Path lengths of the two LHC beams: first results

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Why do we bother?

- **Difference in path lengths between the two beams might imply:**
  - **operating the LHC RF systems for the 2 beams with 2 different frequencies**
  - **having 2 different extraction energies from the SPS**

Pathlength difference

- **Contributions:**
  - **Random differences (integrated field) between the two apertures**
  - **Systematic difference (integrated field) between the two apertures**

Effect of the random contributions

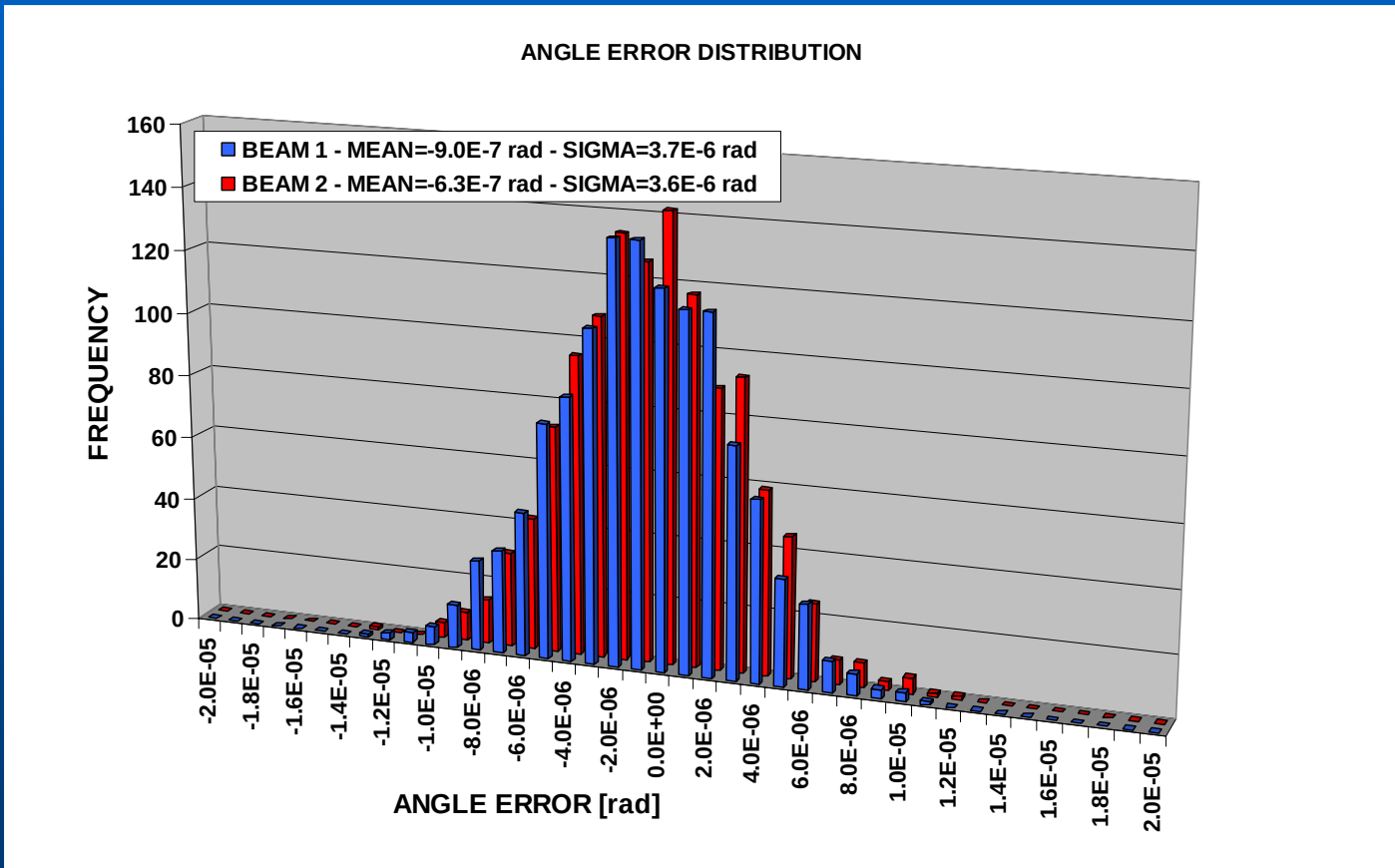
$$\sigma_{\Delta C} \cong 4\sin(\pi Q_x)\frac{\sigma_{x\,CO}}{\langle\beta_x\rangle}\left|\langle D_x\rangle\right| + ...\text{higher order terms}$$

- **For the LHC ($\Delta C \equiv$ difference between the pathlengths of the 2 beams)**
  - **An r.m.s. closed-orbit distortion of 2 mm (possible guess for the commissioning phase – to be compared with the target ~0.4 mm r.m.s.) ➔ $\sigma_{\Delta C}$ ~ 0.19 mm r.m.s. ➔ ΔC_{max} ~ 0.57 mm (3 σ)**

A more realistic model

- **Recently a tool has been made available to generate the machine model with errors.**
- **Generated 2 beams with MB errors, based on:**
  - **~1100 cold-mass warm measurements**
  - **known warm/cold correlations**
  - **present allocation or pre-allocation = ~ 75% of the dipoles**

A more realistic model



A more realistic model

- **Calculate closed orbit with MAD-X for both beams and correct down to ~2 mm r.m.s.**
- **Calculate pathlength C for both beams (i=1,2):**

$$C_i \cong C_0 + \int_{LHC_i} \left(\frac{x_i}{\rho} + \frac{1}{2} x_i'^2 + \frac{1}{2} y_i'^2 + ... \right) ds$$

- **Pathlength difference ΔC=0.12 mm ➔ likely ΔC is dominated by random effects**

Tentative summary

- **Assuming (likely pessimistic) that ΔC_{max} ~ 0.57 mm fopr 2 mm r.m.s. CO distortion then:**
  - **If the two LHC RF systems are driven by the same frequency programme and the SPS is providing 1 beam momentum:**
    - **Momentum mismatch SPS/LHC of $\pm 3.5 \times 10^{-5}$ (assuming that the SPS beam momentum is set half-way) to be compared with the tolerance of $\pm(?)1 \times 10^{-4}$. The 2 beams will be captured in orbits with a maximum radial displacement of 0.1 mm.**
    - **The 2 beams will have a tune difference of 7×10^{-5} /chromaticity unit.**

Tentative summary

- **For the commissioning it is probably wiser to set-up the ramp independently for each ring with a radial loop but with a predefined RF frequency for both rings, in that case no HW modification should be required in the SPS**

- **Once we go to two beam operation If the estimated effects are considered unacceptable (are they?) or we measure larger effects:**
  - **The momentum mismatch and the momentum offset can be "cured" by trimming independently BL_{LHC} ($\pm 3.5\times10^{-5}$) for the 2 beams ➔ implies different cycles in the SPS for beam 1 and 2 ➔ new HW for synchronization in the SPS**

- **The 2 frequency programme in the LHC make sense only if we observe large fluctuations from shot-to-shot between the two apertures**