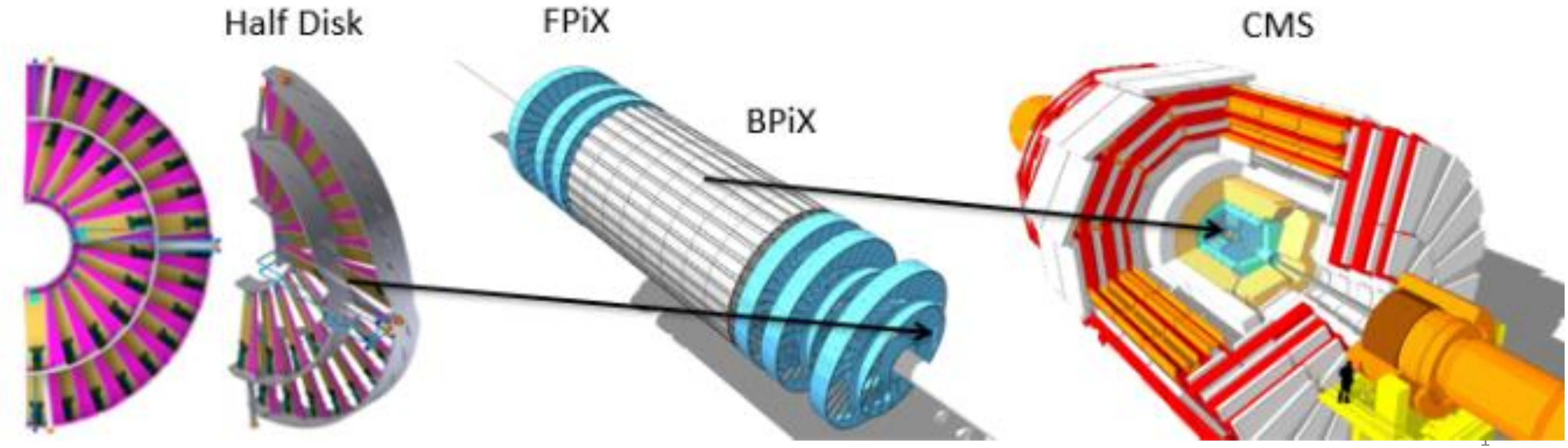
Update from CERN

How are we doing?

We’re about halfway through our long period of running

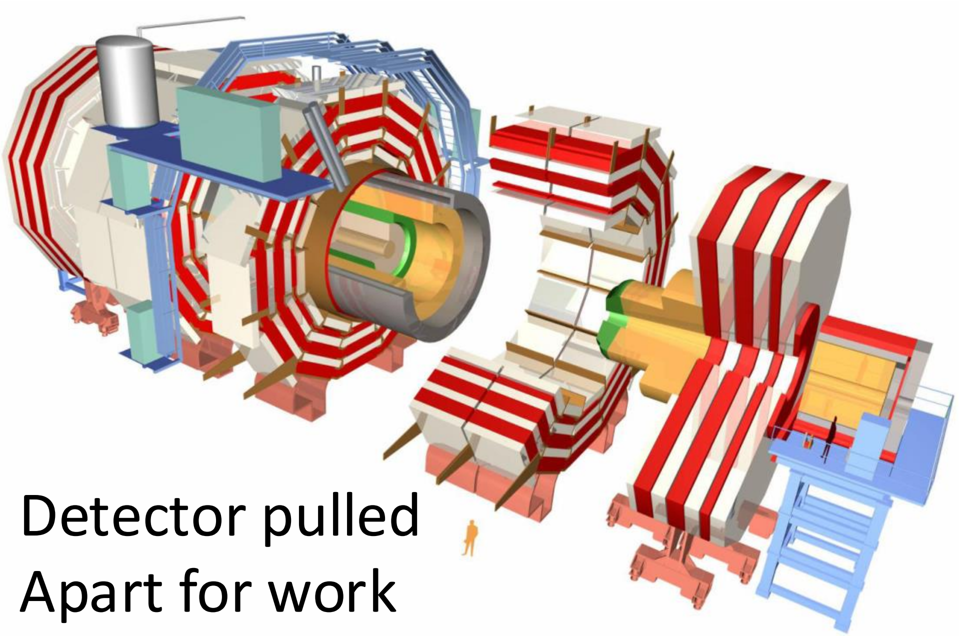


CMS Detector

Student now a Professor!

VANDERBILT UNIVERSITY

Universidad de los Andes Colombia



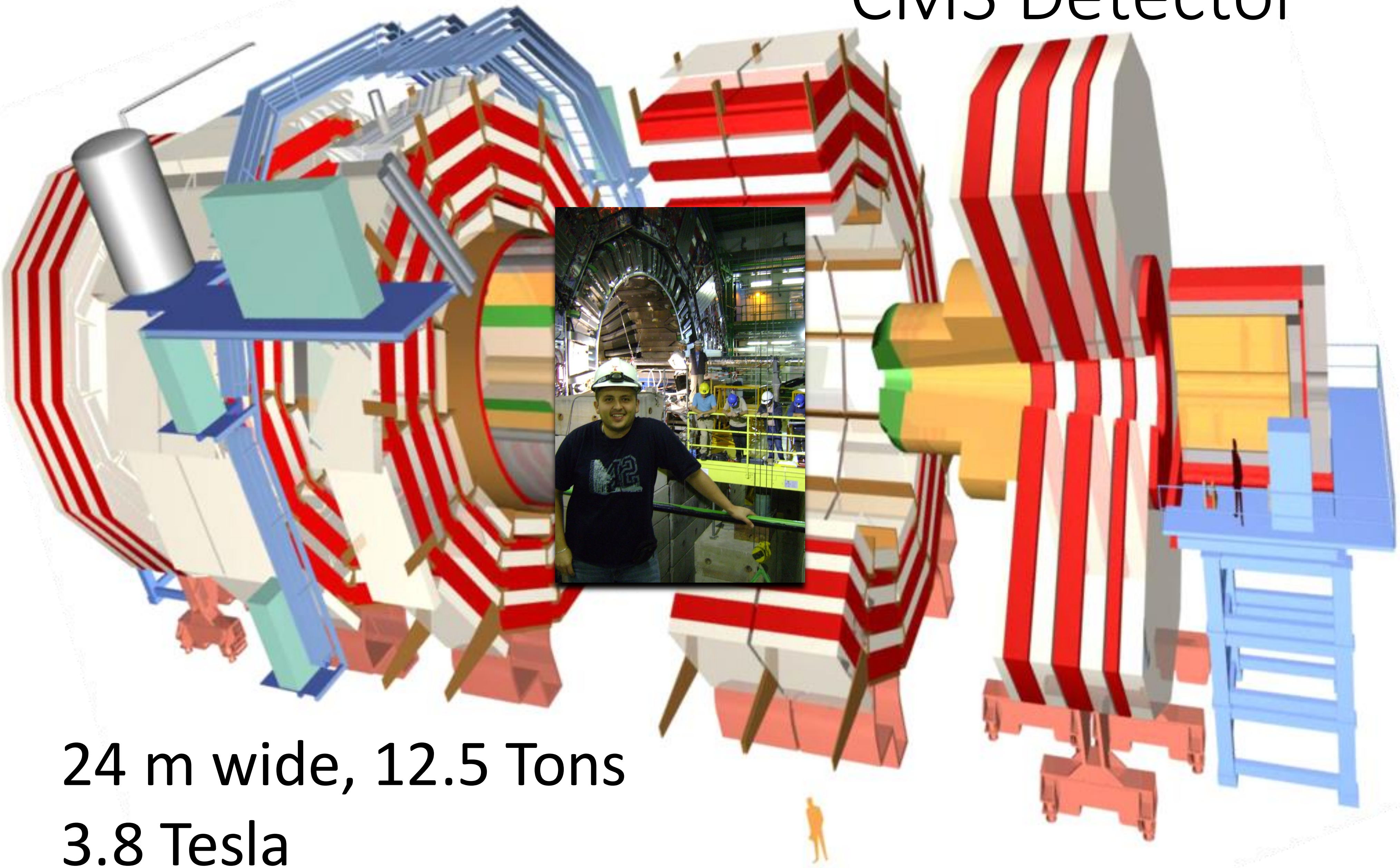
Detector pulled
Apart for work

UF UNIVERSITY of FLORIDA

Fermilab

VANDERBILT UNIVERSITY

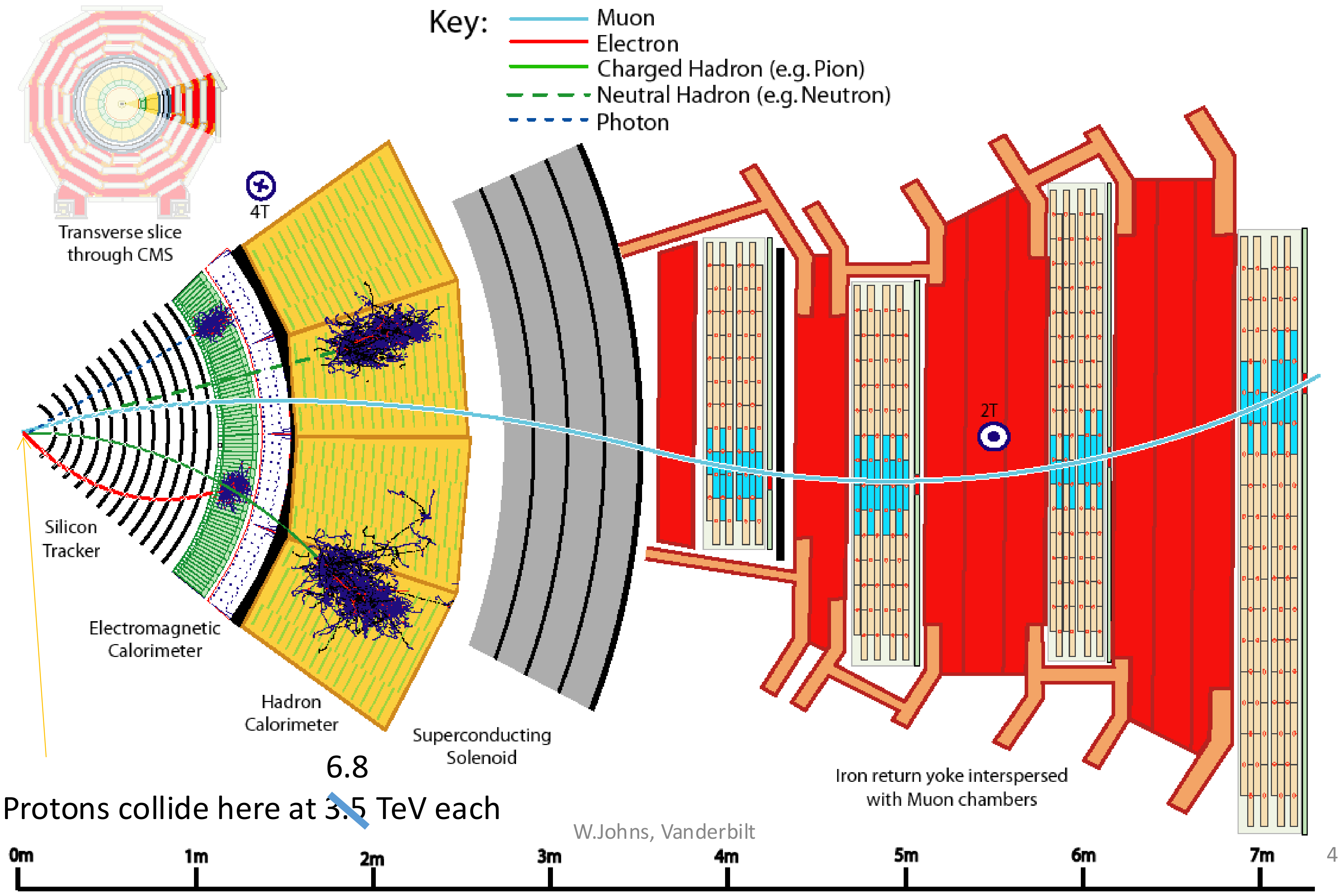
CMS Detector



24 m wide, 12.5 Tons

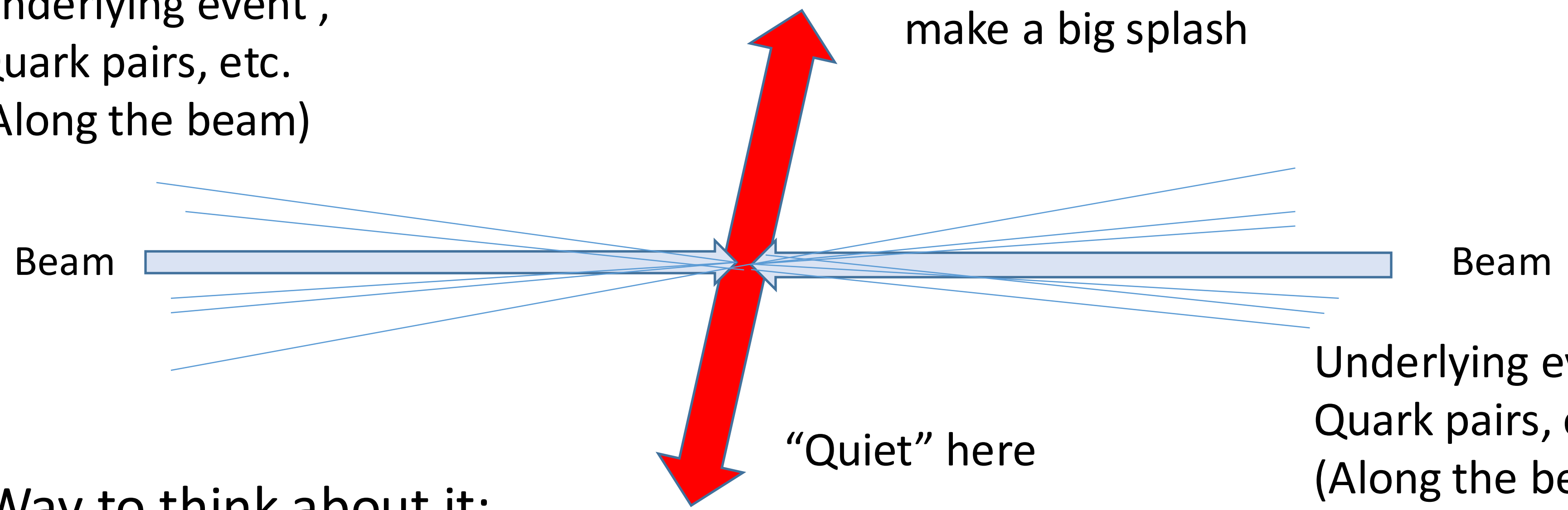
3.8 Tesla

A slice of the CMS experiment



Really quite interesting!

- Lots of particle action along the beam direction
- Not as much transverse to the beam
- Use beam energy to make a Heavy Particle

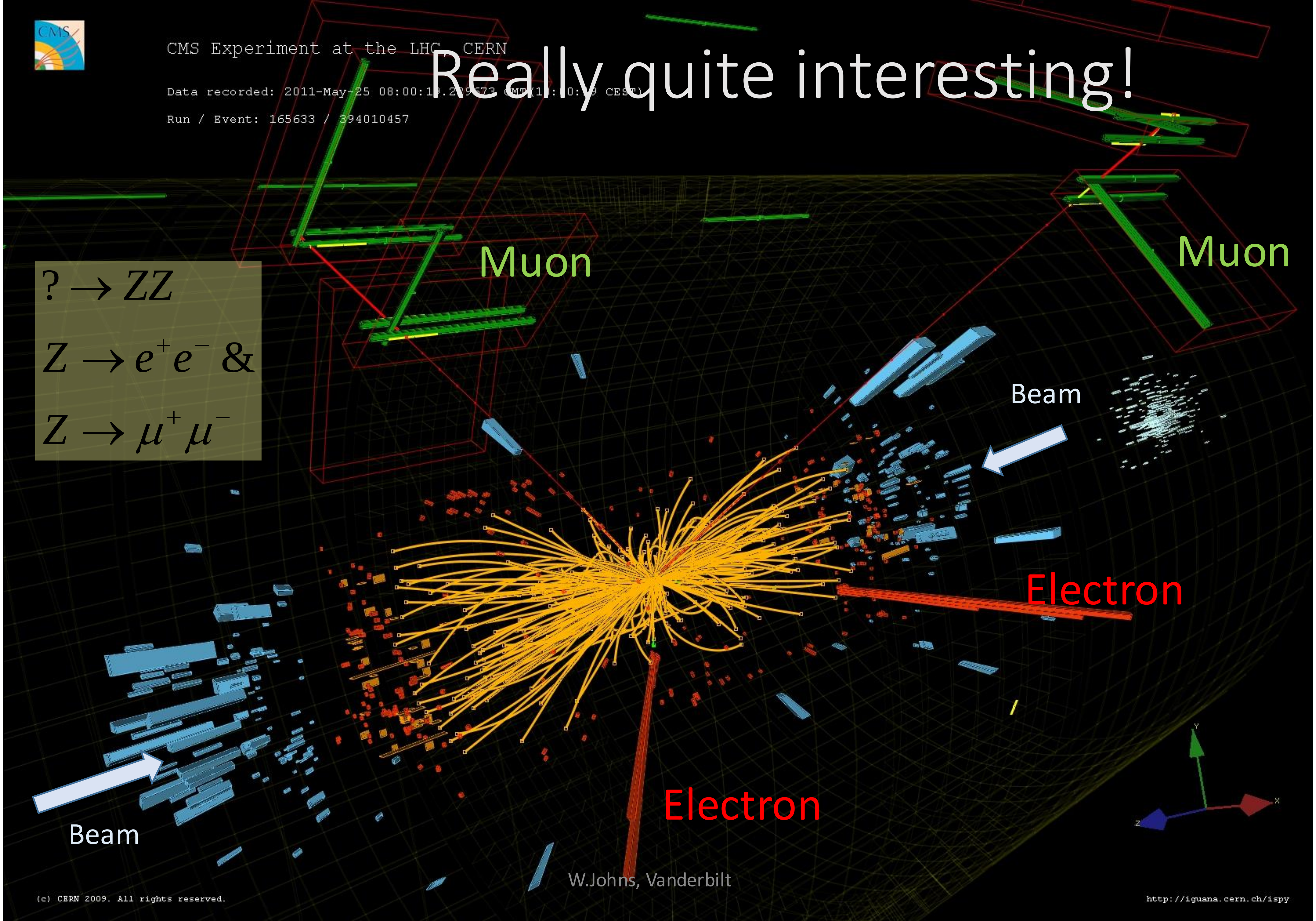


Way to think about it:

Beam energy -> Making a big mass ($E=mc^2$)

Big mass decays into 2 particles - Come at any angle, back to back

Really quite interesting!



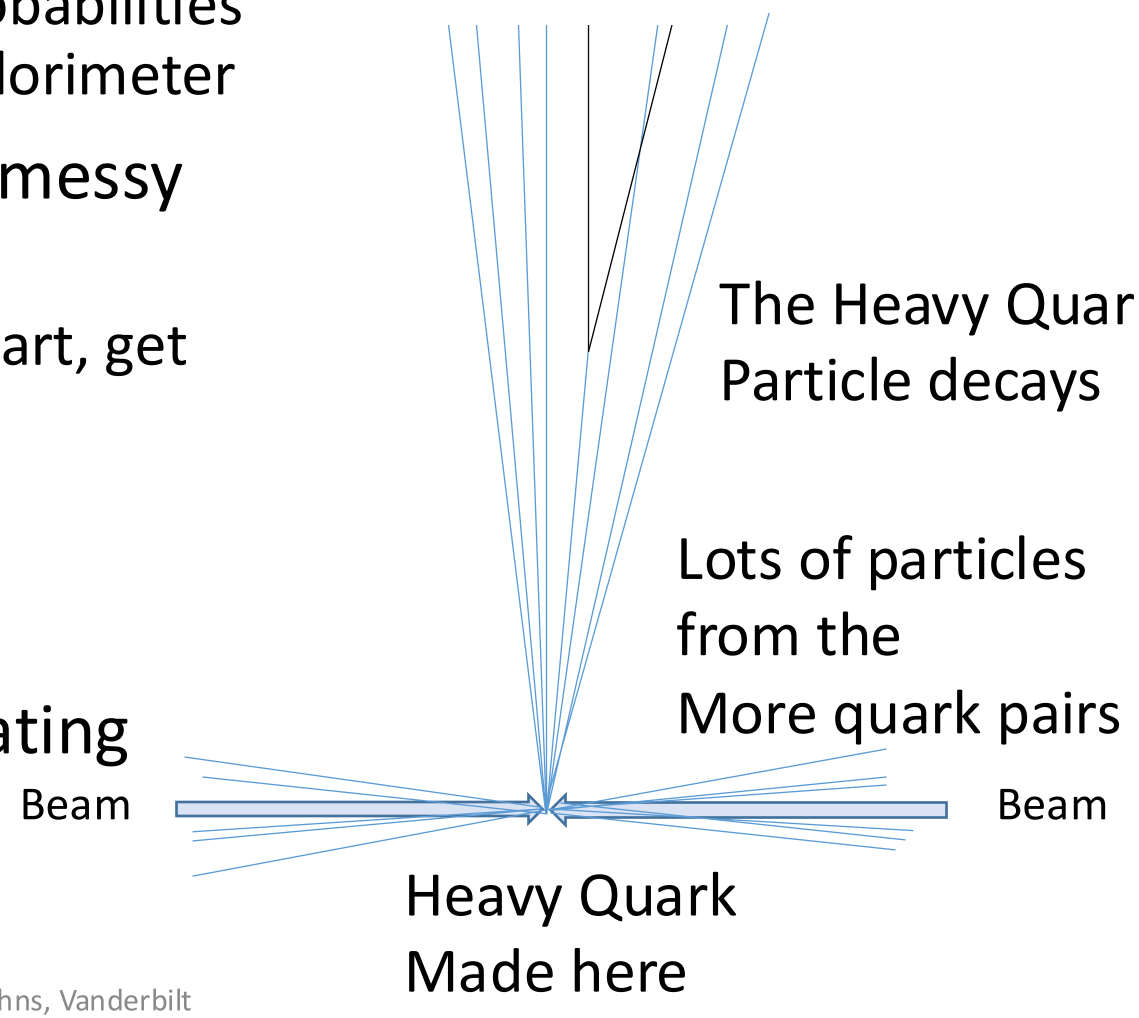
Not all events are as clean…

- Particles can interact violently in the detector
  - It's a question of probabilities – more likely in a Calorimeter
- Some processes are messy by their nature
  - Try to pull quarks apart, get more quarks
- Need the *whole*

  detector to do

  a good job of separating

And you get a mess when you were hoping for one big thing



A high B field (+other stuff) helps

- Consider that a 1 TeV charged particle will only bend by about ~1 mm in the tracker
  - Precision tracking helps a lot
  - If the heavy particle decays to muons, it's a big plus, usually
    - If the process is rare there is a process that creates an exponentially falling background called Drell-Yan production
  - Can use a Tau particle to get at higher mass (especially if coupling is mass dependent)
    - A reconstructed mass peak will spread out more since the tau decays like a heavy quark'd particle
    - But the Tau decay can be clean like a muon, and separable from other processes
      - Think about that heavy quark without the "quark pairs"
  - Can use a calorimeter to measure "momentum"
  - It's also a win-some lose-some since it is easier to trigger on a very stiff (straight) transverse muon
    - So it can help to measure muon momentum again

2. Momentum Measurement (10 points)

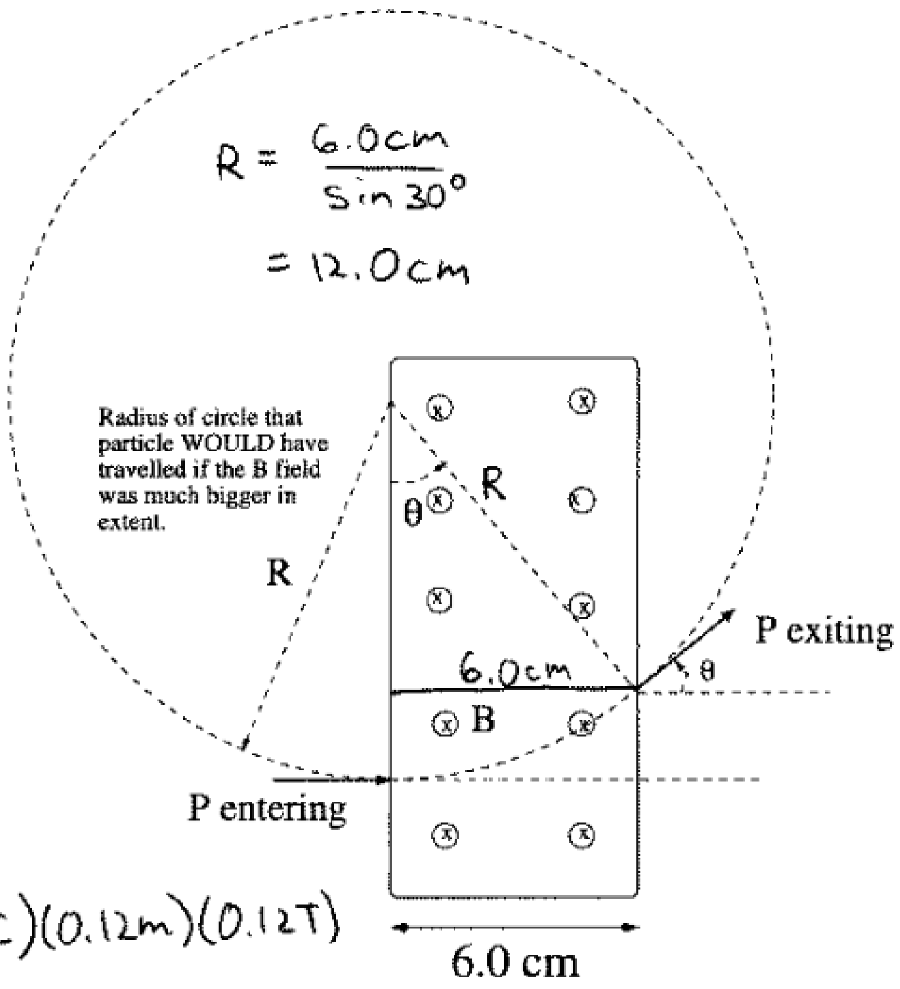
You are using part of a magnetic field to measure the momentum of a charged particle. You know the initial and final DIRECTIONS of the particle's momentum, the charge of the particle, and the extent and the strength of the magnetic field. Find the momentum of the particle for the situation in the diagram below.

$\theta = 30$ degrees

$B = 0.10$ T

$q = 1.6 \times 10^{-19}$ C

$p = mv$



$\frac{mv^{\cancel{2}}}{r} = q\cancel{v}B$

$mv = qrB$

$= (1.6\times10^{-19} C)(0.12 m)(0.12 T)$

$= 1.92\times10^{-21}$ kg m/s

$\boxed{P = 1.92\times10^{-21} \text{ kg } \frac{m}{s}}$

Here's a typical test problem I give. For CMS, we are interested in that 1 mm estimate I made earlier.

The extent of the magnetic field is 1 m and we know the momentum is 1 TeV/c. Now we just need to play a units game:

$$p[\text{in Joules}]\, c = e\, r\, B\, c$$

$$p[\text{in Joules}] * c * (1 \text{ eV} / 1.6\text{x}10^{-19} \text{ J}) = (pc) [\text{in eV}]$$

$$= e\, c\, r\, B / (1.6\text{x}10^{-19} \text{ J/eV})$$

$$p\ [\text{in MeV/c}] = 2.998 * 10^{2} * r\ [\text{in m}] * B\ [\text{in T}].$$

So p [in TeV/c] = $2.998*10^{-4}$*r [in m] * B [in Tesla]

And r = p / ($2.998*10^{-4}$* B [in Tesla]) ~ 1 / (0.0003*3.8)

r = 877 m! so the deviation is 877m - sqrt(877m^2 – 1m^2) or 0.57 mm

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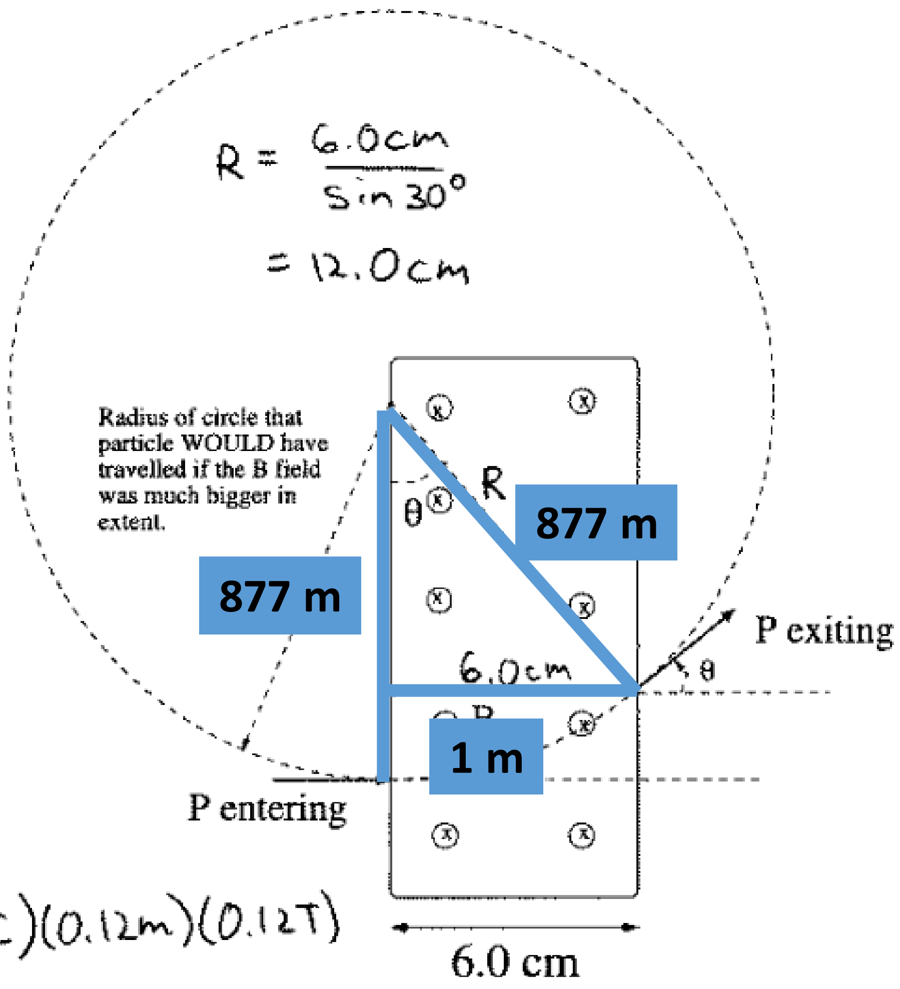

$\frac{mv^2}{r} = qvB$

$mv = qrB$

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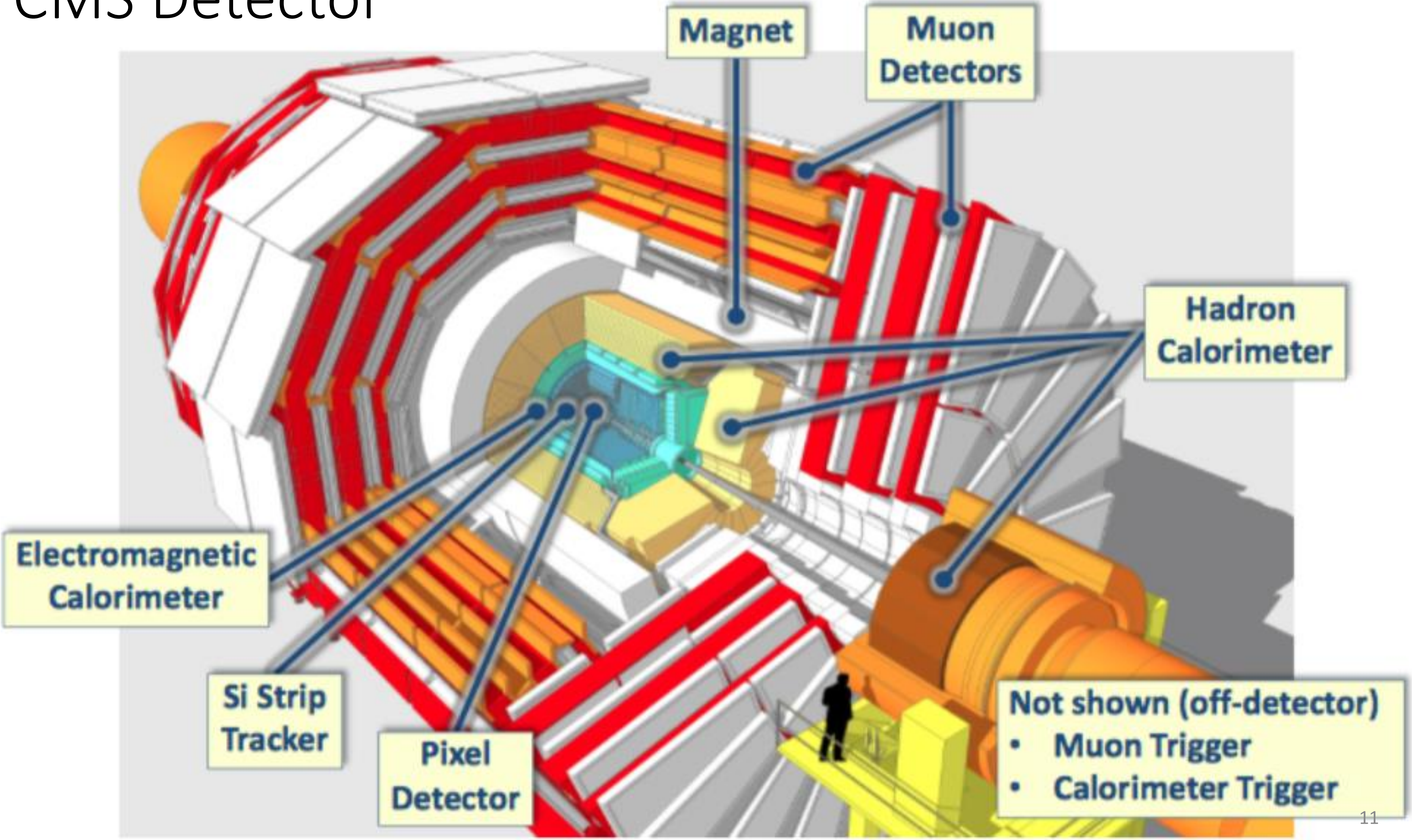
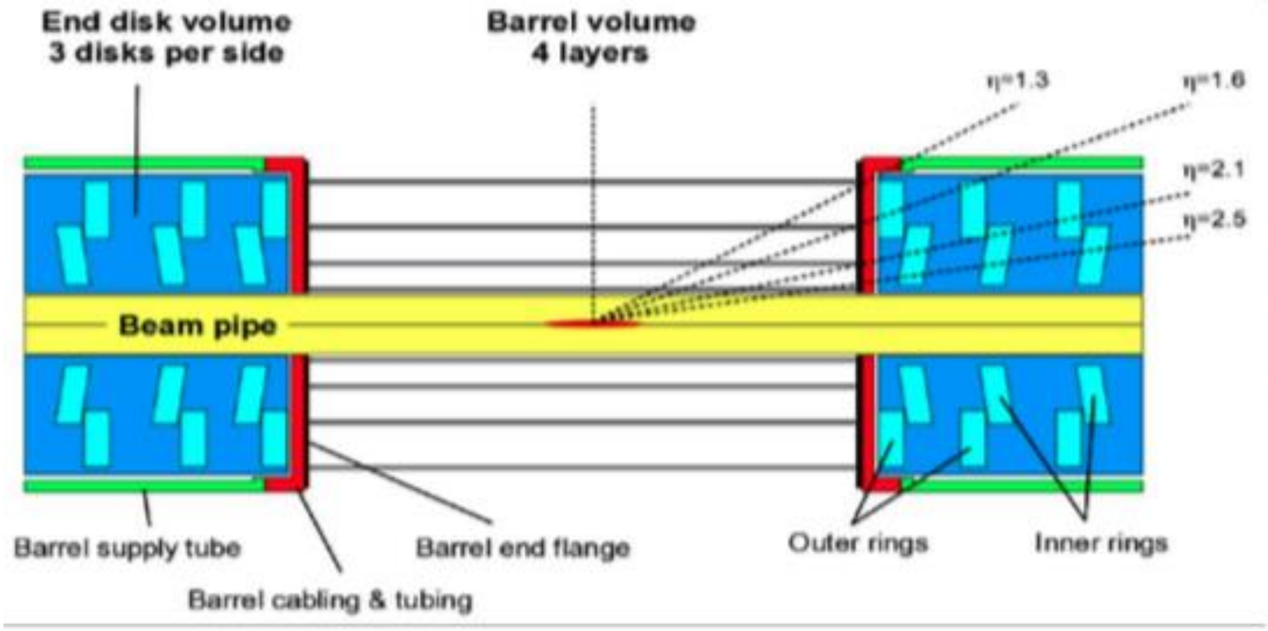
Surprisingly, my biggest challenge is usually trying to get students to work in units of eV

CMS Detector



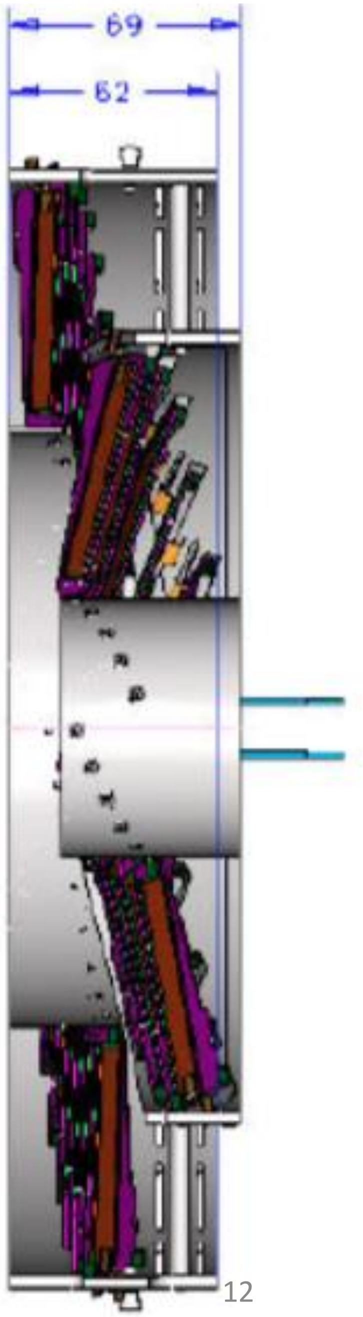
Phase 1 Forward Detector Description

- Half disks with separate inner & outer rings
  - Simpler single 2x8 ROC module design
  - Mounted on thermal pyrolytic graphite (TPG)
- <u>Lighter structure</u>
- 6 Disks of 112 sensors each
  - 672 modules, 10752 (new) ROCs
  - 44.7 M pixels (~2.5x ~~present)~~ Original

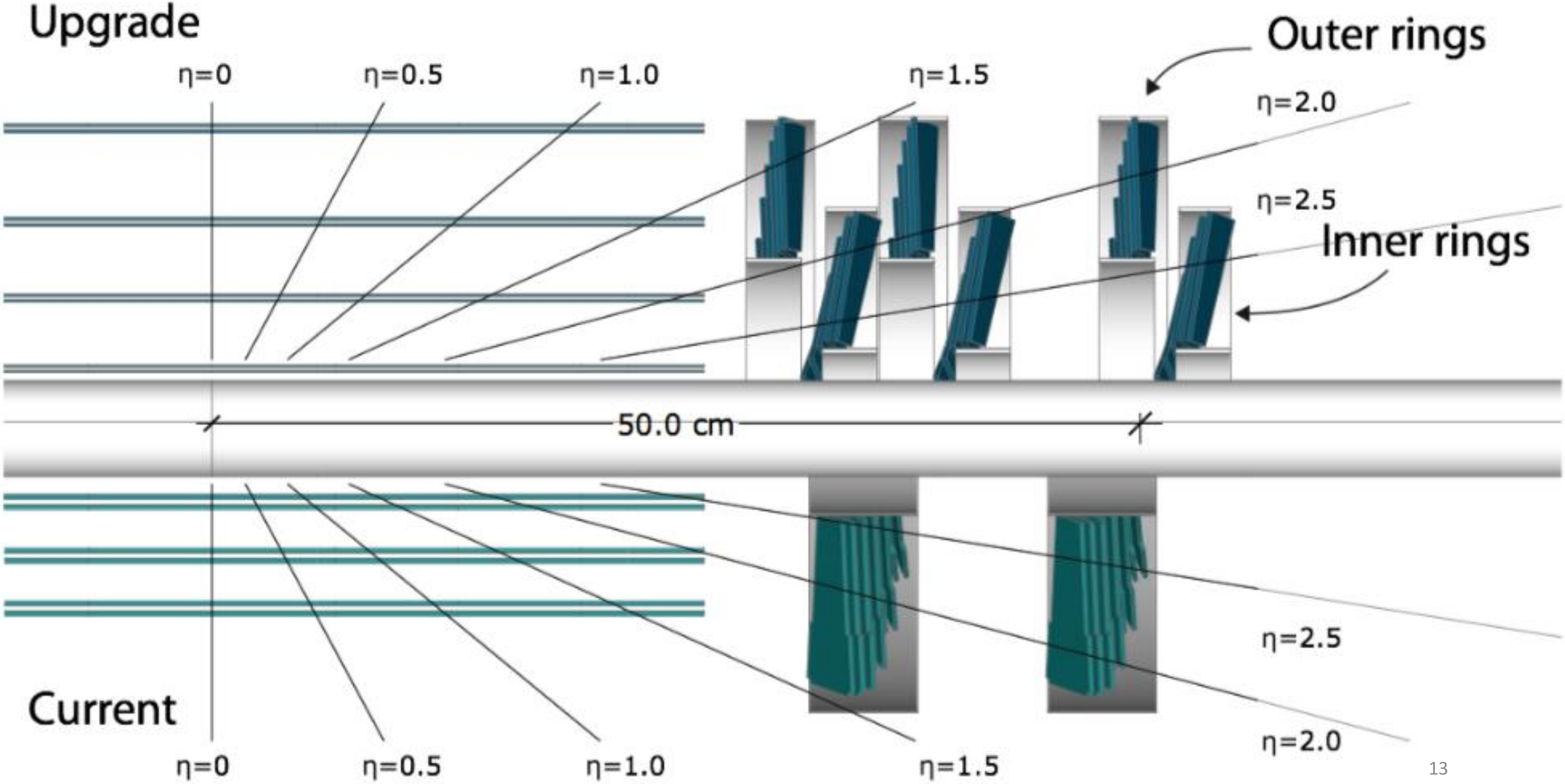


Structure designed for good heat spreading:

Graphite!

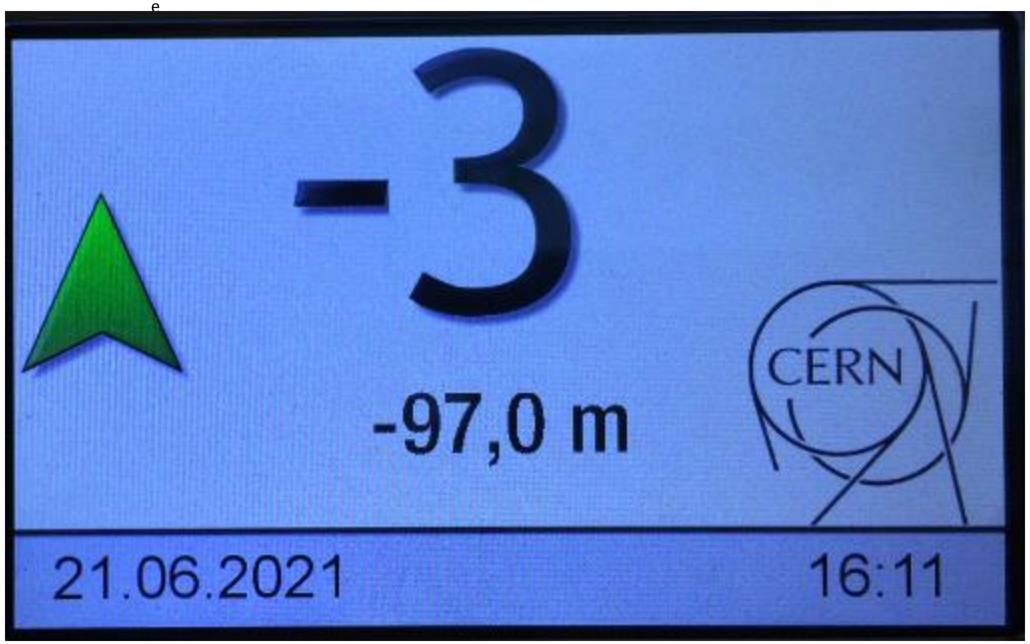


Why did we upgrade?



A reminder of just how far underground we are when we are installing a detector

- Andareminderofwhere



(vintage 2021)

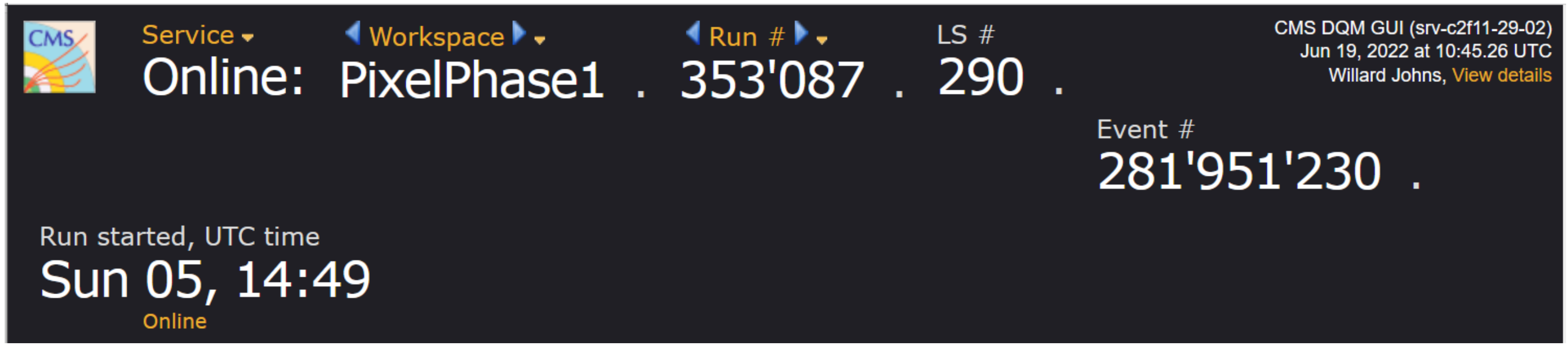
2021 (COVID): A completed Half Cylinder, ready to test

- The last time we installed a major detector in CMS was in 2021 when we re-installed a refurbished pixel detector
- The last talk I remember giving was in 2022 after we had a bit of running where I pointed out some features in the operation of the detector
- This talk was very useful as it allowed me to also give it to my operations crew!
- So how are we doing now?

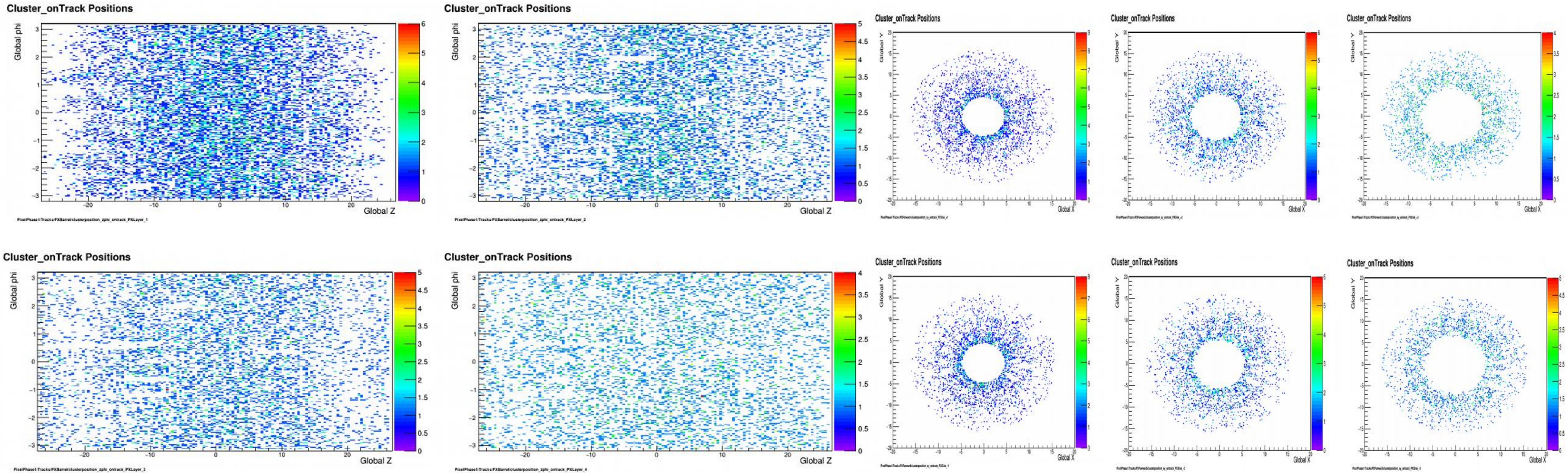
If you are interested in the installation

- The pixel detectors are installed
  - Time lapse: CMS Pixel tracker installation 2021 - YouTube
  - Discussion: Live from the CMS Experiment - YouTube
- … and operational
  - It gets tougher to visit
    - Magnet is on: 2022-03-22 15:14:10 Visit to the CMS detector with its superconducting magnet fully ramped – YouTube
- We have seen lots of collisions with this detector
- Some detectors components are showing their age
  - Important to find a sweet spot for running…always
  - The detectors are an ever changing entity with all this radiation and we need to be clever and adapt to keep running well

How do we know that the data we are taking is ok?

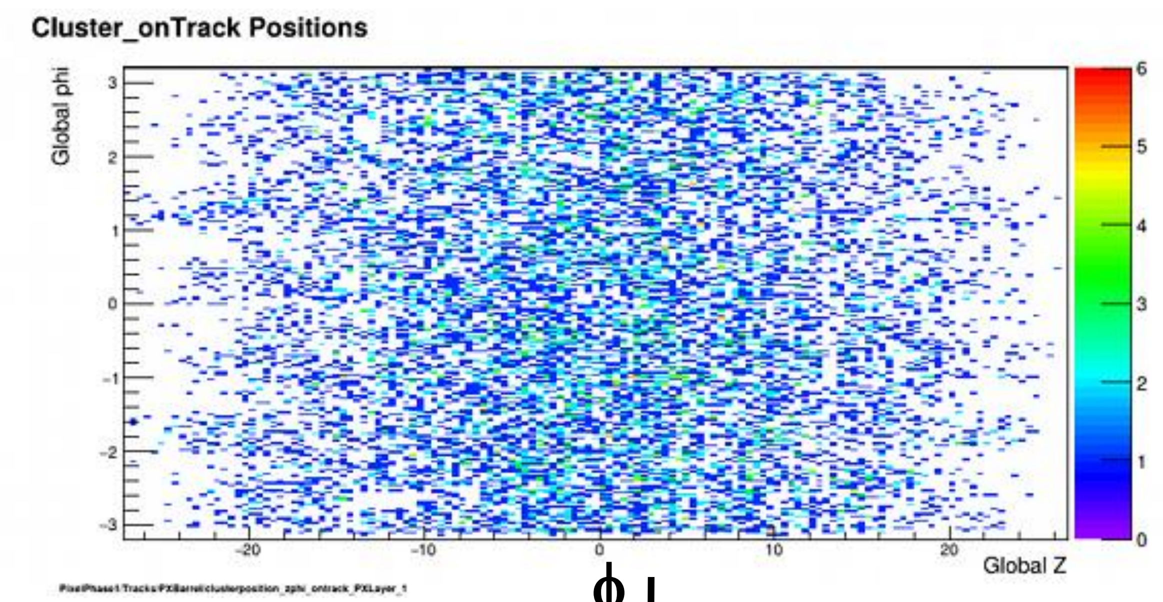


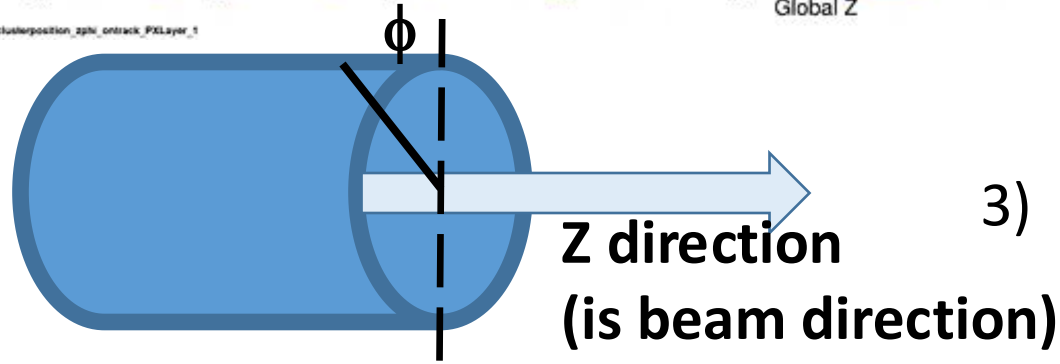
2022 flashback



What are we looking at?

These are the positions of the charge depositions used to reconstruct tracks in CMS
This particular picture represents the inner layer (Layer 1) of the Barrel Detector
Here, we flatten the half cylinder shape in order to visualize the detector (like a map)



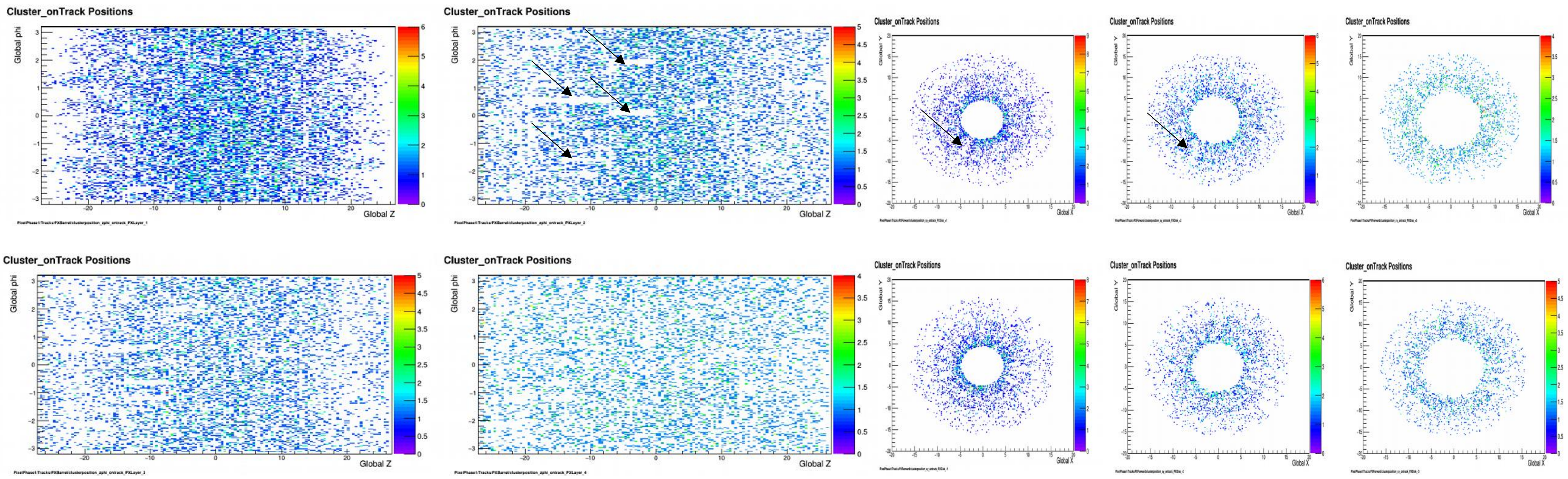


There are a few things here worth noting

1) At higher |Z| in the layer 1, we see less clusters ***used for tracks:*** There are still a lot of clusters at high |Z|, but we can't use them so much since the acceptance of the CMS tracking starts to die out at shallow angles
2) The edges at high |Z| look a little jagged, this is because some Layer 1 detector components are closer to the beam than others
3) There are no gaping irregularities, but we can see a hole maybe at Z= -12 phi = -2.8

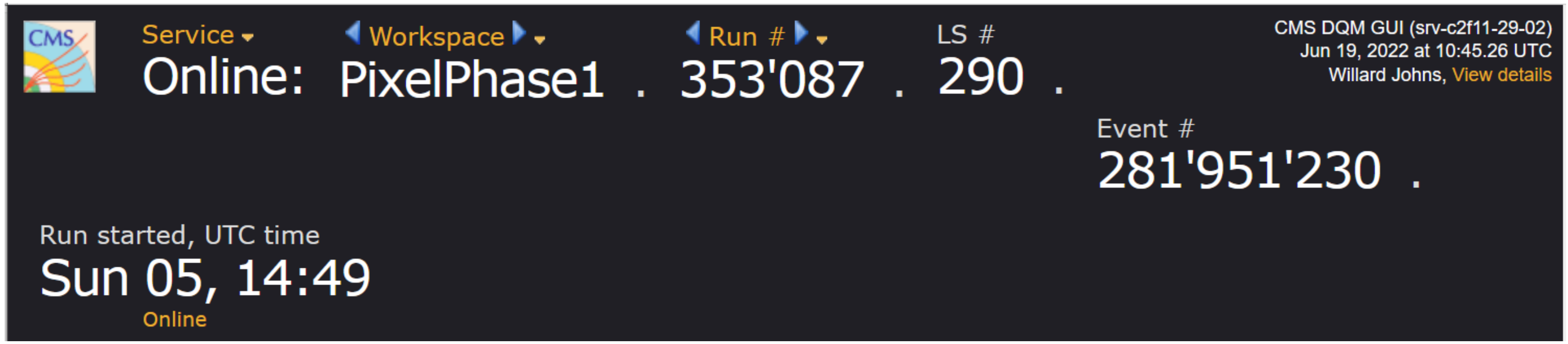
2022 flashback

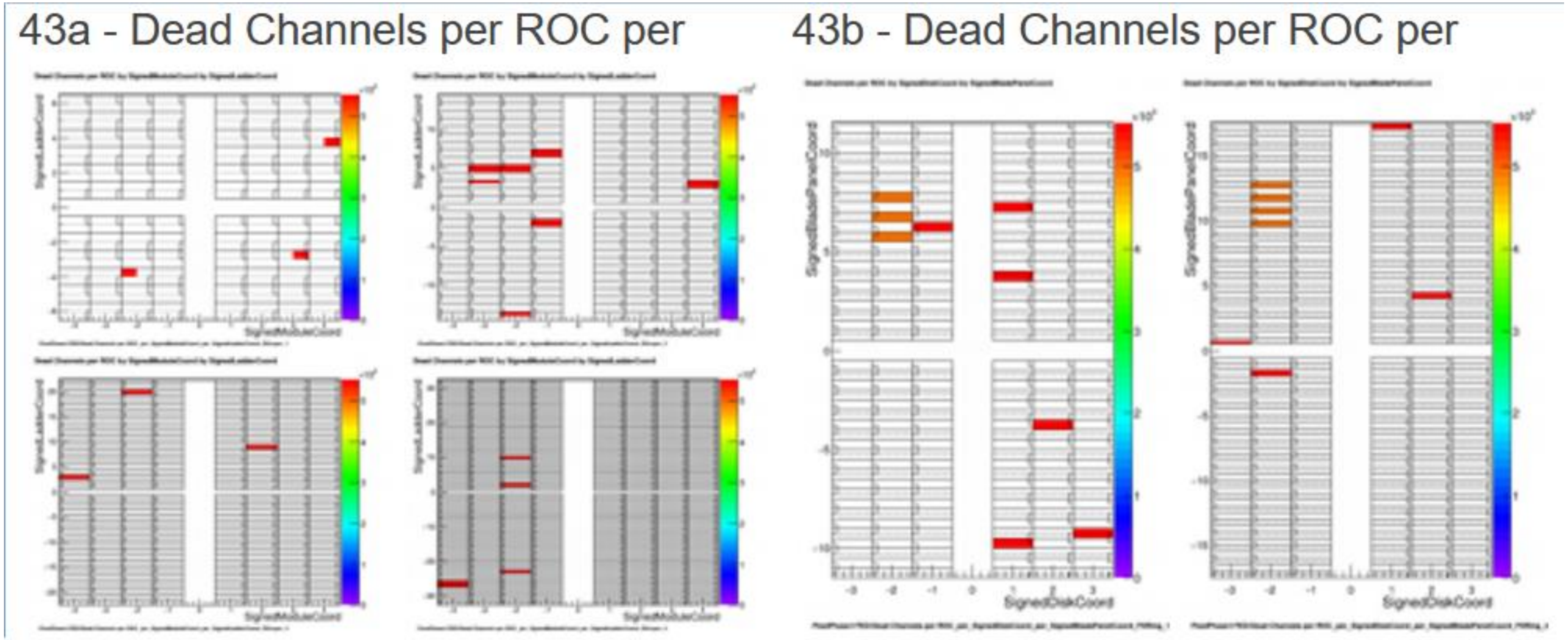
You can see holes in other places of the detector too.



2022 flashback

Detector modules that produce no data tend to be easy to spot.





Here we've also unrolled and flattened the FPiX detector.

Typically, in the pixel, we'll have a few percent of non-working modules

2022 flashback

These plots are very nice since we can get information on the detector components in nearly real time, and the information contains the objects of interest for constructing particle tracks.

We can see the effect of detector tracking acceptance globally.

We can't do all the tricks for track reconstruction in this quicker reconstruction so some effects are obvious

Closer to the collisions

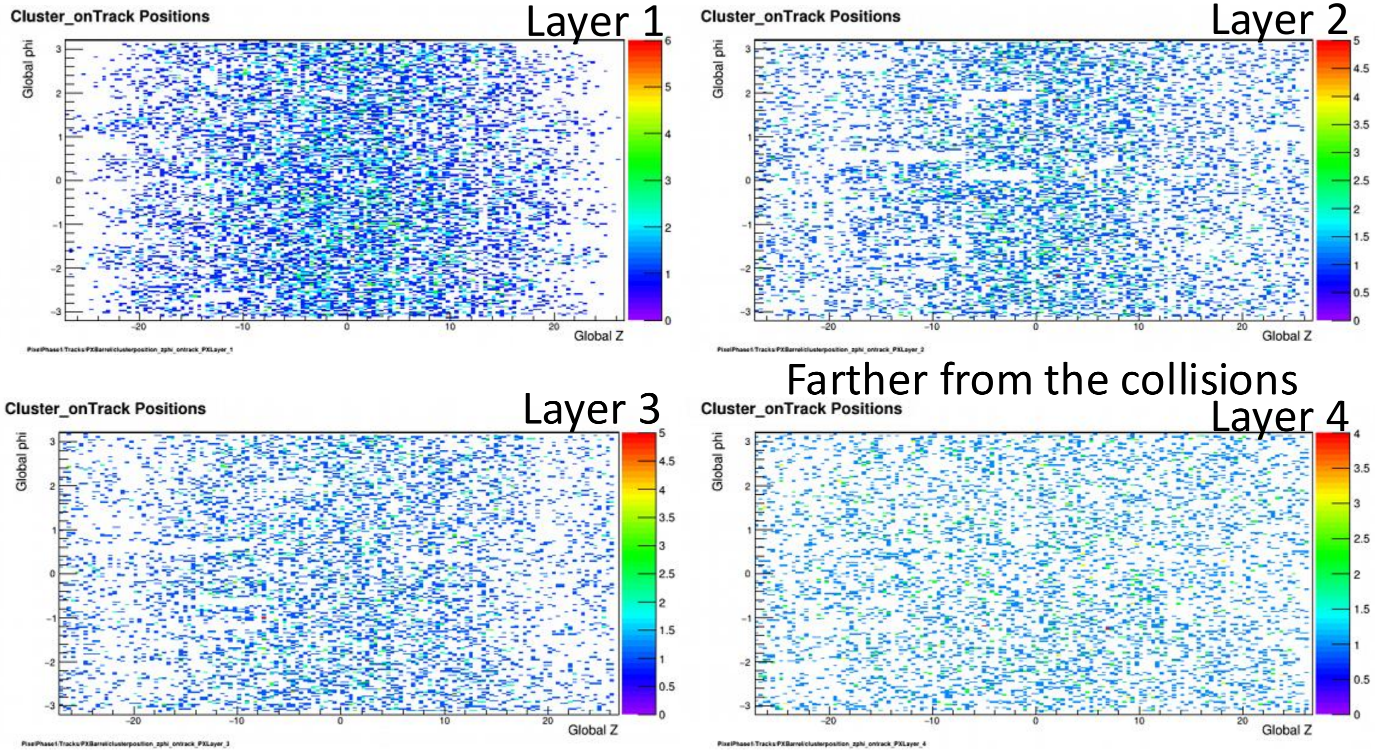
Layer 1

Layer 2

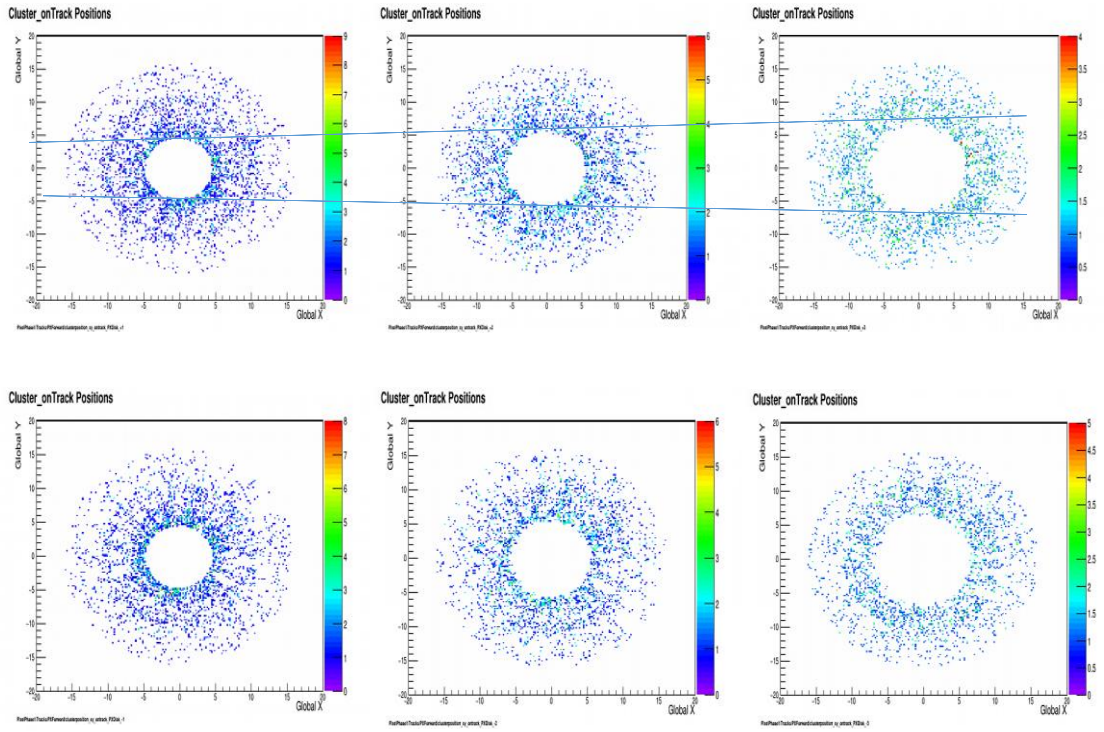
Farther from the collisions

Layer 3

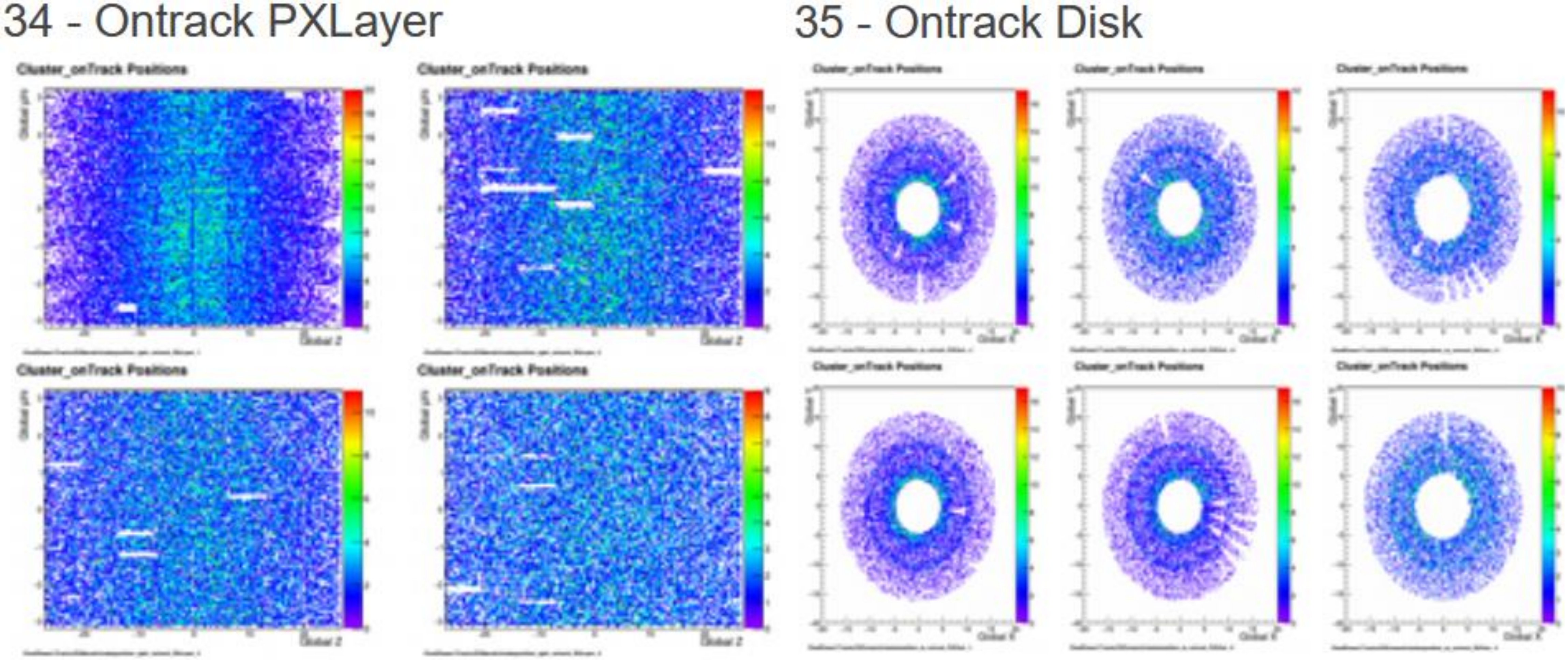
Layer 4



Farther from the collisions



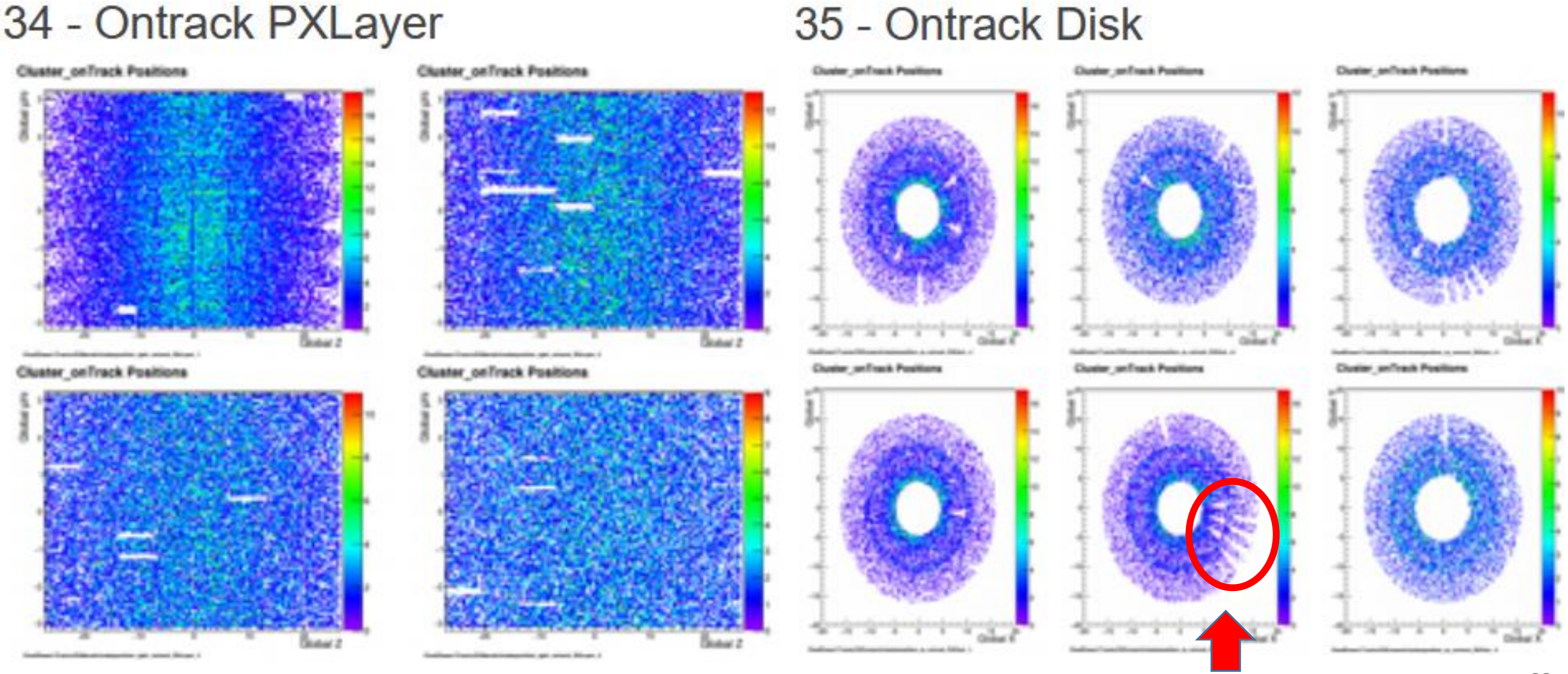
We can also examine data quality after the detector run is over (Offline). There tends to be higher statistics!



With the more thorough reconstruction we are also able to recover more acceptance
(In the FPiX you can also see the overlap of the outer and inner rings!)

2022 flashback

We can also examine data quality after the detector run is over (Offline). There tends to be higher statistics!

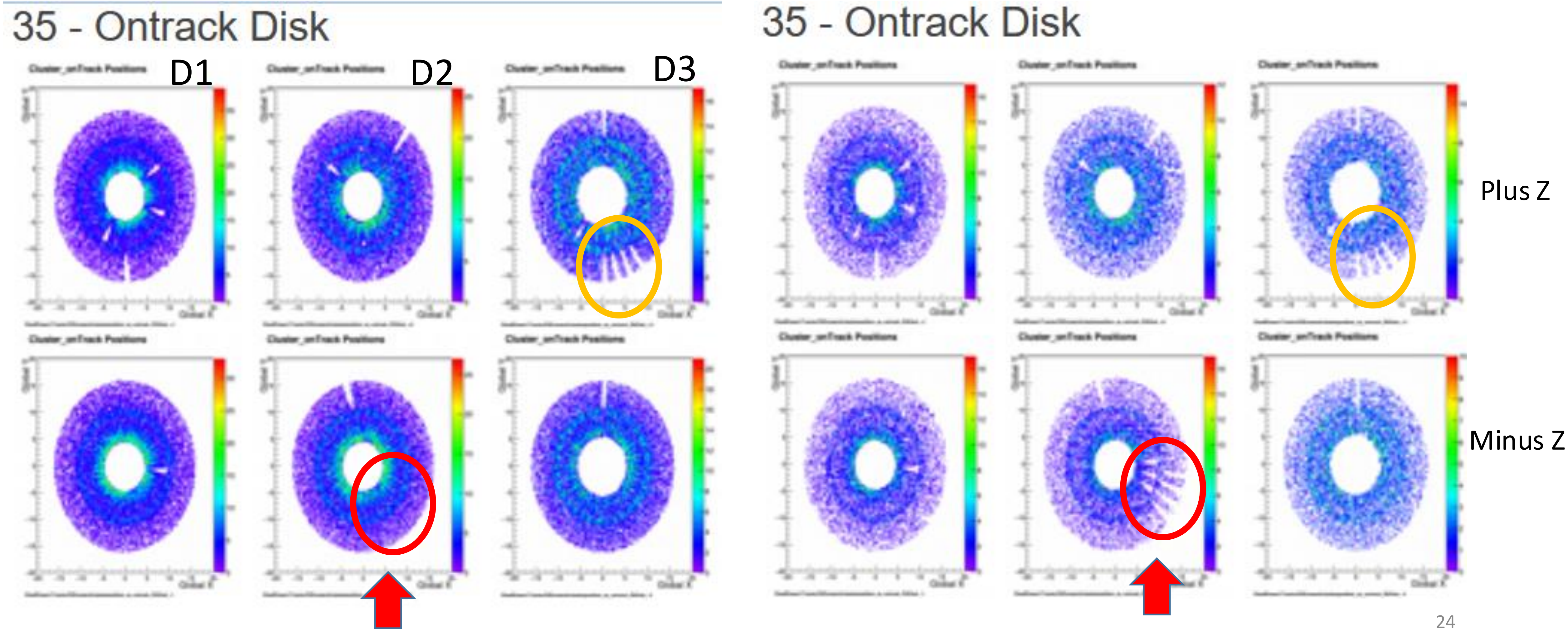


I'm not very happy seeing a pattern like the one in the RED circle in FPiX. It looks like ½ of a 14 channel component known as a PortCard is having an issue.

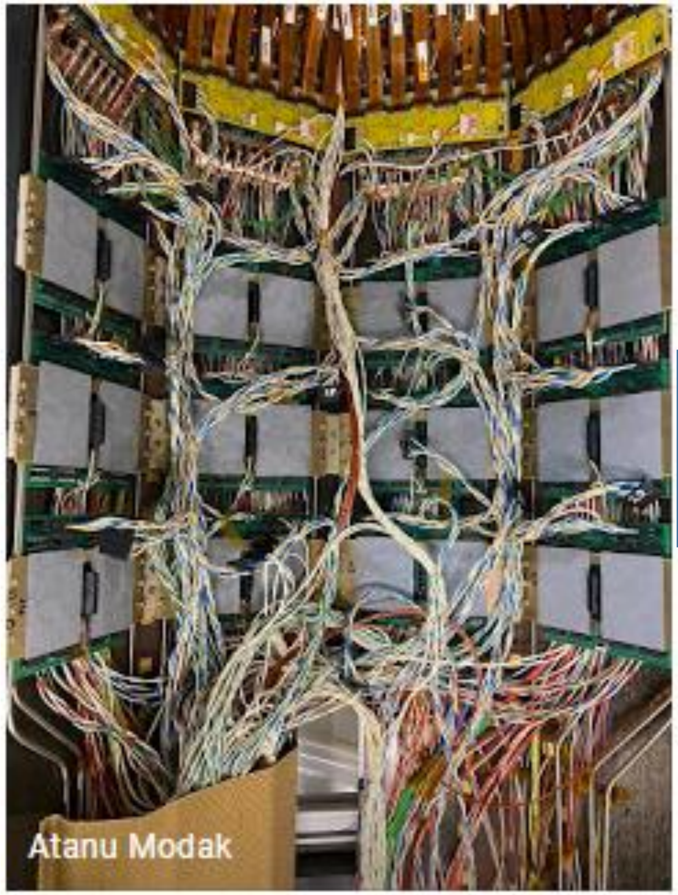
2022 flashback

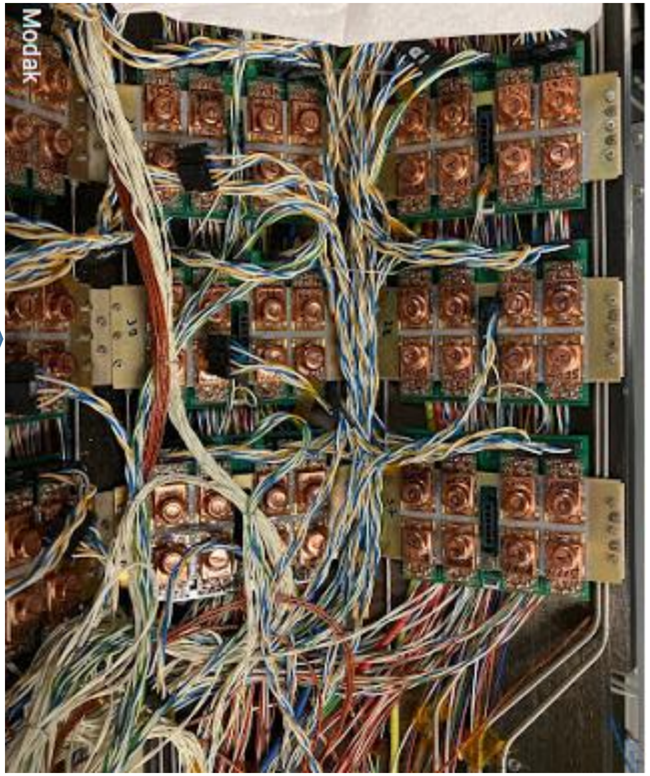
We can examine a previous run to compare.

These detectors are wiley beasts! In a previous run we didn’t have an issue. In the previous run, the issue in yellow concerns me, and it’s in both runs! This issue has The granularity of a DC to DC converter (we use DC-DC converters for the same reason we have transformers in our home power systems: lower current at higher voltages



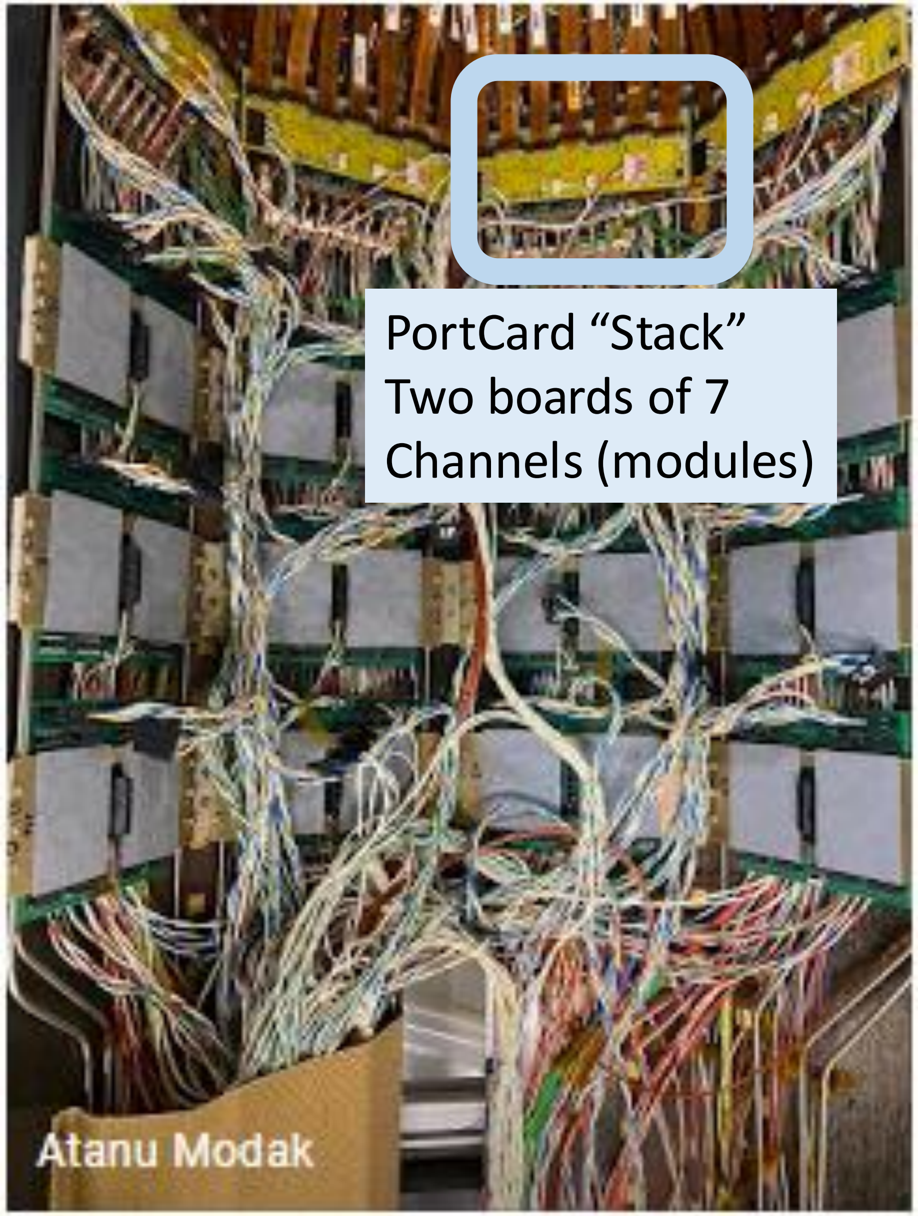
We’ve see these macro-objects earlier





(Where we were at 2021’s talk)

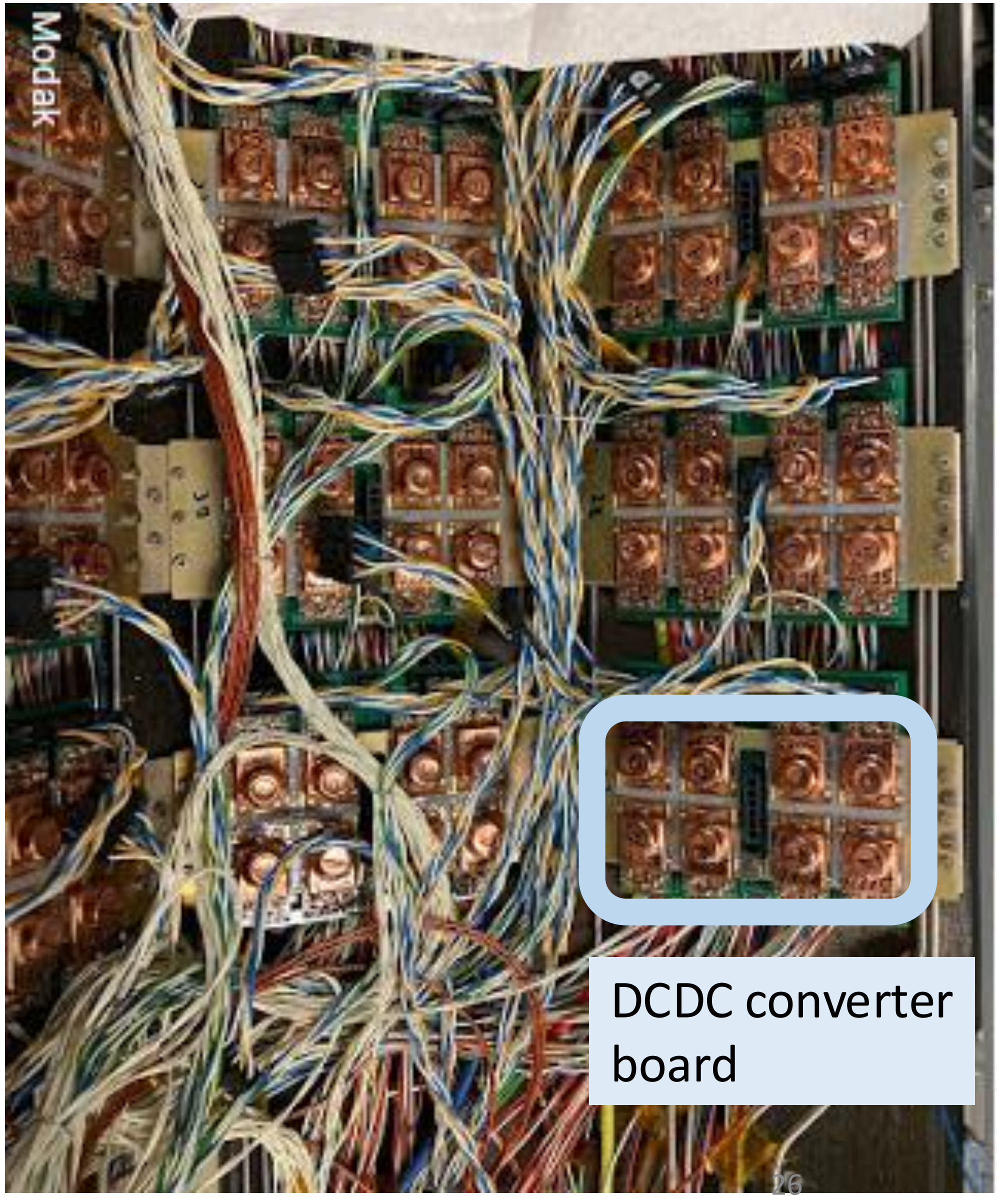
We’ve see these macro-objects earlier



In these pictures we are replacing the DCDC converters with new ones

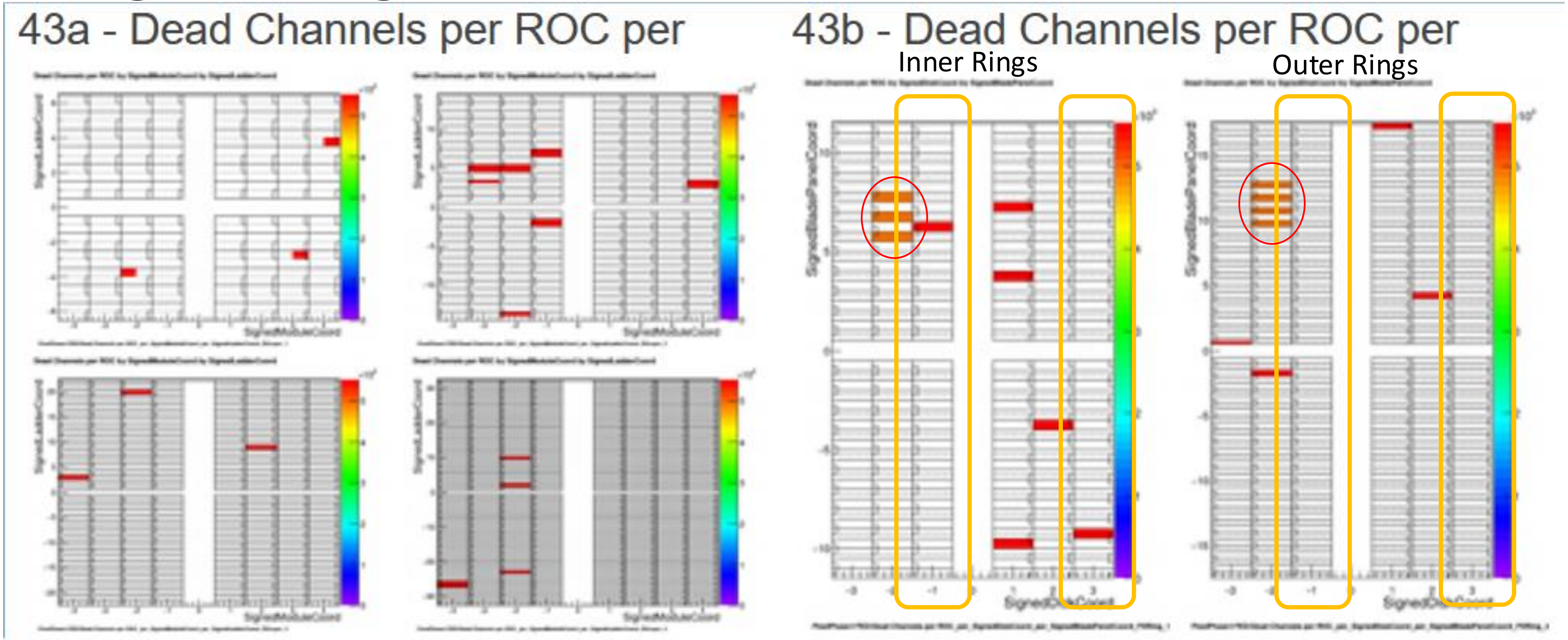
There are 4 pairs of DCDC converters for each PortCard of 14 channels (modules) (so each DCDC pair handles 3-4 modules)

There is a wrinkle: In 2020 we went to a lot of effort to match the DCDC granularity to the HV granularity…



High Voltage or DCDC or ????

2022 flashback



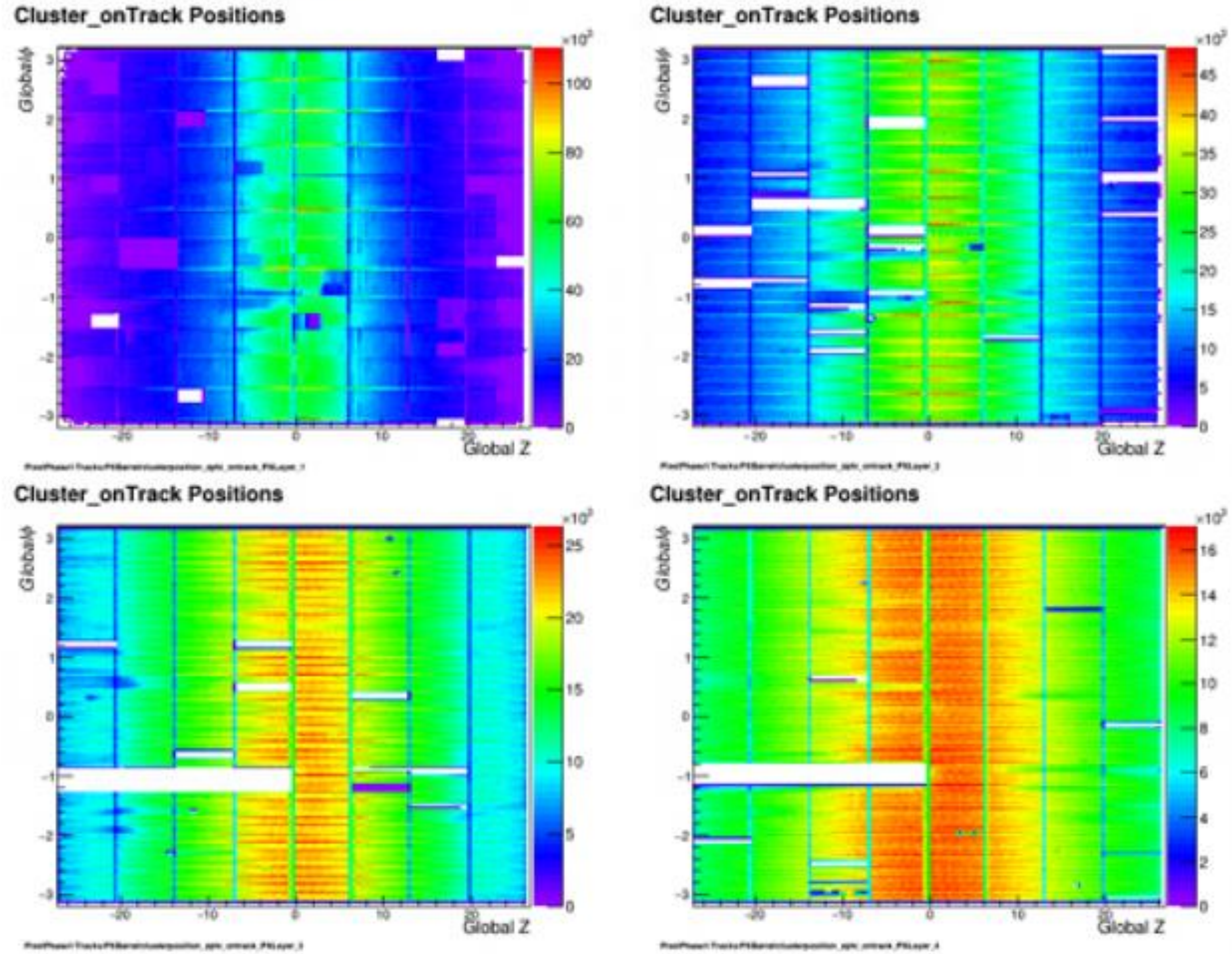
We can clearly see here that the group of seven (RED) show up as “dead”, but there is no indication anywhere in Disk 3 (plus or minus/inner or outer!) that there are a group of 4 dead modules. Could be a high voltage issue and we’ll need to investigate.

Update

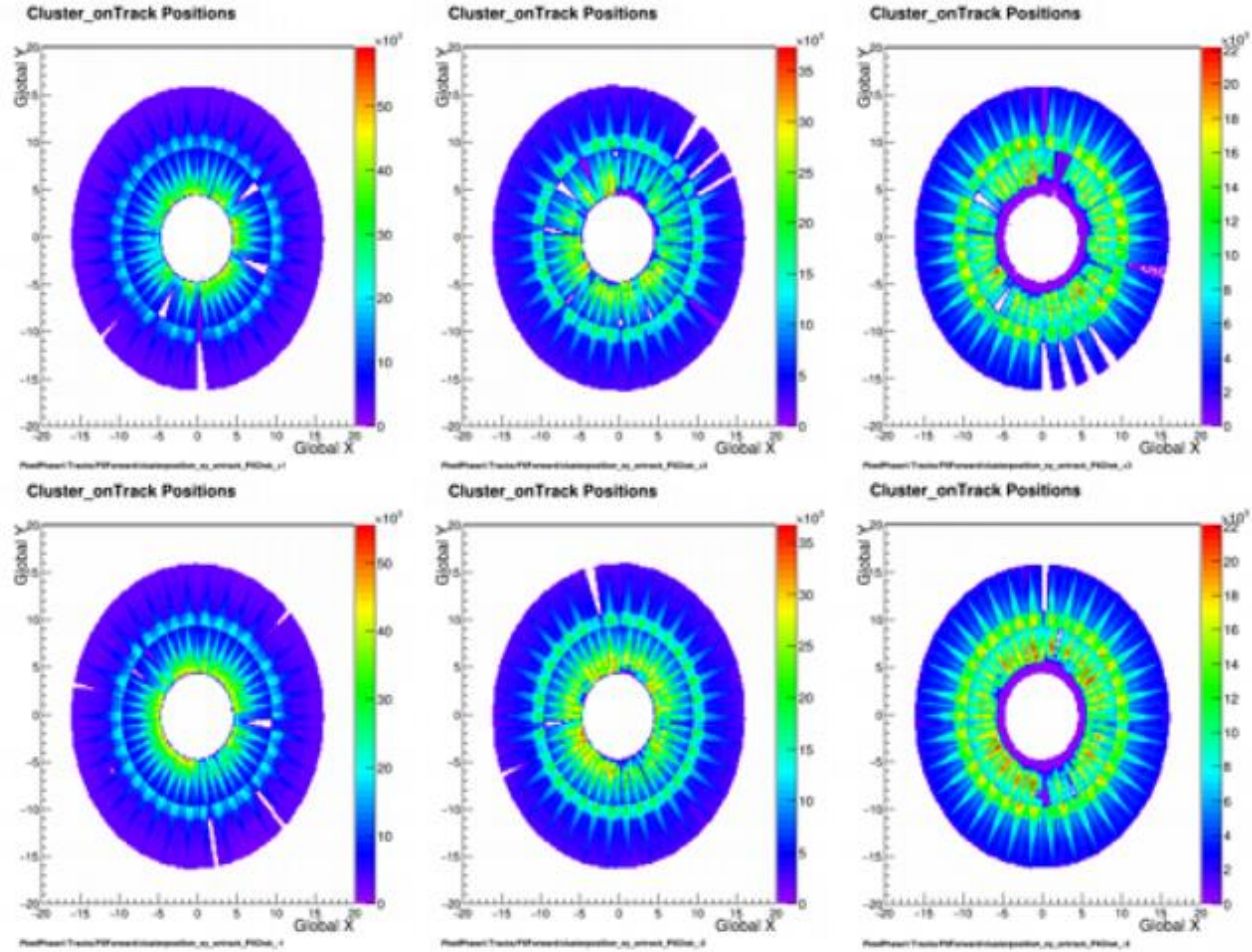
- The modules in disk 3 turned out to be a high voltage problem
- The “port card” came back in a later run in 2022
  - I’ll show you the same output to compare to
- We’ve lost a few more modules in the FPiX, but we lost a large chunk of the BPiX
  - Thankfully we can compensate and it’s not a disaster
  - We’ve had similar losses earlier that we were able to work around
    - One part of the BPiX lost a chip that we could compensate for elsewhere
    - Another part only allows us to load running parameters intermittently

Present Status (2024)

34 - Ontrack PXLayer

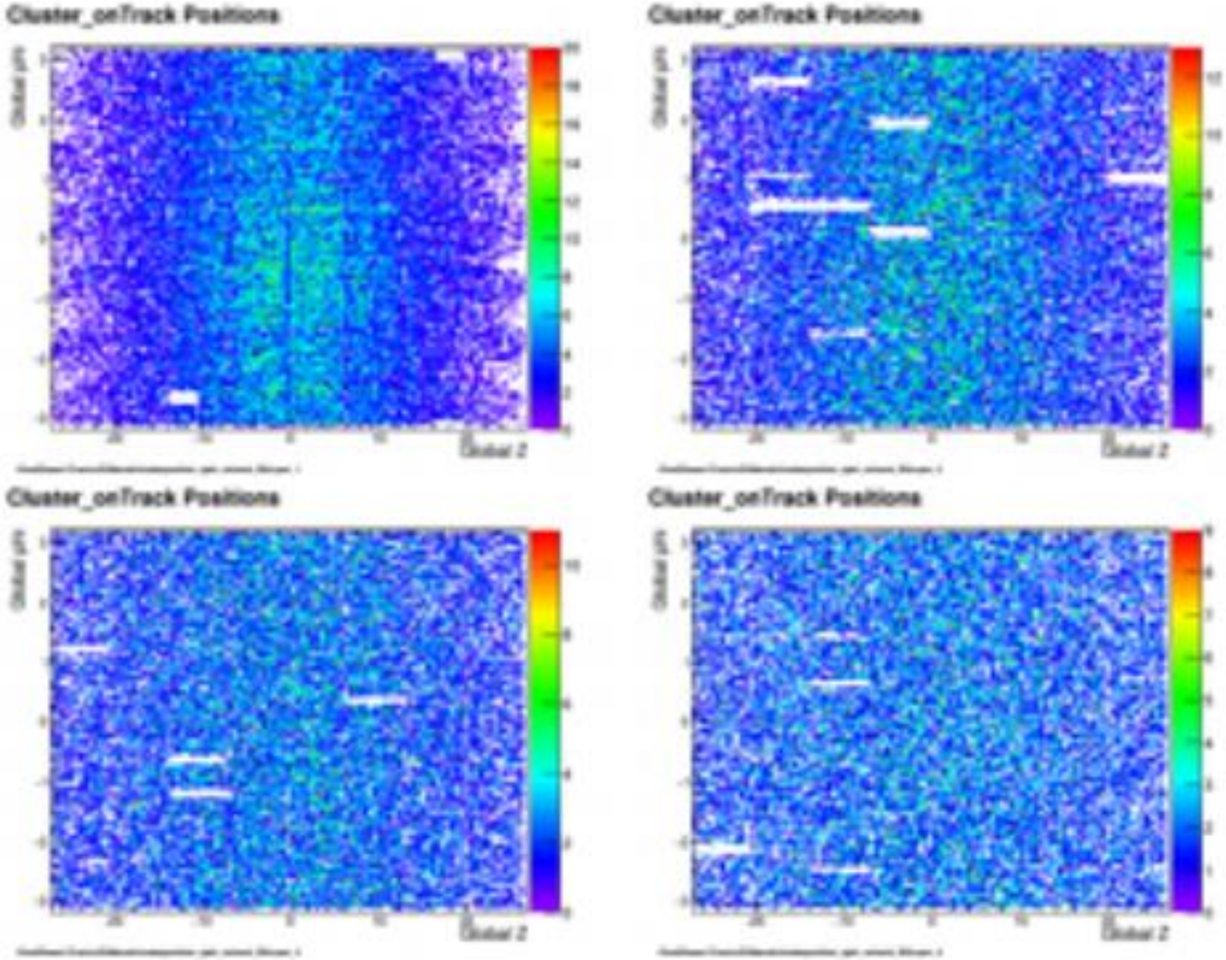


35 - Ontrack Disk



2022

34 - Ontrack PXLayer



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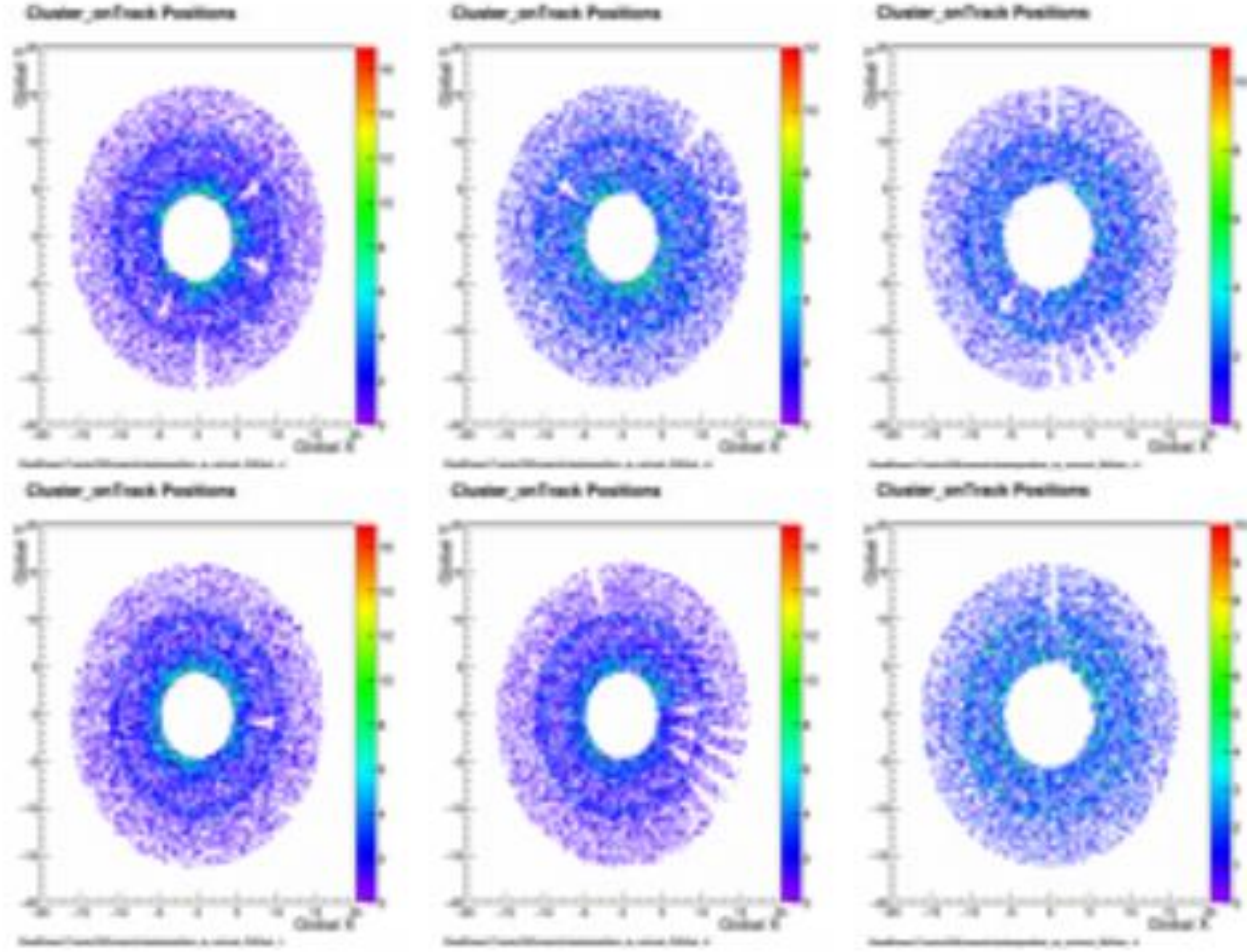
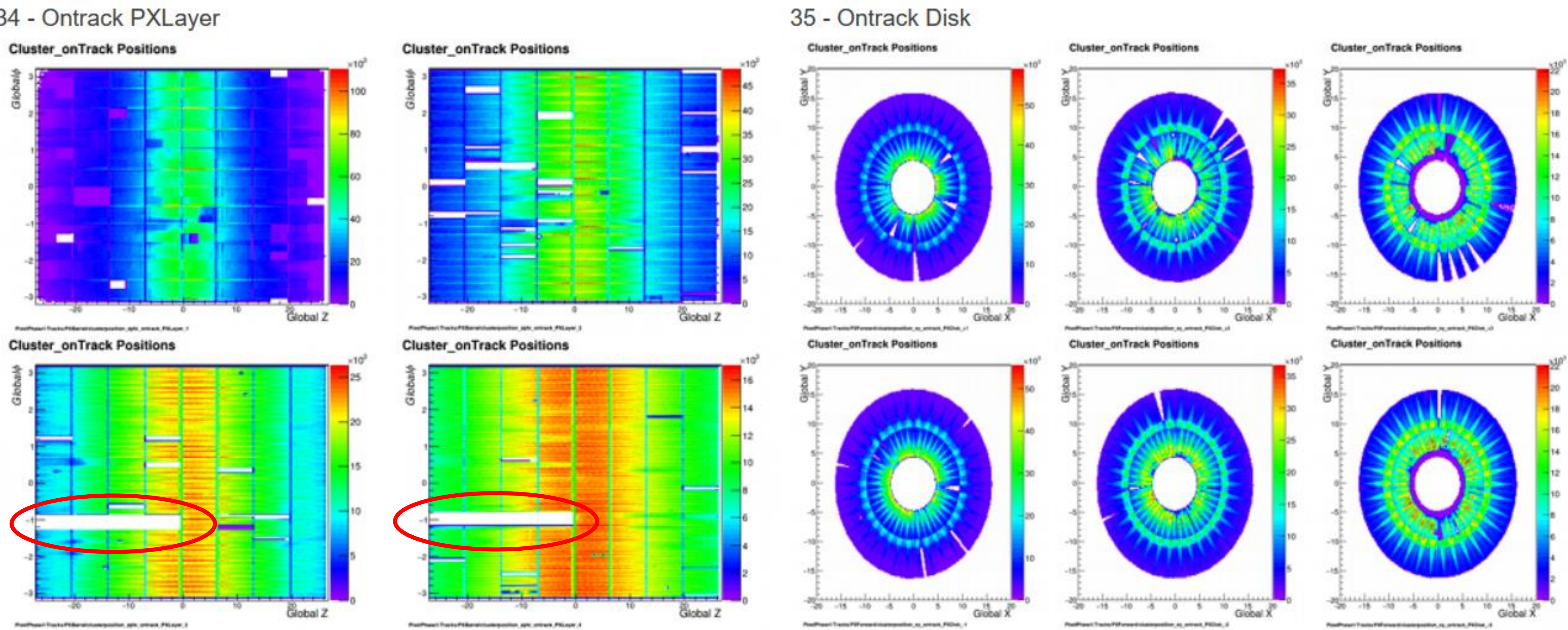


Present Status (2024)

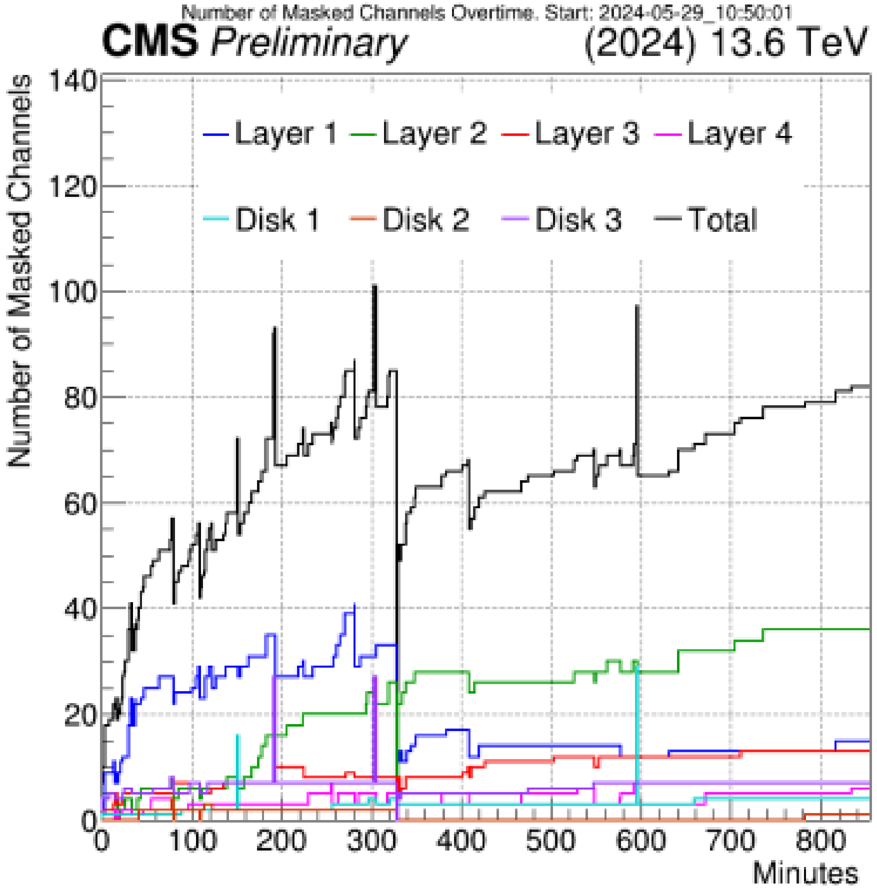


What are the challenges in running in an intense particle environment

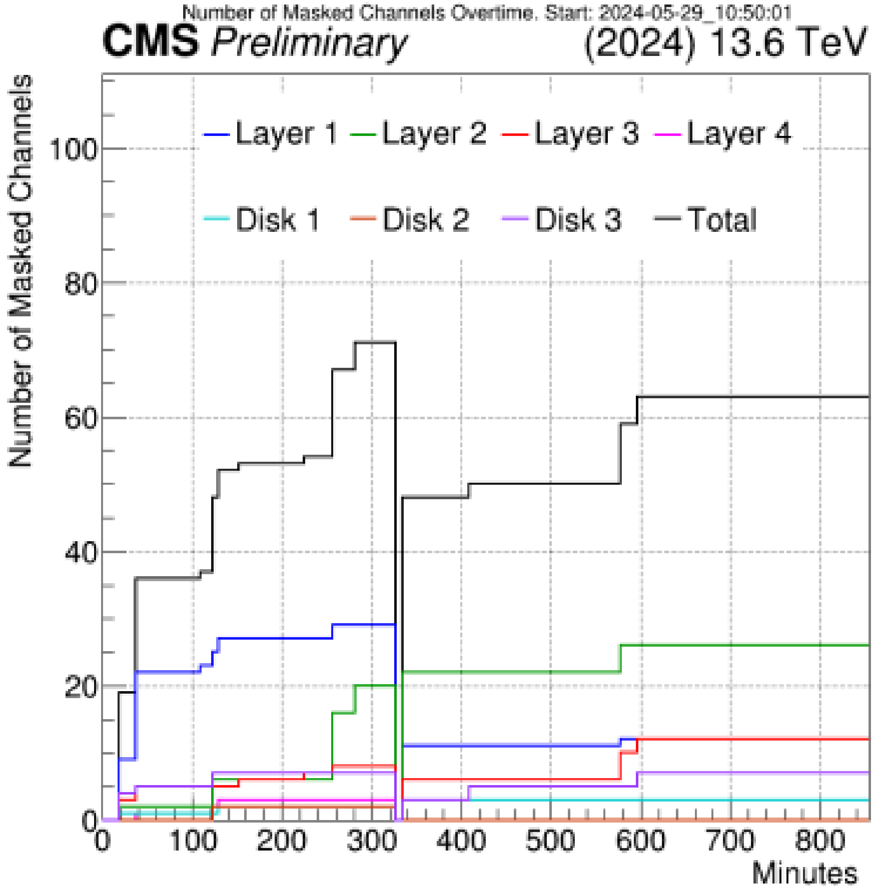
- Our main battle, after keeping the various parts of the detector alive, is to keep the detector operational during collisions
  - Some conditions we can’t fix during a run
    - We need to power cycle these modules after a “fill”
  - Some conditions we fix with a fast reset of the detector
    - These fast resets occur at a rate of ~5/minute
    - Typically, a recovery from a radiation “hiccup”: temporary condition in the module due to radiation
  - Some conditions can’t be fixed with a fast reset
    - Data no longer coming from a module, or the data is hopelessly garbled
    - Here we pause data taking for a few seconds and reload the operational constants to the modules
      - If we do this 3 times and a module is still giving problems, the module is blacklisted and we will either wait until the fill is over, or until the radiation environment lessens to try again

One critical thing for us to look at is the of blacklisted modules

Fill 9687, all masked

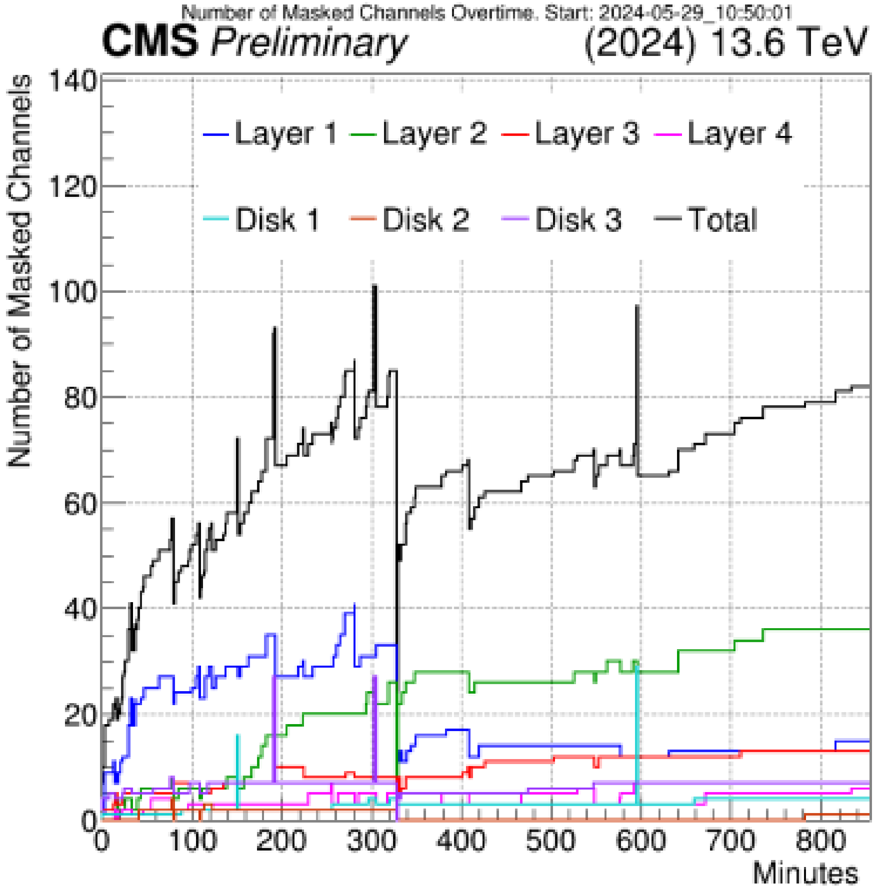


Fill 9687, blacklisted

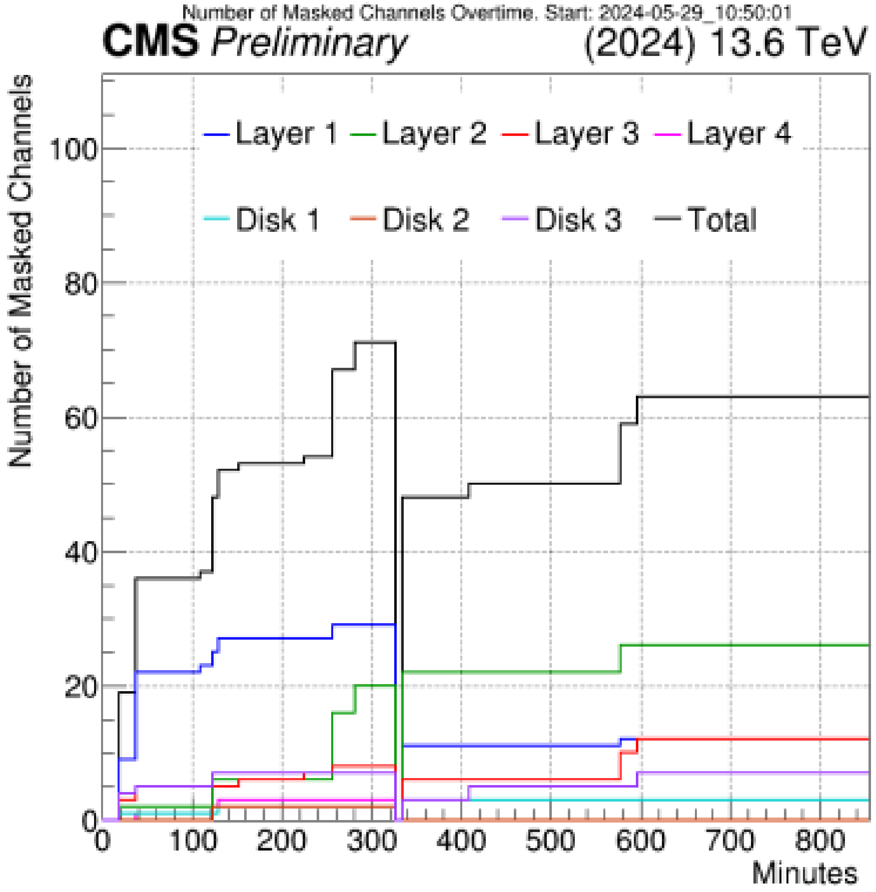


At one point you notice that the modules with a problem (masked) and those blacklisted, go to 0

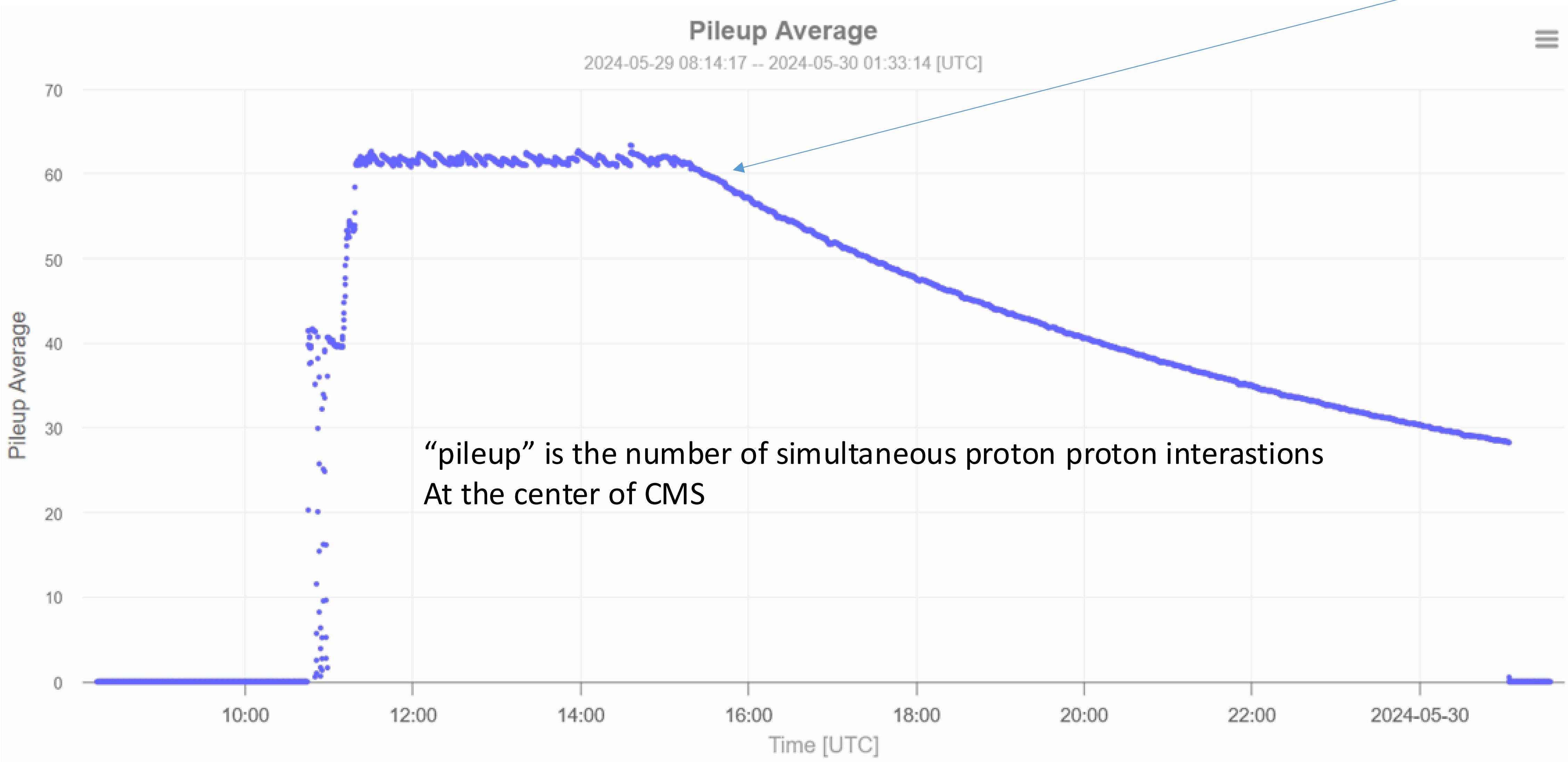
Fill 9687, all masked



Fill 9687, blacklisted



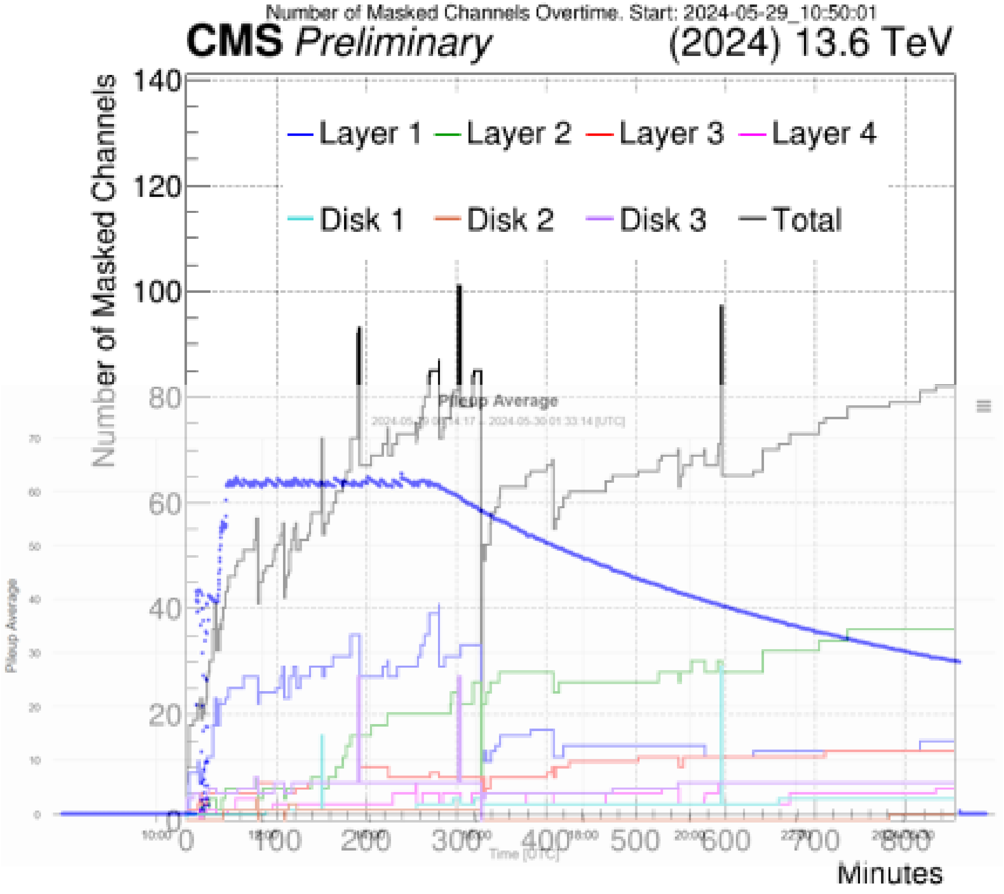
We ask for the data taking to be paused so that we can clear the blacklist when the pileup drops to 60



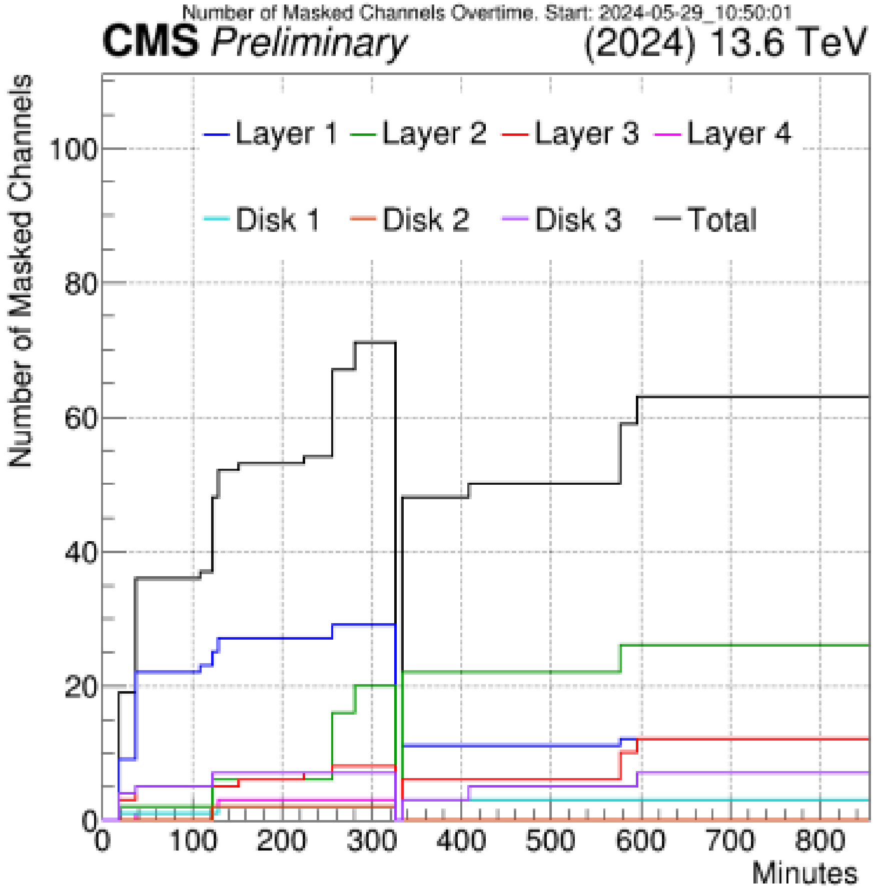
“pileup” is the number of simultaneous proton proton interastions
At the center of CMS

At one point you notice that the modules with a problem (masked) and those blacklisted, go to 0

Fill 9687, all masked

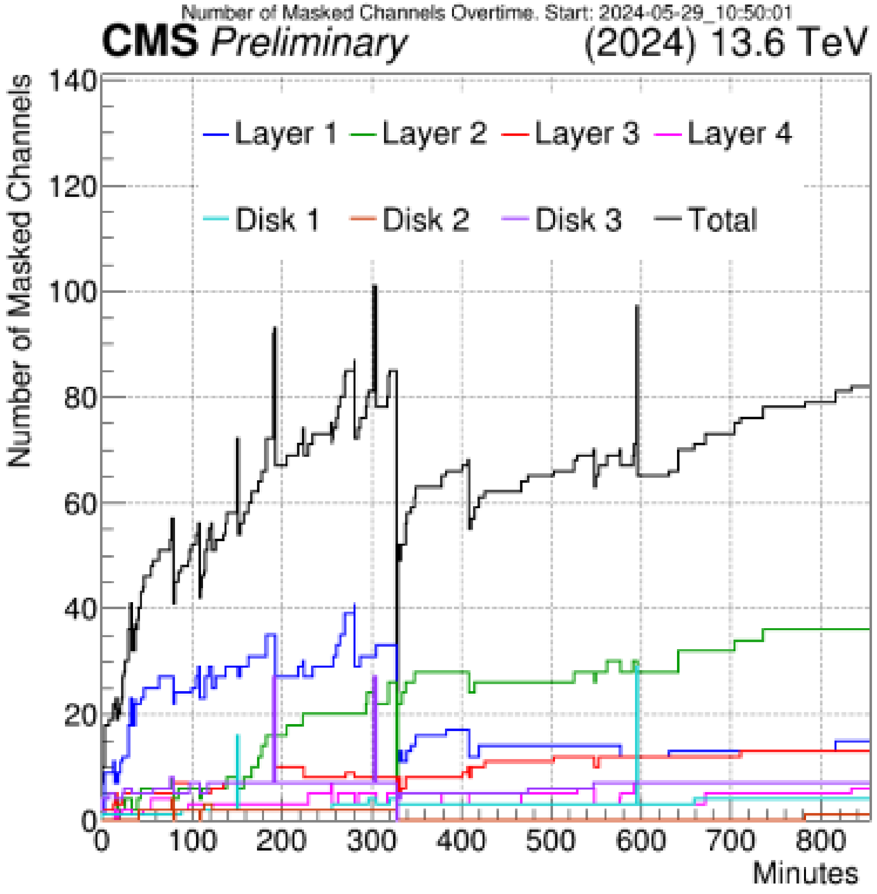


Fill 9687, blacklisted

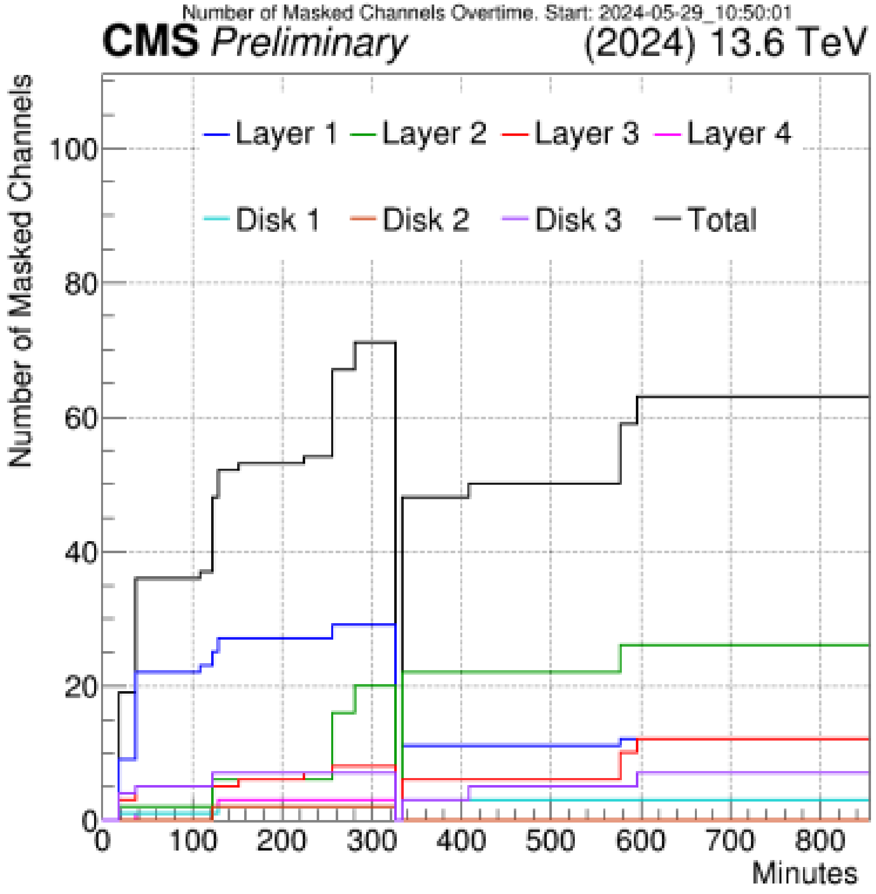


Notice that after the pause, the number of layer 1 modules drops, but other parts not so much

Fill 9687, all masked



Fill 9687, blacklisted



Why does the layer 1 recover better?

- In 2017 we found that one chip on the module, called the TBM or "Token Bit Manager" would have a radiation interaction where it would get stuck and require a power cycle
  - We decided to make a new TBM and a new Barrel layer 1 for replacement and subsequent installation in (haha) 2020
    - Other parts of the layer 1 benefitted from new readout chips and sensors
    - The fixed TBM also included a provision to fine tune the delay for the Layer 1
- In 2021, we reinstalled the refurbished layer 1
  - You can clearly see that we've reduced the number of modules stuck in the blacklist and able to operate
- We are now in a continual battle to keep ahead of radiation effects in the Pixel detector
  - We can try new settings, raising sensor bias voltages to maintain efficiency, and reloading constants more frequently. The latter only possible with a new way to download the constants quickly

Backup

Language of colliders

- The machine delivers a particle Luminosity
  - Proportional to collision frequency, number of particles in each beam bunch, and inversely proportional to the overlap in the beams

$$\mathrm{L} \propto f\, N_1 N_2 /(\Delta x \Delta y)$$

  - And the creation rate for a particular process is given by $\mathrm{R} = \mathrm{L}\sigma$
  - Where the sigma represents the cross-section for the process in question
    - Proportional to the number of “scattered” particles per incident flux (has units of area)
    - One can increase L in a number of ways

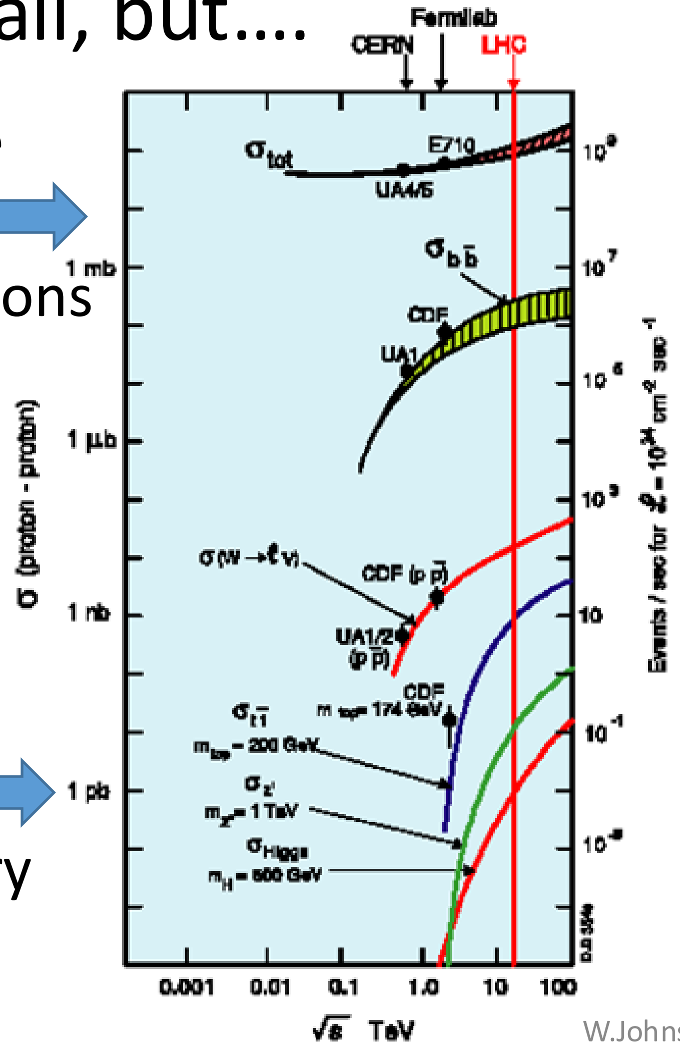
Couple of reasons this is interesting

- Higgs rate will be small, but….

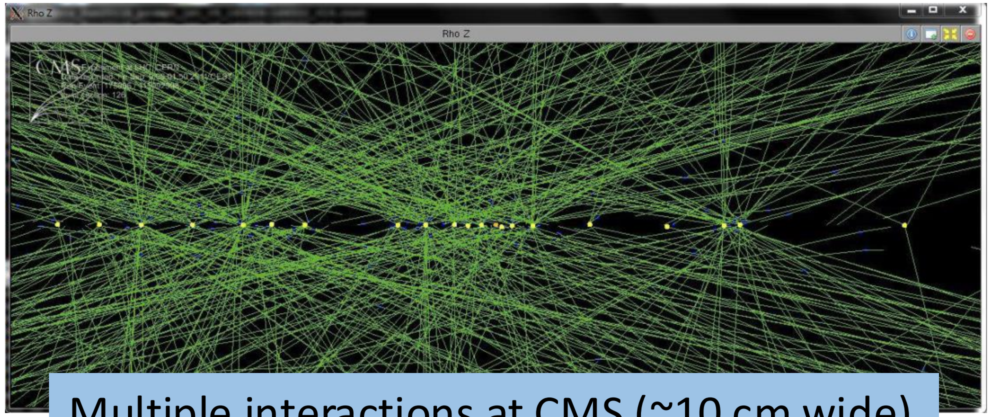
Multiple Interactions

x1000

Higgs Territory



- Increasing N gives more multiple p-p interactions (~20 here):



Multiple interactions at CMS (~10 cm wide)

- “pileup” is challenging for the detector and event reconstruction
- Event reconstruction is faster if the detector conditions are constant and of high efficiency