Mu2e Experiment Status

G. Tassielli

Consiglio di sezione di Lecce

11/7/2014

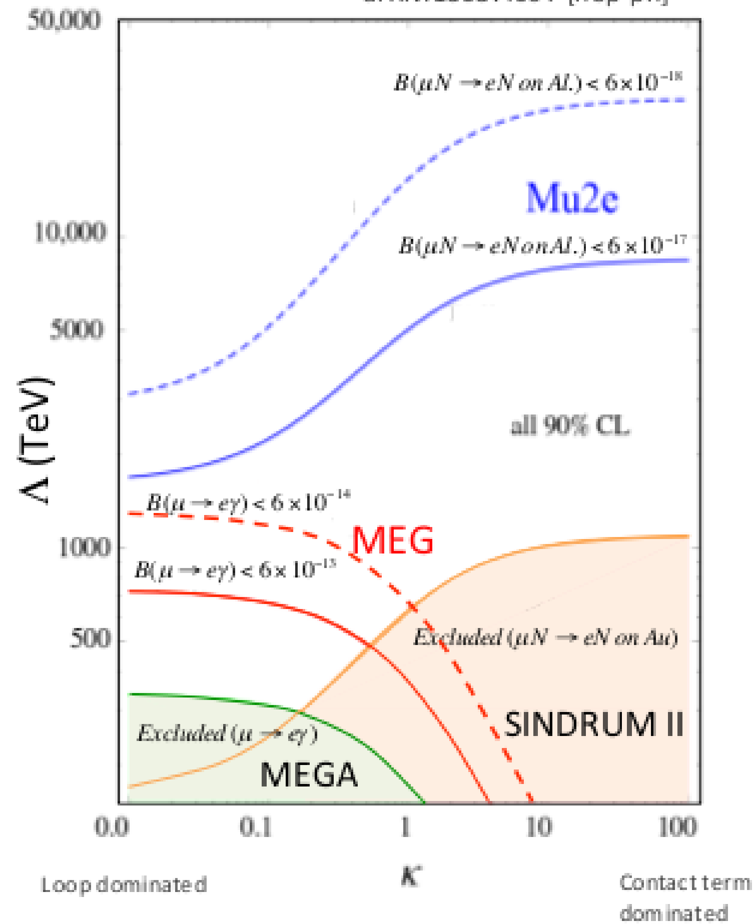
Mu2e in a Nutshell

- Mu2e is a search for Charged Lepton Flavor Violation (CLFV) via the coherent conversion of $\mu^- N \rightarrow e^- N$
  - Most new physics models so far postulated provide new sources of flavor phenomena
  - Observation is unambiguous evidence for new physics.
- Target sensitivity has great discovery potential
  - Goal: Single-event-sensitivity of 2.5 x 10^{-17} (relative to ordinary ⌠ capture)
  - Goal: <0.5 events background
  - Yields Discovery Sensitivity for all rates > few 10^{-16}
  - Factor of 10,000 more sensitive than existing measurement.
  - Quark flavor is violated. Neutrino flavor is violated.
  - Both implied something profound about the underlying physics
  - Both garnered Nobel Prizes
  - Mu2e enables a search for charged lepton flavor violation with unprecedented precision that could prove to be equally profound.

Science drivers

- Explore the unknown, new particles, interactions and physical principles (in the new P5 framework).
- Broad discovery sensitivity across all categories of new physics models
- Sensitivity to 10,000 TeV, well beyond any imaginable accelerator
- Sensitive to new physics at LHC energies that is suppressed by small mixing angles, loop factors
- Sensitive to new physics at 10 TeV, beyond reach of LHC but within reach of 100 TeV pp collider.

A. de Gouvêa, P. Vogel
arXiv:1303.4097 [hep-ph]



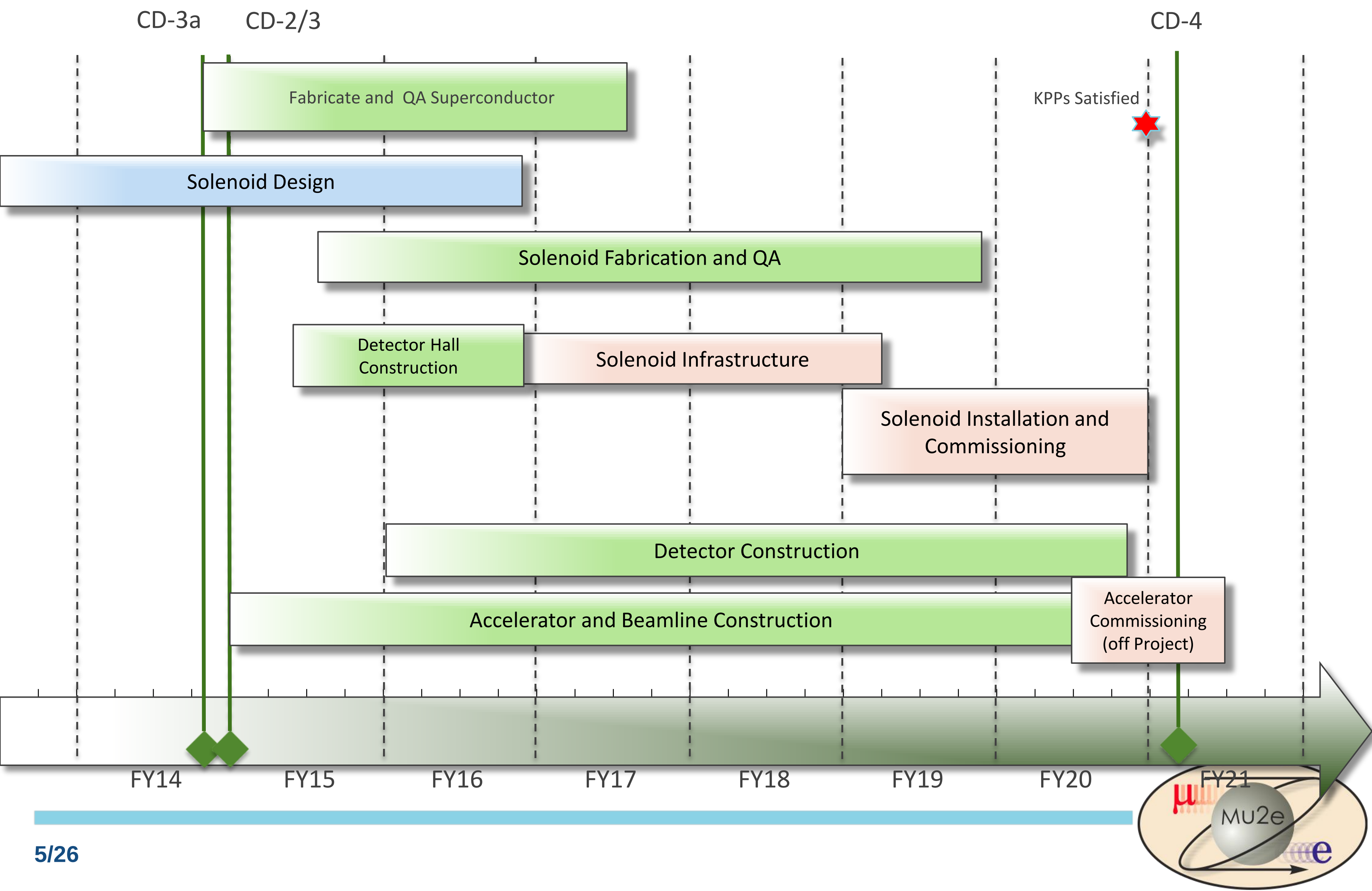
MU2E COLLABORATION

Boston University
Brookhaven National Laboratory
Lawrence Berkeley National Laboratory
University of California, Berkeley
University of California, Irvine
California Institute of Technology
City University of New York
Duke University
Fermi National Accelerator Laboratory
University of Houston
University of Illinois
Lewis University
University of Massachusetts, Amherst
Muons Inc.
Northern Illinois University
Northwestern University
Pacific Northwest National Laboratory
Purdue University
Rice University
University of Virginia
University of Washington

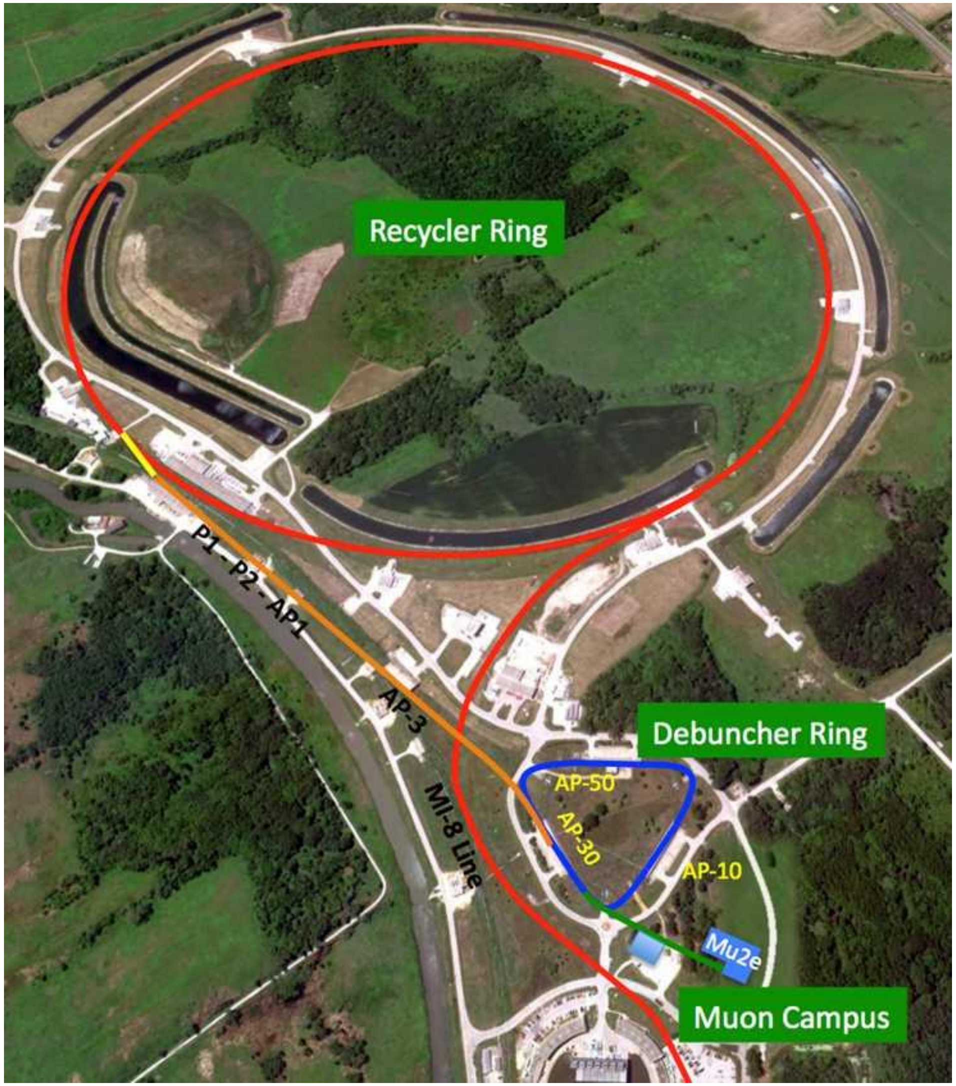
Laboratori Nazionali di Frascati
INFN Genova
INFN Lecce and Università del Salento
INFN Lecce and Università Marconi Roma
INFN Pisa
Universita di Udine and INFN Trieste/Udine

Joint Institute for Nuclear Research, Dubna
Institute for Nuclear Research, Moscow

Schedule


CD-3a
CD-2/3
CD-4
KPPs Satisfied
Fabricate and QA Superconductor
Solenoid Design
Solenoid Fabrication and QA
Detector Hall Construction
Solenoid Infrastructure
Solenoid Installation and Commissioning
Detector Construction
Accelerator and Beamline Construction
Accelerator Commissioning (off Project)
FY14
FY15
FY16
FY17
FY18
FY19
FY20
FY21
Mu2e

Beam Delivery

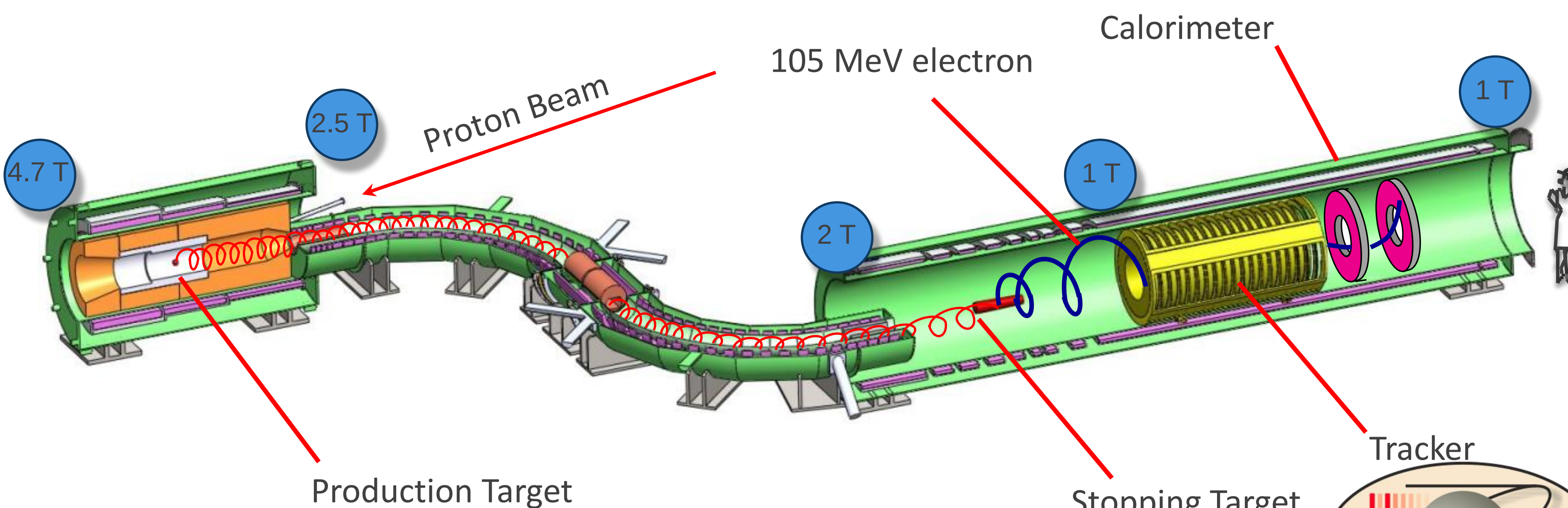


- We make muons by directing 8 GeV protons on to a target.
- Batches of protons from the Booster are transported through existing beamlines to the Recycler Ring where they are re-bunched and transported to the Delivery Ring through existing transport lines.
- Beam is slow extracted from Delivery Ring in microbunches of ~ 10^7 protons every 1695 ns through a new external beamline to the Mu2e production target.
- Run simultaneously with NOvA and Booster Neutrino Program.

Mu2e Apparatus

- Solenoids capture pions, form secondary muon beam, preserve timing structure, provide magnetic field for momentum analysis and help to reject backgrounds
  - Most efficient way of producing an intense, low energy muon beam
- 2 targets
- Tracker – Straw tubes
- Calorimeter – BaF2 crystals
- Cosmic Ray Veto – Scintillator, WLS fibers, SiPMs
- Stopping Target Monitor – Crystal
- Warm bore of solenoids evacuated to 10^{-4} to 10^{-5} Torr.

Cosmic Ray Veto and Stopping Target Monitor not shown

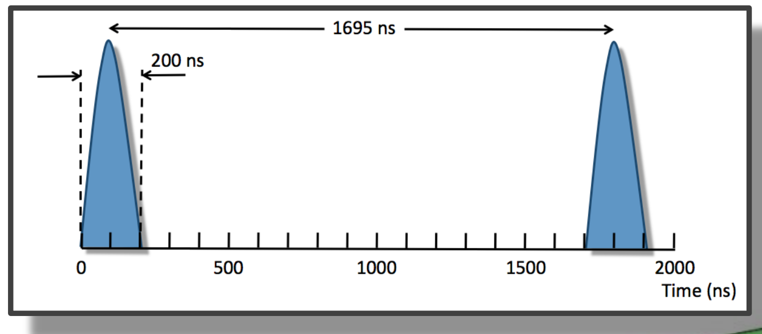


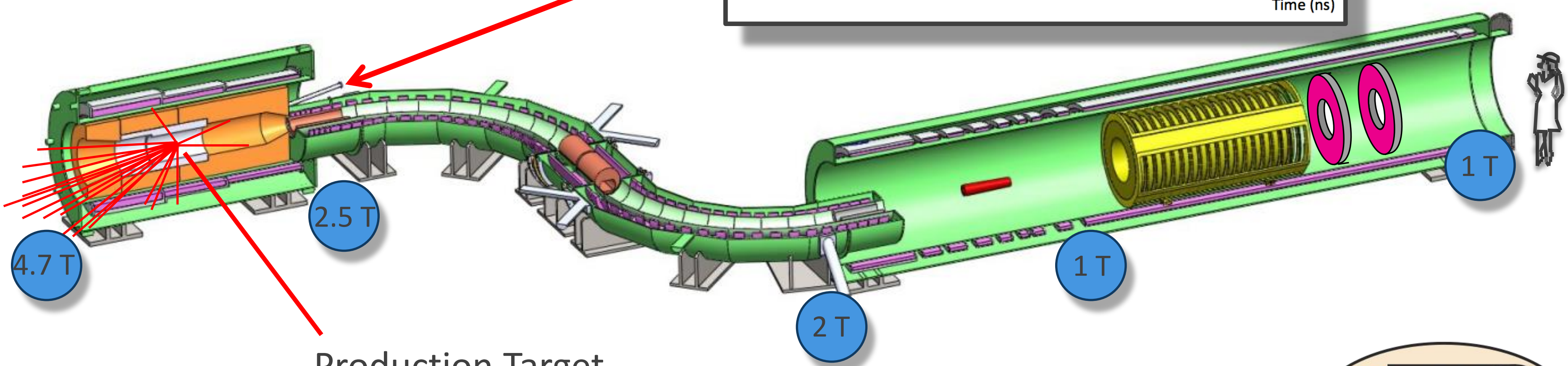
Mu2e Apparatus

Production Solenoid

- Production target
- Graded field
- Captures secondary pions
- Highest field
- Highest radiation exposure

8 GeV protons



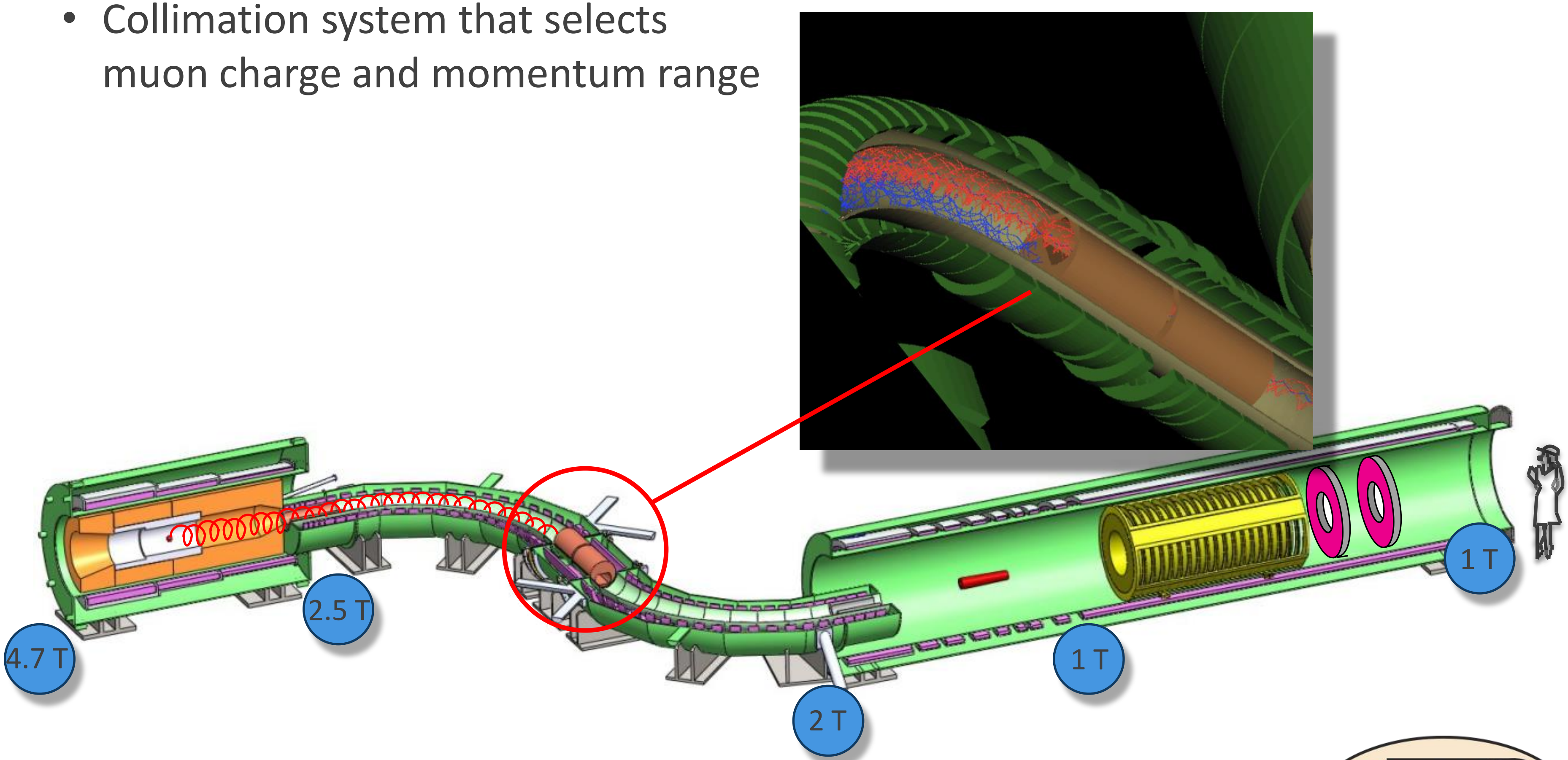


Production Target

Mu2e Apparatus

Transport Solenoid

- Collimation system that selects muon charge and momentum range

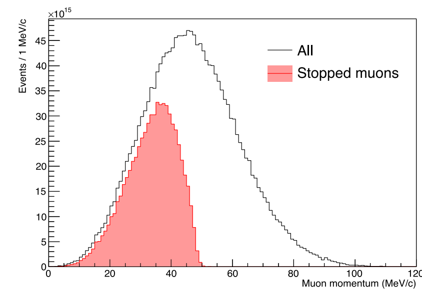


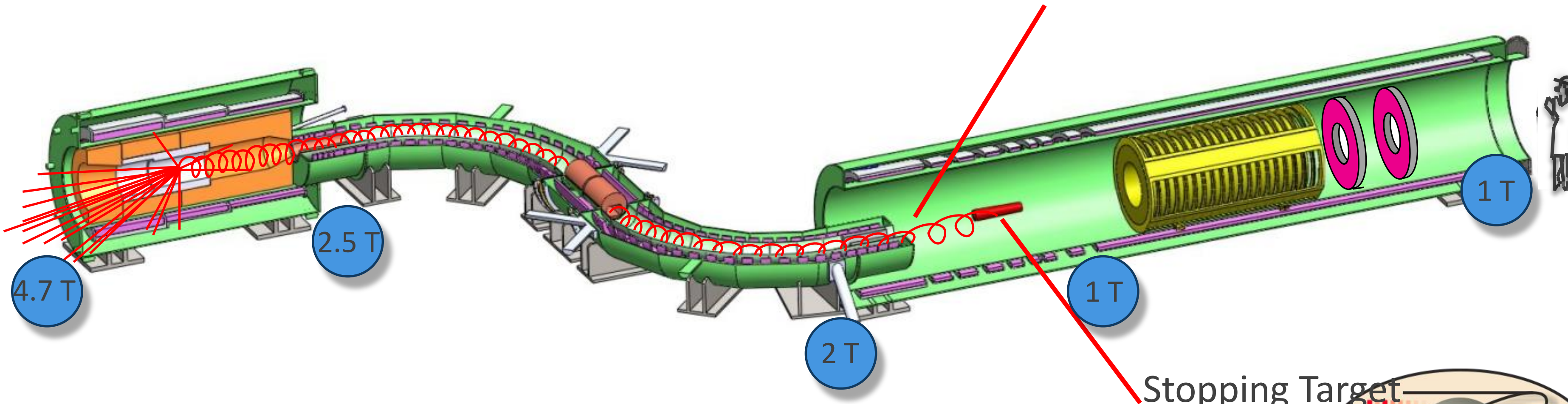
Mu2e Apparatus

Transport Solenoid

- Collimation system selects muon charge and momentum range
- Pbar window in middle of central collimator
- Directs 10^{10} Hz of μ^- to stopping target

40 MeV/c μ^-



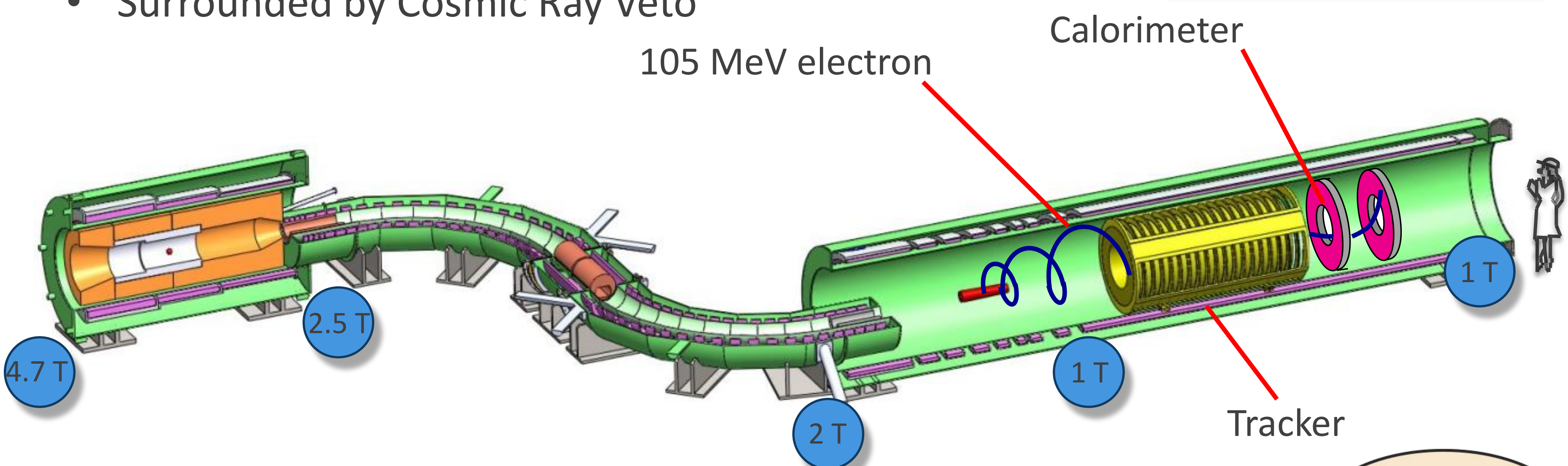


Mu2e Apparatus

Detector Solenoid

- Graded field upstream for acceptance and background suppression
- Uniform field downstream for momentum analysis
- Muon stopping target
- Tracker
- Calorimeter
- Surrounded by Cosmic Ray Veto

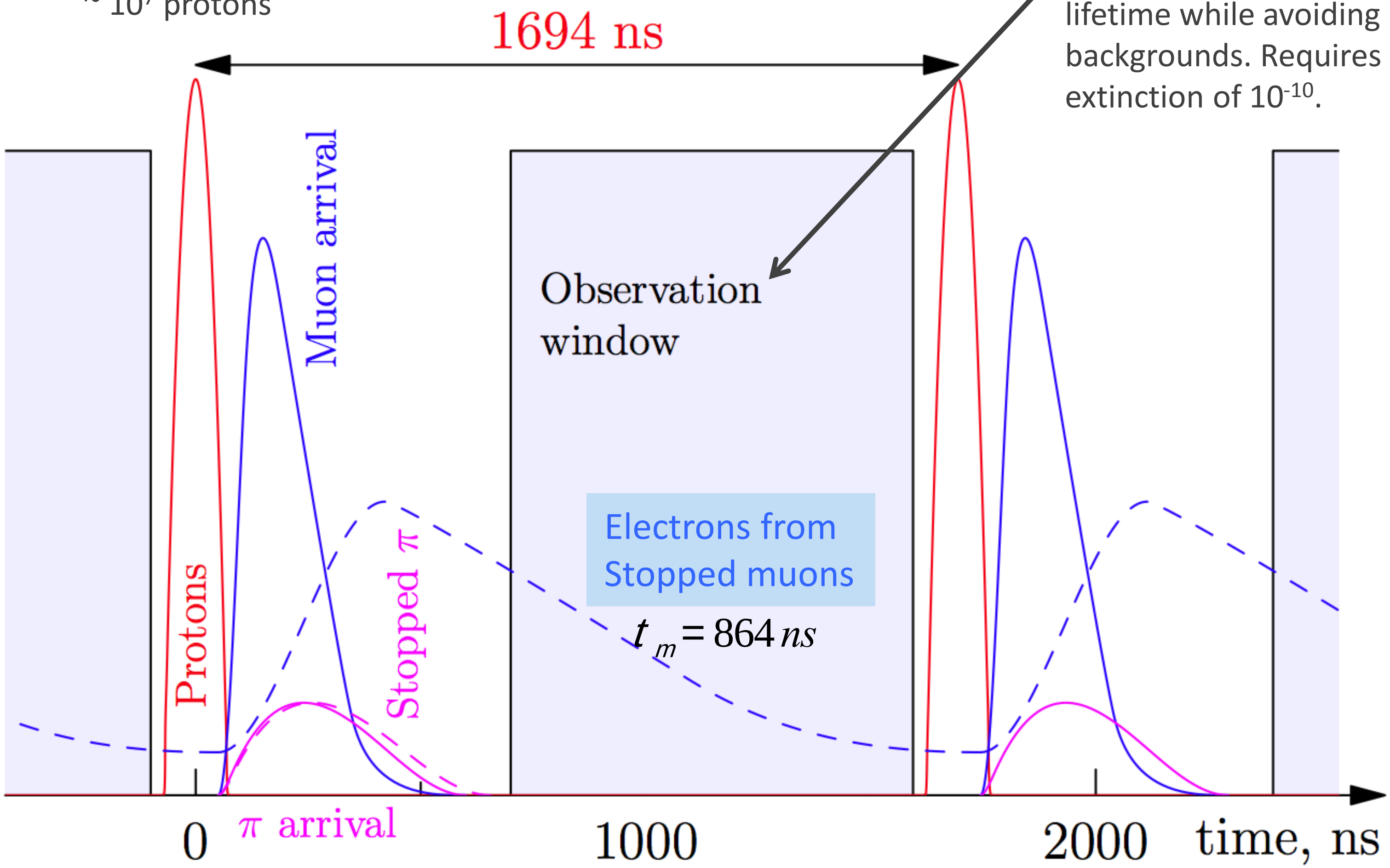
Cosmic Ray Veto not shown



Timing – Delayed Observation Window

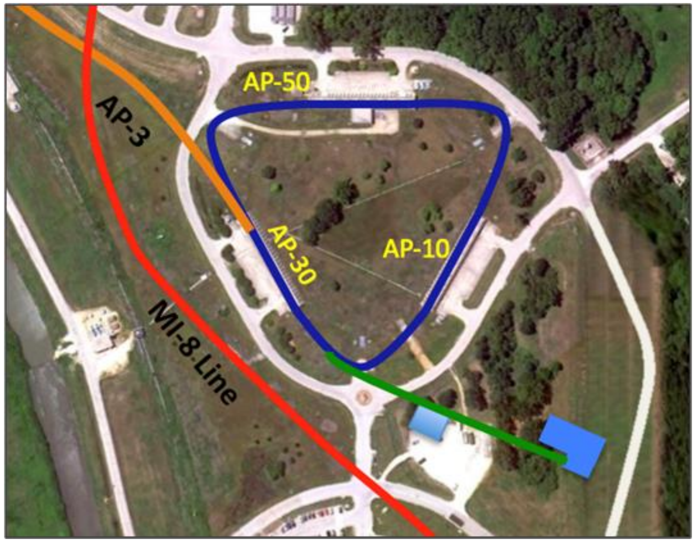
Microbunch of
~ 10^7 protons

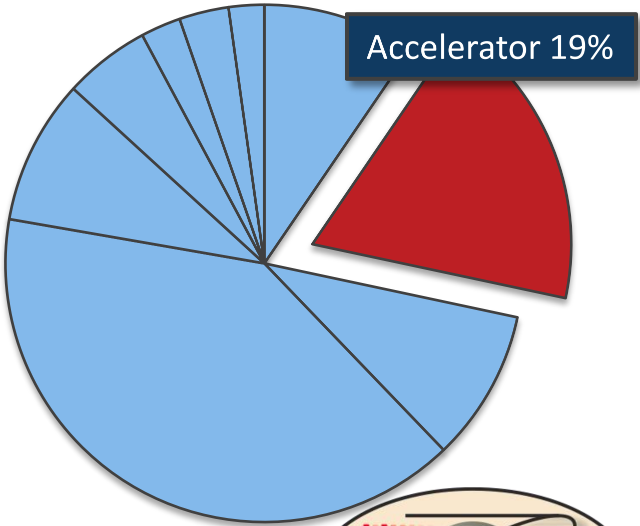
Delayed observation window sees significant fraction of muon lifetime while avoiding prompt backgrounds. Requires beam extinction of 10^{-10}.



Mu2e Accelerator

- Delivery Ring RF System
  - Same RF cavities used in Recycler RF system.
- Resonant Extraction System
- External Beamline
  - Recycled Accumulator magnets
- Extinction System
- Production Target
- Heat and Radiation Shield to protect Production Solenoid
- Proton Beam Absorber
- Radiation Safety
- Significant interface to Muon Campus AIPs and GPPs.

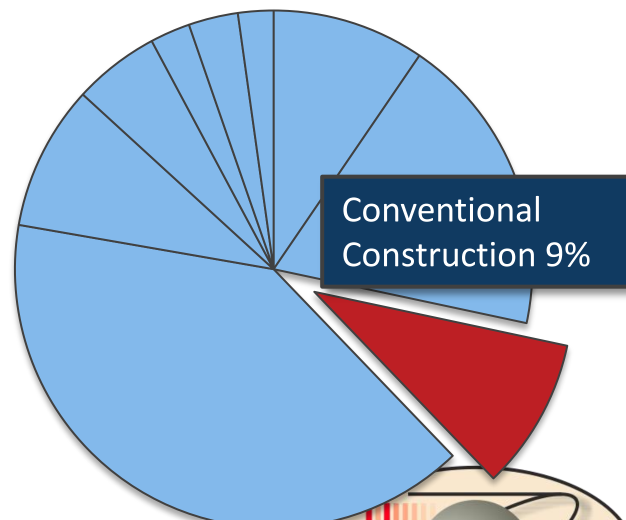




Conventional Construction

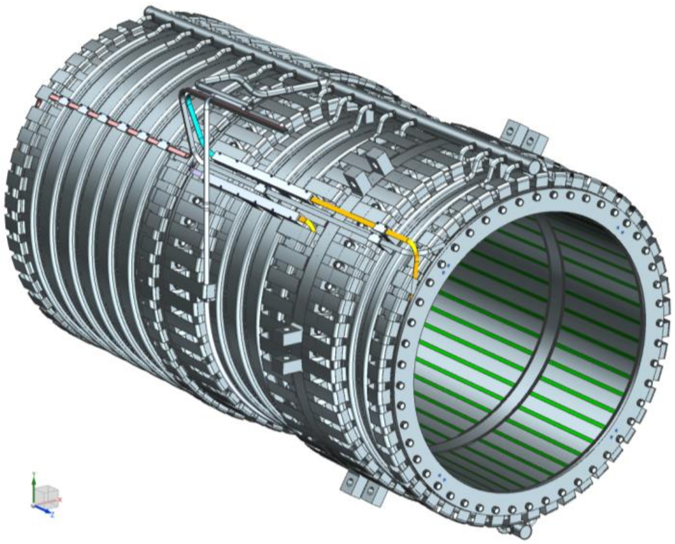
Conventional Construction scope includes

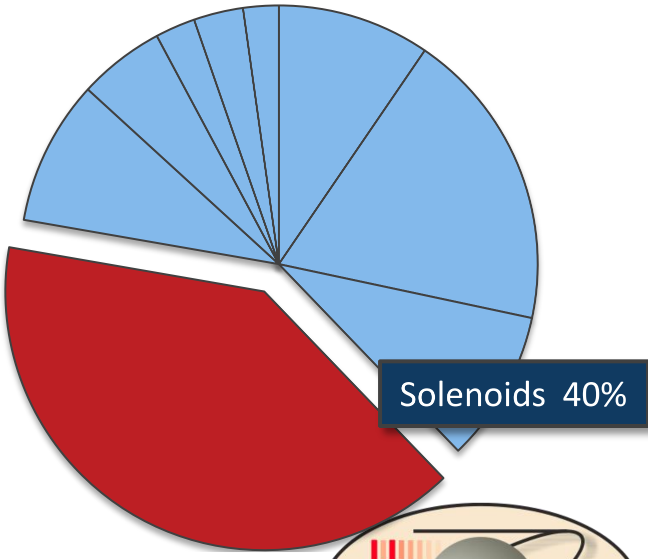
- Mu2e Detector Hall
  - Underground enclosure to house detector
  - Surface building for infrastructure
- Delivery Ring power and ventilation upgrades/reconfiguration.
- Interface to Muon Campus Beamline Enclosure GPP and MC-1 Building.



Solenoids

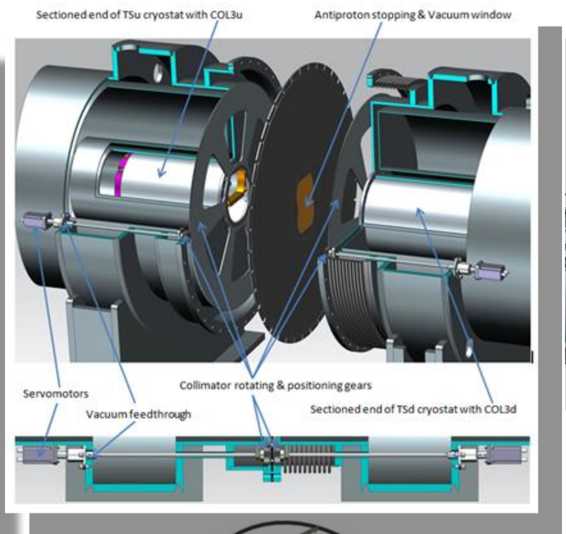
- Solenoids drive the cost and the schedule
  - On or near the critical path for entire duration of Project.
- System includes solenoids, infrastructure, installation, commissioning, field mapping equipment.
- Solenoid conductor being procured based on CD-3a authorization.
  - P.O.s in place
  - ESAAB July 10.
- Evaluation of bids for final design/build of PS and DS complete.
  - Putting P.O. in place. Costs known. Consistent with CD-1 estimates.
- Significant contribution from INFN Genova to TS R&D and QA of production conductor.

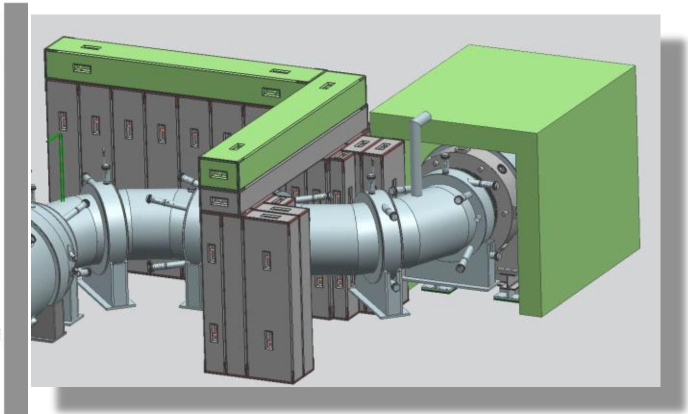


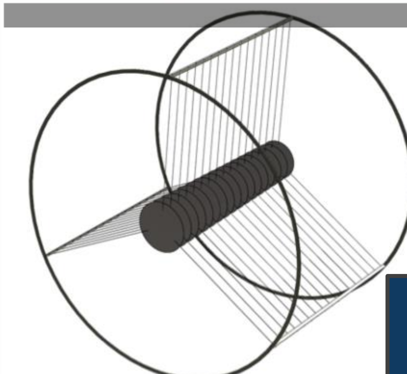


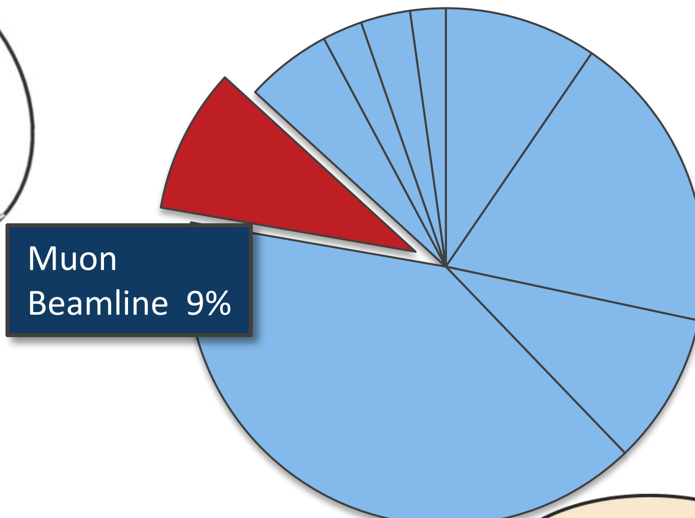
Muon Beamline

- Vacuum System
- Collimators
- Shielding
- Stopping Target
- Stopping Target Monitor
- Proton Absorber
- Muon Beam Stop
- Neutron Absorbers
- Detector Support Structures
- Muon Beamline interfaces to nearly every other system.



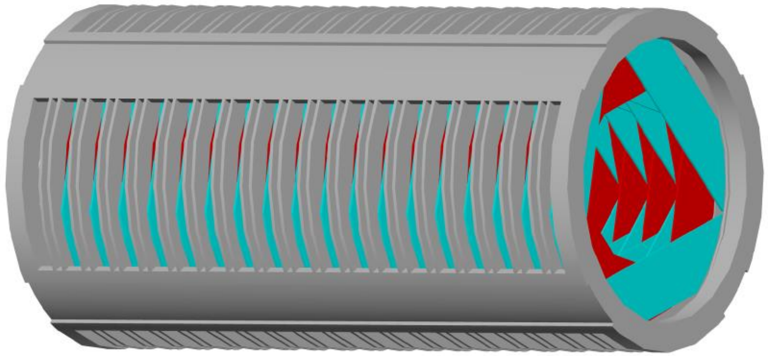


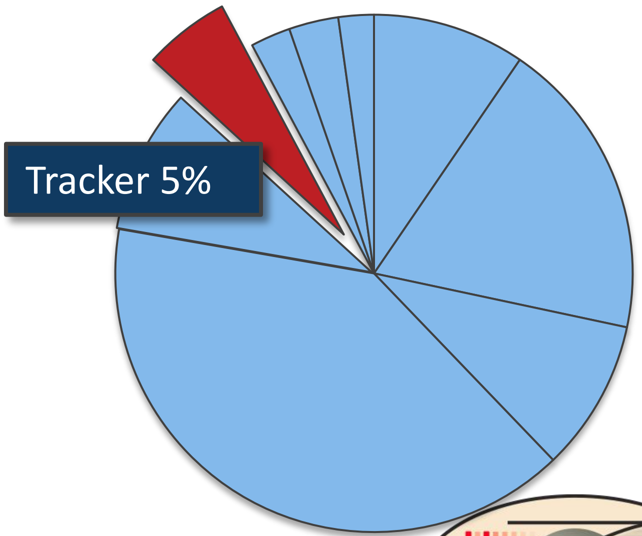




Tracker

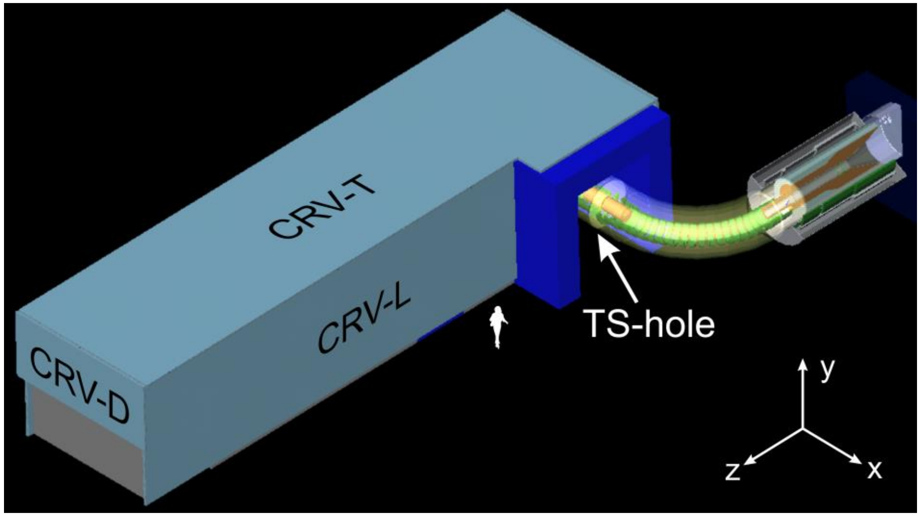
- 23,040 thin wall (15 μm) straws (5 mm diameter) distributed over 20 stations.
  - Thin walls to minimize multiple scattering.
  - Operates in 10^{-4} Torr vacuum and 1 Tesla magnetic field.
- Each straw outfitted with
  - 2 preamps
  - 2 TDCs (time division)
  - 1 ADC (differentiate protons from electrons)
  - Addressable fuse to disable straw
- Operation in vacuum requires cooling system
- Gas system (Ar: CO_2)

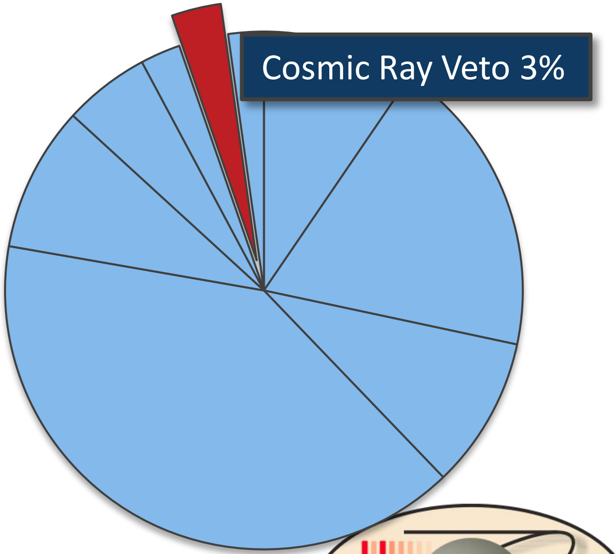




Cosmic Ray Veto

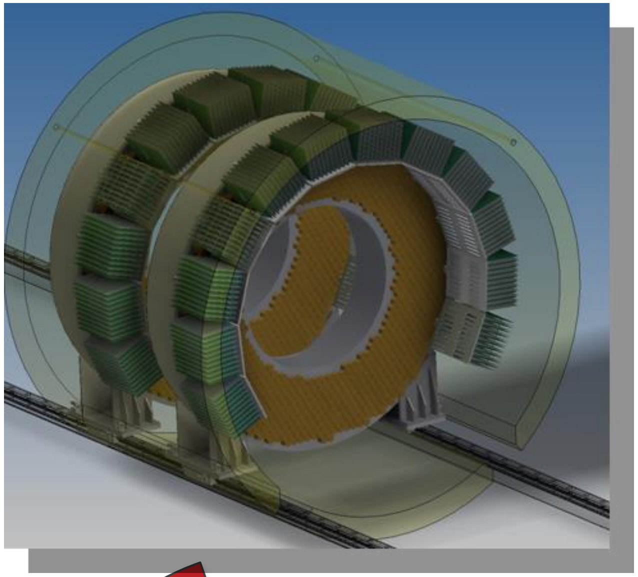
- Nearly hermetic veto on top and sides of DS and half of TS with 0.9999 overall efficiency.
- 4 layers of extruded scintillator
  - 5152 counters,
  - 4.7 m long,
  - 1248 m^2
  - 50 km of WLS fiber
  - Read out with SiPMs
- Shielding of neutrons from production target, stopping target and collimators required.
  - Intense μ^- beam is a significant source of neutrons when they are captured.

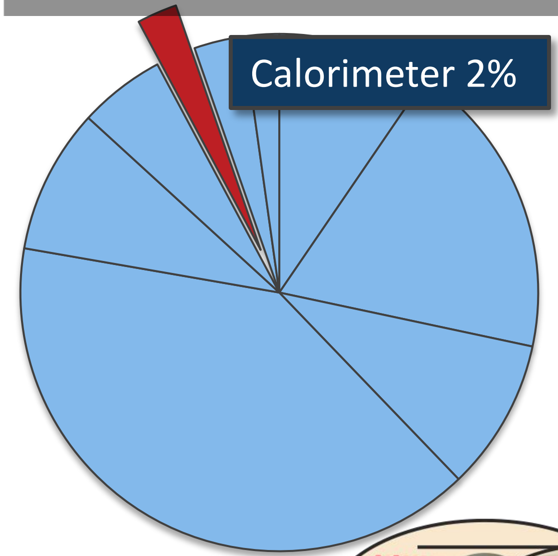




Calorimeter

- Significant scope provided by INFN
- 1860 BaF_2 crystals arranged in 2 disks.
  - Operates in 10^{-4} Torr vacuum and 1 T field.
- Each crystal read out by
  - 2 UV-extended, solar-blind APDs to take advantage of fast component at 220 nm.
- Carbon Fiber mechanical support system
- Flasher system
- Source calibration system
- DOE contribution is
  - 2/3 of crystals
  - 1/2 of APDs
  - Source Calibration system – Recycled from BaBar
  - 50% of installation and commissioning labor
- INFN provides balance of crystals, APDs and installation labor plus
  - Mechanical support
  - Front end electronics and digitizers
  - Laser calibration system





Calorimeter requirements

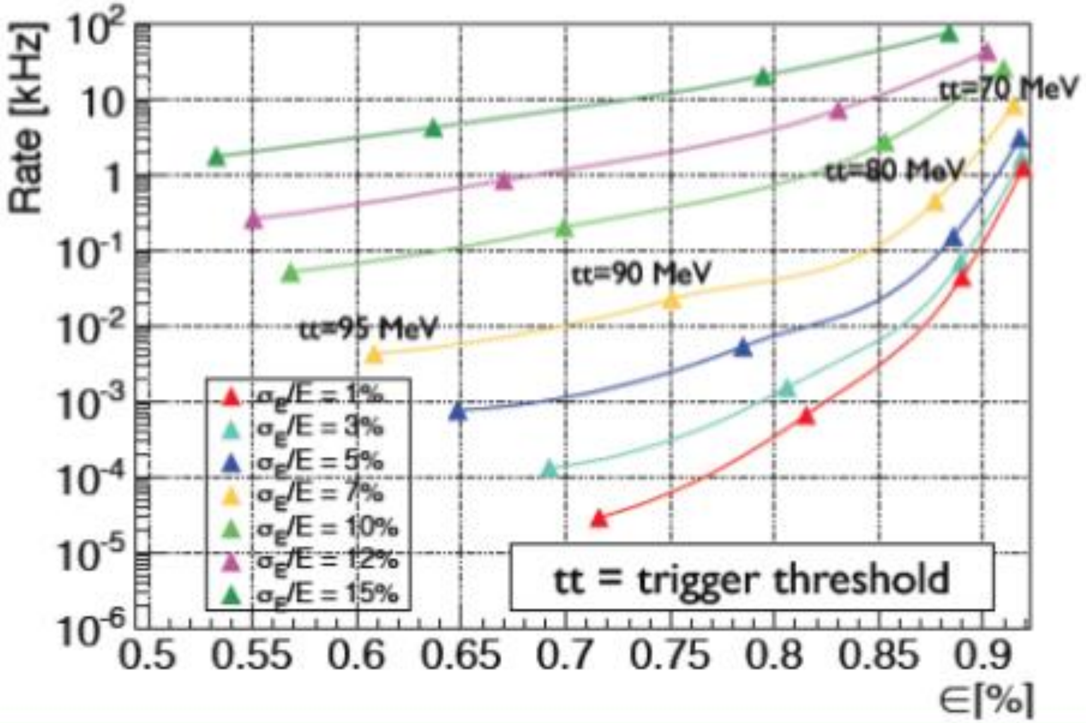
Provide a quality check on the reconstructed track measuring:

- ✓ energy with a resolution of O(5 MeV)
- ✓ time with a resolution ≤ 0.5 ns
- ✓ impact position with a resolution ~ 1 cm
- Helpful tool to perform the pattern recognition of tracks
- Particle identification: muon rejection factor > 100
- Filter the events down to a rate ~ few kHz
- Survive in the Mu2e environment:
- ✦ Operable in 1 T magnetic field
- ✦ Radiation hard (~ 10 kRad/year/crystal)

Calorimeter based trigger filter

- The trigger algorithm applies a threshold on the reconstructed energy
- Signal efficiency and DIO rate were studied convoluting results from G4 with Gaussian functions (sigma's are showed on figures)

If not further surprises, filter will be applied at HLT level.



Calorimeter thr = 70 MeV, effi ~ 90 %, DIO rate ~ 2 kHz @ 5 % resol.

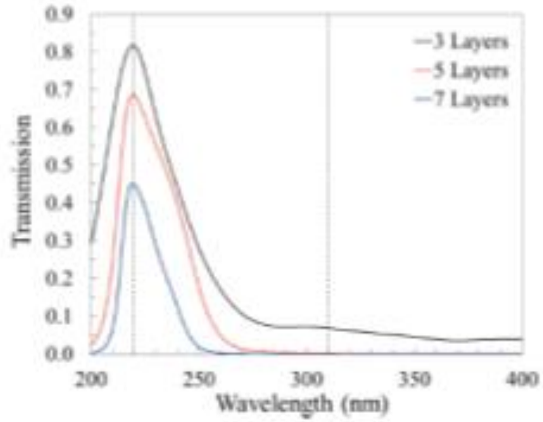
Crystal and photosensor alternatives

BaF2 presents several advantages:

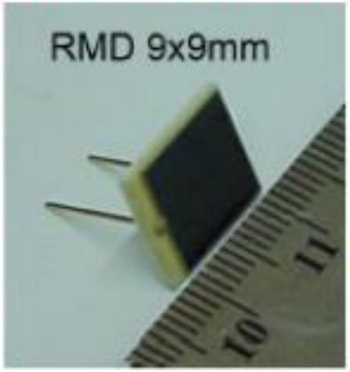
- ✓ **Small decay time**
- ✓ **Non-hygroscopic**
- ✓ **Rad hard**

Crystal	BaF_2	LYSO	CsI	$PbWO_4$
Density (g/cm^3)	4.89	7.28	4.51	8.28
Radiation length (cm) X_0	2.03	1.14	1.86	0.9
Molière radius (cm) Rm	3.10	2.07	3.57	2.0
Interaction length (cm)	30.7	20.9	39.3	20.7
dE/dx (MeV/cm)	6.5	10.0	5.56	13.0
Refractive Index at λ_{max}	1.50	1.82	1.95	2.20
Peak luminescence (nm)	220, 300	402	310	420
Decay time τ (ns)	0.9, 650	40	26	30, 10
Light yield (compared to NaI(Tl)) (%)	4.1, 36	85	3.6	0.3, 0.1
Light yield variation with temperature (% / °C)	0.1, -1.9	-0.2	-1.4	-2.5
Hygroscopicity	None	None	Slight	None

- ✓ 60% QE @ 200 nm (wa
- ✓ ~0.1% QE @ 300 nm
- ✓ capacitance ~ 60 pF
- ✓ operation gain ~ 500



deltadoped APD from RMD



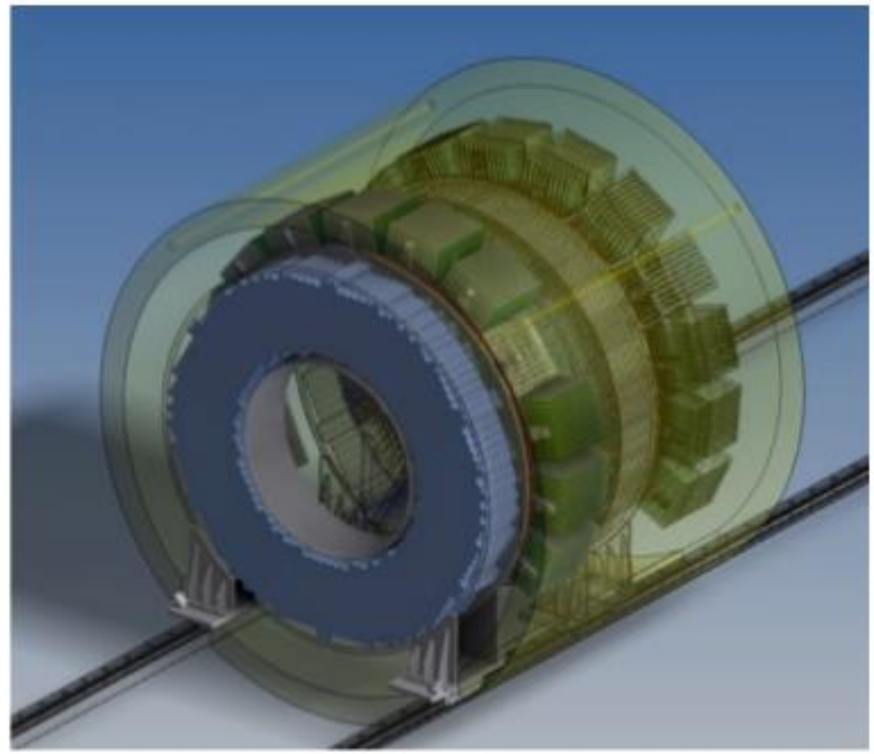
Calorimeter mechanics

C.F. or Honeycomb face
(toward the target)
Aluminum face
(back side: FEE)

Integration of FEE support
Cooling and positioning
Over detector rails

Stainless steel
Support Rings

C.F. shell

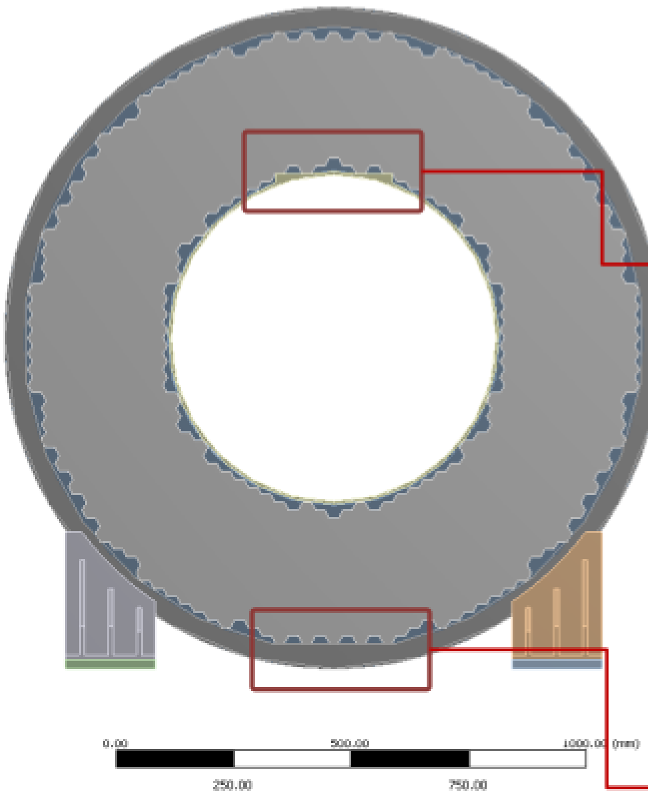


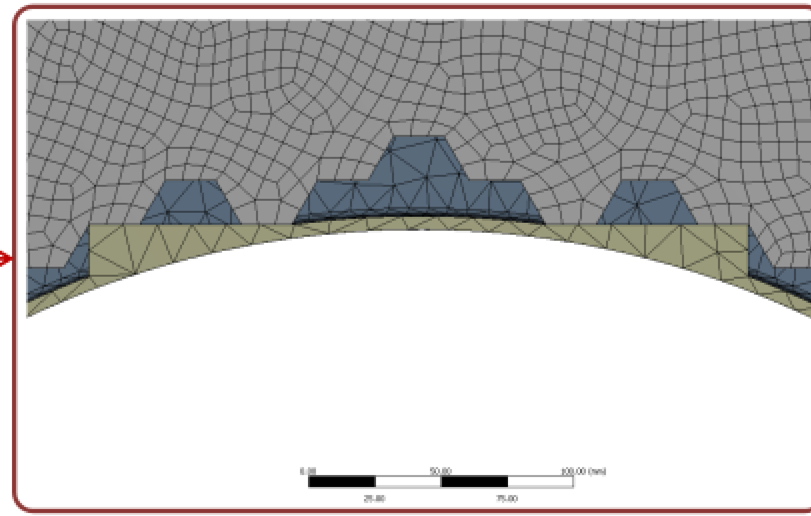
Calorimeter mechanics studies

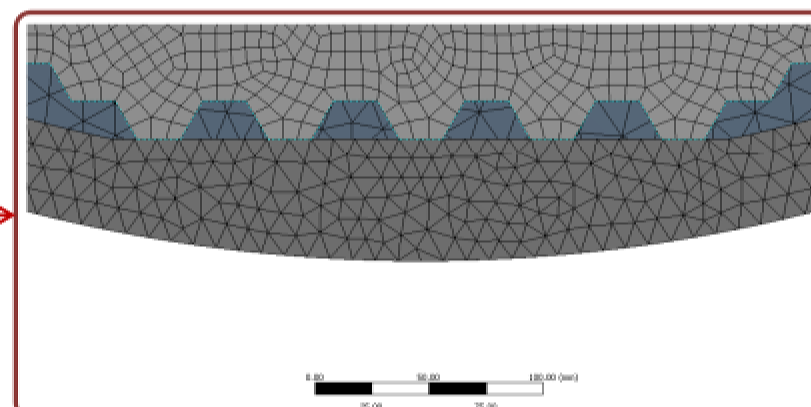
ENGIN SOFT

Key partner in Design Process Innovation

Crystals' supports on the outer-inner disks







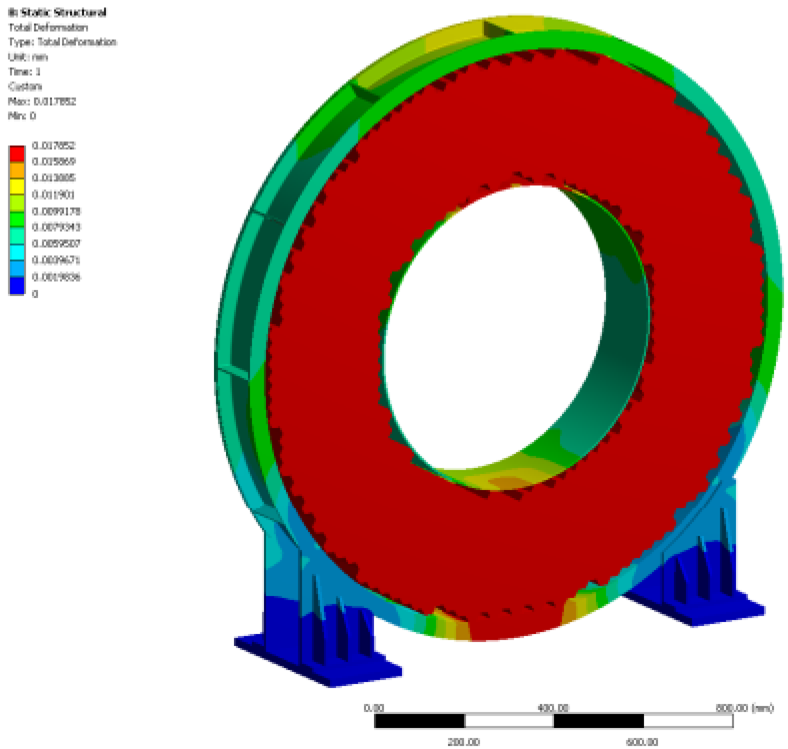
Outer disk radius = 660 mm
Inner disk radius = 351 mm
N. of crystals = 930
Crystal size = 33 mm

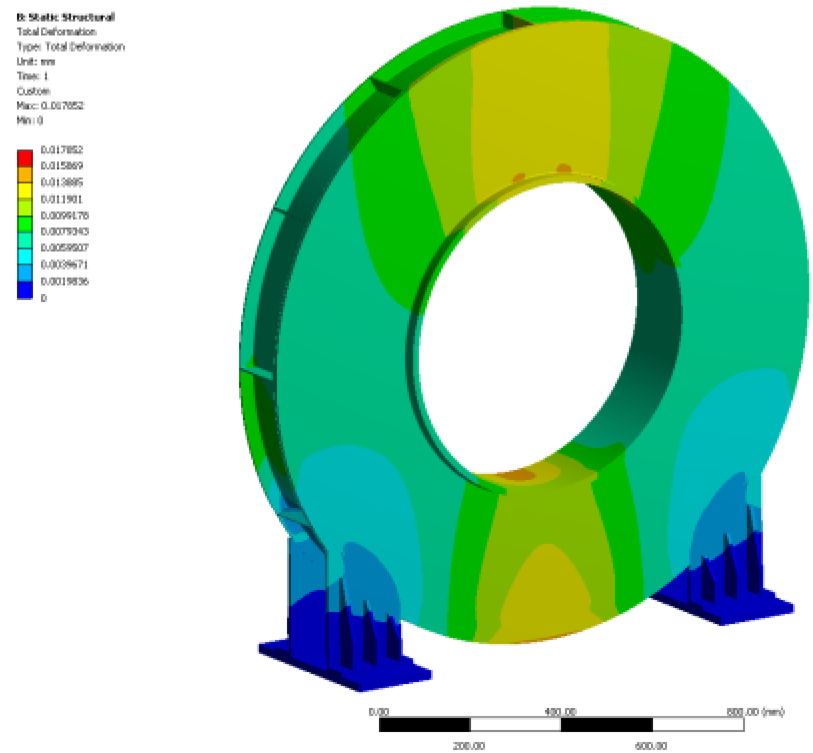
Calorimeter mechanics studies

ENGIN SOFT

Key partner in Design Process Innovation

Conf. 2 – Total deformation – Max value = 0.018mm





Anagrafica e richieste (Lecce)

- Grancagnolo 30%
- Piacentino 50%
- Zavarise 30%
- Maffezzoli 30%

Capitolo	*Descrizione*	Parziali Richiesta	Parziali SJ	Totale Richieste	Totale SJ
MISSIONI	**1.** metabolismo missioni estere (1 m.u.) + missioni interne (1keuro*fte)	7.00			
	2. executive board (4 m.u.)	20.00			
	3. meetings (2 meetings/fte*2.5 keuro/meeting)	8.00		**35.00**	0.00
CONSUMO	**1.** prototipo strutturale di 1/12 di disco con "fake crystals" (meccanica+ materiali + sistemi di misura e controllo)	12.00			
	2. prove strutturali su campioni di BaF2 (3x3x3 cm^3)	3.00		**15.00**	0.00
TRASPORTI	**1.** trasporto prototipo strutturale a/da Frascati	2.00		**2.00**	0.00
APPARATI	**1.** "Disk Mechanics"	37.00		**37.00**	0.00
LICENZE-SW	**1.** mantenimento licenze ANSYS	10.00		**10.00**	0.00