# Muon Collider Accelerator Simulations: 5-year plan

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# Outline

1. Review of submitted simulation plan
2. Proposed updates to plan
3. Help from others
4. MuTAC comments

# 1. Goals & timeline

Years 1-3

- study proposed alternatives for accelerator subsystems
- simulate subsystem performance using defensible parameters
- cross-check most promising subsystems with ≥2 codes
- specify baseline accelerator design

Year 4

- optimize baseline, minimize work on alternatives
- simulate representative matching sections
- carry out representative tolerance studies
- freeze accelerator design

Year 5

- complete design of all remaining matching sections
- do end-to-end simulation of accelerator systems
- do detailed tolerance studies
- do necessary simulations for the MC DFS report

# 1. Activity *1.2* FTE requirements

| scenario | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|
| R7 | 8 | 17 | 24 | 32 | 34 |
| R10D | 9 | 23 | 29 | 27 | 13 |
| RF09a | 9 | 19 | 27 | 29 | 15 |

discuss later

*1.2* includes accelerator facility simulations & engineering design
total effort required ~100 FTE-years
needed effort estimated from Task Lists and/or similar design studies
new FTEs include ~2 engineers and a mix of scientists & postdocs

# 1. PROTON DRIVER TASKS

- assume independent baseline Project X study
- our effort addresses upgrades to meet μ collider specs
  - proton rings to get required μ bunch structure
  - power upgrade to ~4 MW
  - study operating the linac in cw mode
- develop conceptual designs
- evaluate instabilities
- do tracking studies with realistic errors

# 1. TARGET TASKS

- simulations
  - benchmark using MERIT results
  - refine MHD modeling of beam/jet/field interactions
  - optimize nozzle design
  - study Hg jet splash issues for Hg collection pool
- facility design is part of NF RDR activity

# 1. FRONT END TASKS

- study & optimize the major FE subsystems
  - decay, bunching & phase rotation
  - precooling
  - 6D cooling
  - final cooling
- design other needed auxiliary subsystems
  - charge separation & recombination
  - bunch merging
- do FE end-to-end simulations
- try to understand breakdown in RF cavities
  - design suitable normal conducting cavities

# 1. MUON ACCELERATOR TASKS

- need complete design for low energy acceleration (120 MeV to ~25 GeV)
  - study suitability of NF accelerator design
- need complete designs for high energy acceleration (~25 to 750 GeV)
  - recirculating linear accelerator (RLA)
  - fast ramping synchrotron
  - other alternatives (FFAGs, reinject μ in PD linac)
- do single particle tracking simulations thru entire chain
- study collective effects
  - wake fields
  - beam loading

# 1. Collider ring tasks

- need basic lattice designs
  - IR design with appropriate constraints on quad gradients & radii
  - chromatic correction schemes (special regions vs. local)
  - arc cells (FODO vs. achromats)
- need complete design of matching regions
- design chromaticity & nonlinear detuning correction circuits
- simulate dynamic aperture
- simulate secondary particle fluxes
  - iterate IR designs with Physics & Detector Group
- design RF system
- design BPM & closed orbit correction circuits
- detailed studies of coherent effects

# 1. DFS report tasks

- end-to-end simulations of complete facility
- high statistics simulations of system performance
- estimate of uncertainty on performance
- estimate of component tolerances
- simulations needed for DFS report

# 1. DELIVERABLES

- optimized designs for all important subsystems of a high energy MC
- end-to-end simulations of machine performance
  - estimates of uncertainties in performance & machine parameters
- technical basis for a 1st MC cost estimate
  - detailed specifications for important machine components
- list of unresolved R&D issues
- DFS chapters on machine design and performance

# 1. LEVEL OF INVOLVEMENT

- we assume that all current effort on machine design (~8 FTE) will continue thru year 5
  - labs: FNAL, BNL, ANL, LBNL, ORNL, JLAB
  - universities: UC Riverside, Mississippi, Princeton, UCLA
  - SBIR: Muons Inc, Particle Beam Lasers, Tech X
- the major new cost in this plan is for incremental effort to complete the DFS by year 5
  - additional people from our present institutions
  - collaborating with new institutions
  - new cold hires

# 2. Proposed FTE by subject

| | year 1 | year 2 | year 3 | year 4 | year 5 | total |
|---|---|---|---|---|---|---|
| PD | 2 | 5 | 5.8 | 7 | 3 | 22.8 |
| Target | 1 | 2 | 1.7 | 0.2 | 0.1 | 5.0 |
| FE | 4.4 | 5.1 | 11.2 | 10.5 | 3.5 | 34.7 |
| μ Acc | 1.4 | 3.6 | 3.6 | 2.1 | 0.7 | 11.4 |
| CR | 0.7 | 2.9 | 5.1 | 7.1 | 2.6 | 18.4 |
| DFS | 0 | 0 | 0 | 1.8 | 5 | 6.8 |
| total | 9.5 | 18.6 | 27.4 | 28.7 | 14.9 | 99.1 |

Scenario RF09a

reduce year 1->2 bump by ~4 FTEs
keep FE effort ~constant first 2 years to give MuCool time to get RF results
gas-filled cavities in beam, vacuum RF gradients in magnetic field
put early emphasis on PD, μ acceleration, and CR: easiest to utilize existing skills
DFS = end-to-end simulation and DFS report preparation

# 2. Proposed FTE by institution

| | year 1 | year 2 | year 3 | year 4 | year 5 | total |
|---|---|---|---|---|---|---|
| FNAL | 3.6 | 8 | 10 | 12 | 7.4 | 41 |
| BNL | 3.5 | 4 | 4.5 | 5 | 4.1 | 21.1 |
| LBNL | 1.9 | 1.9 | 3.4 | 4.1 | 3.4 | 14.7 |
| Others | 0.5 | 4.7 | 9.5 | 7.6 | 0 | 22.3 |
| total | 9.5 | 18.6 | 27.4 | 28.7 | 14.9 | 99.1 |

Scenario RF09a

use lab projections for available manpower
note lab differences from R10D
make up difference with work by others
assign all proton driver work to FNAL

# 3. Proposed FTE from others

| | year 1 | year 2 | year 3 | year 4 | year 5 | total |
|---|---|---|---|---|---|---|
| PD | 0 | 0 | 0 | 0 | 0 | 0 |
| Target | 0.5 | 1.5 | 1.5 | 0.1 | 0 | 3.6 |
| FE | 0 | 1.4 | 6.7 | 6.1 | 0 | 14.2 |
| μ Acc | 0 | 1.6 | 0.4 | 0 | 0 | 2 |
| CR | 0 | 0.2 | 0.9 | 1.1 | 0 | 2.2 |
| DFS | 0 | 0 | 0 | 0.3 | 0 | 0.3 |
| total | 0.5 | 4.7 | 9.5 | 7.6 | 0 | 22.3 |

Scenario RF09a

# 4. MuTAC comments

**Executive comments**

It is not clear to the committee that the required expertise can be made available on the appropriate time scale.

The committee remains both impressed with the flow of new ideas for muon colliders and concerned that given limited resources, options must be reduced.

**Recommendations** The five year plan should include:

1. Milestones (i.e. figure of merit for gradient/B-field, B-field for cooling channel magnets, B-field for downstream cooling solenoids, etc.) and target values for each milestone that when achieved define success,
2. Mechanism for down selecting among technology choices,
3. Decision on a baseline design to be developed for the muon collider feasibility study should be made as early as possible. The committee is concerned that the three years allowed may be inadequate to complete a defensible study.

# 4. MuTAC comments

**Acceleration comments**

A presentation was made discussing the use of a synchrotron system which uses an 8 GeV recirculating linac for its acceleration system. This is an extremely challenging approach, and will require much further study and understanding. As the specific details that will be outlined in the Five-Year Plan need to be formalized in the very near future, well-understood acceleration processes will need to be used in the write-up, and on-going investigations will need to have lower priority over the upcoming months.

**Recommendations**

4. A master "parameters list" should be developed in order to help keep track of the design status for the 5-year plan. This will also be of use for future committees and new collaborators. A form of "change control" should be implemented to keep track of changes and their impact upon other accelerator systems.
5. A scenario for the final stage of acceleration should be chosen soon and future work should concentrate on its development. A fair amount of effort will be required for a feasible design to emerge.

# 4. MuTAC comments

**Resources comments**

It is not clear from the 5 year plan that a suitable prioritization has been performed across all technical solutions being investigated. The collaboration management needs to be selective in directing resources as appropriate. The type of questions to be addressed includes:

1) Where are the "Other" resources coming from?

2) What is being done now to facilitate the rapid staffing increases, in the event that DOE approves the plan?

3) What down-selection criteria for the RF and cooling channel are acceptable in terms of gradient and B-field? These criteria should be identified now, so that immediate resource re-direction can focus on appropriate solutions.

**Recommendations**

6. The 5 year plan needs to be augmented with details showing how the step function increase in FTEs from the "Other" category is to be managed by the collaboration..

# 4. MuTAC comments

**Simulations comments**

While there is obviously a very strong collaboration between the various laboratories and university groups, as well as industrial partners (in particular, Muons Inc.), the Committee worries about the ability to find the 30+ FTE's required to carry out this part of the mission over the scheduled time period.

**Recommendations**

7. As the collaboration's efforts are geared toward increased RF gradients, possible new cooling channel options, etc., a design/simulation of a muon collider using "today's" realistic and obtainable parameters should be performed as a snapshot of what is doable at this time. This will be useful for future reference and will help dictate directions for further work.