As part of the Fermilab Steering group's activities, we are considering the following option: if LHC tells us that ILC and CLIC (~1 TeV) energies are too low, what is the next collider? Thinking of this option will help us understand R&D steps needed.

Possible scenarios are
a) if LHC does not discover anything, "no" hope to build another "BIG" collider for a while.

b) if LHC discover SUSY particles such as squarks and sgluinos and its results indicate that sleptons are likely at 1-2 TeV, we probably want to build a muon collider.

c) if LHC has results (significant deviations from the Standard Model) indicating that there is new physics/particles at ~10 TeV, we probably want to build a ~100 TeV VLHC.

Are these good arguments? Are there any examples supporting a multi-TeV muon collider or a ~100 TeV?

Thanks very much for your help,
Young-Kee
6/22/07

I believe that all viable theoretical scenarios, except the single light Higgs Standard Model, indicate the need for a higher energy machine beyond LHC.

The single light Higgs Standard Model would indicate the need for a Higgs Factory, perhaps a lower energy ILC optimized to study the production and final states of the Higgs boson

Theoretical Scenarios

MSSM or NMSSM: Susy partners are heavy, eg down and strange squarks at several TeV. TeV scale indicated via Higgs lower bound of 115 GeV. MSSM is fine tuned to few percent level.

Little Higgs Theories: Little Higgs is like a Kaon; Condenses at 175 GeV; produced by chiarl symmetry breaking at 1 TeV caused by new dynamics (QCD-like, or extra dimensions) at 10 TeV

Extra Dimensions: KK-modes at 1/R of order multi TeV scale

Walking, Topcolor Assisted Technicolor + Extensions

Each requires a high energy machine(s) beyond LHC

A Case Study: Top Quark See-Saw Model

Top quark seesaw theory of electroweak symmetry breaking.
S. Chivukula, B. A. Dobrescu, H. Georgi, C. T. Hill
Phys.Rev.D59:075003,1999.

Top Quark weighs 600-700 GeV from condensation by a new strong interaction (eg, topcolor) at 1 TeV scale which breaks electroweak symmetry.

χ-quarks mix with top quark, seesawing mass of top down to 172 GeV.

χ-quark masses are a few (3-4) TeV

Theory is natural with no fine tuning !!!

LHC sees large WW scattering corresponding to a broad Higgs boson

Require a high energy machine to see χ-quarks

Top Quark See-Saw Model

Mass matrix for $t - \chi$ system is,

$$-\left(\overline{t_L} \;\; \overline{\chi_L}\right) \begin{pmatrix} 0 & \mu \approx 600\ GeV \\ m \approx 1\ TeV & M \approx 4\ TeV \end{pmatrix} \begin{pmatrix} t_R \\ \chi_R \end{pmatrix}$$

Diagonalized:

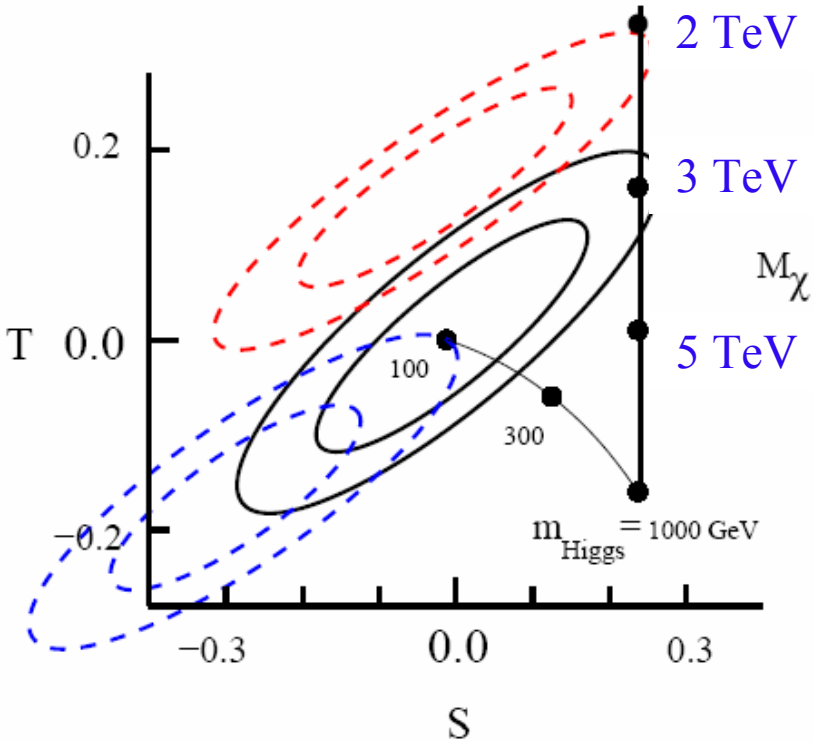
$$\begin{aligned} m_t &\approx \frac{\mu m}{M} \\ m_\chi &\approx M \end{aligned}$$

1998: Top Seesaw DOA (outside of the S-T ellipse $\sim 4\sigma$. (Chivukula, Dobrescu, Georgi, Hill)

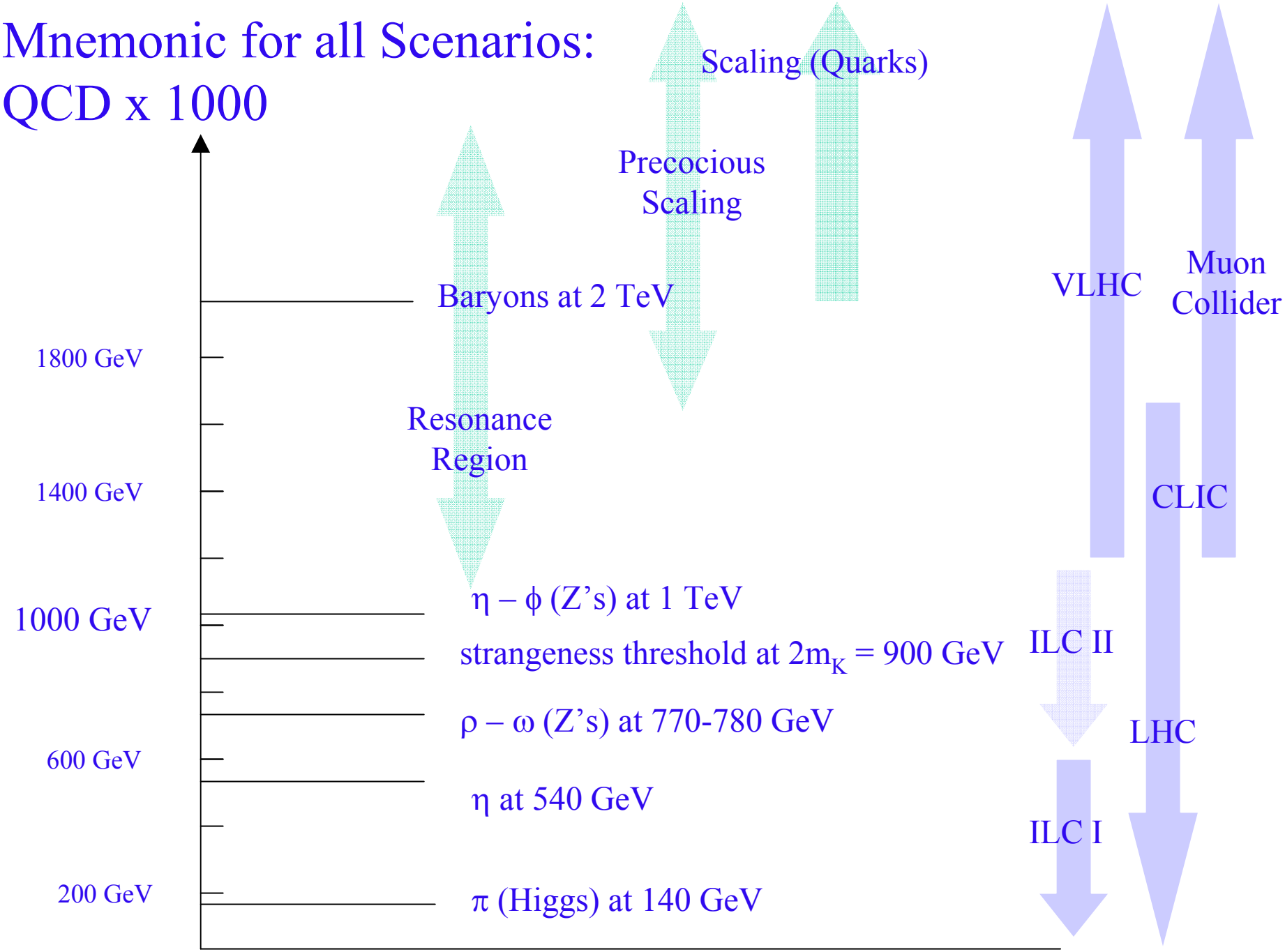
1999: S-T error ellipse shifts along major axis tow upper right (predicted by the theory!).

2001: Inconsistencies in data; keep only leptons → Top Seesaw consistent and SM ruled out at $\sim 2\sigma$!

Theory consistent for natural values of its parameters at the 2σ level (He, CTH, Tait)



Mnemonic for all Scenarios: QCD x 1000



VLHC: http://conferences.fnal.gov/hadroncollider/

International Advisory Committee:

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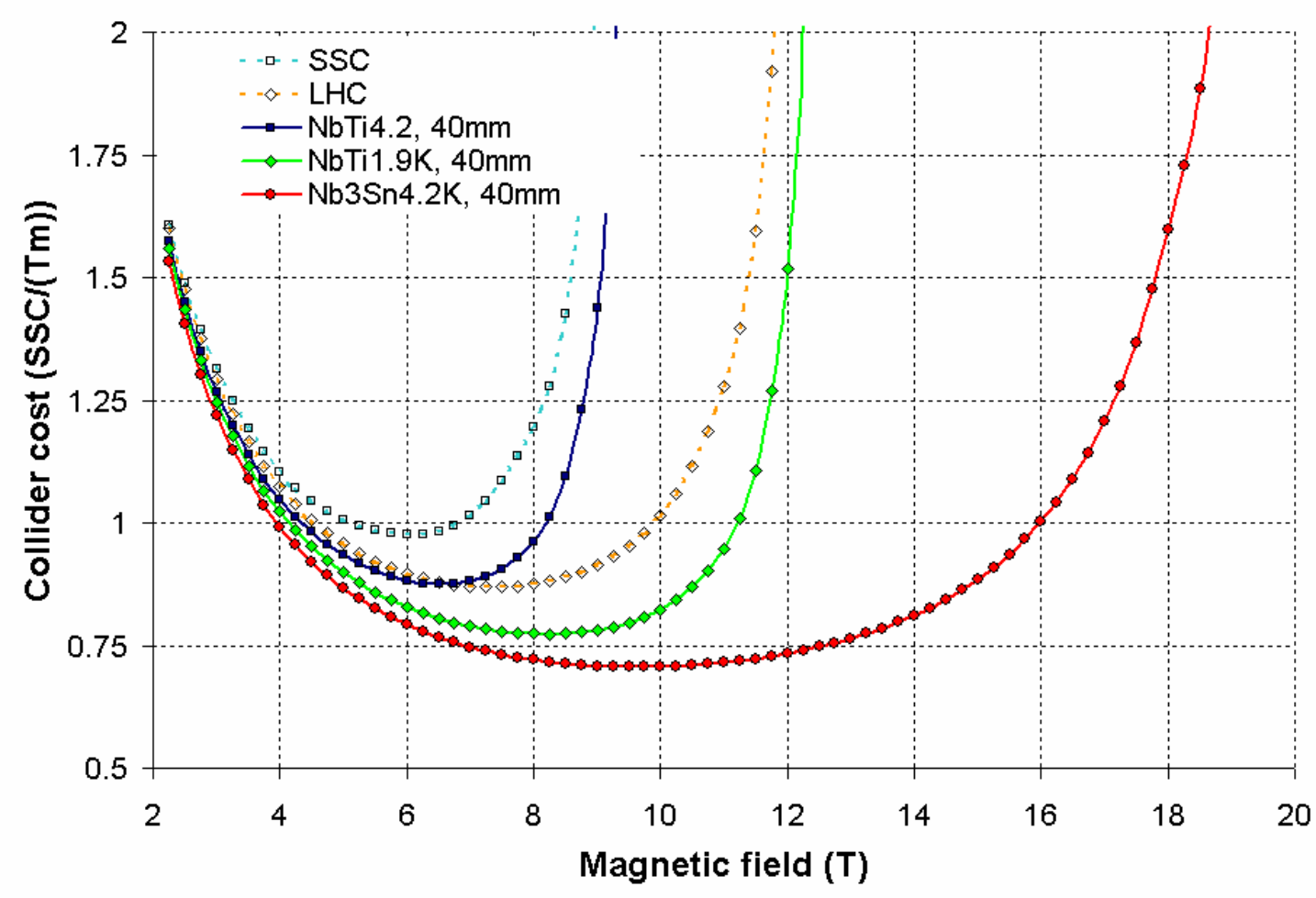
Peter Limon's talk at

http://conferences.fnal.gov/hadroncollider/prel_program_1016.html



Peter Limon:

Stage-2 VLHC Conclusions

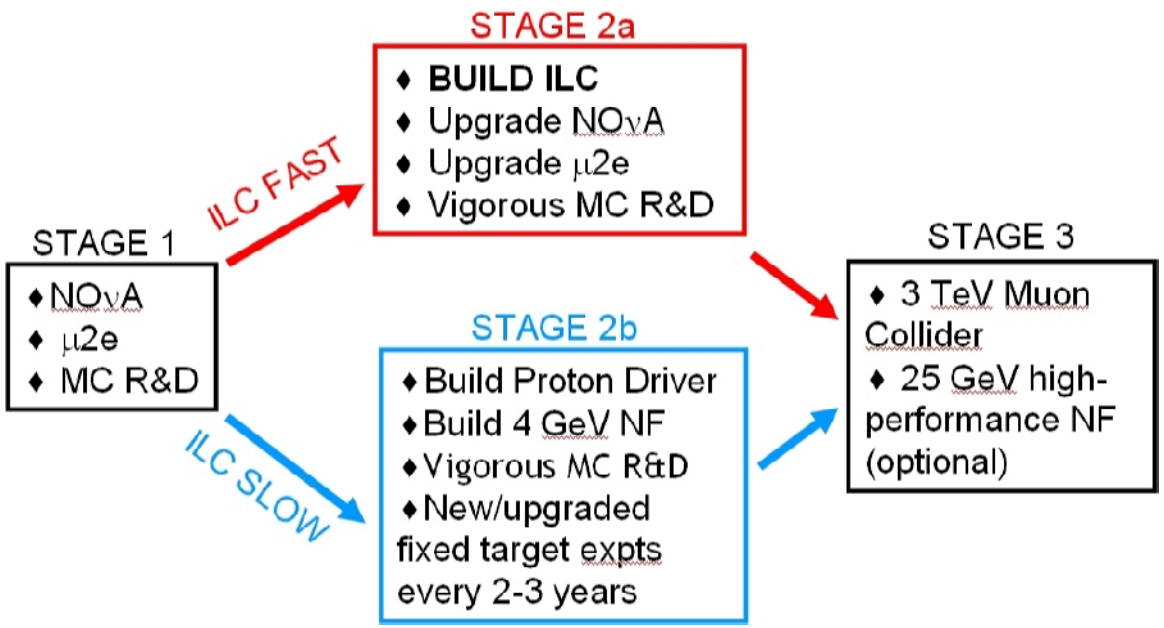
- The Stage 2 VLHC can reach 200 TeV and $2x10^{34}$ or more in the 233 km tunnel.
- A large-circumference ring is a great advantage for the high-energy Stage-2 collider. A small-circumference high-energy VLHC may not be realistic.
  - The optimum magnetic field for a 100-200 TeV collider is less than the highest field strength attainable because of synchrotron radiation, total collider cost and technical risk.
- The minimum aperture of the magnet is determined by beam stability and synchrotron radiation, not by field quality.
- There is the need for magnet and vacuum R&D to demonstrate feasibility and to reduce cost.
  - **This R&D will not be easy, will not be quick, and will not be cheap.**

Muon Collider:

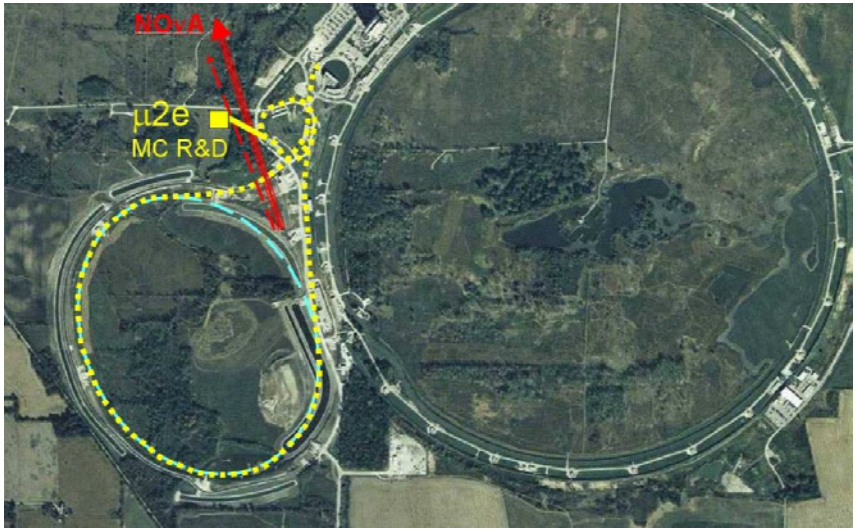
S. Geer's talk:

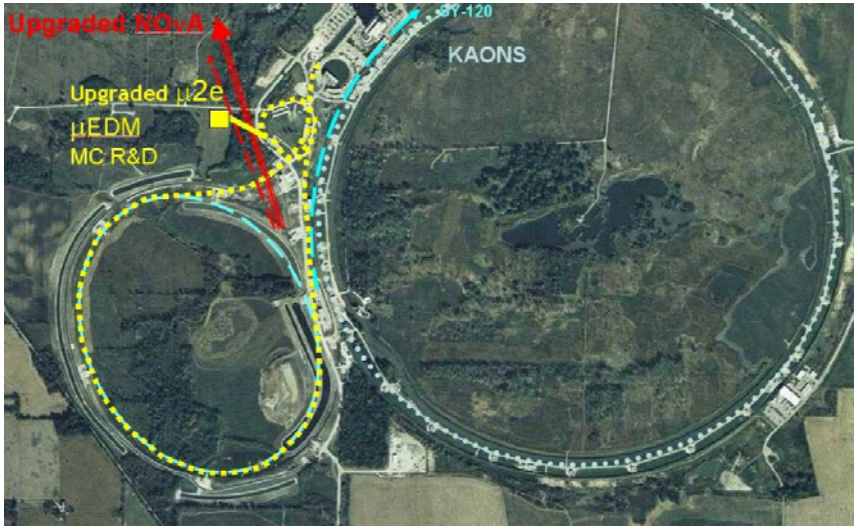
A Staged Pathway to the Energy Frontier

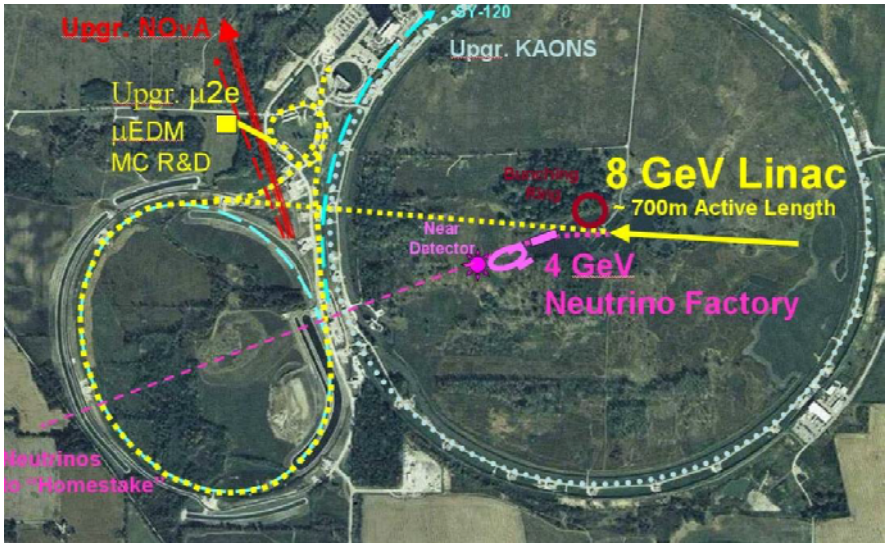
Estia J. Eichten, Steve Geer, Christopher T. Hill, Alvin Tollestrup

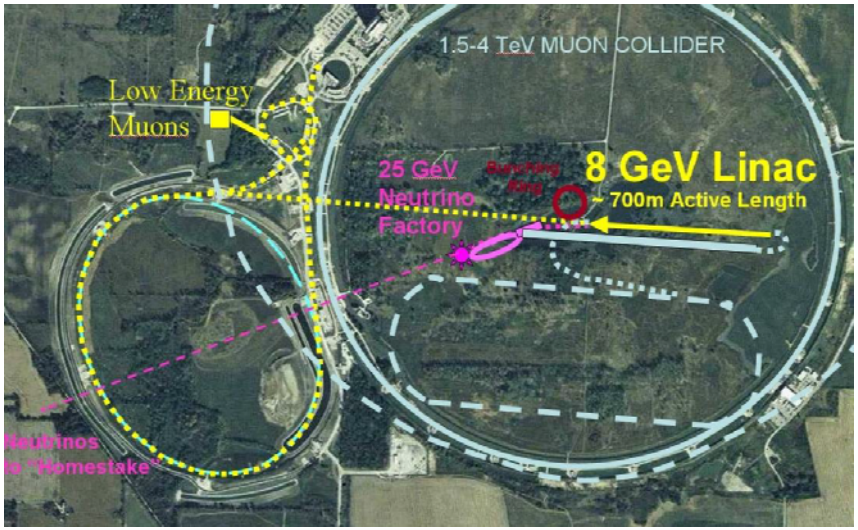


Footprint and Histology









What to do?

Projects subject to LHC breakpoint:

Aggressive R&D program on SCRF !!!

Aggressive R&D program on Muon Cooling:
Feasibility I in 5-7 years !!!

Perhaps need for moderate R&D on VLHC magnets:
Mostly Political Calculus ?!!

Independent of LHC breakpoint:

Mount Experiments: Neutrinos, Mu2E, Kaons

Plan project X (aka proton driver/pion source)