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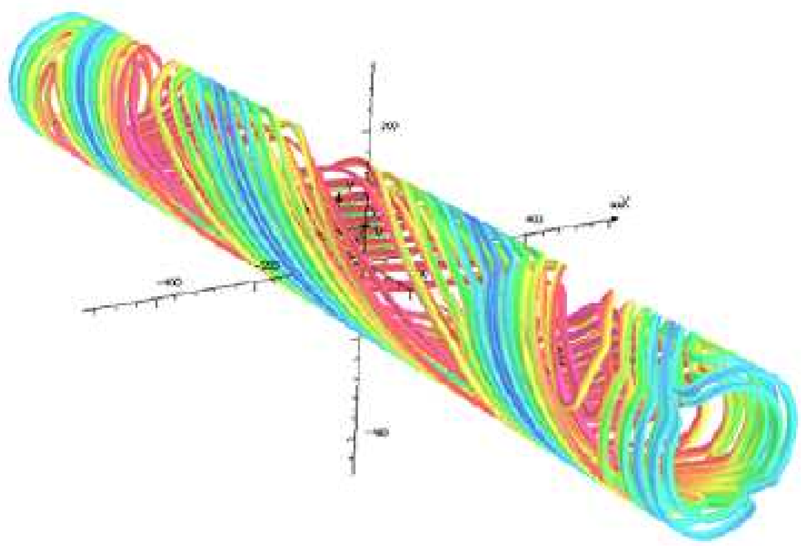
RHIC APEX Meeting

BNL, November 19-20, 2012

THE ON-LINE MODEL OF THE AGS IN ZGOUBI

This is a collective work.
It owes a lot to the Thursday "AGS On-line Model" Meeting



CONTEXT :

(i) A model of the AGS is being developed in the stepwise ray-tracing code Zgoubi since about two years, now allowing sophisticated beam and spin dynamics simulations.

(ii) A command, ZgoubiFromSnaprampCmd, has been created and allows getting a model of the machine at arbitrary timing(s), just like the eponym MadxFromSnaprampCmd does, from AGS snapramp data files.

(iii) Installation of a user's interface to the Zgoubi model of the AGS in the AGS control/command applications environment has been undertaken early this year.

It includes a number of data treatment, analysis and graphic tools.

Contents

1 Objectives regarding the model of the AGS in Zgoubi

- **Make it an efficient aid for machine studies/developments**

- **An aid for the operation**

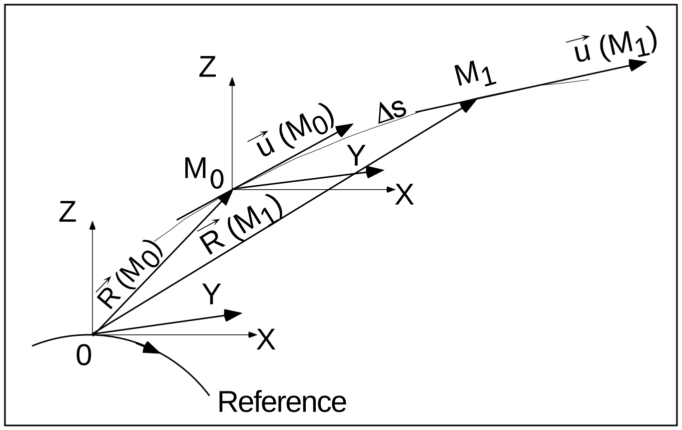
Objectives in the immediate, essentially :

- **Have a dedicated application available in AGS StartUp menu, AgsZgoubiModel**

- **Have that application debugged amahf in closest future**

*** Note : the application is available under "Commissioning" in StartUp, so, anyone who wants to try and crash it, and then report the crash, is welcome !**

2 Brief reminder : Zgoubi method and the AGS



- **Zgoubi solves, step by step, the two equations of motion**

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

$$(B\rho)\,\vec{S}\,' = \vec{S}\times\left[(1+\gamma G)\vec{b}+G(1-\gamma)\vec{b}_{//}+\frac{\beta\gamma}{c}(G+\frac{1}{1+\gamma})\vec{e}\times\vec{u}\right]$$

- **Beyond that, Zgoubi includes a wide variety of optical elements.**

Two have been newly installed, specific to the AGS, namely

- `'AGSMM'` for the main magnets, derived from the old "`MULTIPOL`" routine.

*** K1 and K2 strengths in `'AGSMM'` are deduced from momentum polynomials,"à la Bleser"**

*** They can nevertheless be tweaked - this will be addressed, a few slides from now.**

*** `'AGSMM'` allows for back-leg windings - thus local bumps and this sort of things.**

- `'AGSQUAD'` for the quadrupoles, derived as well from "`MULTIPOL`".

*** `'AGSQUAD'` takes coil currents, which allows direct use of the snapramp data. It then gets strengths from similar polynomials "à la Bleser".**

*** `'AGSQUAD'` allows multiple power supplies - and thus combined families when "fitting".**

• **Routinely used models for the various optical components have been, so far:**

- **Main magnet :**
  - **either, `'AGSMM'`**
  - **or, `'TOSCA'`, a routine that handles measured magnetic field maps .**

    Notes :
    (i) we plan on using soon the OPERA field maps - more convenient for long term tracking,
    (ii) `'TOSCA'` has been upgraded so to allow tweaking K1 and K2,
    (iii) the superimposition of back-leg windings on field maps is under development.

- **All quadrupoles : `'AGSQUAD'`**

- **All other lenses and correctors : `'MULTIPOL'`.**

- **Snakes : `'TOSCA'` routine using their OPERA field maps.**

Note : `'TOSCA'` can read C-snake Helix and Solenoid components separately and then provide arbitrary, adjustable, Helix/Solenoid ratio.

3 The two ways to get a “zgoubi.dat” of the AGS

1/ First method : translation from MAD8 or MADX to Zgoubi

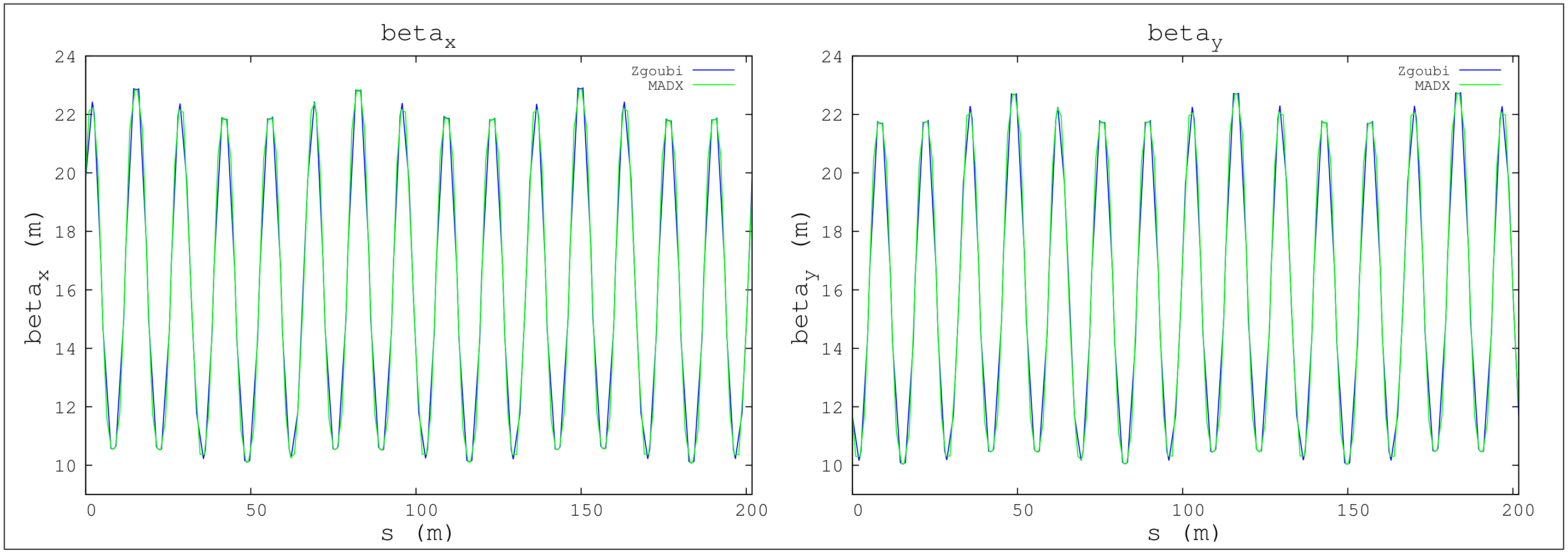
- **Step 1 : get a MAD8 “survey”, or MADX “twiss” model of AGS, at whatever timing, whatever particle, for instance as produced from a snap ramp using “MadxFromSnaprampCmd”**

- **Step 2 : Run the MADX→Zgoubi translator, “madzg”, that yields the equivalent “zgoubi.dat”**

- **Example - In the case of AGS without snakes (bare AGS, in this example), paraxial parameters come out very similar from the two methods :**

ZGOUBI		MADX	
@ ENERGY	2.336297355	@ ENERGY	2.336297355
@ PC	2.139609994	@ PC	2.139609994
@ GAMMA	2.49	@ GAMMA	2.49
@ LENGTH	807.09125	@ LENGTH	807.0912776
@ ALFA	0.013938943	@ ALFA	0.01400421279
@ GAMMATR	8.470032542	@ GAMMATR	8.450271241
@ Q1	8.71146154	@ Q1	8.711241771
@ Q2	8.76489937	@ Q2	8.764687515
@ DQ1	20.857796	@ DQ1	-22.77456732
@ DQ2	1.5952333	@ DQ2	1.741333201
@ DXMIN / MAX	-2.165 / -1.45669	@ DXMAX	2.362567298
@ BETXMAX	22.91360	@ BETXMAX	22.89569733
@ BETYMAX	22752900	@ BETYMAX	22.73971789
@ DXRMS	1.818530	@ DXRMS	1.983354657

Betatron functions, A, B, C periods, Zgoubi and MADX data superimposed



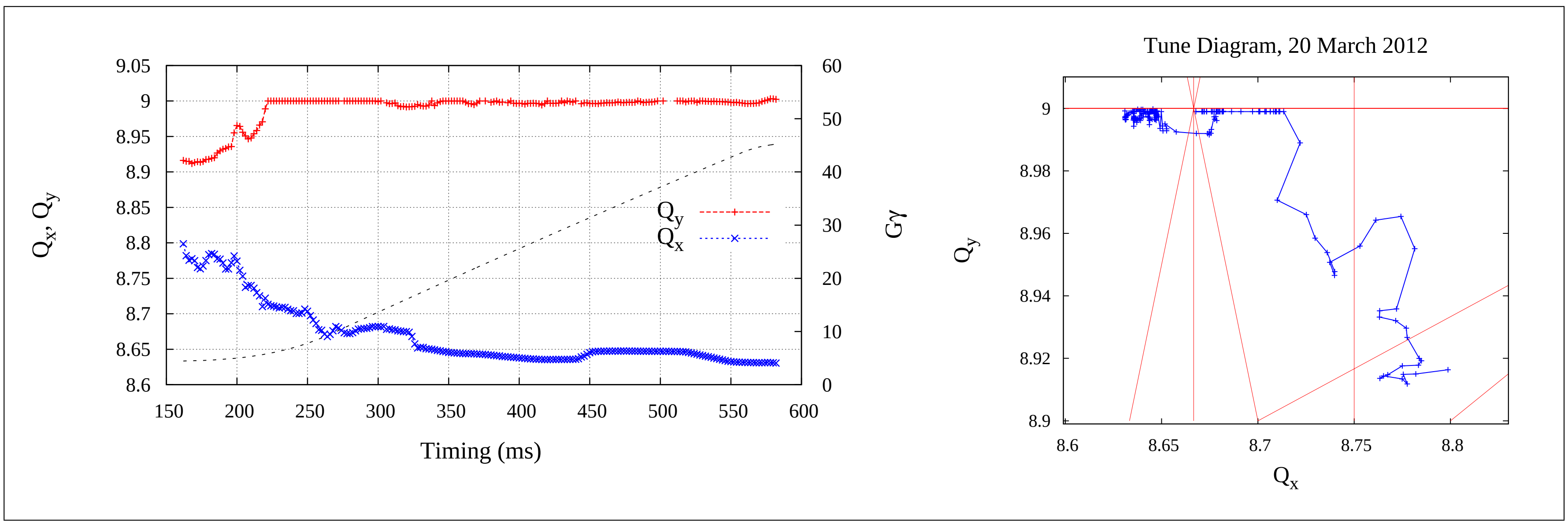
2/ Second method : ZgoubiFromSnaprampCmd

- **This is the on-line command, equivalent to "MadxFromSnaprampCmd".**
  ZgoubiFromSnaprampCmd generates a model from any snap ramp, at arbitrary timing(s).

It uses the "`conversion`" MADX files, that take care of delivering optical strengths from momentum or currents.

- **The command essentially needs the snap ramp address in ppmUser** $\begin{cases} 1 \\ 2 \\ 3 \\ 4 \end{cases}$ **,**
  and the desired (list of) timing(s).

- **Example - Tune scan, using**
  /operations/app_store/RunData/run_fy12/fullRun/Ags/Snapramp/12Mar20/ppmUser4/12Mar20-2146_U



• **These developments also allow modeling the acceleration :**

(i) the “`conversion`” MADX file has been implemented in Zgoubi, providing

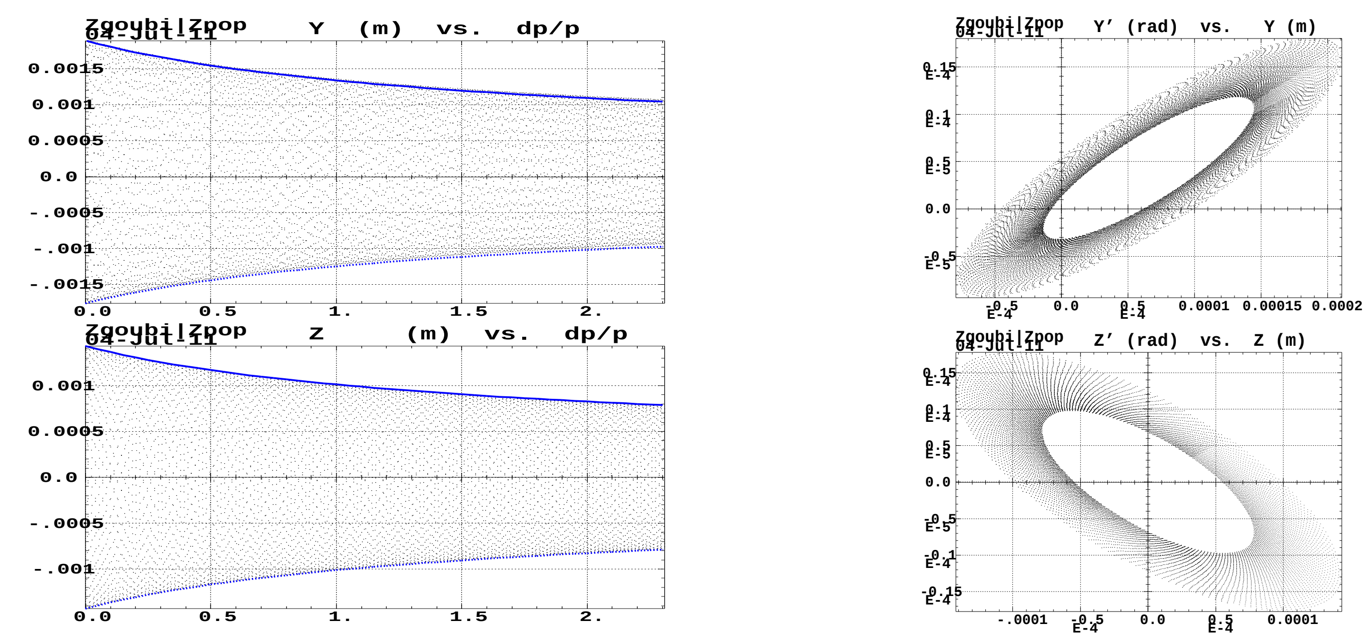
- conversion from momentum to K1 and K2 for main magnets

- conversion from snapramp currents to quadrupole and sextupole strengths,

(ii) whereas snapramp data are read and applied during acceleration, using the power supply command, `'SCALING'`.

• **Example : 150000 turns acceleration. Ion optics, `'AGSMM'` model, in this case.**

- In passing : CPU time is ≈30 minutes (regardless of the number of particles, if run on NERSC computers).



$B\rho/B\rho_0$ =**3.308**

ϵ_{x0}/ϵ_x = **3.325**

ϵ_{y0}/ϵ_y = **3.328**

Damped H (top) and V (bottom) motion over 9→32 GeV. The blue curves on the envelopes (left) are theoretical values, $\hat{x}(0) \times \sqrt{B\rho_0/B\rho}$**.**

4 Background : Zgoubi intruding into everydays' life at the AGS

- **The idea behind having an active background of Zgoubi simulations:**

  (i) keeping Zgoubi busy experiencing all sorts of AGS-related exercises,

  (ii) and, now it exists, challenging the AgsZgoubiModel in the StartUp menu.

- **The goals are**

  - to improve these tools,

  - debug,

  - have them acquire experience and become knowledgeable,

  - make them crash-proof as much as possible.

- **This is illustrated in the examples that follow, taken from everydays' life at the AGS.**

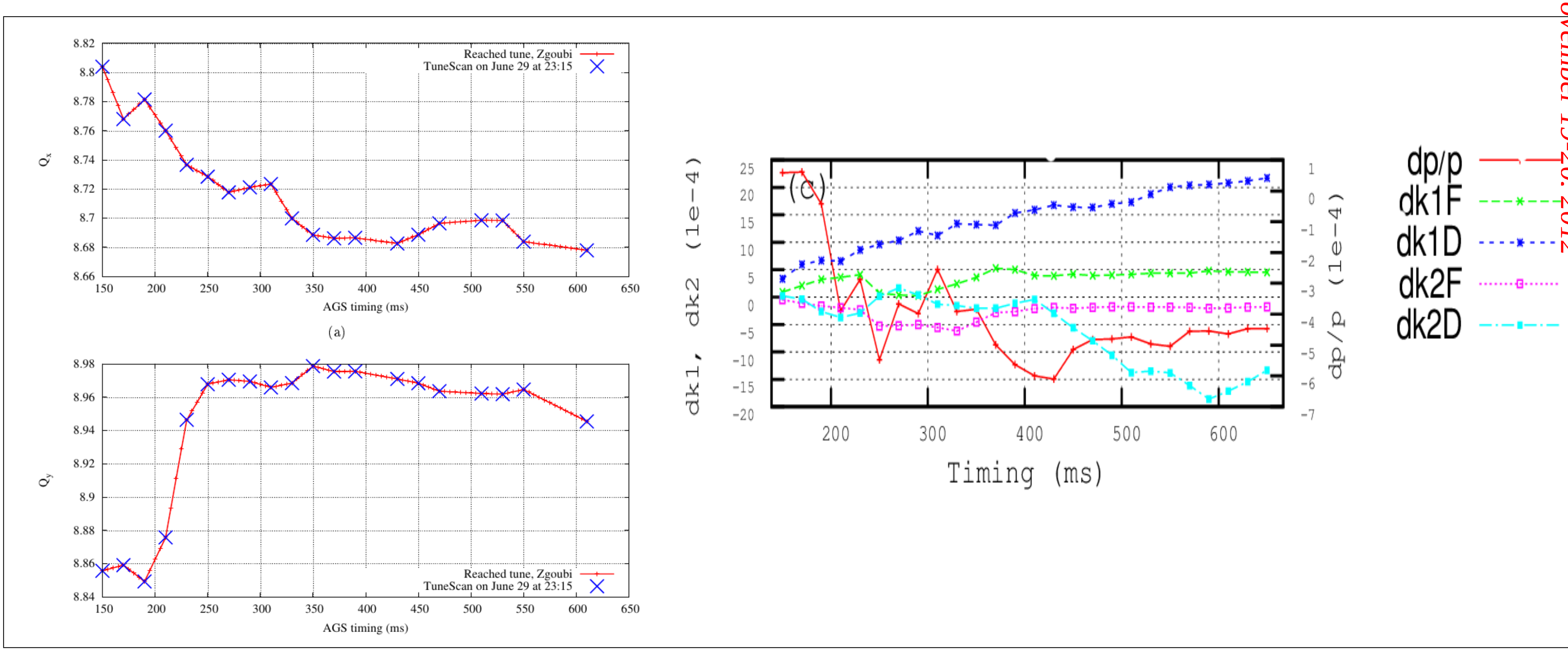
4.1 Tune and chromaticity scans

• We have been working on Q and ξ scans for a few months now, this is part of the benchmarking and development of the model.

• Zgoubi scans can be made to overlap measured data, using 'FIT', by varying essentially

- dK1_F, dK2_D, orbit radius, as to tunes,

- dK2_F, dK2_D, as to chromaticities.



Details : cf. "AGS On-line Model" meeting minutes.

4.2 Polarization, tune-jump studies

• Studies are underway regarding the improvement of polarization transmission in the region of the end of the ramp. It includes

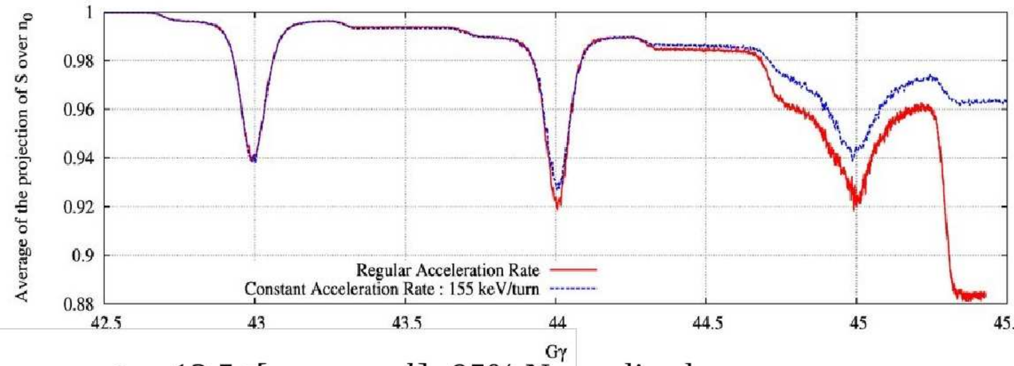
- fine adjustment of the timings of the last tune-jumps,
- extraction on-the-fly.

• Four major ingredients proper to Zgoubi come in here :

- the possibility of using the C- and W-snake 3-D OPERA field maps,
- the acceleration machinery,
- which includes function generators (power supplies),
- spin tracking.

Polarization transmission at the end of the ramp, B-dot either constant or slowing down :

Average of the projection of $\vec{S}$ on $\vec{n_0}$, at A0.



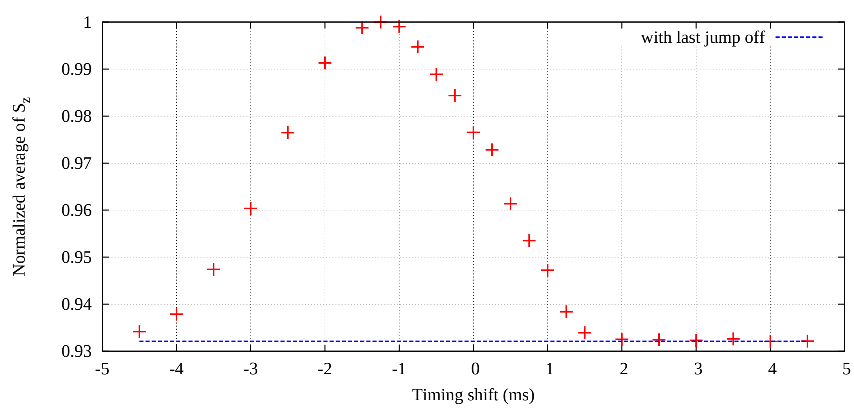
$\varepsilon_x = 13.5\pi[mm \cdot mrad]$ 95% Normalized

$\varepsilon_y = 14.0\pi[mm \cdot mrad]$ 95% Normalized

$\varepsilon_l = 0.7\pi[eV \cdot s]$ rms

Effect of the fine tuning of the jump-quads timing :

Average of S_y at top energy, as a function of the timing of the last tune jump.



Details : recent Spin Meetings, Yann Dutheil

4.3 Polarized Helion study

- **The goal was to review various aspects of ^{3}He↑ transport in booster and AGS.**

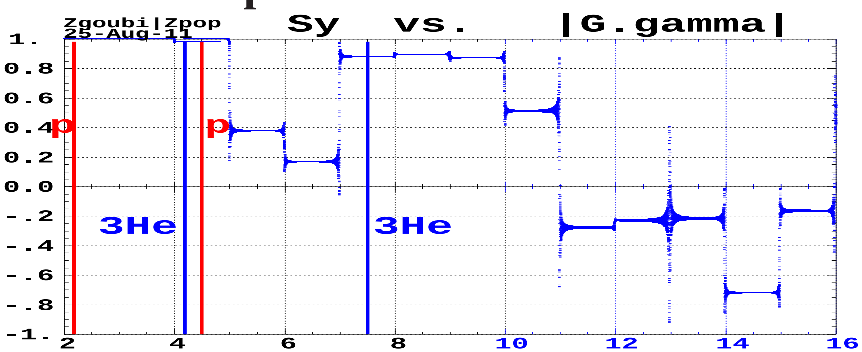
A practical interest in the ray-tracing method is that
- not only does it allow investigating the optics - in presence of the snakes,
- but it also produces polarization related parameters.

A bonus in passing : these investigations included the modeling of Booster in Zgoubi.

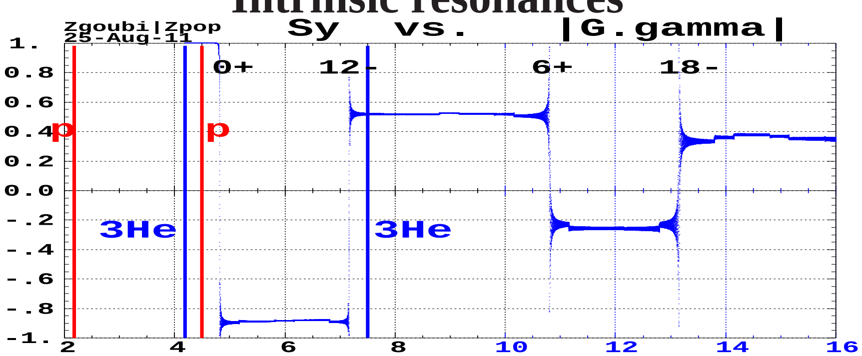
- **As an illustration, below : possible scenarii of injection/extraction $G\gamma$ values :**

Booster

Imperfection resonances

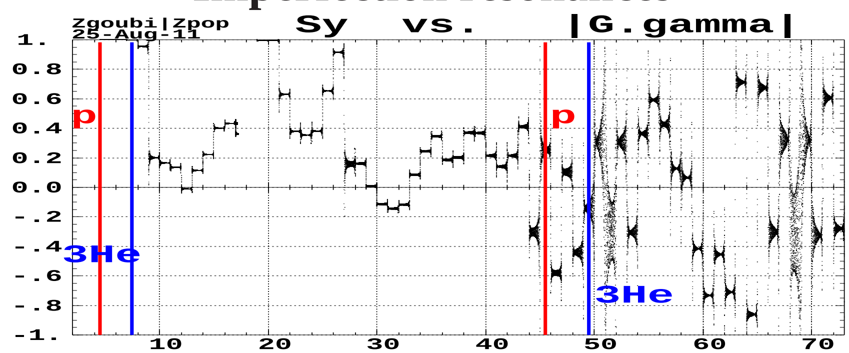


Intrinsic resonances

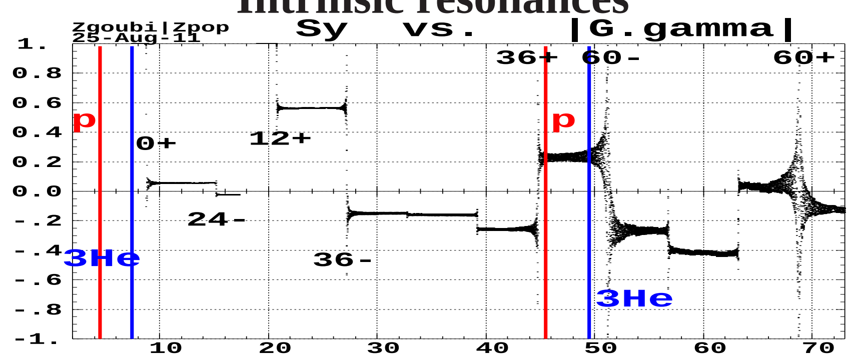


Bare AGS

Imperfection resonances



Intrinsic resonances

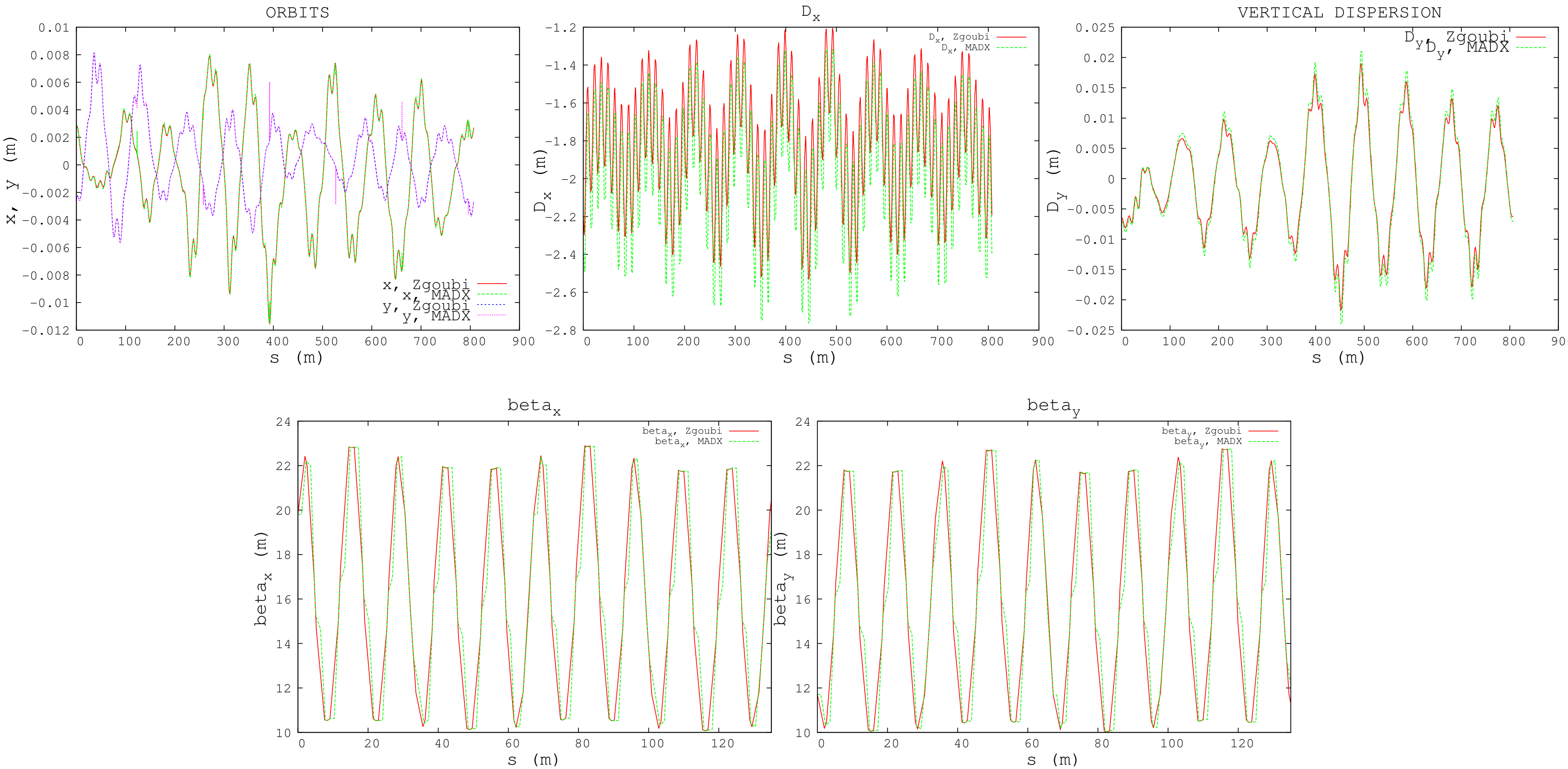


Details, cf. for instance : Workshop on Opportunities for polarized 3He in RHIC, BNL, Sept. 2011 ; RHIC APEX meeting, BNL, 2011.

4.4 AGS optics including survey data

• **MADX ingredients were provided by Vincent, from what zgoubi.dat is obtained using the "madzg" translator as addressed earlier.**

• **Sample comparisons, all defects included : dx, dy, x-rot, y-rot, roll.**



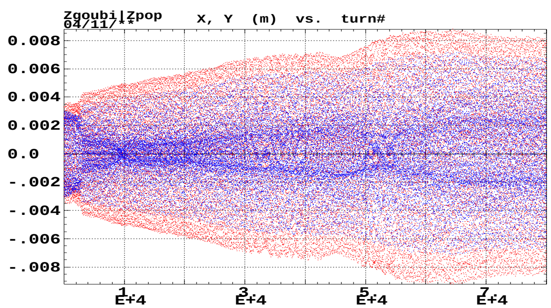
• **More simulations, and comparisons with AGS data are in order/planned.**

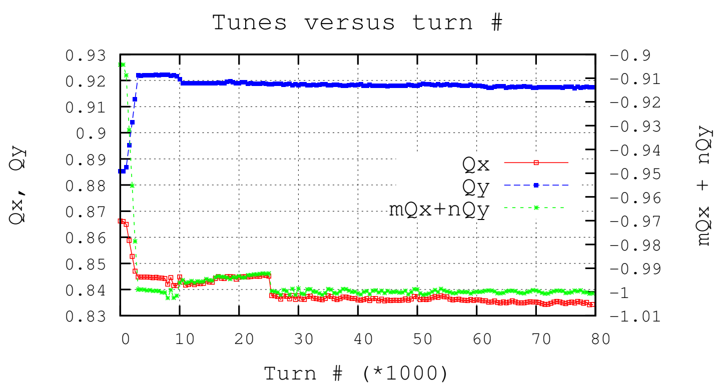
For more results : MOPPC024, IPAC 12 ; minutes of "On-Line AGS Model" Meetings.

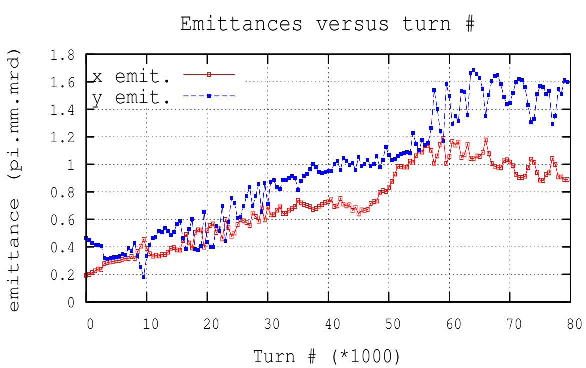
4.5 Coupling studies (1/2)

- Linear coupling is present in the AGS. Snakes contribute, especially at low energy.
- Zgoubi tracking shows non-linear effects, and possibly emittance increase, in presence of cold snake.
- In the illustration below, QH/QV quads settings yield Q1/Q2 = 8.8661/8.8852 during first 1000 turns.

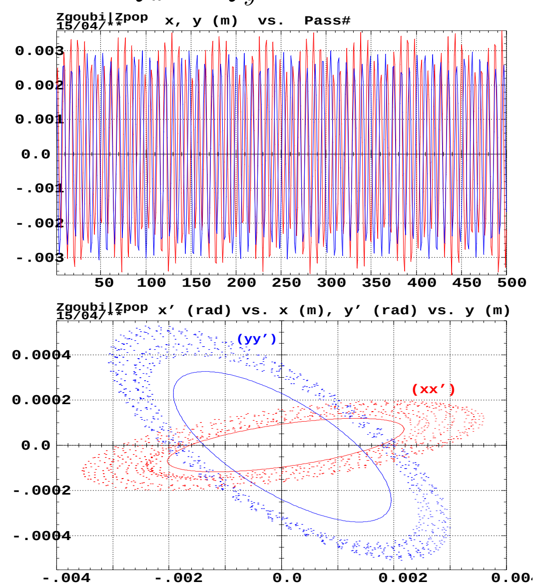
They are then slowly changed to yield Q1/Q2 close to 8.84/8.92 from turn 3000 on.



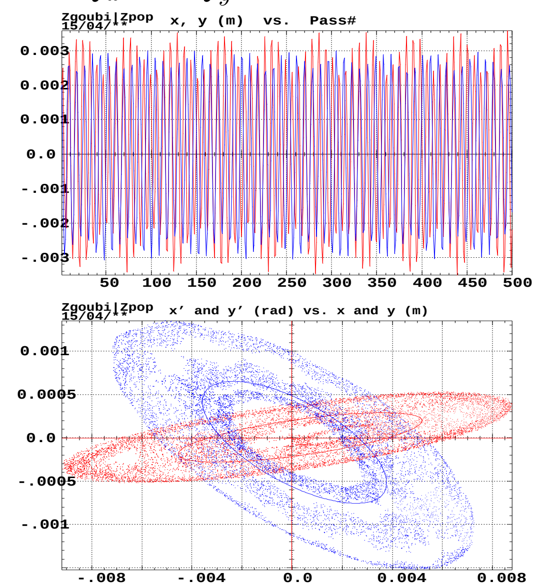




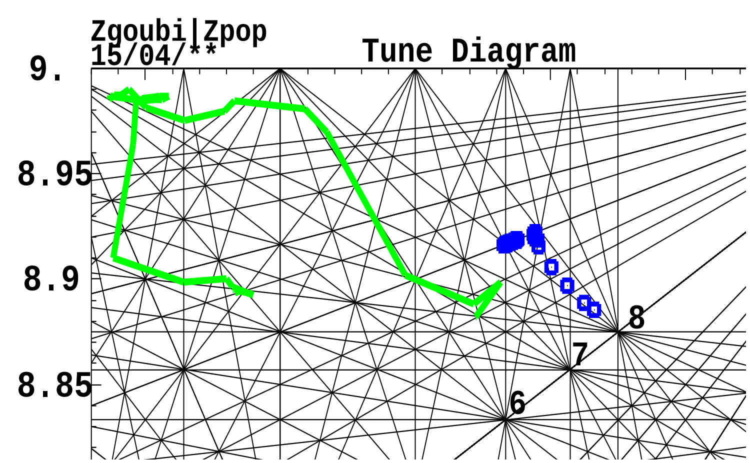
$Q_x - Q_y \approx -0.02$



$Q_x - 2Q_y + \textit{\textbf{int.}} \approx 0.005$



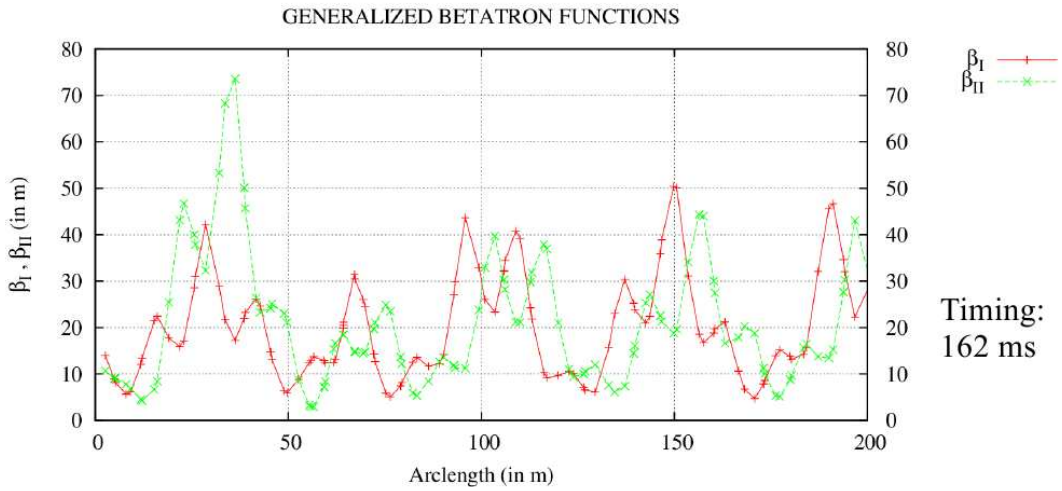
AGS tune-meter scan data in green, Zgoubi model in blue :



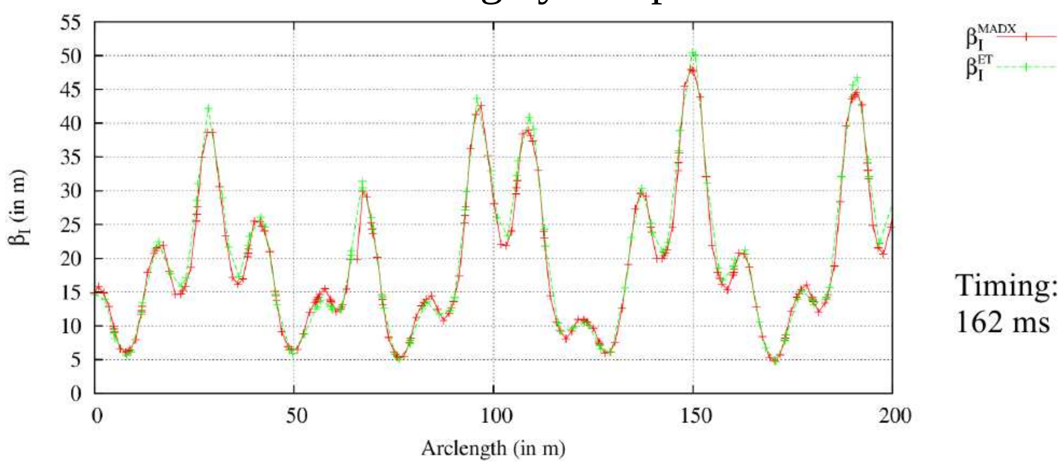
4.6 Coupling studies (2/2)

• **Tools for computation of coupled beta functions and coupled modes from one-turn mapping have been developed this Spring (Edwards-Teng method). Installation in Zgoubi is being completed.**

• **This will allow more accurate insight in machine parameters, tighter modelling of optical functions, in particular at low $G\gamma$ where snakes induce stronger coupling.**



Done some benchmarking by comparisons with MADX



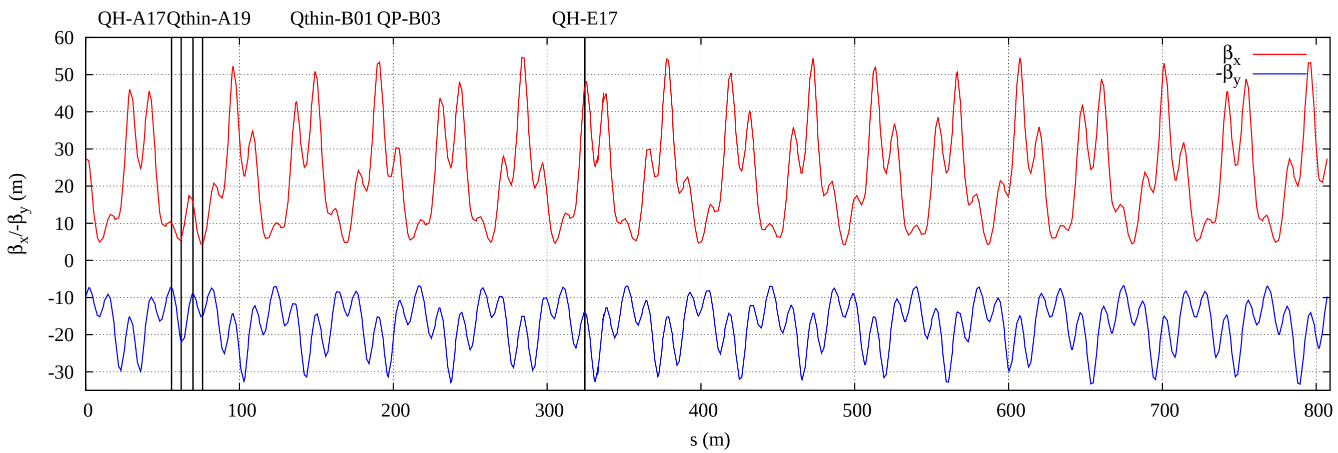
Details : F. Desforges, Tech. Note C-AD/AP, Sept. 2012.

4.7 Measurement of the optical functions

- **i.e., $\beta_x,\ \beta_y$, dispersion, were performed, during this year's run, bare AGS with cold- or warm-snake.**

  - **Principle : inject some local δk, measure the tunes, thus local $\beta = \delta Q/\delta k/4\pi$.**

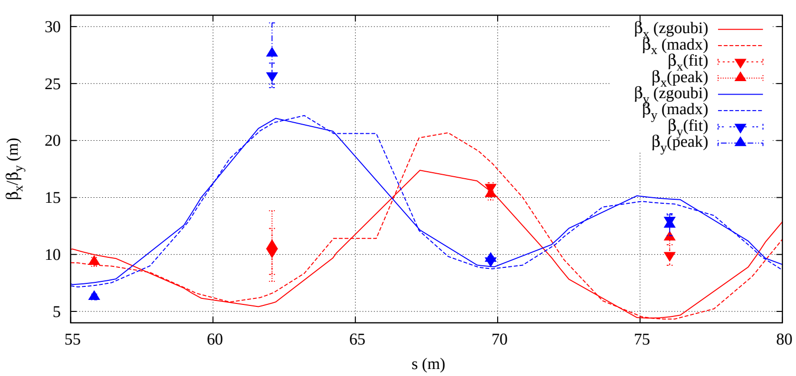
Measurement locations, at snake compensation quads.



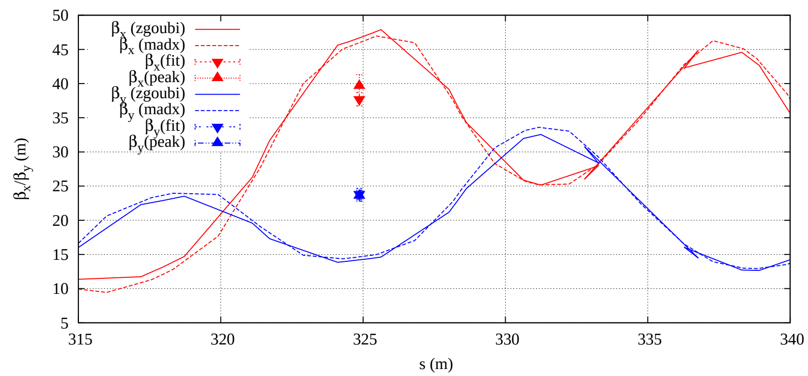
Zgoubi model, bare AGS + C-snake, injection.

Typical outcomes, comparison with Zgoubi model :

QH-A17, Qthin-A19, Qthin-B01, QP-B03



QH-E17

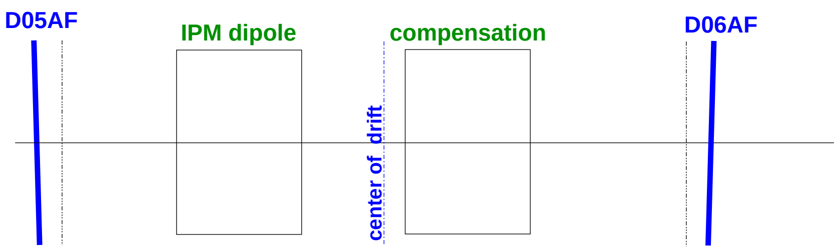


Details : AGS on-line model meeting minutes, Yann Dutheil

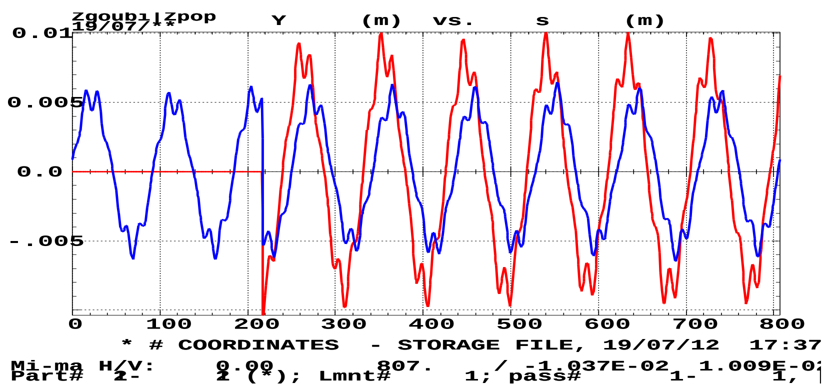
4.8 D5 IPM in AGS

• **Using Zgoubi, the IPM dipole doublet can be simulated accurately, and its effects on the orbit as well, using its OPERA field map(s).**

• **In bonus, this is an additional exercise for the model to swallow and get tested and educated.**

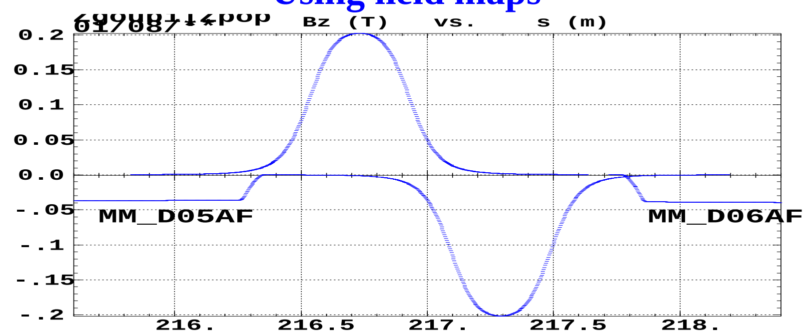


Hard edge model, 2 kG in dipoles.

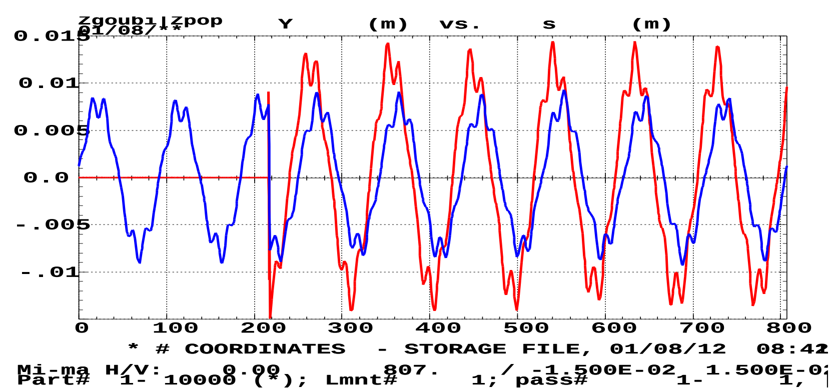


Red : kick due to doublet dipole.
Blue : Horizontal closed orbit.

Using field maps



Vertical field component at traversal of the dipole doublet.



Red : kick due to doublet dipole.
Blue : Horizontal closed orbit.

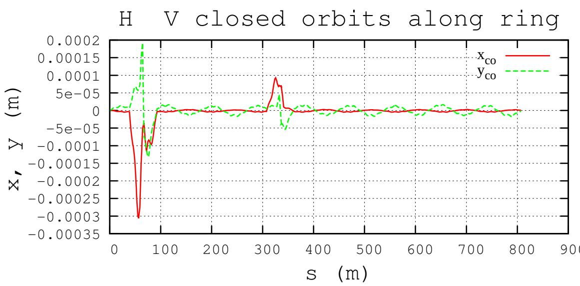
4.9 Precession angle in AGS snakes

• **The question was risen recently of checking the value of the spin precession across the snakes. Comparisons have been performed as part of that task, using RAYTRACE (RK4 integrator) and Zgoubi (Taylor series).**

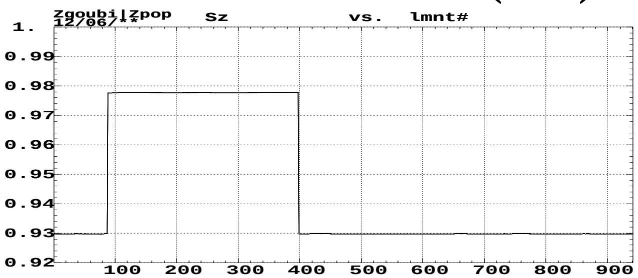
• **Part of the game was, playing with the field(s) in the snakes, beam $G\gamma$, helix radius, etc. :**

CONTEXT :

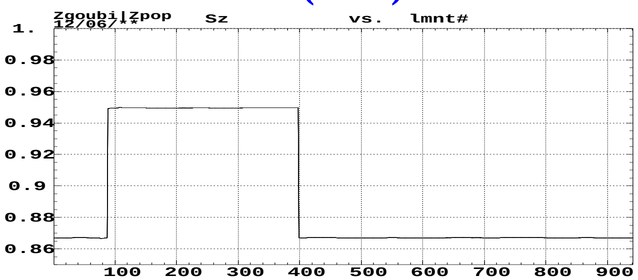
$^3He^{2+}$ in AGS, $\vec{n}_0$ vector at $G\gamma = 42.5$, including orbit bump at snakes.



- Case both snakes 1.5 Tesla (15%) :

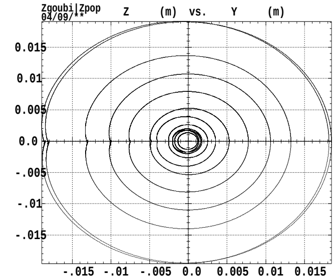


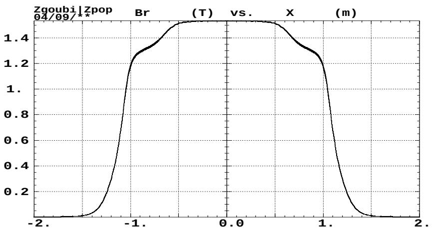
• Case 2.1 Tesla (25%) cold snake :



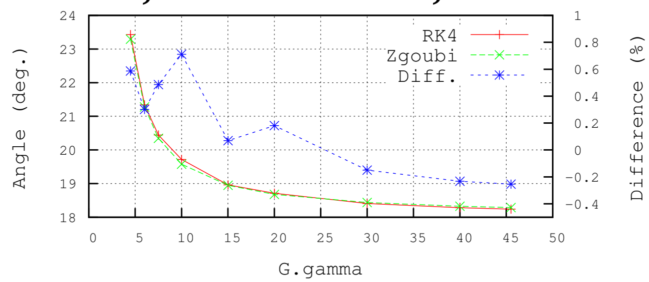
PRECESSION ANGLE STUDY - excerpts, typical -

Projected orbits, field, field integral $\boxed{\int_{snake} B\,dl = 3.2275}$.

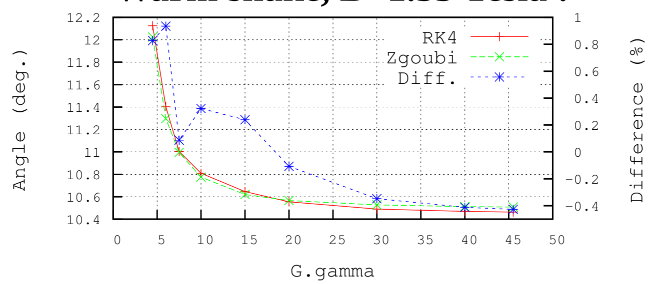




Cold snake, case helix 68.2%, solenoid 42.3% :



Warm snake, B=1.53 Tesla :



4.10 Comments

• **This is the first time ever that such systematic machine parameter studies and BD simulations, and in addition spin dynamics, in a synchrotron, are performed using stepwise ray-tracing methods.**

We haven't experienced any "show-stopper" yet. The results we got so far push us to carry on harvesting data.

Reminder, though :

• **Stepwise ray-tracing methods in synchrotron lattice and BD studies were first developed at MURA for scaling FFAG prototyping, early 1950s, using the first computers.**

• **Stepwise ray-tracing methods have already been used in the AGS to [Ref. N. Tsoupas]**
- determine effects of fringe fields of the main magnets on the extracted beam,
- determine $\vec{n}_0$ at H10.

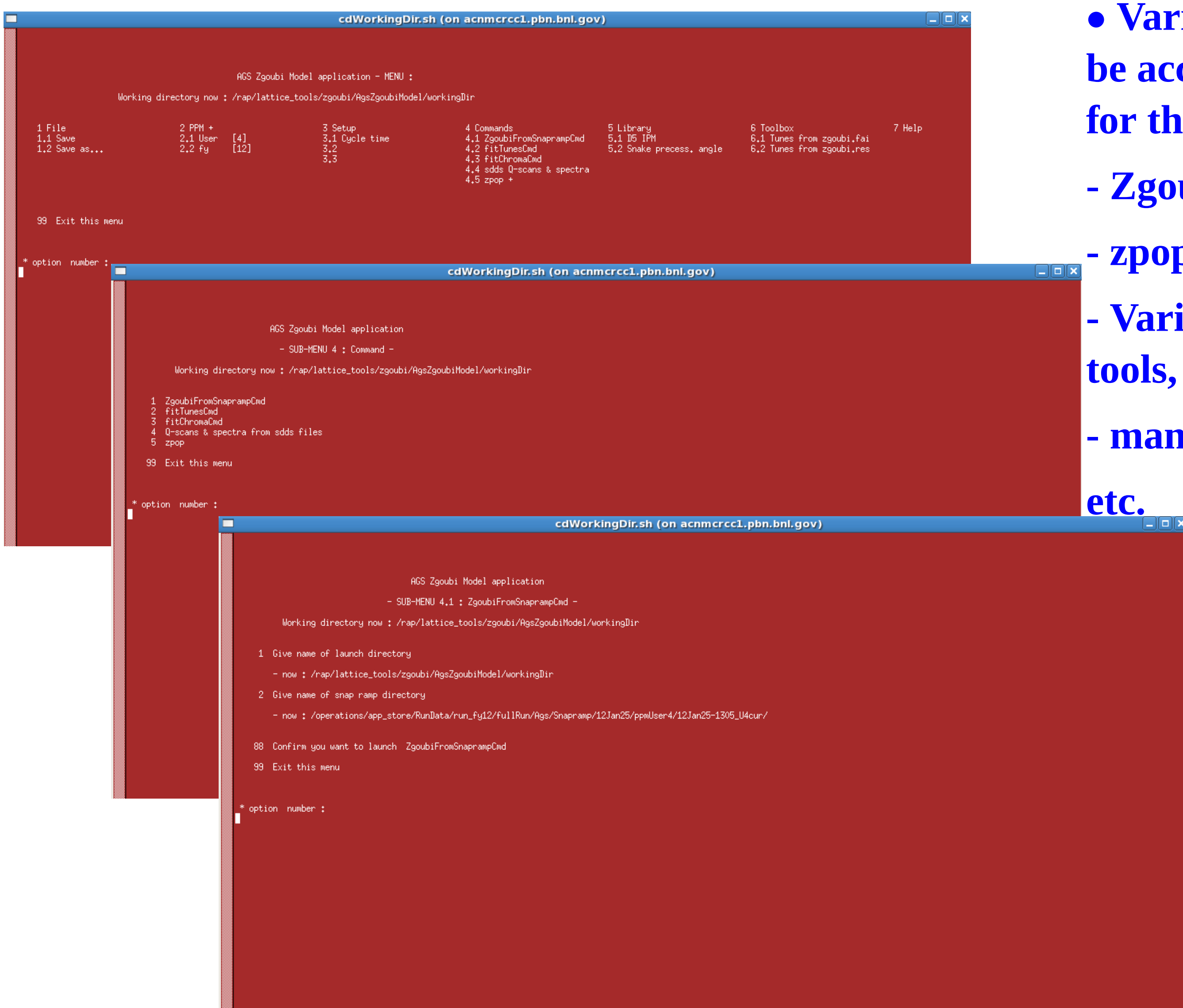
As E. Bleser once mentioned, about field maps, *"we have measured all these data, and no one is using them".*
No longer true ! they are now used routinely together with machine settings from snapramps.

• **Zgoubi is being used since 2 years as the on-line model in the EMMA FFAG prototype experiment at DL. Like AGS, EMMA is a combined function lattice.**

5 “AgsZgoubiModel” application in StartUp/Commissioning

This is a goal we have for the next run : having an application at hand in the StartUp menu, that does as much as possible in an automatized manner.

*** Reminder : the application is available under “Commissioning” in StartUp, so, anyone who wants to try and crash it, and then report the crash, is welcome !**



• Various commands can now be accessed using AgsZgoubiModel, for the moment :

- ZgoubiFromSnaprampCmd,

- zpop, Zgoubi post-processor,

- Various data treatment and analysis tools,

- manipulation of sdds tune files,

etc.

6 AGS APEX plans

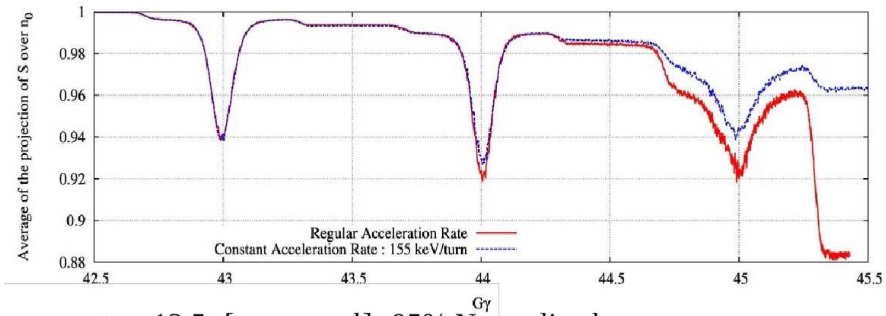
Proposals set up with Haixin, Nick, Yann.

6.1 Measurement of the polarization in AGS during acceleration

MOTIVATIONS

- **Some reduction of polarization may occur during the reduction of the acceleration rate when landing on $G\gamma = 45.5$ flat top.**

Zgoubi modelling confirms that.



$\varepsilon_x = 13.5\pi[mm \cdot mrad]$ 95% Normalized

$\varepsilon_y = 14.0\pi[mm \cdot mrad]$ 95% Normalized

$\varepsilon_l = 0.7\pi[eV \cdot s]$ rms

- **On the other hand, the beam polarization in RHIC depends:**

  a) On the stable spin direction at H10 in AGS,

  b) On the stable spin direction of the AtR at RHIC injection point.

  c) On the beam polarization at the extraction Energy of the AGS

To determine experimentally the optimum extraction energy of the beam from AGS, polarization measurements should be performed in RHIC at three Extraction Energies 45.5, 46.5 and 47.5

MEASUREMENT PROCEDURE

- **1st Part of the experiment:**

  - Setup the AGS magnet cycle with a flat-top at $G\gamma$=45.5

  - Optimize the beam polarization

  - Measure the beam polarization at flat top few times.

- **2nd Part of the experiment:**

  - Setup the AGS magnet cycle with a flat-top at $G\gamma$=47.5 with the same acceleration rate and tunes as for $G\gamma$=45.5 flat top.

  - Optimize the beam polarization at the flat top

  - Run an overnight experiment of polarization measurement during the ramp.

- **A few percent difference between the values of the polarization for the two different AGS magnet-cycles will motivate the implementation of the method of "beam extraction during acceleration".**

6.2 Transmission of the polarization at high energy

1. Horizontal intrinsic resonances at the end of the ramp

MOTIVATIONS

• 6-D bunch simulations in Zgoubi using snapramp AGS data and a constant acceleration rate seem to show that the last two horizontal intrinsic resonance, $G\gamma = 36 + Q_x \approx 44.7$, $G\gamma = 54 - Q_x \approx 45.3$, have a stronger effect on the polarization than the upstream ones.

• Experiments focused on the spin dynamics in the late part of the AGS cycle are planed for

- better understanding the evolution of the polarization across the horizontal intrinsic resonances

- whereas using the Zgoubi code to
(i) prepare and accompany these experiments,
(ii) analyze the outcomes.

MEASUREMENT PLANNED

• Use the "radial command" to radially move the beam at the end of the AGS cycle to modify the crossing speed of these resonances.

Perform polarization measurements, following each change.

2. Jump quad timings

MOTIVATIONS

• **The tune jump quads allow a fast tune jump, $\Delta Q_x \sim 0.04$ in $\sim 100\ \mu$s. The effect of the timing of these jumps is critical.**

• **We want to understand better the influence of the tune jump timings on the polarization transmission.**

MEASUREMENTS PLANNED

We plan to

- experiment different settings of the jump quad timings and compare the results with the expectations, from Zgoubi.

- systematize the comparison between Zgoubi and the measured parameters when varying beam emittance, machine tunes, chromaticities, etc., taking profit from the variety of possibilities allowed by the Zgoubi code.

6.3 Coupling : Turn-by-turn projected emittances

MOTIVATIONS

• Linear coupling is present in the AGS.

Origins of coupling can be
- quadrupole rotation
- main magnet rotation or deformation
- snakes
- accelerating cavities (TEM modes)

• Snakes may also induce non-linear coupling. Zgoubi modeling confirms that.

• Coupling is a cause of a turn-by-turn variation (beating) of the projected beam emittances, with amplitude and frequency depending on defect strength and distance to the resonance.

• Variation of the projected beam emittances may cause variation of the intrinsic spin resonance strength during acceleration.

• We will

- search for realistic conditions in AGS that such variations of the projected beam emittances are significant.
- Propose a method to measure a turn-by-turn variation of the projected beam emittances.

PROPOSED STUDY

Use a $\approx$3 sec long "injection porch".

1. Set up a bare AGS and measure $\epsilon_x,\ \epsilon_y$ as a function of time.

2. Set up the AGS with Warm and Cold Snakes at distant tunes, e.g., Qx=8.684 Qy=8.980 and measure $\epsilon_x,\ \epsilon_y$ as a function of time.

3. Set up the AGS with Warm and Cold Snakes and close tunes, e.g., Qx=8.9073 Qy=8.9075 and measure $\epsilon_x,\ \epsilon_y$ as a function of time.

4. Compare. Accompany/compare with systematic simulations using Zgoubi.

THANK YOU FOR YOUR ATTENTION