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Reliability and Accuracy of PARMELA for RF Guns

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PARMELA

(Phase and Radial Motion in Electron Linear Accelerators)

- History
  - Originally developed in 1980 by K. Crandall (LANL) to design high-intensity electron linacs.
  - Modeling of photo-cathodes added shortly after by L. Young (LANL).
  - Traveling-wave tank and wiggler modeling added in mid 1980s by K. Crandall.
  - Moved from mainframe computers to PCs by mid 1990s. Documentation by J. Billen in 1996 (LA-UR-96-1835).
  - Recent additions (>=2000): 3-D space-charge, CSR calculation (1-D model), quiet start, etc. See *L. Young and J. Billen, PAC03, p. 3521*.
- User Base
  - FY 2003: 371 users world-wide, including 206 in U.S.
  - Labs 48%, academy 28%, commercial companies 20%, private 4%.
- Versions:
  - Los Alamos Accelerator Code Group (LAACG), current version - Parmela 3.40 (Feb. 2006). Available from laacg.lanl.gov.
  - UCLA, JLab (Parmela-FEL), Boeing (Parmela-B), LANL (2), ANL(?), etc.

PARMELA

Main applications: simulations and design of

- RF Guns, Photoinjectors
- FELs
- High-Intensity Electron and Ion Linacs
- Beamlines / Transport Systems
- Commercial Linear Accelerators:
  - Medical
  - Food Sterilization
  - Ion Implanters

PARMELA Features

- Particle tracking code, with time (phase) as independent variable, integrates macroparticle motion in 3D(!) using external fields (2D/3D) + space-charge.
- Up to 3 different particle species *q*,*m* simultaneously.
- Standard space-charge computation is 2D+ *(r,z)* routine (SCHEFF): Lorentz transform to the bunch rest frame – electrostatic field – inverse transform (NB: + elliptical correction; - energy spread).
- Cathode-wall image effects are included; cylindrical wall image currents can be turned on.
- Different initial beam distributions; can read input from EGUN or ISIS.
- Collection of standard elements: DRIFT, SOLENOID, QUAD, BEND, BUNCHER, CELL, TRWAVE, WIGGLER, etc.
- Optional 3-D space-charge (SPCH3D – a la R. Ryne), CSR calculation (1-D model – *B. Koltenbah et al,* 2002), quiet start, etc.
- SBLOAD: wake effects can be included in dynamics simulations - simple model (wakes must be calculated with other codes).

PARMELA Validation: vs. Measurements

- NBS 5-MeV race-trek microtron (1982).
- LANL – AFEL, APEX, etc.
- Boeing high-current injector.
- More recent examples:

Fermilab A0 Photoinjector
UCLA Neptune Facility
DUVFEL (see next slide)
SLAC Gun Test Facility (GTF)

LCLS design effort (<140 MeV)
Industrial & medical linacs
Many others…

Almost every modern electron linac built has been designed with PARMELA.

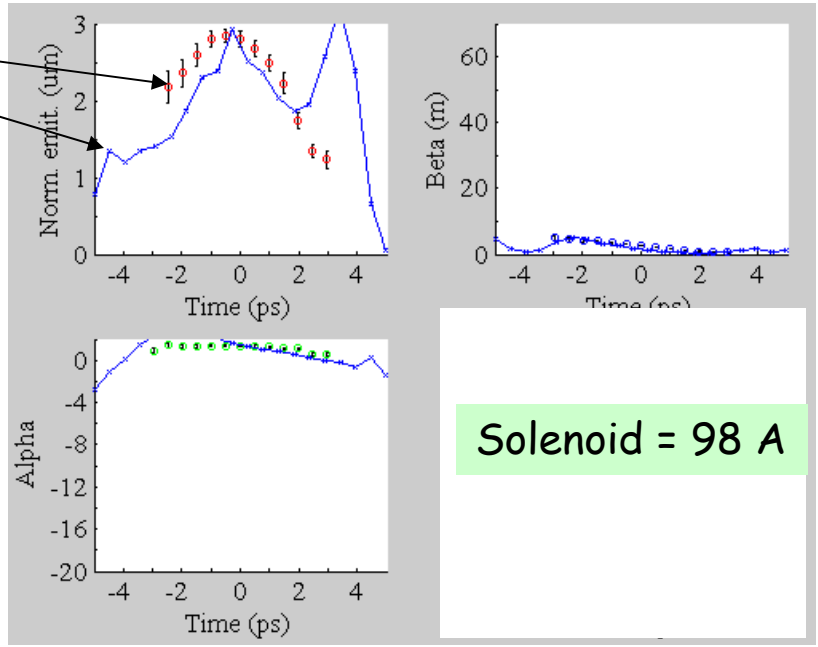
The accelerator system should be very well characterized to derive from such a comparison a conclusion on the code accuracy!

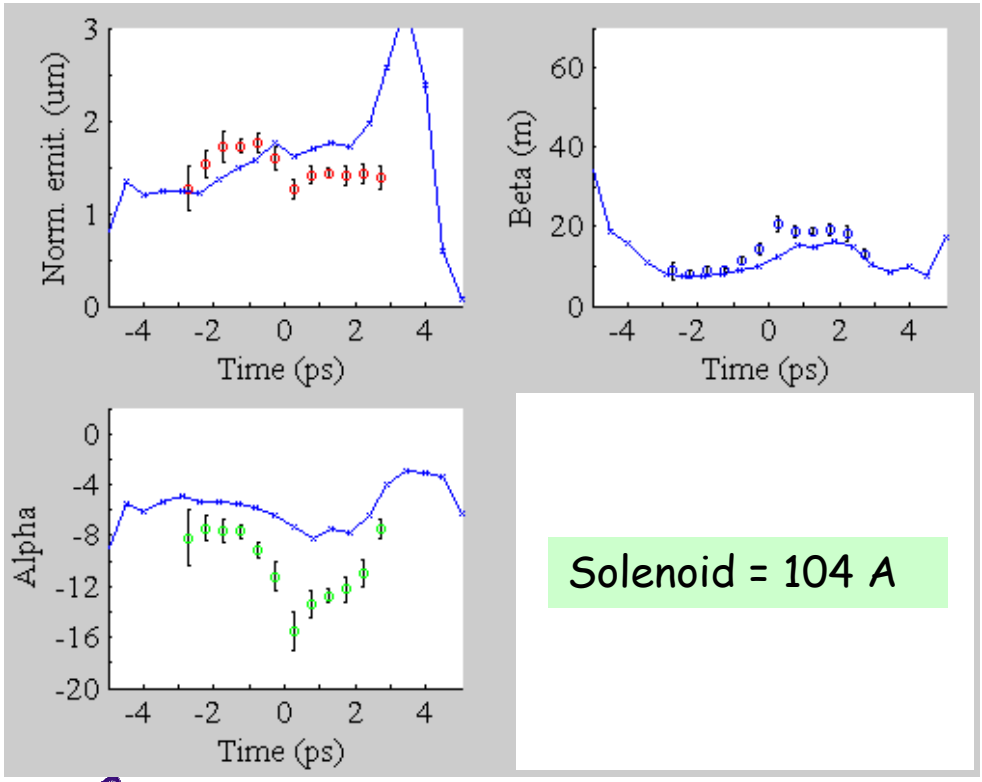
Example 1: JLab FEL. The whole system is modeled, though some parameters are not known accurately.

Example 2: PITZ (DESY-Zeuthen). The PI system only is modeled; the parameters are believed to be characterized rather accurately – good for the code comparison. See http://www-zeuthen.desy.de/~kras/PITZProblem.html /PITZbenchmark.html

Parmela results versus DUVFEL measurements (experiment Spring 02):

Good match of slice emittance and Twiss parameters, while performing a solenoid scan around operating point (typically simulating for 20k particles).





Difficulties in simulations:
- irregular laser longitudinal profile
- cathode: emission hot spot
- thermal emittance
- 3D? – small effects

Courtesy of C. Limborg-Deprey, SLAC (5/10/06)

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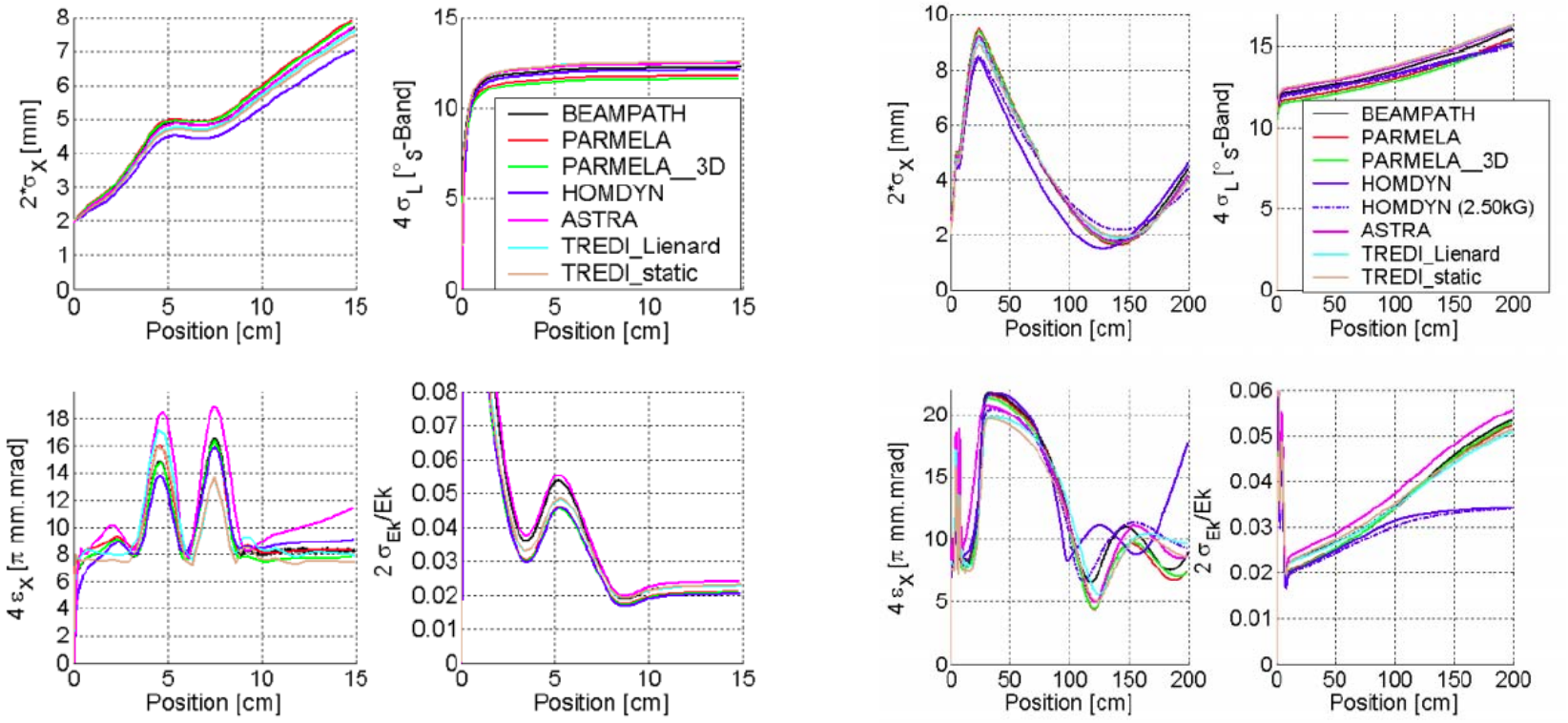
PARMELA Validation: Code Comparison

Test problem 1: S-Band 1.5-cell RF Gun (110 MV/m, 1nC, 10ps) + solenoid

C. Limborg et al. PAC03, p.3548.

Codes: HOMDYN, BEAMPATH, PARMELA-SCHEFF/SPCH3D, ASTRA, TREDI.



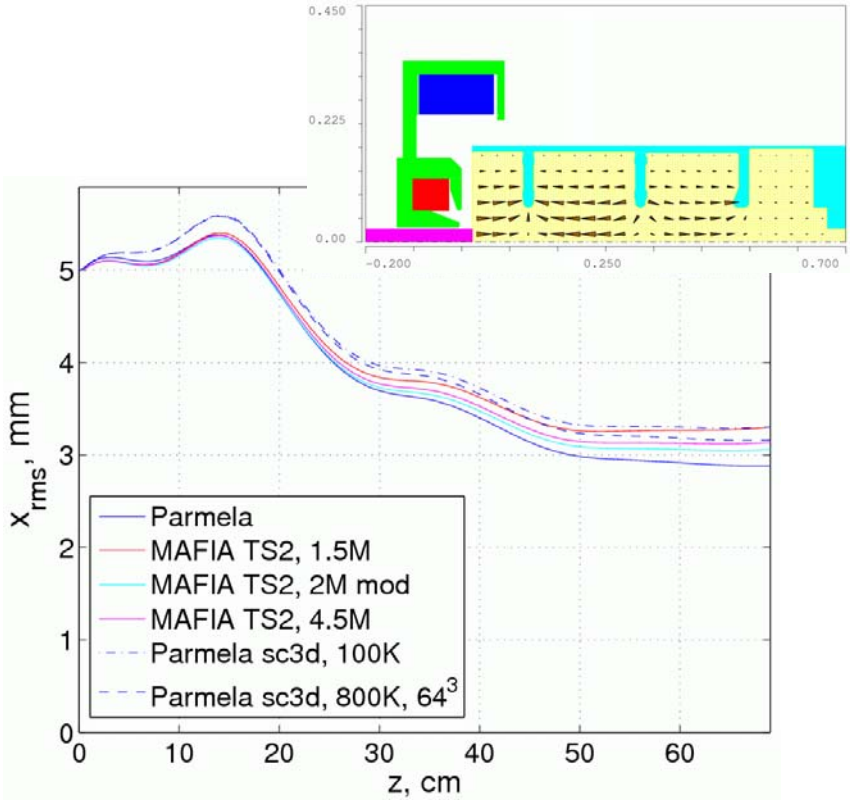
In general, good agreement between different codes.

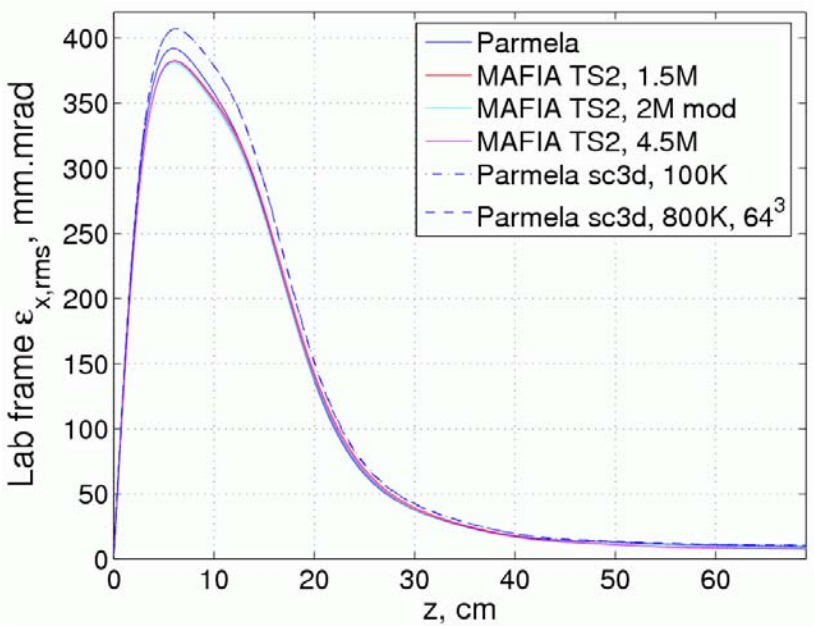
Parmela is often used to benchmark other codes.

PARMELA Validation: Code Comparison

Test problem 2: 700-MHz 2.5-cell NC PI (10 MV/m, 3nC, 10ps) + solenoids

S. Kurennoy. FEL04, p. 534. Codes: PARMELA, MAFIA.



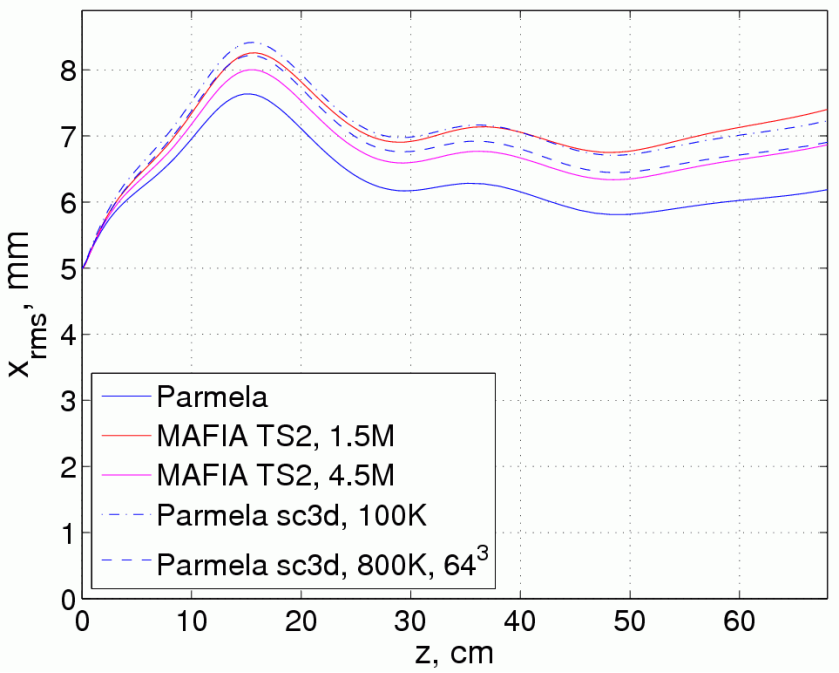


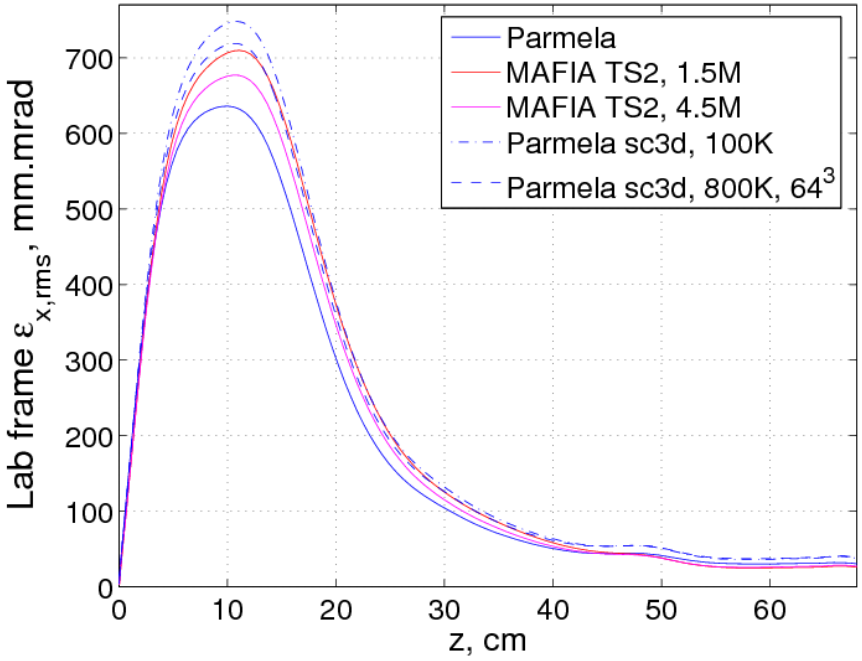
MAFIA TS2 and Parmela results for 3-nC bunch charge.

MAFIA results include wake effects.

PARMELA Validation: Code Comparison

Test problem 2: 700-MHz 2.5-cell NC PI (10 MV/m, 3 → 10 nC, 10ps)
S. Kurennoy. FEL04, p. 534. Codes: PARMELA, MAFIA.





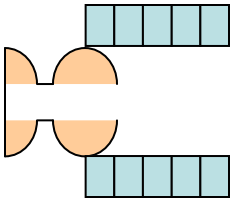
MAFIA TS2 and Parmela results for 10-nC bunch charge.
Wake effects (MAFIA) are small even for 10 nC per bunch.

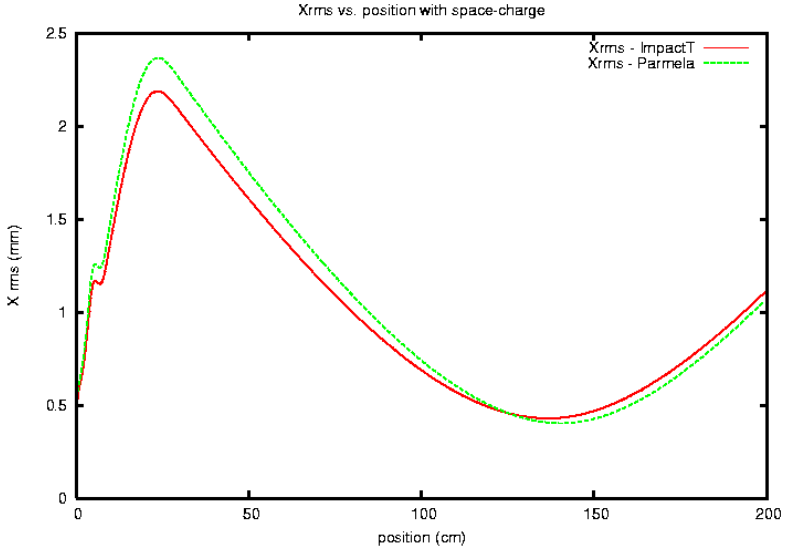
PARMELA Validation: Code Comparison

Test problem 3: LCLS PI (120 MV/m, 1nC, 10ps) + solenoid + drift.

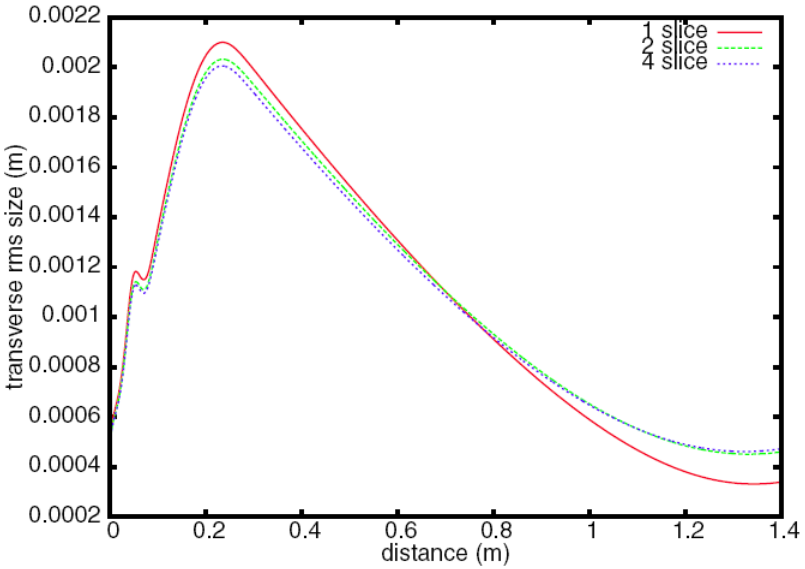
J. Qiang et al. PAC05, 3316; also *PRSTAB **9**, 044204 (2006).*

Codes: PARMELA/SPCH3D, IMPACT-T.





IMPACT-T



Energy spread: use energy slices!

Shifted Green functions for Sp.Ch. – works for large bunch aspect ratios.

PARMELA Weaknesses

- Documentation. Not all features documented (e.g., CSR).
- Single Lorentz transform for space-charge computation: bunch energy spread is ignored. Can be important for high-gradient / long-pulse photoinjectors. Possible improvement – implementation of energy slices (bins) as in IMPACT-T.
- Large bunch aspect ratios can lead to accuracy loss. Standard space-charge routine SCHEFF is 2-D (<1:2), SPCH3D works accurately for aspect ratios up to 1:4.
- Longitudinal mesh adjustments? Can loose accuracy in bunch compressors where the bunch length changes fast.
- Integrator for long runs can loose accuracy unless the phase step is reduced. Test on an exactly solvable problem (*J. Lewellen*).
- CSR 1-D model is not always adequate.
- Wake effects can not be included in photoinjectors due to large changes of beam velocity and bunch shape.
- The code does not provide a thorough check for input consistency.
- Output format changed from earlier versions. Standard?

PARMELA : Summary

- Good tool for both normal and super conducting photoinjectors.
- Likely most widely tested code of this kind. Extensive comparison with measurements; often a benchmark for other codes.
- For photoinjector (PI) design the current Parmela (v3.40) is accurate and reliable provided that:
  - PI layout is close to axisymmetric one (cavity fields, laser spot, etc);
  - PI has a moderate field gradient (~10-30 MV/m) on the cathode;
  - Pulse length is not very long.
- Modifications (e.g., "energy bins") can remove some of these limitations.
- In general, Parmela "does a pretty good job if one puts in the correct information about the accelerator" (*L. Young*). Unfortunately, "Parmela does not do very much checking on what is physically consistent in the input." Some work is still left for the designers…
- Other codes: ASTRA (DESY), IMPACT-T (LBNL): 3-D+(…), etc.