Computational Methods for CSR Calculations

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Overview

- History, Motivation, Effects
- Current state of affairs
  - Methods
  - Codes
- *Commercial Break*
- Outlook

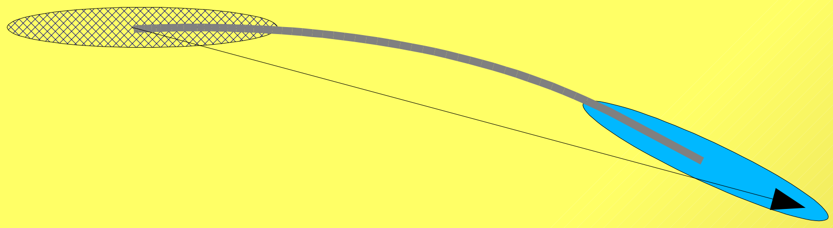
Coherent Synchrotron Radiation: History

- 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 **75**,12 (1949): CSR for arbitrary currents/charges; mostly interested in point charges; unpublished (1945): shielding w/infinite plates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 appliations: 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?



New situation: collective self-interaction.
Radiation from the tail can interact with the head of the bunch.

Overtaking condition:

$$L^3 > 24 R^2 \sigma$$

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...

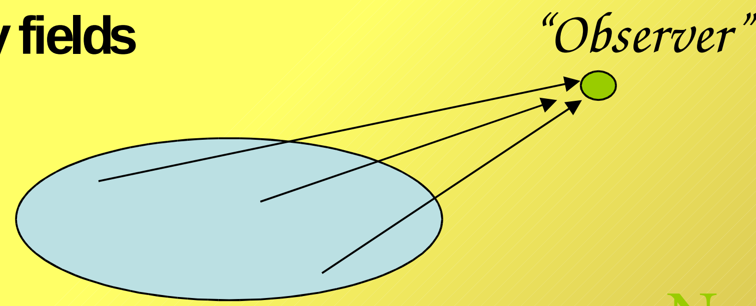
Fields Smoothing in TREDI

Sources of divergences

$\vec{E}_V = e \frac{(\hat{n} - \vec{\ })}{{}^{2}(1- \vec{\ } \cdot \hat{n})^{3} \vec{R}^{2}}$

$\vec{E}_A = \frac{e}{c} \frac{\hat{n} \times [(\hat{n} - \vec{\ }) \times \dot{\vec{\ }}]}{(1- \vec{\ } \cdot \hat{n})^{3} R}$

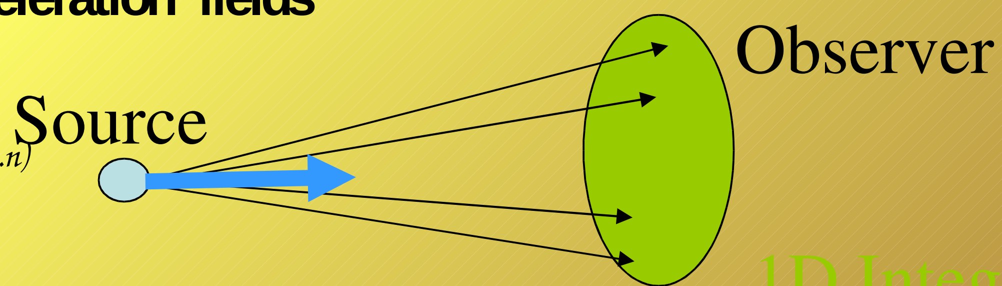
Smoothing of velocity fields



Extended "source" particle eliminates 1/r² divergency

No integration is required (Gauss Theorem)

Smoothing of acceleration fields



Extended "target" particle eliminates (1- .n) divergency

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)

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- Talman: string charges

Uncharted Territory

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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)
http://www.desy.de/csr

	3D	δE	σE	ε
3D	TRAFIC4	-0.058	-0.002	1.4
	TREDI	-0.018	-0.001	1.85
2D	Program by R.LI	-0.056	-0.006	1.32
1D	Elegant	-0.045	-0.0043	1.55
	CSR_CALC	-0.043	-0.004	1.52
	Program by M. Dohlus	-0.045	-0.011	1.62

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~~* 15% cut of charge to reduce noise~~

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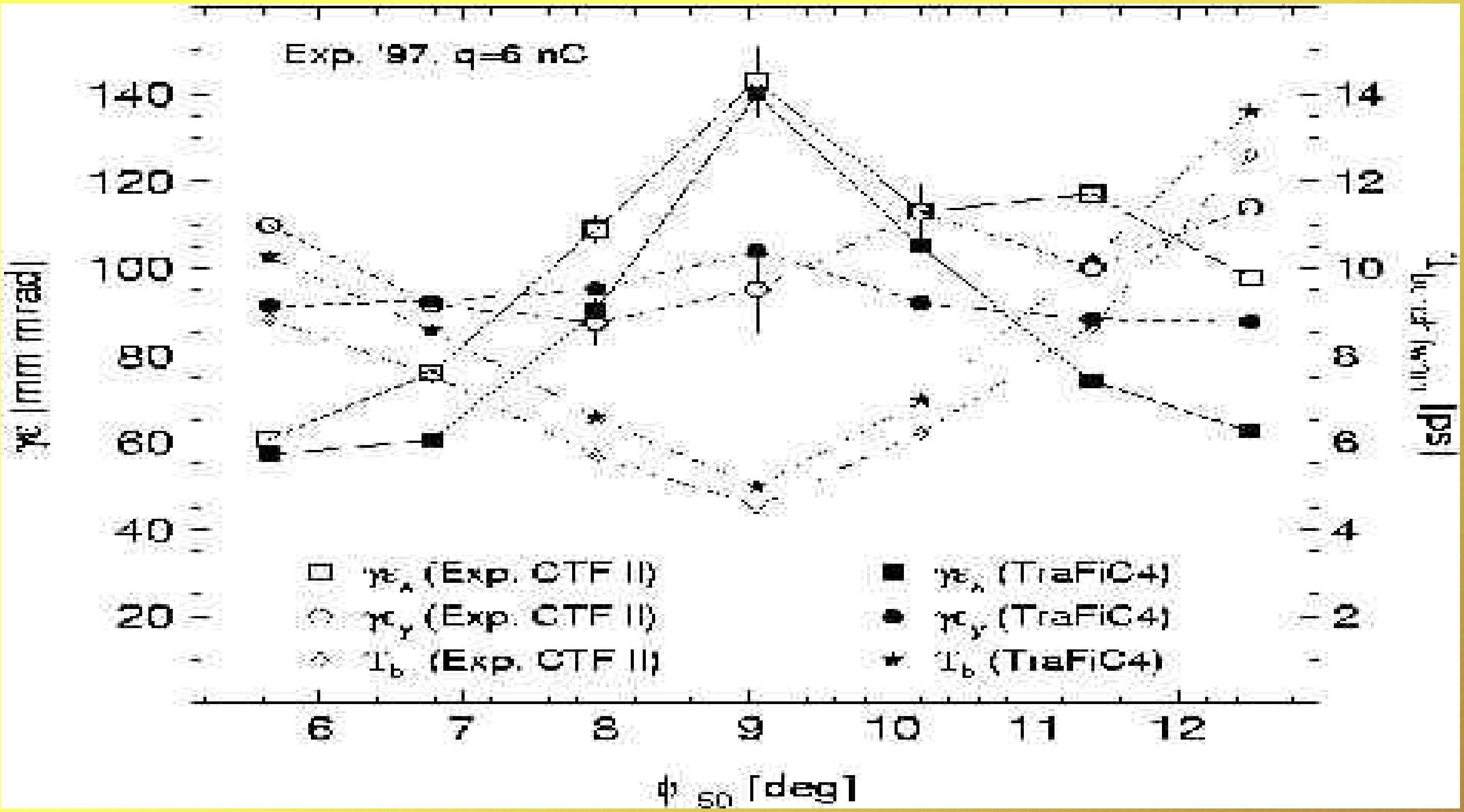
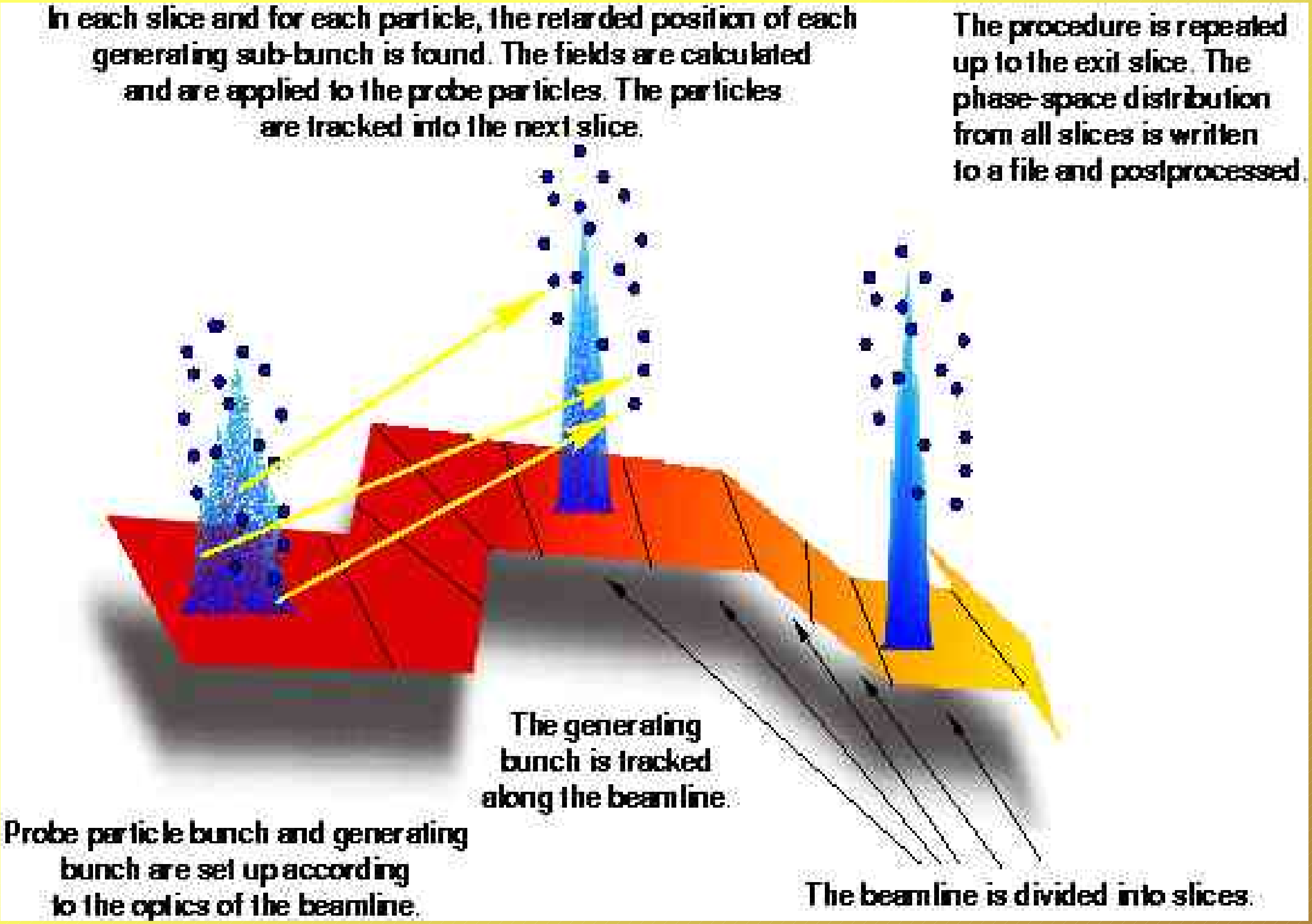
CLIC Experiment



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

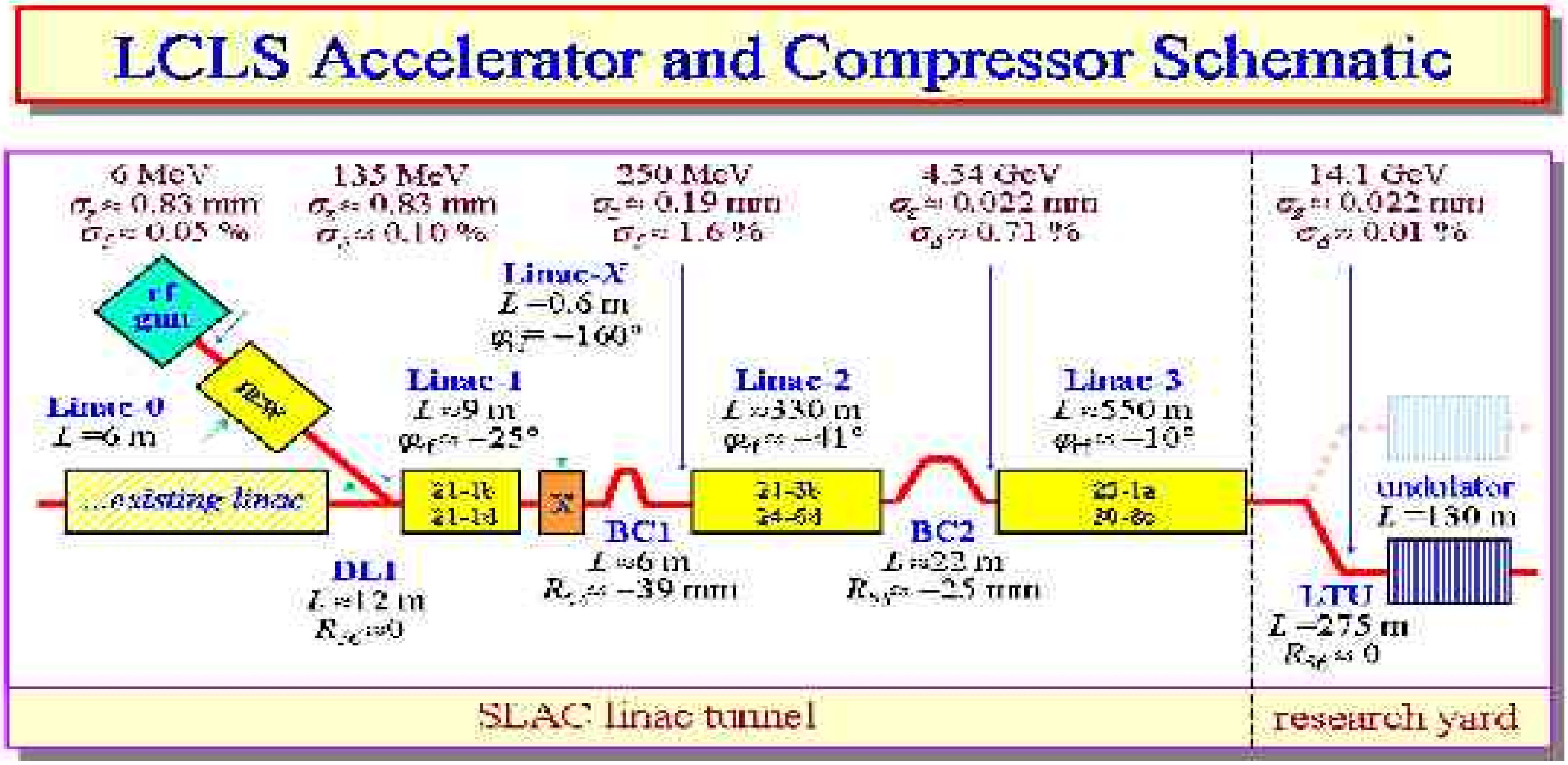
Self-Consistent Procedure



Parallelism

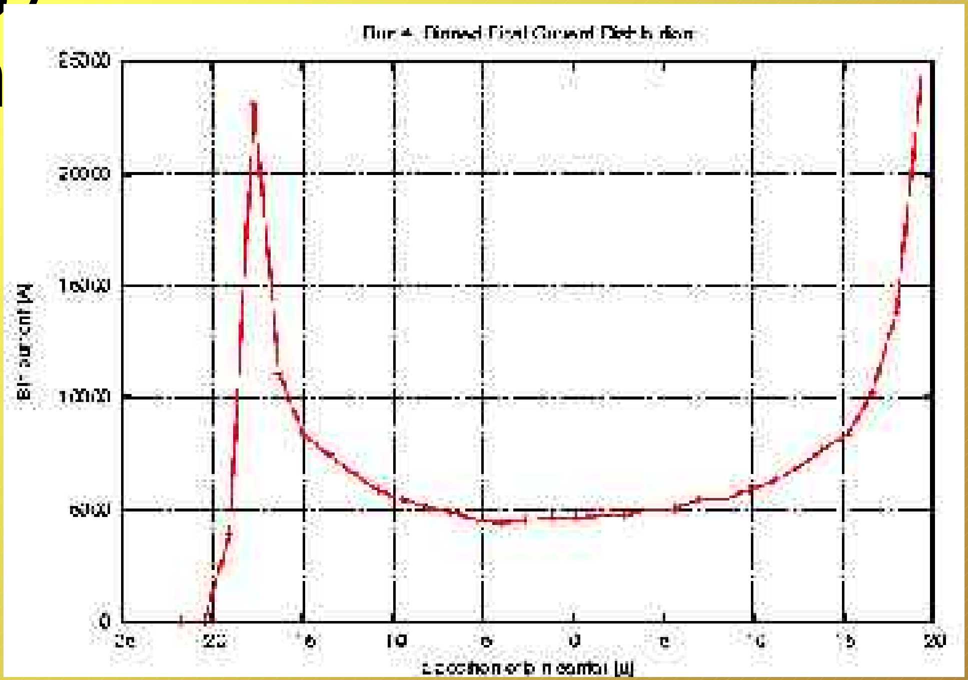
- TraFiC4 supports MPI parallelism
- Dynamic load-balancing
- Two forms of parallelism
  - replicated instances of TraFiC4, fields are calculated on restricted set of trajectories; calculated fields are broadcast to other processes
  - restricted set of trajectories in memory; field solver responds to 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

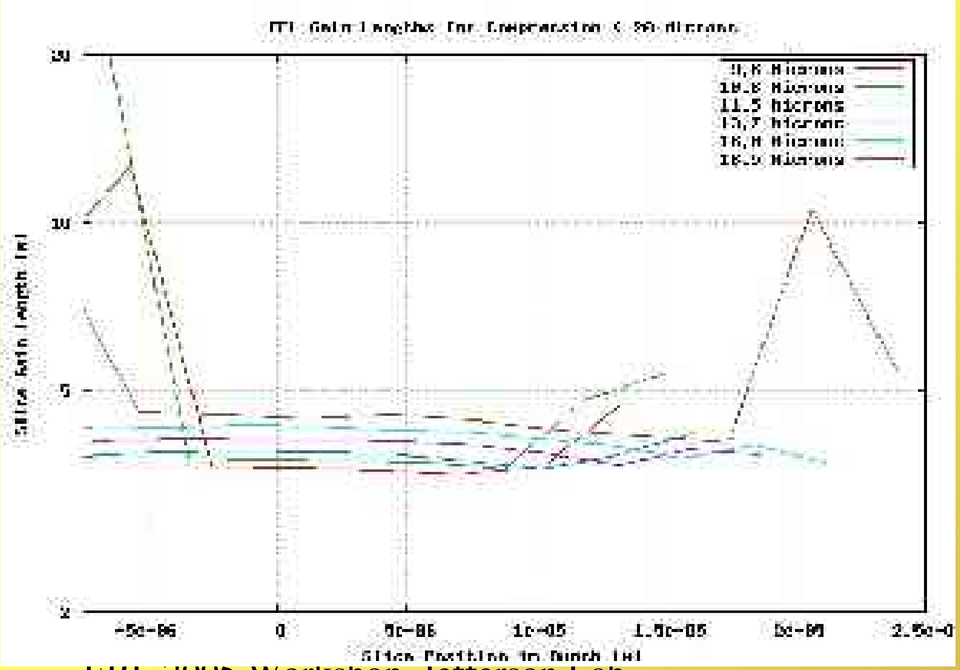


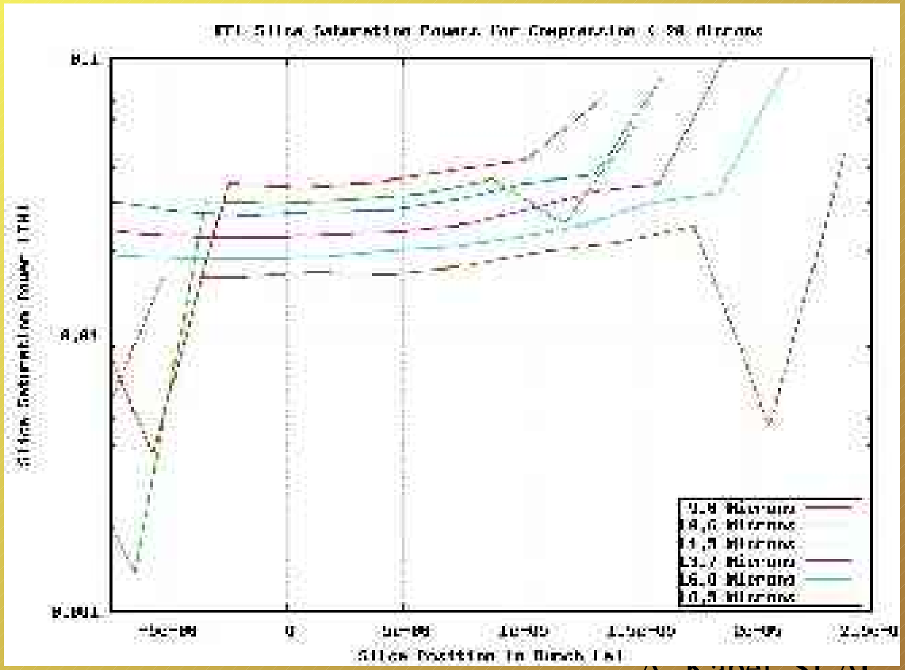
CSR: LCLS BC Optimization

- `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