Welcome to SAD2006

Why SAD?

Since 1986
SAD
Strategic Accelerator Design

Sept. 6, 2006
K. Oide (KEK) @ SAD2006

Pros...

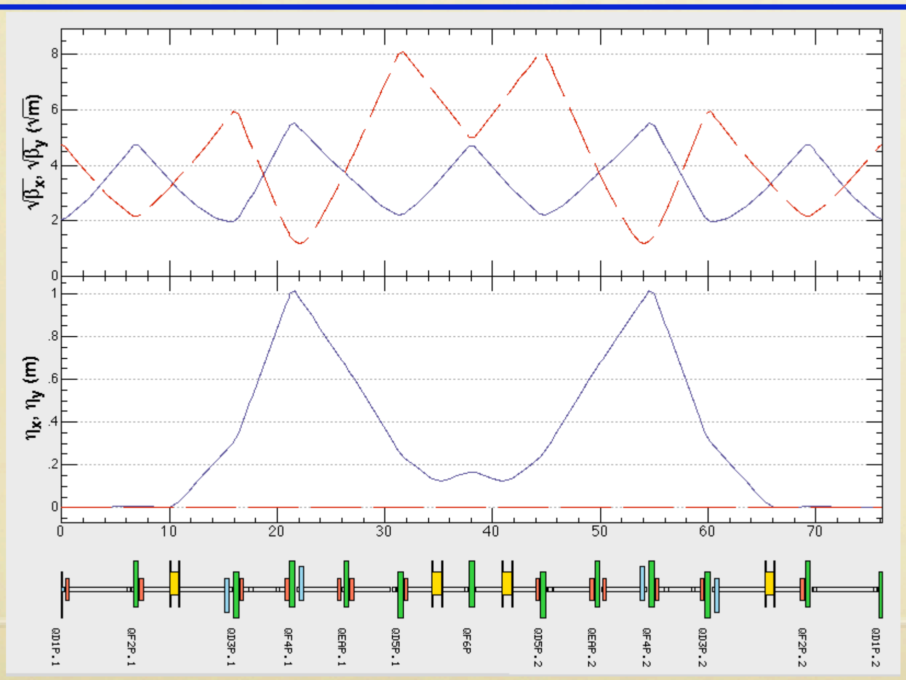
There are tens of computer codes for accelerator design and beam dynamics, but SAD still may have merits which are not overtaken by others yet.

Quick and versatile optics matching	•Any function, any variable: orbit, Twiss, coupling, geometry, emittance, etc., and their functions. •Any interrelation between variables. •More practical, less academic: off-momentum matching, finite-amplitude matching. •Fast and fuzzy:
Unique physics	•Envelope method: radiation, intrabeam, space charge. •Details matter: Fringe field and tiny nonlinearities. •Special methods: Heaviside-Feynman, anomalous emittamce, etc.
Scriptable	•SADScript: *Mathematica*-like language +α. •Class: Object-oriented programming. •Callable from tracking, matching, etc.
Unification of accelerator model and machine control	•EPICS interface. •TclTk GUI: Tkinter and KBFrame. •Seamless and complete description of: design, simulation, control, measurement, and correction.

Matching

```
Get["/ldata/KEKB/KCG/SAD/KEKBOptics.n"];
ler=LEROptics[];
Design orbit length =  3016.2426
 ler@Choose["NormalCell"];
Design orbit length =  76.1482258

FitFunction:=
  Module[{e=Emittance[]},
    {(Emittances/.e)[[1]]-12e-9,(MomentumCompaction/.e)-2e-4}*{1e9,1e4}
  ];

free qf2p qd3p qeap go;
   2    1   3.172       (NEWTON)  -0.1268
   3    1  1.7507E-02   (NEWTON)  -5.5193E-03
   4    1  6.7987E-07   (NEWTON)  -3.8835E-05
Matched. ( 6.8743E-16) DP = 0.02500  DP0 = 0.00000  ExponentOfResidual = 2.0
OffMomentumWeight =     1.000
$$$        f AX    #######  #  -1.33E-15 $$$       f BX     #######  #   4.160830
$$$        f NX    #######  #   1.324966 $$$       f AY     #######  #  3.894E-14
$$$        f BY    #######  #  22.410891 $$$       f NY     #######  #   1.360161
$$$        f LENG  #######  #  76.148226 $$$       f FUN1  0.0       1  2.5417E-8
$$$        f FUN2  0.0      1  -6.433E-9
```

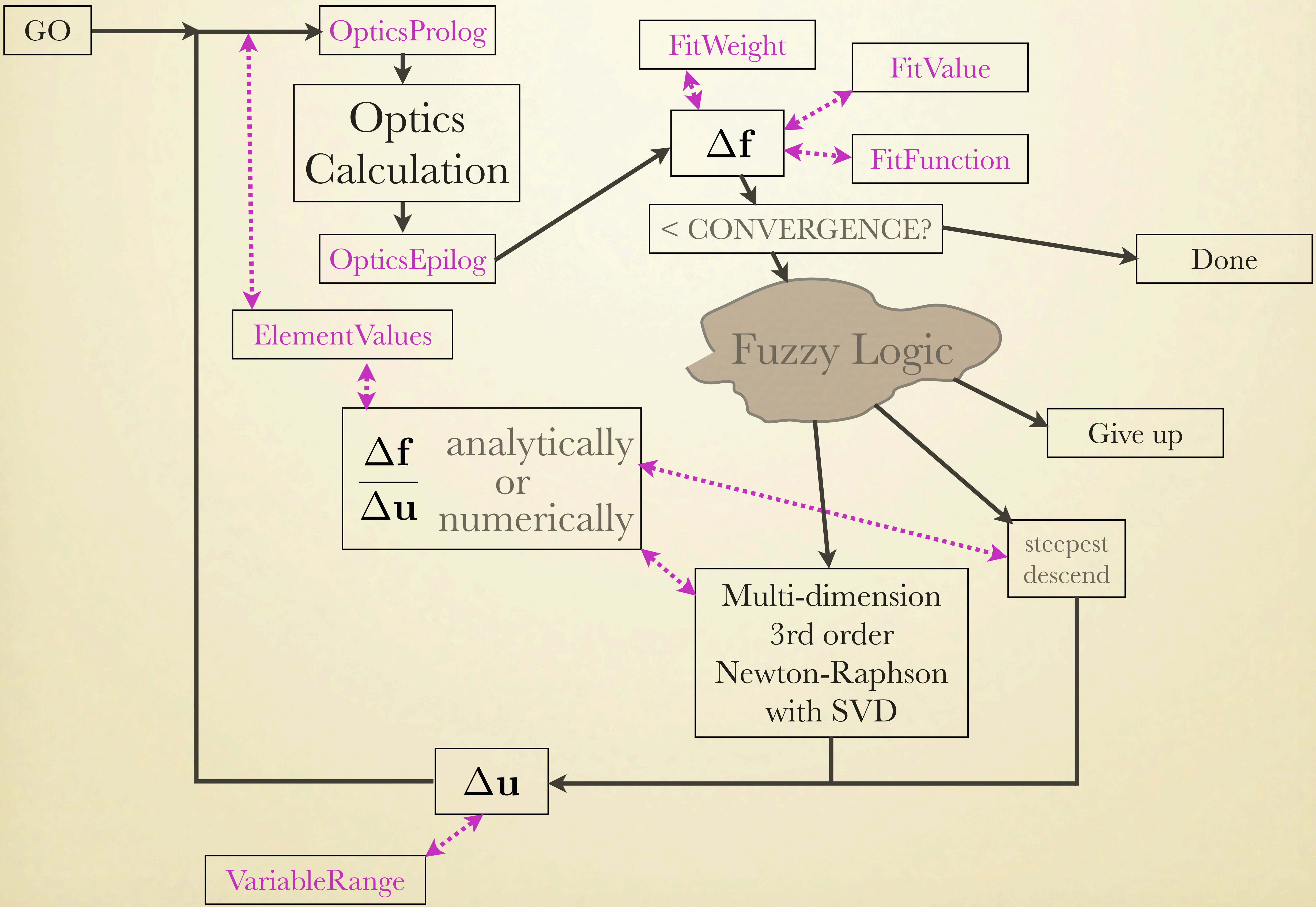
Match Emittance and Momentum Compaction, by FitFunction.



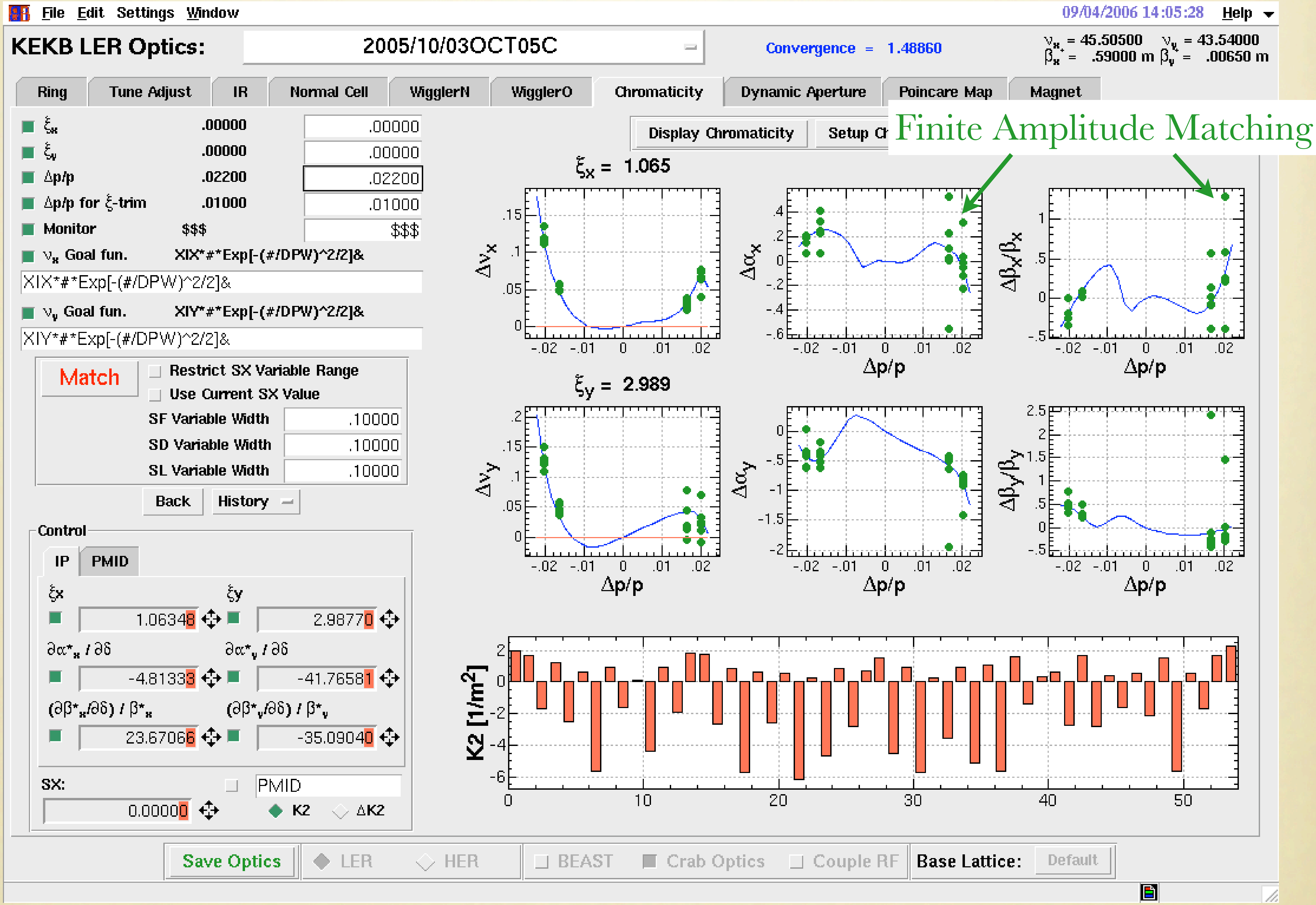

```
 emit

    Closed orbit:
                 x      px/p0         y      py/p0         z       dp/p0
  Entrance :  .000000   .000000   .000000   .000000   .000000   .000000
      Exit :  6.60E-18  1.26E-18  .000000   .000000   -1.1E-19  .000000

    Extended Twiss Parameters:
AX: 6.30E-16 BX: 4.160830                            ZX: 9.41E-20  EX:  .002710
           PSIX: 3.73E-17                           ZPX: -5.5E-19 EPX: -1.9E-17
R1:  .000000 R2:  .000000 AY: -2.3E-15 BY: 22.41089  ZY:  .000000  EY:  .000000
R3:  .000000 R4:  .000000                PSIY:  .000000 ZPY:  .000000 EPY:  .000000
                                                      AZ: -1.1E-35  BZ: 1.000000
                                                                 PSIZ: 1.11E-35
    Units: B(X,Y,Z), E(X,Y), R2: m | PSI(X,Y,Z): radian | ZP(X,Y), R3: 1/m

Design momentum      P0 = 3.5000000 GeV Revolution freq.     f0 = 3936959.1 Hz
Energy loss per turn U0 =  .0271244 MV  Effective voltage    Vc =  .0000000 MV
Equilibrium position dz =  .0000000 mm  Momentum compact. alpha = 2.0000E-4
Orbit dilation       dl =  .0000000 mm  Effective harmonic #  h =  .0000000
Bucket height     dV/P0 =  .0000000

  Imag.tune: 0.0000000          0.0000000          0.0000000
  Real tune: 0.3249656          0.3601606          0.0000000

    Damping per one revolution:
          X : -3.874767E-06    Y : -3.874886E-06    Z : -7.749895E-06
    Damping time (sec):
          X :  6.555315E-02    Y :  6.555112E-02    Z :  3.277505E-02
    Tune shift due to radiation:
          X :  4.730529E-13    Y : -1.015566E-13    Z :  9.392409E-09

    Damping partition number:
          X :    1.0000        Y :    1.0000        Z :    2.0000

Emittance X           = 1.20000E-8 m  Emittance Y           =  .00000000 m
Emittance Z           =  .00000000 m  Energy spread         = 7.33235E-4
Bunch Length          =  .00000000 mm Beam tilt             =  .00000000 rad
Beam size xi          =  .22345896 mm Beam size eta         =  .00000000 mm
```

Successfully matched.

Matching Procedure



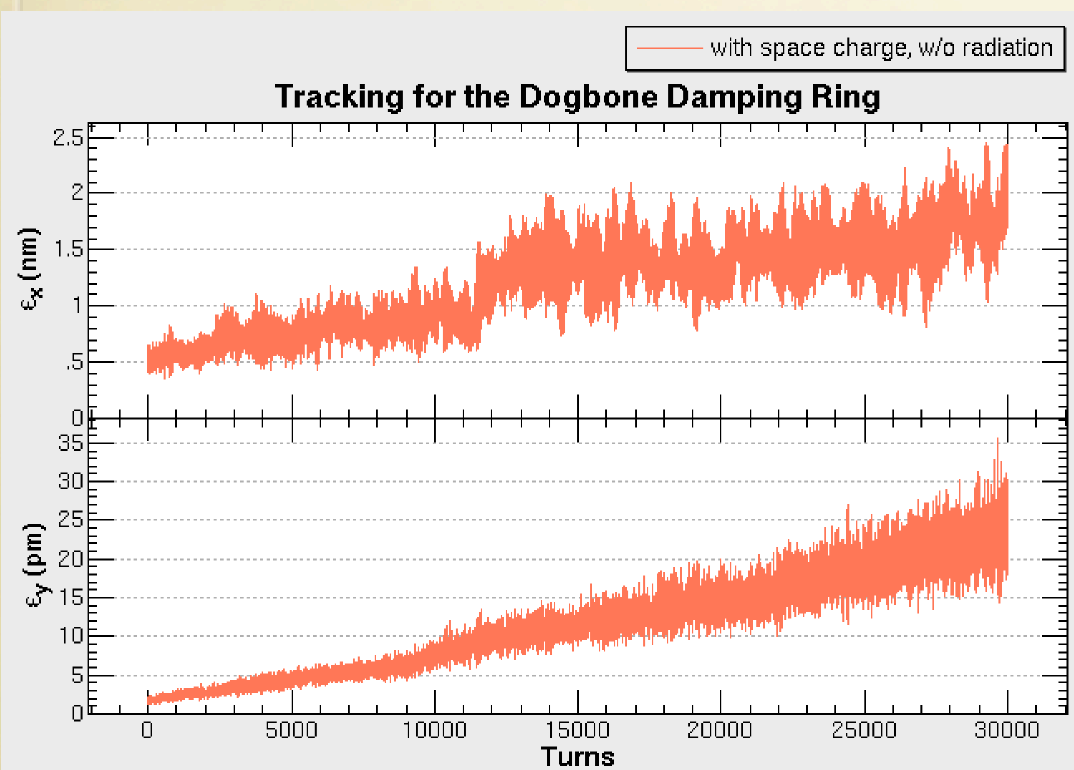
Off-momentum matching



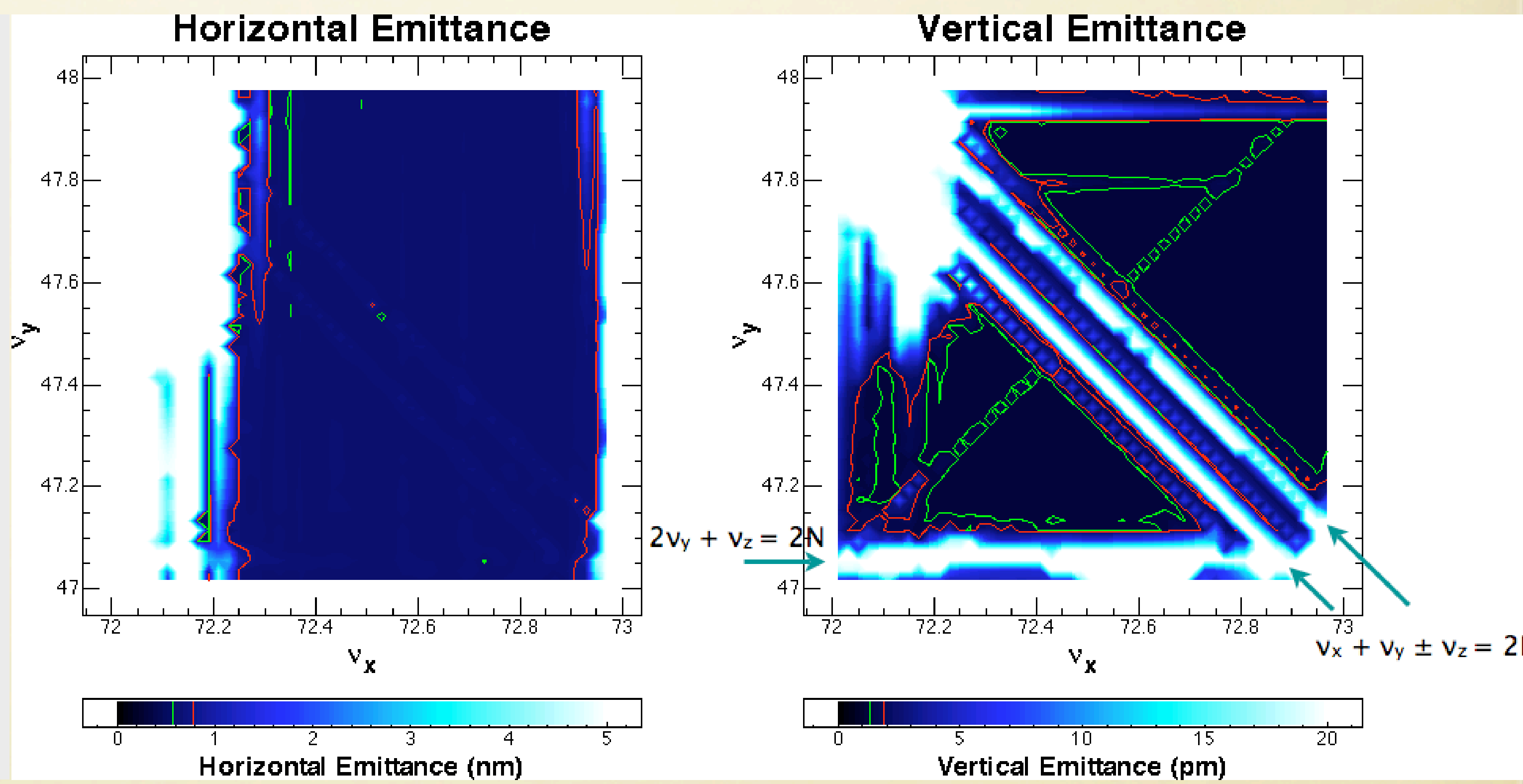
Often more powerful than Taylor expansion!

Space Charge in a Ring

- Strong-weak model, Gaussian distribution
- Equilibrium envelope/emittance calculation with space charge, radiation, intrabeam scattering.



Diffusion process



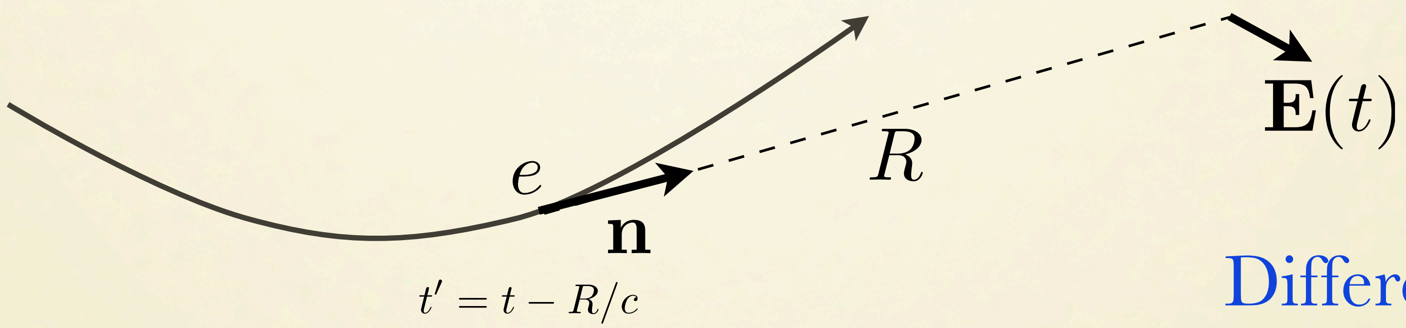
Tune survey

(ILC-DR)

Radiation

- Field of a moving charge(Lienard-Wiechert potential): $A_\mu = \frac{e}{4\pi\varepsilon_0 c}\frac{u_\mu}{u_\nu R_\nu}$

$$\varphi = \frac{e}{4\pi\varepsilon_0}\left(\frac{1-\frac{1}{c}\frac{\partial R}{\partial t}}{R}\right)_{t'=t-R/c}, \quad \mathbf{A} = -\frac{e}{4\pi\varepsilon_0 c^2}\left(\frac{1}{R}\frac{\partial \mathbf{n}R}{\partial t}\right)_{t'=t-R/c}$$



Differentiate by the time at the observation point.

- Electromagnetic field (Heaviside-Feynman):

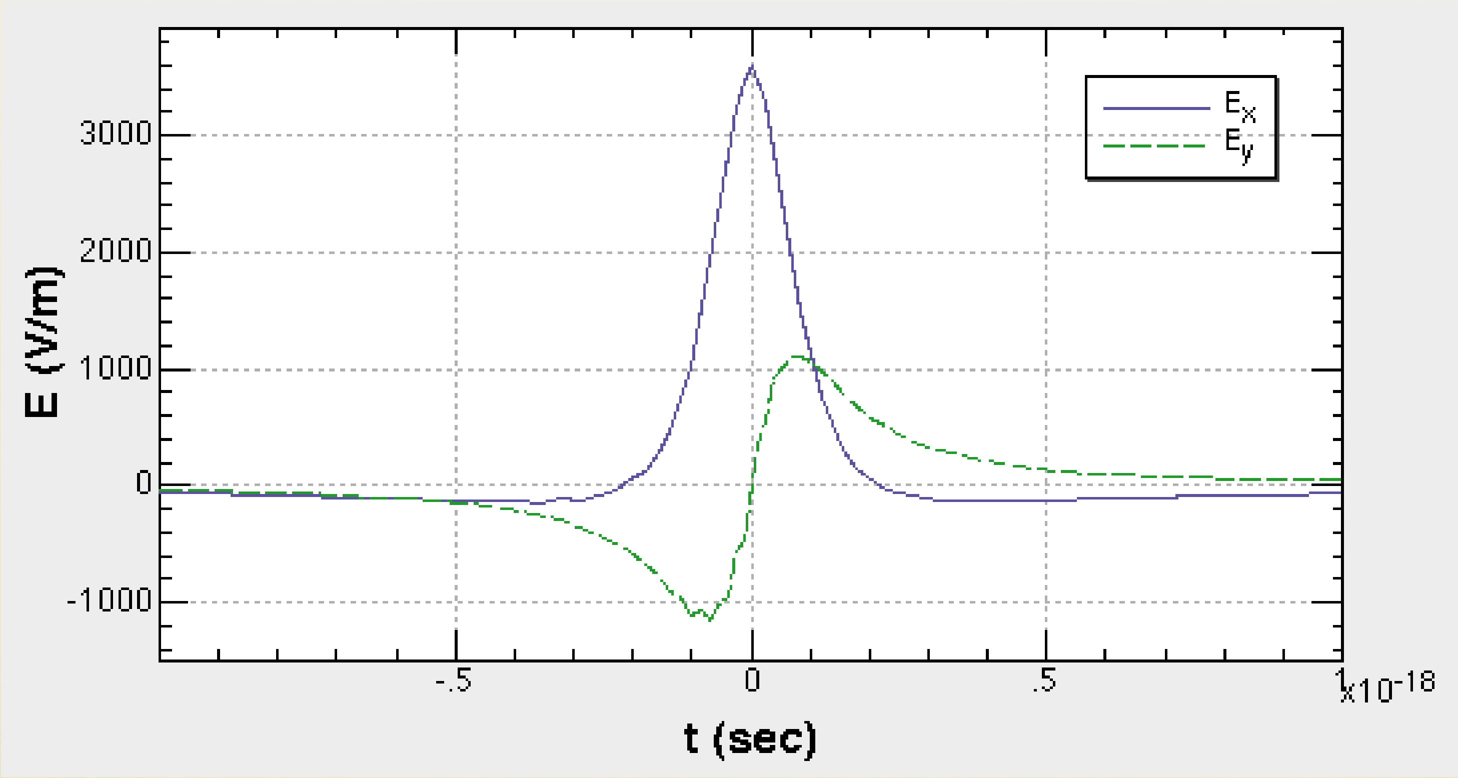
$$\mathbf{E}(t) = -\nabla\varphi - \frac{\partial \mathbf{A}}{\partial t} = \frac{e}{4\pi\varepsilon_0}\left[\frac{\mathbf{n}}{R^2} + \frac{R}{c}\frac{\partial}{\partial t}\left(\frac{\mathbf{n}}{R^2}\right) + \frac{1}{c^2}\frac{\partial^2 \mathbf{n}}{\partial t^2}\right]_{t'=t-R/c},$$

$$\mathbf{B}(t) = \nabla\times\mathbf{A} = \frac{1}{c}\left(\mathbf{n}\times\mathbf{E}\right)_{t'=t-R/c}$$

$$\frac{\partial t'}{\partial t} = 1 - \frac{1}{c}\frac{\partial R}{\partial t}, \text{ etc.}$$

Radiation

- Determine trajectory by tracking with TrackParticles and RADLIGHT.
- Once the trajectory is determined, radiation field at any location is calculated by RadiationField.



(KEKB LER, 100 m downstream of a bend, 1 cm above the horizontal plane.)

Super Storage Ring

- In general, by any transformation, the sum of emittances of two degrees of freedom is higher than the original emittances.

$$\varepsilon_X + \varepsilon_Y \geq \varepsilon_x + \varepsilon_y$$

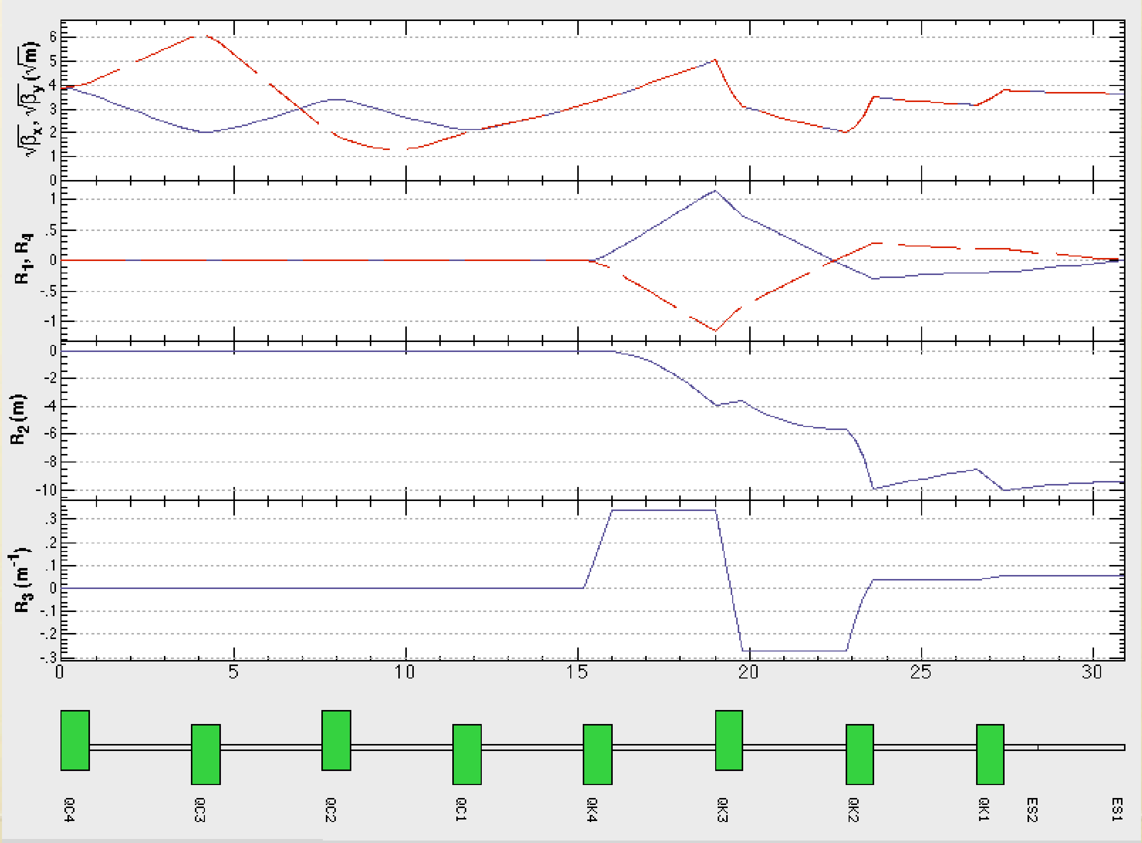
- In a solenoid field, however, it is possible to make the sum of *physical* (not canonical) emittances, much smaller than the original:

$$\varepsilon_{xm}^2 + \varepsilon_{ym}^2 = 2\varepsilon_x\varepsilon_y$$

- The conditions are:

$$\beta_x = \beta_y = 2\frac{B\rho}{B_z}\frac{\varepsilon_x - \varepsilon_y}{\varepsilon_x + \varepsilon_y},$$

$$r_2 = -\beta_x/\sqrt{2},\ r_3 = 1/\sqrt{2}\beta_x$$



Thanks to K. Harada.

Class

```
KEKBOptics=Class[{},

  {IRLoad=True,
    SharedElementList$={}},

  {SharedM=OpenShared[128*200],
    Section="All",
    K2Step=1,
    .....
    ChromaGoalX:="XIX*#*Exp[-(#/DPW)^2/2]&",
    ChromaGoalY:="XIY*#*Exp[-(#/DPW)^2/2]&",
    InitialCond={"AX","AY","BX","BY","DX","DPX","DY","DPY"}},

  SetupLattice[file$_]:=Module[{file,f,s1,s2,s3,s4},
    ....
    SetBeast[];
    $Line=0];

  SetupNormalCell[]:=If[NCLINE===Null,
    Module[{
      l=Take[ExtractBeamLine[],
        {LINE["POSITION",NormalCell[[1]]],
          LINE["POSITION",NormalCell[[2]]]}]},
      NCLINE=BeamLine[PQD1C,l,-PQD1C]]];
   ......


LEROptics=Class[{KEKBOptics},

  {LatticeSetup=False},

  {RingName="ASC",
    BXIP=0.33,
    BYIP=0.008,
    ......
```

Class variables

Instance variables

Instance functions

Subclass

Instance creation

```
ler=LEROptics[];

ler@ReadOpticsFile[ler@DefaultOptics[]];
```

Inheritance

function call

Designed by N. Akasaka.

Cons...

SAD has so many problems, at least:

Incapabilities	•No 6D Twiss: inconvenient for bunch compressor, ERL, etc. •Special elements: curved multipoles, large aperture elements. •Not yet perfectly integrated or maintained: polarization(SODOM), Taylor map, etc. •Strong-strong space charge.
Difficulties	•Tracking, optics, envelope are coded independently. Very hard to check the consistency. •Elements such as BEND or MULT contain so many internal branches depending on the input parameters.
Anti-computer science	•98% FORTRAN (started with HITAC M-series and NEWLIB). •Many historical layers without consistent programming strategy. •Limited 64-bit capability. •No multi-thread. •GUI is limited by TclTk.
User-unfriendly	•Manuals, users guides, programmer's references are very poor, if exist. •Less support. •Hard portability: Installation is not easy except for geeks.