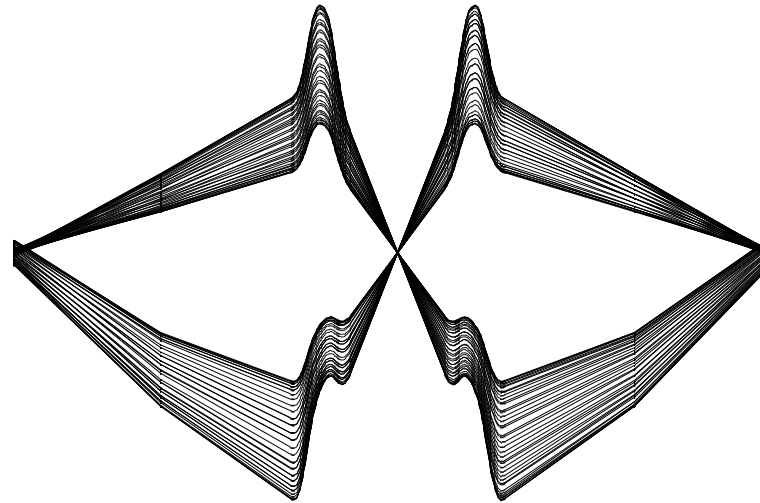


THE RAY-TRACING CODE ZGOUBI



N. Monseu,
with a little help from my friend
Laboratoire de Physique Subatomique et de Cosmologie,

Université Joseph Fourier Grenoble 1, CNRS/IN2P3 , Institut Polytechnique de Grenoble, 53 avenue des martyrs, 38026 Grenoble France

Contents

1	INTRODUCTION : What Zgoubi does	3
2	Zgoubi's NUMERICAL INTEGRATION METHOD	8
	<i>Amongst many simulation possibilities :</i>	31
3	SPIN TRACKING	31
4	SYNCHROTRON RADIATION	35
	<i>A key-tool :</i>	40
5	THE FITTING PROCEDURE	41
	<i>A list of everything :</i>	41
6	Zgoubi's KEYWORDS/PROCEDURES	42
	CONCLUSIONS	42

1 INTRODUCTION : What Zgoubi does

Calculate trajectories of charged particles in magnetic and electric fields.

At the origin (early 1970's) developed for design and operation of

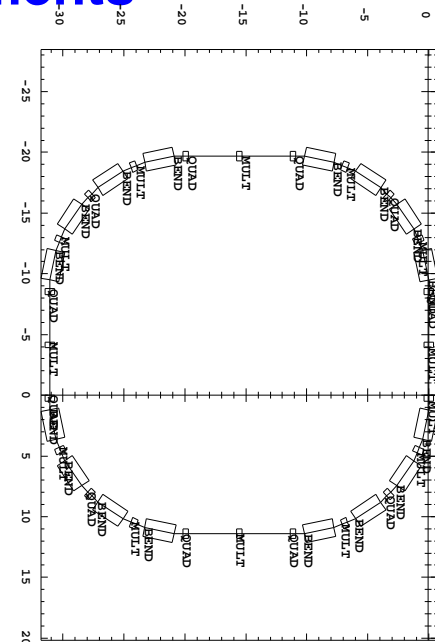
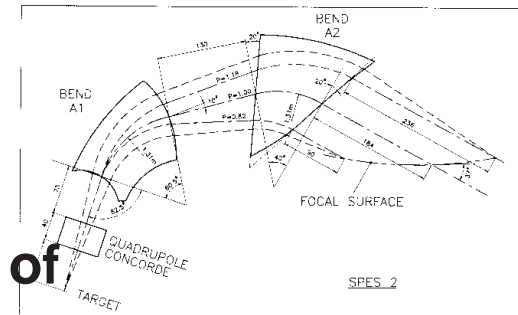
- beam lines
- magnetic spectrometers

Zgoubi has so evolved that it allows today the study of

- systems including complex sequences of optical elements
- periodic structures

and allows accounting for additional properties as

- synchrotron radiation and its dynamical effects
- spin tracking
- in-flight decay
- etc...
- **FAQ : *not space charge (not yet ?)***



Compared to other codes, Zgoubi presents several peculiarities (sometimes merits ?) :

- **a numerical method for integrating the equation of motion,**
 - based on Taylor series,
 - which optimizes computing time
 - provides high accuracy and strong symplecticity,
- **spin tracking,**
 - using the same Taylor-series based numerical method
- **calculation of synchrotron radiation**
 - effects on particle dynamics
 - electric field and spectra
 - * in arbitrary magnetic fields

- **the possibility of using a mesh,**
 - which allows ray-tracing from simulated or measured (1-D, 2-D, 3-D, 4-D (!)) field maps,

- **numerous Monte Carlo procedures allowing**
 - unlimited number of trajectories,
 - in-flight decay,
 - photon emission,
 - etc...

- **a built-in fitting procedure including**
 - arbitrary variables
 - * any data in the input file can be varied
 - a large variety of constraints,
 - * easily extendable to even more

- **multiturn tracking in circular accelerators including**
 - features proper to machine parameter calculation and survey,
 - simulation of time-varying power supplies,
 - * any element individually

The initial version of the Code

- was dedicated to ray-tracing in magnetic spectrometers and beam lines,
- it was developed by **D. Garreta and J.C. Faivre** at CEA-Saclay in the early 1970's.

- **In these early times it was perfected for the purpose of studying**

- the four spectrometers SPES I, II, III, IV at SATURNE, Saclay
- SPEG at Ganil, Caen
- VENUS, PS170 at CERN-PS areas
- and others...

- **The 1980s' development period has strongly benefited of the environment of the *Groupe Théorie, SATURNE, CEA/DSM-Saclay*,**

this is when he acquired its form, much developed since then, of a multi-purpose ray-tracing tool...

- **In the context of a pre-gnuplot era,**

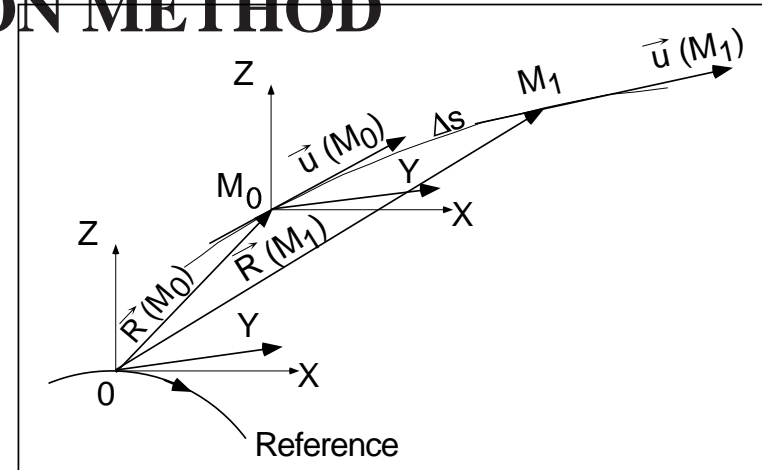
- A graphic/data treatment interface, **zpop**, has also undergone extensive development,
- a performant, well adapted tool for post-processing Zgoubi output

2 Zgoubi's NUMERICAL INTEGRATION METHOD

MOTION, from M_0 to M_1

The equation of motion

$$d(m\vec{v}) = q(\vec{e} + \vec{v} \times \vec{b}) dt$$



- is solved using truncated Taylor expansions of \vec{R} and $\vec{u} = \vec{v}/v$:

$$\begin{aligned} \vec{R}(M_1) &\approx \vec{R}(M_0) + \vec{u}(M_0) \Delta s + \vec{u}'(M_0) \frac{\Delta s^2}{2!} + \dots + \vec{u}''''(M_0) \frac{\Delta s^6}{6!} \\ \vec{u}(M_1) &\approx \vec{u}(M_0) + \vec{u}'(M_0) \Delta s + \vec{u}''(M_0) \frac{\Delta s^2}{2!} + \dots + \vec{u}''''(M_0) \frac{\Delta s^5}{5!} \end{aligned} \quad (1)$$

- In non-zero \vec{E} environment, rigidity at M_1 is re-computed :

$$(B\rho)(M_1) \approx (B\rho)(M_0) + (B\rho)'(M_0)\Delta s + \dots + (B\rho)''''(M_0)\frac{\Delta s^4}{4!} \quad (2)$$

- When necessary, time-of-flight is computed in a similar manner :

$$T(M_1) \approx T(M_0) + \frac{dT}{ds}(M_0) \Delta s + \frac{d^2T}{ds^2}(M_0) \frac{\Delta s^2}{2} + \frac{d^3T}{ds^3}(M_0) \frac{\Delta s^3}{3!} + \frac{d^4T}{ds^4}(M_0) \frac{\Delta s^4}{4!} \quad (3)$$

- In a general manner, the truncated Taylor series

$$\vec{R}(M_1) = \vec{R}(M_0) + \vec{u}(M_0) \Delta s + \dots$$

$$\vec{u}(M_1) = \vec{u}(M_0) + \vec{u}'(M_0) \Delta s + \dots$$

$$(B\rho)(M_1) = (B\rho)(M_0) + (B\rho)'(M_0) \Delta s + \dots$$

$$T(M_1) = T(M_0) + \frac{dT}{ds}(M_0) \Delta s + \dots$$

(4)

require computation of the derivatives

$$\vec{u}^{(n)} = d^n \vec{u} / ds^n$$

$$(B\rho)^{(n)} = d^n (B\rho) / ds^n$$

$$d^n (T) / ds^n$$

- This is the subject of the following slides.
-

INTEGRATION IN MAGNETIC FIELDS

- Let's introduce simplified notations :

$$\vec{u} = \frac{\vec{v}}{v}, \quad ds = v dt, \quad \vec{u}' = \frac{d\vec{u}}{ds}, \quad m\vec{v} = mv\vec{u} = q B\rho \vec{u} \quad \vec{B} = \frac{\vec{b}}{B\rho} \quad (5)$$

$d(m\vec{v}) = q(\vec{e} + \vec{v} \times \vec{b}) dt$ (with $\vec{e} = 0$) then writes

$$\vec{u}' = \vec{u} \times \vec{B}$$

This yields the $\vec{u}^{(n)} = d^n \vec{u} / ds^n$ needed in the Taylor expansions : $\vec{u}' = \vec{u} \times \vec{B}$

$$\begin{aligned} \vec{u}'' &= \vec{u}' \times \vec{B} + \vec{u} \times \vec{B}' \\ \vec{u}''' &= \vec{u}'' \times \vec{B} + 2\vec{u}' \times \vec{B}' + \vec{u} \times \vec{B}'' \\ \vec{u}^{(4)} &= \vec{u}''' \times \vec{B} + 3\vec{u}'' \times \vec{B}' + 3\vec{u}' \times \vec{B}'' + \vec{u} \times \vec{B}''' \\ \vec{u}^{(5)} &= \vec{u}^{(4)} \times \vec{B} + 4\vec{u}''' \times \vec{B}' + 6\vec{u}'' \times \vec{B}'' + 4\vec{u}' \times \vec{B}''' + \vec{u} \times \vec{B}^{(4)} \end{aligned} \quad (6)$$

where $\vec{B}^{(n)} = d^n \vec{B} / ds^n$.

- Field derivatives wrt. path length,

$$\vec{B}^{(n)} = d^n \vec{B} / ds^n$$

- are computed from the derivatives in magnet frame :

$$d\vec{B} = \frac{\partial \vec{B}}{\partial X} dX + \frac{\partial \vec{B}}{\partial Y} dY + \frac{\partial \vec{B}}{\partial Z} dZ = \sum_{i=1,3} \frac{\partial \vec{B}}{\partial X_i} dX_i$$

- following

$$\vec{B}' = \sum_i \frac{\partial \vec{B}}{\partial X_i} u_i$$

$$\vec{B}'' = \sum_{ij} \frac{\partial^2 \vec{B}}{\partial X_i \partial X_j} u_i u_j + \sum_i \frac{\partial \vec{B}}{\partial X_i} u_i' \quad (7)$$

$$\vec{B}''' = \sum_{ijk} \frac{\partial^3 \vec{B}}{\partial X_i \partial X_j \partial X_k} u_i u_j u_k + 3 \sum_{ij} \frac{\partial^2 \vec{B}}{\partial X_i \partial X_j} u_i' u_j + \sum_i \frac{\partial \vec{B}}{\partial X_i} u_i''$$

etc.

- There are oodles of magnetic elements in Zgoubi,
- oodles of ways to simulate magnetic elements,
- allowing an answer to almost everyday's life magnetic situations

What :

Decapole

Dipole

Dodecapole

FFAG magnets

Multipole

Octupole

Quadrupole

Sextupole

Solenoid

Helical dipole ?

Multiple-helix dipole ?

Keyword :

DECAPOLE, MULTIPOL

BEND, DIPOLE[S, -M], MULTIPOL, QUADISEX

DODECAPO, MULTIPOL

FFAG, FFAG-SPI

MULTIPOL, QUADISEX, SEXQUAD

OCTUPOLE, MULTIPOL, QUADISEX, SEXQUAD

QUADRUPO, MULTIPOL, SEXQUAD

SEXTUPOL, MULTIPOL, QUADISEX, SEXQUAD

SOLENOID

yes...

soon ?...

Field maps

1-D, cylindrical symmetry

2-D, mid-plane symmetry

2-D, no symmetry

2-D, polar mesh

3-D

BREVOL

CARTEMES, POISSON, TOSCA

MAP2D

POLARMES

TOSCA

EXAMPLE 1 - Multipoles

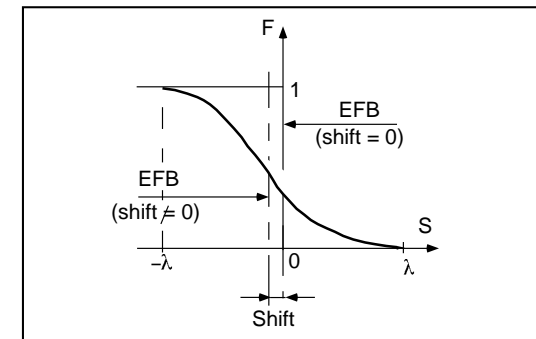
- **Field and derivatives in magnet frame,**
- **are derived from scalar potential**

$$\frac{\partial^{i+j+k} \vec{B}_n(X,Y,Z)}{\partial X^i \partial Y^j \partial Z^k} \quad i + j + k = 0 \text{ to } 4$$

$$V_n(X, Y, Z) = (n!)^2 \left(\sum_{q=0}^{\infty} (-1)^q \frac{G^{(2q)}(X) (Y^2 + Z^2)^q}{4^q q! (n+q)!} \right) \left(\sum_{m=0}^n \frac{\sin\left(m\frac{\pi}{2}\right) Y^{n-m} Z^m}{m!(n-m)!} \right) \quad (8)$$

- **yielding** $B_X = \frac{\partial V}{\partial X}$, $B_Y = \frac{\partial V}{\partial Y}$, $B_Z = \frac{\partial V}{\partial Z}$ **etc.**
- $G(X)$ **is the longitudinal gradient, defined at the entrance or exit of the optical element by**

$$G(s) = \frac{G_0}{1 + \exp(P(s))}, \quad G_0 = \frac{B_0}{R_0^n}$$



while

$$P(s) = C_0 + C_1 \left(\frac{s}{\lambda}\right) + C_2 \left(\frac{s}{\lambda}\right)^2 + C_3 \left(\frac{s}{\lambda}\right)^3 + C_4 \left(\frac{s}{\lambda}\right)^4 + C_5 \left(\frac{s}{\lambda}\right)^5$$

s **is the distance to the EFB.**

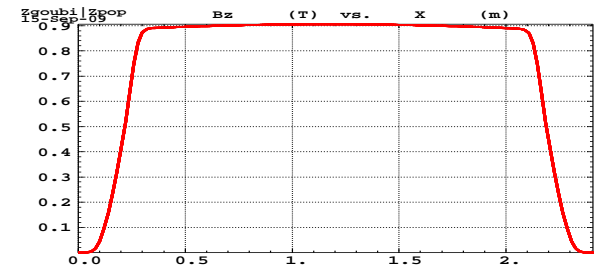
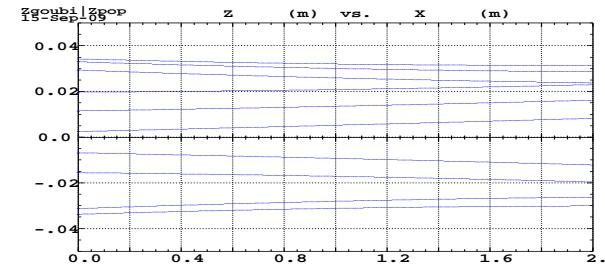
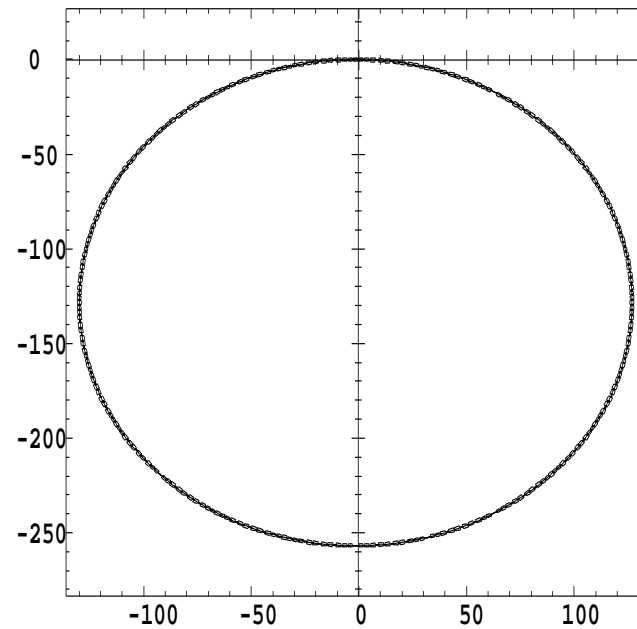
AGS ring based on 'MULTIPOL'

• zgoubi.dat input file, excerpt :

```

AGS ring. Xing 36+nu
'OBJET'
77.64321e3
8
1 1 1
-0.64319816e-2 -0.49829722e-3 0.0 0.0E+00 0.0E+00 1. 'p'
-1.588 19.843 0.
1.033 11.675 .02e-7
0 1 0.
'SCALING'
1 2
MULTIPOL SBEN
-1
77.64321
1
MULTIPOL QUAD
-1
77.64321
1
'PARTICUL'
938.27203d0 1.602176487d-19 1.7928474d0 0. 0.
'SPNTRK'
3
'PICKUPS'
1
#Start
'FAISTORE'
b_zgoubi.fai #End
1
'SPNRNL'
b_zgoubi.spn
'MARKER' #Start
'MARKER' MARK BSUPERA
'MULTIPOL' SBEN ALBF
0 .Dip
200.6554 10.00 0.11712499 0.04848519 -0.00050563 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0. 0. 10.00 4.0 0.800 0.00 0.00 0.00 0.00 0. 0. 0. 0.
4 .1455 2.2670 -.6395 1.1558 0. 0. 0.
0. 0. 10.00 4.0 0.800 0.00 0.00 0.00 0.00 0.00 0. 0. 0.
4 .1455 2.2670 -.6395 1.1558 0. 0. 0.
0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
#20|200|20 Dip ALBF
3 0.0000000000000000 0.0000000000000000 -1.175115045000000E-002
'DRIFT' DRIF D2S
60.9515
'MULTIPOL' SBEN A2BF
0 .Dip
200.6554 10.00 0.11712499 0.04848519 -0.00050563 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0. 0. 10.00 4.0 0.800 0.00 0.00 0.00 0.00 0.00 0. 0. 0.
4 .1455 2.2670 -.6395 1.1558 0. 0. 0.
0. 0. 10.00 4.0 0.800 0.00 0.00 0.00 0.00 0.00 0. 0. 0.
4 .1455 2.2670 -.6395 1.1558 0. 0. 0.
0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
#20|200|20 Dip A2BF
3 0.0000000000000000 0.0000000000000000 -1.175115045000000E-002
'DRIFT' DRIF DPUE
28.7000
'MARKER' MARK PUE_A02
'MULTIPOL' HKIC DHCA02
0 .kicker
0.1000E-03 10.00 0.000000E+00 0.000000 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
.0 .0 1.00 0.00 0.00 0.00 0.00 0. 0. 0. 0.
4 .1455 2.2670 -.6395 1.1558 0. 0. 0.
.0 .0 1.00 0.00 0.00 0.00 0.00 0. 0. 0. 0.
4 .1455 2.2670 -.6395 1.1558 0. 0. 0.
0.000000000 0. 0. 0. 0. 0. 0. 0. 0. 0.
#20|20|20 Kick
1 0. 0. 0.
'MULTIPOL' VKIC DVCA02
0 .kicker
0.1000E-03 10.00 0.000000E+00 0.000000 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
.0 .0 1.00 0.00 0.00 0.00 0.00 0. 0. 0. 0.
4 .1455 2.2670 -.6395 1.1558 0. 0. 0.

```



----- ALBF, transfer matrix

MAD8	0.903966	1.941764	0.000000	0.000000	0.025292
	-0.094164	0.903966	0.000000	0.000000	0.024799
	0.000000	0.000000	1.098925	2.072529	0.000000
	0.000000	0.000000	0.100184	1.098925	0.000000
	-0.024799	-0.025292	0.000000	0.000000	0.378389
Ray-tracing	0.904036	1.94182	0.000000	0.000000	0.0235714
	0.094094	0.904042	0.000000	0.000000	0.0231068
	0.000000	0.000000	1.09884	2.07246	0.000000
	0.000000	0.000000	0.100096	1.09883	0.000000
	0.023107	0.023560	0.000000	0.000000	1.881443E-04

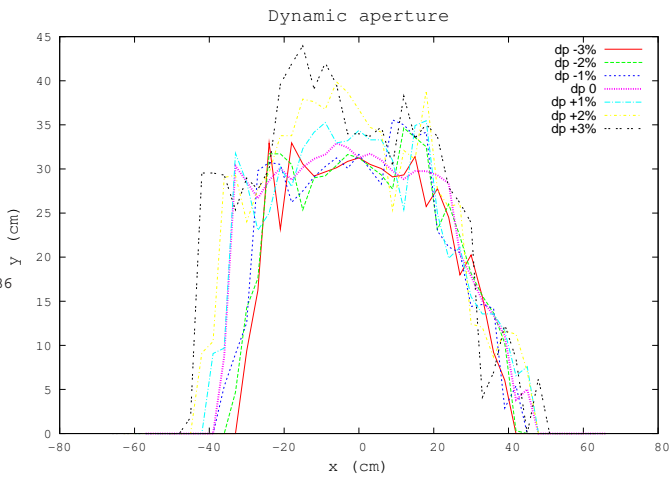
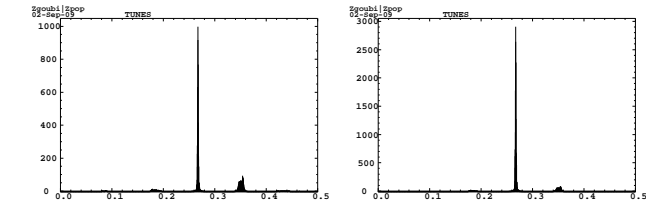
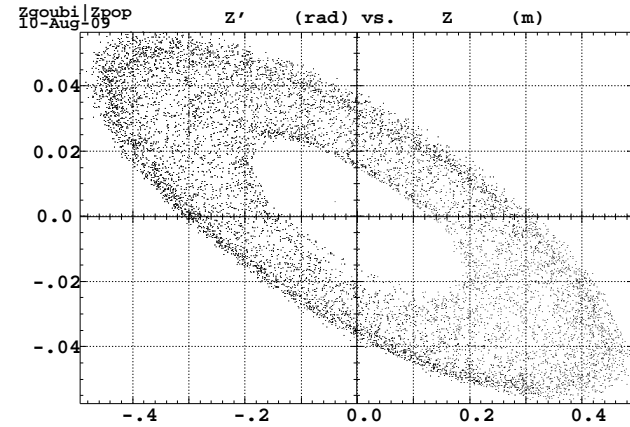
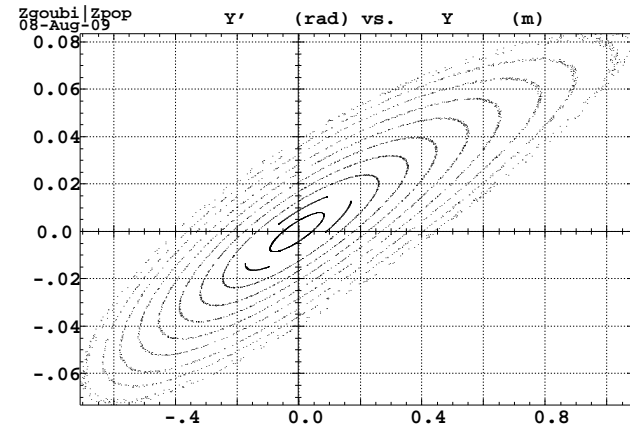
Multiturn tracking, DA finding

• zgoubi.dat input file, excerpt :

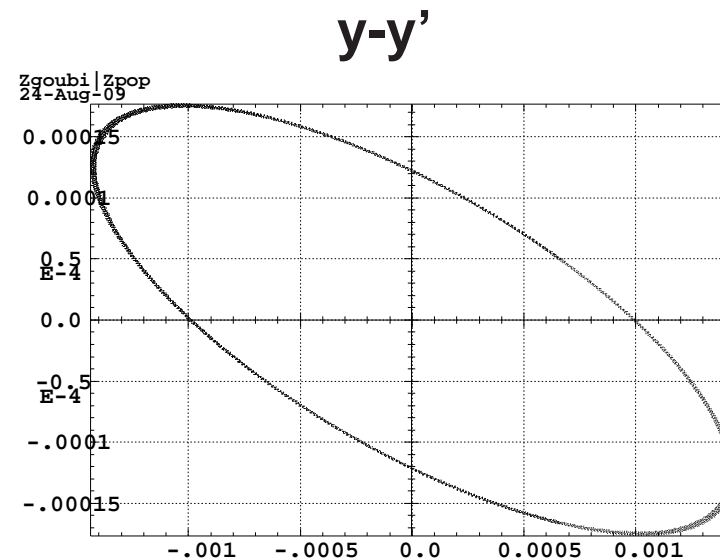
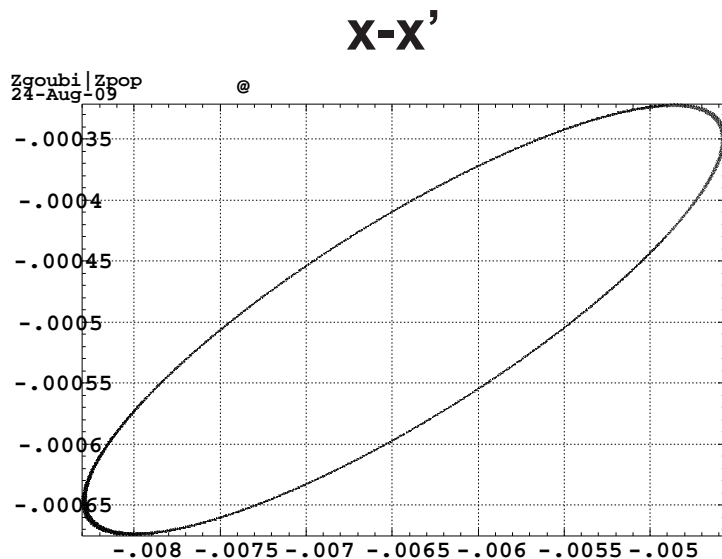
```

AGS ring. Xing 36+nu
'OBJET'
77.64321e3
8
 1 1 1
-0.64319816e-2 -0.49829722e-3 0.0 0.0E+00 0.0E+00 1. 'p'
-1.588 19.843 0.
1.033 11.675 .02e-7
0 1 0.
'SCALING'
1 2
MULTIPOL SBEN
-1
77.64321
1
MULTIPOL QUAD
-1
77.64321
1
'PARTICUL'
938.27203d0 1.602176487d-19 1.7928474d0 0. 0.
'SPNTRK'
3
'PICKUPS'
1
#Start
'FAISTORE'
b_zgoubi.fai #End
1
'SPNPRNL'
b_zgoubi.spn
'MARKER' #Start
'MARKER' MARK BSUPERA
'MULTIPOL' SBEN A1BF
0 .Dip
200.6554 10.00 0.11712499 0.04848519 -0.00050563 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0. 0. 10.00 4.0 0.800 0.00 0.00 0.00 0.00 0. 0. 0. 0.
4 .1455 2.2670 -.6395 1.1558 0. 0. 0.
0. 0. 10.00 4.0 0.800 0.00 0.00 0.00 0.00 0.0 0. 0. 0.
4 .1455 2.2670 -.6395 1.1558 0. 0. 0.
0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
#20|20|20 Dip A1BF
3 0.000000000000000 0.000000000000000 -1.175115045000000E-002
.....
.....
'MULTIPOL' HKIC SML20
0 .kicker
0.2413E+03 10.00 0.000000E+00 0.000000 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
.0 .0 1.00 0.00 0.00 0.00 0.00 0. 0. 0. 0.
4 .1455 2.2670 -.6395 1.1558 0. 0. 0.
.0 .0 1.00 0.00 0.00 0.00 0.00 0. 0. 0. 0.
4 .1455 2.2670 -.6395 1.1558 0. 0. 0.
0.000000000 0. 0. 0. 0. 0. 0. 0. 0.
#20|20|20 Kick
1 0. 0. 0.
'DRIFT' DRIF DSG10
31.7339
'MARKER' MARK ESUPERL
'CAVITE'
2.1 .1 is to fill zgoubi.CAVITE.Out for plot using zpop/7/20
807.043778118095 12.
290.d3 2.617993877991494365 9cavitiesx32kV, phi_s=30deg
'MARKER' #End
'REBELOTE'
9 0.2 99
'END'

```



- 500000 turns in AGS, single particle...

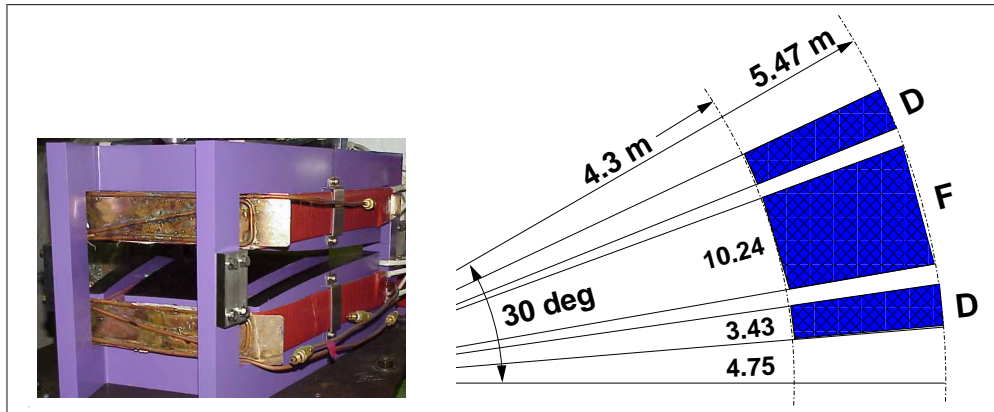


- particle launched on $\epsilon_x/\pi = \epsilon_z/\pi = 0.35$ mm.mrad, at fixed rigidity,
- observed at “Begin AGS”.
- Good symplecticity : no obvious broadening of the invariants, nor visible spiraling.
- Computing speed, real time (*not* CPU), Dell Latitude D630 : 500 turns/minute

EXAMPLE 2 - “FFAG” and “DIPOLES” procedures

The bare AGS lattice is a rather simple case (sorry !).
Zgoubi has been doing much more sophisticated.

- A simulation of $B_{zi}(r, \theta) = B_{z0,i} \mathcal{F}_i(r, \theta) (r/R_0)^k$ including overlapping of fringe fields.
- Case of KEK 150 MeV scaling FFAG DFD triplet :

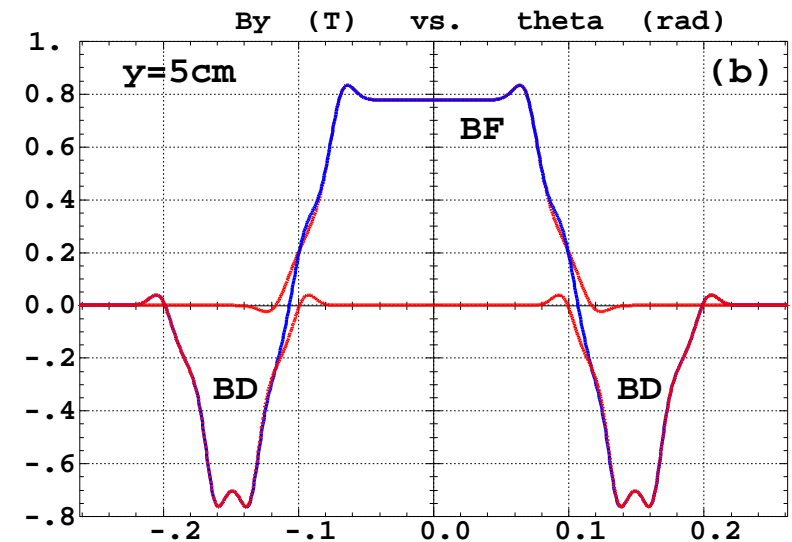


- The geometrical model is based on the superposition of the independent contributions of the N dipoles :

$$B_z(r, \theta) = \sum_{i=1, N} B_{z0,i} \mathcal{F}_i(r, \theta) \mathcal{R}_i(r)$$

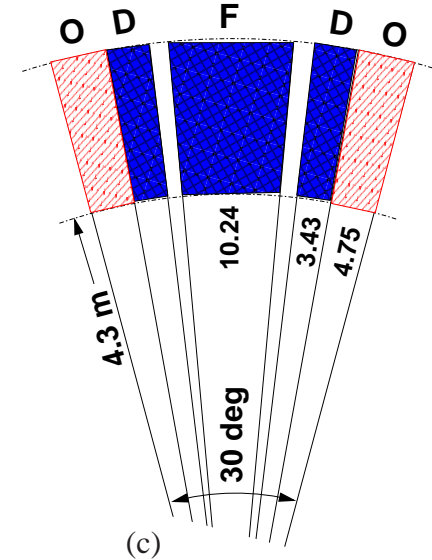
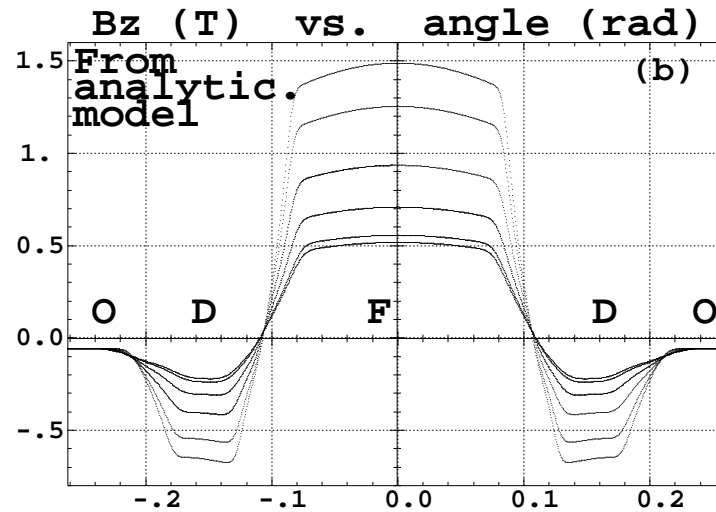
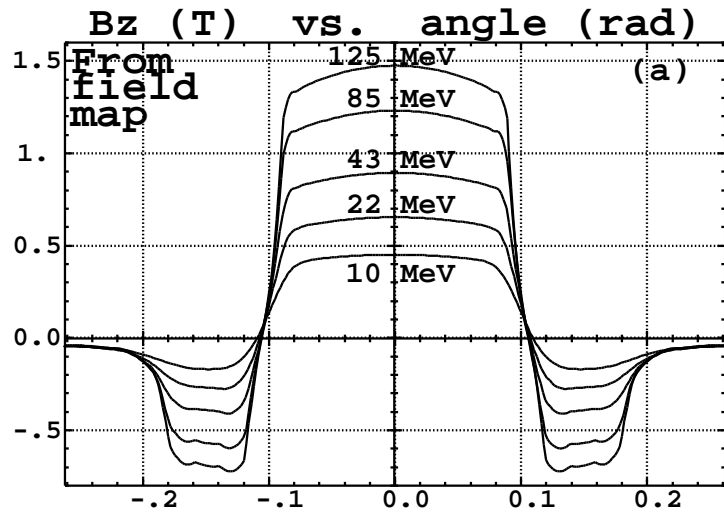
at all (r, θ) in the mid-plane.

- Field off mid-plane is obtained by Taylor expansion + Maxwell.



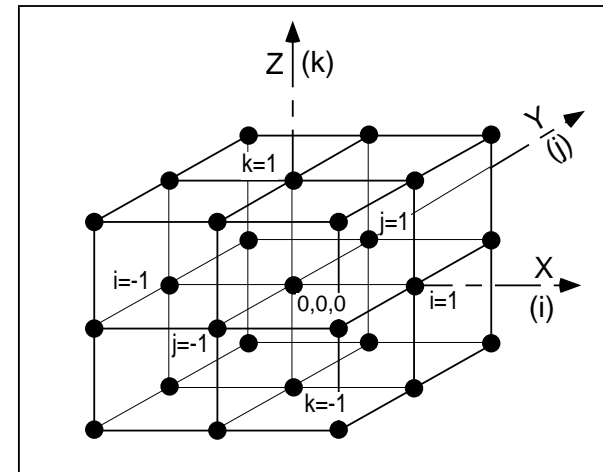
Simulation of the field experienced by a particle crossing along $r_0 = 4.87$ m, 5 cm off mid-plane.
A superposition (blue line) of $N = 3$ independent sources (red lines), at all (r, θ, z) .

EXAMPLE 3 - “TOSCA” procedures

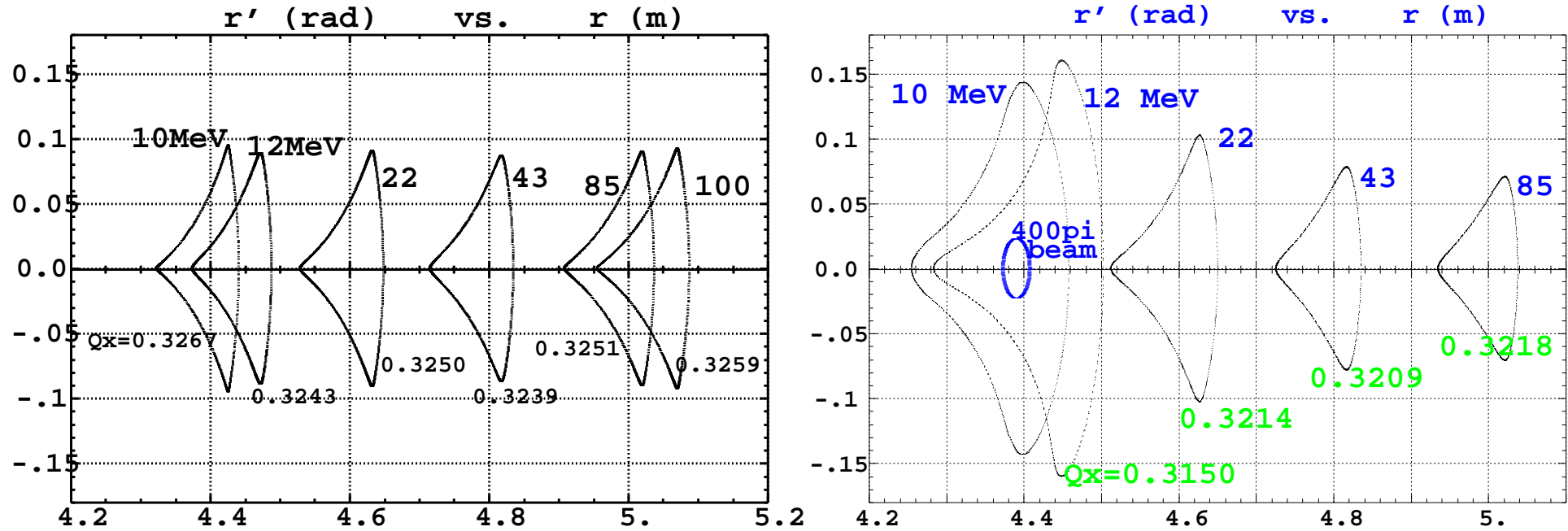


Comparison of magnetic field along closed orbits in the case of,
(a) : TOSCA 3-D map representative of the 150 MeV FFAG, and,
(b) : field from the “3+2”-dipole geometrical model.

(c) geometry of the “3+2”-dipole design, including two additional dipole regions (hatched) that simulate 700 G field extent over the two end drifts.



Tracking in scaling FFAG(cont'd) - Comparison between “FFAG” procedure and 3-D field maps



150MeV FFAG : horizontal phase space, the limits of stable motion, for 5 different values of energy/closed orbit radius.

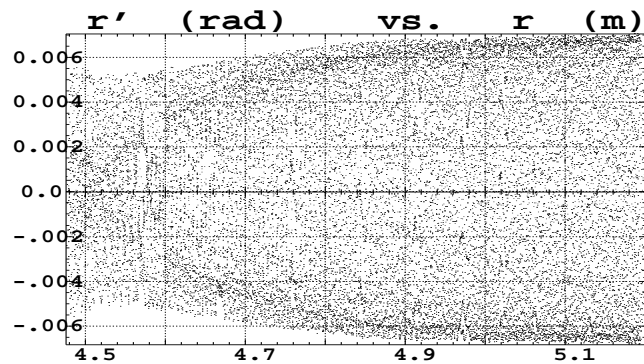
- For comparison : tracking with geometrical model (left), or using TOSCA map (right).

6-D tracking - difficult problem : 1/ using field map, 2/ scaling FFAG

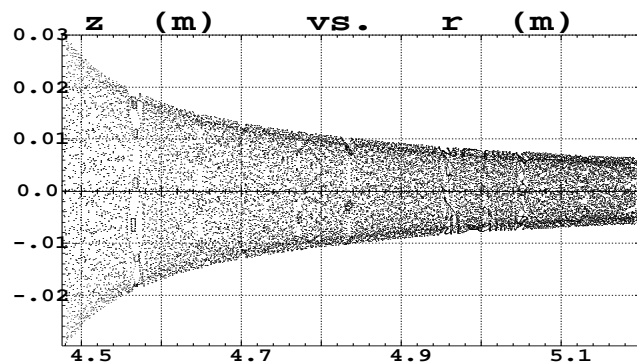
- Or, “where we observe that *high accuracy tracking in field maps is doable*”
- Acceleration from 12 to 125 MeV, ≈ 50000 turns, 1 particle
- The orbit spirals out : 4.5 \rightarrow 5.2 m

- Analytical modelling : “DIPOLLES” or “FFAG”

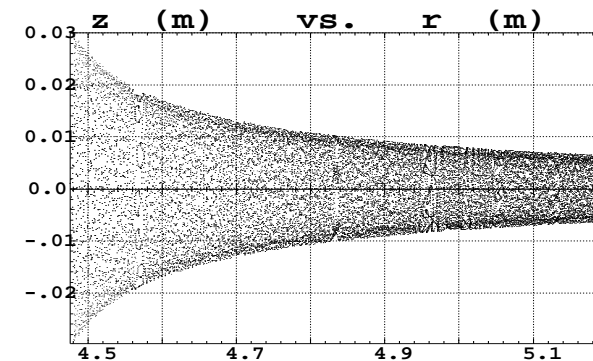
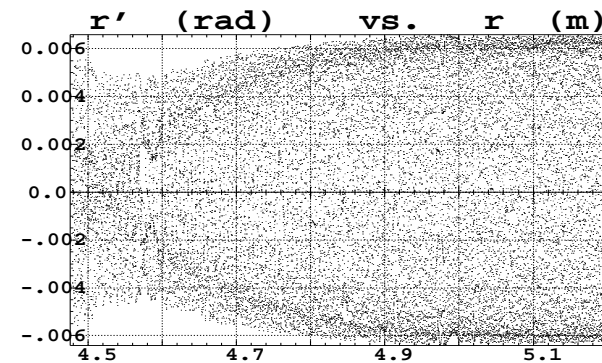
Some x-z coupling, yet $\epsilon_x \approx 0$



ϵ_z -damping $\propto \sqrt{\beta\gamma}$



- “TOSCA” procedure, 2-D field map



- A (rather) large (considering the strong non-linearity of $B \sim (r/R_0)^k$, and fringe fields in addition) step size is used, in both cases : 0.5 cm, with success.

EXAMPLE 3 - HELICAL MAGNET : “HELIX” (analytical) or “MAP2D” (field map) modelling

- “HELIX”, analytical

• Typical zgoubi.dat input :

```
'HELIX'
2
45.2 200. 19.855 0.
3 10.
1.
1 0. 0. 0.
```

- “HELIX” is being extended to multiple-helix magnet,

- so to allow simulating warm-, cold-, any temperature-snake

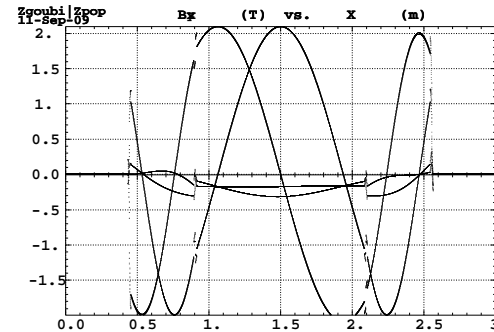
- this will be based on the method used in “DIPOLES”, “FFAG” as seen earlier :

$$B_z(r, \theta) = \sum_{i=1, N} B_{z0,i} \mathcal{F}_i(r, \theta) \mathcal{R}_i(r)$$

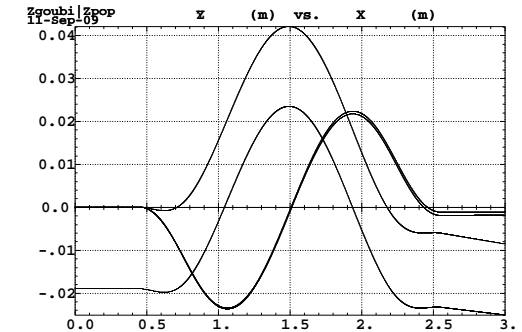
- Using a 2-D field map together with “MAP2D” procedure
- Typical zgoubi.dat input :

```
'MAP2D'
0 2
10. 100. 100.
HEADER_3 helical magnet field map
301 41
csnk-se-1cm.map
0 0 0 0
2
.1 stepSize
2 0. 0. 0. 0.
```

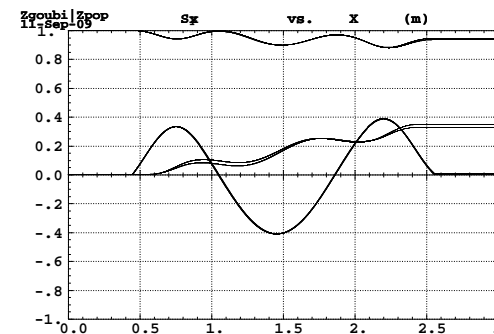
Bx, By, Bz versus z



x, y versus z



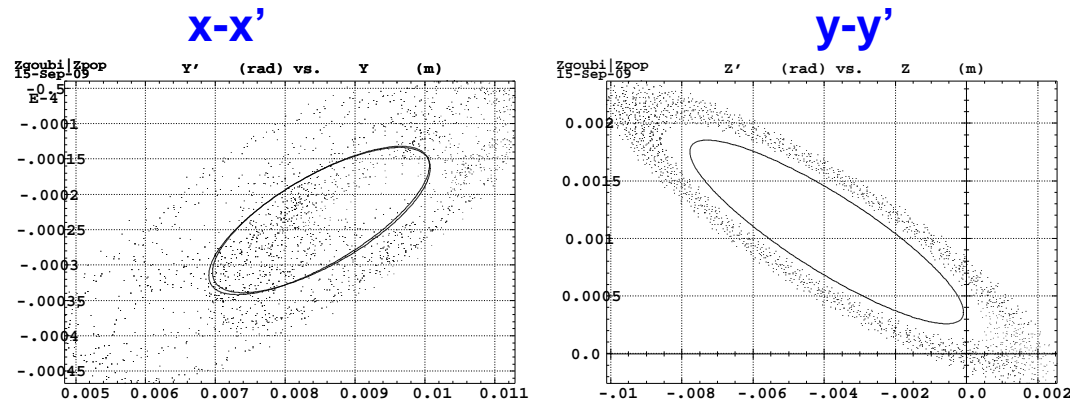
spin, starting vertical



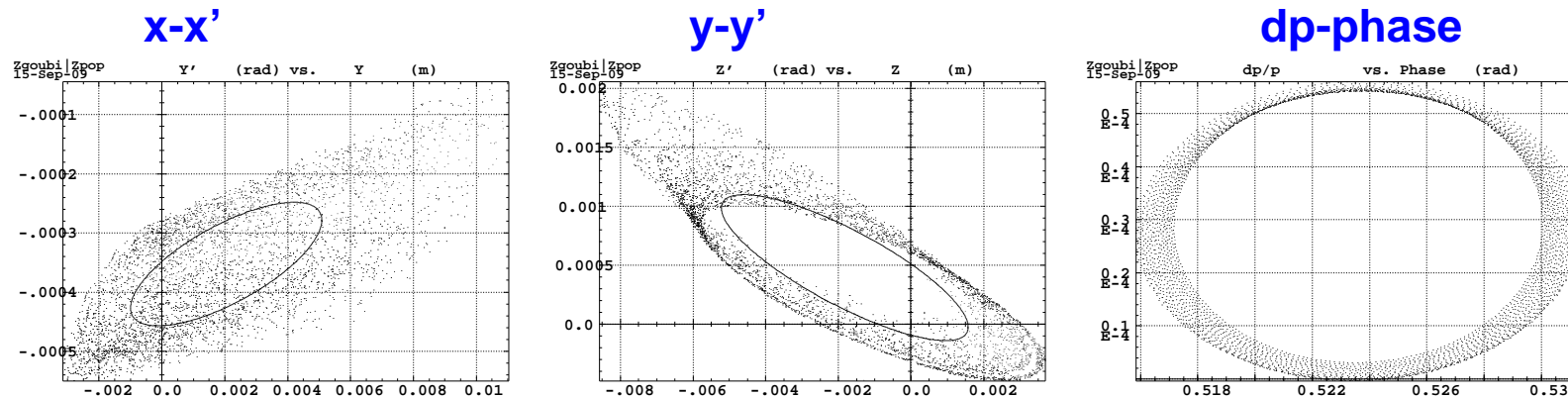
TRACKING AGS WITH HELICAL MAGNET

- A 1 cm mesh size field map is used
- The symplecticity is bad. Two main defects, we are working on that :
 - the mesh is loose, considering existence of strong local variations of \vec{B}
 - the field has discontinuities (the derivatives in Zgoubi do not like that at all !)

No acceleration



With acceleration, 2.104 Tesla/second
(I should not show that... well... I can't help - sorry)



INTEGRATION IN ELECTRIC FIELDS

- With the same ingredients as before,

$$d(m\vec{v}) = q(\vec{e} + \vec{v} \times \vec{b}) dt \text{ can be written under the form } \boxed{(B\rho)' \vec{u} + B\rho \vec{u}' = \frac{\vec{e}}{v}}$$

- Then, based on

$$(B\rho)' \vec{u} + B\rho \vec{u}' = \frac{\vec{e}}{v}, \quad (B\rho)'' \vec{u} + 2(B\rho)' \vec{u}' + B\rho \vec{u}'' = \left(\frac{1}{v}\right)' \vec{e} + \frac{\vec{e}'}{v}, \text{ etc.}$$

$$\vec{u}' = \left(\frac{1}{v}\right) \vec{E} - \frac{(B\rho)'}{B\rho} \vec{u}, \quad \vec{u}'' = \left(\frac{1}{v}\right)' \vec{E} + \left(\frac{1}{v}\right) \vec{E}' \Big|_{B\rho} - 2\frac{(B\rho)'}{B\rho} \vec{u}' - \frac{(B\rho)''}{B\rho} \vec{u}, \text{ etc.}$$

$$\left(\frac{1}{v}\right) = \frac{1}{c^2} \frac{W + m_0 c^2}{qB\rho}, \quad \left(\frac{1}{v}\right)' = \frac{1}{c^2} \frac{(\vec{e} \cdot \vec{u})}{B\rho} - \frac{1}{v} \frac{(B\rho)'}{B\rho}, \text{ etc.}$$

one then calculate the Taylor series for the rigidity,

$$(B\rho)(M_1) \approx (B\rho)(M_0) + (B\rho)'(M_0)\Delta s + \dots + (B\rho)''''(M_0) \frac{\Delta s^4}{4!} \quad (9)$$

- The derivatives

$$\vec{E}^{(n)} \Big|_{B\rho} = \frac{1}{B\rho} \frac{d^n \vec{e}}{ds^n}$$

of the electric field so needed there are obtained from the total derivative **in the frame of the electrostatic element**,

$$d\vec{E} = \frac{\partial \vec{E}}{\partial X} dX + \frac{\partial \vec{E}}{\partial Y} dY + \frac{\partial \vec{E}}{\partial Z} dZ \quad (10)$$

which is to say

$$\begin{aligned} \vec{E}' &= \sum_i \frac{\partial \vec{E}}{\partial X_i} u_i \\ \vec{E}'' &= \sum_{ij} \frac{\partial^2 \vec{E}}{\partial X_i \partial X_j} u_i u_j + \sum_i \frac{\partial \vec{E}}{\partial X_i} u_i' \\ \vec{E}''' &= \sum_{ijk} \frac{\partial^3 \vec{E}}{\partial X_i \partial X_j \partial X_k} u_i u_j u_k + 3 \sum_{ij} \frac{\partial^2 \vec{E}}{\partial X_i \partial X_j} u_i' u_j + \sum_i \frac{\partial \vec{E}}{\partial X_i} u_i'' , \\ \text{etc.} \end{aligned} \quad (11)$$

- There are oodles of magnetic elements in Zgoubi, allowing simulation of almost everyday's life electric situations

What :

2-tube (bipotential) lens
 3-tube (unipotential) lens
 Decapole
 Dipole
 Dodecapole
 Multipole
 N-electrode mirror/lens, straight slits
 N-electrode mirror/lens, circular slits
 Octupole
 Quadrupole
 R.F. (kick) cavity
 Sextupole
 Skewed multipoles

Keyword :

EL2TUB
 UNIPOT
 ELMULT
 ELMULT
 ELMULT
 ELMULT
 ELMIR
 ELMIRC
 ELMULT
 ELMULT
 CAVITE
 ELMULT
 ELMULT

Electric field maps

1D, cylindrical symmetry
 2-D, no symmetry

ELREVOL
 MAP2D_E

INTEGRATION IN COMBINED E+B FIELDS

- When both \vec{e} and \vec{b} are non-zero, the complete equation must be considered,

$$(B\rho)' \vec{u} + B\rho \vec{u}' = \vec{e} / v + \vec{u} \times \vec{b}$$

- Well, one can imagine...

$$\begin{aligned}
 (B\rho)'' \vec{u} + 2(B\rho)' \vec{u}' + B\rho \vec{u}'' &= \left(\frac{1}{v}\right)' \vec{e} + \left(\frac{1}{v}\right) \vec{e}' + (\vec{u} \times \vec{b})' \\
 (B\rho)''' \vec{u} + 3(B\rho)'' \vec{u}' + 3(B\rho)' \vec{u}'' + B\rho \vec{u}''' &= \left(\frac{1}{v}\right)'' \vec{e} + 2 \left(\frac{1}{v}\right)' \vec{e}' + \left(\frac{1}{v}\right) \vec{e}'' + (\vec{u} \times \vec{b})'' \\
 (B\rho)'''' \vec{u} + 4(B\rho)''' \vec{u}' + 6(B\rho)'' \vec{u}'' + 4(B\rho)' \vec{u}''' + B\rho \vec{u}'''' &= \\
 \left(\frac{1}{v}\right)''' \vec{e} + 3 \left(\frac{1}{v}\right)'' \vec{e}' + 3 \left(\frac{1}{v}\right)' \vec{e}'' + \frac{1}{v} \vec{e}''' + (\vec{u} \times \vec{b})''' & \\
 \vec{u}' = \left(\frac{1}{v}\right) \vec{E} + (\vec{u} \times \vec{B}) - \frac{(B\rho)'}{B\rho} \vec{u} & \\
 \vec{u}'' = \left(\frac{1}{v}\right)' \vec{E} + \left(\frac{1}{v}\right) \vec{E}' \Big|_{B\rho} + (\vec{u} \times \vec{B}') \Big|_{B\rho} - 2 \frac{(B\rho)'}{B\rho} \vec{u}' - \frac{(B\rho)''}{B\rho} \vec{u} & \\
 \vec{u}''' = \left(\frac{1}{v}\right)'' \vec{E} + 2 \left(\frac{1}{v}\right)' \vec{E}' \Big|_{B\rho} + \frac{1}{v} \vec{E}'' \Big|_{B\rho} + (\vec{u} \times \vec{B})'' \Big|_{B\rho} - 3 \frac{(B\rho)'}{B\rho} \vec{u}'' - 3 \frac{(B\rho)''}{B\rho} \vec{u}' - \frac{(B\rho)'''}{B\rho} \vec{u} & \\
 \vec{u}'''' = \left(\frac{1}{v}\right)''' \vec{E} + 3 \left(\frac{1}{v}\right)'' \vec{E}' \Big|_{B\rho} + 3 \left(\frac{1}{v}\right)' \vec{E}'' \Big|_{B\rho} + \left(\frac{1}{v}\right) \vec{E}''' \Big|_{B\rho} & \\
 + (\vec{u} \times \vec{B})''' \Big|_{B\rho} - 4 \frac{(B\rho)'}{B\rho} \vec{u}''' - 6 \frac{(B\rho)''}{B\rho} \vec{u}'' - 4 \frac{(B\rho)'''}{B\rho} \vec{u}' - \frac{(B\rho)''''}{B\rho} \vec{u} & \\
 \vec{E}^{(n)} \Big|_{B\rho} = \frac{1}{B\rho} \frac{d^n \vec{e}}{ds^n} \text{ and } (\vec{u} \times \vec{B})^{(n)} \Big|_{B\rho} = \frac{1}{B\rho} (\vec{u} \times \vec{b})^{(n)} \dots &
 \end{aligned}
 \tag{12}$$

EXAMPLE - LESB3, BNL, TWO-STAGE SEPARATED 800-MeV/c KAON BEAMLINE USING 2 WIENFILTERS

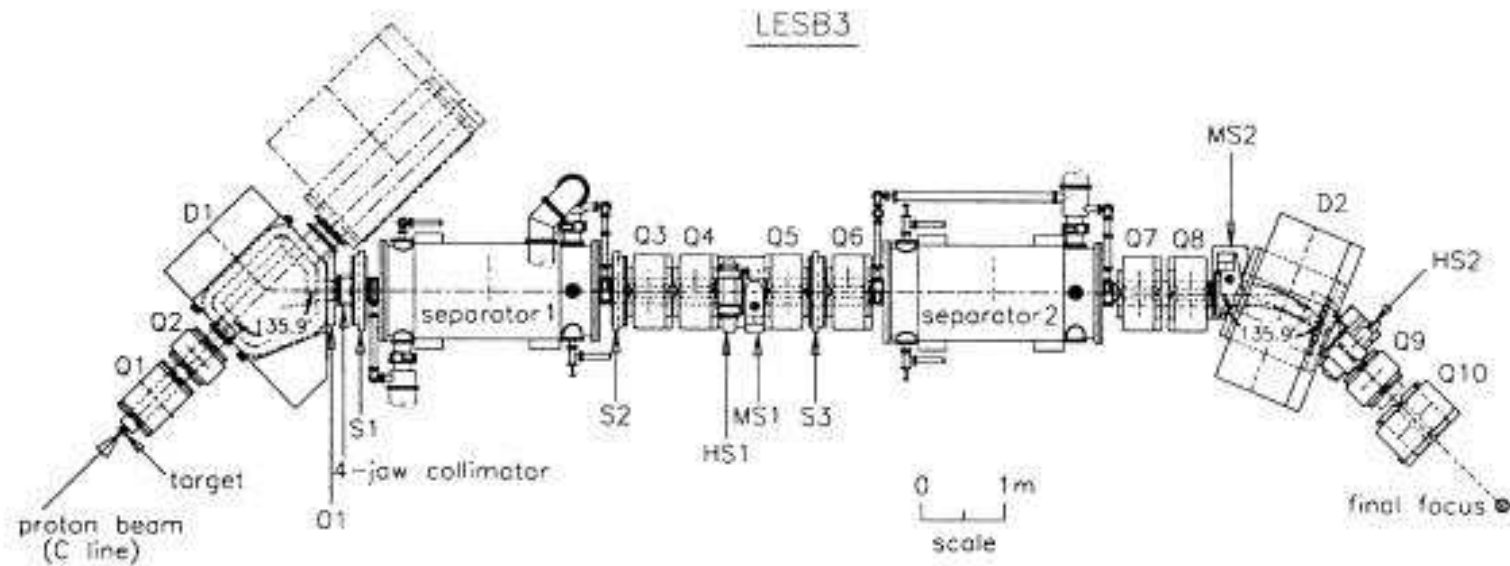


Fig. 1. Lay out of LESB3 beamline.

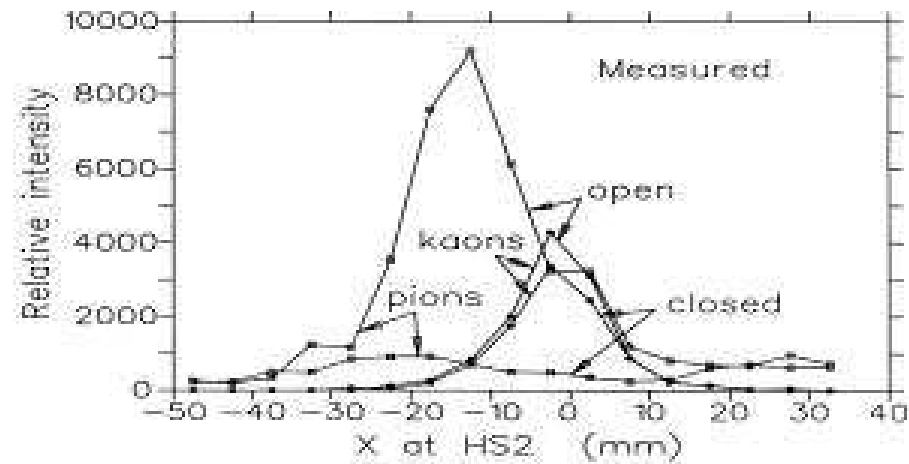


Fig. 16. Measured kaon and pion distributions at HS2 with the four-jaw collimator open and upper-right jaw closed. Compare with Fig. 10(a).

CALCULATION OF THE TIME OF FLIGHT

$$T(M_1) \approx T(M_0) + \frac{dT}{ds}(M_0) \Delta s + \frac{d^2T}{ds^2}(M_0) \frac{\Delta s^2}{2} + \frac{d^3T}{ds^3}(M_0) \frac{\Delta s^3}{3!} + \frac{d^4T}{ds^4}(M_0) \frac{\Delta s^4}{4!} \quad (13)$$

Calculation involves the derivatives $dT/ds = 1/v$, $d^2T/ds^2 = d(1/v)/ds$, etc., these are obtained from :

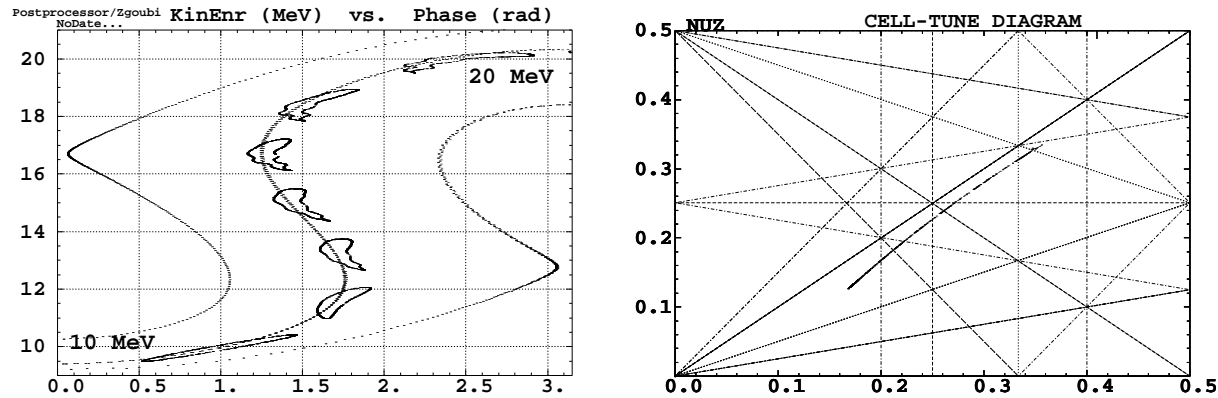
$$\begin{aligned} \left(\frac{1}{v}\right) &= \frac{1}{c^2} \frac{W+m_0c^2}{qB\rho} \\ \left(\frac{1}{v}\right)' &= \frac{1}{c^2} \frac{(\vec{e} \cdot \vec{u})}{B\rho} - \frac{1}{v} \frac{(B\rho)'}{B\rho} \\ \left(\frac{1}{v}\right)'' &= \frac{1}{c^2} \frac{(\vec{e} \cdot \vec{u})'}{B\rho} - 2 \left(\frac{1}{v}\right)' \frac{(B\rho)'}{B\rho} - \frac{1}{v} \frac{(B\rho)''}{B\rho} \\ \left(\frac{1}{v}\right)''' &= \frac{1}{c^2} \frac{(\vec{e} \cdot \vec{u})''}{B\rho} - 3 \left(\frac{1}{v}\right)'' \frac{(B\rho)'}{B\rho} - 3 \left(\frac{1}{v}\right)' \frac{(B\rho)''}{B\rho} - \frac{1}{v} \frac{(B\rho)'''}{B\rho} \end{aligned} \quad (14)$$

• Note that, in the absence of electric field, the Taylor expansion above reduces to (fortunately)

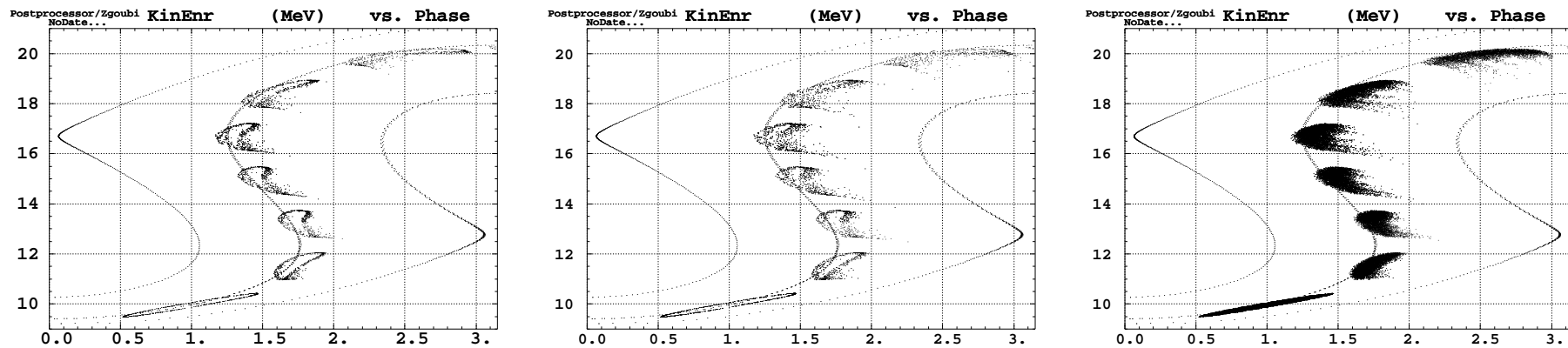
$$T(M_1) = T(M_0) + \Delta s/v \quad (15)$$

EXAMPLE - USE OF THE TOF BY 'CAVITE'

- Longitudinal motion EMMA, electrons, 10 → 20 MeV - similar : muon acceleration in NuFact

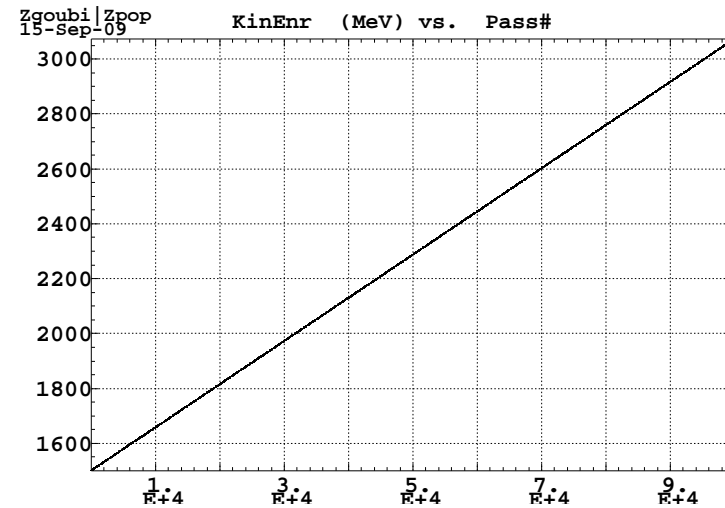
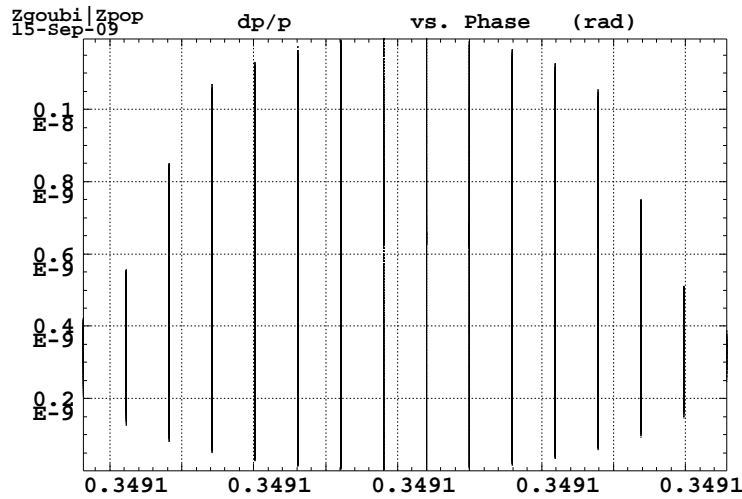


10 to 20 MeV, 125 cavity passes. Voltage : 70 kV peak, RF freq. : 1.3552 GHz.

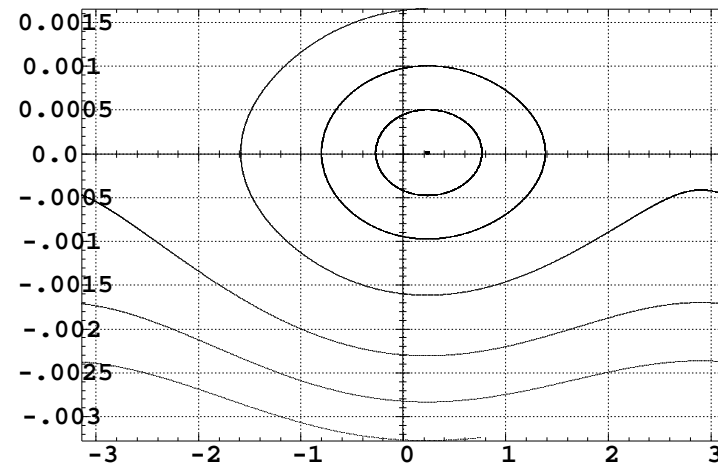


Case of non-zero transverse emittance. Left : $\epsilon_{x,z} = 90\pi$ mm.mrad norm. Middle : $\epsilon_{x,z} = 200\pi$ mm.mrad norm. Right : full 6-D acceleration.

Long term tracking including synchrotron motion



- 140000 turns in AGS, $1.5 \rightarrow 3$ GeV, $\dot{B} = 2.104$ T/s, synchrotrous particle.



- 3 GeV proton synchrotron, 105 m circumference, accelerating bucket, $\dot{B} = 4.2$ T/s.
 - Momentum acceptance : theoretical $1.65 \cdot 10^{-3}$, numerical $1.65 \cdot 10^{-3}$

3 SPIN TRACKING

- The equation of spin precession

$$\frac{d\vec{S}}{dt} = \frac{q}{m} \vec{S} \times \vec{\Omega}, \quad \text{with} \quad \vec{\Omega} = (1 + \gamma G)\vec{b} + G(1 - \gamma)\vec{b}_{//}$$

Normalizing as earlier (remember : “ $u' = u \times \vec{B}$ ”) using $ds = vdt$, $\gamma mv = qB\rho$, $\omega = \Omega/B\rho$, etc., yields the form handled in the Fortran :

$$\boxed{\vec{S}' = \vec{S} \times \vec{\omega}}$$

- $\vec{S}(M_1)$ following a displacement Δs , is obtained from $\vec{S}(M_0)$ using truncated Taylor expansion

$$\vec{S}(M_1) \approx \vec{S}(M_0) + \frac{d\vec{S}}{ds}(M_0) \Delta s + \frac{d^2\vec{S}}{ds^2}(M_0) \frac{\Delta s^2}{2} + \frac{d^3\vec{S}}{ds^3}(M_0) \frac{\Delta s^3}{3!} + \frac{d^4\vec{S}}{ds^4}(M_0) \frac{\Delta s^4}{4!}$$

- Recurrent differentiation yields the $d^n \vec{S} / ds^n$ and $d^n \vec{B}_{//} / ds^n$ and at M_0 :

$$\vec{S}' = \vec{S} \times \vec{\omega}, \quad \vec{S}'' = \vec{S}' \times \vec{\omega} + \vec{S} \times \vec{\omega}', \quad \vec{S}''' = \vec{S}'' \times \vec{\omega} + 2\vec{S}' \times \vec{\omega}' + \vec{S} \times \vec{\omega}'', \quad , \text{etc.}$$

$$\vec{B}_{//} = (\vec{B} \cdot \vec{u}) \vec{u}, \quad \vec{B}'_{//} = (\vec{B}' \cdot \vec{u} + \vec{B} \cdot \vec{u}') \vec{u} + (\vec{B} \cdot \vec{u}) \vec{u}', \quad \text{etc.}$$

SPIN TRACKING AT AGS

$$\gamma G = 48 - \nu_z \text{ (19.59585 GeV)}$$

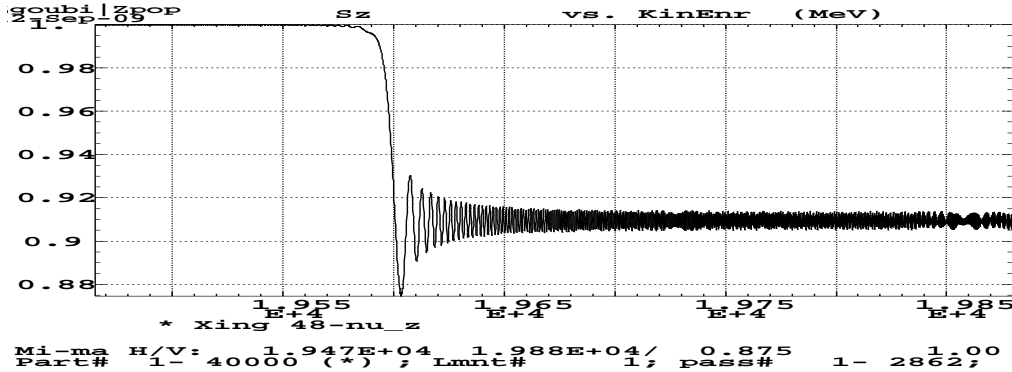
Typical particle and “power supply” data :

```
Xing 48-nu
'OBJET'
67.98605e3
8
  1  1  1
-0.64319816e-2 -0.49829722e-3  0.0 0.0E+00  0.0E+00  1.  'p'
-1.588  19.843  0.
1.033  11.675  0.5 to 2e-6
  0  1  0.
'SCALING'
1  2
MULTIPOL SBEN
-1
67.98605
1
MULTIPOL QUAD
-1
67.98605
1
```

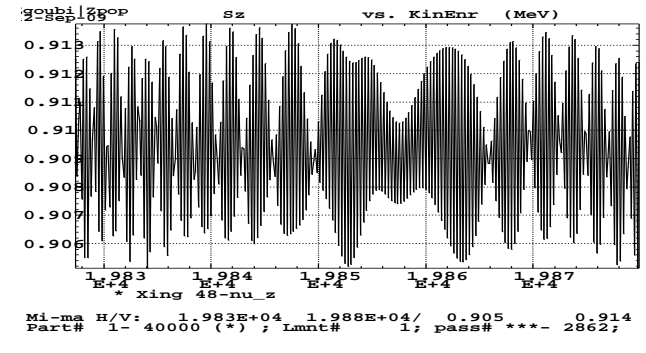
• Resonance strength for various vertical invariant values.

ϵ_z/π ($\times 10^{-6}$)	A^2	$ J_n ^2$	$A^2/\epsilon_z/\pi$	$ J_n ^2/\epsilon_z/\pi$	p_{init}	p_{final}
.125	0.04630575	1.2999233E-06	370446.0	10.39939	1	0.9095
.25	0.09862635	2.7686992E-06	394505.4	11.07480	0.9998	0.812
.5	0.1913054	5.3704412E-06	382610.8	10.74088	0.9996	0.6515
1	0.3895315	1.0935165E-05	389531.5	10.93517	0.9993	0.3545
2	0.8073937	2.2665648E-05	403696.8	11.33282	0.9985	-0.1078

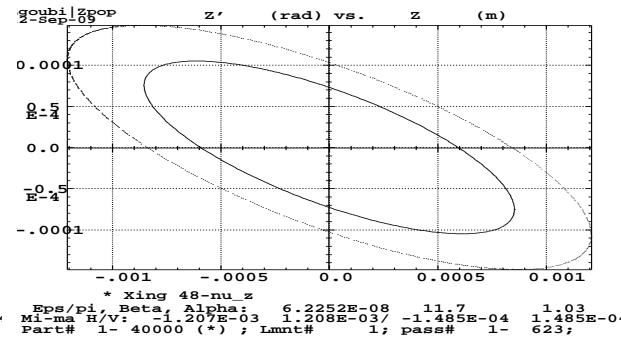
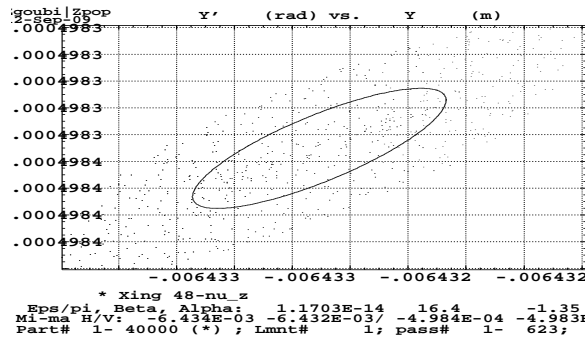
Crossing $\gamma G = 48 - \nu_z$ (19.59585 GeV), $\dot{B} = 2.104 T/s$, $\epsilon_z/\pi = 0.125 \cdot 10^{-6}$



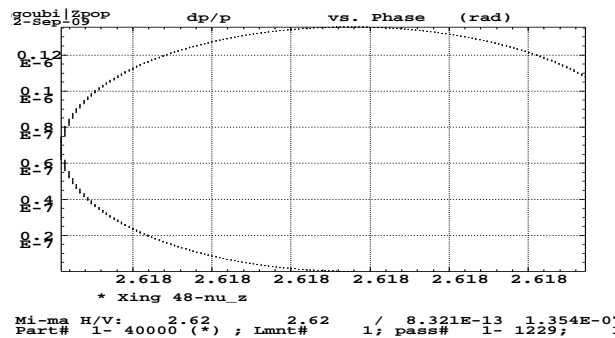
• S_z versus kinetic energy.



• Zoom on final S_z .

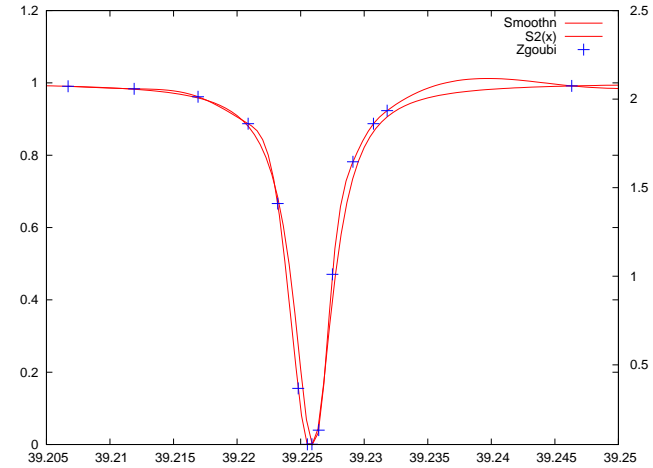
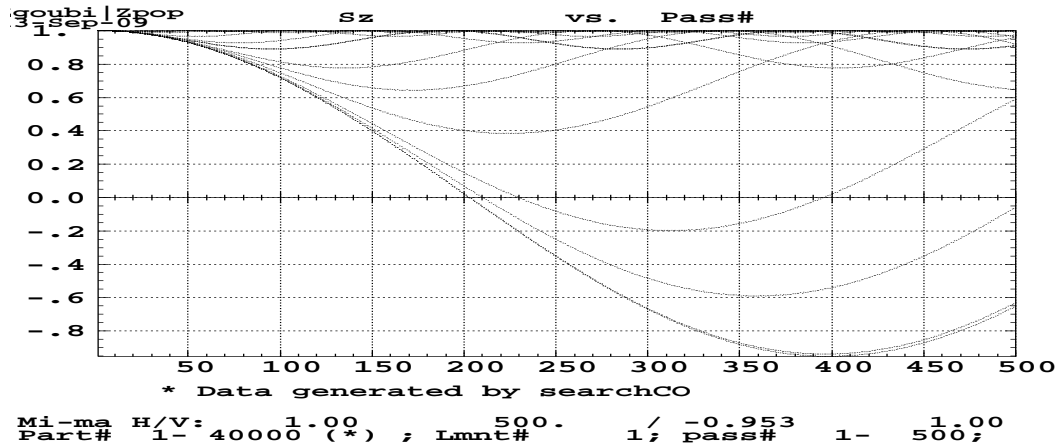


• x-x' and z-z'.

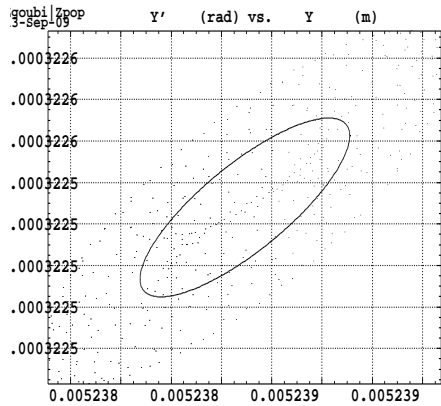


• dp-phase (1350 turns).

Static, $\gamma G = 48 - \nu_z$ (19.59585 GeV) - $\epsilon_z/\pi = 0.125 \cdot 10^{-6}$

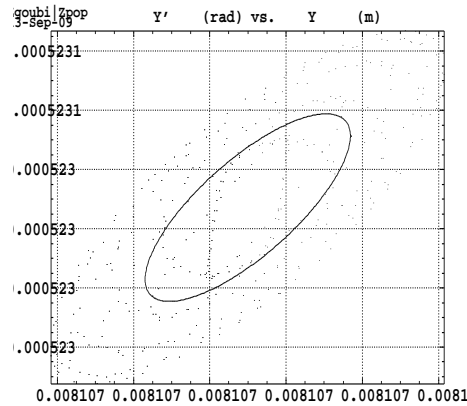


- Top : S_z versus turn number. Bottom : matching with $\bar{S}_z = \left(\frac{\Delta^2}{\Delta^2 + \epsilon^2} \right)^{1/2}$



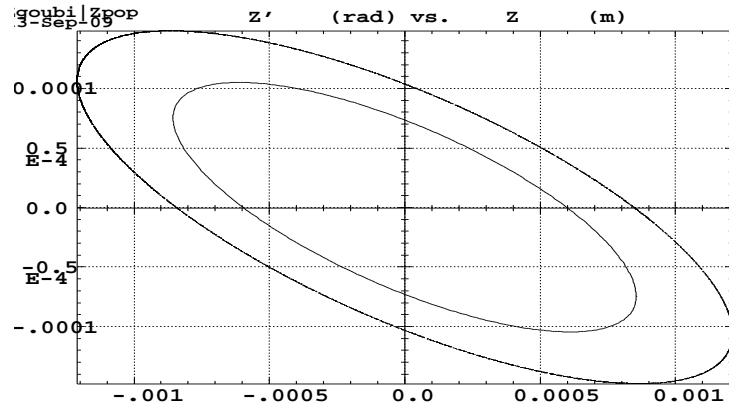
* Data generated by searchCO

Eps/pi, Beta, Alpha: 1.0753E-14 16.2 -1.34
Mi-ma H/V: 5.238E-03 5.239E-03/ 3.224E-04 3.226E-04
Part# 1- 1 (*); Lmnt# 1; pass# 1- 400;



* Data generated by searchCO

Eps/pi, Beta, Alpha: 5.4988E-15 13.2 -1.19
Mi-ma H/V: 8.107E-03 8.108E-03/ 5.230E-04 5.231E-04
Part# 12- 12 (*); Lmnt# 1; pass# 1- 400;



* Data generated by searchCO

Eps/pi, Beta, Alpha: 6.2610E-08 11.7 1.02
Mi-ma H/V: -1.210E-03 1.210E-03/ -1.482E-04 1.482E-04
Part# 1- 1111 (*); Lmnt# 1; pass# 1- 400;

- Left : x-x' of particles at min. and max. p/p_0 . Right : z-z' (all particles superimposed).

4 SYNCHROTRON RADIATION

- Zgoubi allows the simulation of two types of synchrotron radiation (SR) effects
 - stochastic energy loss and ensuing perturbation on particle dynamics
 - radiated spectral-angular energy densities observed in the lab.

Energy loss and related dynamical effects

- The energy loss is calculated after each integration step Δs , in a classical manner, accounting for two random processes :
 - probability of emission of a photon
 - energy of the photon.
- Effects on the dynamic of the emitting particle :
 - alteration of the energy, or extended to
 - angular kick effect

- Main aspects of the method :

- The probability of emission of a photon follows a Poisson distribution (very small number of photons emitted within a step Δs)

$$p(k) = \frac{\lambda^{-k}}{k!} \exp(-\lambda), \quad \text{with} \quad \lambda = \frac{20er_0}{8\bar{h}\sqrt{3}} \beta^2 B\rho \Delta s$$

- k is the number of photons emitted over Δs

For instance :

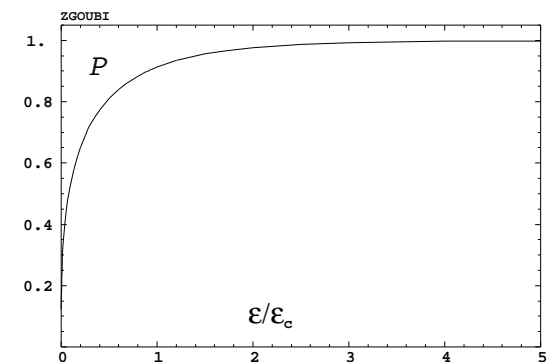
a 1 GeV electron will emit about 20.6 photons per radian; an integration step size $\Delta s = 0.1$ m upon $\rho = 10$ m bending radius results in 0.2 photons per step

- λ is evaluated at each integration step from the current values β , $B\rho$ and Δs , then a value of k is drawn by a rejection method.

- Energy of the k photons is taken at random in :

$$\mathcal{P}(\epsilon/\epsilon_c) = \frac{3}{5\pi} \int_0^{\epsilon/\epsilon_c} \int_{\epsilon/\epsilon_c}^{\infty} K_{5/3}(x) dx$$

$\epsilon_c = \bar{h}\omega_c$, $\omega_c = 2\pi 3\gamma^3 c/2\rho =$ **critical frequency.**



Example - Emittance increase in the e^+e^- linear collider beam delivery system

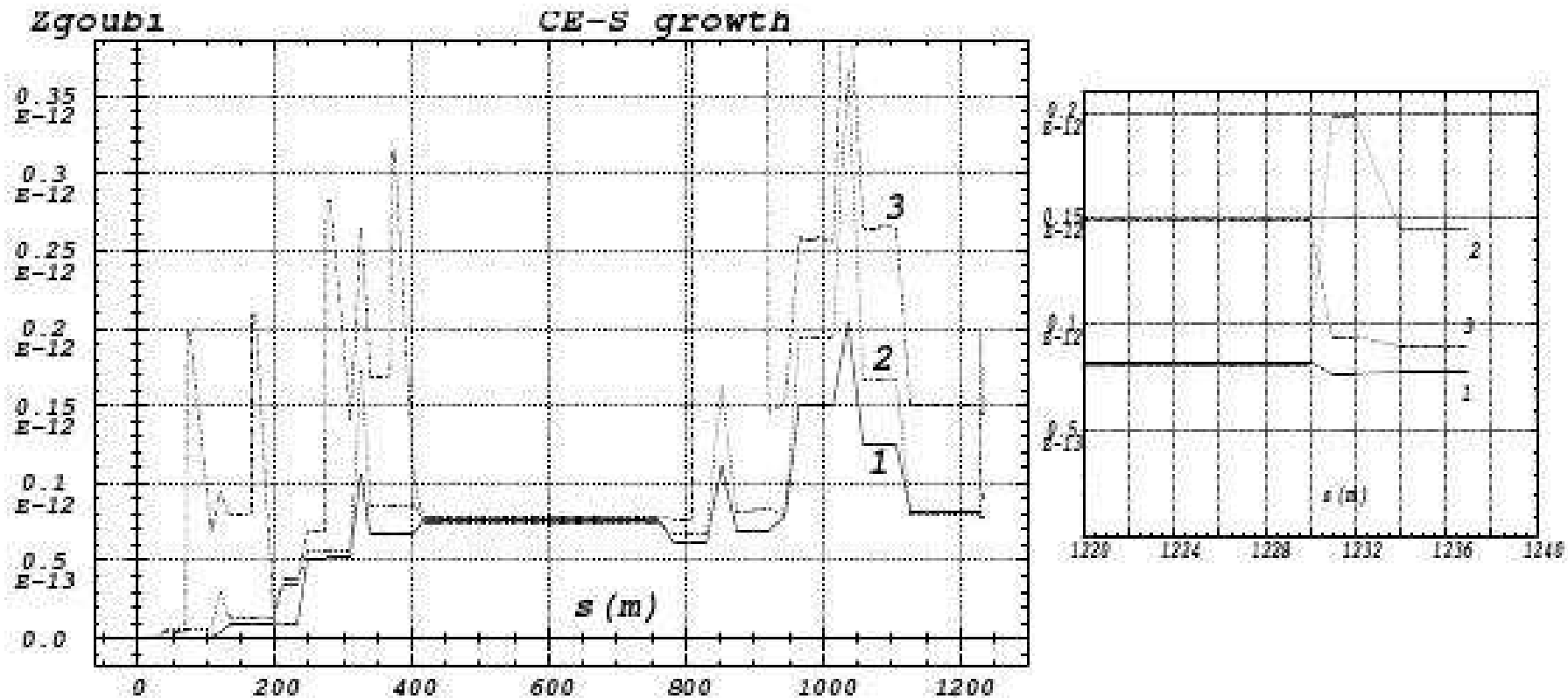
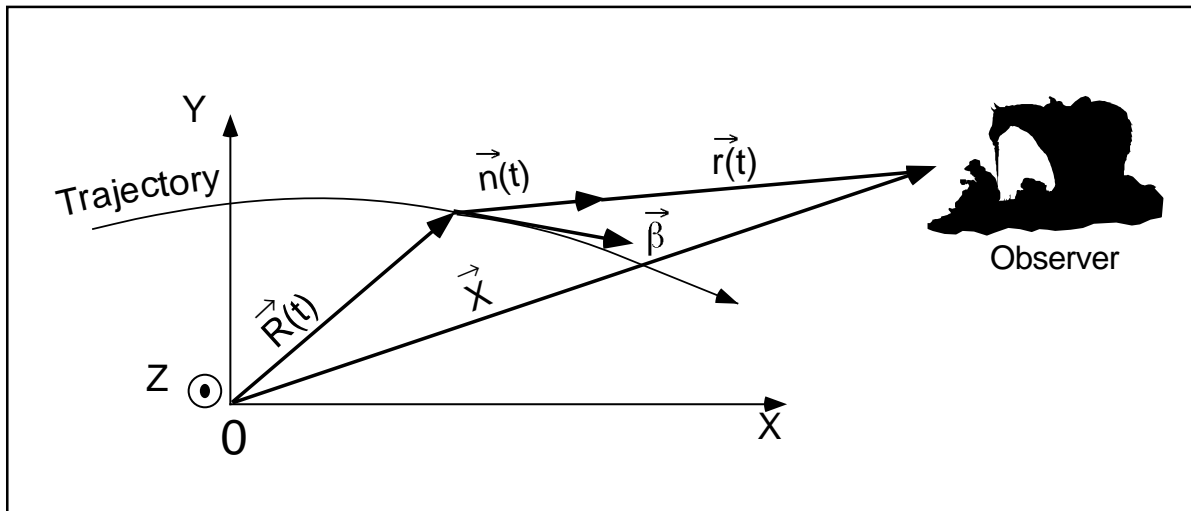


Figure 9: Horizontal CE-S variation ($S_{xx}/\pi(s) - S_{xx}/\pi(0)$) along TESLA-bds as obtained from the ray-tracing of $2 \cdot 10^4$ particles, in various cases of SR simulation (resp^{ly} 1, 2 and 3 in Table 1) :

- solid line : zero initial emittances, sextupoles off ;
- dashed line : initial emittances $\epsilon_x = 10^{-11}$, $\epsilon_z = 10^{-14}$ m.rad, sextupoles off ;
- dotted line : initial emittances $\epsilon_x = 10^{-11}$, $\epsilon_z = 10^{-14}$ m.rad, sextupoles are excited.

The last case shows a strong overshoot (cut out on the Figure) in the $s \approx 850$ m region due to chromatic distortions (see page 16) : this effect appears also in the low- β quad and FF region zoomed on the right plot (broken lines are due to particle coordinates being saved only at optical element ends).

Spectral-angular radiated densities



The ray-tracing ingredients provide the toolkit to compute

$$\vec{\mathcal{E}}(\vec{n}, \tau) = \frac{q}{4\pi\epsilon_0 c} \frac{\vec{n}(t) \times \left[\left(\vec{n}(t) - \vec{\beta}(t) \right) \times d\vec{\beta}/dt \right]}{r(t) \left(1 - \vec{n}(t) \cdot \vec{\beta}(t) \right)^3}, \quad \mathcal{B} = \vec{n} \times \vec{\mathcal{E}}/c$$

In the toolkit, amongst other tools :

$$d\tau/dt = 1 - \vec{n}(t) \cdot \vec{\beta}(t)$$

$$d\vec{\beta}/dt = (q/m) \vec{\beta}(t) \times \vec{b}(t)$$

$$\vec{r}(t) = \vec{X} - R(t) \text{ and } \vec{n}(t) = \vec{r}(t)/|\vec{r}(t)|$$

$$\begin{aligned}\vec{n} &= (n_x, n_y, n_z) = (\cos \psi \cos \phi, \cos \psi \sin \phi, \sin \psi) \\ &= \left[1 - 2(\sin^2 \phi/2 + \sin^2 \psi/2) + 4 \sin^2 \phi/2 \sin^2 \psi/2, \sin \phi(1 - 2 \sin^2 \psi/2), \sin \psi \right]\end{aligned}$$

ϕ and ψ are the observation angles, given by

$$\begin{aligned}\vec{\beta} &= (\beta_x, \beta_y, \beta_z) = \left[\sqrt{(\beta^2 - \beta_y^2 - \beta_z^2)}, \beta_y, \beta_z \right] \\ &= \left[\sqrt{(1 - 1/\gamma^2 - \beta_y^2 - \beta_z^2)}, \beta_y, \beta_z \right] = (1 - a/2 + a^2/8 - a^3/16 + \dots, \beta_y, \beta_z)\end{aligned}$$

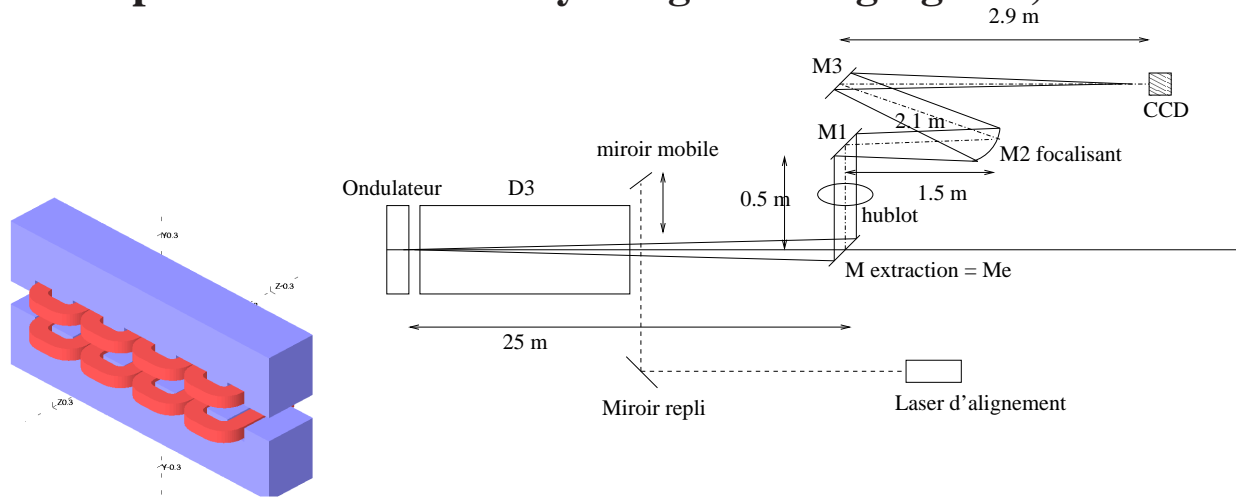
$$a = 1/\gamma^2 + \beta_y^2 + \beta_z^2$$

- The electric field of the radiation is then Fourier transformed, yielding the spectral angular energy density

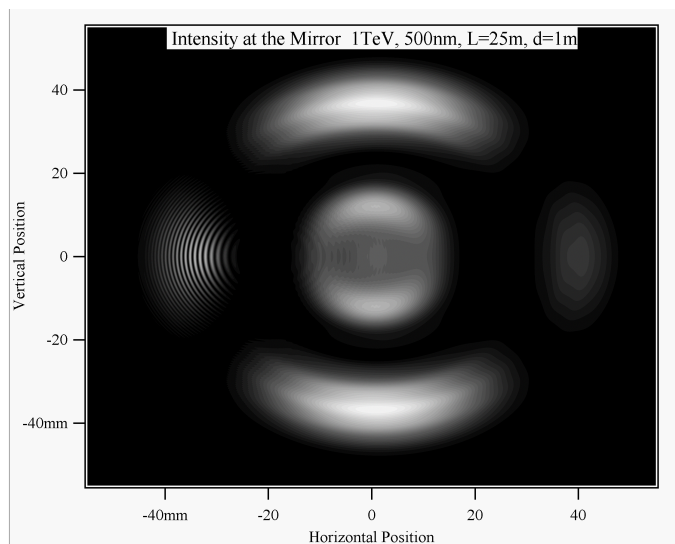
$$\partial^3 W / \partial \phi \partial \psi \partial \omega = 2r^2 \left| FT_\omega \left(\vec{\mathcal{E}}(\tau) \right) \right|^2 / \mu_0 c$$

EXAMPLE - Design of the SR beam diagnostics installations at LHC

This experience has been fully designed using Zgoubi, and then checked using SRW (ESRF).



LHC undulator upstream of a long dipole, and the optical system, drawn on that of LEP.



Intensity emitted (horizontal component) by 1 TeV protons, $\lambda = 500 \text{ nm}$, with a distance $d = 1 \text{ m}$ between the two sources, simulated with Zgoubi (left) and with SRW (right).

5 THE FITTING PROCEDURE

An indispensable tool for

- preliminary adjustments (tunes, etc.) prior to 6-D simulations
- considered very useful for further assessment and optimisation of higher order behavior, DA, transmission, ...

FIT CONSTRAINTS :

Trajectory coordinates (e.g., final coordinates)

Several other types of quantities that are deduced from trajectories, e.g. :

- first and higher order transport coefficients
- beam matrix coefficients (waist, divergence)
- particle fluxes through ellipses (→ transmission efficiency)

- New ! Spin coordinates

In the case of periodic structures :

- closed orbits
- tunes, chromaticities, anharmonicities
- New ! Spin closed orbit**

FIT VARIABLES : all data !

```

'OBJET' * c.o., constant Gap *
226.8235847      68MeV/c muon
2
2 1
499.377      0.      0.      0.      0.      1.2      'b'
1 1 1 1 1 1 1 1 1
'FFAG'
0
3 45.      500.      NMAG, Sector angle, R0
18.17      0.      -0.717      5.      mag 1 : ACNT, dum, B0, K
6.3 0.      EFB 1 : lambda, gap const/varbl
4 .1455      2.2670      -.6395      1.1558      0. 0. 0.
1.23 0.      1.E6      -1.E6      1.E6      1.E6
6.3 0.      EFB 2
4 .1455      2.2670      -.6395      1.1558      0. 0. 0.
-1.23 0.      1.E6      -1.E6      1.E6      1.E6
0. -1      EFB 3 : inhibited by iop=0
0 0.      0.      0.      0.      0. 0. 0.
0. 0.      0.      0.      0. 0.
22.5 0.      3.2      5.      mag 2 : ACNT, B0, K,dums
6.3 0.      EFB 1
4 .1455      2.2670      -.6395      1.1558      0. 0. 0.
3. 0.      1.E6      -1.E6      1.E6      1.E6
6.3 0.      EFB 2
4 .1455      2.2670      -.6395      1.1558      0. 0. 0.
-3 0.      1.E6      -1.E6      1.E6      1.E6
0. -1      EFB 3
0 0.      0.      0.      0.      0. 0. 0.
0. 0.      0.      0.      0. 0.
26.83 0.      -0.717      5.      mag 3 : ACNT, dum, B0, K
6.3 0.      EFB 1
4 .1455      2.2670      -.6395      1.1558      0. 0. 0.
1.23 0.      1.E6      -1.E6      1.E6      1.E6
6.3 0.      EFB 2
4 .1455      2.2670      -.6395      1.1558      0. 0. 0.
-1.23 0.      1.E6      -1.E6      1.E6      1.E6
0. -1      EFB 3
0 0.      0.      0.      0.      0. 0. 0.
0. 0.      0.      0.      0. 0.
0      2 125.      KIRD anal/num, resol(mesh=step/resol)
.5      integration step size
2 0. 0. 0. 0.

```

6 Zgoubi's KEYWORDS/PROCEDURES

Glossary of keywords

AIMANT	Generation of a dipole magnet mid-plane 2-D map	73	MATRIX	Calculation of transfer coefficients, periodic parameters	138
AUTOREF	Automatic transformation to a new reference frame	78	MCDESINT	Monte-Carlo simulation of in-flight decay	61
BEND	Bending magnet	79	MCOBJET	Monte-Carlo generation of a 6-D object	40
BINARY	<i>BINARY/FORMATTED</i> data converter	52	MULTIPOL	Magnetic multipole	115
BREVOL	1-D uniform mesh magnetic field map	80	OBJET	Generation of an object	44
CARTEMES	2-D Cartesian uniform mesh magnetic field map	81	OBJETA	Object from Monte-Carlo simulation of decay reaction	49
CAVITE	Accelerating cavity	83	OCTUPOLE	Octupole magnet	116
CHAMBR	Long transverse aperture limitation	85	ORDRE	Taylor expansions order	63
CHANGREF	Transformation to a new reference frame	86	PARTICUL	Particle characteristics	64
CIBLE	Generate a secondary beam from target interaction	87	PICKUPS	Beam centroid path; closed orbit	139
COLLIMA	Collimator	88	PLOTDATA	Intermediate output for the PLOTDATA graphic software	140
DECAPOLE	Decapole magnet	89	POISSON	Read magnetic field data from <i>POISSON</i> output	117
DIPOLE	Dipole magnet	90	POLARMES	2-D polar mesh magnetic field map	118
DIPOLE-M	Generation of a dipole magnet mid-plane 2-D map	92	PSI70	Simulation of a round shape dipole magnet	119
DIPOLES	Dipole magnet <i>N</i> -tuple	94	QUADISEX	Sharp edge magnetic multipoles	120
DODECAPO	Dodecapole magnet	97	QUADRUPO	Quadrupole magnet	121
DRIFT	Field free drift space	98	REBELOTE	Jump to the beginning of <i>zgoubi</i> input data file	65
EBMULT	Electro-magnetic multipole	99	RESET	Reset counters and flags	66
EL2TUB	Two-tube electrostatic lens	100	SCALING	Time scaling of power supplies and R.F.	67
ELMIR	Electrostatic N-electrode mirror/lens, straight slits	101	SEPARA	Wien Filter - analytical simulation	123
ELMIRC	Electrostatic N-electrode mirror/lens, circular slits	102	SEXQUAD	Sharp edge magnetic multipole	120
ELMULT	Electric multipole	103	SEXTUPOL	Sextupole magnet	124
ELREVOL	1-D uniform mesh electric field map	105	SOLENOID	Solenoid	125
EMMA	2-D Cartesian or cylindrical mesh field map for EMMA FFAg	106	SPNPRNL	Store spin coordinates into file FNAME	141
END	End of input data list ; see FIN	53	SPNPRT	Print spin coordinates	141
ESL	Field free drift space	98	SPNSTORE	Store spin coordinates every <i>IP</i> other pass at labeled elements	141
FAISCEAU	Print particle coordinates	134	SPNTRK	Spin tracking	69
FAISCNL	Store particle coordinates in file FNAME	134	SRLOSS	Synchrotron radiation loss	71
FAISTORE	Store coordinates every <i>IP</i> other pass at labeled elements	134	SRPRNT	Print SR loss statistics	142
FFAG	FFAG magnet, <i>N</i> -tuple	107	SYNRAD	Synchrotron radiation spectral-angular densities	72
FFAG-SPI	Spiral FFAG magnet, <i>N</i> -tuple	109	TARGET	Generate a secondary beam from target interaction ; see CIBLE	87
FIN	End of input data list	53	TOSCA	2-D and 3-D Cartesian or cylindrical mesh field map	126
FIT	Fitting procedure	54	TRAROT	Translation-Rotation of the reference frame	127
FOCALE	Particle coordinates and horizontal beam dimension at distance <i>XL</i>	136	TWISS	Calculation of optical parameters ; periodic parameters	143
FOCALEZ	Particle coordinates and vertical beam dimension at distance <i>XL</i>	136	UNDULATOR	Undulator magnet	128
GASCAT	Gas scattering	60	UNIPOT	Unipotential cylindrical electrostatic lens	129
HISTO	1-D histogram	137	VENUS	Simulation of a rectangular dipole magnet	130
IMAGE	Localization and size of horizontal waist	136	WIENFILT	Wien filter	131
IMAGES	Localization and size of horizontal waists	136	YMY	Reverse signs of <i>Y</i> and <i>Z</i> reference axes	132
IMAGESZ	Localization and size of vertical waists	136			
IMAGEZ	Localization and size of vertical waist	136			
MAP2D	2-D Cartesian uniform mesh field map - arbitrary magnetic field	111			
MAP2D-E	2-D Cartesian uniform mesh field map - arbitrary electric field	112			
MARKER	Marker	113			
MATPROD	Matrix transfer	114			

CONCLUSIONS / 1

zgoubi | Get zgoubi at SourceForge.net

<http://sourceforge.net/projects/zgoubi/>

[Click here to find out more!](#)

FIND AND DEVELOP OPEN SOURCE SOFTWARE

[Find Software](#) [Develop](#) [Create Project](#) [Community](#) [Site Support](#) [About](#)

[SourceForge.net](#) > [Find Software](#) > [zgoubi](#)



zgoubi axis by [fmeot](#), [jbergnbl](#)

[Summary](#) [Files](#) [Support](#) [Develop](#)

[Share](#)

[More](#)

zgoubi is a ray-tracing code in use for charged particle beam dynamics simulations. It can simulate beam dynamics in a large variety of machines and optical systems.

Download Now!

[zgoubi-5.0.0-linux-x86](#) (910.3 KIB)

OR

[View all files](#)

<http://zgoubi.sourceforge.net>

edit

[Show project details](#)

Latest Reviews

Be the first to post your review of zgoubi. Rate and review a project by clicking thumbs up or thumbs down in the right column.

Project Feed

Code committed

[fmeot](#) committed revision 197 to the [zgoubi](#) SVN repository, changing 15 files posted by [fmeot](#) 1 days ago

Code committed

[fmeot](#) committed revision 196 to the [zgoubi](#) SVN repository, changing 5 files

Welcome, Guest! [Log In](#) | [Create Account](#)

enter keyword

[Click Here!](#)

Project Reviews

Be the first person to add a review.

Would you recommend this project?

or

Related Projects

No screenshots:

Tracy

Tracy is a library for beam dynamics simulations. It is based on symplectic integrator.

RINGS

RINGS "Rigorous Investigation of Networks Generated using Simulations" is a scientific code ...

Conrad CRF Engine & Gene Caller

Conrad is both a high performance Conditional Random Field engine which can be applied to a ...

CONCLUSIONS / 2

Possibility of a tutorial tomorrow

2h , half a day, A full day !

Thank you for your attention