Status: Simulation of two beam Multi-Bunch Interactions

- (main) Purpose:
  - Simulation of multi-bunch beam-beam interactions
  - Simulation of measurements in presence of beam-beam interactions
- Stage one (Project Note 356):
  - Simulation of rigid multi-bunch beam-beam interactions
  - Simulation of Q-measurements and multi-bunch modes
- Stage two:
  - Multi-particle simulation
  - → Landau damping of coherent modes
  - → Emittance, higher order modes, offset collisions ...

Design requirements

- **Beam dynamics features:**
  - Must allow any number of bunches
  - Must allow any filling scheme
  - Must allow any collision scheme
  - Must allow any optical configuration
  - Must allow any field computation algorithms
  - Should allow any other kind of interaction between bunches and/or environment
- **Computational features:**
  - Speed is important
  - Parallel processing foreseen from the beginning

For initial beam-beam studies

- **Track all bunches of both beams independently around the ring in opposite direction**
- **Apply head-on and/or long range interactions at each encounter of bunches**
- **All bunches may have different parameters (N_{part}, ϵ^*, etc.)**
- **Show the complete set of possible coupled beam-beam modes**
- **Give initial kicks to single bunches or a range of bunches to simulate excitation (e.g. for tune measurement)**
- **Analyze the motion of selected bunches**

Data for simulation

- **INPUT required (from files):**
  - **Filling pattern**
  - **Collision scheme**
  - **Optics between collision points**
  - **Actions**
  - **General parameters**

Filling scheme definition

→ **defines bunch pattern and steps for tracking**

Simple example: 4 equidistant bunches:

```
# bunch filling example 1a
# 80 possible bunch position: 4 occupied
 1 1 19 0
 1 1 19 0
 1 1 19 0
 1 1 19 0
```

or:

```
# bunch filling example 1b
# 160 possible bunch positions: 4 occupied
 1 1 39 0
 1 1 39 0
 1 1 39 0
 1 1 39 0
```

Filling scheme definition

Four equidistant trains of 9 bunches:

```
# bunch filling example 1c
# 160 possible bunch positions
 9 1 31 0
 9 1 31 0
 9 1 31 0
 9 1 31 0
```

- **Allows simulation of holes or missing bunches**
- **Simulates PACMAN effects**
- **Also used now for beam-beam tracking in MADX (LPN 344)**

Filling scheme definition

```
# nominal bunch LHC filling example
# 3564 possible bunch positions
# 2808 positions occupied

72 0  8 0  72 1  8 0  72 1   8 0 30 0   0 0
72 1  8 0  72 1  8 0  72 1   8 0 30 0   0 0
72 1  8 0  72 1  8 0  72 1   8 0 72 1  39 0
72 1  8 0  72 1  8 0  72 1   8 0 30 0   0 0
72 1  8 0  72 1  8 0  72 1   8 0 30 0   0 0
72 1  8 0  72 1  8 0  72 1   8 0 72 1  39 0
72 1  8 0  72 1  8 0  72 1   8 0 30 0   0 0
72 1  8 0  72 1  8 0  72 1   8 0 30 0   0 0
72 1  8 0  72 1  8 0  72 1   8 0 72 1  39 0
72 1  8 0  72 1  8 0  72 1   8 0 30 0   0 0
72 1  8 0  72 1  8 0  72 1   8 0 30 0   0 0
72 1  8 0  72 1  8 0  72 1   8 0 72 1  39 0
```

Tracking all bunches

- With N possible (full or empty) bunch positions around the ring:
  - $2 \cdot N$ slots where bunches can encounter
  - Defines natural step size for tracking (Q: is example 1b very clever ??)
- At each slot something can happen:
  - Linear transport
  - Non-linear kick
  - Head-on or long range beam-beam interactions
  - etc. (anything can be defined)

Collision scheme definition

- **Defines what happens at each slot**

```
#Collision scheme 1 (for filling example 1c):

   1    2    -5   +5
  21    3    7.535   6.91375
  41   -2    -5   +5
 101    3   23.605 21.74125
 161   -2    -5   +5
 221    3   23.605 21.74125
 281    2    -0   +0
 301    3    7.535   6.91375
```

- **More details, definitions and examples in LHC Project Note 356**

LHC Collision scheme

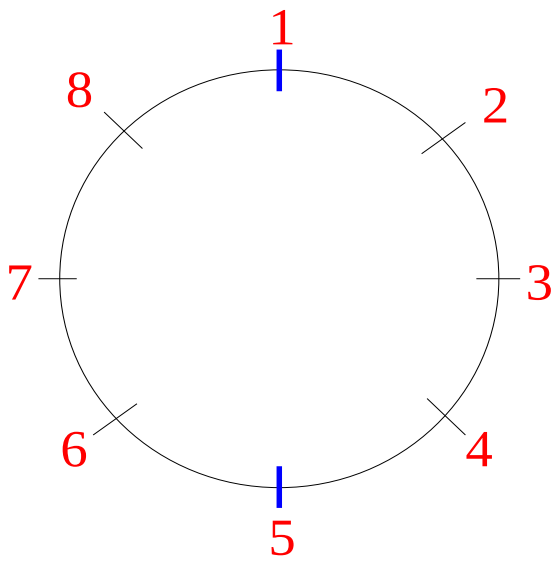
```
#Collision scheme LHC (for LHC filling scheme):

   1  -2   -15  +15
 447   3    8.035   6.871
 447  -3    7.641   7.613
 892  -2   -0  +0
2229   3   23.015  21.733
2229  -3   23.428  21.101
3565   2   -15  +15
4902   3   23.649  20.807
4902  -3   23.160  21.471
6235   2   -0  +0
6684   3    7.611   7.909
6684  -3    8.081   7.135
```

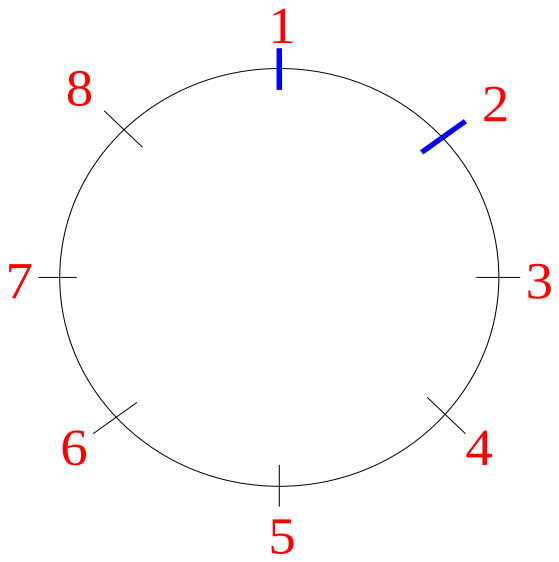
- **Defines four head on collisions and 30 long range collisions**

Collision layout (2 IPs)

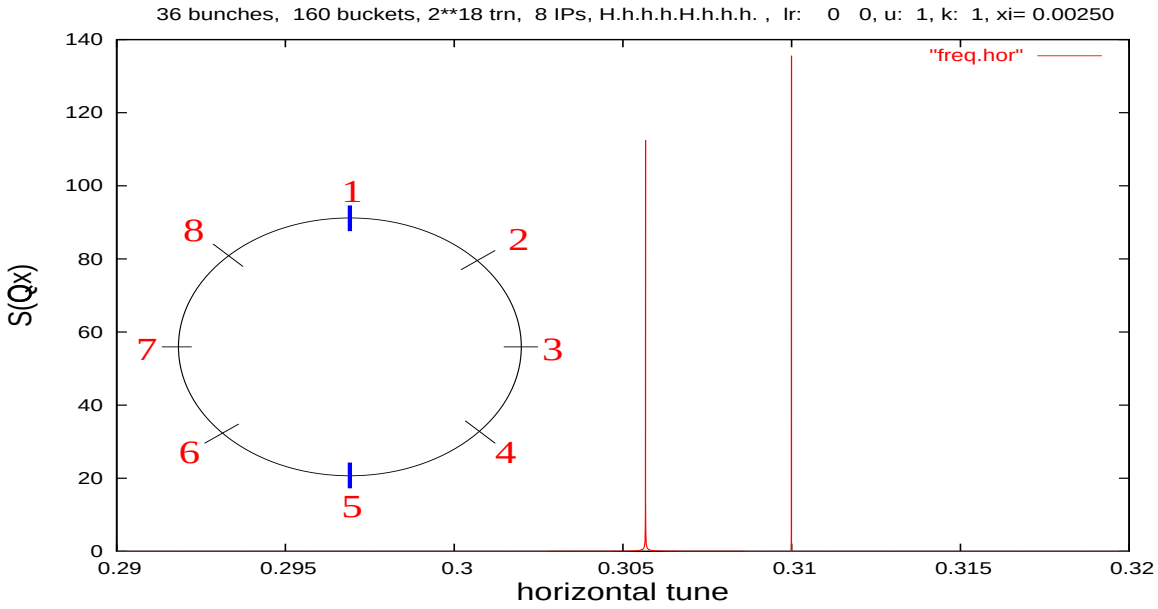
- **Symmetry and periodicity VERY important for beam-beam effects**

→ **For coherent AND incoherent effects**



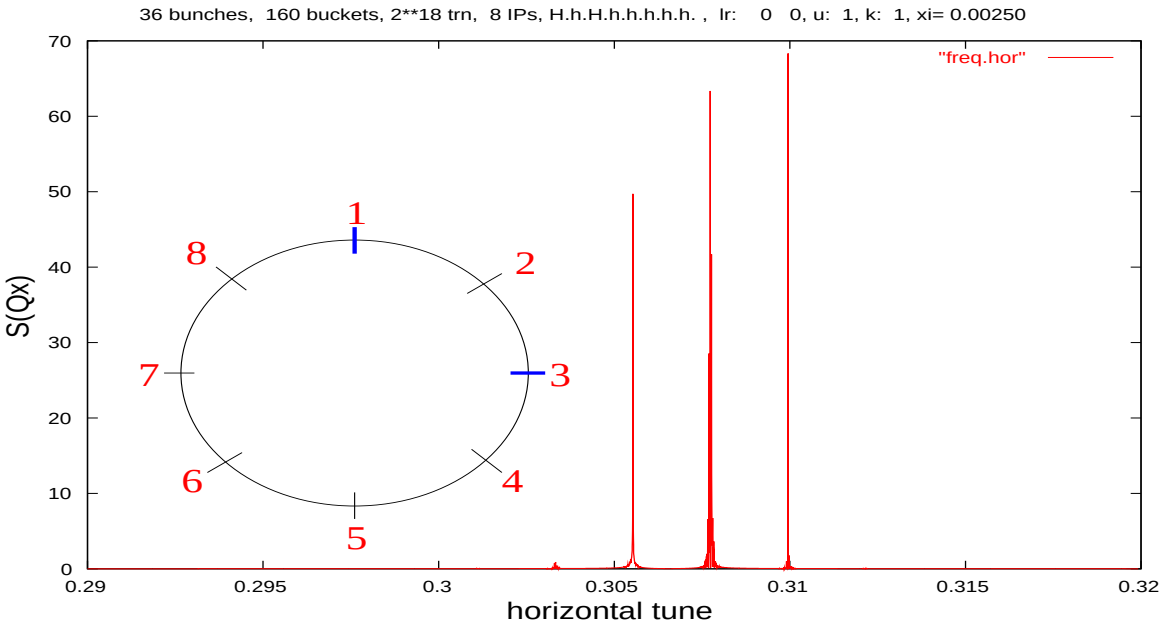


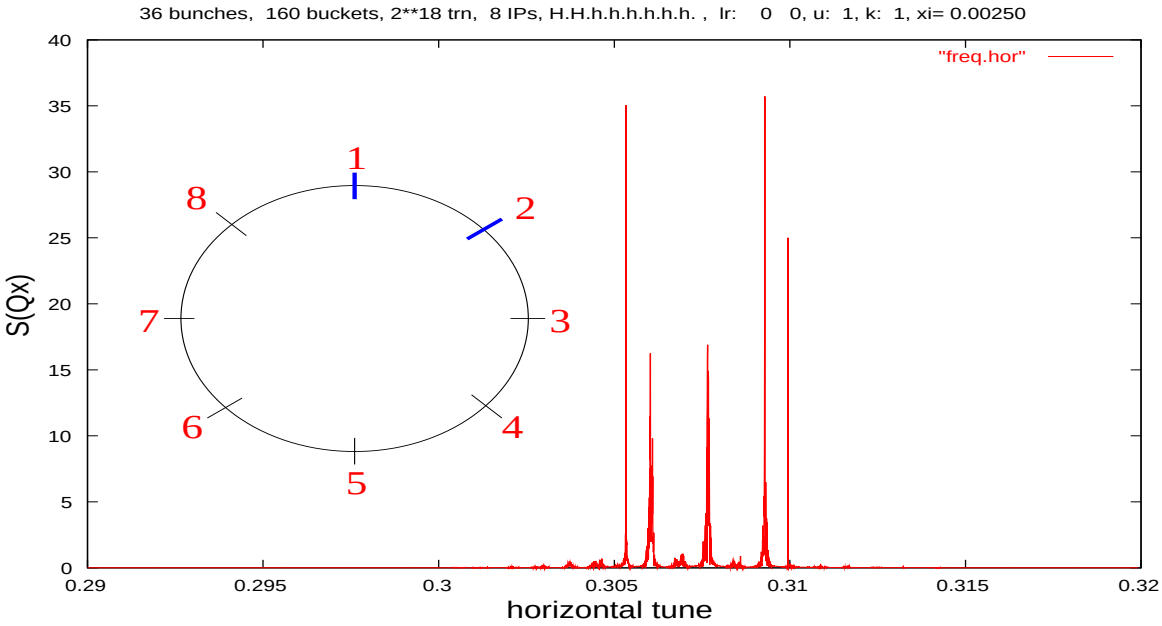
Two collisions: symmetric



- **Complete symmetry between two IPs**
- **Degeneration of modes**
- **Broken by different collision symmetry**

Two collisions: NOT symmetric

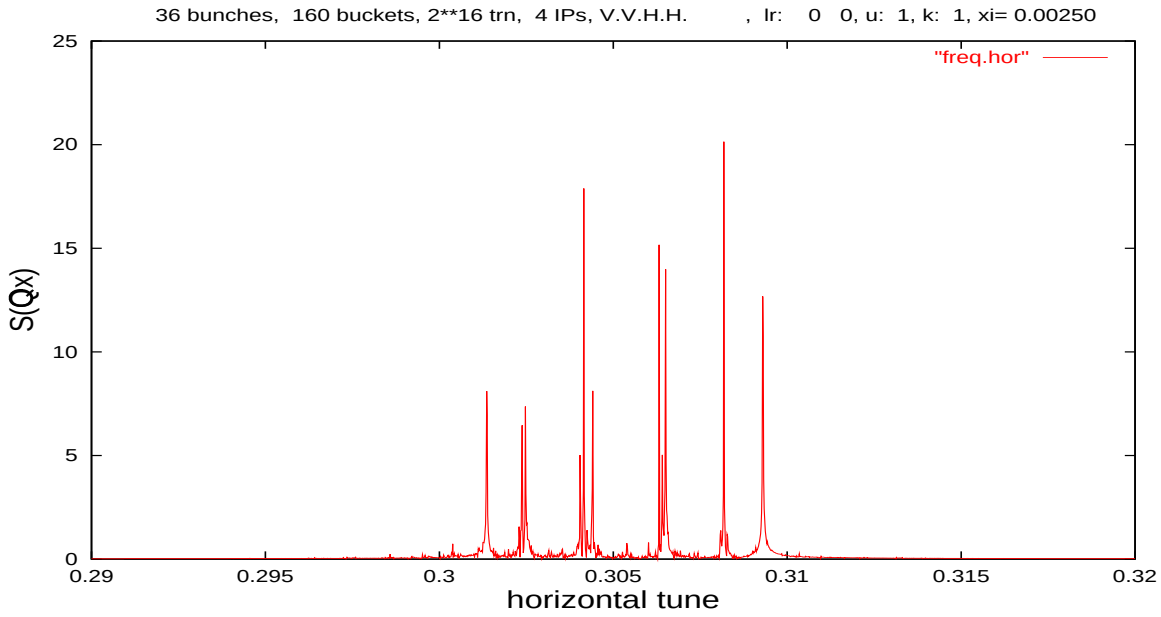


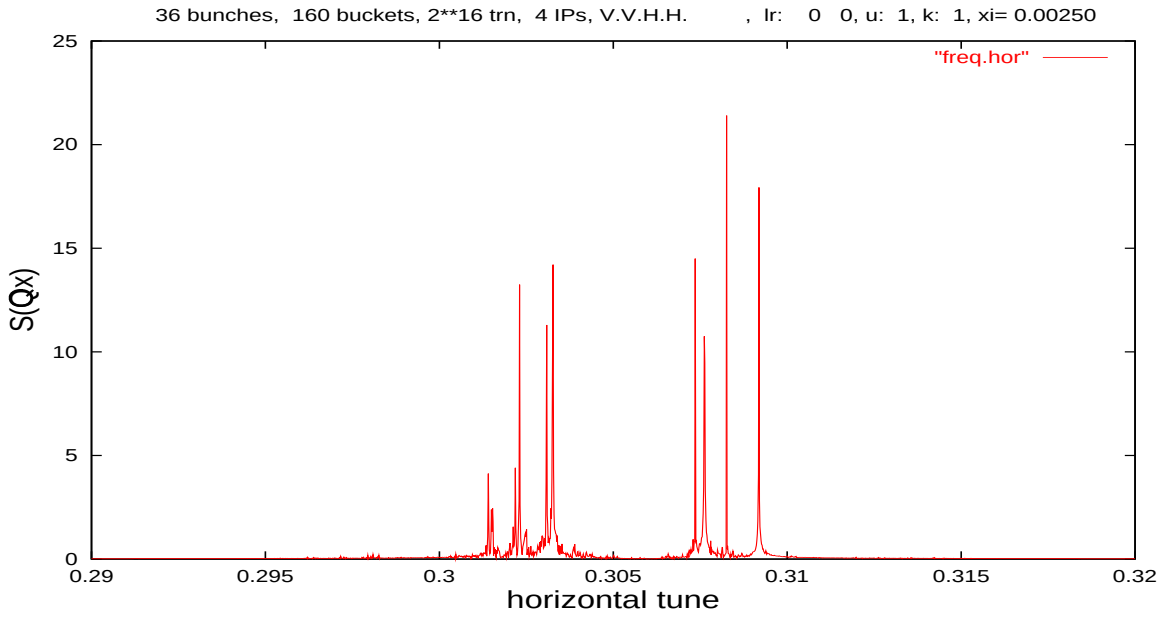


- **Symmetry now broken**
- **Additional modes visible**

Phases between IPs

- **Phase between IPs strongly affect spectra (here: IPs 1, 2, 5 and 8)**





For rigid bunch model:

- More details and results in LHC Project Note 356
  - → Excitation mechanisms
  - → Effect of long range interactions
  - → Effect of/on PACMAN bunches
  - → Effect of alternating versus non-alternating crossings
- Extensions:
  - → Multi-particle model
  - → Parallel implementation
  - → Other field solvers
- Collaboration established with F. Jones, M. Furman, J. Qiang

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