Manipulation of EMMA field maps in view of ray-tracing simulations and parameter matching

INTRODUCTION (1/3)

(i) Magnet computations have been undertaken regarding the EMMA FD cell, in view of comparisons with field measurements and of producing field maps that can be exploited for ray-tracing purposes

(ii) Field maps exploitable for multi-turn tracking may also be produced from magnetic field measurements (see RACCAM case, PAC09, copy in Appendix)

(iii) Field maps probably yield modelling of the magnetic field closest to magnetic measurements

(iv) Ray-tracing, using field models or field maps, is an excellent way of guaranteeing precision of motion simulation, 4-D and 6-D (see reportCEA-DAPNIA-06-04, FM, 2004

(v) Allowing parameter matching based on EMMA field maps would constitute a good tool to assess machine behavior during commissioning

INTRODUCTION (2/3)

Various arrangements of the F and D quads can be foreseen in generating these field maps, namely,

- Case 1 : a single map with the two quadrupoles in a particular state of field (bf, bd) and a particular radial positioning, (xf, xd)

- Case 2 : a pair of maps, one with D on and F off (yet present), and its reciprocal. Each map can then have its field adjusted independently of the other (assuming linear behavior or close enough), the quad distance (xd-xf) is fixed

- Case 3 : a set of pairs of maps of the previous type, each map pair being characterized by a particular quad distance (xd-xf)

- Case 4 : two separate maps, one for D alone and one for F alone. All four parameters bf, bd, xf, xd are then independent

INTRODUCTION (3/3)

A dedicated procedure has been installed in zgoubi to manipulate these field maps, including the use of the built-in FIT procedure for parameter matching.

These slides describe how these various schemes are supposed to be exploited, using zgoubi, and which ones are convenient for matching purposes.

Case 1 - A single map with the two quadrupoles in a particular state of field (bf, bd) and a particular quadrupole positionning, (xf, xd).

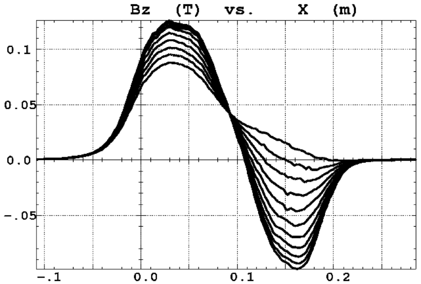
This is a trivial case. The **TOSCA** procedure in zgoubi can be used. It accepts Cartesian and cylindrical field maps.

- **The only variable parameter for FIT purposes is the positioning of the FD block wrt. to the edge of the 42-gone**

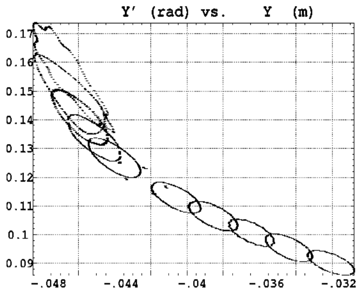
Typical input data list :

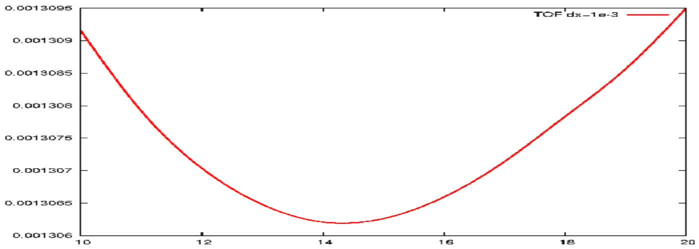
```
Data generated by searchCO
'OBJET'
+5.171103865921708e+01
 2
  11   1                          11 closed orbits  (there are automatic procedures to find these)
 -4.653497E+00  1.556203E+02  1.0E-04  0.0E+00  0.0E+00  6.77210000E-01 '0'      9.999932 MeV
 -4.639023E+00  1.479999E+02  1.0E-04  0.0E+00  0.0E+00  7.41758920E-01 '0'     10.999526 MeV
 -4.592894E+00  1.406840E+02  1.0E-04  0.0E+00  0.0E+00  8.06303420E-01 '0'     11.999224 MeV
 -4.513897E+00  1.335804E+02  1.0E-04  0.0E+00  0.0E+00  8.70847920E-01 '0'     12.999057 MeV
 -4.403899E+00  1.266558E+02  1.0E-04  0.0E+00  0.0E+00  9.35392420E-01 '0'     13.998997 MeV
 -4.248912E+00  1.196375E+02  1.0E-04  0.0E+00  0.0E+00  9.99936920E-01 '0'     14.999023 MeV
 -4.061093E+00  1.127955E+02  1.0E-04  0.0E+00  0.0E+00  1.06448140E+00 '0'     15.999118 MeV
 -3.854773E+00  1.064118E+02  1.0E-04  0.0E+00  0.0E+00  1.12902590E+00 '0'     16.999273 MeV
 -3.640940E+00  1.005393E+02  1.0E-04  0.0E+00  0.0E+00  1.19357040E+00 '0'     17.999476 MeV
 -3.438999E+00  9.534234E+01  1.0E-04  0.0E+00  0.0E+00  1.25811490E+00 '0'     18.999720 MeV
 -3.206953E+00  9.011384E+01  1.0E-04  0.0E+00  0.0E+00  1.32265940E+00 '0'     20.000000 MeV
 1 1 1 1 1 1 1 1 1 1 1
     'PICKUPS'
    1
    #E
    'DRIFT'   a correction to have 39.4481 axis length...
    0.12405
   'TOSCA'
   0  2
   -1E-3  1. 1. 1.
   QPOLES
  394  61 1      0 = MOD                           mod=0 -> field map has caretsian mesh
  Dax265.bothon.perio.table                         Name of field map
   0 0 0 0
   2
   .1
   2 0 0 0
    'DRIFT'   a correction to have 39.4481 axis length...
    0.12405
      'CHANGREF'
        0. 0. -8.57142857152
 'MARKER'  #E
 'END'
```

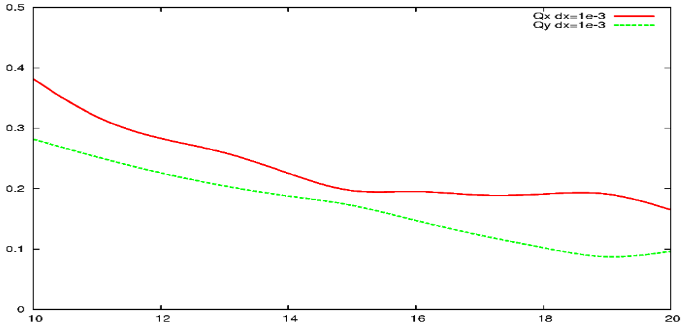
Typical output : B(s), (x,x'), TOF, tunes



* Data generated by searchCO







Case 2 - A pair of maps, one with D on and F off (yet present), and its reciprocal. Each map can then have its field adjusted independently of the other (assuming linear behavior or close enough), the quad distance (xd-xf) is fixed.

What the fortran does : a new, single map is obtained by adding the two.

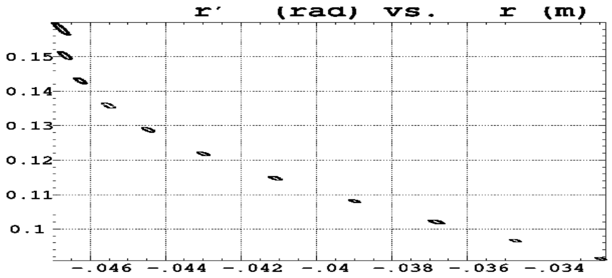
- **bf and bf are FIT-able**
- **Positioning of the FD block with resp. to the 42-gone edge is FIT-able**

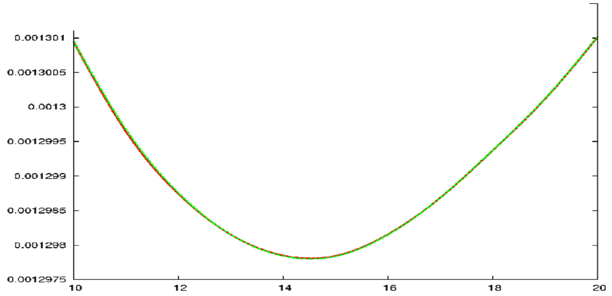
The **EMMA** procedure can be used.

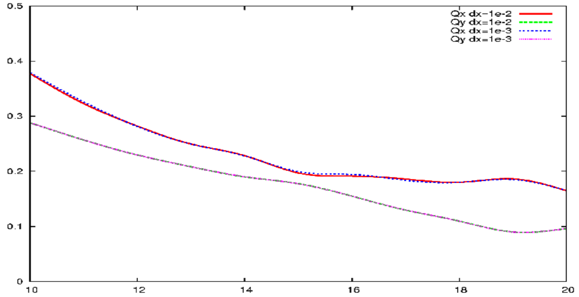
Typical input data list :

```
Data generated by searchCO
'OBJET'
+5.171103865921708e+01
 2
  11   1                           11 closed orbits  (there are automatic procedures to find these)
 ......................
 1 1 1 1 1 1 1 1 1 1 1
     'PICKUPS'
    1
    #E
    'DRIFT'   a correction to have 39.4481 axis length...
    0.12405
     'EMMA'
   0  2
   -1E-3  1. 1. 1.
   QPOLES
   197 81 1   0 =MOD                        mod=0 -> maps have caretsian mesh
   1.  1.  0.                                field coefficients bd,  bf,  xd-xf is unused
 Dax265.Foff.cart.table                     Name of D-on / F-off  field map
 Dax265.Doff.cart.table                      Name of  D-off / F-on   field map
   0 0 0 0
   2
   .1
   2 0 0 0
    'DRIFT'   a correction to have 39.4481 axis length...
    0.12405
      'CHANGREF'
       0. 0. -8.57142857152
 'MARKER'  #E
 'END'
```

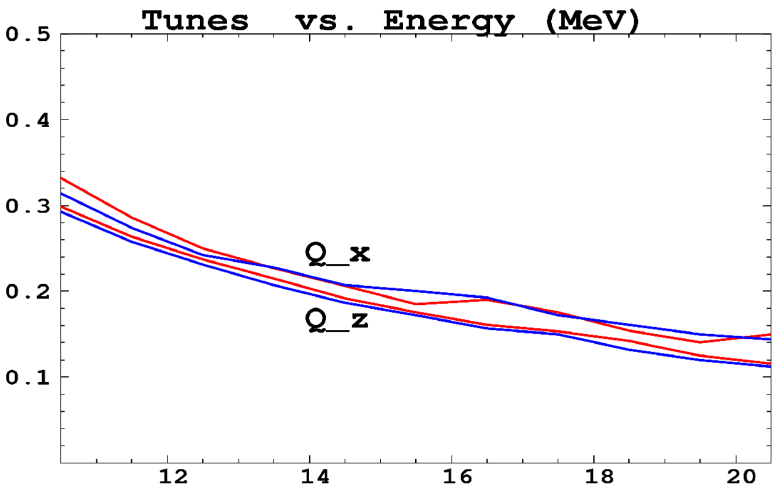
Typical output, (x,x'), TOF, tunes versus energy :



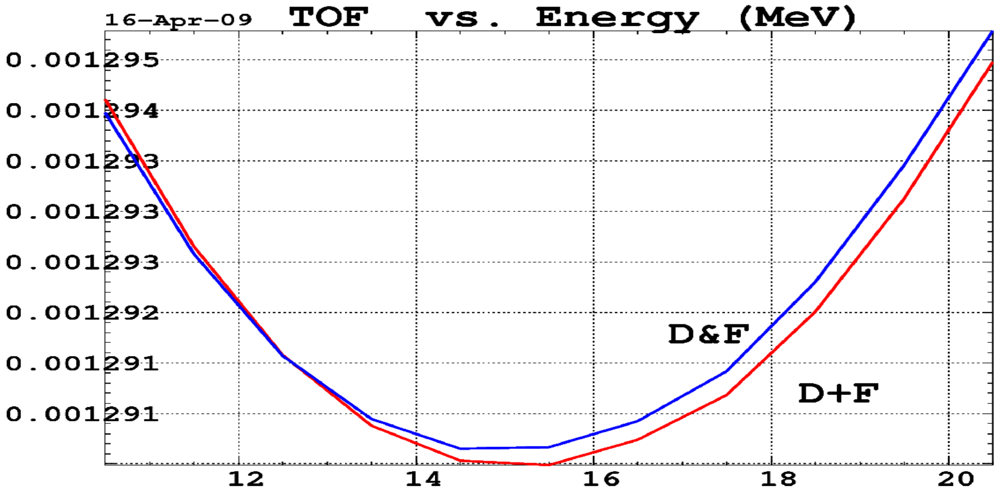




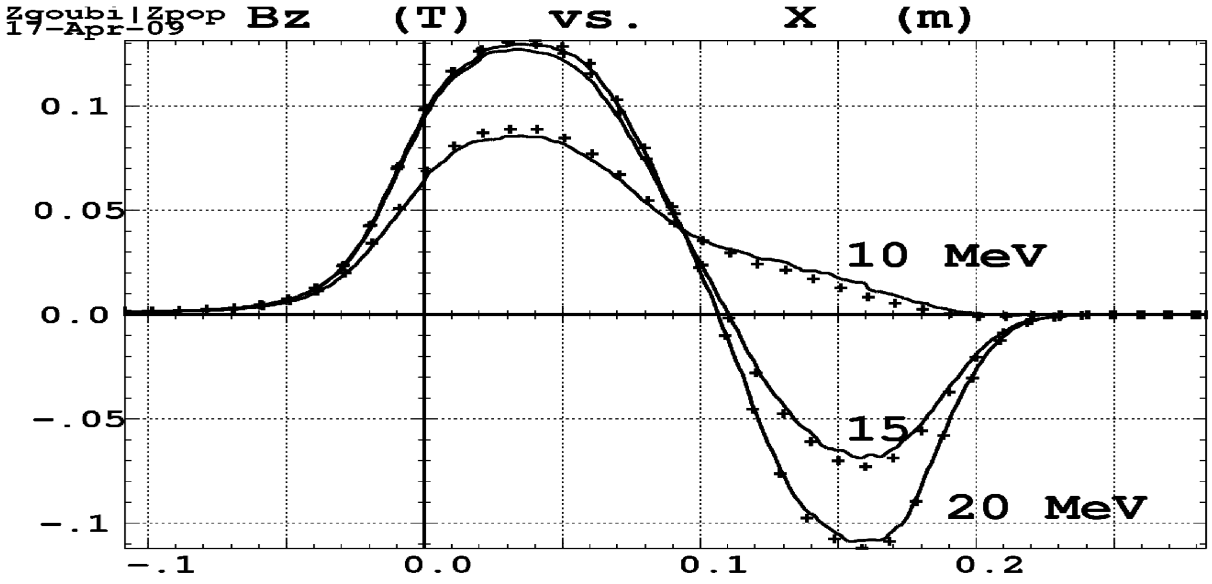
Comparing results from Case 1 and from Case 2 (cf. PAC 09)



Tunes. D&F : blue, D+F : red.



TOF



Field along closed orbits. D&F : solid lines, D+F : markers.

Case 3 - A set of pairs of field maps of the previous kind (Don/Foff, Doff/Fon), each pair being characterized by a particular radial quad distance (xd-xf).
What the fortran does : a new, single map is obtained by interpolation from 2 field map pairs that zgoubi chooses closest to the required (xd-xf).

- **bf and bf are FIT-able, (xf-xd) is FIT-able**
- **Positioning of the FD block with resp. to the 42-gone edge can is FIT-able**

The **EMMA** procedure can be used.

Typical input data list :

```
 Data generated by searchCO
 'OBJET'
 +5.171103865921708e+01
  2
   11   1                              11 closed orbits  (there are automatic procedures to find these)
  ......................
  1 1 1 1 1 1 1 1 1 1 1
      'PICKUPS'
     1
     #E
       'EMMA'                                                            5
      0  0
      -1E-3  1. 1. 1.
    HEADER_9  QPOLES
    101  66  1   24 =MOD                     mod=24 ->  maps have cylindrical  mesh
    1.  1.    2.62                           field coefficients bd,  bf,  required xd-xf= 2.62 cm here
  tableFiles.list                             Name of data file that contains  field map names
    0 0 0 0
      2
      .1
       2
       263.691210410209 0.    266.669690524164592  0.1495996501709425352
      'FAISCEAU'                                                          6
  'MARKER'  #E
  'END'
```

Typical content of tableFiles.list the map file names data file :

Note : the field map file names indicate the (xf-xd) values

Dax200.Doffpolargridcoarse2.table
Dax200.Foffpolargridcoarse2.table
Dax220.Doffpolargridcoarse2.table
Dax220.Foffpolargridcoarse2.table
Dax240.Doffpolargridcoarse2.table
Dax240.Foffpolargridcoarse2.table
Dax260.Doffpolargridcoarse2.table
Dax260.Foffpolargridcoarse2.table
Dax300.Doffpolargridcoarse2.table
Dax300.Foffpolargridcoarse2.table
Dax320.Doffpolargridcoarse2.table
Dax320.Foffpolargridcoarse2.table
Dax340.Doffpolargridcoarse2.table
Dax340.Foffpolargridcoarse2.table
Dax360.Doffpolargridcoarse2.table
Dax360.Foffpolargridcoarse2.table
Dax380.Doffpolargridcoarse2.table
Dax380.Foffpolargridcoarse2.table
Dax400.Doffpolargridcoarse2.table
Dax400.Foffpolargridcoarse2.table
Dax420.Doffpolargridcoarse2.table
Dax420.Foffpolargridcoarse2.table

Case 4 : two separate maps, one for D alone and one for F alone. All four parameters bf, bd, xf, xd are then independent.
What the fortran does : a new, single field map is computed from the two, using the 'CHAMK' second degree polynomial interpolation in zgoubi.

- **bf, bf, xf, xd can be independent FIT variables**

The **EMMA** procedure can be used.

Typical input data list :

```
 Data generated by searchCO
 'OBJET'
 +5.171103865921708e+01
  2
 3   1                  3 closed orbits at 10, 15 and 20 MeV  (there are automatic procedures to find these)
  -4.676687E+00  1.580061E+02  1.0E-04  0.0E+00  0.0E+00  6.77210000E-01 '0'        9.999932 MeV
  -4.300450E+00  1.217784E+02  1.0E-04  0.0E+00  0.0E+00  9.99936920E-01 '0'       14.999023 MeV
  -3.247665E+00  9.134009E+01  1.0E-04  0.0E+00  0.0E+00  1.32265940E+00 '0'       20.000000 MeV
  1 1 1
      'PICKUPS'
     1
     #E
       'EMMA'                                                                5
      0  0
      -1E-3  1. 1. 1.
    HEADER_9  QPOLES
    101  66  1   1 =MOD                           mod=1 ->  maps have cartesian  mesh
    1.  1.    0.  0.                              field coefficients bd,  bf,  required quad positions xd, xf
   Dax265.D.perio.table                           Name of D  field map
   Dax265.F.perio.table                           Name of  F  field map
   0 0 0 0
      2
      .1
       2 0. 0. 0.
      'FAISCEAU'                                                              6
     'CHANGREF'
    10.5  0.  -8.571428571428571429
  'MARKER'  #E
  'END'
```

Using Case 4 ('EMMA' keyword with MOD=1) for FIT-ting TOF and tunes

- We start from closed orbit coordinates (in 'OBJET') corresponding to quad positioning xf=+0.1mm, xd=-0.1mm
- We then set xf=xd=0 instead of +/-0.1mm in 'EMMA' data.
- Then, leaving initial coordinates as sole variables in 'FIT', we request,
  (I) 3 closed orbits and (ii) identical TOF for particles 1 (10 MeV) and 3 (20 MeV)
- The result is below : closed orbit coordinates of case xf=xd=0 are recovered (compare with previous slide)

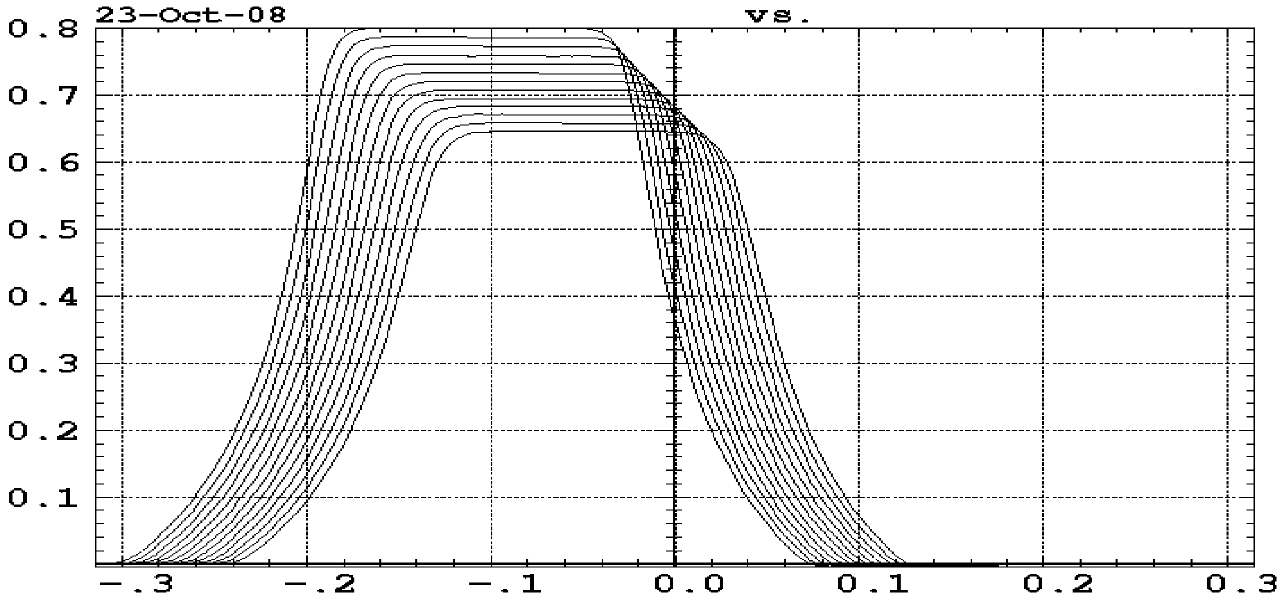
```
Xi2 =       4.71799E-03   Busy...

STATUS OF VARIABLES  (Iteration #   291)
LMNT  VAR  PARAM  MINIMUM     INITIAL      FINAL       MAXIMUM     STEP
  1     1     30      -9.92      -4.68     -4.6829422     0.00     1.990E-13
  1     2     31       0.00      158.      158.27636      336.     6.617E-12
  1     3     40      -9.47      -4.30     -4.3004498     0.00     1.902E-13
  1     4     41       0.00      122.      121.77844      264.     5.196E-12
  1     5     50      -7.43      -3.25     -3.2476651     0.00     1.500E-13
  1     6     51       0.00      91.3      91.340088      199.     3.922E-12
STATUS OF CONSTRAINTS
TYPE  I   J  LMNT#     DESIRED       WEIGHT       REACHED         KI2          *  Parameter(s)
  3    1   2    4       0.0000        0.1000      6.8568641E-03   0.9965        *  0 :                     x0(1)=xf(1)
  3    1   3    4       0.0000        1.000       4.0410647E-03   3.4613E-03    *  0 :                     x'0(1)=x'f(1)
  3    2   2    4       0.0000        0.1000      3.0801139E-10   2.0108E-15    *  0 :                     x0(1)=xf(2)
  3    2   3    4       0.0000        1.000       3.2154901E-10   2.1915E-17    *  0 :                     x0(1)=x'f(2)
  3    3   2    4       0.0000        0.1000      5.6997651E-10   6.8858E-15    *  0 :                     x0(1)=xf(3)
  3    3   3    4       0.0000        1.000       1.0137029E-09   2.1780E-16    *  0 :                     x0(1)=x'f(3)
  3    1   7    4       0.0000        1.000       4.9619763E-08   5.2186E-13    *  1 :   3.   /            TOF(1) = TOF(3)
```

Note : two additional variables may be introduced : instead of setting xf=xd=0 prior to launching the FIT, xf and xd can be left their last value (namely, xf=-0.1mm, xd=+0.1mm) and declared as variables. The FIT will then converge towards xf=xd=0.

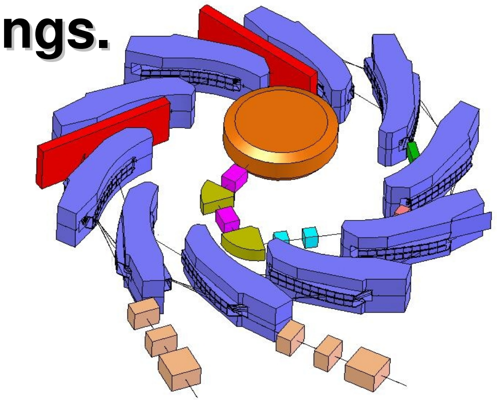
- **RACCAM prototype magnet (1/3)**

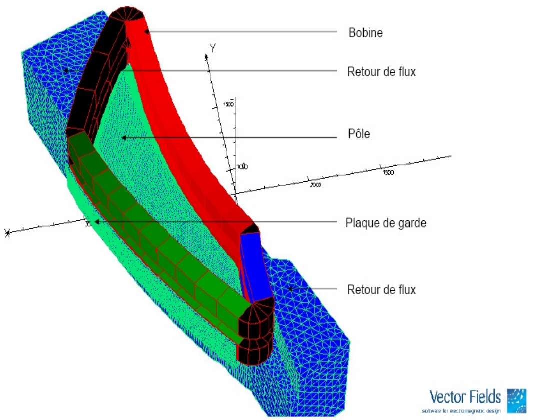
tracking in the measured field maps → see PAC 09 Proceedings.

- **Zero-th order**



Magnetic field measured along 11 arcs, dR=11mm distant. That yields field map with 110mm radial extent, encompassing well the trajectories.





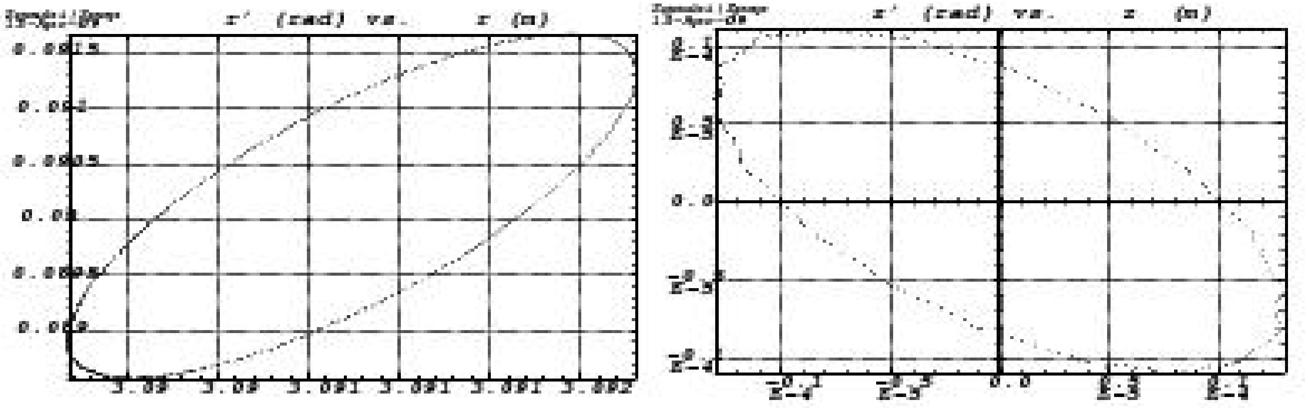
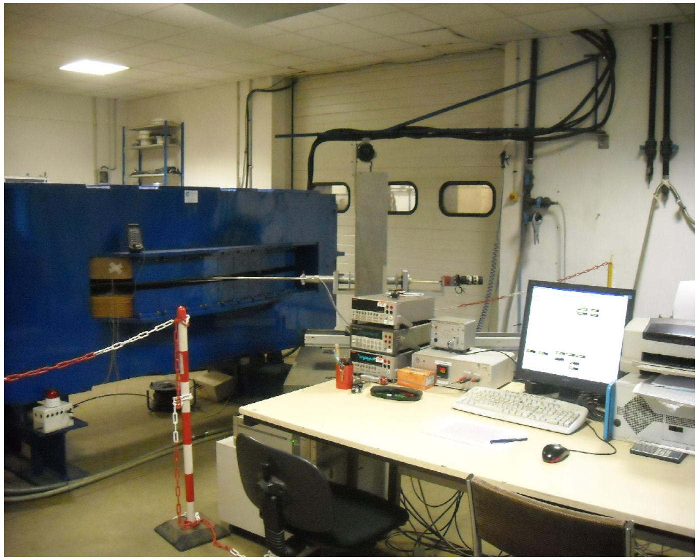
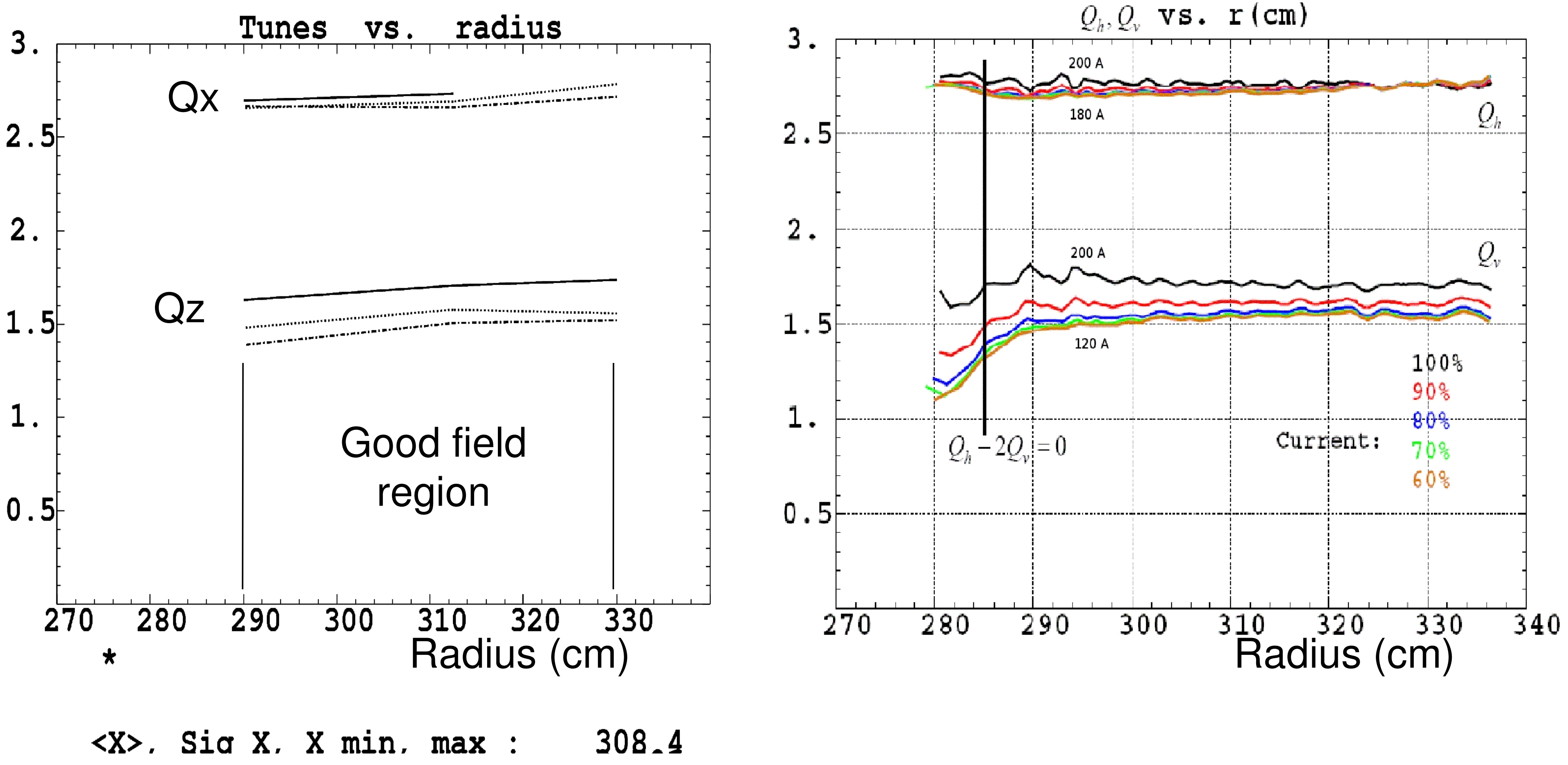


Figure 5: Typical paraxial motion used for tune computation, horizontal (left), vertical (right).



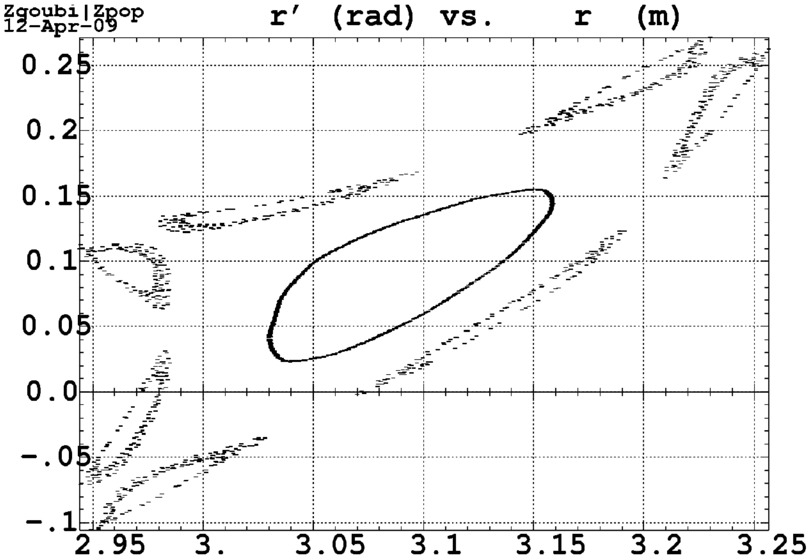
- **RACCAM prototype magnet (2/3)**
- **Tracking in magnetic field maps, first order**

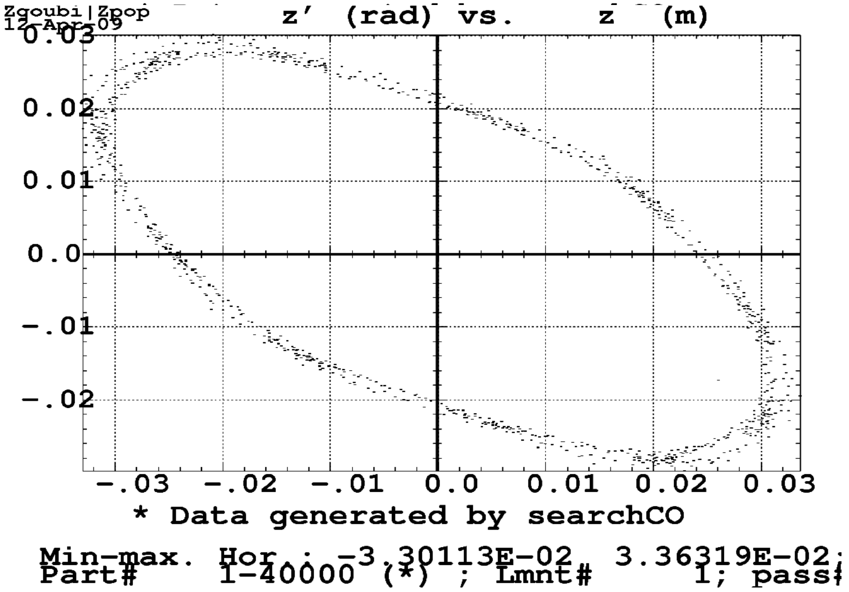
  - Tunes, from magnetic measurements (left) and from design simulations using TOSCA (right)



• RACCAM prototype magnet (3/3)
• Tracking in magnetic field maps, dynamic acceptance

- Very good symplecticity at extreme X and Z excursions...





- Large DA's are obtained, consistent with design specifications

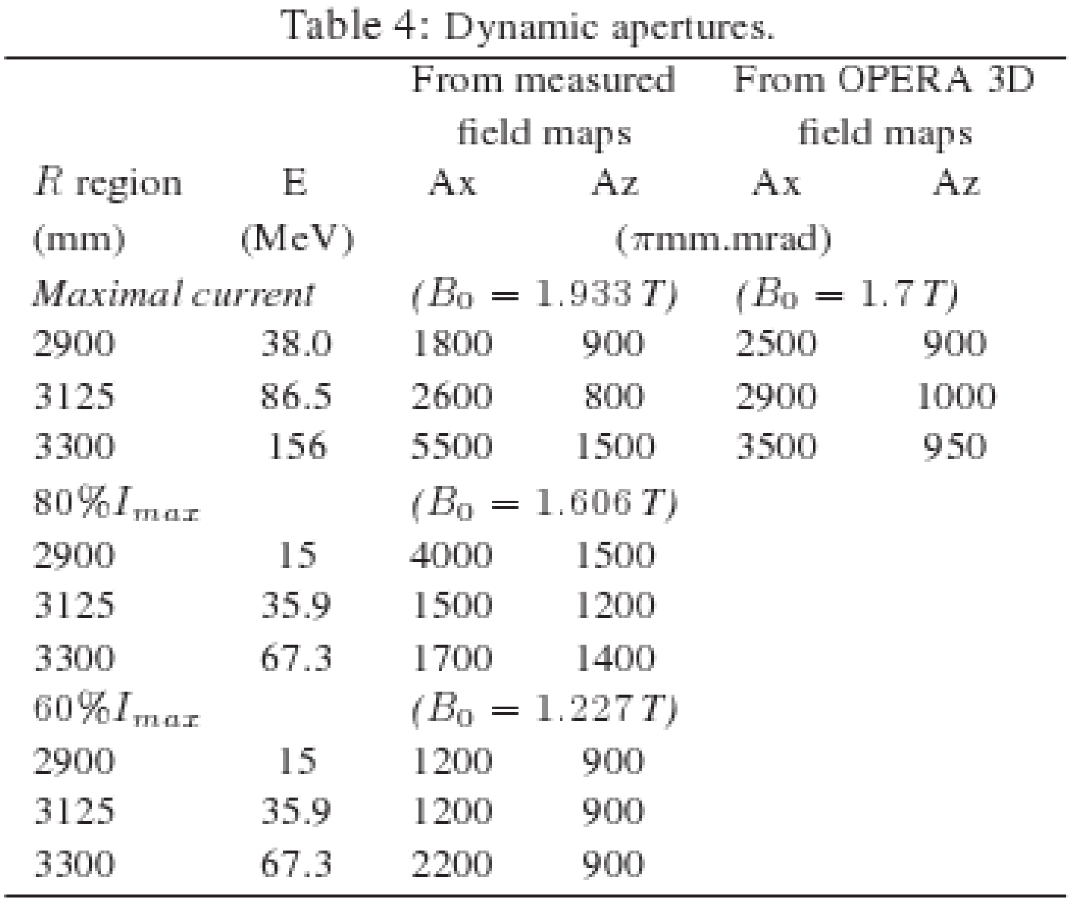


Table 4: Dynamic apertures.

		From measured field maps		From OPERA 3D field maps	
R region	E	Ax	Az	Ax	Az
(mm)	(MeV)		(πmm.mrad)		
Maximal current		$(B_0 = 1.933\,T)$		$(B_0 = 1.7\,T)$	
2900	38.0	1800	900	2500	900
3125	86.5	2600	800	2900	1000
3300	156	5500	1500	3500	950
$80\%I_{max}$		$(B_0 = 1.606\,T)$			
2900	15	4000	1500		
3125	35.9	1500	1200		
3300	67.3	1700	1400		
$60\%I_{max}$		$(B_0 = 1.227\,T)$			
2900	15	1200	900		
3125	35.9	1200	900		
3300	67.3	2200	900		