T2K実験における新型前置検出器

SuperFGDのためのDAQ開発

2022-11-17, 計測システム研究会

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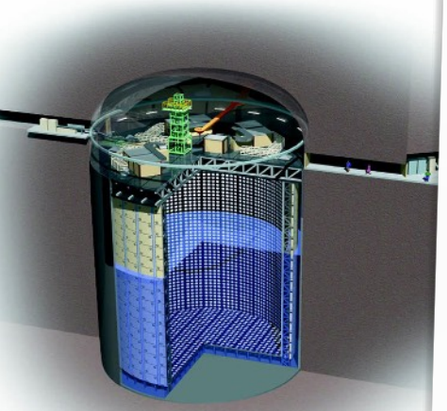
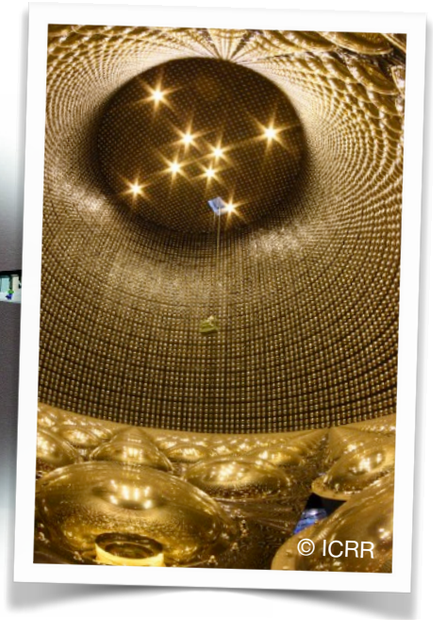
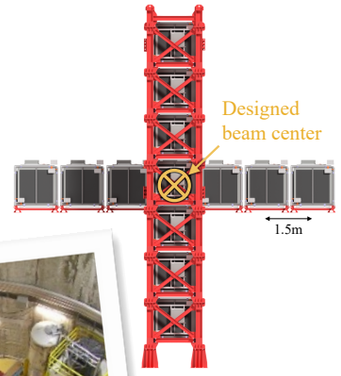
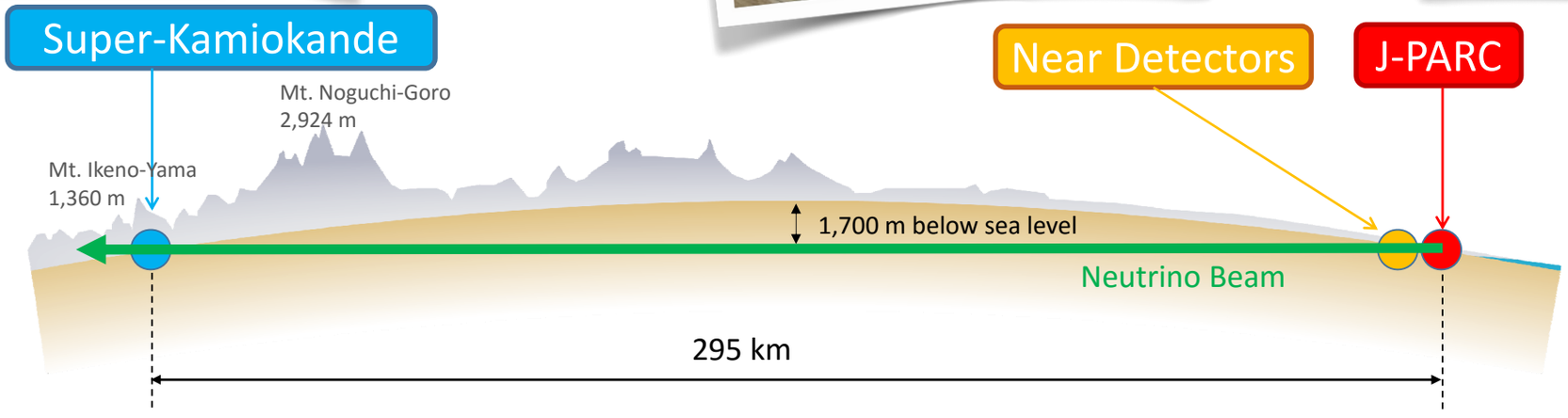
東北大,[a] 京都大 [b]

T2K experiment









$\nu_\tau, \nu_\tau, \nu_\tau, \nu_\tau, \nu_e, \nu_\mu, \nu_\mu \longleftarrow \nu_\mu, \nu_\mu, \nu_\mu, \nu_\mu, \nu_\mu, \nu_\mu, \nu_\mu$

- Study oscillation of neutrino beam from J-PARC accelerator
- ~500 collaborators from institutions in 14 countries

ν-oscillation

(interaction) (propagation)

For neutrinos flavor basis ≠ Hamiltonian basis.

→ Flavor (ν_e | ν_μ | ν_τ) oscillates over $L \times \Delta m^2 / E$,
amplitude controlled by (PMNS) **mixing matrix** U:

atmospheric **reactor** **solar**

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta_{CP}} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta_{CP}} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

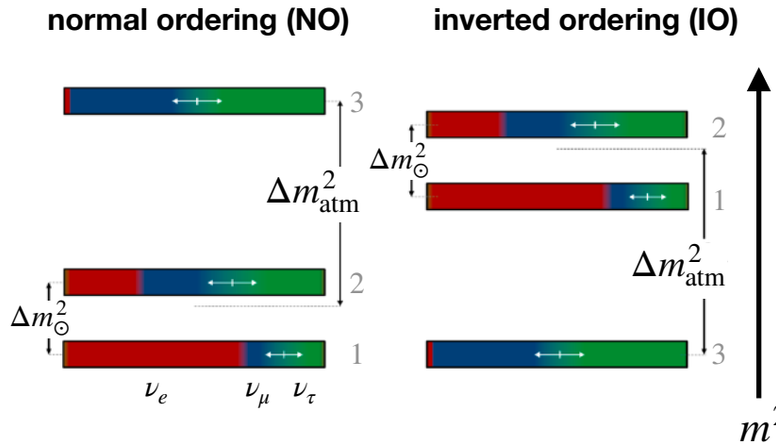
$c_{ij} \equiv \cos\theta_{ij}$
$s_{ij} \equiv \sin\theta_{ij}$

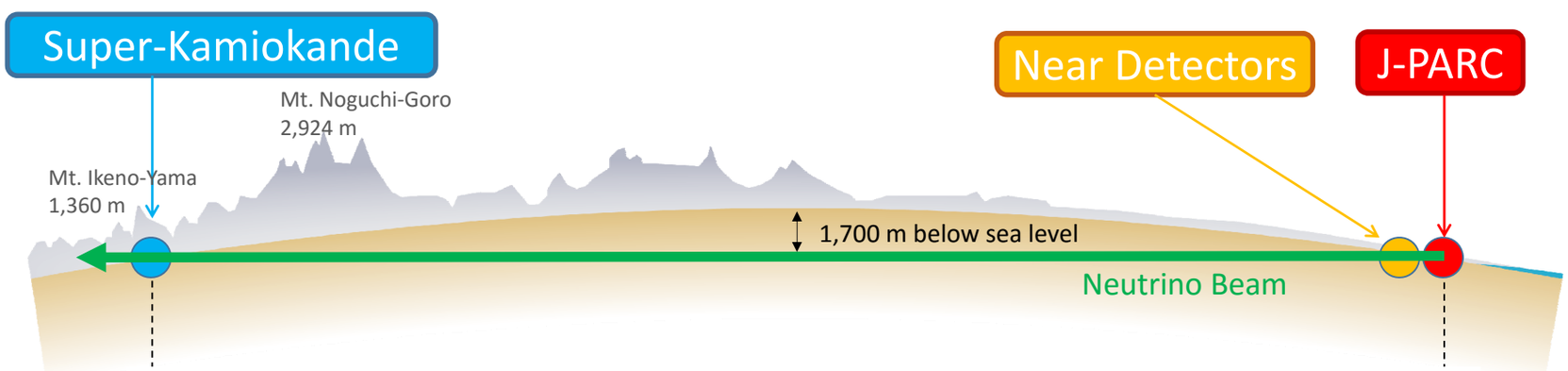
Open questions:

- value of $\delta_{\rm CP}$ → if $\sin\delta_{\rm CP} \neq 0$, CP violation
- sign of Δm^2_{32} (mass ordering)
- is θ_{23} maximal? octant? (i.e. $\theta_{23} < \frac{\pi}{4}$ or $\theta_{23} > \frac{\pi}{4}$)

important params for cosmology (leptogenesis...) and 0ν2β searches

flavor symmetries?





For $\delta_{\rm CP}$,MO look for $\nu/\bar{\nu}$ difference of $\nu_\mu \to \nu_e$ appearance

note:
wrong-sign ν_μ and intrinsic ν_e backgrounds neglected for illustration

Neutrino mode

$\nu_\tau, \nu_\tau, \nu_\tau, \boxed{\nu_e}, \nu_e, \nu_\mu, \nu_\mu \leftarrow \nu_\mu, \nu_\mu, \nu_\mu, \nu_\mu, \nu_\mu, \nu_\mu, \nu_\mu$

Anti-neutrino mode

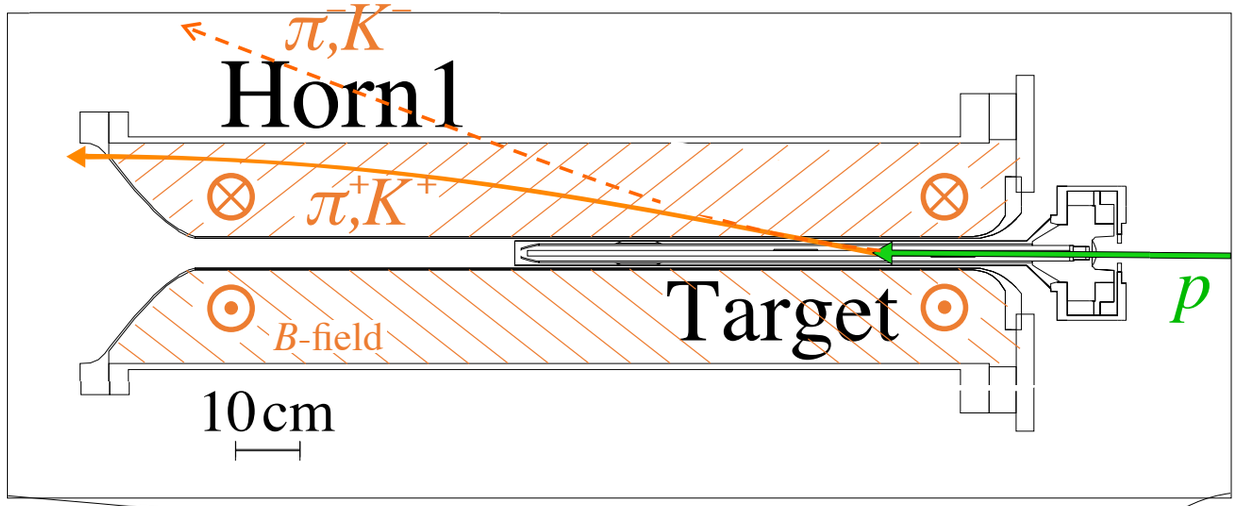
$\bar{\nu}_\tau, \bar{\nu}_\tau, \bar{\nu}_\tau, \boxed{\bar{\nu}_\tau}, \bar{\nu}_e, \bar{\nu}_\mu, \bar{\nu}_\mu \leftarrow \bar{\nu}_\mu, \bar{\nu}_\mu, \bar{\nu}_\mu, \bar{\nu}_\mu, \bar{\nu}_\mu, \bar{\nu}_\mu, \bar{\nu}_\mu$

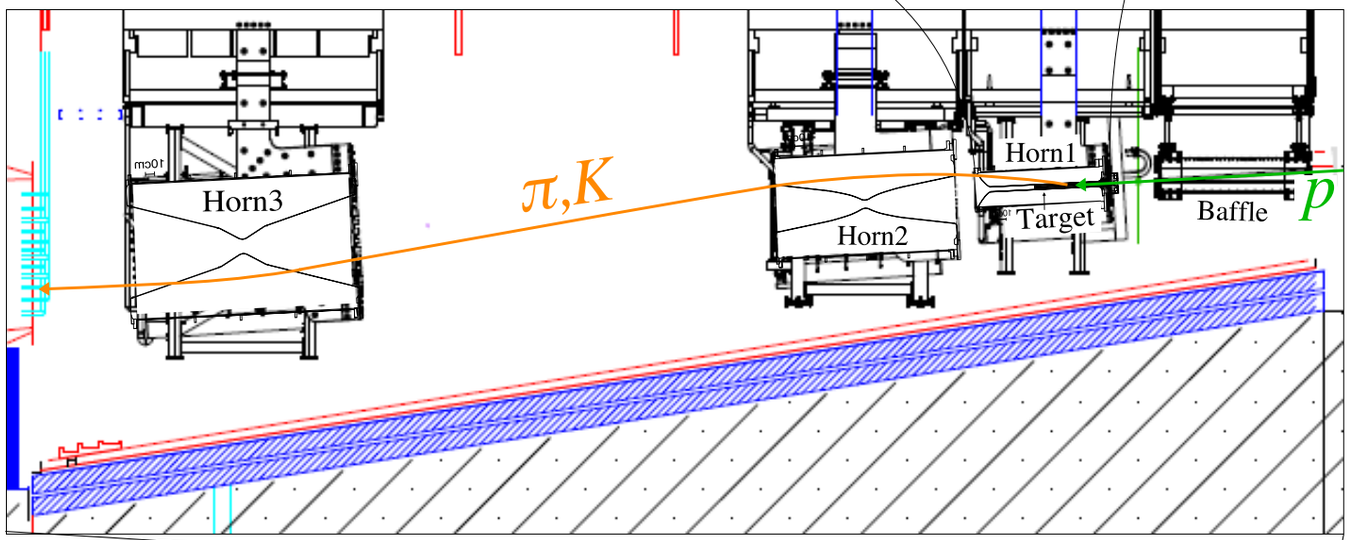
Neutrino beam

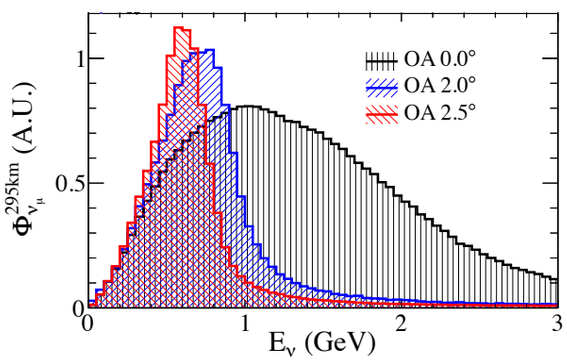
- 30 GeV protons produce π,K in 90 cm graphite target

- Three magnetic horns selectively focus π^+,K^+ or π^-,K^- to produce ν_μ or $\bar{\nu}_\mu$ beam (decay in-flight).

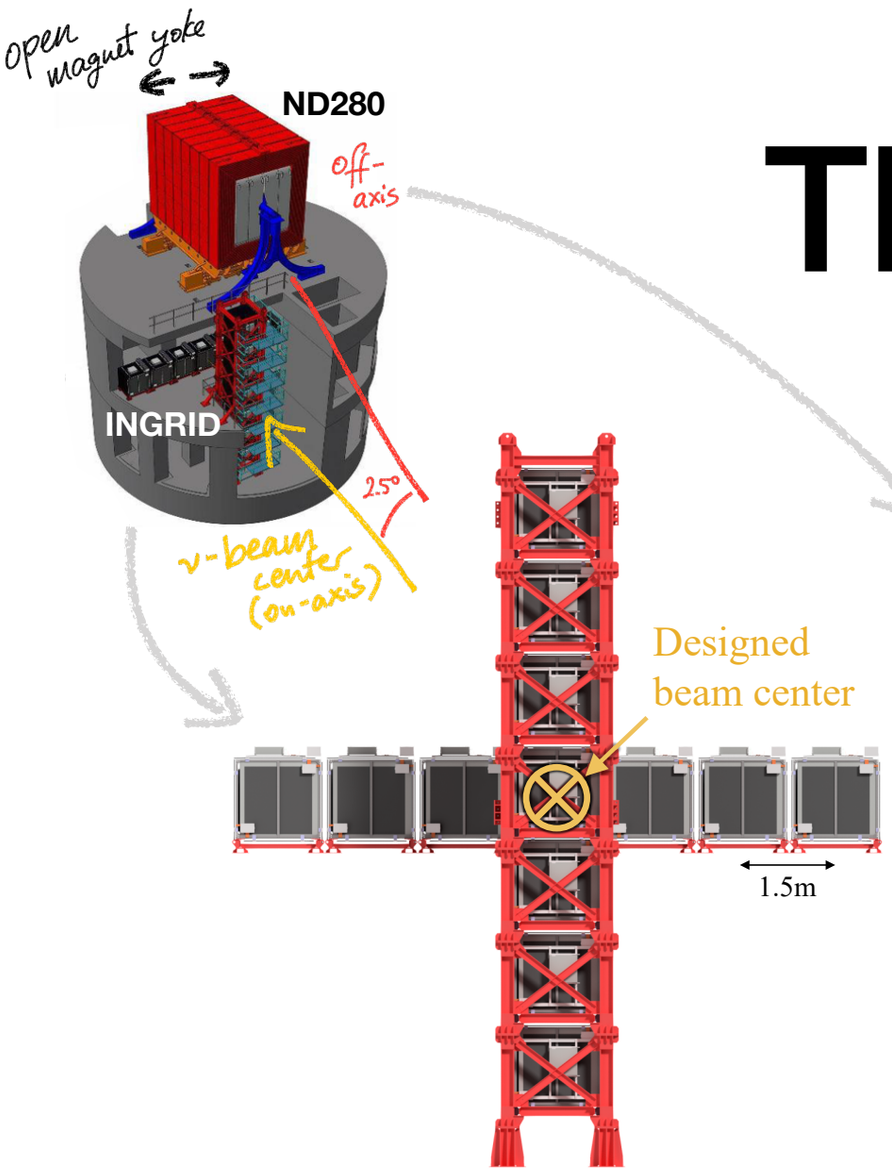
- Narrowband beam thanks to off-axis technique.

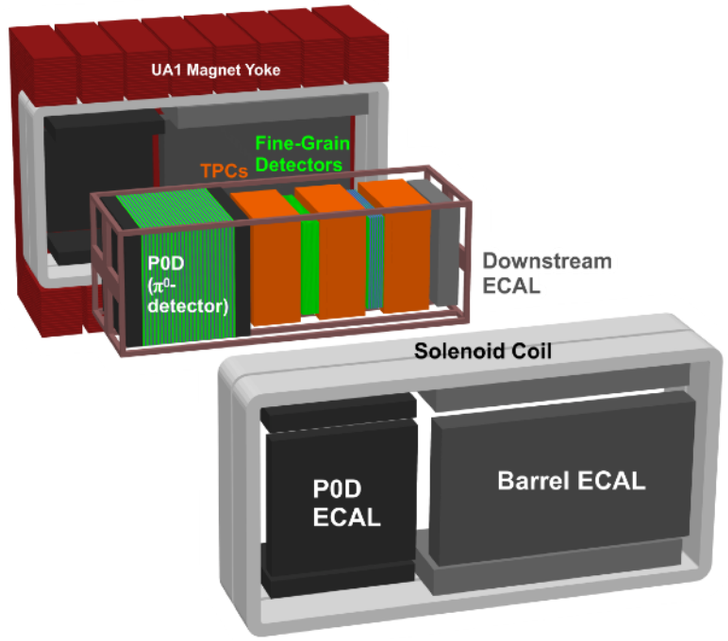


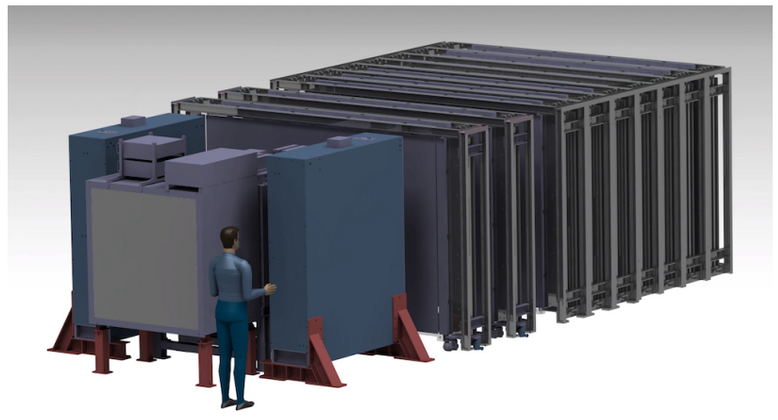




The near detectors







INGRID on-axis detector

- Iron-scintillator sandwich detectors monitor neutrino beam **direction** and intensity

ND280 off-axis detector

- Active **scintillator** + passive **water** targets
- Tracking with **time projection chambers**
- **Magnetized** for charge and momentum measurement

WAGASCI + BabyMIND

- Latest addition at intermediate **1.5º** off-axis flux
- **Water** target with cuboid lattice scintillators for high angle acceptance
- Compact **magnetized** iron muon range detector
- First xsec meas. published: PTEP, ptab014 (2021)

Analysis strategy

- Beam monitors + hadron production experiments
  → **neutrino flux**

- ND280 measurements
  + interaction model
  + external constraints
  → **unoscillated flux × xsec**

- 6 samples at SK
  → ν_μ **disappearance +**
  ν_e **appearance**

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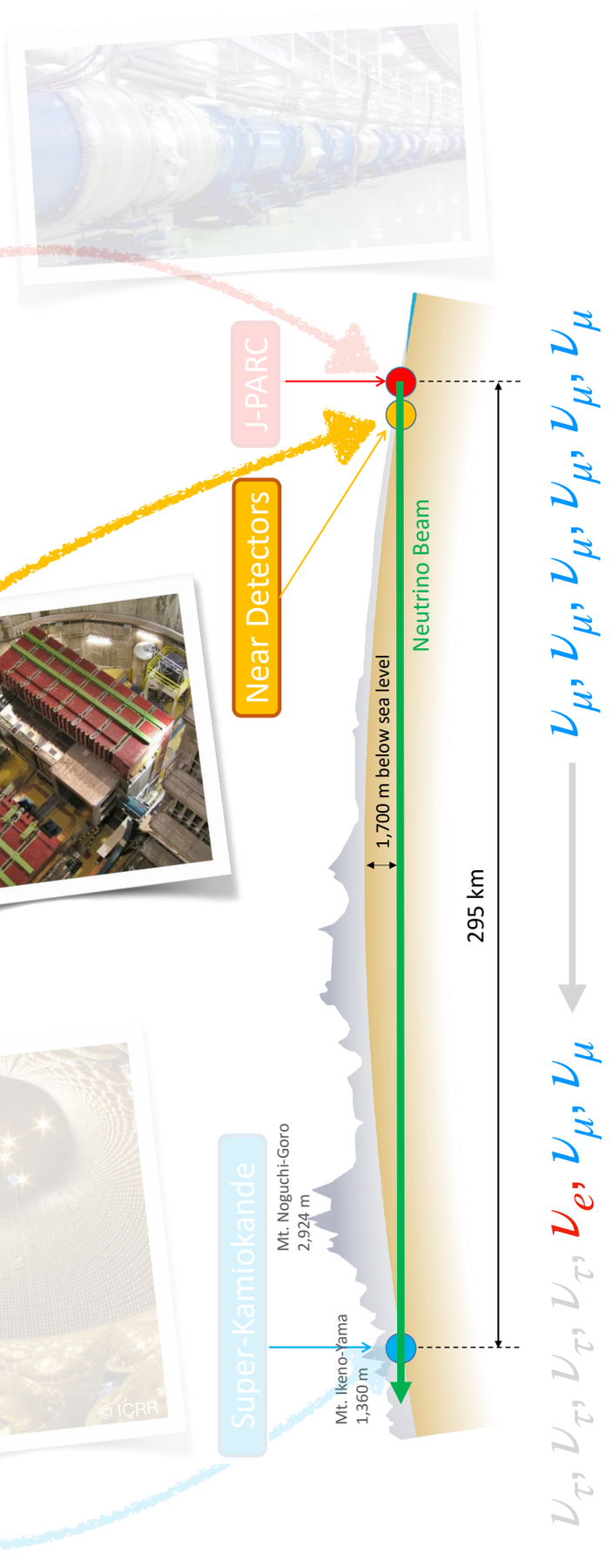

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- Beam mon
production
→ neutrin

- ND280 me
+ interactio
+ external
→ unoscil

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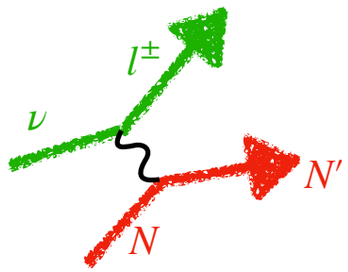
ν_e appe

Important interactions

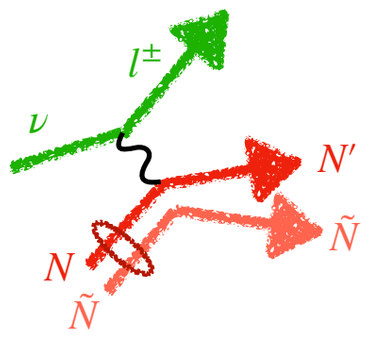
Good E_ν reconstruction

Charged current quasi-elastic (CCQE)

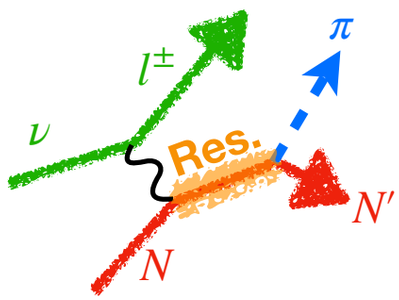


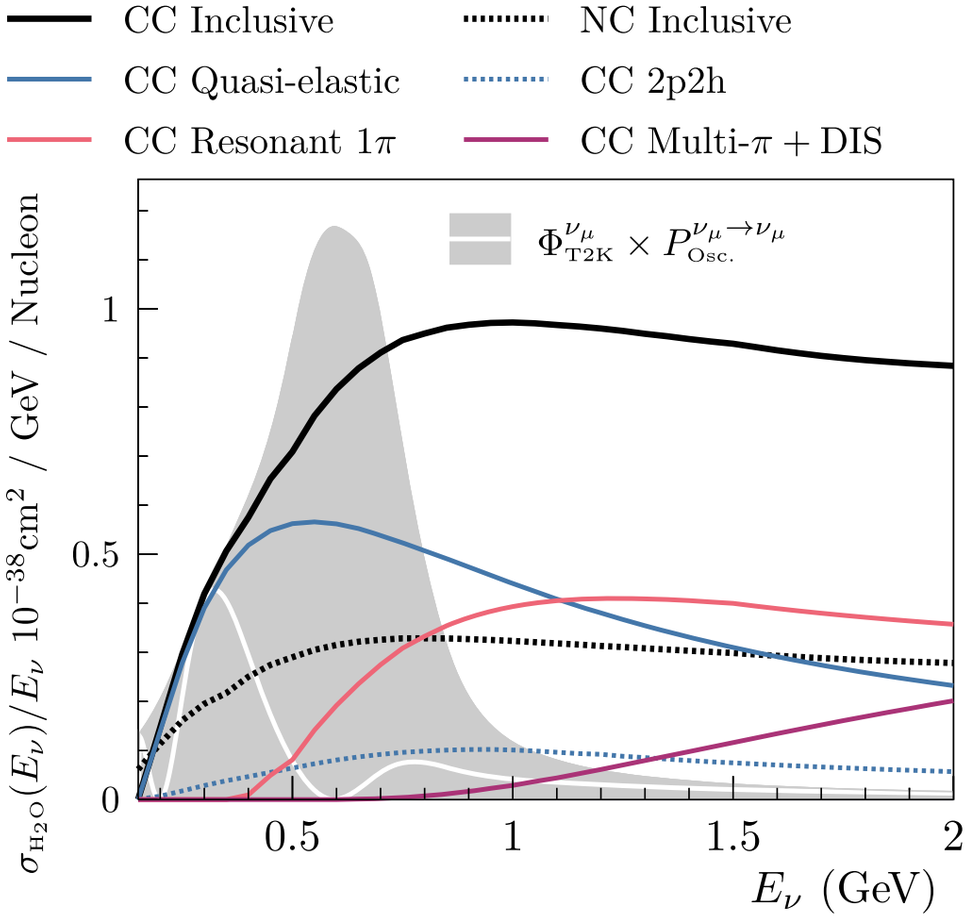
Mis-reconstruction of E_ν (~25% of events)

CC multi-nucleon knock-out (2p2h)



CC Resonant





Eur. Phys. J. Spec. Top. (2021) 230:4469–4481

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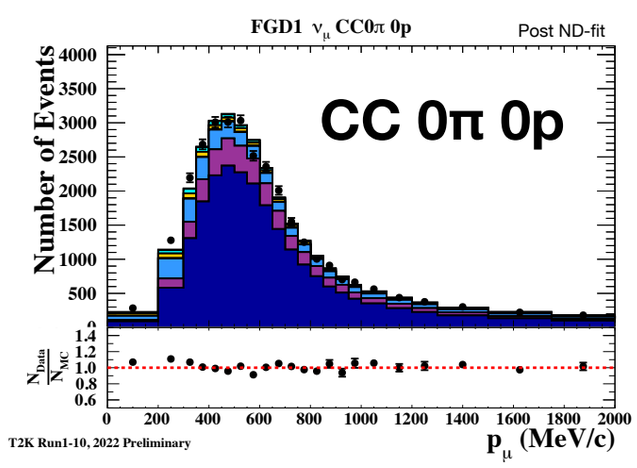
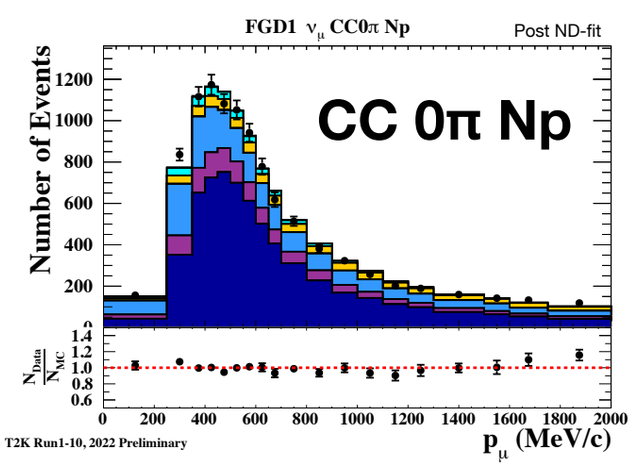
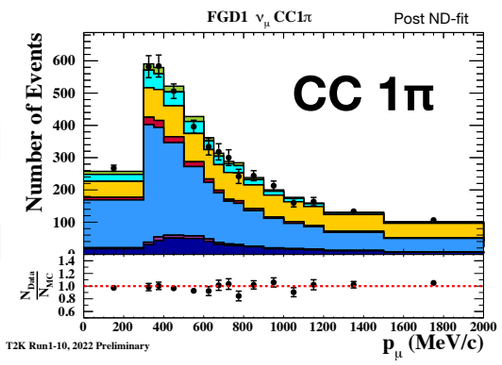
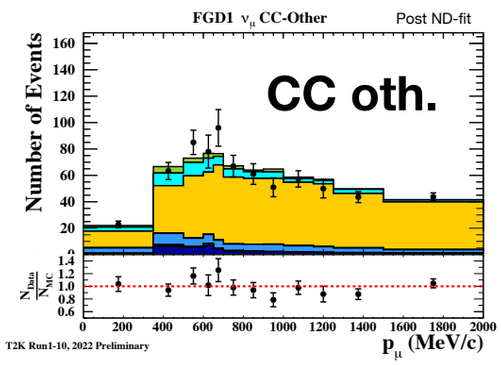
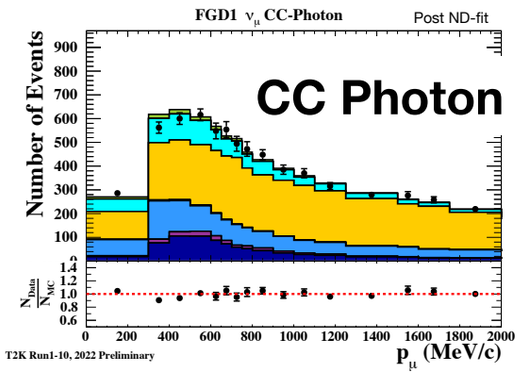




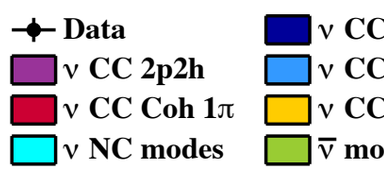


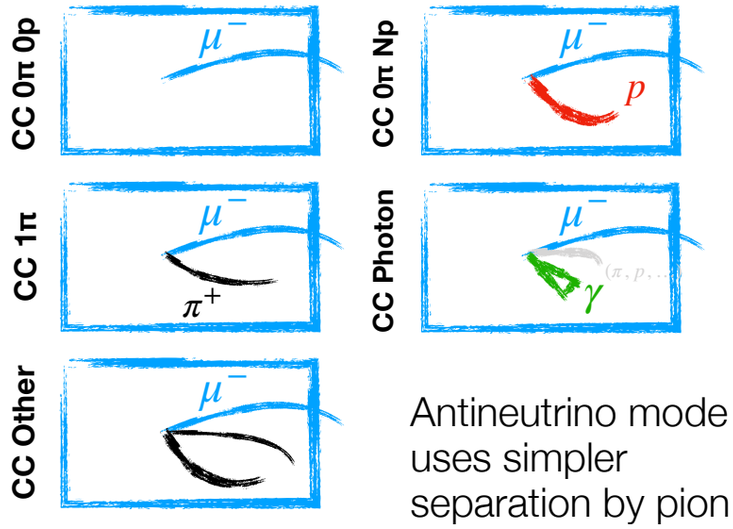




22 samples = (5×1+3×2)×2 **separated by**

1. π,p,γ multiplicity
   → interaction mode





Antineutrino mode uses simpler separation by pion multiplicity only

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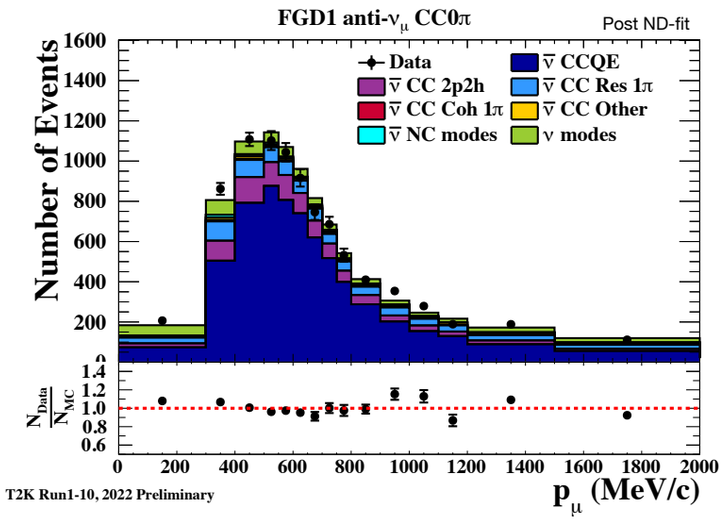
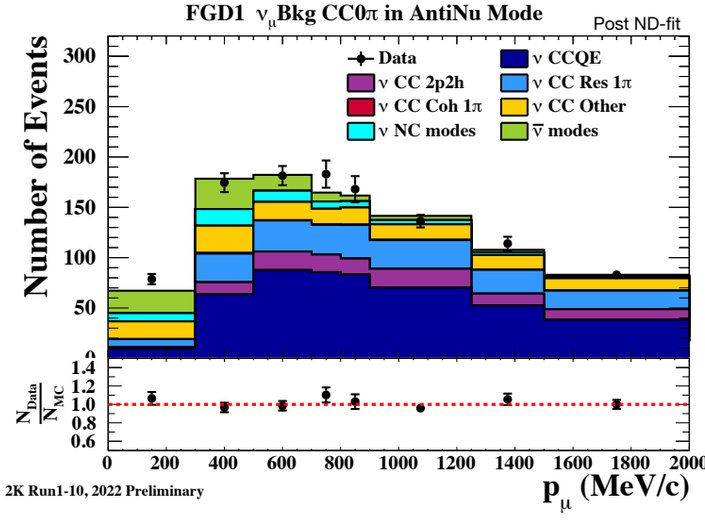
Right-sign

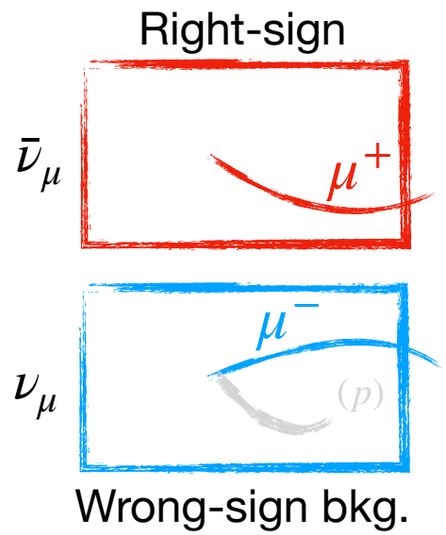


Wrong-sign bkg.



22 samples = (5×1+3×2)×2
separated by

1. π,p,γ multiplicity
   → interaction mode
2. lepton charge
   → wrong-sign bkg
   (in antineutrino mode)
3. C / C+O target
   → ν+O xsec



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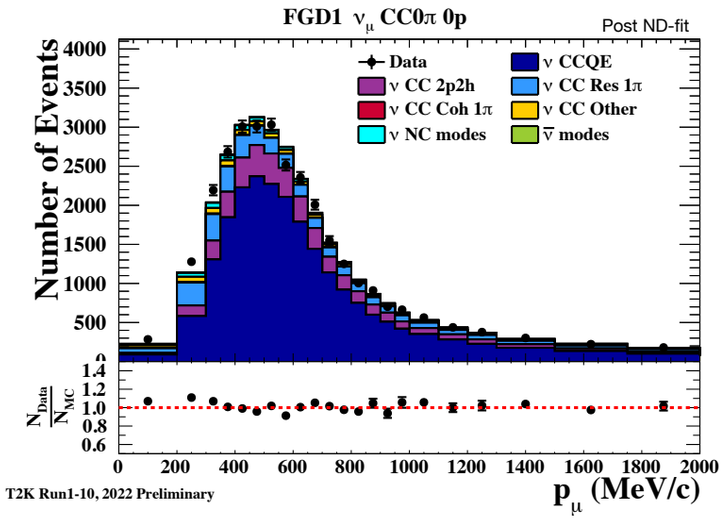
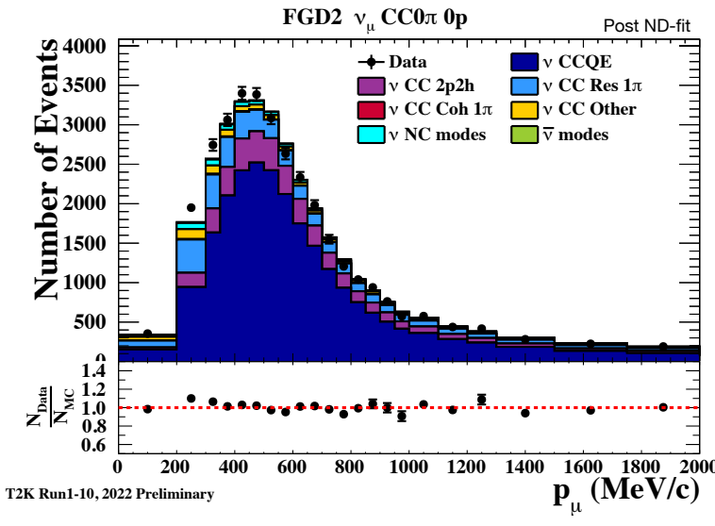
C target



C+O target



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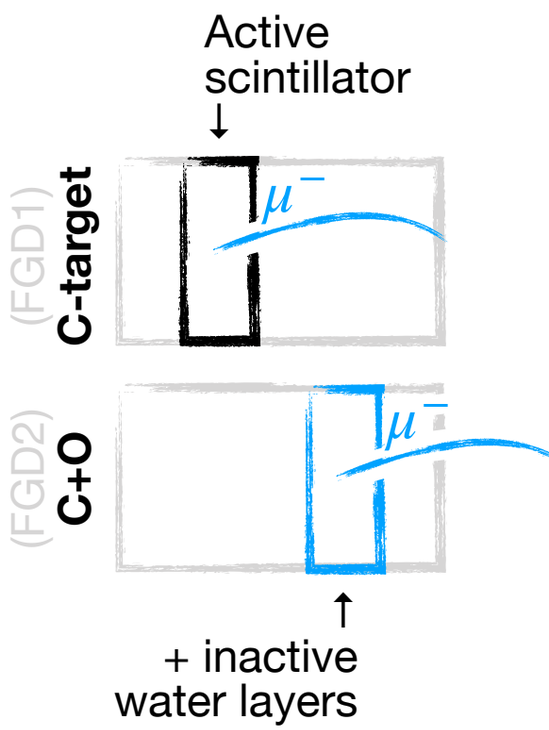

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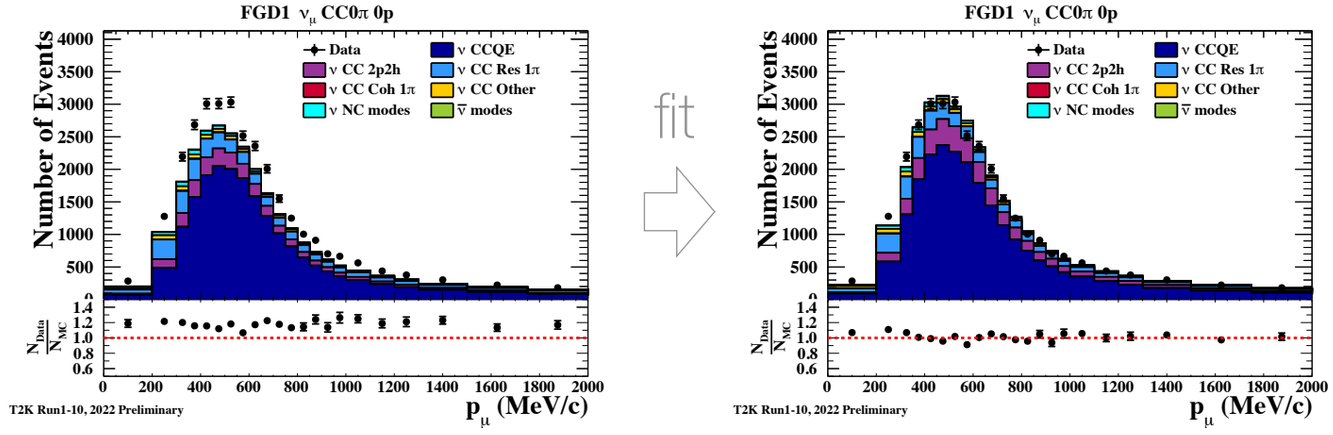
Fit result with correlated flux × xsec propagated to far detector analysis via covariance matrix or joint ND+FD fit.
Both methods give consistent results.

Pre-ND → fit → **Post-ND**



ND fit p-value: **10.9%** (> 5% threshold)

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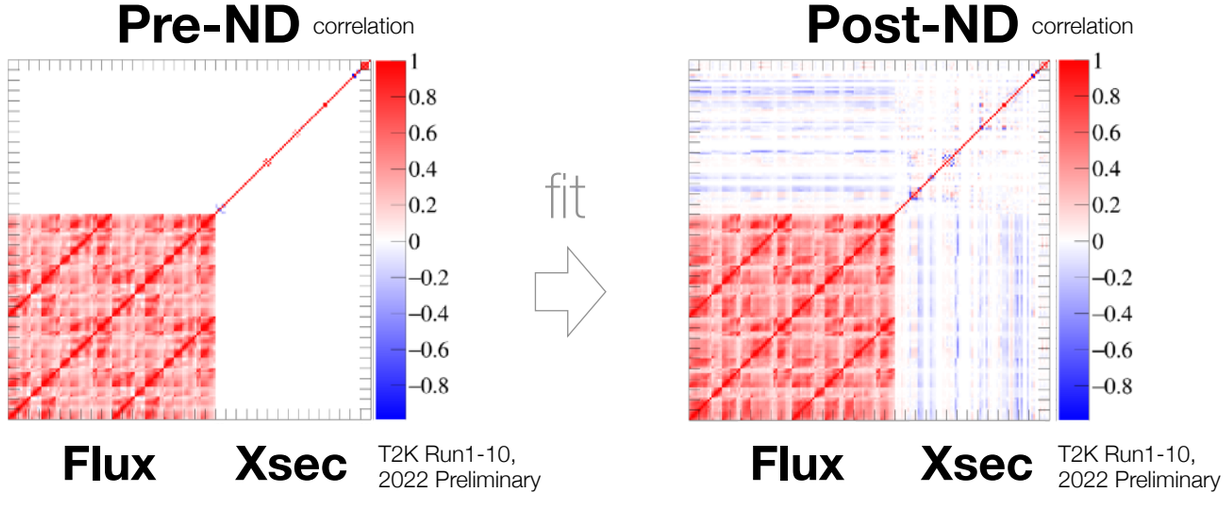

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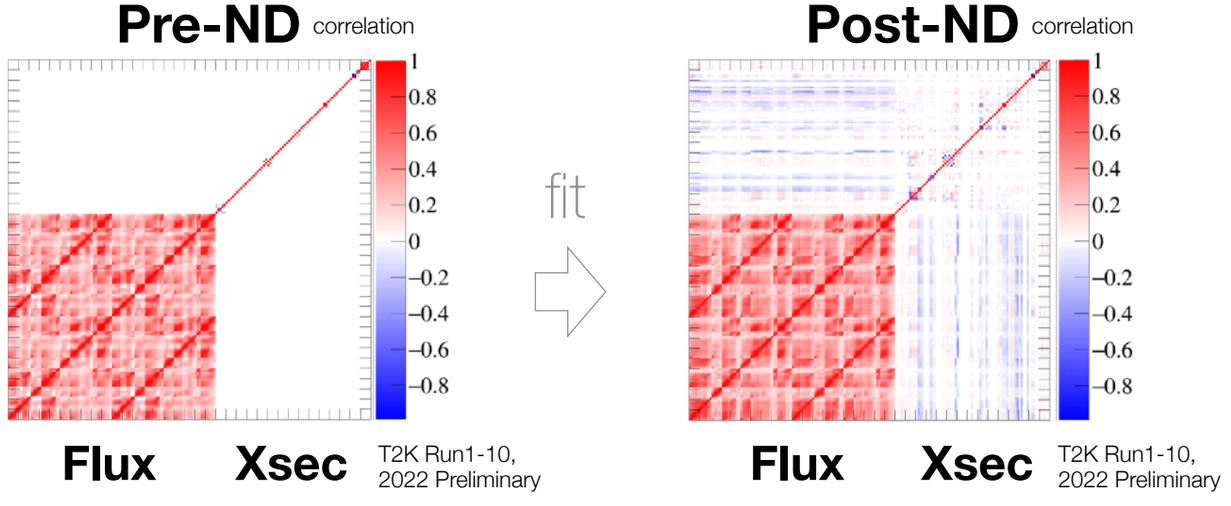

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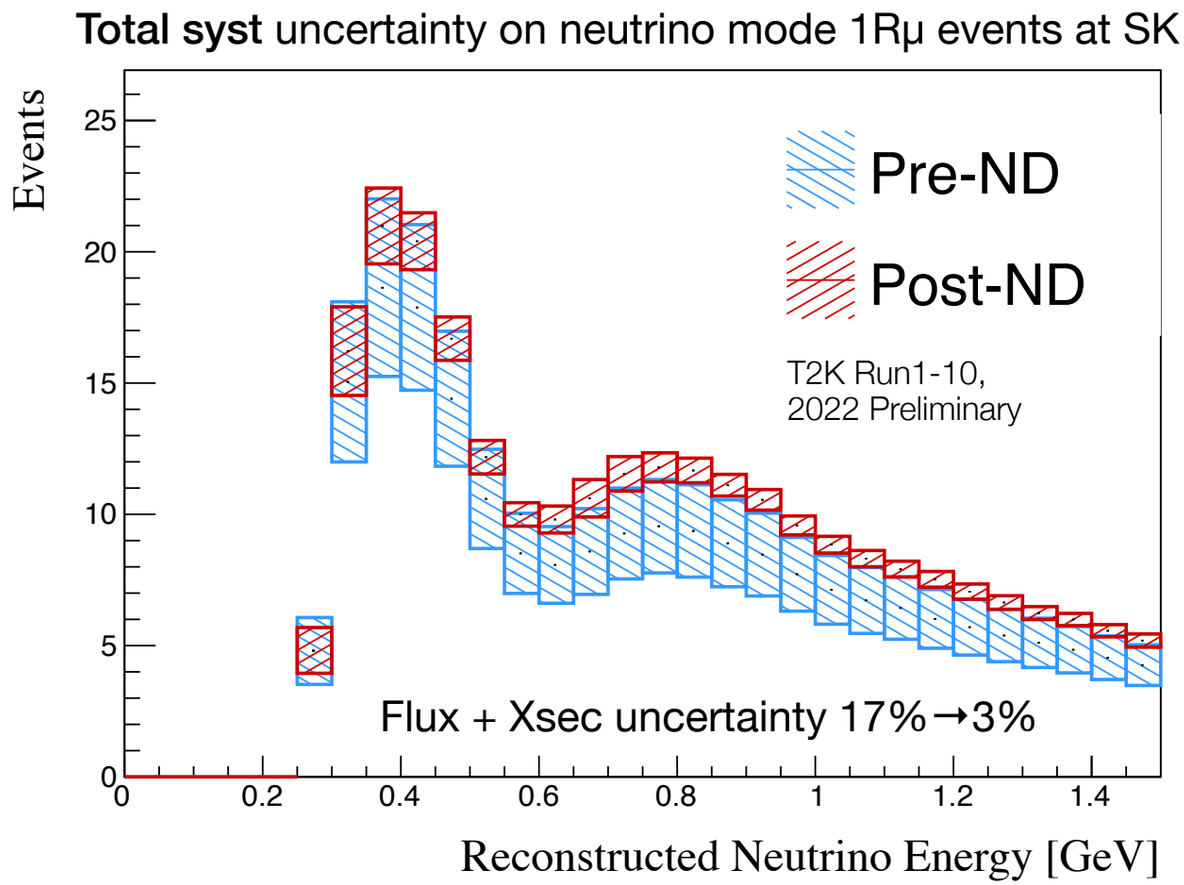
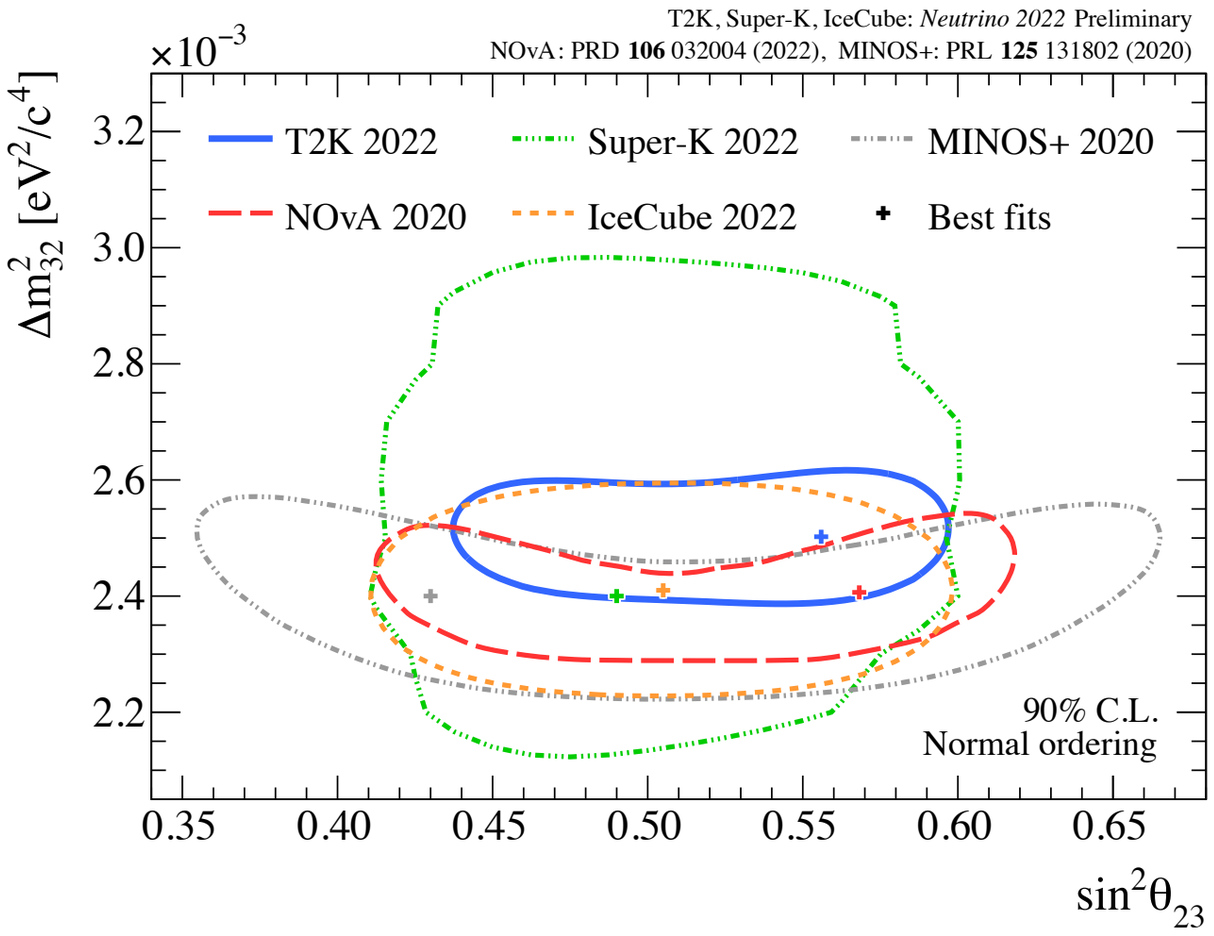
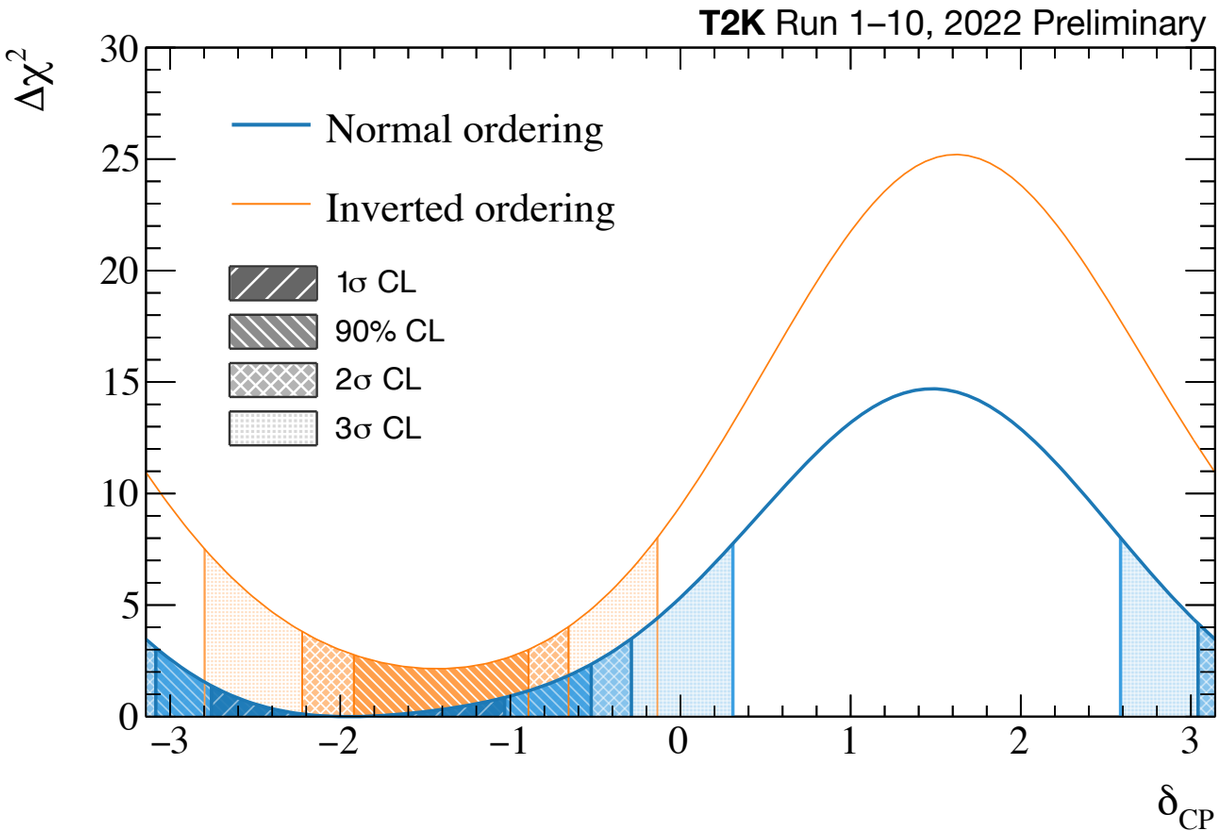




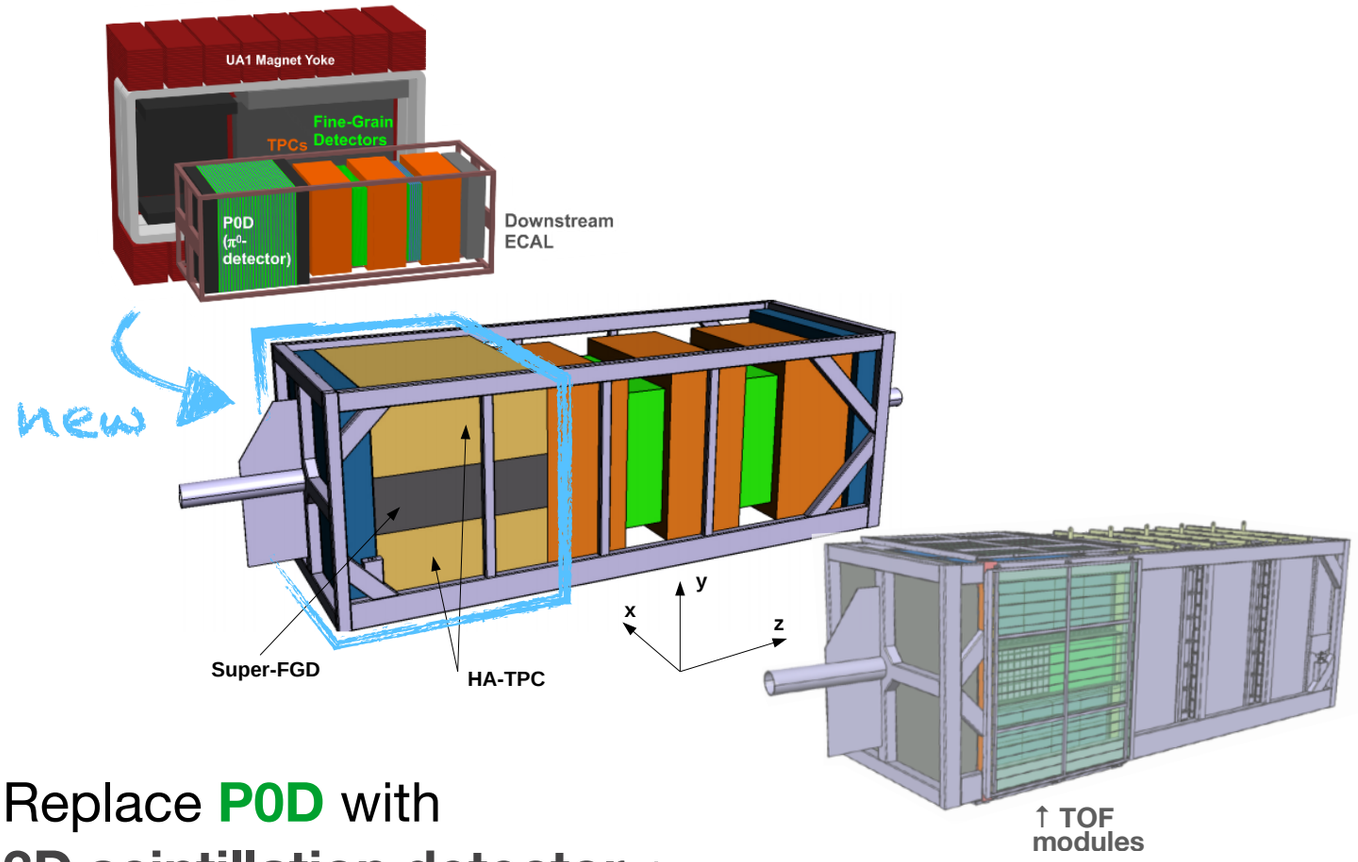
Current results

- World-leading measurement of atmospheric oscillation parameters



- Large region **excluded at 3σ**
- CP-conservation $\{0, \pi\}$ **excluded at 90%**, π is within 2σ
  ↓
  aiming for 3σ evidence for CP-violation before Hyper-Kamiokande by reducing systematic uncertainties

ND280 upgrade



Replace **P0D** with
3D scintillation detector +
high-angle TPCs +
TOF enclosure

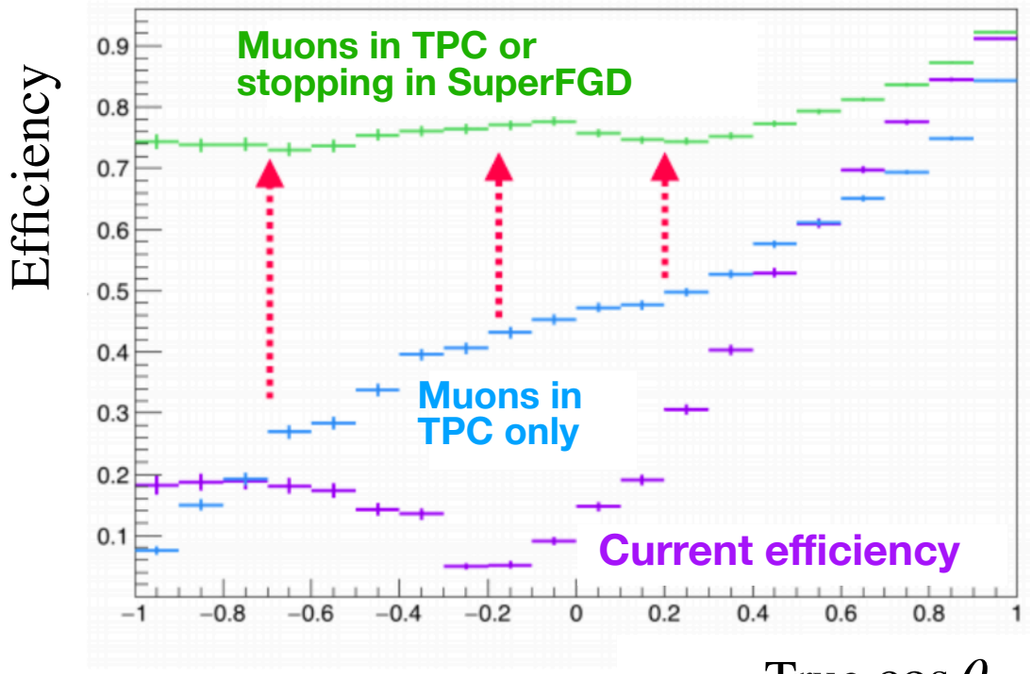
→ 4π acceptance like SK

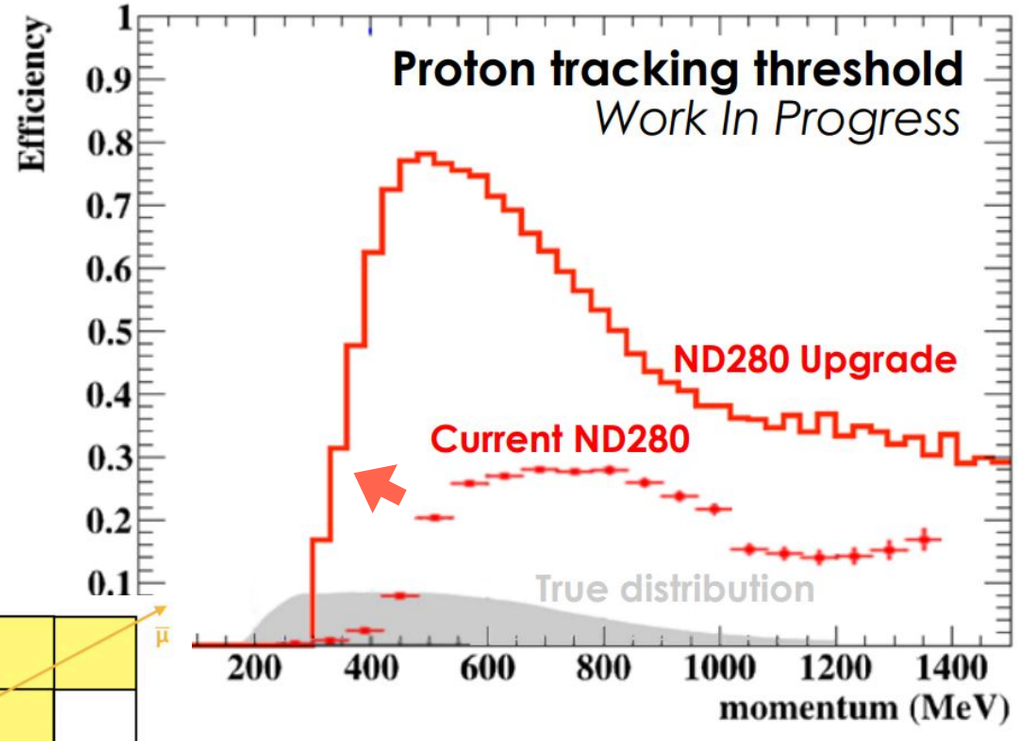
→ lower (proton) mom. threshold

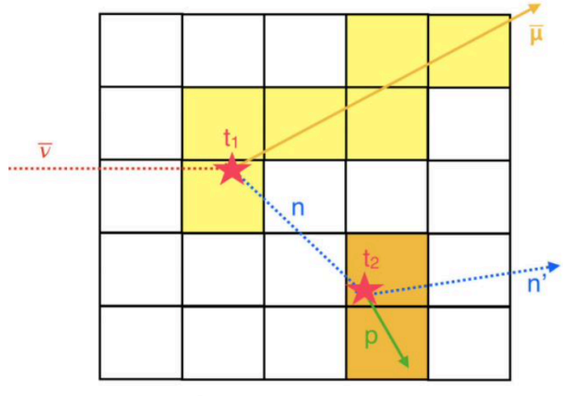
→ neutron kinematics by TOF

→ more target mass (~2x)

Reduce **xsec systematics** and
better understanding of nuclear effects.



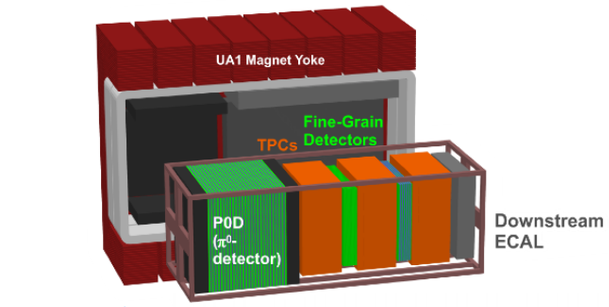


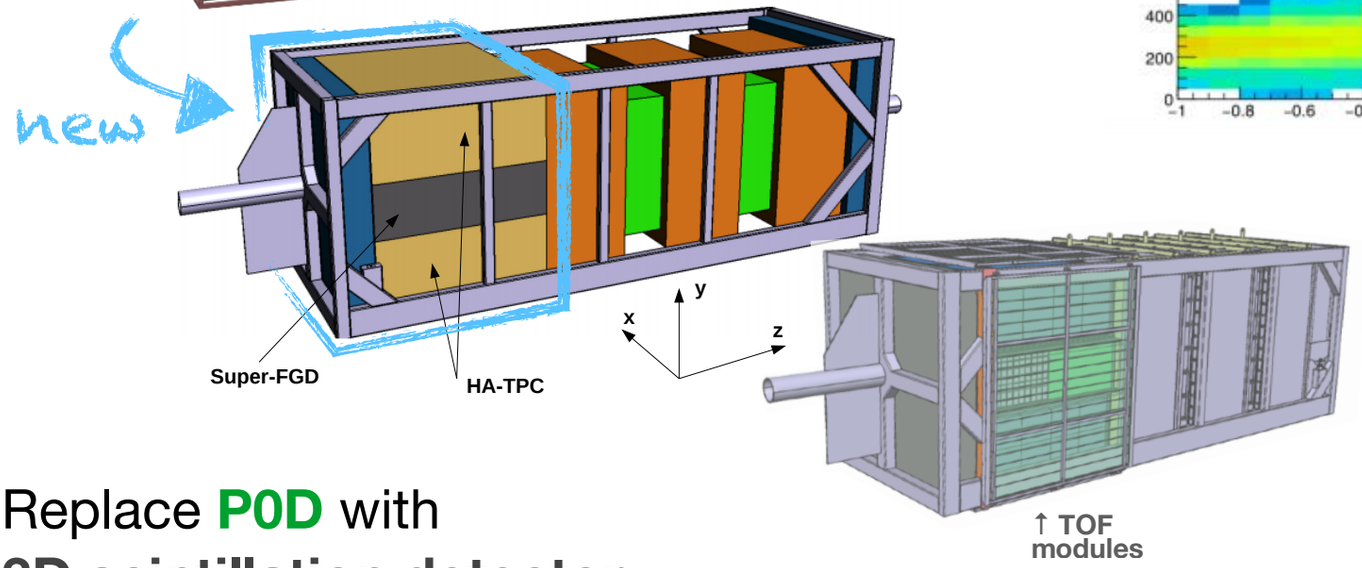


Neutron detection using ToF

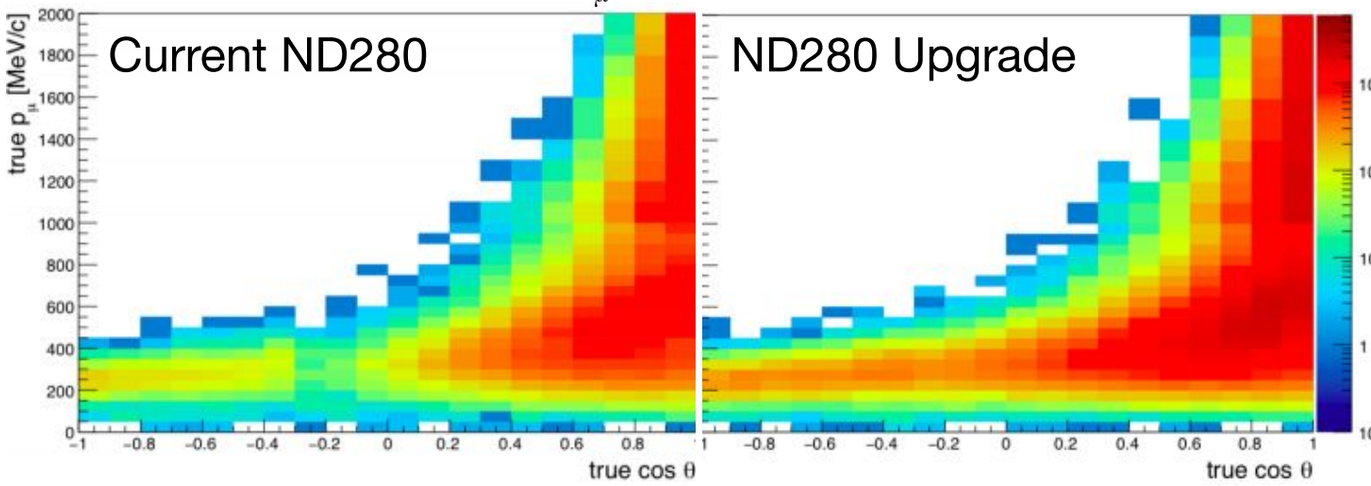
CERN-SPSC-2019-001
arXiv:1901.03750 [physics.ins-det]

ND280 upgrade





Selected ν_μ CC events (NEUT MC)



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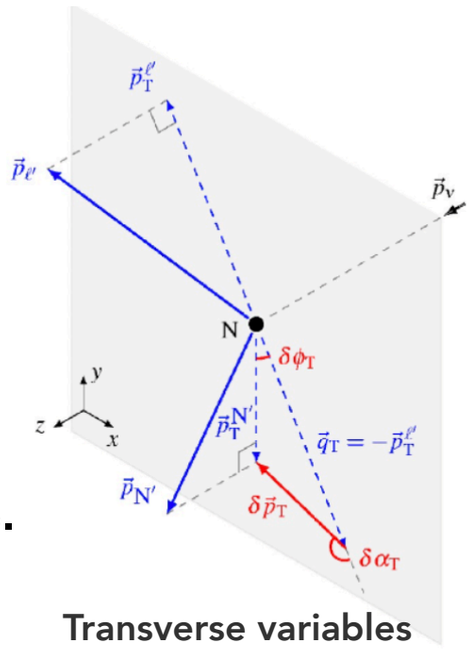
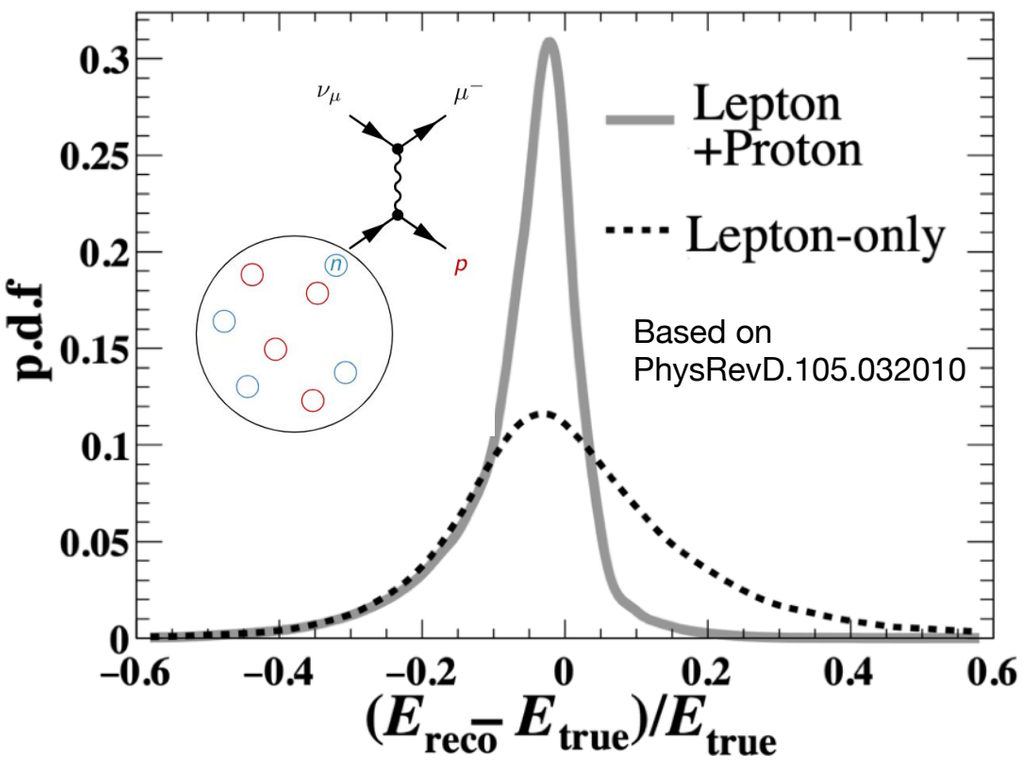
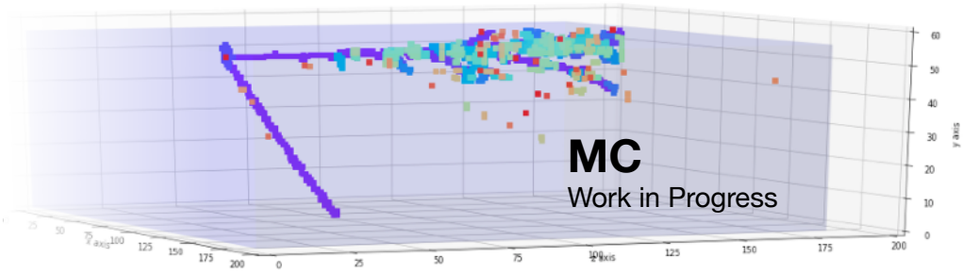
→ more target mass (~2x)

Reduce **xsec systematics** and
better understanding of nuclear effects.



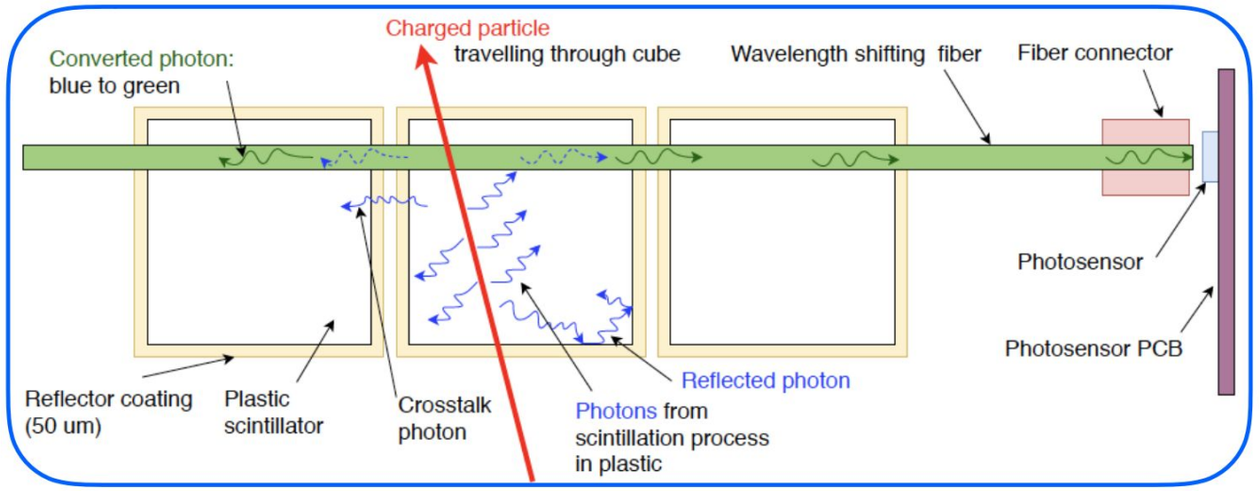
Transverse variables

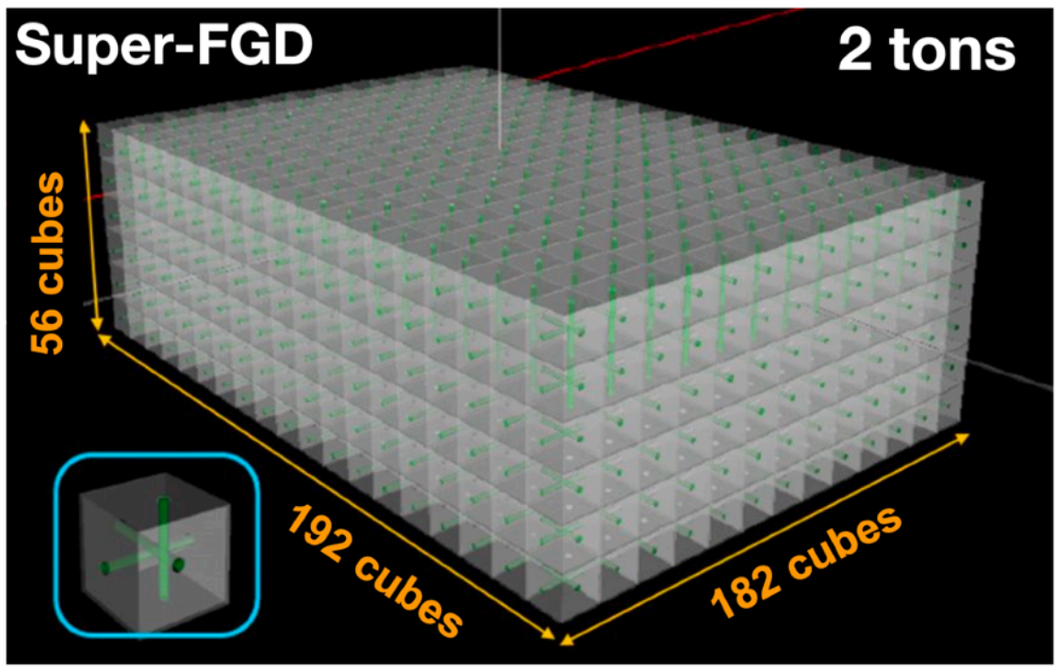




Super FGD

- 2 million scintillator cubes (each 1cm^3)
  = 2 t active target
- 56,382 WLS fibers in x,y,z directions
- Readout by MPPC





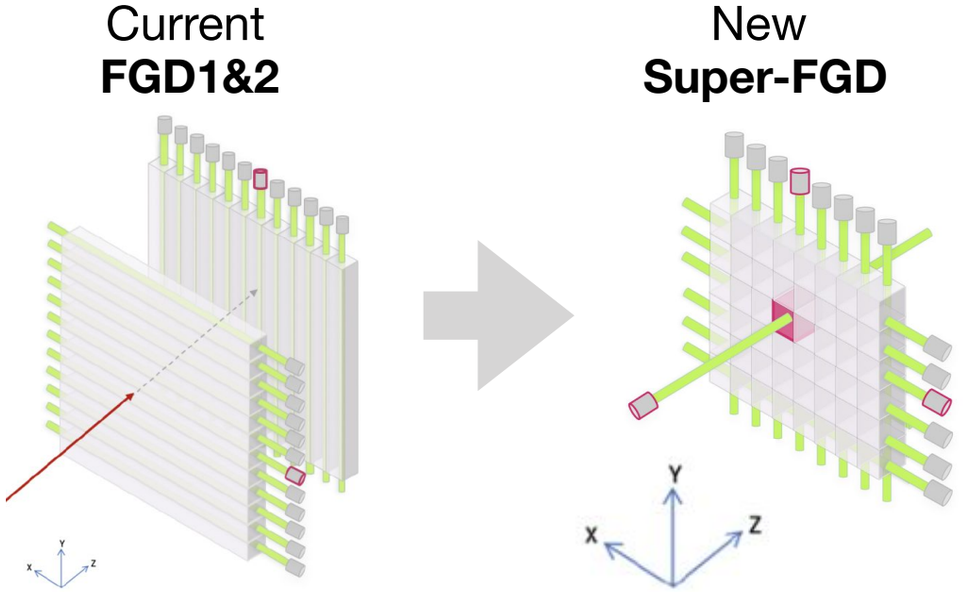


Illustration by Dana Douqa

SuperFGD assembly

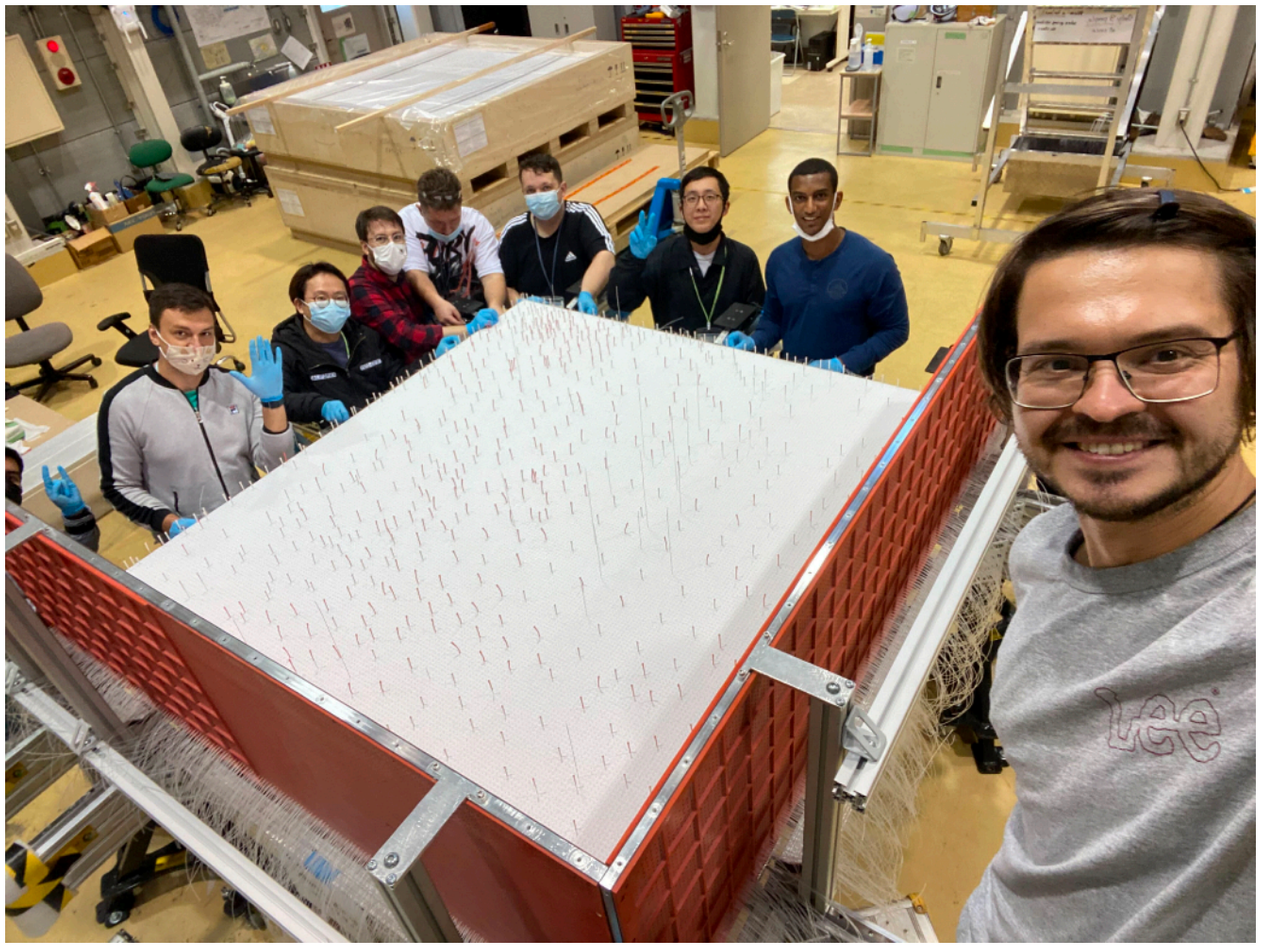
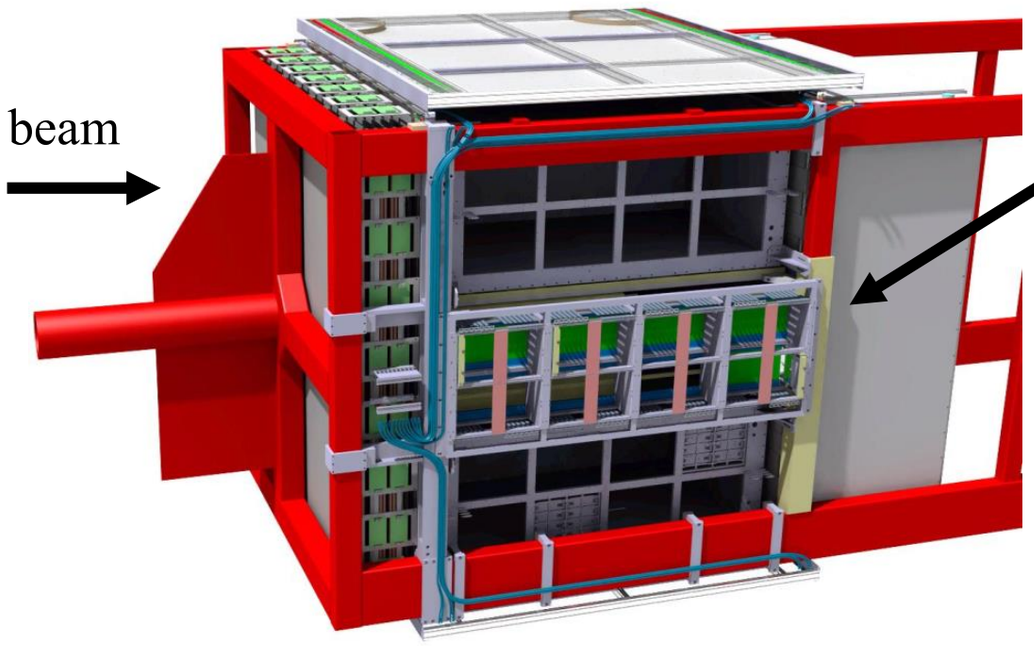


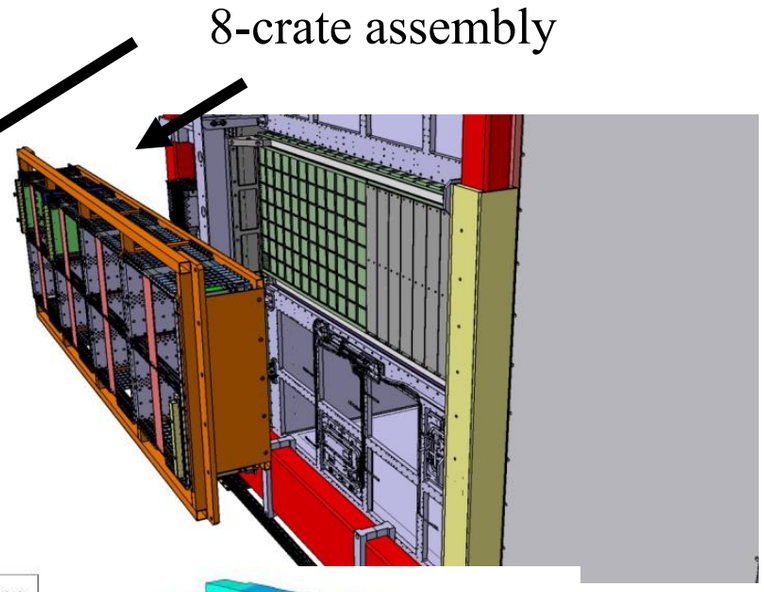
Photo: Aleksandr Mefodev

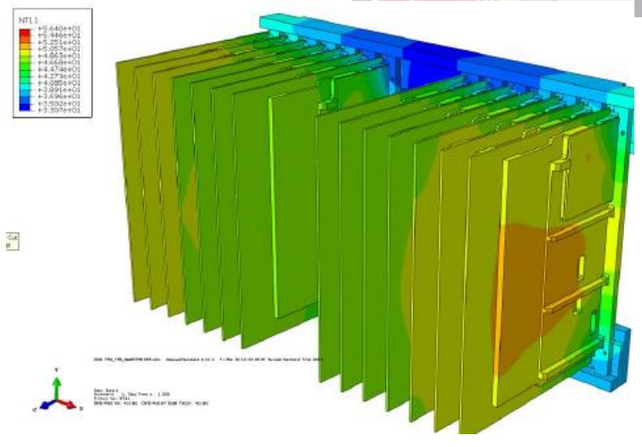
Photo: Kota Nakagiri

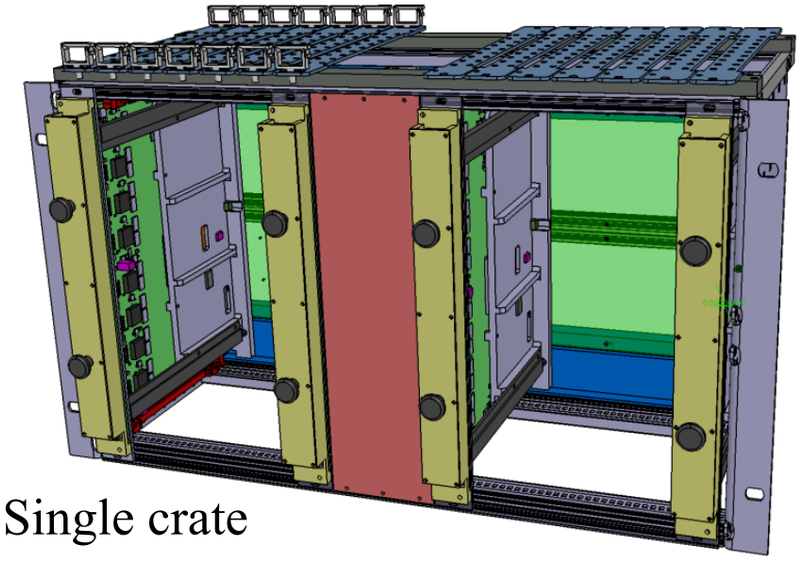
Photos from 2022-10-31

SFGD Electronics









Single crate

- 16 crates – 8 on each side of the detector
- Single crate – 14 Front-end boards, Optical Concentrator Board, Backplane, Power distribution
- Thermal model built to ensure < 60 degrees C

SFGD Electronics

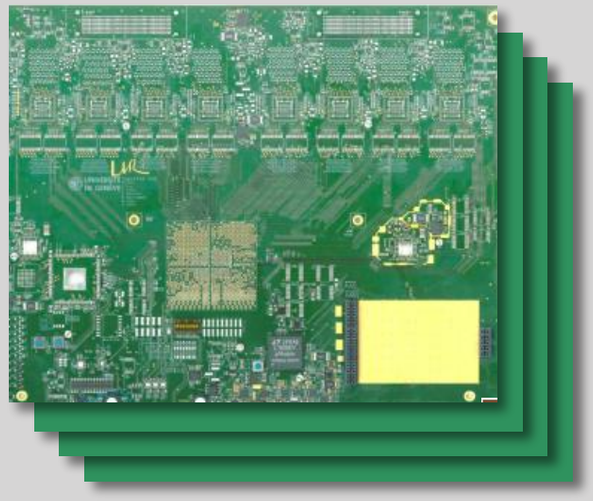
Master Clock Board

Clock and trigger distr.

MPPC-PCBs

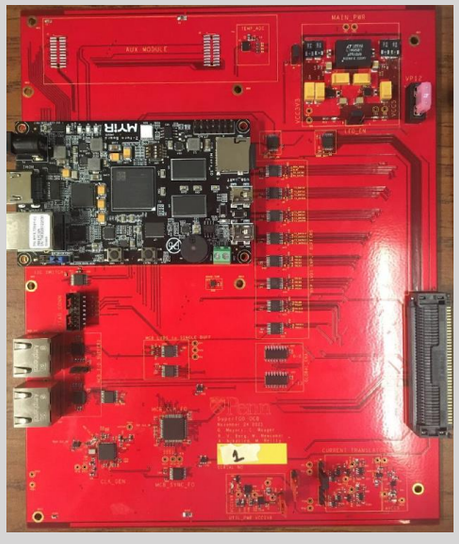
8x8 MPPCs each
4 PCBs per FEB

Front End Board (FEB)



14 per crate, for each:
256 ch → 8 CITIROC → ADC

Optical Concentra-tor Board (OCB)

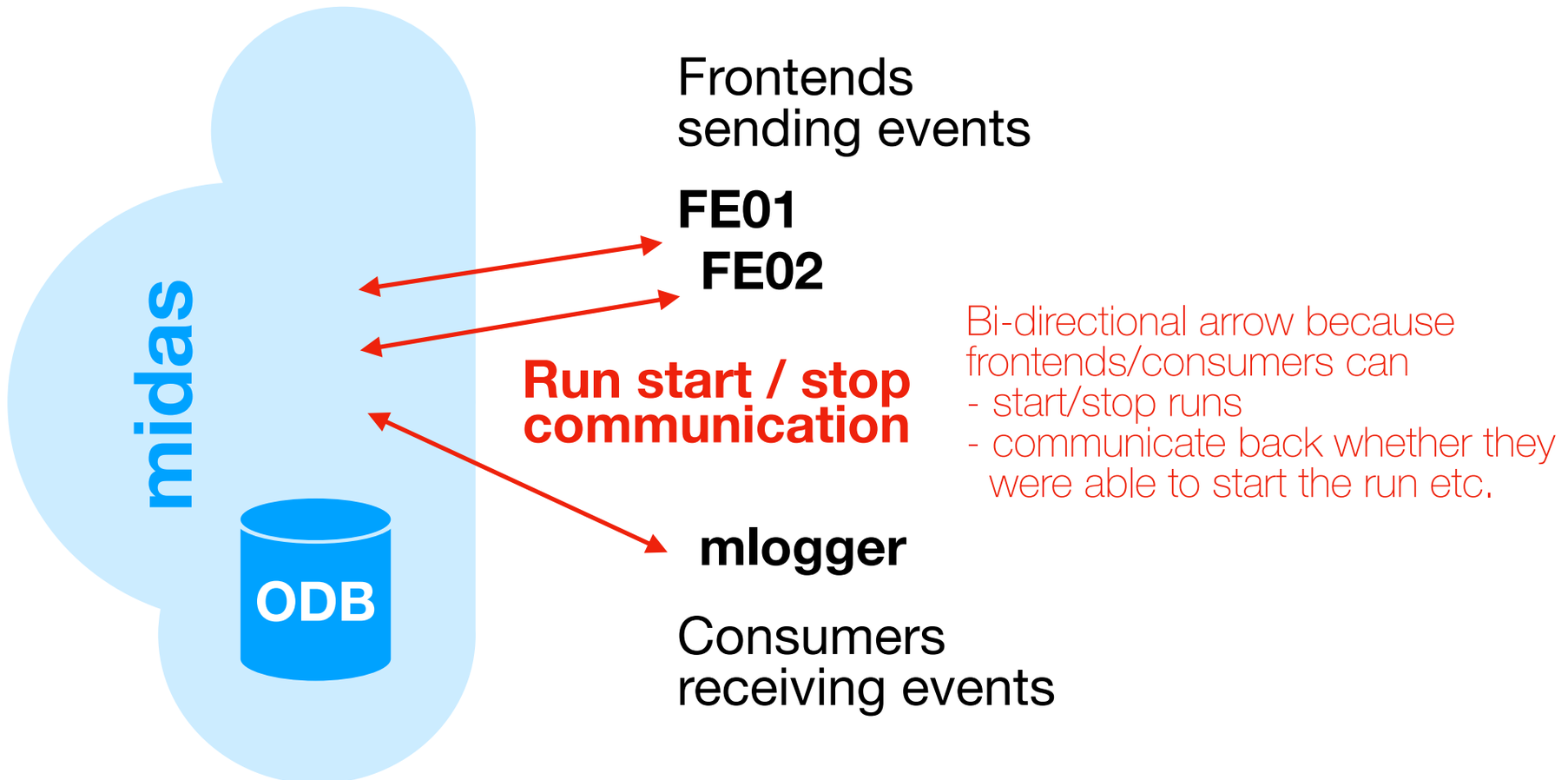


Data aggregation

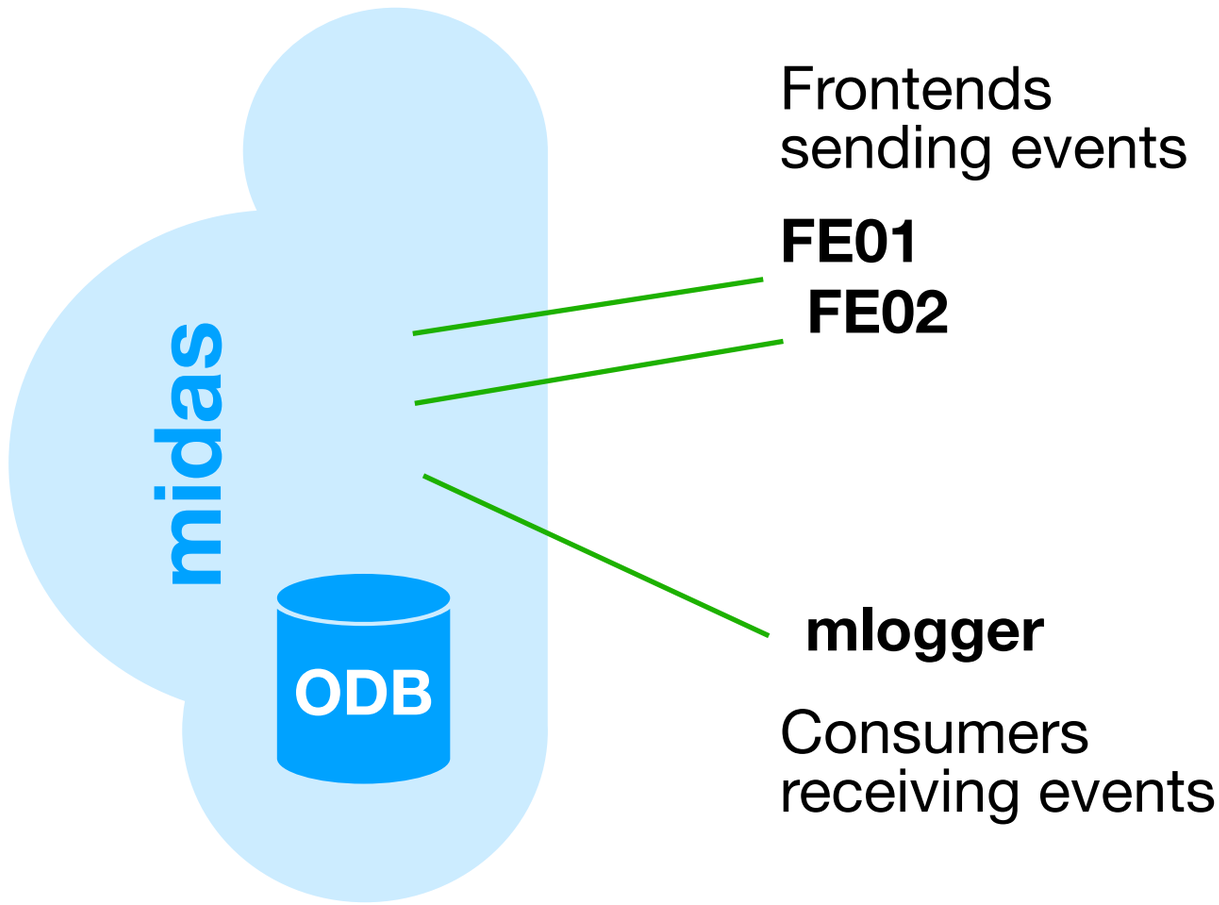
DAQ PC

16 crates on sides of detector

Quick Midas overview

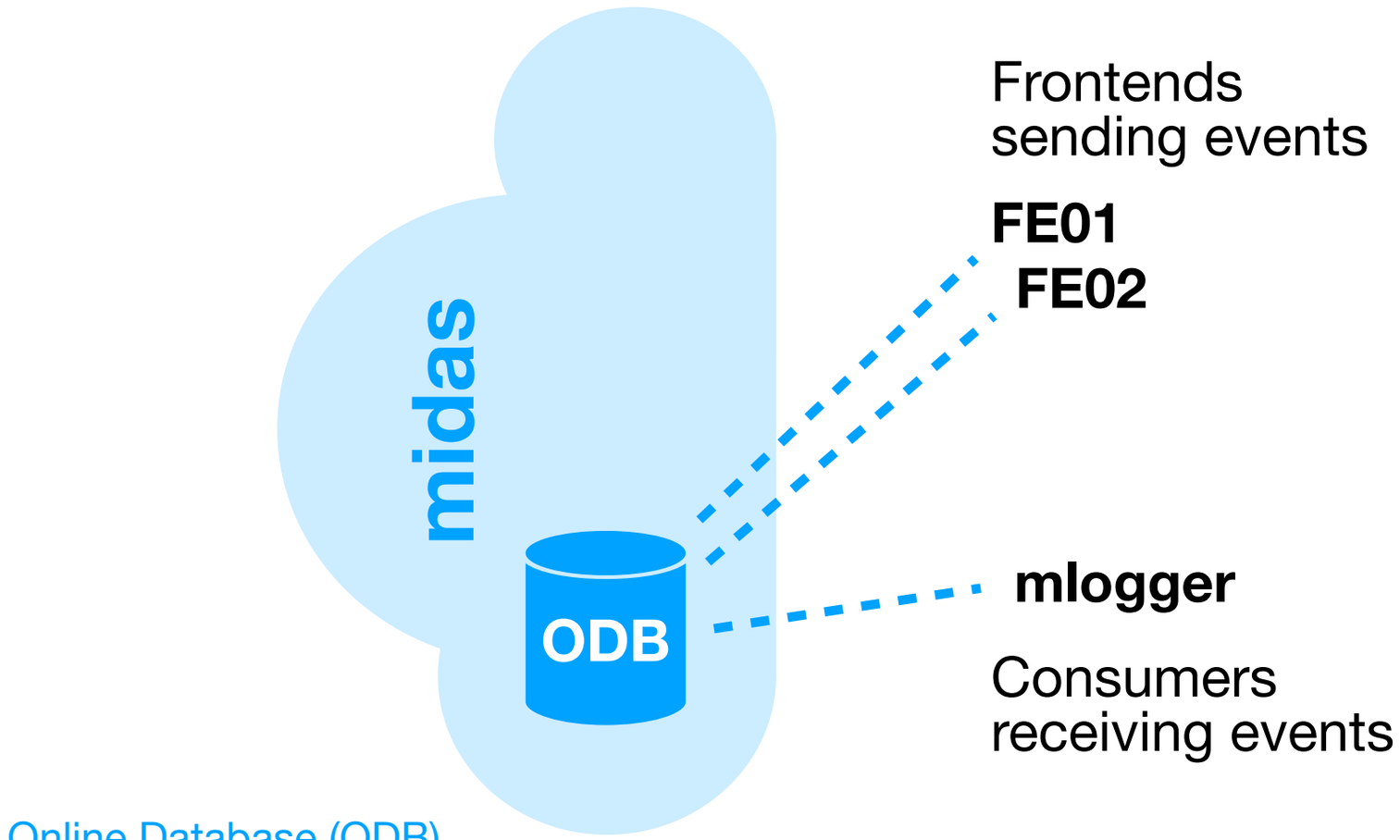


Quick Midas overview



All the communication with midas can happen either through shared memory regions (on same machine) kept track using hidden files in the working directory, or via RCP over TCP/IP, in which case a mserver program handles the access to the shared memory region.

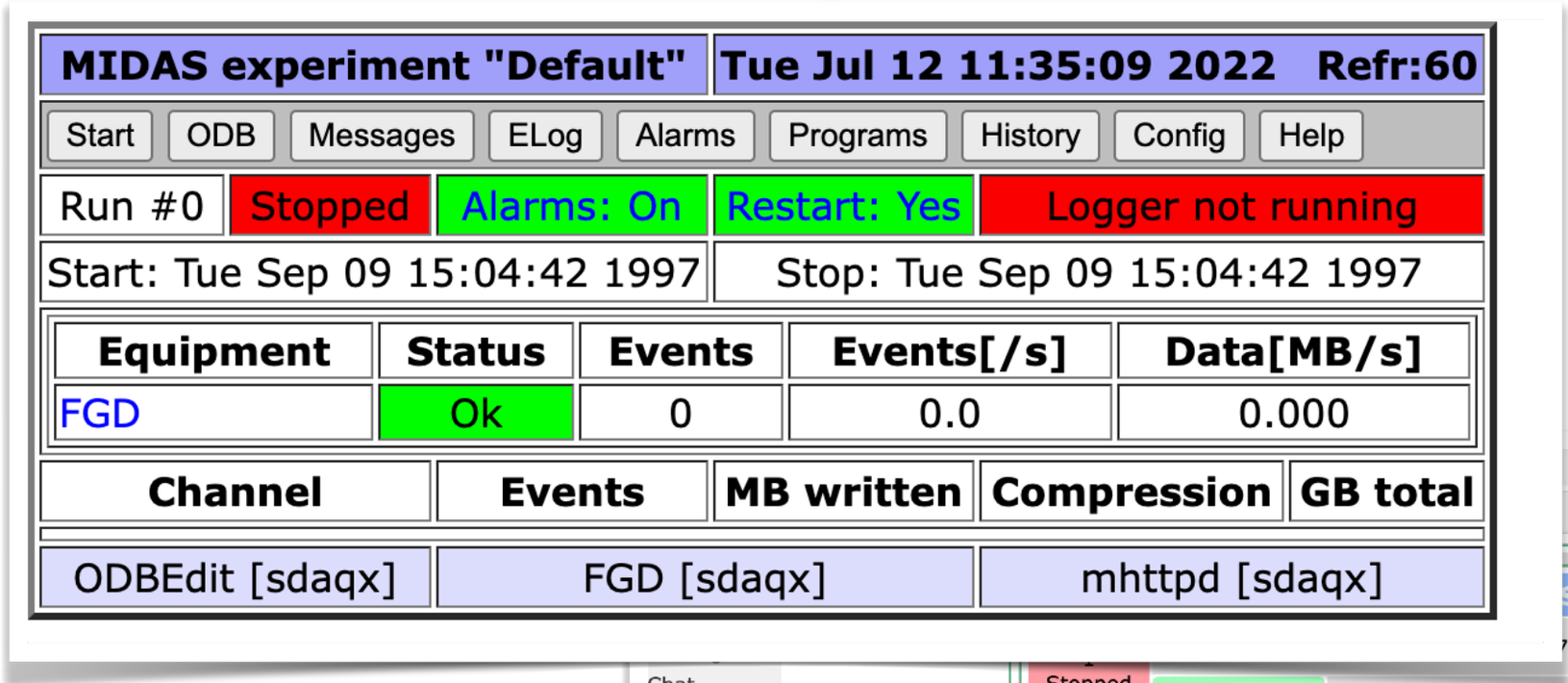
Quick Midas overview



Online Database (ODB)

- structured data for communication between various clients beyond real-time event data
- frontends / consumers can expose user configurable settings, status etc.
- edit via odbedit client program, or start midas web server with mhttpd and use ODB menu

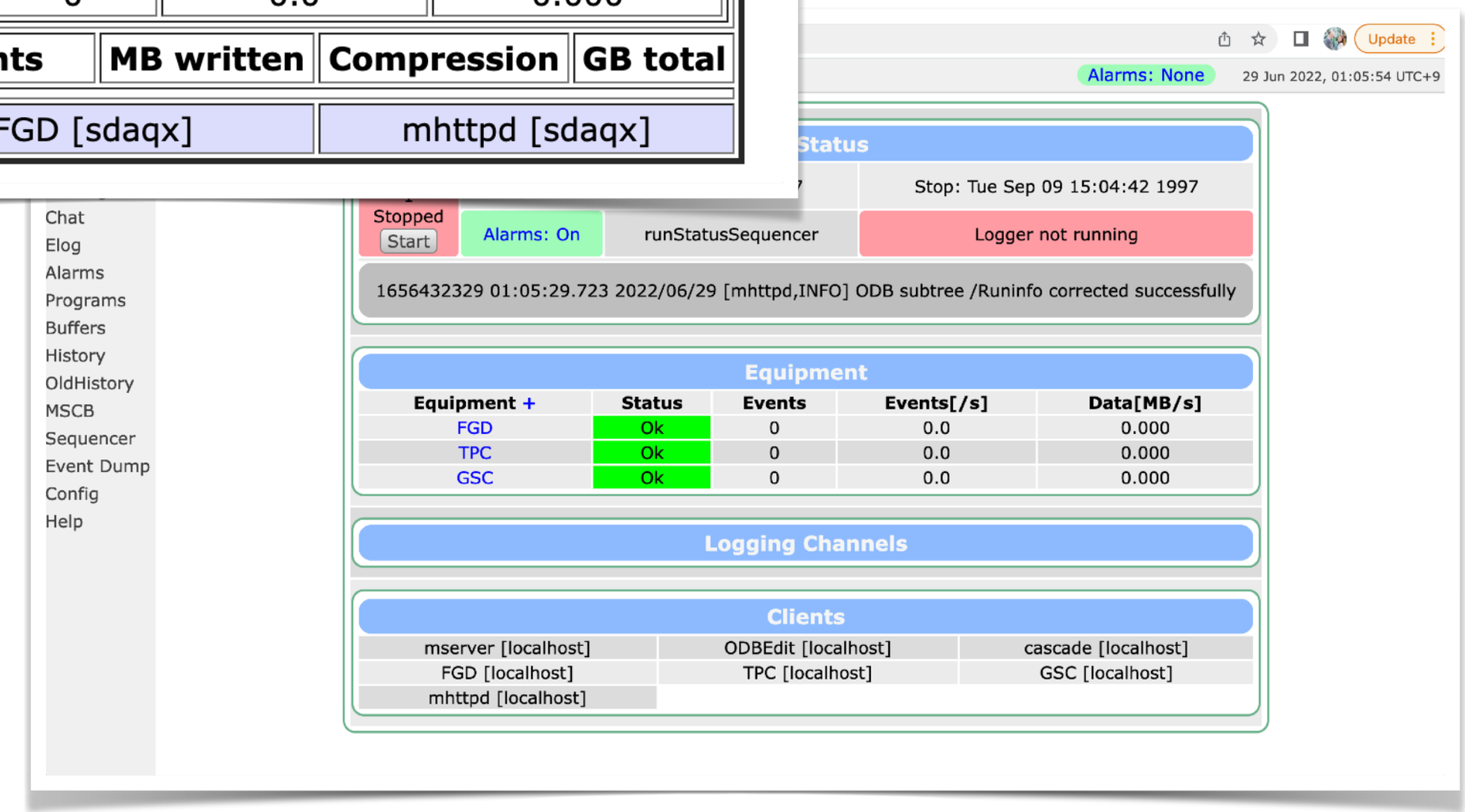
Web interface (mhttpd)



←

“old” midas version

(currently used in ND280, beamline etc.)

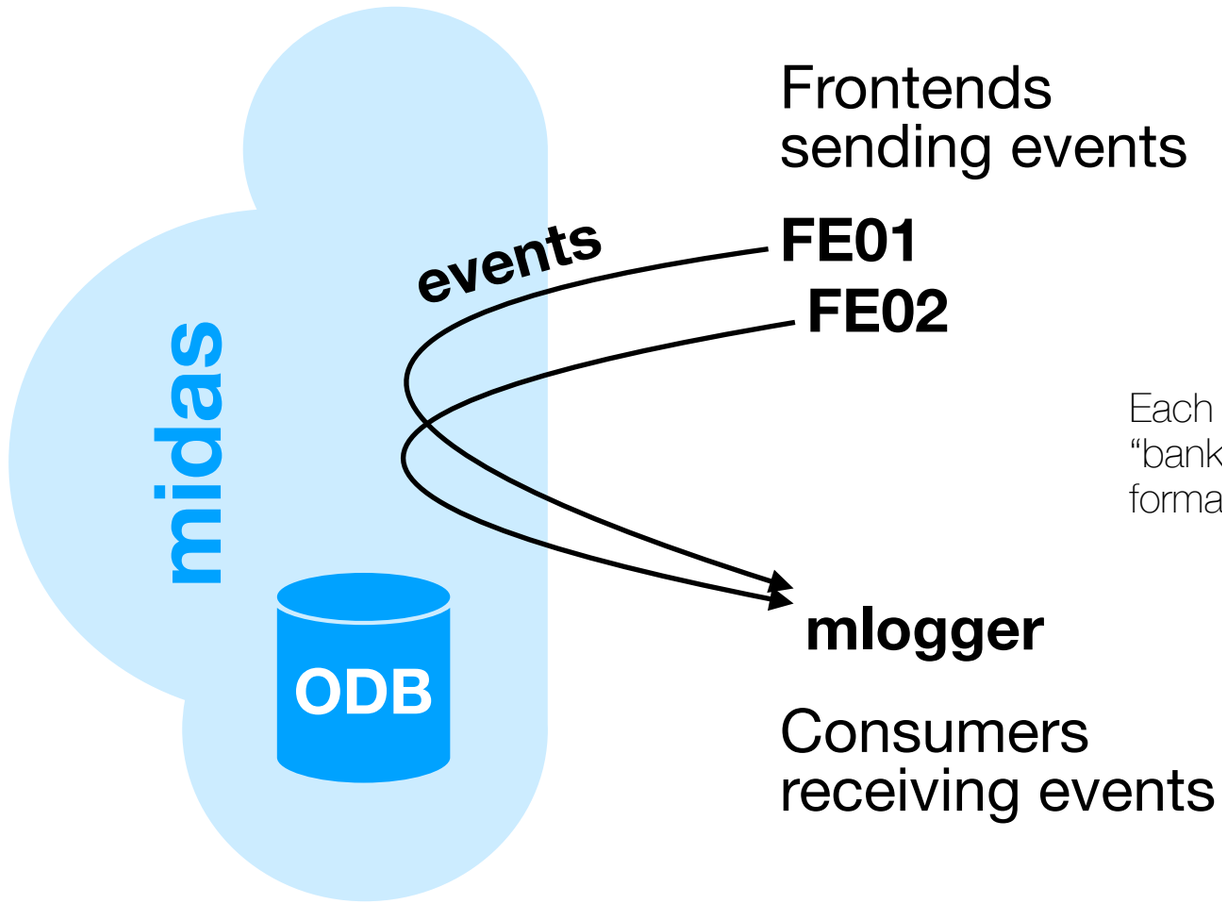


→

“new” midas version

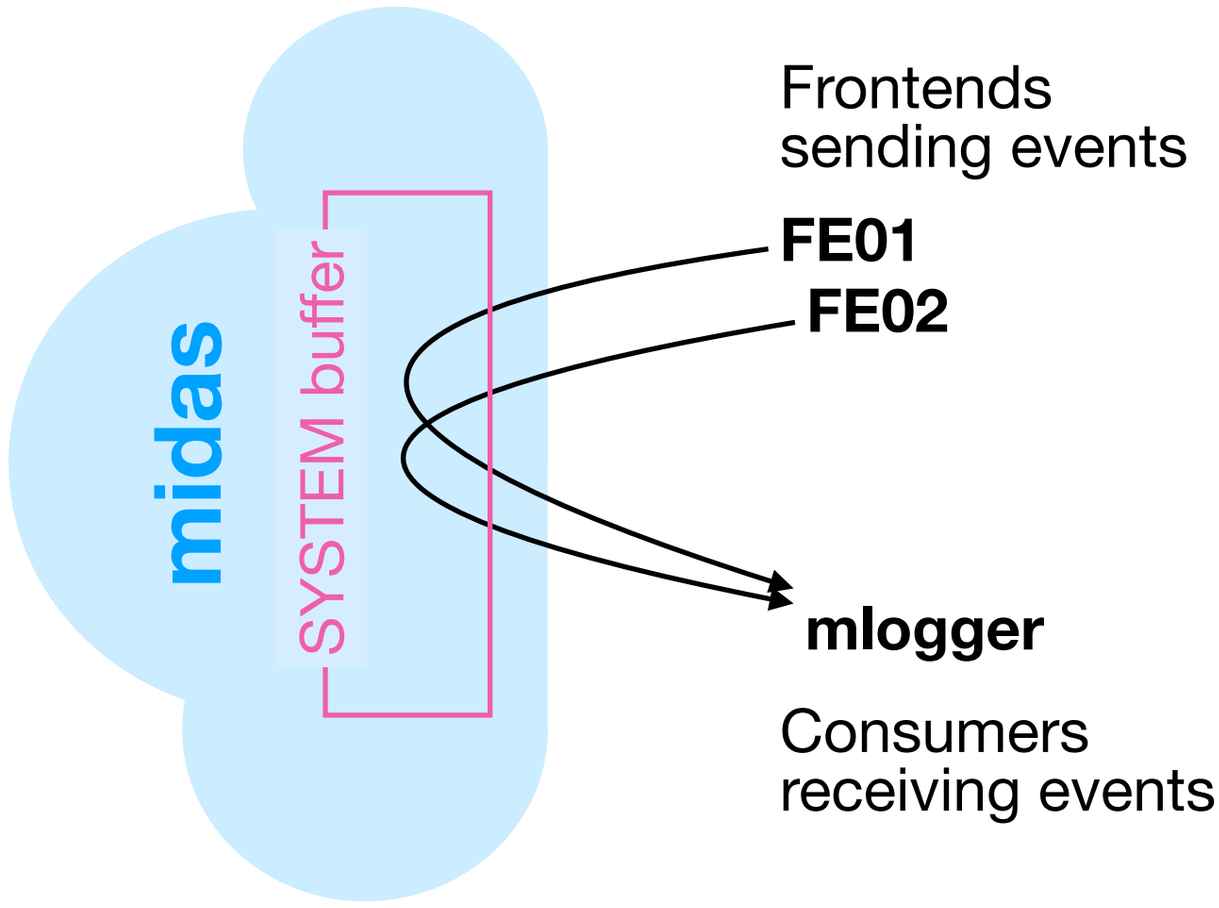
(considered for upcoming DAQ development including SFGD)

Quick Midas overview

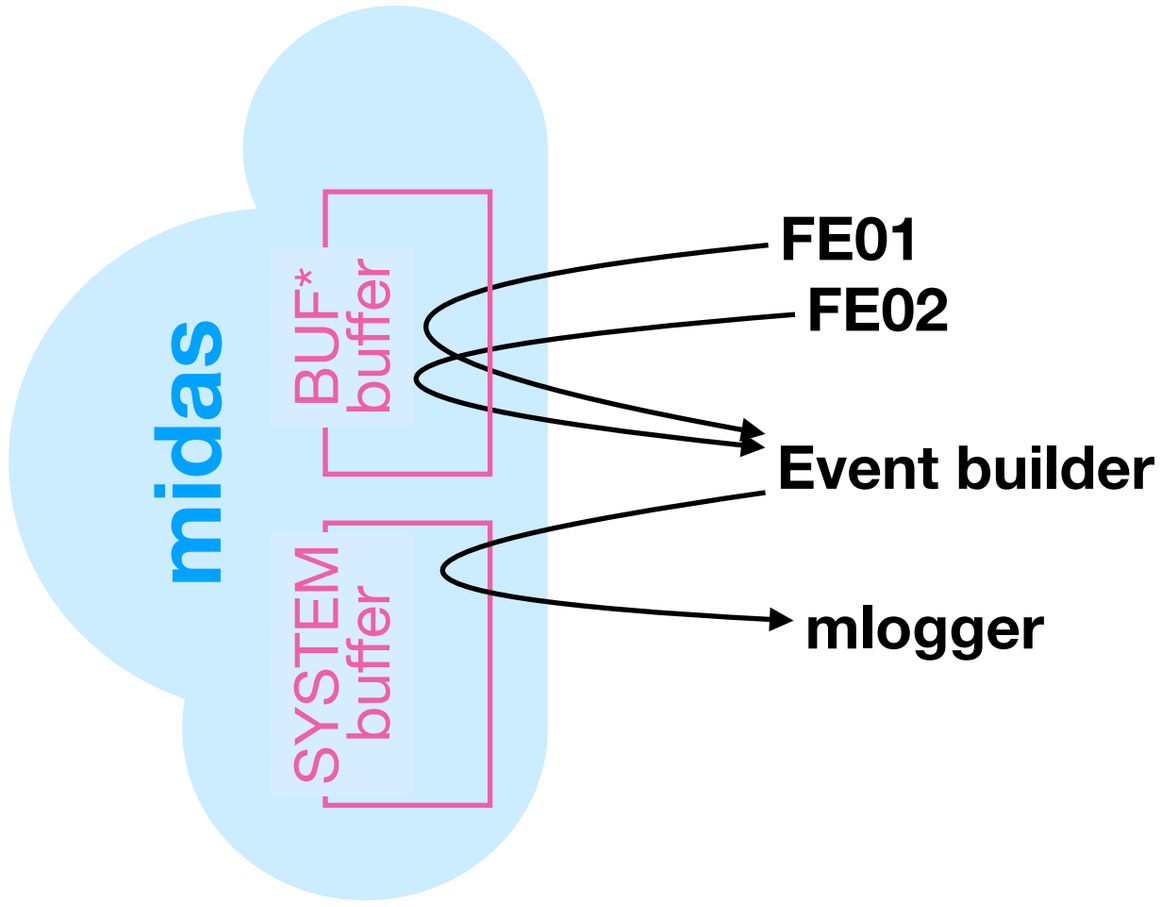


Each event can contain multiple data “banks” (basically arrays of some data format like uint32_t or double etc.)

Quick Midas overview

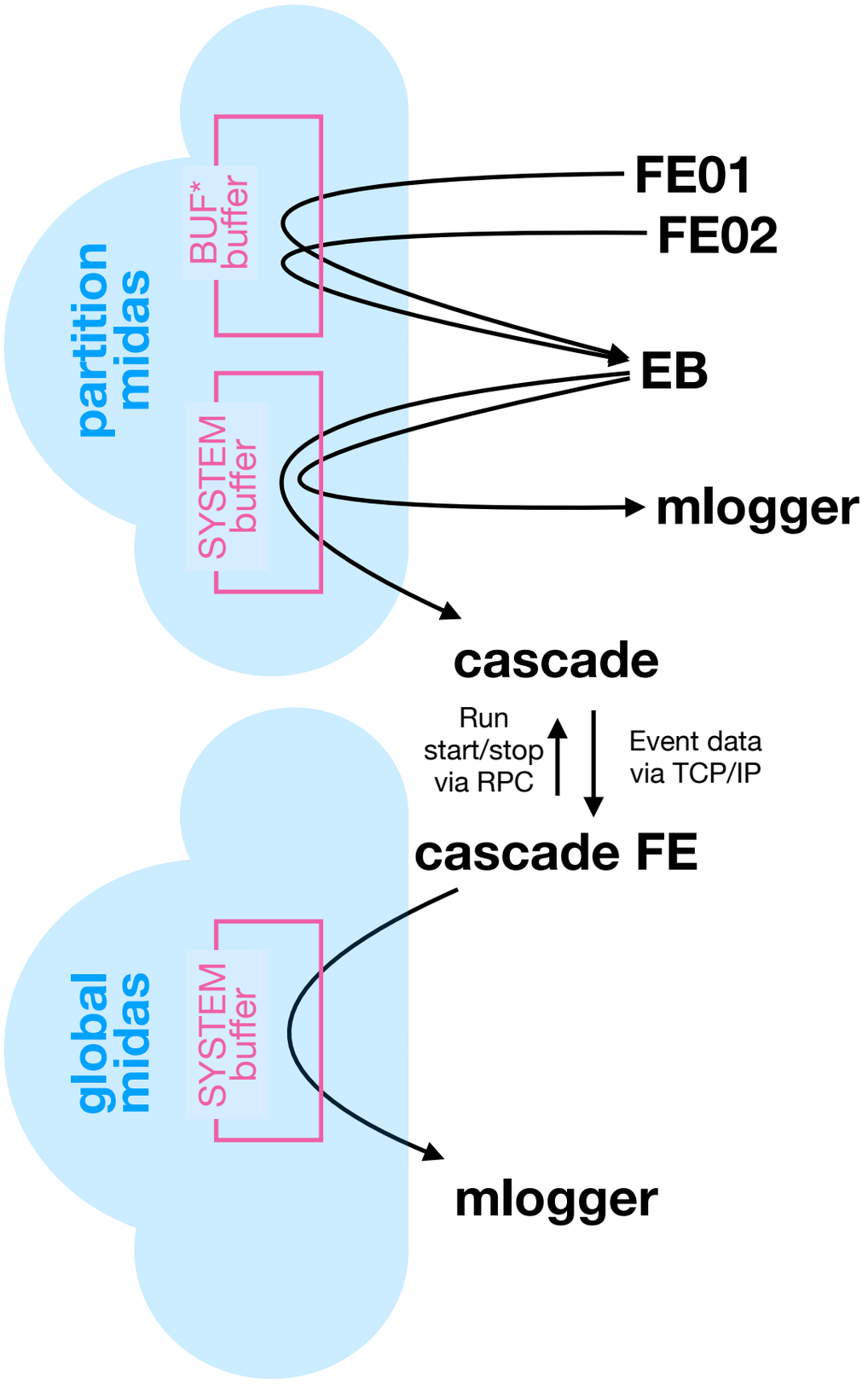


Quick Midas overview



Concatenates events from some buffers into a single event, matching based on serial number

ND280 midas system overview using cascades



Example

list of screen windows

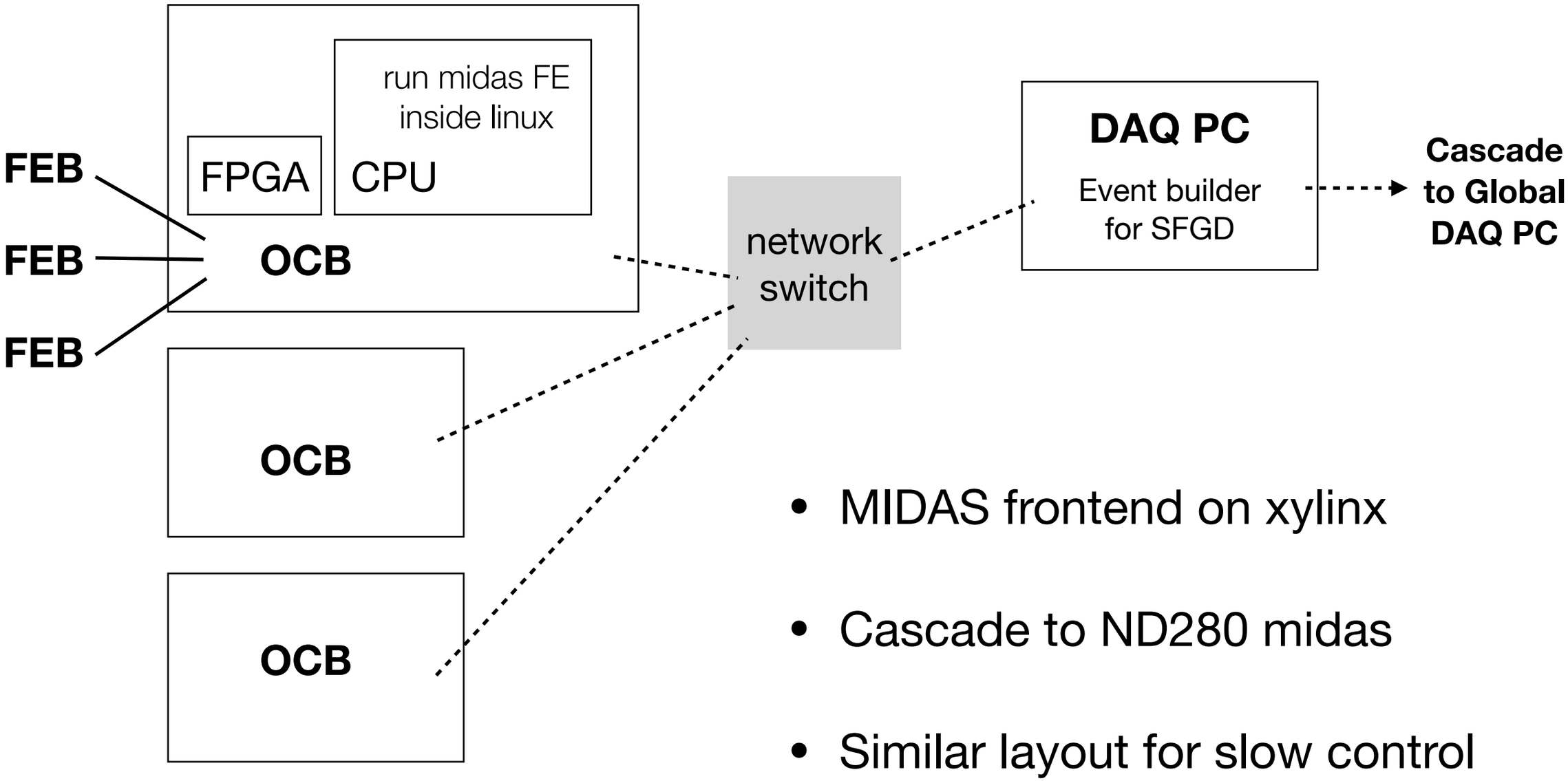
(in ND280 the different midases live on different servers)

```
Num Name

  0 daq@sdaqx:~/fgd/fgddaq_midas2022/online/src/build
  1 daq@sdaqx:~
  2 daq@sdaqx:~/fgd/midas/build
  3 global: mhttpd
  4 global: odbedit
  5 partition: mhttpd
  6 partition: FE01
  7 partition: FE02
  8 partition: EB
  9 partition: cascade
 10 global: cascade FE
 11 global: mlogger
 12 partition: mlogger
 13 daq@sdaqx:~
```

SFGD DAQ integration plan

Details subject to change

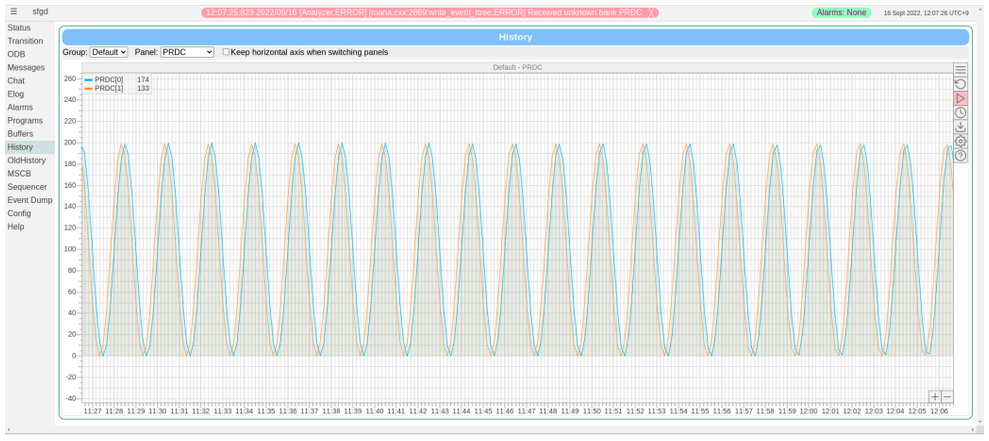


- MIDAS frontend on xylinx
- Cascade to ND280 midas
- Similar layout for slow control

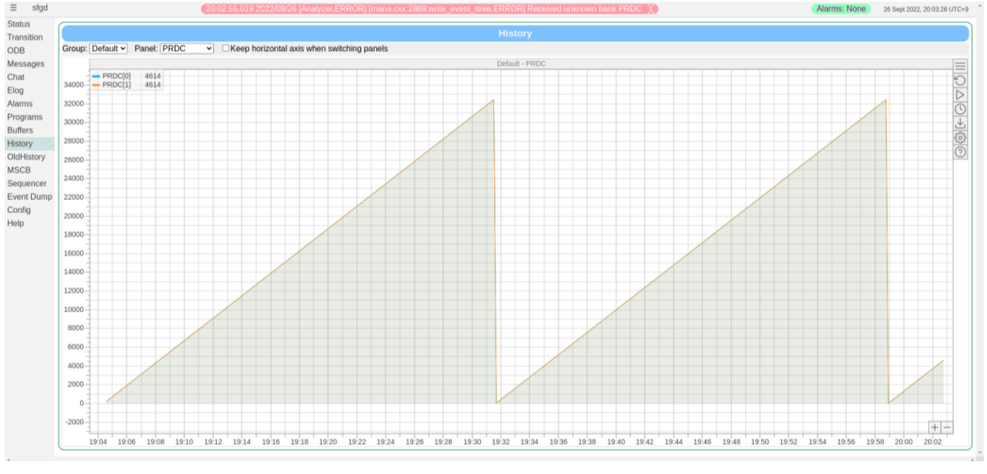
Midas frontend tests on Zturn board

Display of events in DAQ PC

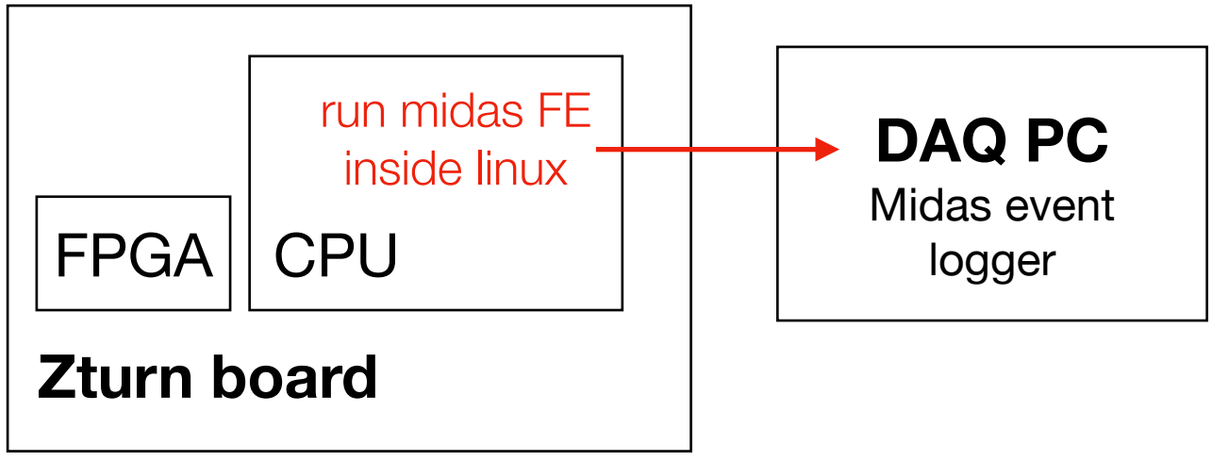
Sinusoidal data generated on Zturn's CPU



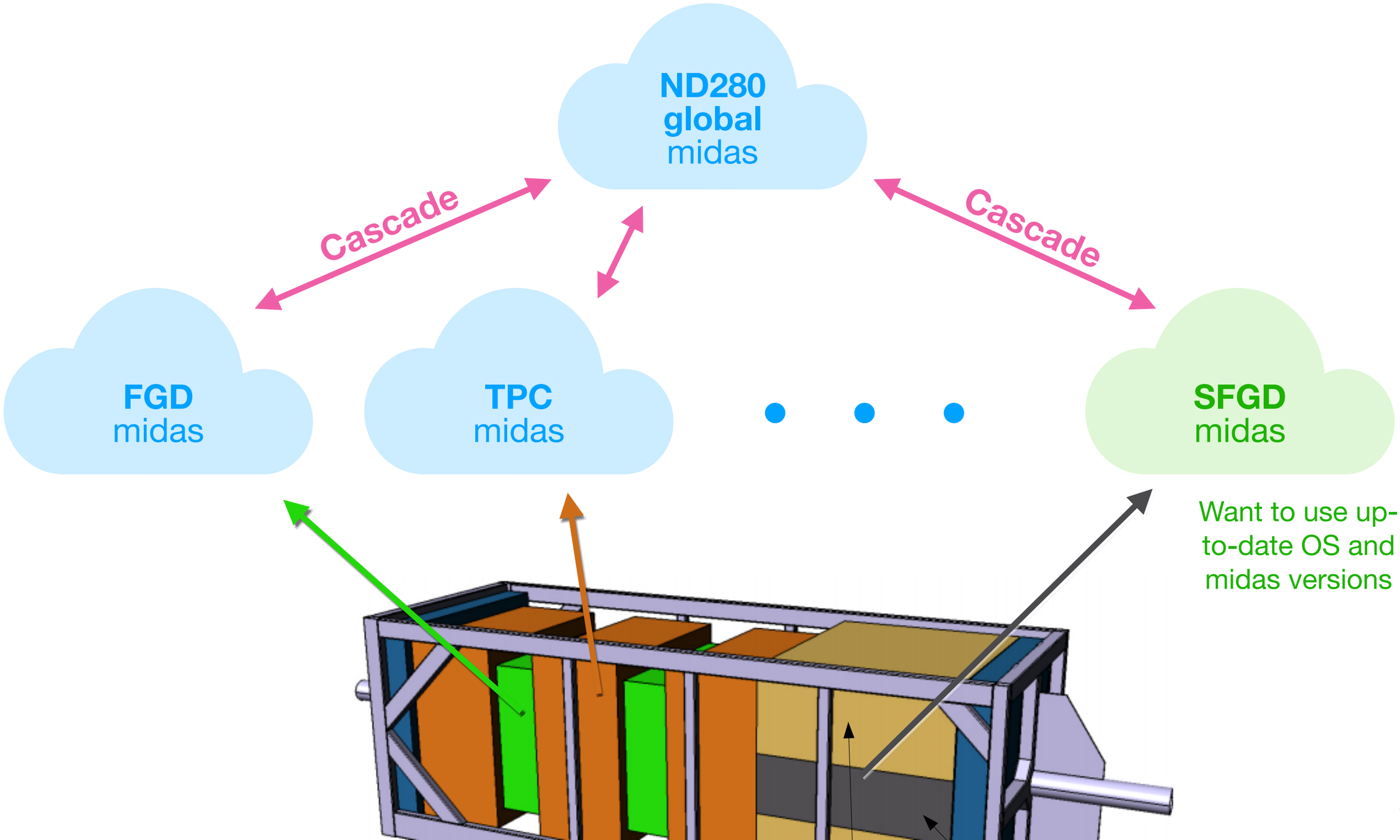
Sawtooth pattern generated on FPGA



- Tried running Midas frontend on CPU inside Zturn board (same board as used by OCB)
- Successful event readout and transfer to DAQ PC for both CPU- and FPGU-generated data



Midas cascade layout



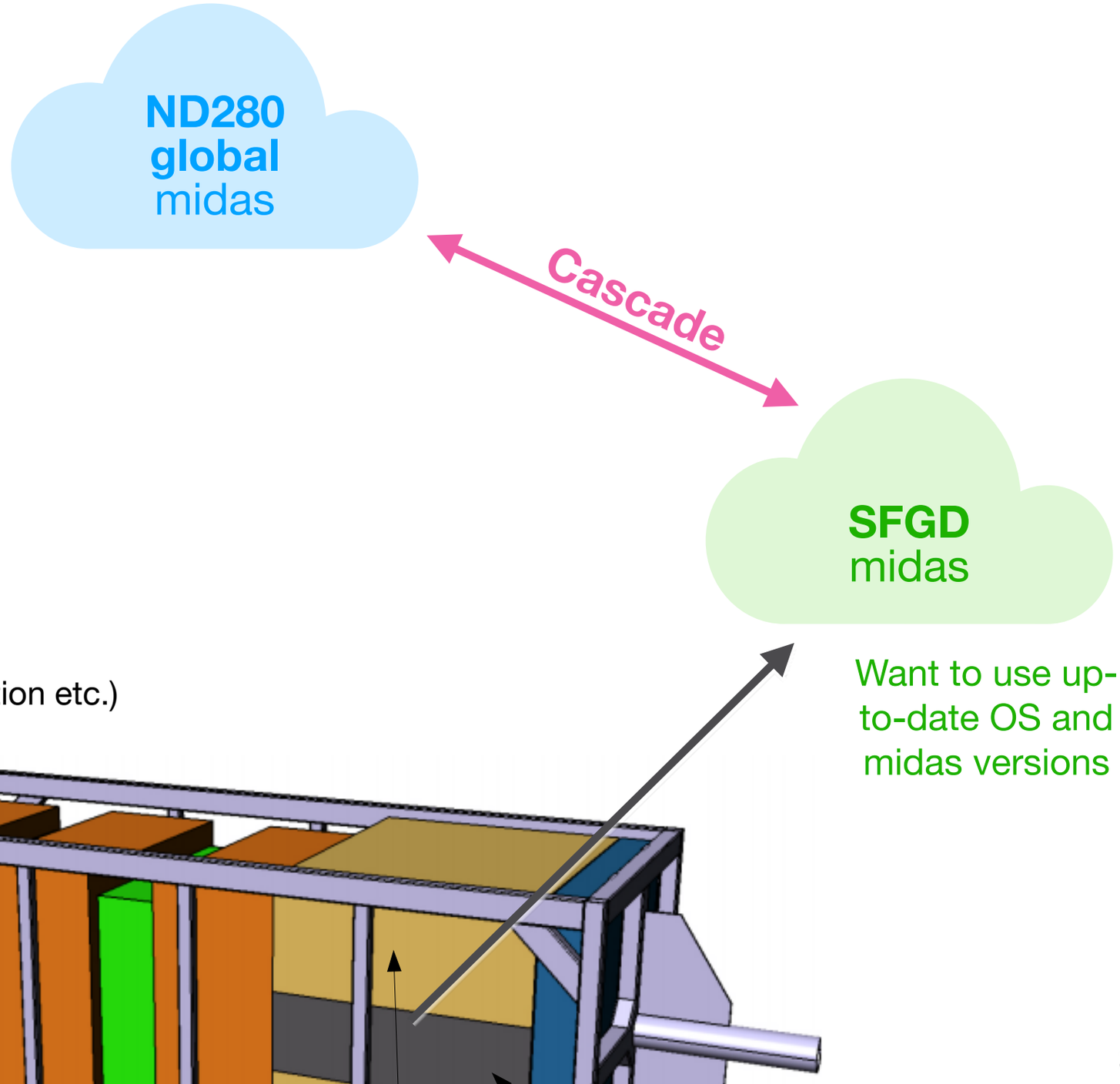
Want to use up-to-date OS and midas versions

Midas cascade layout

Successfully tested

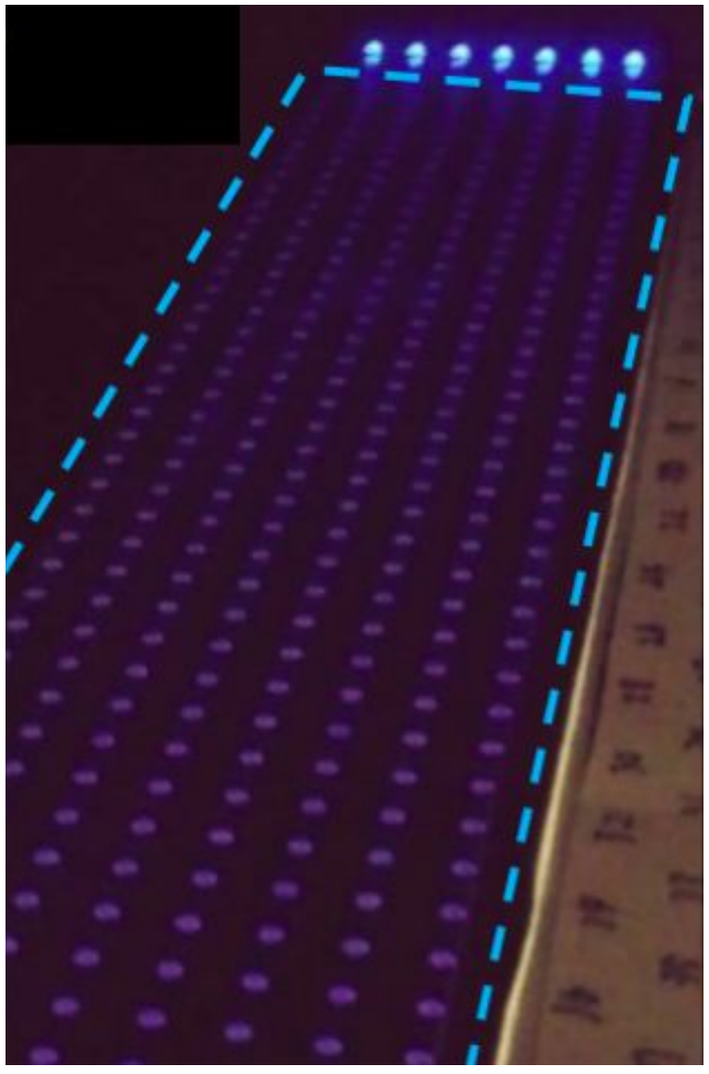
- communication between different OS/midas versions
- higher data rate (~1MB/event, 10MB/sec max) from SFGD compared to other detectors

(required some changes to socket implementation etc.)

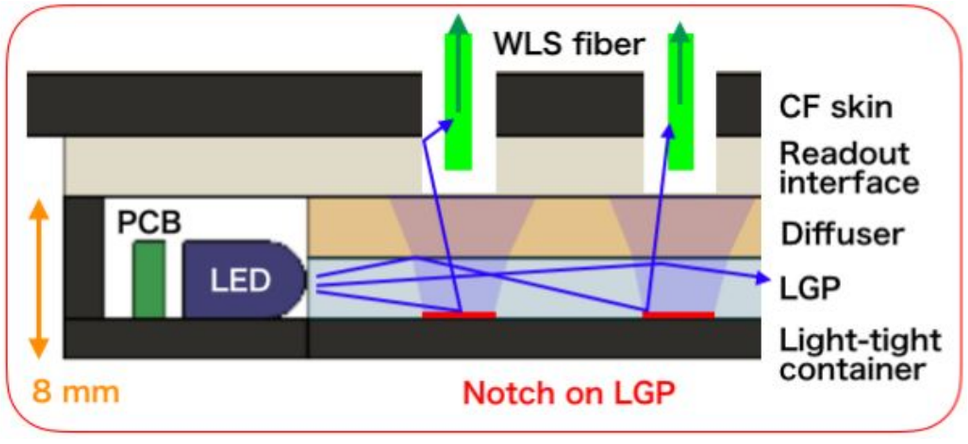


Ongoing works

- Remote frontend development on development boards installed at University of Pennsylvania
- Support for various trigger modes etc.
  (beam, cosmic, calibration)
- High data-rate expected for calibration LED pulses between beam triggers
  → on-line histogramming for data-reduction
- “Vertical slice test” for full communication and readout from one FEB→OCB→DAQ chain planned in Dec-Feb

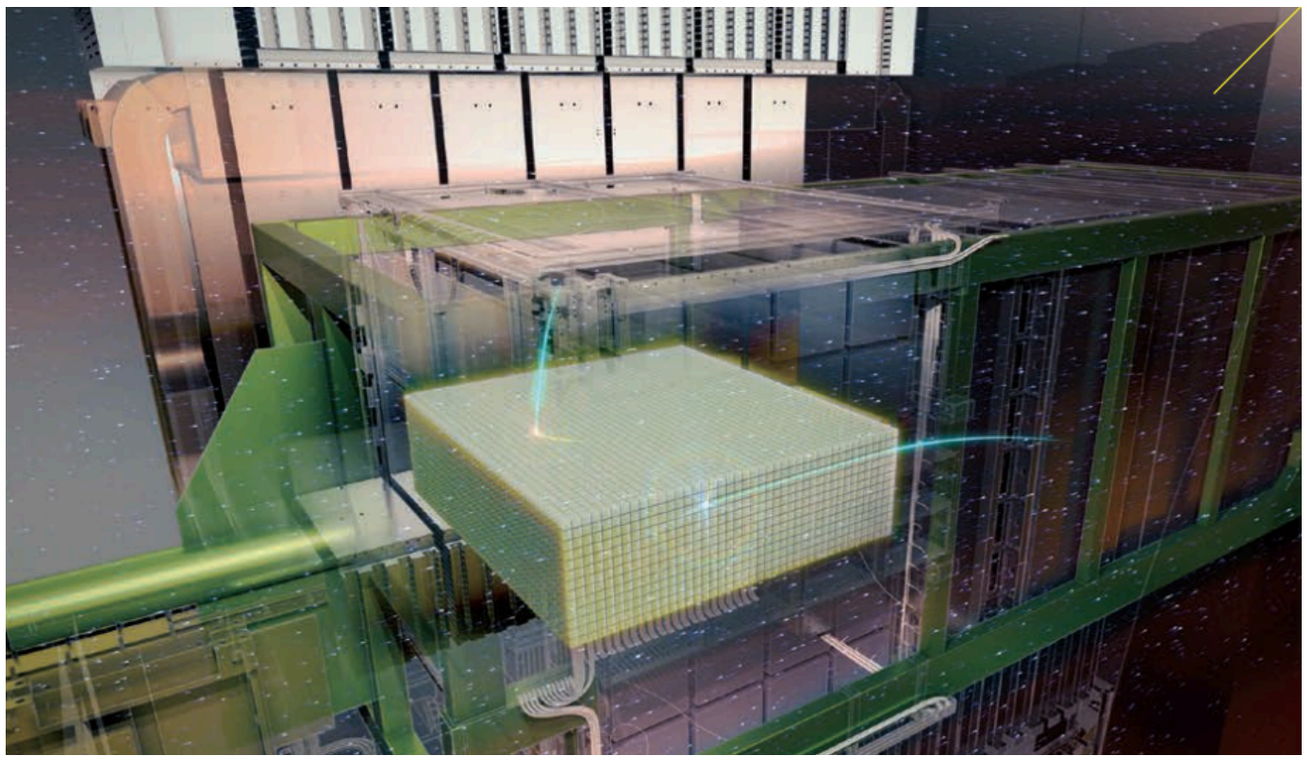


Light Guide Plate (LGP)



See e.g. Jaafar Chakrani, NOW 2022

Summary



Taken from: http://j-parc.jp/c/topics/quarterly/index.html

- T2K near detector is being upgraded for better constraint on flux and interaction systematics
- SuperFGD is a new detector with 2M scintillator cubes and ~56,000 readout fibers in x,y,z directions
- DAQ development for SuperFGD ongoing with midas frontend on CPU of concentrator board and cascade to global ND280 midas system
- With upgrades also to beam line, T2K will rapidly collect more data over the next few years for exciting physics and connect to HyperK operation from ~2027