Coherent Synchrotron Radiation Shielding Experiment at ATF

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Team

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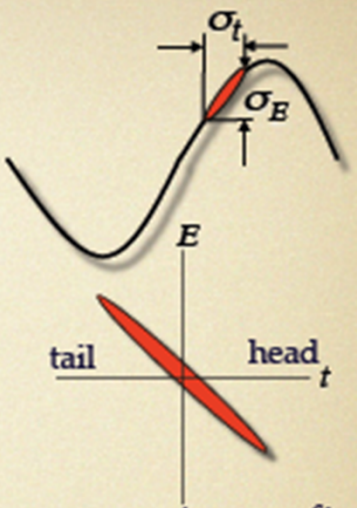
Content

- Experiment description
- Theory- longitudinal CSR wake
- Selected results
- Comparison with theory (qualitative)
- Conclusions

Experimental layout

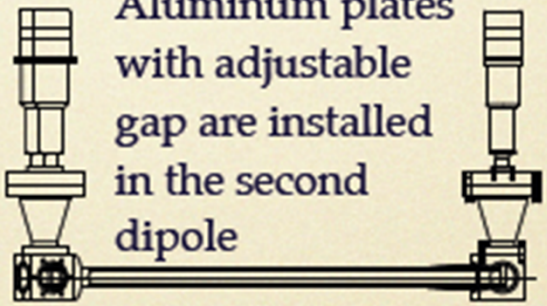


RF Gun

S-band Linac

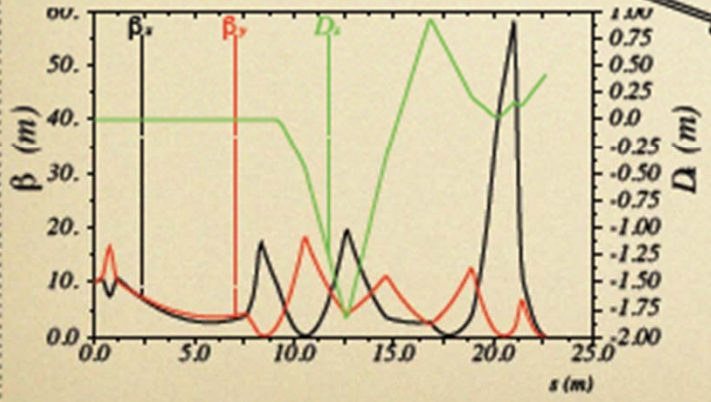
Chicane

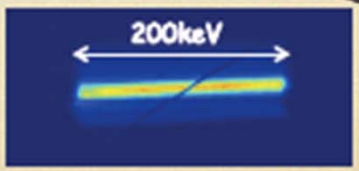
Energy collimator



Aluminum plates with adjustable gap are installed in the second dipole

Energy spectrum after dipole with plates open and closed





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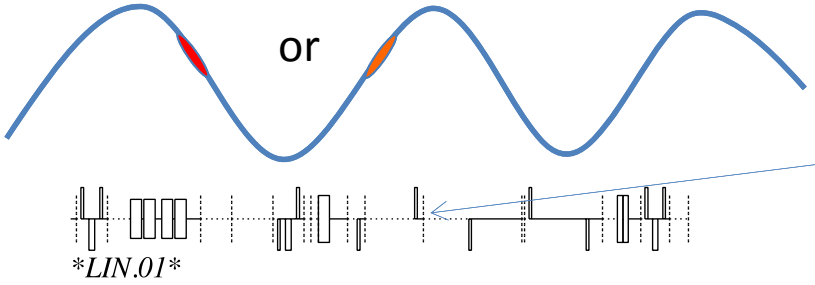
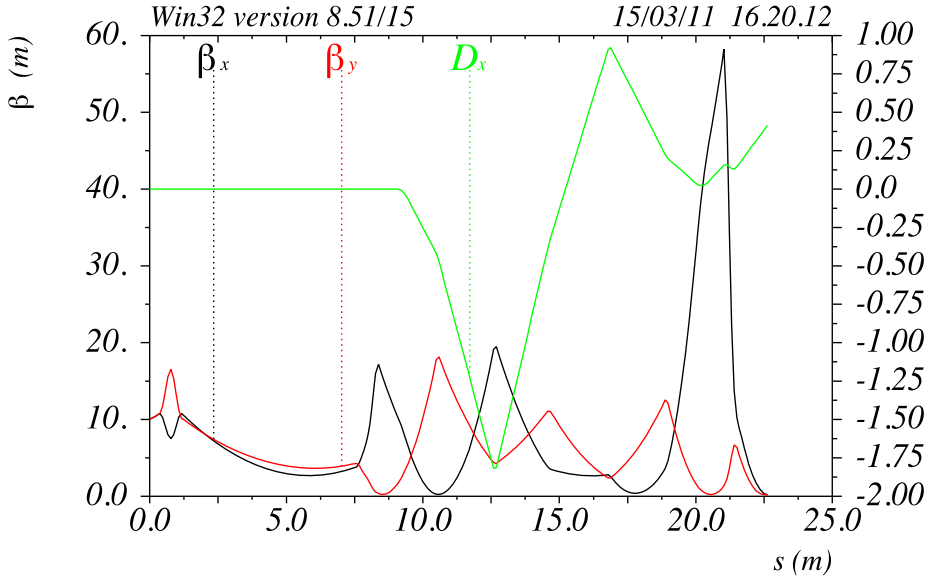
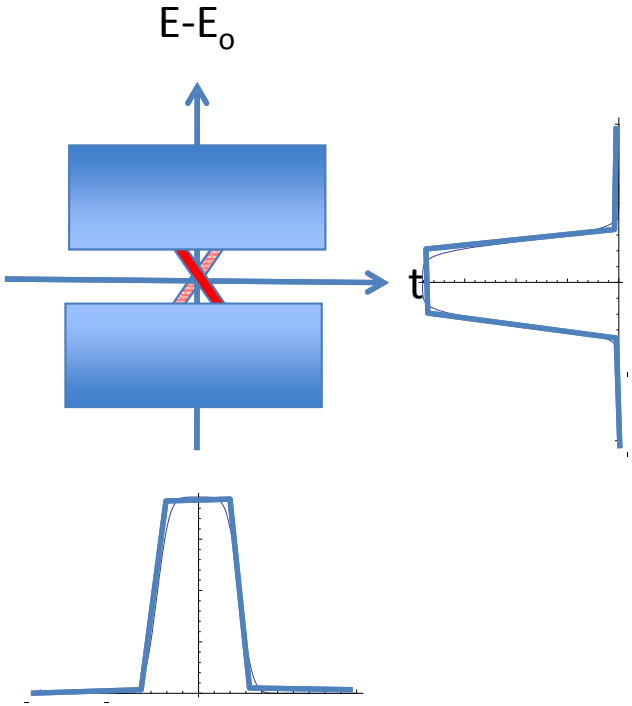
Beam at AFT: we used chirp in the energy



High energy slit

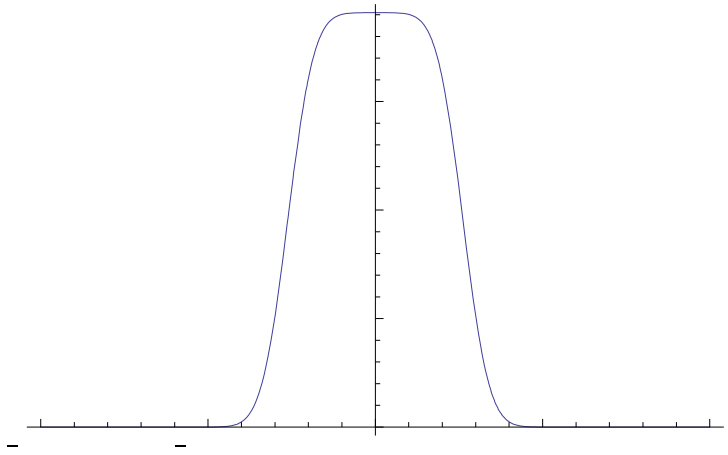




Optical function of the transport line from linac exit to spectrometer beam profile monitor. Energy collimator is located at position of 12.5m and magnet with shielding plates is installed at 20m position

Beam at AFT

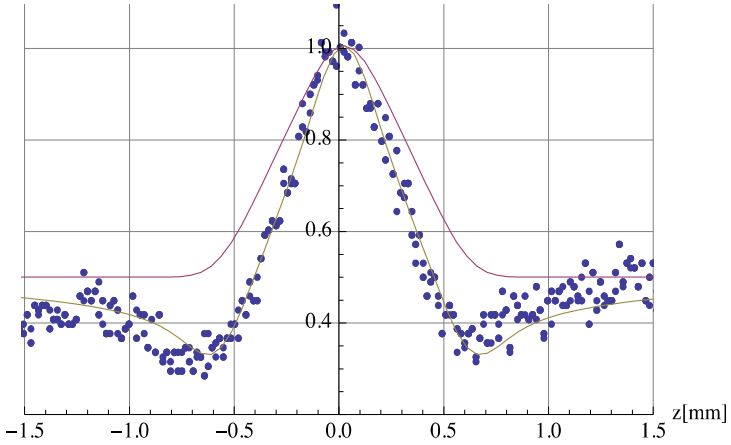
f1[x_, z_, s_] := (Erf[(x + z/2)/s] + Erf[-(x - z/2)/s])/2/z



s/R_o

Energy	57.6	MeV
γ	112.72	
β	0.999960647	
Magnet		
Length	0.4	m
Angle	0.34906585	rad
Radius	1.14591559	m
Beam		
Flat top	5.00E-04	m
Edge	1.00E-04	m
Peak current	70	A
Charge	1.40E-10	C
Ne	8.74E+08	

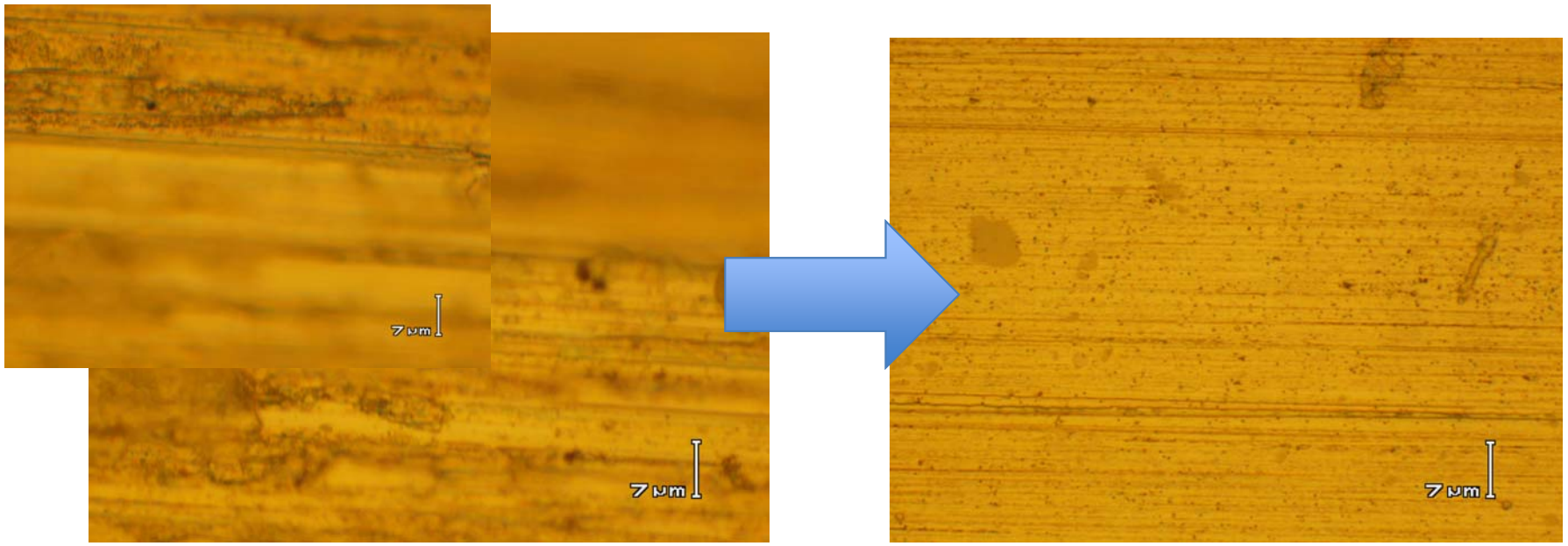
$$\boxed{\frac{e\beta^2}{R_o^{\,2}} N_e L} = 0.3838 \text{ eV}$$



Measured autocorrelation of the electron beam is drawn with points. Autocorrelation of the flat-top 600micron long (FWHM) pulse with 50 microns rise/fall is shown in violet. Autocorrelation of the abovementioned flat top distribution with low frequency cut of the detection system taken into account is plotted in light brown.

Plates

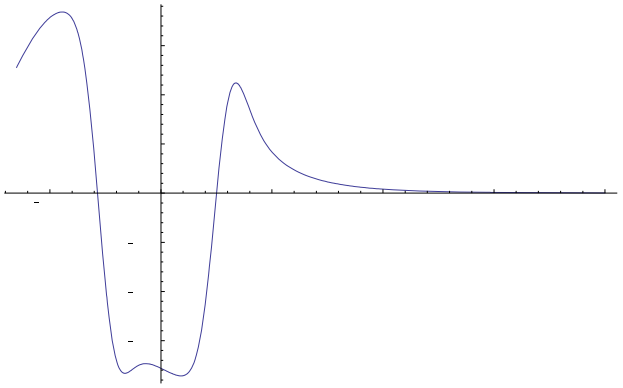
- Remotely controlled two 40+ cm Al plates change vertical gap from 0 to 12 mm
- Previously used rough Al plates were replced by polished plates
- Rough plates: ~30 μm width, ~30 μm spacing, 5-10 μm deep, very long grooves
- Mirror polished plates: ~1μm wide, ~10-30 μm spacing, <1μm deep, very long grooves

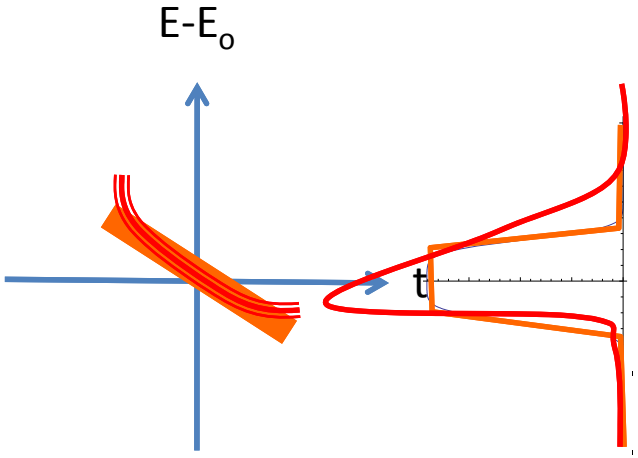


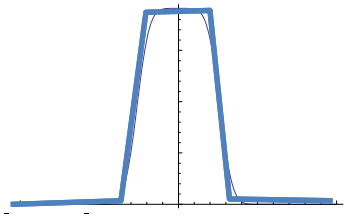
Deformations

$$E = E_o + \varepsilon t + W(t)$$

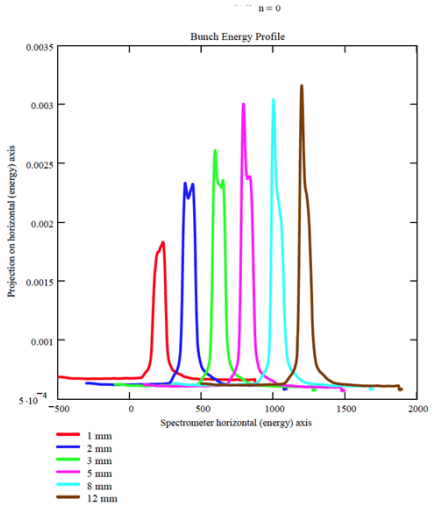
$$f(E) \Rightarrow \frac{f\left(E - W\left(\frac{E - E_o}{\varepsilon}\right)\right)}{\left|1 + \frac{W'\left(\frac{E - E_o}{\varepsilon}\right)}{\varepsilon}\right|}$$

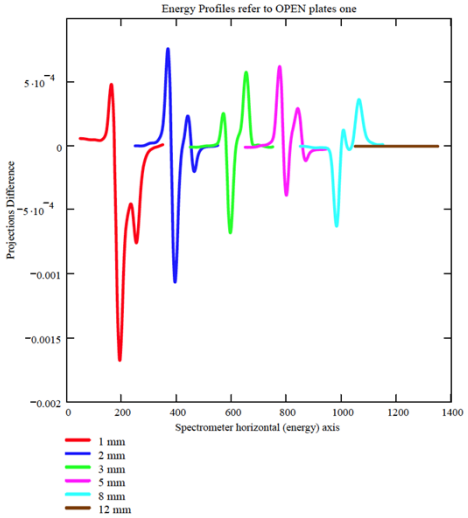


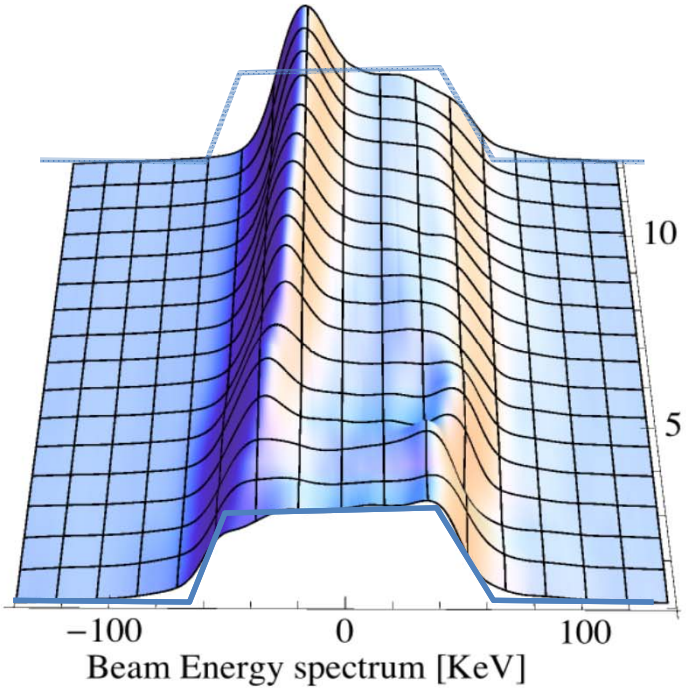


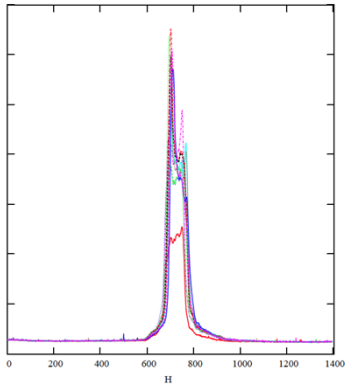


Summary of experimental results









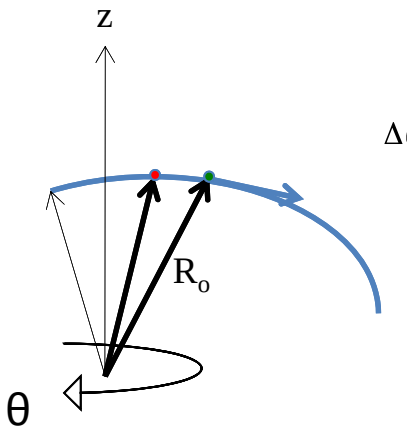
With closed gap the distribution is close to that from the HE slit - opening gap increases the distortions

Exact Theory

$$\vec{r}_r(t') = R_o\left(\hat{x}\cos\theta_r + \hat{y}\sin\theta_r\right);\ \rightarrow \vec{r}_n(t') = R_o\left(\hat{x}\cos\theta_n + \hat{y}\sin\theta_n\right) + \hat{z}nh;$$

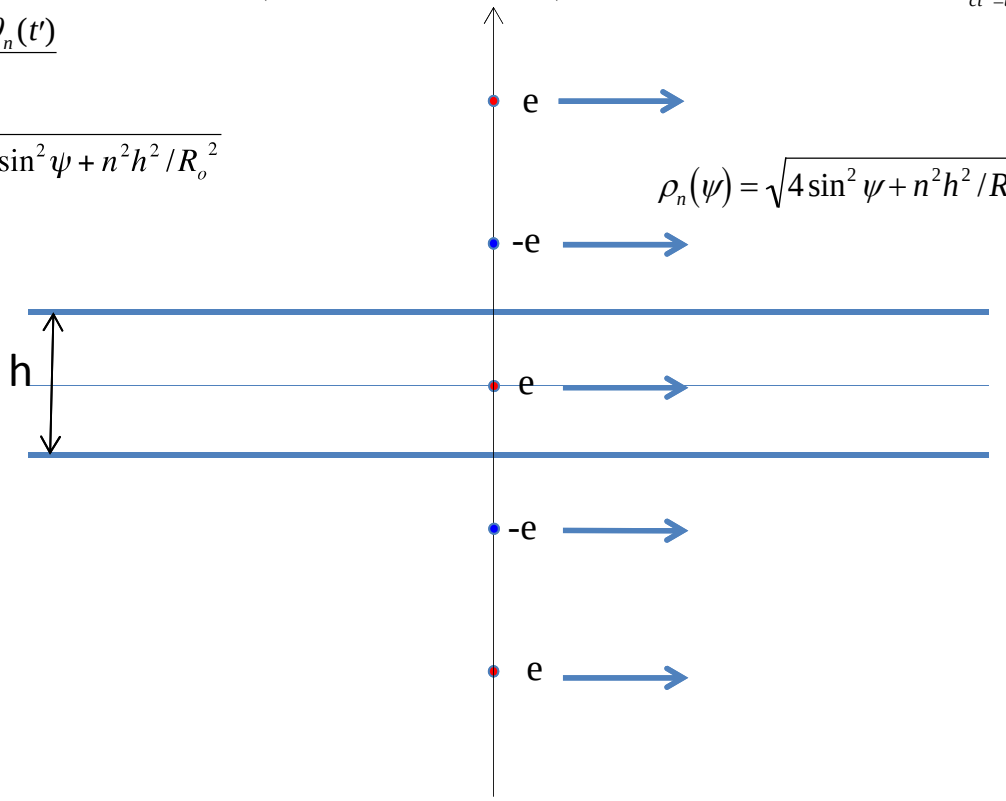
$$\vec{r}_t(t) = R_o\left(\hat{x}\cos\theta_t + \hat{y}\sin\theta_t\right);$$

$$\vec{E}\left(\vec{r}_t,t\right) = \left\{ e\frac{1-\beta^2}{\left(R-\vec{\beta}\vec{R}\right)^3}\left(\vec{R}-\vec{\beta}R\right) + \frac{e}{c\left(R-\vec{\beta}\vec{R}\right)^3}\left[\vec{R}\times\left[\left(\vec{R}-\vec{\beta}R\right)\times\dot{\vec{\beta}}\right]\right]\right\}_{ct'=t+R}$$



$$\psi = \frac{\theta_t(t) - \theta_n(t')}{2}$$

$$\Delta\theta = 2\psi - \frac{\omega}{c}\sqrt{4\sin^2\psi + n^2h^2/R_o^2}$$



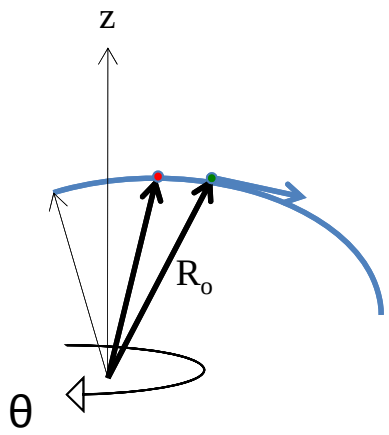
$$\rho_n(\psi) = \sqrt{4\sin^2\psi + n^2h^2/R_o^2}$$

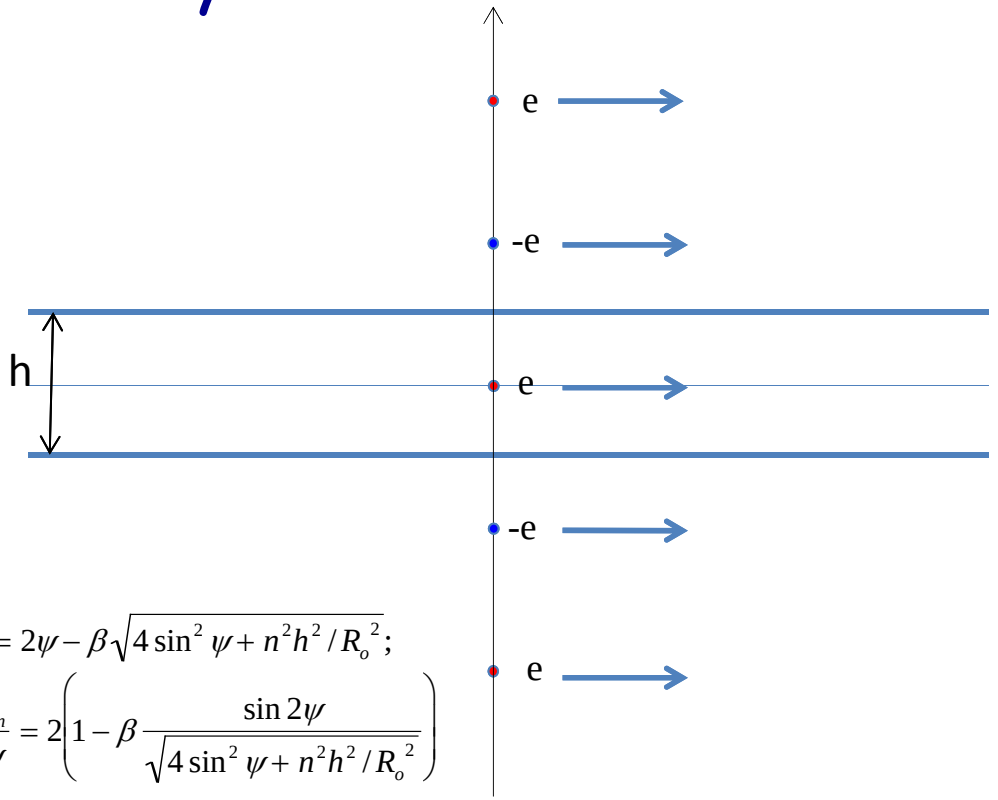
- Tricky part is the retarded time
- I use analytical parametric dependence
- It allowed to calculate exactly radiated field by any charge (real ore reflected)
- Integration with real bunch distribution provides the resulting wake-field

$$E_{rad} = \frac{e\beta^2}{2R_o^2\left(1-\beta\cdot\ sign\psi\cos\psi\right)^3}\left(\beta - \cos\psi\cdot\ sign\psi\right)\left\{\hat{y} - \frac{\hat{x}\cos\psi}{\sin\psi}\right\}$$

$$E_{rad\_n} = \frac{2e\beta^2}{R_o^2\left(\rho-\beta\sin 2\psi\right)^3}\left\{\begin{array}{l}\hat{x}\left(\rho^2\cos 2\psi - \rho\beta\sin 2\psi + 4\sin^4\psi\right) + \\ \hat{y}\left(-\rho^2\sin 2\psi + 2\sin^2\psi\rho\beta + 4\cos\psi\sin^3\psi\right)\end{array}\right\}$$

Exact Theory – cont…





$$W(\varphi) = N_e \sum_n \int E_n(\varphi-\theta)\, f(\theta) d\theta = \sum_n \int E_n(\theta)\, f(\varphi-\theta) d\theta;$$

$$W(\varphi) = N_e \sum_n \int E_n\left(\theta(\psi)\right) f\left(\varphi-\theta(\psi)\right) \frac{d\theta}{d\psi} d\psi;$$

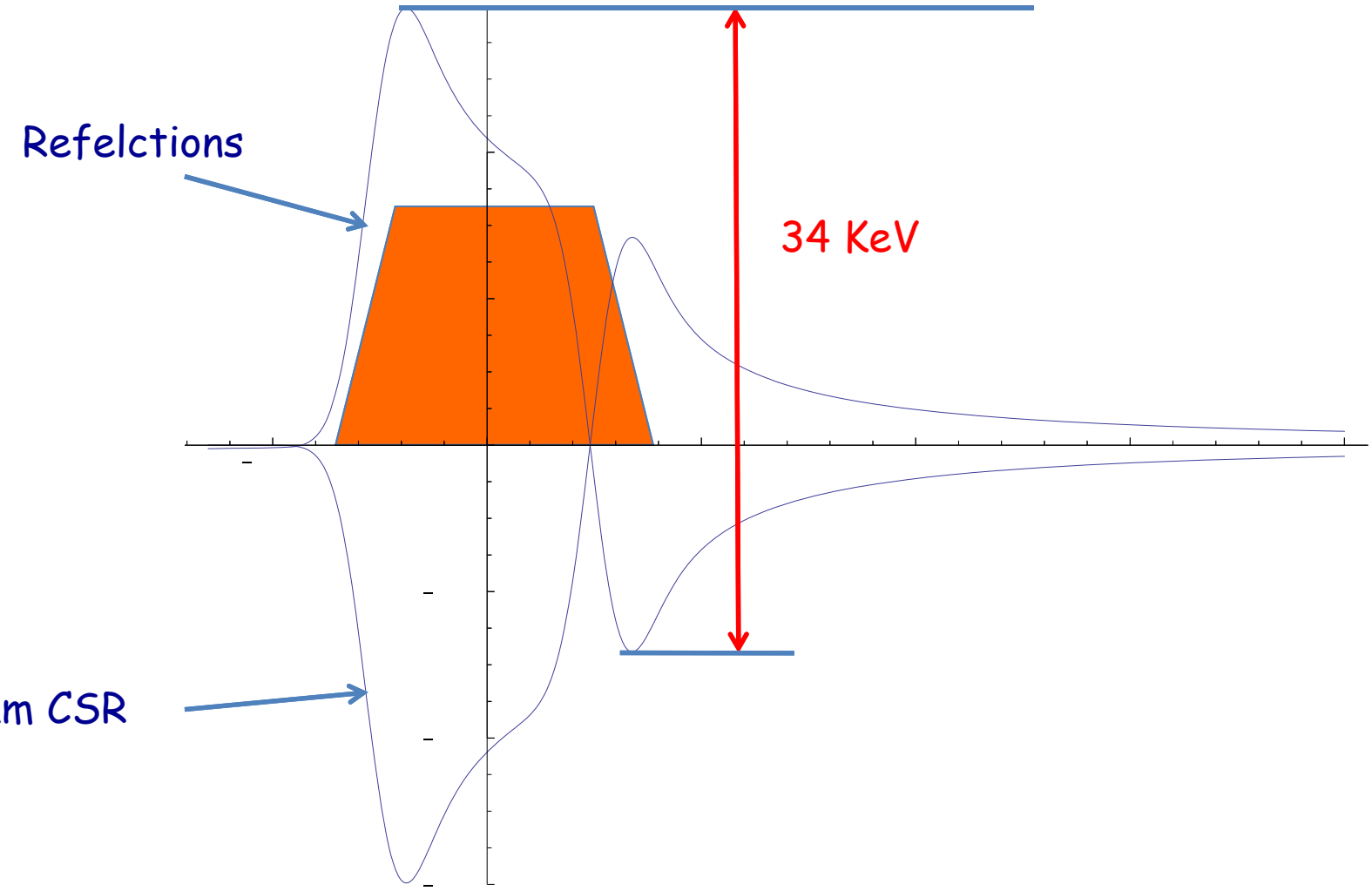
$$\theta_n = 2\psi - \beta\sqrt{4\sin^2\psi + n^2h^2/{R_o}^2};$$

$$\frac{d\theta_n}{d\psi} = 2\left(1-\beta\frac{\sin 2\psi}{\sqrt{4\sin^2\psi + n^2h^2/{R_o}^2}}\right)$$

$$W(\varphi) = \frac{2e\beta^2}{{R_o}^2} N_e \sum_{n=-\infty}^{\infty} (-1)^n \int_{-\infty}^{\infty} \frac{\left(-{\rho^2}_n(\psi)\sin 2\psi + 2\sin^2\psi\rho_n(\psi)\beta + 4\cos\psi\sin^3\psi\right)}{\left(\rho_n(\psi) - \beta\sin 2\psi\right)^3} f\left(\varphi - 2\psi + \beta\rho_n(\psi)\right)\cdot\left(1-\beta\frac{\sin 2\psi}{\rho_n(\psi)}\right) d\psi$$

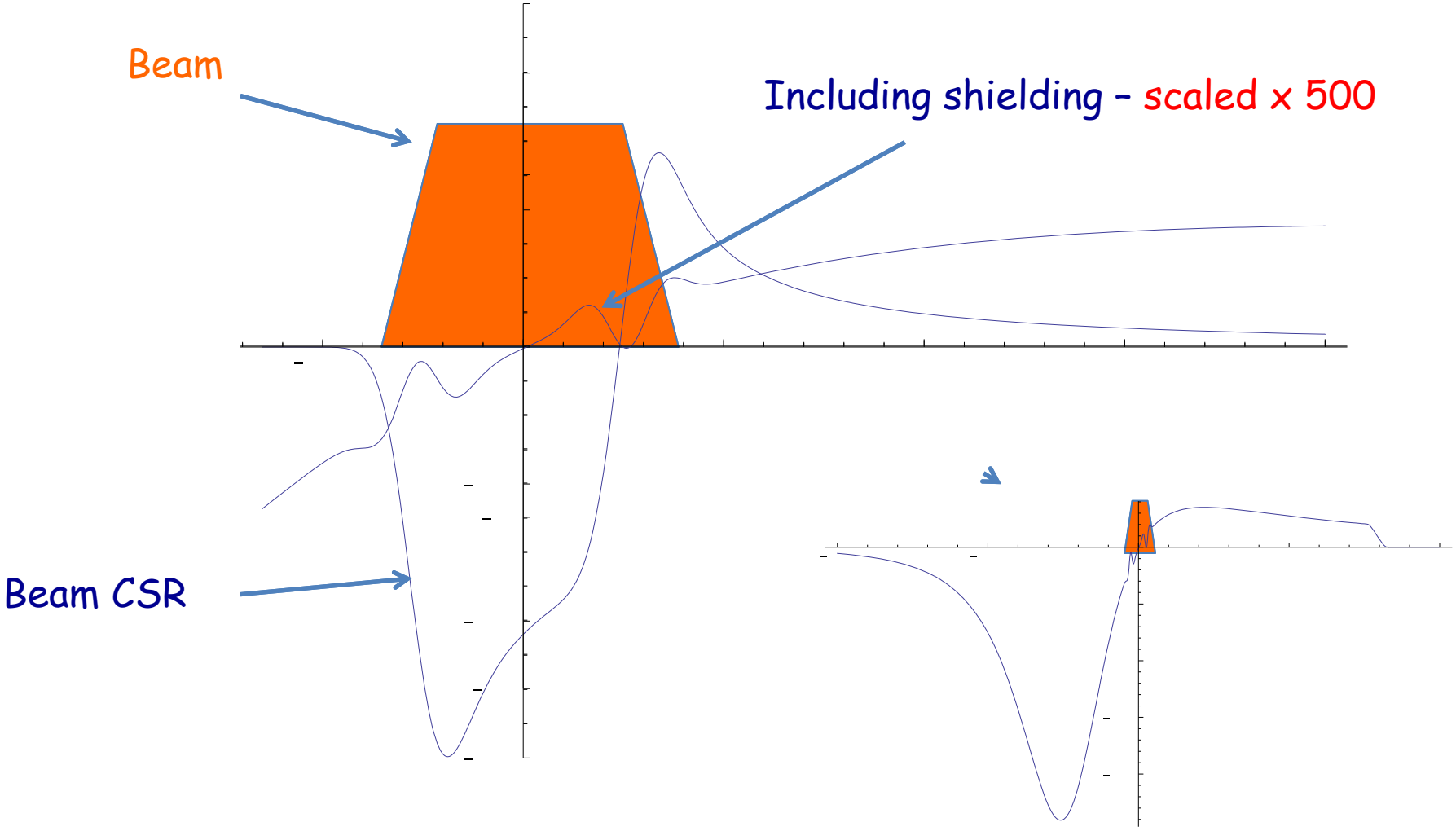
Wakefield – calculations

1 unit – 0.38 eV



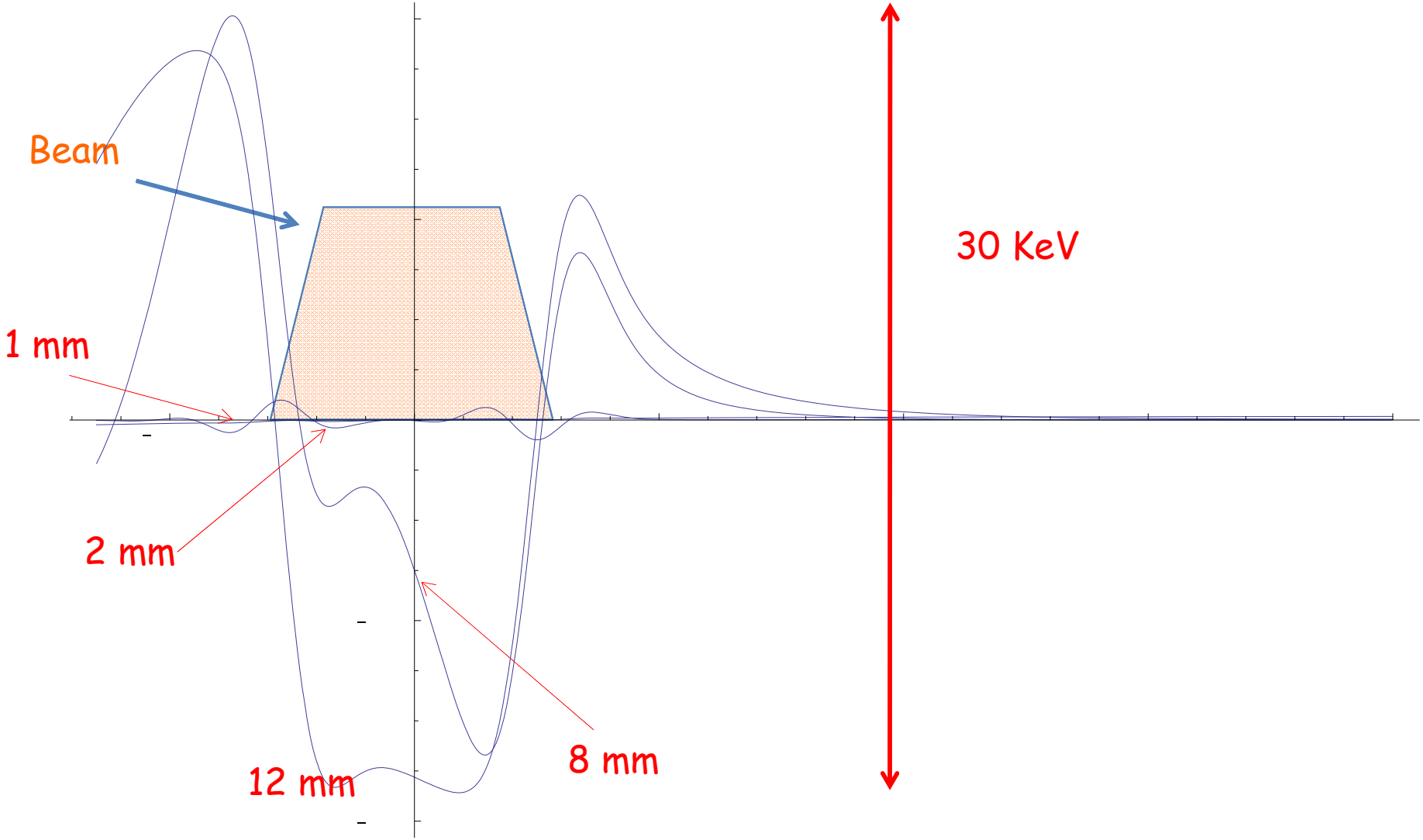
* I used +/- 40 reflections, adding more does not change results

Wakefield – calculations
1mm – suppression by x 1000

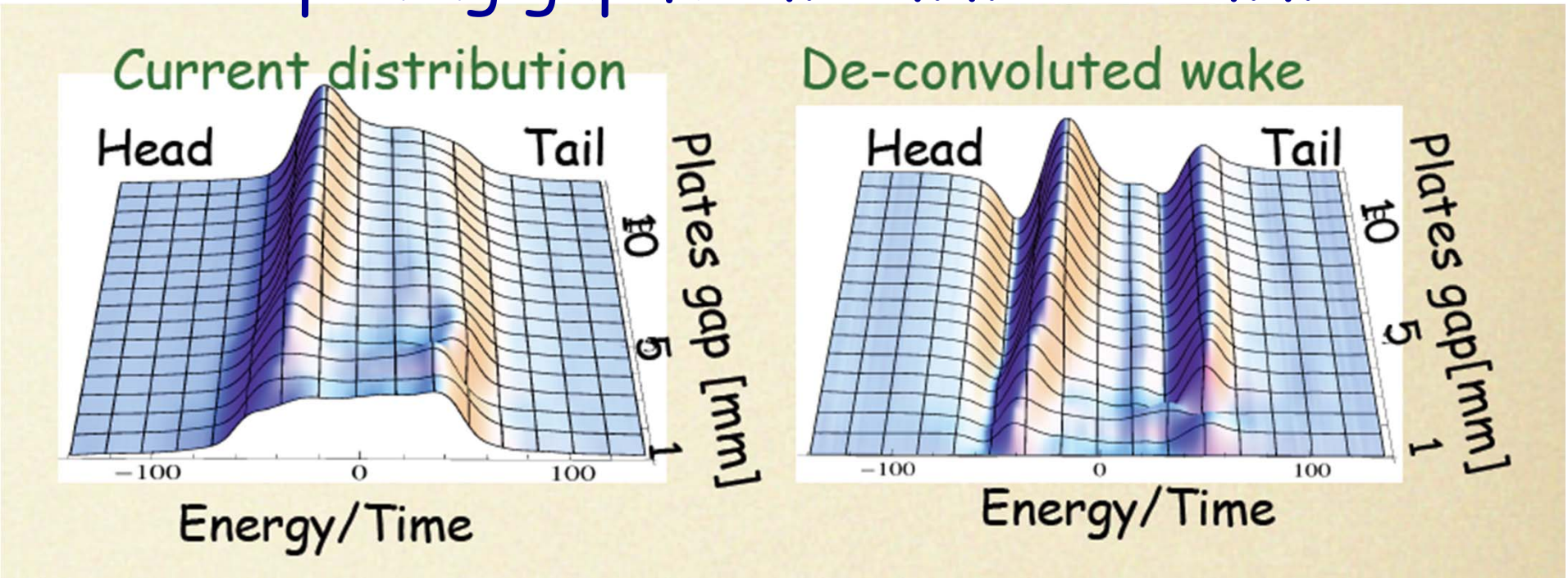


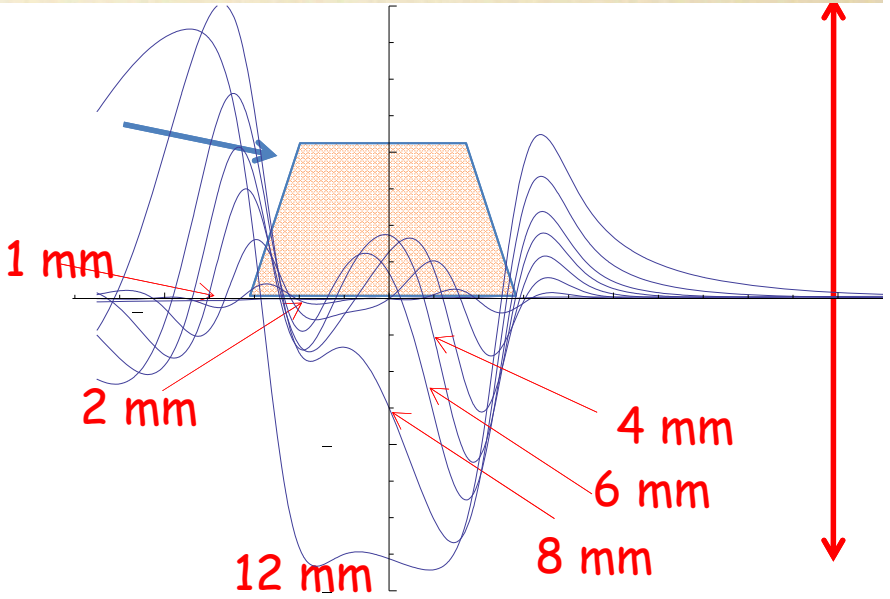
* I used +/- 40 reflections, adding more does not change results

Opening gap from 1 mm to 12 mm



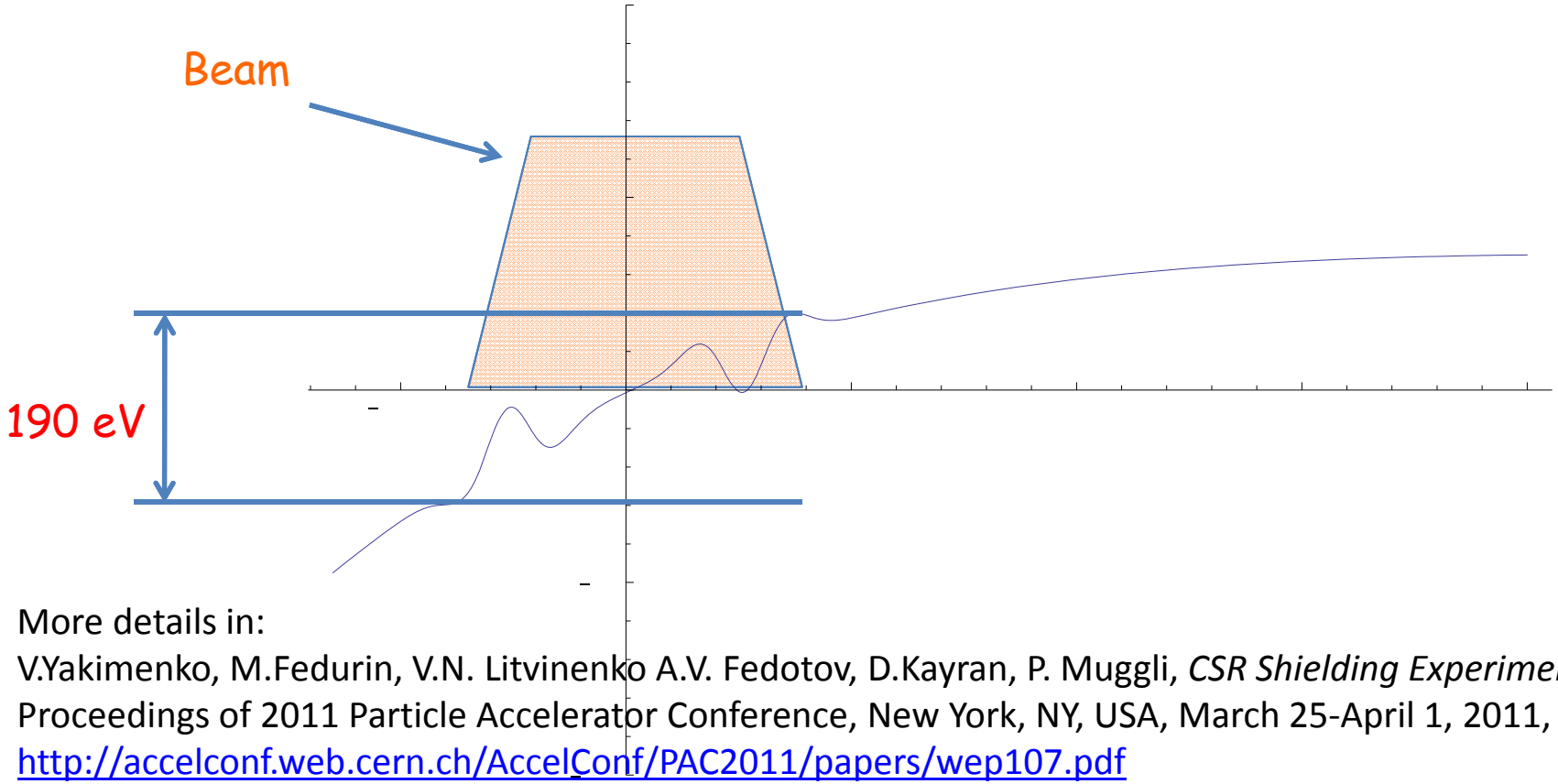
Opening gap from 1 mm to 12 mm





1 mm gap – kills CSR

both the energy loss and the energy spread



More details in:

V.Yakimenko, M.Fedurin, V.N. Litvinenko A.V. Fedotov, D.Kayran, P. Muggli, *CSR Shielding Experiment*, Proceedings of 2011 Particle Accelerator Conference, New York, NY, USA, March 25-April 1, 2011, p. 1677
http://accelconf.web.cern.ch/AccelConf/PAC2011/papers/wep107.pdf

Slides from IPAC'11
http://accelconf.web.cern.ch/AccelConf/IPAC2011/talks/thoba02_talk.pdf

Conclusions

- Small gap vacuum chamber eliminates both average energy loss from CSR as well as RMS energy spread (in contrast to predictions in some papers and previous presentations on CSR!)
- New type of experiments with focus on the f(E) modification were performed at ATF and demonstrated excellent sensitivity to short-range wake-fields (better than 1 keV for 60 MeV beam)
- Exact analytical theory for the case of parallel plates is developed and is in good agreements with the measurement
- Detailed analysis is under way
- We'll present poster and paper at PAC'11 with detail of the experiments, simulations and comparison

Long range wakes