Trends and Plans for the Future in the Accelerator Field

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EPAC'02
Paris, June 5, 2002

Excerpts from ECFA recommendations (1)

In the immediate future:

- The realisation, in as timely a fashion as possible, of a **world wide collaboration** to construct a high-luminosity **linear e^+e^- collider** with an energy range up to **at least 400 GeV** as **the next accelerator project** in particle physics; **decisions** concerning the chosen **technology** and the construction **site** for such a machine should be made **soon**.

- An improved **educational programme** in the field of **accelerator physics** and **increased support for R&D** activity in European universities, national facilities and CERN.

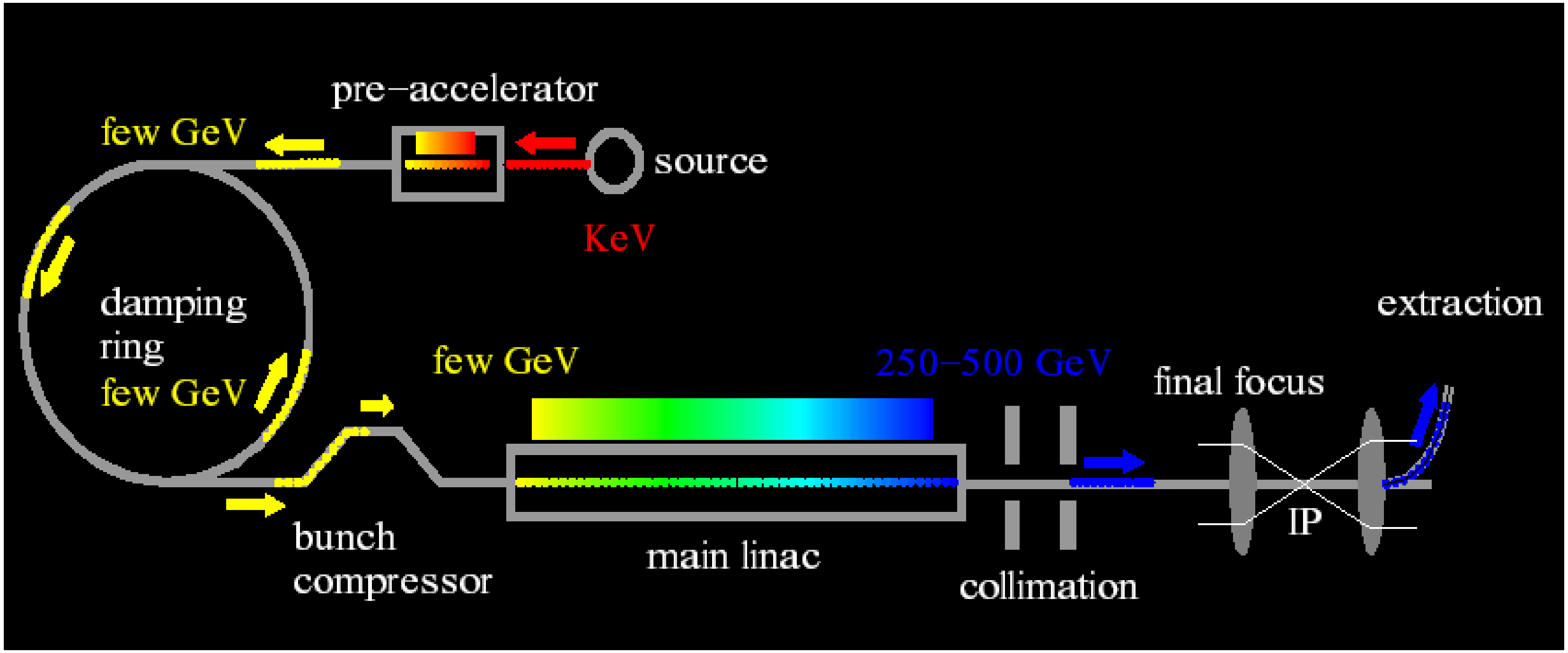
The Physics case for a LC

A Linear e^+e^- Collider with c.m.s energy < 1 TeV and high Luminosity allows:

- To perform the most stringent test of electroweak Standard Model
- to establish Higgs mechanism in the essential elements
- to explore SUSY-sector with high accuracy, model independent
- to extrapolate beyond the kinematically accessible region

LC is fully complementary to LHC!

Generic Layout of a Linear Collider



The main challenges:

Source	polarized positrons	
damping ring	very small vertical emittance	ATF
main linac	high accelerating gradient	TTF, NLCTA
final focus	tiny beamsize	FFTB

Luminosity

$$\mathcal{L} = \frac{n_b N_e^2 f_{rep}}{4\pi\sigma_x^*\sigma_y^*} H_D$$

$\sigma^*_{x(y)}$ horiz. (vert.) beamsize

- beamstrahlung: $\delta_E = \frac{\Delta E}{E} \propto \frac{1}{(\sigma_x^* + \sigma_y^*)^2}$
- flat spotsize $\Rightarrow$ $\delta_E \sim 1/\sigma_x^{*2}$ independent of $\sigma_y^* \propto \sqrt{\epsilon_y \beta_y^*}$
- small emittance $\Leftrightarrow$ small emittance dilution $\Delta\epsilon/\epsilon \propto f_{RF}^6\ \delta y_c^2$
- average beam power $P_B = \sqrt{s}\ n_b N_e f_{rep} = \eta\ P_{AC}$

$\Rightarrow$ High Luminosity $\quad \mathcal{L} \propto \frac{\eta P_{AC}}{\sqrt{s}} \sqrt{\frac{\delta_E}{\epsilon_y}}$ $\quad$ requires

– high efficiency η

– high beam quality (ϵ and $\Delta\ \epsilon/\epsilon$ small)

Technologies

Up to 1TeV:

Normalconducting Cavities:

NLC: X-band (11.4 GHz) (Report for Snowmass: SLAC-R-571)

JLC: X-band and/or C-band (5.7 GHz) (Report this year)

maximum achievable $\mathbf{G}_{\mathbf{acc}}$ roughly proportional f RF

Superconducting Cavities:

TESLA: Standing wave cavities (1.3 GHz)

(Technical Design Report: DESY2001-011,ECFA2001-209)

Fundamental limit for today Nb- Cavities < 55 MV/m

Up to5TeV :

Two-Beam-Acceleration:

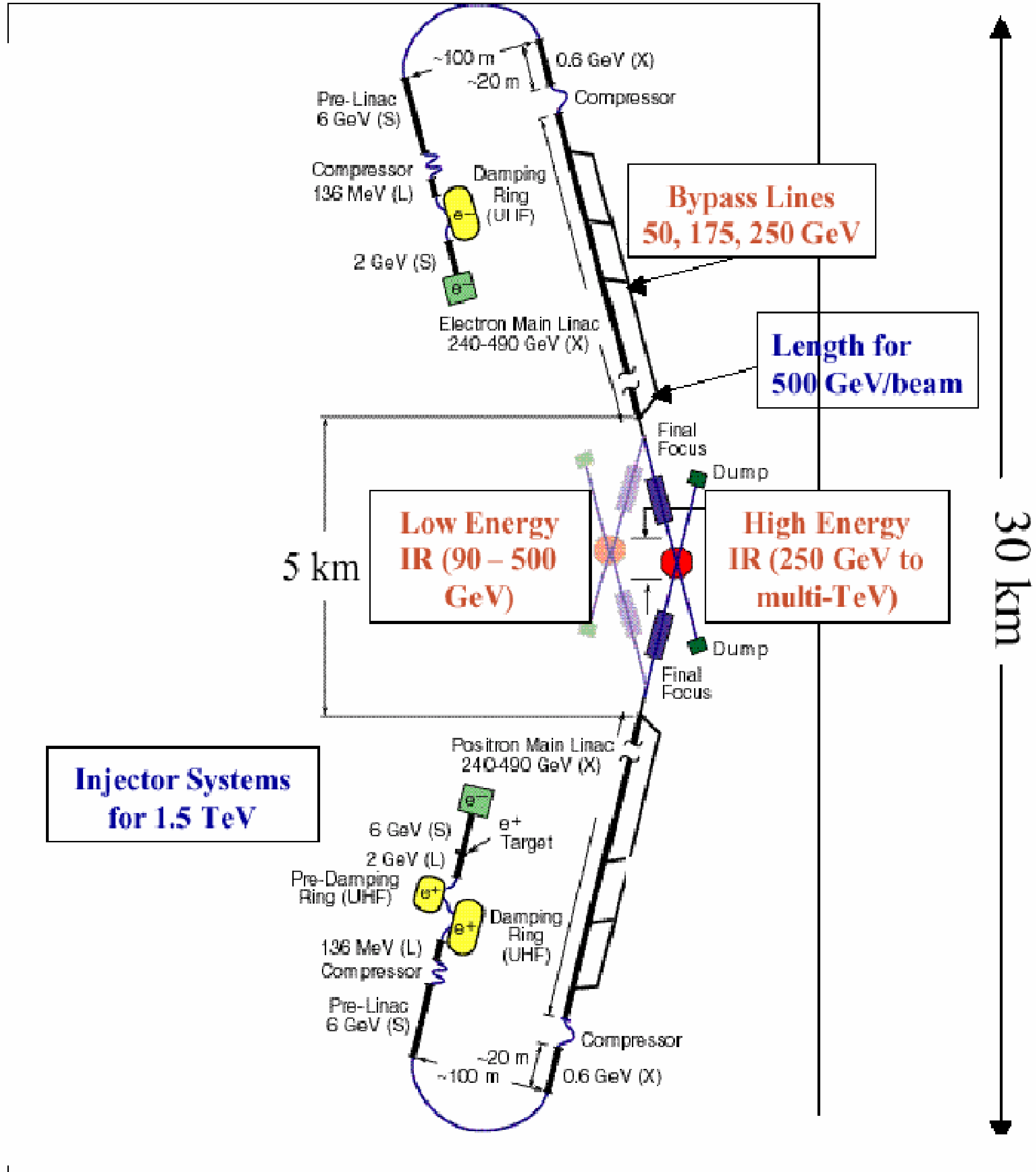
Use of relativistic drive beam as power source

CLIC: normal conducting cavities(30 GHz)(Report CERN2000-008)

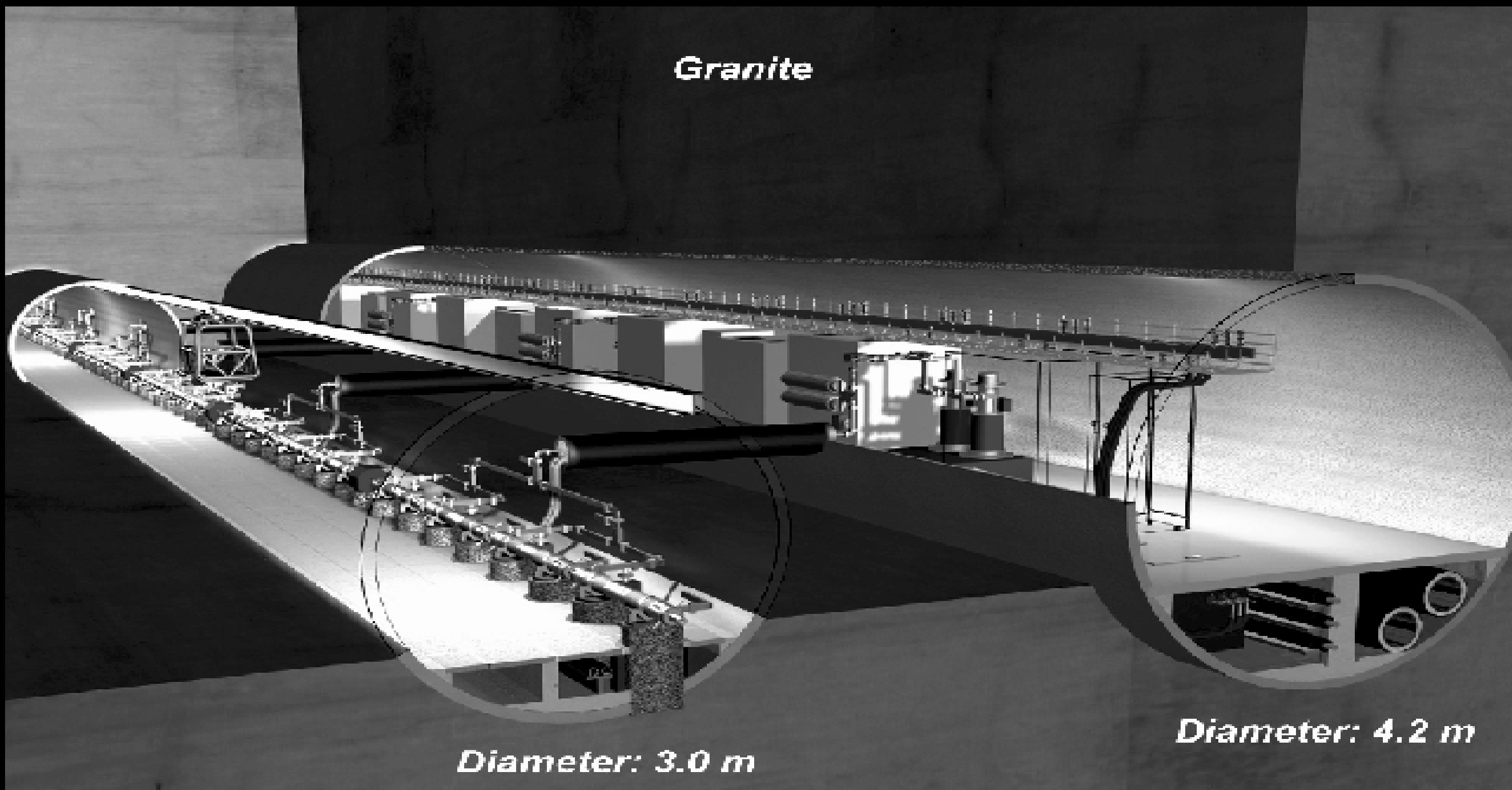
Linacs
Xing
angle

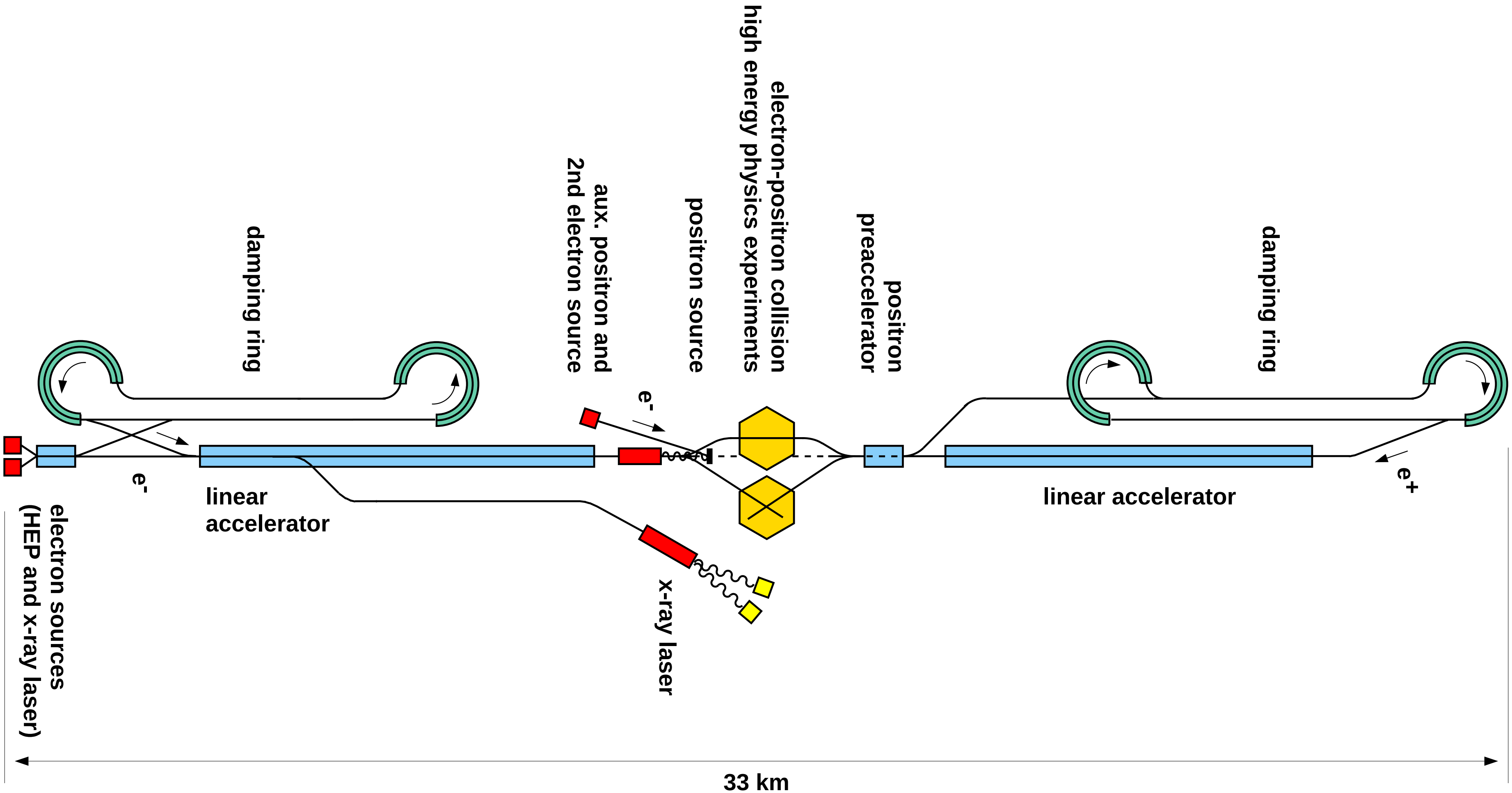
LE IR
90 to
500 GeV

HE IR
.25 to
>1TeV



C-band (5712 MHz) Main Linac





TESLA no Xing angle, positron source position (pol e^+ poss)
TESLA on HERA: ep collisions possible

integrated X-FEL for e.g. solid state physics, chemistry, biology

Comparison of some crucial parameters at 500 GeV

	TESLA	NLC	JLC-X	JLC-C	SLC
G_{acc} [MV/m]	23.5	48	50.2	36	17
f_{rep} [Hz] N_b ΔT_b [ns] $N_e/bunch[10^{10}]$	5 2820 337 head on 2	120 190 1.4 angle .75	150 190 1.4 angle 0.7	100 142 2.8 angle 1.11	
$\sigma^*_{x/y}[nm]$ δ_E[%]	553/5 3.2	245/2.7 4.7	239/2.57 5.3	318/4.3 3.9	./500 0.03
$\mathcal{L}[10^{34}cm^{-2}s^{-1}]$	3.4	2	2.64	1.3	$3 * 10^{-4}$
$P_{beam}[MW]$ $P_{AC}(linacs)[MW]$	22.6 97	13.2 132	17.6 141	12.6 220	.04
L_{tot} [km]	33	30	16	linac 19	
Upgrade path to .8-1 TeV	Gradient 35 MV/m	double cavities	double length	double length	

Path to energies beyond 1 TeV:

Increase length or develop different technology

Achievements at Test Facilities

- **TESLA Test Facility and NLC Test Accelerator**
  accelerated beams with parameters (Gradient, beam intensity, pulse length...) sufficient for 500 GeV Collider

- **Accelerator Test Facility at KEK**
  emittances within a factor (2-5) of damping ring design

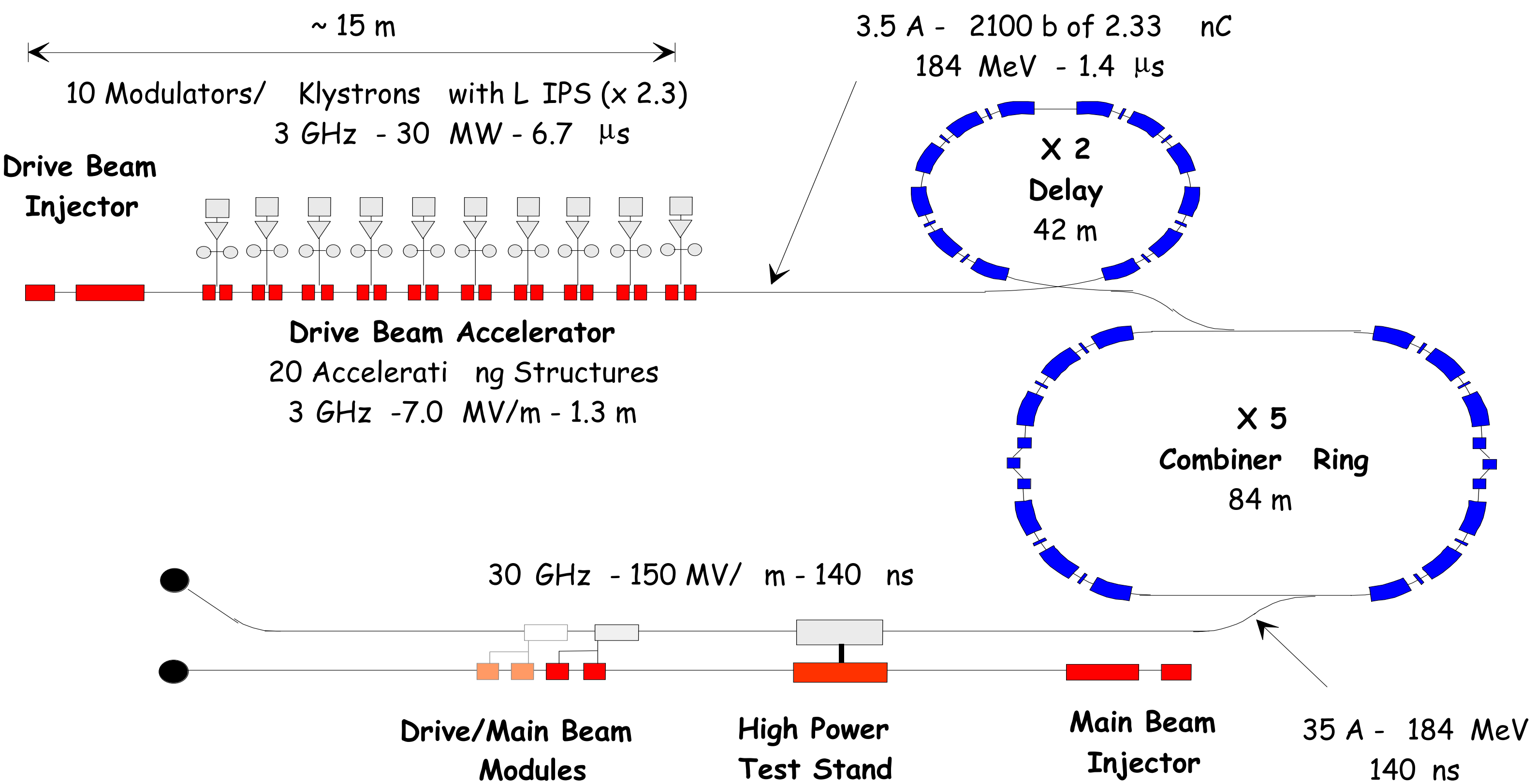
- **Final Focus Test Beam at SLAC**
  Demagnification proven:
  spot sizes measured in good agreement with theory

Excellent progress within international collaborations

CTF3 (CLIC Test Facility 3)

CTF3 conceptual lay-out

CTF3 - Test of Drive Beam Generation, Acceleration & RF Multiplication by a factor 10



TESLA

as an International Project

The OECD Megascience Forum (1995) distinguishes four organisational models for future accelerators:

1. National and regional facilities:
Built, financed and operated by the host country or host region, planning, project- definition done in international co-operation.

2. 'HERA-model':
Large facilities not financed by one country or one region alone, host receives contributions - mostly in kind - from participating countries, planning and project-definition are done in international co-operation, host country or institution is responsible for the operation.

3. Very large projects
Construction and operation realised through contributions in shares, partners contribute through components or subsystems (as in major detectors), facility would be the common property of the participating countries, these would also share the responsibility and cost for operation.

4. Very large projects in the frame of an international organisation like CERN.

Global Accelerator Network

We propose to build TESLA according to model 3, as a world-wide network:

The project is open for participation of international and national research and academic institutions

Makes project part of the national programs of the participating countries

How ?

- Design, construction, and testing of components is done in participating inst.,
- capital investment is done under the responsibility of the participating institutions/countries,
- maintain and run accelerators to a large extent from participating institutions

Why ?

- Make best use of world-wide competence, ideas, resources,
- maintain scientific and technical culture in home labs,
- remain attractive for young scientists,
- contribute to and participate in large, unique projects,
- the site selection would become a less critical issue.

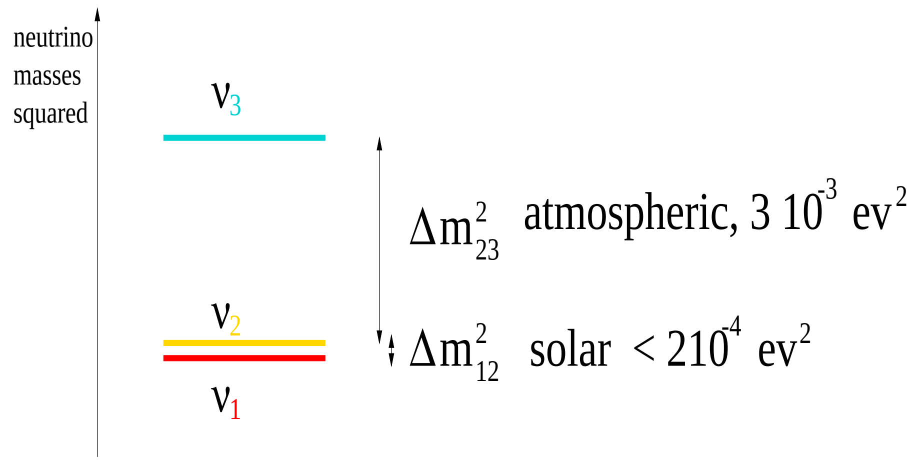
Put accelerator at an existing lab: make optimal use of existing experience, manpower and infrastructure

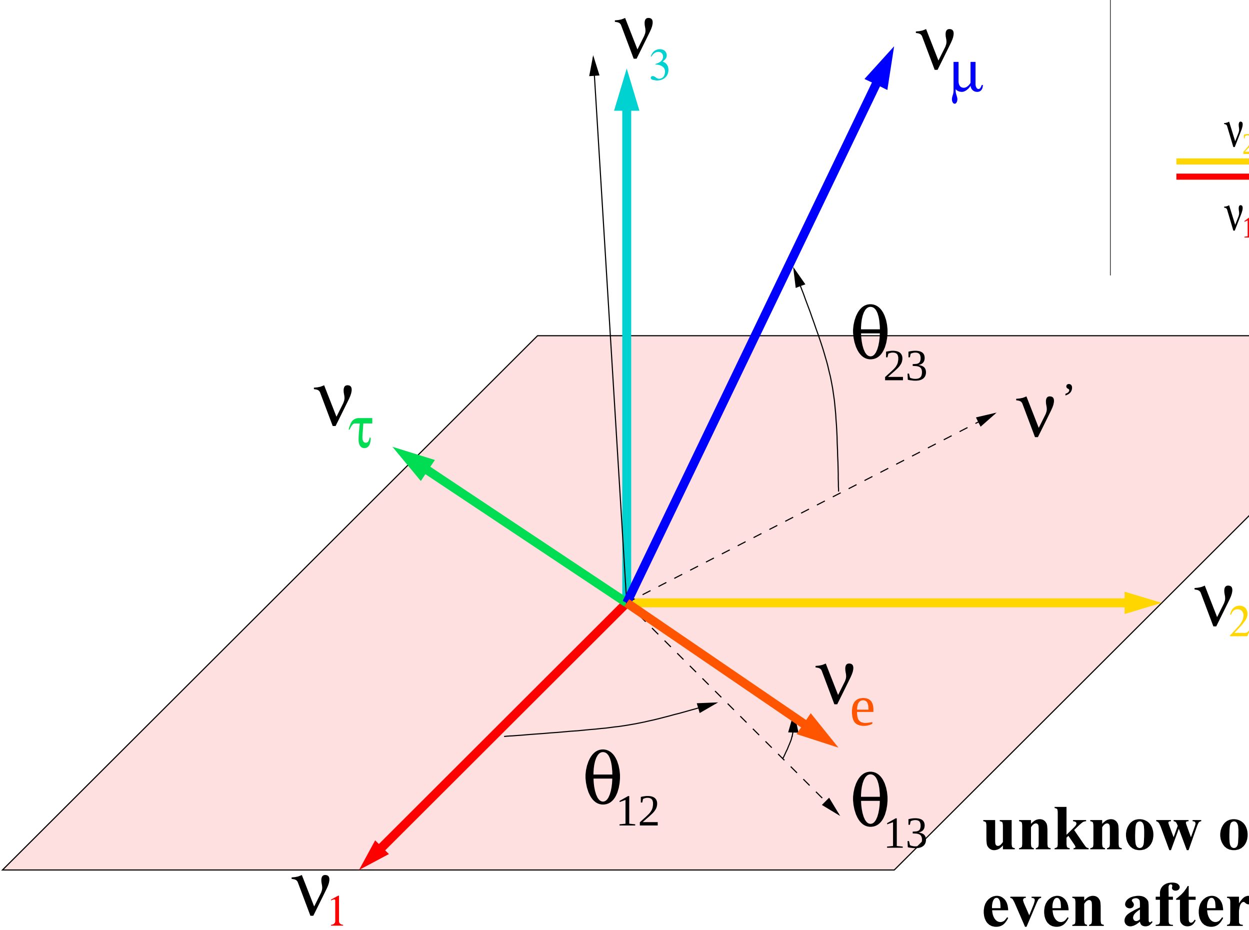
Excerpts from ECFA recommendations (2)

For the long term:

- A co-ordinate collaborative R&D effort to determine the **feasibility** and practical design of a **neutrino factory**, based on a high intensity **muon storage ring.**
- A co-ordinate world wide R&D effort to assess the feasibility and estimate the costs of a 3 to 5 TeV e^+e^- collider (CLIC), a very large hadron collider (VLHC) and a muon collider; **in particular R&D for CLIC is very well advanced and should be pursued vigorously**.

The neutrino mixing matrix





unknow or very poorly known even after approved programme:

θ_{13} phase δ sign of Δm_{13}

GOLDEN MEASUREMENTS at ν- FACTORY

$$\bar{\nu}_e \leftrightarrow \bar{\nu}_{\mu,\tau}$$

$\bar{\nu}_e \longrightarrow \bar{\nu}_\mu$ is the golden measurement at Nufact:
appearance of wrong-sign muons

$$\begin{array}{llll}
\mu^- \longrightarrow \nu_\mu & \bar{\nu}_e & e^- & \\
 & \downarrow & & \\
 & \bar{\nu}_\mu & \longrightarrow \mu^+ & \\
\mu^+ \longrightarrow \bar{\nu}_\mu & \nu_e & e^+ & \\
 & \downarrow & & \\
 & \nu_\mu & \longrightarrow \mu^- &
\end{array}$$

$\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$

Expected Physics outcome of a Long base Line program at a Neutrino factory

High energy ν_e essential & unique

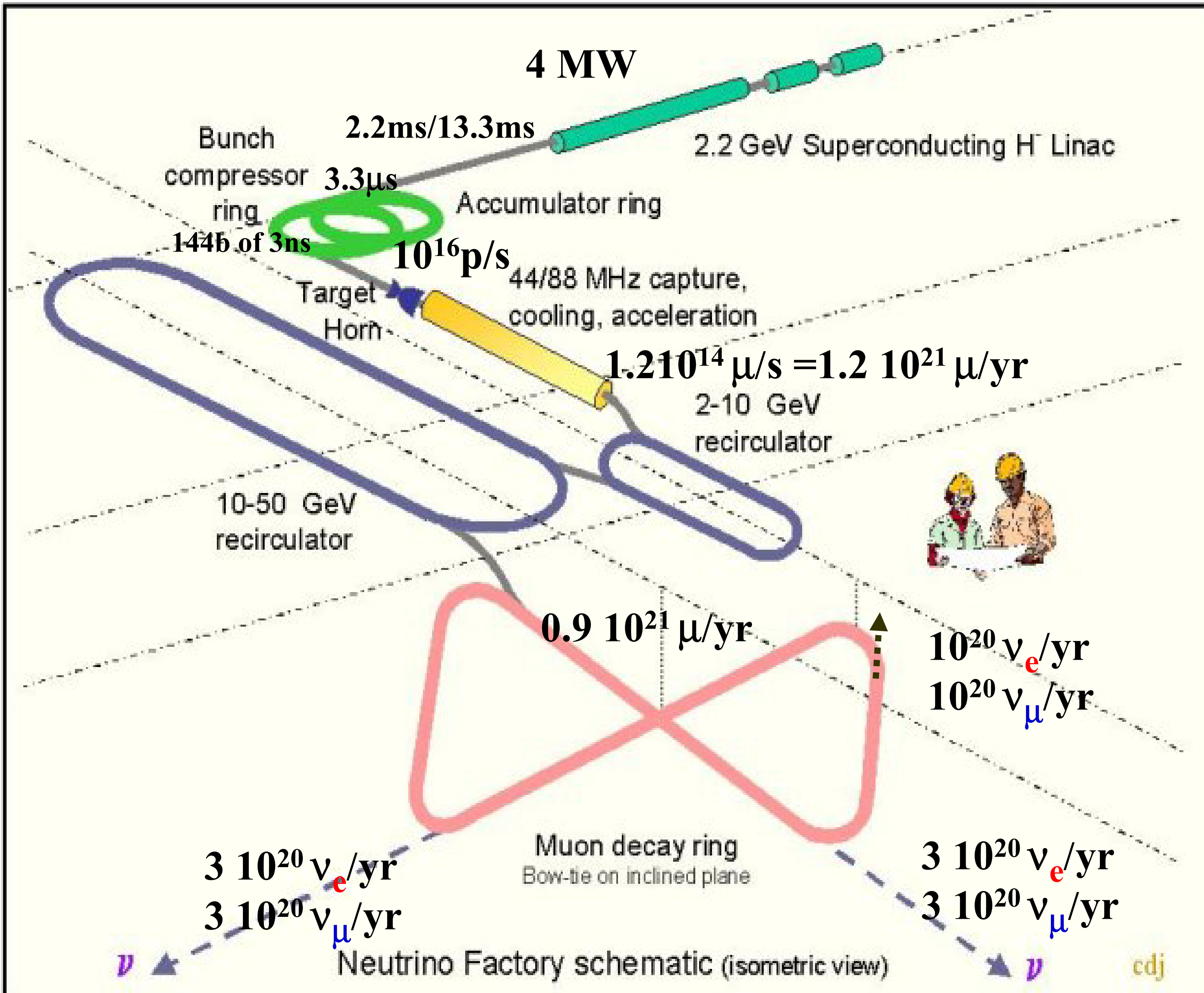
- Measurements of
  θ_{13} , θ_{23} with precision of 10^{-3} or limit at about 10^{-6}
  Δm_{13} with relative precision of 1%

- establish matter effect -> sign of Δm_{13}

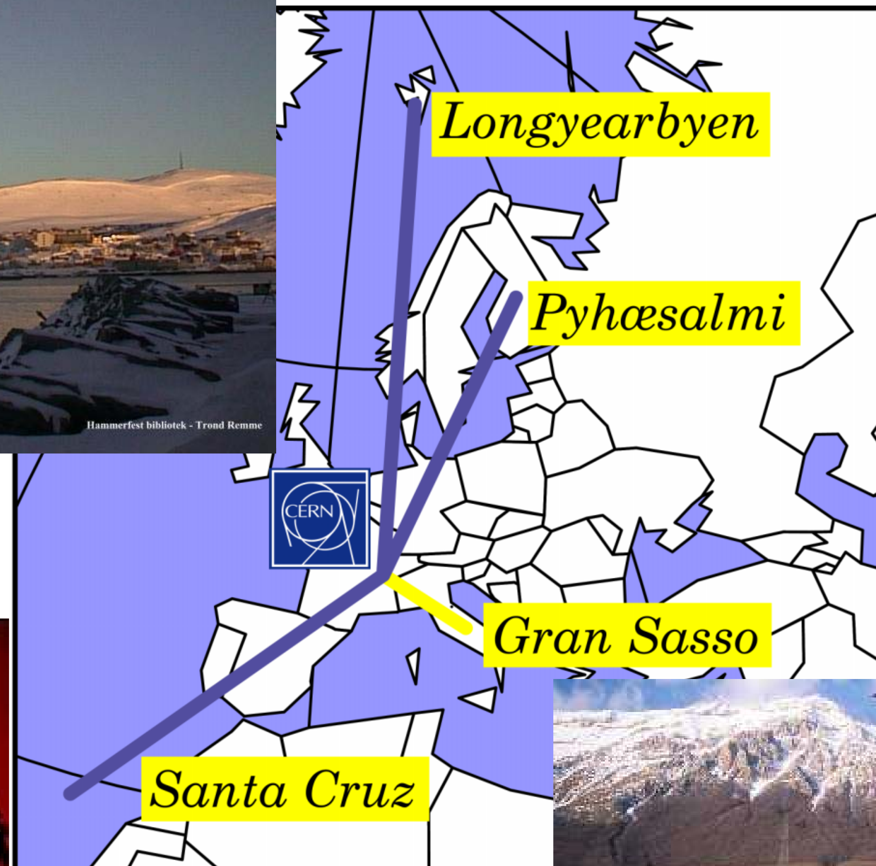
- Will be sensitive to CP violation over the whole Large Mixing Angle solution of the Solar neutrinos (favored now)

- (50 KT, 5 years, 10^{21} muons per year, 3000 km)

CERN baseline scenario (target muon budget)



Where do you prefer to take shifts?



NUFACT R&D: Target station

- Target:
  - Dimension: L $\approx$ 30 cm, R $\approx$ 1 cm

→4 MW proton beam into an expensive cigar…

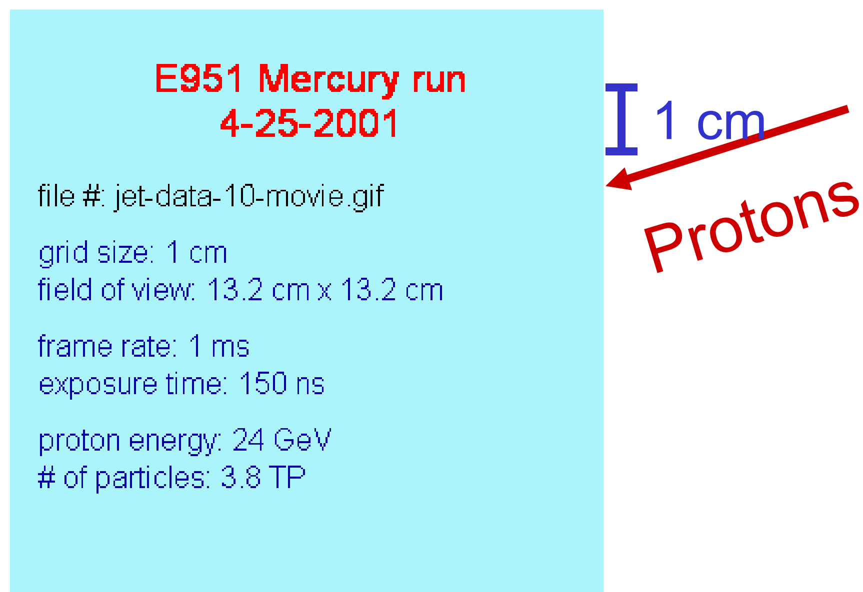
→High Z → small size good for optics

→Liquid → easy to replace ($v_{//} \approx$ 20 m/s) → **Mercury**

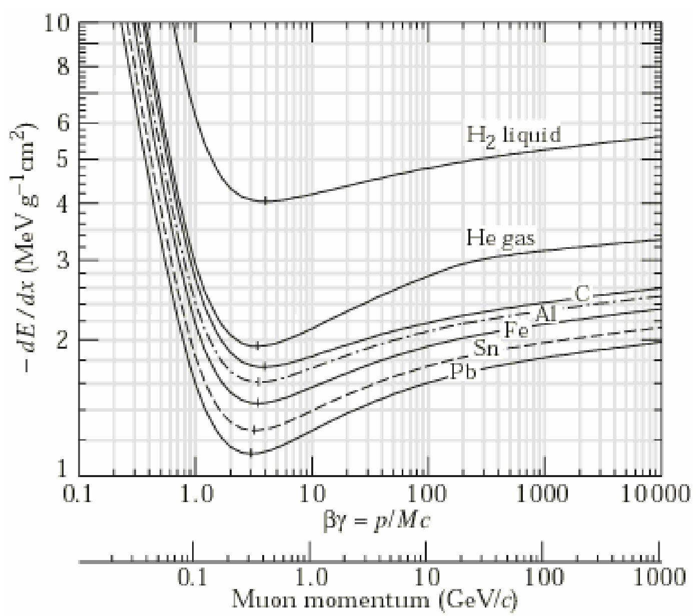
NUFACT R&D: Target station

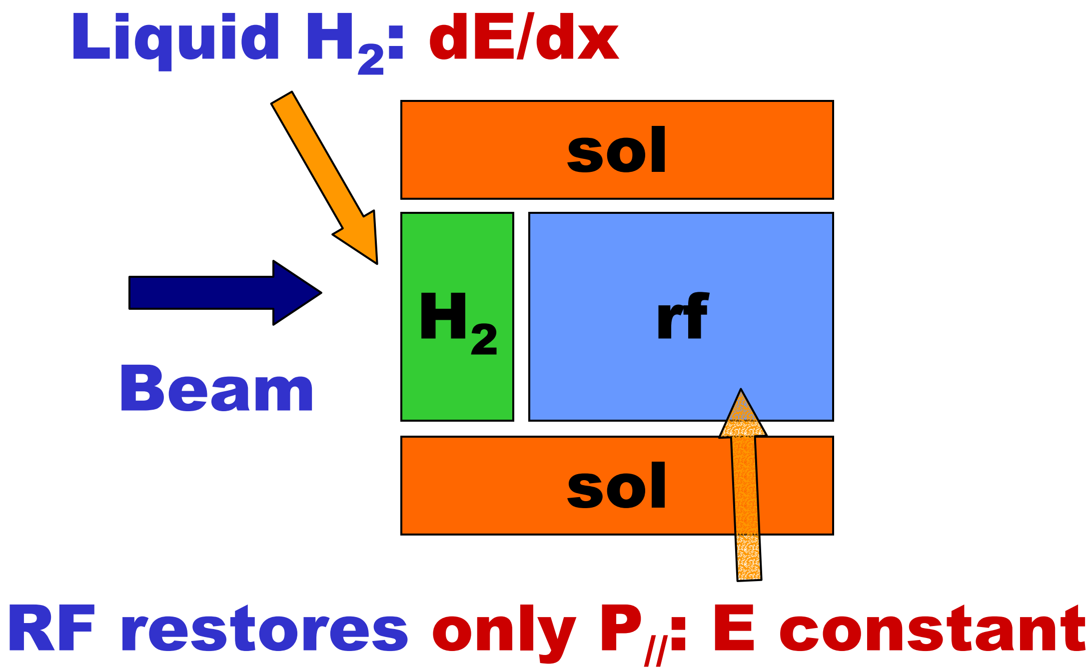
Experiment @BNL and @CERN

- Speed of Hg disruption
- Max $v_{\perp} \approx$ 20 m/s measured
- $v_{//} \approx 3$ m/s
- jet remains intact for more than 20 microseconds.



Ionization Cooling : the principle



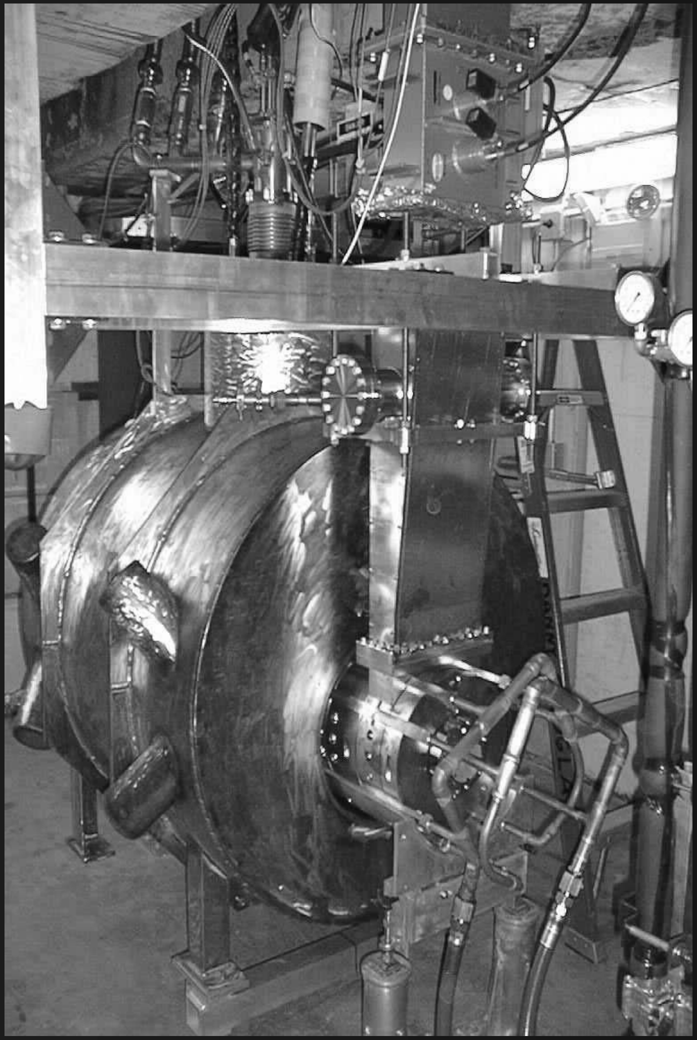


Why is muon cooling so challenging ?

"We need to be able to operate a system in which Liquid Hydrogen is separated by a baking foil from an ignition source containing the energy of 10,000 light bulbs, and all of this is within a system of SC solenoids that might quench from time-to-time. The system must operate safely as 10^{12} charged particles pass."

"We need to understand high gradient NCRF Cavity operation in Multi-Tesla magnetic fields, going well beyond the current state-of-the-art. We must understand and solve our present cavity breakdown problems."

MUCOOL Test Facilities



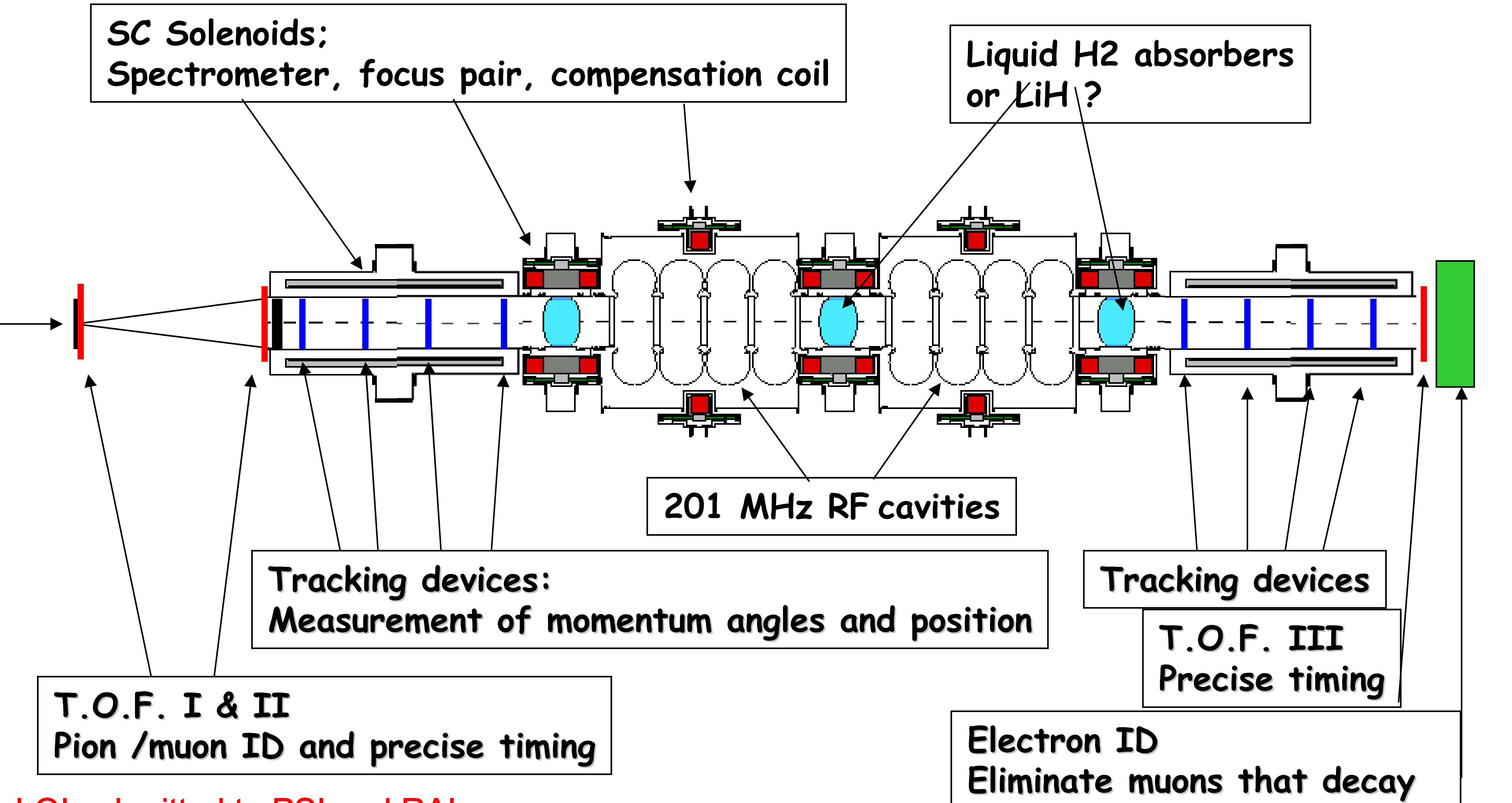
1. High Power RF test facility (FNAL Lab G) with 5T solenoid (LBNL) began operation in May 2001)
   >> 805 MHz high power cavity tests
   >> cooling channel instrumentation studies

2. FNAL Linac Area: Under construction
   >> LH2 filling facility in a few months
   >> 400 MeV proton beam in a year
   >> 200 MHz high-power test facility in 2 years

10% cooling of 200 MeV muons requires ~ 20 MV of RF

single particle measurements =>

measurement precision can be as good as $\Delta\ (\varepsilon_{out}/\varepsilon_{in}) =$



LOI submitted to PSI and RAL.

The two labs agreed to collaborate and to find the experiment a home. 2002: prepare proposal.

Conclusions

LC and ν-factories can be truly considered as case studies for most of the ongoing accelerator activities: they share theoretical problems as well as technological solutions with a large class of machines, where high-brilliance and/or high power are seeked.

The field is very active and vigorous R&D programs are underway.

A lot of attention is to be put into the academic training

World wide cooperation, which has been important in the past, is becoming mandatory and should be studied carefully.