What 's next in Accelerator Particle Physics

(somewhat CERN biased…)

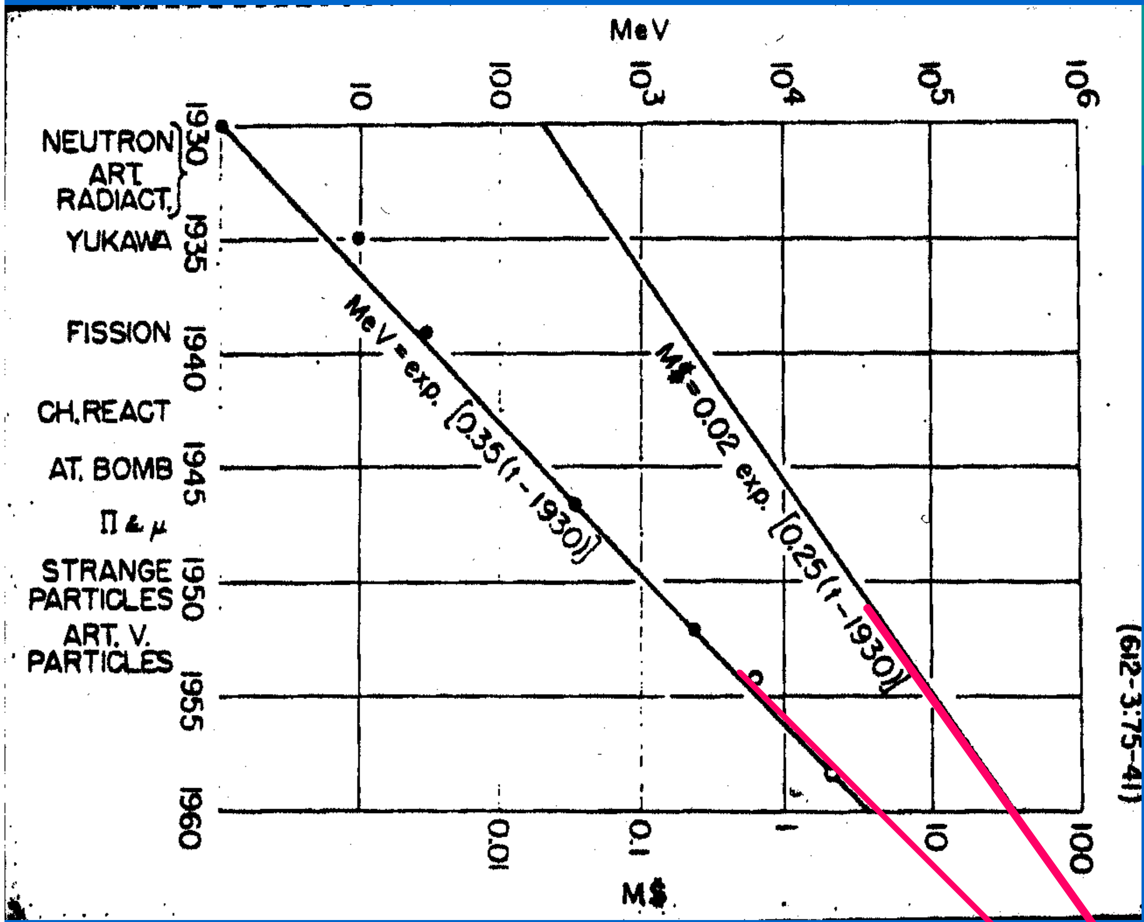
Neutrino Telescopes Conference

Venezia, March 9, 2001

Luciano MAIANI

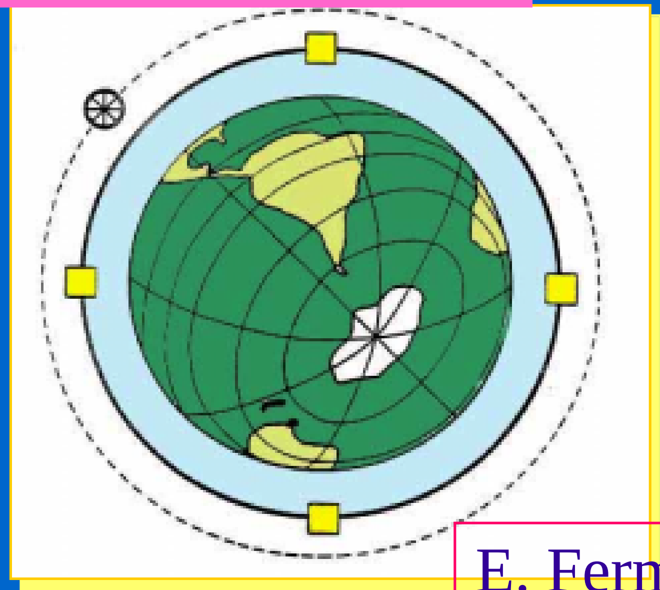
CERN, Geneva, Switzerland

E. Fermi 's maximal accelerator (Seminar at APS, 29.01.1954)



Thanks to Fabiola Gianotti, James Pilcher

VLHC project logo



E. Fermi

Year 1994
Cost 170 B$

2 Tesla

$E_{Beam} = 5\ 10^3$ TeV

Fermi maximal accelerator (cont 'd)

THE UNIVERSITY OF CHICAGO LIBRARY

Thanks to Mark Oreglia, Adrienne Kolb

For these reasons....clamoring for higher and higher....
Slide 1 - MeV - M$ versus time.
Extrapolating to 1994...5 hi 9 Mev or hiest cosmic...170 B$....preliminary design....8000 km, 20000 gauss
Slide 2 - 5 hi 15 eV machine.

Whay we can learn impossible to guess....main element surprise....some things look for but see others.....Experiens on pions....sharpening knowledge....~~spin zero and odd symmetry~~.....certainly look for multiple production...

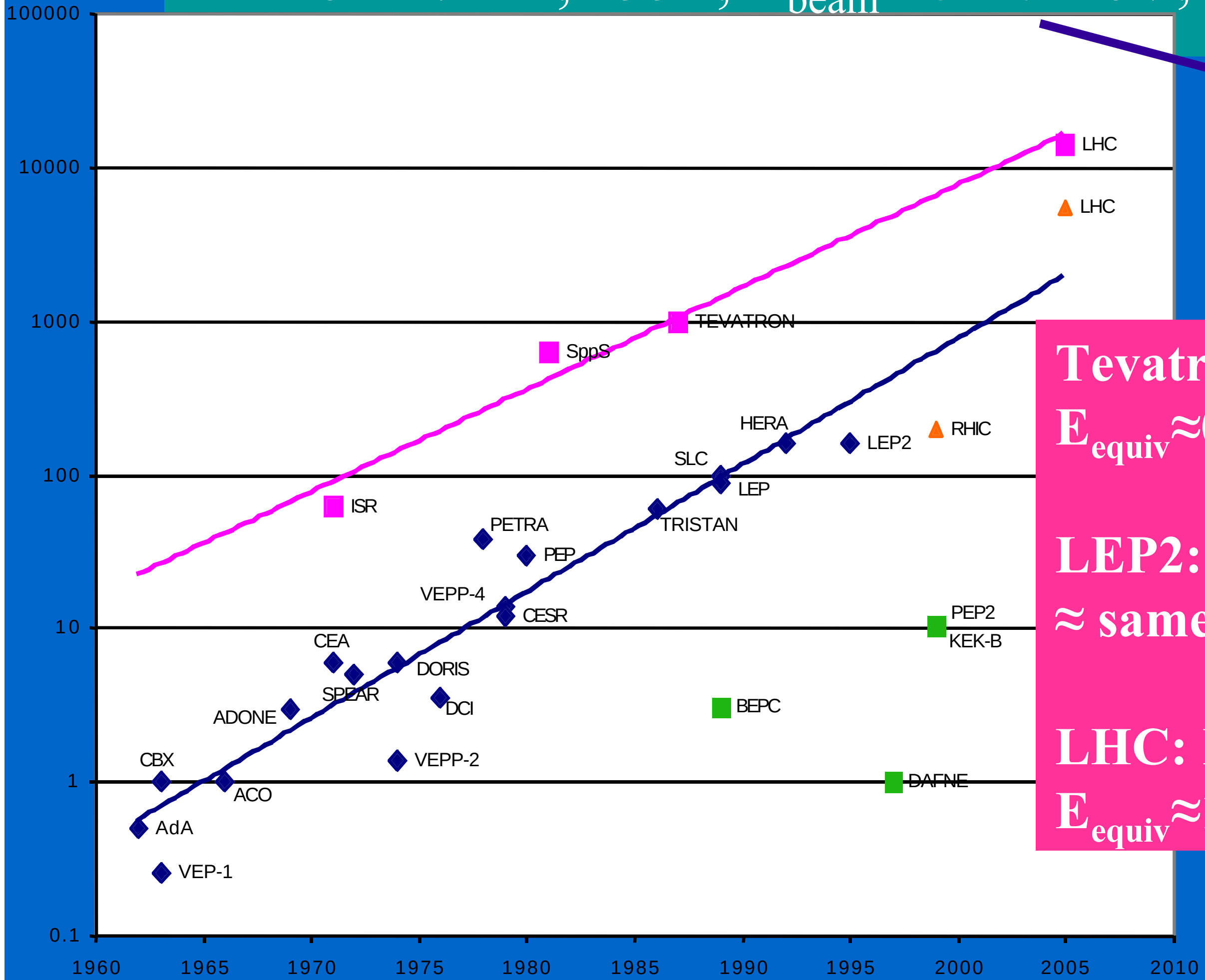
Naturally interest in strange particles....Cosmotron work by Shutt and others....very very cloudy crystal ball....Puzzle of long life times.... large angular moment?....double formation?....at present more probable... ....tried to ~~imkexpkxe~~ photograph what I saw in the ball....and made slide...
Slide 5 - Strange particles in pion nucleon collisions.
...should realize this picture retouched....may have the wrong scale... may be wrong curve.....lots of other things could be seen...could not make them out.....
what happened in pion physics

...ultimate result...understanding...need of precise data. ^ .expect complication....collision of atoms.....however, staring at a problem... *Slide 6*
...also possibility of a ~~xxx~~ lucky break....or theoretical leap.... or more probably a combination of hard work, ingenuity and a little bit of good luck.

Fermi's successors did not fare so badly...

Fermi: P-P, 1994, $E_{beam} \approx 5 \cdot 10^{15}$ eV, 170B US$

(3 TeV in c.o.m. !)

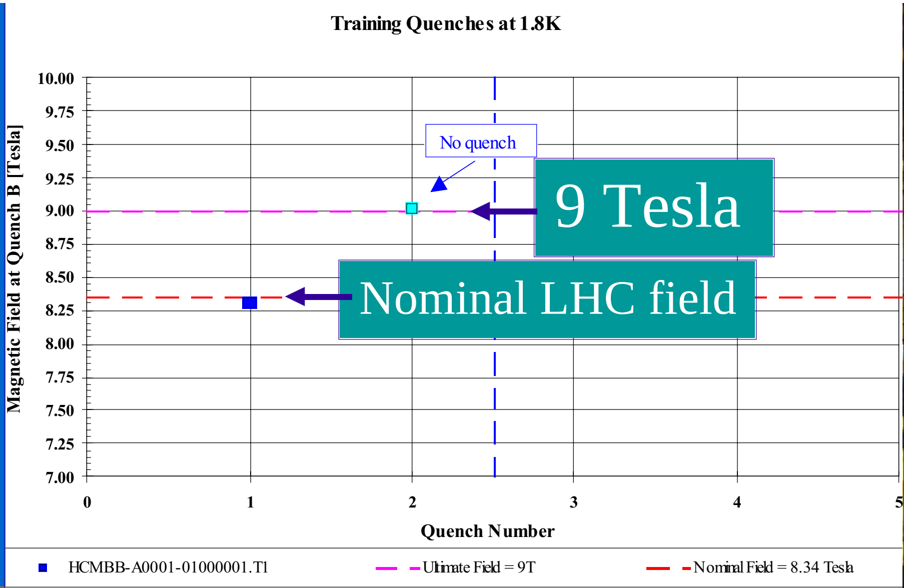


Tevatron: P-Pbar, 1987
$E_{equiv} \approx 0.5\ 10^{15}$ eV

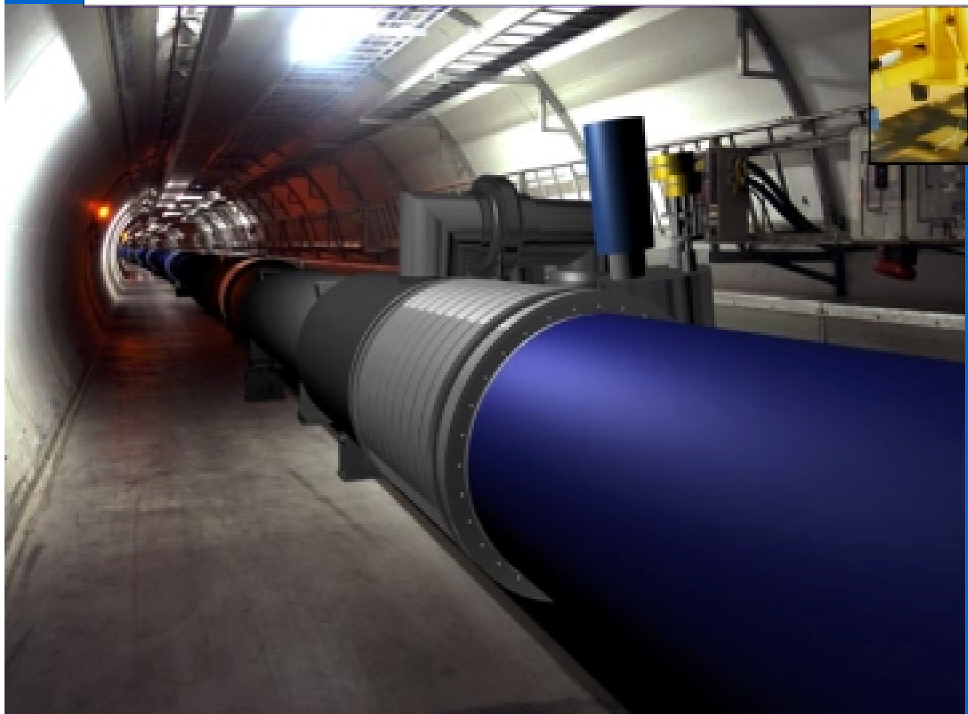
LEP2: $e^+ e^-$, 1995
≈ same en. range as Tevatron

LHC: P-P , 2006
$E_{equiv} \approx 1.1 \cdot 10^{17}$ eV, ≈5B US$

+ X-factories
+Heavy Ions...



The LHC dipole n. 0001



Artist view of the LHC in the LE P Tunnel

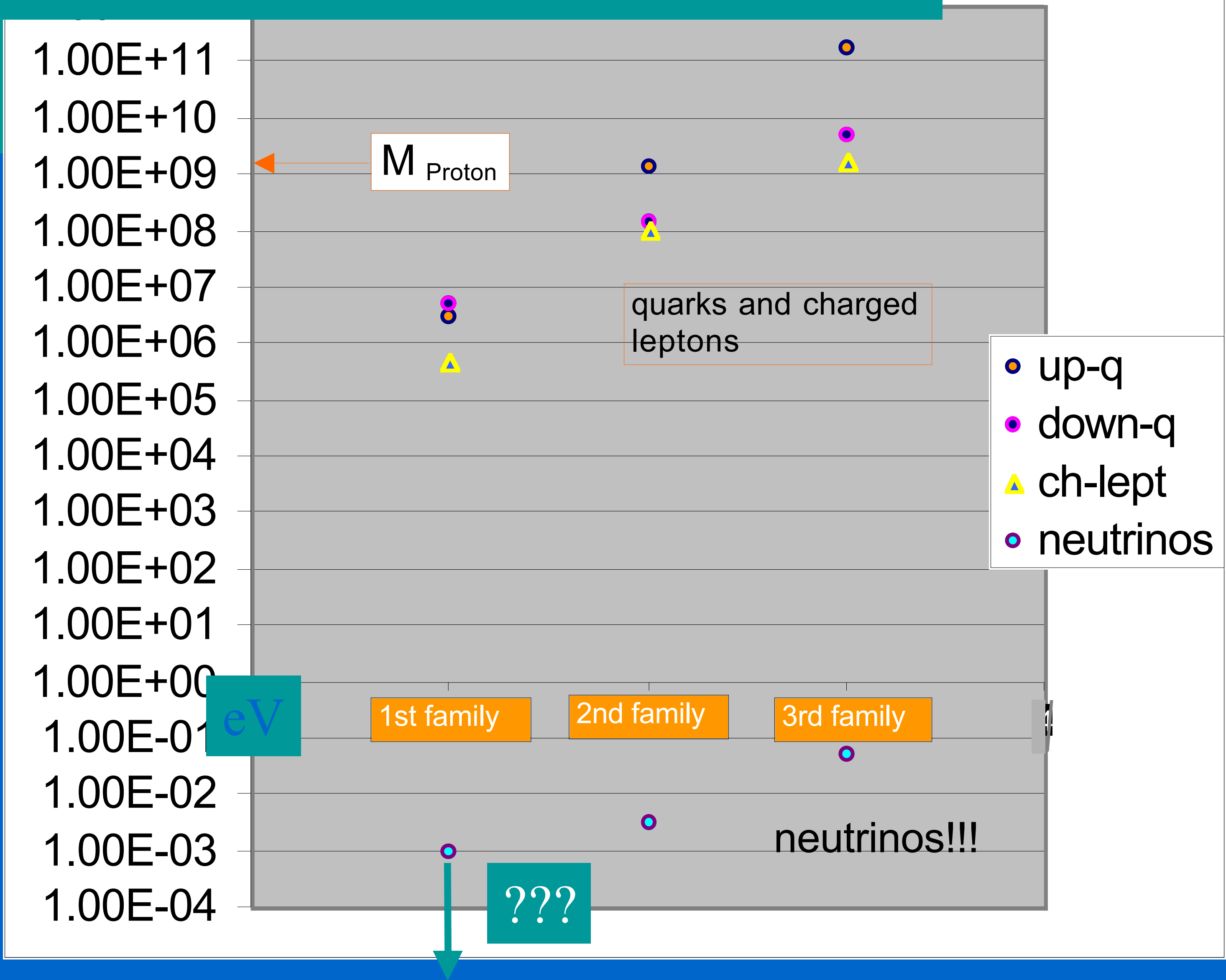
Summary

- What ’s next in Particle Physics
    - Neutrino masses and oscillations
    - Higgs boson search
    - Supersymmetry
    - Extra dimensions?
- Accelerators for the future
    - Towards a nu-factory, CERN ’s SPL
    - VLHC?
    - CLIC
    - The extreme optimist ’ s scenario
- Conclusions

Thanks to:

– J-P. Delahaye, J. Ellis, F. Gianotti, G. Giudice, K. Hubner, L. Evans, A. DeRoeck.

Mass spectrum of quarks and leptons

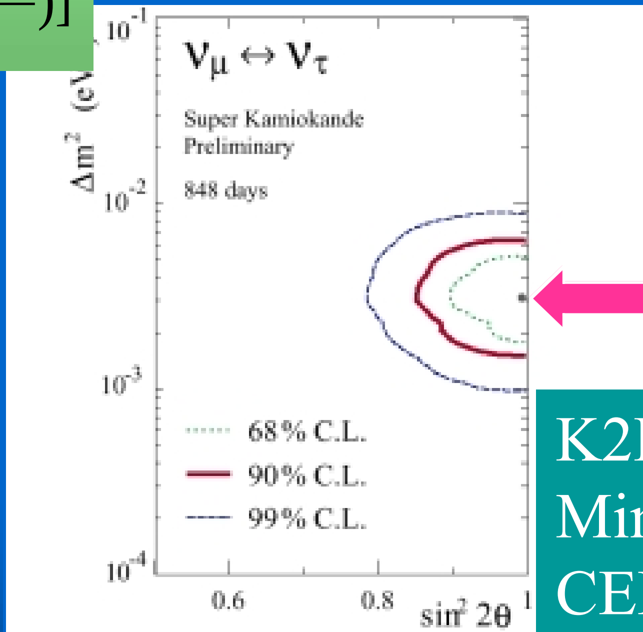


Neutrino mass & oscillations

$$m^2 = [\frac{g<\phi>^2}{\Lambda}]^2 =$$

$$= 1.6 \cdot 10^{-3} eV^2 [g(\frac{<\phi>}{200GeV})^2 (\frac{10^{15} GeV}{\Lambda})]^2$$

K&SuperK discovery!!!



Long Base-Line
ν beams

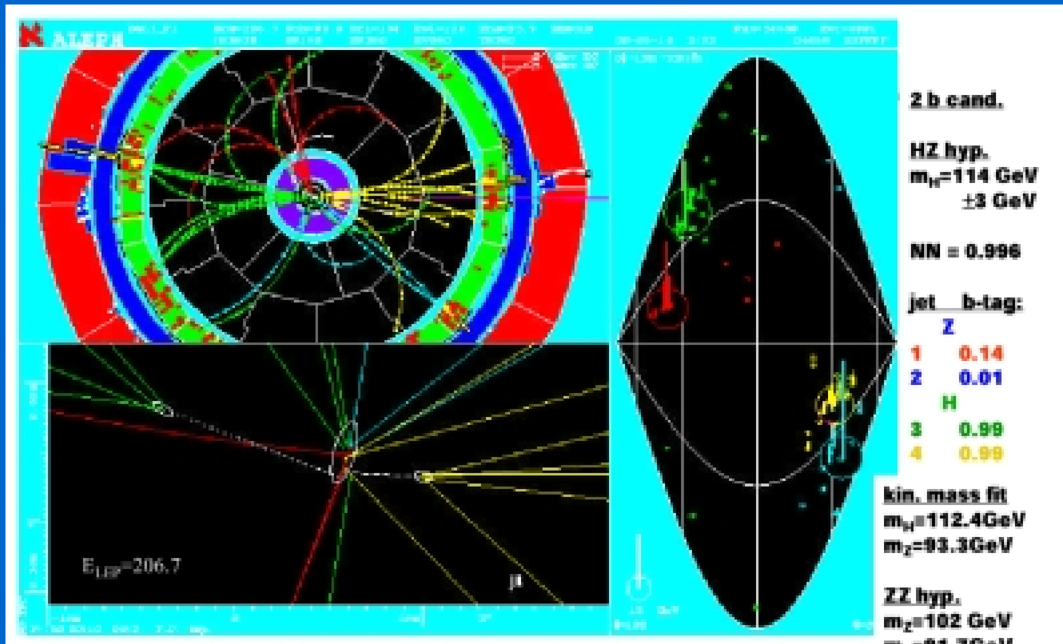
K2K
Minos @ FermiLab
CERN to Gran Sasso

Other oscillation signals:
- Solar ν 's (≈10^{-4} eV ^{2})
Δm^2_{12} may be 10^{-1} - 10^{-2} Δm^2_{13}
CP violation may be visible
- LSND (≈1 eV ^{2})(???)

K2K, new!!!:
CC seen ≈28, expected≈38
L/E≈200 →Δm^2≈2 10^{-3}

Higgs hunting : LEP and elsewhere

- Evidence for a Higgs particle at about 115 GeV / c^2 found in the last months of operation in year 2000



ALEPH: candidate for e+e- →Z+H (Summer 2000)

Statistical Significance

2.2 σ	September 5
2.3 σ	LEP fest
2.9 σ	November 2

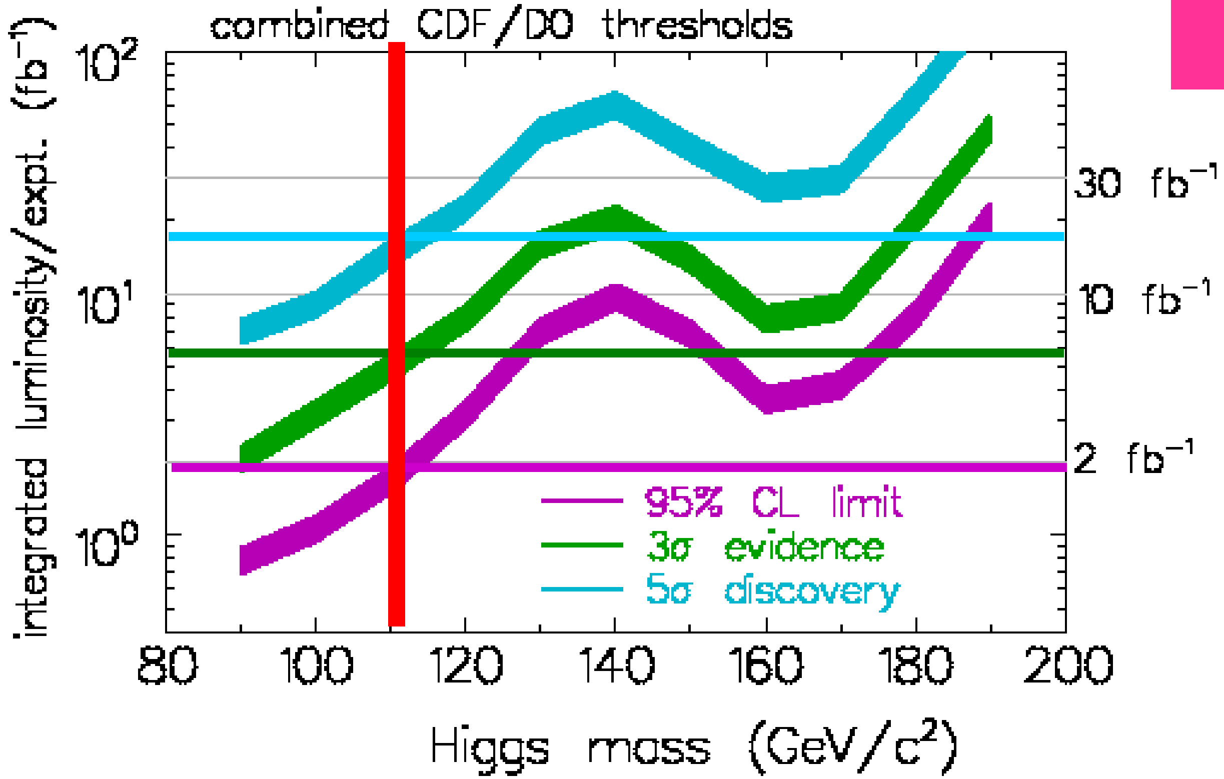
Preliminary !!!

Agreement with SM Higgs cross-sect. for

$$m_H = 115.0^{+1.3}_{-0.9}\ \mathrm{GeV}$$

P. Igo-Kemenes-LEP Seminar-Nov.3, 2000

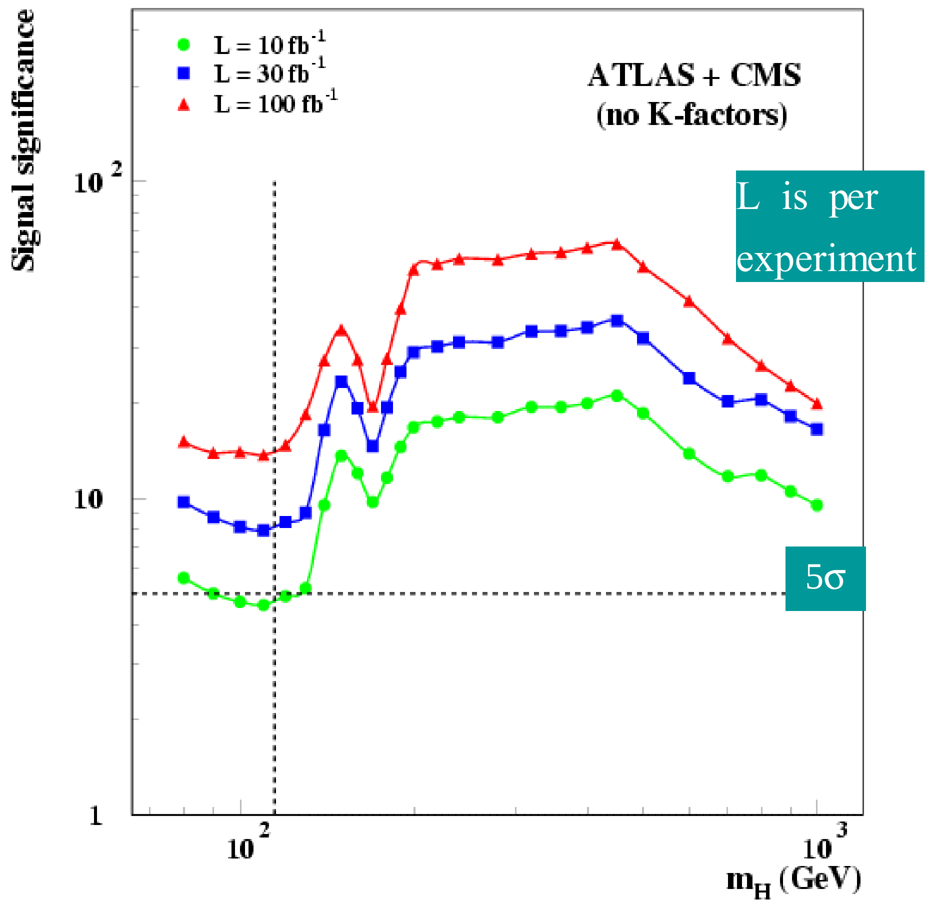
TEVATRON RUNII



Plot taken from Physics at Run II Wo

Higgs Boson at the LHC

- SM Higgs boson can be discovered at $\approx$ 5 σ after $\approx$1 year of operation (10 fb^{-1}/ experiment) for $m_H \approx 150$ GeV
- Discovery faster for larger masses
- Whole mass range can be excluded at 95% CL after ~1 month of running at 10^{33} cm^{-2} s^{-1}.



results are conservative:

-- no k-factors

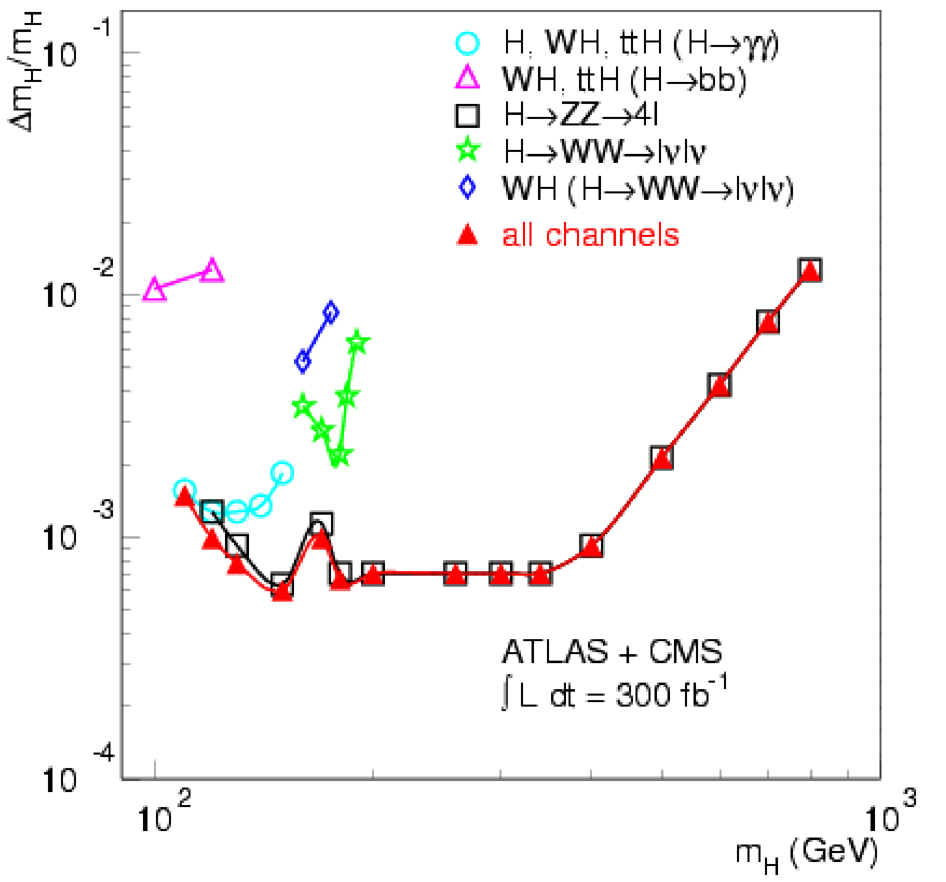
-- simple cut-based analyses

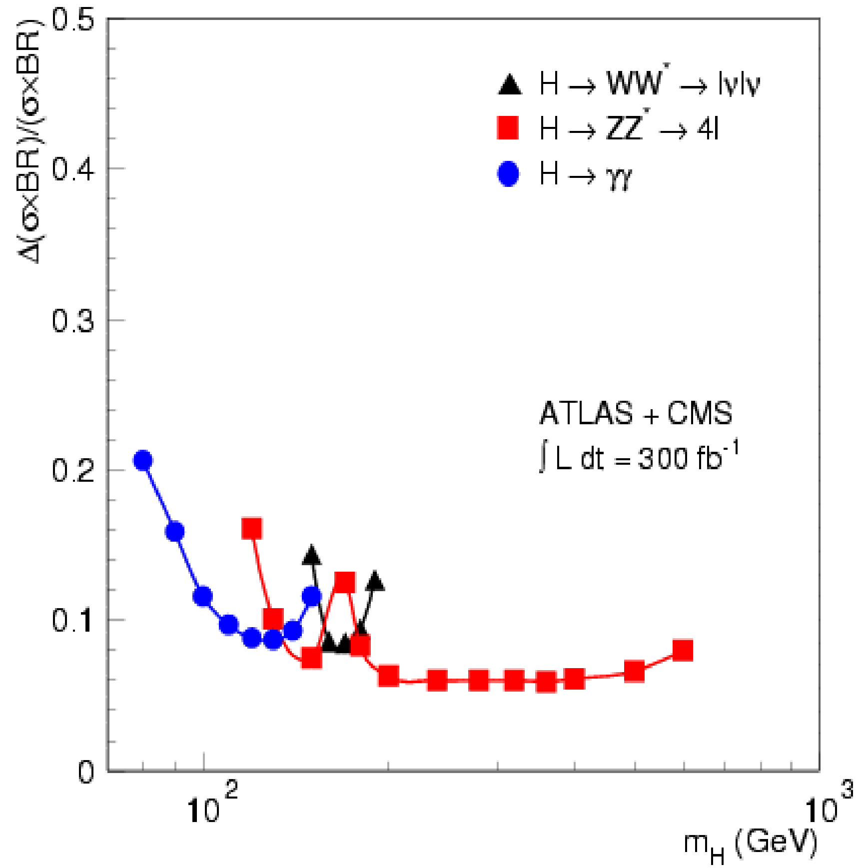
-- conservative assumptions on detector performance

-- channels where background control is difficult not included, e.g $WH \to l\nu b\bar{b}$

F. Gianotti

Measurement of the SM Higgs parameters at LHC: mass to ~0.1%, width to ≤ 10%, rates (σ x BR) to ~10%, ratios of couplings (WWH, ZZH, ttH, bbH) to 10-20%





Higgs decay branching ratios at a Linear e^+e^- Collider (TESLA/NLC/JLC)

accuracy on δBR/BR (M_H = 120 GeV):

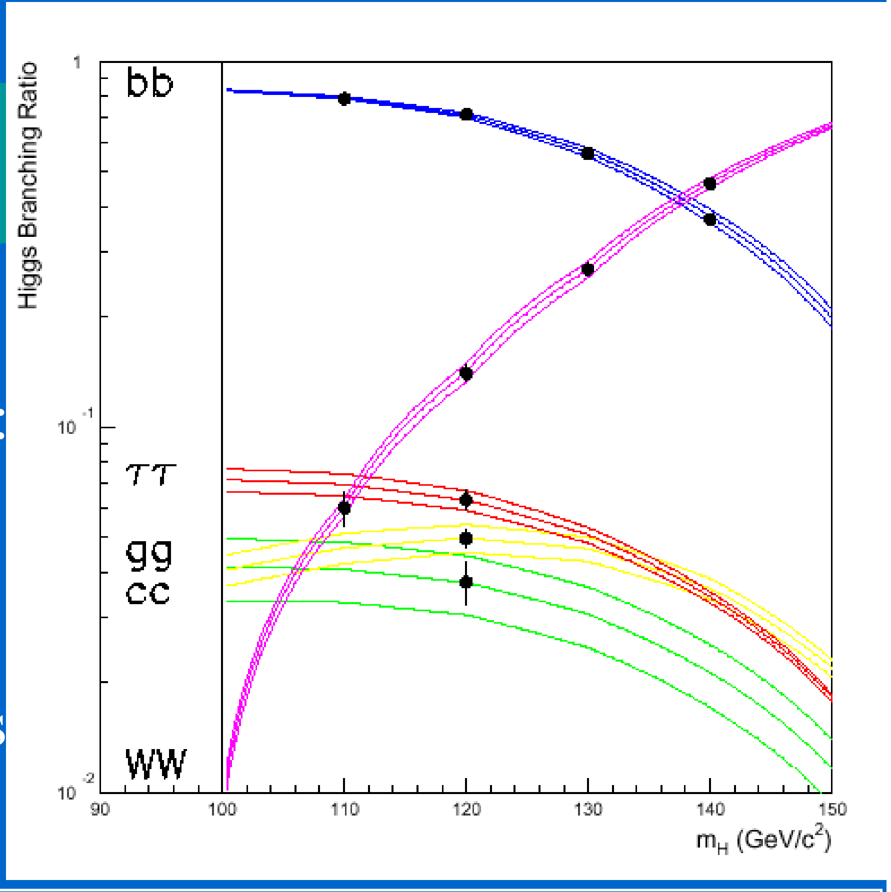
bb : 2:4%   WW* : 5:4%

cc : 8:3%   gg : 5:5%

ττ : 6:0%

ratio of the ττ to the bb branching ratios $=(m_\tau/m_b)^2$

(P. Zerwas, LC study)



Branching ratios of SM Higgs decays into fermion and WW*pairs M. Battaglia, hep-ph/9910271.

Triple Higgs coupling

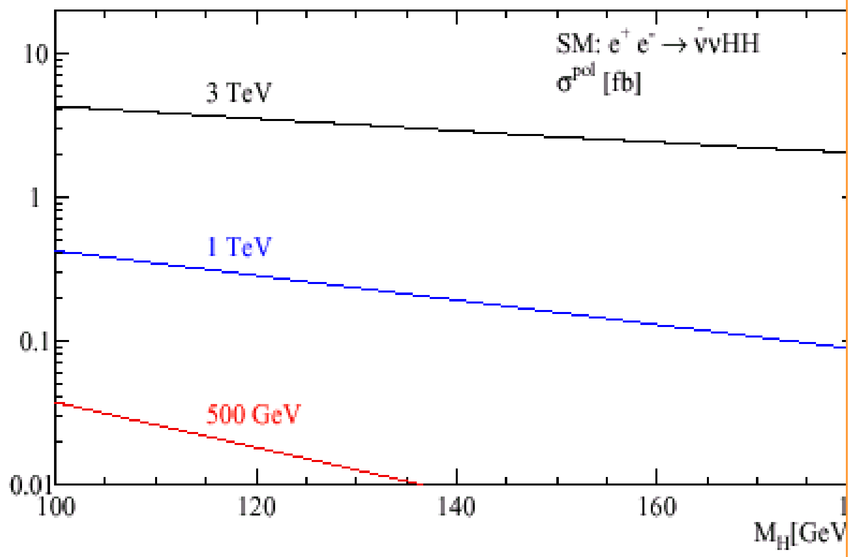
$\sqrt{s} \simeq 3$ TeV to Complement LHC + LC-500 Physics Reach

$\sqrt{s} > 1$ TeV needed to fully understand a 115 GeV/c^2 Higgs Boson: probe shape of the Higgs potential through triple and quartic couplings:

$$V = \lambda v^2 H^2 + \lambda v H^3 + \frac{1}{4}\lambda H^4$$

$$M_H = \sqrt{2\lambda} v$$

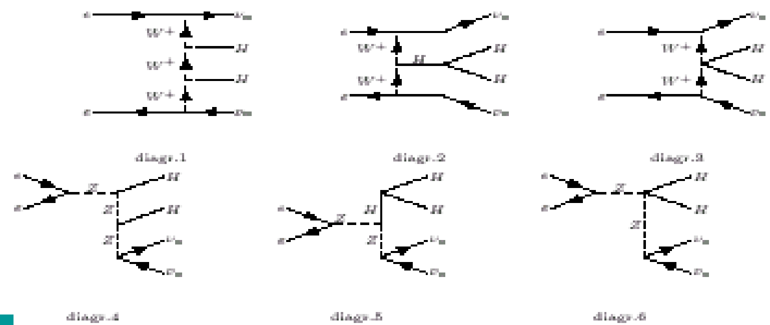
M. Muehl



Study of Triple Higgs Coupling at CLIC

M. Battaglia

- Extract λ_{HHH} from $\sigma(e^+e^- \rightarrow \nu\nu HH)$ for $M_H = 120$ GeV/c^2
- $\sigma(e^+e^- \rightarrow \nu\nu HH) \simeq \sigma(e^+e^- \rightarrow \nu\nu ZZ \rightarrow b\bar{b})$



$$e^+e^- \rightarrow \bar{\nu} + \nu + H + H$$

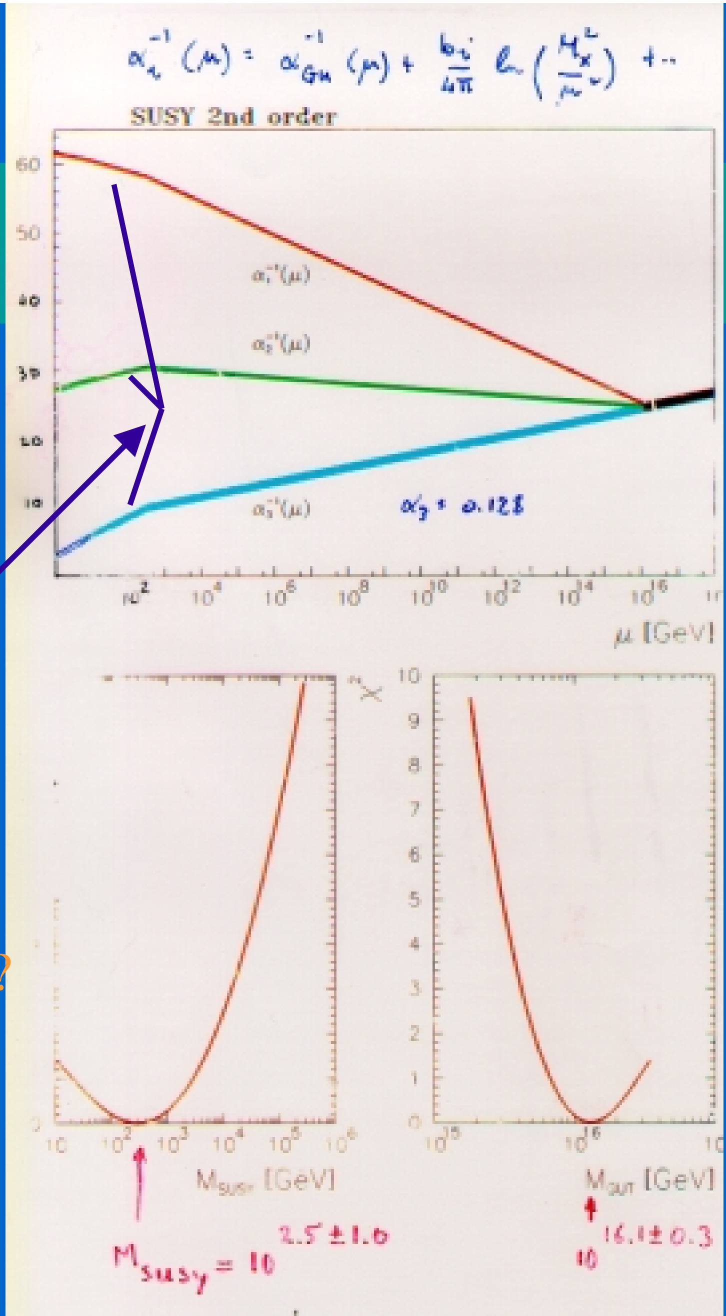
Supersymmetry in the TeV range

- SUSY charges carry 1/2 spin (matter-forces unification)
- A bridge towards gravity $$\{Q_\alpha, Q_\beta\} = \gamma^\mu{}_{\alpha\beta} P_\mu + \dots$$
- TeV scale indicated by hierarchy problem
- Study of SUSY spectrum: deep in multi TeV region

Lightest SUSY Particles may still be around from BIG-BANG

Unification Hints

MSSM



Amaldi, de Boer, Furstenau

See also :
Ellis, Kelley, Nanopoulos;
Langacker, Luo

Courtesy of
G. Ross, LEP fest

Large New Dimensions

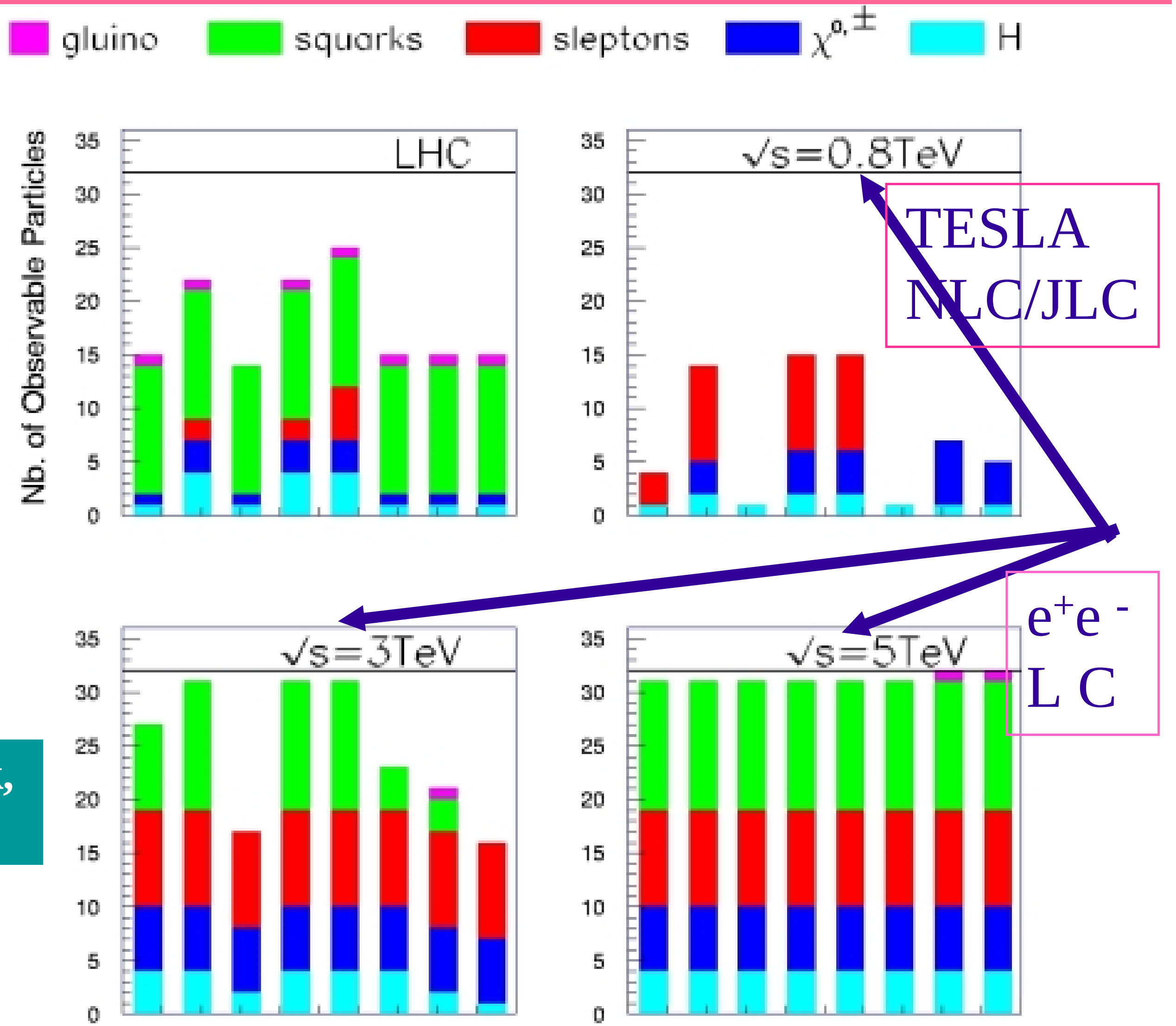
Unification at a TEV???

Dienes, Dudas,
Ghergetta,

Dimopoulos, Raby, Wilczek
Ibanez, GGR

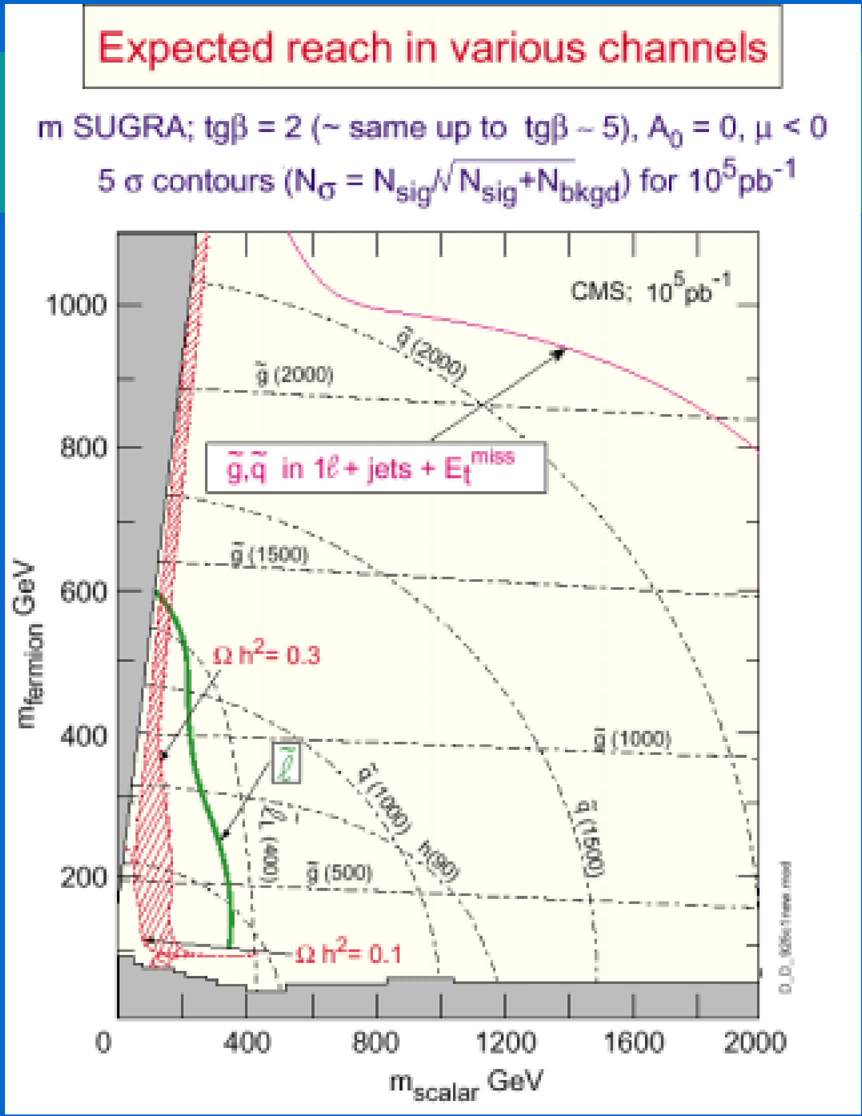
Getting into TeV and many TeV region with complementary probes is necessary to fully understand the Supersymmetry spectrum

Particles discovered in eight sample models at LHC or e^+e^- L C



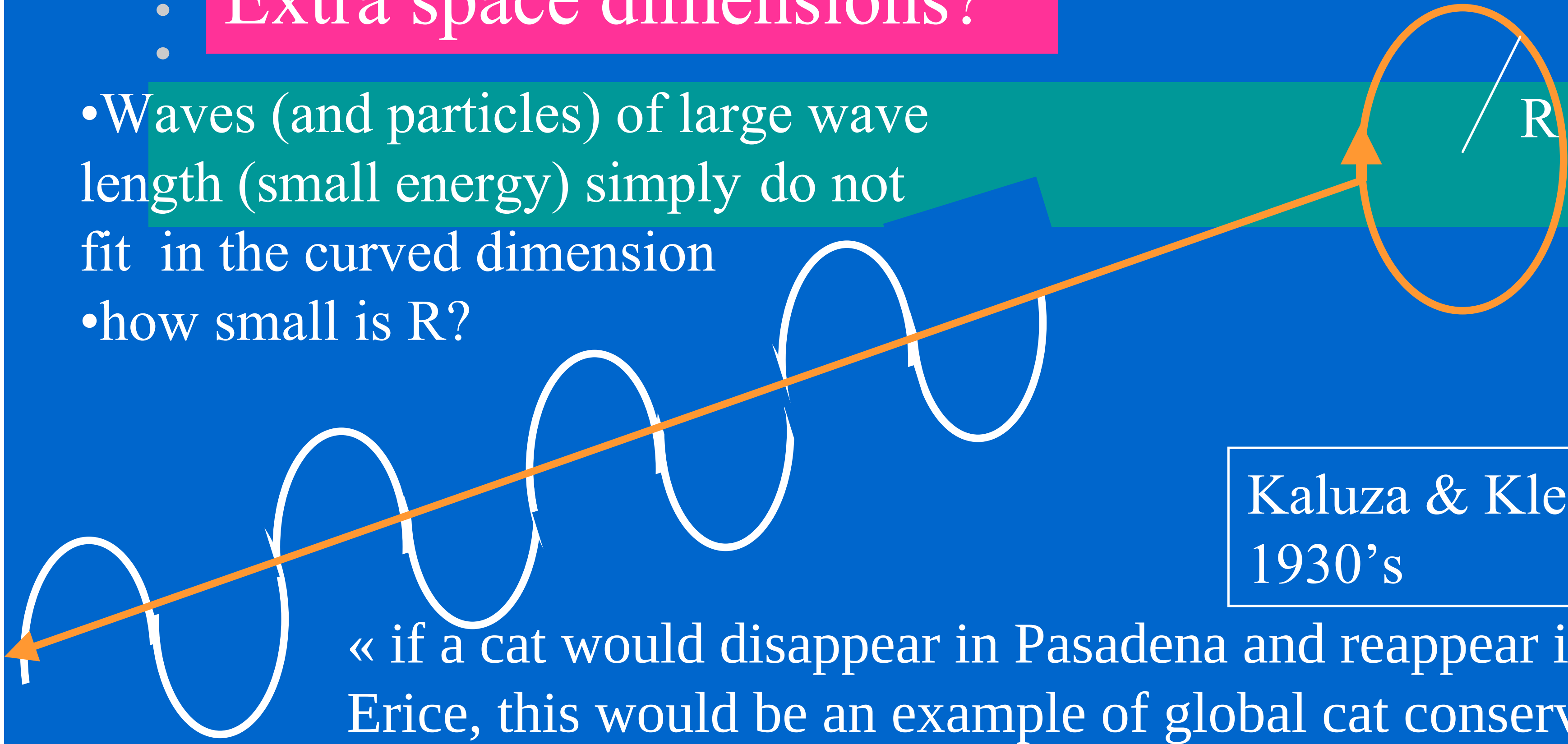
(J. Ellis, F. Gianotti, A.deRoek, CLIC working group)

Expected reach of CMS in various channels & the cosmological parameters



Extra space dimensions?

- Waves (and particles) of large wave length (small energy) simply do not fit in the curved dimension
- how small is R?



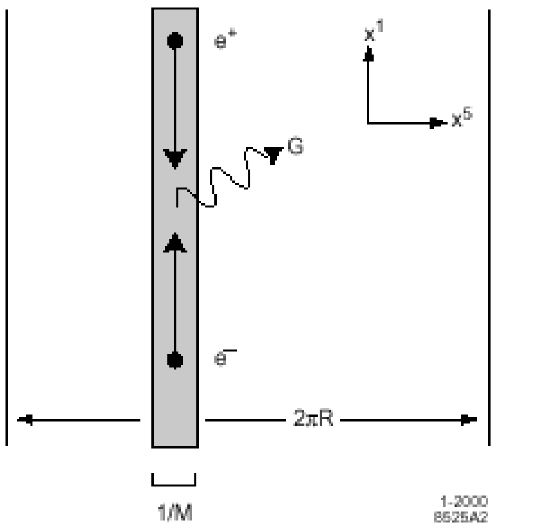
Kaluza & Klein
1930's

« if a cat would disappear in Pasadena and reappear in Erice, this would be an example of global cat conservation. This is not the way cats are conserved » (R.P. Feynman)
.... in 4 dimensions

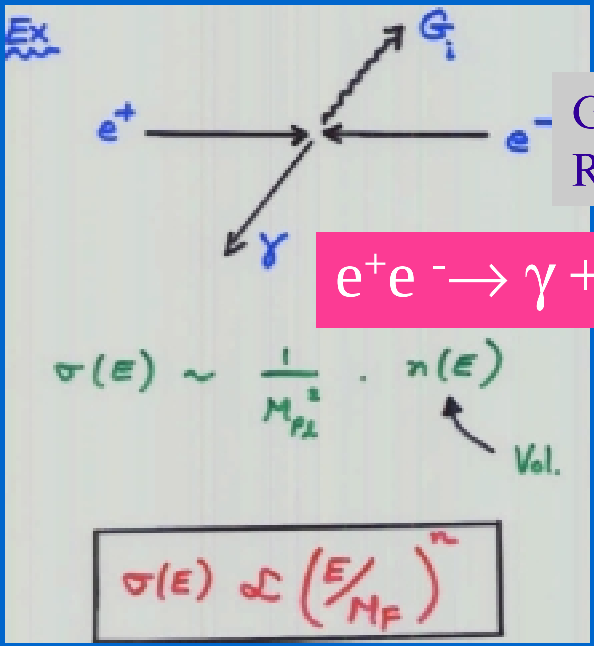
Superstring theory not consistent in 4 dimensions
Extra curved dimensions required
Scale? $\approx 1/M_{Planck}$?

Extra Dimensions at mm scale?

Arkani-Hamed, Dimopoulos, Dvali (1998)



The universe viewed in the small: quarks, leptons, and gauge fields are bound to a D-brane localised in an extra compact dimension.



Giudice, Rattazzi, Wells

$e^+e^- \to \gamma +$ Gravitons

Gravity in 3+D dim.

$$V = \frac{m_1 m_2}{(M_D)^{2+D}} \frac{1}{r^{1+D}} = \frac{m_1 m_2}{(M_{Planck})^2} \frac{1}{r} \left(\frac{R}{r}\right)^D$$

$$R = \frac{1}{M_D} \left(\frac{M_{Planck}}{M_D}\right)^{\frac{2}{D}}$$

$M_D = 1$ TeV

$R \approx$ mm (D=2)

$R \approx$ fermi (D=6)

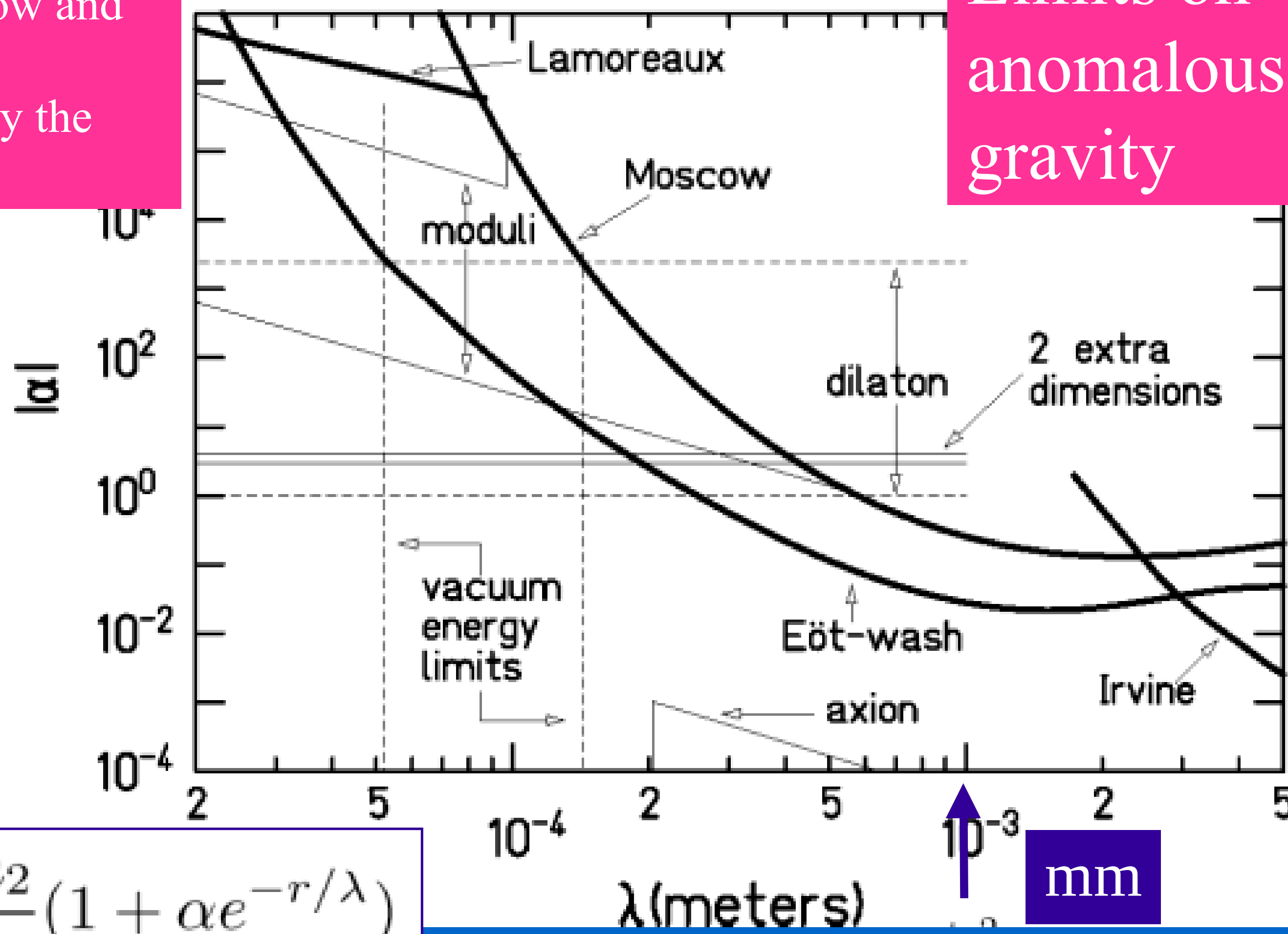
Sub-millimeter tests of the gravitational inverse-square law: a search for “large” extra dimensions

C. D. Hoyle, U. Schmidt, B. R. Heckel, E. G. Adelberger, J. H. Gundlach, D. J. Kapner, and H. E. Swanson
Department of Physics, University of Washington, Seattle, Washington 98195-1560

(February 9, 2001)

region excluded by previous work above lines : Irvine, Moscow and Lamoreaux.
Present constraint shown by the line labeled Eöt-Wash.

Limits on anomalous gravity

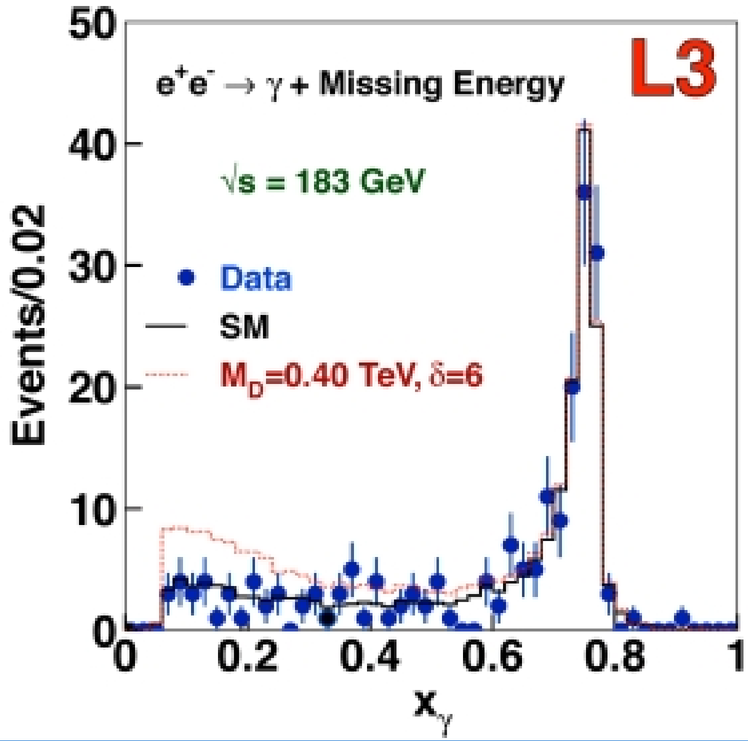


mm

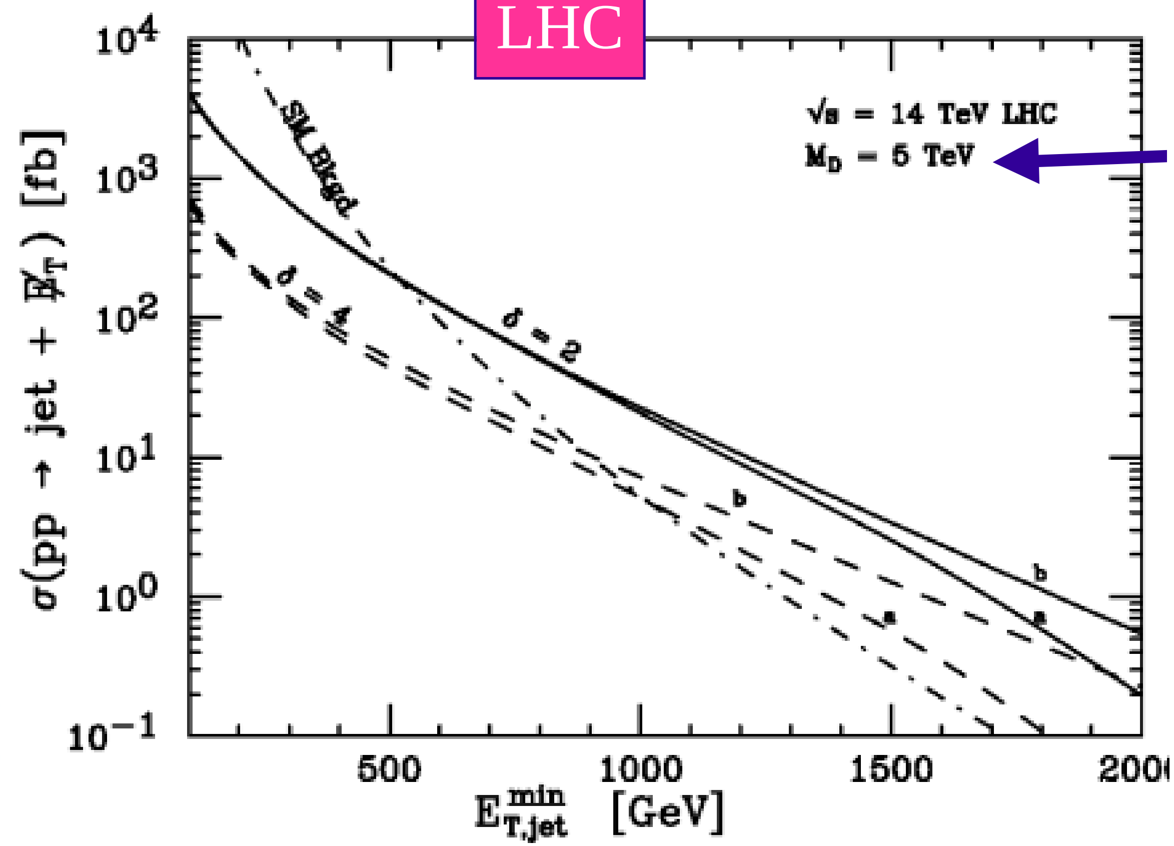
$$V(r) = -G\frac{m_1 m_2}{r}(1 + \alpha e^{-r/\lambda})$$

Limits on mass scale M_D for n Extra Dimensions

LEP



LHC



recall: $R = \frac{1}{M_D}\left(\frac{M_{Pl}}{M_D}\right)^{\frac{2}{n}}$ ≈ 1mm for M_D≈1 TeV, D=2

Strategy for the future

High Energy Frontier:

- LHC
- e^+e^- LC, E_{tot}<1 TeV e^+e^-
- LC, $E_{tot}\approx$ multiTeV (CLIC)
- VLHC

•as soon as possible!
•complementary, necessary step (emittance…)

- exploration of nearby "Beyond the Standard Model"
- Anom. Dim's. up to 40-50 TeV
- The unexpected

Flavour physics:

Neutrino superbeam

Neutrino factory

Θ_{13}; CP violation in lepton sector

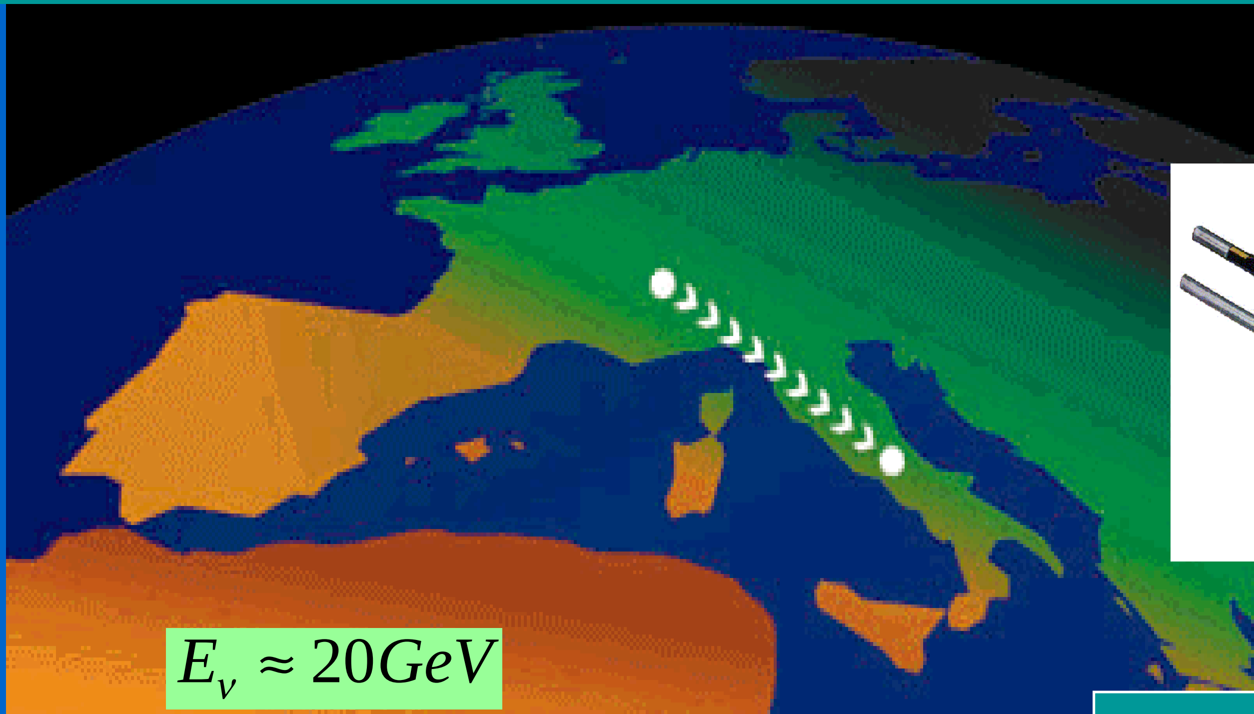
Further in the future:

Muon collider

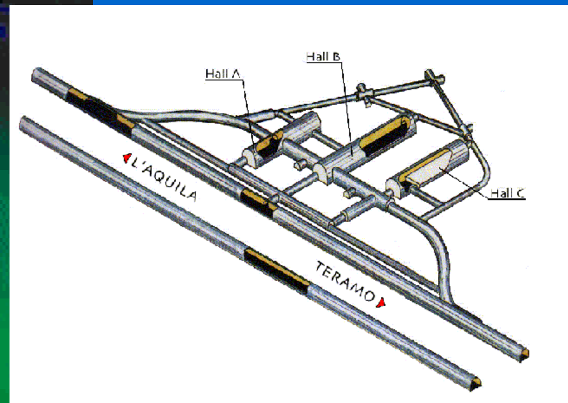
Nu-factory status

- A truly international effort (e.g. FermiLab and BNL studies)
- substantial investment required (proton driver only ≈20%): more emphasis on CNGS2 ?
- @ CERN:
  - studies have started (SPL, high power target, HARP…)
  - European collaboration started (CEA, IN2P3, INFN, RAL…)
  - Co-ordination among Int.'l Laboratories is being proposed (to FNAL, LBL, BNL, Cornell, KEK+ EU laboratories)
- SPL : cost=320MCHF; beneficial to ISOLDE, CNGS, LHC...

CERN neutrino beam to Gran Sasso



$E_\nu \approx 20 GeV$

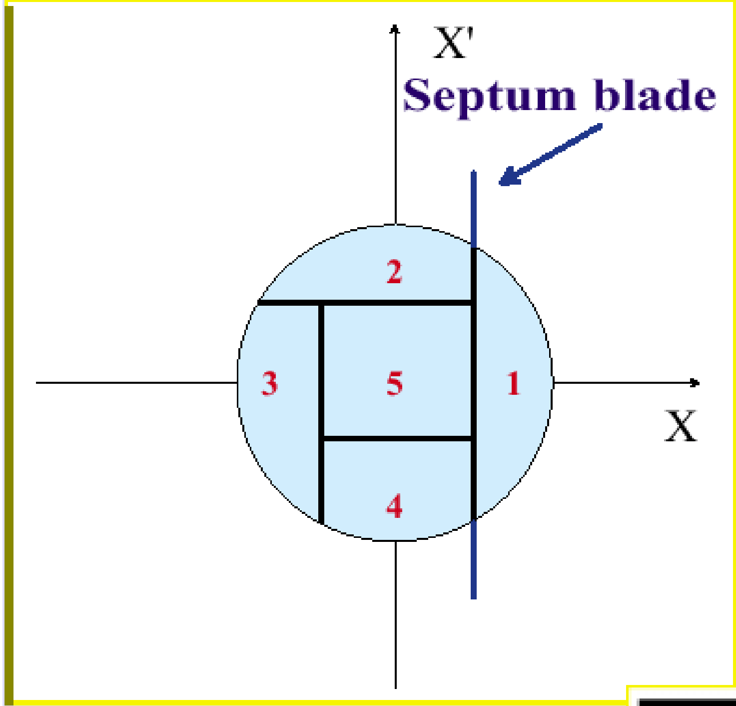


optimized for
τ detection

Commissioning:
Spring 2005

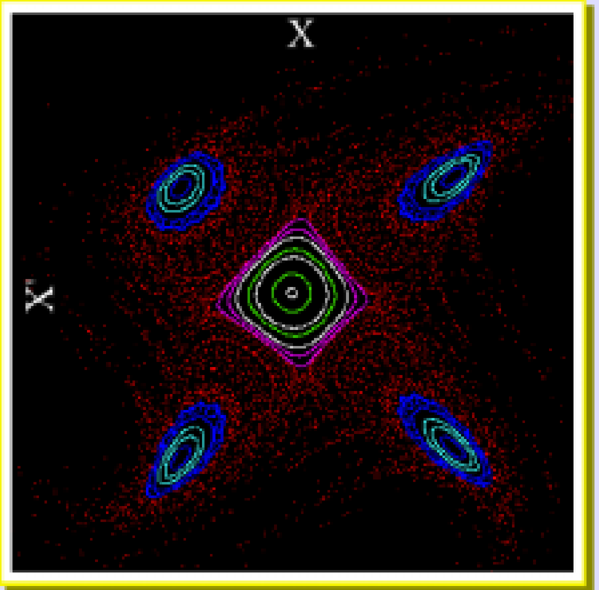
Civil works committed
in spring 2000

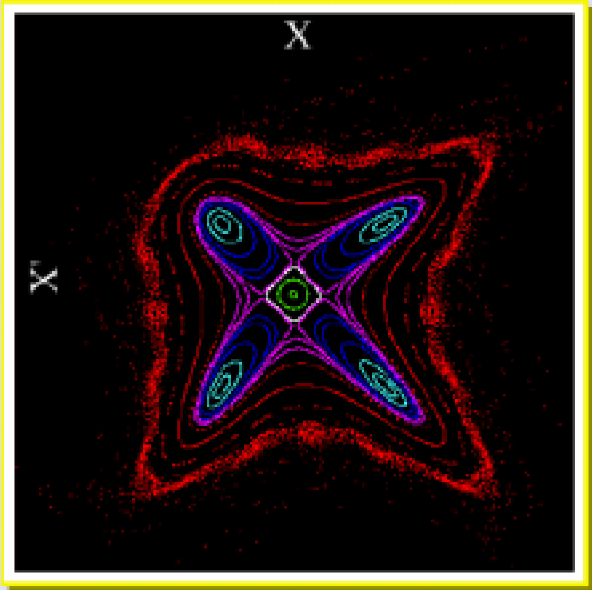
Experimental proposals
OPERA approved Jan 2001



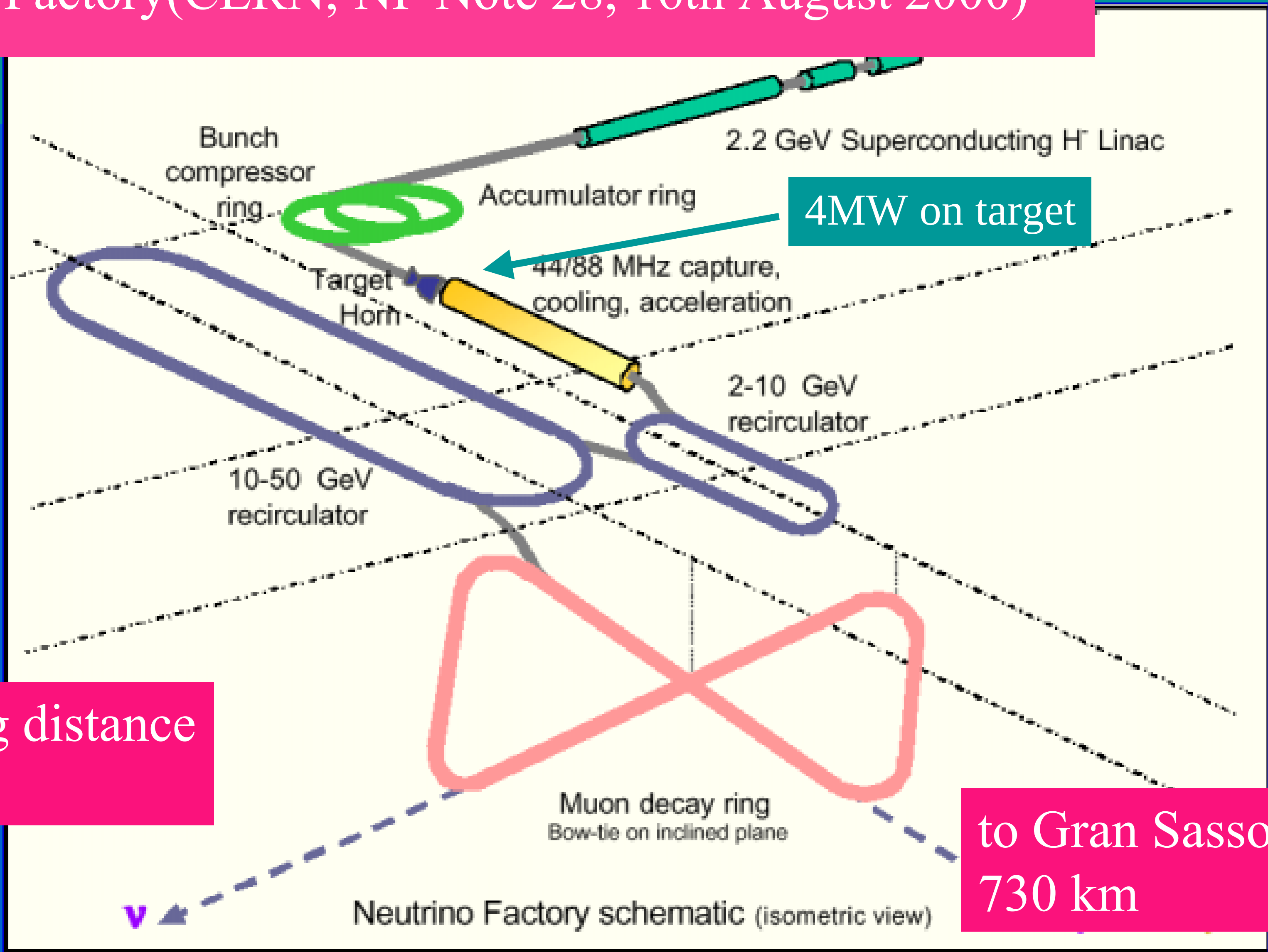
From septum blades to Stability Islands

2000 the intensity delivered to the SPS was between 1 to 1 . 7 •10^{13} ppp.
In 2001 it is planned to deliver up to 2•10^{13} ppp.
For CNGS it is planned to deliver more than 3 •10^{13} ppp.



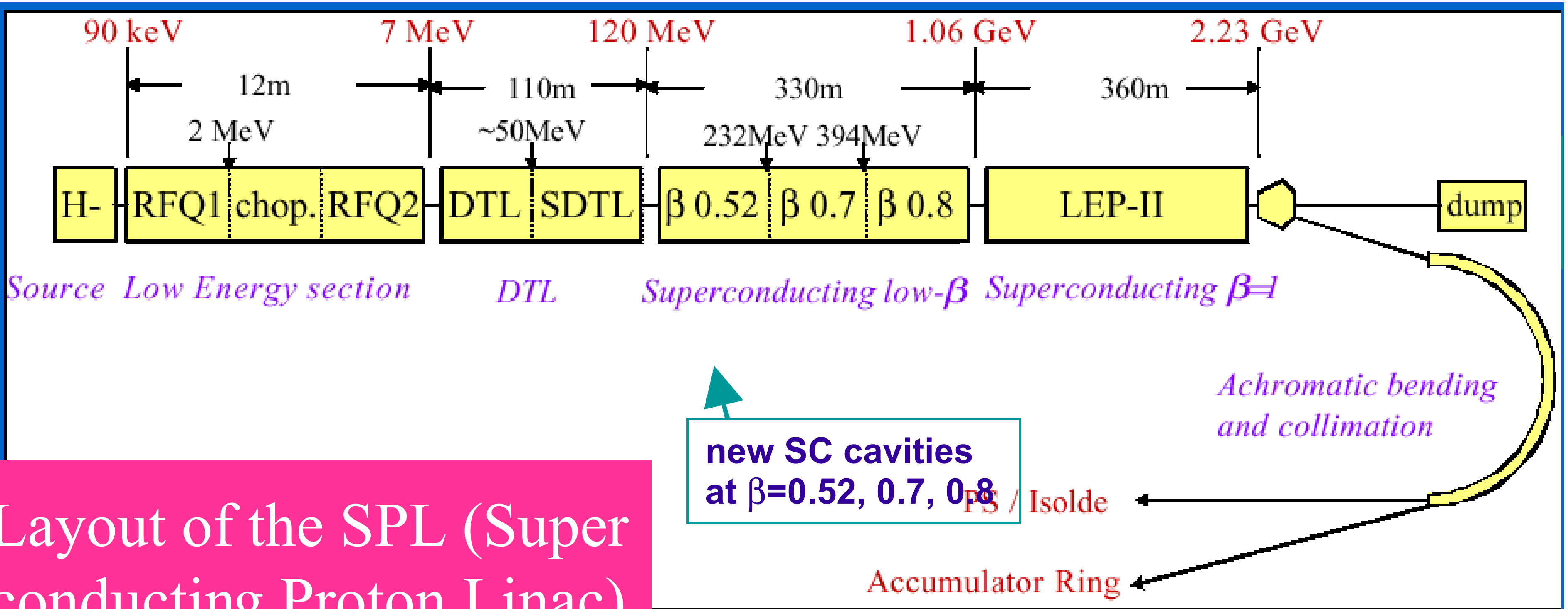


Isometric schematic of the CERN reference scenario for a Neutrino Factory(CERN, NF Note 28, 16th August 2000)



to very long distance Laboratory

to Gran Sasso, 730 km



Layout of the SPL (Super conducting Proton Linac)

The 2.2 GeV Superconducting H^- linac parameters in quasi-CW mode

Beam Current, mA	11
Energy (kinetic), GeV	2.2
Invariant transverse rms emittance, μm	0.6
Beam energy spread (√5σ) MeV	±2
Bunch length (total: √5σ), ps	24
Linac length, m	800
rf frequency, MHz	352
Overall rf power, MW	31
Number of klystrons	46

We have 53 klys.

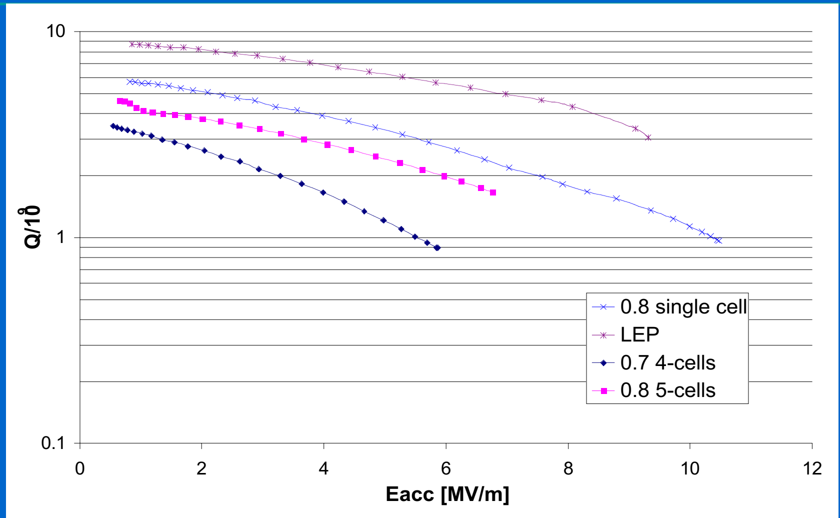
Cost 350MCHF (prel.)
good for Isolde, CNGS, LHC.

The SC cavities for β < 1

The β=0.7 4-cell prototype

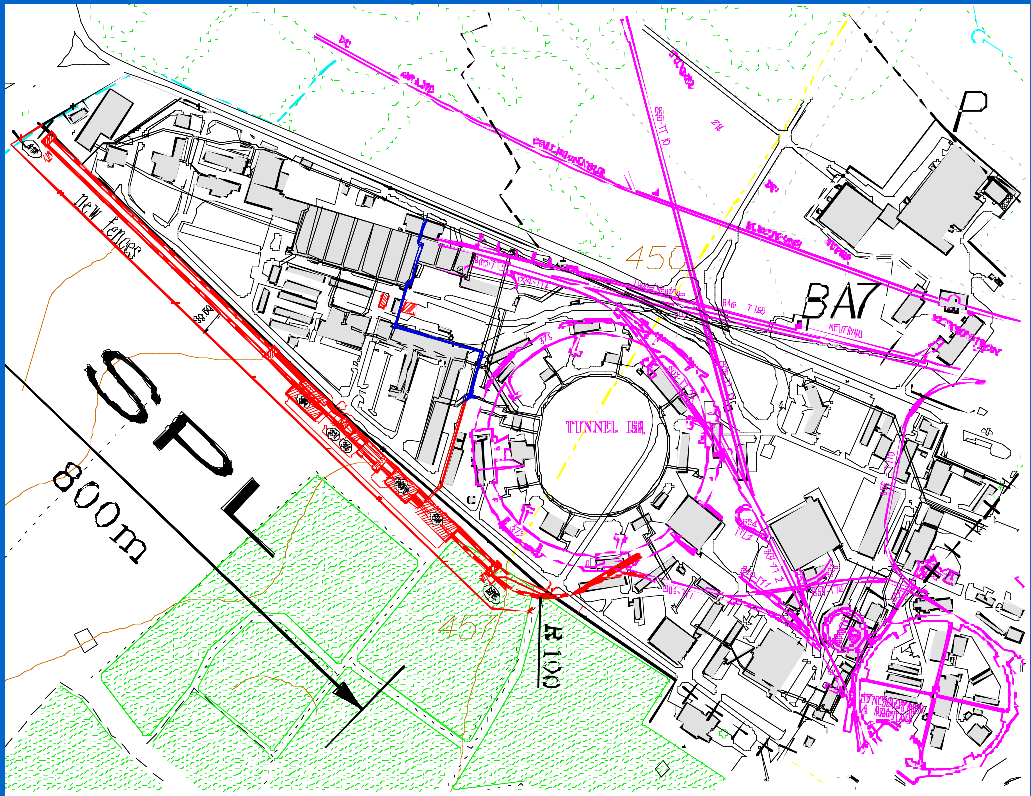
☆ CERN technique of Nb/Cu sputtering for β=0.7, β=0.8 cavities (352 MHz):

- excellent thermal and mechanical stability (**very** important for pulsed systems)
- lower material cost, large apertures, released tolerances, 4.5 °K operation with $Q = 10^9$



☆ Bulk Nb or mixed technique for β=0.52 (one 100 kW tetrode per cavity)

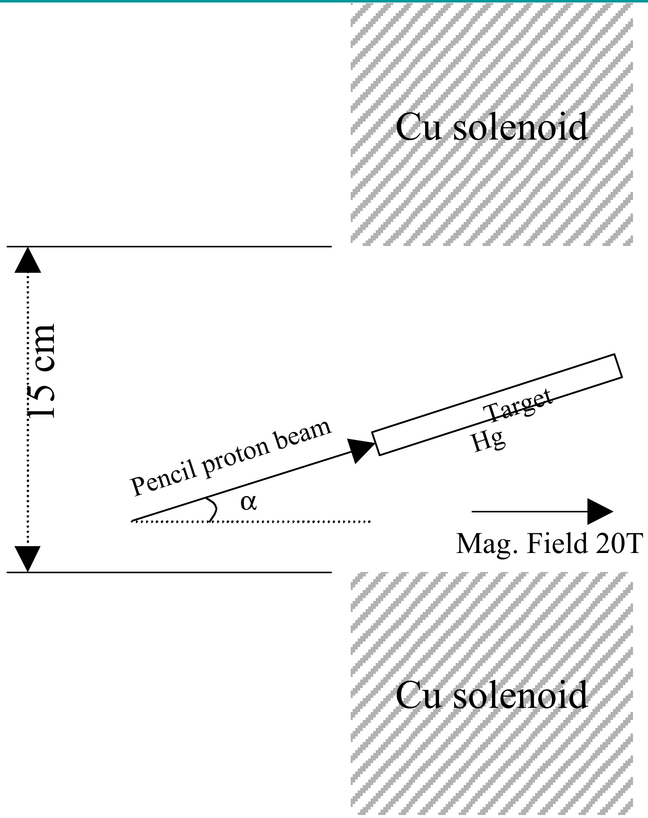
Layout on the CERN site

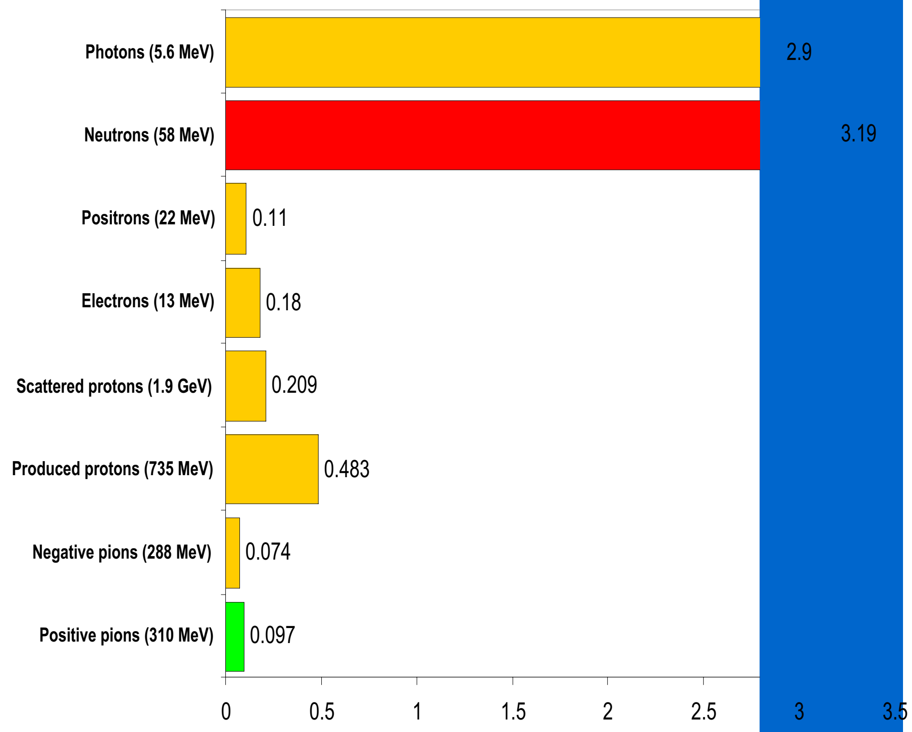


Linac + klystron gallery parallel to the fence of Meyrin site (Route Gregory)

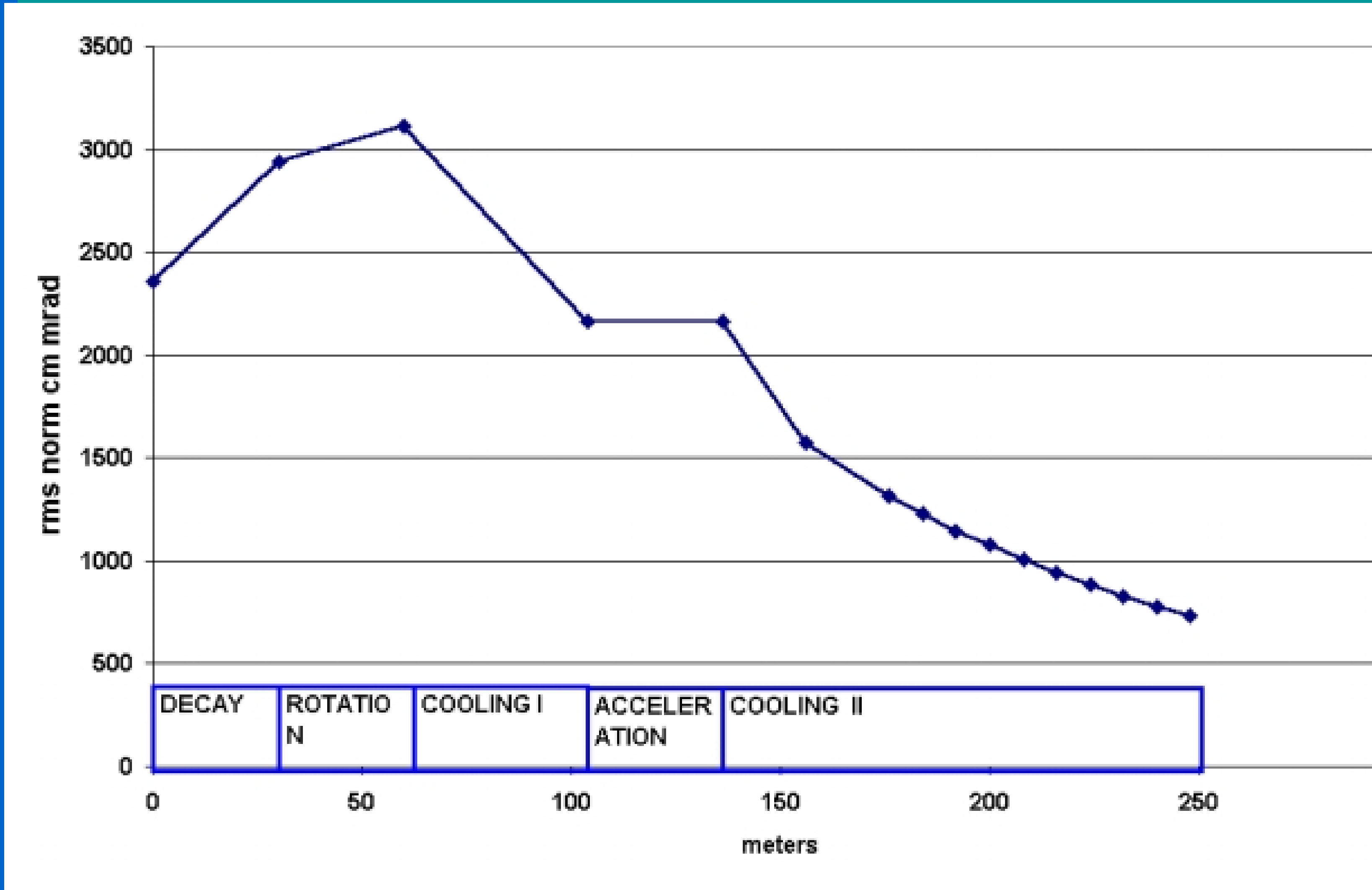
- Economic trench excavation
- Geological advantages (tunnel on“molasse”, no underground water)
- Minimum impact on the environment (empty field)
- Simple connection to PS & ISR via existing tunnels
- Use some of the old ISR infrastructure (electricity, cooling)

Particle yield at the SPL target





emittance evolution in the front end of the neutrino factory

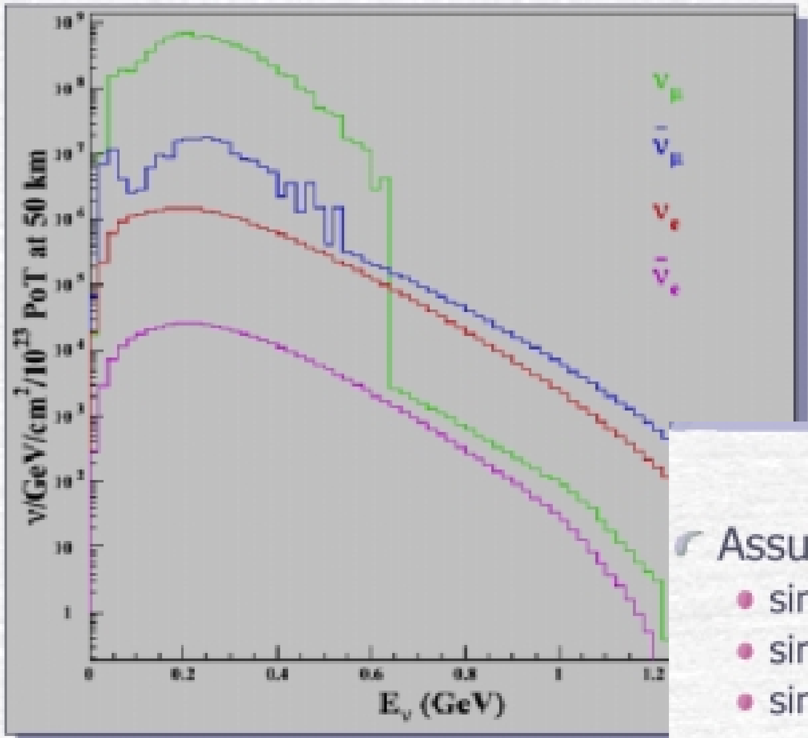


Cooling increases the phase space density of a factor of 16-

NU SUPERBEAMS

D.Casper
(CERN Oscillation Working Group)

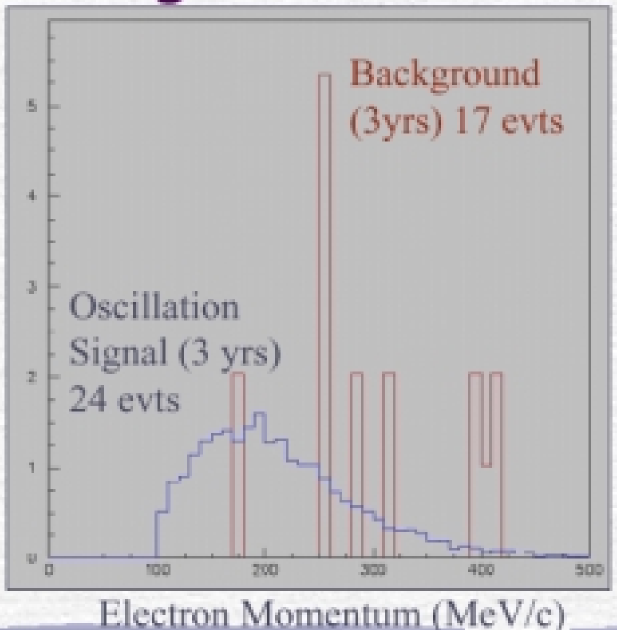
SuperBeam



40kton
Water Cerenkov
L=100km

Oscillation Signal

- Assumptions:
  - $\sin^2 2\theta_{12} = 0.8$
  - $\sin^2 2\theta_{23} = 1$
  - $\sin^2 2\theta_{13} = 0.01$
  - $\Delta m^2_{12} = 5\times10^{-5}\ eV^2$
  - $\Delta m^2_{23} = 3\times10^{-3}\ eV^2$
  - Ignore CP violation for now
- Identical to recent report of Mezzetto
  - Rescale to 70km baseline



Summary

- Most of the phase space covered by FNAL + CERN
- Sensitivity to s13 $\sin^2(2\theta_{13}) \approx 10^{-2} - 10^{-3}$
  - One to two orders of magnitude better than MINOS/OPERA
  - Two orders of magnitude worst than NuFact
- Sensitivity to δ. $\sin^2(2\theta_{13}) \approx 10^{-4} - 10^{-5}$
  - Still to be fully evaluated
  - Limited by
    - Beam background
    - Systematic errors on cross sections

half way from
ν factory !

Juan José Gómez Cadenas
Neutrino Telescopes, Venice,
March, 20001

2/27/2001 31

Very Large Hadron Collider (VLHC)

New study at FNAL (convener: J. Strait) to guide R&D

VLHC1 initial machine 15-20 TeV per beam

VLHC2 second phase: VLHC1 as injector to VLHC2 (87.5 TeV/beam)

both accelerators in same tunnel

	Phase 1	Phase 2
E_{beam} [TeV]	20	87.5
B_{dip} [T]	Low f. → 2.0	High f. → 10.0
R_{bend} [km]	33.3	29.1
Arc packing factor	95.0%	83.0%
R_{arc} [km]	35.1	35.1
C_{arc} [km]	220	220
$L_{straights}$ [km]	20	20
C_{total} [km]	240	240
Luminosity [$cm^{-2}s^{-1}$]	10^34	10^35

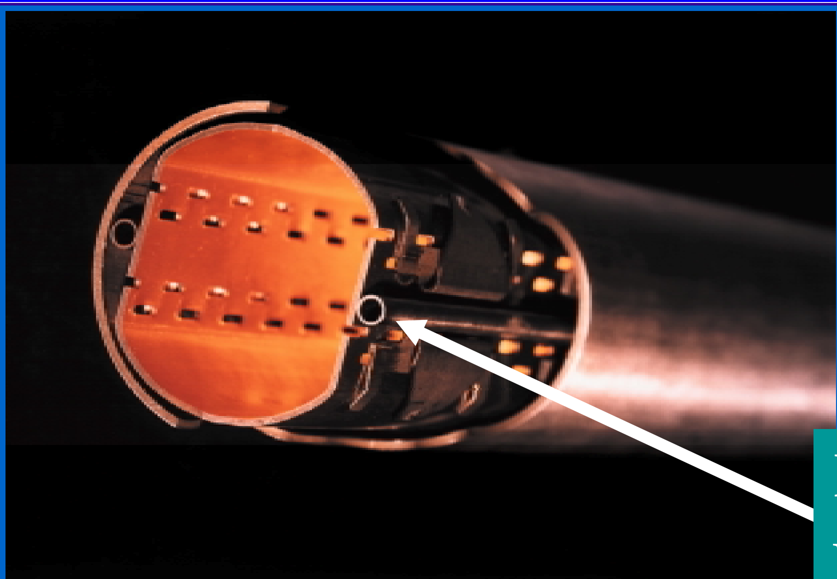
Preliminary parameter list

ELN (INFN)(1996)	**LHC**
100	7
12	8.3
238	27
	10^34

Vacuum Issues (Mauro Pivi / LBL)

Synchrotron radiation			
Photon flux	*Γ, ph/m-sec*	0.34×10^{16}	1.26×10^{16}
Critical energy	*Ec, keV*	0.48	3.4
Power deposited per meter	$P/2\pi_1 O$, *W/m*	0.082	2.12
Total power (per beam)	*P, kW*	47.5	176.6
Energy loss per turn	*ΔE, MeV/turn*	0.53	3.7
Radiation damping time (horizont. ampl.)	τ_D, *hrs*	114	2.6

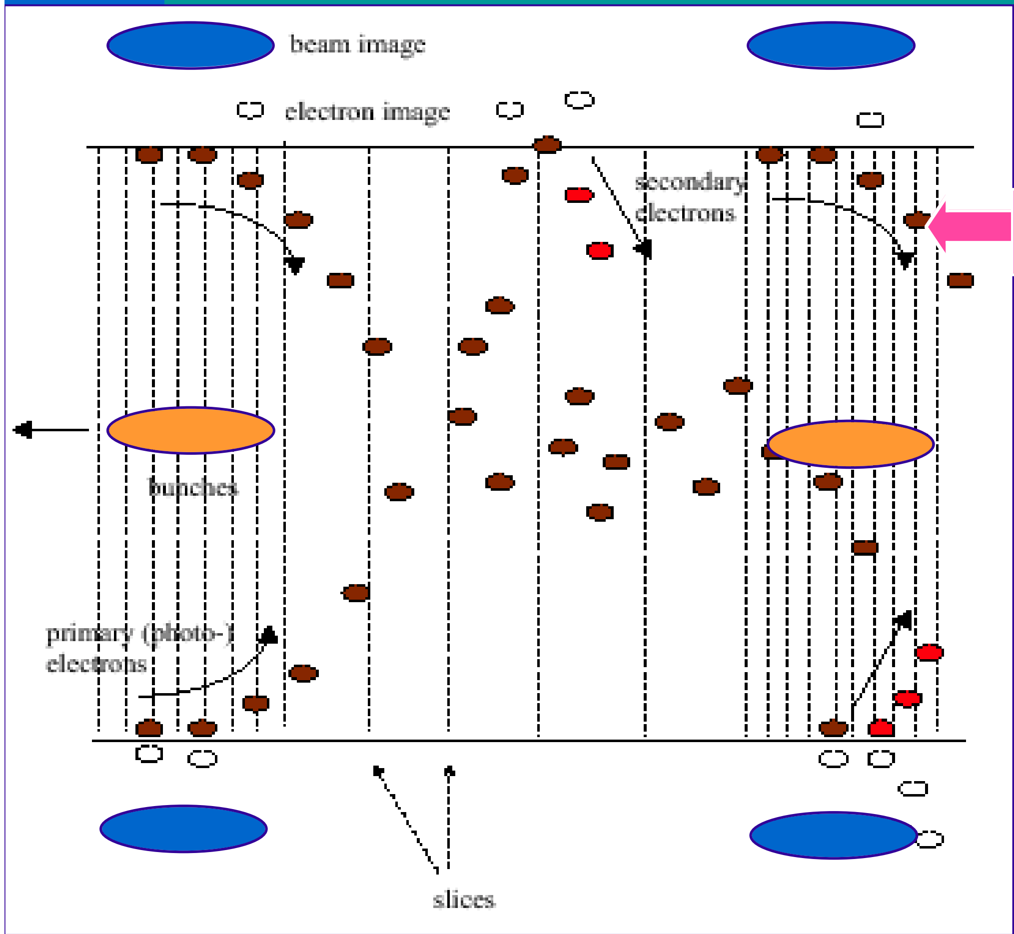
LHC	**ELN (1996)**
0.044	
0.2	2.46
7.6	585
0.007	28
52	1.5



High field:
power deposited by Synchr.Rad.
difficult to take out because of
low temperature!

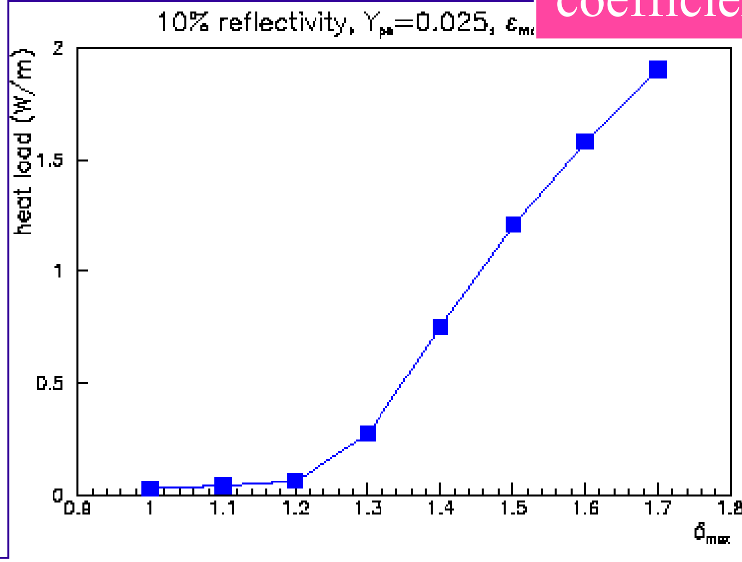
LHC: heat deposited on the inner tube which is kept at $\approx 19^0$K by Ne coolant

Photo electrons acceleration at LHC may produce additional heat load



secondary electrons

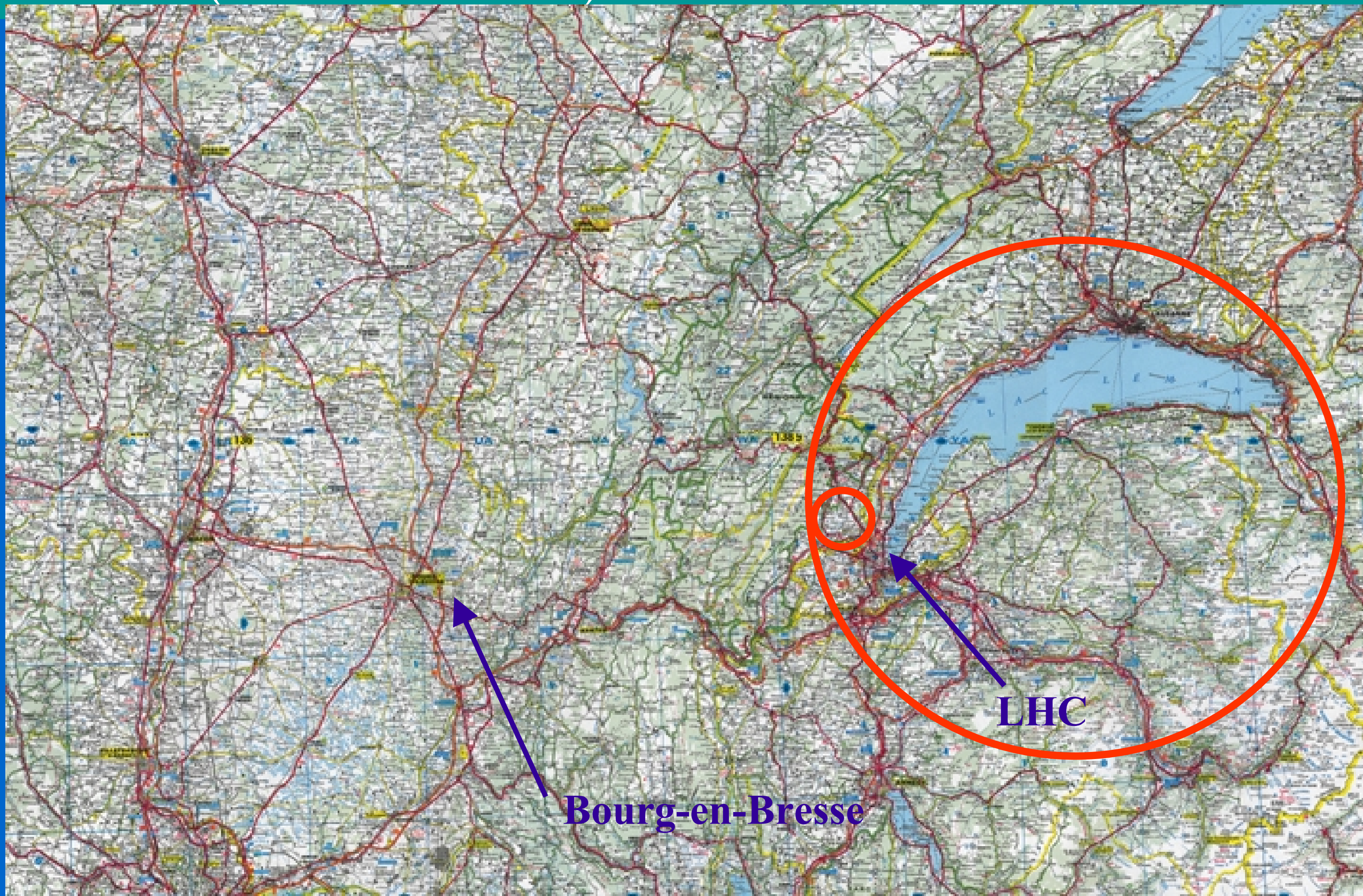
δ=yield coefficient



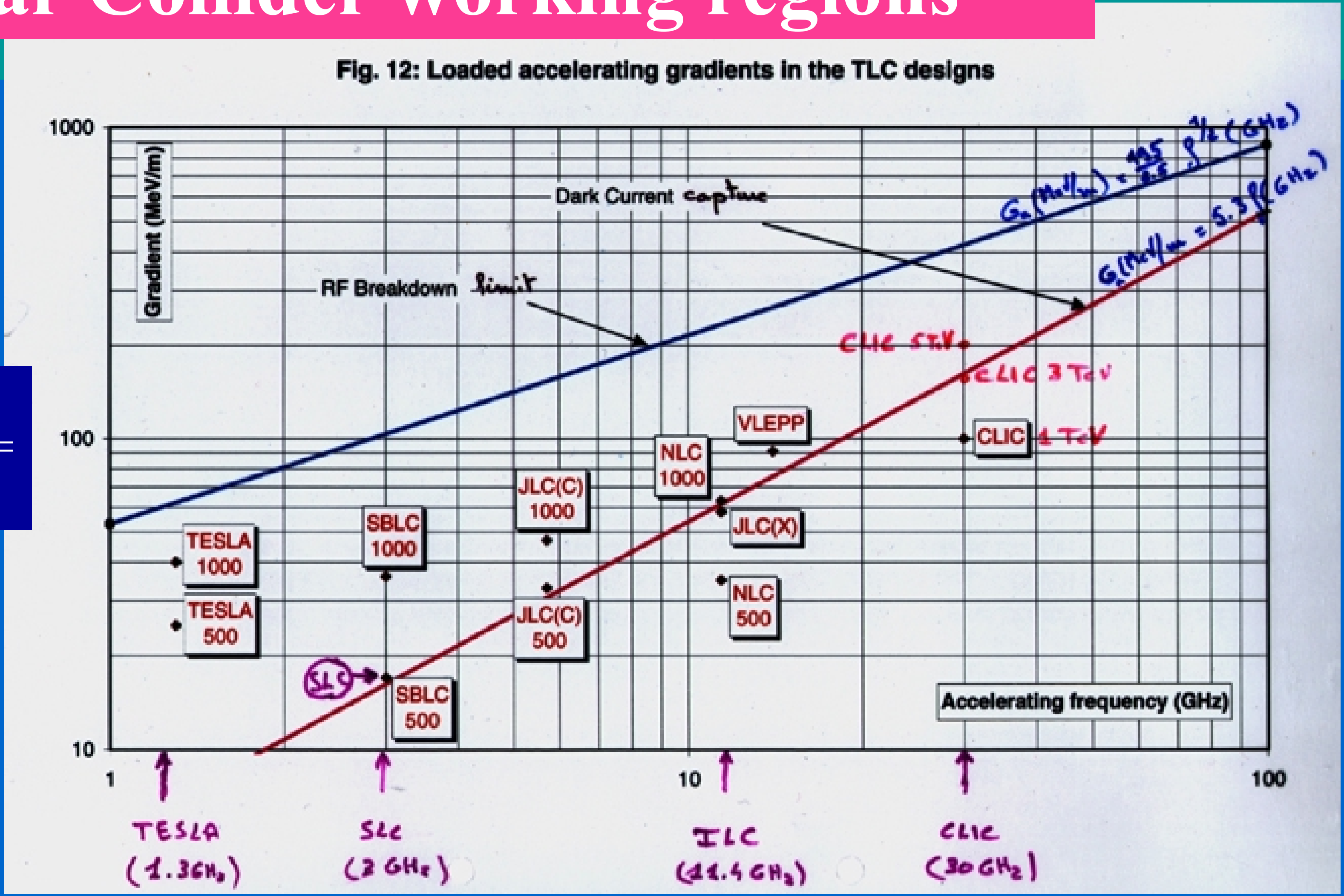
Heat load in LHC dipole chamber vs. maximum secondary emission yield $\delta_{\max}$. Parameters: $\epsilon_{\max} = 450$ eV, $R = 0.1$, and $Y^* = 0.025$. The curve changes slope near the critical yield $\delta_{\max} \approx 1.3$.

VLHC at CERN?

(Circ. = 240 Km)



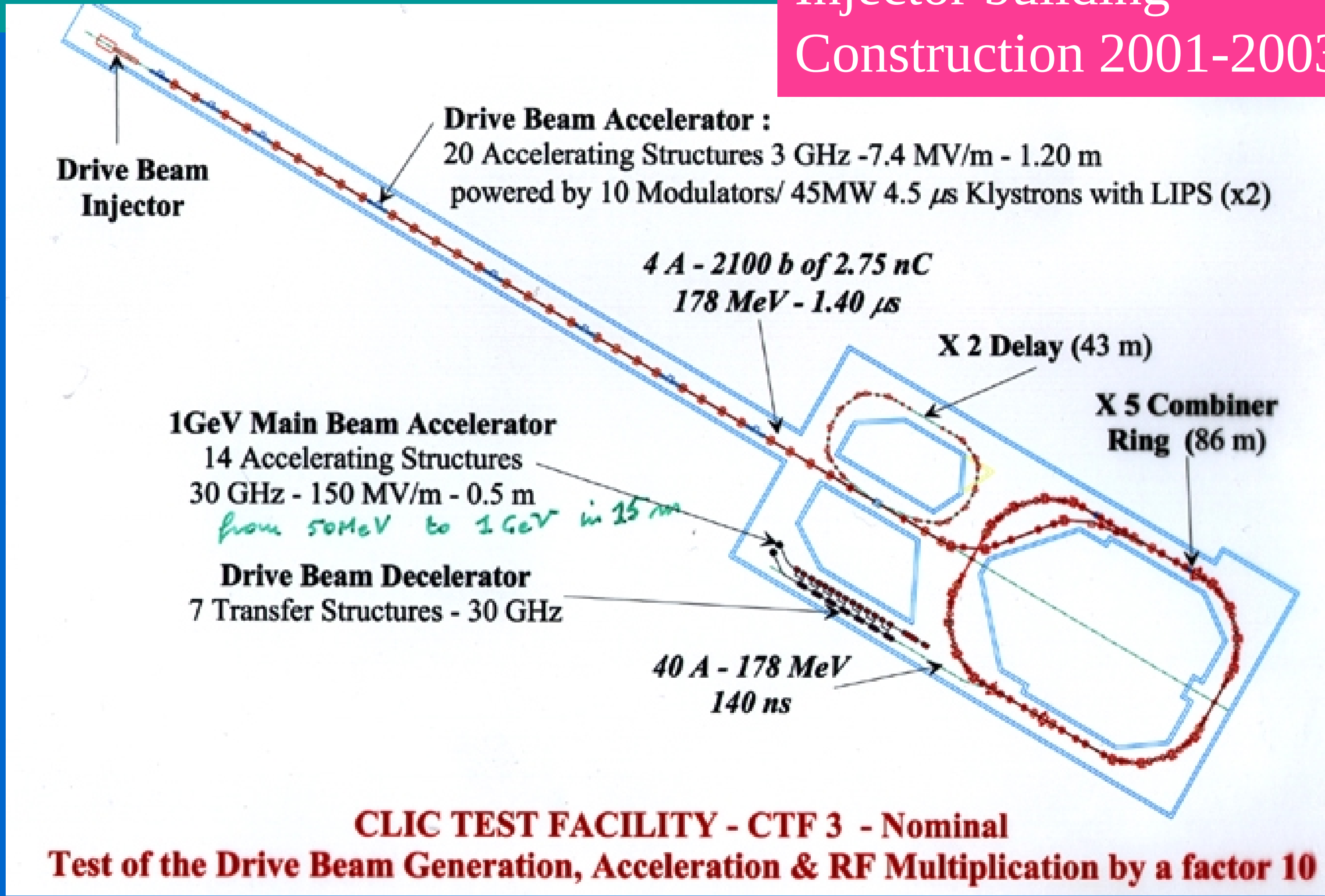
Linear Collider working regions



NOTE:
100 MeV/m=
3TeV/30km

CLIC Test Facility 3

Housed in LEP Pre-Injector building
Construction 2001-2003



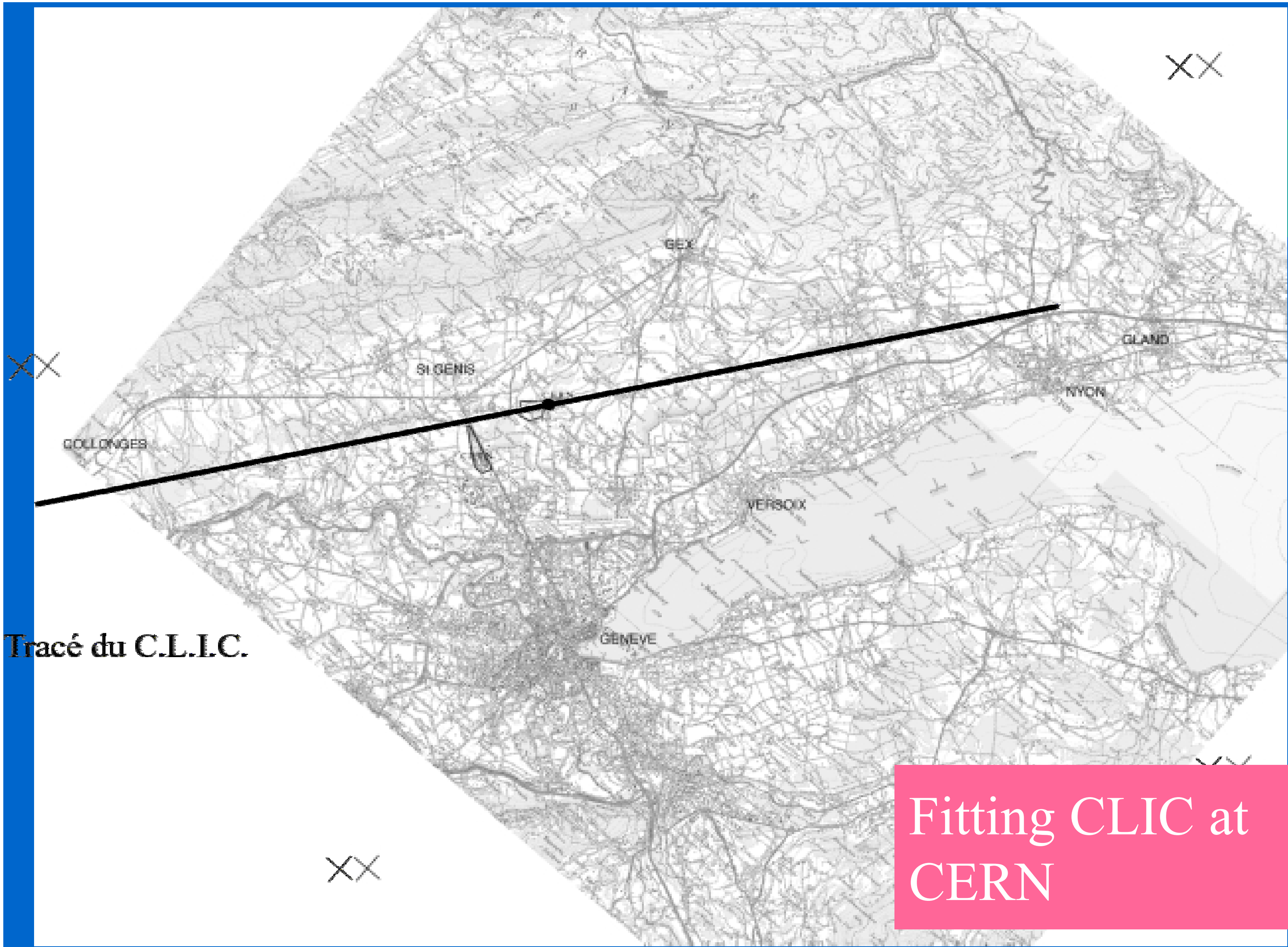
CLIC test facility n.3

- to demonstrate a novel concept of drive-beam generation
- to provide the nominal rf power to a few accelerating sections which in turn will operate with the nominal accelerating gradient.
- CTF3 will be a unique 30 GHz high-power rf source for the tests of all the rf components.
- CTF3 will evolve in a staged approach where construction phases alternate with beam test periods. The plan is to have CTF 3 fully exploited by 2005.

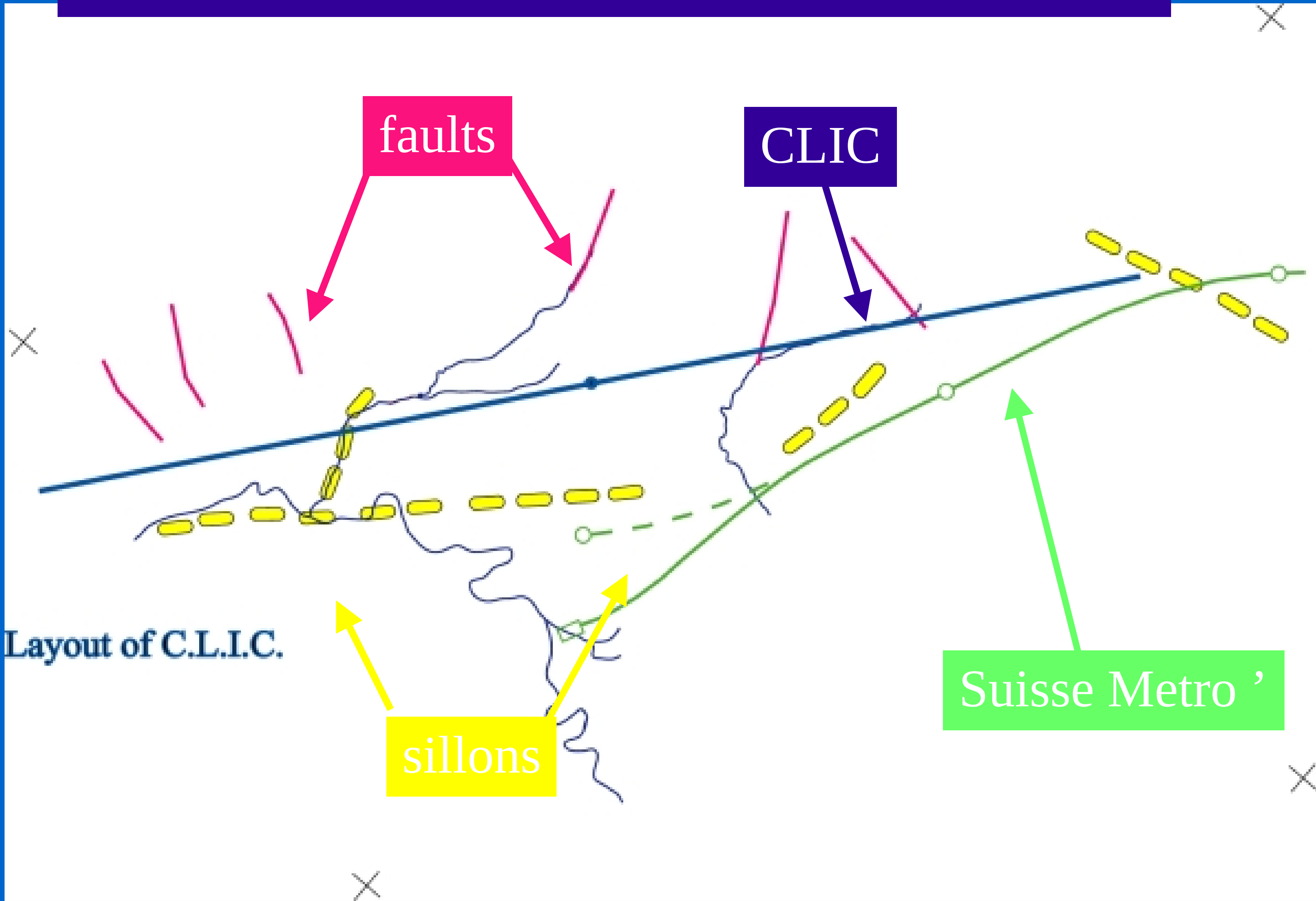
CLIC status

- CTF3 construction starts in 2001
- Next step (after positive results from CTF3): a 600m module
- Collaborations with INFN, IN2P3, SLAC are active
- Closer collaboration with European Laboratories is being discussed (Orsay, RAL, Frascati …)
- CLIC physics studies started at CERN

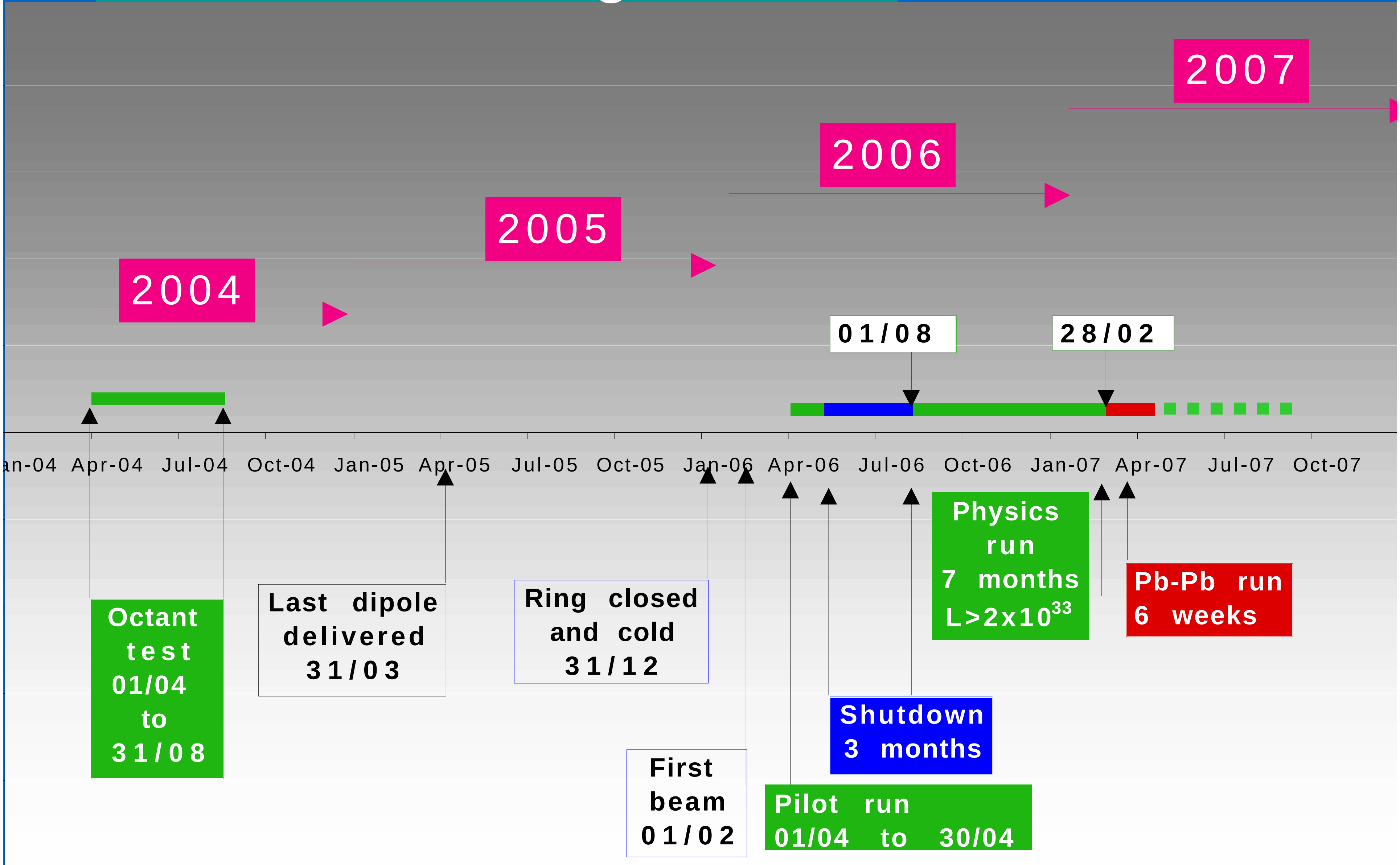
Fitting CLIC at CERN

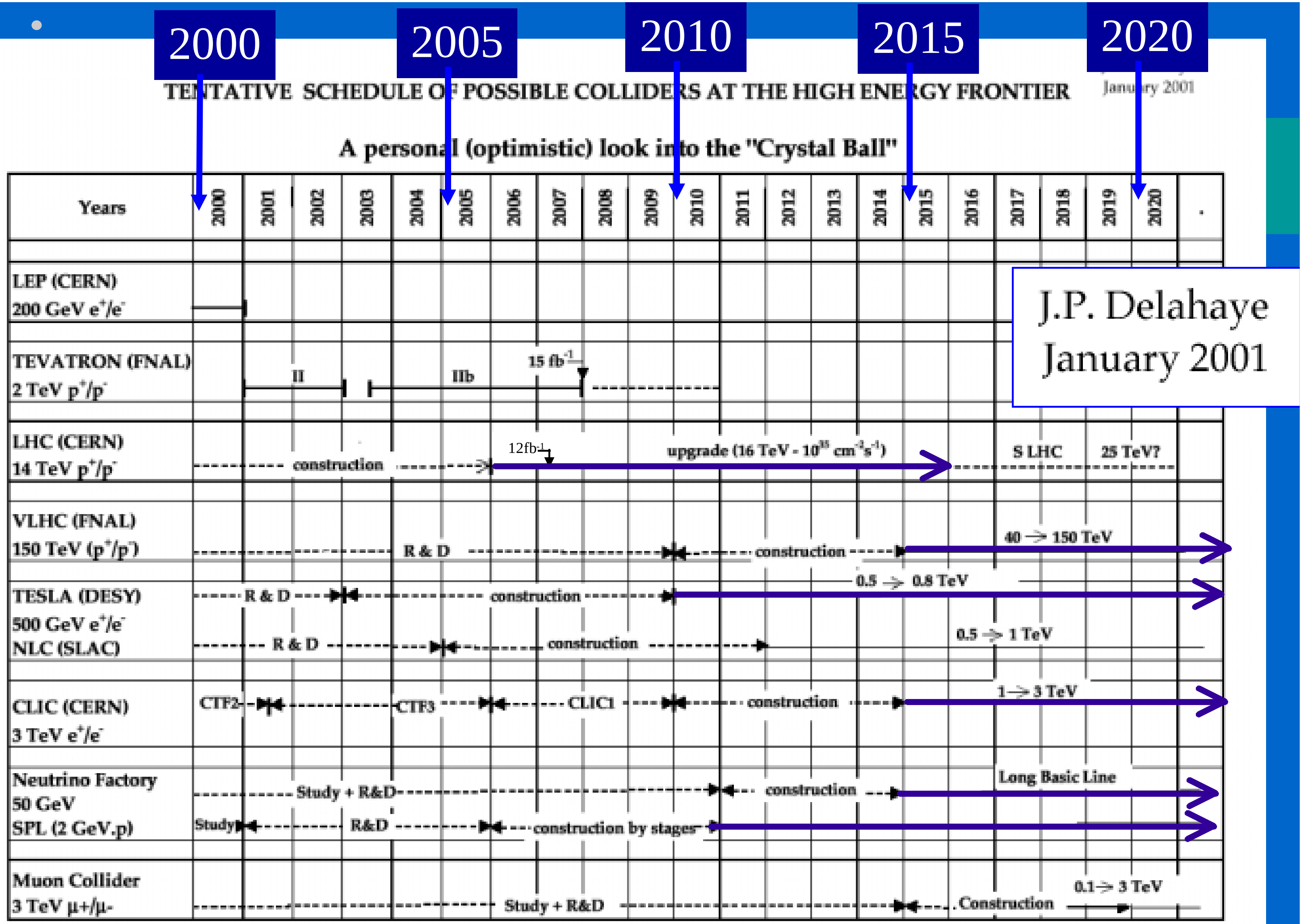


GEOPHYSICAL FEATURES



LHC commissioning schedule




2000
2005
2010
2015
2020
TENTATIVE SCHEDULE OF POSSIBLE COLLIDERS AT THE HIGH ENERGY FRONTIER
January 2001
A personal (optimistic) look into the "Crystal Ball"
Years
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
LEP (CERN)
200 GeV e+/e-
TEVATRON (FNAL)
2 TeV p+/p-
II
IIb
15 fb-1
LHC (CERN)
14 TeV p+/p-
construction
12fb-1
upgrade (16 TeV - 10^35 cm-2s-1)
S LHC
25 TeV?
VLHC (FNAL)
150 TeV (p+/p-)
R & D
construction
40 → 150 TeV
TESLA (DESY)
500 GeV e+/e-
NLC (SLAC)
R & D
construction
0.5 → 0.8 TeV
R & D
construction
0.5 → 1 TeV
CLIC (CERN)
3 TeV e+/e-
CTF2
CTF3
CLIC1
construction
1 → 3 TeV
Neutrino Factory
50 GeV
SPL (2 GeV,p)
Study + R&D
construction
Long Basic Line
Study
R&D
construction by stages
Muon Collider
3 TeV µ+/µ-
Study + R&D
Construction
0.1 → 3 TeV
J.P. Delahaye
January 2001

Global Accelerator Network (ICFA)

Global Accelerator Network (ICFA)

annual budget, in unit of CERN budget (very crude):

EUROPE	1+ 0.6 to 1	
USA	1 to 1.5	
Japan	0.4	
total	3 to 4	say: 4 BCHF/year

Investments over 10 year in the GAN≈ 0.3 budget/ (10 years) ≈ 12 BCHF

Some cost estimate (European accounting, only material cost, ≈ 0.5 US accounting)
in unitis of the LHC material cost (1 LHC≈ 3 BCHF):

NLC (4 B$)	2.1	≈ 12 BCHF
Nu factory (1.1 B$)	1.7	

can we realize the full programme in 15 to 20 years !!!??!!!

Conclusions

- Many fascinating problems in 1-10 TeV region
  - from « normal business »: Higgs, SUSY,
  - to « new world » discoveries : extramensions
- We need to understand neutrinos better
- Support accelerator physics!!!
- Consensus:
  - LHC, sub-TeV e^+e^- LC
  - CLIC, VLHC
  - nu-factory
- Can we make them in reasonable time? Can we afford?
  - We can perhaps realize the full programme in 15 to 20 years, but:
    - Better efficiency in decision making
    - Respect User distribution, to keep young generations in the game

A transition to a new global organisation, similar to EU transition from National Laboratories to CERN ???