CERN Accelerators

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CERN BE/OP
The CERN Accelerator Complex

- 7 TeV
- 450 GeV
- 50 MeV -> 1.4 GeV
- 26 GeV
PS Booster

- 1st Synchrotron in the chain with 4 superposed rings
- 157m Circumference
- Increases proton energy from 50 MeV to 1.4 GeV in 1.2s

- LINAC2 pulse distributed over the 4 rings, using kicker magnets
- Each ring will inject over multi-turns, accumulating beam in the horizontal phase space

- => the beam size (transverse emittance) increases when the intensity increases

The PS Booster determines the transverse **Brightness** of the LHC beam
• The PSB proton beam impinges on a target producing a range of isotopes
• Two mass separators (GPS & HRS) allow selection of isotopes, which are then transported to the users
• Post-acceleration of isotopes
  • REX, normal conducting accelerating structures
  • HIE-ISOLDE, super conducting LINAC

Talk by
Maria Jose Garcia Borge
- Performs multi-turn injection at a rate of 200 ms
- Uses stochastic and electron cooling to reduce transverse and longitudinal beam dimensions
- Sends the beam to the PS that feeds it into the SPS for delivery to the LHC and the North Area

- Receives beam from **LINAC3**
- Different ion species:
  - Pb (lead)
  - Ar (Argon)
  - In (Indium)
  - Xe (Xenon)
  - ...
- The LEIR cycle length is 3.6s
• Oldest operating synchrotron at CERN
• Circumference 628m ($2\pi \times 100m$)
  • 4 x PSB circumference
• Increases proton energy from 1.4 GeV to a range of energies up to 26 GeV
• Cycle length depending on the final energy, ranges from 1.2s to 3.6s

• The many different RF systems allow for complex RF gymnastics:
  • 10 MHz, 13/20 MHz, 40 MHz, 80 MHz, and 200 MHz
• Various types of extractions:
  • Fast extraction
  • Multi-turn extraction (MTE)
  • Slow extraction
- Receives slow extracted beam from the PS at 24 GeV/c
  - Beam pulse length ~400 ms for a cycle length 2.4s
- Secondary particle beams:
  - From 1 GeV to ~ 15 GeV with ~ $10^6$ particles
  - Protons, Electrons, Muons, Pions
- Experiments: CLOUD, previously DIRAC, HARP, ...
- Test beams: LHC, COMPASS, BabyMind, SHiP, AMS, ..... 
- Irradiation Facilities: IRRAD & CHARM
• **Neutron Time of Flight**
  • Fast-extracted single proton bunch from PS at 20 GeV/c on a lead spallation target
  • Every proton yields about 300 neutrons, spanning an energy range from the MeV region up to the GeV region (slow and fast)

• Experimental area 1 (EAR1):
  • Horizontal beam line with 185 m drift tube
• Experimental area 2 (EAR2):
  • Vertical beam line above the target with 20m drift tube

• Measurement of neutron cross sections relevant for nuclear waste transmutation and for nuclear astrophysics
• Neutrons as probes for fundamental nuclear physics

Talk by Maria Jose Garcia Borge
Antiproton Decelerator/ELENA

- Receives fast-extracted proton beam from PS at 26 GeV/c on a tungsten target
- **Every million protons** yields about **one usable antiproton** at 3.5 GeV/c.
- AD decelerates beam in stages down to **5.3 MeV**
- Experiments:
  - ASACUSA, ALPHA, ATRAP, AEGIS

- Presently the **ELENA ring** is under commissioning
  - Decelerates further down to **100 keV**
  - Beam intensity ~ $3 \times 10^7$ antiprotons
• about 30m under ground
• Circumference 6.9 km
  • 11 x PS circumference
• Increases proton beam energy up to 450 GeV with up to ~5x10^{13} protons per cycle

• Provides fast-extracted beam to LHC, AWAKE (PWFA tests) and HiRadMat
• Provides slow-extracted beam to the North Area

Talk by Lau Gatignon
- Receives slow extracted proton beam from the SPS at \textbf{400 GeV/c}
- Beam spill of \textasciitilde4.5 s for a cycle length of 10.8s
- Various targets
- 7 beam lines with a total length of nearly 6 km
- 3 experimental halls

- Uses nearly every year also ion beams from the SPS for a rich primary and secondary ion physics program
• 1232 main dipoles of 15 m each that deviate the beams around the 27 km circumference
• 858 main quadrupoles that keep the beam focused
• 6000 corrector magnets to preserve the beam quality

Main magnets use superconducting cables (Cu-clad Nb-Ti)
• 12’000 A provides a nominal field of 8.33 Tesla
• Operating in superfluid helium at 1.9K, 150 tons of liquid helium
LHC: Luminosity

\[
LUMINOSITY = \frac{N_{\text{event/sec}}}{N_{1}N_{2}f_{\text{rev}}n_{b}} F
\]

- Intensity per bunch
- Number of bunches
- Geometrical Correction factors

Last week: \(<100 \text{ fb}^{-1} \text{ since 2010}\)
1.34 x 10^{20} protons in 2016

only mass of ONE grain of sand accelerated per year!

Only a tiny fraction of <0.1% to LHC
MTE – Multi Turn Extraction

- **SPS North area - fix target beam**
- \( L_{SPS} = 11 \times L_{PS} \)
- How to fill 10/11 of the SPS from the PS? (remaining ‘hole’ for extraction kicker)

- Split the beam in the PS in 5, inject twice!
- **Continuous Transfer (CT)** was mechanically splitting the beam (transversely) with significant losses

- ‘Multi-Turn Extraction’ (MTE) uses nonlinear elements (sextupoles and octupoles) to create 4 islands in the horizontal phase space and extracts them successively followed by the core
PS bunch splitting for LHC

- BCMS beam: 8 instead of 6 bunches from PSB => lower charge/bunch in PSB
- lower transverse emittance => higher LHC luminosity!

Standard: 72 bunches @ 25 ns
BCMS: 48 bunches @ 25 ns + various other schemes

The PS defines the longitudinal beam characteristics.
High Luminosity LHC (HL-LHC) / LIU

- aims at integrated luminosity of 3000 fb⁻¹
- many upgrades of the LHC (magnets, cryogenics, ...) and detectors
- also needs higher brightness and intensity from the injectors => LHC Injector Upgrade (LIU)
- LINAC4: increases injection energy into PSB from 50 to 160 MeV => lower space charge problems
- H⁻ injection into PSB => no emittance blow-up
- PSB extraction to PS from 1.4 to 2.0 GeV => lower space charge
- plus other upgrades in PSB, PS, and SPS

Principle of H⁻ injection in the PSB
International collaboration:

- **pp-collider (FCC-hh)** → defining infrastructure requirements
  
  $\sim 16 \, T \Rightarrow 100 \, \text{TeV in 100 km}$
  
  $\sim 20 \, T \Rightarrow 100 \, \text{TeV in 80 km}$

- including **HE-LHC** option: 16-20 T in LHC tunnel

- **$e^+e^-$ collider (FCC-ee)** as potential intermediate step

- **p-e (FCC-he)** option

- **100 km infrastructure** in Geneva area
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