DRAFT

Long Term Roadmap for DPNC

September 2003

Particle physics is the science to study, at the most fundamental level, the properties of matter, energy, space and time. In the past 50 years, discoveries made by particle physics have changed our view of the material world. We now have a Standard Model (SM) that describes the basic constituents and the structure of the matter to a high level precision that was unimaginable just decades ago. In fact this year is the 30^{th} anniversary of the discovery of the Neutral Current that gave the fist experimental foundation of the SM, and the 20^{th} anniversary of the discovery of the W that proved the revolutionary idea of unification between electromagnetic and weak forces, a corner stone of the SM.

Particle physics is a very dynamic science that sees its principal goals constantly evolving, as new discoveries occur and the technologies of its tools, those of particle accelerators and particle detectors, progress. In the past decades, the focus was on the Standard Model itself, for example the discovery of the top quark and the precise measurement of the SM parameters at LEP (see the report to the Swiss Federal Office for Education and Science from the Forum of Swiss High Energy Physicists, 1990). These great achievements allowed us to start to probe the microscopic world beyond the Standard Model. In fact, the principal goals of particle physics in the coming decades are two fold; one is to provide a unified description of all four known forces (including gravity), and the other is to understand the connection of the cosmic evolution to the particle world (in particular the elucidation of the origins of matter-antimatter asymmetry, of dark matter and of dark energy).

The DPNC is currently engaged in research in three major particle physics programs having a significant discovery potential during the coming 20 years: hadron collider physics, neutrino physics and particle physics in space. These three activities directly address the questions mentioned above. In this sense the department is well embarked on several paths that will lead to the fundamental goals. The aim of this document is to look ahead how these paths might evolve in the time frame of 20 years.

To better relate current activities to future experiments, we will organize the roadmap in three paths (the experiments in bold type are those in which the DPNC currently participates):

A) The path of high energy: **CDF**, **ATLAS**, LHC upgrade, e^+e^- Liner Collider, …
B) The path of neutrino physics: **HARP**, **K2K**, **MICE**, J-PARC, super beam, neutrino factory, …
C) The path of cosmic connection: **AMS**, GLAST, SNAP, …

The scientific staff of the department consists of:

- PO: 4 (Alain Blondel, Maurice Bourquin, Allan Clark, Martin Pohl)
- PT: 2 (Maria Kienzle, Catherine Leluc)

- MER: 4 (John Field, Divic Rapin, Laurent Rosselet, Xin Wu)
- MA: 9
- Assistants: 19

The technical staff of the department:

- Applied physicist: 1
- Mechanical engineer: 3
- Electrical engineer: 4
- Computing engineer: 1
- Technicians: 10

A relevant remark is the central role that CERN is playing in particle physics worldwide. It is essential for Europe, and in particular for Swiss institutes that CERN stays in a leading position well into the 21st century. We strongly support developments at CERN towards a large accelerator construction project after LHC. In view of the important investment made by Switzerland to CERN, the Swiss universities have major intellectual responsibilities to play leading roles in important CERN experiments. The DPNC has the added privilege and responsibility of being in close proximity to CERN. At the DPNC, a predominant proportion of current and future projects depend on CERN (ATLAS, AMS, HARP, neutrino factory). Until now the DPNC has been able to take on major responsibilities in CERN experiments in which it involved. It is crucial that the DPNC continues to receive strong financial support to remain a major center of the competence in particle physics in Switzerland.

The invaluable contribution that CERN is making in the training of young physicists and engineers should also be emphasized. It has a very strong impact on the DPNC and, more generally, on Swiss universities.

Path A. Energy Frontier

A.1 Current Activities

Hadron-hadron interactions at the highest collision energies are a major DPNC priority, and this will continue in the foreseeable future. The DPNC participates in the CDF and ATLAS experiments.

The scientific staff of the group consist currently 2 PO, 2 MER, 5 MA and 7 Assistants. The doctoral students generally split their research activities between hardware-oriented projects on ATLAS, and physics analyses using CDF data.

A.1.1 The CDF experiment

The upgraded CDF detector is fully commissioned and is collecting data at the Fermilab Tevatron, at a collision energy of $\sqrt{s}$ = 1.96 TeV. An integrated luminosity of 4-8 fb^{-1} is foreseen by Fermilab in the period 2003-2009. The physics program of CDF includes:

- precision studies of production and decay mechanisms in the b-quark and t-quark sectors, in the context of the Standard Model;
- searches for extensions to the Standard Model, either indirectly via the search for rare decays in the b-quark and t-quark sectors or directly via the search for new high mass particles compatible with for example super-symmetry or extra dimensions;
- searches for the Higgs particle (except in extreme super-symmetric models, the expected integrated luminosity will not be sufficient).

The CDF experiment will terminate when LHC experiments start producing good quality data, most likely from 2008.

The scientific staff of the group is currently 1 PO (part-time), 1 MER, 1 MA and 4 Assistants.
The group's CDF activity is currently focused on data analyses, including:
- measurement of QCD diphoton production;
- measurement of QCD b-quark production;
- study of orbitally excited charm states;
- study of rare B decays;
- the search for new particles decaying into b-jets.

Discussion is ongoing within the collaboration on whether to upgrade the SVT (a precise tracking trigger device built in part by Geneva), but the DPNC is unlikely to take a major role in hardware if it is approved. The plan is thus to push forward with analyses while fulfilling our SVT maintenance obligations and our general detector operational duty. The DPNC will slowly reduce its CDF effort when the full ATLAS detector commissioning gets under way, likely in 2005.

A.1.2 The ATLAS experiment

The DPNC is a founding member of the ATLAS experiment at the CERN LHC. The experiment is under construction and will collect data from proton-proton interactions at $\sqrt{s}$ = 14 TeV from 2007 on. Bern University is also a member of the ATLAS experiment.

The experiment will extend the mass scale beyond the electroweak breaking scale of the Standard Model with a simple Higgs mechanism (246 GeV). It will search for and study the mechanism of mass generation (presumably the Higgs mechanism). In order to unify the electroweak and strong forces, an extension of the Standard Model is necessary. The favoured hypothesis, supersymmetry, proposes the existence of super-symmetric partners to the known fundamental particles, and data indicate that the threshold for supersymmetric particle production should be < 1 TeV. An alternative hypothesis, involving additional spatial dimensions, might also manifest new particles accessible to the ATLAS experiment. The lightest supersymmetric particle is a favoured candidate for dark matter (see C.2).

The DPNC contributes to the construction and commissioning of the ATLAS experiment, and this will be a major activity until 2007. The DPNC has several major construction responsibilities within ATLAS: the Silicon Tracker (SCT), the Liquid Argon electronics (LAr), and the detector integration (including DAQ):

- With Germany and Italy, it has been financially responsible for the superconductor and coil casings of the barrel toroid magnet.
- It has designed and supervised construction of 4 light carbon fibre cylinders satisfying stringent specifications of thermal and mechanical stability. These barrels are being furbished by the group (completion 2003) and SCT modules will be assembled onto the barrels in Oxford from 2003.
- It has contributed (with Cracow and CERN) to the design and testing of low noise and radiation tolerant frontend SCT electronics (complete).
- It has contributed to the development (complete) and is responsible for the construction of 620 forward SCT silicon modules (production is now starting).
- It is a leading institute for the design and construction of the Readout Driver (ROD) board of the Lar calorimeter. After final prototype system tests the mass production of 200 ROD boards will be launched in 2004.
- It is strongly involved in the LAr data acquisition and monitoring, and with the full commissioning of the SCT.

The DPNC intends to make a major impact on data analysis within ATLAS, and to this end it has started to re-orient its activities towards the creation of a strong physics group by 2007. Activities include:
- the study of several interesting physics channels;
- an increasing involvement in the development and optimization of ATLAS reconstruction and simulation software.

An essential aspect of data exploitation is the provision of adequate computing infrastructure. The DPNC is collaborating with Swiss institutes involved in LHC experiments towards the development of computing facilities at CSCS Manno. The provision of sufficient local computing infrastructure, and the development of competence in Grid architectures (expected to be used at the LHC) remains an important issue to be resolved.

It is evident that the ATLAS activities for the period of 2003-2007 will concentrate on construction, commissioning and preparation of the data analysis framework. The emphasis will subsequently (2007-2017) be on data analyses to ensure participation in major discoveries. The ATLAS experiment is designed to last for at least 10 years, but many important physics results are expected within the first 5 years.

A.2 Energy frontier beyond LHC

Worldwide, discussions and R&D concerning new facilities beyond the LHC are well advanced. The two projects that are relevant to DPNC activities in the coming 15 years are:
- the upgrading of the luminosity and/or the energy of the CERN LHC;
- the construction of a linear e^+e^- Collider (LC) in the energy range $\sqrt{s} = 0.4\text{-}0.8$ TeV.

A.2.1 LHC upgrade

Machine R&D studies are already underway at CERN to upgrade the LHC beyond the existing luminosity specifications (L = 10^{34} cm-^{2} s^{-1}, $\sqrt{s}$ = 14 TeV, and 25 nsec bunch spacing).

A proposal to increase the energy to 27 TeV would require the replacement of the LHC dipoles, and has been placed at a low priority. A second line, to increase the luminosity by ~ 1 order of magnitude, appears to be more realistic. This would imply a denser bunch structure.

Apart from studies of machine feasibility, the physics benefit of such an upgrade as well as the detector implications, are being studied. The physics reach for new massive particles would be increased by 20-30%. The detector and electronics implications are very substantial, because of the increased detector occupancy, the increased radiation (already critical in the Inner Detector of ATLAS), and the smaller bunch spacing. Effectively, the full electronics and data acquisition chain of all detectors, and the entire Inner Detector, would need replacement, after significant R&D.

A decision on an LHC upgrade is unlikely before the first LHC physics results and assessments of the machine performance, and will not be realized before 2015. The DPNC participation would depend on the perceived physics benefit, and the machine/detector viability.

A.2.2 Liner Collider

It is recognized by the particle physics community that a next generation electron-positron Liner Collider (LC) in combination with LHC may be expected to fully map out the physics on the scale of electroweak symmetry breaking.

The DPNC considers that a decision on a sub-TeV LC, upgradable to ~1 TeV, should be reached as soon as possible since it complements well with LHC on Higgs and Top physics. Even if the Higgs is likely to be discovered at LHC, a precise determination of its properties, such as its spin and its couplings, can only be done with a LC. The construction of a LC will play a vital role in producing a future generation of scientists in particle physics and accelerator science.

In the case that the construction approval of a LC is delayed until after a period of data taking at the LHC, the choice of energy for the machine should be reviewed, in the light of results obtained from the LHC, and machine developments (for example CLIC). In fact the DPNC strongly supports CLIC R&D activities at CERN and efforts toward the construction of a multi-TeV LC at CERN.

Participation by the DPNC in the LC physics program would be a natural extension of LHC activities. If such an accelerator is constructed, the DPNC will participate at an important level (1 out of 4 PO). If it is built at CERN the level of participation could be higher, for example similar to the level of our current ATLAS involvement.

The DPNC is already developing detectors which may be applicable to LC: silicon trackers for the ATLAS and AMS experiments; a time projection chamber (TPC) with gas microstrip readout (GEM) for the MICE project; readout and trigger electronics for various experiments.

The DPNC participates in two approved detector R&D projects for TESLA, a project developing Monolithic Active Pixel Sensors using CMOS technology and a project aiming at an application of silicon strip detectors for a very large area intermediate tracking detector. These activities are at a low level but are expected to intensify after AMS and ATLAS commissioning if a decision on the construction of a LC is clearly in view.

Path B. Neutrino Physics

Neutrinos physics has been in the limelight since neutrino oscillations were finally established in 1998, and with them the fact that neutrinos have mass. These facts constitute strong evidence of physics beyond the Standard Model; they open a large number of questions pertinent to the origin of fermion's masses, while three-family neutrino mixing naturally leads to leptonic CP violation, a key ingredient necessary to explain the baryon-antibaryon asymmetry of the universe. This justifies an important investment in accelerator-based beams and experiments.

The longer-term goal for accelerator-based neutrino activities is determined by the possibility to measure accurately the neutrino mixing parameters (value and sign of the neutrino mass differences, and values of the mixing angles) and would culminate with the discovery of leptonic CP violation. The observation of CP (or T) violation absolutely requires appearance experiments, which rules out experiments with neutrinos from the sun or from nuclear reactors. The most promising tool for its observation is the $\nu_e \leftrightarrow \nu_\mu$ oscillation at small wavelength. This transition has not been observed yet, being driven by the small angle θ_{13}, but, for the very reason of its smallness, should exhibit observable asymmetry with the corresponding antiparticle oscillation $\bar{\nu}_e \leftrightarrow \bar{\nu}_\mu$. This explains the emphasis to be given to experiments sensitive to this process at baselines of typically L/E_ν = 500 km/GeV.

B.1 Current Activities

The DPNC has been active in this field since the nomination of Pr. Alain Blondel in 2000. The group, constituted of 1 PO, 2 MA, 4 Assistants (of which 2 are CERN doctoral students), and several visitors, has been active in the definition of a future neutrino physics program for Europe, while taking part in the HARP experiment at CERN, the K2K experiment in Japan and promoting R&D for neutrino factories, with the International Muon Ionization Cooling Experiment (MICE) at RAL.

B.1.1 The HARP and the K2K experiment

The HARP experiment is a service experiment whose main goal is to measure the relatively poorly known production of pions and kaons by protons of 2 to 15 GeV/c incidents on various targets (from hydrogen to lead). Data taking is now completed and analysis is underway. The main contributions of DPNC were in the beam detectors and in the inner detector, the TPC, and in particular the TPC reconstruction program and analysis.

In the K2K experiment, a neutrino beam created by incident protons of 12.9 GeV/c on an aluminum target, is shot over a baseline of 250 km to the well known Super-Kamiokande detector. The typical wide-band beam ν_μ spectrum is peaked around 1 GeV. First observation of neutrino disappearance has been reported, and the experiment is now taking data. The involvement of the DPNC is in the use of the HARP data to improve the knowledge of the low energy part of the neutrino spectrum (below the oscillation maximum at 500 MeV neutrino energy); this is crucial for the observation of ν_μ reappearance, a definite proof of oscillations. The experiment should also provide a substantial improvement in the measurement of the 'atmospheric' mass difference term Δm^2_{13}. Data taking will last until 2005, with analysis expected until 2007.

B.1.3 J-PARC to Super-K

A natural channel to observe $\nu_\mu \leftrightarrow \nu_e$ transitions is to search for electron neutrinos in a muon neutrino beam. The water Cherenkov Super-Kamiokande detector is efficient for electrons and is certainly the largest neutrino detector in use. The sensitivity is normally limited by the limited intensity of neutrino beams at long distance, the ability to observe $\nu_e + N \rightarrow e + X$ in presence of backgrounds from π^0's, and the intrinsic background due to electron neutrinos in the beam.

The newly approved high-intensity Japan Proton Accelerator Research Center J-PARC can offer 50 GeV protons with beam power of up to 0.75 MW with upgrade possibilities of up to 4 MW. The conventional neutrino beam design foresees to use the beam at an angle of about two degrees, which offers the advantage of creating a kinematical peak of neutrino energies at about 600 MeV (a good match to the distance of 300 km to Super-K); furthermore π^0 production at this energy is small, and the beam electron-neutrino background which comes from three body decays, does not peak at the same energy.

The sensitivity of this experiment to the observation of the $\nu_\mu \leftrightarrow \nu_e$ transition should allow a measurement of the neutrino mixing-angle θ_{13} if its value is in excess of 2.5º (the present limit is around 13°). DPNC has signed the letter of intent and foresees to participate in the design of the beam. The J-PARC international scientific committee has recommended the neutrino program as highest priority, and a decision on approval is expected early 2004. The data taking under these conditions would start in 2008 and last 5 years.

The future development for this program is the increase in intensity for the proton source, and possibly the construction of a very large Water Cherenkov detector (‘Hyper-Kamiokande’) with a fiducial mass in the order of 500 to 1000 ktons. This could be considered around 2012. At this level of proton intensity and detector mass, sensitivity to the neutrino mixing-angle θ_{13} down to about 1 degree is achievable and some sensitivity to CP violation can be envisaged.

B.2 Towards a neutrino factory

The DPNC is deeply involved in the definition of this future program and in the associated accelerator R&D. The HARP experiment aims to measure particle production by low energy protons to optimize the accelerator design. The study of focusing ‘horns’ for the neutrino factory and super beam has been made by the DPNC in collaboration with CERN.

A key ingredient in the neutrino factory and is the possibility to reduce the beam size by ionization cooling. This novel technique requires a demonstration of feasibility and we are leading the effort to carry out a Muon Ionization Cooling Experiment (MICE). The experiment has been proposed at Rutherford Appleton Laboratory (RAL) with some help for the beam line from PSI. The proposed contribution concerns the spectrometers, in which a high precision tracker imbedded in a 4T magnetic field should provide precision determination of the input and output emittance of a 200 MEV/c muon beam. [The tracker under development (a TPC with GEM readout) is also an interesting possibility for linear collider tracking detectors]. The experiment is in the approval process with strong recommendations from the relevant committees. The proposed schedule involves a gradual installation with engineering runs in 2006 and 2007, and the demonstration of cooling in 2008.

Meanwhile the accelerator options will be studied by Design Studies, for which funding by the European Union under FP6 will be proposed. (Some funding has already been granted for networking activities).

Path C. Cosmic Connection

Historically, cosmic rays have played a significant role in particle physics, with for example the discovery of the positron, muon, and pion, as well as the first strange particles. Astroparticle physics subsequently played a ‘niche’ role until instrumental developments allowed the construction of large and sophisticated detectors, resulting in important results such as the confirmation that neutrinos have mass.

The subject has recently become extremely important in two ways: the use of particle physics techniques to study cosmological processes, and the study of particle physics questions relating to precision cosmology. Recent experiments (for example WMAP and supernovae searches) suggest that baryonic matter accounts for only 5% of the total energy of the universe, with the remainder comprised of dark matter (25%) and dark energy (75%). The direct identification of dark matter at accelerators or in space, and the understanding of the nature of dark energy, have become two of the most important particle physics questions.

C.1 Current Activities

The DPNC is a founding member of the AMS experiment and participated in the pilot mission AMS-01. AMS has the status of a recognized experiment at CERN (RE1) and will house its head quarters, control and data centers at CERN. It benefits from the support of ESA on the European level and involves ETHZ Zurich, University of Geneva and the Geneva Observatory at the Swiss level.

The AMS-02 project aims to improve the observational basis of cosmic ray physics by providing a large area, high resolution spectrometer to be exposed over a long observation period on the International Space Station (ISS) in a near Earth orbit. It will observe the spectra of electrons, positrons, protons, antiprotons and heavy nuclei up to several tens of TeV. It will search for anomalous components in these spectra and extend the search for antihelium and heavy anti-nuclei into the TeV region. Its main physics goals are:

- *Search for Dark Matter:* Theory suggests that supersymmetric particles like the neutralino could be an important contributor to this dominant component of the Universe. Annihilation of these particles in the galactic halo might produce a visible contribution to the anti-particle and photon spectra.
- *Search for primary antimatter:* The strong evidence supporting the Big Bang origin of the Universe requires matter and antimatter to be equally abundant at the very hot beginning. The absence of sharp annihilation photon peaks excludes the presence of large quantities of antimatter within our cluster of galaxies. Theories which predict either the existence of antimatter in segregated domains or the total absence of antimatter at the present time are highly speculative. AMS will measure primary antimatter at the level of one part on 10^6 if it exists and can reach Earth.
- *Sources and propagation of Cosmic Rays:* AMS-02 will collect of the order of 10^9 nuclei from D all the way to C and O. An accurate determination of chemical composition and isotope abundances over a wide range of energies will provide crucial information regarding the propagation of cosmic rays in the galaxy.
- *High Energy Photons:* AMS-02 will constantly monitor the gamma ray sky, with rather good acceptance and excellent angular resolution, both using conversion in the tracker and the electromagnetic calorimeter. Measurements of high energy gamma ray emission from galactic sources like pulsars and extragalactic sources like active galactic nuclei will complement the observations in other frequency bands to gain a better understanding of astrophysical particle acceleration mechanisms.

The DPNC currently contributes to detector construction at the level of 2 PO, 1 PT, 1 MER, 2 MA and 4 Assistants. It has constructed of the order of 20% of the AMS silicon tracker and will integrate the complete hardware. According to current NASA schedules, AMS will be installed on the International Space Station late in 2006 and take data there until ~2010. The DPNC is co-responsible for the architecture and installation of the AMS Payload Operations and Control Center, from where AMS will be operated, and of the AMS Scientific Operations Center, where all data will be stored and where most of the data analysis will be done. This gives us excellent access conditions to data. Building on our in-house expertise concerning heavy ions in cosmic rays and the detection of cosmic photons with AMS, we intend to take a leading role in AMS scientific data analysis.

C.2 Reaching a New Level of Precision of Particle Physics in Space and Cosmology

Since the cosmic ray flux is falling by almost three orders of magnitude for every decade in energy, it is quite obvious that experiments with very high charged energy particles in space will be limited to energies below the “knee”, where the flux is of order $1/m^2$/year. Beyond this limit, the Earth atmosphere must be used as a calorimeter, and the Earth magnetic field for spectrometry. DPNC is involved in the conceptual design of future detectors that extend the energy frontier of direct charged cosmic ray detection towards its limits.

Another limitation of cosmic ray research comes from the fact that up to almost the highest known energies charged particles do not carry directional information due to the distortion of their trajectories by interstellar and intergalactic magnetic fields. Therefore, the association of cosmic ray phenomena to astrophysical objects is at best indirect. Cosmic photons and neutrinos do not suffer from this deficiency and might therefore have an even more important role in astro-particle physics in the future. The DPNC is studying several options of participating in future, post-GLAST experiments for gamma ray detection spanning a large energy range from X-rays to TeV in a single mission. Physics goals for such a detector would include the search for energy dependent variations of the speed of light, as predicted by attempts for a quantum theory of gravity, using gamma ray bursts as distant photon sources.

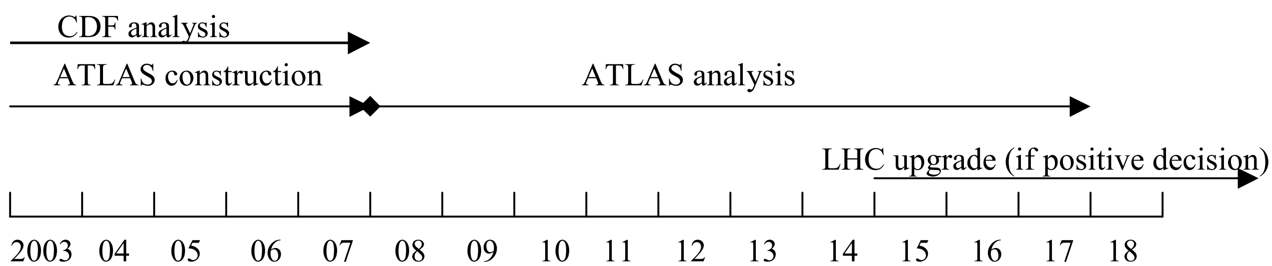
In most models of super-symmetry, the lightest supersymmetric particle (neutralino) is non-interacting, and is consequently a leading candidate for dark matter. As described in Part A.1, the DPNC will be strongly implicated in the search for and possible study of supersmmetric particles at ATLAS. Equally, AMS may be sensitive to the existence of supersymmetric particles if they constitute dark matter. The DPNC is also strongly motivated, if conditions allow, to develop a participation in a future experimental program exploring dark energy (for example SNAP).

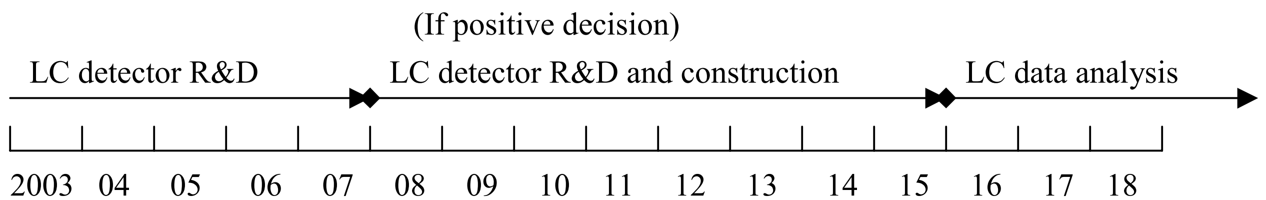
Summary

With strong support from the University and the Confederation, the DPNC has made major contributions to various important particle physics experiments. With over 20 years of experience, and taking the advantage of being in the close proximity of CERN, the DPNC has become a major center of competence in particle physics and astro-particle physics in Switzerland, attracting the best physicists and students from all over the world.

The present document outlines a solid and broad program of research of the department in a field in constant evolution, both in terms of physics goals and tools available. In medium term, strong priorities are given to the ATLAS program at CERN, and the AMS experiment, also a CERN recognized experiment. The long term program assures that the DPNC stays at the cutting edge of our field by readying ourselves towards participations in the LHC upgrade, the next e^+e^- Liner Collider, and a neutrino factory, projects all closely related to CERN. The roadmap also plans for a strong and active program in astro-particle physics, in particular research related to the question of utmost importance in cosmology: the origin of particle-anti particle asymmetry, of dark-matter and dark energy in the universe.

Path A.





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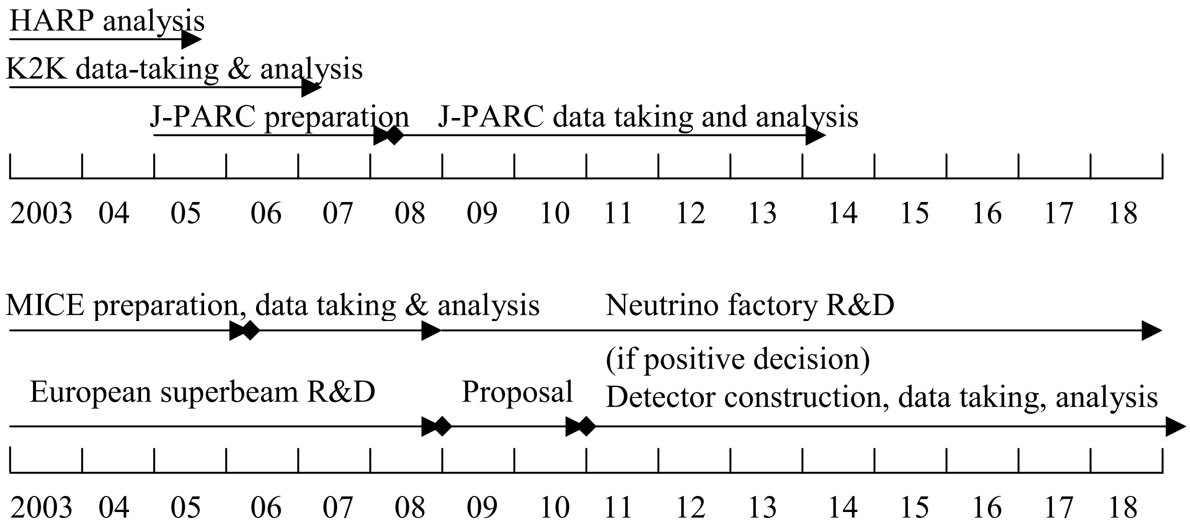
HARP analysis
K2K data-taking & analysis
J-PARC preparation
J-PARC data taking and analysis
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MICE preparation, data taking & analysis
Neutrino factory R&D
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European superbeam R&D
Proposal
Detector construction, data taking, analysis
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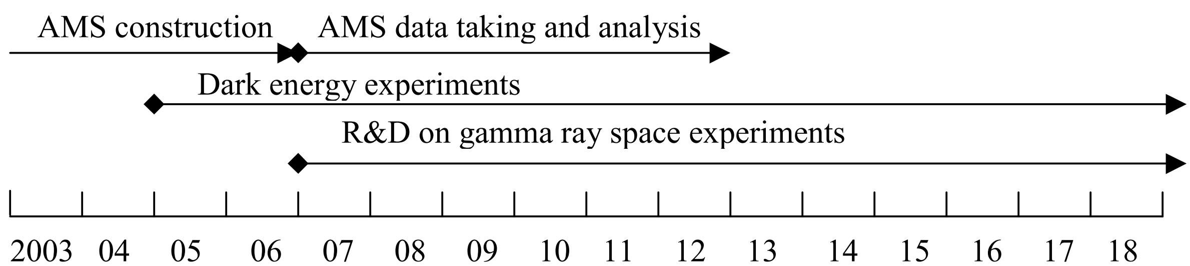
Path C.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