P-Mu2e

R.Carosi + Mu2e Pisa, 28 giugno 2013

P-Mu2e

- Stato dell' esperimento
  - Introduzione
  - Stato approvativo
  - Schedule
  - Stato del detector; decisioni importanti
- Attività 2012-13
- Attività per il 2014
- Utilizzo risorse di sezione (2013, 2014, …)
- Consistenza numerica del gruppo
- Richieste alla CSN1 (finanziamenti)

Mu2e Physics Goals

Goal of Mu2e is to search for the Charged Lepton Flavor Violating process of a muon converting to an electron in the field of a nucleus.

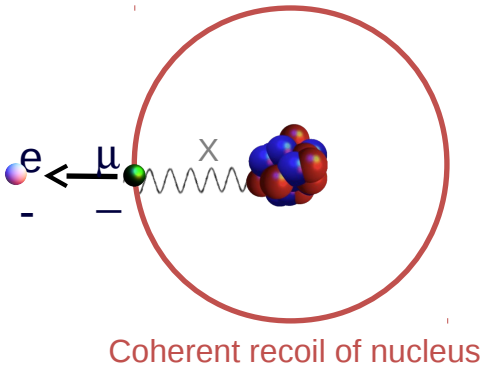
$$R_{\mu e} = \frac{\mu^- + A(Z,N) \rightarrow e^- + A(Z,N)}{\mu^- + A(Z,N) \rightarrow \nu_\mu + A(Z-1,N)},$$

Target sensitivity = 2×10^{-17} ! (Requires 10^{18} stopped μ^- !)

Target background with full data set < 1 event.

Mu2e will have *discovery sensitivity* to a broad array of New Physics models.

Mu2e Physics Goals

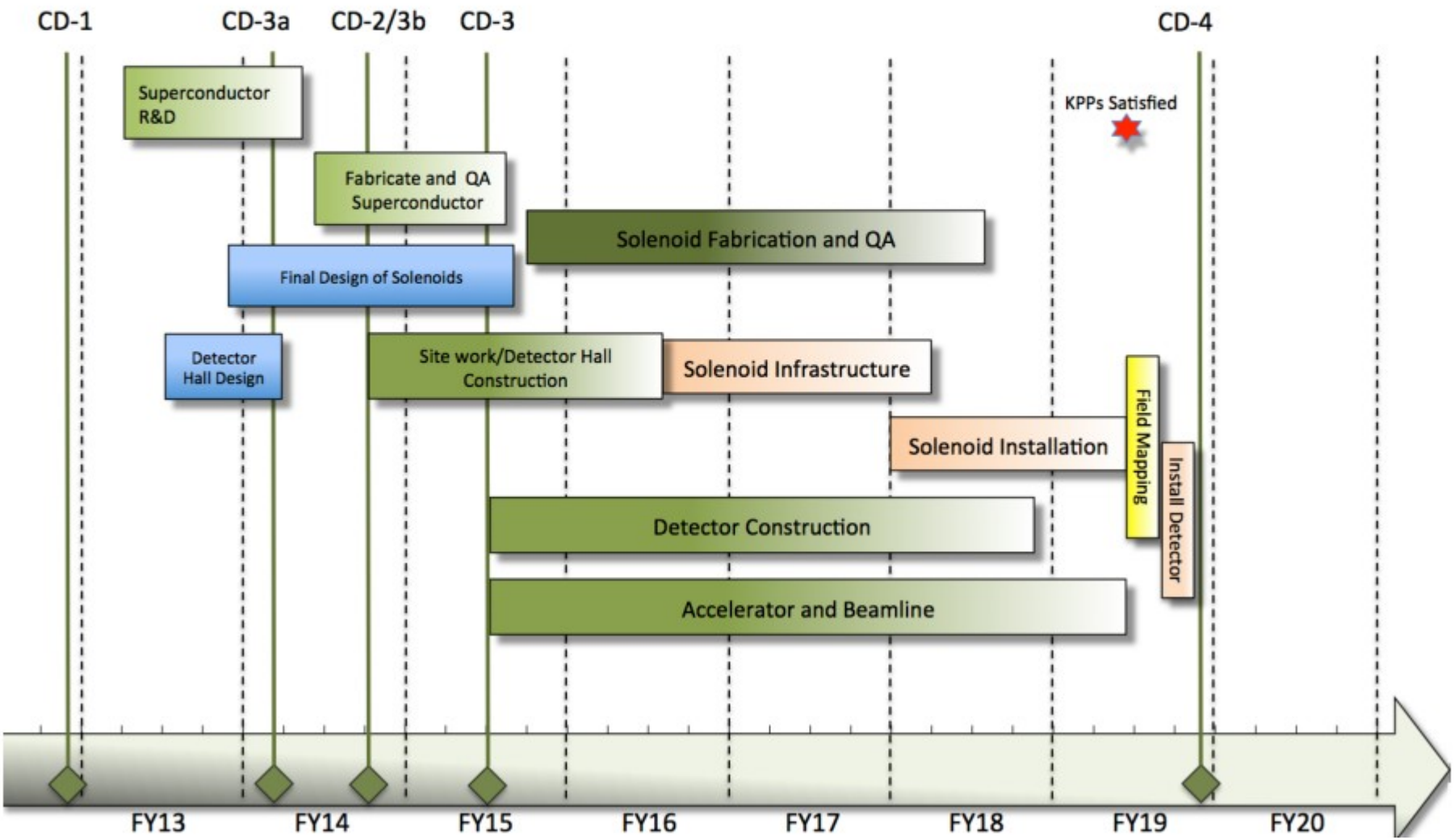


- μ^- to e^- conversion in the field of a nucleus
  - No emission of neutrinos
  - Nucleus remains intact – coherent
  - Signal is a monoenergetic 105 MeV e^-
- Observation is unambiguous evidence of physics beyond the SM
  - Provides information about flavor structure of new physics that is not easily accessible at the LHC.
  - A null result at the proposed sensitivity will severely constrain new physics models.
  - CLFV is predicted at observable rates in most new physics models.
- Mu2e can probe mass scales up to 10^4 TeV, far beyond the reach of the LHC.

Stato dell' esperimento
(processo approvativo)

- 2012:
  - Lehman Review, CDR (arXiv:1211.7019)
  - ***CD1 (June 2012)***
- 2013:
  - Decisioni su detector (importanti per la collab. Italiana):
    - ***Tracker (T-tracker vs I-Tracker)***
    - ***Geometria del calorimetro (Vani vs Dischi)***
    - *Apertura sul Trigger*
  - Mini reviews
  - **Entrata di INFN-Genova (Magnete)**

Schedule


CD-1
CD-3a
CD-2/3b
CD-3
CD-4
Superconductor R&D
Fabricate and QA Superconductor
Final Design of Solenoids
Detector Hall Design
Site work/Detector Hall Construction
Solenoid Fabrication and QA
Solenoid Infrastructure
Solenoid Installation
Field Mapping
Install Detector
Detector Construction
Accelerator and Beamline
KPPs Satisfied
FY13
FY14
FY15
FY16
FY17
FY18
FY19
FY20

CD-1 Cost Estimate

Costs are fully burdened in AY $k

% Estimate uncertainty is calculated for remaining cost.

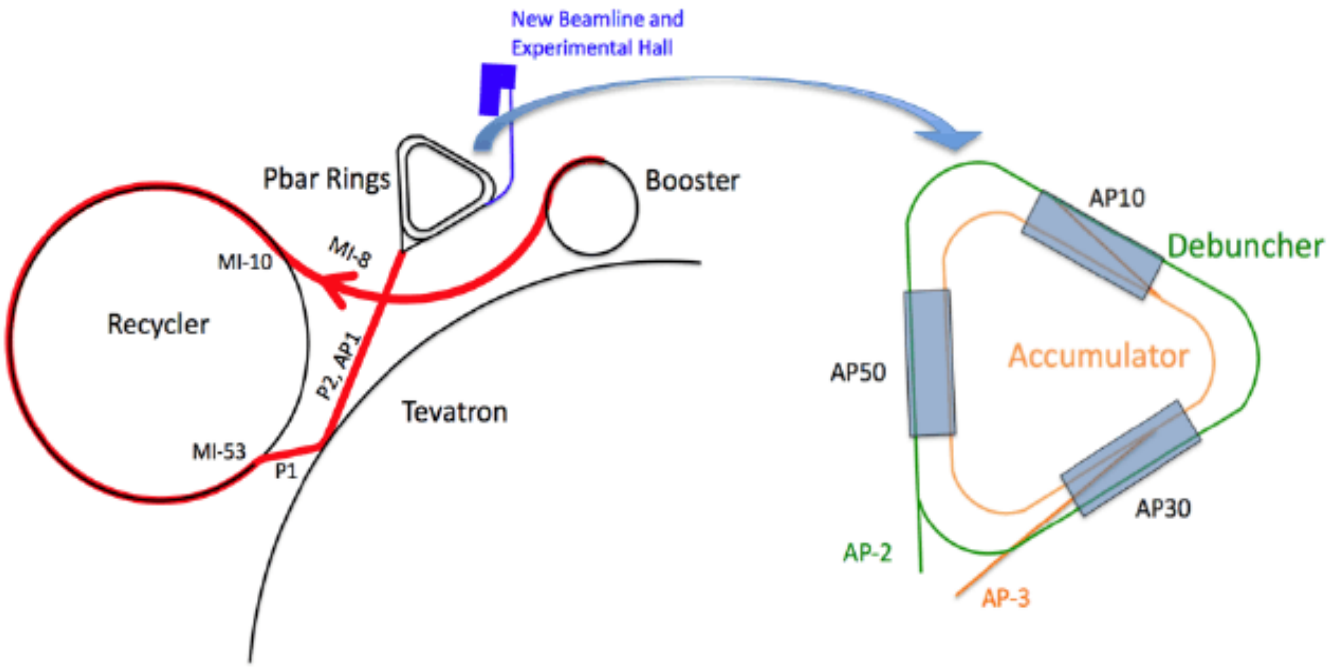
	Base Cost			Estimate Uncertainty			
	Labor	M&S	Total	Labor	M&S	Total	Total Cost
WBS 1 Project Management	$18,660	$1,832	$20,491	0	$83 (14%)	83(0%)	**$20,574**
WBS 2 Accelerator	$21,033	$14,329	$35,362	$5,439 (33%)	$4,500 (33%)	$9,939 (33%)	**$45,301**
WBS 3 Conventional Construction	$2,566	$15,969	$18,535	$799 (33%)	$5,179 (33%)	$5,979 (33%)	**$24,514**
WBS 4 Solenoids	$31,602	$40,111	$71,713	$10,683 (38%)	$15,837 (40%)	$26,520 (39%)	**$98,233**
WBS 5 Muon Beamline	$5,910	$5,033	$10,942	$1,342 (30%)	$1,778 (36%)	$3,120 (33%)	**$14,062**
WBS 6 Tracker	$2,247	$4,725	$6,971	$511 (28%)	$1,404 (35%)	$1,915 (33%)	**$8,886**
WBS 7 Calorimeter	$351	$3,943	$4,294	$109 (34%)	$1,161 (29%)	$1,270(30%)	**$5,564**
WBS 8 Cosmic Ray Veto	$885	$3,533	$4,418	$261 (35%)	$1,098 (32%)	$1,359 (33%)	**$5,777**
WBS 9 Trigger and DAQ	$4,032	$909	$4,941	$1,279 (36%)	$182 (20%)	$1,461 (32%)	**$6,402**
Total	**$87,286**	**$90,384**	**$177,669**	**$20,423 (27%)**	**$31,221 (36%)**	**$51,644 (32%)**	**$229,313**

Cost Range of $200M - $310M

Bird's Eye View

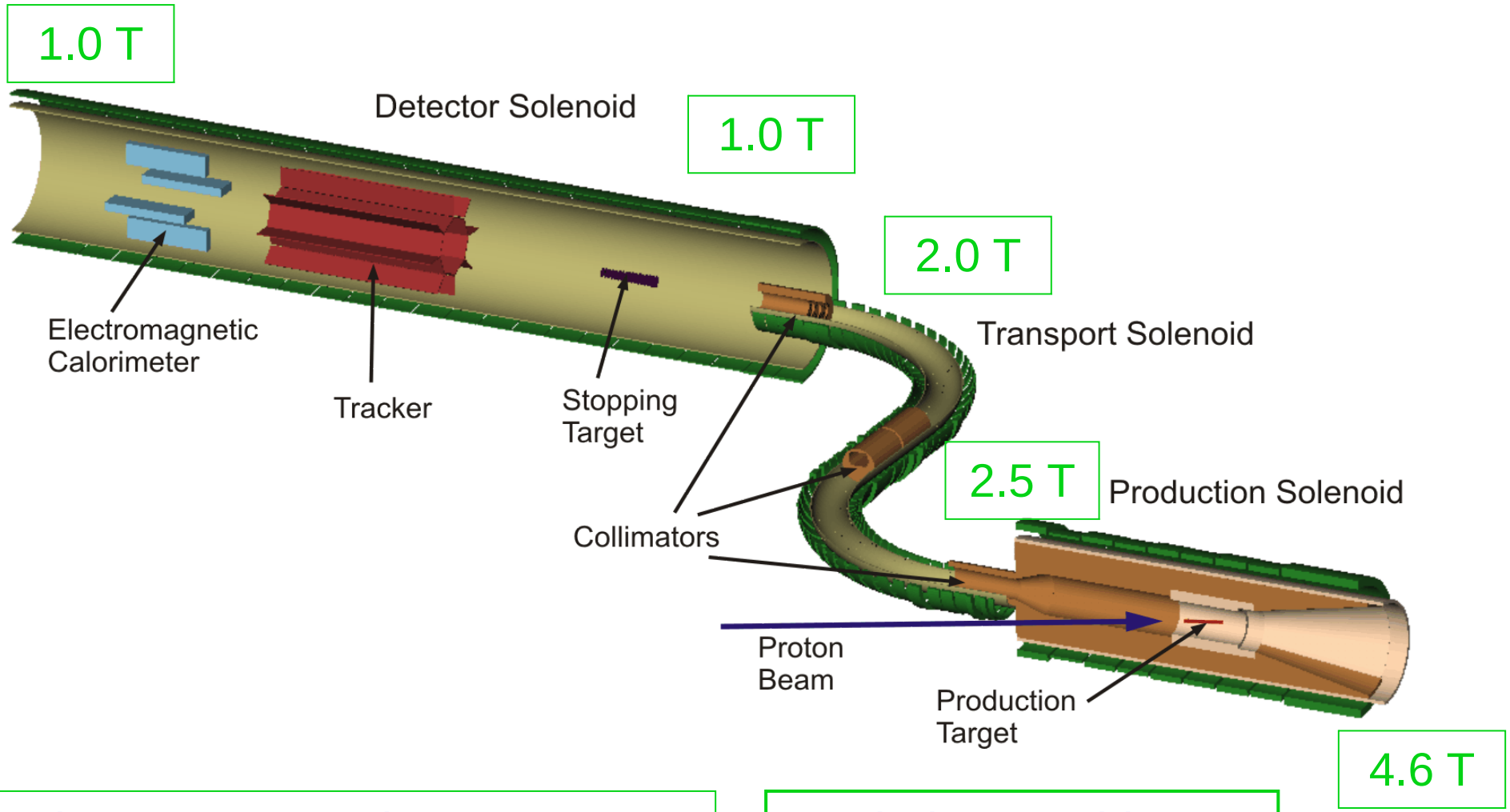
New location is here

Beam delivery



Booster → Recycler → Debuncher

Mu2e Apparatus

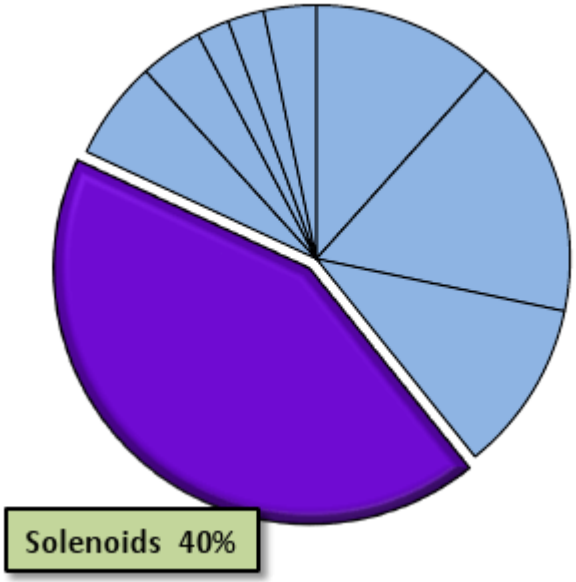


Tracker + ECAL: Uniform 1.0 T

Graded Solenoids: Magnetic Mirror

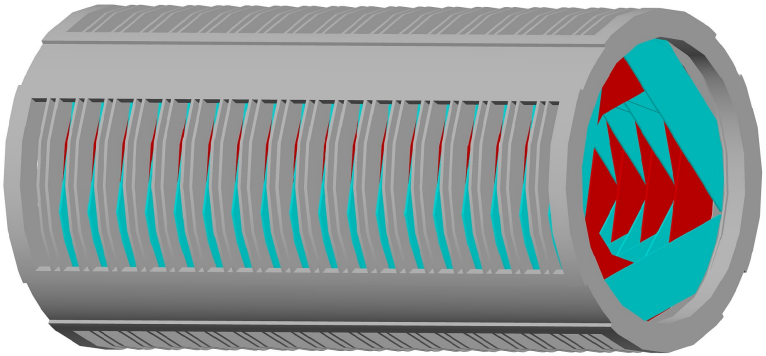
Solenoids

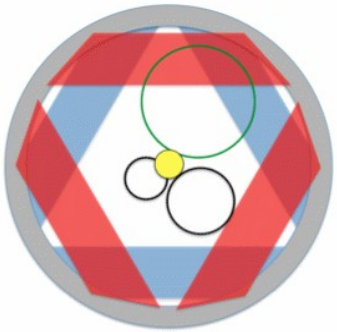
- Solenoids drive the cost and the schedule
  - On or near the critical path for entire duration of Project.
- System includes solenoids, infrastructure, installation, commissioning, field mapping equipment.
- Solenoid procurement is a CD-3a item.
  - Plan that is costed for this review is to procure Detector and Production Solenoids in industry.
  - Make-buy analysis not complete, so plan could change.
    - Have to know this well before CD-2.

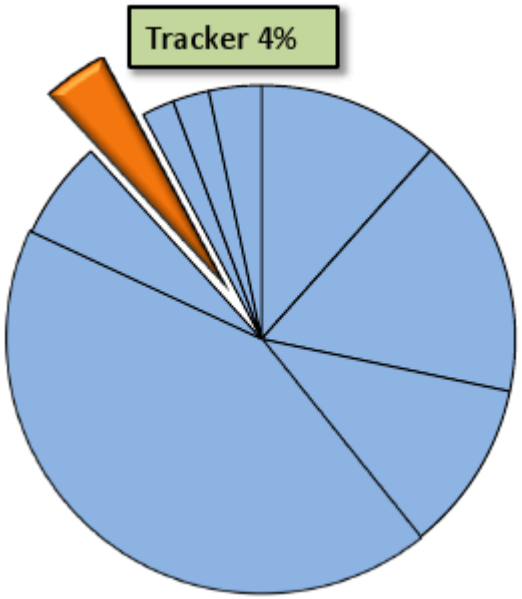


Tracker

- 21,600 thin wall (15 μm) straws (5 mm diameter) distributed over 18 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: CO2)





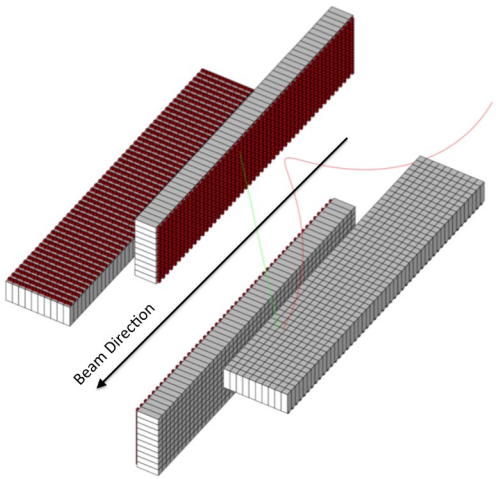


$\sigma \sim 180$ keV

2013: T-tracker selected (over I-tracker)

Calorimeter

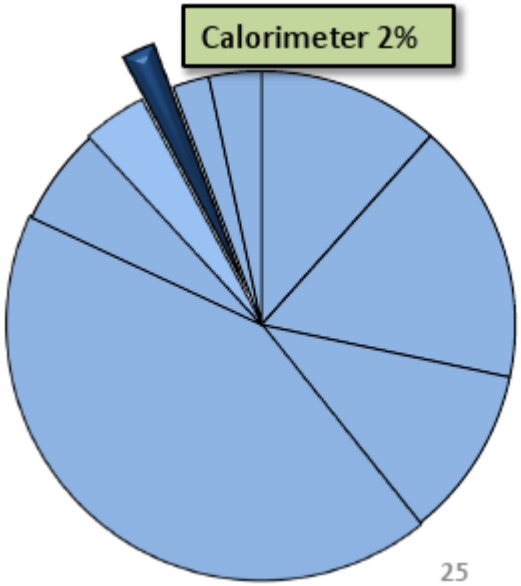
- Majority of scope provided by INFN
- 1936 LYSO crystals arranged in 4 vanes.
  - Operates in 10-4 Torr vacuum and 1 T field.
- Each crystal read out by
  - 2 APDs
  - preamp
  - ADC
  - TDC
- Carbon Fiber mechanical support system
- Flasher system
- Source calibration system
- DOE contribution is
  - 1/3 of crystals
  - 1/3 of APDs
  - Front end electronics
  - Calibration system



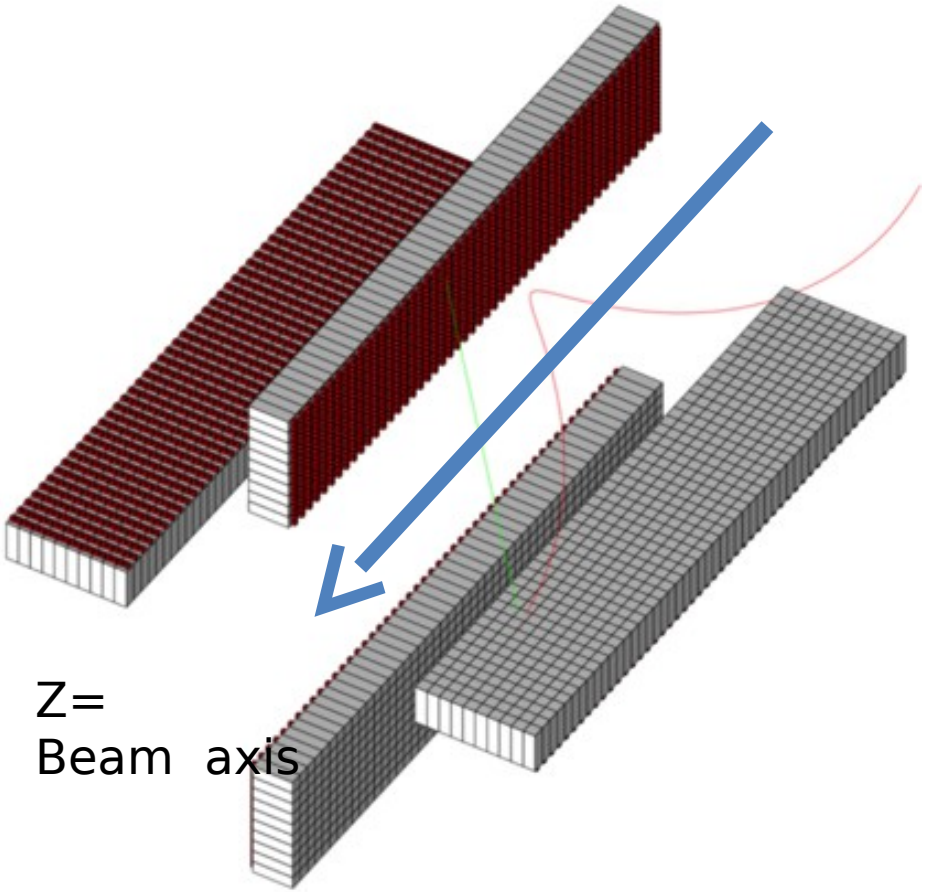
11x44 x4=1936

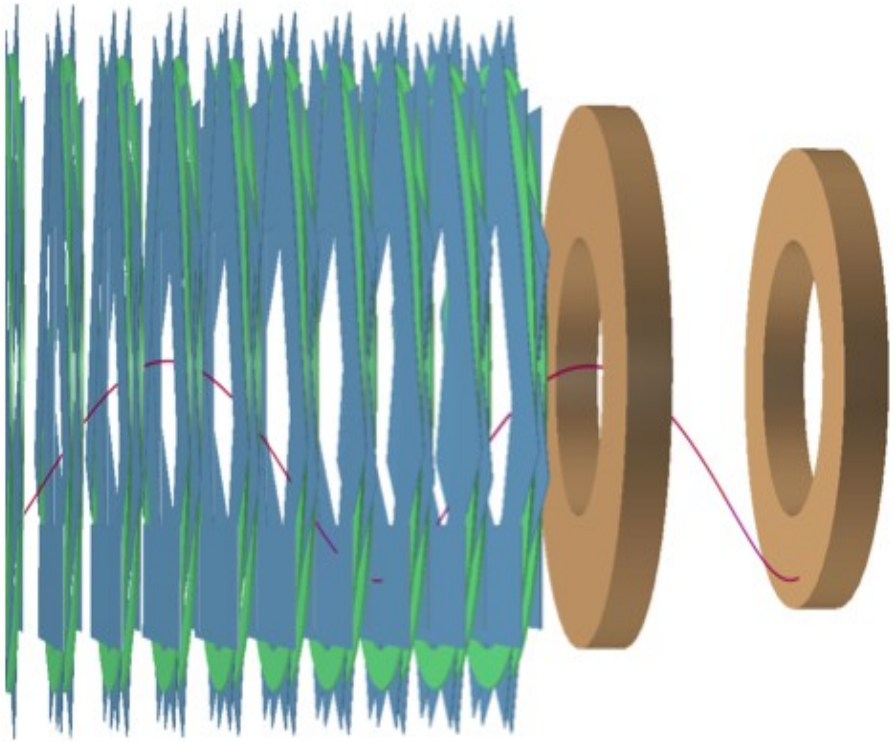
3x3x11 cm
(~10 X_0)

σ ~ 2%



Alternative: Vanes vs Disks





- 1936 LYSO crystals in 4 vanes
- Electrons spiral into the transverse, checkerboard face of the array.
  - APDs and FEE on back side.

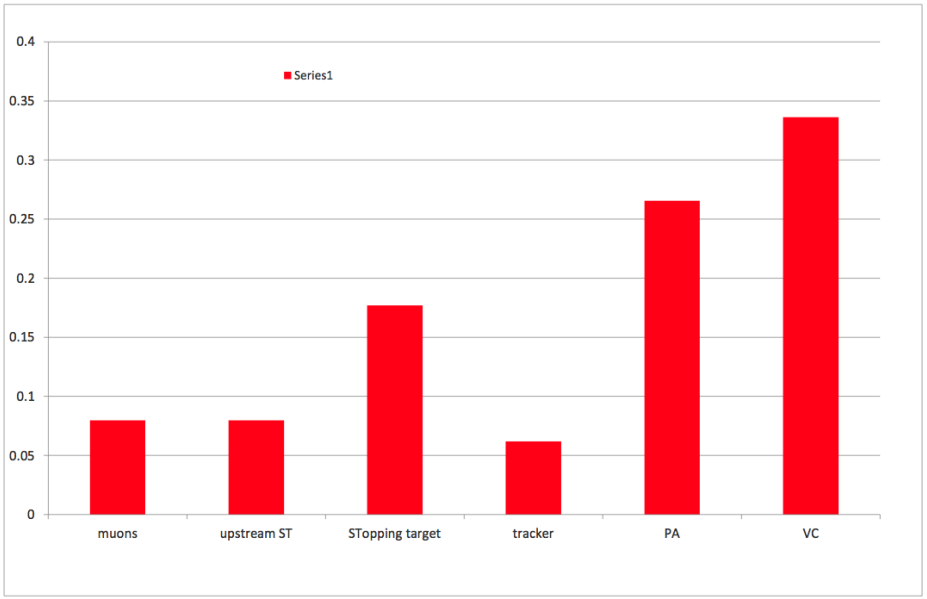
- Two disks facing the target composed of 2640 hexagonal crystals.
- More symmetric for e+, e-, better shielding for photo-sensors, more background
- Similar impinging angle on calo surface

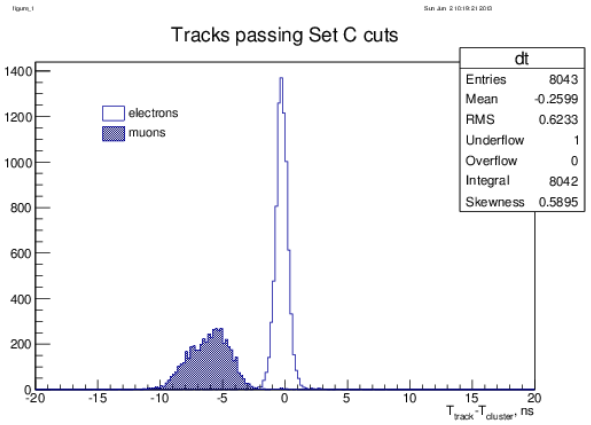
2013: Disks selected

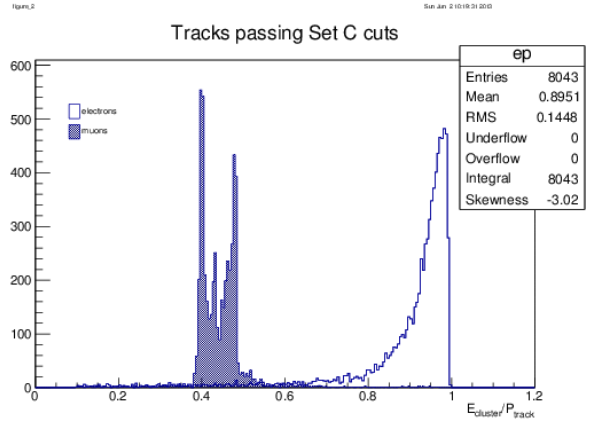
Attività a Pisa: Calorimetro

- Fondo da raggi cosmici (~10% dopo il CRV)
  - CR possono produrre *delta rays* con l' impulso “giusto” e nell' accettanza del detector
  - Molti sono prodotti nel calorimetro
  - Decadimenti di mu dei CR
  - Mu diffusi e intrappolati nel campo magnetico
- Uso del TOF e del rapporto E/p
  - $TOF = \Delta T = T_{cluster} - T_{track}$
  - $E/p = E_{cluster} - P_{track}$
- EMC indispensabile per l' indentificazione/reiezione

Cosmic Rays Background







Preparazione Test Beam(s)

- Rispetto a Mainz 2011:
  - Matrice 5x5
  - Migliorare:
    - Raffreddamento
    - Meccanica
    - Calibrazione (laser)
- Nuovi test 2013-14:
  - e^-/γ (~100 MeV): Frascati (2013, x2) Mainz (~febbraio 2014)
  - 13 cristalli LYSO (già comprati) + 13 (USA)
  - DAQ (Pisa: FS,RC,GP; LNF)
  - Digitizer
- Test radiation hardness
- APD vs SIPM

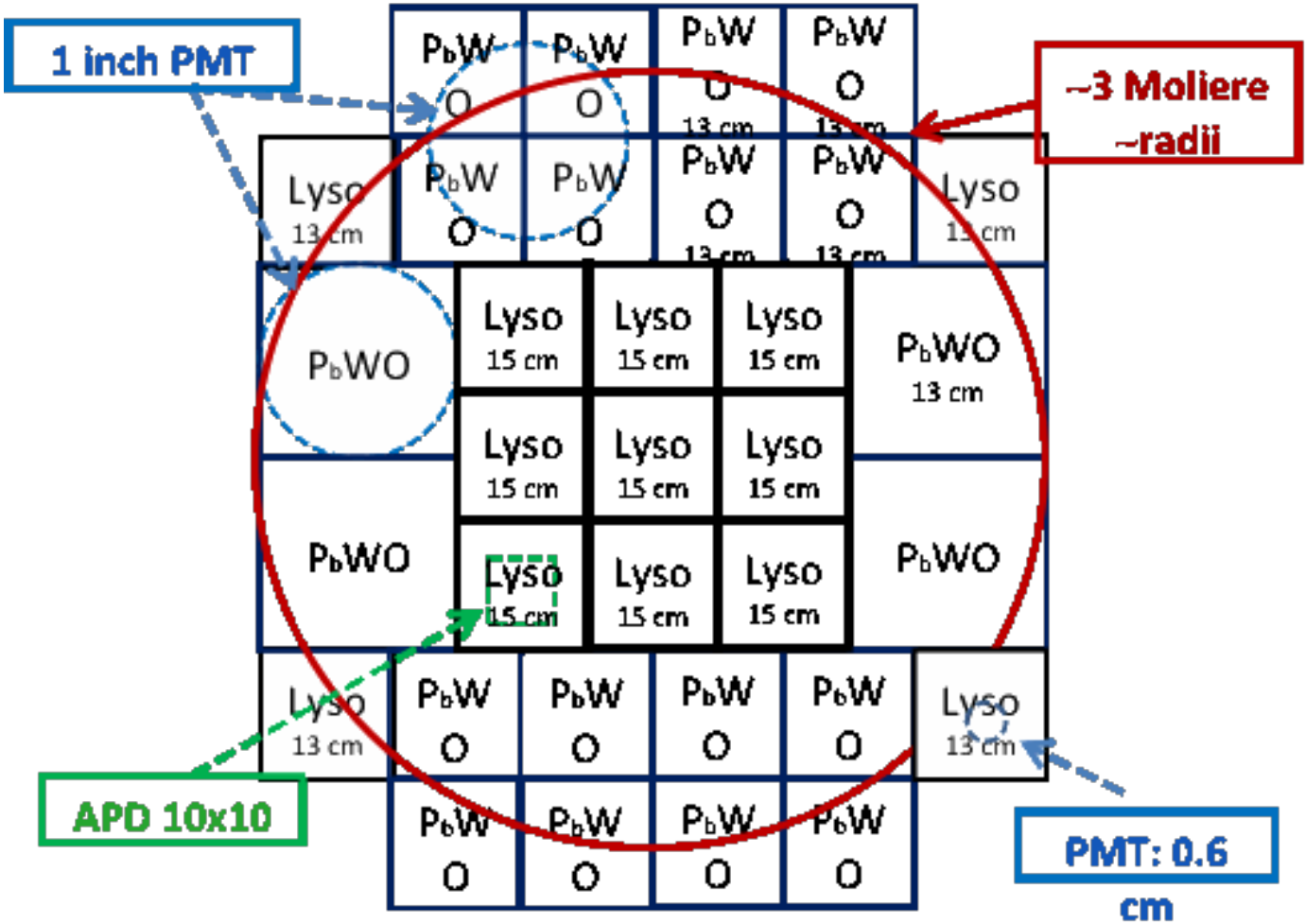
Calorimeter Prototype: Mainz Test Beam

Many improvements:

- Outer matrix enlarged and optically separated
- Inner matrix longitudinal dimension of 15 cm with new SICCAS crystals

  20x20x150 mm³ -->

  10x10 mm² APD
- Coverage of ~3 Rm
- 13 cm LYSO on corners not inserted



LYSO and APD's OK in Sep 2010

QA @ LNF: LRU< 10%, LY~400 pe/MeV, Mech.Tolerance OK

Cordelli/Happacher/Sarra/Saputi (LNF)

Trigger

- Baseline: “triggerless”
- DAQ input rate (totale, stimato): ~30GB/sec
- Bunch spacing 1.7μs, duty cycle 30%, 177k bunch/sec, data size ~170 kB
- 2880 cores,
  - → ~60 bunches/sec/core
  - → 16 msec/bunch
- Offline tracking filter ~300 msec/bunch (not optimized)
- We need ~20x speedup
- Option: calorimeter filter (trigger), FPGA, electronics.

Plans

- Electromagnetic calorimeter software:
  - Simulation
  - Reconstruction algorithms
  - Trigger algorithms
  - Simulation in the Mu2e framework
- Electronics
  - Digitizer
    - Prototype
    - Comparison with Caen
  - Low voltages? (started 2012, summer students)
  - Tests with APD, SIPM, crystals
  - Trigger proto-board
- Investigate different crystals (PbF, CsI)

Utilizzo risorse di sezione

- Elettronica
  - Tecnologo (FS)
  - Laboratorio
    - Allestimento lab.
    - R&D per
      - Apd,Sipm, cristallo
      - Digitizer
      - Trigger

Consistenza del gruppo (Pisa)

- R. Carosi 50% (RL)
- F. Cervelli 40% (RN emerito)
- S. Di Falco 20%
- T. Lomtadze 30%
- L. Ristori 20% (EB)
- G. Gallucci 20% (*assegnista*)
- G. Pezzullo 100% (*dottorando*)
- F. Spinella 20% (*tecnologo*)

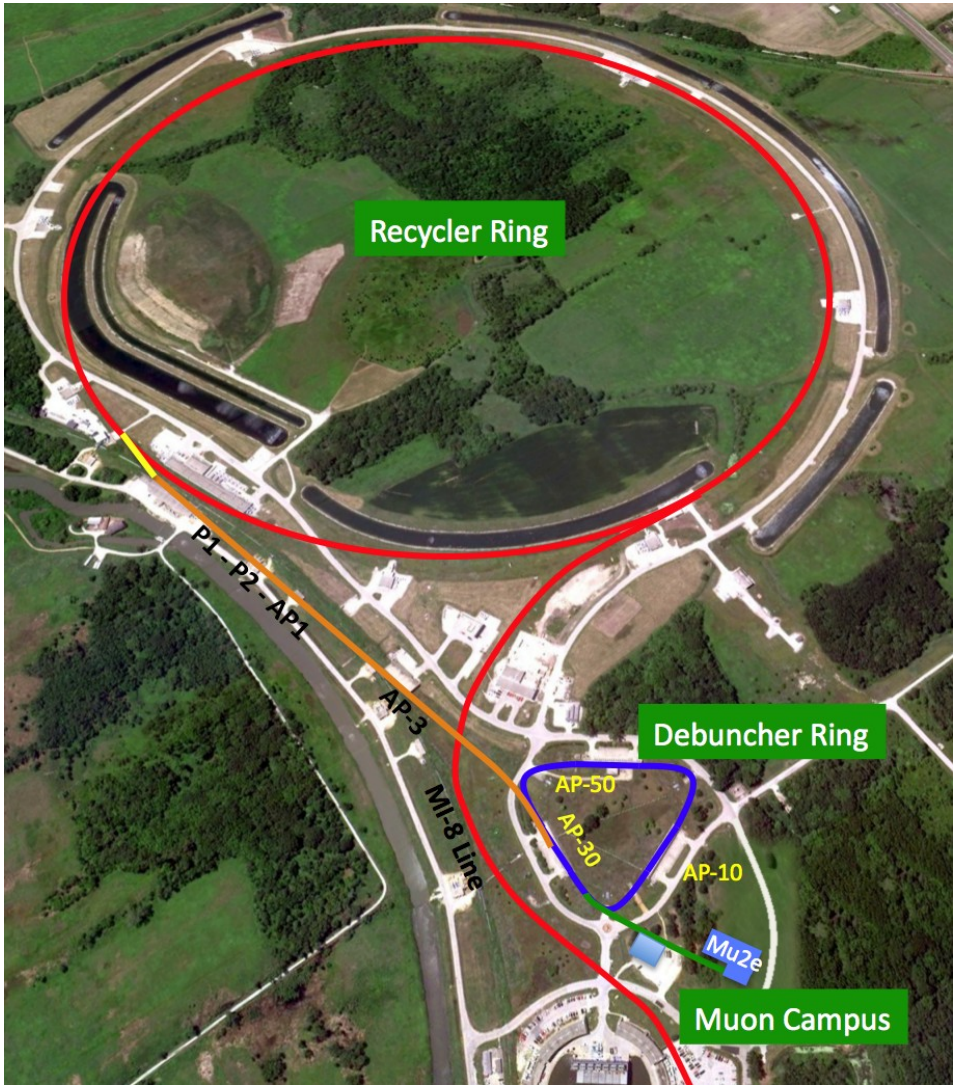
Totale: 3.0

Richieste alla CSN1
(da finalizzare)

- Missioni:
  - MI: 5k€
  - Coll. Meet. (x2, 0.5mU)
  - Reviews (x1, 0.5mU)
  - Simulation (0.5mU)
  - Test beam (0.5mU) (tot → 2mU = 10k€)
- Consumi:
  - Cristalli LYSO: ?
  - Cristalli CsI 4x(2.5x2.5x20 cm^3)+4x(2.5x2.5x15 cm^3) 8k€
  - Sviluppo digitizer:
    - Realizz. boards WF 16ch per confrontare funzionalità vs Caen digitizer ~9k€ (usabili per TB)
    - Stazione test bench per le boards
  - R&D elettronica
    - Alimentatore HV (1k€)
    - Preamp & FFE (0.5k€)
    - APD/SIPM
    - Allestimento lab (5k€)
    - Interfaccia ottica per test beam
- Inventariabile:
  - Oscilloscopio ~10k€

Backup slides

Mu2e Beam Delivery



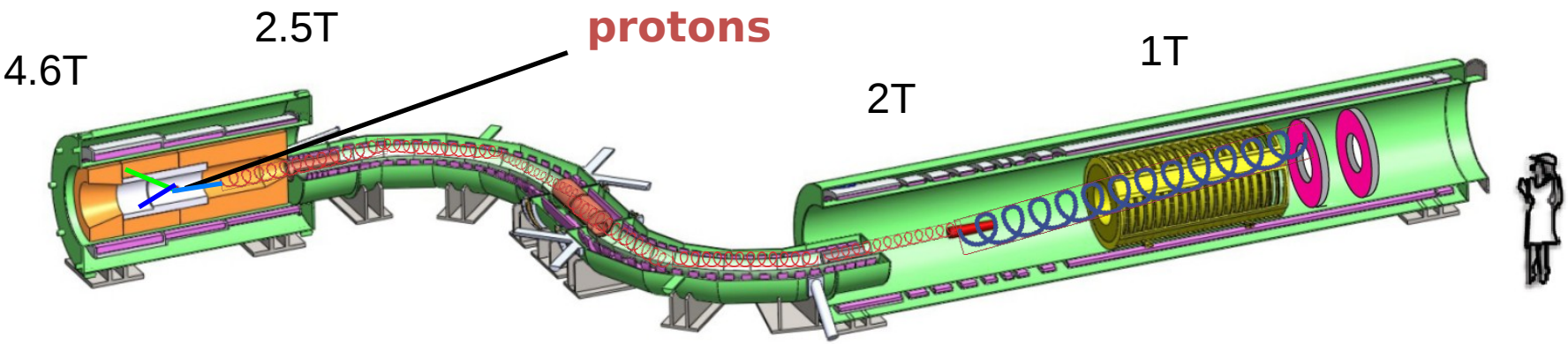
- We make muons by slamming 8 GeV protons into a target.
- Batches of protons from the Booster are transported through existing beamlines to the Recycler Ring where they are re-bunched and transported to the Delivery Ring through existing transport lines.
- Beam is slow extracted from Delivery Ring in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

Parameter		CeF_3	LSO/LYSO:Ce	BGO	PWO	PWO-II
ρ	g/cm^3	6.16	7.40	7.13	8.28	
X_0	cm	1.77	1.14	1.12	0.89	
R_M	cm	2.60	2.30	2.30	2.00	
τ_{decay}	ns	30	40	300	6.5	
λ_{max}	nm	330	420	480	420	
n at λ_{max}		1.63	1.82	2.15	2.24/2.17	
relative LY	% (LY NaI)	5	75	9	0.3 at RT 0.8 at -25°C	0.6 at RT 2.5 at -25°C
hygroscopic		no	no	no	no	
dLY/dT	%/°C	0.1	0	-1.6	- 2.7 at RT	-3.0 at RT
dE/dx (MIP)	MeV/cm	6.2	9.6	9.0	10.2	

Mu2e overview

Production Target / Solenoid (PS)

- Proton beam strikes target, producing mostly pions
- Graded magnetic field contains backwards pions/muons and reflects slow forward pions/muons



Target, Detector and Solenoid (DS)

- Capture muons on Al target
- Measure momentum in tracker and energy in calorimeter
- Graded field “reflects” downstream conversion electrons emitted upstream (isotropic process)

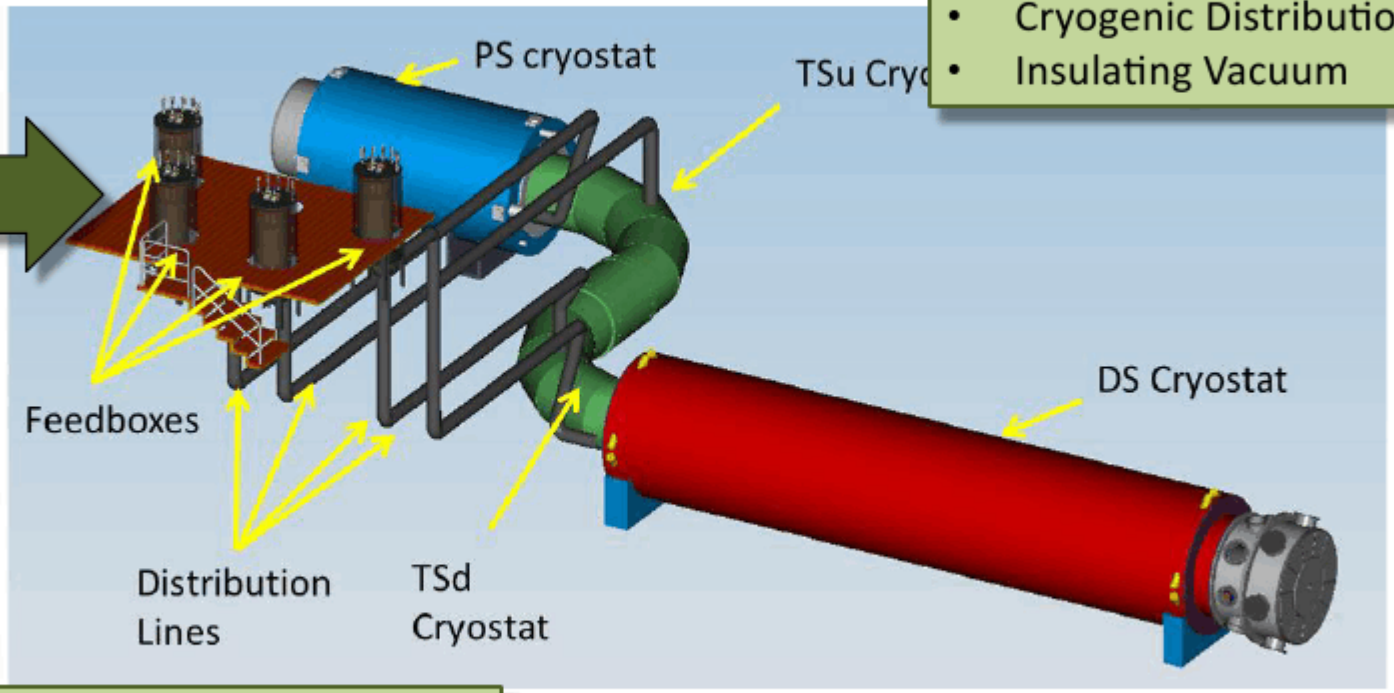
Transport Solenoid (TS)

Selects low momentum, negative muons
Antiproton absorber in the mid-section

Solenoids

~65/35 of Base Cost Solenoids/Infrastructure

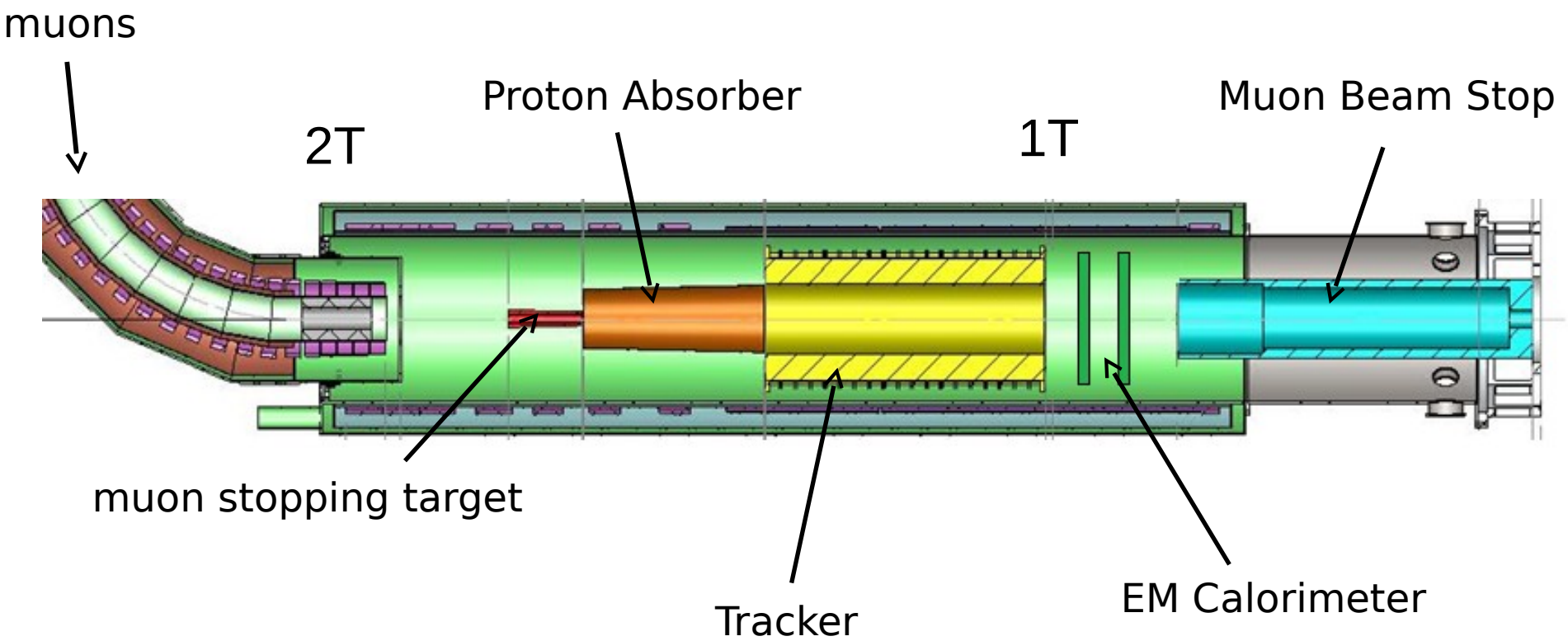
- Production Solenoid (PS)
- Transport Solenoid (TS)
- Detector Solenoid (DS)
- Cryogenic Distribution
- Insulating Vacuum



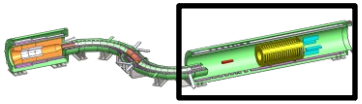
- Power Supply
- Quench Protection

- Field Mapping
- Ancillary Equipment
- Installation and commissioning

Detector



Graded field “reflects” downstream a fraction of conversion electrons emitted upstream (isotropic process)

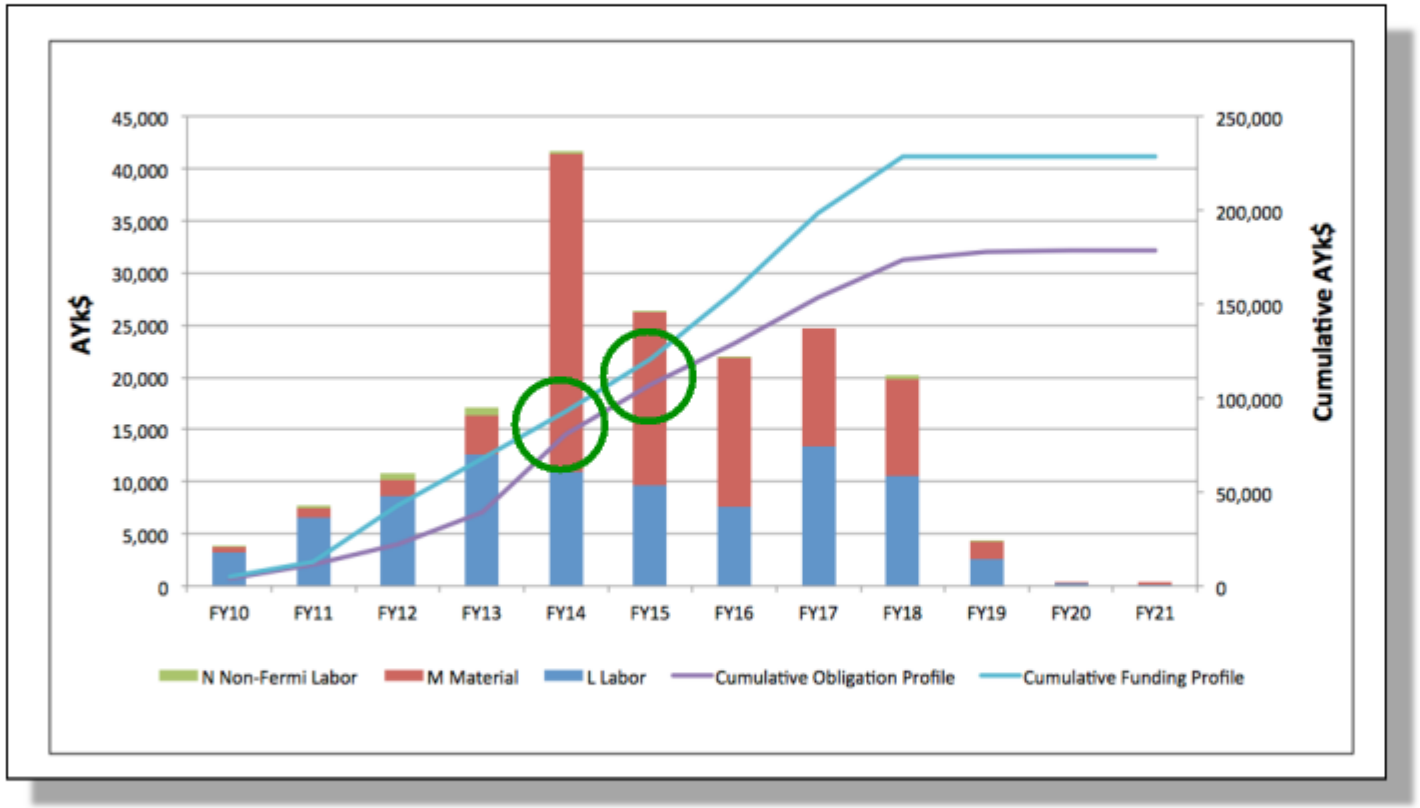


CD Milestones

Description	Date
CD-0: Approve Mission Need	Nov. 24, 2009 (A)
CD-1: Approve Alternative Selection and Cost Range	1st Qtr. FY 2012
CD-2: Approve Performance Baseline	1st Qtr. FY 2013
CD-3a Approve Limited Construction	1st Qtr. FY 2013
CD-3b: Approve Start of Construction	1st Qtr. FY 2014
CD-4: Approve Project Completion	1st Qtr. FY 2018

CD-2,3 and 4 milestones will change once we generate an RLS. Funding problems could introduce additional delays.

Obligation Profile



We're building-up a buffer now so that we can move quickly in FY2014 with conductor, solenoid and detector hall POs

Available Contingency

FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21
92%	72%	15%	12%	22%	29%	32%	28%	28%	28%

Test Beam Plan

- Test beam 2013-2014
  - DAQ (Pisa: FS, RC, GP; LNF)
  - 13 Cristalli LYSO (comprati)
  - Mainz ~ febbraio '14
- Reasonable size prototype
  - 5x5 matrix 3x3x13(11) cm LYSO crystals
  - Test the limit of energy resolution (MAMI 2013-14)
  - Test mechanics and final size of crystals
  - ~13 crystals already financed
  - Need 13 more (5x5+1 spare) ~36k€
  - ***WF digitizer prototype*** ~5k€