# Wake Field Effects on High-Brightness Photo-Injector Electron Beams (ASTRA simulations)

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Photo-Injector Physics Meeting
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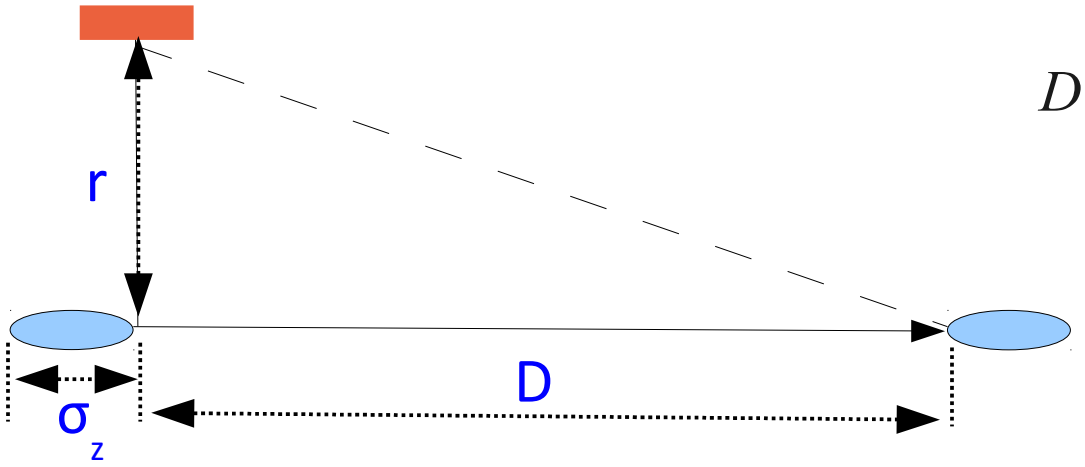
# Wake Field Theory Study References

- References:
  - A. Chao, “Physics of Collective Beam Instabilities in High Energy Accelerators,” John Wiley & Sons, Inc., Chap 2.
  - K. Bane, “Wakefields of Sub-Picosecond Electron Bunches,” SLAC-PUB-11829 (April 2006).
  - P. B. Wilson, “Introduction to Wakefields and Wake Potentials,” SLAC-PUB-4547 (Jan. 1989).




Catch-up distance

$$D = \frac{r^2 - \sigma^2}{2\sigma_z} \approx \frac{r^2}{2\sigma_z}$$

APS photoinjector:

$\sigma_z$=0.71mm

r=9.6mm

=>D=6.5cm

# Wake Field in ASTRA

- **A S**pace Charge **TR**acking **A**lgorithm (**ASTRA**)
  - Author: Klaus Floettmann, DESY, Hamburg
  - Language: Fortran 90
  - Platforms: LINUX, Windows and (less supported) Mac.
  - Download and References: http://www.desy.de/~mpyflo/

- Wake Field in **ASTRA**:
  - Martin Dohlus et al.
  - Reference:
    - "Fast Particle Tracking With Wake Fields", M. Dohlus et al. http://arxiv.org/abs/1201.5270

# Wake Field in ASTRA*

- Dependency on longitudinal coordinate is tabulated;
- Dependencies on transverse coordinates are Taylor-expanded (on a $2^{nd}$ order);
- Charge density is calculated on a grid by a binning and smoothing technique.
- Point-to-point interaction between all particles is calculated by a convolution method.

*Fast Particle Tracking With Wake Fields", M. Dohlus et al.
http://arxiv.org/abs/1201.5270

# Wake Field Functions for the SLAC S-band Accelerating Structures

- Transverse Wake Fields:
  - "Short-range dipole wakefields in accelerating structures for the NLC", Karl Bane, SLAC-PUB-9663, March 2003. (Thanks to P. Emma for sending this reference).

$$w_y = 6.65\text{x}10^{15}\left[1-\left(1+\sqrt{\frac{s}{s_0}}\right)\text{e}^{-\sqrt{\frac{s}{s_0}}}\right]\frac{V}{C\cdot m^2},\ s_0 = 0.8449\,mm;$$

- Longitudinal Wake Fields:
  - "A new Green's Function for the wake potential calculation of the SLAC S-band constant gradient accelerating section", A. Novokhatski, NIM A, 684 (2012) 46-51. (Thanks to A. Zholentz for sending this reference).

$$w_z = 315.4\text{x}10^{12}\left(1+\frac{s}{4s_0}\right)\text{e}^{-\sqrt{\frac{s}{s_0}}}\frac{V}{C\cdot m};\ s_0 = 0.435\,mm$$

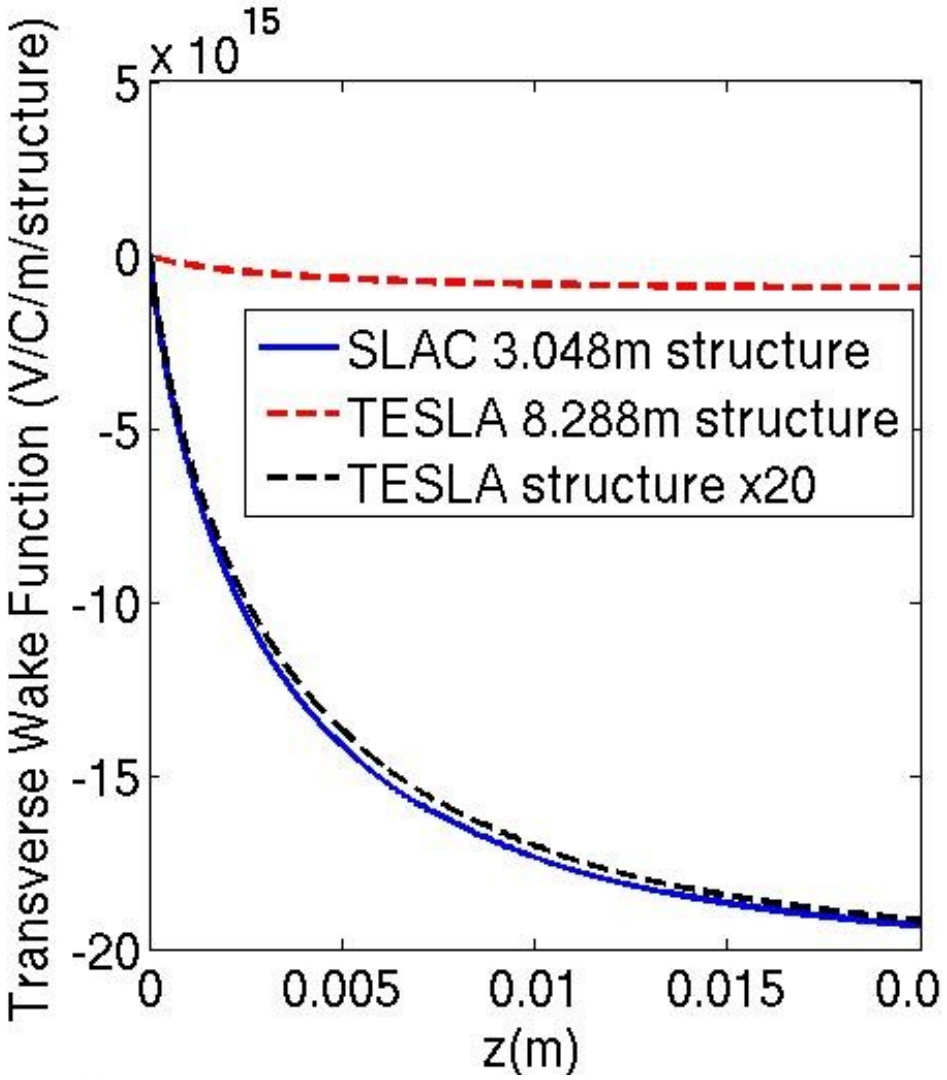
# Generating SLAC TWS Wake Field Maps for ASTRA

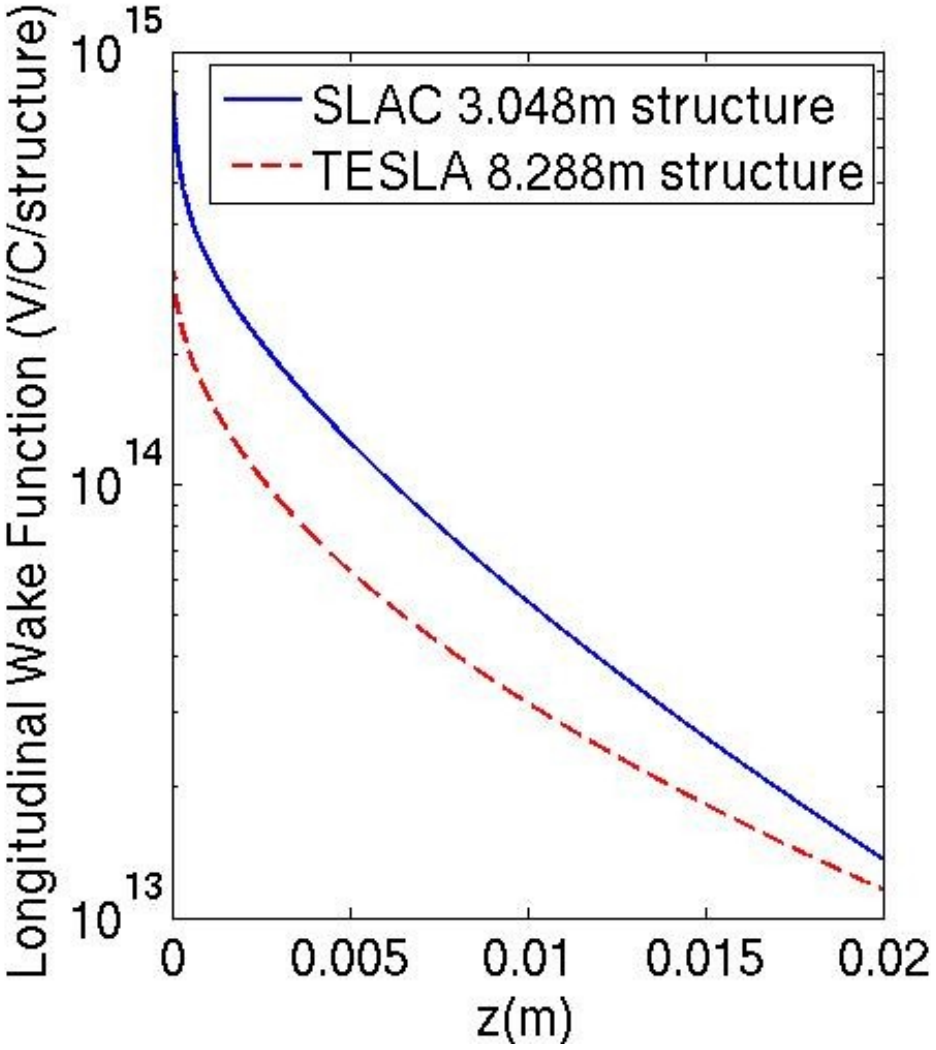
- From the transverse and longitudinal wake function, numerical field maps for ASTRA are generated for a 3.048 m SLAC structure:
  - Monopole mode (referred to as "longitudinal wake"),
  - Dipole mode (referred to as "transverse wake"),
  - Combined monopole and dipole modes.
- The SLAC structure wake field maps are compared with TESLA structures.
- The TESLA structure wake function can be found in TESLA report 2003-19 (T. Weiland, I. Zagorodnov). The structure length is 8.288m (Thanks to Martin Dohlus for providing the TESLA structure field maps).

$$w_y^{TESLA} = 1.21\text{x}10^{14}\left[1-\left(1+\sqrt{\frac{s}{s_0}}\right)\text{e}^{-\sqrt{\frac{s}{s_0}}}\right]\frac{V}{C\cdot m^2},\ s_0 = 0.92\,mm;$$

$$w_z^{TESLA} = 41.5\text{x}10^{12}\,\text{e}^{-\sqrt{\frac{s}{s_0}}}\frac{V}{C\cdot m};\ s_0 = 1.74\,mm$$

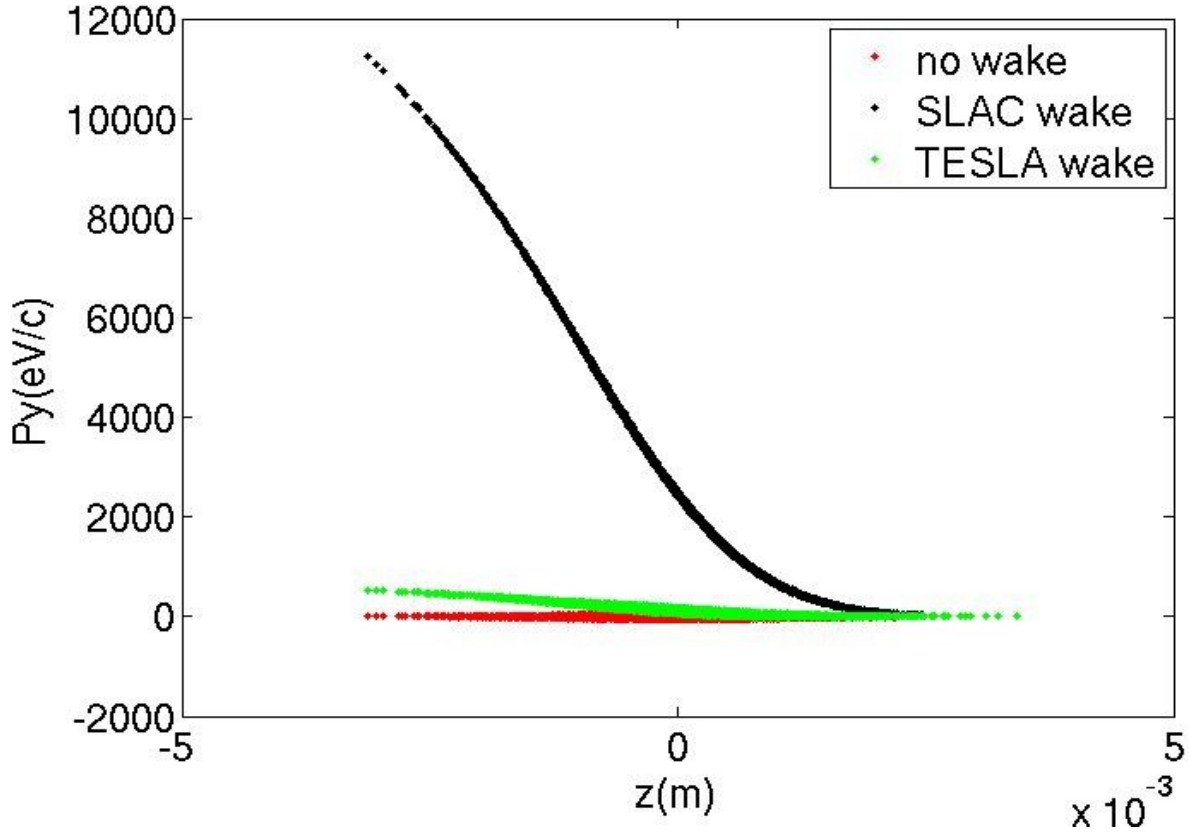
# Compare the Wake Function of TESTLA and SLAC Accelerating Structures



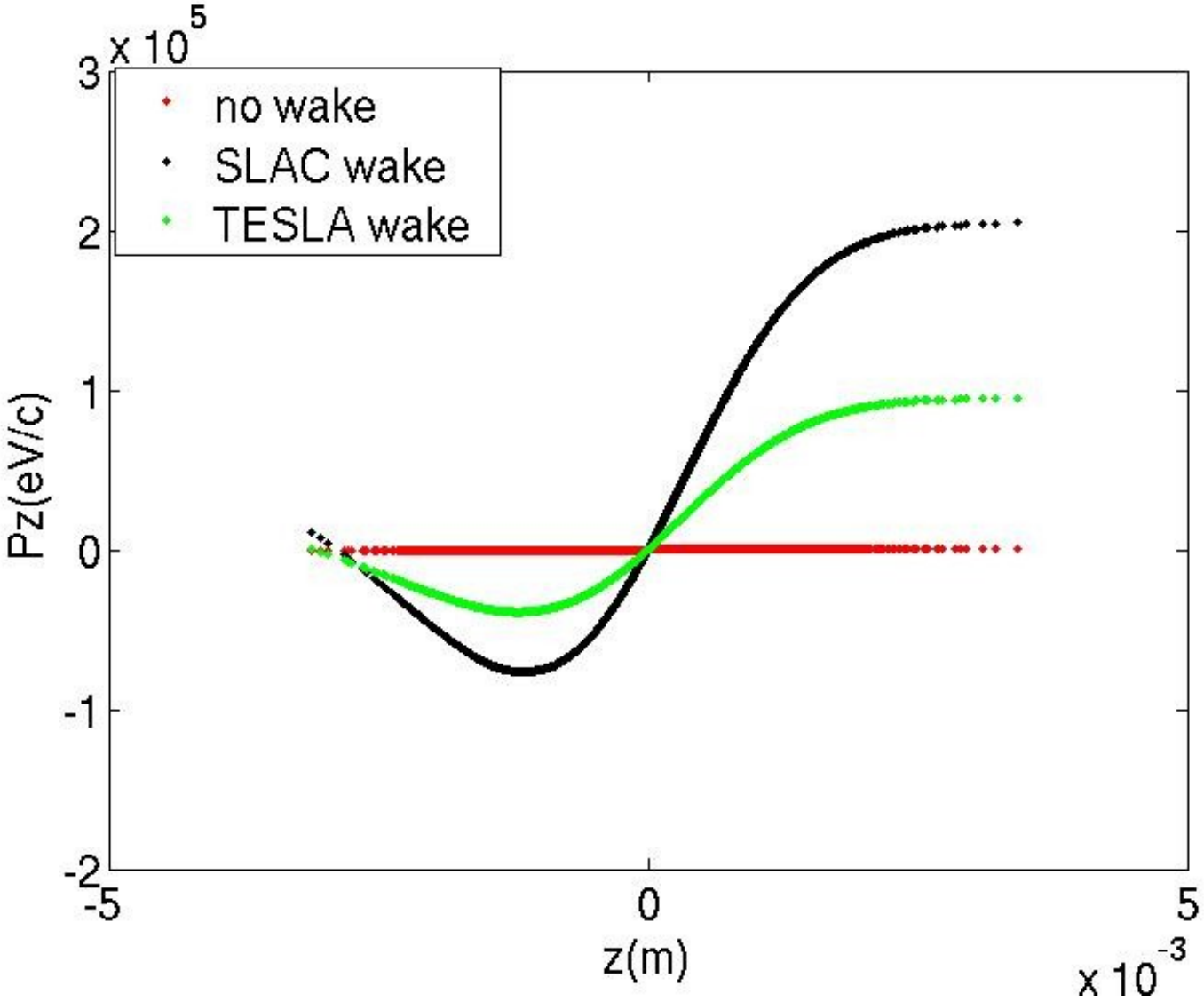



# Test of Transverse Wake in ASTRA

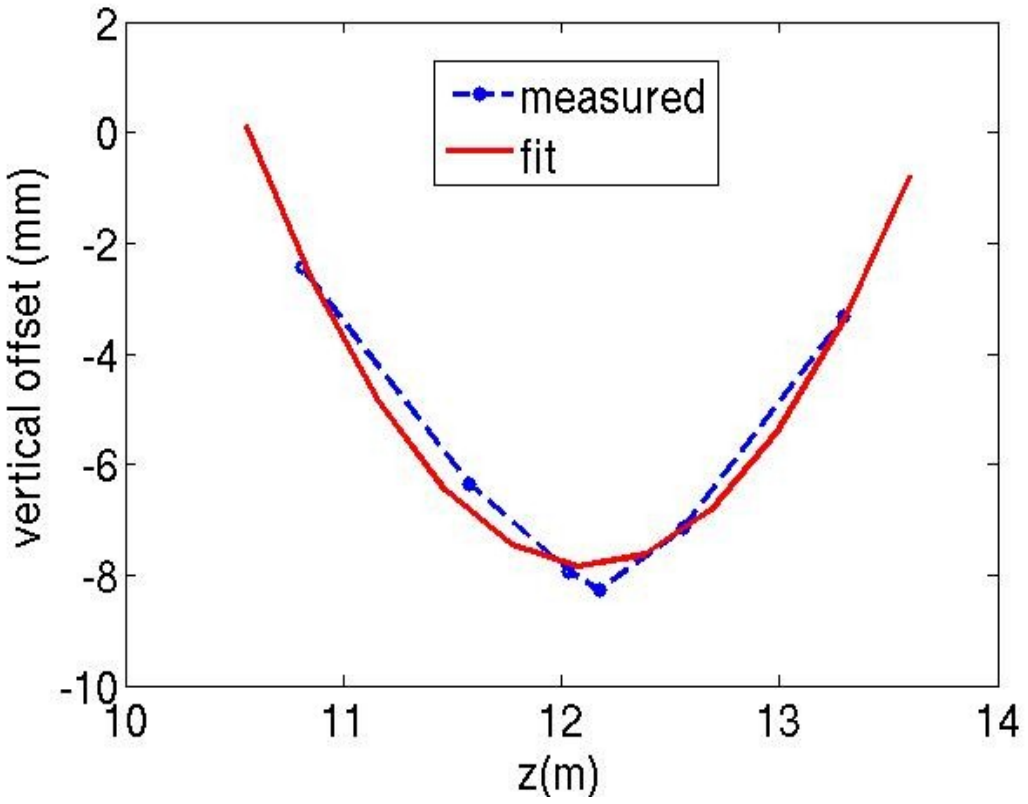
- Test beam: 2000 particles, 1mm rms in x, y and z; 1nC; 50MeV; 1mm offset in y.



# Test of Longitudinal Wake in ASTRA



# Survey of the L2:AS1: Large Vertical Offsets Along the 10ft-Long Structure

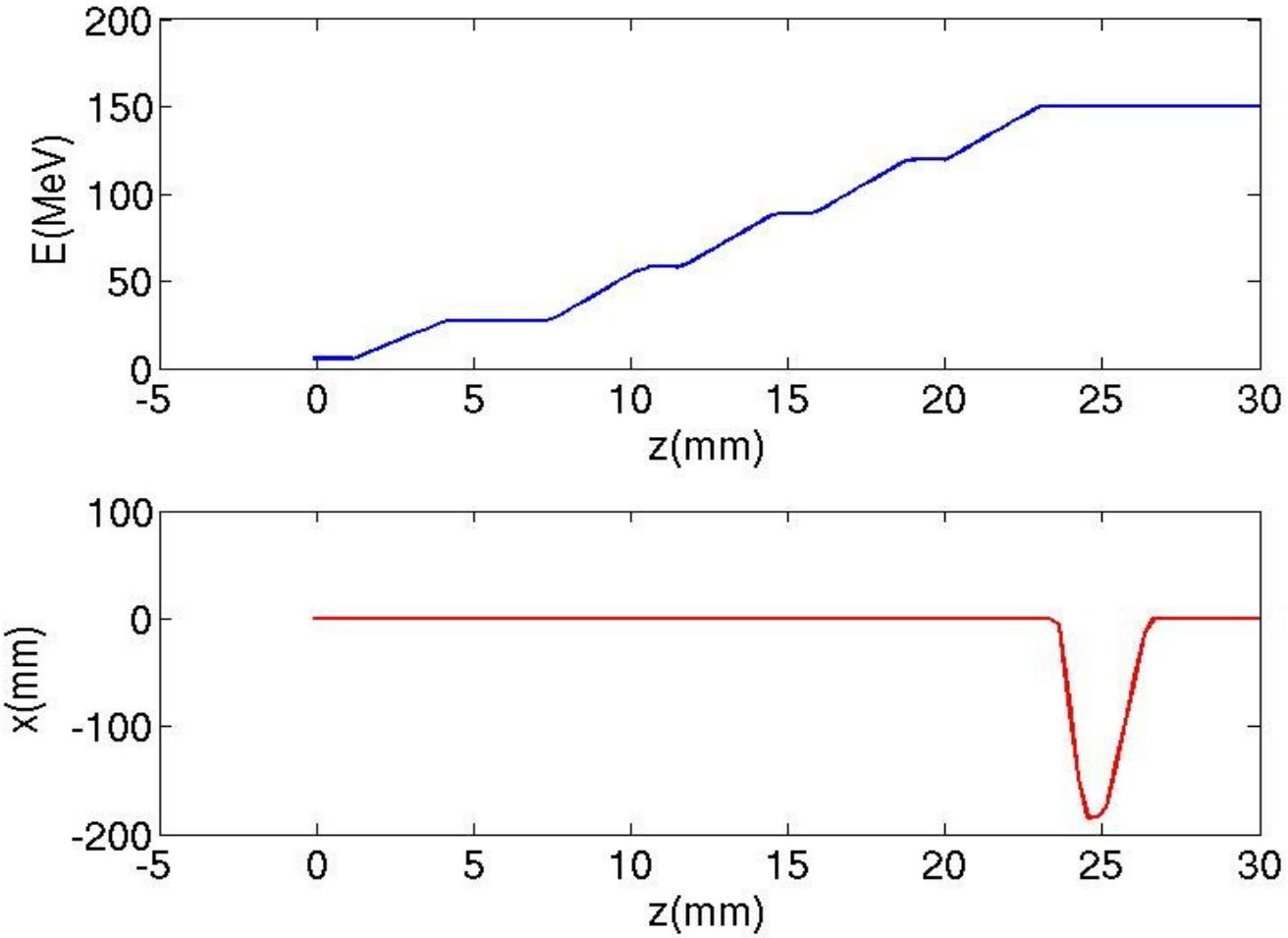



Survey Group measurement data can be retrieved from ICMS under APS_1435365 .

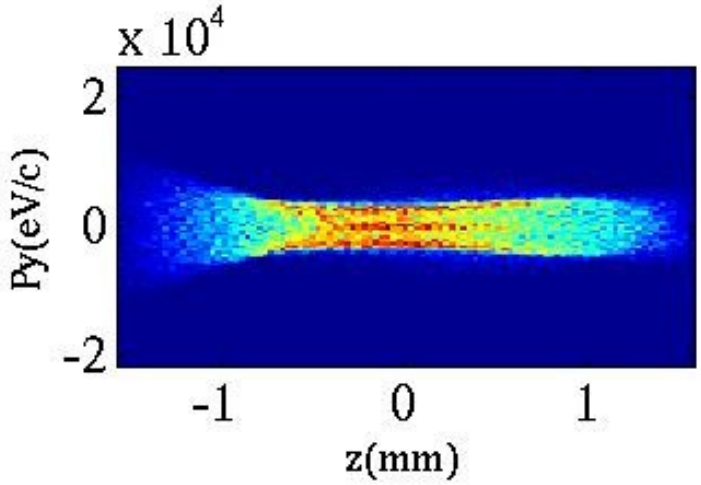
## Implementation in ASTRA

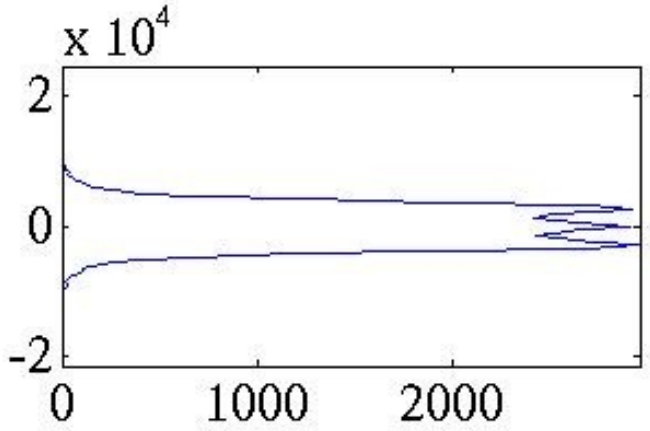
- Divide the 10-ft structure into 10 sections;
- Assign each section a y-offset using the fitted curve;
- Scale the wake field strength by a factor of 0.1 from the whole structure wake field map;
- Can be done but not included at this time: x-offset, divide each structure into more sections, adding L2:AS2 offsets etc.

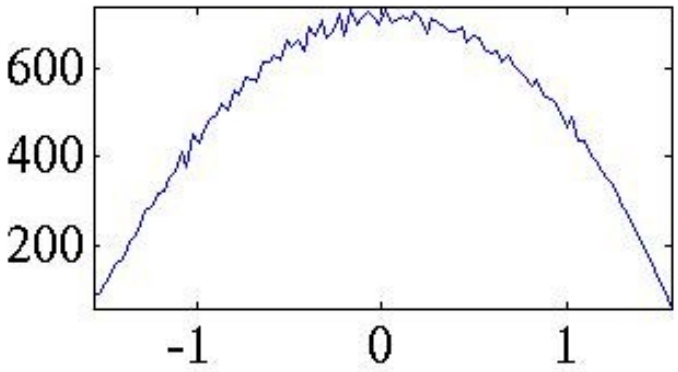
# APS LINAC Beam Line
# (Thanks to Chunxi Wang for the initial input deck).



# Without Wake Field: z-Py at the exit of L2:AS1 (Bunch charge 1 nC, 58 MeV, σz=0.71 mm)

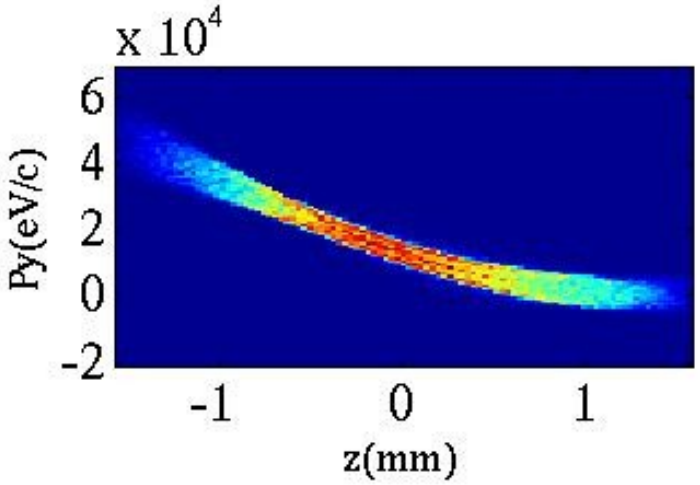


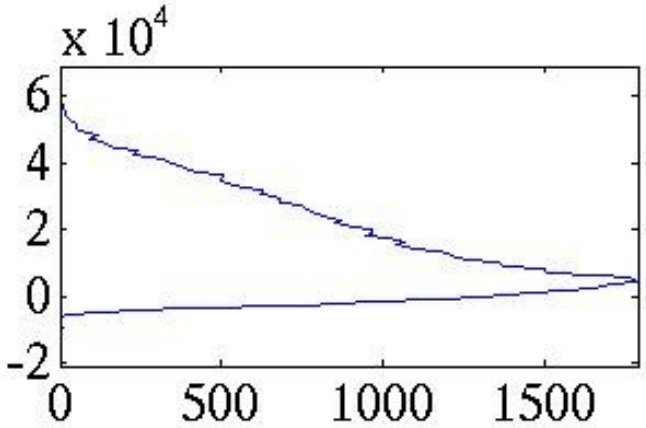



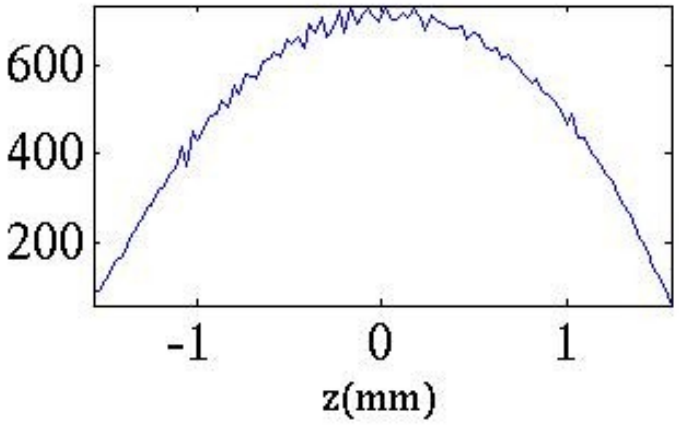




No correlation between Py & z.

# Transverse Wake Field Effects: z-Py at the Exit of L2:AS1 (Bunch charge 1 nC, 58 MeV, σz=0.71 mm)

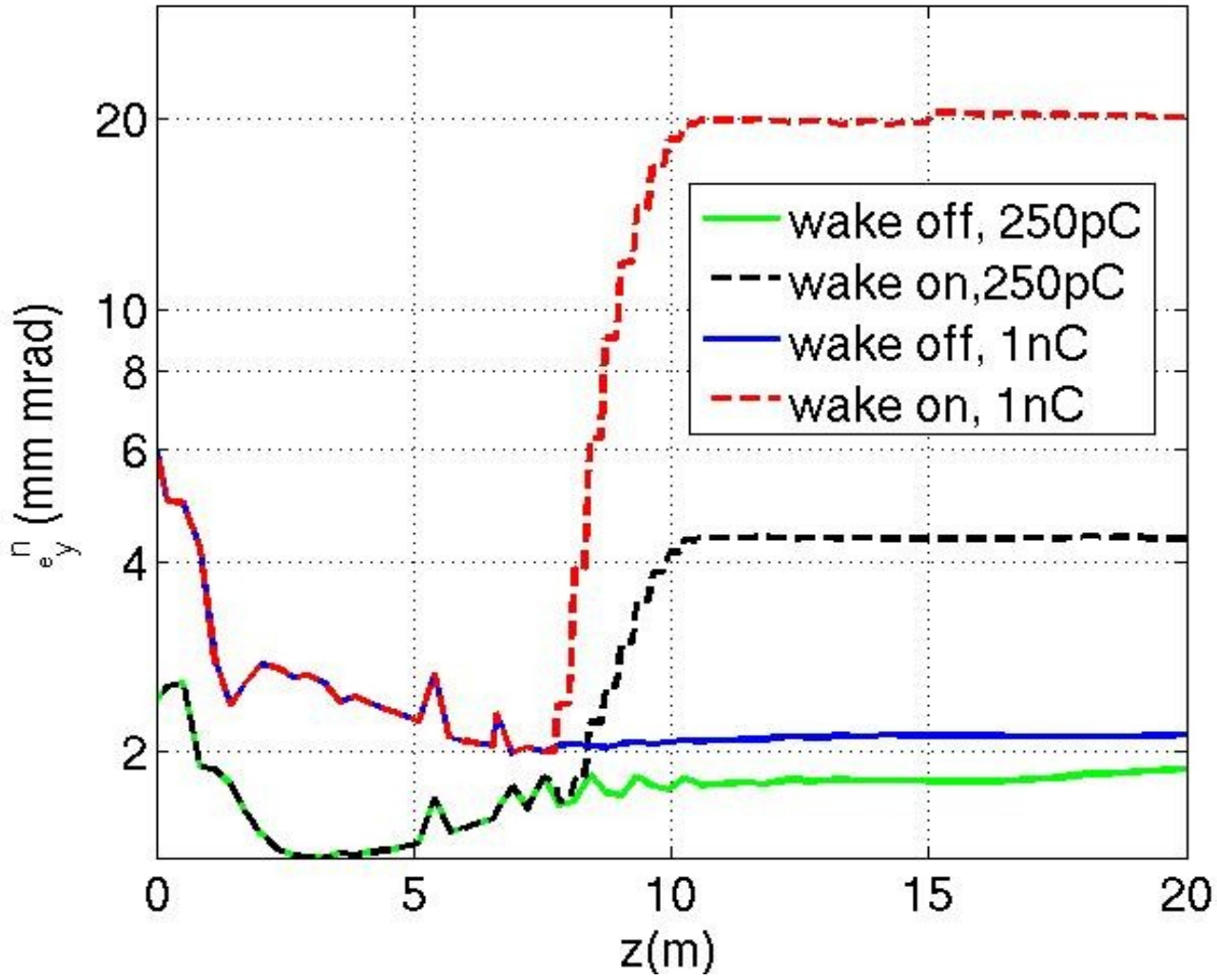



Correlation between Py & z as induced by vertical wake field due to the vertical offsets of L2:AS1 (a 10-ft long SLAC TWS).

# Effect on Vertical Emittance from the Transverse Wake from Misaligned L2:AS1

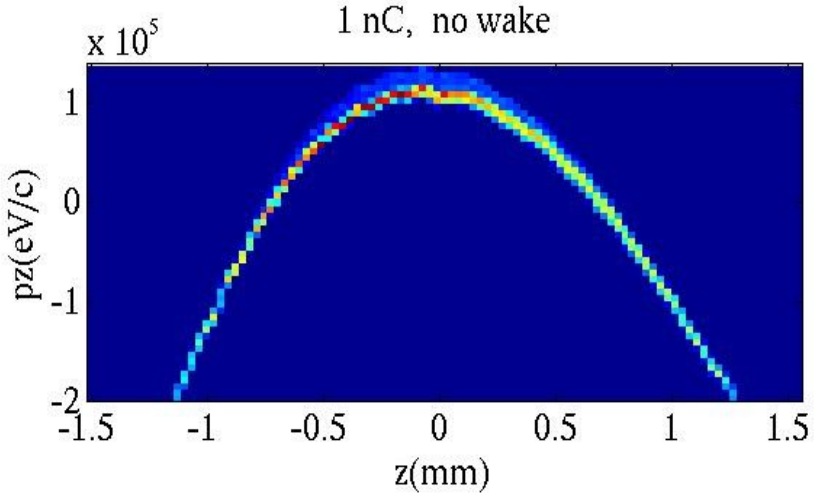


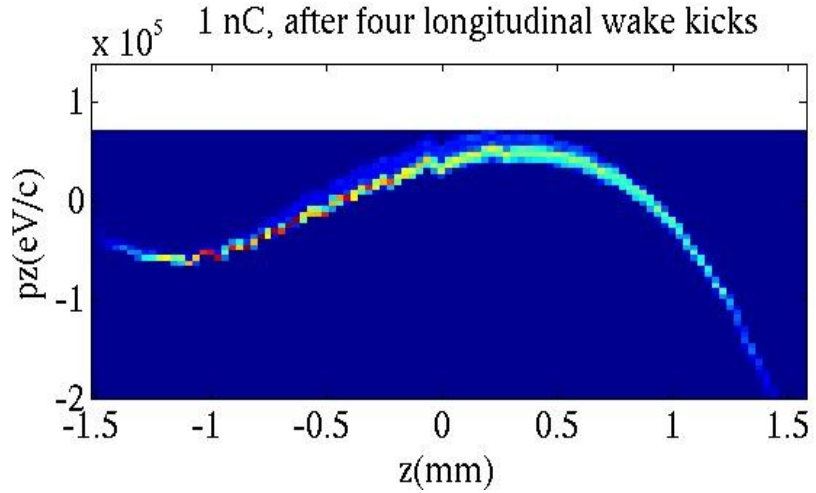

Vertical Emittance:

1nC: 2.1mm mrad
==>20.0 mm mrad

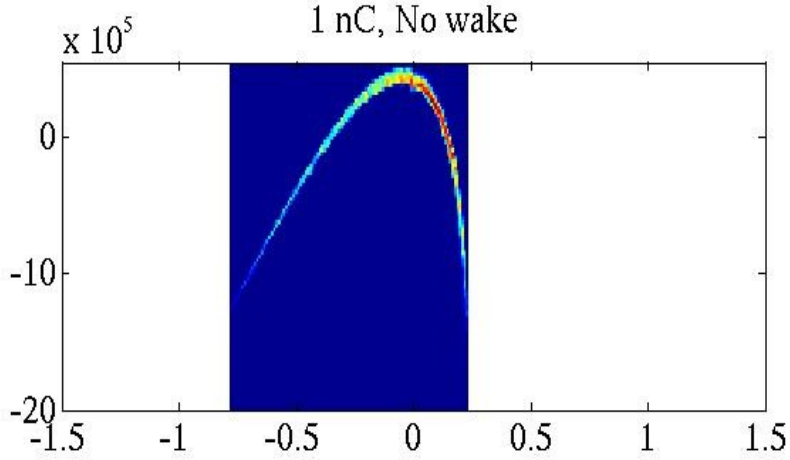
250pC: 4.4 mm mrad
==>19 mm mrad

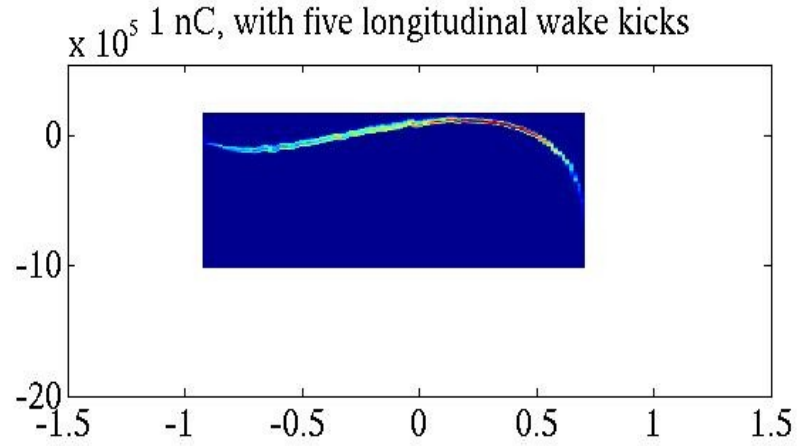
# Longitudinal Wake Effects on Bunch Compression
# Longitudinal phase-space (linear part is taken out)




Before Bunch Compression




After Bunch Compression

# Longitudinal Wake: one kick after each structure (5 total)

1.00nC: σ=0.24==>0.42 mm

0.25nC: σ=0.11==>0.17 mm