Fermilab Beam Test Experience

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CPAD

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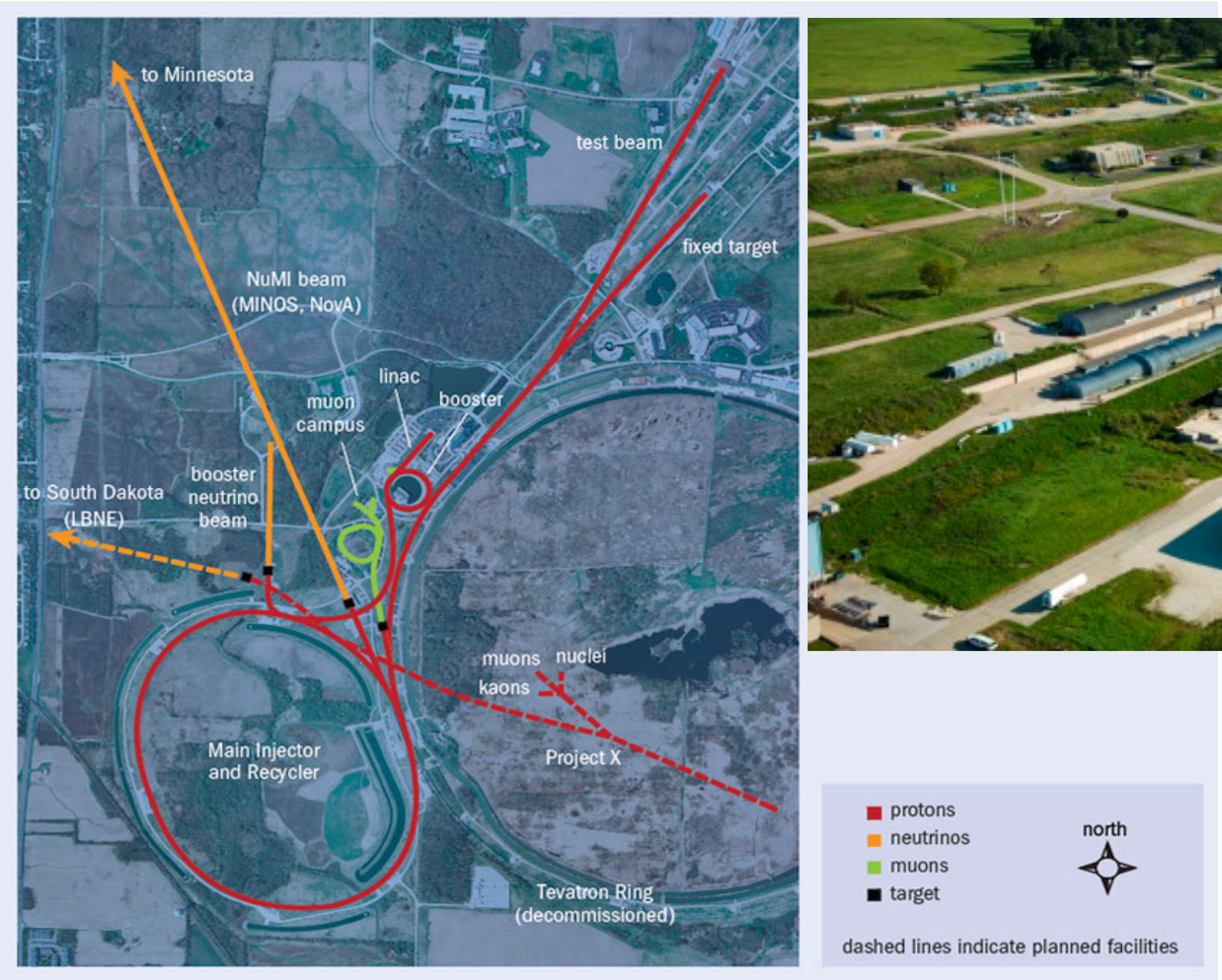
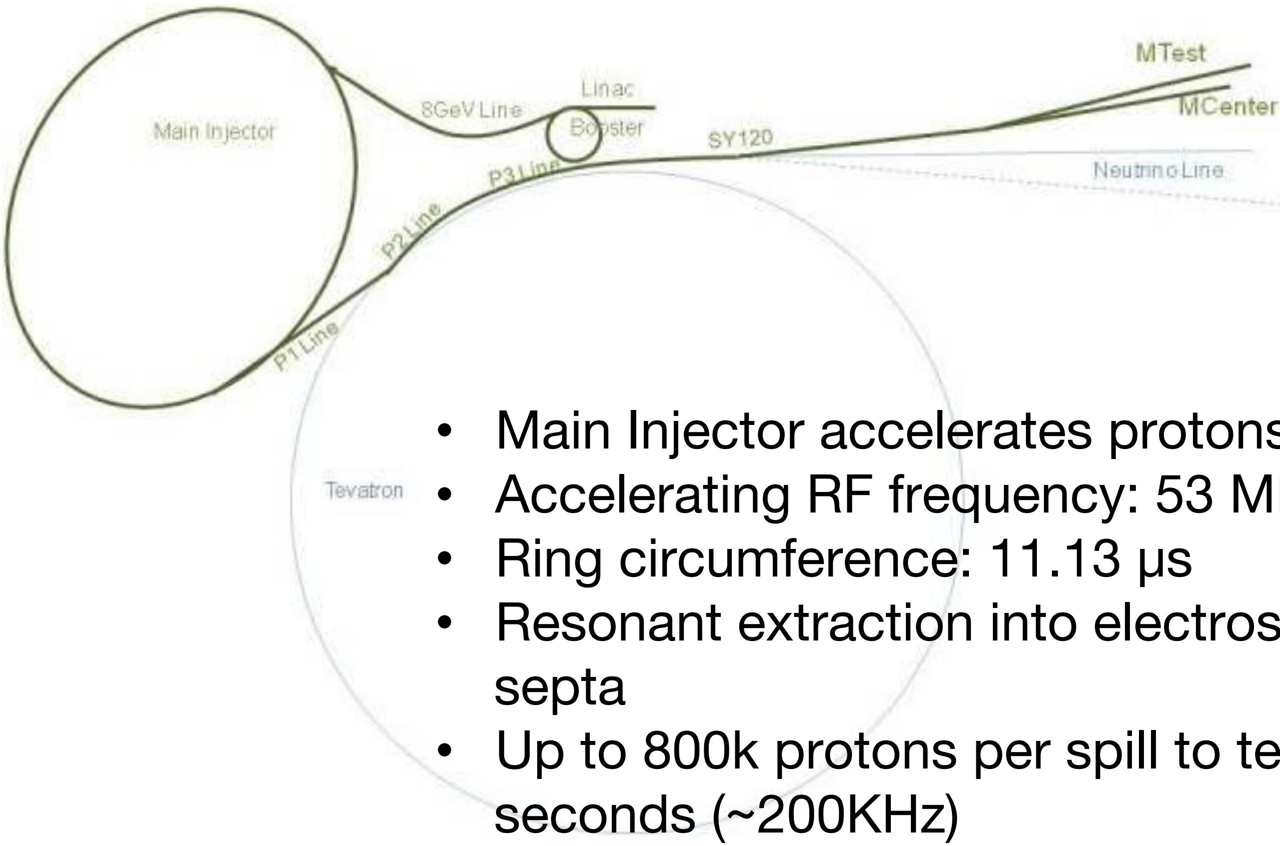
Fermilab Test Beam Facility (FTBF)

http://ftbf.fnal.gov/



Fermilab Test Beam Facility Overview



- Main Injector accelerates protons to 120 GeV
- Accelerating RF frequency: 53 MHz
- Ring circumference: 11.13 μs
- Resonant extraction into electrostatic and magnetic septa
- Up to 800k protons per spill to test area over 4.2 seconds (~200KHz)
- Repeated every 60 seconds
- Secondary beams including kaons, pions, electrons and muons
- Energies of 1-60 GeV possible (3% resolution)

Availability

DRAFT

Fermilab Accelerator Experiments' Run Schedule

		FY 2017	FY 2018	FY 2019	FY 2020	
		Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	
NuMI	MI	MINERvA	MINERvA	MINERvA ?	OPEN	ν
		NOvA	NOvA	NOvA	NOvA	
BNB	B	MicroBooNE	MicroBooNE ?	SBN: MicroBooNE	SBN: MicroBooNE	
		SBN: ICARUS	SBN: ICARUS	SBN: ICARUS, SBN:ICARUS	SBN: ICARUS	
		SBN: SBND	SBN: SBND	SBN: SBND	SBN: SBND	
Muon Campus		g-2	g-2	g-2	OPEN	μ
		Mu2e	Mu2e	Mu2e	Mu2e	
SY 120	MT	FTBF - MTEST	FTBF - MTEST	FTBF - MTEST	FTBF - MTEST	p
	MC	OPEN, LArIAT	FTBF - MC	FTBF - MC	FTBF - MC	
	NM4	SeaQuest	OPEN	OPEN	OPEN	
		Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	

- RUN / DATA
- STARTUP/COMMISSIONING
- INSTALLATION/COMMISSIONING
- M&D (SHUTDOWN)

Length of summer maintenance shutdowns for FY17 and beyond under discussion.

FY17 is last year of approved SeaQuest running.

g-2 hope to get some commissioning beam data during FY17, just before summer shutdown.

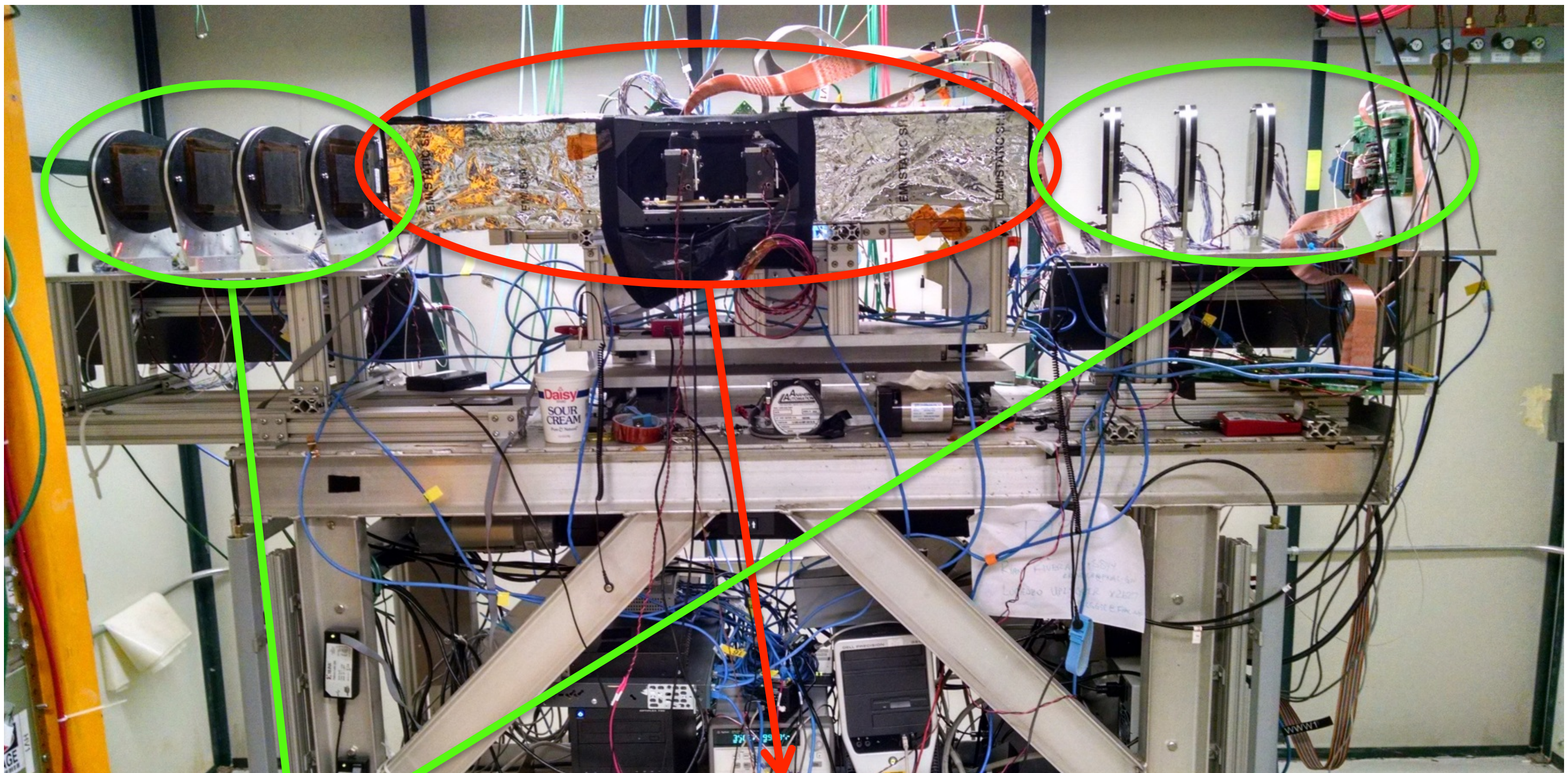
MicroBooNE running in FY18 not yet proposed or considered.

MINERvA FY19 run not yet approved. Needs consideration after NuMI polarity determined.

Tracking at FTBF

- At present 2 tracking telescopes are installed:
  - The legacy pixel telescope built using leftover CMS modules
  - The new strip based telescope

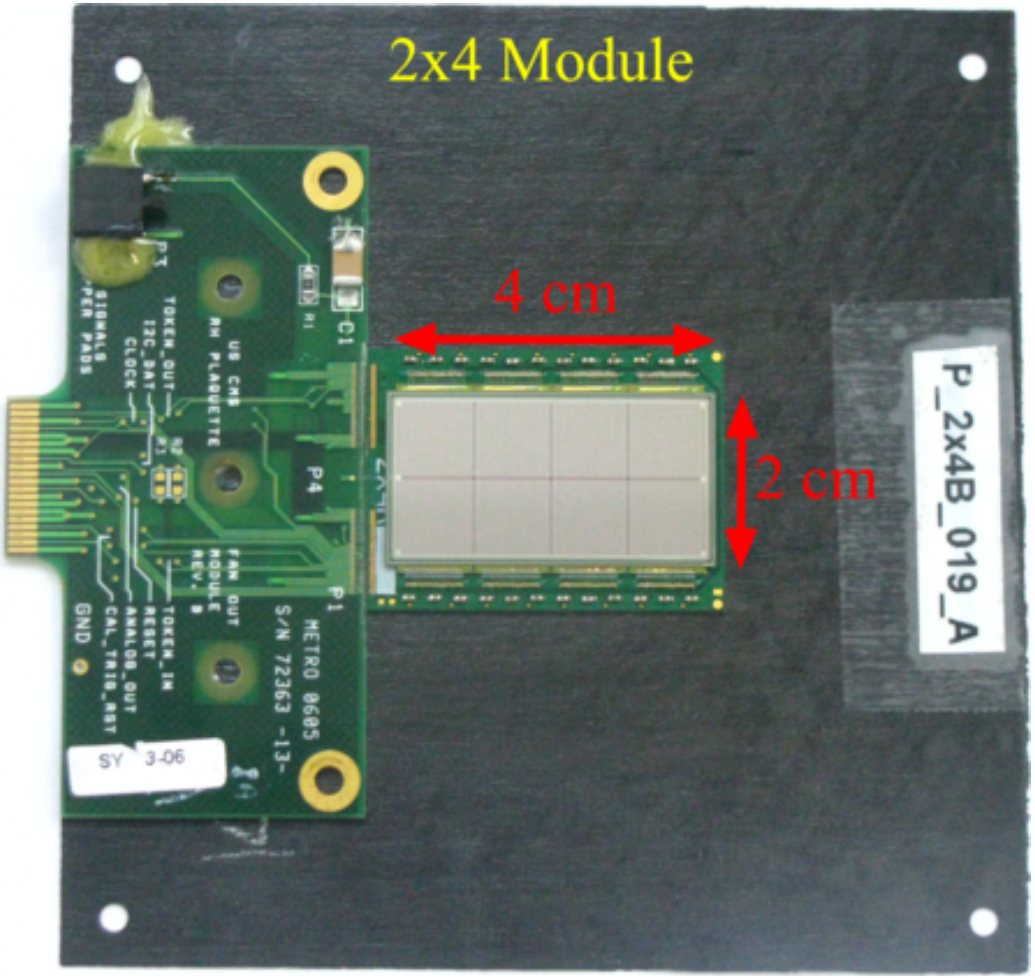
http://www.sciencedirect.com/science/article/pii/S0168900215015521



Pixel Telescope

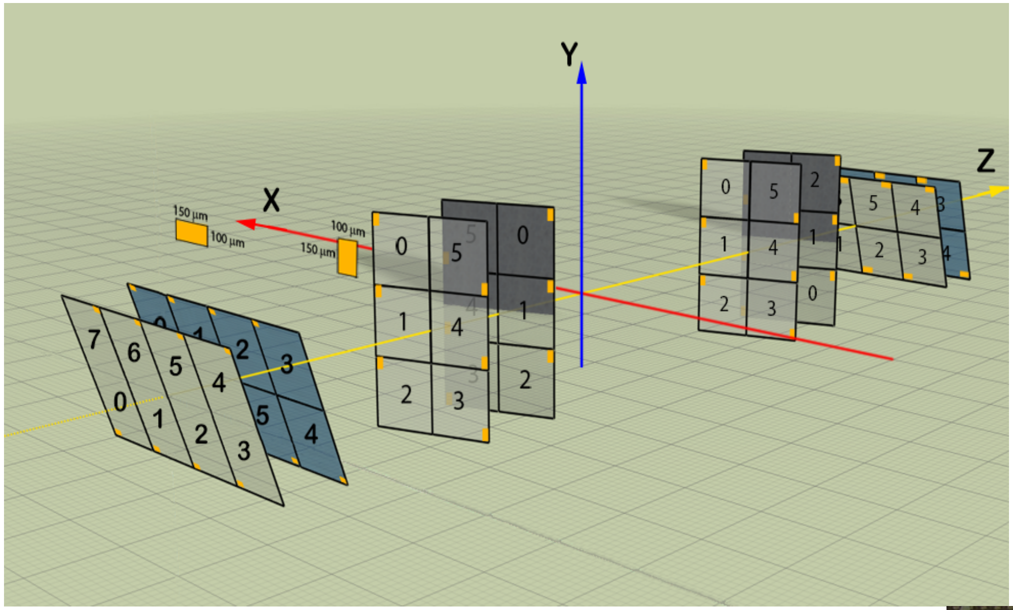
Strip telescope

Leftover modules from the CMS FPIX production

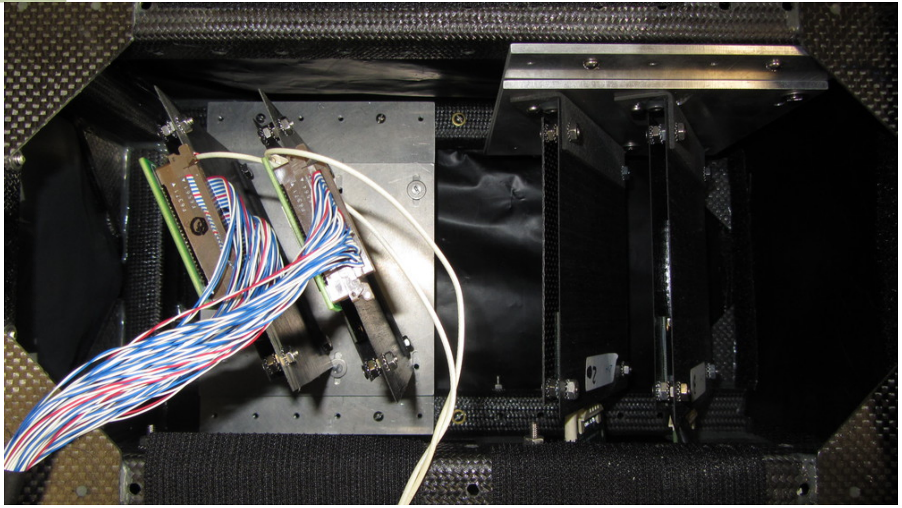


- PSI46 analog readout chip (ROC)
- 100x150 μm^2 pixel pitch
- Modules with 8 (2x4) or 6(2x3) ROCs

Schematic view of the pixel telescope planes

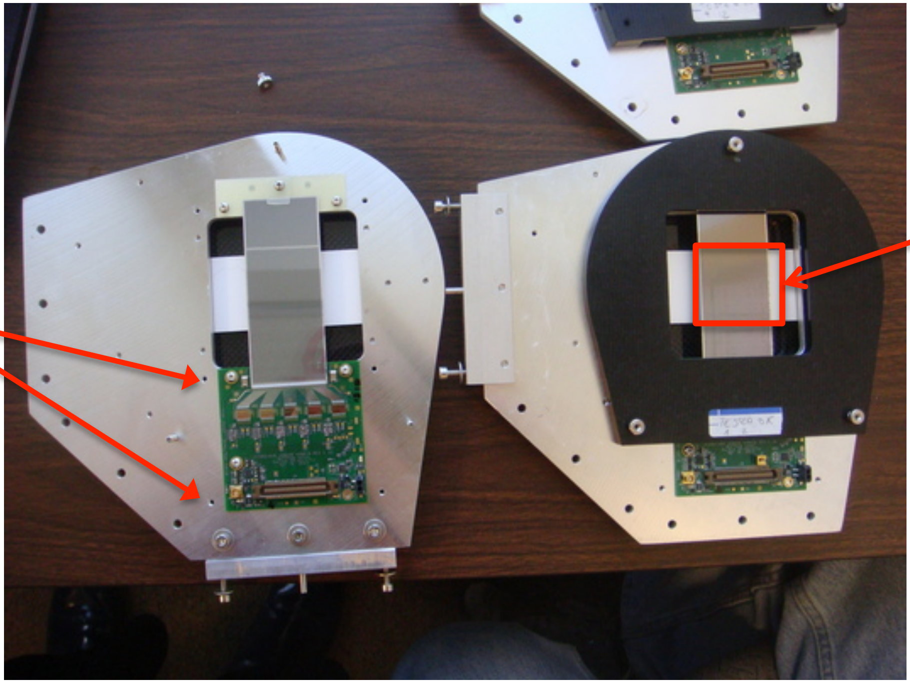


- 8 modules tilted at 25° to maximize charge sharing
- Coverage area only 1.6x1.6 cm^2
- Resolution on the DUT of ~7um



Silicon strip telescope station

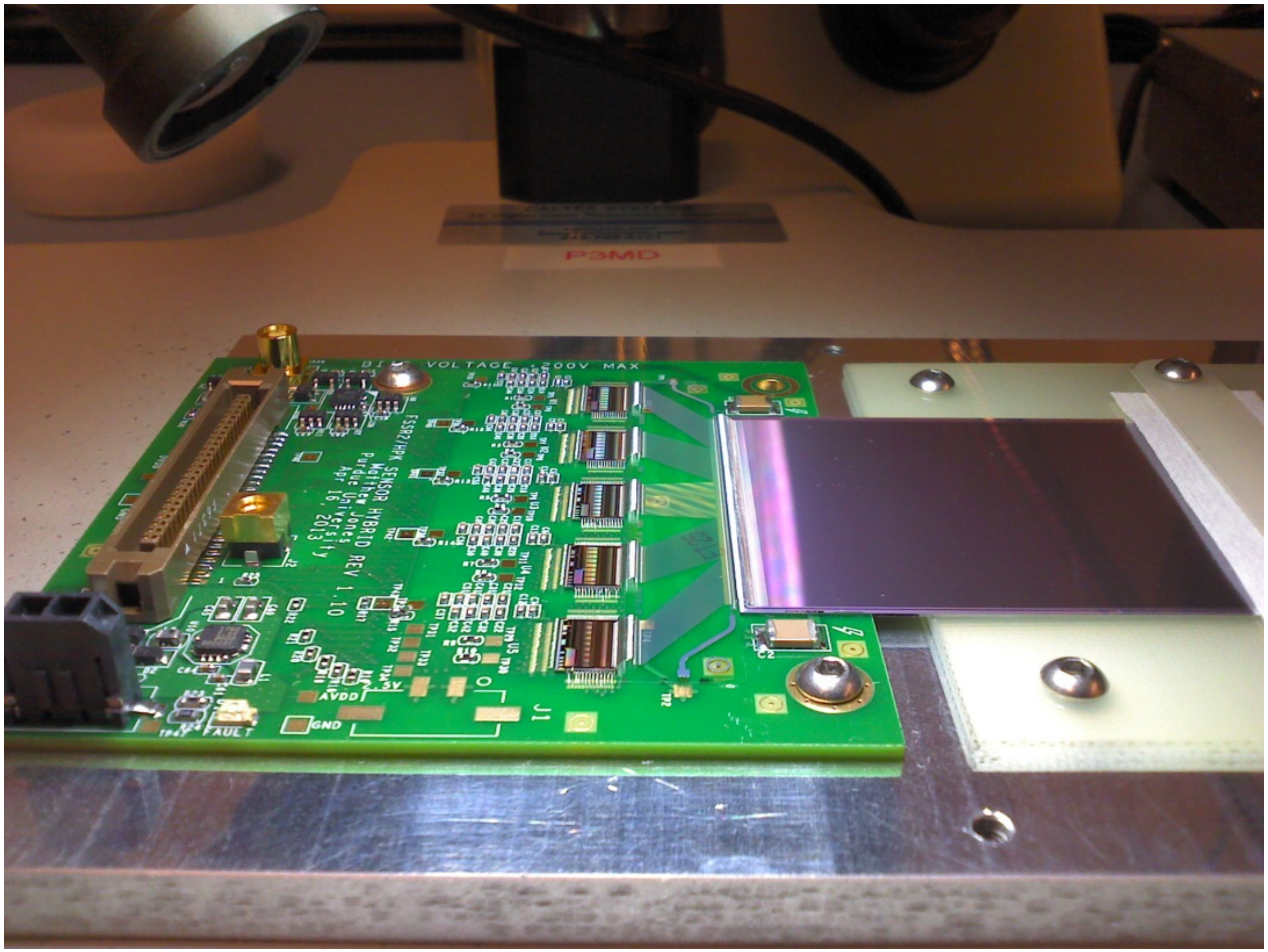
Extra holes to allow a different mounting configuration for a total coverage of 7x7 cm^2



The 3.8x3.8 cm^2 overlap area

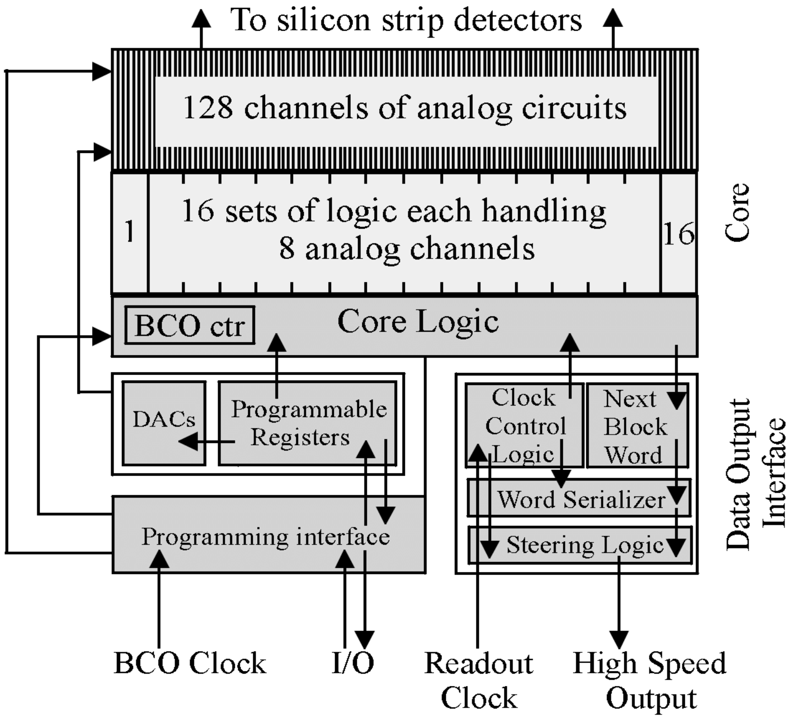
- The Silicon strip telescope has a coverage of ~3.8 x 3.8 cm^2 which is almost 6 times than the current pixel telescope coverage.
- Improved resolution with a 30 μm strip pitch (expected on DUT ~5μm)
- Minimal material in the path of the beam
- The software, firmware, hardware and DAQ have been developed in a very productive collaboration between Purdue University and Fermilab
- 10 stations (XY) have already been built but only 7 are currently installed

Sensor assembly



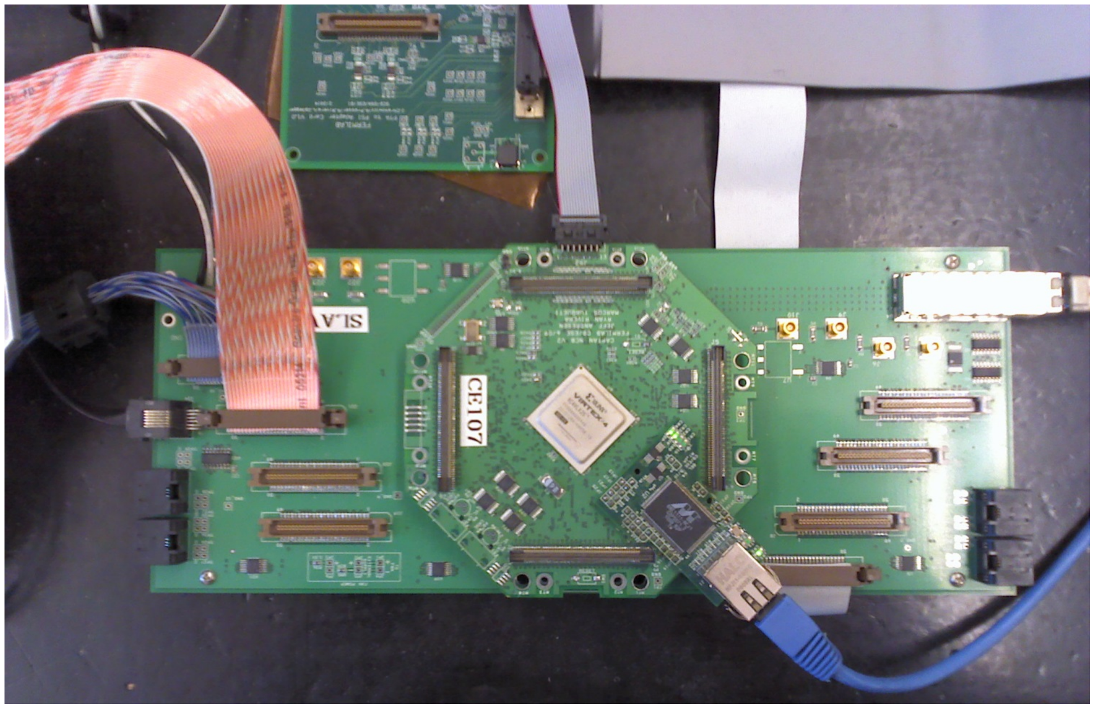
FSSR2 Readout chip

- 0.25 µm CMOS process
- 128 analog inputs
- 8 programmable 8-bit thresholds
- Independent beam crossing clock and readout clocks
- Readout clock runs at up to 70 MHz
- Data driven – no external trigger required
- Data tagged with 8-bit bunch counter
- “Fast-OR” trigger output



CAPTAN Data Acquisition Board

- DAQ based on the CAPTAN (Compact and Programmable daTa Acquisition Node) designed few years ago at Fermilab
- Simple FPGA board with an Ethernet link

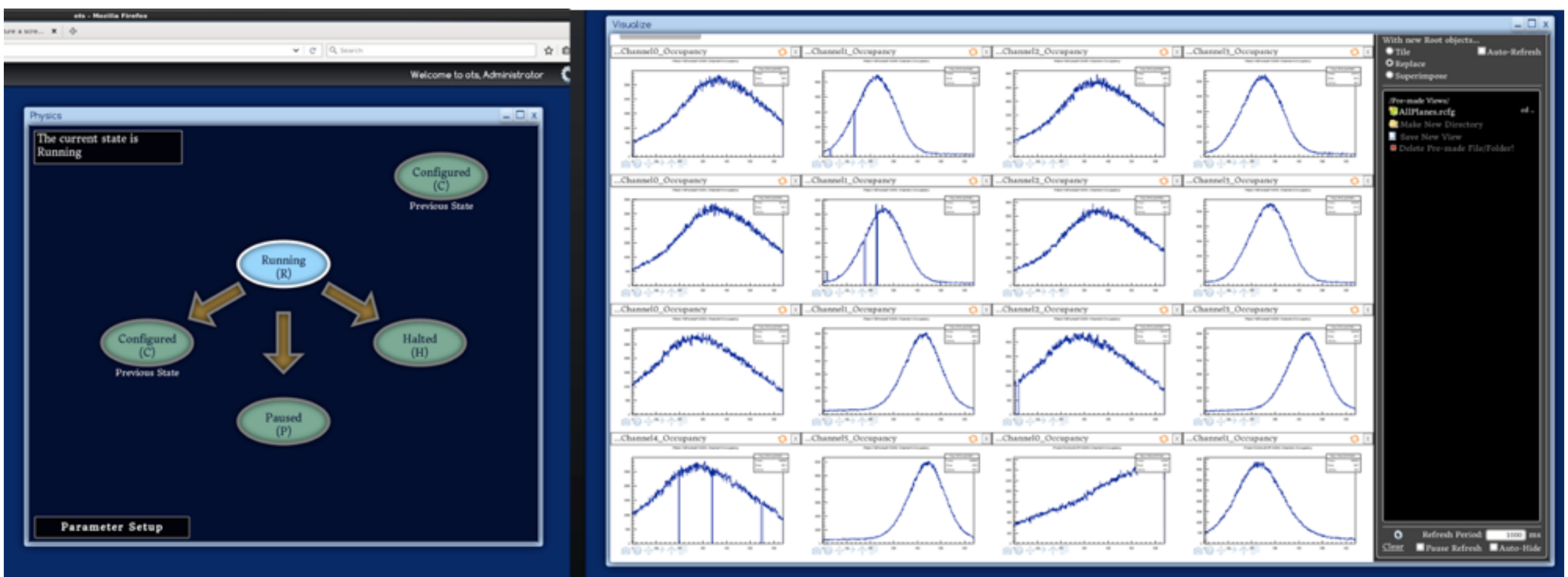


The CAPTAN based DAQ and the detectors, both for pixels and strips, have NO DEAD TIME and all particles can be recorded!

OTSDAQ

- The Fermilab computing division is developing an Off The Shelf Data Acquisition (OTSDAQ)
- OTSDAQ is used to take data with the silicon strip telescope
- It allows an easy integration with any other device, provided the low level C++ interface to the device
- Few experimenters, CMS Outer Tracker and CMS Timing, have been fully integrated in OTSDAQ and took data synchronized with the strip telescope

  https://cdcvs.fnal.gov/redmine/projects/otsdaq/wiki



Sharing triggers

- Since most of the experimenters already have their own DAQ, we offer 2 possible ways of synchronization with the telescopes:

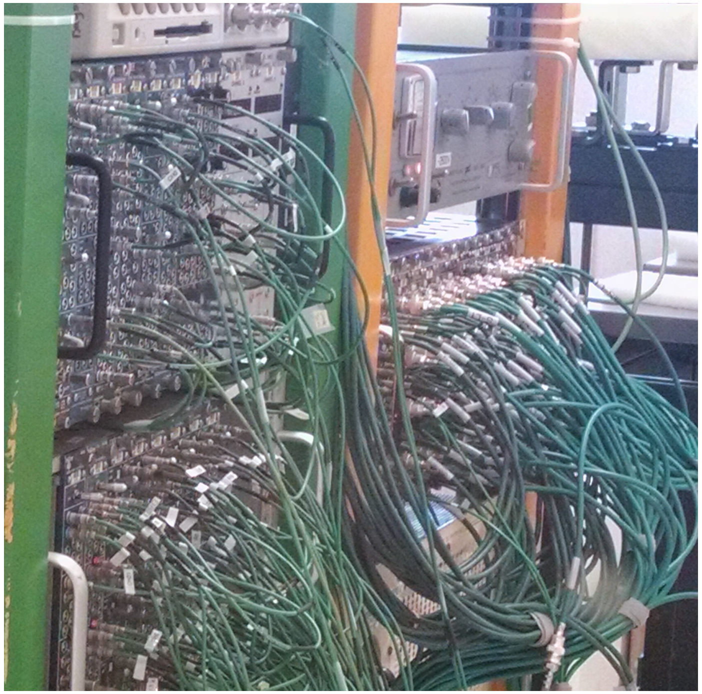
  1. We share a common trigger and then events are later reconstructed and merged together using the trigger number.

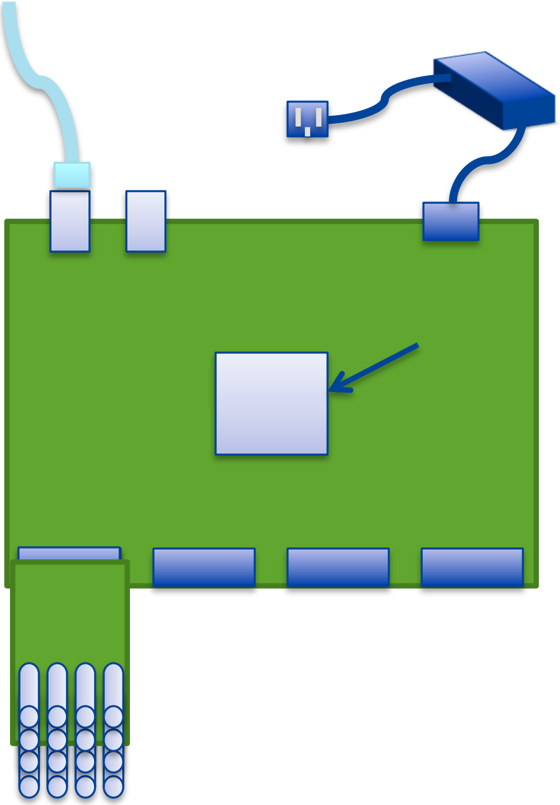
  2. We timestamp the events using a shared common clock, typically the accelerator clock, and then reconstruct and merge the events using the timestamp.

- The most common approach with the many experimenters who used the telescopes so far has been 1). Normally users form their trigger, which is then shared with our telescopes.

NIM upgrade

What was a concept that I presented 3 years ago to modernize the PREP pool when CPAD was at FNAL is now a reality!

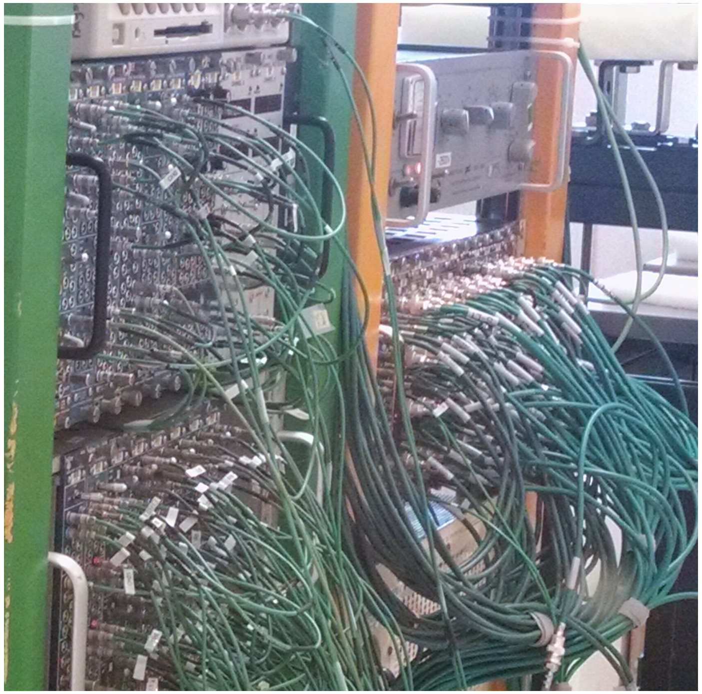




NIM upgrade

What was a concept that I presented 3 years ago to modernize the PREP pool when CPAD was at FNAL is now a reality!

We built a board (NIM+) that accept NIM/TTL signals and it can be plugged in any FPGA board that has standard FMC connectors



Upgraded NIM synchronization

The advantages of using the new NIM+ board are many with respect to the 1970s NIM technology:

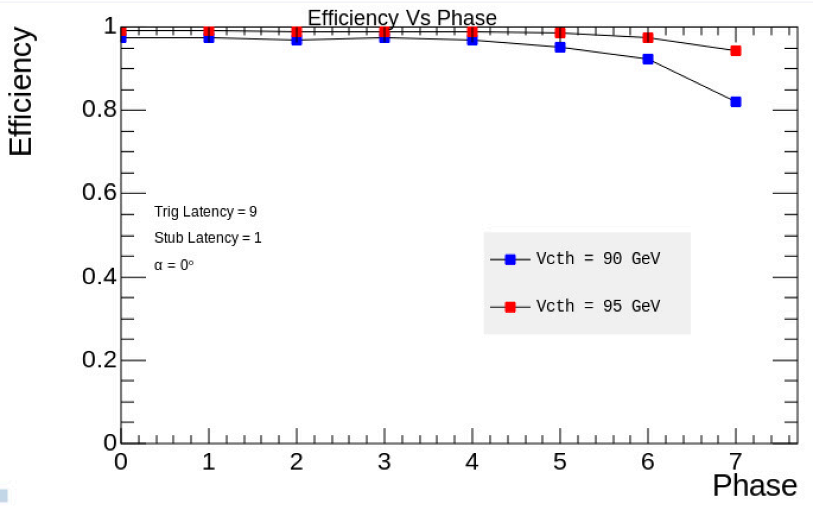
1. It is remotely accessible through the network, which means that the board can be left in the enclosure, if necessary, and the working parameters, like delays and discrimination levels, can be changed without stopping the beam for an access, saving a huge amount of time!
2. Any logic can be implemented in the FPGA without requiring any extra module.
3. Many users with different trigger rates can run at the same time since trigger numbers can be recorded and saved in the data stream allowing event reconstruction in case a user can record only a fraction of the total triggers. (NIM+ runs in OTSDAQ)
4. Clock masking can be easily done in the FPGA.
5. We can finally teach new students how to program an FPGA and how to write firmware, an asset that will pay off in the future

6. …and for sure many many more advantages...

CMS Outer tracker test beam

- We deployed the NIM+ board last May for the CMS Outer tracker test beam, and for 3 other experiments running during the same period.

- Since the CMS chip runs at 40 MHz while the FNAL accelerator runs at 53MHz, the NIM+ allowed us to scan the 25ns (40MHz) clock period into 8 phases, each 3.125 ns, selecting the best particle arrival time on the detector with respect to the clock.



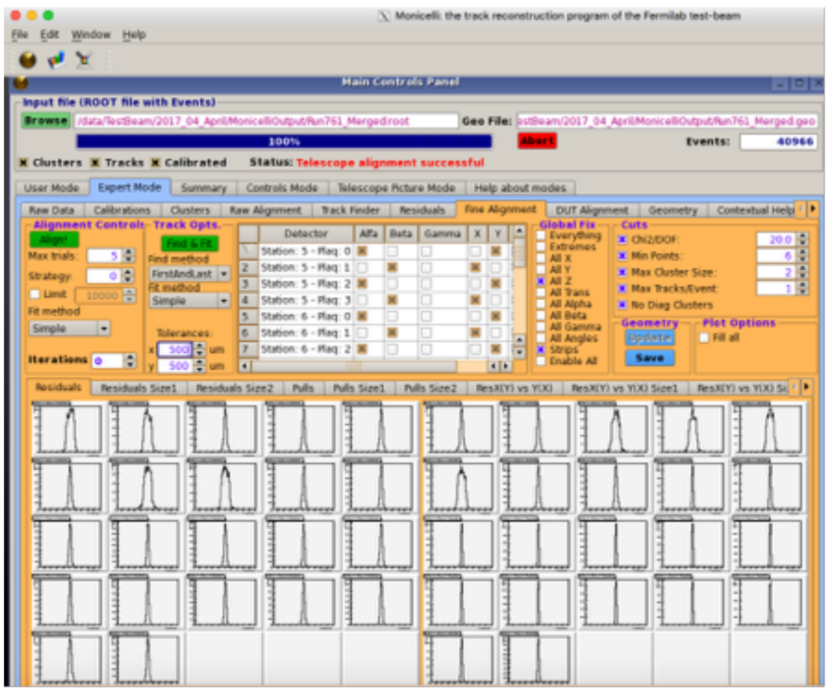
- Another possible way that we are considering, is to generate the 40MHz clock from the 53MHz (~3/4) and then accept every other 4 particles.

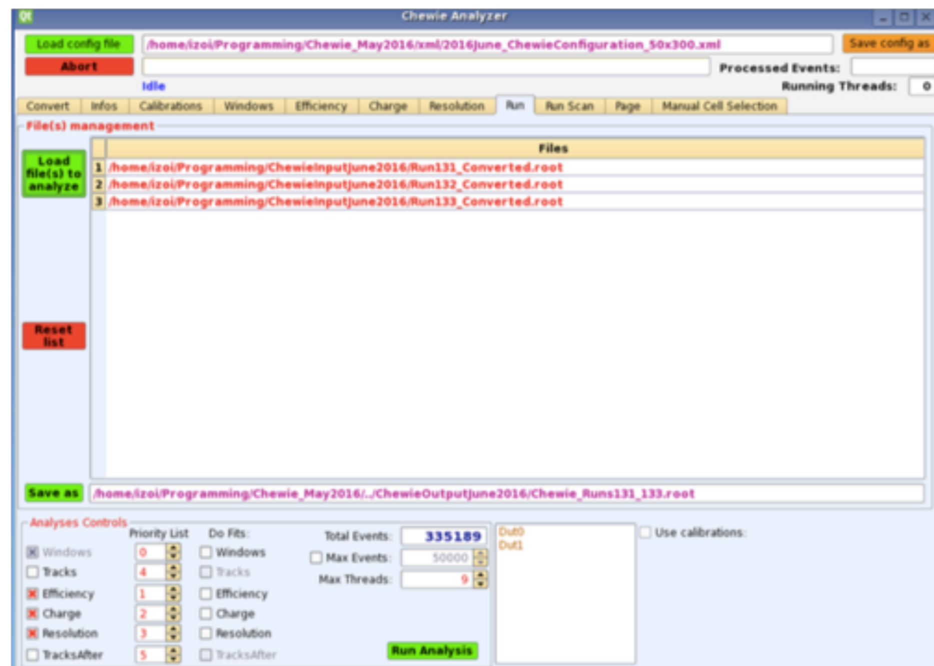
Past and future experimenters

- The CMS readout chip is fully integrated in the system and most of the CMS phase II pixel sensor R&D is done using the FTBF facility telescopes
- We are planning on providing support for the RD53 new pixel readout chip fully integrating it in OTSDAQ
- The CMS phase II Outer Tracker upgrade is also taking advantage of our tracking telescopes especially in anticipation of the next LHC long shutdown, and their system is already integrated in OTSDAQ
- The CMS phase II Timing upgrade is also using the telescopes for their studies and they are also integrated in OTSDAQ
- Many other experiments used the telescopes in the past, CIRTE, GEM detector, scintillator tiles MPPC readout, CMS HGCAL…

Offline analysis tools

- Offline analysis is fully supported by two software codes developed from a joint collaboration of Milano U and FNAL (*Dinardo, Moroni, Menasce, Uplegger et al.*), used for test beams of the CMS pixel phase II upgrades
- <u>**Monicelli** : Tracking and Alignment software</u>
- <u>**Chewie** : Analysis software, it provides several measurements: efficiency, charge collection efficiency, resolution</u>

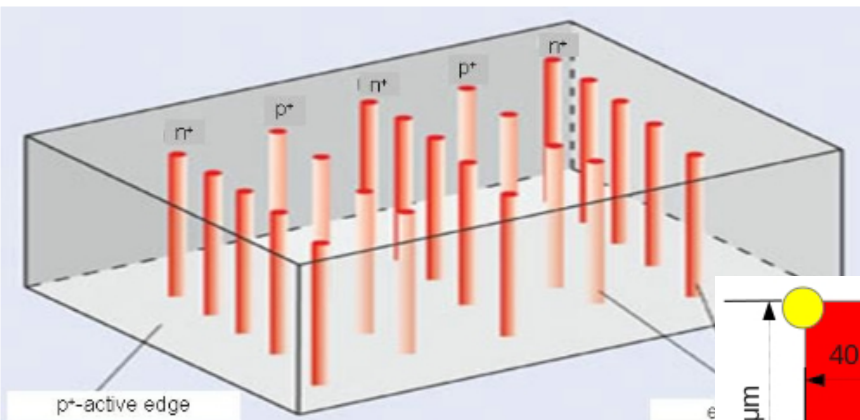




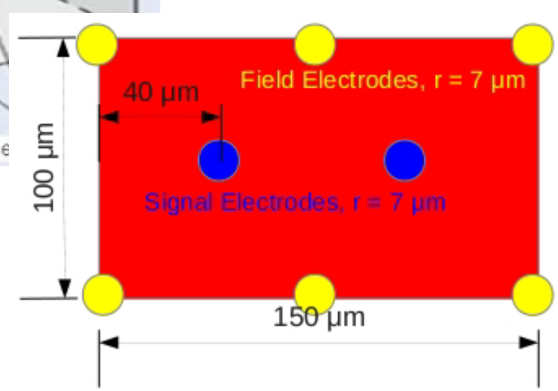
Offline analysis tools

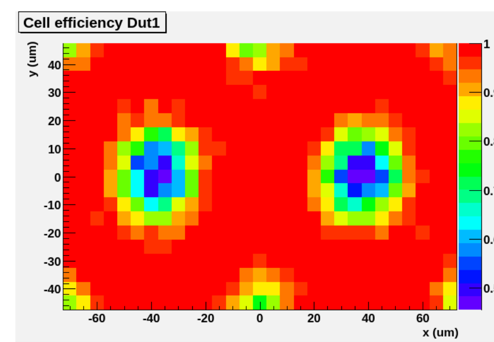
- Monicelli is used for alignment and track reconstruction
  - Users typically are only interested in reconstructed tracks and we use this software to provide them

- Chewie is customized for pixels and strips and allows to analyze the data producing the relevant histograms for efficiency, charge and resolution studies



You can see the 7 μm electrodes with the telescope when the sensor is hit by the beam





FTBF support

- FTBF provides full support starting from DAQ integration to track reconstruction and, in case of strip and pixel detectors, can also provide offline analysis tools.
- As soon as users decide to use the telescope then we immediately discuss the easiest way to synchronize the users and the telescopes DAQs.
- After the data taking we reconstruct tracks using Monicelli and we provide the ntuples with the necessary track information.
- In case of CMS phase II tracker detectors we are also providing support with the Chewie data analysis tool.

Procedure for Getting Resources

- First step is to write the TSW (Technical Scope of Work) and contact facility manager
  - Agreement between users and the lab over what resources are used.
    - Do you need significant engineering or tech support? Computing support?
    - Small amount of KA25 funding might be available.
  - TSW information can be found here:
    http://programplanning.fnal.gov/tsw_orc/
    - Can be a broad document, cover multiple years and uses
    - Approval process typically takes 4-6 weeks, but can be faster.
    - Please be specific about engineering and technical help needed.
- Please contact us! We are excited to collaborate with universities.

http://ftbf.fnal.gov/

T992 collaboration

- Formed to test rad hard devices for future experiments
- We mostly tested CMS phase II pixel sensors: 3D, thin planar and diamonds
- Currently we are testing CMS pixels and Outer tracker devices for phase II upgrades
- We will integrate the RD53 chip into our DAQ
- If you need to test any device for future upgrades you should contact me uplegger@fnal.gov. It might be much easier to come and test your devices since we already have a multi year TSW

Conclusions

- Two tracking telescopes are permanently installed at the FTBF facility
- Experimenters who need tracking to study their devices can easily integrate their DAQ sharing triggers or timestamps
- In case users want to fully integrate their data taking with the strip telescope they need to use OTSDAQ
- CMS tracker devices for phase II are fully integrated with the telescopes
- We are planning on fully integrating the RD53 readout chip
- Offline analysis tools are available for any pixel and strip detectors

Extra infos can be found at this link:
https://twiki.cern.ch/twiki/bin/viewauth/CMS/FermilabTestBeam