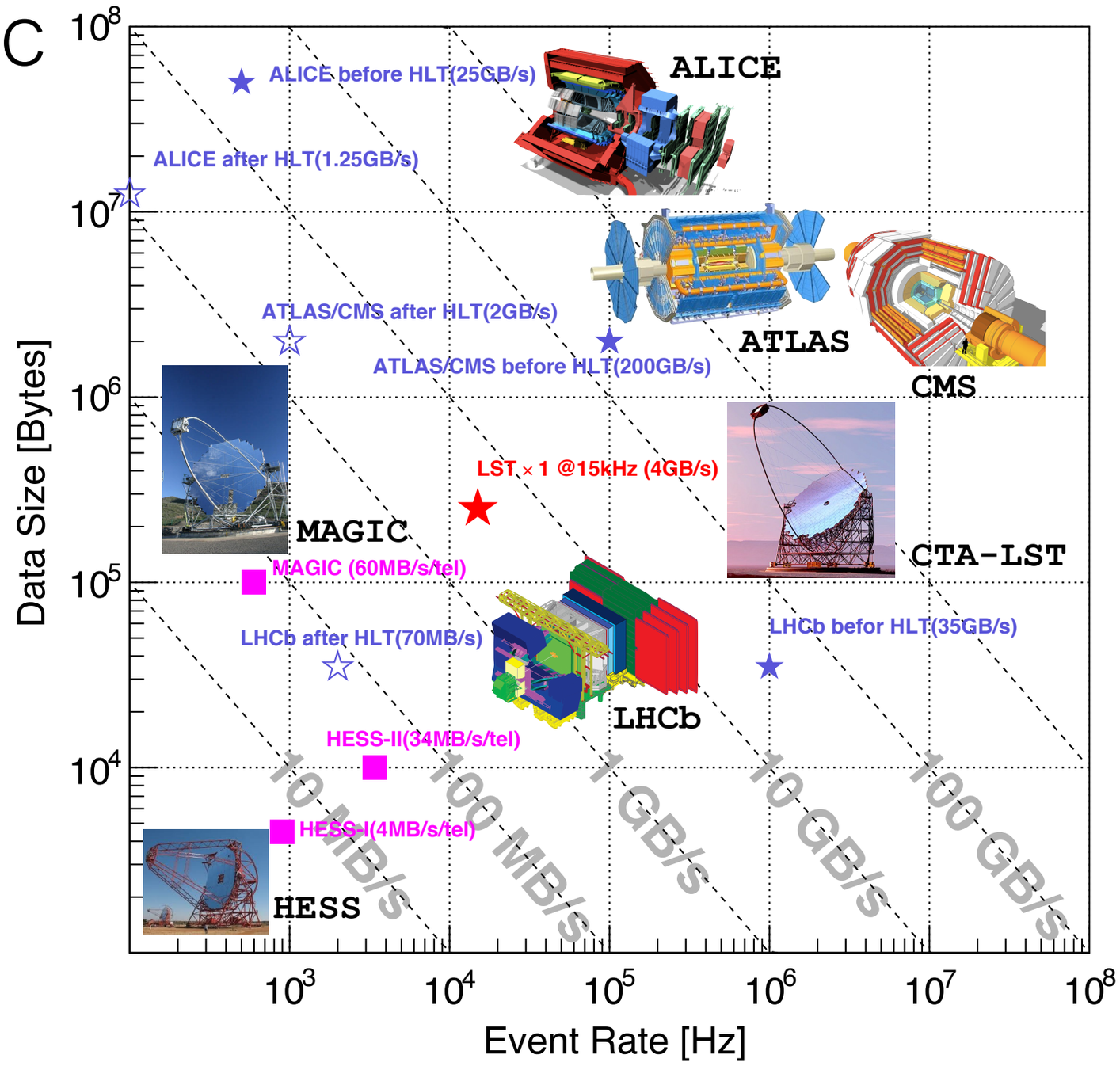

**For 3 E ranges, dedicated types are designed.**

# So much stress on LST DAQ

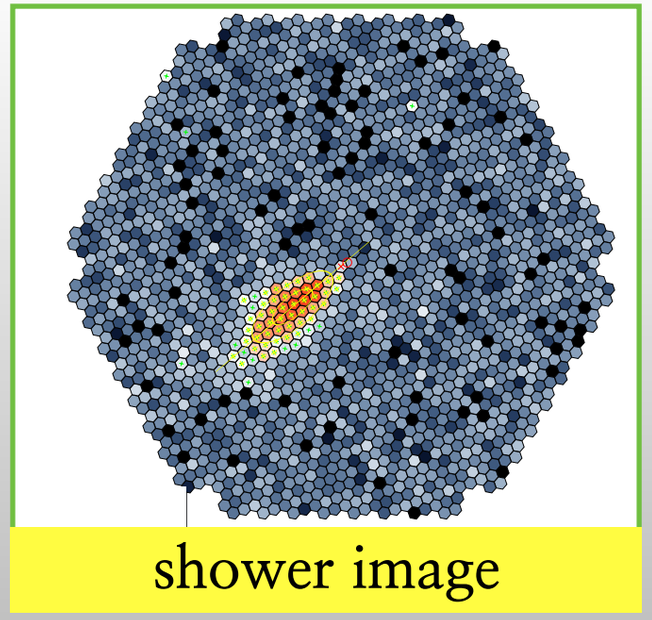
LST design based on MAGIC

- E threshold ~ 20GeV
  (MAGIC : 30GeV)
- FoV ~ 4.5°
  (MAGIC : 2.5°)
- Stereo with 4 tels.
  (MAGIC : 2tels)

**Estimated DAQ rate**
15kHz ～**32Gbps/tel**
(MAGIC : 600Hz)

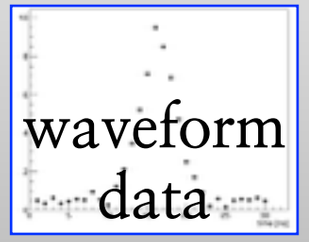


# Trigger rate and DAQ rate



shower image

by



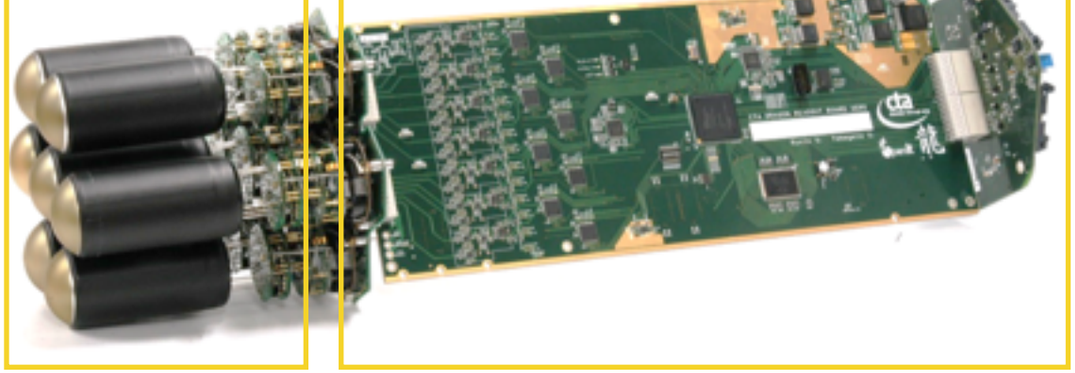

×1855

=

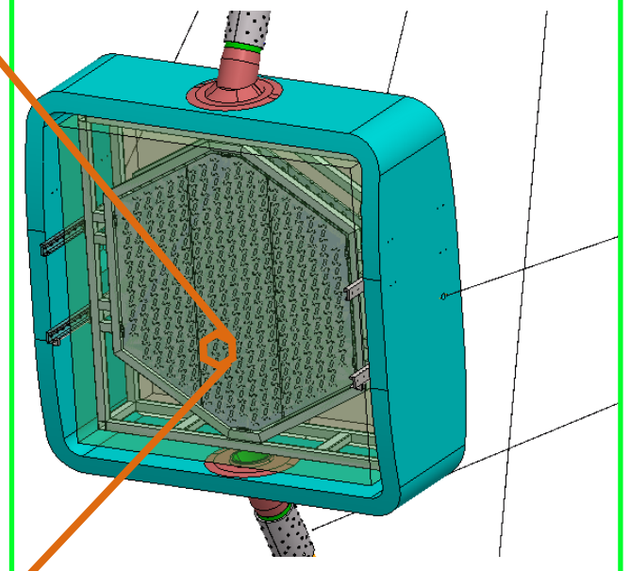
1event ~ 265kB
(1kB/module x 265 )
15kHz ~ 32Gbps

PMT
×7

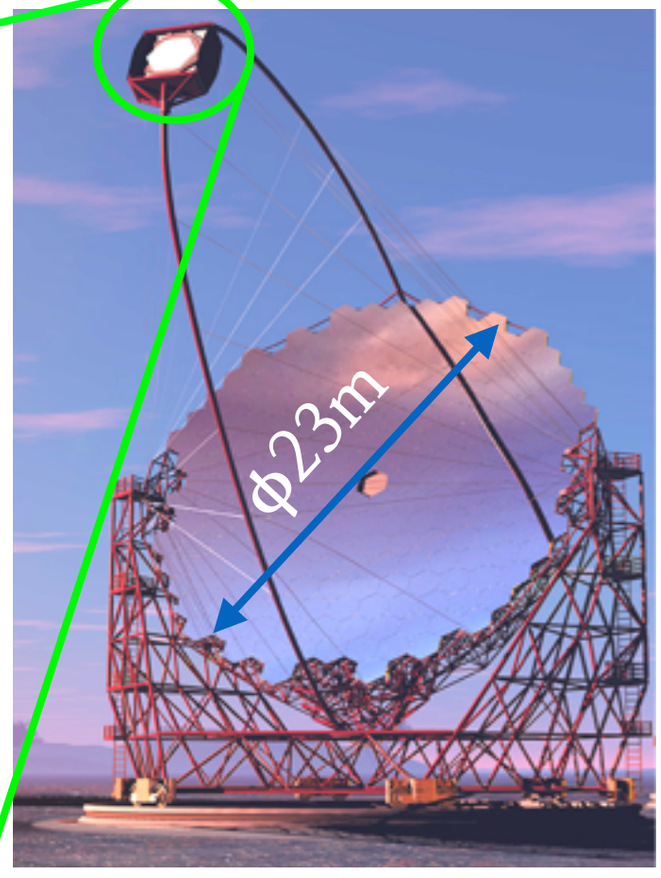
Frond End Board
“Dragon”



module×265



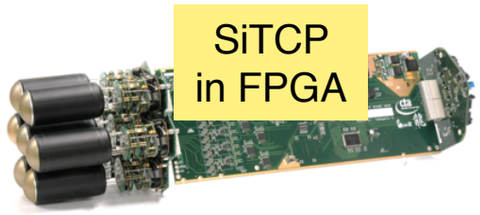
Camera




Telescope(LST)

# Hardware design for DAQ

Based on the connection via TCP/IP protocol



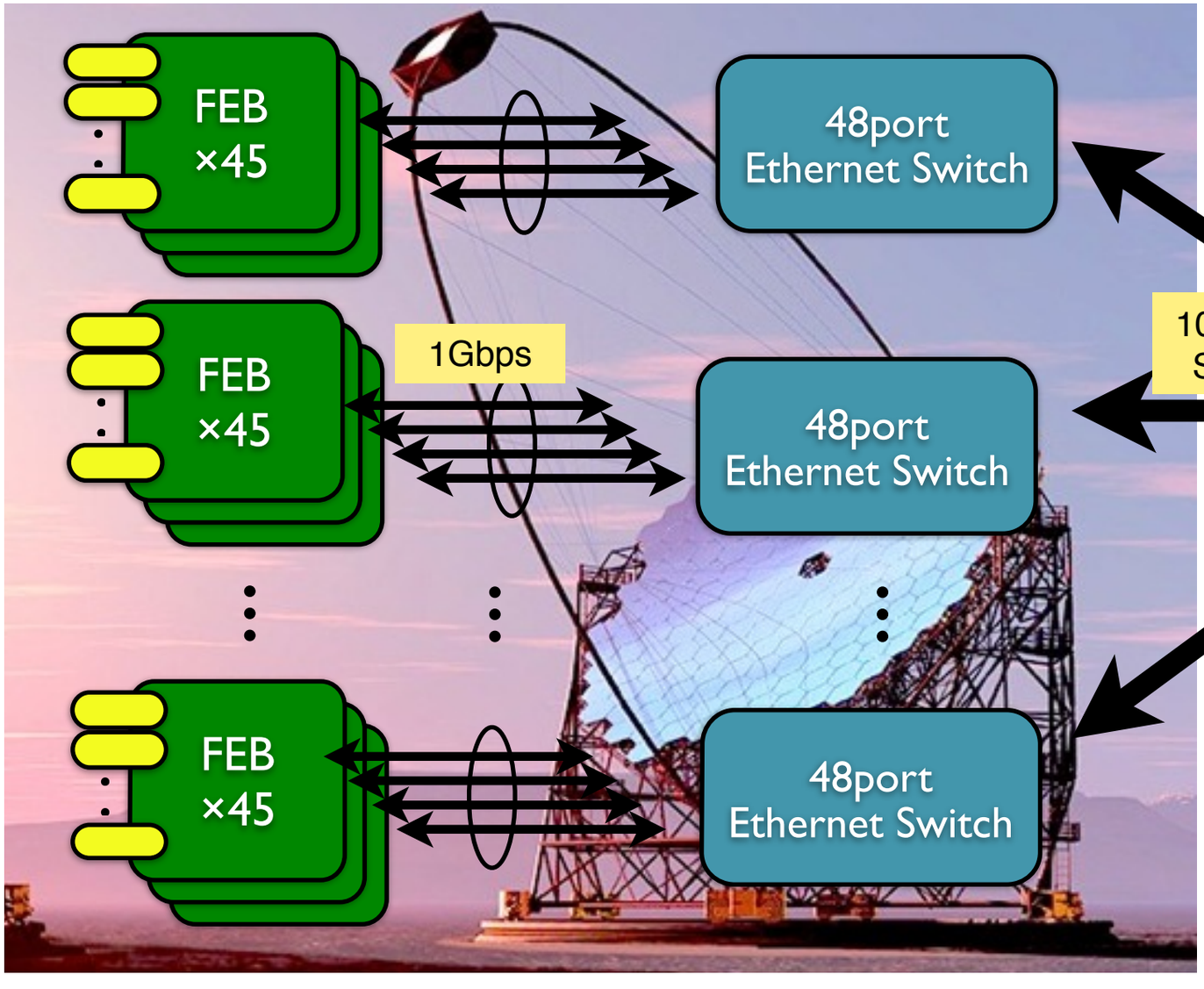

PMT
×1855

FEB
×265

120Mbps
x 265

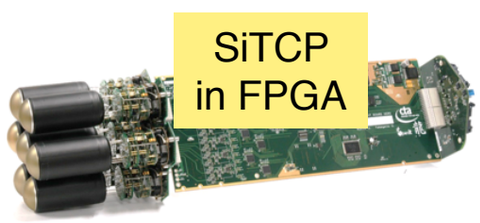
Switch
×6

5.4Gbps
x 6



# Hardware design for DAQ

Based on the connection via TCP/IP protocol



SiTCP in FPGA

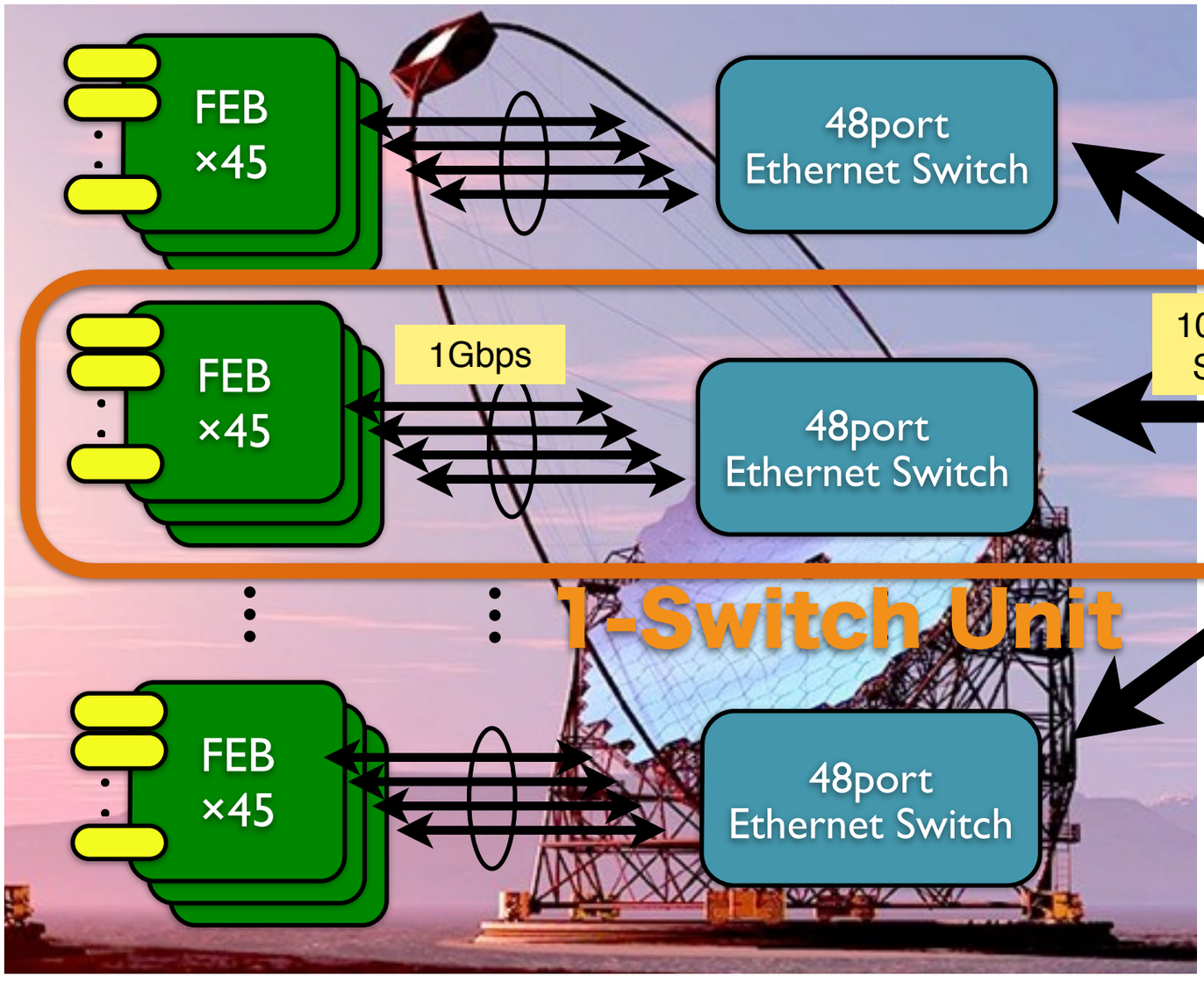
PMT ×1855

FEB ×265

120Mbps x 265

Switch ×6

5.4Gbps x 6




Central Control

Control signals

Monitoring Data

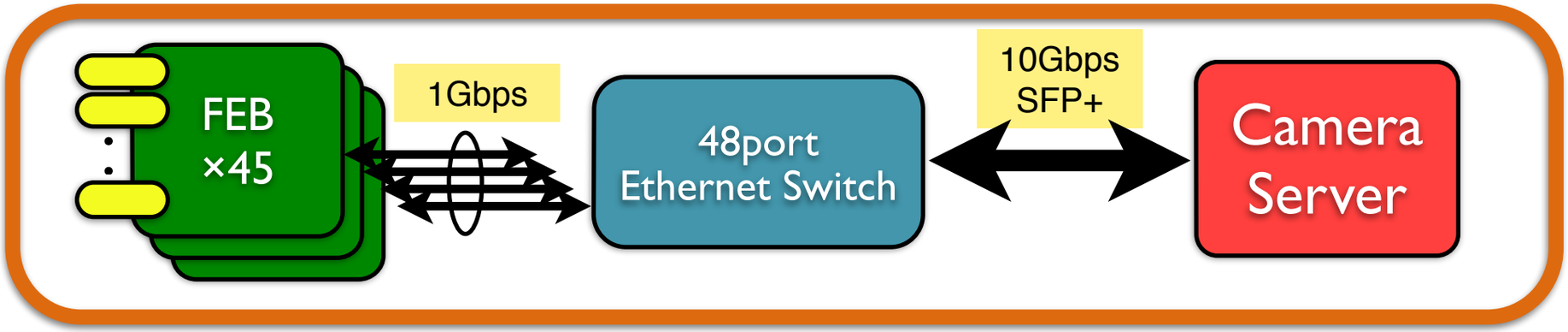
10Gbps SFP+

Camera Server

Obs. Data

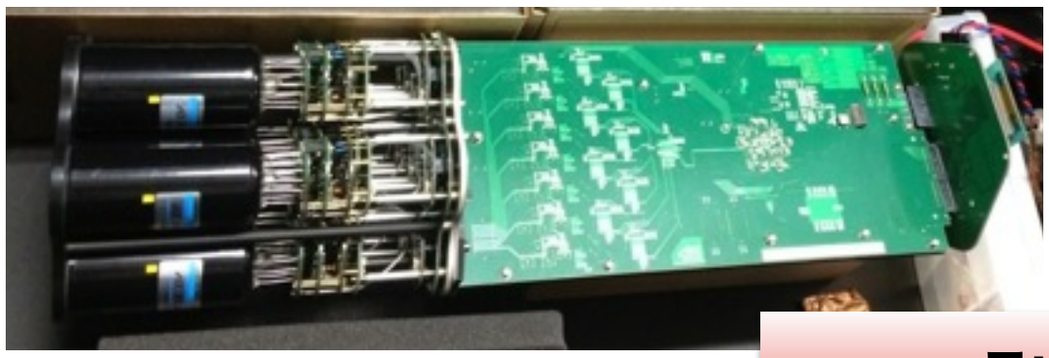
Data Store

# Representative devices used



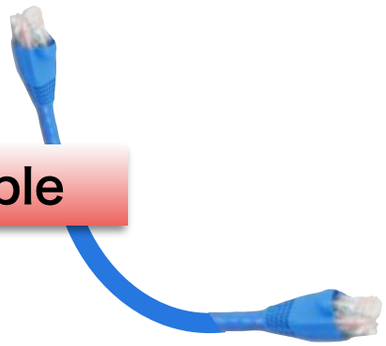

1-Switch Unit

## Dragon FEB



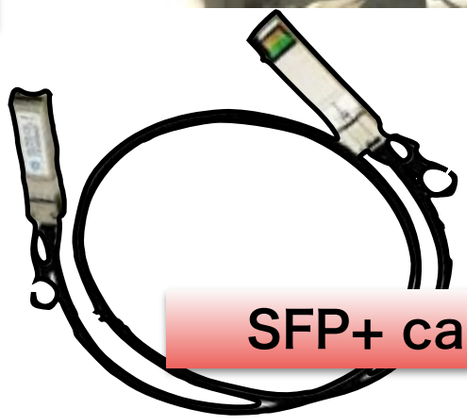
## Camera Server


## Cat6 cable



## Ethernet Switch


## SFP+ cable



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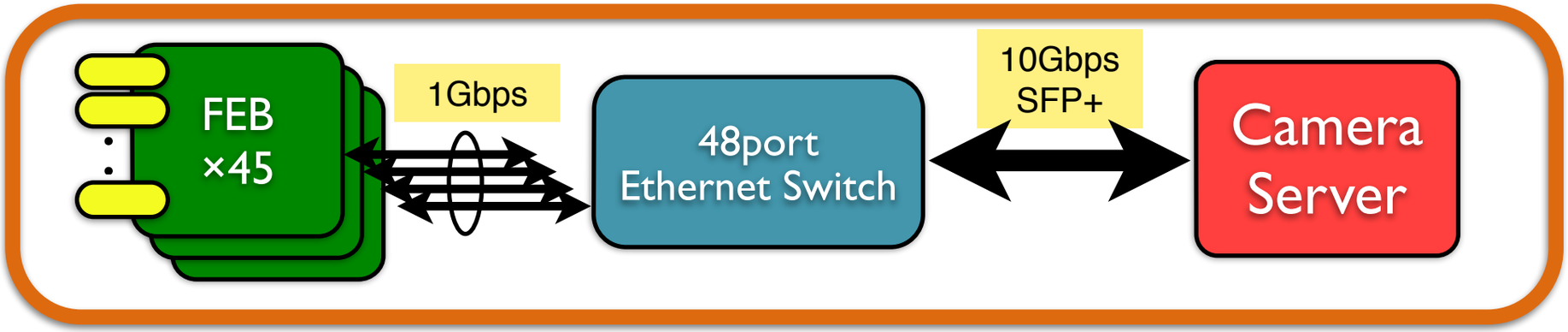
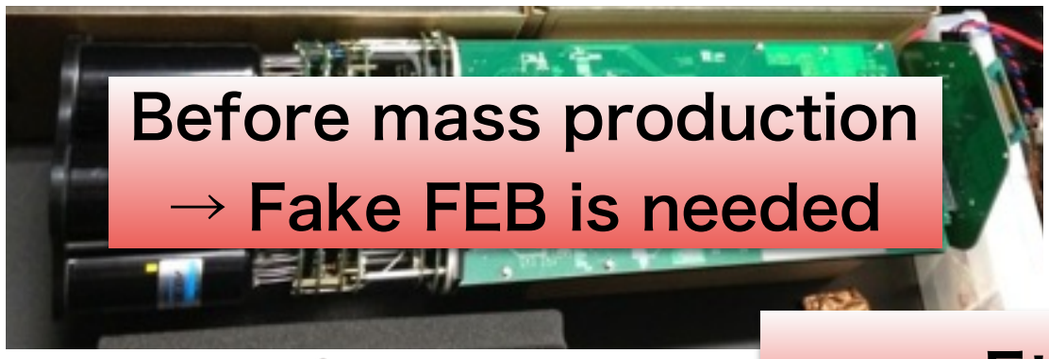
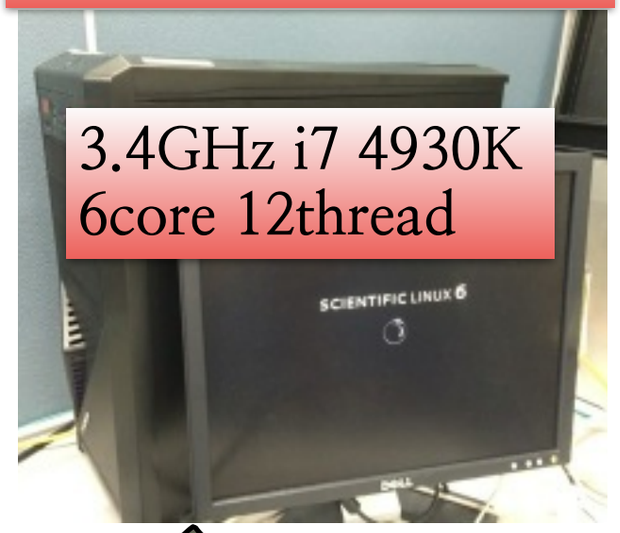



## 1-Switch Unit

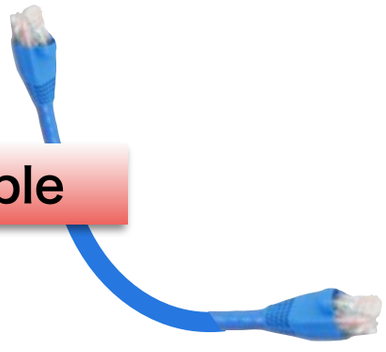
### Dragon FEB




### Camera Server

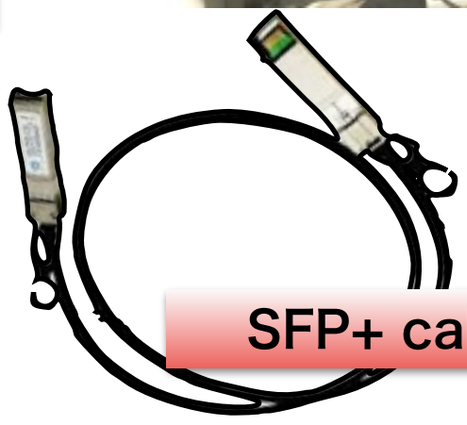



### Cat6 cable

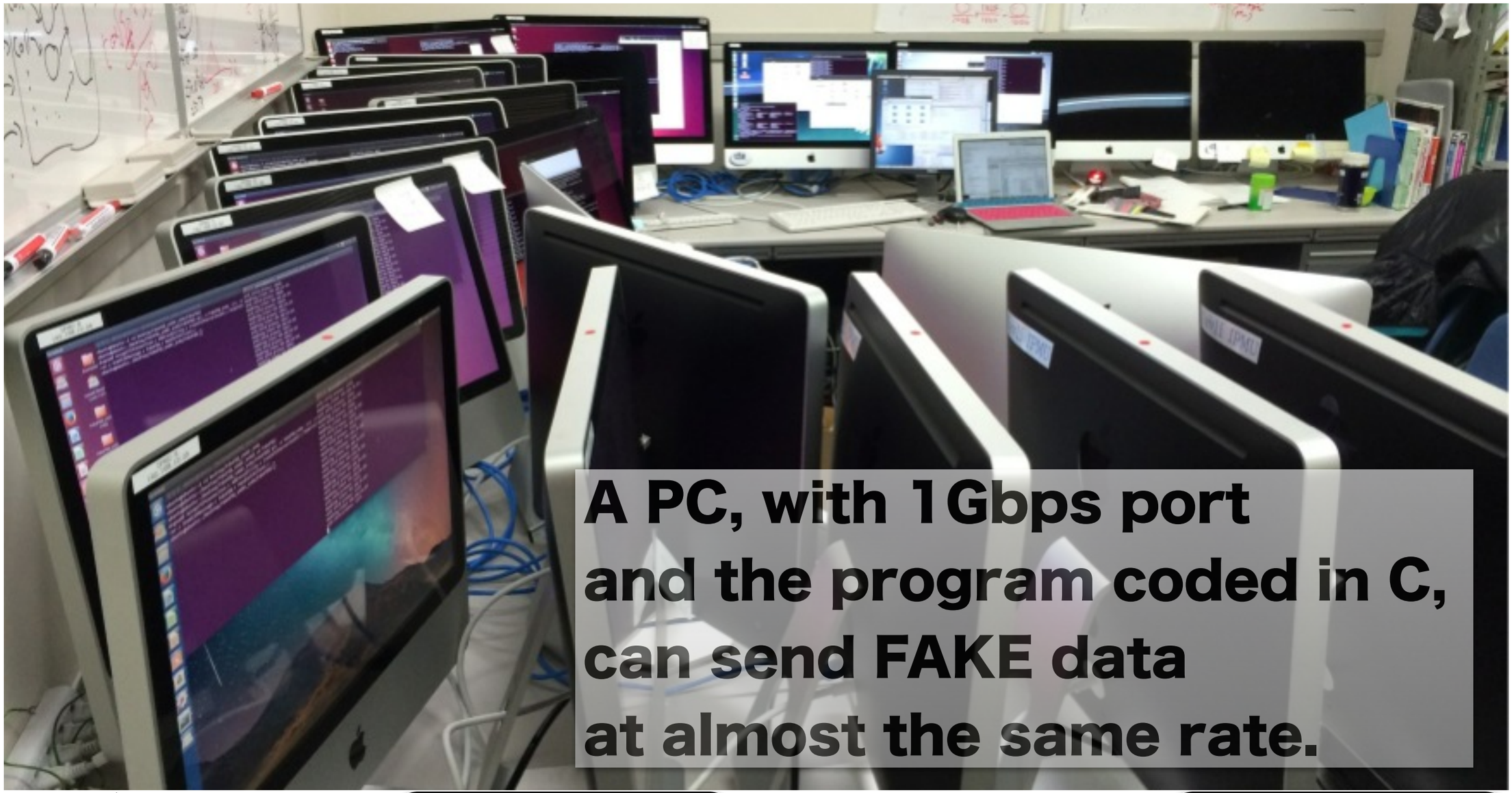


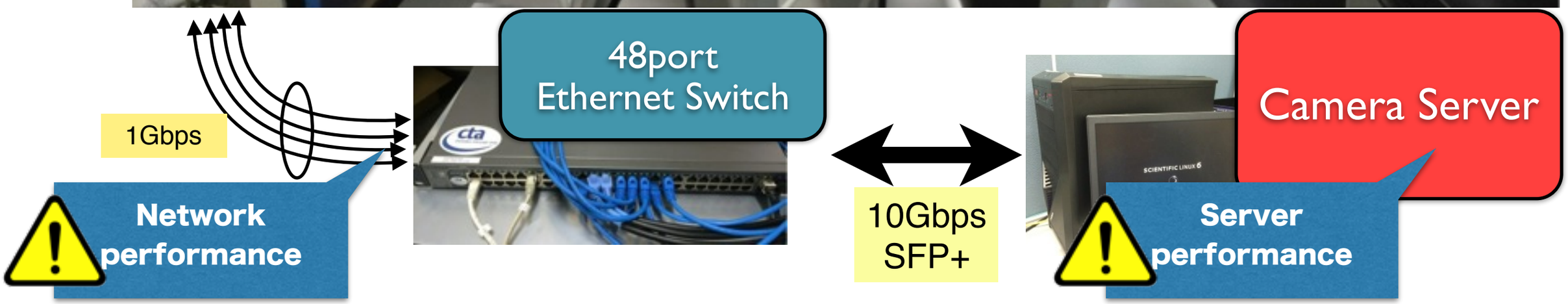
### Ethernet Switch


### SFP+ cable



# “Fake” FEBs — 26 iMac

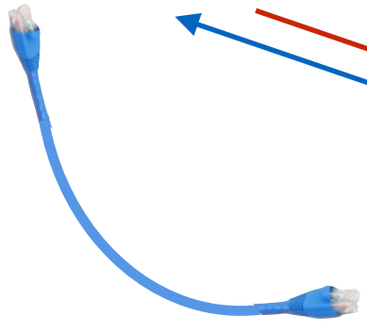


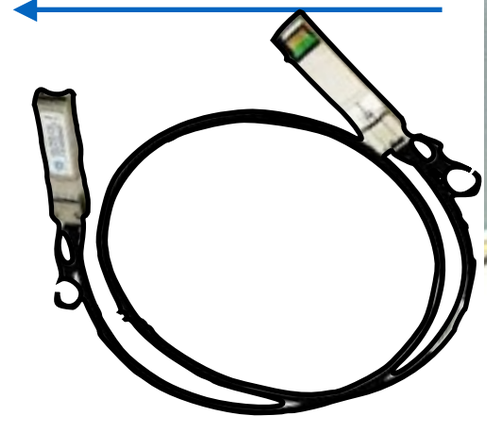



# UDP based trigger functionality

**Dragon FEB is triggered by hardware signal.**
**Fake FEB is triggered by UDP packet.**


Trigger
Data



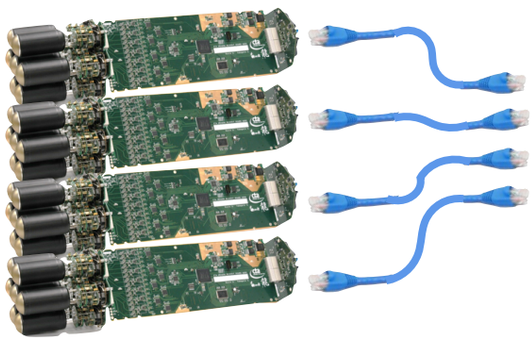


Camera Server

**LSTDAQ**
**TriggerGenerator**

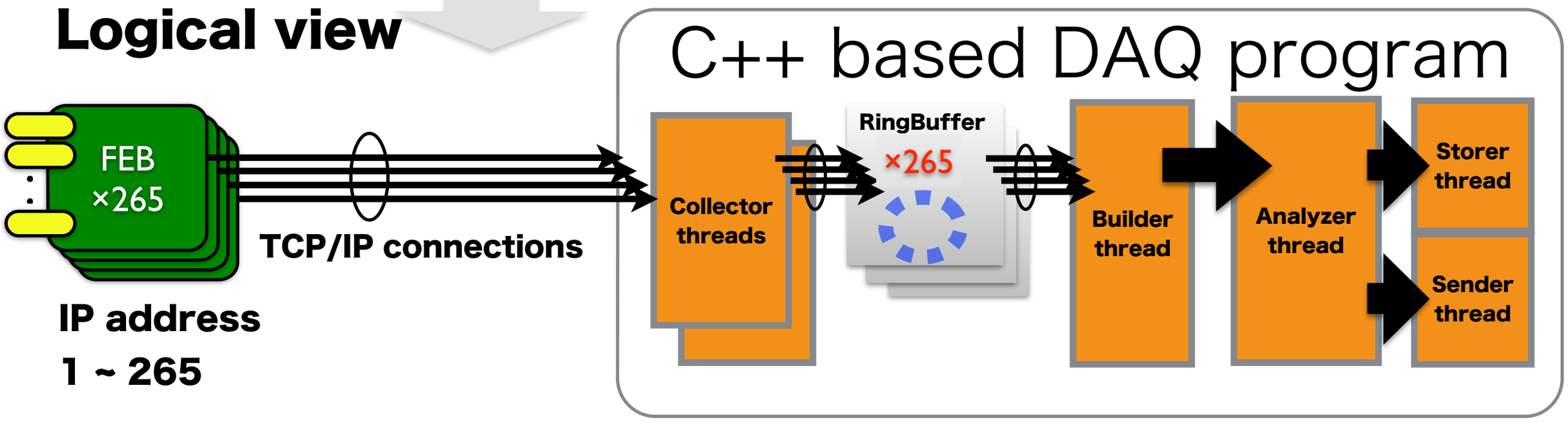
- Trigger flows opposite to data
  → data flow is secure
- UDP focuses on realtime
- Simultaneous distribution by broadcasting
- Trigger number inside the packet (for event building)

# DAQ program



Physical view

Logical view



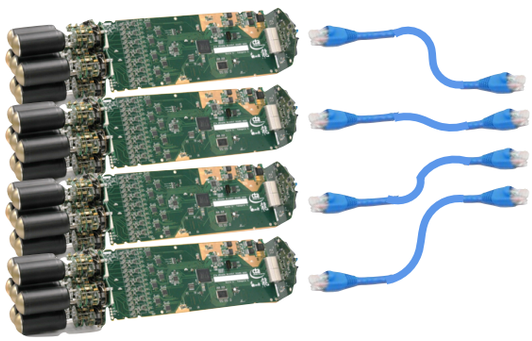

・RingBuffers — Temporal buffer to perform eventbuilding

・Parallel computing by multi-thread

collector — connects to FEBs via TCP/IP, and stores arrived data from sockets to RingBuffers. # of collectors is configurable.

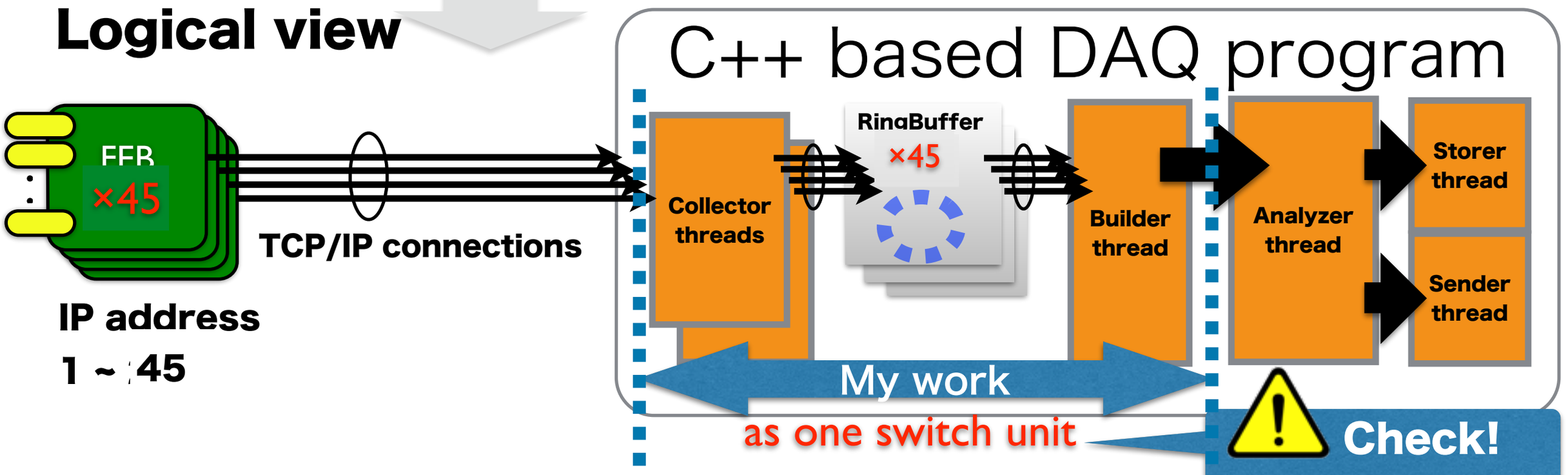
builder — performs event building, in which data from all connections are combined one by one.

# DAQ program



Physical view

Logical view

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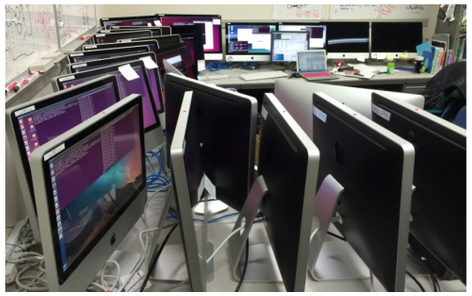
# Performance of Network & CPU( thread )

# Performance vs # of collectors



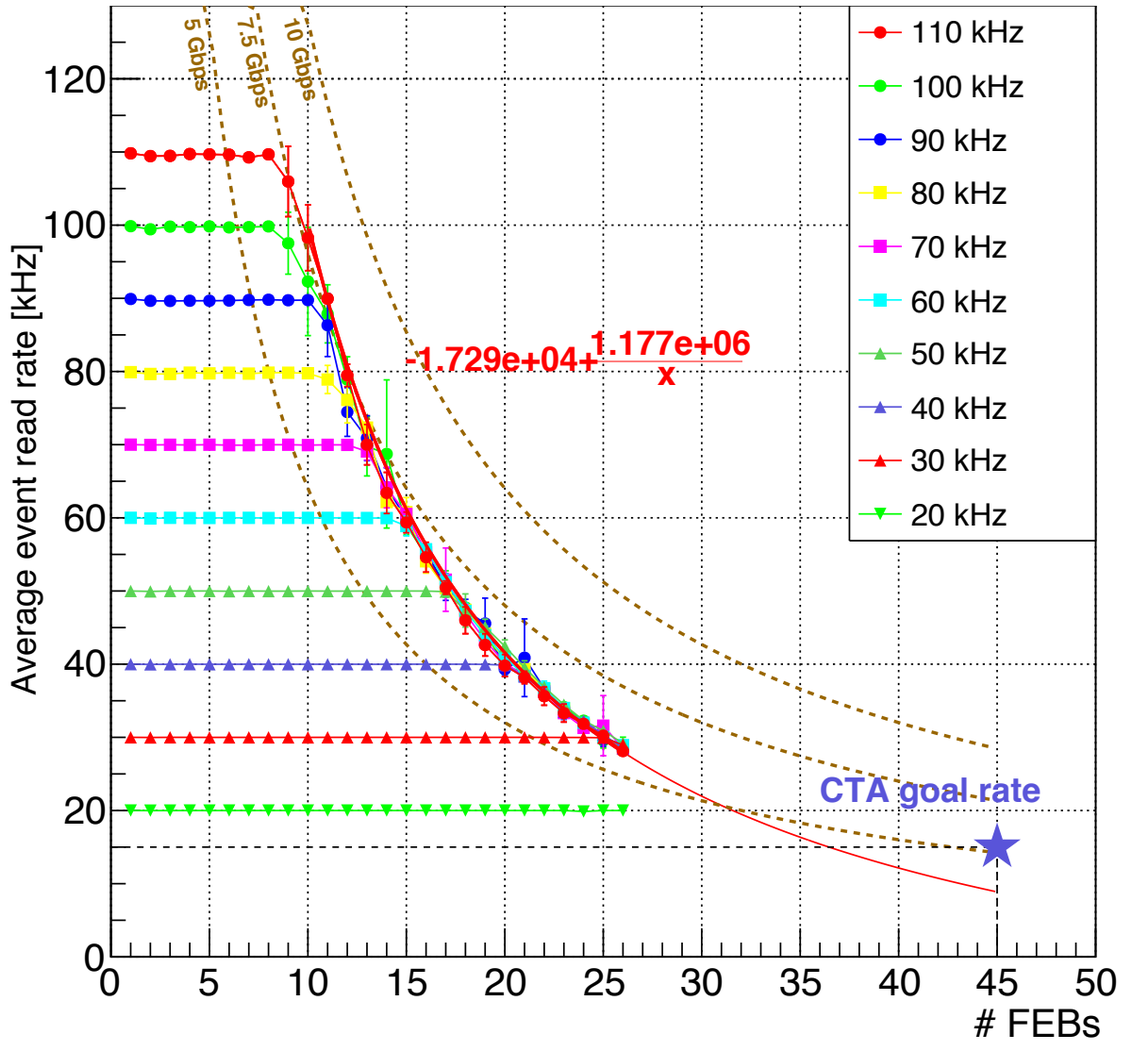
1Gbps
Ethernet ×N

48port
Ethernet Switch

10Gbps
SFP+

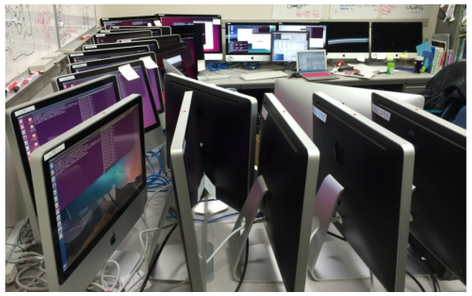
Camera Server

1 collector




Below goal rate

# Performance vs # of collectors



1Gbps
Ethernet ×N

48port
Ethernet Switch

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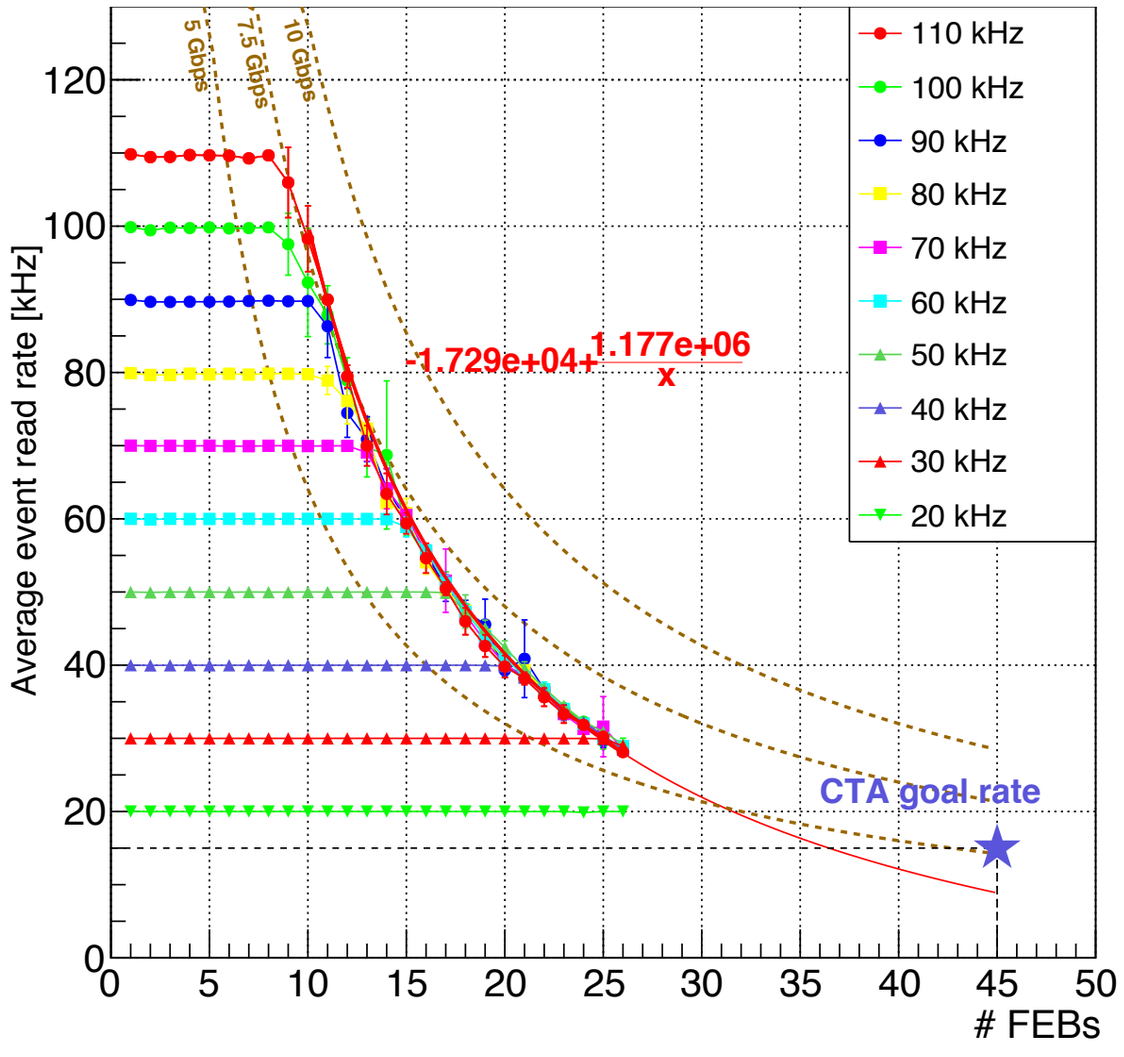
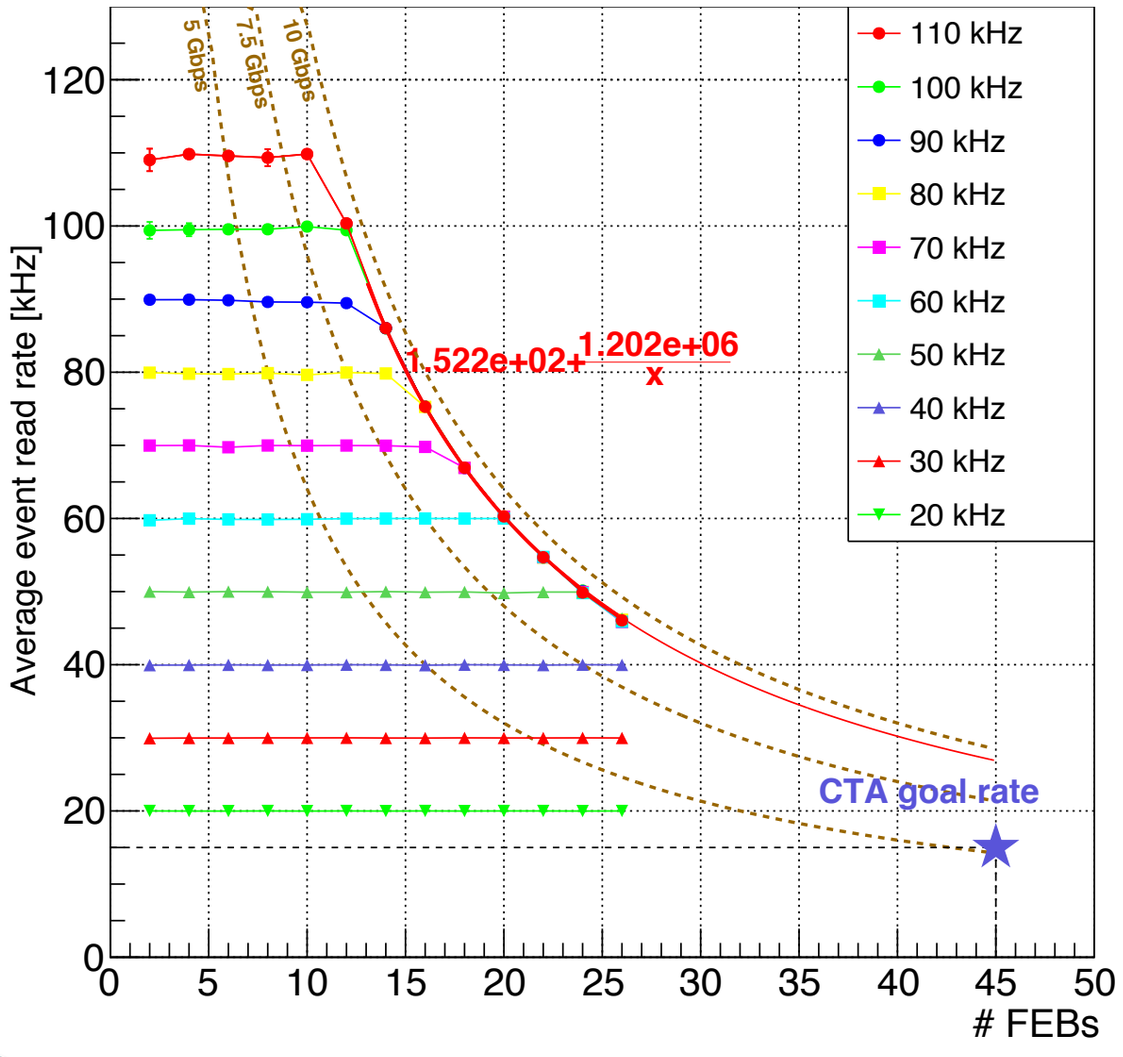
SFP+

Camera Server

## 1 collector



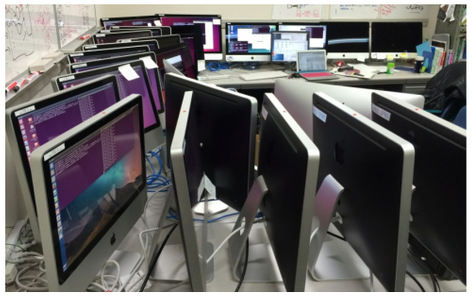

## 2 collectors

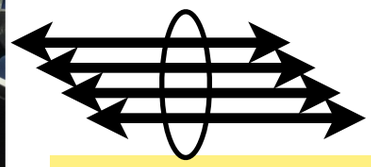



Below goal rate

Safety factor 2 is expected.

# Performance vs # of fiber connections





1Gbps
Ethernet ×N

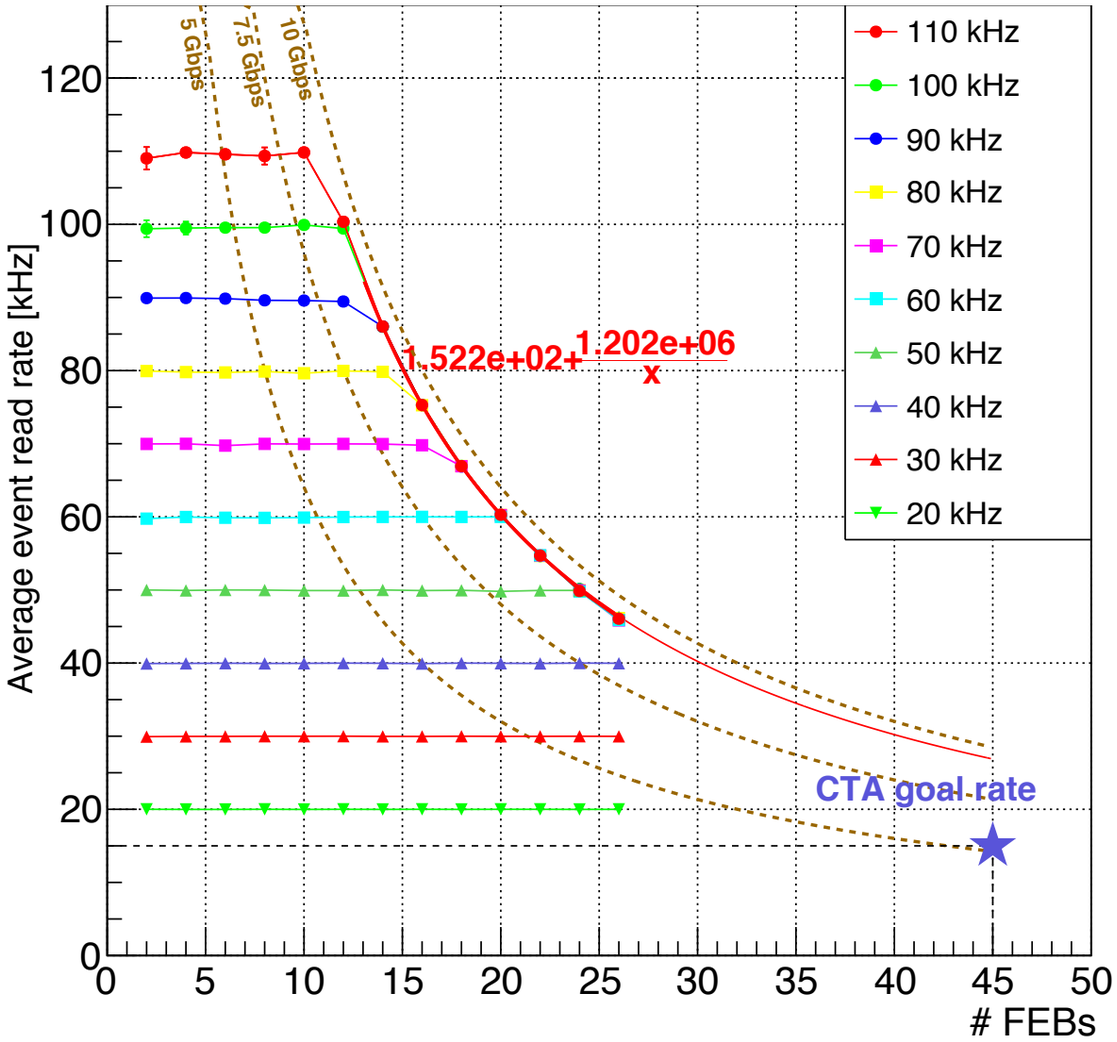
48port
Ethernet Switch

10Gbps
SFP+

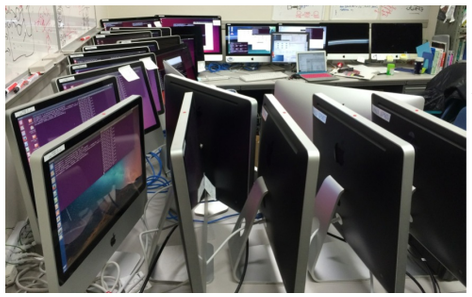
Camera Server

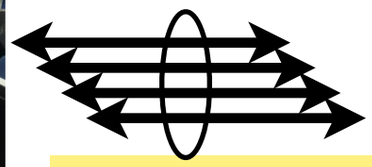
2collectors, 1 ×10Gbps SFP+

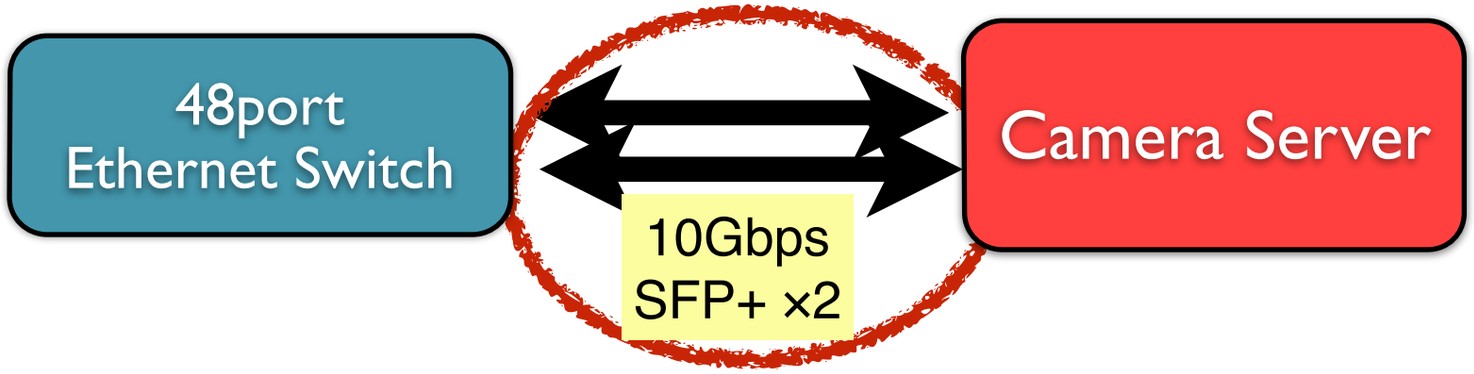
**Limited by 10Gbps connection**



# Performance vs # of fiber connections

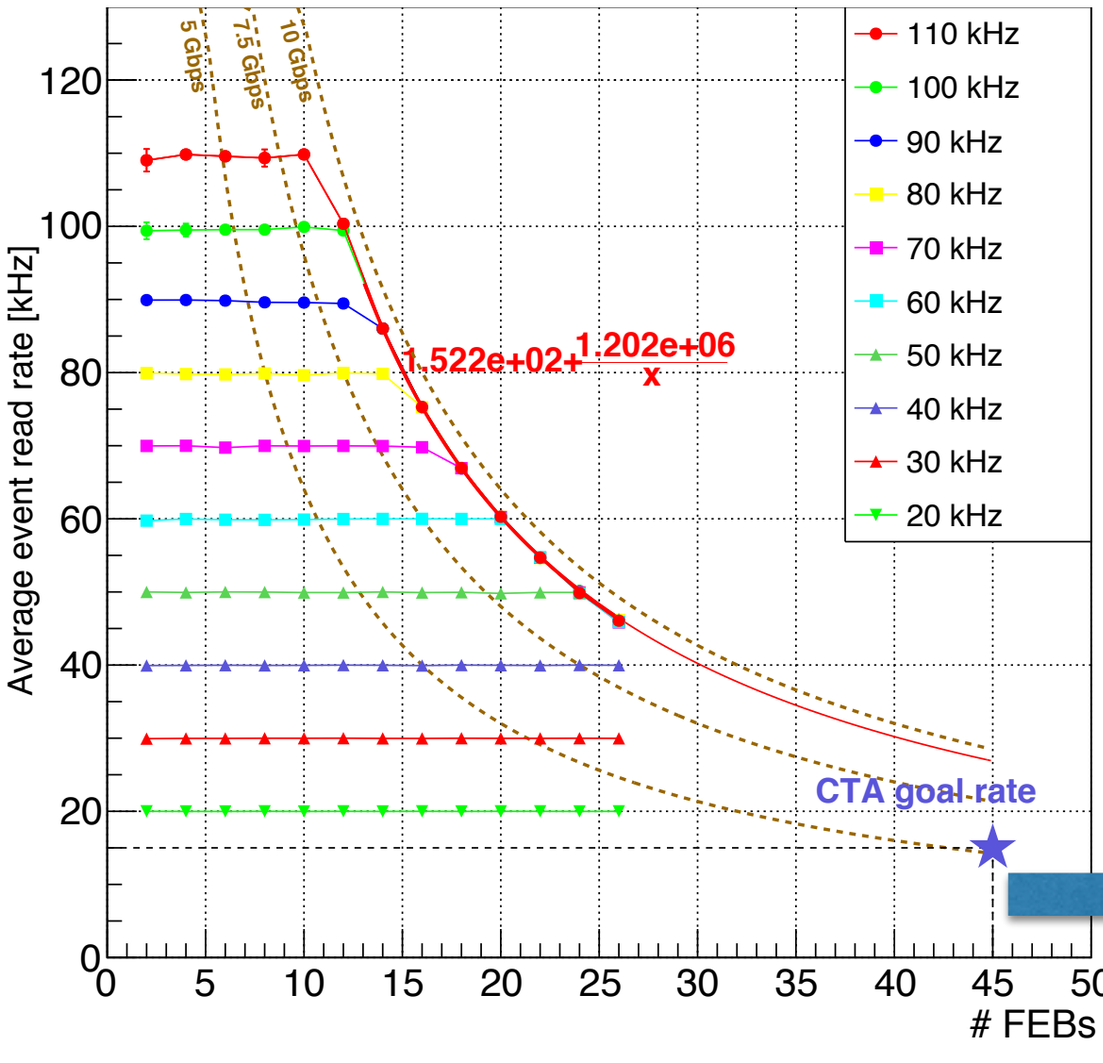




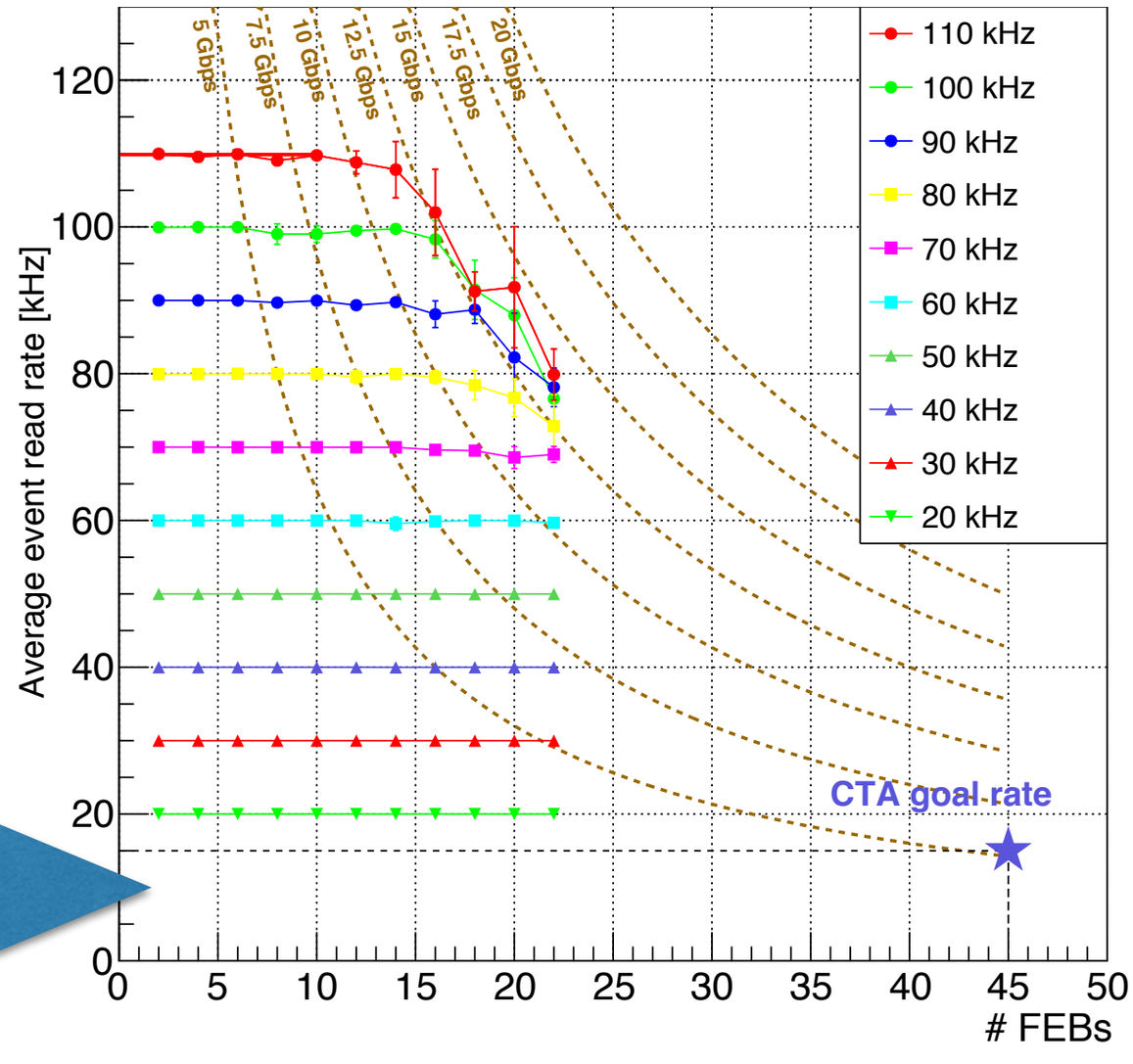

2collectors, 1 ×10Gbps SFP+

**Limited by 10Gbps connection**




2collectors, 2×10Gbps SFP+

**Limited by CPU core speed**



# Stability

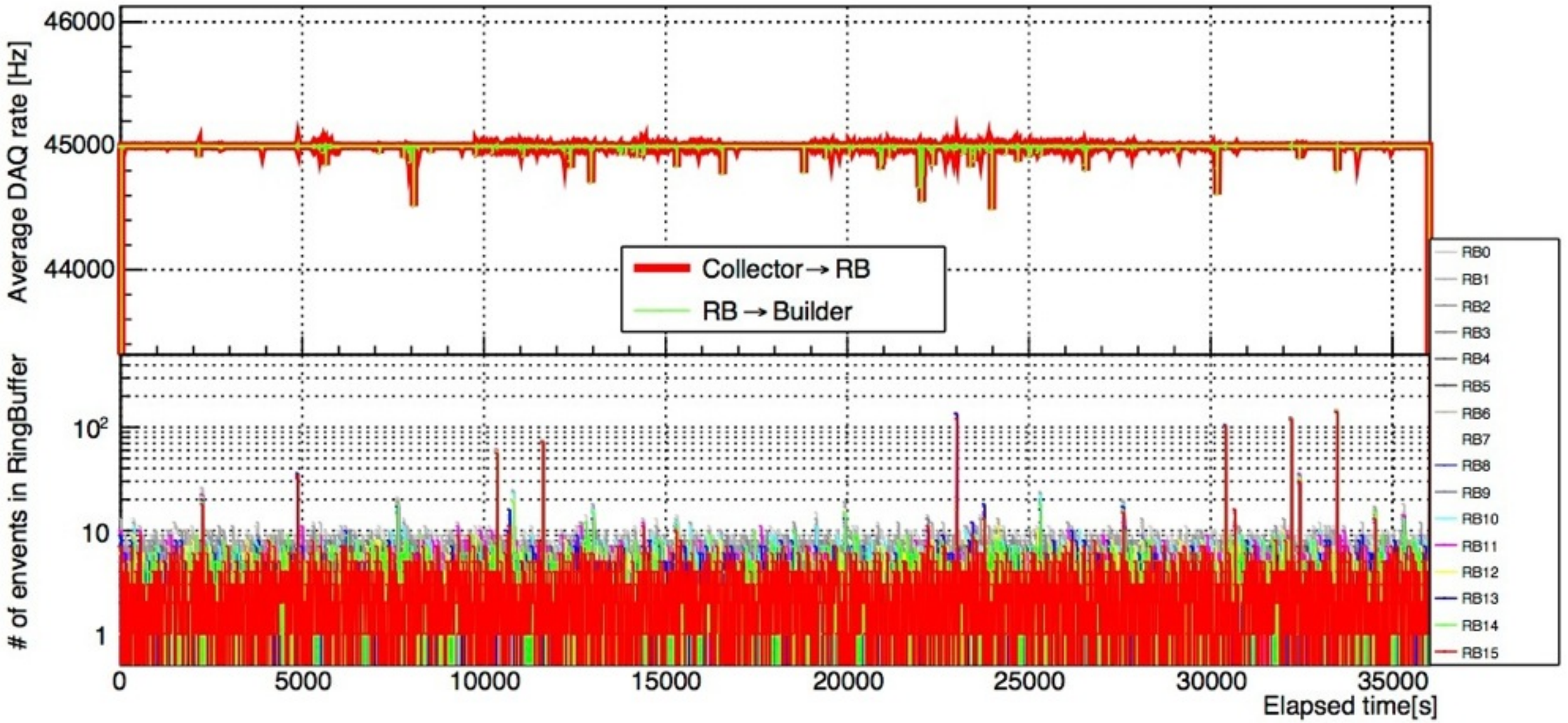
# Long-term test (10hours)

・Data acquisition

from 16 Fake FEBs at 45kHz trigger rate

(Same stress as from 48 FEBs at 15kHz trigger rate)

**・Performance meets the goal rate.**



# Summary

- The challenge for the lowest Energy threshold among all existing IACTs forces CTA-LST to have a very high trigger rate of ~15kHz, which leads to ultra high DAQ rate of ~40Gbps.

- I developed a first version of the DAQ program (in C++) as well as “fake FEB” for evaluating its performance.

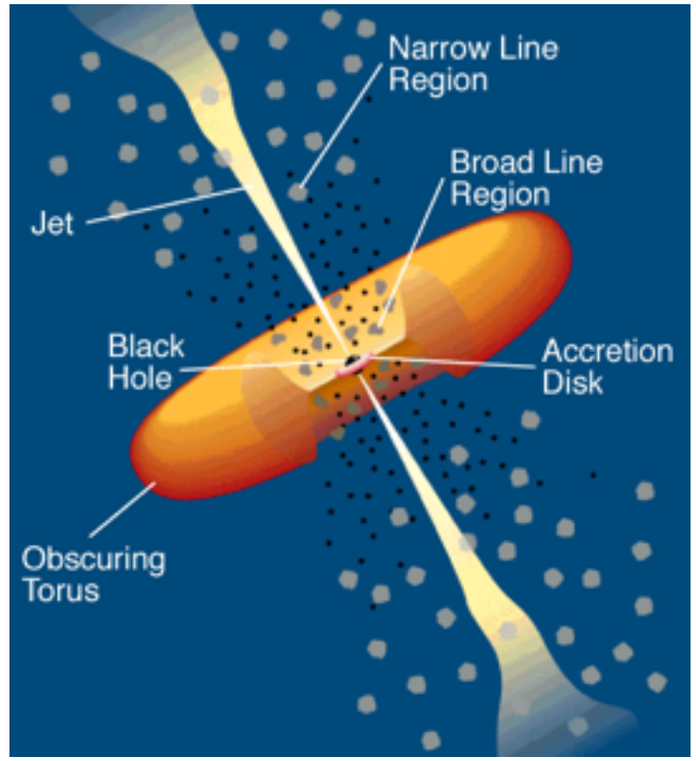
- The system fulfills the demanding requirements of CTA LST

  →Need to operate with 2 (or more) collectors.

# Active Galactic Nuclei (AGNs)

## Why do we need to study AGNs (→ Jets) ??

Although widely studied during the last <u>half century</u>
at different frequencies (from low-frequency radio
up to very high γ-ray photon energies) ,
they are still superficially understood objects.




Many key questions regarding extragalactic jets remain open:

- Jet composition *(B and ultrarelativistic e-e+; something else?)*
- Jet magnetic field *(how strong? what is its structure?)*
- Jet launching *(rotating SMBHs vs accretion disks)*
- Jet evolution and energetics *(kinetic power, lifetimes, „feedback")*
- Particle acceleration *(shocks? turbulence? reconnection?)*
- What produces variability on various timescales (years down to minutes)

**Gamma-ray astronomy provides a new window to study these objects.**

→ **High quality data only since few years:**
→ **At GeV energies with Fermi-LAT (since summer 2008)**
→ **At TeV energies with new generation of Cherenkov Telescopes (since 2004)**
→ **MAGIC had a substantial upgrades in 2012**

**During my PhD at MPP I would like to use this gamma-ray instrumentation to understand better these extreme objects**

# Motivation to do PhD in Max Planck Institute

**I want to work with MAGIC telescopes,**
**in order to do physics with high-quality gamma-ray observations,**
**and to get experience with a running instrument (operations and mentainance).**

## Study of AGN with MAGIC

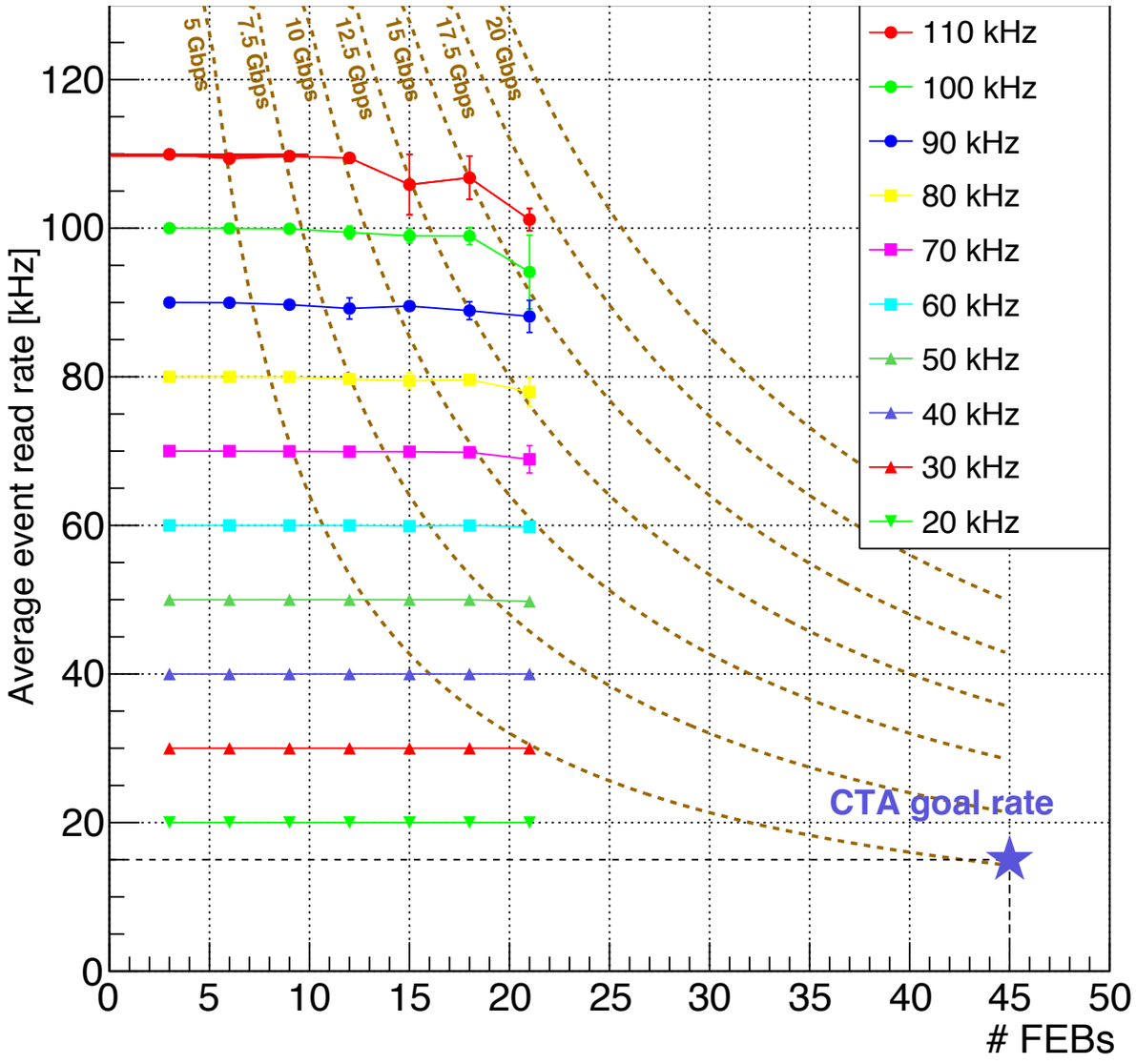
- **Jet (Composition, magnetic field, source, evolution)**
- **Particle acceleration in jet**
  **(shock, turbulence or reconnection)**
- **Source of variability of jet**
  **(years to minutes)**

## Comissioning of LST

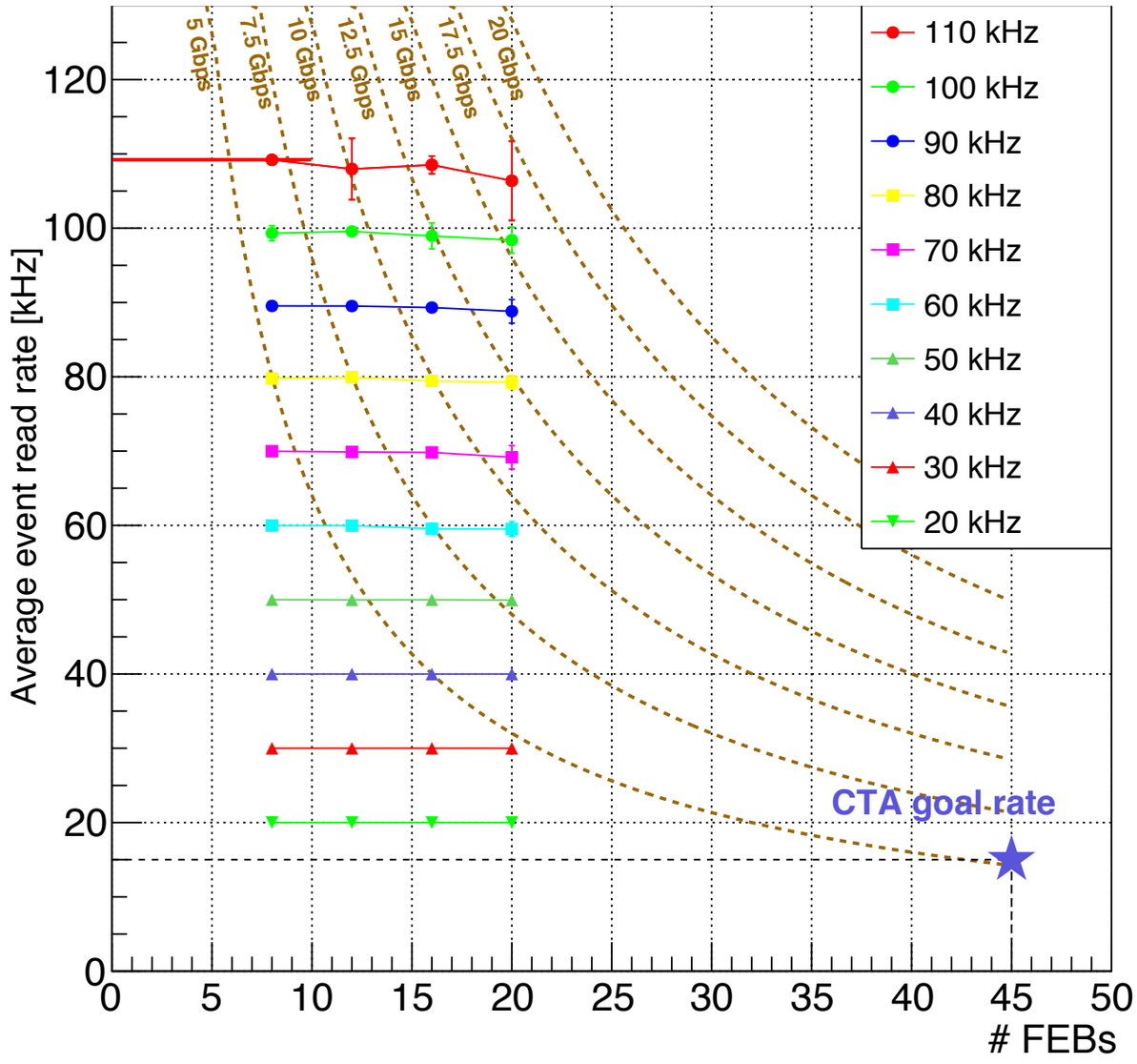
- **Technical:**
  **data reduction strategy, error handling …**
- **Physics:**
  **future AGN scientific program …**

# Effect of Doubling fiber connections

3 collectors




4 collectors

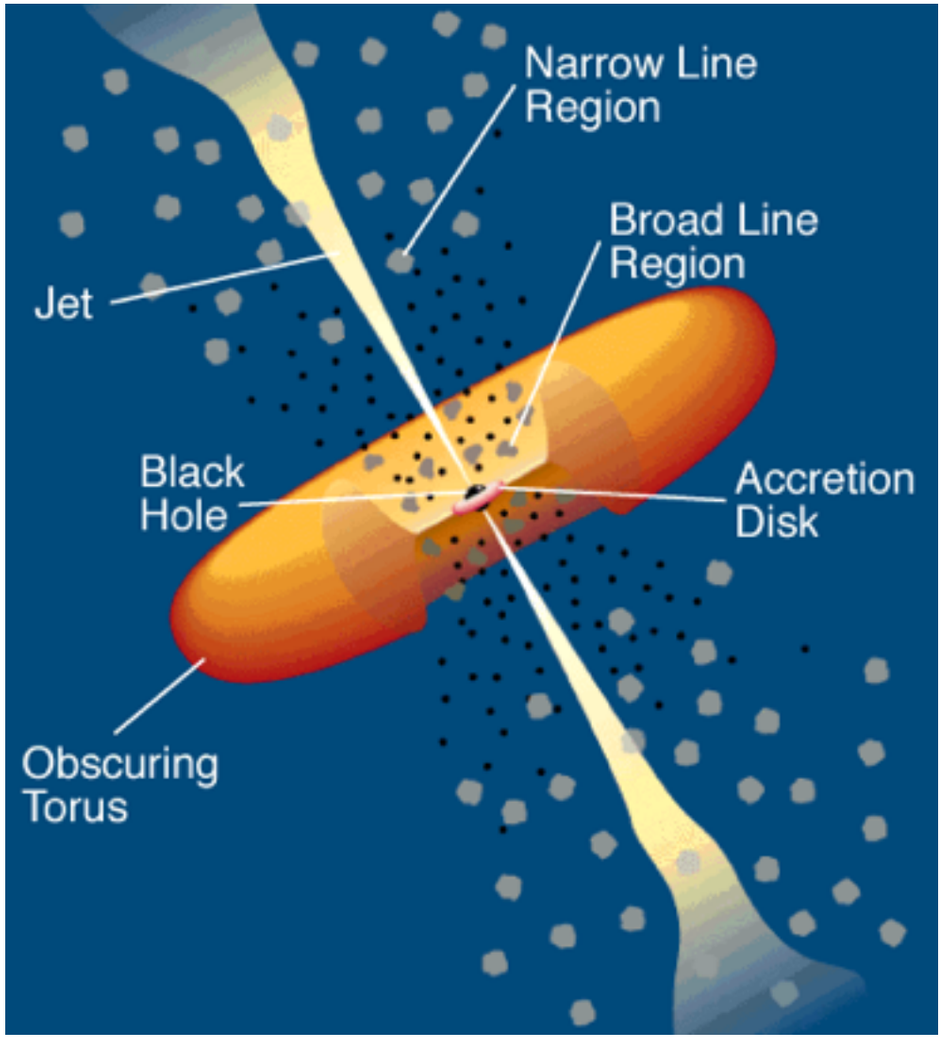


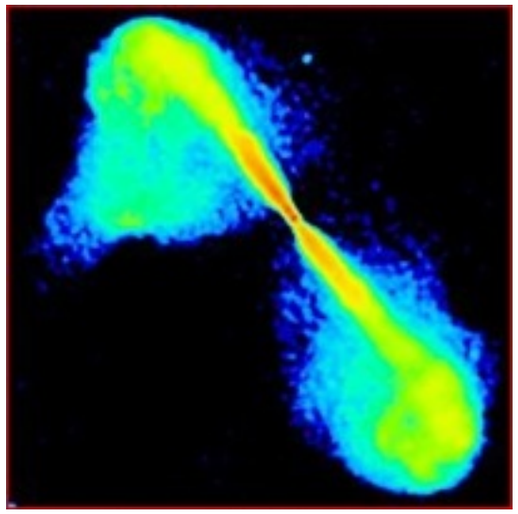

With theoretically 20Gbps connection, the limit cannot be seen.

# Active Galactic Nuclei (AGNs)

**Pictorial description of an AGN**

**Image Credit: C.M.Urry & P. Padovani**



Jets are extremely well collimated streams of plasma emanating from the centers of active galactic nuclei (AGNs), and propagating with relativistic bulk velocities up to kpc/Mpc distances.

Extragalactic jets are **the largest structures in the Universe**, reaching even Mpc scales. They are everywhere **up to the highest redhsifts.**

Jets are produced by rapidly rotating supermassive (~ $10^6$-$10^9$ $M_\odot$) black holes surrounded by magnetized accretion disks. Thus, jets **are direct probes of black hole physics.**

Jets are **extremely efficient accelerators of particles** to ultrarelativistic energies. They are known to produce electrons with $10^{14}$ eV energies, and are claimed to accelerate protons up to the highest observed energies $\geq 10^{20}$ eV .