Cooling Channel Study: ICool - Geant4 Perf. Cmp.

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Outline..

- Motivation
- Techniques.
- Summary of fixes...
- Current results, what's left to do.
- Outlook : What have we learned in terms of beam physics?

Motivation

- Two independent codes are better than one.. But.. what's the point of dragging the comparison for weeks (months!..)
  - ==> Firm up advances in simulation techniques.
  - Study of tolerances on basic lattice parameters!
- Goal : reach agreement in the yield in the 9.75 or 15 mm transv. cut, 150 mm. long. at the end of the cooling channel, within 10%

Techniques & Methods

- Measure the emittances, yield in acceptance, transmission, starting from the same beam, in ICOOL and G4
- If disagreement:
  - turn off stochastics processes.
  - Study particular tracks (motion in 6D phase spaces, and probing the fields along the paths)
  - compare and/or exchange fields.
  - Re-tune.. re-tune until agreement reached.

G4 - Status..

- All Front-end (after proton target) elements coded up ..(8 construct. class + Field classes.),
- Only the I.L. to Buncher matching section, the Buncher and the Cooling channel have been studied, tuned and benchmarked.
- Installation/tuning of Double Flip cooling channel in progress.
- About 175 "knobs" + dozen of hard-typed numbers. .. (not documented yet..)

So did we reached this goal ? Today ?

- Not quite!
  - a ~10 to 15 % relative difference in yield in 15 mm. cut between ICOOL and G4 remains, after buncher + 44 m. of cooling, in absence of straggling and multiple scattering, after re-tuning...
  - => with stochastic process undertainties and the complete channel, ~ 30 % relative uncertainty in yield at the end of the cooling channel.

Fixes done so far..

- Re-tuning of the (1-3) to (2-1) lattice matching section (Fringe fields were not properly added up when the match was designed, this summer).
- Mis-interpretation of the emittance cut: geometrical emittance was used instead of invariant. (G4 -Analysis, not Ecalc9).
  - ==> a factor two off in yield..
  - On ~ Dec 20, ~ 35% relative difference, after 44m of cooling.

Fixes done so far...

- Earlier (Nov.-Dec.) : Re-tuning of the (1-3) to (2-1) lattice matching section (Fringe fields were not properly added up when the match was designed, this summer).
- Mis-interpretation of the emittance cut: geometrical emittance was used instead of invariant. (G4 -Analysis, not Ecalc9).
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ICalc9 vs G4 Analysis

- ICalc9 emittances and yield within the emittance cuts are computed based on the second order moments. These moments are computed arounf the center of the beam in 6D phase space. Not the center of the beam line, or the nominal momentum.
- x-y' (L) and x'x (over focus) correlations are subtracted.
- G4 compute x, y, x', y' around beam line, does not subtract correlation
- finite statistics + mis-tuned ==> 10% effect on the sample we studied.
- A year ago, Bob P. urges us to adopt the most stringent algorithm, he was/is right!.

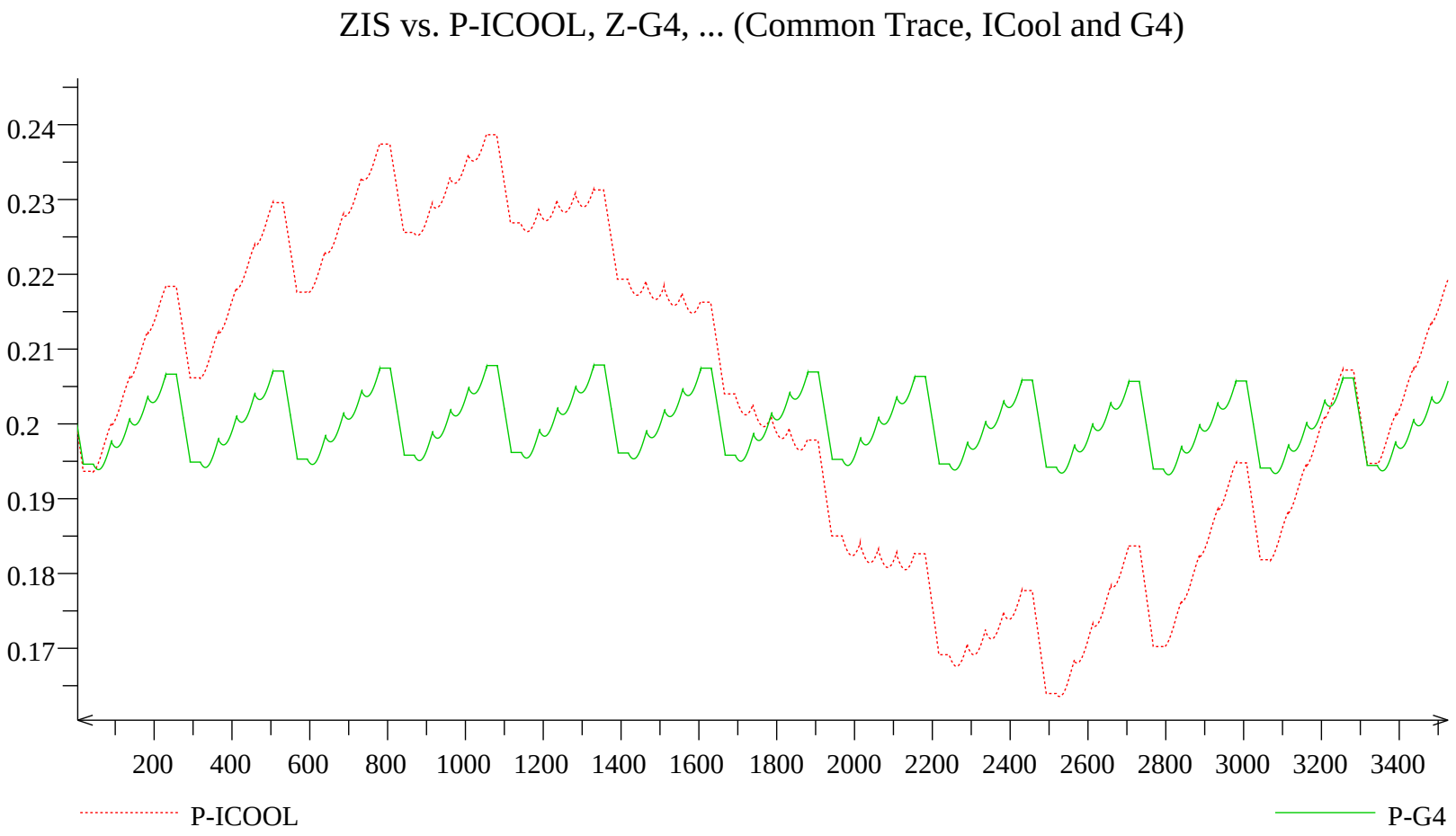
Longitudinal re-tuning.

- Average Energy loss in G4 was (is?) 0.297 MeV/cm of LH2, (4.2 MeV/gr/cm^2) or 10.4 per 35 cm absorber (at a density of 0.0708 gr/cm^2). ICool de/dx is ~8% higher, at ~ 4.6 MeV/gr/cm^2)..
- It matters, because, close to the end, we are cooling near the equilibrium..
- We need to know at which density we will be running, and get to the correct value (PDG log-scale plot a bit imprecise..).

R.F. re-tuning...

- (1-x) lattice running at 15.48 MV/m, suggested phase is 40 degree. With G4 de/dx, phase had to be set to 30 degree.
- Phasing the cells: ICOOL assumed that the reference particle has strictly constant momentum. G4 took into account the variation of momentum across the cell (loosing in absorber, ganing in r.f.) The ICool "0-ampl." particle had a residual sync. motion of 7.5 MeV, ~1 to 2 MeV for G4.

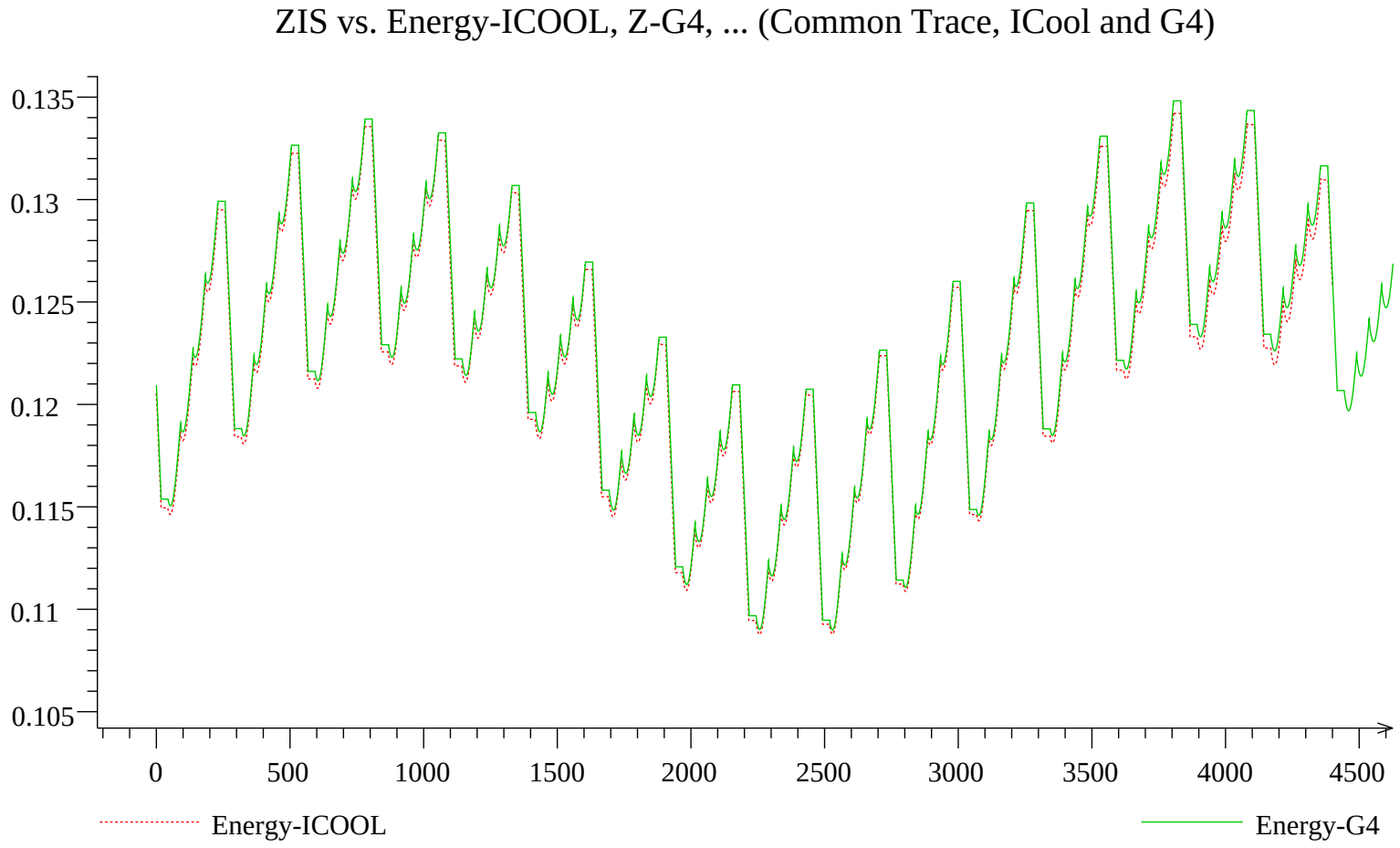
Phasing the r.f. ..



Longitudinal re-tuning...

- Set G4 r.f. phase according to ICOOl.
- Set LH2 density such that de/ds = 8% higher.
- ==> ref. part and critical traces (i.e., muons that are kept in ICOOL and lost in G4) now agree within 1 MeV.
- With Ecalc9 cuts, no stochastic terms, no decay, at Z = 44 m. ICOOL got 18.8 % into 15 mm., G4 got 16.2 %.

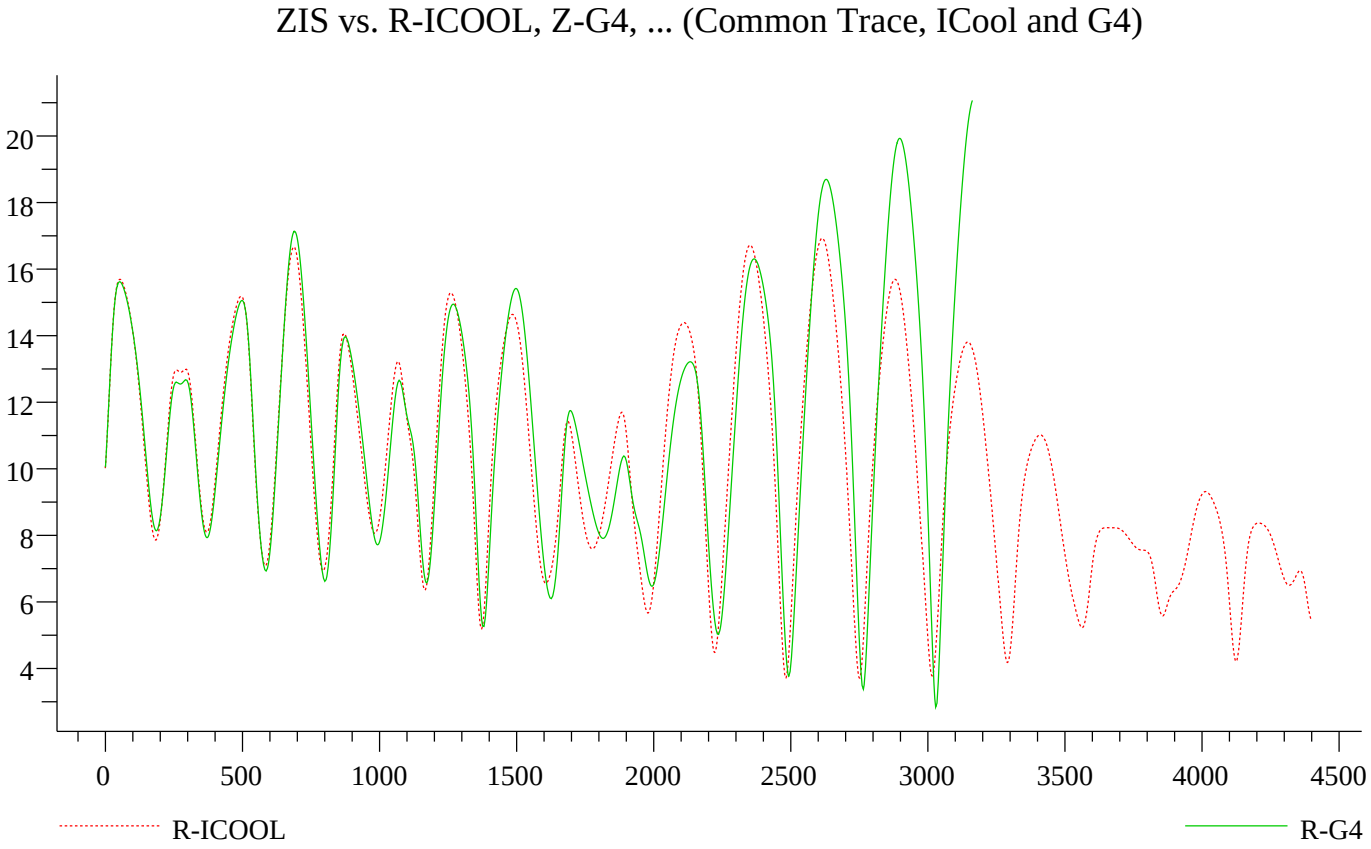
E vs Z for the "0 amplitude" (Long. and Transv.) particle.



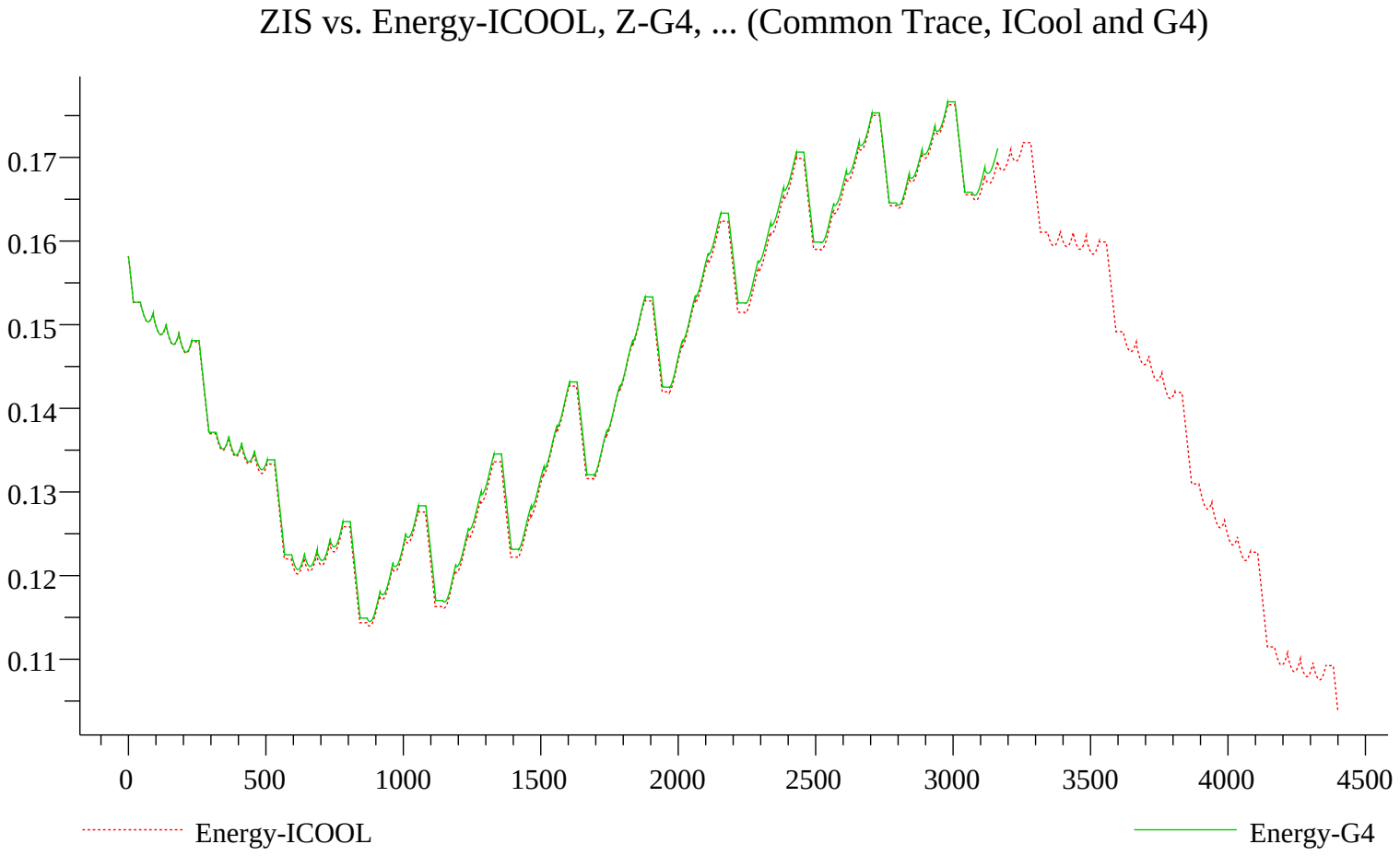
Best r.f. tune ?

- The longitudinal re-tuning in G4 brought us an increase of ~10 % or so, why?
  - more de/dx => more cooling (no m.s. increase because it was off!)
  - higher (30 -> 40 deg.) accel. phase ==> less bucket area. However, there little gain in increasing this bucket size, because high P muons (low P to a lesser extend) are lost due to the pi (2pi) resonance.

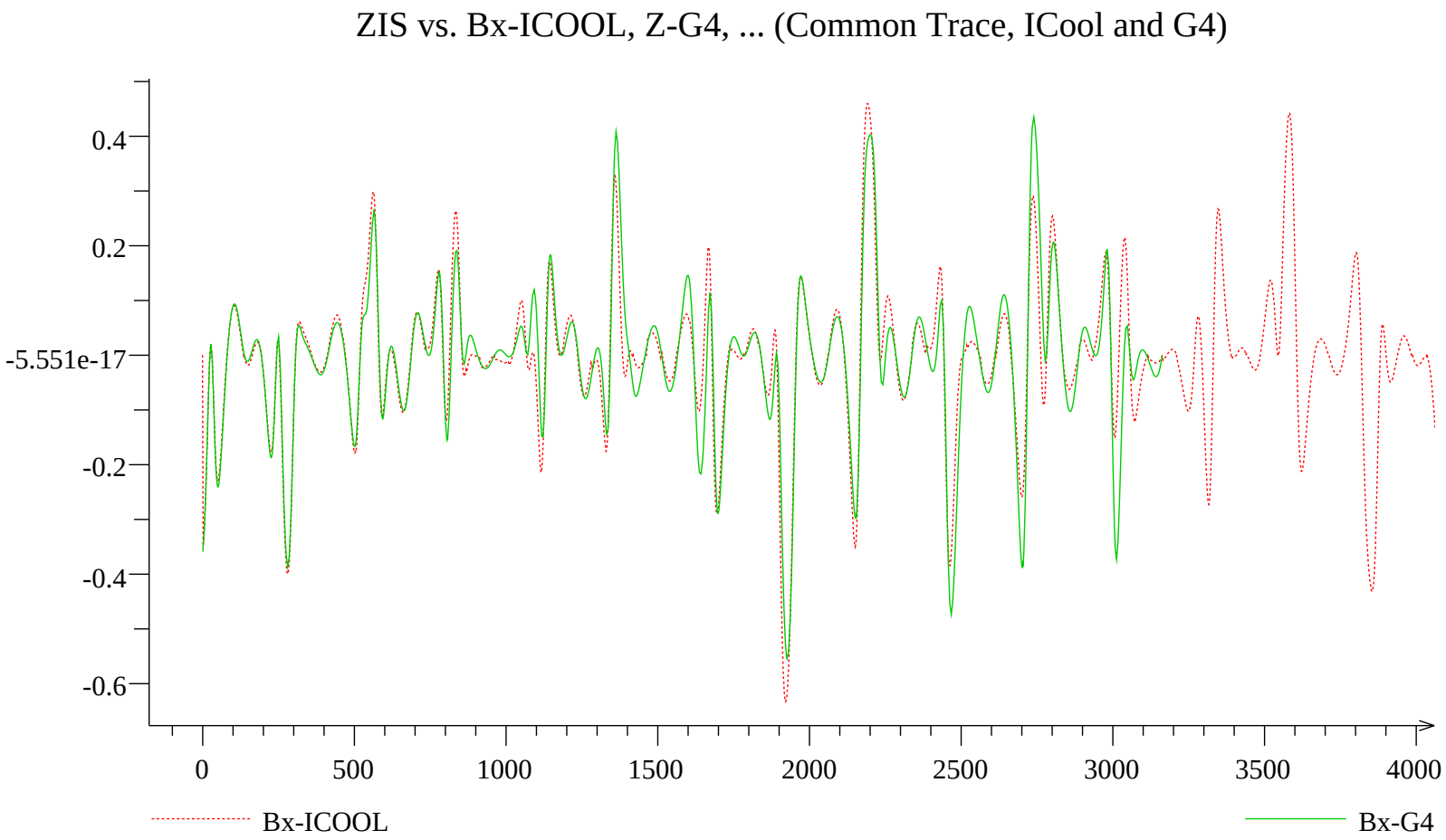
Transverse motion...
A large amplitude particle..



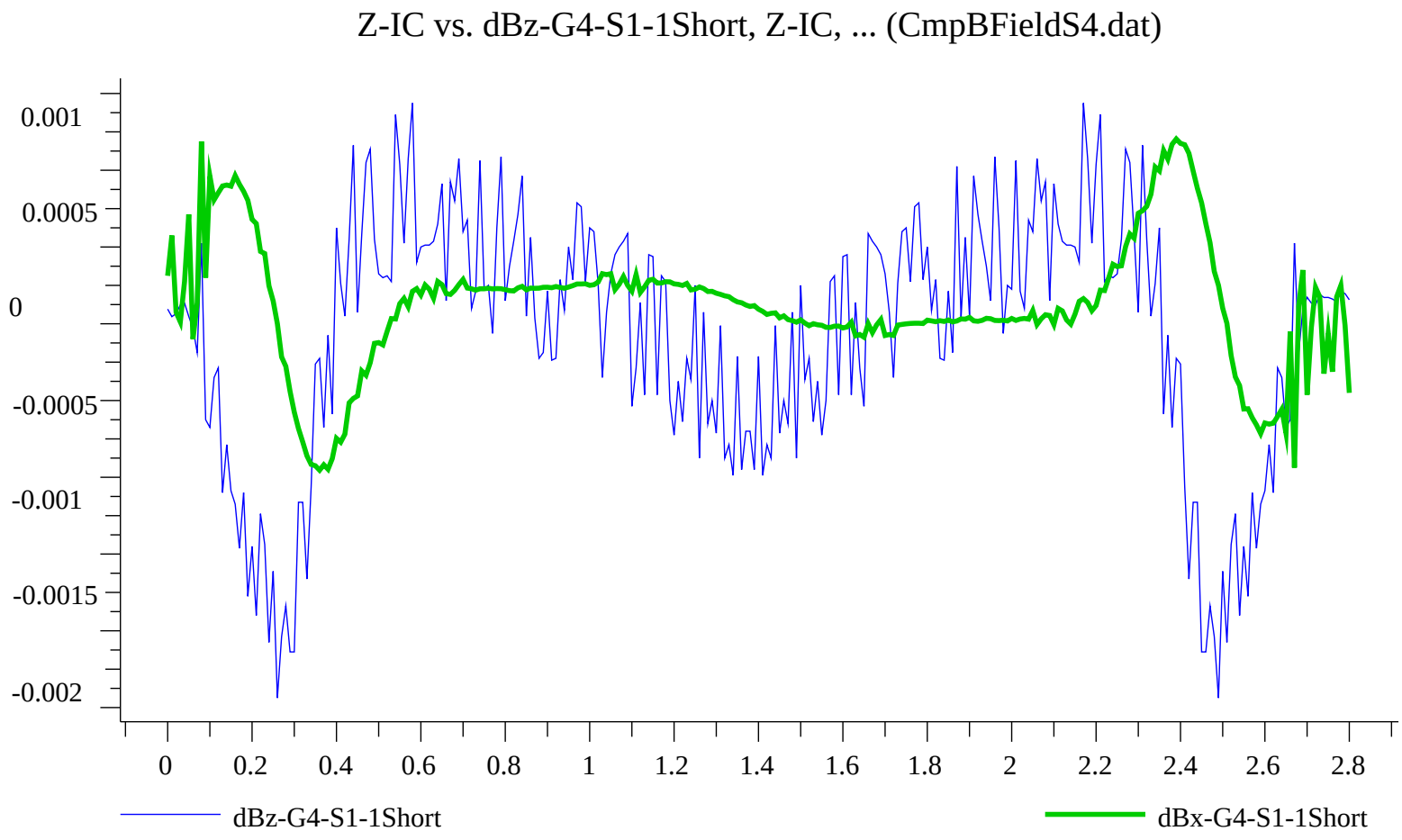
Longitudinal motion.. Reaching P = 260 MeV/c, on the pi resonance ..



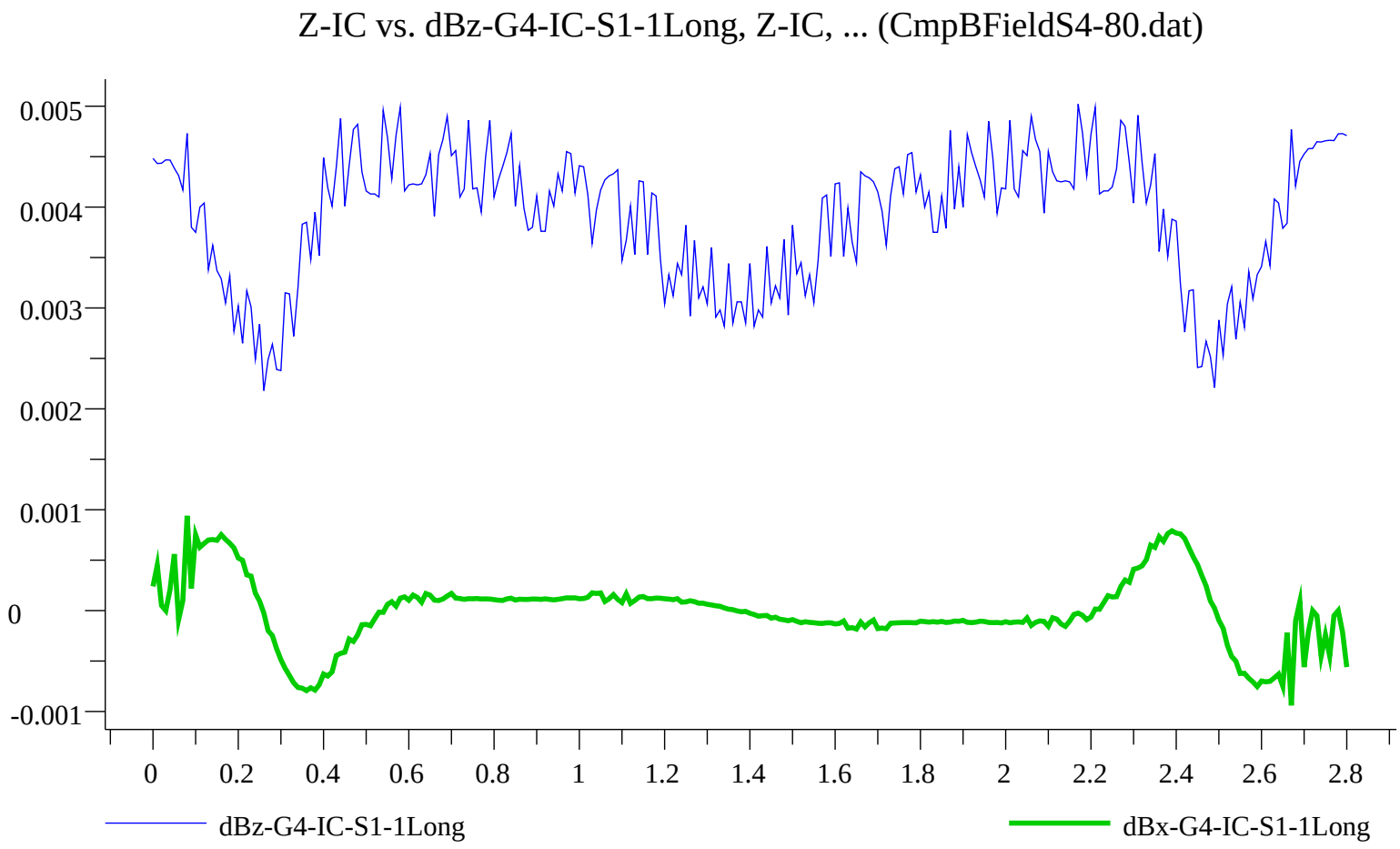
Transverse fields: ~ 100 Gauss difference, even at the beginning of the trajectory.



Fixing the Field Maps.. Yes, we can do it.. The ICool-G4 diff, 1-1 cell.



In the cooling channel..



Status... Incorrect Fringe Fields can improve performance!

- To obtain ~15 Gauss accuracy, need to extend the range of the maps to + 30 X the radius of the coil!
- Difference of a few hundred Gauss remains in the channel, due to fringe fields across ICOOL regions.
- And they do matter (i.e., if I use the ICOOL field, the particle shown before get accepted in G4 => not the Runge - Kutta integration, but the field..).

Why bother ?
And Can we do better?

- This is not the most delicate part of the cooling channel (in terms of transverse beam optics).
- Tolerances on Coil alignments: difficult to interpret, if do not know what the field should be!.
- Given the complicate (i.e., nearly resonant) trajectories, a precision of ~ 10^-3 in field map is mandatory.
- Achievable, at high CPU cost, though..

Conclusion

- Tedious work, and we are not done yet ...
  - multiple scattering sensitivity,
  - Over the entire length of the cooling channel
  - Are the current parameters close to optimum? (Matching sections in particular..)
- More accuracy in field calculation and tracing than anticipated is really necessary ("1% job" is not good enough).
- Tolerance calculation in G4 in progress...