Long-Term Muon Collider Vision

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Fermilab

Outline

- Where are we now
  - ILC situation has changed and that affects everything
  - Fermilab Steering group work
  - P5 presentations
  - CLIC as competitor
- Where we need to go
  - Muon Collider Feasibility Study by 2013
  - R&D beyond the MCFS
- Way to proceed

FNAL Steering Group (2007)

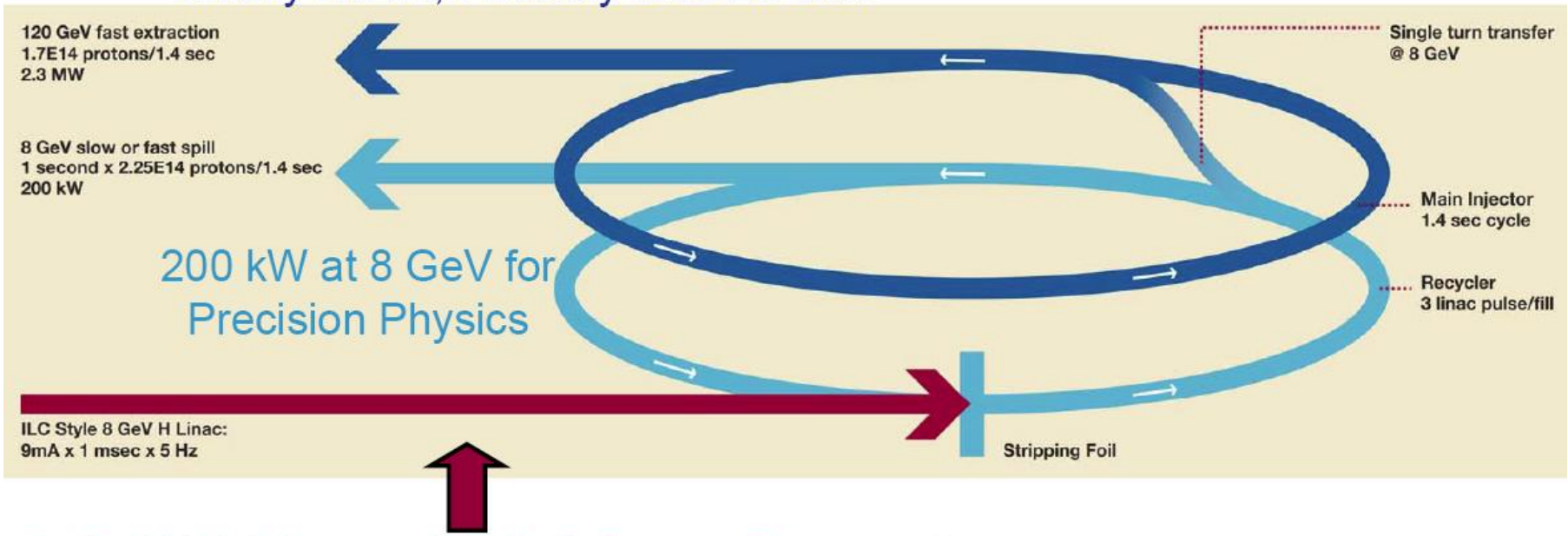
Charge: *"…to develop a strategic roadmap for the evolution of the accelerator-based program in the US in order to provide discovery opportunities over the next two decades should the ILC construction be delayed beyond its technically limited schedule."*

Fermilab and national particle and accelerator physics community

Eugene Beier	U. Penn
Joel Butler	Fermilab
Sally Dawson	BNL
Helen Edwards	Fermilab
Thomas Himel	SLAC
Steve Holmes	Fermilab
Young-Kee Kim (chair)	Fermilab / U.Chicago
Andrew Lankford	UC Irvine
David McGinnis	Fermilab
Sergei Nagaitsev	Fermilab
Tor Raubenheimer	SLAC
Vladimir Shiltsev	Fermilab
Maury Tigner	Cornell
Hendrick Weerts	ANL

SG Proposal: Project X

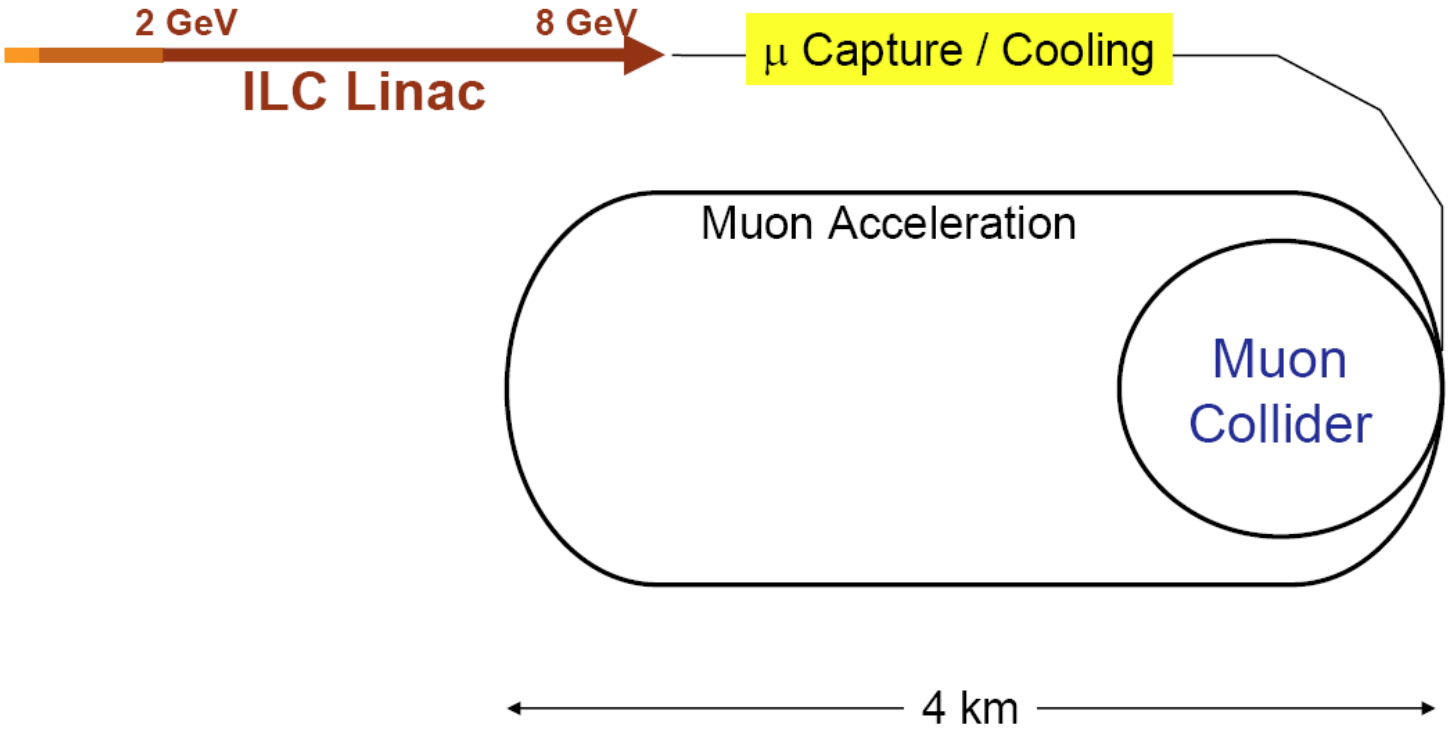
~2.3 MW at 120 GeV for Neutrino Science
Initially NOvA, Possibly DUSEL later



8 GeV H^- Linac with ILC Beam Parameters
(9mA x 1msec x 5Hz)

Project X as …

First Stage of Future World Facilities



Excerpts from the Steering Group Report

An Accelerator-Based Particle Physics Roadmap for Fermilab

- In all scenarios,
  - starting now, give R&D support to Project X. Emphasize
    - expediting R&D and industrialization of ILC cavities and cryomodules
    - overall design of Project X
  - increase R&D for future accelerator options concentrating on neutrino factory and muon collider.

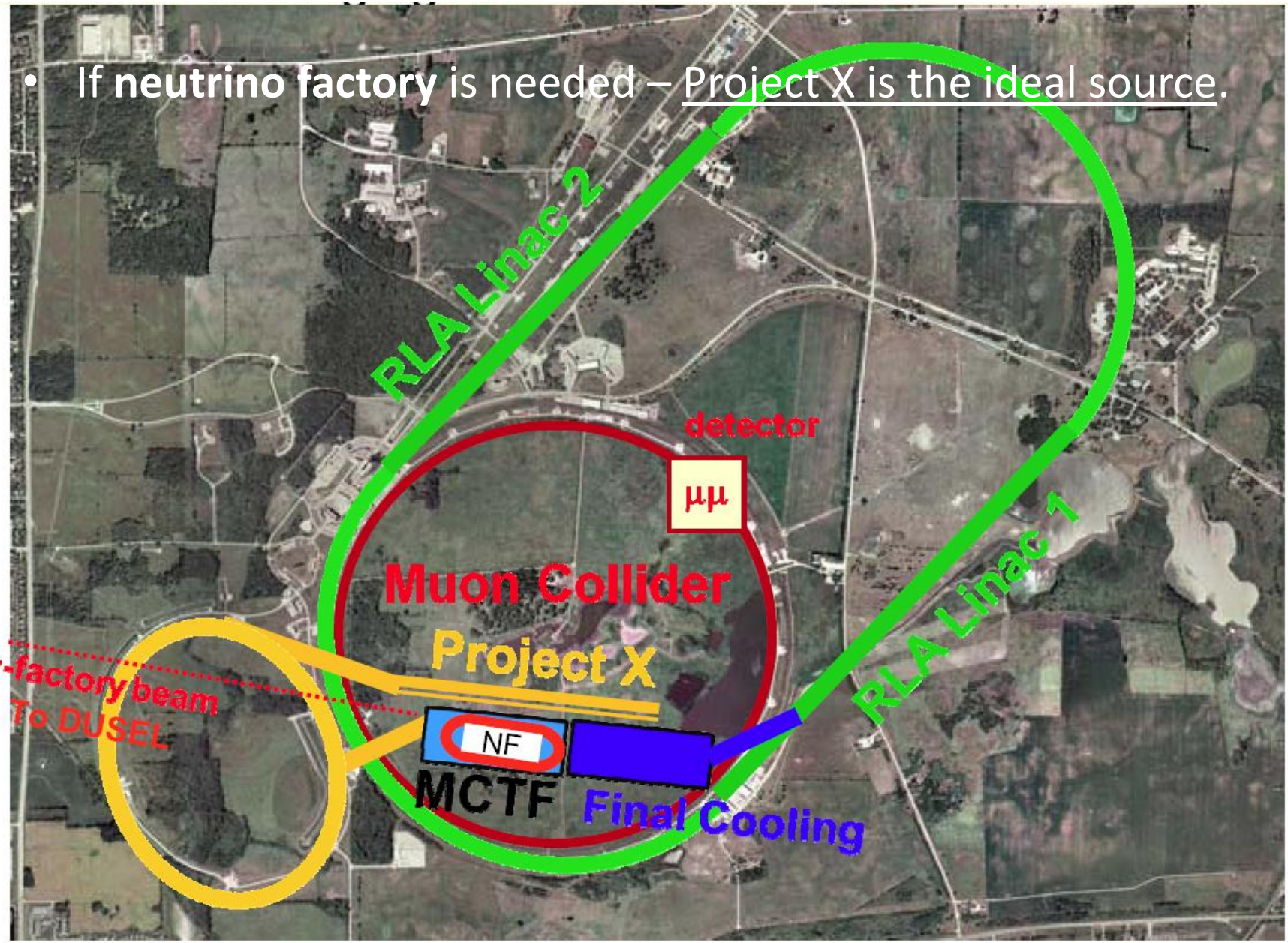
- *Schedule and Cost: significant evaluation of cooling and other feasibility items might be carried out in approximately **five to seven years** given support for a technically limited schedule. A rough comparison with the U.S. ILC development intensity prior to the ITRP decision would indicate the need for a minimum of **$20M annually and 100 FTE** of appropriate skills.*

FY08 omnibus bill → HEPAP P5 subpanel

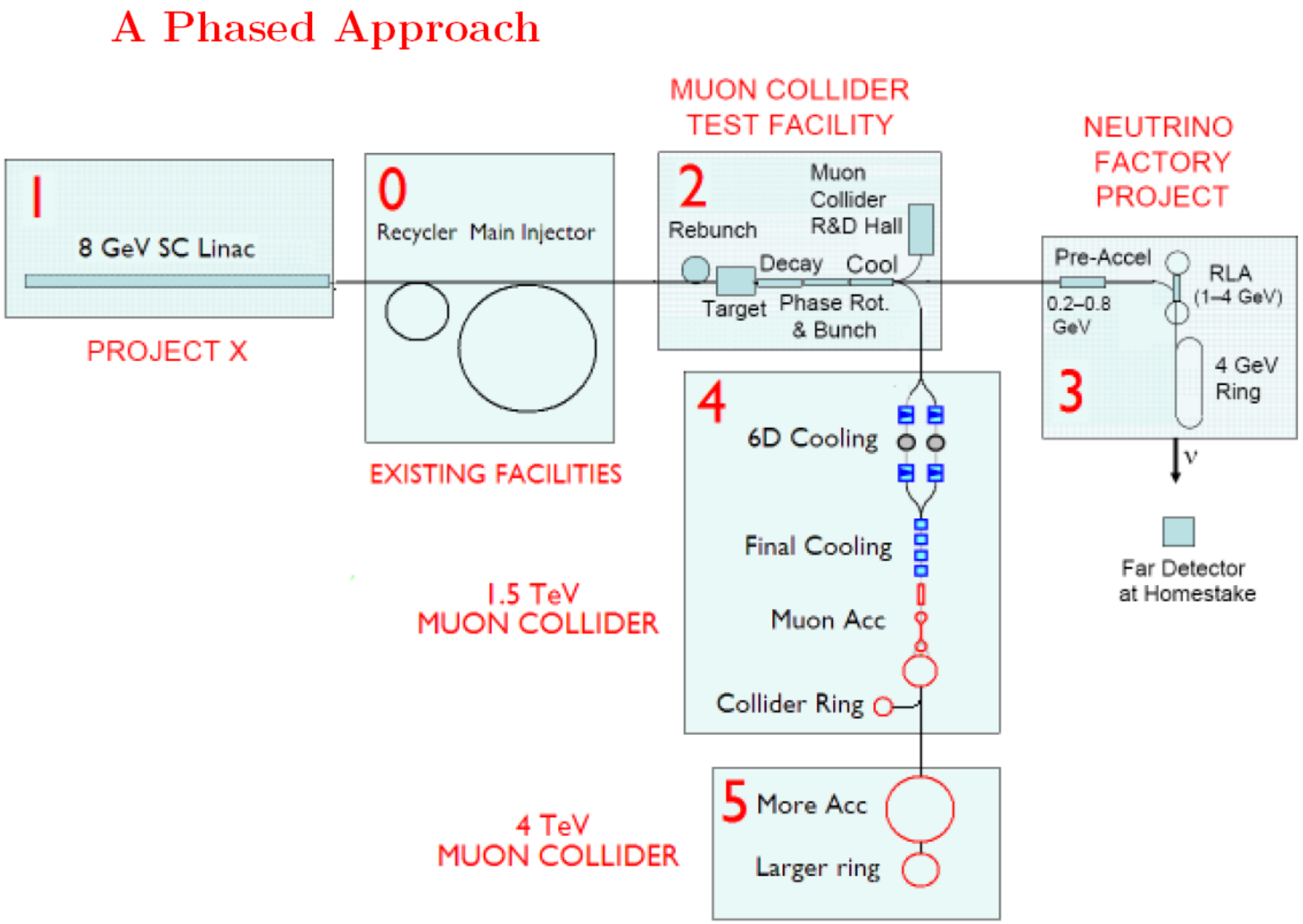
- **Charge to P5:** provide recommendations (to HEPAP and D.Kovar) on the priorities for an optimized high energy physics program over the next 10 years (FY09-FY18), under ***four*** funding scenarios:
  - Constant effort at the FY 2008 funding level (i.e.; funding in FY 2009 at the level provided by the FY 2008 Omnibus Bill inflated by 3.5% and thereafter inflated by 3.5% per year in the out-years)
  - Constant effort at the FY 2007 funding level (i.e.; funding in FY 2009 at the level provided in FY 2007 inflated 3.5% per year over two years and thereafter inflated by a 3.5% in the out-years).
  - Doubling of funding over a ten year period starting in FY 2007 (i.e.; funding in FY 2009 at the level provided in FY 2007 inflated 6.5.% per year over two years and thereafter inflated by 6.5% per year in the out-years)
  - Additional funding above the previous level, in priority order, associated with specific activities needed to mount a leadership program that addresses the scientific opportunities identified in the EPP2010 report.
- **3 meetings (FNAL, SLAC, BNL)**

P.Oddone (2008, P5): MC @ FNAL

- If **neutrino factory** is needed – Project X is the ideal source.

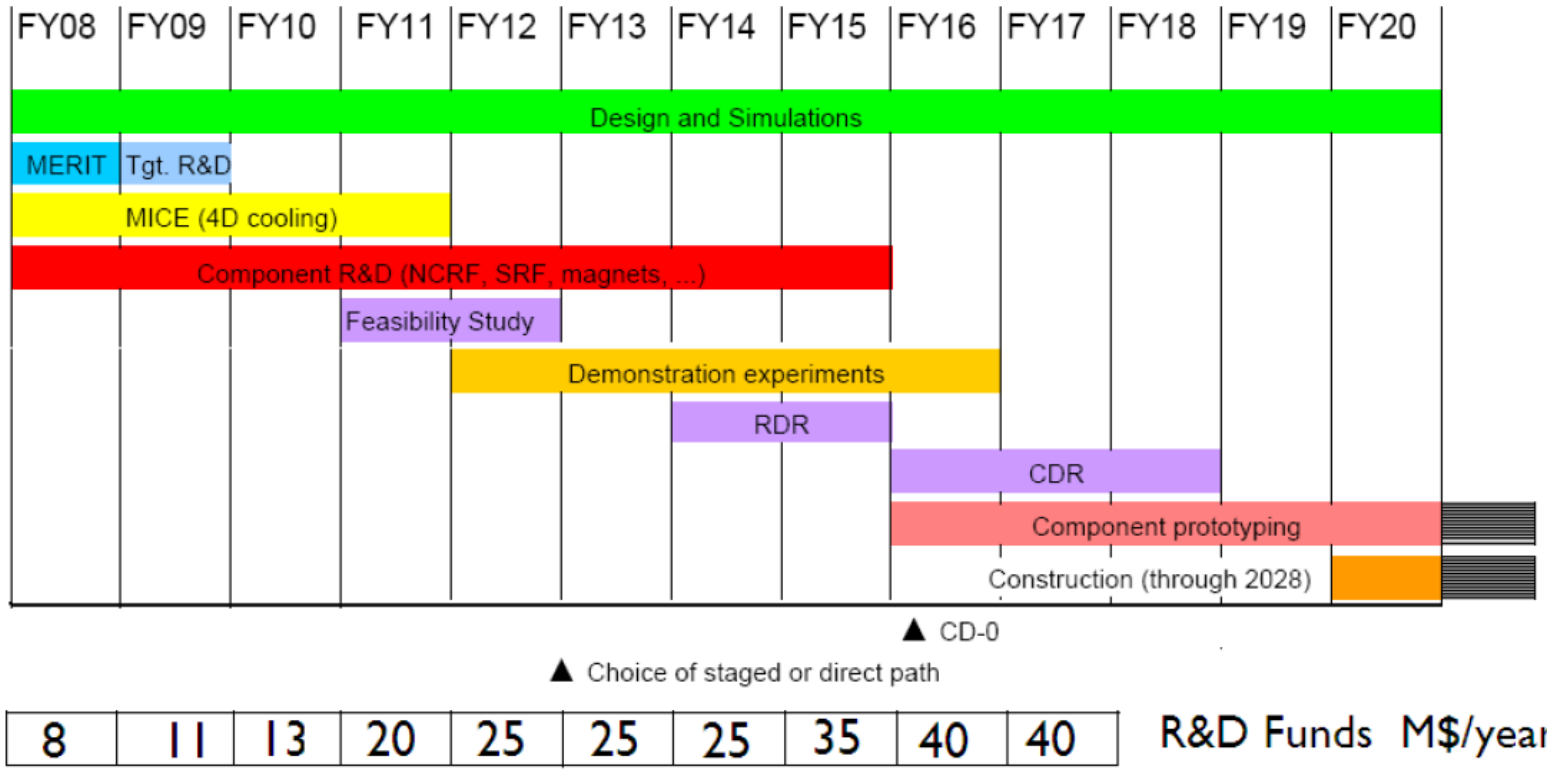


R.Palmer (P5 @ BNL): MC



R.Palmer @ P5 mtg at BNL

Time Line and Funding Needs



- Funding request includes that for Neutrino Factory R&D
- Funding increase ($\approx 3\times$) needed if Muon Collider is to be credible option by 2012

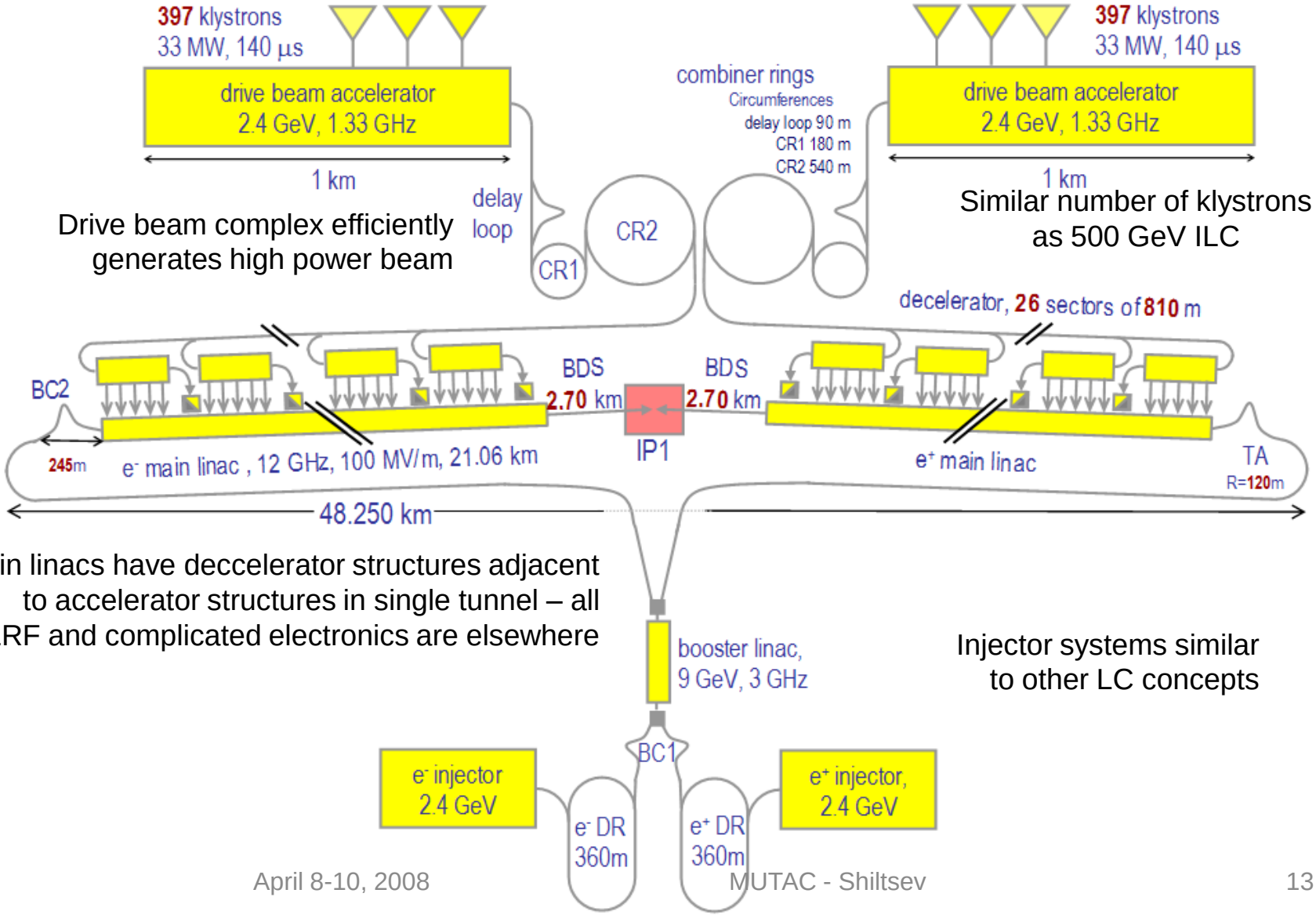
R.Palmer: conclusions

- A broad and significant R&D program is already underway
- With an expanded program, we expect to be able to complete a "Feasibility Study" by 2012, that would
  - Establish the feasibility of a Muon Collider
  - Greatly narrow the technology options
  - Include, as near as possible, an end-end simulation, and
  - Give a first rough cost estimates for two energies
- A Muon Collider could then be part of a phased program:
  - Project X
  - Muon Collider R&D area
  - Neutrino Factory
  - 1.5 TeV collider
  - 4 TEV collider
- But for a Muon Collider to be a realistic option in 2012, increased funding for R&D is needed now

What's magic about 2012-13?

- **First LHC results expected to point to the energy scale of the next lepton collider**
- **ILC EDR will be delivered, cost and fate will be decisively determined**
- **CLIC CDR will be delivered, cost and feasibility understood**

CLIC Schematic (Parameters for 3 TeV, 48.3km)



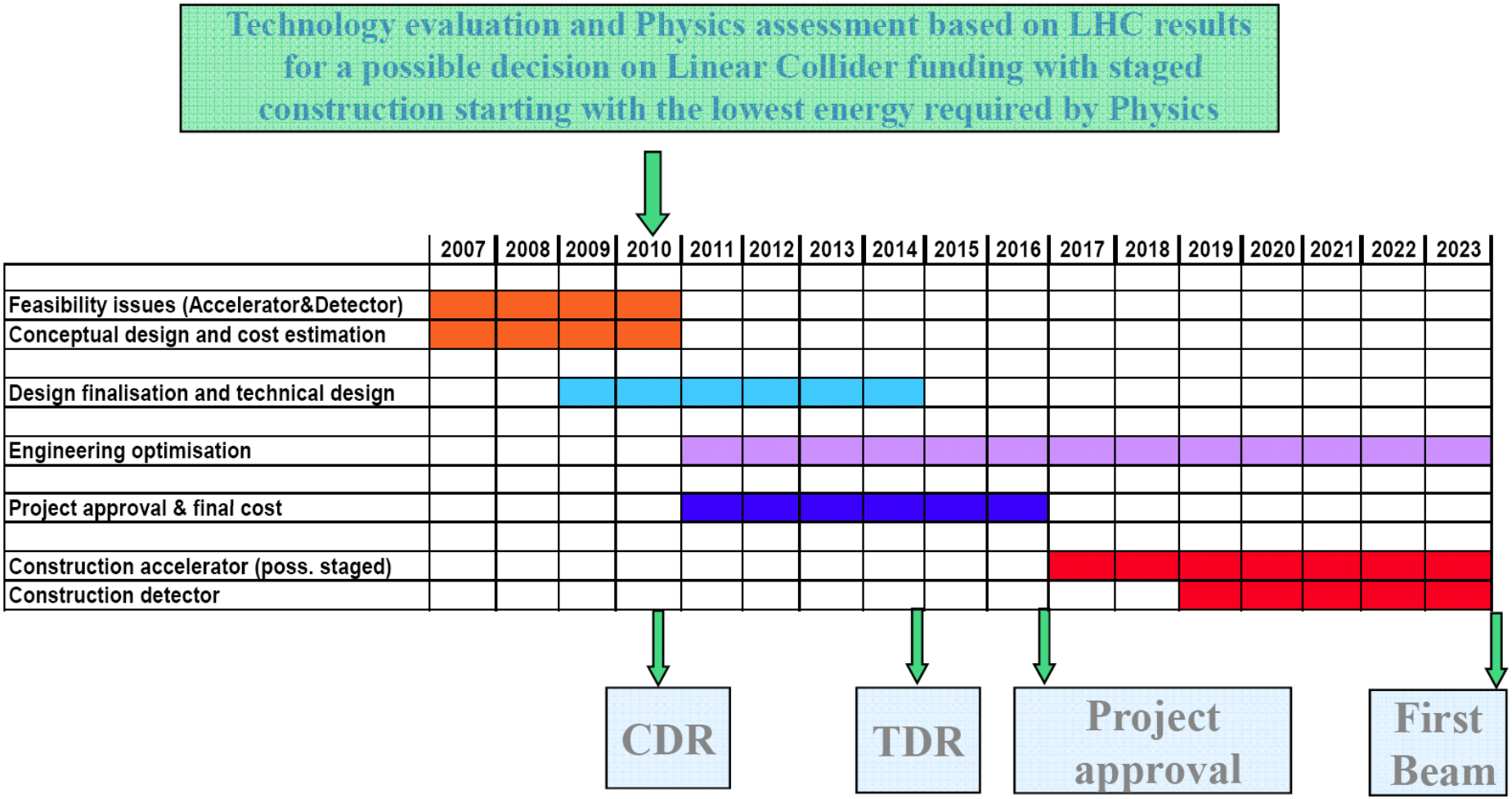
Drive beam complex efficiently generates high power beam

Similar number of klystrons as 500 GeV ILC

Main linacs have deccelerator structures adjacent to accelerator structures in single tunnel – all LLRF and complicated electronics are elsewhere

Injector systems similar to other LC concepts

CLIC Timescale
(J.-P.Delahaye to CERN SPC, 2007)



M.Tigner (P5 BNL): Accel R&D

- This AARD program needs to be aligned with the overall HEP program and its vision for the "medium term" and "longer term" adopted by DOE/NSF following on the P5/HEPAP recommendations to come shortly
  - this will require refocusing, taking great care not to cut off possibilities for the future inadvertently
  - implementation recommendations might best come from a special group able to interpret physics program needs and vision in terms of accelerator R&D elements, priorities and costs

- His *personal* opinion on "medium term": CLIC – *"nay"*, plasma – *"nay"*, Muon Collider – *"yes, should give a try"*

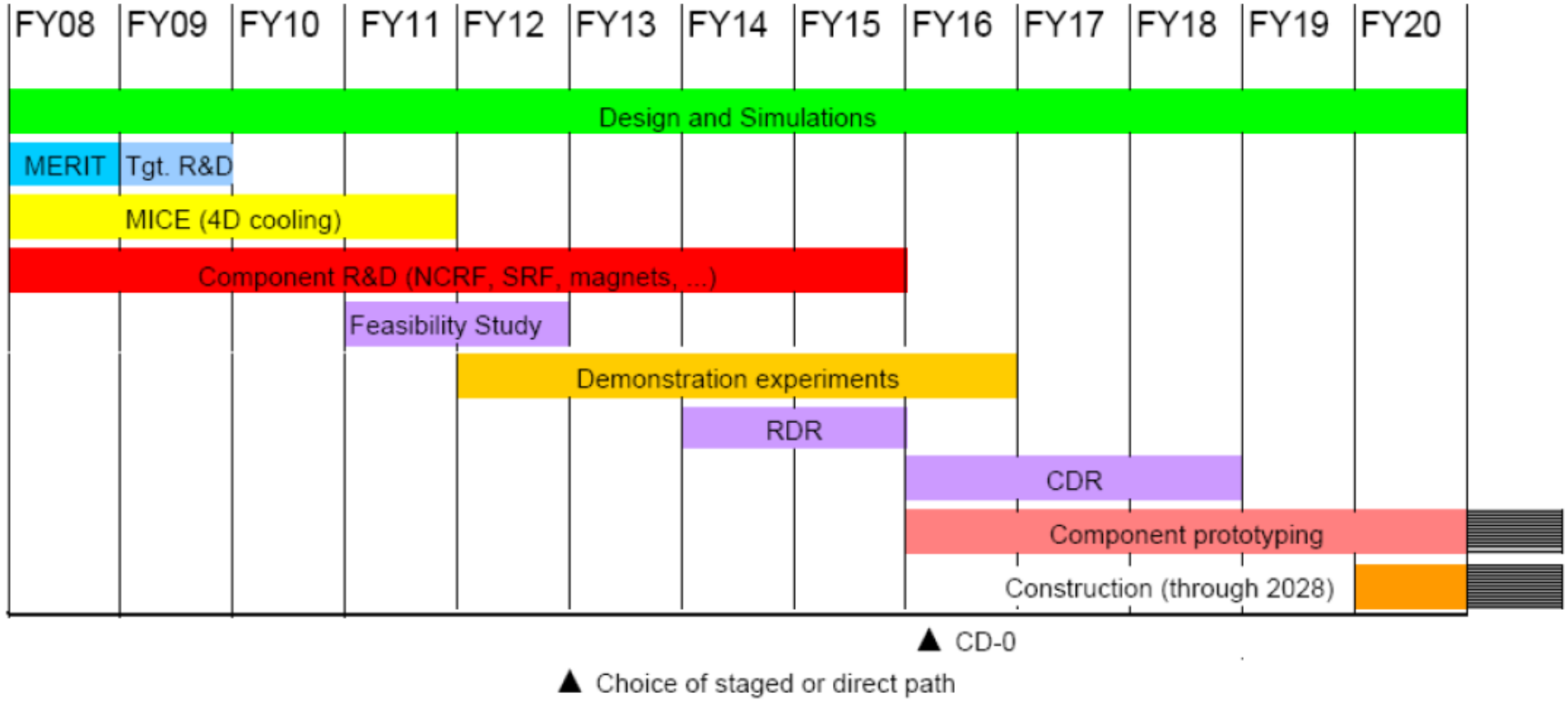
Schedule of Events

- **P5 retreats and discussions in Mar-Apr**
- **DoE OHEP budget retreat – end of Mar**
- **MUTAC – (now) early April**
- **P5 recommendations – mid-April**
- **DoE OHEP Accelerator Science reviews ("across the field") – ~~Summer~~ Fall'08**

Where we will/want to be this Fall

- **We believe that P5 will come out with recommendation to HEPAP with notion of MC/NF as possible future facility which needs further R&D**
  - ➢ **linked to Project-X**
- **DoE Review of Accelerator Science in the Fall**
  - ✓ **With the goal of nation-wide assessment of AARD activities**
  - ✓ **Exercise to set mid-term and long-term R&D priorities**
- **OHEP will put Muon Collider / Neutrino Factory as priority "mid-term" R&D program**
  - ✓ **the goals and timeline to be formulated soon afterward**
  - ✓ **Lab directors will be asked to organize implementation**

Time Line and Funding Needs



8	11	13	20	25	25	25	35	40	40

R&D Funds M$/year

- Funding request includes that for Neutrino Factory R&D
- Funding increase ($\approx 3\times$) needed if Muon Collider is to be credible option by 2012

Timeline

- ***Now to 2013:***
  - ✓ ***R&D program to gain credibility***
  - ✓ ***Decision on "NF-first" or "MC-direct" or "none"***
- ***By 2016-18 ("MC-direct" path, PrX constr'n):***
  - ✓ ***More R&D and demonstration experiments***
  - ✓ ***RDR work and CD-0 by 2016-18***
- ***3-5 years after CD-0 :***
  - ✓ ***CDR and component prototyping***
  - ✓ ***build Muon Collider Test Facility next to Project-X***
  - ✓ ***Get thru CD-1, -2 and -3 by early 2020's***

Next 5 (Critical) Years

- **What is needed to be considered as a feasible lepton collider candidate in 2013:**
  1. **Coherent MC design at the level of ZDR**
  1. **MICE experiment (successful) results**
  1. **Key RF questions answered**
  2. **Prospects of HTS magnets understood**
  3. **Muon acceleration techniques explored**
- **The way: *Muon Collider R&D Program***
  - ✓ **To carry out exp. R&D and prepare MC ZDR**

Elements of the Program (1)

- **Muon Collider Feasibility Study :**
  - Main deliverable: ZDR
- **Key elements of the Study:**
  - Determine which of three main cooling schemes is most viable/attractive : HCC, Guggenheim, FOFO-snake
  - Develop ring design (consistent with cooling parameters)
  - Complete engineering study, fabrication and bench test for at least one viable 6D cooling channel technology
  - End-to-end simulations (incl complete cooling scheme)
  - Narrow down MC parameters (for one or two energies)
  - Formulate physics objectives, outline detector design
  - Preliminary cost estimates

Muon Collider : as of now

Max. Center-of-mass energy	1.5-4	TeV
Peak Luminosity	(1-7)x10^{34}	1/cm^2s
Total # muons/beam	1-8	10^{12}
Repetition rate	6-65	Hz
Beam emittance	2-25	pi um
Proton Driver beam power	2-8	MW
Total AC Power Consumption	60-170	MW

Elements of the Program (2)

- **Demonstration of transverse cooling in MICE :**
  - Main deliverable: find the effect and confirm simulations
- **Observations and comments:**
  - This is an international activity, with US playing big role
  - NFMCC manages US-MICE
  - Experiment schedule is slipping – in big part due to limited funding
  - Getting results by 2012 is already challenging
  - Extra M&S and corresponding Labor support could insure success by the deadline

Elements of the Program (3)

- **Address main questions concerning MC RF :**
  - RF in muon cooling section and in collection section
  - Main deliverable: experimental data needed to decide on optimal configuration
- **Key studies:**
  - 201MHz and 805MHz vacuum RF gradient vs B-field, direction
  - Ways to increase gradient (magnetic insulation, Be-win)
  - High Pressure H2 RF: gradient vs pressure , vs magnetic field, with ionizing beam; "test can"→ 805MHz cavity→201MHz cavity
  - Achievable gradients in low-frequency SC RF

Elements of the Program (4&5)

- **Understand prospects of high-field HTS magnets :**
  - Is HTS viable for final stages of cooling?
  - Main deliverable: reasonably large solenoid (3-5 cm dia, 10-20 cm long) with interestingly high filed (30T+)
  - Several steps needed: material R&D, cable, technology, inserts, magnets
- **Explore feasibility of main acceleration methods:**
  - Main acceleration is a big (largest) cost and power driver
  - Possibilities: SC RF (1.3GHz), pulsed synchrotron, FFAG
  - Deliverables: at least engineering study, ideally – experimental tests (e.g. pass 1e12 e- thru NML SC RF cryomodule; or key elements of pulsed magnets, etc)

Needed Resources (est.) (M$, loaded)

MC only – w/o NF

	FY09	FY10	FY11	FY12	FY13
MCFS-I	1.6	2.6	4.0	5.2	6.7
MICE	2.3	3.6	1.6	1.0	0.7
RF studies	1.0	1.1	1.5	1.7	1.9
HTS R&D	0.8	0.9	1.7	2.0	2.4
Acceleration	0.3	0.5	0.9	1.1	1.7
TOTAL	6.0	8.7	9.7	10.8	13.4
M&S	2.3	2.9	3.1	3.8	4.4
SWF	3.7	5.8	6.6	7.0	9

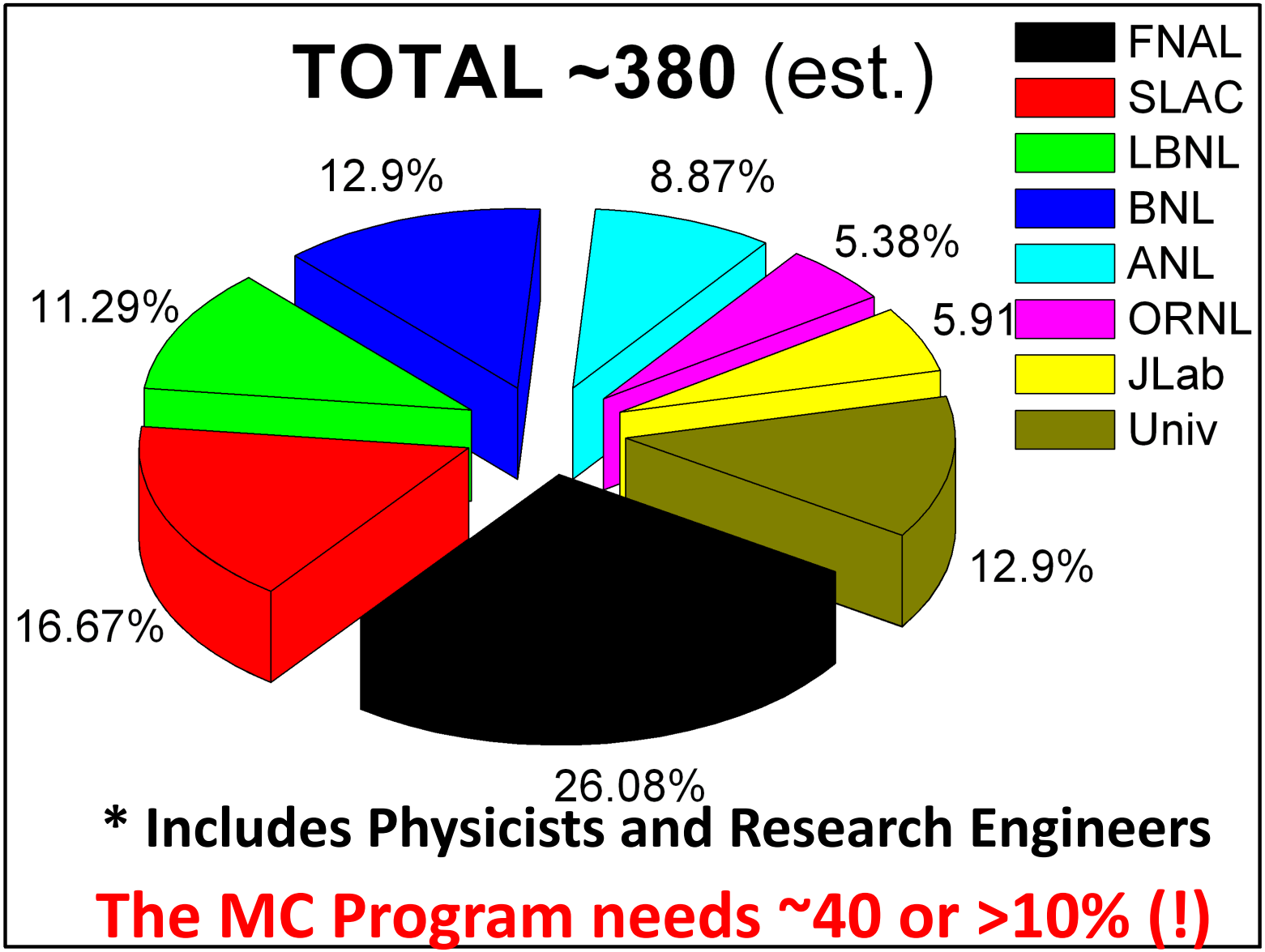
Compare with Current Budget
(M$, fully loaded for both MC and NF)

	FY07 Spent	FY08 Allocated
NFMCC	3.6	3.6
M&S	1.4	1.4
SWF	2.2	2.2
MCTF	4.4	4.1
M&S	1.1	0.9
SWF	3.3	3.2
TOTAL	**8.0**	**7.8**

Components of Success

- **Funding: need to be on DoE OHEP priority list (community guidance)**
- **People: need backing from from Nat'l Labs (FNAL, BNL, LBNL, ANL, JLab, SLAC, Cornell) , Universities and Int'l component (MICE)**
- **FNAL ownership is very desirable**

Accelerator Experts in US



*** Includes Physicists and Research Engineers**

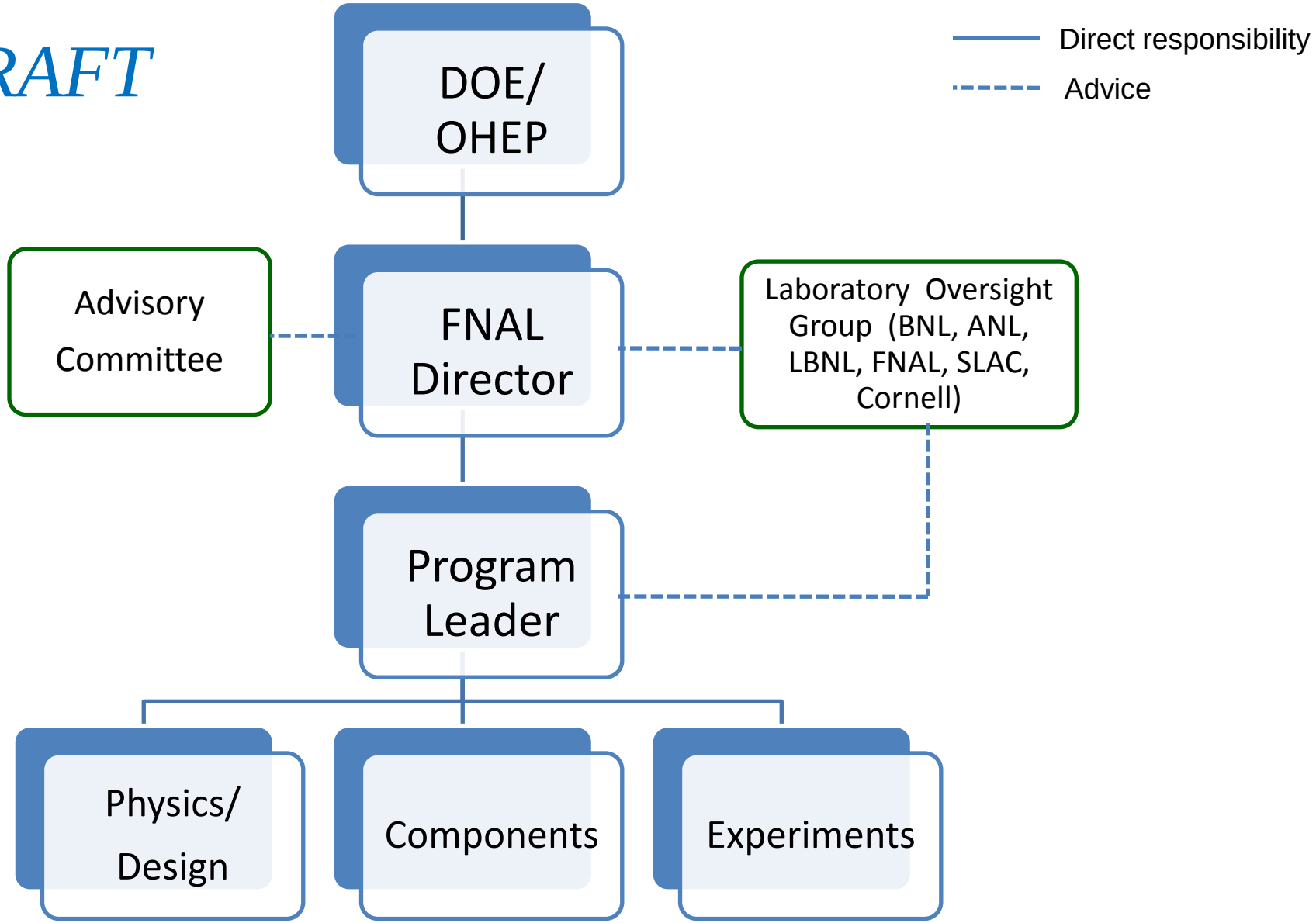
The MC Program needs ~40 or >10% (!)

Accelerator Field Priorities (now-2013)

1. Operation:
   - Tevatron, RHIC, light sources, SNS, beam facilities
2. Construction and pre-constr. R&D
   - LCLS, ERL, Project-X, SNS upgrade, LHC upgrade, etc
3. Design:
   - ILC, Project-X, ERL, RIA, LHC upgrade, etc
4. Accelerator R&D:
   - Near term: ILC, SC RF, Project-X, LARP
   - Mid- and long-term : High-gradient RF collaboration, ***NFMCC/MCTF***, ATF, L'OASIS/BELLA, AWA, FACET, FNPL, UMER, etc

Muon Accelerator Research Program

DRAFT



Summary

- **To be a credible lepton collider option in 2013, a focused Muon Collider Research Program needs to be initiated and executed with major deliverables:**
  - **Muon Collider ZDR and preliminary cost estimates**
  - **MICE experiment results**
  - **Study results on RF, HTS and main acceleration**
- **Significant increase of support is needed (more than 2-fold to ~14MS/yr in 2013)**
  - **Subject of P5 recommendation and DoE approval**
  - **DoE Review in Fall'08 is critical, we(MCCC) must be prepared**
- **Evolution of existing organizations will be needed**
  - **to get access to resources in the National Labs**
  - **Do it in the OHEP-recommended fashion**
  - **Set focused priorities, timeline, deliverables**

back-up slides

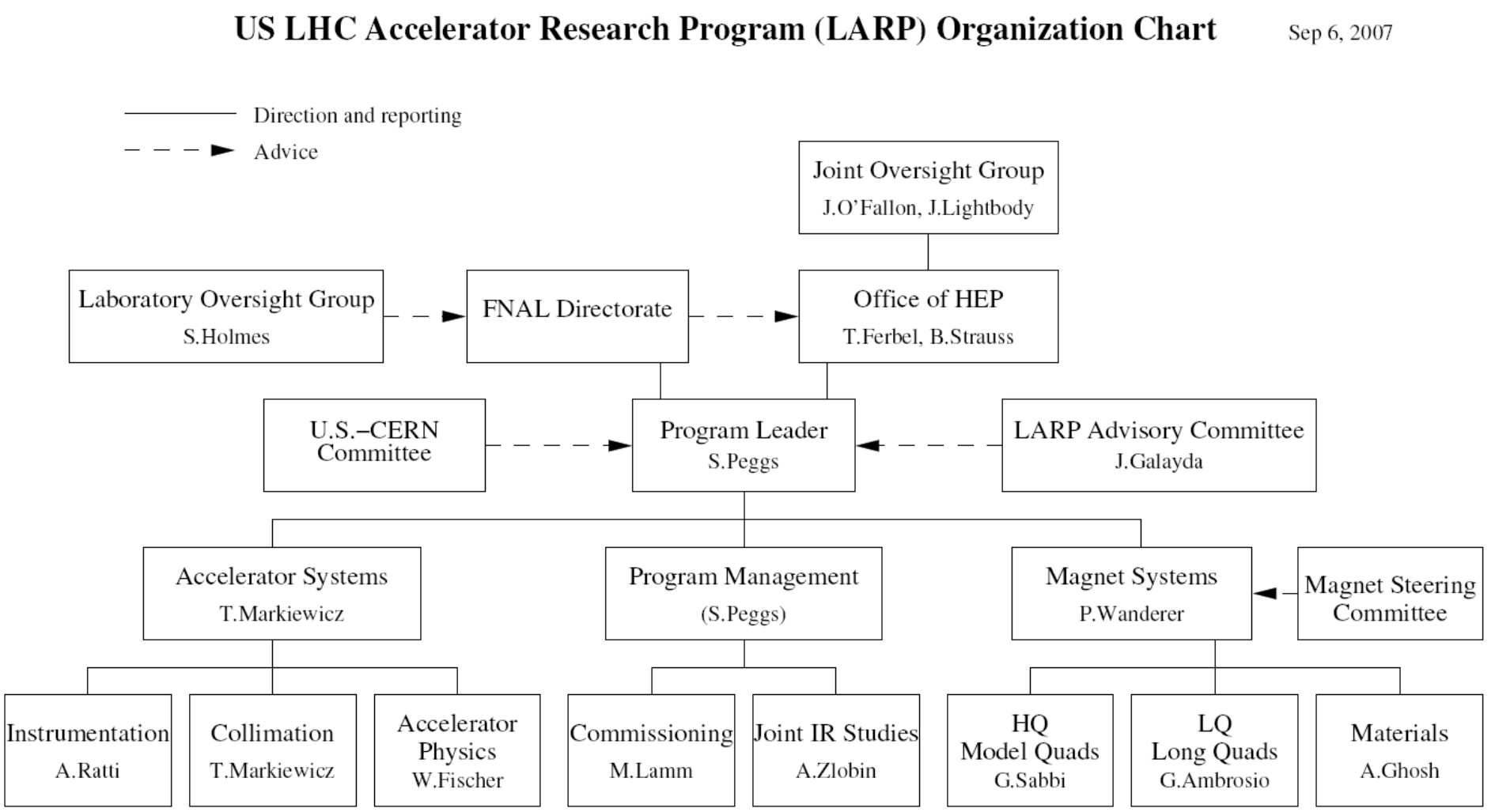
Current Situation:

- Neutrino Factory and Muon Collider Collaboration:
  - Co-spokesmen: H.Kirk (BNL) and A.Bross (FNAL)
  - Focus on:
    1. MICE experiment in UK
    2. MERIT experiment at CERN
    3. Component development and testing
- Muon Collider Task Force
  - Co-leaders: S.Geer and V.Shiltsev
  - Focus on:
    1. Collider Design and simulations
    2. Deep cooling 6D experiment/component development
    3. Final cooling schemes
    4. Main acceleration system (RLA)
- MCCC (coordination committee) since 2007:
  - Kirk, Bross, Geer, Shiltsev+Zisman (NFMCC Project Leader)

Resources Needed (M$, loaded)

	FY09		FY10		FY11		FY12		FY13	
	M&S	SWF	M&S	SWF	M&S	SWF	M&S	SWF	M&S	SWF
MCFS-I	0.4	1.2	0.6	2.0	1.2	2.8	2.0	3.2	2.3	4.4
MICE	1.3	1.0	1.6	2.0	0.4	1.2	0.2	0.8	0.1	0.6
RF studies	0.2	0.8	0.3	0.8	0.5	1.0	0.5	1.2	0.5	1.4
HTS R&D	0.3	0.5	0.3	0.6	0.7	1.0	0.8	1.2	1.0	1.4
Acceleration	0.1	0.2	0.1	0.4	0.3	0.6	0.3	0.8	0.5	1.2
Total M&S	2.3		2.9		3.1		3.8		4.4	
Total SWF		3.7		5.8		6.6		7		9
TOTAL	6.0		8.7		9.7		10.8		13.4	

LARP Org Structure



MARP Goals (draft)

- **Advance International Cooperation in High Energy Accelerators**
- **Advance High Energy Physics**

  Help bring the US HEP to energy frontier machine (Muon Collider) or intensity frontier (Neutrino Factory)

  Develop design of Neutrino Factory and Muon Collider

  Develop accelerator components and setup facilities to gain deeper knowledge of accelerator science and technology
- **Advance U.S. Accelerator Science and Technology**

  Keep skills sharp by establishing vigorous accelerator R&D program

  Conduct forefront accelerator research and development

  Prepare U.S. scientists to design next generation colliders

  Develop technologies necessary for next generation colliders

MARP=Muon Accelerator Research Program: Mission (draft)

- The US Muon Accelerator Research Program enables U.S. accelerator specialists to take an active and important role in the research, development and design of muon accelerators for High Energy Physics research. In particular, MARP will support U.S. institutions in activities in accelerator science, modeling, component R&D, accelerator instrumentation and diagnostics, and establishment of experimental facilities for Neutrino Factory and Muon Collider. Furthermore, the work we do will be at the technological frontier and will thereby improve the capabilities of the U.S. accelerator community in accelerator science and technology to more effectively operate our domestic accelerators and to position the U.S. to be able to lead in the development of the next generation of high-energy colliders.