40th Anniversary of the First Proton-Proton Collisions in the ISR

ISR Design and Construction

- Historical context
- Approval and Design
- Construction
- Commissioning

Early History

First proposal of colliding beams:

Rolf Wideröe

Patent granted 1943

Patent grant published 1953

Basic idea

- ✓ Counter-rotating p or d beams
- ✓ for high E_{cm} interaction
- ✓ Ring-shaped vacuum tube
- ✓ Magnetic guide field
- ✓ ep also proposed!

B.Touschek‘s comment

Problem: low beam intensity

>> never built

Erteilt auf Grund des Ersten Überleitungsgesetzes vom 8. Juli 1949
(WiGBl. S. 175)

BUNDESREPUBLIK DEUTSCHLAND

AUSGEGEBEN AM
11. MAI 1953

DEUTSCHES PATENTAMT

PATENTSCHRIFT

Nr. 876 279

KLASSE 21g GRUPPE 36

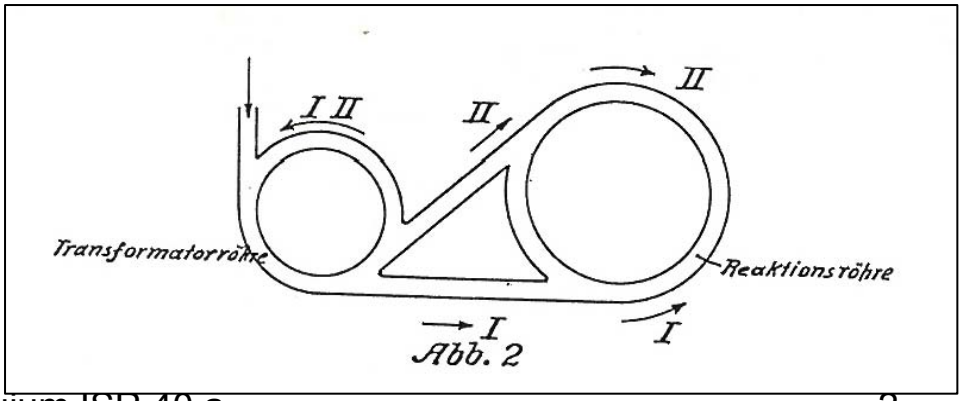
W 687 VIIIc / 21g

Dr.-Ing. Rolf Wideröe, Oslo
ist als Erfinder genannt worden

Aktiengesellschaft Brown, Boveri & Cie, Baden (Schweiz)

Anordnung zur Herbeiführung von Kernreaktionen

Patentiert im Gebiet der Bundesrepublik Deutschland vom 8. September 1943 an
Patentanmeldung bekanntgemacht am 18. September 1952
Patenterteilung bekanntgemacht am 26. März 1953



Early History (II)

- D.W.Kerst et al.1956
  Midwestern Universities Research Association (MURA)

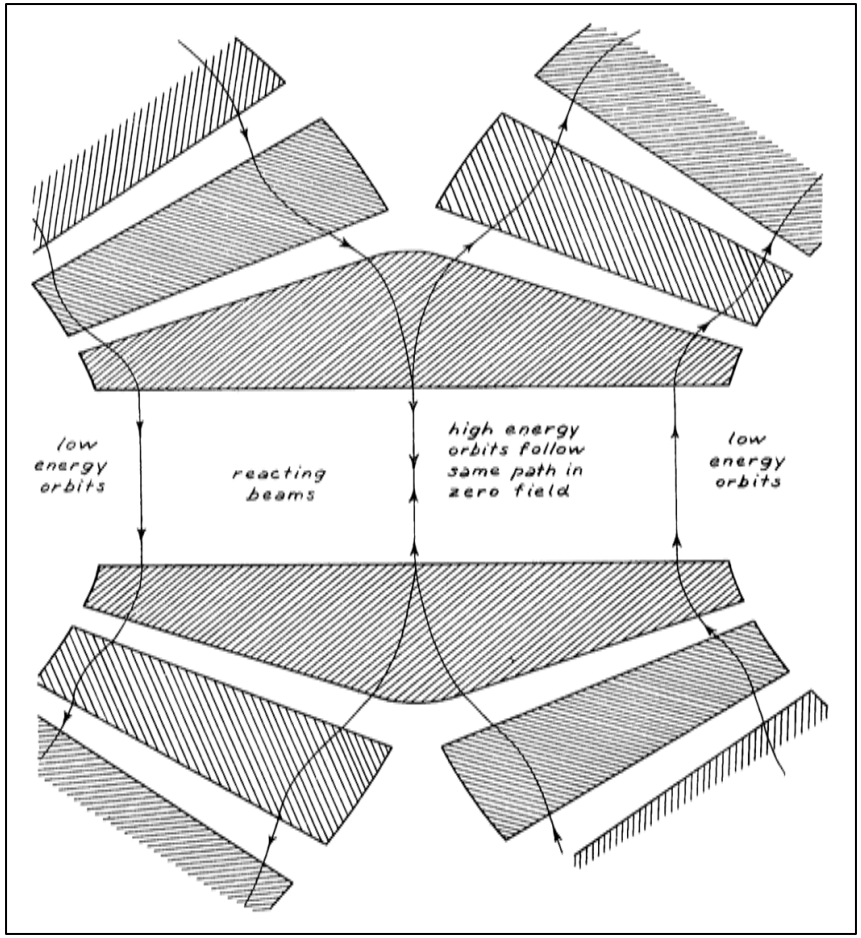
Detailed technical proposal:

rf accumulation for high proton intensity (Symon & Sessler 1956)

in two Fixed-Field Alternating Gradient (FFAG) rings with a common straight section

I=38 A, L= 2 x 10^{32} cm^{-2} s^{-1}

Proposal never materialized



D.W.Kerst CERN Symposium 1956

Early History (III)

- G.K.O'Neill 1956

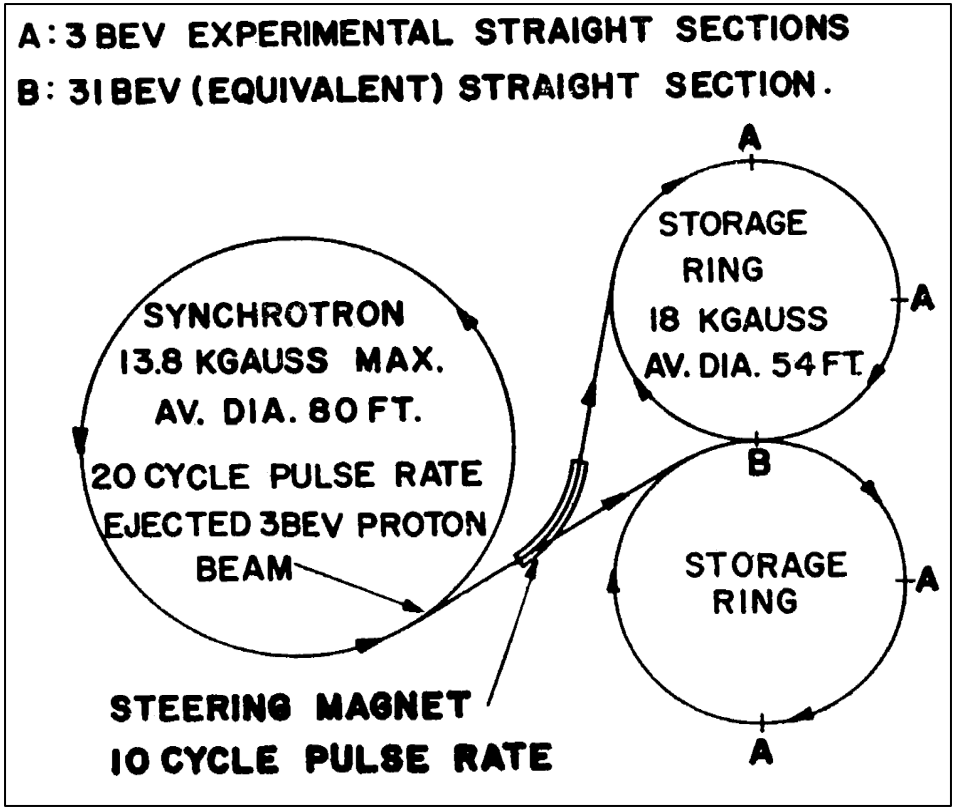
Two storage rings side by side with common straight section

Optics structure as in synchrotrons

Similar ideas:

- D.B.Lichtenberg et al., MURA
- W.M.Brobeck, LBNL

No follow up in US
but O'Neill → e- e- rings



G.K.O'Neill CERN Symposium 1956

The Emergence of the ISR

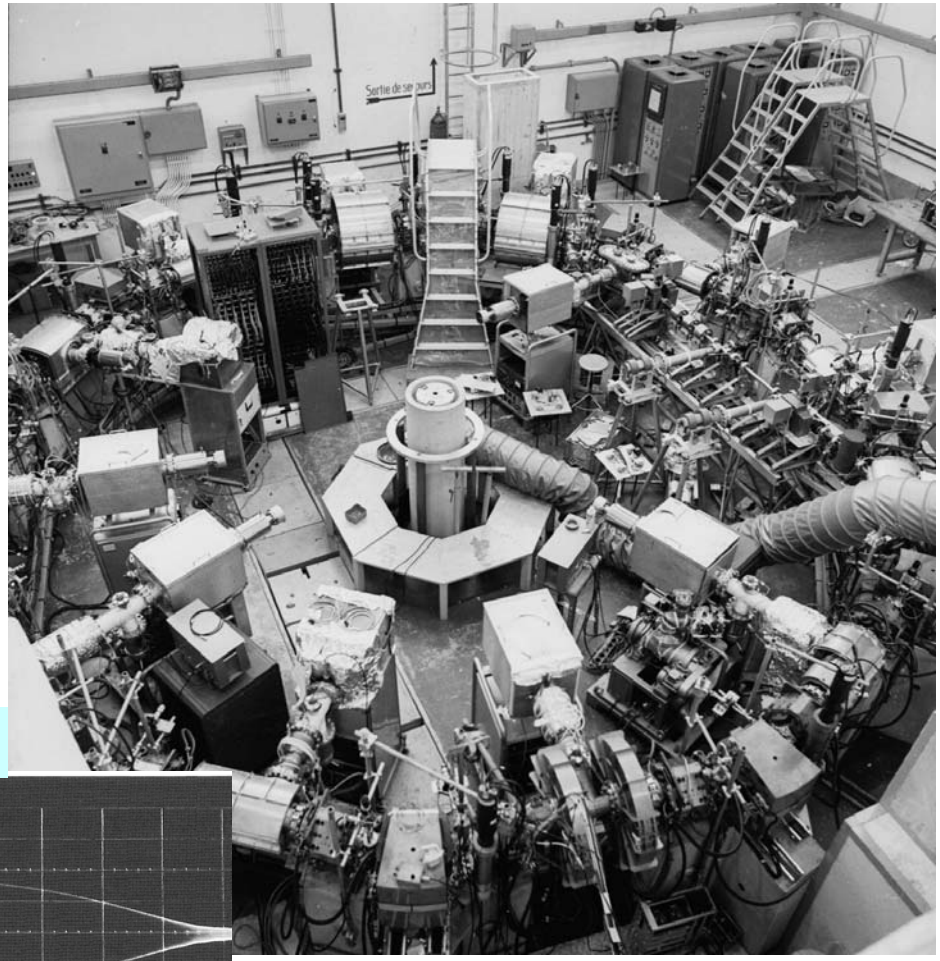
- 1956 Creation of the Accelerator Research (AR) (PS under constr.)
  Study of plasma acceleration, Collider (FFAG) > stopped 1960
- 1960 Proton collider based on synchrotron rings
  Proposal of tangential rings or near tang.rings (Dec.1961)
  Idea of 2 MeV electron ring model to study beam storage
- 1961 Debate until 1964: storage rings or a super „CPS“?
- 1962 New layout >> Intersecting rings
- 1963 Stacking in CESAR: first successful beam accumulation
  ECFA recommends ISR fed by CPS and 300 GeV
- 1965 June Council: ISR as supplementary CERN programme
  December Council: OK by all member states except Greece
  ISR Project Leader: Kjell Johnsen

Prevailing argument : „remain competitve for as low a cost possible“

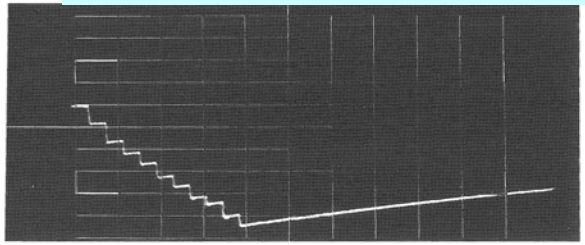
CERN Electron Storage Ring (CESAR)

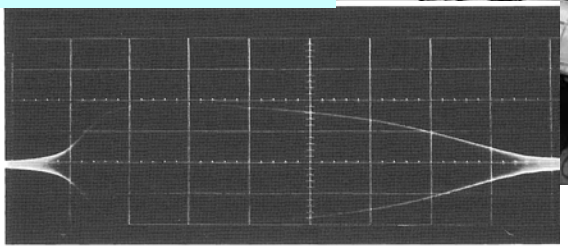
Idea : Mimic proton ring
>>no synchrotron radiation
>> β~1 particles in low-B ring
Purpose: test rf stacking
test UHV techniques

1.8 MeV electron storage ring
2πR = 24 m B=130 G
Design and construction:60-63
Operation: 1964 -1967



rf stacking 1964 I=I(t) d=f(dp/p)



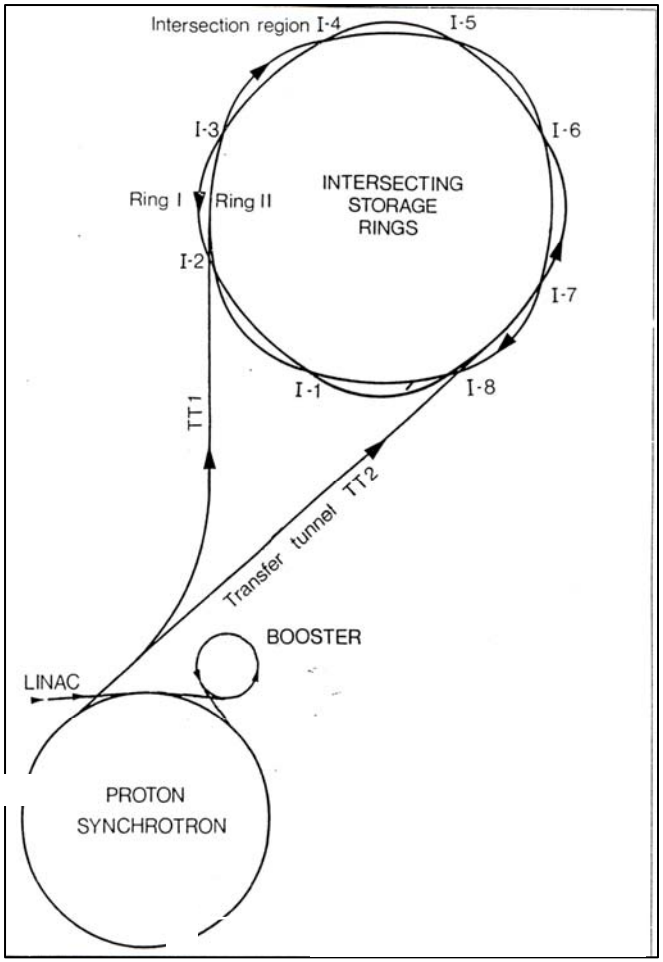


ISR Design

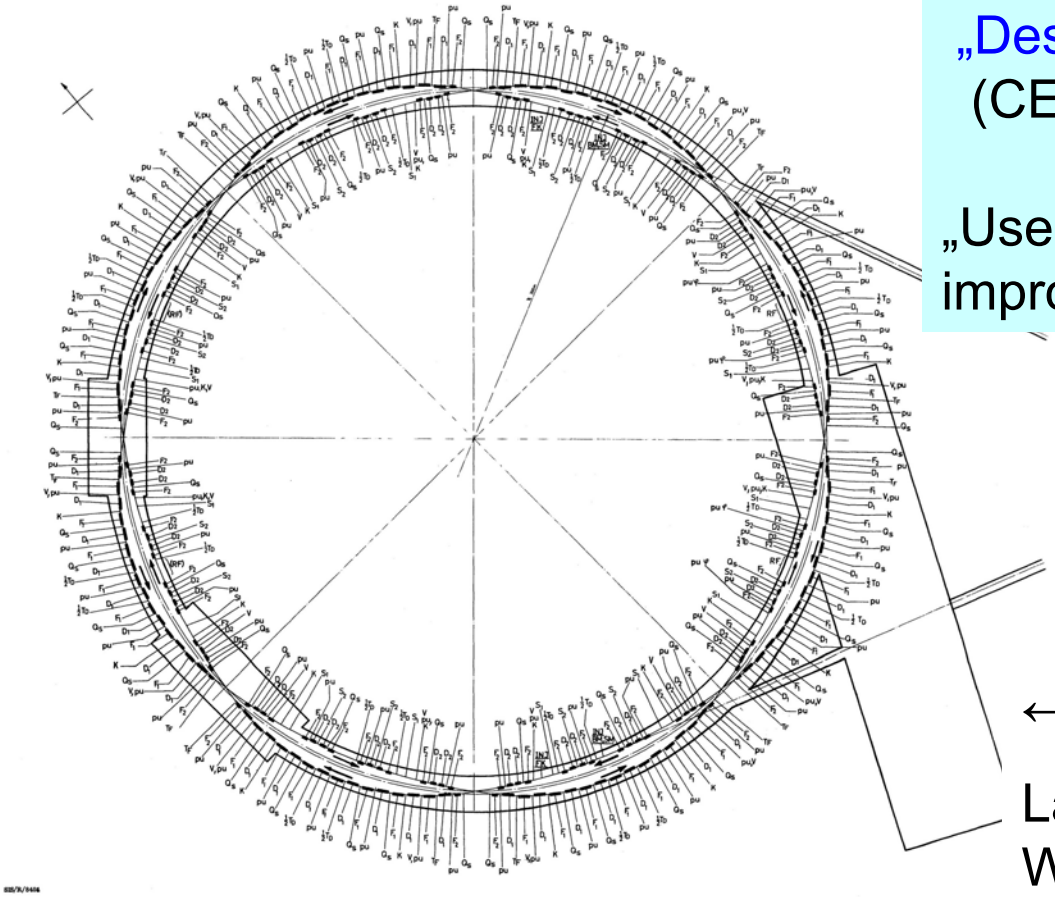
No basis for extrapolation available but experience <u>and team</u> from CPS extremely important

Lattice requirements: ≠ CPS

- Horizontal aperture determined by rf stacking $\Delta x = \alpha_p \Delta p/p$
- Long straight sections for experiments inserted in mid F and mid D where closed orbits of all momenta are ‖



ISR Design



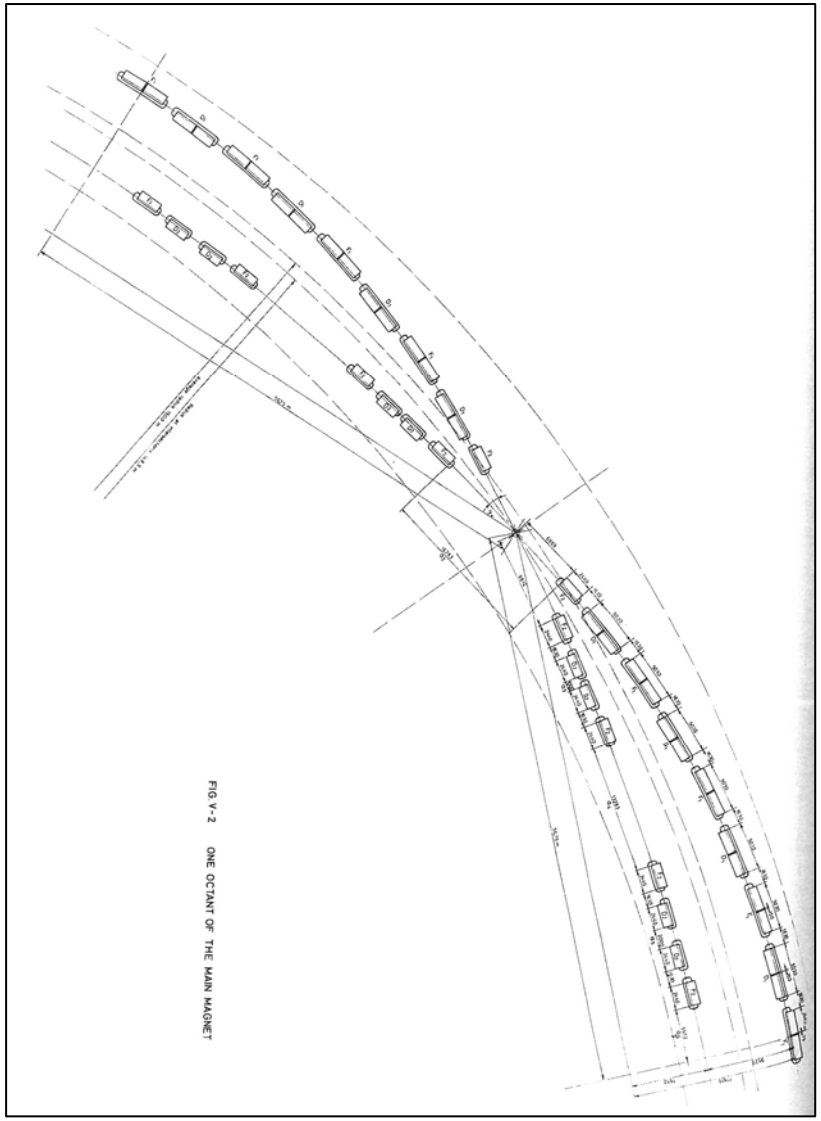
1964:
„Design Study of ISR for CPS“
(CERN/542)

„Use of storage rings as improved facility for the CPS“

←Hall for fixed-target exp.

Later: extraction channel to West Hall but never equipped

ISR Beam Optics



Optics type:

- Separated function
- Combined function>>chosen for:

-Access magnet gap for vacuum,

-Pole-face windings

Combined function cheaper

Structure:

FOFDOD (as CPS)

FODO >> chosen

Minimum distortion of β-function by long straight sections

Access problem at FD junction

ISR Combined-Function Magnet

P_{max} = 28 GeV/c

$2\pi R$ = 942.64 m = 1.5 $(2\pi R)_{CPS}$

Leads to >>

B = 1.2 T, ρ = 78.6 m

132 Magnets (192 Blocks)

L_{short}= 2.44 m

L_{long} = 5.03 m

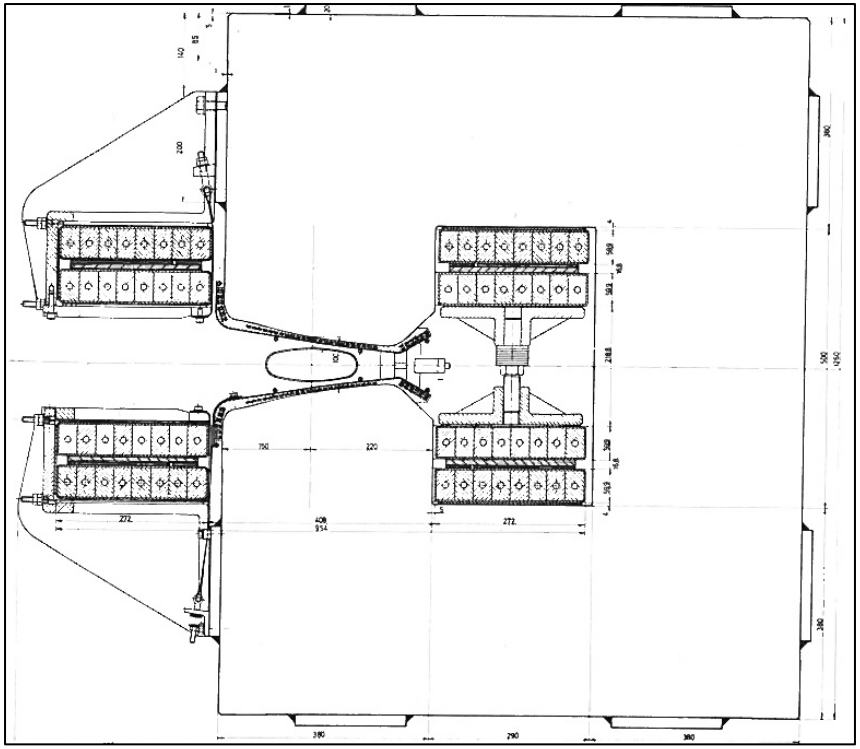
Copper coil 32 turns

Synchrotron radiation loss/turn:

$\Delta E \sim (E/m_o c^2)^4/\rho = 6.10^{-14}$ GeV

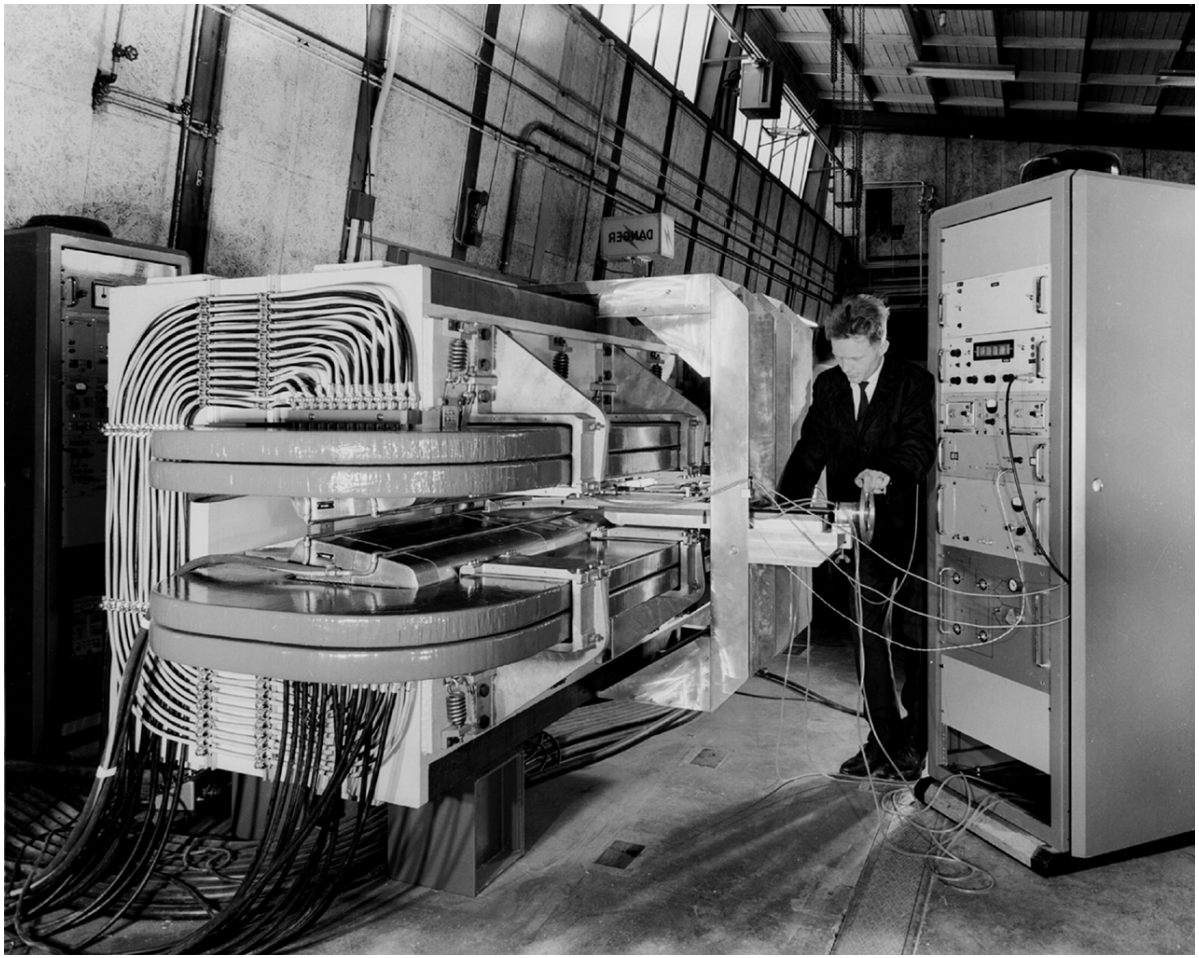
Hence fear:

>> no radiation damping>>beam loss by resonances and beam-beam effects (>new territory!)



Magnet cross-section

ISR Magnet Measurement



ISR Magnets still in use!
LHC Beam Dump

ISR Vacuum System

Design considerations:

Luminosity ~ $I_1.I_2/h_{eff}$

L decay:

collisions with residual gas

- Beam loss: <50% in 12h

by nuclear and single-Coul.scat.

- Growth of h_{eff}: <40% in 12 h

by multiple Coulomb scattering & non-linear resonances

>> L/L_0 = 18% after 12 h

Required:

P_{av}= 10^{-9} Torr N_2 equivalent

P = 10^{-11} Torr in the IPs

Technology choices:

Chosen after CESAR tests where P< 10^{-10} Torr reached

Stainless steel chamber (low μ)

Bake-able in situ at 300°C (initially baked to 200°C)

Flanges with metal seals

Sputter ion pumps (350 l/s)

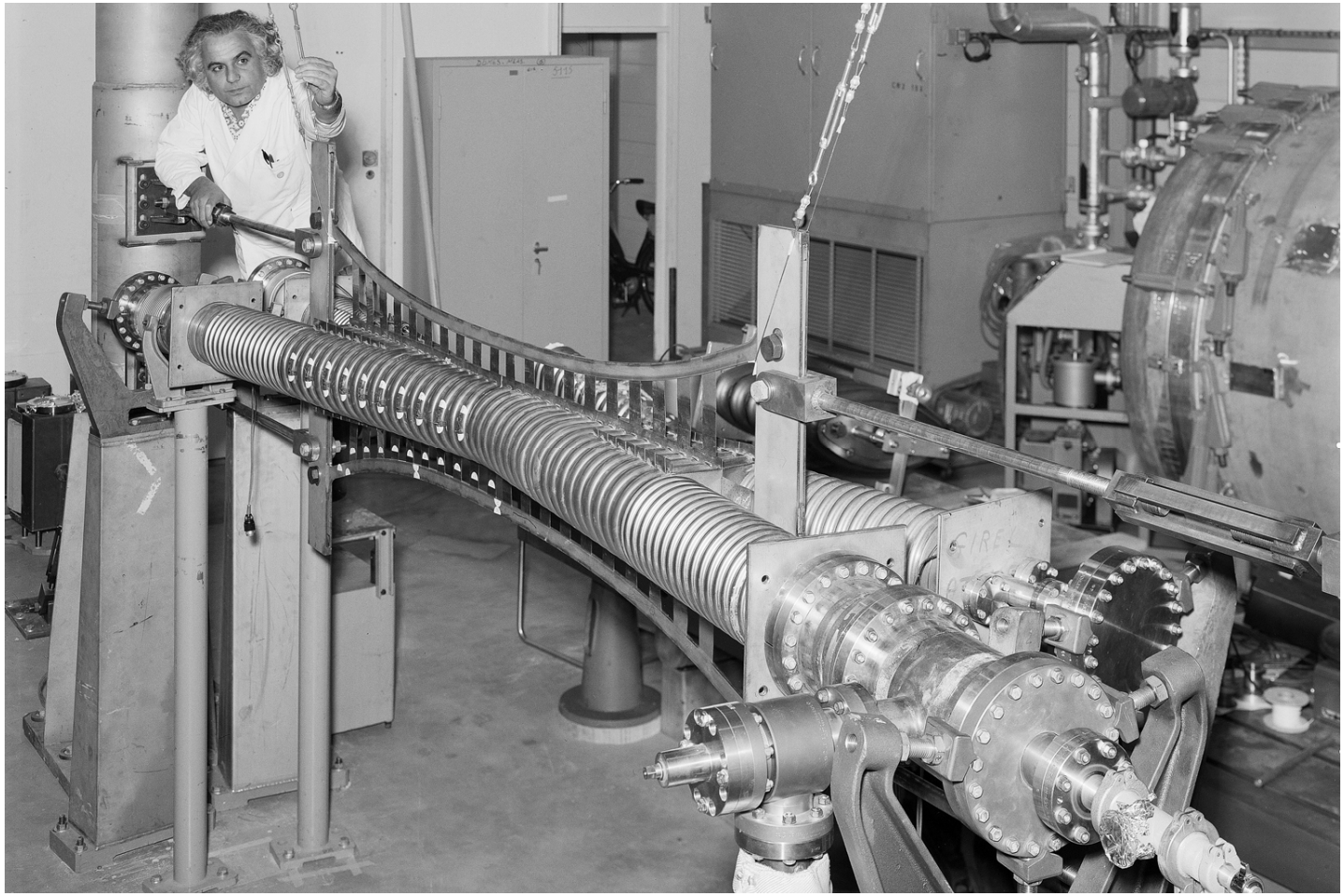
Ti-sublimation pumps (2000 l/s) at critical places

Clearing electrodes

Damping resistors to control induced e-m fields

Thin-Walled Vacuum Chamber at Interaction Point

Stainless steel and Inconel (0.2 mm) and Ti



ISR Tunnel

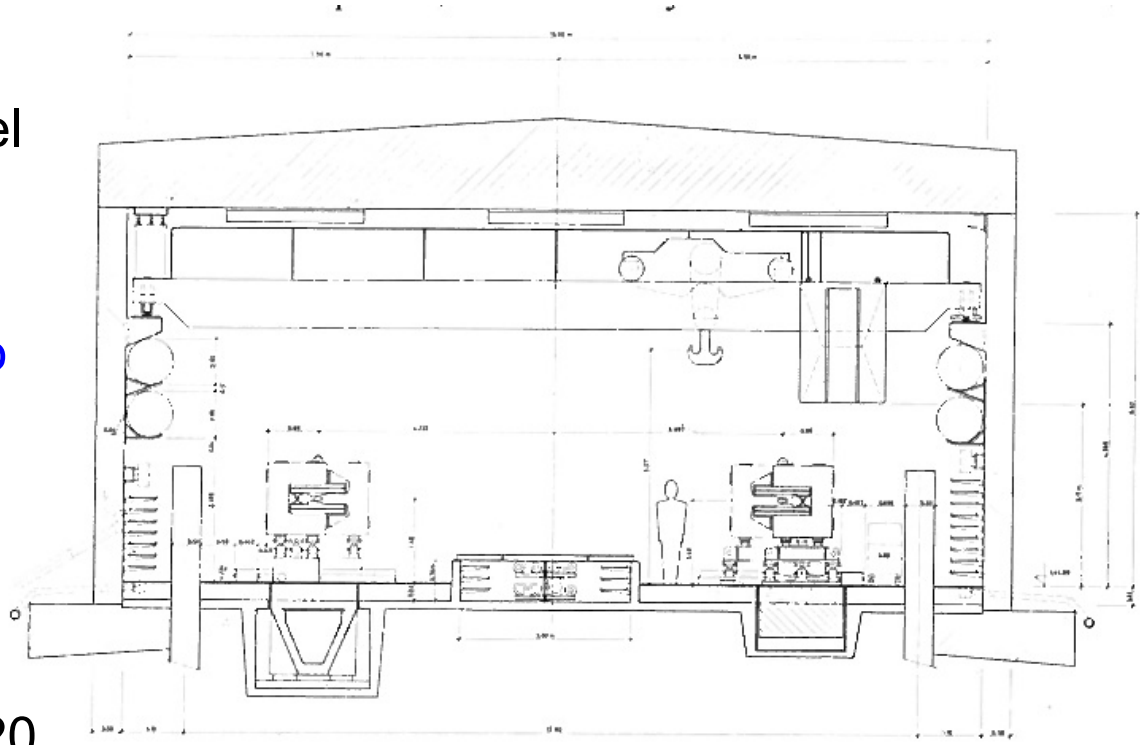
Cut-and-fill

based on molasse level 12 m above CPS to reduce excavation

Erection in 2 phases to protect the magnet foundations:

-prefabricated walls at 20 cm higher floor

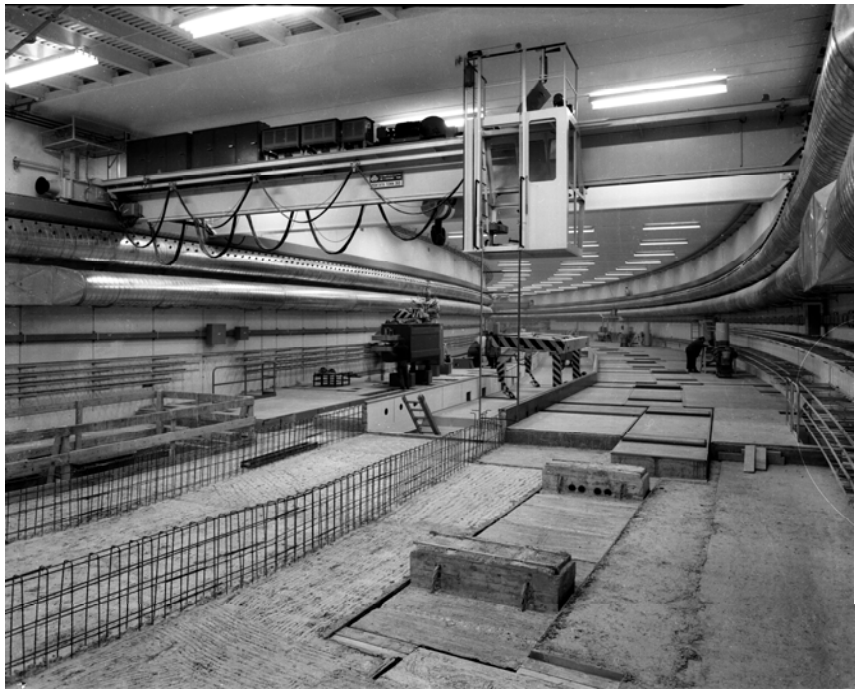
-digging of remaining 20 cm and ditches for the magnet foundations after closing of tunnel



15 m wide, 6.5 m high (4.0 m under hook)

ISR Tunnel construction

Excavation (1Mm³)



Completed tunnel with trial of magnet positioning

Construction schedule and milestones

1965 December: Approval
1966 November: Excavation start
1967 All magnet components ordered
1968 Magnet steel production: started beginning 1968, delivery October (11 kt)!
West Hall: available for magnets
1969
Prefabricated ring walls closed
Magnet cores: all fabricated, 2/3 installed
ISRC created (chair W.Jentschke)

ISR Magnets in West Hall

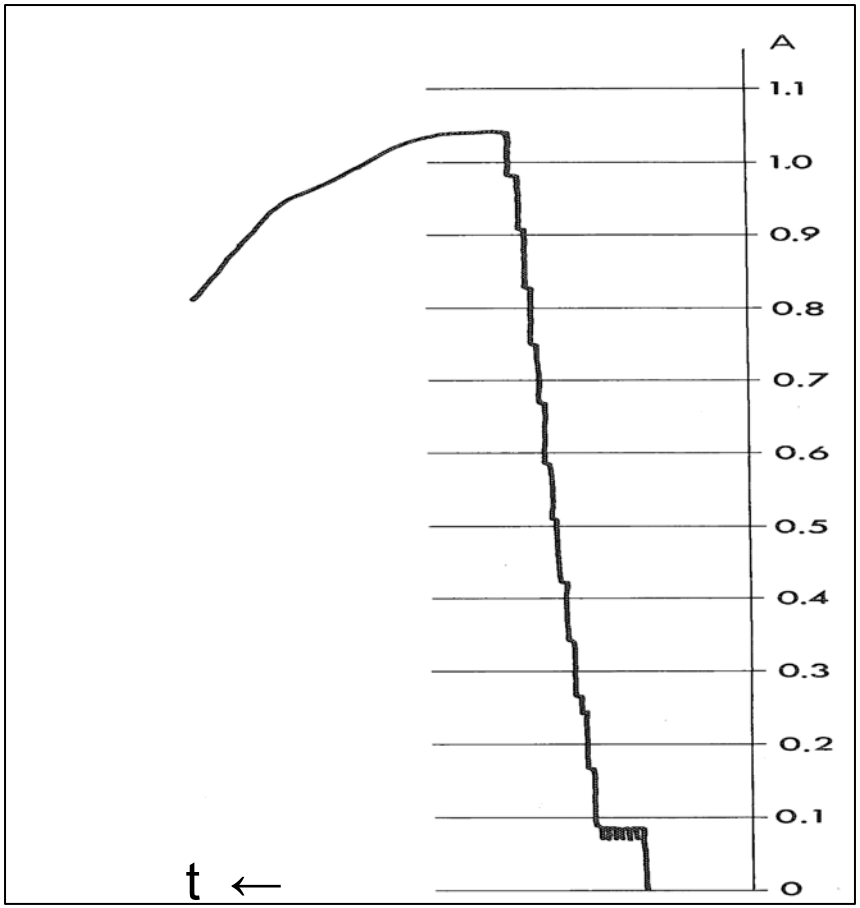
Assembly, Testing, Storage

The final race in 1970

- April: transfer line tests started
- May: Last magnet installed
- July: Earth shielding complete
- October 29th: ring 1 ready

Injection and circulating beam at 15 GeV/c !

Q-value as predicted
Closed orbit: $\Delta x = \pm 10$ mm
(uncorrected) $\Delta y = \pm 4$ mm
Rf stacking to 0.65 A ($\eta = 70\%$)



Stacked current = f(t)

Commissioning 1971

January 27:
first collisions

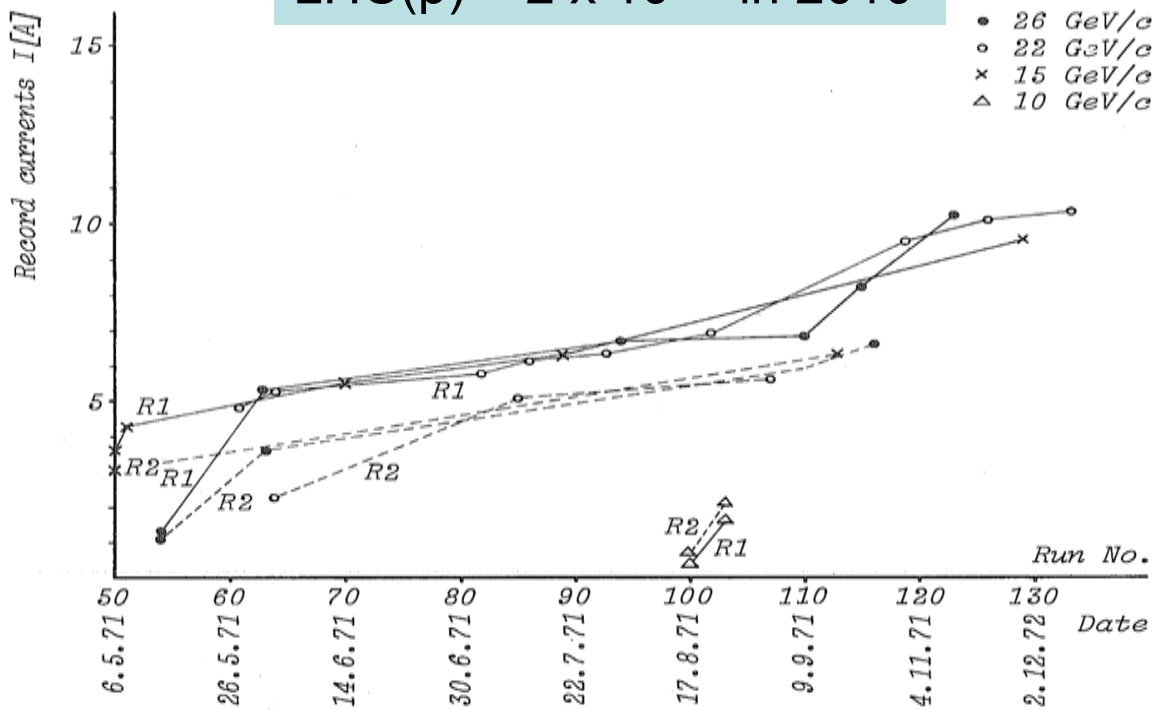
February:
1st physics run
May:
Physics at 26.5 GeV/c
(Ecm as 1500 GeV
beam fixed-target)

Beam decay:
< 1% per h at 6 A
Design < 6% per h

1800 h of operation
95 % availability

Max.Luminosity:
3×10^{29} $cm^{-2}s^{-1}$

ISR Design = 4×10^{30}
LHC(p) = 2×10^{32} in 2010



Inauguration

Completion 1 March 1971
- ahead of schedule
- within budget
  (332 MCHF in 1965 prices)

Inauguration 16 October 1971→

Main players:

- Eduardo Amaldi (1963 ECFA)
- Kjell Johnsen (project leader)
- Viktor Weisskopf (DG 61 – 65)

Conclusions

ISR : fine and unique instrument

- extraordinary beam lifetime
- record luminosity until 1991

despite - lack of synchrotron radiation damping

- beam-beam effects & non-linear resonances

Overdesigned? No, broad and solid basis for

- its own spectacular improvement
- the hadron colliders to come (SPS, Tevatron, RHIC,LHC)

„First considered a window into the future,
but it turned out to be more“ (Weisskopf 1984)

Thanks to E.Brouzet, P.Bryant, B.de Raad, C.Hauviller, H.Koziol