Merlin

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Introduction

- Briefly explain what Merlin is and what it can do
- Make clear the tracking algorithms used, so comparisons with other codes can be made
- Show some pretty results
- Explain where we want to go

Merlin in a Nutshell

- Merlin is a C++ class library for doing charged particle accelerator simulations
- Current library has >300 classes
- Has a long (and dubious) heritage (APTkit, CLASSIC)
- Originally designed to study ground motion effects in BDS
- Now been extended to model, well, (almost) everything ☺
- More info: http://www.desy.de/~Merlin

Don't Panic – this is not a talk about C++

The Accelerator Model

- Supported Standard Components
  - Drifts, Dipoles, Quads, Sextupoles, Octupoles
  - BPM, Profile Monitor (Wire scanner)
  - Solenoid
  - RF acceleration (SW and TW structures)
  - X and Y corrector dipoles
  - X-Y corrector windings
    (can be added to any multipole magnet)
- Non-Beamline Components
  - Magnet movers, Magnet Supports, Girders

The Component Library is always growing…

The Accelerator Model

- All Accelerator Components have:
  - An E-M field (Tesla, volts/meter)
  - A physical aperture
    [circular and rectangular currently supported]
  - An accelerator geometry
    [responsible for alignment, coordinate frame transformations etc.]
  - Most support ‘channels’ [see later]

Particle Tracking Module

- 6-d particle tracking (ray tracing):

$$x_i \in \{x, x', y, y', ct, \delta = \Delta p/p_0\}$$

- Particles assumed relativistic (β=1)
- Tracking uses 6-d second-order TRANSPORT maps up to sextupole:

$$x_i = R_{ij}\, x_j + T_{ijk}\, x_j\, x_k$$

- Higher-order multipoles modelled as chromatic thin-lens kicks at centre of element

Beam Energy and Tracking

- **B** fields stored (not K_n)
- Particle bunch carries its own *reference* momentum (P_{ref})
- Particle δ_i referenced to P_{ref}
- P_{ref} used to calculate map ($\mathbf{R} + \mathbf{T}$)

Particle Bunch

P_{ref}

Note: $\langle P_i \rangle = P_{\text{ref}} (1 + \langle \delta \rangle)$

Beam Energy and Tracking

- Special case: Sector Bend
- P_0 for (**R**+**T**) taken from bend curvature and field: $P_0 = ecB/h$
- δ_i are scaled accordingly:

$$\delta_i \to \frac{P_{ref}}{P_0}(1+\delta_i)-1$$

- Fixed geometry (h=$const$)
- Changing B or P_{ref} changes orbit

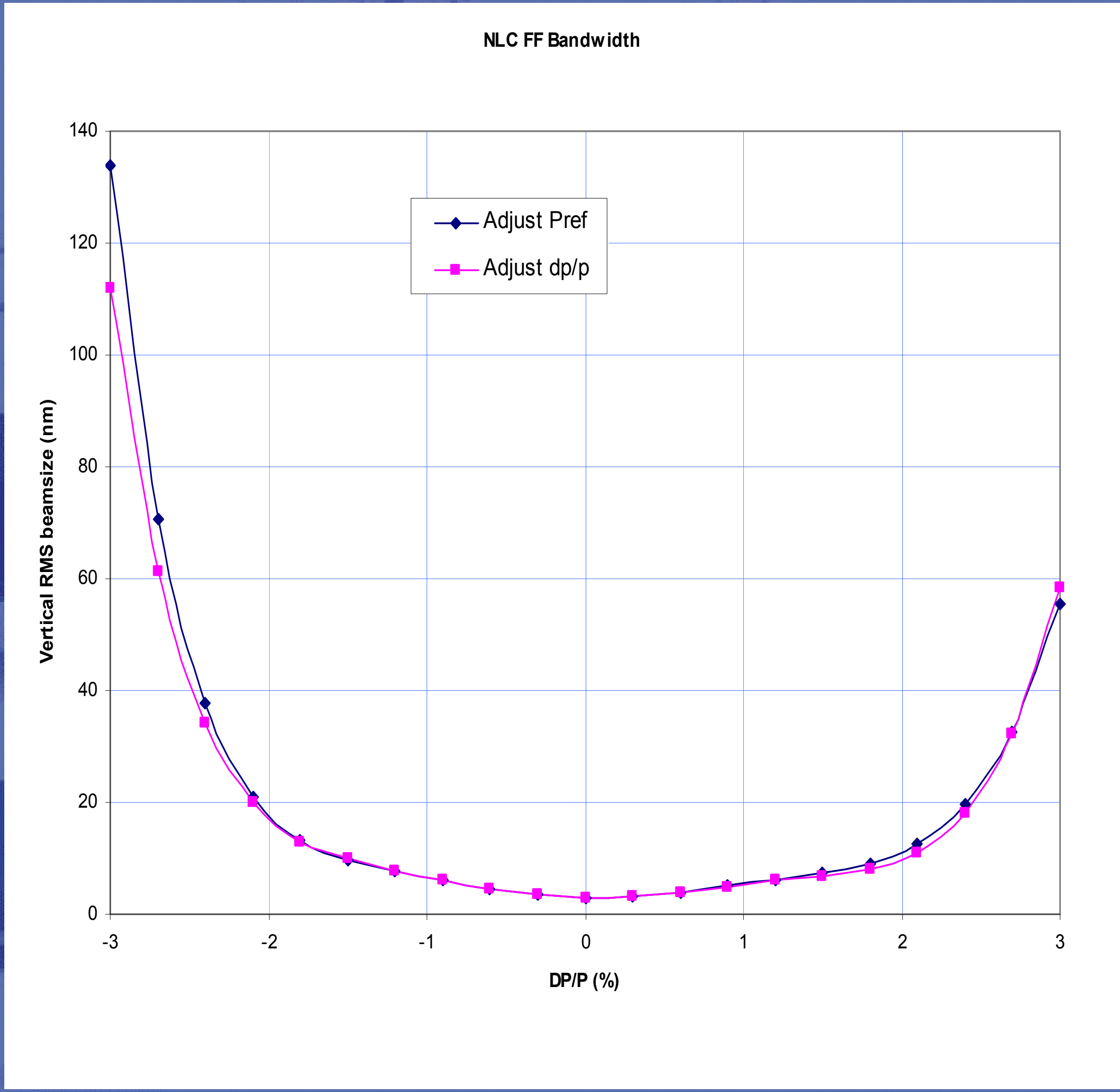
Note: full second-order map for mixed function magnet *plus* pole face rotation and curvature included

Beam Energy and Tracking

- Sector Bend map expanded around 'matched' momentum for given B field
- All other magnet maps are expanded about the bunch reference momentum P_{ref}

Beam Energy and Tracking

Small difference between adjusting P_{ref} and $\Delta p/p$ for FF systems (probably FD)



How acceleration is Modelled

- By default, cavities modelled by linear map in the transverse plane:
  - TRANSPORT matrix + end field for TW
  - ‘Chambers’ matrix for SW
- Matrix calculated for P_{ref} (no chromatic effects)
- Alternative: use matrix calculated for each particle (i.e. $P_{\mathrm{ref}}\,(1+\delta)$)
  - More accurate, but slow!
  - No significant difference seen (so far!)

How acceleration is Modelled

- Longitudinal Phase Space
  - Two Methods:

$$\delta_i \rightarrow \frac{\delta_i + \bar{V}\left[\cos(\phi_0 - kz_i) - \cos(\phi_0)\right]}{1 + \bar{V}\cos(\phi_0)}$$

$$P_{\mathrm{ref}} \rightarrow P_{\mathrm{ref}} + V\cos(\phi_0)$$

Full acceleration
Use for linac studies

$$\delta_i \rightarrow \delta_i + \bar{V}\cos(\phi_0 - kz_i)$$

$$P_{\mathrm{ref}} \rightarrow P_{\mathrm{ref}}$$

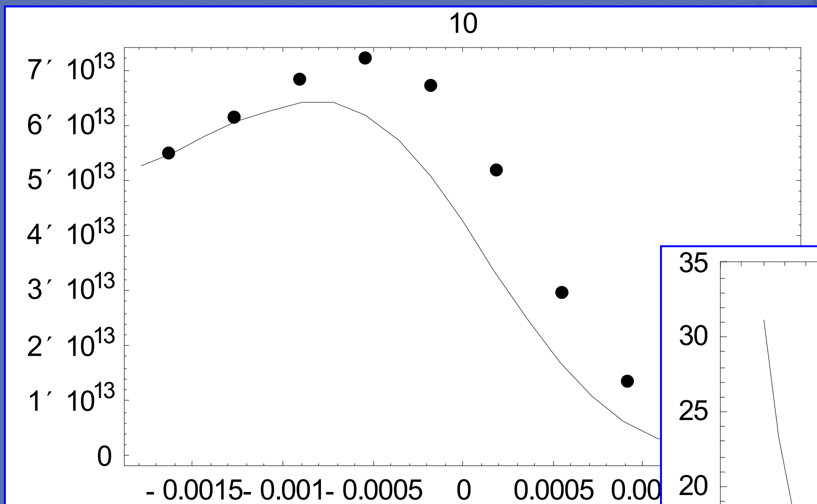
No acceleration
Used for storage rings

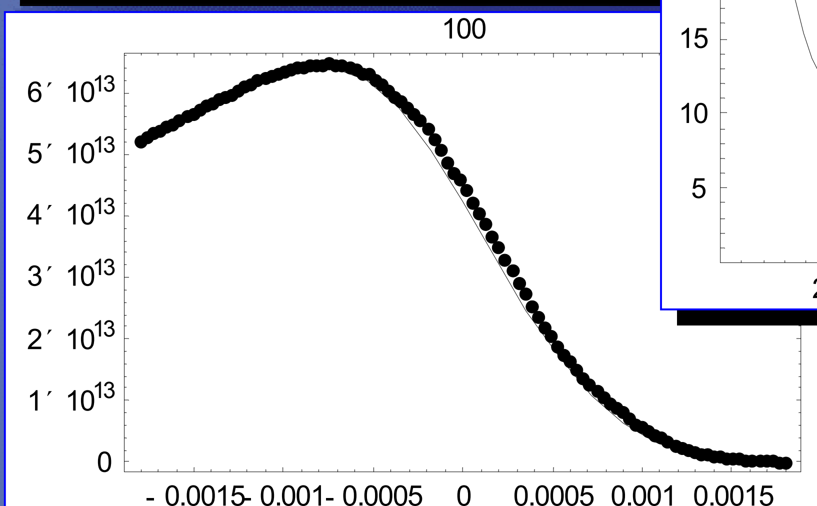
$$\bar{V} = \frac{V}{P_{\mathrm{ref,initial}}}$$

Wakefields

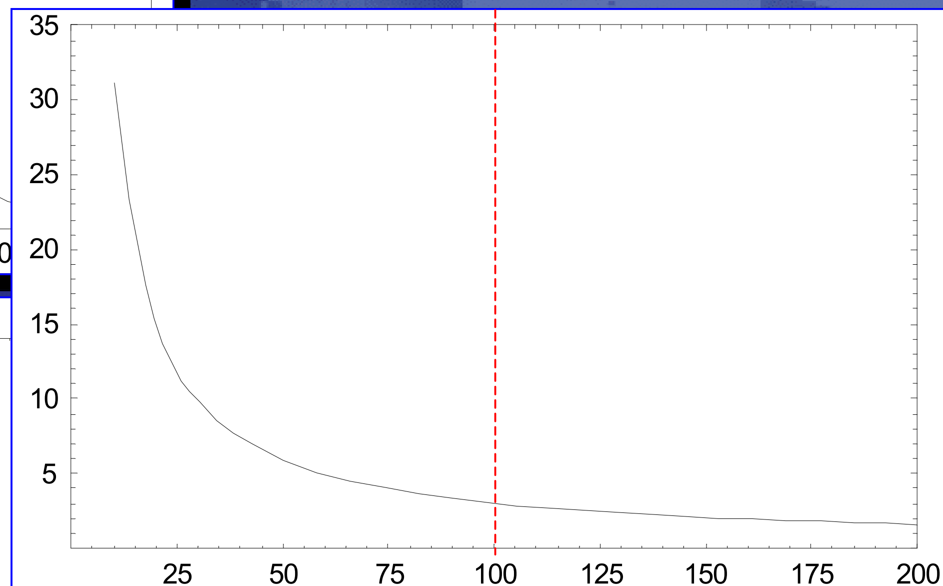
- $W_{\|}$ and $W_{\perp}$ modelled as impulse approximation
- Applied at exit of every cavity
- Longitudinal charge distribution estimated by binning particles (within $\pm 3\sigma_z$)
- Particles are re-binned after bends (when needed)
- All particles in a bin (‘slice’) receive same kick (no interpolation)
- For transverse wake, $\langle x \rangle$ and $\langle y \rangle$ of each bin is statistically calculated for each impulse

Wakefields





% error in loss parameter (K) as a function of bin number



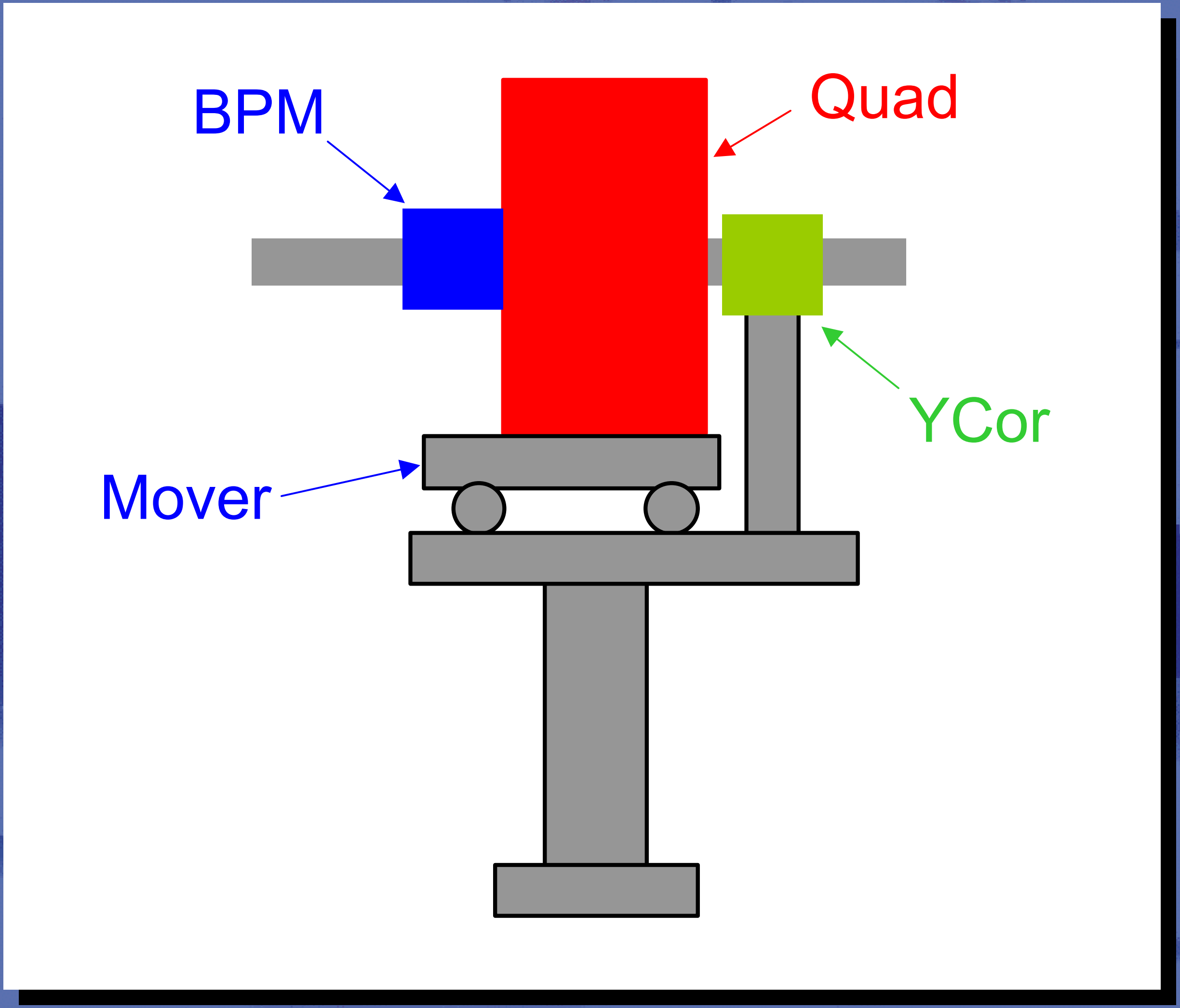
Based on NLC S-band wake with $\sigma_z = 600\mu m$ gaussian bunch (10^5 particles)

Alignment

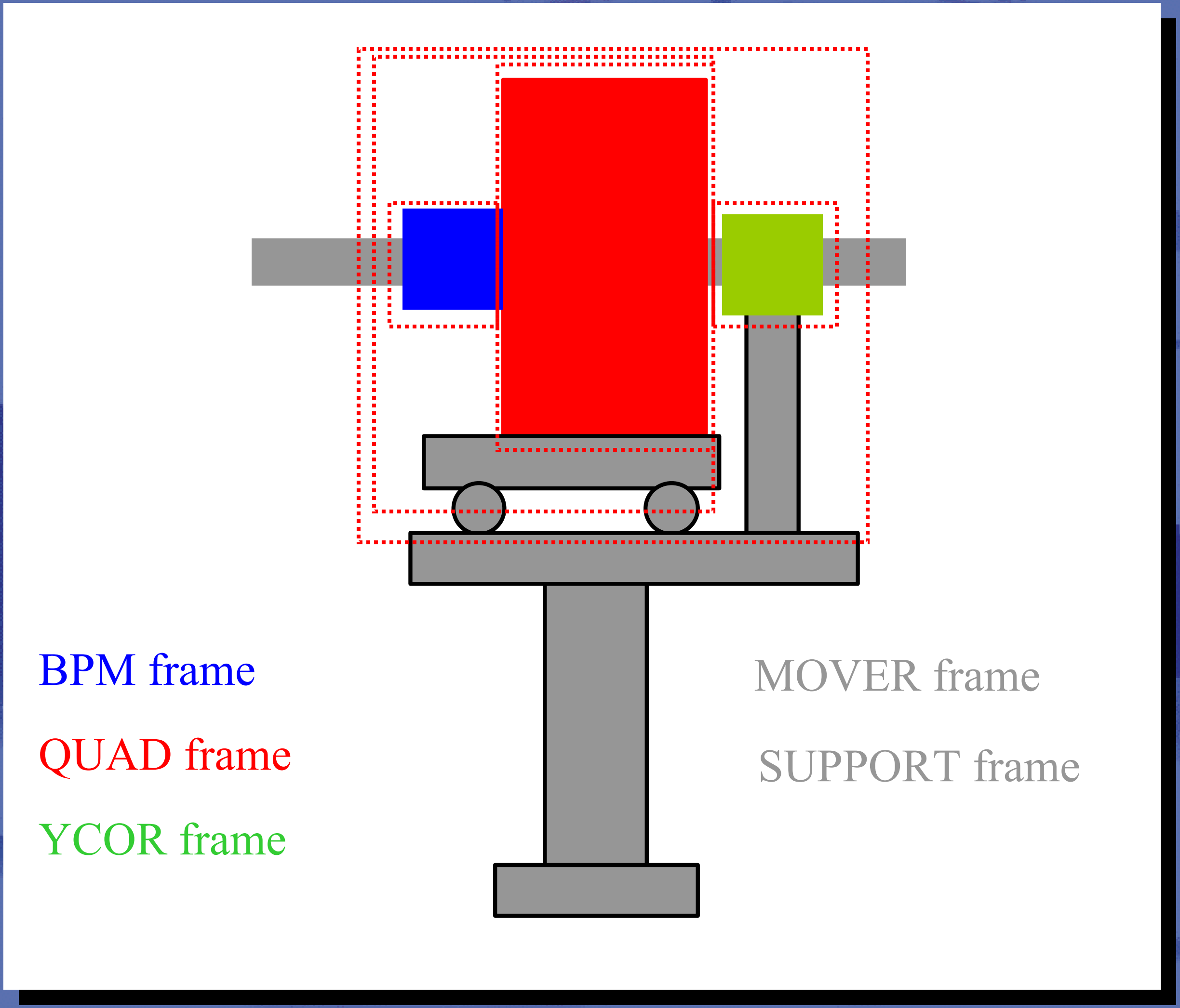
- Full 3-d alignment $(x, y, z, \theta_x, \theta_y, \theta_z)$
- For θ_x, θ_y small angle approximation assumed
- Bunch is transformed into local component frame for tracking

Note: for tilted cavities, transverse RF kick and cross-talk between $W_{||}$ correctly model (I think!)

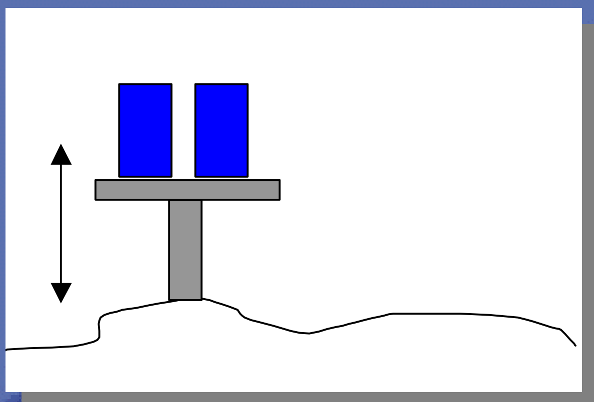
Alignment: nest frames



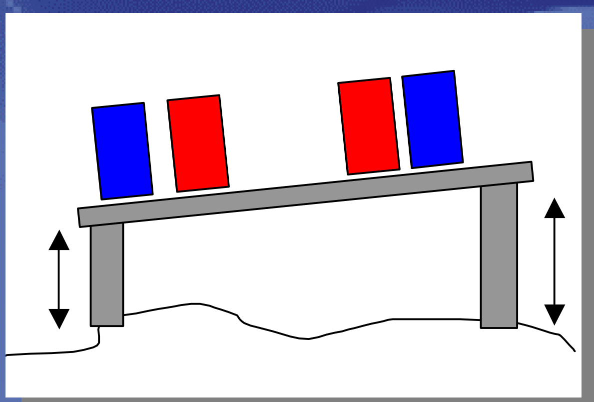
Alignment: nest frames



Ground motion: Girders and Supports



Single Support



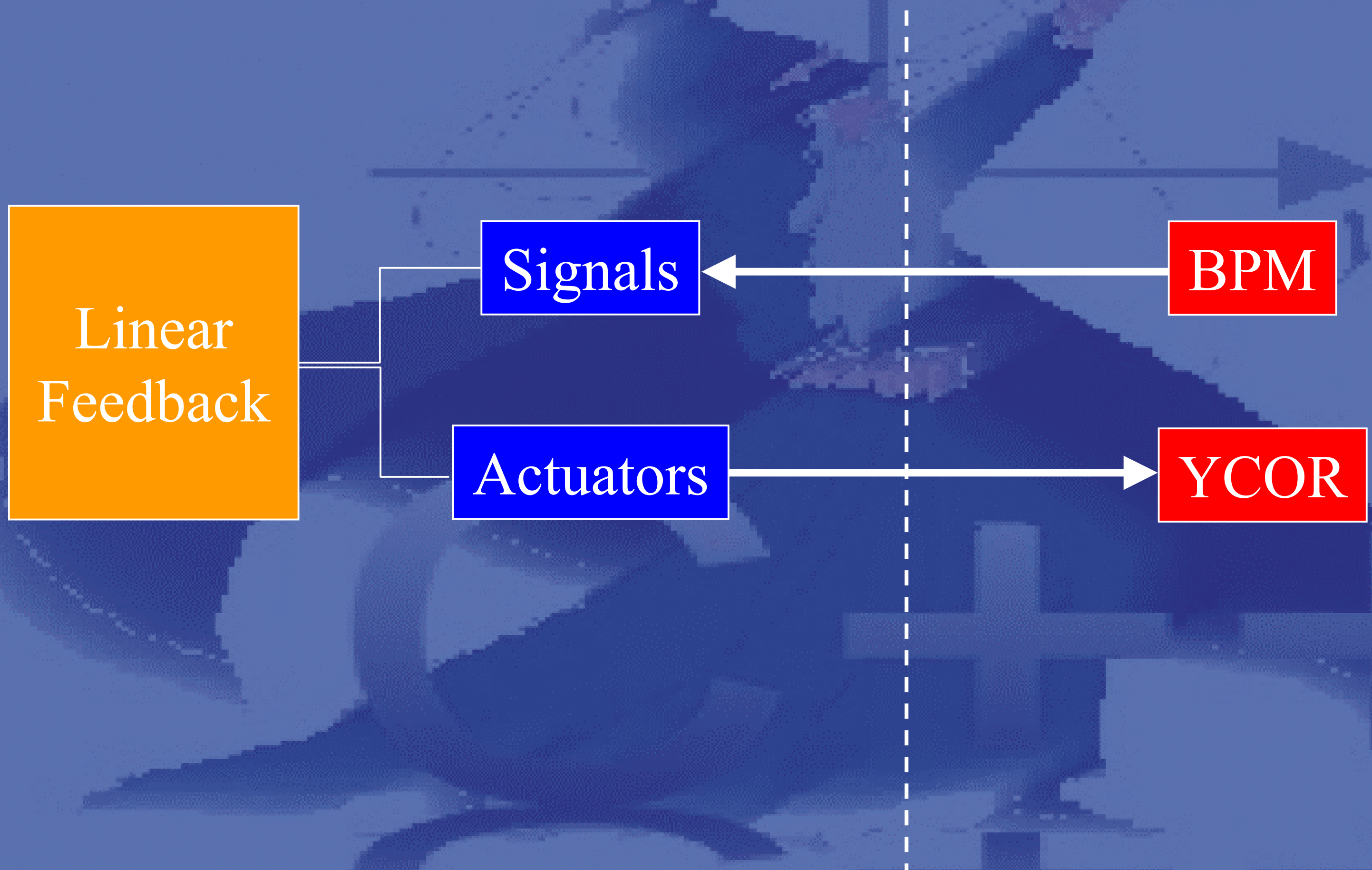
Girder Support

- Ground motion applied to 'Support Structures'
- ATL currently only *spectrum* supported

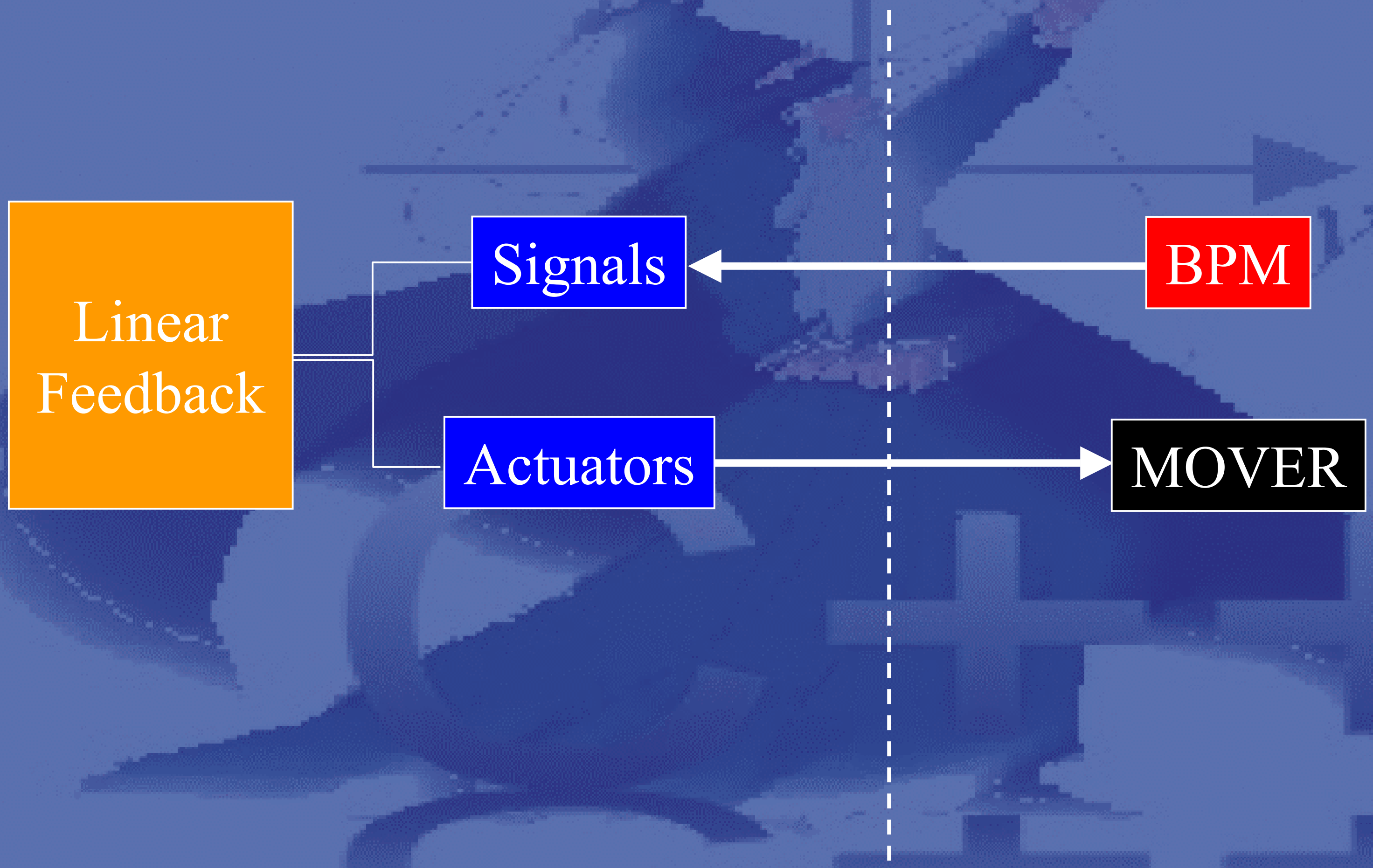
Tuning: the Channel concept

- Tuning ‘knobs’ and algorithms all work via *channels*
- Channels mimic the control system
- Channels are ‘generic’; algorithms can be easily re-used with other devices

Tuning: the Channel concept

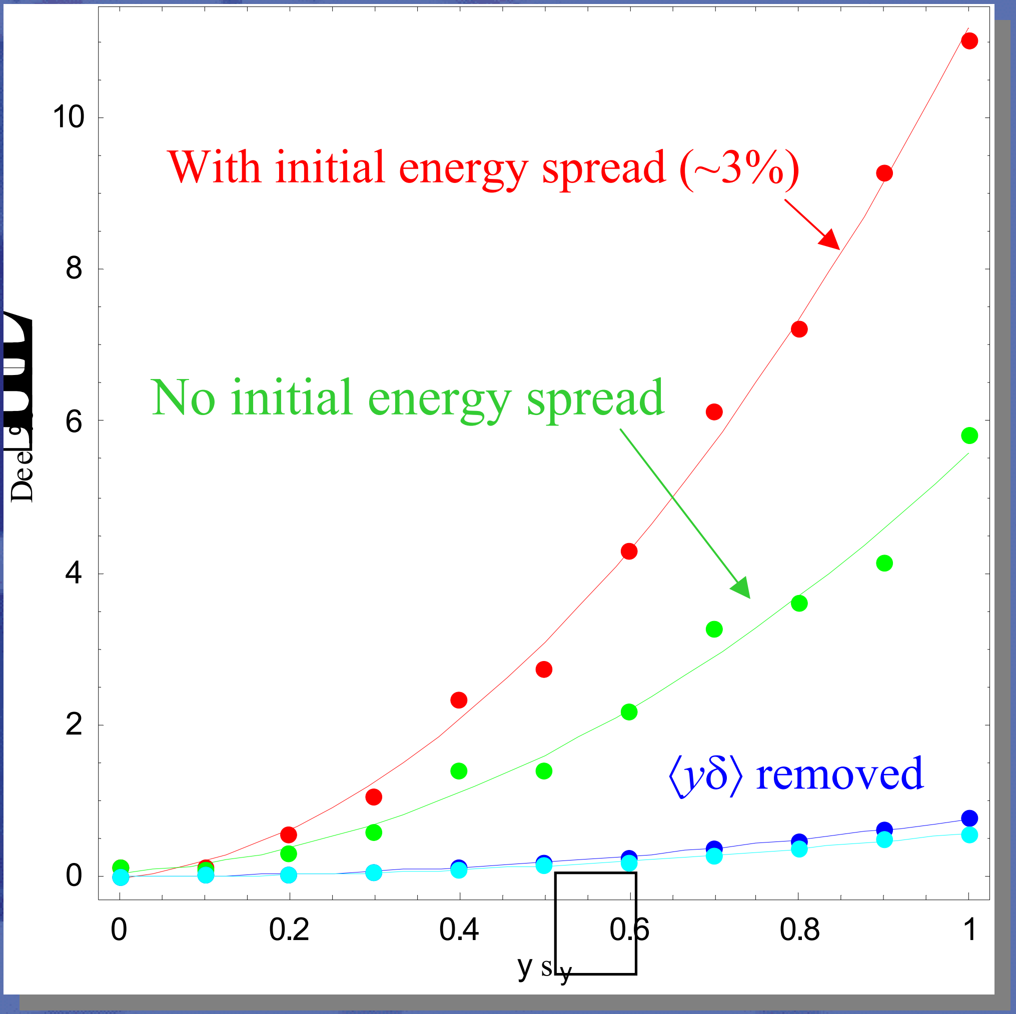


Tuning: the Channel concept



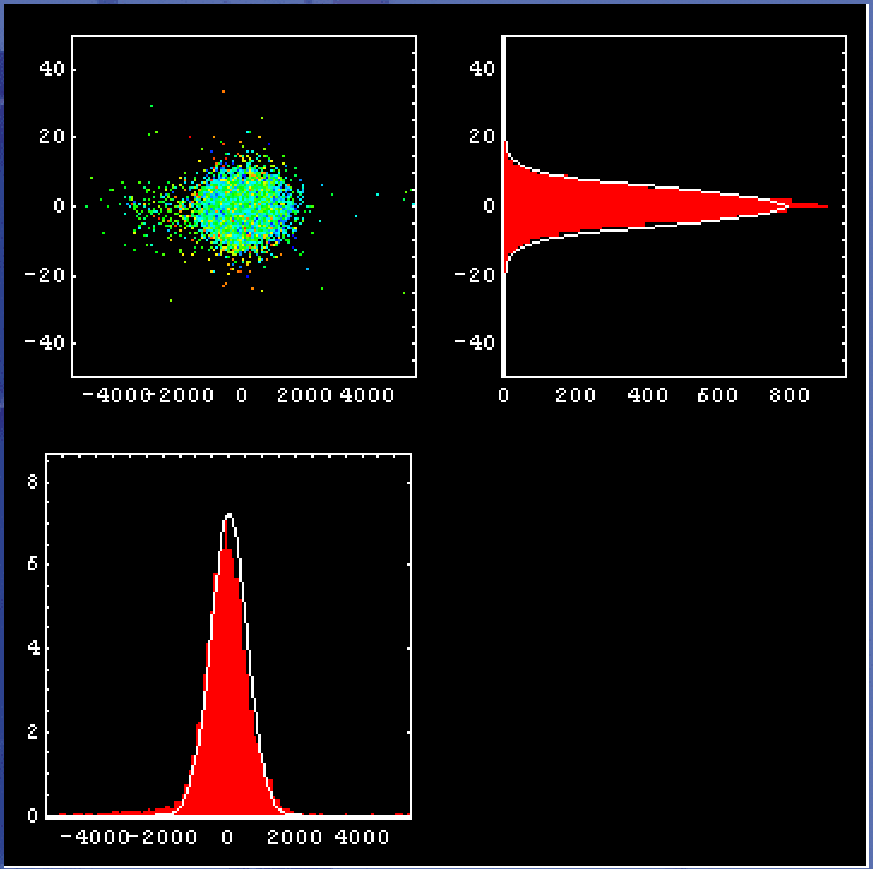
TESLA examples

- TESLA linac with coherent betatron oscillation
- Once linear $\langle y\delta\rangle$ correlation removed, $\Delta\varepsilon/\varepsilon < 1\%$
- No filamentation



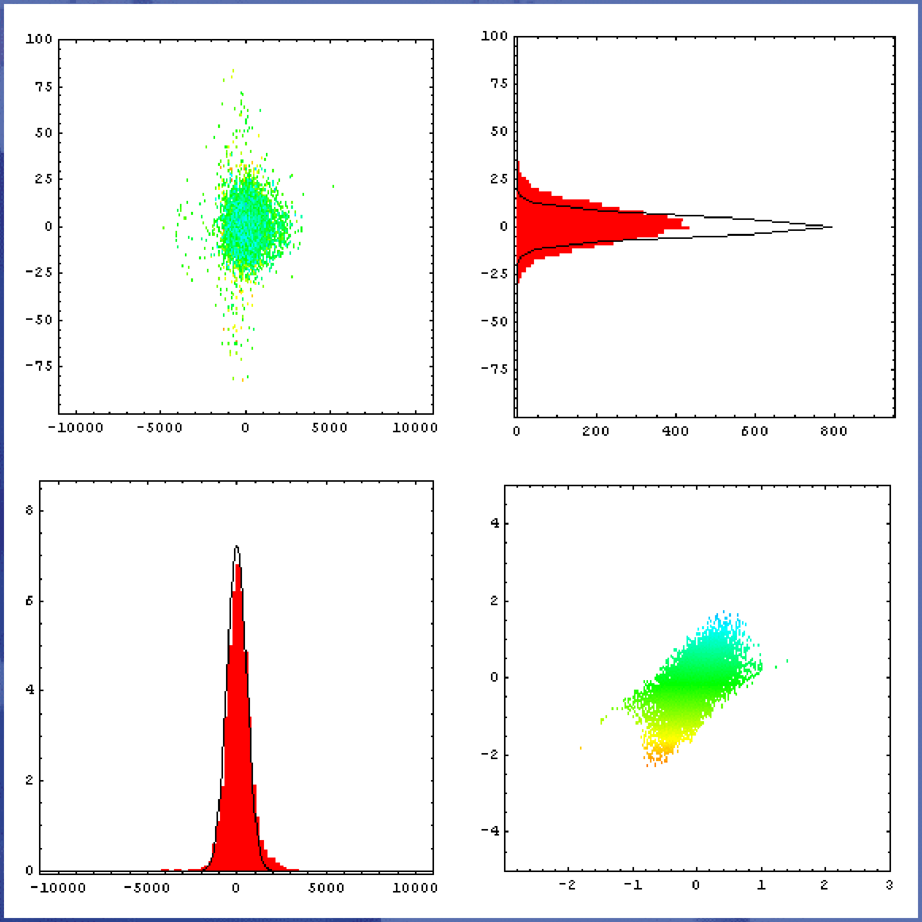
TESLA Examples: DR→IP

- X-Y scatter plots at IP
- 35μm random 'vibration' applied to all magnets
- Centroid jitter removed



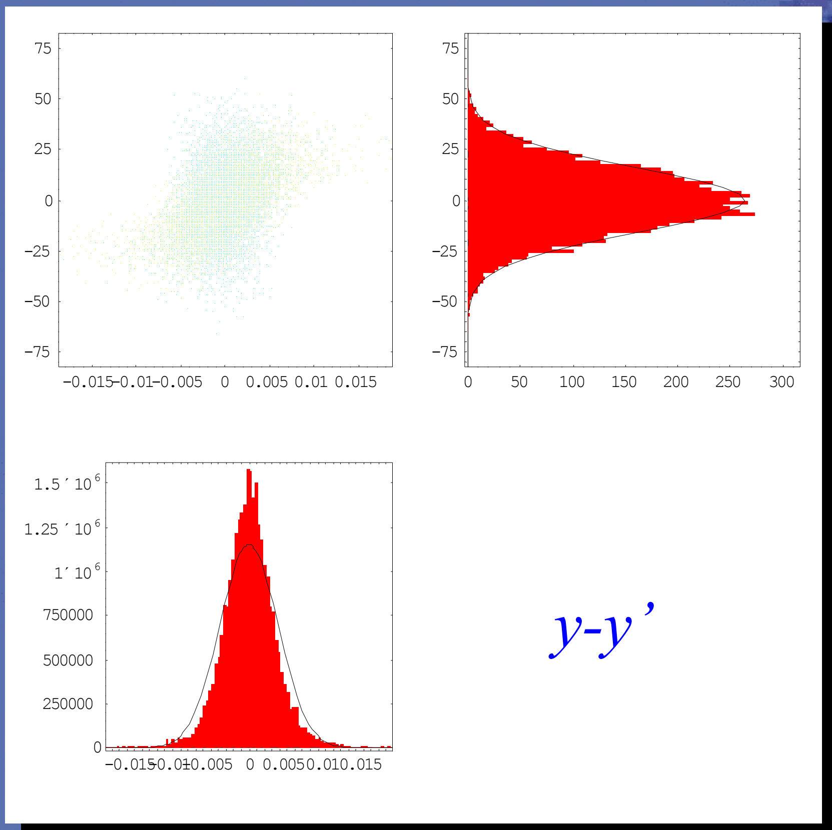
TESLA Examples: DR→IP

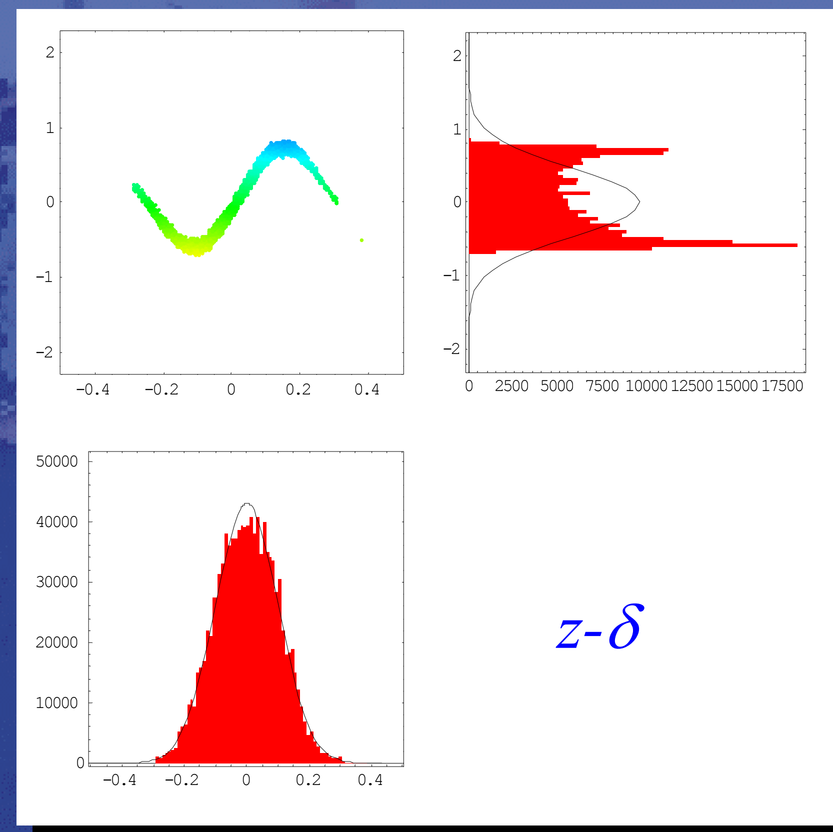
- X-Y scatter plots at IP
- Adjusting bunch compressor RF phase by ±2.5°



z-δ plot

NLC examples: DR→IP





$E_{beam} = 247.53$ GeV, $\sigma_{x,y} = 236, 3.76$ nm, $\delta_{RMS} = 0.46\%$

Storage rings too!

- Thanks to Andy Wolski (LBL)
- Code to support DR studies:
  - Closed orbit, tunes etc.
  - Emittance calculations (Chao's method)
  - Dynamic aperture studies
  - Realistic wiggler maps
    (AW Merlin extensions, not in core library – yet!)

What's next?

- More benchmarking with other codes
  See next two talks ☺
- Resolve NLC results
- Repeat for CLIC
- Studies of static and dynamic errors with tuning
  - SLAC ground motion models (spectrums)
  - Implement BBA modules
    DF steering written but not tested
  - Implement tuning knobs (trivial)
- Start modelling 'machine from start-up'