MAP Design & Simulation Overview

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Muon Accelerator Program Review

Fermilab

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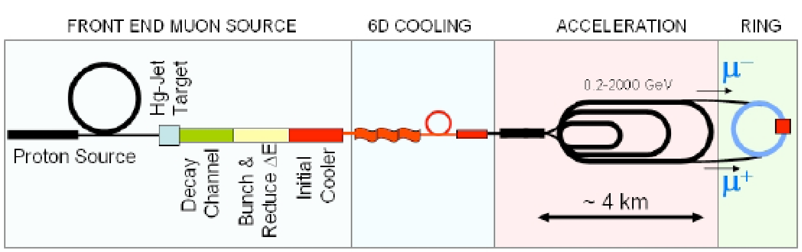
Design & Simulation Goals

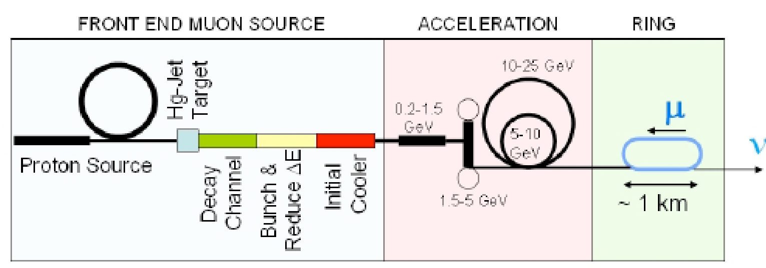
- Design & Simulation (D&S) is one of three major efforts in MAP
- primary goals are to provide needed D&S effort to
  - produce a design report for a neutrino factory (NF) by FY14
  - determine feasibility of a multi-TeV muon collider (MC) by FY16
- provide detailed description of major facility subsystems
- optimize subsystem performance
- do end-to-end simulations of beam behavior
- estimate uncertainties in performance & tolerances in machine parameters
- provide required part counts for preliminary costing
- identify items that need additional R&D

Present Design Configurations

	MC	NF
proton driver	4 MW, upgraded Project X	same
target	liquid Hg jet in 20 T	same
front end channel	enhanced Study 2a	same
6D cooling	3 good candidates	---
final cooling	high field solenoid	---
LE μ acceleration	linac + 2 RLA + FFAG	same
HE μ acceleration	rapid-cycling synchrotrons	---
final ring	2.5 km collider, $\beta^* = 1$ cm	racetrack, long straight
performance	$\geq 10^{34}$ / cm^2 s	10^{21} total μ decays/yr for both signs



Schematic
Not to scale



Example 1.5 TeV MC parameters

proton driver energy (GeV)	8
proton driver power (MW)	4
proton driver repetition rate (Hz)	15
μ beam energy (TeV)	0.75
μ per bunch (10^{12})	2
ε_{TN} (μm)	25
ε_{LN} (mm)	70
energy spread in collider ring (%)	0.1
β* (cm)	1
Avg. luminosity (10^{34} cm^{-2} s^{-1})	1.25

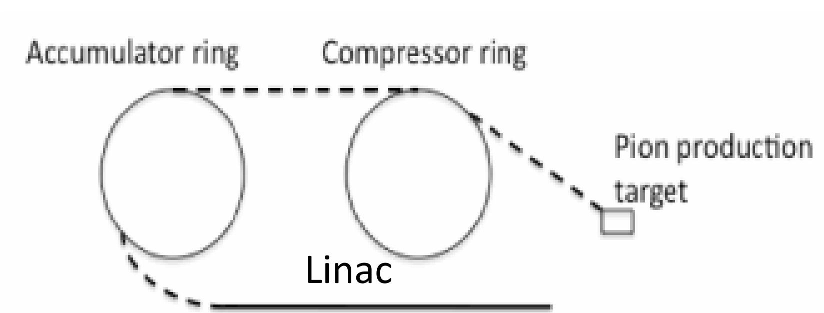
MAP Level 2 D&S Organization

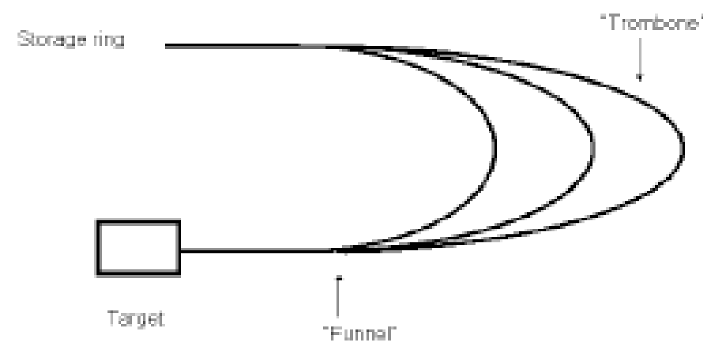
1. Proton Driver
   - Keith Gollwitzer, FNAL, head of Antiproton Source Dept.
2. Front End
   - Harold Kirk, BNL, co-spokesperson MERIT targetry experiment
3. Cooling
   - Tom Roberts, Muons Inc., author of G4beamline code
4. Acceleration
   - J. Scott Berg, BNL, accelerator convener for IDS-NF
5. Collider Ring
   - Yuri Alexahin, FNAL, head of APC Theory/Simulation Dept.
6. Machine-Detector Interface (MDI)
   - Nikolai Mokhov, FNAL, head of APC Energy Deposition Dept., MARS code

Proton Driver Status

- PD group closely follows developments on Project X
- compatibility with NF/MC is one of the Project X design requirements
- MAP effort addresses upgrades needed to meet NF and MC specs
- initial design done by Muons Inc with funding from Project X
- more detailed recent work is being done by V. Lebedev
- present concept
  - Project X upgrade to ~4 MW
  - accumulator, compressor rings for proton bunch structure
  - trombone & funnel optics at target for MC

(cf. Keith Gollwitzer talk)





Proton Driver R&D Tasks

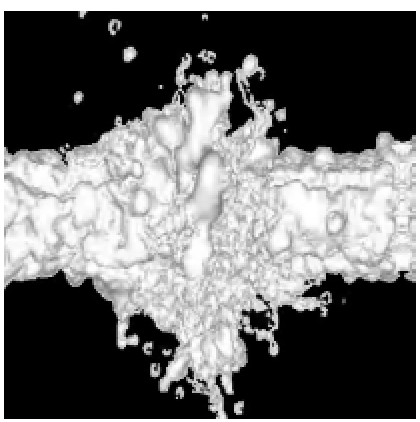
- increasing power of Project X beam to 4 MW
  - study increasing Project X current, pulse duration, rep rate
- injection into the accumulator ring
  - study accumulating many turns via charge-stripping of H^- beam
  - feasibility of stripping techniques
  - methods to prevent overheating
- producing a ~2 ns rms proton bunch at the target
  - challenging goal for 8 GeV, high intensity beam
  - design bunch compression ring
  - design trombone & funnel optics to target

R&D issues for all Level 2 areas are covered more completely in the parallel session talks and in the technical document

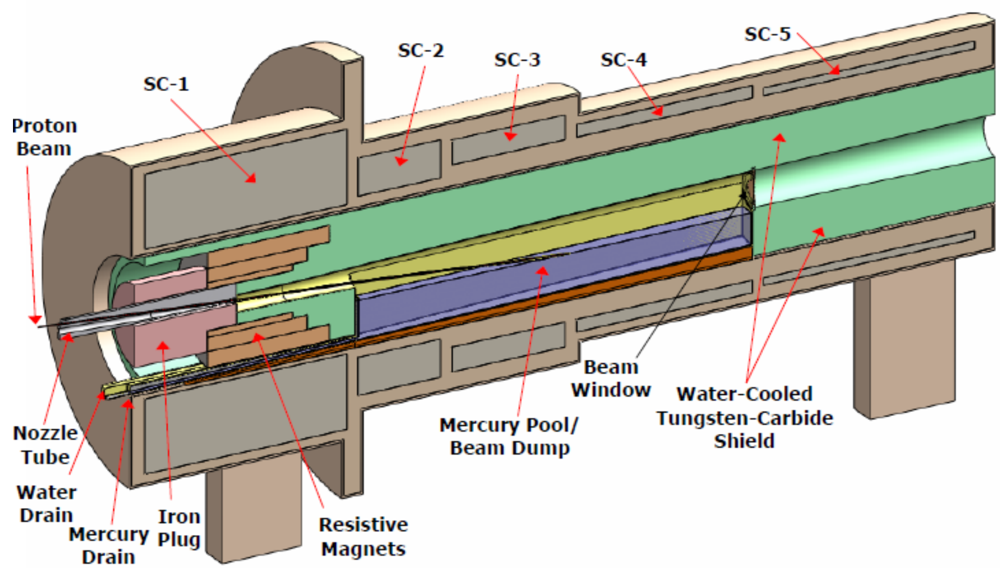
Front End Status: target

- front end ≡ target system + beam channel
- target system ≡ Hg jet target + tapered solenoid +shielding + beam dump + infrastructure
  - have a well-developed concept
  - many details benchmarked by the MERIT experiment
- ongoing effort on MHD simulations

(cf. Kirk McDonald talk)



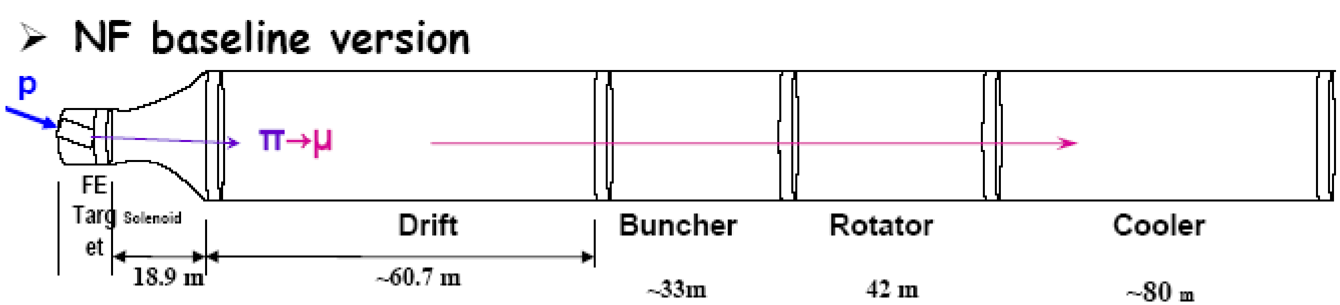
FRONTIER simulation



Front End Status: beam channel

- FE beam channel ≡ decay channel + buncher + phase rotation + NF cooling
- problems with RF in magnetic field complicates these designs (cf. Alan Bross talk)
  1. maximum gradient in vacuum-filled cavities falls off with increasing B
  2. gradient OK in gas-filled cavities, but effects of intense beam unknown
- this has required studying many modified channel designs
  e.g., gas-filling (hybrid), magnetic insulation, bucked lattices
- baseline is a new shorter bunching & phase rotation channel design for 8 GeV

(cf. Harold Kirk talk)

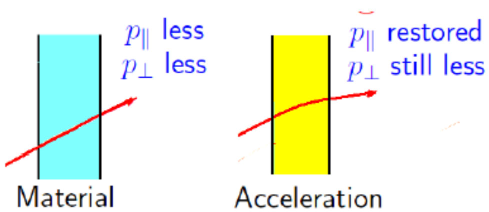


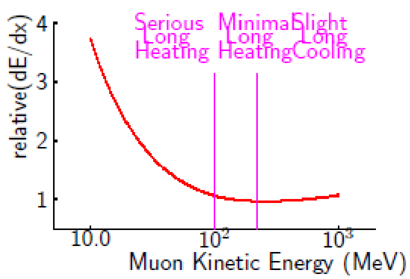
Front End R&D Tasks

- understand shape distortions and possible cavitation in the Hg jet
- shielding the superconducting magnets near the target
  - reduce heat loads on cryogenic system
- target facility engineering design
  - e.g., magnets, dump, beam windows, mercury plumbing, remote handling
- compare pion production codes, benchmark to HARP, MIPP
- understanding RF breakdown mechanisms
  - effect of magnetic field on vacuum-filled cavities
  - effect of beam on gas-filled cavities
- adopt solution to RF breakdown problem in channel design

Ionization Cooling

- our proposed technique for cooling muon beams is ionization cooling



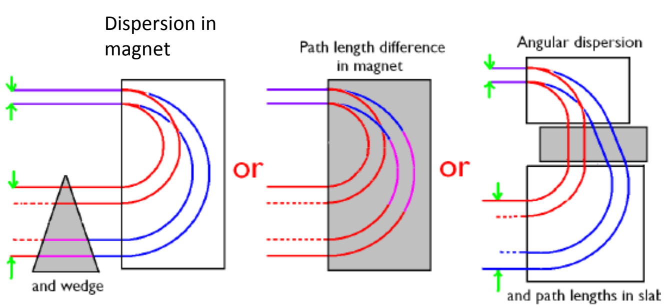


- cooling from dE/dx, heating from scattering

$$\varepsilon_{TN}^{eq} \sim \beta_T / (\beta\, L_R\, dE/dx)$$

- want strong focusing → low β_T
- hydrogen and LiH used for absorbers

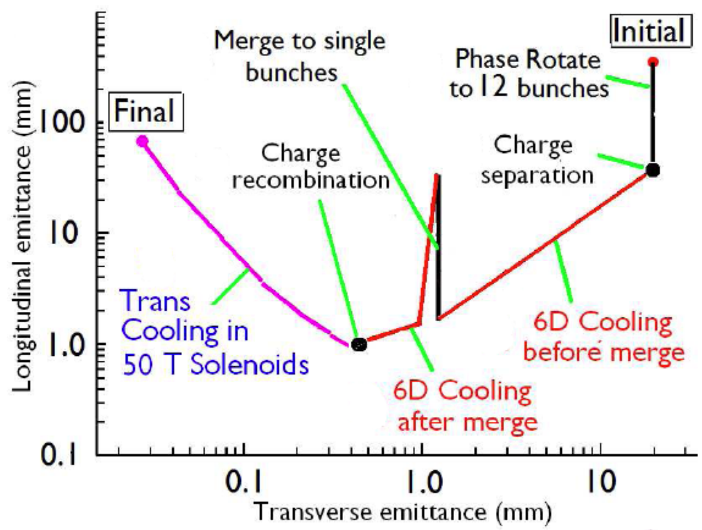
- typical μ momentum ~ 200 MeV/c



- longitudinal cooling requires emittance exchange
- requires a dispersive channel
- heating from straggling, curvature of dE/dx

Cooling Overview

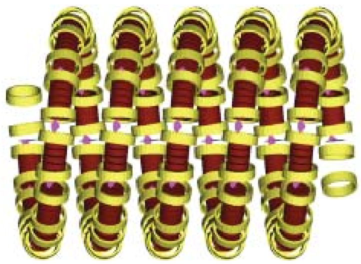
- cooling by ~10^6 in ε_{6N} is one of most challenging requirements for MC
- cooling systems ≡ 6D cooling + final transverse cooling + auxiliary systems
- auxiliary system
  - charge separation & recombination
  - bunch merging
- we have written new codes, ICOOL & G4beamline, to study cooling
- we have developed several scenarios for reaching this cooling goal



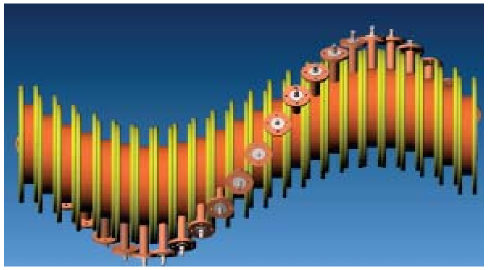
Example
cooling scenario

Cooling Status: 6D cooling

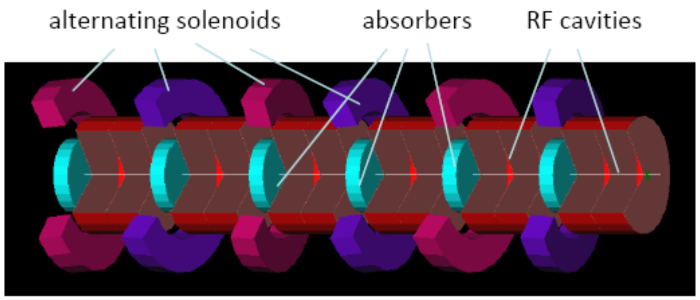
- we have three potential designs for 6D cooling (cf. Tom Roberts talk)
  - Guggenheim
    - easy engineering access
  - Helical Cooling Channel (HCC)
    - gas may allow using high RF gradient
  - Helical FOFO-snake
    - transmits both charges
- simulations show we can reach $\varepsilon_{TN} \sim 0.4$ mm, $\varepsilon_{LN} \sim 1$ mm with Guggenheim and HCC channels



Guggenheim



HCC

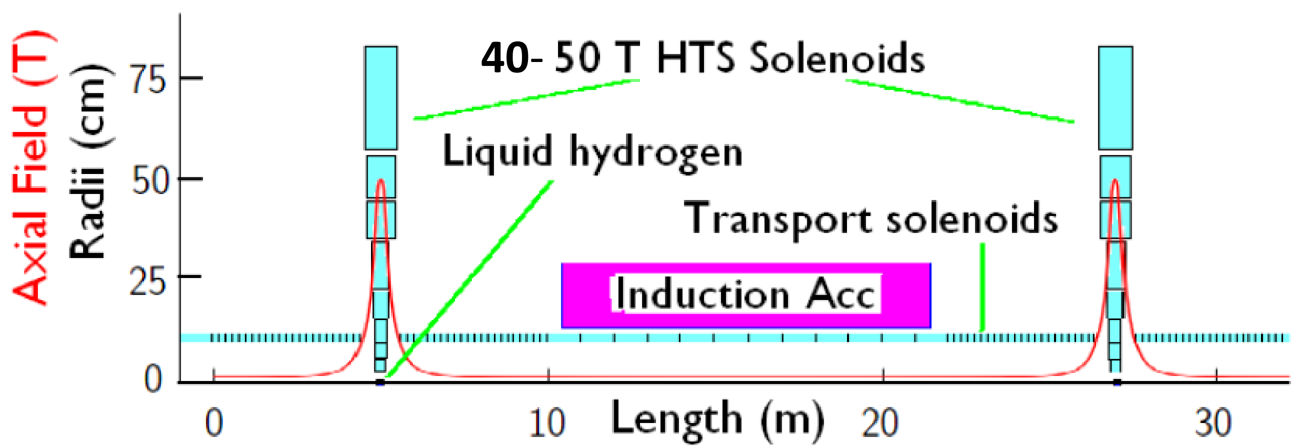


FOFO-snake

Cooling Status: final cooling

- a high-field solenoid channel can provide required final cooling
  - preliminary simulations with 40 and 50 T show it can reach ε_{TN}=25 µm goal
  - transmission is reduced at 40 T, but it still looks acceptable
- other options
  - Parametric Ionization Cooling channel + REMEX
  - Li lens channel

(cf. Bob Palmer talk)

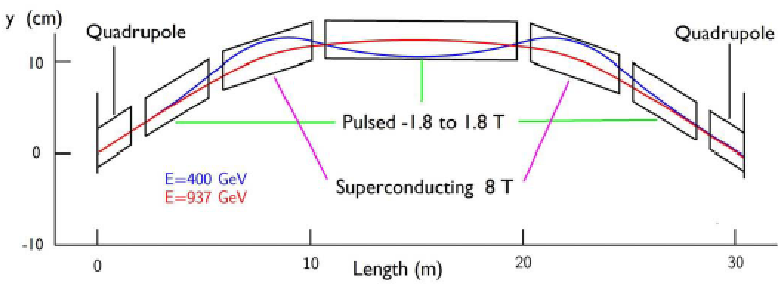


Cooling R&D Tasks

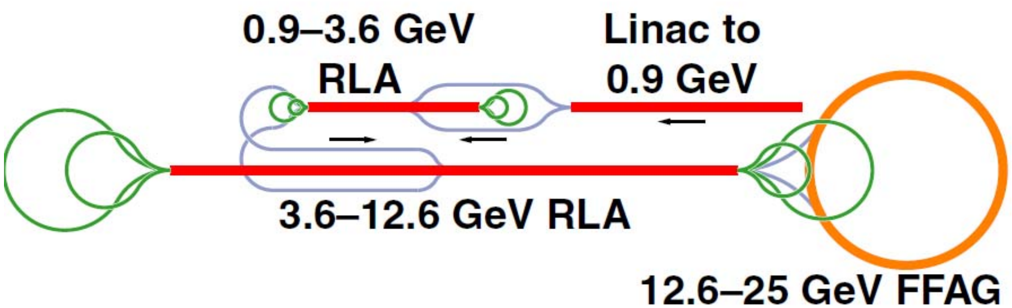
- incorporate solution to problem of RF in magnetic field in cooling channel designs
- understand dependence of final cooling channel performance on the solenoid field strength
- design auxiliary cooling systems
  - charge separation with bent solenoid channel will probably work
  - compare bunch recombination with planar wigglers and helical channels
- simulation code development
  - upgrade ICOOL and G4beamline to follow cooling developments
- do end-to-end simulation of cooling channel
  - simulate all missing stages of channel, auxiliary systems, matching sections
  - all simulations done with a consistent level of detail

μ Acceleration Status

- have a 25 GeV accelerator design for IDS-NF (cf. Scott Berg talk)
- Rapid Cycling Synchrotron (RCS) is preferred choice for the high energy (750 GeV) accelerator
  - gives large number of passes through RF system
- RLA is other option for high energy acceleration



RCS half-cell
dipoles oppose at injection
act in unison at extraction



μ Acceleration R&D Tasks

- study feasibility of 25 GeV accelerator design for MC and NF
- study feasibility of RCS concept for high energy acceleration
- design auxiliary accelerator systems
  - e.g., injection, extraction, RF
- study effects of 2 10^{12} muons in a bunch
  - loading RF cavities, wakefields

Collider Ring Status

- have a preliminary 1.5 TeV collider ring design (cf. Yuri Alexahin talk)
- looks encouraging so far: large momentum acceptance, good dynamic aperture
- helped by μ lifetime limits us to ~1000 turns
- working with SciDAC group on beam-beam simulations

Beam energy	TeV	0.75
Average luminosity / IP	10^{34}/cm^2/s	1.25
Number of IPs, N_{IP}	-	2
Circumference, C	km	2.5
β^*	cm	1
Momentum compaction, α_p	10^{-5}	-1.5
Normalized emittance, $\varepsilon_{\perp N}$	π·mm·mrad	25
Momentum spread	%	0.1
Bunch length, σ_s	cm	1
Number of muons / bunch	10^{12}	2
Beam-beam parameter / IP, ξ	-	0.09
RF voltage at 800 MHz	MV	16
Synchrotron tune	-	0.0006
Repetition rate	Hz	15

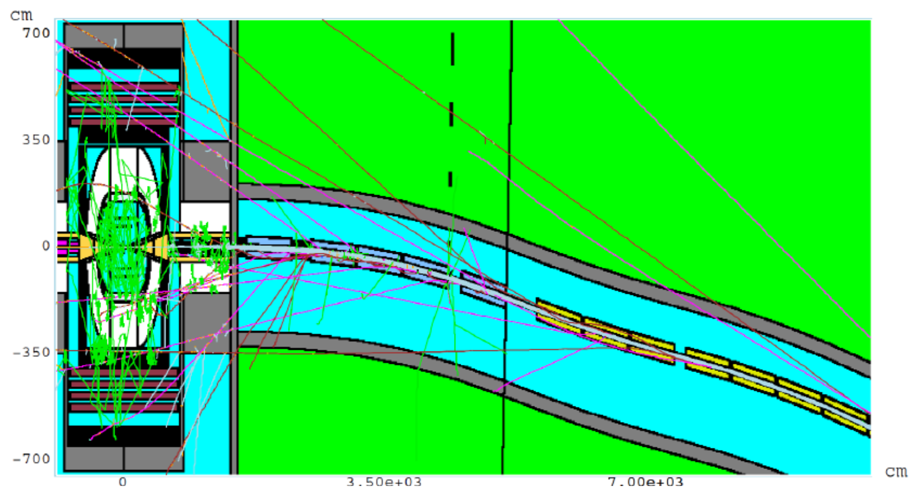
Recent collider ring example

Collider Ring R&D Tasks

- beam dynamics studies
  - higher order chromaticity, tracking with fringe fields
- study feasibility of obtaining β* = 1 cm
  - effects of alignment, jitter, other errors
  - beam-beam effects
- examine effects of electrons from μ decays
  - study heat load, radiation damage
- design auxiliary ring systems
  - RF, injection, abort, diagnostics, …

Machine-Detector Interface Status

- MDI group was set up to coordinate work on
  - collider ring design
  - detector design
  - physics analysis
  - ring magnet design
- requires iterating separate designs until they work together
- have made a preliminary MARS15 model of IR



Machine-detector interface R&D Tasks

- simulation of radiation levels
  - determine component lifetime, heating
- design of IR absorber cones
  - detector background
- control of beam halo
  - can't collimate, need deflection system
- design of auxiliary IR systems
  - beam pipe, cryogenics
- quantify significance of off-site neutrino-induced radiation
  - should be OK at 1.5 TeV

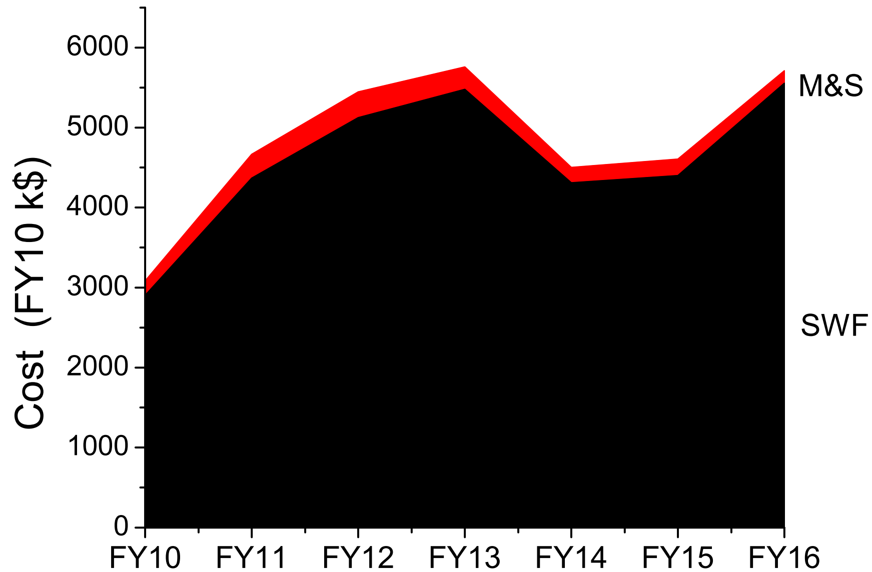
Down-selection for D&S

- we have an initial NF machine configuration now
- some MC systems still have several possible technical choices
- MAP plan aims to specify a single MC configuration
  by using a series of down-selection milestones
- formal procedure is described in the MAP proposal, including
  - technical review of simulated performance, engineering feasibility, relative costs
  - MAP Director makes final decision
- this will lead to a single design configuration for MC in FY13
- each milestone has corresponding deliverable
  - technical report summarizing the case for various options

D&S Milestones & Deliverables

Date	Milestone	Deliverable
FY10	specify target initial configuration	MAP Rev, Des Report
FY11	specify front end initial configuration specify NF μ acceleration initial configuration	MAP Rev, Des Report MAP Rev, Des Report
FY12	specify collider ring initial configuration specify cooling initial configuration	Ext Rev, Des Report MAP Rev, Des Report
FY13	specify proton driver initial configuration specify MC μ acceleration initial configuration	Ext Rev, Des Report MAP Rev, Des Report
FY14	finish D&S for **Interim MC DFS report** finish D&S for **Final IDS-NF RDR report**	Formal Report Formal Report
FY15	provide specifications & parts count for MC costing	Design Report
FY16	provide description of remaining MC R&D items finish D&S for **Final MC DFS report**	Design Report Formal Report

D&S funding profile



- D&S costs are predominantly for personnel
- M&S is for travel, workshops
- total funding peaks at 5.8 M$ in FY13
- includes funding for cost estimation, peaking in FY16

FTE Plan for NF D&S

- FTE plans were determined from task effort estimations and effort on previous studies

area	FY10*	FY11	FY12	FY13	FY14	FY15	FY16	total
D&S	1	2	2	2.2	0.3	0	0	7.5
site	0	1	1	0.5	0	0	0	2.5
targetry	0	1	1.8	1.1	0.2	0	0	4.1
total	1	4	4.8	3.8	0.5	0	0	14.1

- FY11 additions
  - engineer – NF site geology at Fermilab
  - engineer – target systems
  - postdoc – NF front end & μ acceleration

* actual

FTE Plan for MC D&S

area	FY10*	FY11	FY12	FY13	FY14	FY15	FY16	total
PD	0.55	1.35	2	3.15	4.1	5.1	3.3	19.5
FE	1.85	1.5	1	1	0.6	0.6	0.5	7.0
cool	4.64	4.65	4.5	4.3	4	3	2.2	27.3
accel	0.5	1	2.8	3	2.4	2.4	0.9	13.0
ring	0.9	1.8	2	2.4	2.4	2.4	2.3	14.2
MDI	0.6	1	2	2.4	2.9	3.1	2.9	14.9
total	9.04	11.3	14.3	16.3	16.3	16.6	12.1	95.9

- we believe the required rate of growth for plan is achievable
- FY11 additions
  - postdoc — collider ring & MDI
  - postdoc — proton driver & MC acceleration

* actual

Summary

- MAP plan for D&S addresses major issues for design of NF and MC
- have assembled experienced leadership team to guide this effort
- sufficient resources are available in the plan to reach our goals by FY16
- D&S milestones and Interim Design Reports will allow us to adequately monitor our progress
- this work will provide valuable input to particle physics community about viability of NF and MC options for future physics research