From Neutrino Factory to Muon Collider

Q1: Imagine a NF is built; explain the technological gap and additional R&D needed to build a muon collider

Q2: Present the ongoing R&D effort for the muon collider, emphasis on European contribution (if any) and projects that labs could participate.

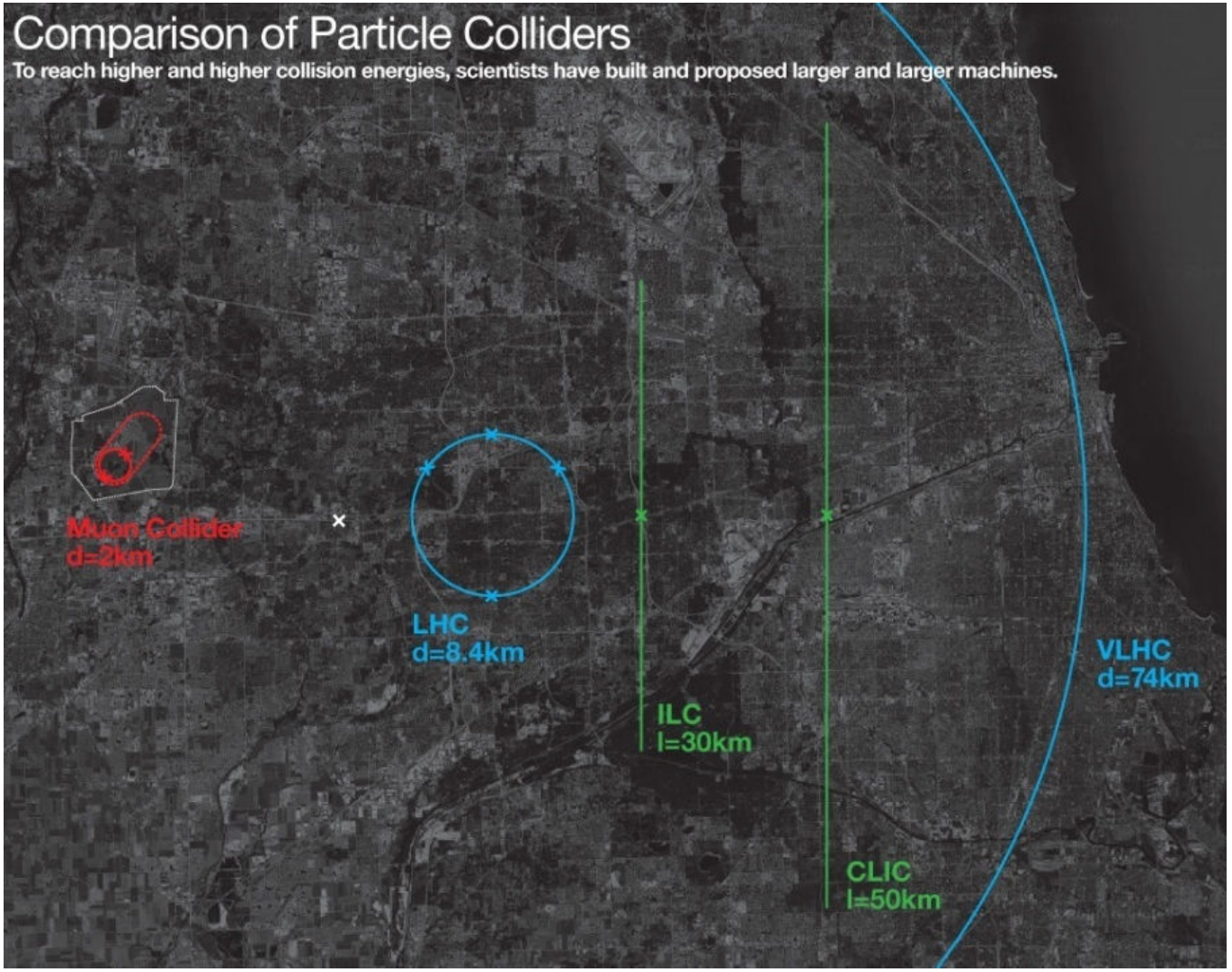
Q3: As an energy frontier machine, how a muon collider based at CERN could look like?

Muon Collider Motivation

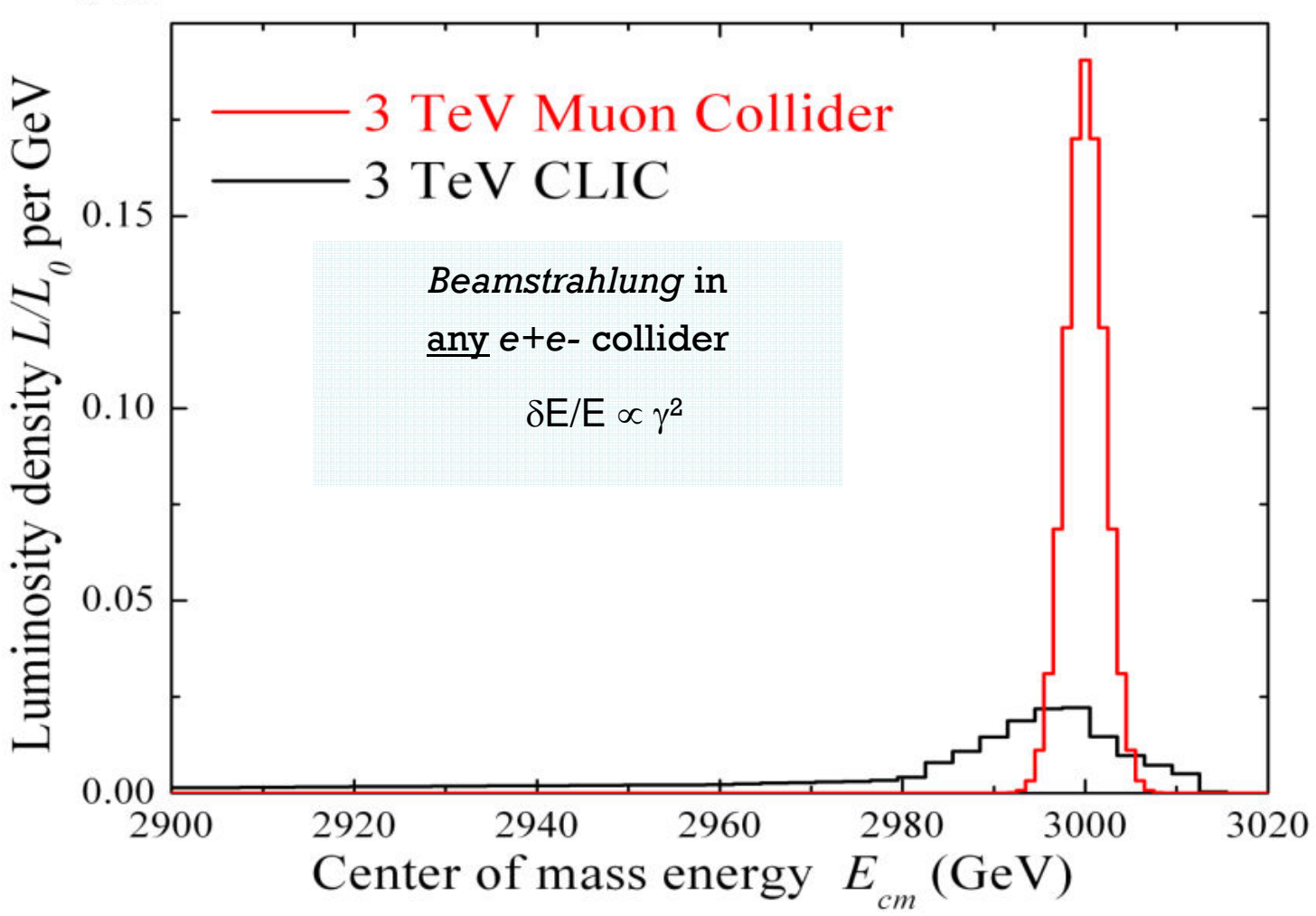
- If we want a multi-TeV lepton collider after the LHC, a Muon Collider is an attractive option because muons do not radiate as readily as electrons ($m_\mu / m_e \sim 207$):

  - COMPACT
    Fits on laboratory site
  - MULTI-PASS ACCELERATION
    Cost Effective
  - MULTIPASS COLLISIONS (~1000 turns)
    Relaxed emittance requirements & hence tolerances
  - NARROW ENERGY SPREAD
    Precision scans
  - $\Delta T_{bunch} \sim 10\ \mu s$ … (e.g. 4 TeV collider)
    Lots of time for readout
    Backgrounds don't pile up
  - $(m_\mu/m_e)^2 = \sim 40000$
    Enhanced s-channel rates for Higgs-like particles

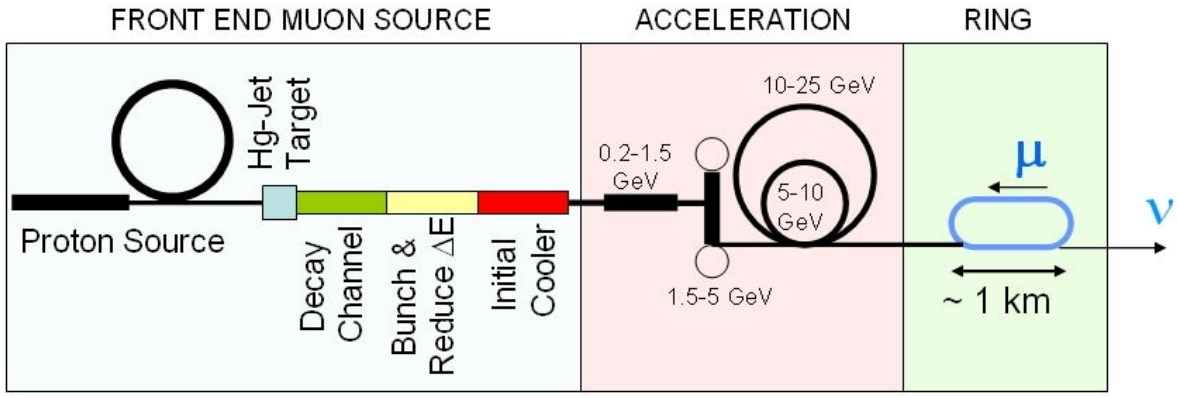
Muon Collider Motivation - 2



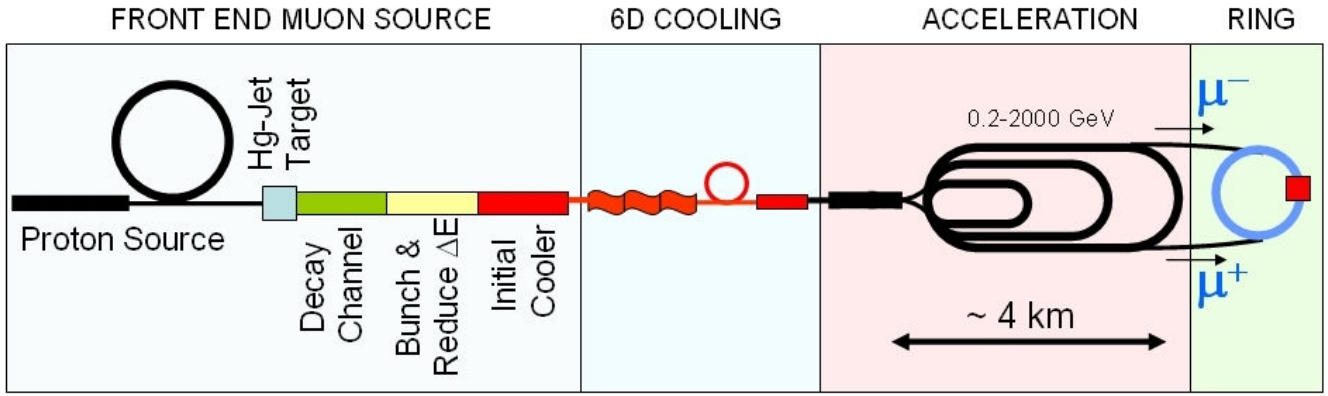
Muon Collider Motivation - 3



Muon Collider Schematic



NEUTRINO FACTORY



MUON COLLIDER

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

Beyond the Front End

Neutrino Factory

COOLING:

$\varepsilon_{\perp}$ ~ 7mm

ACCELERATION:

4-25 GeV

STORAGE RING

Racetrack or Triangle

DETECTOR

Magnetized calorimeter

Muon Collider

COOLING:

$\varepsilon_{\perp}$ ~ 3 – 25 μm and $\varepsilon_{//}$ ~ 70 mm

ACCELERATION:

O(TeV)

STORAGE RING

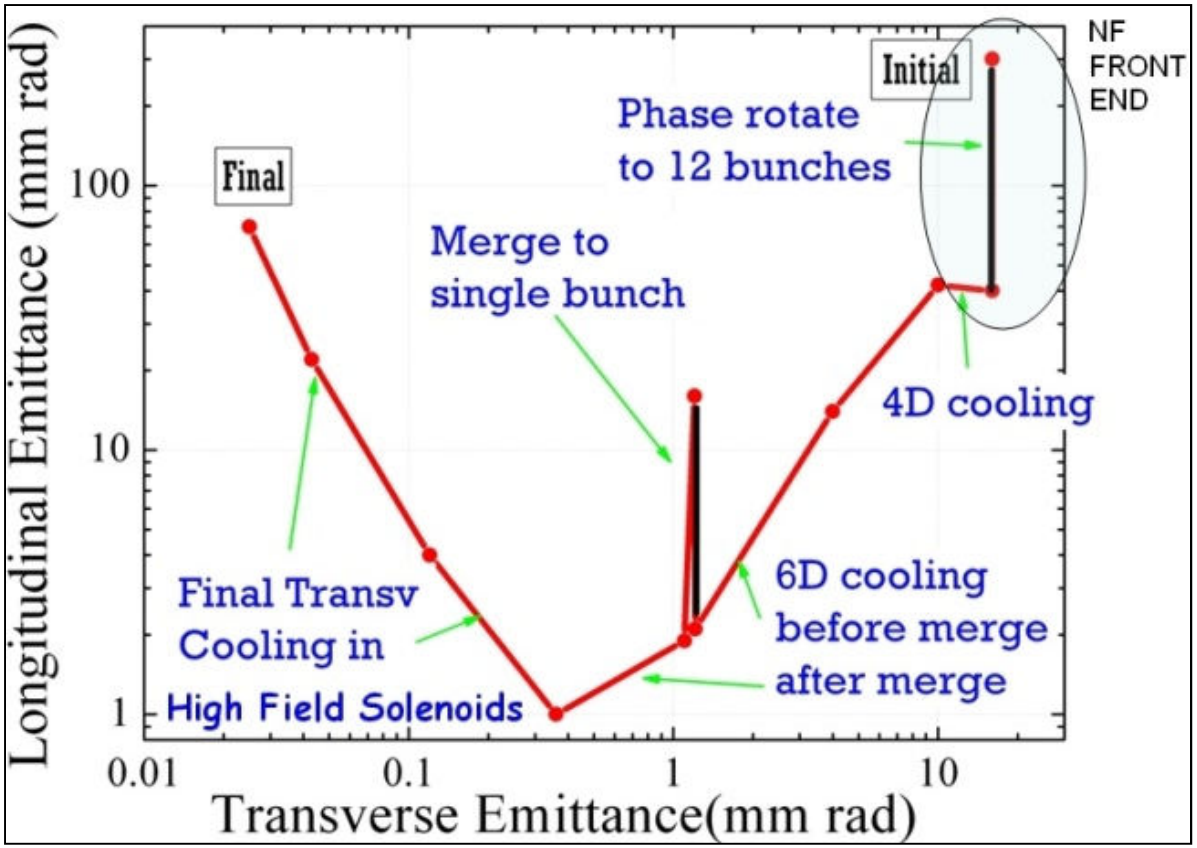
Collider Ring, low β IP, shielding

DETECTOR

Collider detector

6D Cooling

- MC designs require the muon beam to be cooled by ~ $O(10^6)$ in 6D [c.f. $O(10)$ in 4D for a NF]

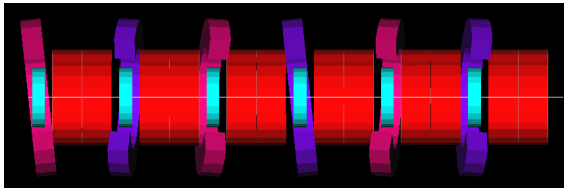


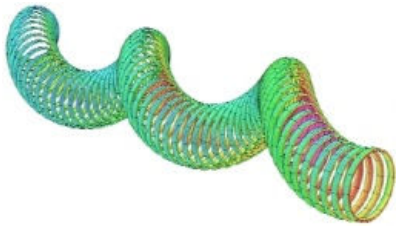
REQUIRES BEYOND STATE OF ART TECHNOLOGY → **R&D**

Muon Collider 6D Cooling R&D

New beamline built at FNAL to test 6D cooling channel components in the MuCool Test Area

First beam test will be with high pressure RF cavities.





Detailed Simulations for candidate 6D cooling schemes

HTS cable R&D

HCC magnet tests

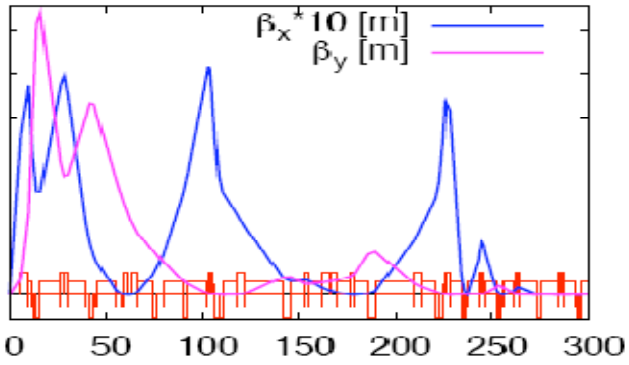
Magnet development for 6D cooling channels

Acceleration Scheme

- Early Acceleration (to 25 GeV ?) could be the same as NF. Needs study.
- Main Acceleration – Attractive Candidates
  - RLAs (extension of NF accel. scheme ?)
  - Rapid cycling synchrotron – needs magnet R&D
  - Fast ramping RLA
- Options need further study → particle tracking, collective effects, cavity loading, ...

Collider Ring

- Muons circulate for ~1000 turns in the ring
- Need high field dipoles operating in decay backgrounds → R&D
- First lattice designs exist



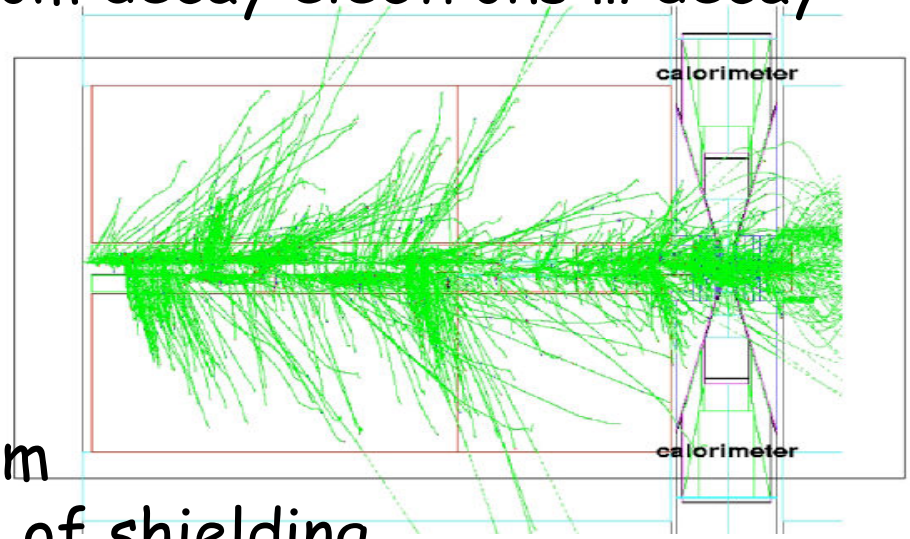
DESIGN PROCESS

- New ideas → conceptual designs for various options
- Comparison of different schemes, choice of the baseline
- Detailed lattice design with tuning and correction "knobs"
- Dynamic aperture studies with magnet nonlinearities, misalignments and their correction
- Transient beam-beam effect compensation
- Coherent instabilities analysis

WE ARE HERE

Shielding Detector Backgrounds

- MC detector backgrounds studied actively 10 years ago (1996-1997). The most detailed work was done for a 2×2 TeV Collider → √s=4 TeV.
- Large background from decay electrons … decay angles O(10) mrads. Electrons stay inside beampipe for ~6m.
- Shielding strategy: sweep the electrons born further than ~6m from the IP into ~6m of shielding.



- Detailed studies show that, with careful design, this shielding strategy works extremely well.

Background Levels

- Electrons born in the 130m long straight section: 62% interact upstream of shielding, 30% interact in early part of shielding, 2% interact in last part, 10% pass through IP without interacting.

- Detailed shielding design done plus background simulations using two codes (MARS & GEANT) → consistent results. Tungsten cone in forward direction with angle 20° (c.f. CLIC = 7°). With modern detector technologies, perhaps angle can be reduced & tungsten can be instrumented.

- Hit densities at, r=5cm are 0.2 hits/mm^2. Comparable to CLIC estimates. Also, ideas on how to further reduce hits by x100.

- SYNERGY with CLIC Detector R&D and design studies.

MC R&D – The Next Step

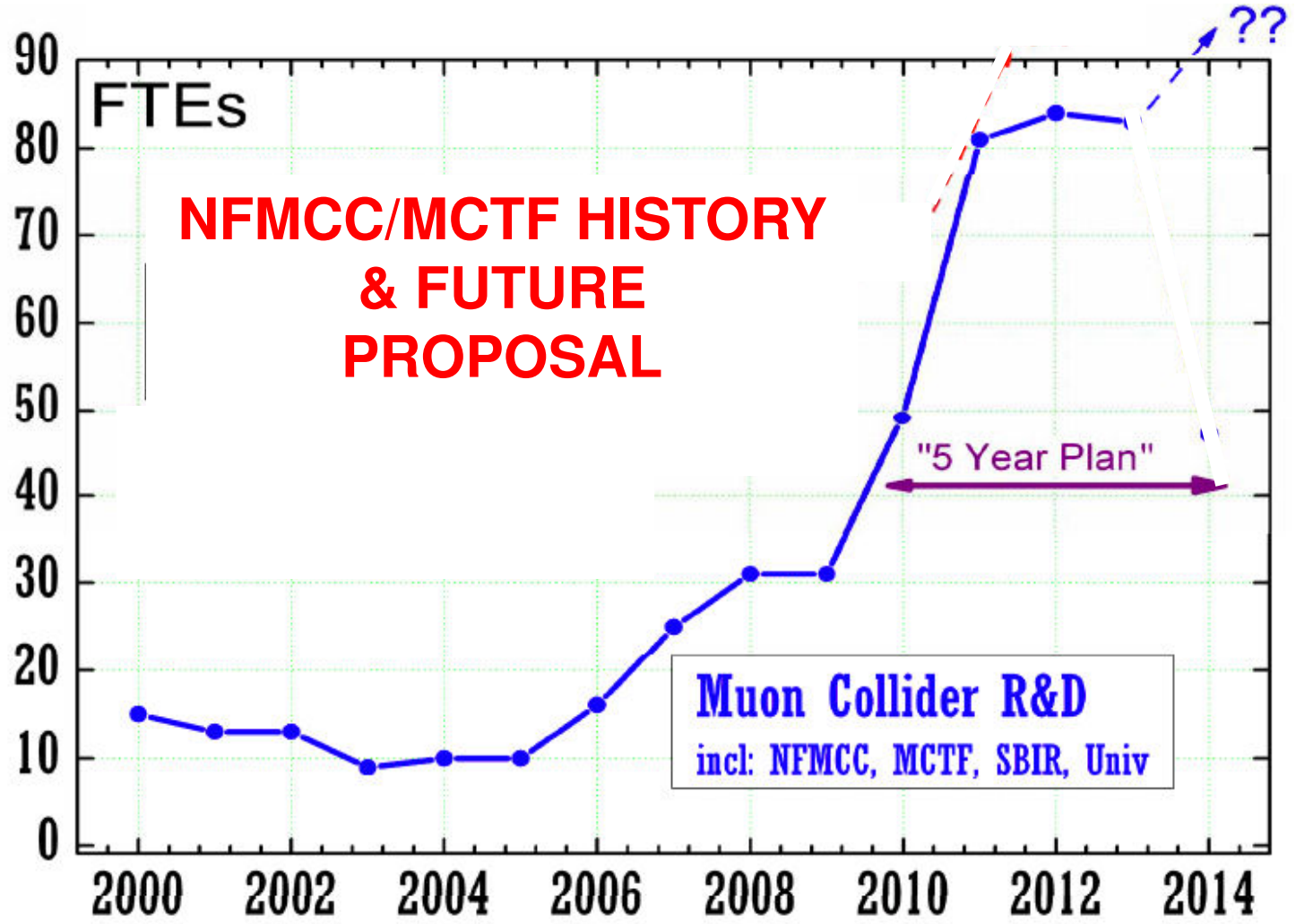
- In the last few years MC-specific R&D has been pursued in the U.S. by Neutrino Factory & Muon Collider Collaboration (NFMCC) & Muon Collider Task Force (MCTF)

- The NFMCC+MCTF community has submitted to DOE a proposal for the next 5 years of R&D, requesting a greatly enhanced activity, aimed at proving MC feasibility on a timescale relevant for future decisions about multi-TeV lepton colliders.

NFMCC/MCTF Joint 5-Year Plan

- **Deliverables in ~5 years:**
  - -Muon Collider Design Feasibility Report
  - - Hardware R&D results → technology choice
  - - Cost estimate
  - - Also contributions to the IDS-NF RDR
- **Will address key R&D issues, including**
  - - Maximum RF gradients in magnetic field
  - - Magnet designs for cooling, acceltn, collider
  - - 6D cooling section prototype & bench test
  - - Full start-to-end simulations based on technologies in hand, or achievable with a specified R&D program
- **Funding increase needed to ~20M$/yr (about 3x present level); total cost 90M$**

R&D – Ongoing


FTEs
NFMCC/MCTF HISTORY
& FUTURE
PROPOSAL
??
"5 Year Plan"
Muon Collider R&D
incl: NFMCC, MCTF, SBIR, Univ
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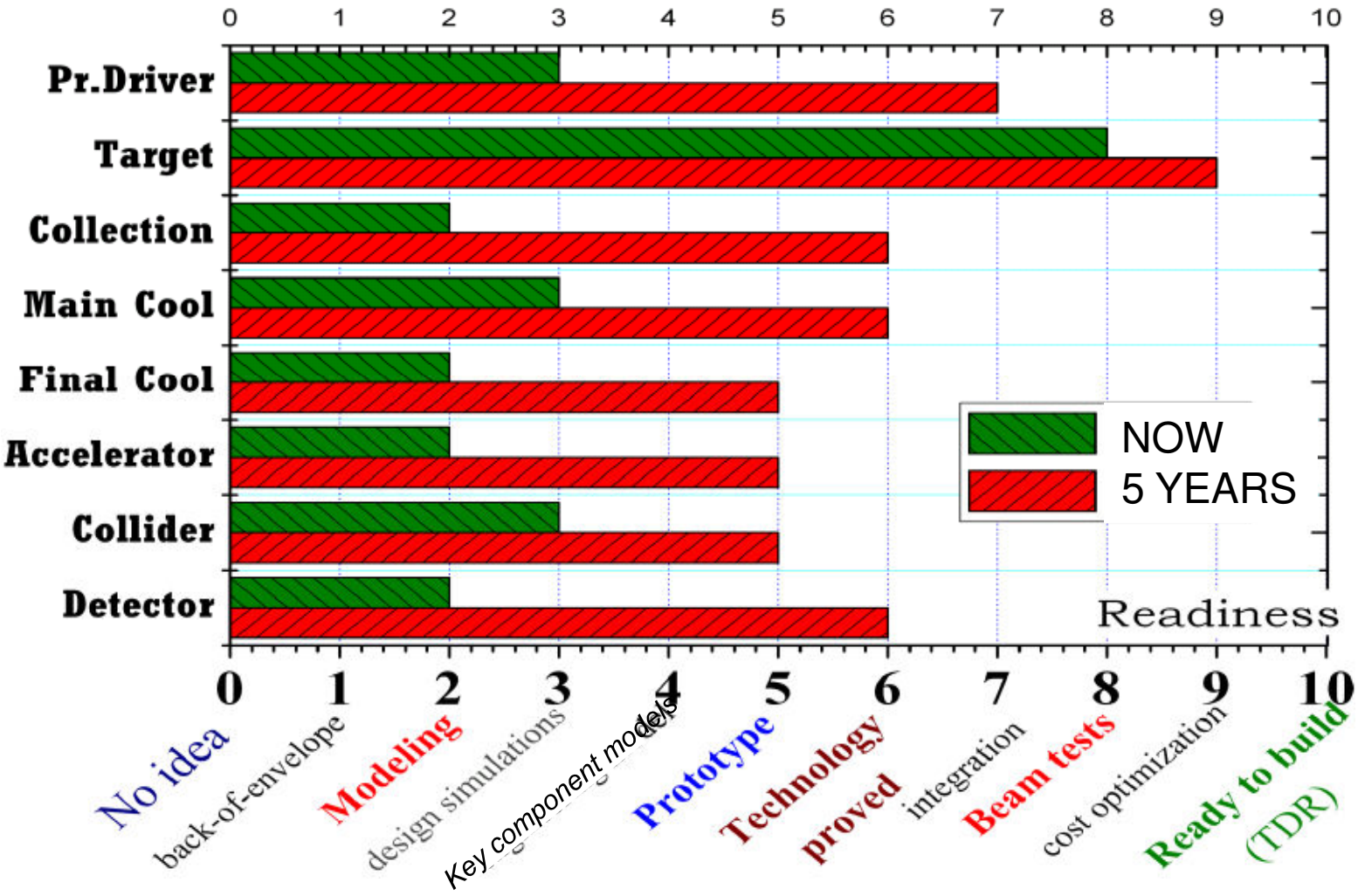
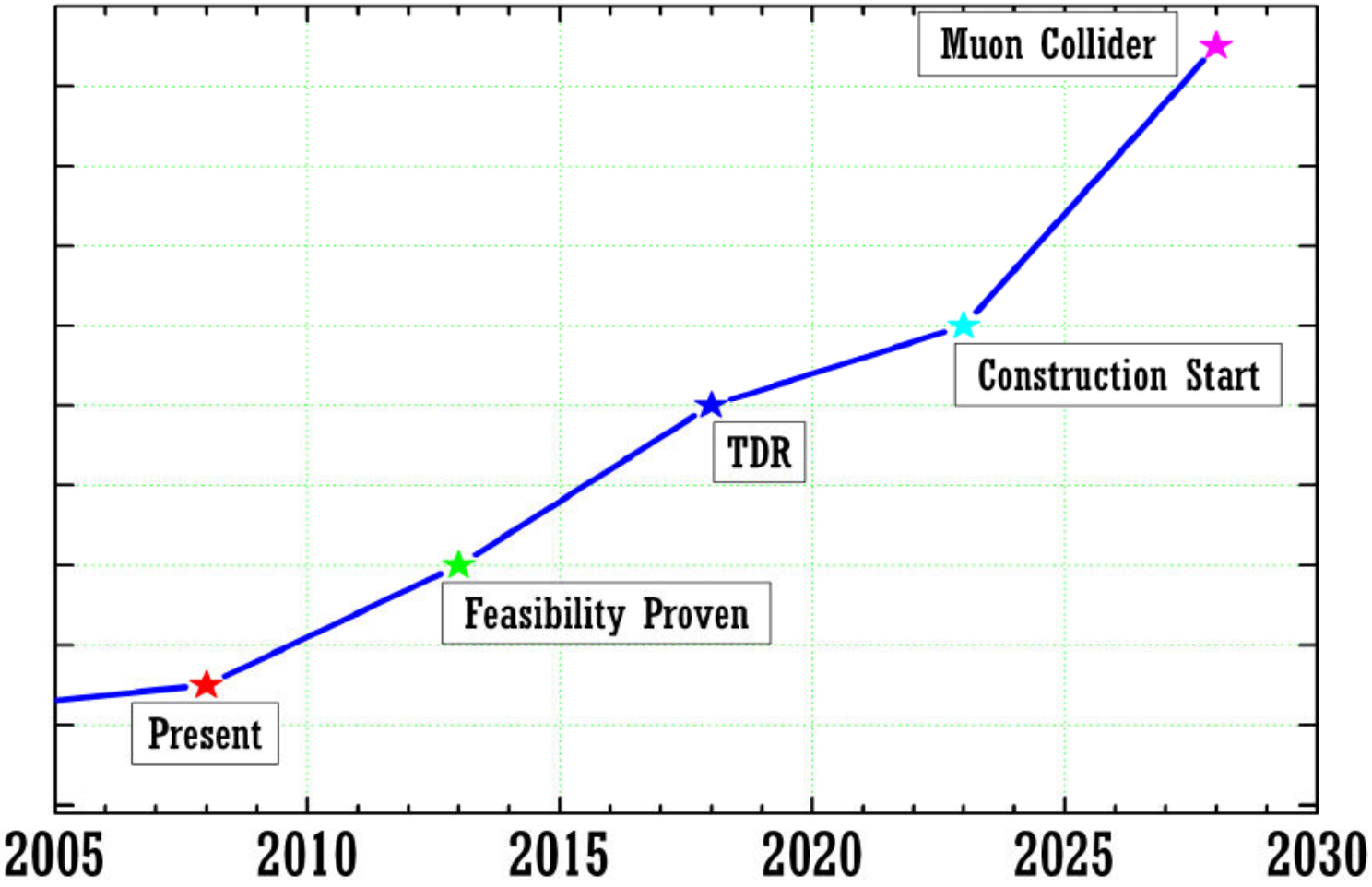
Anticipated Progress



Aspirational Bigger Picture

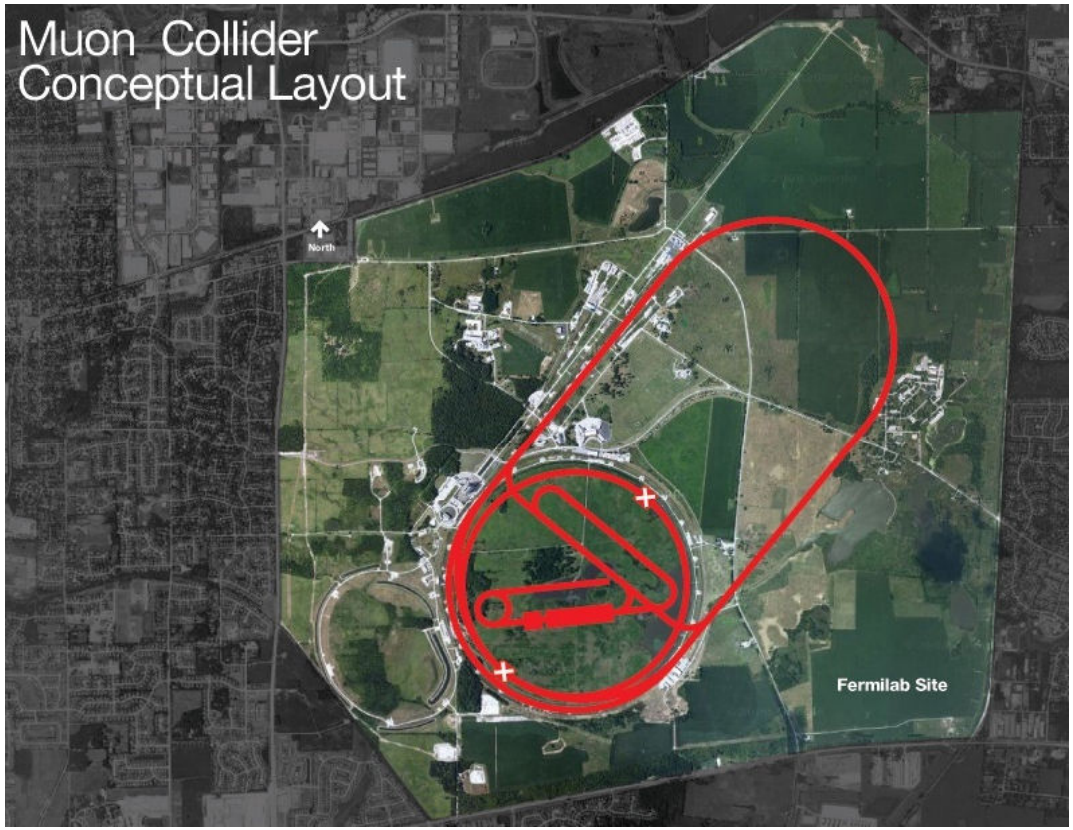


European MC R&D

- Key European contributions (leadership & technical) to the NF/MC front-end
  - MICE, MERIT, EMMA, ISS/IDS
- Some areas would seem natural for increased activity (exploiting expertise, prior investments, and future synergies):
  - Rebunching MW proton beams
  - Initial 6D cooling tests at MICE
  - 6D cooling experiment design studies
  - CERN-specific MC site study
  - Detector studies (synergy with CLIC)

Note: Workshop at FNAL Nov. 10-12

Site Dependent Studies

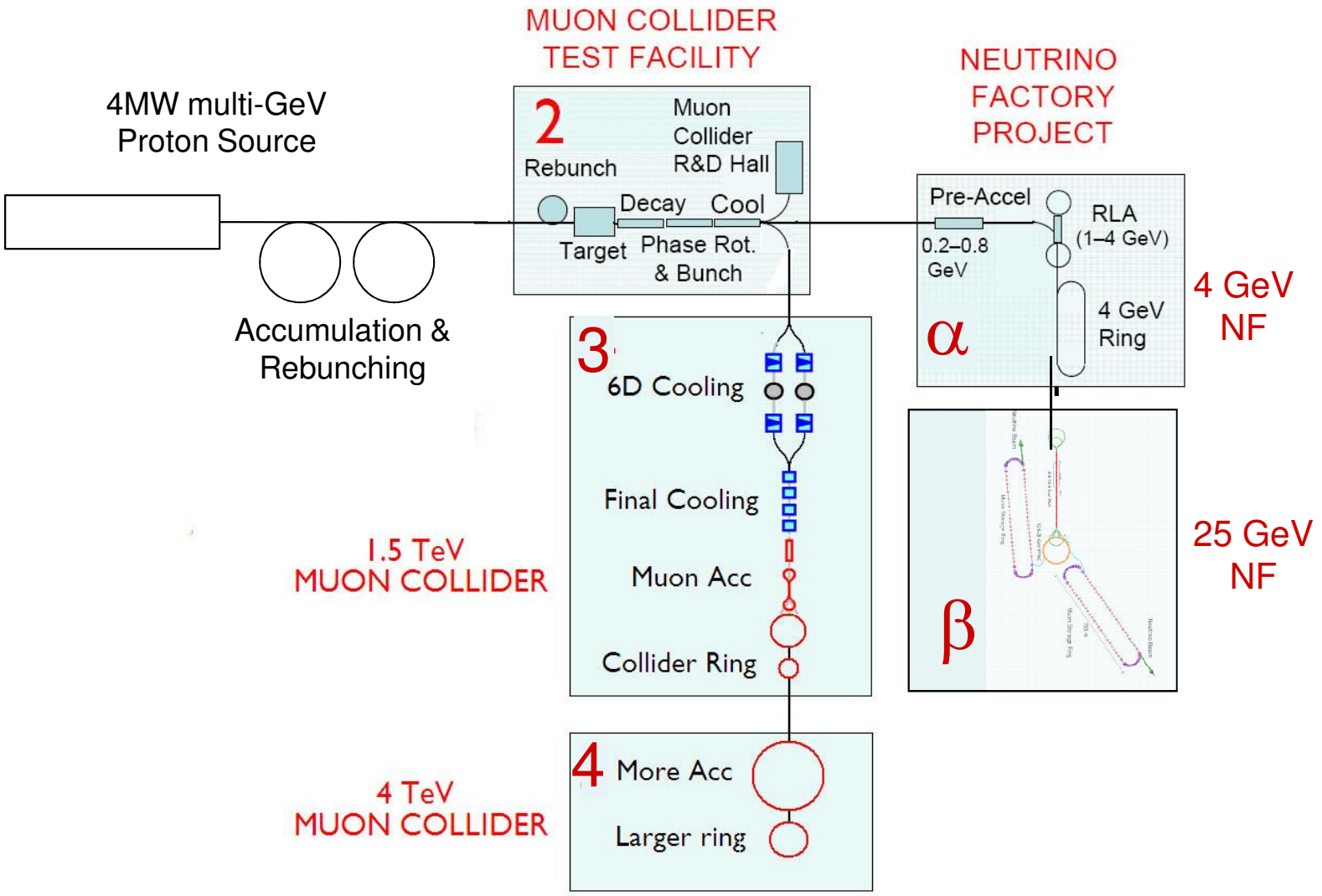


Plan to go beyond generic conceptual layouts, to specific layouts accounting for site-specific details:

- Geology
- Existing infrastructure

Would welcome CERN participation (e.g. CERN site dependent study)

Illustrative Staging Scenario



Final Remarks

- Lots of progress on the Front-End development for Muon Colliders
  - high intensity proton sources
  - NF R&D (IDS-NF, MERIT, MICE, …)
- Time has come to ramp up the Muon Collider specific R&D (keep tuned !)
- Main pushes on MC & CLIC R&D have become regionalized … that's OK, but ….
- … not so good if the R&D programs become completely diagonalized by region
  - cross-participation is healthy
- Lots of possibilities for increased European activity on MC R&D that exploit expertise, prior investments, & common interests