Temporary Muon Spectrometer Design

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Near Detector Conceptual Design Review

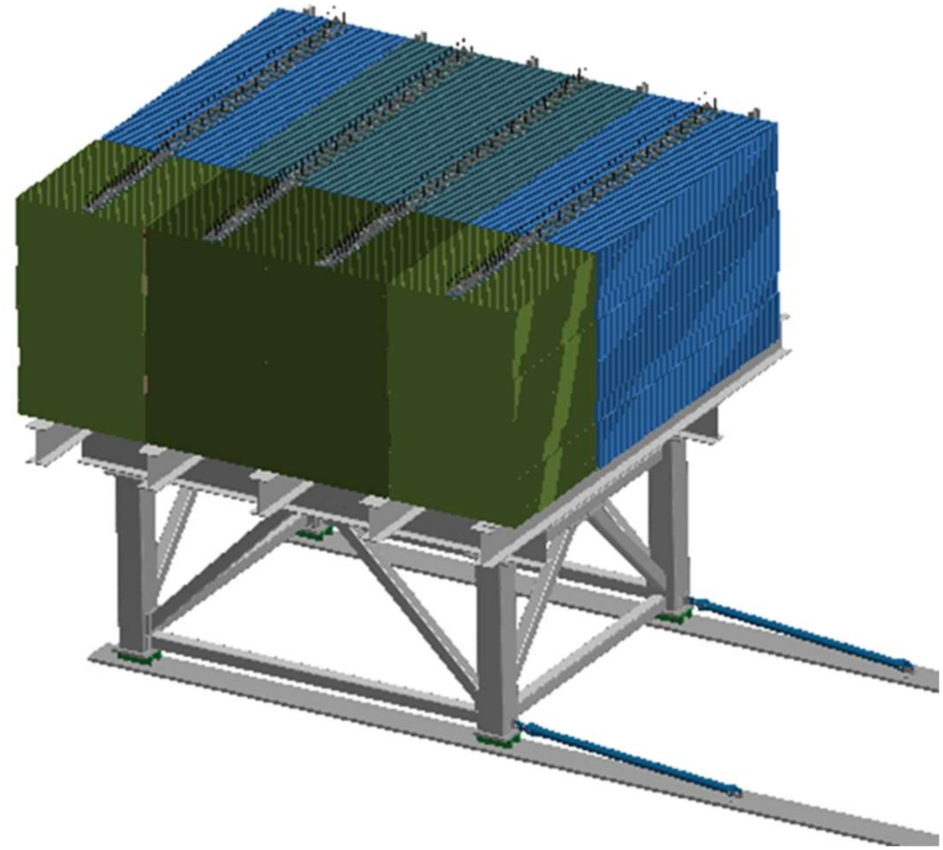
7-9 July 2020

Who am I

- Manager – Engineering Services at ANL
- Licensed Structural Engineer
- 30 years of experience on HEP experiments
  - US Project Engineer for the ATLAS Tilecalorimeter at CERN
  - L3 Manager on MINOS
  - L3 Manager on NOvA
  - High Voltage Engineering Lead on DUNE FD
- Other experience
  - Designed and managed the construction of 12m Davis-Cotton prototype telescope for CTA
  - Designed a Schwarzschild-Couder Telescope for Gamma Ray astronomy at Veritas.
  - Designed and fabricated 8m carbon fiber X-Calibur X-Ray balloon experiment
  - Designed and fabricated cryostat/camera for CMB-S3
  - Designed multiple high precision positioning devices for the ANL APS

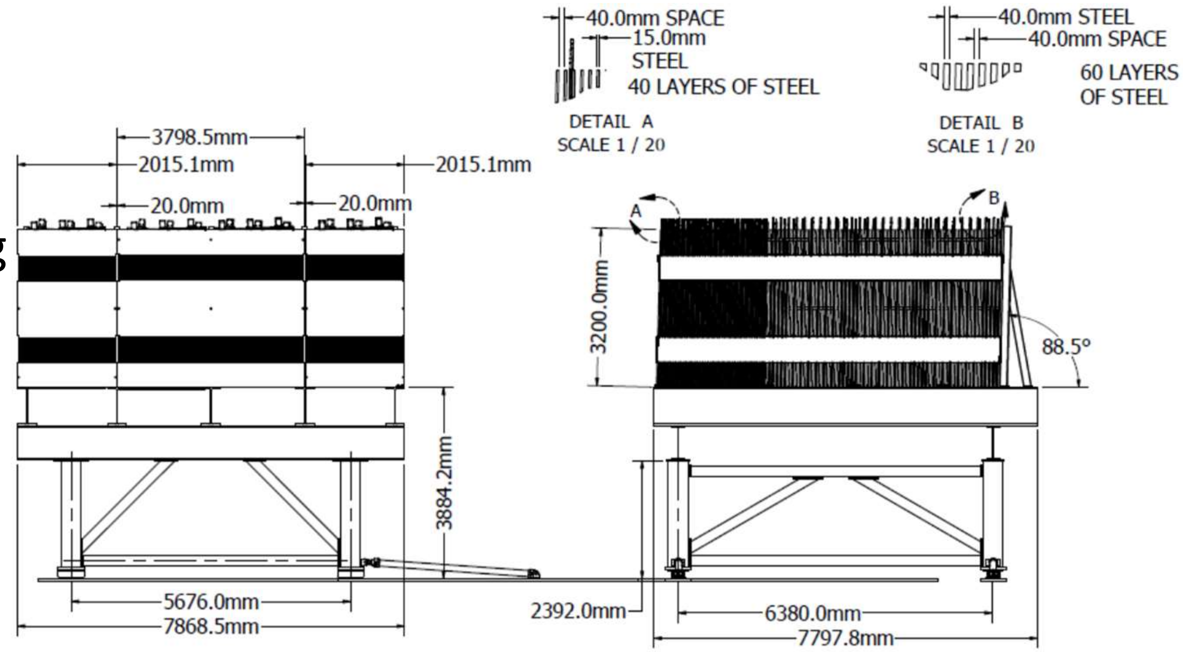
- Asked to develop a preliminary design in ~4 months with costing
- Design based on requirements defined by Tom/Tim/Dan
- Design based on experience with MINOS and Mu2e Veto scintillator modules (and the design/fabrication/construction of many other experiments)
- Preliminary design for:
  - Support structure
  - Magnet steel
  - Magnet coil
  - Scintillator modules
  - Assembly in Hall Underground

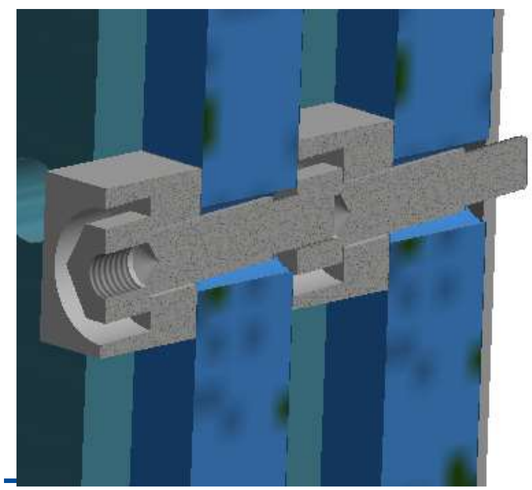
- 100 layers of alternating steel and scintillator
- Each layer has four modules; each containing 48 MINOS-like scintillator slats, 3.5 cm wide
- The entire stack is surrounded by two belts of coils (shown later) providing a 1.5T vertical field
- It can move in the x-direction (PRISM)

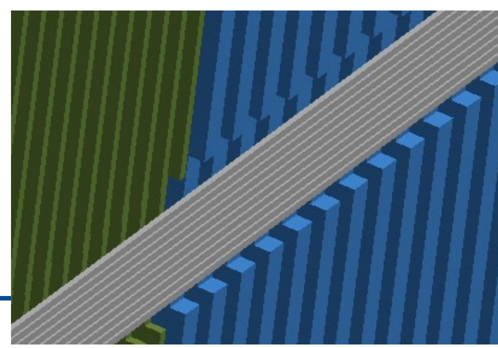


Overview of Muon Spectrometer Design

- 3 columns of steel
  - Easier to handle smaller plates
- Notches cut in steel for magnet coils
- Steel supported at bottom and leaning 1.5deg
- Bearing between plates around edges

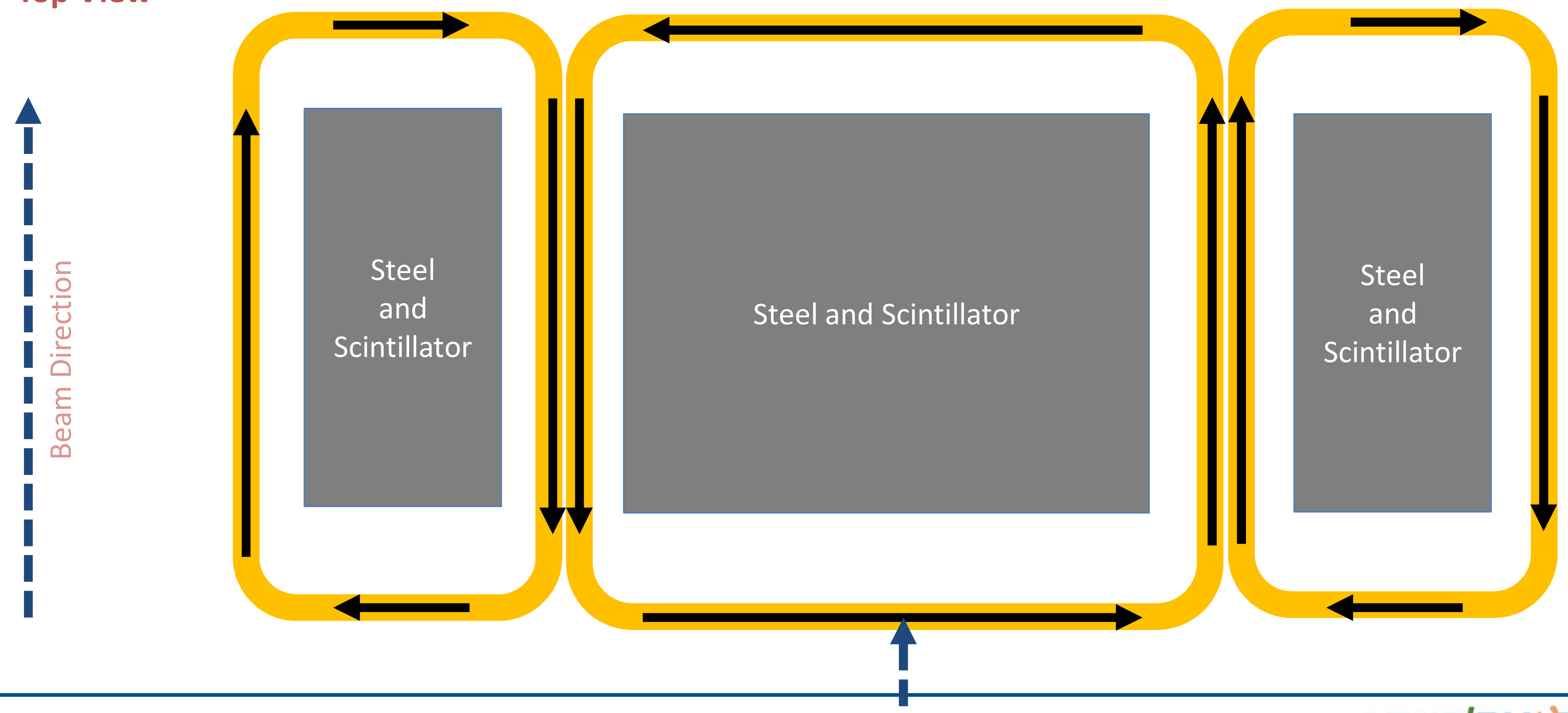




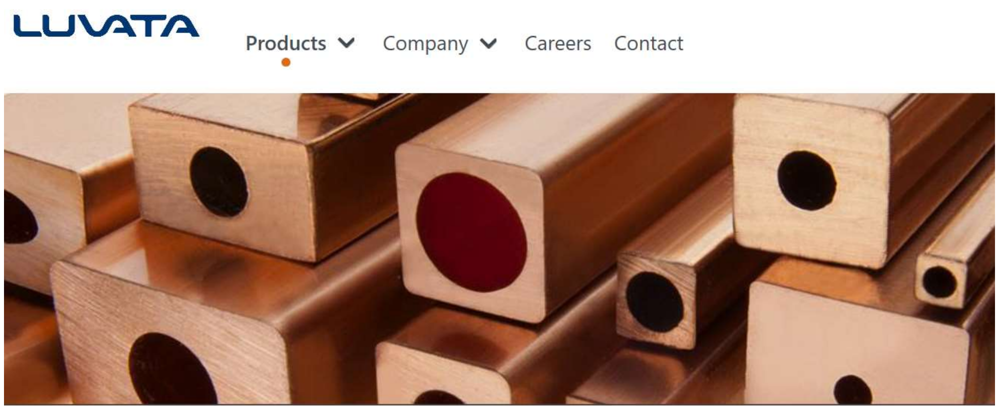


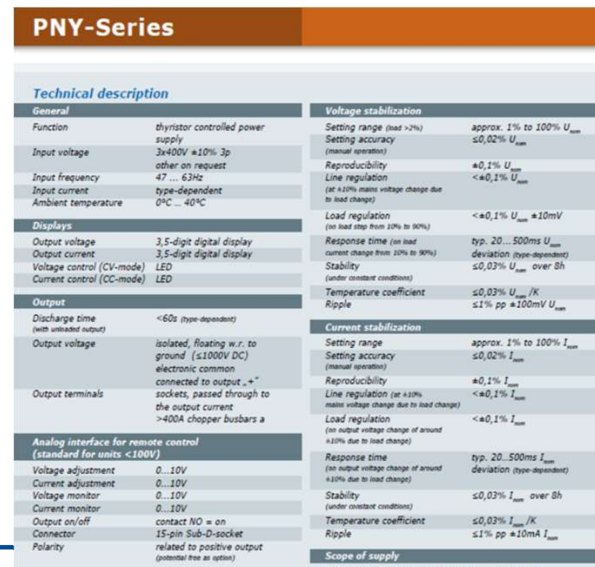
Top View

Arrows indicate current direction



- 100 wraps per coil
- 150 A / 70V per coil – 10.5 kW per coil ~~63kW total heat to extract
- Preliminary design based on copper bar with central hole for cooling (10 x 10 with 5 hole)
- Heinzinger PNY Power Supply
- Need to evaluate assembly and location of coils and cooling





PNY-Series

Technical description

General	
Function	thyristor controlled power supply
Input voltage	3x400V ±10% 3p other on request
Input frequency	47 ... 63Hz
Input current	type-dependent
Ambient temperature	0°C ... 40°C
Displays	
Output voltage	3,5-digit digital display
Output current	3,5-digit digital display
Voltage control (CV-mode)	LED
Current control (CC-mode)	LED
Output	
Discharge time (with unloaded output)	<60s (type-dependent)
Output voltage	isolated, floating w.r. to ground (≤1000V DC) electronic common connected to output „+"
Output terminals	sockets, passed through to the output current >400A chopper busbars a
Analog interface for remote control (standard for units <100V)	
Voltage adjustment	0...10V
Current adjustment	0...10V
Voltage monitor	0...10V
Current monitor	0...10V
Output on/off	contact NO = on
Connector	15-pin Sub-D-socket
Polarity	related to positive output (potential free as option)

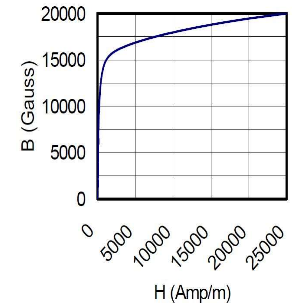
Voltage stabilization	
Setting range (load >2%)	approx. 1% to 100% U_{nom}
Setting accuracy (manual operation)	≤0,02% U_{nom}
Reproducibility	±0,1% U_{nom}
Line regulation (at ±10% mains voltage change due to load change)	<±0,1% U_{nom}
Load regulation (on load step from 10% to 90%)	<±0,1% U_{nom} ±10mV
Response time (on load current change from 10% to 90%)	typ. 20...500ms U_{nom} deviation (type-dependent)
Stability (under constant conditions)	≤0,03% U_{nom} over 8h
Temperature coefficient	≤0,03% U_{nom} /K
Ripple	≤1% pp ±100mV U_{nom}
Current stabilization	
Setting range	approx. 1% to 100% I_{nom}
Setting accuracy (manual operation)	≤0,02% I_{nom}
Reproducibility	±0,1% I_{nom}
Line regulation (at ±10% mains voltage change due to load change)	<±0,1% I_{nom}
Load regulation (on output voltage change of around ±10% due to load change)	<±0,1% I_{nom}
Response time (on output voltage change of around ±10% due to load change)	typ. 20...500ms I_{nom} deviation (type-dependent)
Stability (under constant conditions)	≤0,03% I_{nom} over 8h
Temperature coefficient	≤0,03% I_{nom} /K
Ripple	≤1% pp ±10mA I_{nom}

Scope of supply

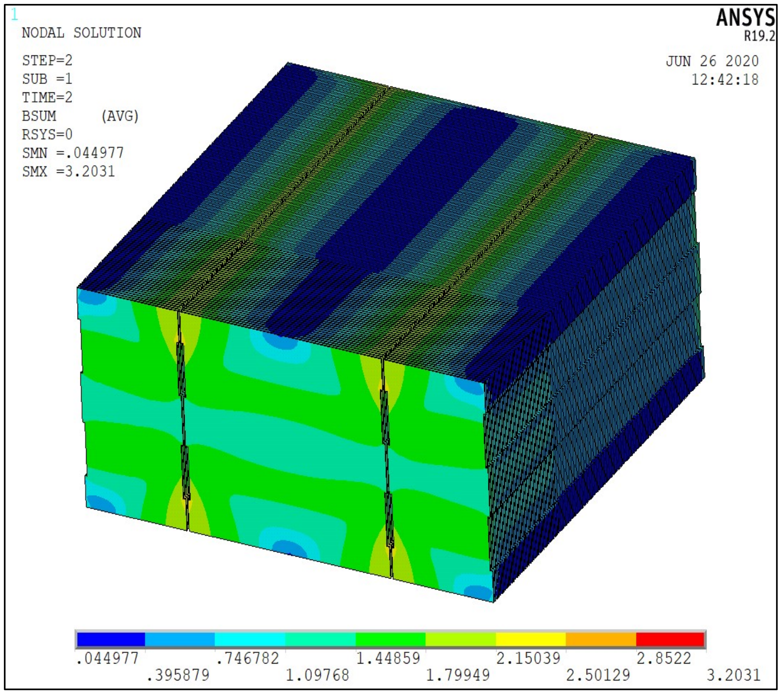
- Heinzinger PNY unit according to type description

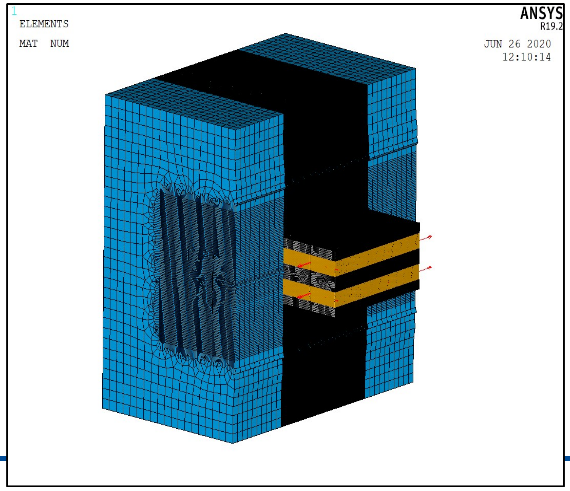
Numerical Solutions of Maxwell's Equations with ANSYS

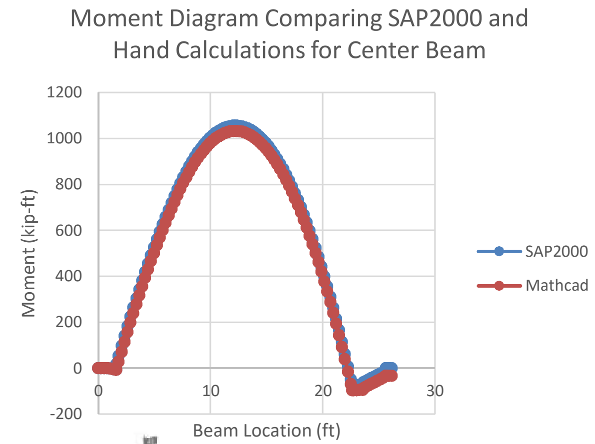
- We have a 15000 Ampere-turn model
  - Field quality is good
  - Goal is to slightly over-saturate.
    - Saturation is at ~ 1.5 T
- 100 wraps per coil – 150 A/70V
- Further work is needed to optimize



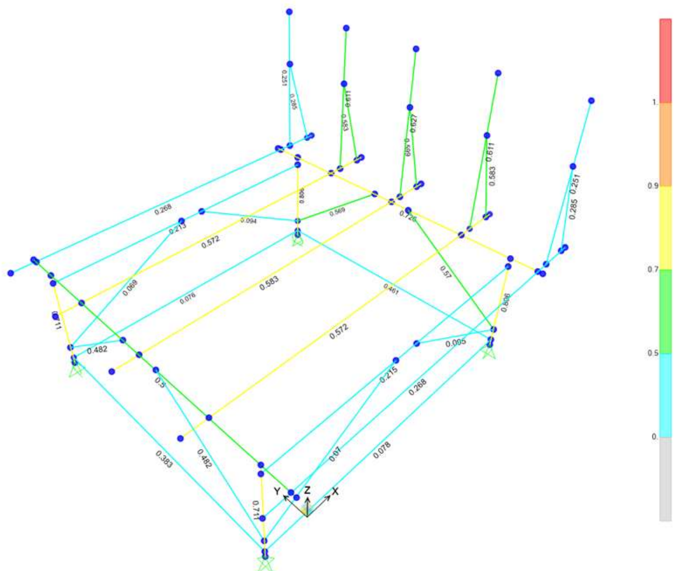
MINOS Steel

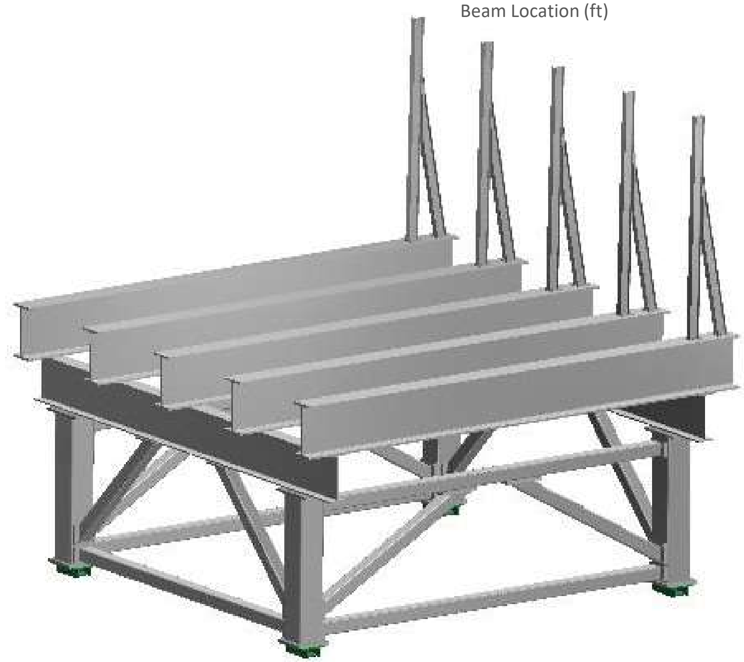






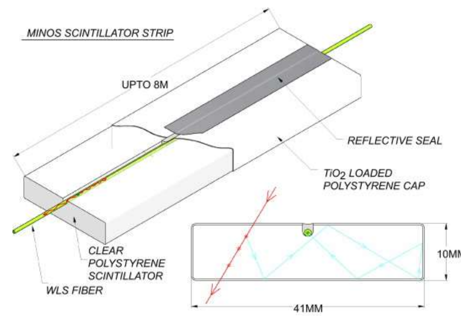
- I-beam structure to support 544 tons of steel
- Empirical and FEA calculations performed to size beams. Examined static and seismic loading
- Size of beams driven by requirement to keep deflections less than ¼”

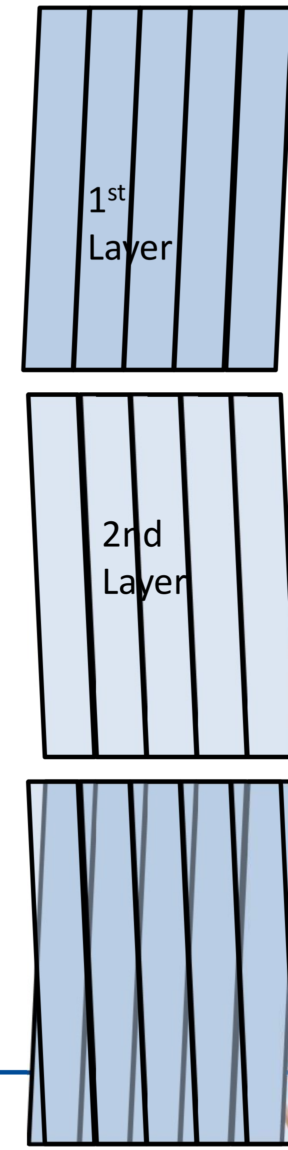


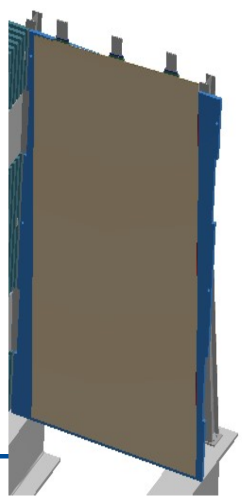


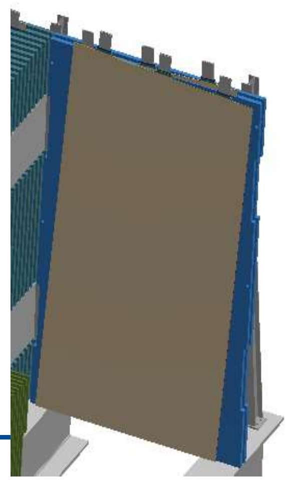
Scintillator Module Design

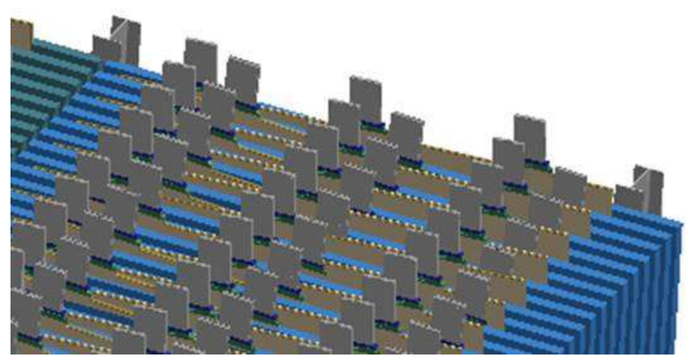
- Design is very MINOS-like
- Spectrometer has 100 planes
- Each plane has four modules (192 channels)
- Each module is a self-contained box containing
  - 48 scintillator bars 3.5 cm wide with wavelength-shifting fiber
  - SiPM, ADC and associated electronics
- Panels (which are rectangular) are tilted ±3^{o} in alternating layers
- 30mm gaps between modules in different steel columns



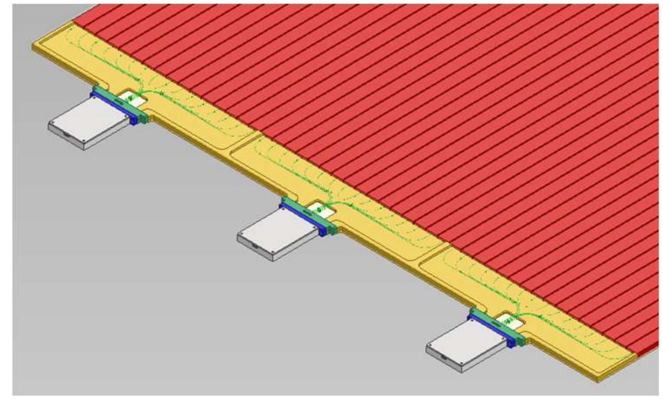




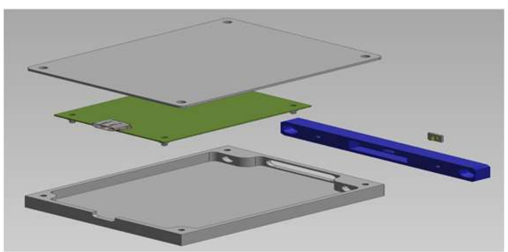


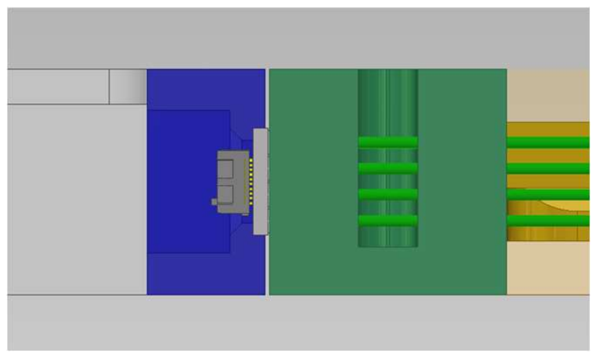


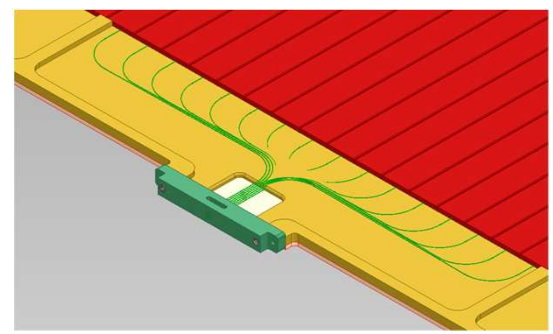
Scintillator Modules



- 48 scintillator per module – 3 groups of 16 fibers per SIPM
- Scintillator glued into a sandwich between aluminum covers- fiber manifold at one end and 3deg wedge at bottom
- Each module has three 16-channel Hamamatsu SiPMs
- Each module has six 8-channel Texas Instruments AFE-5807 analog front ends/12-bit ADCs
- Digital signals are combined and reformatted off-detector
  - And then on to the DAQ

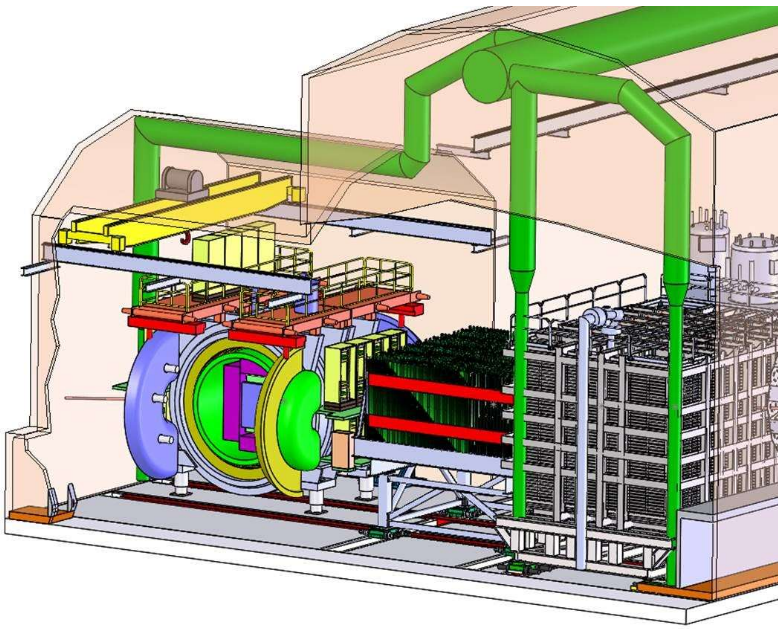






- Steel support structure will be assembled underground
- Steel plates are then stacked and secured
- Modules are slid vertically between steel plates

- 15ton overhead crane



- A preliminary design has been developed based on given design requirements
- Design is based on initial calculations of structure and magnet
- Module design based MINOS and Mu2e veto
- Conceptual design is the basis for cost estimate