

Futuri collider adronici e leptonici

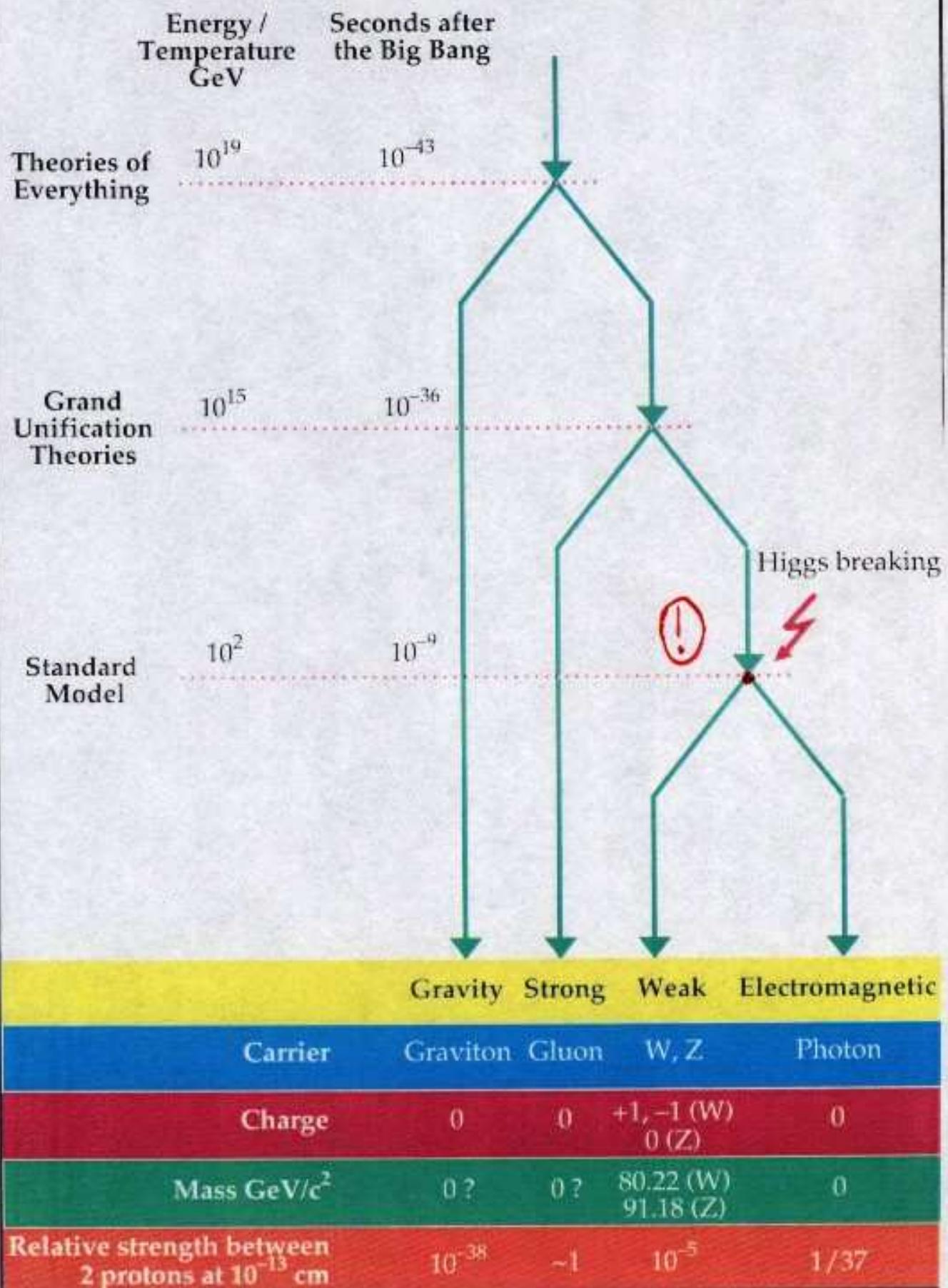
Gianrossano Giannini

Università & INFN Trieste

TRIESTE-LEP-2000

26 APRILE 2000

Sessione plenaria



MODELLO STANDARD E OLTRE

Problemi aperti

- **UNIFICAZIONE**

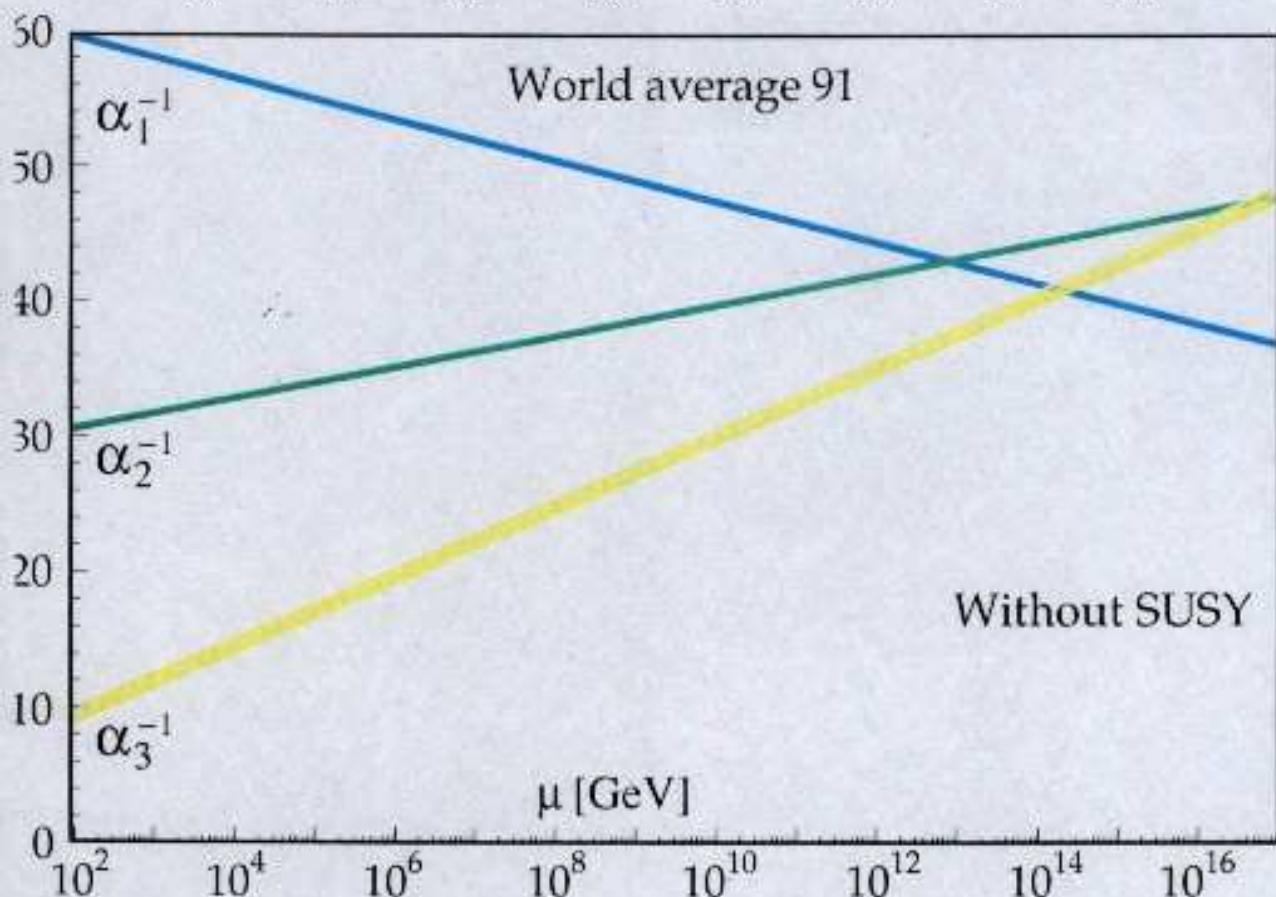
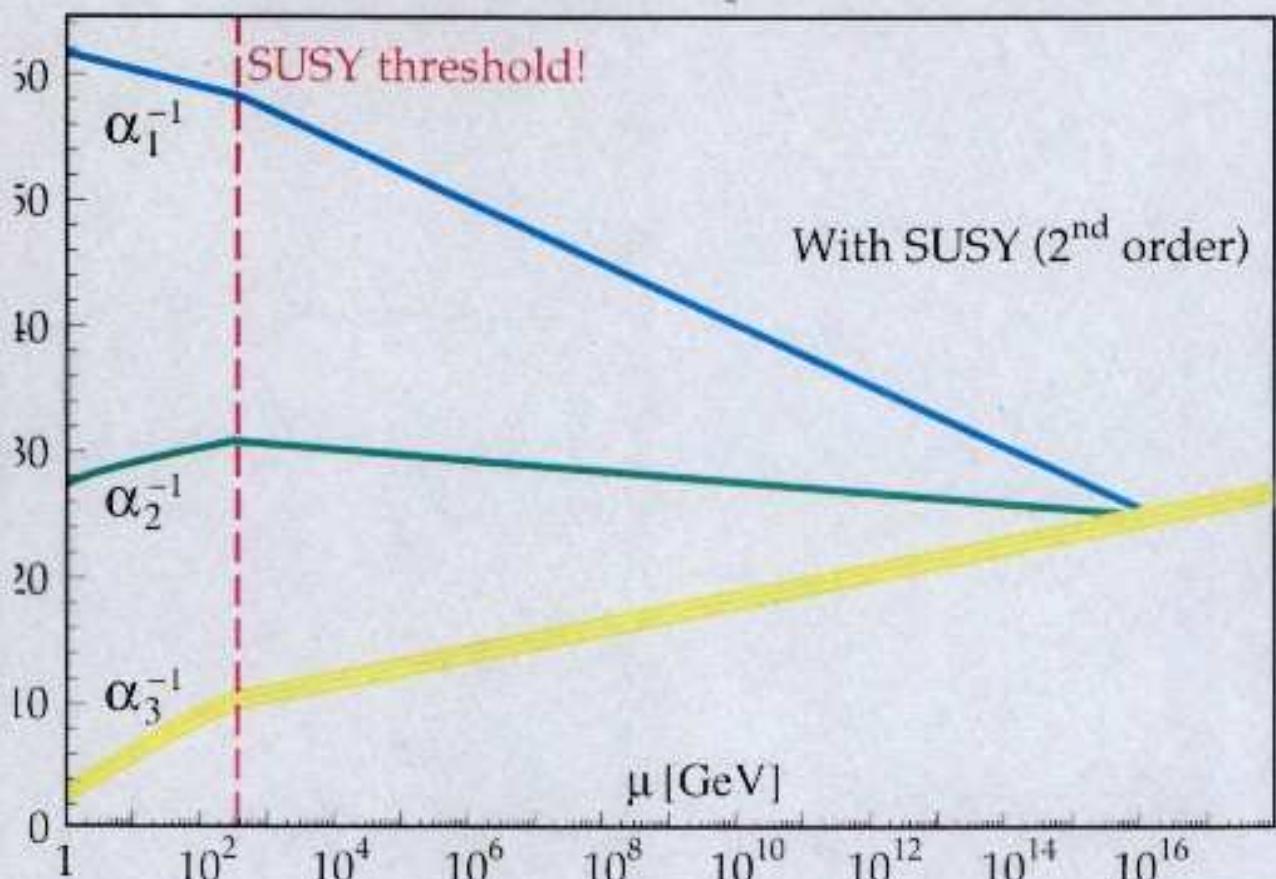
- Perché tanti parametri ?
- GUT ? Tutte le forze di gauge in un unico schema di grande unificazione?

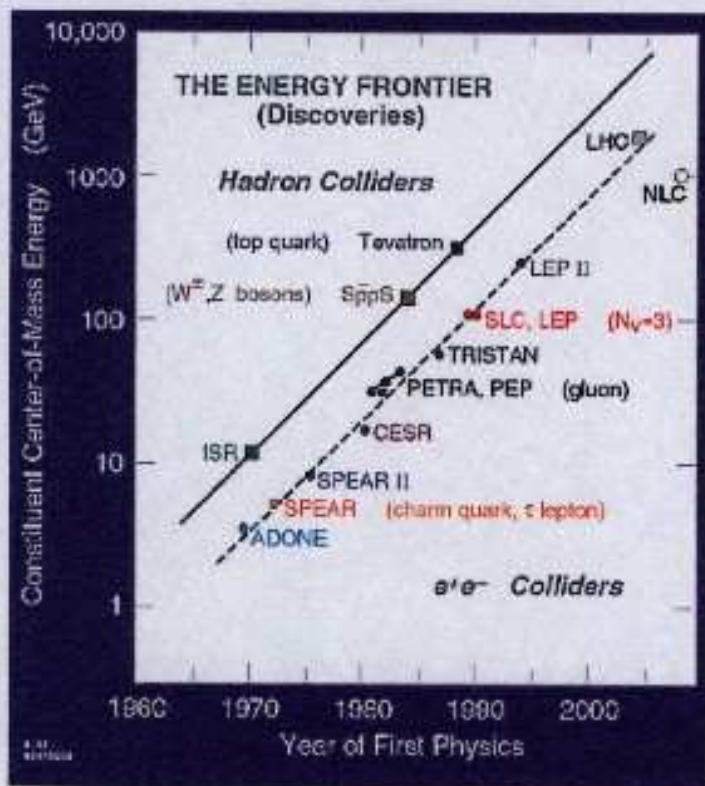
- **FLAVOUR**

- Perché più famiglie di quark e leptoni ?
- weak mixing ? violazione di CP ?
- compositeness ? simmetrie extra ?

- **MASSA**

- Masse originate dal bosone di Higgs ?
perche cosi' piccole? naturalezza?
- Supersimmetrie?





LIVINGSTON PLOT

- ESPLORAZIONE
- SCOPERTA
- MISURE DI PRECISIONE

To Understand Elementary Particles

ELEMENTARY PARTICLES		
Quarks	Leptons	Force Carriers
u c t	e	γ
d s b	μ ν	g Z
l e u	τ ν τ	W
		I II III

WHY?

Stephen Hawking: 50% chance we will reach a unified understanding within the next 20 years.



Alvaro de Rujula (CERN): Huh! No chance without further experimental information.



Introduction to HEP '99; Bruce King; Montauk, NY, 27 September, 1999

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IL FUTURO

DIPENDE DAI RISULTATI DI

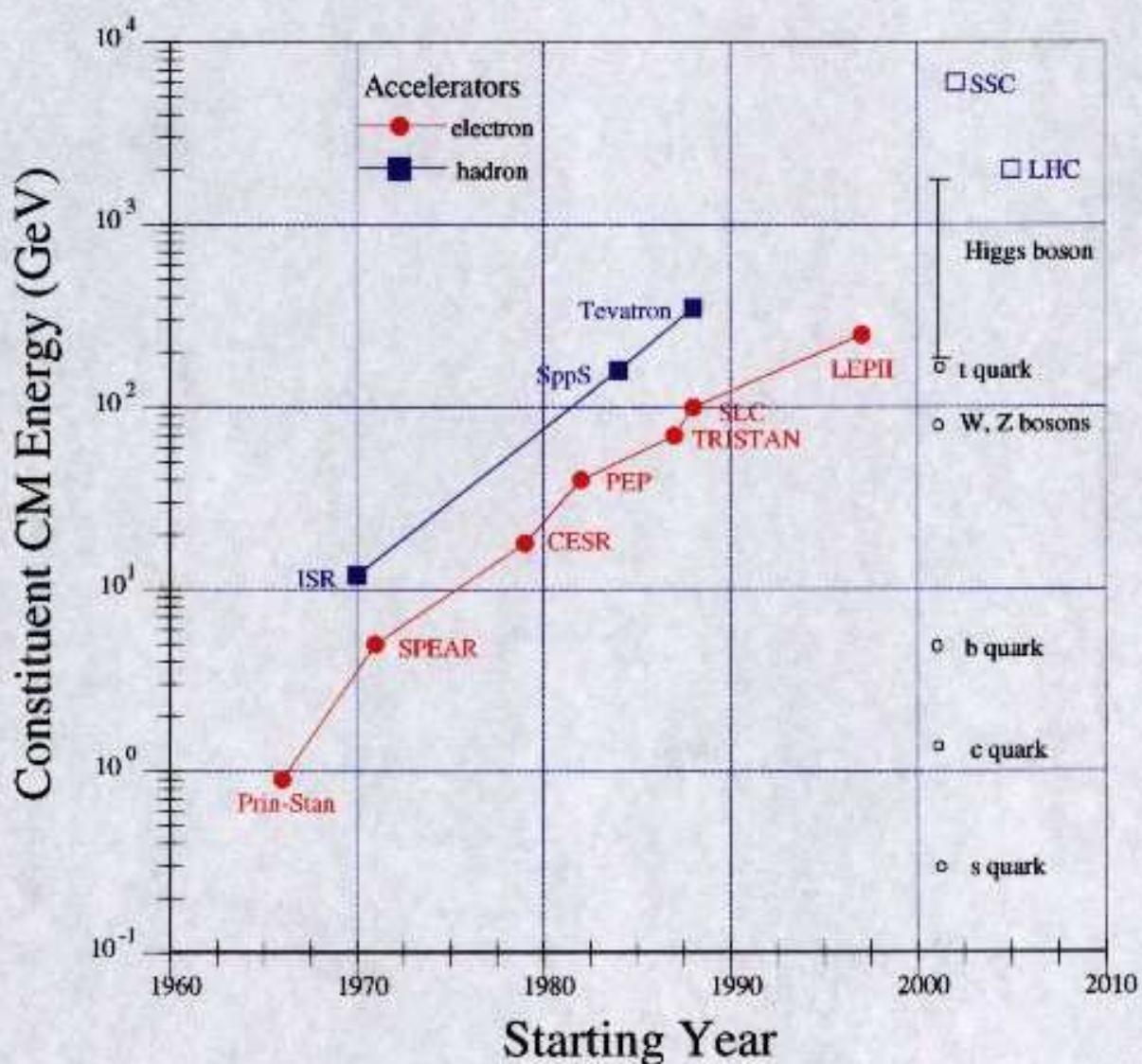
LEP II, Tevatron e LHC

- ELECTROWEAK SYMMETRY BREAKING SECTOR
Unica area dello S.M. non ancora confermata
- HIGGS LEGGERO ESISTE ?
Standard Model, Weakly interacting,
VEV: $v = 246 \text{ GeV}$
 - Proprietà: MASSA, ACCOPPIAMENTI
 - Ampiezze di decadimento,
Rates di produzione
- SE LHC NON LO VEDE
 - E.W. Symmetry Breaking Sector
Strongly interacting

Progress in High Energy Physics

Depends on Advancing the

Energy Frontier



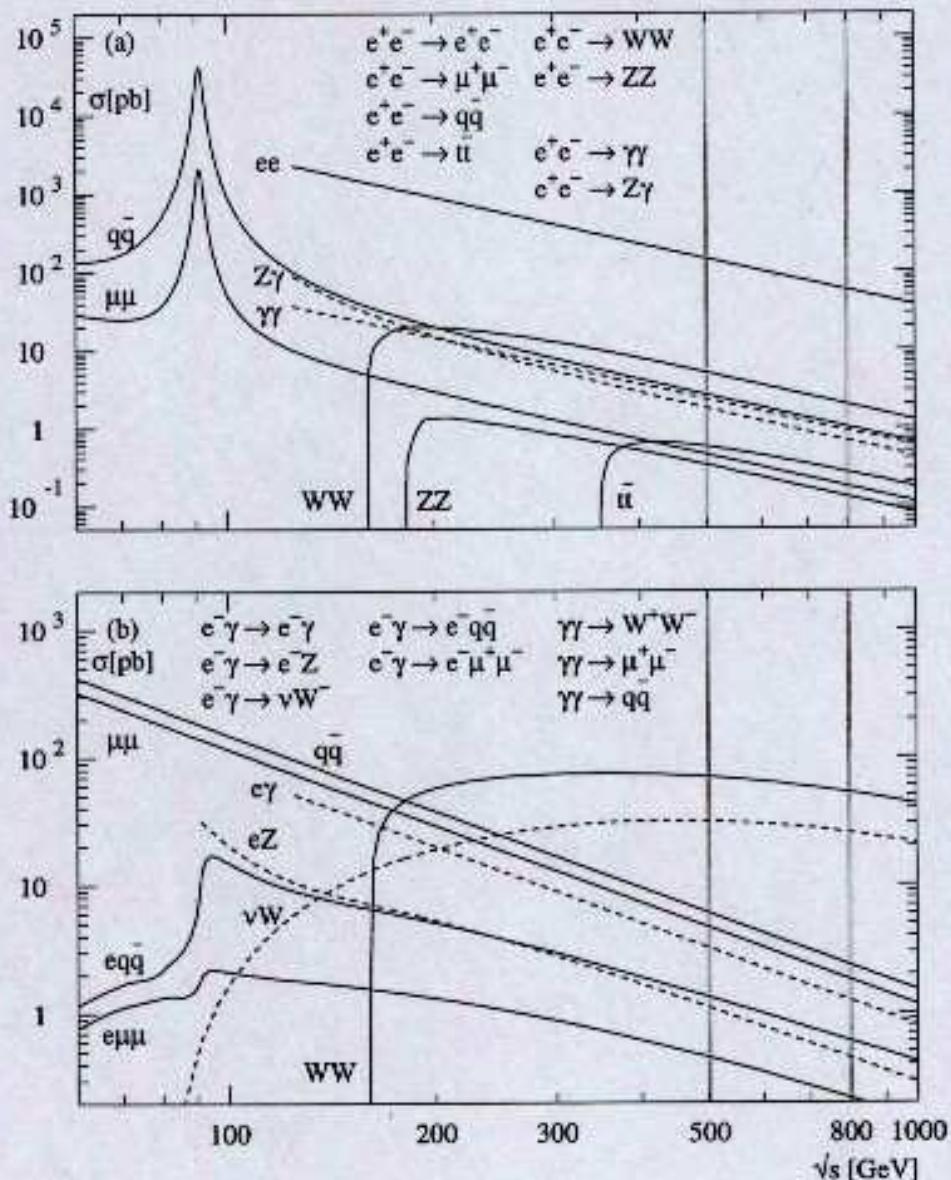
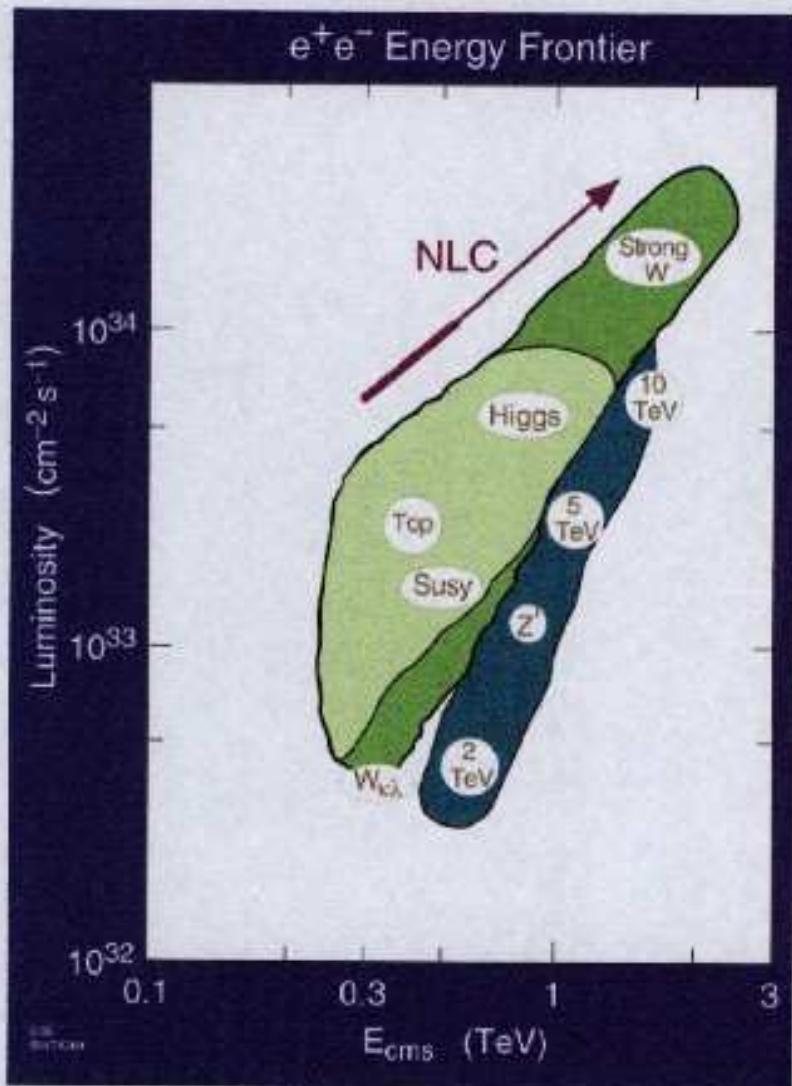


Figure 1.1: (a) The basic processes of the Standard Model: e^+e^- annihilation to pairs of fermions and gauge bosons. The cross sections are given for polar angles between $10^\circ < \theta < 170^\circ$ in the final state. (b) Elastic/inelastic Compton scattering and $\gamma\gamma$ reactions. \sqrt{s} is the invariant $e\gamma$ and $\gamma\gamma$ energy. The polar angle of the final state particles is restricted as in (a); in addition, the invariant $\mu^+\mu^-$ and $q\bar{q}$ masses in the inelastic Compton processes are restricted to $M_{inv} > 50$ GeV.



e^+e^- NEXT LINEAR COLLIDER

Luminosity Requirements

Figure of merit:

$$\sigma_{QED} = \frac{100 \text{ fb}}{s \text{ (TeV}^2)} \left(\frac{\alpha(s)}{\alpha(M_Z^2)} \right)^2$$

Integrated luminosity needed:

$$\left(\int \mathcal{L} dt \right) \sigma_{QED} \gtrsim 1000 \text{ events}$$

One year's running, the luminosity requirement is

$$\mathcal{L} \gtrsim 10^{33} \cdot s \text{ (cm)}^{-2} \text{ (sec)}^{-1}$$

- $\sqrt{s} \simeq 10 \text{ TeV}$, requiring

$$\int \mathcal{L} dt \gtrsim 1 \text{ (fb)}^{-1}, \quad \mathcal{L} \gtrsim 10^{35} \text{ (cm)}^{-2} \text{ (sec)}^{-1}$$

- $\sqrt{s} \simeq 100 \text{ TeV}$, requiring

$$\int \mathcal{L} dt \gtrsim 100 \text{ (fb)}^{-1}, \quad \mathcal{L} \gtrsim 10^{37} \text{ (cm)}^{-2} \text{ (sec)}^{-1}$$

Can we really handle these luminosities?

POSSIBLE FUTURE e^+e^- LINEAR COLLIDER

	TESLA	JLC/NLC	CLIC
Energy [TeV]	0.8	1	3
Lum. [$10^{34}/\text{cm}^2/\text{s}$]	5.0	1.3	10
Rf freq. [GHz]	1.3	11.4	30
Rep. Rate [Hz]	3	120	75
$N [10^{10}]$	1.4	0.95	0.4
Bunch Spacing [ns]	189	2.8	0.67
Ave. Current [A]	0.012	0.6	1.0
Pulse len. [μs]	850	0.27	0.10
$\gamma\epsilon_x^*/\gamma\epsilon_y^*$ [mm-mrad]	8/0.01	4.5/0.10	0.6/0.01
σ_x^*/σ_y^* [nm]	391/2	234/3.9	40/0.6

$$Q = \int_{\text{rep}} \frac{m_b N^2}{4\pi \delta_x^* \delta_y^*} H_D$$

Status of the R&D on TESLA

Advantages of superconducting cavities for a linear collider

Due to low RF losses in the walls of
s.c. cavities

- High conversion efficiency from
mains to beam power
- Long RF pulse possible
Many bunches spaced far apart
allowing
 - head on collision
 - fast bunch to bunch orbit feedback

Luminosity of e+/e- collider is given by:

$$L = \text{const} \cdot H \cdot P \frac{\sqrt{\delta}}{E} \frac{\eta}{\sqrt{\epsilon}}$$

- H Luminosity enhancement factor caused by selffocussing
- E cm energy of collider
- δ average beamstrahlungs loss
- P mains power
- η conversion efficiency mains to beam power
- ϵ normalised vertical emittance at IP



To achieve high luminosity

high conversion efficiency

and

small vertical emittance at I.P.

are needed

A very relevant quantity in optimizing the performance of a Linac is the shunt impedance per unit length

$$\frac{(\text{Accelerating Gradient})^2}{\text{RF loss per unit length}}$$

This quantity depends on RF frequency ω
for normalconducting acc. structures

$$\sim \sqrt{\omega}$$

Thus favouring high RF frequencies

For superconducting acc. structures it scales approximately like

$$\frac{\omega}{A\omega^2 + B}$$

Favouring RF frequencies around

$$\sim 1 \text{ GHz}$$

As low RF frequencies are preferred
for s.c. cavities

→ Ideally suited to accelerate
low emittance beam
as emittance dilution by wakefields
is small $W_L \sim \omega^3$

$$L \sim \frac{\eta}{\sqrt{\epsilon}}$$

The combination of high conversion
efficiency from mains to beam power
and small emittance dilution make
superconducting linear collider the
ideal choice with respect to achievable
luminosity

Major challenges to be mastered

so that superconducting linear collider
becomes feasible:

- Increase of gradient from ~5 MV/m
to 25MV/m
- Cost reduction of structure per meter
by ~4 to achieve 2000\$/MV

Encouraged by R&D results from

CEBAF,CERN,Cornell,DESY,KEK,Saclay
and Wuppertal

nucleus of TESLA collaboration decided
in 1991 to set up infra structure at DESY

necessary to process and test 1.3Ghz sc
Niobium cavities produced by industry

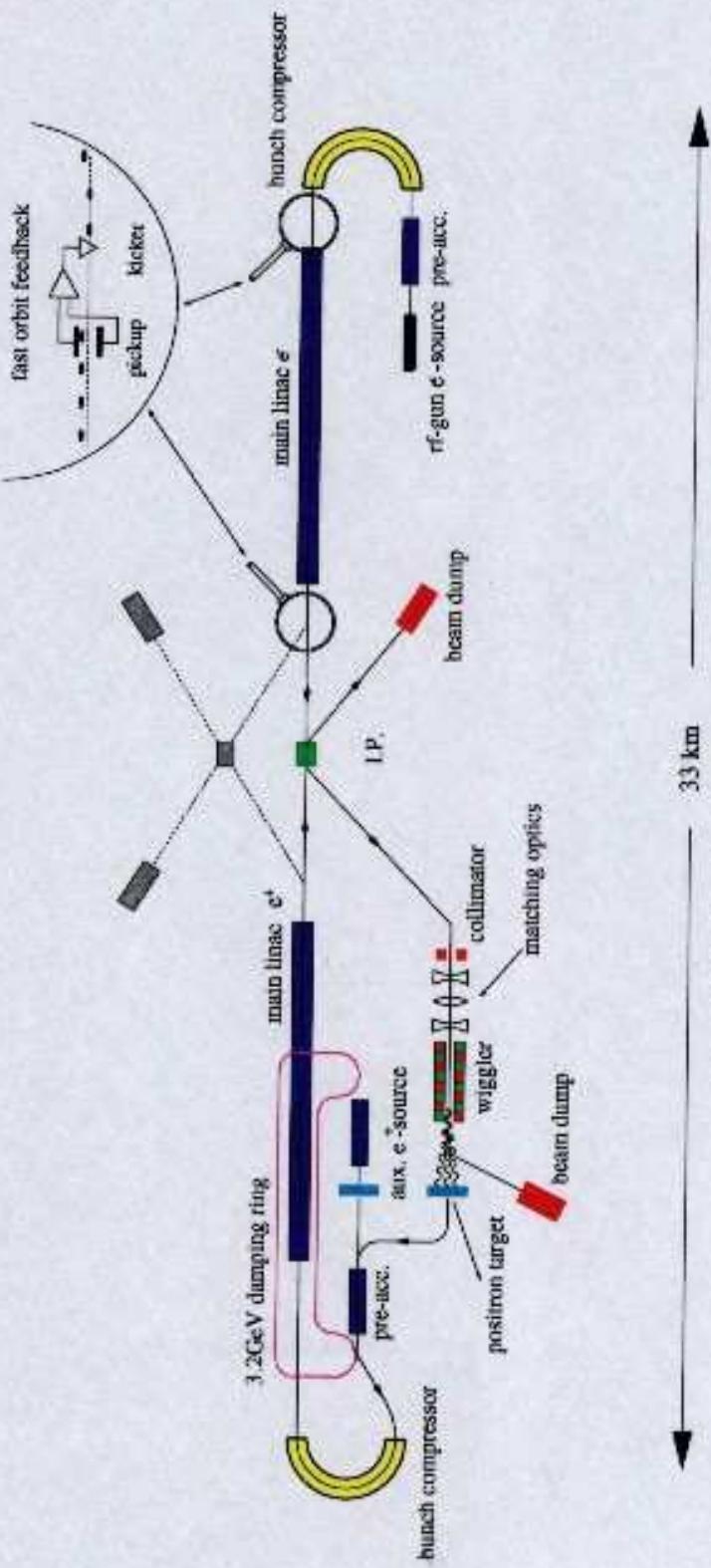
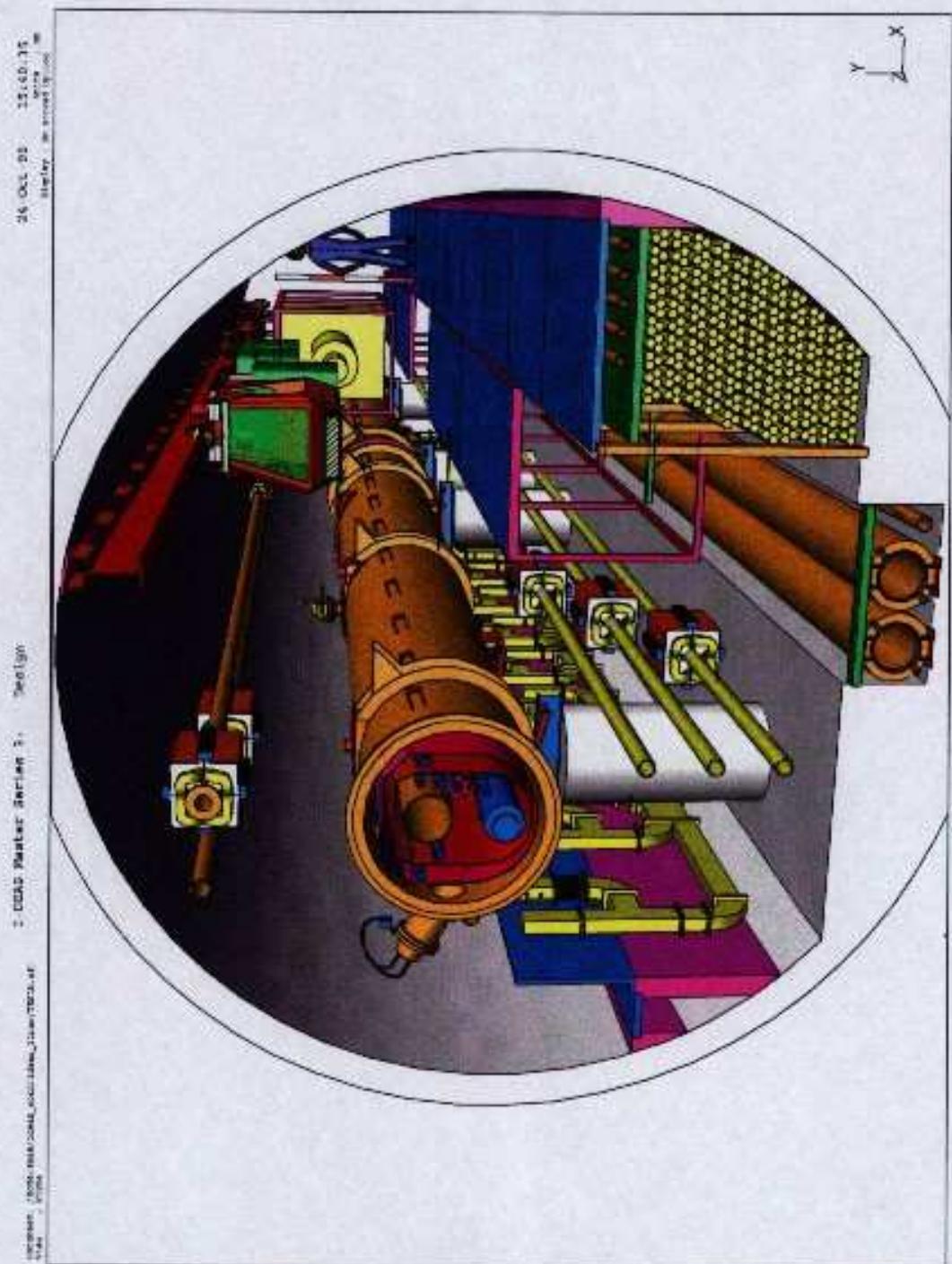
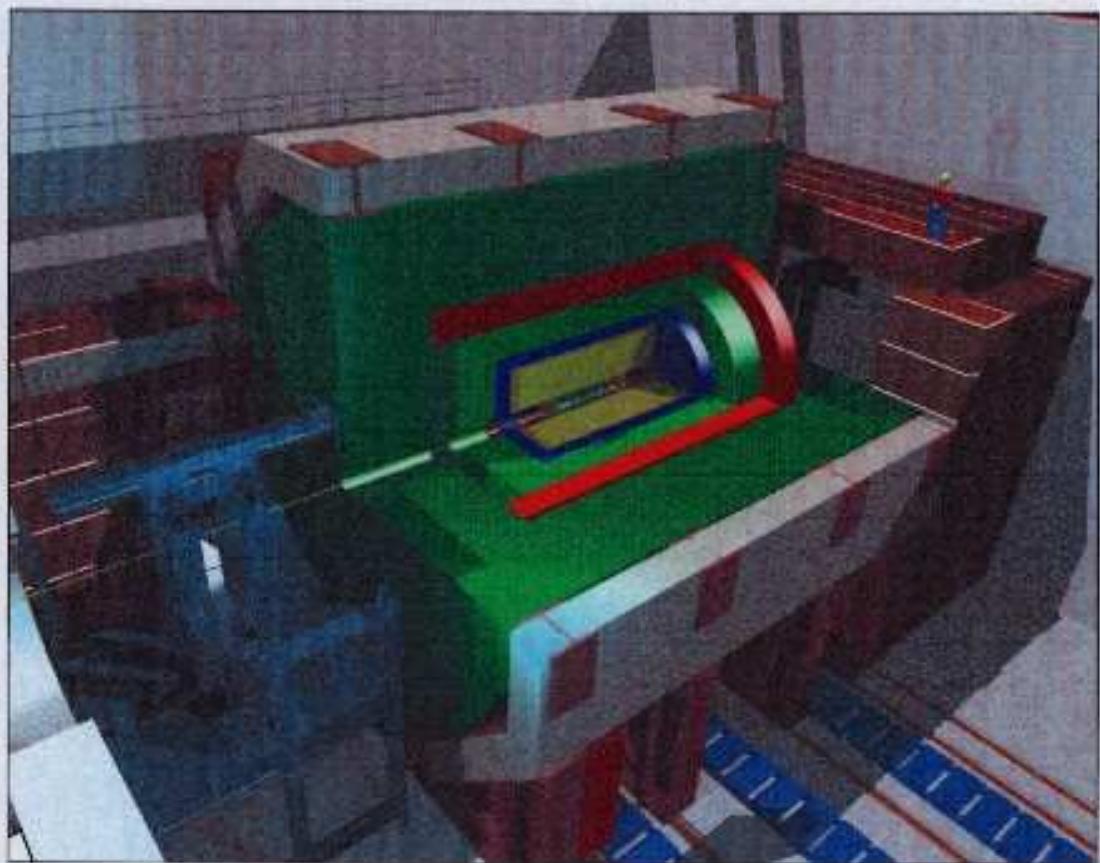


Figure 3.1.4: Sketch of the overall layout of TESLA.





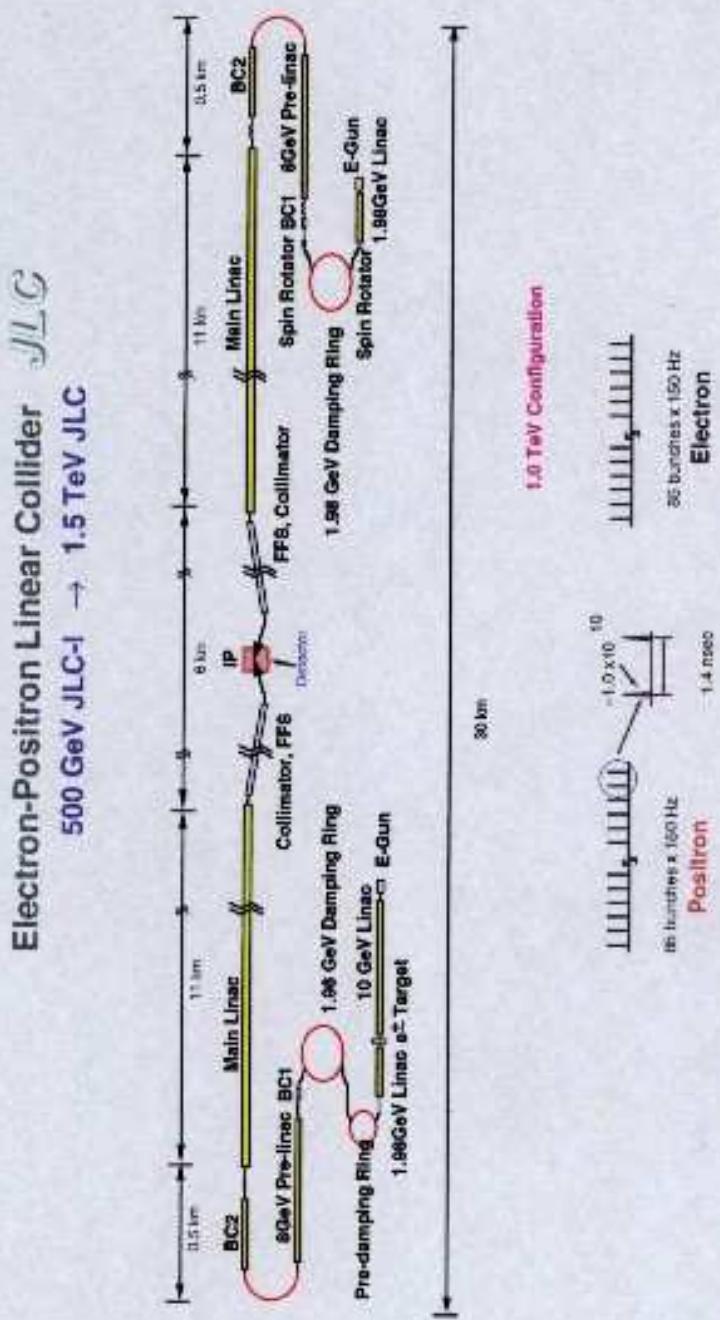
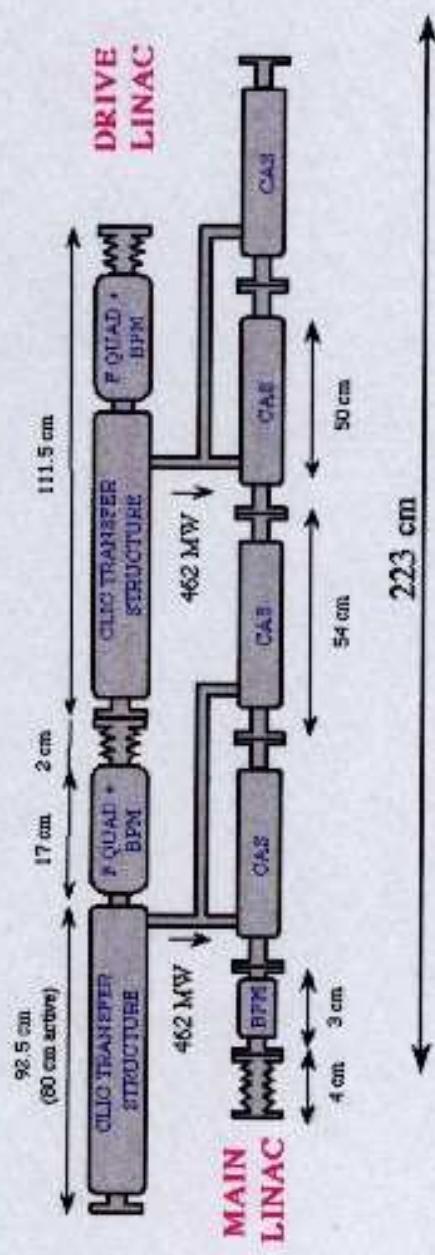


Figure 1.1: Schematic layout of JLC.

JLC Design Study, April, 1997

TWO BEAM ACCELERATION (TBA)

(4 CAS + 2 TRS)/module
Drive beam with 1856 bunches of 17.5 nC/bunch



CLIC module layout
3 TeV

| Welcome | General Description | Overall Layouts | Publications |

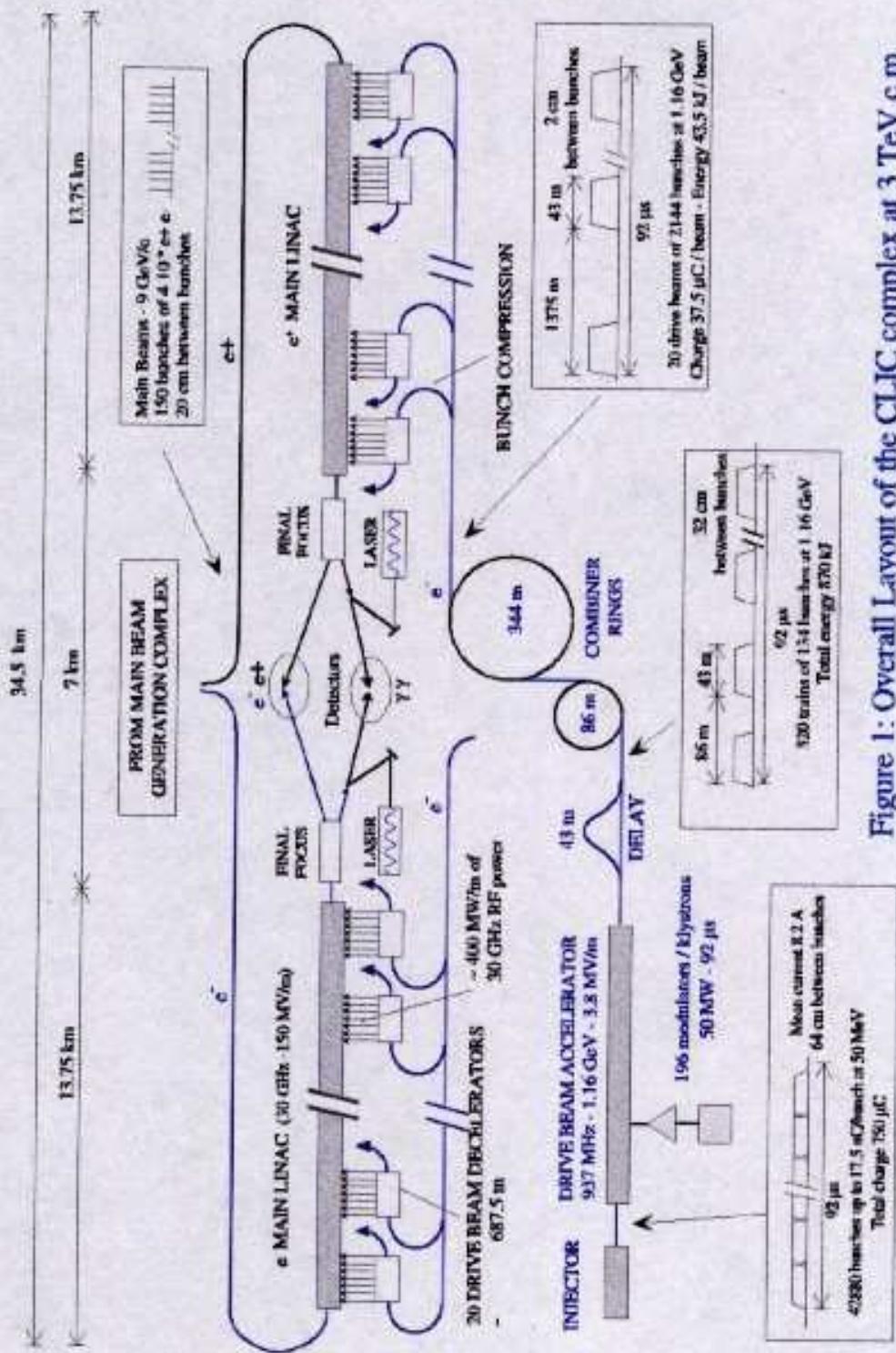
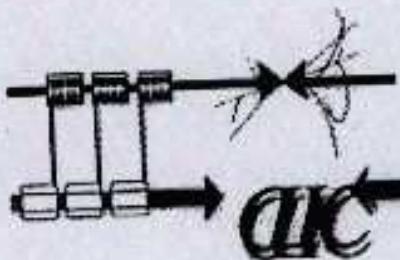


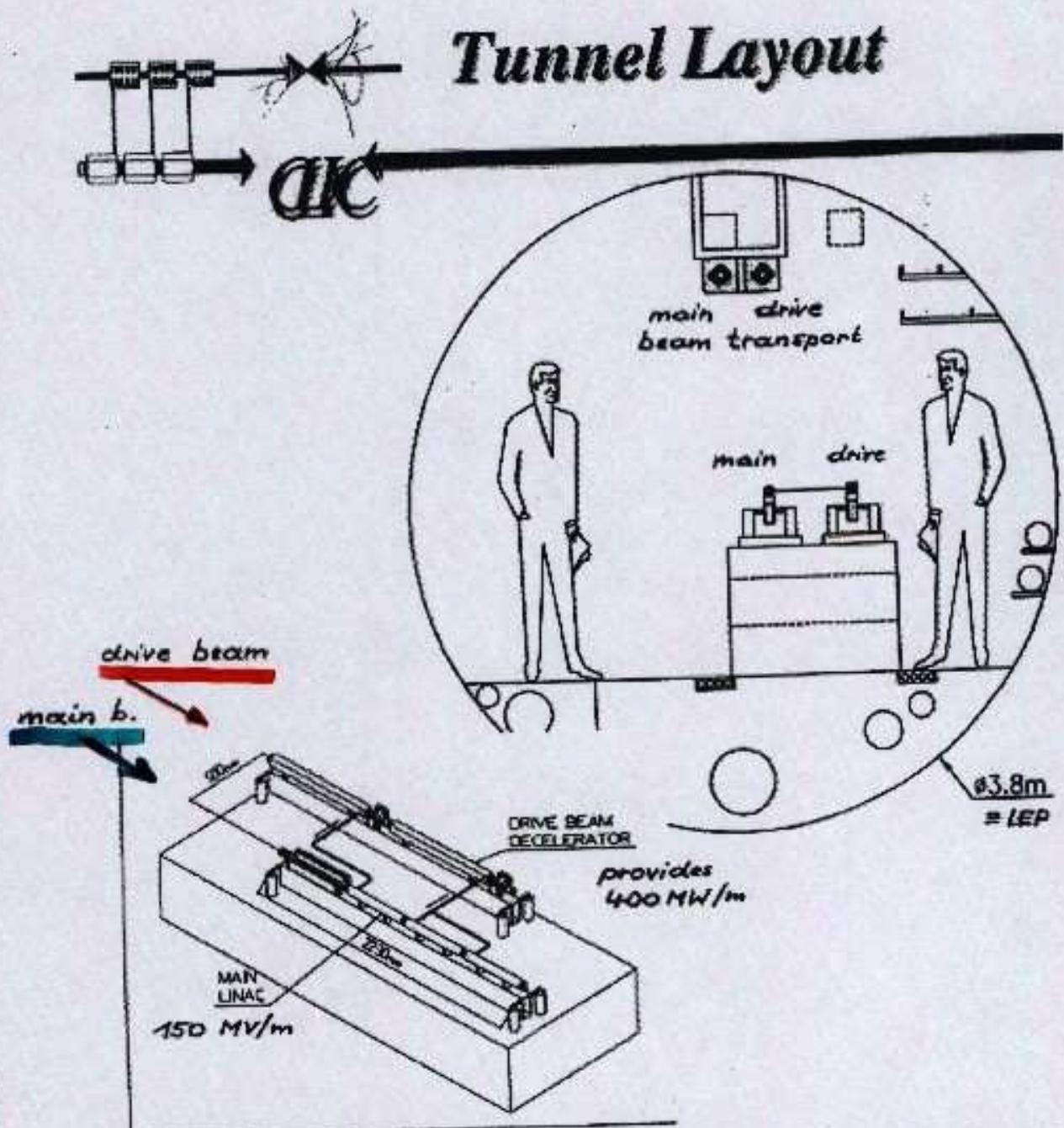
Figure 1: Overall Layout of the CLIC complex at 3 TeV c.m.



CLIC Parameters

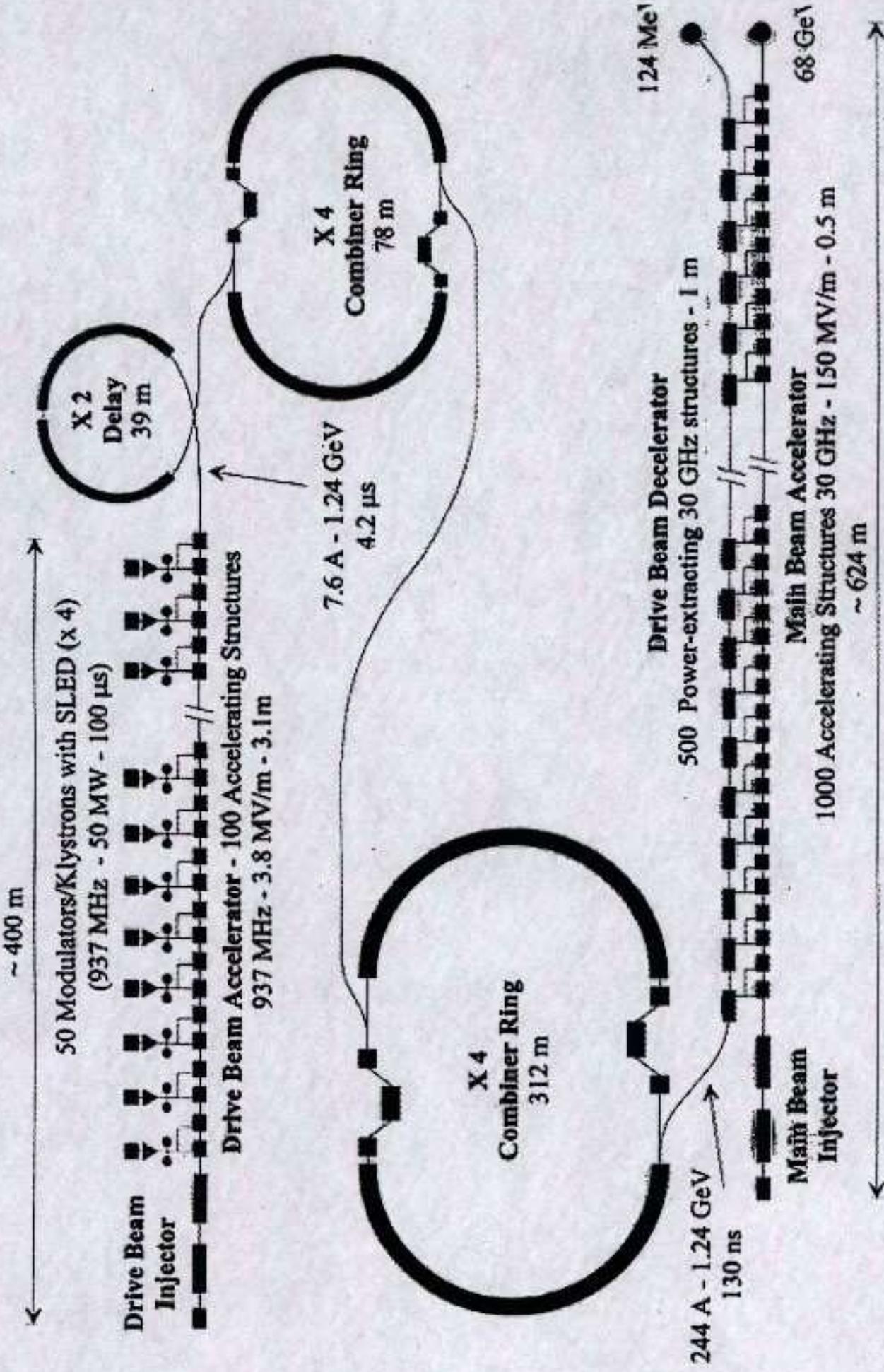
Beam param. at I.P.	0.5 TeV	1 TeV	3 TeV	5 TeV
Luminosity ($10^{34} \text{cm}^{-2}\text{s}^{-1}$)	1.4	2.7	10.0	10.0
Lum. ($1\% \Delta p/p$) ($10^{34} \text{cm}^{-1}\text{s}^{-1}$)	1.0	1.5	3.0	2.4
Mean energy loss (%)	4.4	11.2	31	37
Photons /electrons	0.7	1.1	2.3	3.2
Rep. Rate (Hz)	200	150	100	50
$10^9 e^\pm / \text{bunch}$	4	4	4	4
Bunches / pulse	154	154	154	154
Bunch spacing (cm)	20	20	20	20
H/V ϵ_n (10^{-8}rad.m)	200/2	130/2	68/2	78/2
Beam size (H/V) (nm)	202/2.5	115/1.75	43/1	31/0.78
Bunch length (μm)	30	30	30	25
Accel.gradient (MV/m)	150	150	150	172
Two linac length (km)	5	10	27.5	40
Power / section (MW)	229	229	229	301
RF to beam effic. (%)	40.1	40.1	40.1	40.1
AC to beam effic. (%)	9.8	9.8	9.8	8.5
AC power (MW)	100	151	302	290

Tunnel Layout



- No active RF components (no klystrons / modulators)
- Single small-diameter tunnel (3.8 m - same as LEP)

CLIC 1 - Test of 1 Drive Beam of full energy



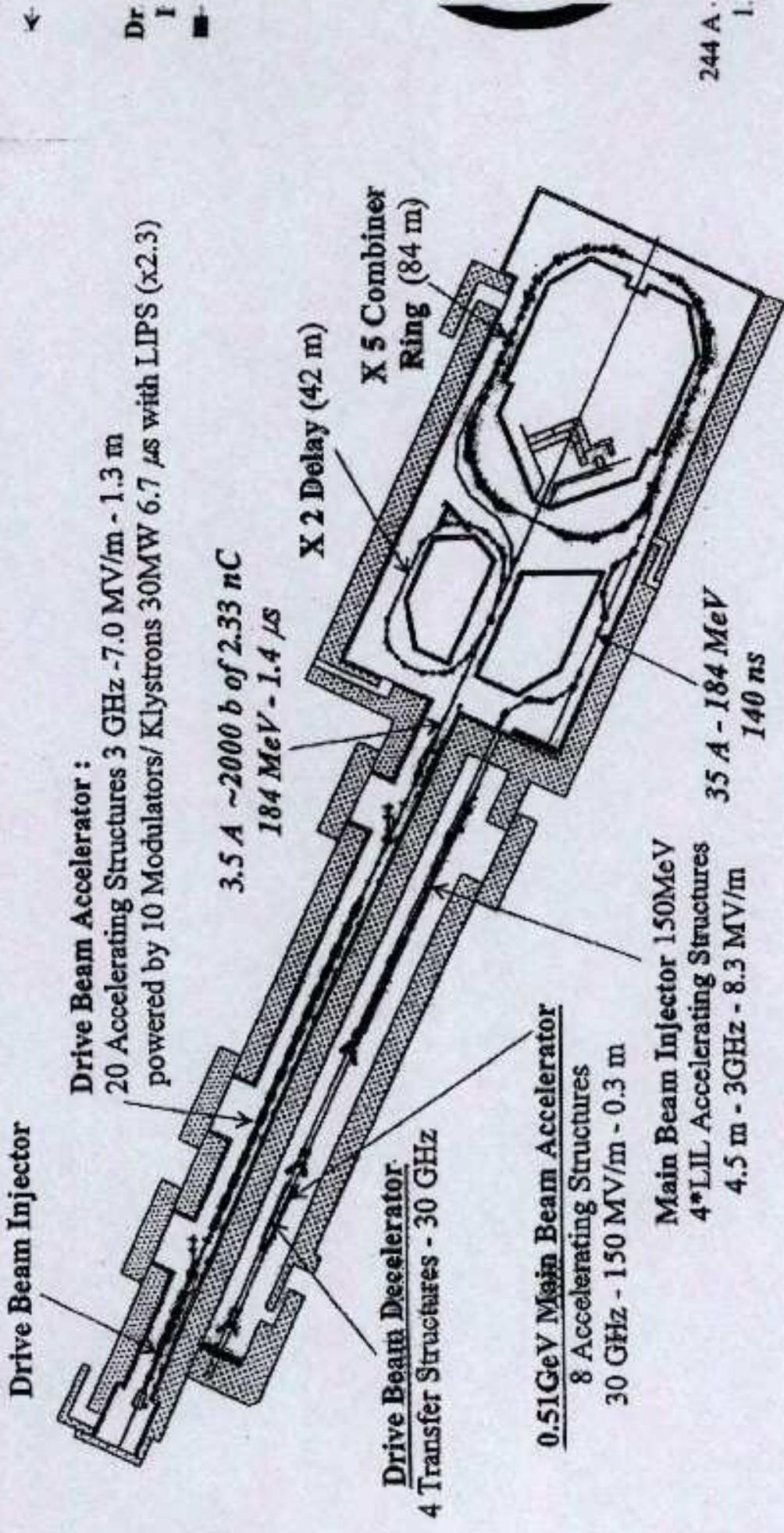


Figure 9 : A possible housing of the CLIC Test Facility (CTF3) in the LEP Preinjector building

VLHC

VERY LARGE HADRON COLLIDER
"DISCOVERY MACHINE"

$E_{cm} \rightarrow 100 \text{ TeV}$

$\sigma \rightarrow > 10^{34} \text{ cm}^{-2} \text{s}^{-1}$

STUDIATE 2 VERSIONI
CON MAGNETI SUPERCONDUTTORI

• HIGH FIELD $> 12 \text{ T}$
 $(\sim 100 \text{ Km})$

• LOW FIELD $\sim 2 \text{ T}$
 (500 Km)

"COST EFFECTIVE"!?



The Recommendations

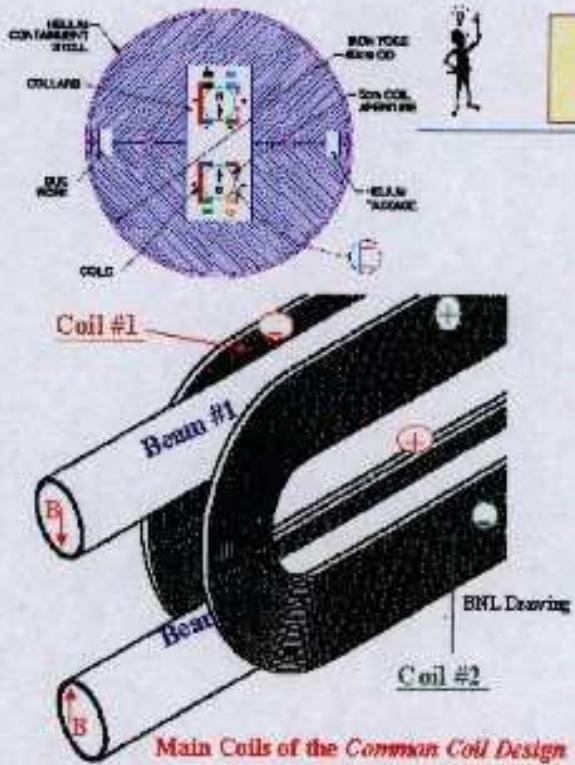
- ... The Gilman Subpanel recommends an expanded program of *R&D on cost reduction strategies, enabling technologies, and accelerator physics issues for a VLHC.*
- ... identifying *design concepts for an economically and technically viable facility.*

SS: Since the cost is unlikely to come down by a large amount with the same way of doing things (i.e. making VLHC by simply scaling up SSC or LHC designs and technologies),

the charge from VIHC Steering Committee:

- ... *explore and develop innovative concepts that will result in significant cost reductions.*





Common Coil Design (The Original Concept)

- Simple 2-d geometry with large bend radius (no complex 3-d ends)
- Conductor friendly (suitable for brittle materials - most are, including HTS tapes and cables)
- Compact (compared to single aperture D20 magnet, half the yoke size for two apertures)
- Block design (for large Lorentz forces at high fields)
- Efficient and methodical R&D due to simple & modular design
- Minimum requirements on big expensive tooling and labor
- Lower cost magnets expected

Research Goals

Superconducting Magnet Program

BERKELEY LAB

SLAC 16.4

Innovation: Magnet Designs for Future Colliders

DOE Program Review of HEP, March 3-4, 1999

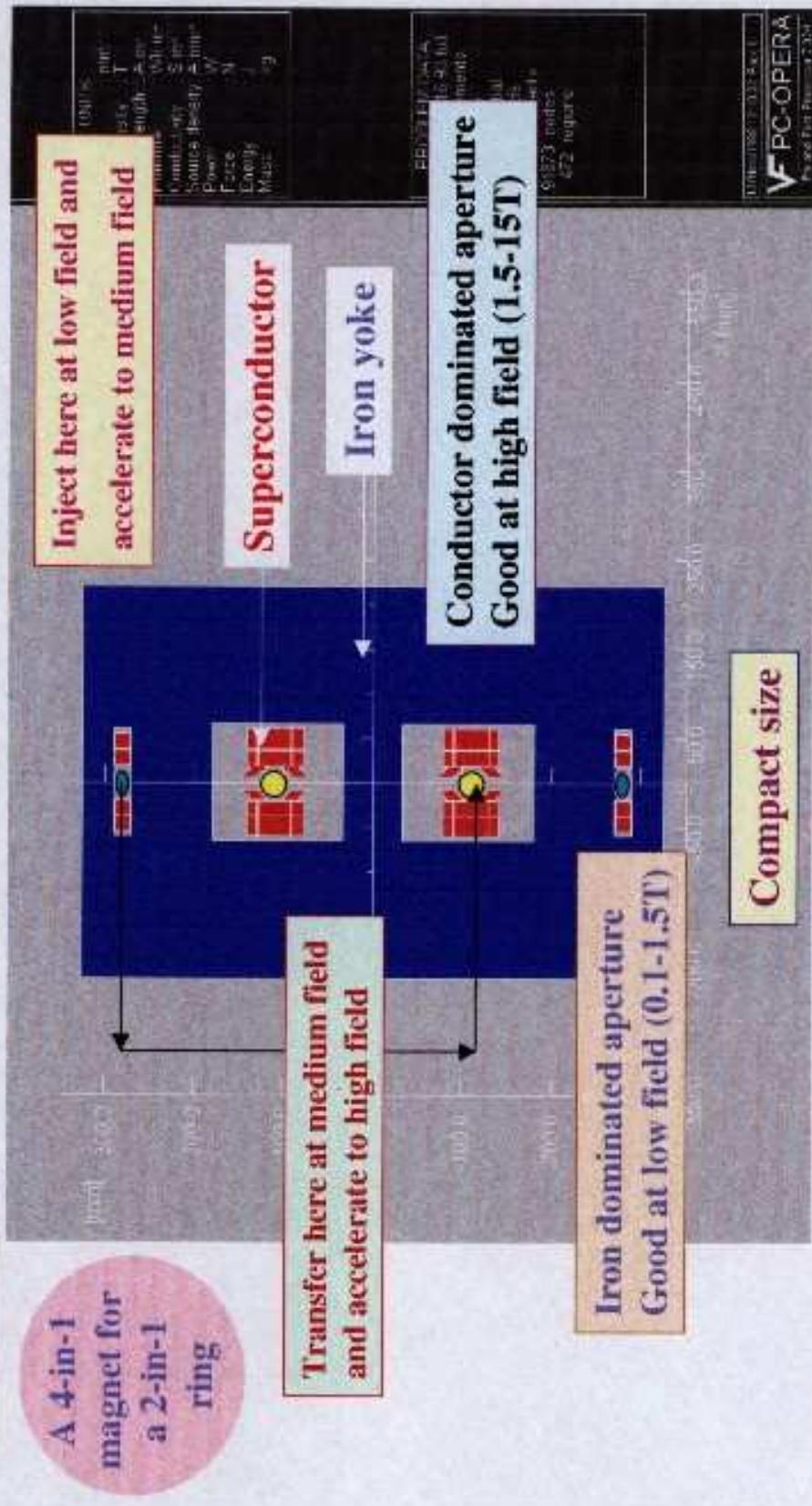




BERKELEY LAB

A Common Coil Magnet System for VLHC

(May eliminate the need of a high energy booster)



Ramesh Gupta

Superconducting Magnet Program

BERKELEY LAB

Slide No. 6

Common Coil Magnet System with a Large Dynamic Range

VLHC Workshop, Port Jefferson, NY; Nov. 16, 1998



Muons: One of the 3 Imperfect Projectiles for Colliders



electrons

$$E_{\text{beam}} = \left(\frac{E}{m}\right)^4$$

synch. radiation &
beamstrahlung

protons

strongly interacting,
composite
signal: noise as low as $-1 \cdot 10^{14}$!
detector backgrounds limit luminosity
only use $\sim 10\%$ of Col/M energy

muons

unstable
decay length $\approx E_{\text{GeV}} \times 6.2 \text{ m}$
weak, fast, replenish beam,
decay products

Discovery reach of
-couple of TeV

Discovery reach of
or d τ 2-10 TeV

Discovery reach of
or 10-100 TeV ???

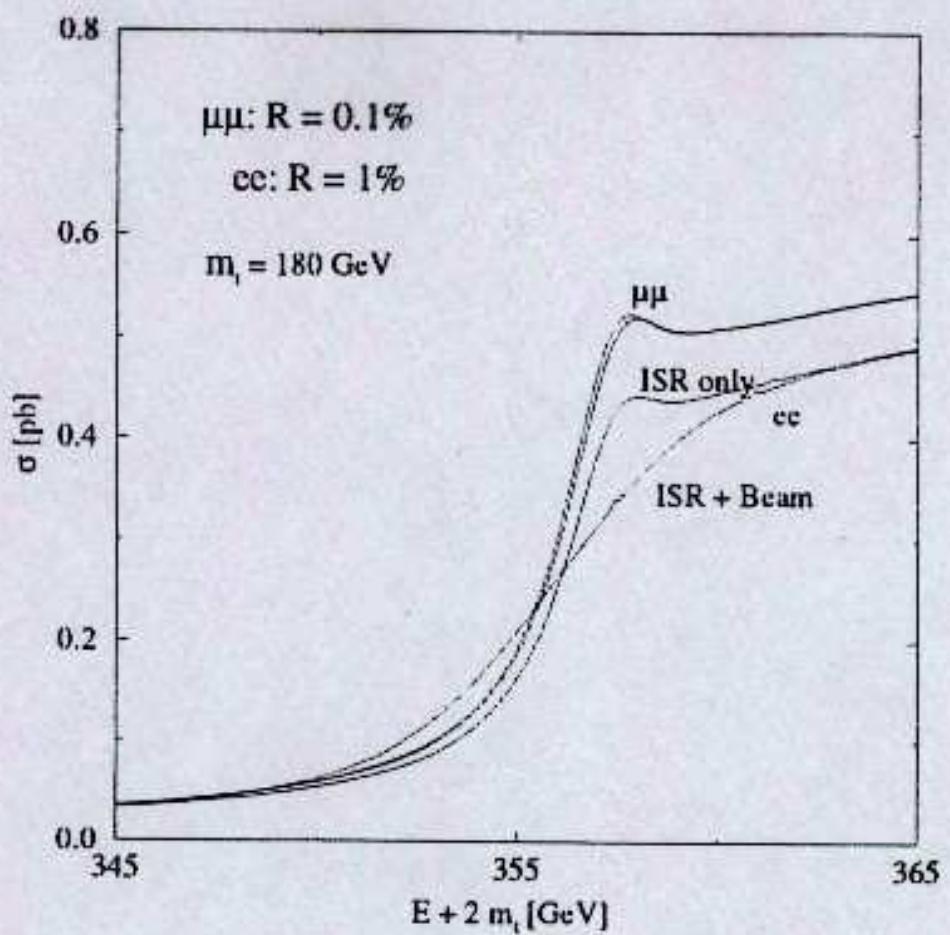
Introduction to HEMC'99, Bruce King, Montana, NY, 27 September, 1999

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$\mu^+\mu^-$ COLLIDER

Vantaggi Principali

- + ECONOMICO di collider e^+e^- a scale del TeV (LHC) o pp collider
- + PRECISO Stato Iniziale (- ISR) per produzione in soglia . -R.S.
- Polarizzazione $\mu = 0.25$
 - E_{beam} a 10^{-5} grazie precessione di spin (g-2)
- Produzione di Higgs leggeri in canale s
- Accoppiamento Higgs $\approx (m_\mu/m_e)^2 = 40000$
- Misura diretta larghezza Higgs
- Fasci di neutrini intensi ($x10^2 - 10^4$) disponibili
 - Neutrino factory
 - Oscillazioni dei neutrini
 - Violazione di CP nel settore dei neutrini



$\mu^+\mu^-$ COLLIDER

Caratteristiche Principali

- $> 10^{15} p/s, E(p) \approx 15 \text{ GeV}$
 - Bersaglio ad alto Z (Hg jet or rotating target)
 - Potenza fascio: 4MW
- Cattura $\pi, P_t < 200 \text{ MeV}/c$: solenoide 20 T
- Canale decadimento π : solenoide 1T
- Riduzione spazio delle fasi 10^6
 - “ μ ionization cooling”
- Accelerazione:
- Accumulazione : ≈ 1000 giri, $L = E(\text{GeV}) * 6.7 \text{ km}$

Versioni

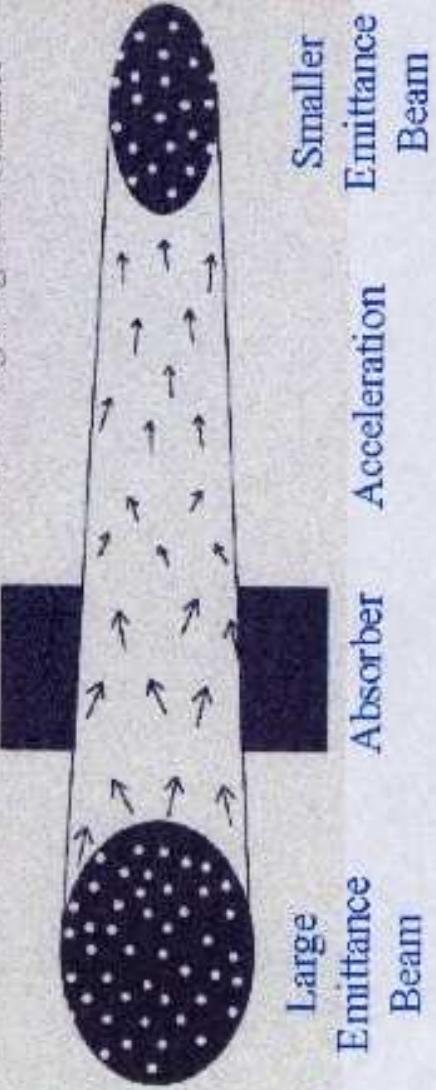
Energia(TeV)	Luminosità($cm^{-2}s^{-1}$)
0.1	$10^{31} - 10^{32}$
0.4	10^{33}
3	10^{34}

44 / 4 / 2023 ④ A

Ionization Cooling: A simple concept that only works for muons

(Illustrations by David Neuffer)

Confining Magnetic Channel



Cooling = reduction of rel. invariant 6-D phase space volume: $\xi_{\text{in}} \equiv \prod_{i=x,p} \Delta p_i \Delta x_i$

Introduction to HIMC'99: Bruce King: Brookhaven, NY, 27 Sep 1999

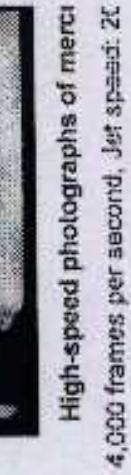
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$\mu^+ \mu^-$ COLLIDER

CoM energy (TeV)	3	0.4	0.1
p energy (GeV)	16	16	16
p 's/bunch	2.5e13	2.5e13	5e13
Bunches/fill	4	4	2
Rep. rate (Hz)	15	15	15
p power (MW)	4	4	4
μ /bunch	2e12	2e12	4e12
μ power (MW)	28	4	1
Wall power (MW)	204	120	81
Collider circum. (m)	6000	1000	350
Ave. bending field (T)	5.2	4.7	3
Depth (m)	500	100	10
Rms $\Delta P/P$ (%)	0.16	0.14	0.003-0.12
6d ϵ_6 (πm) ³	1.7e-10	1.7e-10	1.7e-10
Rms ϵ_n (π mm-mrad)	50	50	85-290
β^* , σ_z (cm)	0.3	2.6	4.1-14.1
σ_r spot (μm)	3.2	26	86-294
σ_θ IP (mrad)	1.1	1.0	2.1
Tune shift	0.044	0.044	0.051-0.022
n_{turns} (effective)	785	700	450
Luminosity ($\text{cm}^{-2}\text{s}^{-1}$)	7e34	1e33	1e31-1.2e32
Higgs/year			2-4e3

Figure 7: Sketch of an accelerator complex to produce neutrino beams via a muon storage ring.



High-speed photographs of mercury jets
4,000 frames per second; Jet speed: 20 m/s

5 MUON COLLIDER R&D PROGRAM

5.1 Targetry and Capture at a Muon Collider Source

- Targetry area also c

Targetry R&D Goals

- Long Term: Provide of the front-end of conditions.
- Near Term (1-2 years): metal jet target in (separately) in strong technology if enclosed.
- Mid Term (3-4 years): beam tests; Test 7C downstream of target

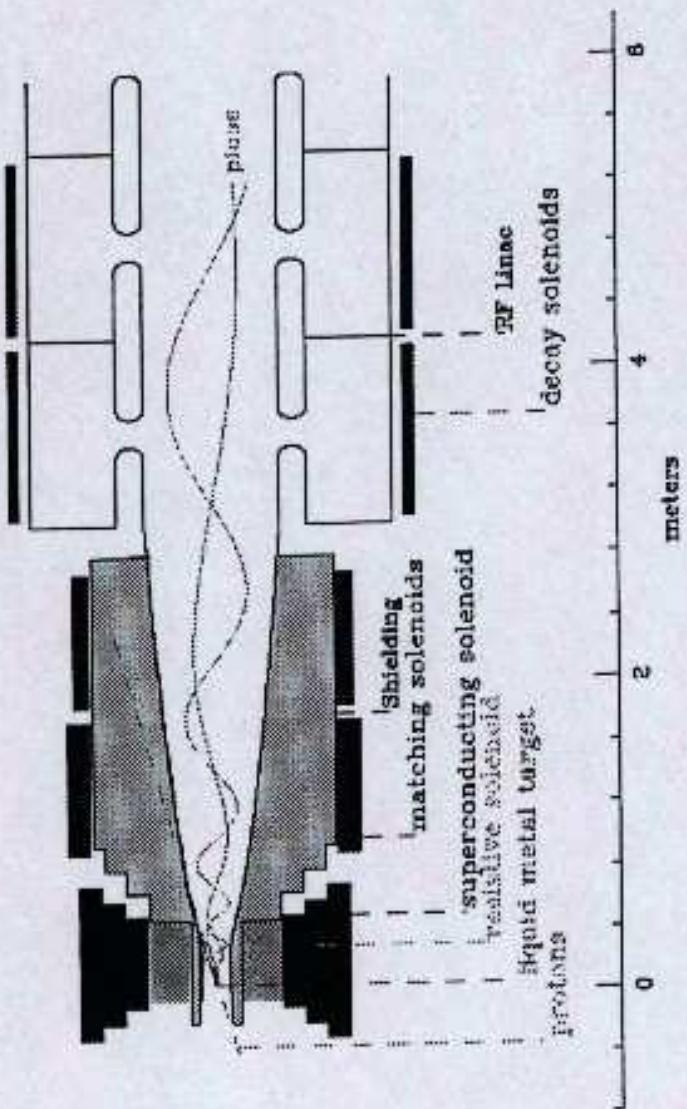


Figure 8: Baseline targetry scenario using a liquid metal jet inside a 20-T magnet.

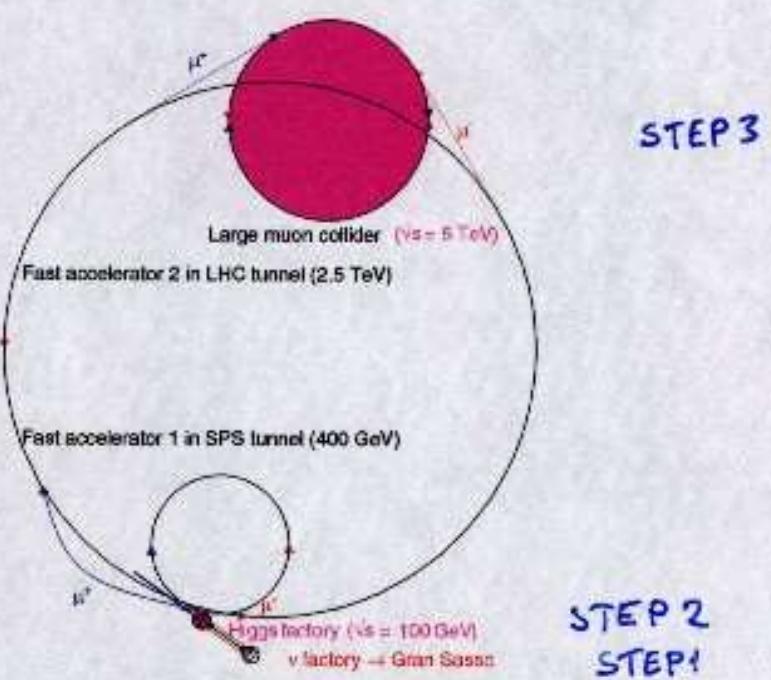
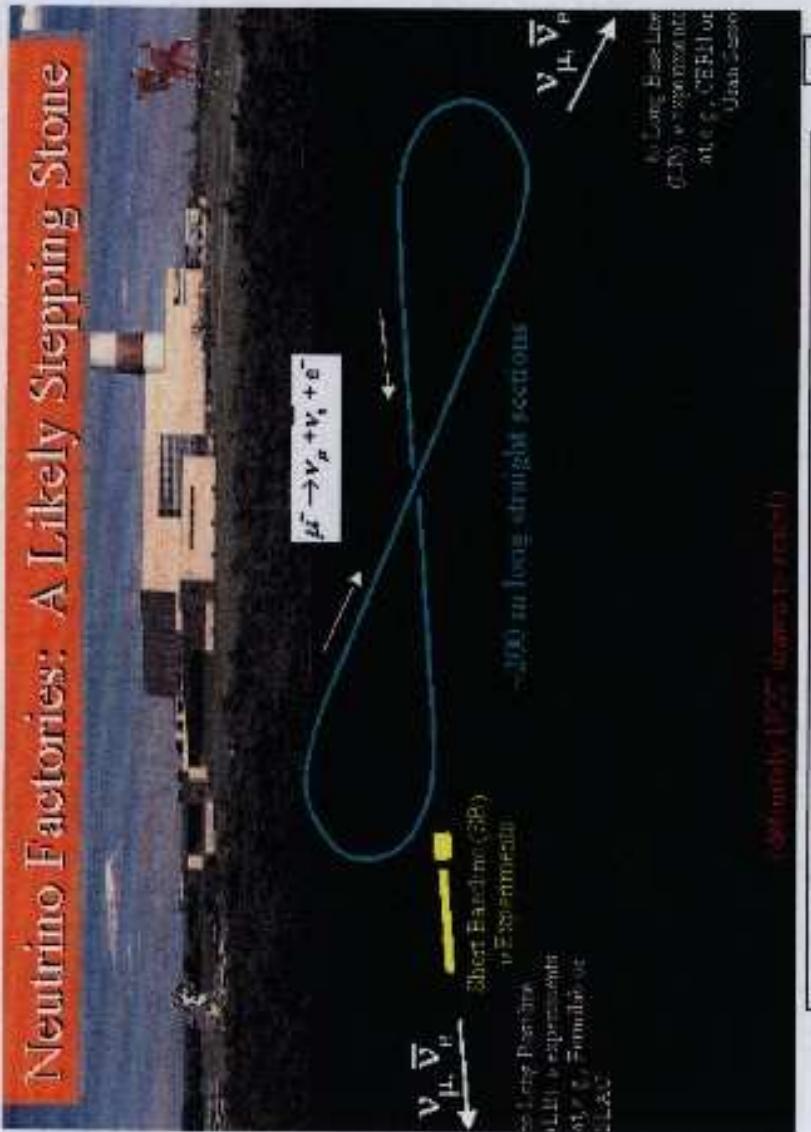


Fig. 1: Possible layout of a muon complex on the CERN site.

44 45 46 47 48 49 50 51

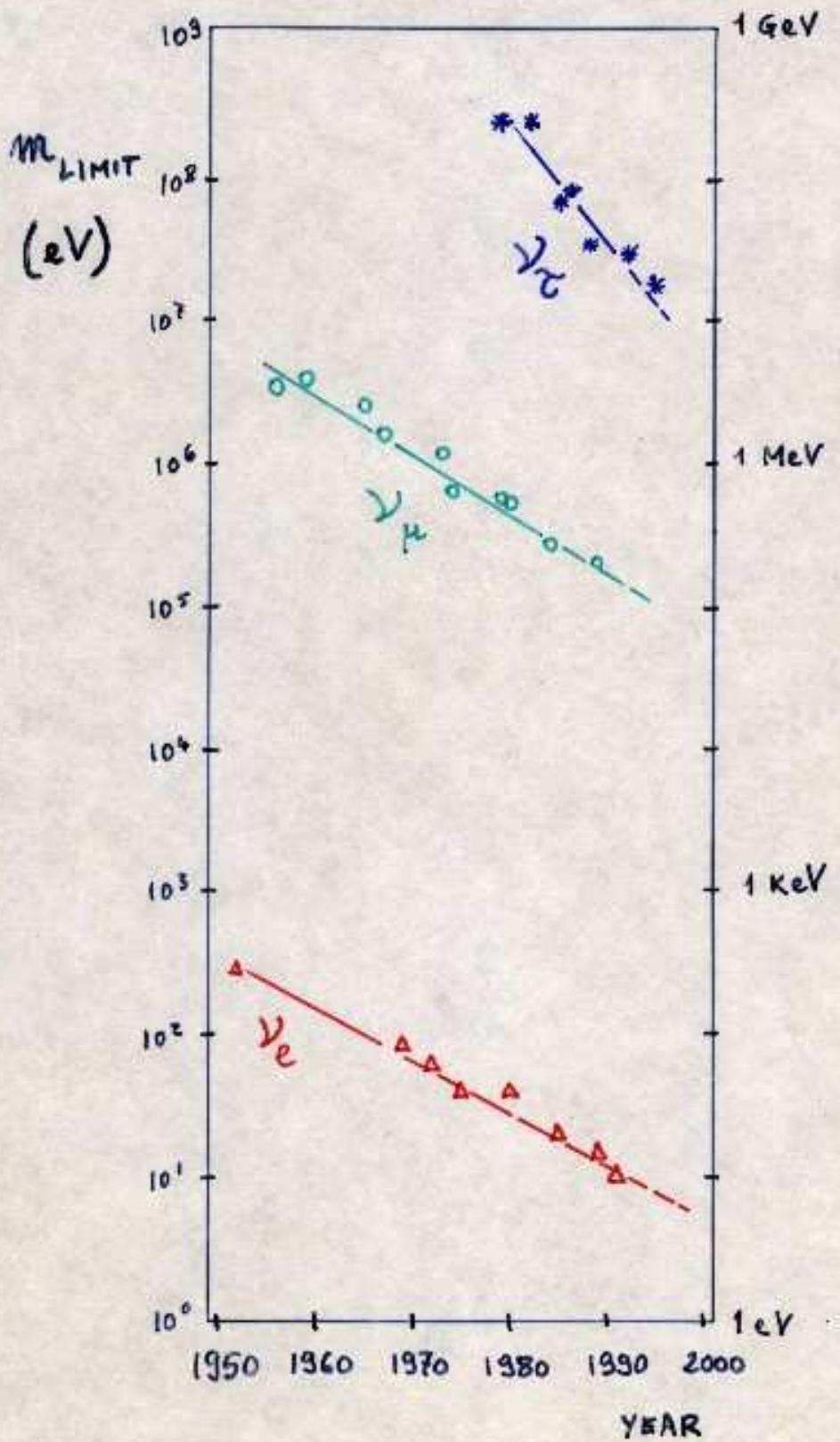
Neutrino Factories: A Likely Stepping Stone



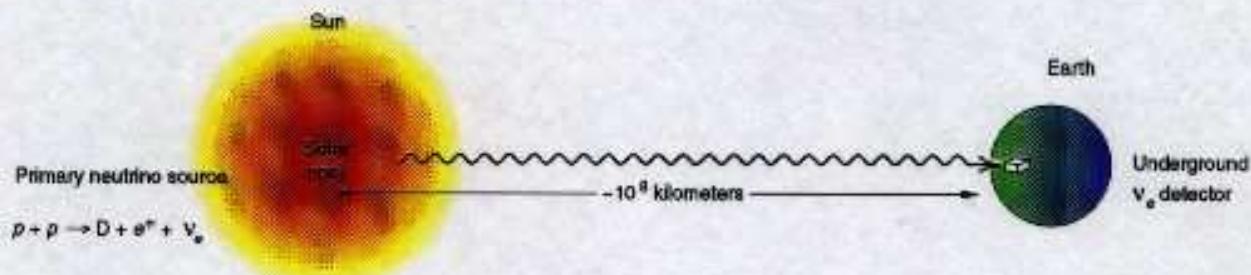
Introduction to HEMC'99; Boes Klug; Minneap., MN, 27 September, 1999

[18]

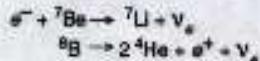
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SOLAR ν : (ν_e)

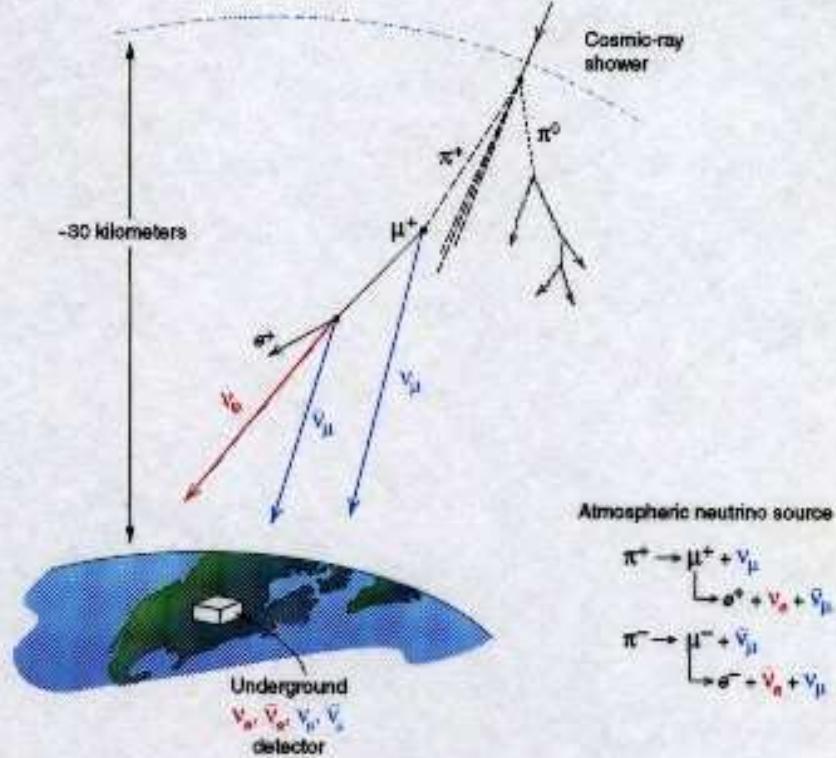


Other sources of neutrinos:



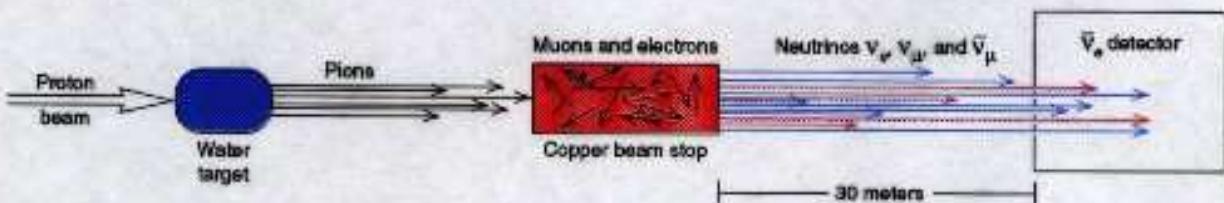
ATMOSPHERIC ν :

($\nu_\tau \bar{\nu}_\tau \nu_\mu \bar{\nu}_\mu \nu_e \bar{\nu}_e$)



ACCELERATOR ν :

($\nu_\mu \bar{\nu}_\mu \nu_e$)



REACTOR ν :

($\bar{\nu}_e$)



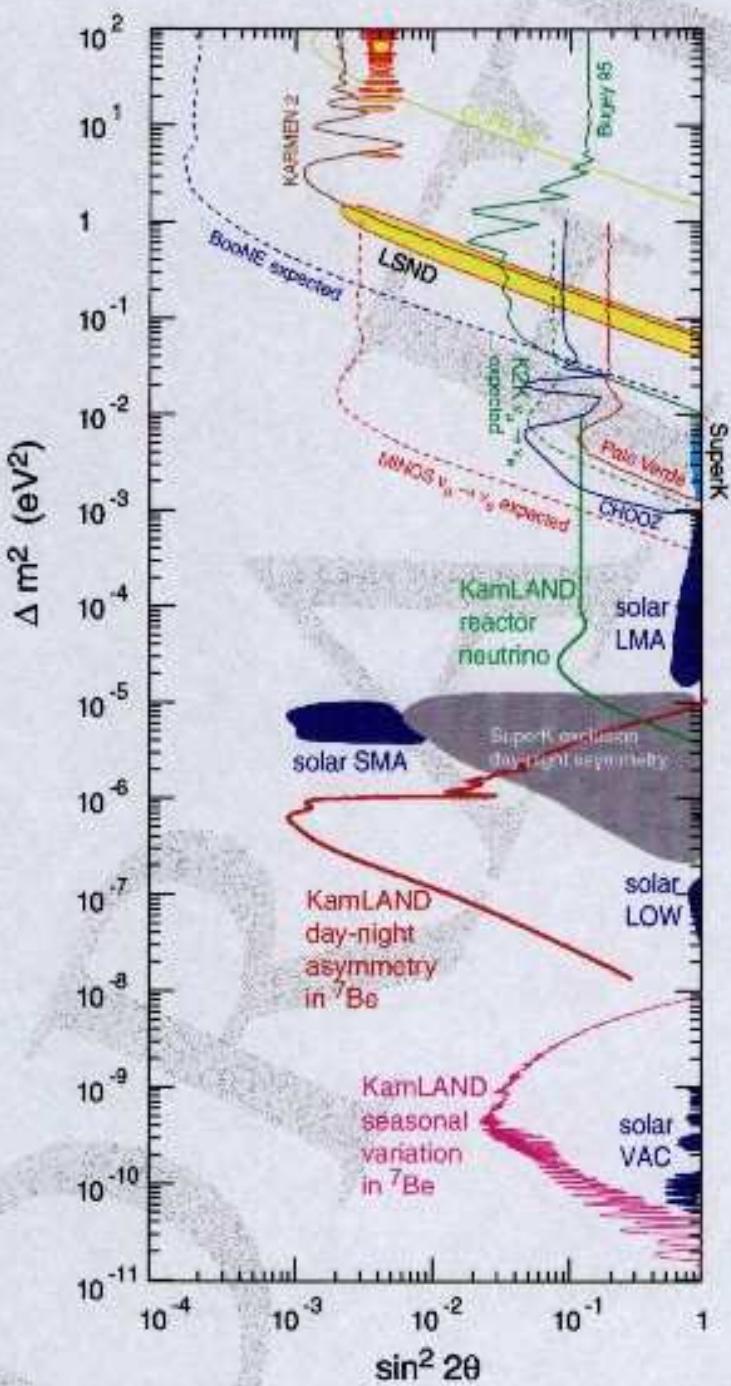
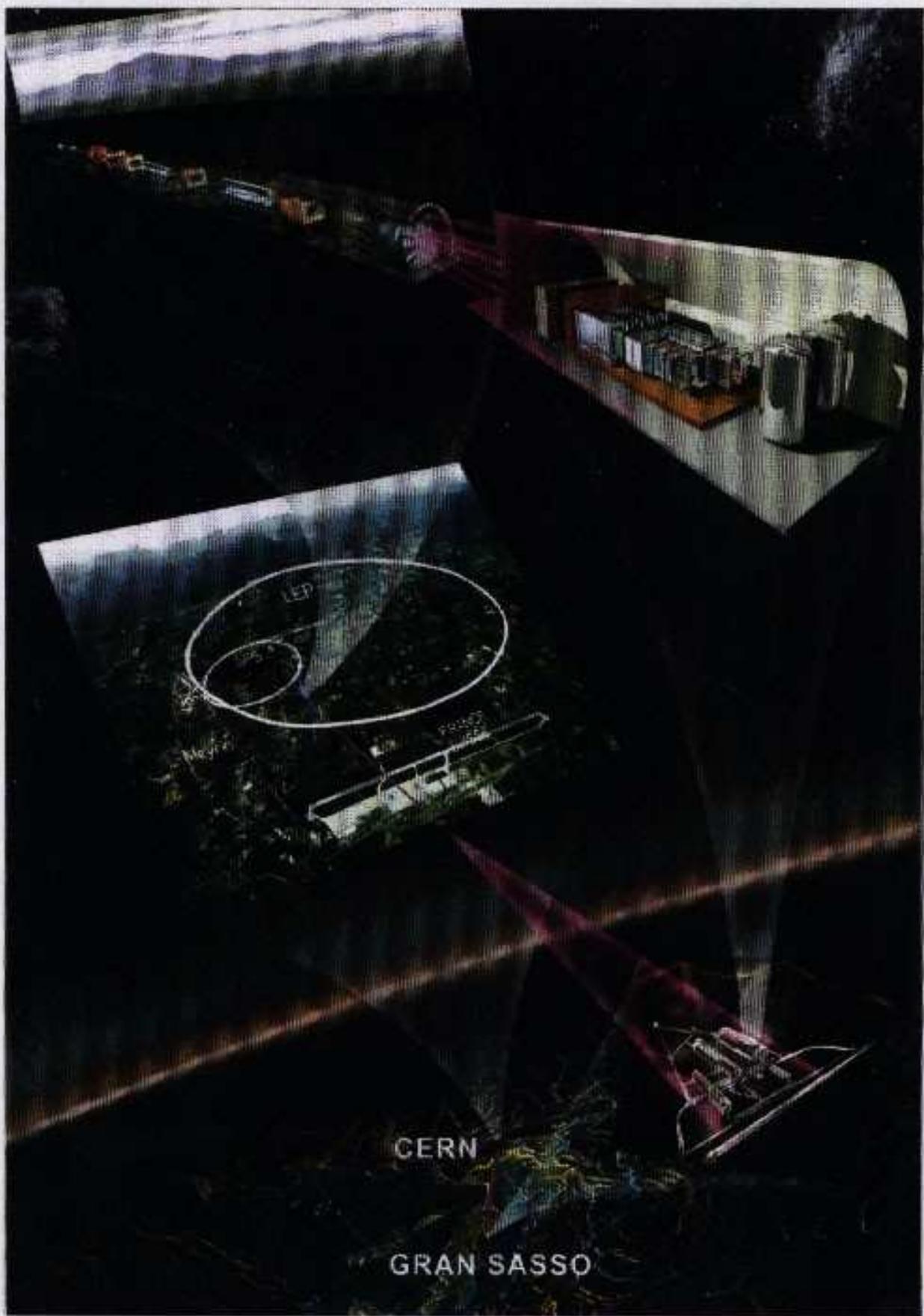


Figure 14: The current and expected limits at some of the future neutrino oscillation experiments. Note that different oscillation modes are shown together.



CERN

GRAN SASSO

Long and Very Long Baseline Experiments



NuFact ocation	Distance to Gran Sasso	Mean density
CERN	732 km	2.8 g/cm ³
Canary Islands	2900 km	3.2 g/cm ³
FNAL	7400 km	3.7 g/cm ³
KEK	8815 km	4.0 g/cm ³

R > 3500 km & R < 4500 km

$$\rightarrow \rho (\text{g/cm}^3) = 7.25 - 5 * 10^{-4} * R$$

R > 4500 km & R < 6360 km

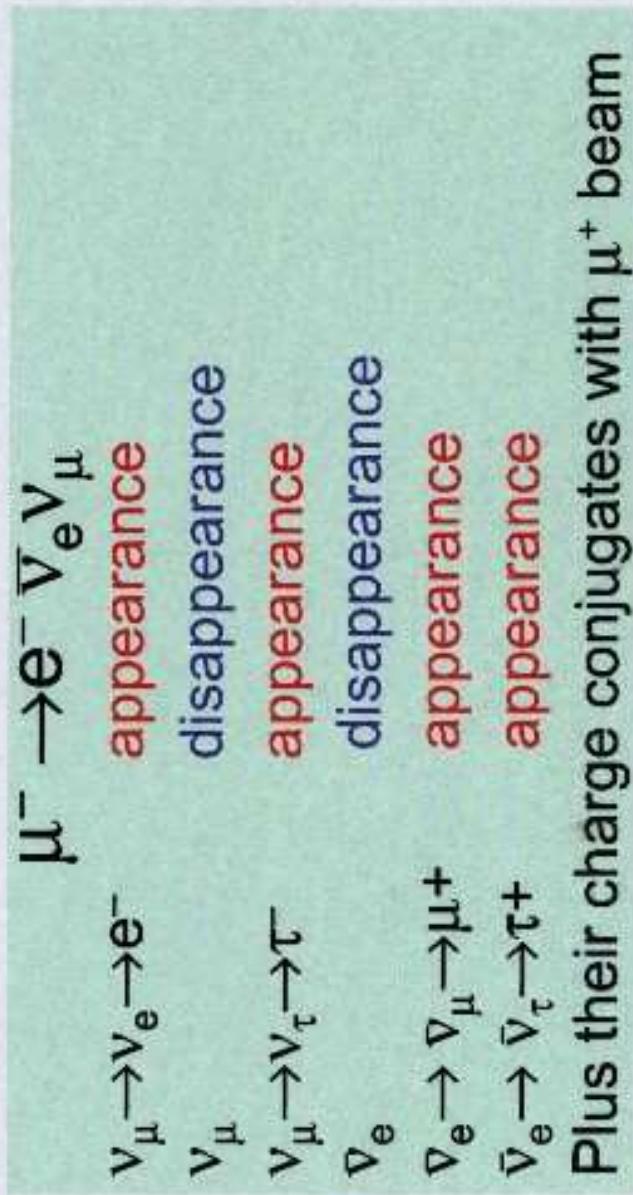
$$\rightarrow \rho (\text{g/cm}^3) = 7.74 - 7 * 10^{-4} * R$$

R > 6360 km

$$\rightarrow \rho = 2.8 \text{ g/cm}^3$$

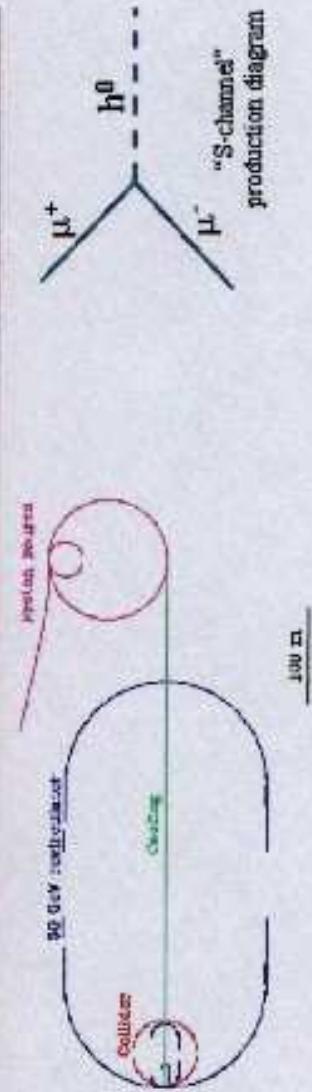
Event Classes

- * Electron (no charge discrimination)
- * Right sign muons
- * Wrong sign muons
- * NC-like events (no prompt lepton identified)





“S-Channel” Higgs Factory at ~105-150 GeV



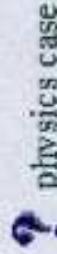
- coupling proportional to $(M_{\text{lepton}})^2 \Rightarrow$ won't work for electrons
- unique chance for sub-MeV measurement of Higgs mass & width
- current status of our feasibility studies:

mom. spread



luminosity

- couple thousand Higgs/year
unless can cool further



physics case

need prior discovery with $M_H \sim 115\text{-}150 \text{ GeV/c}^2$

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ΔΔ ΔΔ ΔΔ

The Physics Parameters ...

FUTURO →

Center of mass energy, E_{COM} 0.1 to 3 TeV
Additional Description MC Collab.
status report

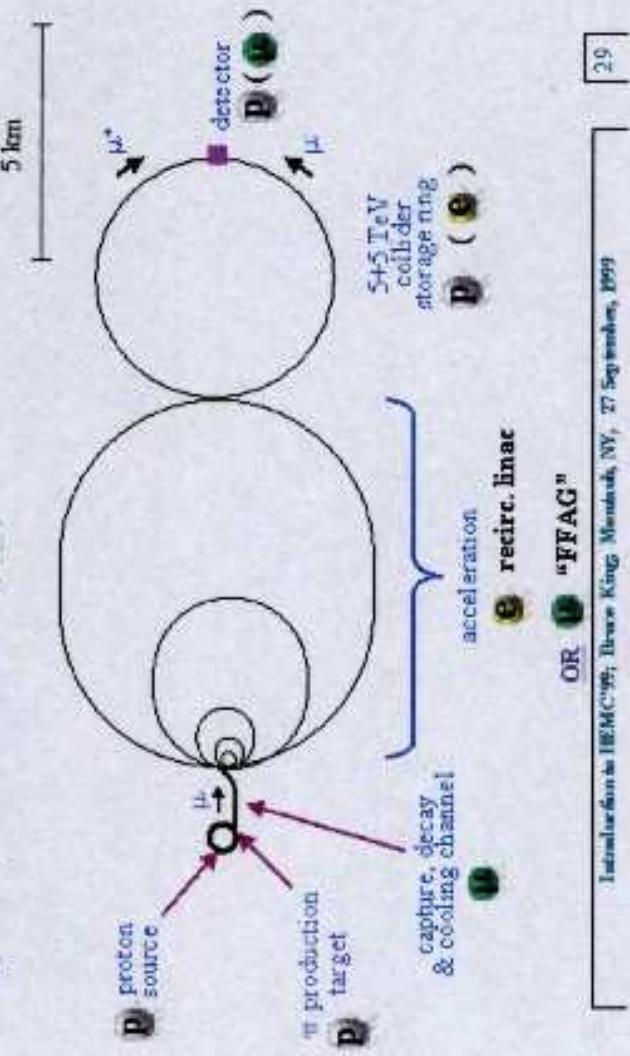
	WOW	NOW	HOW
10 TeV	10 TeV	100 TeV	100 TeV
evolutionary	evolutionary	revolutionary	ultra-cold
extrapolation	extrapolation	extrapolation	beam etc.

collider physics parameters:	10 inv. attobarns/year	1 inverse zeptobarns/yr
luminosity, $L [\text{cm}^{-2} \text{s}^{-1}]$	$8 \times 10^{30} \sim 5 \times 10^{34}$	1.0×10^{36} 400 1.0×10^{36} 400 1.0×10^{38}
integrated $L [\text{fb}^{-1}/\text{yr}]$	0.08 ~ 540	10 000
# of $\mu\mu \rightarrow ee$ [events/year]	650 ~ 10 000	8700
# of 100 GeV SM Higgs/det/year	40000 ~ 6×10^5	1.4x10 ⁷
frac CoME spread, $\sigma_E/E[10^{-3}]$	0.02 ~ 1.1	0.42
	0.08	0.08
	0.07	0.07

44 | 4 | 2 | 29 | 3 | Δ

Muon Colliders: A Hybrid Technology

A mix-and-match of electron (e) & proton (p) accelerator components, with novel additions (μ)...

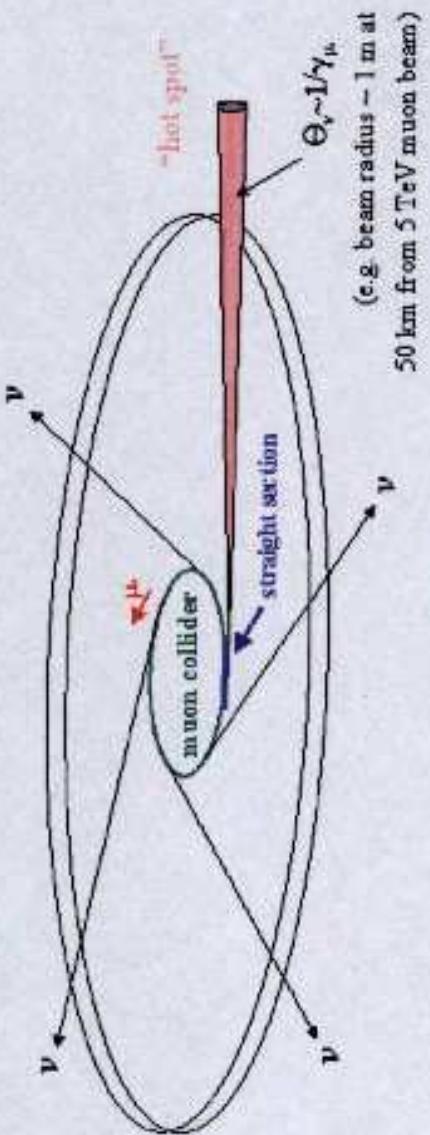


Similar to the ILC, from the ICHEP'99, Bronx King, New York, 27 September, 1999

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The Neutrino Radiation Disk



ν beam stronger at str. sections: e.g. even 0.1 m str. section is \sim twice disk average

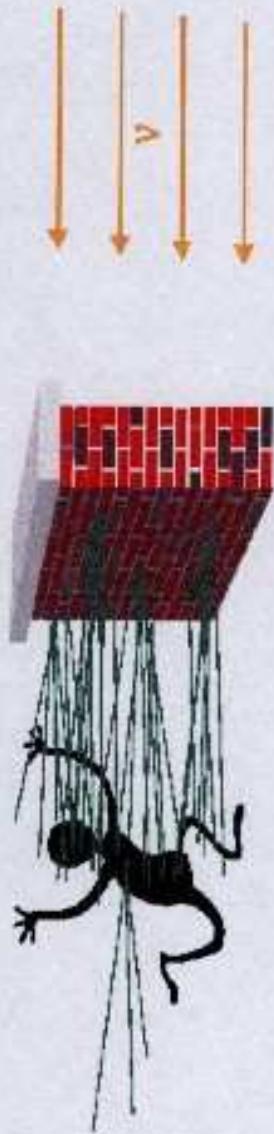
Neutrino Radiation Disk by Bruce J. Knie: HEMC99 workshop, Montauk NY, 29 Sep 1999

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The Radiation Hazard !!

The hazard is charged particles from ν interactions in the surroundings...



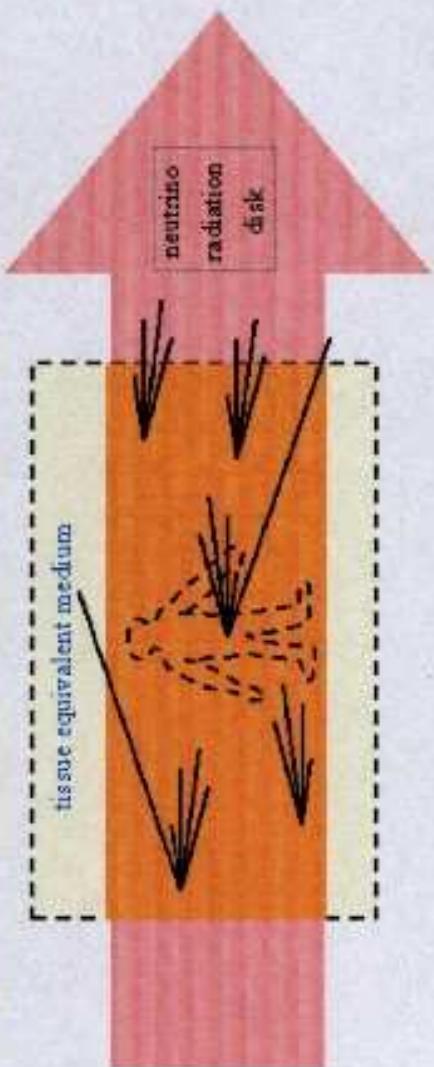
Interactions in the people themselves account for only ~0.1% of the total dose.

Neutron Radiation talk by Bruce I. King; IEMC'99 workshop, Montauk, NY, 29 September, 1999

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“Equilibrium Approximation” for Dose Calculation



Dose absorbed = energy of neutrino interactions in person

(N.B. breaks down at many-TeV energies)

Neutrino Radiation talk by Ilana L. King, ICRC-2009 workshop, Minnaboth, NV, 29 September, 2009



Predicted Radiation Dose up to ~TeV Energies*

$$\text{RadiationDose [mSv]} \approx 0.4 \times N_{\mu\mu} [10^{20}] \times \left(\frac{\text{length of str. section}}{\text{collider depth}} \right)^4 \times (E_{coll} [\text{TeV}])^3$$

1 mSv/yr = U.S. Federal off-site limit ~natural background

- a conservative, order-of-magnitude analytic calculation
- collider depth \sim (distance to surface)² for a non-tilted ring and locally spherical Earth
- the formula overestimates the dose at many-TeV energies

See Johnstone/Mokhov talk for follow-up Monte Carlo studies.

*ref B.J. King, "Neutrino Radiation Hazards at Muon Colliders", physics/9903017

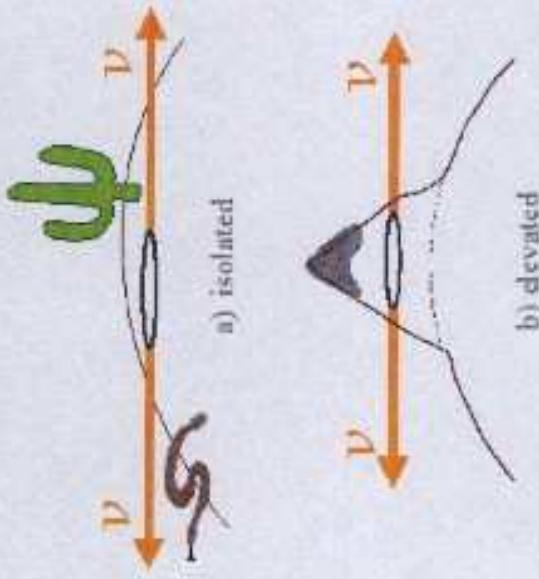
Neutrino Radiation talk by Bruce J. King; HEMC99 workshop, Monterich, NY, 29 September, 1999

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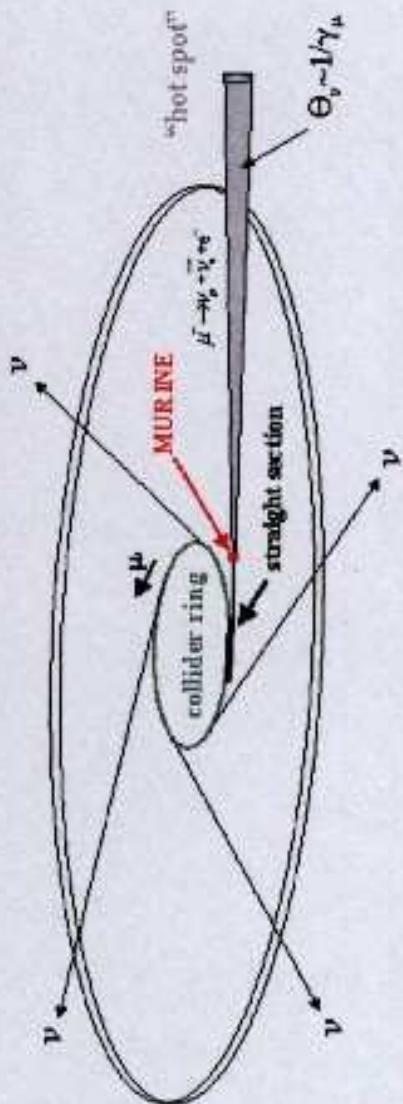


Very high energies & luminosities require a site chosen to allow higher ν radiation ...



The following talk by Colin Johnson will give a first pass at possible sites.

Neutrino Production at Muon Colliders



FREE & very intense beams! A natural
by-product of muon colliders.



Physics Processes

MURINE's have the same **weak** interactions as HERA, while avoiding the dominating soft electromagnetic interactions.



HERA is **dominated** by relatively "soft" electromagnetic interactions.
(Doesn't happen at MURINE.)

MURINE's only have "hard"
(interesting) **weak** interactions.
HERA has **soft** weak interaction events in the "hard scattering tail".

E_{C0M} & Luminosity Comparisons

At a MURINE:

$$\mathcal{L} [\text{cm}^{-2} \cdot \text{s}^{-1}] \sim N_{\text{Avogadro}} \times n_{\mu} [\text{s}^{-1}] \cdot f_{\text{ss}} \times \ell [\text{g} \cdot \text{cm}^{-2}]$$

Luminosity Avogadro's # decay/s/ sec. target mass/area

Facility	E _{C0M}	LUMINOSITY*
HERA (2000 upgrade)	332 GeV	$7.10^{31} \text{ cm}^{-2} \cdot \text{s}^{-1}$ life time total of 1 inverse femtobarn
5 TeV MURINE	0 to 97 GeV	$3.10^{38} \text{ cm}^{-2} \cdot \text{s}^{-1}$ 3 inverse zeptobarn/year
50 TeV MURINE	0 to 306 GeV	$7.10^{36} \text{ cm}^{-2} \cdot \text{s}^{-1}$ 70 inverse attobarn/year

* n_{μ} = instance-mean parameter value; $f_{\text{ss}} = 0.02$, DOI for 5.0 TeV MURINE; $\ell = 30 \text{ g/cm}^2$

WOW! A million times the luminosity!

Nuclino Physics at a HEMC; Bruce King (BNL); HE MC'09, Montauk, NY; 28 Sep 2009, 1999

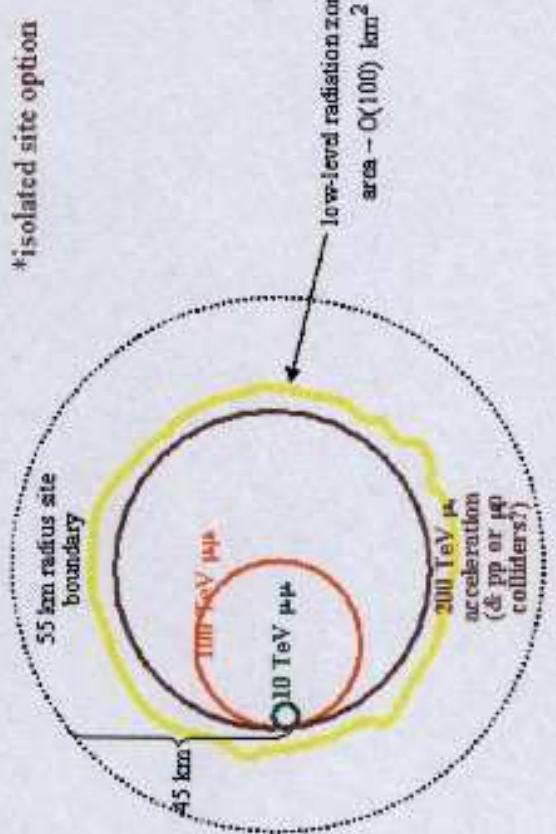
8

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FUTURO CONTANO



The Ultimate HEP Complex* !?



Even apart from neutrino radiation, a 55 km site radius is an appropriate size scale for housing the largest potentially plausible muon & proton colliders.

Neutrino Radiation talk by Bruce A. King: HEMC99 workshop, Minnedita, NV, 29 September, 1999

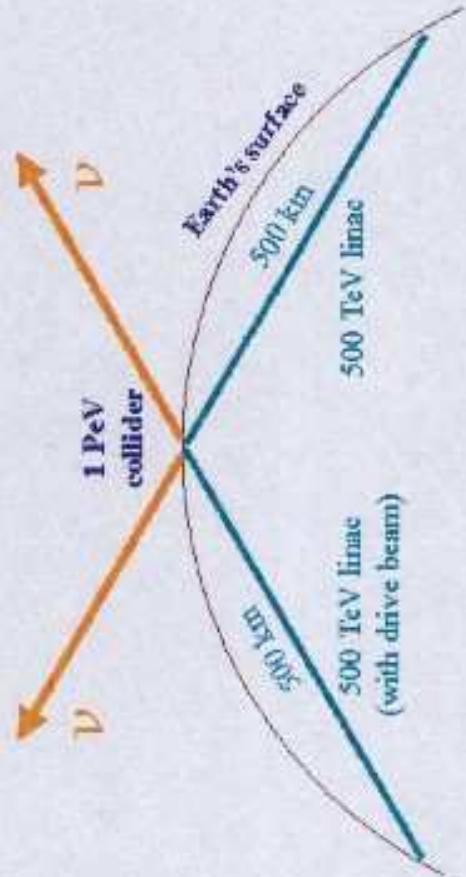
[10]

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[Navigation icons: back, forward, search, etc.]

Post-Ultimate Complex ?!?

FUTURO REMOTO



[Navigation icons: back, forward, search, etc.]

Neutrino Radiation talk by Bruce J. King: EHEC'99 workshop, Monterah, NY, 29 September, 1999

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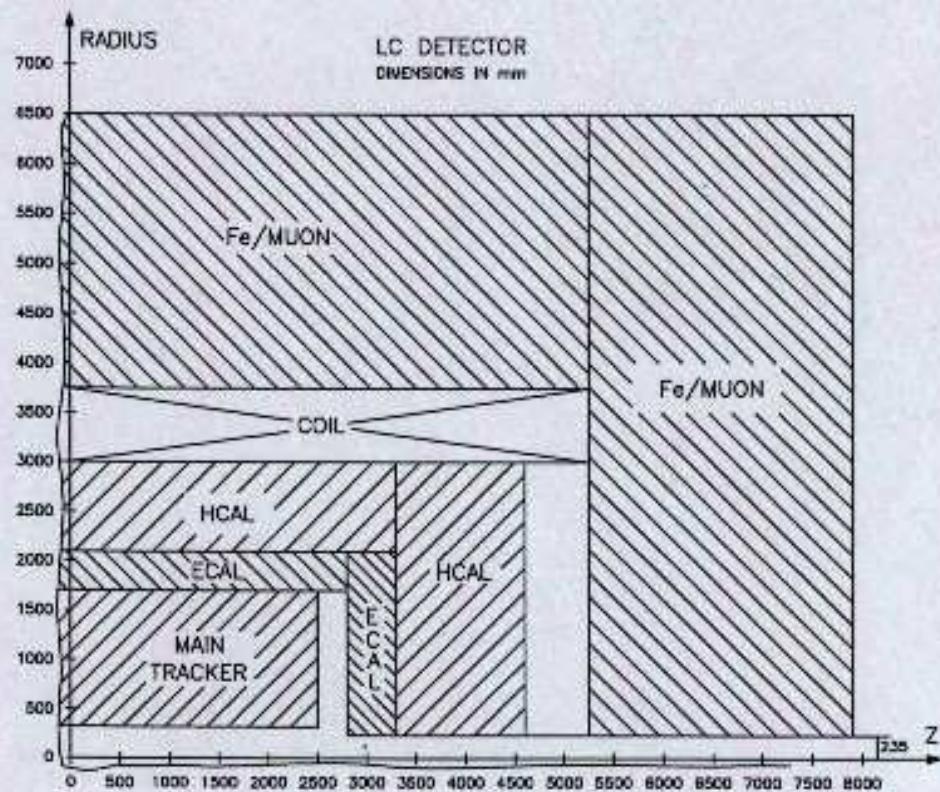


Figure 2.1.1: Schematical layout of one quadrant of the LC Detector.

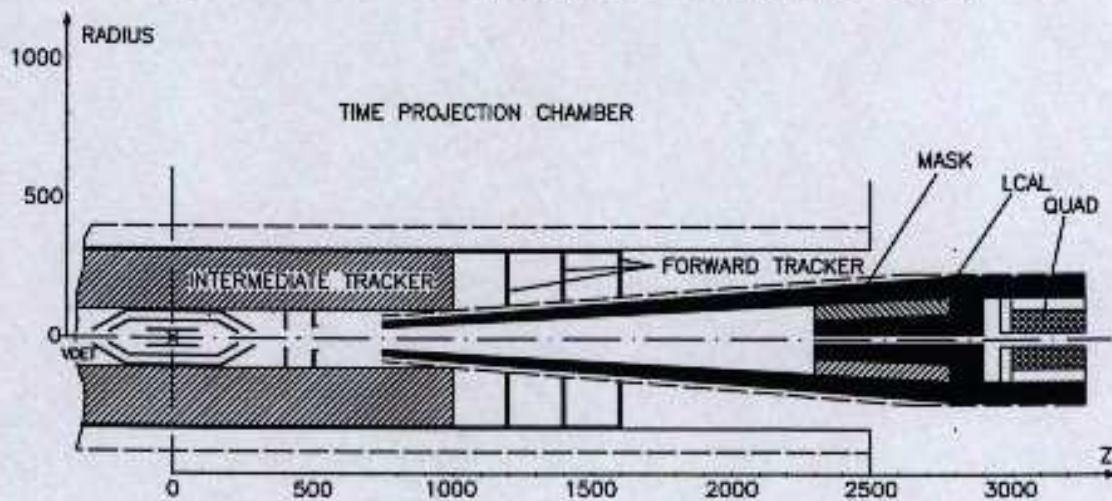


Figure 2.1.2: Schematic layout of the inner region of the detector.

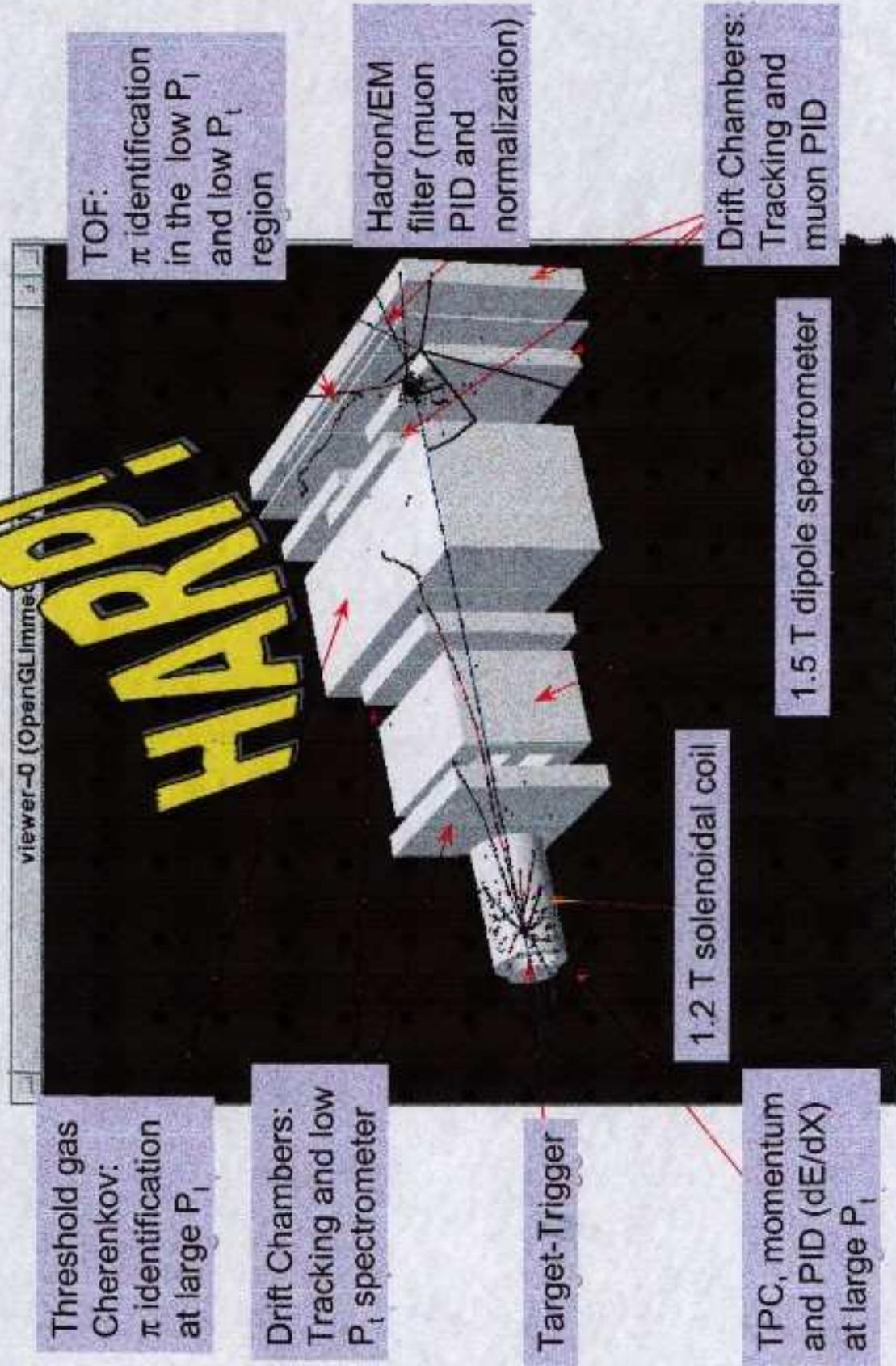
Subdetector	Technique chosen (Radiation Lengths)	Alternative techniques
Barrel		
Beam pipe	(0.3% X_0)	
Vertex detector	CCD or APS (1.6% or 2.4% X_0)	Silicon strip
Intermediate tracker	Honeycomb straw tubes (0.23% X_0)	Scintillating fibers with drift chamber; Silicon strip
Intermediate layer	Double-sided silicon strip (1% X_0)	
Main tracker	Time projection chamber (3% X_0 to outer field cage)	MSGC; Silicon strip
(Total thickness to outermost tracking radius = 6.1% (CCD) or 6.9% (APS) X_0)		
Presampler	Scintillating fibers	
E-M calorimeter	Pb-scintillator Shashlik cal.	Spaghetti calorimeter; Crystals
Hadron Calorimeter	Cu-scintillator Shashlik	
Tailcatcher, muon identifier	Resistive plate chambers	Limited streamer
Forward		
Luminosity calorimeter	Scintillating fibers in Pb	Spaghetti calorimeter Silicon-tungsten Shashlik
Instrumented mask	Quartz fibers in W	
Forward tracker	Silicon strip and/or pixels	
Forward muon tracker	Toroids with honeycomb tubes	

Table 2.1.3: *Techniques chosen for the LC detector.*

Subdetector	Radial extent		Longitudinal extent	
	r_{\min} [mm]	r_{\max} [mm]	$ z_{\min} $ [mm]	$ z_{\max} $ [mm]
Beam pipe		20		
Vertex detector	25	100		300 (including endcaps)
Forward tracker discs			at 400, 500, 1200, 1400, 1600	
Intermediate tracker	120	300		1000
Intermediate Si layer	300	320		1600
Main Tracker (TPC)	320	1700		2800
Sensitive volume	386	1626		2500
ECAL Barrel	1700	2100		2800
ECAL Endcap	235	2100	2800	3300
HCAL Barrel	2100	3000		3300
HCAL Endcap	235	3000	3300	4600
Coil Cryostat	3000	3750		5250
Iron Barrel	3800	6400		5250
Iron Endcap	235	6400	5250	7900
Toroid	400	3000	7900	9400
	Angular range			
	θ_{\min} [mrad]	θ_{\max} [mrad]		
TESLA Mask (conical part)	55 $r_{\text{outer}}=62 \text{ to } 225 \text{ mm}$	80	750	2800
SBLC Mask (conical part)	85 $r_{\text{outer}}=62 \text{ to } 225 \text{ mm}$	125	750	1800
TESLA Lcal	30	55	2300	2800
SBLC Lcal	30	85	1300	1800

Table 2.1.4: Dimensions of the LC subdetectors.

Keywords: Acceptance, PID, Redundancy



ν MIXING

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = U \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

FLAVOUR
(INTERACTION)
EIGENSTATES

MASS
(PROPAGATION)
EIGENSTATES

PRODUCTION
& DETECTION

TIME EVOLUTION

MIXING MATRIX
(UNITARY)

$$U = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix}$$

2 FAMILY EXAMPLE :

$$\begin{pmatrix} \nu_e \\ \nu_\mu \end{pmatrix} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \end{pmatrix}$$

$$\left\{ \begin{array}{l} |\nu_e\rangle = \cos\theta |\nu_1\rangle - \sin\theta |\nu_2\rangle \\ |\nu_\mu\rangle = \sin\theta |\nu_1\rangle + \cos\theta |\nu_2\rangle \end{array} \right.$$

ν OSCILLATIONS

MASS EIGENSTATES TIME EVOLUTION

$$|\nu_m(t)\rangle = e^{-iH_m t} |\nu_m(0)\rangle = e^{-iE_m t} |\nu_m(0)\rangle$$

FLAVOUR EVOLUTION (2 FAM. EXAMPLE)

$$\begin{aligned} P(\nu_e \rightarrow \nu_e, t) &= |\langle \nu_e(0) | \nu_e(t) \rangle|^2 \\ &= 1 - \underline{\sin^2 2\theta} \sin^2 \left(1.27 \frac{\Delta m^2 (\text{eV}^2) L}{E (\text{MeV})} \right) \end{aligned}$$

DISAPPEARANCE

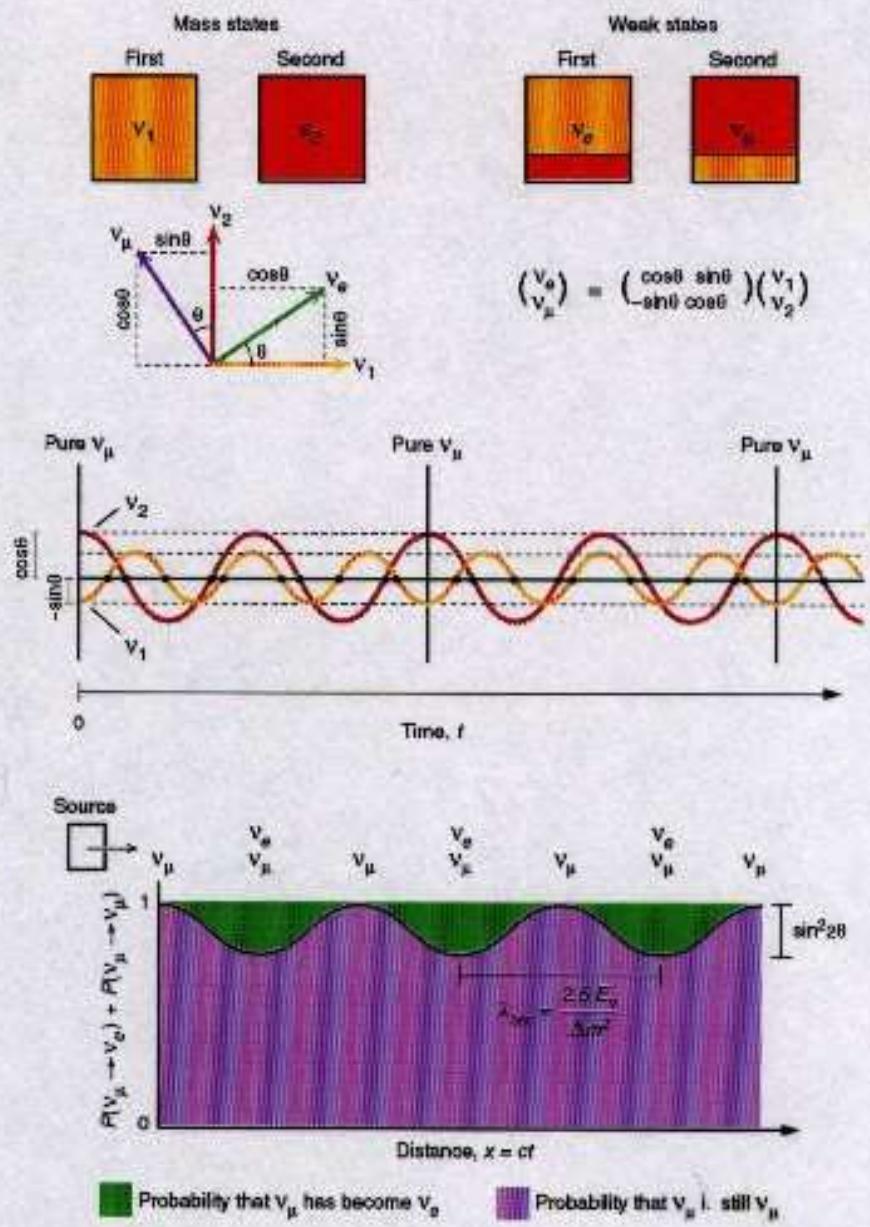
$$P(\nu_e \rightarrow \nu_\mu, t) = \underline{\sin^2 2\theta} \sin^2 \left(1.27 \frac{\Delta m^2 (\text{eV}^2) L}{E (\text{MeV})} \right)$$

APPEARANCE

$$\Delta m^2 = m_2^2 - m_1^2$$

$$E \cong p \left(1 + \frac{m^2}{2p^2} \right) \quad E_2 - E_1 \cong \frac{m_2^2 - m_1^2}{2p}$$

2 PARAMETERS : $\Delta m^2, \sin^2 2\theta$



Three neutrino mixing

- * Mixing determined by 3 angles and $2 \Delta m^2$

$$U = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{13}s_{23}e^{i\delta} & c_{12}c_{23} - s_{12}s_{13}s_{23}e^{i\delta} & c_{13}s_{23} \\ s_{12}s_{23} - c_{12}s_{13}c_{23}e^{i\delta} & -c_{12}s_{23} - s_{12}s_{13}c_{23}e^{i\delta} & c_{13}c_{23} \end{pmatrix}$$

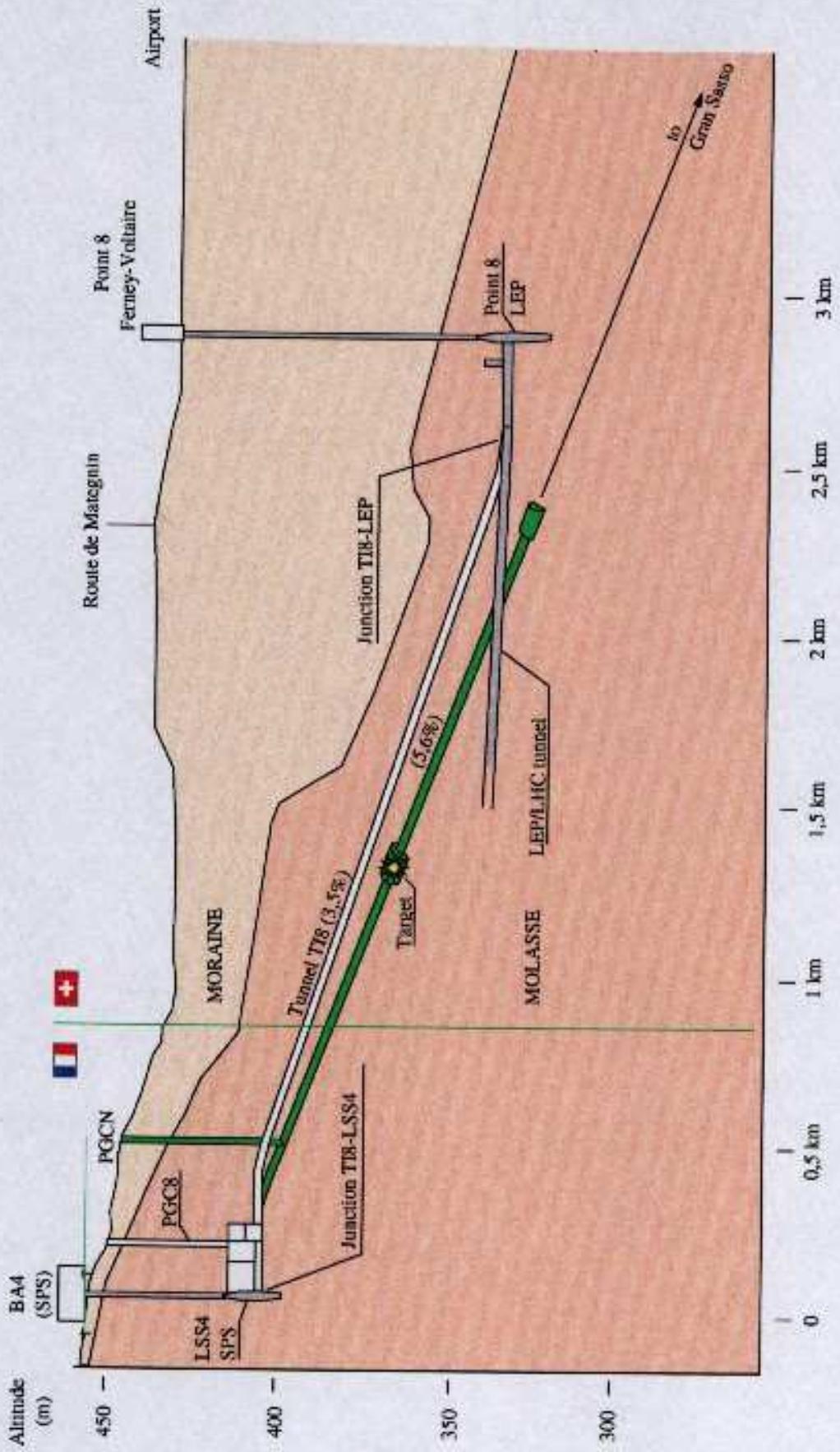
CKM-like

- * Assume that oscillations from solar and atmospheric decouple $\Rightarrow \theta_{13} \in [0, \pi/4]$, $\theta_{23} \in [0, \pi/4]$, Δm^2_{32}

$$\begin{aligned} P(\nu_e \rightarrow \nu_e) &= 1 - \sin^2(2\theta_{13})\Delta_{32}^2 \\ P(\nu_e \rightarrow \nu_\mu) &= \sin^2(2\theta_{13}) \sin^2(\theta_{23})\Delta_{32}^2 \\ P(\nu_e \rightarrow \nu_\tau) &= \sin^2(2\theta_{13}) \cos^2(\theta_{23})\Delta_{32}^2 \\ P(\nu_\mu \rightarrow \nu_\mu) &= 1 - 4 \cos^2(\theta_{13}) \sin^2(\theta_{23})[1 - \cos^2(\theta_{13}) \sin^2(\theta_{23})]\Delta_{32}^2 \\ P(\nu_\mu \rightarrow \nu_\tau) &= \cos^4(\theta_{13}) \sin^2(2\theta_{23})\Delta_{32}^2 \\ P(\nu_\tau \rightarrow \nu_\tau) &= 1 - 4 \cos^2(\theta_{13}) \cos^2(\theta_{23})[1 - \cos^2(\theta_{13}) \cos^2(\theta_{23})]\Delta_{32}^2 \end{aligned}$$

where

$$\Delta_{32}^2 = \sin^2\left(1.27\Delta m_{32}^2 \frac{L}{E}\right)$$



$$E = 50 \text{ GeV} \quad \# \mu = 10^{22}$$

L	# CC	BKGND	$\sin^2 2\theta_{13}$	Δm^2
732	3.7×10^7	37	3×10^{-4}	3×10^{-4}
3000	2.4×10^6	3.2	10^{-4}	10^{-4}
4000	$\sim 10^6$	< 1	8×10^{-5}	8×10^{-5}
6500	5×10^5	< 1	10^{-4}	10^{-4}

OPTIMAL DISTANCE ~ 4000 km

STILL, VERY HIGH SENSITIVITY AT ANY DISTANCE
BETWEEN 732 - 6500 km.

WHAT IS THE RIGHT L FOR
CP STUDIES ?