Issues in Simulating the Effects of Wakefields

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LET Workshop

13th December 2007

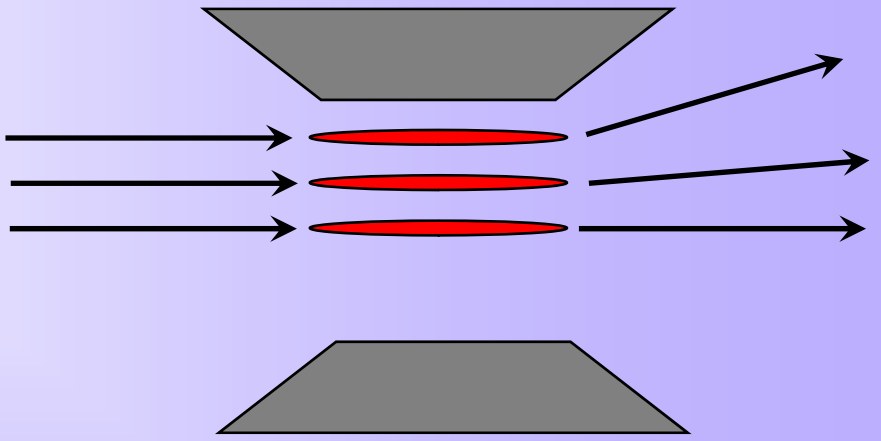
Wakefields at the ILC

Wakefields are important like never before

- Luminosity is everything
- High charge densities
- Small-aperture collimators

Beyond the Kick Factor

$$\Delta y' = (N r_e / \gamma)\ \kappa_t\ y$$

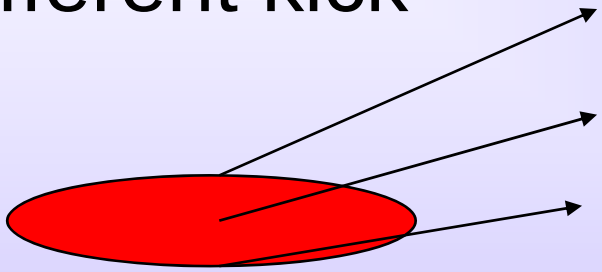


Many analyses just

1) Determine κ_t
2) Apply Jitter Amplification formula

Increased bunch emittance

Particles in bunch with different y get different kick



Increase in $\sigma_{y'}$ at collimator gives increased σ_y at IP. Amplification factor similar to jitter but different

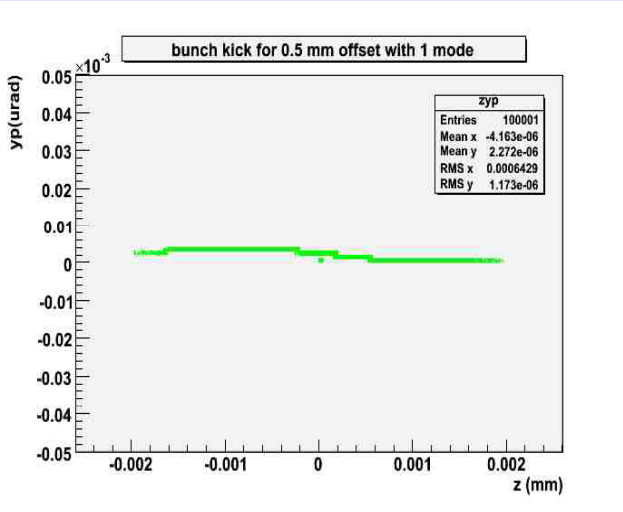
(Zimmerman, Bane and Ng: EPAC 96)

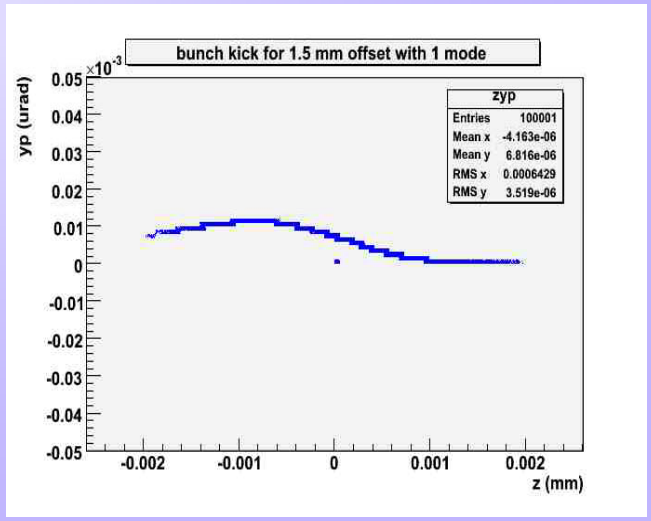
Many Kick Factor formulae

- See http://www.hep.man.ac.uk/u/adina/ for a partial list (6 slides of formulae)
- Different regimes (inductive, intermediate, diffractive)
- Disagreements between published formulae, formulae implemented in programs, etc

Head – tail difference: Banana bunches

Particles in bunch with different z get different kick. No effect on start, bigger effect on centre+tail

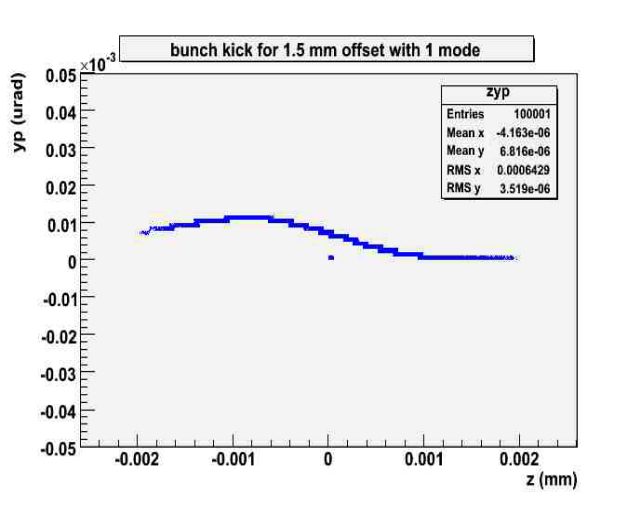


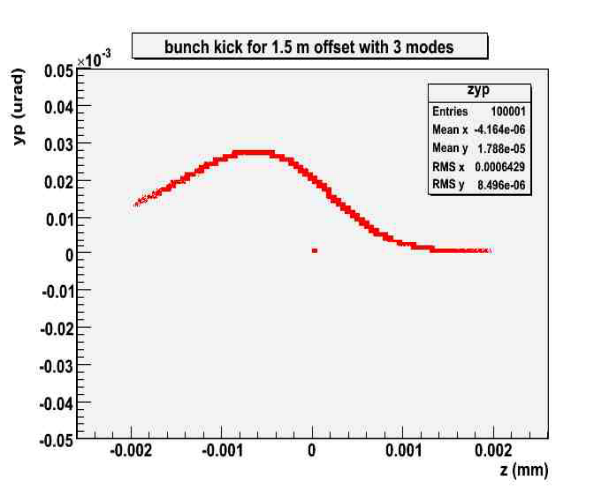


Plots by Adriana Bungau using MERLIN

Higher order modes

Kick Factor is just the dipole mode





Higher order modes matter (only) for large displacements

Non-Gaussian bunches

- Kick factor assumes bunch Gaussian in 6 D
- Contains bunch length σ_z in (some) formulae
- Even if true at first collimator, Banana Bunch effect means it is not true at second
- Replace $\kappa_t = \int\int W(s\text{-}s')\ \rho(s)\ \rho(s')\ ds'\ ds$ by numerical sum over (macro)particles and run tracking simulation

Wake functions

- Integrated effect of leading particle on trailing particle depends on their transverse positions and longitudinal separation.
- Dependence on transverse positions restricted by Laplace's equation and parametrisable using angular modes
- Dependence on longitudinal separation s much more general

$$w_x = \sum m\ W_m(s)\ r^{m-1}\ \{C^m cos[(m-1)\theta] + S^m\ sin[(m-1)\theta]\}$$
$$w_y = \sum m\ W_m(s)\ r^{m-1}\ \{S^m\ cos[(m-1)\theta] - C^m\ sin[(m-1)\theta]\}$$

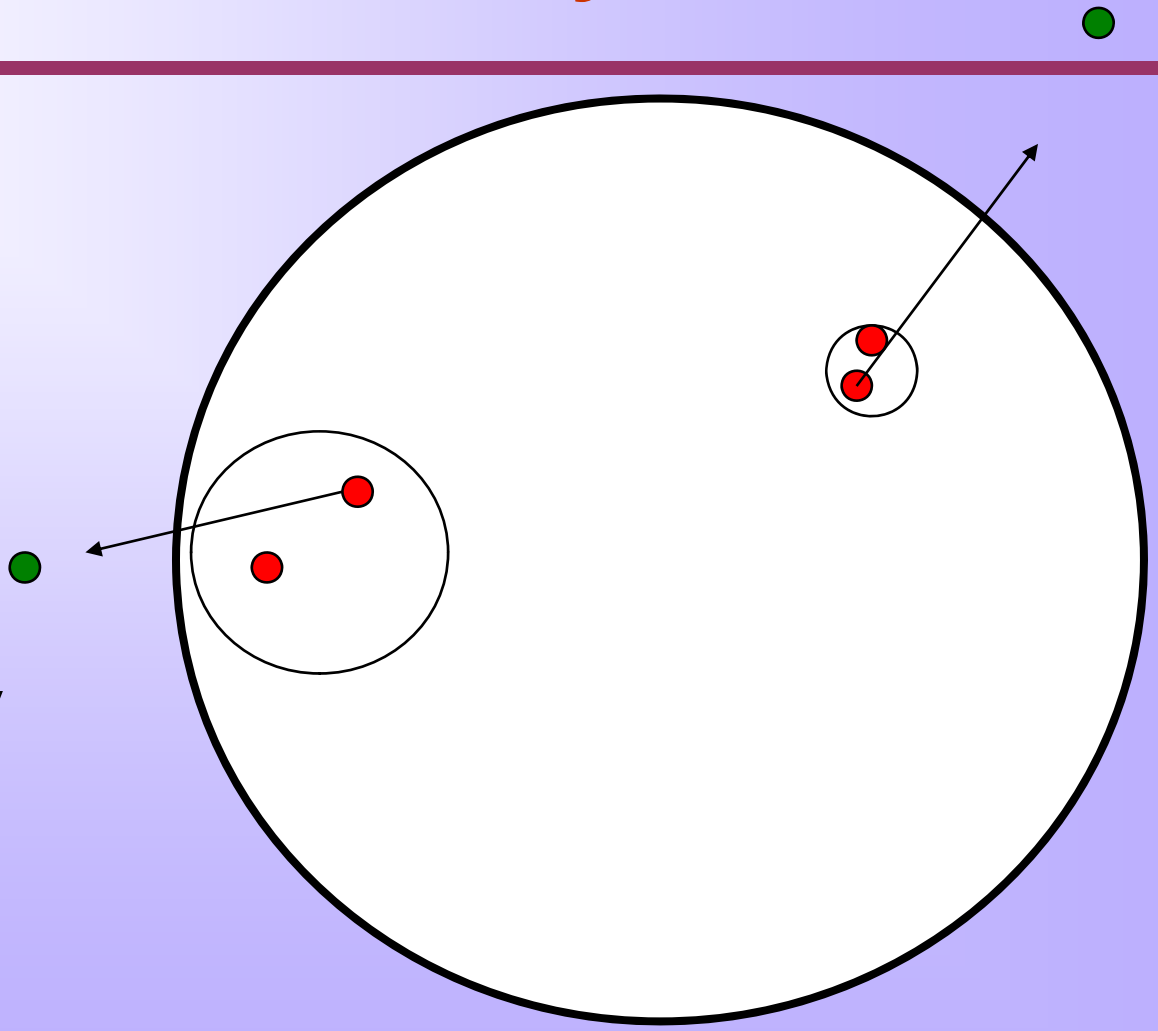
with

$$C^m = \sum r'^m\ cos(m\theta') \qquad S^m = \sum r'^m\ sin(m\theta')$$

Using slices, summation is computationally rapid

Geometry

- For large bunch near wall, angle of particle kick not just ‘transverse’
- This trignometry should be included



Merlin

Basic MERLIN

- Dipole only and ‘Transverse’ wakes

New features in MERLIN

- Arbitrary number of modes
- Correct x-y geometry
- Easy-to-code wake functions
- Still only for circular apertures at present

Placet

- Rectangular apertures
- 1st and higher order
- Stupakov/Yokoya formulae
- Geometric wakefield: each slice effects only itself (justification…)
- Not easy to add new formulae

Lucretia

- Short range wakes in cavities/collimators
- First order only
- Sum and store effect of slice n on slice m

CHEF

- Dipole mode only (as far as I can tell)
- Increase computation speed by evaluating convolution $\int W(s-s')\,\rho(s')\,ds'$ using Fourier Transforms
- $O(N \log N)$ rather than $O(N^2)$. N is number of slices
- Is this improved efficiency important? If so, can other simulation programs use it?

Wake function formulae: EM simulations

Few examples:

One is (for taper from a to b)

$$w^m(s)=(1/a^{2m}-1/b^{2m})e^{(-mz/a)}\Theta(z)$$

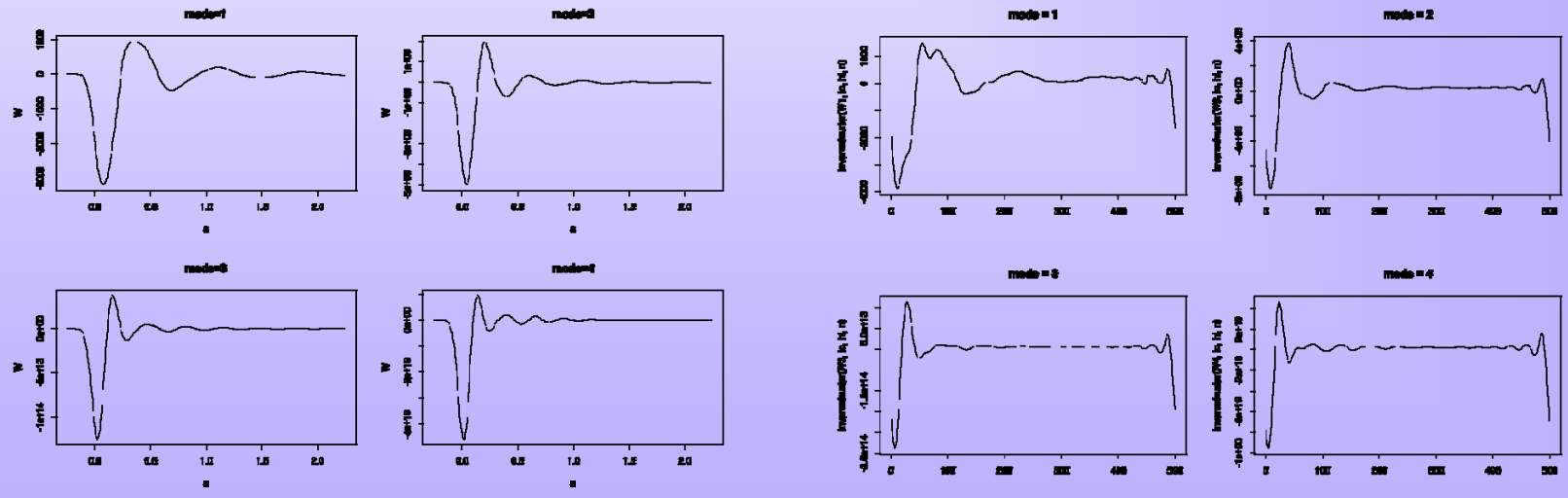
Raimondi

Need to use EM simulation codes and parametrise

- Run ECHO2D or GdfidL or …
- Has to be done with some bunch: point in transverse coordinates, Gaussian in z.
- Need to do this several times with different transverse positions: extract modal bunch wake functions $W^m(s)$ using any symmetry

Deconvolution

- Still have problem that this is wake field due to bunch of width σ_z, not point particle delta wakes
- Taking $\sigma_z \rightarrow 0$ does not work (computation time!)
- Deconvolute/unfold using Fourier Transforms
- Examples show ECHO2D simulations of modes 1-4 for simple collimator and the extracted delta wakes



Experimental Results

- Measure kick as function of y
- Kick factor + higher terms
- Desperately short of data
- Set of measurements this year and next year – some results (Steve Molloy's talk in Wakefest). Need more!

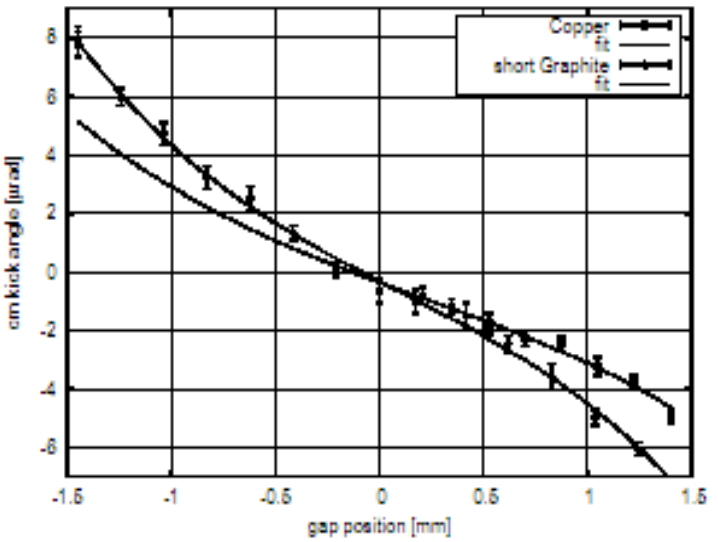


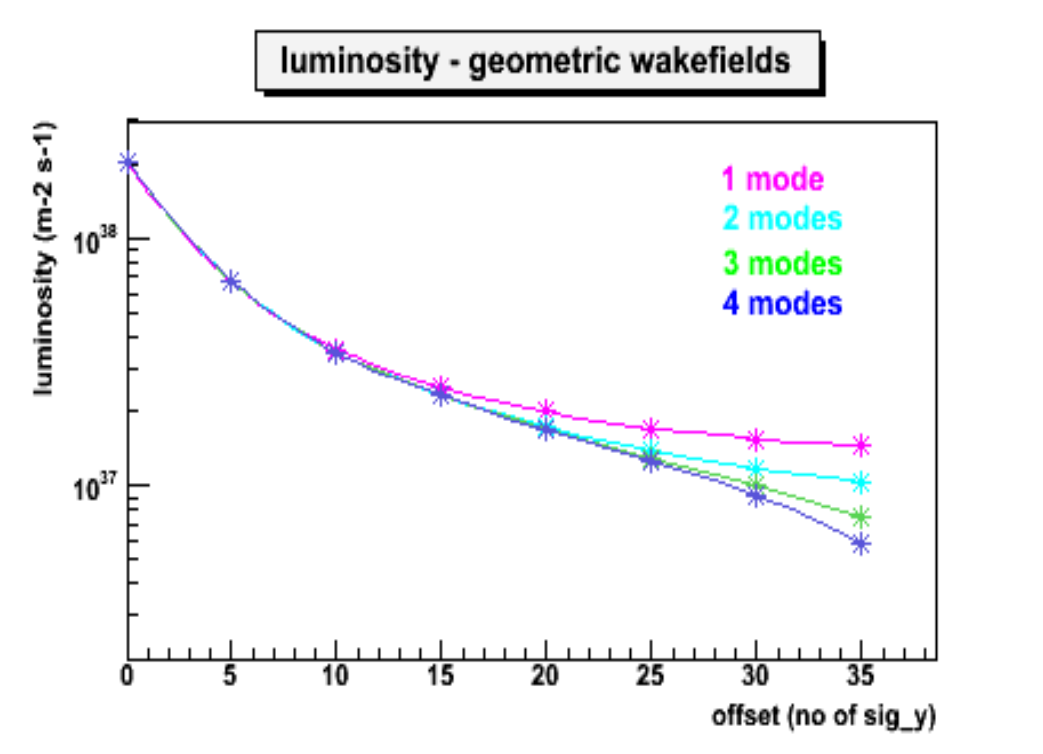
Figure 2: Beam deflection as a function of gap position for the short graphite collimator and the copper collimator.

*From Onoprienko, Tenenbaum et al, now in PRST:AB **10** 034401 (2007)*

Does it matter?

First suggestions are that effects of high order modes etc are small

This is not sufficiently solid to spend $N Bn of taxpayers' money



Plot by Adriana Bungau using MERLIN

Conclusions

Nobody has all the answers

The physics is complicated (and interesting)

Plenty of room for exploring different approaches in computation, maths, and experiment

There's more to Wakefields than Kick factors!