

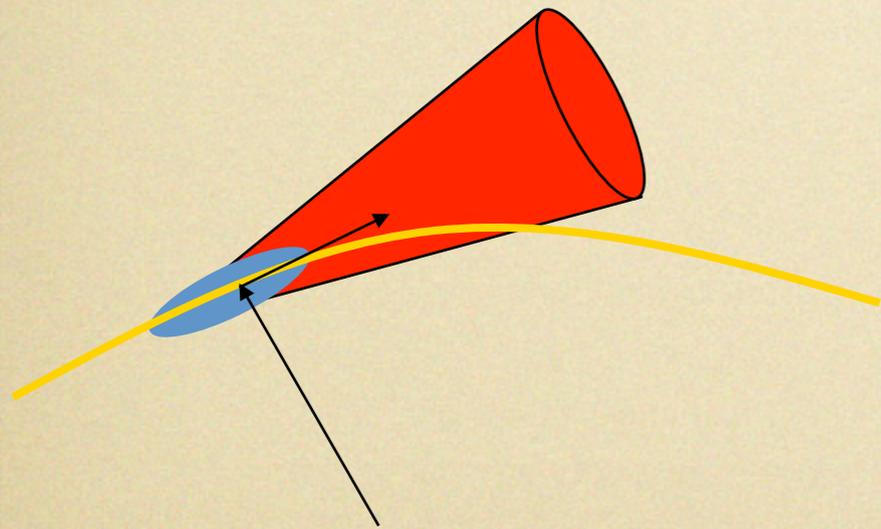
Experimental Demonstration  
of Suppression of Coherent  
Synchrotron Radiation  
Wake-field  
with pair of conductive  
plates

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# Coherent Synchrotron Radiation and its effect on the beam

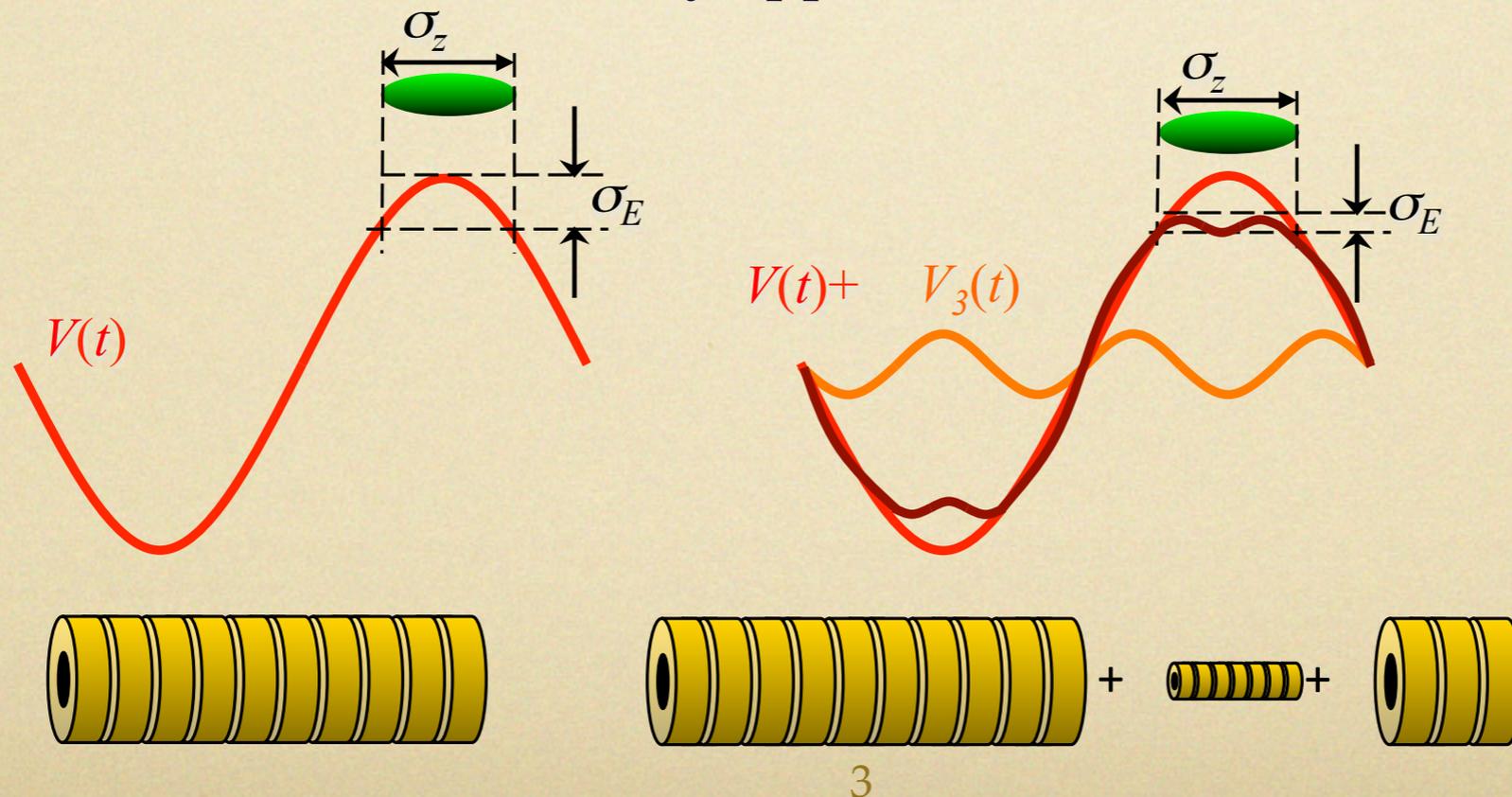
- The synchrotron radiation from multiple electrons is in phase, resulting in a quadratic dependence of the power emitted on the number of electrons, when the wavelength of radiation is comparable to the length of an electron bunch or the length of any structure on the bunch.
- Because the number of electrons participating in the coherence can be large, the potential power enhancement is very large, making coherent synchrotron radiation (CSR) a subject of great interest to both synchrotron users and accelerator designers.



- The interaction of an electron bunch and its synchrotron radiation begins when an electron bunch bends through a magnetic field and emits a cone of synchrotron radiation. Because of their bent trajectory, electrons in the front of the bunch sense a longitudinal component of the radiation field that can either accelerate or decelerate the electron, depending on its position.

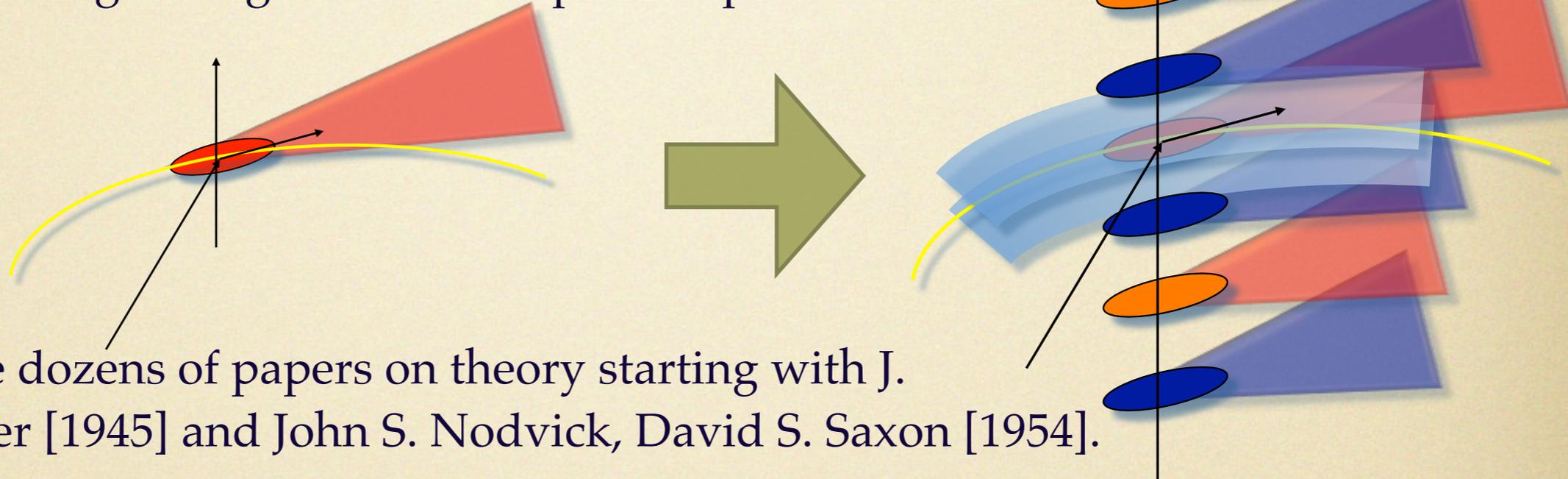
# Motivation

- CSR induced microwave instability is a limiting factor and were studied at many storage rings.
- Linacs are not restricted by the dynamic properties of storage rings and, therefore, can achieve an unprecedented electron beam brightness limited only by the electron gun. Coherent Synchrotron Radiation (CSR) can have and frequently has a detrimental effect on the quality of short intense electron bunches.
- Using longer electron bunches to suppress CSR may cause increase in energy spread due to RF curvature. Use of third harmonic cavity to flatten RF waveform would increase cost of linac by approx. 25%.



# Shielding plates to suppress CSR

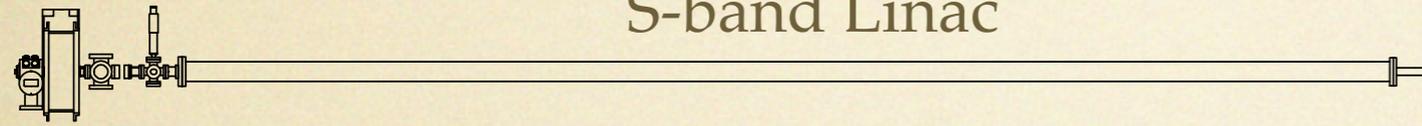
- The presence of a conducting walls can strongly change CSR wakefields. CSR wakefields suppression can be calculated by using the image charge method for parallel plates.



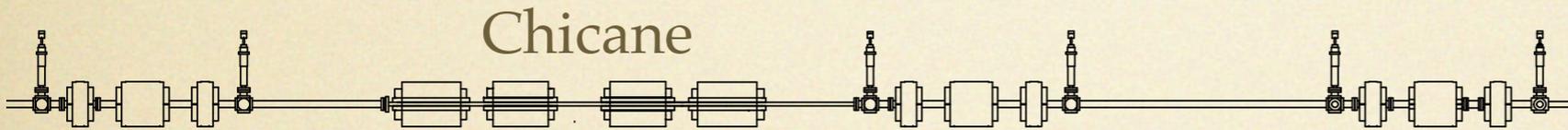
- There are dozens of papers on theory starting with J. Schwinger [1945] and John S. Nodvick, David S. Saxon [1954].
- Dedicated experiments to study CSR suppression demonstrated suppression of average energy loss:
  - The intensity of coherent synchrotron radiation was measured in the presence of finite parallel plate metallic shields with a variable gap by using the Tohoku 300 MeV Linac [1998].
  - Mean energy loss was studied at CTF-II [2001].

# Experimental layout

RF Gun



S-band Linac

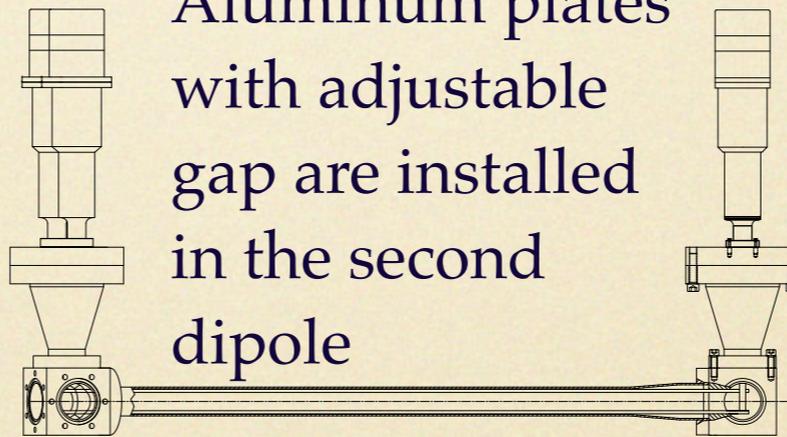


Chicane

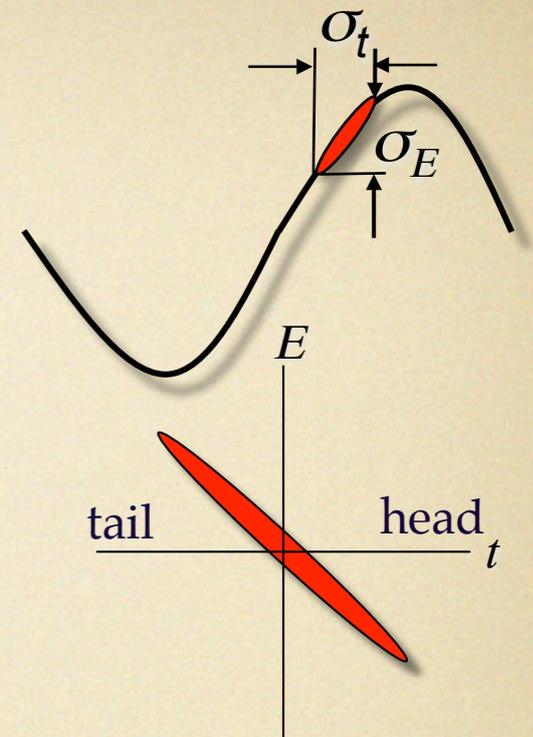
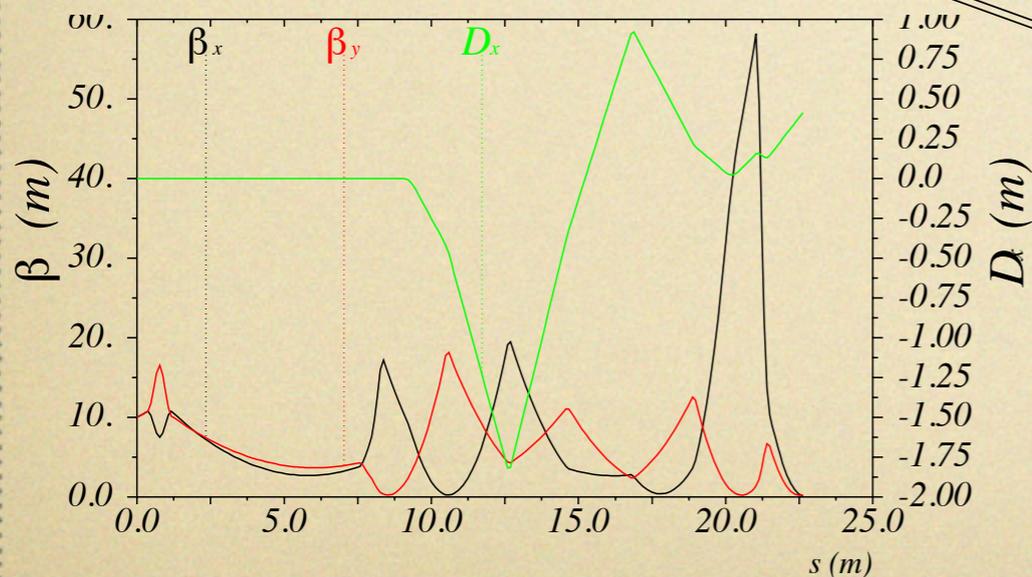
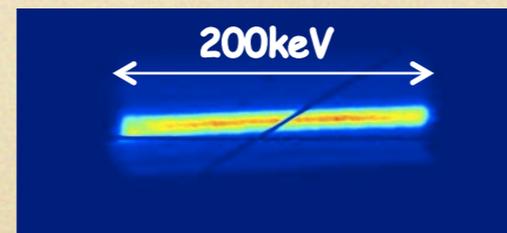
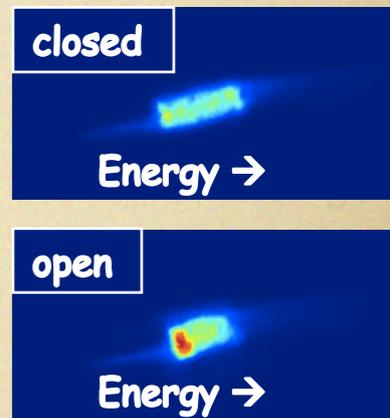
Energy collimator



Aluminum plates with adjustable gap are installed in the second dipole

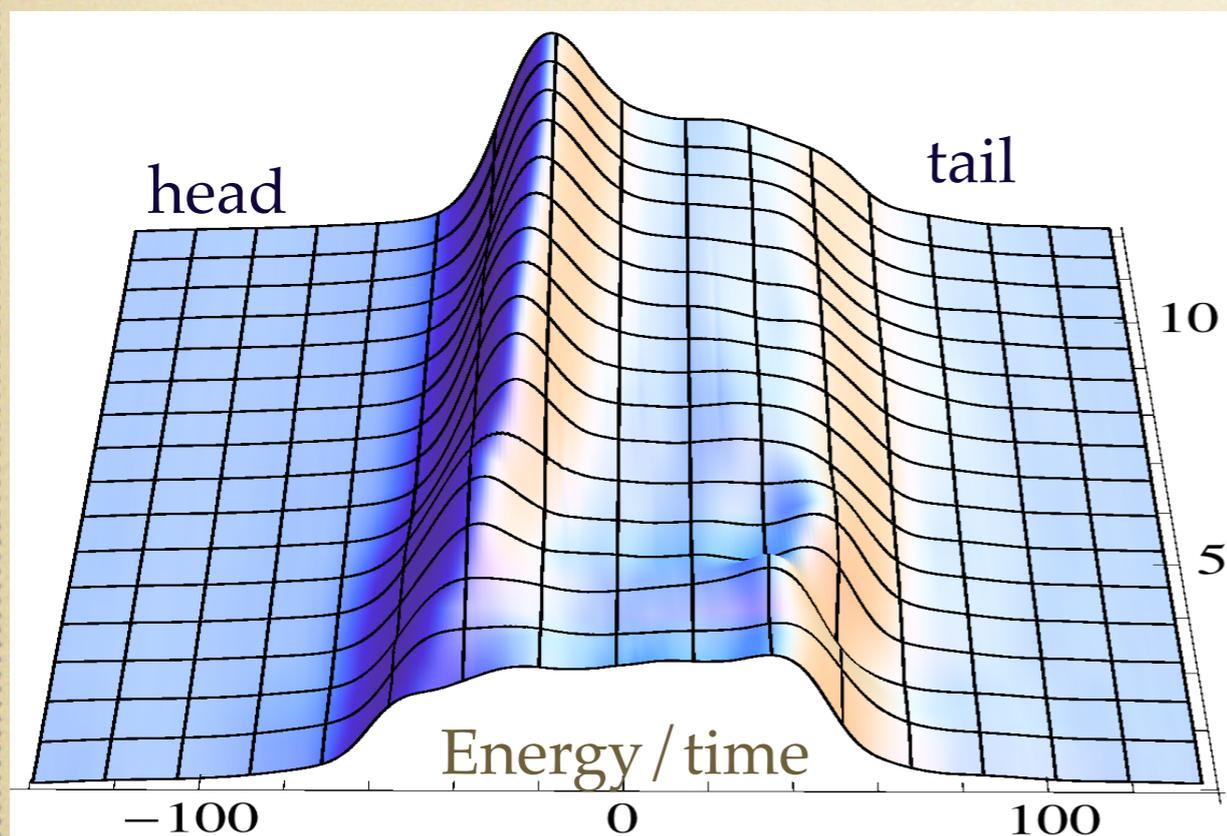


Energy spectrum after dipole with plates open and closed

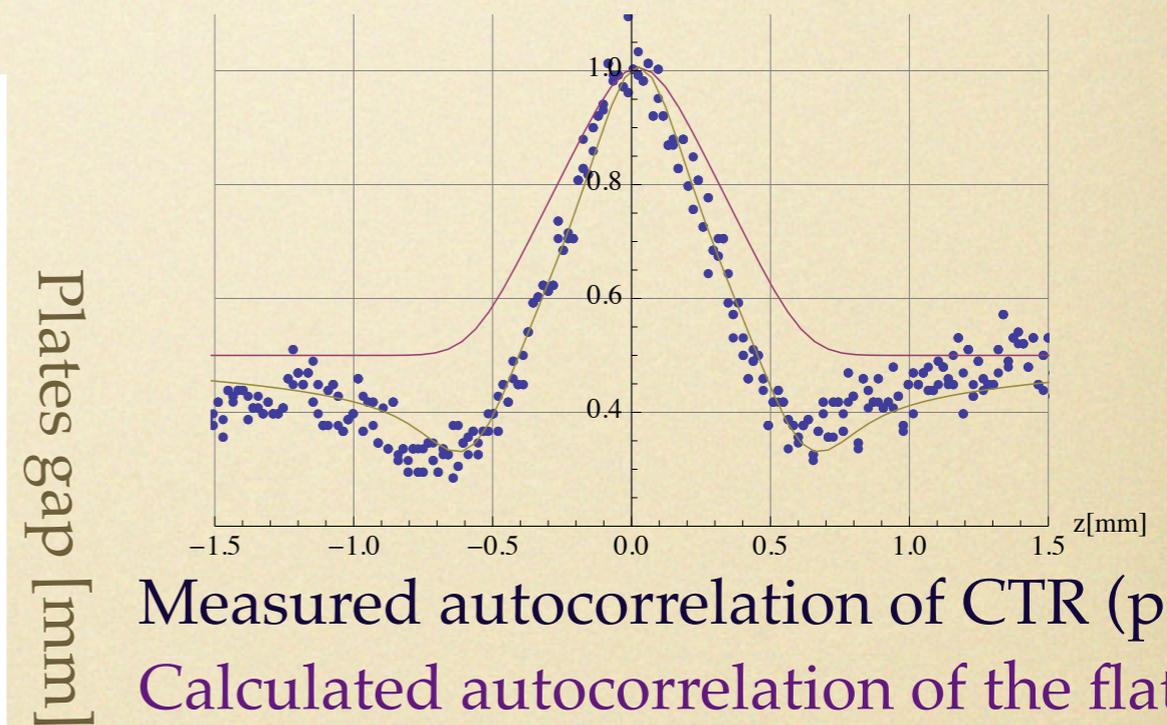


# Experimental results

- We studied changes in energy spectrum of 1.4 ps bunch (with correlated energy chirp) after its passing through dipole with shielding plates
- Relative energy variation at  $10^{-5}$  level was reliably measured to experimentally quantify CSR effect on the beam energy spread.



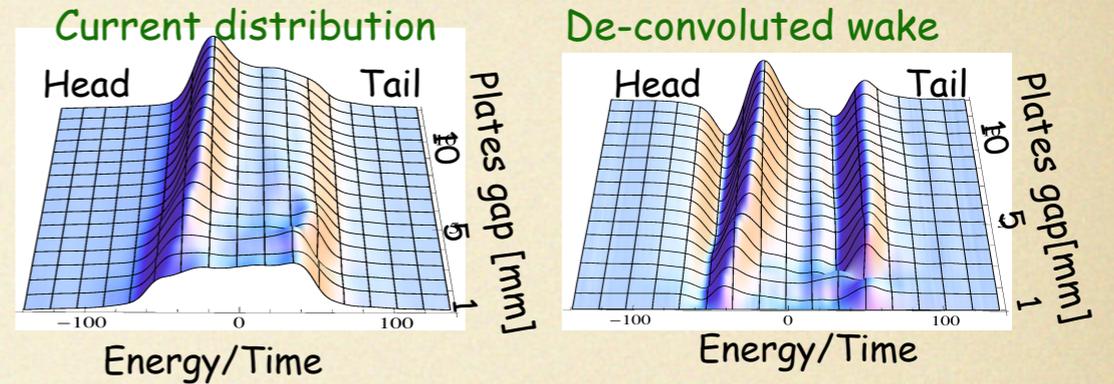
Measured beam energy spectrum as function of the gap between the shielding plates



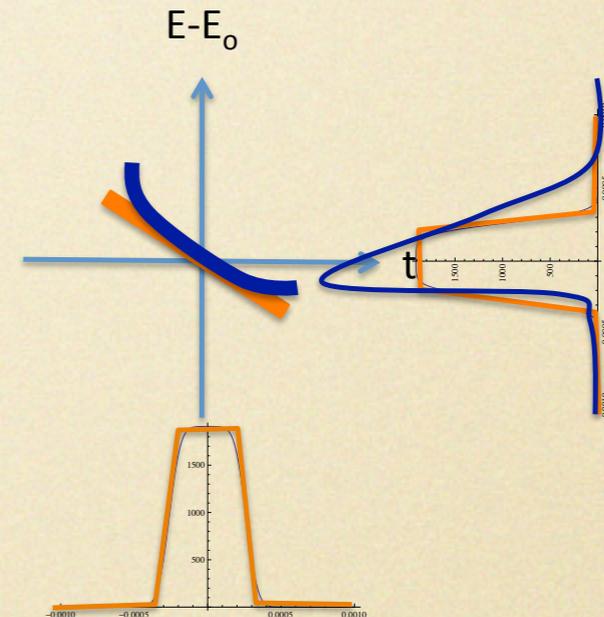
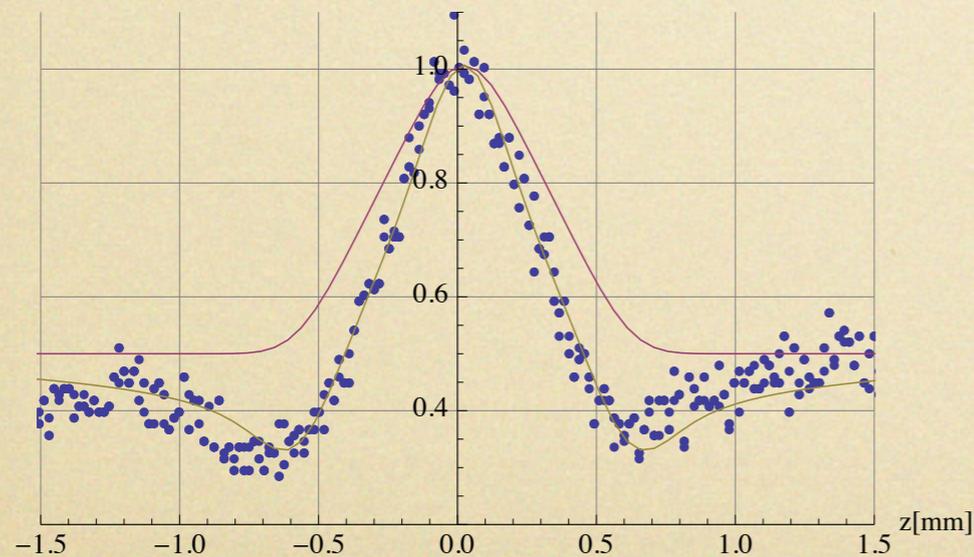
Measured autocorrelation of CTR (points).  
Calculated autocorrelation of the flat-top 600micron long (FWHM) pulse with 50 microns rise / fall (violet line).  
Calculated autocorrelation with low frequency cut-off is similar to the measured (brown line).

# Experimental Challenges

- Proper data analysis:
  - Use local energy variation instead of RMS values for energy spread change due to CSR



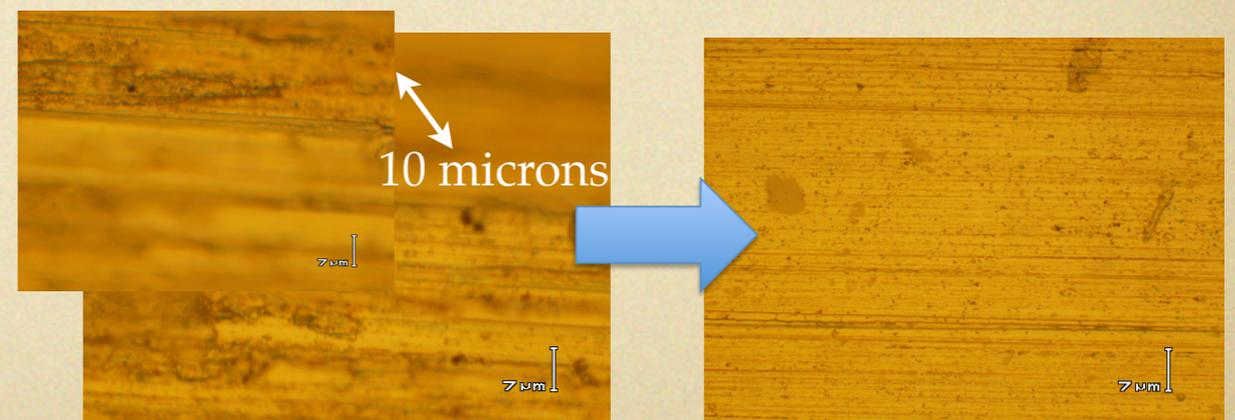
- Frequency filtering in CTR interferogram to understand pulse duration



Measured autocorrelation of CTR (points).  
 Calculated autocorrelation of the flat-top 600micron long (FWHM) pulse with 50 microns rise / fall (violet line).  
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# Experimental Challenges

- Beam stability:
  - temperature stabilization
  - RF phase feed back loops
  - cutting out slice of the beam with same energy
  - taking data on a rainy Friday after 6pm...
- 100% charge transmission through 70 cm long plates closed to 1mm gap:
  - low emittance
  - precise compensation of vertical dispersion
- Surface roughness:
  - Use of mirror polished Al plates

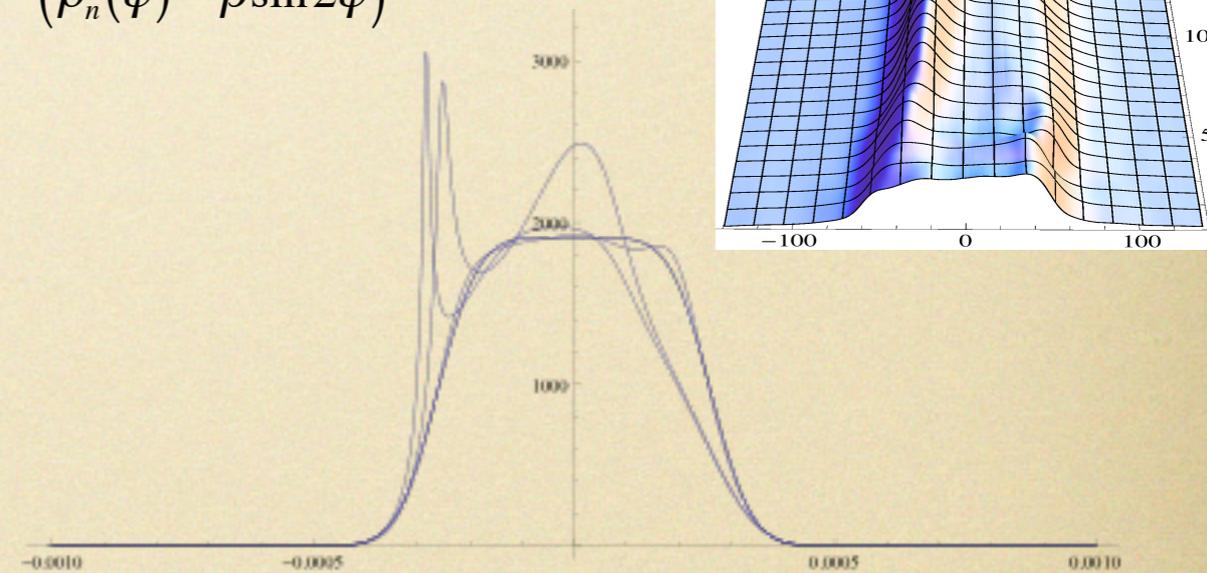
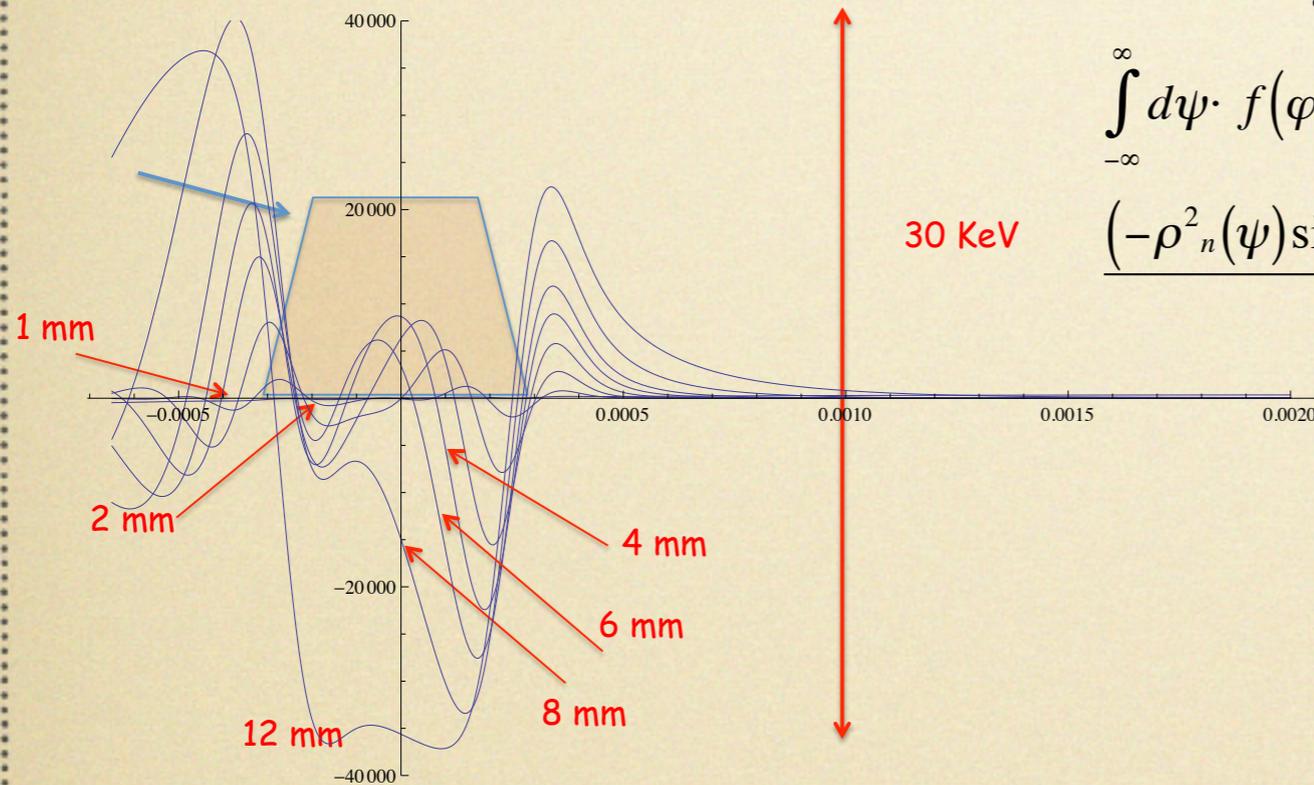


# Comparison to theory

The simple geometry of two parallel conducting plates allows for the derivation of an exact analytical expression for the CSR wake-field for an arbitrary longitudinal bunch profile. Using classical expressions for the retarded radiated field\*, one can express the total longitudinal CSR wake-field as:

$$W(\varphi) = \frac{2e\beta^2}{R_o^2} N_e \sum_{n=-\infty}^{\infty} (-1)^n \cdot \rho_n(\psi) = \sqrt{4 \sin^2 \psi + n^2 h^2 / R_o^2}$$

$$\int_{-\infty}^{\infty} d\psi \cdot f(\varphi - 2\psi + \beta\rho_n(\psi)) \cdot \left( 1 - \beta \frac{\sin 2\psi}{\rho_n(\psi)} \right) \cdot \frac{(-\rho_n^2(\psi) \sin 2\psi + 2 \sin^2 \psi \rho_n(\psi) \beta + 4 \cos \psi \sin^3 \psi)}{(\rho_n(\psi) - \beta \sin 2\psi)^3}$$



CSR wake-field as the function of the gap between the plates. The vertical scale is 0.38 eV per unit, the horizontal scale is in radians.

Simulations of the beam energy spectrum dependence on the gap between the plates: the two distributions with “horns” are for 12 and 8 mm gaps. The two others are for 1 and 2 mm gaps.

\*L.D. Landau and E.M. Lifshitz, “The Classical Theory of Fields”, Pergamon Press, Fourth Edition, 1975, p. 162, formula (63.8)

# Conclusion

- We presented clear experimental observation of suppression of the longitudinal CSR wake in a dipole magnet by two conducting plates.
- At very small gaps we observed the suppression of both the energy loss and the **energy spread** induced by CSR.
- Our analytical results are in good agreement with observations.

# Acknowledgments

- We would like to thank Ilan Ben-Zvi for his encouragement of this work.
- ATF staff for help with installation.
- Work supported by supported by Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH10886 with the U.S. Department of Energy

