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

18 January 2011
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 \(\rightarrow\) e- e- rings
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 competitive for as low a cost possible“
CERN Electron Storage Ring (CESAR)

Idea: Mimic proton ring
  >> no synchrotron radiation
  >> $\beta \sim 1$ particles in low-B ring

Purpose: test rf stacking
  test UHV techniques

1.8 MeV electron storage ring
$2\pi R = 24 \text{ m} \quad B = 130 \text{ G}$

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 and team from CPS extremely important

Lattice requirements: $\neq$ 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 $\parallel$
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 $\beta$-function by long straight sections

Access problem at FD junction
ISR Combined-Function Magnet

\[ P_{\text{max}} = 28 \text{ GeV/c} \]
\[ 2\pi R = 942.64 \text{ m} = 1.5 \left(2\pi R\right)_{\text{CPS}} \]

Leads to >>

\[ B = 1.2 \text{ T}, \quad \rho = 78.6 \text{ m} \]

132 Magnets (192 Blocks)
\[ L_{\text{short}} = 2.44 \text{ m} \]
\[ L_{\text{long}} = 5.03 \text{ m} \]
Copper coil 32 turns

**Synchrotron radiation loss/turn:**
\[ \Delta E \sim \left(\frac{E}{m_0c^2}\right)^4/\rho = 6.10^{-14} \text{ GeV} \]

Hence fear:

>> no radiation damping>>beam loss by resonances and beam-beam effects (>new territory!)
ISR Magnet Measurement
ISR Magnets still in use!
LHC Beam Dump
ISR Vacuum System

Design considerations:
Luminosity ~ $I_1 \cdot I_2 / \rho_{\text{eff}}$
L decay:
collisions with residual gas
- Beam loss: <50% in 12h
by nuclear and single-Coulomb scattering
- Growth of $\rho_{\text{eff}}$: <40% in 12 h
by multiple Coulomb scattering
& non-linear resonances
>> $L/L_0 = 18\%$ after 12 h

Required:
$P_{\text{av}} = 10^{-9}$ 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 $\mu$)
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)
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:
$3 \times 10^{29} \text{ cm}^{-2}\text{s}^{-1}$

ISR Design = $4 \times 10^{30}$
LHC(p) = $2 \times 10^{32}$ 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)
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