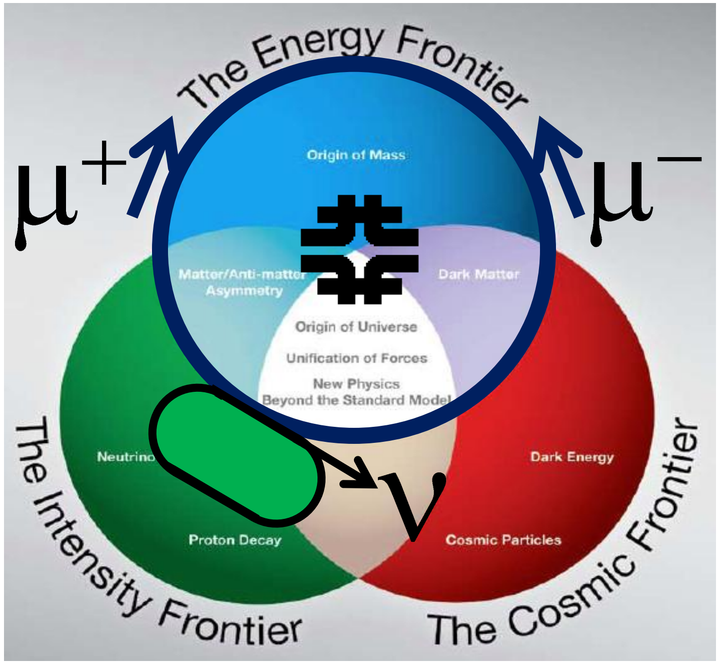


Muon Accelerator Program - MAP

MUON COLLIDER R&D

Steve Geer

Accelerator Physics Center

Fermi National Accelerator Laboratory

HEPAP Meeting

Washington D.C., March 18, 2011

MUON COLLIDER MOTIVATION

- If we can build a muon collider, it is an attractive multi-TeV lepton collider option because muons don't radiate as readily as electrons (m_μ / m_e ~ 207):

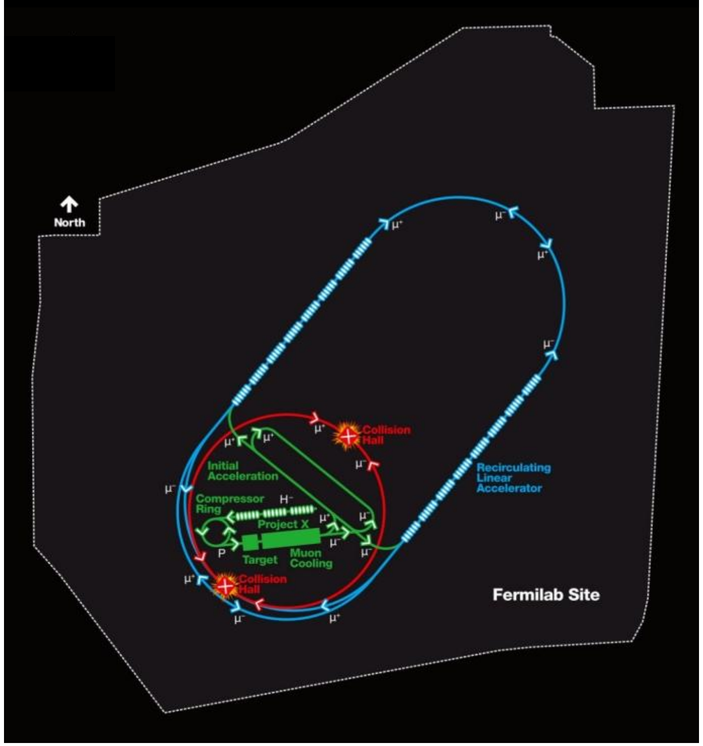
COST

- COMPACT
  Fits on laboratory site
- MULTI-PASS ACCELERATION
  Cost Effective operation & construction
- MULTIPASS COLLISIONS IN A RING (~1000 turns)
  Relaxed emittance requirements & hence relaxed tolerances

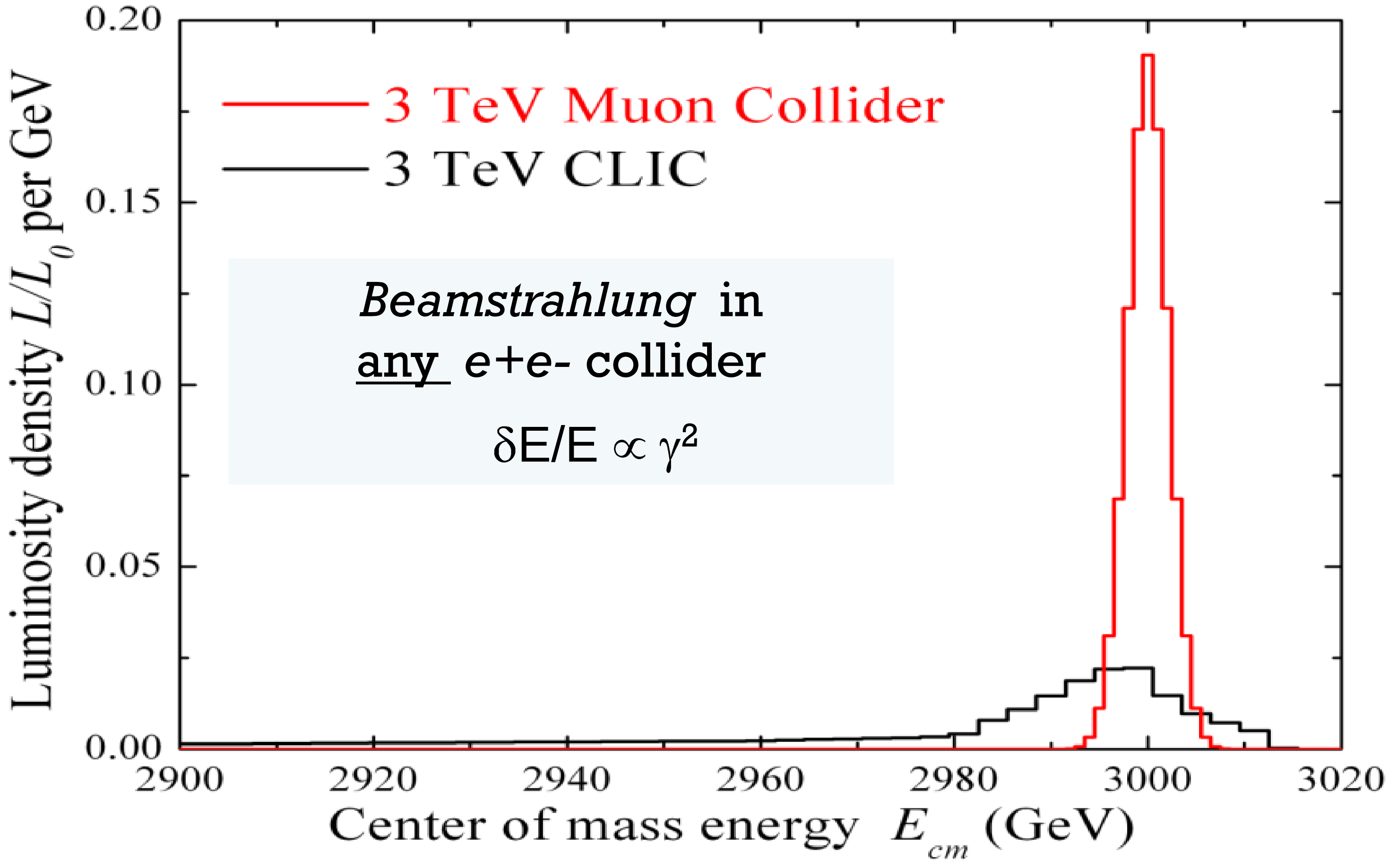
PHYSICS

- NARROW ENERGY SPREAD
  Precision scans, kinematic constraints
- TWO DETECTORS (2 IPs)
- ΔT_{bunch} ~ 10 μs … (e.g. 4 TeV collider)
  Lots of time for readout
  Backgrounds don't pile up
- $(m_\mu/m_e)^2$ = ~40000
  Enhanced s-channel rates for Higgs-like particles

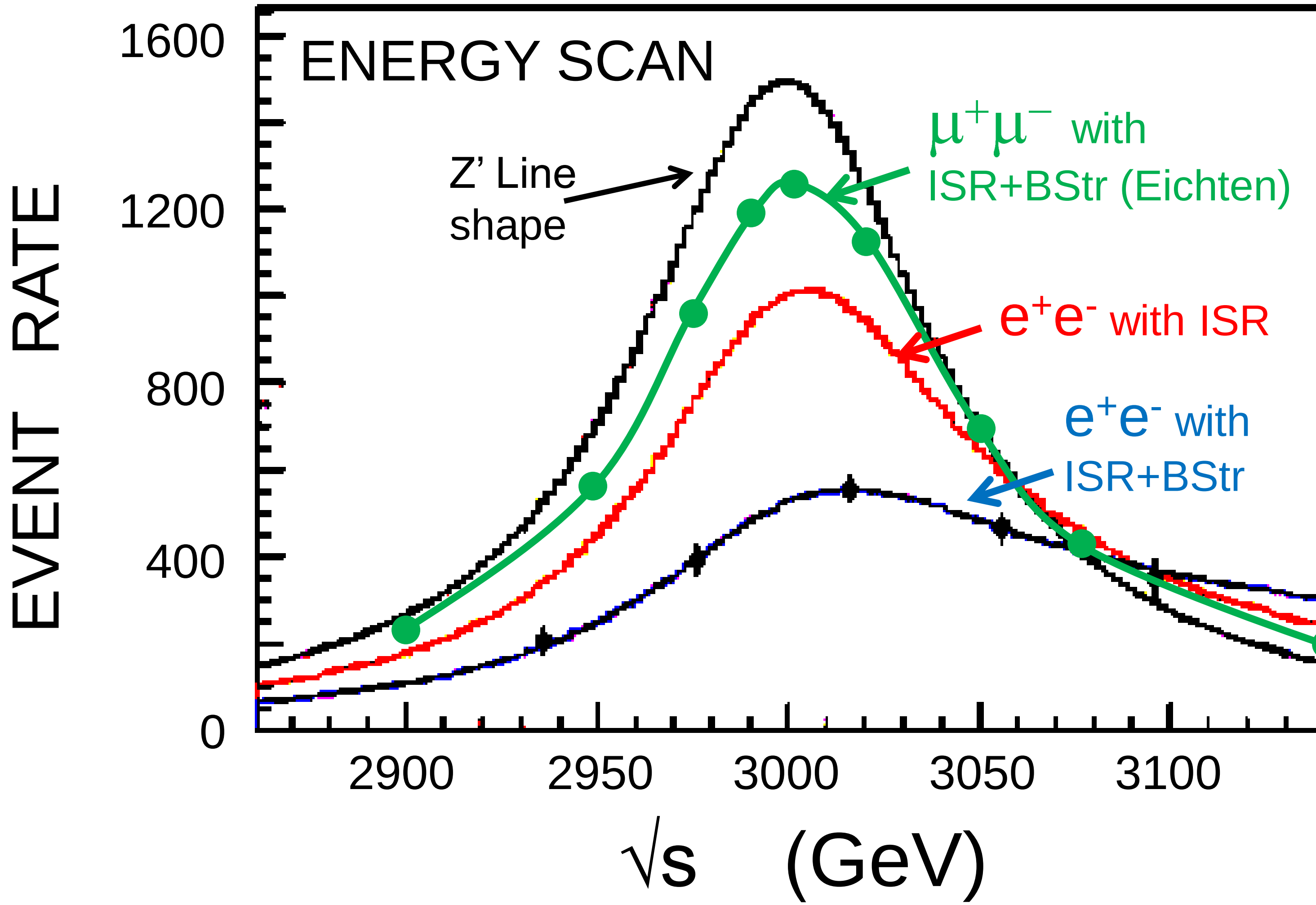
A 4 TeV Muon Collider would fit on the Fermilab Site



ENERGY SPREAD



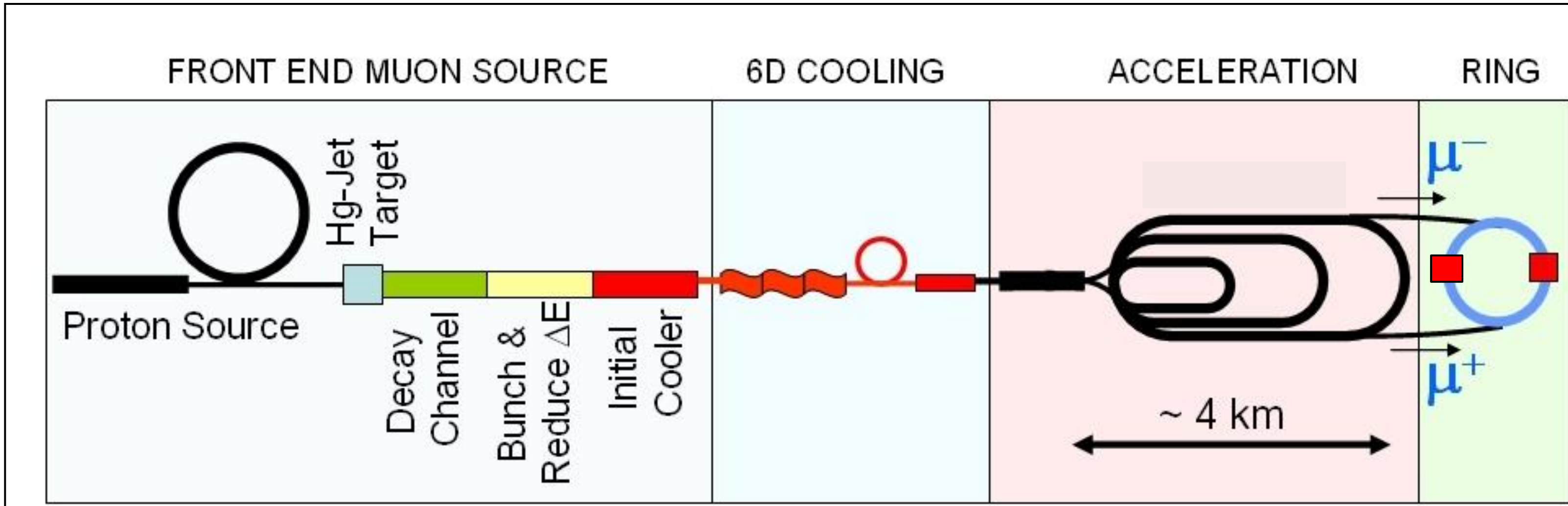
$l^+l^- \rightarrow Z' \rightarrow \mu^+\mu^-$



CHALLENGES

- Muons are produced as tertiary particles. To make enough of them we must start with a MW scale proton source & target facility.
- Muons decay $\Rightarrow$ everything must be done fast and we must deal with the decay electrons (& neutrinos for CM energies above ~3 TeV).
- Muons are born within a large 6D phase-space. For a MC we must cool them by O(10^6) before they decay $\Rightarrow$ New cooling technique (ionization cooling) must be demonstrated, and it requires components with demanding performance (NCRF in magnetic channel, high field solenoids.)
- After cooling, beams still have relatively large emittance.

MUON COLLIDER SCHEMATIC



Proton source:
Example:
upgraded
PROJECT X
(4 MW, 2±1 ns
long bunches)

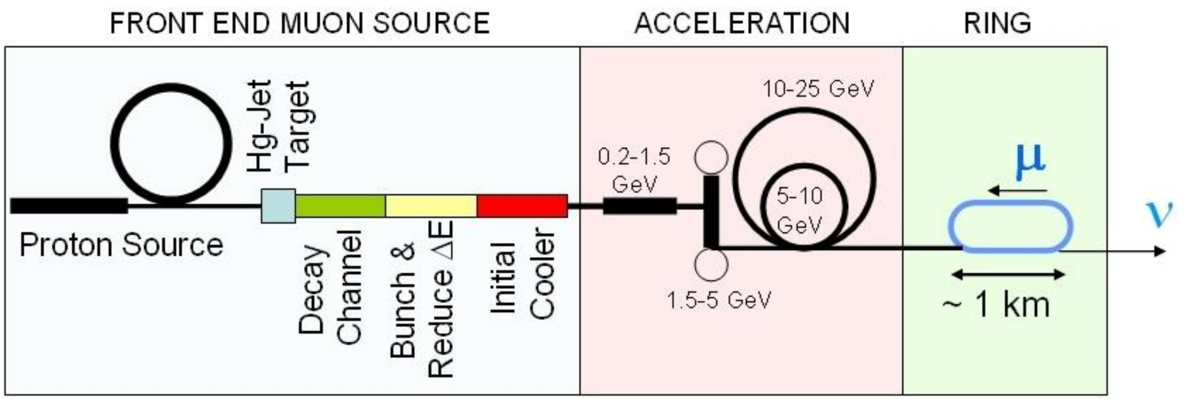
10^{21} muons per year that fit within the acceptance of an accelerator:

$\varepsilon_{\perp N}$=6000 μm

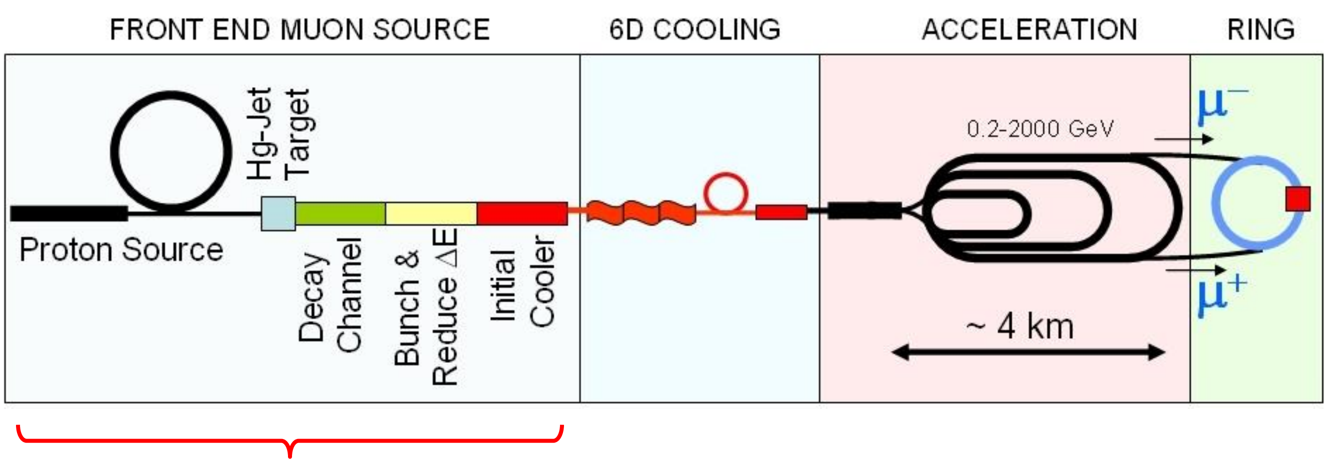
$\varepsilon_{//N}$=25 mm

$\sqrt{s}$ = 3 TeV
Circumference = 4.5km
$\mathcal{L} = 3\times10^{34}$ cm^{-2}s^{-1}
μ/bunch = $2\mathrm{x}10^{12}$
σ(p)/p = 0.1%
$\varepsilon_{\perp N}$ = 25 μm, $\varepsilon_{//N}$=70 mm
β* = 5mm
Rep Rate = 12Hz

Muon Collider cf. Neutrino Factory



NEUTRINO FACTORY



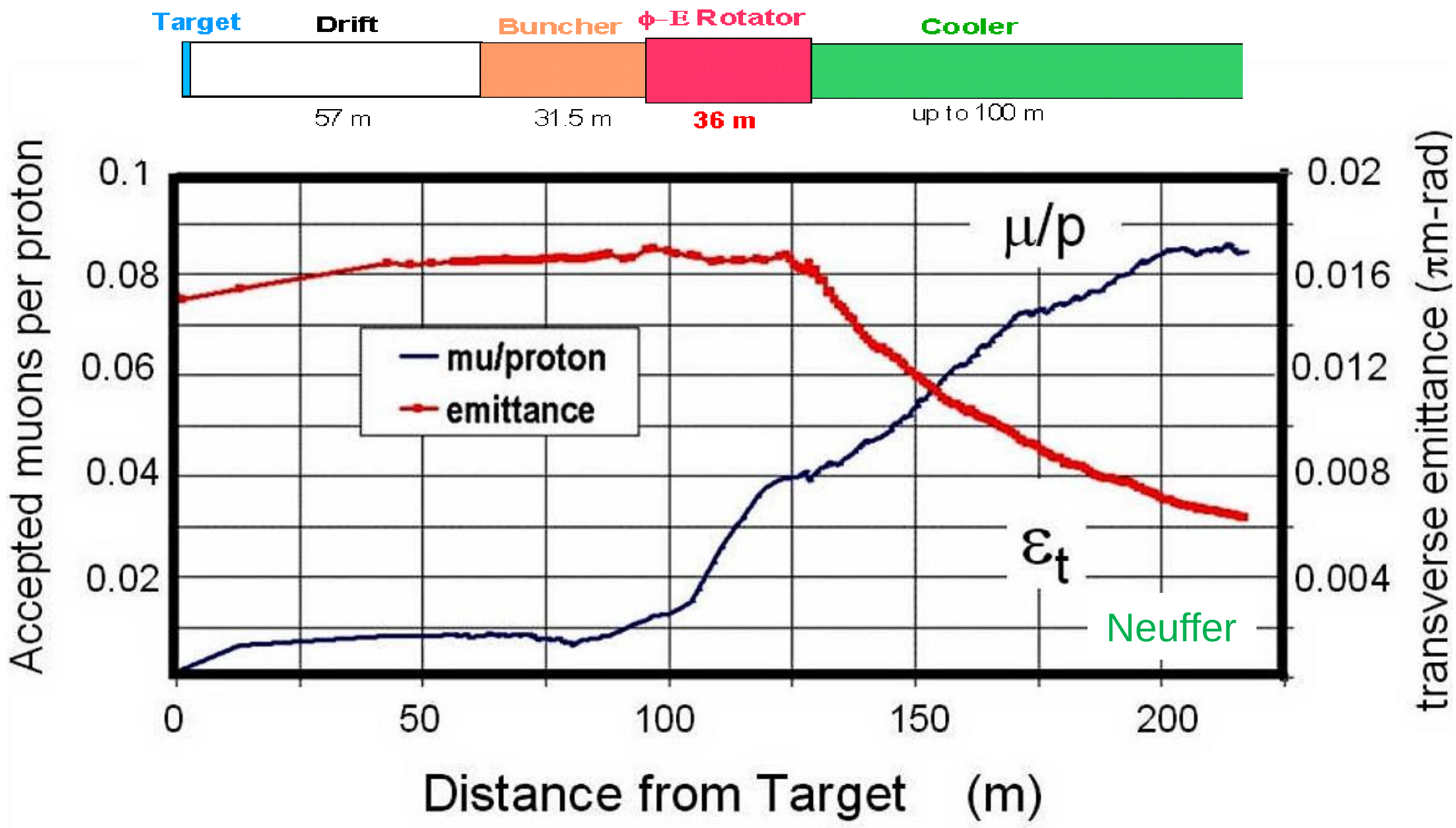
MUON COLLIDER

In present MC baseline design, Front End is same as for NF

A DECADE OF PROGRESS
NF Feasibility Studies

- Successful completion of NF feasibility studies 1, 2, 2a, & International Scoping Study; launching of the ongoing International Design Study for a NF (IDS-NF)
  - Solid basis for planning the MC Design Feasibility Study (DFS)
  - Real progress on understanding how to make enough muons, capture them into bunches, reduce their energy spread, and begin to reduce their transverse phase space (ionization cooling).
- IDS-NF community plans to produce a Reference Design Report (RDR) in ~ 2 years.
  - Interim Design Report (IDR) being finalized now, and is to be reviewed by an ECFA sub-panel May 5-6, 2011

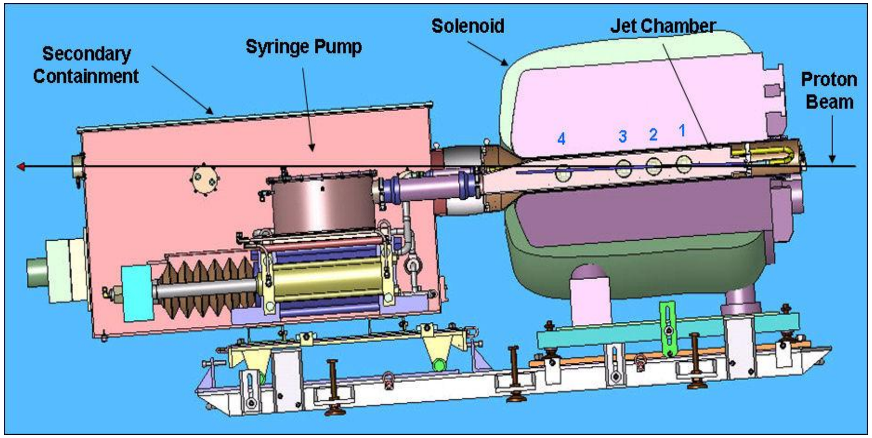
A DECADE OF PROGRESS
Front-End design & simulations

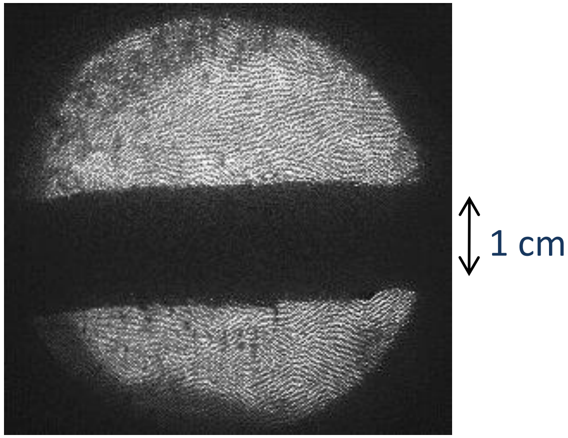


With a 4MW proton source, this will enable O(10^{21}) muons/year to be produced, bunched, cooled & fit within the acceptance of an accelerator.

A DECADE OF PROGRESS
Successful completion of MERIT

- Proof-of-principle demonstration of a liquid Hg jet target in high-field solenoid ran at CERN PS in Fall 2007.
- Successfully demonstrated a 20m/s liquid Hg jet injected into a 15 T solenoid, & hit with a suitably intense beam (115 KJ / pulse !).
- Results suggest this technology OK for beam powers up to 8 MW with rep. rate of 70Hz !

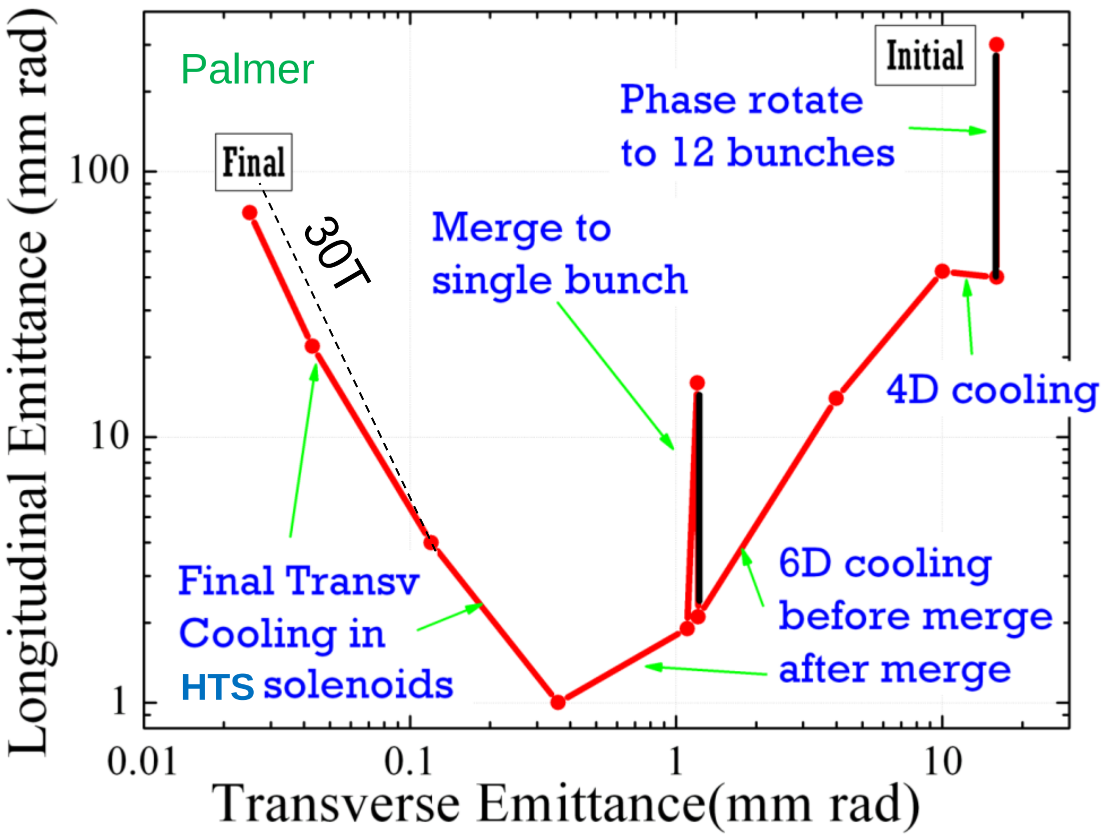




Hg jet in a 15 T solenoid
Measured disruption length
= 28 cm

Ionization cooling concepts & simulations

- Development of a cooling channel design to reduce the 6D phase space by a factor of $O(10^6)$ → luminosity $O(10^{34})$ cm^{-2} s^{-1}



- Some components beyond state-of-art:
  - Very high field HTS solenoids & High gradient RF cavities operating in few Tesla fields
- Challenging are the solenoids in the last stages of cooling:
  - Original design needed 50 T solenoids. Recent improvements suggest 30 T sufficient.

A DECADE OF PROGRESS
MuCool Test Area

MTA built at end of FNAL Linac for ionization cooling component testing

5 T magnet, RF power at 805 MHz & 201 MHz, clean room,
LH_2 handling capability, 400 MeV beam from linac.

FIRST BEAM IN MTA 28 FEBRUARY 2011 !

Liq. H_2 absorber (KEK)

42 cm ∅ Be RF window (LBNL)

201 MHz cavities (LBNL et al.)

High Pressure RF Cavity (FNAL & Muons Inc.)

A DECADE OF PROGRESS

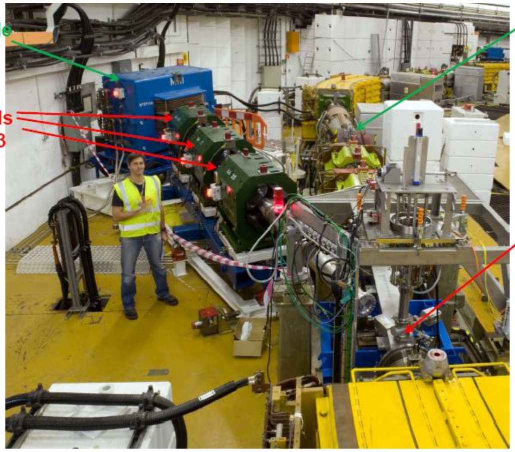
Muon Ionization Cooling Experiment (MICE)

- Multi-stage experiment at RAL to be completed ~2014

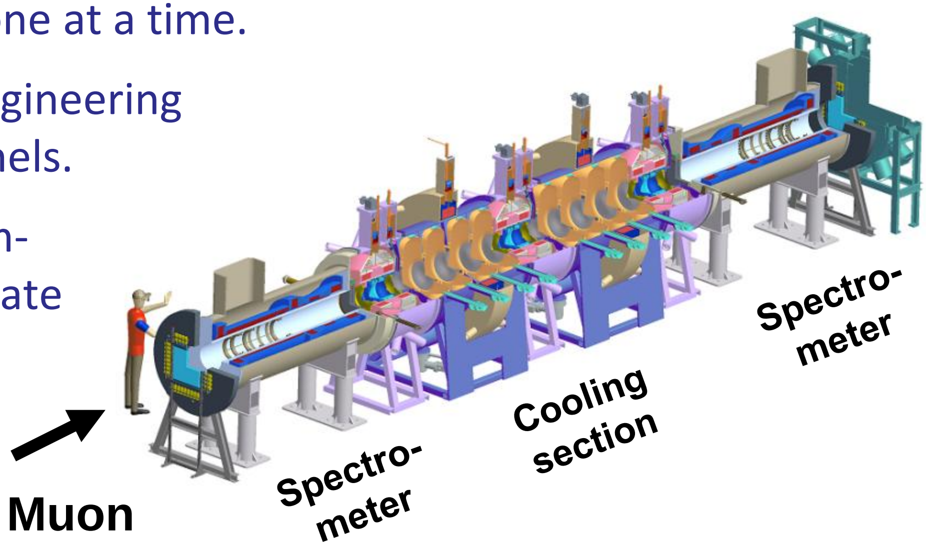
- Tests short cooling section, in muon beam, measuring the muons before & after the cooling section. one at a time.

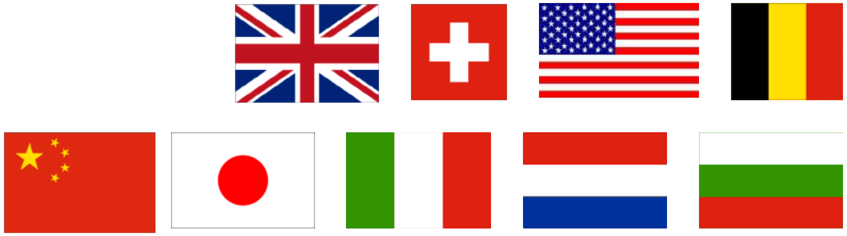
- Learn about cost, complexity, & engineering issues associated with cooling channels.

-Vary RF, solenoid & absorber param-eters & demonstrate ability to simulate response of muons



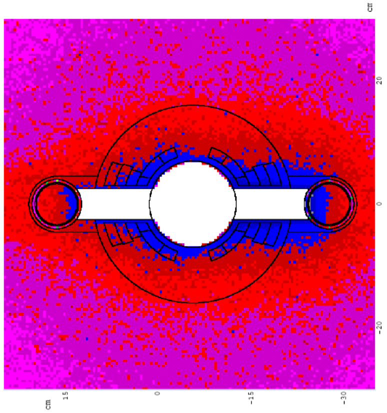
MICE – upstream beamline





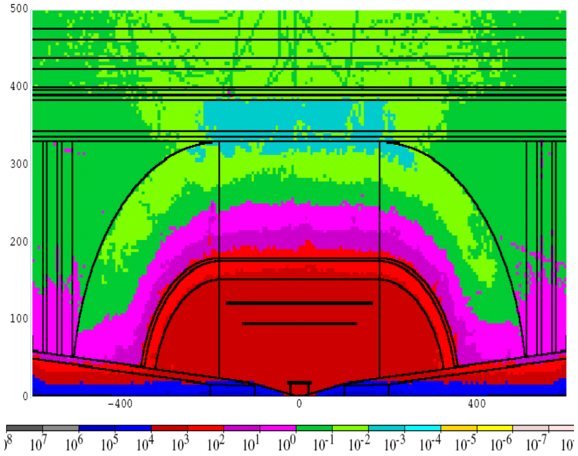
A DECADE OF PROGRESS
Ring, Magnets & Detector Studies

- Emittances are large, but the muons circulate for only ~1000 turns before they decay.
  - First lattice designs exist.
- Need high field dipoles & quadrupoles that operate in large muon decay backgrounds



MARS energy deposition map for 1.5 TeV collider dipole

- Have studied open mid-plane magnet design (radiation & heat loads, field non-uniformity & affect on lattice performance) → looks OK. More engineering studies needed.
- Detector shielding & performance studies under way – initially for $\sqrt{s}$=1.5 TeV.
  - Initial shielding configuration exists
  - Reliable MARS simulations exist
  - Initial detector studies beginning
  - Much needs to be understood & optimized



THE BIRTH OF MAP

- Oct 1, 2009 letter from Denis Kovar to FNAL Director:

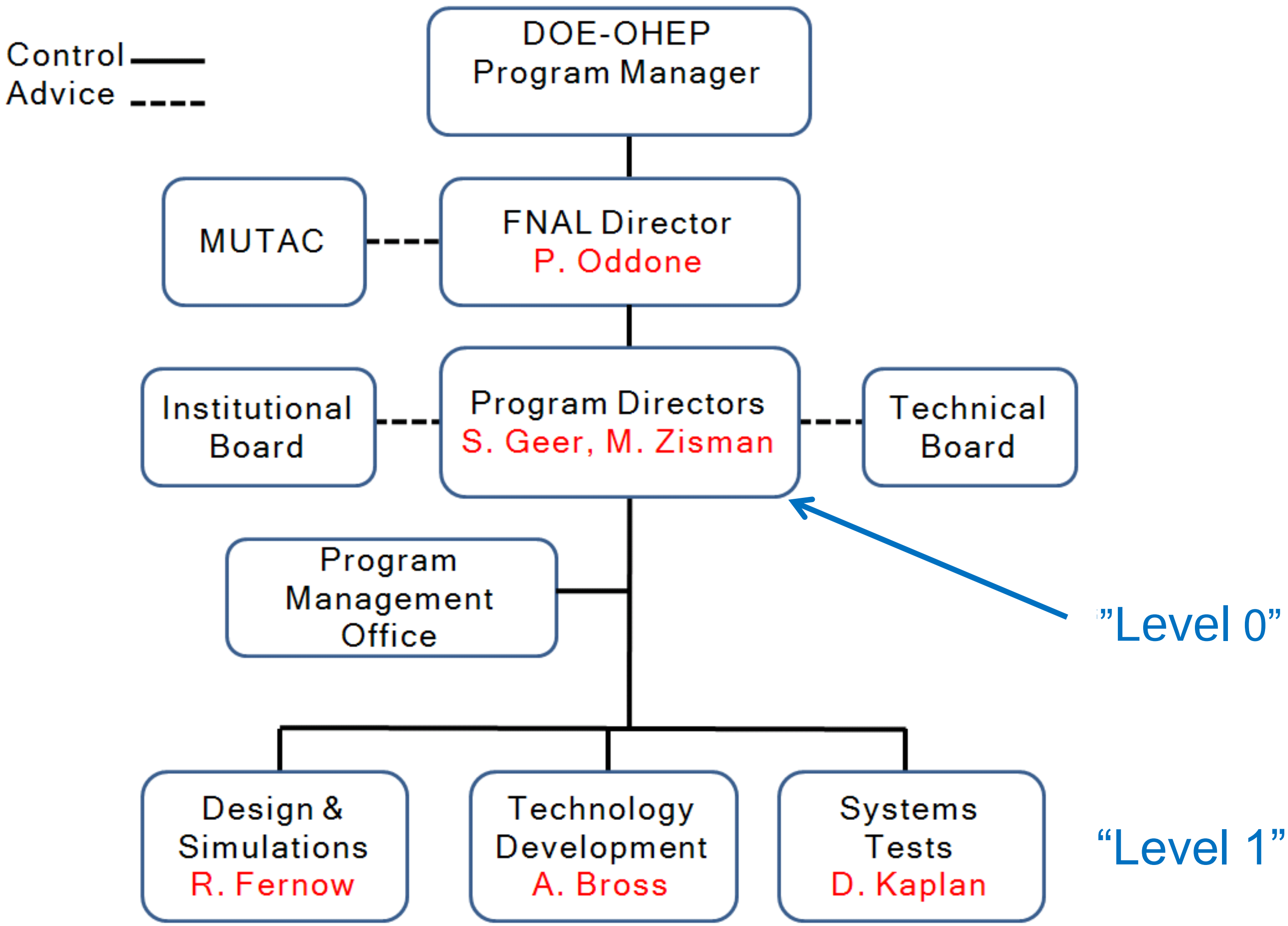
  "Our office believes that it is timely to mount a concerted national R&D program that addresses the technical challenges and feasibility issues relevant to the capabilities needed for future Neutrino Factory and multi-TeV Muon Collider facilities. ..."

- Letter requested a new organization for a national Muon Collider & Neutrino Factory R&D program, hosted at FNAL.
- **M**uon **A**ccelerator **P**rogram organization is now in place & functioning: >200 participants from 15 institutions:
  - ANL, BNL, FNAL, JLab, LBNL, ORNL, SLAC, Cornell, IIT, Princeton, UCB, UCLA, UCR, U-Miss, U. Chicago
  - http://map.fnal.gov/
- MAP R&D proposal reviewed August 2010 … committee concluded that the *"proposed work was very important to the field of high energy physics."*

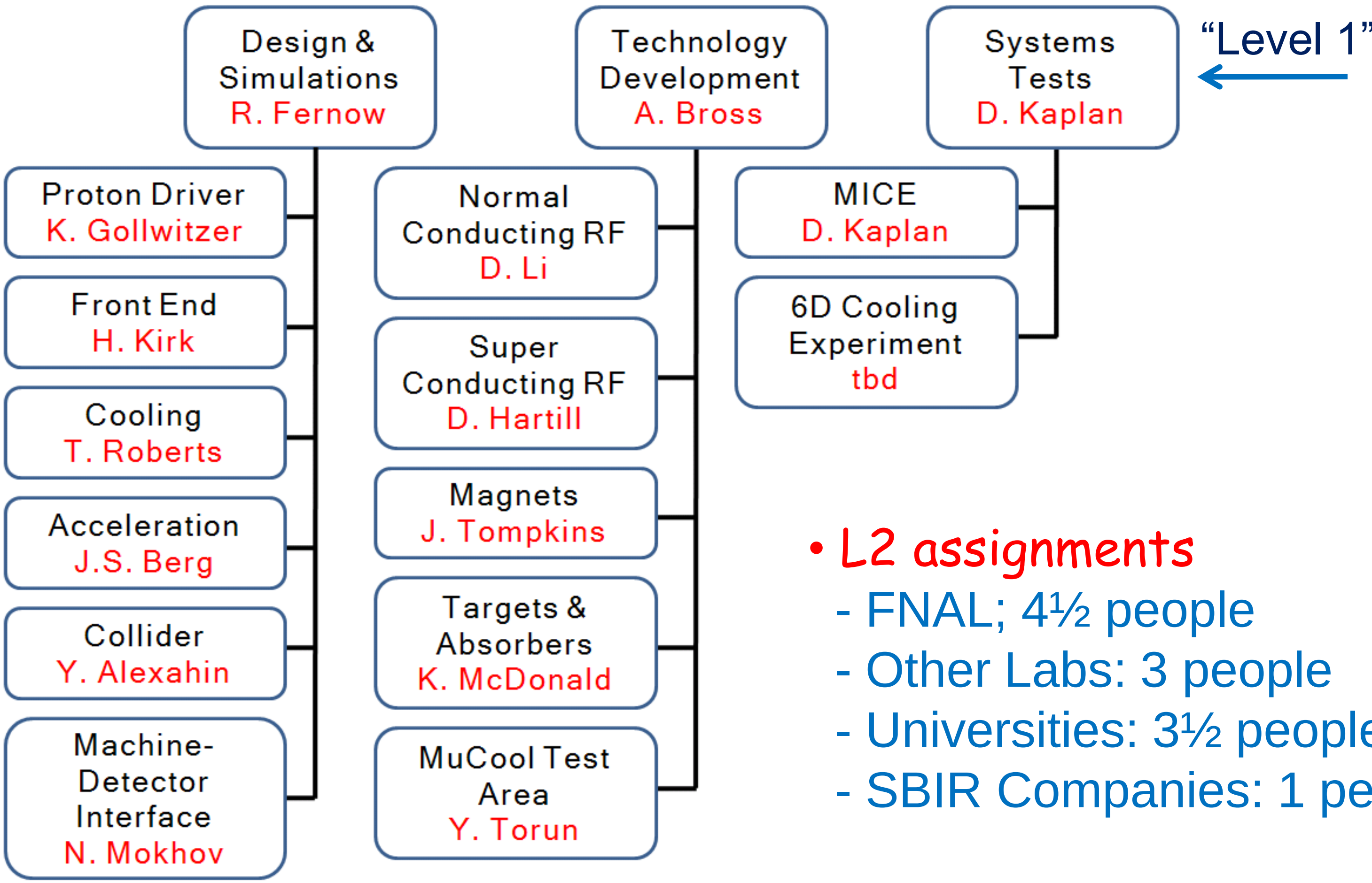
MAP MISSION STATEMENT

The mission of the Muon Accelerator Program (MAP) is to develop and demonstrate the concepts and critical technologies required to produce, capture, condition, accelerate, and store intense beams of muons for Muon Colliders and Neutrino Factories. The goal of MAP is to deliver results that will permit the high-energy physics community to make an informed choice of the optimal path to a high-energy lepton collider and/or a next-generation neutrino beam facility. Coordination with the parallel Muon Collider Physics and Detector Study and with the International Design Study of a Neutrino Factory will ensure MAP responsiveness to physics requirements.

MAP ORGANIZATION



ORGANIZATION: L1 & L2



- *L2 assignments*
  - FNAL; 4½ people
  - Other Labs: 3 people
  - Universities: 3½ people
  - SBIR Companies: 1 person

PROPOSED MAP PLAN / DELIVERABLES

- Deliver on our commitments to making MICE and the IDS-NF studies a success.

- Deliver a Design Study to enable the community to judge the feasibility of a multi-TeV Muon Collider (~FY16):

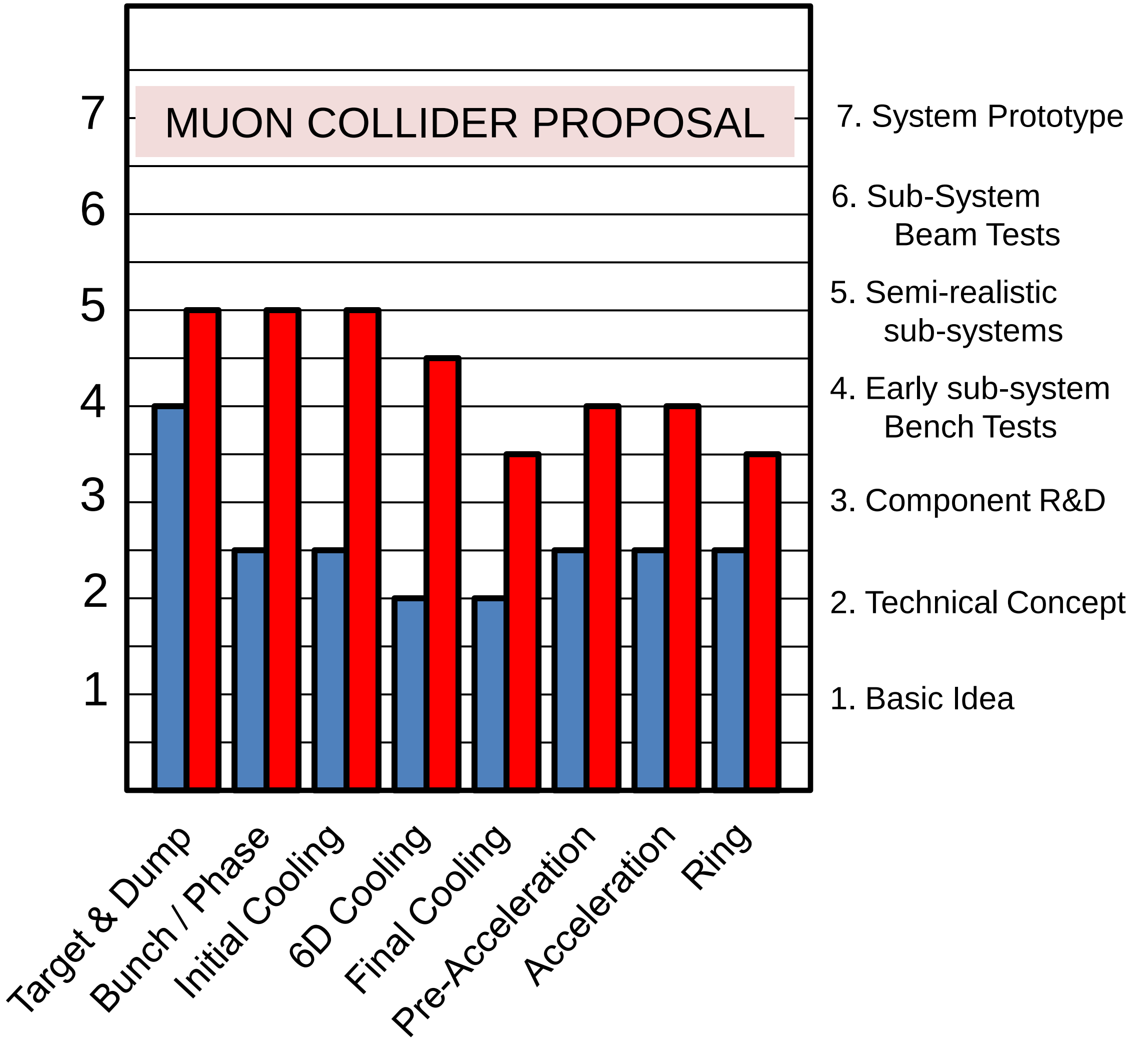
(i) an end-to-end simulation of a MC complex based on technologies in-hand or that can be developed with a specified R&D program.

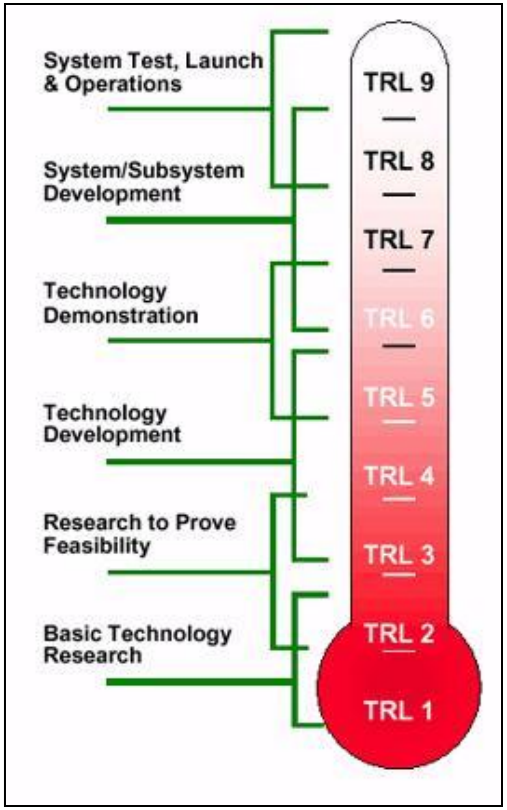
(ii) hardware R&D and experimental tests to guide & validate the design work.

(iii) Rough cost range.

(iv) R&D plan for longer term activities (e.g. 6D cooling expt)

IMPACT OF MUON COLLIDER DESIGN FEASIBILITY STUDY





Based on NASA Technology Readiness Levels

PAST-PRESENT-FUTURE

First ~10 years	FY07 – FY09	FY10	NOW	≥FY11
NFMCC	NFMCC + MCTF	Interim MAP	MAP	MAP

~4 M$ ~9 M$ ~10 M$ ~15 M$ (requested)

INFORMING THE COMMUNITY

http://conferences.fnal.gov/muon11/

FINAL REMARKS

- MAP is up and running:
  - MAP Management plan about to be approved (we are told) by DOE-OHEP
  - MAP Director search is under way (https://fermi.hodesiq.com/job_detail.asp?JobID=2339416)

- There is a real chance to show, within ~6 years, that a multi-TeV Muon Collider is feasible with an estimated cost range, and to specify the remaining R&D needed.
  - The proposed plan requires ~15M$/yr (FY10 dollars)
  - Many challenges, but we believe we can succeed

START WITH PROJECT X

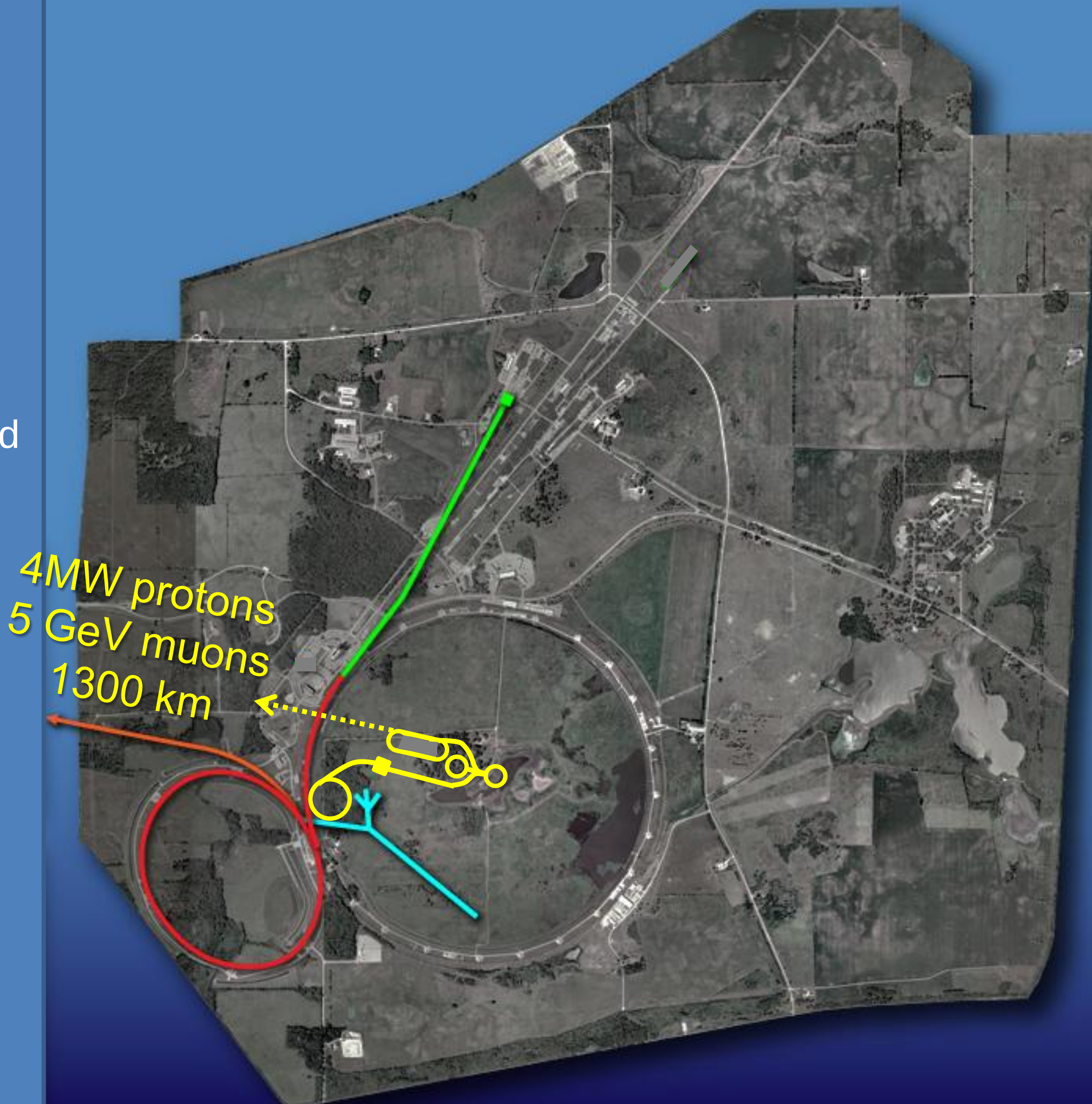
Neutrinos
Muons
Kaons
Nuclei

“simultaneously”

ADD NEUTRINO FACTORY

Enhanced Neutrinos
Enhanced Muons
Muon Collider test bed
Kaons
Nuclei

"simultaneously"



ADD MUON COLLIDER