A pp and an e+e- Collider in a 100 km ring at Fermilab
VLHC/VLEP

Pushpa Bhat

Fermilab

& C.M. Bhat, W. Chou, E. Gianfiece-Wendt, J. Lykken,
M. Medina, G.L.Sabbi, T. Sen, R. Talman

July 25-26, 2013

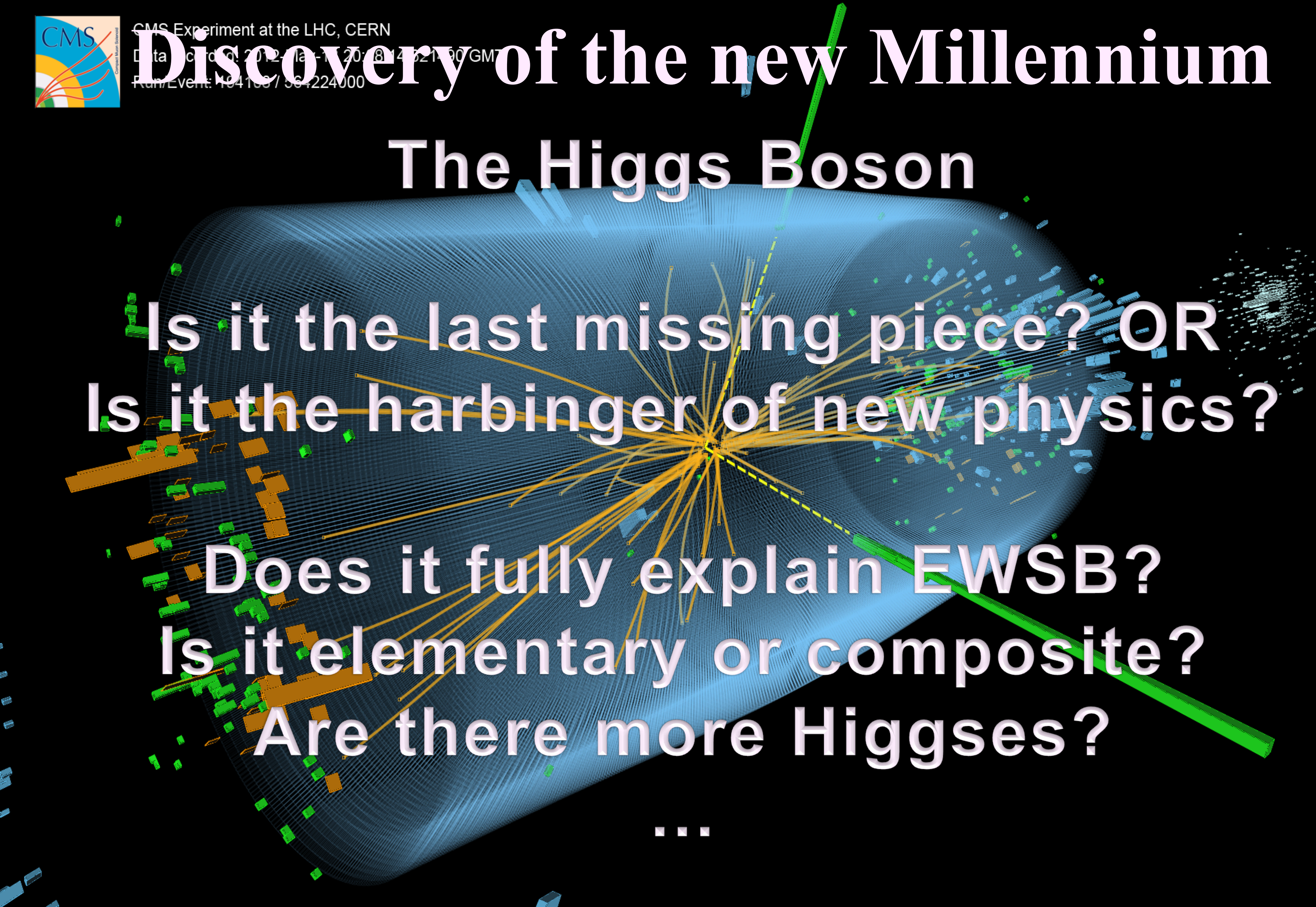
TLEP Workshop, Fermilab

A year ago on July 4th


The Economist
In praise of charter schools
Britain's banking scandal spreads
Volkswagen overtakes the rest
A power struggle at the Vatican
When Lonesome George met Nora
JULY 7TH–13TH 2012
Economist.com
A giant leap for science
Finding the Higgs boson


Science
21 December 2012 | $10
BREAKTHROUGH of the YEAR
The HIGGS BOSON
AAAS

Discovery of the new Millennium



The Higgs Boson

Is it the last missing piece? OR
Is it the harbinger of new physics?

Does it fully explain EWSB?
Is it elementary or composite?
Are there more Higgses?

...

So far so good.. hoping for better!

- Thanks to the discovery, the world HEP community is excited, interest in future energy frontier colliders has been reignited, and some old shelved ideas are finding new life.
- The LHC data, so far, indicate that the new particle has properties consistent with a SM Higgs boson. But its measured mass is tantalizingly consistent also with an SM-Higgs-like boson from new physics beyond the SM.
- We are where we had suspected to find ourselves – a low mass SM-like Higgs found, and nothing else! So far. But, that could change!

Physics at the Terascale

- To fully elucidate EWSB and understand the Terascale landscape
  - Study the Higgs boson that has been found (Mass, width, spin-parity, couplings)
  - Search for other physical states at higher mass scales
    - Evidence for SUSY, extra dimensions, heavier gauge bosons W', Z', heavier fermions, ..
  - Measure vector boson scattering and couplings
    - Longitudinal vector boson scattering and VBF production
- An e+e- collider would be a nice complement to the LHC. A hadron collider at ~100 TeV would be a lot more useful!

The Case for a VLHC

- Hadron colliders with their broad-band parton collision energies are Discovery Machine, and can make precision measurements!
- Historically, each time collision energy of hadrons went up significantly, we have discovered new particles.
- Top quark discovered at the Tevatron, after searches at SLC and LEP! And, Higgs discovery came at the LHC.
- However, since we have not found any new physics at $\sqrt{s} = 8$ TeV, if we do find new physics at 13-14 TeV it is likely to be at the limit of LHC reach. (Low hanging fruits?)
- "Regardless of what we will find at the LHC we will eventually want to have a hadron collider operating in the 100 TeV range." - U. Baur, HEPAP subpanel, June 2001

The Case for a VLHC

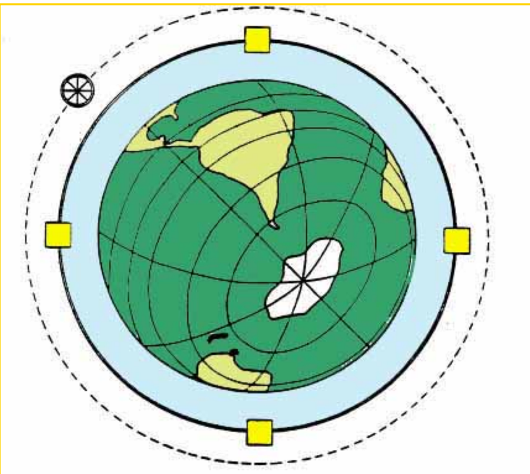
- If some new physics is found at the LHC at 13-14 TeV, then it makes a lot more sense to take a big jump in energy (~an order of magnitude) rather than a small one (~x2)
  - If some heavy "partner" particles are found, VLHC can find the full suite of partners (SUSY)
  - If exotic resonances are found, VLHC can fill out the "tower" of resonances, confirming extra dimensions
  - Complete measurements of vector boson scattering, explore fully the mechanism of EWSB, and SUSY breaking if SUSY is found
- Higgs Boson:
  - VLHC would enable precision measurements of the Higgs including Higgs self-coupling, and rare decays of the Higgs!
- VLHC has direct discovery potential in 10's of TeV range

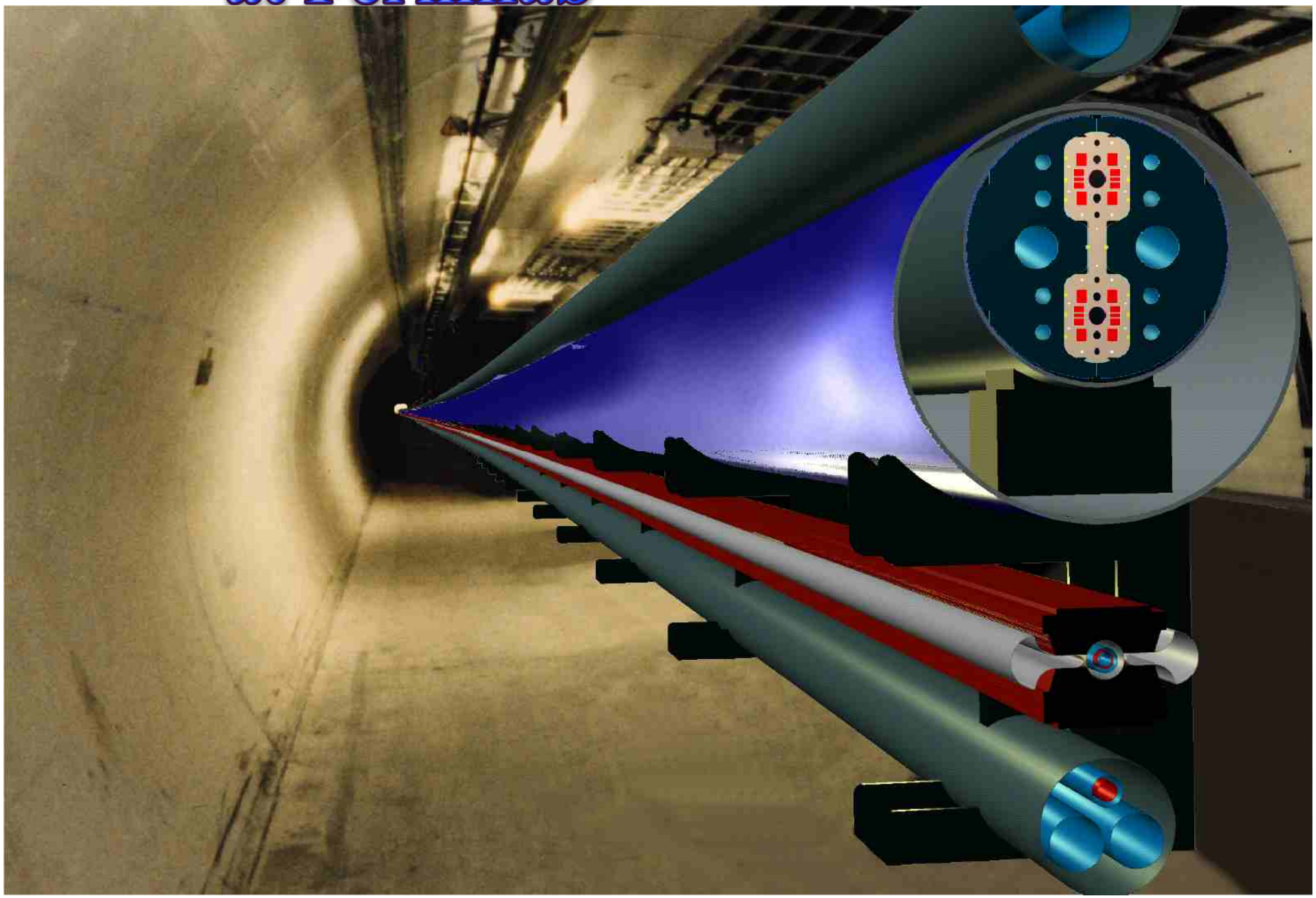
Some History

- US HEP/AP Community has been through some phases of "design" and "construction" for 80 – 500 km machines, in the past three decades.
  - SSC was going to be 87.1 km in circumference, and $\sqrt{s} = 40$ TeV. 23 km tunnel bored and 17 shafts in Texas. $2B spent!
    - Conception: Snowmass 1983, Design: 1988-90; Construction initiated: 1988, Halted: 1993.
  - "VLHC"(1995 -2005) in various incarnations – Primarily 233 km; E_{CM} from 40 TeV (Stage 1) – 200 TeV (Stage 2) . http://vlhc.org/
  - Also considered VLLC (Very Large Lepton Collider) in VLHC tunnel
  - Pipetron: Low Cost Approach to a VLHC, To achieve > 100 TeV E_{CM} collider at the lowest possible $/TeV
- Many workshops, machine/physics/detector studies, HEPAP, VLHC steering committee, etc., R&D for magnets and many other aspects.

Very Large Hadron Collider
at Fermilab

vlhc.org





FNAL-TM-2149
(2001)

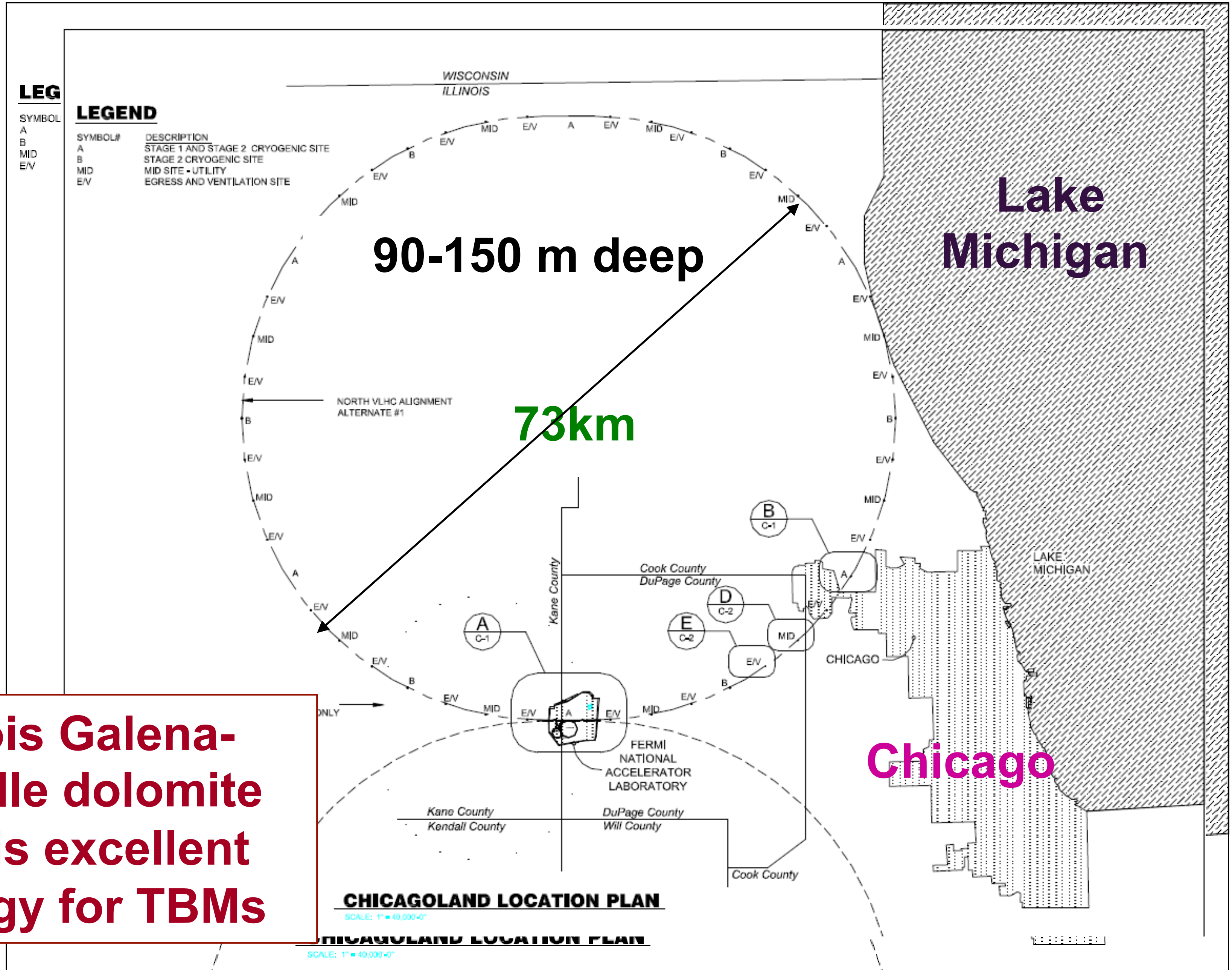
- Design Study for a two-stage Very Large Hadron Collider

VLHC in 2001

- Take advantage of the space and excellent geology near Fermilab.
  - **Build a <u>BIG</u> tunnel.**
  - **Fill it with a "cheap" 40 TeV collider.**
  - **Later, upgrade to a 200 TeV collider in the same tunnel.**

	Stage 1	Stage 2
Total Circumference (km)	233	233
Center-of-Mass Energy (TeV)	40	200
Number of interaction regions	2	2
Peak luminosity ($cm^{-2}s^{-1}$)	1×10^{34}	2.0×10^{34}
Dipole field at collision energy (T)	2	11.2
Average arc bend radius (km)	35.0	35.0
Initial Number of Protons per Bunch	2.6×10^{10}	5.4×10^{9}
Bunch Spacing (ns)	18.8	18.8
β^* at collision (m)	0.3	0.5
Free space in the interaction region (m)	± 20	± 30
Interactions per bunch crossing at L_{peak}	21	55
Debris power per IR (kW)	6	94
Synchrotron radiation power (W/m/beam)	0.03	5.7
Average power use (MW) for collider ring	25	100

233 km VLHC

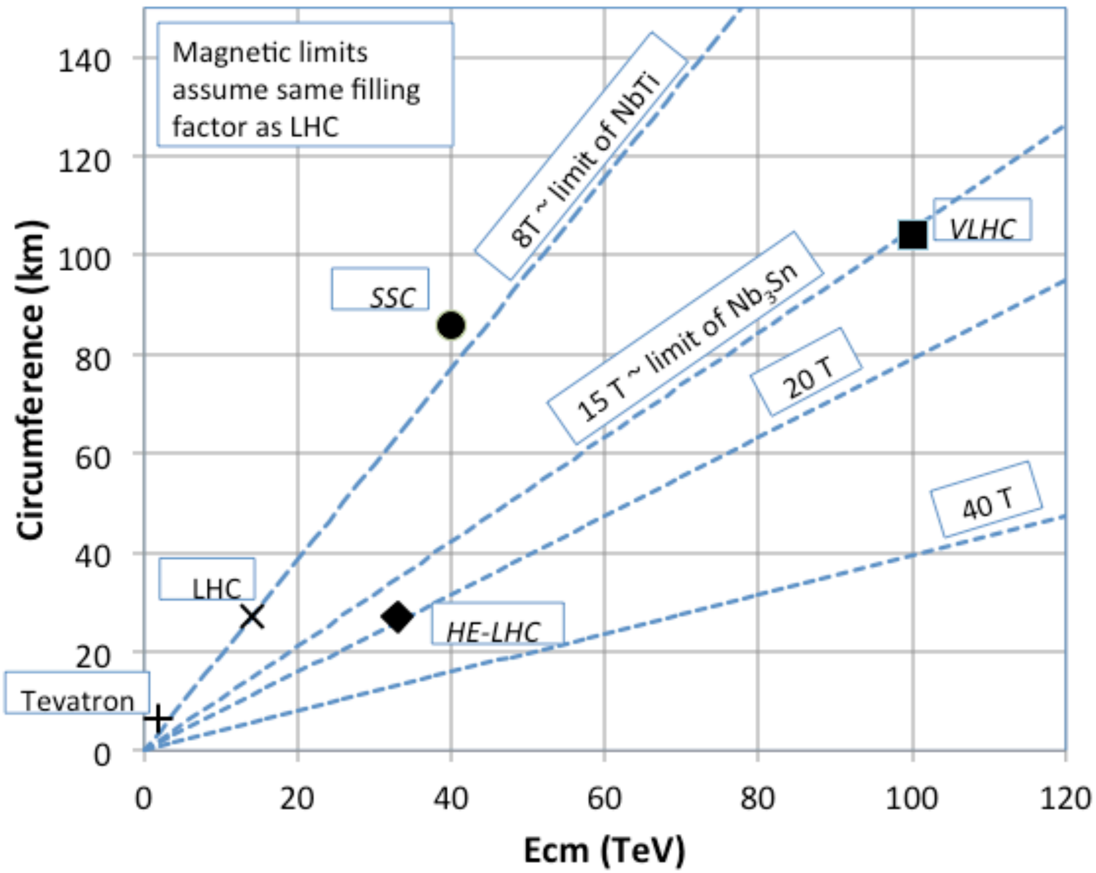


Illinois Galena-Plattville dolomite layer is excellent geology for TBMs

Site studies in Illinois

- We know a lot about the geology and tunneling in Illinois.
  - Thick, homogeneous dolomite at a depth of 300 – 500 ft
  - The Chicago TARP (Tunnel and Reservoir plan): 176 km of tunnel (9 - 33 ft in dia, up to 350 ft underground) completed
  - Studied for SSC, VLHC, ILC,..
- Many siting options for large rings have been studied.

VLHC (2013)



Use high field (~15 T) Superconducting magnets in a 100 km ring for a 100 TeV pp collider

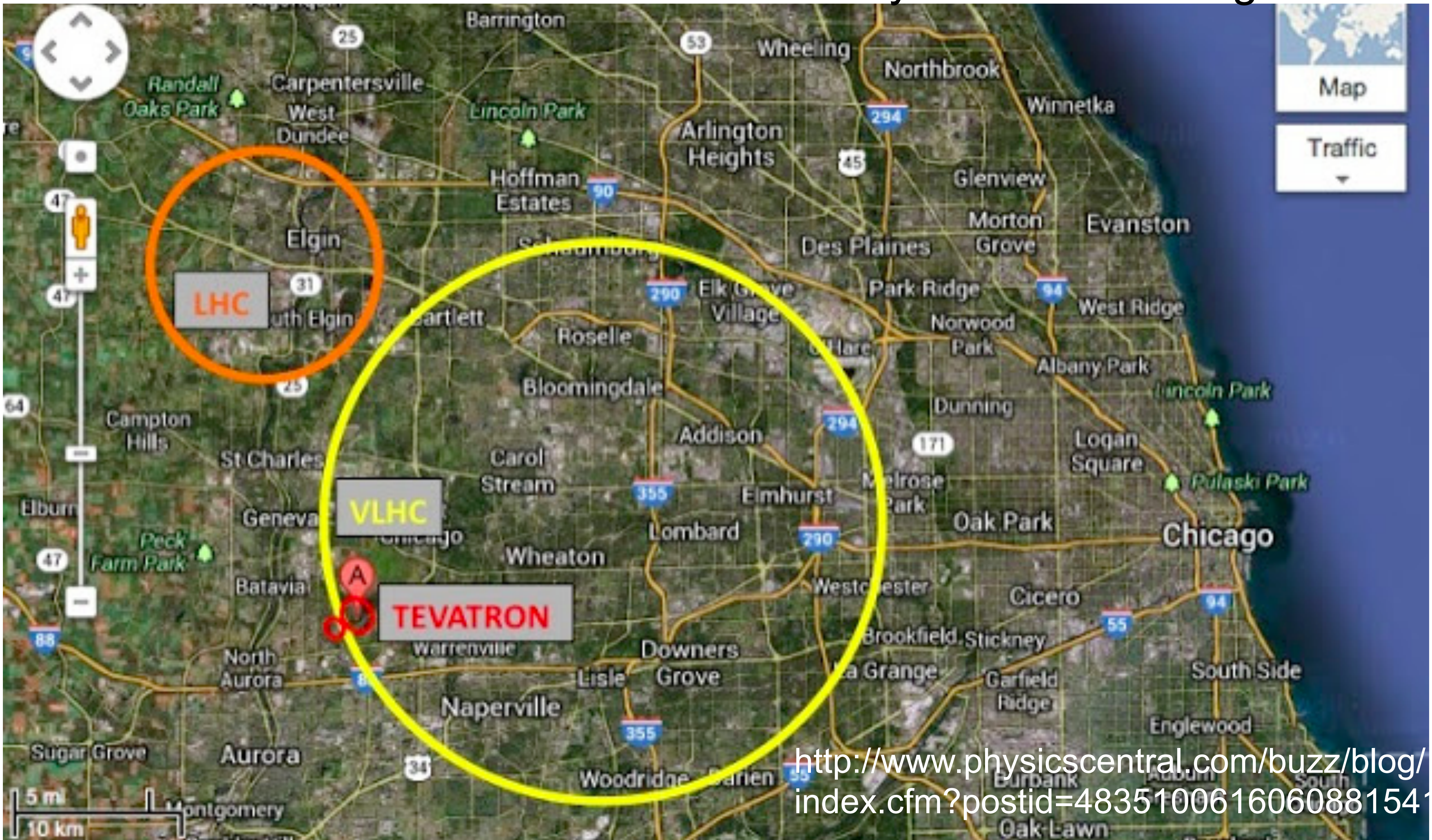
http://arxiv.org/pdf/1306.2369v1.pdf

And/OR host a 240-350 GeV VLEP in 100 km tunnel

Combine the efforts: TLEP/VHE-LHC/VLHC/VLEP

100 km ring for VLHC/VLEP

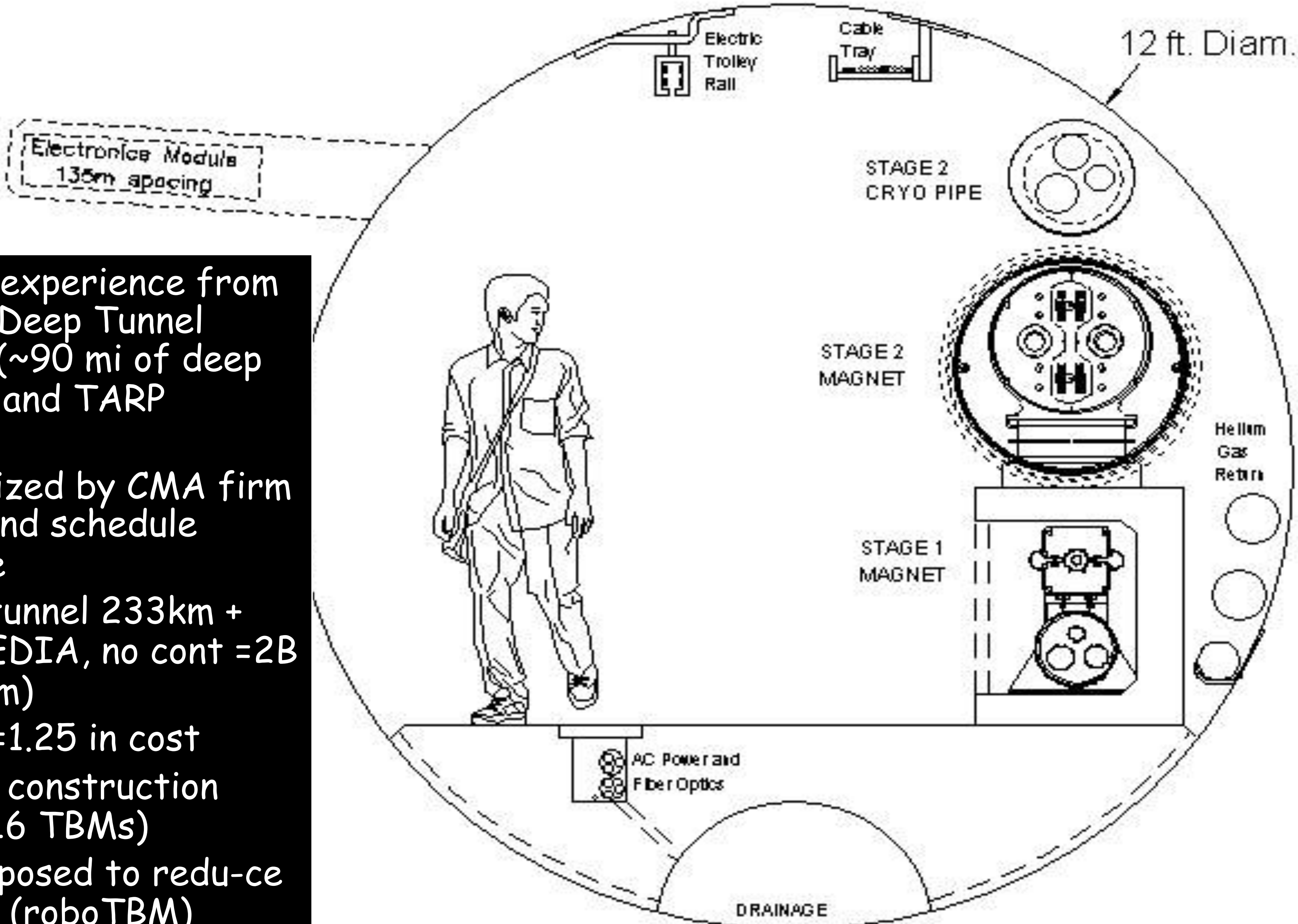
http://arxiv.org/pdf/1306.2369v1.pdf PhysicsCentral Blog



Back-up

VLHC (2001) Tunnel Cross Section

- A lot of experience from Chicago Deep Tunnel project (~90 mi of deep tunnels) and TARP project
- Summarized by CMA firm in cost and schedule estimate
- 12’ dia tunnel 233km + shafts+EDIA, no cont =2B $ (9k$/m)
- 16’/12’=1.25 in cost
- ~60 wks construction (4m/hr 16 TBMs)
- R&D proposed to redu-ce the cost (roboTBM)



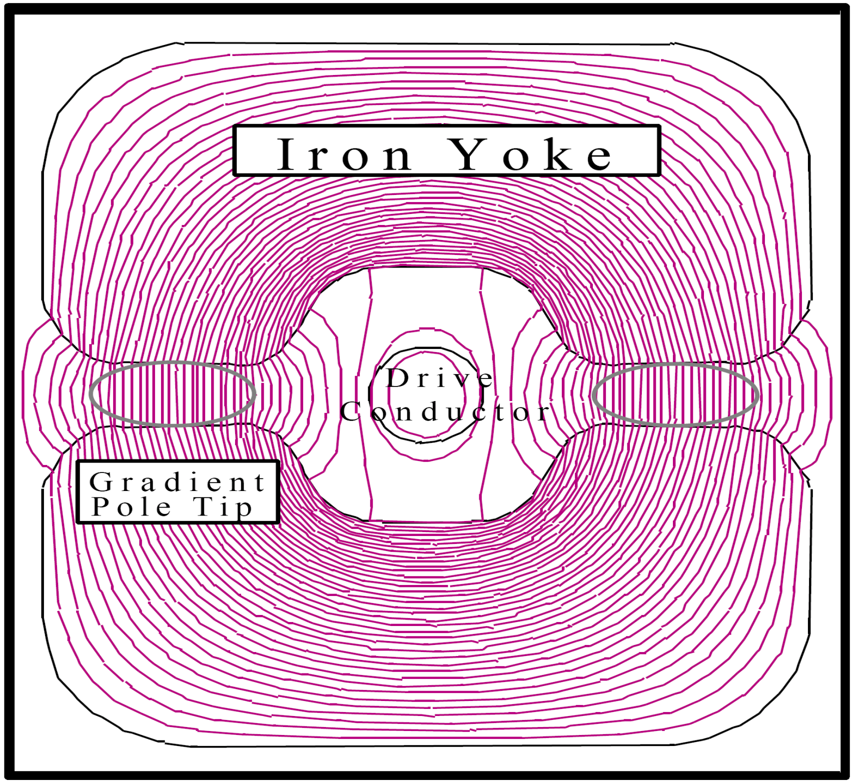
VLHC.org

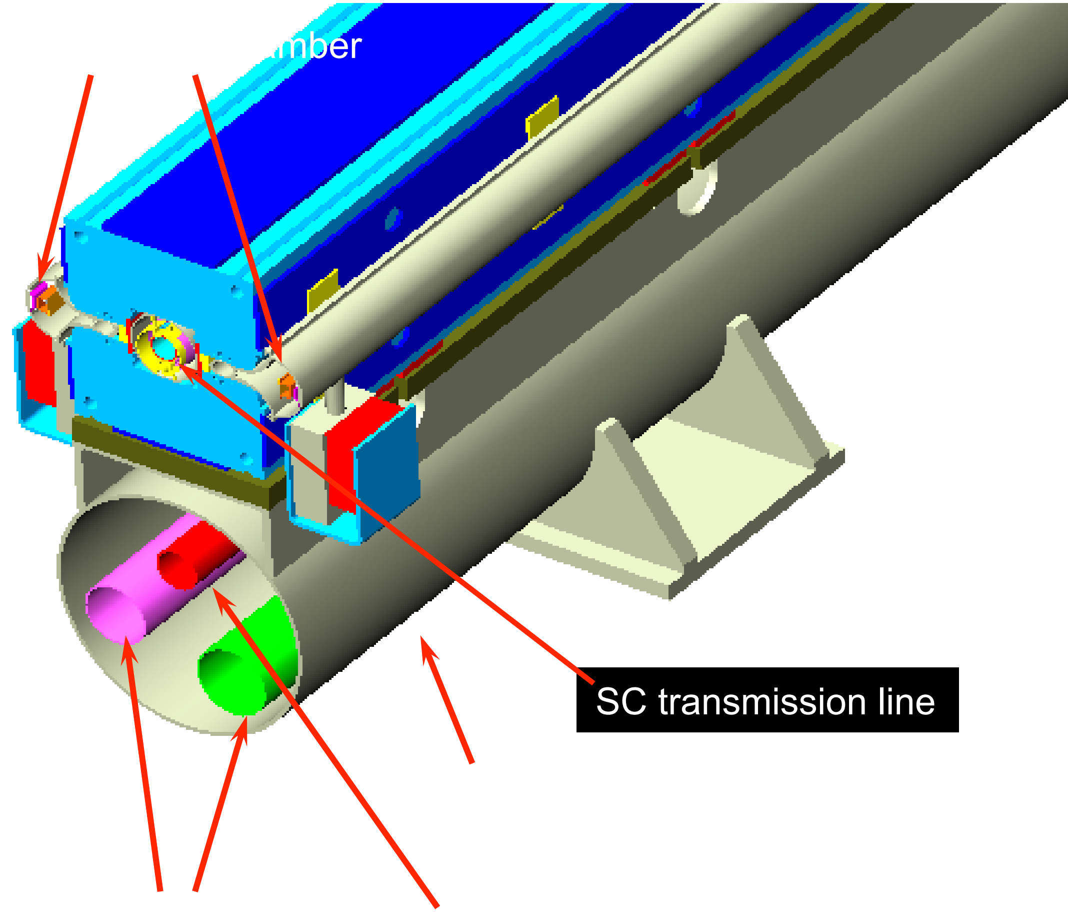
What's done by 2005

- Tunnel cost and schedule exercise by CMA firm
- Transmission line design
- 100kA power supply and HTS leads built, QPS
- 104kA transmission line test in MP6
- Superferric magnets designed & optimized
- 14 m of SF magnets built and tested
- Good accelerator quality B-field measured at inj energy up to 1.96T
- Collider Phase I designed (ZDR)
- Many AP issues addressed (e.g.instabilities)
- Thorough bottoms-up cost estimate

Shiltsev 2007

Transmission Line Magnet

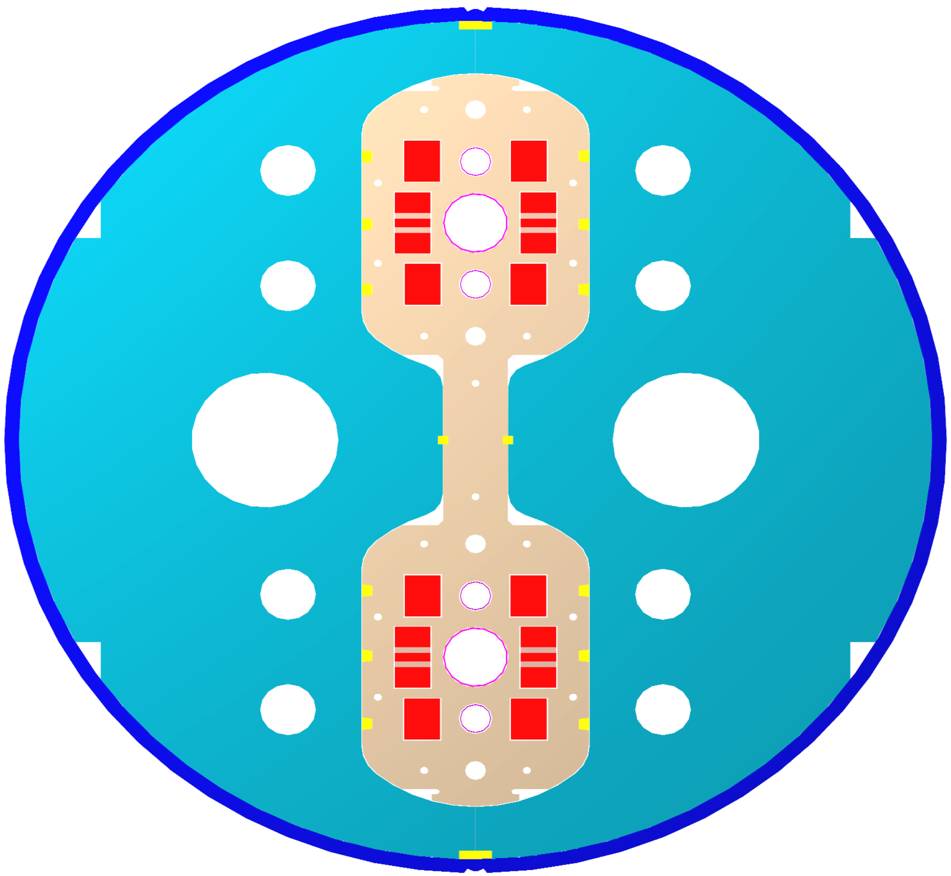


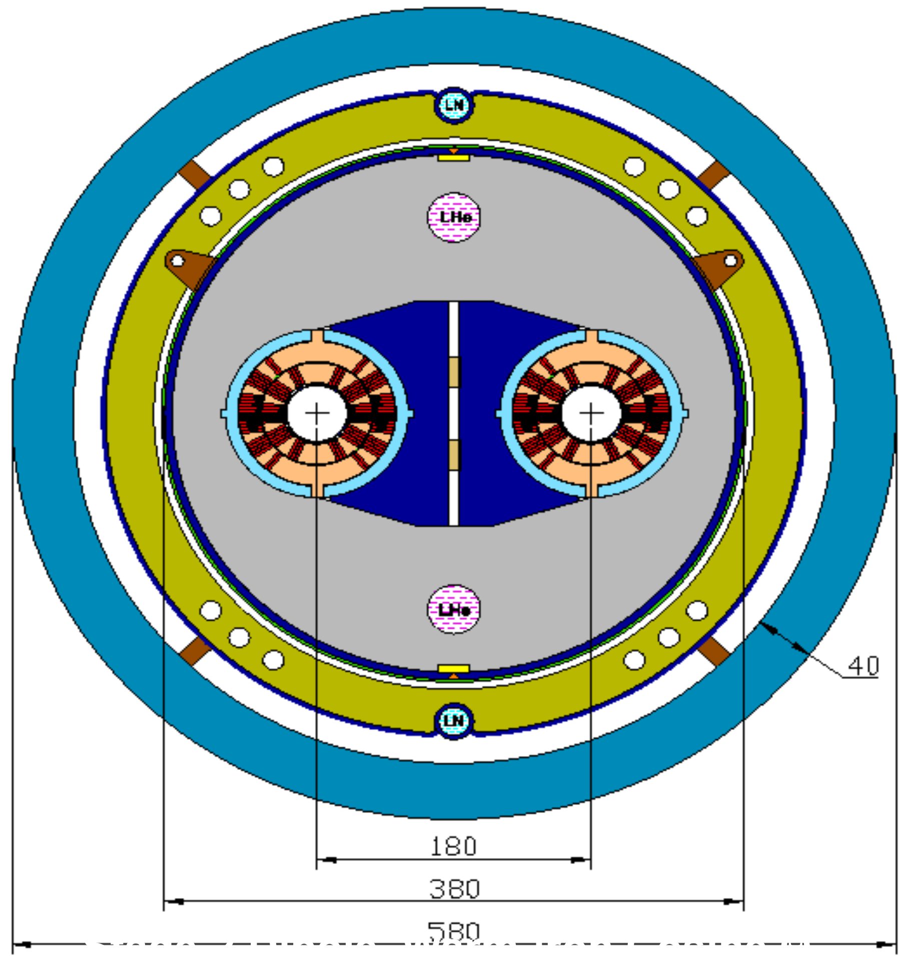


- warm iron and vacuum system
- superferric: 2T bend field
- 100kA Transmission Line
- alternating gradient (no quads)
- 65m Length

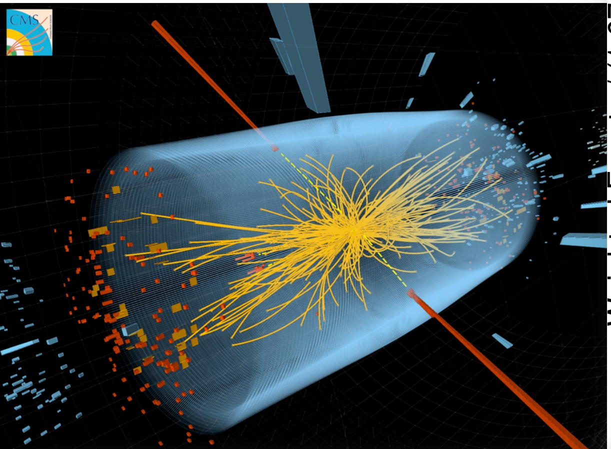
Stage-2: 10T+ Magnets

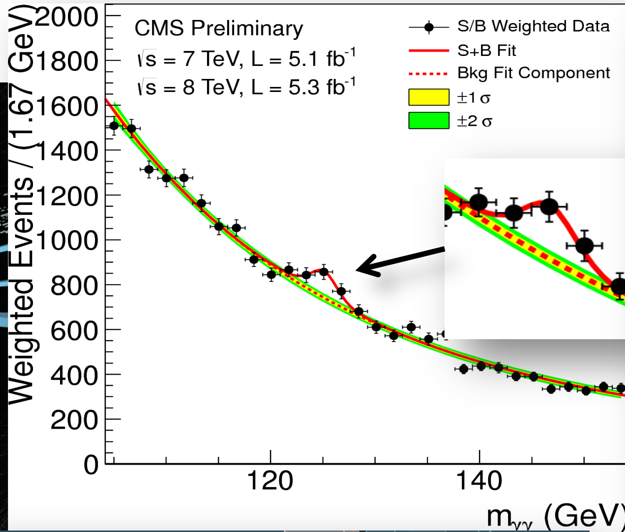
- There are several magnet options for Stage 2. Presently Nb_3Sn is the most promising superconducting material, e.g. LHC IR Upgrade magnets are being developed by US LARP

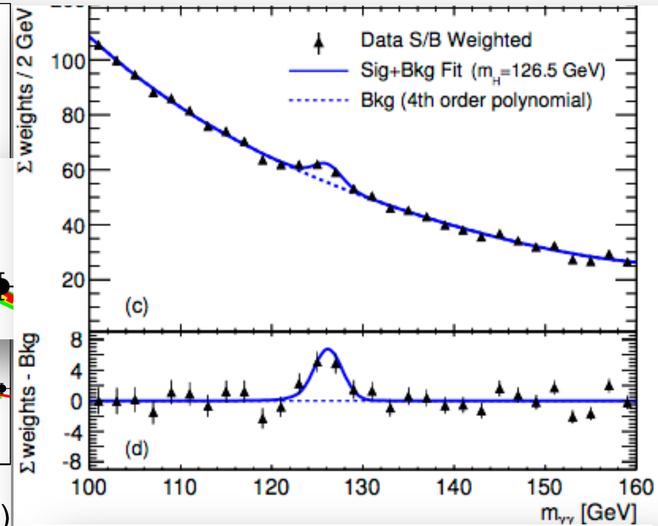


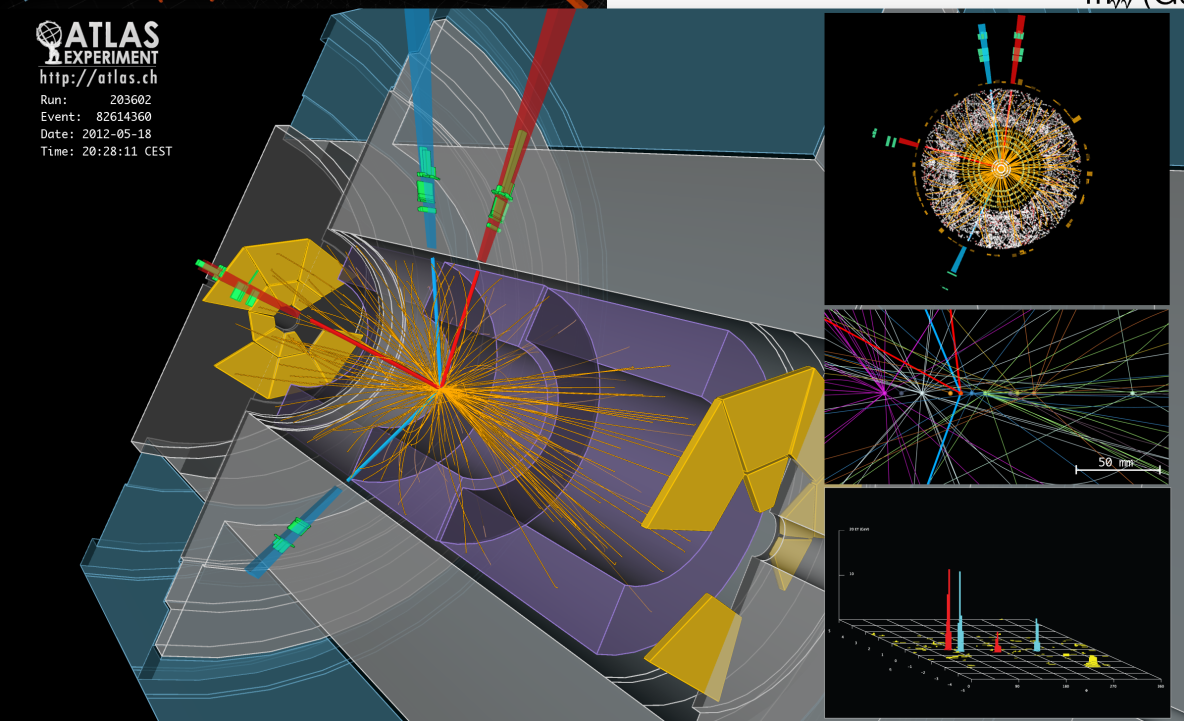


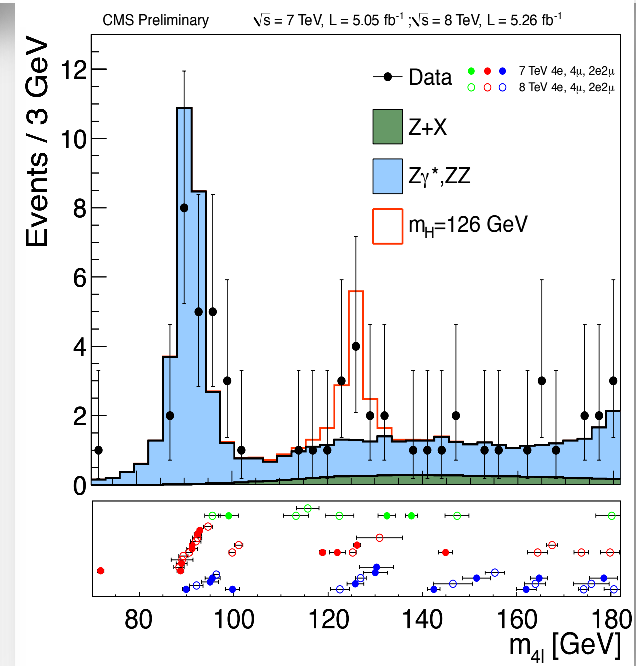
Discovery of the new Millennium





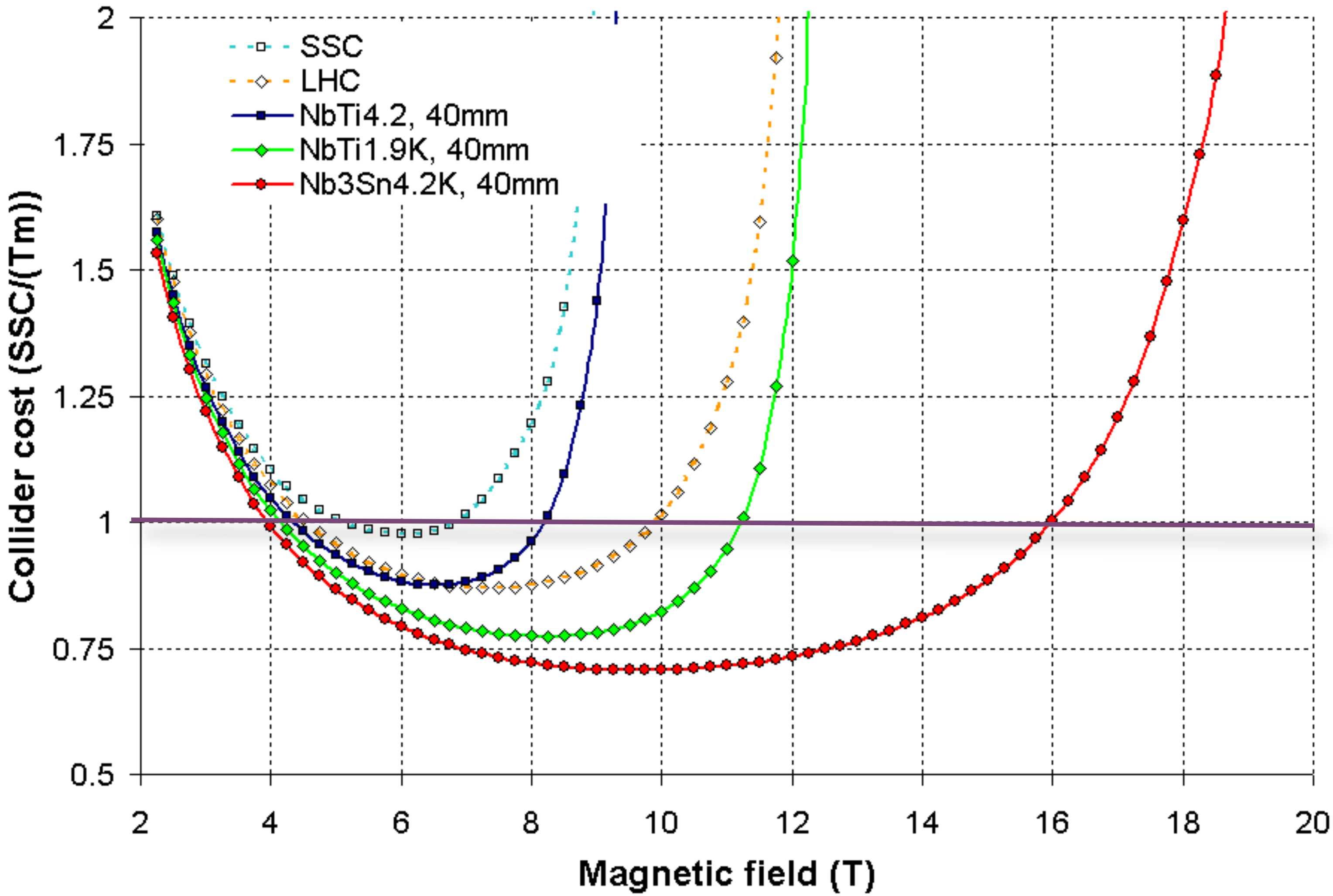






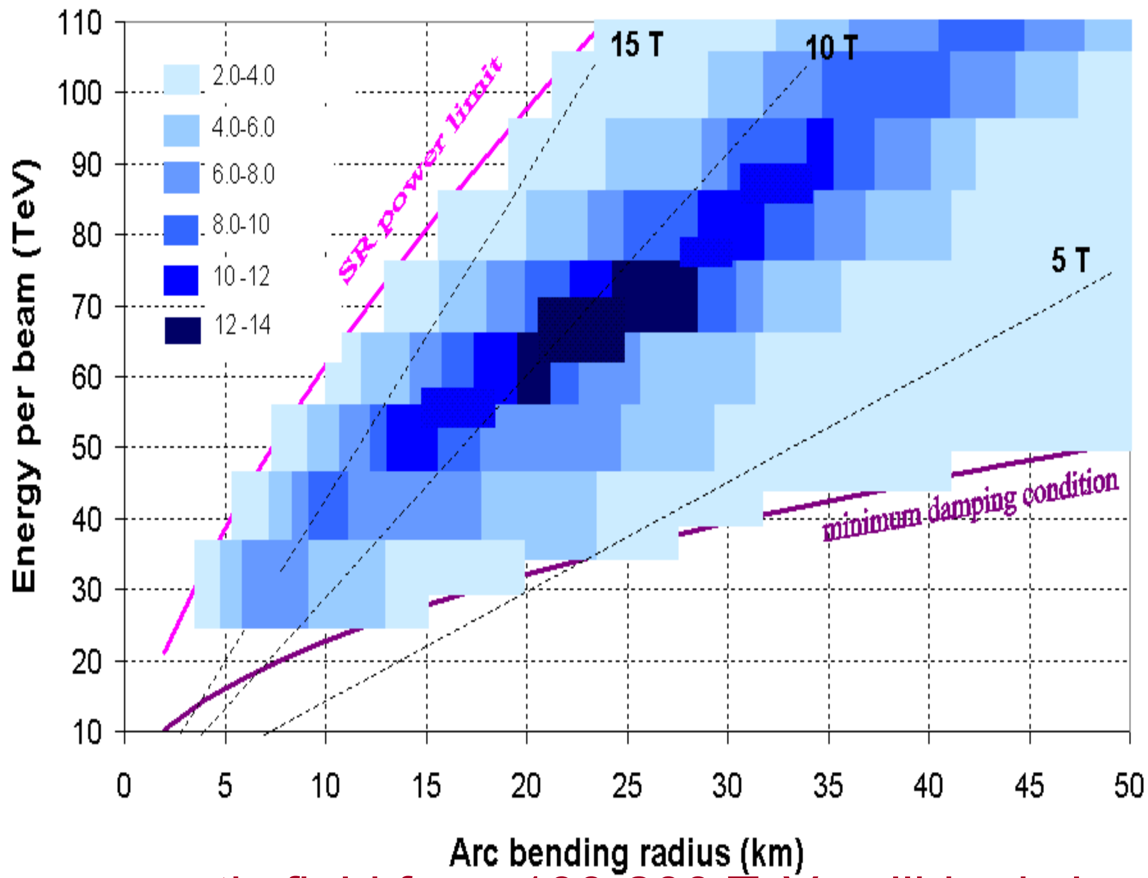
Cost based on SSC estimates

P. Limon
VLHC2001



Optimum Magnetic Field

P_{SR}<10 W/m/beam peak $t_L > 2\ t_{sr}$ Int/cross < 60 L units $10^{34}\ cm^{-2}s^{-1}$



P. Limon
VLHC2001

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 → smaller circumference may not be optimal.