R&D for Accelerators of Particle Physics

Main directions

- Linear electron-positron colliders
- Advanced neutrino beams
- Very large hadron collider
- New Acceleration techniques

Work is conducted in parallel by many formal and informal collaborations

Main burden is carried by the large laboratories of Particle Physics

Brief overview of the highlights

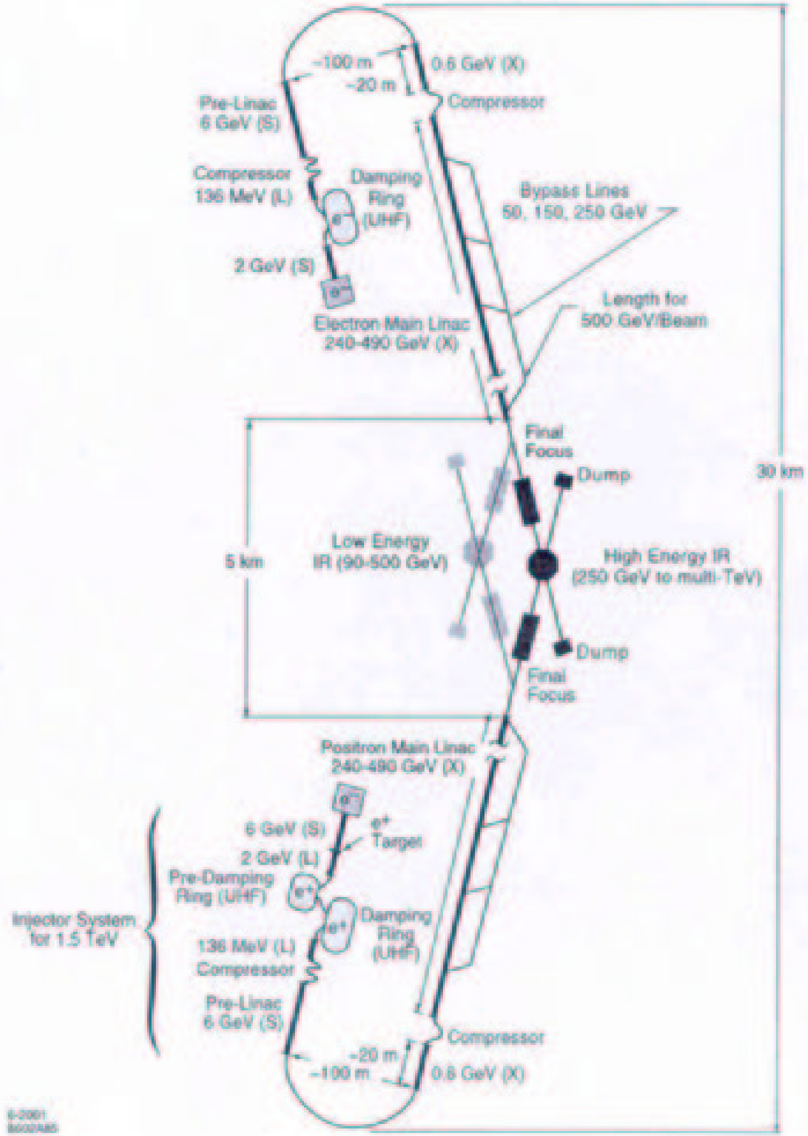
1. Linear e+e⁻ Collider

Basic layout:
Two acceleration systems:
*Injection system,
*Linear accelerator, and
*Final focus system

E_{cm} = 0.5 TeV later
0.8 to 1.5 (3?-5??)TeV

Studies in
EU (TESLA/DESY) **Proposal**
((CLIC/CERN))
JA (JLC/ KEK)
US (NLC/SLAC)

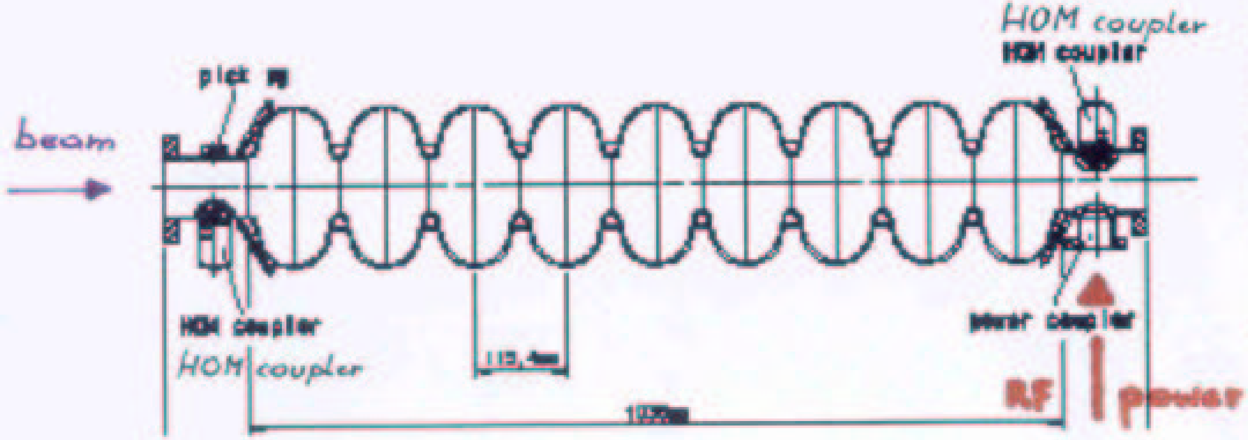
Example NLC layout



1.1Particle Acceleration in Linear Colliders

1.11 Superconducting radio-frequency cavities

Standing-wave structures of coupled n-cells (n<= 9)
Material: Nb operating at 2 K to eliminate Ohmic losses
Example : TESLA 9-cell cavitiy operating at rf = 1.3 GHz, accelerating gradient E_a(nominal) = 23.4 MV/m with Quality factor $Q_0 = 10^{10}$ (stored energy/dissipation per radian of osc.)
Advantages : very high efficiency of power transfer (rf-> beam) though power required for cryogenic system; iris can be made larger (sacrifice eff.) > adverse hom wakefields low > higher beam current > higher Luminosity



. ← TESLA TDR 2001

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Progress in the past: 1970 1986 1994 2000

E_a (MV/m) : **2** (HEPL) **4** (TRISTAN) **6** (LEP/CEBAF) **7.5/10**

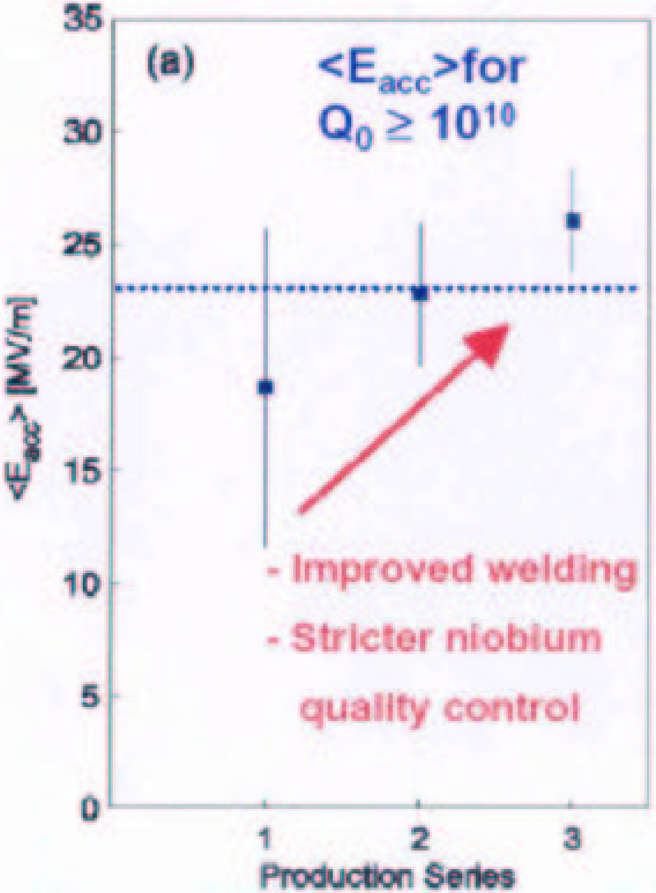
then pioneering by TESLA

Ingredients of progress:

Elimination/suppression of

- Multipacting (proper shape)
- Defects in material (scan Nb)
- Field emission (clean sufaces)

TESLA (L.Lilje, LC02)



Outlook:

*Electro-polishing: 36 MV/m in single cells, 32 MV/m in 9-cells (35 MV/m required for E_{cm}=800 GeV)

*New, cheaper cell fabrication: Hydroforming, spinning, Cu-Nb clad + hydroforming.

1.12 Normal conducting Accelerator Structures

(CERN, KEK SLAC)

Advantages: high accelerating field Ea=70 to 150 MV/m (goal)
>> linac shorter and/or upgrade potential >> reach ~3 TeV ?

Issues under study:

- higher frequencies chosen for less stored e-m energy and less peak rf power >> but iris small >> wakefields >> would lower beam current and >> luminosity
  Remedy: damping elements in the cells
- Very high surface fields >> Cu damaged
  Remedy: i) design for low surface field (< 350 MV/m)
  ii) Material with high melting point as W

E_a(peak acc.field) achieved with 30 GHz accel.structures:

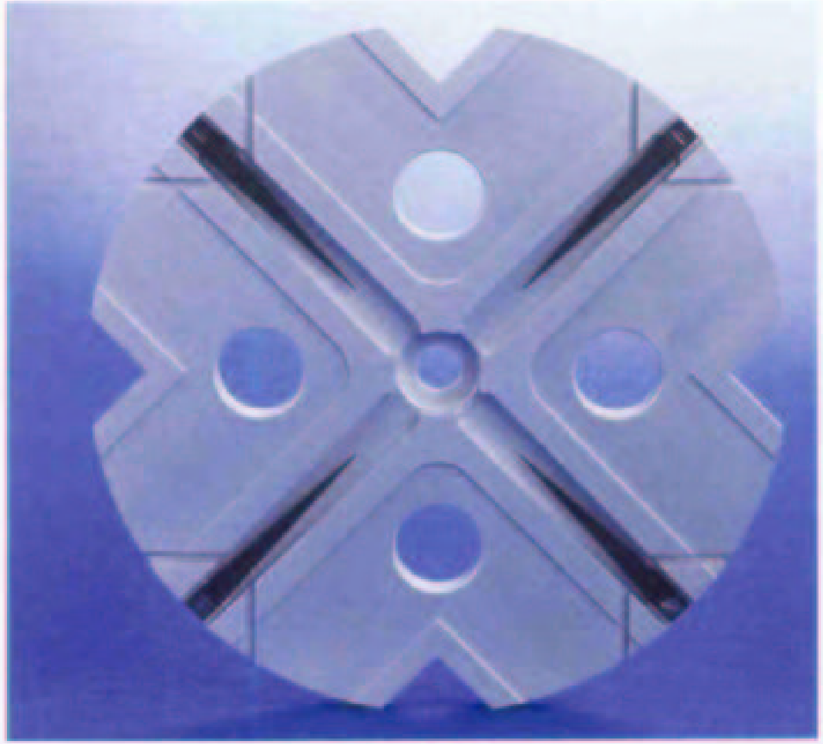
	old	new design
E_a with Cu	70	115 MV/m
E_a with Cu/W	-	152 MV/m (E_{surf} ~340 MV/m)

(Caveat: tested with 16 ns rf pulse, nominal 130 ns not yet available)

TDS design and modeling

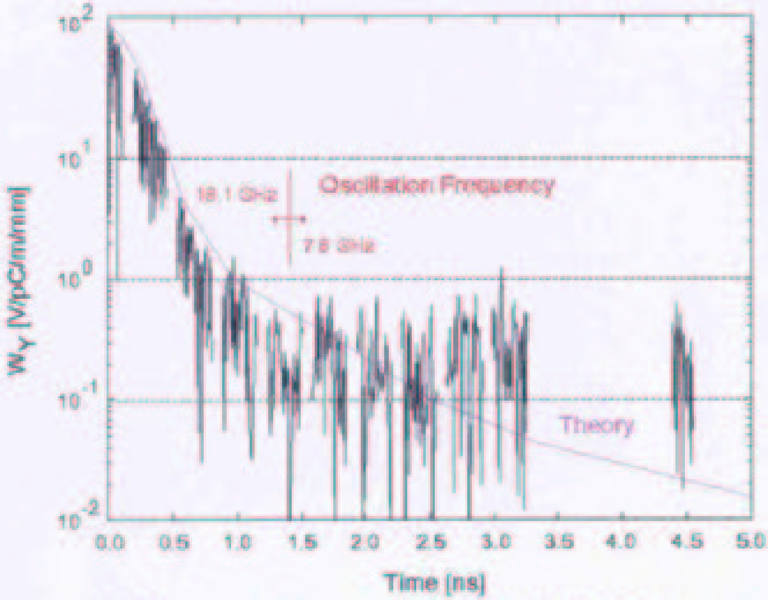
CERN / CLIC

- Strong damping, moderate detuning
- Damping computed via double-band circuit model. Circuit elements determined from MAFIA frequency-domain calculations. Load modeled using HFSS.



ASSET demonstration of damping

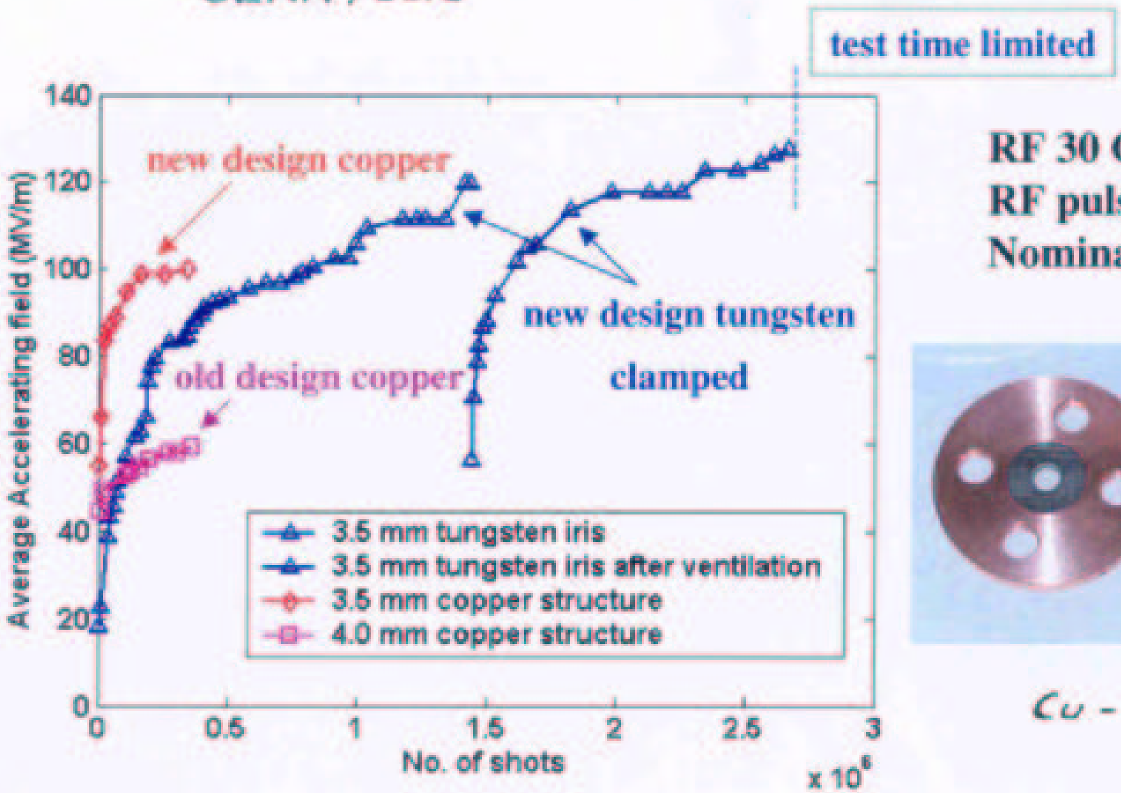
11.4 GHz Model



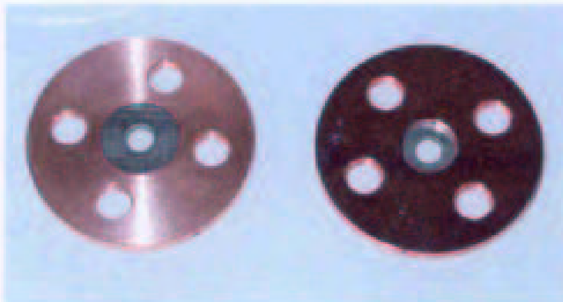
Measurement with SLAC beam

CTF2 HIGH-GRADIENT TEST RESULTS

CERN/CLIC



RF 30 GHz
RF pulse length 15 ns
Nominal CLIC 130 ns



Cu - W(iris)

1.2 Generation of small emittance beams

Luminosity/Beam power ~ $(E_{cm} . \sigma_y)^{-1} = (E_{cm} . \varepsilon_{yn} \ \beta_y)^{-1/2}$

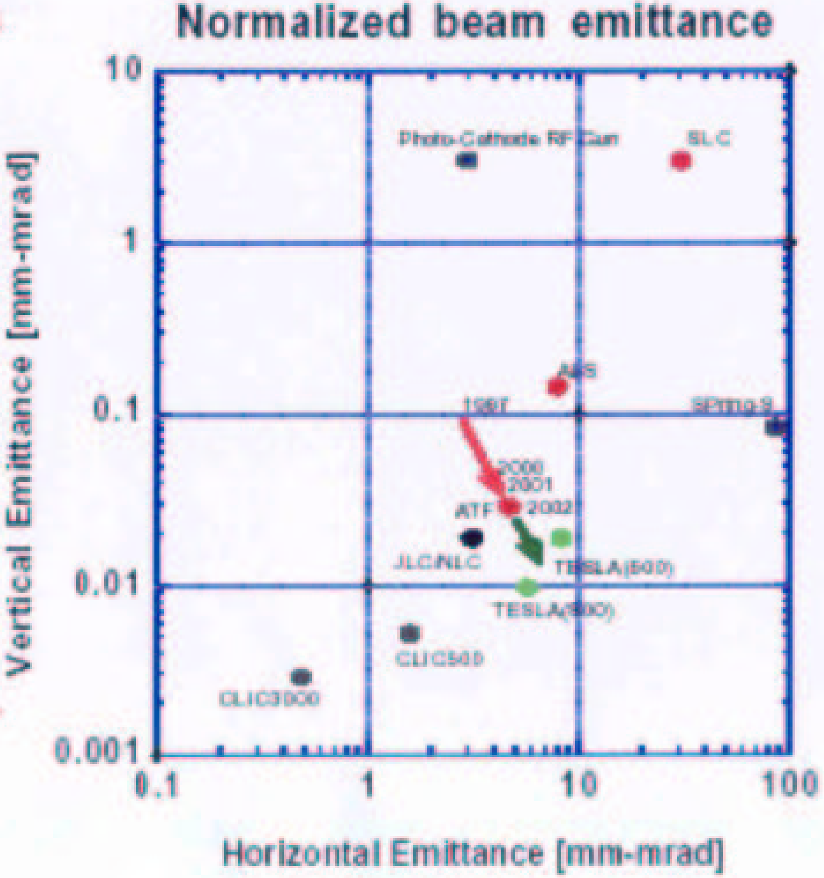
>> vertical beam size in interaction point >> very small,

e.g.TESLA σ_y = 5 to 3nm

Obtained by

- Strong focusing β_y=0.4mm
  LEP had β_y =50mm
- Small emittances
  ε_{yn}= 30 to 20 nm.rad

needs damping rings >> strong damping by synchrotron radiation



Prototype : ATF/KEK/Japan =>

Courtesy: J.Urakawa

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2. Advanced Neutrino Beams

2.1 Neutrinos from π and K mesons (JA, US, EU)

$$\mu^+ \rightarrow e^+ \nu_e \overline{\nu_\mu} \qquad b)$$

$$p \rightarrow target \rightarrow \pi^+(K^+) \rightarrow \mu^+ + \nu_\mu \qquad a)$$

a) Used at present and medium term (KEK, FNAL, CERN)

b) Proposed for ν-factory based on μ storage rings; Issues:
- proton beam power up to 4 MW (p-accel., target)
- ionisation cooling of μ beams (test proposed
- rapid μ acceleration ($c\,\tau_\mu = 658m$)

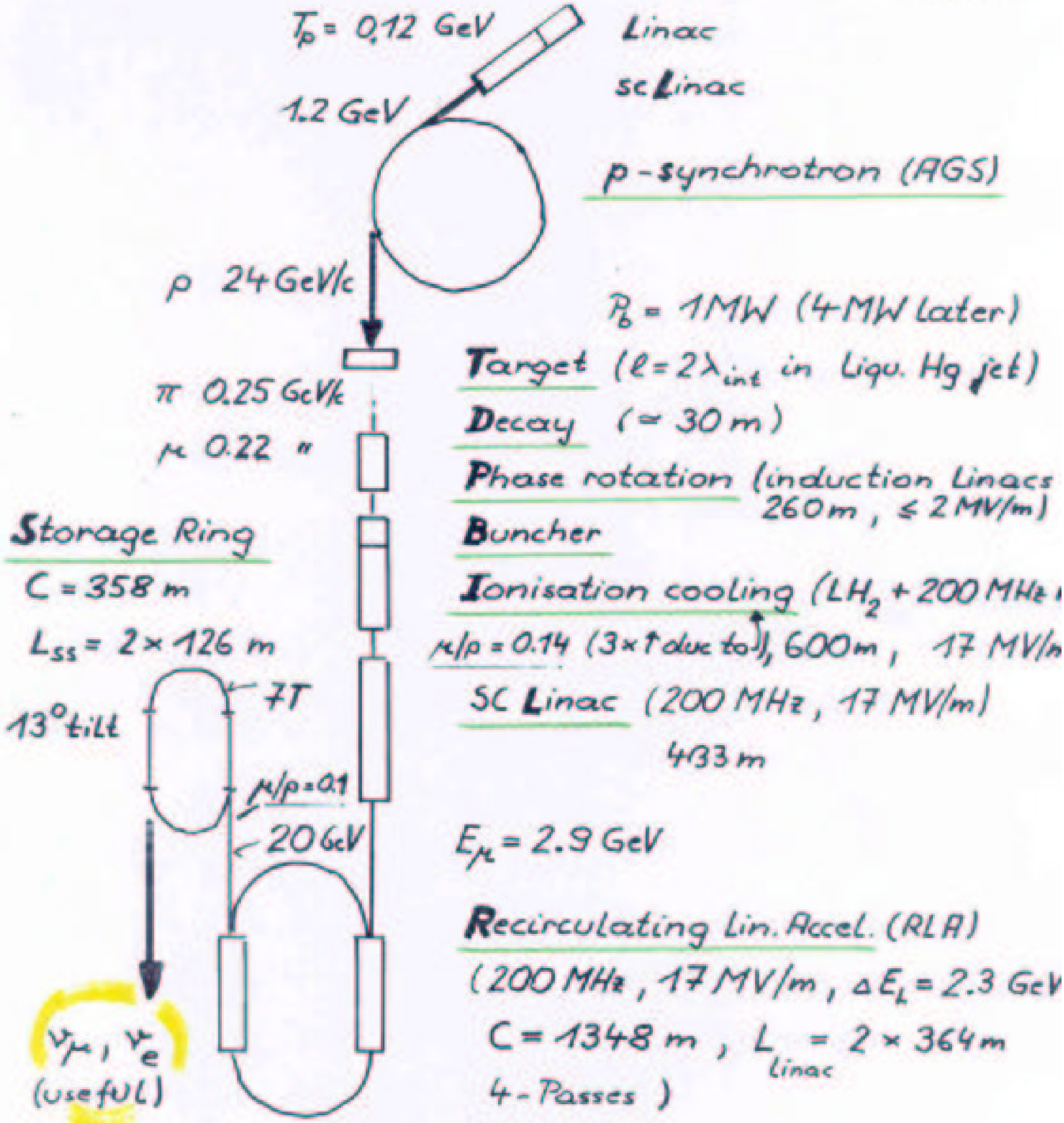
2.2 Neutrinos from beta-decay (studied in EU) : e.g.

$$^{6}He^{++} \rightarrow {}^{6}_{3}Li^{++} e^- \overline{\nu_e}$$

proposed for ν-factory based on storing beta emitters at high energy (γ = 100) in a storage ring ; Issues:
- generation of beta emitters (ISOL technique
- losses during acceleration -> contamination

2.1 Neutrino Factory

Example: US Study II (eds. Ozaki, Palmer, Zisman, Gallardo) 2001

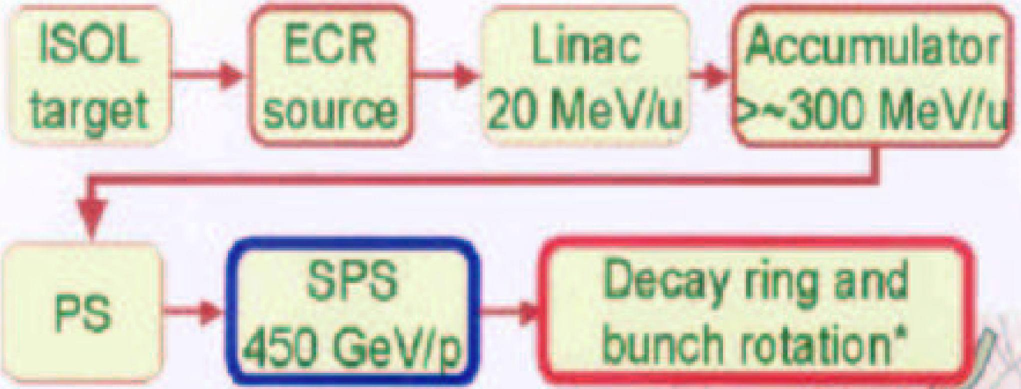


$N_\nu = 1.2 \times 10^{20} / (1\,MW, 10^7 s)$

aimed at detector 3000 km away

$\Sigma V_{RF} \cong 8\,GV$ = 2.5 × LEP !

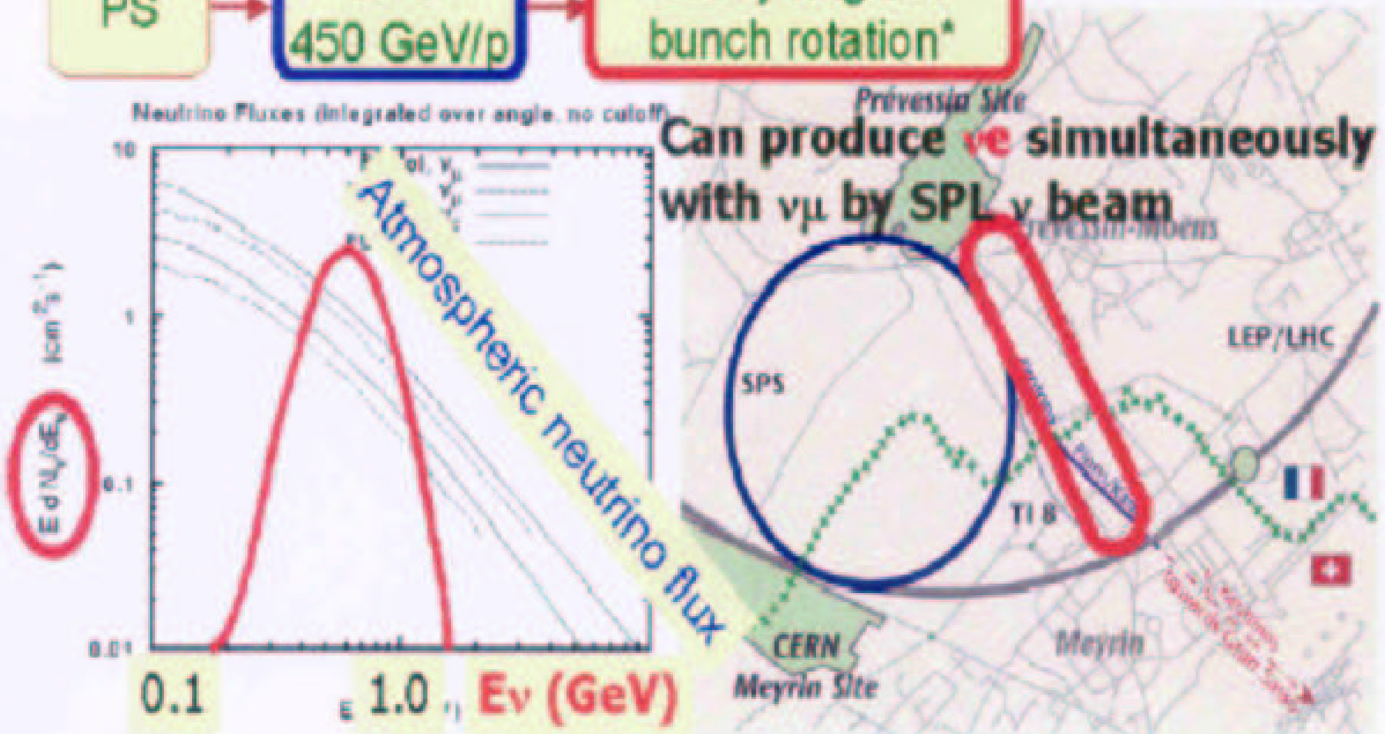
2.2 Neutrino Factory based on beta-emitters



Decay ring

$L_{ss} = 2.5$ km

$\dot{N}_{He} \cong 6 \times 10^{11}\ s^{-1}$ in total



3. Very Large Hadron Collider (VLHC)

Staged approach for large proton-proton collider after LHC (E_{cm}=7 TeV) and Linear Collider:

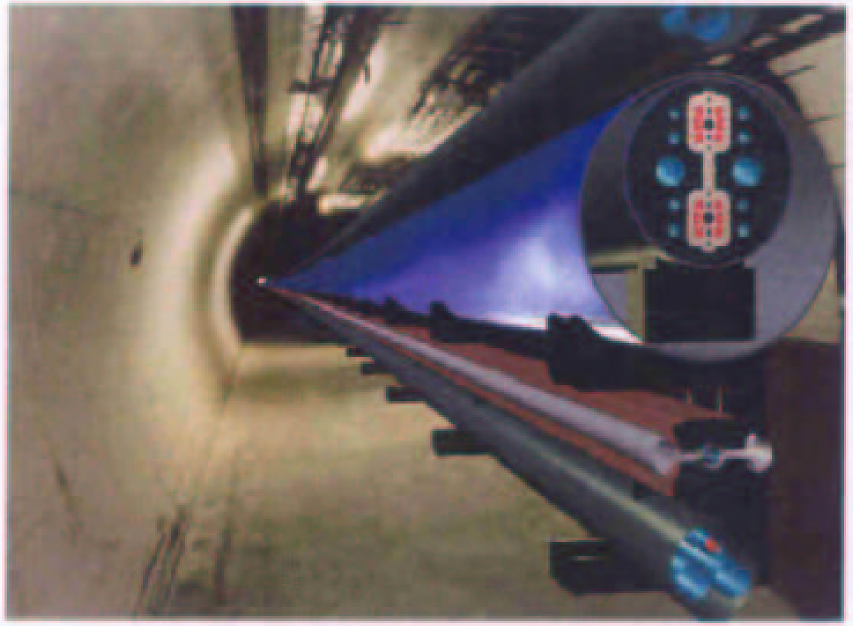
- Build big, cheap tunnel (e.g. 233 km circumference)

- with E_{cm}=40 TeV p-p collider with low-field magnets
  (bending magnets with B= 2T, superferric)
  use existing (FNAL) accelerator chain as injectors

- later>> 200 TeV p-p collider with L=$2x10^{34}$ cm^{-2} s^{-1}
  with 11 T superconducting bending magnets

VLHC Parameters and Layout in tunnel

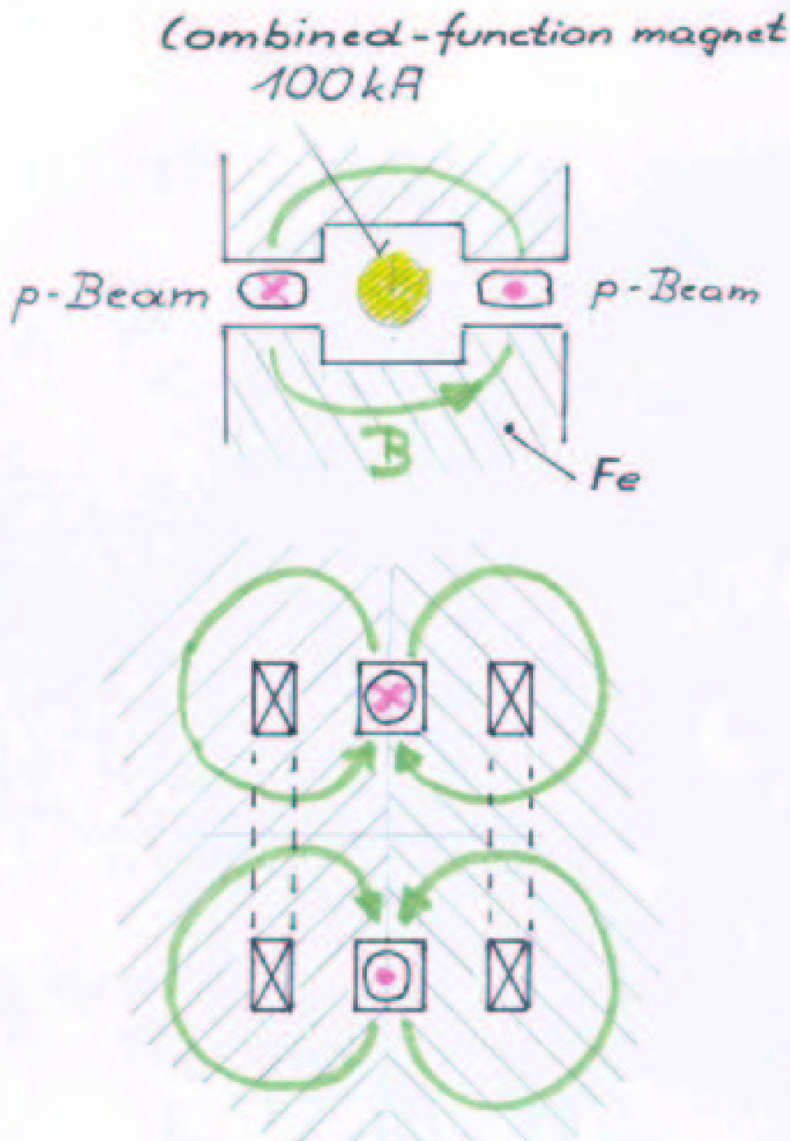
Stage	1	2
E_{cm}	40	200 TeV
L	1	$2\ 10^{34}$
B	2	11 T
τ_L	24	7 h
P_{debris}	6	94 kW
P_{syn}	0.03	6 W/m
E_{inj}	0.9	10 TeV



cf. P.Limon/FNAL
MT-17(2001)

R&D Activity for VLHC (US/FNAL)

- low-field dipoles of novel design
  - --100 kA power supply and transmission line conductor developed
  - --tests 1.5 m long magnet in 2002, 3 and 6 m magnet in 2003
- high-field dipoles (11-12 T)
  - -- Nb_3Sn common coil magnets
  - -- quadrupole development also for L(LHC) upgrade?
- Synchr.radiation absorption at cryogenic temperatures: above a few W/m >> by photon stops >> need less coil aperture than beam screen.



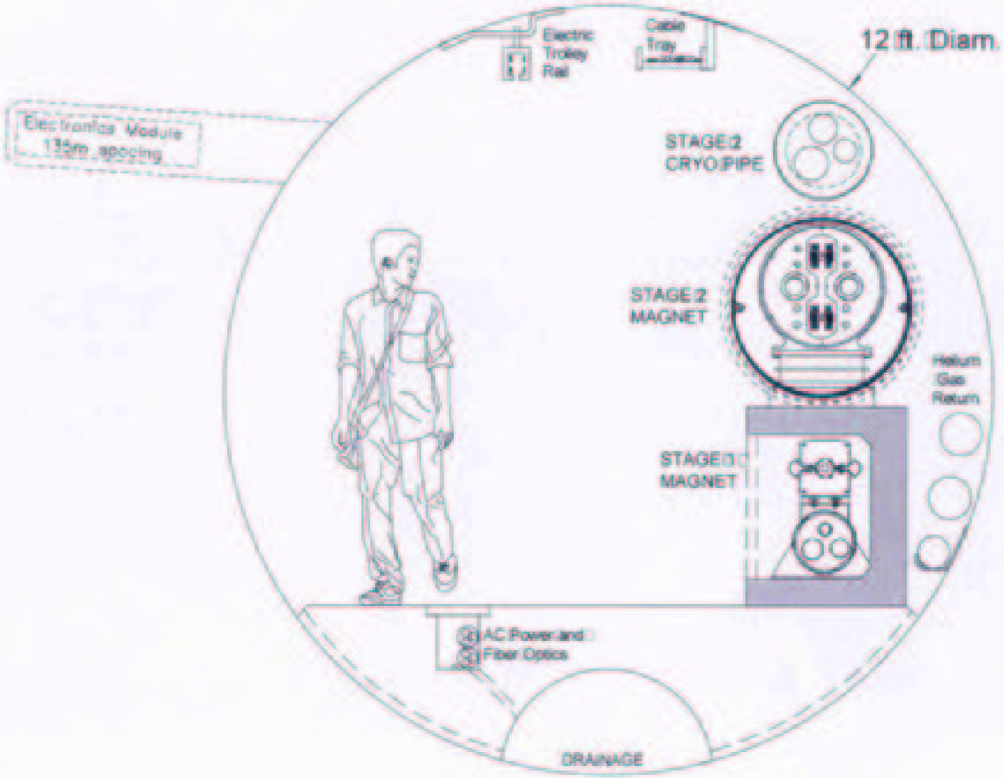
Common coil design

SC Magnets
at Fermilab

Transmission Line Conductor R&D

- All conductor types to be used for the superferric magnet were successfully tested in our Superconductor Test Facility in MW9. A magnetic field from a dipole magnet generated up to 100 kA current in the superconducting loop

Stage 2 VLHC Tunnel



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4. Advanced Acceleration Techniques

Present goal: produce e-(e+) beams in the multi-GeV range
Wakefield accelerators
*Fields in **structures**: - wall corrugations
- dielectric cladding
Excitation by an e^- drive beam (collinear or 2 beam conf.)
*Fields in **plasma**: advantage -> no breakdown
Excite of plasma oscillations by laser (100 GeV/m over 1mm)
by e^- beam (1 GeV/m over ~1 m)
Laser accelerators
• Use directly field of lasers **combined** to get longit.accel.
• **Inverse-FEL**: photons accelerate beam in wiggler
Issues (studied in US, little in JA and EU (F/Ec.Pol.):
* Short λ >> accepts only short bunches
* Strong focusing>> difficult inj.matching and alignment
* Efficiency (ac to beam): still very low

Conclusions

*Next particle physics accelerator after LHC → Linear collider (in parallel with LHC luminosity upgrading ?)
LC still needs vigorous R&D (check options, upgrading, cost red.)

*Next but one: ν-factory, multi-TeV LC, VLHC, μ+μ- collider,…
course of physics unpredictable → be prepared !

*Lead times long and longer: e.g. first idea/ first beam
HERA (77/91:14a), LEP(76/89:13a), LHC(83/07: 24a !)

*R&D resources: globally 30 MUS$ (materials big labs)
Hardly commensurate with road-map of particle physics
Insufficient effort in EU for advanced acceleration techniques

*Vigorous R&D → continues spin-off
at present : ~15000 non-HEP accelerators in operation
Accelerators and technologies → vital tools and input for e.g. medical diagnostics(MRI) /therapy, condensed matter research (Synchrotron rad.sources incl.FEL, n-spallation sources) etc.