Muon Collider Design & Simulation R&D Opportunities

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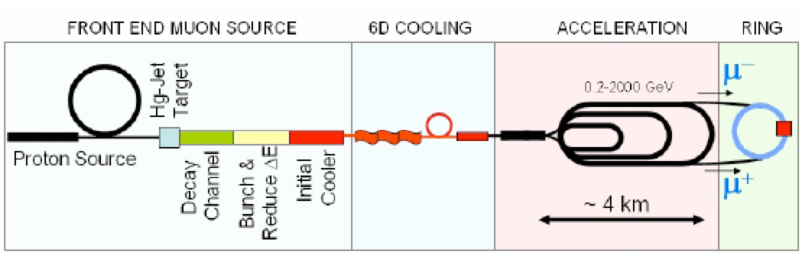
Informal Exploratory Meeting
Fermilab
6 October 2010

Muon Collider Design & Simulation Goals

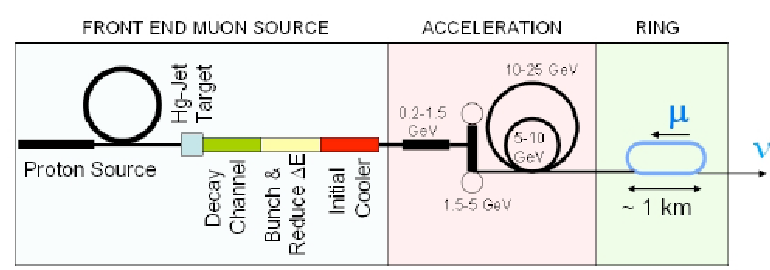
- primary goals are to provide needed Design & Simulation (D&S) effort to
  - produce a design report for a neutrino factory (NF) by 2014
  - determine feasibility of a multi-TeV muon collider (MC) by 2016
- provide detailed descriptions of major facility subsystems
- optimize subsystem performance
- do end-to-end simulations of beam behavior
- estimate uncertainties in machine performance
- determine tolerances on machine parameters
- provide required part counts for preliminary costing
- identify items that need additional R&D

Present Design Configurations

	MC	NF
proton driver	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 circumference collider	racetrack, long straight
performance	$\geq 10^{34}$ / cm^2 s	10^{21} total μ decays/yr for both signs



Schematic
Not to scale

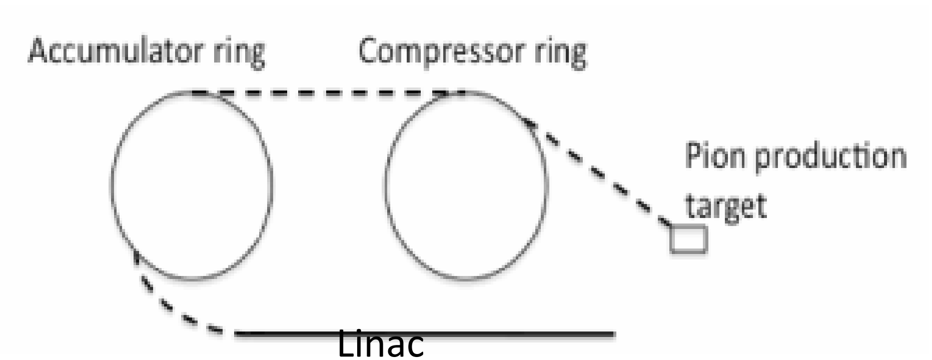


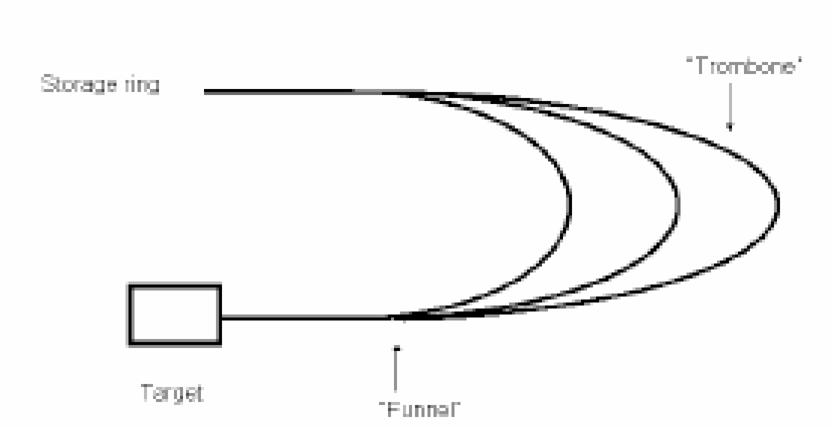
Example 1.5 TeV MC parameters

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

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 concept done by Muons Inc with funding from Project X
  - Project X upgrade to ~4 MW
  - accumulator, compressor rings for proton bunch structure
  - trombone & funnel optics at target for MC



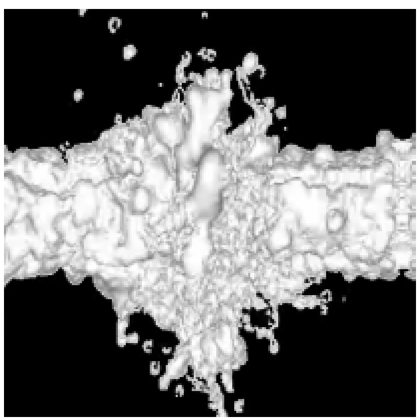


Proton Driver R&D Tasks

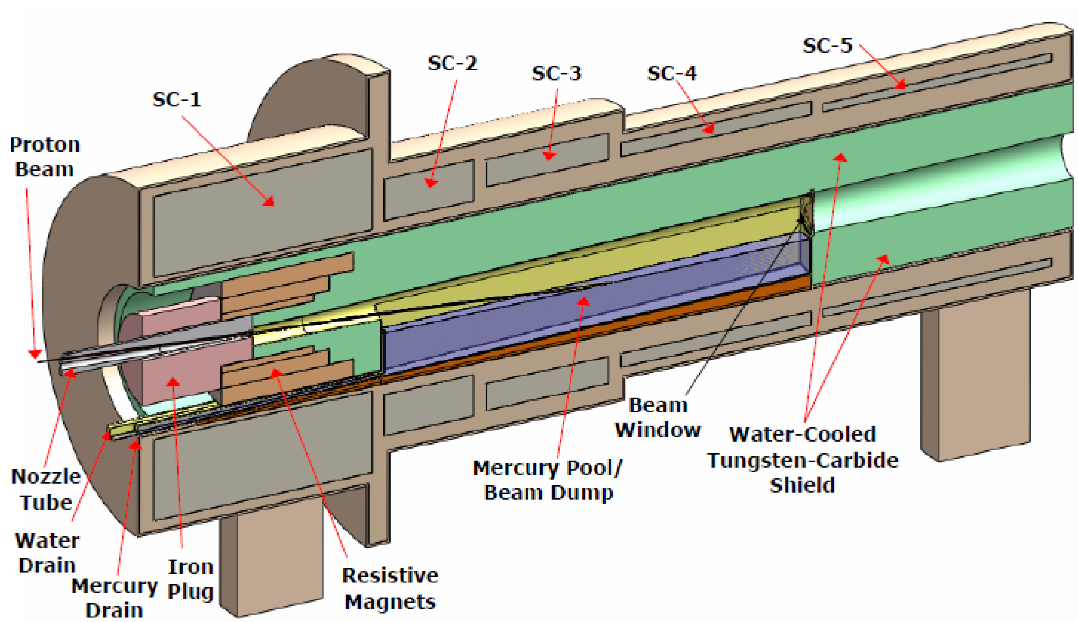
- increasing power of Project X beam to 4 MW
  - study increasing Project X current, pulse duration, rep rate
- injection into the accumulator ring
  - study accumulating many turns via charge-stripping of H^- beam
  - feasibility of stripping techniques
  - methods to prevent overheating
- producing 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

Target System Status

- 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 magnetohydrodynamic simulations



FRONTIER simulation



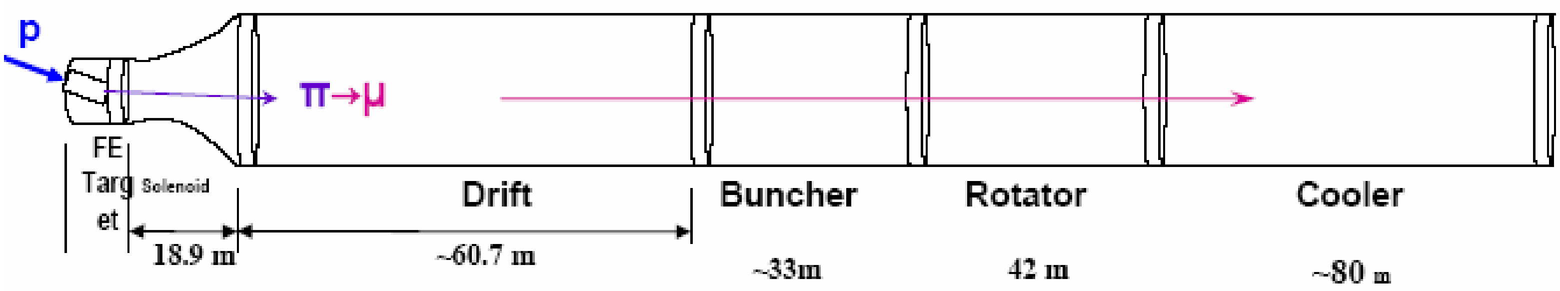
Target R&D Tasks

- understand shape distortions and possible cavitation in the Hg jet
  - improved nozzle design
- understand differences in energy deposition
  between MARS and Fluka
- shielding the superconducting magnets near the target
  - reduce heat loads on cryogenic system
  - heat removal from shielding
- target facility engineering design
  - e.g., magnets, dump, beam windows, mercury plumbing, remote handling

Front End Status

- FE beam channel ≡ decay channel + buncher + phase rotation + NF cooling
- problems with RF in magnetic field complicates these designs (next 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 us to study many modified channel designs
  e.g., gas-filling (hybrid), magnetic insulation, bucked lattices
- have a new baseline design
  - optimized for 8 GeV protons on target
  - fewer μ bunches in the bunch train

➢ NF baseline version

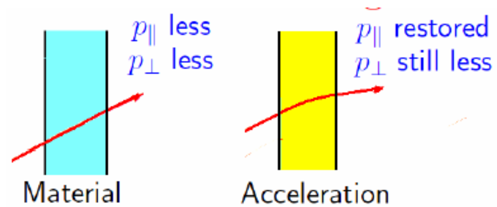


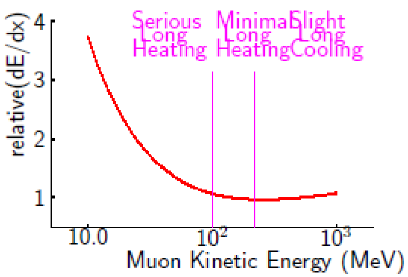
Front End R&D Tasks

- compare pion production codes, benchmark to HARP, MIPP
- removing protons and electrons in beam from target
- understanding RF breakdown mechanisms
  - effect of magnetic field on vacuum-filled cavities
  - effect of beam on gas-filled cavities
- incorporate solution to RF breakdown problem in channel design

Ionization Cooling

- our proposed technique for cooling muon beams is ionization cooling

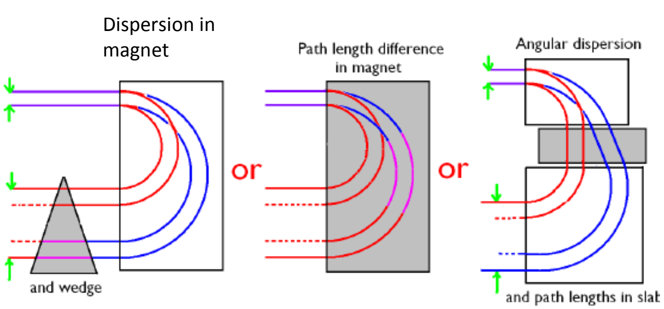




- cooling from dE/dx, heating from scattering

  $\varepsilon_{TN}^{eq} \sim \beta_T / (\beta L_R\, dE/dx)$
- want strong focusing → low β_T
- hydrogen and LiH used for absorbers

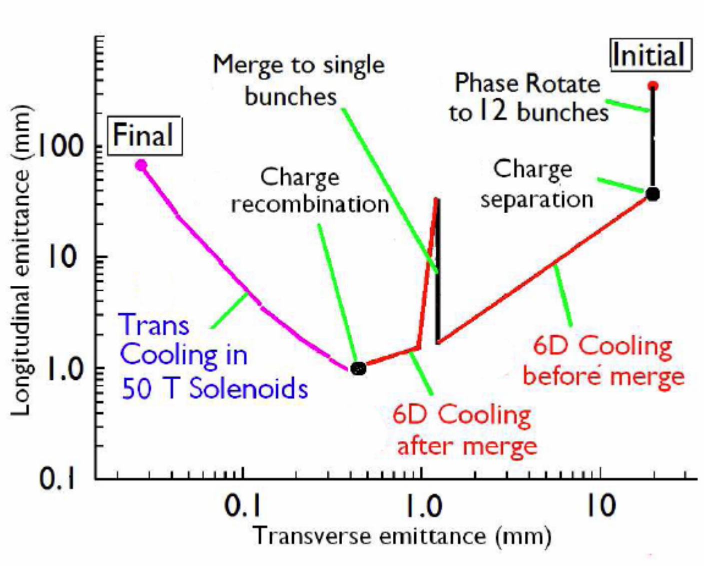
- typical μ momentum ~ 200 MeV/c



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

Cooling Overview

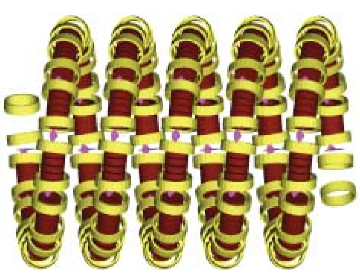
- cooling by ~10^6 in ε_{6N} is one of most challenging requirements for MC
- cooling systems ≡ 6D cooling + final transverse cooling + auxiliary systems
- auxiliary system
  - charge separation & recombination
  - bunch merging
- we have written new codes, ICOOL & G4beamline, for cooling channel design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



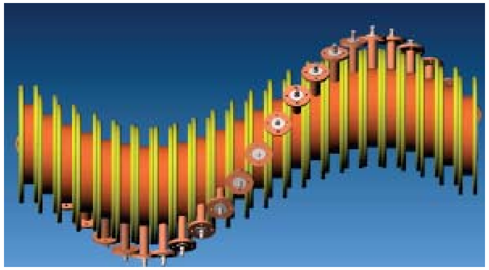
Example
cooling scenario

Cooling Status: 6D cooling

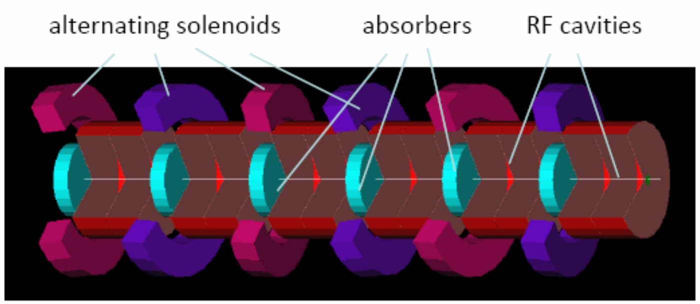
- we have three potential designs for 6D cooling
  - Guggenheim
    - easy engineering access
  - Helical Cooling Channel (HCC)
    - gas may allow using high RF gradient
  - Helical FOFO-snake
    - transmits both charges
- simulations show we can reach ε_{TN} ~ 0.4 mm, ε_{LN} ~ 1 mm with Guggenheim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



Guggenheim



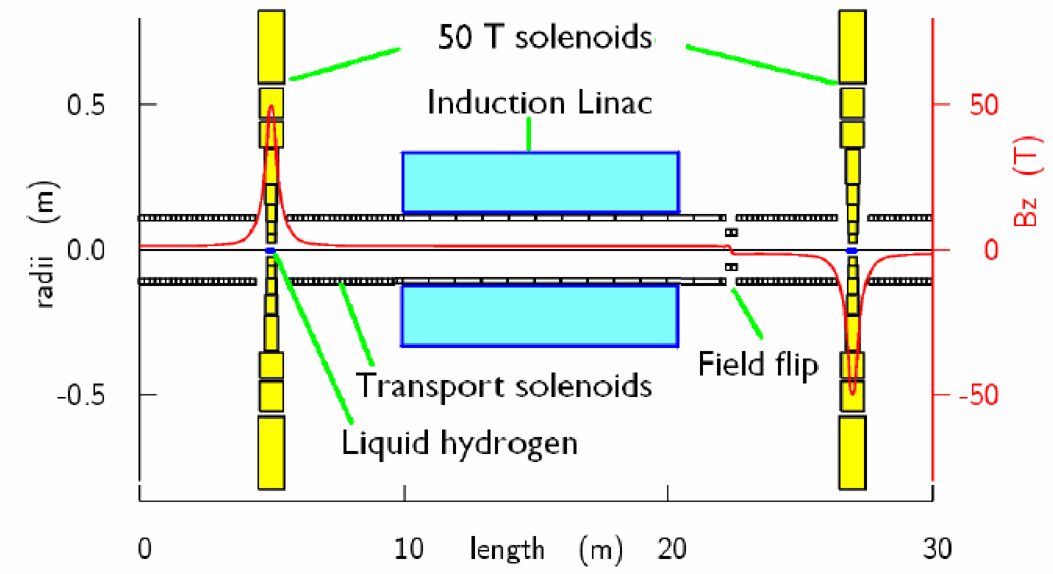
HCC



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

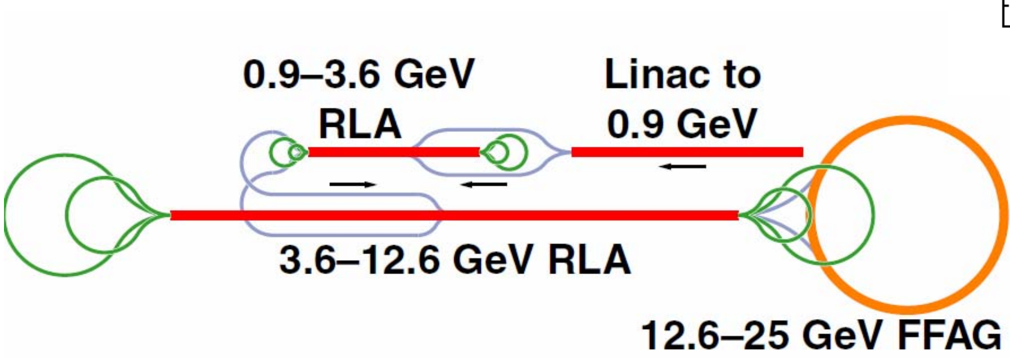


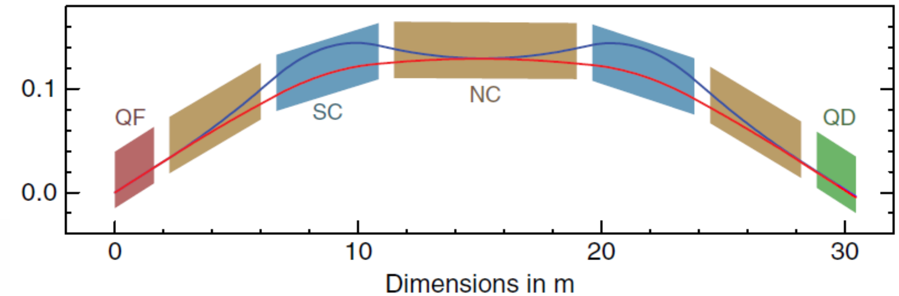
Cooling R&D Tasks

- 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
- study collective effects in absorbers

μ Acceleration Status

- have a 25 GeV accelerator design for IDS-NF
- Rapid Cycling Synchrotron (RCS) is preferred choice
  for the high energy (750 GeV) accelerator
  - gives largest number of passes through RF system
- RLA is the 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
  - basic lattice design
  - simulations with high synchrotron tune
  - study effect of tune on collective effects
- 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
- looks encouraging so far: large momentum acceptance, good dynamic aperture
- helped by μ lifetime limits us to ~1000 turns
- started 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

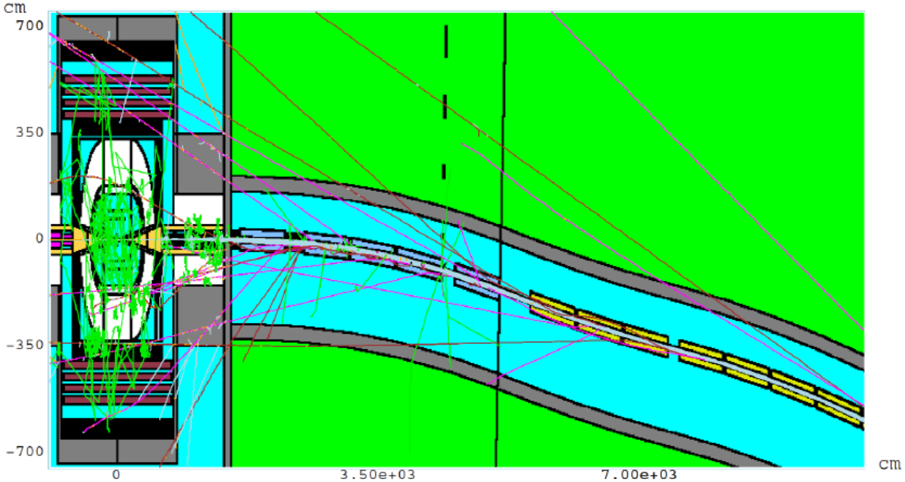
Recent collider ring example

Collider Ring R&D Tasks

- lattice design
  - need μ collimation scheme, β* tuning section
- beam dynamics studies
  - tracking with fringe fields, systematic multipole correction
  - impedance, wakefield studies
- study feasibility of obtaining β* = 1 cm
  - effects of alignment, jitter, other errors
  - stability of coherent beam-beam oscillations
  - plasma beam-beam compensation?
- examine effects of electrons from μ decays around ring
  - study heat load, radiation damage
- design auxiliary ring systems
  - RF, injection, abort, closed orbit, 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

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

Summary

- determining the feasibility of a muon collider will take a major effort
- there are many interesting machine questions that need to be examined
- MAP proposal aims to increase our current effort on MC machine R&D
- but at present we only have a small number of people (~9 FTEs)
- we welcome new collaborators to help out