CERN Complex

- Introduction: Why are we interested in particle accelerators?
  ➔ CERN's main Mandate / Objective

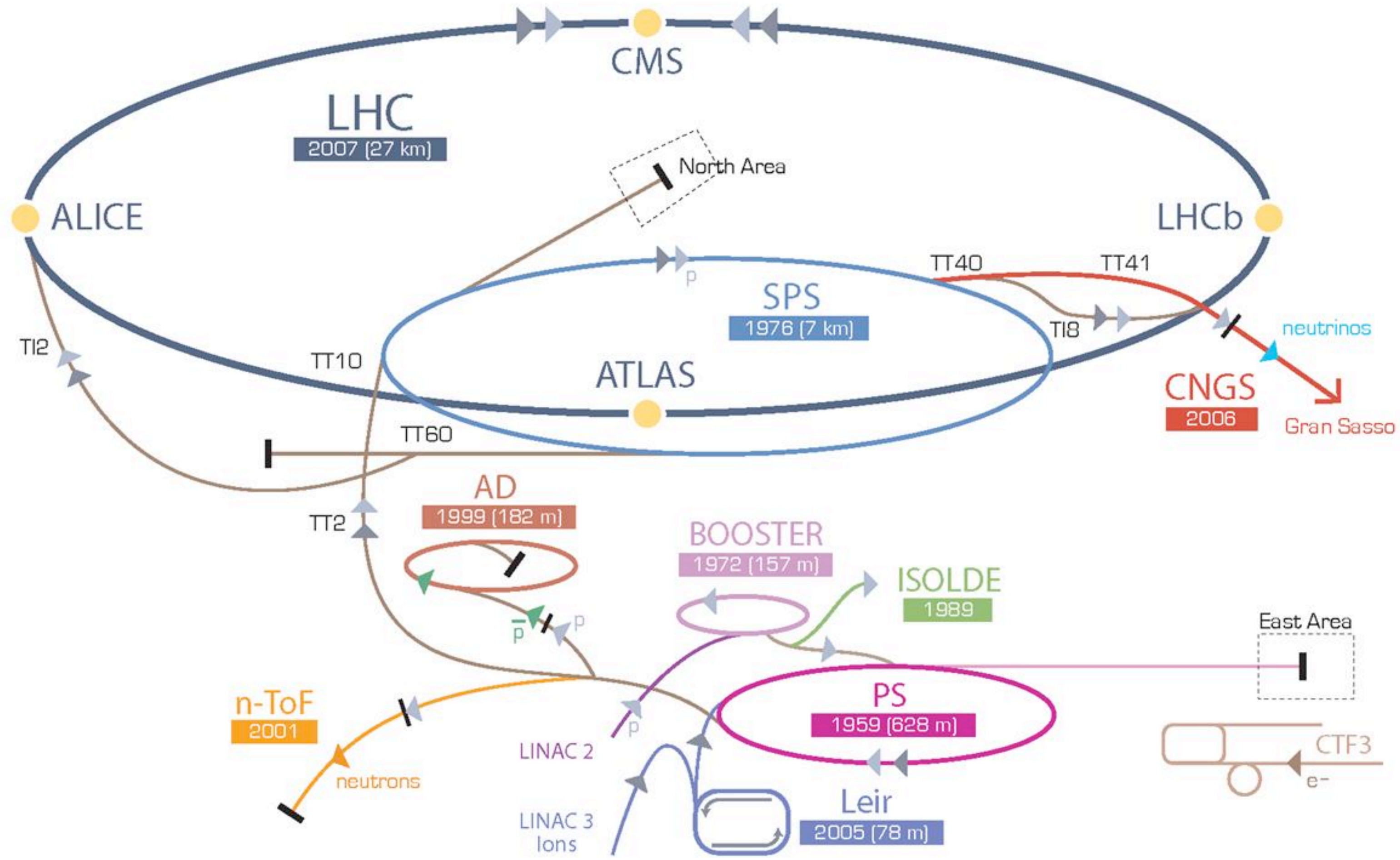
- Acceleration concepts from a historical CERN view

- CERN's main projects and their goals organized by Particle type and physics program:
  ➔ proton, lepton and ion beams
  ➔ fixed target program and collider operation
  ➔ antimatter and isotopes

- The LHC

- Potential future projects for CERN

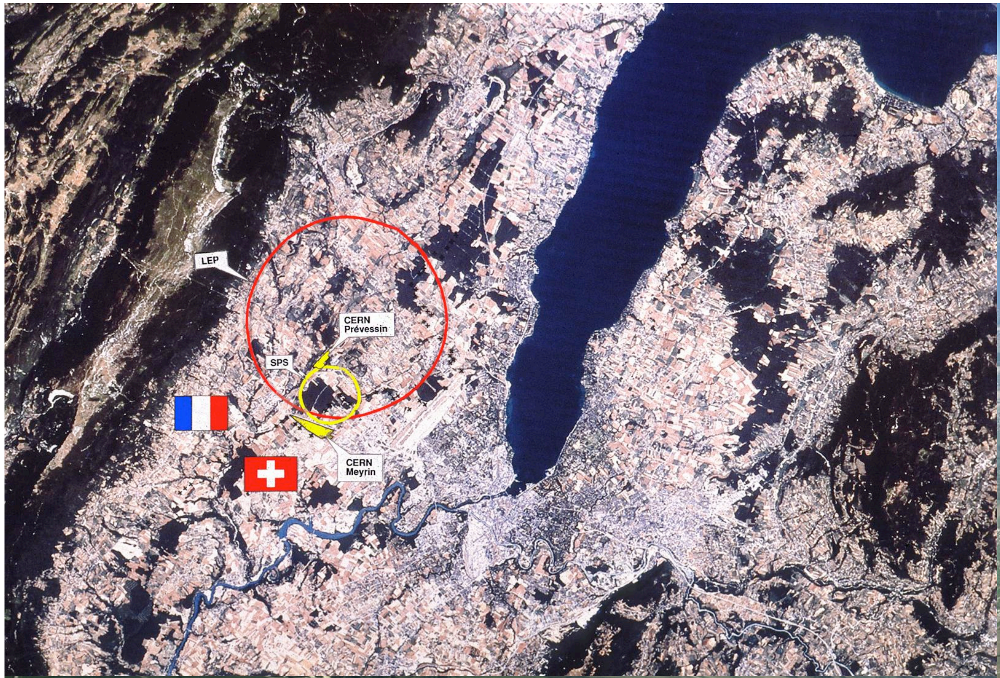
CERN Accelerator Complex



▸ p (proton) ▸ ion ▸ neutrons ▸ p̄ (antiproton) proton/antiproton conversion ▸ neutrinos ▸ electron

LHC Large Hadron Collider SPS Super Proton Synchrotron PS Proton Synchrotron

AD Antiproton Decelerator CTF3 Clic Test Facility CNGS Cern Neutrinos to Gran Sasso ISOLDE Isotope Separator OnLine DEvice
LEIR Low Energy Ion Ring LINAC LINear ACcelerator n-ToF Neutrons Time Of Flight


LEP
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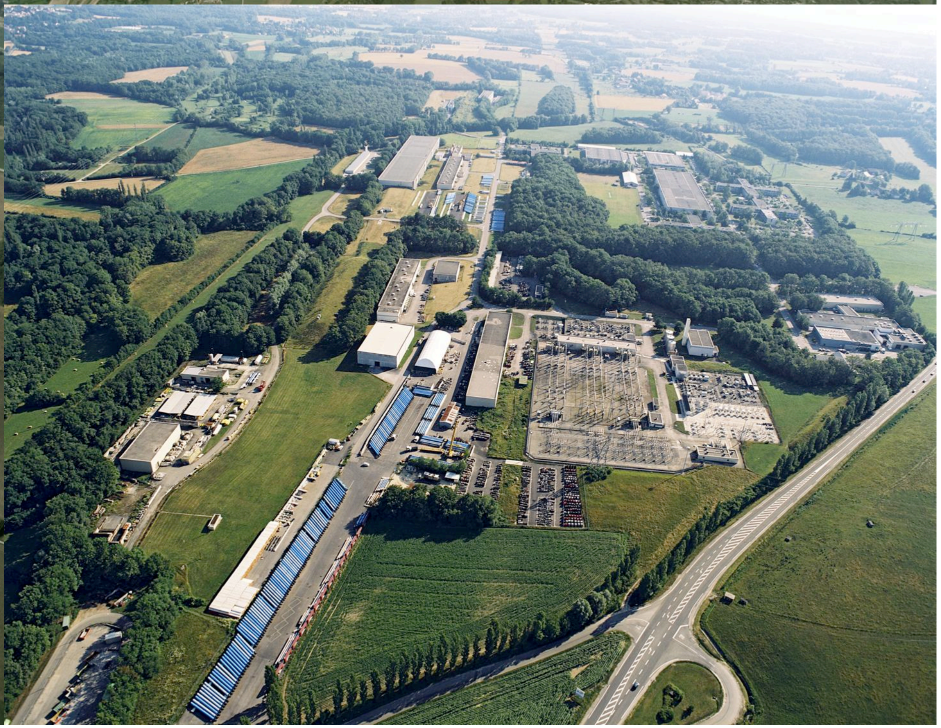
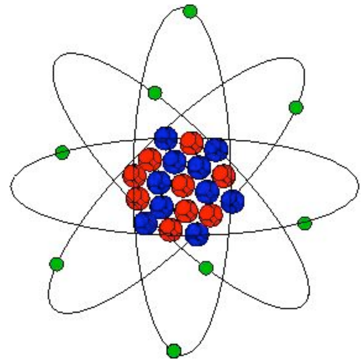


Motivation for Particle Accelerators: Part I

- Chronology: Nuclear Physics



- 1803: Dalton → Atom
- 1896: Marie & Pierre Curie → Atoms can decay
- 1896: Thomson → Electrons
- 1906: Rutherford → Atom = Nucleus + Electrons
- 1906: Rutherford → Nuclei can decay

  $\alpha + N \rightarrow O + H^{-}$

→ Nuclear disintegration

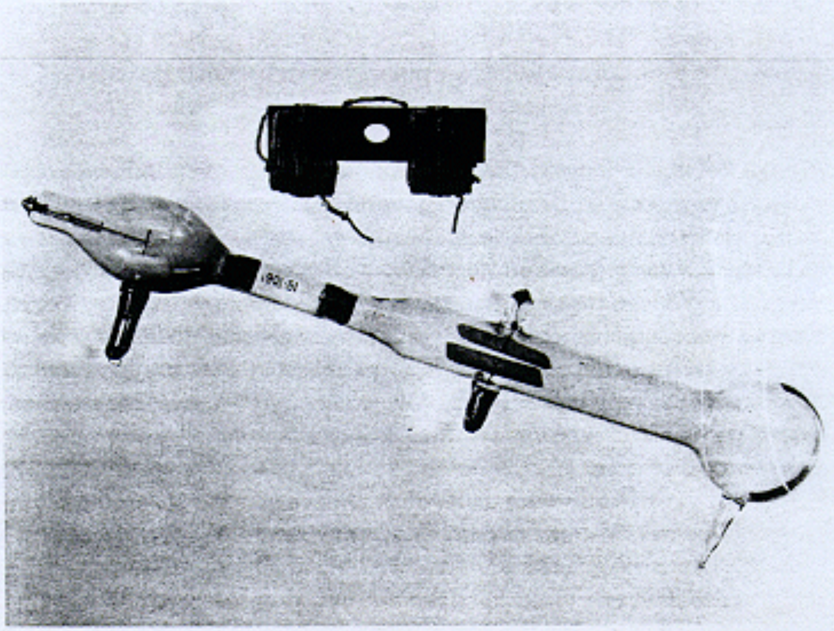
→ Particle accelerators

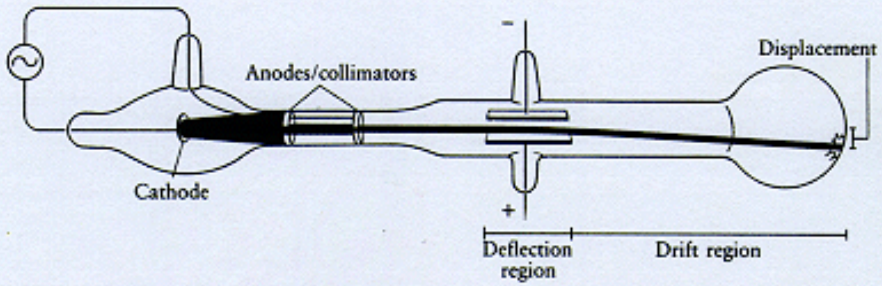
1986:

Thomson

experimental evidence for the electron

Nobel Price for Thomson in 1906





Above: One of the tubes with which J. J. Thomson measured the mass-to-charge ratio of the electron. Below: A schematic view of Thomson's apparatus. The cathode is connected by a wire through the glass tube to a generator that supplies it with negative electric charge; the anode and collimator are connected to the generator by another wire so that negative electric charge can flow back to the generator. The deflection plates are connected to the terminals of a powerful electric battery, and are thereby given strong negative and positive charges. The invisible cathode rays are repelled by the cathode; some of them pass through the slits in the anode and collimator, which only admit a narrow beam of rays. The rays are then deflected by electric forces as they pass between the plates; they then travel freely until they finally hit the glass wall of the tube, producing a spot of light. (This figure is based on a drawing of Thomson's cathode-ray tube in Figure 2 of his article "Cathode Rays," *Phil. Mag.* 44(1897), 293. For clarity, the magnets used to deflect the rays by magnetic forces are not shown here.)

1906 – 1911:

Rutherford

experimental evidence of atom structure

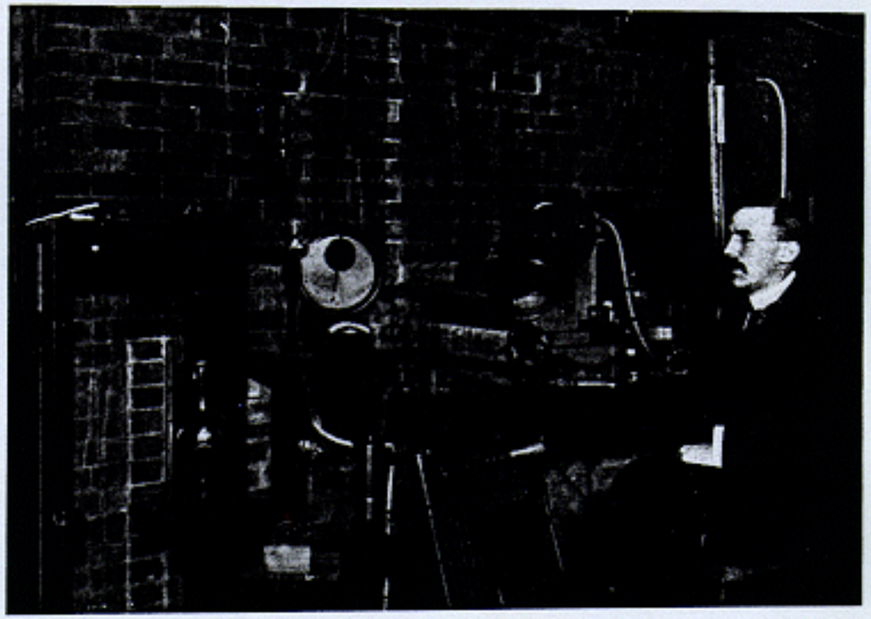
Nobel Prices for

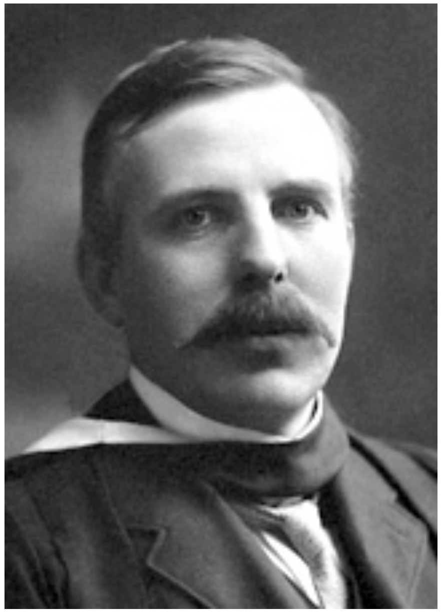
-Rutherford in 1908

-N. Bohr in 1922

Rutherford's first laboratory, in the basement of Canterbury College in New Zealand.

Rutherford in his laboratory at McGill University, Montreal, in 1905.





Motivation for Particle Accelerators: Part II

Particle Physics

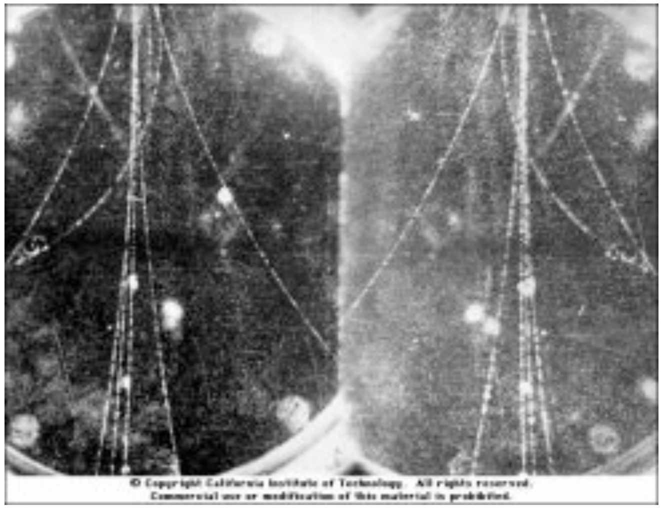
- Theory
  - 1905: Einstein → $E = m c^2$
  - 1930: Dirac → Antimatter
  - 1935: Yukawa → π Meson
- Experiments (Cosmic Rays and Cloud chamber)
  - 1932: Anderson → e^+
  - 1937: Anderson → μ

→ Need for accelerators to create: p^- and π Meson!

1932:

Anderson

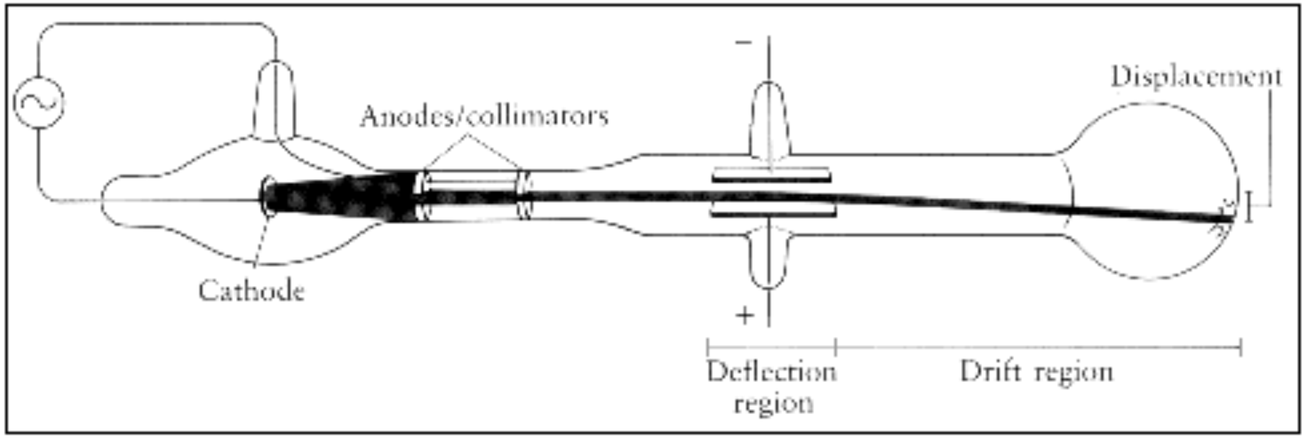
experimental evidence for the positron



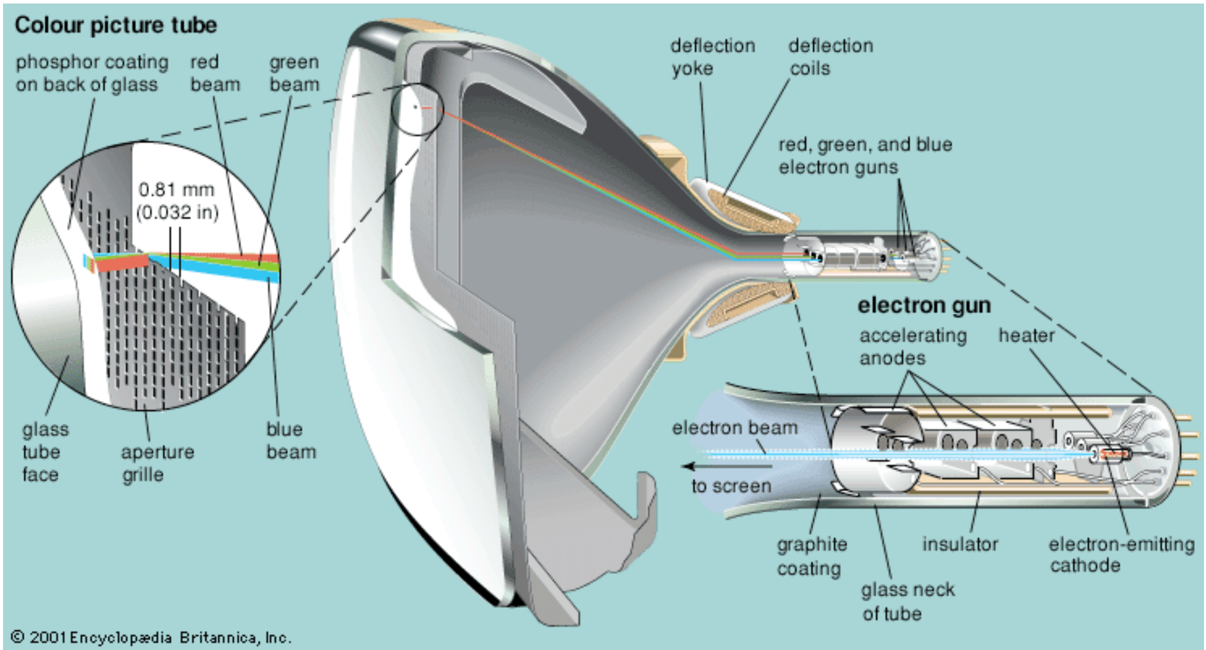
Nobel Price for Anderson in 1936

Particle Source: e^-

- Electrons: Cathode Ray Tube (Thomson)

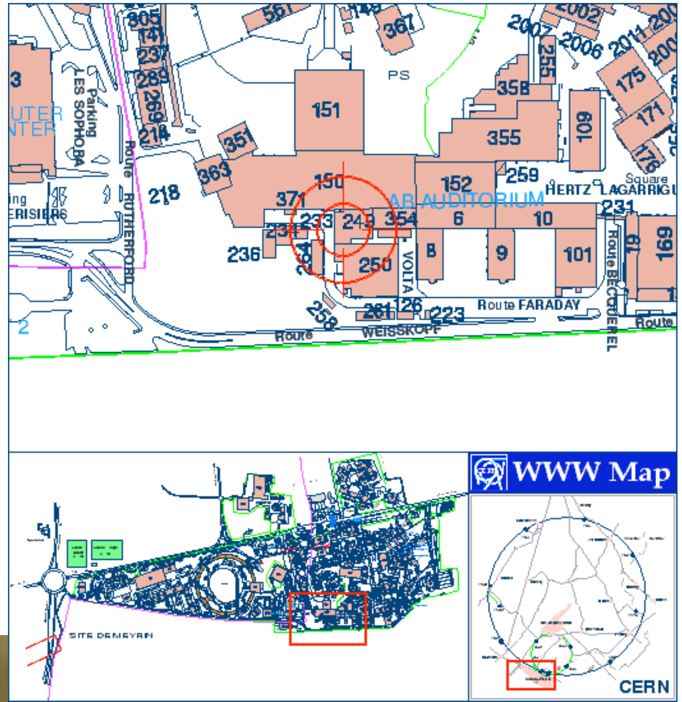


- Day to day application: Old television sets

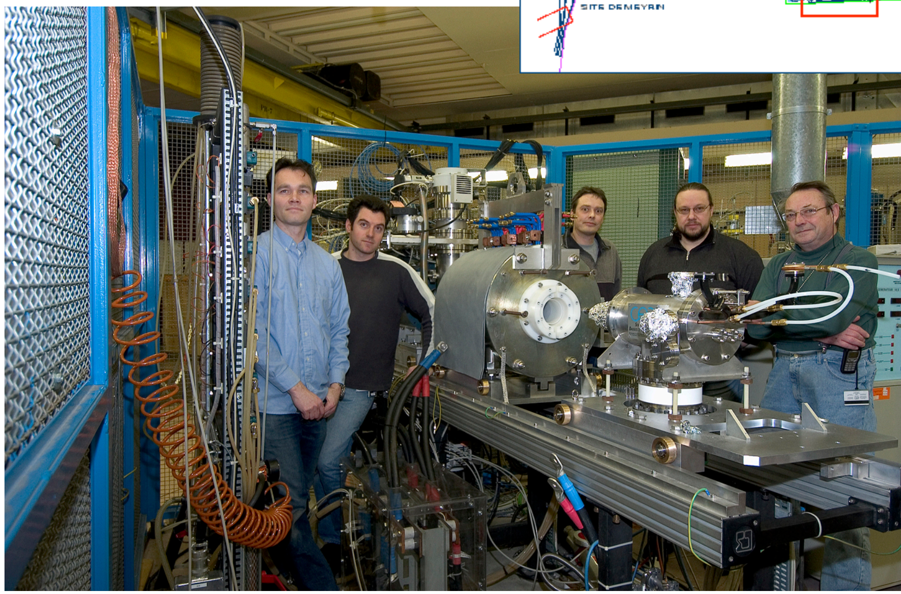


CERN Sources for LINAC2 and LINAC3

- LINAC2: Duoplasmatron Proton Source



- LINAC3: Microwave Pb ion Source



→ *More details in the talk by Detlef Kuchler*

Acceleration Concepts

- Lorentz Force:

$$\frac{dp}{dt} = q \cdot \left(\vec{E} + \vec{v} \times \vec{B} \right)$$

→ energy gain only due to electric fields!

- Scalar and Vector Potential:

$$\vec{E} = -grad\phi - \frac{1}{c}\frac{\partial \vec{A}}{\partial t}$$

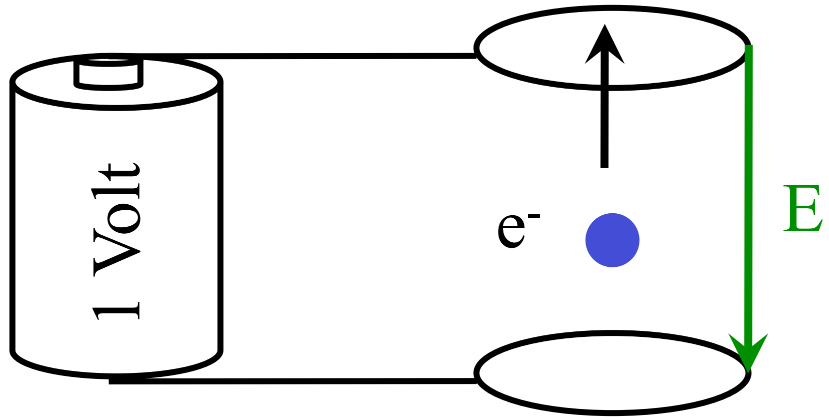
- Electrostatic acceleration → $A = 0$
- Acceleration with time varying fields → $\phi = 0$

Units

- Energy gain:

  1 eV

  ➔ 1.6 10^{-19} Joule



- Common units:

keV	MeV	GeV	TeV
10^3	10^6	10^9	10^{12}

- Total particle energy:

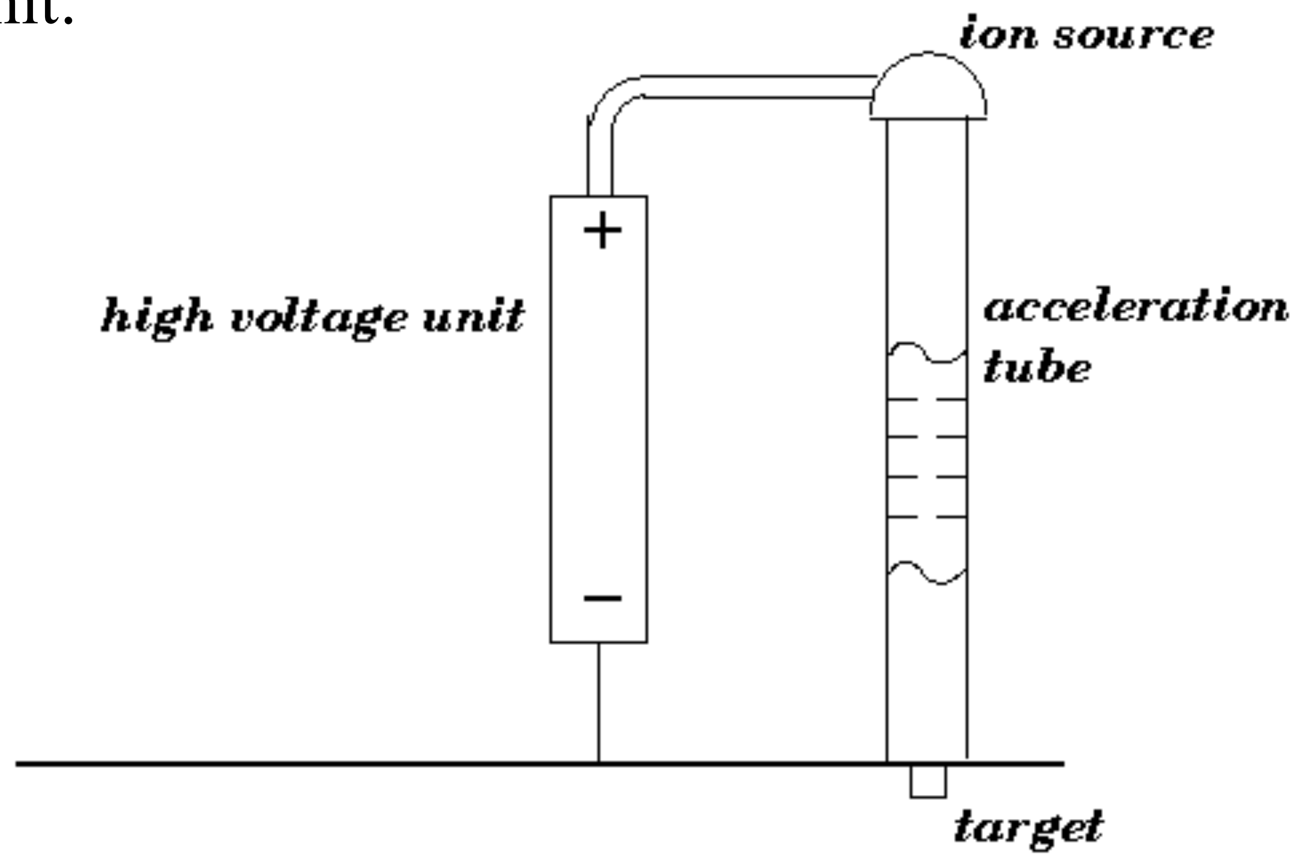
$$\gamma = 1/\sqrt{1-\frac{v^2}{c^2}}$$

Relativity: $E = m c^2$; $m = m_0 \gamma$

→ electron: $m_0 = 9.11\ 10^{-31}$ kg ➔ 0.51 MeV
proton: $m_0 = 1.67\ 10^{-27}$ kg ➔ 0.94 GeV

Electrostatic Acceleration

- High Voltage Unit:

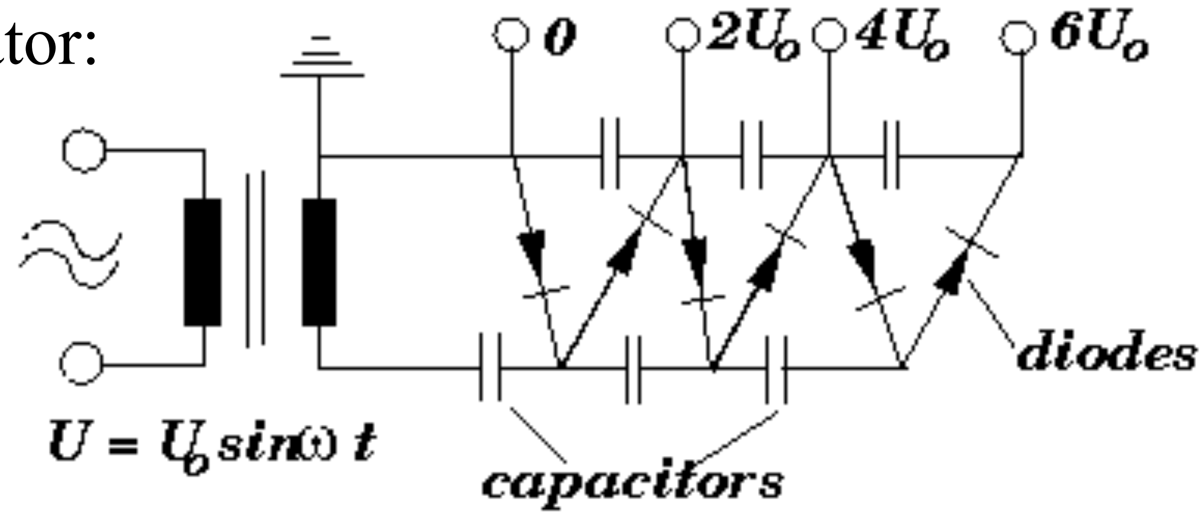


- Limited by voltage across high voltage unit

→ V = 200 kV

Electrostatic Acceleration

- Cascade Generator:



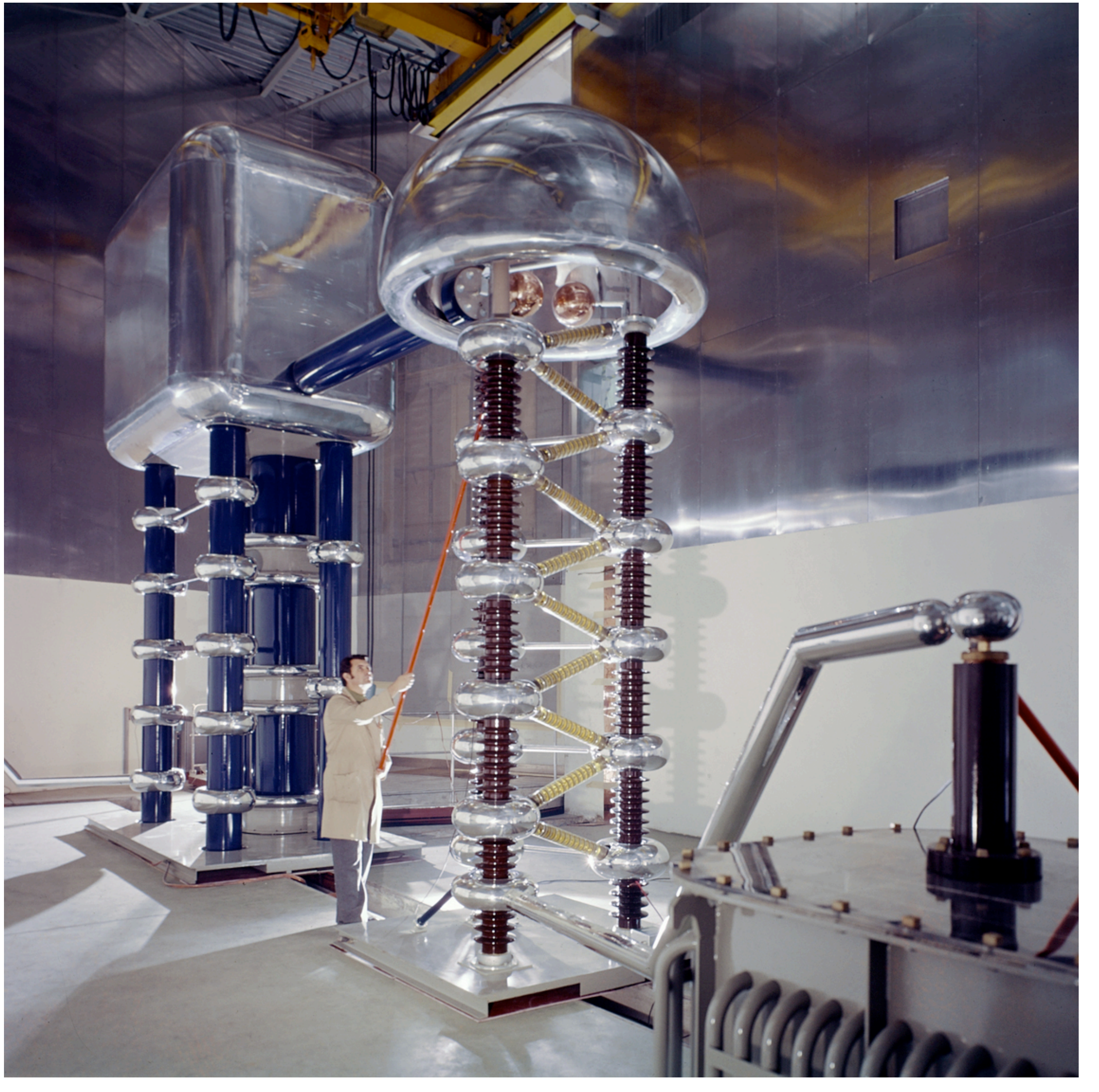
➔ can generate DC voltage above 200 kV

- First construction by Crockkroft and Walton in 1928:
  design for 800 keV acceleration voltage

- Used by Rutherford in 1932 for nuclear disintegration of Li
  p + Li ➔ 2 He using 700keV protons
  Nobel price in 1952

Electrostatic Acceleration

- Used at CERN as pre-accelerators for LINAC 1 (520 keV) and LINAC 2 (750 keV) until 1984 and 1993 respectively when they were replaced by RFQs

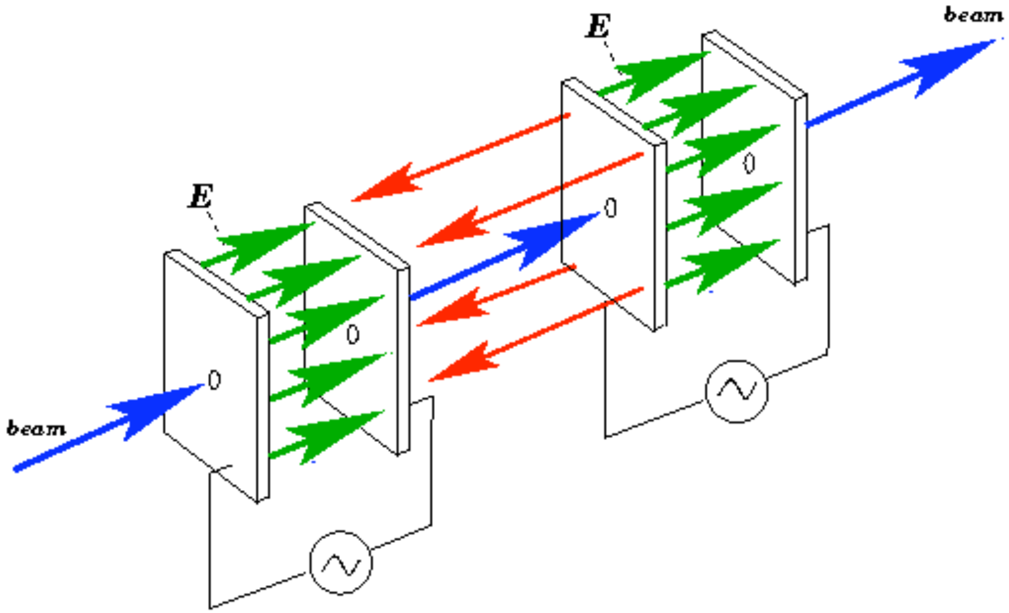


LINAC 2 ➔

Acceleration with Time Varying Fields

- Linear Acceleration:

- Need for shielding when electric field points in the wrong direction:

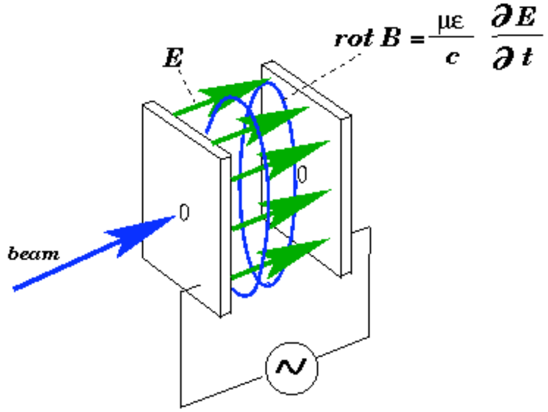


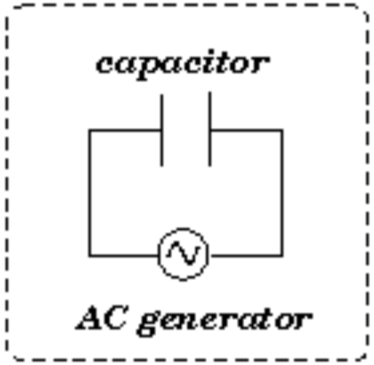
- Beam needs to be organized in packages ➔ bunched beam

- Total acceleration voltage 'only' limited by accelerator length

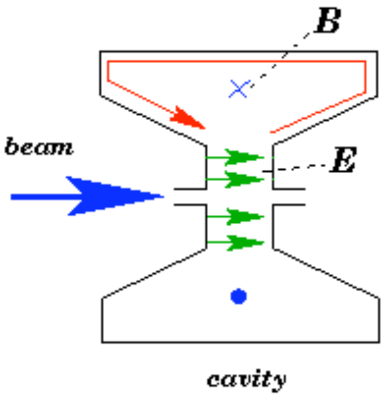
Linear Acceleration and Cavity Resonator

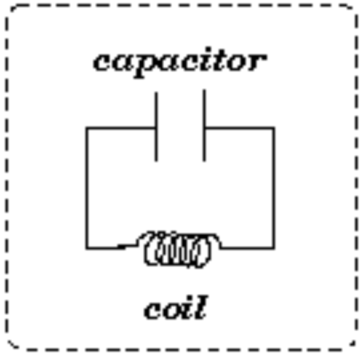
- Capacitor circuit: Impedance and vacuum!

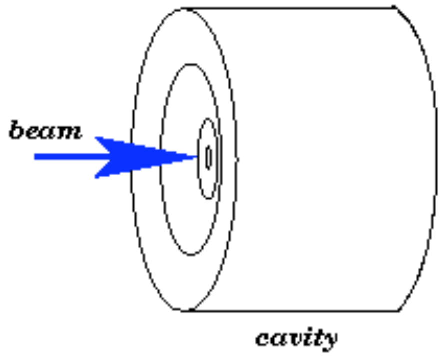




- Electromagnetic resonator Resonator:





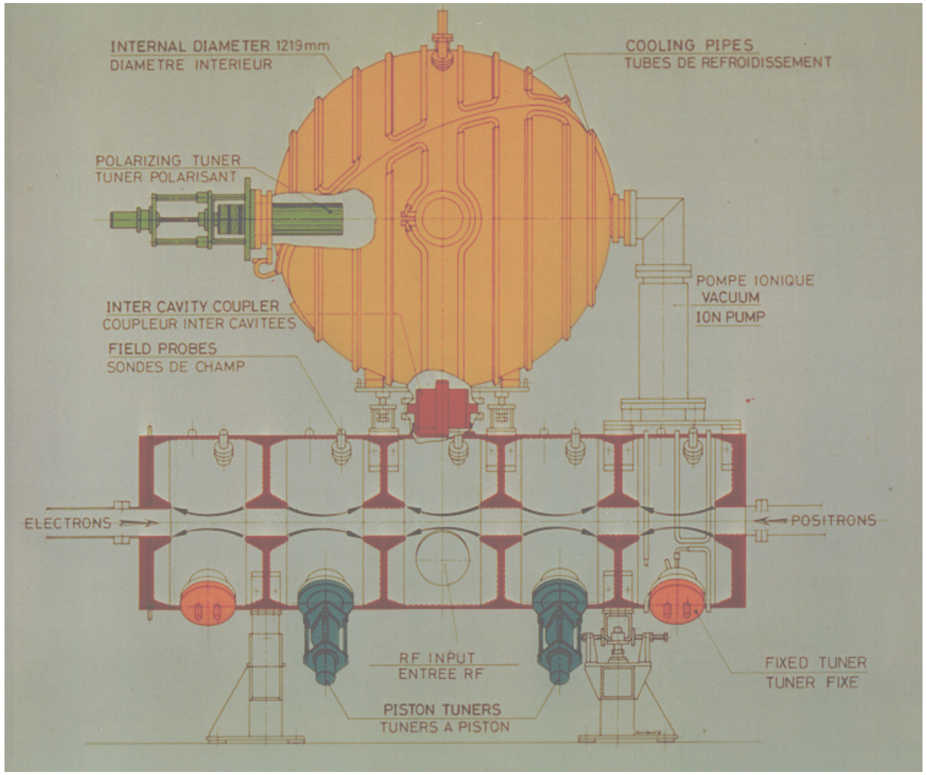


Resonance structure characterized by: f, Q, R

Linear Acceleration and Cavity Resonator

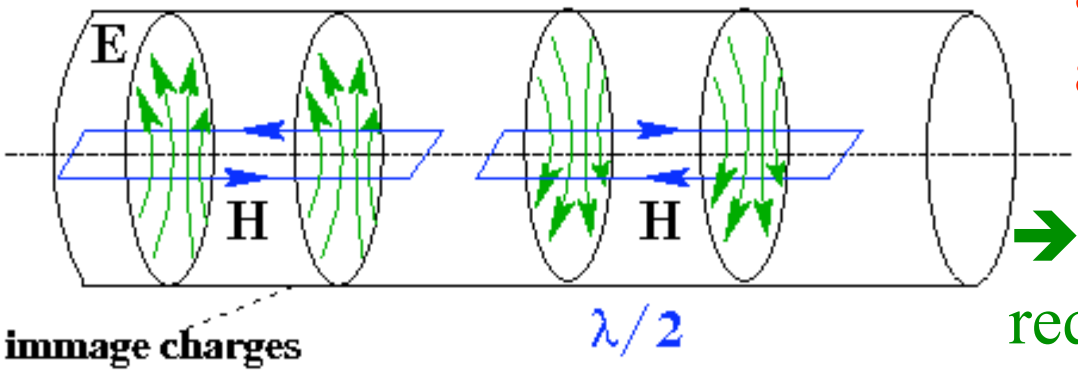
- PS 19 MHz Cavity resonator

- LEP 352 MHz ; 1.5MV / m



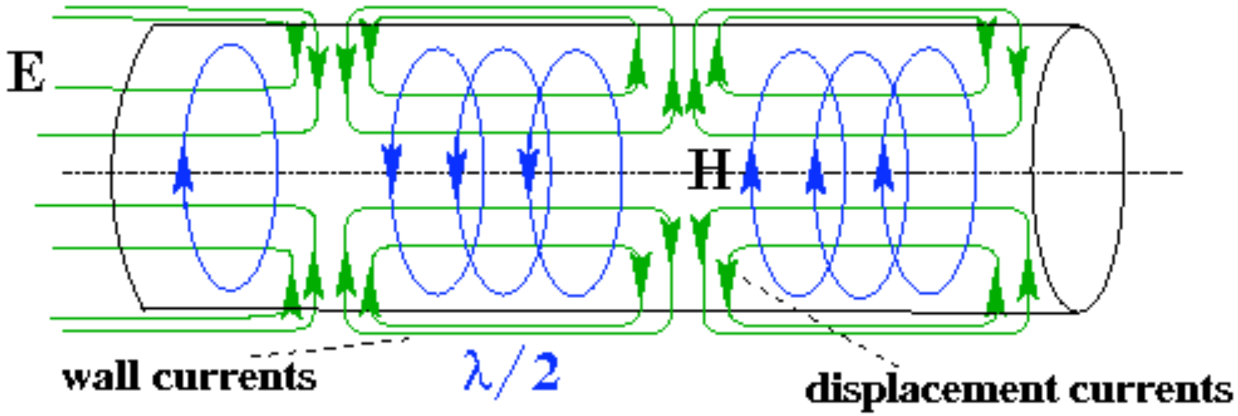
Electro-Magnetic Field Modes inside Resonator

- Transverse Electric: $E_z = 0$ everywhere ➔ no acceleration along cavity axis!



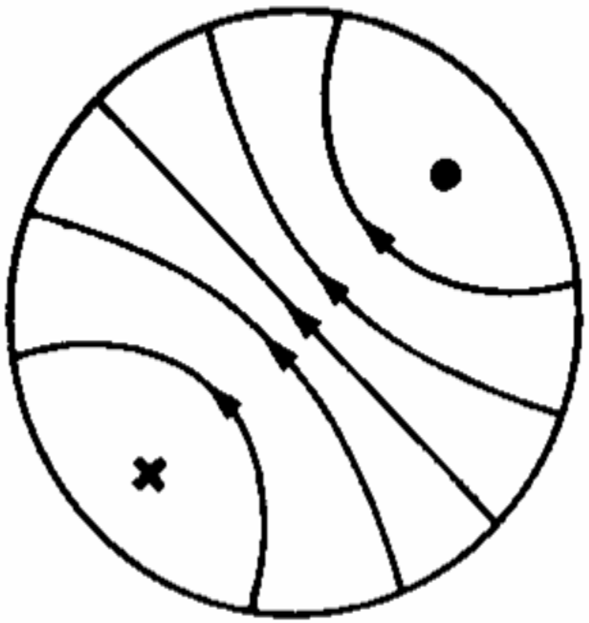
➔ acceleration requires additional boundary conditions

- Transverse Magnetic: $B_z = 0$ everywhere

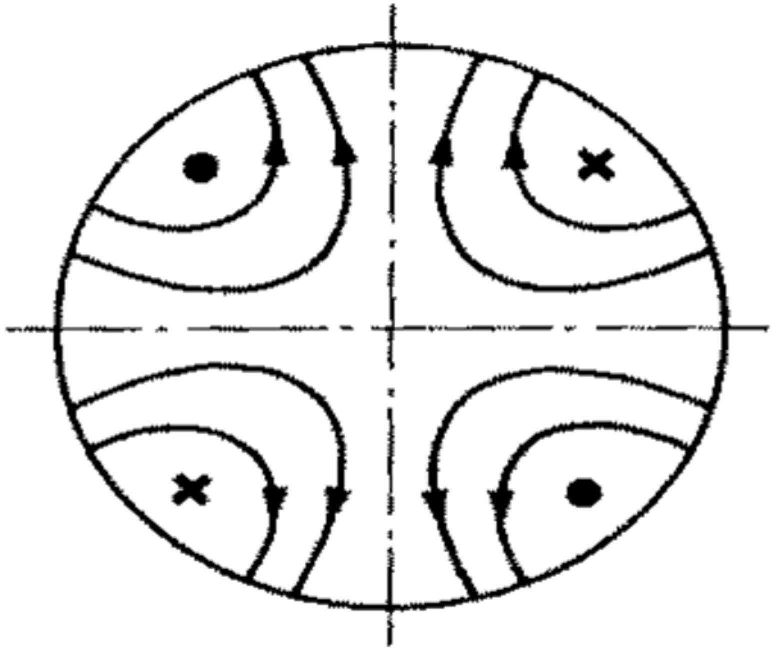


$E_z \neq 0$ but not always in the right direction ➔ acceleration and deceleration! ➔ requires shielding!

Acceleration Using TE Modes



Empty cavity; mode TE_{11}



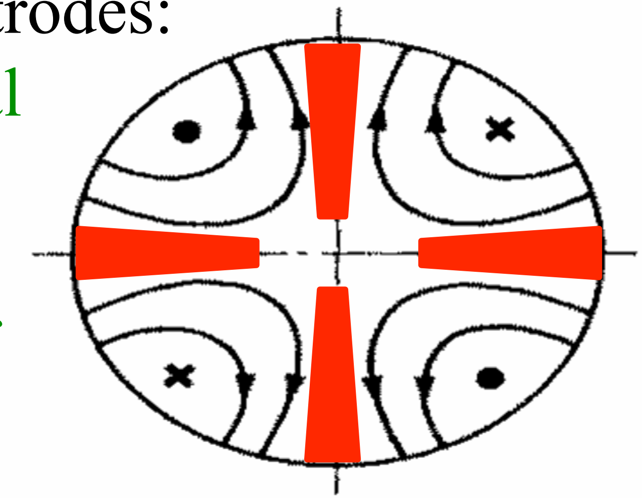
Empty cavity; mode TE_{21}

- TE modes have no E field in the direction of wave propagation

  ➔ not usable for particle acceleration as such
  ➔ provide transverse focusing
  ➔ can provide longitudinal acceleration via modulation of boundary conditions

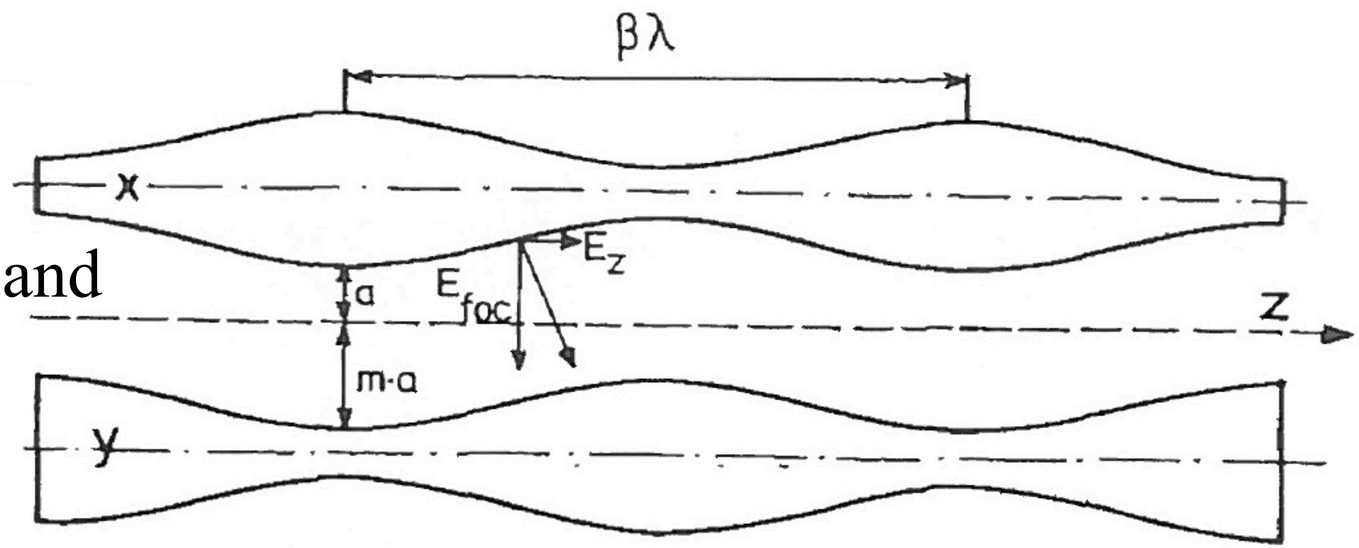
Acceleration Using TE Modes: RFQ

- RFQ: longitudinally modulated electrodes:
  - ➔ electric field lines must be normal to electrode surface
  - ➔ longitudinal shape modulation of electrodes generates longitudinal electric field component
  - ➔ acceleration in direction of particle motion



Empty cavity; mode TE_{21}

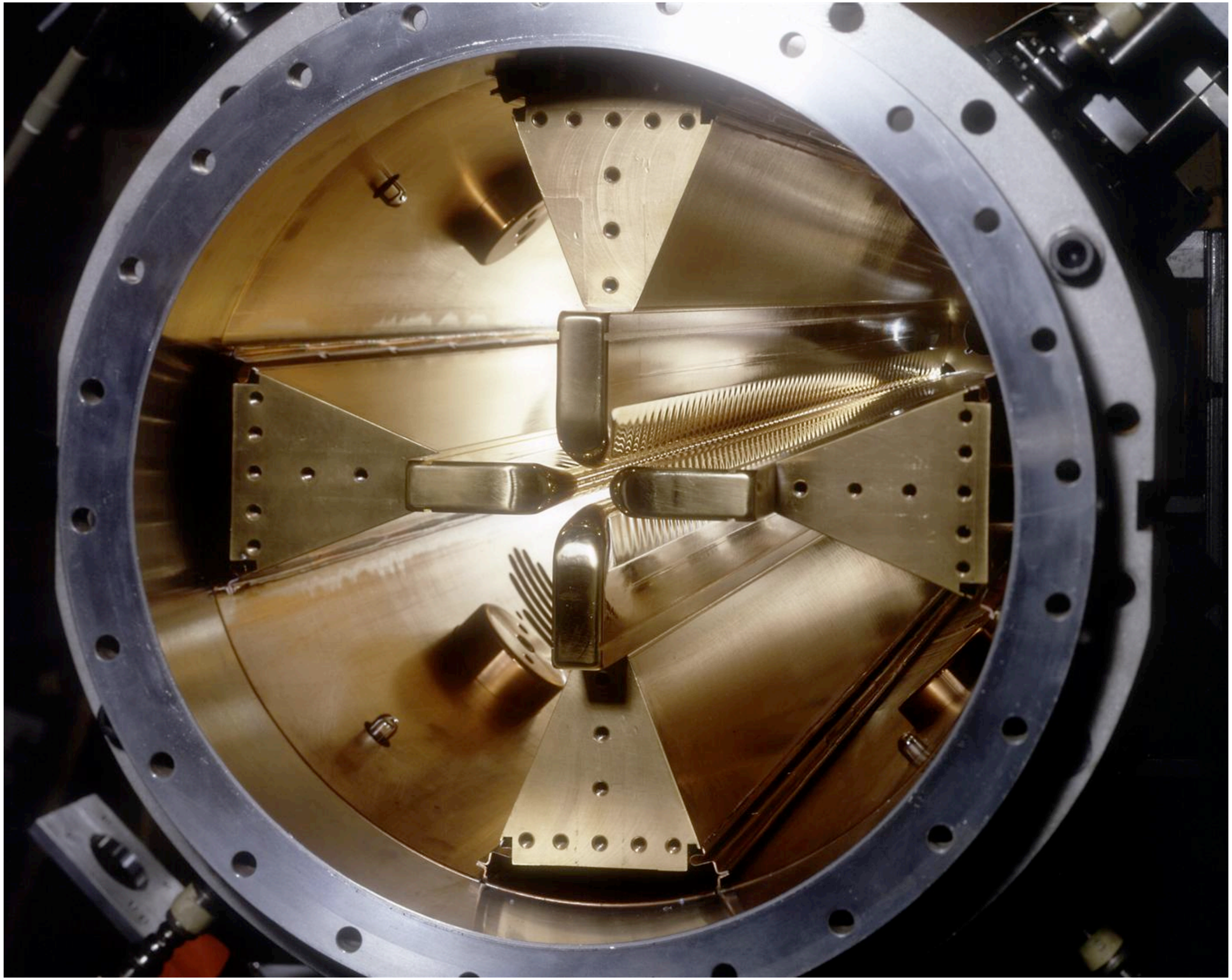
Kapchinskii and Teplvakov Russia 1970



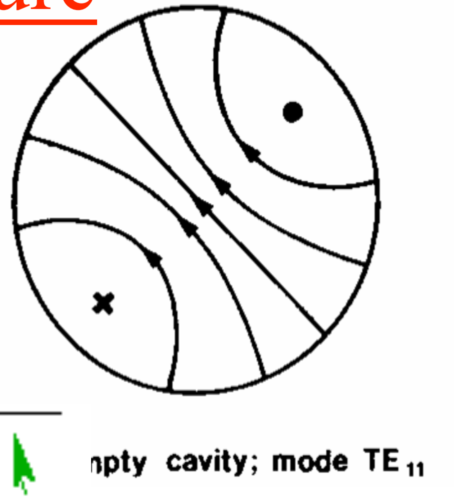
Acceleration Using TE Modes: RFQ

Linac 1:

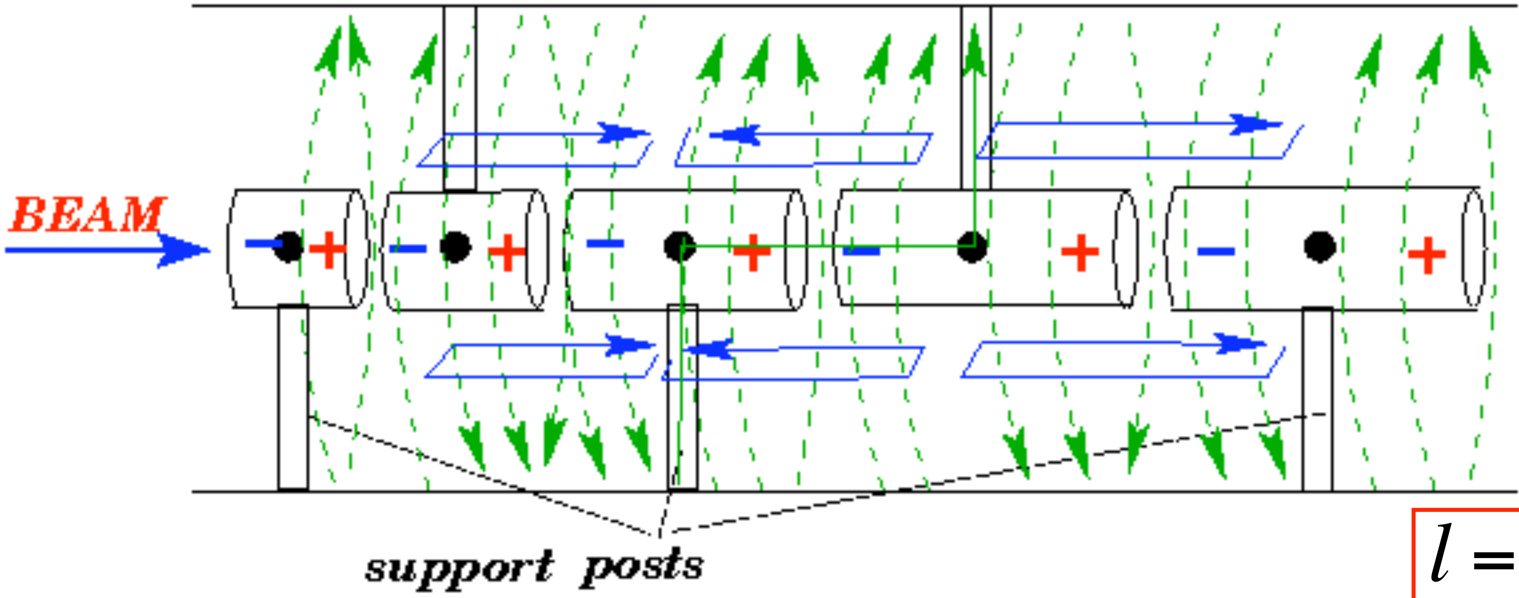
Replaced the Chrockkroft-Walton generator in 1983 and accelerated protons to an energy of 520 keV when LINAC1 was used as injector for LEIR: 1981-1996



Acceleration Using TE Modes: I-H Structure



- Use higher order mode for low energy particles
- Install tubes to deflect E-field into the longitudinal direction:



$$l = v_{part} \cdot \lambda / 2c$$

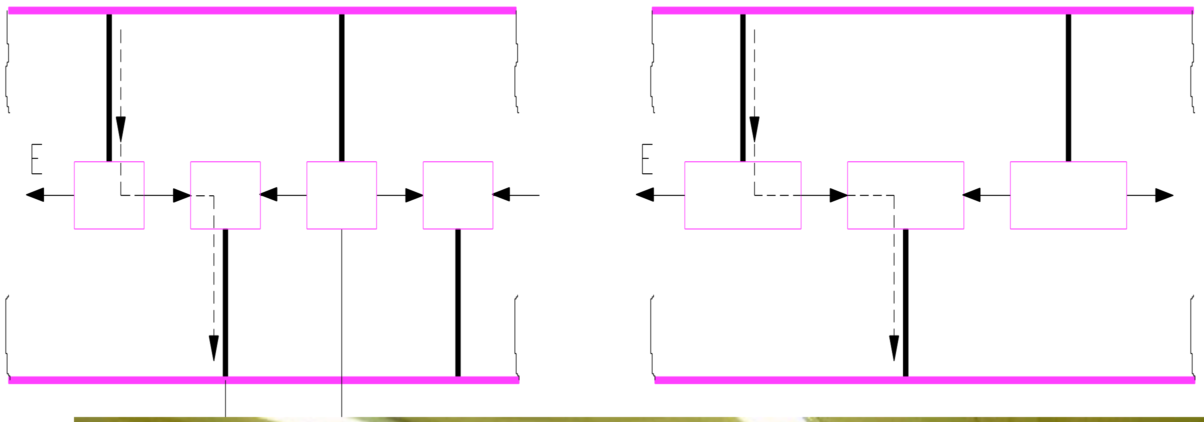
- Constant acceleration voltage between posts:

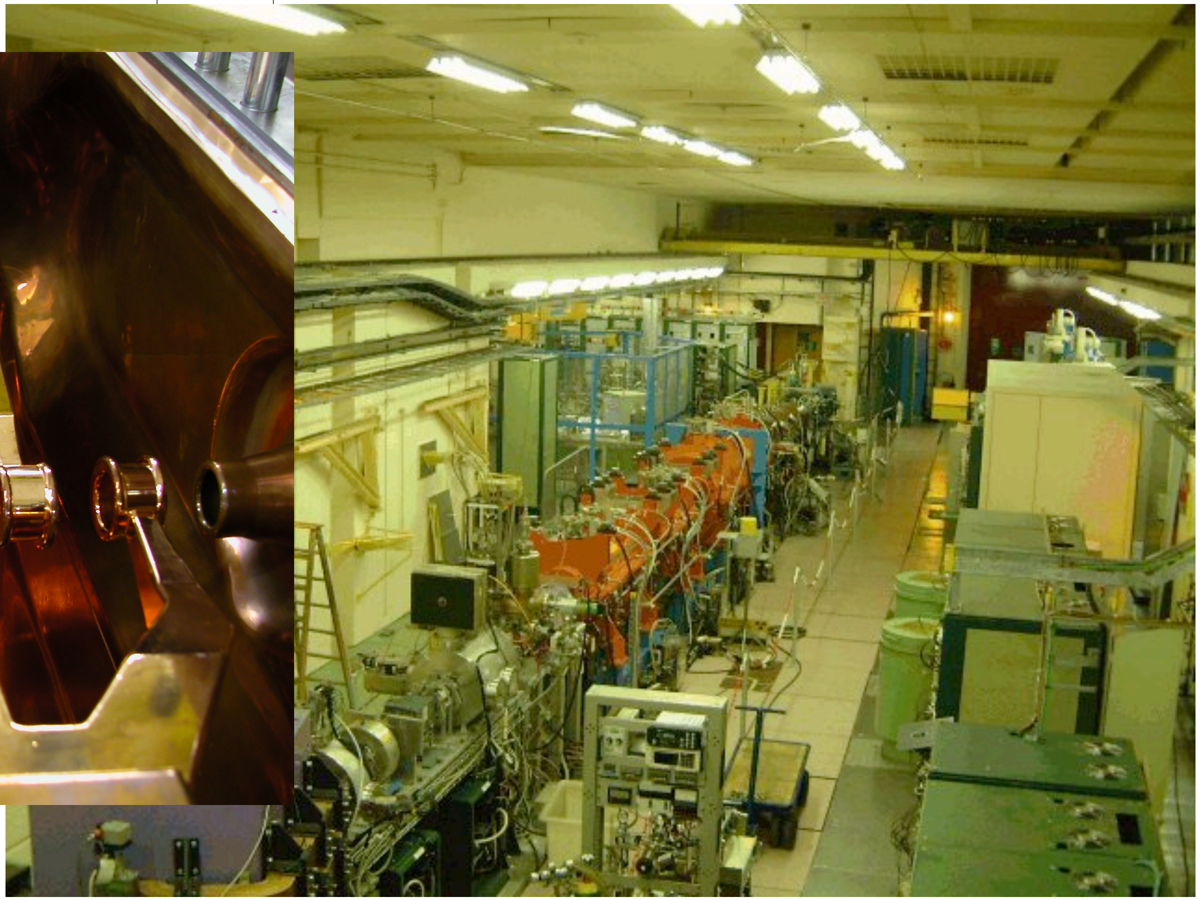
➔ pre-accelerator for Pb ions in LINAC3 at CERN

➔ becomes less efficient as particle velocity approaches ‘c’

Interdigital-H Structure at CERN:

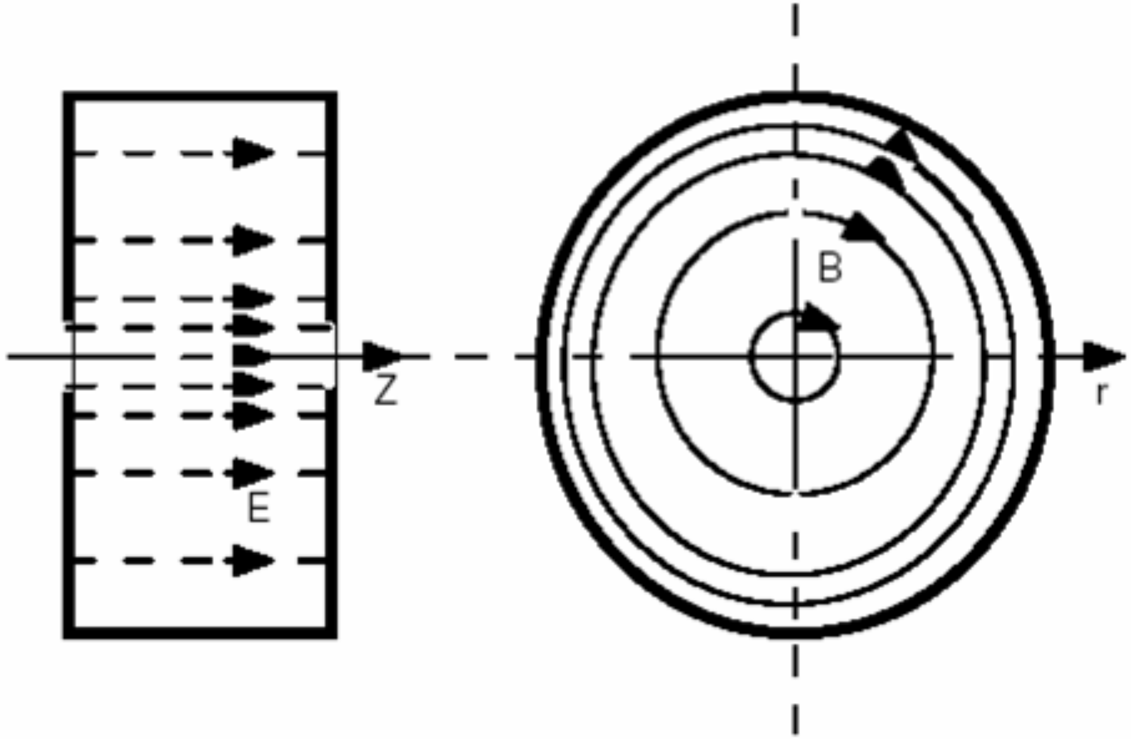
LINAC 3:





Acceleration Using TM Modes

- TM01:



- TM modes have an E field in the direction of wave propagation

  ➔ directly usable for particle acceleration!

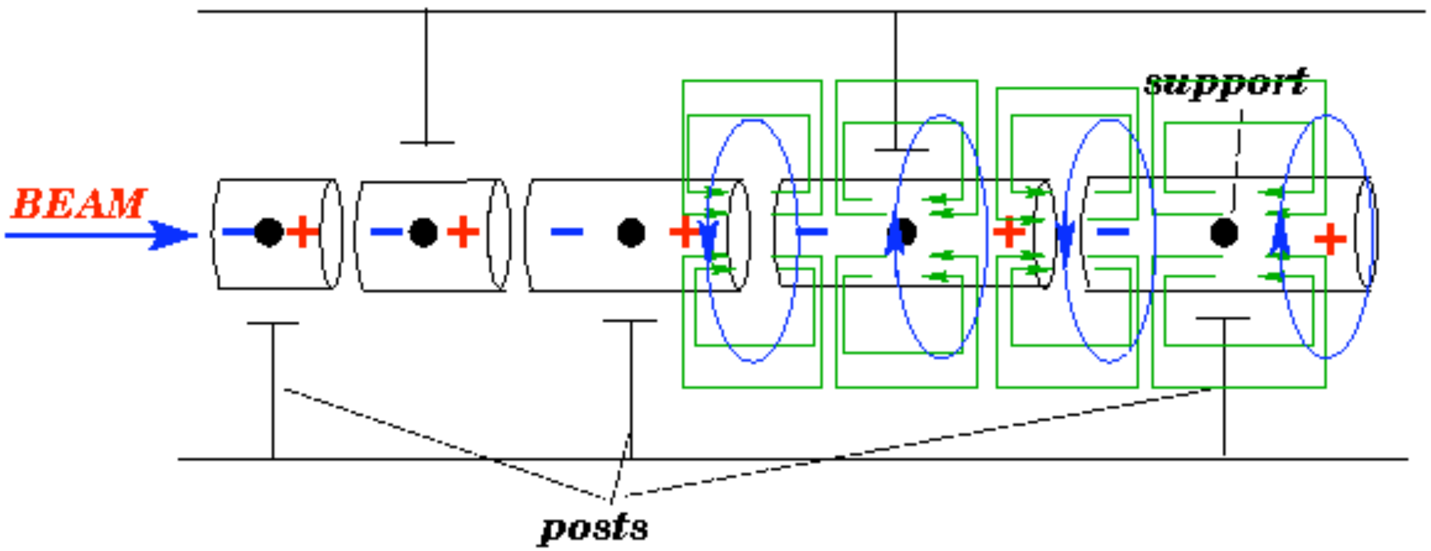
  ➔ but field does not always point in the right direction

    ➔ requires shielding

  ➔ does not provide transverse focusing

Acceleration Using TM Modes

- Use higher order mode for low energy particles
- Install shielding where the E-field has the wrong sign

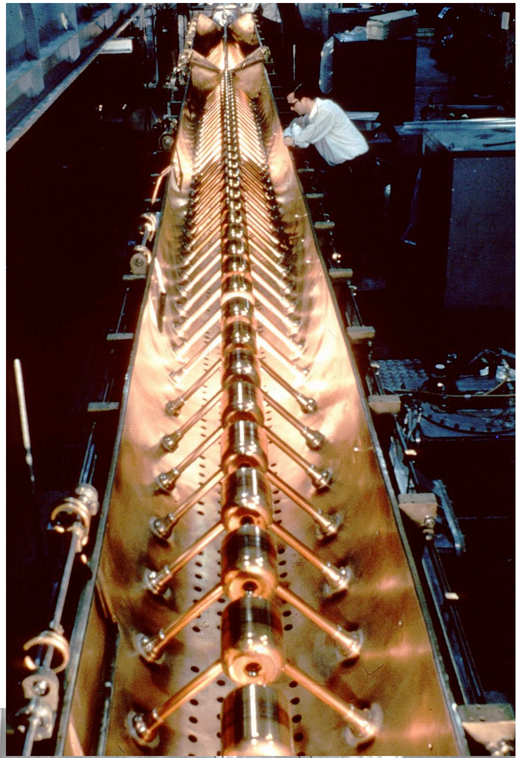


$$l = v_{part} \cdot \lambda / c$$

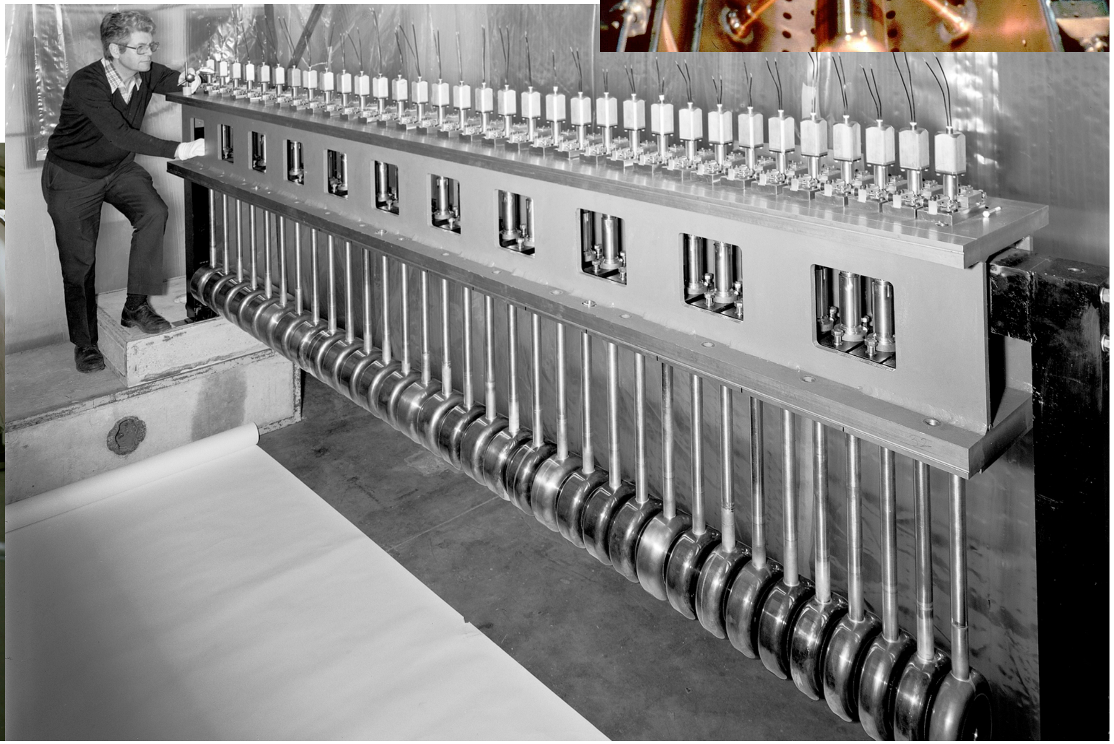
- If the shielding is passive one can go to high frequencies
  - ➔ Alvarez structure: 200 MHz provides good tube sizes
  - ➔ more efficient than IH structure for $v \approx c$
  - ➔ shielding tubes can provide room for focusing elements
  - ➔ pre-accelerator for most proton accelerators

Alvarez Tank for CERN LINACs:

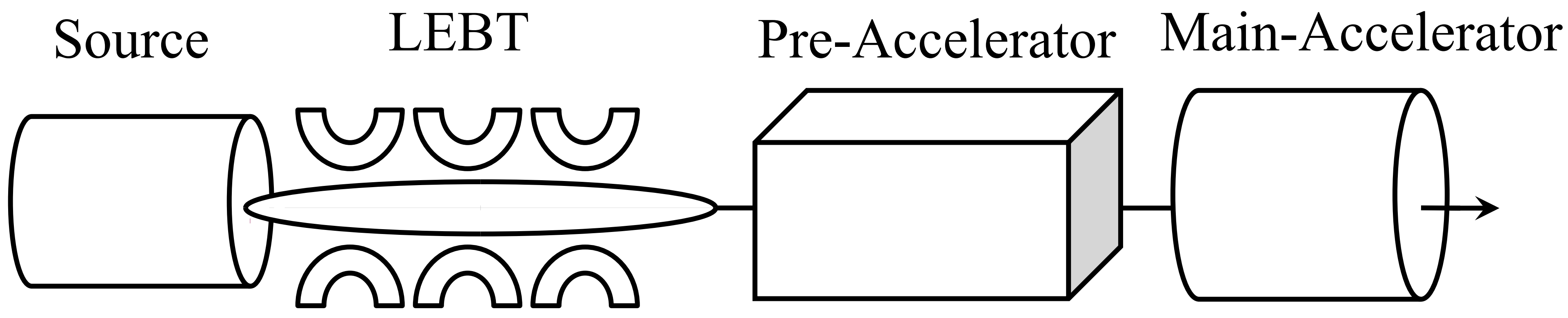
- LINAC 1:



- LINAC 2:



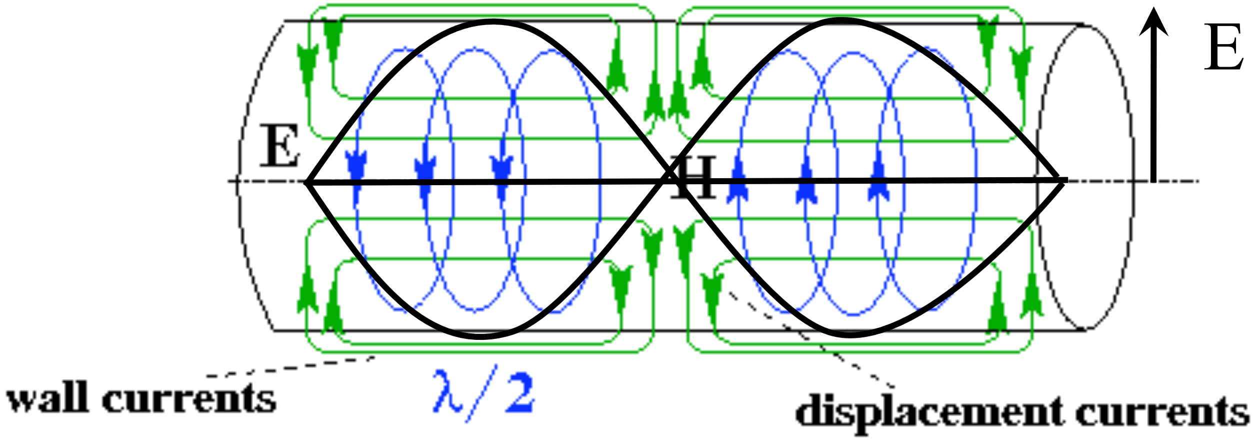
Conceptual Layout of Hadron Acceleration



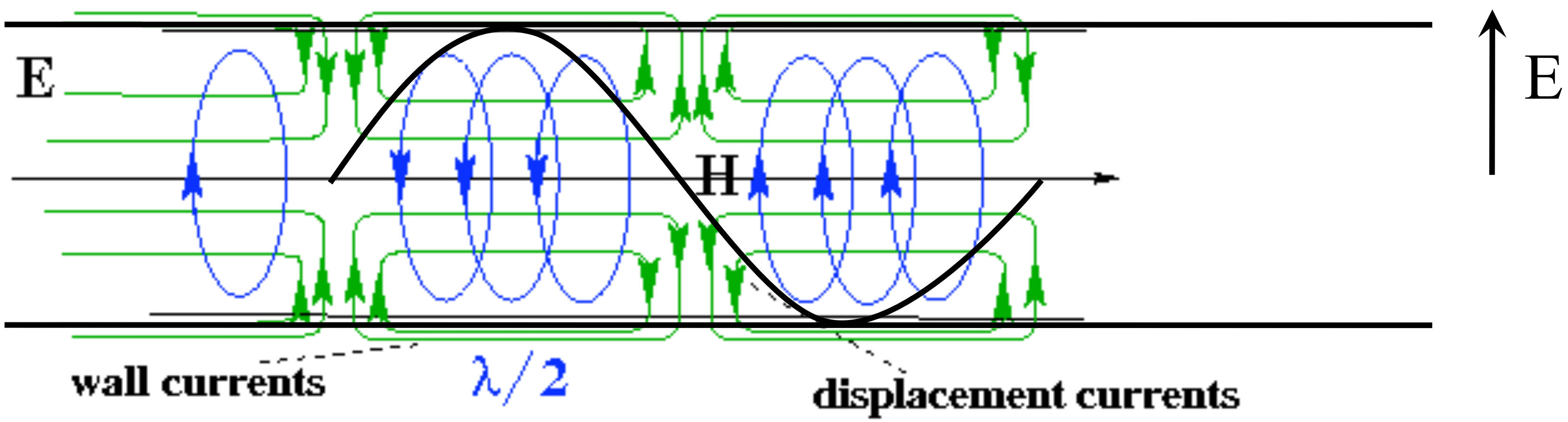
- Source: particle production ➔ Detlef Kuchler's talk
- Low Energy Beam Transport: focusing of source particles
- Pre Accelerator: Cascade generator or RFQ (Van de Graaf?)
- Main Accelerator: ➔ later in this presentation

Acceleration with Time Varying Fields: Travelling Waves

- Standing waves: fixed nodes of the EM wave inside cavity

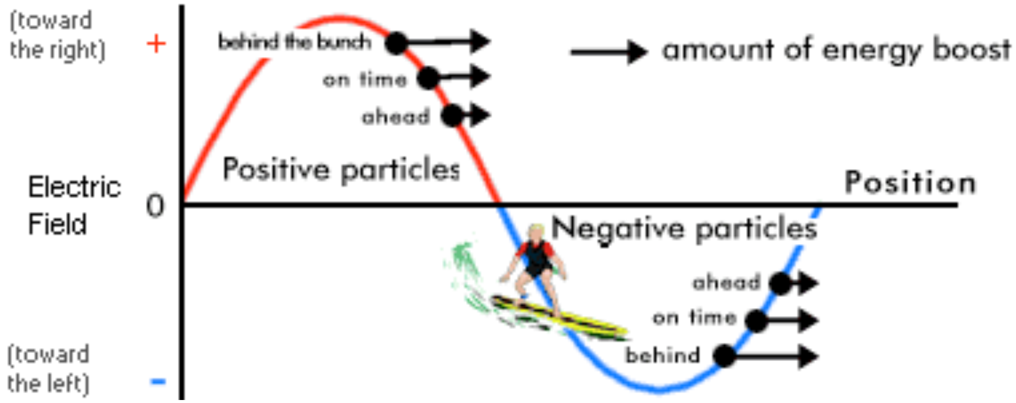


- Travelling waves: nodes move inside the cavity



Acceleration with Time Varying Fields: Travelling Waves

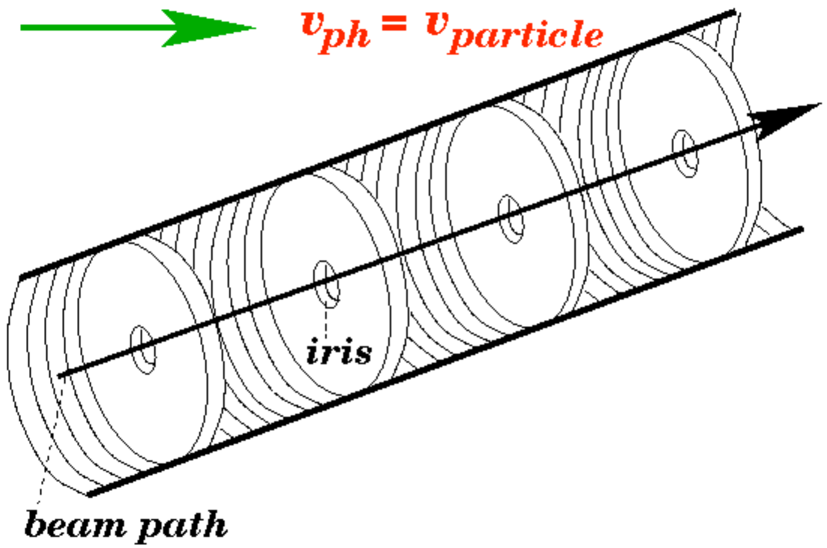
- Travelling waves: particles ride on the crest of the EM wave



- Problem: phase velocity of the EM wave vs particle velocity

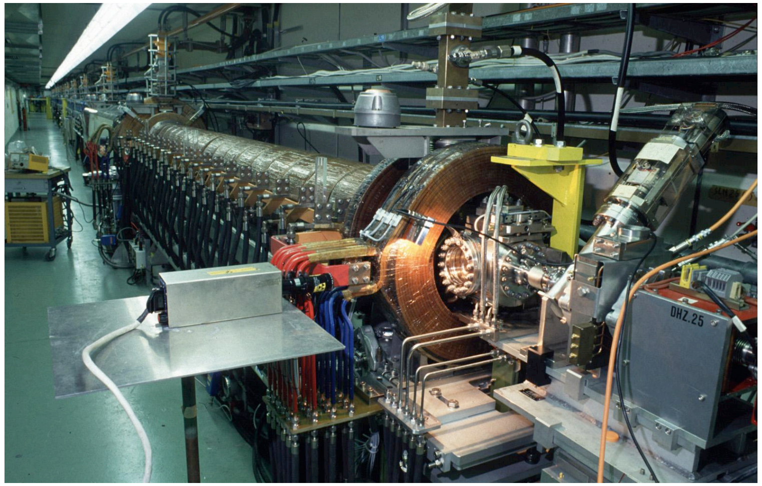
Loaded Waveguide

required RF power was only available before World War 2 (radar development)

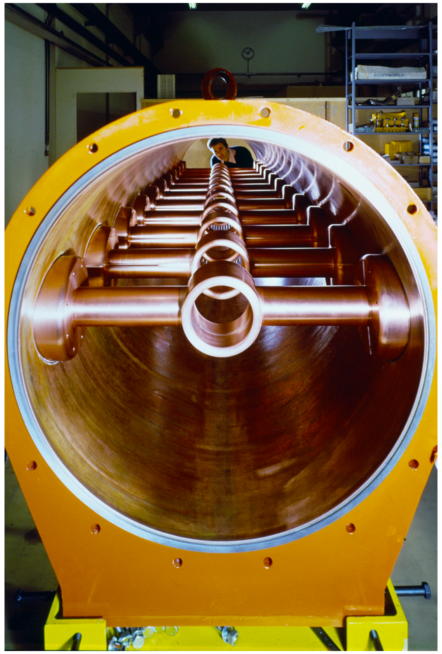


Acceleration with Time Varying Fields: Travelling Waves

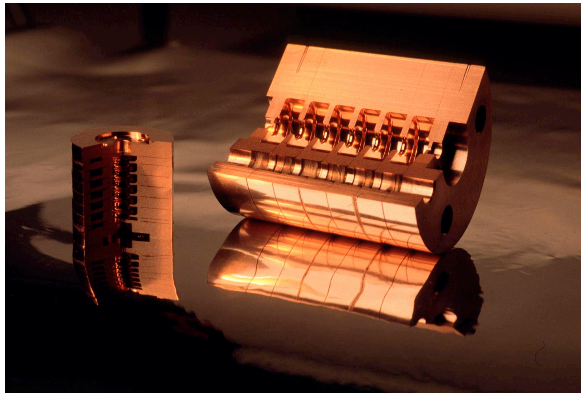
- LIL injector for LEP

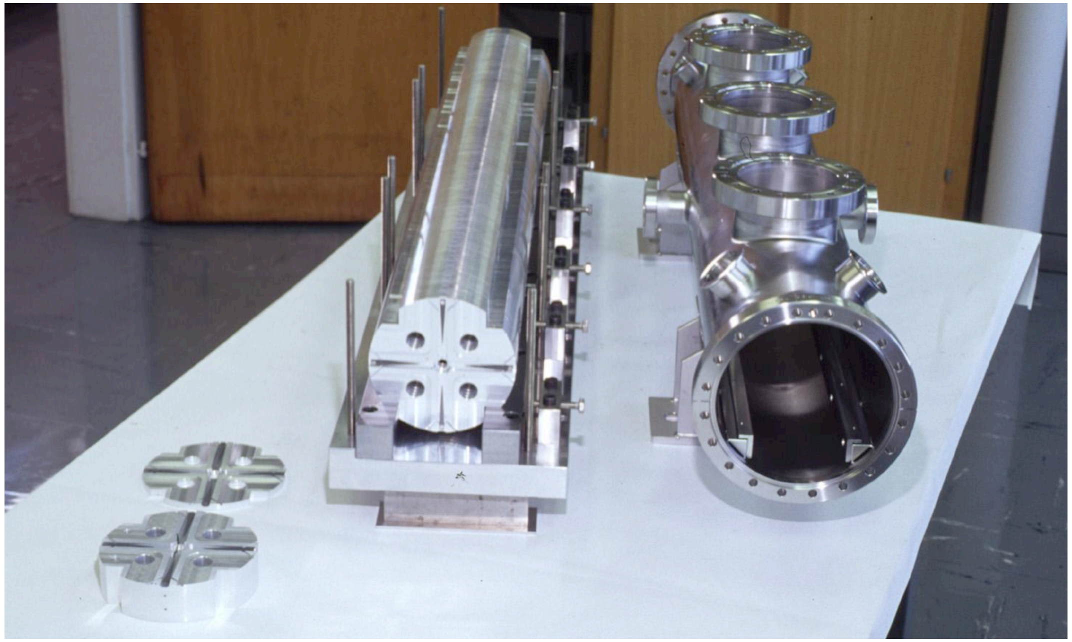


- SPS



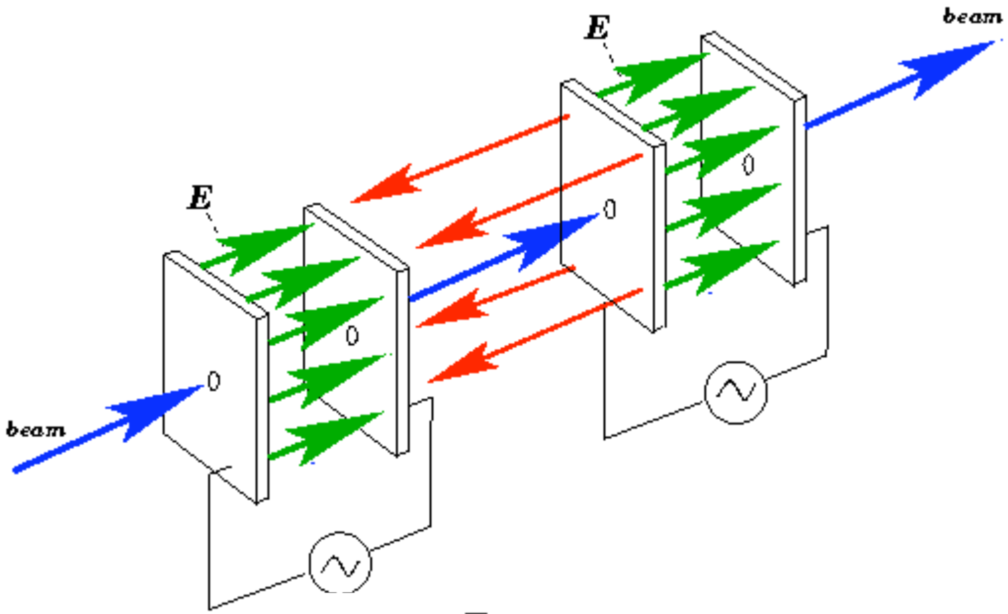
- CLIC



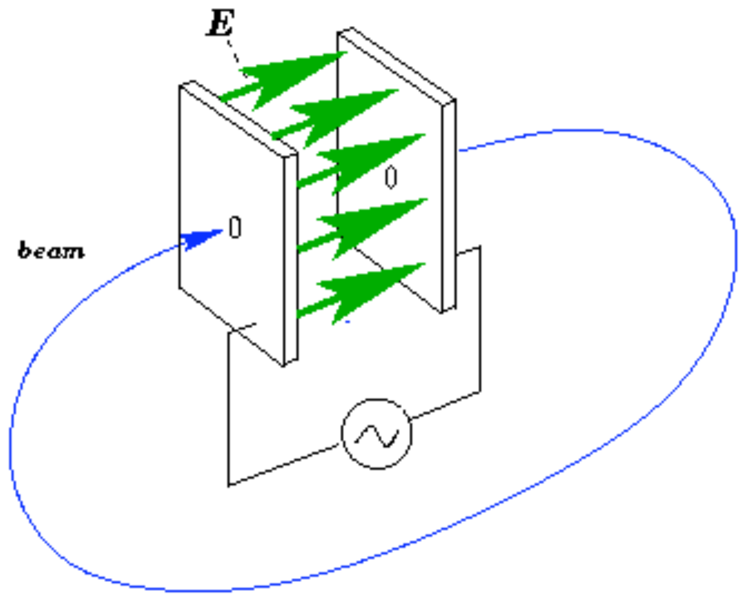


Acceleration with Time Varying Fields: Circular Machines

- Linear Acceleration:
  - Total acceleration voltage 'only' limited by accelerator length



- Circular Acceleration:
  - Requires magnetic fields for trajectory guidance
  - 'efficient' use of acceleration voltage
    ➔ beam energy limited by magnetic bending field

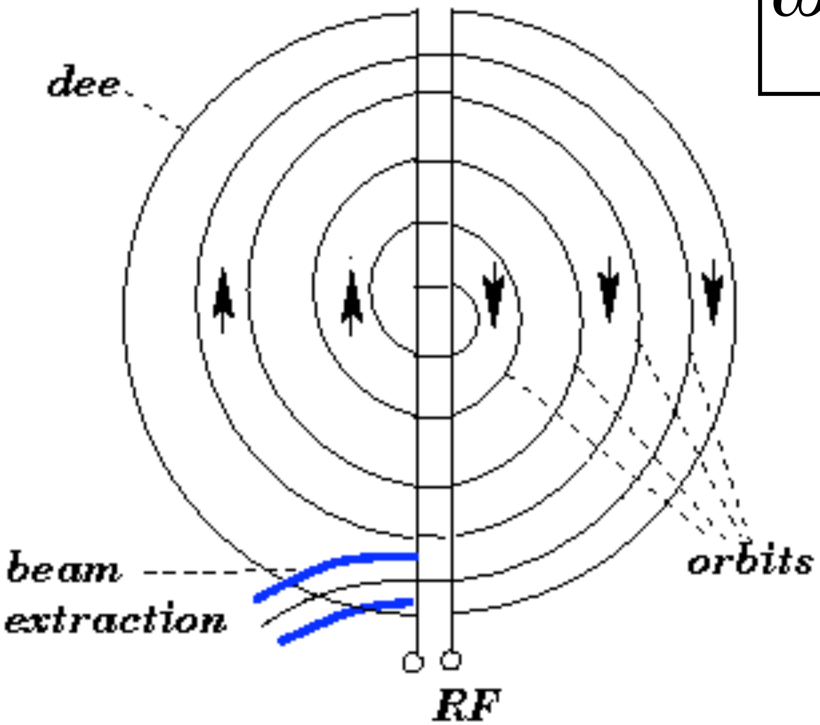


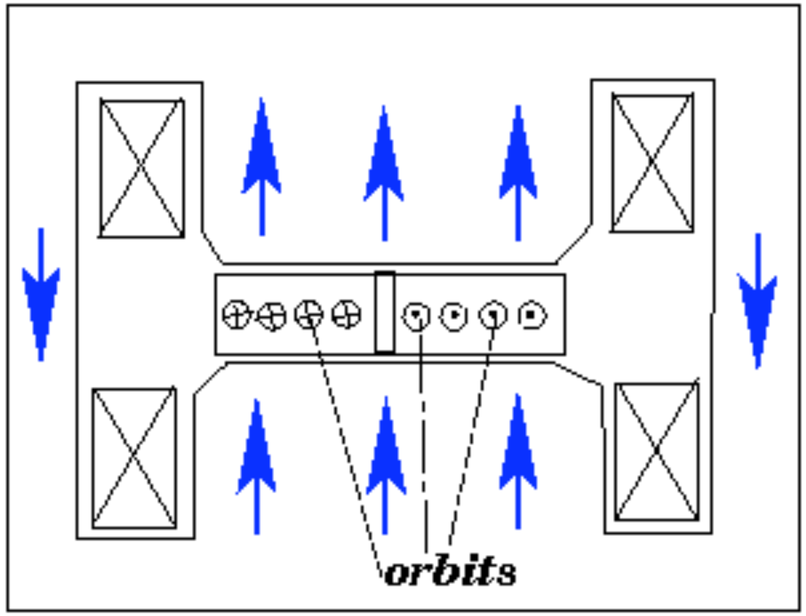
Acceleration with Circular Machines: Cyclotron

- Cyclotron:

$$\omega = \frac{q}{m} \cdot B$$

$$r = \frac{m}{q} \cdot \frac{v}{B}$$





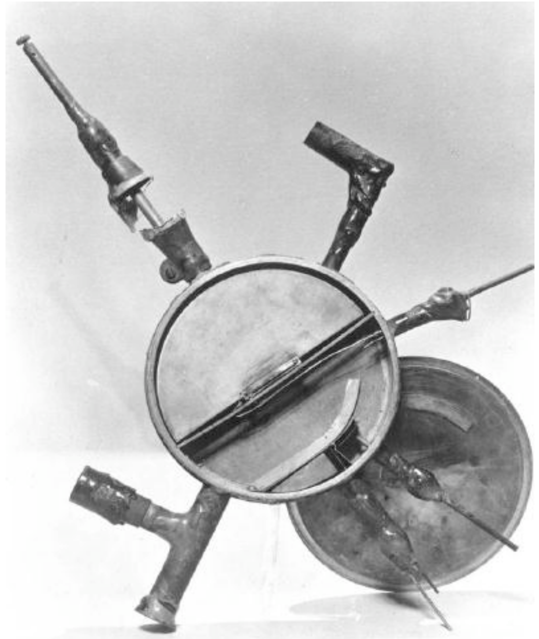
m = const ➔ f_{rev} = const for B = const

- Lawrence 1929

Acceleration with Circular Machines: Cyclotron

- 1931: Livingston
  4.5 inch ➔ H^- to 80 keV

- 1932: Lawrence
  11 inch ➔ p to 1.2 MeV
  Nobel Price in 1939



1999: T. Koeth
12 inch rebuild

Acceleration with Circular Machines: Cyclotron

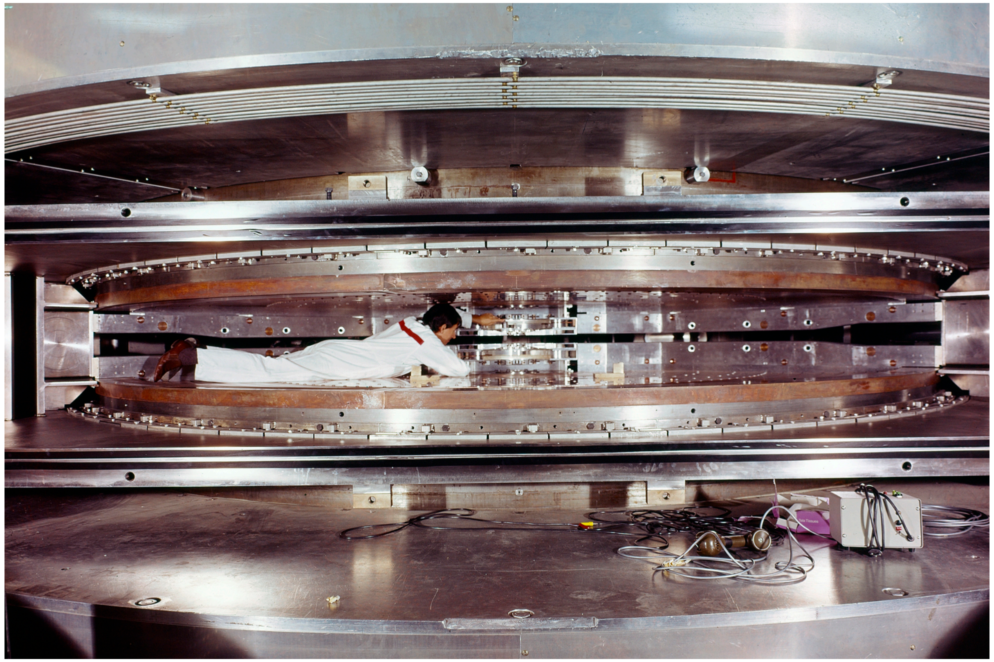
- Synchro Cyclotron:

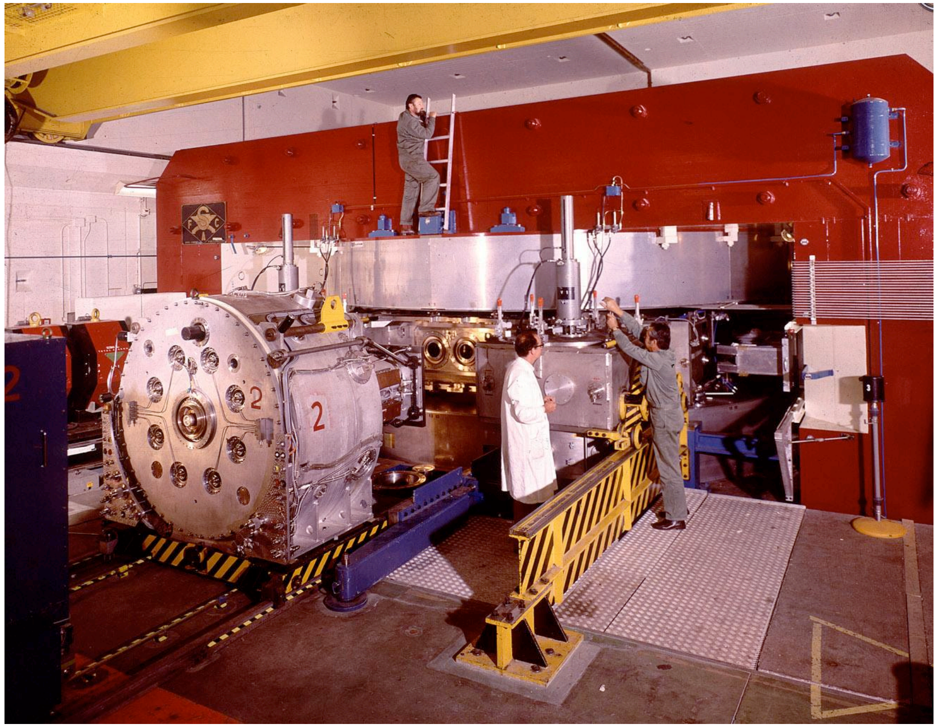
$\gamma >> 1$ ➔ $f_{rev} \neq$ constant

➔ vary RF frequency over cycle

➔ short bunch trains and large dipole magnet

- CERN 600 MeV Synchro Cyclotron 1954 to 1990





Acceleration with Circular Machines: Synchrotron

- Keep R = constant: → compact magnet design

$$r = \frac{m_0}{q} \cdot \frac{\gamma}{B} \cdot v$$

ultra relativistic particles: $v \approx c$

→ vary B field proportional to γ!

$$\omega = \frac{q}{m_0} \cdot \frac{B}{\gamma}$$

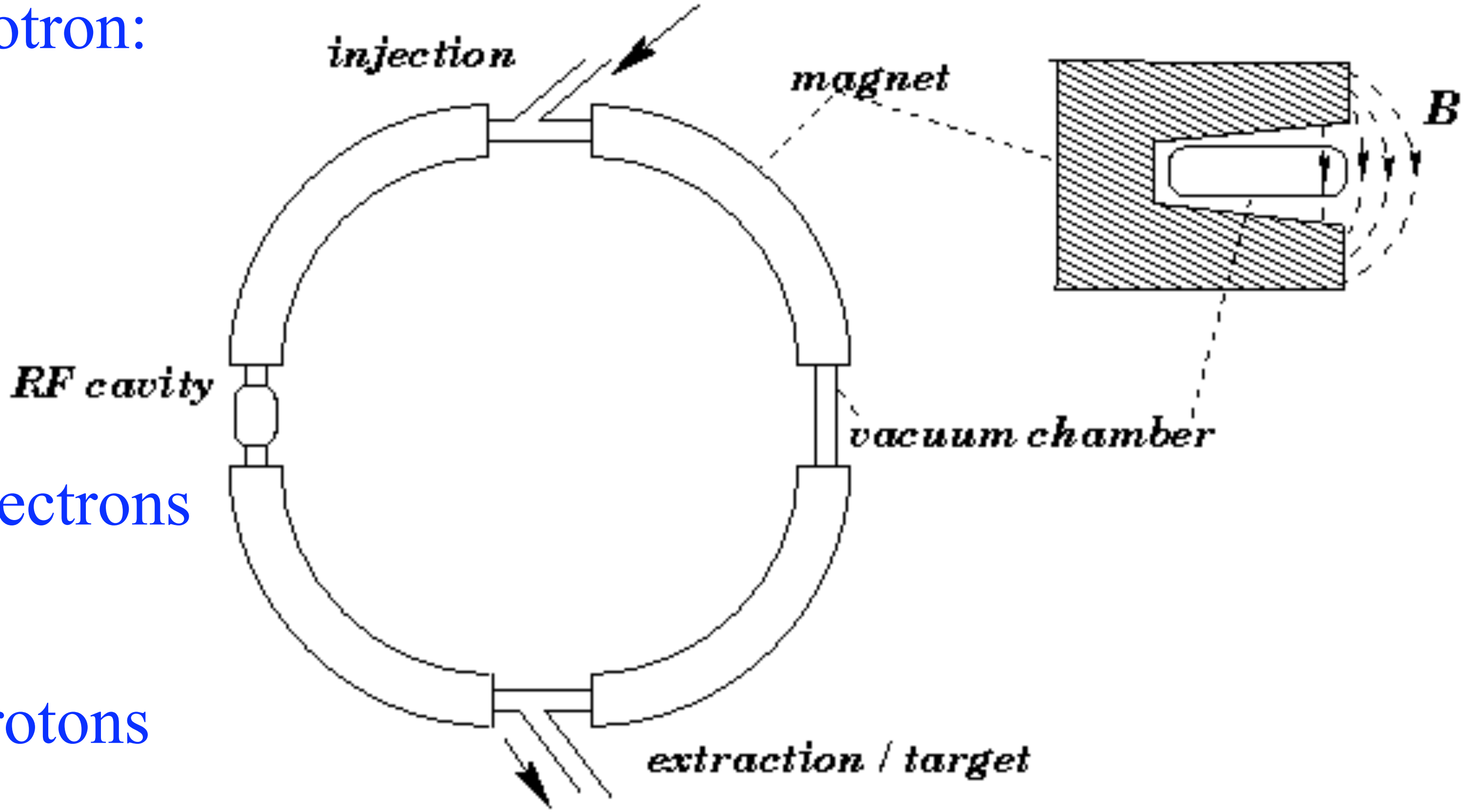
→ revolution frequency is approximately constant!

→ high beam energies require strong magnets and Large storage rings

→ main work horse for high energy particle acceleration

Acceleration with Circular Machines: Synchrotron

- Synchrotron:



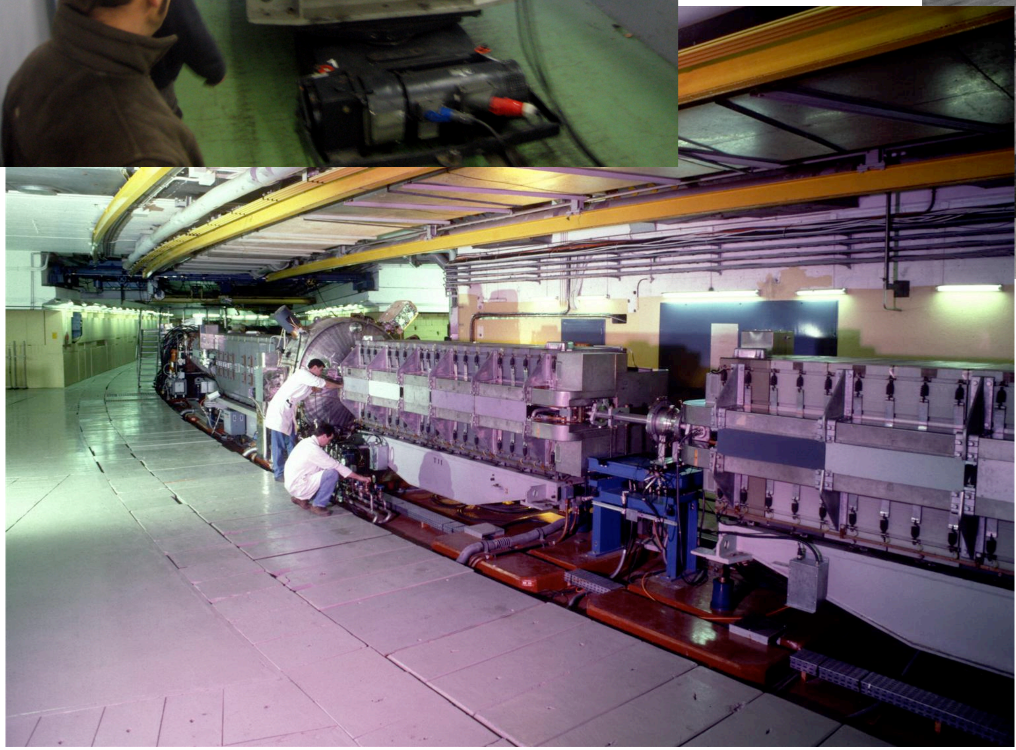
- 1949 electrons
- 1952 protons

high beam energies require strong magnets and
Large storage rings

→ main work horse for high energy particle acceleration

Acceleration with Circular Machines: Synchrotron

- 1959 CERN Proton Synchrotron: first Synchrotron at CERN



First Alternate Gradient Synchrotron in the world!

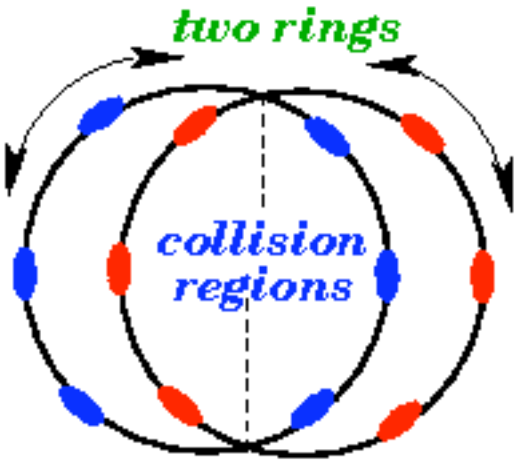
High Energy Physics Research: Collider Concept

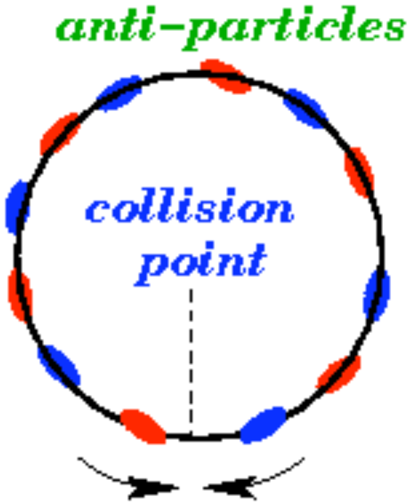
- Fixed target physics (up to 1960's): $E_{CM} \propto \sqrt{E_{beam}}$
- Collider beam physics (after 1960's): $E_{CM} = 2\,E_{beam}$

  -not all particles collide in one crossing ➔ long storage times

  -implies 2 beams and beam-beam interactions ➔ amplitude growth

- Collider options:





Lepton versus Hadron Colliders

- Leptons:

  elementary particles → well defined collision energy
  (precision experiments)

  light particles ($\gamma >> 1$) → synchrotron radiation
  (size, damping, magnet type)

- Hadrons:

  multi particle collisions → energy spread
  (discovery range vs. background)

  heavy particles ($\gamma < 10^4$) → no synchrotron radiation
  (no damping, superconducting magnets)

- In praxis one needs both options: Z_0

  1985 discovered in SppS with $p^+ p^-$ collisions

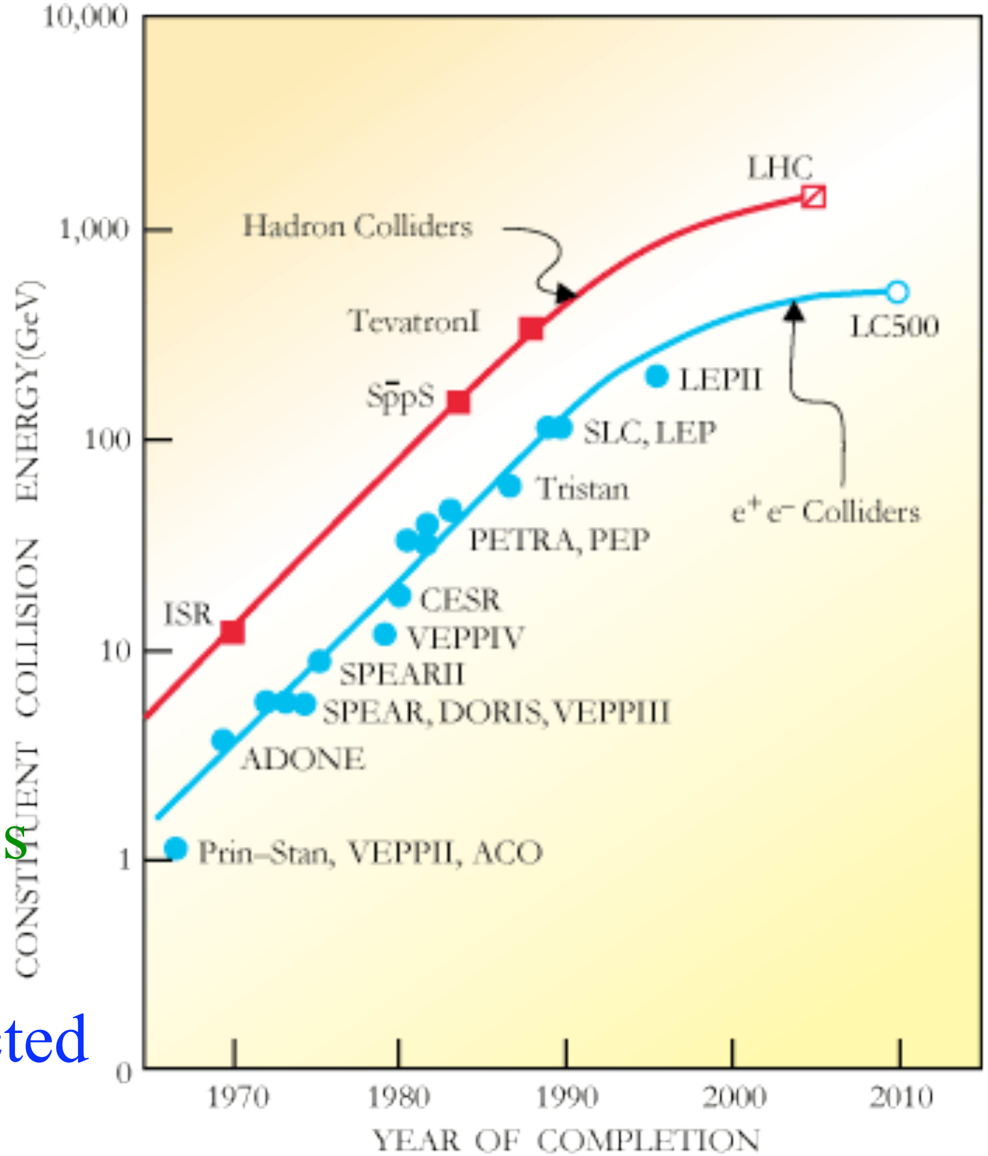
  1990 precision measurement in LEP with $e^+ e^-$ collisions

Evolution of Collider Machines

- Development of the Standard Model:

- Up to 1980's:
  flood of new 'particles'!
  -Introduction of Standard Model
  -Interpretation as QCD resonances
  -prediction of new particles

- 1980's to now:
  dedicated search for predicted particles



→ need for 'discovery' and 'high precision' machines

CERN's Proton Beam Program Chronology

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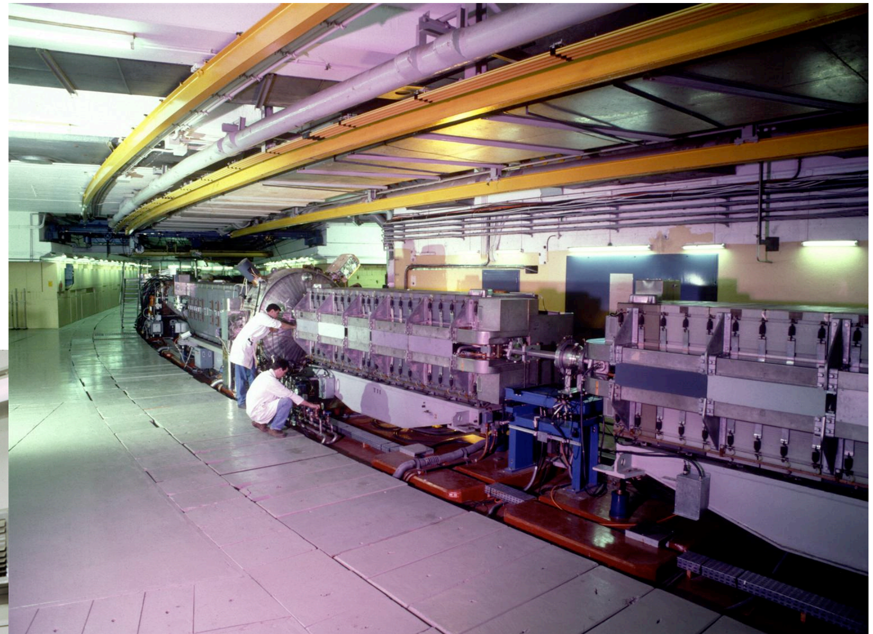
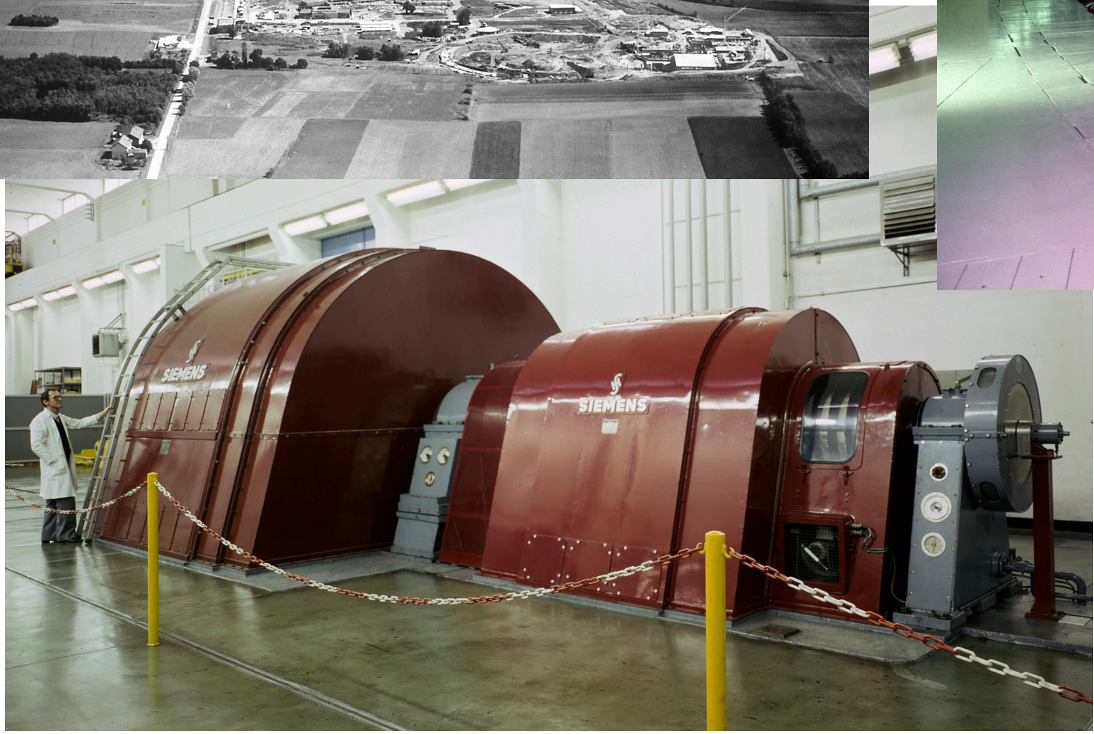
1976	SPS	450GeV	Synchrotron	7km circum; fixed target; proton & Pb ion beams; CP violation & quark-gluon plasma
1977	ICE	46 MeV	Storage ring	Initial cooling experiment
1978	LINAC2	50 MeV	Linac	Cockcroft Walton ➔ RFQ in 1993
1981	SppS	315GeV	Synchrotron	Collider; discovery of W and Z ➔ NP 1984
2008	LHC	7 TeV	Synchrotron	Collider; SC magnets 8.4 T; Higgs?

CERN's Proton Program: PS

- 1959 First Alternate Gradient accelerator





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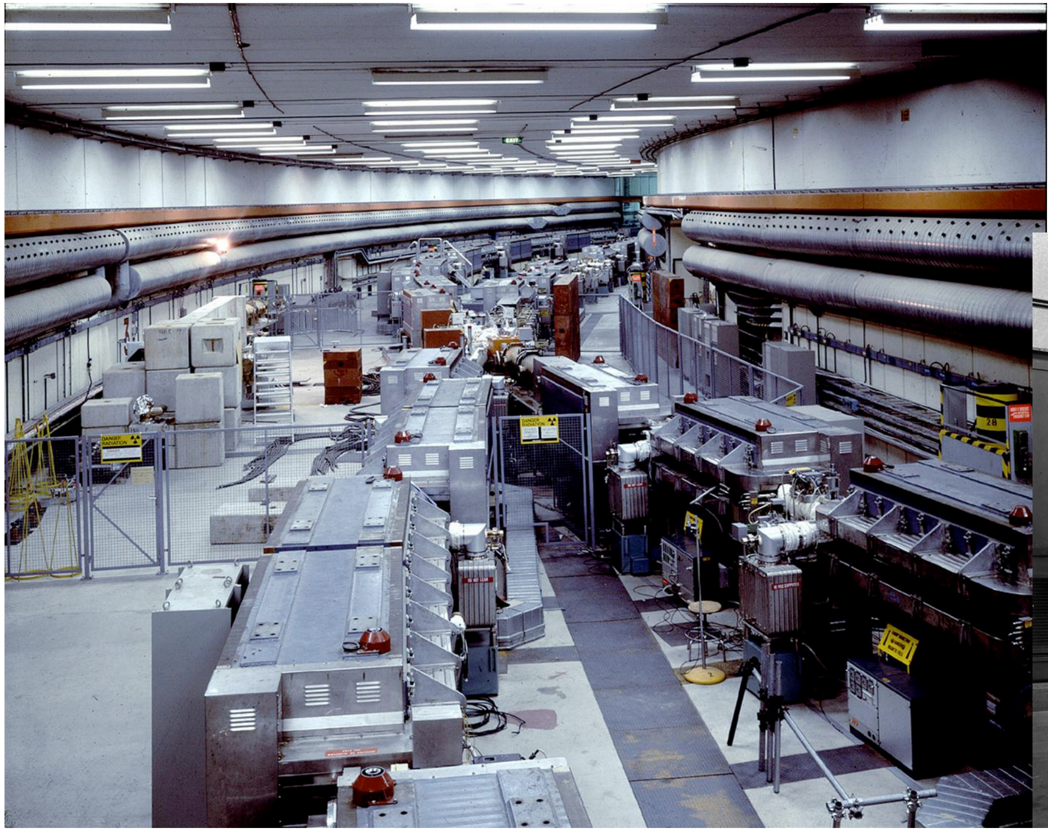
CERN's Proton Program: ISR

- 1971 First Proton Collider; SC magnets; 50A max beam current (32A in operation); p-p; p-d; p-α; α−α; p-p-bar



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CERN's Proton Program: PSB

- 1972: 10 fold increase in proton beam intensity

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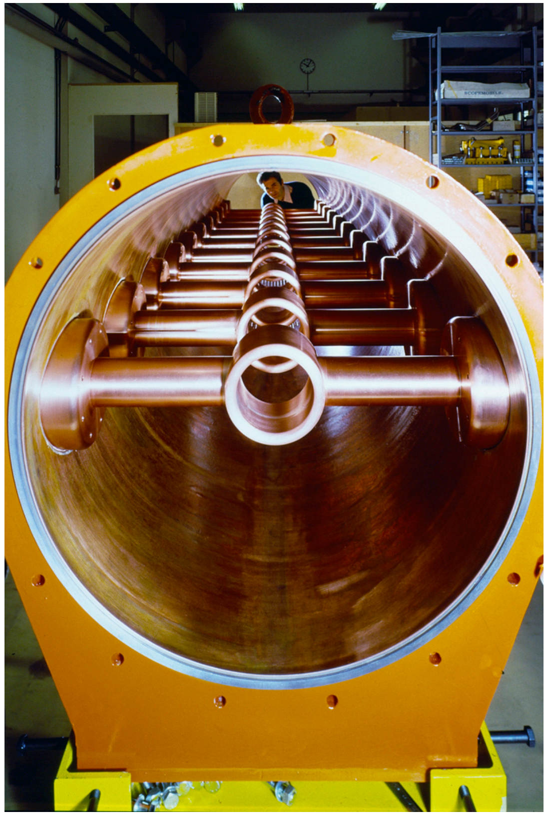
CERN's Proton Program: SPS

- 1976:
  fixed target physics
  with 300 GeV to
  450 GeV proton
  and Pb ion beams



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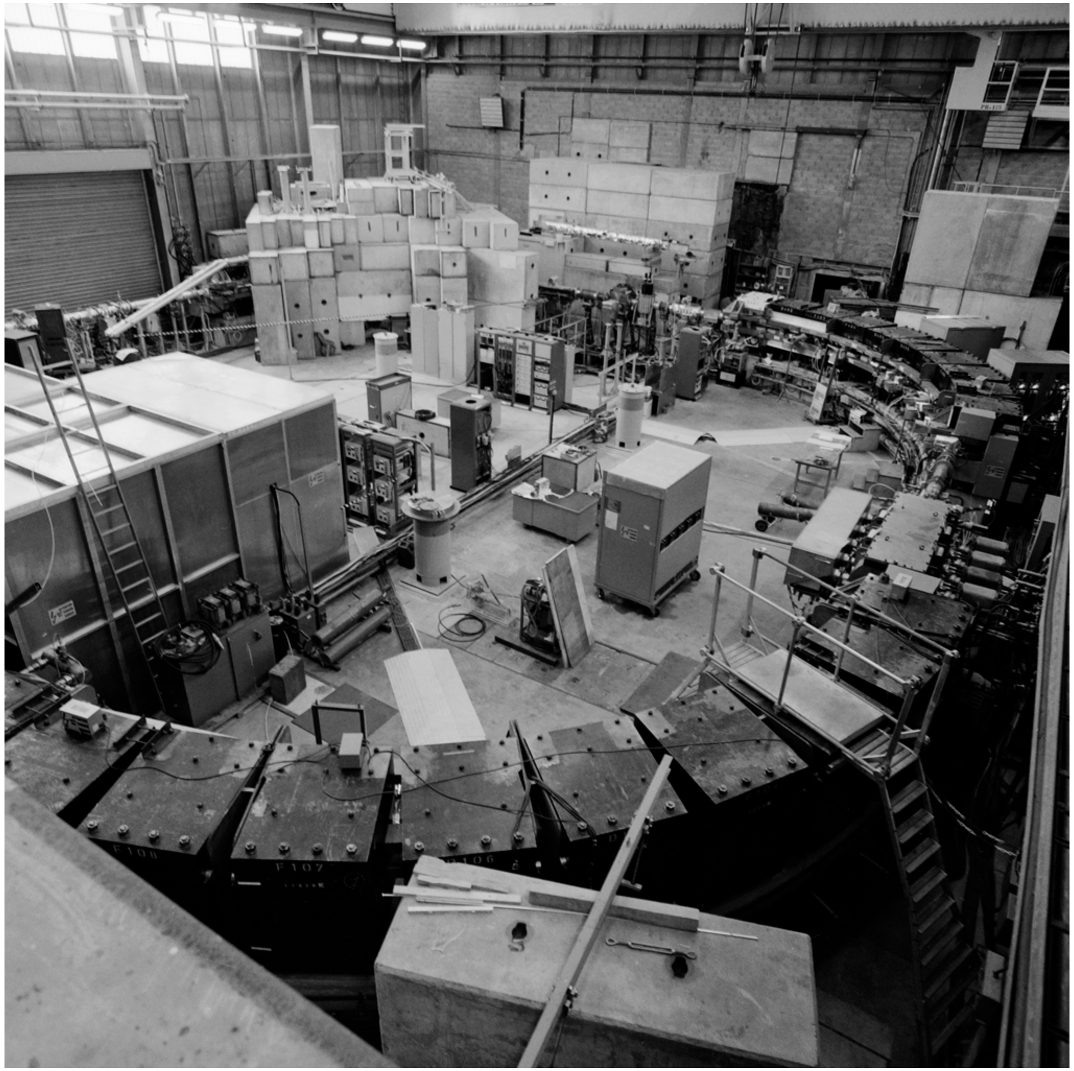
CERN's Proton Program: ICE

- 1977: Initial cooling experiment as preparation for SppS

Build from old magnets
from g-2 experiment;
Stochastic cooling 1978
Electron cooling 1979



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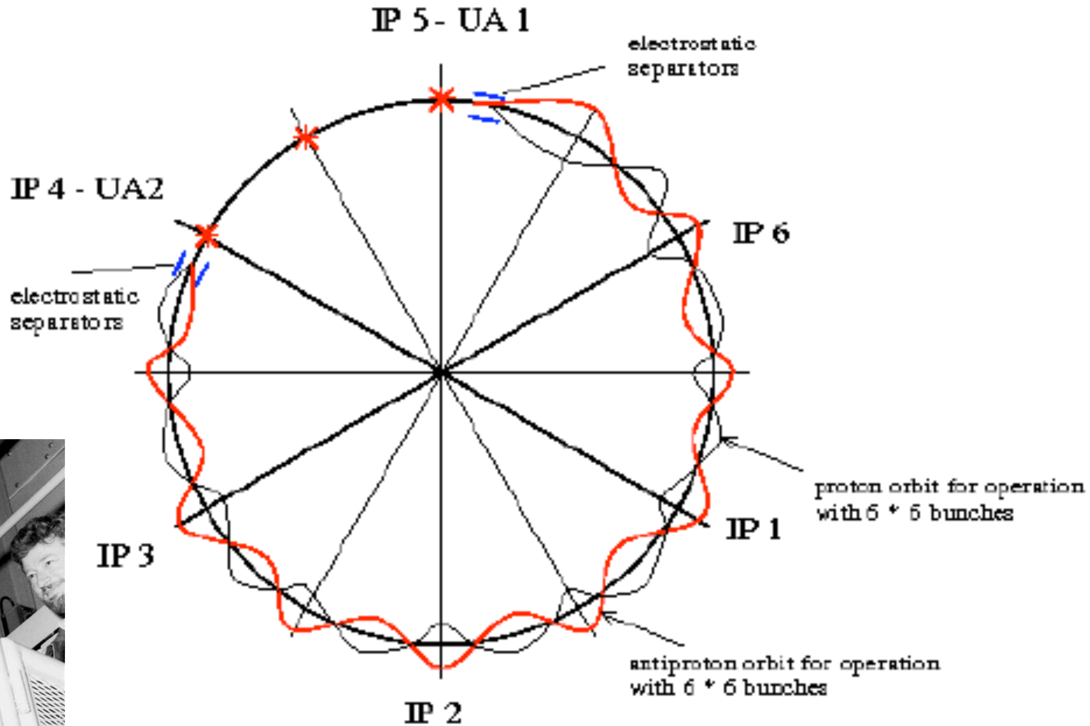
2008	LHC	7 TeV	Synchrotron	Collider; SC magnets 8.4 T; Higgs?

CERN's Proton Program: SppS

- 1981:
  Proton anti-proton Collider 315 GeV; beam energies;
  Nobel Price in 1984



-6 on 6 bunches with pretzel scheme

-elaborate powering scheme for adjusting phase advance between experiments and injection and dump regions

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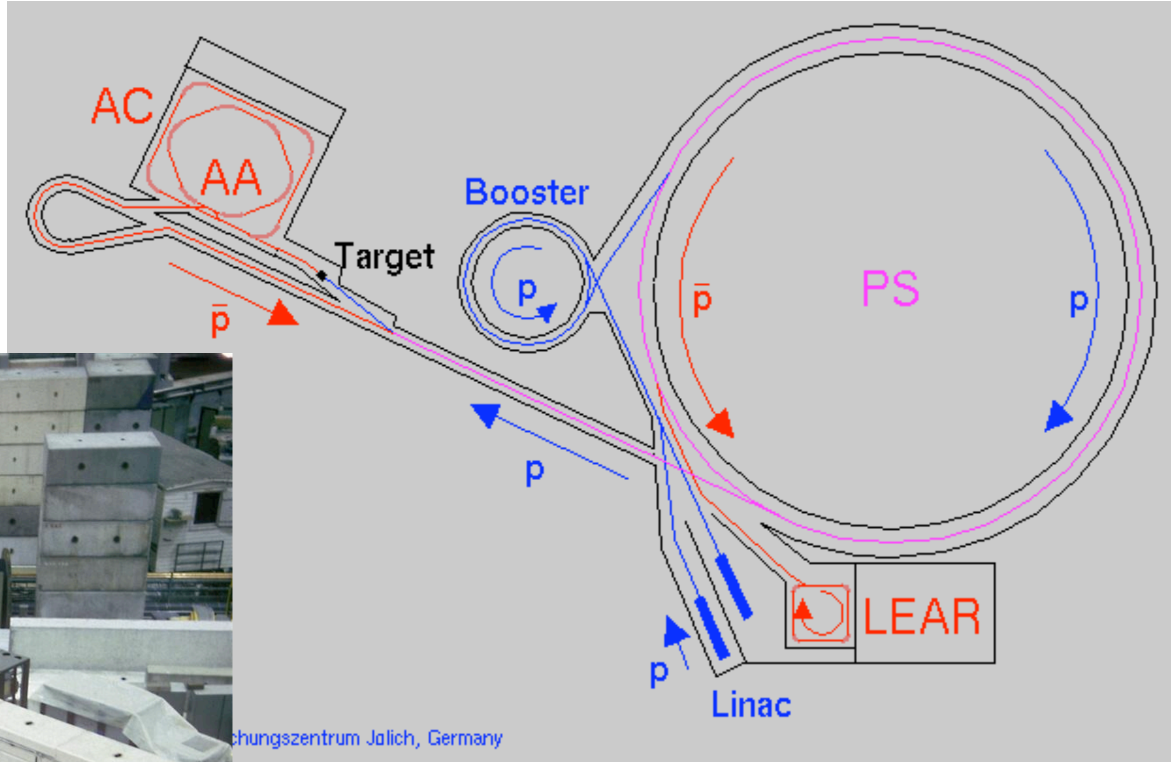
CERN's Anti-Proton Beam Program Chronology

Year	Name	Energy	Type	Key features and Physcs
1977	ICE	46 MeV	Synchrotron Storage ring	Initial cooling experiment (protons); stochastic cooling in 1978; electron cooling of 46 MeV proton beam in 1979 using 1.3 A electron beams of 26 keV.
1980	AA	3.57 GeV	Synchrotron Storage ring	Anti-proton accumulation and stochastic cooling;
1982	LEAR	609 MeV	Synchrotron Decelerator & Storage Ring	Low Energy Anti-proton Ring ➔ electron cooler installed from ICE ➔ anti-proton physics program; observation of first anti-Hydrogen
1986	AC	3.57 GeV	Synchrotron Storage Ring	Anti-proton collector; higher acceptance then AA ➔ 10 fold increase in anti-proton production
1999	AD	100 MeV	Synchrotron Decelerator	Anti-proton deceleration; ATHENA experiment and observation of anti-Hydrogen in 2002; build from AC parts

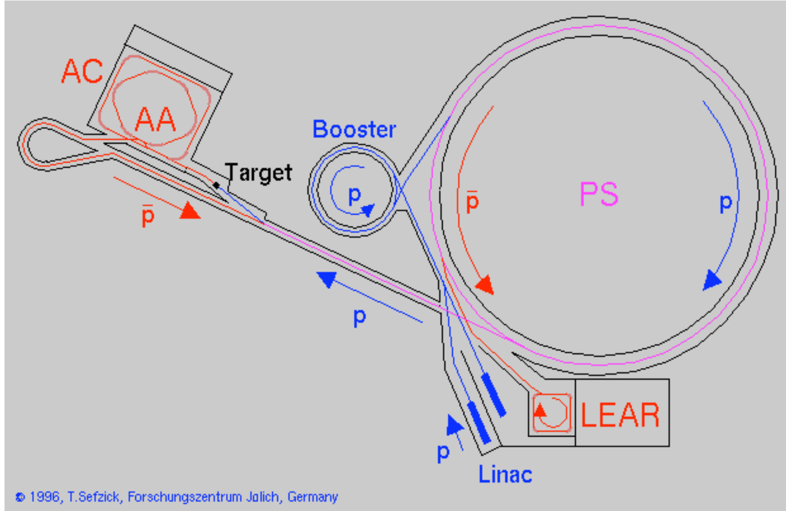
CERN's Proton Program: AA and AC

- AA and AC in the PS South hall



CERN's Anti-Proton Program: AA and AC

- Proton from PS onto fixed target 26GeV ➔ 1 anti-proton at $\approx$ 3.5 GeV for 10^6 p
- p^- collected in AC (acceptance) stacked and stochastically cooled at 3.5 GeV in AA (few 10^{11} p^- /d)
- Anti-protons are accelerated to 26 GeV in PS
- Anti-protons are accelerated to 270 GeV in SPS
- NP for Rubbia and Van der Meer in 1984
- -AA start in 1980 dismantled in 1997
  -AC build in 1986 converted to AD in



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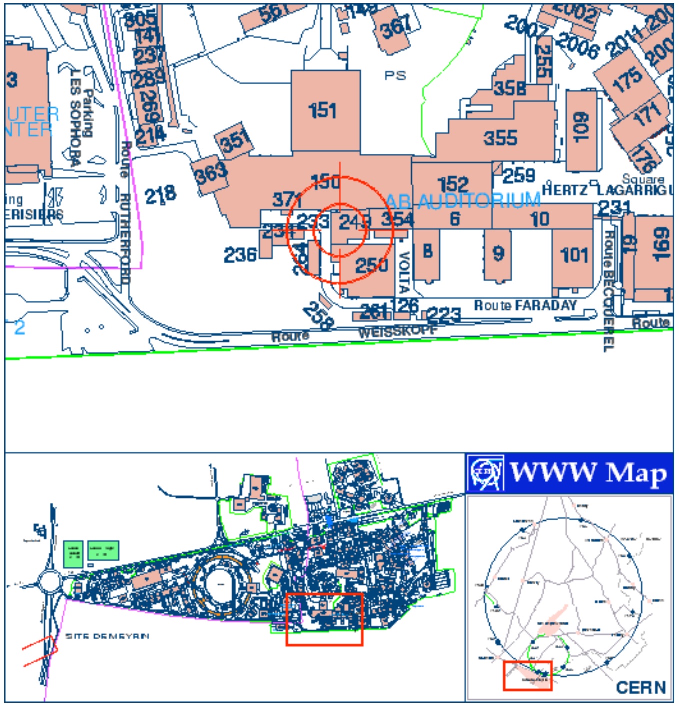
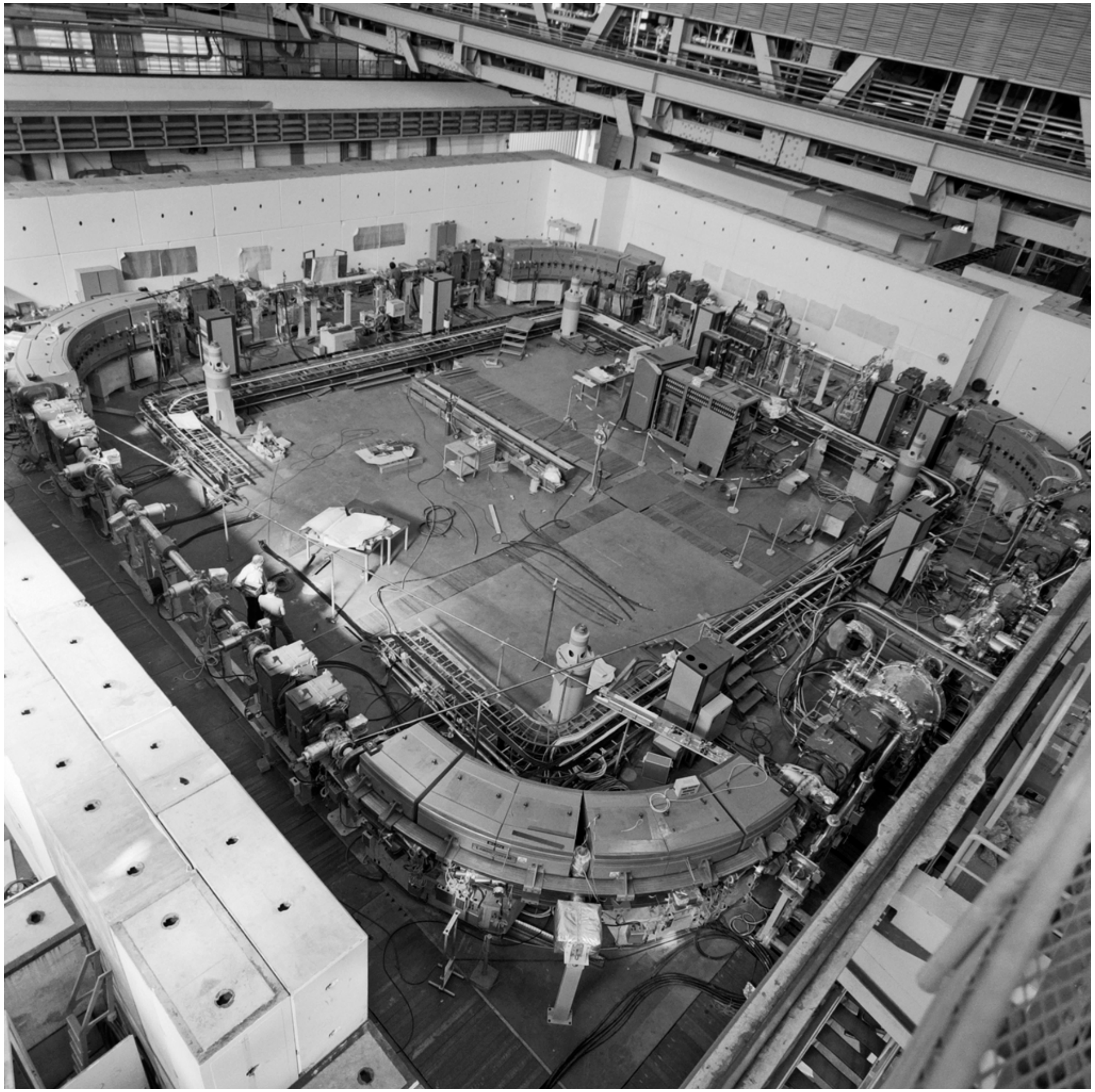
CERN's Proton Program: LEAR

- LEAR next to the LINAC 2 installation:

  converted into
  LEIR 2005-2006





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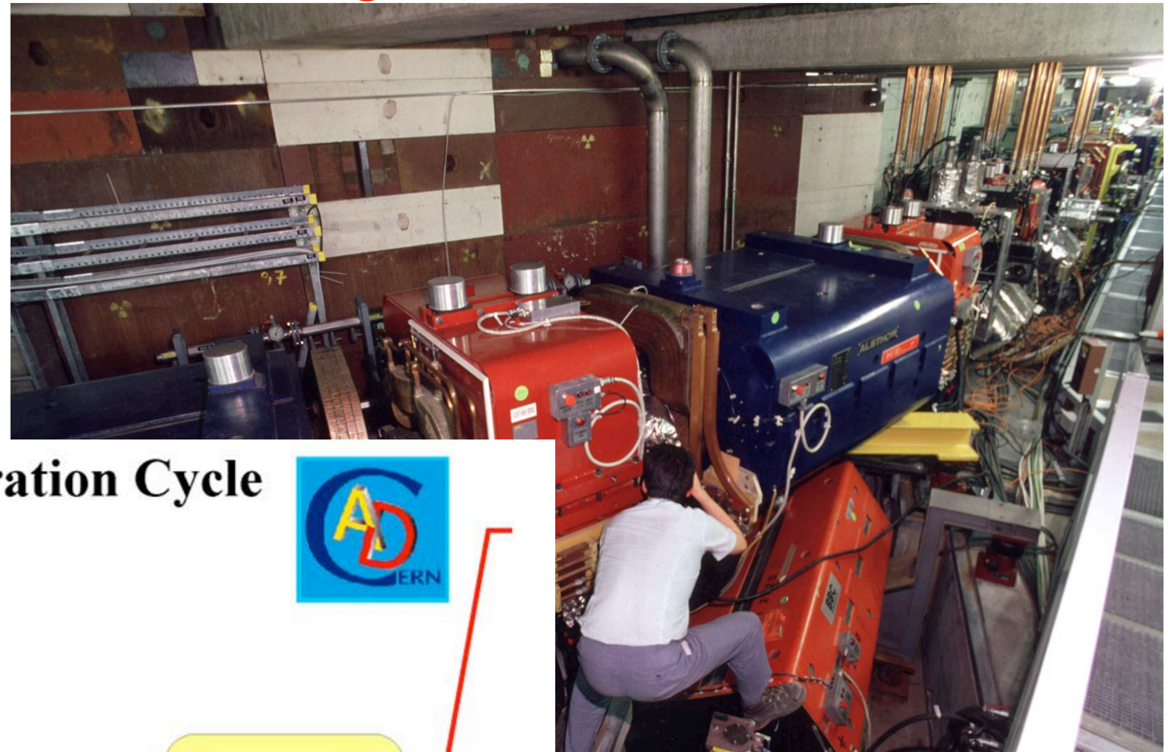
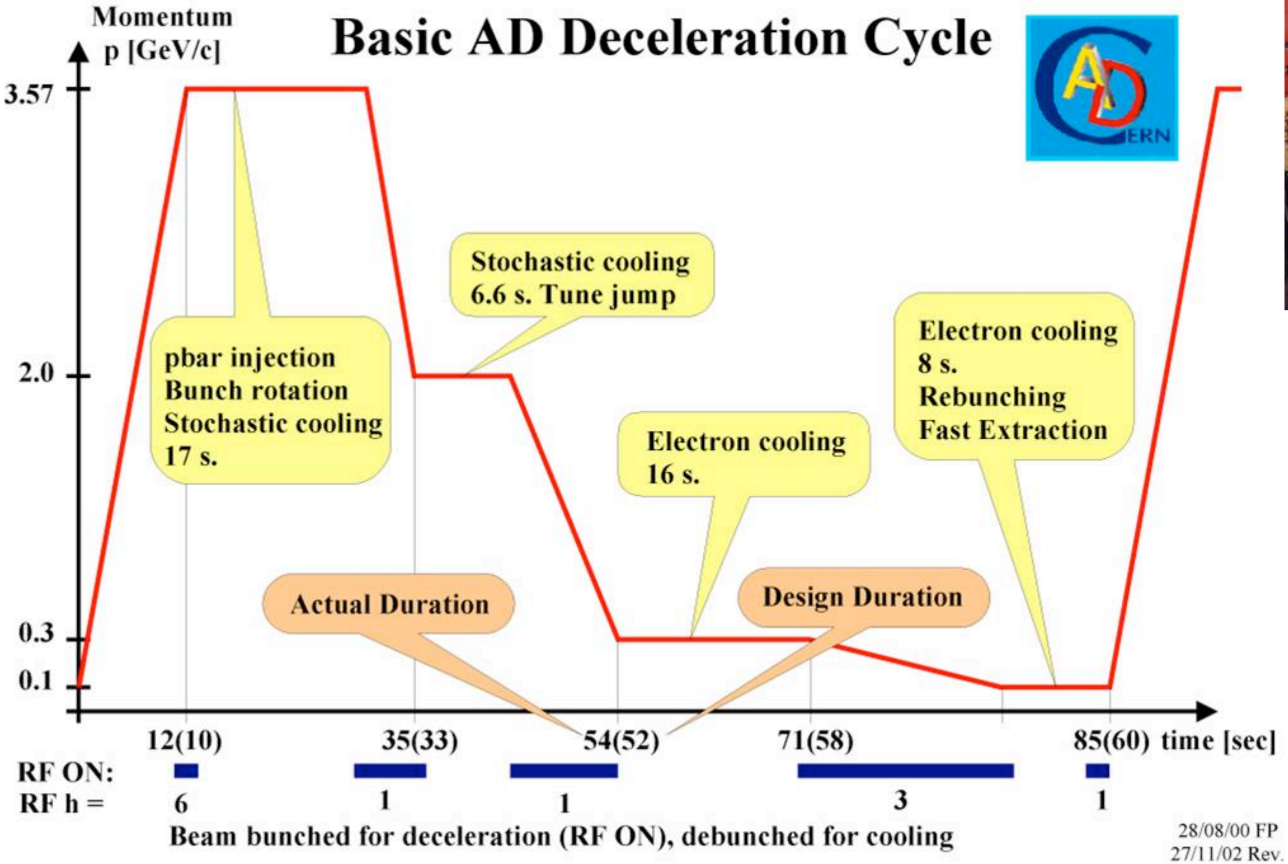
CERN's Proton Program: AD

- 1999: AD installation



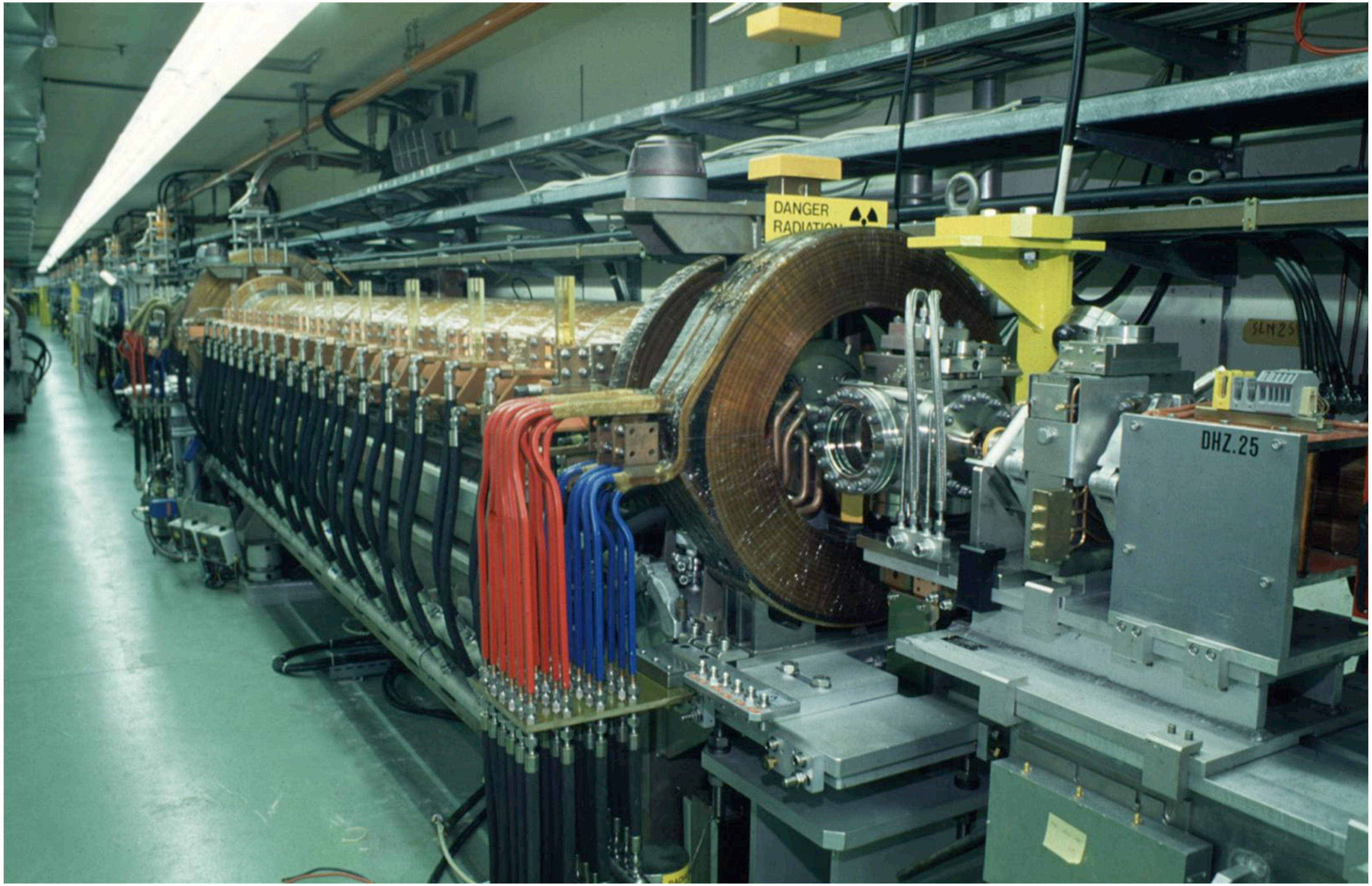


CERN's Lepton Beam Program Chronology

Year	Name	Energy	Type	Key features and Physics
1986	LIL	0.5 GeV	LINAC	Low Current Linac; dismantled in 2000;
1986	EPA	0.5 GeV	Storage ring accumulator	Accumulation of 500 MeV Leptons before acceleration to 3.5 GeV in the PS; dismantled in 2000; located in current CTF3 building.
1959	PS	3.5 GeV	Synchrotron	alternate gradient; multi-purpose machine → RF!!!
1976	SPS	20 GeV	Synchrotron	Acceleration from 3.5 GeV to 20 GeV
1989	LEP	45 GeV to 104 GeV	Synchrotron	Ground breaking in 1983; dismantled in 2000; NC RF for LEP I and SC RF for LEP II; 3650 MV total voltage for LEP II; beam separation; polarization; NEG vacuum pump; precision measurement for Z and W; confirmation of Standard Model with 3 lepton-neutrino families; Higgs search in 2000 → 104.5 GeV
1998	CTF		LINAC	NC high frequency structures; 30 GHz
2001	CTF3	100 MeV to 1 GeV	LINAC	Drive beam concept
????	CLIC	0.5 GeV to 3 TeV	2 x LINAC Collider	Wake fields; alignment; spot size at IP

CERN's Lepton Program: LIL

- LIL



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CERN’s Lepton Program: EPA

EPA

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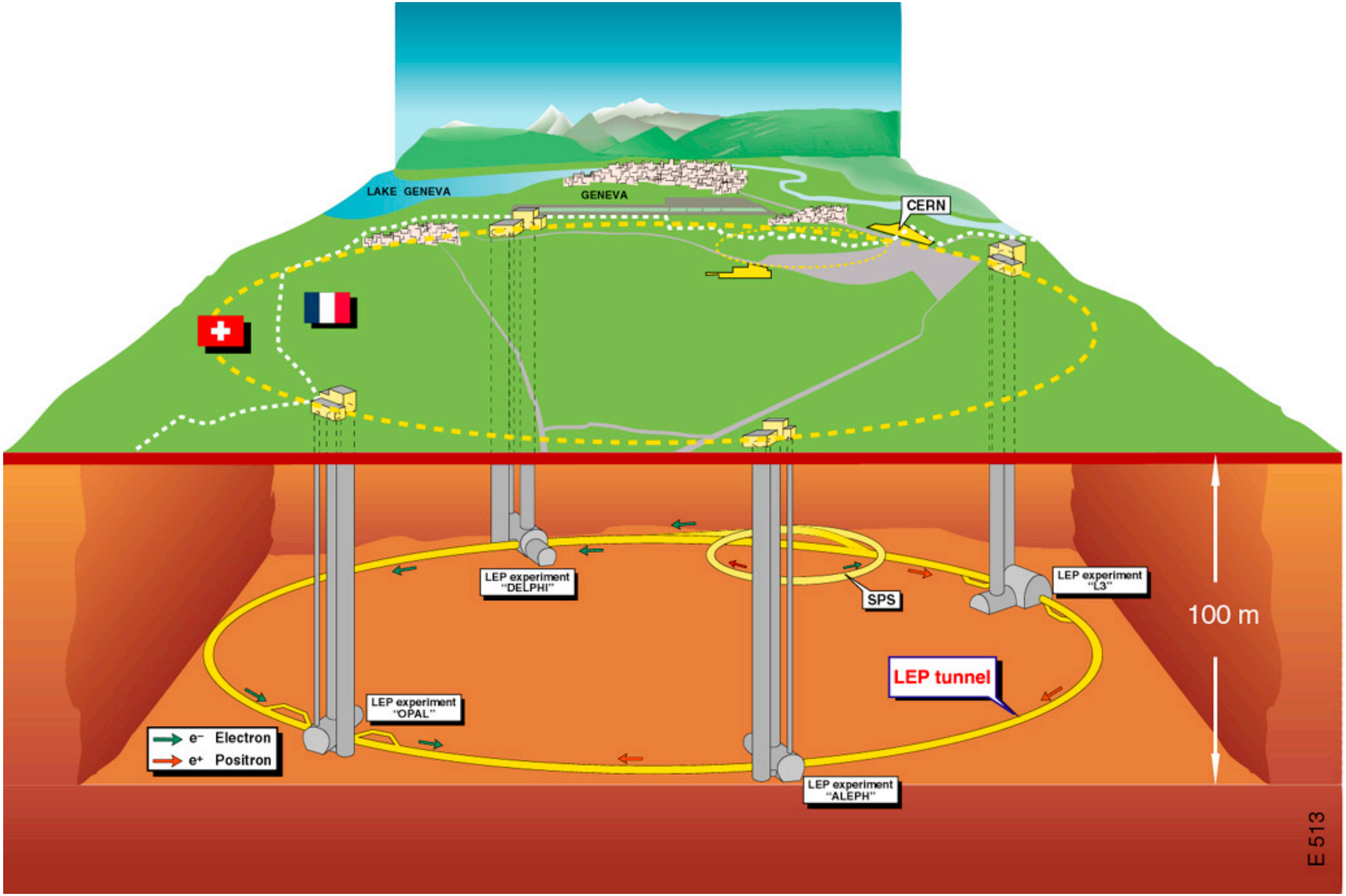
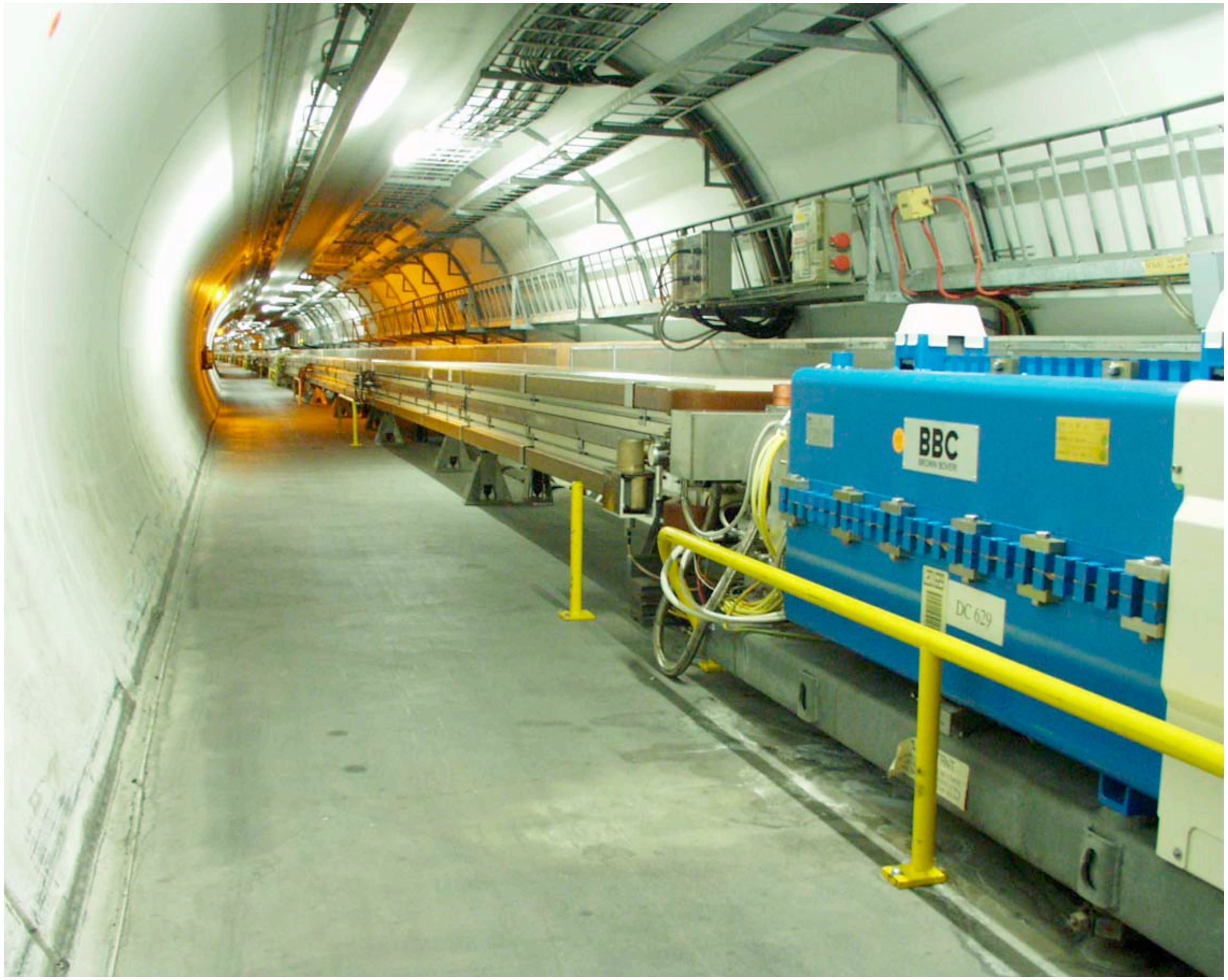
CERN's Lepton Program: LEP



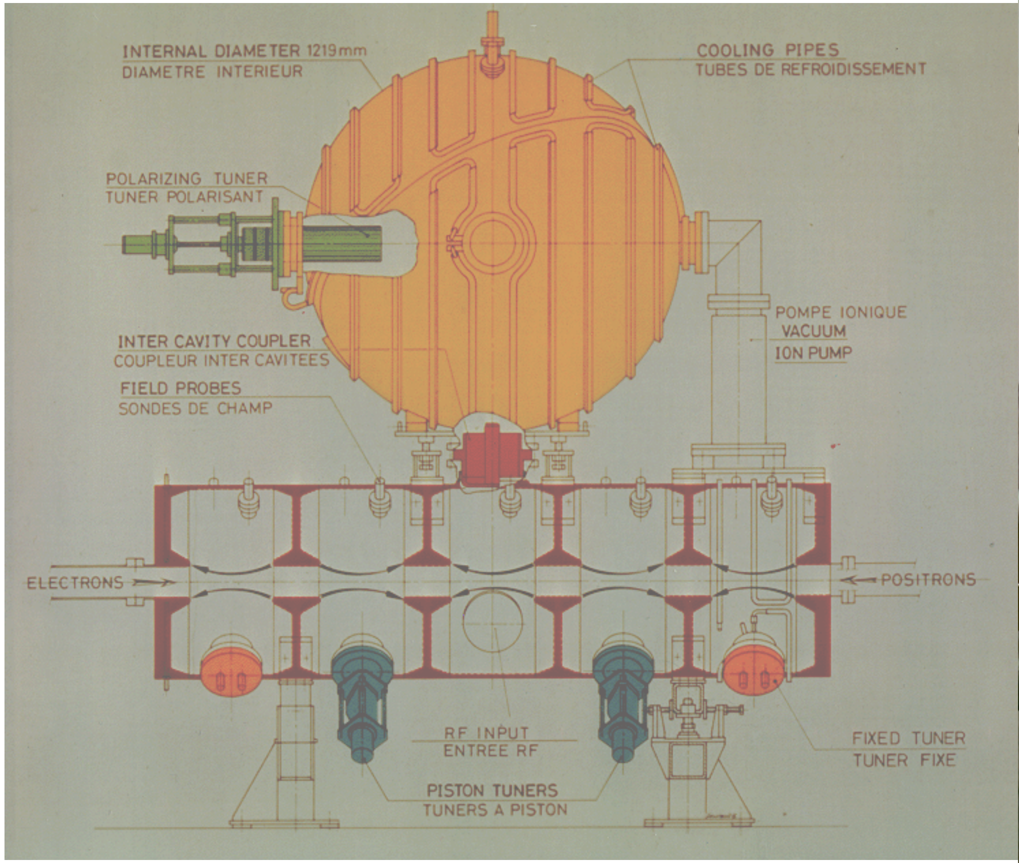
CERN's Lepton Program: LEP

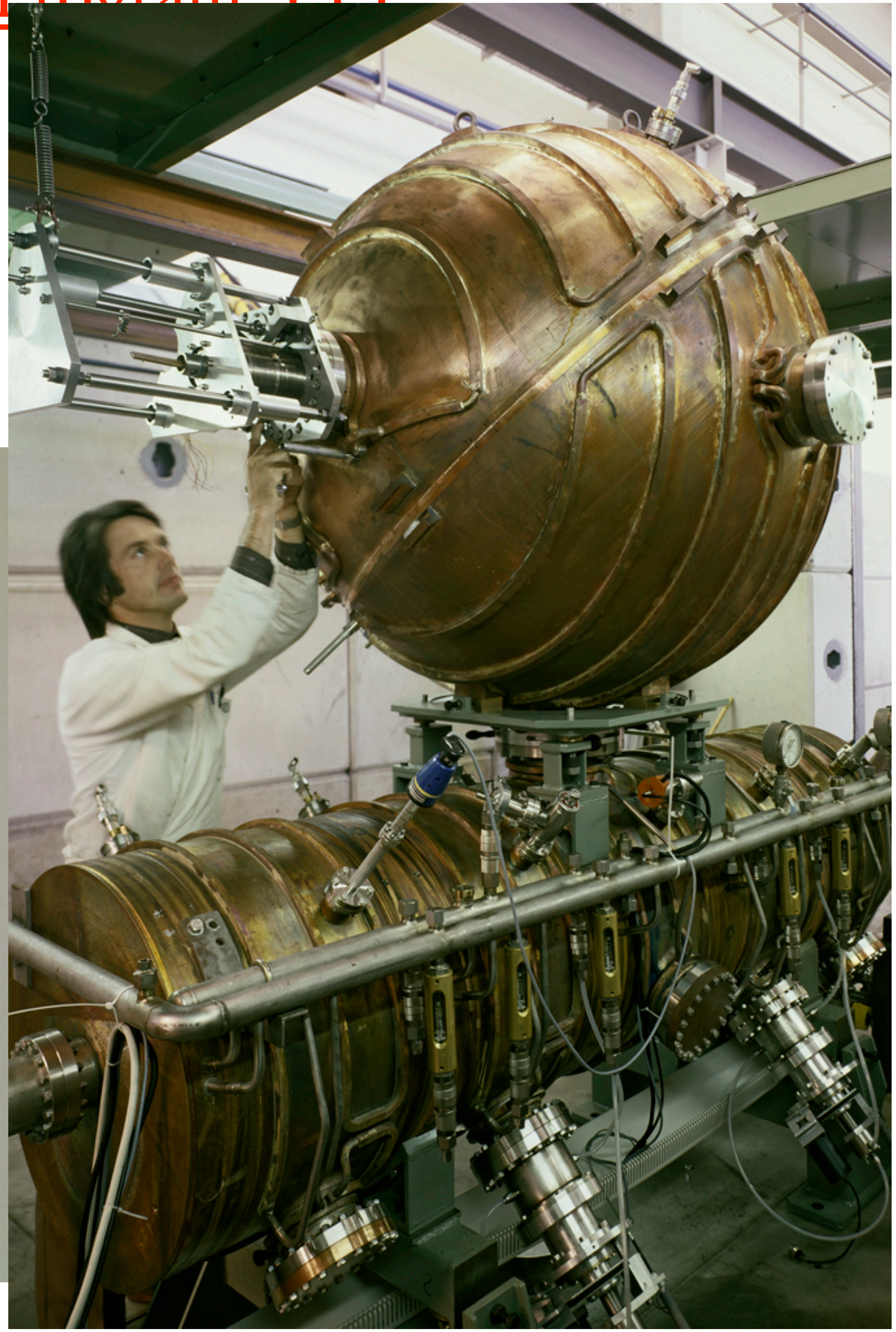
- LEP:
  -27 km tunnel
  -'low tech'
  magnets
  -'high tech'
  cavities
  -precision
  measurement
  (moon, seasons,
  TGV ….)



CERN's Lepton Program: LEP

- LEP I: nc Cu Cavities;
  350 MHz; 2.5 MV / cavity
  LEP 1: 260 MV turn
  @ 45 GeV





CERN's Lepton Program: LEP

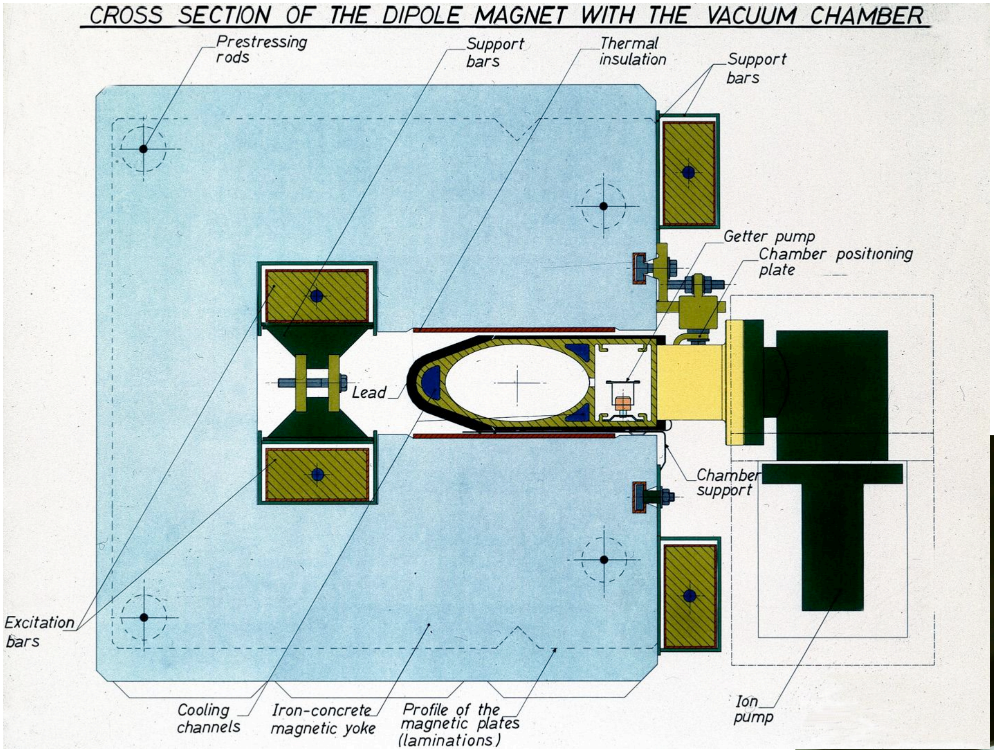
- LEP II: sc Nb Cavities; 350 MHz 4 cell structures;
  8.5 MV to 10 MV / cavity for Nb sheet and Nb film cavities

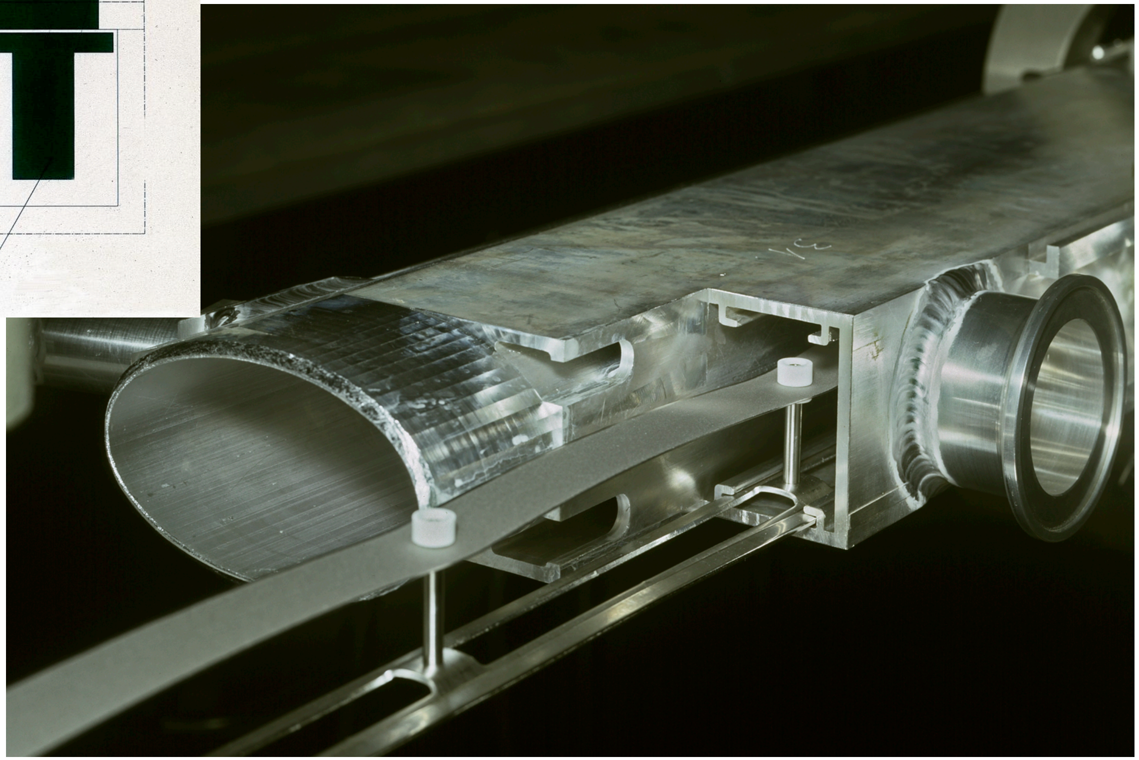
LEP II: 2.8 GV
@ 100 GeV

CERN's Lepton Program: LEP

LEP

SR power LEP 1: 2.1 MW
LEP 2: 23 MW





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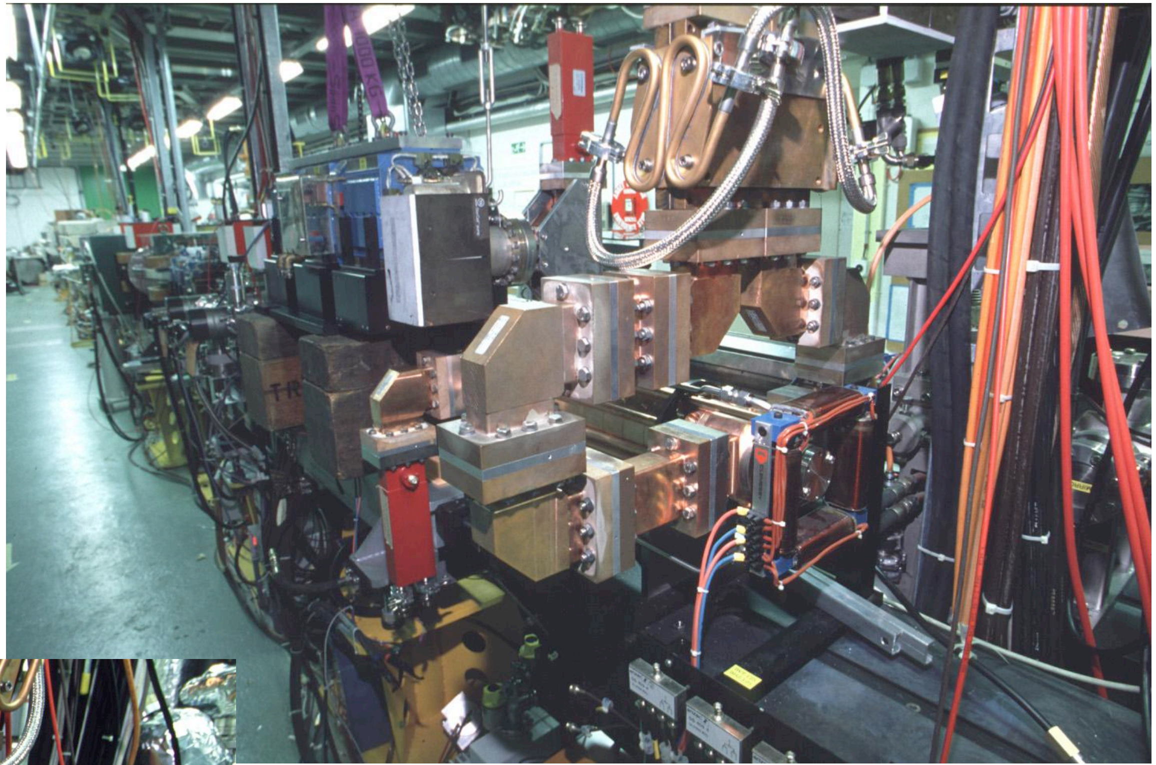
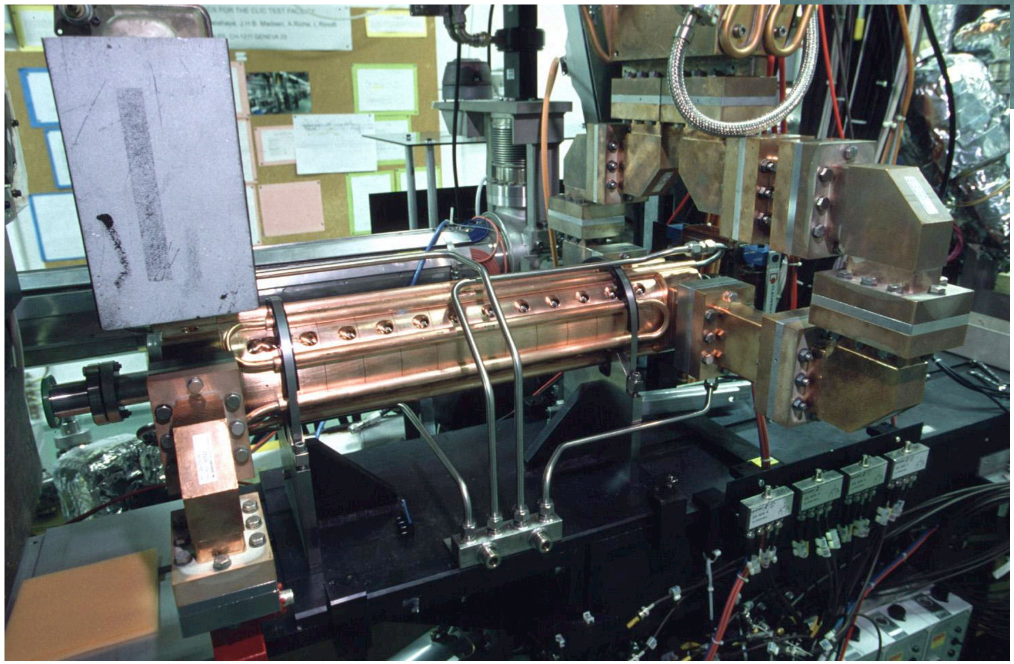
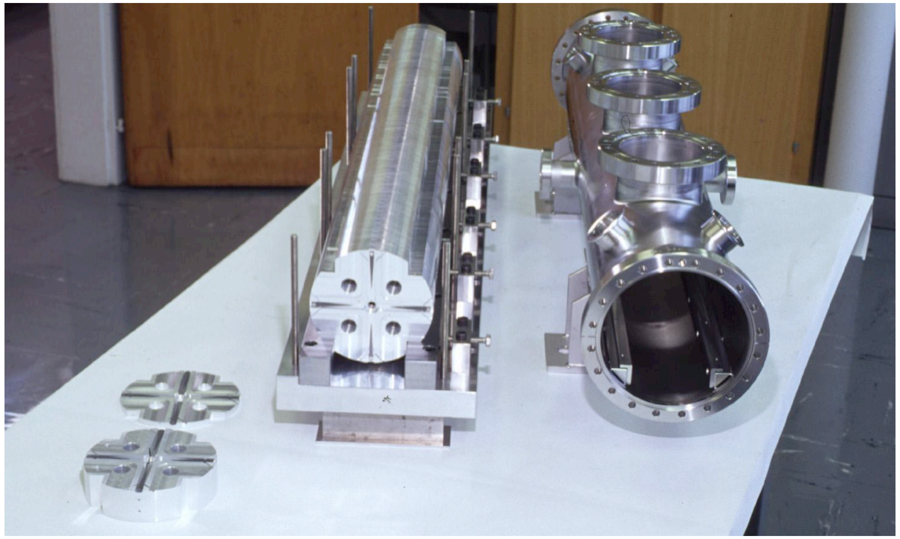
1959	PS	3.5 GeV	Synchrotron	alternate gradient; multi-purpose machine ➔ RF!!!
1976	SPS	20 GeV	Synchrotron	Acceleration from 3.5 GeV to 20 GeV
1989	LEP	45 GeV to 104 GeV	Synchrotron	Ground breaking in 1983; dismantled in 2000; NC RF for LEP I and SC RF for LEP II; 3650 MV total voltage for LEP II; beam separation; polarization; NEG vacuum pump; precision measurement for Z and W; confirmation of Standard Model with 3 lepton-neutrino families; Higgs search in 2000 ➔ 104.5 GeV
1998	CTF		LINAC	NC high frequency structures; 30 GHz
2001	CTF3	100 MeV to 1 GeV	LINAC	Drive beam concept; 12 GHz
????	CLIC	0.5 GeV	2 x LINAC Collider	Wake fields; alignment; spot size at IP

CERN's Lepton Program: CTF

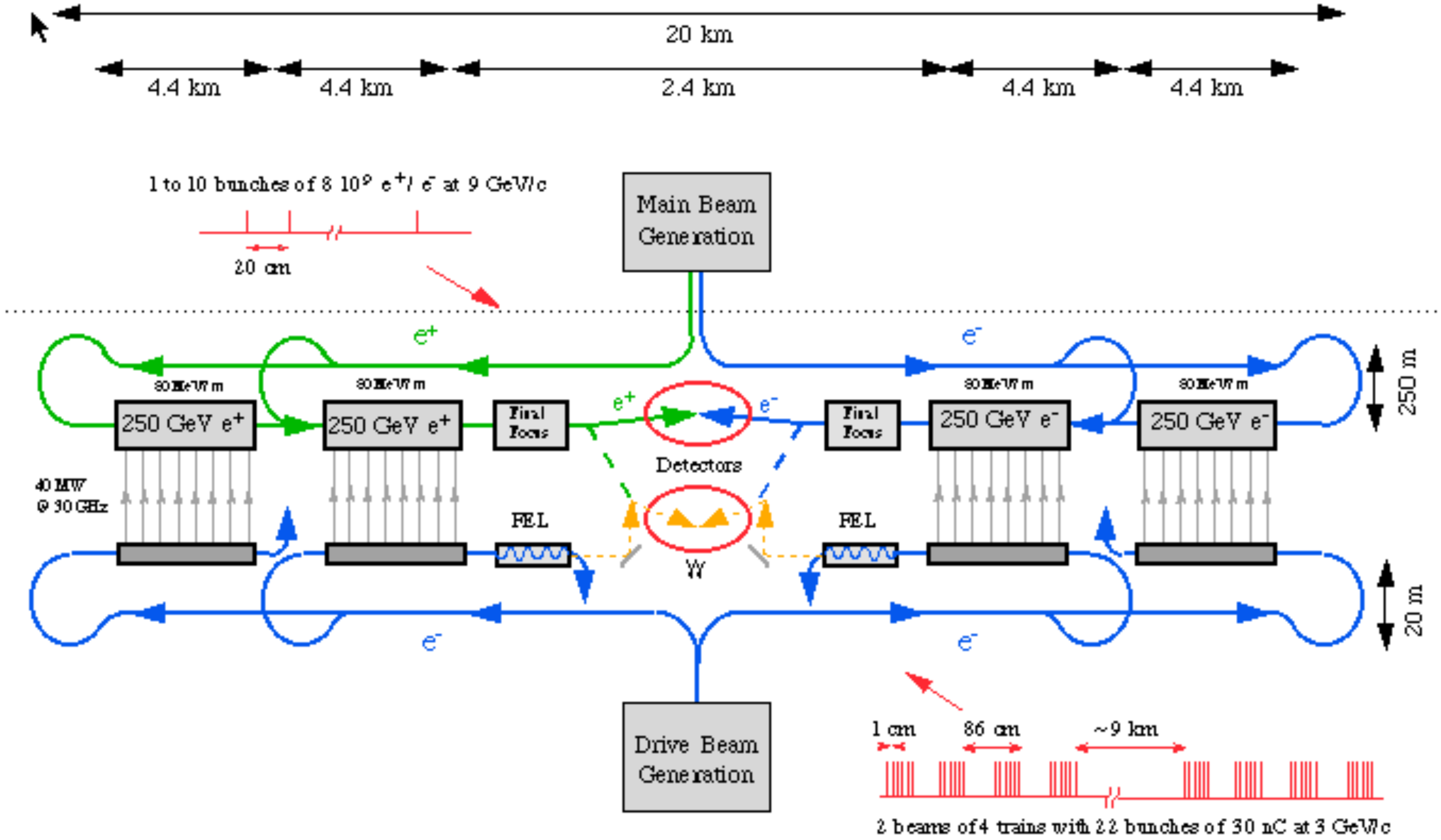
- CLIC Test Facility



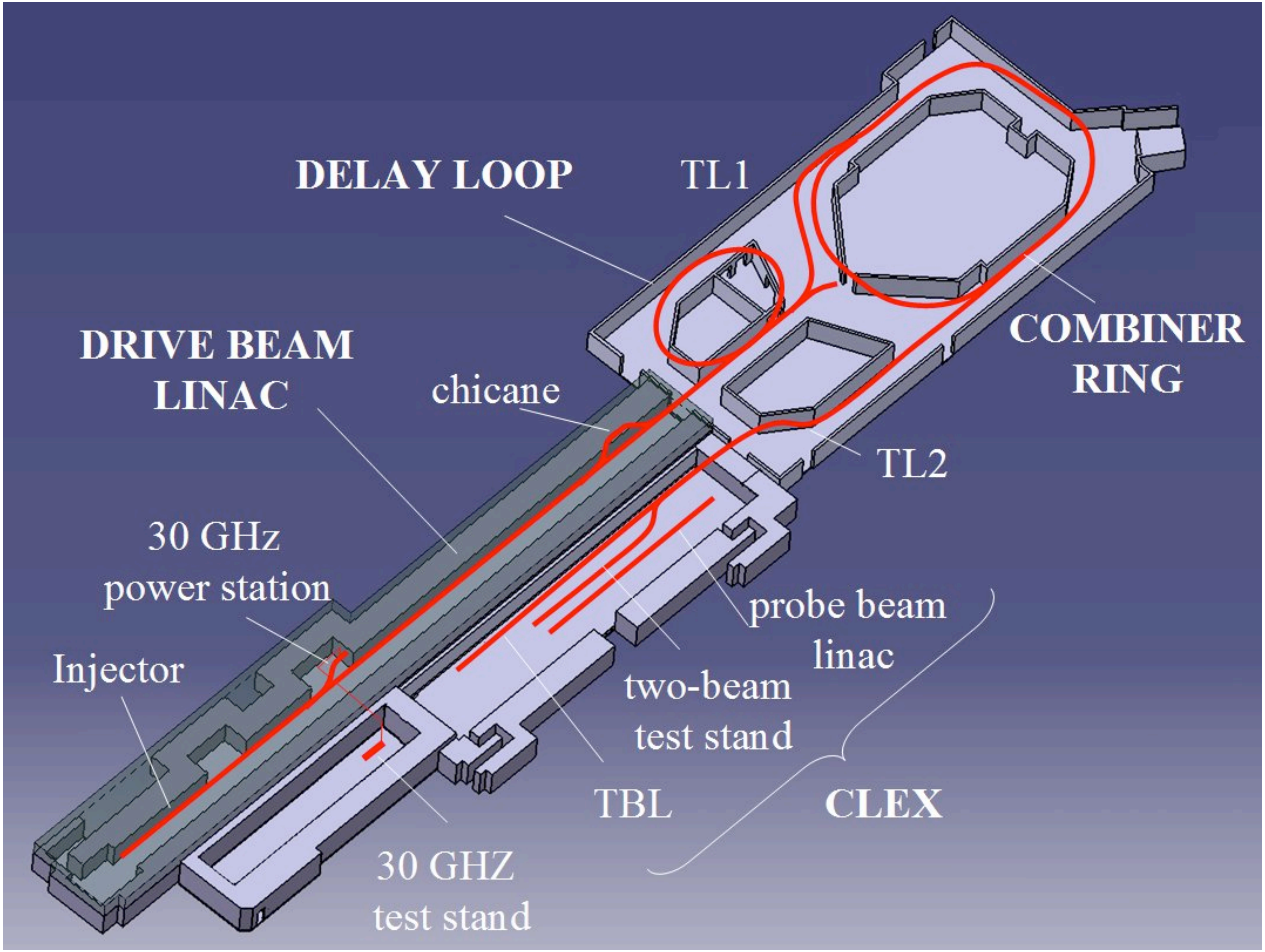




CERN's Lepton Program: CLIC

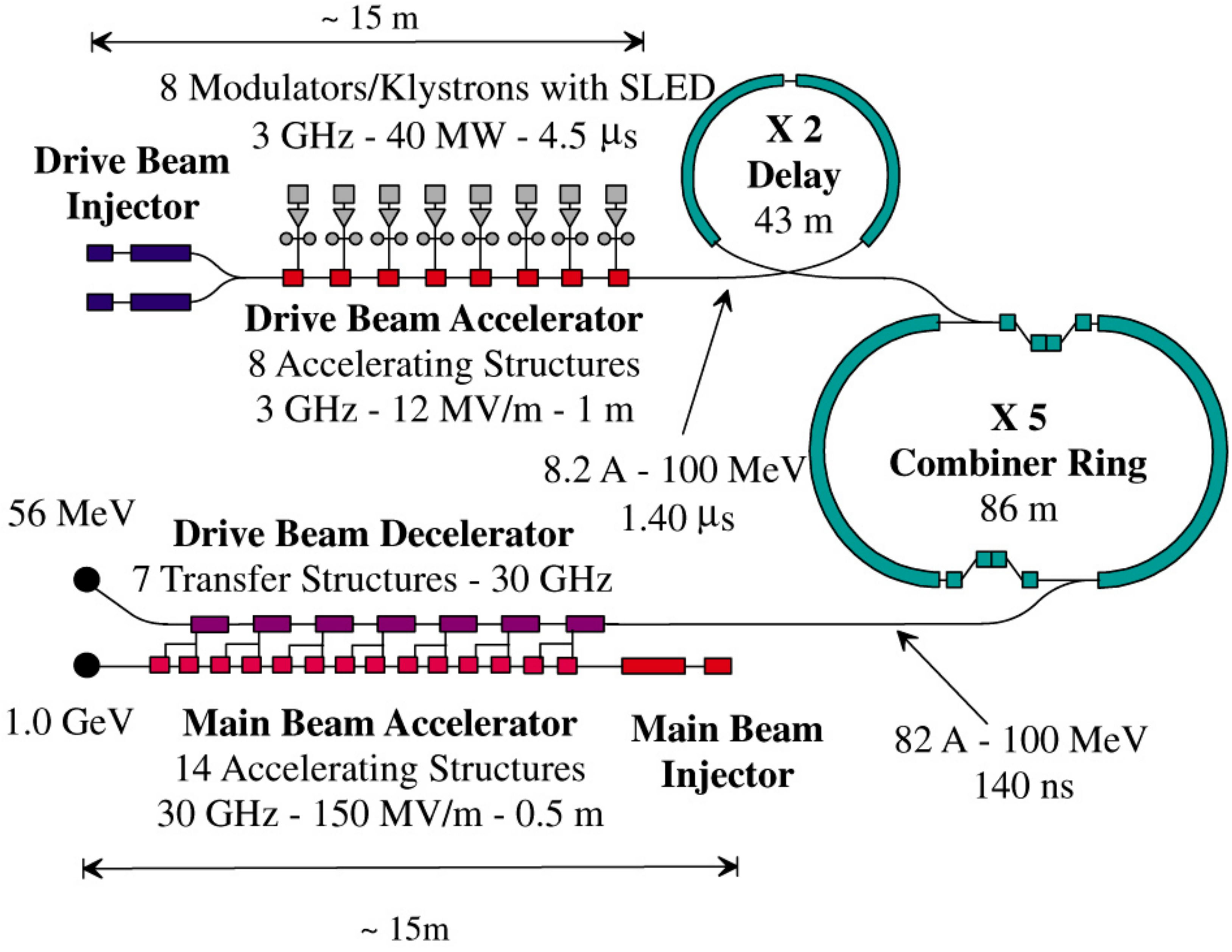


Schematic Layout of the CLIC complex at 1 TeV c.m.


DELAY LOOP
TL1
COMBINER
RING
DRIVE BEAM
LINAC
chicane
TL2
30 GHz
power station
probe beam
linac
Injector
two-beam
test stand
TBL
CLEX
30 GHZ
test stand

CTF 3

Test of Drive Beam Generation, Acceleration & RF Multiplication



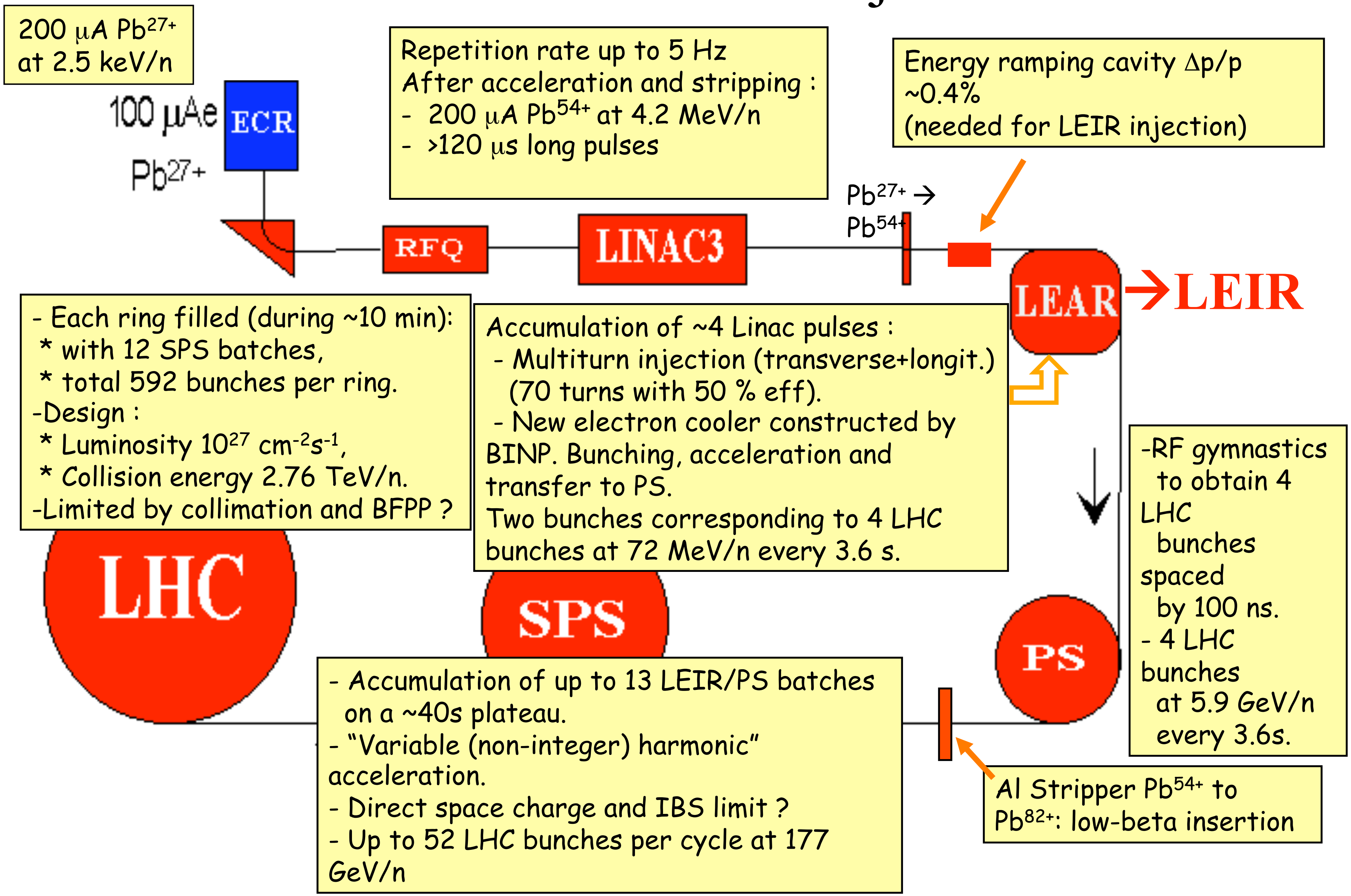
CERN's Lepton Program: CTF3

CTF3 Combiner Ring

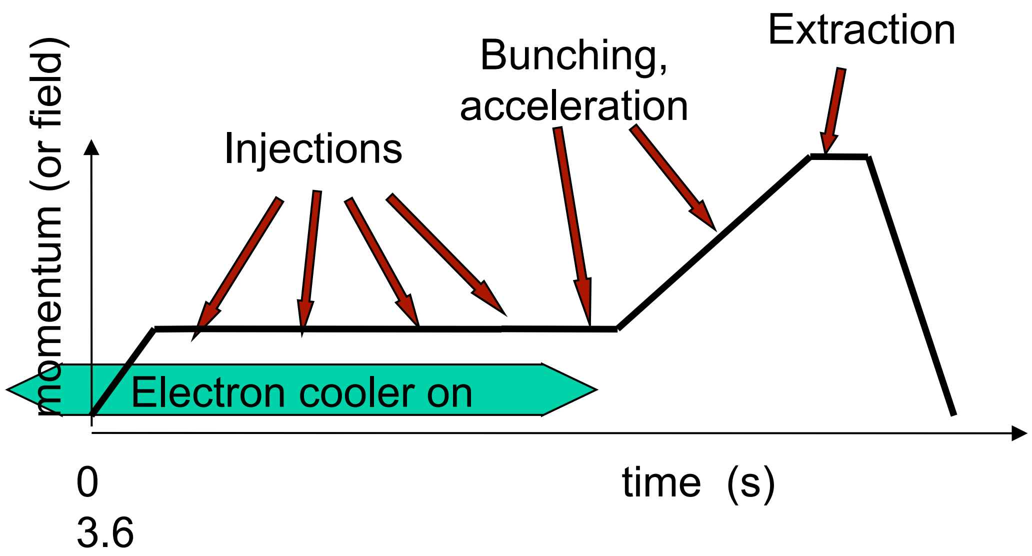
CERN's Ion Beam Chronology

Year	Name	Energy	Type	Key features and Physcs
1959	LINAC1	50 MeV	Linac	Oxygen and Sulphur ions for SPS fixed target physics
1978	LINAC2	50 MeV	Linac	Oxygen and Sulphur ions for SPS fixed target physics
1994	LINAC3	26 GeV	Synchrotron	Preparation of 208Pb53+ beams using a 18 GHz ECR ion source; RFQ and 3 tank IH structure
2005	LEIR	31 GeV	Synchrotron	Converted LEAR ring; stochastic cooling
2008	LHC	7 TeV	Synchrotron	Collider; SC magnets 8.4 T;

Overview of the LHC Ion Injector Chain

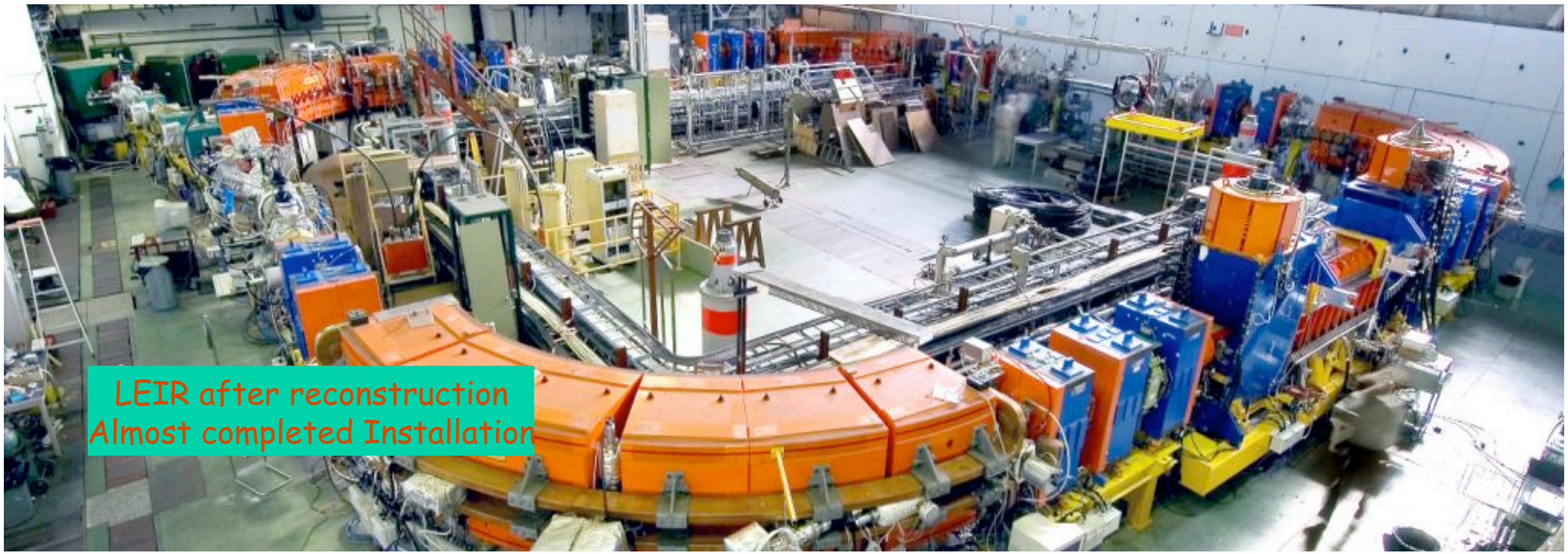


LEIR - Overview



Accumulation:

- Elaborate multiturn injection :
  - Stacking in three phase planes,
  - Needs momentum ramping and dispersion at injection,
  - 70 turns with >50% efficiency every 200 ms to 400 ms.
- Fast electron cooling :
  - New cooler constructed (BINP)



CERN's Experimental Accelerator Installations

Year	Name	Energy	Type	Key features and Physcs
1963	CESAR	1.75 MeV	Storage Ring Accumulator	Study for ISR preparation, 24m circumference; study of stacking procedures; transverse beam stability and vacuum stability (6E-11 Torr); dismantled in 1968
1967	ISOLDE	0.6 GeV	Target and specrtometer	Isotope Separator Online; receiving beam from the SC until 1990
1973	ISOLDE-2	0.6 GeV		SC upgrade to 4 micro ampere
1974	g-2	0.6 GeV	Storage ring	Muon storage ring; burst of Pions are injected and polarized Muon's from their decay are captured on stable orbits; magnetic precession of Muons creates modulation in the decay-electron counting from which the anomalous moment can be derived
1992	ISOLDE	0.8-1.4 GeV		New ISOLDE facility with beam from the PSB
2000	REX-Isolde	450GeV	Trap and Linac	Penning trap for charge breeding; cooling; charge stage multiplication with EBIS; mass separator and accelerator (RFQ, I-H struc)
2008	CNGS	450GeV	Target and SPS	Neutrino beam production

CERN's Proton Program: CESAR

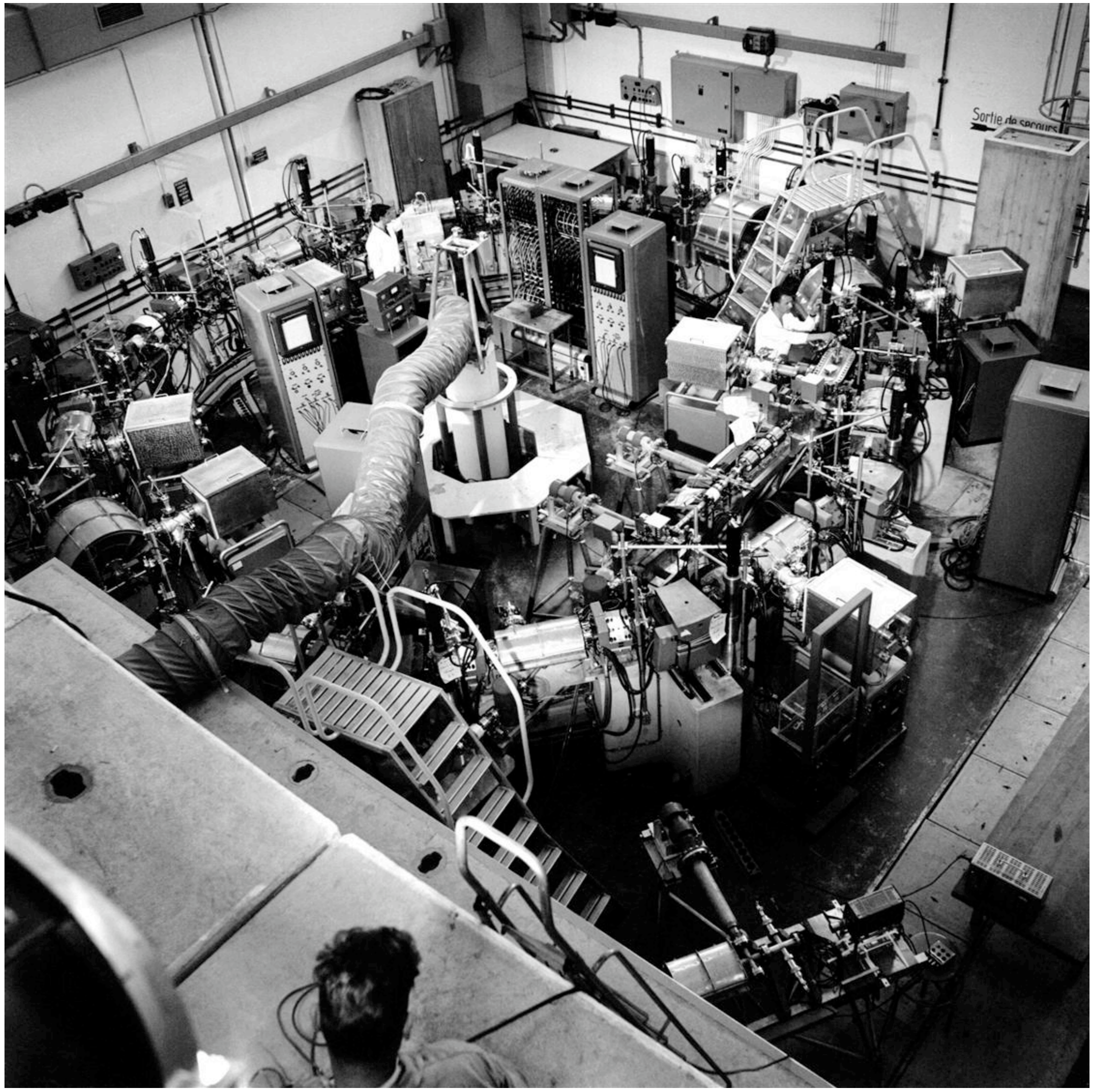
- 1963:

Experimental storage ring in preparation for the ISR:

-test of stacking

-vacuum

-beam stability



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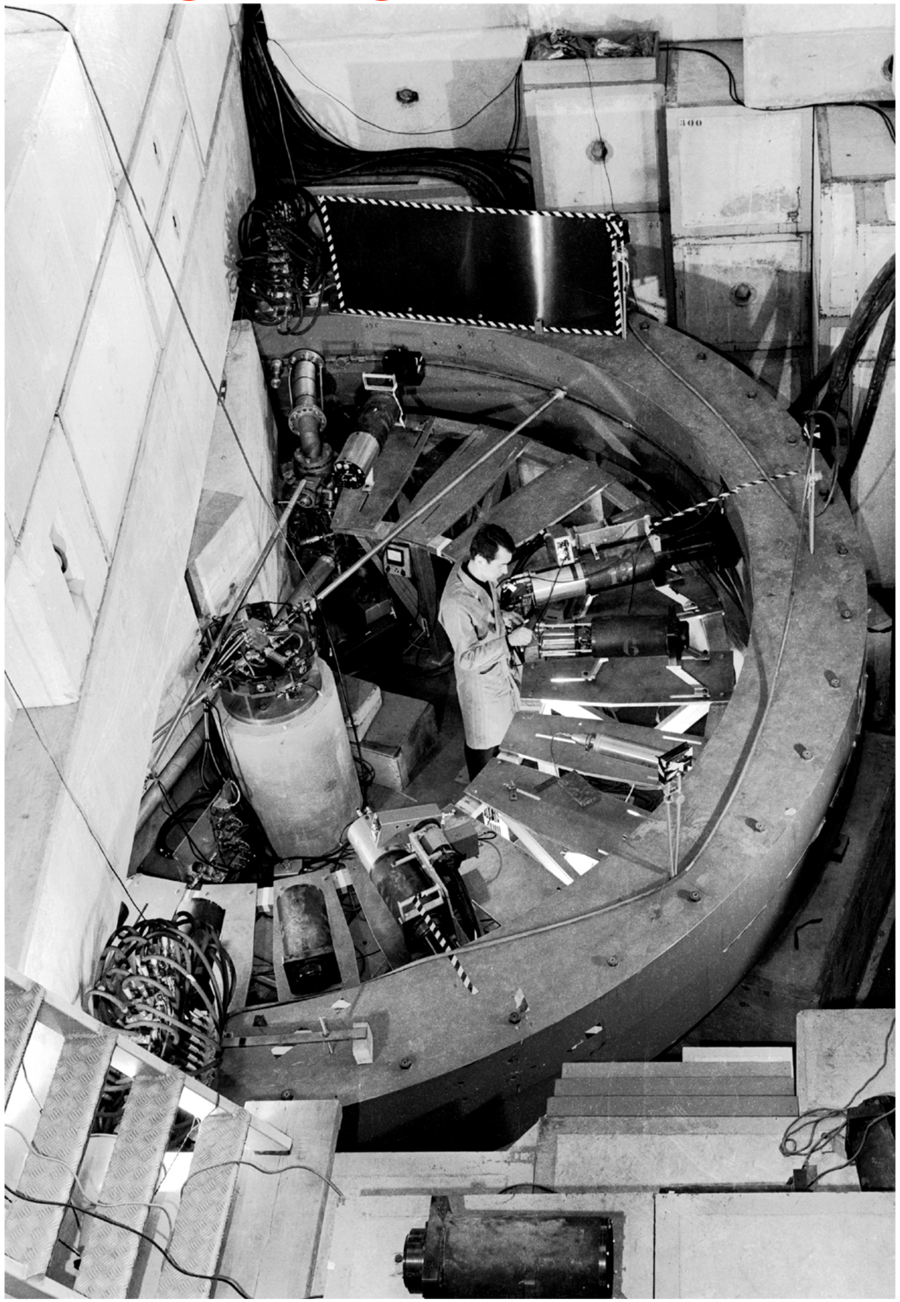
2008	CNGS	450GeV	Target and SPS	Neutrino beam production

CERN's Proton Program: g-2

- 1974:
  Bursts of Pions are created from SC beam on target and injected into the g-2 storage ring.

  Counting rate of electrons from Muon decay is modulated by precession of Muons in magnetic field



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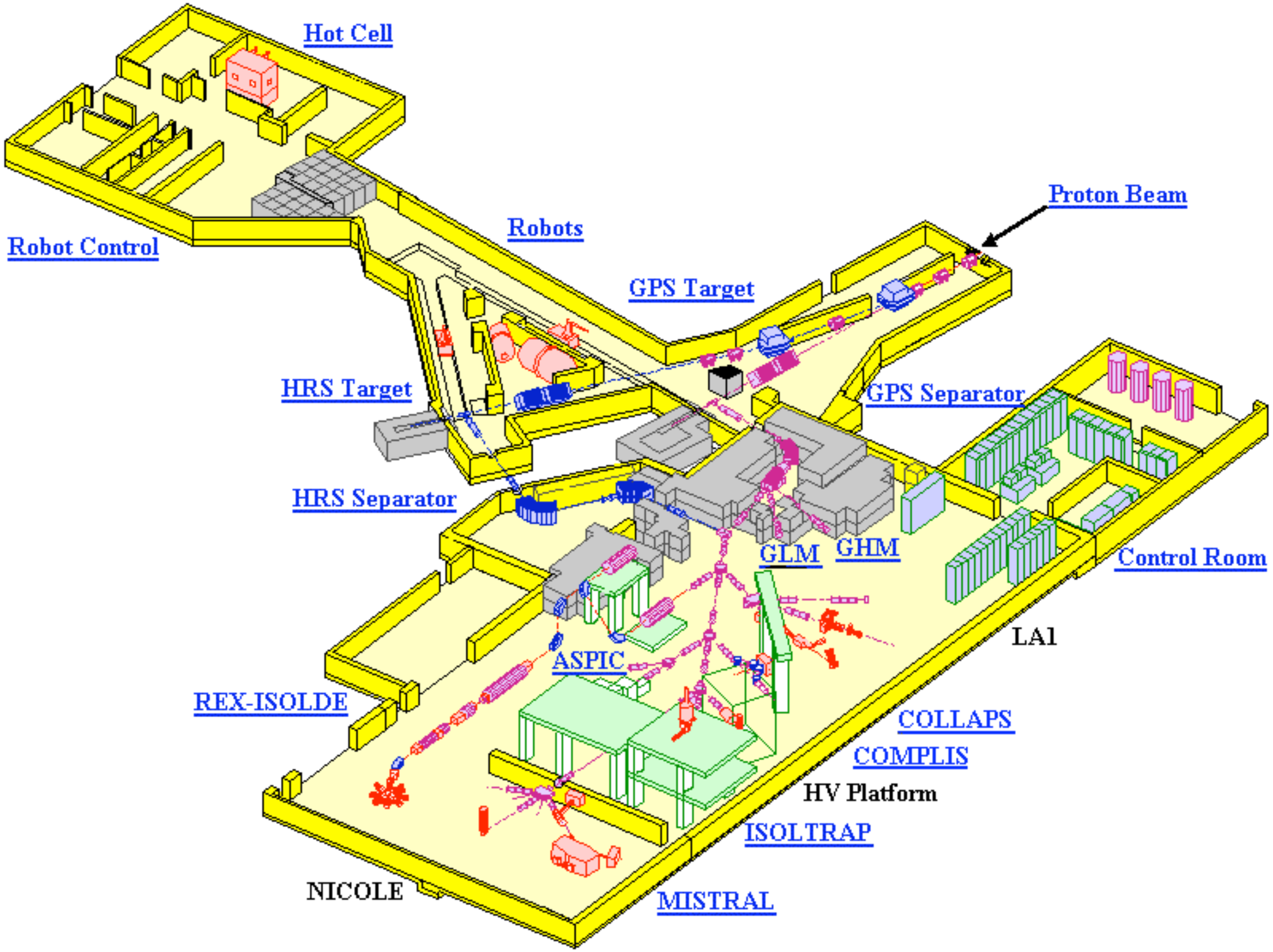
2008	CNGS	450GeV	Target and SPS	Neutrino beam production

CERN's Proton Program: ISOLDE

ISOLDE Installation at CERN

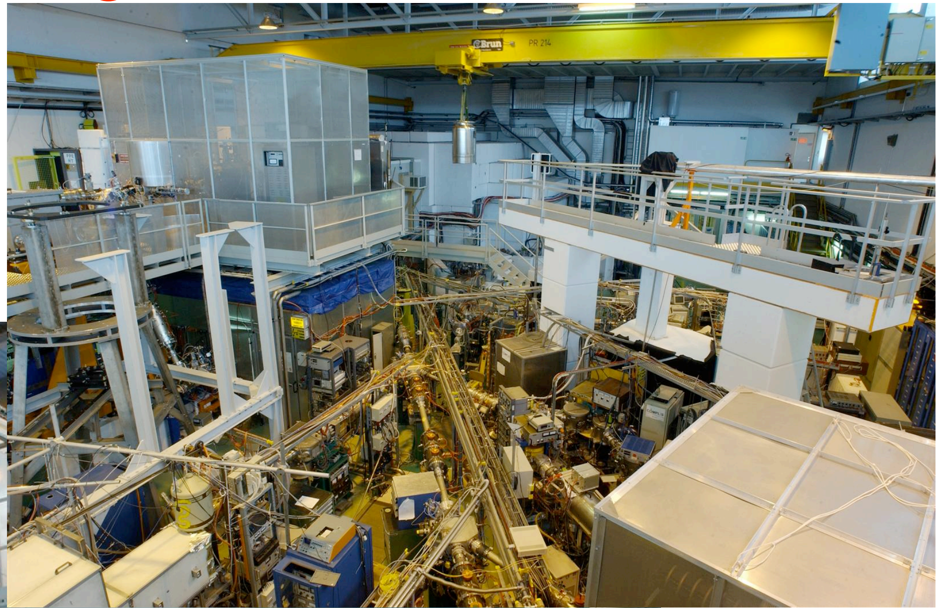
CERN's Proton Program: ISOLDE

- 1973: Isotope Separation Online



CERN's Proton Program: ISOLDE

- ISOLDE Hall



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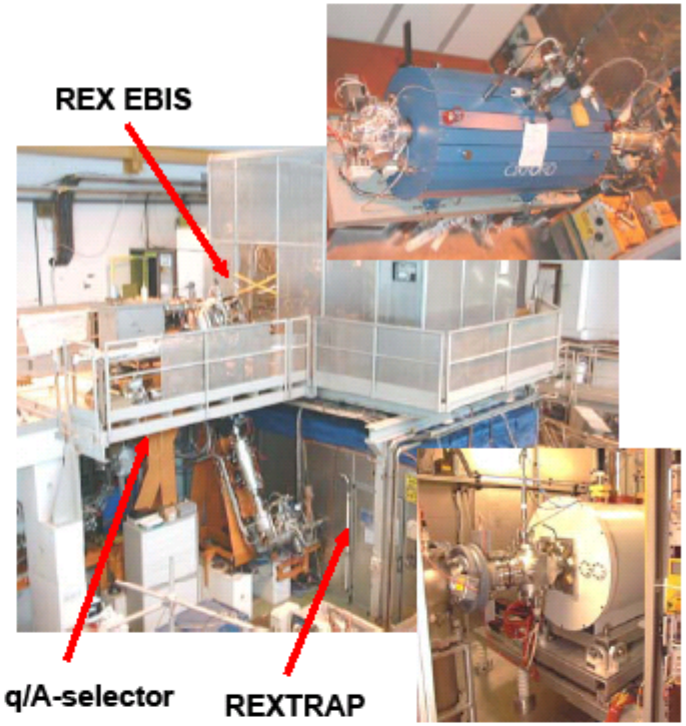
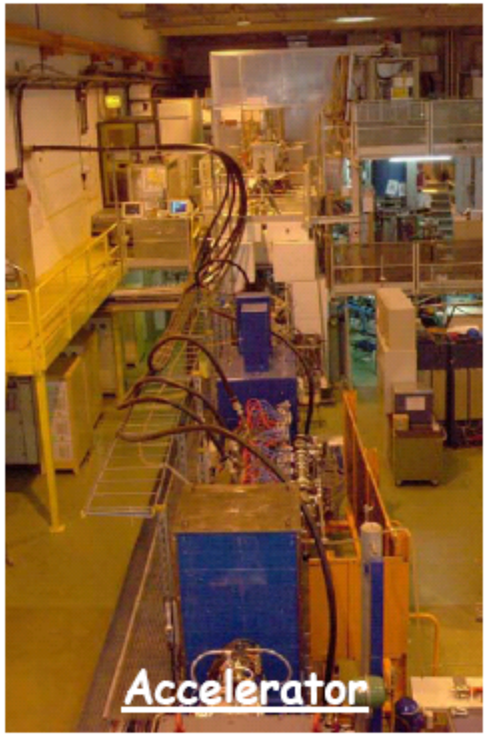
CERN's Proton Program: REX-ISOLDE

2000: Radioactive Beam Experiment at ISOLDE

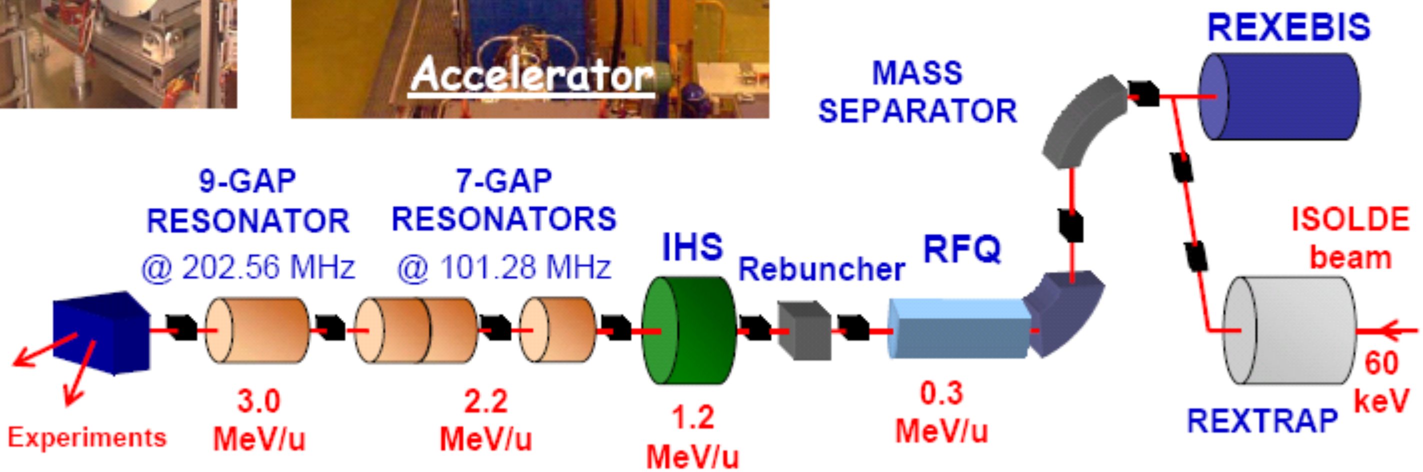


Charge Breeder



Efficiencies
(design values):

Trap Bunching:	90%
Beam Transport:	>85%
EBIS Injection:	>50%
EBIS Qi/ΣQi:	30%
Linac:	90%



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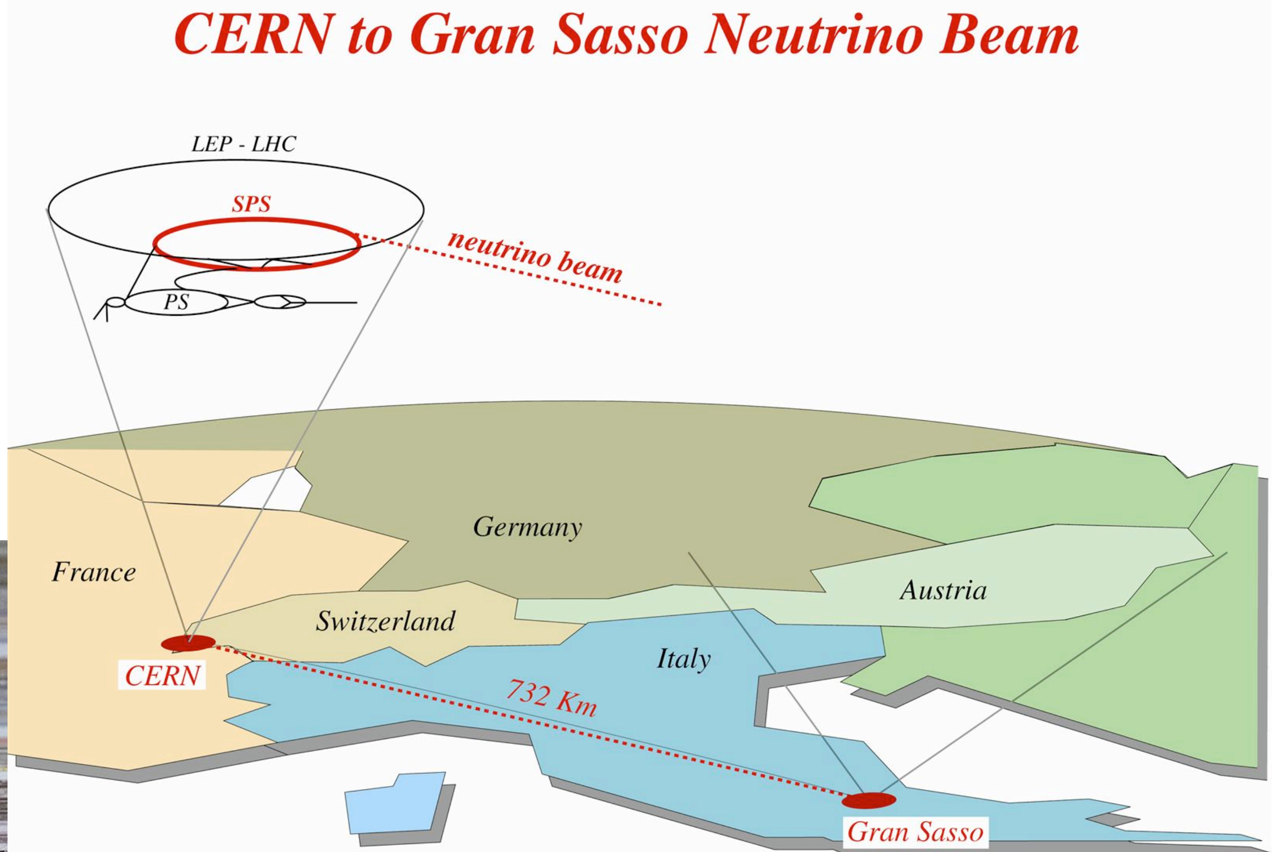
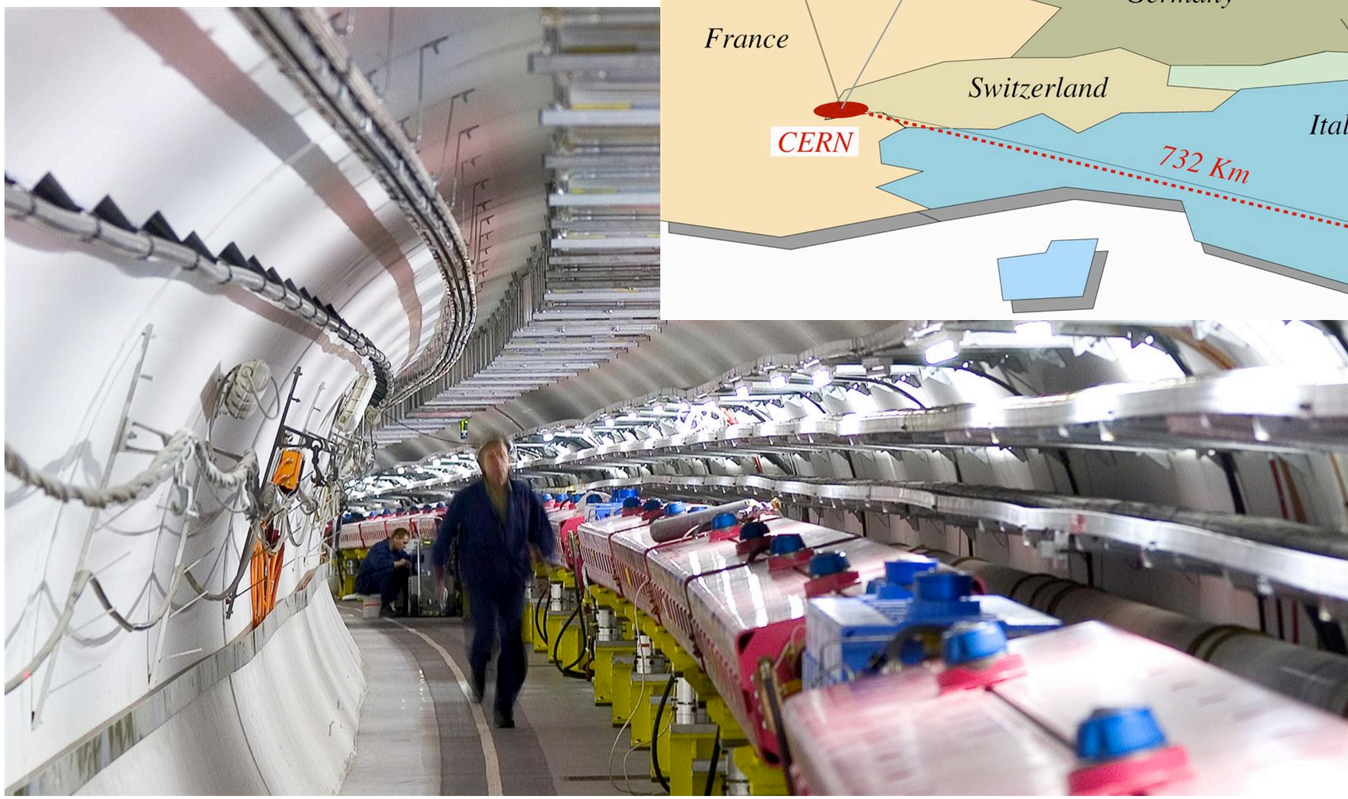
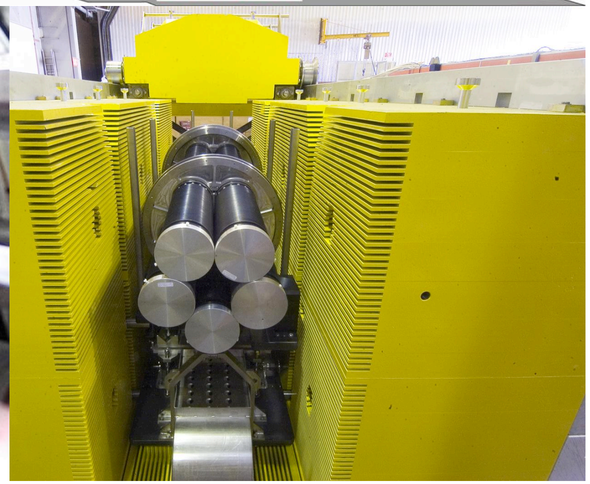
2008	CNGS	450GeV	Target and SPS	Neutrino beam production

CERN's Proton Program: CNGS

2008:
CERN Neutrinos to Grand Sasso







LHC Goals & Performance

- Collision energy: Higgs discovery requires $E_{CM} > 1$ TeV

  p collisions → $E_{beam} > 5$ TeV → LHC: E = 7 TeV

- Instantaneous luminosity: # events in detector $= L \cdot \sigma_{event}$

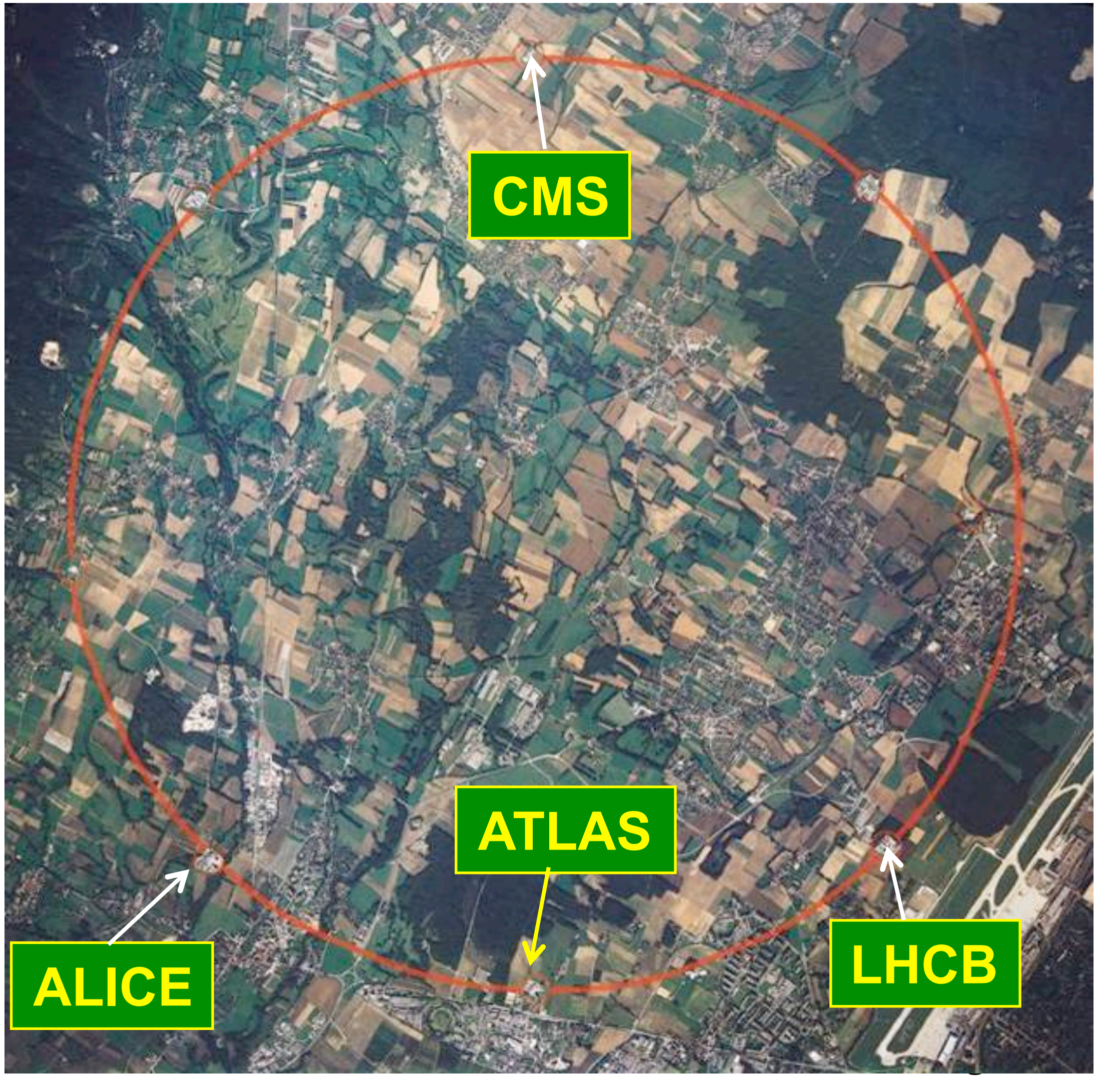
  rare events → $L > 10^{33} cm^{-2} sec^{-1}$ → $L = 10^{34} cm^{-2} sec^{-1}$

- Integrated luminosity: L $= \int L(t)dt$

  depends on the beam lifetime, the LHC cycle and 'turn around' time and overall accelerator efficiency

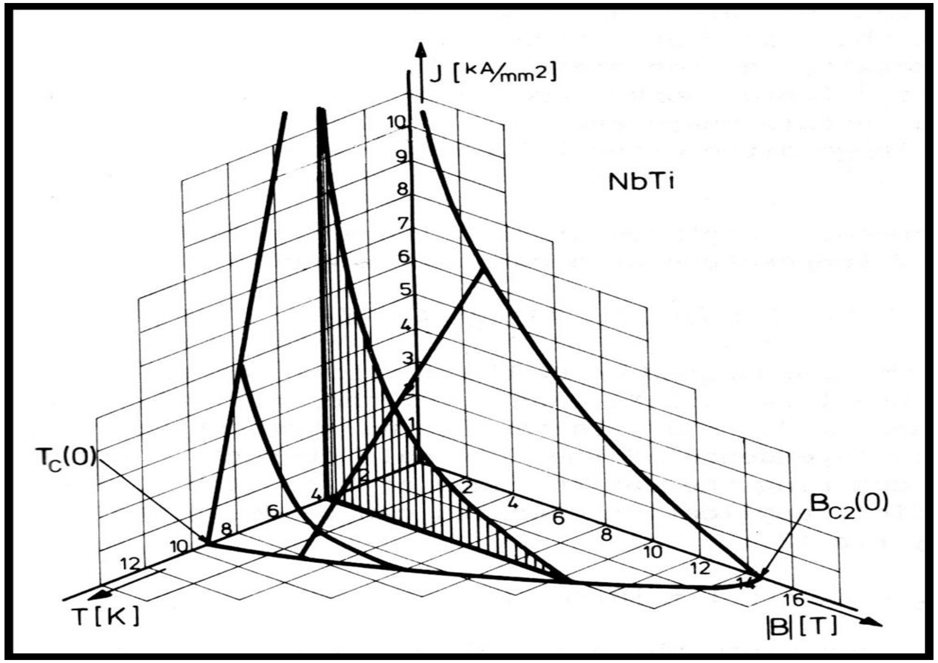
LHC Layout

- built in old LEP tunnel
  - → 8.4 T dipole magnets
  - → 10 GJ EM energy
  - → powering in 8 sectors
- 2808 bunches per beam with 1.15 10^{11} ppb
  - → 360 MJ / beam
  - → crossing angle & long range beam-beam
- Combined experiment/ injection regions



LHC: Magnet Technology

- Critical surface of NbTi:



-high ambient magnetic field lowers the capability to sustain large current densities

-low temperatures increase the capability to sustain large current densities

-LHC: B = 8.4 T; T = 1.9 K
j = 1 - 2 kA / mm^2

- existing machines: Tev: B=4.5T;HERA: B=5.5T; RHIC: B=3.5T

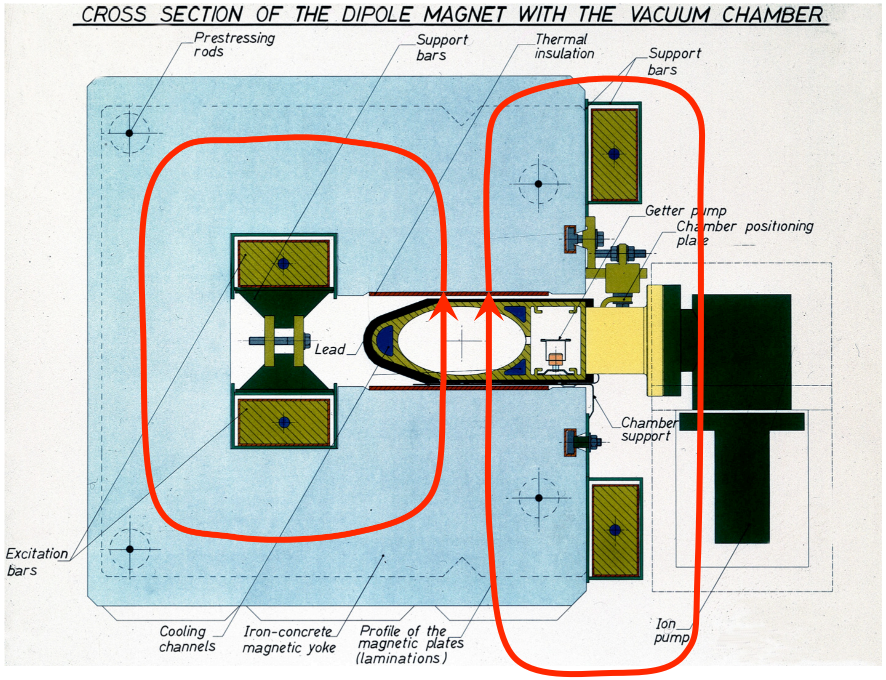
- He is superfluid below 2K and has a large thermal conductivity!

LHC: Magnet Field Imperfections

- dipole magnet designs:

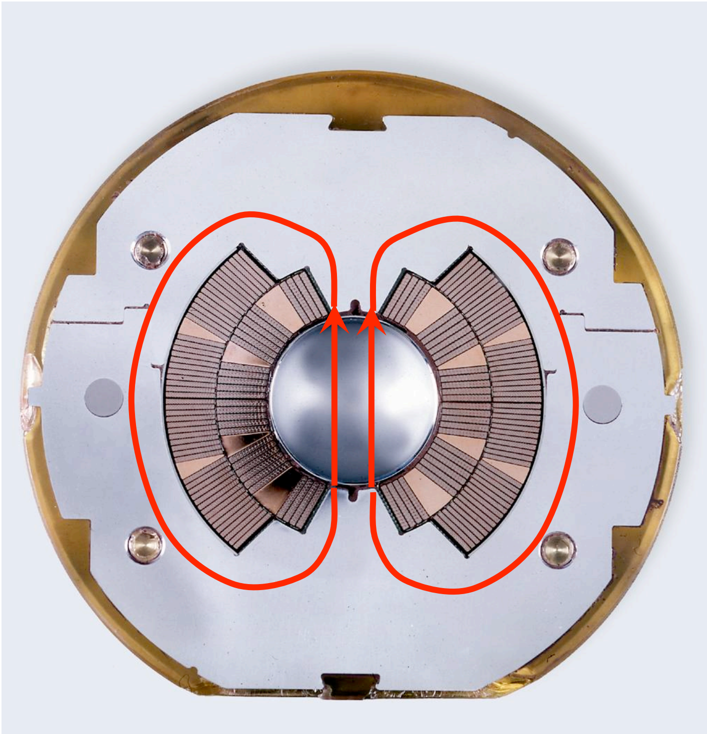
LEP dipole magnet:

conventional magnet design relying on pole face accuracy of a Ferromagnetic Yoke



LHC dipole magnet:

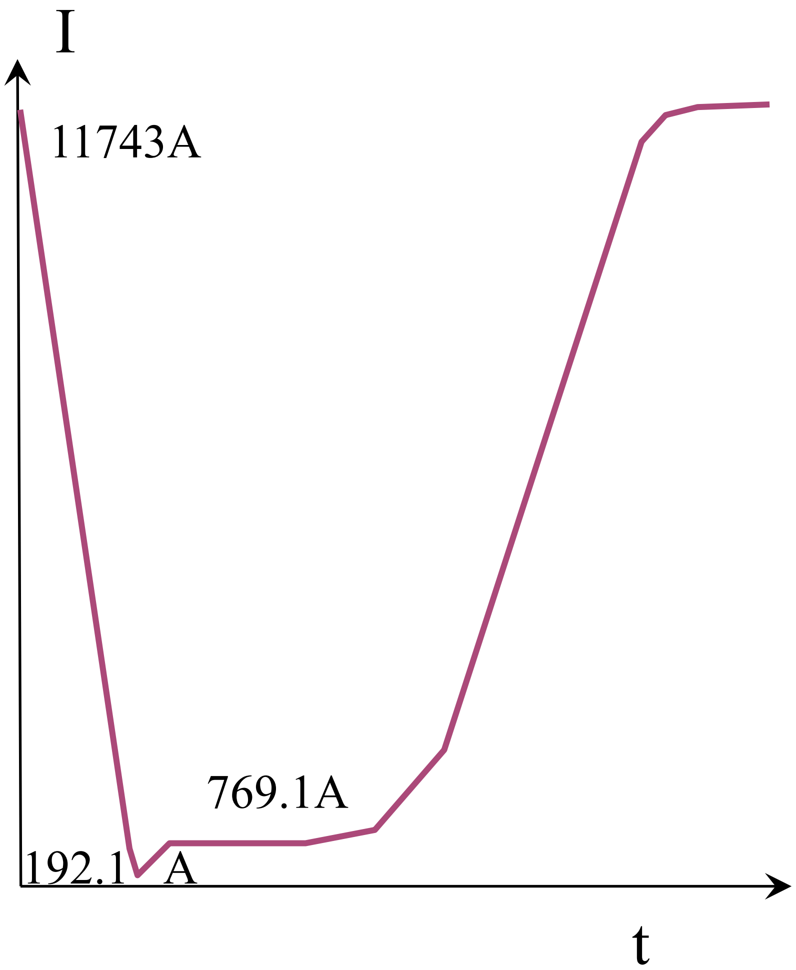
air coil magnet design relying on precise current distribution

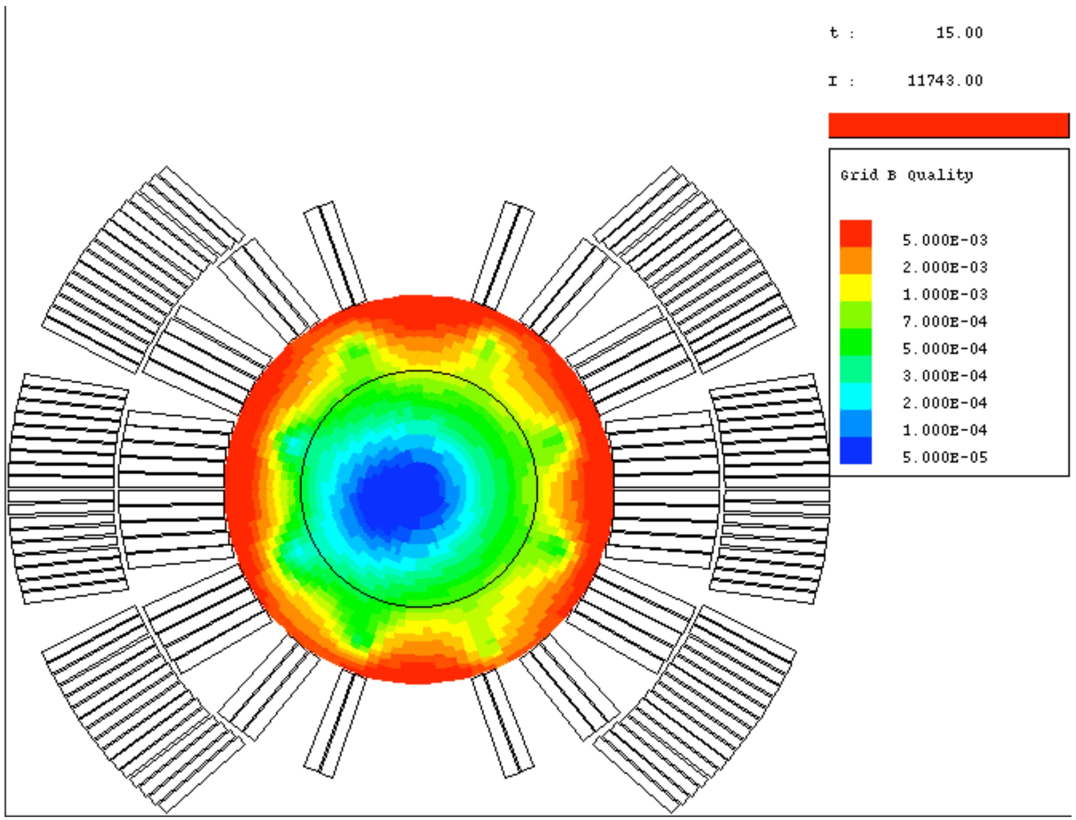


Field Imperfections: Super Conducting Magnets

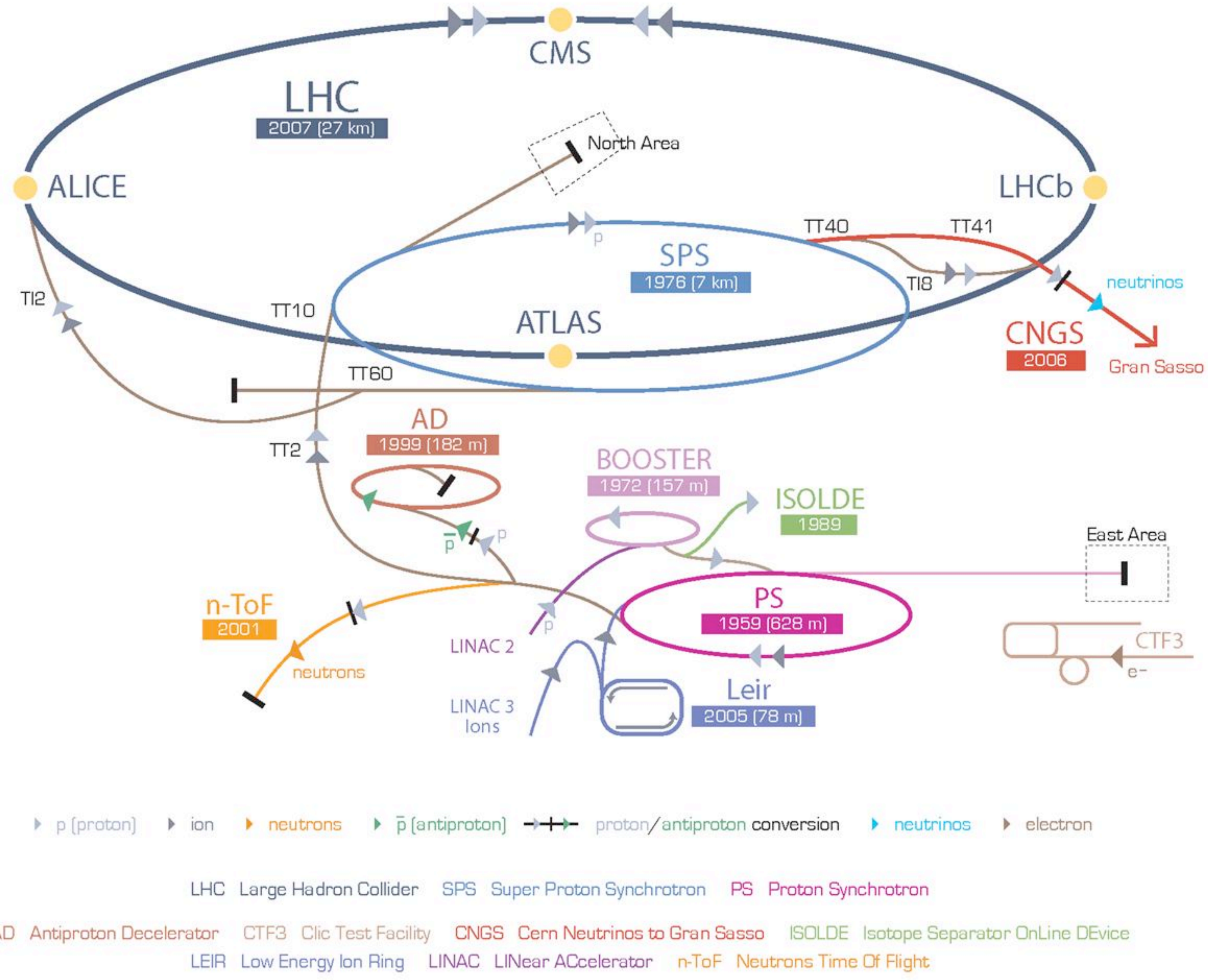
- time varying field errors in super conducting magnets

Luca Bottura CERN, AT-MAS





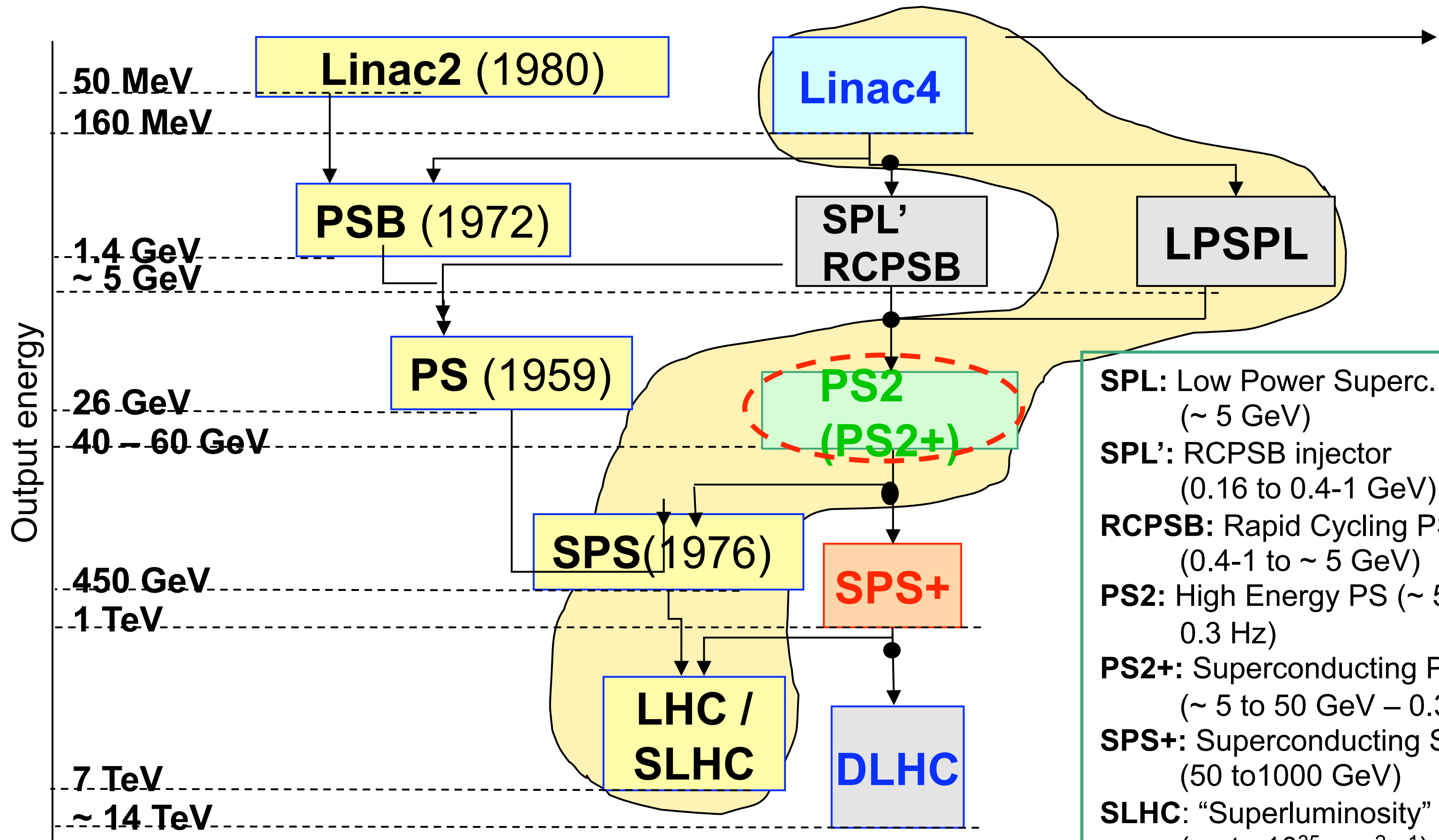
CERN Accelerator Complex



Potential Future Projects for CERN

Proton Accelerators for the Future (PAF) study – identified upgrade scenarios

- Reliable operation for the LHC (allow ultimate LHC beam)
- Options for future programs



From: PAF study group, in particular R.Garoby

SPL: Low Power Superc. Proton Linac (~ 5 GeV)
SPL': RCPSB injector (0.16 to 0.4-1 GeV)
RCPSB: Rapid Cycling PSB (0.4-1 to ~ 5 GeV)
PS2: High Energy PS (~ 5 to 50 GeV – 0.3 Hz)
PS2+: Superconducting PS (~ 5 to 50 GeV – 0.3 Hz)
SPS+: Superconducting SPS (50 to1000 GeV)
SLHC: "Superluminosity" LHC (up to 10^{35} $cm^{-2}s^{-1}$)
DLHC: "Double energy" LHC (~14TeV)

References:

- Transparency 2: CERN DDS 0606052-A4-at-144-dpi; http://cdsweb.cern.ch/record/979035
- Transparency 3: CERN DDS
- Transparency 5:
  -Picture of Thomson ➔ http://nobelprize.org/nobel_prizes
  -Cathod Ray tube ➔ S. Weinberg, 'The Discovery of Subatomic Particles', Scientific American Library, 1983.
- Transparency 6:
  -Picture of Rutherford and Bohr ➔ http://nobelprize.org/nobel_prizes
  -Rutherford laboratory ➔ S. Weinberg, 'The Discovery of Subatomic Particles', Scientific American Library, 1983.
- Transparency 8:
  -Pictures of Anderson with cloud chamber and $e^+ e^-$ pair production
  http://livefromcern.web.cern.ch/livefromcern/antimatter/history/AM-history01-a.html
  -Picture of Anderson ➔ http://nobelprize.org/nobel_prizes
- Transparency 9:
  -Cathode ray tube ➔ http://dbhs.wvusd.k12.ca.us/webdocs/AtomicStructure/Disc-of-Electron-Images.html
  -TV tube ➔ Encyclopedia Britannica
- Transparency 10:
  Penning Source: Talk from Richard Scrivens
- Transparency ?:
- Transparency ?:
- Transparency ?:
- Transparency ?: