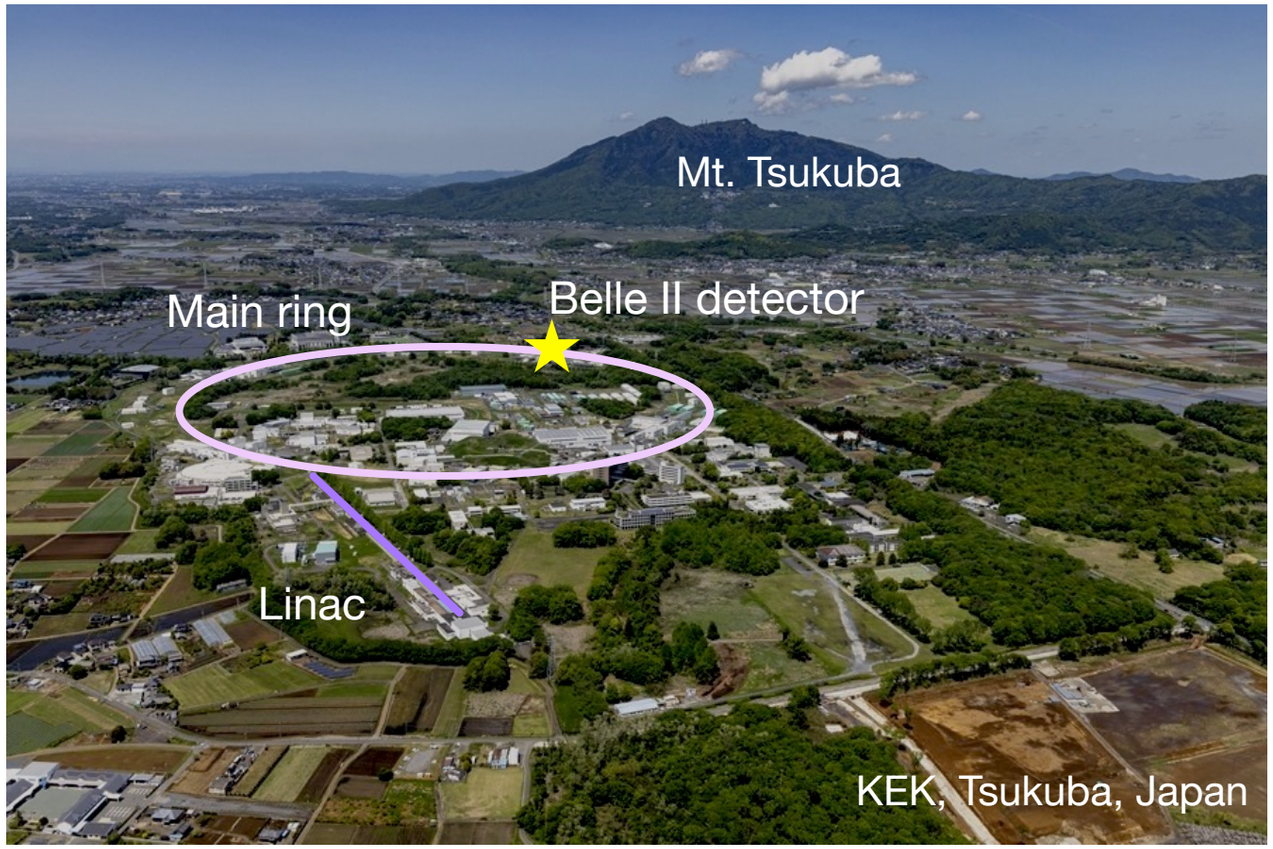
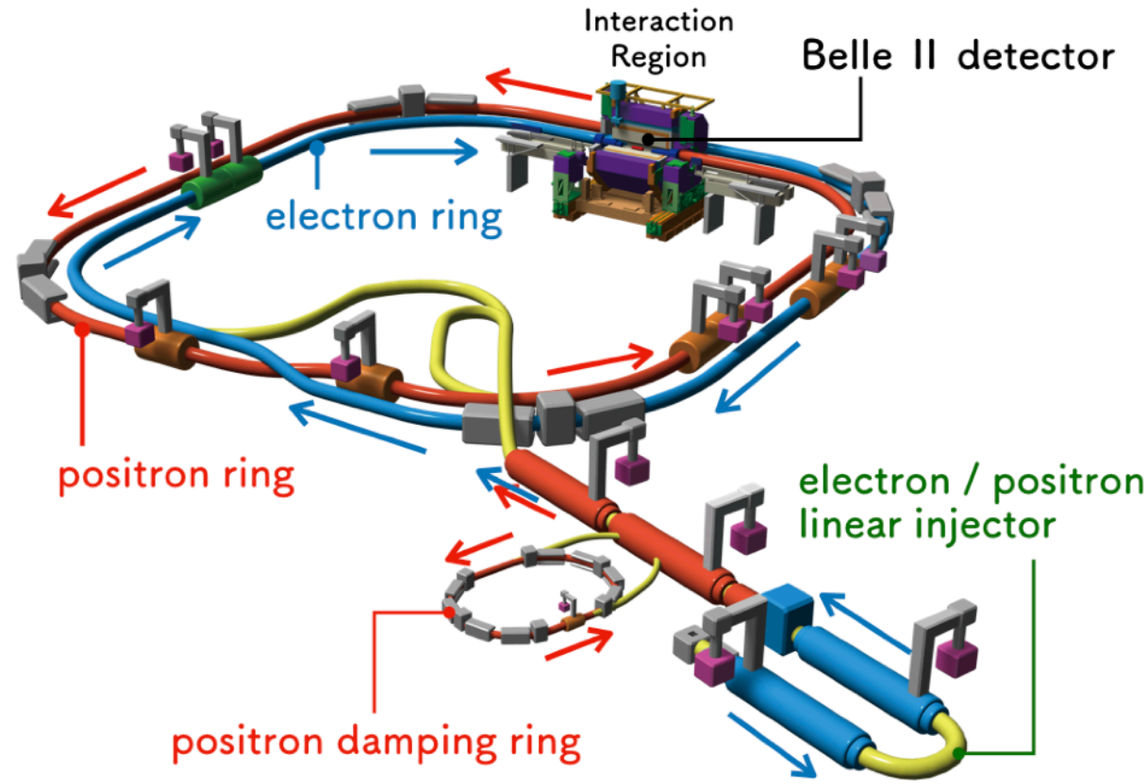
Operation of Belle II drift chamber at B-factory

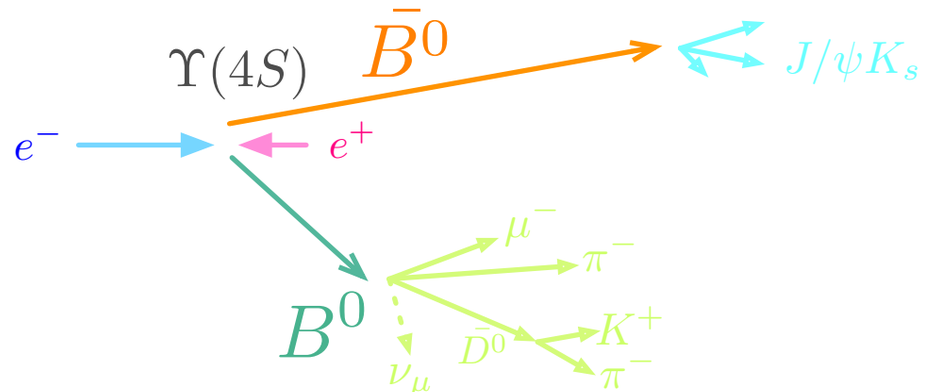
Nanae Taniguchi (KEK IPNS)
Belle II collaboration

SuperKEKB・Belle II



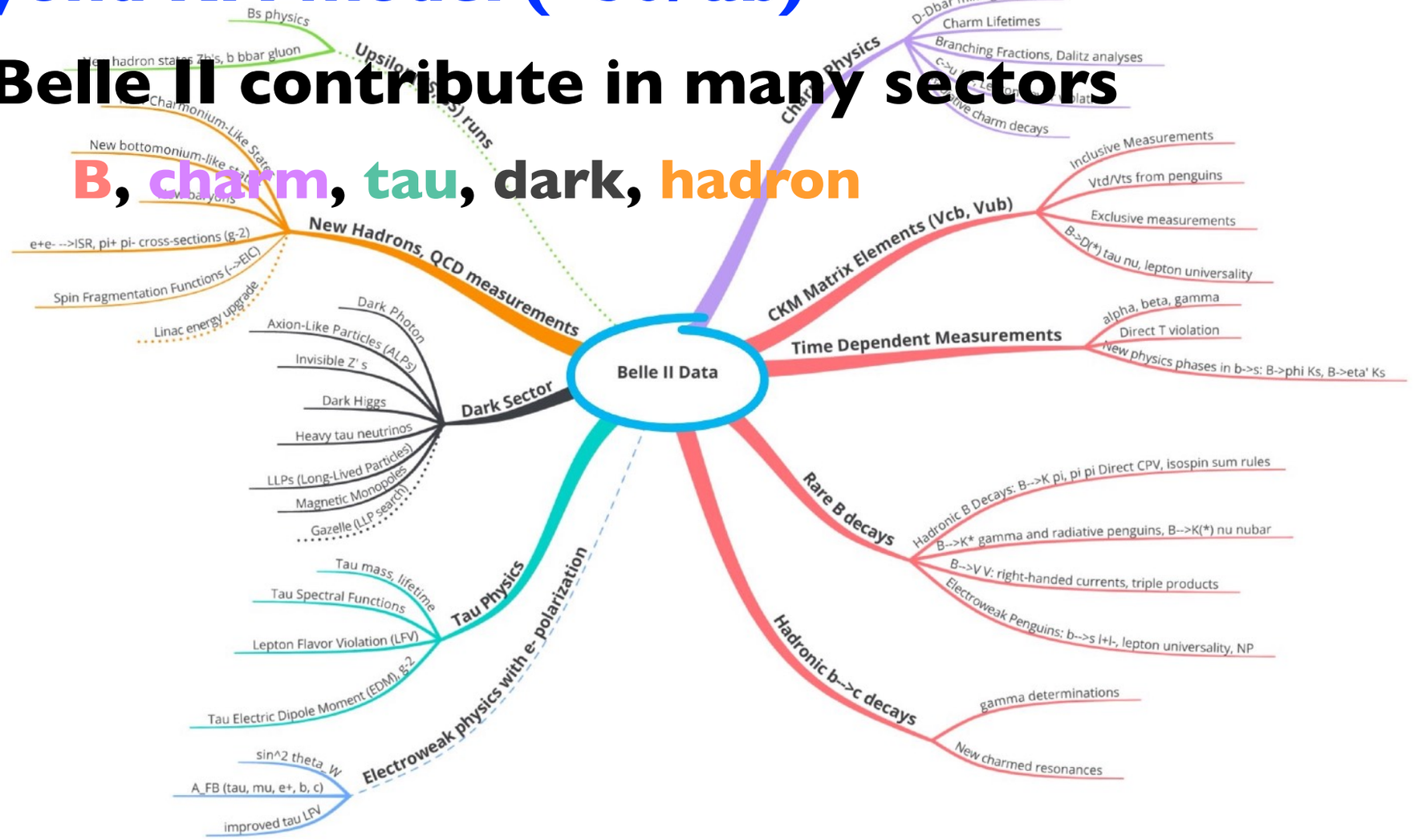


- Asymmetry energy, electron (7 GeV) positron (4 GeV) collider at Y(4S) mass
  - circumference ~ 3km
- target luminosity = $6 \times 10^{35}/cm^{-2}/s^{-1}$



Belle II physics program

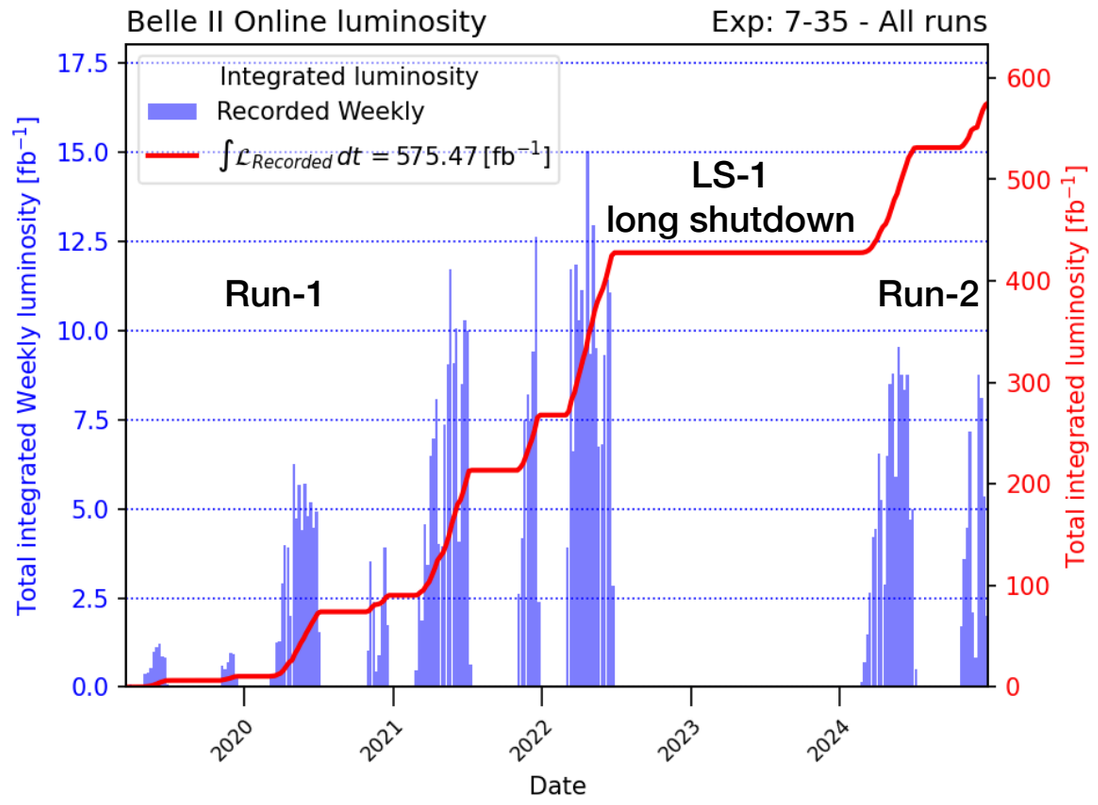
- **Belle (1999 - 2010) : was constructed to substantiate KM model (~1/ab) achieved!!**
- **Belle II (2018 -) : is designed to find new physics beyond KM model (~50/ab)**
  - **Belle II contribute in many sectors**
  - **B, charm, tau, dark, hadron**

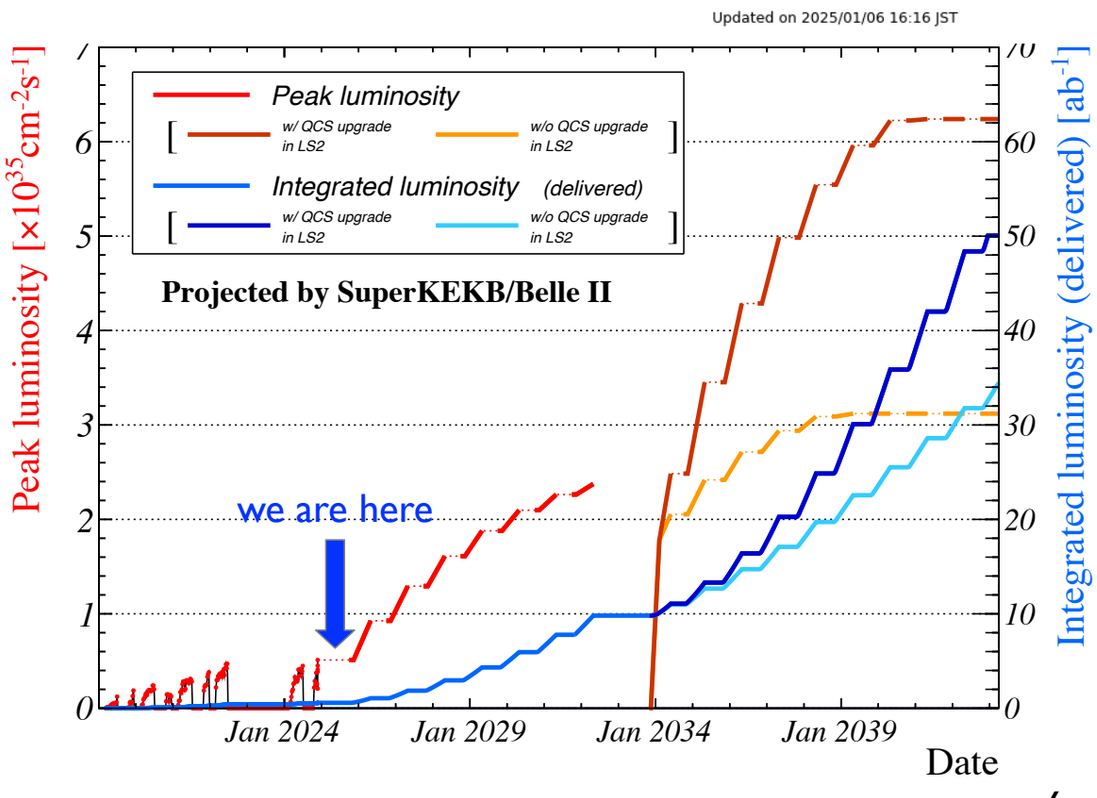


Operation Timeline

- 2018; first collision event
- 2019; physics run started
- 2020; updated luminosity record by KEKB ($2x10^{34}$)
- 2022; $4.7x10^{34}$
- 2022; 424/fb
  - ~1/2 of Belle-I
- long shutdown (LS-1)
  - new collimator
  - installation of full-layer pixel detector
- 2024; Run 2 start
- 2024; $5.2x10^{34}$ (Belle II OFF)

Progress toward the target luminosity is step by step.

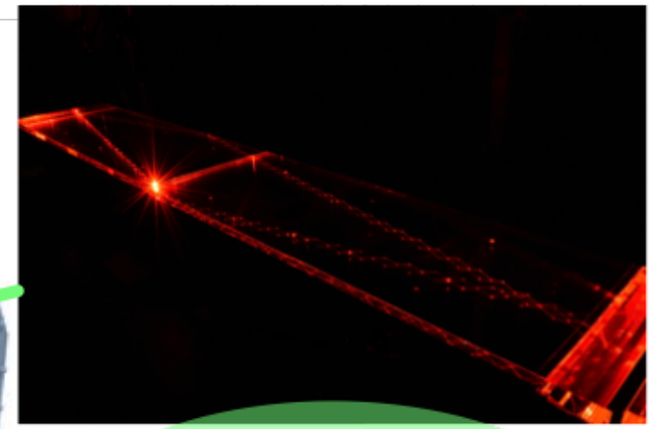




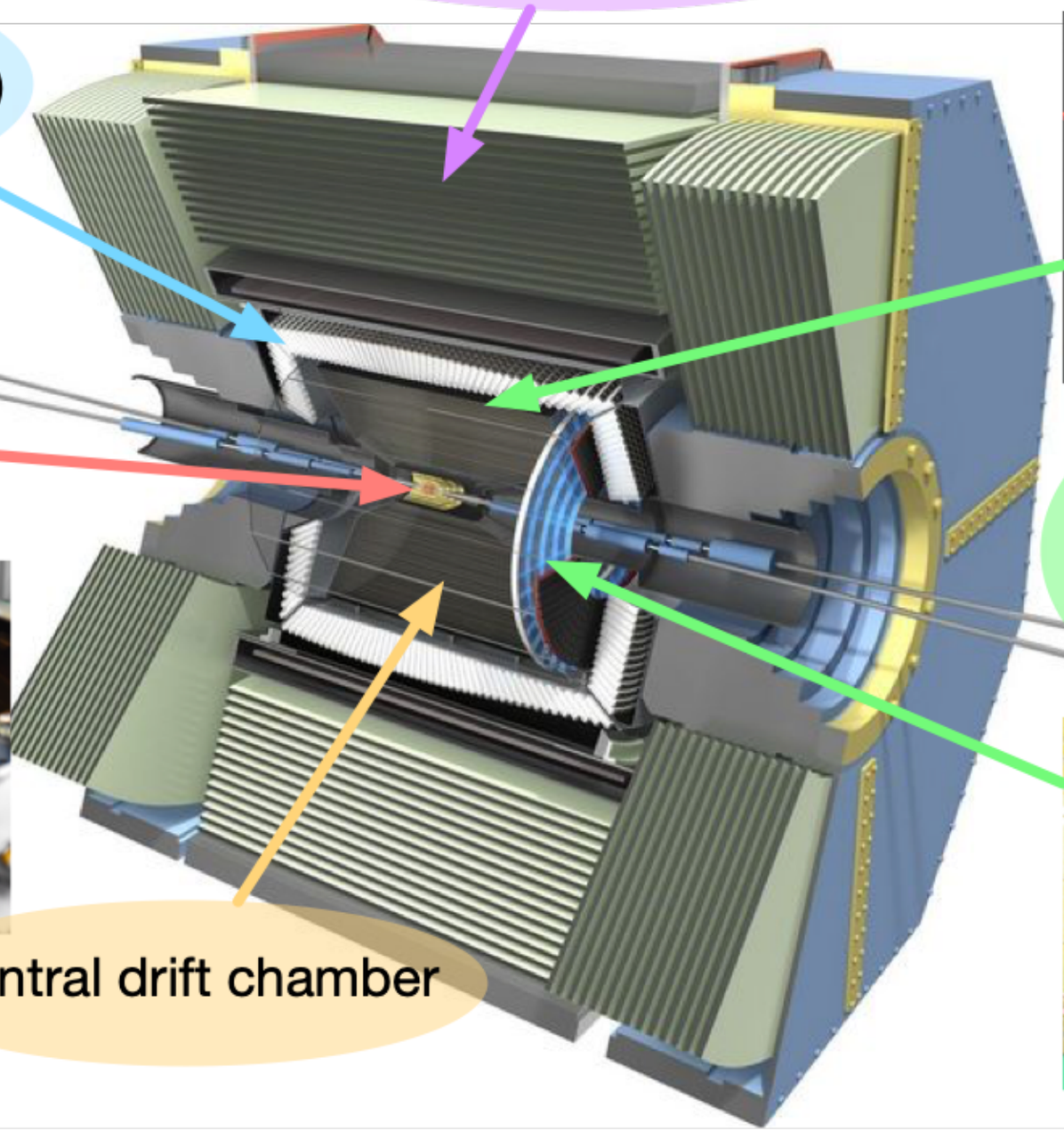
Belle II detector

KL and muon detector
resistive plate counter (barrel)
scintillator+WLSF+MPPC (endcaps)

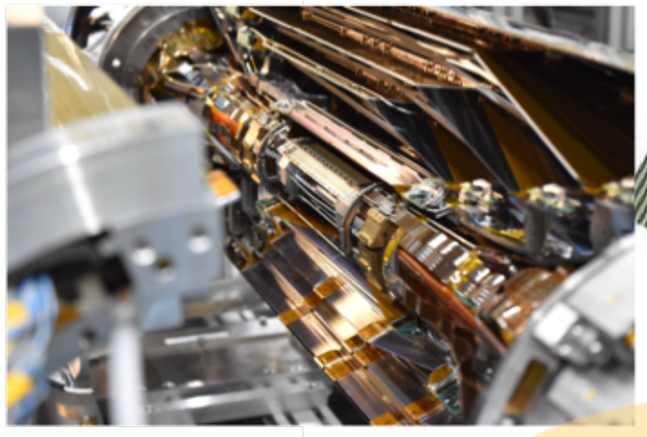
EM calorimeter; CsI(Tl)

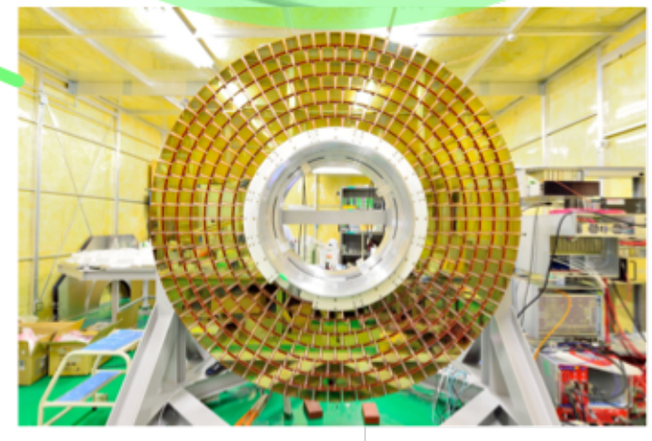


Vertex Detector
semiconductor
pixel + strip



Particle ID
Time of propagation
counter (barrel)
aerogel RICH (endcap)

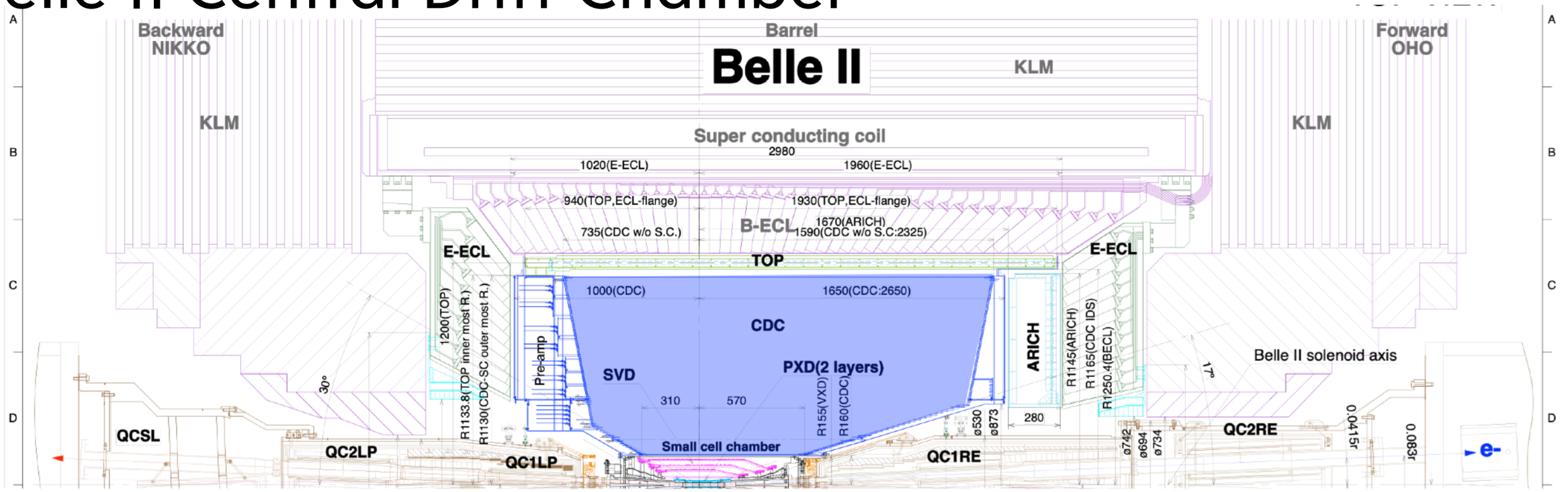




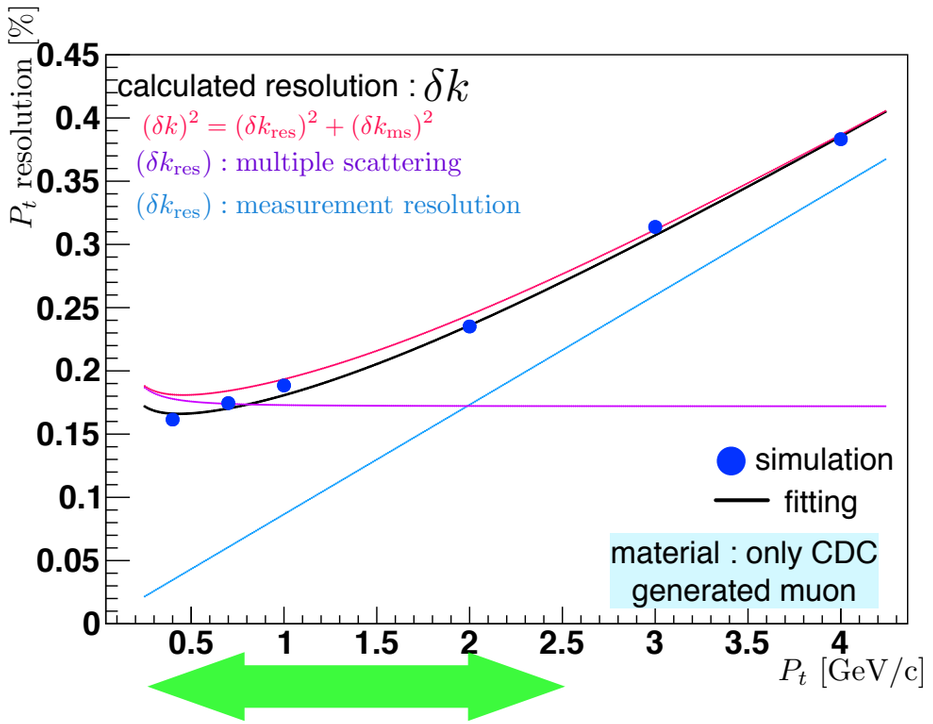
Central drift chamber

challenge ! preserve detector performance
while luminosity (beam background) increases

Belle II Central Drift Chamber



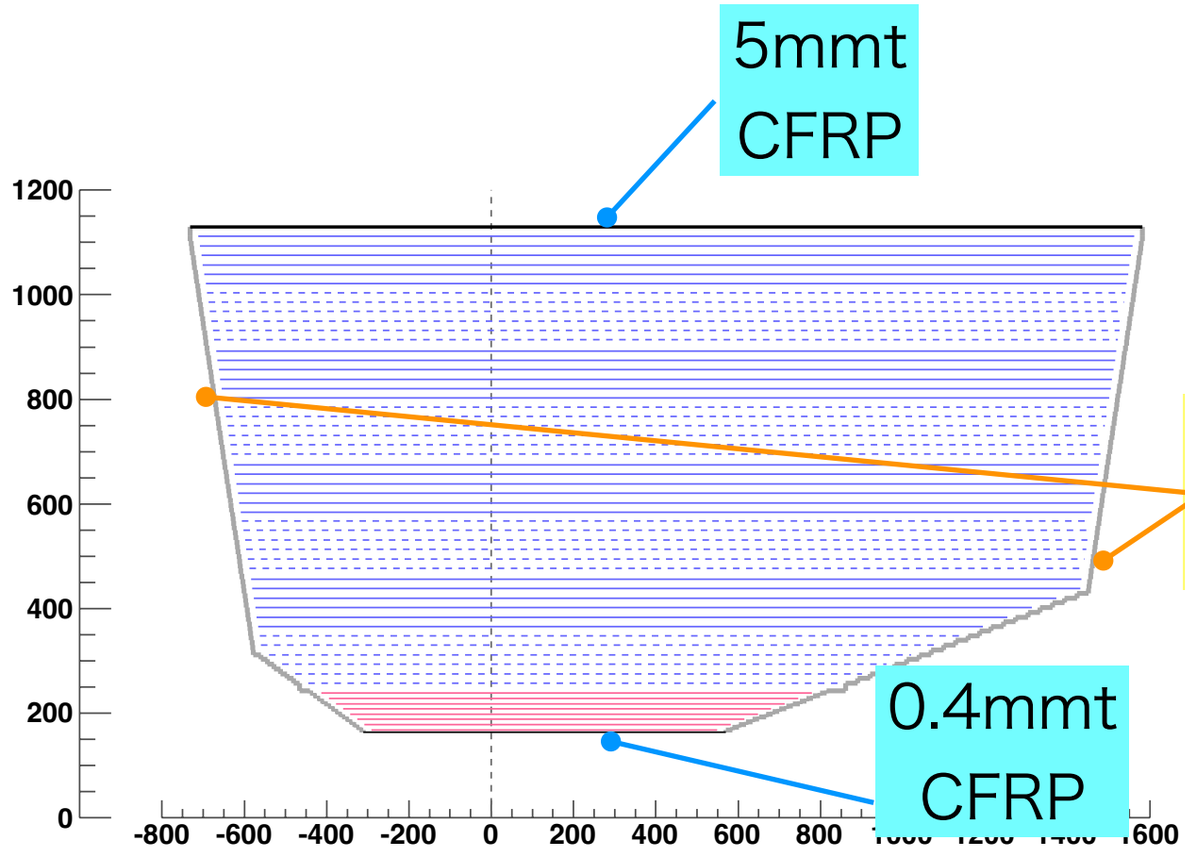
- Role of charged particle tracker of Belle II
  - momentum measurement
    - magnetic field = 1.5T
  - dEdx measurement for particle identification
  - track trigger
- CDC = Central Drift Chamber
  - wire
    - sense x 14336; Au-W (ϕ30um)
    - field x 42240; Al (ϕ126um)
  - gas
    - He:ethane = 50:50



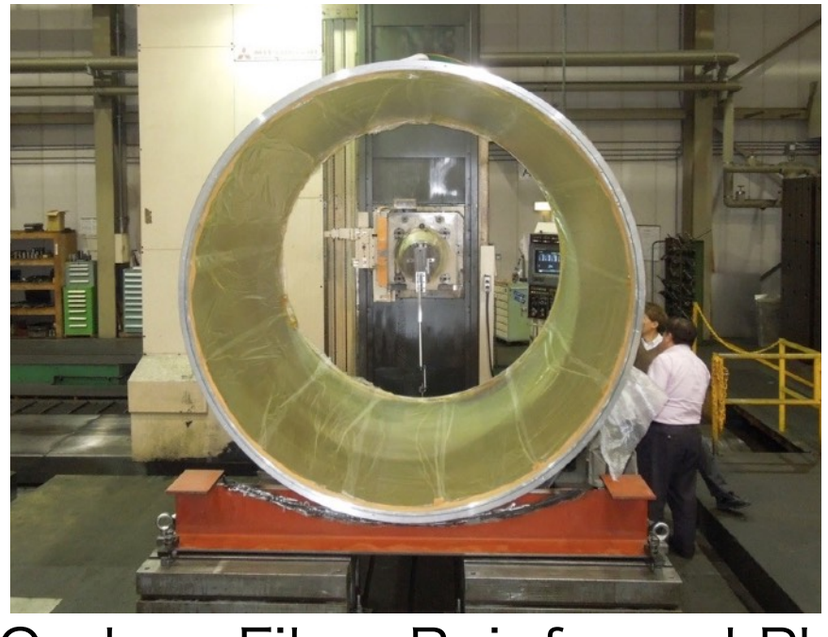
multiple scattering is dominant

low material

< 600kg



Aluminum endplate

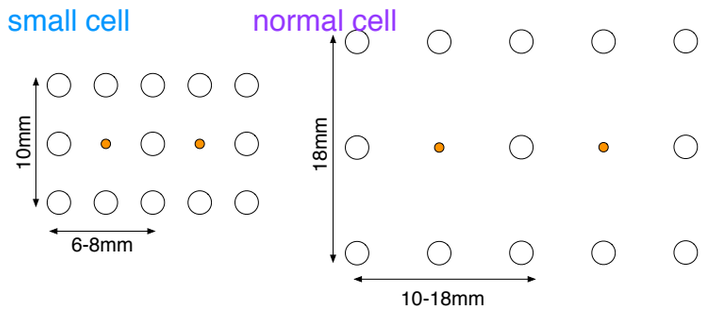


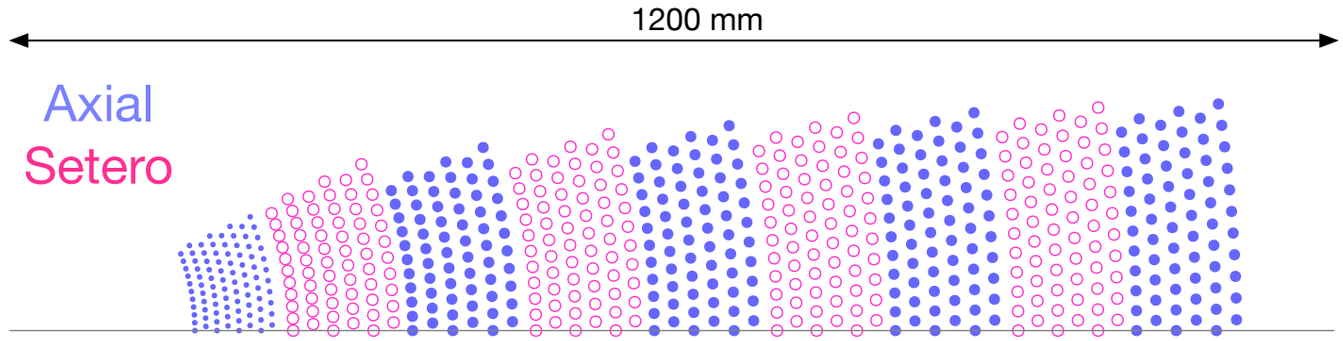
Carbon Fiber Reinforced Plastics (CFRP)

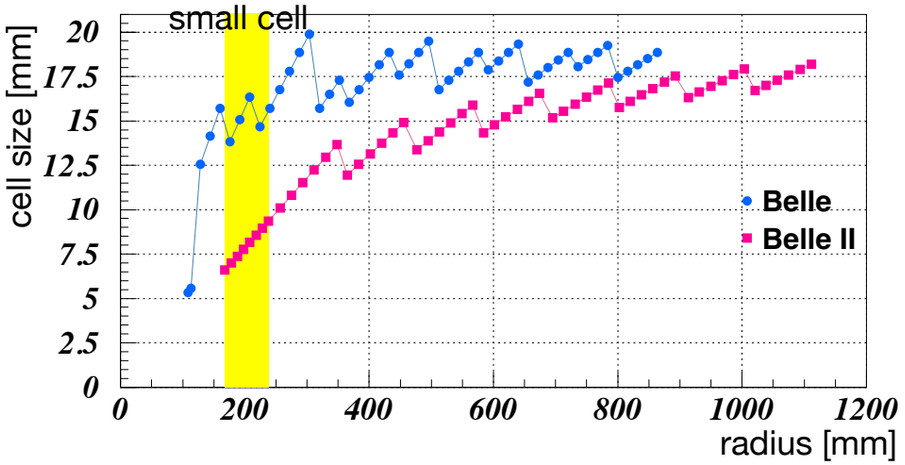
Au-W of ϕ30um; x14336
Al of ϕ126um; x 42240

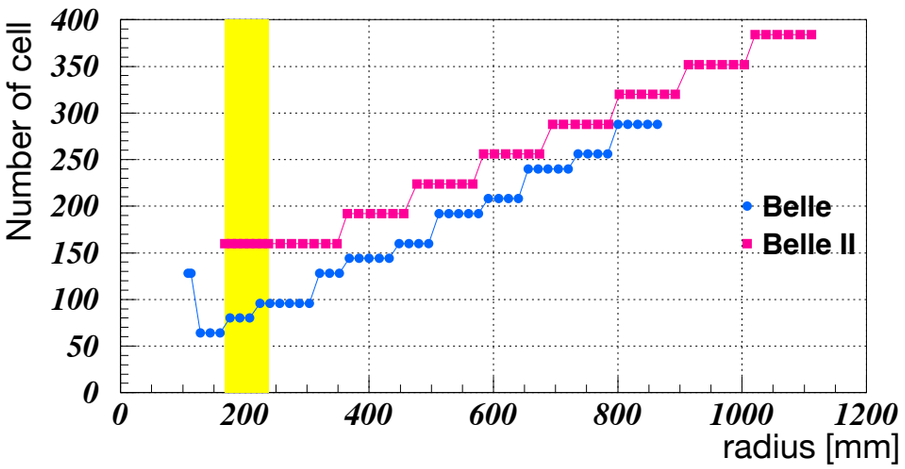
Gas; He:ethane (50:50)

cell configuration



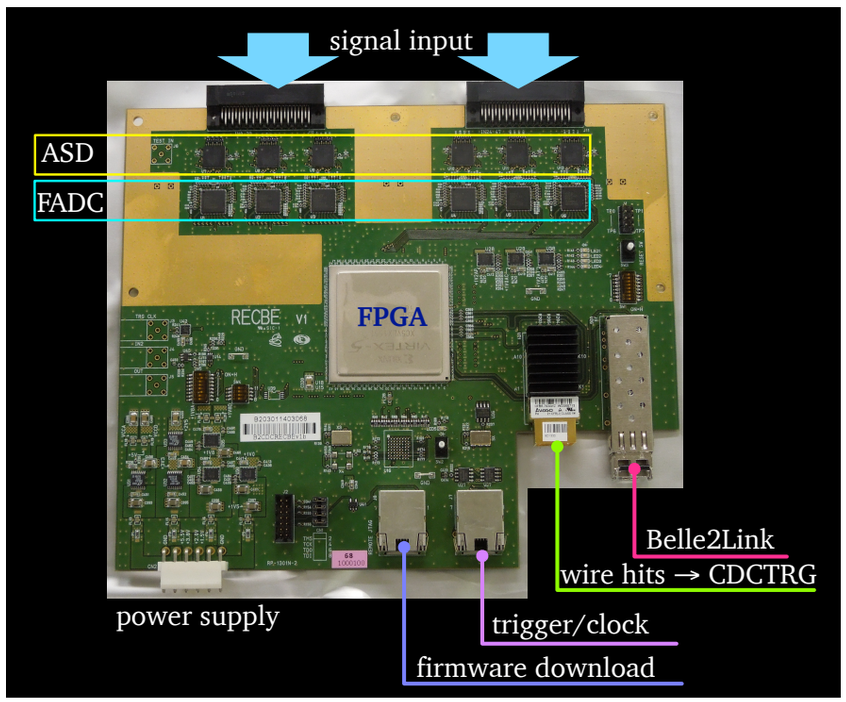


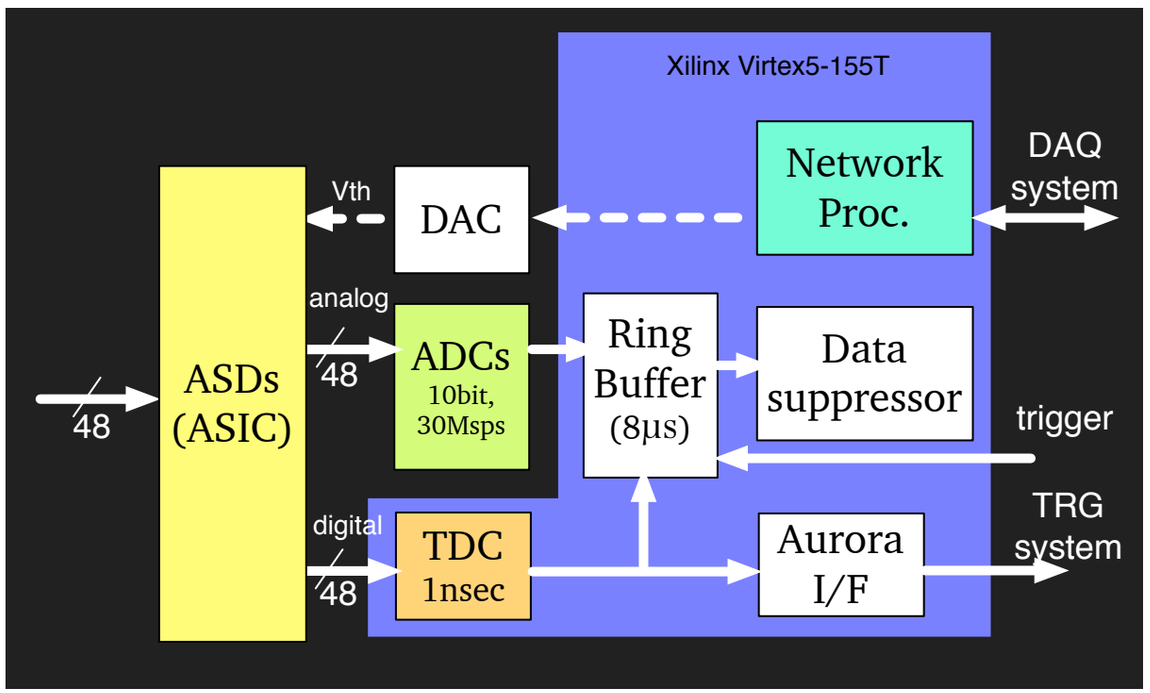




- 56 layers in total
  - radius of innermost/outermost = sense wire 168/1111.4 mm
- ‘super layer’ structure
  - 5-axial super layers and 4-stereo super layers
    - stereo (+/-)45 ~ 74
  - innermost super layer = small cell (2+6 layers)
- 6 layer/super-layer; it is required by track trigger (CDCTRG)

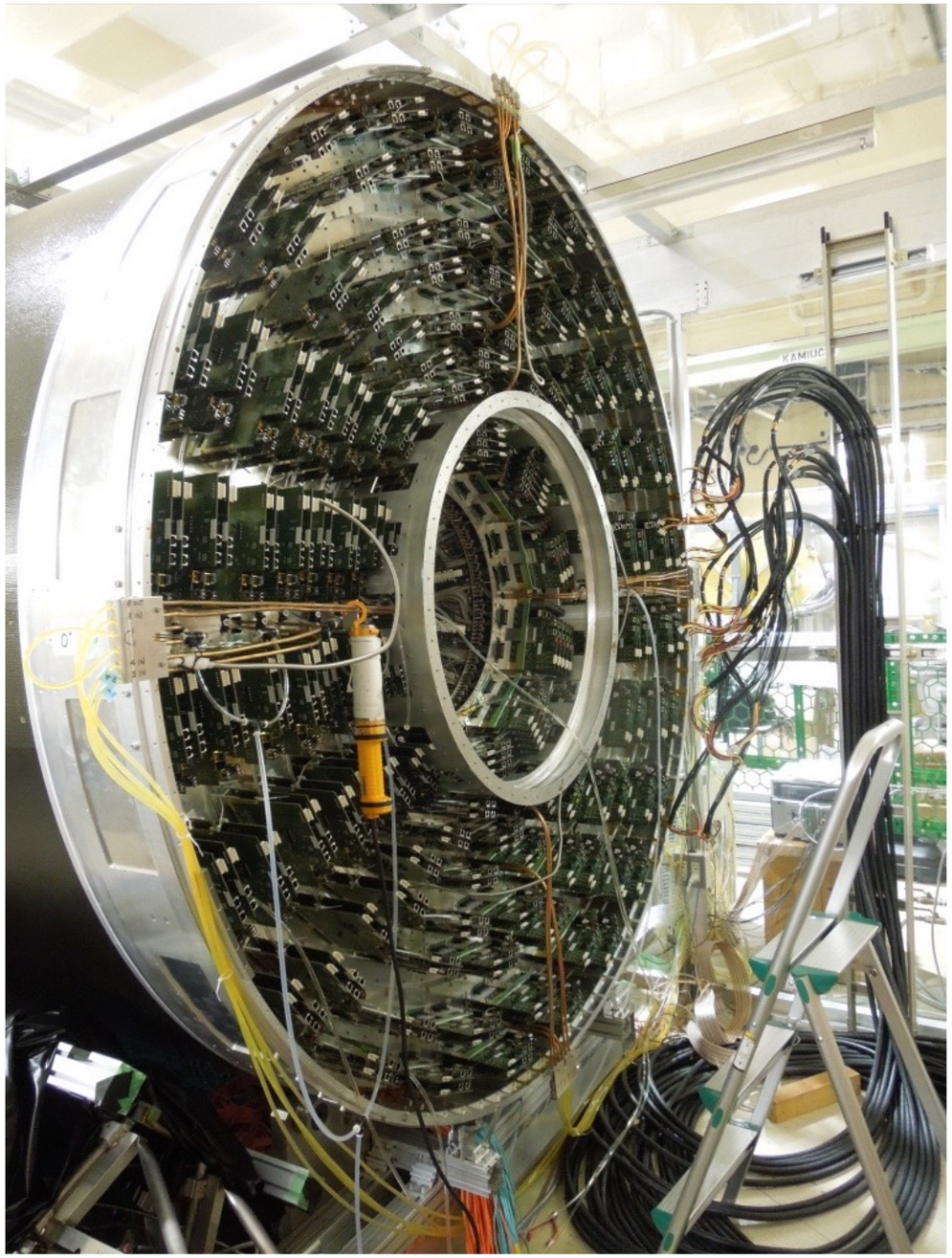
signal readout electronics





- The number of signals = 14336
- FPGA-based front-end electronics
  - TDC with 1 nsec resolution for drift time measurement
  - ADC with 32MHz sampling for dEdx (charge) measurement
  - 48ch/board
- upgrade of readout board is ongoing
  - to improve radiation tolerance, cross talk, ..

signal readout electronics

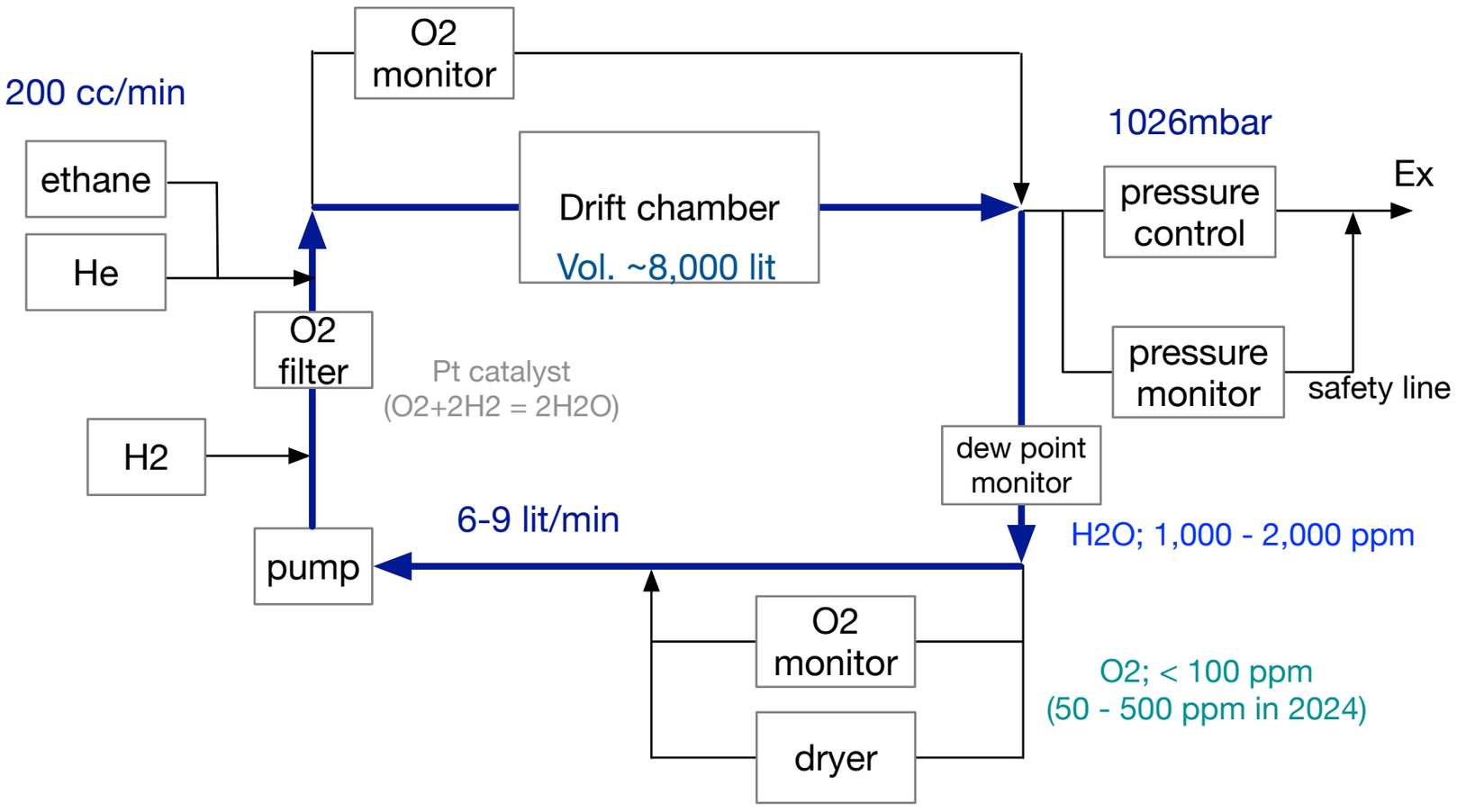


- readout board is located in detector
  - BWD side. direction of lower energy beam (positron)
- power consumption 15W x 299 ~ 4.5kW
  - water cooling
- as firmware has been updated to implement additional functions, power consumption has become larger

← 5kW

電気ファンヒーター TEH-50

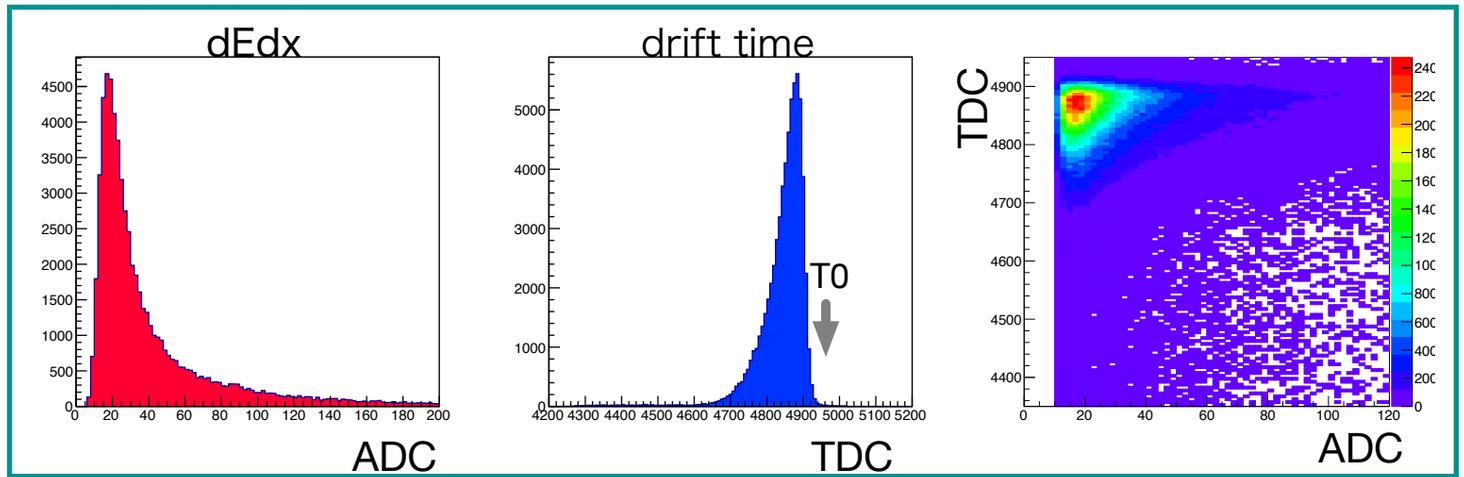
gas system

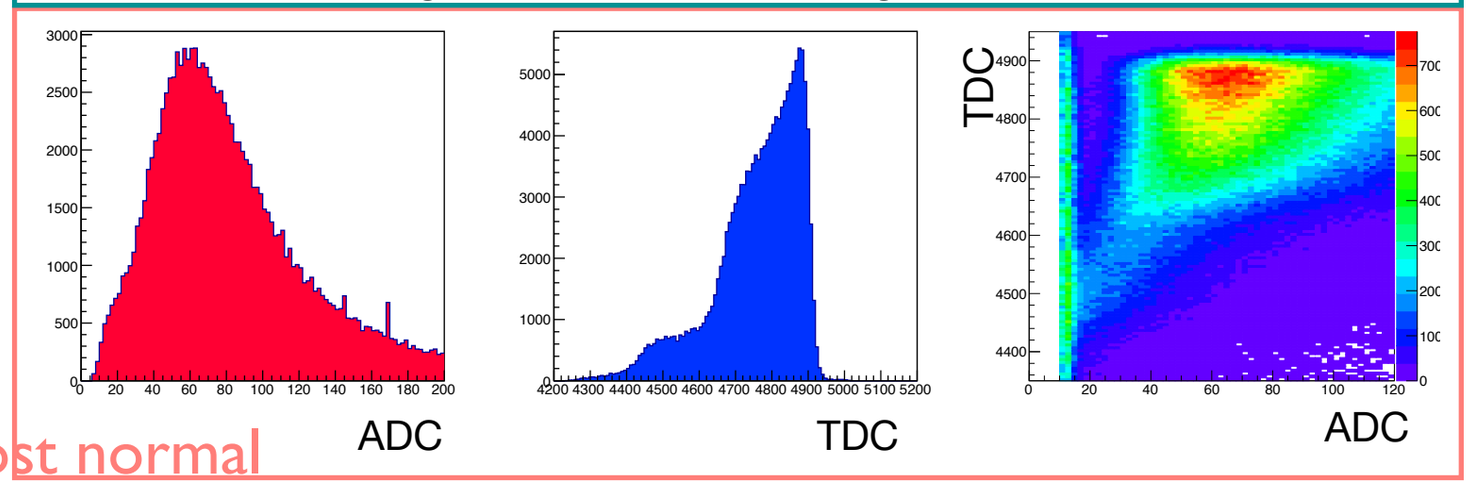


- it is key for stable operation and performance
- keep absolute pressure constant ~1026 mbar to keep gas gain stable
- gas circulating (6-9 lit/min)
  - O2/H2O are removed and monitored in the circulation line
  - O2; electro-negative. capture electron created via ionization → gain degradation

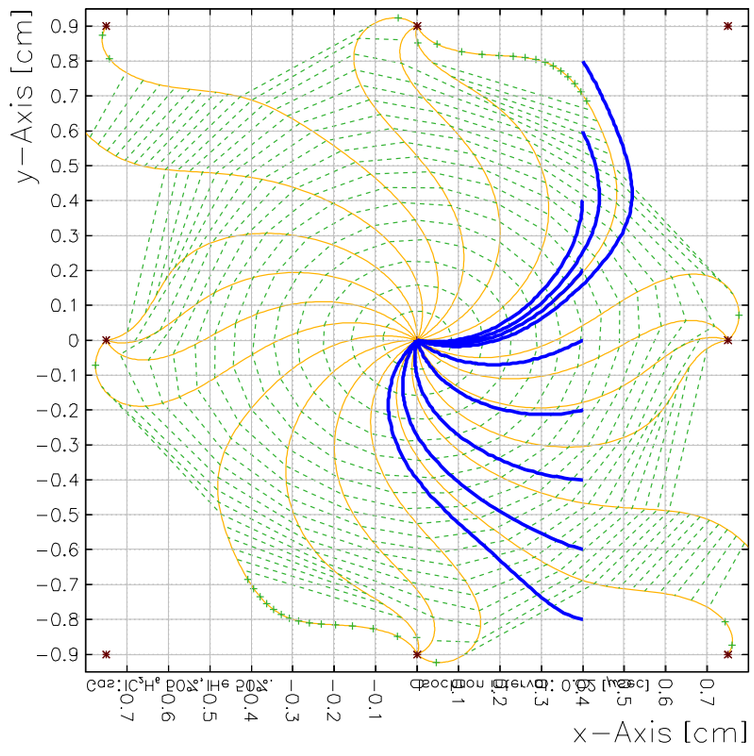
gas condition

much O2 content — due to trouble, O2 contamination became large..



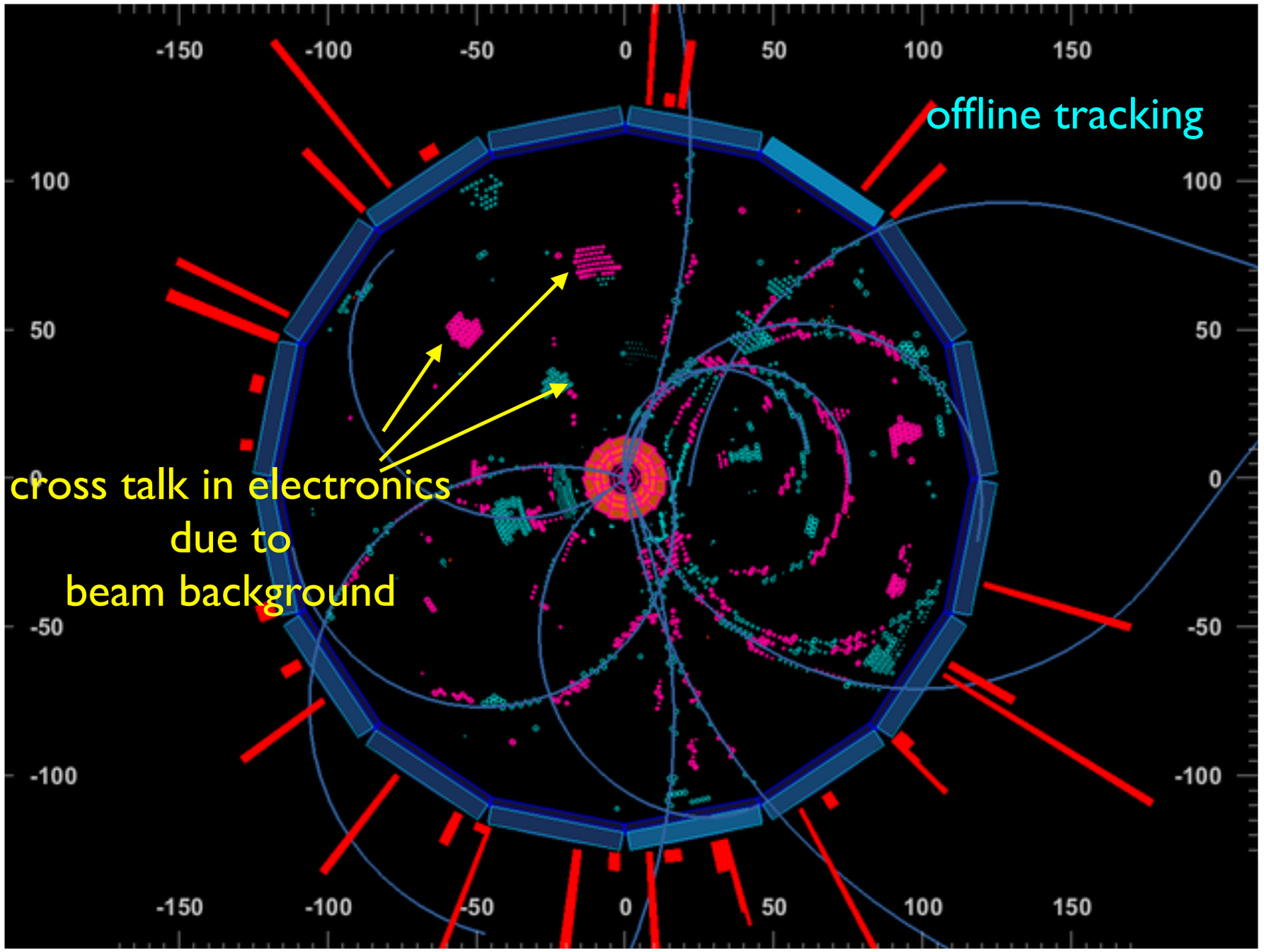


almost normal (less O2 content) — effort for removing O2 by O2 filter



operation in beam

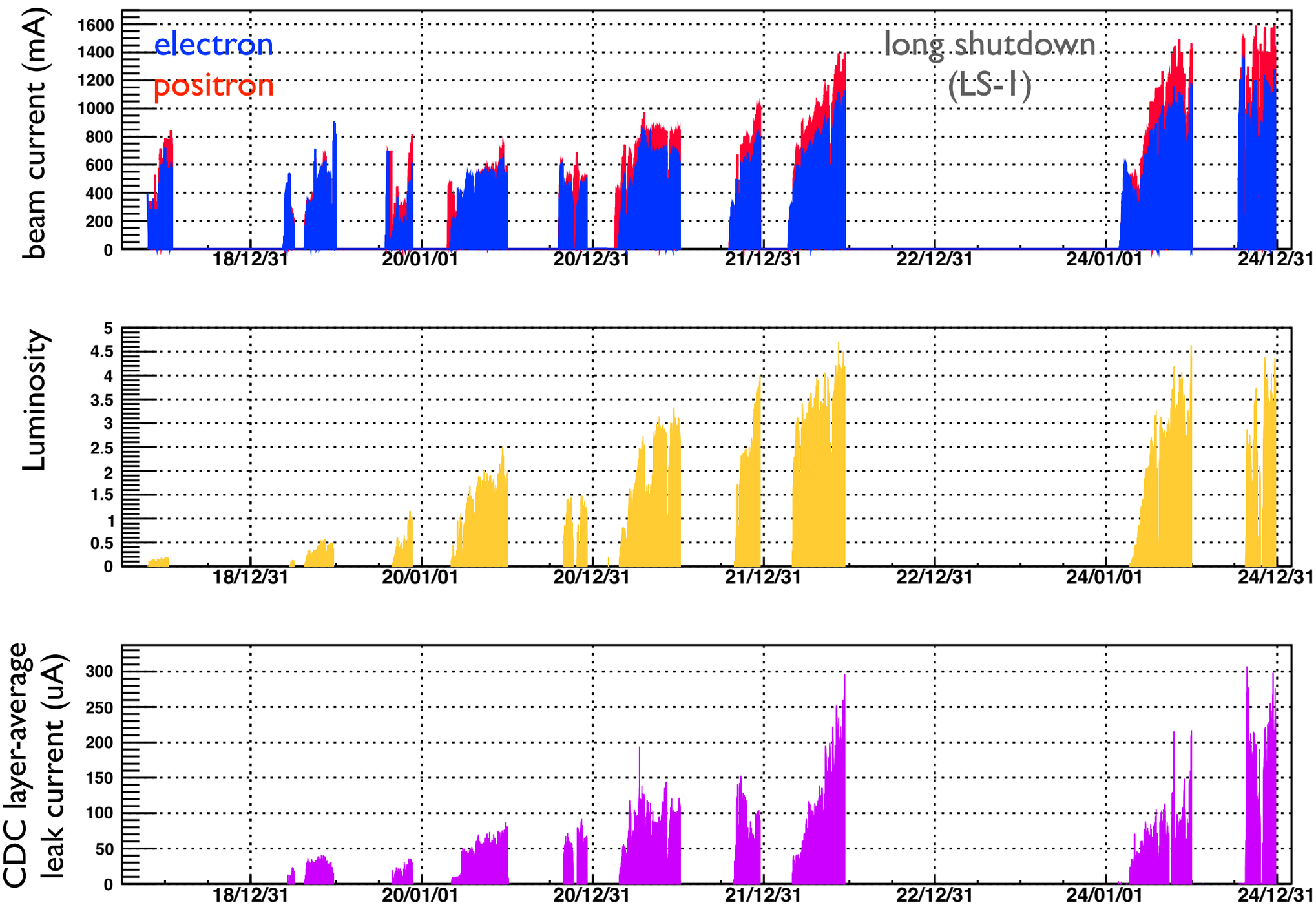
B decay event



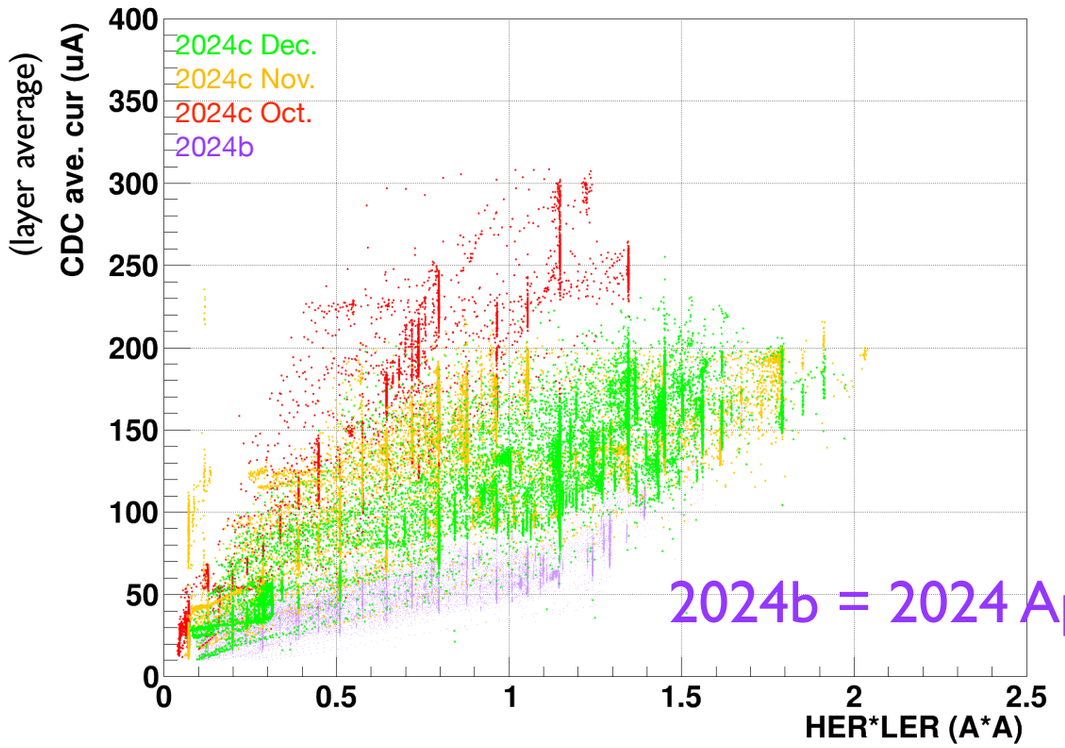
Belle II Central Drift Chamber construction and operation

- 2009~2011 design, started machining
- 2012 started wire stringing
- 2014 finished wire stringing
- 2016 installation of CDC into Belle structure
- 2017 commissioning using cosmic ray (w/ and w/o B field)
- 2018 the first collision
  - leak current increasing in outermost layers
- 2019 physics run started
  - started to add water in gas mixture
  - started to see gain degradation due to much water and high background
- 2024 leak current blow-up in innermost layers

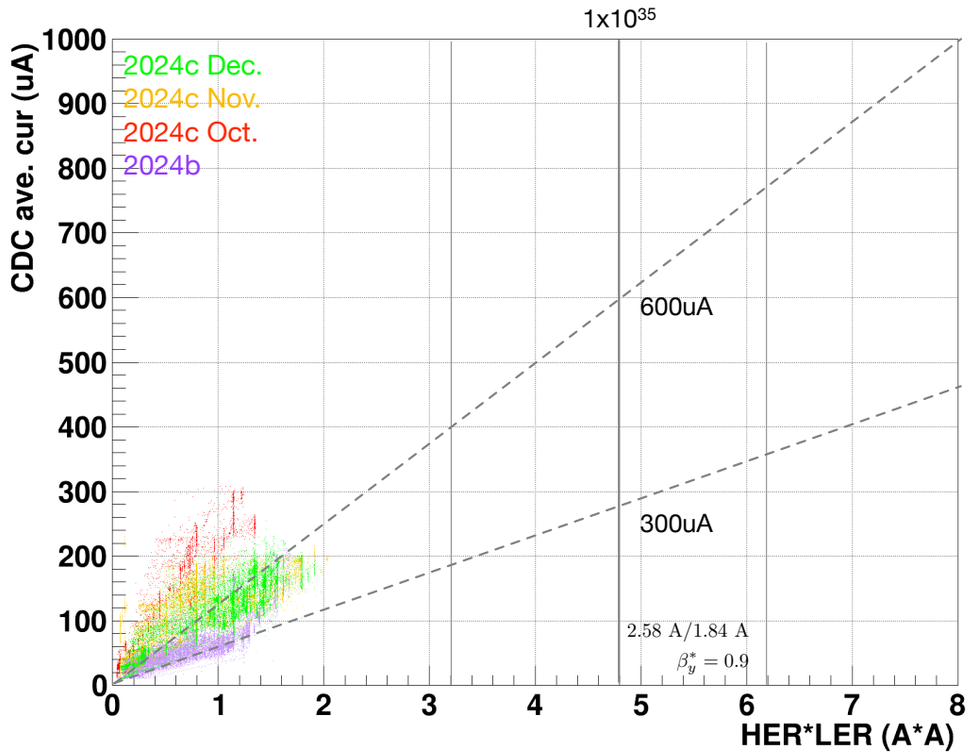
operation history



chamber current v.s. beam currents



2024b = 2024 Apr. ~ June



- Beam background still fluctuates largely due to accelerator tuning.
- Strongly dependent on accelerator parameters and collimator settings
- It also affects detector performance and introduces large uncertainties in future prospects.

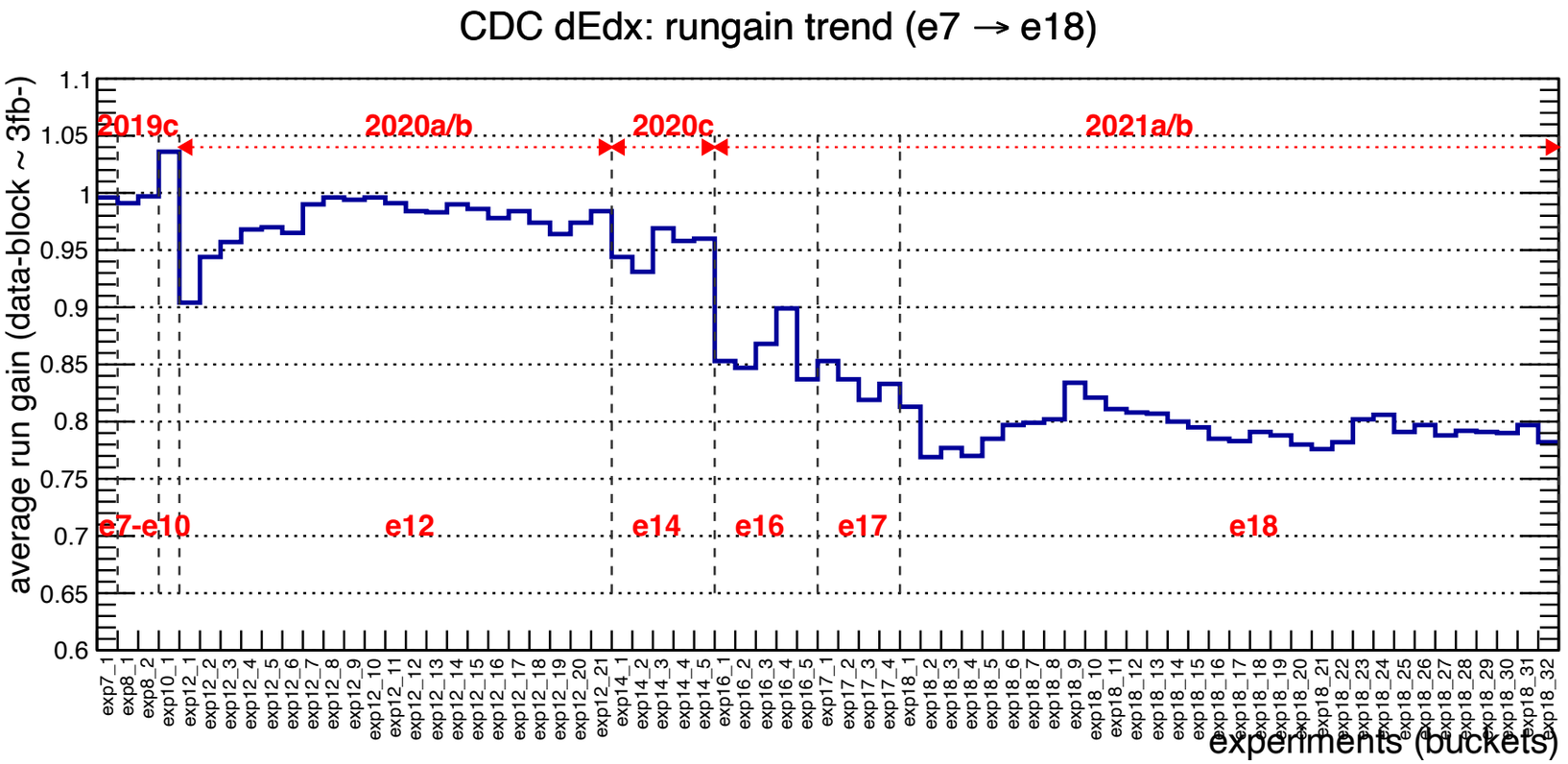


FIG. 5. dE/dx gain vs. experiment number for proc13 data.

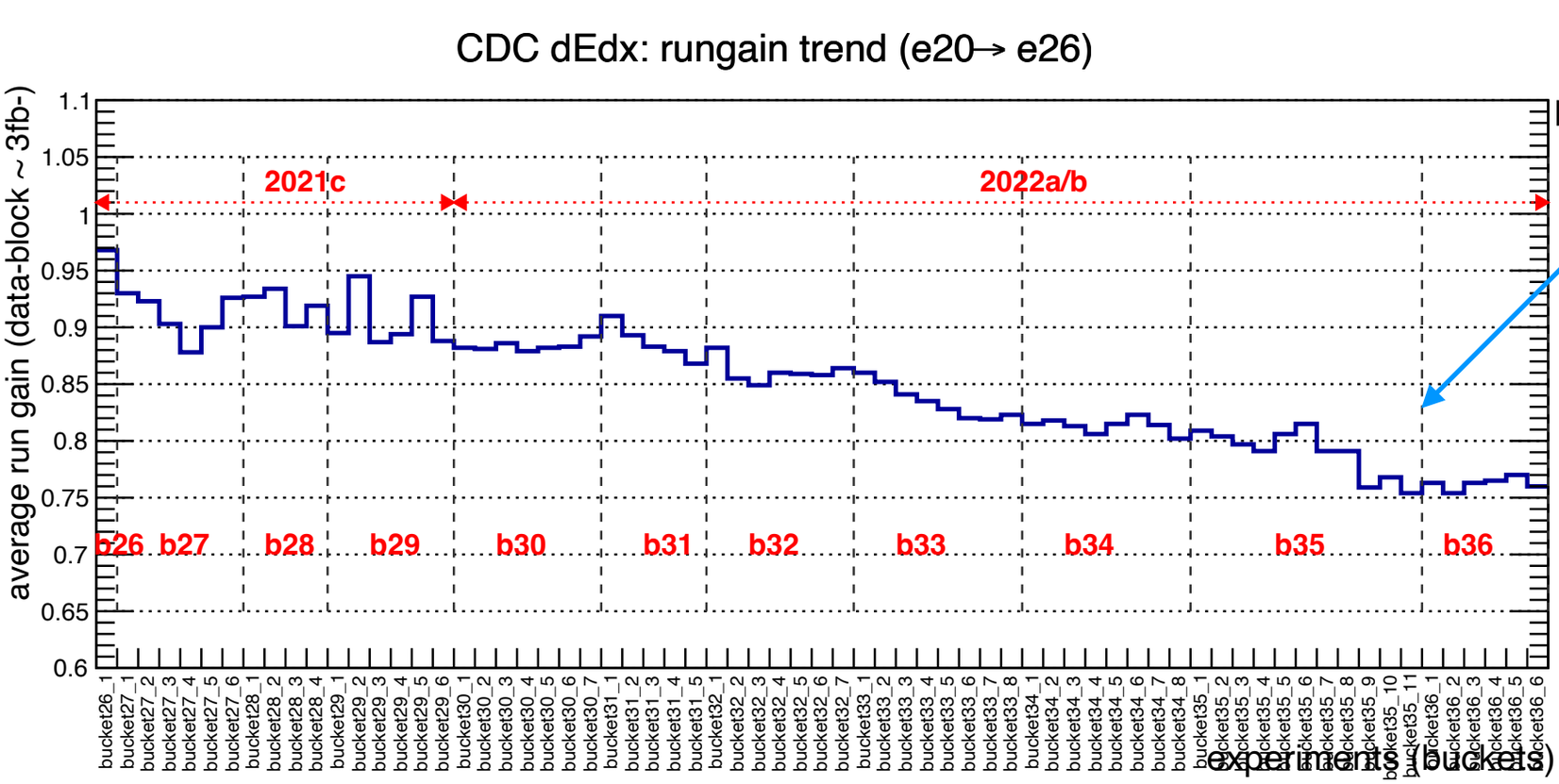
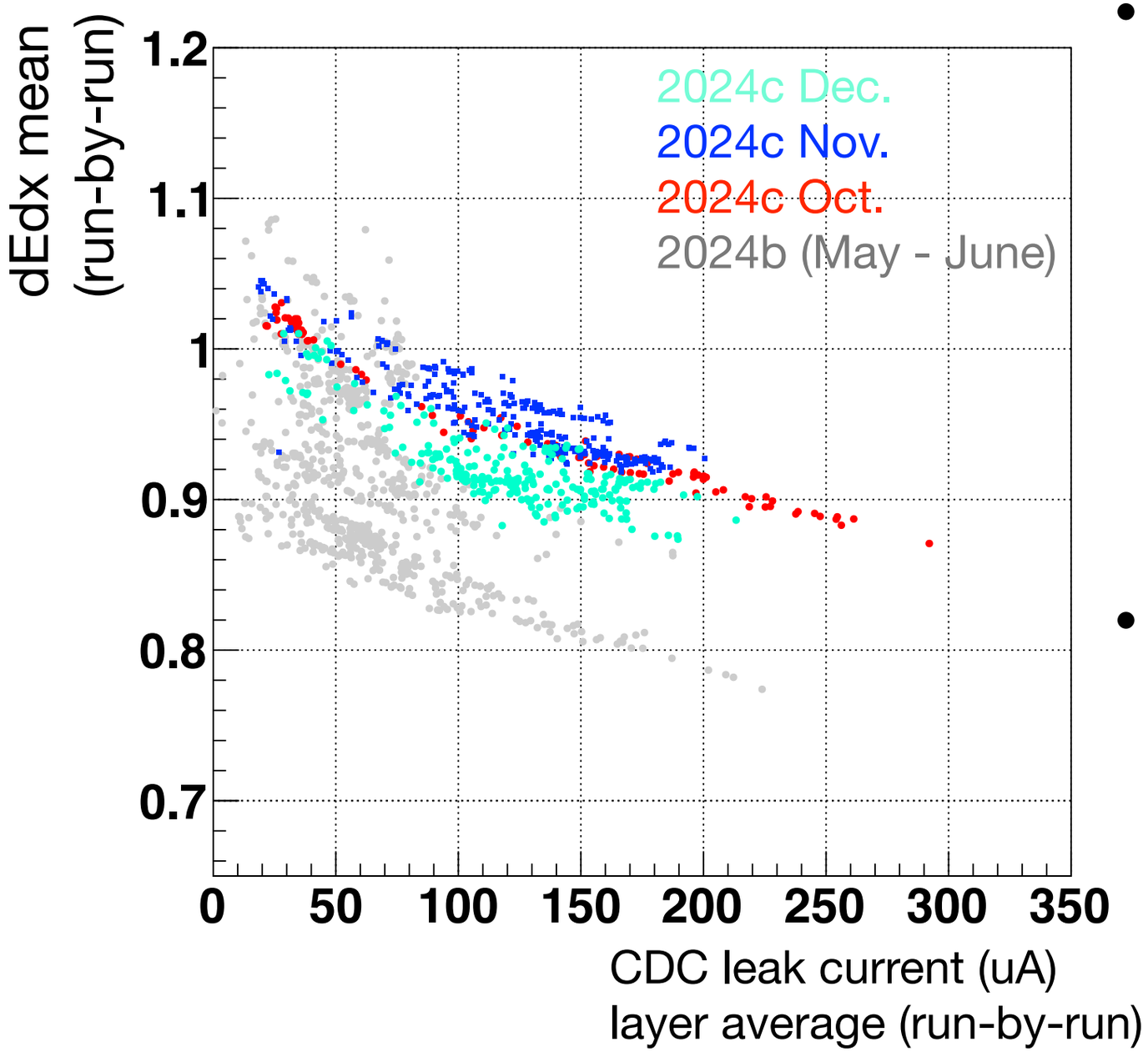


FIG. 6. dE/dx gain vs. data bucket for prompt calibration data.

The main cause of the initial gain drop was the injection of a large amount of water into the gas, due to improper monitoring of the water content.

Based on the consumption rate of the bubbler water, the water content is estimated to have reached the order of more than 1%.

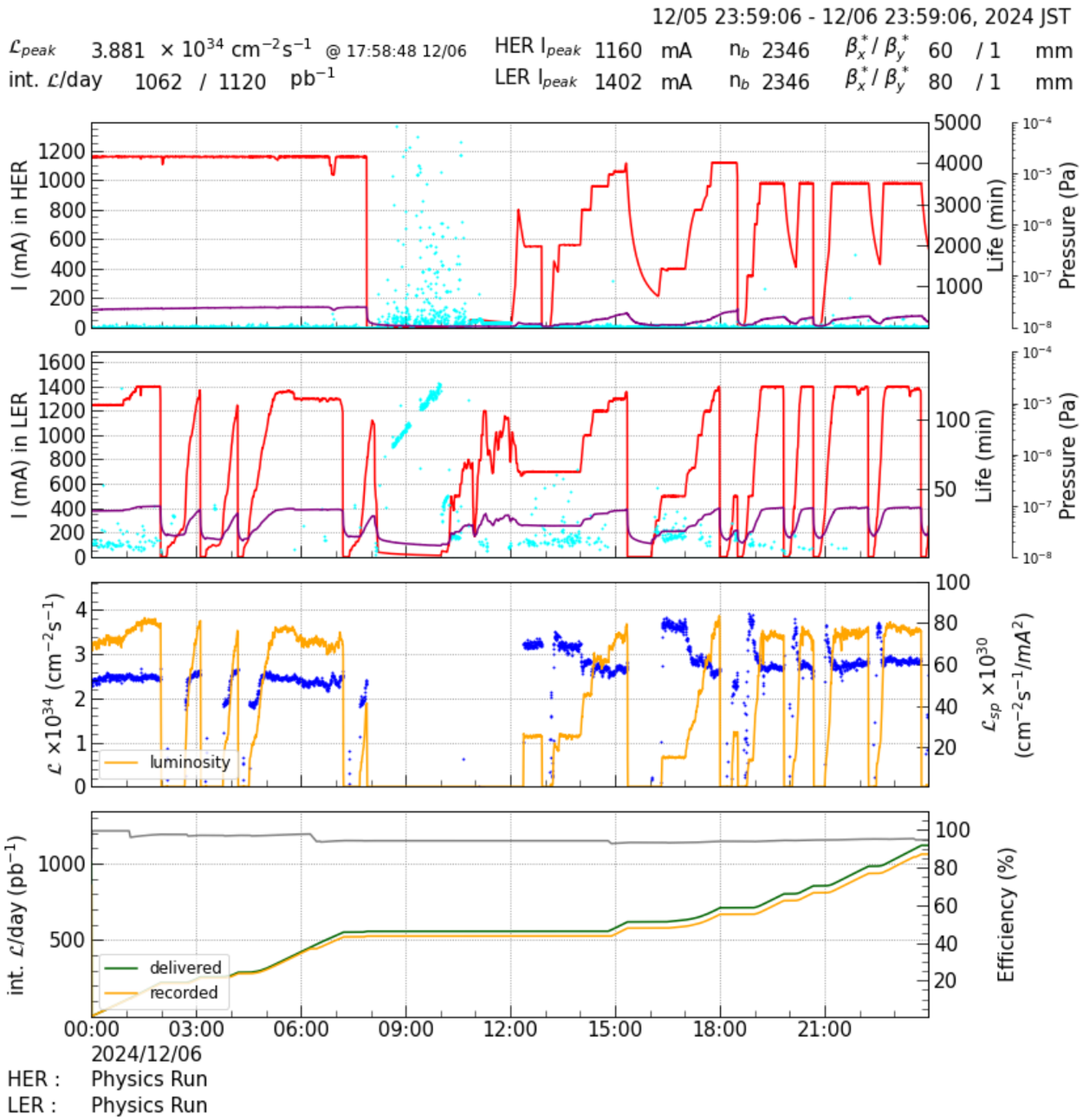
gain v.s. chamber current



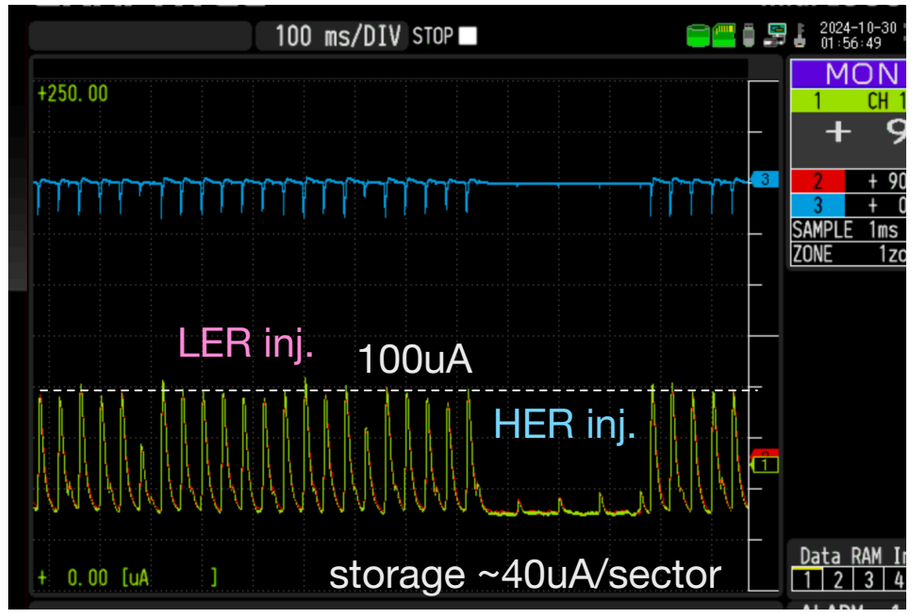
- In the long shutdown after the 2022 run, we improved the gas system and enhanced monitoring/control of water content. This allowed clearer observation of the correlation between detector performance and background.
- In the spring 2024 data, due to troubles with the oxygen filter, the oxygen level was not sufficiently controlled, which appeared as overall gain variations.

time dependent gain drop

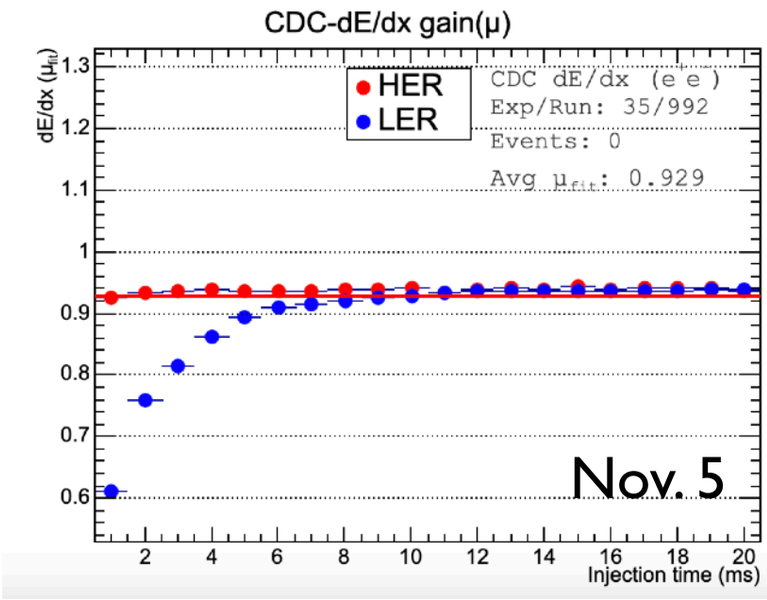
- SuperKEKB requires frequent top-up injections even during physics runs



Leak current of L4-3

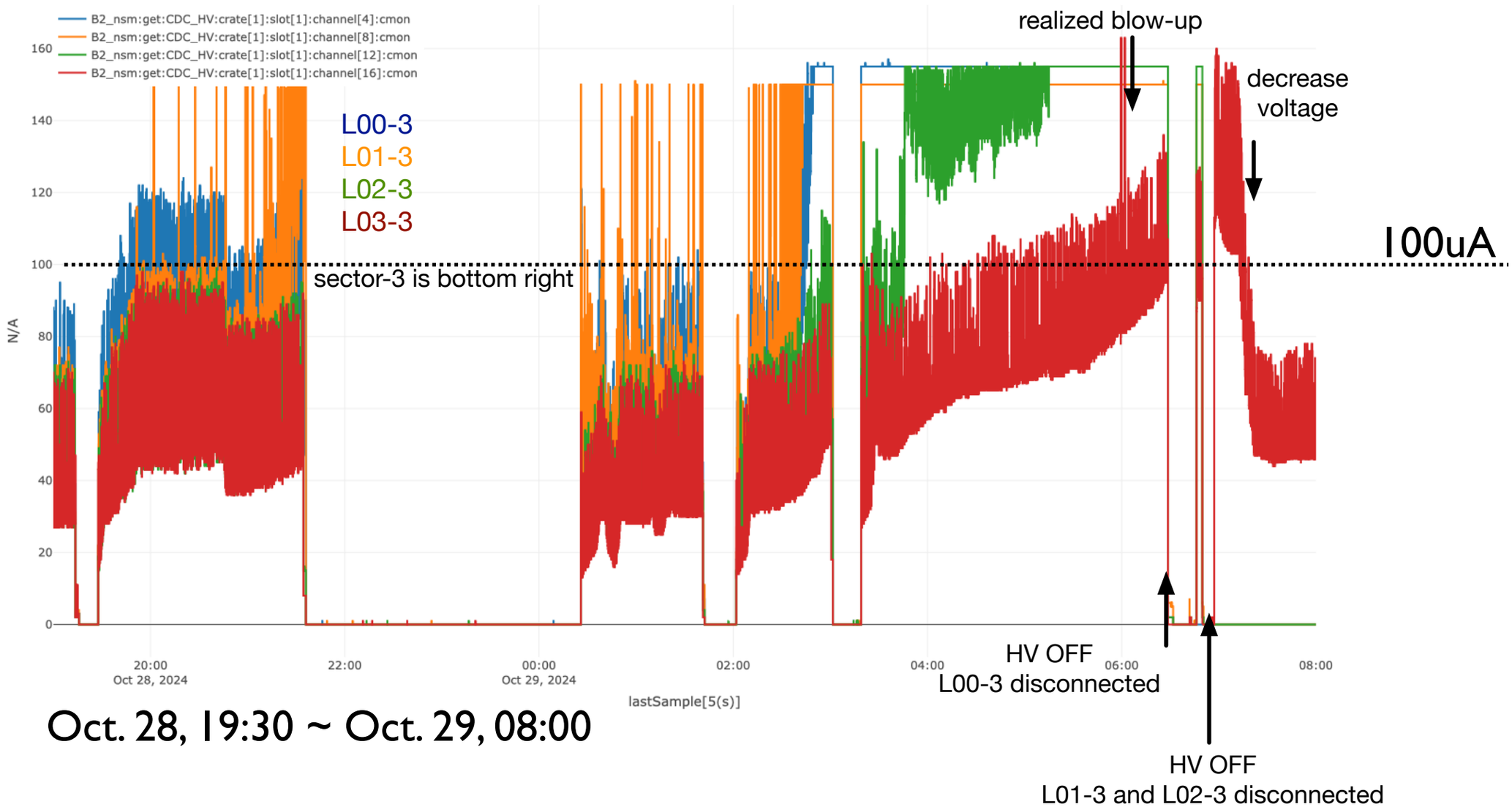


LER injection background is high

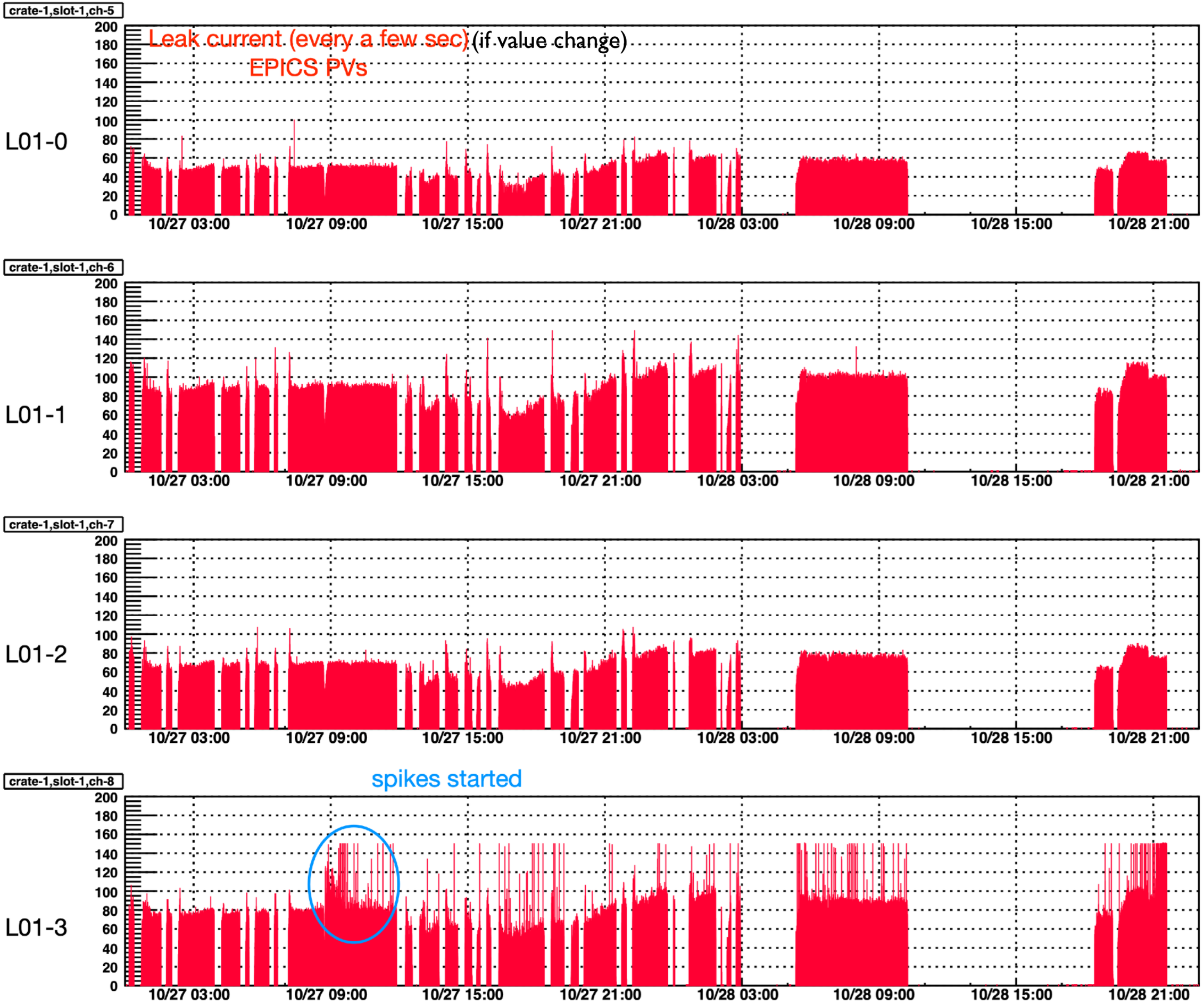


CDC leak current blow-up Oct. 29, 2024

- leak current of innermost layers in sector-3 increased and was persistent high
  - 1 layer is divided to 4 sectors
- leak current doesn't exceed the limit (140~160uA) determined by current limiter module to avoid HV trip at beam injection
- usually, duration monitor, running at cdchv server, prevent such persistent current. however, it was off at the beginning of 2024c for tuning.
  - emergency trip signal is sent to the corresponding channel

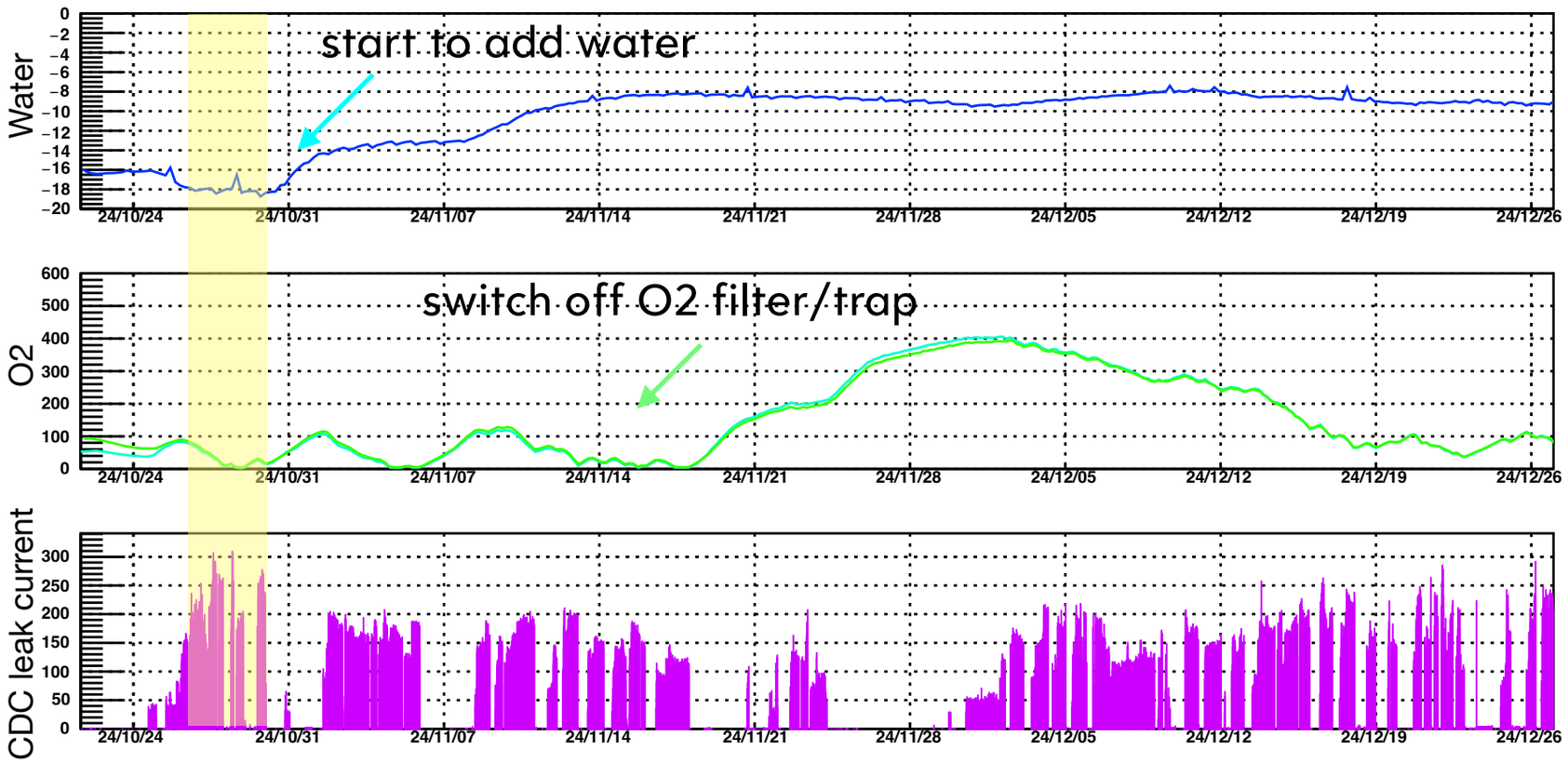


Oct. 28, 19:30 ~ Oct. 29, 08:00

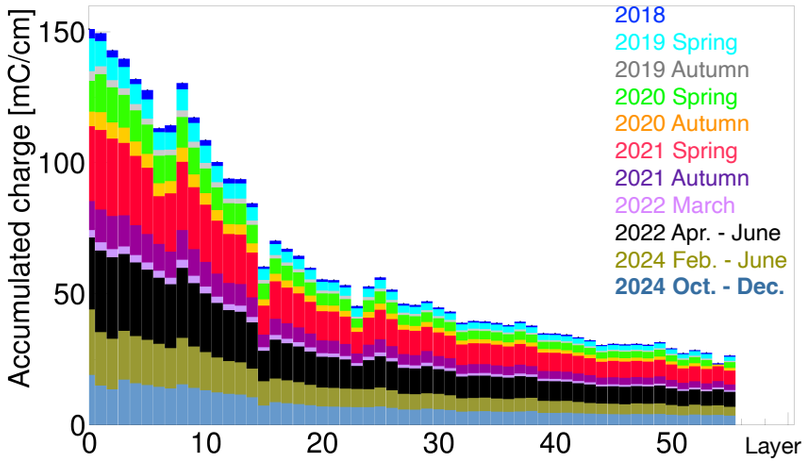

crate-1,slot-1,ch-5
Leak current (every a few sec) (if value change)
EPICS PVs
L01-0
crate-1,slot-1,ch-6
L01-1
crate-1,slot-1,ch-7
L01-2
crate-1,slot-1,ch-8
spikes started
L01-3
200
180
160
140
120
100
80
60
40
20
0
10/27 03:00
10/27 09:00
10/27 15:00
10/27 21:00
10/28 03:00
10/28 09:00
10/28 15:00
10/28 21:00

gas condition

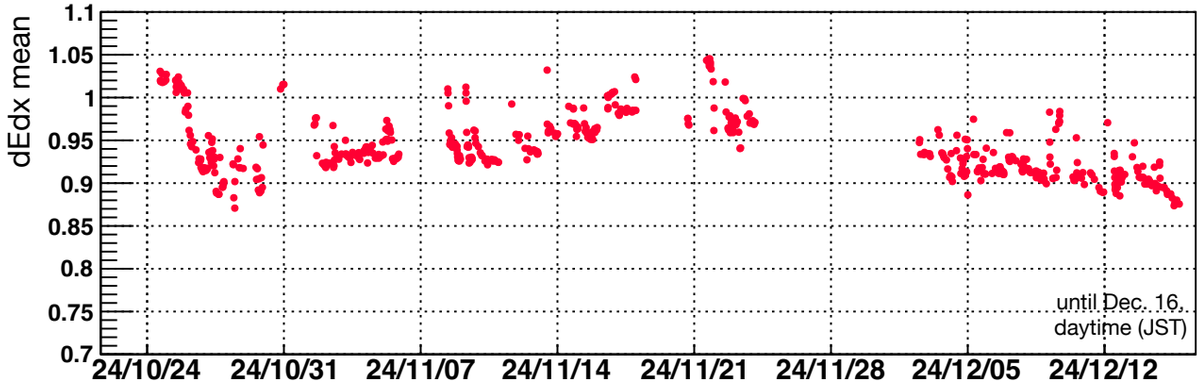
- When we encountered HV trouble at the end of Oct., both Oxygen and water content were low.
- To mitigate discharge (incl. Malter effect), we increased water content by adding water and stopped to remove Oxygen by switching off O2 filter(trap)
  - remarks; operation voltage for sector-3 in Layer-0,1 and 2 was lower after the trouble
- Oxygen content increase by 20-30ppm/day from air w/o beam, but it start to decrease once CDC leak current is induced by beam



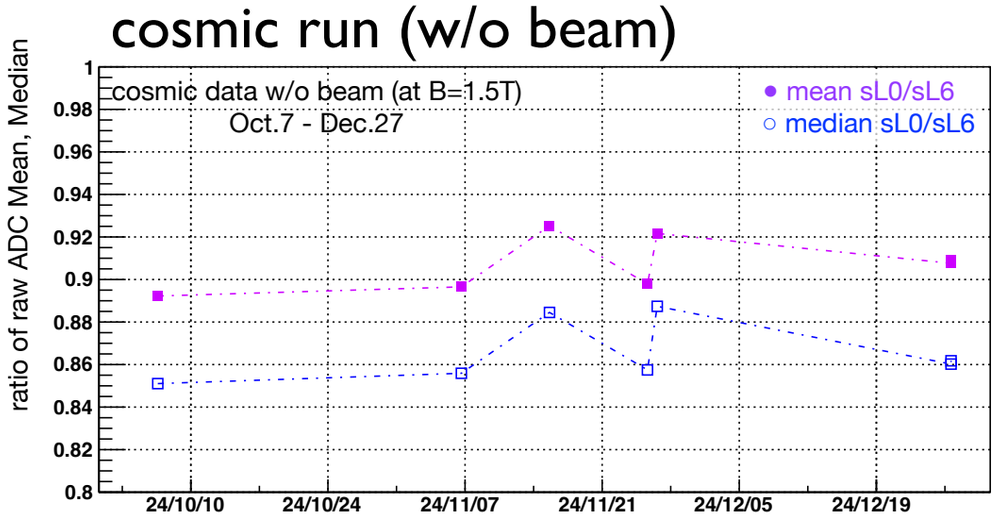
aging effect due to accumulated charge



physics run (beam data)



cosmic run (w/o beam)



- accumulated charge of inner layer has reached ~150mC/cm
- In the beam runs, a gain drop of 10–15% was observed, while in the cosmic-ray data without beam, no significant gain drop was seen
- No clear difference was observed between the inner(SL0) and outer(SL6) layers.
- Gain drop in physics runs mainly caused by beam background.
- In the future, since the accumulated charge will exceed 1 C/cm, countermeasures against aging-induced gain drop will be required.

trial of fresh gas flow rate increase in next beam operation

- it is believed that rate of gas volume exchange is effective to mitigate aging effect and to remove reversible pollution
- Belle II replace one full volume every day by circulation gas, while replace one full volume every month by fresh gas
  - it is slower compared with other experiments
- we plan to increase fresh gas flow rate in the next beam operation in short time
- 10 times higher fresh gas flow rate is possible (0.2→2 lit/min)
  - fresh gas supply line with 2 lit/min is already installed
  - cost is concern
- effective duration of the test still needs to be discussed.

	BaBar DCH	Belle II CDC
Integrated charge	30 mC/cm in **9 years**	30 mC/cm for innermost layers in 2022a/b alone i.e. **3.5 months**
Gas mixture	He:C_4H_{10} 80:20 with 3500 ppm H_2O	He:C_2H_6 50:50 with ~1300 ppm H_2O
Volume	5.3 m^3	7.5 m^3
Recirculation rate	15 l/min, i.e. one full volume every **6 hours**	4+2x0.5 l/min, i.e. one full volume every **25 hours**
Fresh gas rate	2.5 l/min, i.e. one full volume every **36 hours**	0.2 l/min, i.e. one full volume every **28 days**

total fresh gas flow rate (lit/min)	cylinder duration of ethane (day)	cylinder duration of He (day)	gas volume exchange
0.2	51.7	27.7	full volume per 1 month
2	5.2	2.8	full volume per 3 days

aging test and alternative gas

- The accumulated charge is expected to exceed 1 C/cm.
- It is necessary to estimate the gain drop at higher accumulated charge and the resulting degradation of CDC performance.
  - Is the gain drop linear?
- Another study item is whether the aging effect can be mitigated by changing the gas mixture.
  - performance of drift chamber with alternative gas should be studied
  - If the gas mixture is changed, the compatibility of the readout electronics must be verified.
- non-CH gas (e.g. He-CO2-CF4) is a candidate

summary

- Belle II (2018 -) : is designed to find new physics beyond KM model (~50/ab)
- Progress toward the target luminosity is step by step.
- Challenging to preserve detector performance as luminosity (beam background) increases
- In the CDC, the central charged particle tracker of Belle II, increasing background has affected detector performance and operation.
- Studies are being carried out to understand these effects and to test possible countermeasures for future prospects.

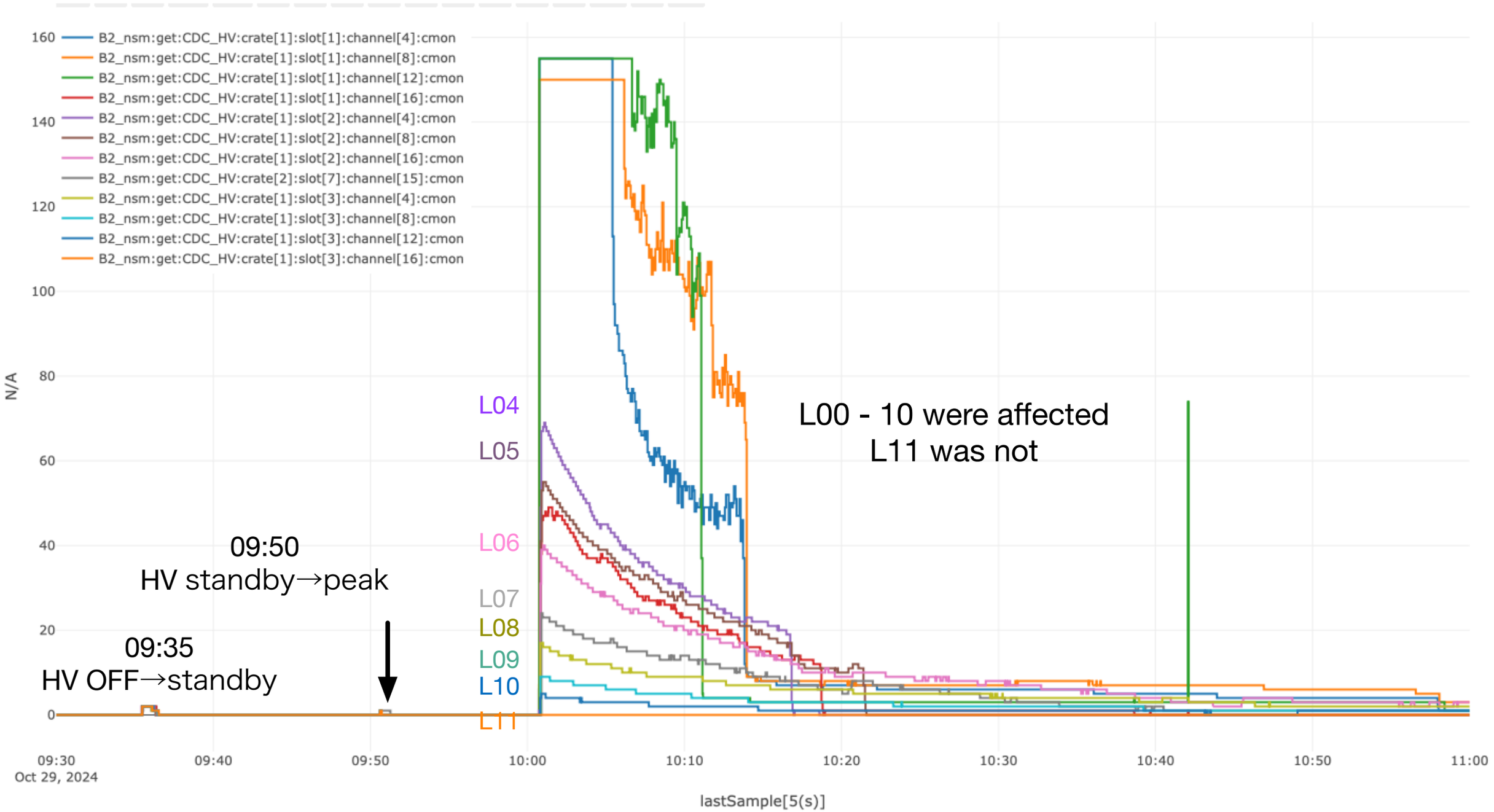
backup

HV test w/o beam (Oct. 29) just after beam operation

Remarks; On Oct. 30 (maintenance day), we could apply nominal voltage for all sectors and no leak current increasing was observed during ~4 hours HV test.

Same HV test was done during owl shift on Nov. 7 and no trouble for ~8 hours at nominal voltage

HV test w/o beam (Oct. 29)
just after beam operation



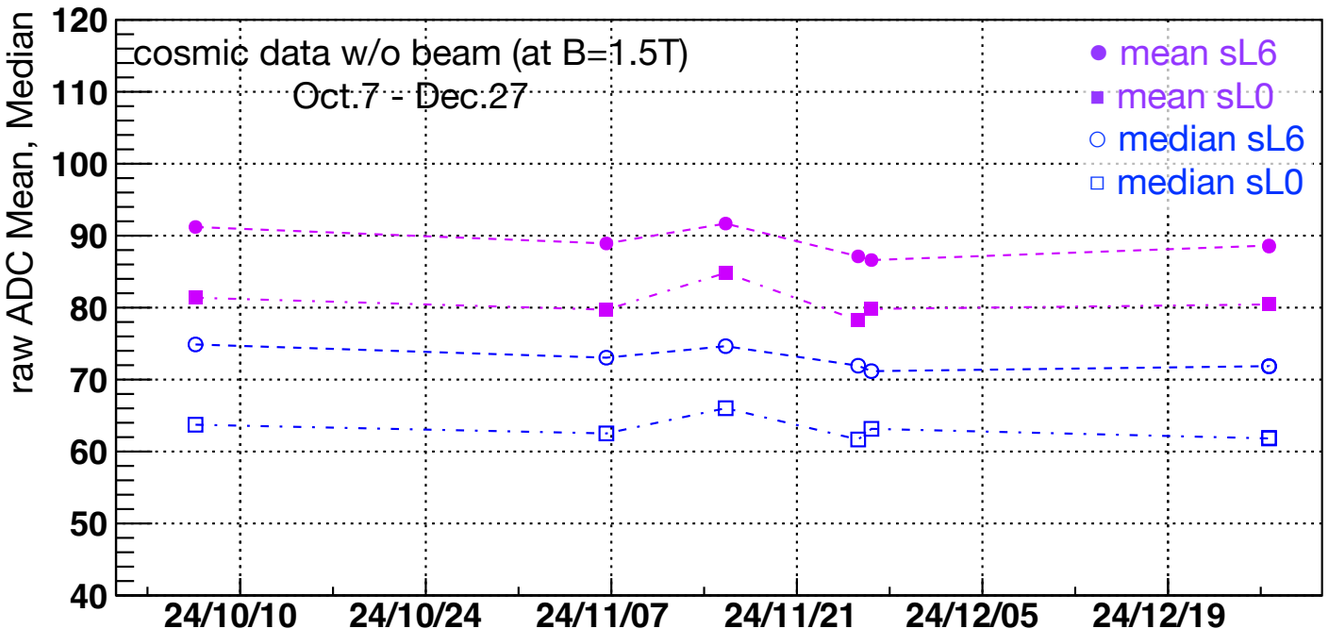
modification of CDC gas system to add O2 for 2025c

- in early 2024c run, we observed chamber current blow-up in the innermost layers
- we turned off the corresponding sectors, and added water and stopped removing Oxygen to prevent further trouble in other layers
- Oxygen can only be removed using a filter; there is no system to add or increase O2 content.
- effect of Oxygen in gas mixture
  - pros ; Oxygen help to suppress glowing CH-polymer
    - $CH_2 + O_2 \Rightarrow CO_2, C_2, H_2O, H_2$
  - cons : contribute on aging by forming SiO_2. Silicon is included in gas seal.
- we plan to modify gas system to add O2
  - it is similar to a system to inject Hydrogen
  - discussion is ongoing based on a drawing provided by the company
  - KEK mechanical expert is checking the drawing
- it will be installed in Sept.- Oct. , before 2025c

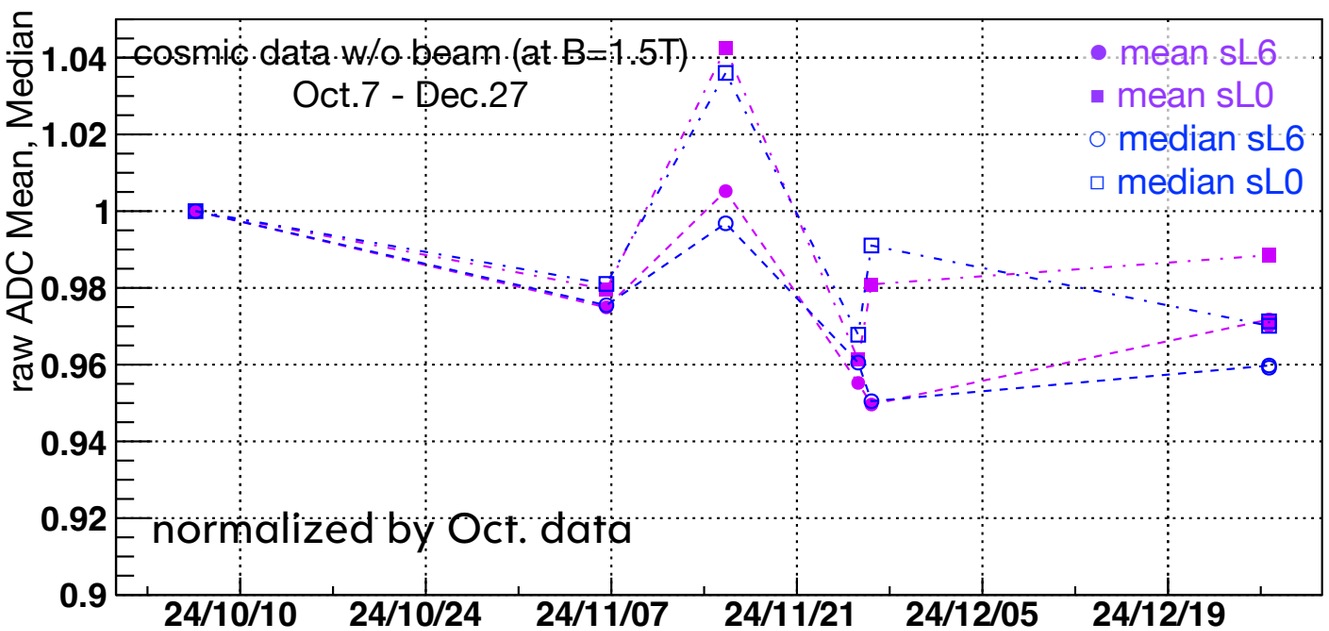
Oxygen consumption at beam on

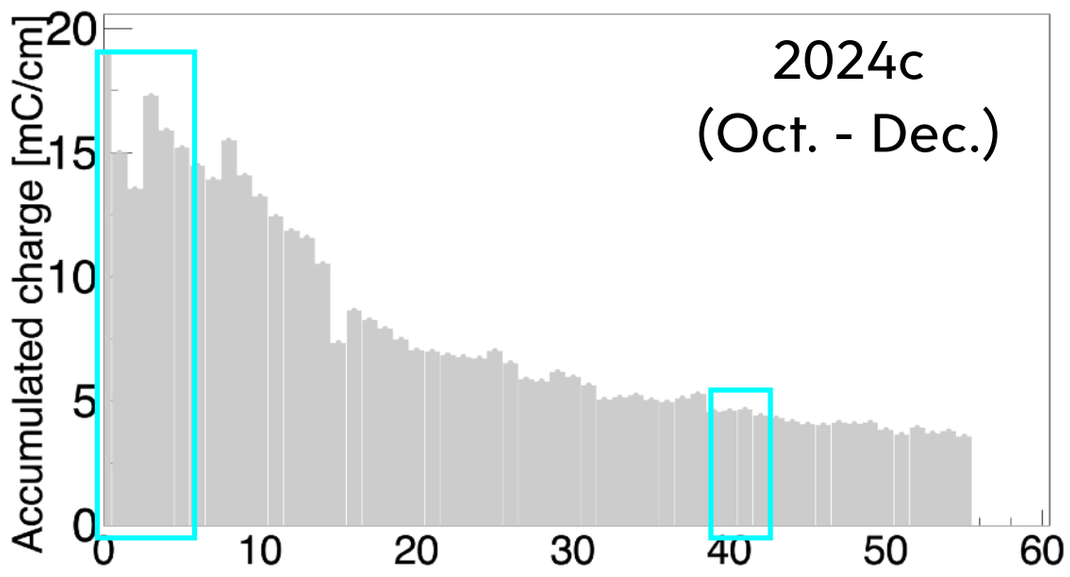
- we have observed Oxygen content in CDC gas mixture decreased when CDC on and beam on
  - ‘radicals’ may be created from C2H6, O2 and H2O via gas avalanche
  - CH2 + O2 => CO2, CO, H2O, H2
    - It could explain why CO2 content is larger than Ar in gas analysis result though CO2 ~0.3% and Ar ~1% in Air
  - H2 + O2 => H2O (H2 are also consumed)
    - It may be a reason why O2 filter doesn’t work when beam ON
    - Pt catalyst need to store some amount of H2 on the surface
-

cosmic data w/o beam in 2024c

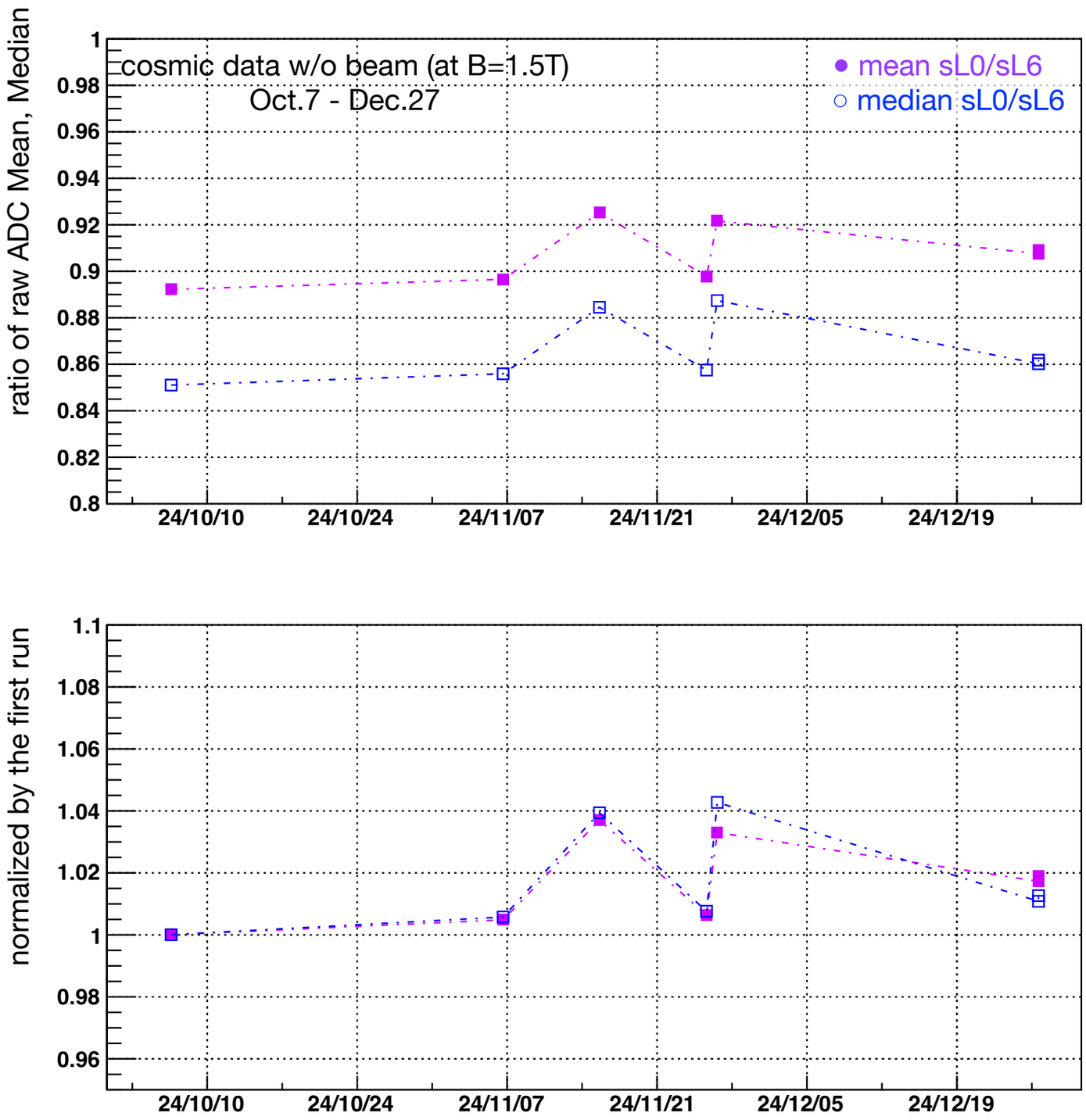


- clear super-layer dependence is not seen
- change of SL0 and SL6 is consistent within 2-3%
- accumulated charge is different by factor ~3

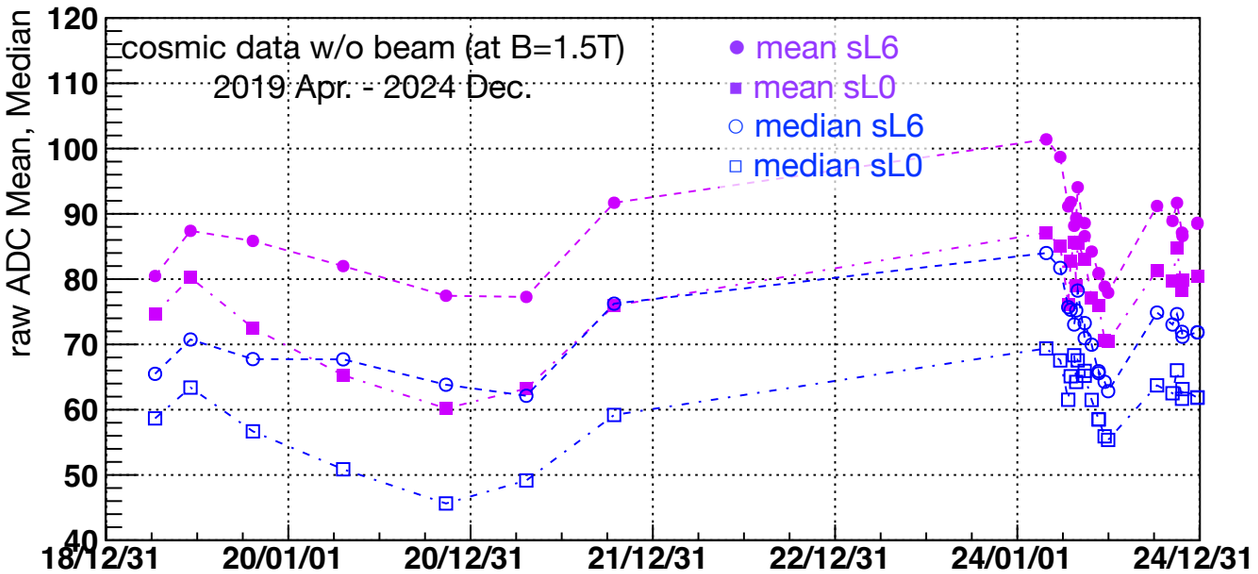


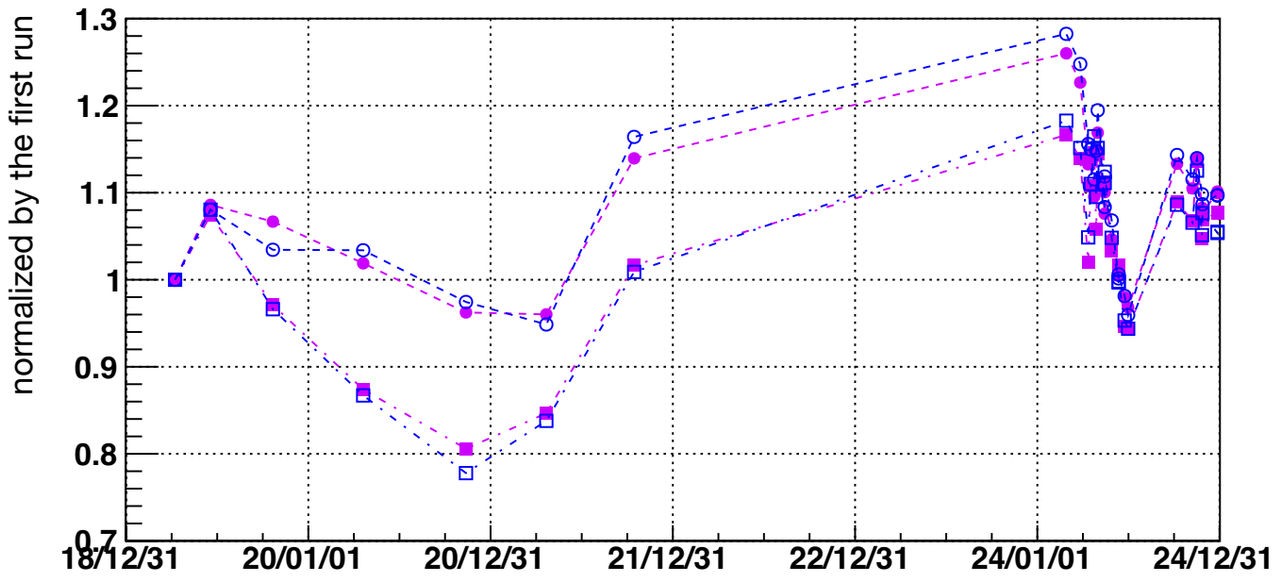


cosmic data w/o beam in 2024c



cosmic data w/o beam in 2019-2024





- started to add water since 2019 Jan.
  - H2O ~2,000ppm (assume sensor was proper yet)
  - O2 content is unknown, but probably low < 500ppm
- in 2021c, decreased target of water content
- much water until 2022b
- in the end of 2024c
  - H2O ~3,000ppm
  - O2 ~100ppm
-

cosmic data w/o beam in 2019-2024