ICOOL: simulation code for neutrino factory and muon collider front end design

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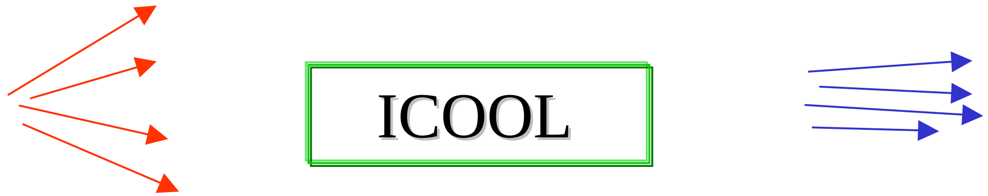
MC Cooling Simulation History

- begin looking at possibility of muon collider (1994)
- early cooling simulations
  - rms equations and other private coding
  - SIMUCOOL
  - MCM
  - PARMELA’
- start work on ICOOL (~Spring 1996)
- FNAL meeting on cooling software (Oct. 1997)
  - consolidation of coding effort (common libraries and file formats)
  - continue development of generic ICOOL
  - push development of DPGeant

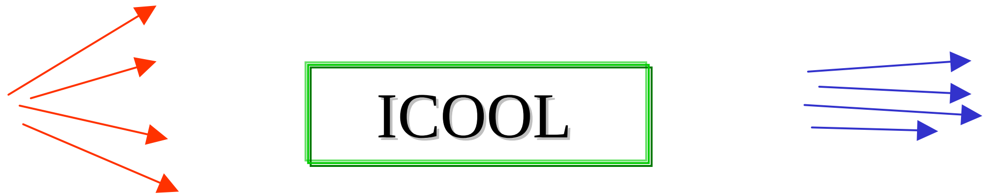


Design Philosophy

- adopt the best features of existing codes
- try to write clean, structured, modular code from scratch
- define problem in terms of ASCII input data files
  - avoid code patches
- break problem into sequence of TRANSPORT-like regions
- use accurate models of particle interactions
  - adapt code from Geant v3.21
- provide flexible field description
- make code portable across MC collaboration
  - generic F77, character graphics
- provide hooks for user pre- and post- processing

Program features

- single particle, 3-D tracking in materials and electromagnetic fields
- moment equations for straight regions (optional)
- uses reference orbit coordinate system
- includes physics processes appropriate to <1 GeV muons
- systems described as sequence of longitudinal regions
- “pseudoregions” can be inserted for special tasks
- region looping commands for repetitive systems
- automatic initialization of rf cavity phases
- numerous built-in diagnostics



Command file structure

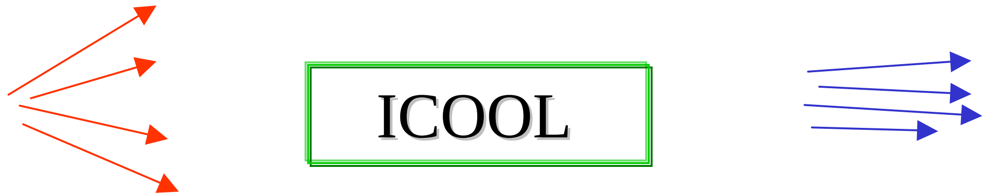
- simulation control variables
- beam definition
- physics interactions
- diagnostics
- region definition

Particle Generation

- gaussian or uniform initial distributions
- uses electrons, muons, pions, kaons and protons
- can impose correlations on initial beam, e.g.
  - angular momentum in solenoid
  - forward velocity vs. transverse amplitude
  - rf bucket
  - Twiss parameters
- or read in an external beam file

Interactions

- appropriate for 50-1000 MeV/c muons in matter
- continuous processes
  - energy loss (e.g. Bethe-Bloch)
  - straggling (e.g. gaussian, Vavilov)
  - multiple scattering (e.g. gaussian, Moliere)
- discrete processes
  - decay   (can continue tracking charged decay product)
  - delta rays (correlated scattering – energy loss)
  - pion absorption
- space charge guesstimate



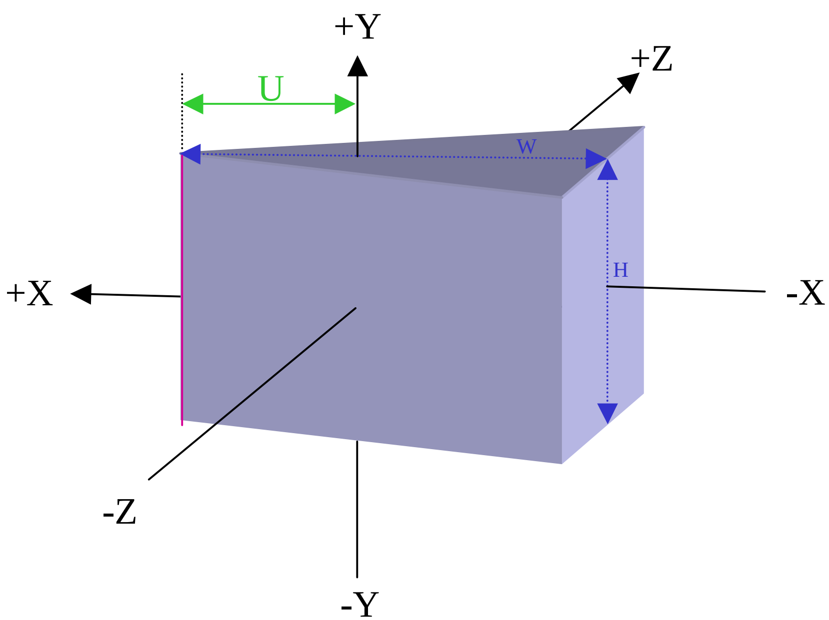
Space charge

- loop order allows crude estimate of space charge
  - outer loop on regions
  - inner loop on particles
- ICOOL is not a PIC code !
- algorithm
  - at start and end of region only
  - transform time -> space distribution
  - get space charge of bunch on each particle
  - kick particle momentum vector

Tracking

- accelerator coordinates are used in regions containing a dipole field
- the independent variable in the equations of motion is *ds*
- the dependent variables are the transverse positions, momentum, and the polarization
- exact differential equation used (no transverse expansion)
- curvature can be followed in both transverse planes
- particle stepping can be done using fixed steps or by using an adaptive stepsize algorithm
- particle stepping is done using fourth-order Runge-Kutta integration
- not symplectic

Geometry description



- generic region is a cylinder
  - fixed length along reference orbit
  - can be subdivided into 4 radial parts
  - particles can pass back and forth
- no limit to number of regions
- wedge geometry
  - used to reduce momentum spread in dispersive regions
  - can have flat or polynomial shaped surface

Field description

- very flexible
- field at a point comes from superposition of
  - region field
  - cell field
  - background field
- fields can be described by
  - predefined analytic models (hard and soft edge)
  - r - ø grid from sum of coils or cylindrical current sheets
  - on-axis fields or multipoles
  - user-supplied grid

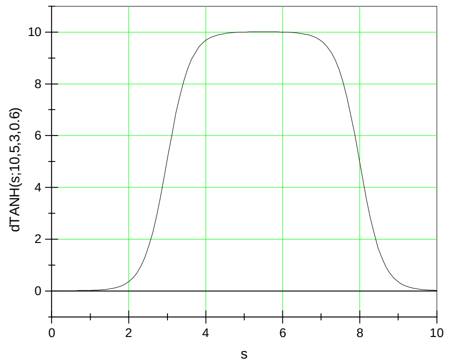
Electromagnetic field models

- Bent solenoid (4)
- Annular current loop, sheet and blocks (11)
- Kickers (4)
- Sector dipole (4)
- Alternating solenoid lattice (2)
- Accelerator (12)
- Quadrupole, sextupole, other multipoles (8)
- Current carrying rod, horn (7)
- Helical (7)
- Straight solenoid (7)

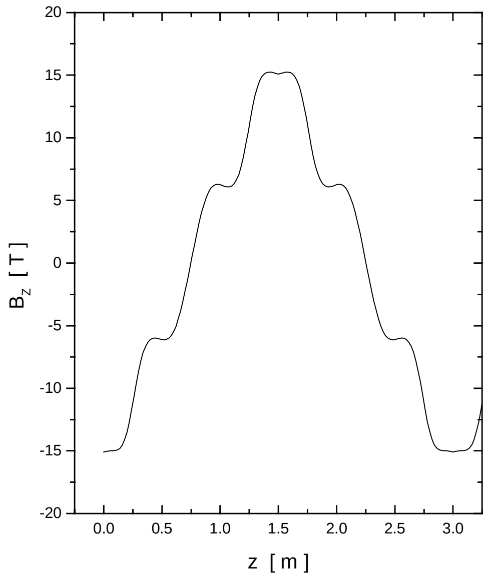
dTANH field model

- used to describe varying longitudinal fields and end fields
- can be differentiated as many times as needed for higher order field expansions
- can add fringe fields from neighbor regions

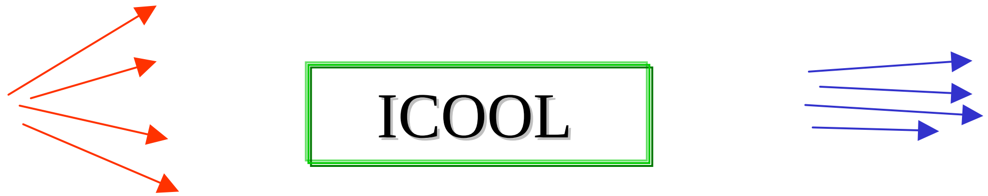
$$f(s;B,C,E,\lambda) = B/2\ [\ \tanh((s-E)/\ \lambda) - \tanh((s-C-E)/\ \lambda)]$$



Coil and sheet model



- used to describe longitudinally varying solenoid lattices
- cylindrically symmetric
- fields from analytic solutions using elliptic integrals
- can interpolate field from grid



Off-axis field expansions

- must supply on-axis fields

  table of field components

  Fourier coefficients
- uses Maxwell equations for off-axis values
- up tp 5^{th} order expansions available

Example: 1^{st} order expansion in curved region

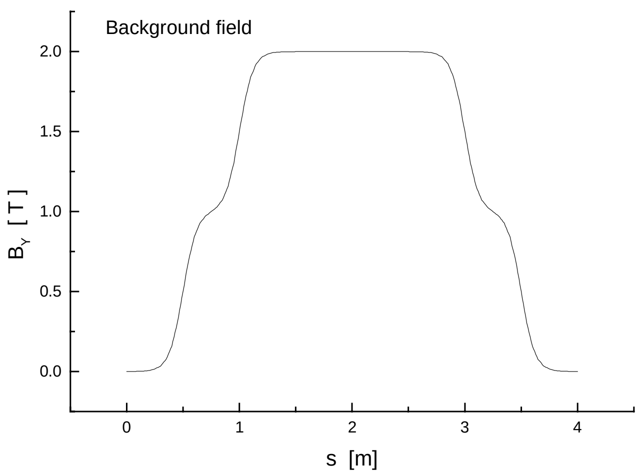
$$B_X(s) = a_0(s) + (a_1(s)-b_S'(s)/2)\ x + b_1(s)\ y$$

$$B_Y(s) = b_0(s) + b_1(s)\ x + t_{02}(s)\ y$$

$$B_S(s) = (b_S(s) + a_0'(s)\ x + b_0'(s)\ y\ )\ /\ (\ 1 + h(s)\ x + g(s)\ y)$$

$$t_{02}(s) = -a_1(s) + b_S'(s)/2 - h(s)\ a_0(s) - g(s)\ b_0(s)$$

Background fields

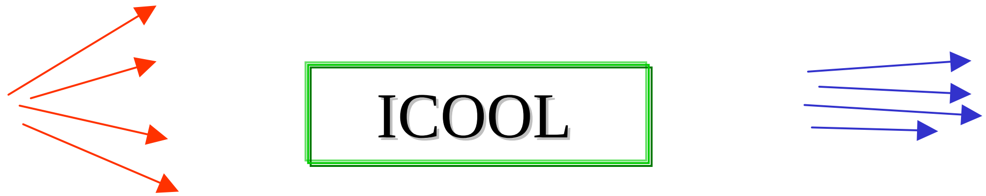


- can construct from combinations of built-in fields
- field built up on 3D grid
- uses special psuedocommands
  - BACKGROUND
  - BFIELD
  - ENDB
- can use special type STUS

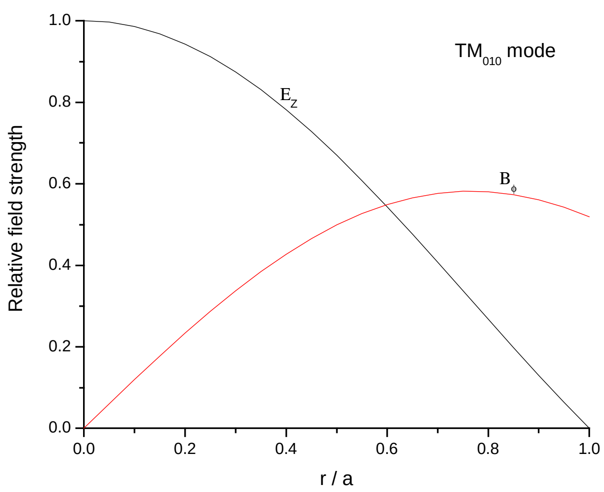
  e.g. error fields

RF fields

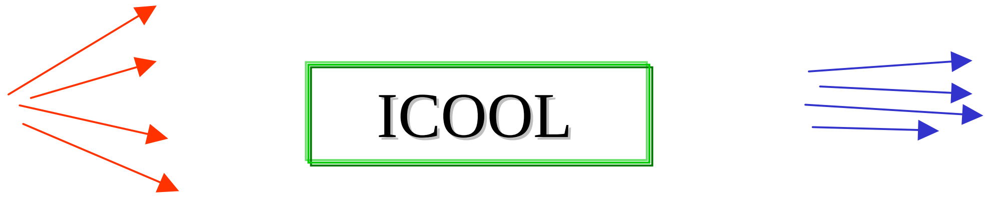
- acceleration and deflection fields, e.g.
    - pillbox and traveling wave cavities
    - induction linac
    - kickers
- uses reference particle to preset cavity phases, e.g.
    - model 3: constant velocity
    - model 4: takes energy gain and loss into account
- can apply additional phase shifts, if desired



Pillbox cavity



- cylinder
- TM_{010} mode
- fields independent of z
- vary sinusoidally with time
- **E** and **B** 90^{o} out of phase

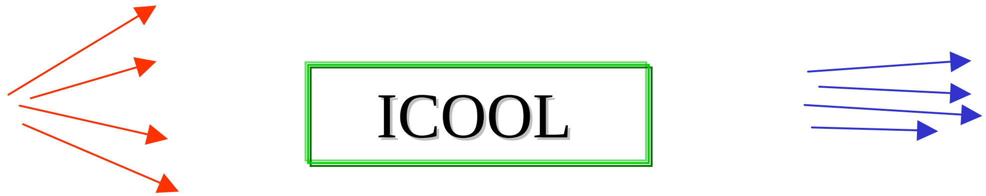


Region definition

- region commands describe a longitudinal section
  - region field
  - material
  - geometry
- uses 16 pre-defined materials
- uses 8 pre-defined geometry types
- pseudoregion commands accomplish tasks at given location
  - e.g. generate output, rotate coordinates, impose transport matrix, etc.

Loop structures

• 3 types of nested loop structures: REPEAT, CELL, SECTION
• groups of commands can be repeated with REPEAT structures
    e.g. RF cavities
• groups of REPEAT structures and individual regions can combined in CELL structures
    can be repeated as often as desired
    has associated CELL field superimposed on the region fields
    has ability to alternate polarity
    e.g. periodic cells in machine lattice
• groups of REPEATS and CELLS can be combined in SECTION structures
    e.g. multiple turns in a ring



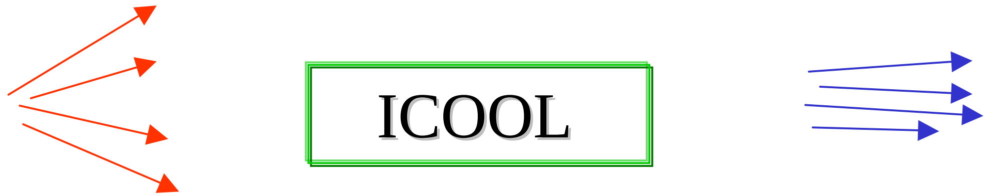
Diagnostics

- many levels of print out
- region summary table
- histograms
- scatter plots
- variable as function of z (Z-history)
- mean, standard deviation at end of regions (R-history)
- emittances, polarization, covariance matrices
- particle and field information files for post-processing

ICOOL

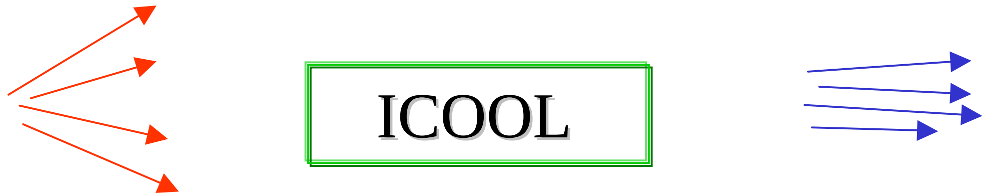
******************** REGION SUMMARY ********************

IZ	IS	IC	CTAG	BTAG	SLEN	ZLO	ZHI	IR	FTAG	MTAG	MGEOM
1			PRODUCTION								
2			REF PARTICLE								
			BEGIN SECTION LOOPING								
			CELLS = 12								
3	1	1	BSOL	NONE	0.30000E+00	0.00000E+00	0.30000E+00	1	NONE	LH	WEDGE
4	1	1	BSOL	NONE	0.85000E-01	0.30000E+00	0.38500E+00	1	NONE	VAC	CBLOCK
5	1	1	BSOL	NONE	0.33000E+00	0.38500E+00	0.71500E+00	1	ACCE	VAC	NONE
6	1	1	BSOL	NONE	0.33000E+00	0.71500E+00	0.10450E+01	1	ACCE	VAC	NONE
7	1	1	BSOL	NONE	0.33000E+00	0.10450E+01	0.13750E+01	1	ACCE	VAC	NONE
8	1	1	BSOL	NONE	0.33000E+00	0.13750E+01	0.17050E+01	1	ACCE	VAC	NONE
9	1	1	BSOL	NONE	0.33000E+00	0.17050E+01	0.20350E+01	1	ACCE	VAC	NONE
10	1	1	BSOL	NONE	0.33000E+00	0.20350E+01	0.23650E+01	1	ACCE	VAC	NONE
11	1	1	BSOL	NONE	0.85000E-01	0.23650E+01	0.24500E+01	1	NONE	VAC	CBLOCK
12			OUTPUT								
13	1	1	BSOL	NONE	0.30000E+00	0.24500E+01	0.27500E+01	1	NONE	LH	WEDGE



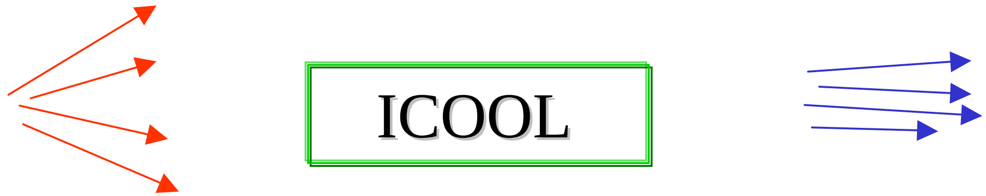
Input files

for001.dat	problem commands
for003.dat	beam data (optional)
for0xx.dat	optional input data, e.g.
	coil or current sheets specs
	induction linac pulse
	cavity phases
	field grid



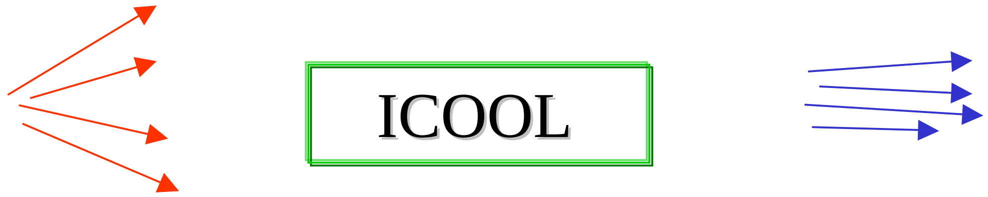
Output files

for002.dat	log file
for004.dat	beam output data at fixed s; enables restart (optional)
for009.dat	particle and field data; for postprocessing (optional)
for0xx.dat	optional diagnostic data, e.g. field grids rf diagnostics



Web distribution

- Go to MC home page (http://www.cap.bnl.gov/mumu/)
- Source code (Fortran 77)
- Windows executable
- Manual
- Descriptive files and tutorials
- Utility programs
- Example problems with output

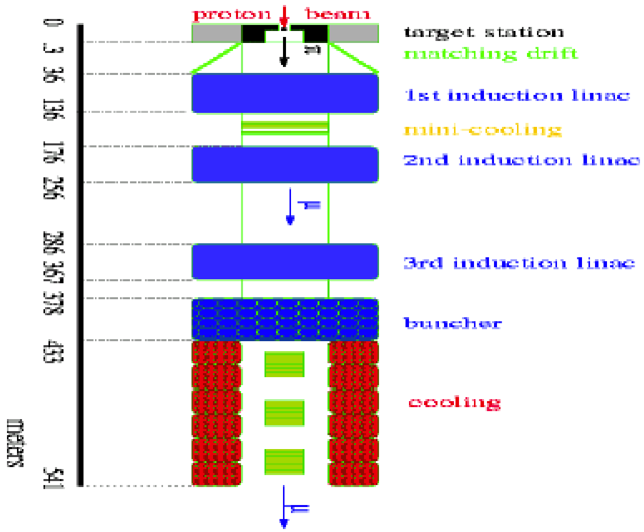


Other related codes

- preprocessors
  - NIME (W. Fawley)
  - XICOOL (S. Bracker)
  - GEN, SHEET (R. Palmer)
- postprocessors
  - user specific (many)
  - ECALC9 (G. Penn)
- optimizers
  - OPTICOOL, OPTICOSP (S. Bracker)
  - MINCOOL (R. Palmer)

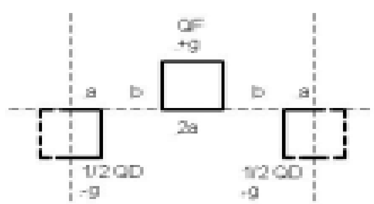
ICOOL

Schematic of the Front End



- ICOOL has been used for very complicated simulations
- Study 2 of U.S. neutrino factory
  - 1466 regions
  - 5000 initial pions
  - 7.5 hours on 500 MHz PC

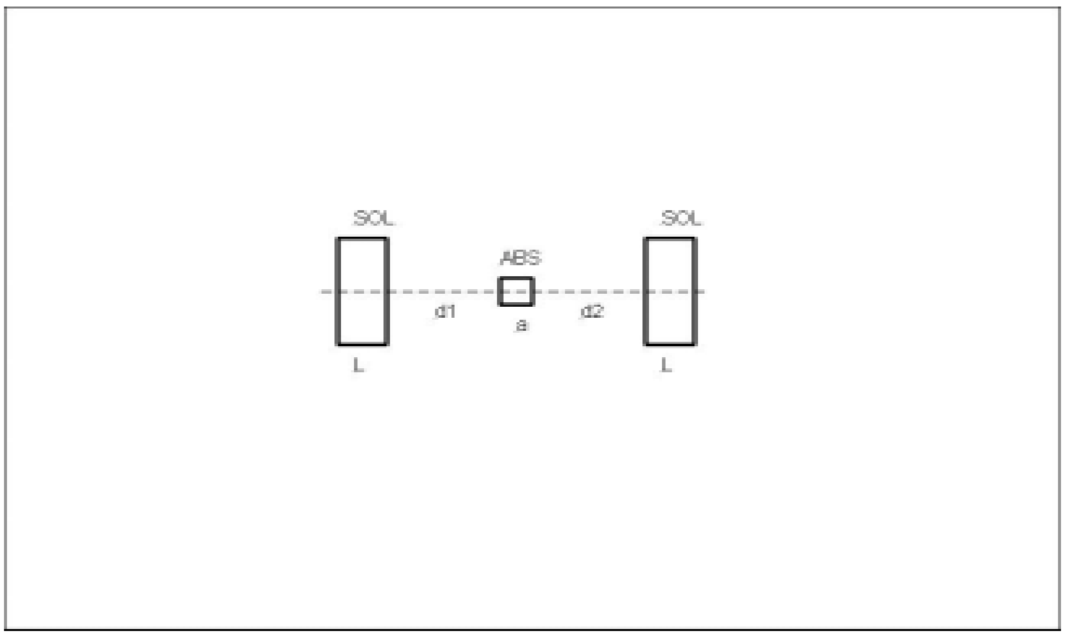
Example 1: Hard-edge FODO channel



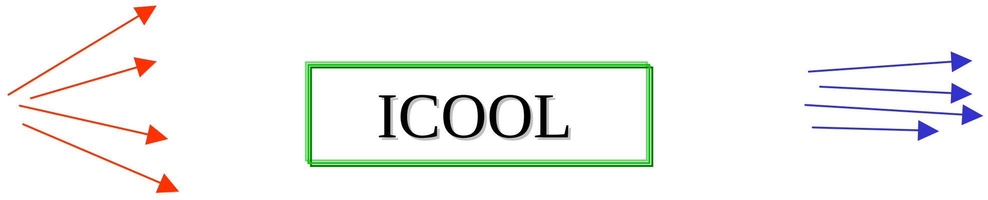
- basic deck structure
- Gaussian beam
- REPEAT
- print out
- correlations
- R-history

Example files can be found at
http://pubweb.bnl.gov/people/fernow/for/nufact03/school

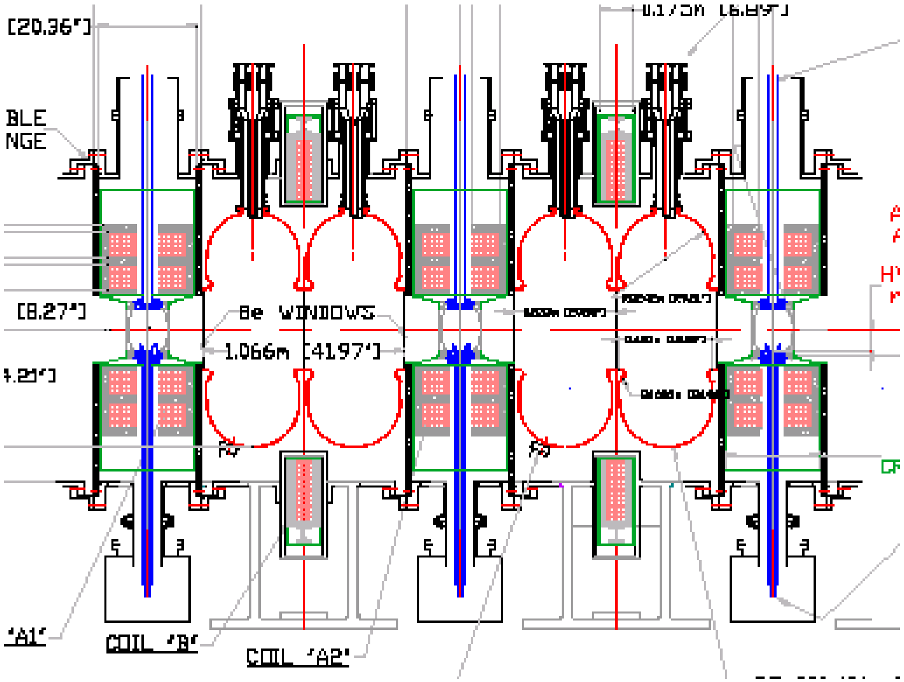
Example 2: Solenoid focus into absorber



- material
- uniform beam
- histograms
- scatterplots
- Z-history

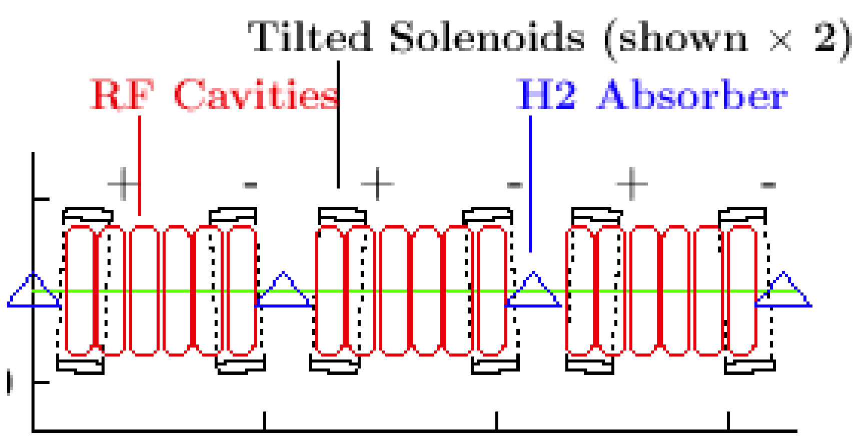


Example 3: FS2 (2,1) cooling channel



- reference particle
- CELL
- ext. beam file
- sheet file
- emittance

Example 4: RFOFO cooling ring



- NSECTIONS
- wedges
- postprocessor file
- multipole file