Geant3 as a tool for Muon Cooling and Acceleration simulations

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Format of talk

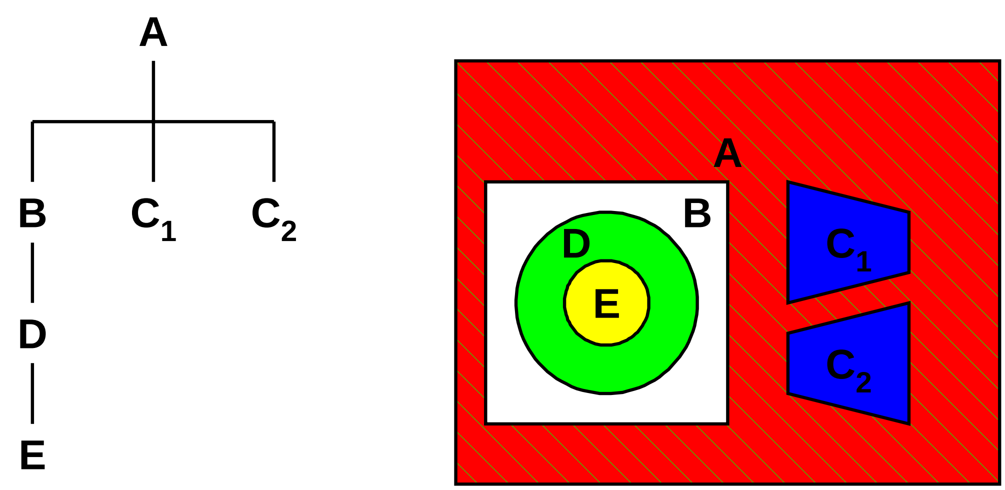
- Geant3- Brief description- Best description to date of dE/dx + particle interactions in a simulation code
- Our contribution- Added data driven geometry
- Added electric fields. Both E+B fields are described in general field maps.
- Coupled it to Minuit- MITER
- Result is a tool which can be used for muon cooling + acceleration simulation.
- Modeling- Algebraic, Cosy, Icool, Geant- Each has its niche.
- Before we build a system it needs the best simulation done
- Injection/Extraction studies

- Data Driven geometry using RCP structures developed for D0 Run I.
- No geometry constants in the code.
- Code is Generic. Geometry information contained in structured RCP files. All different simulations have same structure. Understand one understand all.

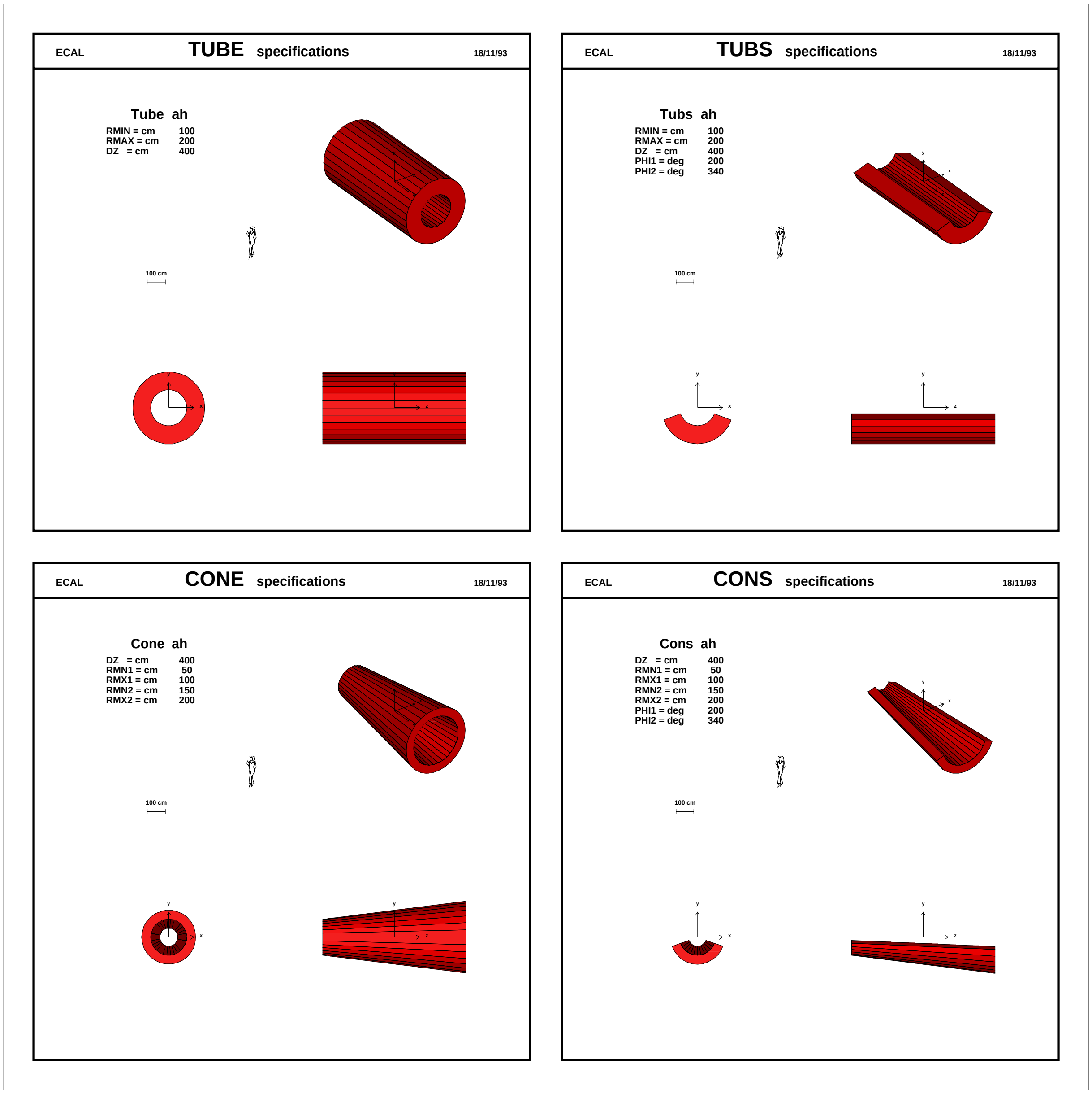
```
\ARRAY DETECTOR_SYSTEMS                                'MOTHERS'
     !media 0-99. rot matrices 0-999
'MUCOOL'                  !media 0-99. rot matrices 0-999
'TARGET'                  !target for internal target measurement
'MAPS'                    !Will DO MAPS between any two points in the ring if
     this RCP file is specified.
\END
```

Geant geometry

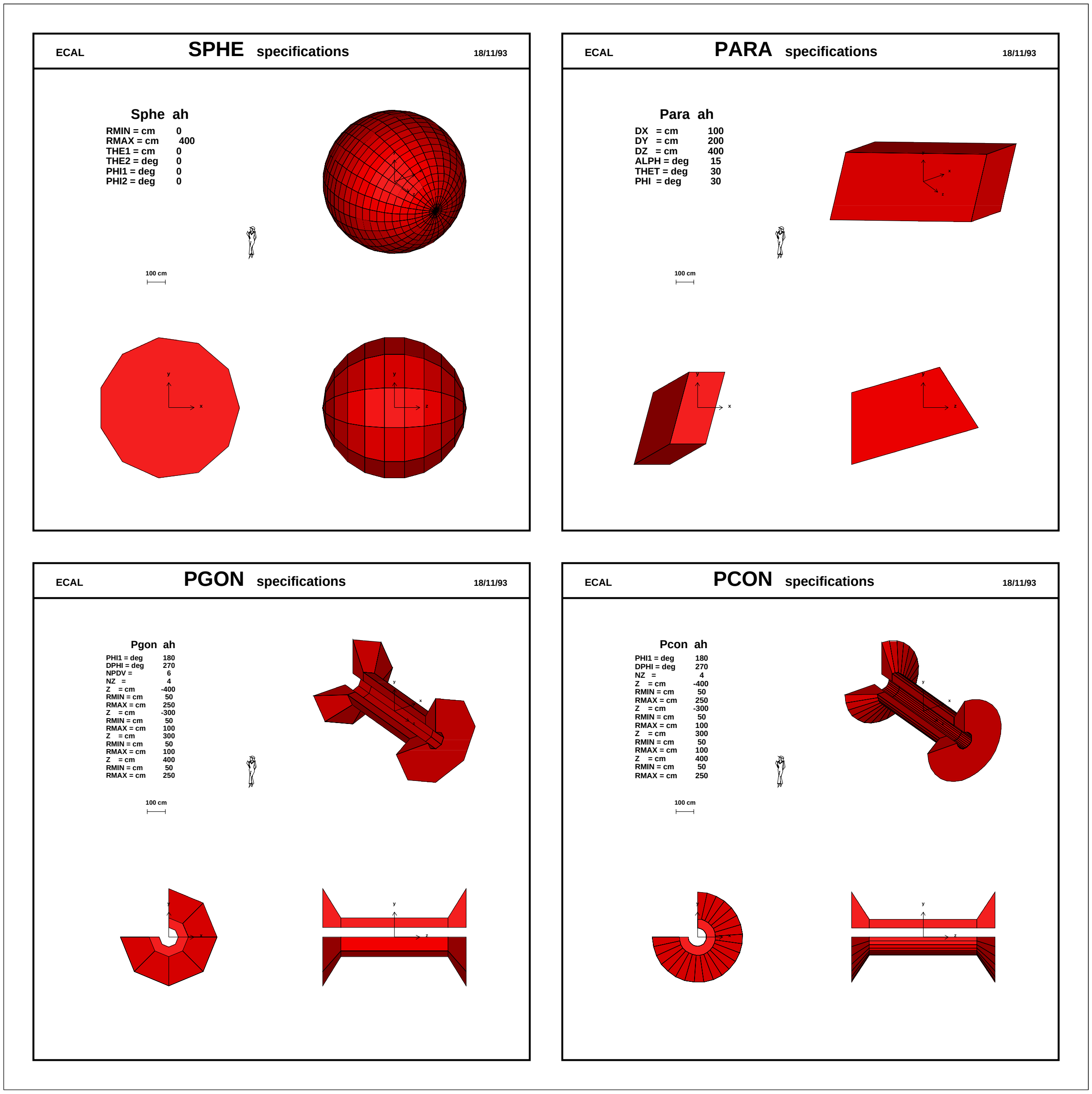
- Geant geometry description is like a "Matryushka doll" Mother volume contains daughter volumes in several layers. Complex shapes can be simulated.



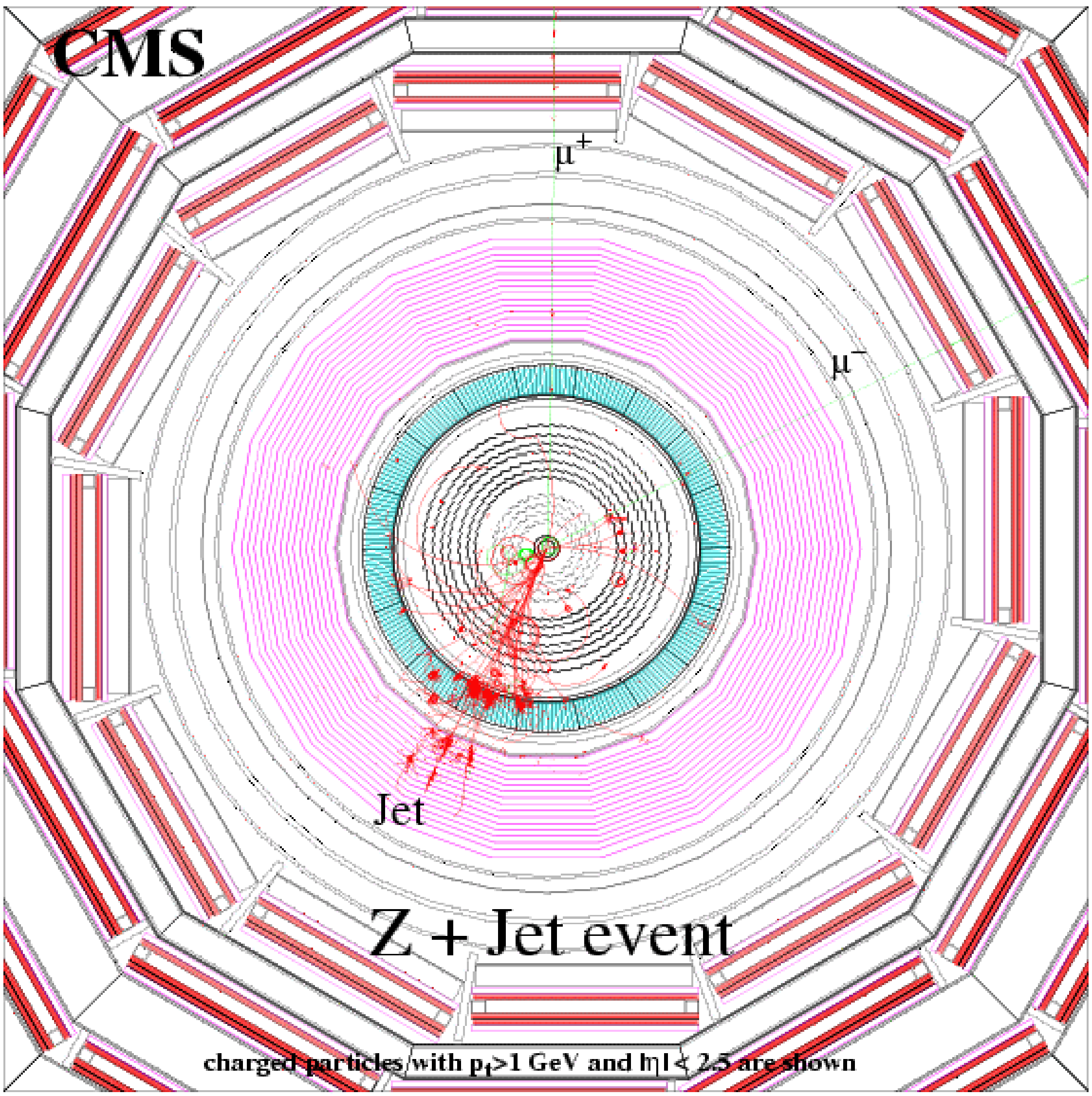
Geant Geometry



Geant Geometry



Geant Geometry- Complex example- CMS detector



Geant geometry

- Can simulate complex absorber shapes easily. Can calculate deposition of energy due to dE/dx of muons + decay electrons accurately. Can make the simulation very realistic. Needed before building.
- Also, magnetic fields are described as field maps (not expansions about the closed orbit). This enables easier investigation of perturbations to optics of say ring coolers by the introduction of injection/extraction systems.
- Geant does not have electric fields. We have changed the Runge-Kutta routine in Geant to use electric fields correctly. Integration of tof done correctly.

Geant3 modified

- Electric fields added
- dE/dx, multiple scattering done well in Geant3
- Electromagnetic showers and hadronic interactions done well
- Arbitrarily complex geometry shapes available by nesting Geant3 shapes
- One can feed in 3D magnetic fields that are realistic.
- We hope to study the problem of injection/extraction into ring coolers using these tools.

Equations of motion in presence of electric and magnetic fields

$\vec{p}$, E is the particle 4 vector, $\vec{u}$ is the tangent to the trajectory, s the arc length,
v the velocity, η is the Lorentz factor
c the velocity of light,
m_0 the particle mass, q the charge
$\vec{\varepsilon}$ is the electric field, $\vec{B}$ is the magnetic field

$$\frac{d\vec{p}}{dt} = q(\vec{\varepsilon} + \vec{v} \times \vec{B})$$

$$\frac{d\vec{p}}{dt} = \frac{d\vec{p}}{ds} \times \frac{ds}{dt} = v\frac{d\vec{p}}{ds}$$

$$\vec{p} = \vec{u} m_0 c \eta$$

$$p\frac{dp}{ds} = \vec{p} \circ \frac{d\vec{p}}{ds} \Rightarrow \frac{dE}{ds} = q(\vec{\varepsilon} \circ \vec{u}) \quad (1)$$

$$\frac{d\vec{u}}{ds} = \frac{d^2\vec{x}}{ds^2} = \frac{q}{p}\left(\vec{u} \times \vec{B} + \frac{\vec{\varepsilon}}{v} - \frac{\vec{\varepsilon} \circ \vec{u}}{v}\vec{u}\right) \quad (2)$$

$$\frac{dt}{ds} = \frac{1}{v} \quad (3)$$

Runge-Kutta Equations

Runge-Kutta is performed on 3 equations simultaneously.Nystrom algorithm

$$y'' = f(y', y, x)$$

solves to

$$y(x+h) = y(x) + hy'(x) + (h^2/6)(K_1 + K_2 + K_3) + O(h^5)$$

$$y'(x+h) = y'(x) + (h/6)(K_1 + 2K_2 + 2K_3 + K_4) + O(h^5)$$

$$K_j = f(y'_j, y_j, x_j) \text{ for } j = 1,2,3,4$$

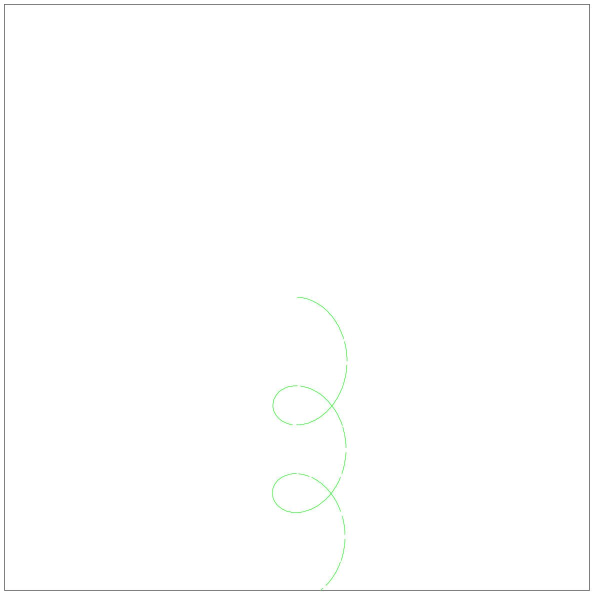
$$x_1 = x, x_2 = x_3 = x + h/2, x_4 = x + h$$

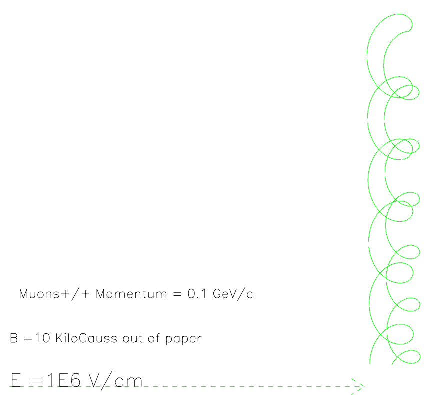
$$y_1 = y(x), y_2 = y_3 = y(x) + (h/2)y'(x) + (h^2/8)K_1$$

$$y_4 = y(x) + hy'(x) + (h^2/2)K_3$$

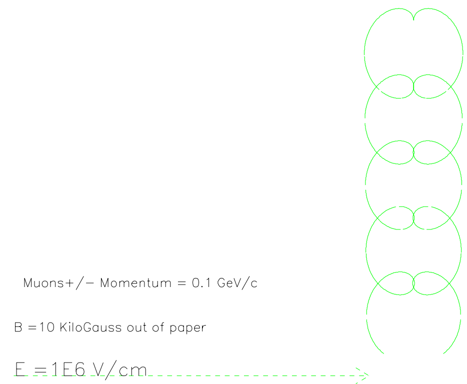
$$y'_1 = y'(x), y'_2 = y'(x) + (h/2)K_1, y'_3 = y'(x) + (h/2)K_2,$$

$$y'_4 = y'(x) + hK_3$$

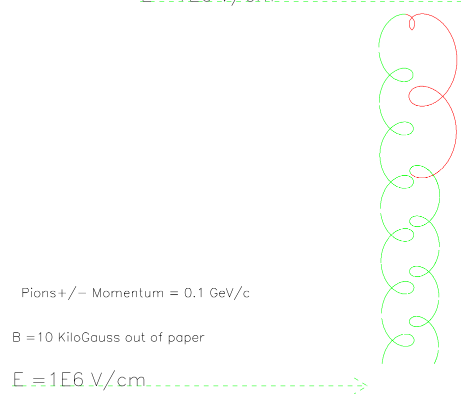




Muons+/+ Momentum = 0.1 GeV/c
B =10 KiloGauss out of paper
E =1E6 V/cm

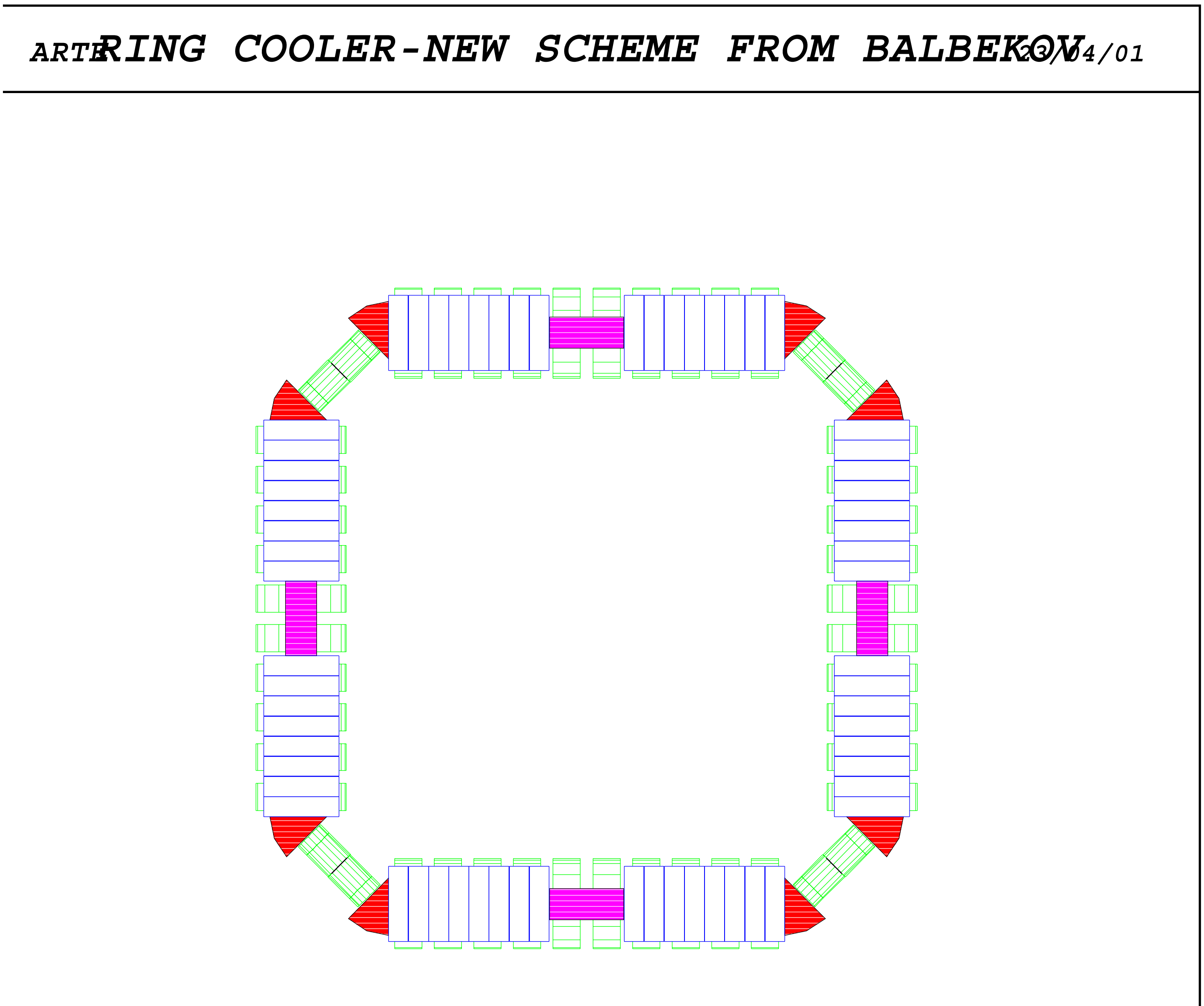


Muons+/− Momentum = 0.1 GeV/c
B =10 KiloGauss out of paper
E =1E6 V/cm

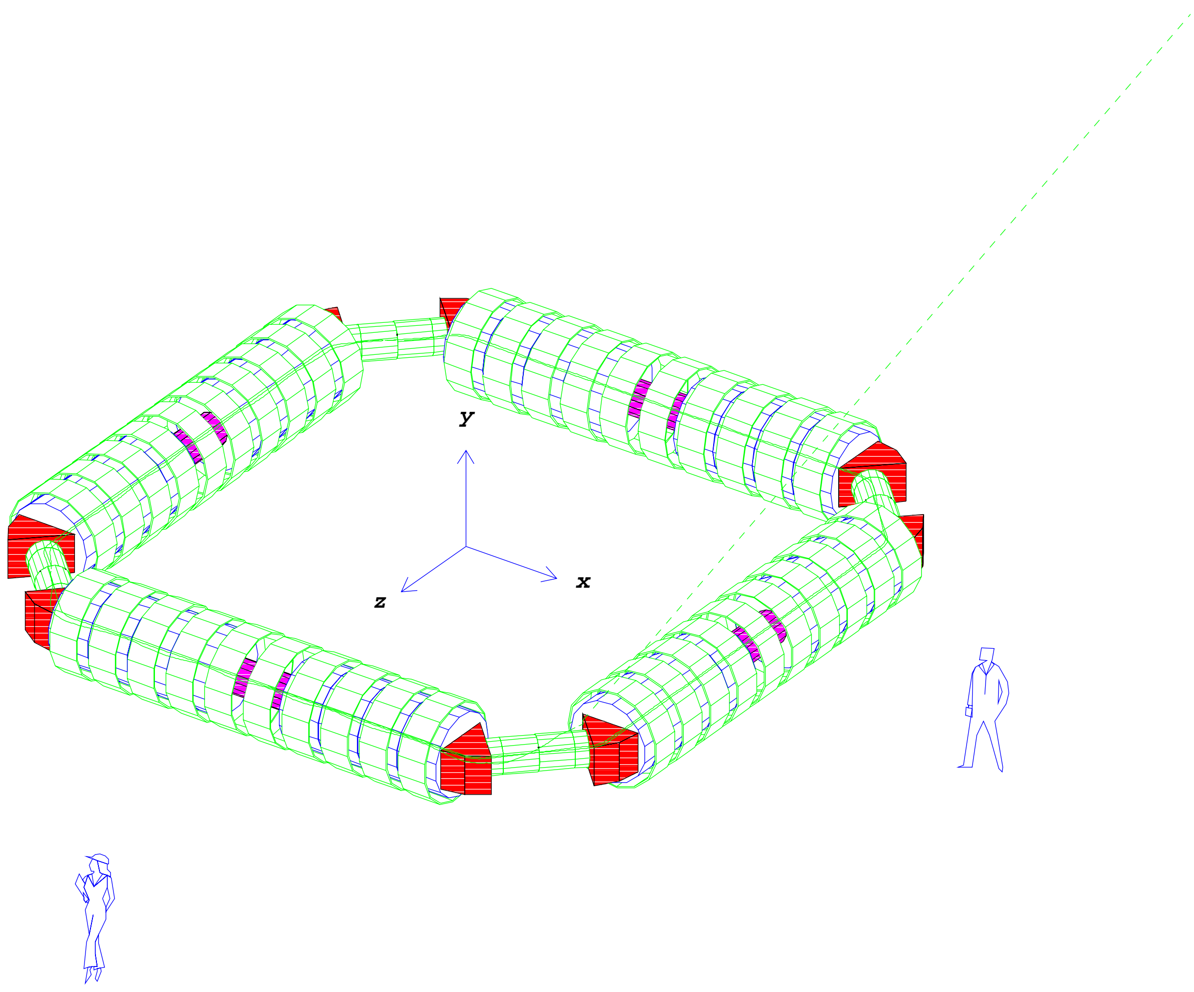


Pions+/− Momentum = 0.1 GeV/c
B =10 KiloGauss out of paper
E =1E6 V/cm

Geant Simulation of ring cooler



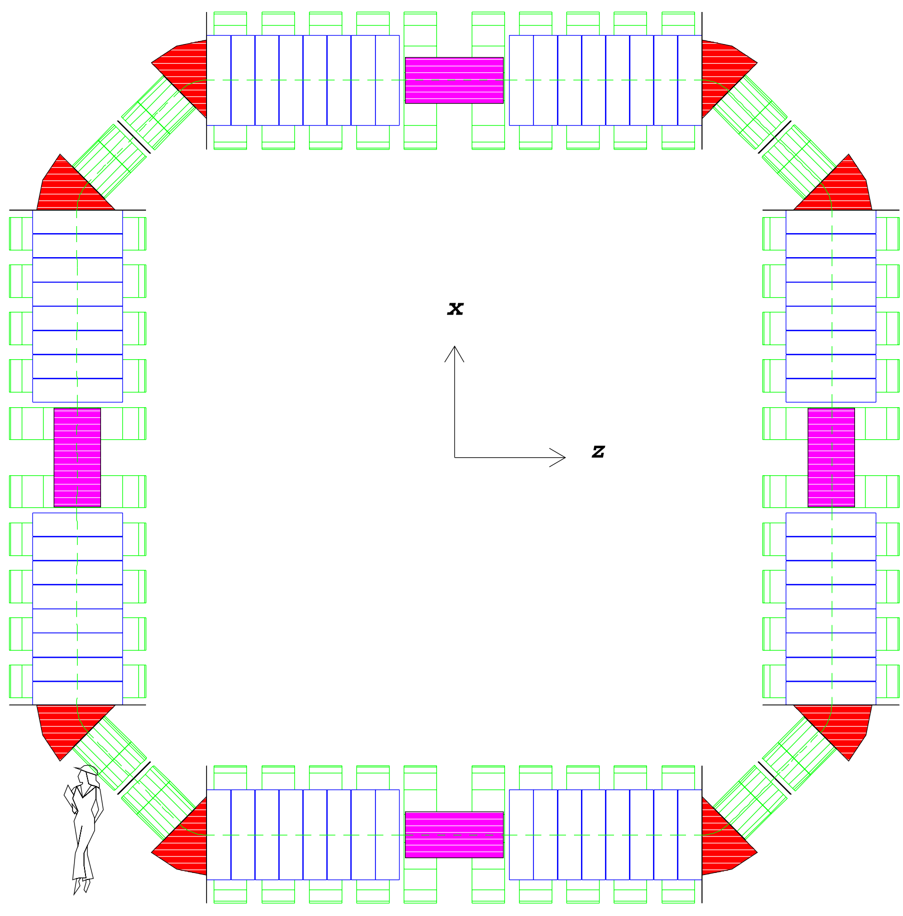
Geant Simulation of ring cooler

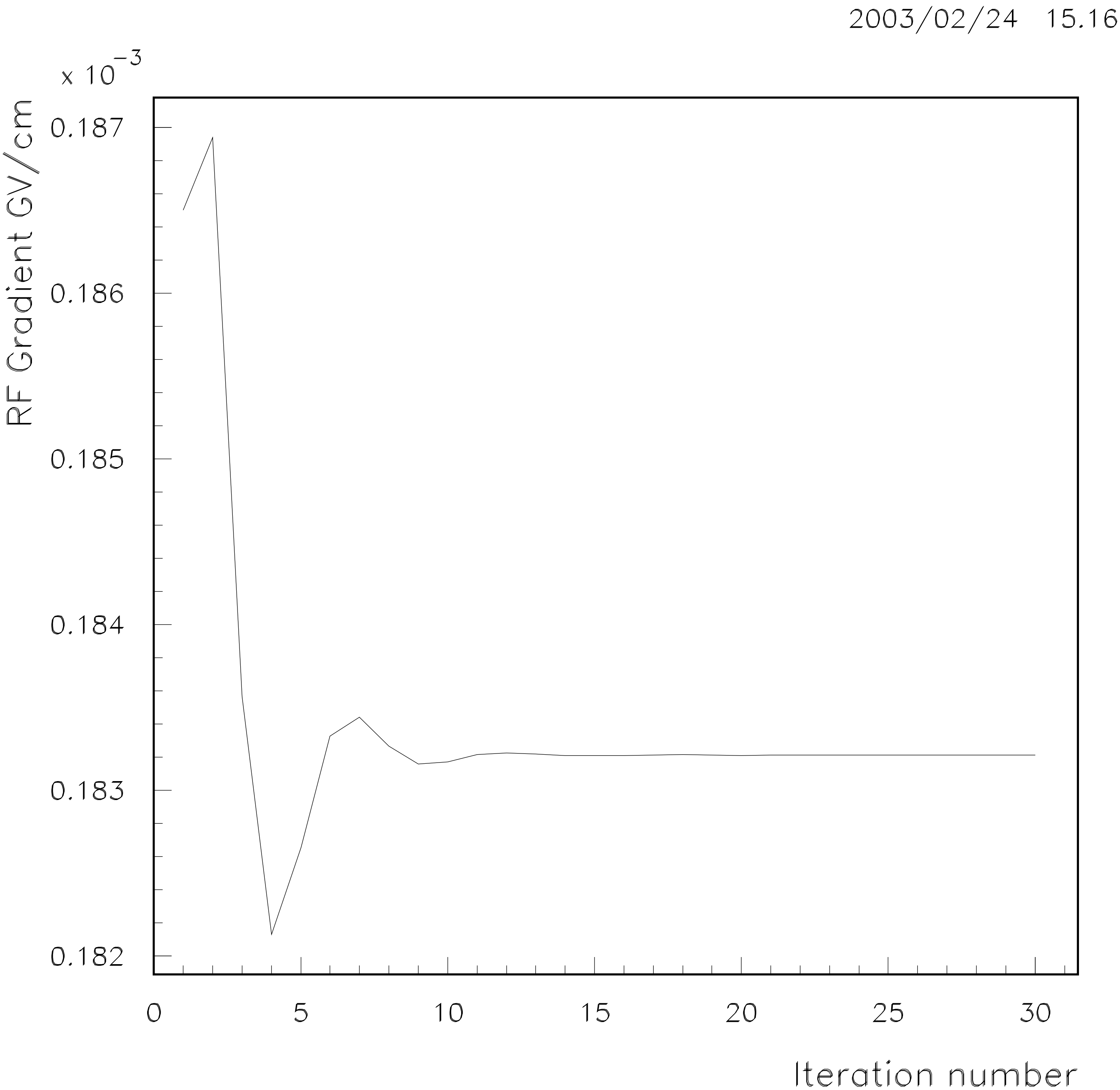


MITER

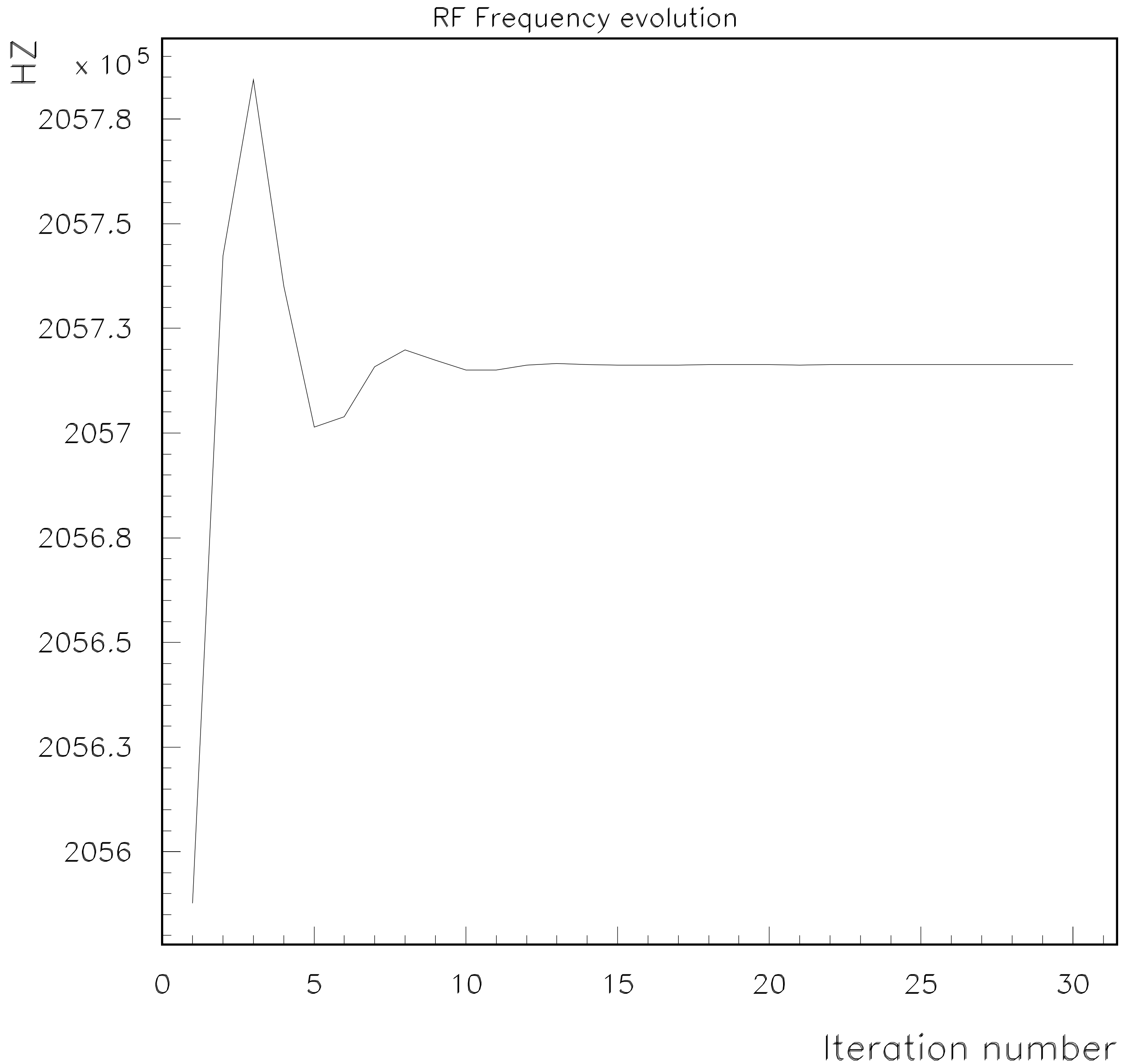
- Separate program that calls Geant.
- Has interface to MINUIT
- Present algorithm
- Remove all absorbers.
- Acquire times at which on momentum particle crosses all rf volumes (16x4)
- Start particle at beginning of quadrant and track one turn
- Work out rf frequency for a harmonic number =28
- Replace main absorbers. No wedges.
- Iterate One Turn with no straggling or multiple scattering or decay.
- Re-work out the times.
- Re calculate RF gradient such that loss per absorber = gain / quadrant.
- Re work out the rf frequency. Iterate 30 times till convergence.
- RF entry at –15 degrees and exit at ~ 75degrees. Sin Wave.

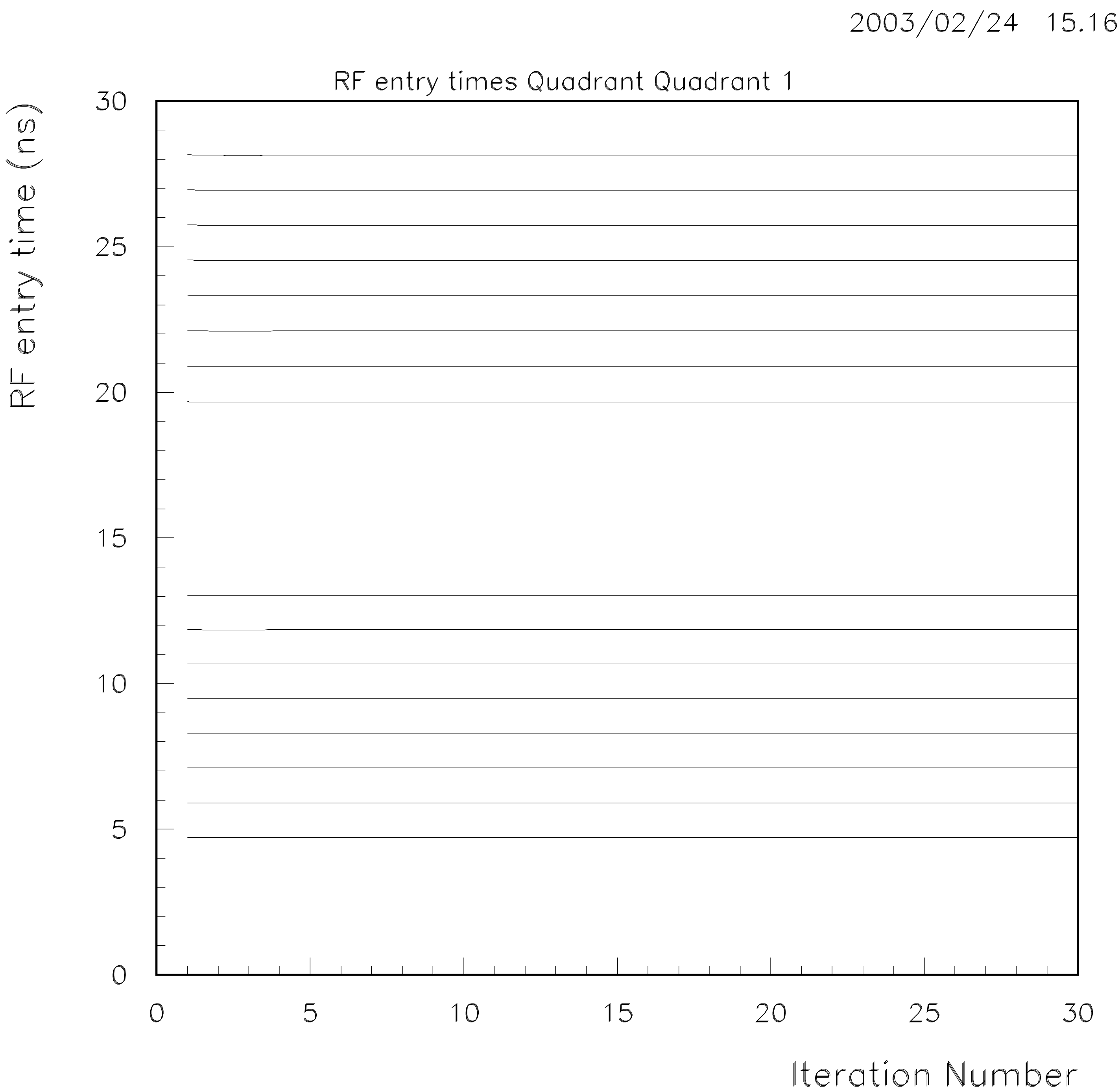
ARTE RING COOLER-NEW SCHEME FROM BALBEKOV 24/02/03

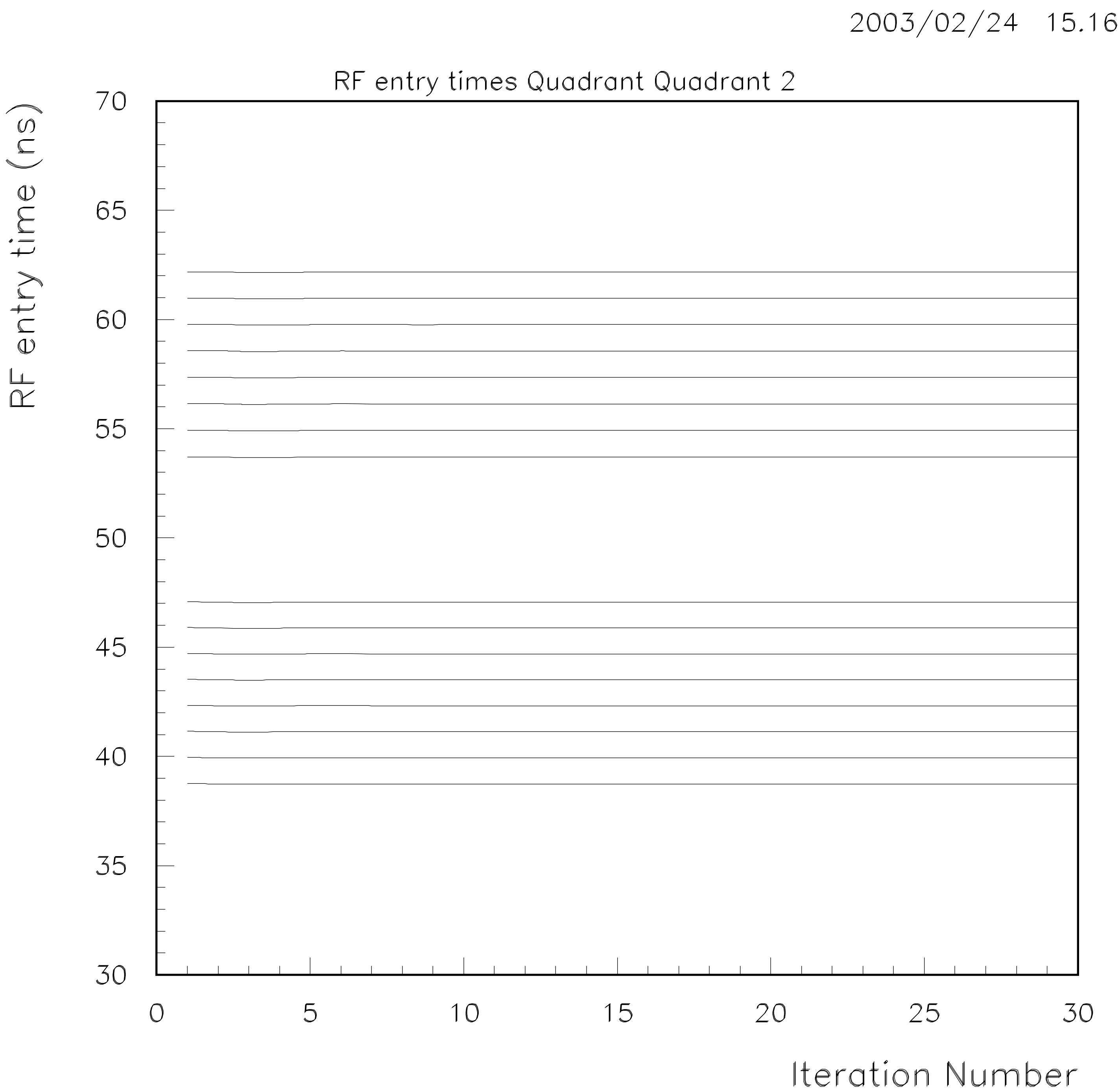




2003/02/24 15.16
x 10^-3
RF Gradient GV/cm
0.187
0.186
0.185
0.184
0.183
0.182
0
5
10
15
20
25
30
Iteration number

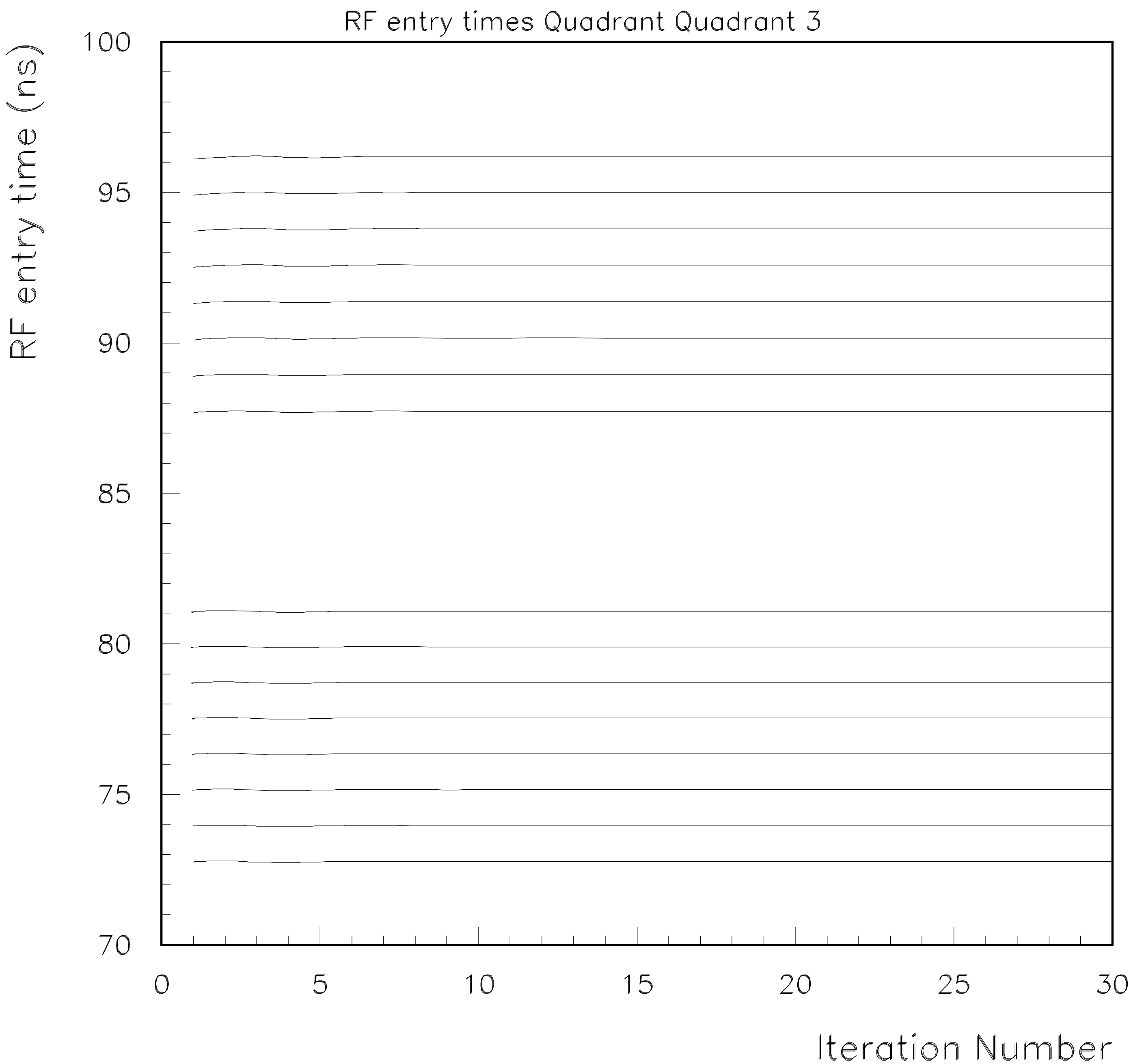

RF Frequency evolution
HZ
x 10^5
2057.8
2057.5
2057.3
2057
2056.8
2056.5
2056.3
2056
0
5
10
15
20
25
30
Iteration number


2003/02/24 15.16
RF entry times Quadrant Quadrant 1
RF entry time (ns)
Iteration Number
0
5
10
15
20
25
30



2003/02/24 15.16
RF entry times Quadrant Quadrant 2
RF entry time (ns)
70
65
60
55
50
45
40
35
30
0
5
10
15
20
25
30
Iteration Number

2003/02/24 15.16



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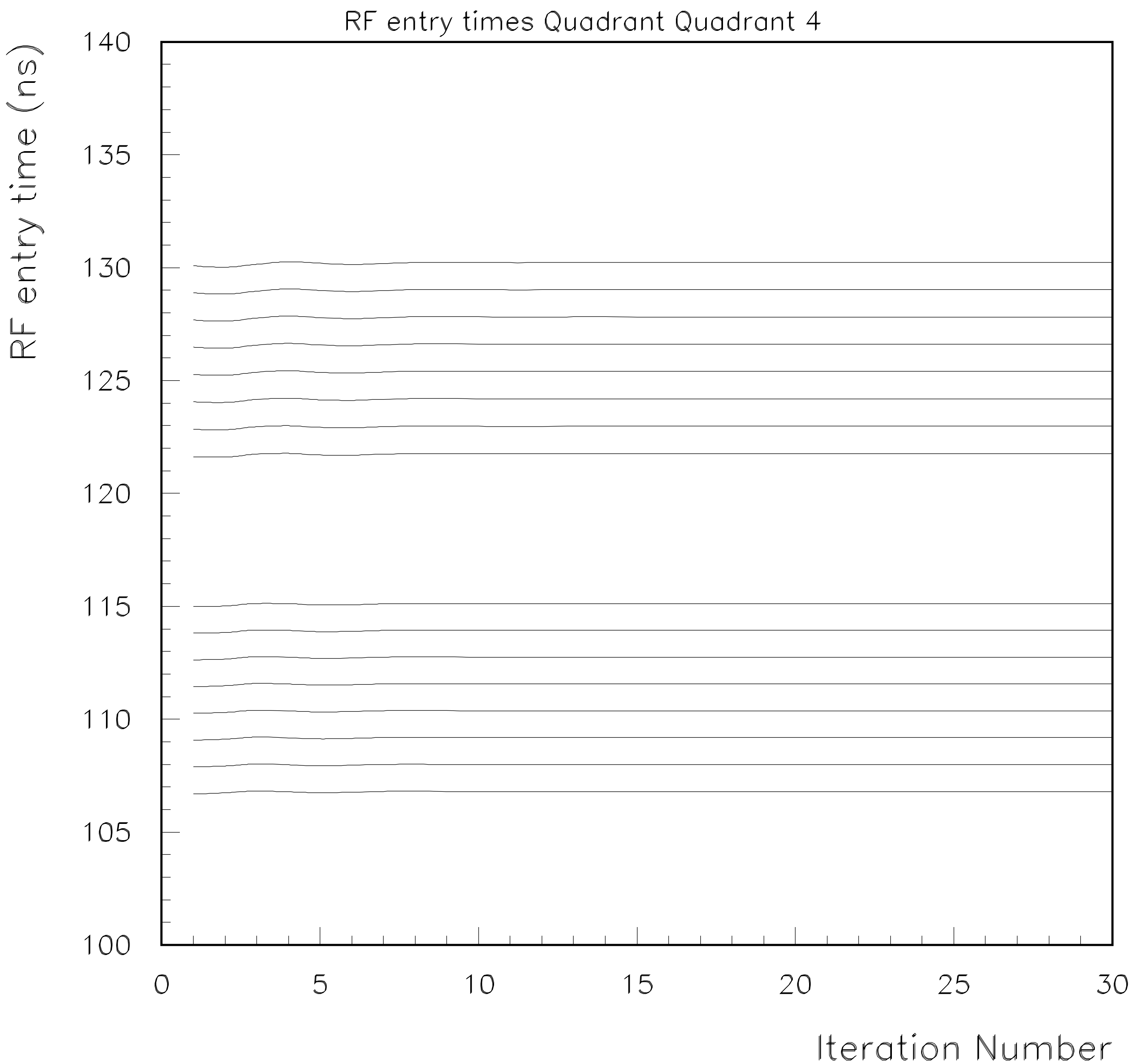

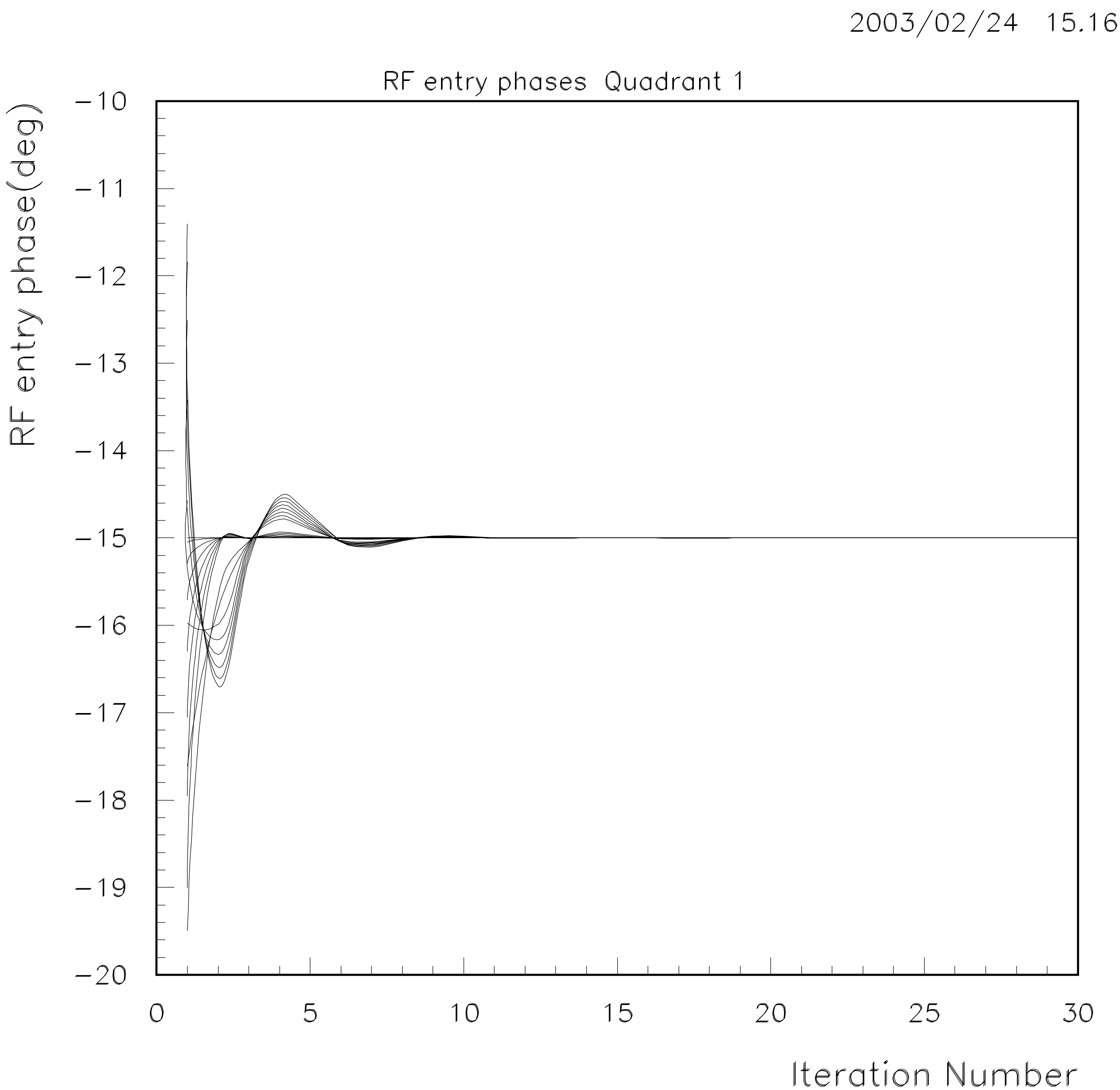
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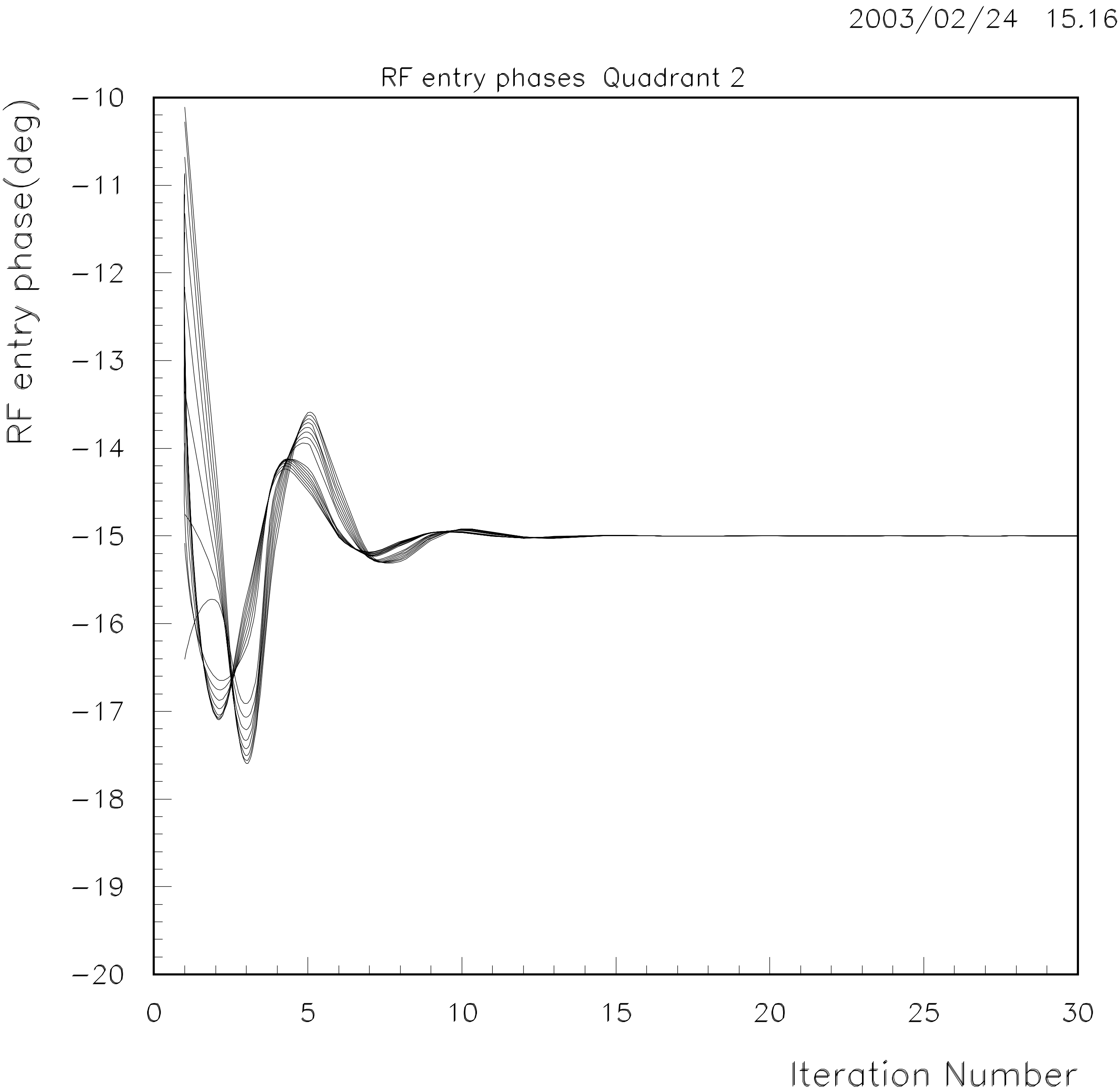
RF entry phases Quadrant 1
RF entry phase(deg)
−10
−11
−12
−13
−14
−15
−16
−17
−18
−19
−20
0
5
10
15
20
25
30
Iteration Number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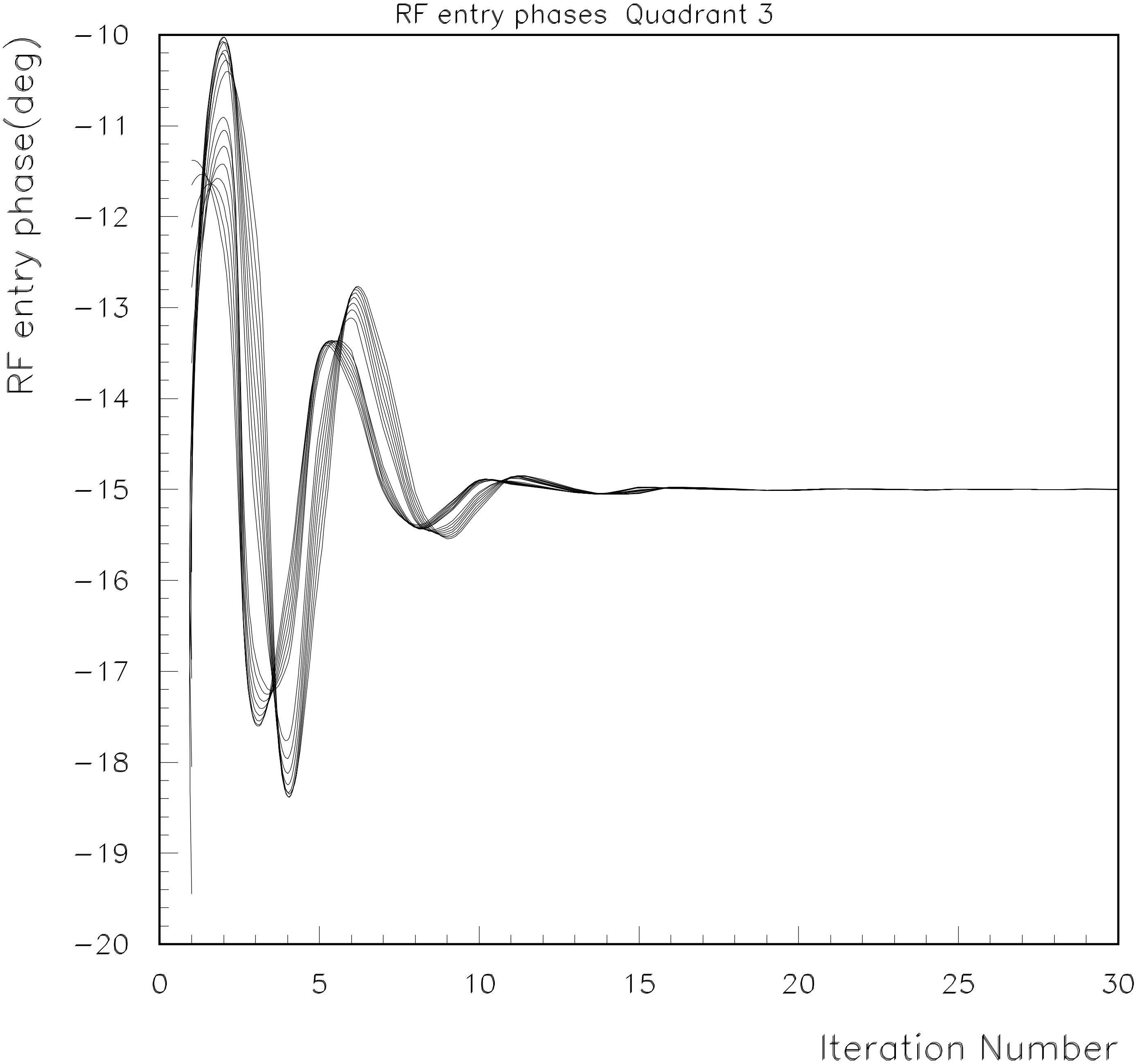
RF entry phases Quadrant 2
RF entry phase(deg)
−10
−11
−12
−13
−14
−15
−16
−17
−18
−19
−20
0
5
10
15
20
25
30
Iteration Number

2003/02/24 15.16



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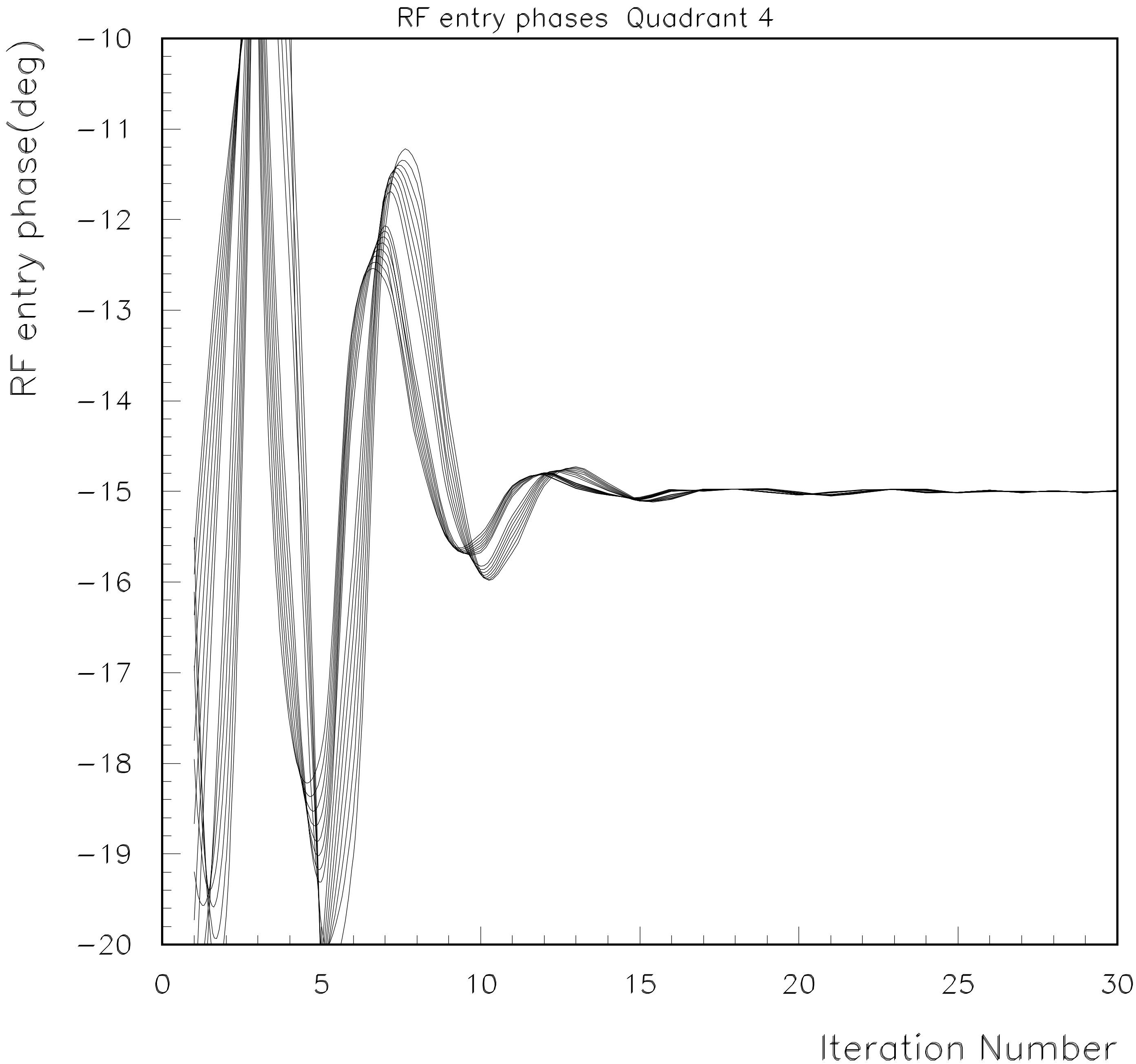

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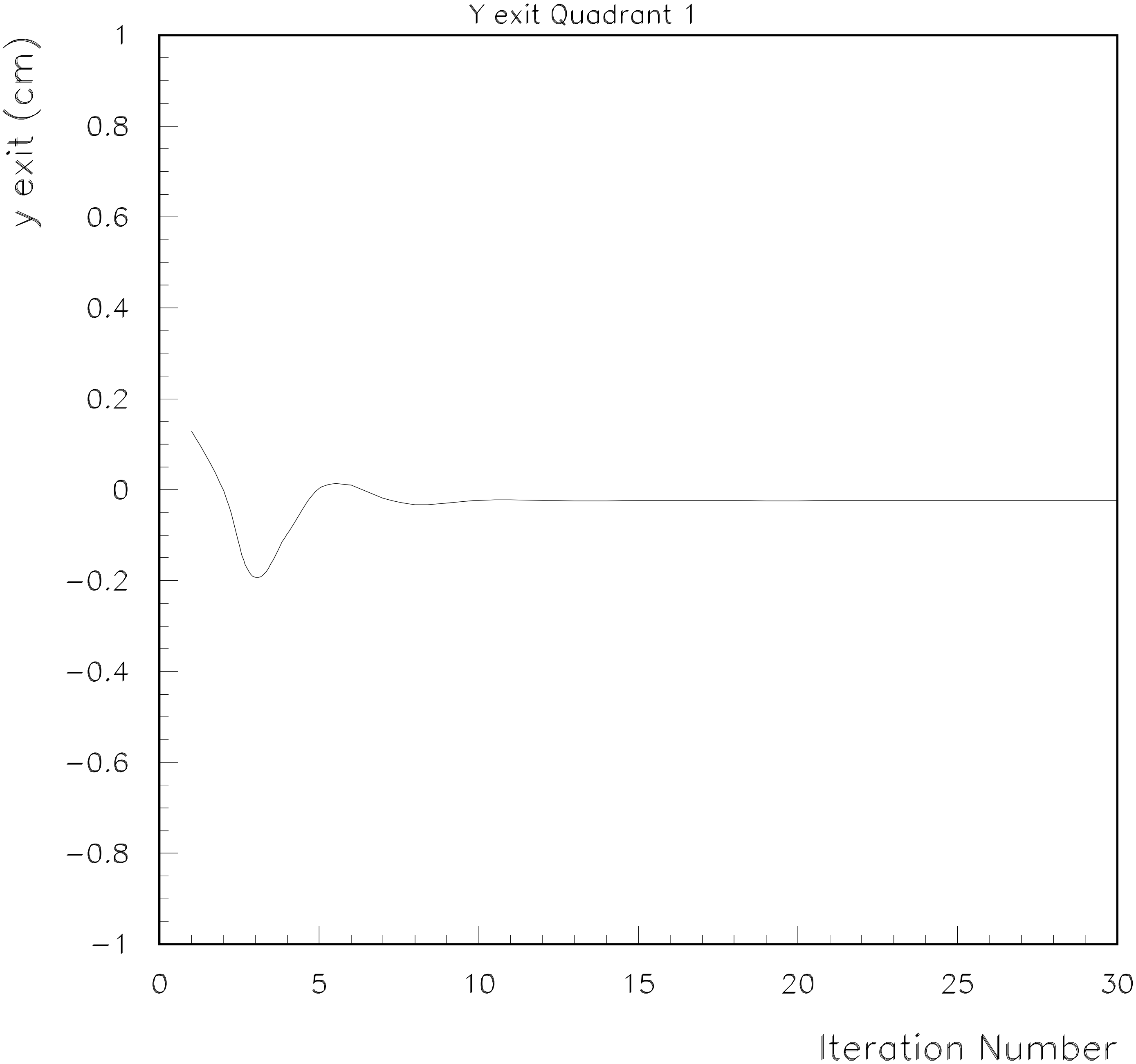
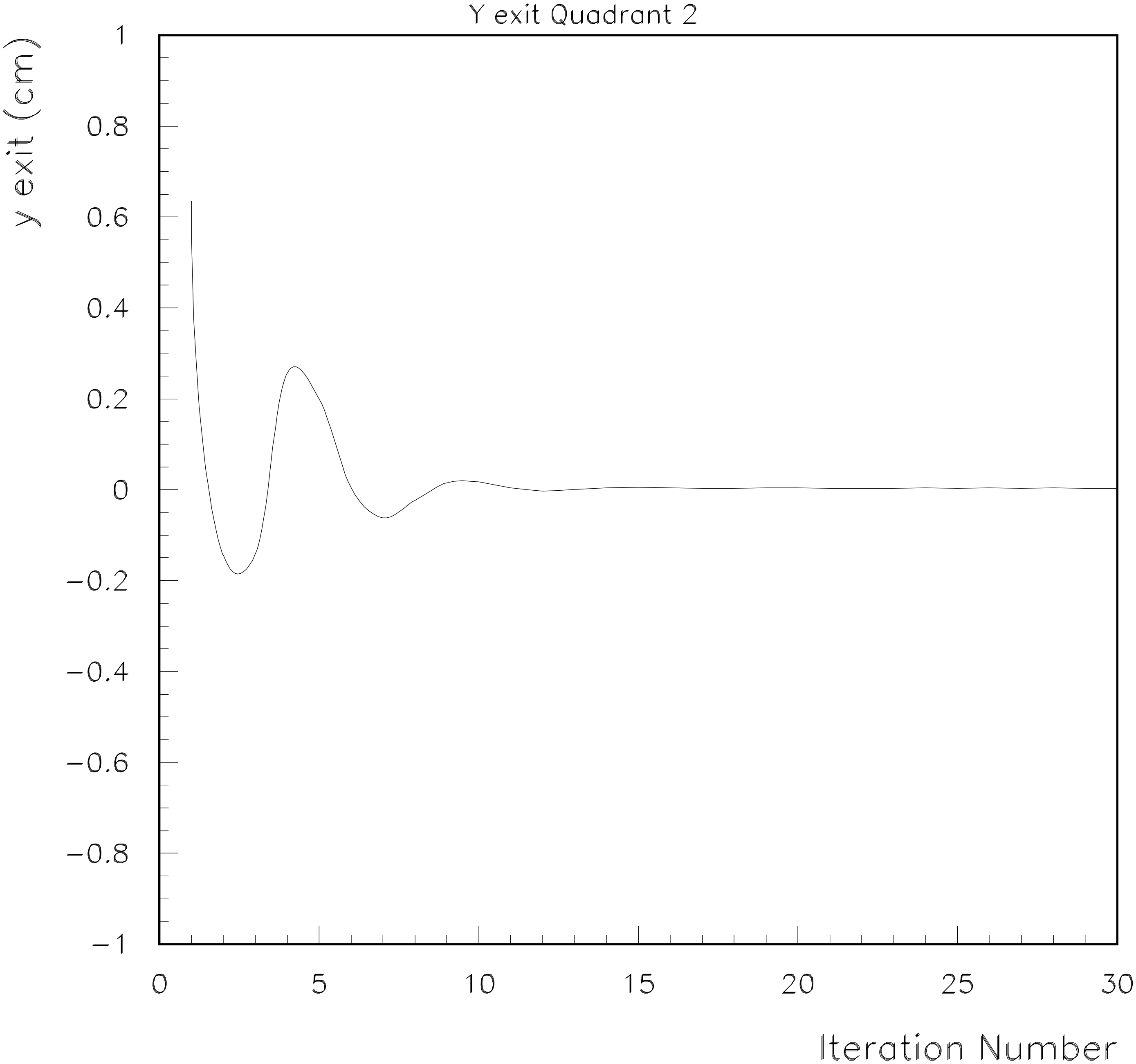
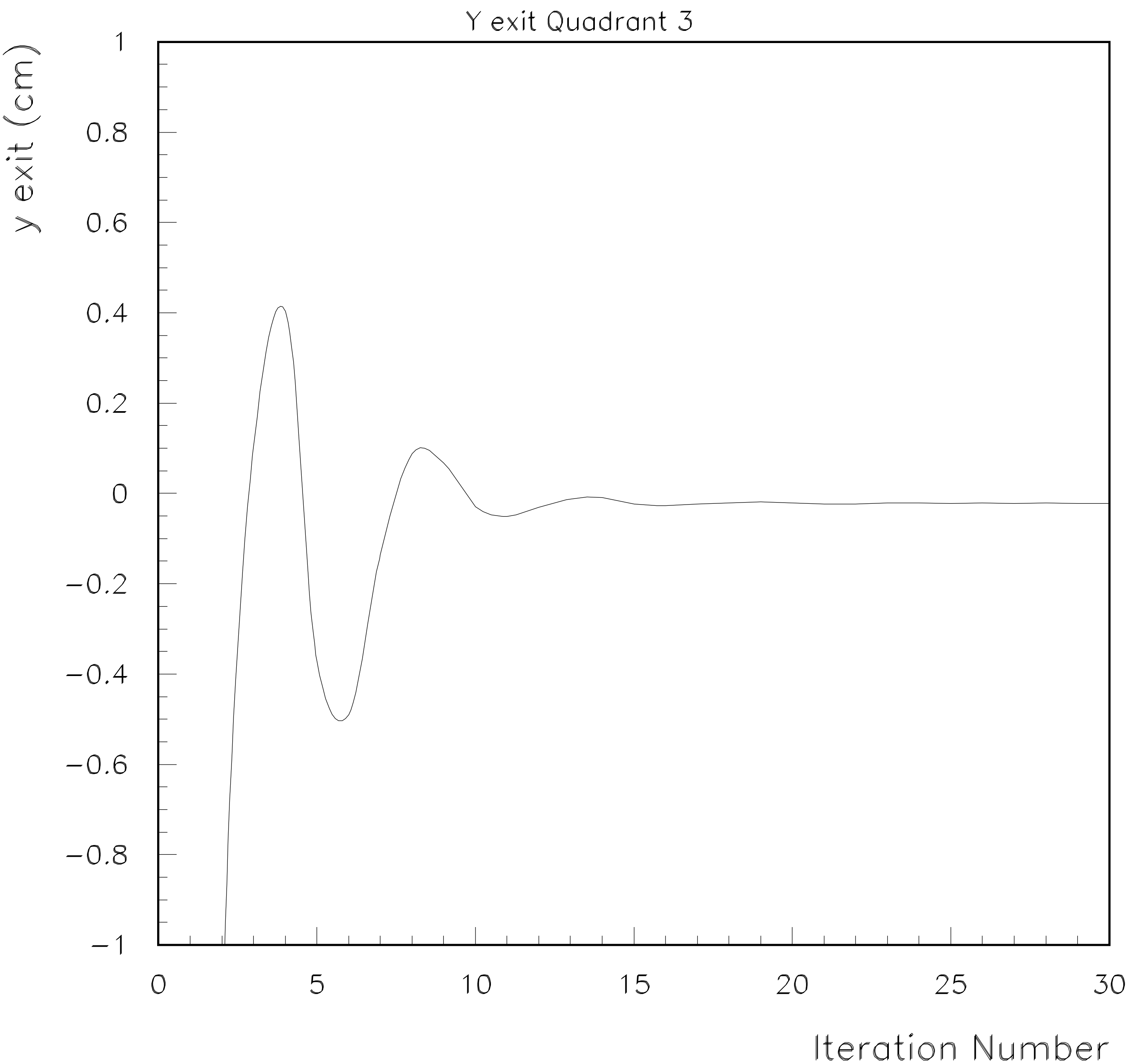
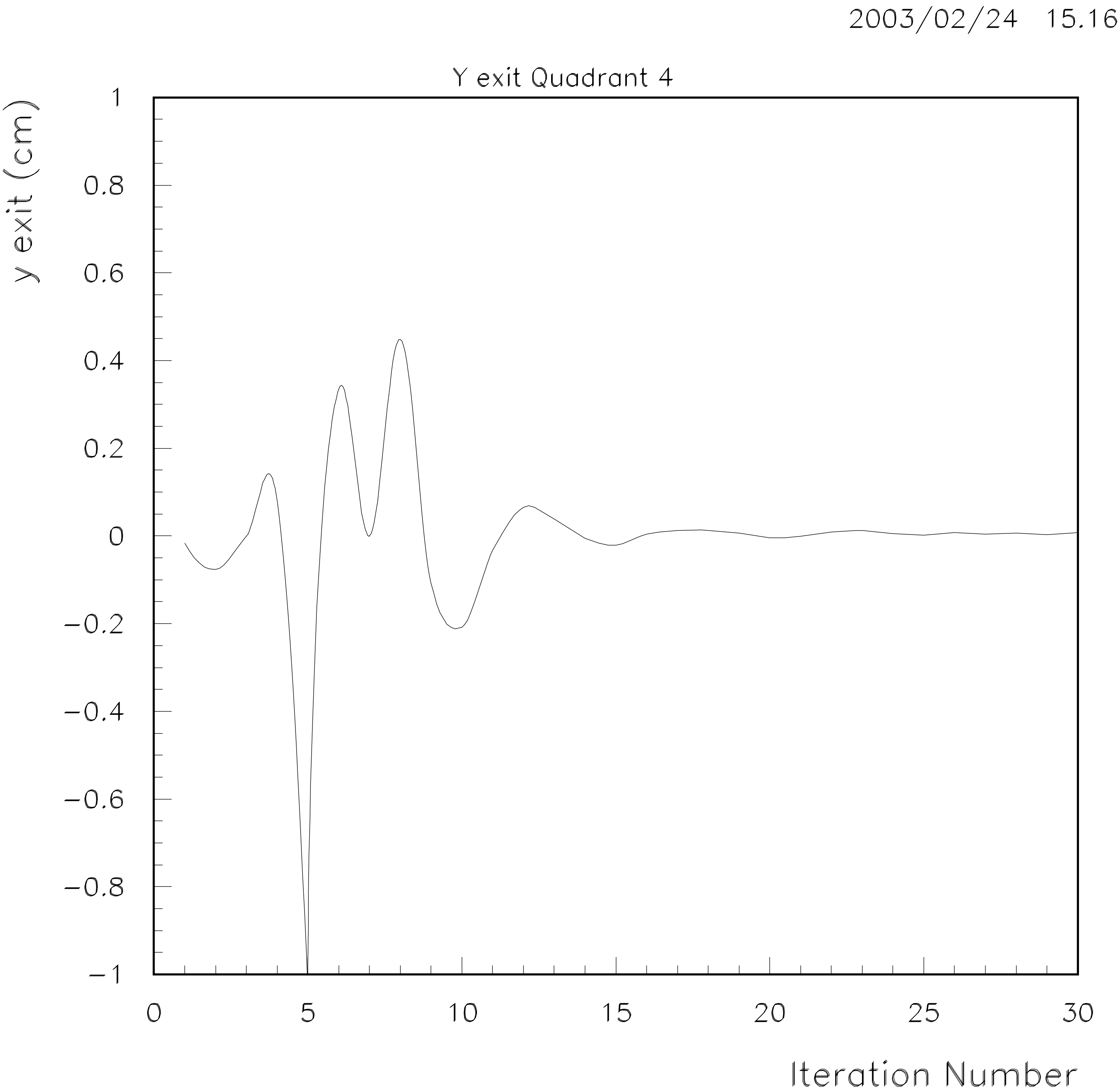


2003/02/24 15.16

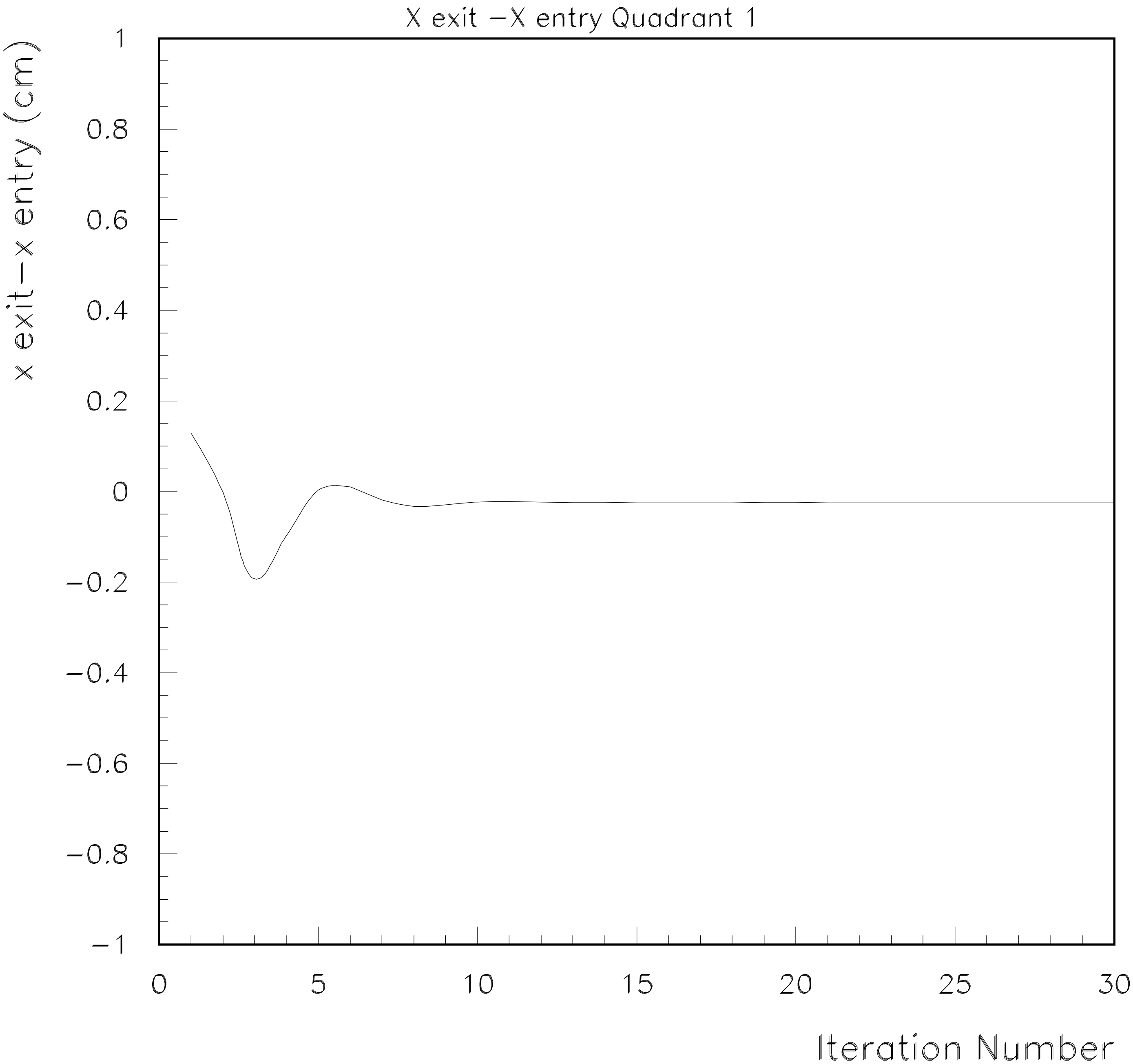


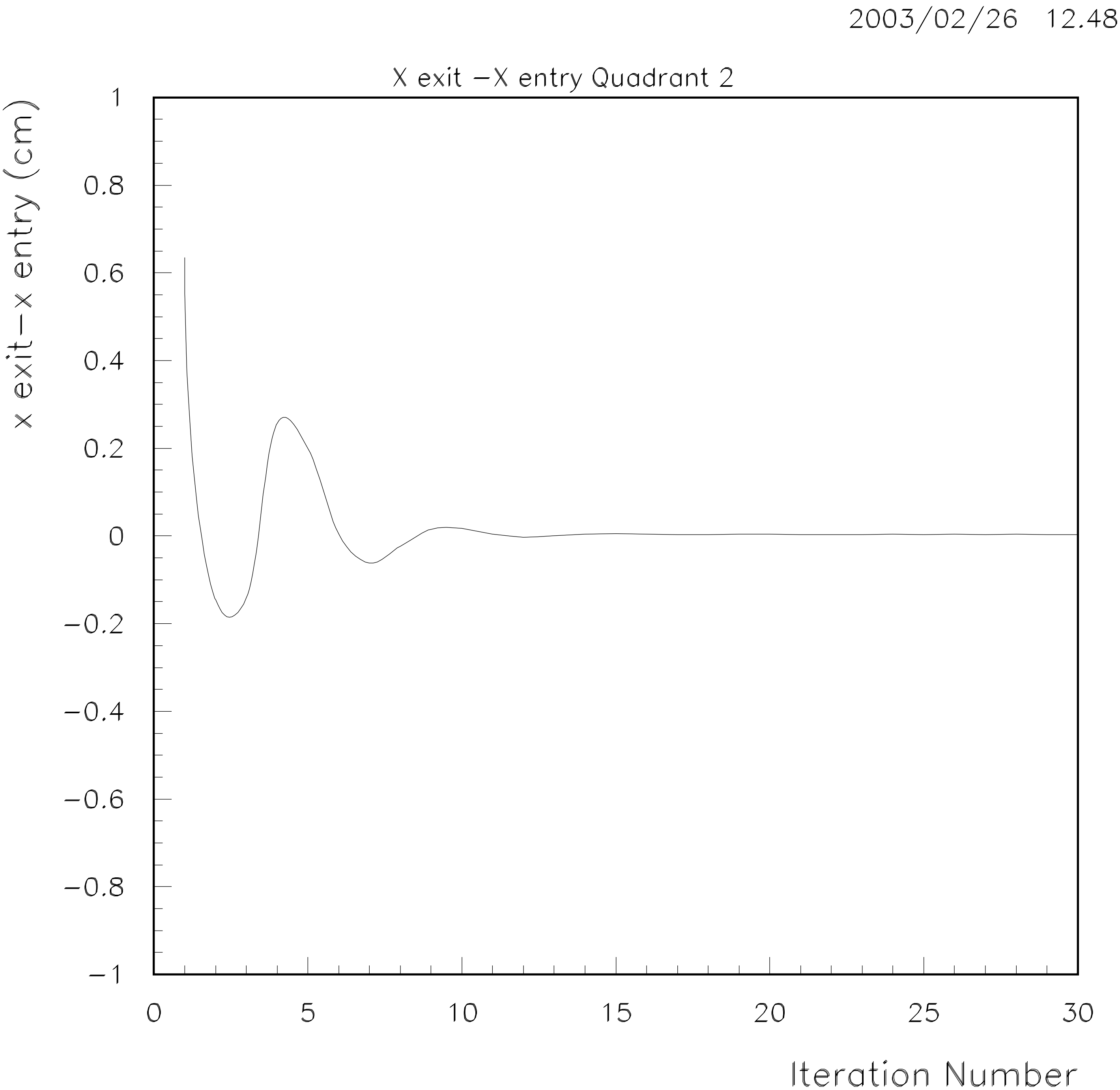
2003/02/24 15.16



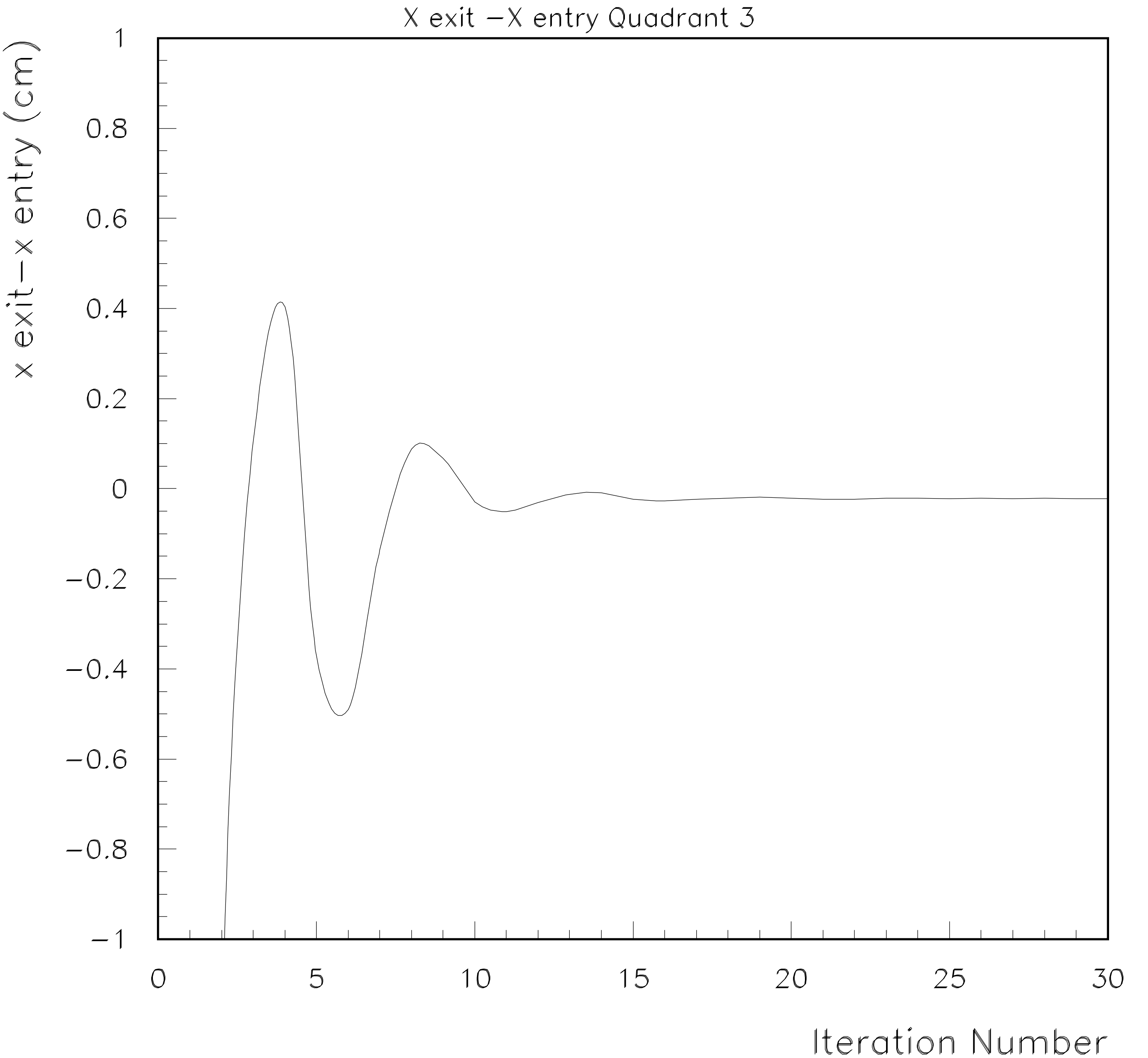

2003/02/24 15.16
Y exit Quadrant 4
y exit (cm)
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
0
5
10
15
20
25
30
Iteration Number

2003/02/26 12.48




2003/02/26 12.48
X exit −X entry Quadrant 2
x exit−x entry (cm)
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
0
5
10
15
20
25
30
Iteration Number

2003/02/26 12.48



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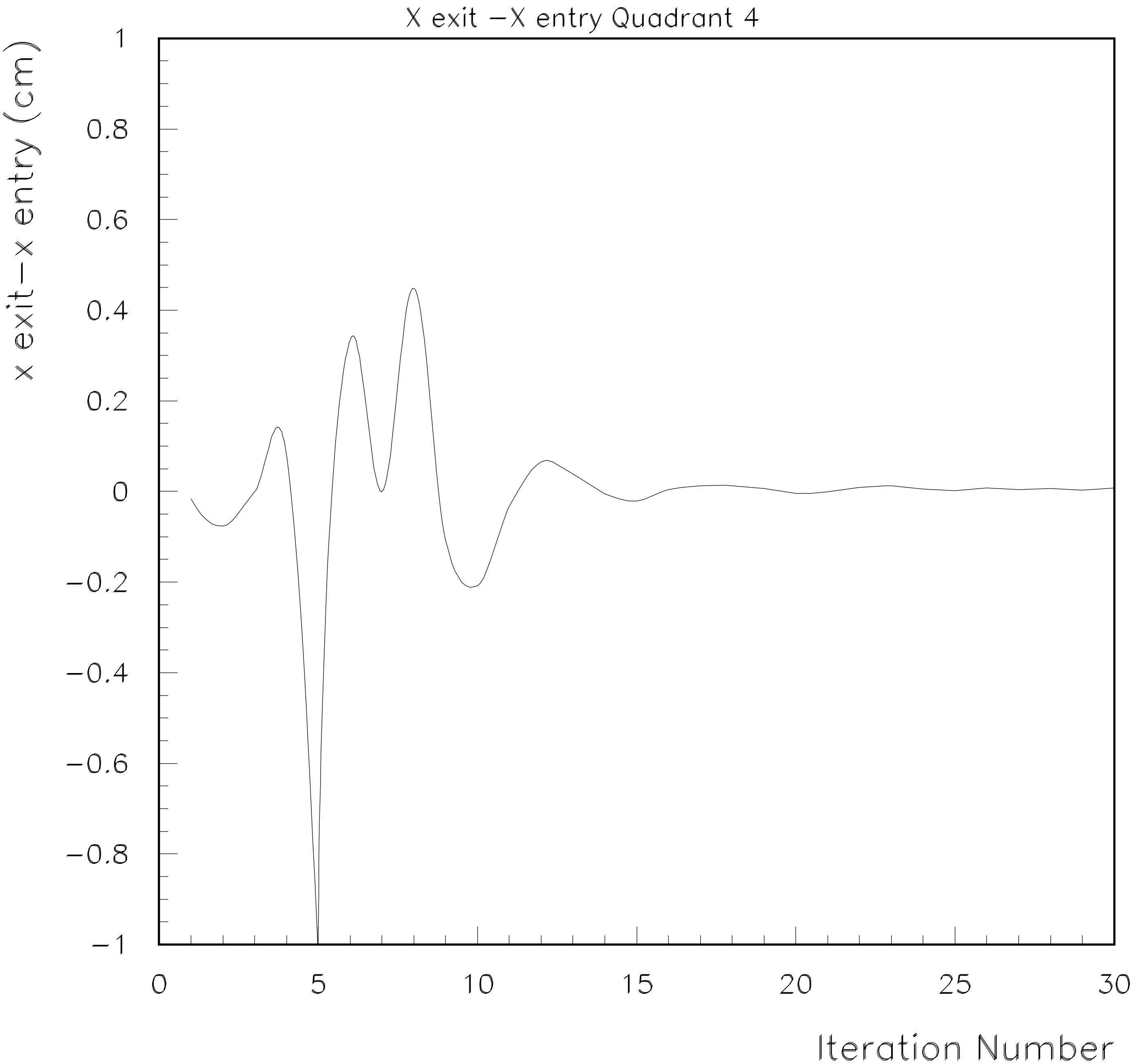

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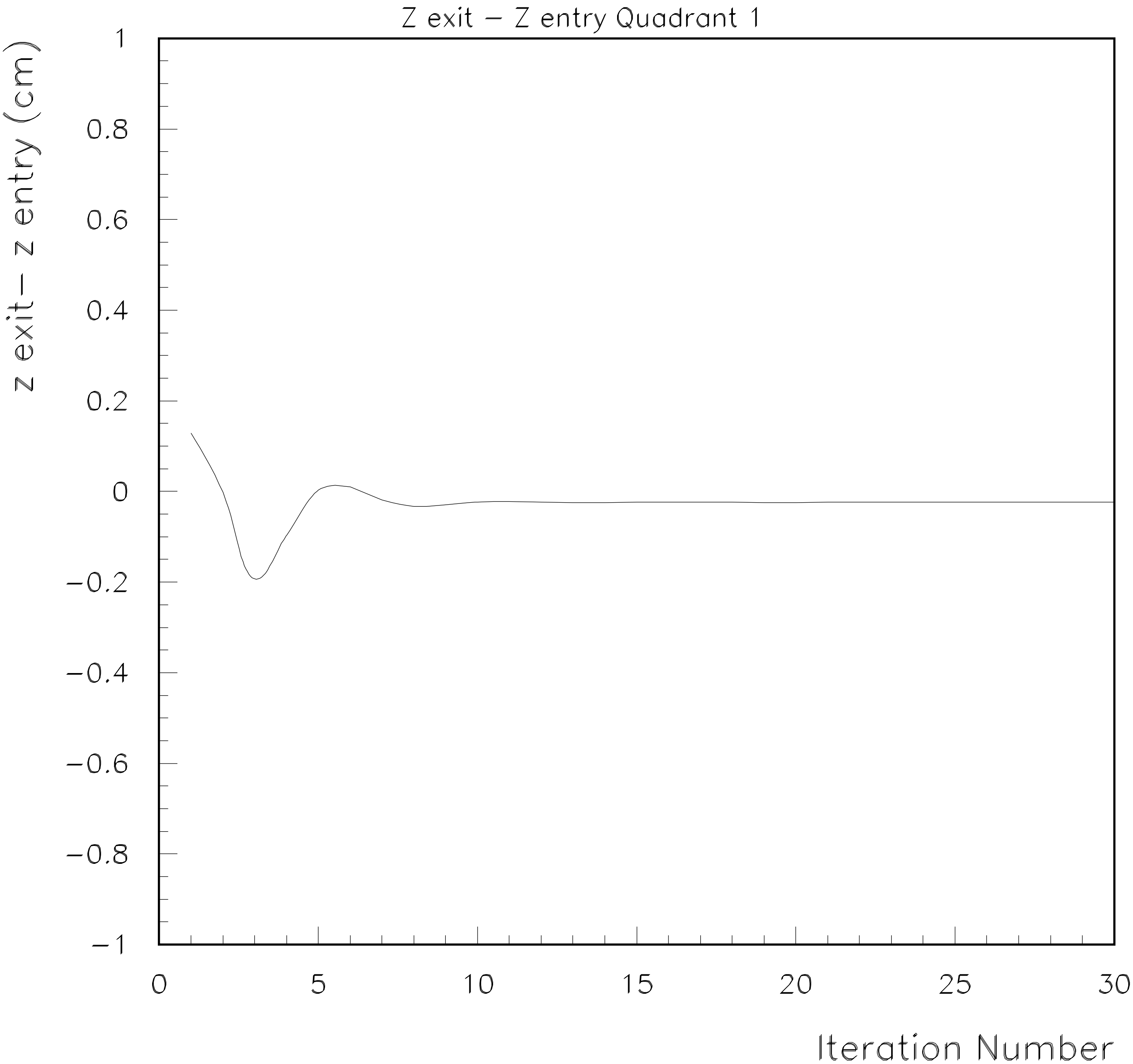

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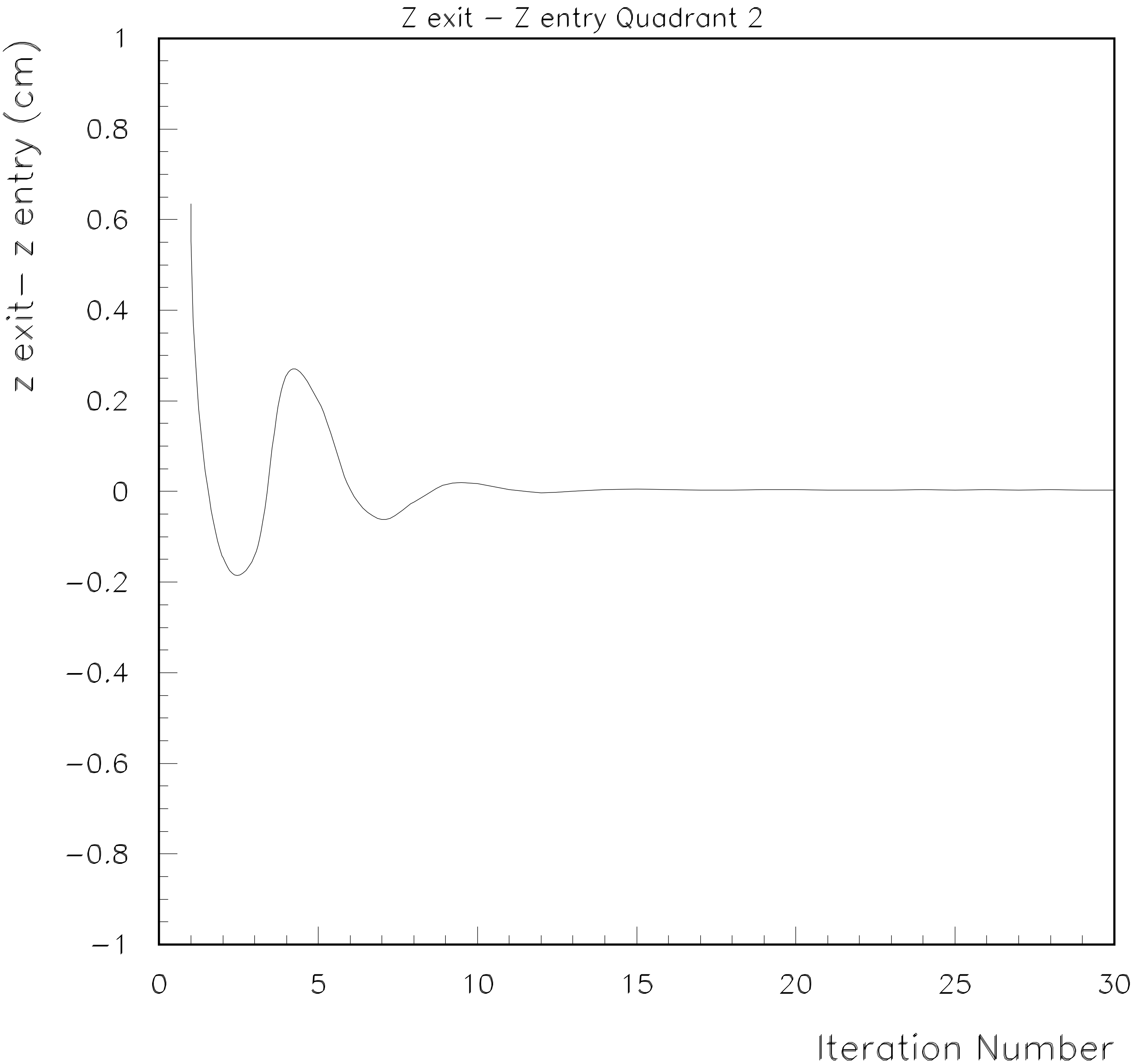

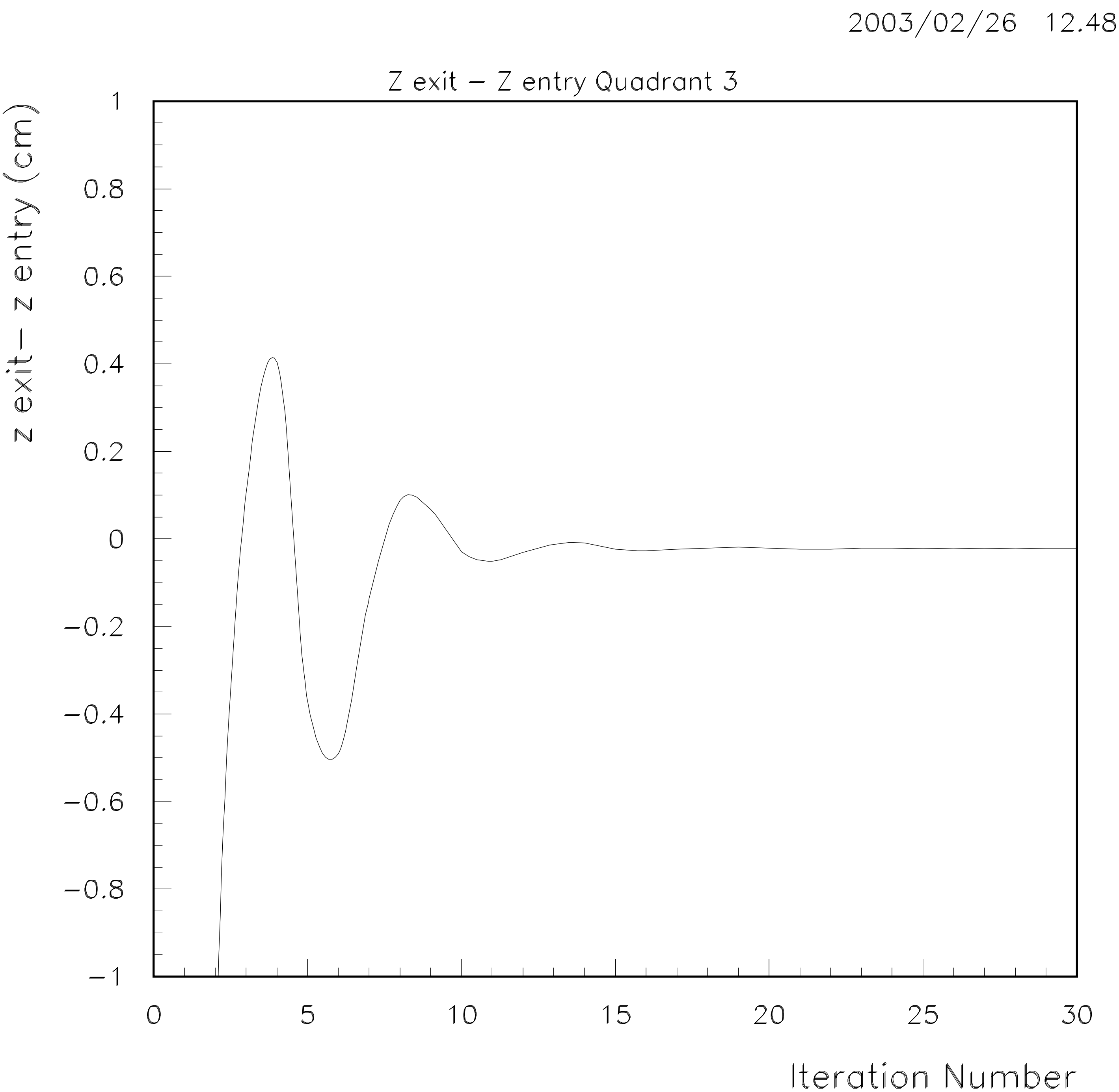

2003/02/26 12.48
Z exit – Z entry Quadrant 3
z exit– z entry (cm)
1
0.8
0.6
0.4
0.2
0
–0.2
–0.4
–0.6
–0.8
–1
0
5
10
15
20
25
30
Iteration Number

2003/02/26 12.48