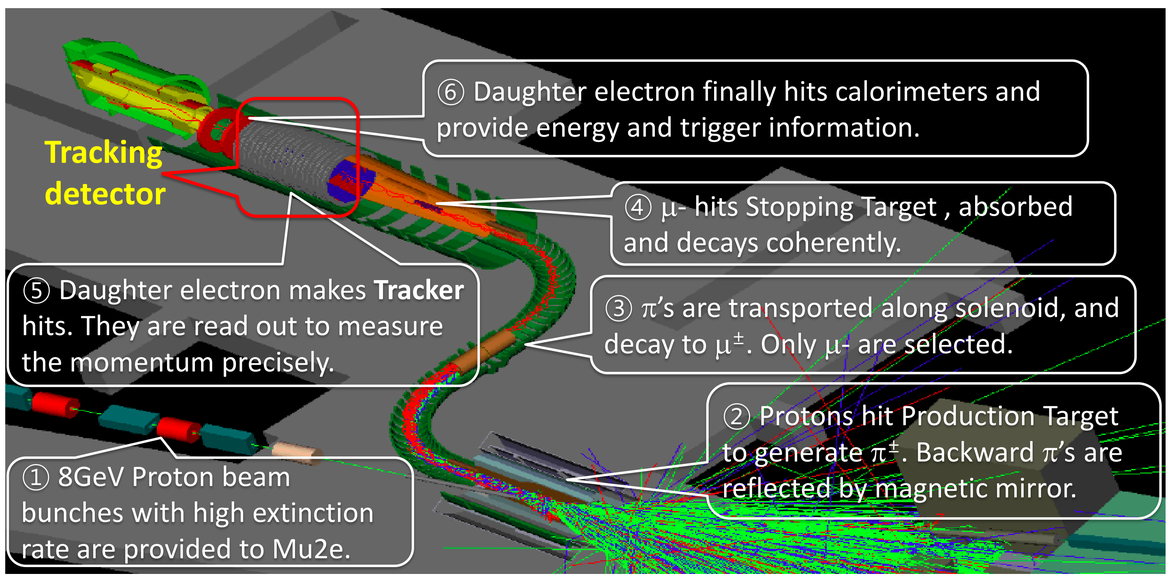
The Straw-tube Tracker for the Mu2e Experiment

MyeongJae Lee (LBNL) *on behalf of Mu2e collaboration*

The Mu2e experiment will search for neutrinoless conversion of muons into electrons in the field of an aluminum nucleus. The signature of this process is an electron with energy nearly equal to the muon mass. Precise and robust measurement of the outgoing electron momentum is an essential element to the experiment. We describe the design of a low mass tracking system to meet this requirement. The tracker must operate in a vacuum and a 1 T magnetic field. We have chosen to use about 20,000 thin-walled Mylar straws held under tension to avoid the need for supports within the active volume. In addition to measuring distance from the wire by drift time, subnanosecond measurement of signal propagation time will be used to measure position along the wire. Charge will be measured using ADCs to provide particle identification capability. To minimize the number of vacuum penetrations, digitization will be performed on the detector. Readout will use a triggerless, streaming architecture with data transmitted on optical fiber.

Mu2e Experiment

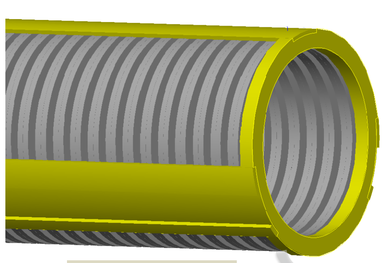
Mu2e Detector

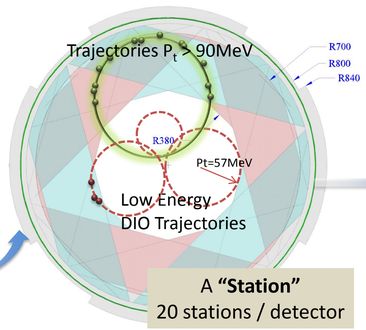


Tracking detector requirement

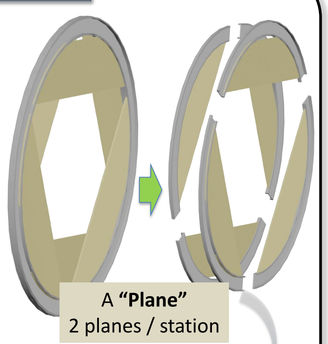
Categories	Requirements	Solutions
Operation environment	**1T** uniform magnetic field, 10^{-4} Torr **vacuum**	
Track measurement	**Low mass detector** to minimize Coulomb scattering Sufficient (~20) number of hits for track reconstruction **Blind to low momentum** DIO electrons, sensitive to P_t>90 MeV electrons **Momentum resolution** of conversion electron after reconstruction : **<180 keV/c** Acceptance > 20%	Cylinder shape tracker with Straw detectors
Reliability	Reliable operation for at least 3 years Straw should withstand 1 atm pressure difference Leak rate < 7ccm	Leak / Creep test required for individual straws
Radiation hardness	Withstand 5MHz/straw max hit rate No straw aging up to 2C/cm integrated charge deposition Neutron radiation hardness of electronics up to $2x10^{12}$ n/cm2	Aging test for straw Neutron tolerance test for electronics
Digitizer	TDC resolution 500ps, Δt resolution 70 ps Minimum 7 effective number of bits of ADC, 50MS/s	FPGA TDC and Commercial ADC

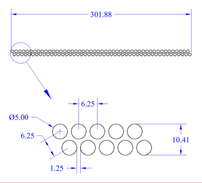
Mechanical design


Tracking detector

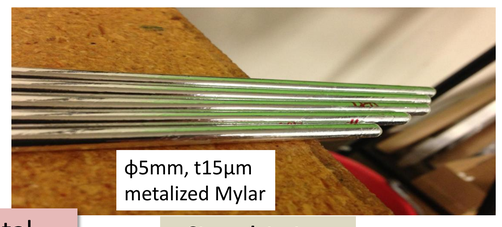


A **"Station"**
20 stations / detector


A **"Plane"**
2 planes / station



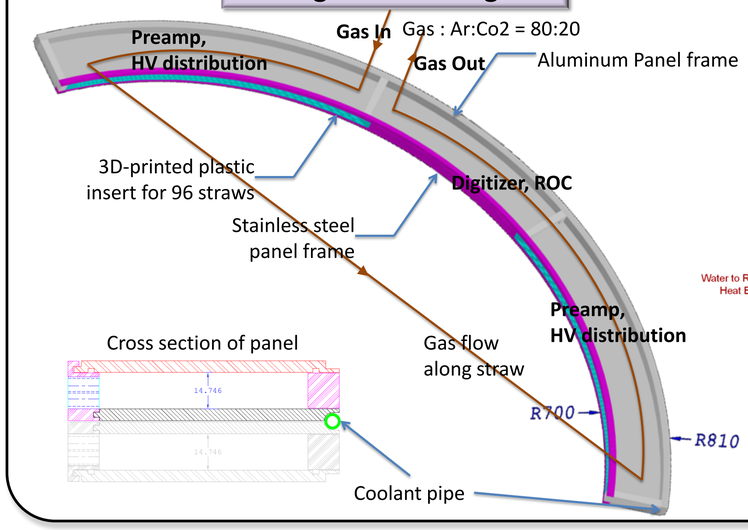
23,040 straws in total



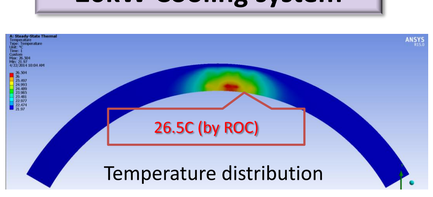
Straw detectors
96 straws / panel

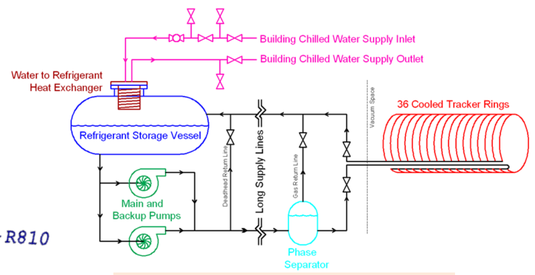

A **"Panel"**
6 panels / plane

Single Panel design



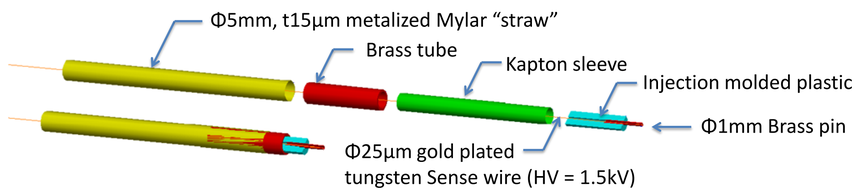
20kW Cooling system





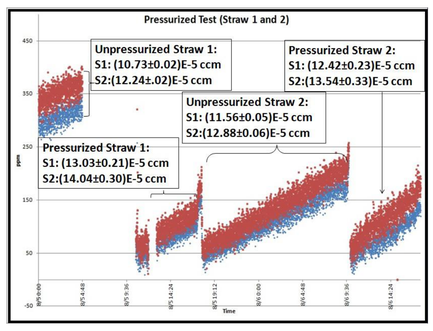
Cooling system using SUVA®

Straw R&D

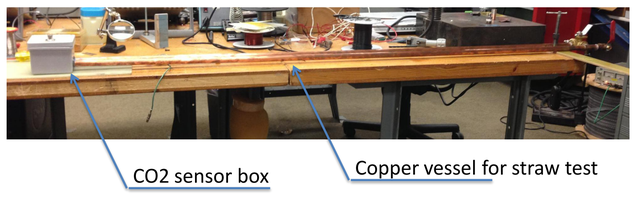


Leak test

- Measuring CO2 leak from straw through plastic, to N2-purged vessel.
- No pressure or 2 atm pressurized
- Leak rate < $3.5x10^{-4}$ ccm



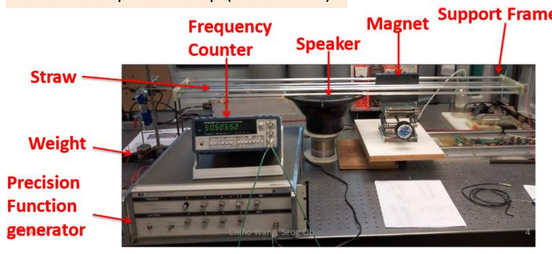
Leak test setup (Rice Univ.)



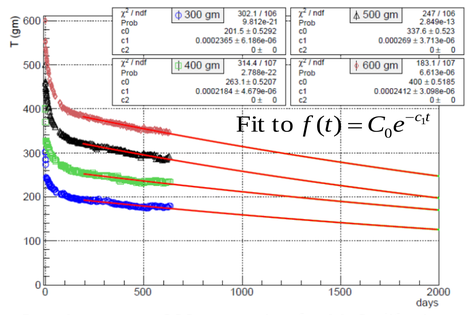
A deformed straw by CO2 leak

Creep test

Straw Creep test setup (Duke Univ.)



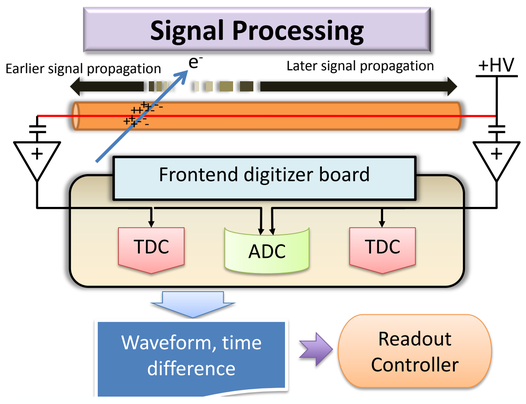
- Glue straws on a support frame (120cm) with tensions: 300gm, 400gm, 500gm, 600gm.
- Measure straw tension by resonant frequency as a function of time.

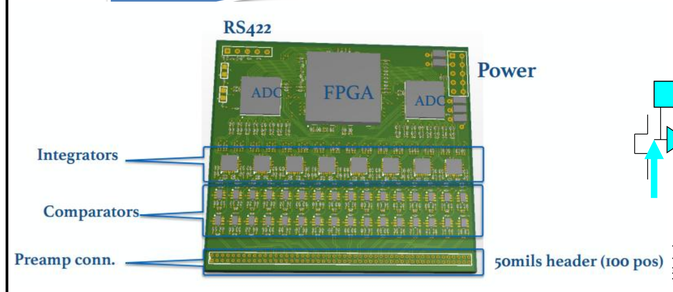


- Requirement : >200gm tension for Mu2e life time
- 600gm tensioning is OK for Mu2e life time.
- >6 years operation (for Mu2e-II) could be fine

Frontend electronics

Signal Processing

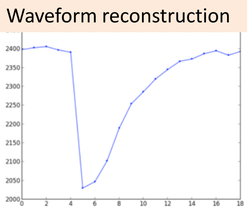




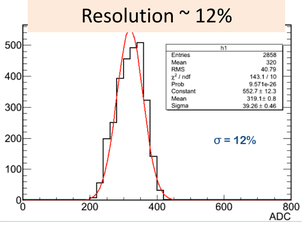
Commercial ADC

- MAXIM MAX19527 FADC
- 8ch, 50MS/s, 12bit, Effective number of bits = 10.5

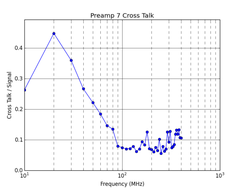
Waveform reconstruction

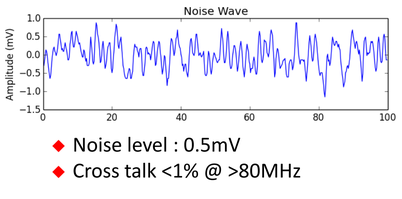


Resolution ~ 12%



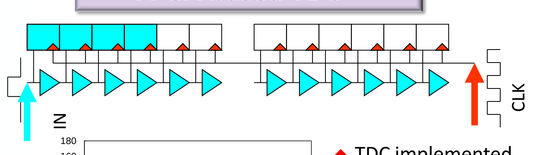
Preamplifier

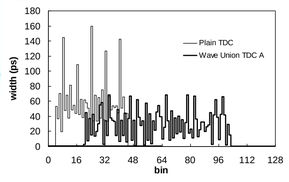




- Noise level : 0.5mV
- Cross talk <1% @ >80MHz

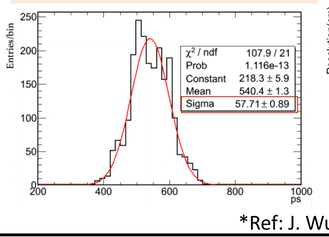
FPGA based TDC(*)



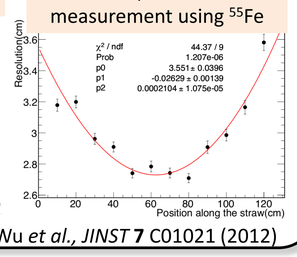


- TDC implemented @ ALTERA Cyclone III FPGA
- Uneven bin width resolved by periodic calibration
- 32ch, 62.5MHz base clock, on-chip CRC check
- Resolution = 39ps

σ(Δt) ~ 57 ps (incl. preamp)



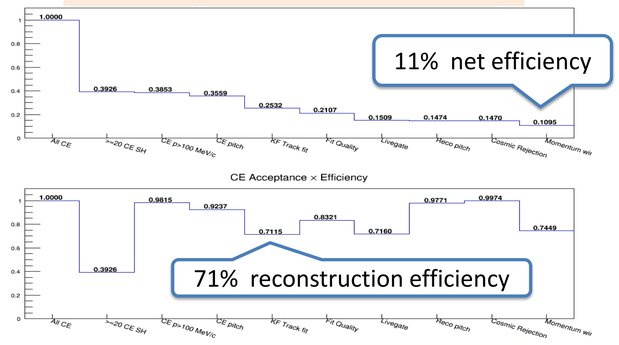
Hit position measurement using ^{55}Fe



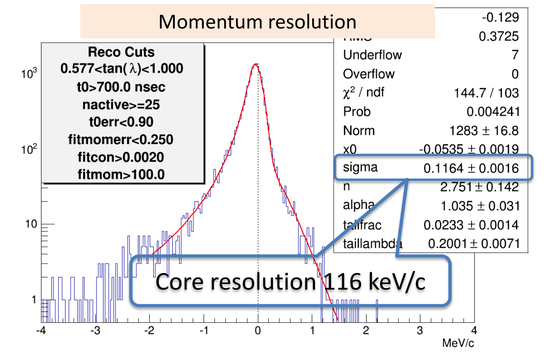
*Ref: J. Wu *et al., JINST* **7** C01021 (2012)

Simulated Tracker performance

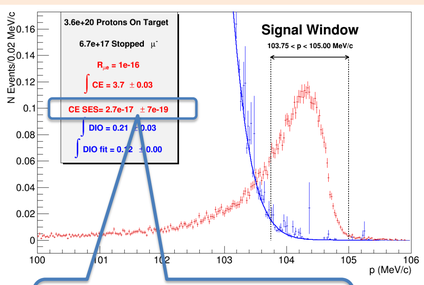
Tracker Acceptance x Reconstruction efficiency



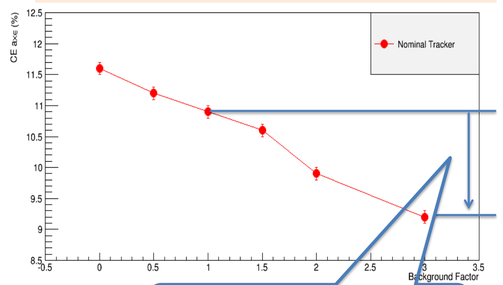
Momentum resolution



Simulated DIO / CE momentum distribution



Efficiency dependence to background rate



Mu2e Collaboration : 28 institutions, 160 collaborators (as of June, 2014)

USA : Boston University, Brookhaven National Laboratory, University of California(Berkeley), Lawrence Berkeley National Laboratory, University of California (Irvine), California Institute of Technology, City University of New York, Duke University, Fermilab, University of Houston, University of Illinois (Urbana-Champaign), Lewis University, University of Massachusetts (Amherst), Muon Inc., Northern Illinois University, Northwestern University, Pacific Northwest national laboratory, Purdue University, Rice University, University of Virginia, University of Washington

Italy : Laboratori Nazionale di Frascati, Instituto Nazionale di Fisica Nucleare Genova, Instituto Nazionale di Fisica Nucleare Lecce, Università del Salento, Instituto Nazionale di Fisica Nucleare Lecce, Università Marconi Roma, Instituto Nazionale di Fisica Nucleare (Pisa), Universita di Udine, INFN Trieste/Udine

Russia : Joint Institute for Nuclear Research (Dubna), Institute for Nuclear Research (Moscow)