Accelerators

- Acceleration mechanism – always electromagnetic
- Start with what's available: e^- or p
- Significant differences between accelerators of
  - e^- :
    - Always ultra-relativistic, therefore constant speed
    - Lose energy quickly through radiation when accelerator (including when bent in a circle)
  - p :
    - Range of speed until energy exceeds many GeV
    - ~no radiation energy loss

Electrons or protons?

- Proton-based accelerators
  - Must deal with varying speed of protons as they gain momentum
  - Must deal with high radiation levels (protons interact strongly)
  - Are limited in energy only by magnetic field and length ($$)
  - Collide quarks at the basic level; CM energy of the colliding quarks is not determined by the beam energy (in general is much less)
  - Produce huge amounts of uninteresting strong interaction events

- Electron-based accelerators
  - Must compensate for large electron energy loss through radiation
  - Therefore must be linear at highest energies
  - Collide fundamental particles; CM energy is determined by beam energies
  - Produce a fairly high fraction of interesting physics events

Facilities

- Major accelerator labs

- Significant accelerators and experiments
  - Hadron facilities
  - Electron facilities
  - Neutrino beamlines

Labs

- The following labs have forefront particle physics accelerators:
  - CERN, European centre for particle physics in Geneva, Switzerland
  - SLAC, Stanford Linear Accelerator Center in California
  - FNAL, Fermi National Accelerator Laboratory in Batavia, Illinois
  - KEK, the Japanese high energy accelerator lab in Tsukuba
  - JPARC, new Japanese high energy proton accelerator in Tokai
  - DESY, the German particle physics laboratory in Hamburg
- Some smaller labs with important accelerators are
  - Cornell University, in Ithaca, New York
  - Italian National Lab at Frascati (near Rome, Italy)
  - Institute for High Energy Physics in Beijing, China
  - TRIUMF in Vancouver, PSI in Zurich, GSI in Darmstadt
- Notable labs that no longer host accelerators for part. phys.:
  - Brookhaven, USA; LAL-Orsay, France; LBL-Berkeley, USA; RAL, United Kingdom; Argonne, USA

Summary of facilities

	VEPP-2000 (Novosibirsk)	VEPP-4M (Novosibirsk)	BEPC (China)	BEPC-II (China)	DAΦNE (Frascati
Physics start date	2005	1994	1989	2007	1999
Physics end date	—	—	—	—	~2007
Maximum beam energy (GeV)	1.0	6	2.2	1.89 (2.1 max)	0.700
Luminosity (10^{30} $cm^{-2}s^{-1}$)	100	20	10 at 1.843 GeV/beam 5 at 1.55 GeV/beam	1000	80 preser 200 achieva
Time between collisions (μs)	0.04	0.6	0.8	0.008	0.0027

	CESR (Cornell)	CESR-C (Cornell)	KEKB (KEK)	PEP-II (SLAC)	
Physics start date	1979	2002	1999	1999	
Physics end date	2002	—	—	—	
Maximum beam energy (GeV)	6	6	$e^- \times e^+$: 8×3.5	e^-: 7–12 (9.0 nominal) e^+: 2.5–4 (3.1 ") (nominal $E_{cm} = 10.5$ GeV)	1 (
Luminosity (10^{30} $cm^{-2}s^{-1}$)	1280 at 5.3 GeV/beam	35 at 1.9 GeV/beam	11305	6777	100
Time between collisions (μs)	0.014 to 0.22	0.014 to 0.22	0.008	0.0042	

	HERA (DESY)	TEVATRON (Fermilab)	RHIC (Brookhaven)			LHC (CERN
Physics start date	1992	1987	2000			2007
Physics end date	—	—	—			—
Particles collided	ep	$p\bar{p}$	pp (pol.)	Au Au	d Au	pp
Maximum beam energy (TeV)	e: 0.030 p: 0.92	0.980	0.1 40% pol	0.1 TeV/u	0.1 TeV/u	7.0
Luminosity (10^{30} $cm^{-2}s^{-1}$)	75	50	6	0.0004	0.07	1.0×10^4
Time between collisions (μs)	0.096	0.396	0.213			0.025
Crossing angle (μ rad)	0	0	0			300

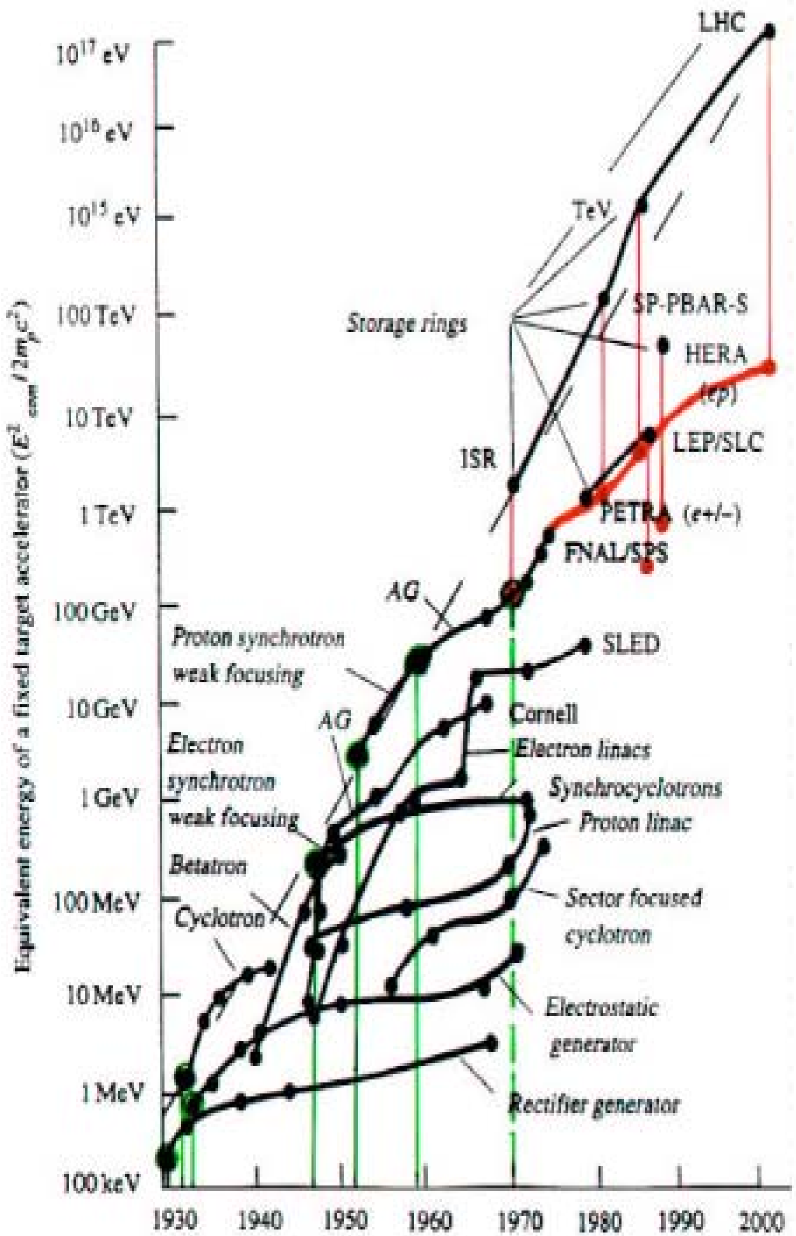


Figure 1: Livingston chart.

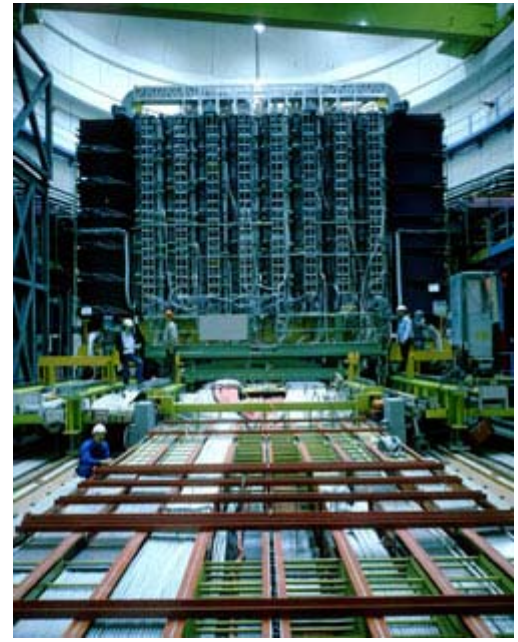
Major physics programs

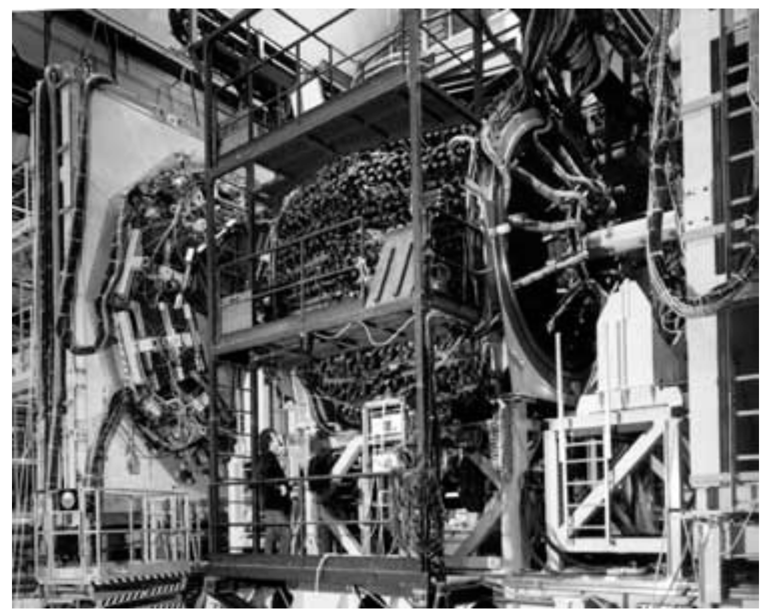
- SP$\underline{P}$S – CERN proton—anti-proton collider
- Tevatron – Fermilab proton—anti-proton collider
- LHC – CERN proton—proton collider

- LEP – CERN e^+e^- collider
- SLC – Stanford Linear e^+e^- Collider
- KEKB and PEPII – e^+e^- B factories
- CESRc and BEPC – e^+e^- charm factories

- High intensity neutrino beams (from proton accelerators) at Fermilab, CERN and JPARC (Japan)

SP$\underline{\text{P}}$S collider





- Operated at CERN from 1981 to 1990
- 450 GeV in centre-of-mass, collided protons and anti-protons
- Experiments UA1 and UA2 discovered W and Z bosons
- Nobel prize to Rubbia and van der Meer (who developed "stochastic cooling" for storing antiprotons)

Tevatron

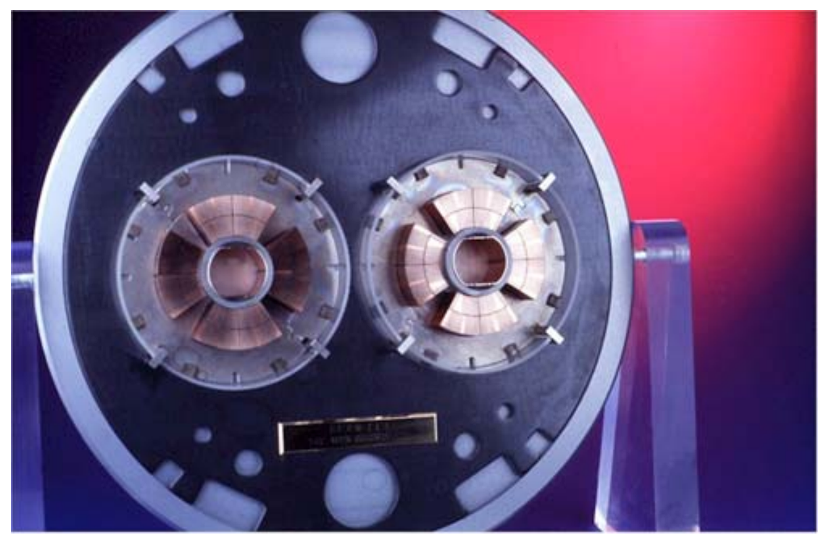
- Operating at Fermilab since 1987
- 800-1000 GeV centre-of-mass energy
- Experiments CDF and D0 discovered top quark
- Highest energy accelerator until LHC starts

Old synchrotron (200 GeV)

Tevatron (superconducting)

LHC – the energy frontier

- Under construction; first collisions in 2007
- Design energy 14 TeV (14,000 GeV) in centre-of-mass
- ATLAS and CMS general-purpose detectors, LHCb specialized detector for b physics
- Expect to see new physics at the ~TeV energy scale



SLAC linear accelerator

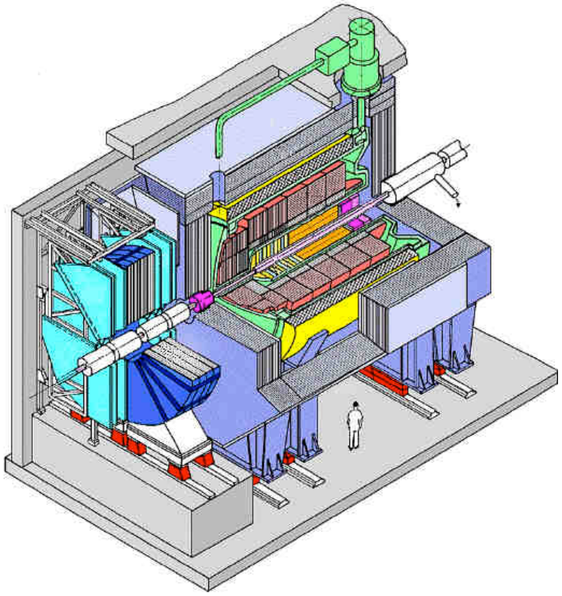
- Accelerates electrons up to 50 GeV
- First beam in 1966; 5km long
- Pivotal experiments scattering electrons from nuclear targets – evidence for sub-structure in the nucleon
- Used for linear collider (90 GeV c.m. → Z^0 boson) from 1989-1995
- Will be converted to a free-electron laser in 2008

Hera – lepton-hadron scattering

- Collides 30 GeV e^- and 820 GeV p since 1990 at DESY

- Experiments Zeus and H1 measure the momentum fractions of proton constituents as a function of momentum transfer in the collision

- Continues ground-breaking scattering experiments from SLAC linear accelerator



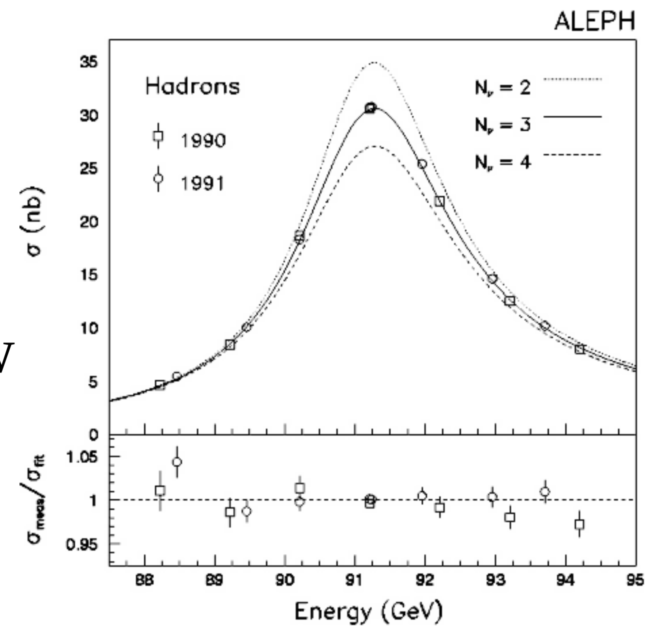
LEP

- e^+e^- collider operating from 1989-1995 at 90 GeV and up to 208 GeV until 2000

- Experiments ALEPH, DELPHI, L3, OPAL

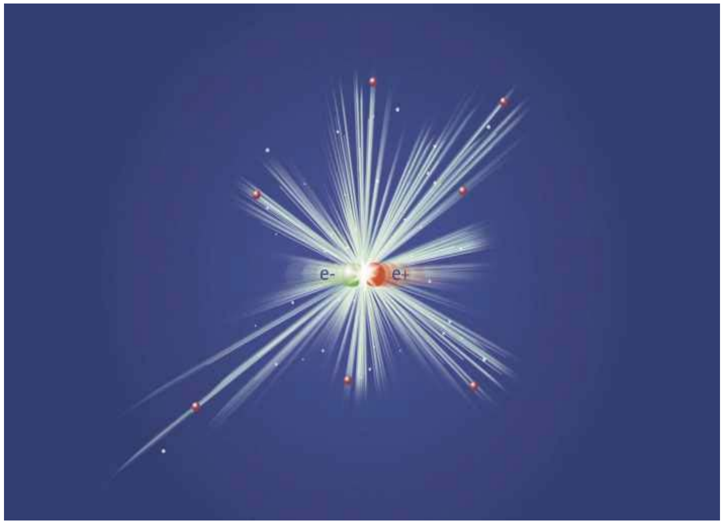
- Confirmed Standard Model at 10^{-3} level and ruled out 4th generation of light neutrinos

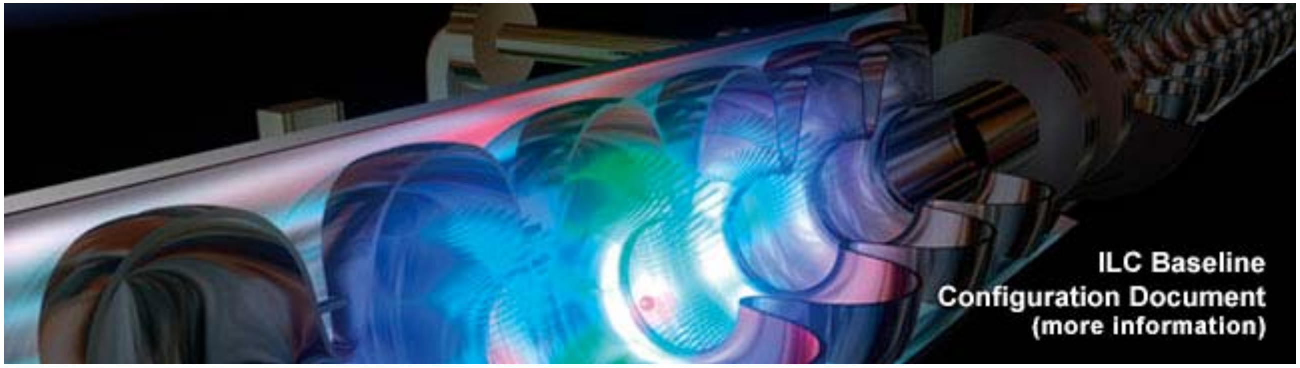
- Ruled out Higgs Boson with mass below 114 GeV and made many important measurements



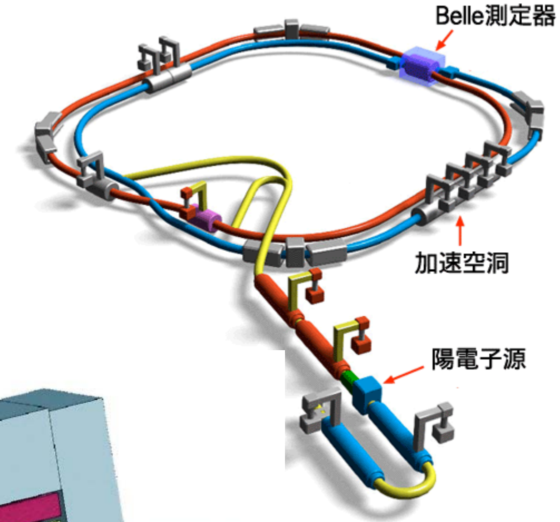
International Linear Collider

- Higher energy e^+e^- colliders must be linear due to synchrotron radiation
- ILC in planning stages; cm energy will be 0.5-1.0 TeV
- Will be able to measure with precision particles that LHC may discover

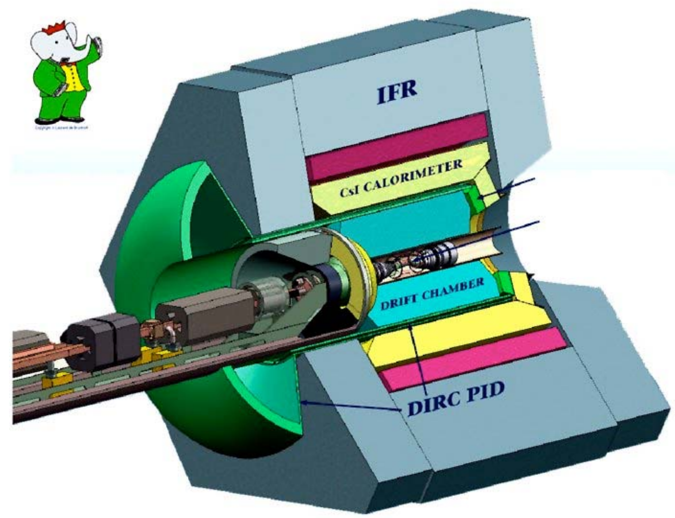




B factories



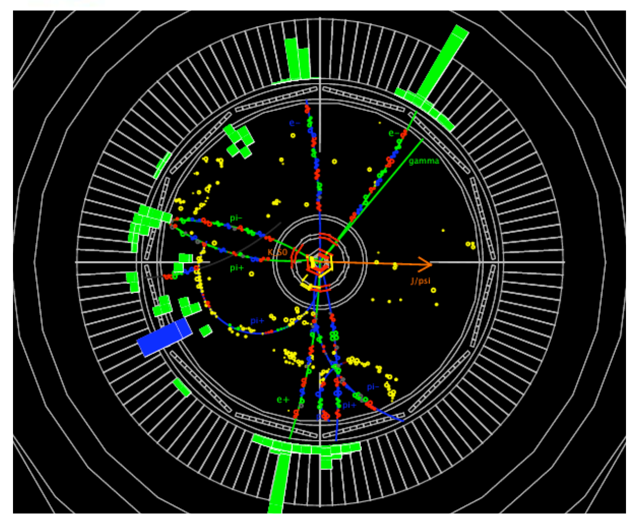
- e$^+$e$^-$ colliders build at SLAC and KEK to study CP violation in B mesons;
  c.m. energy = 10.6 GeV



- Started in 1999; quickly set luminosity records

- Observed CP violation in many individual decay modes

- Precision tests of weak interactions of quarks

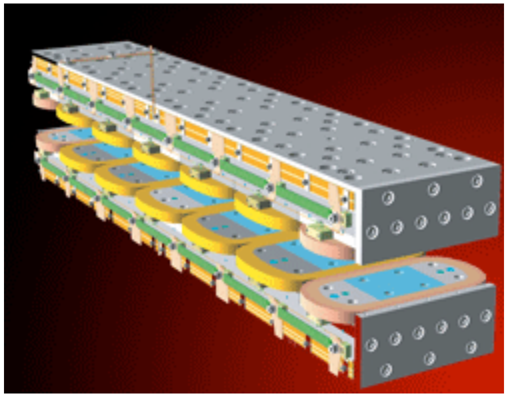


Charm factories

- CESR collider at Cornell converted to lower energy (10 → 4 GeV); decreases damping time using "wigglers"

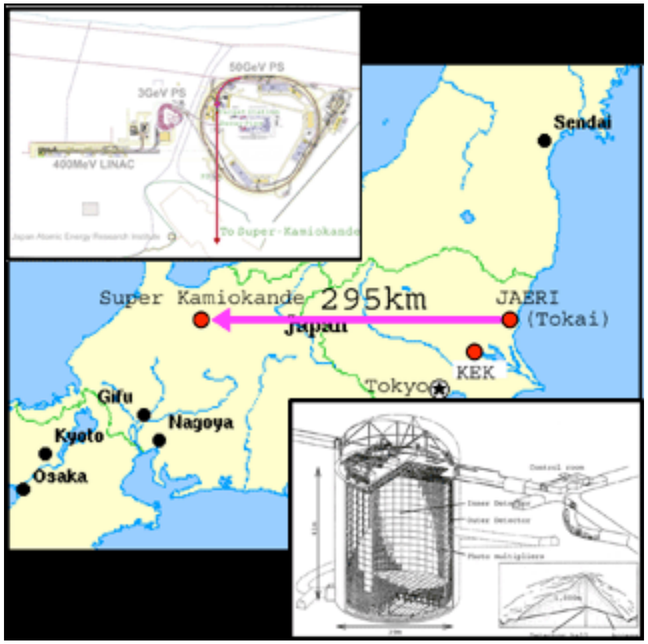
- CLEOc detector making important measurements of charmed particles

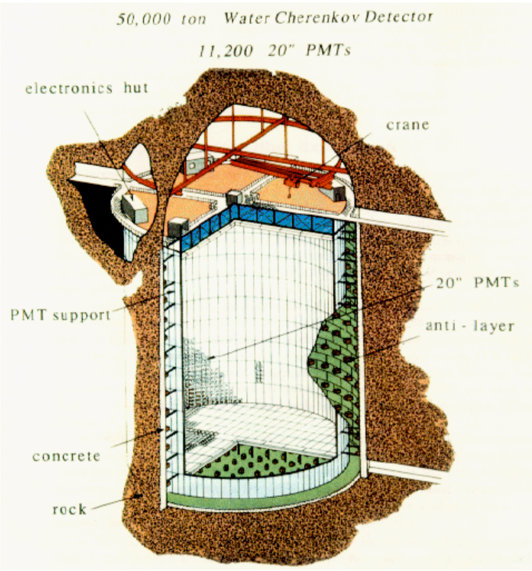
- BEPC at IHEP in China is being upgraded in luminosity; expected start of BEPC-II is end 2006



Neutrino beams

- Neutrinos are generated from π→μν decay
- Pions are produced by smashing multi-100 GeV protons into a target – keeping the target from melting is hard!
- Capturing large pion flux and collimating them into an evacuated "decay tube" is challenging
- The neutrino beams contain a spread of energies due to the angle at which the ν is emitted in the π rest frame relative to the direction of the π in the lab frame
- Fermilab, CERN and JParc have intense ν beams





Other uses of accelerators

- Synchrotron radiation (intense, high energy X ray source from accelerated electrons) for studying biological materials and condensed matter
- Production of isotopes for use in radio-medicine
- Medical imaging (e.g. proton-based, as at TRIUMF)
- Food processing, …
- Most accelerators built now are for these uses, not for particle physics