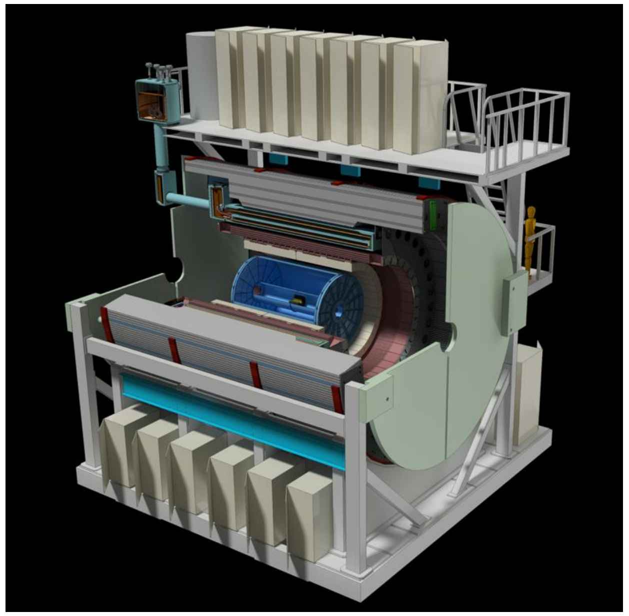


Streaming Readout of the sPHENIX Tracking System

Martin L. Purschke

BROOKHAVEN NATIONAL LABORATORY

Manhattan

Long Island, NY

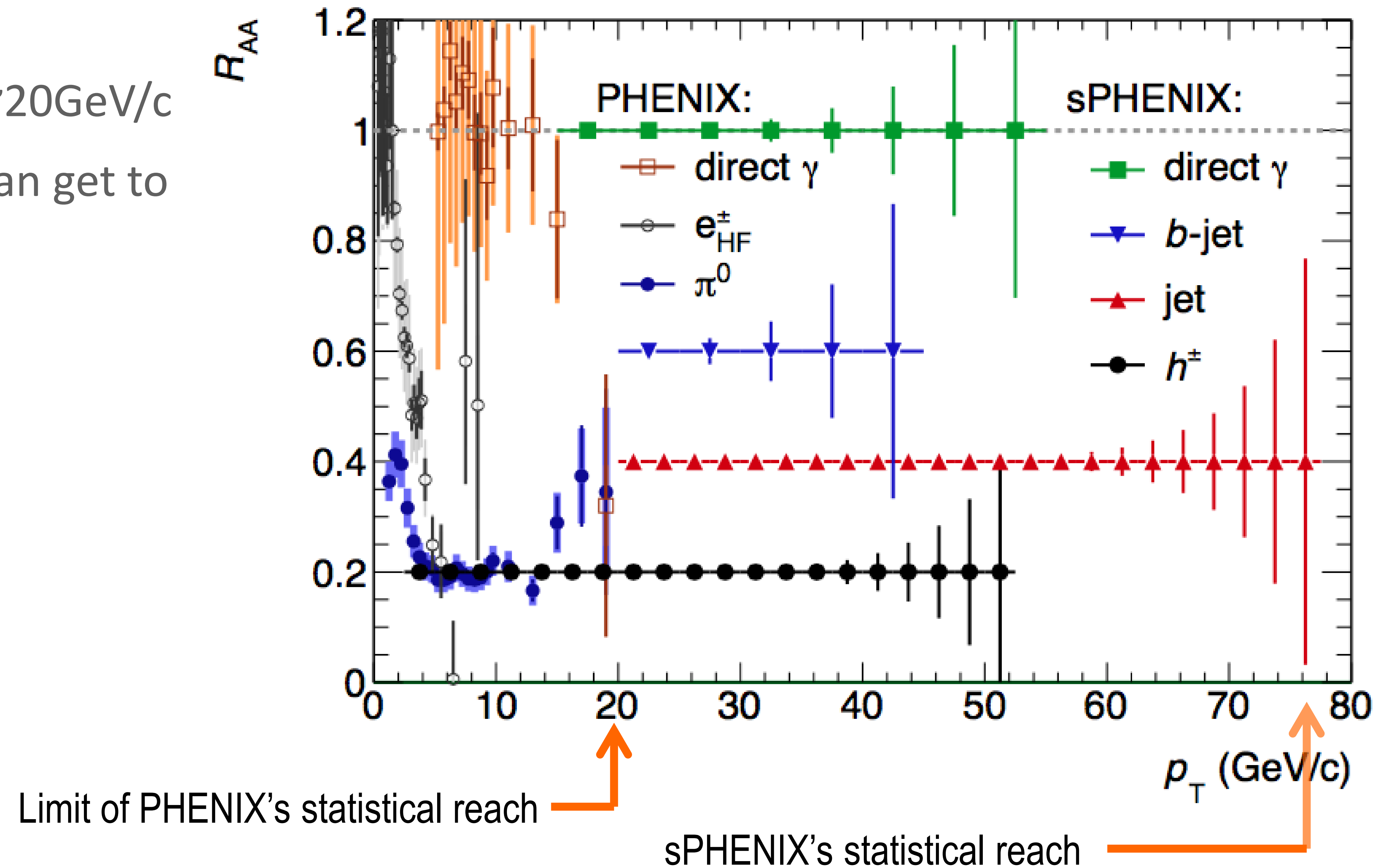
RHIC from space

T-Shirt Plot: Statistical Reach for some probes

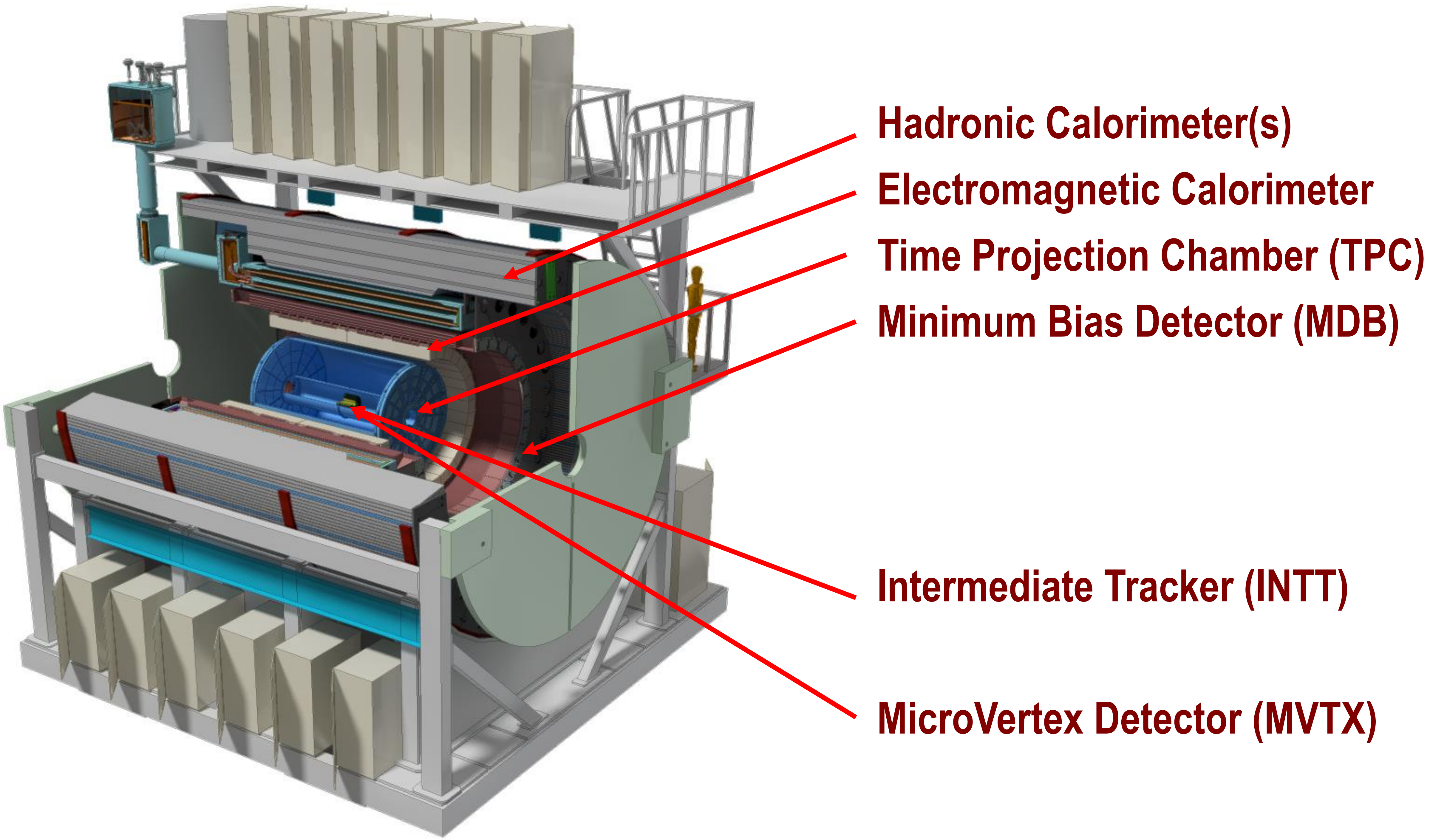
The way PHENIX gets to high PT is through π^0s

That reaches to ~20GeV/c

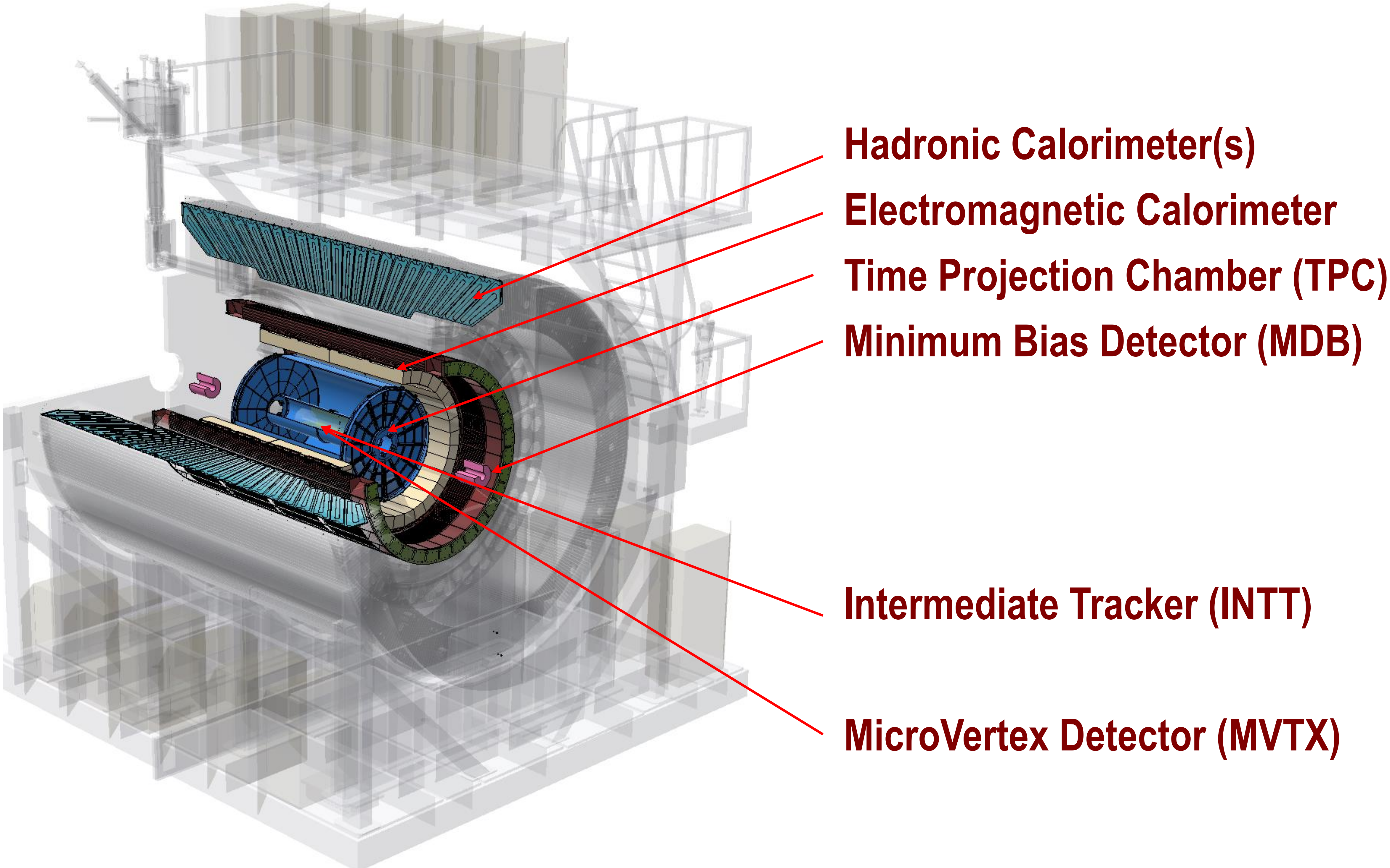
In sPHENIX, we can get to 4x that with jets



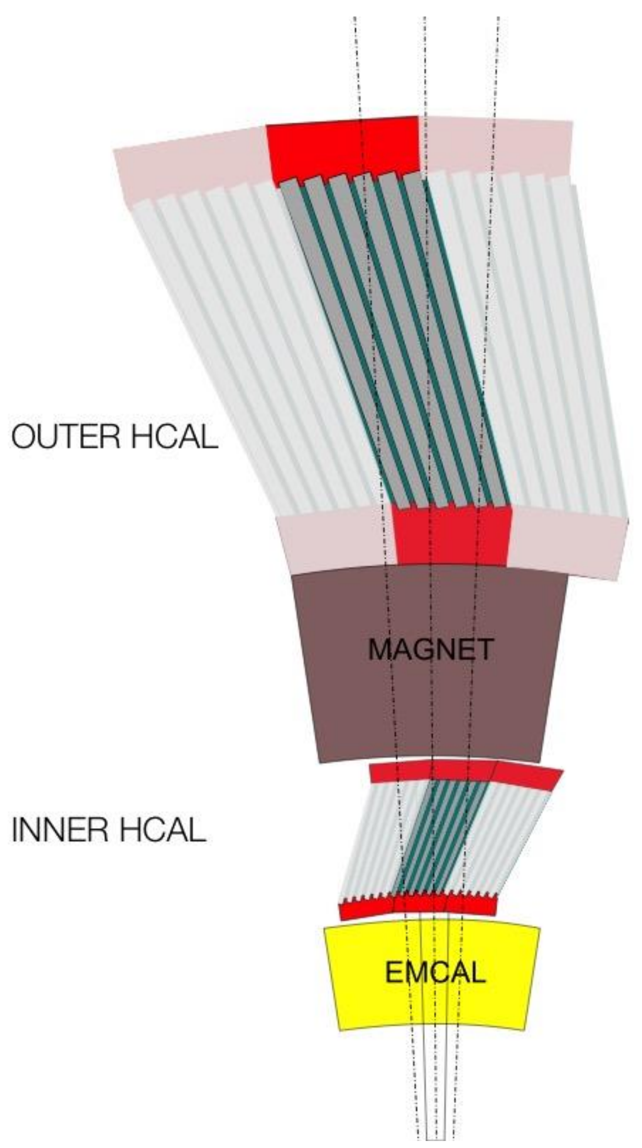
sPHENIX – the Concept

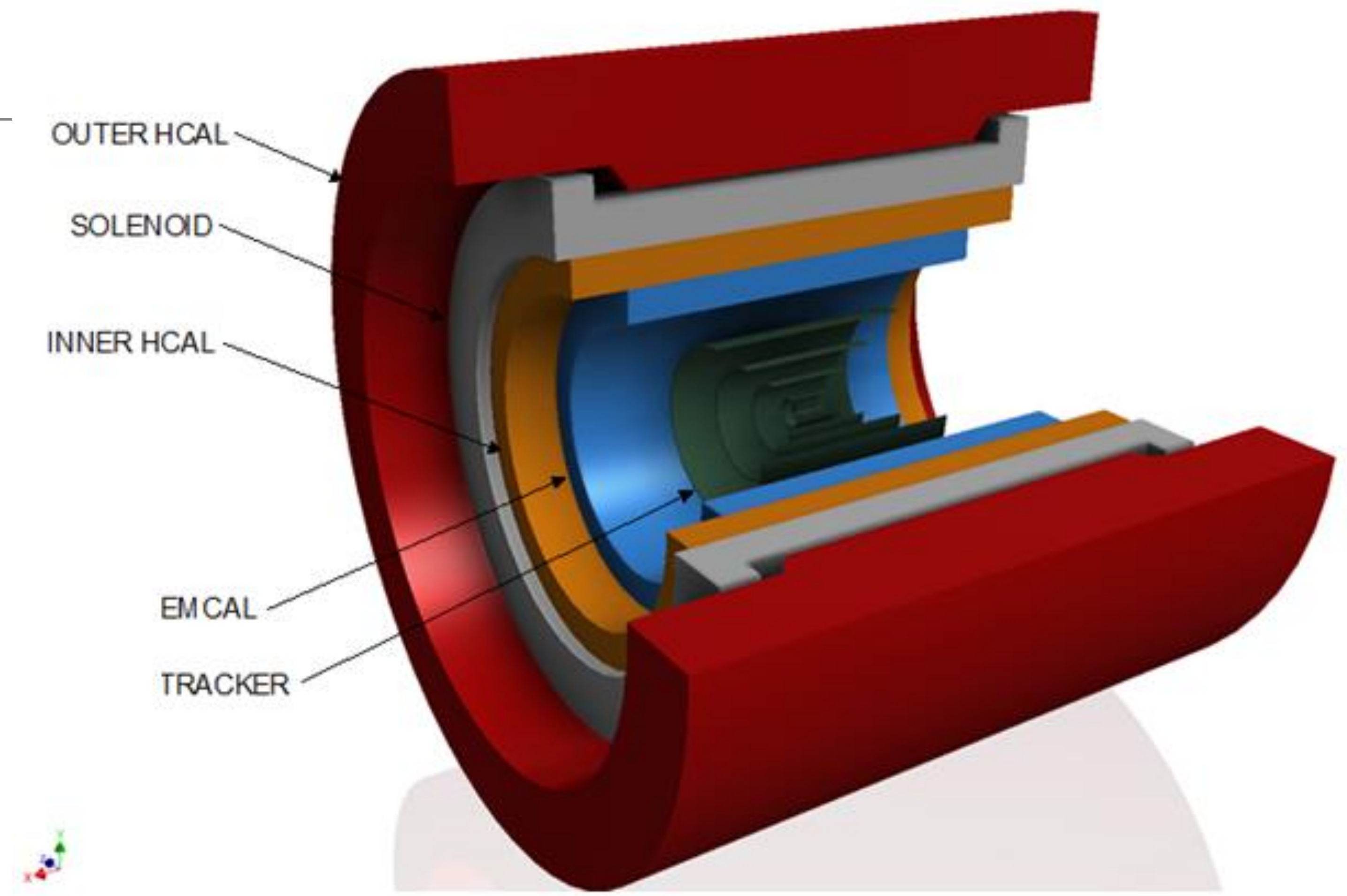


sPHENIX – the Concept



sPHENIX – Calorimetry





- Outer HCAL $\approx 3.5\lambda_I$
- Magnet $\approx 1.4X_0$
- Inner HCAL $\approx 1\lambda_I$
- EMCAL $\approx 18X_0 \approx 1\lambda_I$

We have already presented the calorimeters last time, I'll focus on the tracking (and the TPC) today

s with

oid.

enoid.

2 x 24 x 64 readout channels

$\sigma_E/E < 100\%/\sqrt{E}$ (single particle)

SiPM Readout

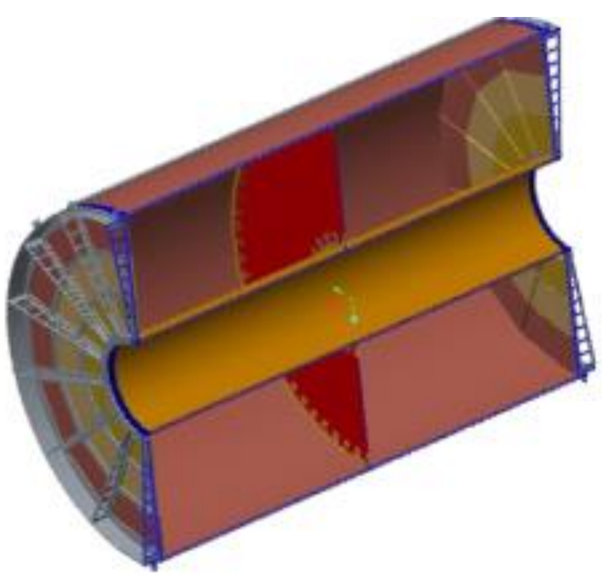
Three Tracker Components

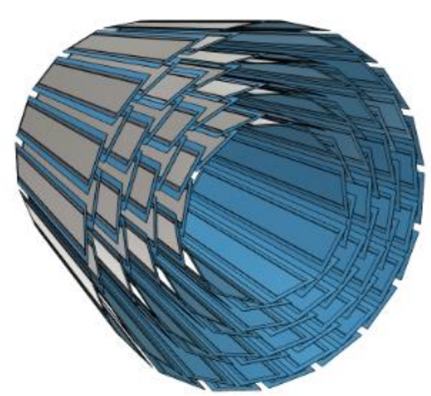
Micro-Vertex Detector (MVTX) Three-layers identical to Inner ALICE ITS (r = 2.3cm, 3.1 cm, 3.9 cm)

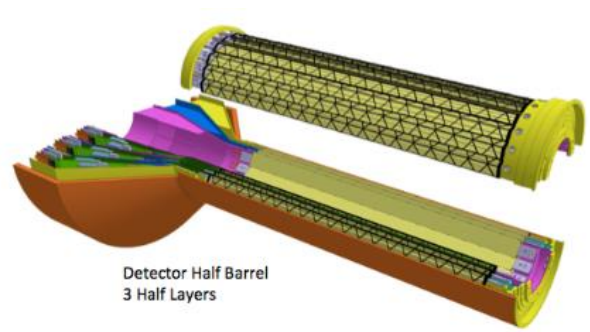
Intermediate Silicon Strip Tracker (INTT) Four layer Si strip detector. (r = 6 cm, 8 cm, 10 cm, 12 cm)

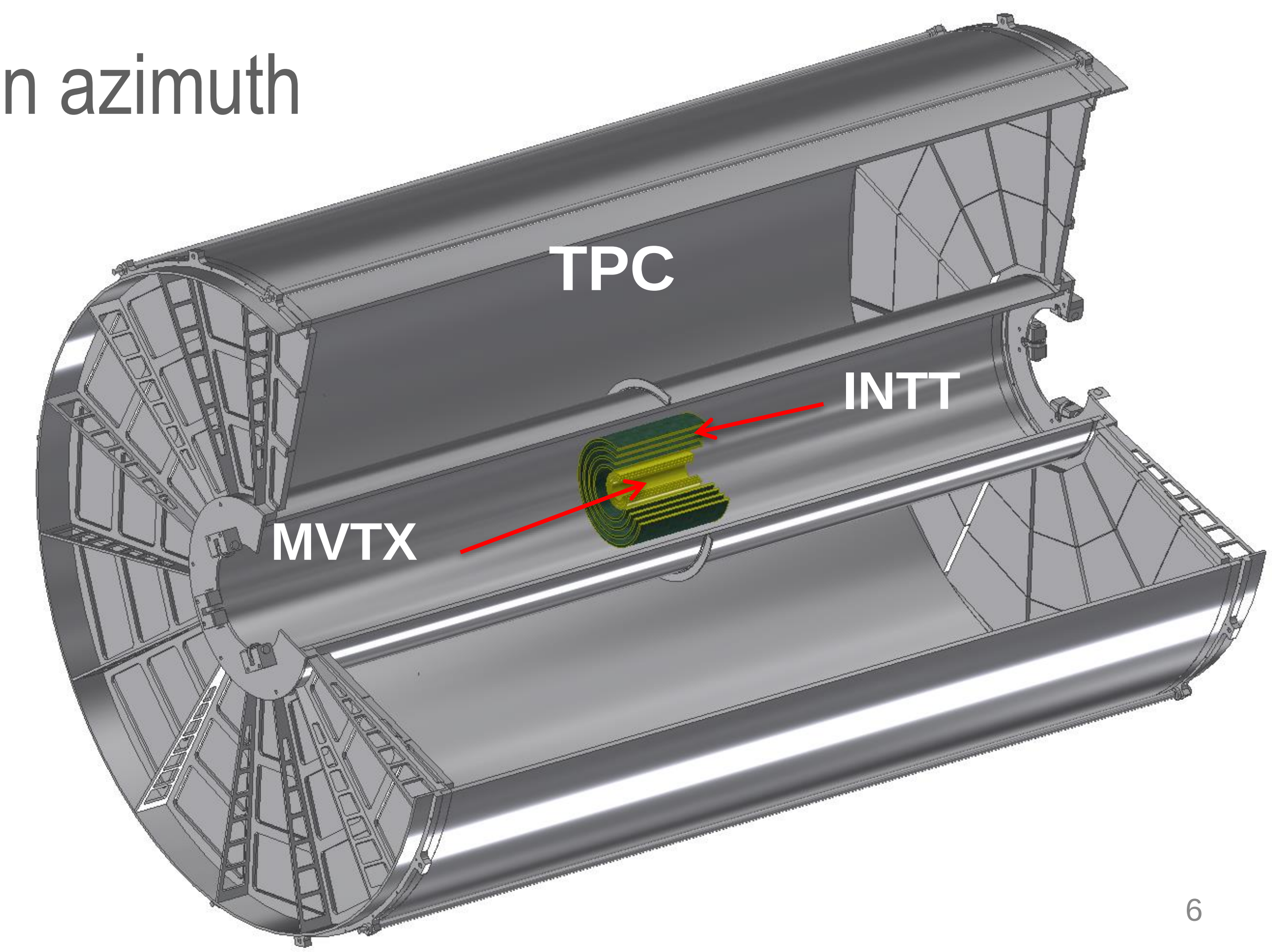
Compact Time Projection Chamber (TPC) (20 cm < r < 78 cm)

All cover at minimum | η | < 1.1 and 2π in azimuth







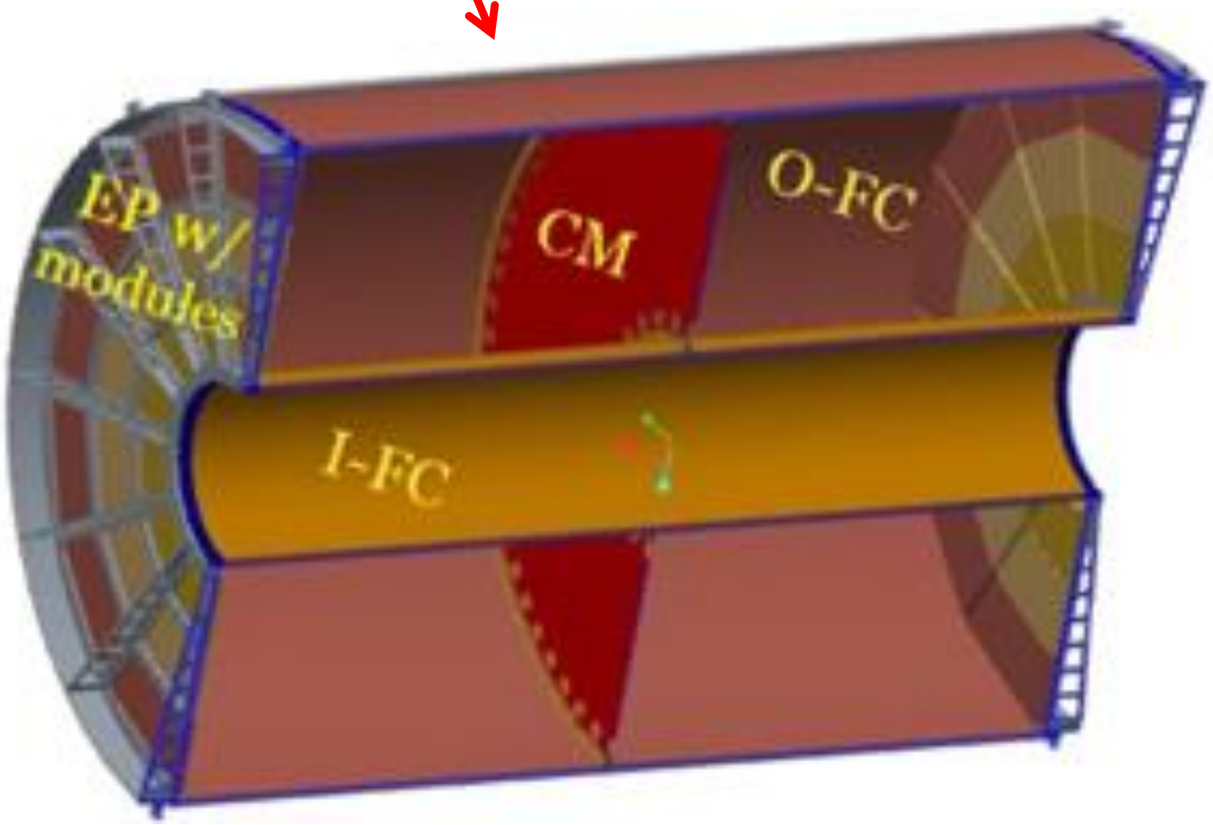


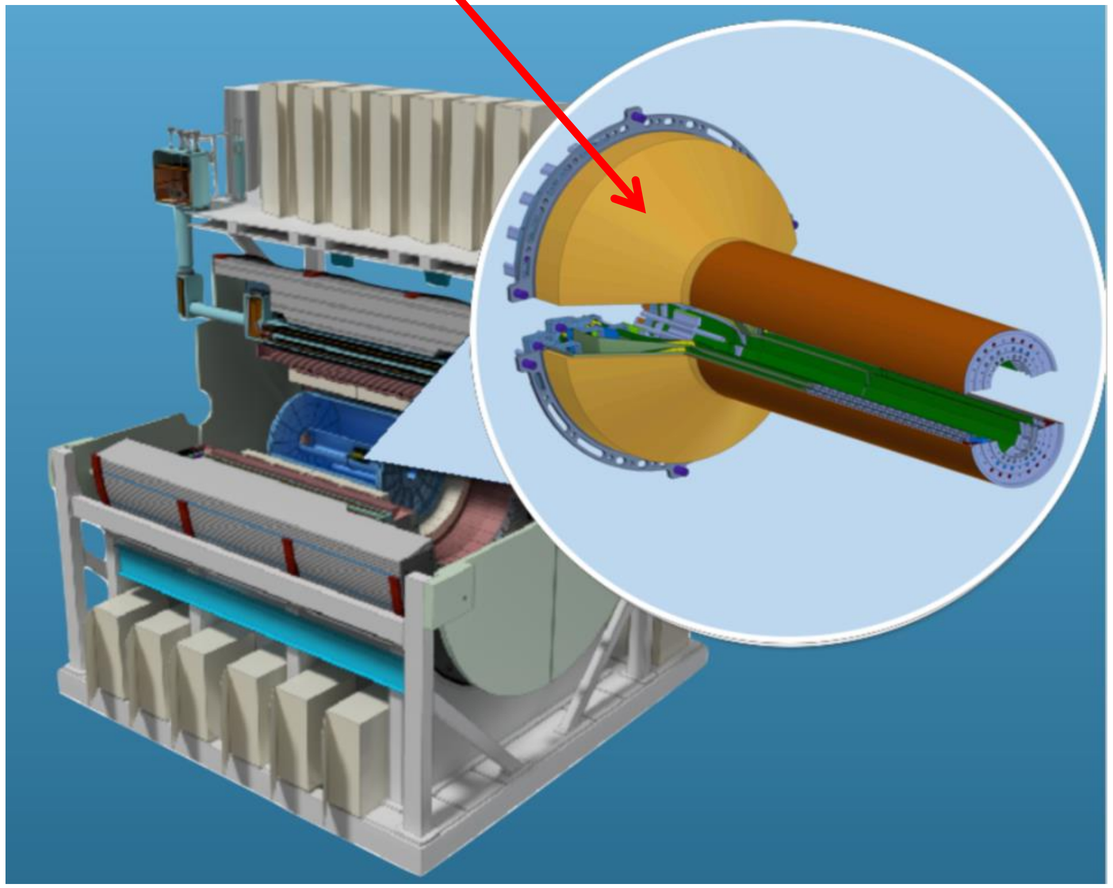
Streaming Readout Detectors

TPC

I will mostly concentrate on the TPC.

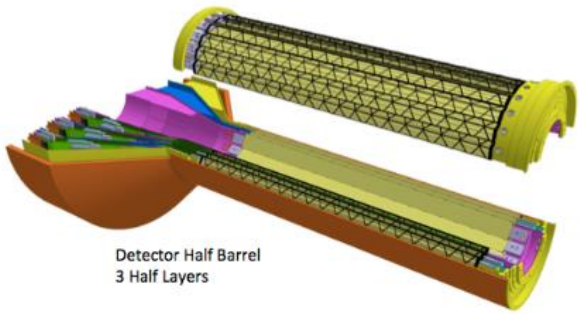
MVTX

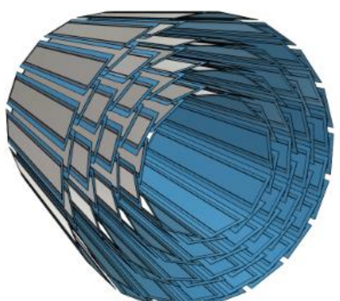


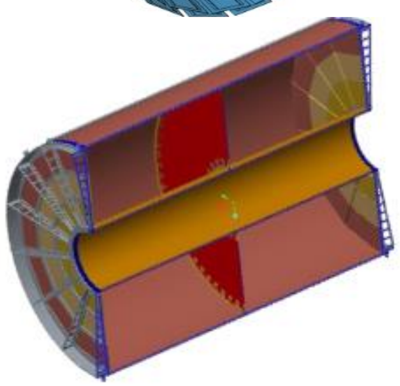


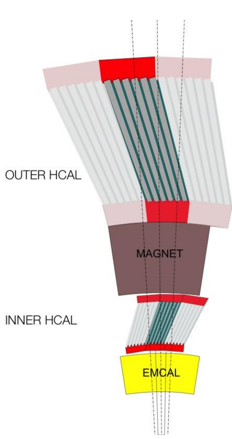
This is a next-gen "gate-less" TPC design

Data and more data









MVT ~ 20GBit/s

Inter ~ 7GBit/s

This number is still changing and depends on our noise levels (and a successful change in the front-end ASIC). Could be more!

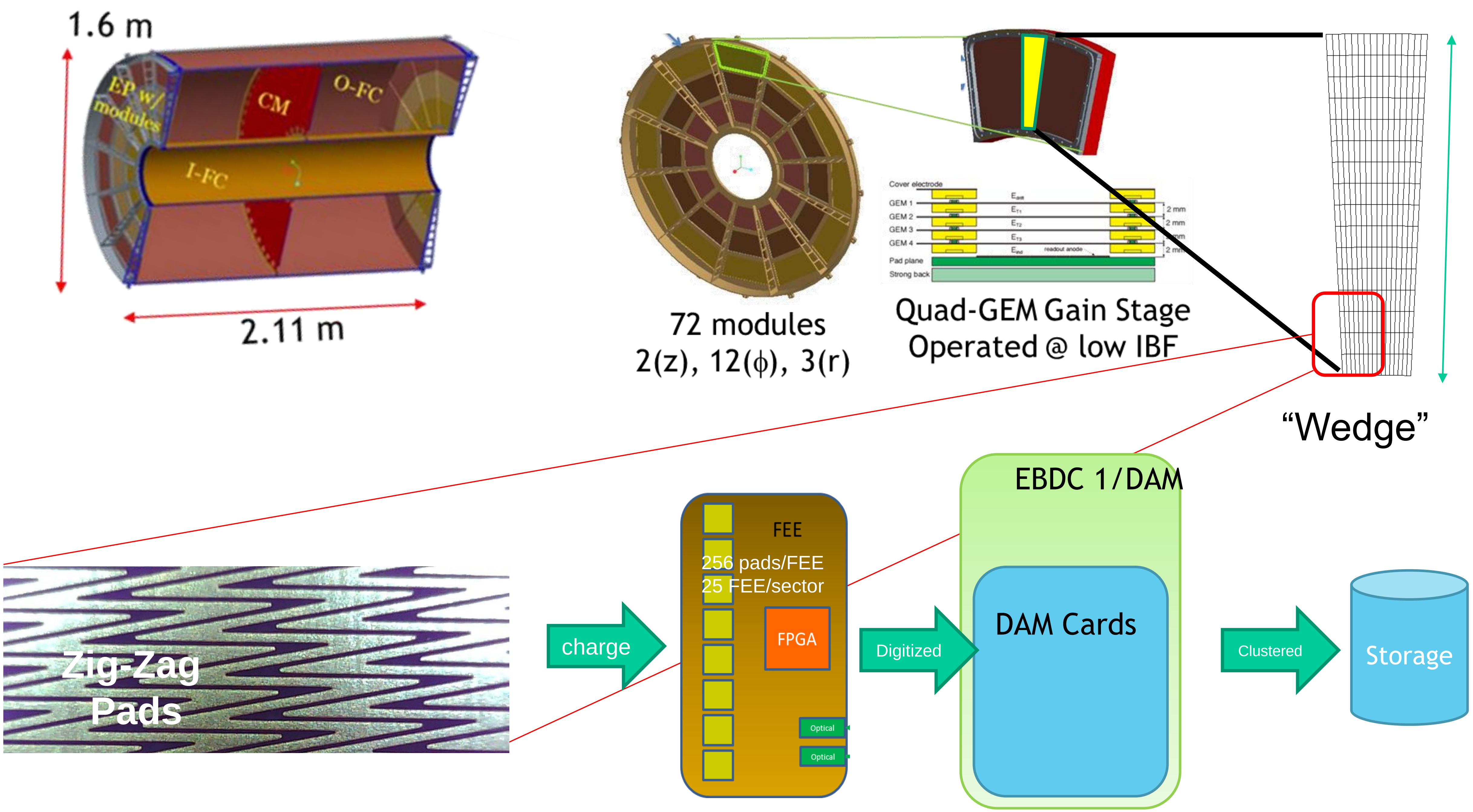
Compact Time Projection Chamber (TPC) ~ 100Gbit/s

Calorimeters (primarily Emcal, hadronic cal.) ~ 8GBit/s

135GBit/s

Makes for an event size of about 1MByte (or more)

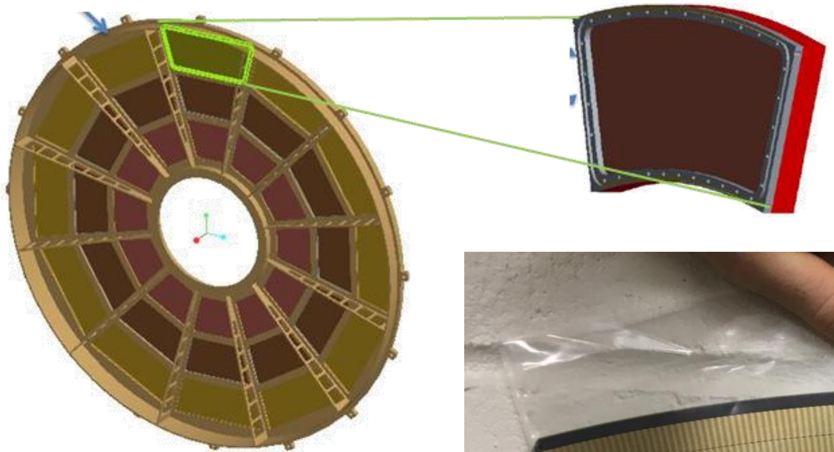
The TPC



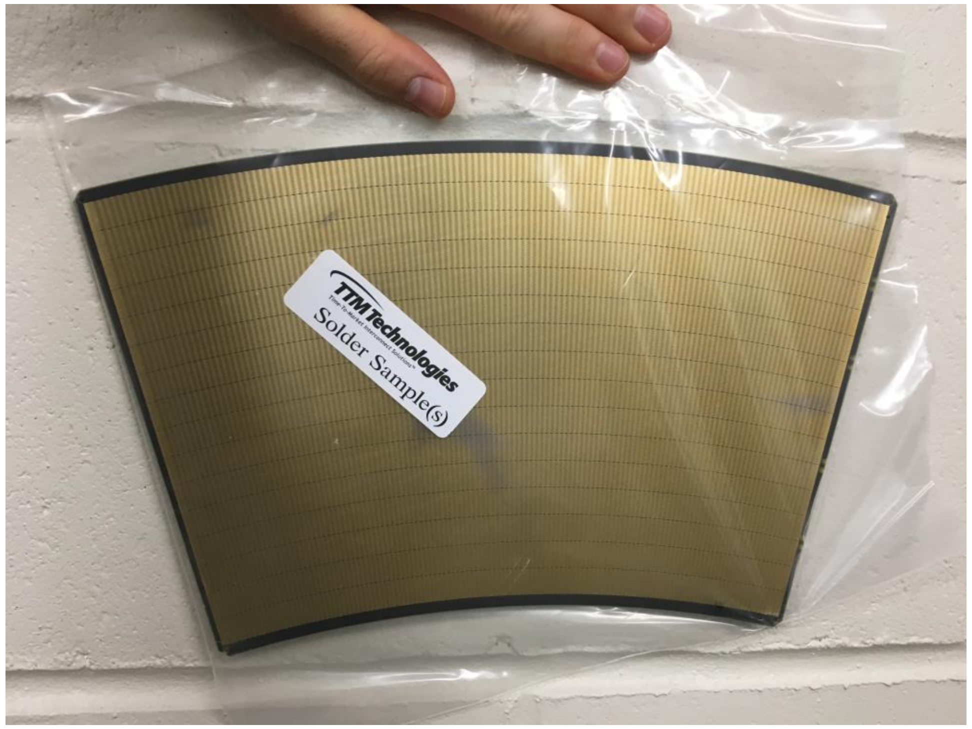
DAM = "Data Aggregation Module"

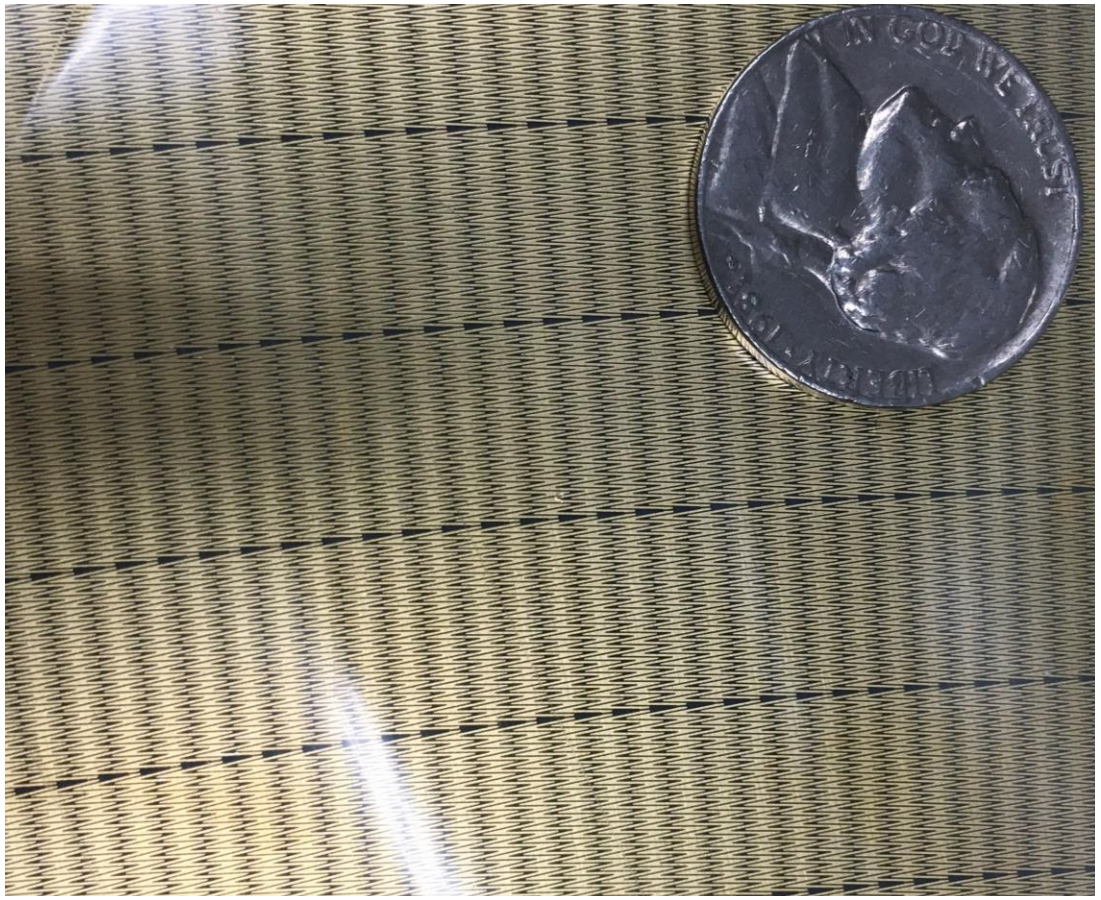
EBDC – "Event Buffer and Data Compression"

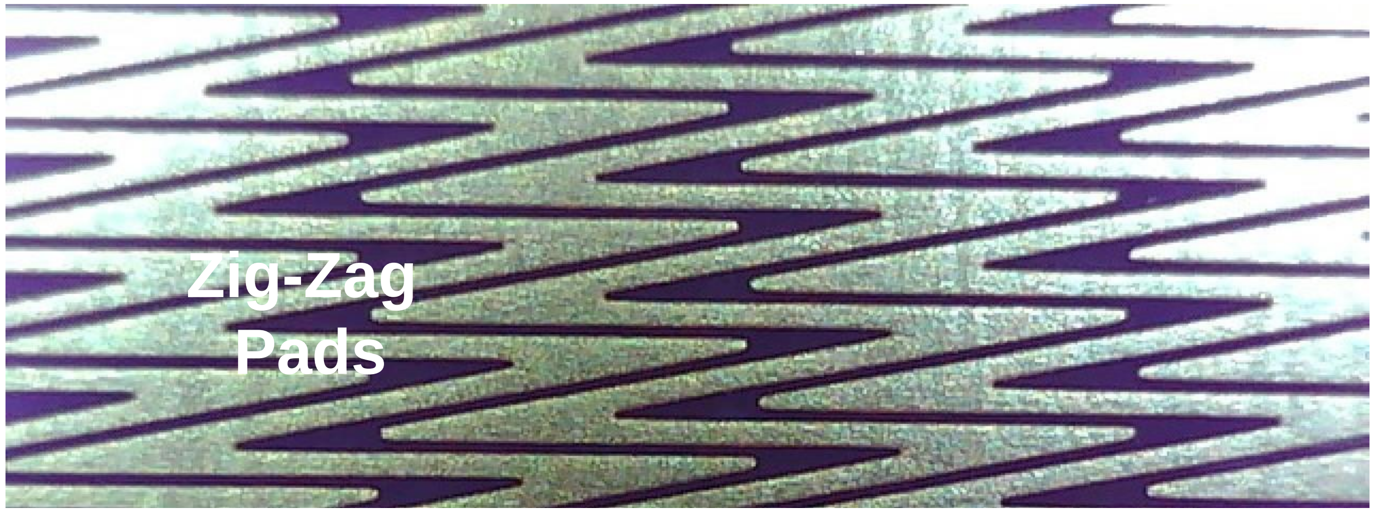
The ZigZag Pads



72 modules
2(z), 12(ϕ), 3(r)







12.5mm resolution in r

150 μm in phi

~160,000 ADC channels

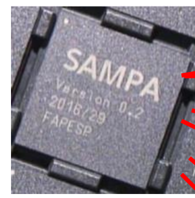
The Readout

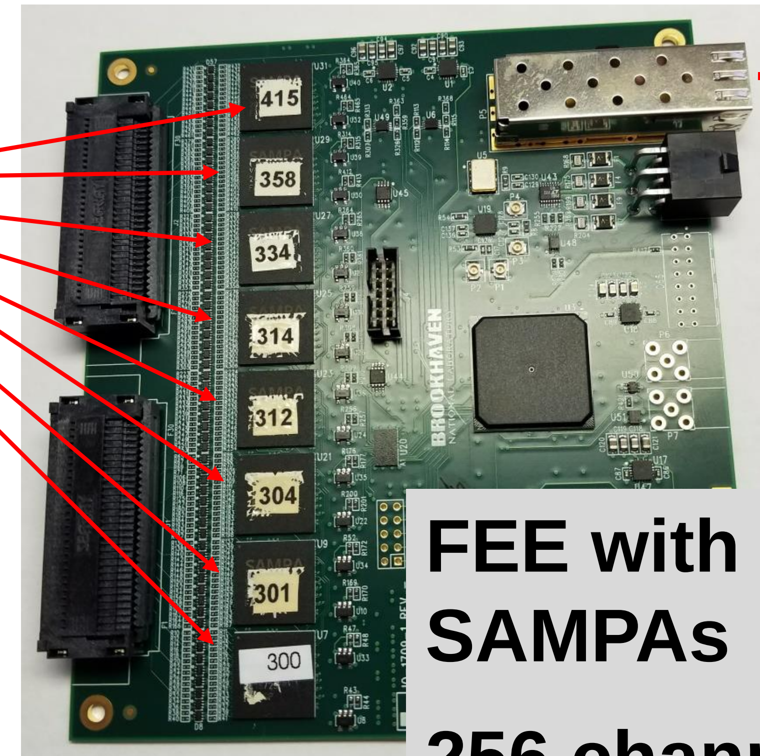
ALICE SAMPA chip

32 channels 10bit sampling ASIC

Preamp/shaper, ADC

Optional DSP functions

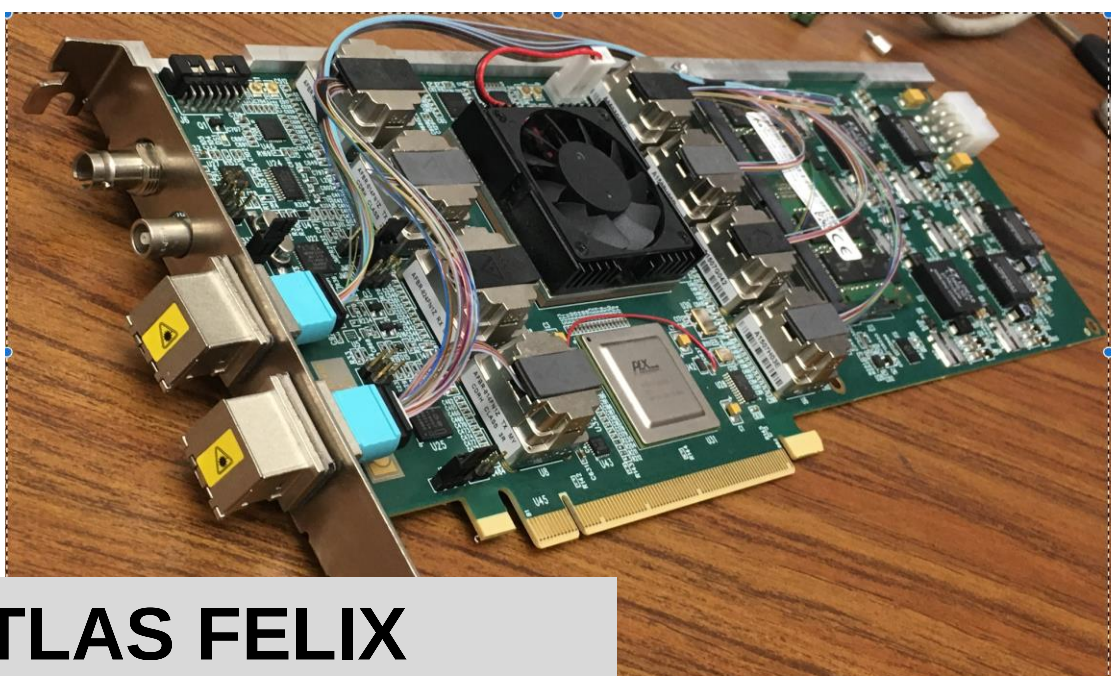




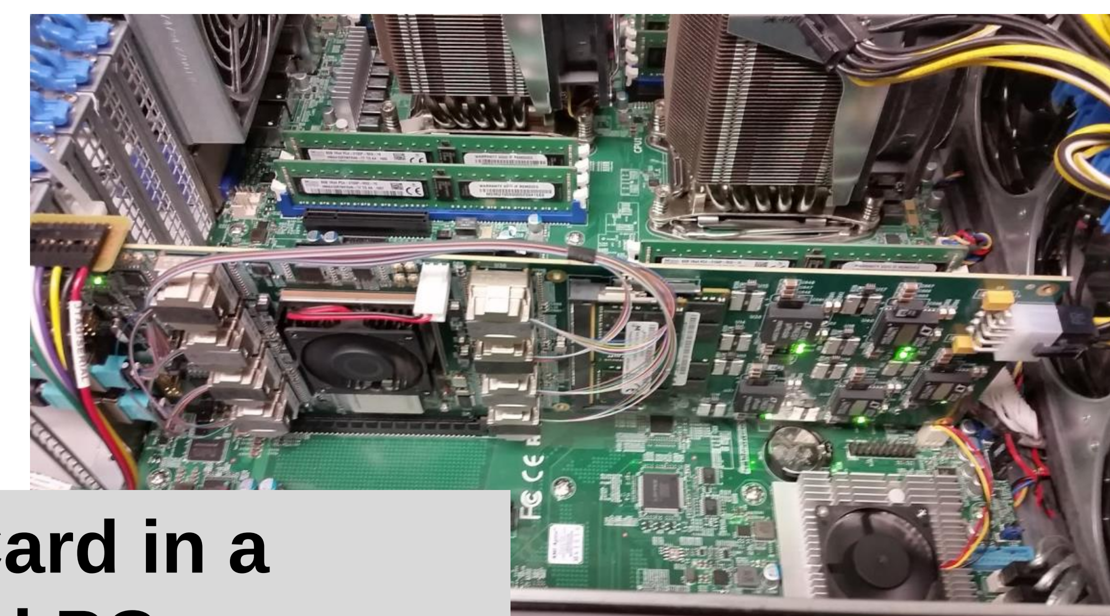
5GBit/s fiber link

FEE with 8 SAMPAs

256 channels

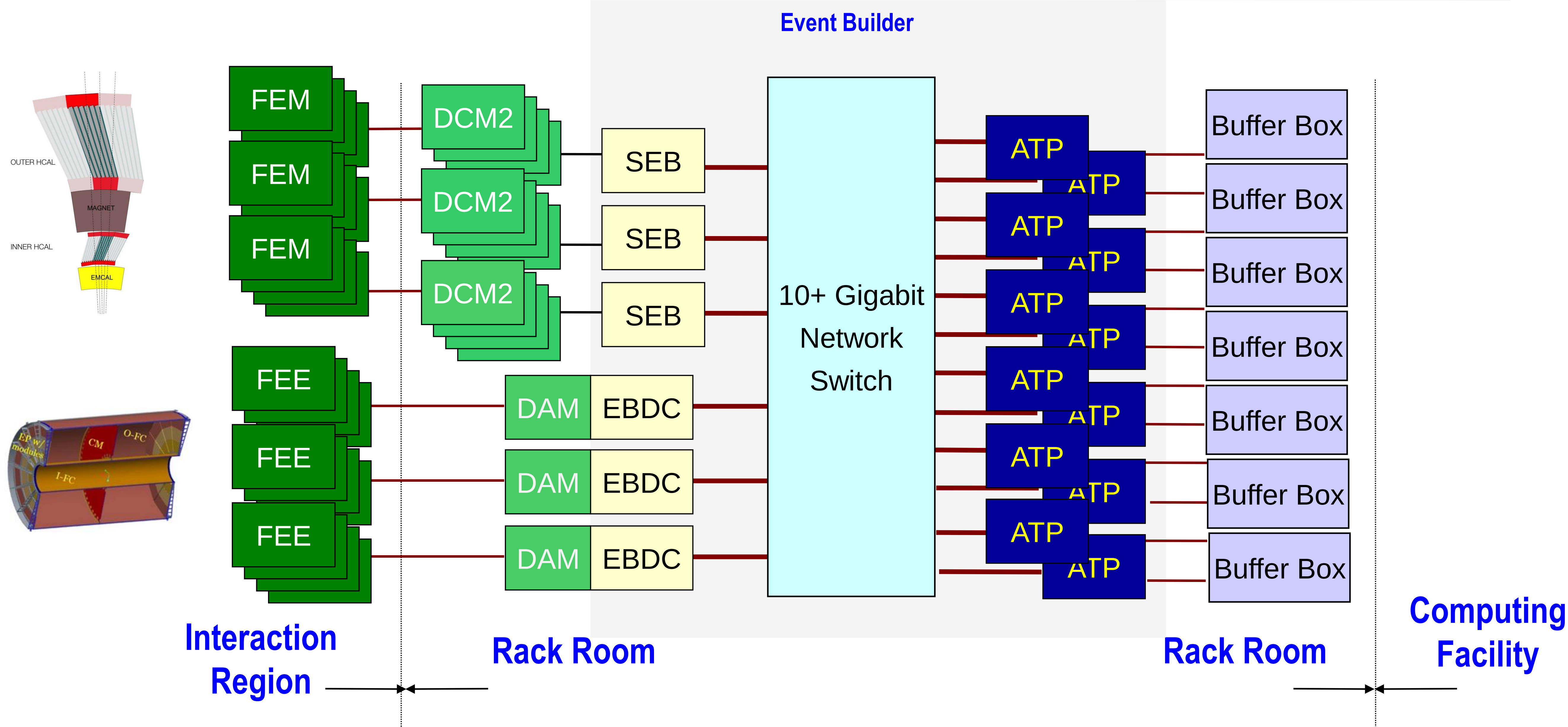


ATLAS FELIX Card ("DAM") – 24 FEE's



FELIX Card in a standard PC ("EBDC")

DAQ Overview



- DCM-2 receives data from digitizer, zero-suppresses and packages
- SEB collects data from a DCM group (~35)
- EBDC Event Buffer and Data Compressor
- ATP Assembles events and compresses data (~60)
- Buffer Box data interim storage before sending to the computing center (7)

How I explain Streaming Readout to the Public Affairs guys

Think of the recordings of a shopping mall's security cameras

You keep, say, a month worth of video

Most of the time, absolutely nothing of interest happens

But when there's something going on, a burglary or so, you go back and cut out the 15 minutes of video in question for the cops

Think of those 15 minutes as the long-term stored data

Translate to sPHENIX…

We record the arrival of charge continuously

But at the end, we are really only interested of the piece of "recording" at the time we triggered an actual event

So stored "events" for the TPC will be a series of short "charge recording segments" covering the times when we triggered the rest of the experiment.

Event Building – or not?

If we stay with the “security camera” paradigm for a moment, that works nicely for events that are far apart – 15mins video at 3pm, another 15 mins at 5:30, and so on.

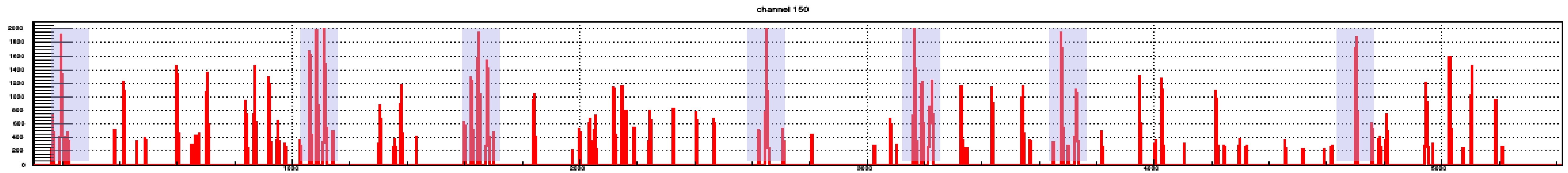
But if the events become so frequent that many of them are closer together than those 15 mins, the video clips now have a lot of overlap.

Then you might as well keep one continuous “movie”. Segmenting not only offers no longer any savings, but even increases your storage demands due to overlap.

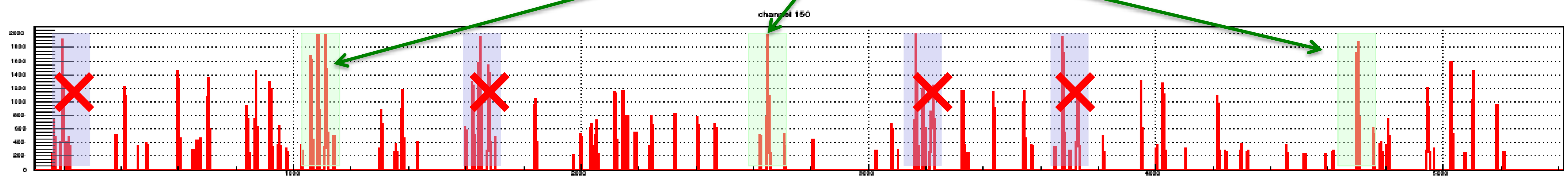
We are preparing for both scenarios.

TPC streaming readout + triggered events

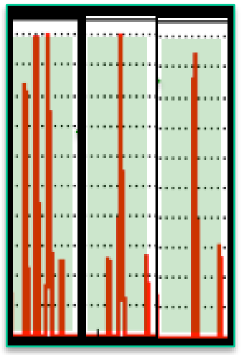
The streaming data are recorded all the time, and broken up in chunks above threshold



Only chunks correlated with triggered events are then kept



This results in a greatly reduced data stream
Would allow to reduce the streaming output to a classic event-building problem
"late-stage triggered mode"



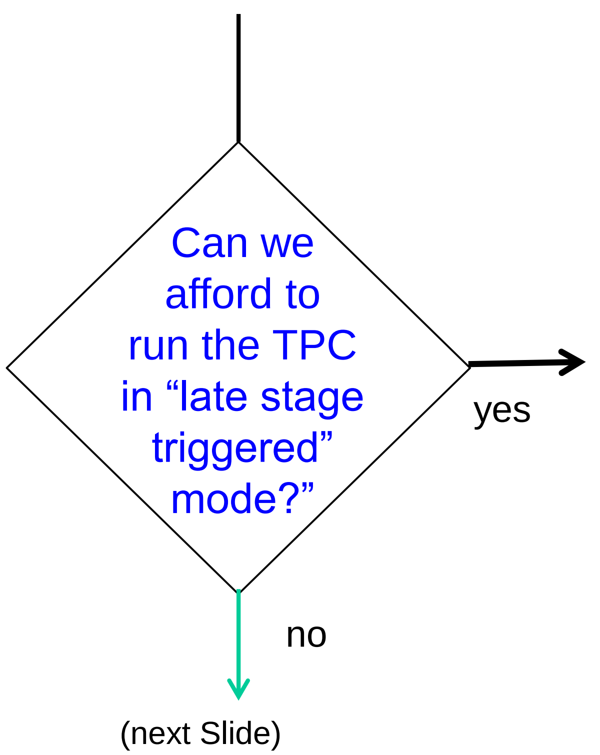
Caveat: if the accepted events' waveforms overlap too much, we incur a partial data replication
Ok up to ~15%...

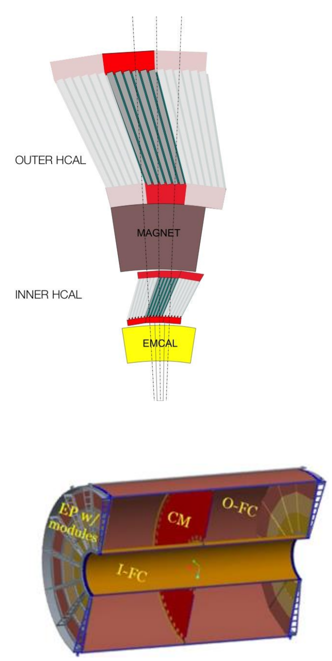
TPC Continuous readout

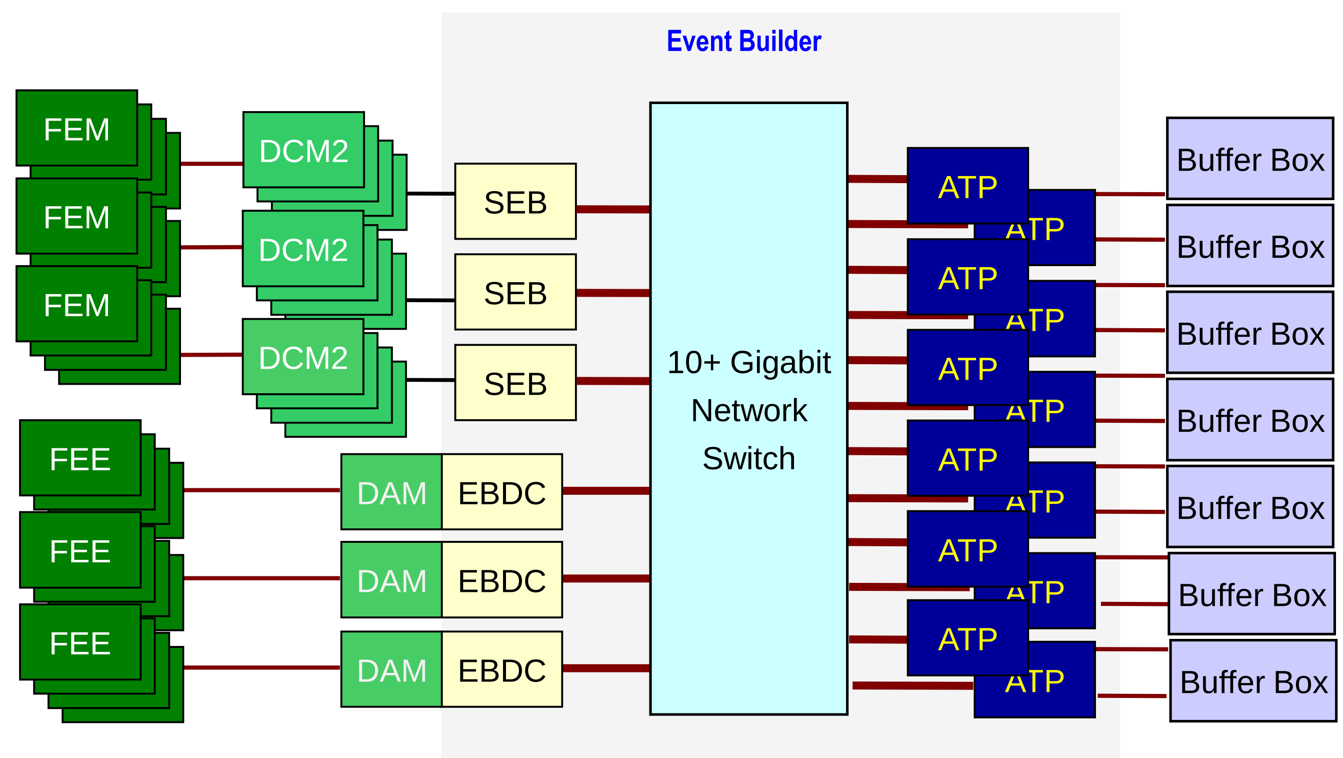
We are designing a “hybrid” DAQ back-end that combines trigger and continuous readout

Capable of catering to the “classic” triggered detectors (chiefly the calorimeters)

At the same time, we read the streaming detectors







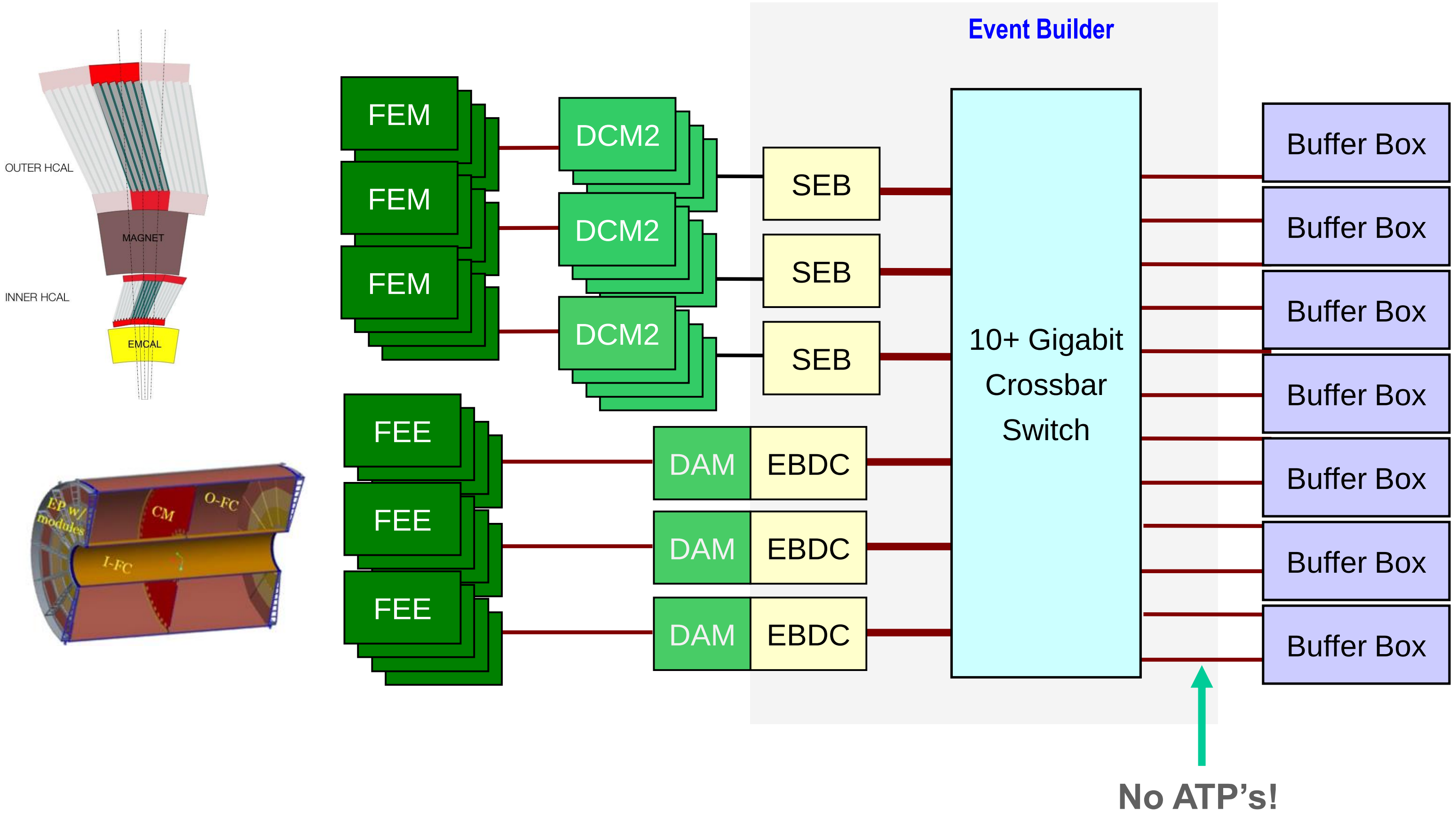
Reduction to a classic event building problem as shown before

If we cannot do it…

We would then not assemble events fully and log the individual data streams

Shift the event building to a semi-offline process

Assemble some 10% of events for online monitoring



Easier to implement than a full event builder!

But "verification" plays a much larger role

"no event mixing at the DAQ level"

This has been discussed for some time, and we have no doubt it would work

Envisioned Data Rates

Streaming TPC is the 800-pound gorilla in the room – 140 peak, ~100Gbit/s average

Could be more, time will tell

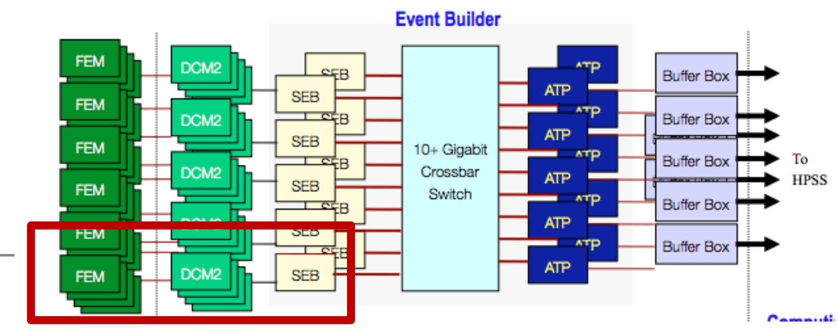
Other systems –> 135Gbit/s total average

Still some front-end design considerations to be worked out – none of them will decrease the rate, on the contrary..

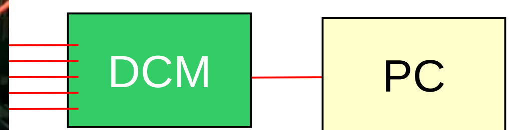
“Average” vs “really long-term average” rates may help

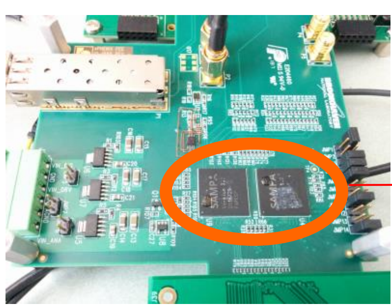
Still, we expect some **50PB** of data volume in our first physics run.

RCDAQ - R&D-themed part of the system

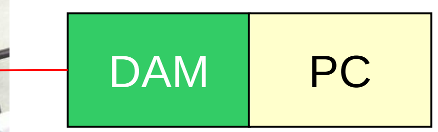


sPHENIX Calorimeter electronics





TPC SAMPA Chip and ATLAS Felix Board

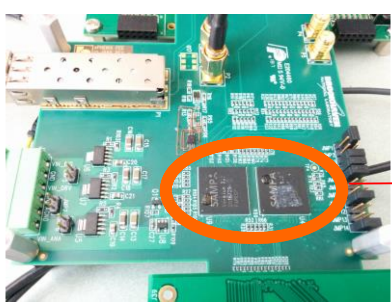


RD51 SRS, DRS4, VME gear… some 40 supported devices

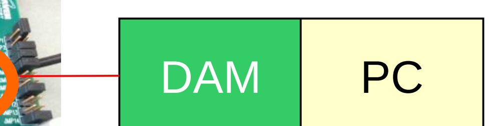
- **The RCDAQ DAQ System**
- Cut out the event builder (not much need right now)
- Log data at the EVB "input point" instead
- Same technology, reading out our front-end here will seamlessly integrate into the big thing
- Powerful scripting/automation features
- "Real" online monitoring often has it roots in test beam code
- Addt'l support for a large variety of non-sPHENIX gear
- ~20 RCDAQ copies around in the sPHENIX orbit
- About a dozen more systems in use by external groups
- Supported on high-end 32core PC to Raspberry Pi

FEE R&D and DAQ integration

- Each new piece of readout electronics gets its readout implemented in RCDAQ
- Completely reusable in the “Big DAQ”
- Use RCDAQ’s amenities for otherwise tedious tasks
- This early setup uses the full FELIX readout chain



TPC SAMPA Chip and ATLAS Felix Board



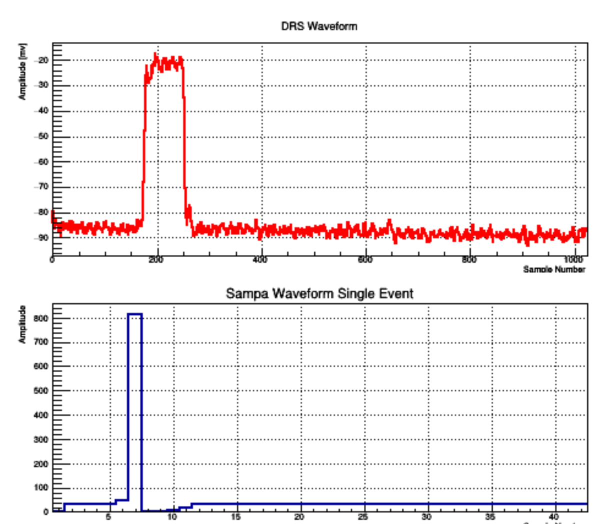
Example: Gain linearity measurements

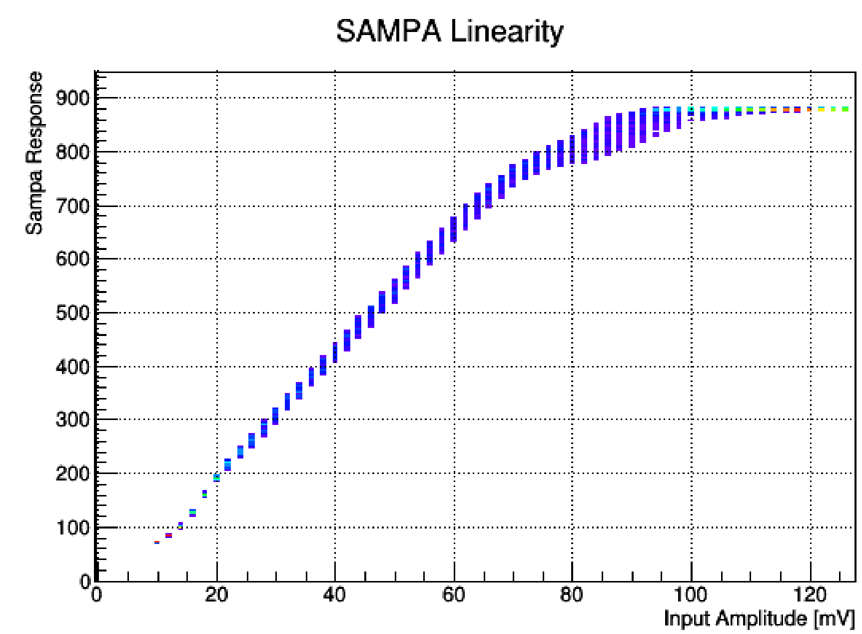
Script it! Humans will make mistakes w/ repetitive tasks

Step through some 60 2mV steps in a pulse generator

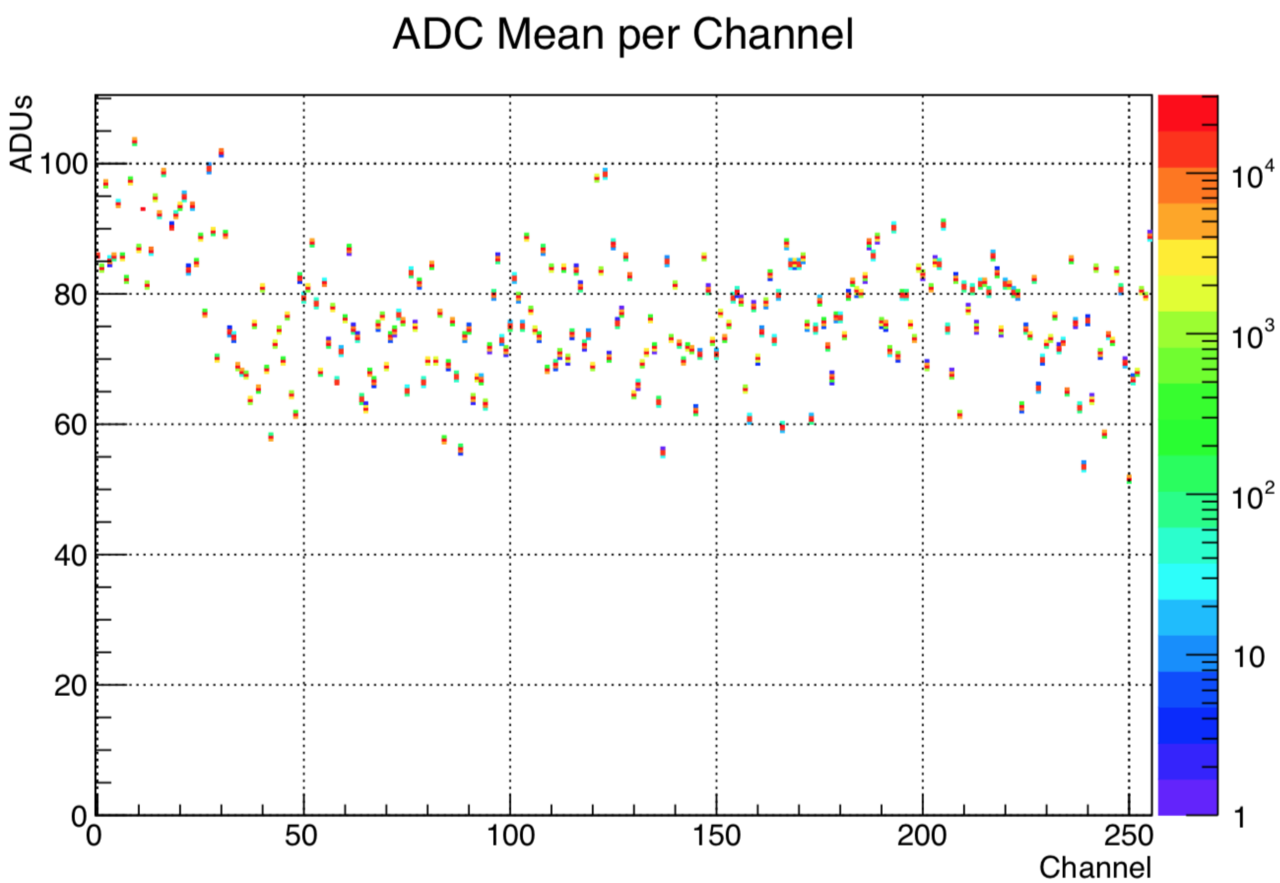
Measure SAMPA response together with a DRS4 measurement

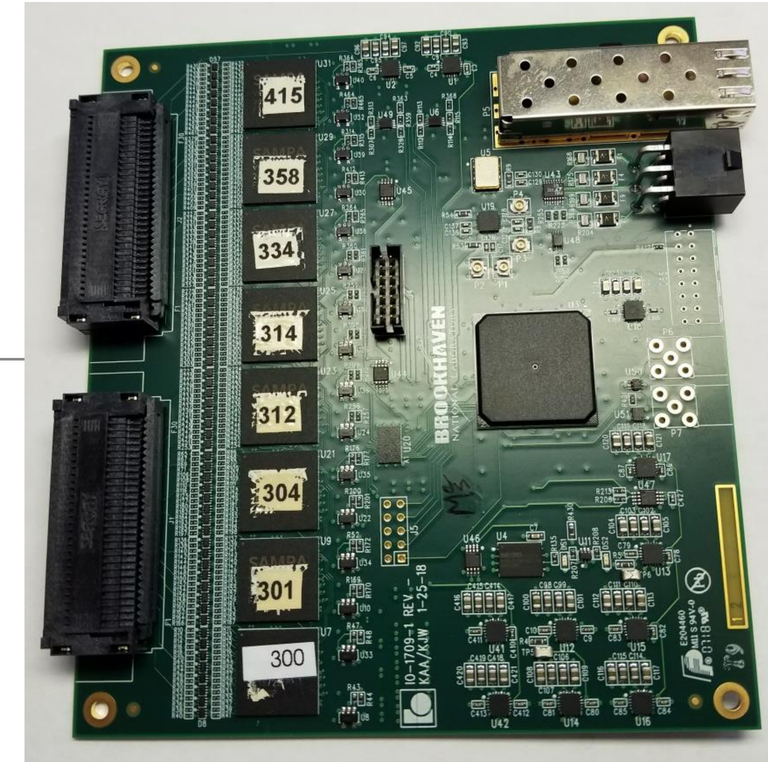
```
for amplitude in $(seq 10 2 130)
 do
     $PULSER_EXEC write $amplitude
     rcdaq_client daq_begin
     wait_for_run_end.sh
 done
```

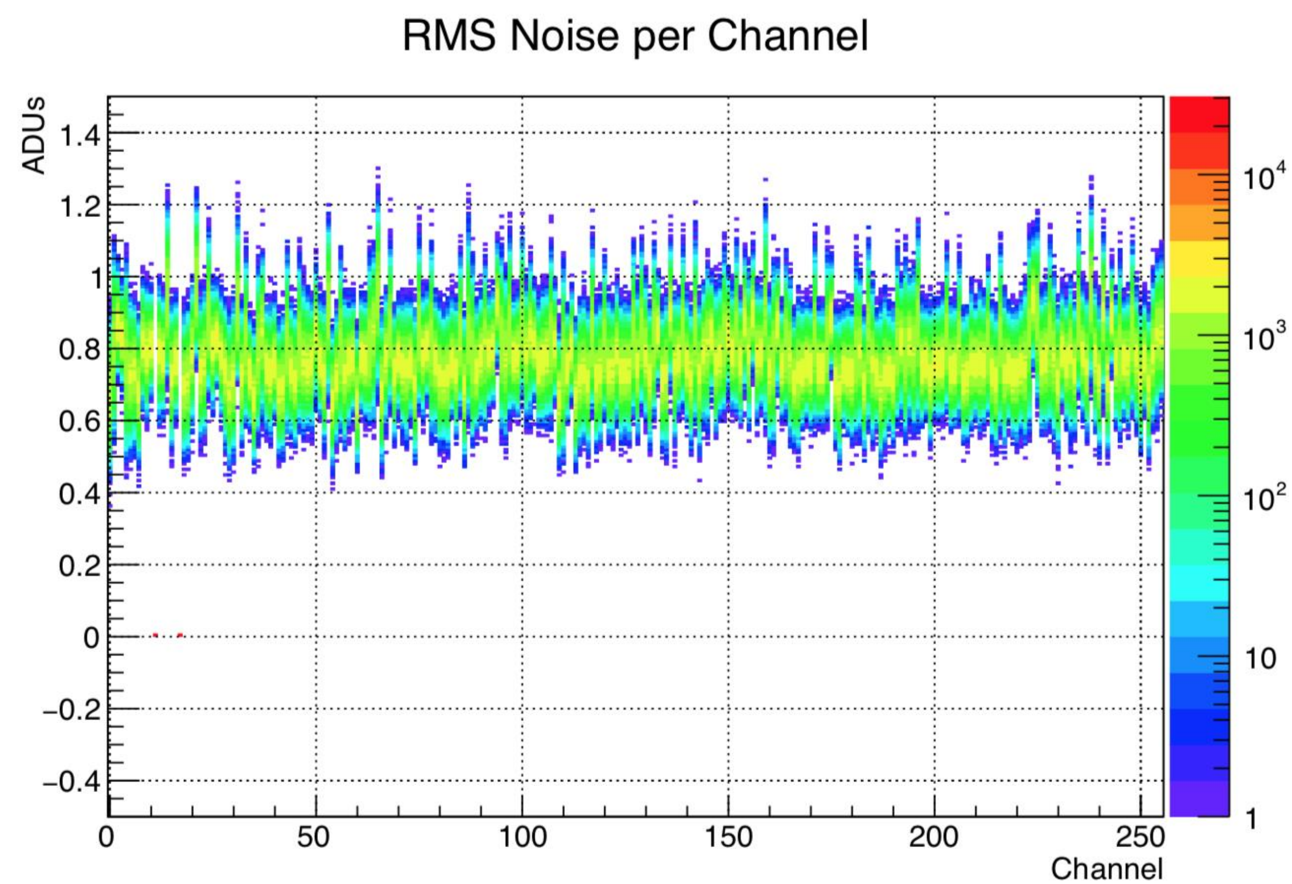




Hot off the press…







This is from Friday Evening

The first full readout chain data from the 8-chip card

Looks good so far, but the main point here is that we can actually read the card 10 days after it was delivered

Summary

Current focus on understanding the total data rate and reduction strategies

Actual GEM data and simulated data in hand to understand the tracking performance

Ability to read **all** flavors of sPHENIX detector electronics (some are prototypes)

Most electronics has withstood the “strain of a testbeam” (TPC to go there next week)

Solid concept and simulations with streaming readout

Streaming-supporting data formats etc in place

We also have data from the MicroVertex detector, no time to show more today

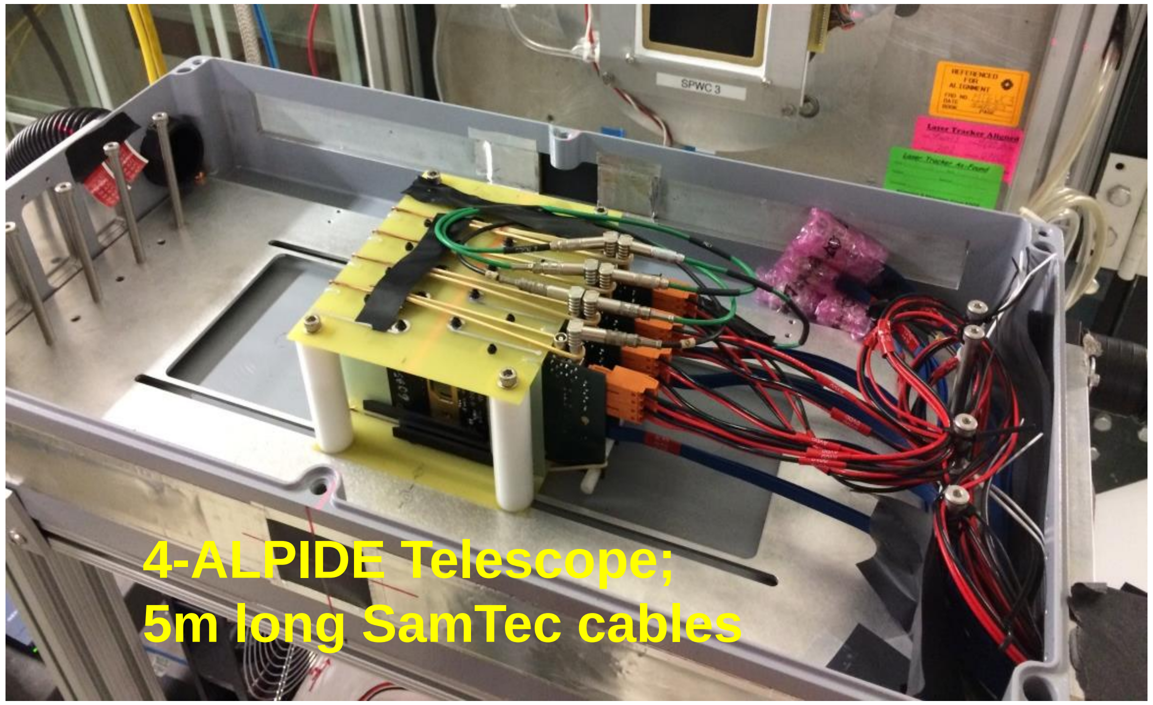
MVTX, briefly

The MVTX prototype was taken to the FermiLab test beam

ALICE “ALPIDE cards”

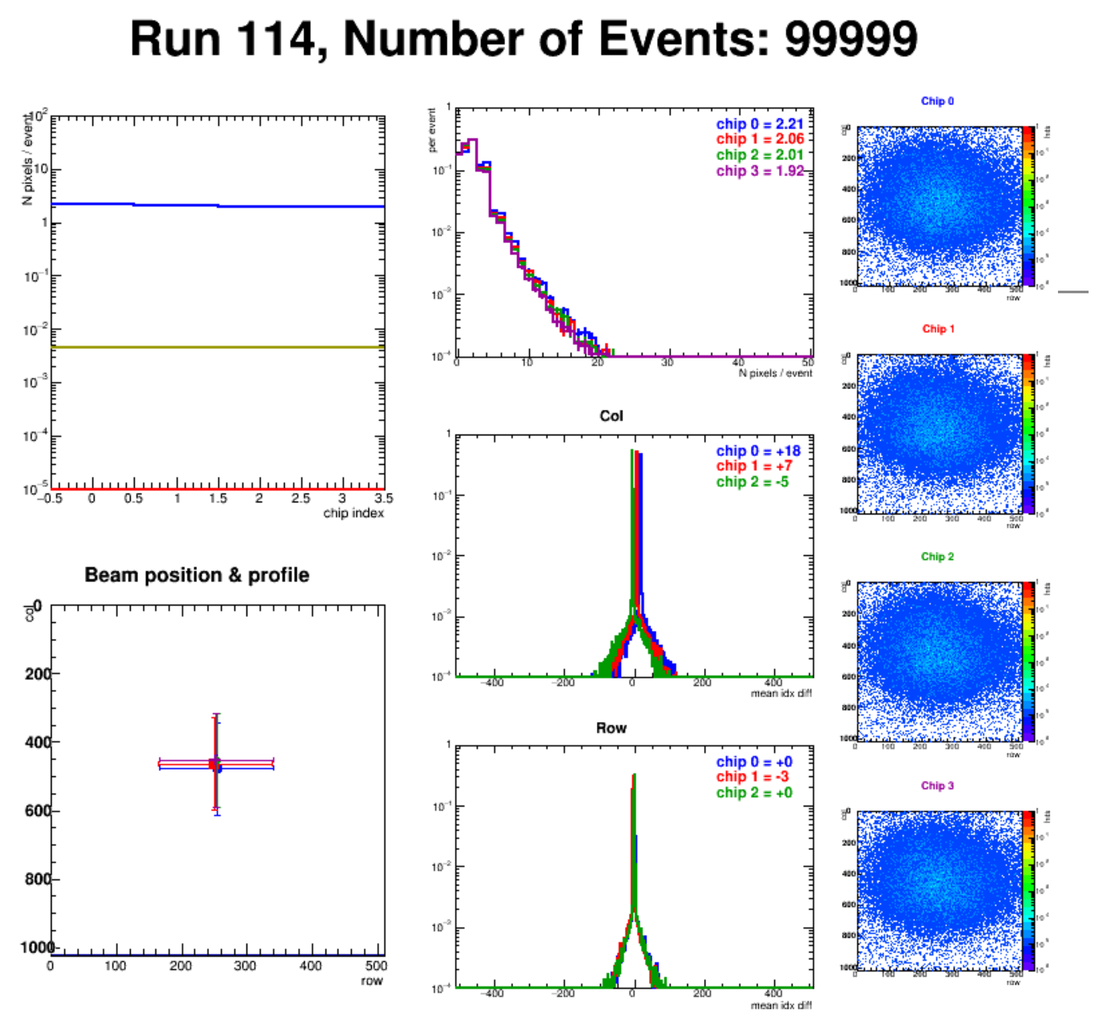
MVTX also uses the FELIX card (and RCDAQ)

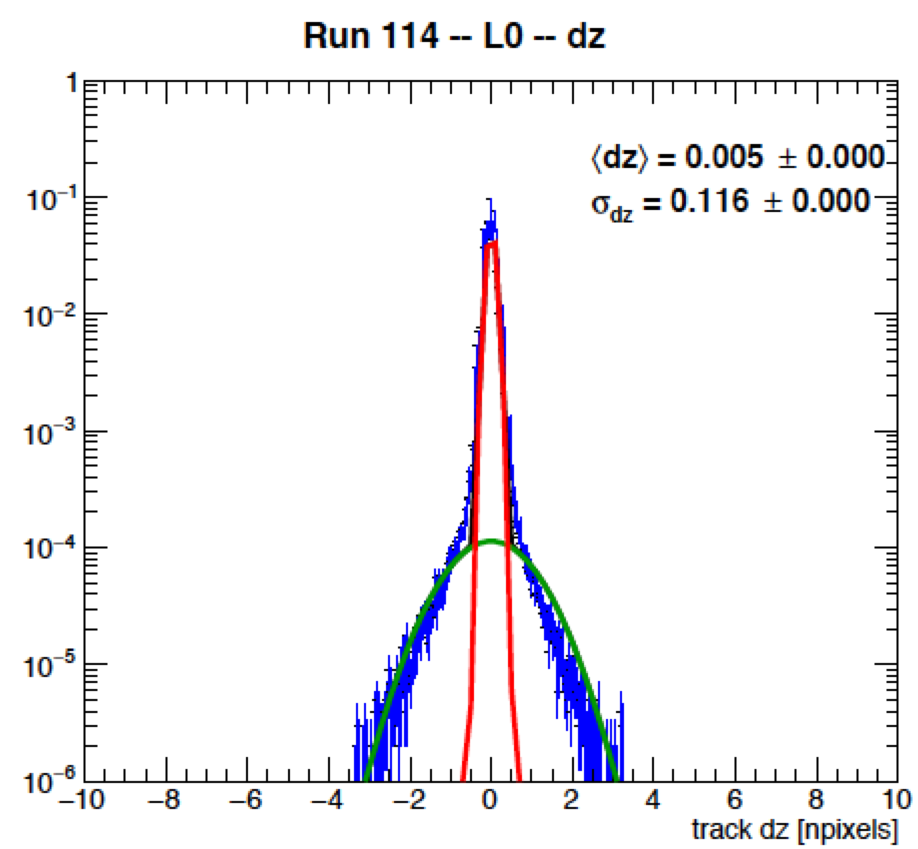
4-layer “MAPS telescope”



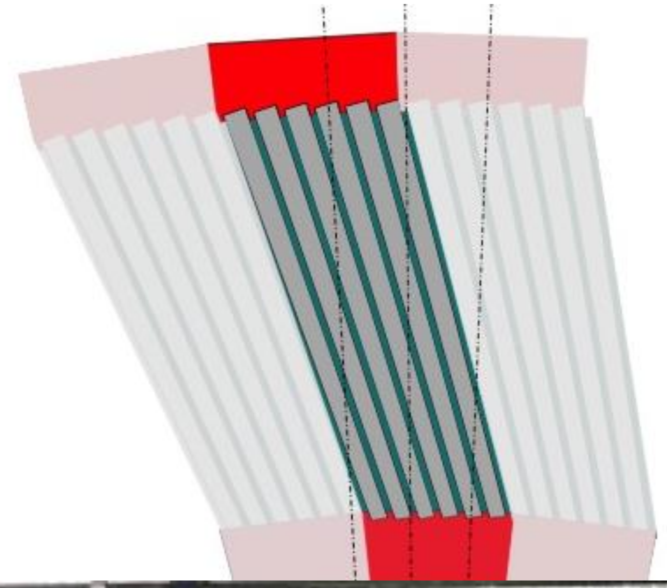
And it worked…

- Successfully operated the full readout chain
    - RU Configured and readout 4 ALPIDEs
    - FELIX successfully integrated into RCDAQ
- Sensor Performance
    - Cluster Size
    - Threshold parameters
    - trigger delay
- High multiplicity events
    - ALPIDE occupancy runs with 10cm lead bricks
- Online Monitoring
    - Hit distribution, relative alignment
- Analysis confirmed telescope performance
    - Hit resolution < 5 um





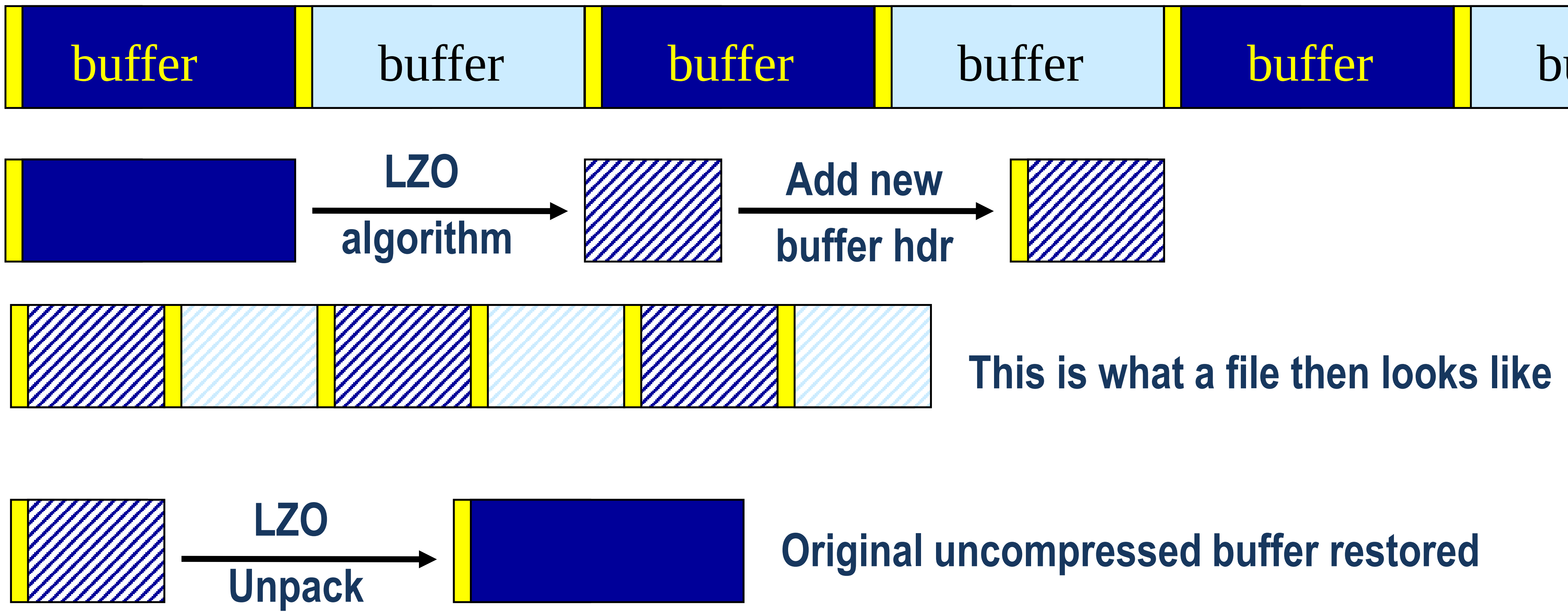
The last Test Beam



Data compression

After all data *reduction* techniques (zero-suppression, bit-packing, etc) are applied, you typically find that your raw data are still gzip-compressible to a significant amount

Introduced a compressed raw data format that supports a late-stage compression

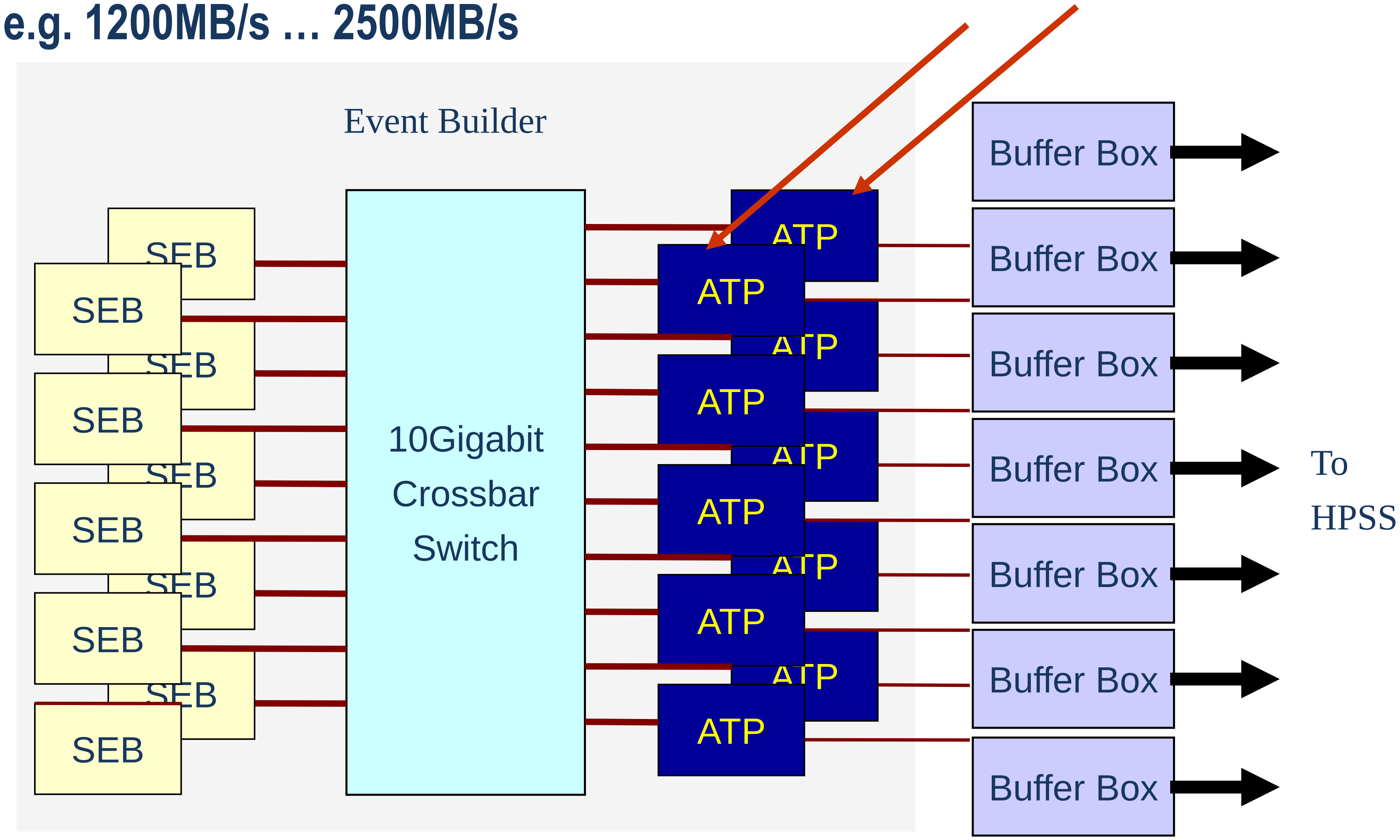


All this is handled completely in the I/O layer, the higher-level routines just receive a buffer as before.

Switch to distributed compression

The Event builder has to cope with the uncompressed data flow, e.g. 1200MB/s … 2500MB/s

The compression is handled in the "Assembly and Trigger Processors" (ATP's) and can so be distributed over many CPU's -- that was the breakthrough



The buffer boxes and storage system see the compressed data stream, 700MB/s … 1300MB/s

Current compression levels: 100G become ~55G

The BaBar Magnet

We had looked at magnets, but none of the available ones were quite right, then --

The BaBar magnet secured from SLAC after SuperB canceled, arrived at BNL in February 2015

Considerable additional equipment also acquired (power supplies, dump resistor, quench protection, cryogenic equipment)

Already passed a 100A low power cold test

Well suited to our needs without compromises

- 1.5 T central field
- 2.8 m diameter bore
- 3.8 m long
- 1.4X_0 coil+cryostat

This really gave a tremendous boost to this project!

Assembly Instructions ☺