Operational challenges for Belle II CDC in 2024 and beyond

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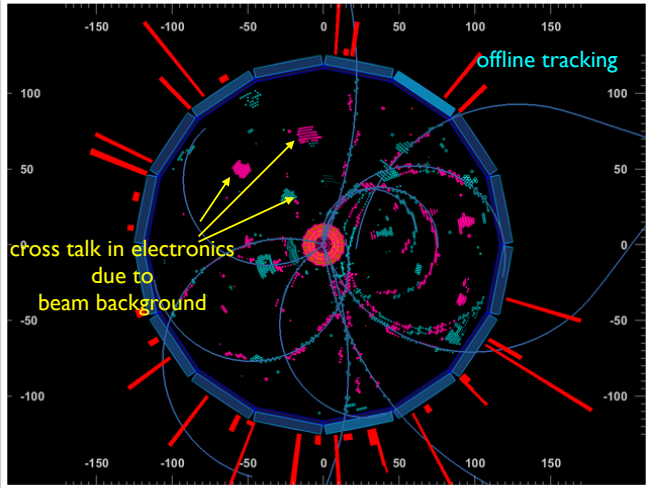
CDC: the heart of Belle II

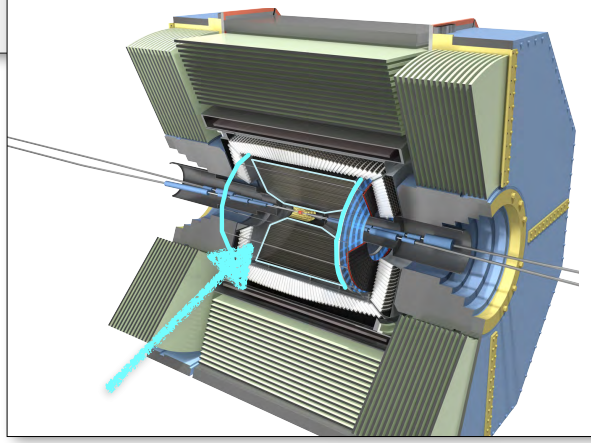
Nanae Taniguchi (KEK)

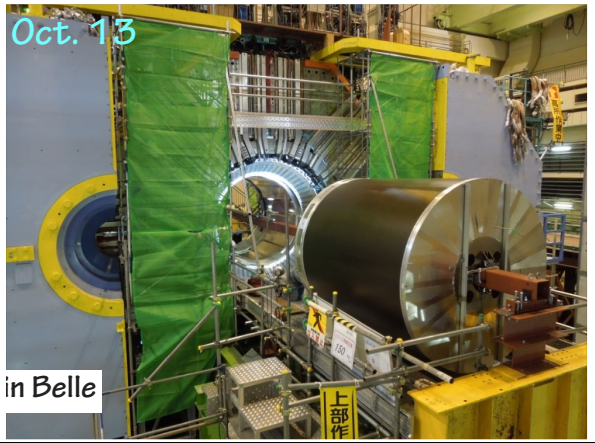
B decay event



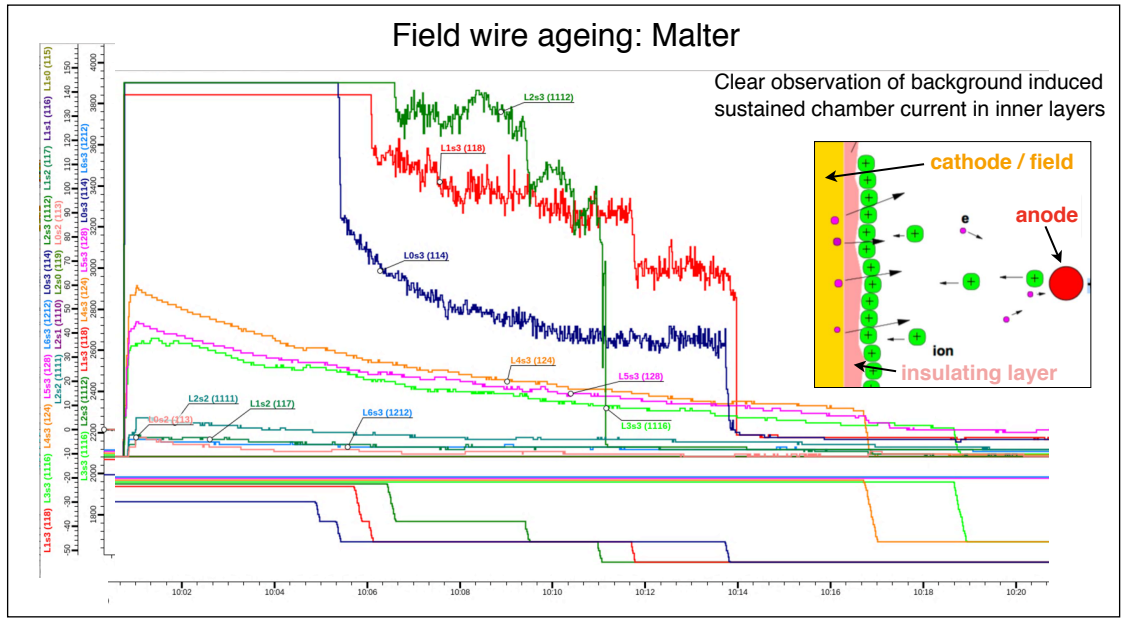
- "CDC" is main tracker of Belle II
- Roles of tracking detector in Belle II
  - measure momentum of charged particles
  - particle identification
  - provide track trigger signal
-

the most important !!





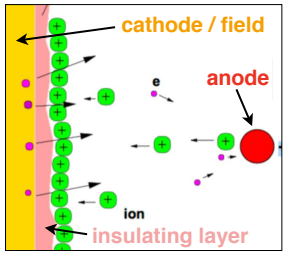
Key Drivers of Changes in CDC Performance



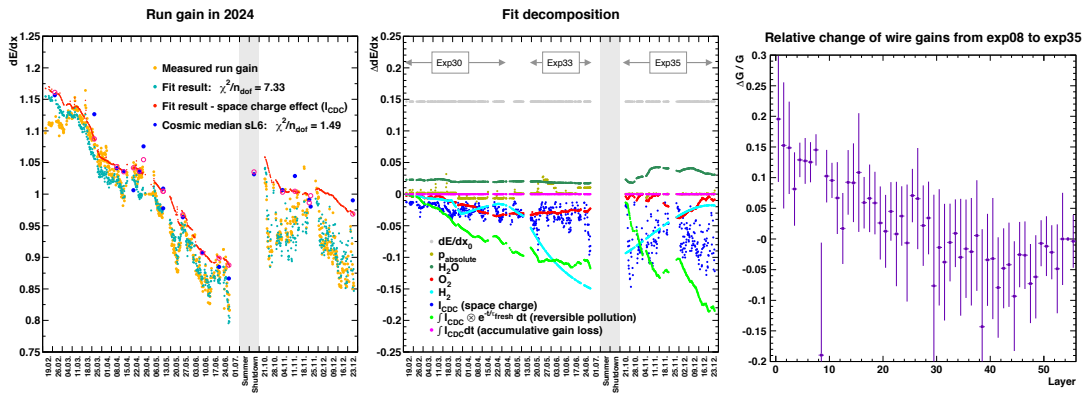
Key Drivers of Changes in CDC Performance

Field wire ageing: Malter

Clear observation of background induced sustained chamber current in inner layers



Gain drop and sense wire ageing



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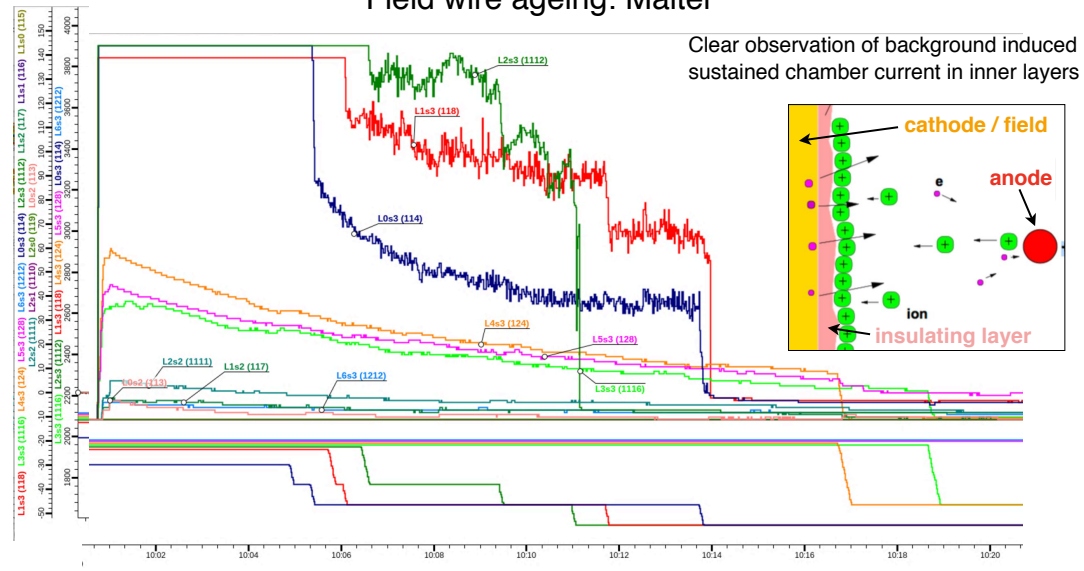
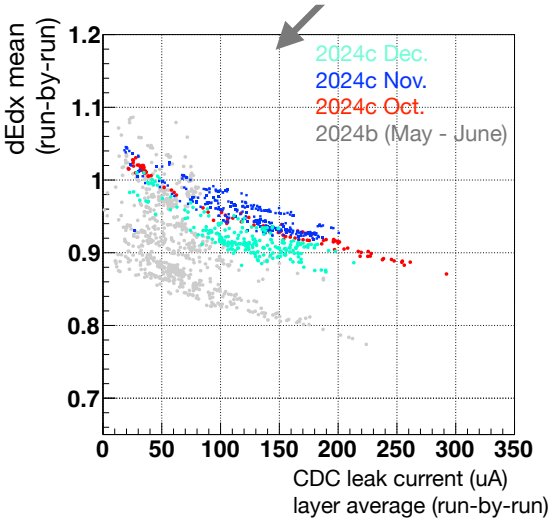
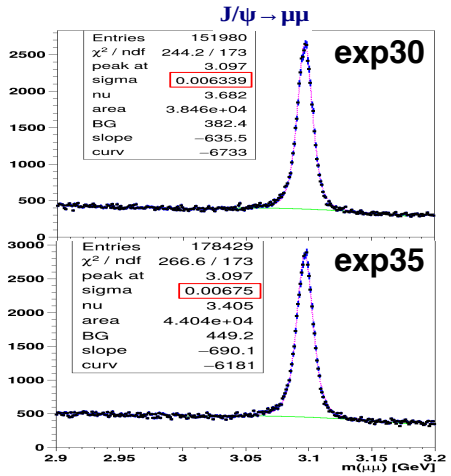


Background dependent hit efficiency (space charge vs rate limitation)

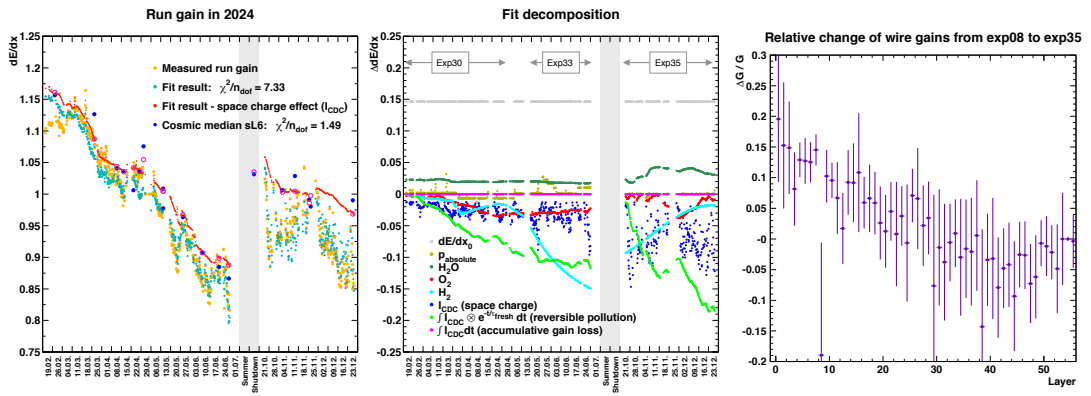




σ/σ: 6.75 / 6.34 = 1.065

$$\frac{\sigma_{p_t}}{p_t} \propto \frac{p_t}{\sqrt{N+5}}$$

Gain drop and sense wire ageing



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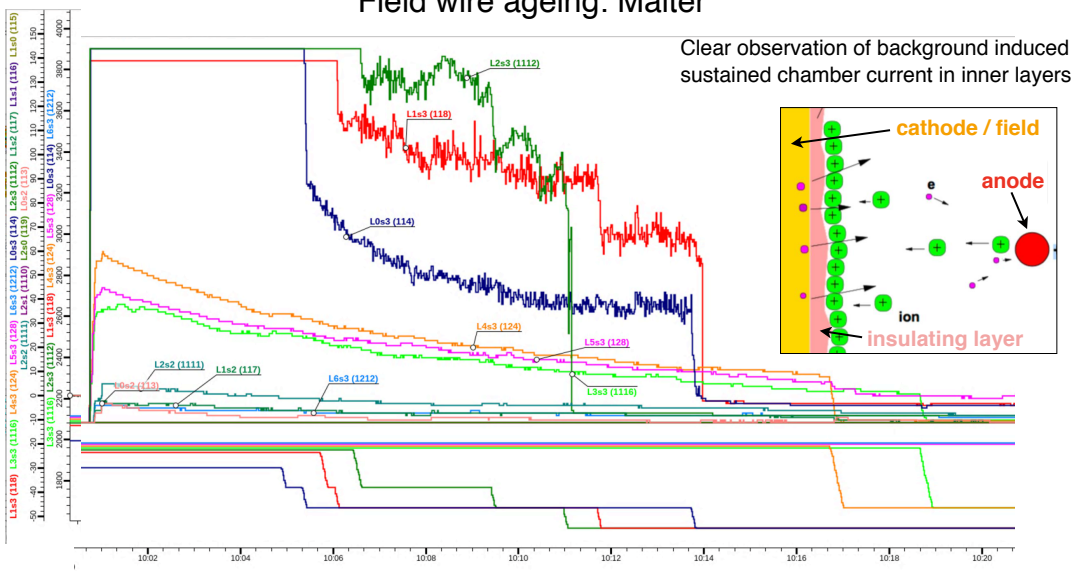

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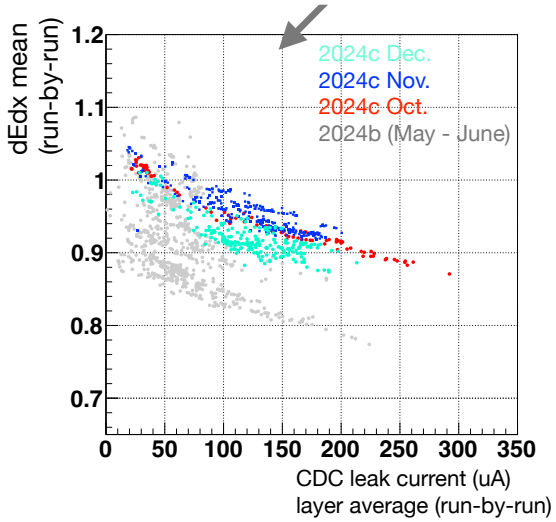

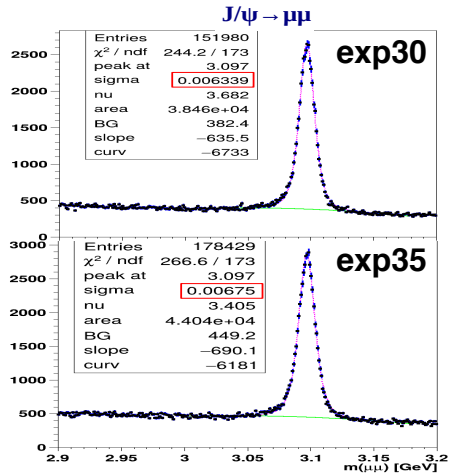

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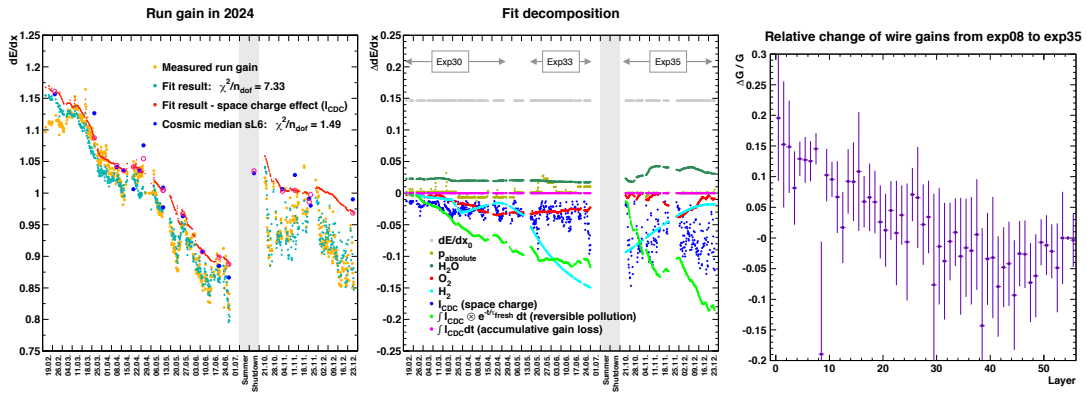
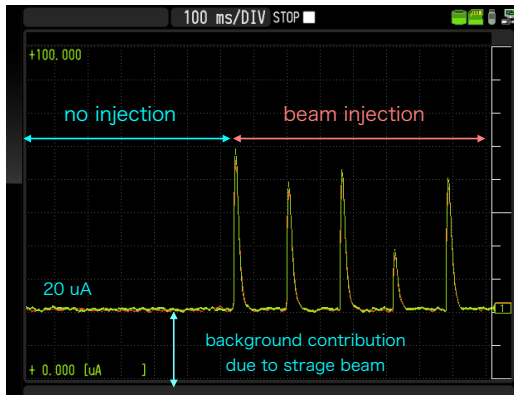
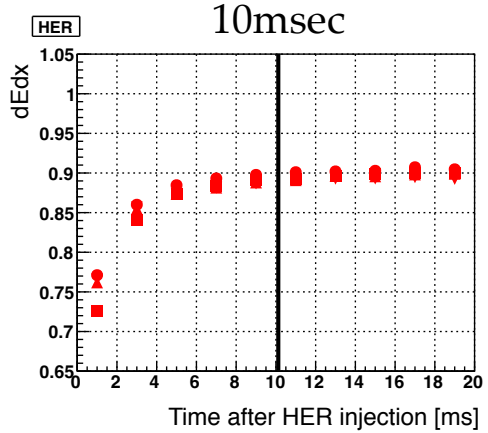


Injection related background





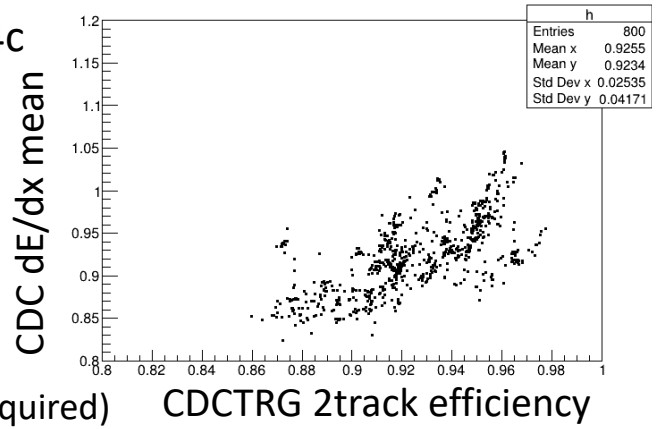
Examples of the Impact of an unstable CDC Run Gain in 2024

CDCTRG efficiency issue

T.Koga

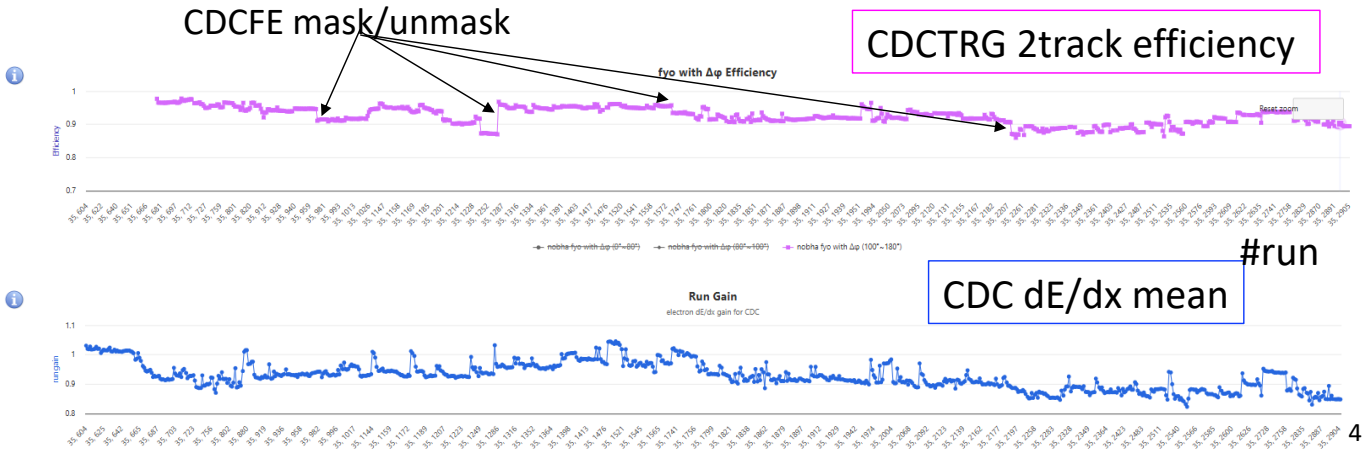
-CDCTRG efficiency is unstable in 2024c

- -~2% by dead CDCFE and MGR
- -~6% by CDC detector gain drop (larger effect if CDC dE/dx < 0.9)



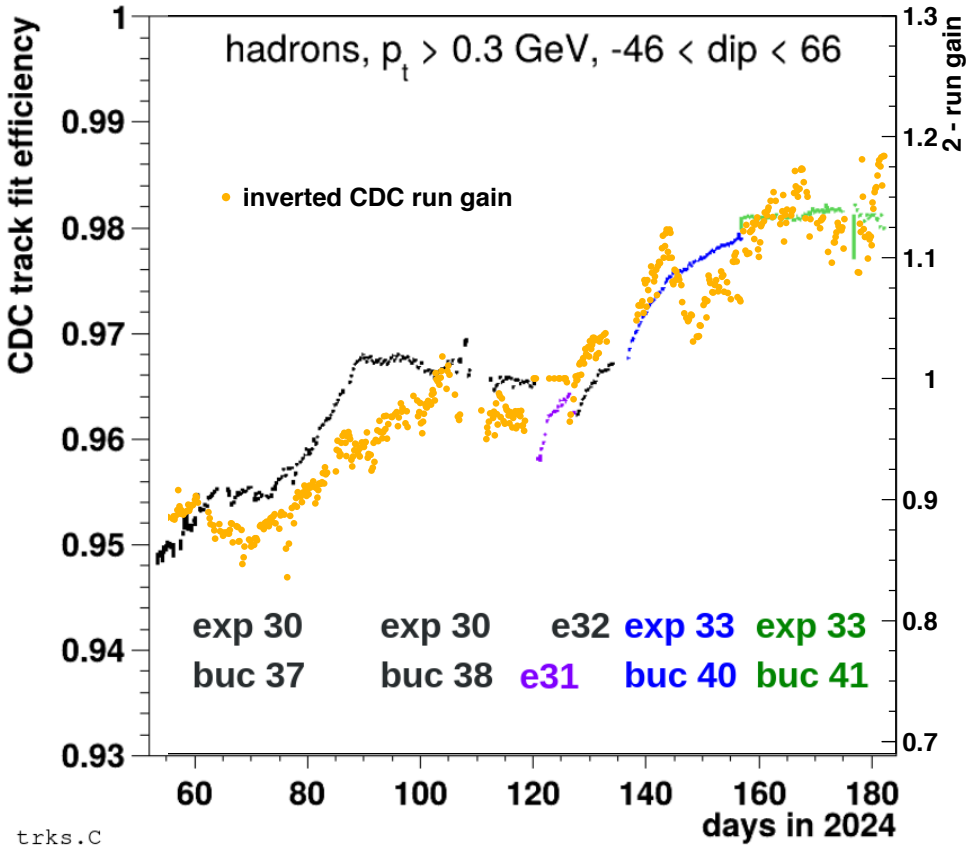
-Consider counter measure by 2025c

- -lower ADC threshold
- -loosen #hit requirement (4 of 5 layer hits required)

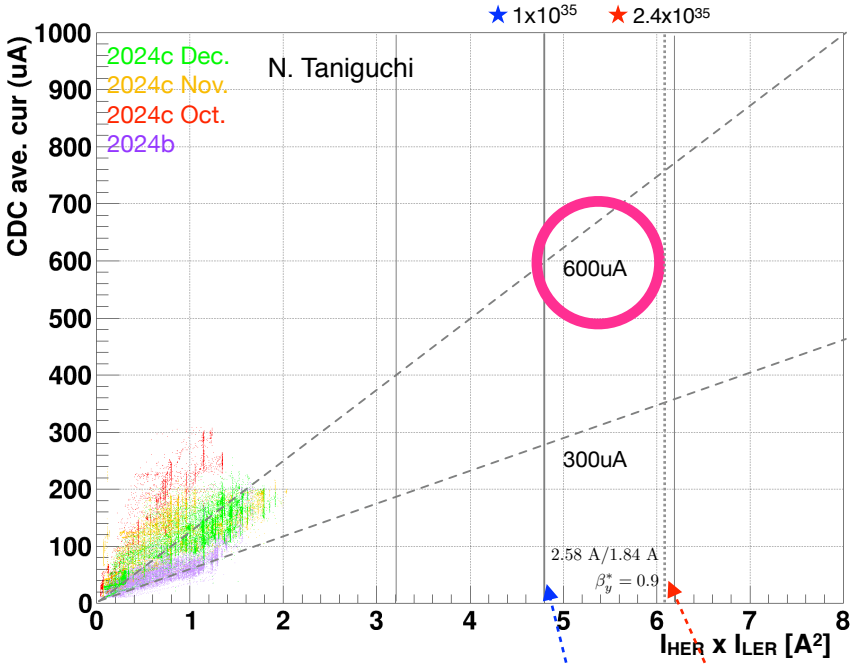


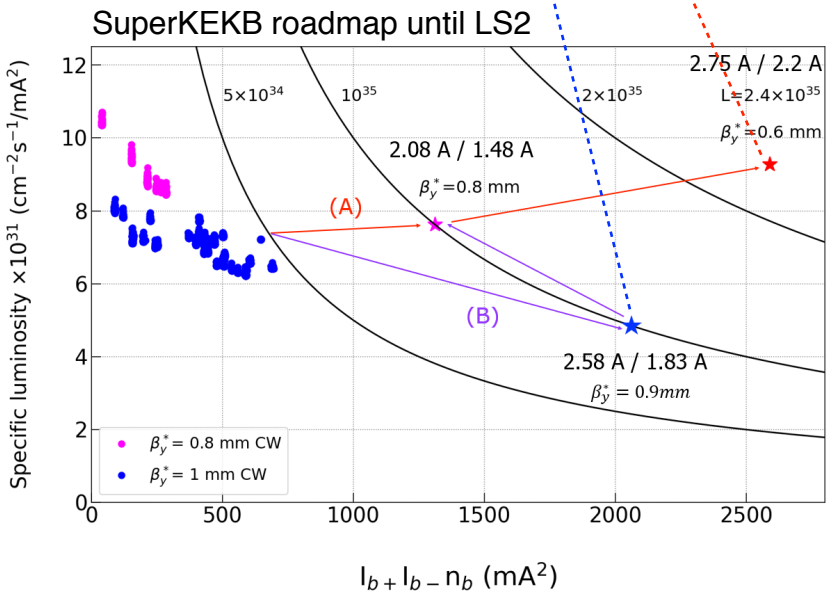
CDC track fit issue

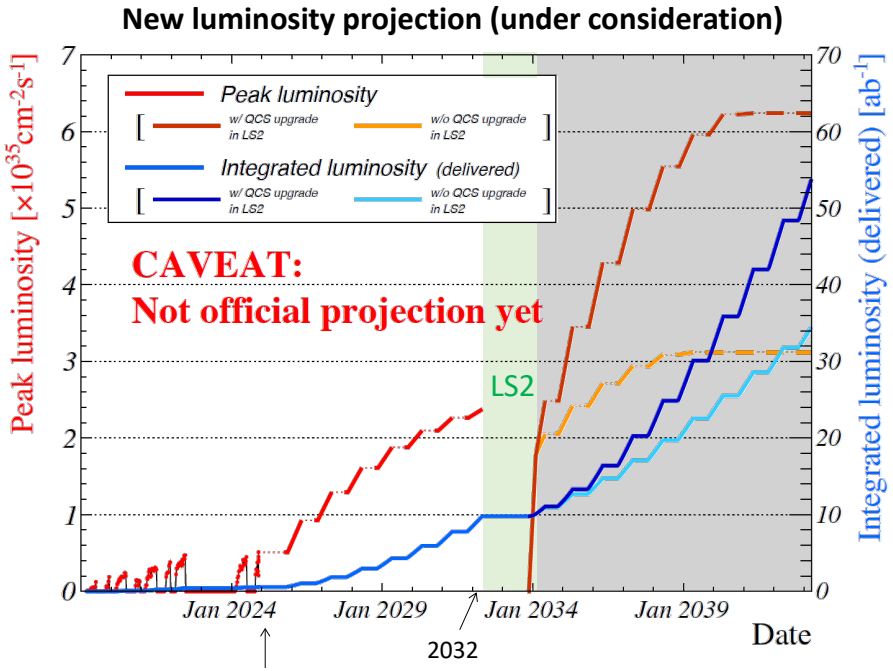
D.Pitzl



The Difficulty of Longer-Term Projections







We are here: 10^{-1} in L_{peak} & 10^{-2} in L_{int} away from goal

- Uncertainties in the projections are very large for both the SuperKEKB upgrade path and the CDC performance response

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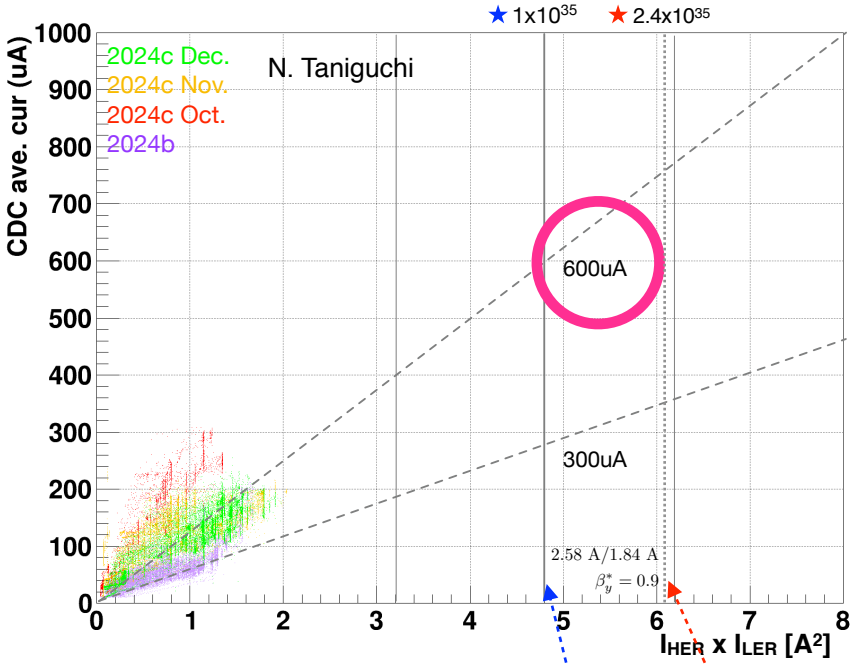
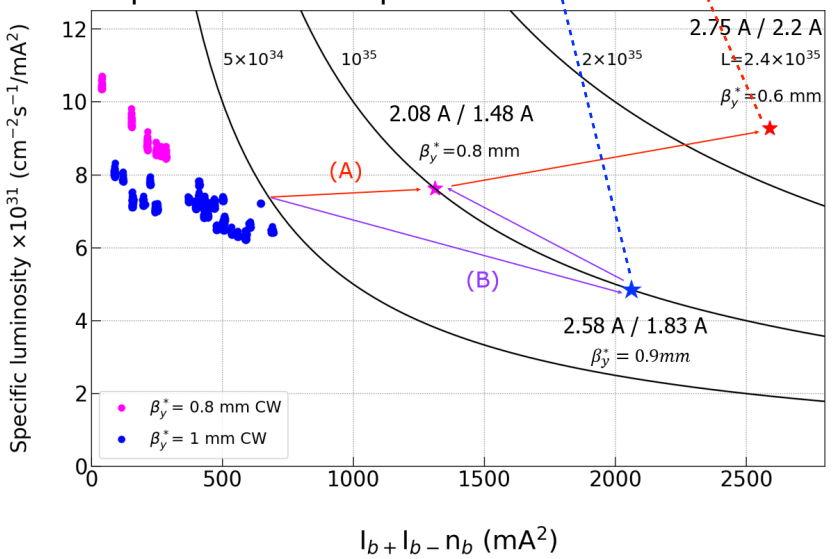
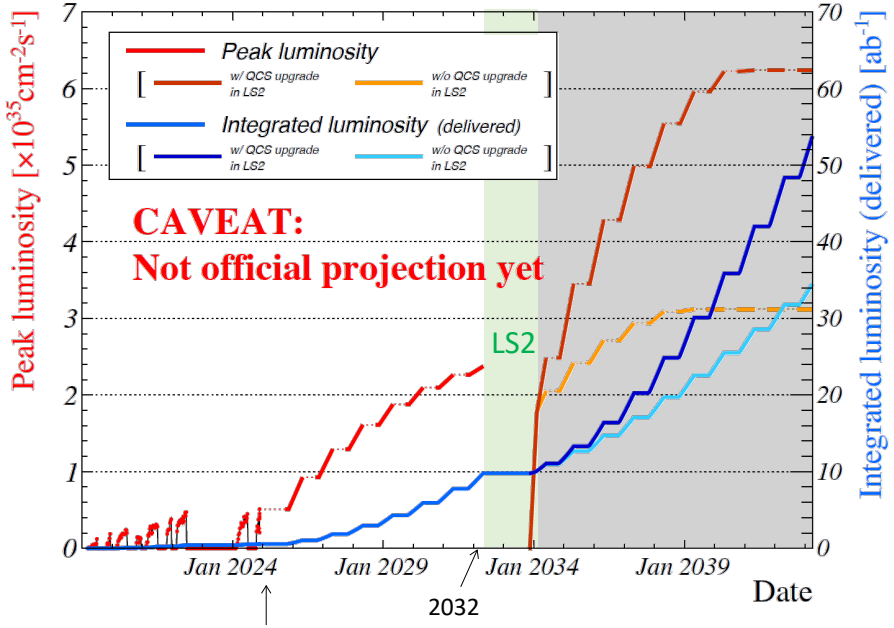


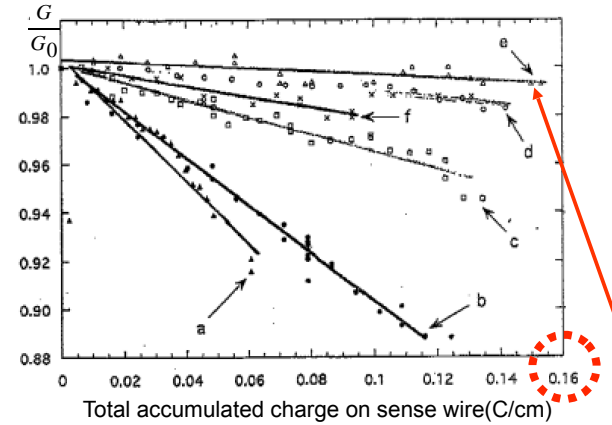


New luminosity projection (under consideration)



We are here: 10^{-1} in L_{peak} & 10^{-2} in L_{int} away from goal

Pre-Belle study: sizeable extrapolation uncertainty

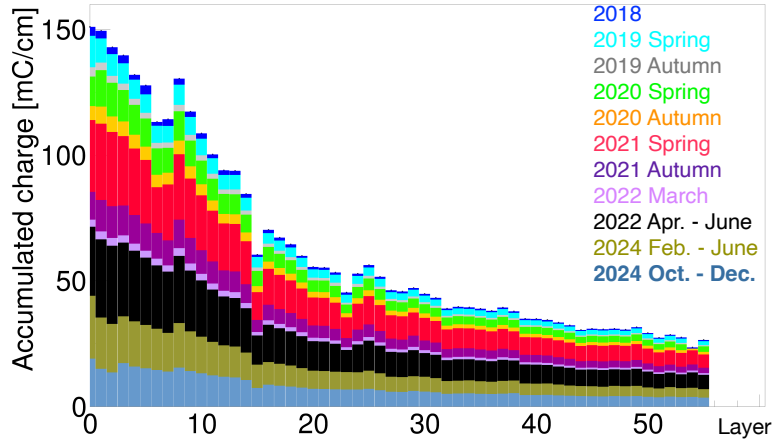


$$\frac{|\Delta G|}{G_0}\frac{1}{Q_{int}} \sim \frac{6\,\%}{C/cm}$$

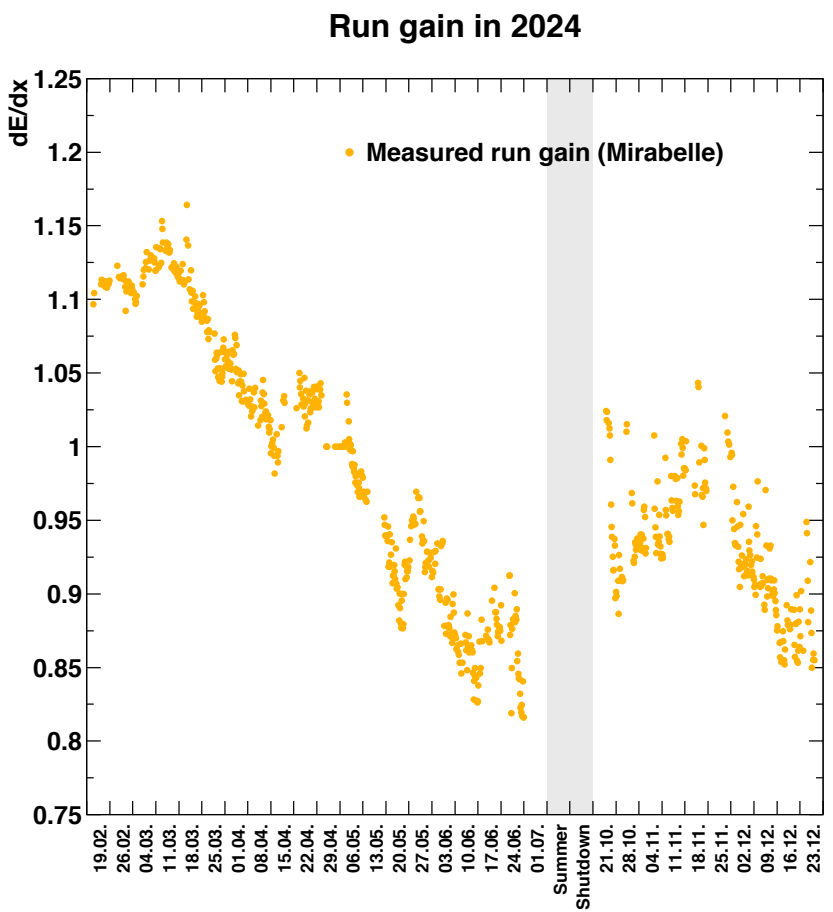
d: '94 SUS tube
e: '94 SUS tube + O_2 filter
f: '94 Plastic tube

Note: **No serious** performance degradation seen in Belle CDC up to **~1C/cm**

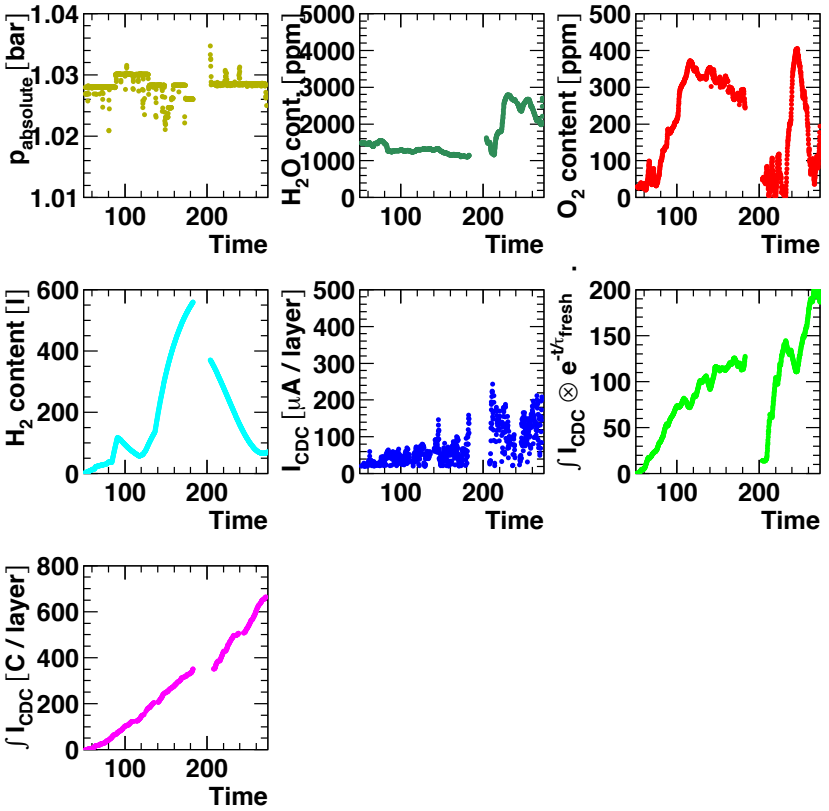
- Uncertainties in the projections are very large for both the SuperKEKB upgrade path and the CDC performance response
- With improved control of CDC operating conditions in the future (e.g. gas conditions), the expected performance degradation up to LS2 may perhaps remain acceptable **if pre-Belle ageing results are confirmed**



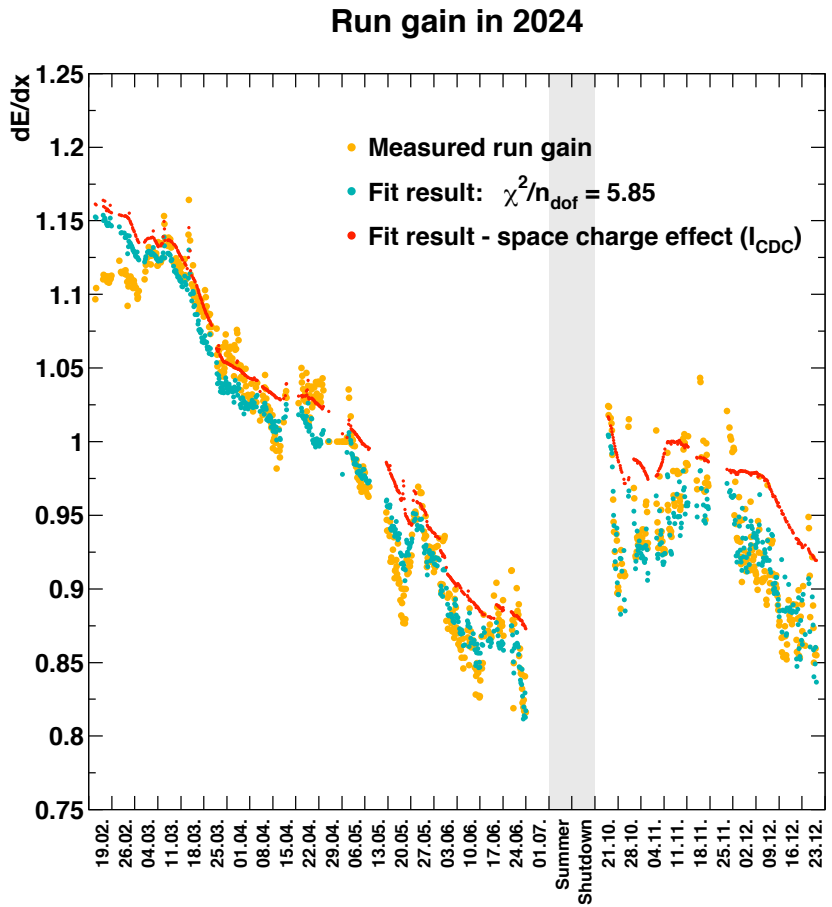
Run Gain in 2024

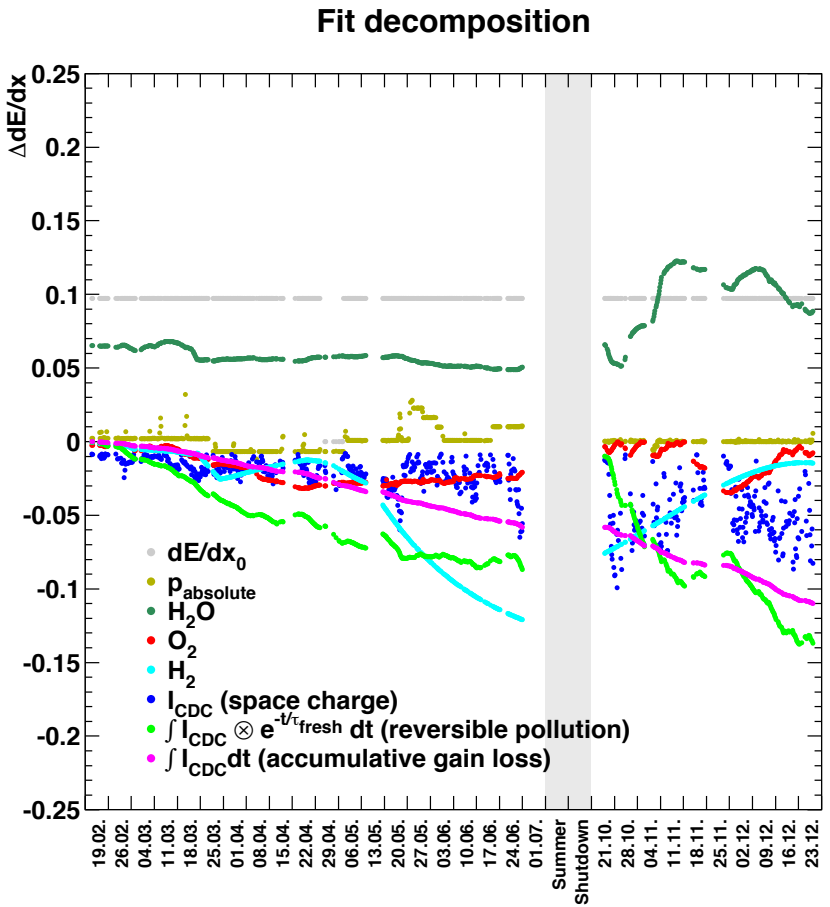


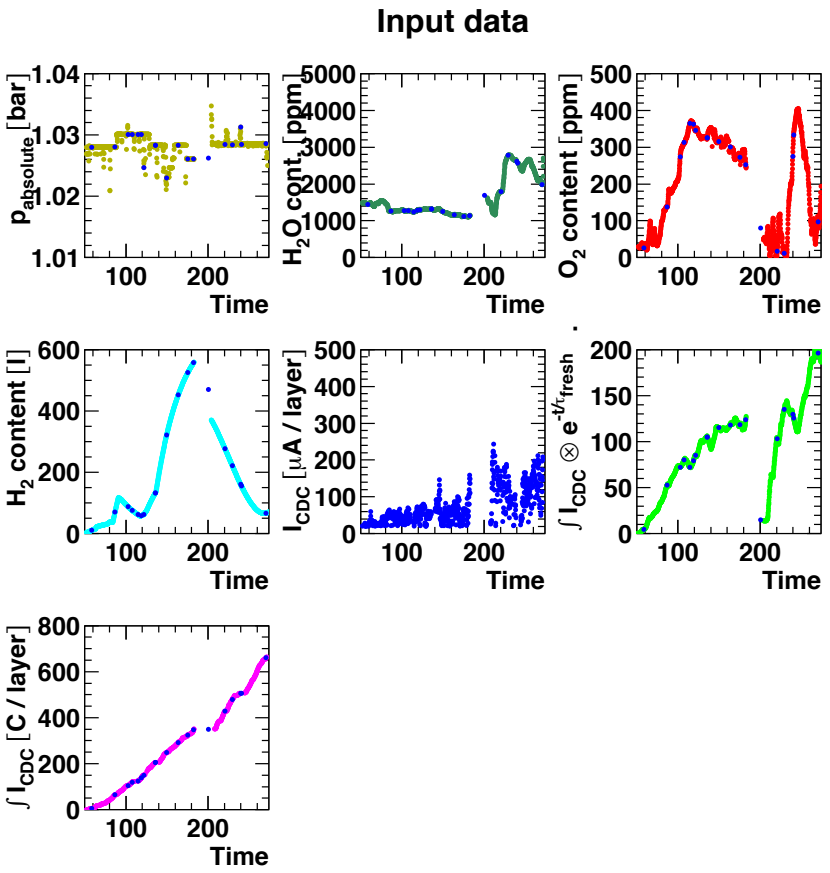
- Pre-LS1, limited control and poor monitoring quality of key parameters allowed only a **qualitative** description of the observed time dependence
- Much improved monitoring capabilities introduced during and after LS1 are used here to attempt a more **quantitative** analysis
- Variables considered so far as input for parametrisation
  - Absolute pressure
  - H_2O content
  - O_2 content
  - H_2 content estimated using H_2 - and fresh gas flow rate
  - I_{CDC} to account for space charge effect
  - Accumulation/removal of hypothetical trace contaminant in the gas produced in the avalanche (derived from I_{CDC} and fresh gas flow rate)
  - Integrated charge (irreversible)
- Exploit the characteristic time dependence of input variables x_i to determine individual contributions by a fit to the run gain data
  - $dE/dx_{Fit} = 1 + \Sigma f_i x_i$



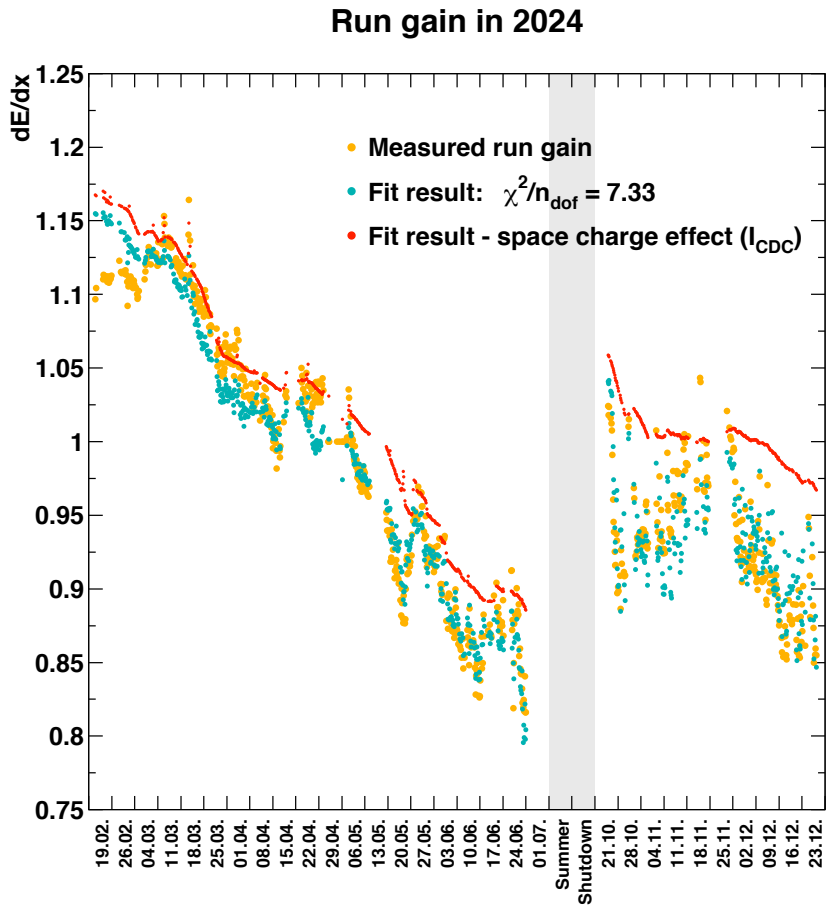
Scenario 1: All Parameters included

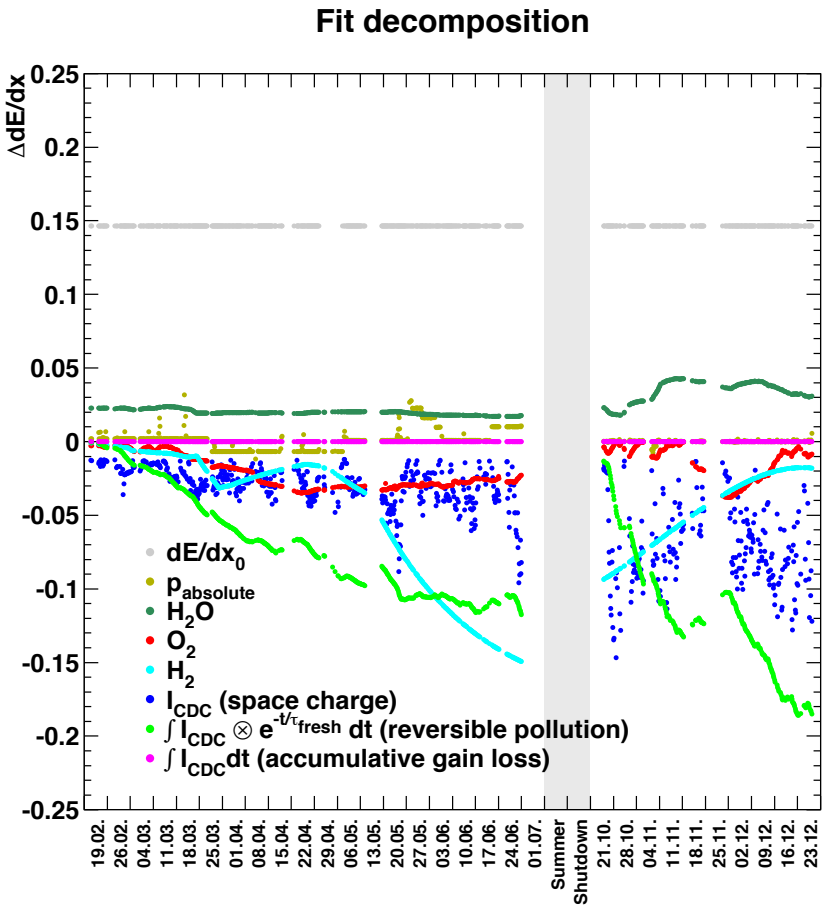


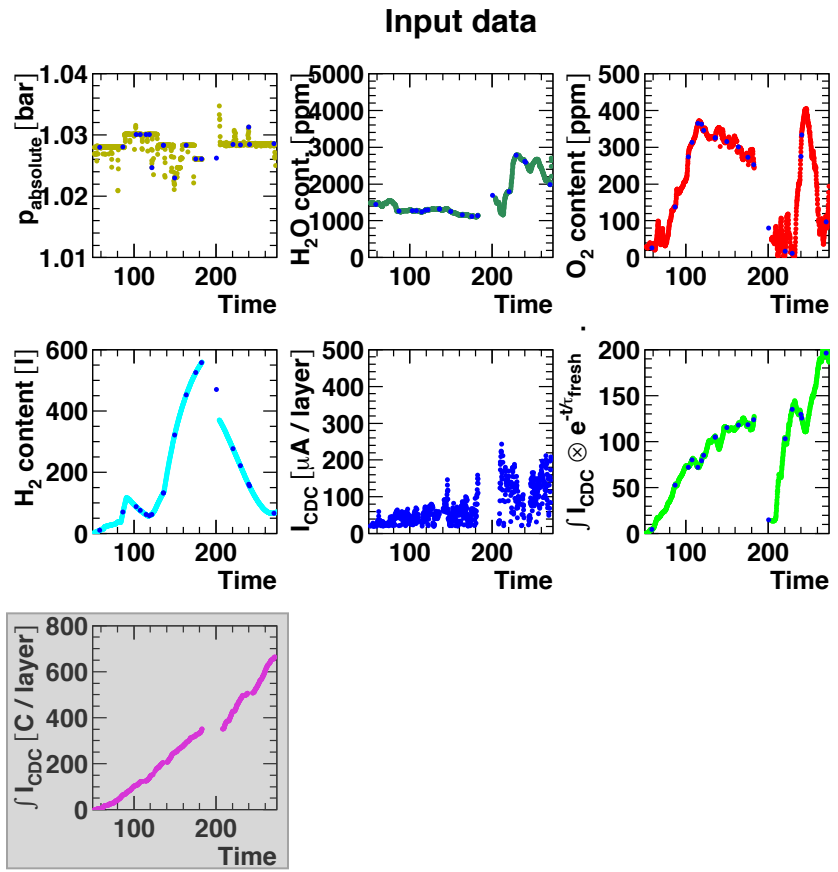




Scenario 3: Remove $\int I_{CDC}\,dt$ from Fit

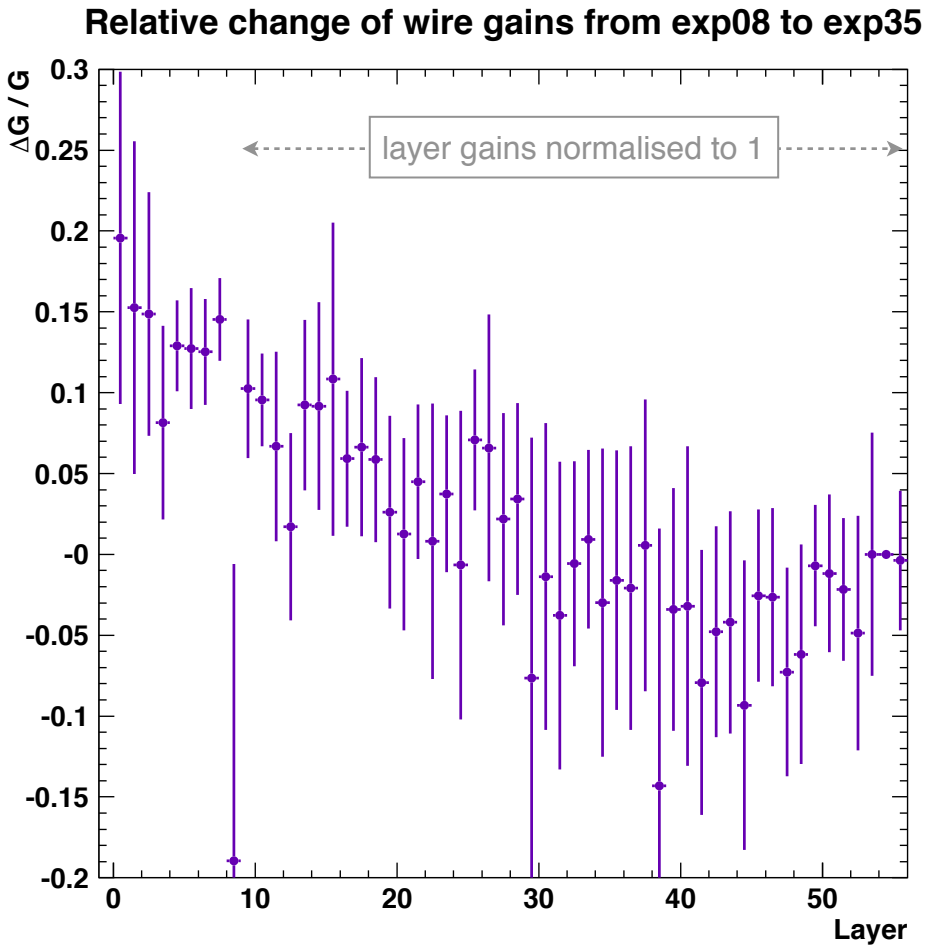


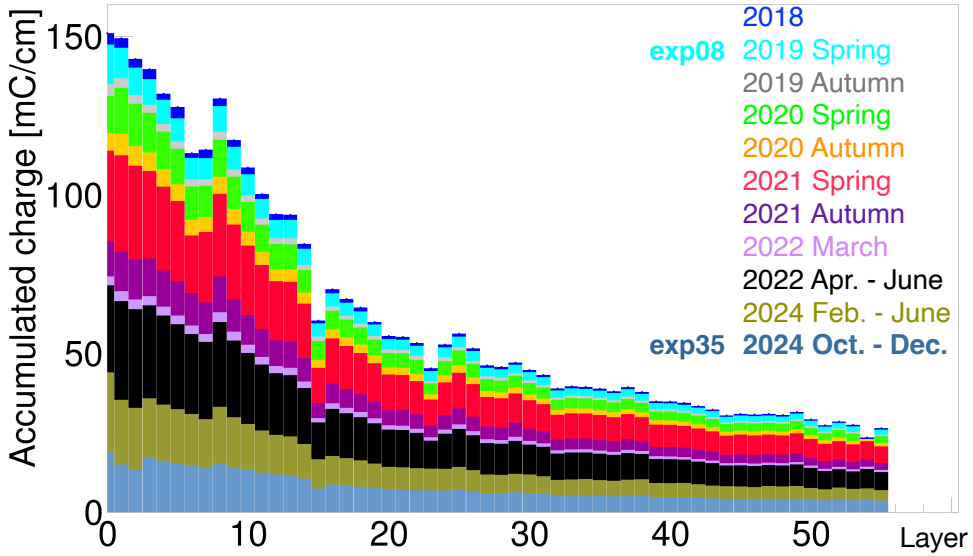


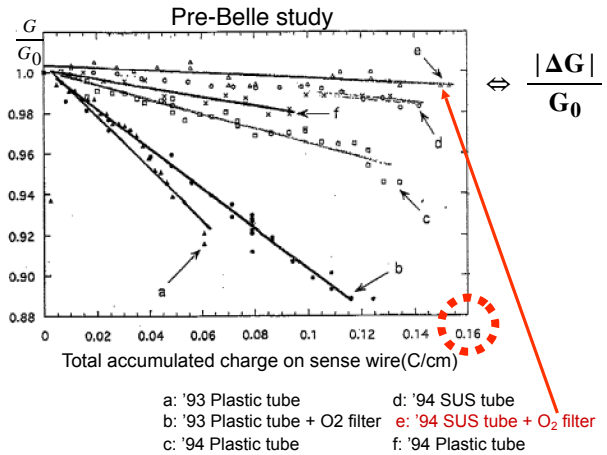


- Dominant contributions to gain loss
  - impurity build-up
  - space charge / voltage drop
  - H_2 content (avoidable)

Alternative Approach to Permanent Gain Loss: Wire Gains 2019-2024







$$\Leftrightarrow \frac{|\Delta G|}{G_0}\frac{1}{Q_{int}} \sim \frac{6\,\%}{C/cm}$$

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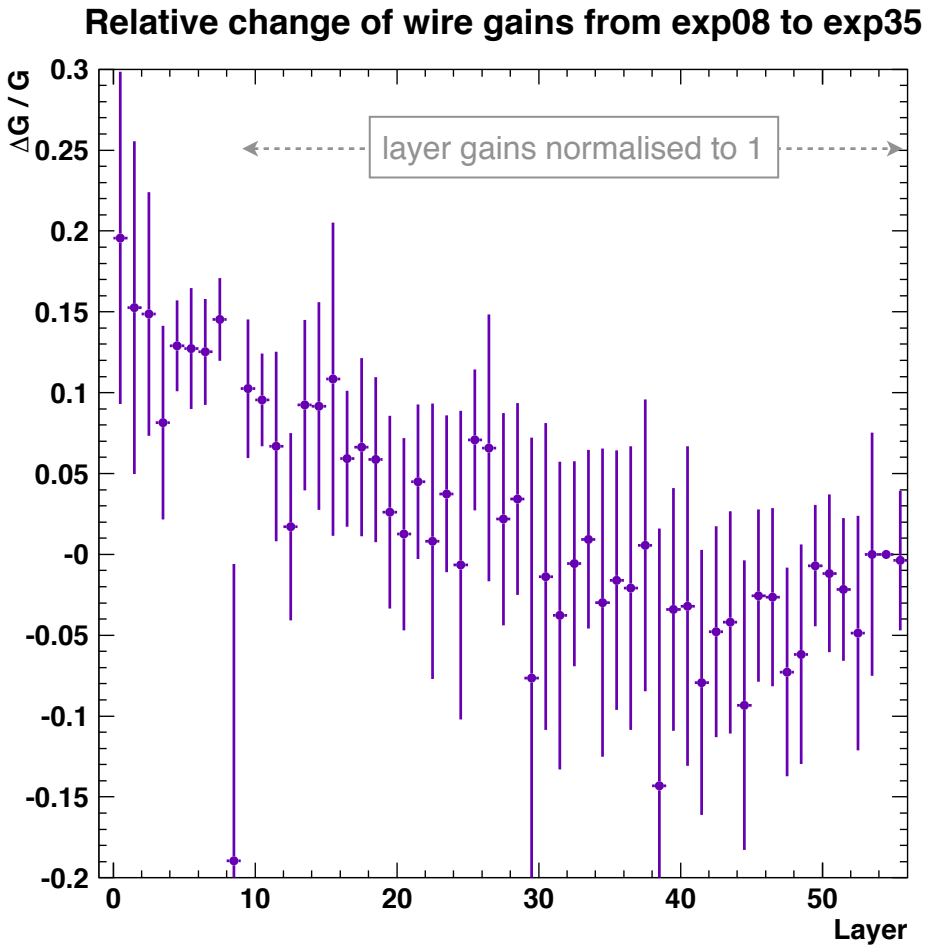
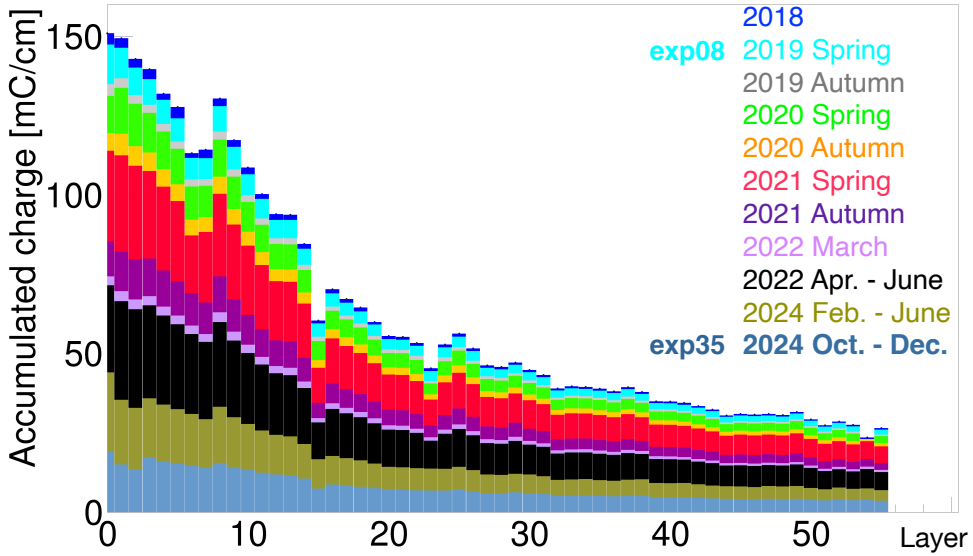
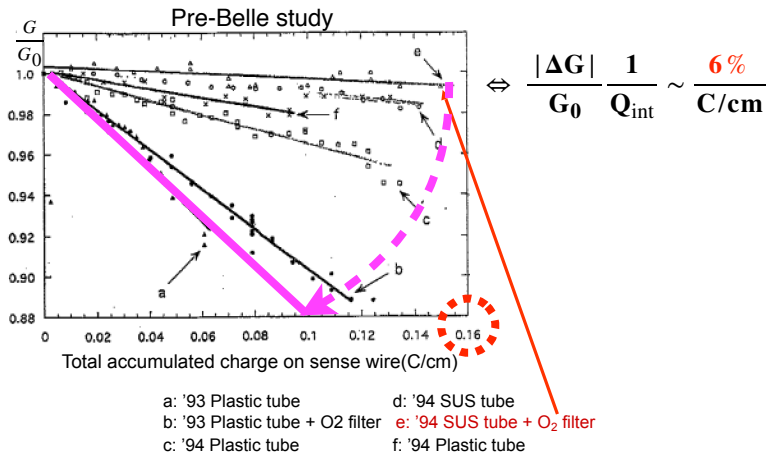




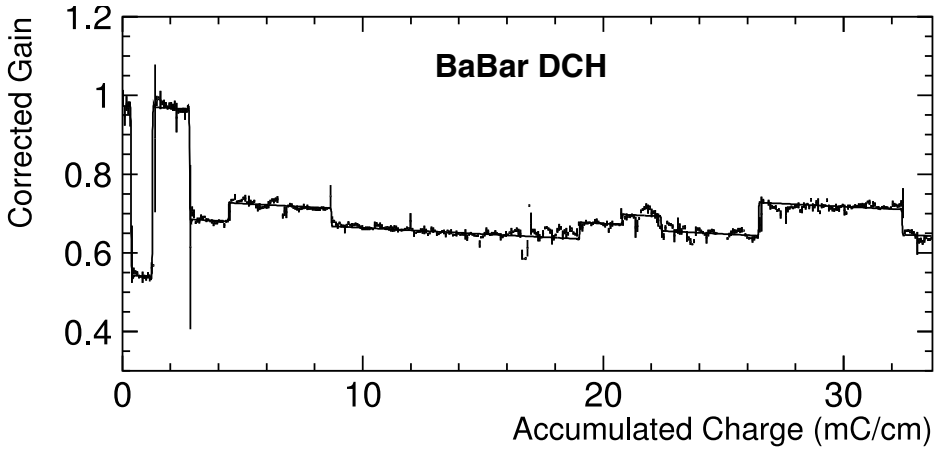


$$\Leftrightarrow \frac{|\Delta G|}{G_0}\frac{1}{Q_{int}} \sim \frac{6\,\%}{C/cm}$$

$$\text{For example for layer 1}: \frac{15\,\%}{120\,mC/cm} = \frac{0.13\,\%}{mC/cm} \approx 20 \times \frac{6\,\%}{C/cm}$$

Comparison with BaBar DCH and BES III MDC

	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	8 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**



https://arxiv.org/abs/1305.3560

Figure 51: Relative DCH gain (corrected for temperature and pressure variations) as a function of accumulated charge on the wires. The steps correspond to changes in operating voltage; the curve is a fit to the reduction in gain, giving $\delta G/G = (0.337 \pm 0.006)\%$ per mC/cm.

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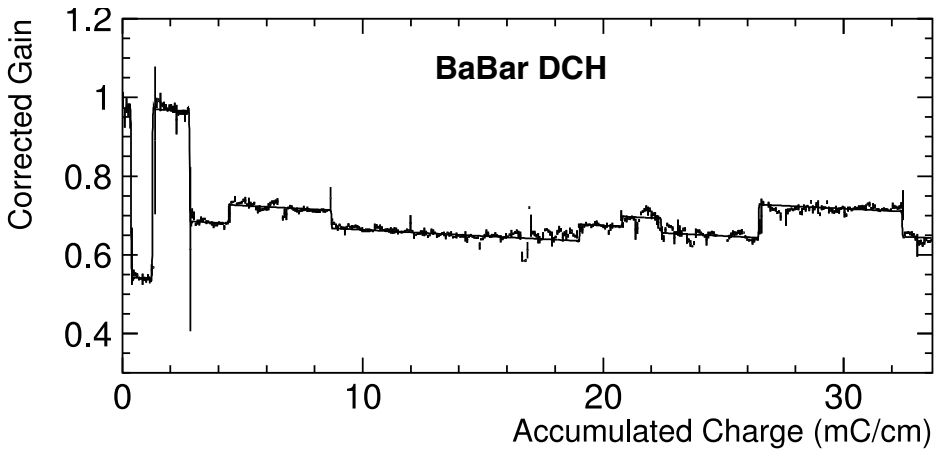

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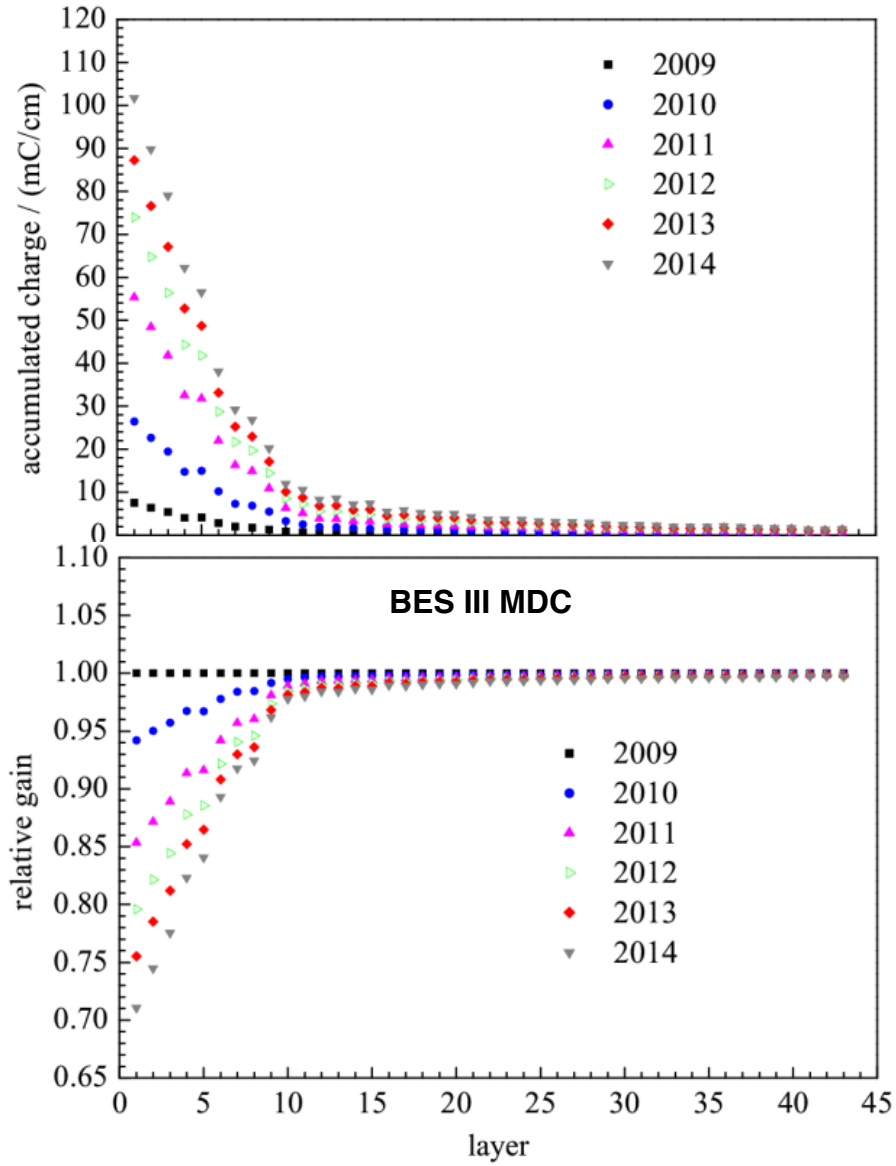


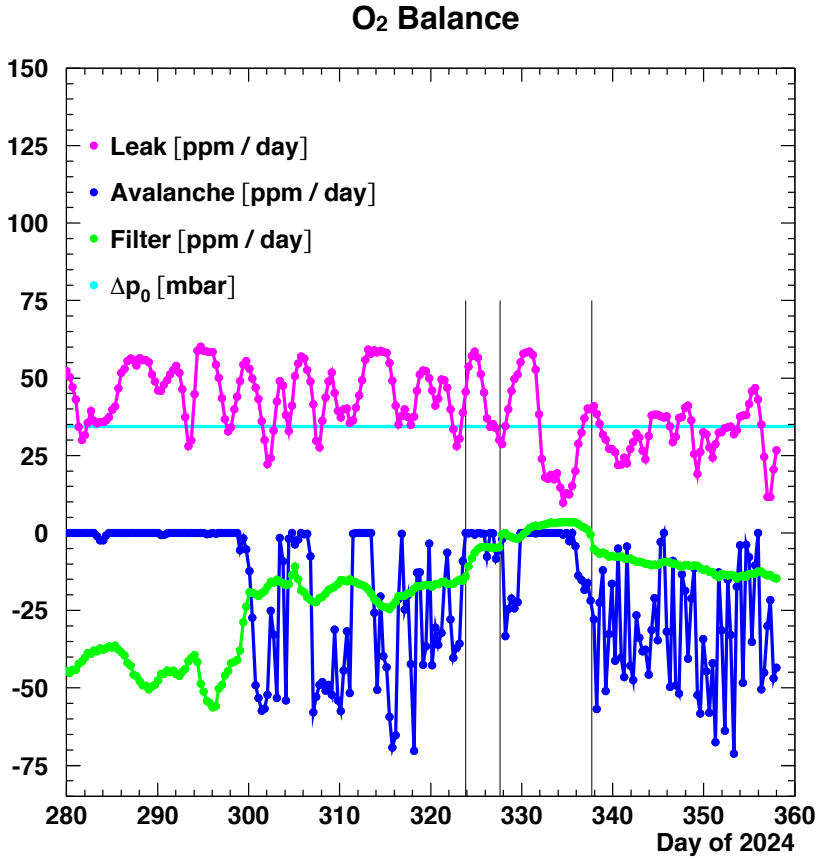
https://arxiv.org/abs/1504.04681

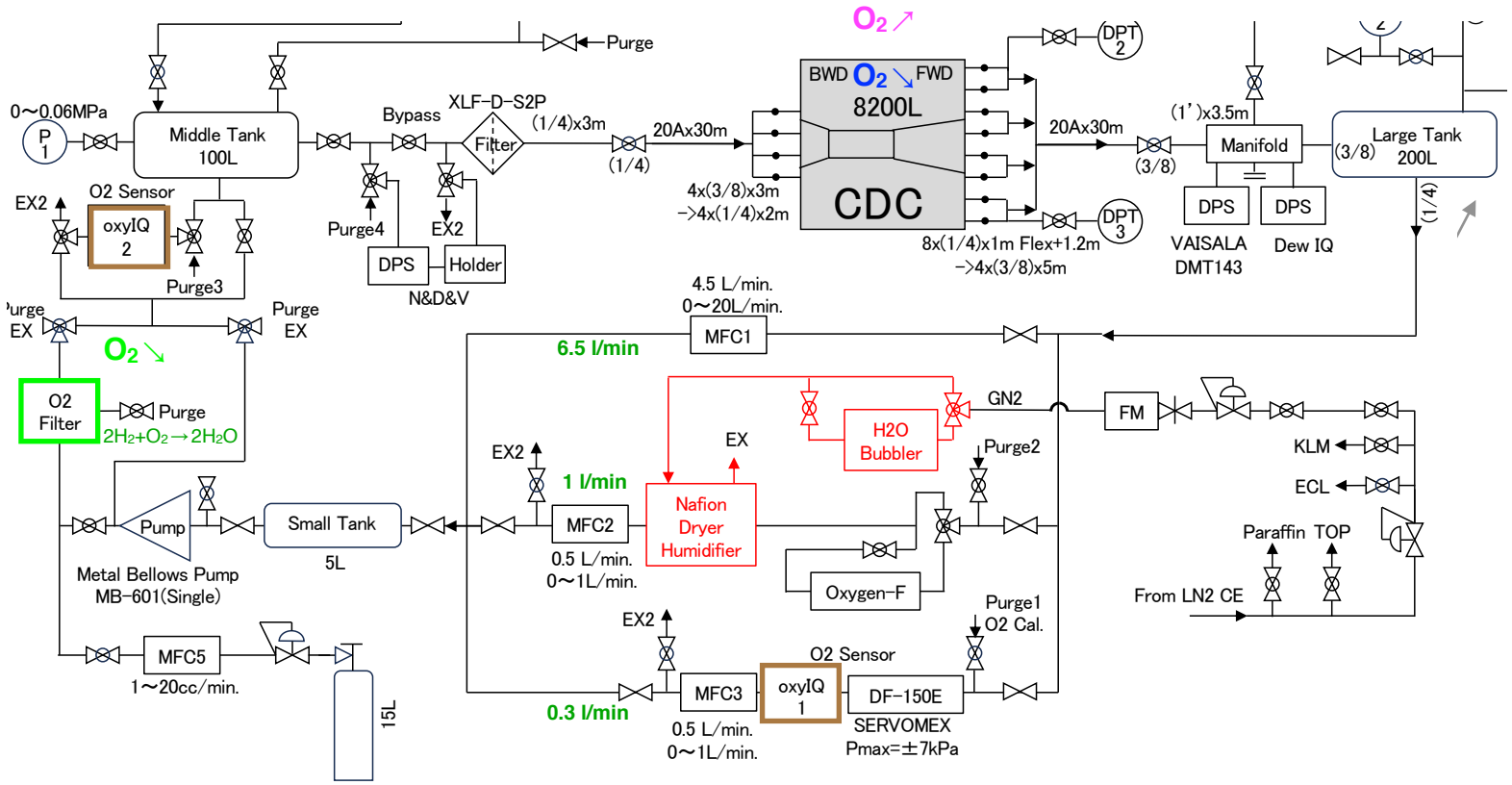
He / C_3H_8 = 60 : 40 with 0.2% H_2O (from 2012): $\frac{1}{Q/L}\frac{\Delta G}{G} = \frac{0.3\,\%}{\mathrm{mC/cm}}$

Unexpected Observations

- H_2O content
  - with the exception of scenario 8 (no pollution & no ageing contribution, very bad χ^2), all scenarios require an **increasing gain** with H_2O content, contrary to expectations
- Integrated charge
  - unless omitted from the fit, the result is **more than one order of magnitude** larger than that obtained in the pre-Belle ageing study
- Hypothetical contamination with trace contaminants from the avalanche
  - unless omitted from the fit, all scenarios require a **sizeable contribution** of such a component
  - this is an argument for a substantial increase of the fresh gas flow rate during beam operation
- Given that beams will only be back in fall, we will use **cosmic runs** to check the evolution of the charge median as an additional monitor of the run gain, in order to disentangle the various effects
  - e.g. change H_2O and O_2 contents in controlled way to ‚calibrate' sensitivity
  - take data with reduced HV and study impact on efficiency and resolution

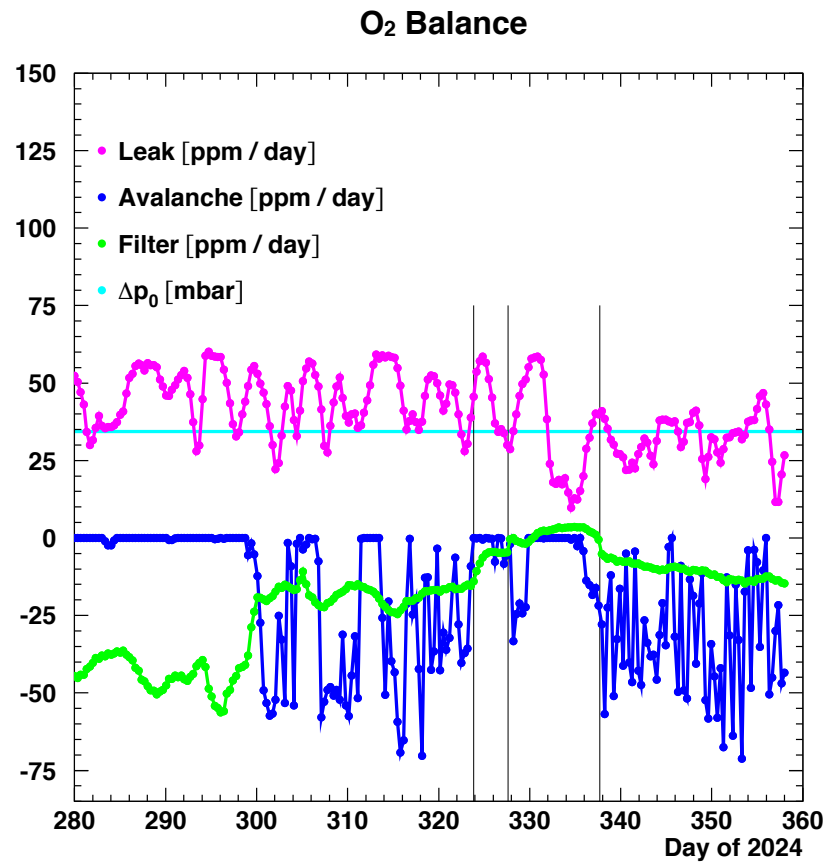
Other Surprising Findings in 2024c

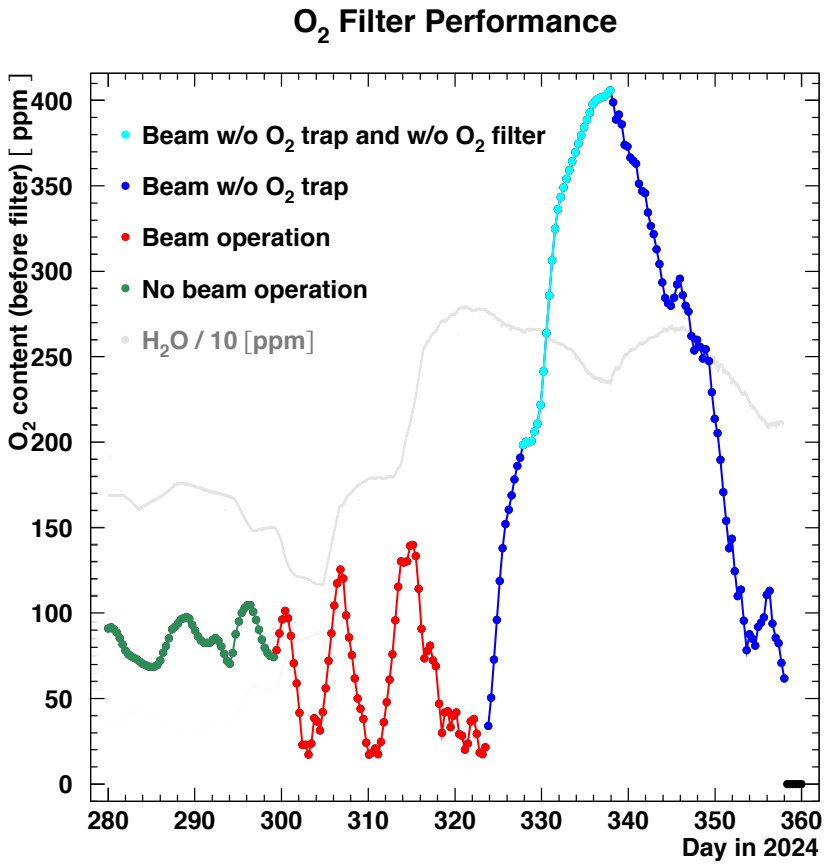


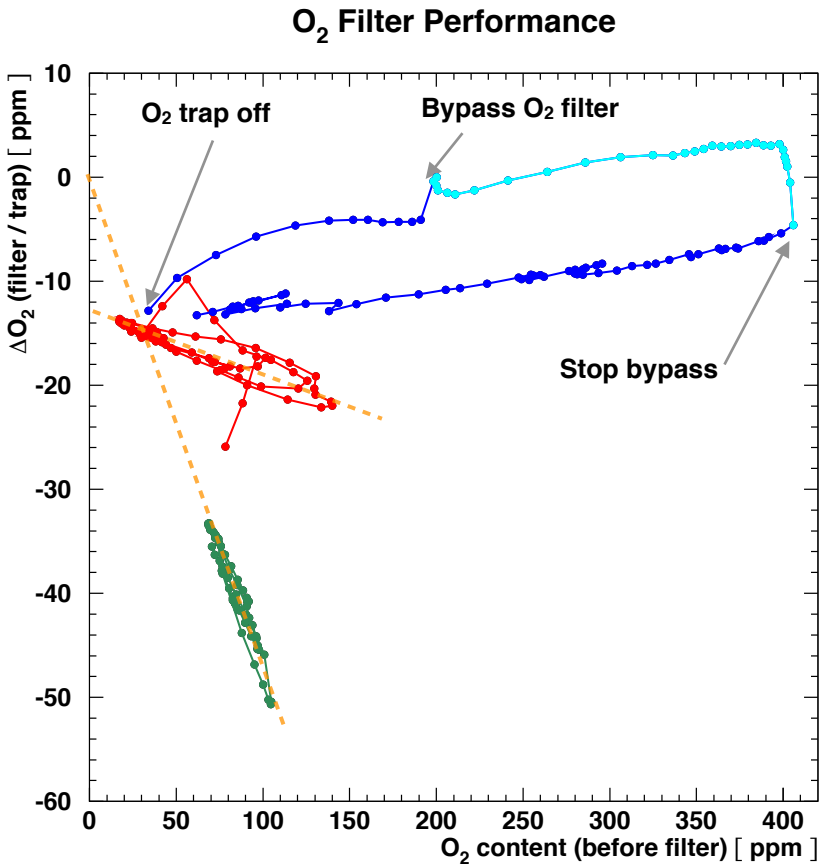


- Safe and reliable CDC operation requires stable gas conditions
  - e.g. He-C_2H_6 ratio, H_2O and O_2 content, gas pressure
  - O_2 inflow proportional to pressure difference between CDC and environment
- Increased monitoring capabilities introduced in summer 2024 allowed more detailed studies

Other Surprising Findings in 2024c



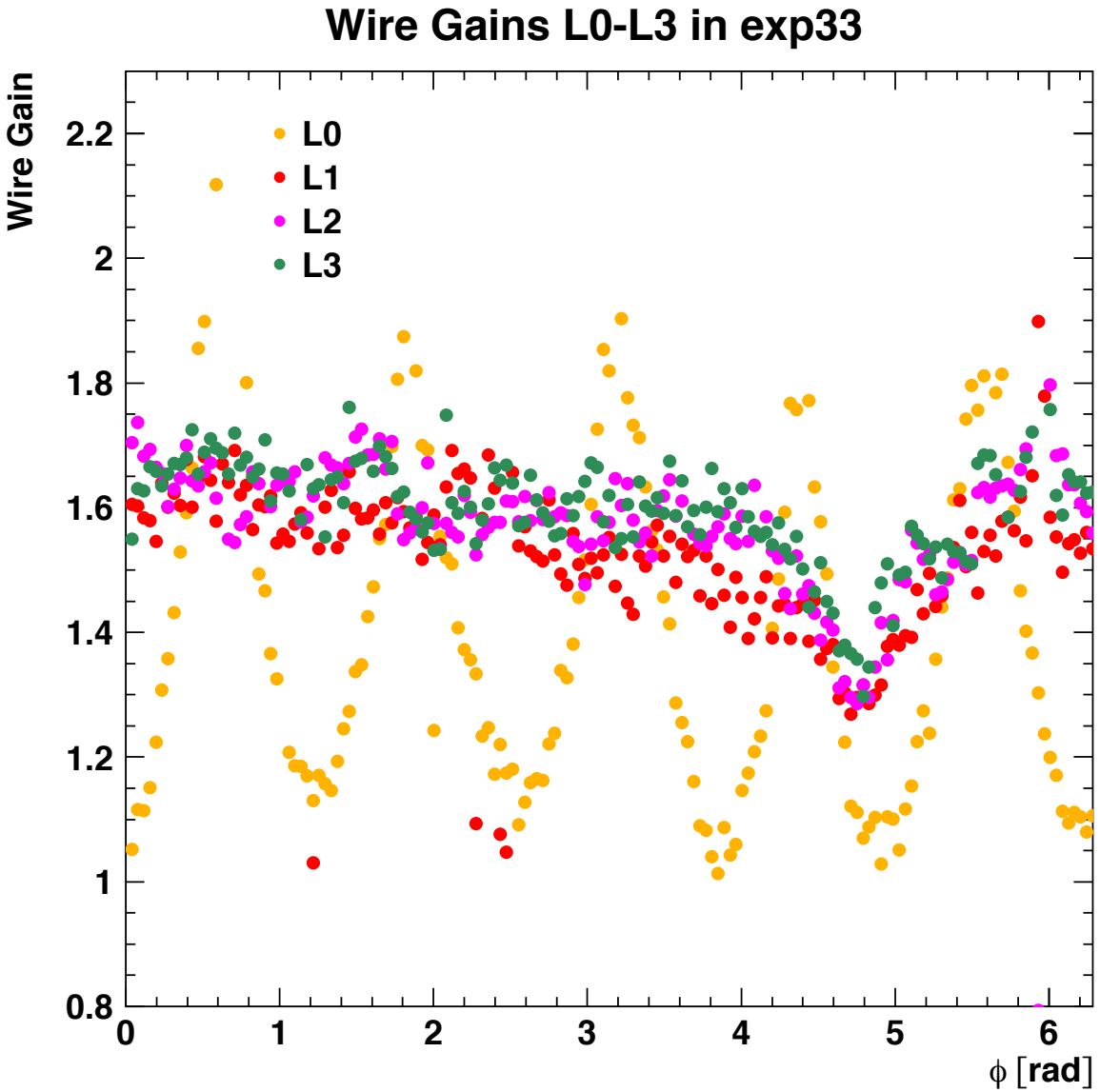




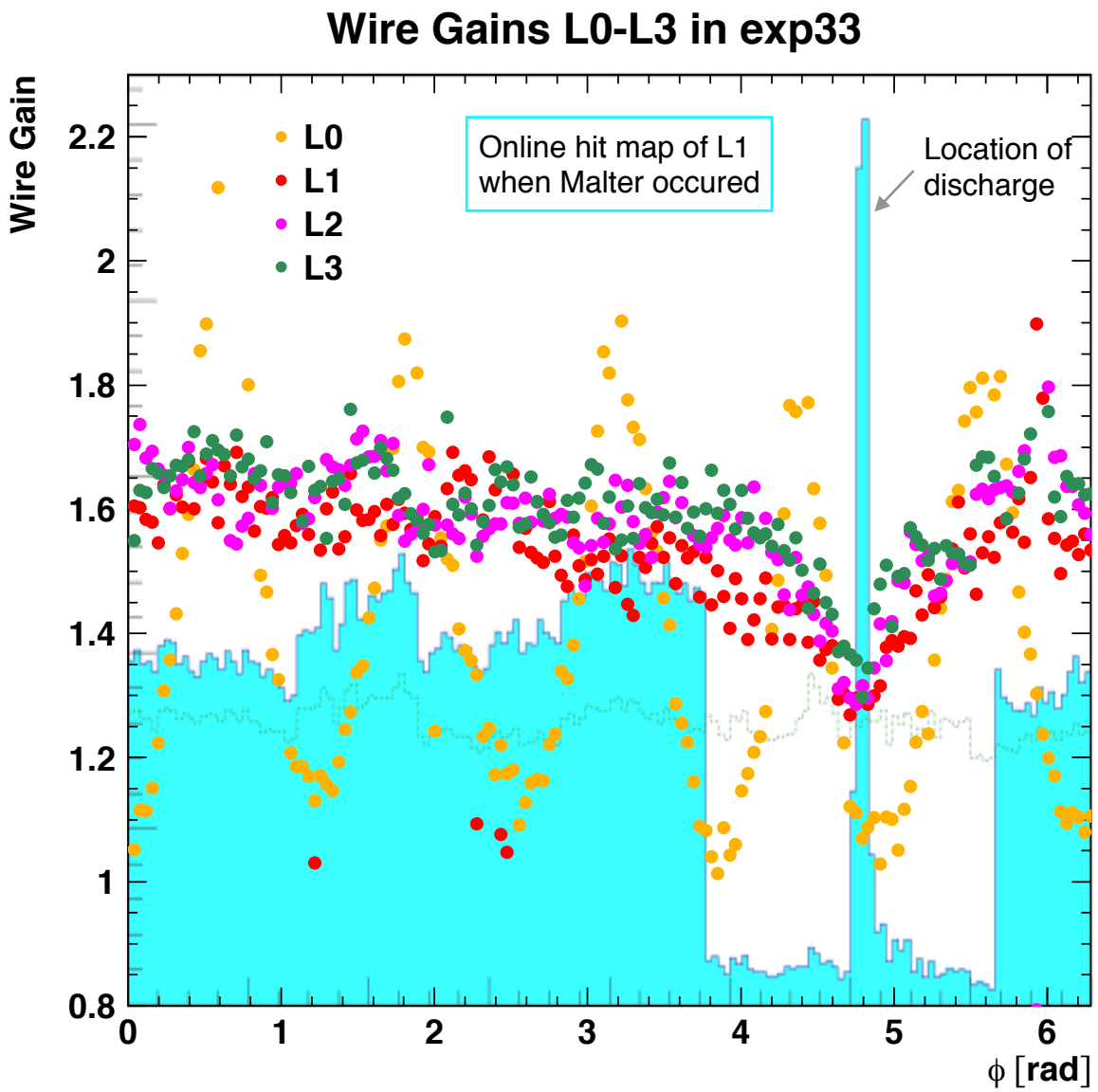
- Safe and reliable CDC operation requires stable gas conditions
  - e.g. He-C_2H_6 ratio, H_2O and O_2 content, gas pressure
  - O_2 inflow proportional to pressure difference between CDC and environment
- Increased monitoring capabilities introduced in summer 2024 allowed more detailed studies
- Several unexpected findings

- significant O_2 consumption when CDC draws current (avalanche)
  - on average, each ion produced in the avalanche causes ~ 3 O_2 molecules to undergo a chemical reaction
- behaviour of O_2 filter changed abruptly when CDC operated with beam
  - prior to beam operation the probability of an O_2 molecule being absorbed (converted) is 50%
  - within a few hours, this probability is reduced by almost an order of magnitude

Wire Gains and online Hit Map when Malter Effect started



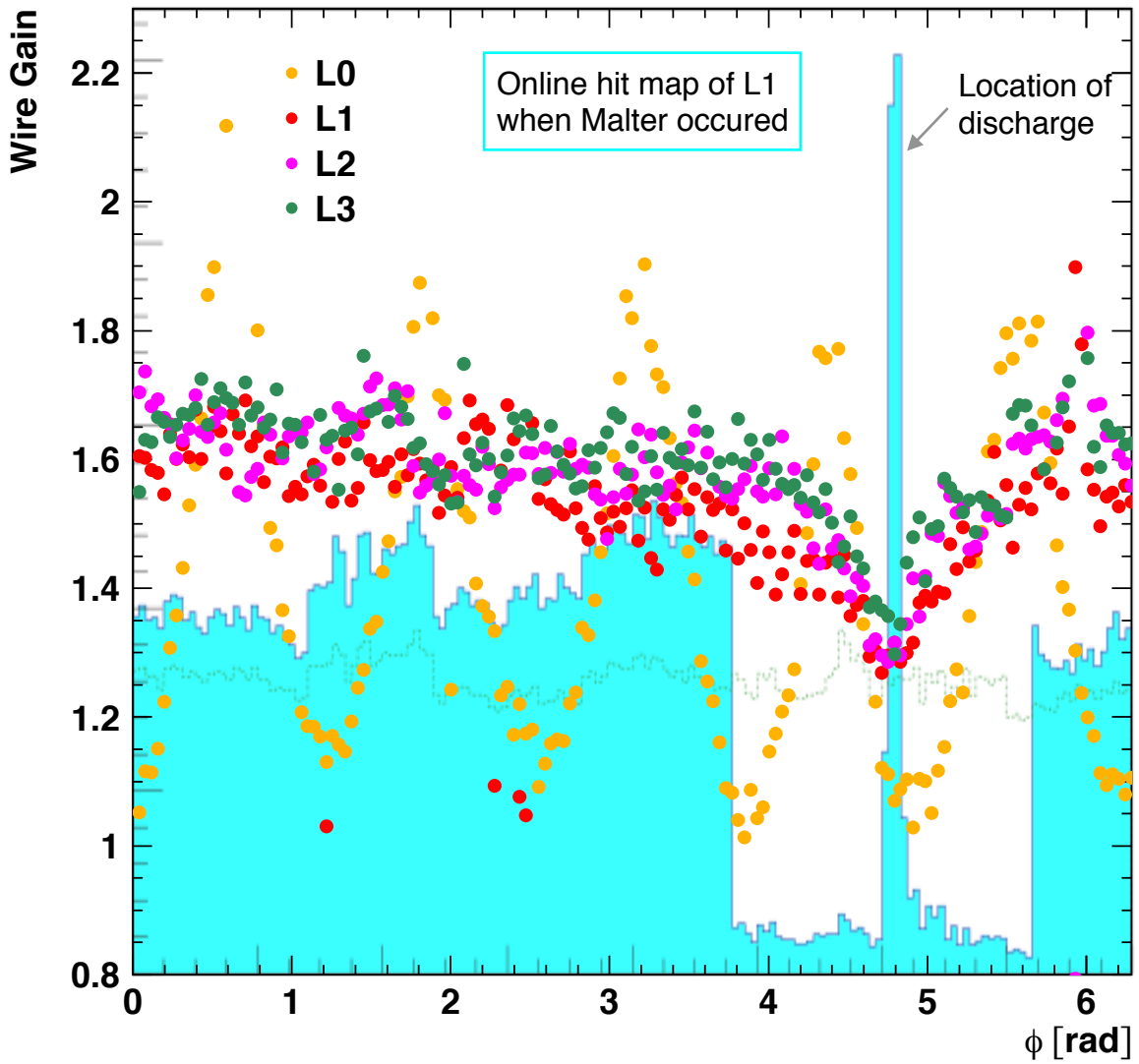
Wire Gains and online Hit Map when Malter Effect started



Coincidence or deeper reason?

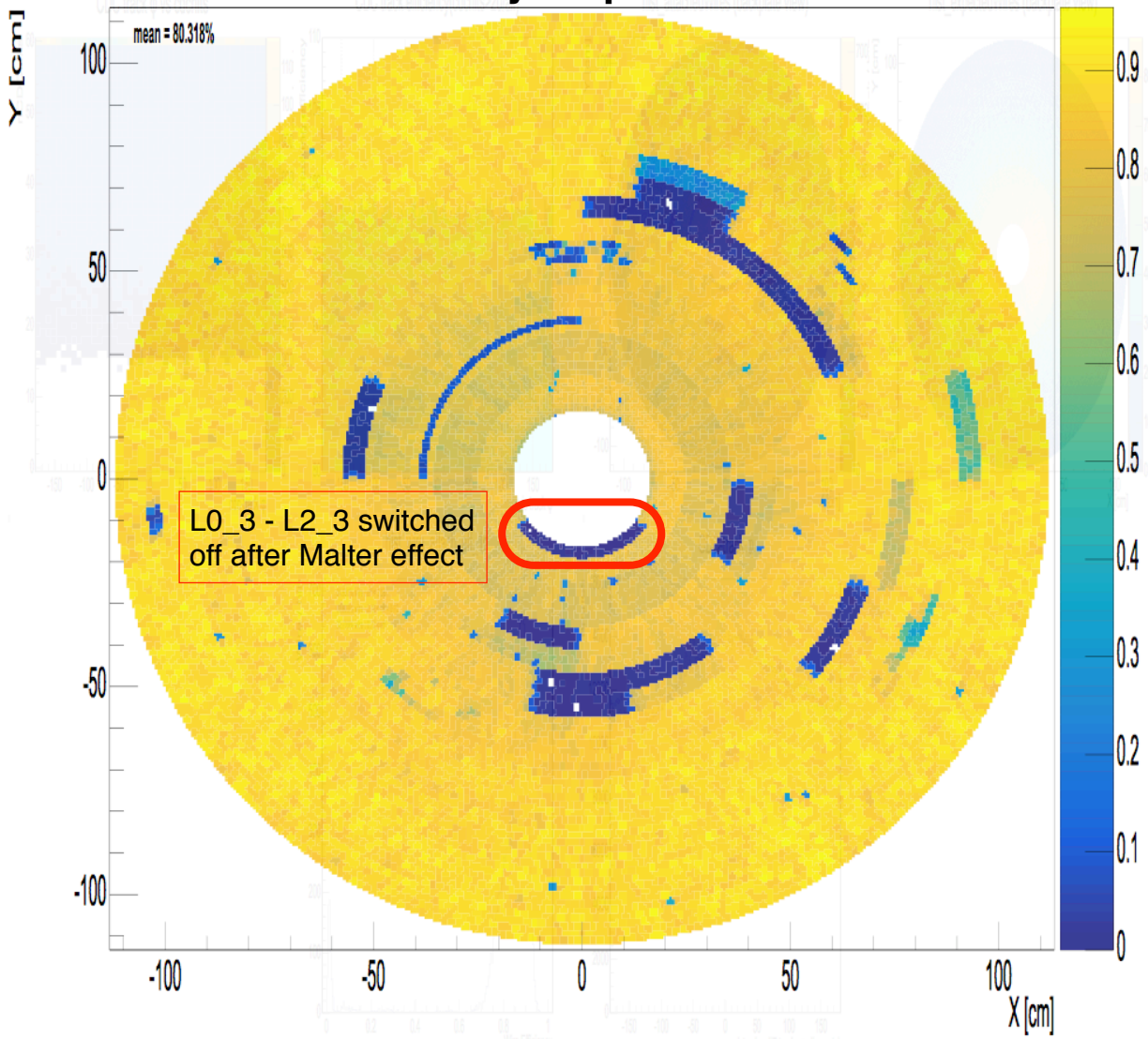
Wire Gains and online Hit Map when Malter Effect started

Wire Gains L0-L3 in exp33



Coincidence or deeper reason?

Online CDC hit efficiency map after Malter occurence

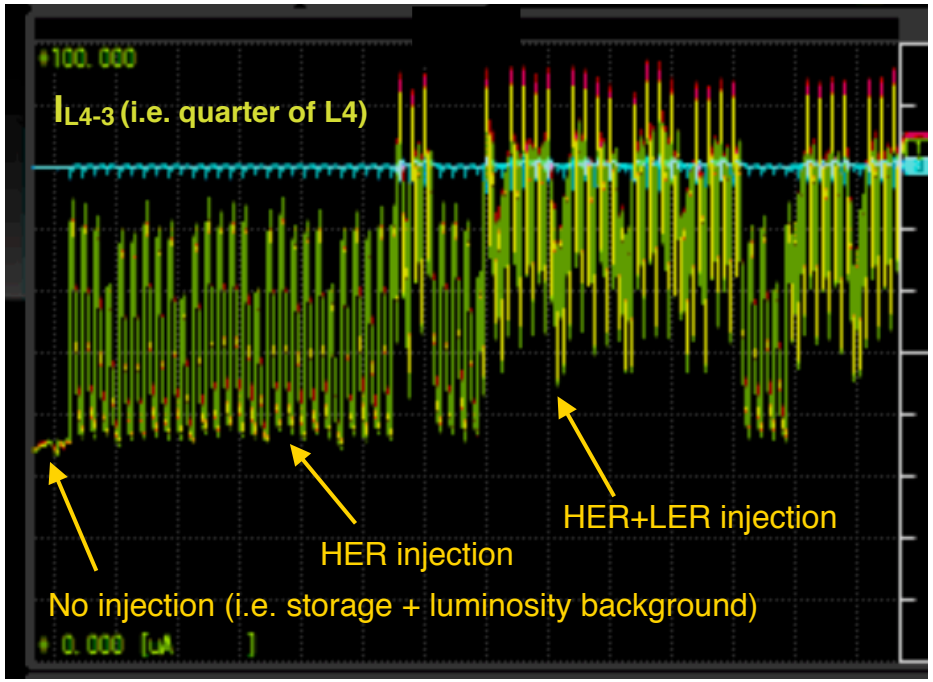


Most dead sectors due to problems with frontend electronics

Short-term Effect of Injection on CDC Gain

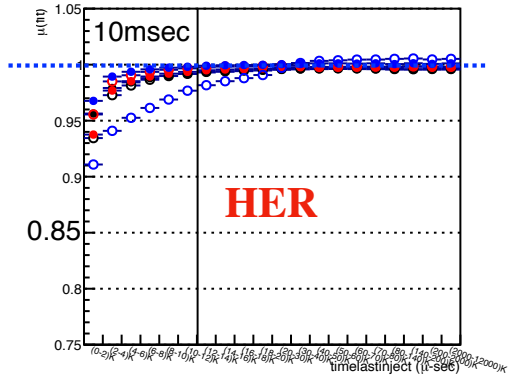
Worst conditions reached at the end of 2022b

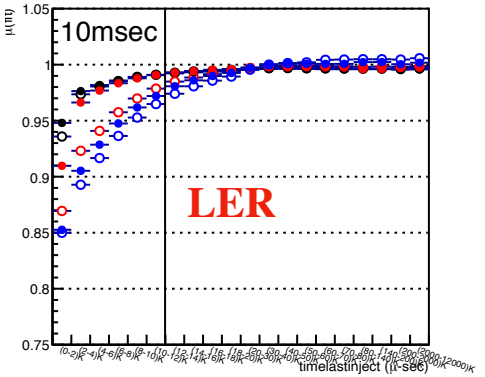
I_{HER} = 1035 mA, Q = 1.7 nC, rep rate = 25 Hz
I_{LER} = 1293 mA, Q = 2.0 nC, rep rate = 21 Hz
n_{bunch} = 2346, 2-bunch injection for both beams



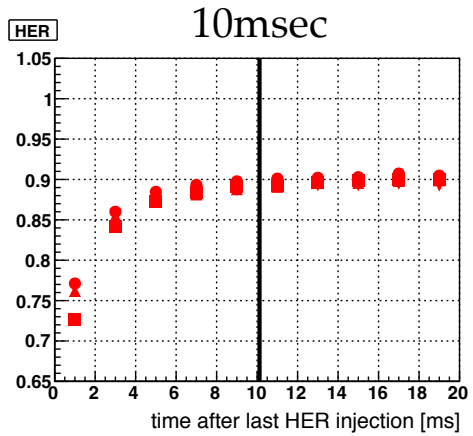
dE/dx vs time after last injection

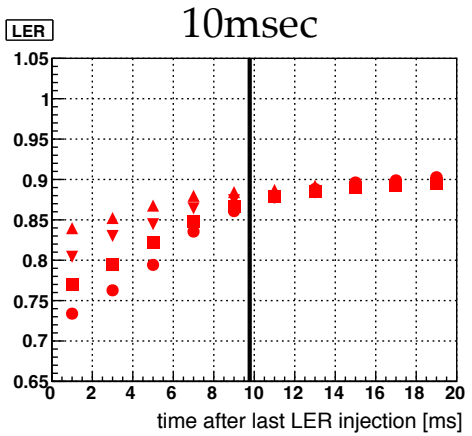
2022





2024





- Level of injection background varies greatly with time and injection parameters, e.g.
  - bunch charge; 1- or 2-bunch injection; repetition rate (so far limited to 25 Hz per beam); injection duty cycle
- Generally very similar time dependence before and after LS1
  - typically takes 10-20 ms to return to base level

- However, due to the reduced beam lifetime caused by the Touschek effect, to achieve the target beam currents, the bunch charge must be increased, the 2-bunch injection mode must be used consistently, and a high injection duty cycle is required
- Note: Doubling repetition rate to **2x50 Hz** being considered for LS2
  - $\Rightarrow \overline{\Delta t_{inj}}$ = 10 ms, i.e. will never operate in stable regime

Conclusions

- The 2024 run has taught us a lot about the operation of the CDC at higher beam backgrounds
  - but at the moment there are still a number of open questions
  - decided to use the beam-off time until autumn for dedicated cosmic ray studies

- With the expected future increase in beam background, it is important to anticipate how CDC performance will evolve in the coming years

- Must now develop strategies
  - on how to maintain an acceptable level of CDC performance up to LS2
  - for what detector modifications will be required to fully exploit the bulk of the Belle II data to be collected after LS2

- In parallel, efforts to understand and mitigate beam backgrounds must continue as a high priority
  - need to even intensify collaboration between Belle II and SuperKEKB

Backup

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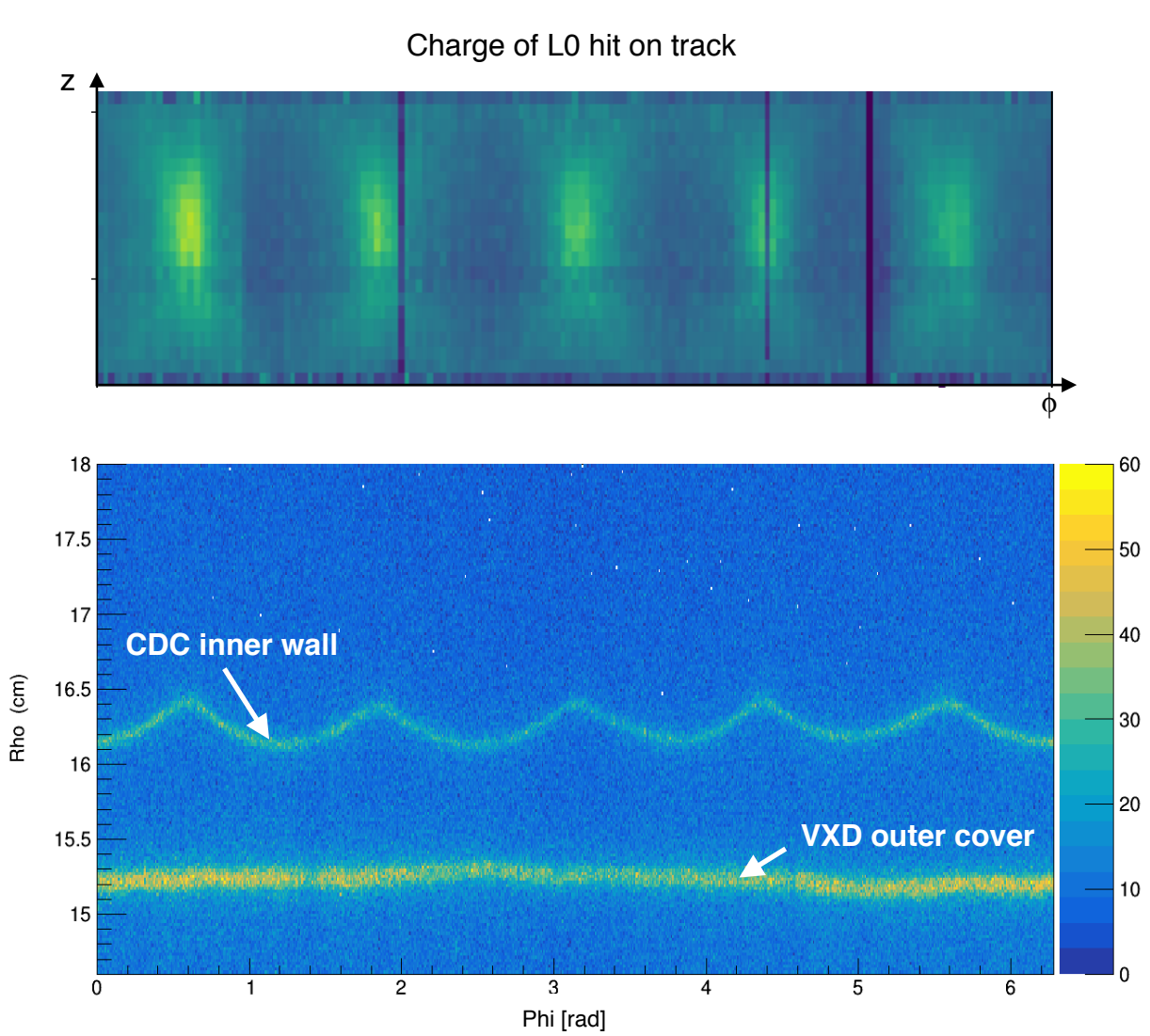
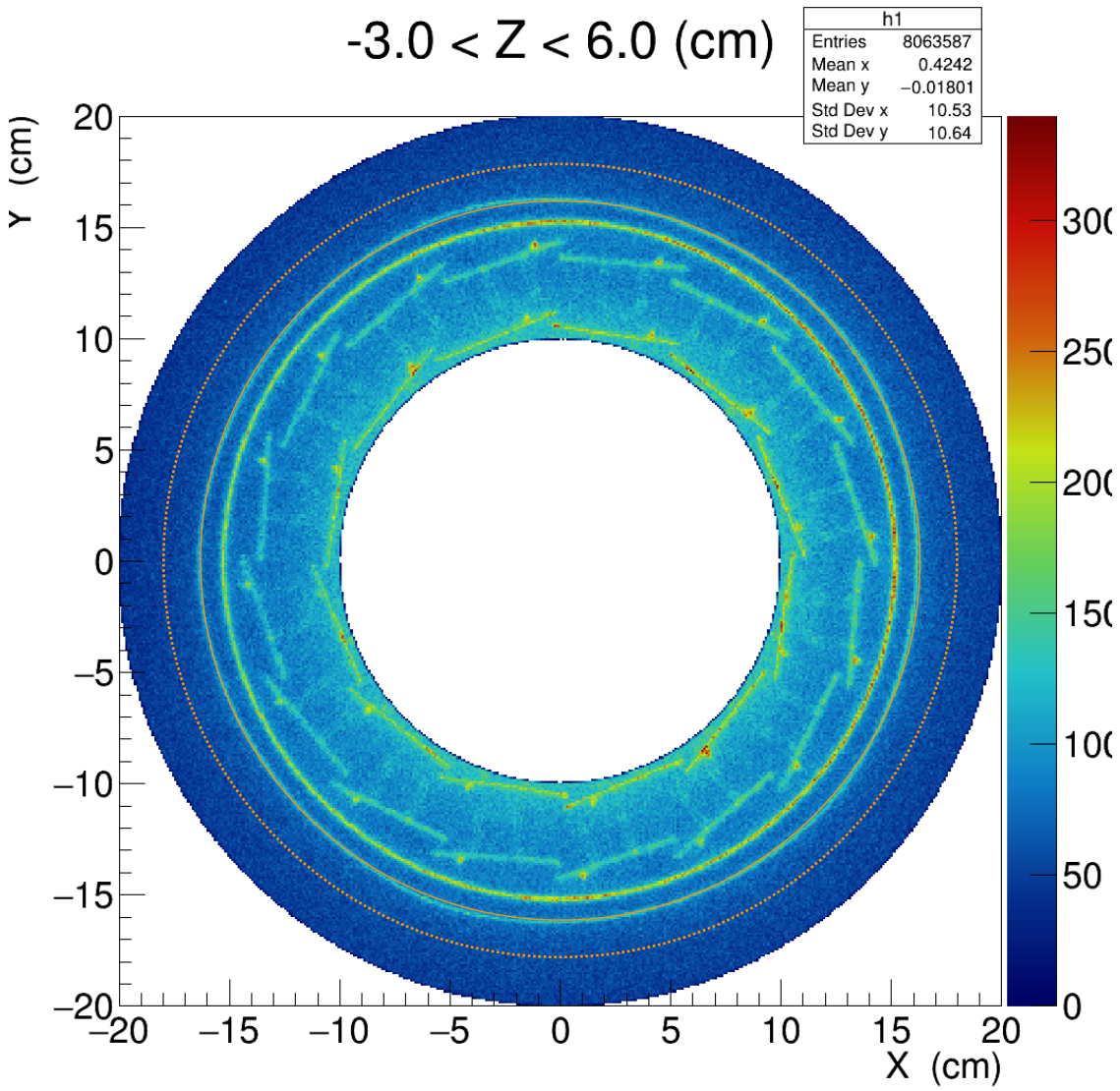
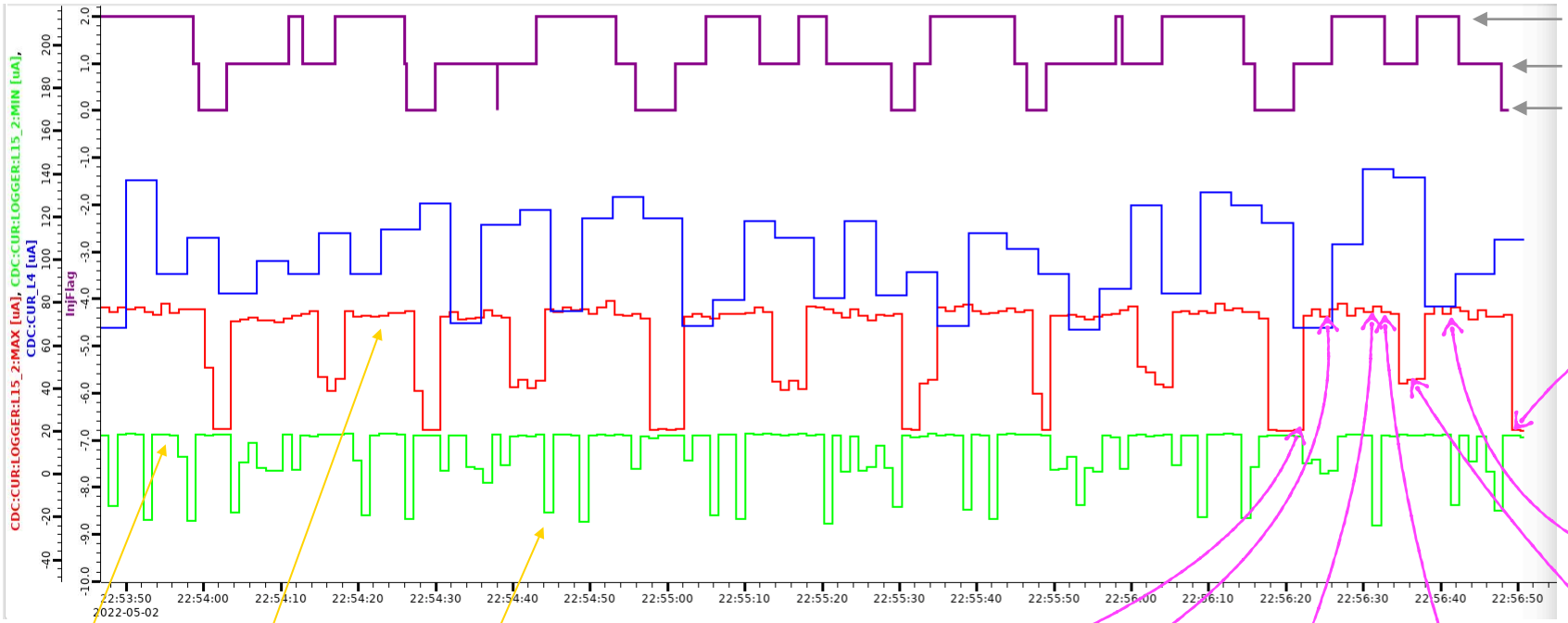
Nuclear Interaction Vertex Image of Region between CDC & VXD

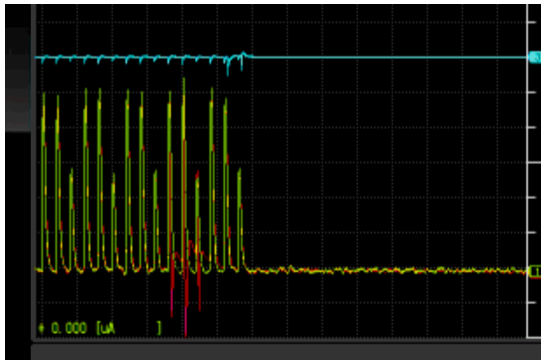


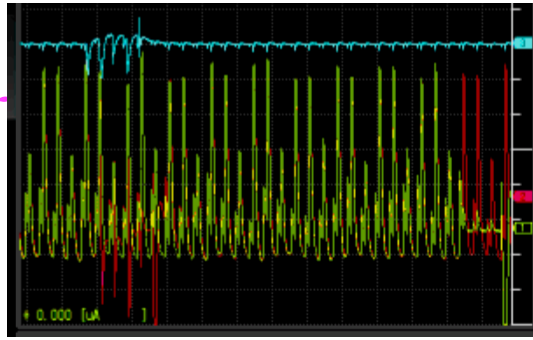


CDC inner wall (0.4mm CFRP) deformed due to accidental overpressure during CDC construction

Injection: Three Minutes of typical CDC Operation in May 2022







Min. current

Max. current

Neg. spikes