Muon Collider

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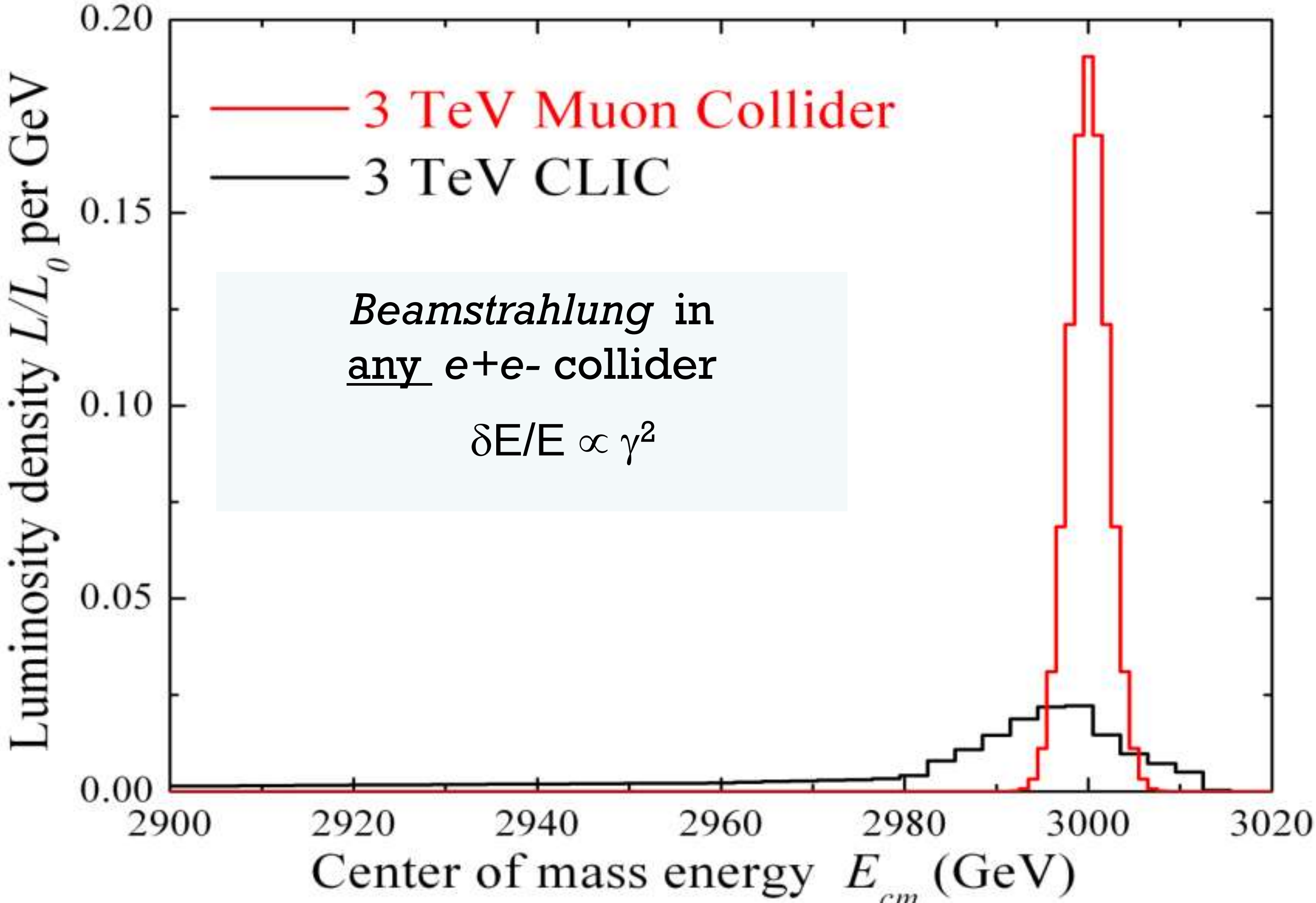
Muon Collider

- 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 (cost)
  - two detectors (2 IPs)
  - synergetic with Neutrino Factory

Energy Spread



Beamstrahlung in
any *e+e-* collider

$\delta E/E \propto \gamma^2$

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

Informing the 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

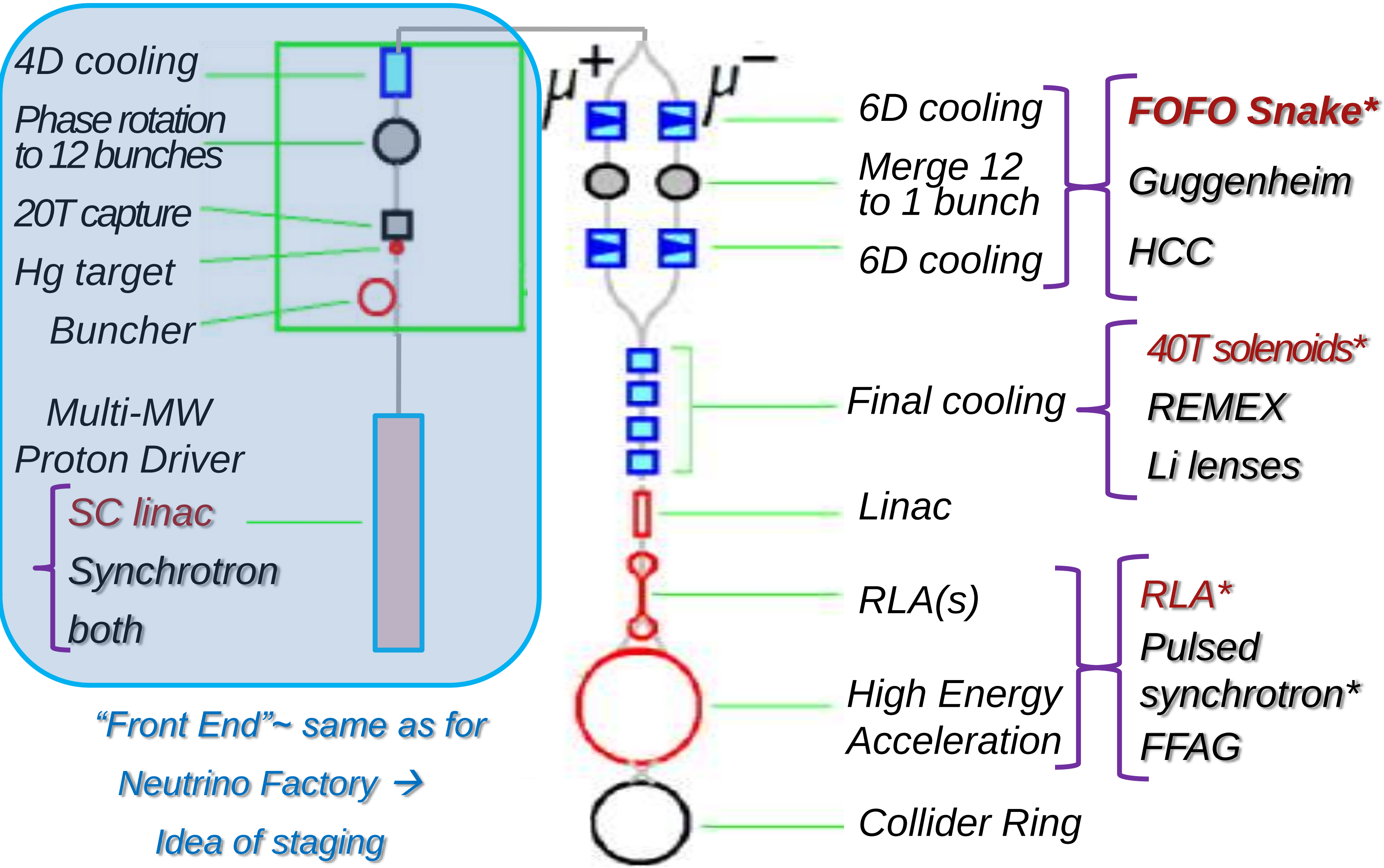
Higgs, MultiHiggs, H0-A0, scalar resonances, CP-violation etc.

From ***C.Hill, Telluride-2011 Summary***

Let's Set Up The Stage

- ILC: 0.5TeV, 36 km of accelerators, 16B$, 230 MW
  - 24,000 elements for individual control… **feasible**
- CLIC: 3TeV com, ~60 km, 15-20B$, 568 MW
  - Some 220,000 elements to control, 2beam-ac**feasible?**
- Alternatives on the table:
  - No need in a lepton collider if LHC detectors are smart
  - Plasma Accelerator (!! **1TeV** ?@*! **2040** !&%!?!) …or
- Muon Collider: 1.5-4TeV, 14-20 km of accelerators fits FNAL site, ***N*** B$, ~150 MW, Neutrino Factory
  - ~6,000 elements **feasible? – depends on luminosity**

Muon Collider Scheme: 7+ machines



"Front End"~ same as for

Neutrino Factory →

Idea of staging

4 TeV Muon Collider Conceptual Layout

http://www.fnal.gov/pub/muon_collider/

Project X
Accelerate hydrogen ions to 8 GeV using SRF technology.

Compressor Ring
Reduce size of beam.

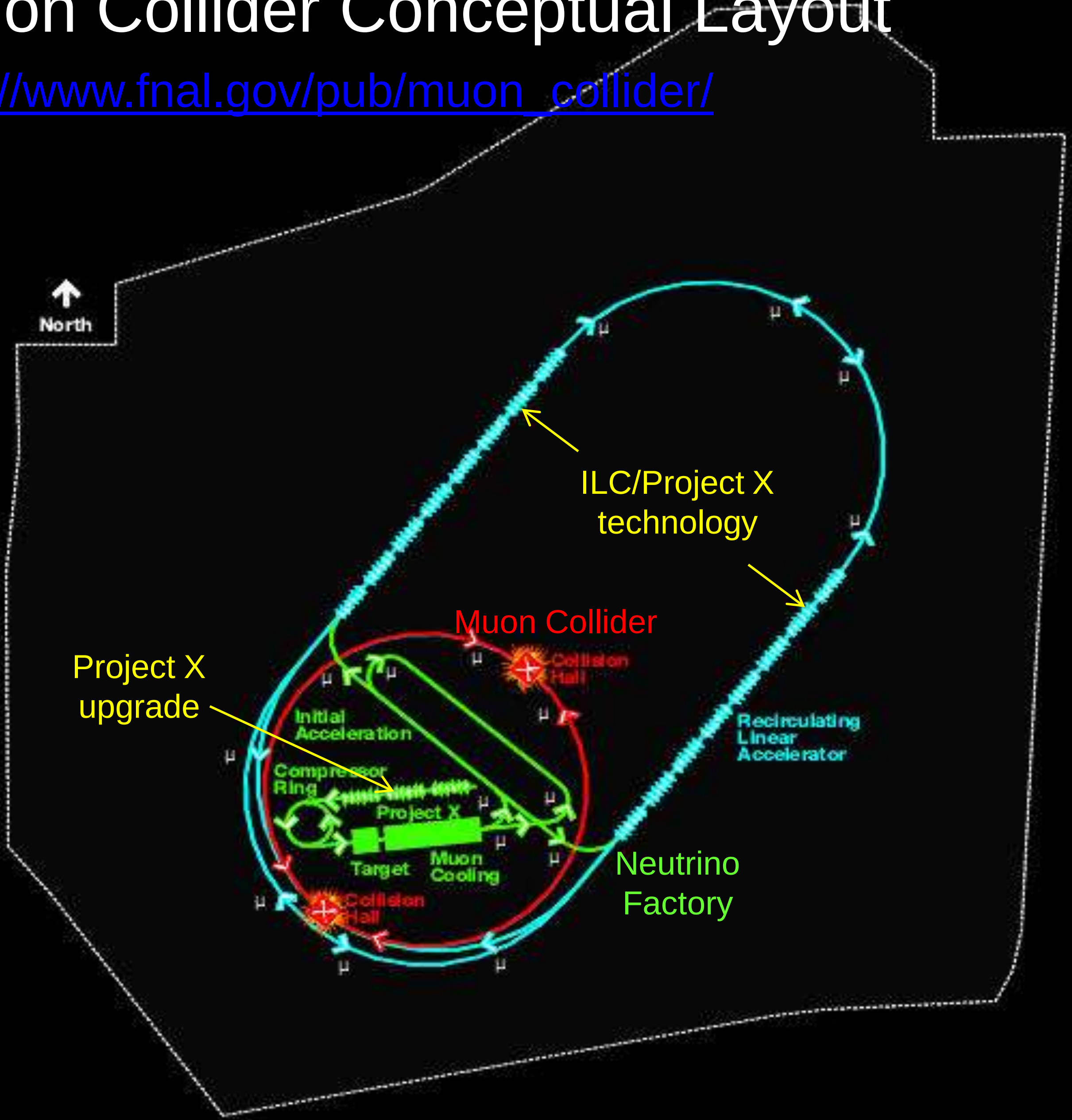
Target
Collisions lead to muons with energy of about 200 MeV.

Muon Cooling
Reduce the transverse motion of the muons and create a tight beam.

Initial Acceleration
In a dozen turns, accelerate muons to 20 GeV.

Recirculating Linear Accelerator
In a number of turns, accelerate muons up to 2 TeV using SRF technology.

Collider Ring
Located 100 meters underground. Muons live long enough to make about 1000 turns.

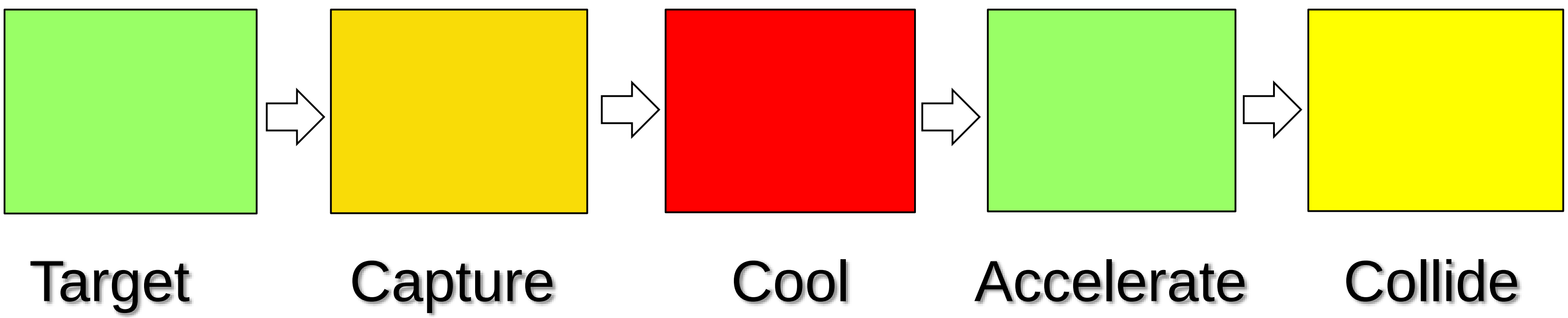


Muon Collider Challenges

- Muons are produced as tertiary particles. A MW scale proton source & target facility needed to make enough of them
- 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. Without beam cooling, luminosity limited at O(10^{31} cm^{-} s^{-1}). For a high luminosity collider O(10^{31} cm^{-} s^{-1}), the phase spaces has to be reduced by O(10^{6}) before muons decay $\Rightarrow$ 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 functional layout

http://www.fnal.gov/pub/muon_collider/



Color indicates degree of needed
R&D (difficulty) and demonstration

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
  - gas filled RF cavities in magnetic fields offer a possible shortcut - done already with no beam, beam studies started '11
- Need demonstration of 6D cooling
  - 4D 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 field). Ideally upwards of ~30T
  - Program started at several labs FNAL, BNL, LBNL

Challenges and Progress

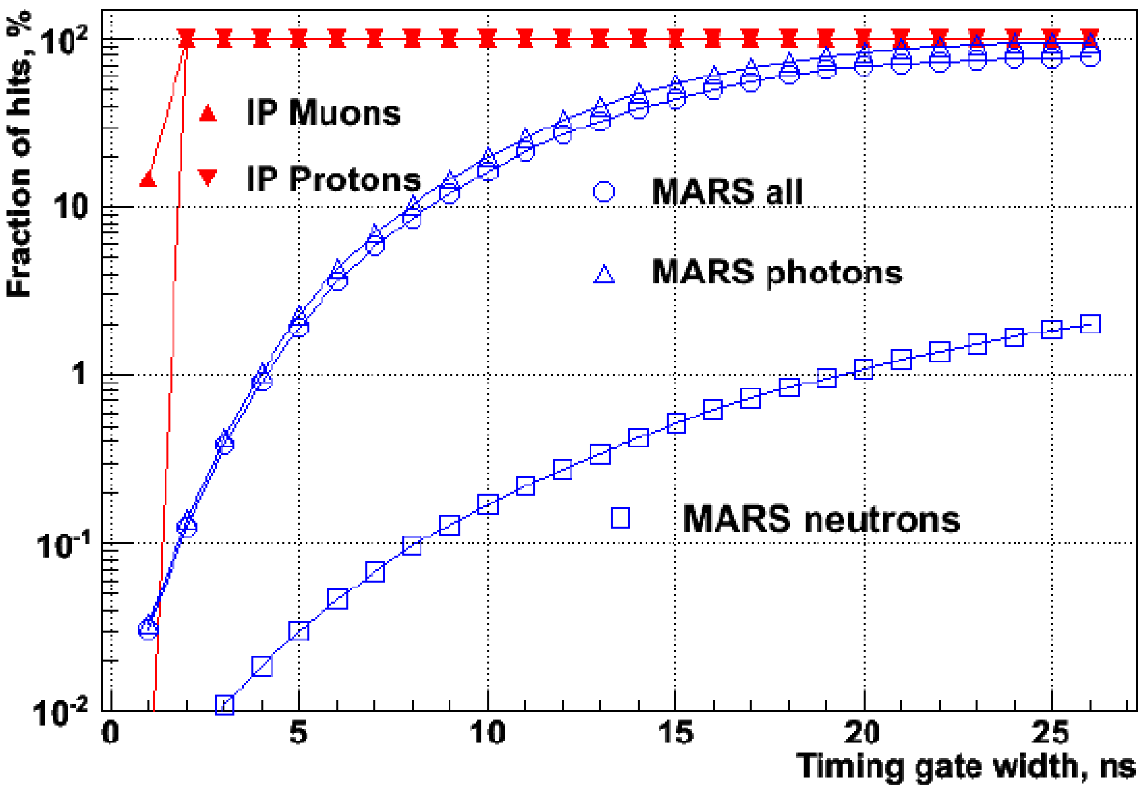
- Muon collider requires substantial acceleration (few km)
  - that ideally would use ILC technology
  - major wall plug power consumer (out of perhaps 160 MW total)

- 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)

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

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.
- 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 & 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 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 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 expt)
- Deliver on our commitments to making MICE and the IDS-NF studies a success.
- Annual cost ~10M$ now → ~15 M$ requested after FY11

Summary

- Muon Collider is a complex project
  - not as much as CLIC or plasma… closer to the Tevatron
- Many opportunities for scientists to contribute:
  - MuCool - an experimental program aimed at developing a solution to our *“RF Challenge”*
    - now coming on strongly, entering a new exciting phase
  - 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&running
  - 6DICE experiment and Hardware R&D need help, too
  - Detector R&D