Toward a Muon Collider

Vladimir Shiltsev / Fermilab

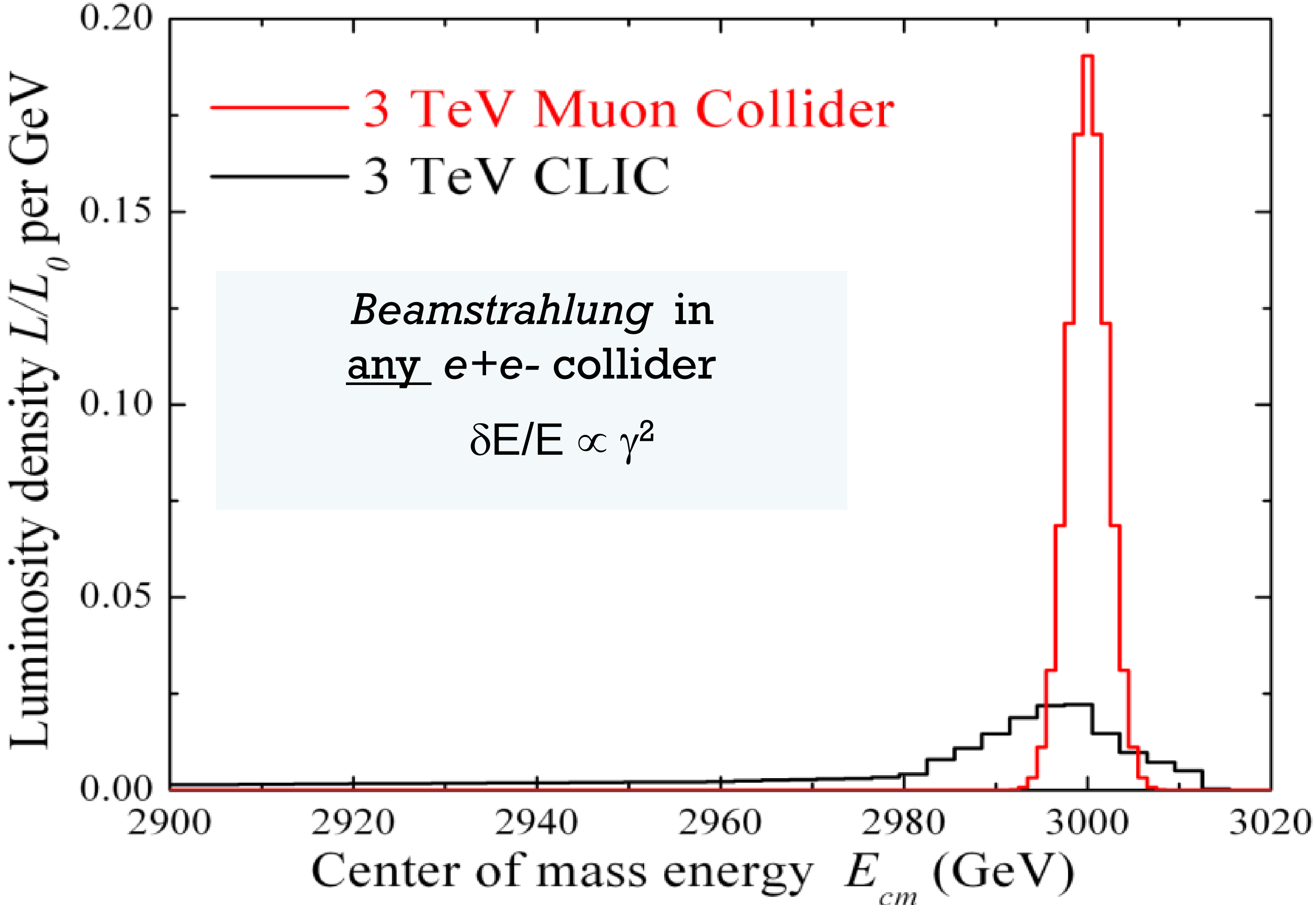
NuFact'11

CERN, August 5, 2011

Muon Collider

- Collider based on a secondary beam: we do this with antiprotons. For muons must do it in milliseconds
- The biggest advantages are:
  - no beamstrahlung → narrow energy spread
  - no synchrotron radiation → multi-pass acceleration
    → multi-pass collisions in a ring ~1000
    → compact facility (cost)
  - two detectors (2 IPs)
  - synergetic with Neutrino Factory

Energy Spread



- 100% of luminosity in (dE/E) ~ 0.1%

MC Community

"…To review the physics case for a Muon Collider, accelerator R&D progress, the outstanding challenges, future plans, and opportunities for new and existing groups to participate in the R&D. "

The Top Six (Physics Benchmarks)

Process	***Observables***	***Experimental considerations***	***Theoretical considerations***	***Strategy***
Z'	M, Γ couplings final states	energy scale = M ? beam energy resolution initial state polarization ? cone size	coupling strength L – R chiral compelling models	first priority if confirmed at LHC; may enable low-L machine
Contact Terms				
WW fusion	M couplings states?	beam energy initial state polarization cone size !	coupling strength strong dynamics (broad TeV scale Higgs)	High priority if no low mass Higgs at LHC
SUSY/BSM select processes	many states decay chains m's, Br's, σ's	beam energy resolution initial state polarization missing ET cone size	Mainstream theory perturbative dynamics MSSM or else?	Simply depends upon confirmation at LHC
Dark Matter	γ or Z + missing ET	cms frame is known initial state polarization? missing ET cone size	Very interesting how powerful are limits? Need the paper asap !	High priority appears easy to do

Higgs, MultiHiggs, H0-A0, scalar resonances, CP-violation etc.

From ***Chris Hill, Telluride-2011 Summary***

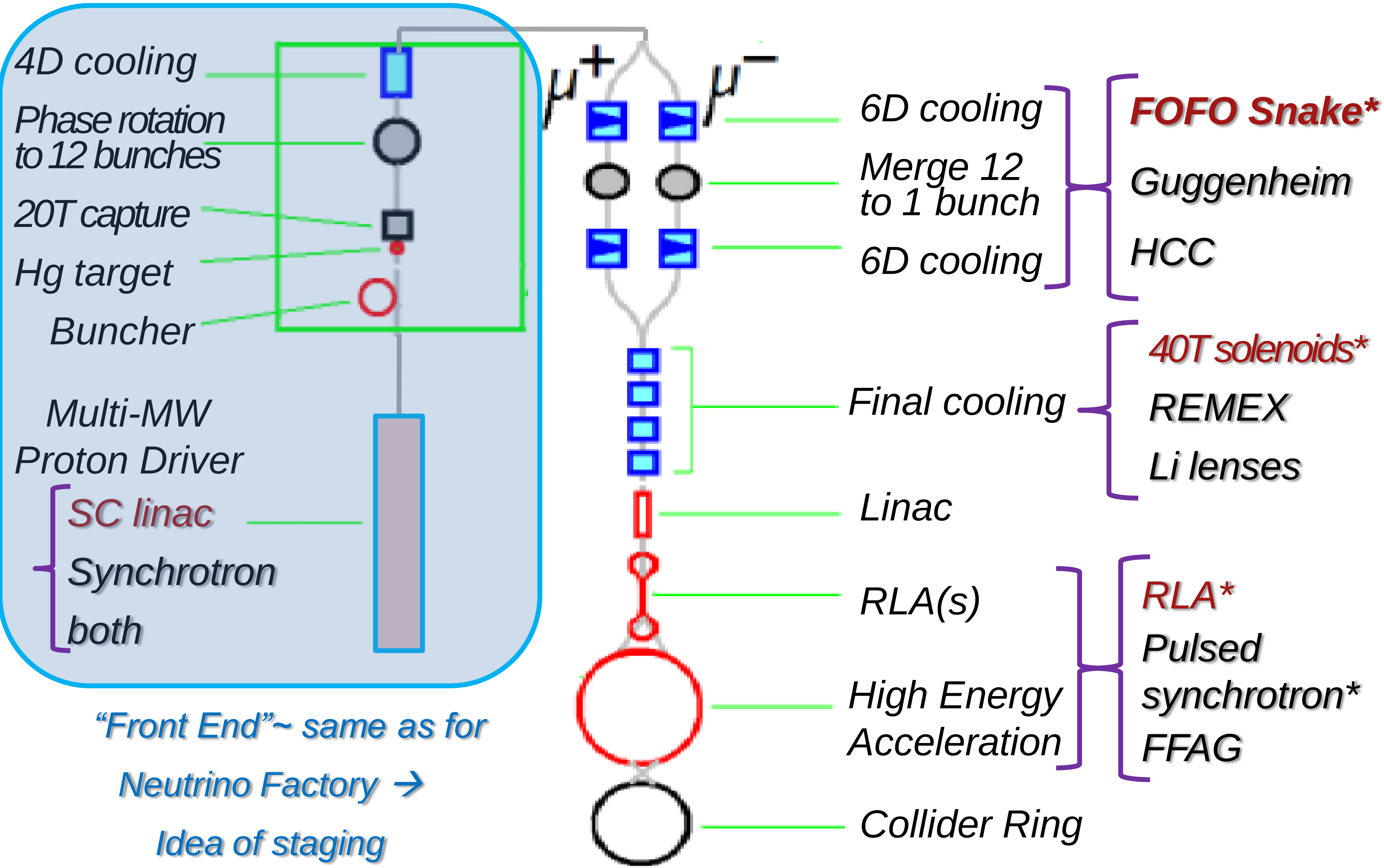
Global LC Stage (as we see it)

- ILC: 0.5TeV, 36 km of accelerators, 16B$, 230 MW
  - **Technically feasible, prohibitive cost ?**
- CLIC: 3TeV com, ~60 km, 15-20B$ (?), 560 MW
  - **Conceptual and performance feasibility TBD, cost ???**
- Alternatives on the table:
  - No need in a lepton collider (LHC answers all questions)
  - Plasma Accelerator **(Qs: >1TeV? <2040? <200MW)…or**
- Muon Collider: 1.5-4TeV, <20 km of accelerators fits FNAL site, *N* B$ (?), ~150 MW, Neutrino Factory
  - **feasiblity – depends on luminosity**
  cost – depends on energy

Fermilab Muon Collider Challenges

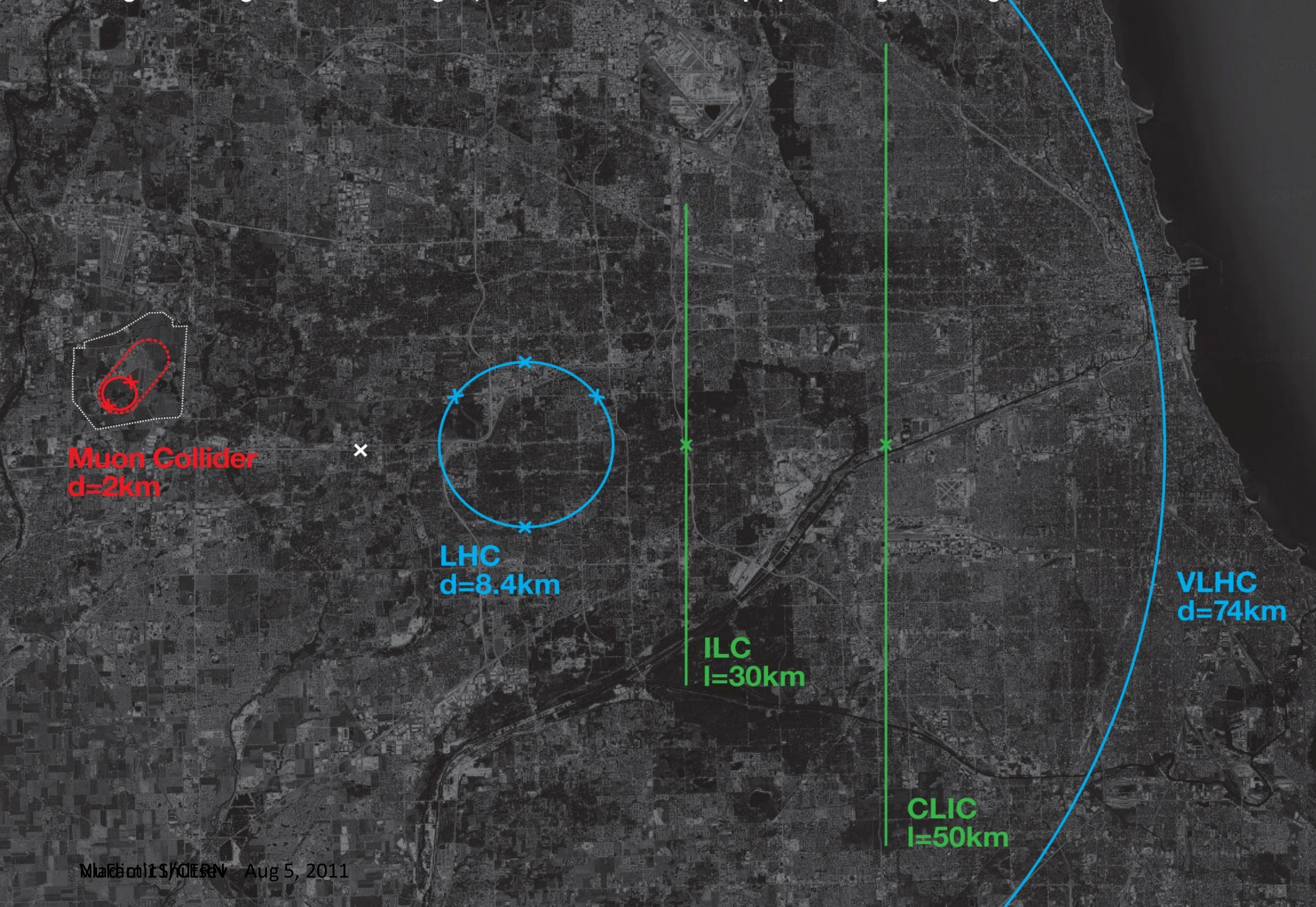
- Muons are produced as tertiary particles. A MW scale proton source & target facility needed to make enough of them
- Muons decay ⇒ everything must be done fast and we must deal with the decay electrons (& neutrinos for CM energies above ~3 TeV).
- Muons are born within a large 6D phase-space. Without beam cooling, luminosity limited at $O(10^{31}\ \mathrm{cm}^{-}\ \mathrm{s}^{-1})$. For a high luminosity collider $O(10^{34}\ \mathrm{cm}^{-}\ \mathrm{s}^{-1})$, the 6D phase space has to be reduced by $O(10^{6})$ before muons decay ⇒ New cooling technique (ionization cooling) must be demonstrated, and it requires components with demanding performance (normal-conducting RF in magnetic channel, high field solenoids.)

Muon Collider Scheme: 7+ machines



Comparison of Particle Colliders

To reach higher and higher collision energies, scientists have built and proposed larger and larger machines.



Challenges and Progress

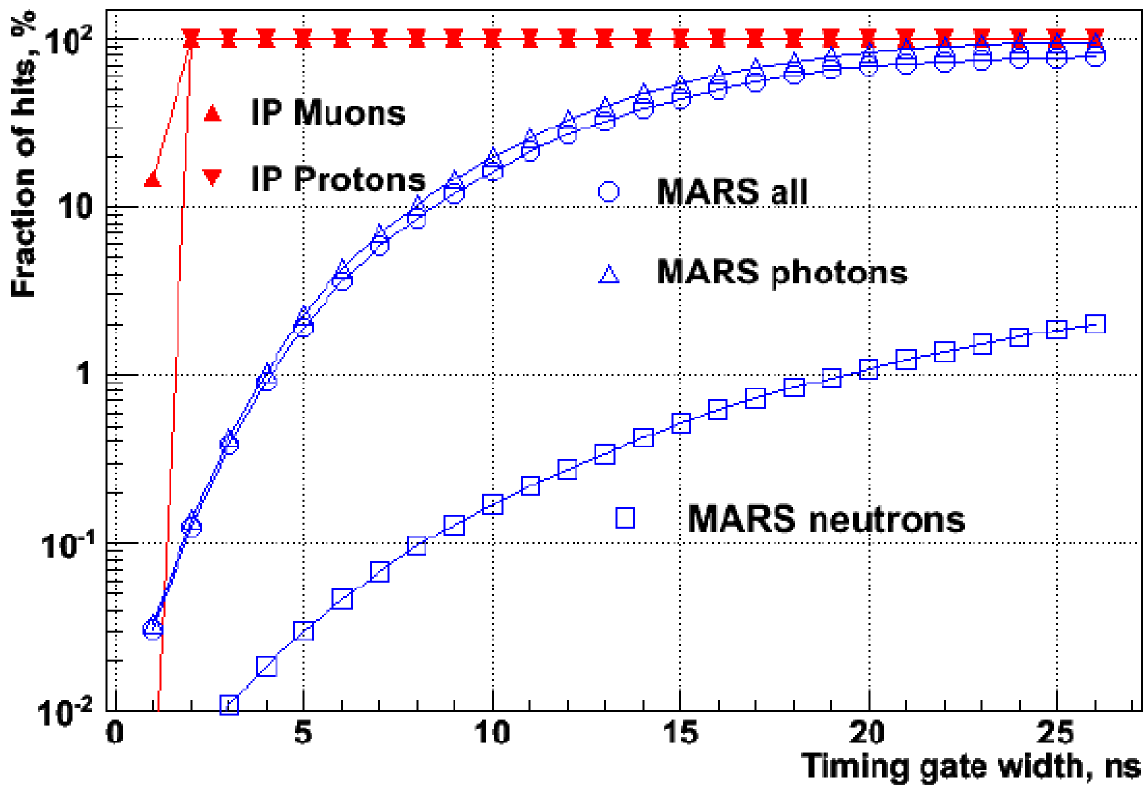
- Multi-MW proton target with long lifetime :
  - Liquid Hg jet MERIT experiment demo up to 8 MW
- Capture and cooling could be done effectively provided we learn how to operate RF cavities inside magnetic fields
  - R&D program at Fermilab's MuCool Test Area (reported by Y.Torun)
  - gas filled RF cavities in magnetic fields offer a possible shortcut - done already with no beam, beam studies ongoing (reported by K.Yonehara)
- Need demonstration of ionization cooling technique:
  - 4D (transverse) MICE experiment in progress (~2014)
  - 6D cooling experiment after 2015
- Need development of very high fields solenoids for last stages of cooling (luminosity proportional to B-field, Ideally >30T)
  - Program started at several labs FNAL, BNL, LBNL

Challenges and Progress

- MC requires substantial acceleration (few km)
  - that ideally would use ILC technology
  - major wall plug power consumer (out of ~150 MW total)
- Need end-to-end system simulation to understand beam dynamics, ultimate losses, emittances
  - Recent substantial progress with collider ring, optimized cooling channels and proton beam compression ring designs
- Understand full physics reach with backgrounds and masks regions (neutron peak/yr = 0.1xLHC@10^{34})
  - new machine-detector interface design with only 10 deg cone
  - (Telluride, CO June 27-July 1, workshop) – next slide

Background Reduction

- **Choose TOF – T0 time gate width**
  - To detect hits from IP particles with ~100% efficiency (use muons as the fastest, protons as the slowest particles)
  - Then it will define the rejection of the hits from muon collider background particles
  - For now ignore the Si front-end resolution time
  - The gate starts at TOF-T0 = -1ns
- **2-3 ns time gate width ?**



From N.Terentiev (CMU), N.Mokhov (FNAL) , Telluride-2011

Fermilab Muon Accelerator Program

- Oct 1, 2009 letter from DOE/OHEP Dennis 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 Fermilab.
- **Muon Accelerator Program (MAP)** R&D proposal reviewed August 2010 … committee concluded that the *"proposed work was very important to the field of high energy physics."*
- **MAP** organization is now in place & works: *http://map.fnal.gov/*

  >200 participants from 16 institutions (Nat'l Labs, Univ's, SBIR Company)

  - MAP budget: 10.4M\$ in FY11, 12M\$ in FY12 (req. ~20M\$ in FY16)

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.

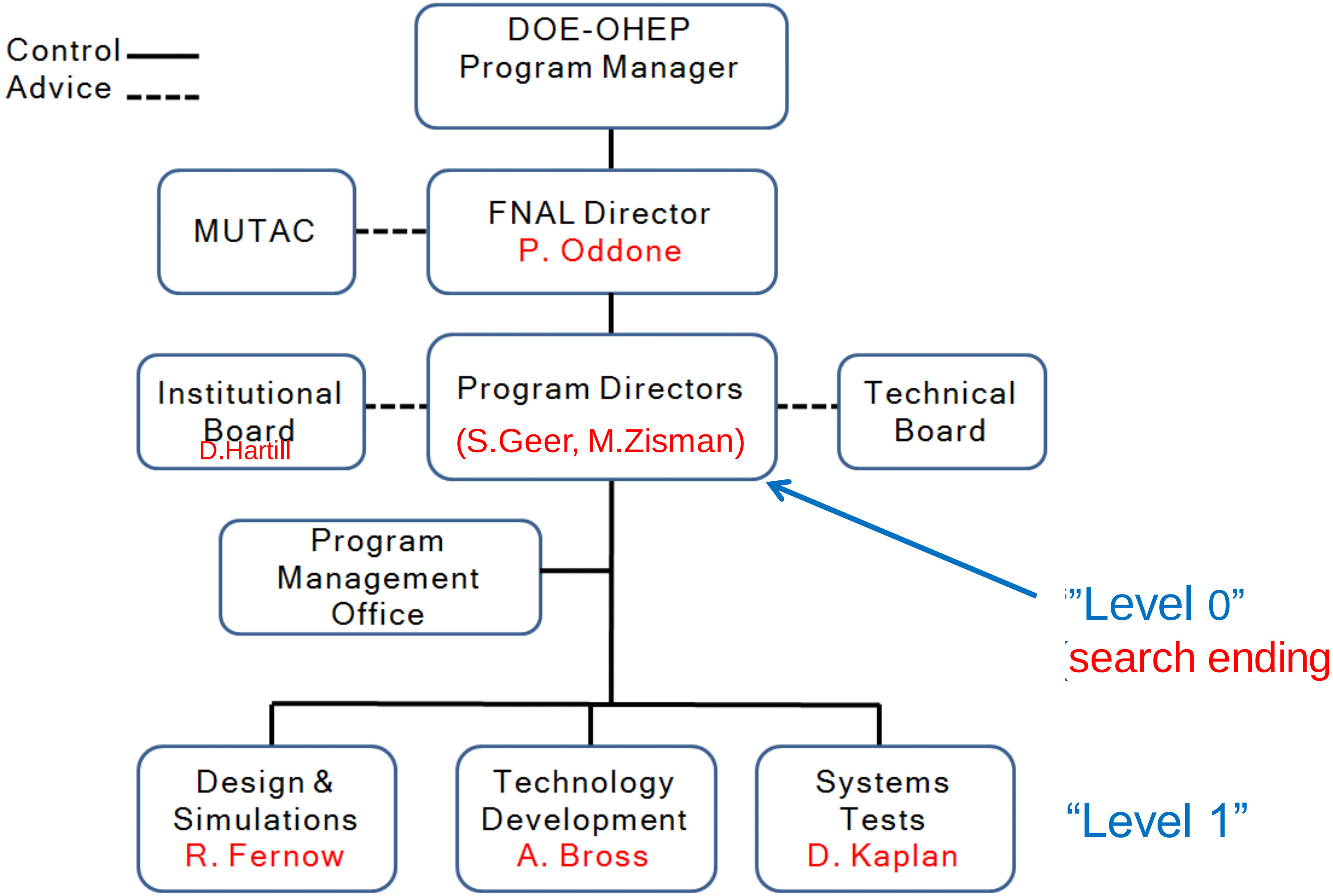
Coordination with the parallel Muon Collider Physics and Detector Study and with the International Design Study of a Neutrino Factory will ensure MAP responsiveness to physics requirements.

Fermilab

MAP Plan and Deliverables

- 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 & exp. tests to guide & validate the design
  - (iii) Rough cost range.
  - (iv) R&D plan for longer term activities (e.g. 6D cooling exp't)
- Deliver on our commitments to making MICE and the IDS-NF studies a success.
- Total cost ~100M$ over 6 years

MAP Organization



Organization: Levels 1 & 2

"Level 1"

- **Design & Simulations** – R. Fernow
  - Proton Driver – K. Gollwitzer
  - Front End – H. Kirk
  - Cooling – T. Roberts
  - Acceleration – J.S. Berg
  - Collider – Y. Alexahin
  - Machine-Detector Interface – N. Mokhov
- **Technology Development** – A. Bross
  - Normal Conducting RF – D. Li
  - Super Conducting RF – D. Hartill
  - Magnets – J. Tompkins
  - Targets & Absorbers – K. McDonald
  - MuCool Test Area – Y. Torun
- **Systems Tests** – D. Kaplan
  - MICE – D. Kaplan
  - 6D Cooling Experiment – tbd

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

2011 Technical Progress

- Physics & Detector
  - "Top 6 benchmarks ", gated detectors concept (Telluride'2011)
- Design and Simulations
  - Project-X SC linac design parameters adjusted to fit MC needs
  - improved designs of capture magnet, phase rotation, charge separation & merge designs, 6D and final cooling simulations
  - sequence of acceleration with better transmission (Workshop)
  - promising solutions for p-compression and μ-collider rings
- Technology development
  - RF in [BxE] tested, RF in high pressure H2 with beam started
  - HCC SC coils tested; HTS SC studies; Ring SC magnets Workshop
- Systems tests
  - MICE works with muon beam
  - MICE SC solenoids design issues addressed; fixes planned/started

Collaboration Potential

- Though MAP is a US national program, it already has international component (MICE and IDS-NF)
  - We need more and actively seeking new collaborators
- Many opportunities for scientists to contribute:
  - MAP HardwareR&D, design studies and experiments:
    - E.g. , MuCool - an experimental program aimed at developing a solution to the RF challenge - now coming on strongly
  - MICE is exploring muon ionization cooling which is a key R&D step towards future muon facilities
    - muon beam and the beam-line detectors are up and running
  - Next generation 6DICE experiment planning
  - Detector R&D

To Conclude:

- Advantages and physics potential of the Muon Collider are more and more appreciated, and promising recent technical advances urge to increased R&D efforts
- Muon Accelerator Program – proposed by us and approved by DOE/OHEP - is up and running
- 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
- We are seeking wider recognition by worldwide HEP community and bigger international contribution to the quest toward this new energy frontier facility