Spin studies
status report, LPSC
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Abstract

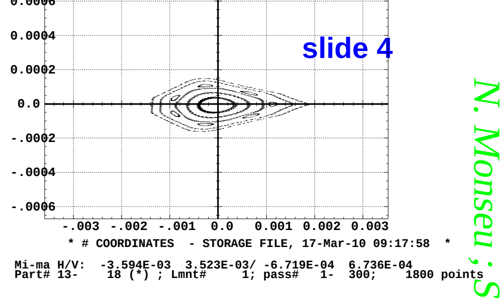
this talk give an overview of the work I’ve done on spin dynamics since Elba.

- **reminder of previous studies, done with F.Méot.**
- **Spin dynamics and the ISF.**
- **Beam and spin dynamics simulations on a simple example.**
- **Foreseen work.**

Contents

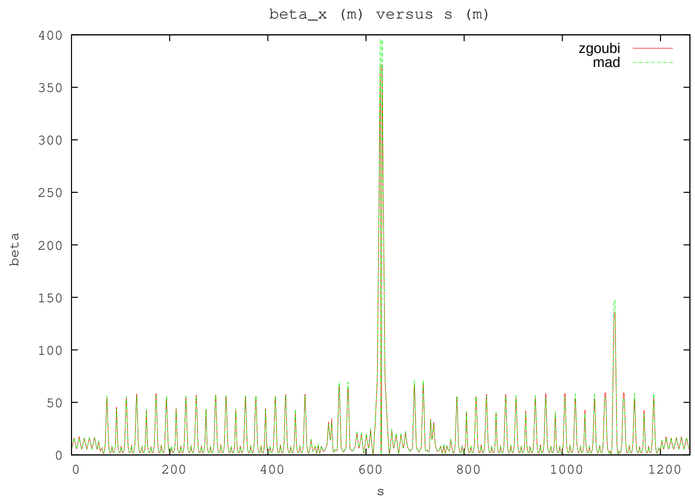
1 Reminder of previous presentation

All the work here will soon be published as an internal LPSC report, which contents could also be found in presentation done in Annecy and Elba.

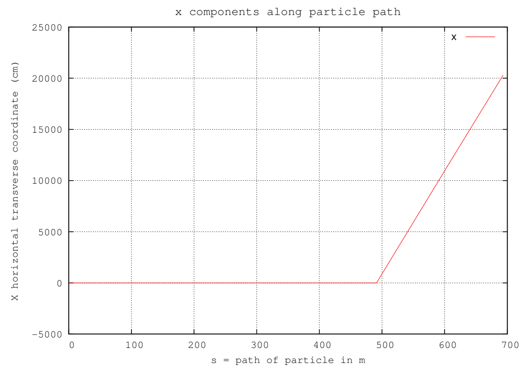


Zgoubi : Step by step tracking. 1

- **Zgoubi is a step by step tracking code, tacking as input a description of the electromagnetic field of the lattice and some particle coordinates. It's intrinsically non linear.**



- **We showed however a good agreement with MAD8 when we forced Zgoubi to be as linear as possible (hard edge models).**



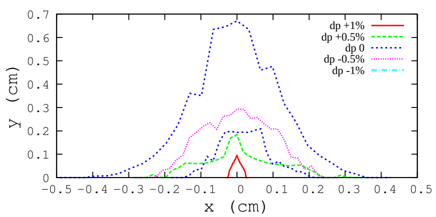
- **Some important problems remain : Coupled twiss functions calculation are not implemented, Solenoid model could be improved off-axis, and 'debugged on axis' (I think there is a divergence hidden somewhere in the magnetic field calculation...).**

Zgoubi : Step by step tracking. 2

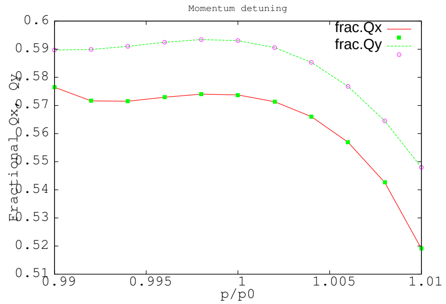
- We can, and at some point will, study a lot of **beam dynamics**
  - full **6D motion**.

  - and also :

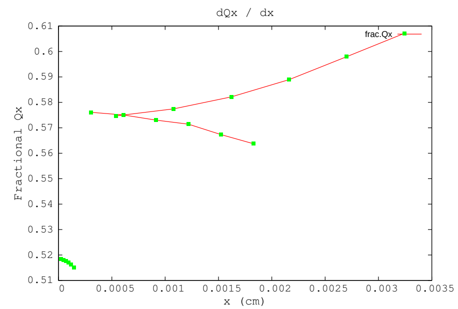
DAs



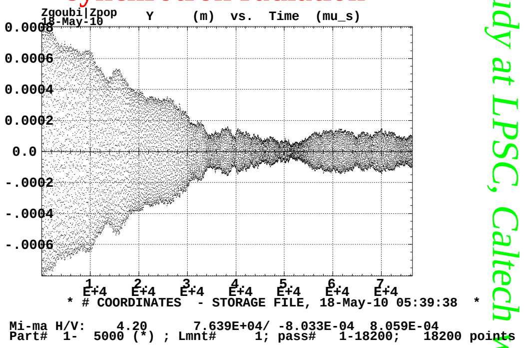
Momentum detuning



amplitude detuning

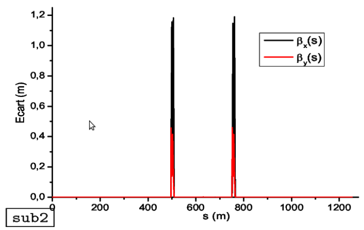


synchrotron radiation

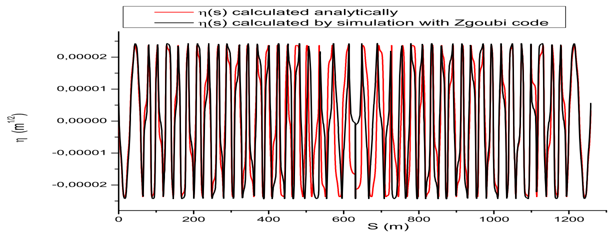


at least because it's absolutely necessary to understand spin dynamics.

- An **error study** has been started by an undergrad students. Preliminary results have shown problem to solve (mainly coupled motion and interpolation of twiss functions within the elements), and some tool development have been started in this area.



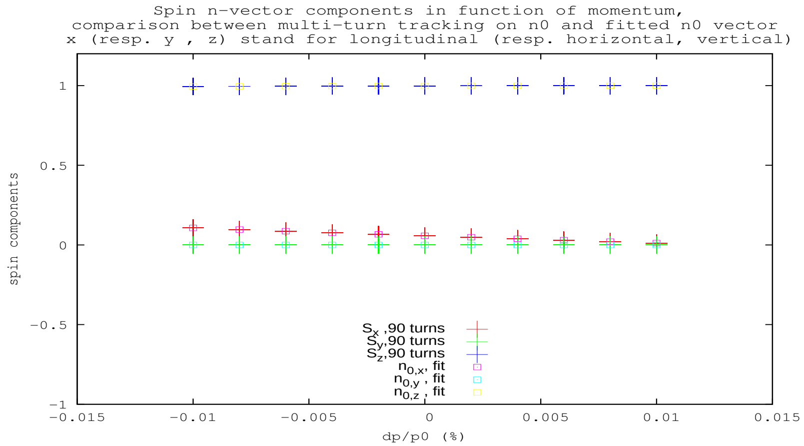
left : difference between interpolated β function and Zgoubi calculation. Peaks are located close to the solenoids, we supposed it was due to coupling effect. right : closed orbit induced by a small dipole kick. Comparison with theory is done. agreement is good on the amplitude, but bad in phase.

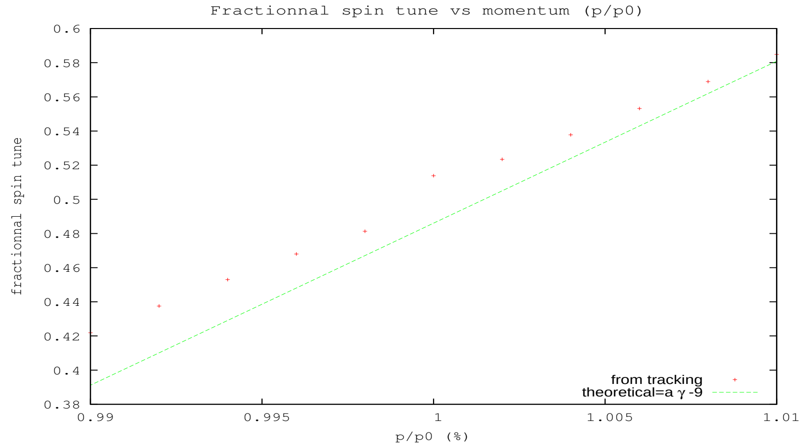


Spin dynamics tool developments

- **My PhD work is mainly concerning this parts.**

- **Tools have been done, up to this summer, to study spin dynamics *on closed orbits*. Stable spin direction and spin tune were calculated. And a small bending mismatch was pointed out for LER V12 (the latest version ?).**





- **Off closed orbit, or real full 6D motion, was only foreseen, but simple case needed to be studied first.**

2 What's New ?

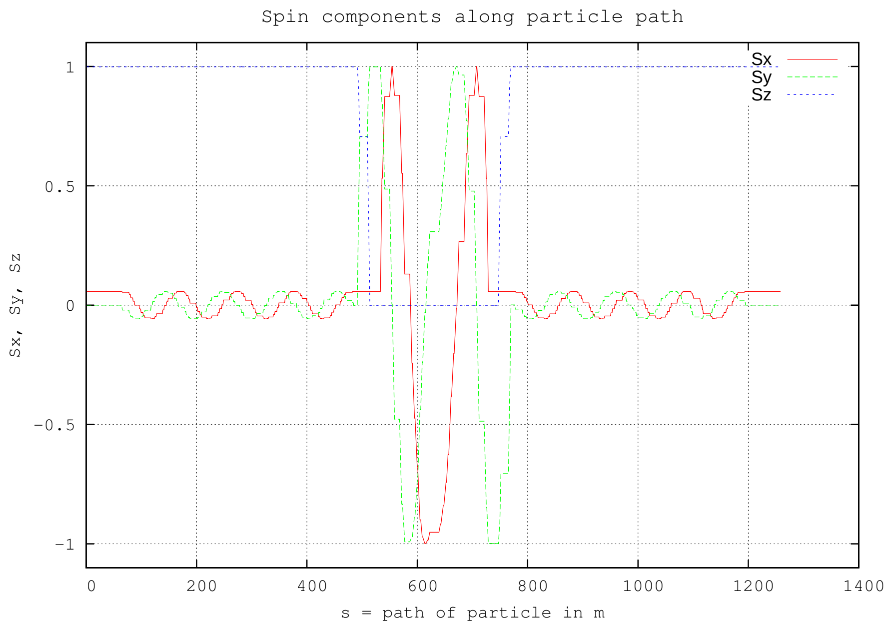
2.1 Theoretical consideration

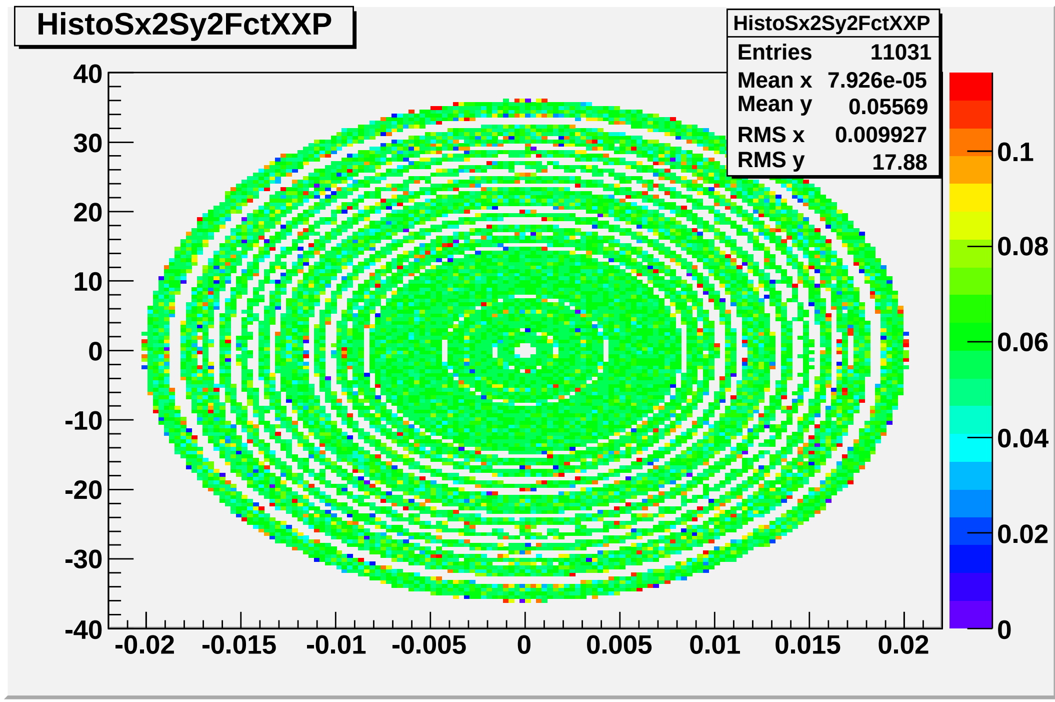
- **Invariant Spin Field has been studied. This is the full 6D extension of the stable spin direction concept. Simulation performed over 2D motion (showed later).**

- **Amplitude Dependant Spin Tune study has been studied on the paper. No simulation performed.**

2.2 Preliminary results for SuperB lattice

- **they show the same mismatch, ISF is not vertical in the arcs.**





3 ISF

3.1 definition

• **On closed orbit, one can easily defined a stable spin direction, as after one turn, the particle is coming back to the same point.**

• **But if the particle performs an orbital motion, it does not come back to the same phase space point.**

• **Invariant Spin Field is a phase space spin distribution such that if a particle has its spin aligned wrt. this field at some phase space point, after one turn around the ring, even if the particle is at a different phase space point, its spin does remain aligned wrt. the ISF.**

• **ISF could also be understood as a local spin precession axis.**

• **few words about ADST : its only the amplitude dependant precession rate, as spin tune was the precession rate on closed orbit.**

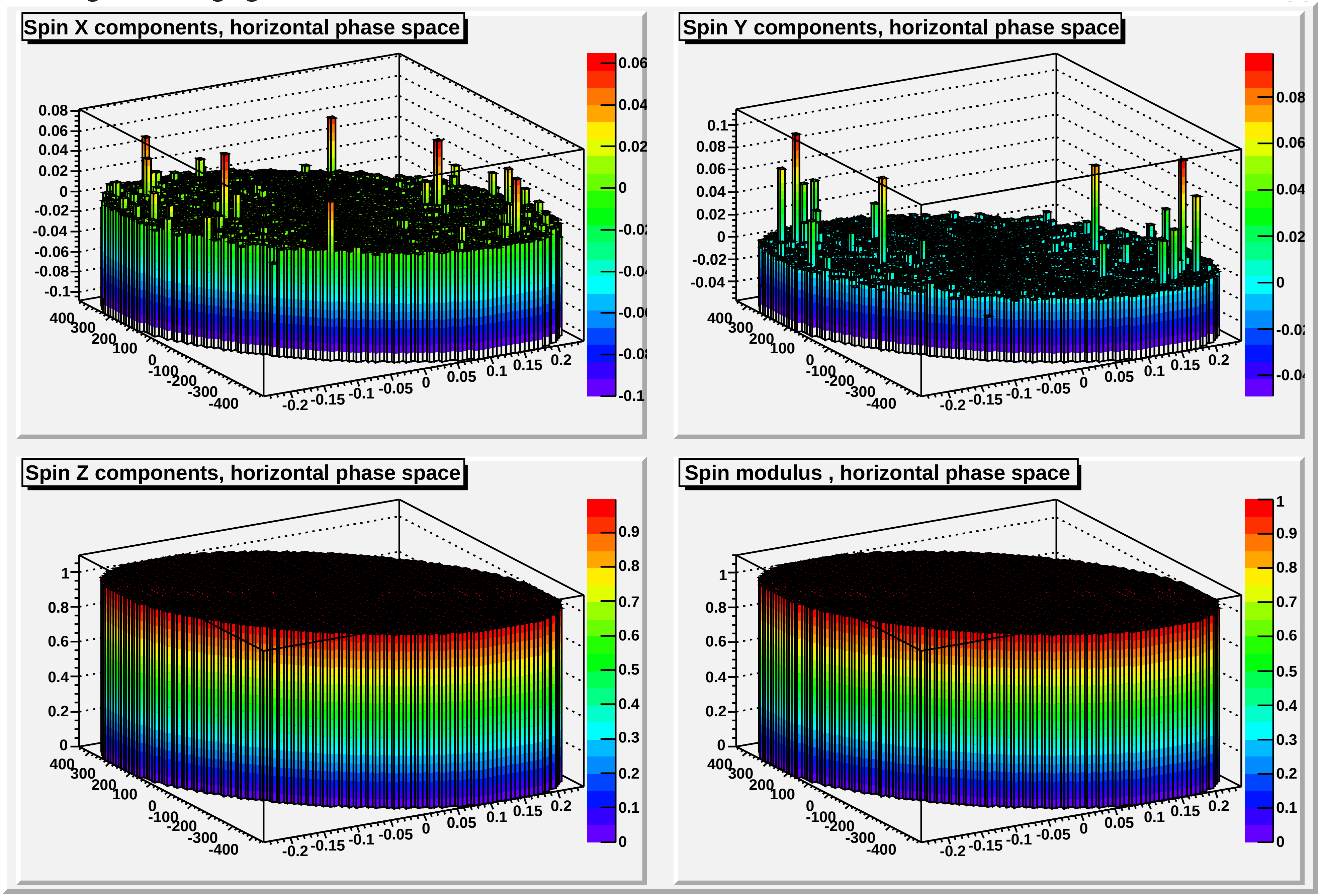
3.2 Stroboscopic averaging

- **method developped by Heinemann and Hoffstaetter**
- **to get invariant spin field from tracking data (see e.g. Georg Heinz HOFFSTAETTER, Springer tracts in modern physics vol. 218 ; High energy polarized proton beams, a modern view.).**

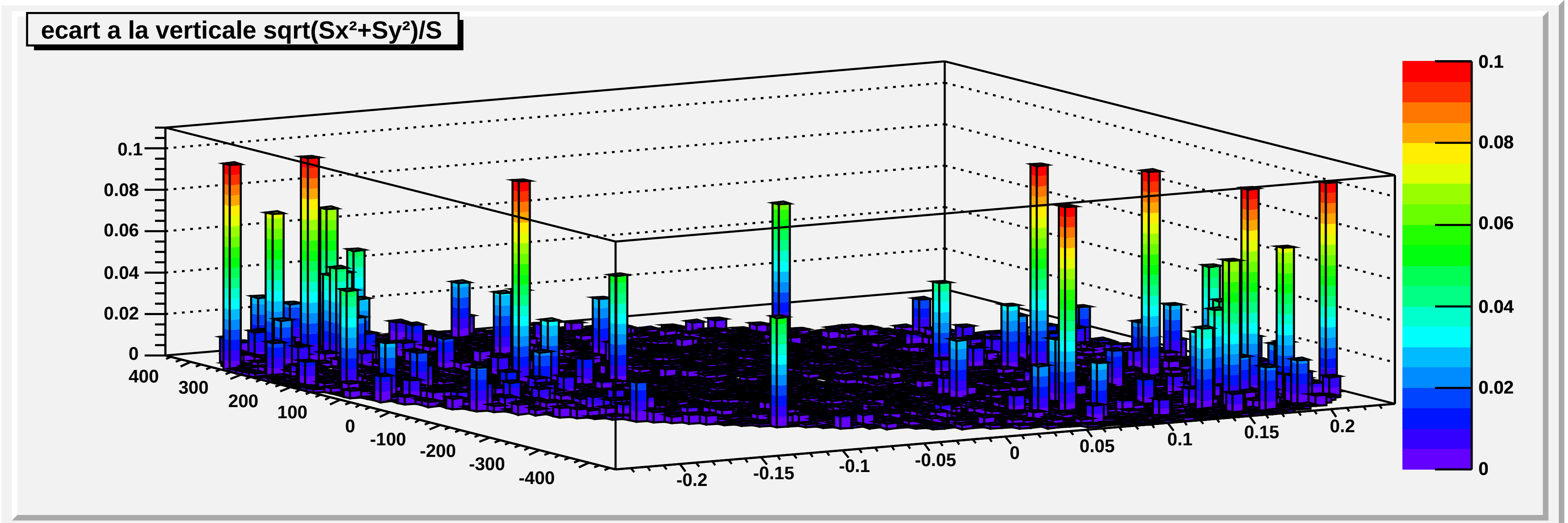
the average of spin components, over a small enough phase space area, and over a large enough number of turns, is the local precession axis of the particles spin.

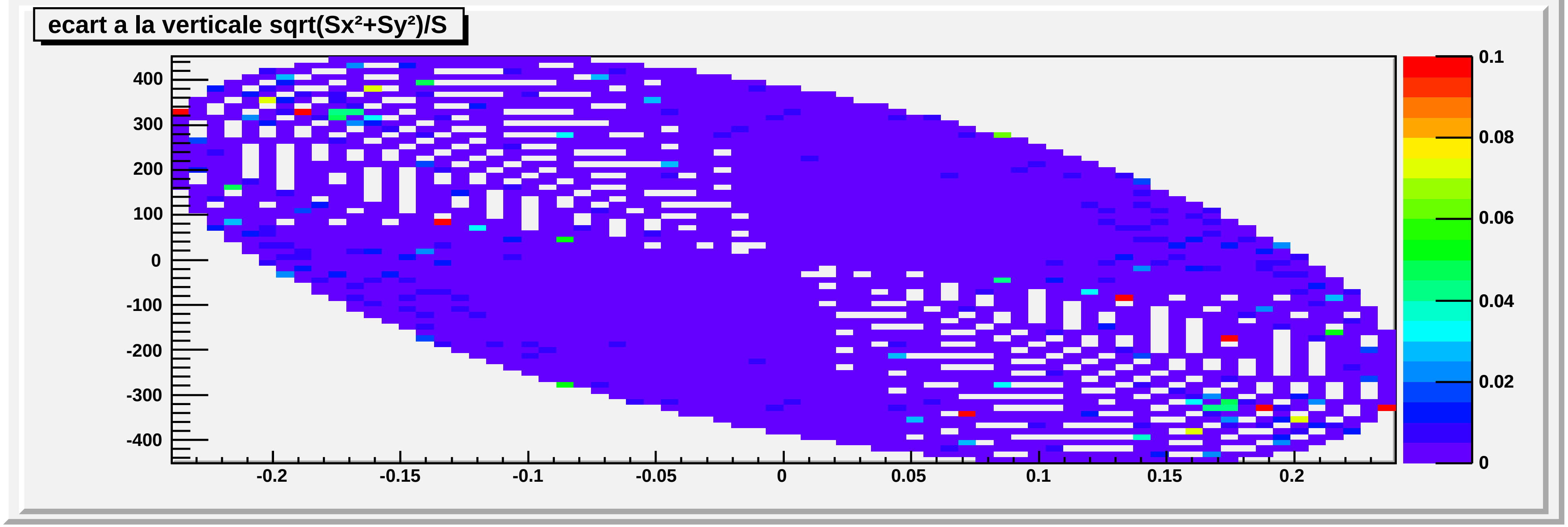
The number of *particle.turn* **needed for convergence of this averaging process over a** *small enough* **phase space area and a** *large enough* **number of turn has to be studied at least numerically.**

histogram averaging over each bin :



angle between spin average direction and vertical axis $\frac{\sqrt{S_x^2+S_y^2}}{\sqrt{S_x^2+S_y^2+S_z^2}}$:





N. Monseu ; Super-B spin study at LPSC, Caltech workshop 12 2010

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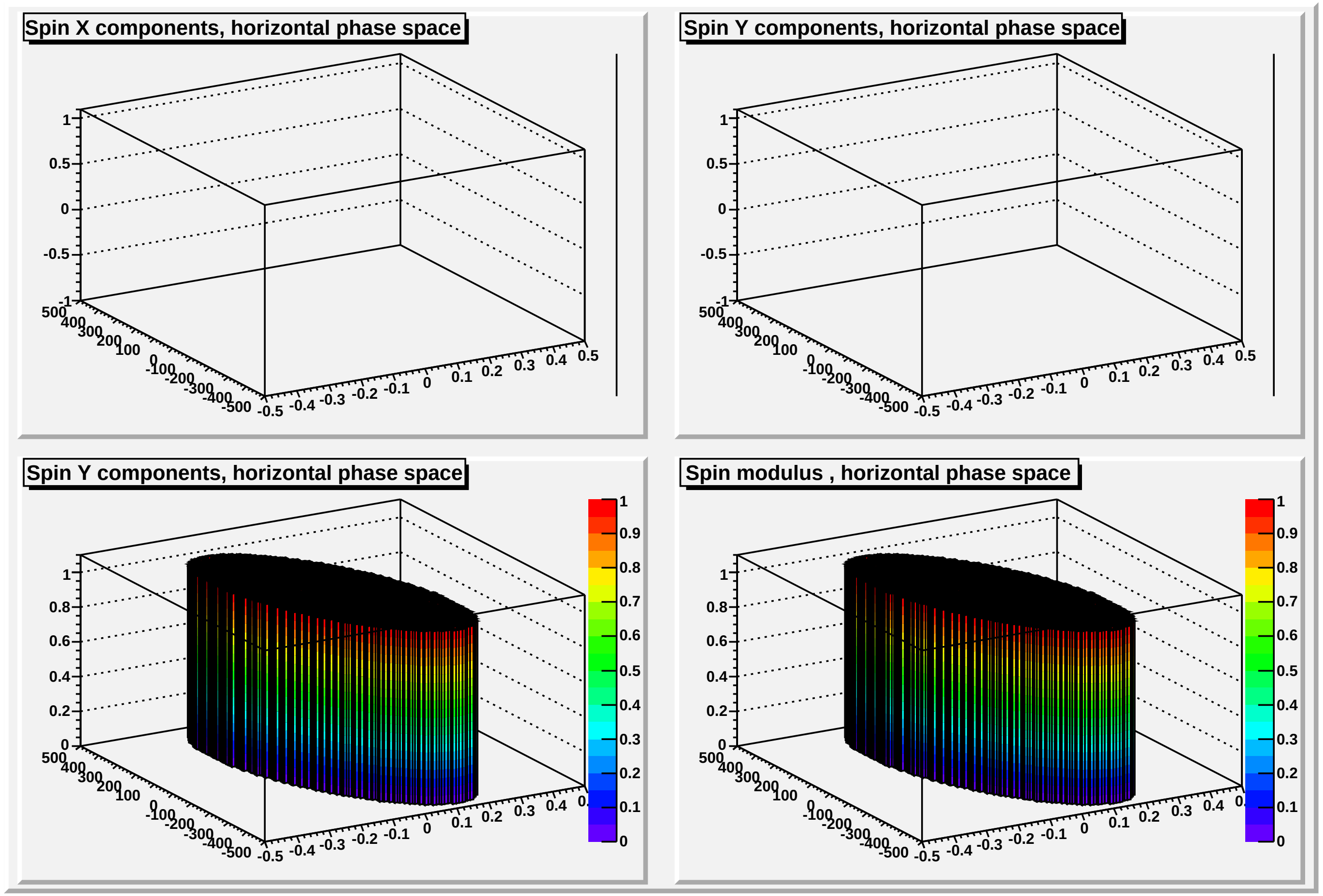
4 ISF : Convergence , turn number and bining effect

To develop tools, one need to fully understand the lattice, so I choose a simple fodo lattice :

- **This lattice (flat 128 fodo cells ring) is proposed and studied by Yokoya in KEK report 92-6.**
- **Non-spin dynamics simulation (in backup) are strongly needed as spin is strongly coupled to orbital motion.**
- **If we inject vertical spins, they remain vertical. It's exactly what we expected, but this does not help to prove convergence.**

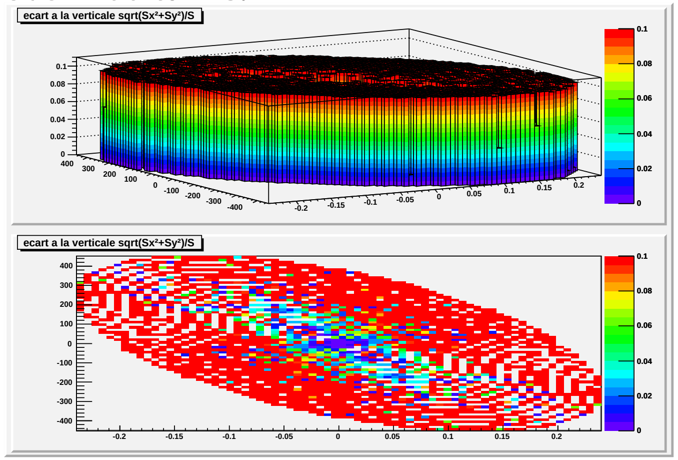


- **To study the convergences, different number of turn and size of bin have been simulated... with spin non-vertical.**

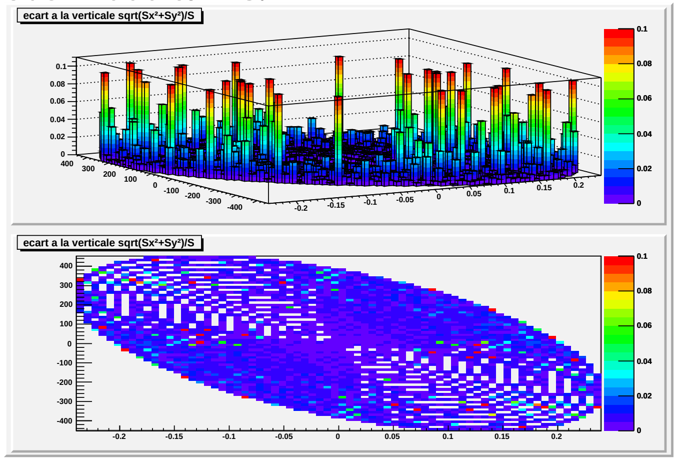
Turn Number study

These simulation has been done for 861 particles in horizontal phase space. Particles are disposed on a grid with an X step of 0.01 cm and an X' step of 0.0001 mrad. Their spin is of modulus 1, with an $S_X = 0.1$. Histogram 70x70.

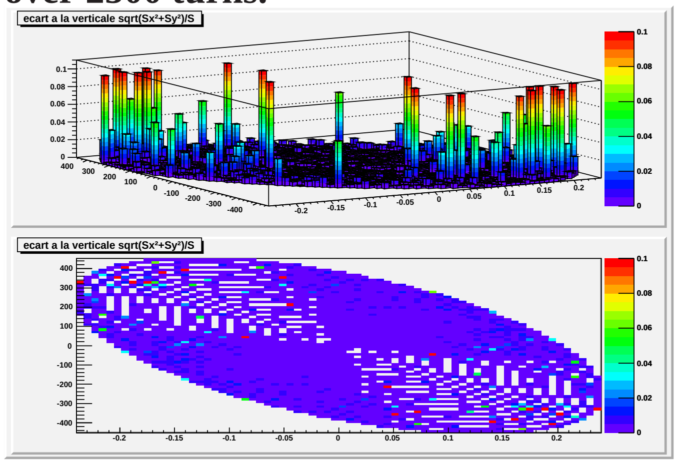
over 100 turns.



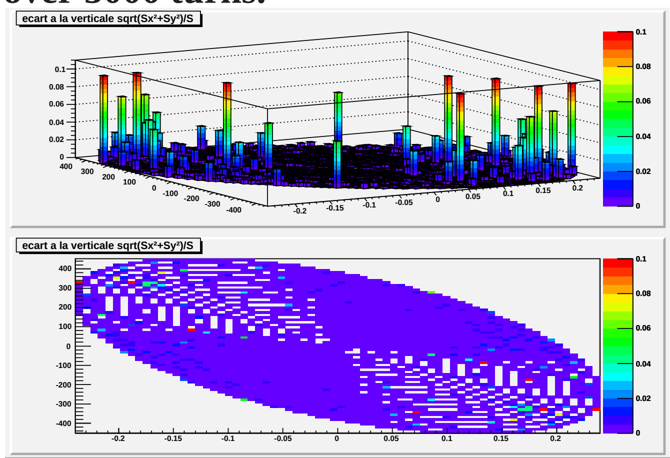
over 1000 turns.



over 2500 turns.



over 5000 turns.

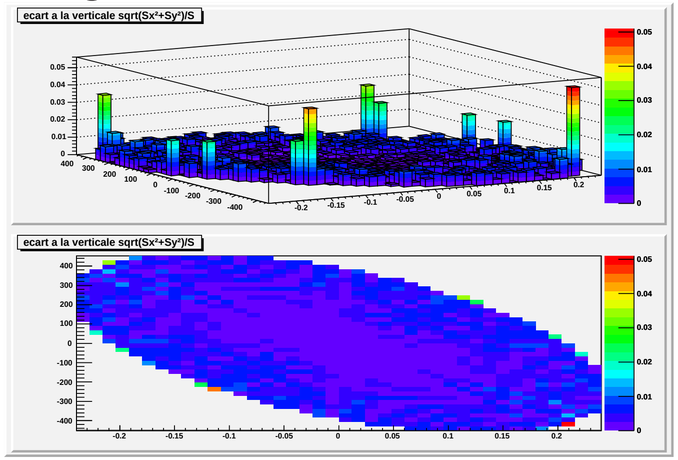


Around 1000 particle.turns per bin are needed for convergence.

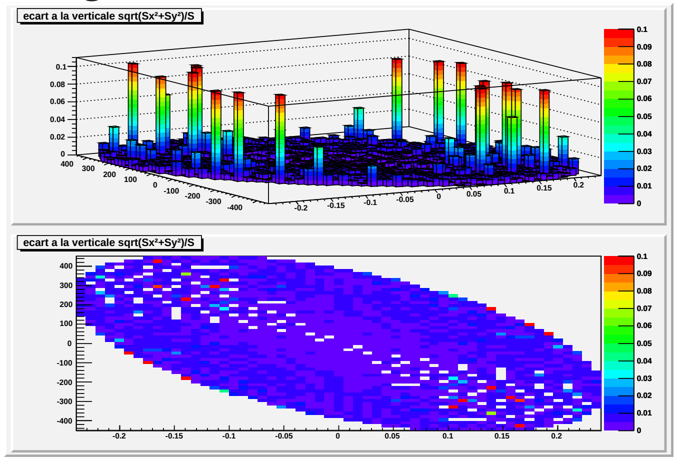
Bin number study

These simulation has been done for 2500 turn and 861 particles in horizontal phase space. Particles are disposed on a grid with an X step of 0.01 cm and an X' step of 0.0001 mrad. Their spin is of modulus 1, with $S_X = 0.1$.

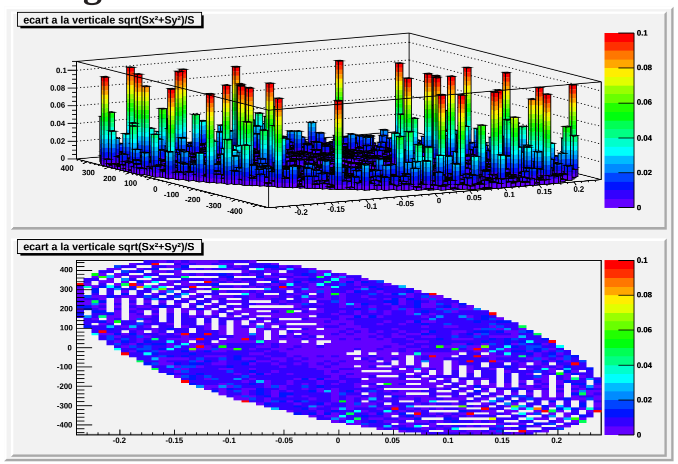
histogram 40x40.



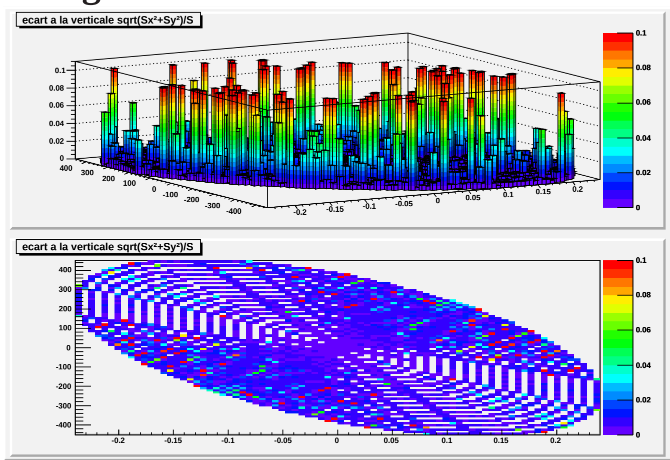
histogram 55x55.



histogram 70x70.



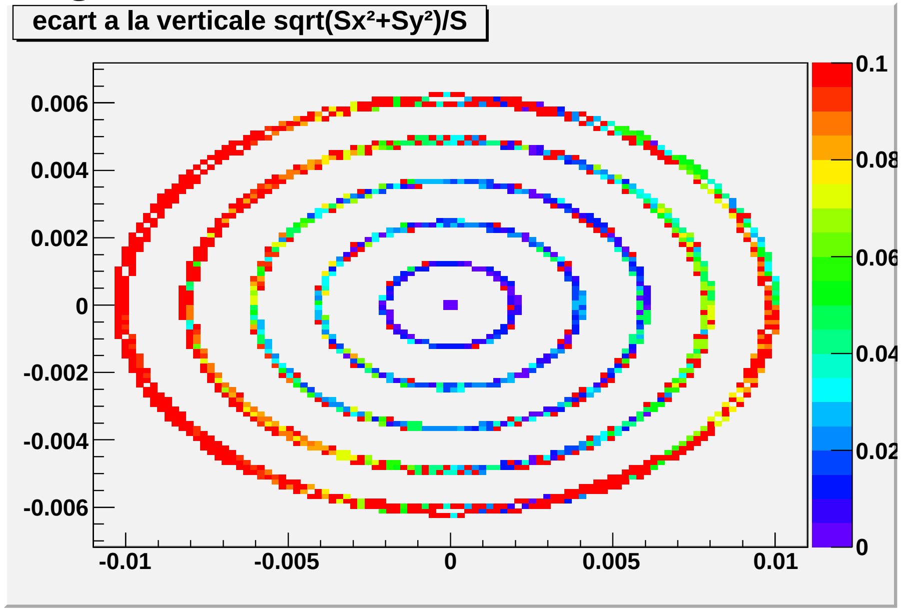
histogram 80x80.



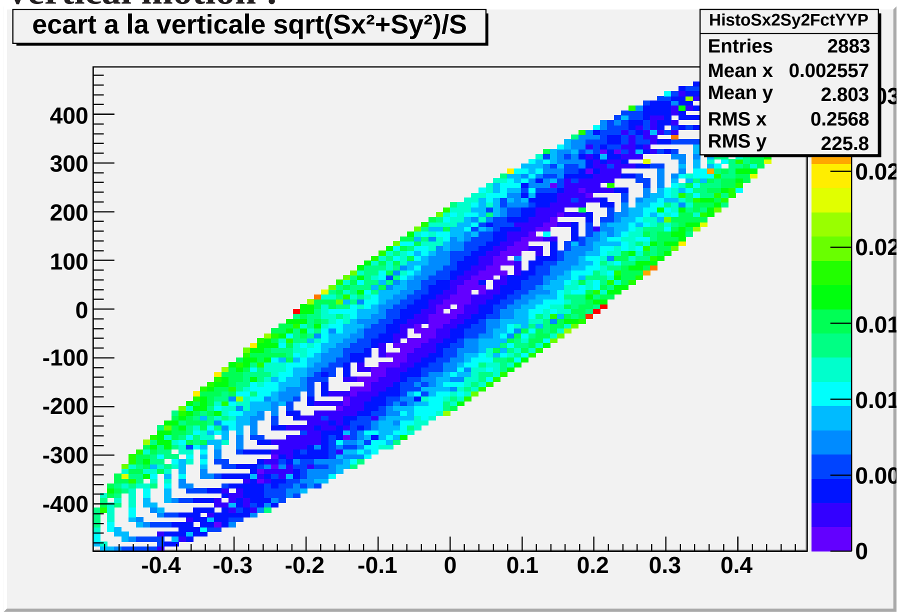
Again, around 1000 particle.turns per bin are needed for convergence.

Vertical and longitudinal motion

Longitudinal motion :



Vertical motion :



Preliminary results !

I Can't deeply analyse and explain this two plots right now.

Simply, they show that when particle perform an orbital motion, even in a perfect ring, the precession axis could be slightly tilted from the vertical.

Explaination come from the non vertical field encountered by the particles. And this is exactly why the beam dynamics has to be well understood.

5 Conclusion and foreseen work

Short term. I'm on it...

- **Computing time is becoming an issue. Parallel calculation has to be added.**

- **Improving the main data output could also help a lot (skip useless data, write a binary file?).**

- **Stroboscopic averaging method is implemented, but tool is well suited for 2D analysis only. Tool will be upgrade to full 6D motion analysis.**

- **ADST (spin tune) has to be simulated. Fourier analysis should work.**

- **6D motion is now working. Need to feed Zgoubi with some numbers for the Super-B LER V12 cavities.**

Middle term.

- As soon as convergence is proved for a full 6D motion, detailed 6D Compton IP ISF could be provided.

(Warning : it's not the bunch polarization, but it could help to understand what happen to spin there)

- Expected Polarization has to be computed from 'all ring ISF'.

- Continue to study error effect.

- try to study more 'non-spin' beam dynamics and correlation with spin dynamics.

Long term.

• **Acceleration cavity & SR loss do work. After cross-check and verification on SR simulation, spin diffusion could be simulated if we manage with computing time.**

• **Implement Sokolov-Ternov effect.**

• **Add a beam-beam element (weak-strong or strong-strong by couplig Zgoubi with GP++)**

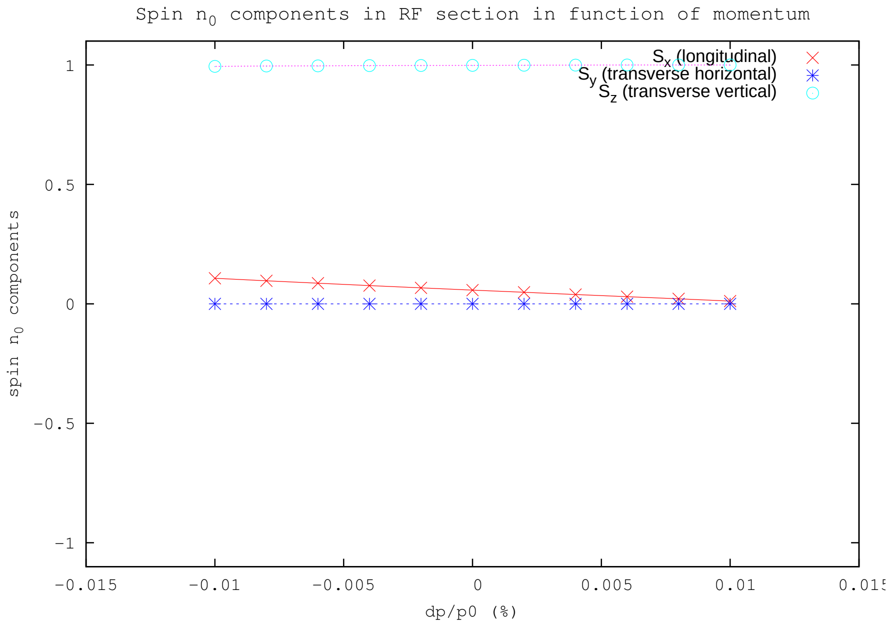
Remark : the DESY workshop on spin simulation tool pointed out an interest in coupling codes (e.g. coupling Zgoubi with GP++).

Thank you for your attention

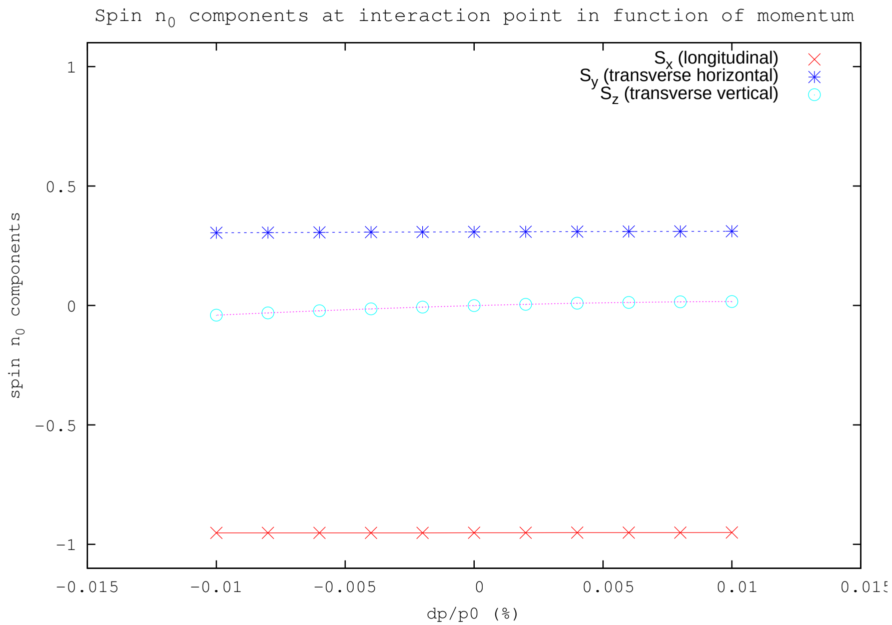
BACK UP

Spin tracking

$n_0(\delta)$, evolution of 'spin closed orbit' with momentum



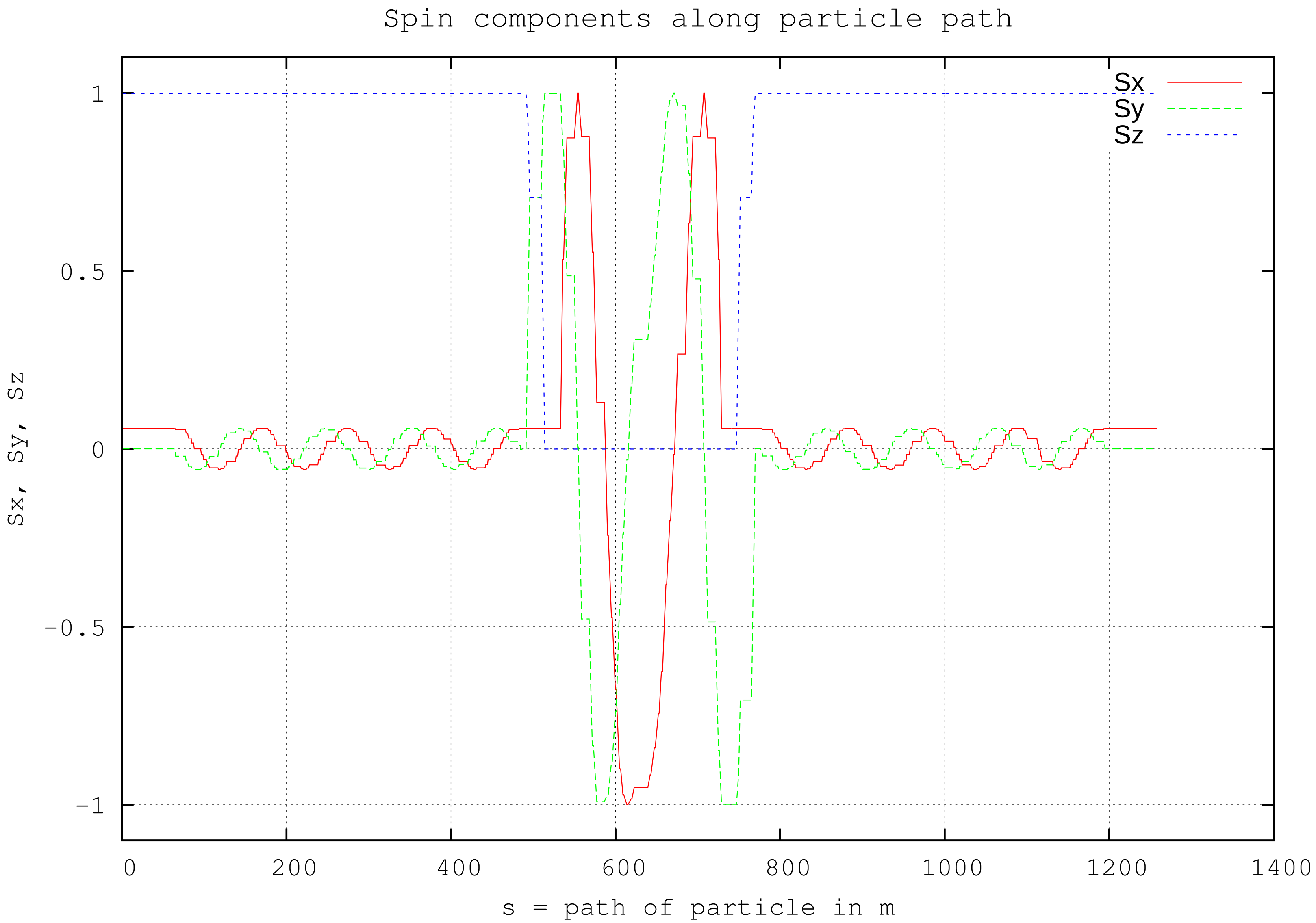
$\vec{n}_0$ components at injection (middle RF) in function of momentum



$\vec{n}_0$ components at IP in function of momentum

- **We still have the same few problem as for V11.**
- **$\vec{n}_0$ is not longitudinal at IP**
- **$\vec{n}_0$ is not (0,0,1), i.e. vertical, in the arcs of the ring. With $\frac{dp}{p} = +1.252\%$ it's ok.**
- **reminder : $\vec{n}_0$ is extracted from matching ('FIT') process, this works only on closed orbit**

Spin along elements



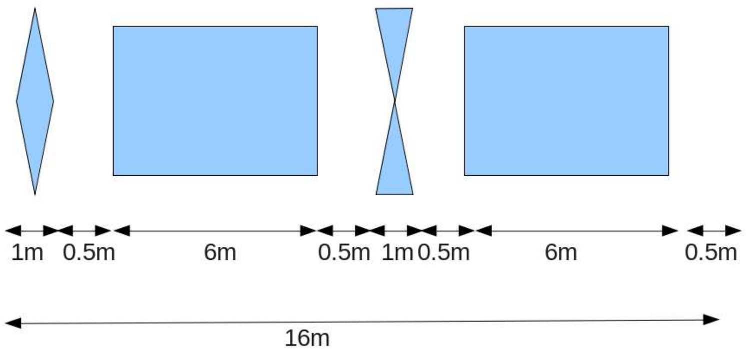
single-turn tracking for 1 particle, spin aligned on $\vec{n}_0$, on momentum.

Beam dynamics results

A Yokoya's fodo ring

Lattice hypotheses

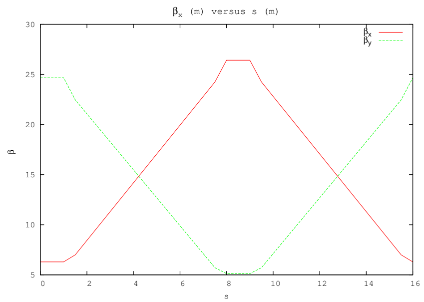
This lattice is described in KEK report 92-6. The Ring is made of 128 FODO cells.



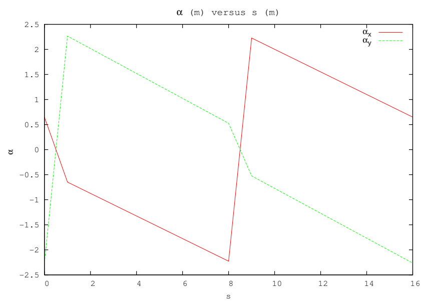
cell is made of a focusing quad (1m, $+0.18243216/m$, a defocusing quad (1m, $-0.16763610/m$) and two rectangular bending magnets (6m, $2\pi/256$) in between. Magnets are separated by drift spaces of length $0.5m$. So the total cell length is 16m.

Twiss functions over the first cell of the ring

β function

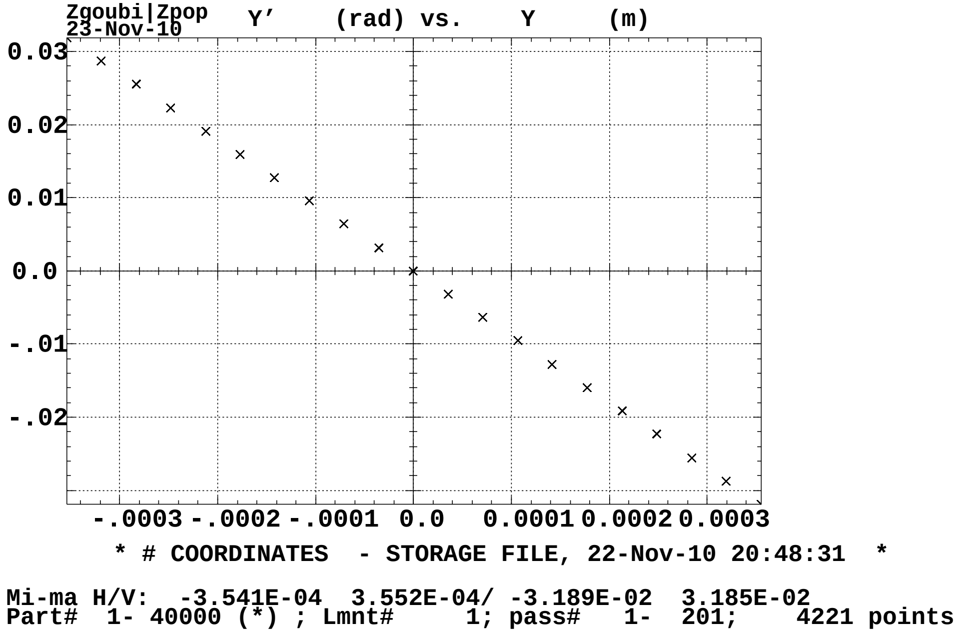


α function

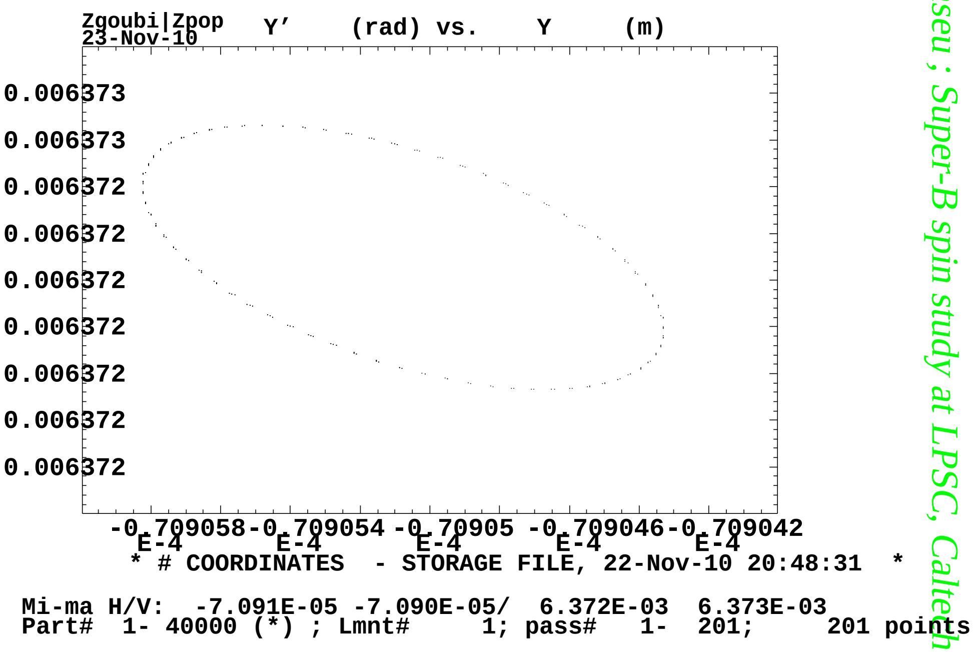


Remark : from this two figures one can see that number of points is not enough if one want to integrate β function, because zgoubi transport twiss function only at the end of each elements, and not *within* the elements. Some comments have to be done : without coupling between plane, interpolation is feasible to get more points, or we could split elements. If one study a lattice with coupling, a better method has to be implemented. This problem occures for SuperB, and has been spotted by Yann Dutheil during his stay with us from may to july 2010.

Closed orbits



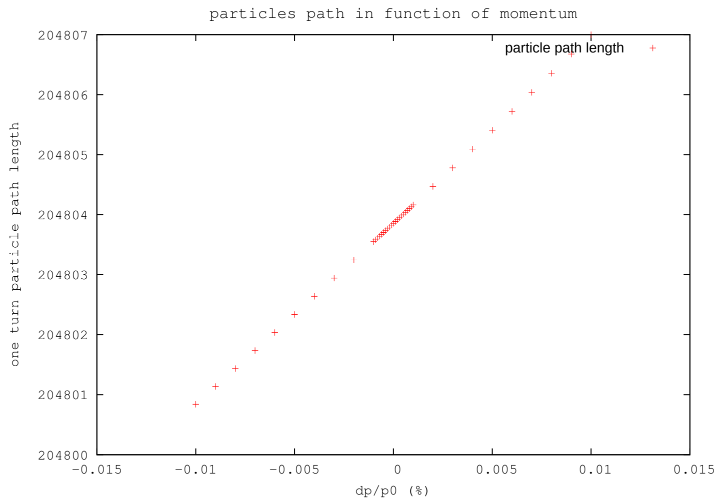
Closed orbits for 21 different energies, in the horizontal phase space. This graph shows particles coordinates from tracking over 200 turns, for each energy.



Zoom on one orbits, 200 turns.

Remark :It is clear from these plots (especialy the zoom on one small ellipse) that the process converges up to the fifth decimal, i.e. few μm and few μrad, which is far enough for our purpose here, and could be easily be change if one need more precision. In the case of SuperB, this is hundred time the beam size at the IP, and about a tenth of the maximum stable amplitude on momentum.

momentum compaction



$$\alpha = \frac{\Delta C/C}{\Delta P/P} = \frac{(C_{+1} - C_{-1})/C_0}{+1\% - -1\%} = 1.46481614165E-03 \quad (1)$$

particles path length, in function of momentum

$\gamma_{tr} \approx 26.1281368133$**, as expected in an electron ring, with 20 GeV electron, we are far beyond transition energy.**

Longitudinal motion

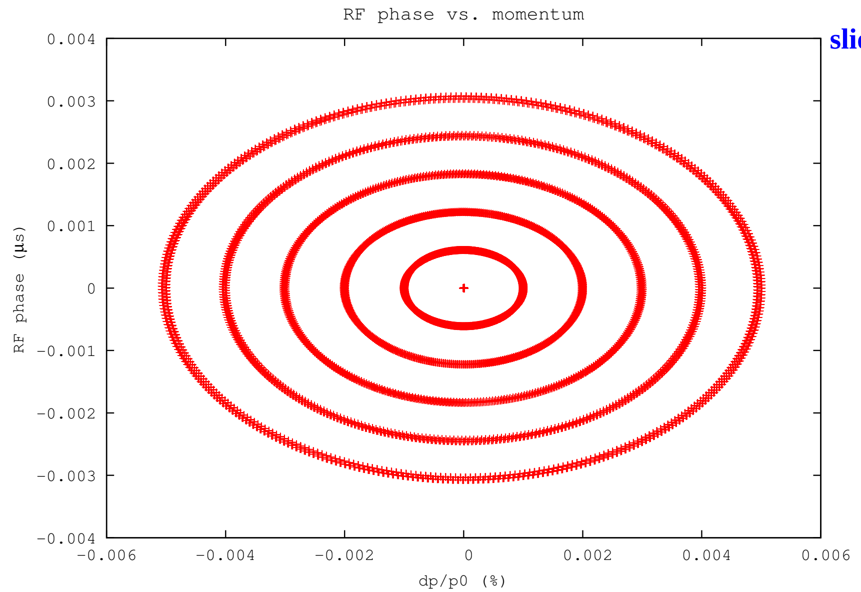
$$f_{rf} = \frac{1}{T_{tour}} = \frac{v_s}{L_s} = 1.46380280461E-05 \quad (2)$$

The two cavities are symmetrically located between splitted quads. the ring is so divided in two equivalent halfs made of 64 fodo cells and a cavity. RF peak voltage is 75 MV. Yokoya gives indicates relative energy spread ($\sigma_e = 1.113E-3$**) and synchrotron tune where (**$\nu_s = 0.06365$**) at the energy 20.27 GeV.**

$L_{synch.}$ **is path length of the synchronous particle,** $v_s = \beta c$ **its velocity. 4th harmonic has been choosen for our two cavities, so frequency is** $f_{cav} = 585521.12184223789 s^{-1}$ **for both cavities**

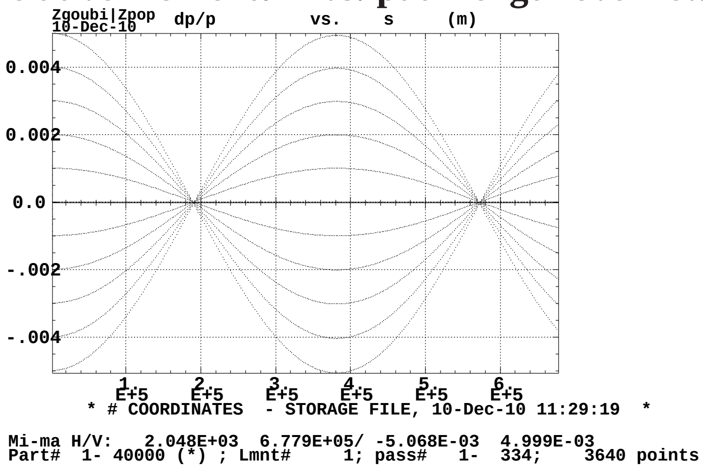
Longitudinal motion

- **relative momentum $\frac{\delta p}{p_0}$ in percent**
- **RF 'phase' ($t_{cav} - n_{turn} * t_{synch.}$) in μs**
- **with t_{cav} being the arrival time of each particles in the cavity, n_{turn} the turn number of the incoming particle and $t_{synch.}$ the one turn time of the (virtual) synchronous particle)**
- **11 particles from -0.5% to $+0.5\%$.**

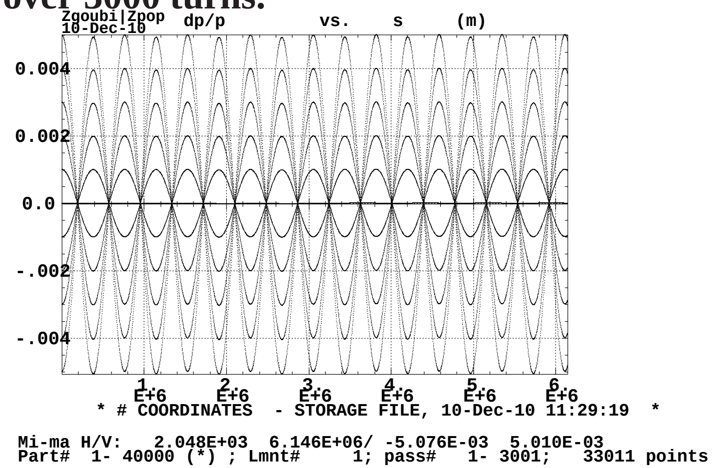


phase space over a 3000 turn tracking.

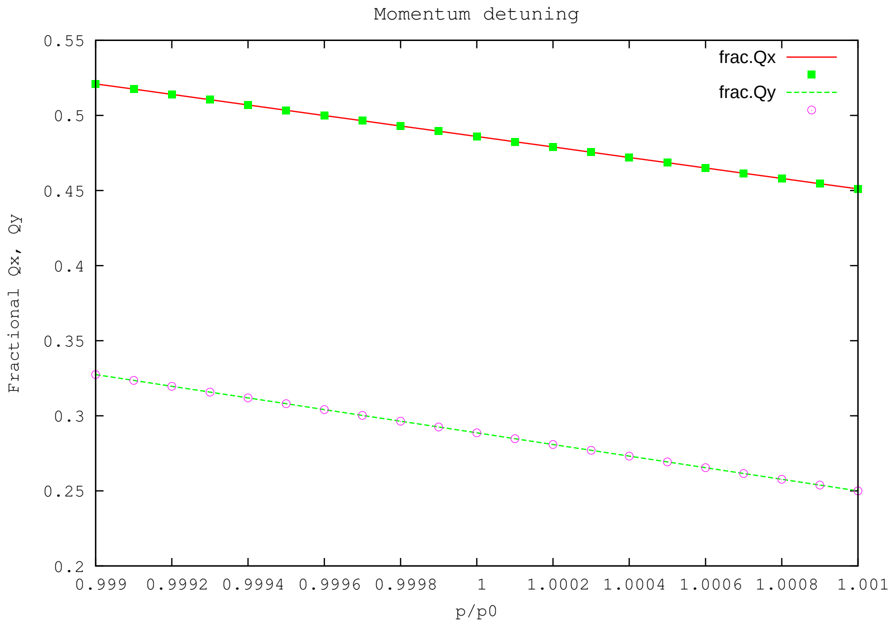
relative momentum vs. path length over few turns.



over 3000 turns.



Momentum detuning



Amplitude detuning

add a picture here asap. this is really important to study this part, as spin resonances 'take into account' orbital motion.