Possibilities for production of ideal electron bunch shapes for dielectric wakefield accelerators.

Evgenya I. Simakov and Dmitry Yu. Shchegolkov

Los Alamos National Laboratory, Los Alamos, NM 87545

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Outline

- Background and motivation, MaRIE.
- DWAs and energy spread in a witness bunch.
- Bunch shaping with an emittance exchanger.
- Possible experiments.

Background and motivation, MaRIE

Motivation

• The pre-conceptual design for MaRIE is underway at LANL, with the design of the 12 GeV electron linac being one of the main research goals.

• Requirements the for linac: high gradient and high quality electron beam:

- electron bunch charges of 0.1 to 1 nC;
- normalized rms emittances of 0.1 to 1 μm;
- and rms energy spreads of less than 0.1%.

• Exactly the same phenomena, that causes the dominant energy spread effect in beams in conventional linacs can be used to generate extraordinary gradients and small energy spreads in and dielectric structures via wakefield acceleration.

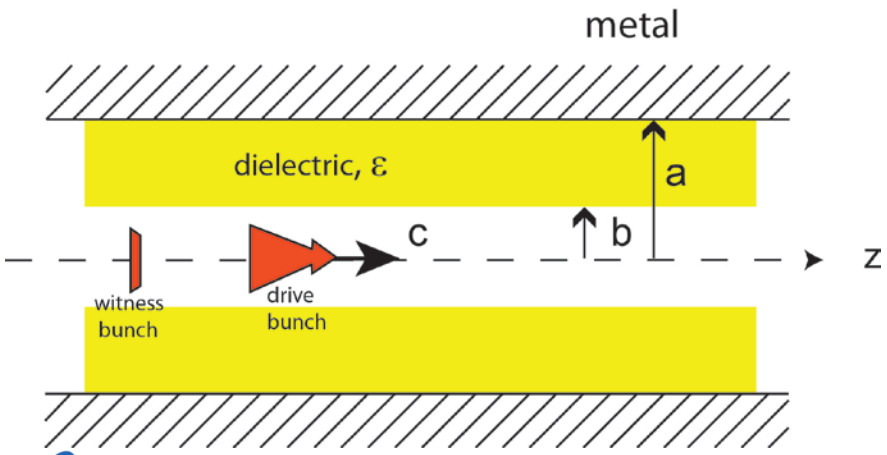
First ideas: Workshop on Application of dielectric wakefield accelerators (DWAs) to next generation X-ray free-electron laser facilities, Argonne National Laboratory, April 20-21, 2011.

DWAs and energy spread in a witness bunch

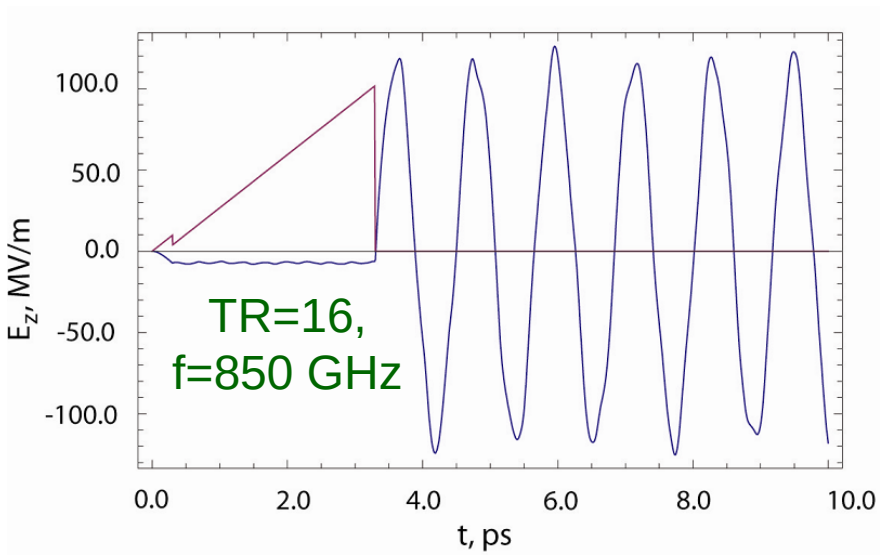
DWAs and high transformer ratios

By shaping the drive electron beam in a DWA into a double-triangular shape one may achieve high transformer ratios, way higher than TR=2, which is the limit for the Gaussian-shaped beam.

A schematic of the dielectric wakefield accelerator

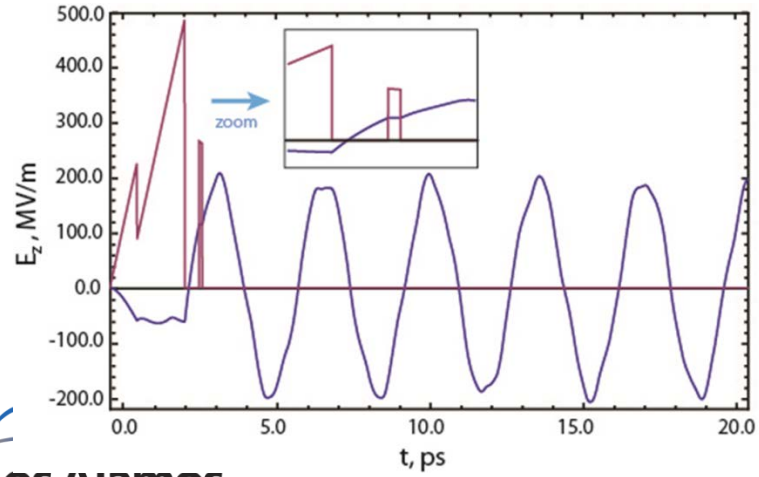


High transformer ratio wakes excited by double-triangular beams in DWAs



Minimization of the energy spread in a witness bunch

By additionally customizing the shape of the main bunch we designed the configuration which minimizes the wakefield-induced energy spread in the main bunch. The energy spread may be made as low as 0.001%.



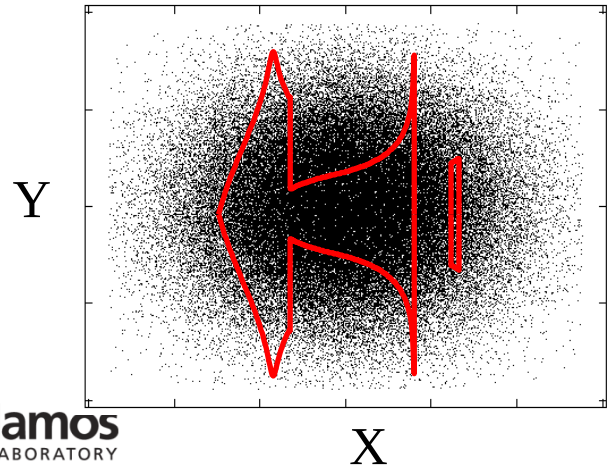
Beam pipe ID, *2b*	1.14 mm
Dielectric tube ID, *2a*	1.24 mm
Waveguide cutoff	298 GHz
Charge of the drive bunch	5 nC
Length of the drive bunch	2.350 ps
Charge of the witness bunch	250 pC
Length of the witness bunch	100 fs
Time between the bunches	2.8017 ps
Transformer ratio	3.38
$\Delta G/G$	$9*10^{-6}$

Cutting out the shaped bunches out of a Gaussian bunch

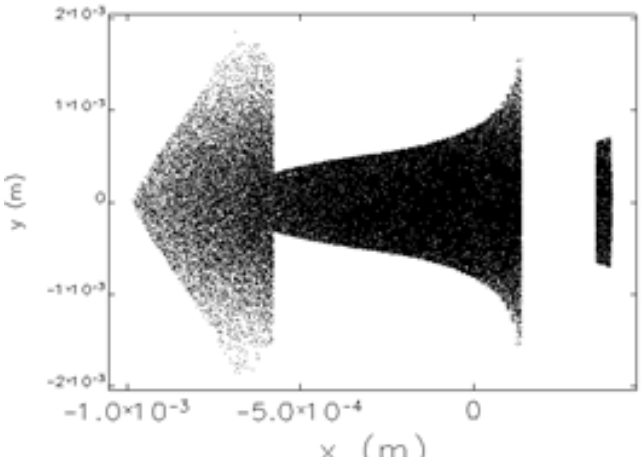
Parameters of a Gaussian bunch (from FNAL folks):

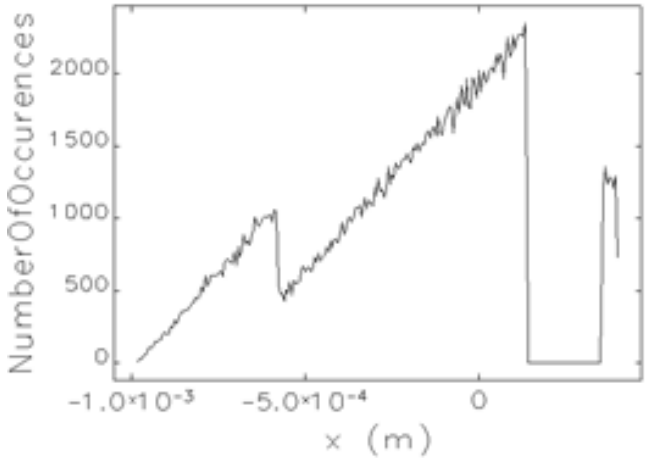
ε_{nx}	5.33 mm*mrad
ε_{ny}	10 mm*mrad
Bunch length	1.2 mm
Fract. mom. spread	0.001

The shape of the mask that cuts out the correct bunch shapes out of the Gaussian distribution.



Particle distribution in Elegant:





Bunch shaping with an emittance exchanger

Emittance Exchange

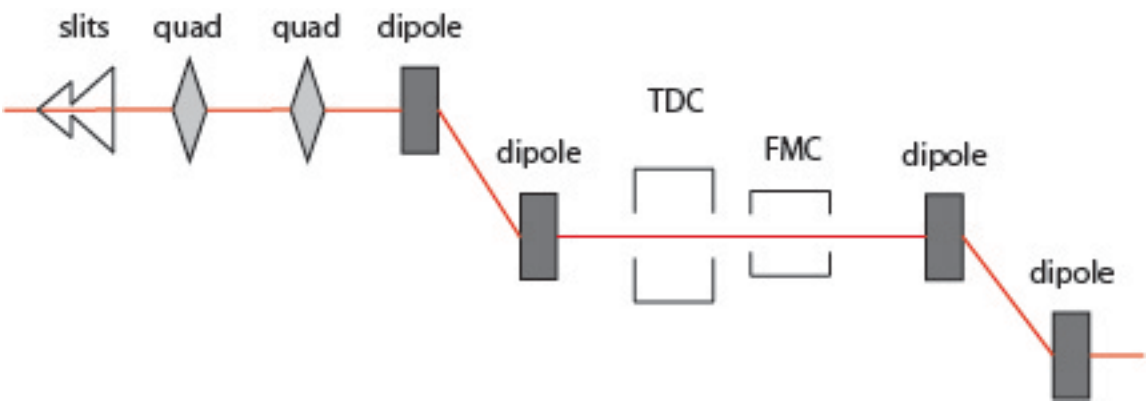
We have to turn the x-y distribution into z-y distribution with an emittance exchanger. We need to construct the emittance exchanger with the following matrix elements:

R_{51}=1 (or whatever stretch factor)

$R_{52} \approx R_{53} \approx R_{54} \approx R_{55} \approx R_{56} \approx 0.$

First order

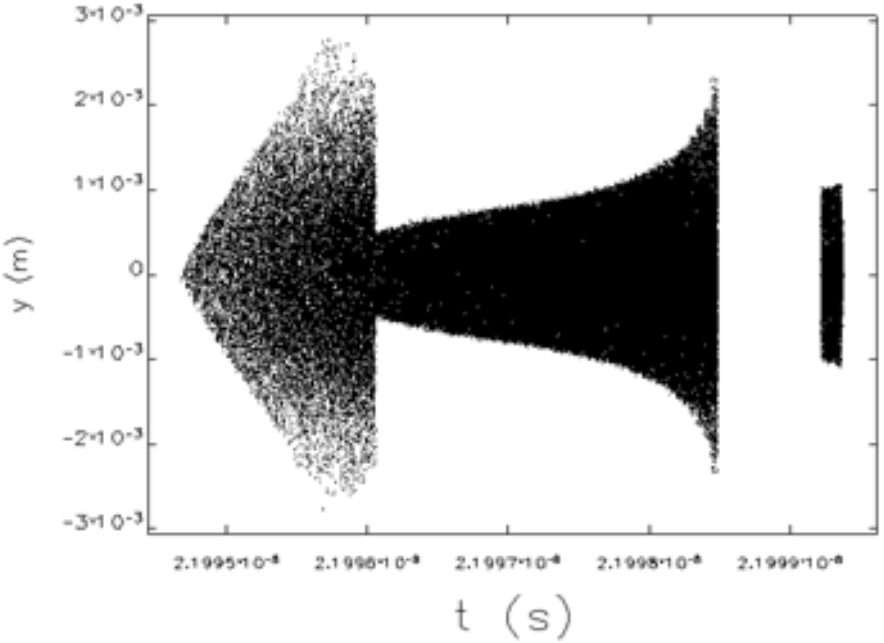
The following set of elements allows one to have the correct R-matrix in the first order:

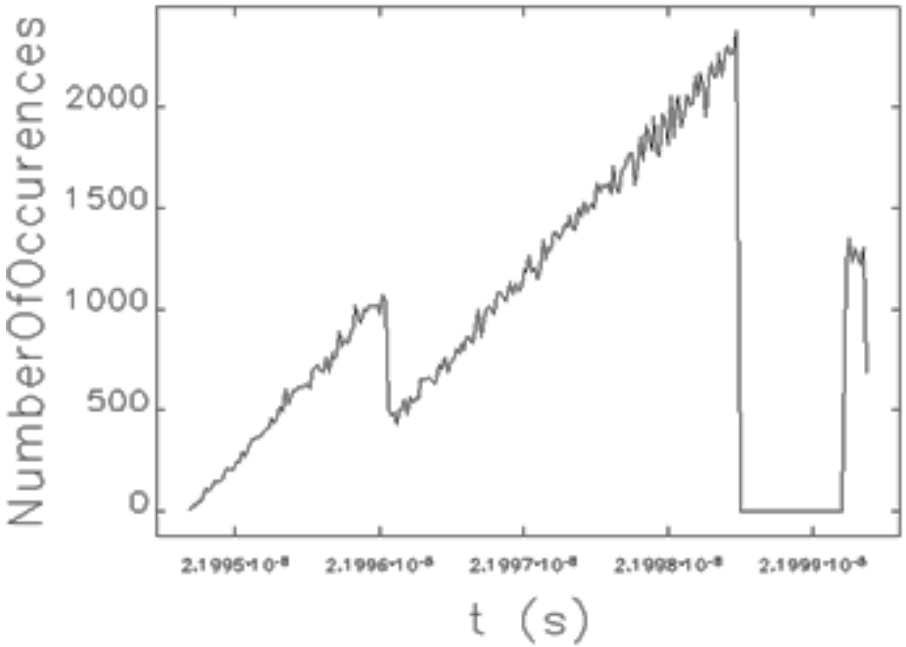


- Thick TDC produces a momentum kick and non-zero R_{55} , R_{56} .
- This can be compensated with a FMC.
- Two quads allow us to have zero R_{52} and whatever R_{51} .

First order (continued)

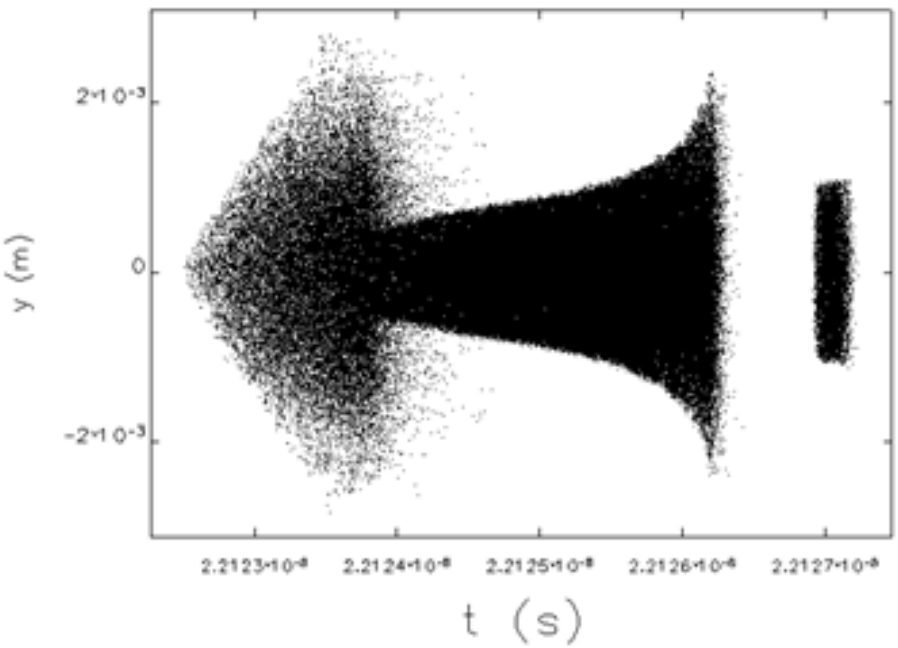
Output from Elegant:

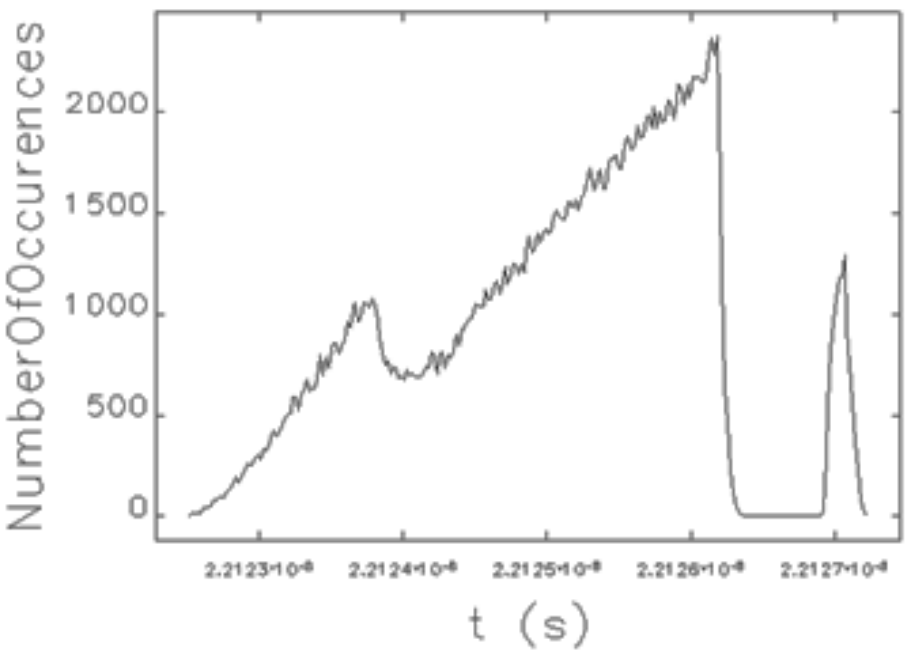




Second order

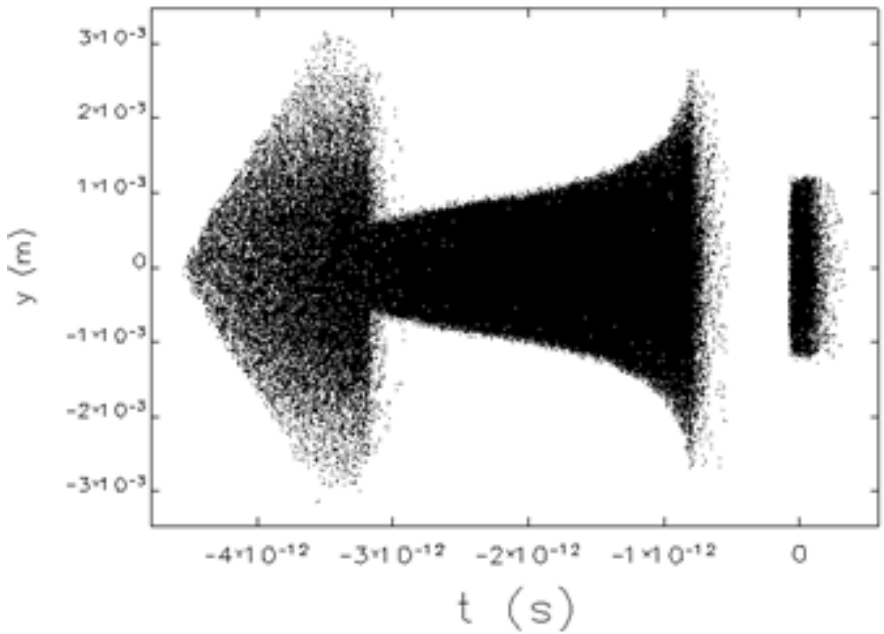
T-matrix (second order) produces visible aberrations:

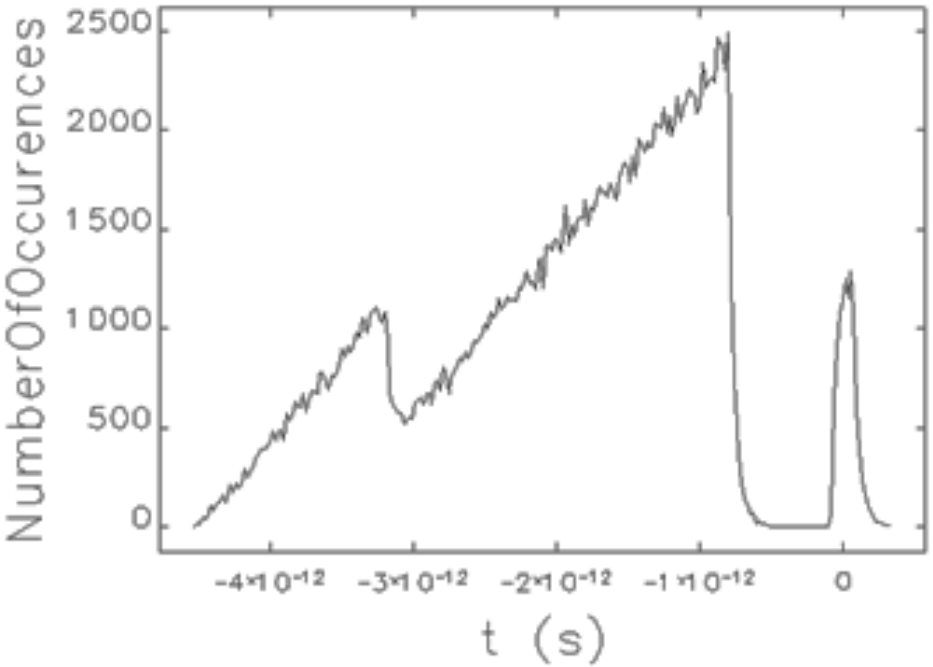




T555 matrix element

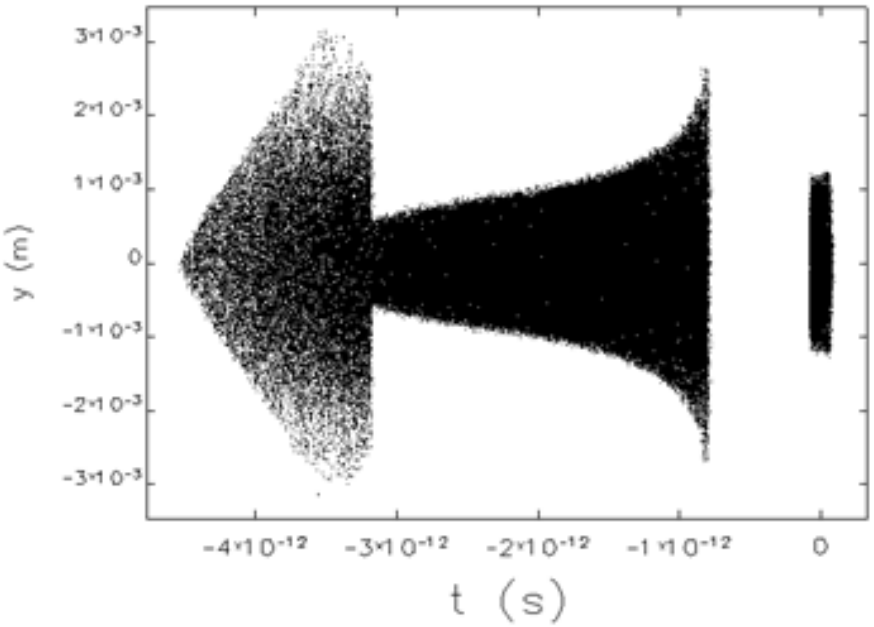
Aberrations are mostly due to the second order matrix element T555. This is the computation with T555 only:

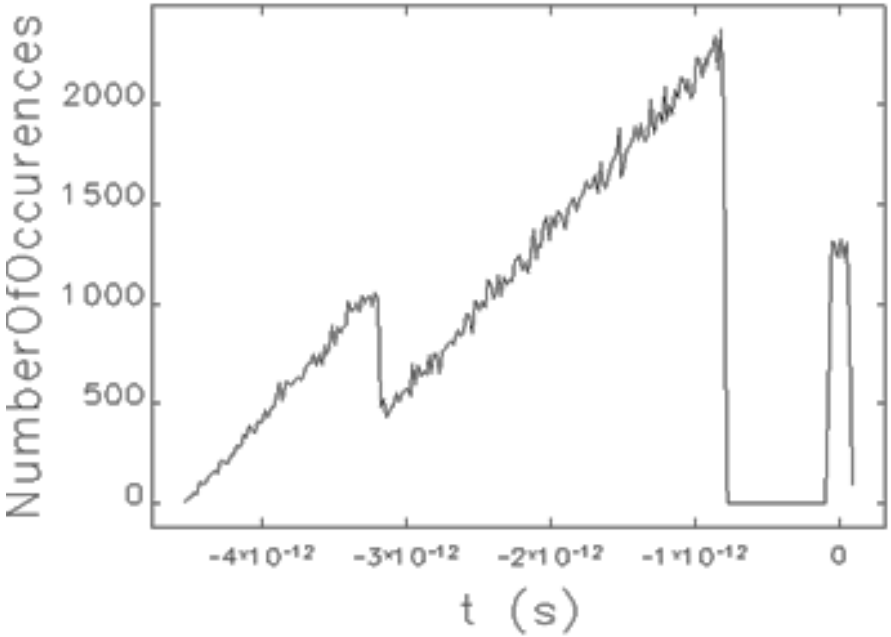




T555 does not affect shorter bunches

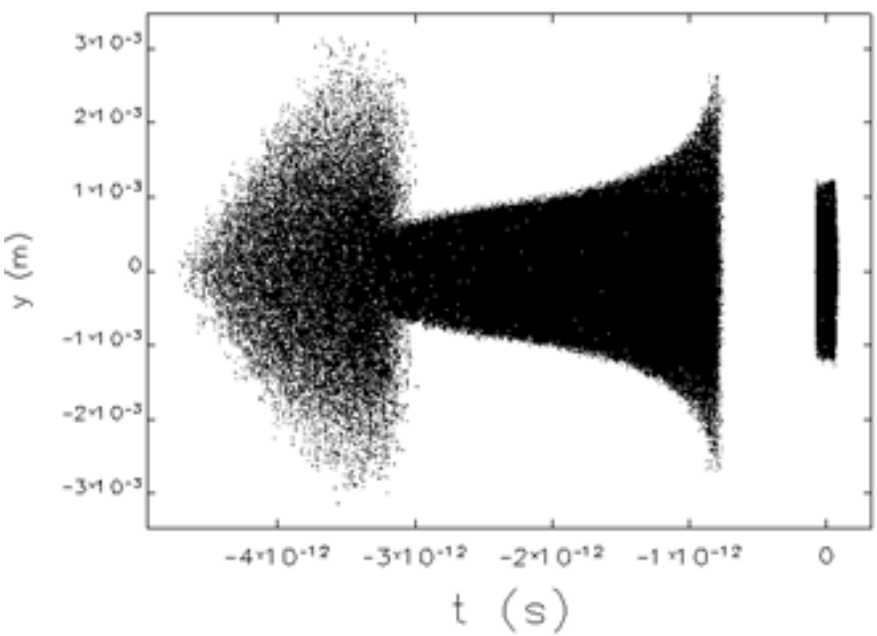
T_{555} effect is less pronounced for shorter bunches. This is 0.4 mm bunch instead of 1.2 mm bunch:

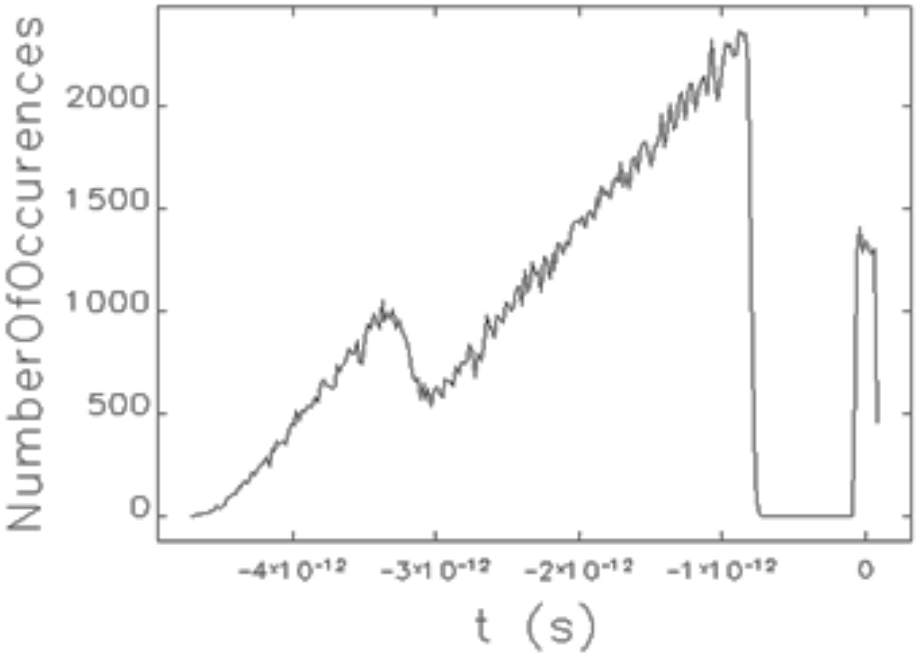




T551 matrix element

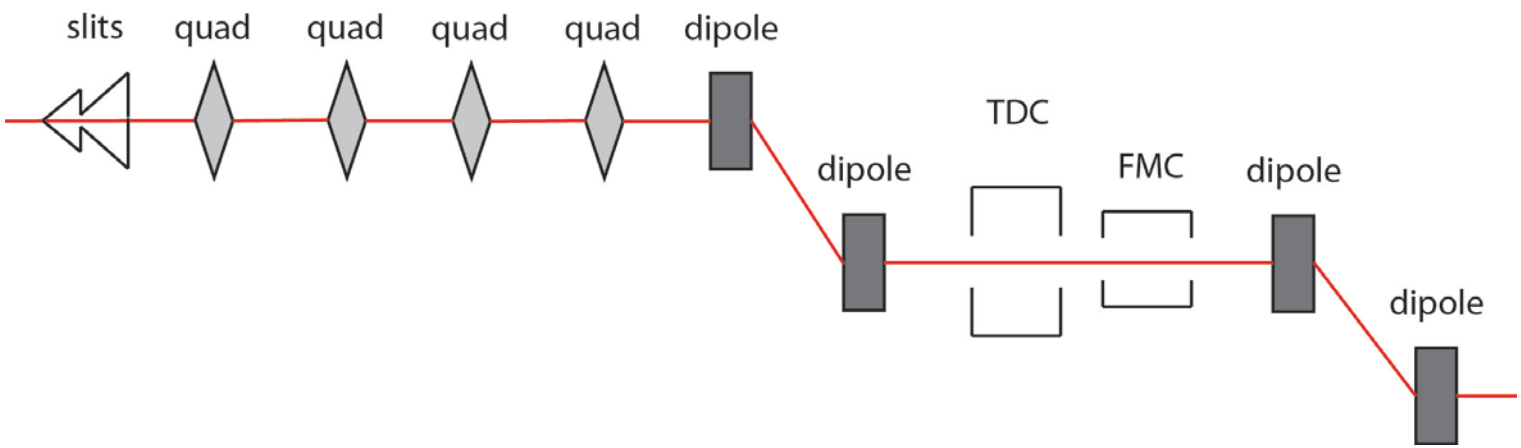
Another matrix element contributing to aberrations of the drive bunch is T551:





Control over beam width with additional quads

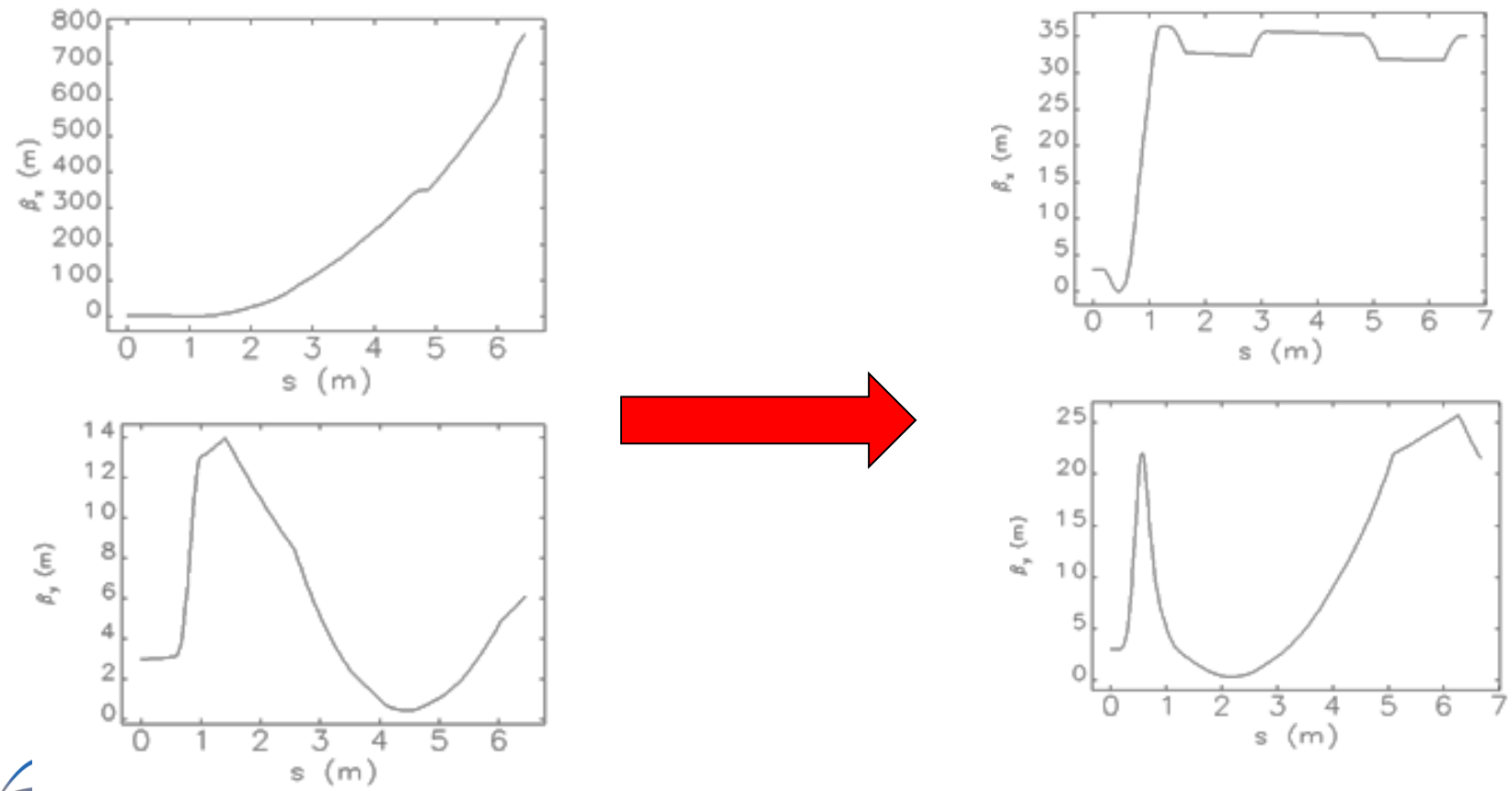
Adding two more quadrupoles at the beginning of the beam line allows us to control the width of the bunch along the beamline and reduce the T551 effect:



Four quads also allow us to control T665 element which causes the energy skew and undesirable energy spread.

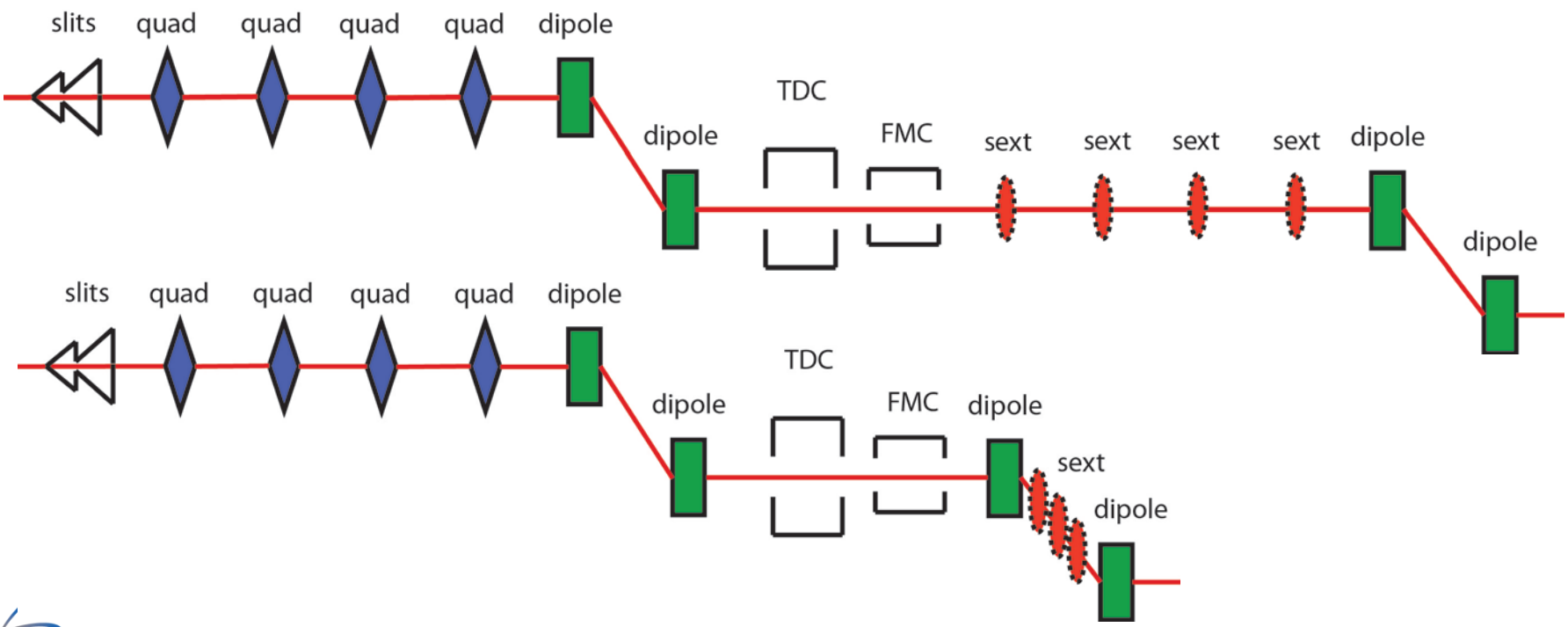
Reducing beta-functions to decrease T551

Beta-functions in the line with 2 quads versus the line with 4 quads:



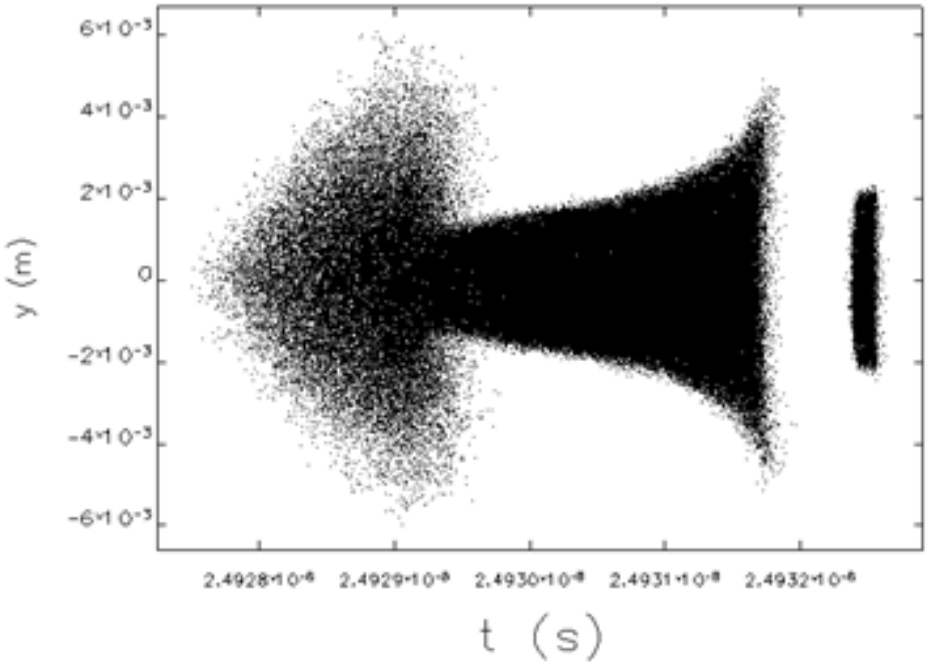
EEX with corrective elements

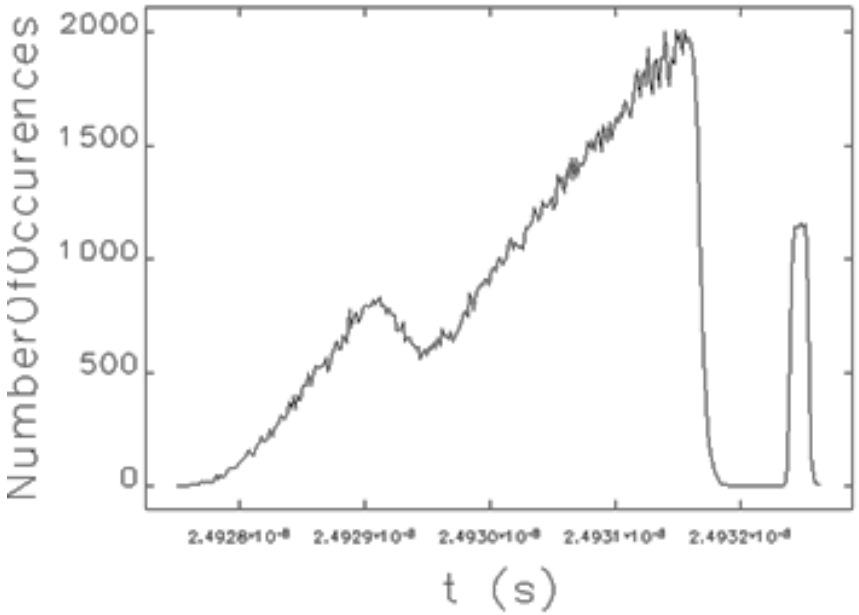
The only way to correct the aberrations due to T555 is to add a number of corrective sextupoles to the beamline. There are two ways to position sextupoles:



Sextupoles after the deflecting cavity

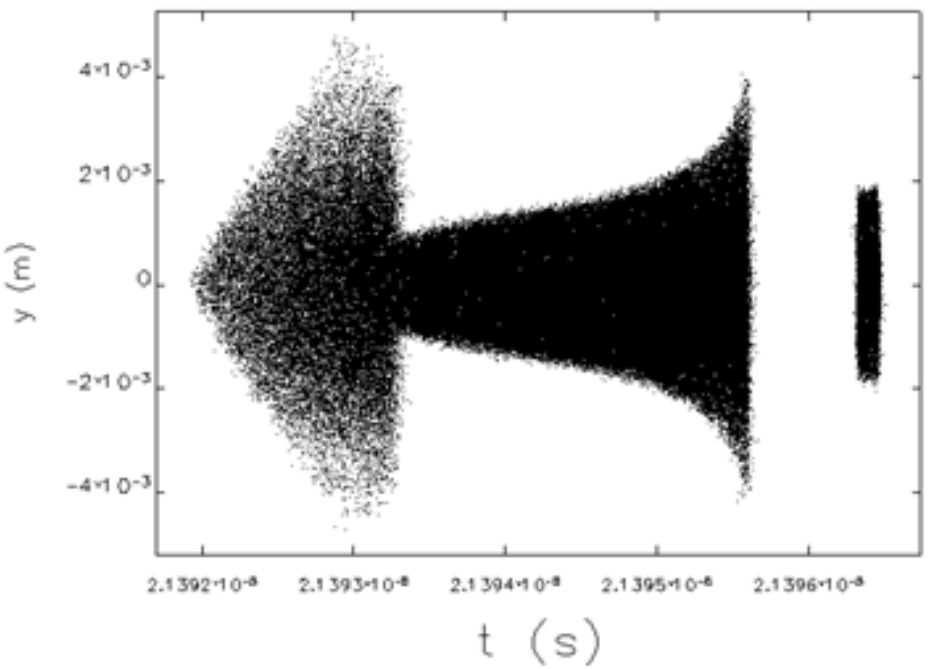
We may place a number of sextupoles in between the deflecting cavity and the second dogleg. They correct some nonlinearities, however they also create additional nonlinearities.

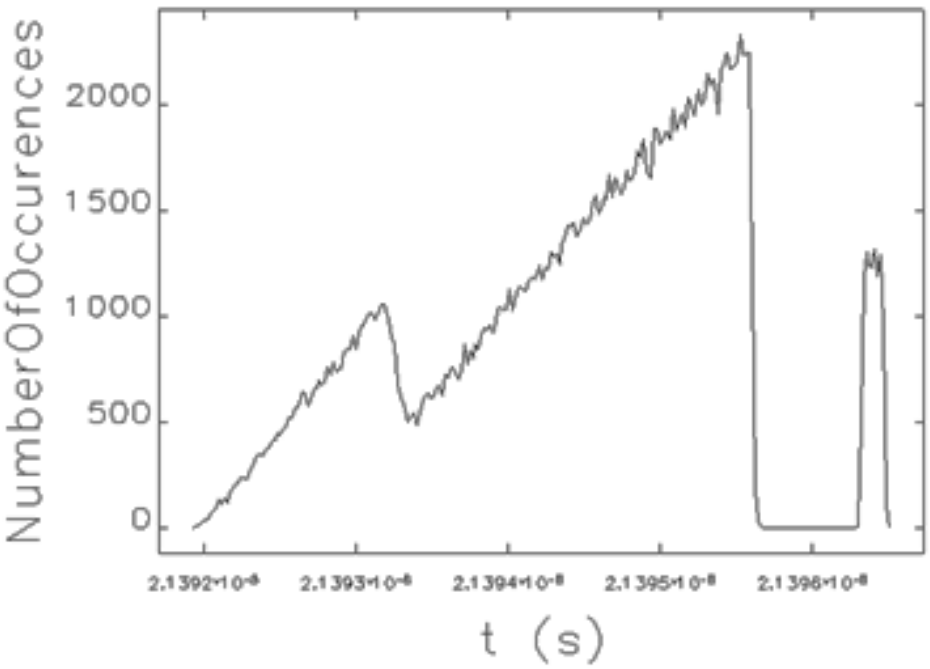




Sextupoles in the second dogleg

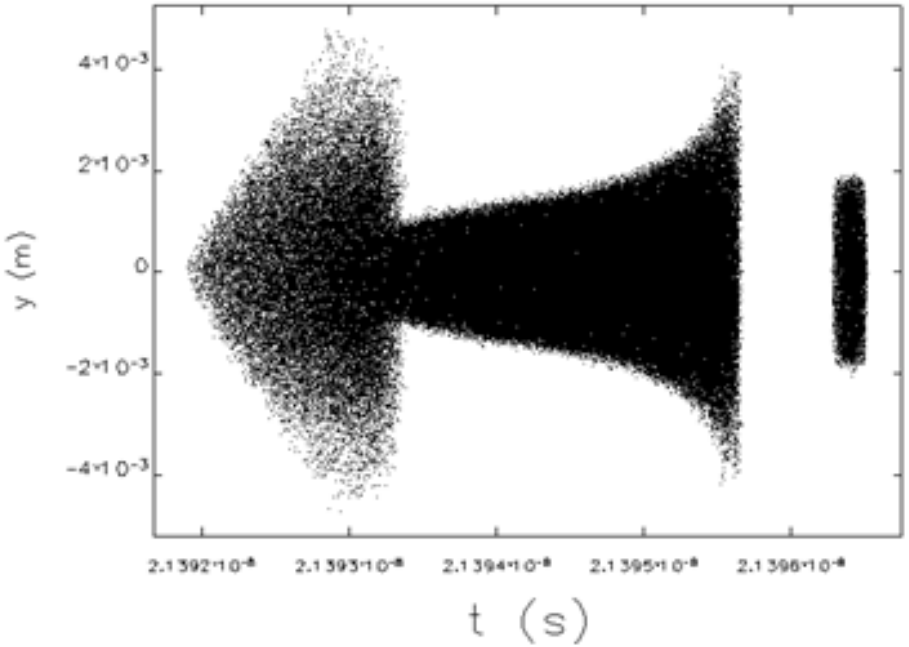
There is limited space in the second dogleg to place sextupoles. However, less sectupoles and less strength is required to correct the nonlinearities:

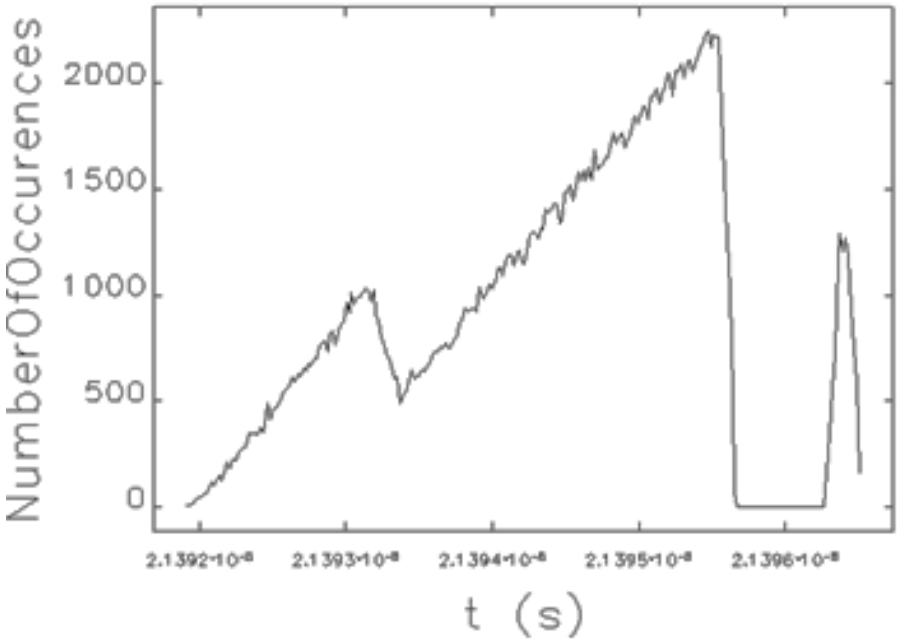




Space charge

Space charge is destructive to a tightly focused beam. This is the effect of a 1nC of space charge in the designed geometry:





Possible experiments

Current plans

We have an active proposal with LANL LDRD to experimentally demonstrate a high-brightness DWA with an acceleration gradient above 100 MV/m and less than 0.1% induced energy spread in the accelerated beam (funded 10/12-09/15).

- Possible experimental facilities
  - ATF at BNL
  - ASTA at FNAL
  - AWA at ANL

- Please let us know when your facility becomes available!

Desired experimental milestones

We would like to experimentally demonstrate the following:

- Simultaneous generation of a double triangular drive bunch and a shaped witness bunch.
- High transformer ratio in a dielectric wakefield accelerator.
- Significant gradients in a dielectric wakefield accelerator.
- Study the effects of nonlinearities in the beamline.
- Study space charge and CSR effects.

Impact of DWA acceleration for MaRIE

- An 8.8-GeV DWA afterburner for the MaRIE upgrade will boost the energy of the electron beam from 12 GeV to 20.8 GeV.
- With the current 12 GeV MaRIE linac design, generation of the third harmonic (126 keV) photons is suppressed in the wiggler.
- Photon energy above 120 keV is required for the K-shell ionization of uranium and other actinides, an important MaRIE mission and part of its funding justification.
- The DWA afterburner upgrade would allow an order of magnitude greater production of 126-keV photons.