Available on CMS information server **CMS DP -2020/009**

CMS Performance Note

The content of this note is intended for CMS internal use and distribution only

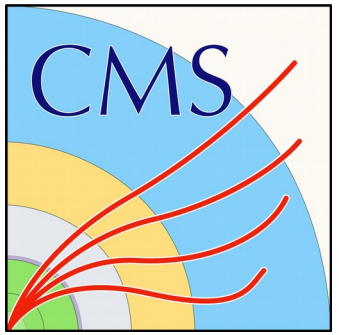
10 February 2020

Development of the CMS Phase-1 Pixel Online Monitoring System and the Distribution and Evolution of Temperatures and Sensor Leakage Currents

CMS Collaboration

Abstract

This Detector Performance Summary shows typical temperature readings and leakage current measurements in the CMS Phase-1 Pixel detector during proton-proton collisions as well as cosmic ray data taking. The impact of different CO_2 mass flows on the overall cooling performance is also presented.



Development of the CMS Phase-1 Pixel Online Monitoring System and the Evolution of Pixel Leakage Current

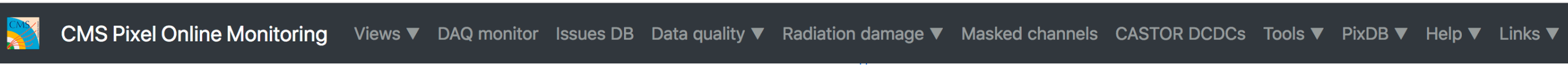
---

https://twiki.cern.ch/twiki/bin/view/CMSPublic/CMSPixelOperationPlots2018

cms-tracker-runcoord@cern.ch
cms-dpg-conveners-tracker@cern.ch

Pixel Online Monitoring

Motivation of Pixel Online Monitoring Development

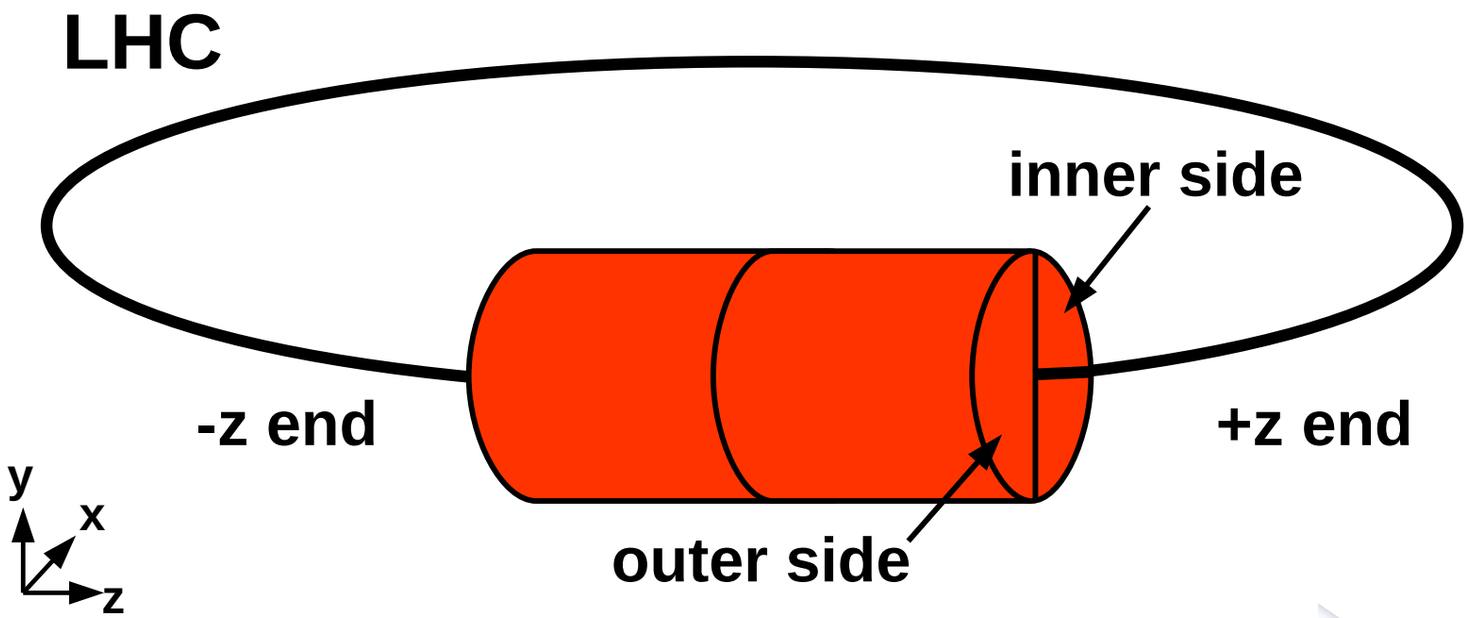


- **A webpage for visualizing and monitoring the following parameters online/offline for instance:**

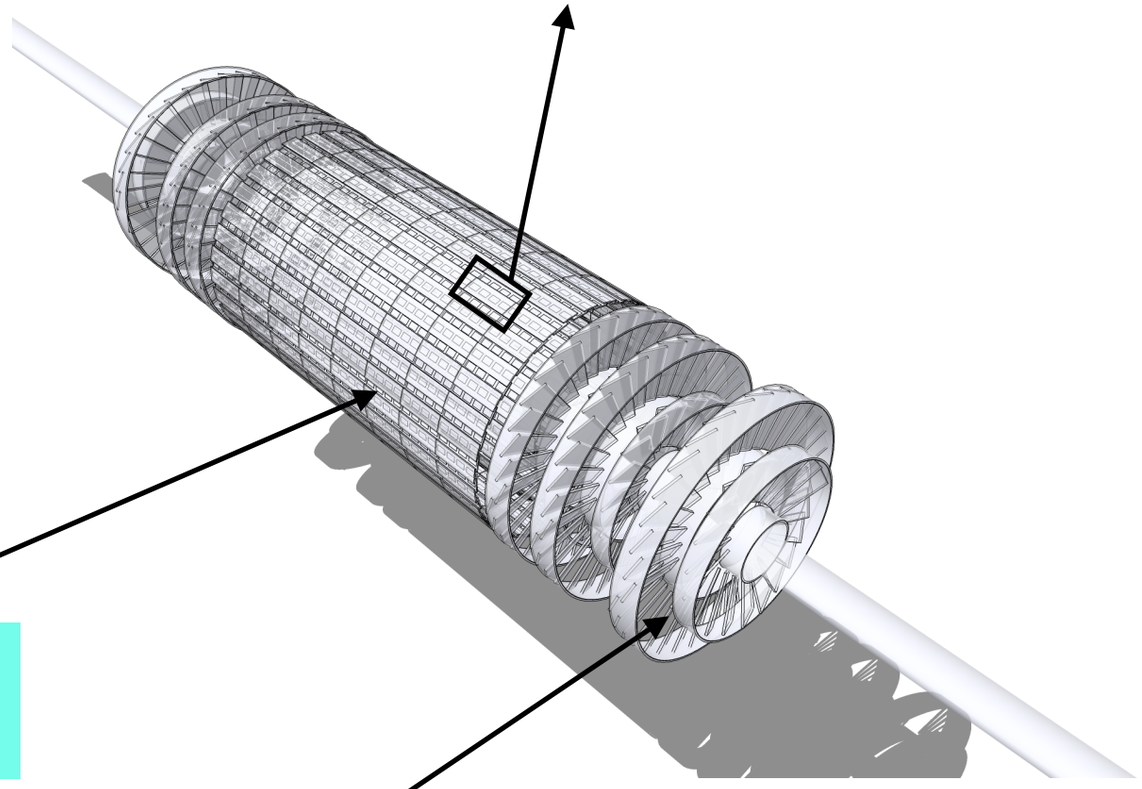
- Environment variables:
  - Dew point
  - Air pressure
  - Air temperature
  - Humidity
- Detector variables:
  - Power supply voltage
  - Current in power supply group
  - Module temperatures
  - Cooling flow status
- CMS Run variable property:
  - Instantaneous / integrated luminosity
  - Detector run status
  - Data acquisition status
  - Data quality monitoring

- **Function of online monitoring system:**
  - **Correlate these information to have an optimized analysis on the detector performance**
  - **Have a good navigation on the detector operation**

Pixel detector assignment



- In the LHC coordinates, pixel detector has four half cylinder, respectively at:
  - Inner side +z end (BpI)
  - Inner side -z end (BmI)
  - Outer side +z end (BpO)
  - Outer side -z end (BmO)

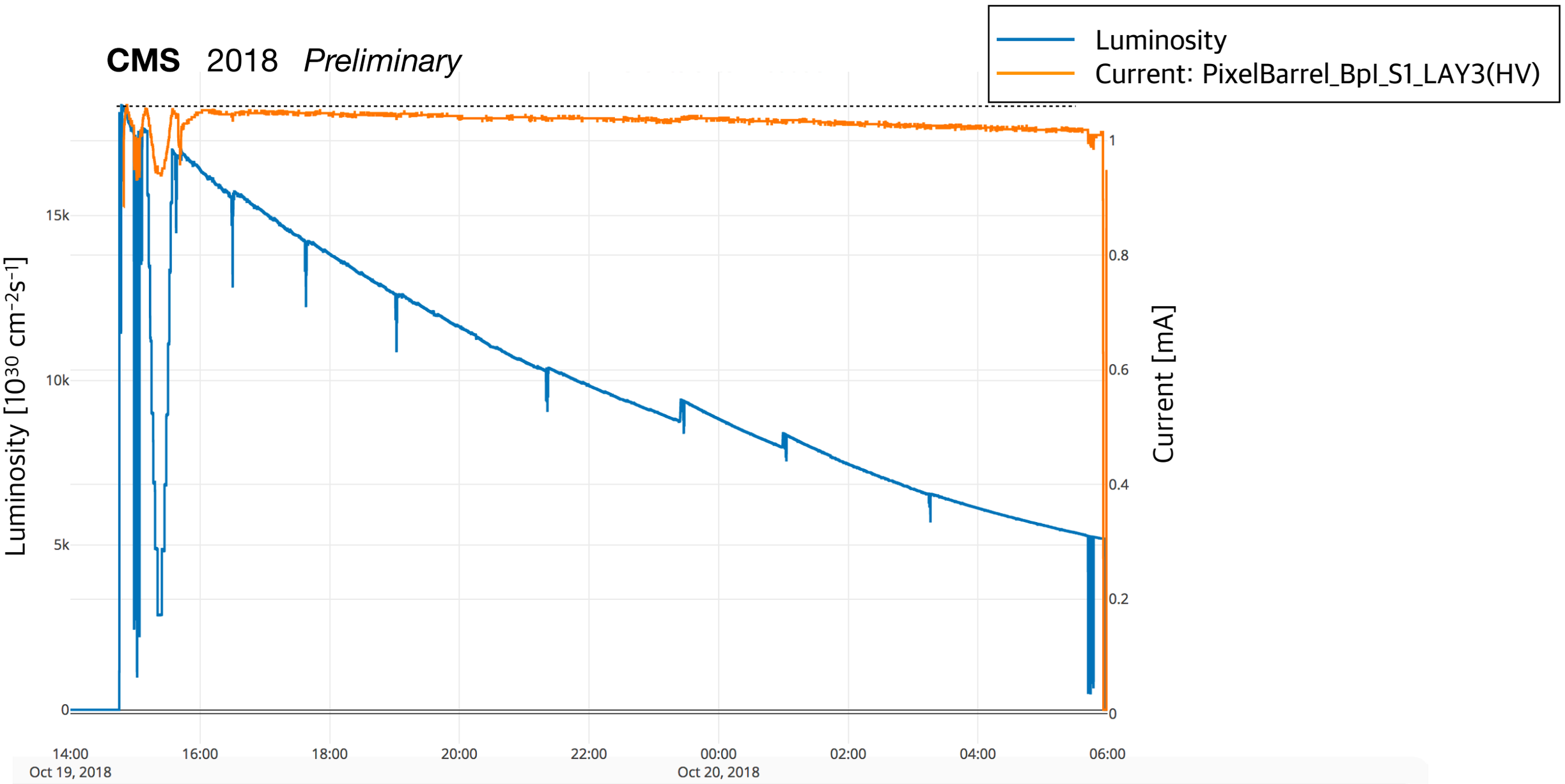


- In pixel barrel, each half cylinder has four concentric layers
- Different layers consist of different numbers of ladders

- In pixel endcap, each half cylinder has three disks
- Each disk has two concentric rings
- Different rings consist of different numbers of blades (modules in each blade panel)

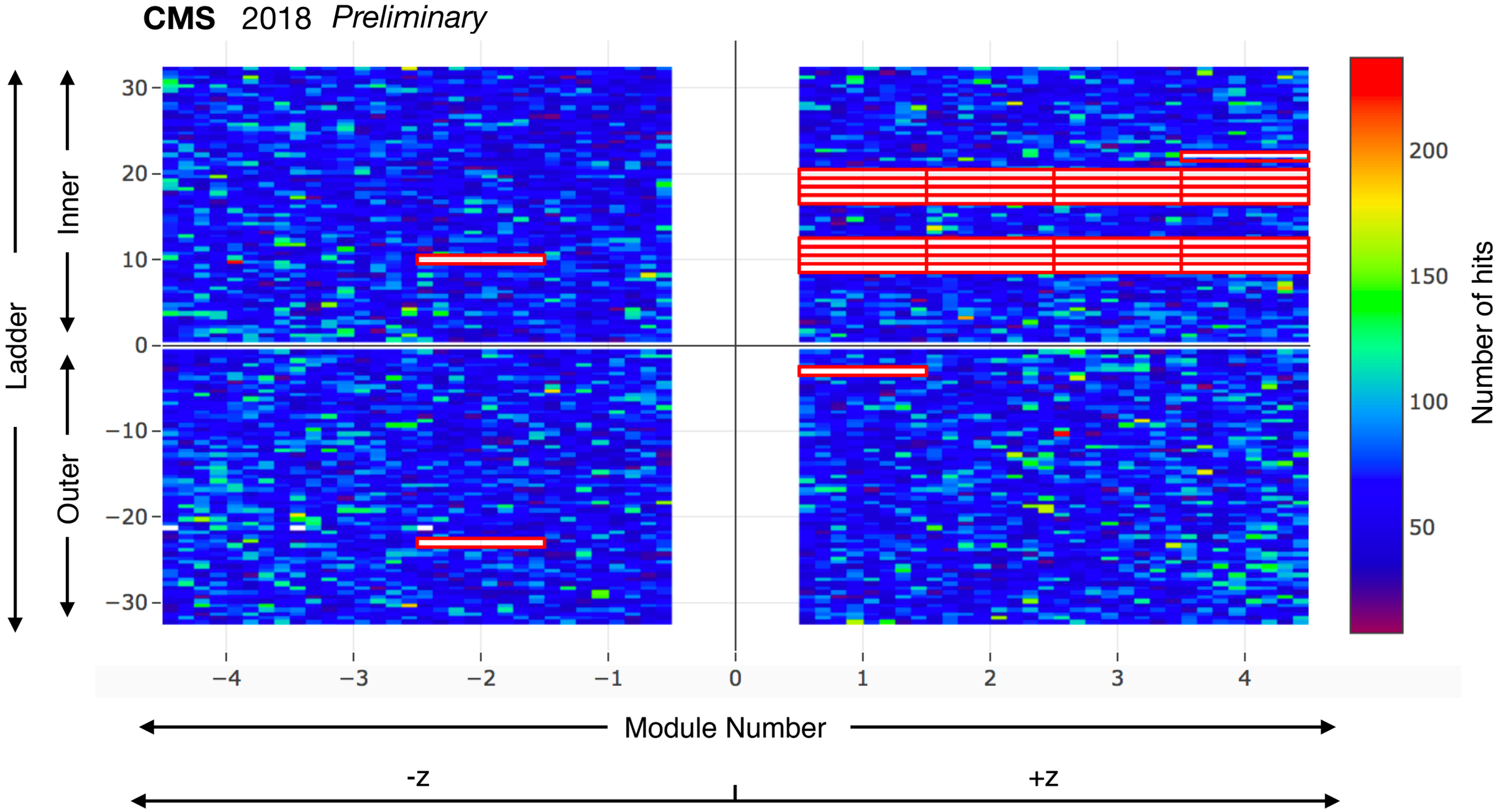
Correlation between high voltage current and instantaneous luminosity

- During a normal LHC fill 7320 (CMS Run 324968, CMS Run 324970) (2018.10.19 14:49 — 2018.11.20 05:58)
  - The trend of instantaneous luminosity & HV current of one sector in layer 3 of Pixel Barrel (sector 1 in +z inner)



- Emittance scan took place after the stable beam of p-p collision established , which leaded to some fluctuations of luminosity and leakage current
- At the end of the fill, pixel HV went off (STANDBY mode)
- The HV current (leakage current) was dropping through the decreasing instantaneous luminosity

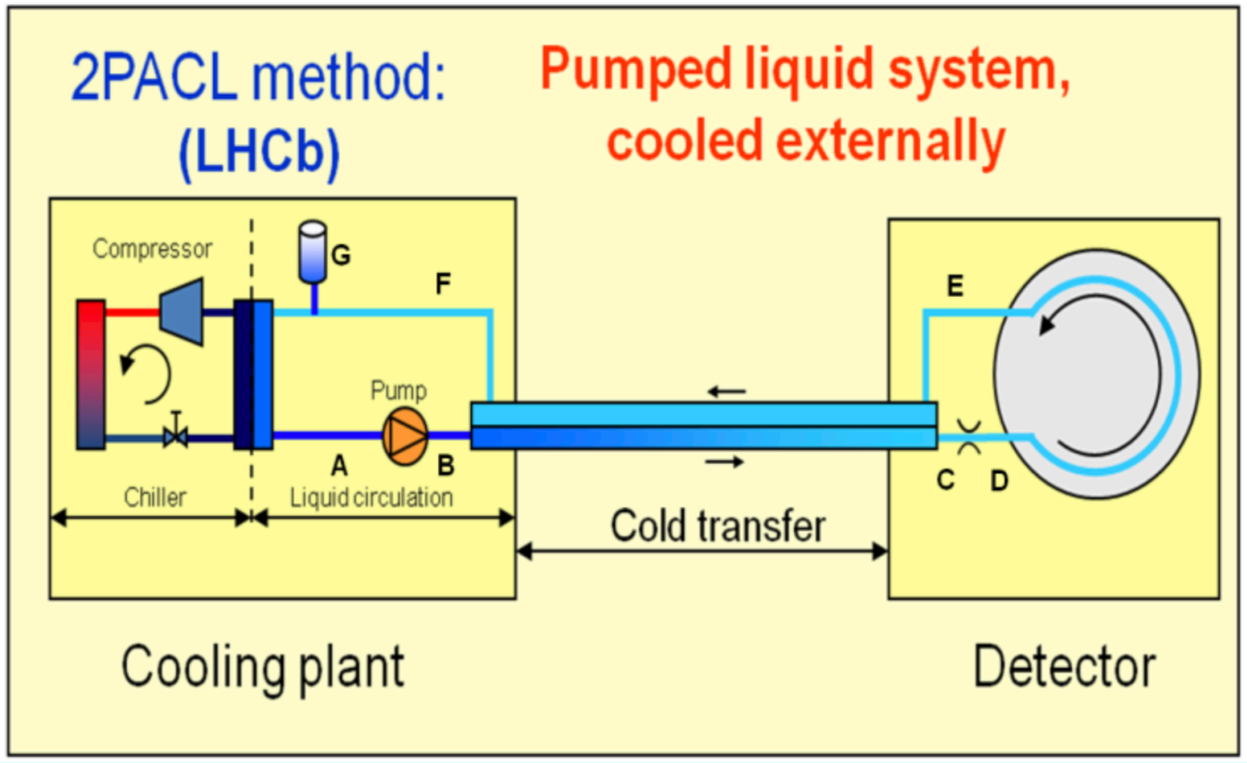
Pixel digital occupancy

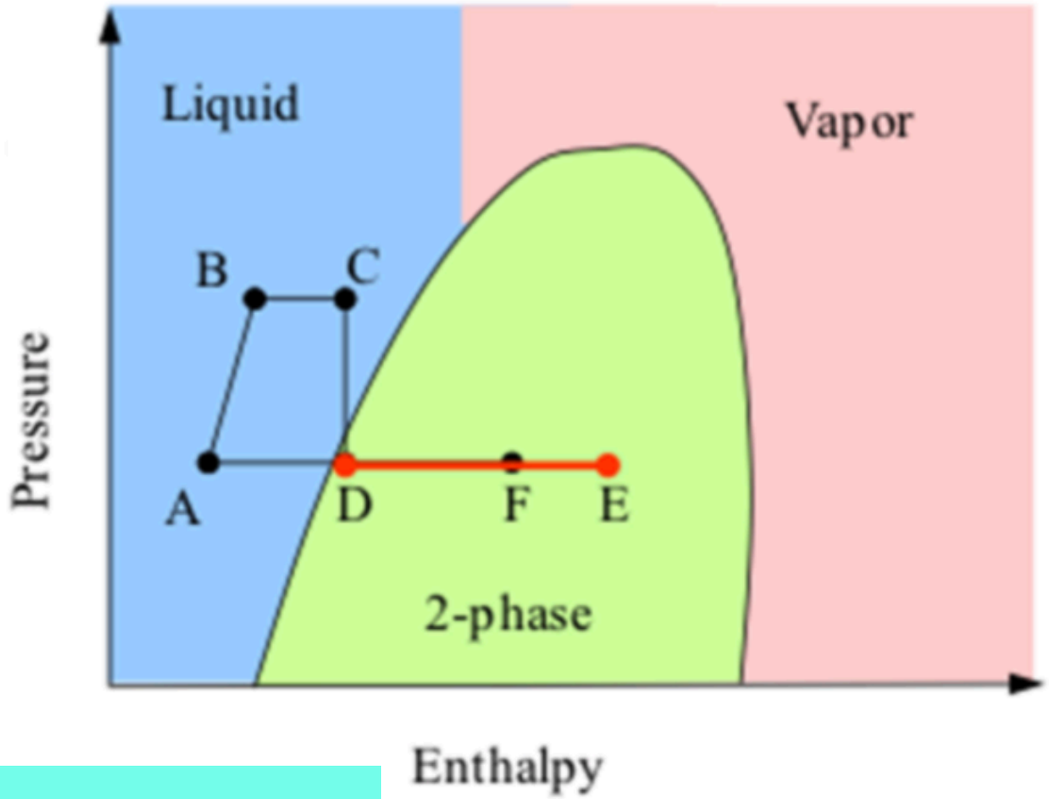


- This plot shows the digital occupancy of pixel layer 4 during CMS Run Number 322013 (2018.08.31)
- Four half cylinders, each cylinder has 32 ladders, and each ladder has 4 modules, and each module has 8 readout chips
- In the plot, one bin corresponds to one readout chip (ROC)
- Every red marked rectangle represent a region recorded with **entries in database of known problems (keep track)**

Pixel Barrel cooling loops & temperature distribution

Pixel detector cooling loop schematics & flow

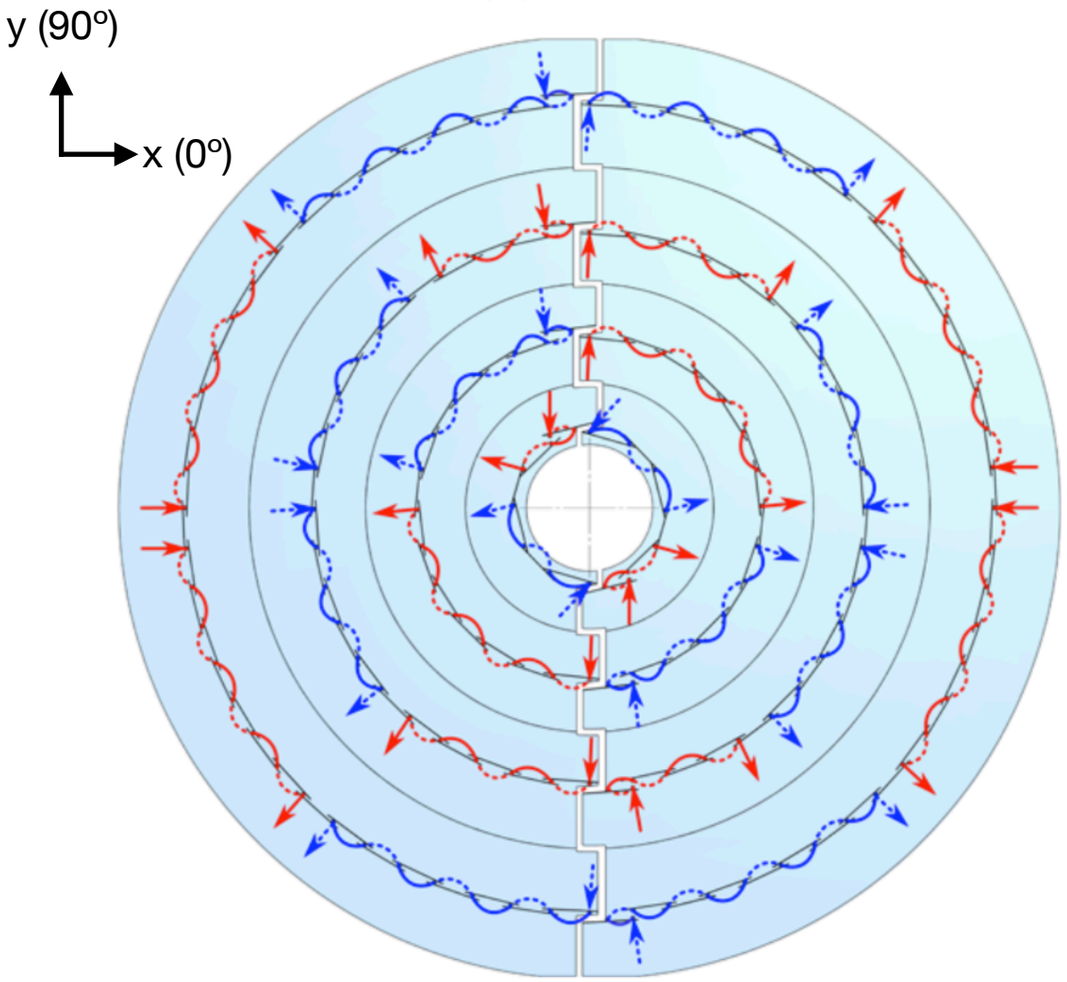




- 2-phase accumulator controller (2PACL):
  - Point A: CO_2 flow is cooled by the chiller and liquified
  - Point B: CO_2 liquid pressure is increased by a pump
  - Point B ~ C: CO_2 liquid is heated up by a thermal contact with the returning vapor mixture
  - Point C ~ D: CO_2 flow is distributed to evaporator capillaries to decrease the pressure
  - Point D: CO_2 flow reaches the 2-phase state at **inlet** of the detector
  - Point D ~ E: CO_2 evaporates gradually (absorbing heat in the detector)
    - CO_2 cooling becomes more efficient
    - CO_2 temperature drops
  - Point E: CO_2 flow returns to the cooling plant from **outlet**
  - Point E ~ F: CO_2 liquid/vapor mixture are transferred back to the cooling plant
  - Point G: CO_2 liquid/vapor are sent into a accumulator vessel

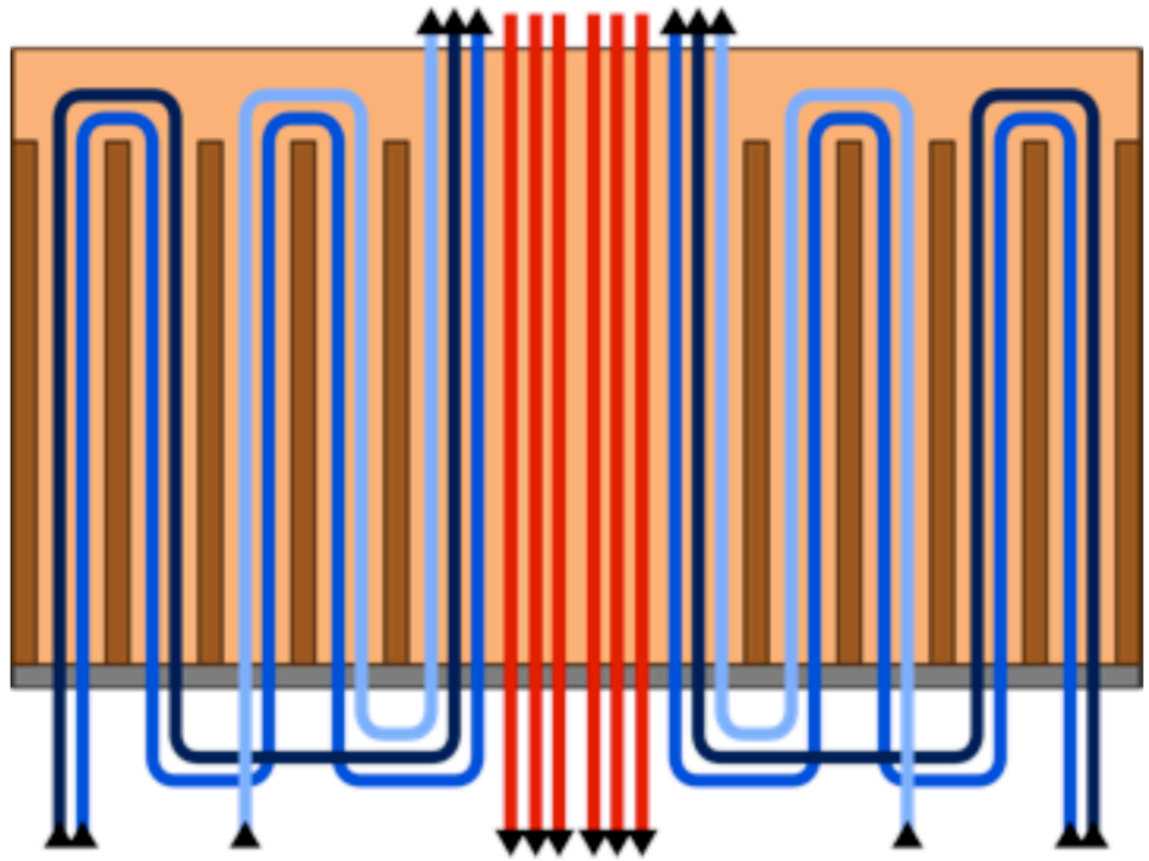
Pixel barrel cooling loop schematics & flow

x-y plane section



View along z on the supply line

(Pre-heating of pixel detector)

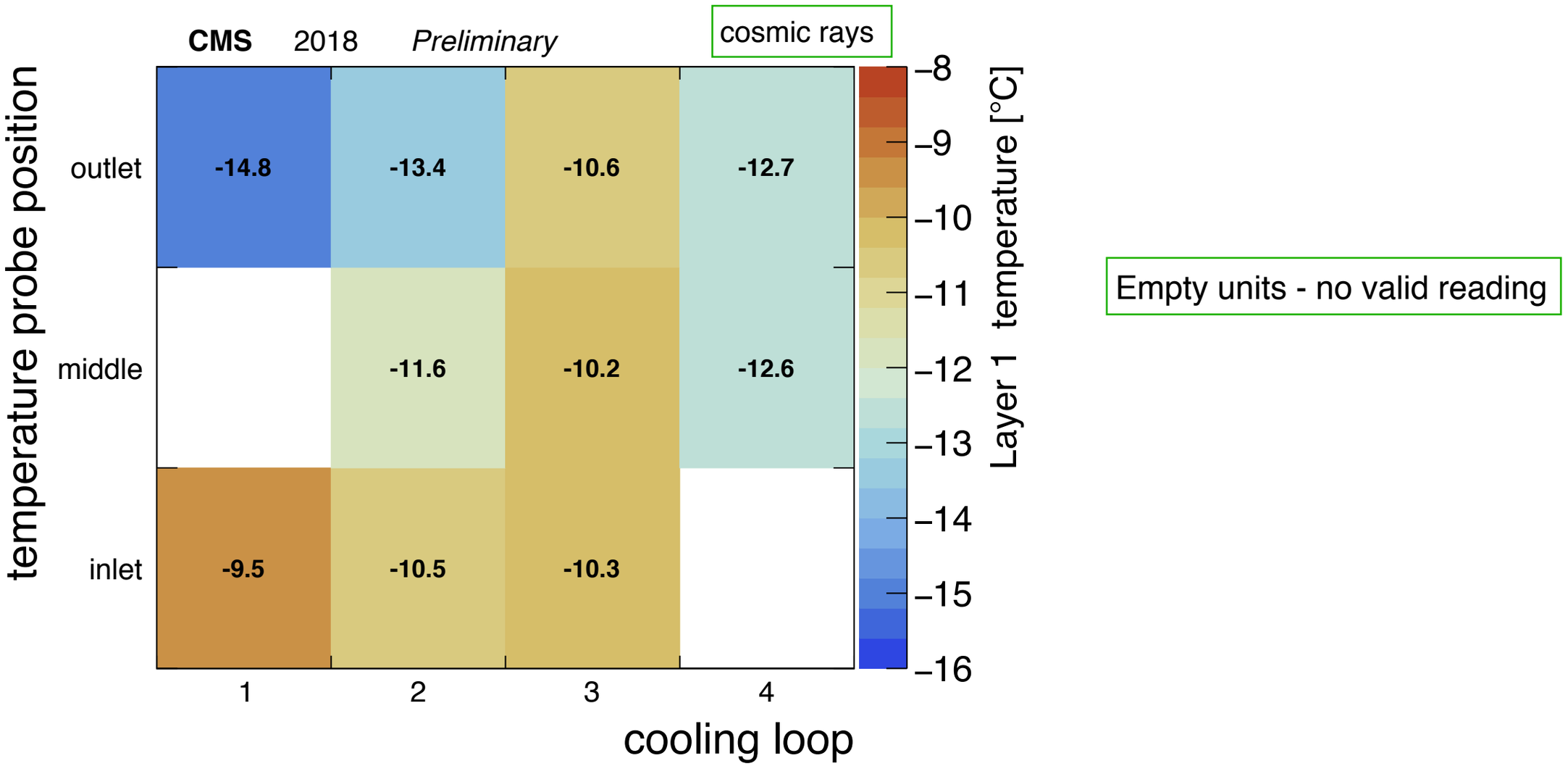


- Each loop cools down the full barrel length over a given azimuthal (ϕ) range
- Inlet and outlet of each loop are located in the same z-end
- Arrows: direction of CO_2 flows
- **Note**: Inlet arrow and outlet arrow of two loops in layer 3 are respectively swapped
  - Loop covering 90º~135º
  - Loop covering 270º~315º

- Light blue/blue/dark blue lines: inlet (enter) cooling flow pipes
- Red lines: outlet (return) cooling flow pipes
- Arrows: direction of CO_2 flows

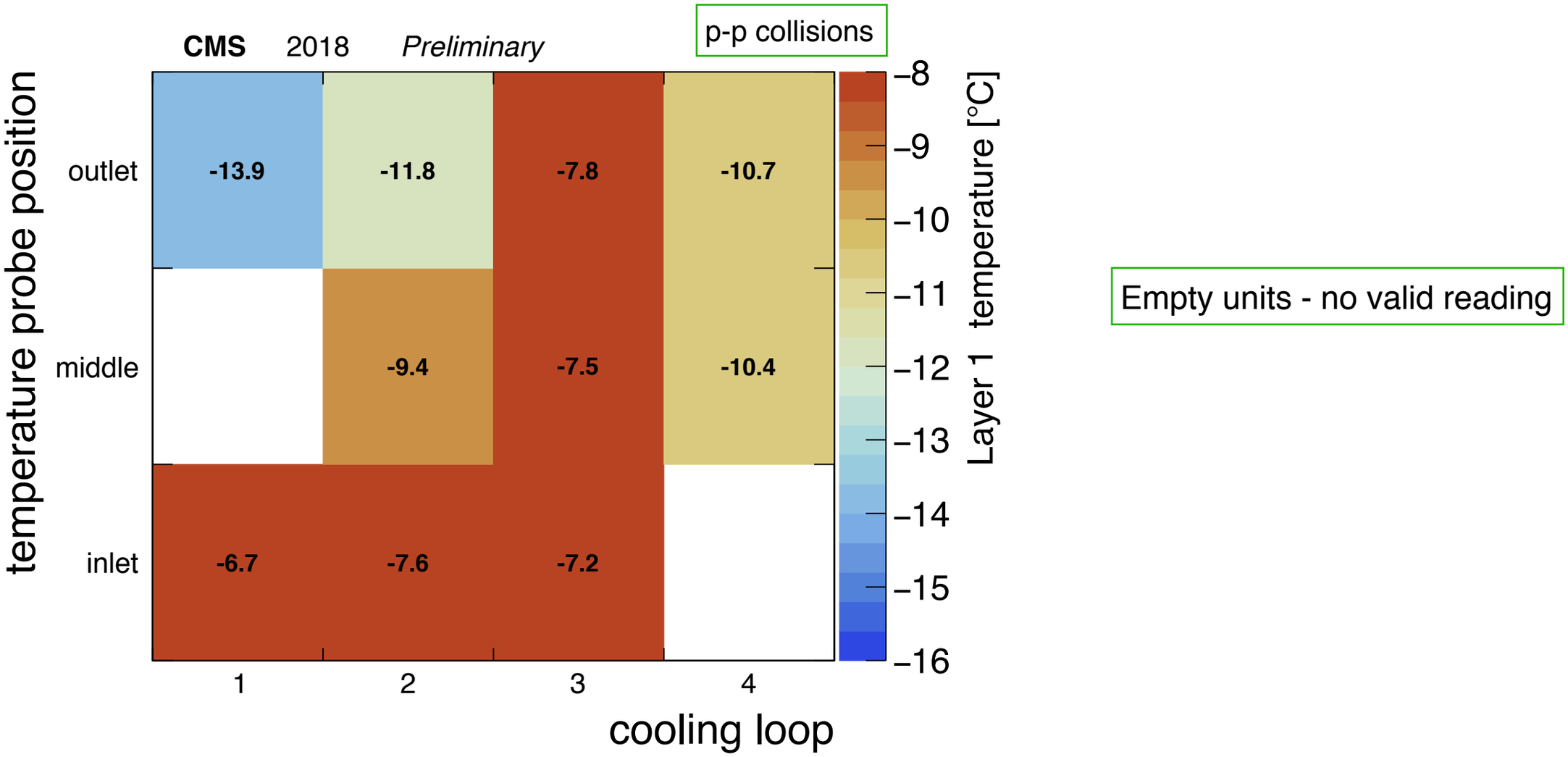
Average temperature accuracy:
± 0.5 degree celsius

Pixel barrel temperature gradient along each cooling loop (layer 1)



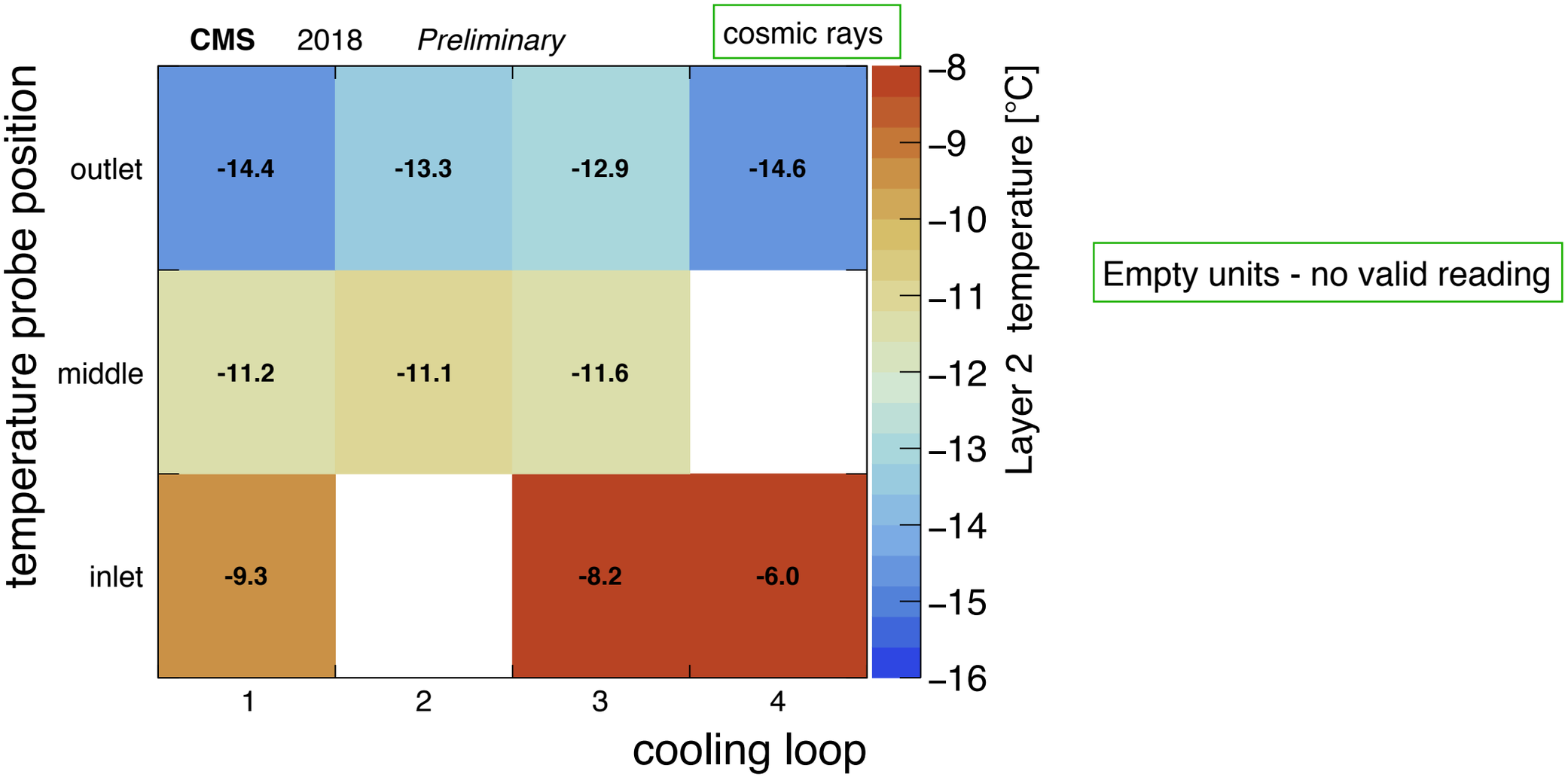
- Each cooling loop has three temperature probes, which are located respectively at the beginning (inlet), middle, end (outlet) positions
- These groups of temperature were obtained during CMS Run Number 320448 (Cosmic run on Jul.28)
- It shows the gradient of the temperature along each cooling loop of Pixel Barrel layer 1 (totally 4 cooling loops)
- As expected for CO_2 cooling, the temperature at the outlet is lower than at the inlet

Pixel barrel temperature gradient along each cooling loop (layer 1)



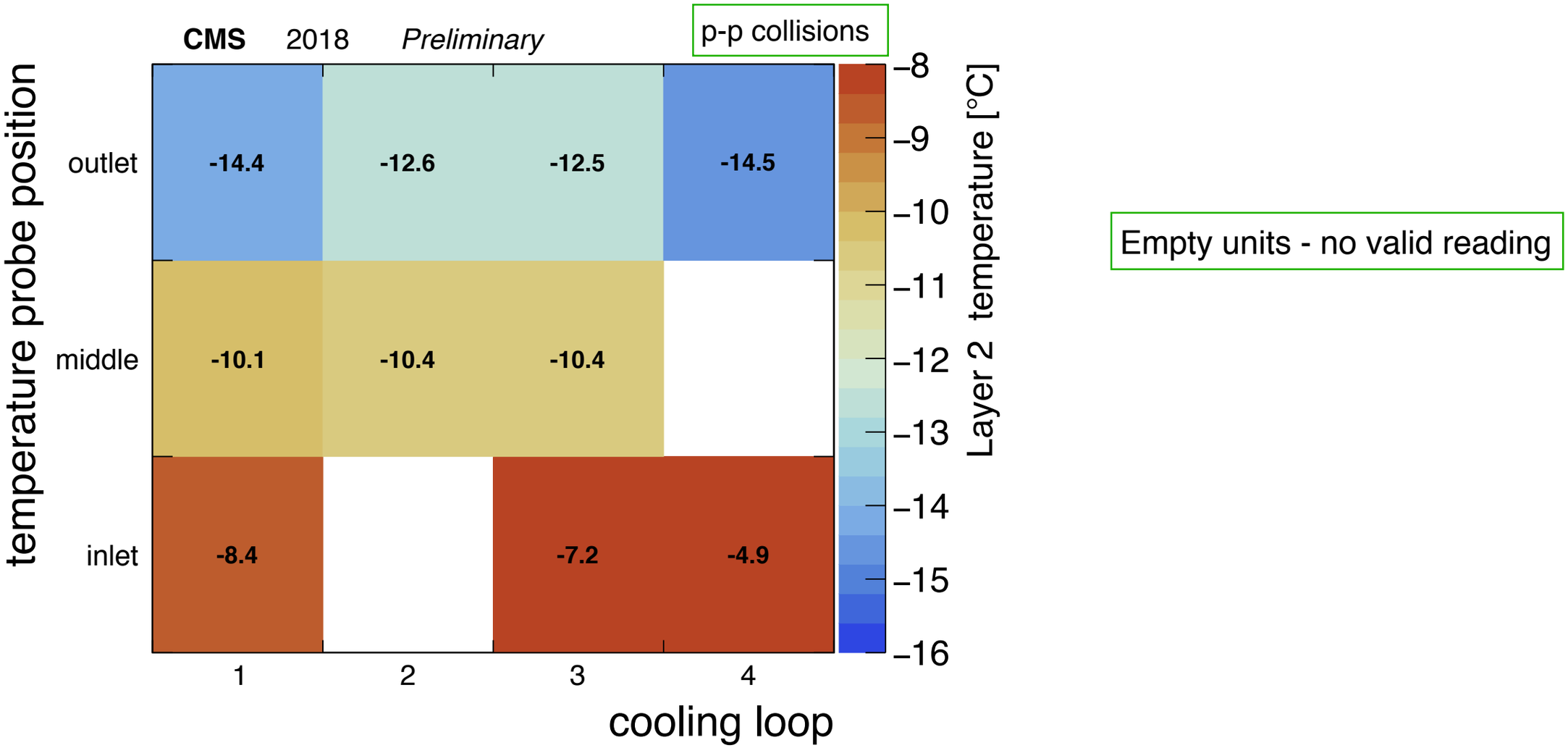
- Each cooling loop has three temperature probes, which are located respectively at the beginning (inlet), middle, end (outlet) positions
- These groups of temperature were obtained during CMS Run Number 322625 (stable beam run on Sep.10)
- It shows the gradient of the temperature along each cooling loop of Pixel Barrel layer 1 (totally 4 cooling loops)
- As expected for CO_2 cooling, the temperature at the outlet is lower than at the inlet

Pixel barrel temperature gradient along each cooling loop (layer 2)



- Each cooling loop has three temperature probes, which are located respectively at the beginning (inlet), middle, end (outlet) positions
- These groups of temperature were obtained during CMS Run Number 320448 (Cosmic run on Jul.28)
- It shows the gradient of the temperature along each cooling loop of Pixel Barrel layer 2 (totally 4 cooling loops)
- As expected for CO_2 cooling, the temperature at the outlet is lower than at the inlet

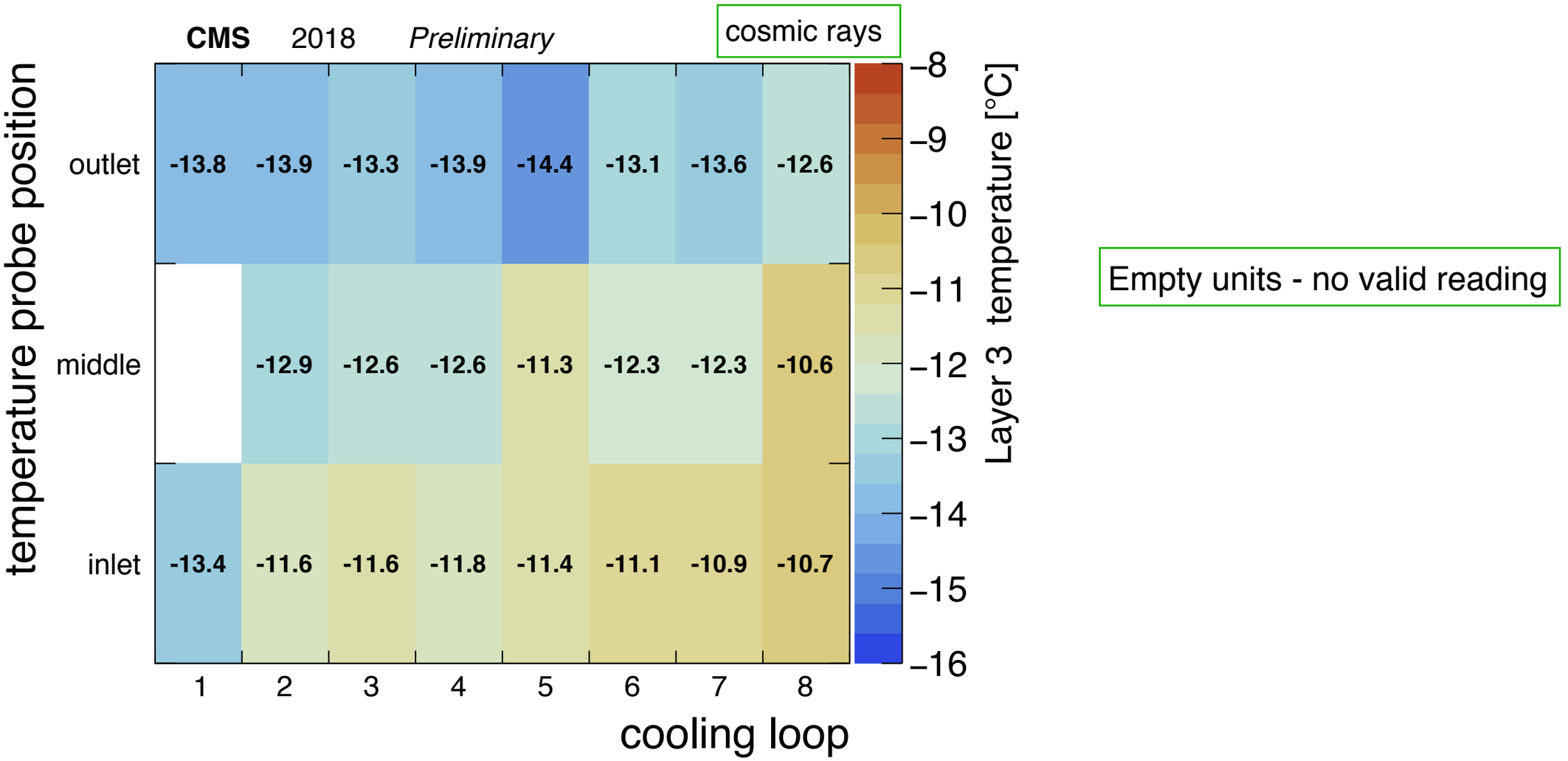
Pixel barrel temperature gradient along each cooling loop (layer 2)



Empty units - no valid reading

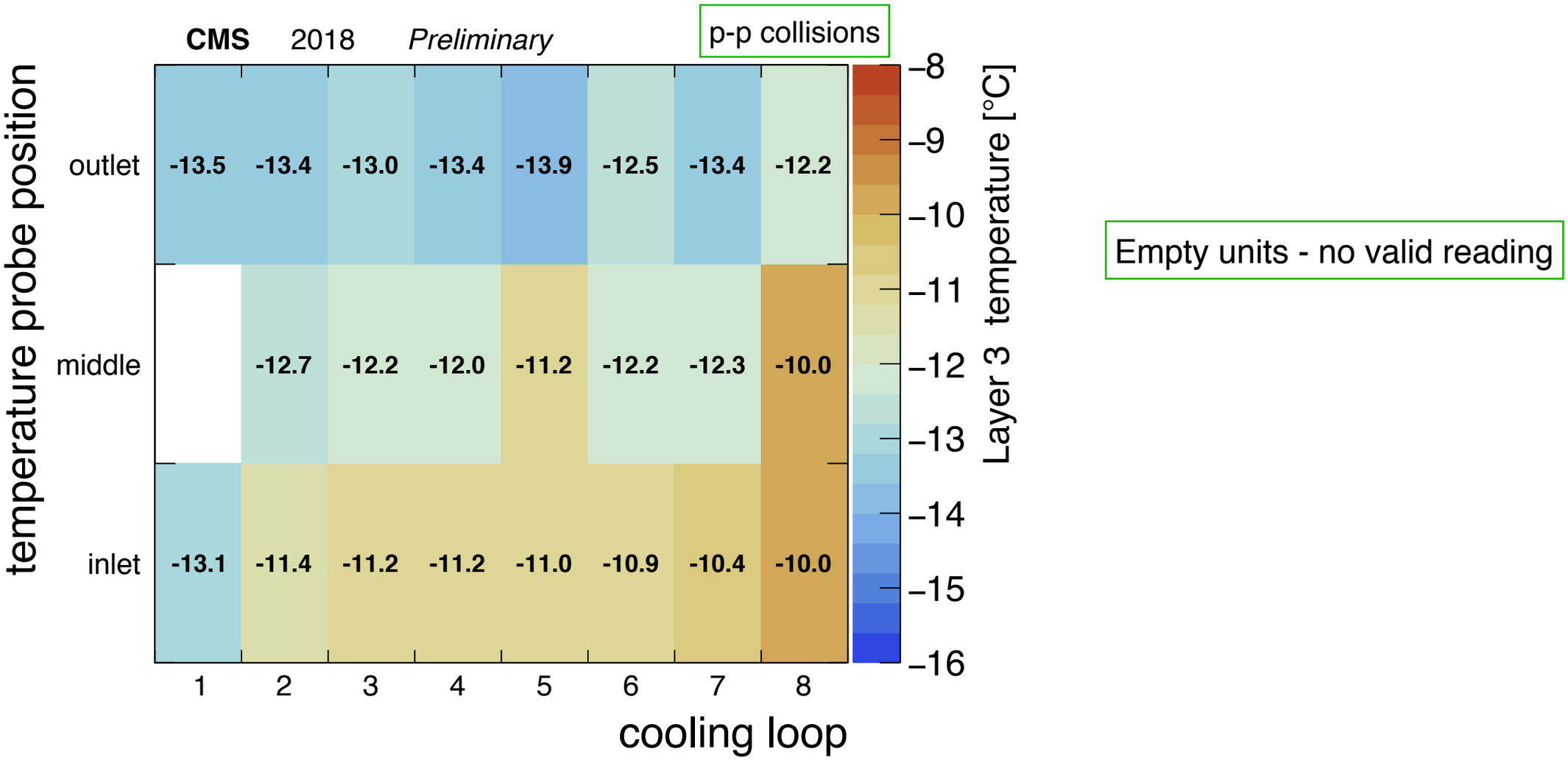
- Each cooling loop has three temperature probes, which are located respectively at the beginning (inlet), middle, end (outlet) positions
- These groups of temperature were obtained during CMS Run Number 322625 (stable beam run on Sep.10)
- It shows the gradient of the temperature along each cooling loop of Pixel Barrel layer 2 (totally 4 cooling loops)
- As expected for CO_2 cooling, the temperature at the outlet is lower than at the inlet

Pixel barrel temperature gradient along each cooling loop (layer 3)



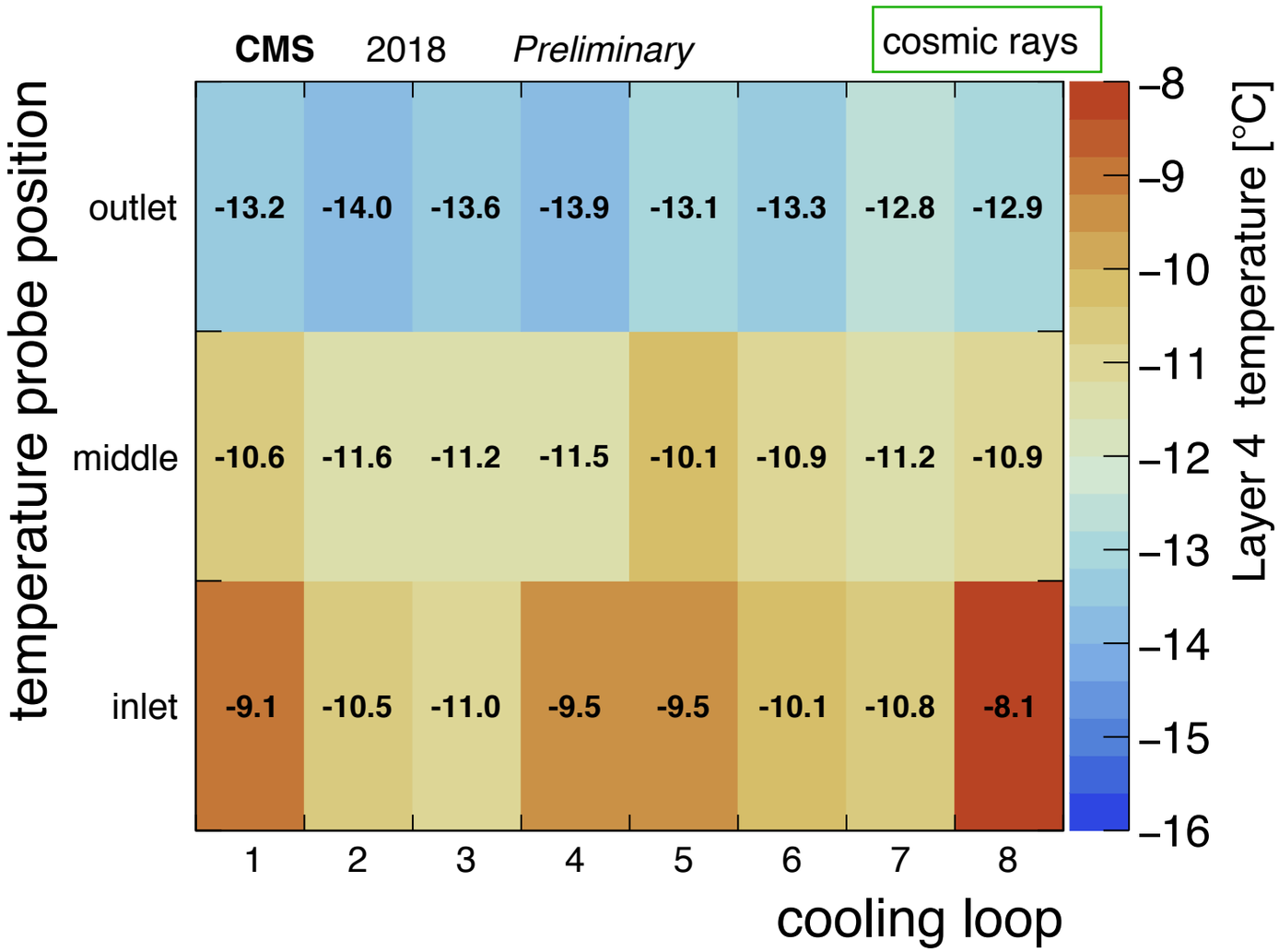
- Each cooling loop has three temperature probes, which are located respectively at the beginning (inlet), middle, end (outlet) positions
- These groups of temperature were obtained during CMS Run Number 320448 (Cosmic run on Jul.28)
- It shows the gradient of the temperature along each cooling loop of Pixel Barrel layer 3 (totally 8 cooling loops)
- As expected for CO_2 cooling, the temperature at the outlet is lower than at the inlet

Pixel barrel temperature gradient along each cooling loop (layer 3)



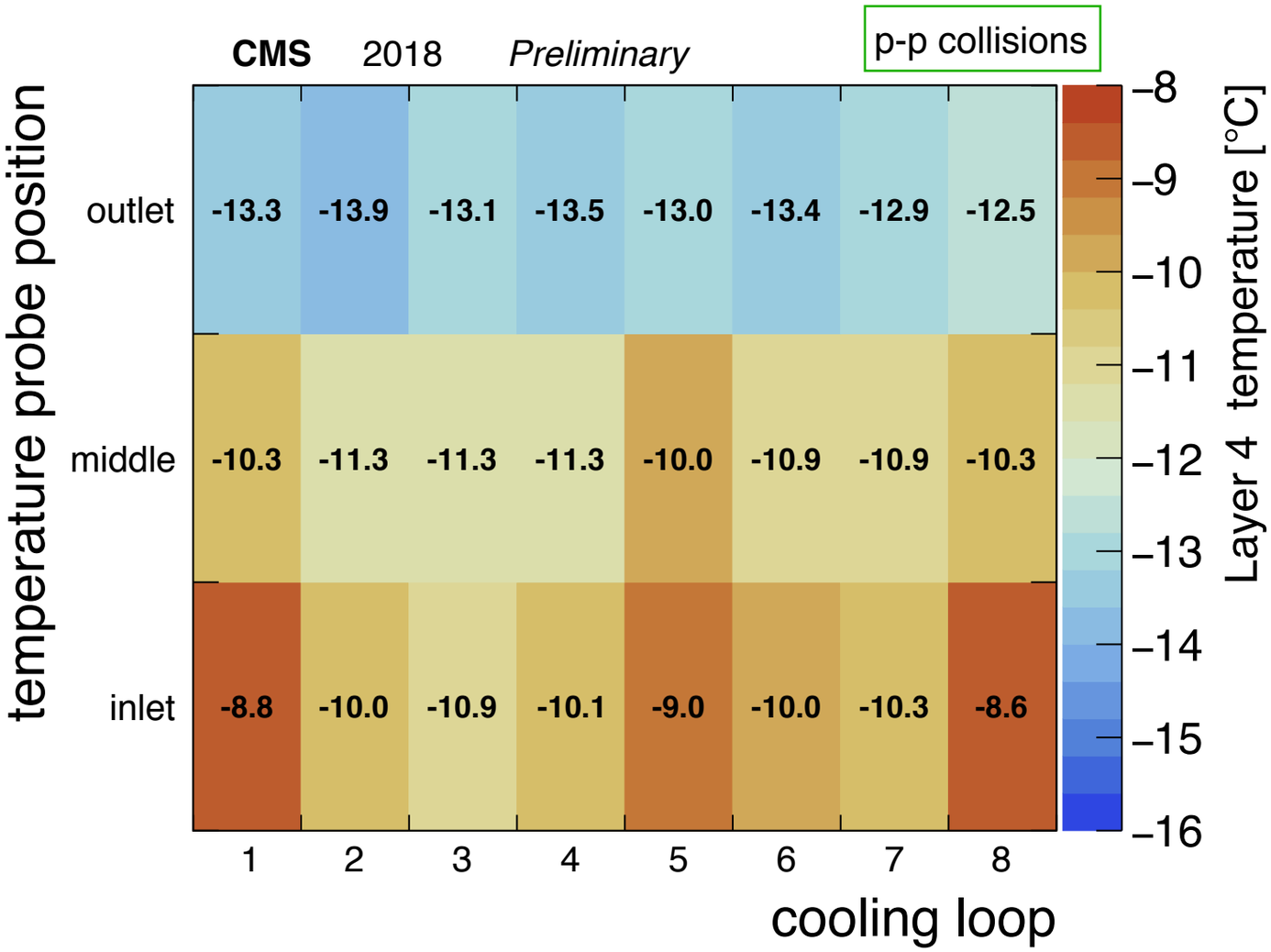
- Each cooling loop has three temperature probes, which are located respectively at the beginning (inlet), middle, end (outlet) positions
- These groups of temperature were obtained during CMS Run Number 322625 (stable beam run on Sep.10)
- It shows the gradient of the temperature along each cooling loop of Pixel Barrel layer 3 (totally 8 cooling loops)
- As expected for CO_2 cooling, the temperature at the outlet is lower than at the inlet

Pixel barrel temperature gradient along each cooling loop (layer 4)



- Each cooling loop has three temperature probes, which are located respectively at the beginning (inlet), middle, end (outlet) positions
- These groups of temperature were obtained during CMS Run Number 320448 (Cosmic run on Jul.28)
- It shows the gradient of the temperature along each cooling loop of Pixel Barrel layer 4 (totally 8 cooling loops)
- As expected for CO_2 cooling, the temperature at the outlet is lower than at the inlet

Pixel barrel temperature gradient along each cooling loop (layer 4)



- Each cooling loop has three temperature probes, which are located respectively at the beginning (inlet), middle, end (outlet) positions
- These groups of temperature were obtained during CMS Run Number 322625 (stable beam run on Sep.10)
- It shows the gradient of the temperature along each cooling loop of Pixel Barrel layer 4 (totally 8 cooling loops)
- As expected for CO_2 cooling, the temperature at the outlet is lower than at the inlet

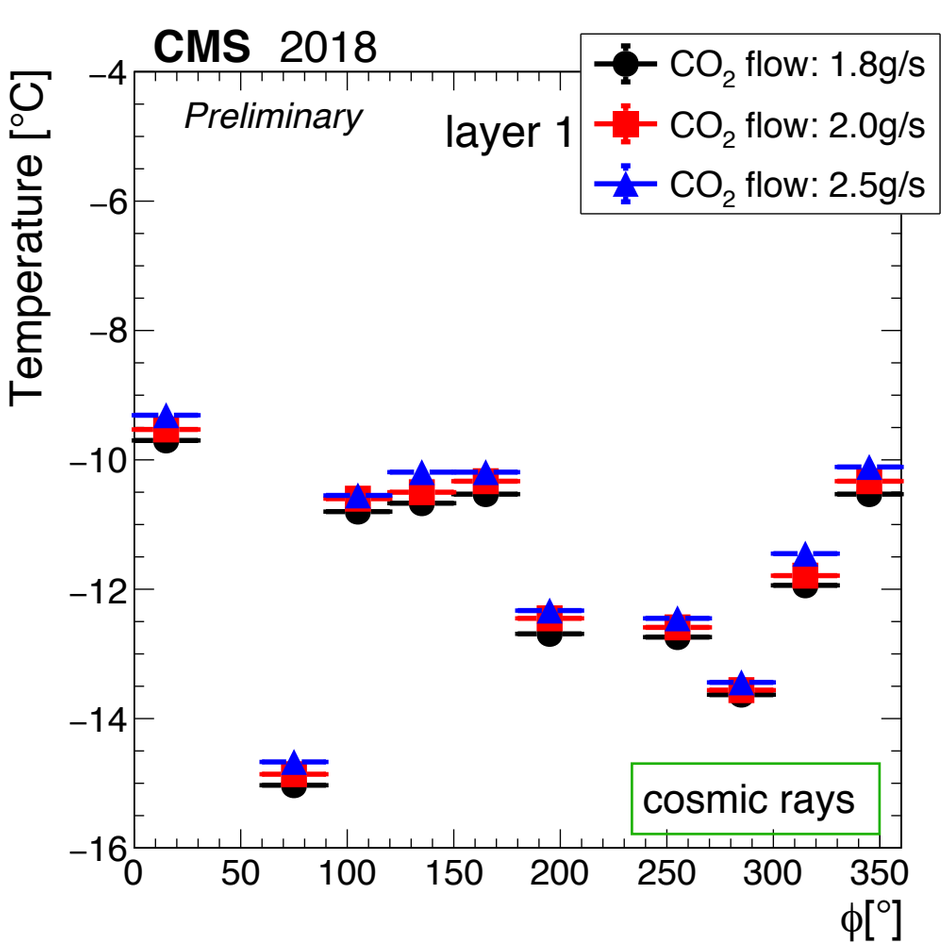
Pixel barrel temperature w.r.t different CO_2 mass flow

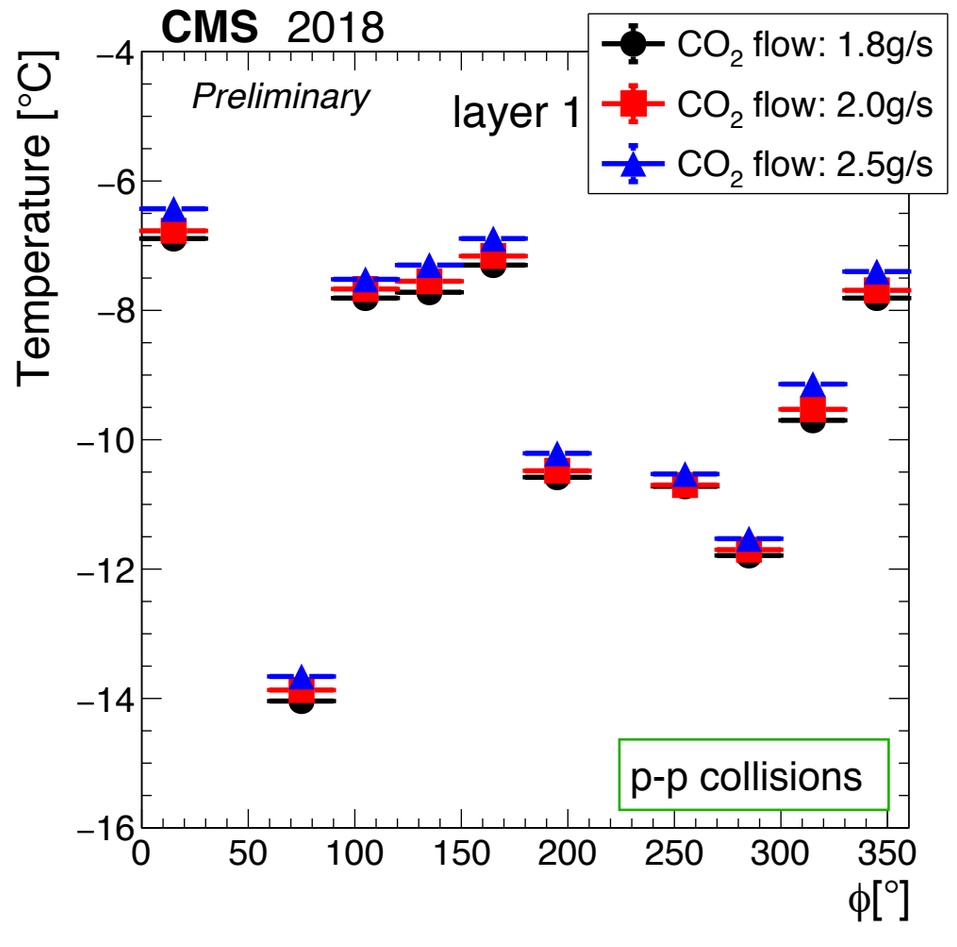
- Plot the temperature values in varying azimuthal coordinates in the pixel barrel detector with different CO_2 flow supplies
- Compare the temperature distributions between cosmic rays and p-p collisions

Stable beam condition for pixel barrel temperature w.r.t CO_2 flow comparison

CMS Run Number	322625	325022	325057
Time stamps	2018.09.10 03:45 (20 mins after stable beam declaration)	2018.10.21 21:19 (20 mins after stable beam declaration)	2018.10.22 14:14 (20 mins after stable beam declaration)
L1 Trigger rate (Hz)	75521.5	62756.4	74043.8
Initial inst. lumi ($cm^{-2}s^{-1}$)	$1.44 * 10^{34}$	$1.90 * 10^{34}$	$1.82 * 10^{34}$
CO_2 flow (g/s)	**2.5**	**2.0**	**1.8**

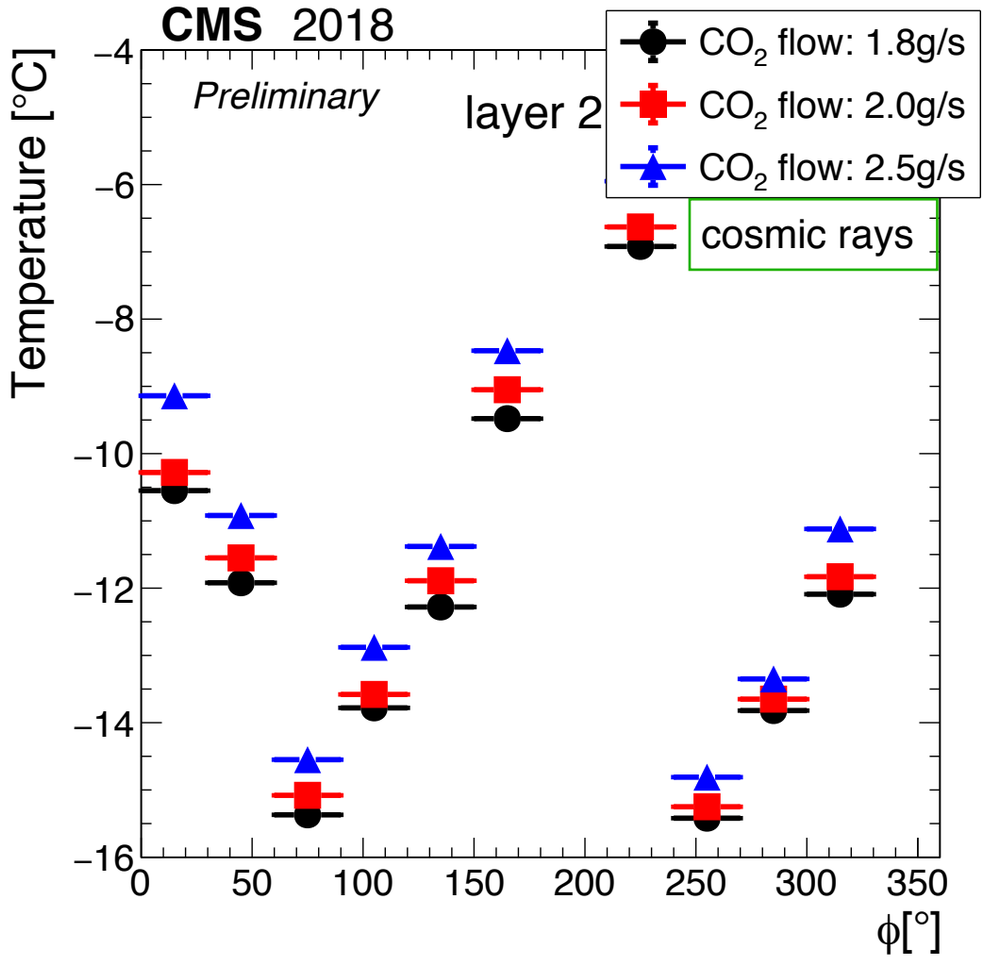
Pixel barrel temperature w.r.t azimuthal coordinate (layer 1)

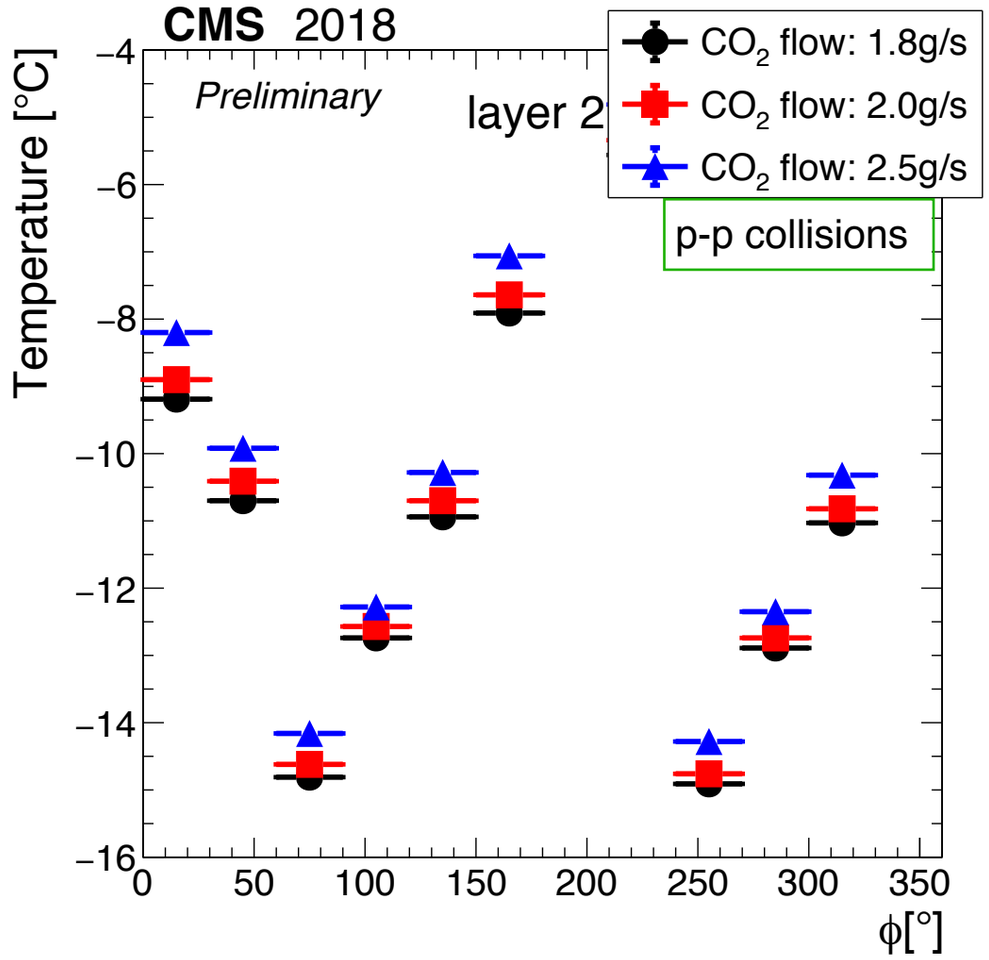




- Left plot: temperature measured without beam; Right plot: temperature measured with beams (20 mins after stable beam declared)
- The azimuthal coordinate yields the CMS coordinates
- Layer 1 has 4 cooling loops, each of which covers approximately one quadrant in azimuthal plane
- Each cooling loop has three temperature probes (few of them give invalid readings — excluded from the plots)
- Assume each temperature probe occupies the one third of the azimuthal plane coverage of each cooling loop
- **As a result of the 2-phase state of CO_2 cooling flow, decreased CO_2 flow leads to its absorbing heat more sufficiently, resulting in more efficient cooling, lower temperature, less temperature spread (explanations in slide 8)**

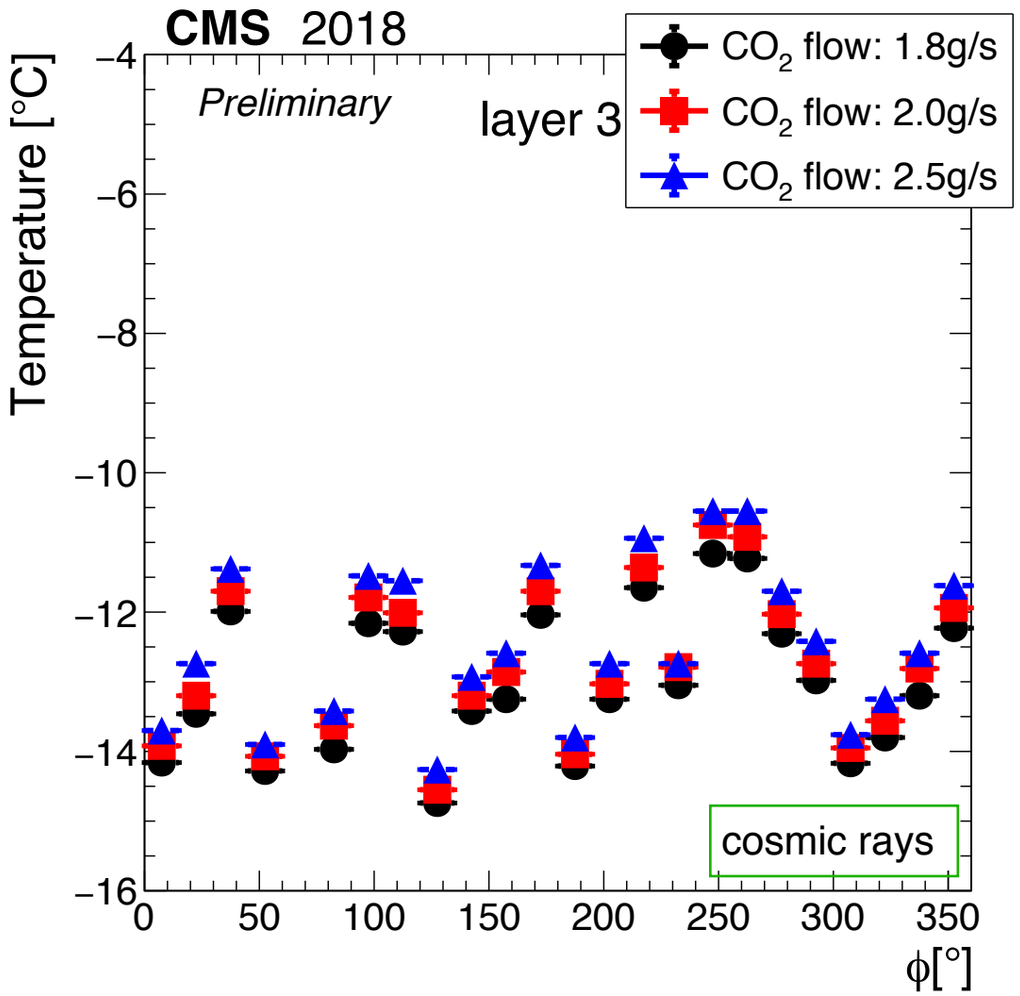
Pixel barrel temperature w.r.t azimuthal coordinate (layer 2)

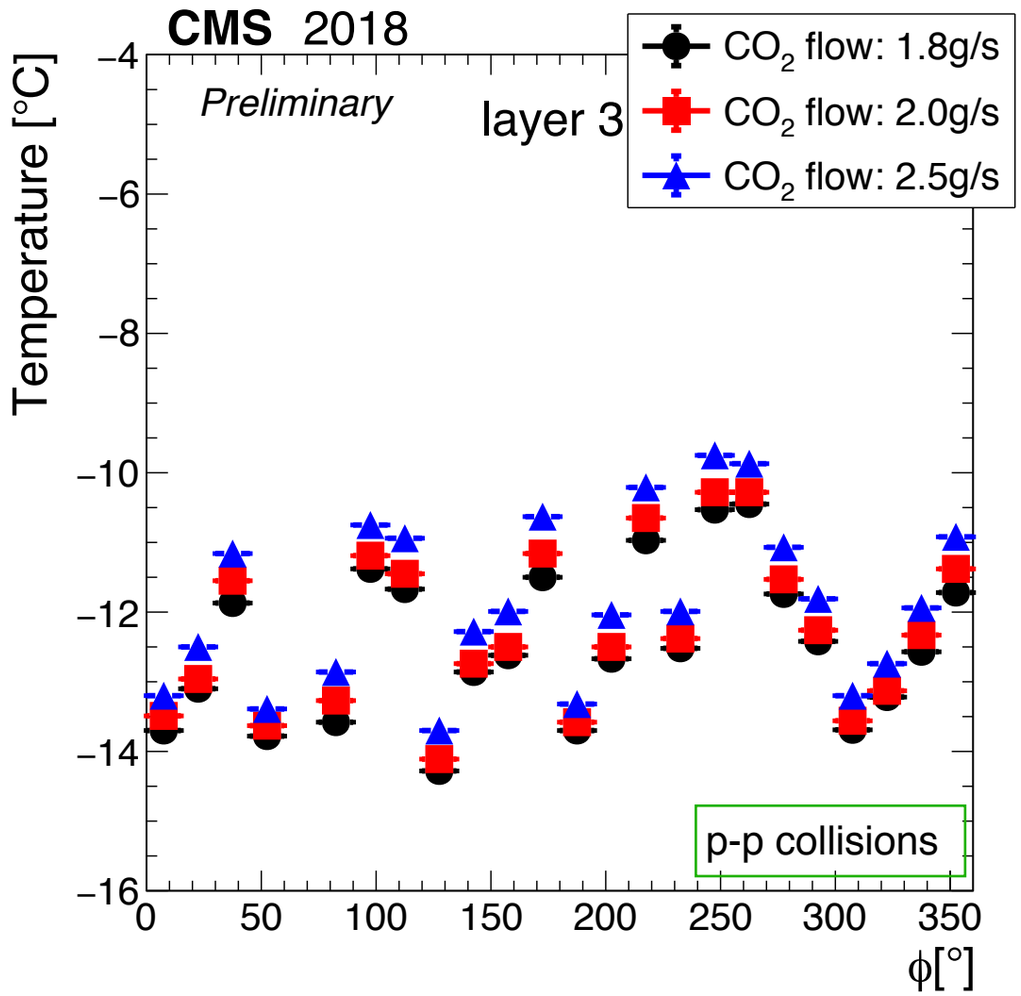




- Left plot: temperature measured without beam; Right plot: temperature measured with beams (20 mins after stable beam declared)
- The azimuthal coordinate yields the CMS coordinates
- Layer 2 has 4 cooling loops, each of which covers approximately one quadrant in azimuthal plane
- Each cooling loop has three temperature probes (few of them give invalid readings — excluded from the plots)
- Assume each temperature probe occupies the one third of the azimuthal plane coverage of each cooling loop
- **As a result of the 2-phase state of CO_2 cooling flow, decreased CO_2 flow leads to its absorbing heat more sufficiently, resulting in more efficient cooling, lower temperature, less temperature spread (explanations in slide 8)**

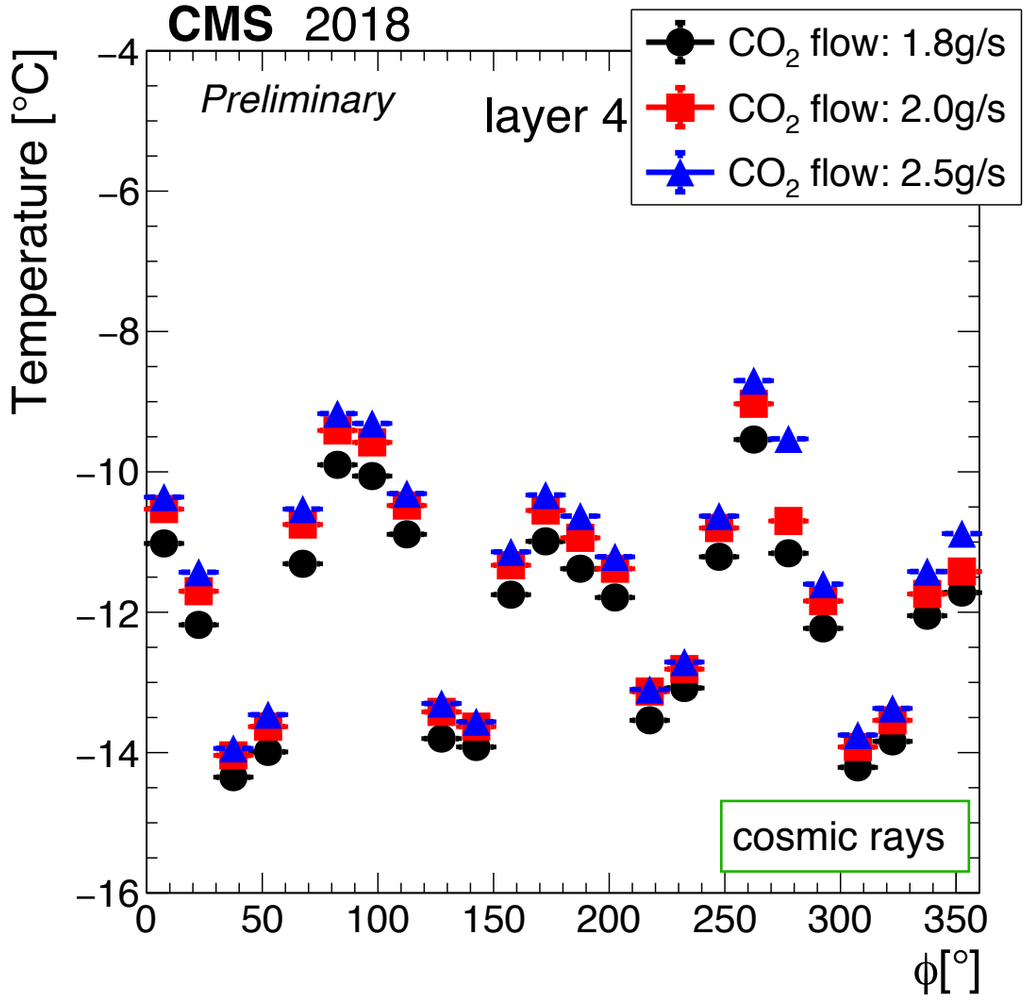
Pixel barrel temperature w.r.t azimuthal coordinate (layer 3)

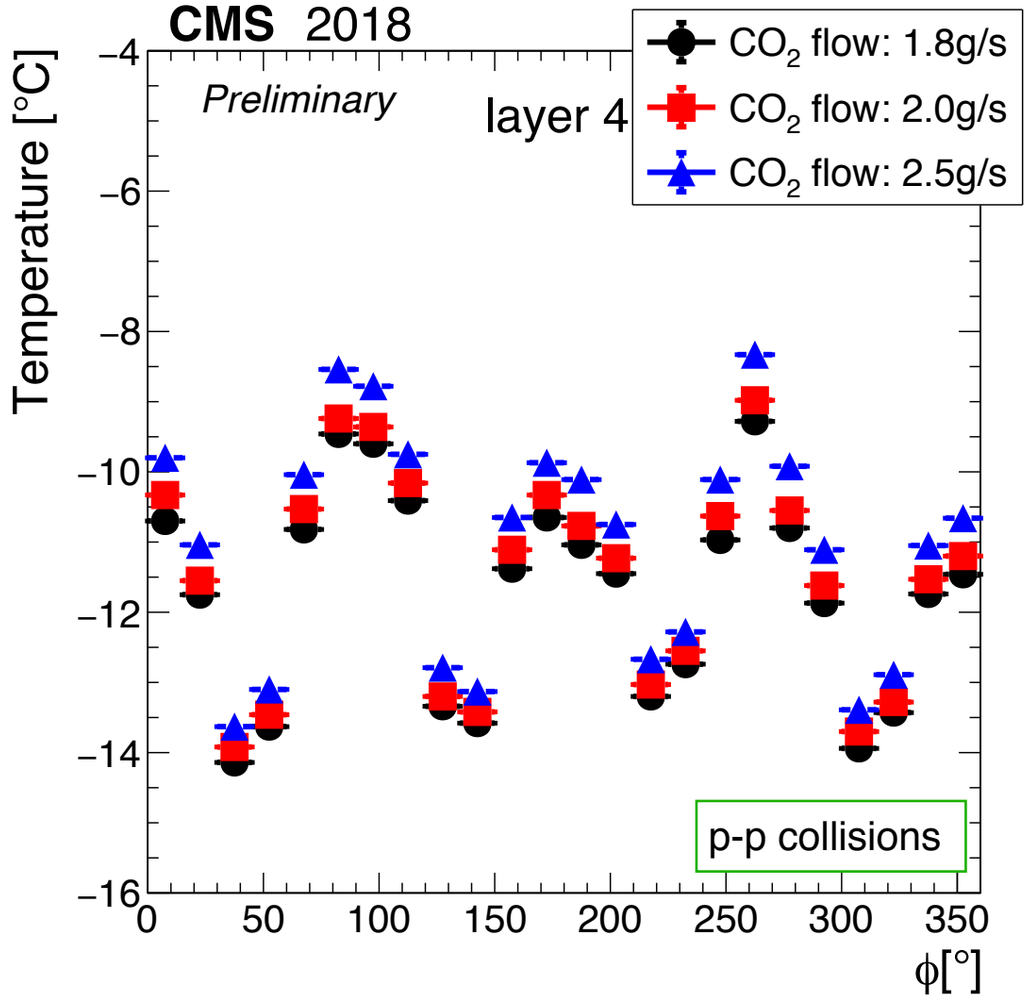




- Left plot: temperature measured without beam; Right plot: temperature measured with beams (20 mins after stable beam declared)
- The azimuthal coordinate yields the CMS coordinates
- Layer 3 has 8 cooling loops, each of which covers approximately one quadrant in azimuthal plane
- Each cooling loop has three temperature probes (few of them give invalid readings — excluded from the plots)
- Assume each temperature probe occupies the one third of the azimuthal plane coverage of each cooling loop
- **As a result of the 2-phase state of CO_2 cooling flow, decreased CO_2 flow leads to its absorbing heat more sufficiently, resulting in more efficient cooling, lower temperature, less temperature spread (explanations in slide 8)**

Pixel barrel temperature w.r.t azimuthal coordinate (layer 4)

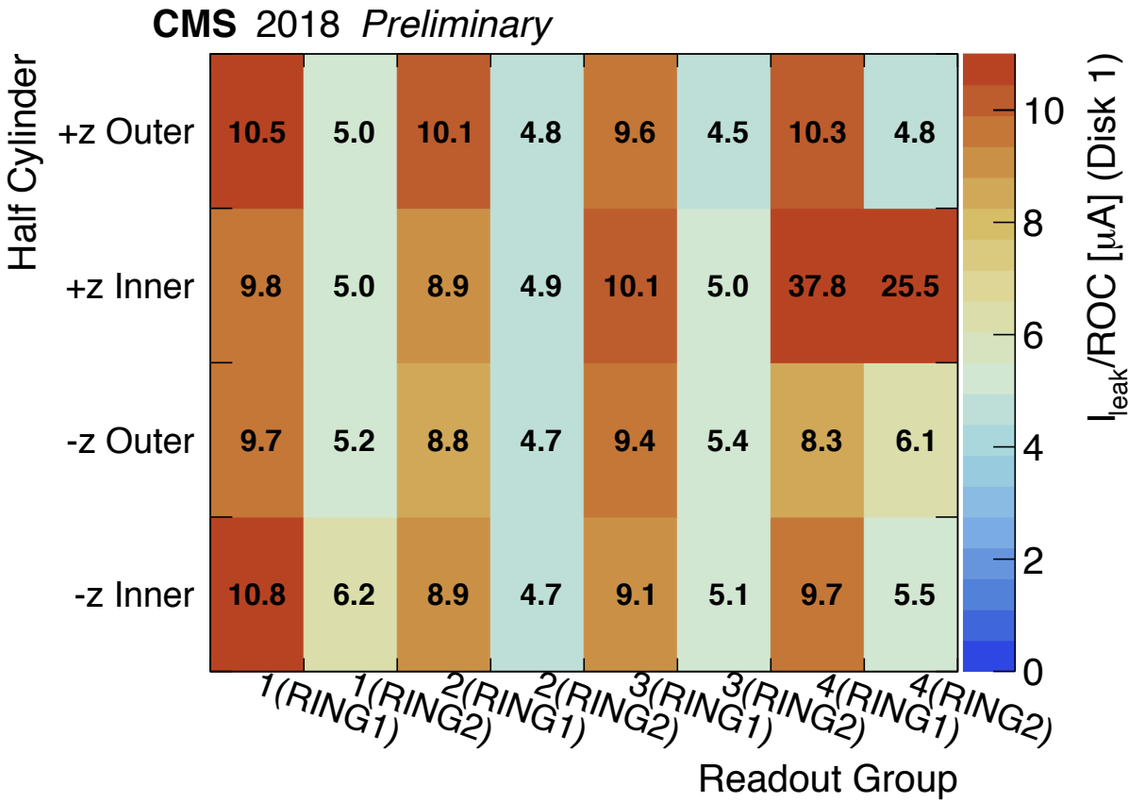


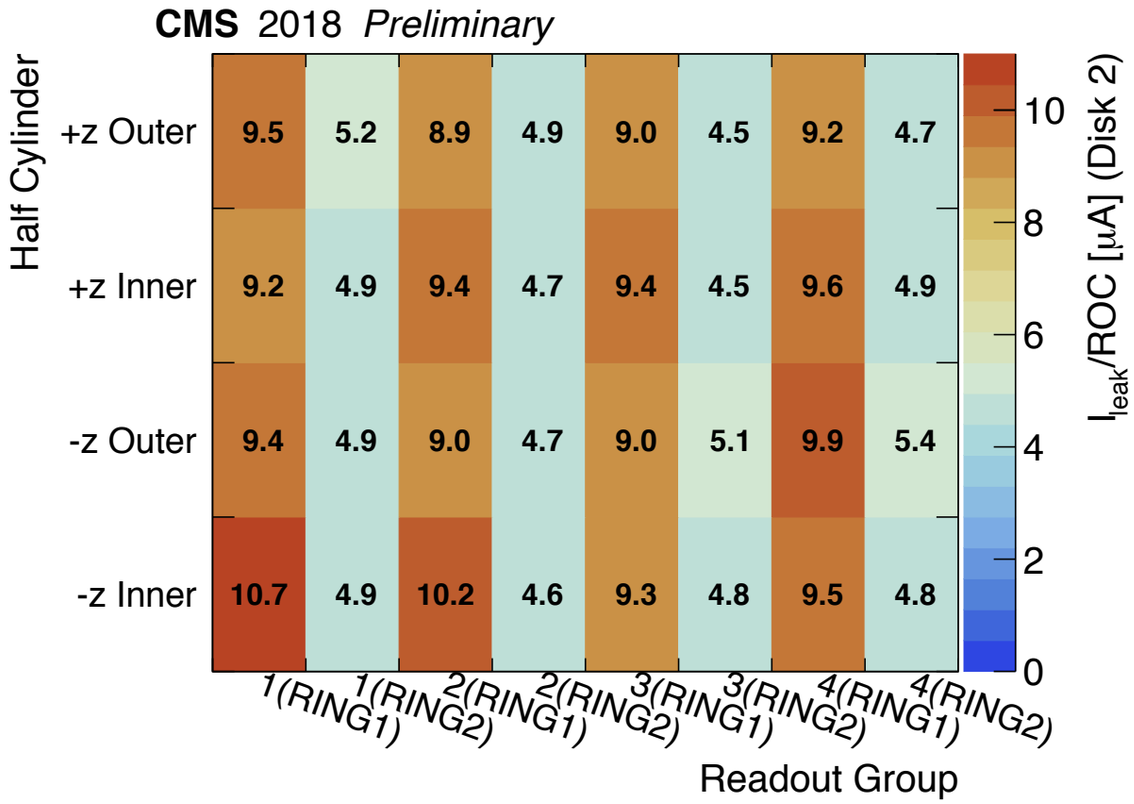


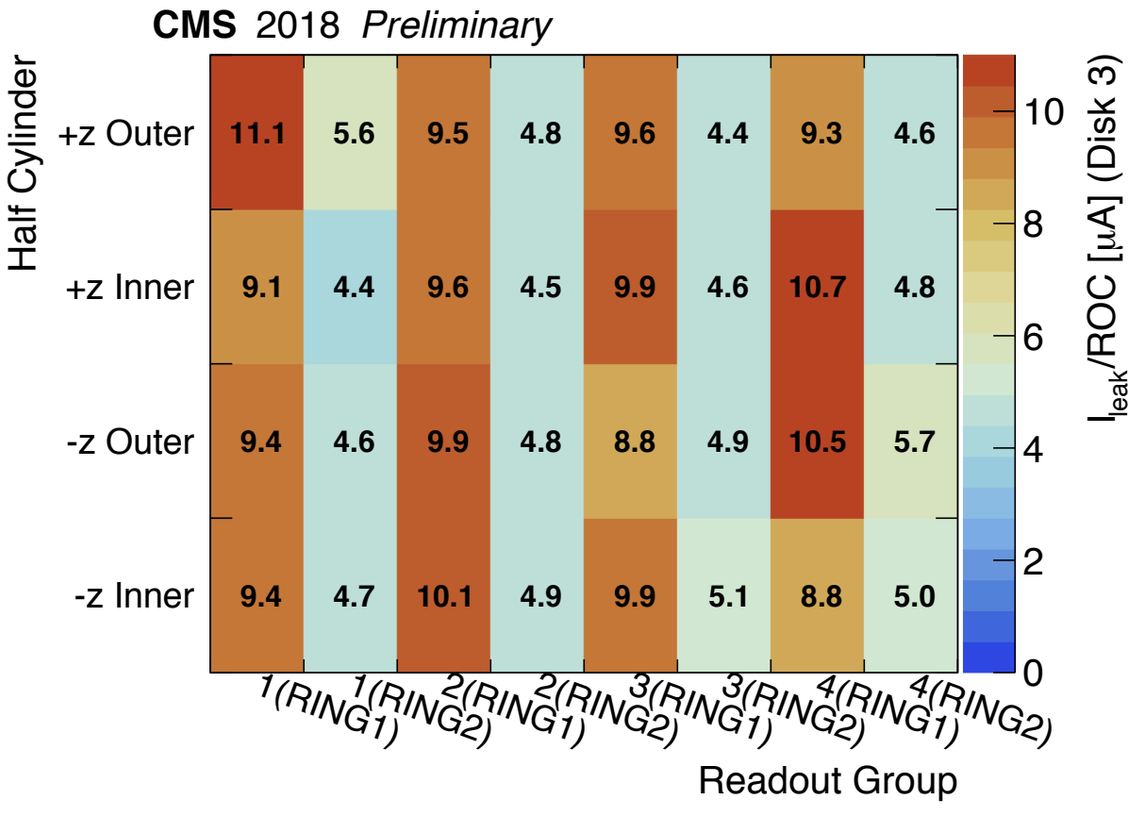
- Left plot: temperature measured without beam; Right plot: temperature measured with beams(20 mins after stable beam declared)
- The azimuthal coordinate yields the CMS coordinates
- Layer 4 has 8 cooling loops, each of which covers approximately one quadrant in azimuthal plane
- Each cooling loop has three temperature probes
- Assume each temperature probe occupies the one third of the azimuthal plane coverage of each cooling loop
- **As a result of the 2-phase state of CO_2 cooling flow, decreased CO_2 flow leads to its absorbing heat more sufficiently, resulting in more efficient cooling, lower temperature, less temperature spread (explanations in slide 8)**

Pixel Endcap leakage current distribution

Pixel endcap leakage current distribution



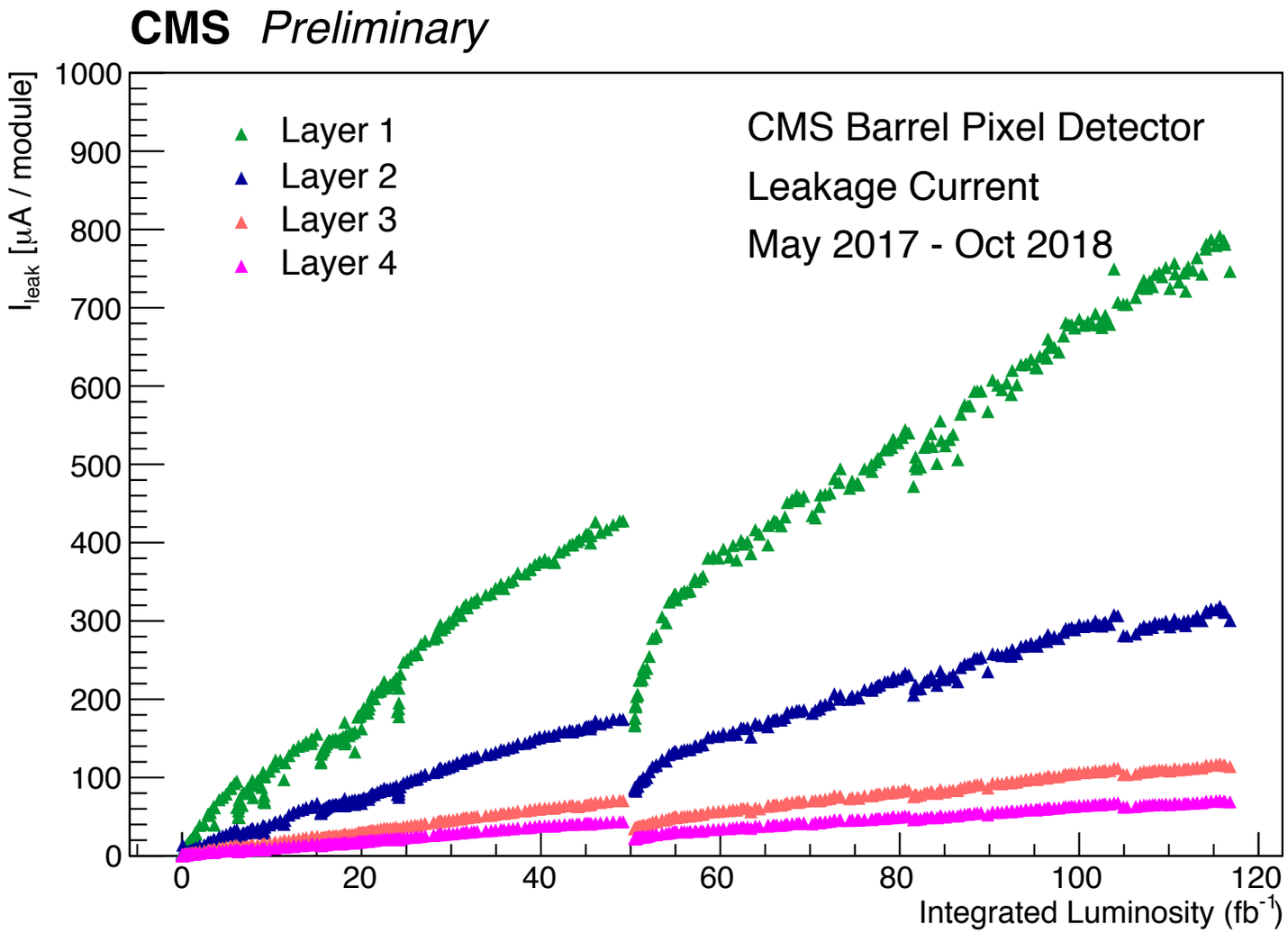




- Pixel endcap detector consists of two endcaps or cylinders
- Each **half cylinder** is a quadrant with 3 disks
- HV currents were measured at 10 minutes after stable beam declared during LHC nominal fill 7144 (Sep.9th)
- Currents were normalized by the number of connected readout chips (ROC) for each power group
- Each cylinder consists of 2 rings, and modules in RING1 are closer to the beam than those in RING2, so higher leakage current is observed in RING1 than in RING2
- The module leakage current distribution in the same ring is roughly uniform
- Note: a power group in disk 1 has significant high current that has been seen since 2017, to be investigated during the long shut down 2 (LS2)

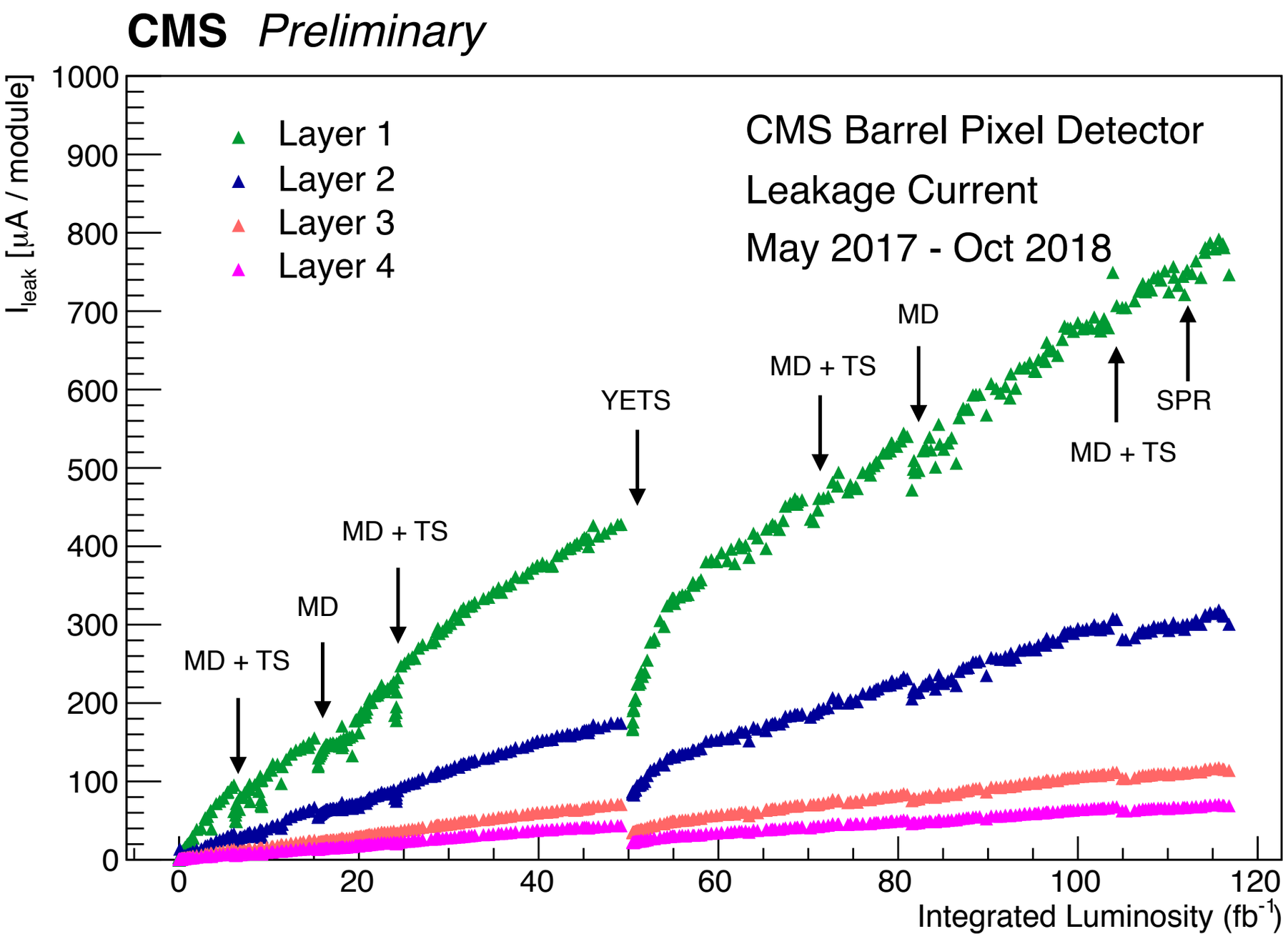
Pixel leakage current evolution

Pixel barrel module leakage current evolution



- LHC fills from beginning of 2017 until end of October in 2018 data-taking are employed (proton-proton collisions)
- Currents measured within 20 minutes from Stable Beam declaration
- Average current per pixel module measured from power groups (**no temperature correction**)
- Leakage current increased gradually due to accumulated radiation dose through the year
- Closer to beam spot -> more accumulated radiation dose -> higher leakage current (layer 1 > layer 2 > layer 3 > layer 4)
- There are some drops of leakage current from the global trend because of:
  - Annealing during Machine development or technical stop period
  - Power supply replacement
  - HV setting change

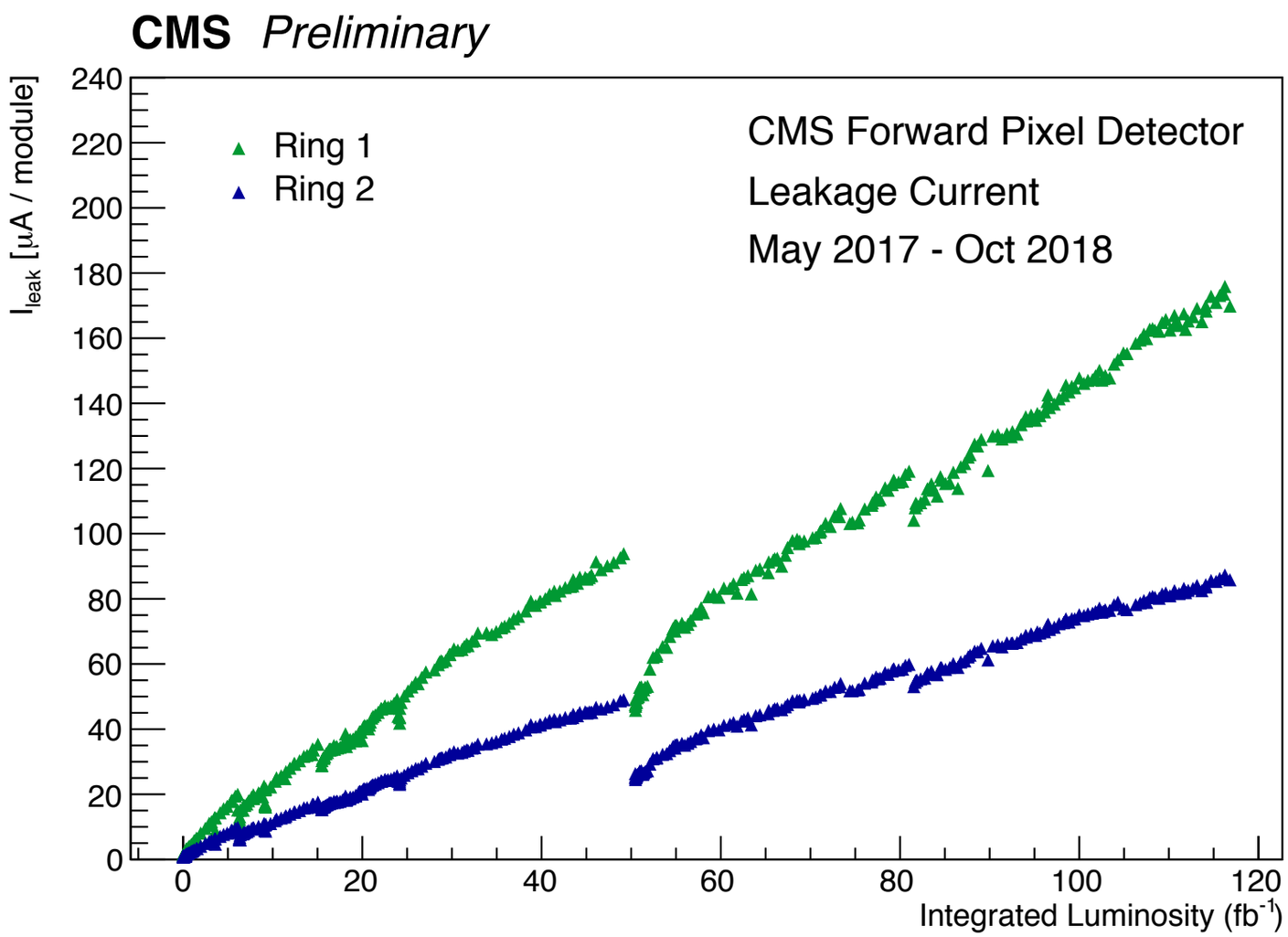
Pixel barrel module leakage current evolution



- MD: Machine development
- TS: Technical stop
- YETS: Year-End technical stop
- SPR: special physics run

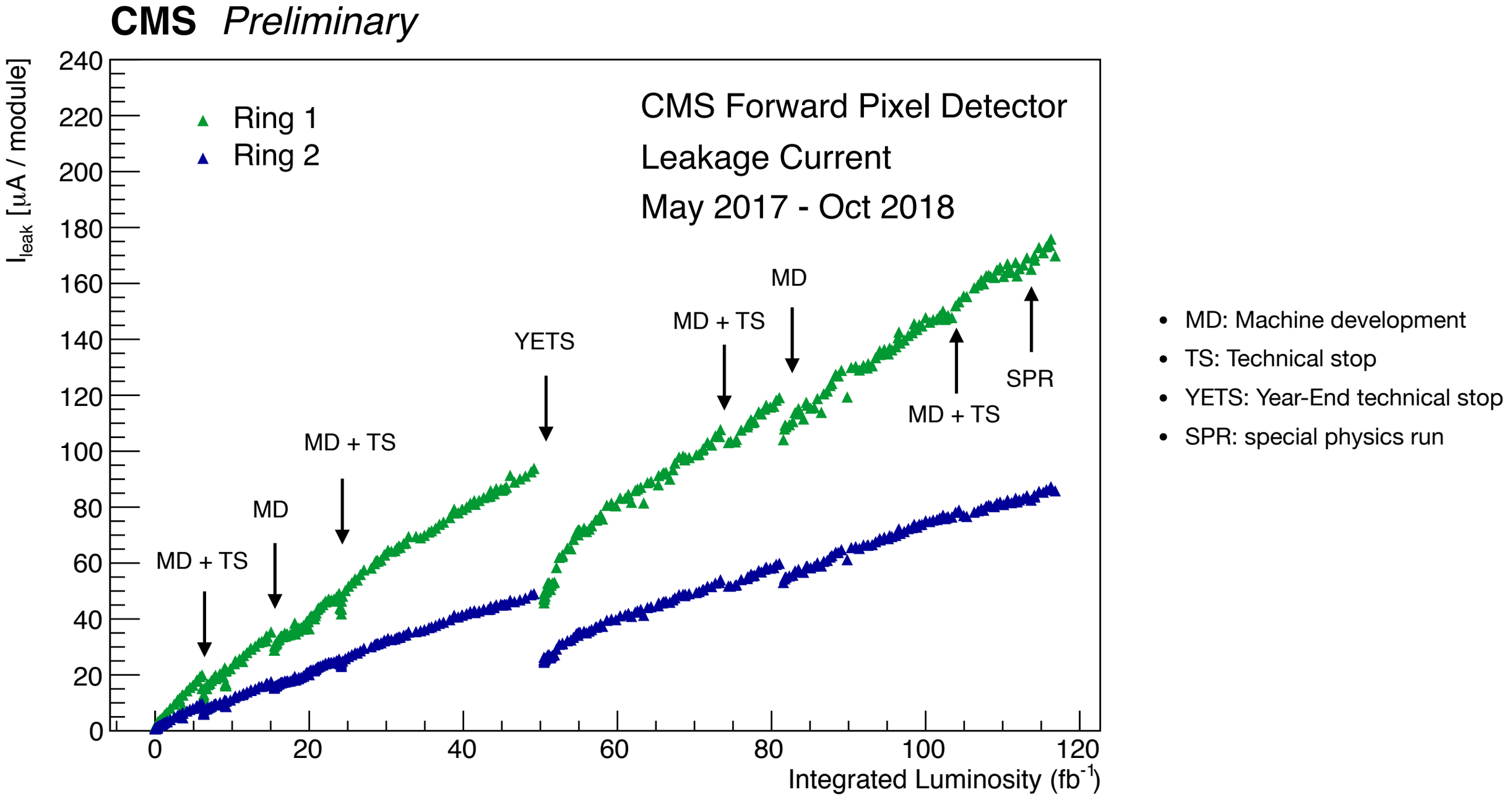
- LHC fills from beginning of 2017 until end of October in 2018 data-taking are employed (proton-proton collisions)
- Currents measured within 20 minutes from Stable Beam declaration
- Average current per pixel module measured from power groups (**no temperature correction**)
- Leakage current increased gradually due to accumulated radiation dose through the year
- Closer to beam spot -> more accumulated radiation dose -> higher leakage current (layer 1 > layer 2 > layer 3 > layer 4)

Pixel endcap module leakage current evolution



- LHC fills from beginning of 2017 until end of October in 2018 data-taking are employed (proton-proton collisions)
- Currents measured within 20 minutes from Stable Beam declaration
- Average current per pixel module measured from power groups (**no temperature correction**)
- **Note: The 4th power group giving much higher current in disk 1 (seen in slide 25) is removed from the average**
- Leakage current increased gradually due to accumulated radiation dose through the year
- Closer to beam spot -> more accumulated radiation dose -> higher leakage current (ring 1 > ring 2)
- There are some drops of leakage current from the global trend because of:
  - Annealing during Machine development or technical stop period
  - Power supply replacement
  - HV setting change

Pixel endcap module leakage current evolution



- MD: Machine development
- TS: Technical stop
- YETS: Year-End technical stop
- SPR: special physics run

- LHC fills from beginning of 2017 until end of October in 2018 data-taking are employed (proton-proton collisions)
- Currents measured within 20 minutes from Stable Beam declaration
- Average current per pixel module measured from power groups (**no temperature correction**)
- **Note: The 4th power group giving much higher current in disk 1 (seen in slide 25) is removed from the average**
- Leakage current increased gradually due to accumulated radiation dose through the year
- Closer to beam spot -> more accumulated radiation dose -> higher leakage current (ring 1 > ring 2)