Design and Performance of FMS PostShower (FPOST)

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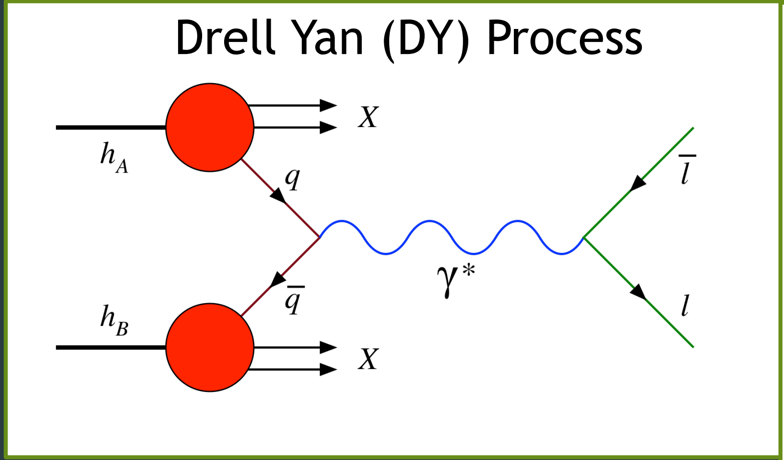
APS DNP 2017

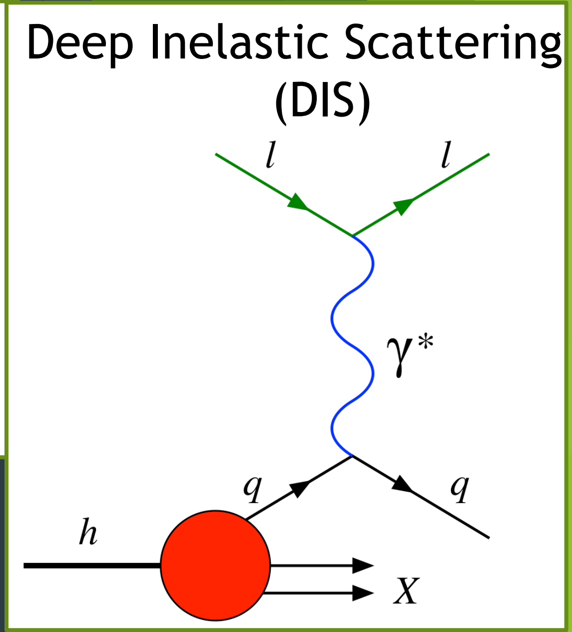
Outline:

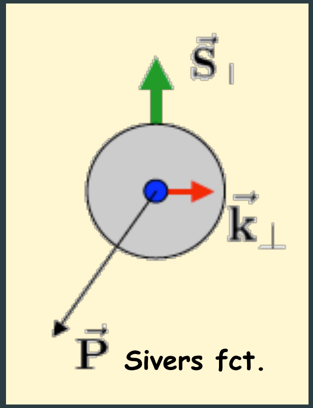
1. Proton
2. New Detector
3. Data Quality

Mapping the Quark momentum in the Proton

- Transverse momentum of quarks in the proton is described by transverse momentum distribution functions (TMDs)
- Sivers function is part of these TMDs and correlates the transverse momentum of the quark to the proton spin
- The Sivers function measured in proton proton collisions (pp) compared to Deep Inelastic Scattering (DIS) should have equal magnitude but opposite sign
- In pp the Sivers function can be measured through the transverse single spin asymmetry (A_N) for Drell Yan (DY)
- Goal is to measure A_N in Drell Yan ($q\bar{q} \rightarrow e^+e^-$)



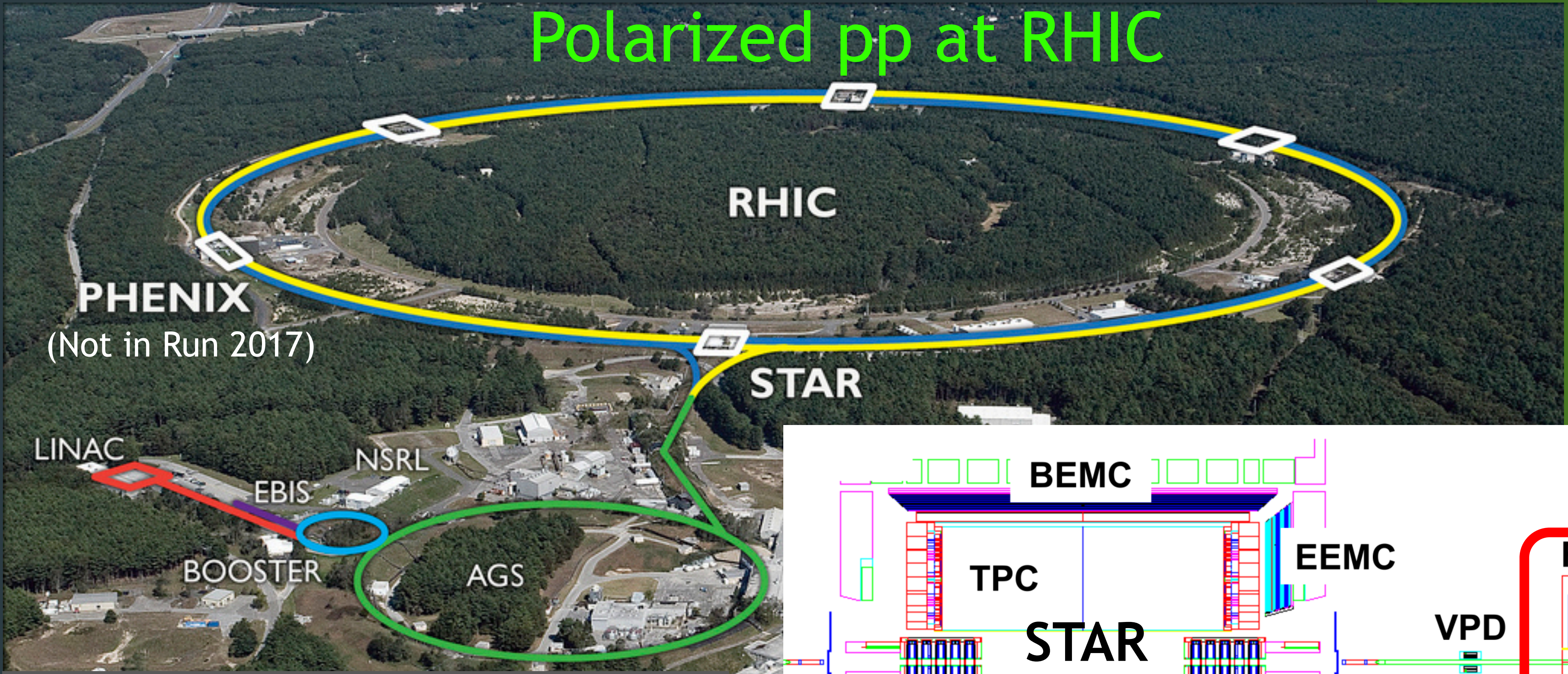


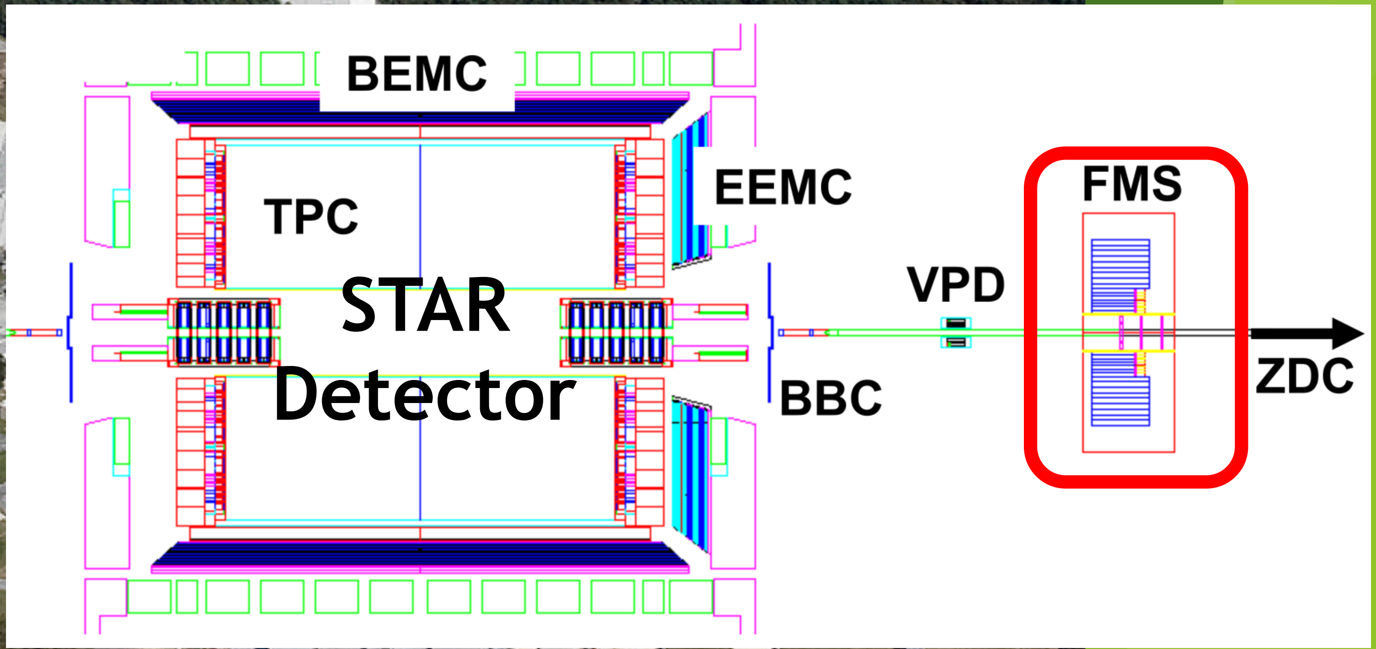


$$A_N = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$

$$Sivers: A_N^{DY} = -A_N^{DIS}$$

Polarized pp at RHIC



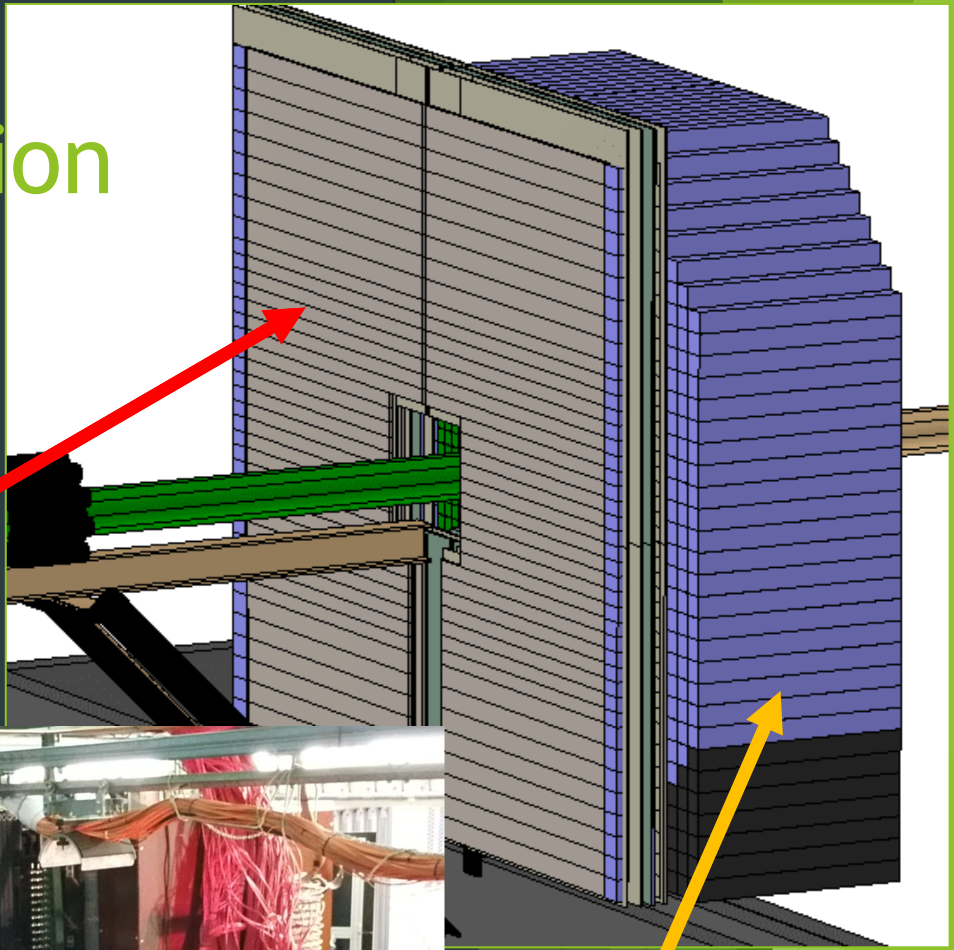


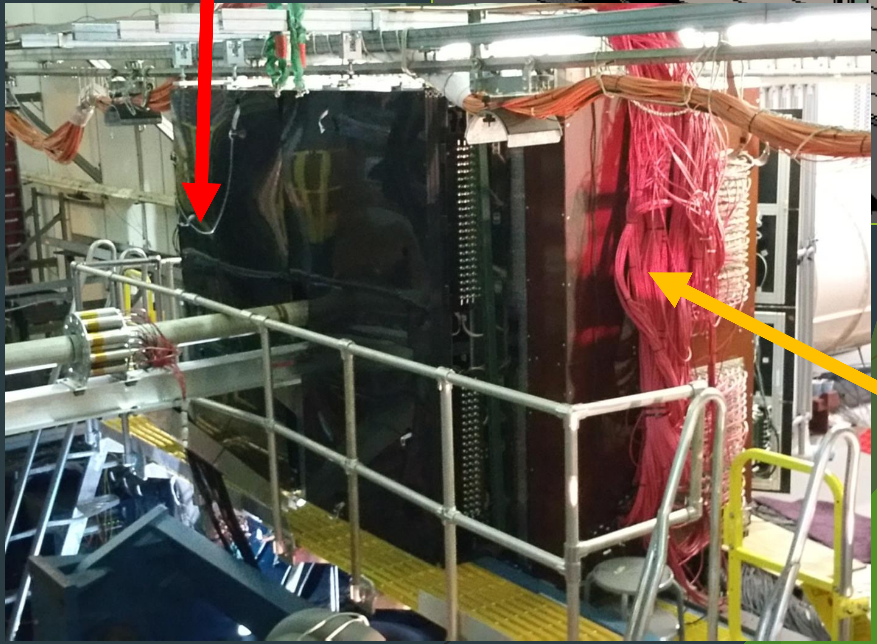
Run 2017

- Transversely polarized proton proton (pp) collisions at $\sqrt{s} = 510\ GeV$
- Average Beam Polarization <*P*>=55%
- Total Integrated Luminosity ~400 pb^{-1}

STAR Forward Instrumentation

- The existing forward electromagnetic calorimeter (FEMC) is called the FMS
  - Consists of 1,264 Lead-glass cells with PMT readouts
  - Forward Psuedorapidity $2.5 < \eta < 4$
- A preshower detector (FPS) to the FMS was installed as part of the FEMC
  - Scintillator Hodoscope using silicion photomultiplier (SiPM) readout
  - Consists of two horizontal and vertical layers followed by a lead converter followed by another layer
  - FPS can be used to separate photons, electrons, and hadrons in the FMS
  - Advantage of SiPMs is they are compact and not sensitive to magnetic fields

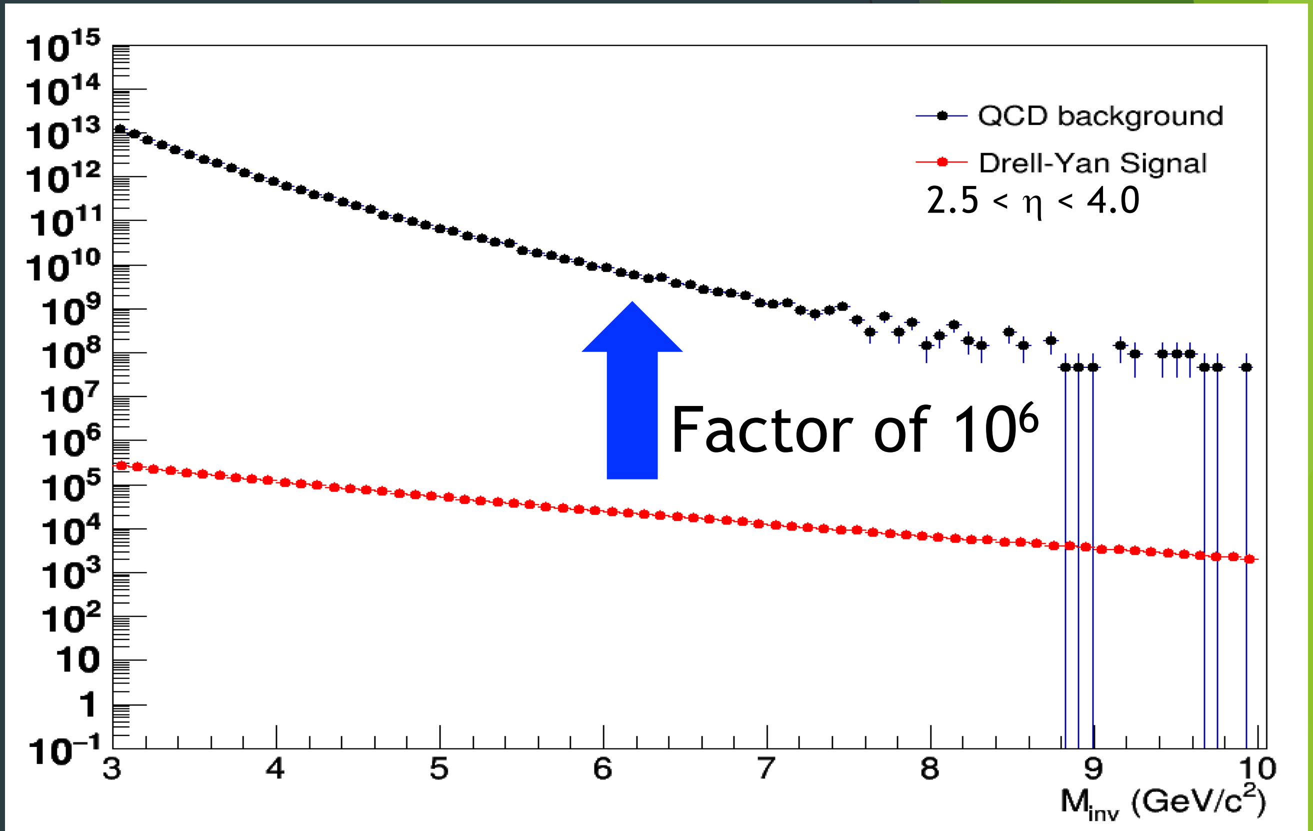




How we are going to measure it

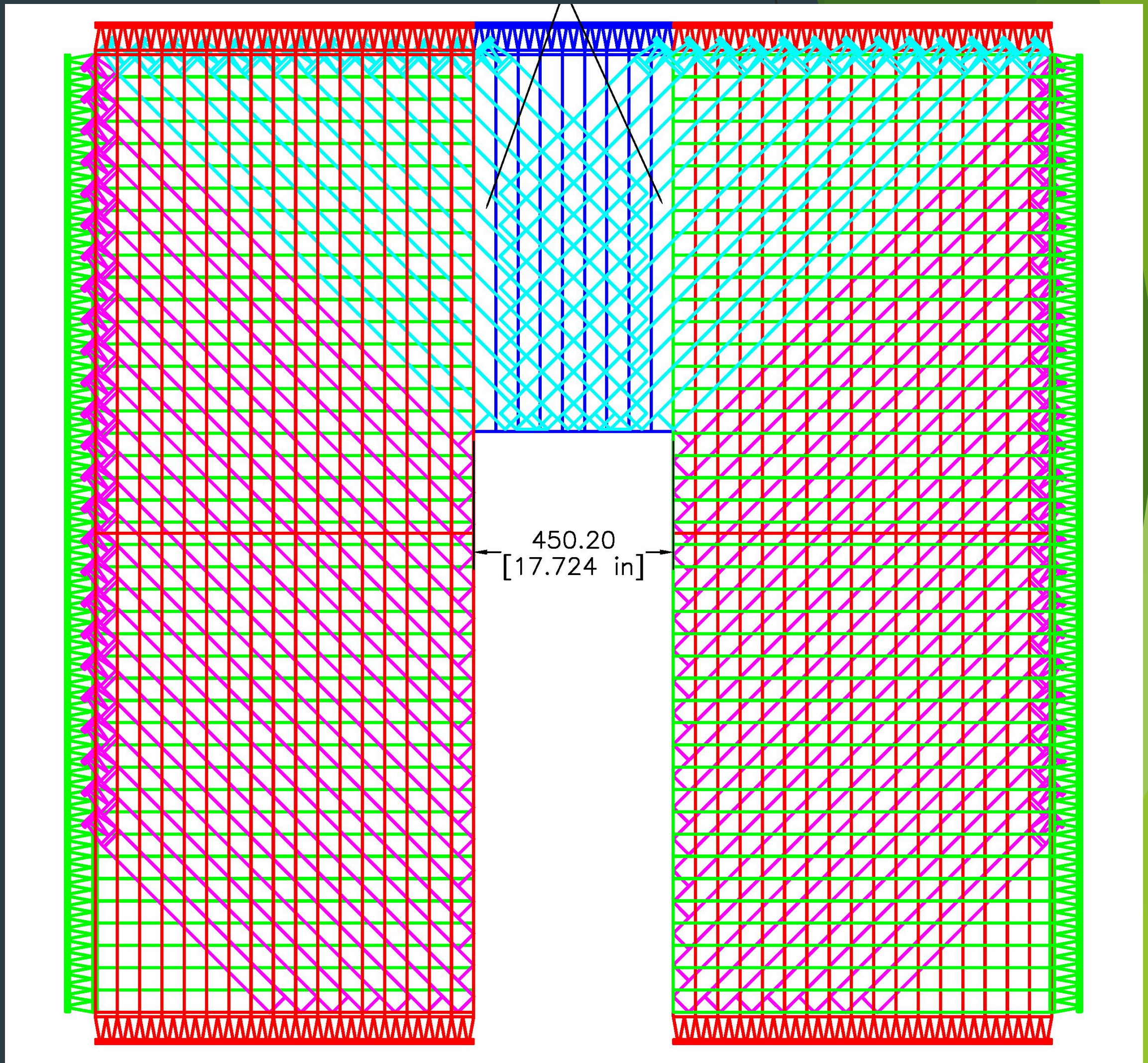
- Looking for DY ($q\bar{q} \rightarrow e^{+}e^{-}$) in forward region in polarized pp collisions
- Large QCD background from hadrons in pp collisions
- Need a way to reject hadron pairs by a factor of 1,000,000 (10^6)
- A hadronic calorimeter is ideal for this but we only need to veto not measure hadrons
- FMS and FPS are able to distinguish hadrons from electrons but by not nearly enough
- New scintillator hodoscope detector, which is a postshower to the FMS (FPOST) provides the necessary rejection

Simulations of DY at STAR (before Run17)



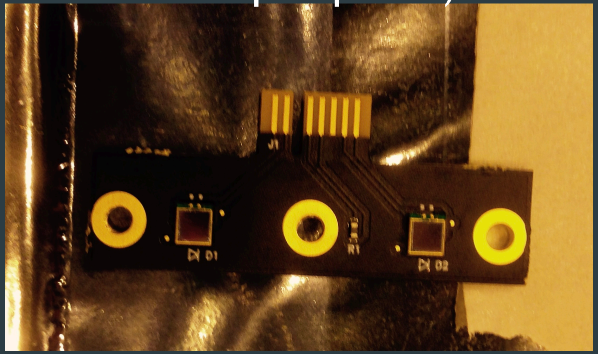
The FMS Postshower

- Similar in layout, design, and technology to the FPS
  - Scintillator hodoscope with SiPM readout
  - Lead converter not needed behind FMS
- 3 Layers total:
  - A horizontal and vertical layer to get position in xy plane
  - A diagonal one to remove ambiguities in hits
- 241 channels
- Full Coverage of FMS



Pretty Pictures

SiPMs are Hamamatsu S12572-50
(3x3 mm^2 50 μm pitch)



SiPM and light
guide holder

Fully Mylar
Wrapped
Scintillator

One layer of FPOST
with scintillators glued
onto G10 board

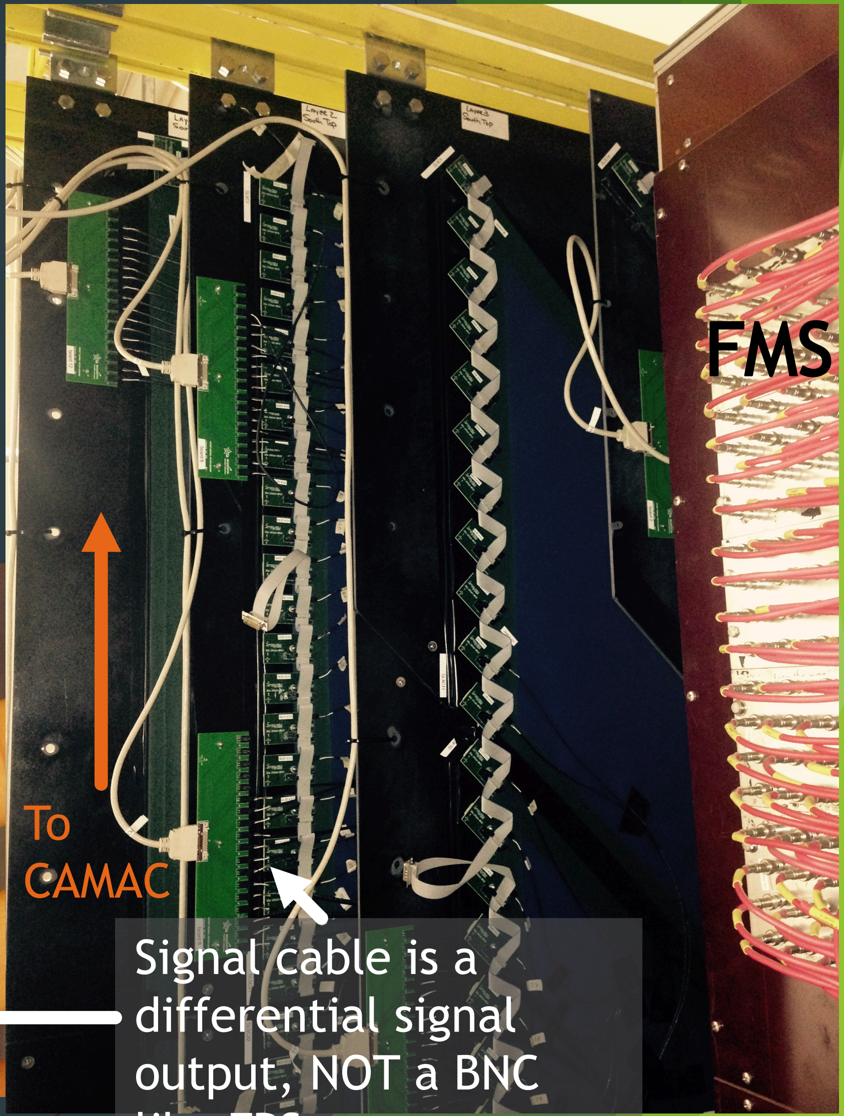
One fully wrapped and covered
FPOST layer ready to be hanged

Fitting the FPOST in a Tight Spot

- Not much room behind the FMS to fit the FPOST
- FPOST placed on movable rails to to allow access to the back of FMS
- Cable mass reduced by using a differential signal
  - Signal Cables fed to a panel which carried up to 16 channels to a differential to single-end signal adapter (CAMAC)
- Compactness of SiPMs saves space on the readout
- SiPMs subject to Radiation damage from neutrons
  - Affects the current and signal in the SiPM
  - FEE board contains both a way to control and read the voltage and current from the SiPM
  - These measurements were used to generate Current vs. Voltage (IV) curves to understand and monitor this damage

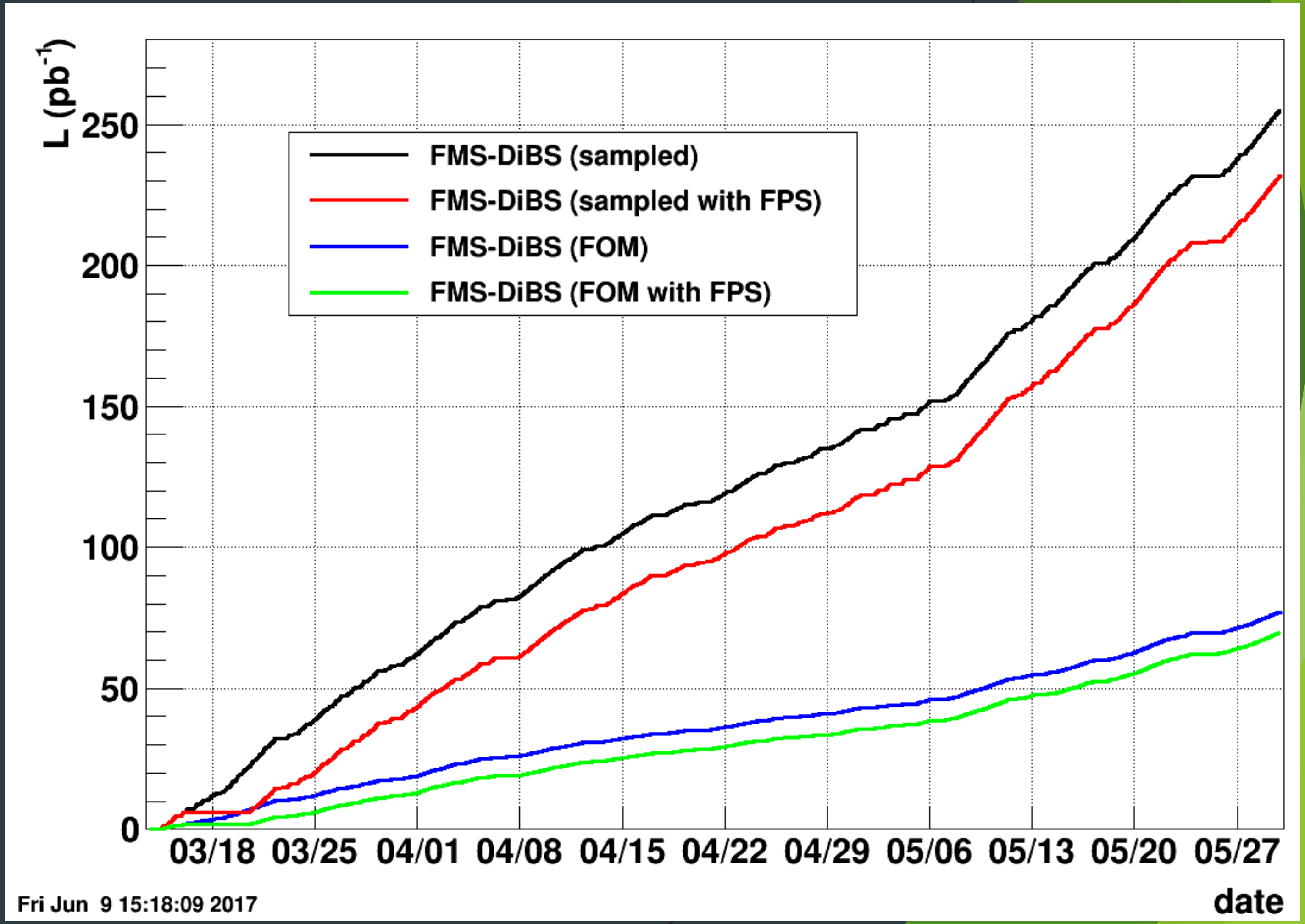
FPOST FEE board

Fully hanging FPOST view from south side



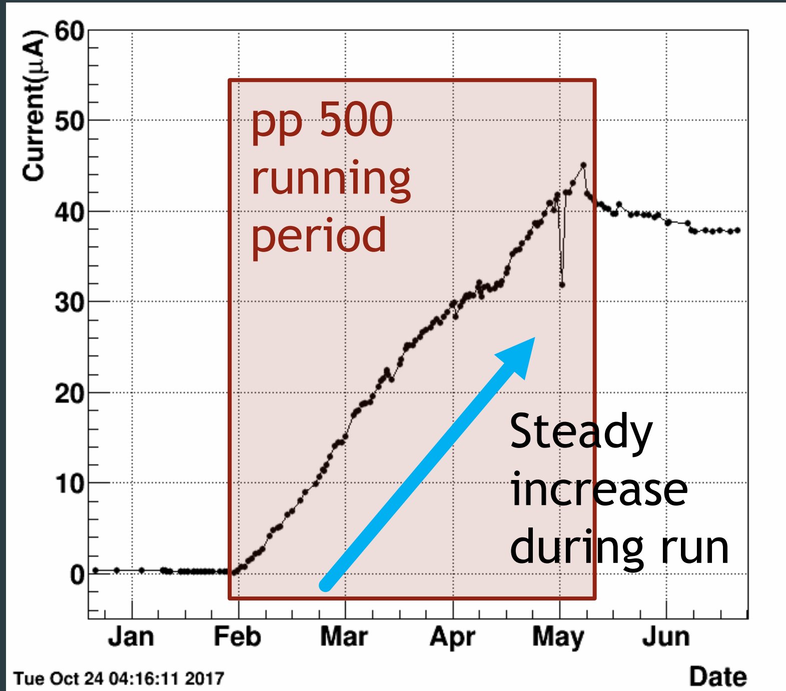
FMS subsystem performance

- To collect DY events the FMS used a Di-Board sum (DiBS) trigger
- FPS and FPOST are not a part of the trigger but collect data in parallel with FMS
- Figure of Merit (FOM) includes luminosity and P^2
- FPS and FPOST data monitored for quality and radiation damage of SiPMs throughout run

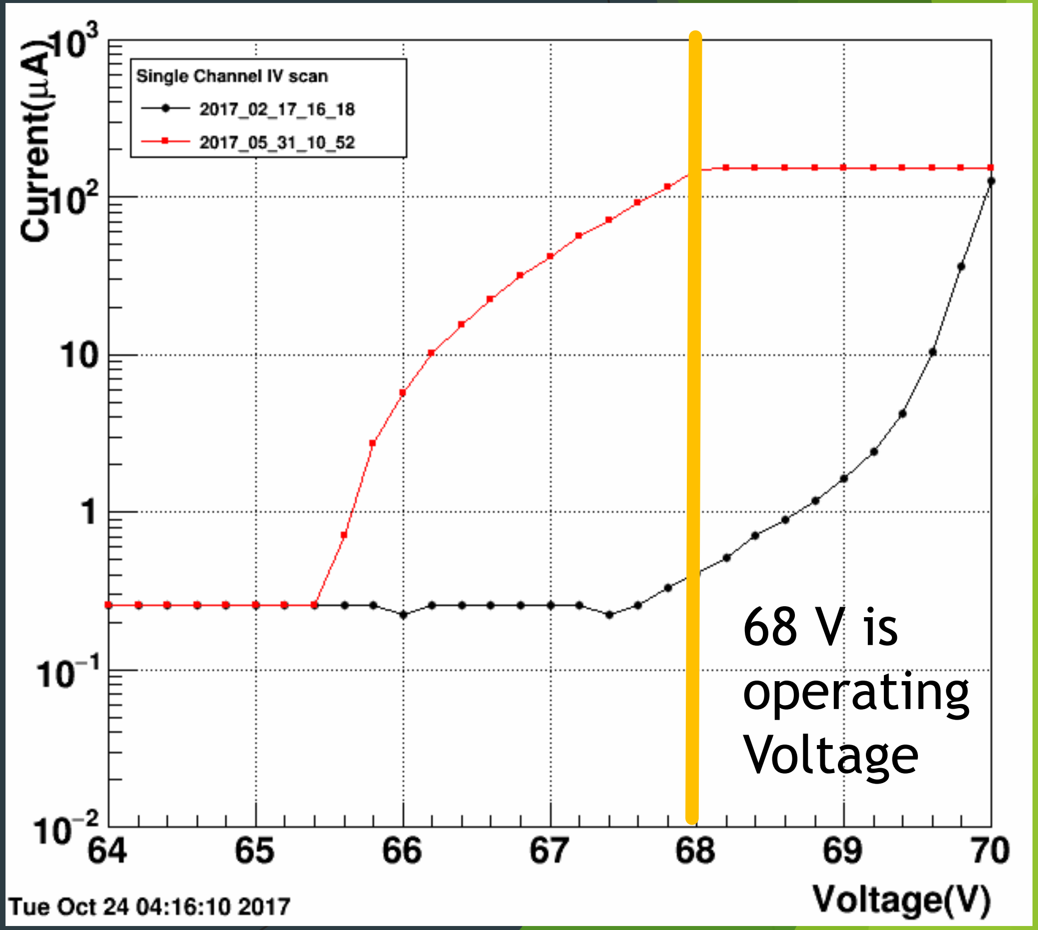


Radiation Damage effect on SiPMs

- Goal is to find a breakdown voltage from the IV curves shown on the far right and see how it changes over the period of the run
- Significant Change in both shape and location of rise in IV curve during run
  - Black is before beam was in RHIC
  - Red is at end of beam operation
- Plot at right shows current at 68 V for same channel

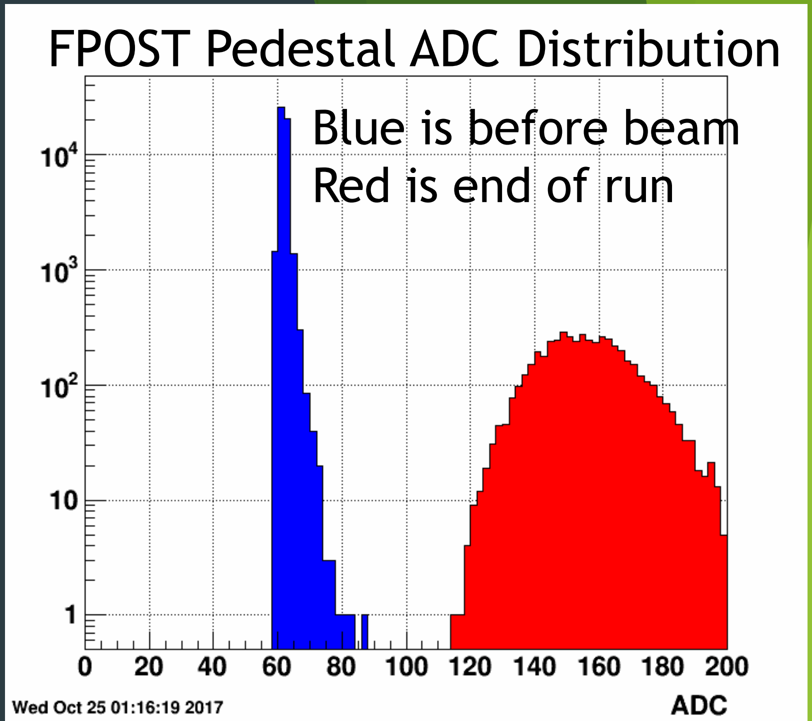


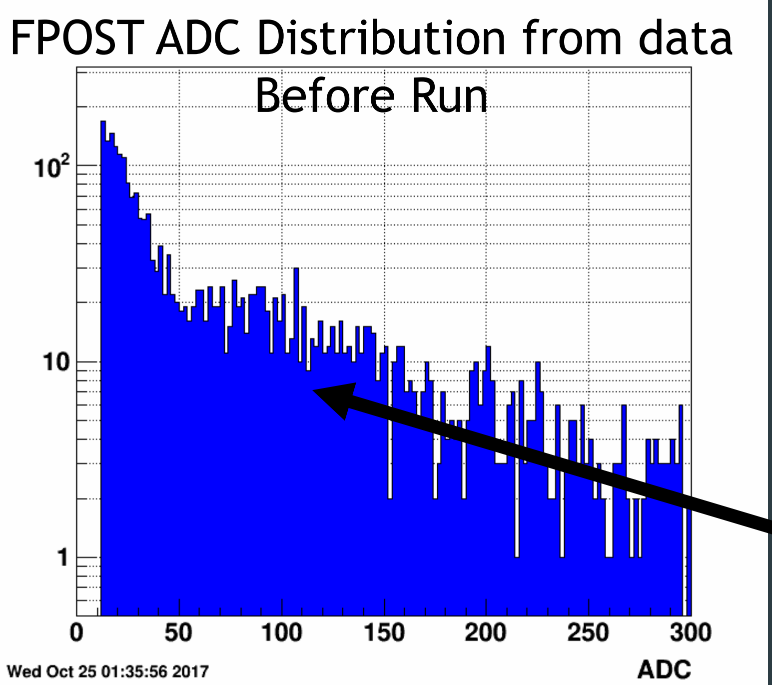
Current vs. Voltage (IV) curve for a particular SiPM (Black before operation, red after)

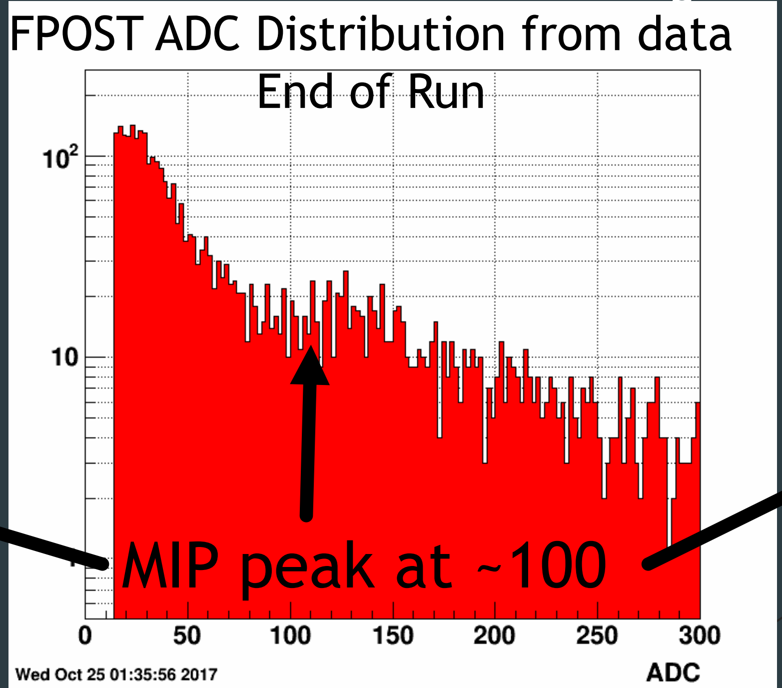


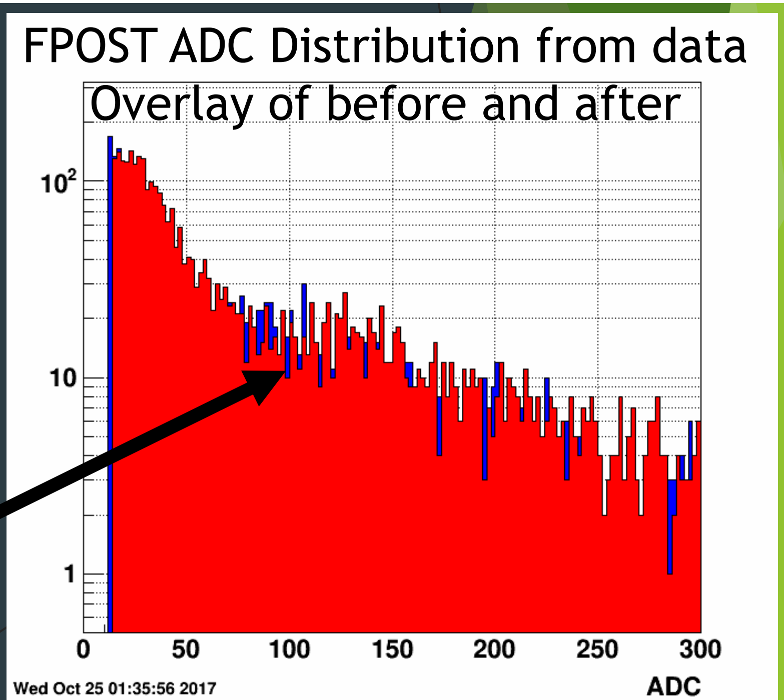
Data from FPOST

- Significant change in pedestal Mean and RMS by the end of the run
- Plots on bottom shows typical ADC distribution for FPOST
- For All plots:
  - Blue is when beam was first in the machine
  - Red is at end of run when beam operation stops
- Not much change in ADC distribution even after radiation damage









Summary

- Measurement of DY is important to EIC and future physics to show sign change since EIC will be able to measure A_N in DIS
- New detector successfully constructed, installed, and operated to measure DY
- FPS and FPOST are the first detectors at RHIC to use SiPMs
- We were able to show effectiveness of SiPMs as readouts
  - Also important to sPHENIX/EIC since its design also uses SiPMs
- Successfully took data throughout the run by monitoring IV curves and ADC distributions
- Working on calibrations and to understand effects of radiation damage
- Working on distinguishing hadrons from DY pairs and photons in simulations

Backup

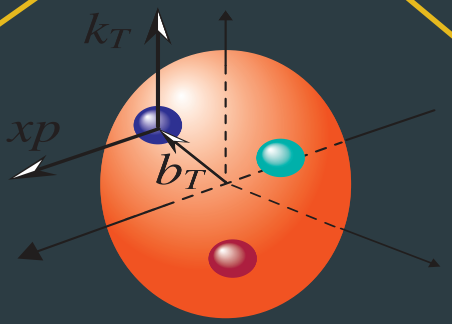
More on Transverse Momentum Distributions

Wigner function
$W(x, b_T, k_T)$

Momentum space

$\int d^2 b_T$

$f(x, k_T)$
TMDs



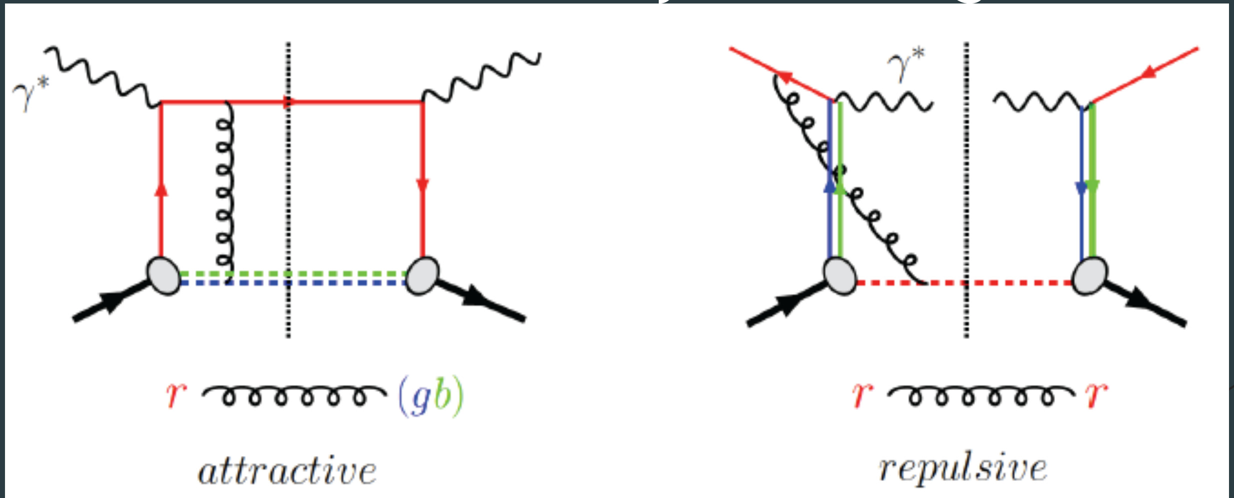
$\int d^2 k_T$

Coordinate space

$f(x, b_T)$
GPDs

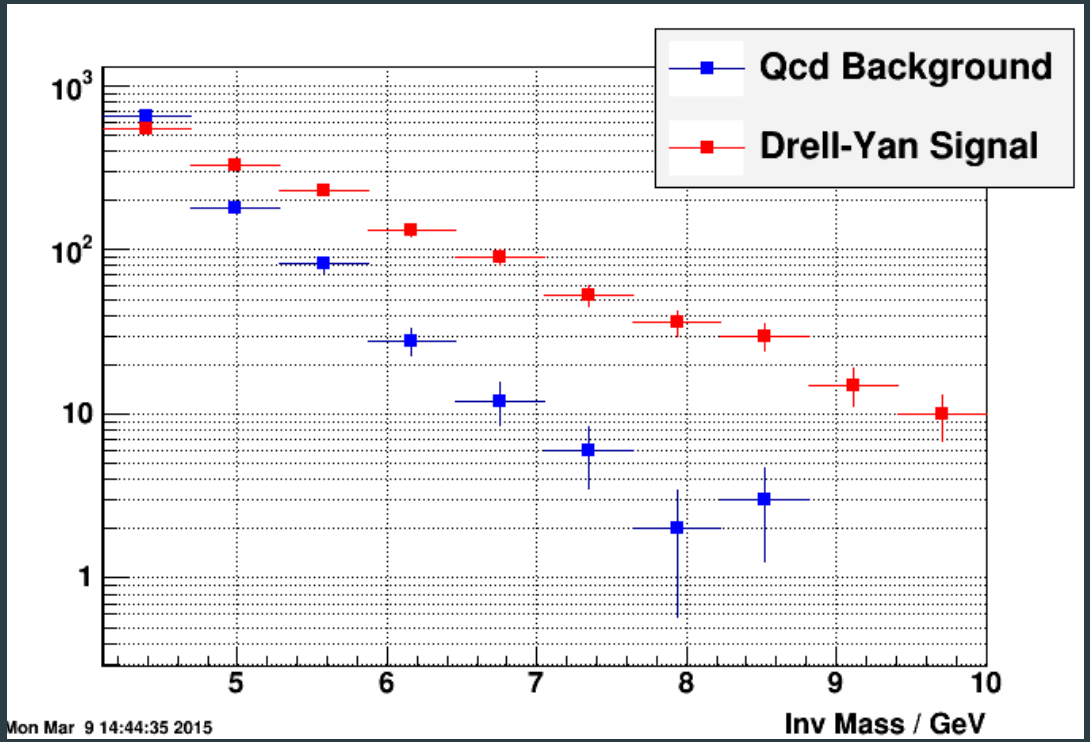
Sivers Function Feynman Diagrams

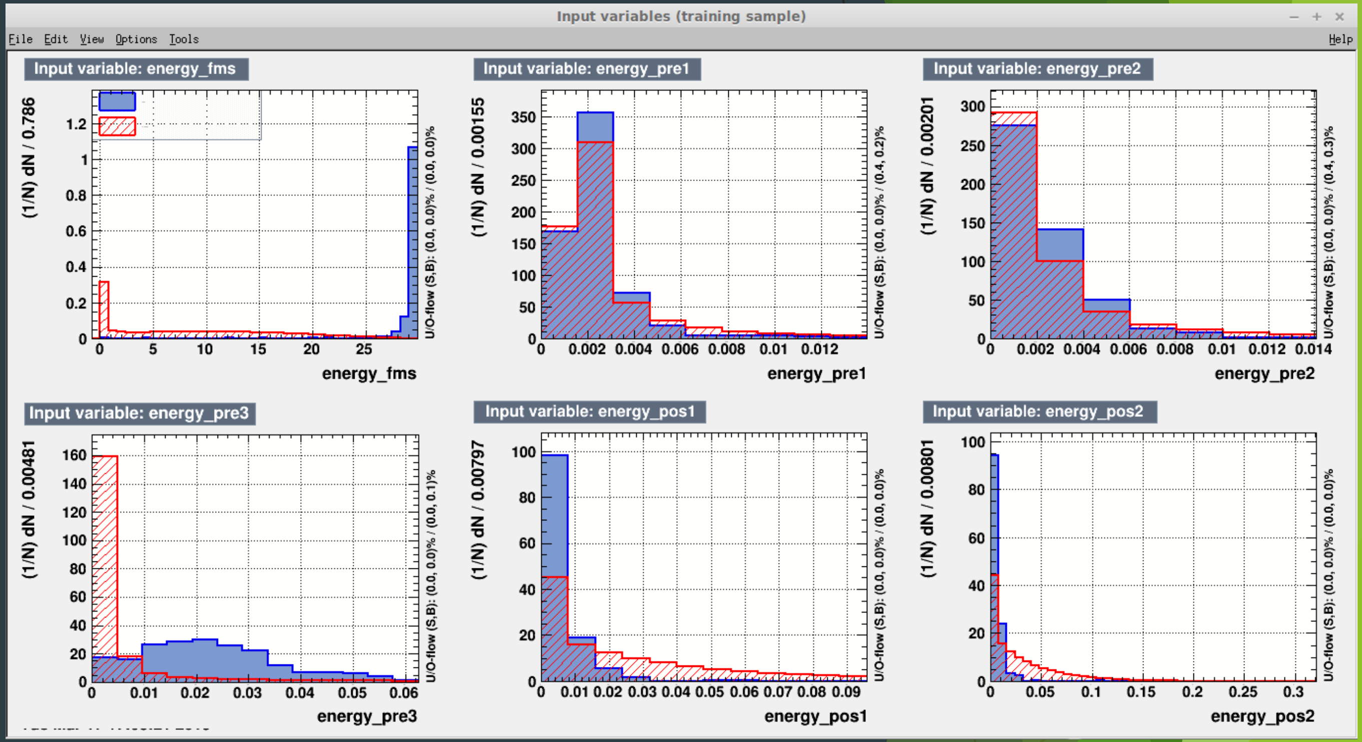
DIS:
γq-scattering
attractive FSI



pp:
qqbar-anhilation
repulsive ISI

Overcoming the Challenge of Eliminating Hadrons

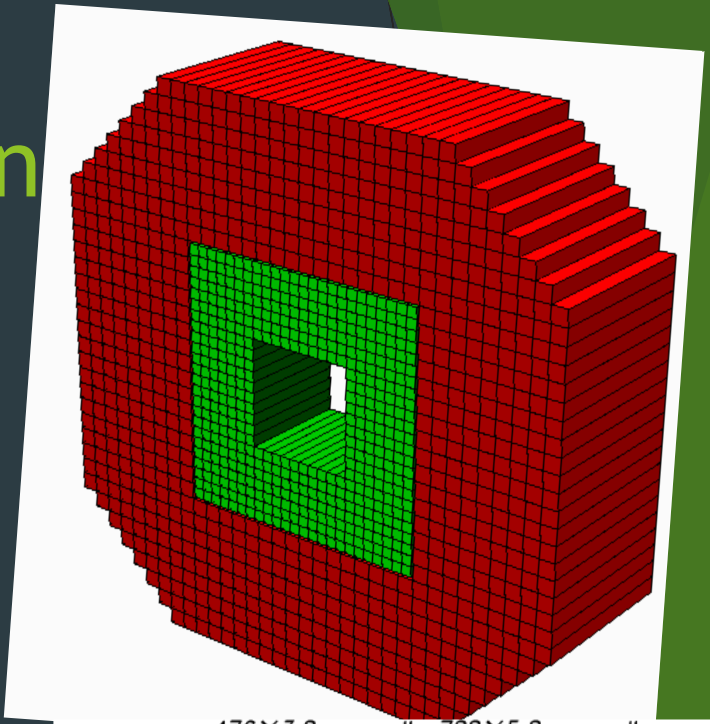


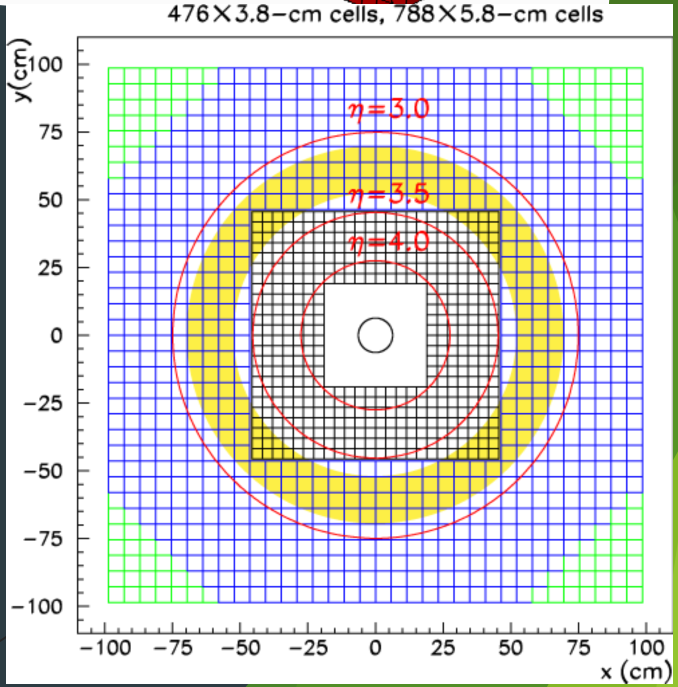


- Hadron Rejection:
  - FMS ~1/100
  - FPS ~1/10

Additional FMS Information

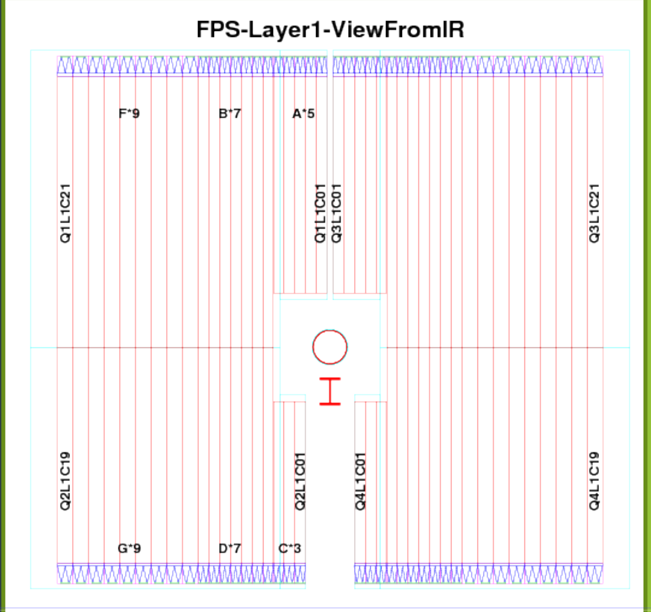
- Large (5.8 x 5.8 cm) outer cells (red)
- Small (3.8 x 3.8 cm) inner cells (green)
- Each cell is ~18 radiation lengths deep
- Size of FMS is about 1 meter on each side of beam pipe
- Utilize Cherenkov lights (NOT the scintillation lights)
- Lead-Glass cells turn dark after being exposed to radiation
  - Exposure to the UV rays in sunlight clears Lead-Glass cells
  - To minimize the effects of this damage to the data taking a UV curing system was installed and successfully used in Run 2017
  - It was used to clean the Lead-Glass cells during downtime and ramping of the beam

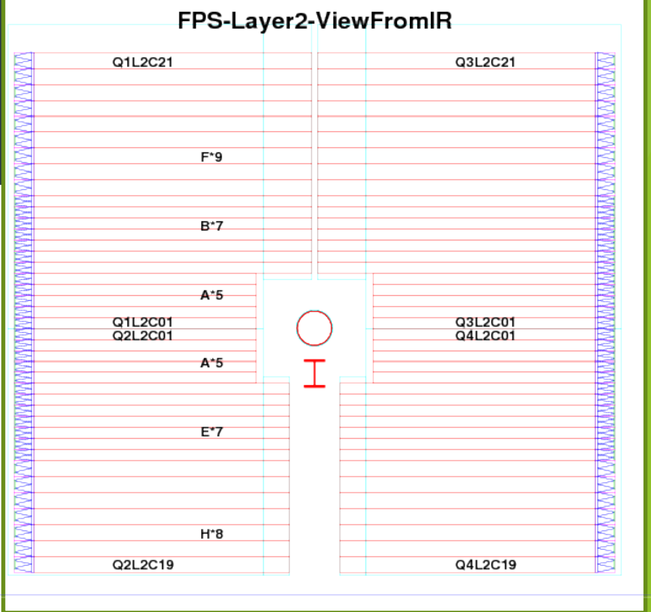


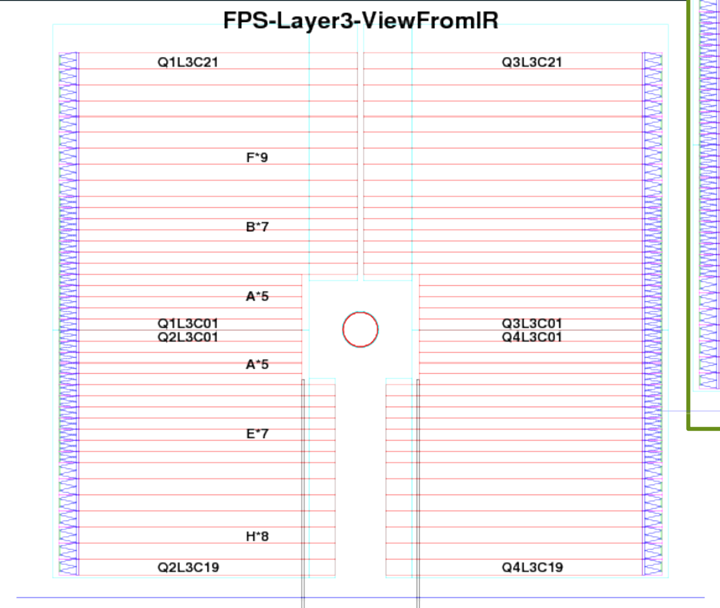


Additional FPS Information

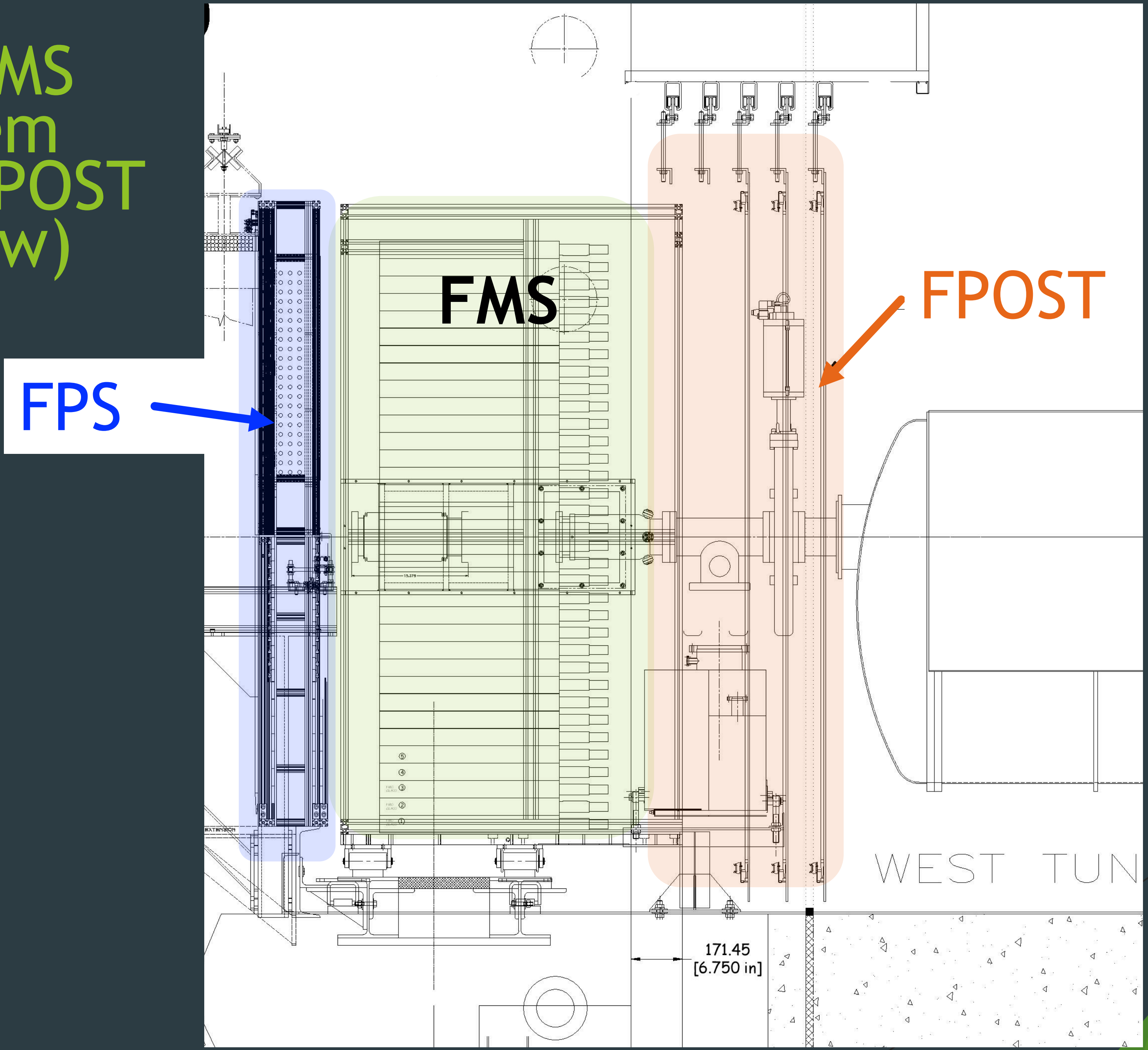
- Actually consists of two different SiPMs
  - Layer after lead convertor uses one type the other two use another
- Size of channels also vary with distance from beam pipe.
  - Done for increased resolution near beam pipe to match size of small cells in FMS
- Uses multidrop cable for power, uses lemo for signal then to BNC
- How vetos in FPS work
  - A photon will have no MIPs in layers 1 and 2 but a hit in 3
  - An electron will have a MIP in all three layers and an electromagnetic shower in the FMS
  - A hadron will also have a MIP in all three layers but will leave much less energy in the FMS.







Whole FMS Subsystem Including FPOST (Side View)



FMS Subsystem (Top View)