About LW & Astra Simulations of The Pitz Gun

results from measurement and simulation

methods (LW, PIC, Astra) and setup

comparison LW $\leftrightarrow$ Astra

more analysis of LW results

about Astra results: sensitivity to numerical parameters

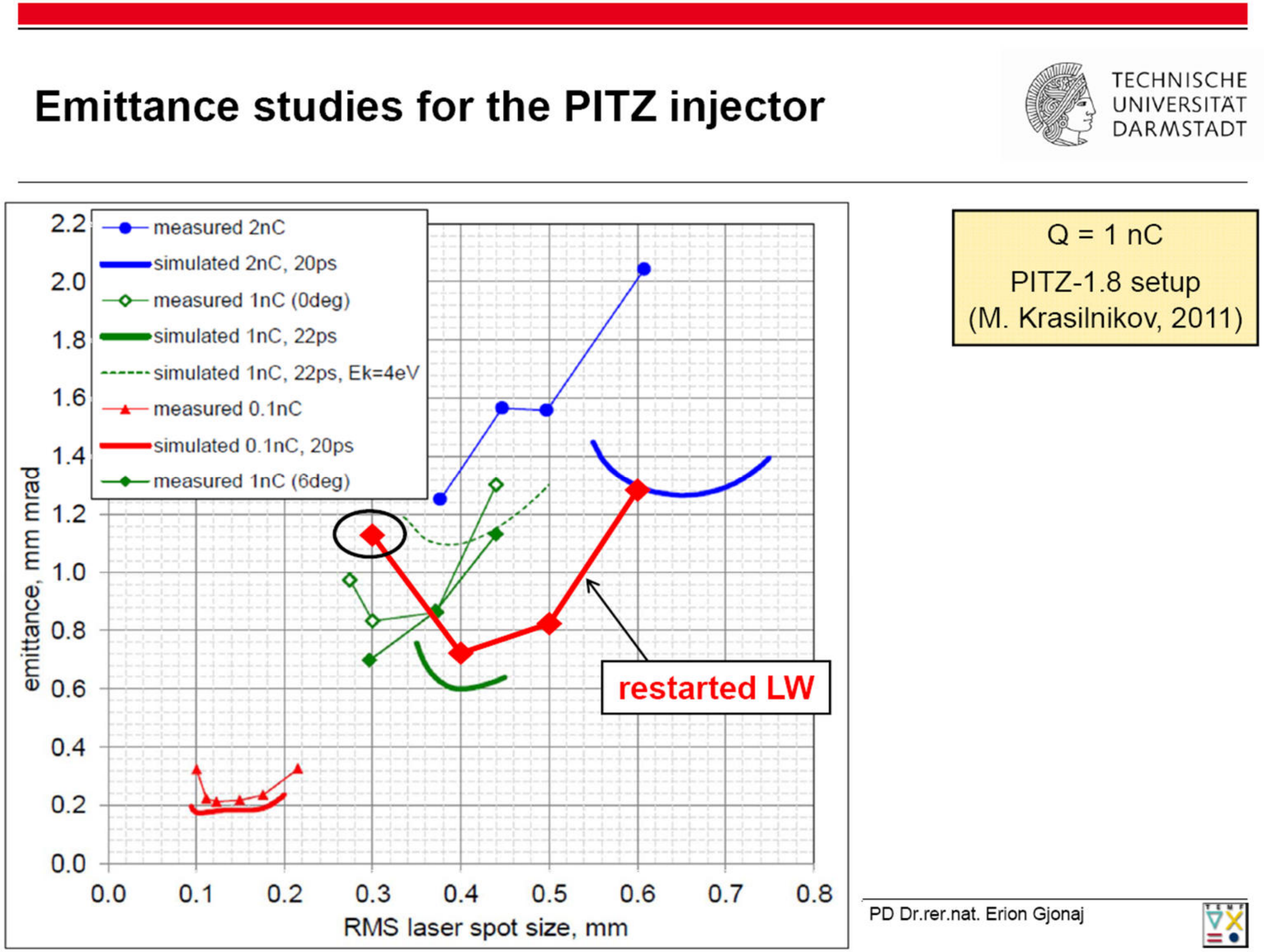
about approaches: some analytical calculations

second inspection

summary

results from measurement and simulation

see: DESY/TEMF Meeting - Status 2011
http://www.desy.de/xfel-beam/data/talks/files/03-Gjonaj_Erion_DESY_16.12.2011_new.pdf



methods (LW, PIC, Astra) and setup

LW = Lienard Wichert

exact solution of Maxwell problem (based on retarded trajectory)
no spatial mesh
numeric integration of EoM; fixed time step

higher order PIC; PIC = particle in cell

exact numerical approach for Maxwell problem
spatial mesh & time step
numeric integration of EoM; fixed time step

extensive convergence test in 2010
carefull comparison in 2011
→ simulation of PITZ injector
for z <= 5 cm

Astra

approximation based on uniform motion
rz - Poisson approach; spatial mesh
numeric integration of EoM; variable time step

methods (LW, PIC, Astra) and setup

setup

bunch charge = 1 nC
bunch length = 21.5 psec (Lt=0.0215 rt=0.002)

rms-radius = (radius/2) = 0.2 … 0.6 mm

MaxE = 60.58 MV/m
phi = 223.386 deg (or auto phase = -1.404 deg) $\rightarrow$ E0 = 41.6 MV/m

estimated SC limitation (DC field and planar diode)

$$Q_{\mathrm{SC-limit}} = \varepsilon_0 E_0 \pi R^2$$

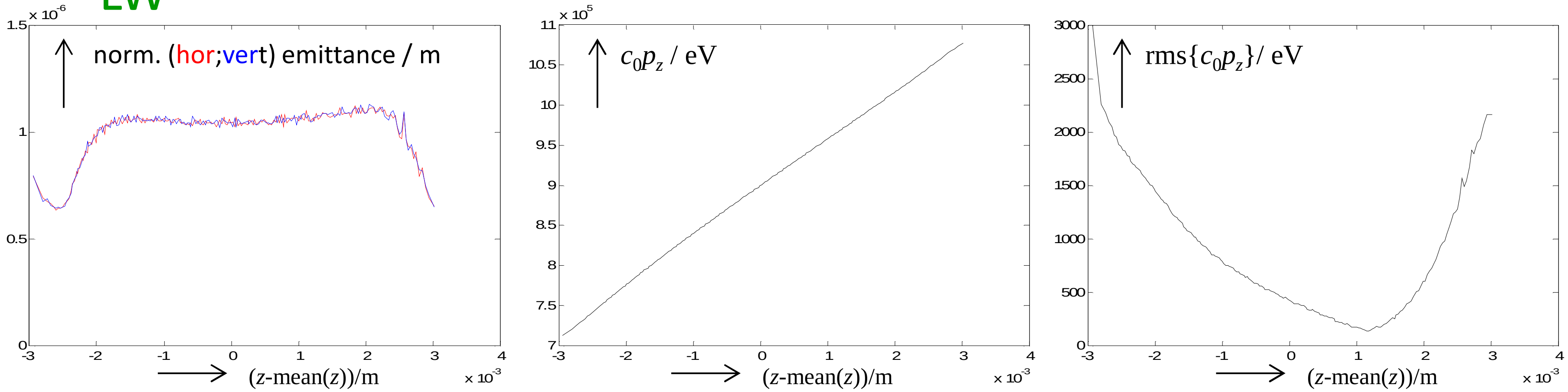
R_{rms}/mm	$Q_{SC\text{-}limit}$/nC
0.2	0.185
0.3	0.417
0.4	0.741
0.5	1.157

comparison LW $\leftrightarrow$ Astra

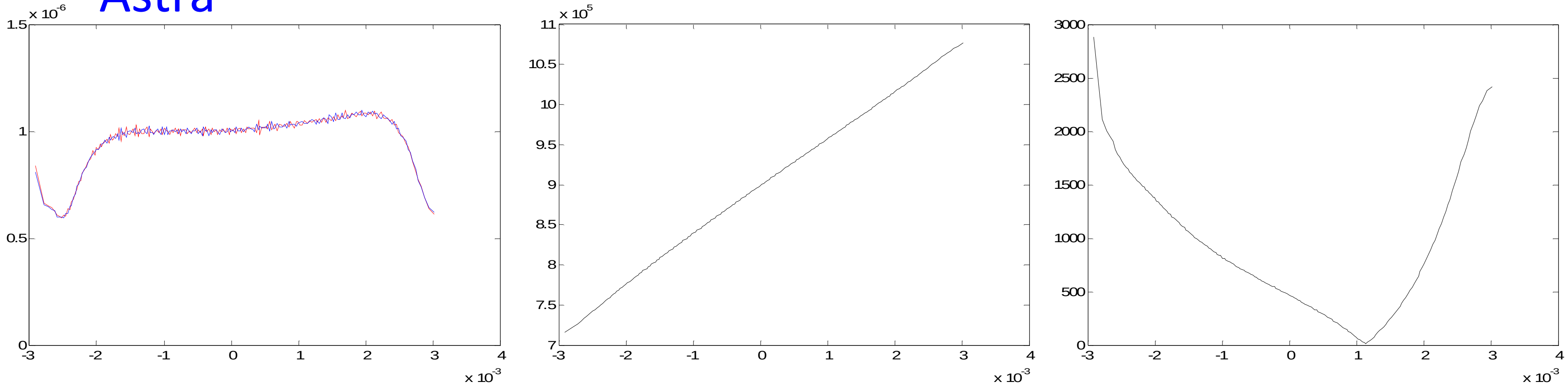
comparison LW ↔ Astra

rms laser spot size = 0.6 mm, slice properties

LW



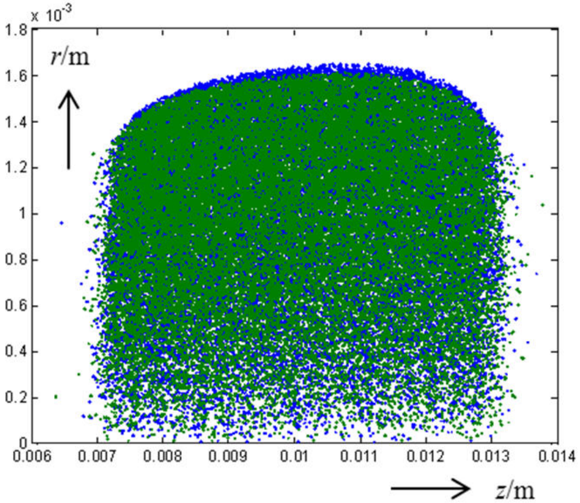
Astra

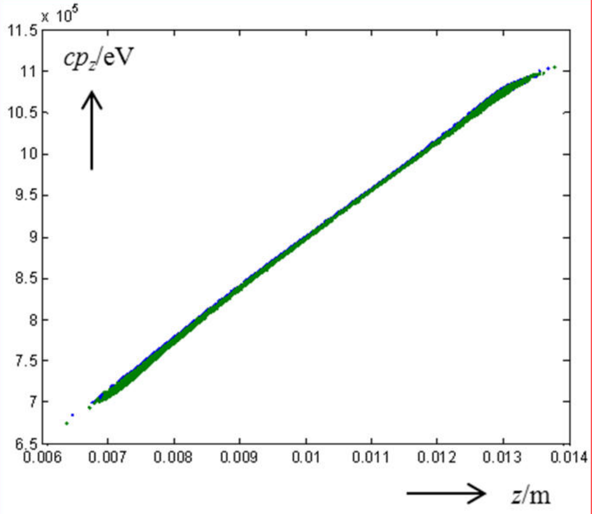


see also: s2e-seminar 2011-Feb-07
http://www.desy.de/xfel-beam/data/talks/files/2011_02_s2e_Gun_TEMF_Auswertung.pdf

comparison LW ↔ Astra

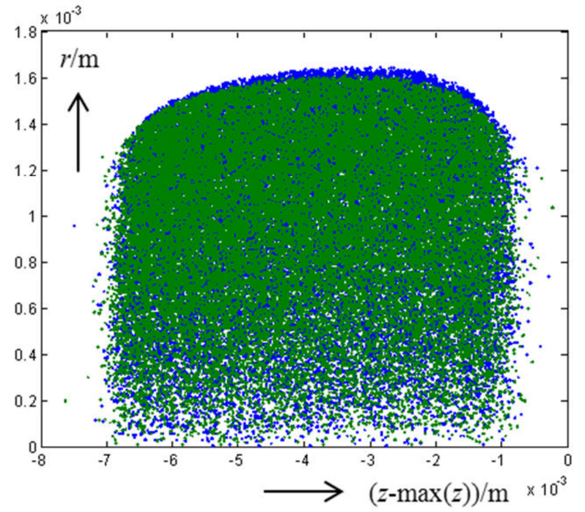
rms laser spot size = 0.6 mm

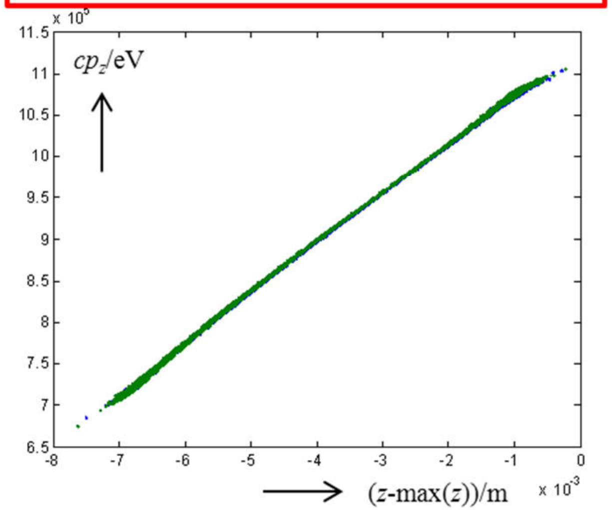


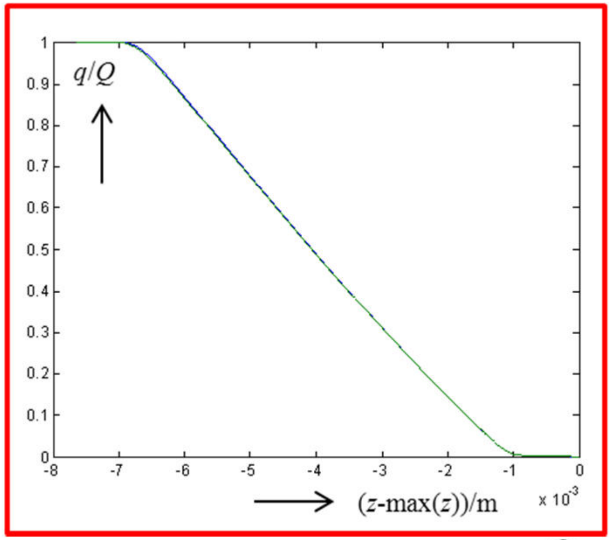


$$Q = \sum q_i$$

$$q(z) = \sum_{z < z_i} q_i$$

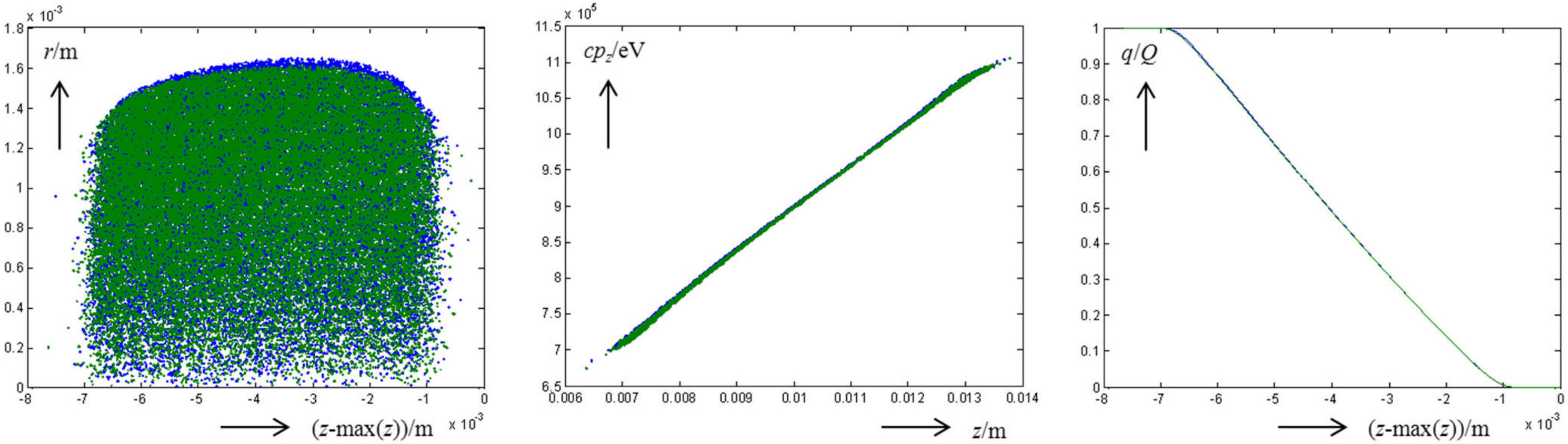






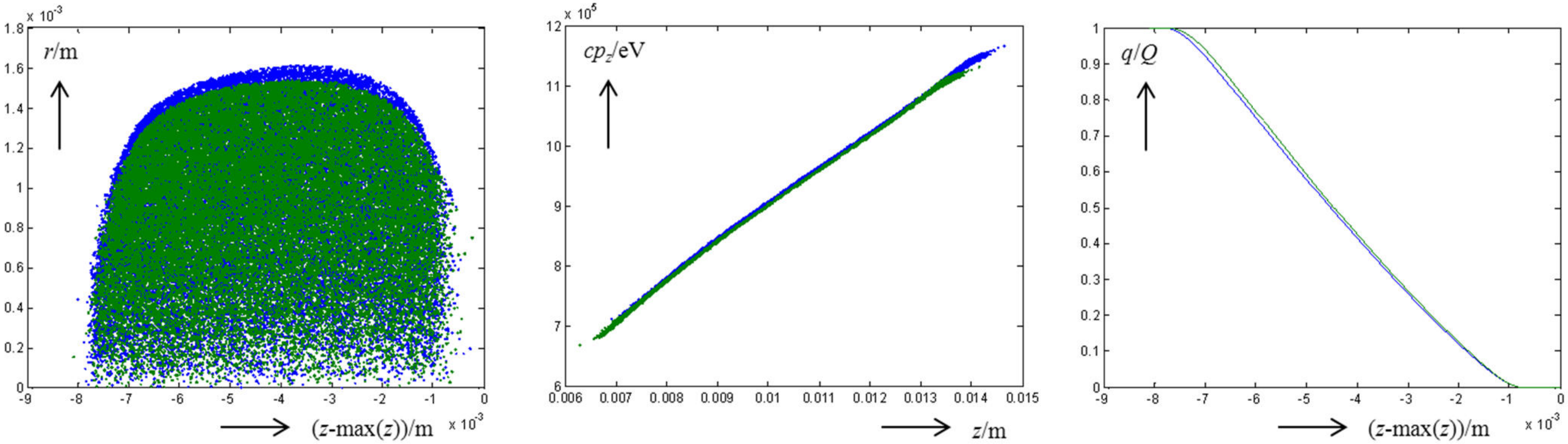
comparison LW ↔ Astra

rms laser spot size = 0.6 mm



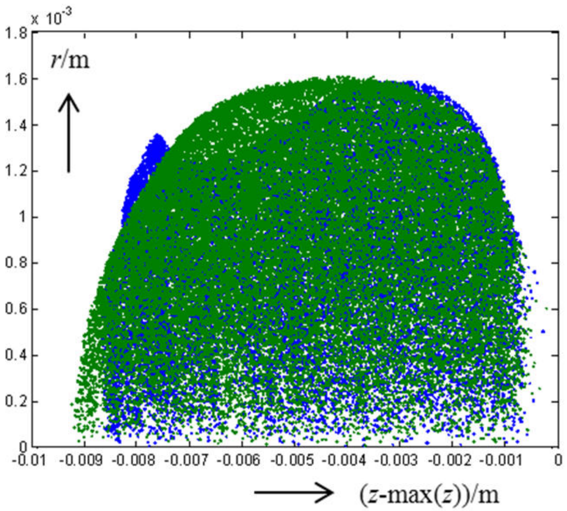
comparison LW ↔ Astra

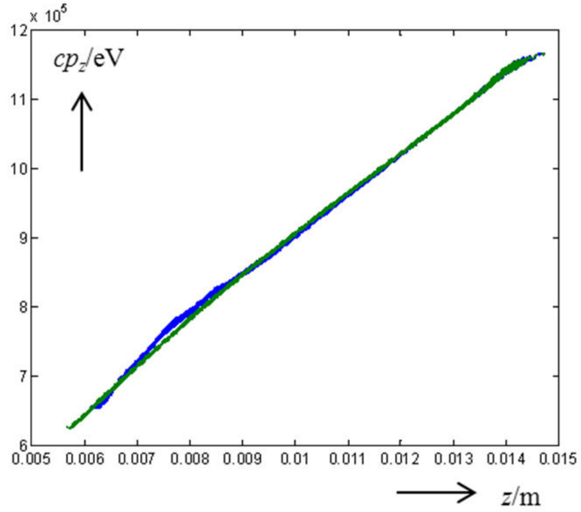
rms laser spot size = 0.4 mm

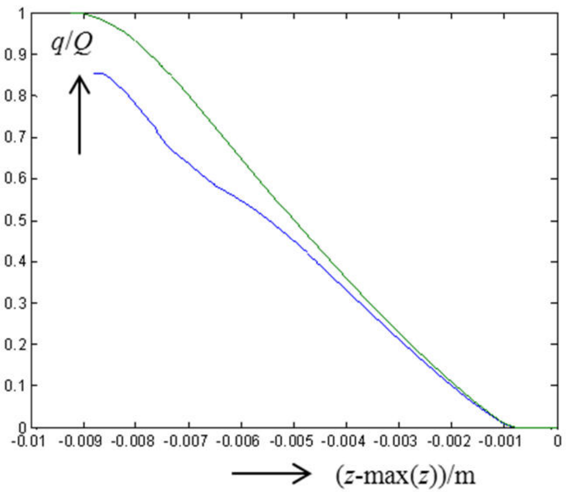


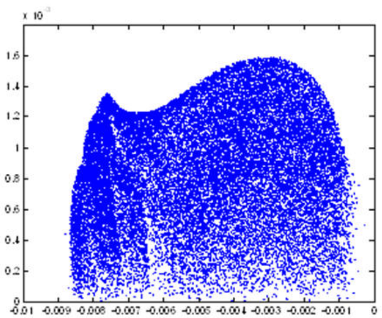
comparison LW ↔ Astra

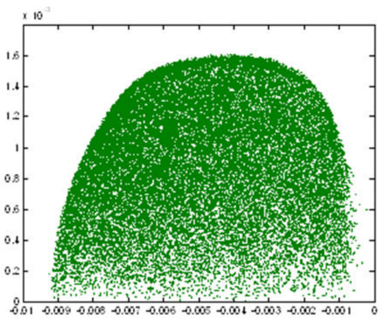
rms laser spot size = 0.3 mm





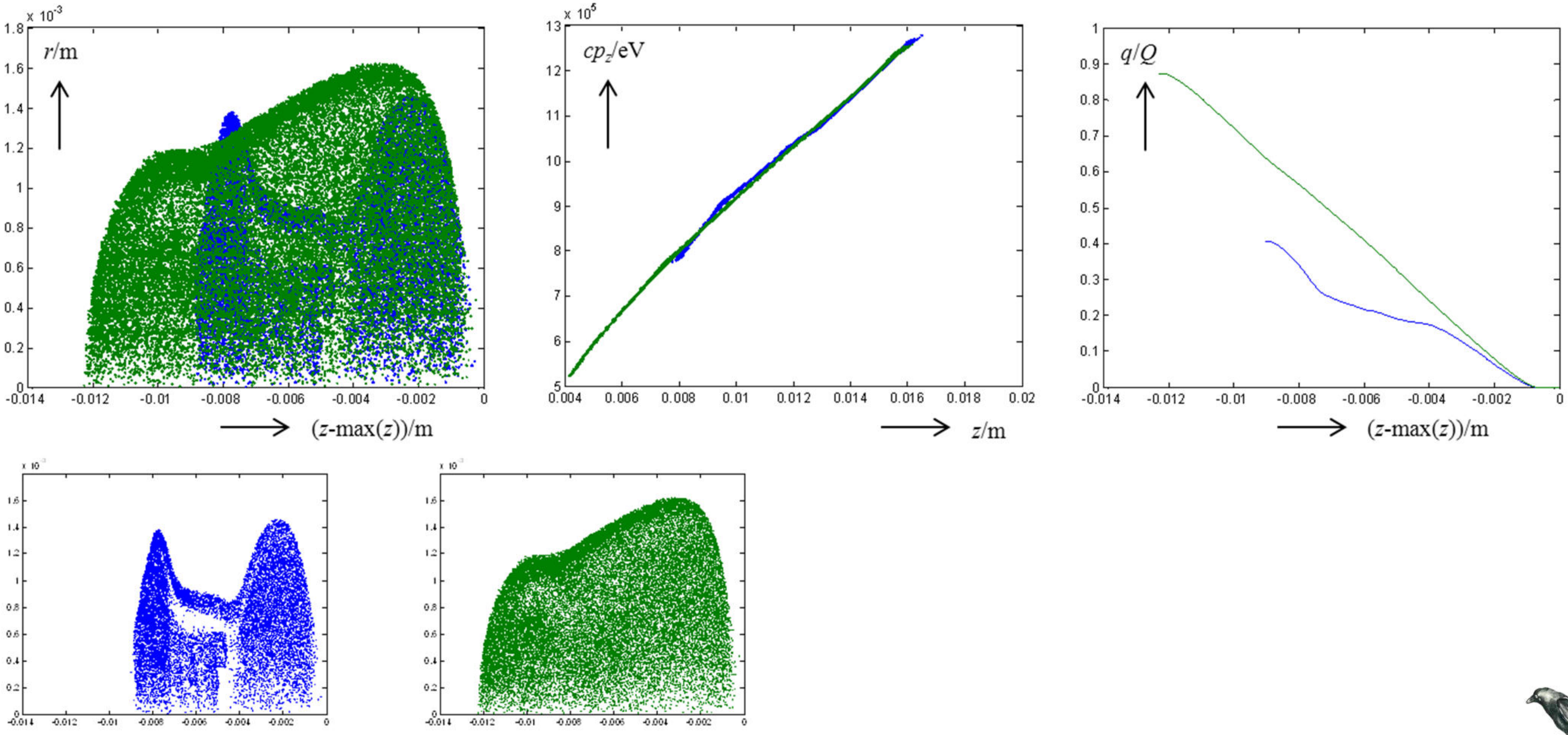






comparison LW ↔ Astra

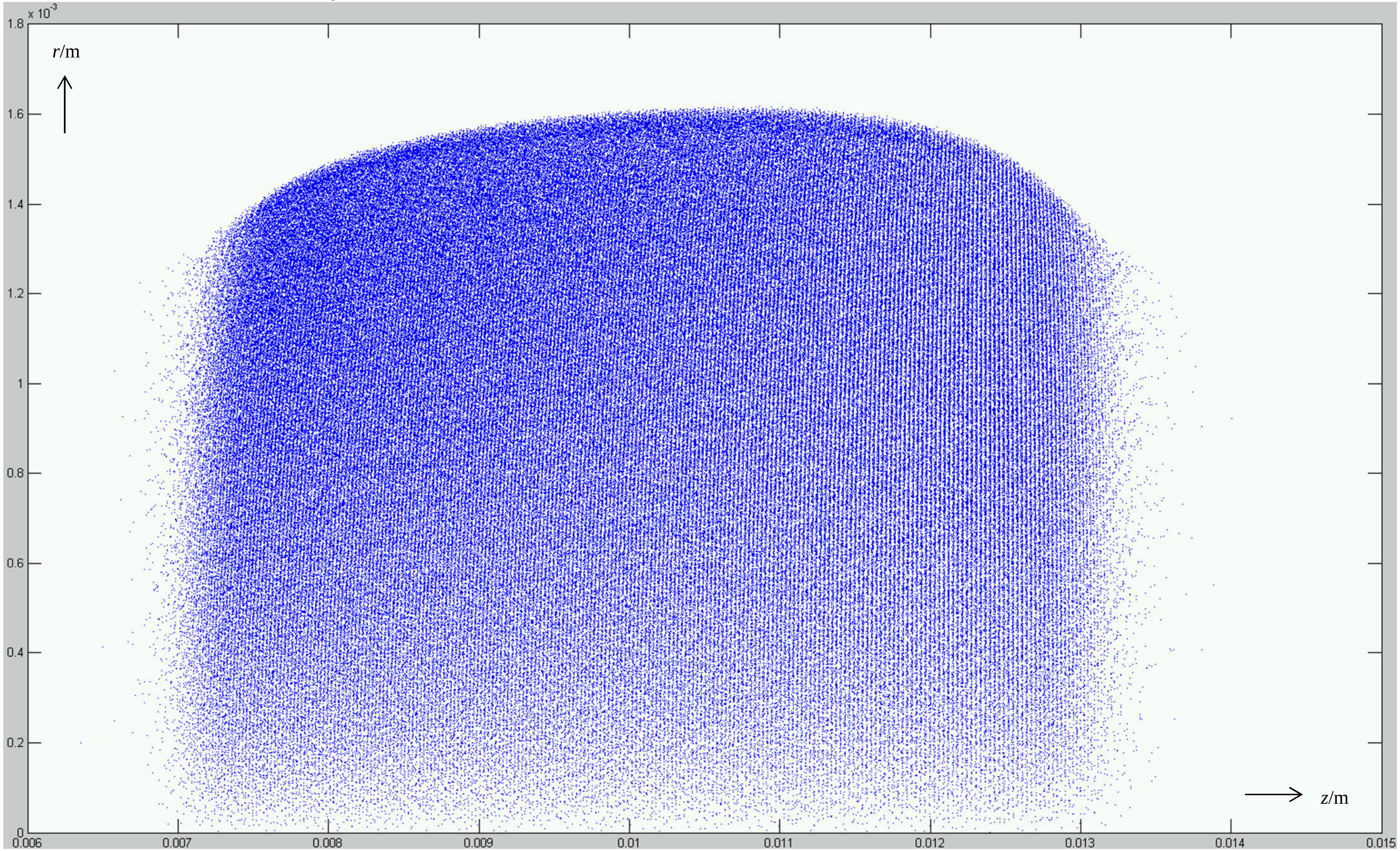
rms laser spot size = 0.2 mm



more analysis of LW results

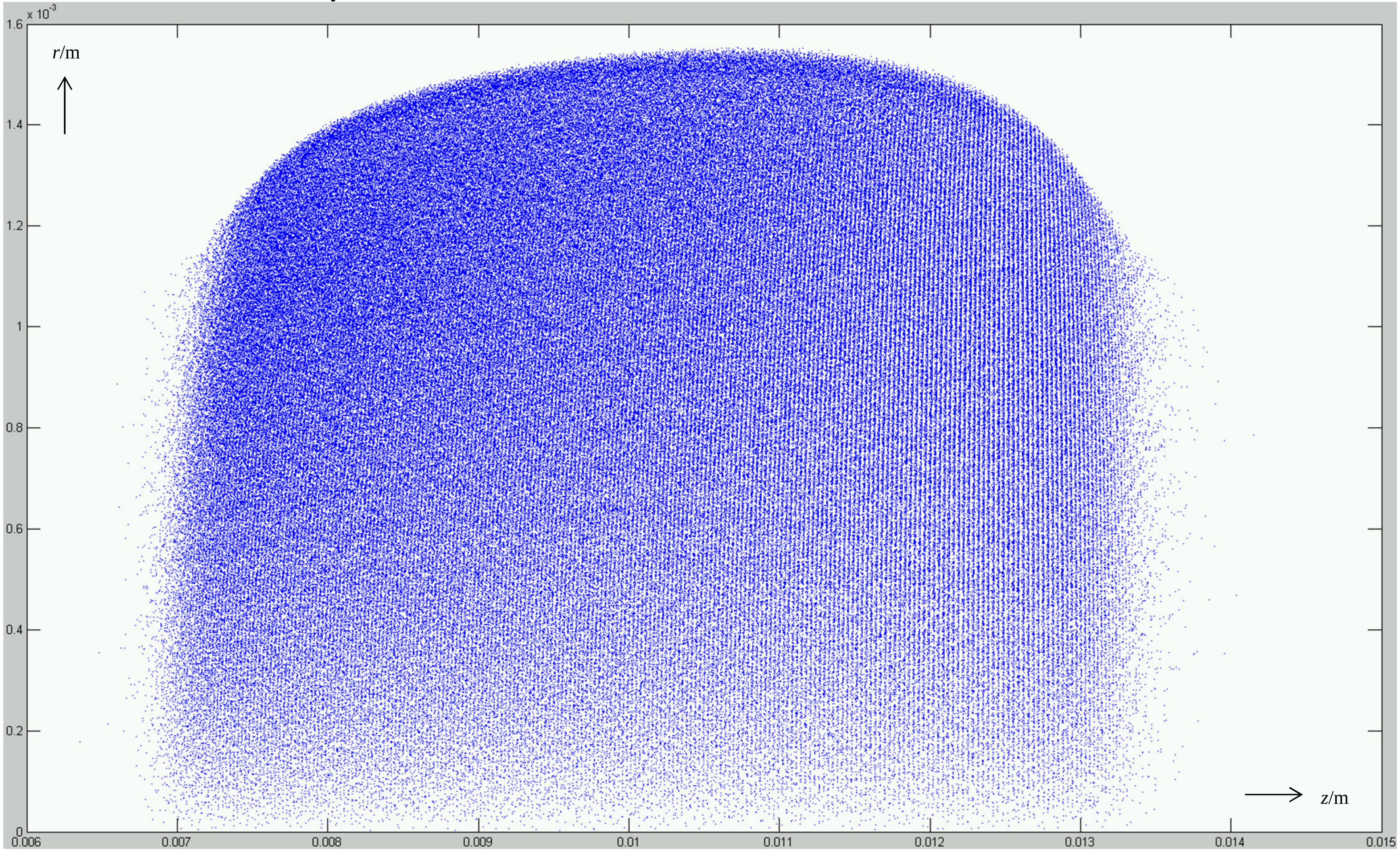
more analysis of LW results

rms laser spot size = 0.6 mm



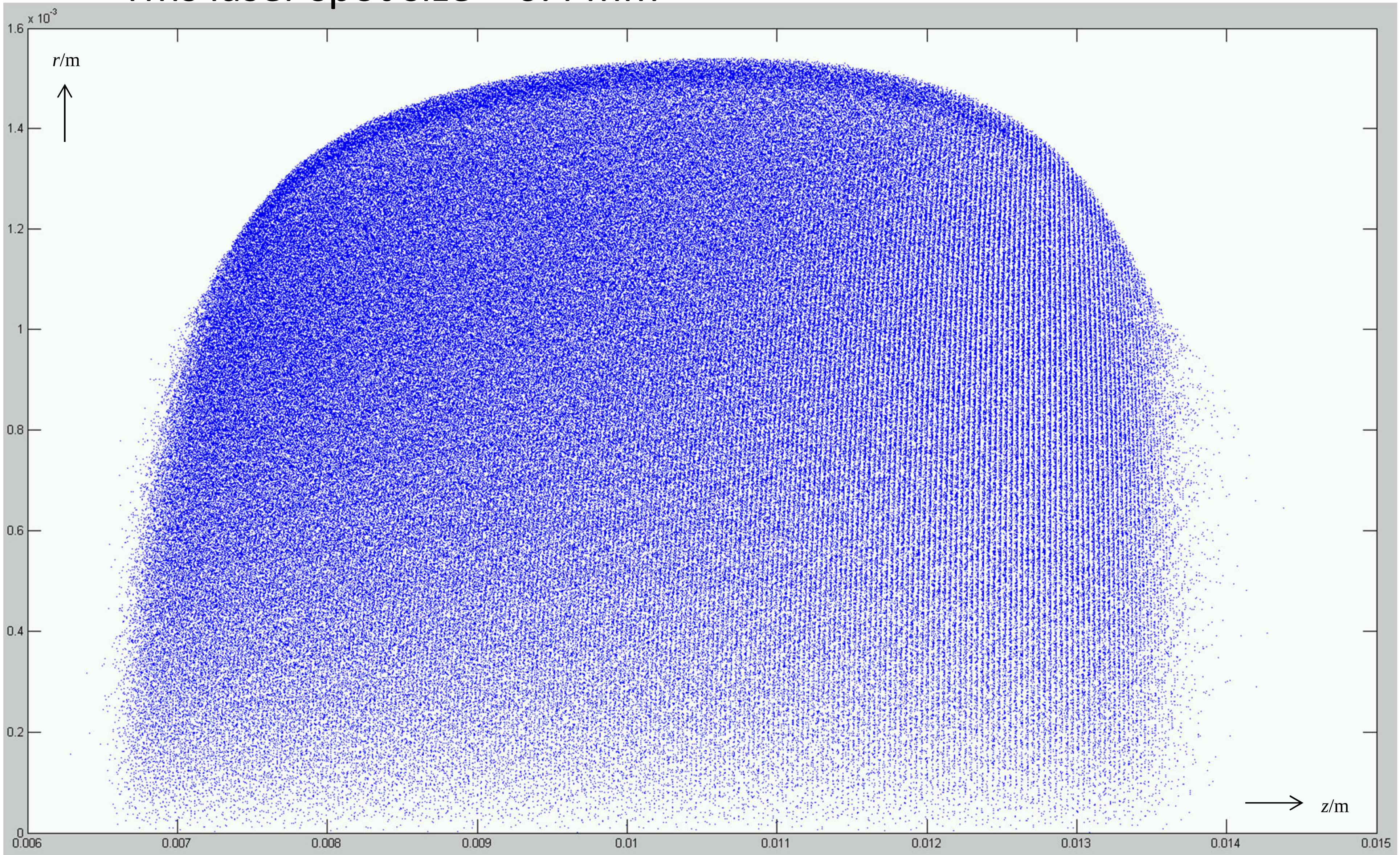
more analysis of LW results

rms laser spot size = 0.5 mm



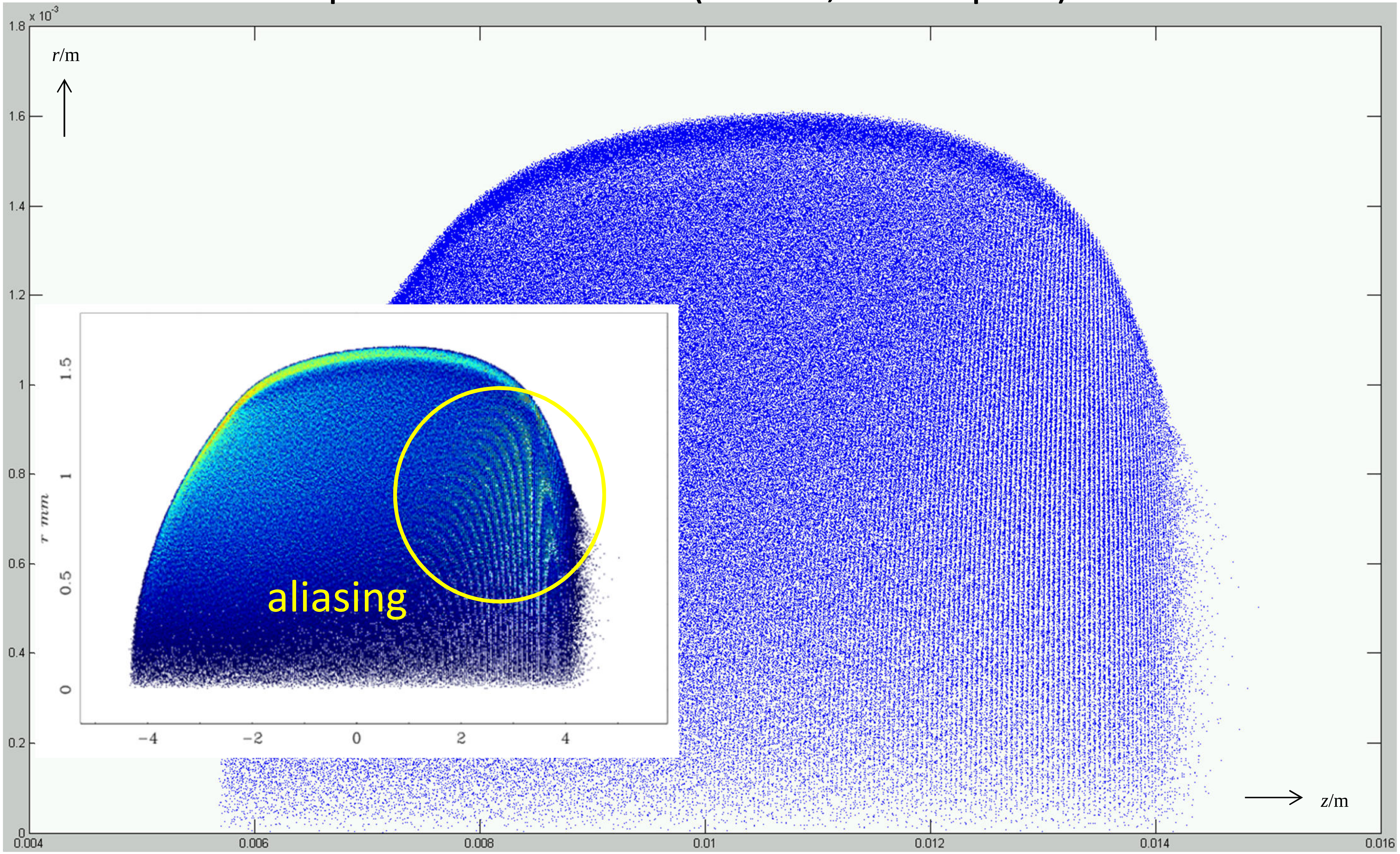
more analysis of LW results

rms laser spot size = 0.4 mm



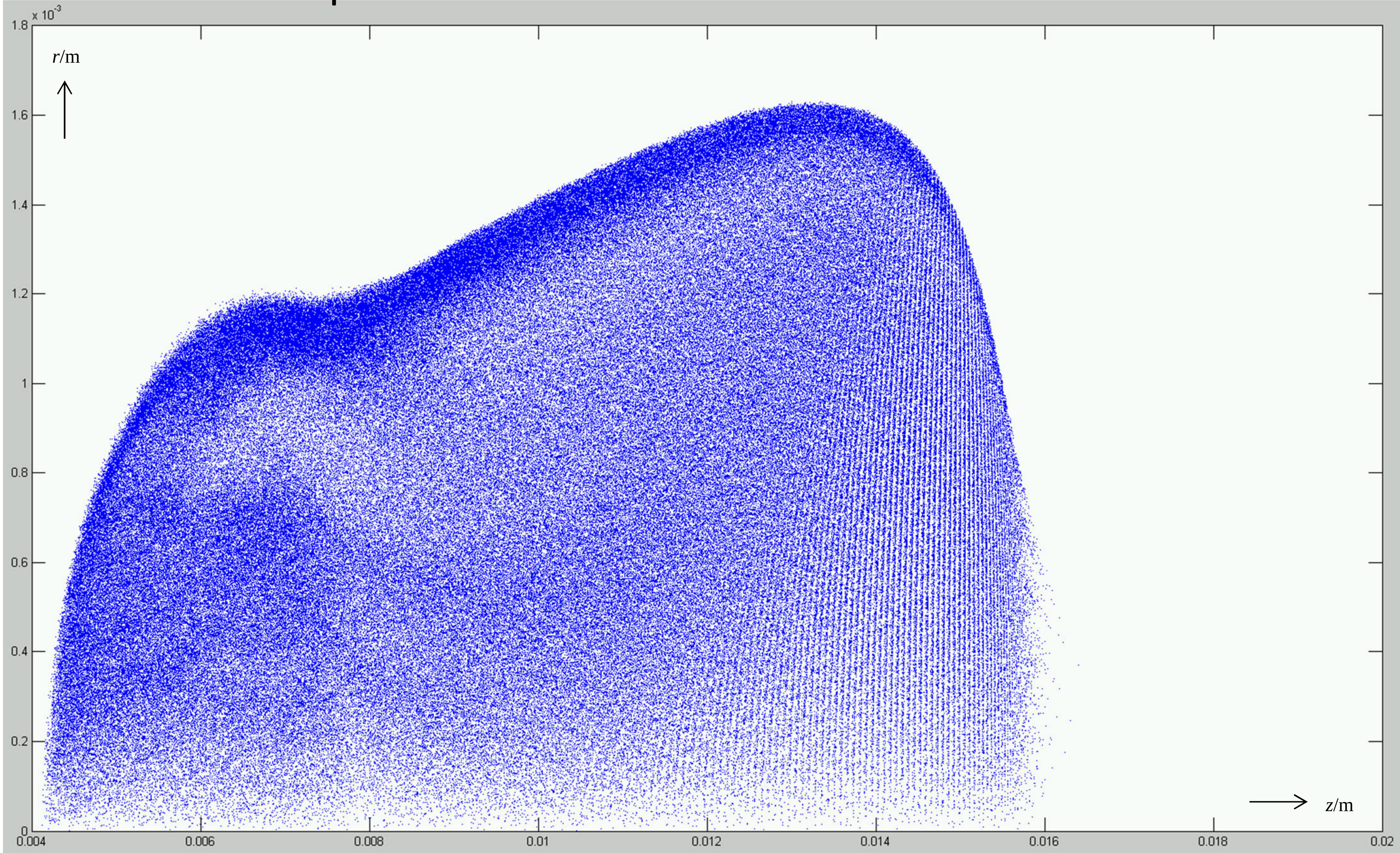
more analysis of LW results

rms laser spot size = 0.3 mm   (0.5MP; dt=0.1psec)



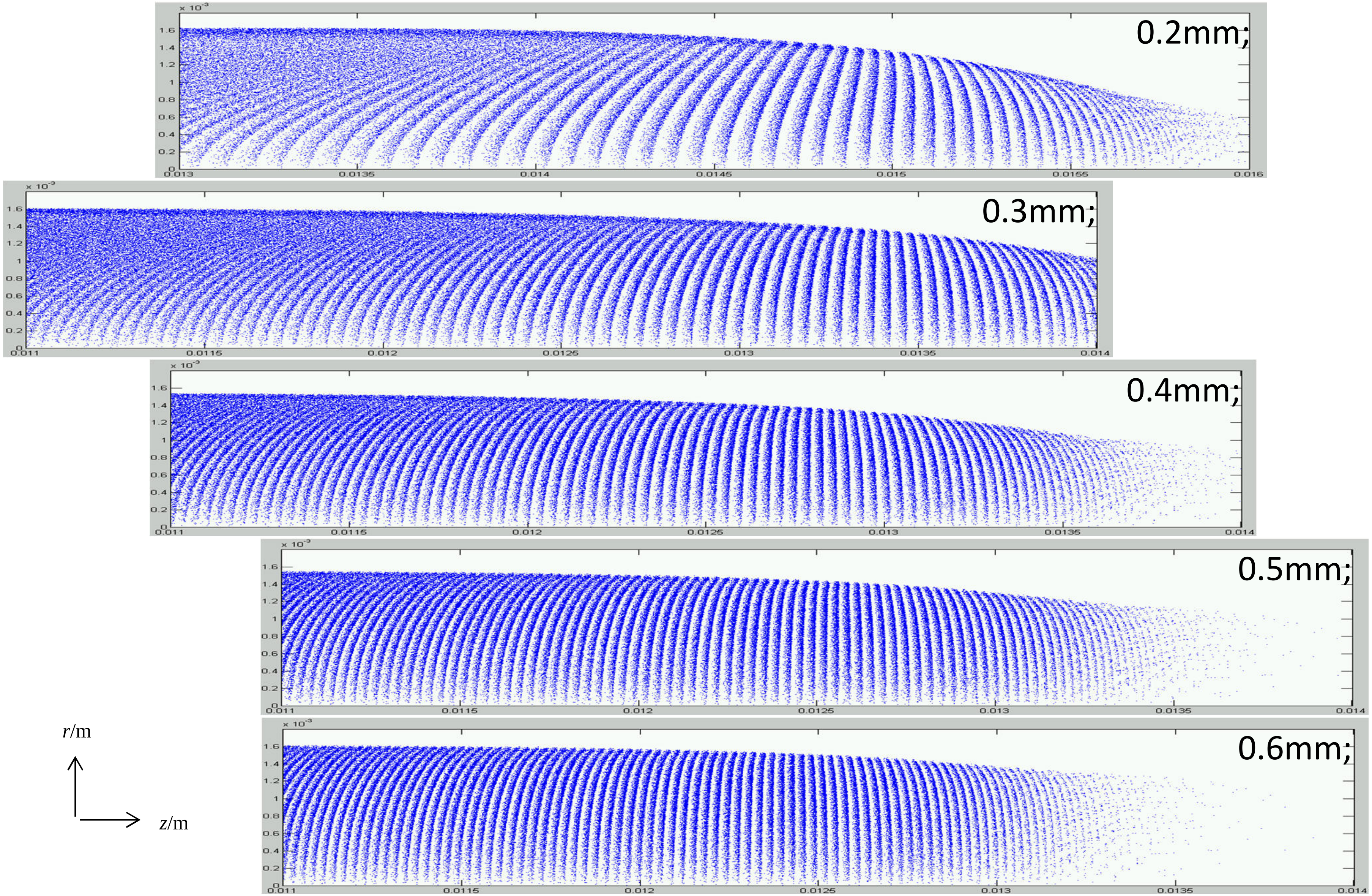
more analysis of LW results

rms laser spot size = 0.2 mm



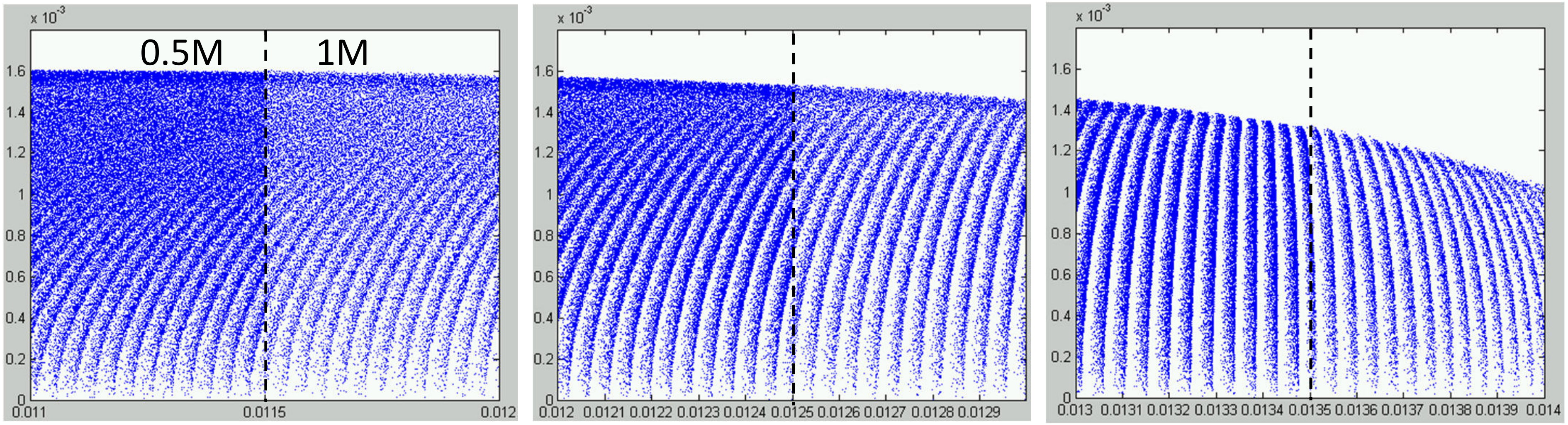
more analysis of LW results

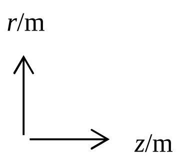
micro modulation



more analysis of LW results

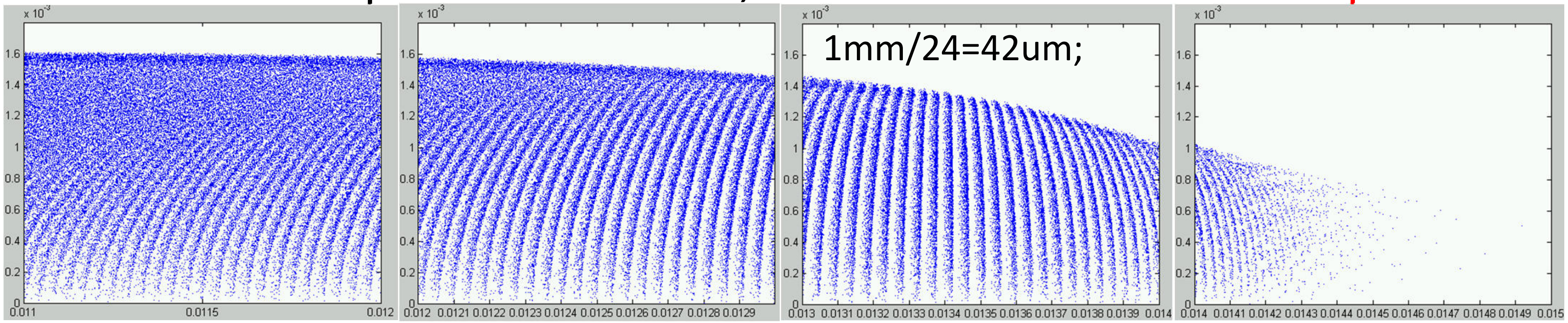
rms laser spot size = 0.3 mm
simulation with more particles





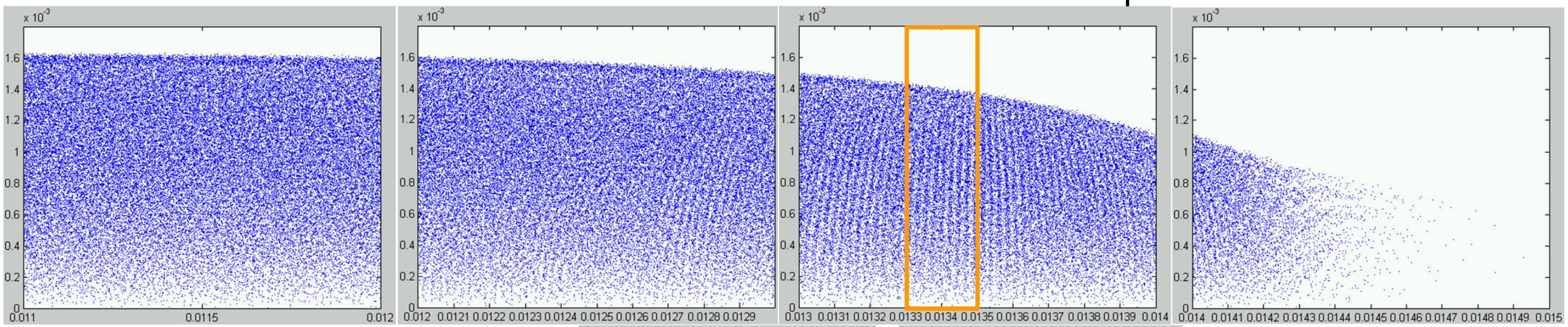
more analysis of LW results

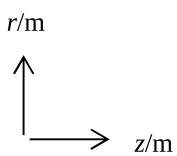
rms laser spot size = 0.3 mm; calc. with different time step

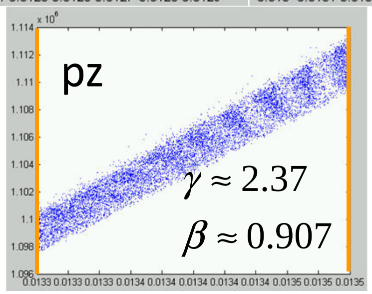


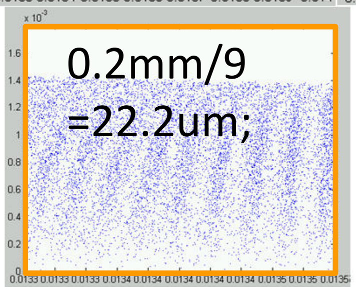
dt = 0.10 psec

dt = 0.05 psec



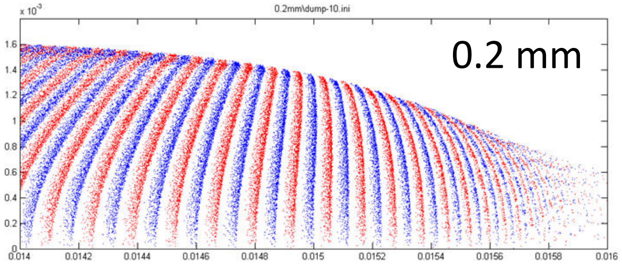




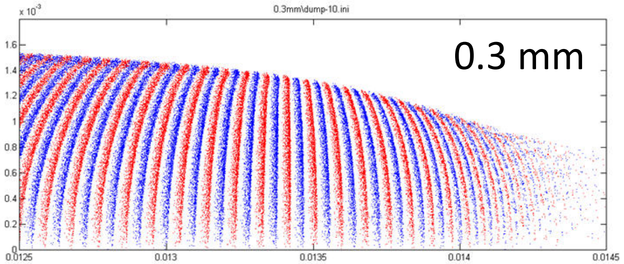


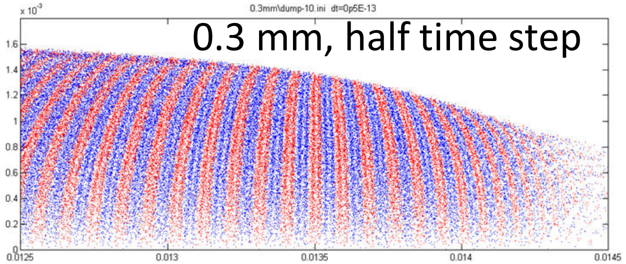
$v \cdot \delta t = 14\ \mu\mathrm{m}$

more analysis of LW results



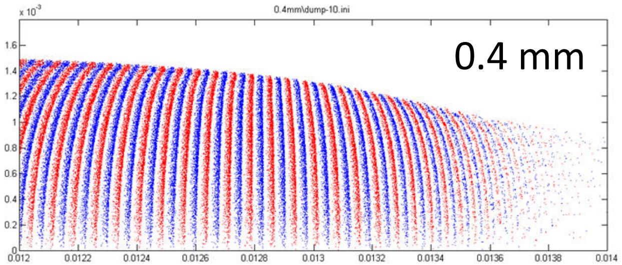
← this bunch needs more compression !



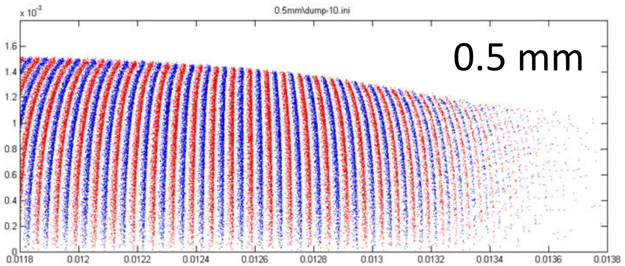


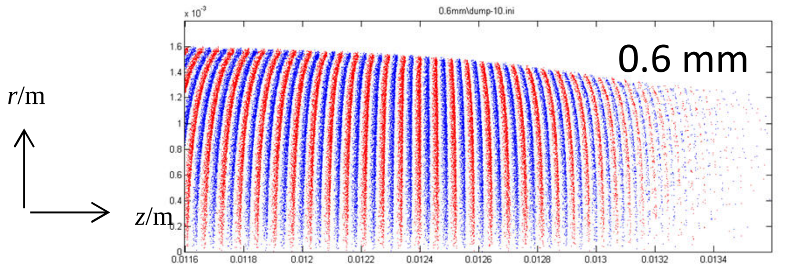
↑ dt = 0.05 psec

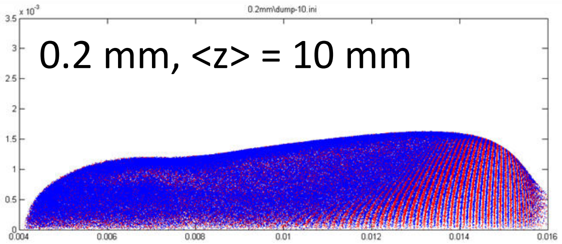
← dt = 0.10 psec



“micro bunching” vs. injection time
color frequency = 2x 0.1psec

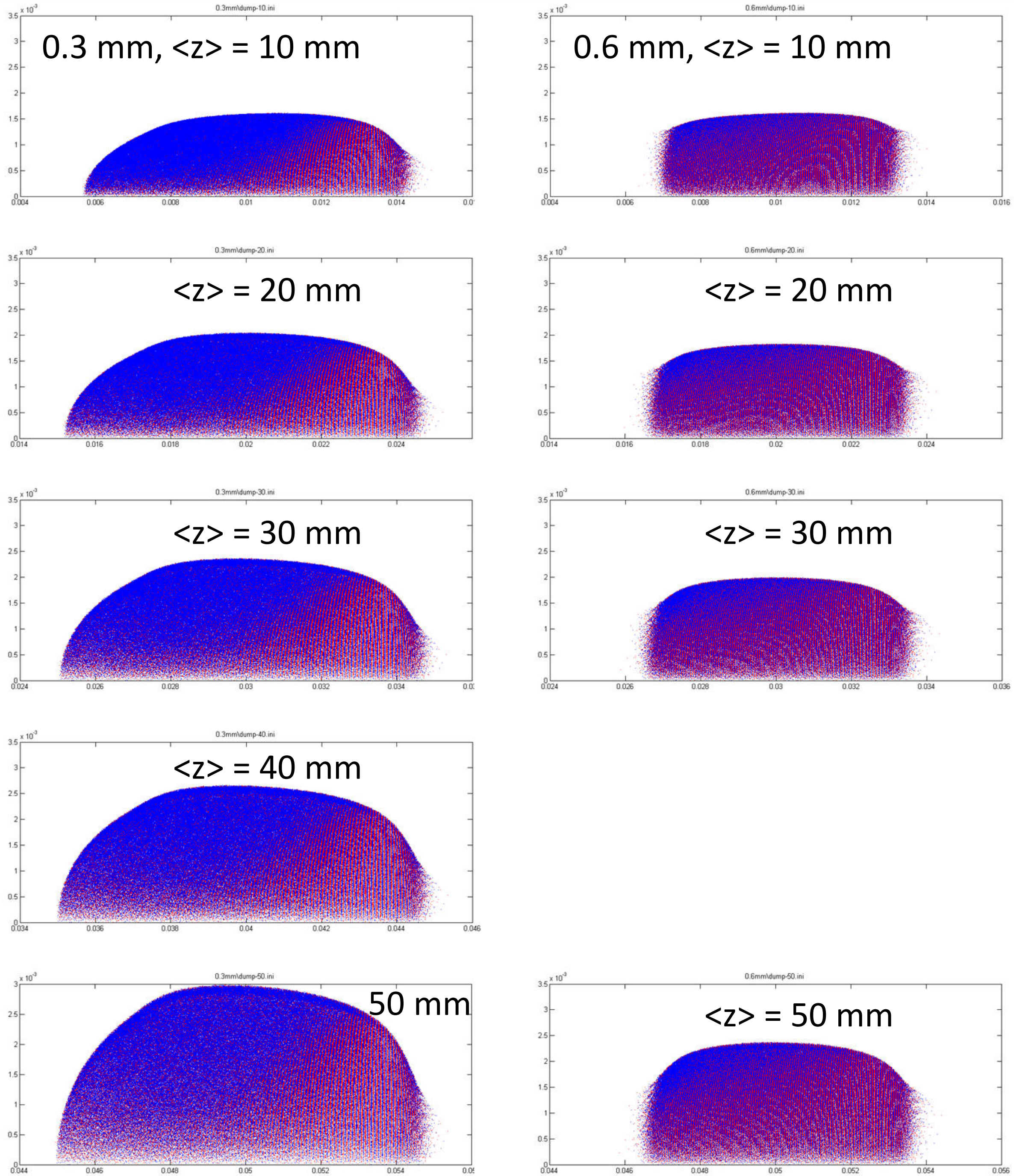


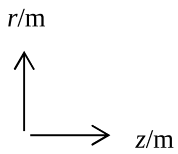




more analysis of LW results

different longitudinal position

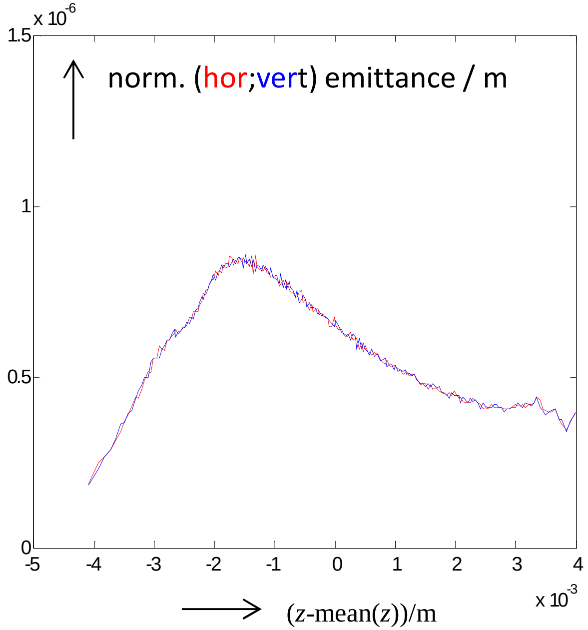


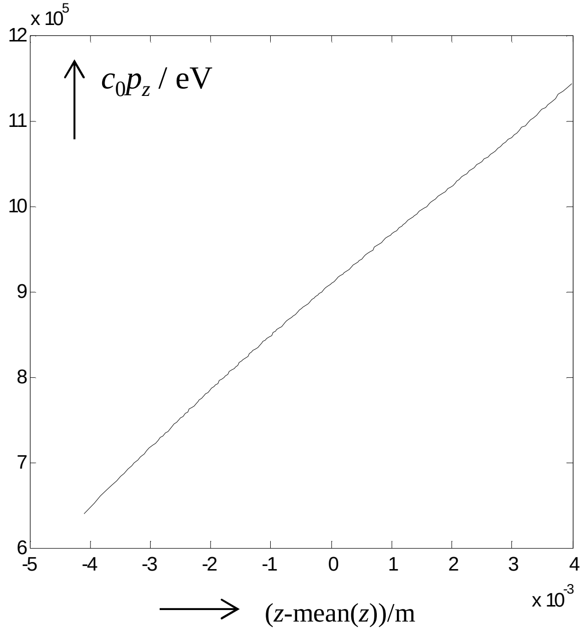


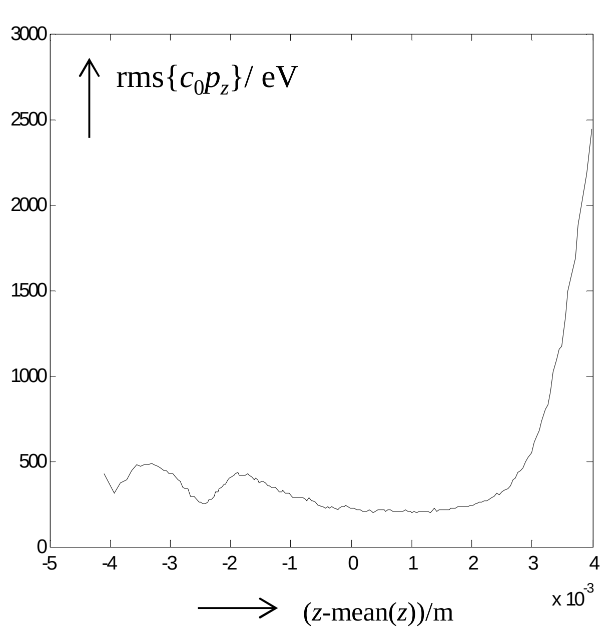
more analysis of LW results

rms laser spot size = 0.3 mm; slice properties

500k, 0.1psec



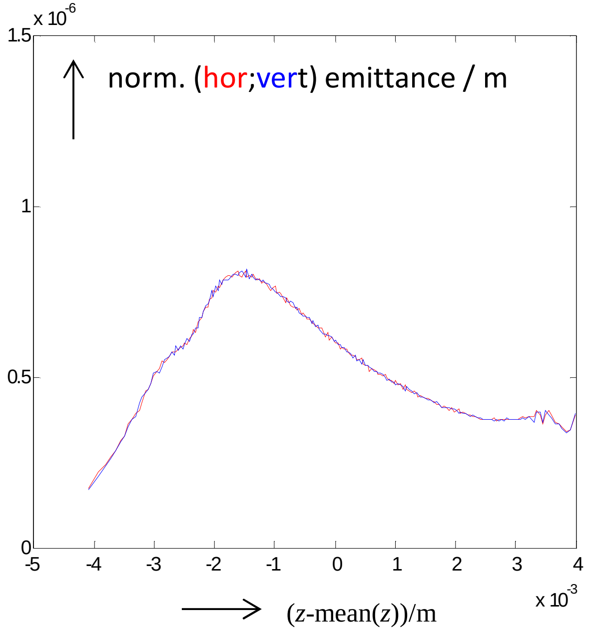


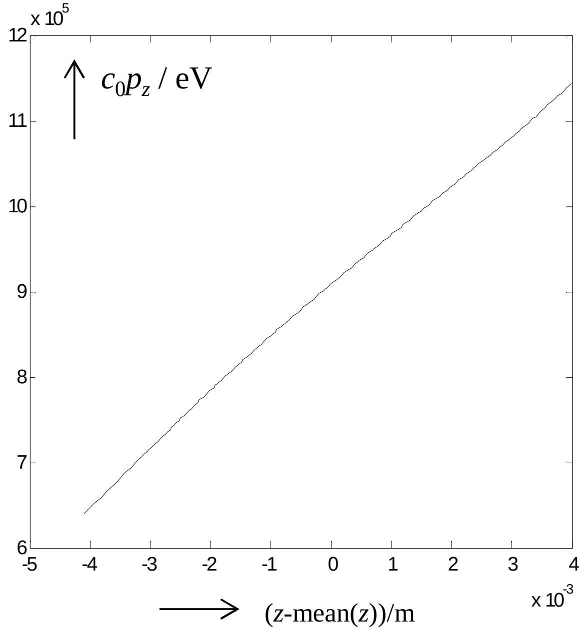


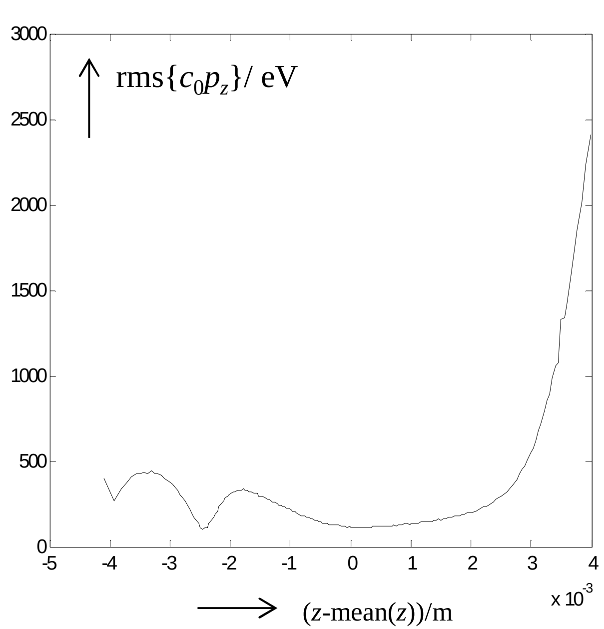
more analysis of LW results

rms laser spot size = 0.3 mm; slice properties

1M, 0.1psec



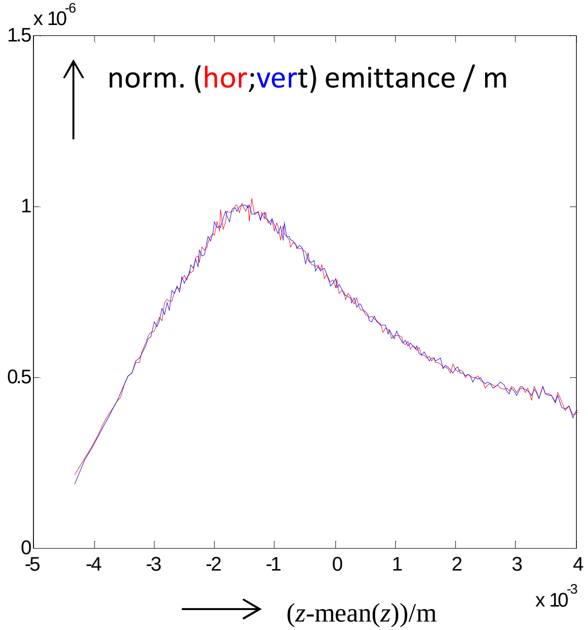


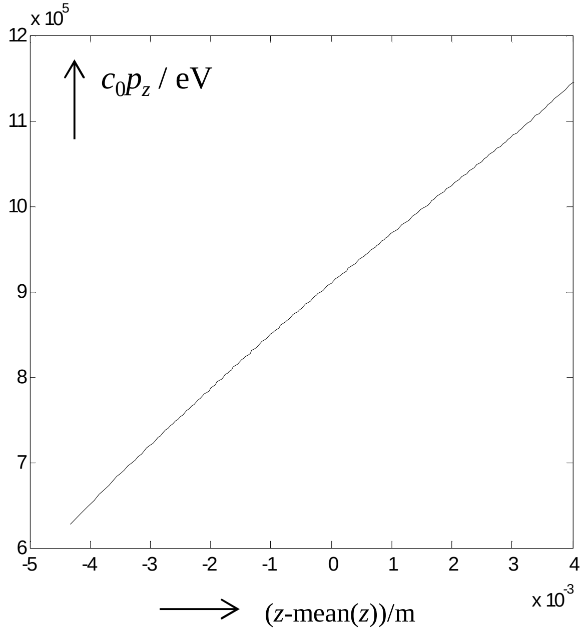


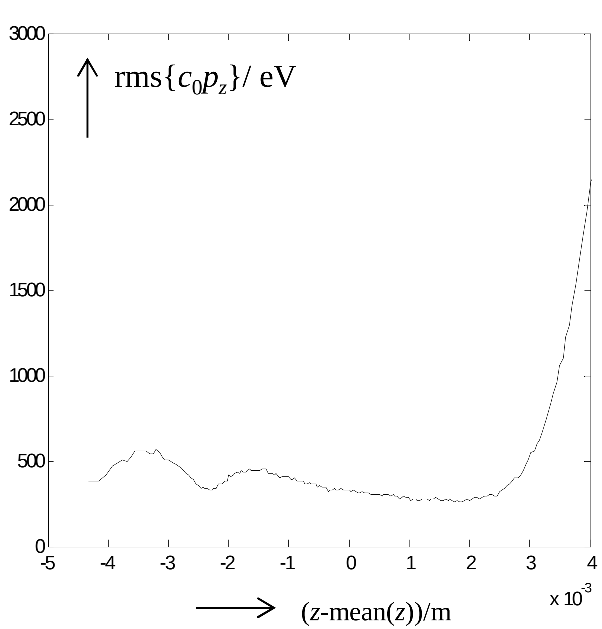
more analysis of LW results

rms laser spot size = 0.3 mm; slice properties

500k, 0.05psec







about Astra results

about Astra results: sensitivity to numerical parameters

rms laser spot size = 0.6 mm
no SC limitation

is it possible to provoke numerical microbunching?
(fine mesh, big time step)

no: Astra is too clever; during emission it does not use the user defined time step

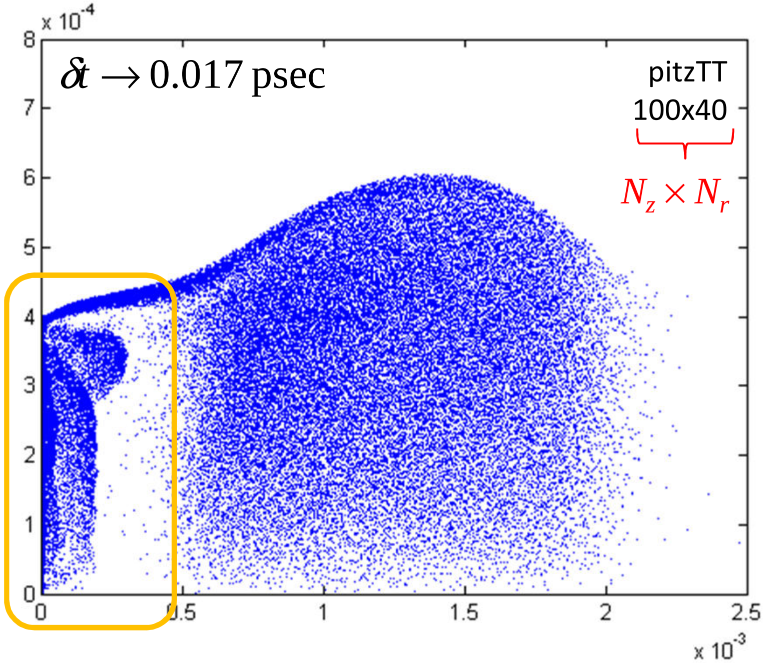
---

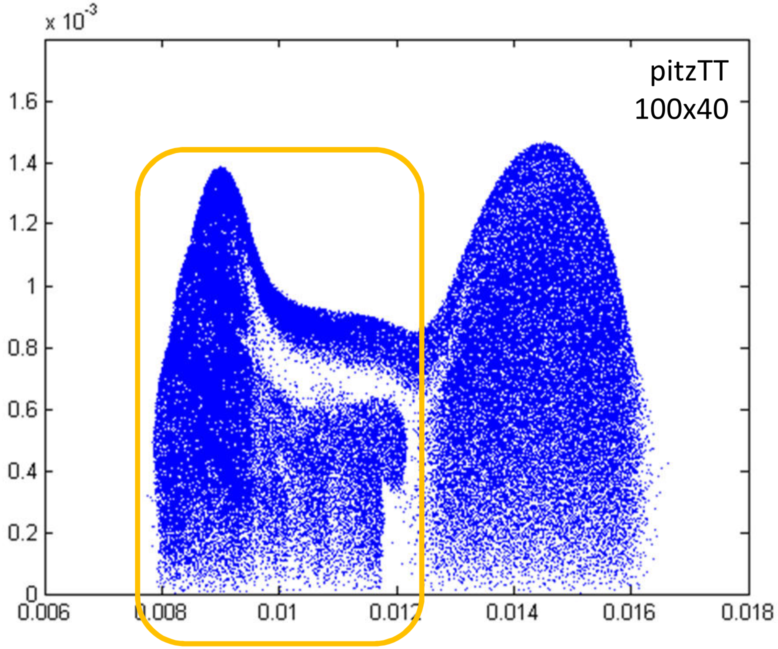
rms laser spot size = 0.2 mm
strong SC limitation: late emission is pulsing

Hammersley ↔ random
mesh lines
time step

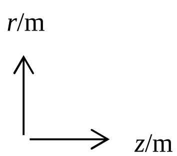
about Astra results: sensitivity to numerical parameters

rms laser spot size = 0.2 mm
strong SC limitation: late emission is pulsing





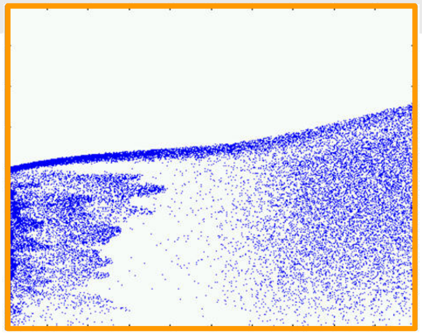
emitted particles 40.5%

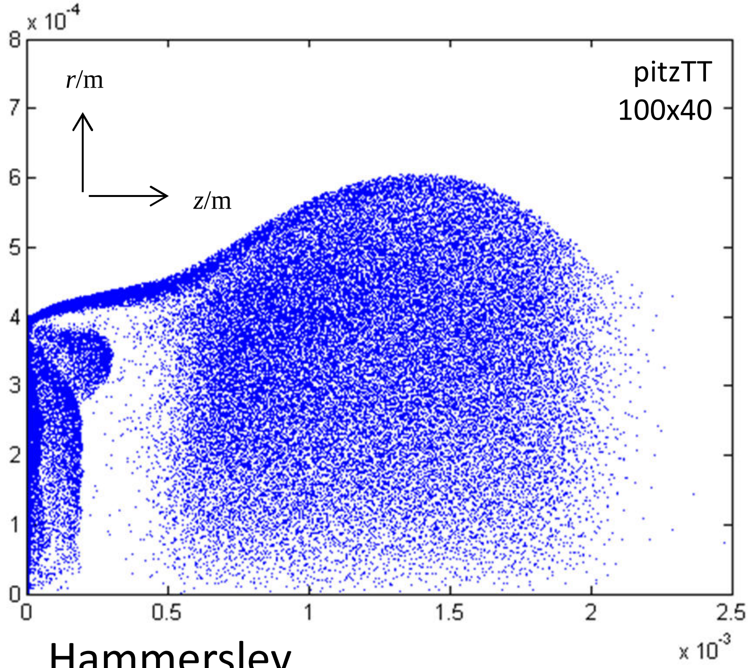


about Astra results: sensitivity to numerical parameters

rms laser spot size = 0.2 mm

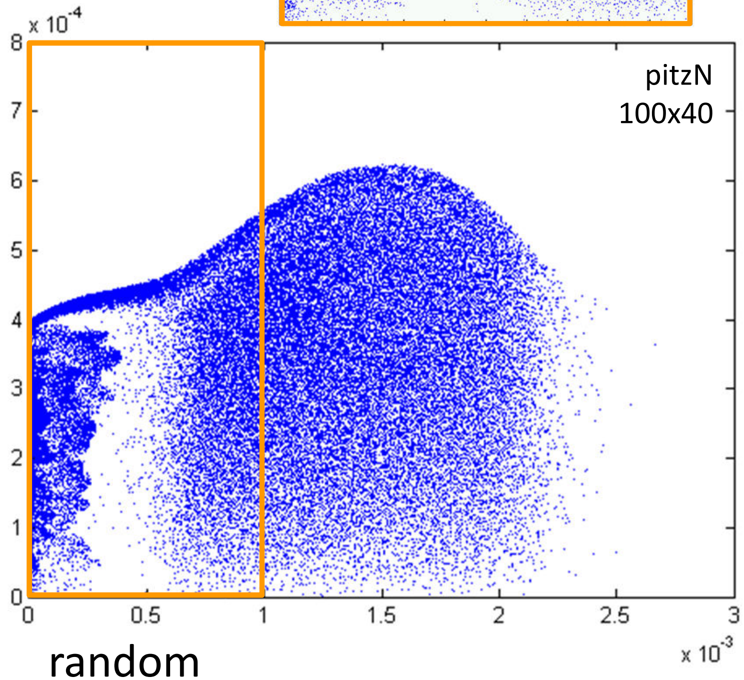
strong SC limitation: late emission is pulsing





Hammersley

emitted particles 40.5%



random

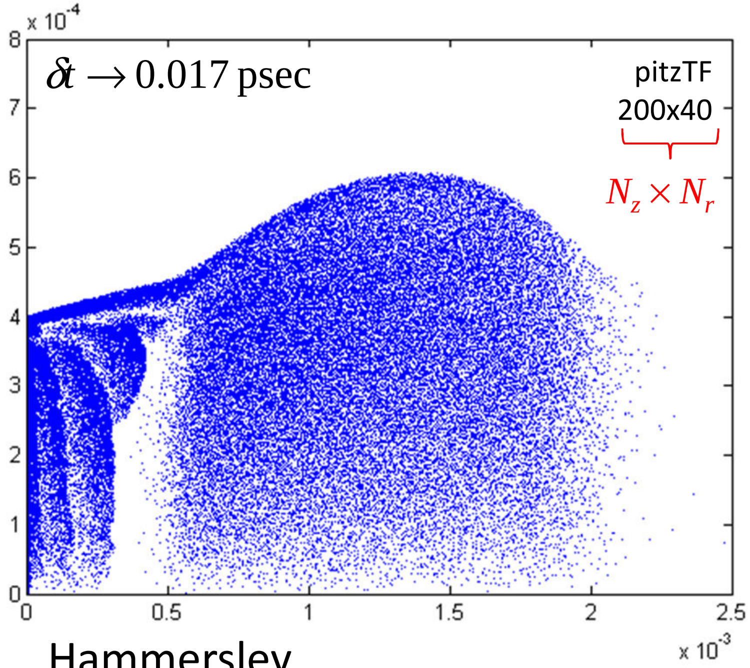
emitted particles 40.5%

pulsing (multiple fronts) is no artifact of pseudo random gen.

about Astra results: sensitivity to numerical parameters

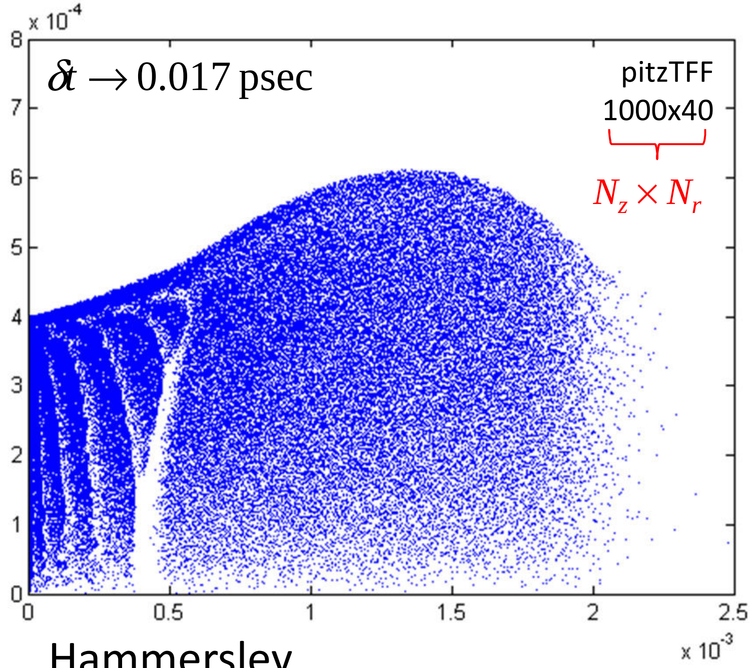
rms laser spot size = 0.2 mm

strong SC limitation: late emission is pulsing



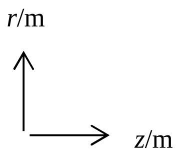
Hammersley

emitted particles 41.9%



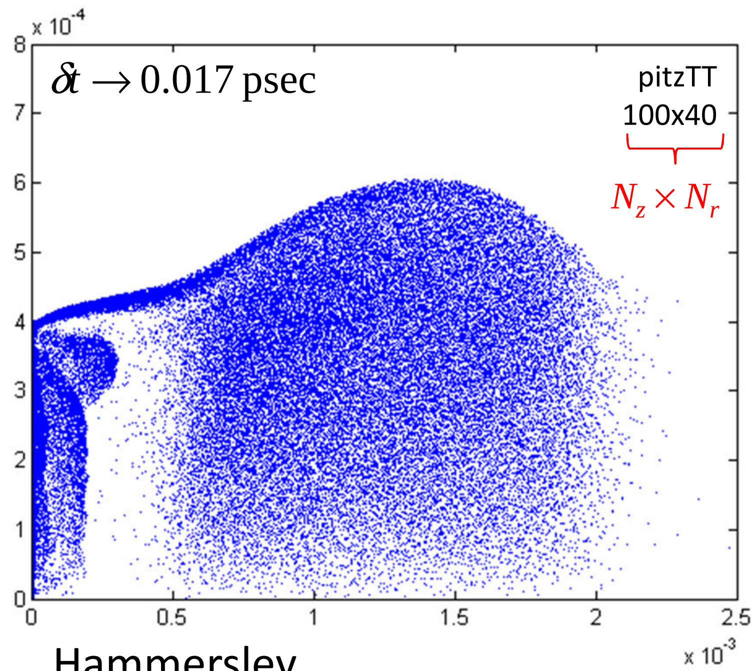
Hammersley

emitted particles 45.4%

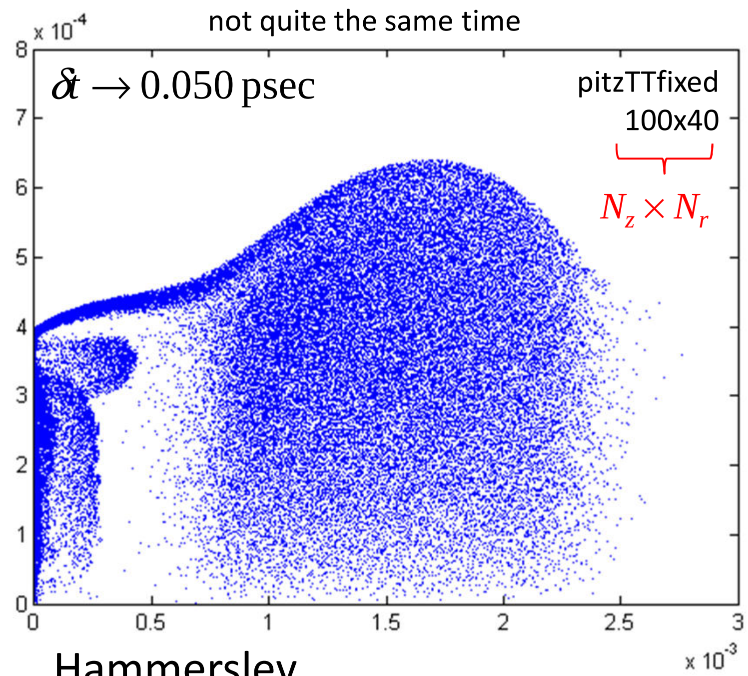


about Astra results: sensitivity to numerical parameters

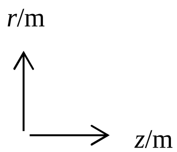
rms laser spot size = 0.2 mm
strong SC limitation: late emission is pulsing



Hammersley
emitted particles 40.5%



Hammersley
emitted particles 39.1%



about Astra results: sensitivity to numerical parameters

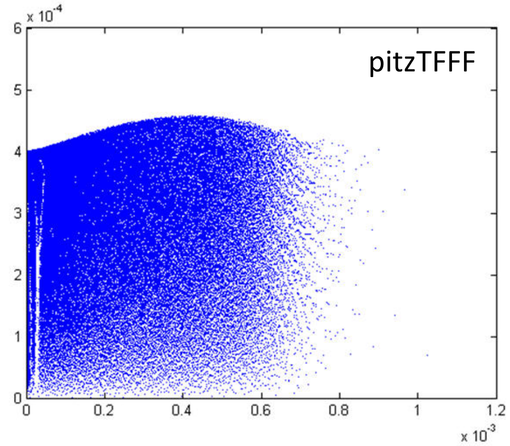
rms laser spot size = 0.2 mm

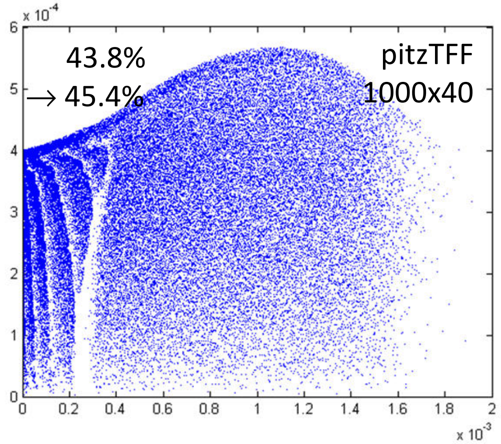
strong SC limitation: late emission is pulsing

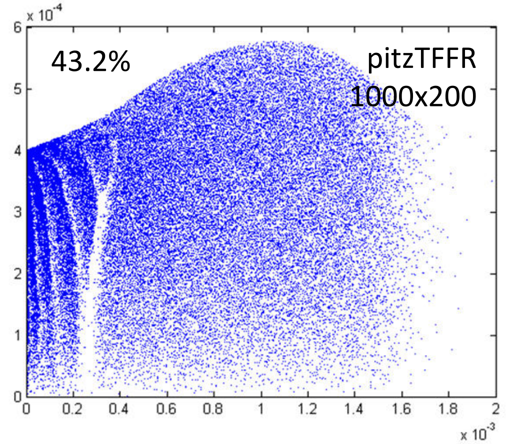
still running: pitzTFFF, 10000x40

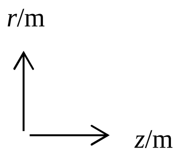
pitzTFFR, 1000x200

$\delta t \rightarrow 0.017$ psec



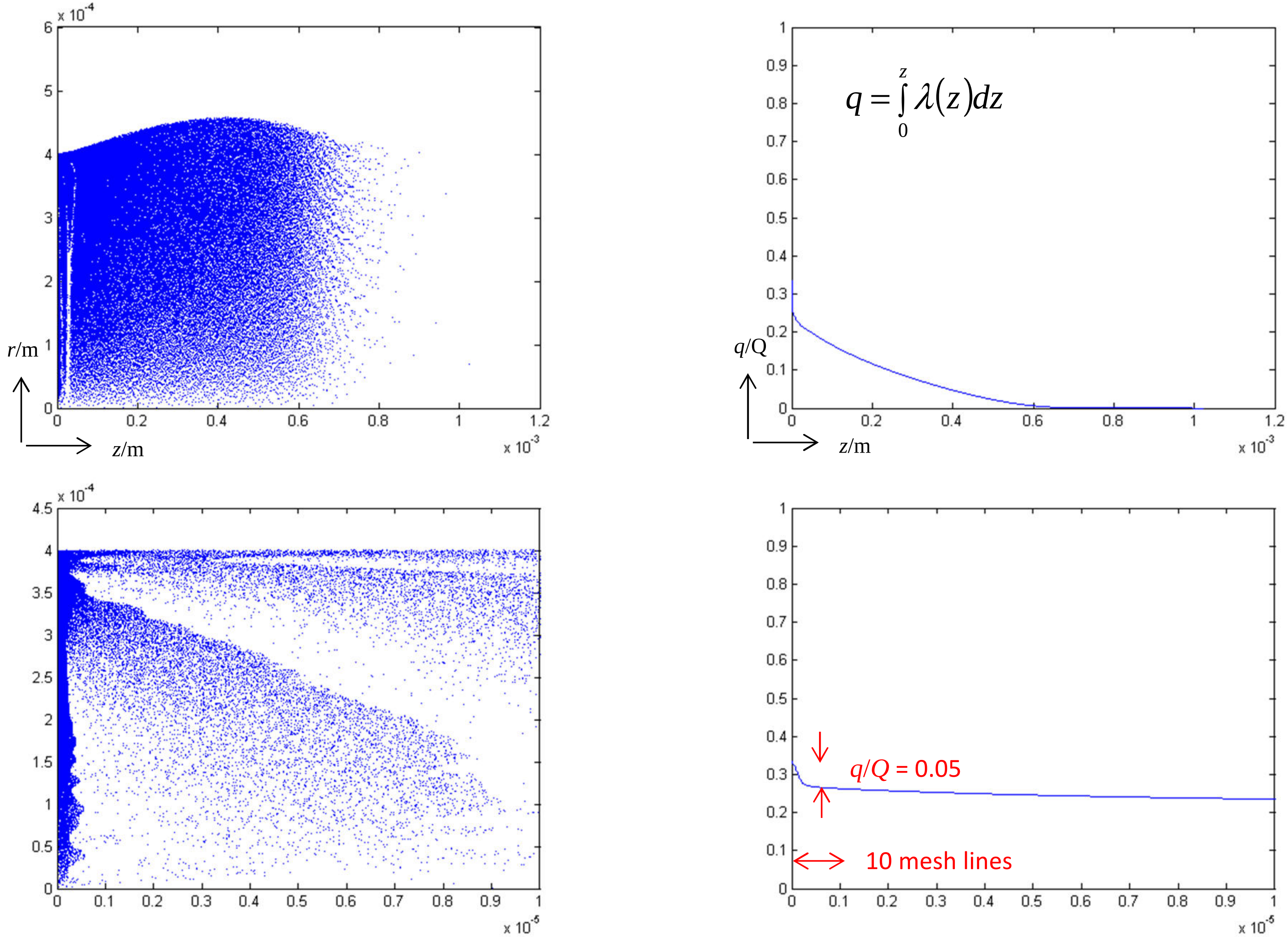






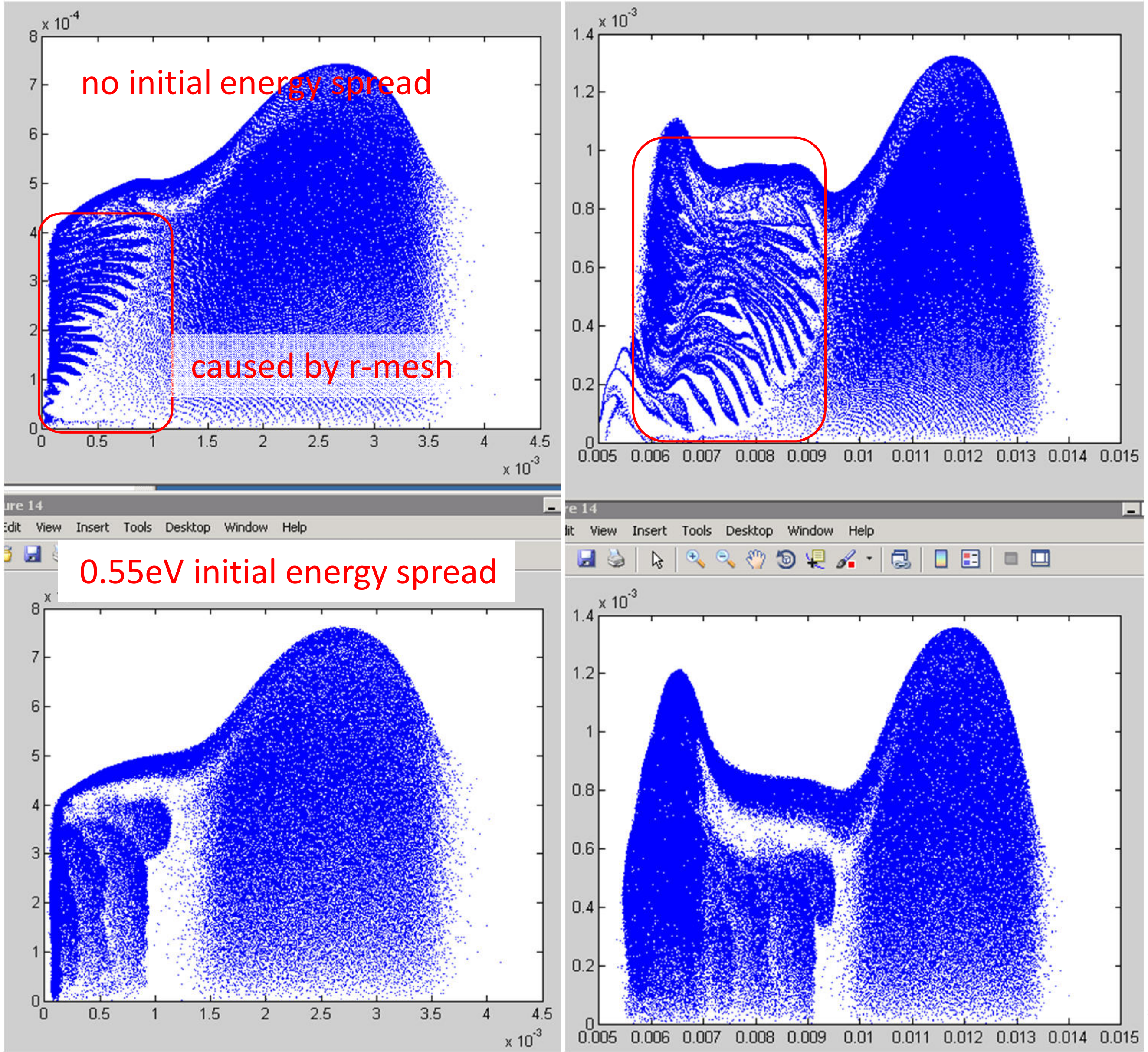
about Astra results: sensitivity to numerical parameters

pitzTFFF 10000x40



about Astra results: sensitivity to numerical parameters

result is extremely sensitive on
initial conditions
and
both mesh settings



about approaches

about approaches: some analytical calculations

the planar diode

exact solution of Maxwell problem

$$\frac{\partial E_z(z,t)}{\partial z} = \frac{1}{\varepsilon_0} \lambda(z,t)$$

no explicit appearance of retarded time

exact solution of EoM

$$z_\nu(t) = \frac{qE_\nu}{\mathcal{E}_0} \left(\sqrt{1 + \left(\frac{\mathcal{E}_0}{qE_\nu} c(t - t_\nu) \right)^2} - 1 \right)$$

with ν = slice index,
t_ν = ejection time of slice ν,
$E_\nu = E_z(0, t_\nu)$,
$E_z(0,0) = E_{\mathrm{acc}}$ external field

---

a three dimensional driven problem

$$\rho(r,z,t) = \frac{\lambda(z,t)}{\pi R^2} \begin{cases} 1 & \text{if} \quad r < R \\ 0 & \text{otherwise} \end{cases}$$

in the following: three different approaches to calculate $\mathbf{E}(\mathbf{r},t)$
comparison for $E_z(z,t) = \mathbf{e}_z \cdot \mathbf{E}(z\mathbf{e}_z, t)$

three approaches

"M" exact Maxwell solution

$$\rho_{\mathrm{M}}(r,z,t) = \rho(r,z,t)$$

"SUM" solution: slices in individual uniform motion

$$\rho_{\mathrm{SUM}}(r,z,t) = \rho(r,\tilde{z},t_0)\frac{d\tilde{z}}{dz}$$

with $z = \tilde{z} + v(\tilde{z},t_0)(t - t_0)$

and $z(v,t)$ the slice velocity

"BUM" solution: bunch in uniform motion

$$\rho_{\mathrm{BUM}}(r,z,t) = \rho(r, z + (t - t_0)v, t_0)$$

with $v = v(t_0) = \frac{p_{\mathrm{com}}}{m}$

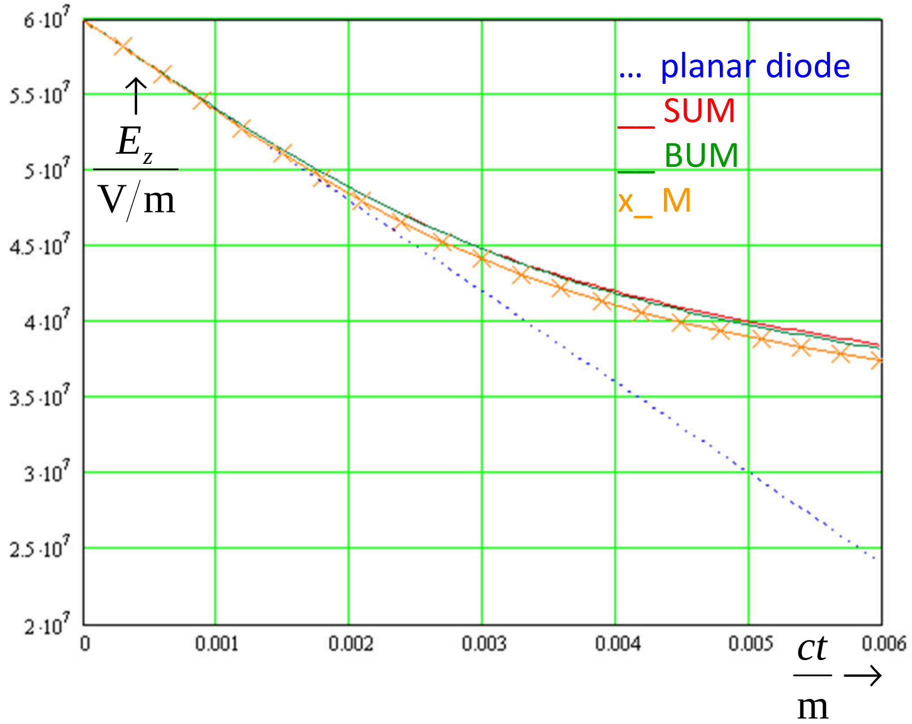
and "com" = center of mass

about approaches: some analytical calculations

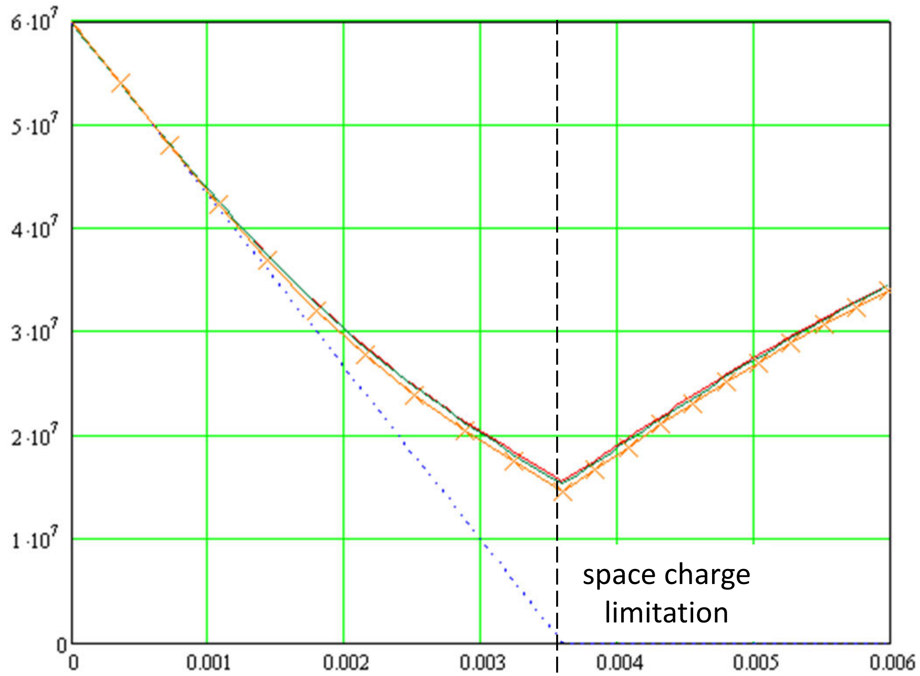
injection ($z = 0$)

$q = 1\,\mathrm{nC}$	bunch charge
$E_{\mathrm{acc}} = 60\,\mathrm{MV/m}$	accelerating field
$cT_i = 6\,\mathrm{mm}$	time of injection (rectangular)

$R = 1\,\mathrm{mm}$ (rms = 0.5 mm)

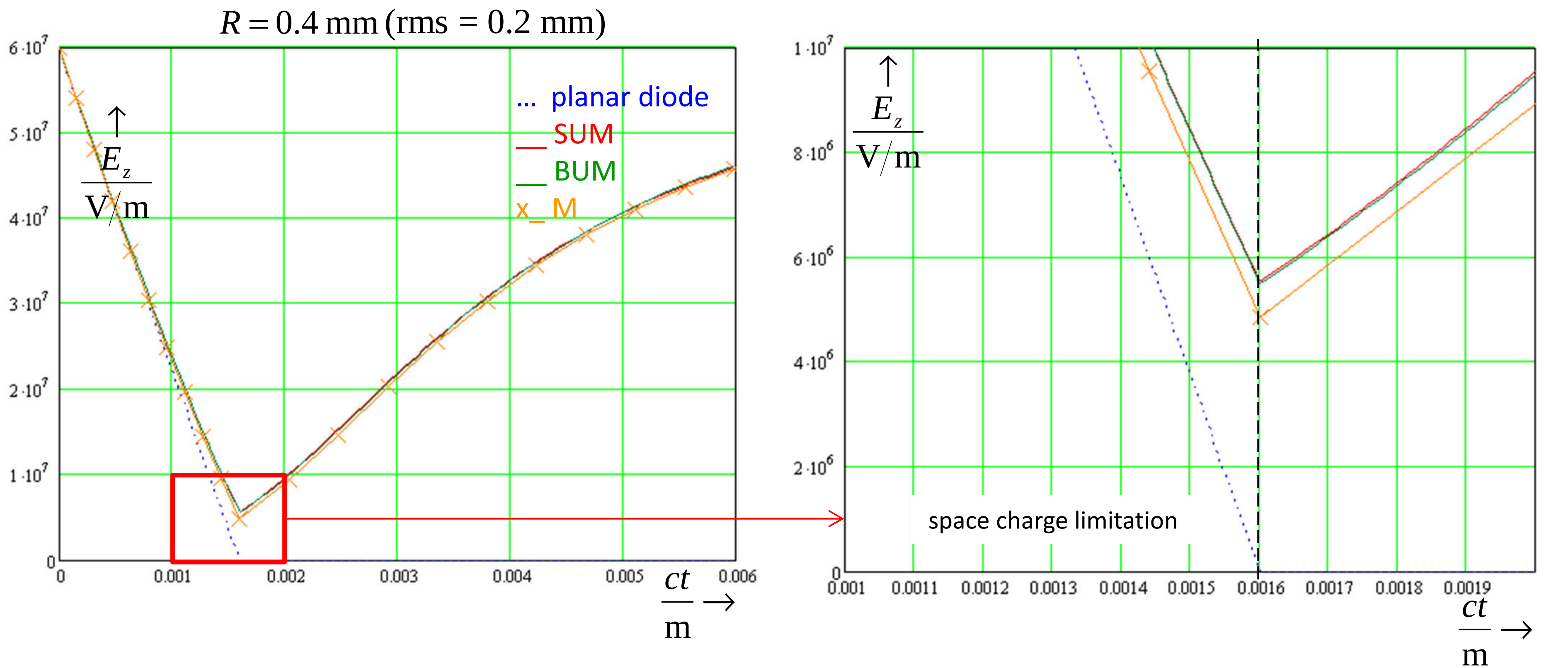


$R = 0.6\,\mathrm{mm}$ (rms = 0.3 mm)



about approaches: some analytical calculations

injection ($z = 0$)



M calculates stronger field reduction than UM & BUM !

after injection ($t > T_i$)

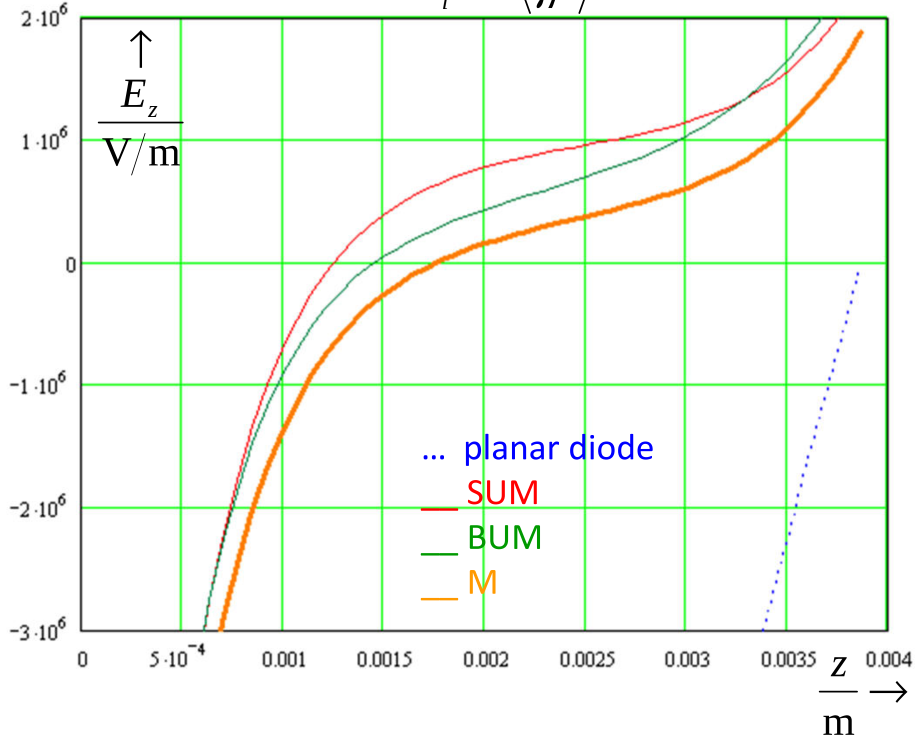
$q = 1\,\mathrm{nC}$ bunch charge

$E_{\mathrm{acc}} = 60\,\mathrm{MV/m}$ accelerating field

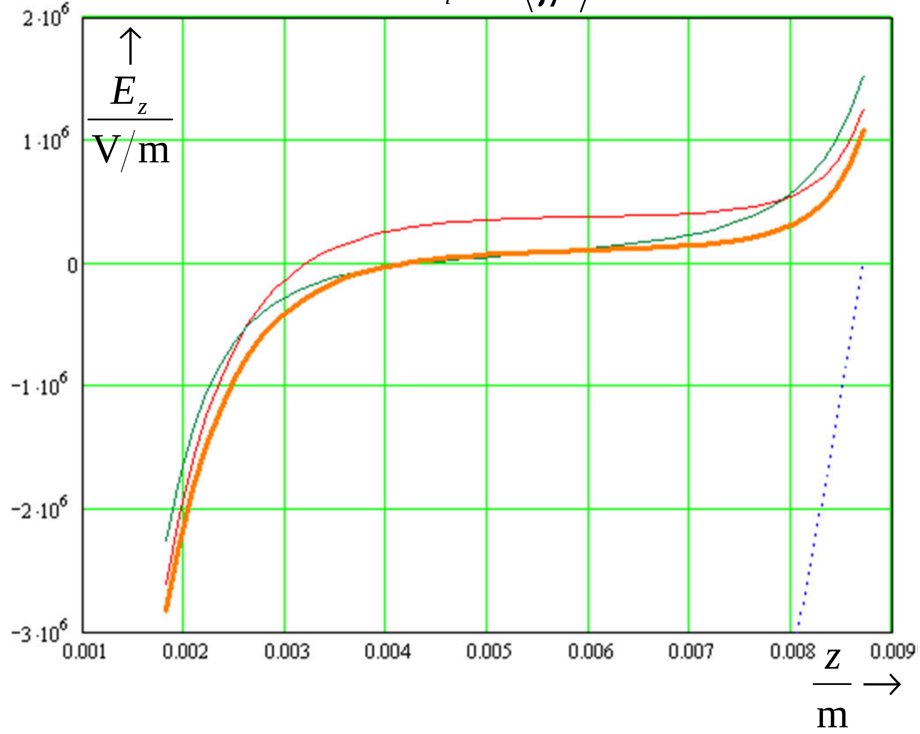
$cT_i = 6\,\mathrm{mm}$ time of injection (rectangular)

$R = 1\,\mathrm{mm}$ (rms = 0.5 mm)

$t = 1.5T_i \qquad \langle\gamma\beta\rangle \approx 0.53$

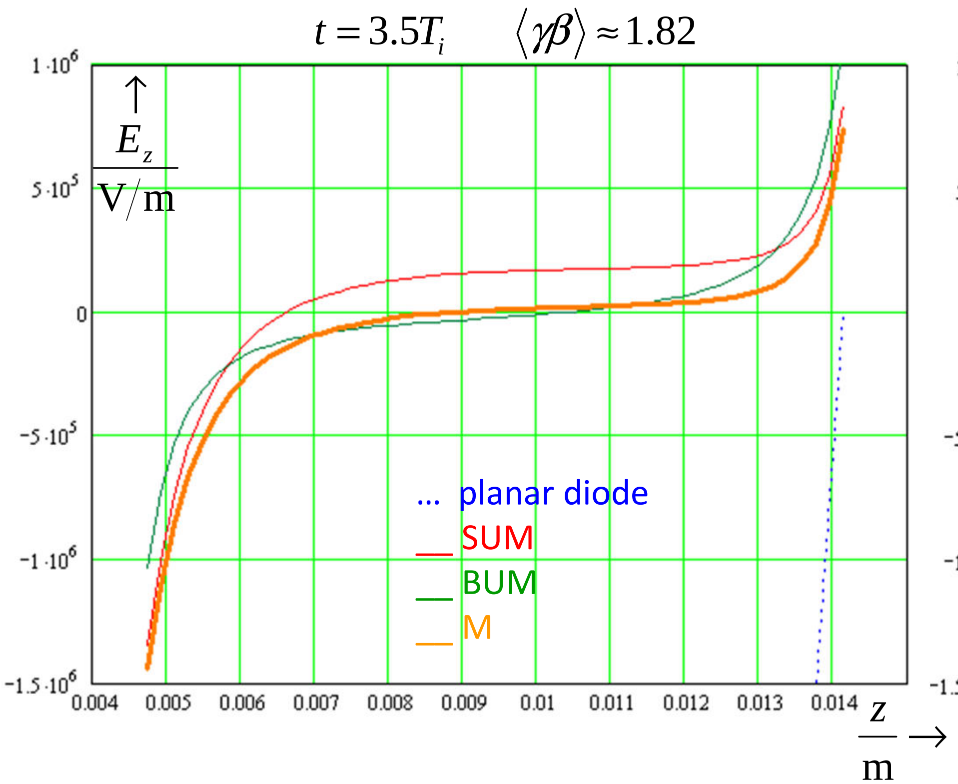


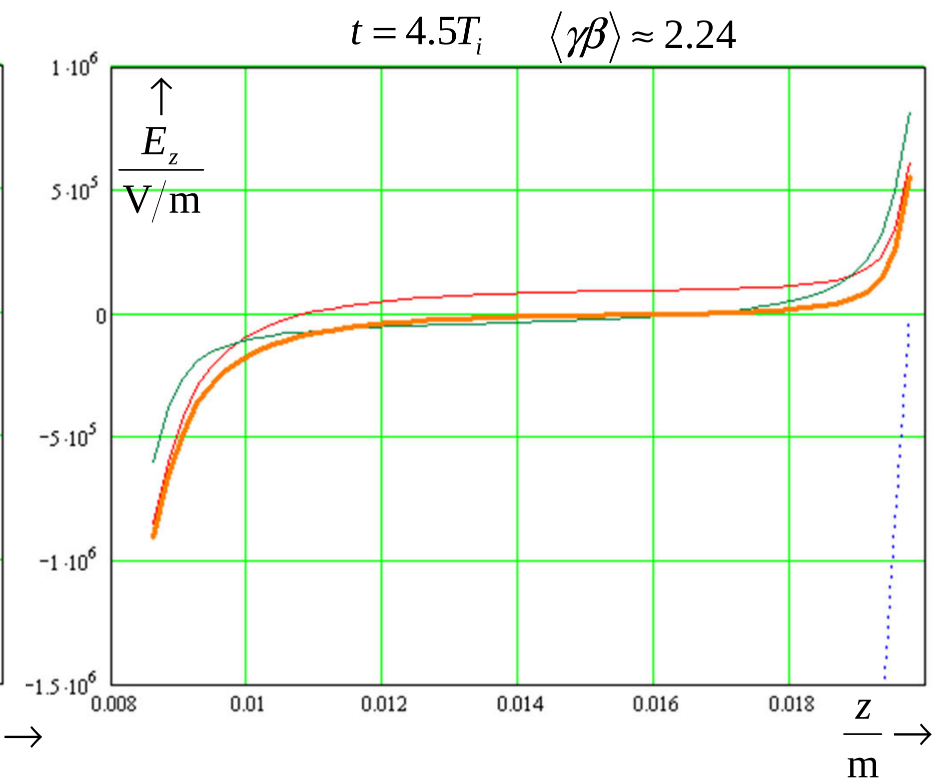
$t = 2.5T_i \qquad \langle\gamma\beta\rangle \approx 1.43$



about approaches: some analytical calculations

after injection ($t > T_i$)

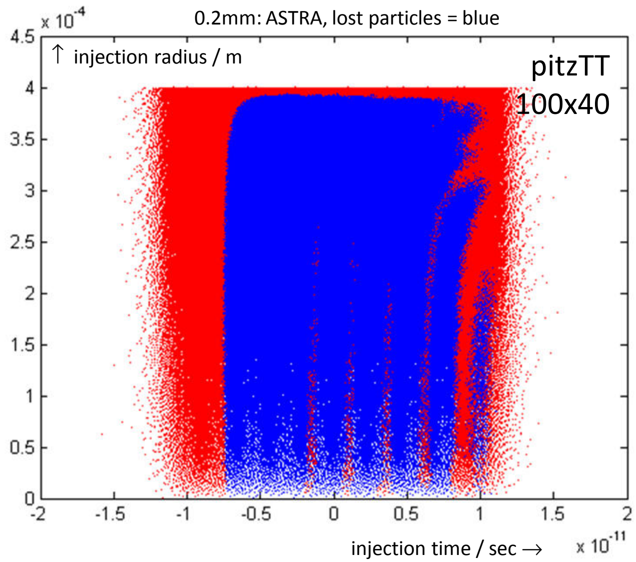


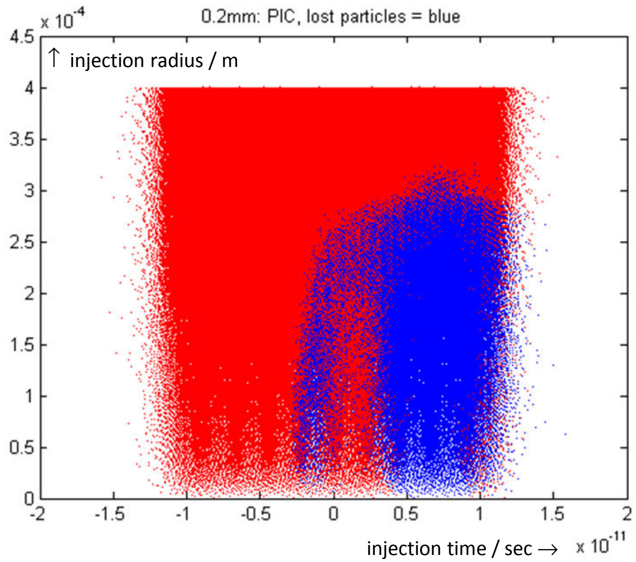


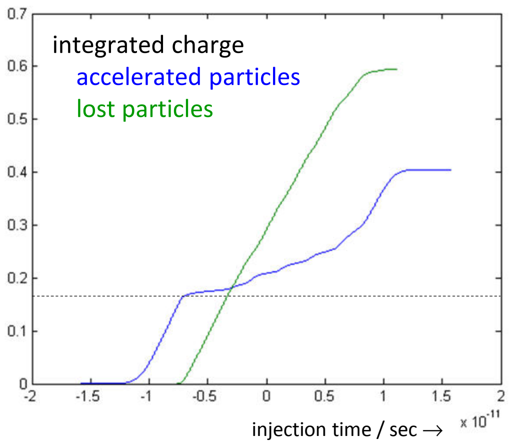
second inspection

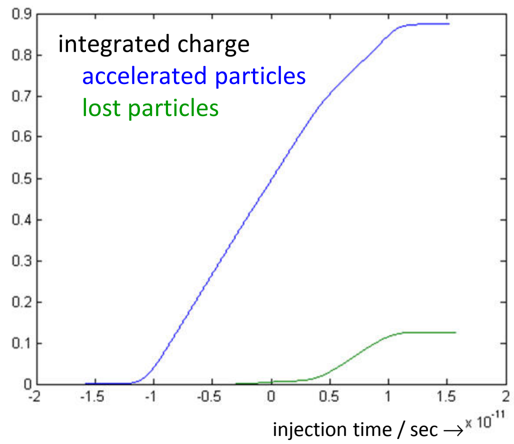
second inspection

lost particles vs. accelerated particles (@ injection)









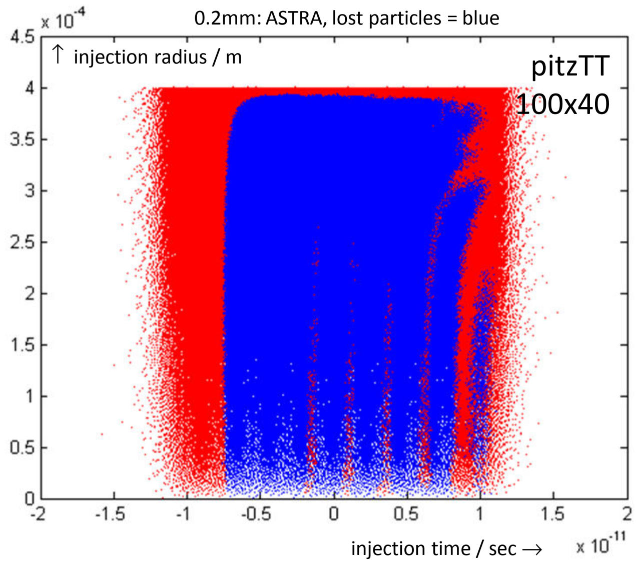
$$Eacc := \left| 60.58 \cdot \sin\left(223.386 \cdot \frac{\pi}{180}\right) \right|$$

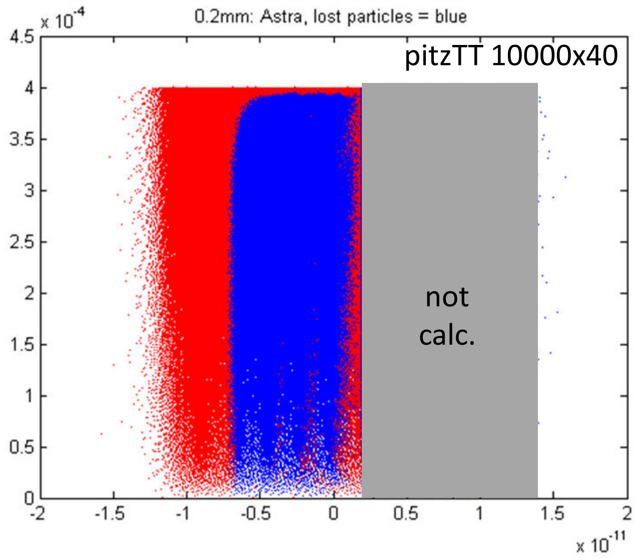
$$Eacc = 41.613$$

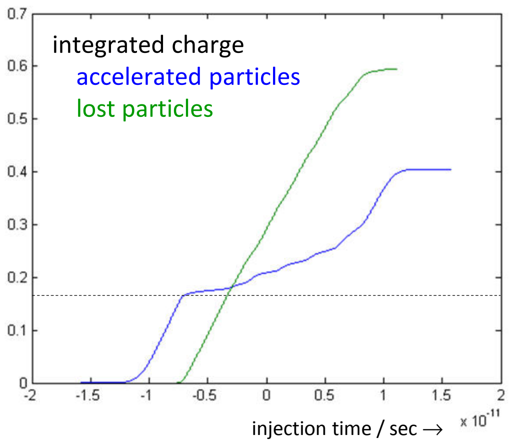
$$Eacc \cdot 10^{6} \cdot 8.854 \cdot 10^{-12} \cdot \pi \cdot 0.0004^{2} = 1.852 \times 10^{-10}$$

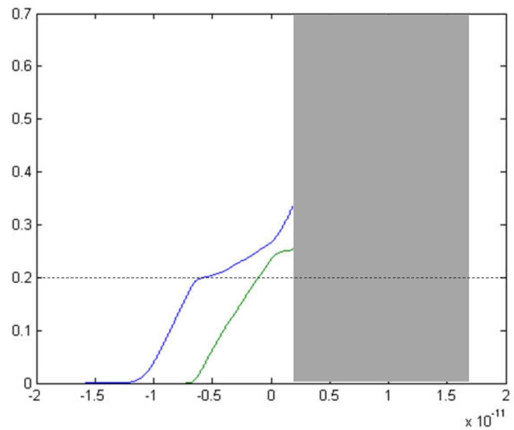
second inspection

lost particles vs. accelerated particles (@ injection)









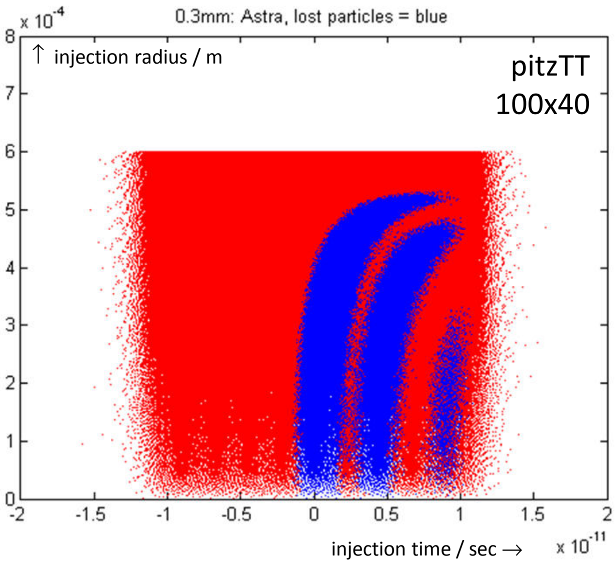
$$\mathrm{Eacc} := \left|60.58 \cdot \sin\left(223.386 \cdot \frac{\pi}{180}\right)\right|$$

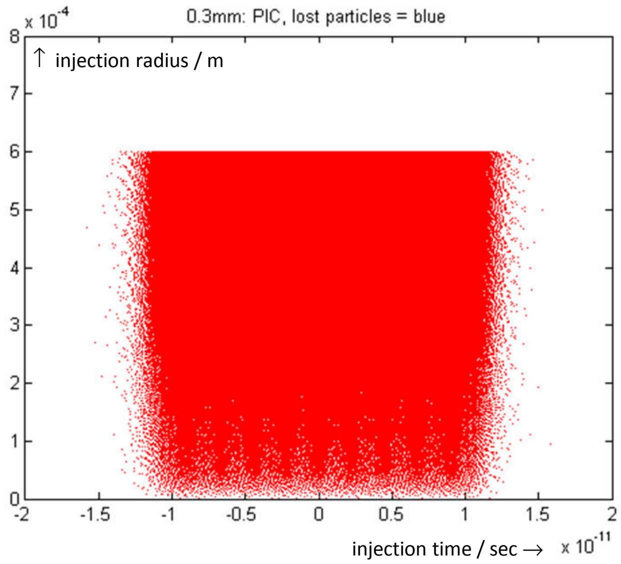
$$\mathrm{Eacc} = 41.613$$

$$\mathrm{Eacc} \cdot 10^{6} \cdot 8.854 \cdot 10^{-12} \cdot \pi \cdot 0.0004^{2} = 1.852 \times 10^{-10}$$

second inspection

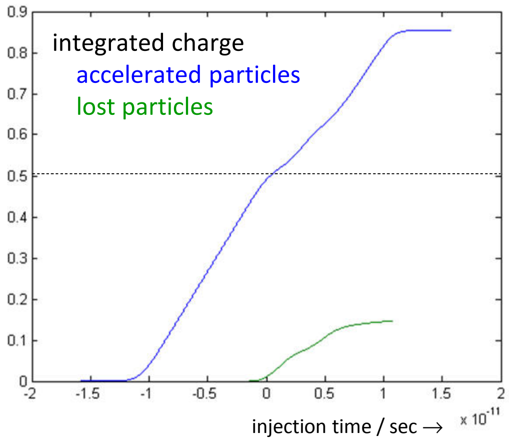
lost particles vs. accelerated particles (@ injection)





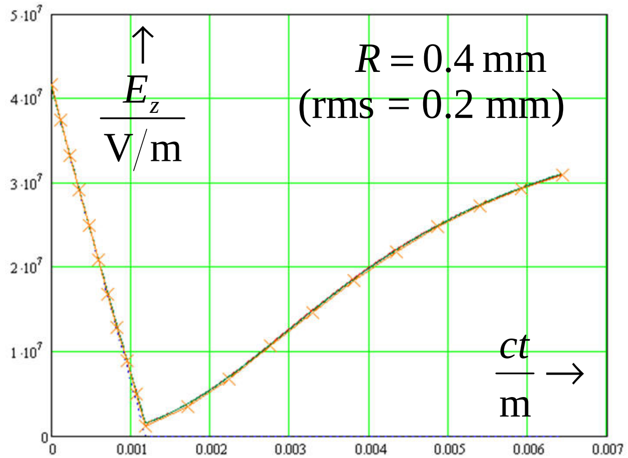
$$Eacc := \left|60.58\cdot 10^{6}\cdot \sin\left(223.386\cdot \frac{\pi}{180}\right)\right|$$

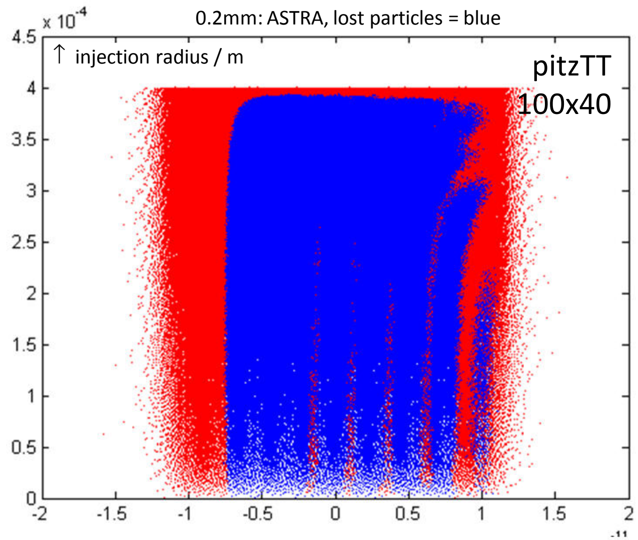
$$Eacc\cdot 8.854\cdot 10^{-12}\cdot \pi\cdot 0.0006^{2} = 4.167\times 10^{-10}$$

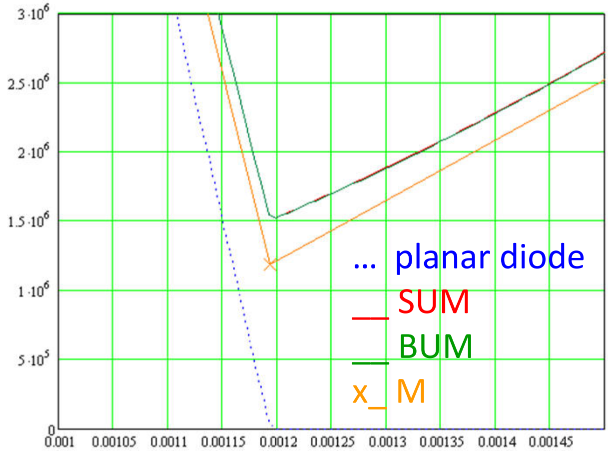


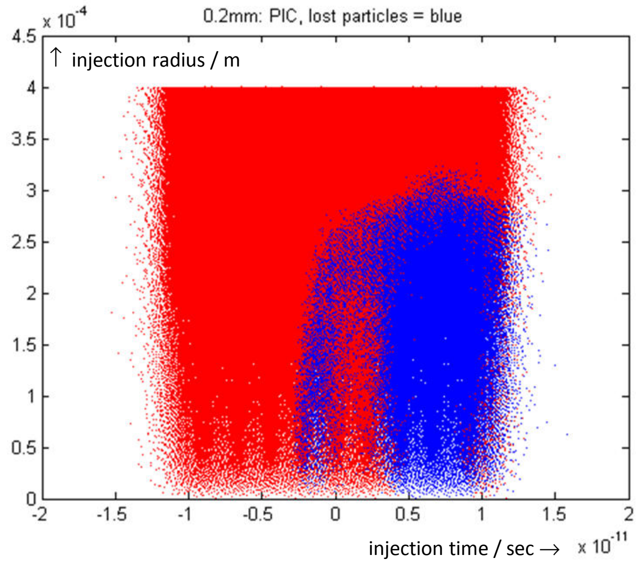
second inspection

correct numbers: q = 1nC Ti = 21.5 psec   Eacc=41.61 MV/m









M-shielding should be stronger than BUM-shielding!

summary

SC limited emission: differences between measurement and ASTRA

ASTRA
- incomplete model
- predicts strong SC limited emission
- SC limited emissions needs extreme mesh resolution
  (usually not fulfilled at end of emission)
- very sensitive to initial conditions (is it real physics?)
- SC shielding seems to agree with analytical model

LW
- should include all effects
- has been benchmarked with PIC or vice versa (but: same tracker)
- less SC shielding: seems to agree with measurement
- problems with boundary condition at injection (mirror-point-charge)
- micro modulation: related to time step and time of injection
- analytical model (Maxwell ↔ Poisson) predicts stronger shielding

measurement …?!