Research Infrastructure

(Future Facilities)

E. Fernandez, UAB/IFAE

- Start with main physics questions and make list of facilities needed to address them.

  HEPAP Subpanel (Bagger-Barish, 2001): *"The science ahead, the way to discovery."*

  Recommended the creation of a Particle Physics Project Prioritization Panel (P5).

- Prioritization of facilities.

  HEPAP HEP Facilities Committee (Guillman, 2003): *"HEP Facilities recommended for the DOE Office of Science Twenty-Year Roadmap."*

- Other reports:

  National Research Council (NRC): *"Connecting Quarks with the Cosmos: Eleven Science Questions for the New Century"* (2003).

  Office of Science and Technology Policy (OSTP): *"The Physics of the Universe: A Strategic Plan for Federal Research at the Intersection of Physics and Astronomy"* (2004).

  HEPAP Subpanel charged by DOE/NSF: *"Quantum Universe: The Revolution in 21st Century Particle Physics"* (2004).

  NRC Report: *"Neutrinos and Beyond: New Windows on Nature"* (2003).

  APS Report*: "The Neutrino Matrix"* (2004).

- In Europe.

  ECFA Working Group (Foà, 2001): *"Report of the Working Group on the Future of Accelerator-Based Particle Physics in Europe."*

  Several reports on specific projects:

  -TESLA Technical Design Report (2001).

  -ECFA-DESY workshop reports on LC.

  -ECFA/CERN studies of a European Neutrino Factory complex (2004).

  -A 3 TeV LC based on CLIC Technology (2000).

- OECD Global Science Forum: *"Report of the Consultative Group on High-Energy Physics" (2002).*

Future facilities for High Energy Physics

Four main (complementary) lines:

1. **The energy frontier:**

   High energy proton-proton colliders.

2. **The precision frontier:**

   Electron-positron linear colliders.

3. **Precision in the rearguard:**

   Neutrino physics, flavour physics, proton-decay...

4. **Non-accelerator particle physics:**

   A very wide and open field.

The Energy and Precision Frontiers

A few facts:

1. The LHC will start in 2007 and the first solid results will be known in (say) 2009 or 2010.

2. There is ample consensus, developed over many years, in that the next step in HEP is an e^+e^- Linear Collider (LC).

3. Construction of the LC will not start before 2010.

The Energy and Precision Frontiers

An a few questions:

1. What is the LHC going to tell us by 2010?

2. Will the results of the LHC influence the decision to build a LC?

3. Will the results of the LHC influence the energy choice of the LC?

We do not know (at 100% CL) the answers. Strategy means Plan of Action (now) while these questions are unanswered.

The Energy Frontier: the LHC

- It is almost guaranteed that the LHC will unveil new physics

  The $W_L\ W_L \rightarrow Z_L\ Z_L$ cross-section violates unitarity unless there is a Higgs (with m< 780 GeV), or a new scale (E< 1.2 TeV), within the LHC reach.

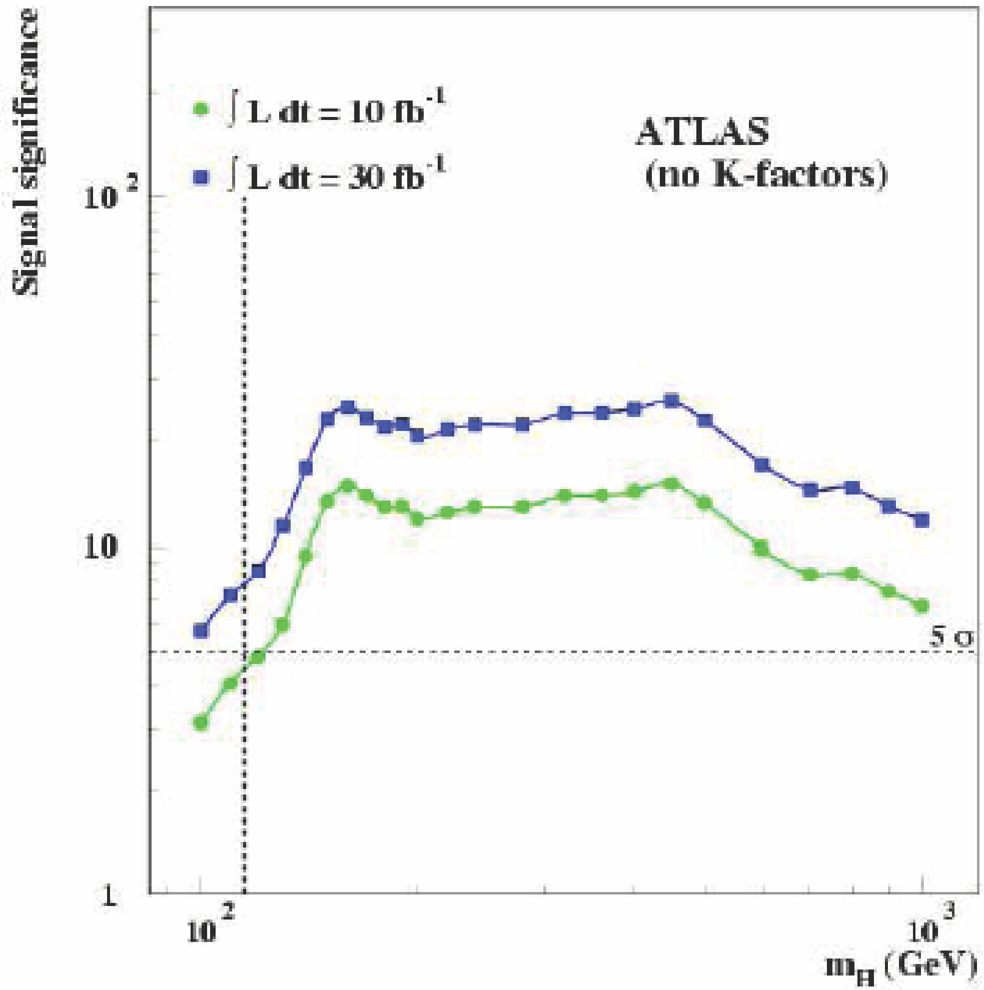
- The spectacular agreement between data and the SM radiative corrections are consistent with a SM Higgs, with a mass

$$114\ \mathrm{GeV}/c^2 < M_H < 219\ \mathrm{GeV}/c^2$$

The Energy Frontier: the LHC

The LHC can discover the SM Higgs if its mass is below 1 TeV at 5σ with 5 fb^{-1}

A 95% exclusion requires 1 fb^{-1}

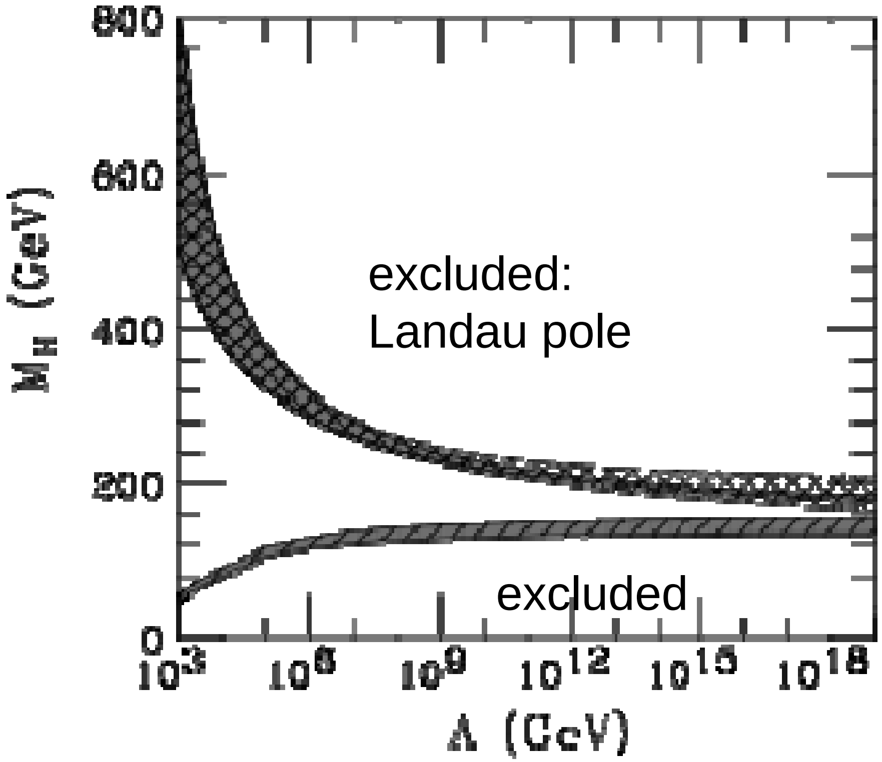


The Energy Frontier: the LHC

- In the SM the Higgs potential has a very specific form:

$$V(H) = -\mu_H^2 |H|^2 + \lambda |H|^4$$

The running of the quartic coupling produces an unstable (changes sign) or infinite Higgs mass unless there is a new scale. Where the scale is, depends on the mass.



The Energy Frontier: the LHC

Even if a low mass Higss is found, there is still another argument for the existence of new physics: the Hierarchy problem:

> radiative corrections to the Higss mass grow with the scale of new physics. If this scale is large (> 1TeV) the corrections are huge and have to be compensated (fine-tuned) by a correspondingly large bare mass.

This is “un-natural”.

One way out is “low-energy (<1TeV) supersymmetry”. However the existing limits on the Higgs from LEP already suggest, within the MSSM, that the scale is > 1 TeV.

The Energy Frontier: the LHC

- SUSY has many other appealing features:

  a) symmetry Fermions ↔ Bosons

  b) “alleviates” the Hierarchy Problem

  c) points towards Unification of Interactions

  d) the lightest supersymmetric particle is a natural candidate for Dark Matter.

The LHC should discover supersymmetry:

$M_{susy} < 1.5$ TeV → $\int \mathcal{L} dt = 1$ fb^{-1}

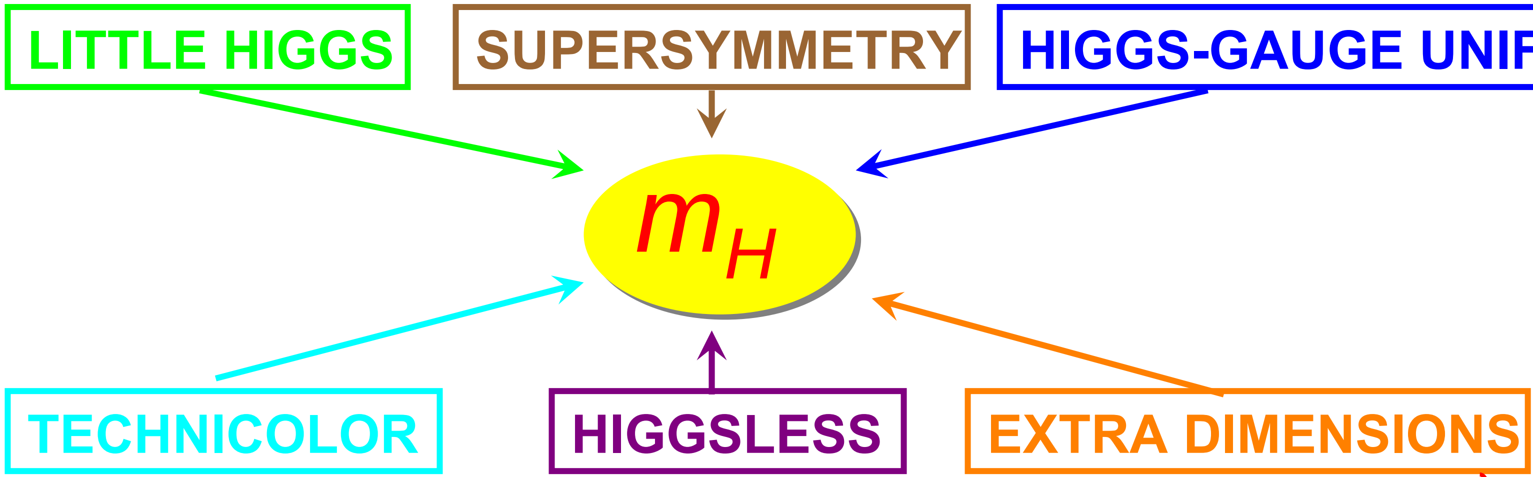
$M_{susy} < 2.0$ TeV → $\int \mathcal{L} dt = 10$ fb^{-1}

From G.F.Giudice at Orsay workshop

What screens the Higgs mass?

boson	fermion	vector
$\phi \to \phi + a$	$\psi \to e^{ia\gamma_5}\psi$	$A_\mu \to A_\mu + \partial_\mu a$
no $m^2\phi^2$	no $m\bar{\psi}\psi$	no $m^2 A_\mu A^\mu$
Spont. broken global symm.	Chiral symmetry	Gauge symmetry

Symmetry



Dynamical EW breaking	Delayed unitarity violat.	Fundamental scale at TeV

Dynamics

- Very fertile field of research
- Different proposals not mutually excluded

The Energy and Precision Frontiers

- It is likely that by 2010 we will know a great deal about the Higss and about new physics (other than the Higgs).

- **In almost all the scenarios (for discoveries at LHC) there is a clear need for precision measurements that can best be done at a LC with an energy between 0.2 TeV and 1 TeV.**

Linear Collider: quantum numbers and c.m. energy are exactly known.

The Precision Frontier

- A distinctive feature of a LC is the possibility of making a threshold scan for any new state.

a) For the t-tbar threshold δm_t ~0.1 GeV

From Klaus Mönig at Lepton-Photon Symposium

The top Quark Mass and why we need it

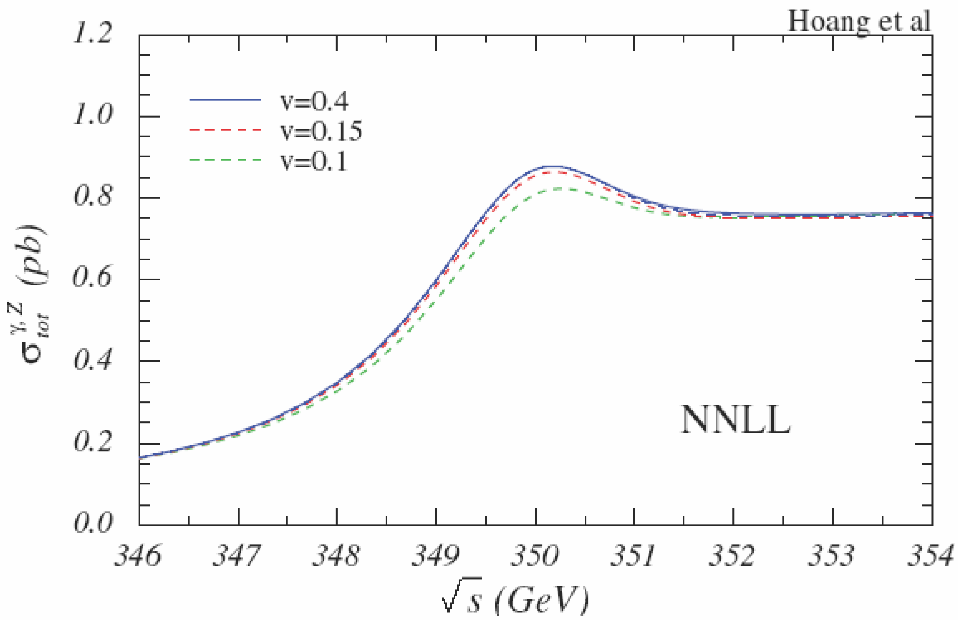
- The top mass can be measured accurately with a threshold scan
- With the appropriate mass definition the cross section is theoretically well under control
- With a 10-point scan

$$\Delta m_t = 34\,\mathrm{MeV}$$
$$\Delta \Gamma_t = 42\,\mathrm{MeV}$$
$$\Delta \alpha_s = 0.0023$$

can be achieved

- This should lead to

$$\Delta m_t(\overline{\mathrm{MS}}) \approx 100\,\mathrm{MeV}$$



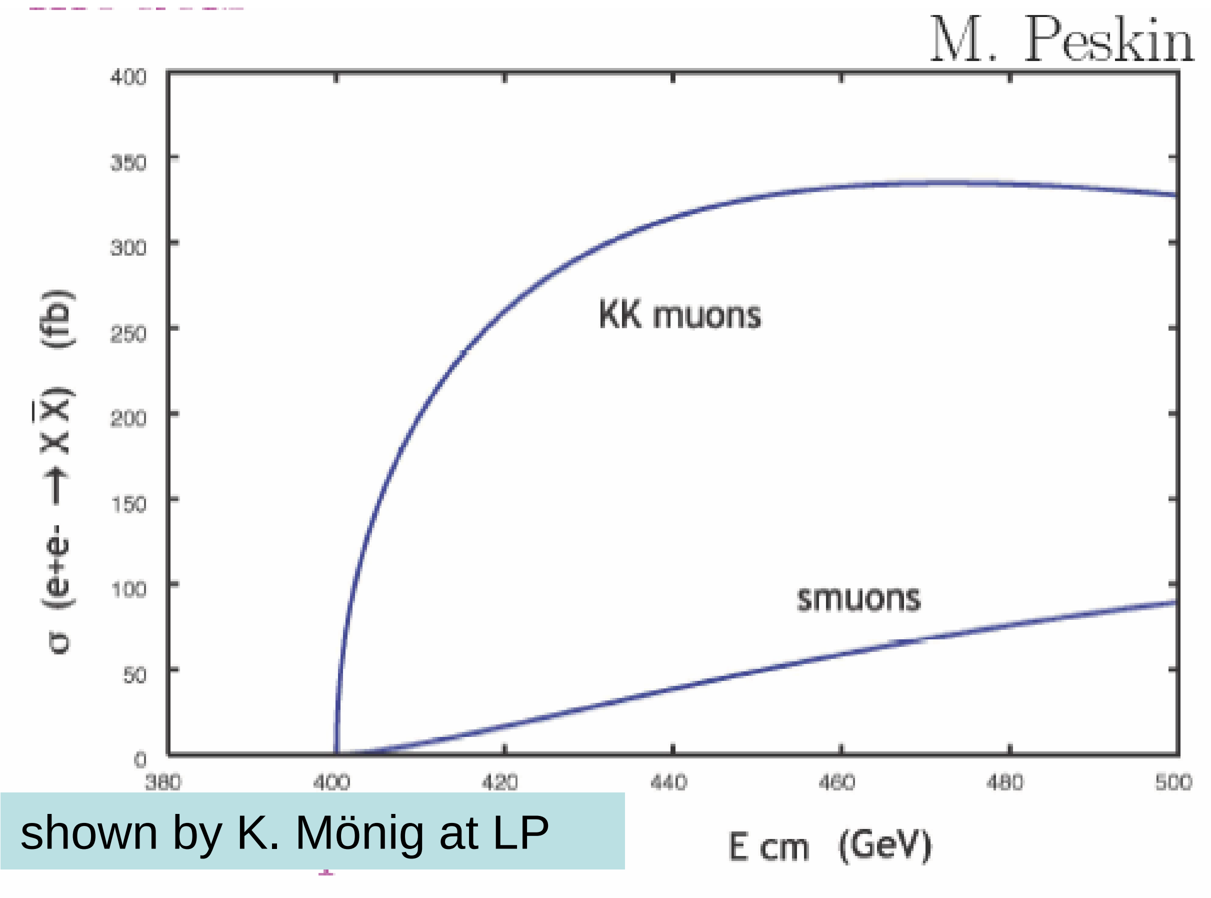
(v=top velocity parameter, should be > 0.15)

The Precision Frontier

- A distinctive feature of a LC is the possibility of making a threshold scan for any new state.

  a) **From the scan at the t-tbar threshold δm_t 0.1 GeV.**

  b) **From smuon-smuonbar check whether it is SUSY or something else.**

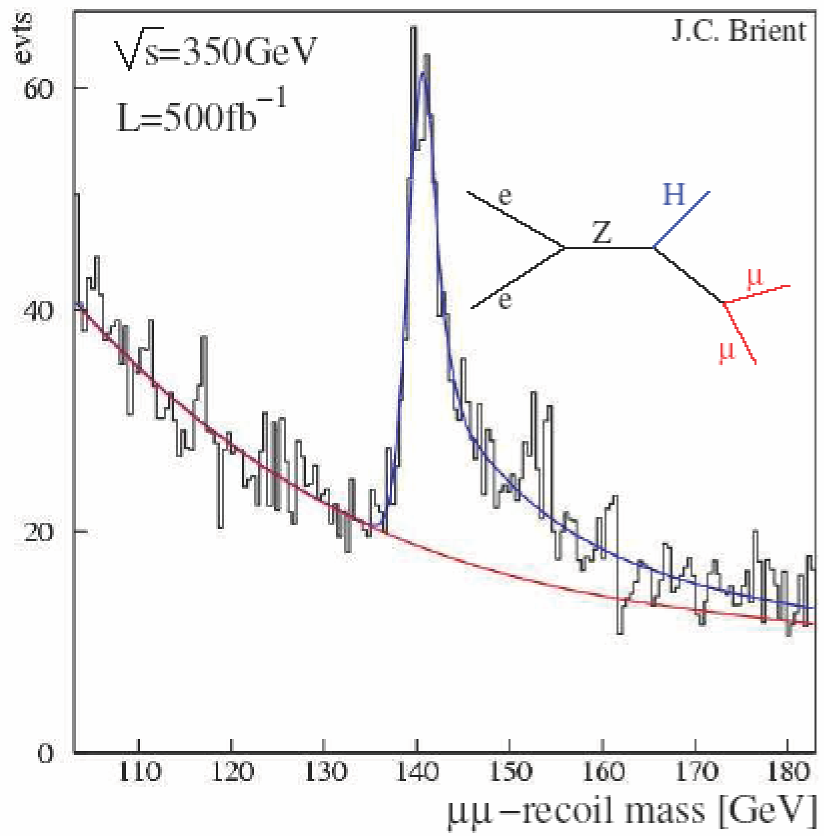


shown by K. Mönig at LP

Is it really the SM Higgs that gives rise to e-w symmetry breaking, or something else?

Measure Higgs couplings to fermions and bosons precisely, and check for the proportionality to the masses.

The Higgs line-shape →



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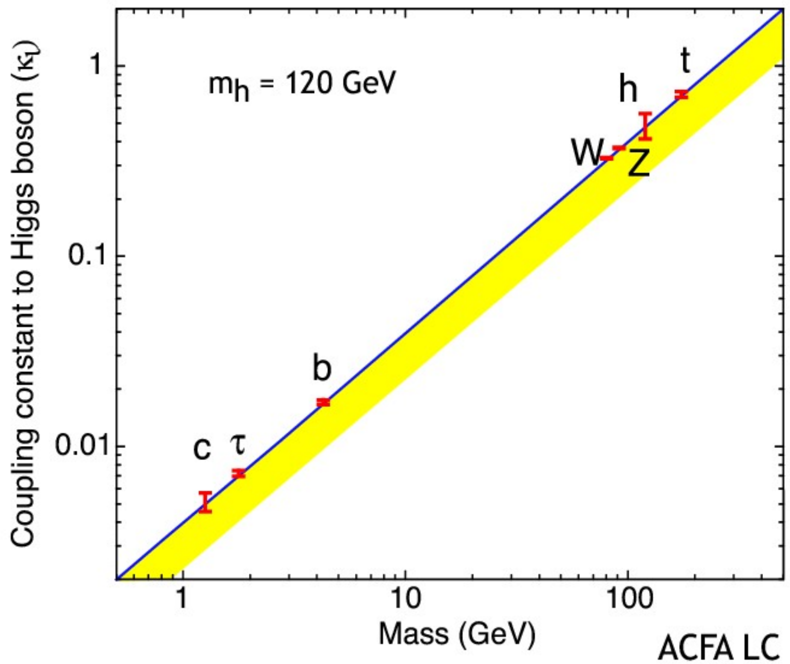


ACFA LC study

- **Blue line: standard model predictions.**
- **Models with extra dimensions -- yellow band, (at most 30% below the Standard Model**
- **The red error bars: level of precision attainable at the ILC**

ILC: a model of world-wide cooperation

- 2002: ICFA establishes the ILC Steering Committee (ILCSC) with Maury Tigner as Chair, now Shin-Ichi Kurokawa (2006)

- 2003: ILCSC established International Technology Recommendation Panel (ITRP). Cold technology recommended and adopted in 2004.

- 2005: ILCSC appointed Global Design Effort Director (Barry Barish).

From J. Dorfan at LP symposium 06

GDE – Near Term Plan

- **Staff the GDE**
  - **Administrative, Communications, Web staff**
  - **Regional Directors (one per region)**
  - **Engineering/Costing Engineer (one per region)**
  - **Civil Engineer (one per region)**
  - **Key Experts for the GDE design staff from the world community**
  - **Fill in missing skills (later)**

Total staff size about 20 FTE (2005-2006)

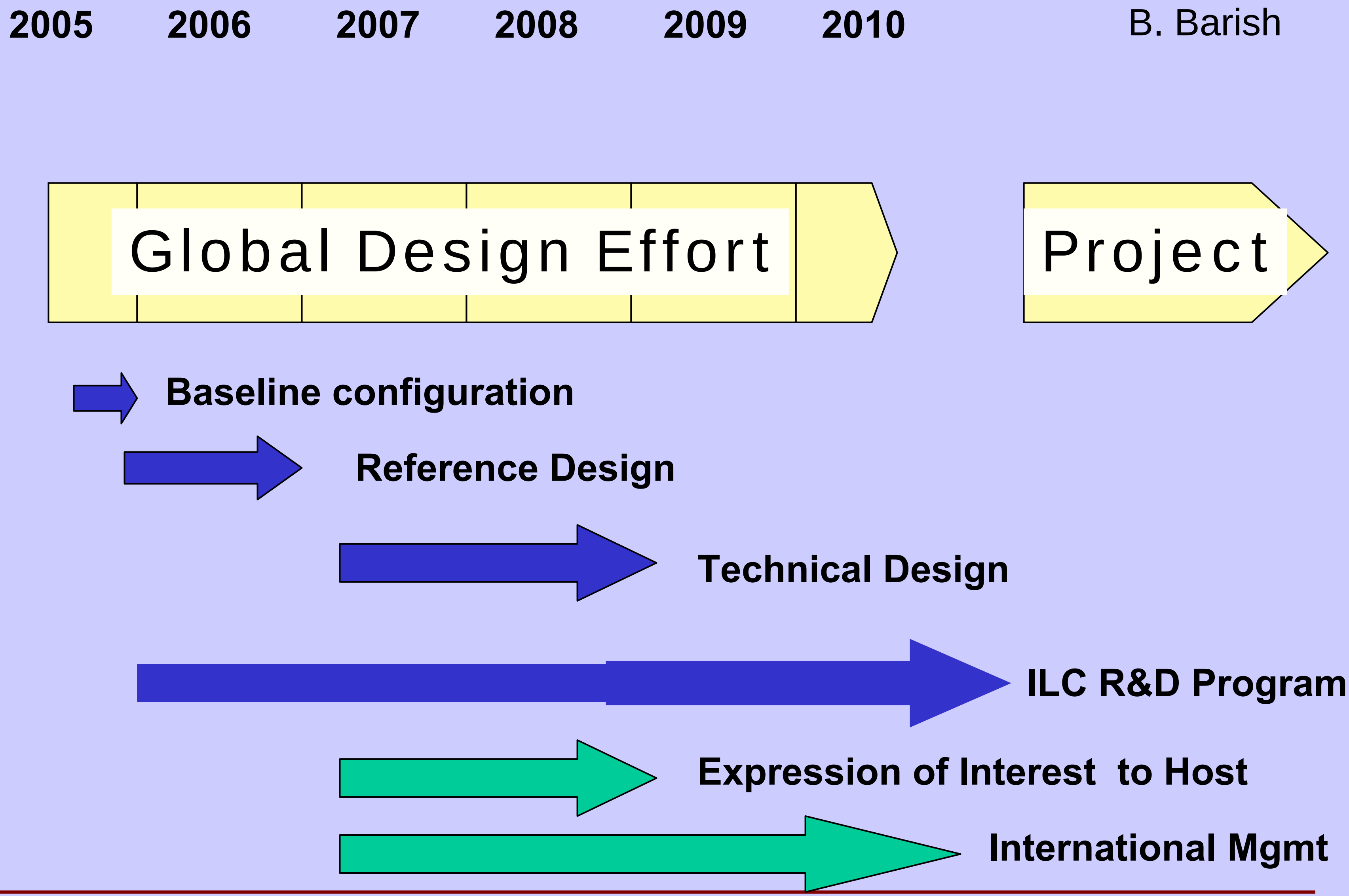
From J. Dorfan at LP symposium 06

GDE – Near Term Plan

- **Organize the ILC effort globally**
  - **First Step --- Appoint Regional Directors within the GDE who will serve as single points of contact for each region to coordinate the program in that region.**
    - **Gerry Dugan (North America), Fumihiko Takasaki (Asia), Brian Foster (Europe)**
  - **Make Website, coordinate meetings, coordinate R&D programs, Weekly "Director's Corner", etc**
    - **http://www.interactions.org/linearcollider/**
- **R&D Program**
  - **Coordinate worldwide R & D efforts, in order to demonstrate and improve the performance, reduce the costs, attain the required reliability, etc. (Proposal Driven to GDE)**

The GDE Plan and Schedule

From ANL Colloquium (Jan 06) of B. Barish



3. Precision in the rearguard

Neutrino physics, flavour physics, proton-decay...

A major initiative in Neutrino Physics in Europe is a distinct possibility, after the LHC is constructed.

To allow for such a possibility should be part of the European strategy.

Neutrino oscillations are now well established

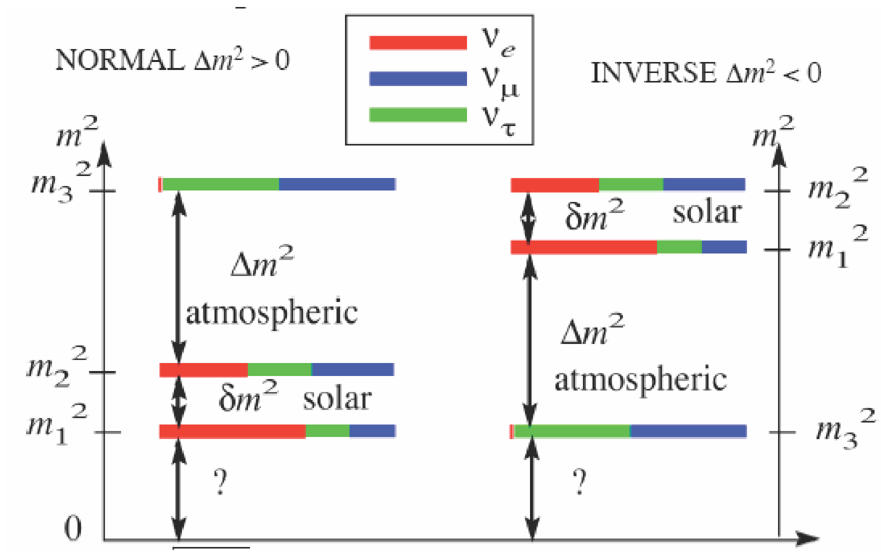
There are at least 3 mass states, ν_1,ν_2,ν_3

$\nu_1 \approx 2/3\ \nu_e \qquad \nu_2 \approx 1/3\ \nu_e \qquad \nu_3 \approx 0\%\ \nu_e$

Two mass differences

$\Delta m^2_{atm} \equiv \Delta m^2_{32} = m^2_3 - m^2_2 = \pm[2.4 \pm 0.3] \times 10^{-3}\ eV^2]$

$\delta m^2_{sol} \equiv \Delta m^2_{21} = m^2_2 - m^2_1 = (0.8 \pm 0.3) \times 10^{-5}\ eV^2$



Mixing angles:

$\theta_{12} \approx \theta_{sol} \approx 34° \pm 2°$

$\theta_{23} \approx \theta_{atm} \approx 45° \pm 3°$

$\theta_{13} < 12°$ (at 3σ)

$\sin^2\theta_{13} \equiv |U_{e3}|^2 < 0.04$

Many open questions in neutrino physics

1. **Dirac or Majorana masses? Connection with GUT-scale physics**

   $0\nu2\beta$–decay $\rightarrow$ major experiment in Europe?

2. **Absolute mass scale**

   $0\nu2\beta$-decay, KATRIN, cosmology

3. **Mass hierarchy**

   Oscillation experiments, $0\nu2\beta$-decay, KATRIN

4. **Is there CP violation in the leptonic sector? Connection with leptogenesis $\rightarrow$ need θ_{13}**

5. **Improved knowledge of mixing parameters**

6. **Are there sterile neutrinos?**

(4–6) → **Oscillation experiments**

Present and near-term experiments:

1. **MINOS (FNAL to Sudan); taking data**

   ν_μ disappearance: Improve δm^2_{23}, $\sin^2 2\theta_{13}$

2. **CNGS (CERN to GranSasso); about to start**

   ν_τ appearance, check ν_μ to ν_τ oscillation, $\sin^2 2\theta_{13}$

3. **Double-Chooz (Chooz nuclear reactor); when?**

   ν_e disappearance, $\sin^2 2\theta_{13}$

4. **Other reactor experiments elsewhere?**

And also SK, SNO and Kamland are taking data

Medium-term experiments (none in Europe):

> x 10 improvement on **$\sin^2 2\theta_{13}$**; off-axis technique

T2K (Tokai to Kamioka)

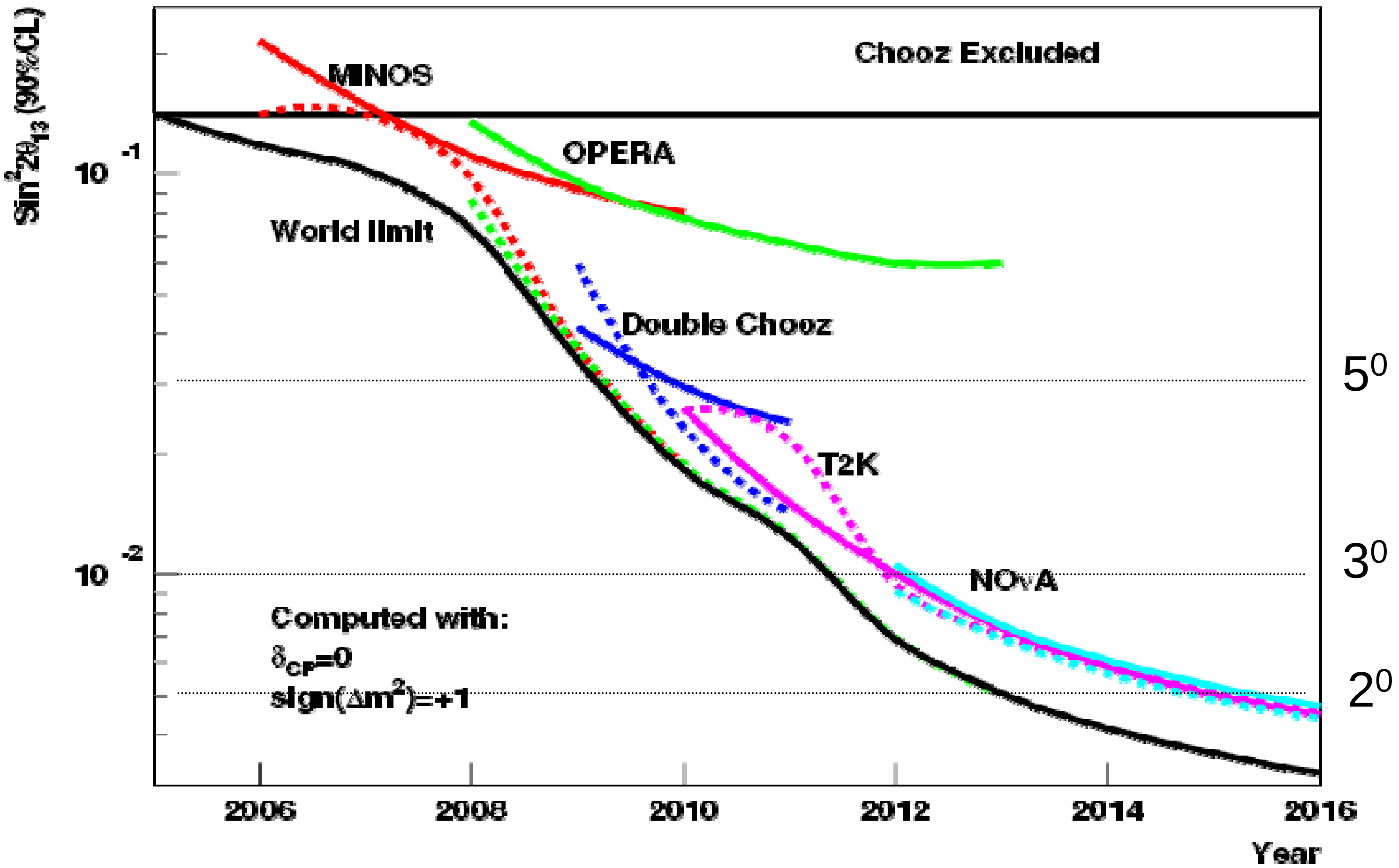
- **Accelerator + beam line being built**
- **Near detector being designed**
- **Far detector already there (SK)**
- **Start in 2009**

NOνA (FNAL to Ash River)?

- **Not yet approved**
- **NUMI beam line needs to be upgraded**
- **Near and Far detectors have to be built**
- **Longer baseline is advantageous**

θ_{13} as a function of time

M. Mezzetto



What strategy ?

Consensus: wait until the value of $\sin^2\theta_{13}$ is measured to be above 0.01 or the upper limit is put below that figure. **The optimization for the next step is different depending on that value.**

This should happen by ~ 2011-2012

The outstanding physics questions will be the value of θ_{13} and/or the mass hierarchy and the amount of CP violation.

Upgrades of T2K and Nova:

T2K upgrade path (THK):

- **4MW proton beam, Hyper-K detector**
- **Possibility: 2dn detector in Korea at 2nd oscillation maximum (same energy).**

NOνA upgrade path (SuperNova)

- **New proton driver**
- **2nd detector at a different off-axis angle, hence different energy, as to sit at the second oscillation maximum.**

In Europe: Possibility of low-energy Super-Beam at CERN:

Super-beam from the SPL ($E\nu_\mu$=0.25 GeV) + 440k-ton water Cherenkov detector at Frejus

More ambitious projects:

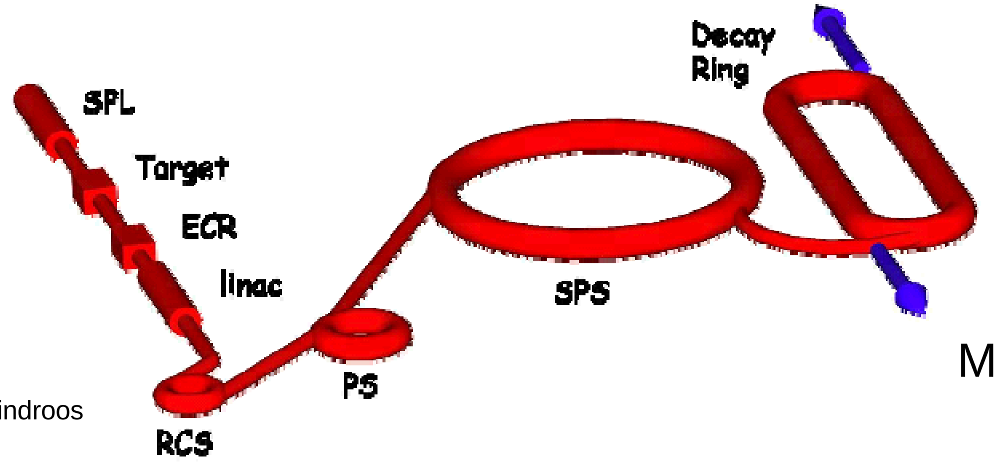
Super Beam + Beta-Beam + large detector

High-γ Beta-Beam

Neutrino Factory

work in progress, still many ideas being discussed

Beta-Beam concept



Mats Lindroos

Pure ν_e or $\bar{\nu}_e$ beams

$${}^{6}_{2}He^{++} \rightarrow {}^{6}_{3}Li^{+++}\,\bar{\nu}_e\,e^-$$

$${}^{18}_{10}Ne \rightarrow {}^{18}_{9}F\,\nu_e\,e^+$$

$${}^{150}Dy + e^- \rightarrow {}^{150}Tb\,\nu_e$$

Monocromatic ν_e: Bernabeu et al.

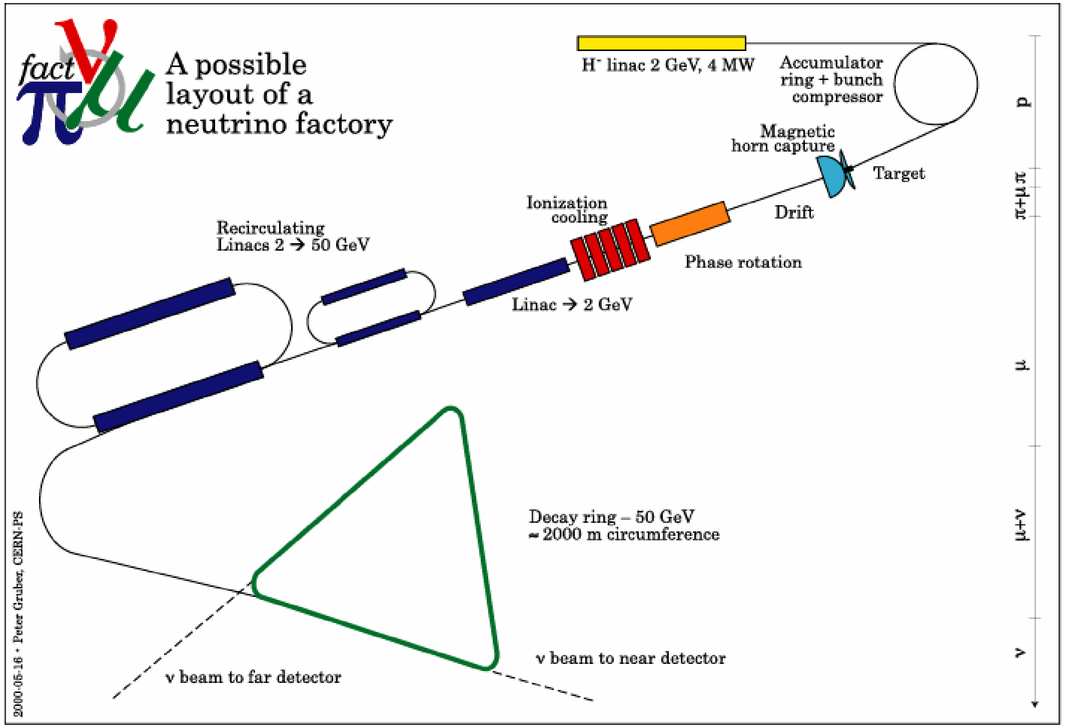
$E_\nu=2\gamma E_0$ with E_0~3 MeV, γ=Lorentz boost of ion.

Maximum energy with the SPS is 0.6 GeV (γ=150).

Higher energy possible but it requires a S-SPS and the corresponding storage ring.

Possibility of high intensities (C. Rubbia et al.)

Neutrino Factory



Possibility of high energies, hence very long baselines

$\nu_e, \bar{\nu}_e, \ \nu_\mu, \bar{\nu}_\mu$

One can build many observables allowing for a very reach physics program.

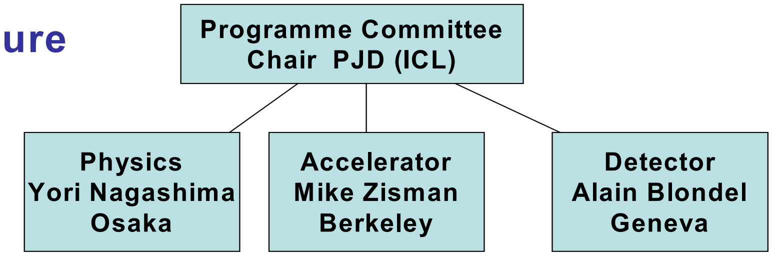
Neutrino community is also self-organizing:

- **BENE Network (part of CARE EU network, FP6): goal is to have a CDR for a major neutrino facility by 2010.**
- **International Scoping Study (ISS): (requested by UK): started in 2005 will conclude in August 2006.**
- **Japan: Neutrino Factory collaboration**
- **US: Neutrino Factory and Muon Collider Collaboration**
- **NuFact Conferences (yearly)**
- **NNN (Next Generation of Nucleon Decay and Neutrino Detectors) workshops**

- Studies: MEMPHYS, EURISOL ....
- Experiments: HARP MERIT **MICE**

International Scoping Study:

Structure



- Each WG has a Council with members from the 3 regions

- **Emphasis**
  - Solutions which consider the accelerator AND detector
  - A truly international study
- **Meetings - open to all**
  - 1. CERN Sep 22-24, 2. KEK Jan 23-25,
  - 3. RAL Apr 25-28, 4. Irvine Aug 21,22
  - All details etc. See web site
    http://hepunx.rl.ac.uk/uknf/wp4/scoping/

The time is ripe for launching an

International Design Study

A (personal) remark on “astroparticle” physics

Dark matter and dark energy are at the top of physics questions.

We hope that dark matter is made of some yet unknown elementary particle. Europe is a major player (direct searches, LHC).

Dark energy is a complete mystery. For elementary particle theory the problem has always been there. What has changed is that dark energy does not seem to be **exactly** zero! Does this have anything to do with particle physics?

Most advances on this field, observational cosmology, have not come from Europe (COBE; SCP, HZSST, WMAP, SDSS ...), although very good work is also being done here (2Df, Boomerang, VSA, SLNS...and PLAK in the near future).

A (personal) remark on “astroparticle” physics

Major future initiatives (JDEM, LSST...) and more immediate ones from the ground (DES, SPT, PanStars...) , are being prepared in the US with substantial particle physicist and HEP labs involvement.

Particle physicist can contribute enormously to a major initiative because of:

ideas

technology

sociology

Isn’t this the time for a major initiative in Europe lead by the particle physics community?

My answer is YES!

Outlook

- HEP physics is on the verge of a major event: the start of the LHC.
- Discoveries at the LHC will ultimately indicate the next step.
- The emphasis today is on being prepared for the next decisions in the best possible way.
- International global cooperation has emerged as a necessity. It should also be recognized as an important opportunity.
- All major projects should now be global, and as such should be planned and organized globally.