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

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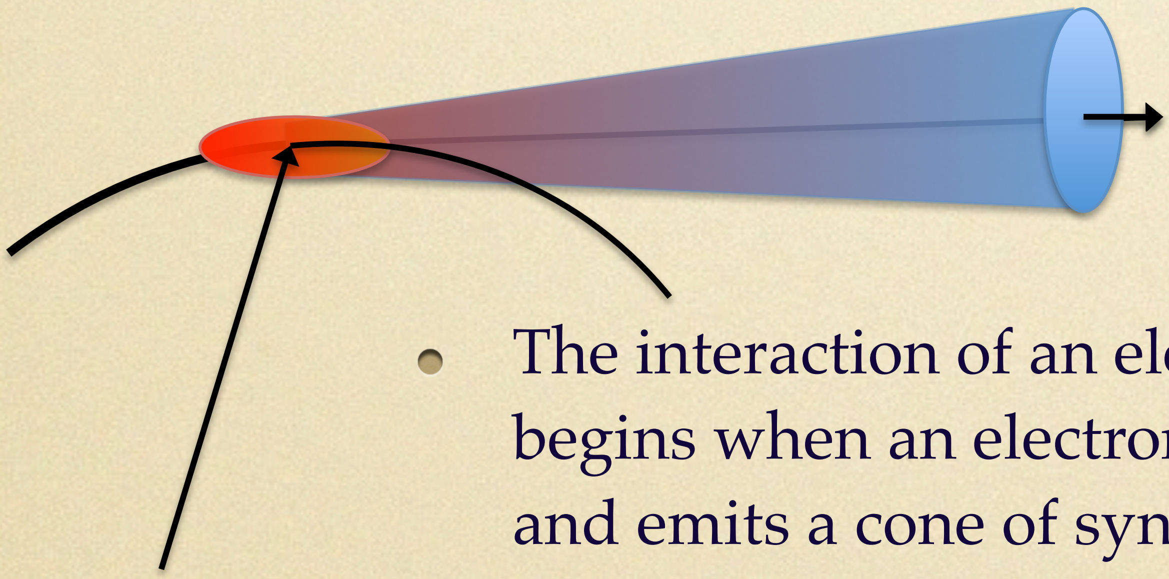
Coherent Synchrotron Radiation and its effect on the beam

- 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.



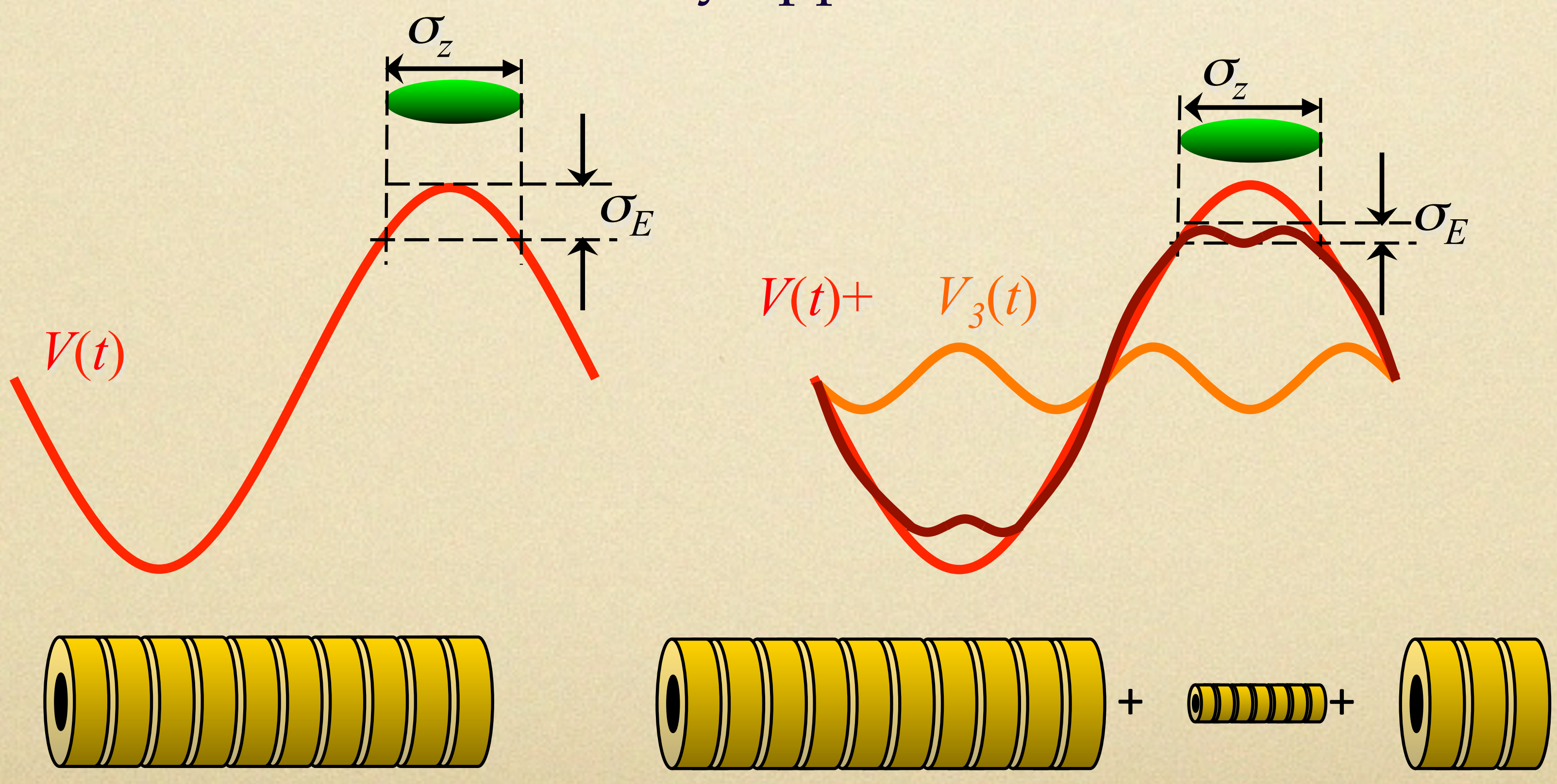
- The interaction of an electron bunch and its synchrotron radiation begins when an electron bunch bends through a magnetic field and emits a cone of synchrotron radiation. Because of their bent trajectory, electrons in the front of the bunch sense a longitudinal component of the radiation field that 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 increases cost of linac by approx. 25%.



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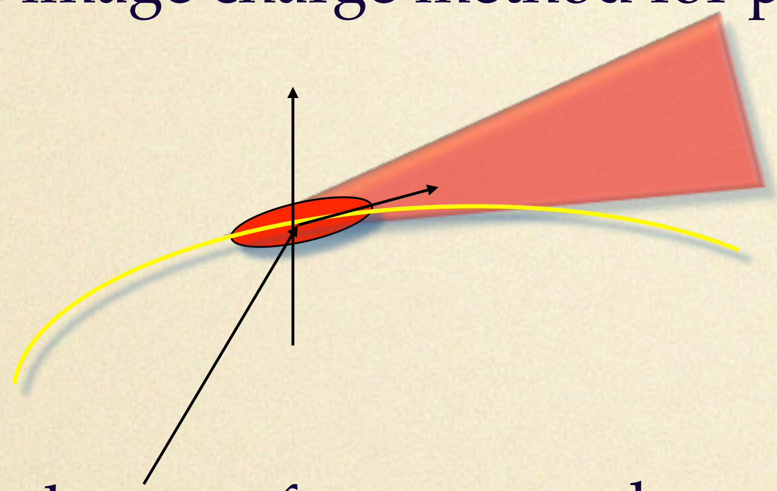
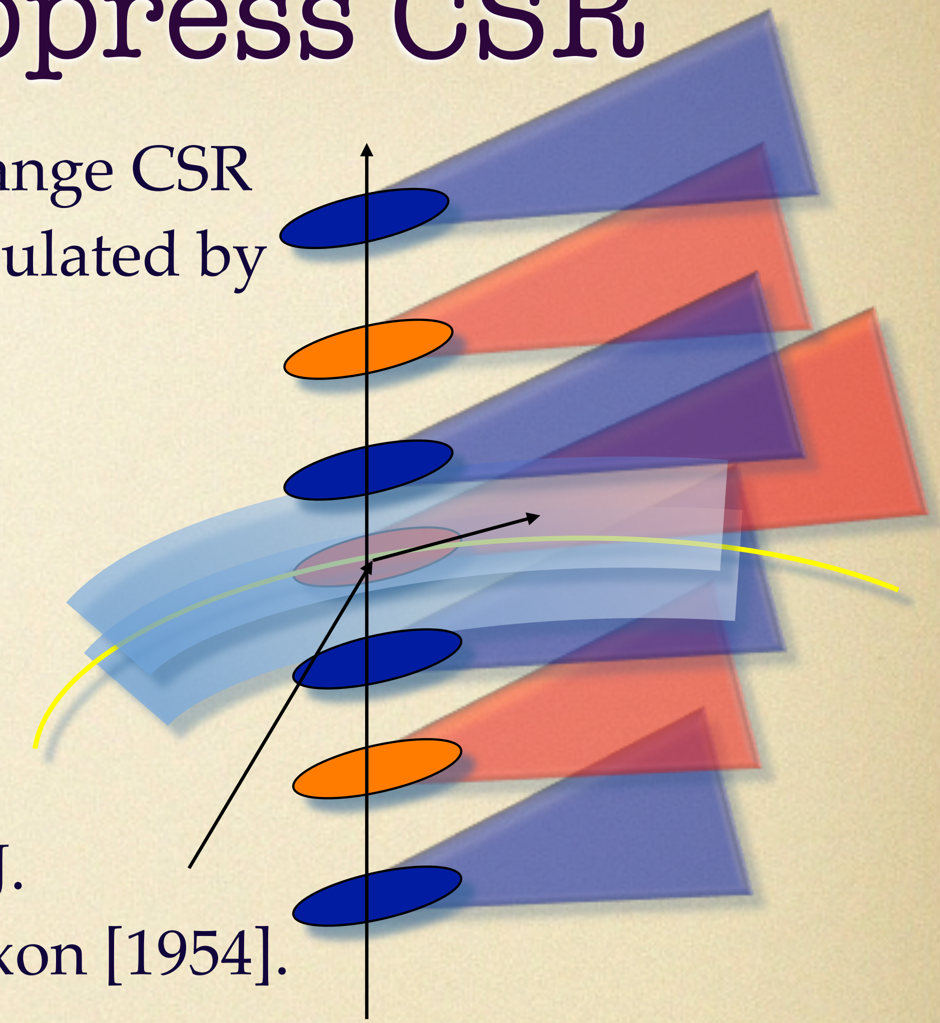
Shielding plates to suppress CSR

- 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].

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Wakefield calculations

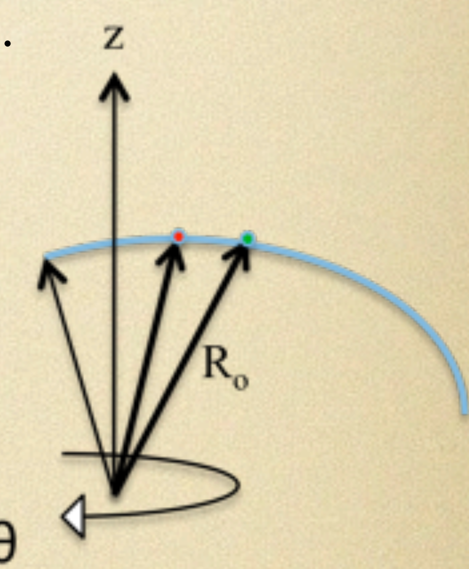
The simple geometry of two parallel conducting plates allows for the derivation of an exact analytical expression for the CSR wake-field for an arbitrary longitudinal bunch profile.

$$f(\varphi);\ \varphi = (s - s_o)/R_o$$

Using classical expressions for the retarded radiated field*, one can express the total longitudinal CSR wake-field as:

$$W(\varphi) = \frac{2e\beta^2}{R_o^2} N_e \sum_{n=-\infty}^{\infty} (-1)^n \int_{-\infty}^{\infty} d\psi \cdot f\left(\varphi - 2\psi + \beta\rho_n(\psi)\right) \cdot \left(1 - \beta \frac{\sin 2\psi}{\rho_n(\psi)}\right) \cdot$$

$$\frac{\left(-\rho_n^2(\psi)\sin 2\psi + 2\sin^2\psi\rho_n(\psi)\beta + 4\cos\psi\sin^3\psi\right)}{\left(\rho_n(\psi) - \beta\sin 2\psi\right)^3}$$



and

$$\rho_n(\psi) = \sqrt{4\sin^2\psi + n^2h^2/R_o^{\ 2}}$$

is dimensionless distance between the radiation and the observation point, where *n* in the image number of the reflection in the plates and *h* is the full gap between the plates.

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

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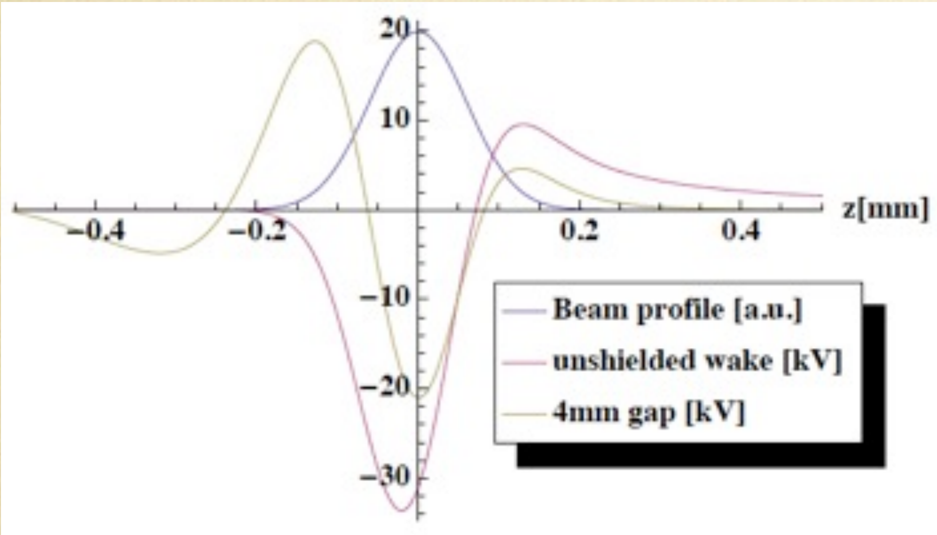
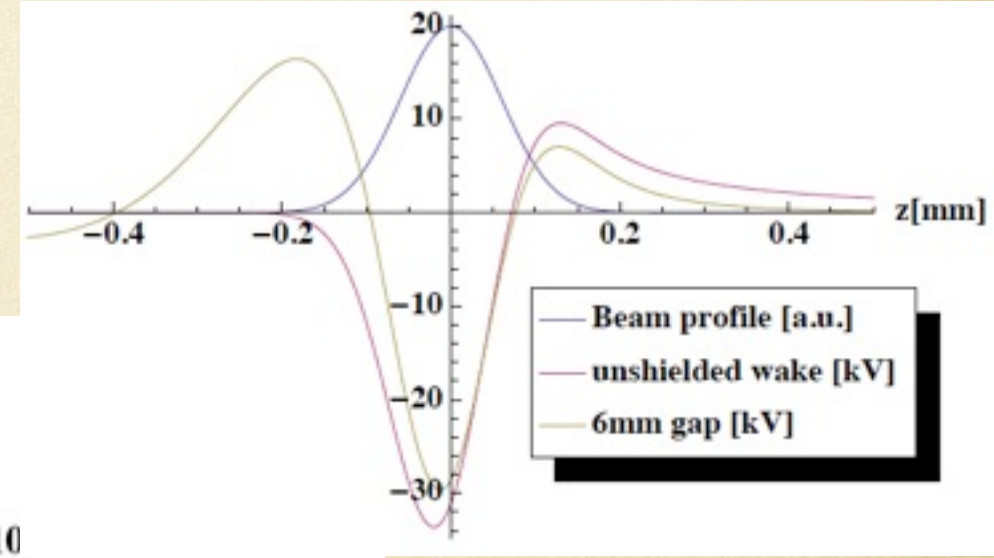
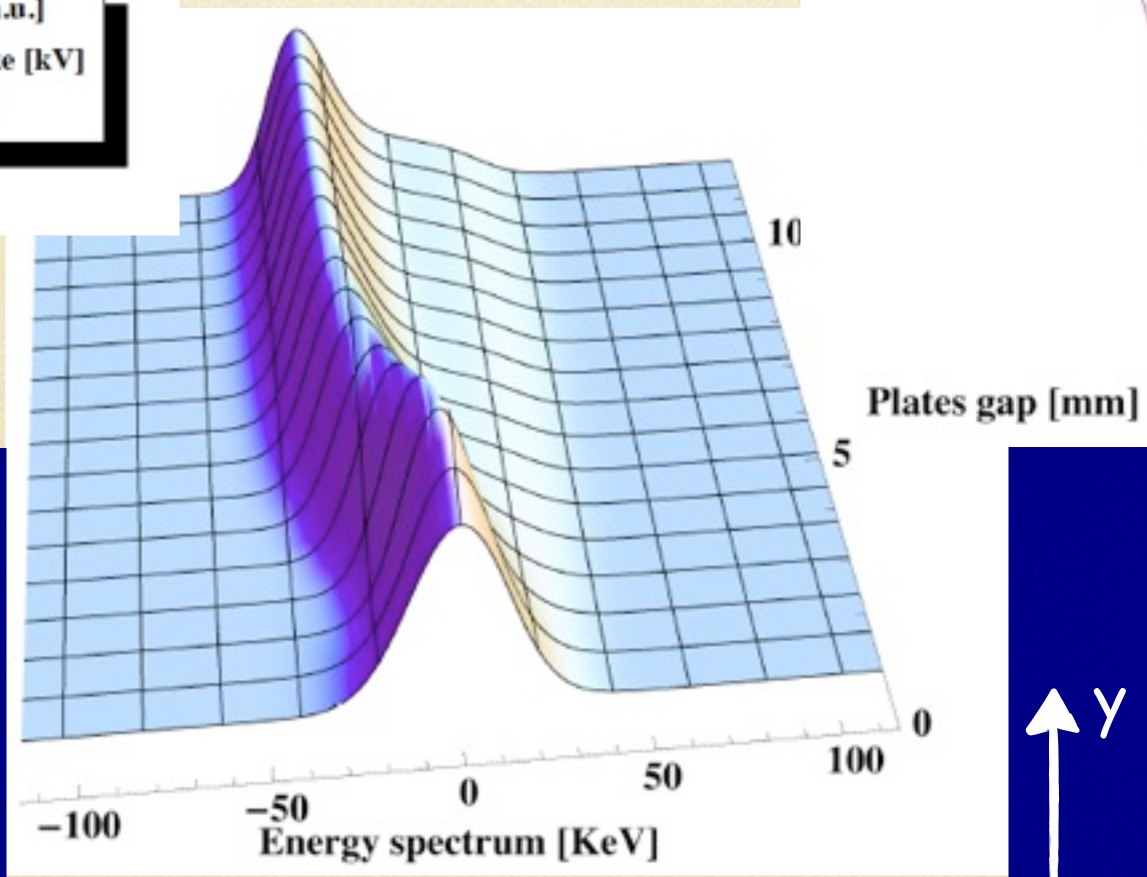
Suppression of Energy loss

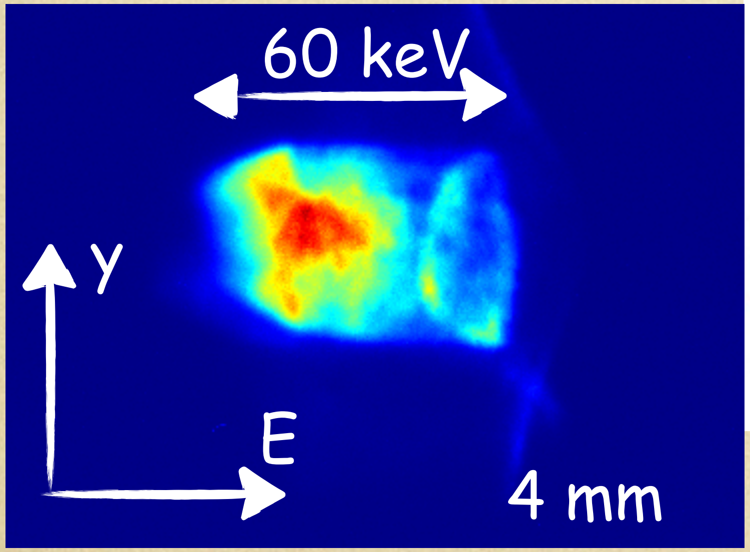
- Good agreement between theory and experiment was seen in our experiment as well in prior experiments
- Beam with no correlated energy chirp (0.3ps long) was used in this measurement



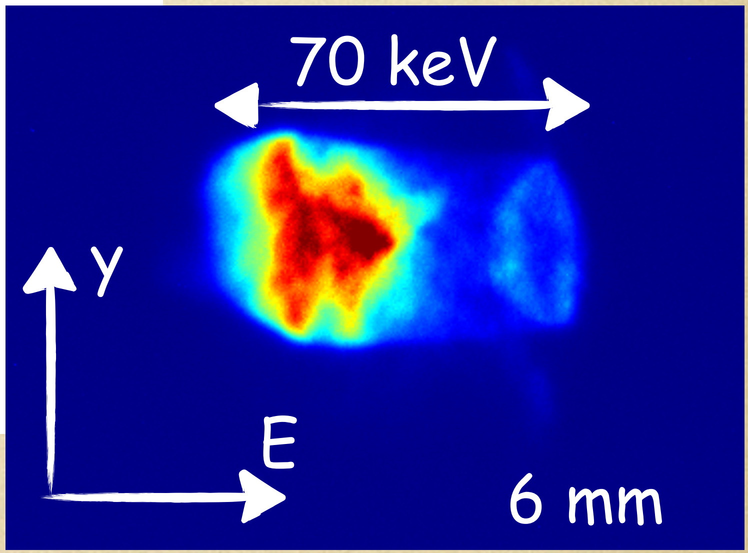




Energy spectrum plates at 4 mm gap



Energy spectrum plates at 6 mm gap



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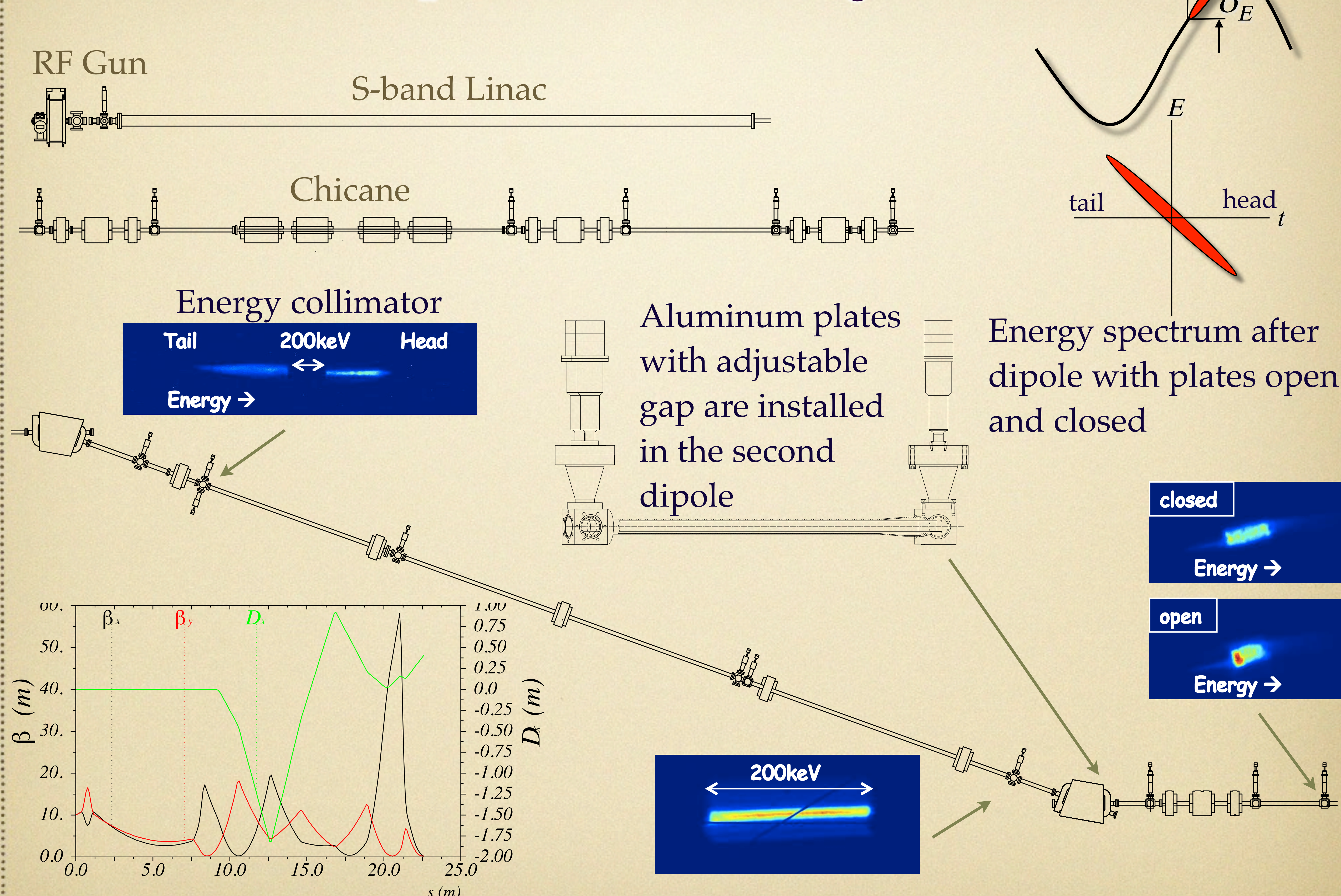
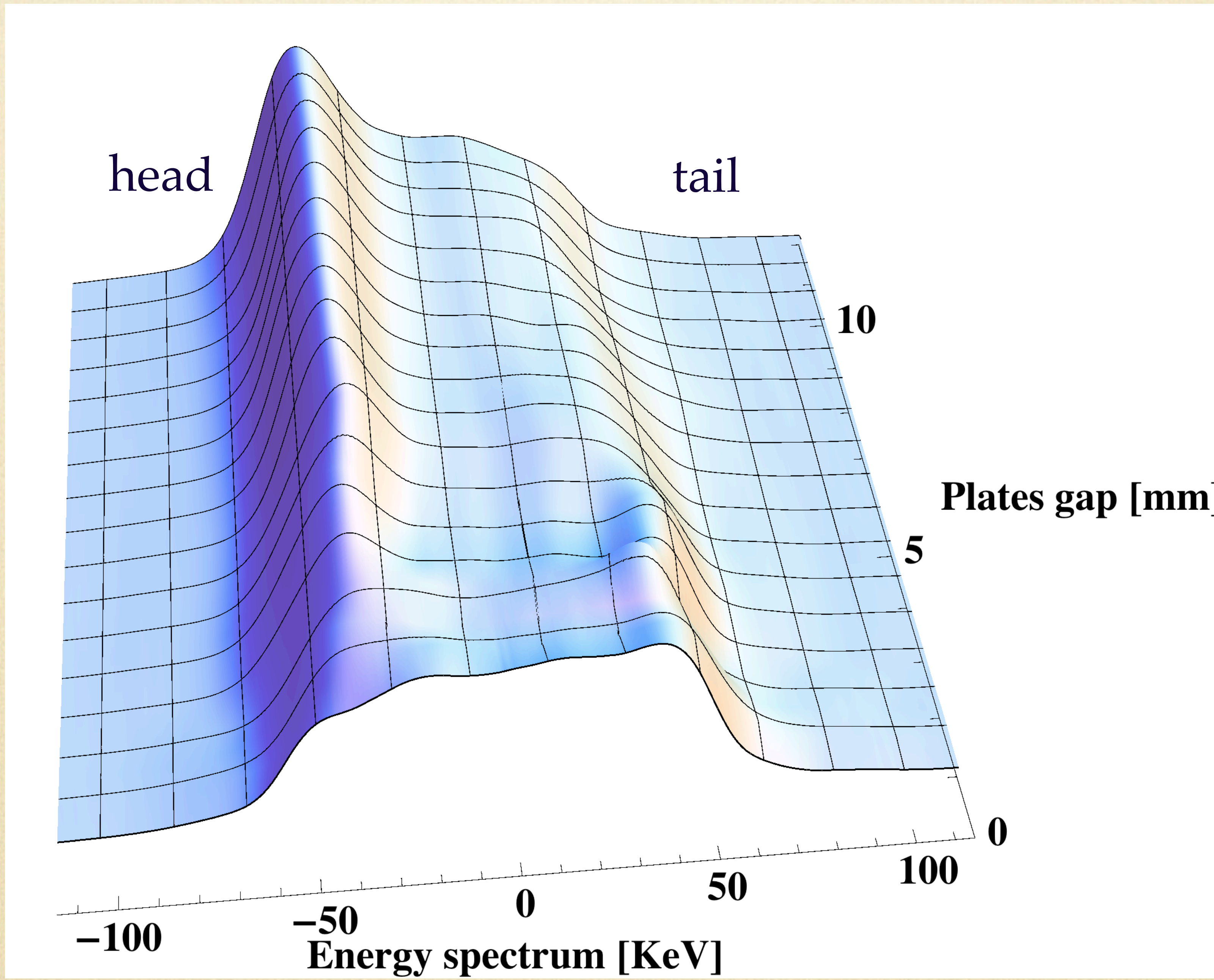
Experimental layout



Experimental results

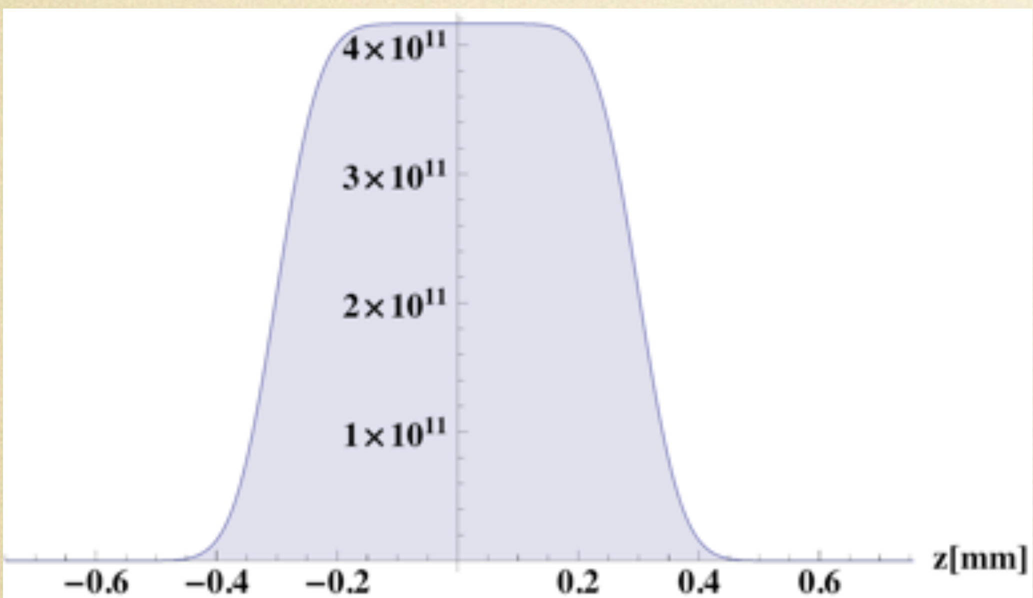
Measured beam energy spectrum as function of the gap between the shielding plates



Energy / time

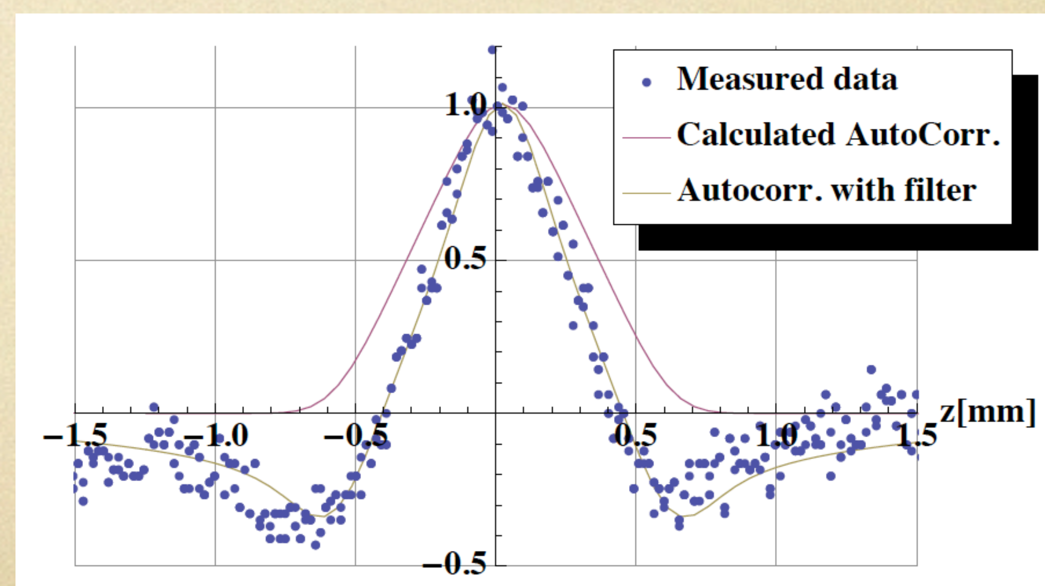
Experimental results

- 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.



Deducted beam distribution in time. This distribution was used to simulate CSR Wakefields.

Measured autocorrelation of CTR (points).
Calculated autocorrelation of the flat-top 600 μm long (FWHM) pulse with 80 μm rise/fall (violet line).
Calculated autocorrelation with low frequency cut-off is similar to the measured (brown line).



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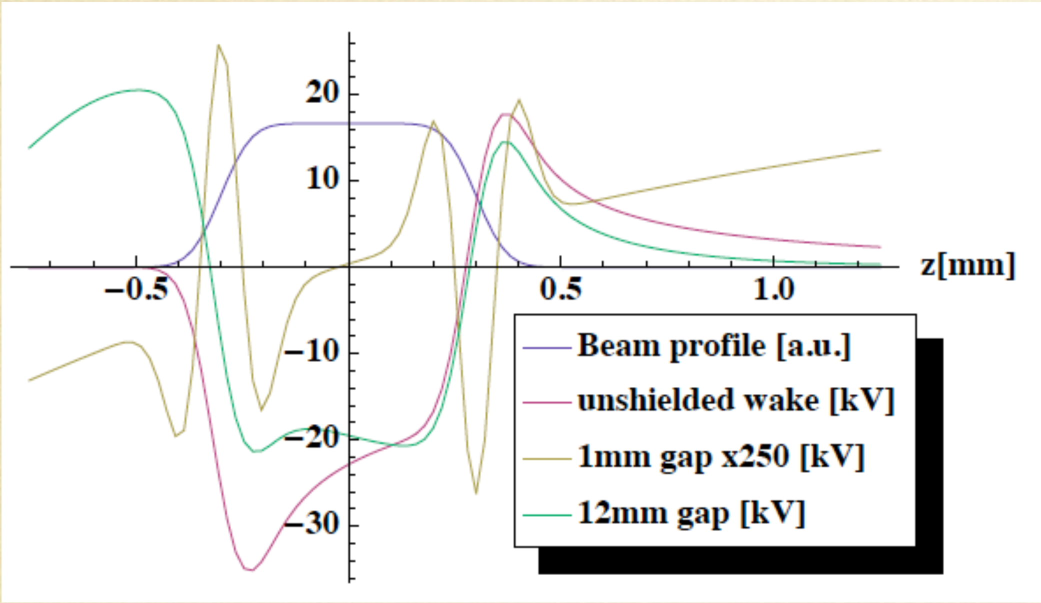
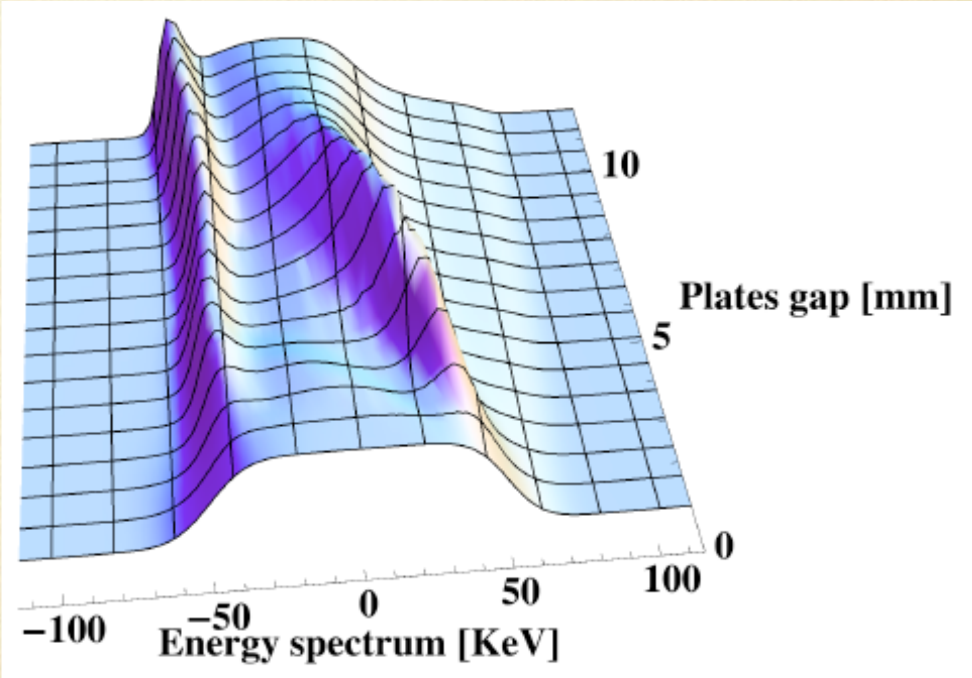
Simulations results

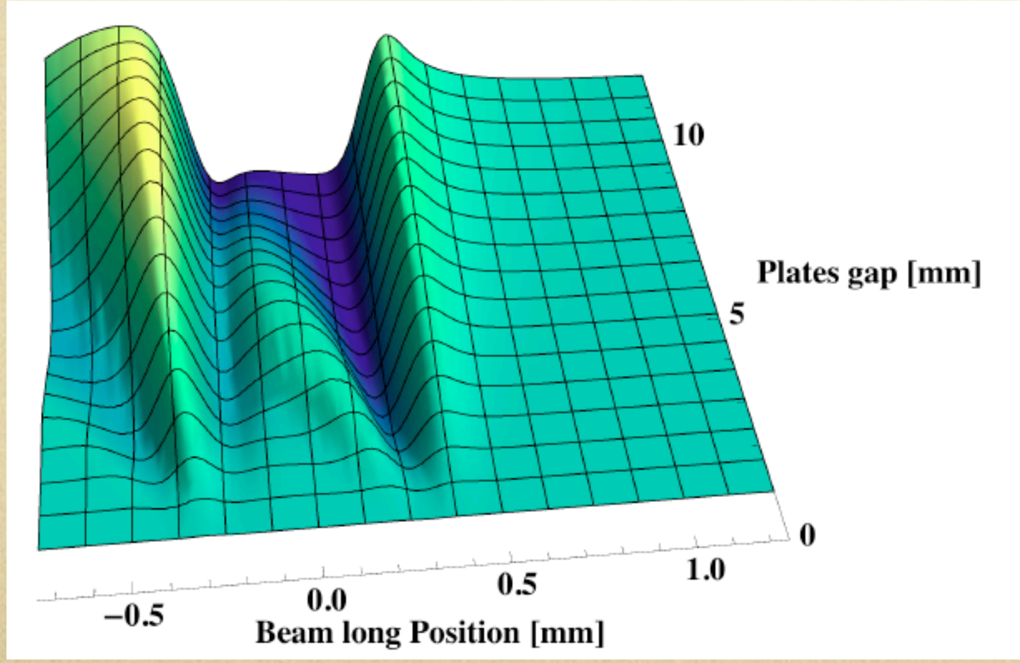
CSR wake-field as the function of the gap between the plates.For visibility the CSR wake-field for 1 mm gap is multiplied by 250.

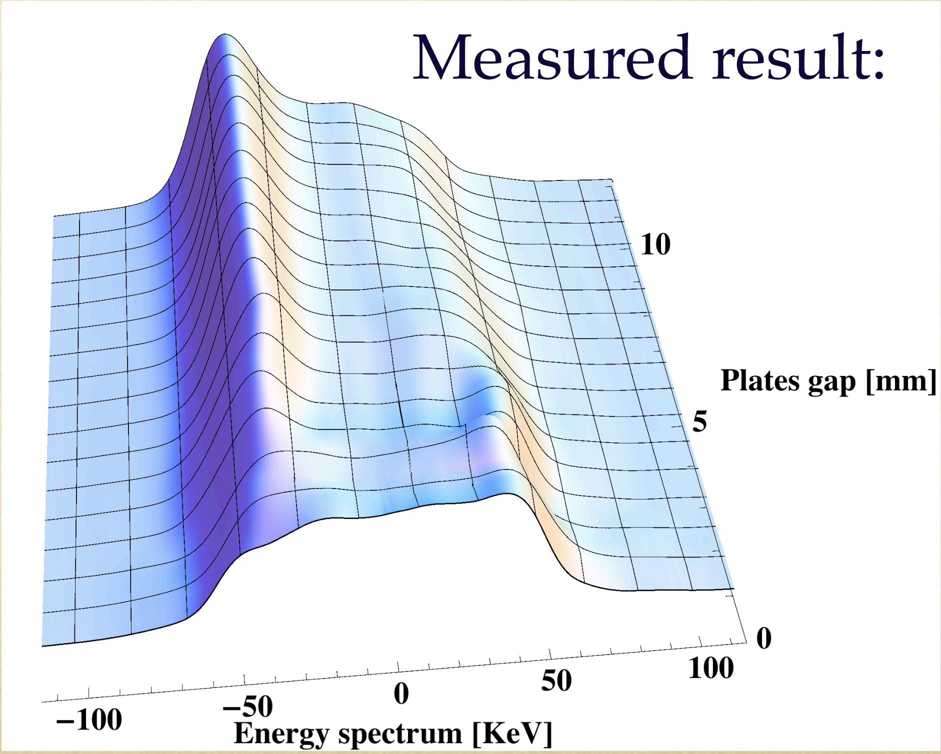


Simulations of the beam energy spectrum dependence on the gap between the plates.



Calculated CSR wake-fields for shielding plates between 1 mm and 12 mm gaps.





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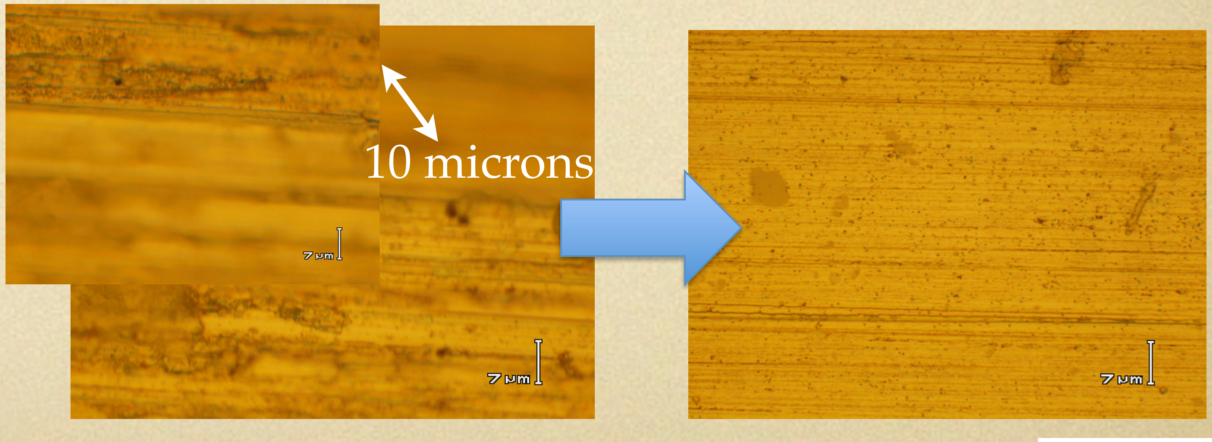
Experimental Challenges

- 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



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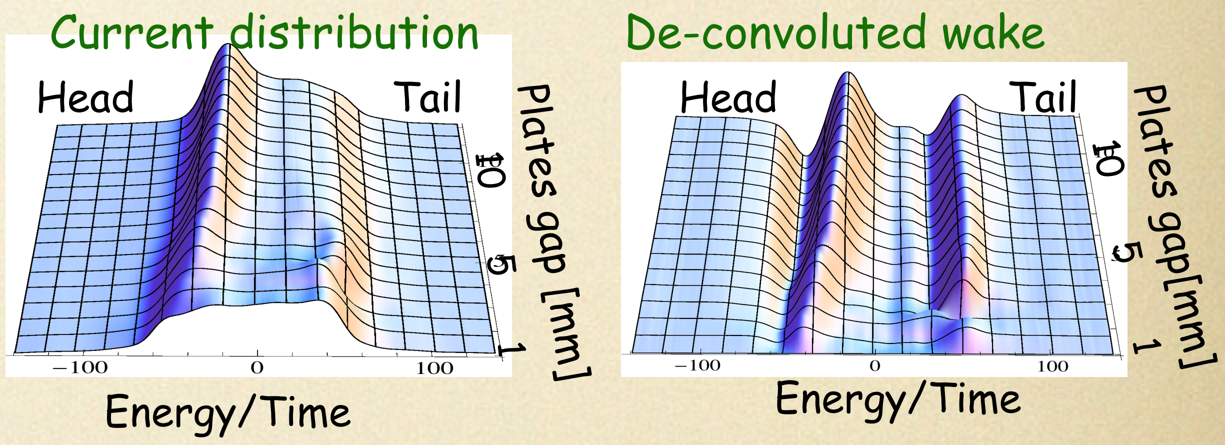
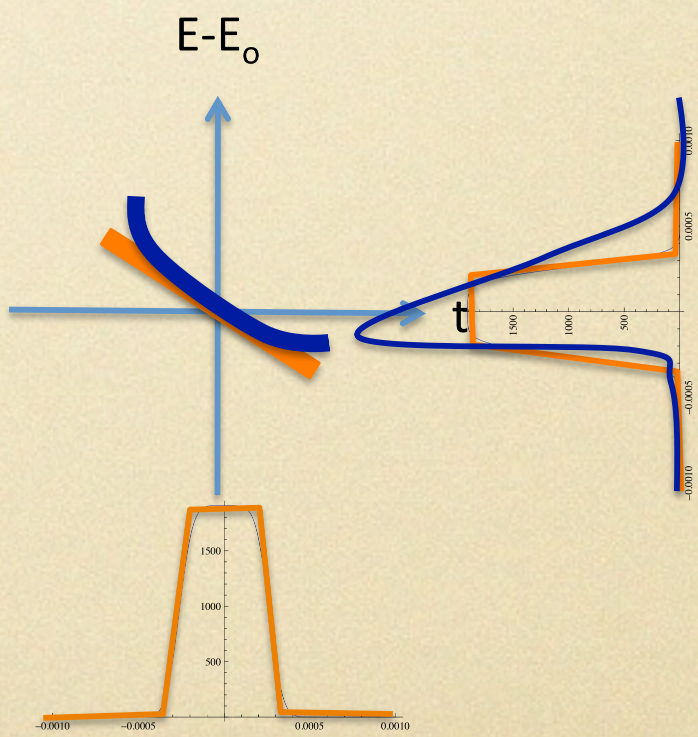
Experimental Challenges

- Selecting beam parameters to make observable effect dominated by CSR



- 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



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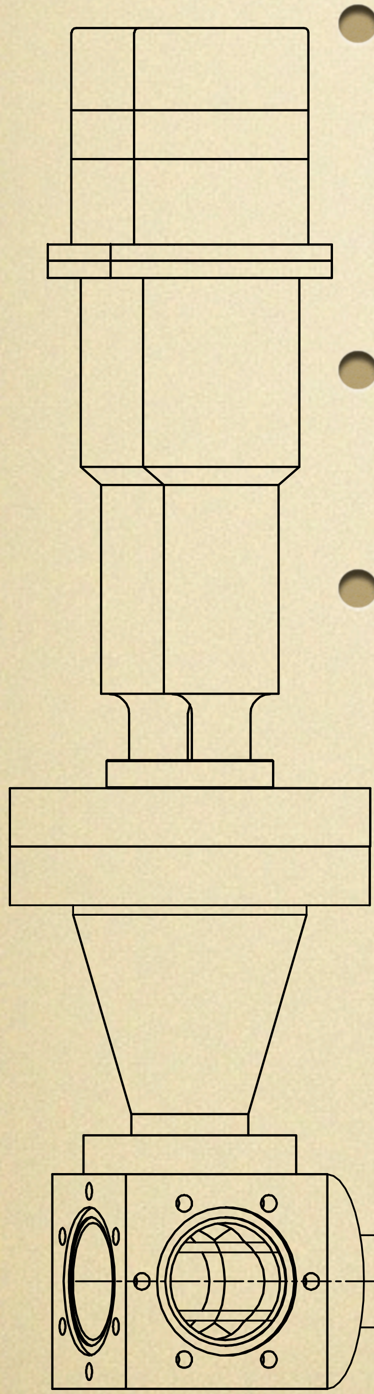
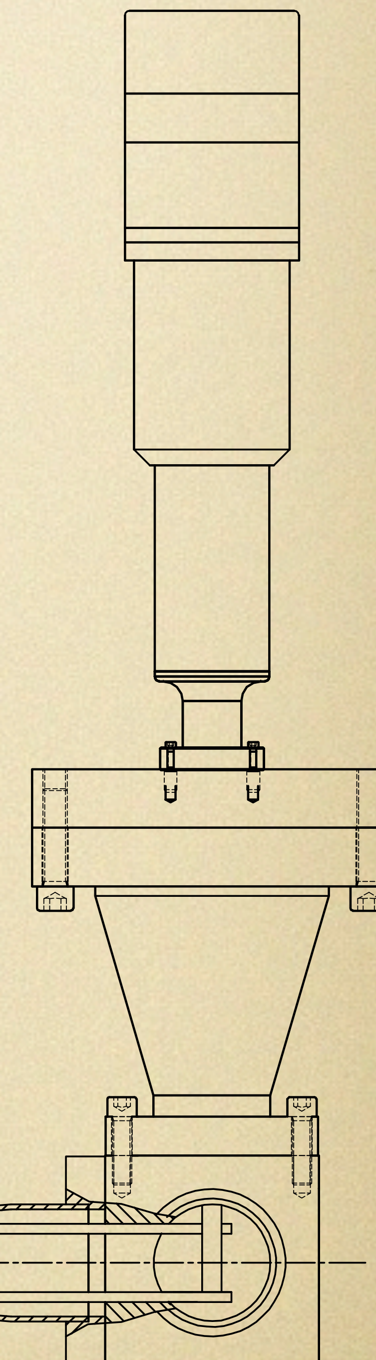
Conclusion

- 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





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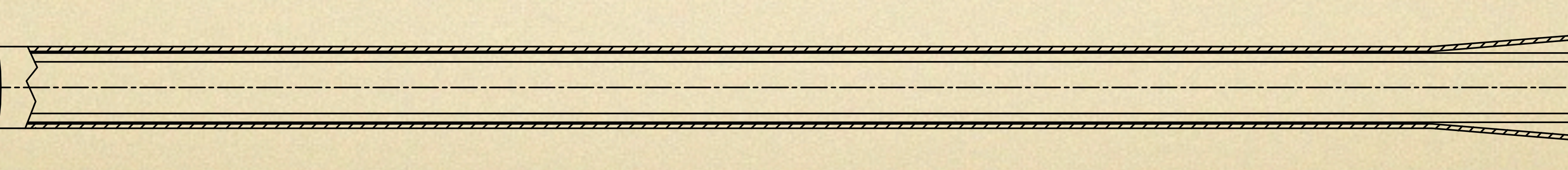

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