# BeamX -- towards a 3D self-consistent computational model of beam-beam effects.

*W.Herr & F.W.Jones*

Featuring…

- Reasonable [parallel] computing time
- Longitudinal motion under applied Vrf
- Long-range collisions without significant time penalty
- Crossing angle
- Hourglass effect    β(s)
- Bunch density profile    λ(s)
- [Limited so far to single bunch-pair and single IP]

*Review of methods • Current status & Activities*

# Ingredients

- Basic 2D
  - Macroparticle ensembles ~$10^5$ per beam
  - 2D field solver -- hybrid FMM (grid-multipole solver)
  - One-turn map of transverse coordinates -- "kick-rotate" model
- Add Longitudinal
  - Map (symplectic integrator) representing RF cavity
  - Bunch-slicing ~10 bins in rf phase
  - Loop over slice-to-slice [2D] collisions
  - Synchro-beam mapping (drift fore and aft of the IP) --Hirata et al.
  - Crossing angle (Lorentz transformation to head-on frame)
- Add Parallel
  - MPI (Message Passing Interface) toolkit
  - Distribution of tasks to processors in Master-Slave configuration
  - Data-flow architecture

# Characteristics of transverse field solver

- FMM:
  - Adaptive quad-tree algorithm handles virtually any shape and size of distribution (including a mix of distance scales)
  - Known error bounds and settable accuracy
  - O(Np) complexity
  - Gives potential and fields parameterized over entire solution region (for space charge, allows computation of image forces for any shape vacuum chamber)
- Hybrid FMM:
  - Discrete charges (Np) $\rightarrow$ Gridded charges (Ng) $\rightarrow$ FMM field-solve at grid-charge locations $\rightarrow$ Force interpolation
  - O(Ng) -- competes with FFT-based methods: O(Ng log Ng)
  - Empty cells removed from computation – no penalty for separated beams!

# FMM Quad-Tree Adaptive Subdivision

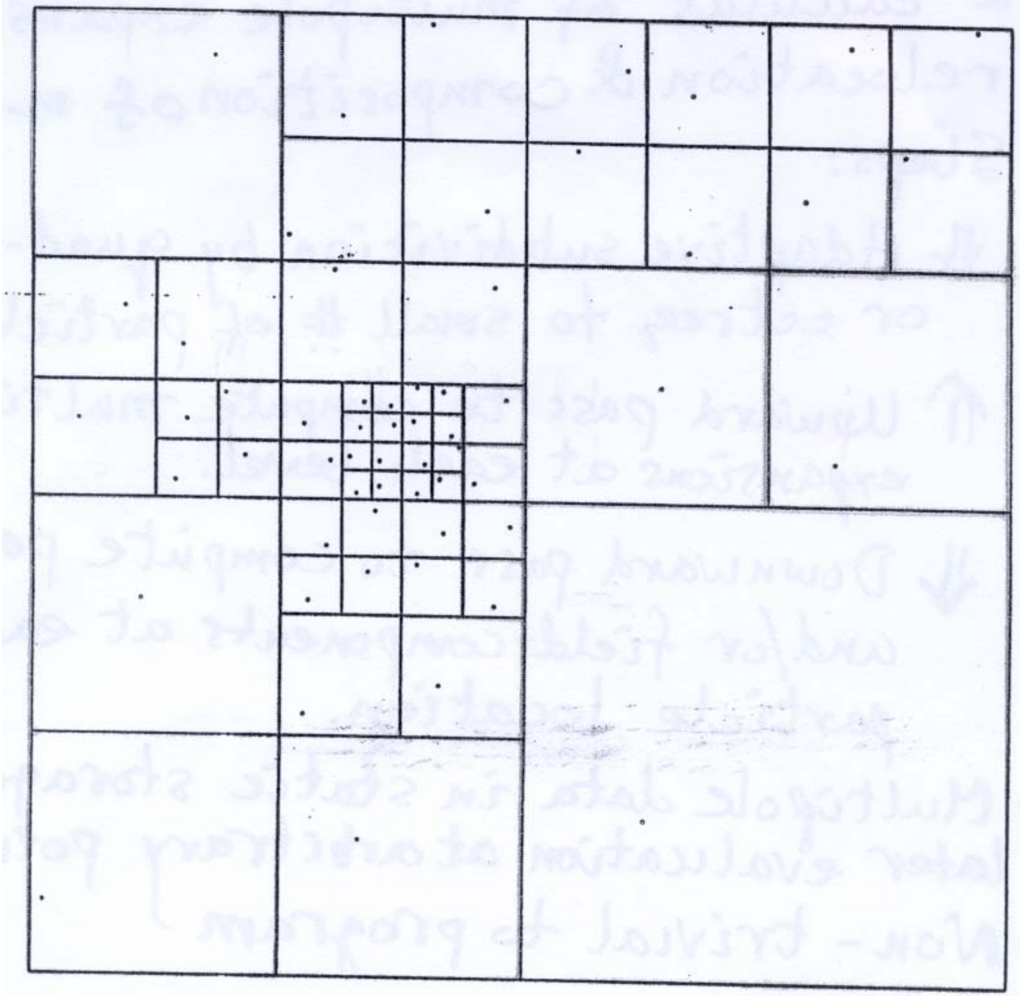
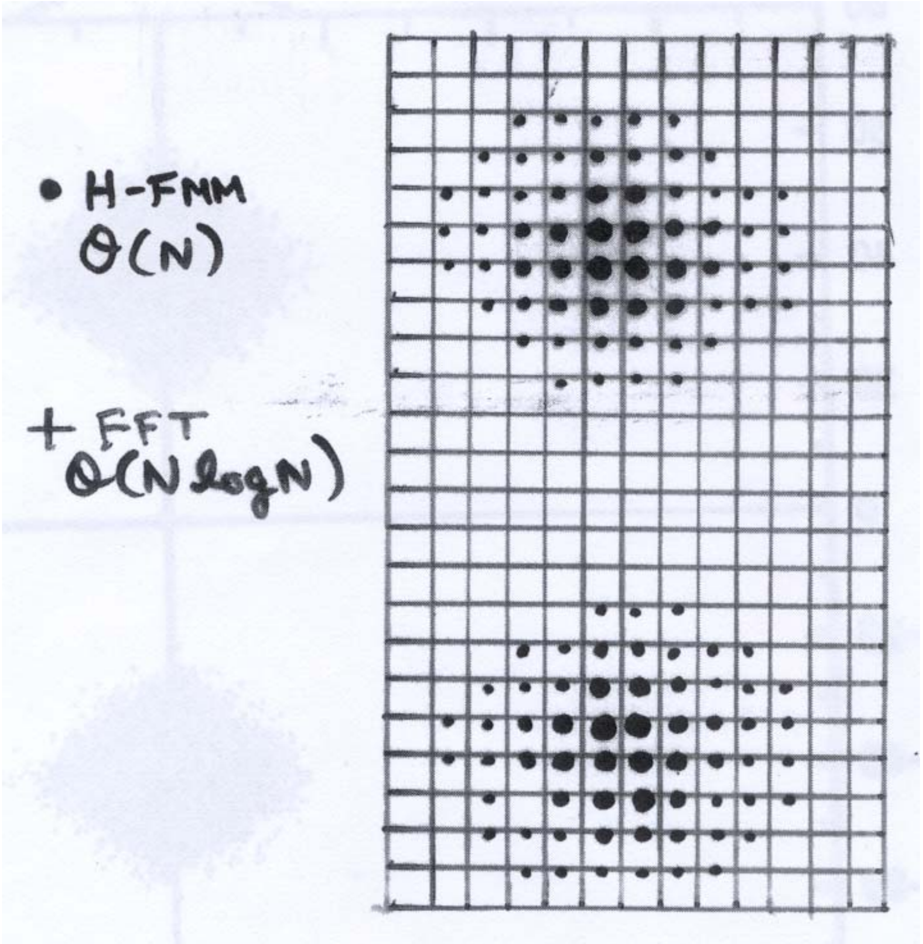


**Figure 2.8**
**The hierarchy of meshes partitioning the computational cell.**

# H-FMM vs FFT for separated beams



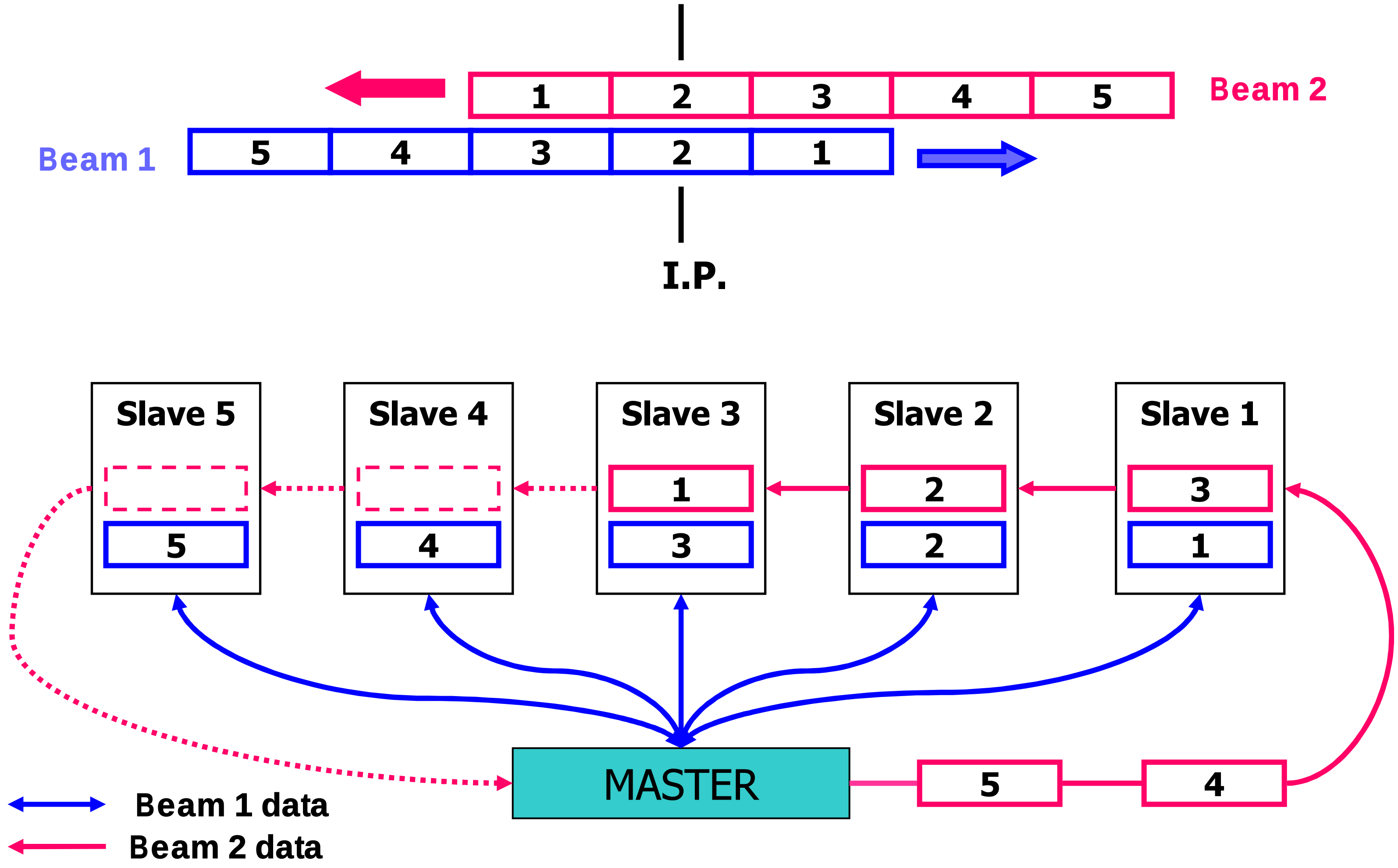
- The preprocessor uses a grid with PIC-style charge assignment
  - Not for "discretisation" of field equations but rather for:
    - Speed (charge reduction) $O(N_p) < O(N_g \log N_g)$
    - For smoothing and elimination of close encounters
  - Grid may be tailored to the distribution – not constrained by regularity/aspect ratio requirements.
  - Grid is optional and need not cover entire beam:
    - All-purpose preprocessor handles gridded & discrete charges

# Seeking Parallelism

- First-level parallelism
  - For beams with $N_s$ slices, from $1 \rightarrow N_s \rightarrow 1$ slice-pairs overlap as beams cross each other.
  - Slice-pair interactions can be done on different processors
  - Computation time reduced by factor ~ $N_s/2$
  - Scaling reduced from $O(N_s^2)$ to $O(N_s)$
  - Allows ~ 1 day turnaround for 5 slices and $10^5$ collisions
  - Good fit to HP CluMP system at U. of Calgary
  - Needs load-balancing and other tuning

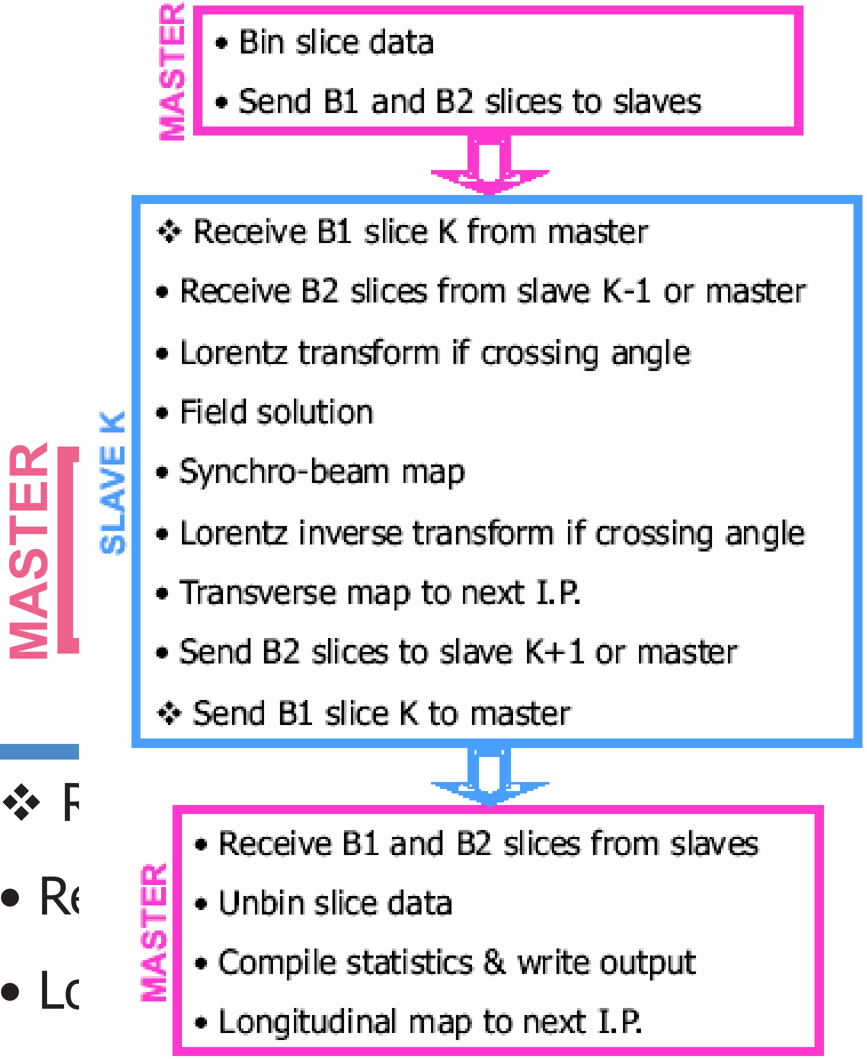
- Second-level parallelism
  - Parallelised FMM algorithm -- major effort
  - Force decomposition à la Ellison/Vogt/Sen -- no need to deconstruct FMM!

# BeamX Data Flow



# Division of Labour

Division of Labour

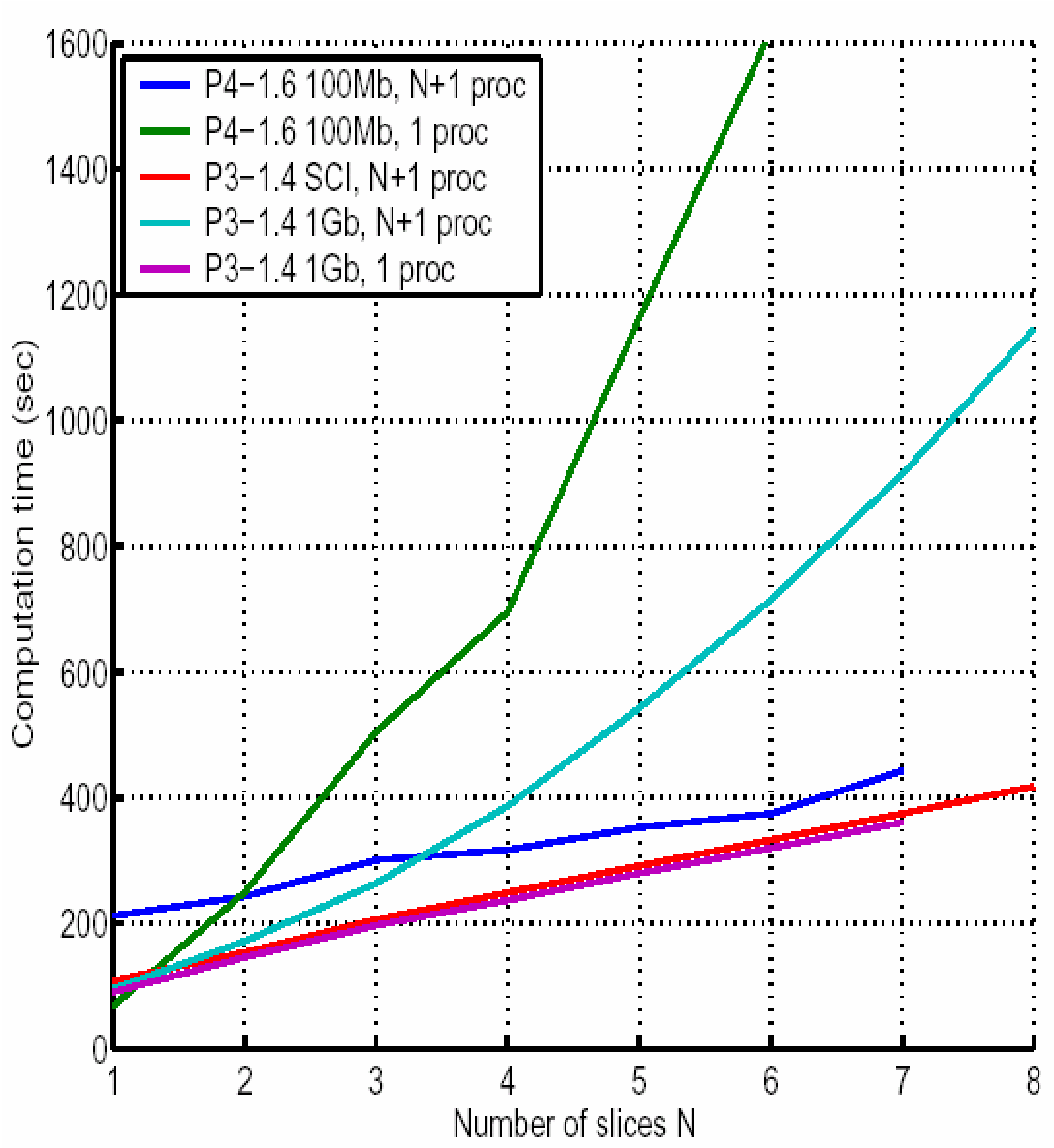



*In this scenario the master does not have to perform any control or synchronization functions for the slaves.*

*All processes are essentially free-running and the data flow itself imposes and maintains the proper ordering of events.*

# Performance

Parallel algorithm implemented with MPI on different clusters yields the expected benefit, reducing $O(N^2)$ scaling to linear scaling with number of slices.

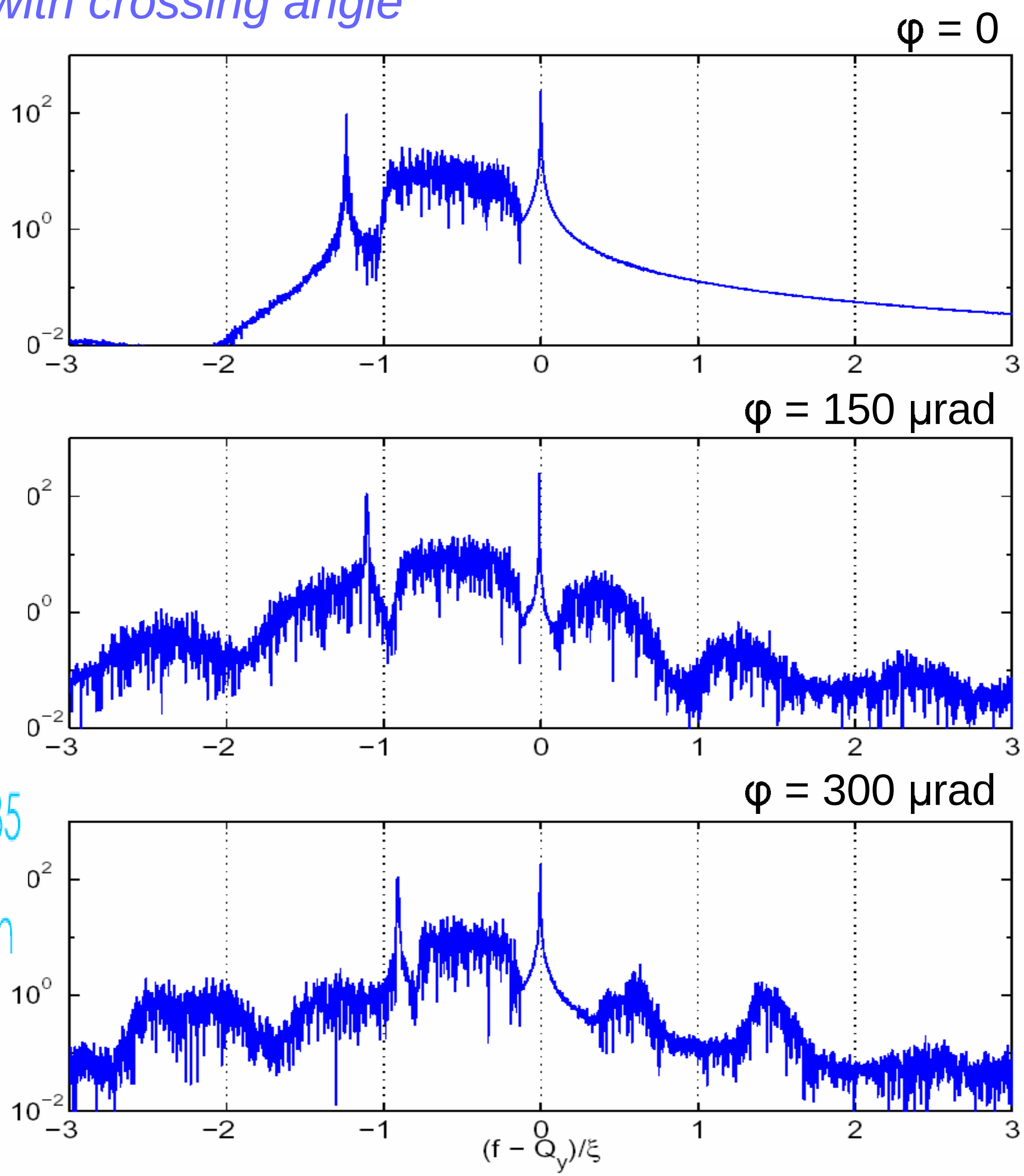


# *LHC coherent spectrum with crossing angle*

φ = half-angle

## RUN PARAMETERS

- 131072 turns
- 50000 macroparticles
- 5 longitudinal slices
- 36 x 36 field solution grid
- Qx = 64.31 Qy = 59.32 Qs = 0.00335
- Intensity $1.1\times10^{11}$ protons per bunch



# Current scenario

- Original resources dried up: TRIUMF mini-cluster was cannibalized and U. of Alberta cluster too busy (Atlas)

- New resources are available: Westgrid (Ca$50M)
  - 3 major installations: SGI SM, HP CluMP, IBM blade
  - ☺ Some hope for “livable” turnaround times: 0.5 – 2days.
  - ☹ Very competitive and large startup penalty
  - Do profiling and tuning on CluMP (if sustainable)

- Early results: spectra, phase space, rms emittance look reasonable.  Quantitative validation (various) is needed.

# *Activities*

- Testing, validation, debugging (the usual)

- Model refinement
  - Longitudinal field component: small effect but non-trivial to treat. Currently calculated from beam stats assuming Gaussian.
  - Chromaticity: can implement as $\delta$-parameterized rotation matrix at IP preserving the lattice optics (invariant ellipse)

- Computational refinement
  - Parameter sweeps to observe discretization errors and to try to isolate effects (now in progress)
  - Profiling and load-balancing (once platform is stabilised)
  - Parallel FMM via force decomposition (potentially useful for 2D code too)

## General objective

- To provide some ground-work for future large-scale beam-beam simulations.

## 3D (macroparticle, self-consistent) beam-beam simulation is not a crowded field

- Cf. Chiang – Furman – Ryne "BeamBeam3D"
  - Very similar scope to BeamX but different methods: adaptive bunch-slicing, shifted Green's functions, particle/domain based parallel decomposition
  - Resources: $$ DOE Advanced Computing and NERSC