Muon Collider Accelerator Design and Simulation 5 year Plan

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MUTAC Review
FNAL

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Background

- NFMCC & MCTF joint 5-year plan calls for a muon collider Design Feasibility Study (DFS) to be completed in ~2013
- design and simulation work on accelerator systems will be a major part of this study
- last year a small group worked on preparing this simulation plan
  - what design & simulation tasks need to be done
  - how much effort might be required to accomplish it

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Possible schedule

(2009-2010) explore proposed alternative accelerator subsystems
simulate performance using defensible parameters
cross-check promising systems with ≥2 codes

(2011) specify a baseline accelerator design
optimize baseline, minimize work on alternatives
simulate representative matching sections
carry out representative tolerance studies

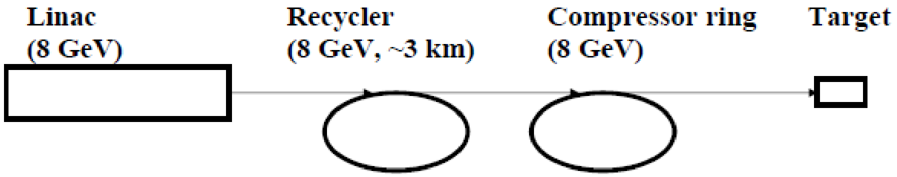
(2012-2013) freeze accelerator design
complete design of all transfer lines & matching sections
do end-to-end simulations of all accelerator systems
do detailed tolerance studies
do necessary simulations for the DFS report

Overview of accelerator tasks

1. Subsystem design & simulations
    - proton driver
    - target
    - front end
    - μ acceleration
    - collider ring
2. End-to-end simulations
3. Cost estimation

Proton driver

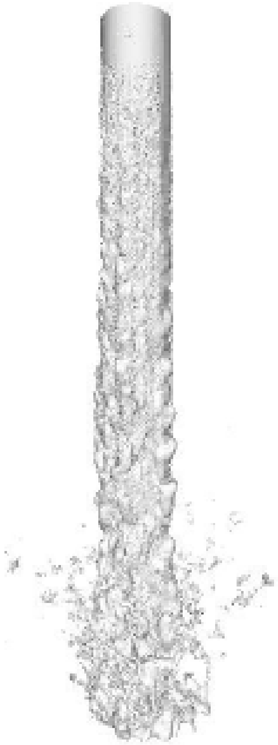
- envision using Project X as the proton driver
- assume a baseline Project X design independent of our efforts
- we would explore additions & modifications needed to meet our requirements
  - proton beam power ~ 4 MW
  - proton bunch length ~2 ns
  - time structure of bunches at target
- design new accumulator & compressor storage rings to provide flexibility
- investigate a combiner to allow >1 bunch on target simultaneously
- develop 1st order design concepts: parameters, layout, lattice optics, etc.
- evaluate intensity-dependent effects: space charge, electron cloud, etc.
- develop strategies to mitigate any intensity-dependent effects
- tracking studies with realistic errors



(a possible layout)

Target

- benchmark results of MERIT experiment with simulations
  - production rates
  - disruption of mercury jet by proton beam
  - jet shape distortions caused by magnetic field
- understand differences between MERIT & facility requirements
- study optimized nozzle designs



(jet disruption)

Overview of front-end systems

- front-end differs most from conventional facilities
- very difficult to manipulate the diffuse, short-lived bunch of muons
- uncertainty on the optimum way to prepare μ for acceleration
- much of our simulation work has addressed this system
- modeling fields, optimizing layout, increasing realism, studying errors

Front-end simulations

1. decay, bunching & phase rotation*
2. precooling*
3. 6D cooling
4. final cooling
5. front-end-code development*
6. breakdown in normal-conducting RF cavities*

*synergy with neutrino factory studies

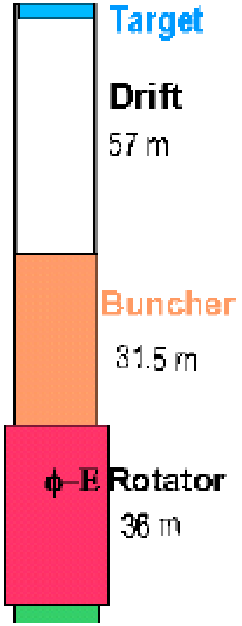
Phase rotation & precooling

Capture section

- capture π, allows decay to μ, forms bunches, reduces energy spread
- study Neuffer's new 12-bunch scheme
- study using alternating solenoid lattices for buncher & phase rotation
- study capturing at higher energy

Precooler section

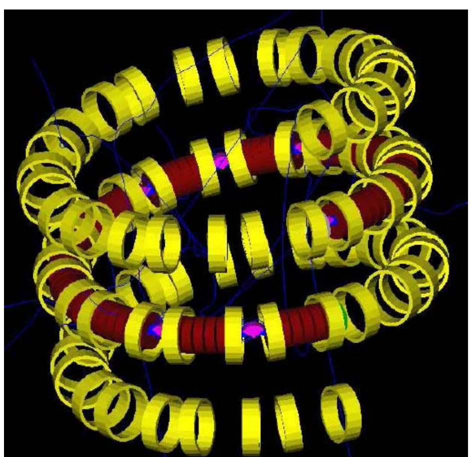
- first stage of transverse cooling, similar to NF
- investigate Study 2a channel with LiH → H_2 gas



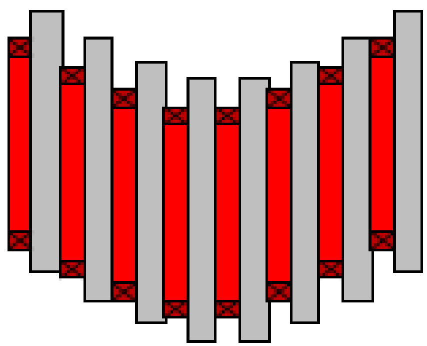
(12-bunch layout)

6D cooling

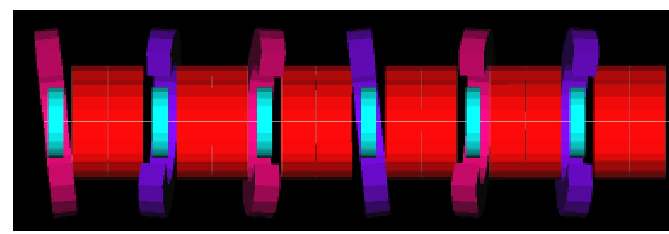
- bulk of ionization cooling is done here
- study three main schemes, each with several variants
  - Guggenheim channel
  - Helical Cooling Channel (HCC)
  - Helical FOFO-snake
- charge separation, recombination, bunch merging may be necessary



(Guggenheim)



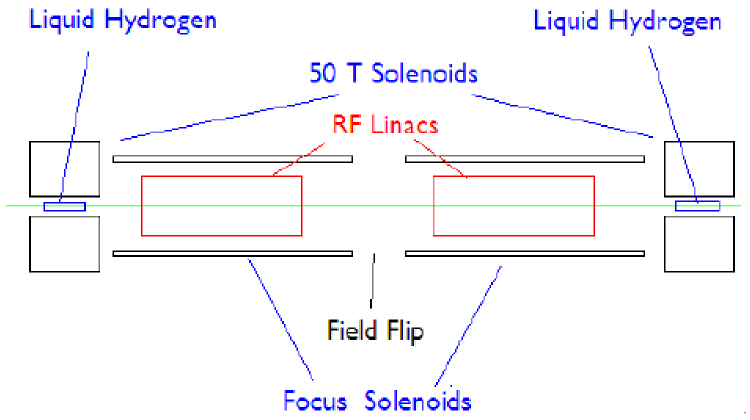
(HCC)



(Helical FOFO snake)

Final cooling

- reduces final ε_{TN} to 2 - 25 μm
- study two main schemes
  - 50 T solenoid channel
  - Parametric Ionization Cooling & Reverse Emittance Exchange (Muons Inc.)
- investigate other late stage possibilities
  - low-β bucked coil lattice
  - lithium lens channel
  - conventional REMEX with wedges
- may need some high-energy bunch merging



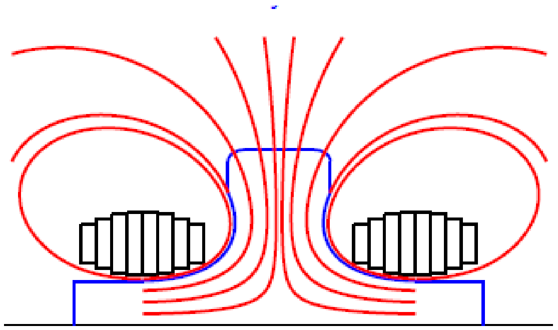
(50 T channel)

Front-end code development

- special codes are required for front-end system design
  - combine aspects of particle interaction physics & beam transport
- novel designs frequently analyzed first with special-purpose codes
- successful ideas get incorporated into general purpose simulation codes
  - ICOOL
  - G4Beamline (Muons Inc.)
- codes need continual upgrades
  - correct errors
  - handle new cooling configurations
  - resolve discrepancies

Breakdown in NC RF cavities

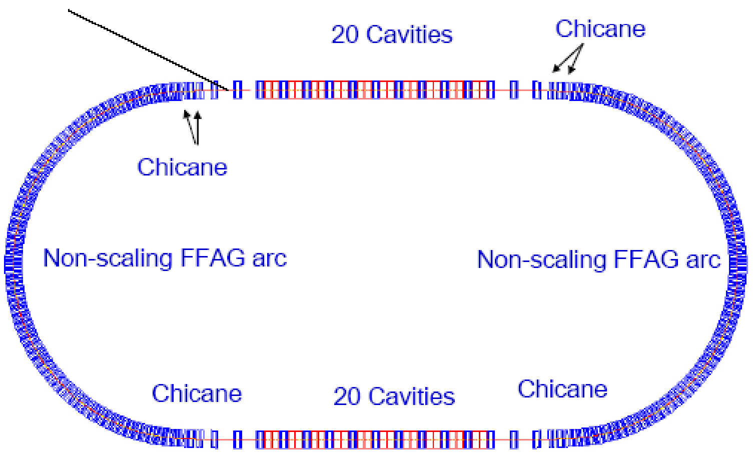
- there is a lot of uncertainty over performance of RF in strong B fields
- we want to use simulations to understand ongoing experimental measurements
- need to develop breakdown models
- one idea requires design of optimal magnetically-insulated cavities
- design of new cooling lattices needed for some proposals
  - using gas-filled cavities
  - using magnetically-insulated cavities



(magnetically-insulated cavity)

μ Acceleration

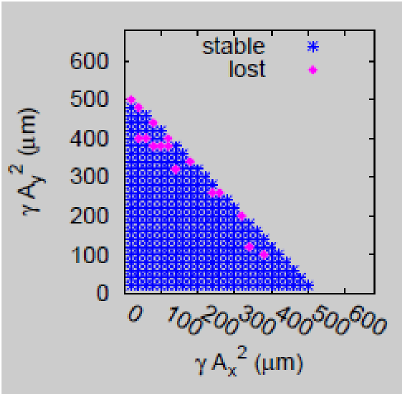
- need to accelerate μ bunches from 140 MeV to 750 GeV
  using e.g. {linac, RLA, FFAG, RCS}
- need complete lattice designs
- engineering studies of required magnets and RF
- study cost effectiveness of proposed schemes
- do single particle tracking
- study collective effects
  e.g., impedance driven
  parasitic collisions



(racetrack FFAG)

Collider ring

- goal: to provide high luminosity $\mu^+\mu^-$ collisions
- 3 designs are currently being studied
- ring designs are strongly coupled with detector design
- need to carry out basic lattice designs of IR & arc cells
- examine chromatic correction schemes
- design special matching sections
  e.g., injection, collimation, beam abort
- study dynamic aperture and coherent effects
- design RF systems and other needed hardware



(dynamic aperture)

End-to-end simulation

- design all missing transfer lines & matching sections
- pass actual beam distributions from one section to next
- make high statistics runs
- understand any differences between codes
- study sensitivity to physics models (front end)
  e.g., π production, scattering, straggling
- study sensitivity to hardware errors
  e.g., fields, gradients, RF phases
- examine μ polarization
- make dedicated space charge study of critical areas

Estimated effort needed for DFS (FTE)

	FY08	FY09	FY10	FY11	FY12	FY13
PD	0.3	1	4.5	5	7.5	3.8
T	1	1	3	4	0.5	0
FE	5.2	5.4	9.7	10.5	9.6	5
A	1	1	2.9	3.2	2.7	1.6
CR	0.4	0.4	2.8	6.1	6.6	2.6
Total	7.9	8.8	22.9	28.8	26.9	13

- these estimates draw on our experience from Study 1, Study 2, Study 2a and ISS
- this includes effort needed for end-to-end simulations, but not the cost estimate.

Deliverables

- DFS report on feasibility of building a muon collider
- Cost estimation

  DFS report will provide necessary technical basis
  for 1st rough cost estimate for a 1.5 TeV muon collider

  set up Work Breakdown Structure

  requires assistance of engineers

  most of the effort in 2013
- R&D list

  identify unresolved μμ issues that need further R&D

2008 MUTAC recommendations

1. need for coordinated effort on benchmarking of key processes and cross-checking codes
   - there is a Muon Inc-BNL SBIR proposal to do this
   - incorporated as task in the 5-year plan
2. parametric studies of various scenarios → optimal choice of subsystem design
   - typically done at some level for all good designs, done in detail for HCC
   - incorporated as task in the 5-year plan
3. do significant simulations to more accurately evaluate performance of chosen MC scheme
   - incorporated as major task for year 3 of 5-year plan
4. results from MERIT should be used as a test bed for benchmarking codes with planned experiments
   - active program trying to compare MERIT results with simulations
   - e.g. MHD code development, comparison with MARS
   - incorporated as task in the 5-year plan

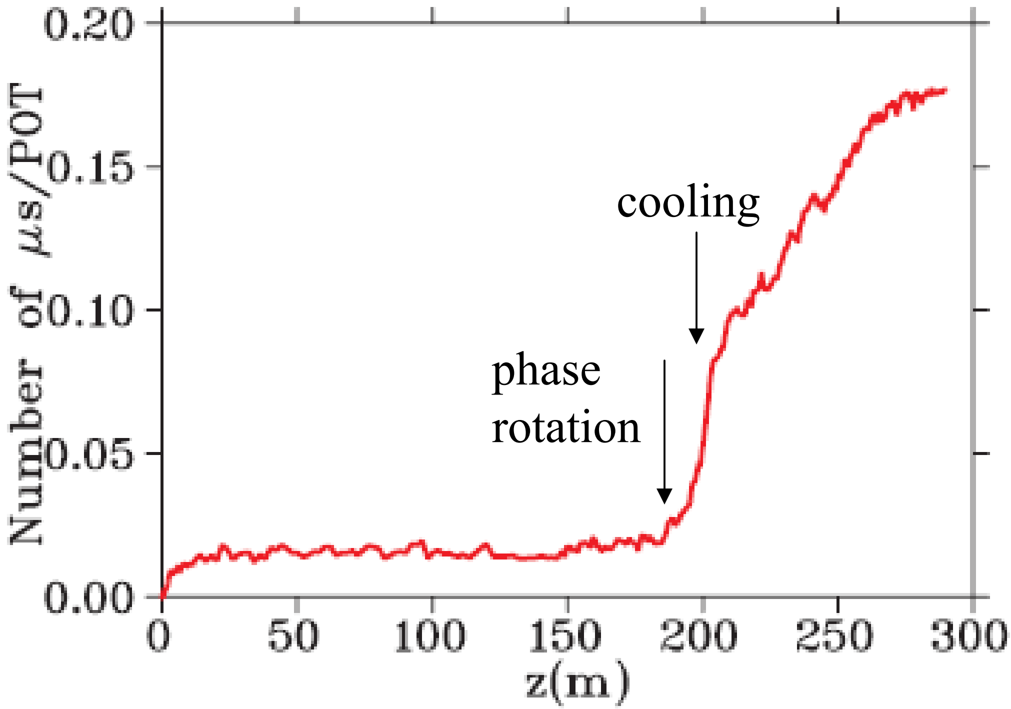
Summary

- have developed a 5 year plan for preparing a muon collider DFS
- outlined required tasks and estimated effort required
- will require a substantial increase in FTEs working in this area
- at end we will
  1) assesses feasibility of building a muon collider
  2) provide 1st defensible estimate of cost to build facility
  3) provide a list of key remaining R&D issues
- could provide HEP community with a powerful option for exploring the high energy frontier

Appendices

- cooling or scraping?
- realistic Guggenheim

Study 2a



cooling gives
x 1.7 more μ into
<u>same</u> acceptance

FIG. 15. (Color) The muons per incident proton on target into the accelerator normalized transverse acceptance of $A_T = 30$ mm rad and normalized longitudinal acceptance of $A_L = 150$ mm for a momentum cut $0.1 \leq p \leq 0.3$ GeV/c.

Study 2

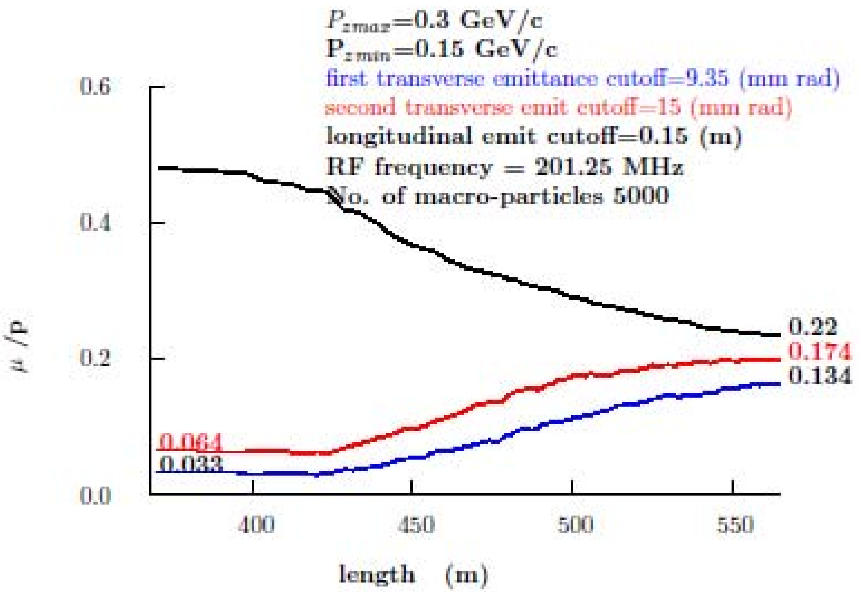


Figure 5.13: Particle transmission: number of muons per incident proton on target in the buncher and cooling sections. Top curve is overall transmission; lower two curves are for 150 mm longitudinal acceptance with two different transverse acceptance cuts: (middle) 15 mm·rad transverse acceptance; (bottom) 9.35 mm·rad transverse acceptance. This result was obtained with ICOOL.

cooling gives
x 3 more μ into
same acceptance

Study 2

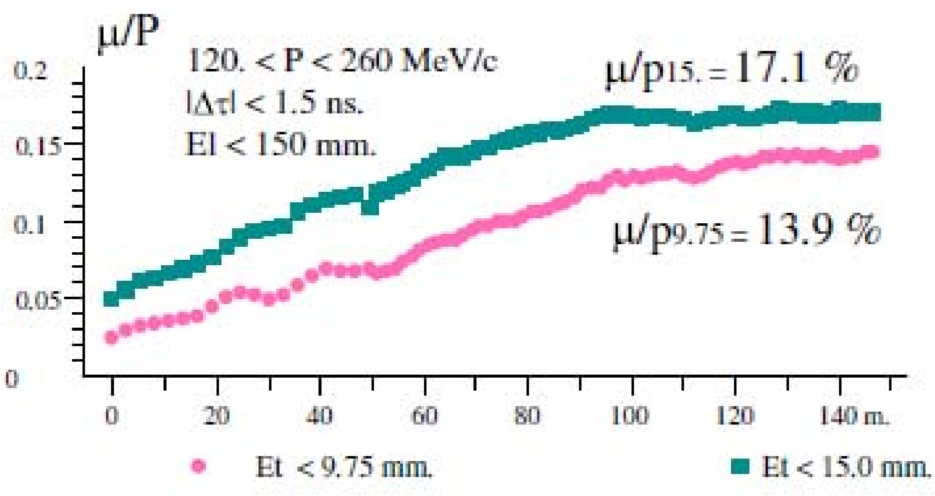
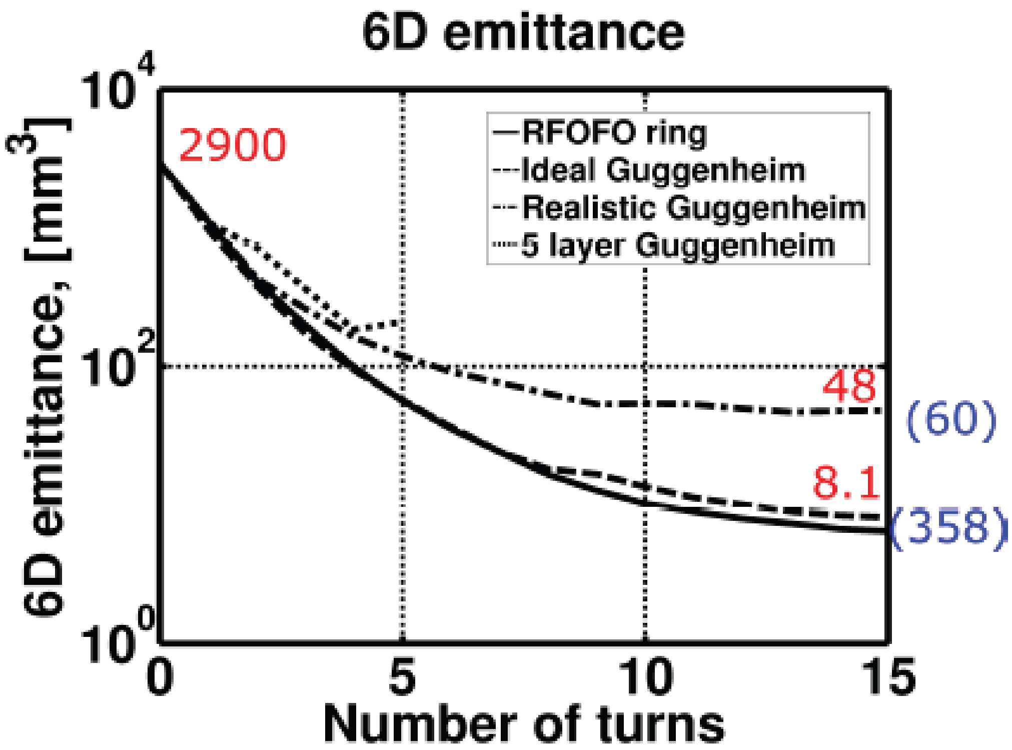


Figure 5.14: The muon-to-proton yield ratio for the two transverse emittance cuts, clearly showing that the channel cools, *i.e.*, the density in the center of the phase space region increases. Since the relevant yield μ/p_{15} no longer increases for $z \leq 110$ m, the channel length was set to 108 m. This is a Geant4 result.

MCTF

Realistic Guggenheim



- higher equilibrium emittance because of windows
- need to taper before 15 turns (HEMC 201 MHz uses 4 turns)