RCS and PS2 activities at CERN

Link to Beta-beams

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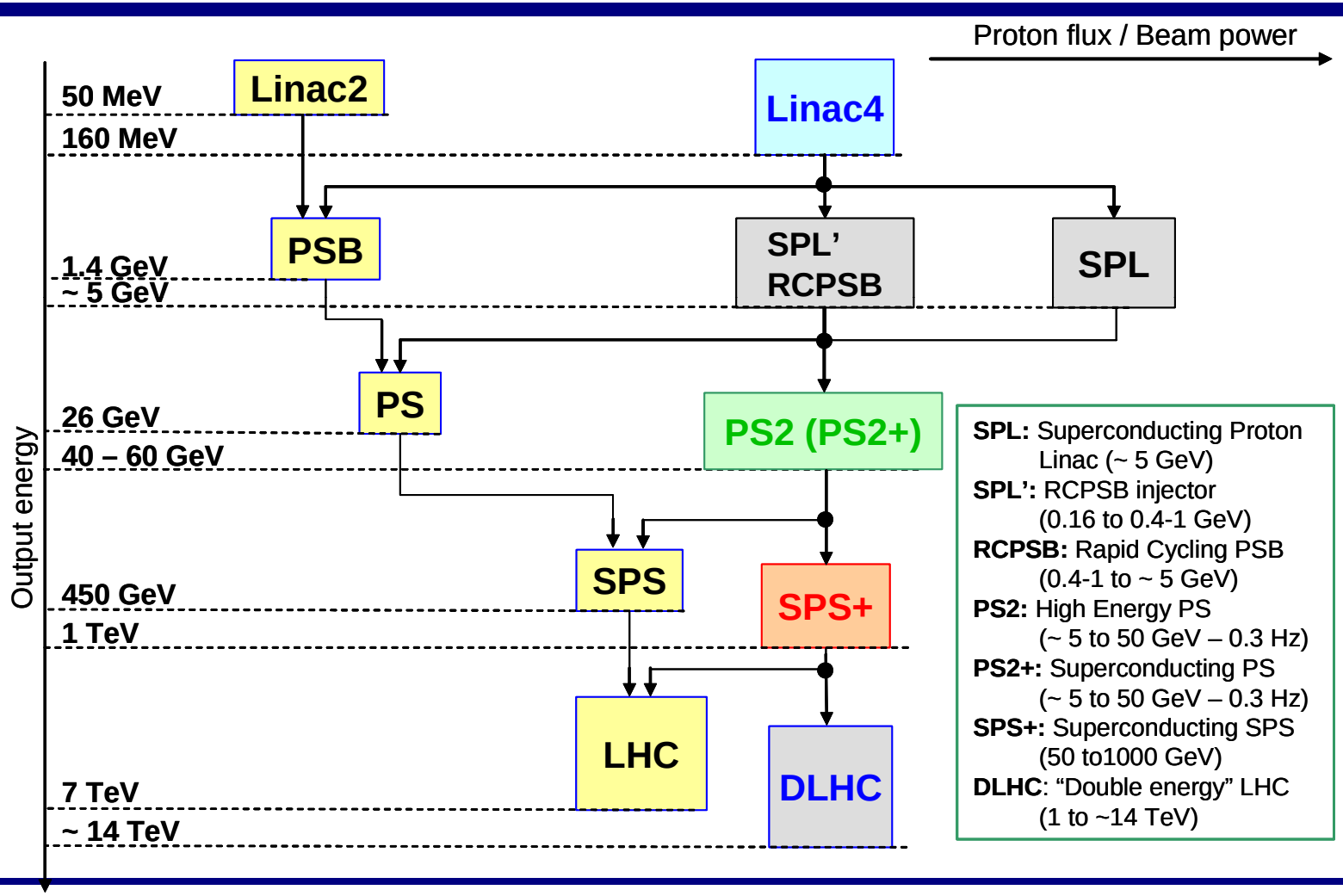
Evolution of the CERN accelerator complex – Studied by PAF working group



CERN proton upgrade studies

- **Assure high reliability and availability of injector chain for LHC operation**
  - **PS magnet coils problems, main power converter problems**
- **Increase performance of injector chain for LHC operation**
  - **Higher beam brightness by more favourable energy ranges**
- **Improved performance for other physics applications**
- **Prepare for long-term (energy) upgrade of complete accelerator chain**
  - **Higher PS2 ejection energy to reduce SPS+ energy swing**
- **General consideration started begin 2006**
  - **Increased effort for PS2 since September 06**
  - **Increased effort for RCS since April 07 (based on BB RCS)**

PS2 main parameters (protons)

- **Injection energy via beam brightness:**
  - **Reach twice brightness of the ultimate 25 ns LHC beam (20% reserve for losses): 4.0×10^{11} per LHC bunch (inst. 1.7×10^{11})**
    - Determines line density at injection incoherent SC tune spread.
  - **4 GeV injection energy (previously 3.5 GeV)**

- **Machine length increased slightly to 15/77 SPS**
  - **~ twice longer than PS because of higher ejection energy (50 GeV)**
  - **Previously 1/5 SPS (i.e. 2.2 x PS)**
  - **Needed to assure RF cogging with SPS for 40 MHz systems**
    - h=180 (PS2 ejection) to h=924 (40 MHz) and 4620 200 MHz SPS

PS2 main parameters (protons)

- **PS2 RF systems (2 principal routes)**
  - **40 MHz only h=180 (with SPL as injector with 40 MHz chopping).**
    - With present lattice (γt) bunches at ejection can be shortened to fit SPS 200 MHz buckets
  - **10 MHz (h=15) as main systems (with RCS as injector on h=1)**
    - Additional 20, 40 MHz systems for splitting (cf. PS) each bunch in 12 LHC bunches (h=15 x 3 = 45 x 2 x 2 = h=180)
- **Apertures**
  - **Determined by high intensity fixed target beam**
    - Scaling from high intensity PS beam at 1.4 GeV
    - Normalized sigma emittances 15/8 mm mrad (h/v)
    - Adiabatic emittance damping by $(\beta\gamma)_{1.4}/ (\beta\gamma)_{4.0}$

Beta-beam with PS2 (i)

- **Beta-beam baseline design with 3.5 GeV (p equ.) injection into existing PS corresponds to space charge limit!**
  - **We raised the injection energy to control the space charge**

$$\Delta Q_{S.C.} \propto -\frac{N_b}{\varepsilon_n} \cdot \frac{1}{\beta\gamma^2} \cdot \frac{1}{B_b}$$

    - B_b will decrease like the ratio of circumferences when putting the same bunch in a machine with different circumference (Δ**Q increases with R**)!

- **PS2 is a >twice larger machine and thus the space charge tune spread would double $\rightarrow$ unsustainable.**

Beta-beam with PS2 (ii)

- **Increased injection energy to gain by ratio of $\beta\gamma^2$**
  - **5.5 GeV instead of 3.5 GeV (Bρ increase by ~50% to 21.2 Tm)**
    - Very large working range for RCS…no real option
- **Reduce bunch intensity by a ~ factor 2**
  - **To compensate for overall intensity produce twice more bunches**
  - **One option is RCS at twice the frequency (20 Hz instead of 10 Hz)**
    - Increased repetition rate for RCS (50 ms)
    - Only 50 ms accumulation time in ECR
    - ~40 instead of 20 bunches in the decay ring (OK for physics)
    - Half the bunch intensity means half peak current in decay ring bunches (good for RF) and half space charge.
- **Keep harmonic number identical to PS (i.e. longer bunches)**
  - **Requires enlargement of frequency range of PS2 RF (lower side).**
  - **No other changes in the beta-beam scheme.**

PS2 RF scenarios with Beta-beam(iii)

- **PS2 40 MHz only option**
  - **Incompatible with beta-beams**
    - Beam from RCS does not fit 40 MHz bucket
    - Short bunch would give enormous space charge
  - **Note it is also incompatible with LEIR ion beams for LHC!!!**
- **PS2 10 MHz tuneable system (+20/40 MHz systems)**
  - **Compatible with beta-beams with changes**
    - Doubling the number of bunches and repetition rate (h=40/42)
- **PS2 10 MHz system with enlarged tuning range**
  - **Fully compatible with beta-beams**
    - Same harmonic number (h=20 or 21)
  - **Preferred scenario for beta-beams.**

PS2 aperture with beta-beam

- **Emittance definition for beta-beam baseline**
  - **We exploited fully the PS aperture to have the largest possible emittances for the beta-beam to reduce space charge at PS injection and also SPS injection**
    - At a PS injection energy of 3.5 GeV proton equivalent (from RCS)
- **The PS2 aperture is defined from protons and is significantly reduced because of adiabatic damping**
    - Adiabatic emittance damping by $(\beta\gamma)_{1.4}/ (\beta\gamma)_{4.0}$
- **We can only profit little from the upgrade to 4 GeV since we defined the emittances assuming 3.5 GeV p-equivalent**
    - Adiabatic emittance damping only ~$(\beta\gamma)_{3.5}/ (\beta\gamma)_{4.0}$ p-equivalent
  - **The beta-beam ions DO NOT FIT the PS2 aperture**
  - **Aperture increase for Beta-beams needed in PS2.**

RCS main parameters (protons)

- **Injection energy via beam brightness:**
  - **Reach twice brightness of the ultimate 25 ns LHC beam (20% reserve for losses): 4.0×10^{11} per LHC bunch (inst. 1.7×10^{11})**
    - Determines line density at injection and incoherent SC tune spread.
  - **400 MeV injection energy (Br = 3.2 Tm)**
  - **4 GeV ejection energy (see PS2)**
- **Machine length 1/5 PS2 (~270 m)**
- **RF systems**
  - **H=1 RF system (700 kHz – 1.2 MHz) for single bunch filling of protons to PS2.**
- **PS2 filling scheme**
  - **H=1 RCS to H=15 PS2, 14 cycles, 1 empty bucket for kicker gap.**
  - **10 Hz RCS operation → PS2 filling time 1.3s cf. to 1.2 s presently**

Beta-beams with proton RCS (i)

- **Injection energy :**
  - **100 MeV/n for He and Ne**
  - **Smallest Br for Ne = 2.7 Tm**
    - Requires small enlargement of field range on lower side → OK.
- **Machine length**
  - **Slight increase wrt. baseline RCS → slight increase of SC**
    - Acceptable (7.5%)
- **RF systems**
  - **H=1 RF system for beta-beam will require enlargement of tuning range on lower side 480 kHz instead of 700 kHz**
    - Eventually also needed for LEIR ions (alternatively h=2).
- **PS2 filling scheme**
  - **H=1 RCS to H=20 (21) PS2, no change to baseline**

Beta-beams with proton RCS (ii)

- **Injection system :**
  - **Multi-turn injection system needed**
    - Not needed for ions from LEIR (single-turn bunch-to-bucket).
    - Not needed for protons (H- charge exchange)
- **Apertures**
  - **Again, like for PS2, beta-beam requires larger apertures because of our baseline emittance definition and scaling.**
    - Proton reference (1.4 GeV PS) → scale to Br (400 MeV)
    - Beta-beam ions (3.5 GeVequiv.) → scale to Br (100 MeV/n)
      - (Present CERN estimate based on BB aperture requirements)

SPS for beta-beams with PS2 upgrade

- **Space charge at SPS injection**
  - **Due to the higher PS ejection energy of 50 GeV p-equivalent strongly reduced space charge effects (~factor 4).**
  - **Most probably no need any longer for keeping long bunches to fight space charge – to be confirmed.**
    - No dedicated 40 MHz system needed for beta-beam in SPS.
- **Bunch transfer to SPS**
  - **The PS2 systems for LHC bunch train production and bunch shortening (20/40 MHz) should also allow the ion bunches to be short enough to go directly into SPS 200 MHz buckets.**

Summary

- **Beta-beam in (proton) PS2 requires**
  - **Enlarged tuning range of 10 MHz system**
  - **Enlarged apertures**
- **Beta-beam in (proton) RCS requires**
  - **Slightly enlarged working range for main magnets**
  - **Enlarged tuning range for RF system**
  - **Multi-turn injection system**
  - **Enlarged apertures**
- **Beta-beam in SPS profits from PS2 upgrade**
  - **Strongly reduced space charge**
  - **No extra 40 MHz system required**