Computational Methods for CSR Calculations

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Overview

- History, Motivation, Effects
- Current state of affairs
  - Methods
  - Codes
- Commercial Break
- Outlook
Coherent Synchrotron Radiation: History

- L. I. Schiff, Rev. Sci. Instr., 17,6(1946): CSR bunch energy loss
- Schwinger, Phys. Rev. 75,12 (1949): CSR for arbitrary currents/charges; mostly interested in point charges; unpublished (1945): shielding w/infinite plates
- Nodvick and Saxon, Phys. Rev. 96,1 (1954): finite plates
50 Years Later:

• Previous work: far zone, energy losses, circular accelerators

• FEL applications: ultra-short bunches, high charges, low energy, tight bending radii

• Derbenev, Rossbach, Saldin, Shiltsev, TESLA-FEL 95-05 (1995)

• Murphy, Krinsky, Glukstern PAC 1995

• Saldin, Schneidmiller, Yurkov, TESLA-FEL 96-14 (1996)
Why the Interest?

Radiation from the tail can interact with the head of the bunch.

\[ L^3 > 24 R^2 \sigma \]

*Overtaking condition:*

_Easily fulfilled for FEL facilities!_
Consequences:

- Long-Range:
  - Induced correlated energy deviation; dispersion mismatch leads to projected emittance growth
  - Non-linear transverse forces; leads to emittance growth
  - Delicate balance between dispersive and transverse forces (Talman; Lee; Derbenev; Li)
  - Transverse variation of longitudinal forces
Consequences:

- **Short-Range:**
  - CSR is always present on bent trajectories
  - Longitudinal force will induce density variations
  - Density variations will be amplified
  - First seen in high-resolution studies (Borland)
  - Analytical models (Stupakov; Schneidmiller)
Simulation Desiderata:

- General (Beamline)
- Self-consistent
- Spatial Resolution
- Dimensionality
- Low Noise

- General (Bunch)
- Interfacing
- Post-Processing
- Speed
Choice of Field Solver

• Smart codes:
  – Projection & Analytic Formulae
  – Analytic formulae

• Retarded codes:
  – Projection & Retarded integration
  – Smooth distribution & Retarded integration
  – Smooth particles & Retarded integration
Regularization & Noise: Choice of Macroparticles

- **Point Particles**: very noisy (retardation!), very singular
- **Pin Particles**: singularity on trajectories
- **Paper Particles**: discontinuity when traversing
- **Pencil Particles**: best & most expensive solution
- **Phasespace Particles, Vlasov...**
Fields Smoothing in TREDI

Sources of divergences

**Smoothing of velocity fields**

- Extended "source" particle eliminates $1/r^2$ divergence

**Smoothing of acceleration fields**

- Extended "target" particle eliminates $(1-n)$ divergence

No integration is required (Gauss Theorem)

1D Integral

Equivalent to a spread in transverse momentum i.e. particles have an emittance

(courtesy L. Giannessi)
A Taxonomy of Codes

• Field Calculation:
  – First Principles (Retarded Potentials)
  – Analytically known
  – Mixed strategies

• Particle/Current Representation:
  – Vlasov/Vlasov
  – Macro-particles/Macro-particles
  – Macro-particles/Vlasov

• Dimensionality Particle/Current
A Taxonomy of Codes

Nameless (R. Li) FMM32
ELEGANT (Borland) AMV31
TraFiC4 (Dohlus, Limberg, A.K.) FMM33
CSRTrack (Dohlus, Limberg) MMV33
TREDI (Giannessi and Quattromini) FMM33
Nameless (P. Emma) FMV31
A Taxonomy of Codes

Recent approaches:

Agoh and Yokoya: Grid calculations of field
Warnock, Ellison, Bassi: PF, new field integration scheme

Uncharted Territory

Complete EM simulation
Huygens methods (lacunae-based ABC)
A Taxonomy of Codes

Recent approaches:

- Agoh and Yokoya: Grid calculations of field
- Warnock, Ellison, Bassi: PF, new field integration scheme
- Talman: string charges

Uncharted Territory

- Complete EM simulation
- Huygens methods
# ICFA Beam Dynamics mini workshop

**Coherent Synchrotron Radiation and its impact on the dynamics of high brightness electron beams**

**January 14-18, 2002 at DESY-Zeuthen (Berlin, GERMANY)**

![Website](http://www.desy.de/CSR)

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*15% cut of charge to reduce noise*
CLIC Experiment
TraFiC4 - discerning features

- Fully 3D
- Arbitrary beamlines
- Choice of
  - accuracy
  - regularization scheme
  - self-consistency
- Sampling bunches
- Field observation grids
- User-defined bunch population
- Shielding
- Extremely Slow
Self-Consistent Procedure

In each slice and for each particle, the retarded position of each generating sub-bunch is found. The fields are calculated and are applied to the probe particles. The particles are tracked into the next slice. The procedure is repeated up to the exit slice. The phase-space distribution from all slices is written to a file and postprocessed.

Probe particle bunch and generating bunch are set up according to the optics of the beamline.

The beamline is divided into slices.
Parallelism

- TraFiC4 supports MPI parallelism
- Dynamic load-balancing
- Two forms of parallelism
  - replicated instances of TraFiC4, fields are calculated on restricted set of trajectories; calculated fields are broadcast to other processes
  - restricted set of trajectories in memory; field solver responds to computation requests from other processors
CSR: LCLS BC Optimization
LCLS Bunch Compressor

- Formation of current cusps and low energy spread requires high resolution
- 2+2 Dimensions
- Still ~6000 macroparticles
- Run on 256 processors
CSR: LCLS BC Optimization

- TraFiC4: 3-D, self-consistent, weighted macroparticles, particle-to-particle, retarded potentials
- Completely rewritten (C++/F77)
- (W/R. Uplenchvar): New parallelization scheme saves memory
- Now routinely run ~5000 macroparticles on NERSC
LCLS Bunch Compressor

- Slice output data, calculate FEL figures of merit
- Result: FEL performance will increase well below the design bunch length
Conclusion

• CSR has been investigated for 50/10 years
• Still contentious issues
• Variety of differing approaches
  – converging result
  – diverging ideologies
• There's no silver bullet (yet); all approaches involve tradeoffs