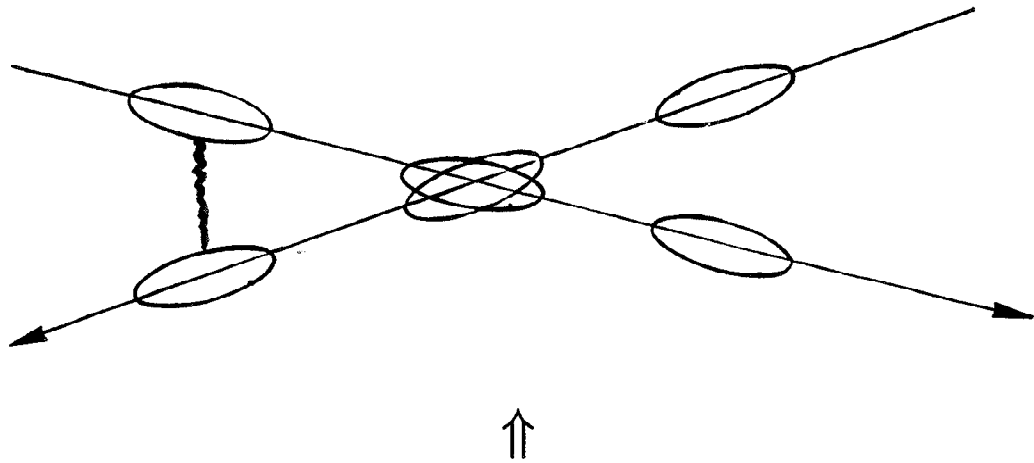


Computer simulation of the
coherent beam-beam effect in the
LHC

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- High luminosity for LHC requires many bunches (more than 4000)
- \Rightarrow crossing angle to avoid unwanted collisions



Common beam pipe

- Long range interactions
- Coherent dipole kicks
 - Spread acceptable for $\alpha = 200\mu rad$
 - Coherent oscillations possible

LHC parameters

- Number of long range collisions:

43 m between IP and separator

$\Rightarrow \approx 38$ per interaction! (for 15 ns bunch spacing)

Coupling between all bunches:

\Rightarrow multi-bunch modes

- Separation:

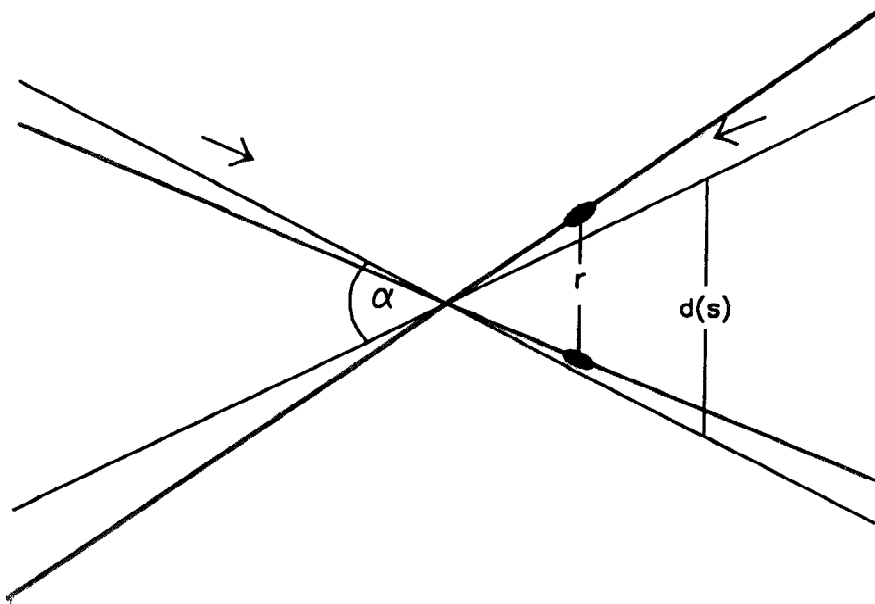
$$d_{sep} = d(s)/\sigma(s) = \alpha\beta^*/\sigma^* = const.$$

$$\Rightarrow \approx 6 - 7\sigma$$

\Rightarrow non-linear force

Simulation model

- Linear, uncoupled machine
- Beam-beam kick (rigid bunches):



$$f(x) \propto (1 - e^{-\frac{x^2}{2\sigma^2}})/x$$

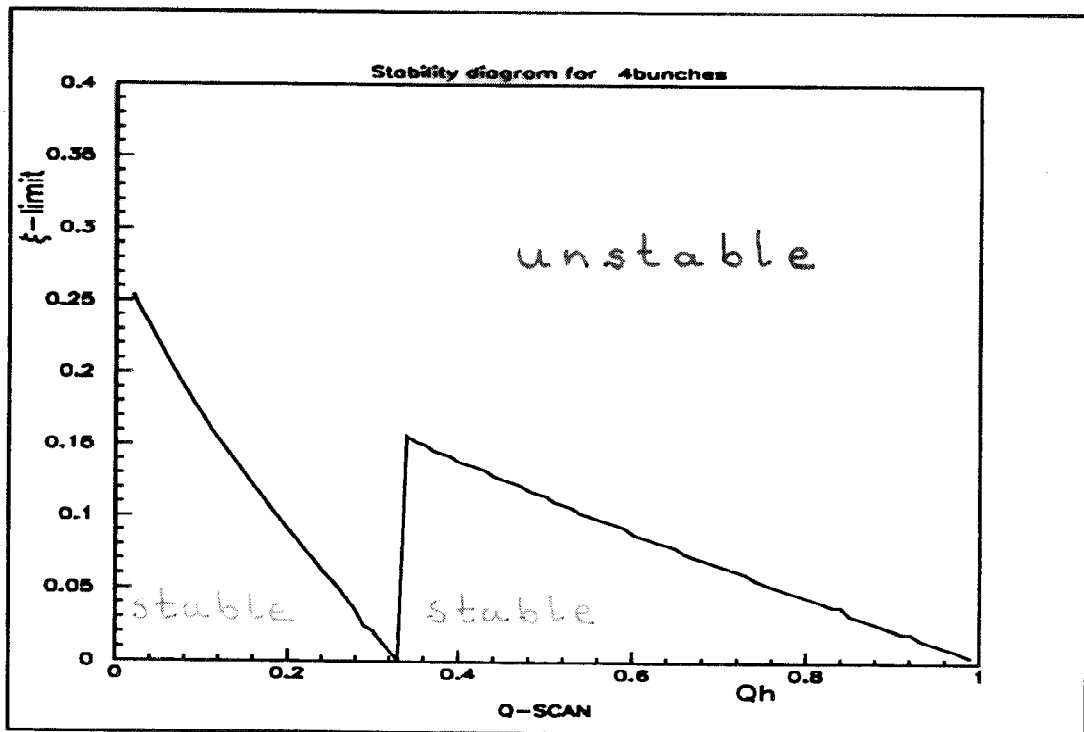
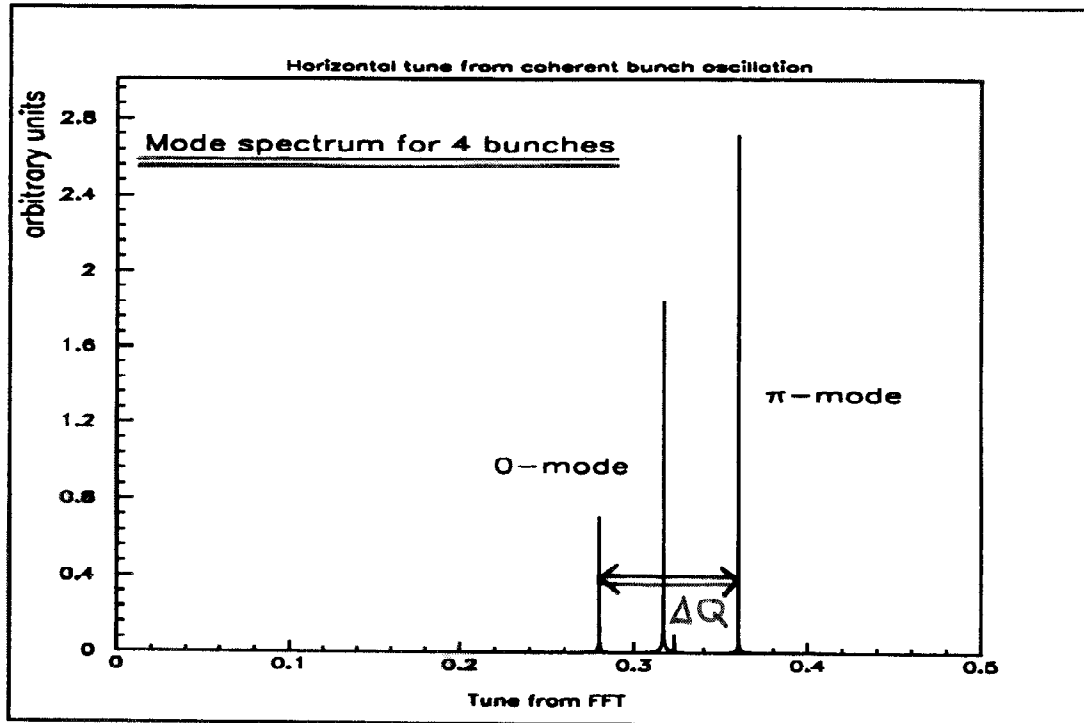
$$\delta x' = f(r) - f(d(s))$$

(only oscillations around orbit)

- Clustered long range collisions

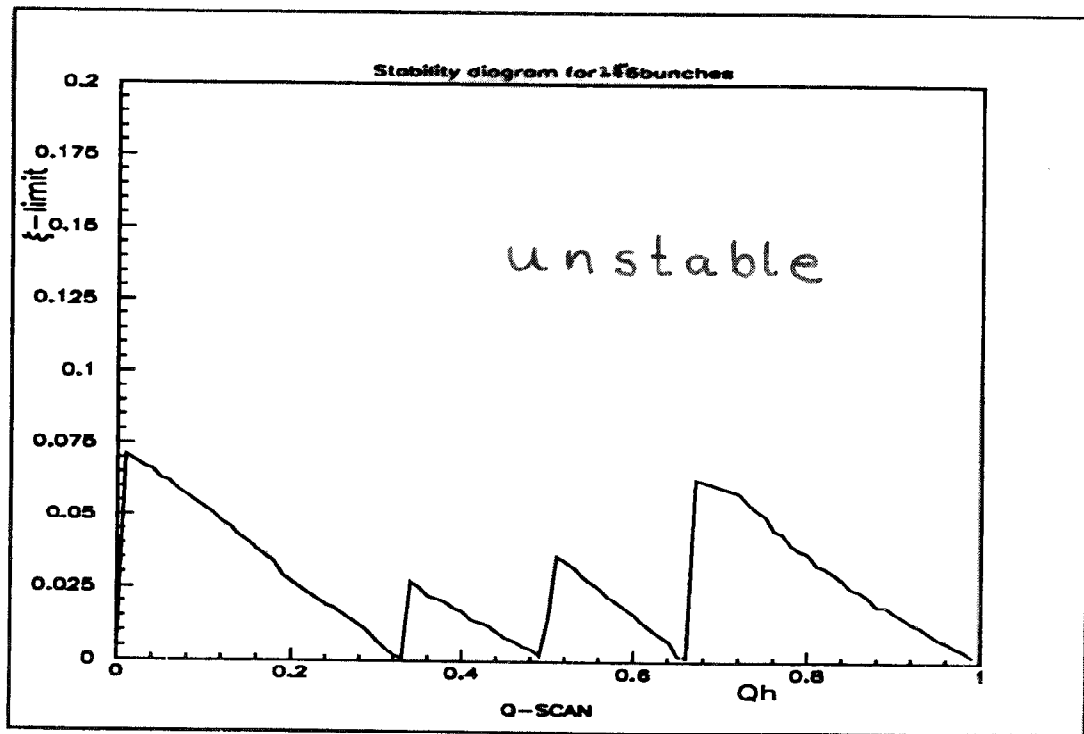
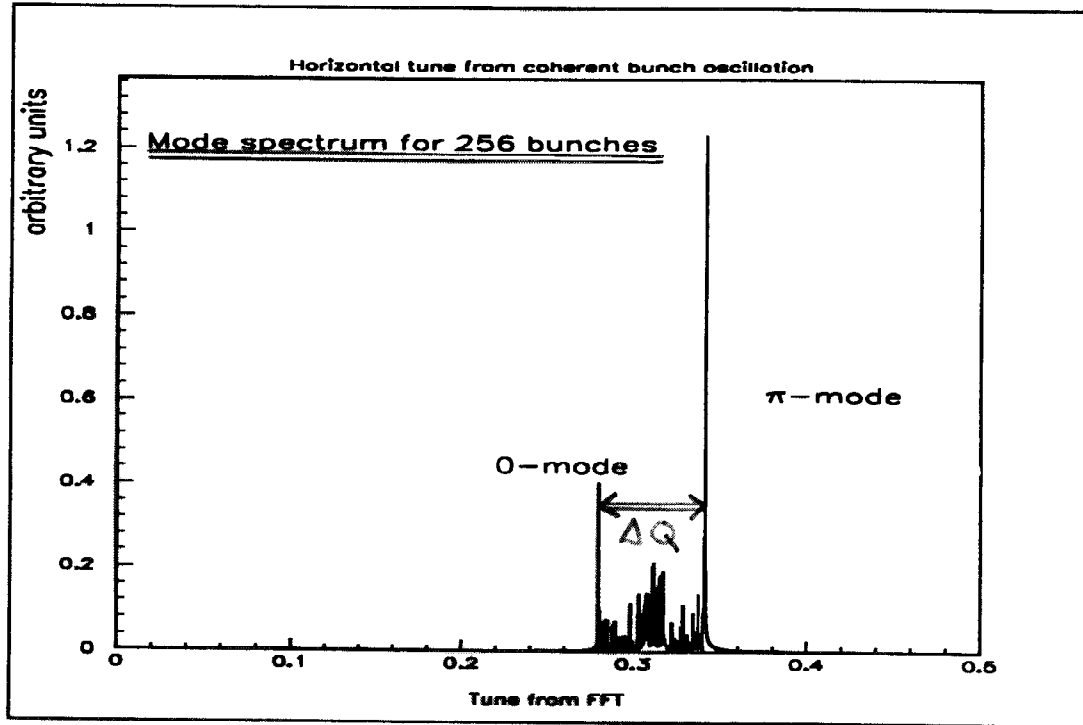
- **Simulation of 4000 bunches unfeasible
(up to 256 bunches used)**
- **Follow oscillations of rigid bunches
around closed orbit**
- **Detect instability if oscillation grows**
- **For stability:
ALL modes must be stable**

Equally spaces IP



LR-only

Clustered IP



LA only

Frequency span (π -mode) ΔQ

- Depends only on:

Separation

Number of long range interactions

Linear beam-beam tune shift ξ

- From long range kicks:

$$\approx 11 \xi \Rightarrow 0.037$$

- Total with head-on kicks:

$$\approx 7.5 \xi \Rightarrow 0.026$$

- Stability limit for 3rd order:

$$\underline{\xi_{limit} \approx 0.0080}$$

(Nominal for LHC: $\xi = 0.0034$)

Decoherence effects

- Many long range kicks on one bunch
- All kicks at different phases of the bunches
- \Rightarrow decoherence effect
- For many long range collisions:
 \Rightarrow small width $\leq 10^{-5}$

Conclusions

- Coherent dipole oscillations can be excited
- Non-linear resonances can be seen (3rd order)
- Many modes due to multi-bunch coupling
- $\xi_{limit} \approx 0.008$
- But strong decoherence effect
- Coherent beam-beam effects unlikely to limit LHC performance