History of the CERN Proton Synchrotron
The Early Days

- **Setting the scene**
- **Design period**
- **Decision and Construction**
- **Running-in**
- **Beginning as user facility**

Setting the scene

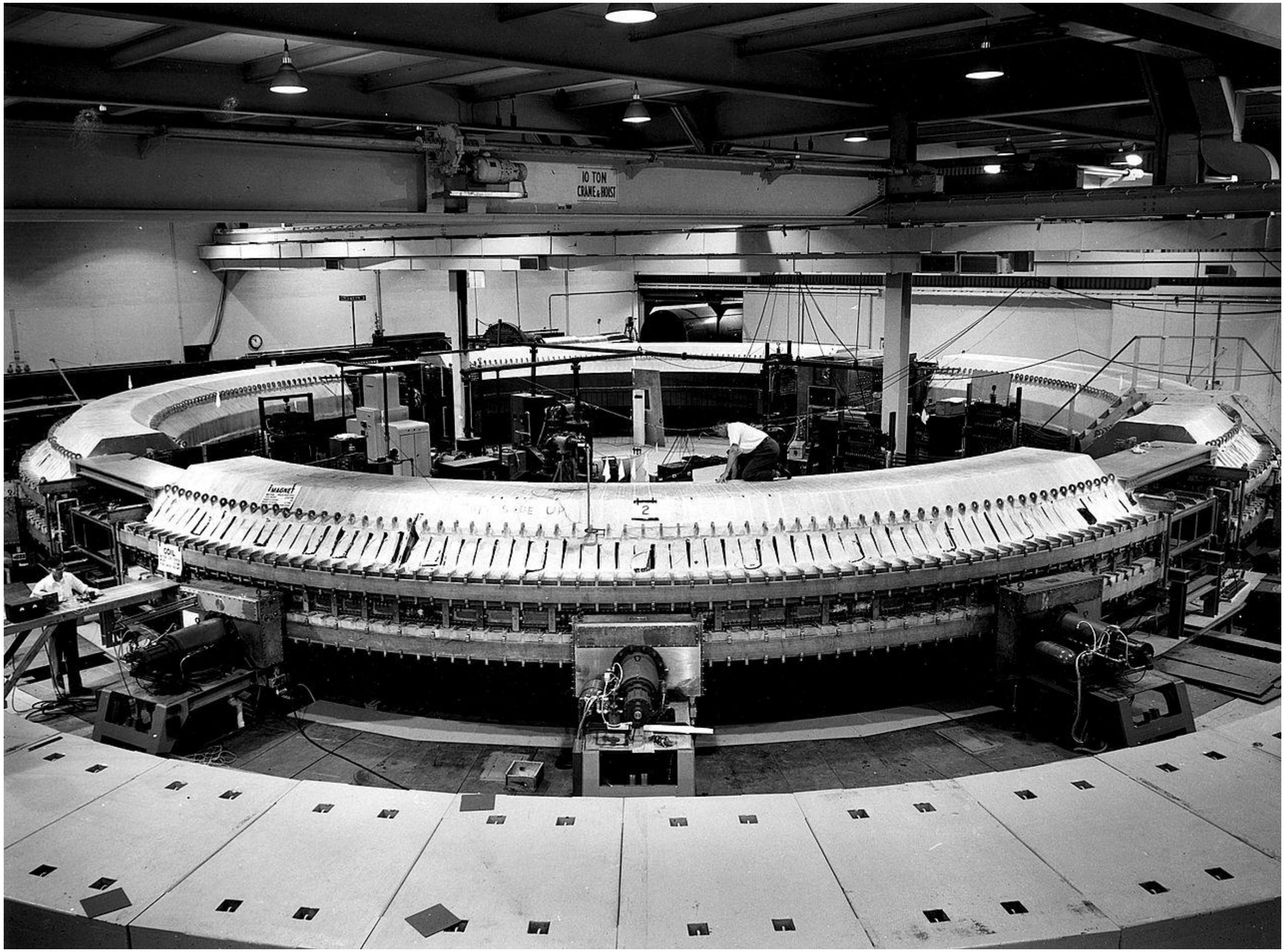
- **1st Session of Council Paris June 1952: Appointments: E.Amaldi, C.J.Bakker, O.Dahl, L.Kowarski, N.Bohr**

c) Mr. O.Dahl (Bergen), Head of the Study Group in charge of studies and investigations regarding accelerators of particles for energies higher than 1 BeV.

Brief for Study Group: Conclude "...which proton energy in the range 1 and 20 BeV is most useful....Then the feasibility will be studied...."

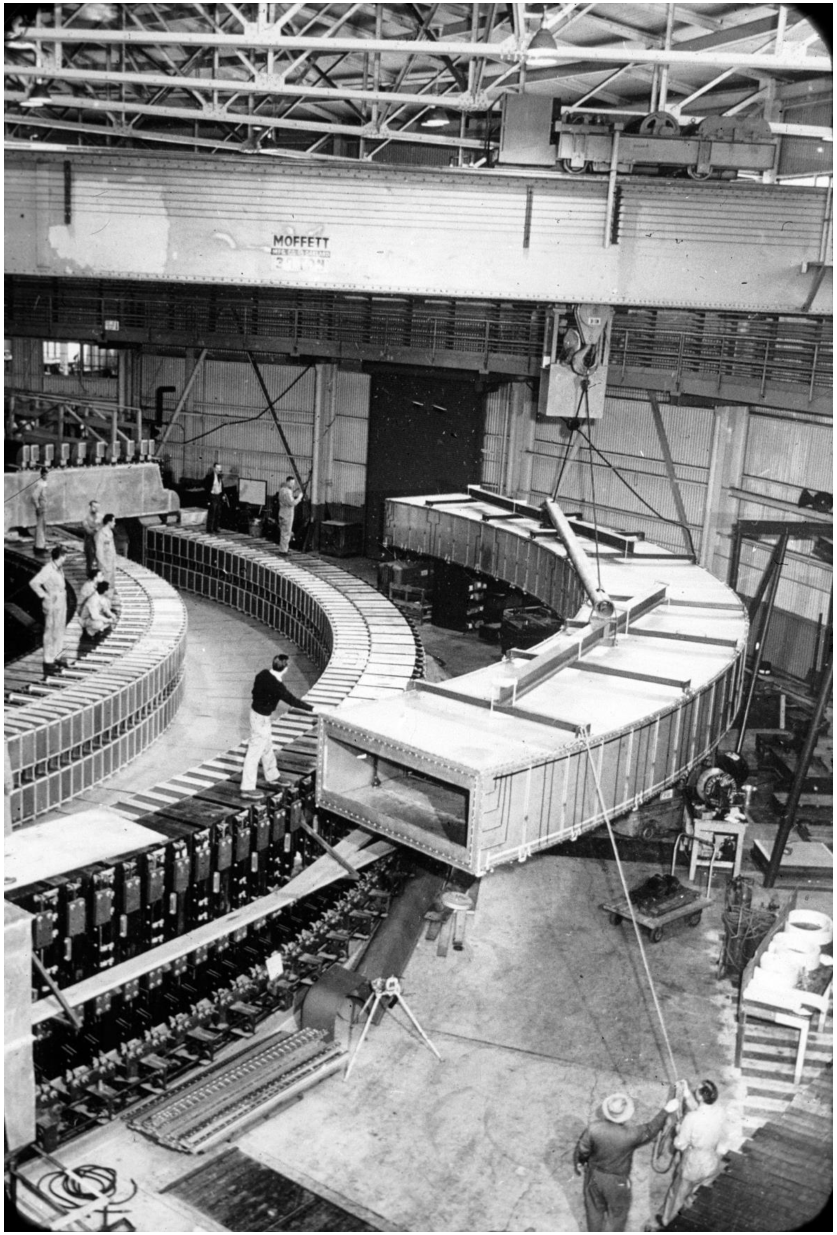
- **End June 1952: Study group presents a 10 – 15 GeV synchrotron, a scaled-up version of the 3 GeV weak-focusing BNL Cosmotron (1 GeV reached then). (Bevatron 6 GeV under construction at LBL)**
- **Council asked for design and planning of 10 GeV version**

Cosmotron at BNL



1952 – 1966 3.3 GeV in 1953 Magnets 1730 t 2πR = 144.5 m

Vacuum chamber 20 x 60 cm



Bevatron
LBL

1954 – 1971(93)
6.2 GeV in 1953
Magnets 1000 t
2πR = 128 m

Vacuum chamber 31 x 122 cm

Getting down to business

- **August 1952: Dahl, Goward & Wideroe visited BNL**
  Got introduced to Alternating-Gradient (AG) Principle = Strong-Focusing Principle with effect of drastic reduction of magnet size.
- **October 1952 in 3rd Council: O.Dahl presented**

Project	Energy	Magnet	Constr. time	Cost MCHF
I (w-f)	10 GeV	6000 t	6 - 7 years	60
II (AG)	30 GeV	700 t	5 - 6 years	60

advocating project II also because
" it offers new opportunities for new contributions to the art of experimental physics"!
Council entrusts his Group with studying Project II and, by the way, chooses Geneva as site.

Cold feet

- **Design is not robust:**
- **Magnet imperfections and alignment errors => loss of beam stability. Learn from celestial mechanics:**

Detailed studies by Adams, Hagedorn, Hine, Lawson, Lüders, Schoch & Sigurgeirson.
e.g. betatron phase space with 3rd order resonance
(Hagedorn & Schoch CERN 57-14)

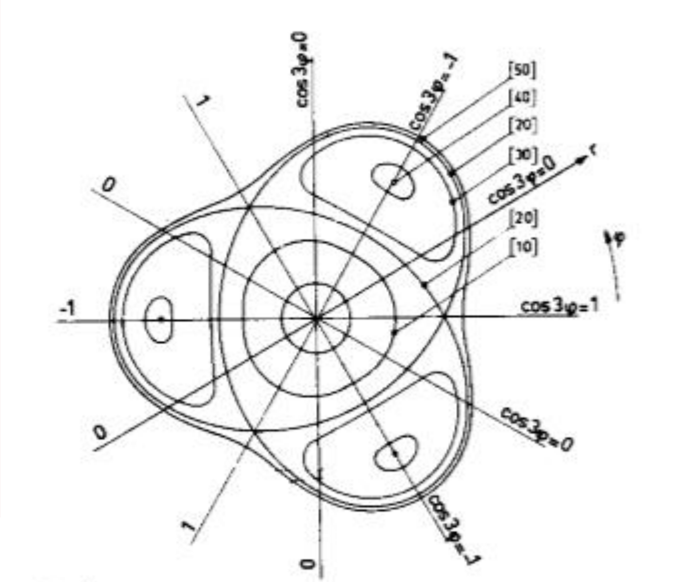


Fig. 4

Analogue model developed by M.Barbier & A.Schoch
(Barbier and Schoch, CERN 58-5)
CERN-PHOTO-5512288

Valse of parameters

- **Lead to many design iterations: e.g.**

Date	Jan.53	April 53	March 54	Final 59*)
Field index n	4000	900	278	288.4
W magnet (t)	800	≤ 10000	3300	3400 Fe
Vac.dimension (cm)	4 x 5	≤16 x 20	8 x 12	7 x 14
				Cost 100 MCHF

Effective help by Hildred and John Blewett from BNL !

*) M.G.N.Hine, Synchroton Data, HEACC 1959 p.383

Decision and construction

- **October 1953 <u>7th Council</u> decided to follow Cockcroft**

  ➔ AG synchrotron 25 GeV, Bmax= 12 kG

  After Heisenberg's conclusion: design for easy reach of 20 GeV but enable 30 GeV
- **1954 – 1959: Design, manufacturing, construction**

PS tunnel construction 1955 - 1957

CERN-PHOTO-5611532

1st PS combined-function magnet end 1956

CERN-PHOTO-5612555

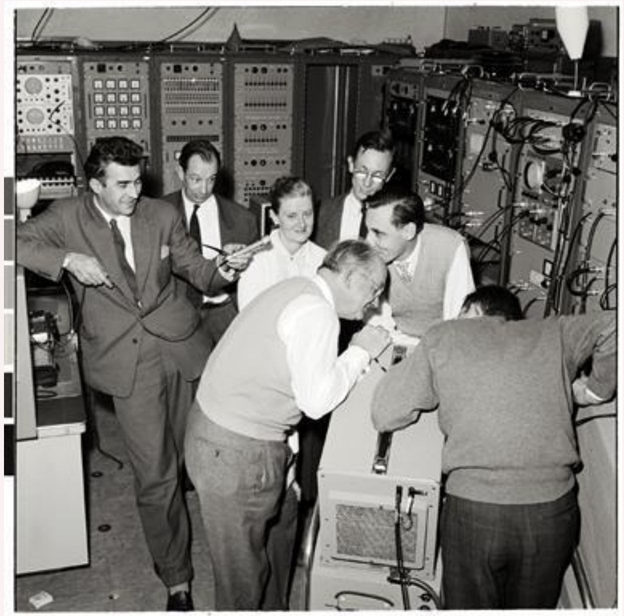
1959 Running-in

- **August 24: linac at 50 MeV (= design)**
- **September 16: first turn in PS**

Drama: Beam did not cross transition energy!
i.e. $E_{tr} \approx 6$ GeV => longitudinal focusing vanishes
Remedy: radial loop feed-back acts on RF phase instead on RF amplitude W.Schnell, HEACC 1959

- **November 24: 24 GeV**
- **December 8: 28.3 GeV**

3.10^{10} p/pulse



CERN-HI-5911001-

Thus the situation in December 1959 was that the synchrotron had worked successfully up to its design energy and, already, beyond its design current, but with its builders and operators in a state of almost complete ignorance on all the details of what was happening at all stages of the acceleration process.

J.Adams, 1st PS Quarterly report, CERN 60-23, p.7

Confronting the reality of big science

- 1960: accelerator reached N=3 x 10^{11} p/p => 3 x design, T_{op}=102 d, η_{inj} = 25 to 60%, short and long pulse, 14 internal targets

- Slow start of experimental programme: dearth of experimental proposals and serious lack of beam transport elements (e.g. equipment borrowed, power by welding machines etc.)
- However, 1st run in January and ≈ 10 experiments in total with 30 cm H_2 bubble chamber, counters and emulsion experiments.

- In 1961 set-back: 1st ν-experiment (2 neutrino species ??) planned for spring 1961 was abandoned => flux 10 x too small (found out by von Dardel) creating dissatisfaction and disillusionment

Discovery of ν_μ in 1962 => AGS/BNL (Started July 1960)

V.Weisskopf, Council June 1962:
"It is no good in this field to be excellent and always late"

Gathering momentum

- **2nd ν-experiment in 1963 and 1964 with two seminal advances in technology by NPA-division to improve the rate of**
  $p \rightarrow \text{target} \rightarrow \pi^+ \rightarrow \mu^+, \nu_\mu$

CERN-PHOTO-6305065

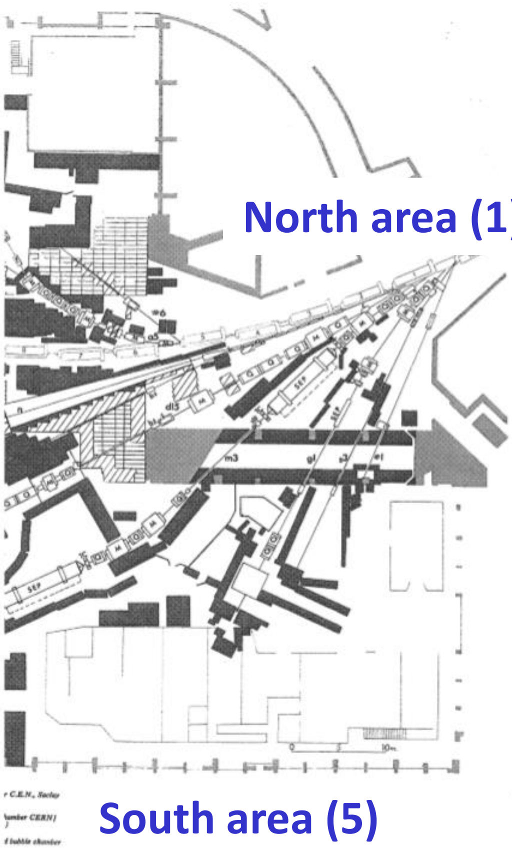
Fast proton ejection
Plass, Kuiper CERN 59-30

Horns create strong pulsed magnetic fields to focus π 's
S.Van der Meer CERN 61-07

CERN-PHOTO-6303202

1963 PS in full swing

<N> = 6.10^{11} p/p, realignment Δ (h,v) ≈ 3 mm



Beam layout in the experimental areas

Fig. 11

1. South hall

a_6: *Beam for testing equipment using a permanent magnet. It gives several thousand particles at about 700 MeV/c when target 1 is operating.*

g_1: *Beam with single-stage electrostatic separation 2×10^4 π at 1 GeV/c. Contamination: ~1%. Δ p/p = ± 1%. Experiments on β decay of the Λ^0.*

m_6: *Beam with double-stage electrostatic separation for bubble chambers. Maximum: 20 5.7 GeV/c p̄ or 30 3.5 GeV/c K. Δ p/p = ± 0.3%. Contamination: 10%. Experiments on p̄ and fast or slow K physics. The beam may be used for an electronics experiment; the maximum p̄ flux is about 10 000 p̄ at 2.5 GeV/c for 7×10^{11} p in the synchrotron. Contamination: 10%. Δ p/p = ±1%. Experiments on the physics of p̄p annihilation into leptons.*

d_{11}: *High-energy π beam; about 10^4 π at 10 GeV/c with 19.2 GeV/c primary protons and 13 GeV/c (for 24 GeV/c protons). This beam has also been used for electrons. It could be designed for 17 GeV/c. Experiments: production of peripheral γ, K* physics, calibration of equipment.*

n: *Neutrino beam using the beam extracted from the synchrotron on a copper target. 10^4/cm^2 neutrinos for 7×10^{11} accelerated protons.*

2. North hall

a_4: *High-intensity π beam. 2×10^4/cm^2 with Δp/p ~1% at 1 GeV and an image of 0.7 cm^2. It can give up to 10^5 π per pulse with less accurate geometry. Since the first part of this beam is fixed, there are several possible versions of the end: emulsion experiments on the magnetic moment of the Λ and Σ, π scattering, spark chamber calibration, resonances in the π + d reaction, etc. By adding another magnet, 3 GeV/c can be reached.*

3. East hall

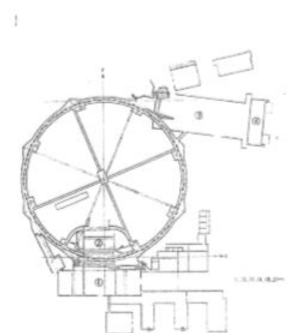
o_2: *Beam with single-stage separation by three electrostatic separators; two RF separators are to be installed in 1964. Separated antiprotons and K mesons up to 12 and possibly 15 GeV/c will thus be sent into a large bubble chamber. It may also give high-energy π and p (19 GeV/c). It has already given 100 separated 6 GeV/c K per pulse (Δ p/p = ±0.5%).*

o_3: *The first part is the same as the o_2, but before the separators its direction is changed by two bending magnets. Narrow 8 and 17 GeV/c 100 π at "pencil beam" (for 10^{11} p) producing jets in a H_2 target inside a freon bubble chamber. (Δ p/p = ±0.5%.)*

c_4: *This beam, which is being set up, is the successor to the c_4, c_4, c_2 and others, originally installed in the South hall. Scattered protons of the same energy as those of the synchrotron: 10^4 p at 10, 17 and 20 GeV/c, Δ p/p = ± 0.5%. (A similar beam gave 10^4 p per synchrotron pulse with a momentum spead of 7-8%.)*

Monitoring beams

These beams point straight at targets Nos. 1, 6, 10, 60 and 61; they are used by the experimenters and by the synchrotron for monitoring the beam sharing



CERN Annual report 1963

Tribute

- **Founding fathers** for their wisdom and foresight in choosing a design with a large potential for a long-term evolution and a striking versatility

- **PS and NPA staff** which made it work and exploited this potential with tenacity and perseverance

- **CERN staff** at large which continuously has upgraded, adapted and improved the PS, its external beams, injectors and associated accelators as AA, AC, AD, LEAR, LEIR and ELENA.

Thanks

Reviews

L.van Hove and M.Jacob, Highlights of 25 years of physics at CERN, Phys.Rep., 1, (1980).

G.Plass, The CERN Proton Synchrotron: 50 years of reliable operation and continued development, Eur.Phys.J. H 36 (2012) 439-454.

S.Gilardoni and D.Manglunki (eds.), Fifty years of the CERN Proton Synchrotron, Vol. 1, CERN-2011-004 (2011); Vol.2, CERN-2013-005 (2013).