# Implications running LHC with 50ns spacing and small emittances

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## Bunch spacing 50 ns and small emittance:

- Running with 50 ns spacing
  - see LHC Project Note 415 (2007)
- Running with (much) smaller emittances, expect effects on:
  - Luminosity
  - Beam-beam effects (long range and head-on)
  - Collimation

## Reminder:

**Luminosity with crossing angle $\alpha$ in x-plane (round beams):**

$$\mathcal{L} = \frac{N_1 N_2 f n_b}{4\pi \sigma_x \sigma_y} \cdot S \quad \rightarrow \quad \frac{N_1 N_2 f n_b}{4\pi \epsilon \beta^*} \cdot S$$

**$S$ is the reduction factor**

**For small crossing angles and $\sigma_s \gg \sigma_{x,y}$**

$$\Rightarrow S \approx \frac{1}{\sqrt{1 + (\frac{\alpha}{2} \frac{\sigma_s}{\sigma_x})^2}} = \frac{1}{\sqrt{1 + (\frac{\alpha^2}{4} \frac{\sigma_s^2}{\beta_x \epsilon})}}$$

# Beam-beam parameter and tune shifts

**Head-on (no crossing angle):**

$$\Delta Q \approx \xi = \frac{N \cdot r_o \cdot \beta^*}{4\pi\gamma\sigma^2} = \frac{N \cdot r_o}{4\pi\epsilon_n}$$

**Head-on (crossing angle $\alpha$ in x-plane):**

$$\Delta Q_x \approx \xi \cdot S = \frac{N \cdot r_o \cdot \beta^*}{4\pi\gamma\sigma^2} \cdot S = \frac{N \cdot r_o}{4\pi\epsilon_n} \cdot S$$

$$\Rightarrow S \approx \frac{1}{\sqrt{1 + (\frac{\alpha}{2}\frac{\sigma_s}{\sigma_x})^2}} = \frac{1}{\sqrt{1 + (\frac{\alpha^2}{4}\frac{\sigma_s^2}{\beta_x\epsilon})}}$$

- **Head-on effects strongly increased !**

# Long range beam-beam separation

$$d_{sep} \approx \frac{\alpha \cdot \sqrt{\beta^*}}{\sqrt{\epsilon}} \quad \text{(in drift)}$$

$$\Delta Q \propto \frac{1}{d_{sep}^2} \propto \epsilon \qquad \text{and} \qquad \Delta Q \propto \frac{1}{BS}$$

- **LHC: ($\frac{\alpha}{2} \approx$ 142.5 (!) $\mu$rad, $\beta^* \approx$ 0.55 m): S $\approx$ 0.80**
- **To small $\alpha$: not enough separation**
- **To large $\alpha$: little (or no) luminosity gain**
- **Smaller $\epsilon$ for given $\alpha$, $\beta^*$: larger $d_{sep}$, but also larger $S$**
- **Long range effects practically not existing ..**

# Control of beam-beam effects

- **Can increase $\beta^*$, reduces long-range beam-beam problems**
- **Can decrease crossing angle $\alpha$, reduces geometrical factor**
- **Can keep $\beta^* \cdot \epsilon$ = const., but does not solve head-on problems**

# Consequences for beam-beam effects

- **Long range effects:**
  - **Much weaker, fewer LRI, better separation**
- **Head-on effects:**
  - **Much stronger for same luminosity and nominal bunch intensity**
  - **May need controlled increase of emittance before collisions (SPS or LHC ??)**
  - **Optimization of $I$ and $\beta^*$ needed**
  - **Problematic if bunch to bunch emittance spread significant (larger than 10 - 20 %)**

# How to increase the total intensity in the LHC ?

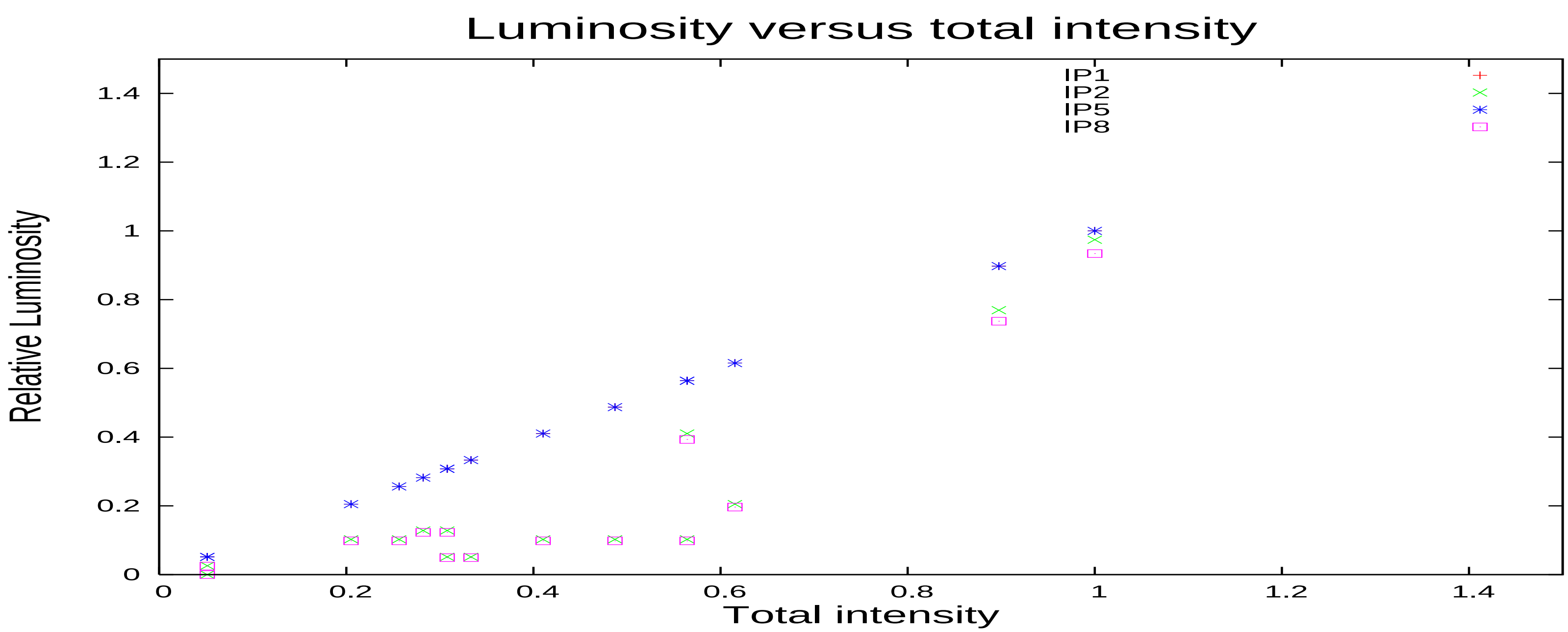
- **Basically two options:**
  - **All bunches and increase intensity per bunch**
  - **Large (full) intensity per bunch and increase number of bunches (i.e. batches)**
- **Consequences for:**
  - **Beam-beam effects**
  - **Luminosity control in experiments**

# Reminder: experimental luminosities

- IP1 and IP5: largest possible luminosity for any configuration
- IP8: high luminosity, but 1 - 5 $\cdot$ $10^{32}$ $cm^{-2}$ $s^{-1}$ for any configuration
- IP2: low luminosity, if possible for any configuration
- Try to find strategy to increase total intensity fulfilling these requirements

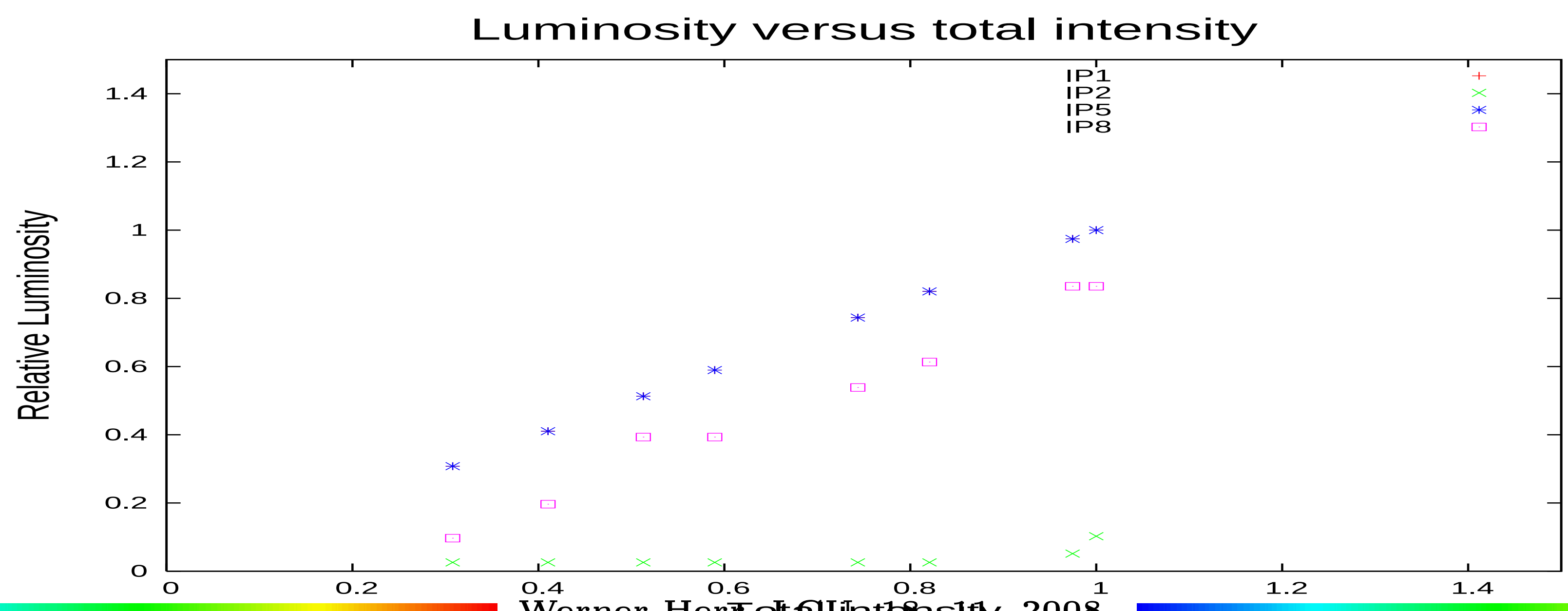
# Luminosity as function of total intensity

- **Increase of total intensity by additional SPS-LHC injections**
- **Spacing 25 ns, selected SPS-LHC transfers shifted**



# Luminosity as function of total intensity

- **Increase of total intensity by additional SPS-LHC injections**
- **Spacing** **50 ns**, **selected SPS-LHC transfers shifted (see LPN 415)**



# Issues to be followed up

- **Redo part of da simulation with beam-beam for comparison**
- **Working point (tune spread dominated by head-on)**
- **Controlled emittance increase (SPS or LHC ??)**
- **Optimization of beam parameters required**
- **Bunch to bunch spread of intensity and emittance**
- **Electron cloud**
- **...**
- **Initial luminosity control in experiments largely easier**