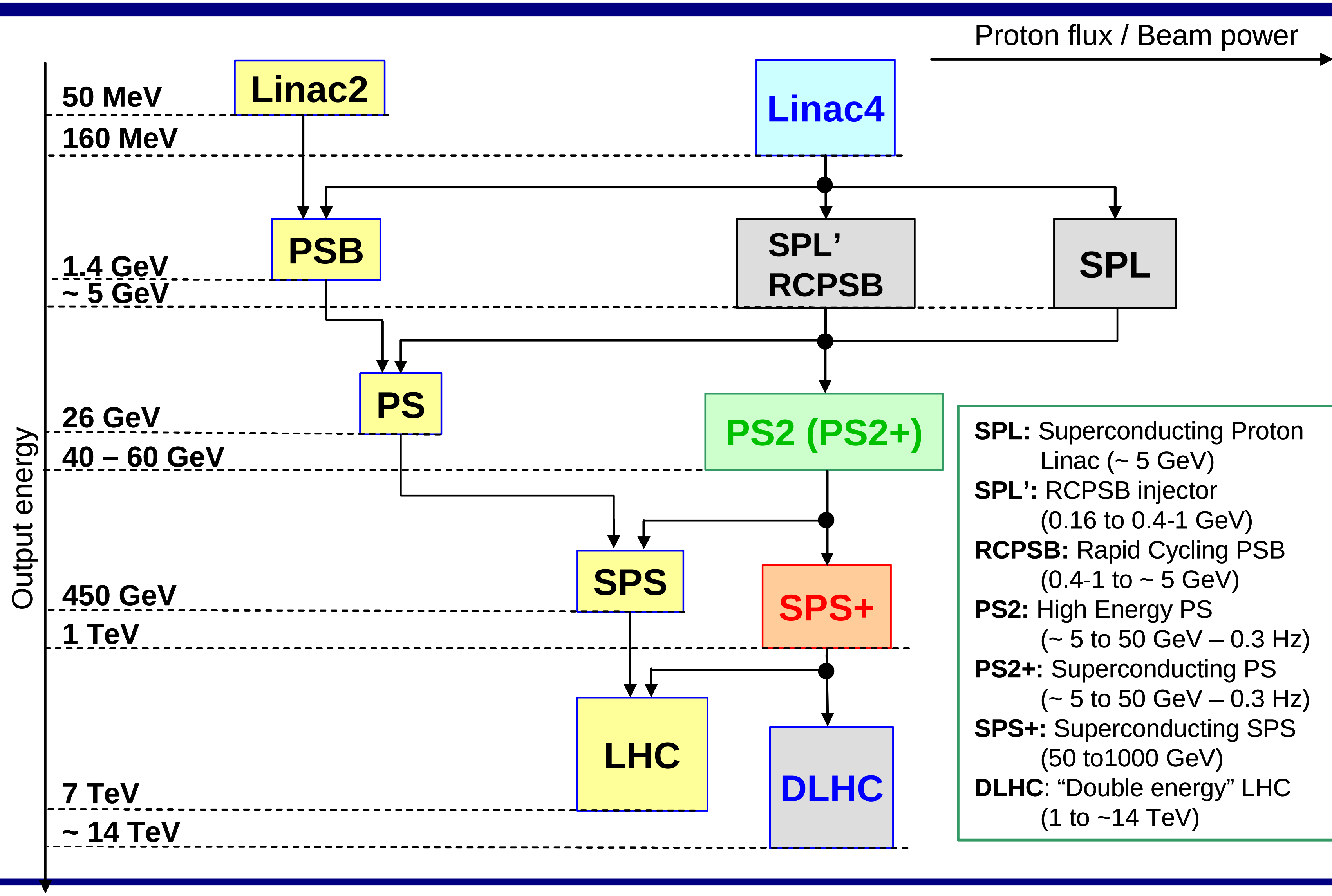
PS2 developments at CERN

Michael Benedikt

AB Department, CERN

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



PS replacement

- **Assure high reliability and availability of injector chain for LHC operation**
  - **PS main magnet coils and laminations**
  - **Rotating machine main power converter**
- **Increase performance of injector chain for LHC operation**
  - **Higher beam brightness by more favourable energy range**
  - **Shorter filling time by improved cycling schemes**
- **Improved performance for other physics applications in energy range PS to SPS (10 to 450 GeV).**
- **Prepare for long-term (energy) upgrade of complete accelerator chain**
  - **Higher PS2 ejection energy to reduce SPS+ energy swing**

Goals for PS2 design

- **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})**
  - **"Ultimate" bunches at 12.5 ns, twice ultimate at 25ns, etc.**
    - Determines average line density in the machine at injection and therefore the injection energy via incoherent SC tune spread.
- **Significantly higher injection energy into SPS.**
  - **Injection into SPS well above transition energy**
  - **Reduced space charge at SPS injection, smaller tr. emittances.**
  - **Potential for long-term SPS replacement with higher energy.**
    - Ejection energy determines PS2 machine size
- **As versatile as existing PS**
  - **Protons, ions, high intensity physics beams, slow extraction, etc.**

Considerations on injection energy

- **Incoherent space charge tune spread at injection:**
  - **Existing PS with 1.4 GeV injection energy just capable of producing the ultimate LHC beam (ΔQ ~-0.2)**

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

    - B_b… bunching factor (average / peak density for single bunch)
    - B_b will decrease by factor 2 when putting the same bunch in a machine with twice larger circumference (**ΔQ increases with R**)!

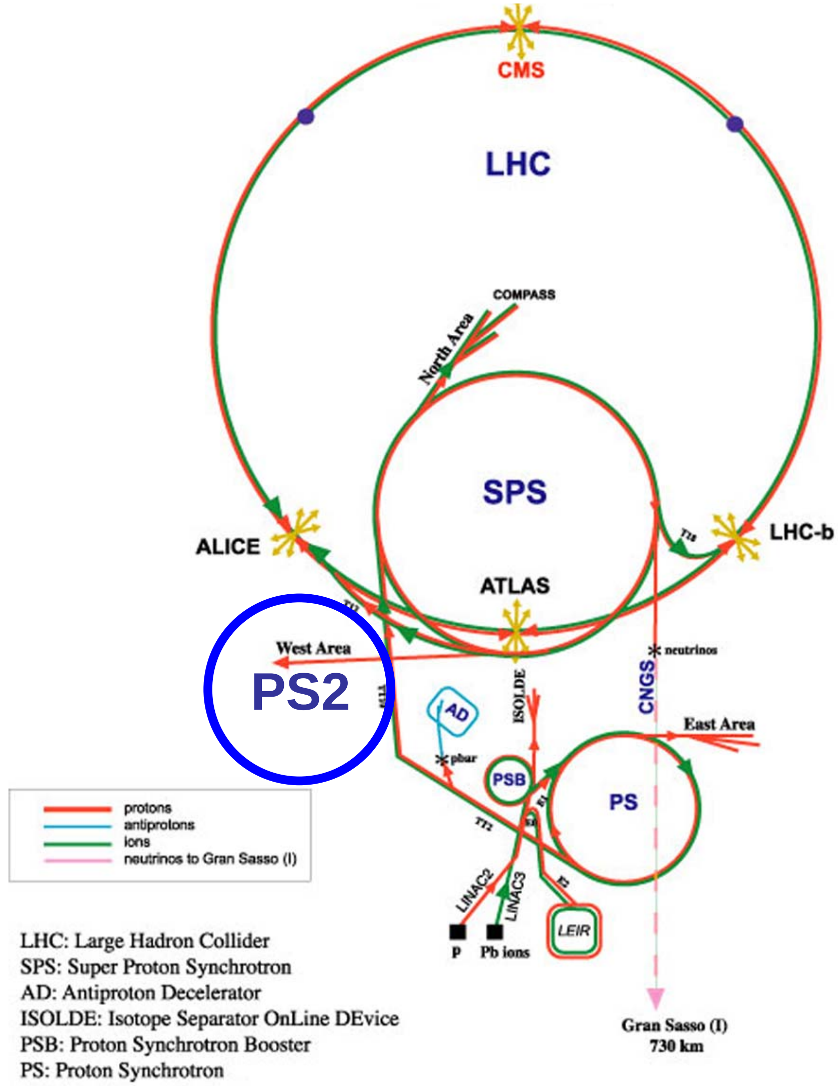
- **PS2: twice ultimate brightness in a twice larger machine**
  - **4 times larger incoherent tune spread at given energy.**
  - **Compensation with ratio $\beta\gamma^2$ at injection:** $\left(\beta\gamma^2\right)_{PS2} \geq 4 \cdot \left(\beta\gamma^2\right)_{PS}$
    - **Injection energy PS2: 3.5 to 4 GeV**

Considerations on machine size

- **Existing PS with 25 GeV top energy:**
  - **Combined function magnets with classical lattice.**
  - **Bending radius of 70 m (~440 m length) (B = 1.25 T at 25 GeV)**
  - **114 m (174 m) of (fully used) straight sections.**
  - **Average radius 100 m and machine circumference 628 m.**
- **PS2: extraction energy ~50 GeV (NC) ~75 GeV (SC)**
  - **Separated function (eventually complicated lattice for imag. γ_t)**
    - Assume quads will occupy 30 % of integrated dipole length
  - **NC: dipole at ~ 1.8 T (i.e. bending radius ~100 m, length ~ 630 m)**
  - **SC: accordingly higher field (similar radius but higher energy)**
  - **Additional space for quadrupoles: ~200 m**
  - **Larger space requirements for insertions: ~300m**
    - **PS2 will have ~twice PS radius i.e. 200 m and 1250 m length**

PS2 integration

- **For staged upgrade:**
  - **Tangent to TT2/TT10**
- **For simultaneous upgrade:**
  - **more flexible**



Performance of PS2 for proton operation

- **Twice average line density of PS**
- **Twice longer machine**
- **Twice extraction energy**
- **Identical acceleration time**

Theoretically factor 8 increase in power (assuming identical normalised emittances)

- **Shorter cycle time in some cases (LHC without double batch)**

- **Actual performance will depend on injector upgrade**
  - **In case of staged approach: i.e. PS2 before injector upgrade**
    - Line density limited to achievable PS density
    - Increased cycling time because of double batch filling from PS.

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 by factor 2 when putting the same bunch in a machine with twice larger circumference (**ΔQ increases with R**)!

- **PS2 is a twice larger machine and unfortunately we have already played the card of increasing energy**
  - **Space charge tune spread will double $\rightarrow$ unsustainable.**
    - Either increase injection energy of reduce bunch intensity!
- **PS2 ejection at 50 GeV will reduce SPS space charge by ~4.**

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…
    - Better lifetime at injection and accumulation
    - Lowered space charge at SPS injection
- **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.

Summary PS2 preliminary parameters

Parameter	unit	PS2	PS
Injection energy kinetic	GeV	3.5 – 4.0	1.4
Extraction energy kinetic	GeV	~ 50	13/25
Max. intensity LHC (25ns)	ppb	4.0×10^{11}	1.7×10^{11}
Max. intensity FT	ppp	1.2×10^{14}	3.3×10^{14}
Max. stored energy	kJ	1000	70
Max ramp rate	T/s	1.5	2.2
Repetition time (50 GeV)	s	~ 2.5	1.2/2.4
Max. effective beam power	kW	400	60

Summary

- **Design goals and first parameters for a PS2 study at CERN were defined and are mainly driven from LHC operation.**
- **For the beta-beam, the longer PS2 creates space charge problems requiring either higher injection energy or changing the bunch intensity and numbers**
- **The PS2 could be designed with optimised loss management for beta beam and will be advantageous for the SPS via space charge reduction.**

Integration in existing complex - Injection

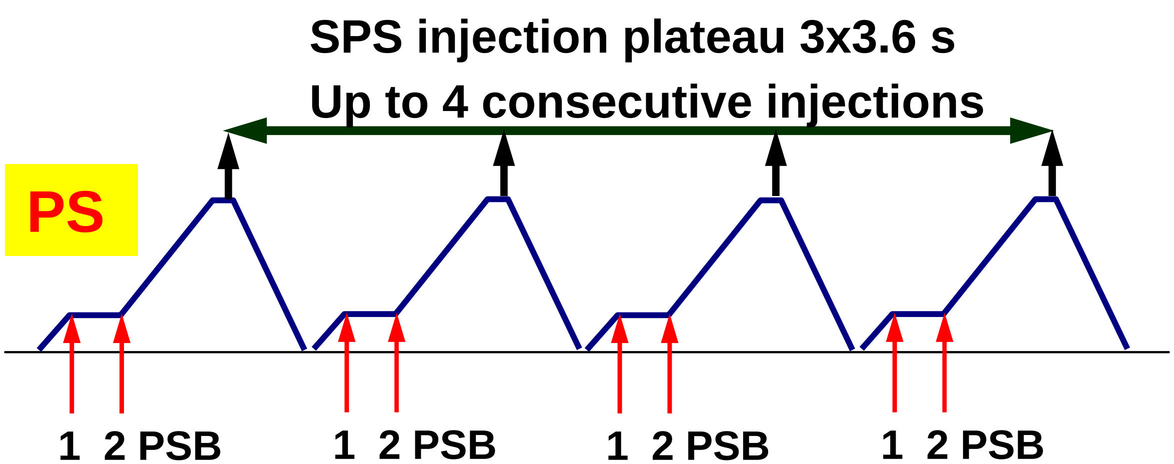
- **With staged approach i.e. PS2 before p- injector upgrade**
  - **Injection from existing PS (to bridge PSB to PS2 energy gap)**
    - PS running only at low energy, below transition (γ_t ~ 6.1).
  - **Performance limited by**
    - PS SC limit at injection (line density corresponding to ultimate)
    - Filling pattern and cycling time (double batch PS -> PS2).
- **With injector upgrade i.e. PSB replacement**
  - **Linac4 & SPL-option**
    - H- injection at 3.5 to 4 GeV
  - **Linac4+ & RCS option (>10 Hz)**
    - Bunch to bucket transfer, classical single-turn injection (>10 Hz)
- **Ion operation**
  - **Beam from LEIR at ~1.3 GeV p-equivalent. Alternative options?**

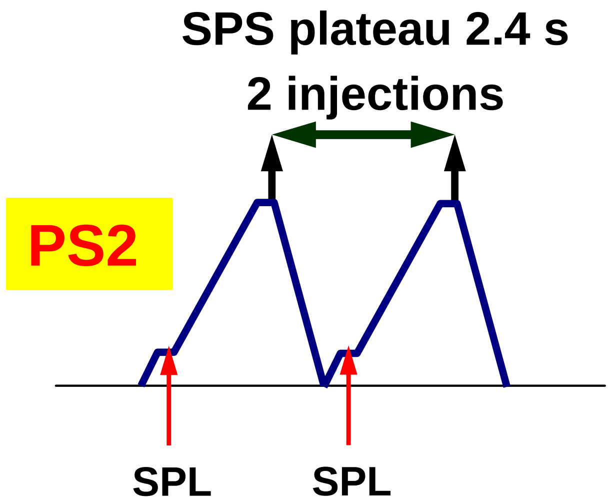
Integration in existing complex - Extraction

- **Several extractions towards the SPS:**
  - **Fast (single turn type)**
    - LHC beams
  - **“Continuous Transfer” Multi-turn extraction (5-turn)**
    - Filling of complete SPS for fixed target physics.
  - **Both extractions also with ion beams**
- **Extraction for physics at PS2**
  - **Slow resonant extraction**
    - High intensity fixed target similar to SPS?
  - **Need for dedicated fast extraction?**
- **Experimental area for PS2?**
  - **PS EAST hall very limited for radiation protection reason**

LHC beams

- **Example 12.5 ns beam (assuming SPL or RCS injector):**
  - **PS2 will provide “ultimate” LHC bunches with 12.5 ns spacing**
  - **Bunch train for SPS twice as long as from PS**
  - **Only 2 injections (instead of 4) from PS to fill SPS for LHC**
  - **PS2 cycle length 2.4 s instead of 3.6 s for PS**
    - Reduces SPS LHC cycle length by 8.4 of 21.6 s (3x3.6 – 1x2.4)
    - Accordingly reduced flat bottom with beam in LHC (35% reduction).





High-intensity physics beams

- **SPS fixed target beam (assuming SPL or RCS injector):**
  - **PS2 will provide twice line density of PS high-intensity FT beam**
  - **Twice circumference gives up to 4 times more intensity (~1.2E14)**
  - **Five-turn extraction will fill SPS with single shot instead 2 from PS (Circumference SPS = 5.5circumference PS2)**
    - Twice more intensity in SPS
    - Twice higher line density in SPS
    - No injection flat bottom in the SPS