# Simulation of 3d granular dissipative gas under different kinds of excitations & with different number of balls N

## Result 9: $V_z$ sum as a function of z, for different e= 0.7 to 0.9 and bi-parabolic excitation,

**R. Liu[1], M. Hou[2], P. Evesque**
**Lab MSSMat, UMR 8579 CNRS, Ecole Centrale Paris**
**92295 CHATENAY-MALABRY, France,** e-mail: pierre.evesque@ecp.fr

## Abstract:

*This group of papers publishes a series of simulations on the dynamics of N equal-size spheres* (D=1) *in a* 3d *rectangular cell* ($L_x$=20D, $L_y$=20D, $L_z$=60D) *excited along z in 0 gravity*.(N=100, 500, 1000, 1200, 2000, 3000, 4000, 4500). *Different Oz excitation kinds have been used (symmetric and non symmetric bi-parabolic, symmetric and non symmetric saw teeth, thermal wall). No rotation is included, dissipation is introduced via a restitution coefficient* $e= -V'_n/V_n$ *, where* $V'_n$ *and* $V_n$ *are the relative ball speed along normal to ball centres after and before collision.*

**Pacs # : 5.40 ; 45.70 ; 62.20 ; 83.70.Fn**

---

Recently, much work has been done to simulate dissipative granular gas in 0g [1] which looks coherent with classic continuous theoretical approach [2]. However, experimental results obtained with rocket experiment (Mini-Texus 5, Maxus 5, Maxus 7) or Airbus A300-0G (Novespace) as well as satellite SJ-8 have found [3] some disagreement with these classical publications and understanding [4, 5]. Few other results [6,7] contradict the common statement [1,2] and/or is in agreement with our simulations [7].

The goal of theses simulations is to demonstrate that behaviour of granular dissipative gas is more complex (i) than what can think at first sight, (ii) that the role of boundary collisions can be observed directly on the ball dynamics and (iii) that the system can not be understood as a system controlled by a single temperature at a given positions.

## Figure symbols and abbreviations:

| | |
|---|---|
| e0.9: coefficient of restitution $e$ = 0:9 | N***: number of particles $N$ = *** |
| BP: bi-parabolic driving | ST: saw-tooth driving |
| Sym: symmetrical driving | Nsym: Non-symmetrical driving |

Protocol is given in appendix. Data are reported for a given physical quantity (n(z), pdf,…) as a function of the ball number in the cell and for a given restitution coefficient e and a given wall driving. Then e is varied. Then driving is varied. The data are divided in papers, which are divided into driving cases label A , B and subdivided into sections corresponding to different e (0.7,0.8, 0.9).

# 1) Non-symmetric bi-parabolic excitation

## 1.1) with e= 0.7

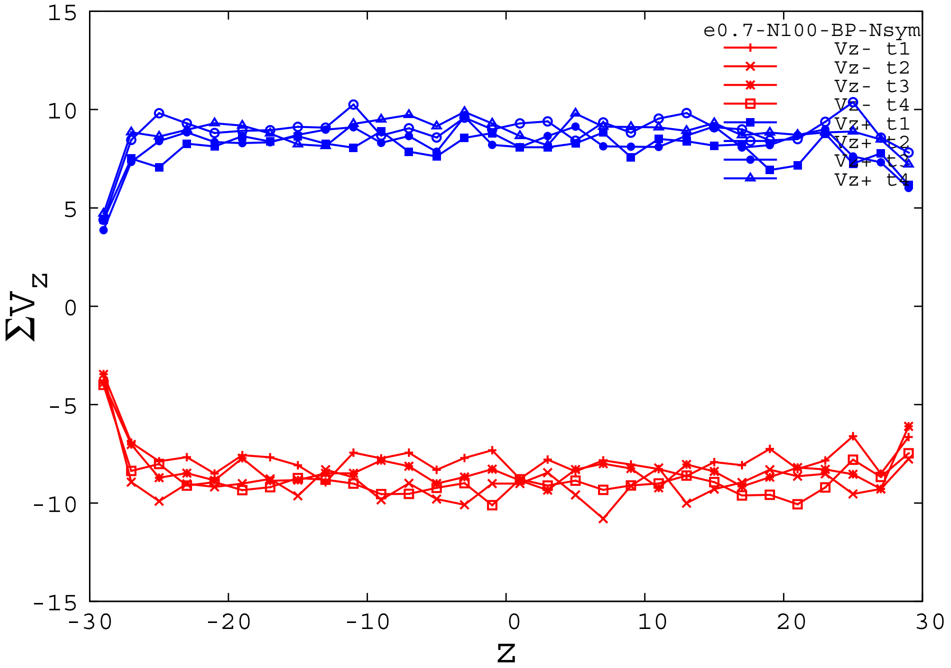


*Figure 1.1 - 1: Simulations of granular gas is 3d rectangular cell*

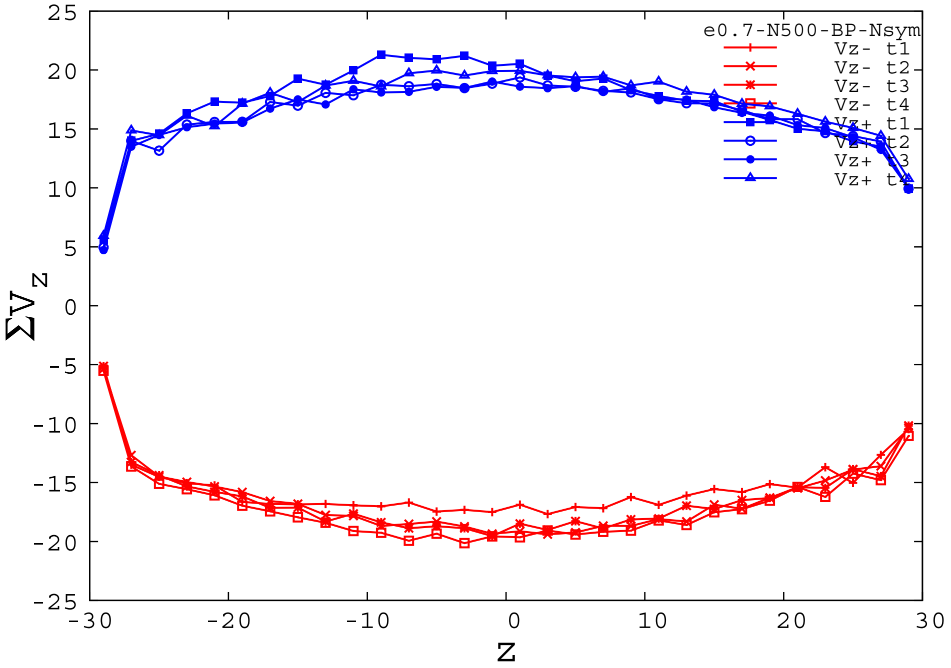


*Figure 1.1 - 2: Simulations of granular gas is 3d rectangular cell*

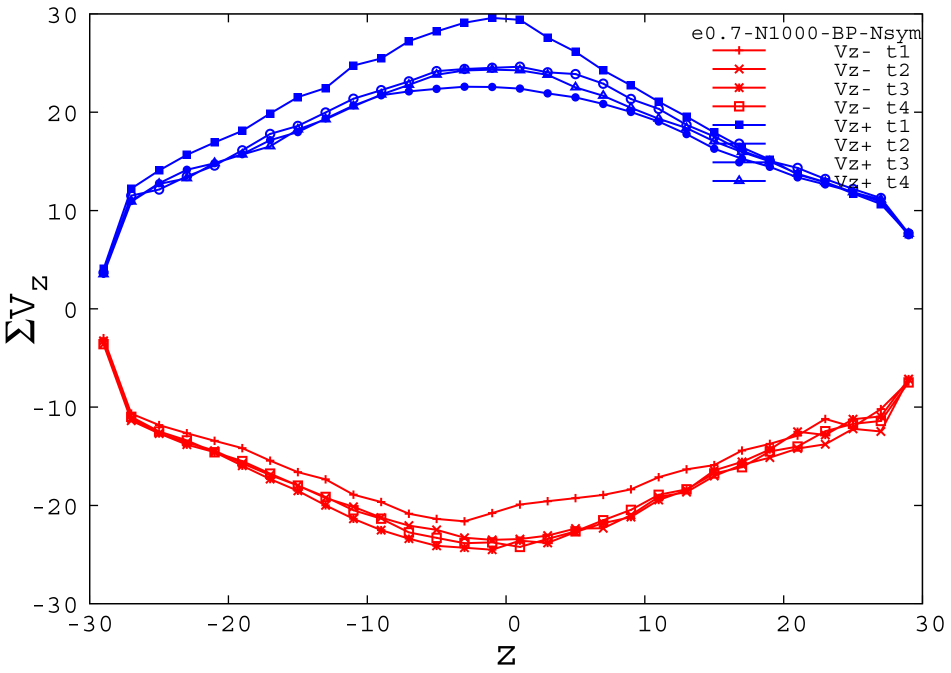


*Figure 1.1 - 3: Simulations of granular gas is 3d rectangular cell*

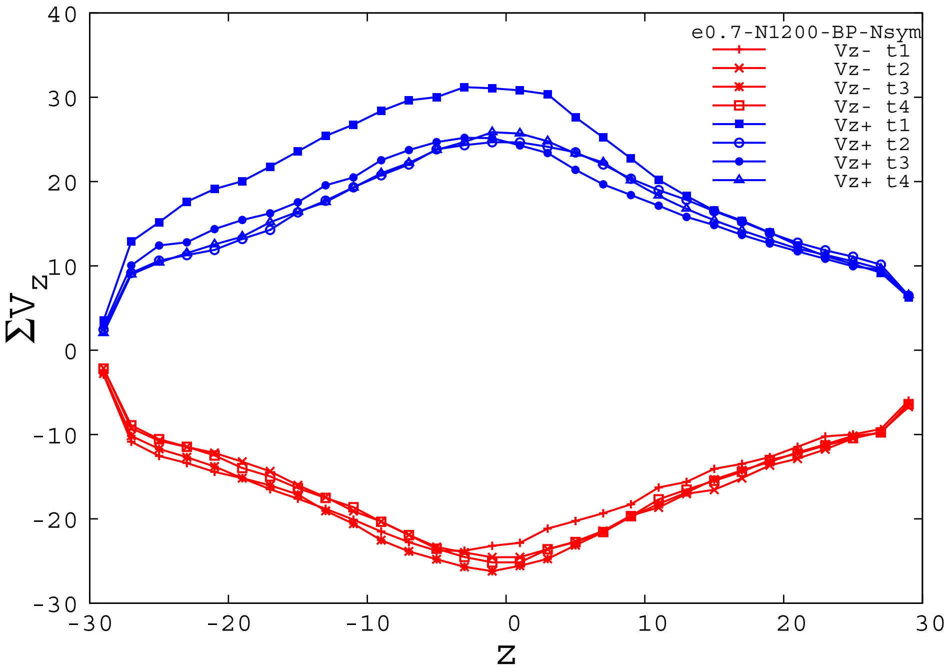


*Figure 1.1 - 4: Simulations of granular gas is 3d rectangular cell*

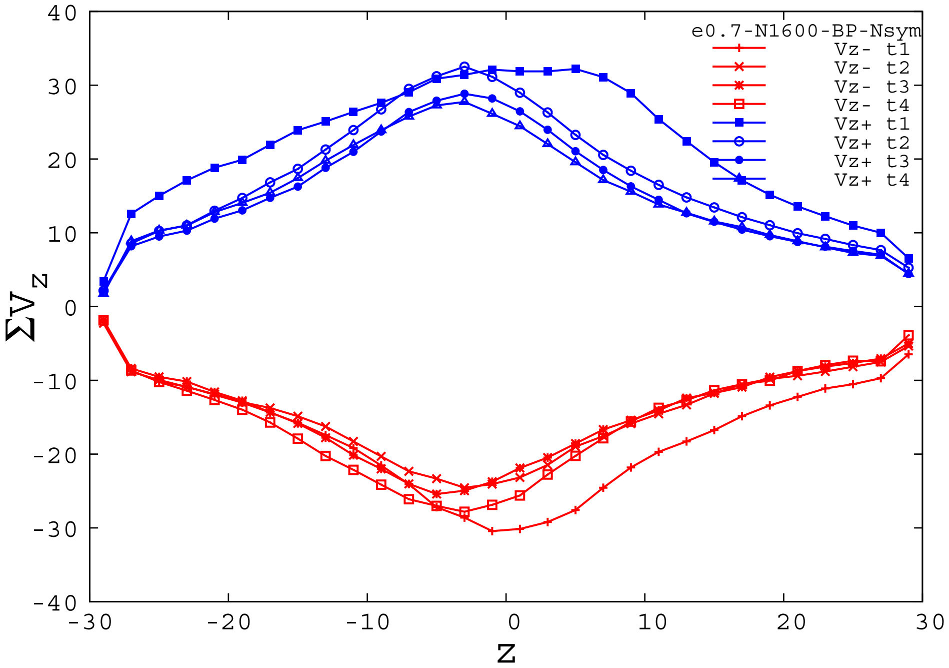


Figure 1.1 - 5: Simulations of granular gas is 3d rectangular cell

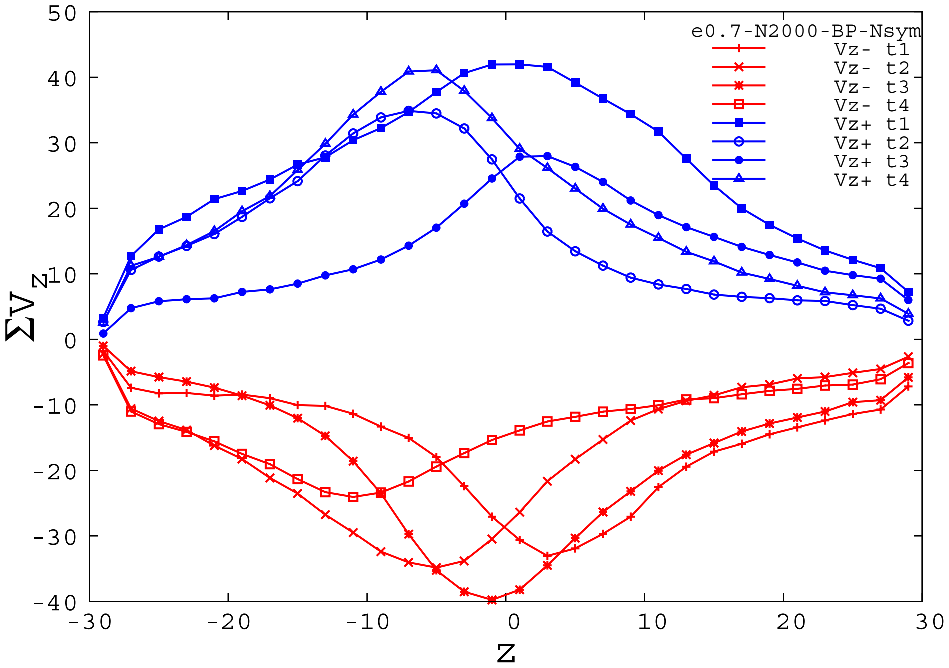


Figure 1.1 - 6: Simulations of granular gas is 3d rectangular cell

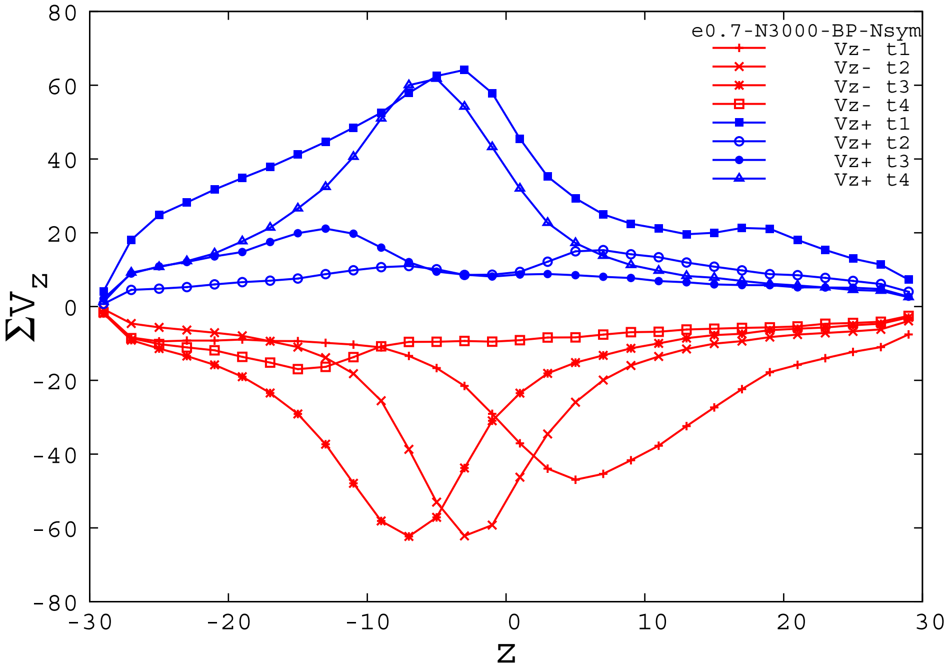


*Figure 1.1 - 7: Simulations of granular gas is 3d rectangular cell*

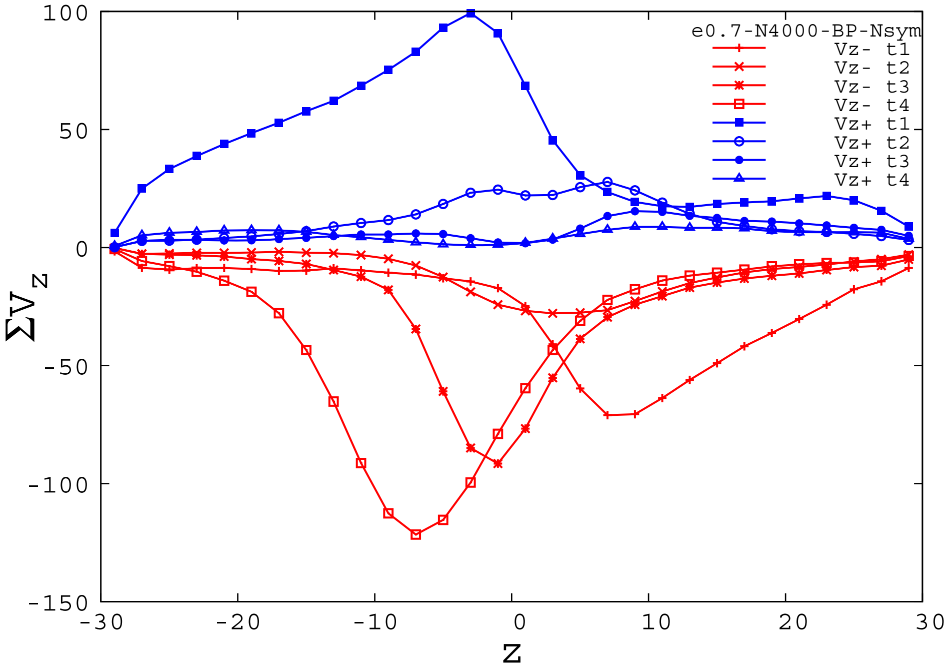


*Figure 1.1 - 8: Simulations of granular gas is 3d rectangular cell*

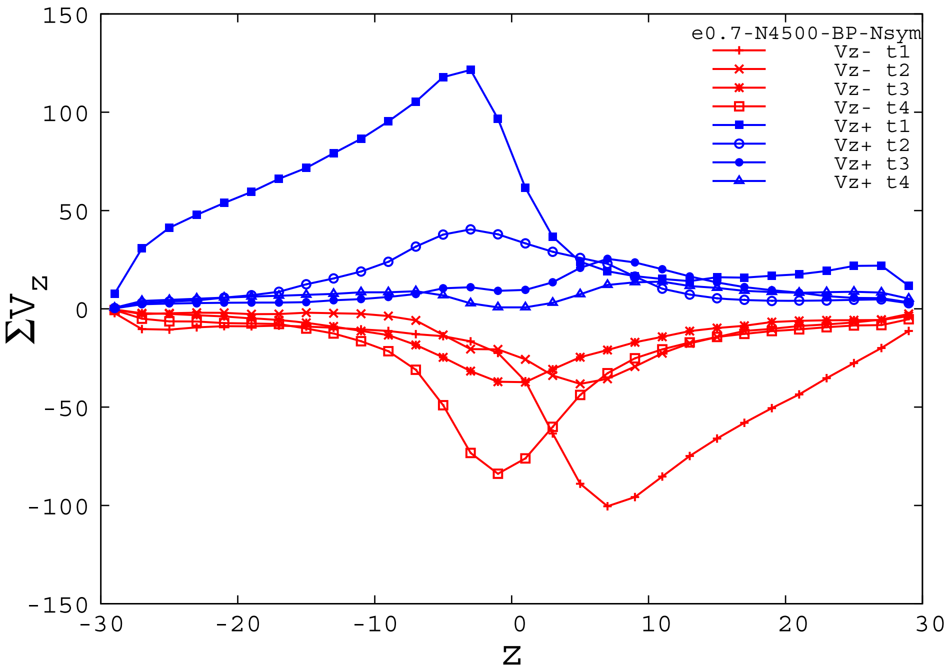


**Figure 1.1 - 9: Simulations of granular gas is 3d rectangular cell**

## 1.2) with e= 0.8

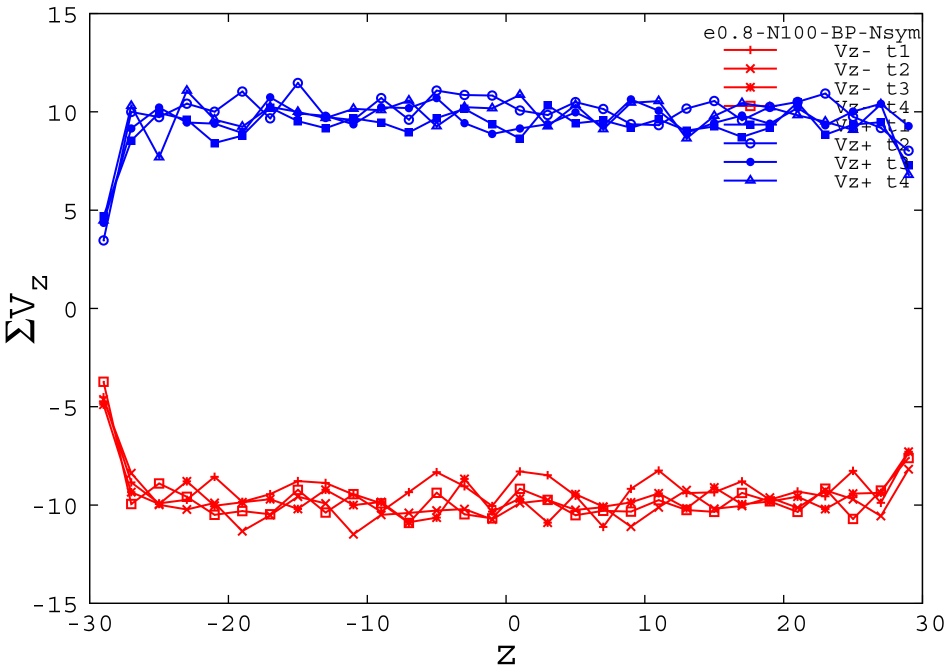


**Figure 1.2 - 1: Simulations of granular gas is 3d rectangular cell**

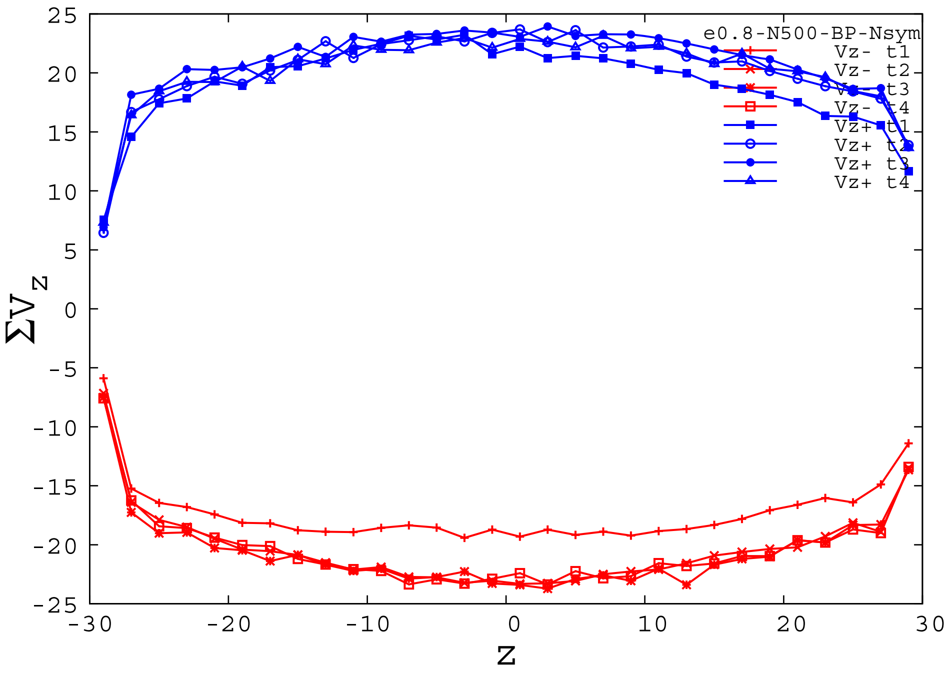


Figure 1.2 - 2: Simulations of granular gas is 3d rectangular cell

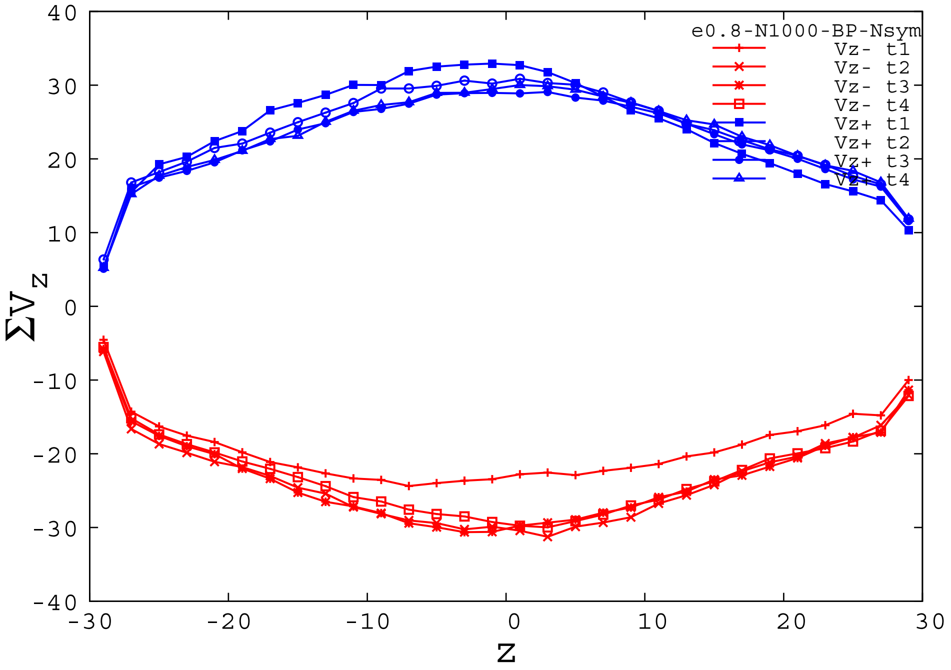


Figure 1.2 - 3: Simulations of granular gas is 3d rectangular cell

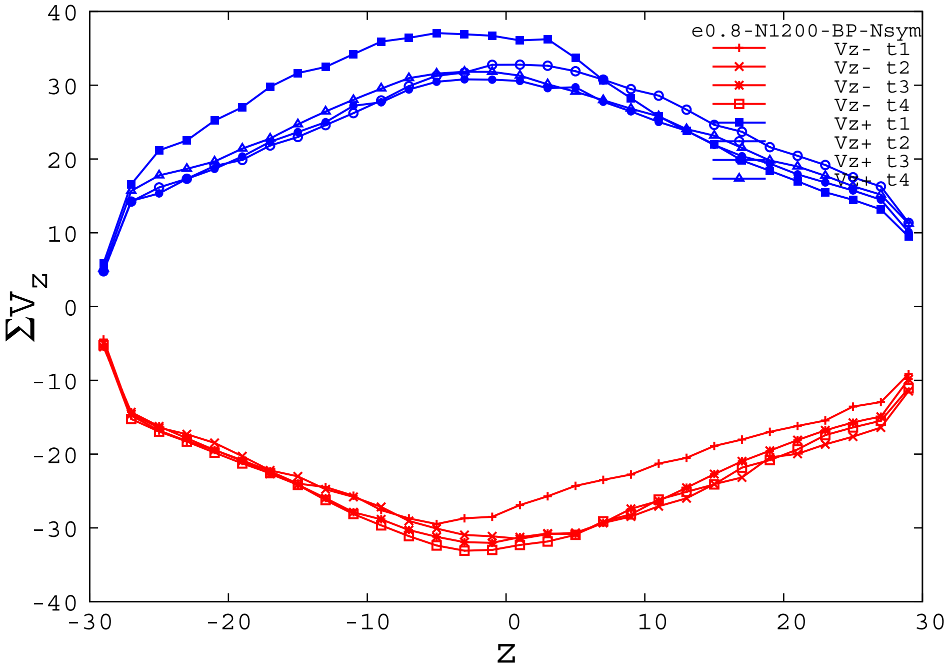


*Figure 1.2 - 4: Simulations of granular gas is 3d rectangular cell*

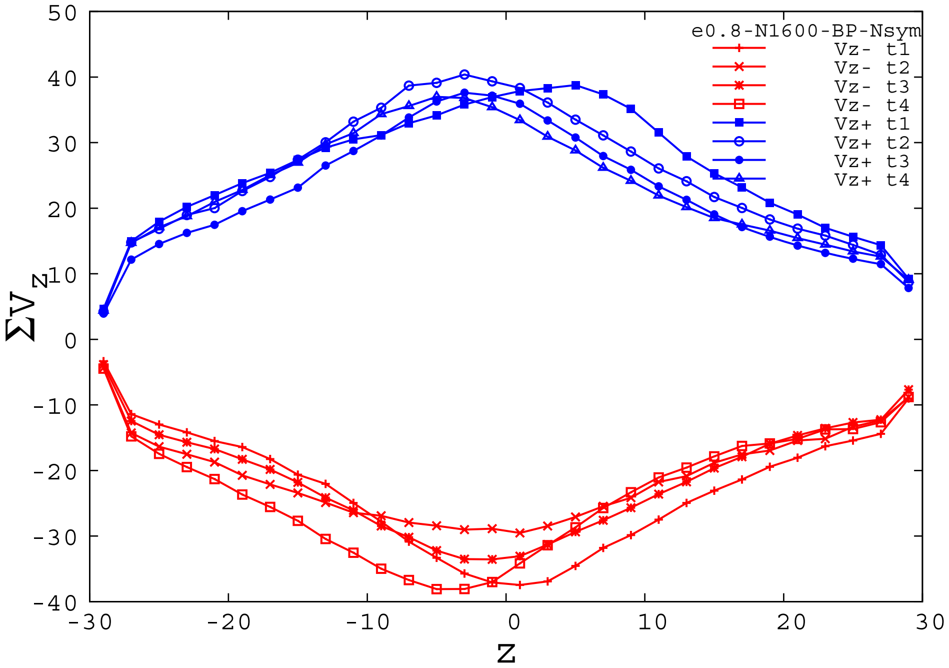


*Figure 1.2 - 5: Simulations of granular gas is 3d rectangular cell*

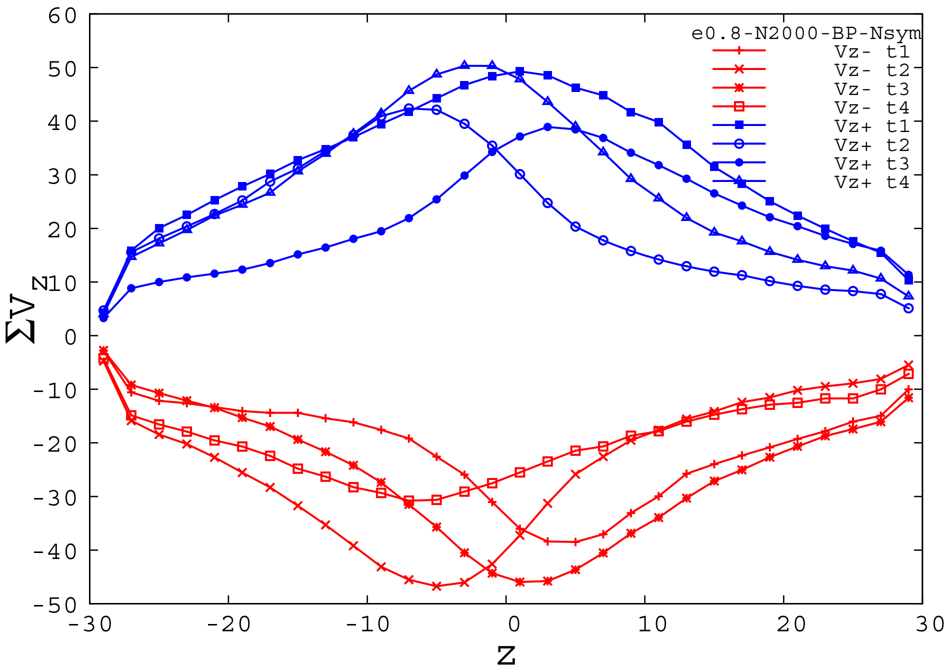


Figure 1.2 - 6: Simulations of granular gas is 3d rectangular cell

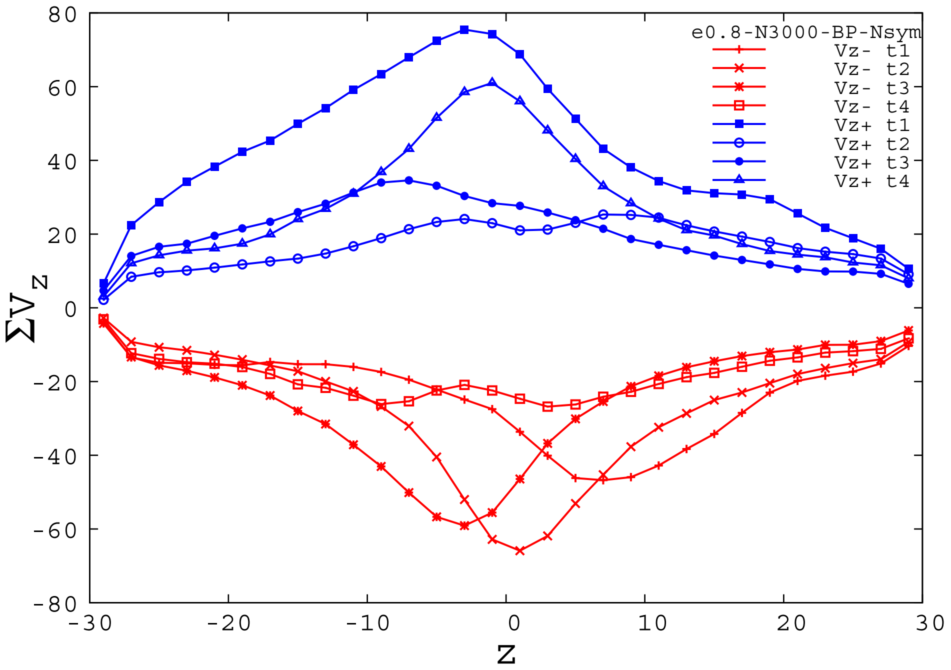


Figure 1.2 - 7: Simulations of granular gas is 3d rectangular cell

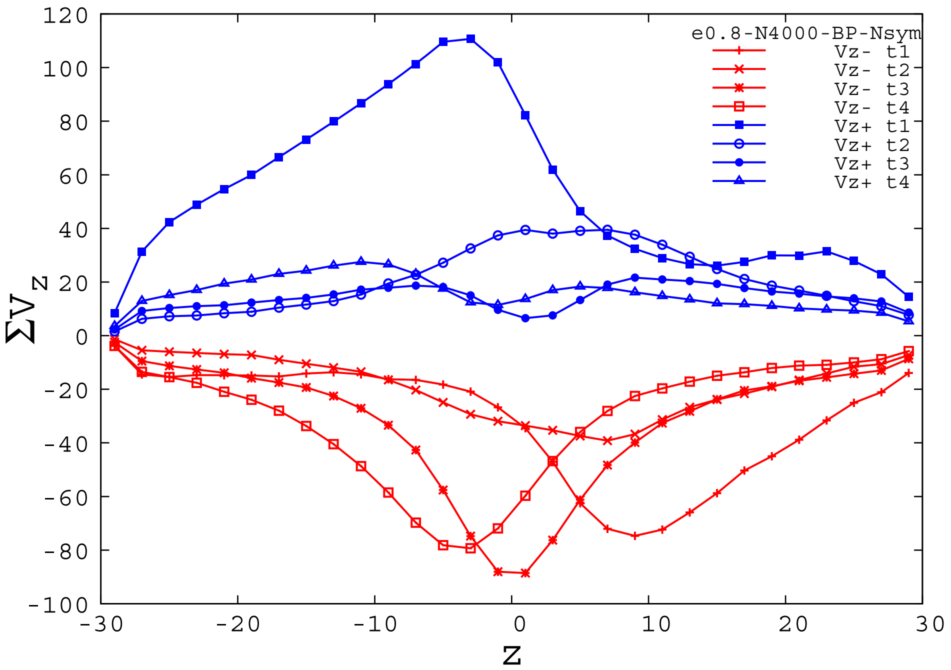


**Figure 1.2 - 8: Simulations of granular gas is 3d rectangular cell**

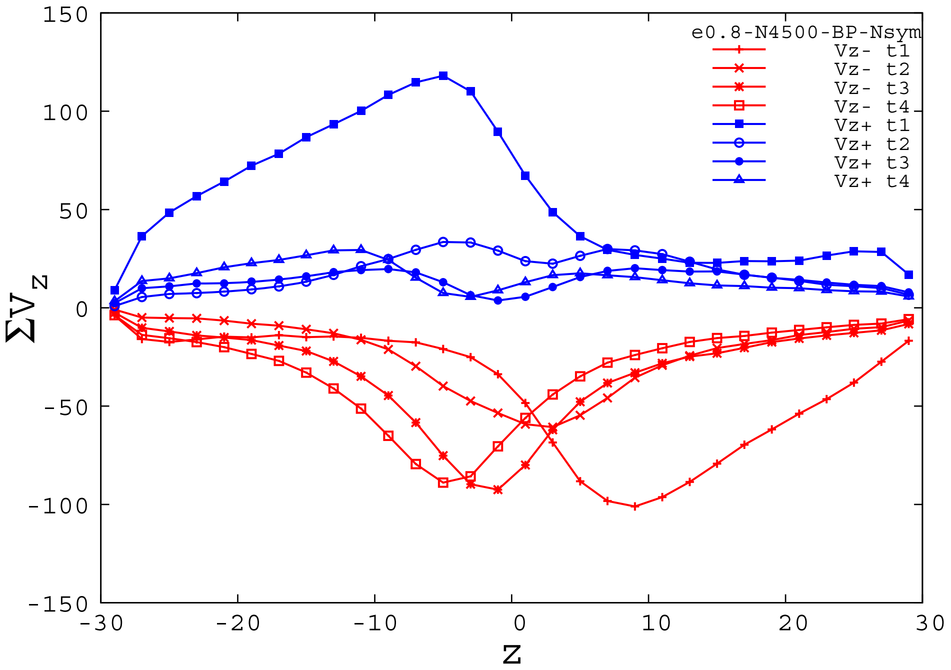


**Figure 1.2 - 9: Simulations of granular gas is 3d rectangular cell**

### 1.3) with e= 0.9

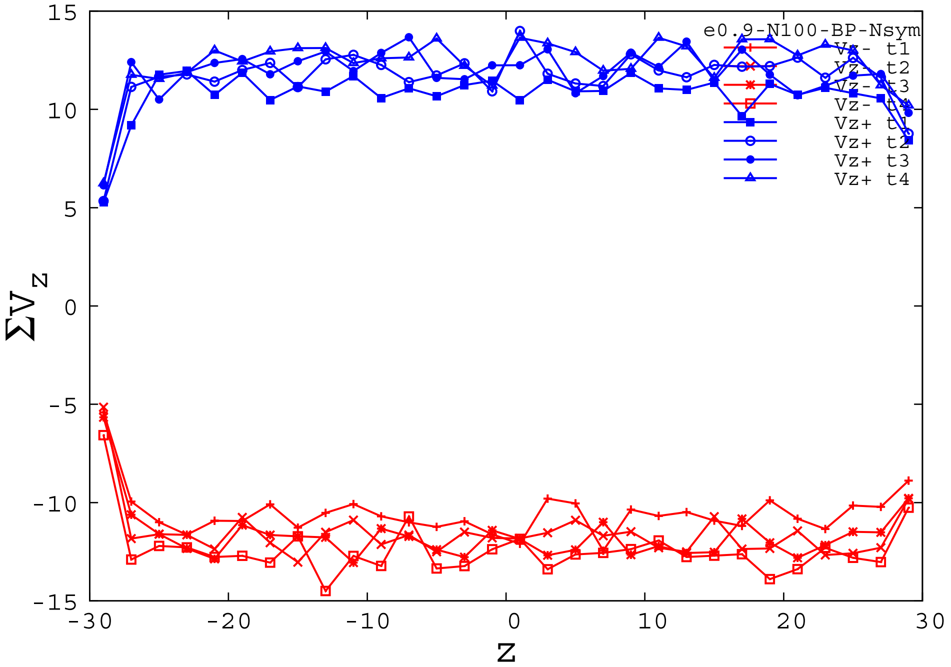


Figure 1.3 - 1: Simulations of granular gas is 3d rectangular cell

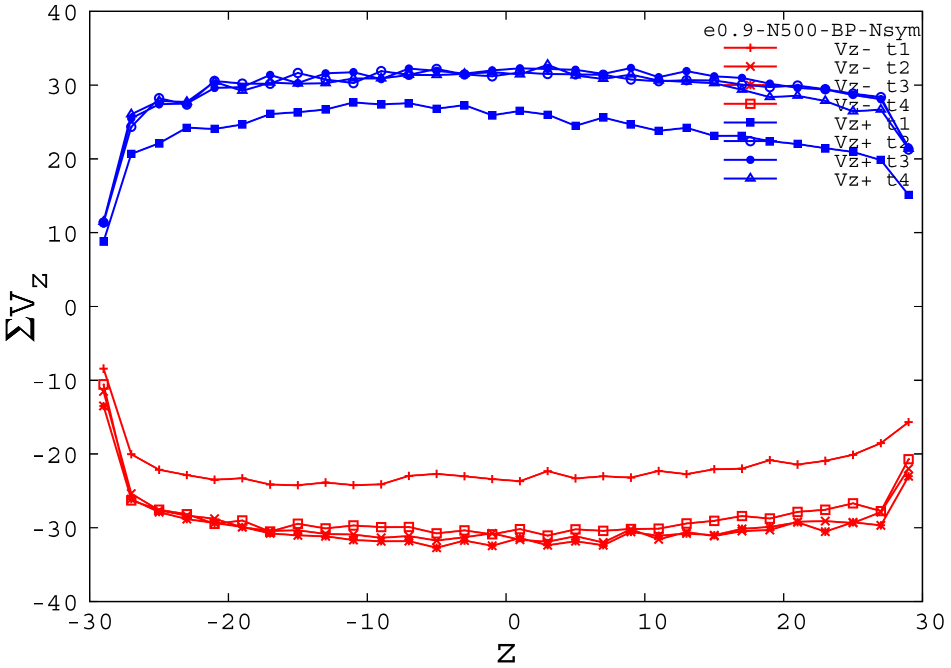


Figure 1.3 - 2: Simulations of granular gas is 3d rectangular cell

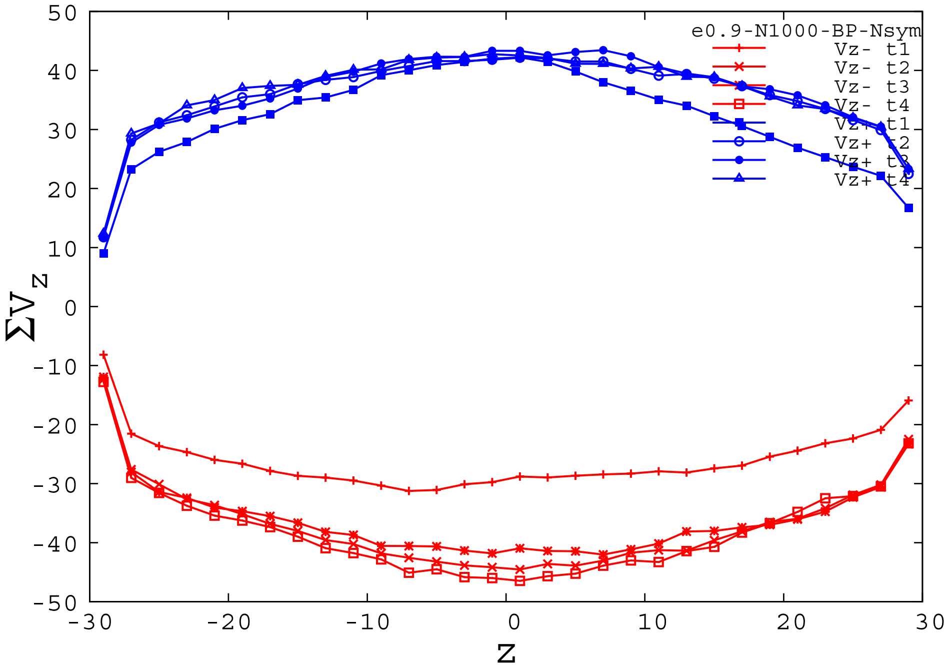


*Figure 1.3 - 3: Simulations of granular gas is 3d rectangular cell*

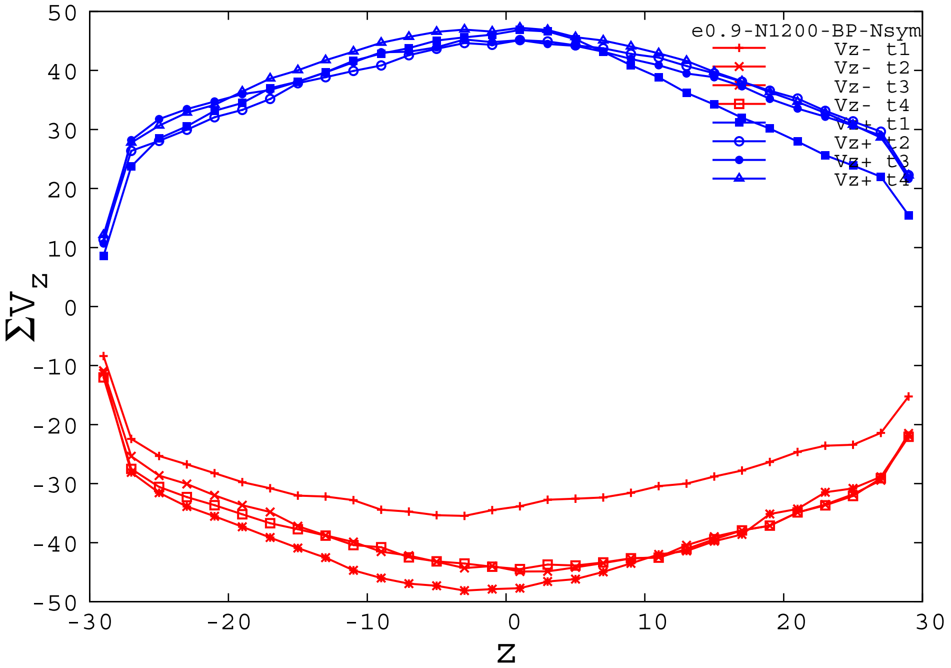


*Figure 1.3 - 4: Simulations of granular gas is 3d rectangular cell*

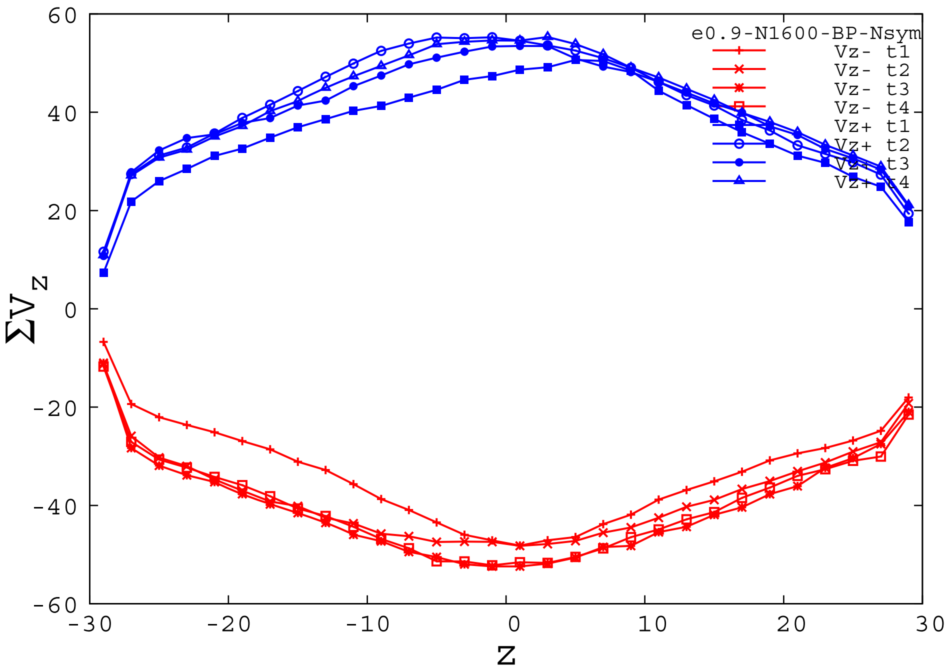


Figure 1.3 - 5: Simulations of granular gas is 3d rectangular cell

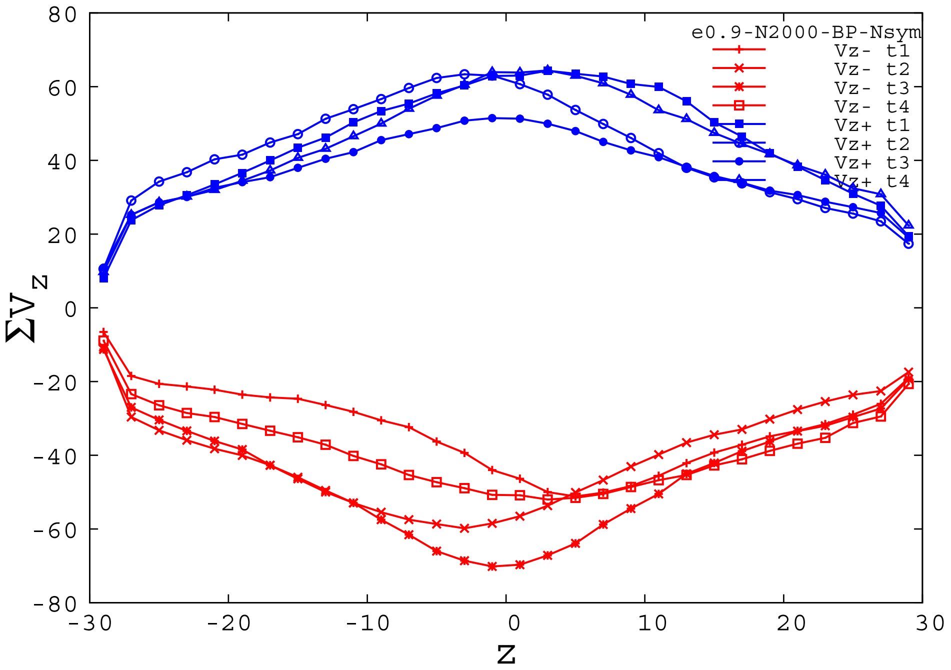


Figure 1.3 - 6: Simulations of granular gas is 3d rectangular cell

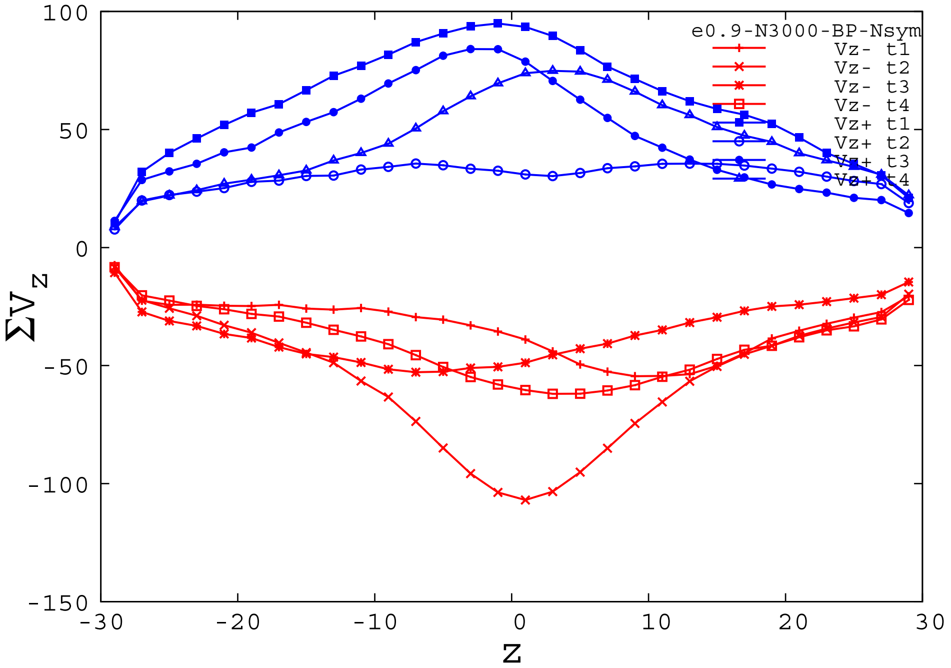


*Figure 1.3 - 7: Simulations of granular gas is 3d rectangular cell*

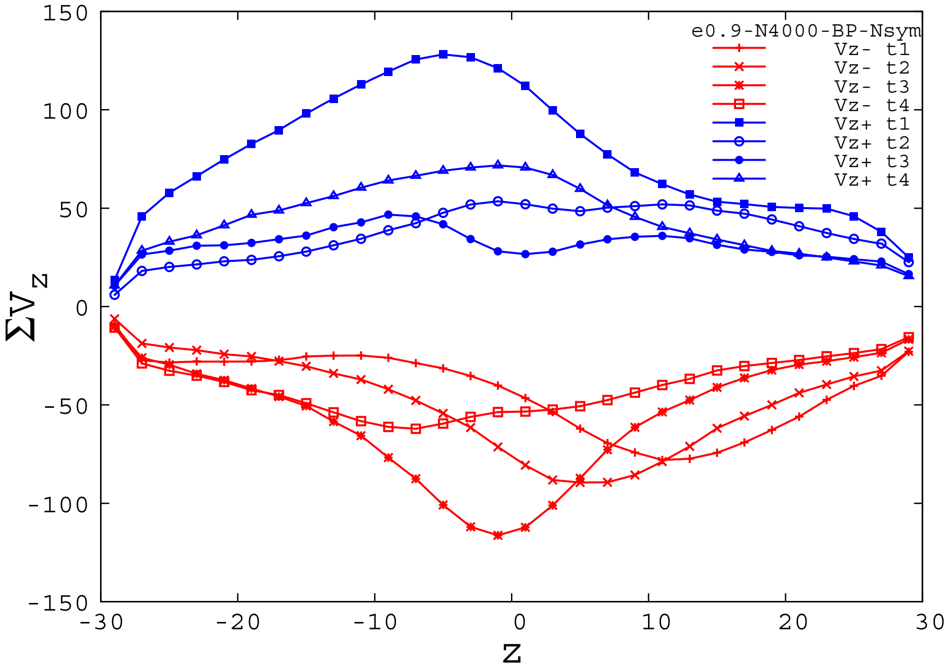


*Figure 1.3 - 8: Simulations of granular gas is 3d rectangular cell*

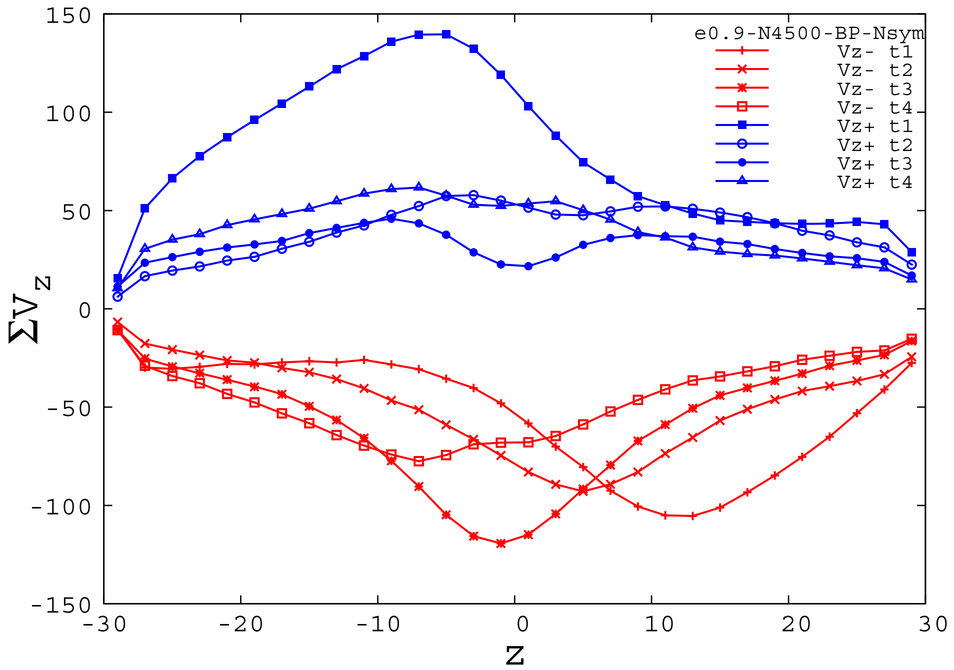


Figure 1.3 - 9: Simulations of granular gas is 3d rectangular cell

## 2) Symmetric bi-parabolic excitation

### 2.1) with e= 0.7

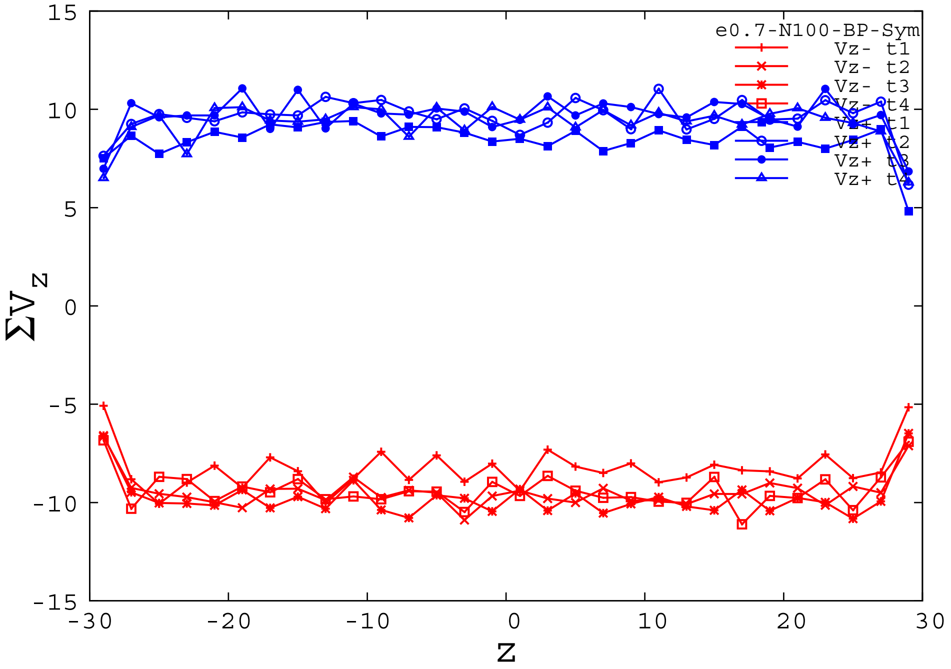


*Figure 2.1 - 1: Simulations of granular gas is 3d rectangular cell*

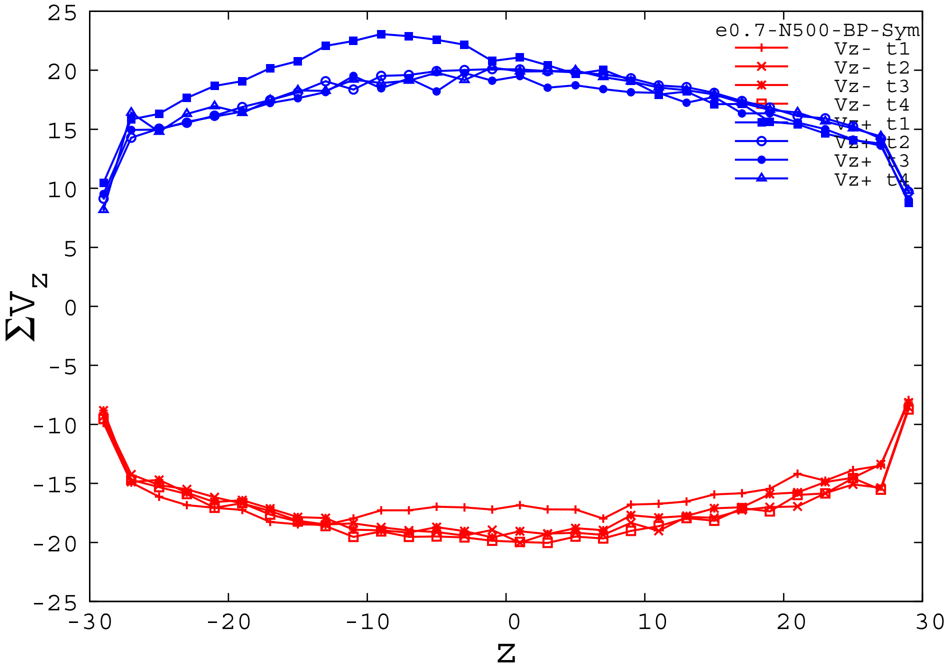


*Figure 2.1 - 2: Simulations of granular gas is 3d rectangular cell*

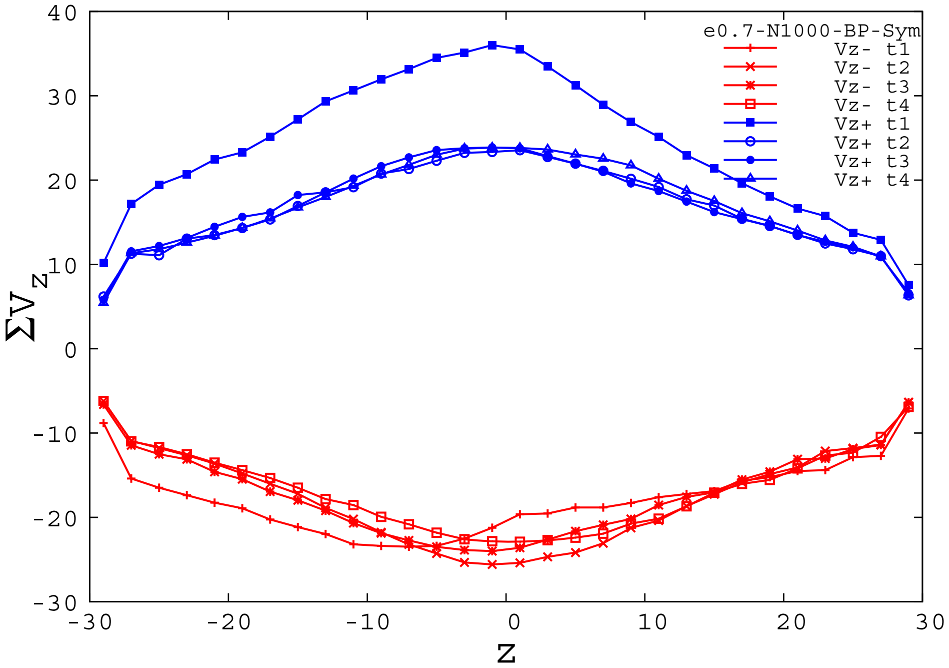


*Figure 2.1 - 3: Simulations of granular gas is 3d rectangular cell*

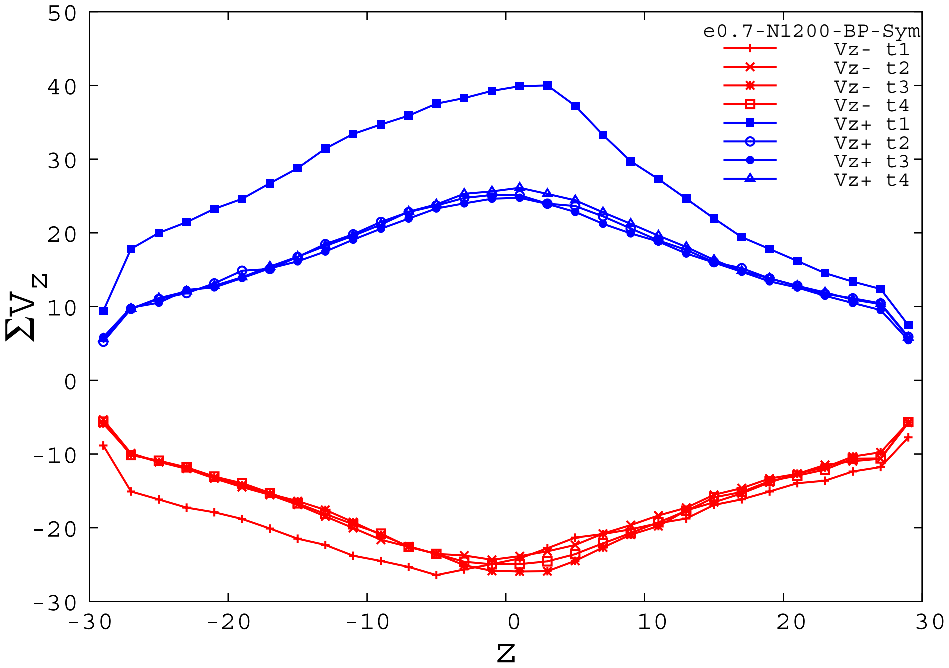


*Figure 2.1 - 4: Simulations of granular gas is 3d rectangular cell*

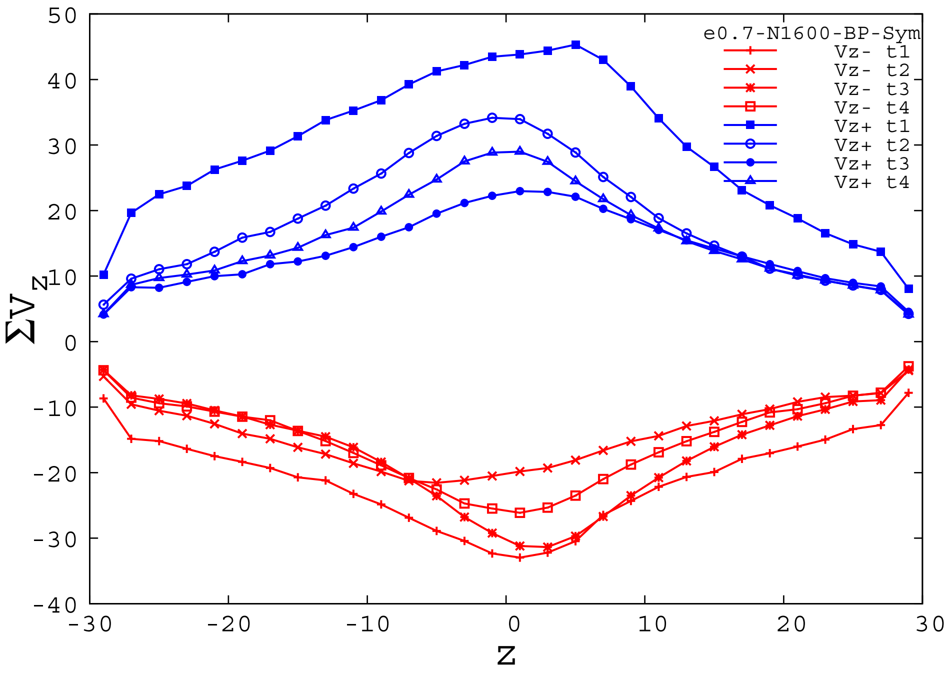


*Figure 2.1 - 5: Simulations of granular gas is 3d rectangular cell*

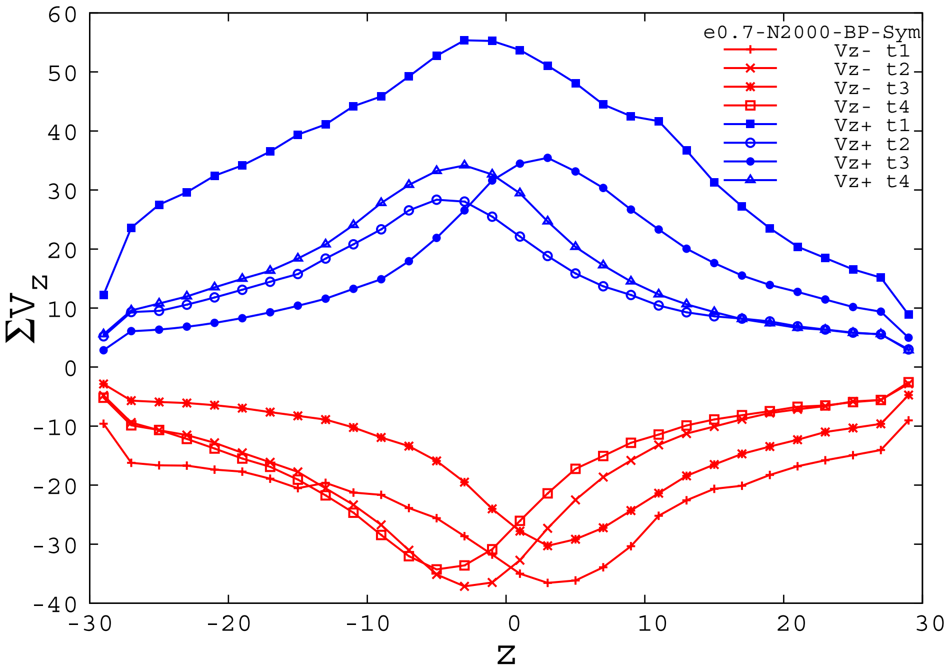


*Figure 2.1 - 6: Simulations of granular gas is 3d rectangular cell*

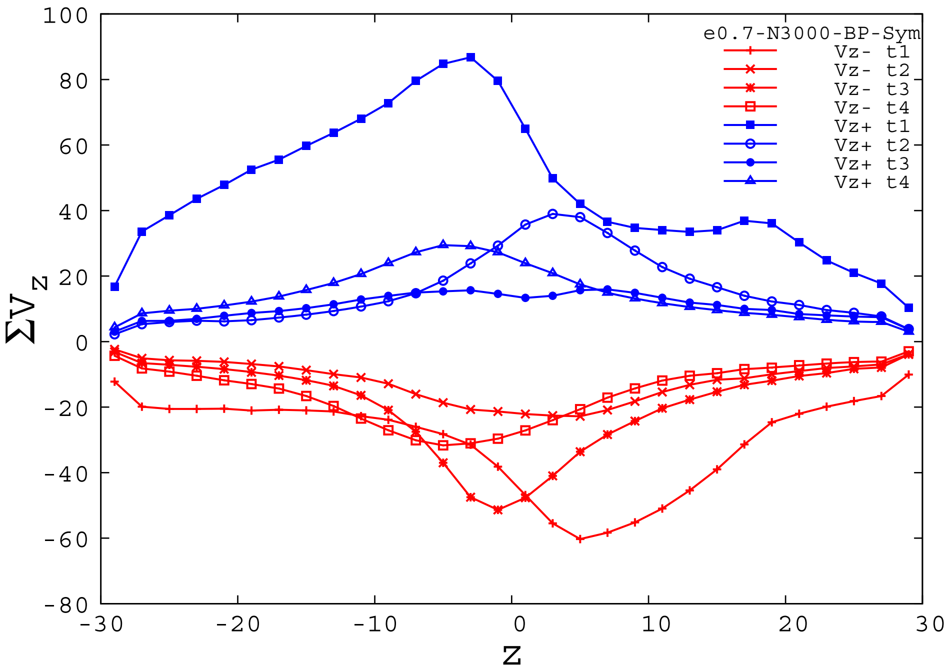


*Figure 2.1 - 7: Simulations of granular gas is 3d rectangular cell*

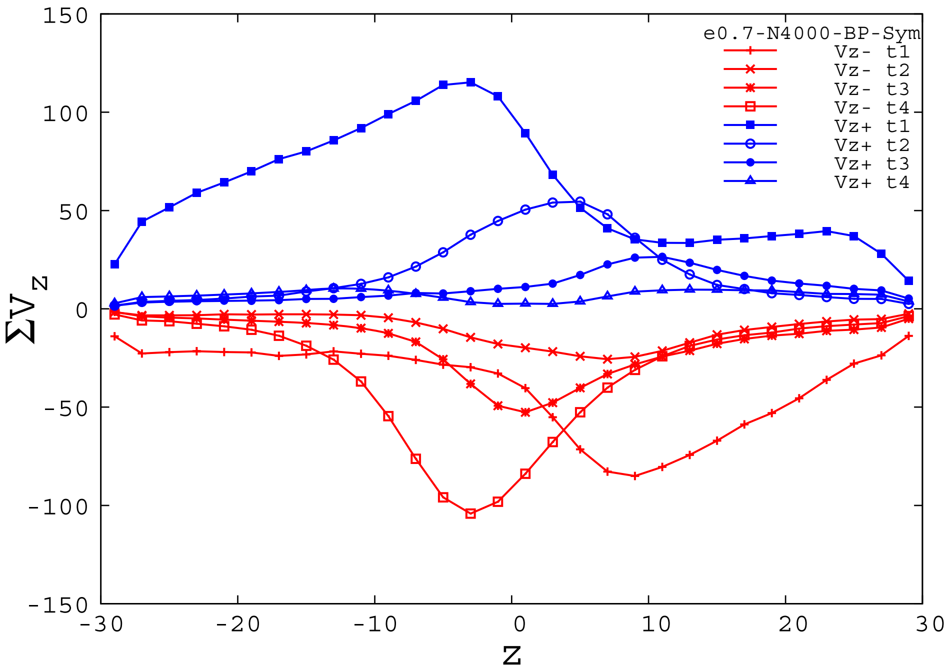


*Figure 2.1 - 8: Simulations of granular gas is 3d rectangular cell*

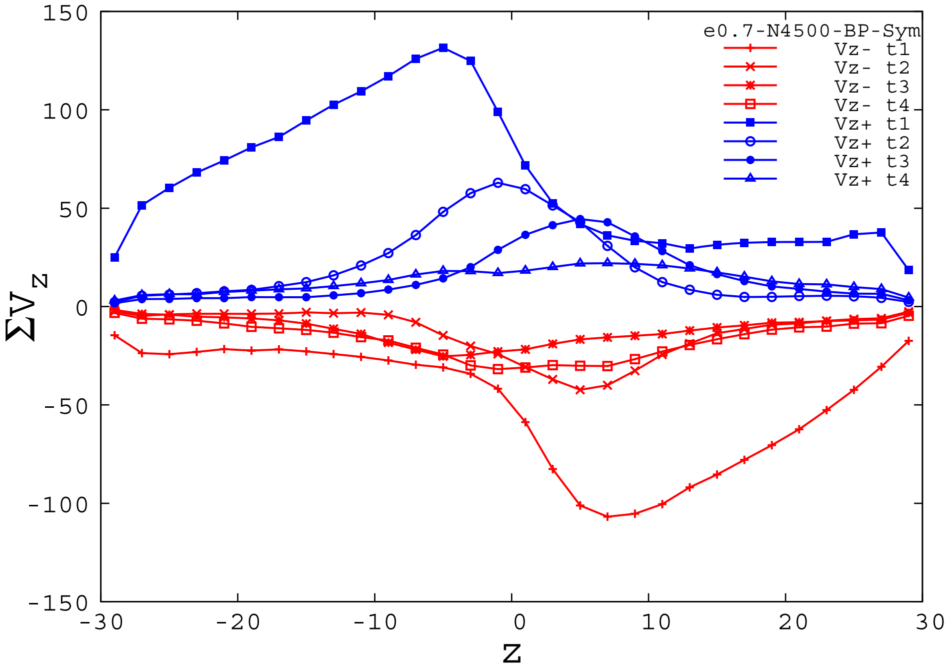


*Figure 2.1 - 9: Simulations of granular gas is 3d rectangular cell*

## *2.2) with e= 0.8*

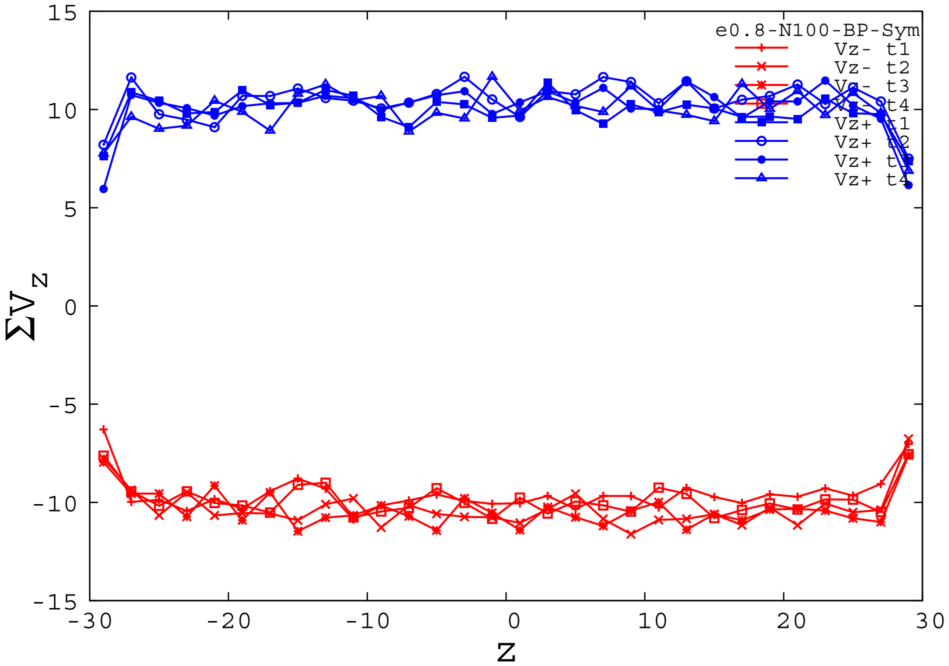


*Figure 2.2 - 1: Simulations of granular gas is 3d rectangular cell*

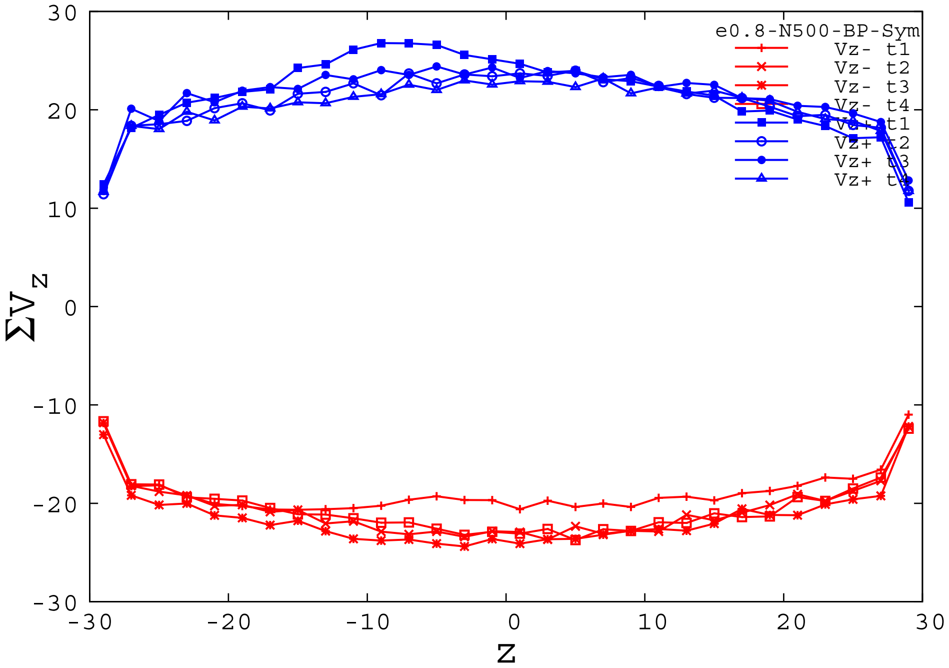


Figure 2.2 - 2: Simulations of granular gas is 3d rectangular cell

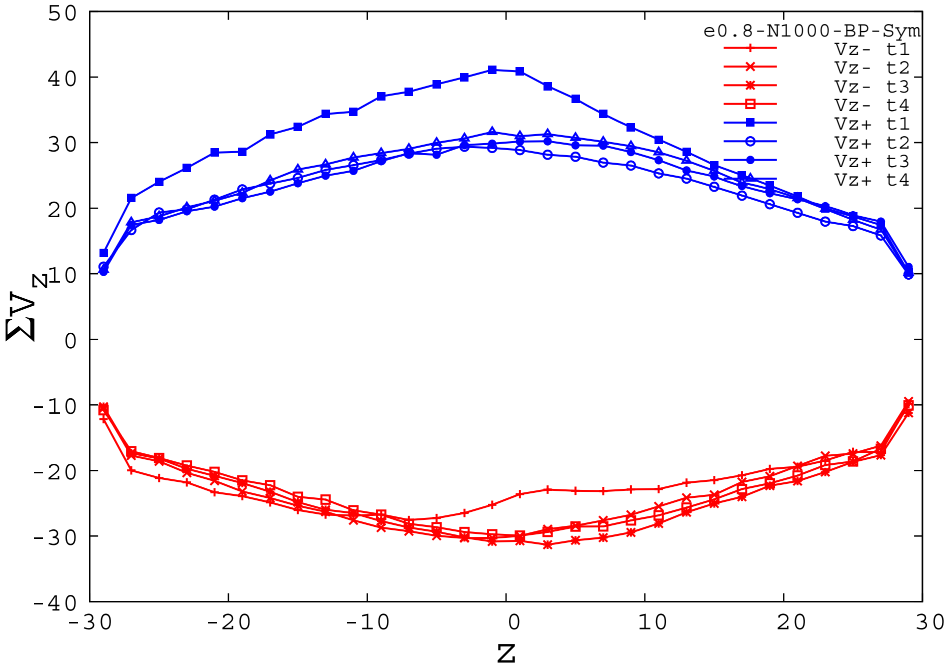


Figure 2.2 - 3: Simulations of granular gas is 3d rectangular cell

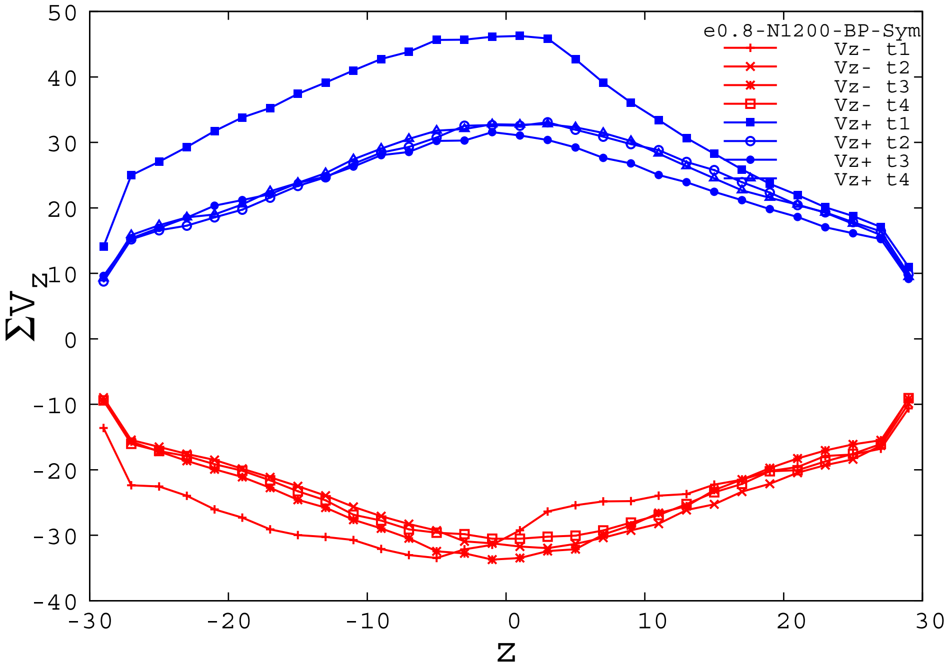


Figure 2.2 - 4: Simulations of granular gas is 3d rectangular cell

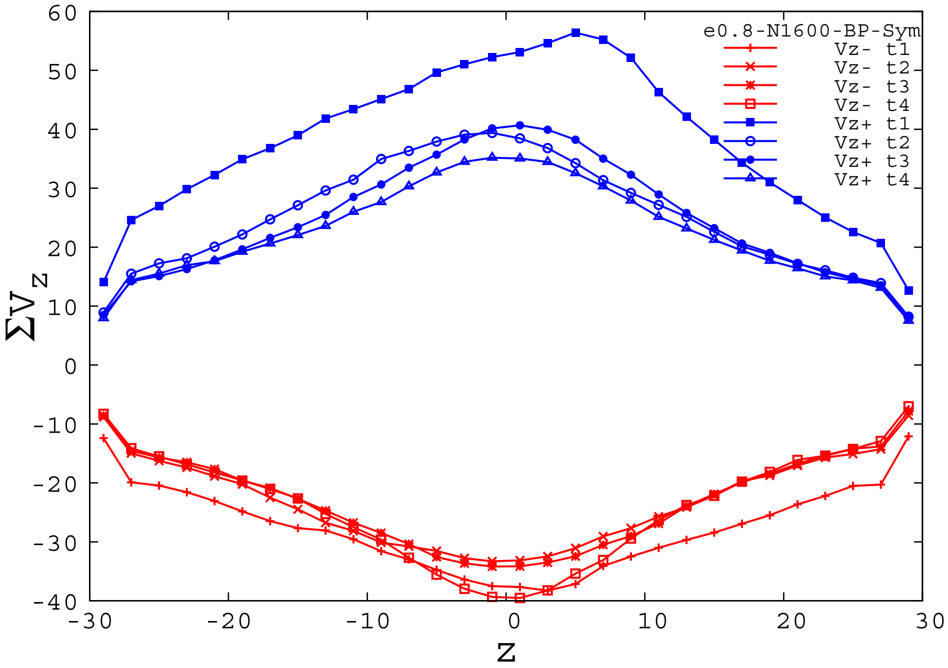


Figure 2.2 - 5: Simulations of granular gas is 3d rectangular cell

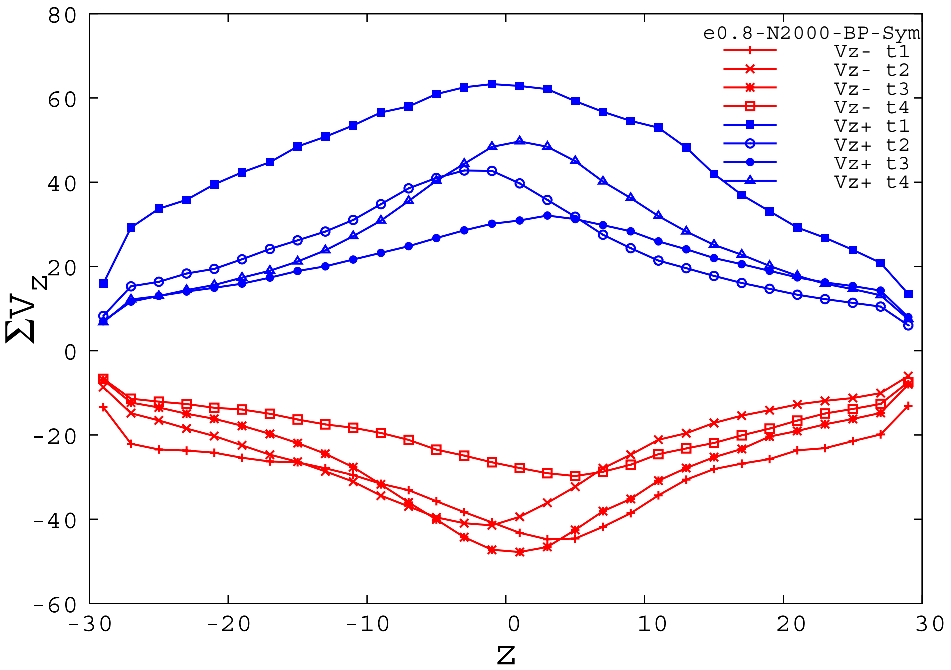


*Figure 2.2 - 6: Simulations of granular gas is 3d rectangular cell*

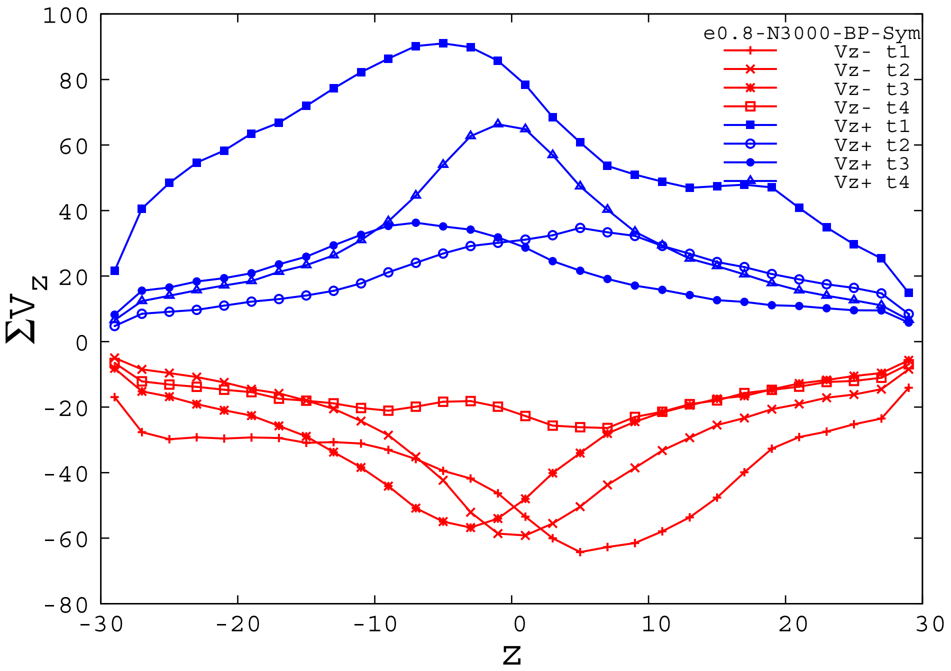


*Figure 2.2 - 7: Simulations of granular gas is 3d rectangular cell*

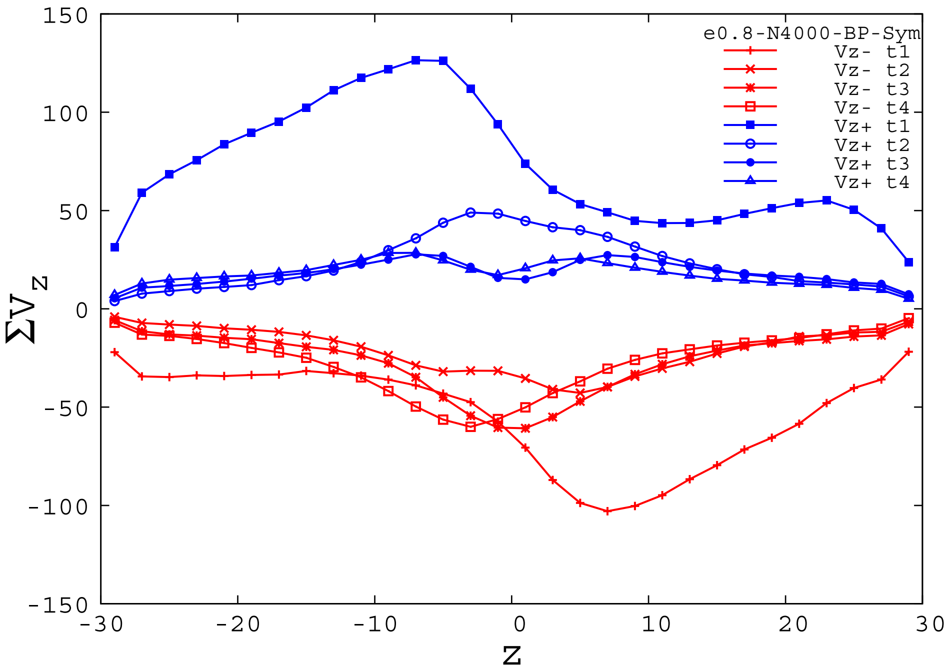


*Figure 2.2 - 8: Simulations of granular gas is 3d rectangular cell*

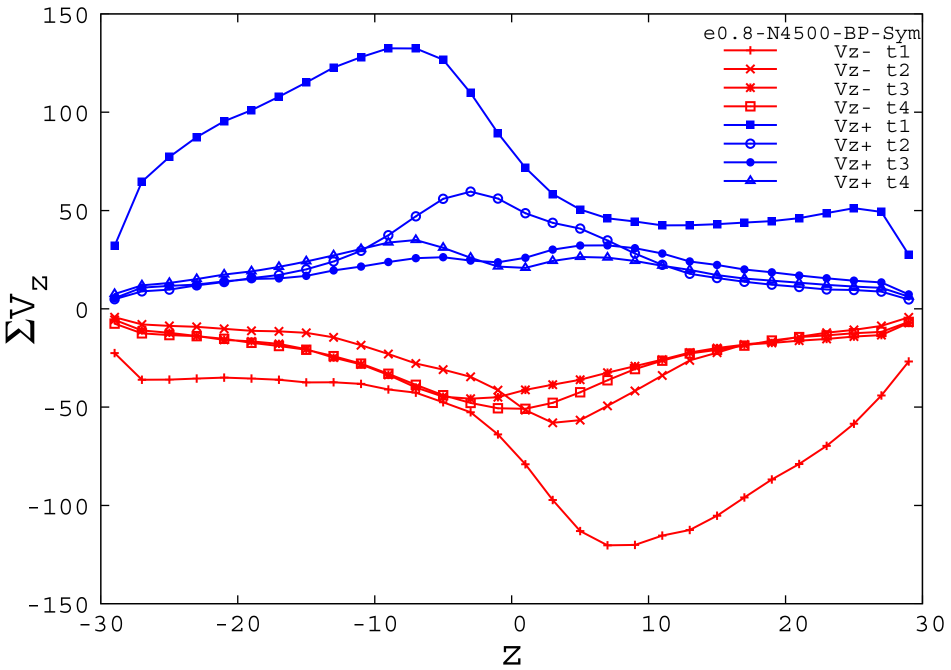


*Figure 2.2 - 9: Simulations of granular gas is 3d rectangular cell*

### 2.3) with e= 0.9

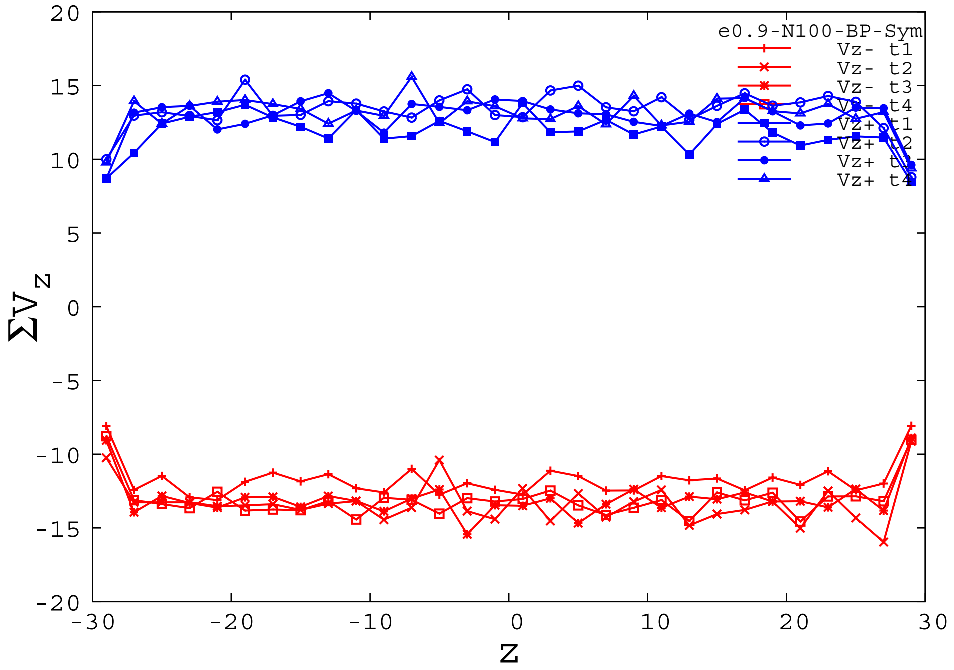


Figure 2.3 - 1: Simulations of granular gas is 3d rectangular cell

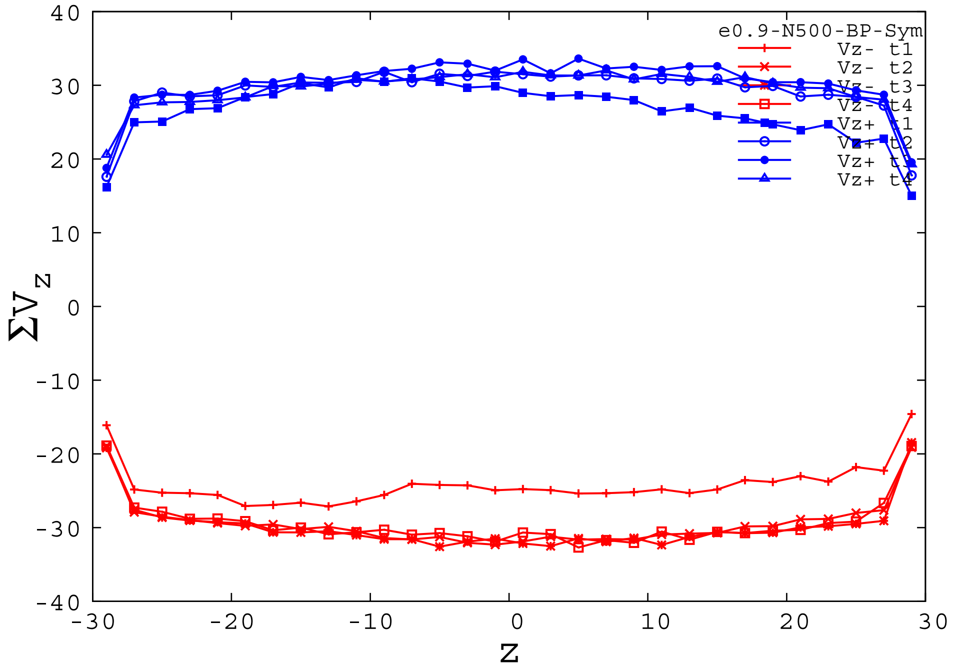


Figure 2.3 - 2: Simulations of granular gas is 3d rectangular cell

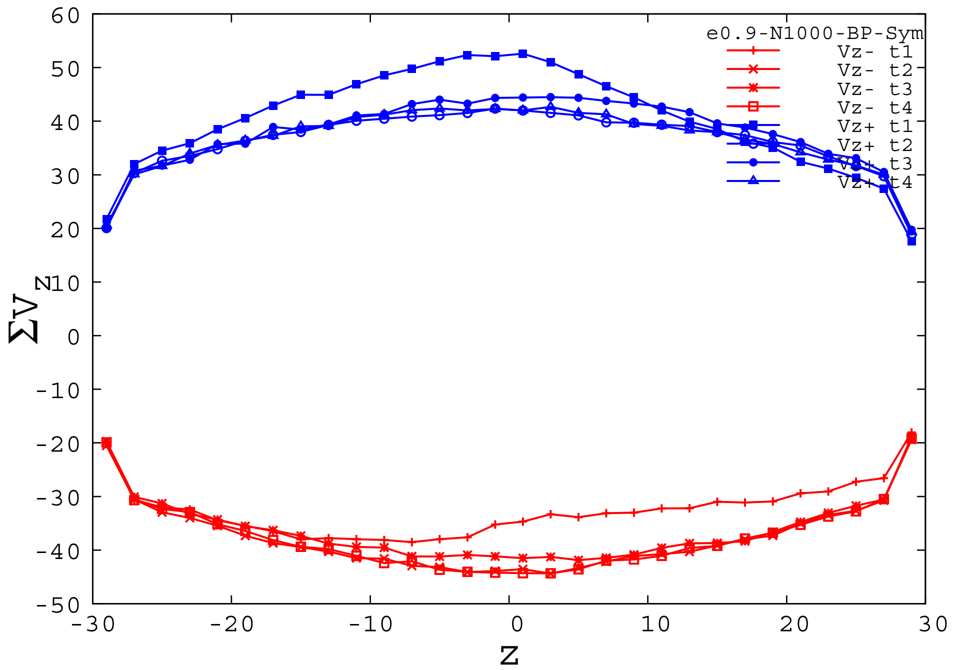


*Figure 2.3 - 3: Simulations of granular gas is 3d rectangular cell*

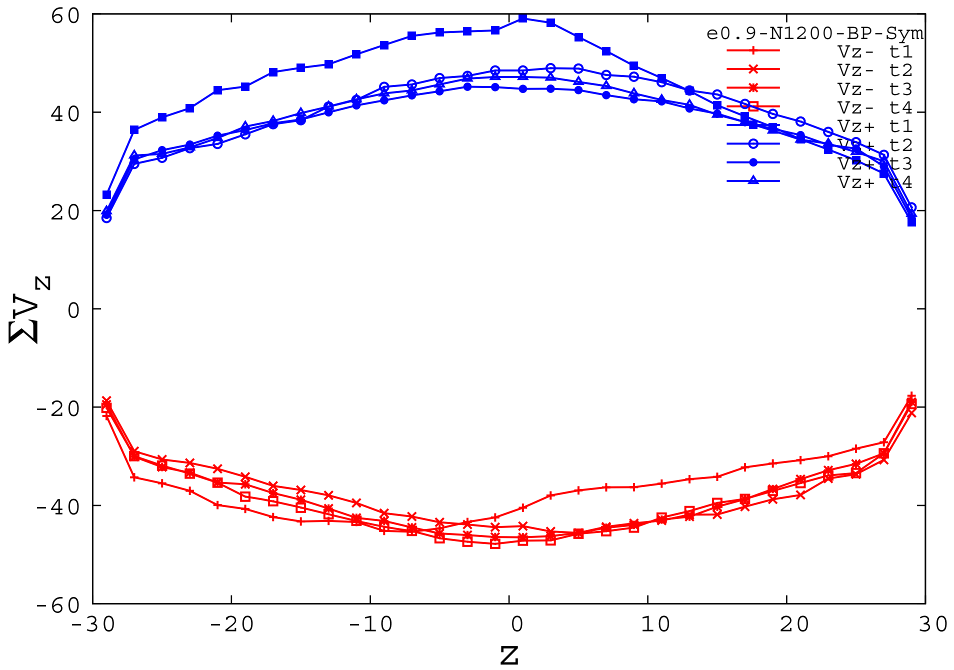


*Figure 2.3 - 4: Simulations of granular gas is 3d rectangular cell*

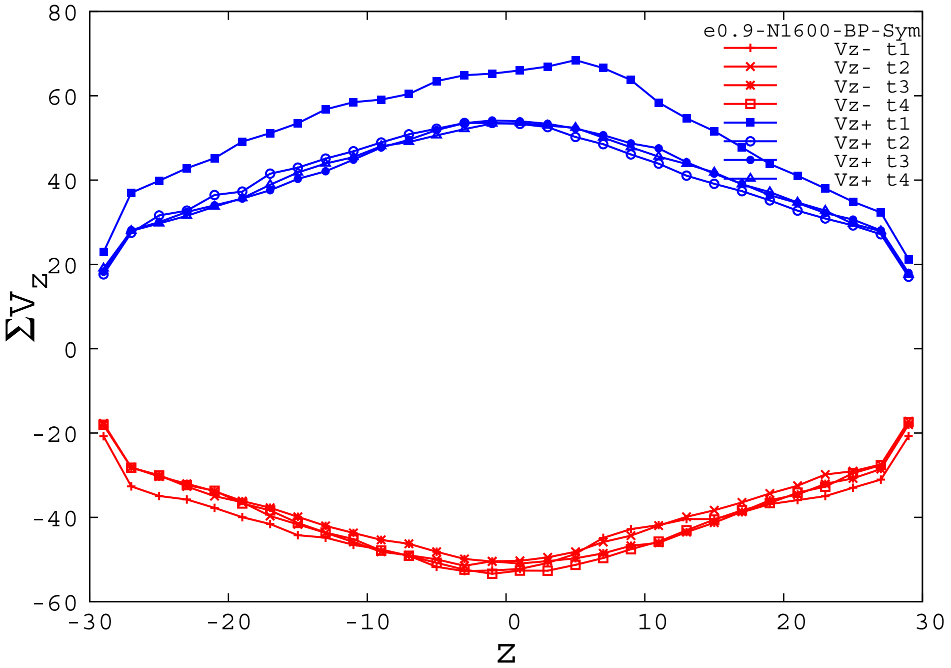


*Figure 2.3 - 5: Simulations of granular gas is 3d rectangular cell*

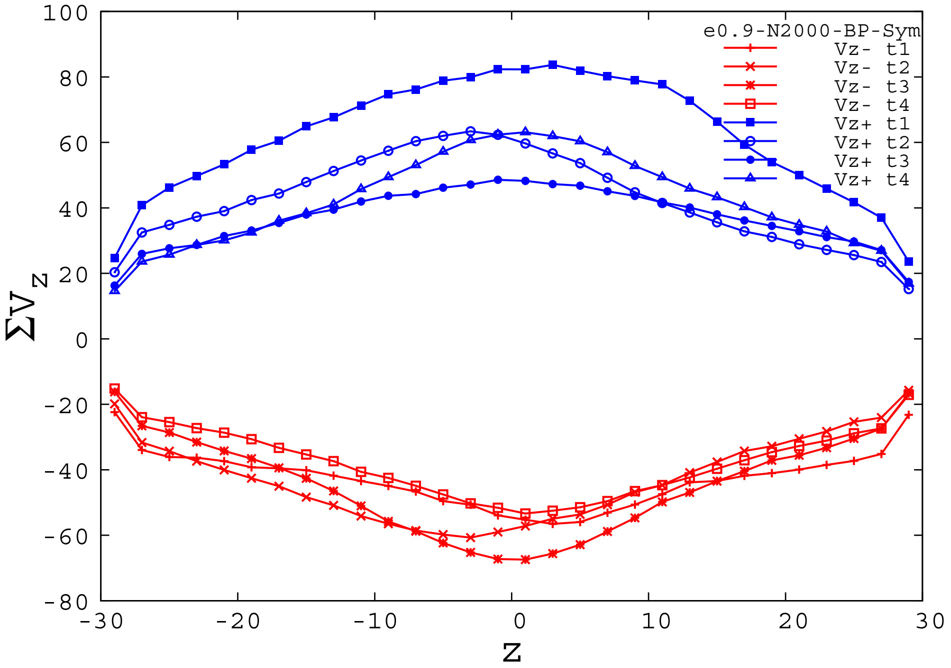


*Figure 2.3 - 6: Simulations of granular gas is 3d rectangular cell*

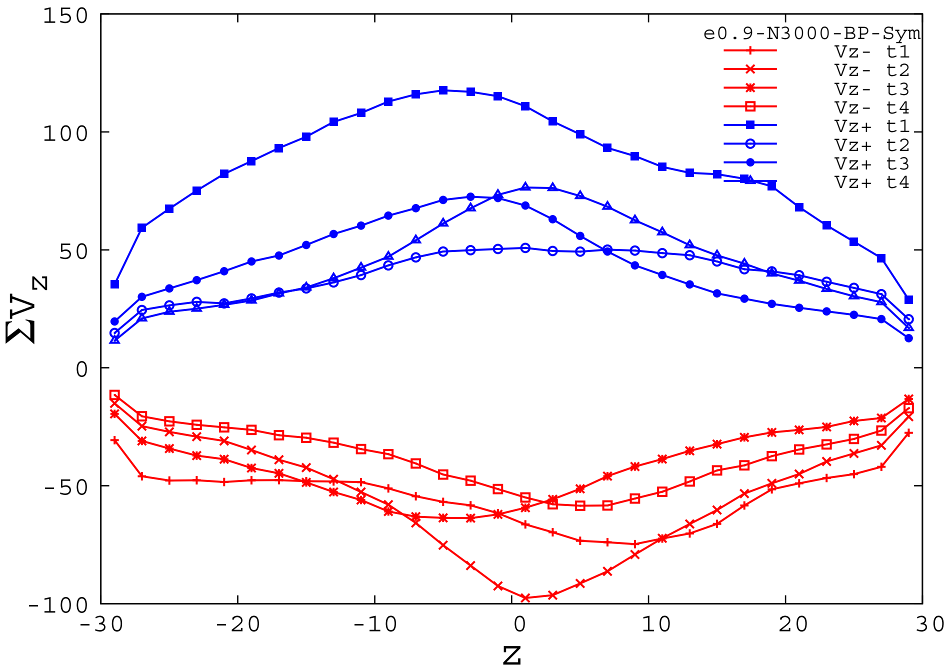


**Figure 2.3 - 7: Simulations of granular gas is 3d rectangular cell**

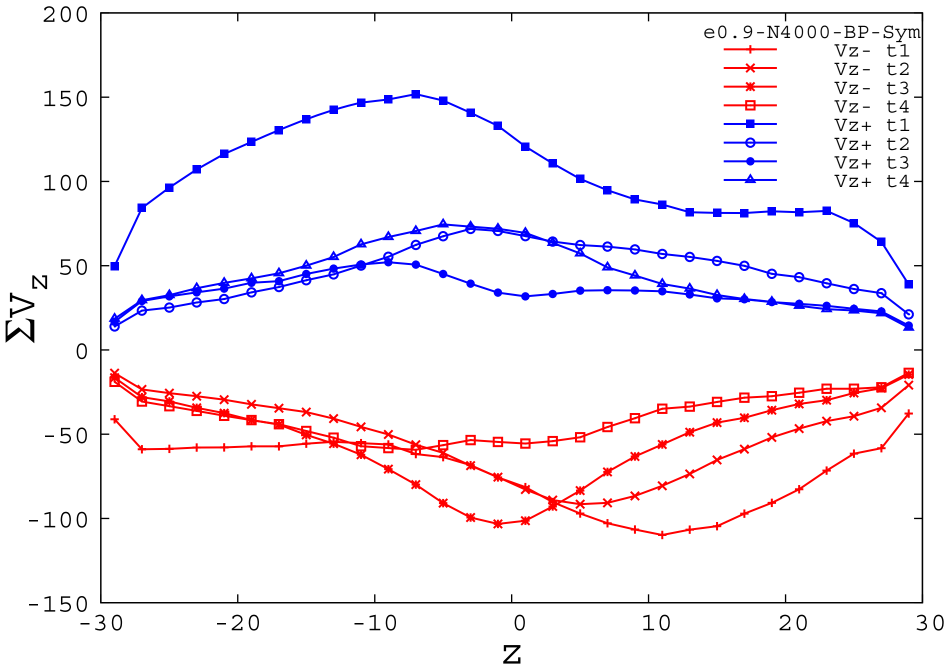


**Figure 2.3 - 8: Simulations of granular gas is 3d rectangular cell**

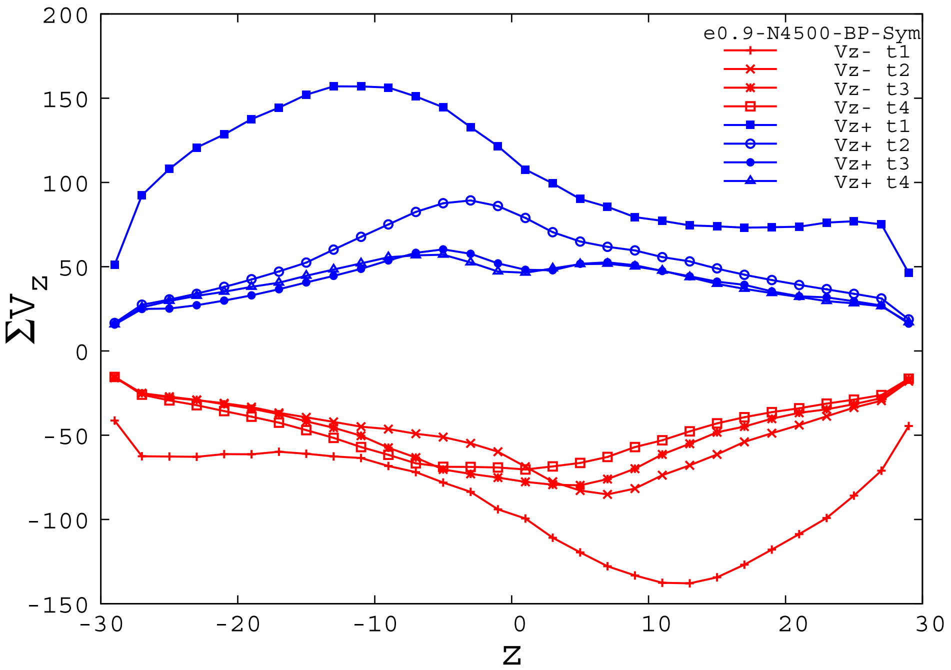
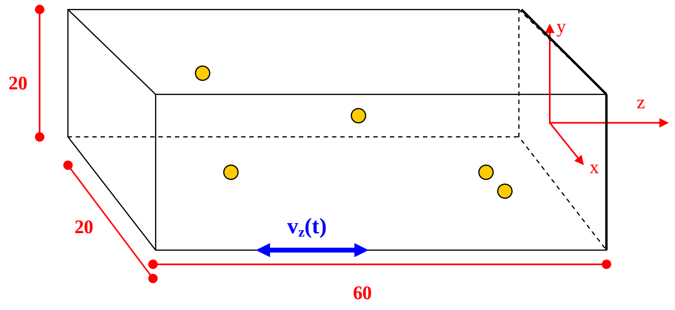


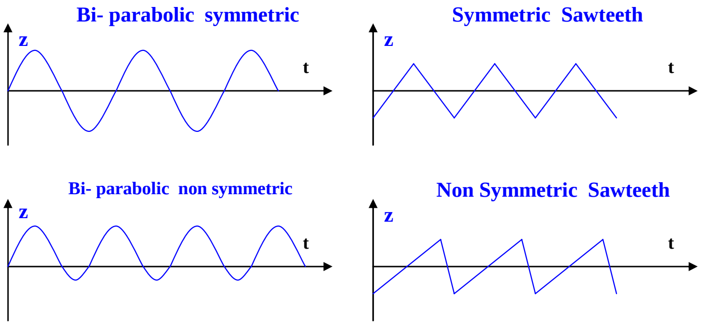
*Figure 2.3 - 9: Simulations of granular gas is 3d rectangular cell*

# Appendix : Simulation technique

A program of molecular dynamics working in C has been used to simulate the dynamics of a colliding gas of equal spheres with dissipation, with equal mass m. Ball-ball collision is treated using inelastic restitution coefficient $e=v_f/v_i$ (=0.9,0.8 or 0.7), excluding rotation effects and rotation parameters. Ball diameter D is the space unit (D=1). Rectangular box is used with dimension (x,y,z) = (20*20*60). Oz is along vibration; Transverse directions are Ox and Oy, no transverse motion of the box is imposed.



*(a)The shape of the container*



(b) Different excitation types of the vertical walls

We study 3d dynamics of N spheres (N=100, 500, 1200, 2000, 3000, 4000, 4500) with different excitation (symmetric and non symmetric bi-parabola and sawteeth drivings, thermal excitation ($\exp(-v^2/kt)$). In thermal excitation, balls which collide with moving wall get a random distribution according to the thermal noise. In bi-parabolic driving, the wall speed is assumed continuous and acceleration $+\Gamma_1$ is applied during $T_1$, then changes to $-\Gamma_2$ during $T_2$ and conversely; so a period $T=T_1+T_2$, and the continuity condition leads to $\Gamma_1 T_1=\Gamma_2 T_2$. This excitation is quite similar to a symmetric sinus wave when $\Gamma_1= \Gamma_1$.

The program finds ball-ball and ball-wall collisions and the snapshots of ball positions and speeds are recorded every (N/10) collisions; The program stops after 100*N collisions and contains 1000* snapshots of 3d- cell and balls. Steady state is obtained after some time. The cell is cut into 59 bins perpendicular to vibration direction, and the different local quantities are averaged over two consecutive bins.

Dynamics is studied in displaying different parameters such as the **p**robability **d**istribution **f**unctions (**pdf**) of the speed coordinates $V_z$, and $V_x$ (along and perpendicular to excitation respectively) at different position z, the density distribution n(z) , the speed distribution $V_z(z)$ as a function of the position z, the mean speed $<V_z>=\Sigma_{particles} mV_z/(\Sigma_{particles} m)$, which is also the mean flow, the mean temperature $kT/m = \Sigma_{particles} V^2{}_z/(\Sigma_{particles})$ and the mean pressure $P_z= \Sigma_{particles} mV^2{}_z$. Only normal restitution coefficient e is introduced to take account of dissipation; No rotation and friction is included.

We also separate the particles into two sets at a given instant, *i.e.* those ones which move towards $z^+$ (positive $V_z$ ), and those ones which move towards $z^-$ (negative $V_z$ ) and we plot the same quantities with respect to these directions, i.e. the density distribution $n^{(\pm)}(z)$ , the speed distribution $V_z(z)$ as a function of the position z, the mean speed $<V^{(\pm)}{}_z>=\Sigma_{particles} mV^{(\pm)}{}_z/(\Sigma_{particles} m)$, which is also the mean flow in + or - z, the mean temperature $kT/m = \Sigma_{particles}(V^{(\pm)}{}_z)^2/(\Sigma_{particles})$ and the mean pressure $P_z= \Sigma_{particles} m(V^{(\pm)}{}_z)^2$ , on graphs.

## Figure symbols and abbreviations:

e0.9: coefficient of restitution $e = 0{:}9$
ST: saw-tooth driving

N***: number of particles $N$ = ***
Sym: symmetrical driving

BP: bi-parabolic driving
Nsym: Non-symmetrical driving

*Acknowledgements:* CNES, CNSA, ECP, ESA and IOP-CAS are greatly thanked for partial funding. This work has been obtained during a stay of Liu Rui in Lab MSSMat which has been supported by China grant.

[1] Invited scholar at ECP, from IOP-CAS, Alan liurui04@mails.gucas.ac.cn

[2] Invited Professor at ECP, from IOP-CAS, mayhou mayhou@aphy.iphy.ac.cn

## References

[1] T. Poschell & S. Luding, *Granular Gases,* Lectures Notes in Physics **564**, (Springer-Verlag, Berlin, 2001); *Granular Gas Dynamics*, Lectures Notes in Physics **624**, edited by T. Poschel and N. V. Brilliantov, (Springer-Verlag, Berlin, 2003); A. Barrat, E. Trizac & M.H. Ernst, “Granular gases: dynamics and collective effects”, arXiv:cond-mat/0411435 v2, 3/12/2004, published in J. Phys. C (2005); S.Luding, R.Cafiero, H.J. Herrmann, "Driven Granular Gas", in *Granular Gas Dynamics*, Lectures Notes in Physics 624, edited by T. Poschel and N. V. Brilliantov, (Springer-Verlag, Berlin, 2003), 293

[2] J. Javier Brey, F. Moreno, R. Garcıa-Rojo and M. J. Ruiz-Montero, "Hydrodynamic Maxwell Demon in granular systems", *Phys. Rev.* **E 65**, p. 11305 (2001). I. Goldhirsch, “Rapid granular flow”, *Annu. Rev. Fluid Mech.* **35**, 267 (2003) ;

[3] E. Falcon, R. Wunenburger, P. Evesque, S. Fauve, C. Chabot, Y. Garrabos & D. Beysens; *Phys. Rev. Lett.* **83** (12 juillet 1999) 440-443 ; E. Falcon, P. Evesque, F. Palencia, C. Lecoutre-Chabot, S. Fauve, D. Beysens & Y. Garrabos, Collision statistics in a dilute granular gas fluidized by vibrations in low gravity, *Europhys. Lett* **74**, 830- (2006) ; M. Leconte, Y. Garrabos, E. Falcon, C. Lecoutre-Chabot, F. Palencia, P. Evesque, D. Beysens, , *Journal of Statistical Mechanics: Theory and experiment,* P07012 (2006); P. Evesque, Y. Garrabos, C. Lecoutre, F. Palencia, and D. Beysens, Dilute dissipative granular gas in Knudsen regime and in micro-gravity: evidence for a “velostat” as boundary conditions, Powders & Grains 2005, Stuttgart, July 18-22, 2005,in *Powders & Grains 2005*, (Garcia-Rojo, Herrmann, McNamara ed., Balkema 2005), pp. 1107-1111; P. Evesque, E. Falcon, R. Wunenburger, S. Fauve, C. Lecoutre-Chabot, Y. Garrabos & D. Beysens, “Gas-cluster transition of granular matter under vibration in microgravity”, In "Proceedings of theFirst international Symposium on Microgravity Research & Applications in Physical Science and Biotechnology", Sorrento, Italy, 10-15 Sept 2000, pp. 829-834 ; P. Evesque, F. Palencia, C. Lecoutre-Chabot, D. Beysens and Y. Garrabos, ISPS 2004 (Toronto- 23-27 may 2004); *Microgravity Sci. Technol.* **XVI-1**, 280-284 (2005); M. Leconte, Y. Garrabos, F. Palencia, C. Lecoutre, P. Evesque, D. Beysens, "Inelastic ball-plane impact: An accurate way to measure the normal restitution coefficient", *Appl. Phys. Lett.* **89**, 243518 (2006); M. Hou, R. Liu, G. Zhai, Z. Sun, K. Lu , Y. Garrabos and P. Evesque , Velocity distribution of vibration-driven granular gas in Knudsen regime, *MicroGravity Sc. Technol.* (accepted 2008)

[4] P. Evesque: Comparison between Classical-Gas behaviours and Granular-Gas ones in micro-gravity : *Poudres & Grains* **15**, 60-82 (2001) ; P. Evesque: Is Dissipative Granular Gas in Knudsen Regime Excited by Vibration Biphasic? *Poudres & Grains* **15**, 18-34 (2005); P. Evesque: On the role of boundary condition on the speed- & impact- distributions in dissipative granular gases in Knudsen regime excited by vibration *Poudres & Grains* **15**, 1-16 (2005) ; P. Evesque: *Poudres & Grains* **13**, 20-26 (2003), http://www.mssmat.ecp.fr/html_petg/rubrique.php3?id_rubrique=1 P. Evesque, "A model of dissipative granular gas: the ultimate case of complete inelasticity of grain-grain collision", Powders & Grains 2005, Stuttgart, July 18-22, 2005,in *Powders & Grains 2005*, (Garcia-Rojo, Herrmann, McNamara ed., Balkema 2005), pp. 1131-1134

[5] P. Evesque: Boundary conditions and the dynamics of a dissipative granular gas: slightly dense case; *poudres & grains* **16 (3)**, 38-62 (Septembre 2007), and ref there in.

[6] J. S. van Zon and F. C. MacKintosh, "Velocity Distributions in Dissipative Granular Gases", *Phys.Rev. Lett.* **93**, 038001 (2004)

[7] W. A. M. Morgado & E. R. Mucciolo; Numerical simulation of vibrated granular gases under realistic boundary conditions; arXiv:Cond-Mat/0204084v1 (2002)

## ***poudres & grains* - *ISSN 1257-3957 :*** **Accord de transfert de droits d'auteur:**

**À remplir obligatoirement**

Le droit d'auteur pour l'article mentionné ci-dessus est par le présent acte transféré à la revue *Poudres & Grains*, ISSN 12577-3957, domiciliée à l'Ecole Centrale Paris, et à l'Association Pour l'Étude de la Micro-mécanique des Milieux Granulaires (AEMMG). II prendra effet à partir de la date d'acceptation de publication.

La revue *Poudres & Grains* est diffusée en support papier et est disponible sur internet; elle est téléchargeable sur support électronique.

Par la présente, les auteurs

- certifient que l'un d'entre eux est détenteur d'un doctorat scientifique ou d'un diplôme équivalent.
- certifient que le présent article obéit aux règles d'une déontologie scientifique rigoureuse: les faits expérimentaux sont véridiques ; les résultats obtenus, tant théoriques qu'expérimentaux, sont décrits honnêtement….
- certifient accepter et favoriser le débat honnête entre scientifiques.
- certifient refuser les querelles de personne.
- certifient avoir respecter les droits des autres auteurs scientifiques, et de l'antériorité scientifique en particulier.
- acceptent d'ouvrir cet article à la discussion scientifique et que cette discussion soit publiée par la Revue *Poudres & Grains*, dans la mesure où cette discussion est conforme à la déontologie scientifique (pas d'attaque de personne,…).

*Tout manquement à ces règles supprime l'accès à la publication. Les auteurs sont seuls responsables du contenu de l'article.*

*Les auteurs conservent les droits suivants* :

(1) Tous les droits de propriété (tels que les droits de brevet) sauf le droit d'auteur.

(2) Le droit de conférer ou de refuser la permission, aux tiers, pour la réédition en totalité ou en partie de l'article, ou d'en faire la traduction. Dans le cas d'un article réédité intégralement, le tiers doit aussi obtenir l'autorisation écrite de *Poudres & Grains*.

(3) Le droit d'utiliser la totalité ou une grande partie de l'article pour leur propres travaux futurs.

(4) Dans le cas d'un travail fait pour un employeur, le droit de l'employeur et des auteurs de faire des copies de cet article pour leur propre usage, mais à l'exclusion de toutes fins commerciales.

Signature de l'un au moins des auteurs titulaires d'un doctorat (qui accepte d'informer les éventuels coauteurs) ou dans le cas d'un travail effectué dans le cadre d'une mission, de l'employeur.

**Titre de l'article:**

**Auteurs:**

| | | |
|---|---|---|
| Signature: | Signature: | Signature: |
| Nom (en imprimé) | Nom (en imprimé) | Nom (en imprimé) |
| Titre | Titre | Titre |
| Institut ou Société | Institut ou Société | Institut ou Société |
| Date: | Date: | Date: |