Super-B: CSR effects.

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Super-B General Meeting VIII

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Perugia, Hotel Gio'

- Do really CSR-Coherent Synchrotron Radiation have a heavy impact on the design parameters of Super-B?
  - Did we miss CSR at B-factories?
- Problem consists of two parts:
  - Appropriate calculation of the CSR fields.
  - Beam dynamics simulation based on the CSR field presentation.

CSR loss factor of a bunch passing a bend in free space

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On the coherent radiation of an electron bunch moving in an arc of a circle

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LONGITUDINAL WAKEFIELD FOR AN ELECTRON MOVING ON A CIRCULAR ORBIT

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Bending radius ρ, magnet length l_m and *r.m.s. bunch length* σ define the loss energy of a bunch

$$\sigma \gg \frac{\rho}{\gamma^3} \quad \left(\text{for } E = 3\text{GeV } \gamma = 6\times 10^4\right)$$

$$\sigma \ll \frac{\rho}{\gamma^3}$$

$$K_{CSR} = \frac{Z_0 c}{4\pi} \frac{l_m}{\left(4\rho\sigma^2\right)^{2/3}}$$

$$K_{SR} = \frac{Z_0 c}{6\pi\rho^2} l_m \gamma^4$$

RF power is needed to compensate:

1) Beam incoherent and coherent synchrotron radiation losses

$$U_{turn} = \frac{Z_0 c}{\rho}\left(\frac{e}{3}\left(\frac{E}{m_0 c^2}\right)^4 + \frac{Q}{2}\left(\frac{\rho}{2\sigma}\right)^{4/3}\right)$$

$$P_{s.r.} = U_{turn} \times I$$

Beam energy *E*, bending radius ρ, beam current *I* , electronic charge *e*, bunch charge *Q*, bunch length σ, rest mass of electron m_0, free space impedance Z_0 and speed of light *c*.

Energy loss per turn for coherent synchrotron radiation (CSR) increases with the bending radius as $\rho^{1/3}$

Main power loss comes from incoherent radiation
Example from PEP-II

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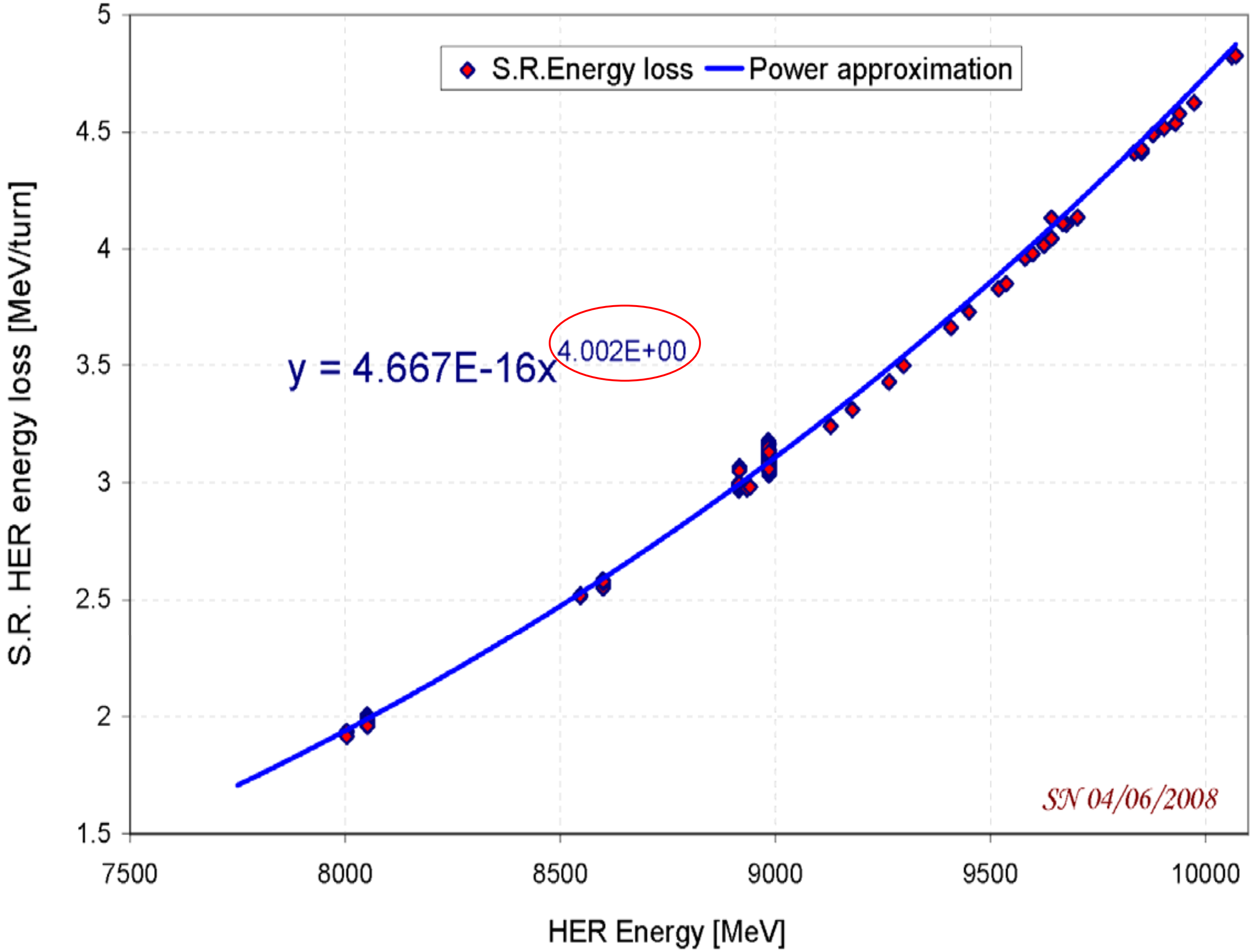
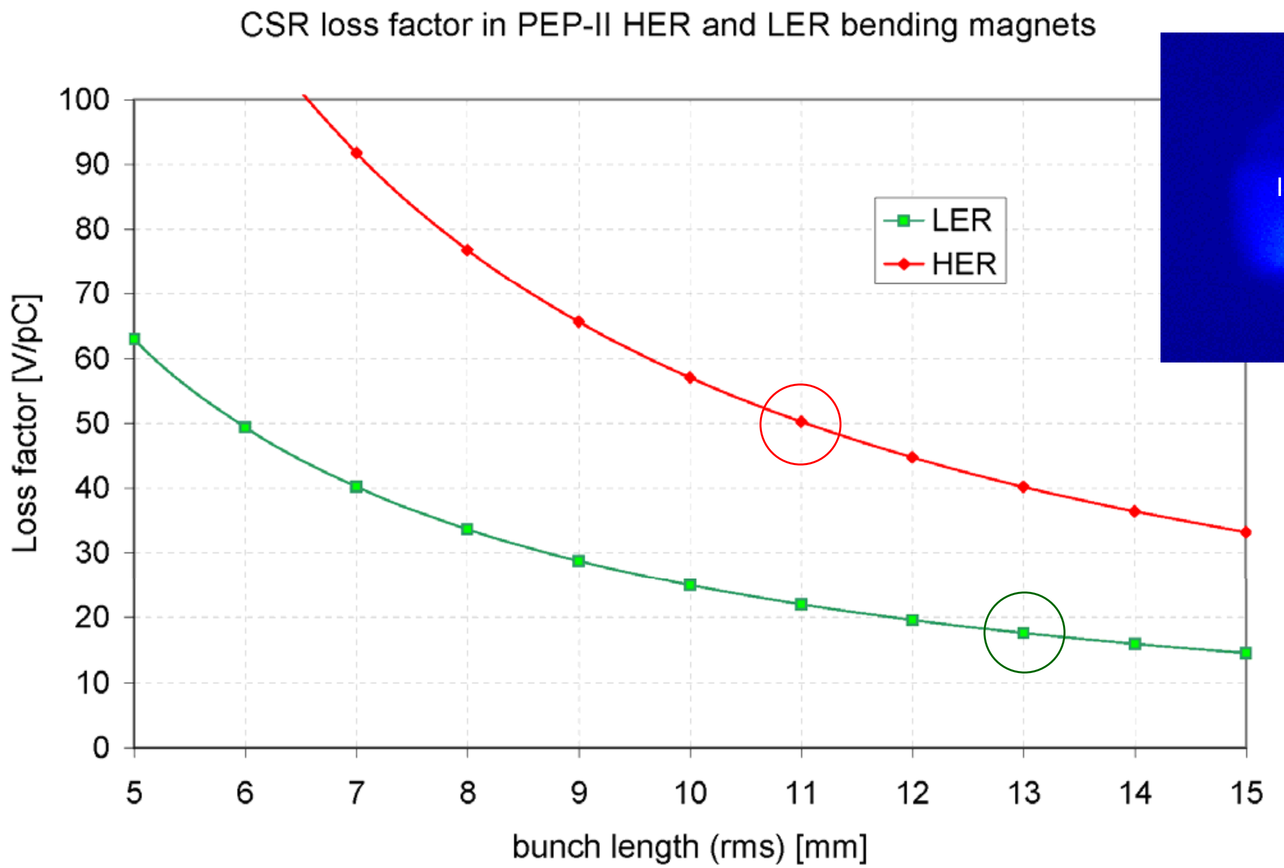
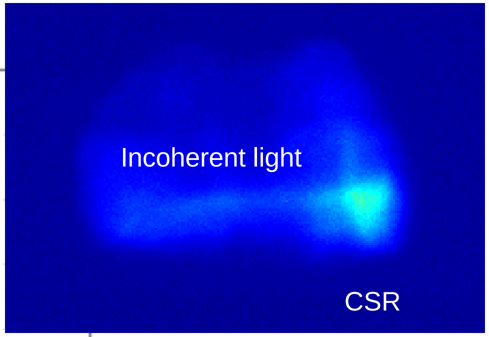
Measurement at PEP-II HER during energy scan



CSR losses in PEP-II
(according to formulas without chamber shielding)





Example S.R.
from a horizontal bend

Numbers are relatively large in comparison with geometrical wake fields.
More studies are needed to include shielding of the beam chamber walls.

Infinite parallel plates

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Suppression of Coherent Radiation by Electrons in a Synchrotron*

JOHN S. NODVICK† AND DAVID S. SAXON
University of California, Los Angeles, California
(Received May 25, 1954)

$$K_{pp}(\rho,h,\sigma)=\frac{2}{3}\frac{Z_0 c}{\pi\rho}\times\frac{\rho}{h}\sum_{n=1}\left(\frac{\sin n\sqrt{3}\frac{\sigma}{\rho}}{n\sqrt{3}\frac{\sigma}{\rho}}\right)^2\times\sum_{j=1,3,..}^{\gamma_j<n}\frac{\gamma_j^4}{n^3}\times\left[K_{1/3}^2\left(\frac{\gamma_j^3}{3n^2}\right)+K_{2/3}^2\left(\frac{\gamma_j^3}{3n^2}\right)\right]$$

$$\gamma_j = j\pi\frac{\rho}{h}$$

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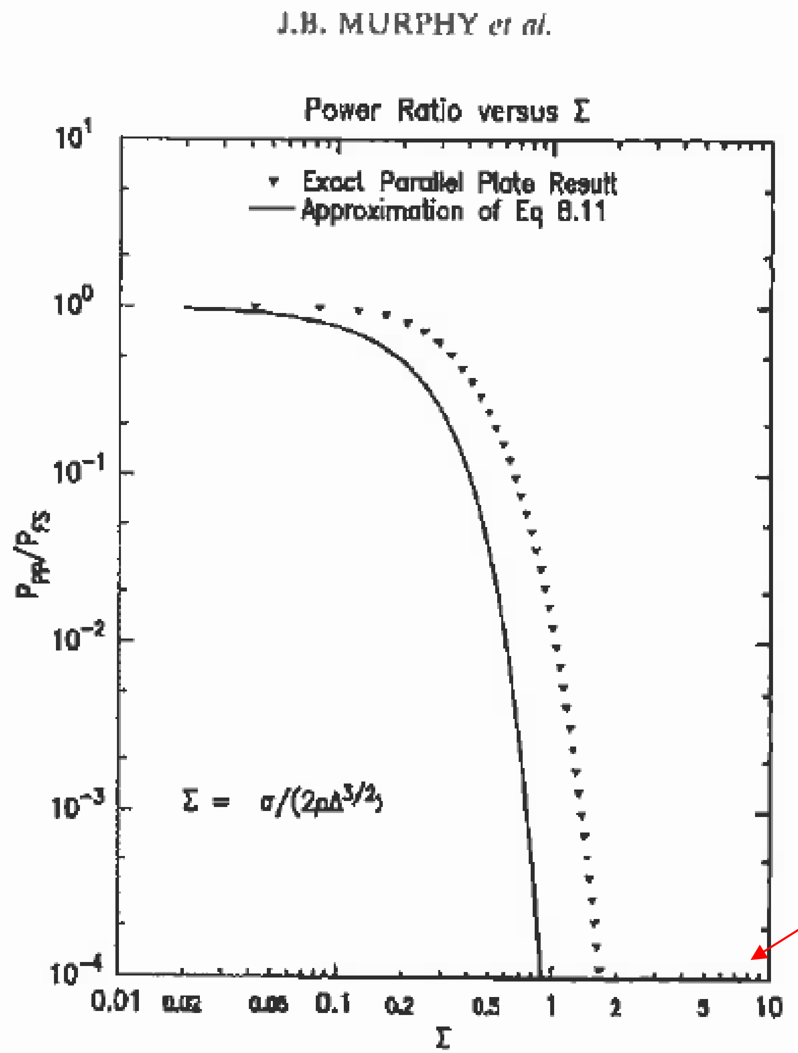
Shielding from parallel plates



$$\Sigma = \frac{1}{2}\frac{\sigma}{h}\sqrt{\frac{\rho}{h}}$$

$PEP-HER$	$PEP-HER$
$\sigma = 11mm$	$\sigma = 13mm$
$h = 25mm$	$h = 27mm$
$\rho = 164m$	$\rho = 13.8m$
$\Sigma = 16.8$	$\Sigma = 5.4$

CSR was strongly shielded in PEP-II

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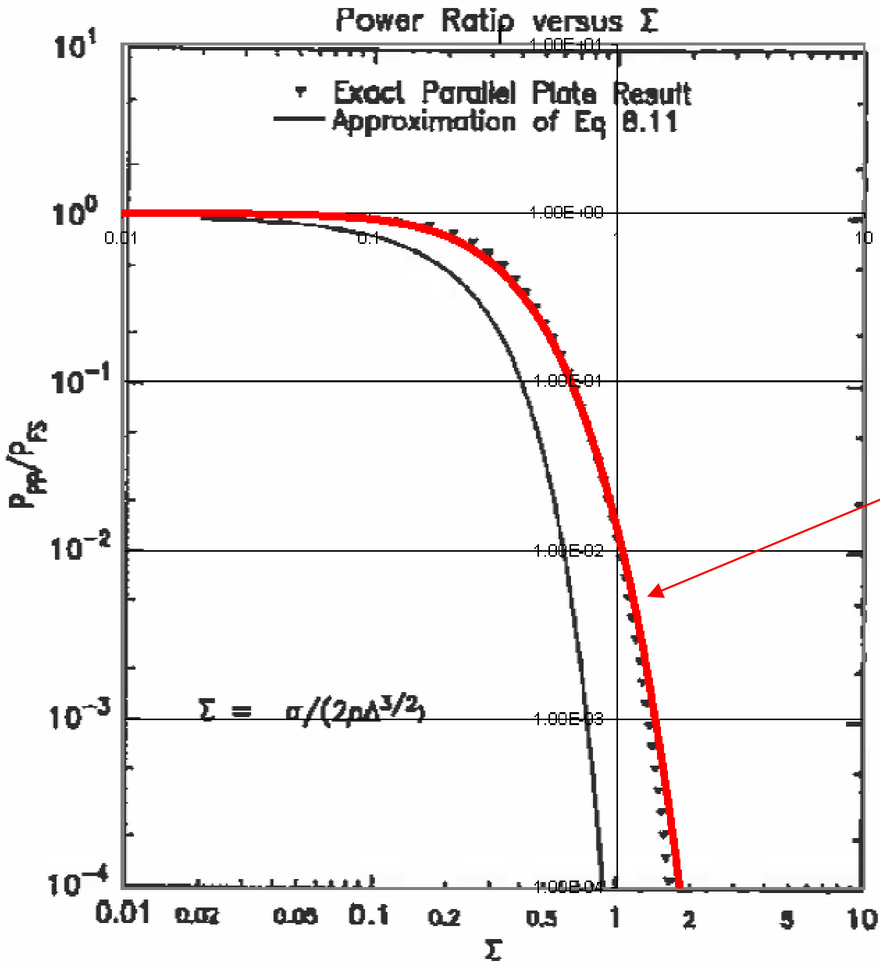
Shielding from parallel plates. Approximation.



$$\tilde{\Sigma} = 2\sqrt{12} \times \Sigma = \frac{\sqrt{12}\sigma}{h}\sqrt{\frac{\rho}{h}}$$

$$\frac{P_{pp}}{P_{FS}} = \frac{\tilde{\Sigma}}{\sinh(\tilde{\Sigma})}$$

hyperbolic sine

Loss factor (per one turn) due to CSR

$$K_{CSR} \approx \frac{Z_0 c}{2\rho}\left(\frac{\rho}{2\sigma}\right)^{4/3} \times \frac{\tilde{\Sigma}}{\sinh(\tilde{\Sigma})}$$

$$\tilde{\Sigma} = \frac{\sqrt{12}\sigma}{h}\sqrt{\frac{\rho}{h}}$$

Other approaches

- Frequency domain
- Several assumptions
- Simplified equations

T.Agoh & K.Yokoya. Equation of Evolution

Assuming that s-dependence of the field is weak, neglect the term of 2nd derivative with respect to s:

$$\frac{\partial^2 \boldsymbol{E}_\perp}{\partial s^2} \ll 2ik\frac{\partial \boldsymbol{E}_\perp}{\partial s}$$

Equation to describe CSR

$$\frac{\partial \boldsymbol{E}_\perp}{\partial s} = \frac{i}{2k}\left[\left(\boldsymbol{\nabla}_\perp^2 + \frac{2k^2 x}{\rho}\right)\boldsymbol{E}_\perp - \mu_0 \boldsymbol{\nabla}_\perp J_0\right]$$

- First derivative with respect to s

  Field evolution (transient behavior) along the beam line

  We can solve it numerically step by step with respect to s.

- Ex and Ey are decoupled.

K.Oide approach

★ Ignore $\frac{\partial^2 \overline{E}}{\partial \phi^2}$ terms (AgoH-YokoYA)

THEN WE OBTAIN FIRST ORDER DIFFERENTIAL EQUATIONS FOR $\overline{E}_{r,\phi}$.

$$\frac{\partial \overline{E}_r}{\partial \phi} = \frac{i}{2(k^2R^2-1)}\left[kR\left(\left(k^2(r^2-R^2)+1\right)\left(\overline{E}_r+\overline{E}_{r0}\right)+r\frac{\partial}{\partial r}\left(\overline{E}_r+\overline{E}_{r0}\right)+r^2\left(\frac{\partial^2 \overline{E}_r}{\partial r^2}+\frac{\partial^2 \overline{E}_r}{\partial y^2}\right)\right)\right.$$
$$\left.+\left(k^2(r^2+R^2)-1\right)\overline{E}_\phi+r\frac{\partial \overline{E}_\phi}{\partial r}+r^2\left(\frac{\partial^2 \overline{E}_\phi}{\partial r^2}+\frac{\partial^2 \overline{E}_\phi}{\partial y^2}\right)\right]$$
$$\frac{\partial \overline{E}_\phi}{\partial \phi} = \frac{i}{2(k^2R^2-1)}\left[kR\left(\left(k^2(r^2-R^2)+1\right)\overline{E}_\phi+r\frac{\partial \overline{E}_\phi}{\partial r}+r^2\left(\frac{\partial^2 \overline{E}_\phi}{\partial r^2}+\frac{\partial^2 \overline{E}_\phi}{\partial y^2}\right)\right)\right.$$
$$\left.+\left(k^2(r^2+R^2)-1\right)\left(\overline{E}_r+\overline{E}_{r0}\right)+r\frac{\partial}{\partial r}\left(\overline{E}_r+\overline{E}_{r0}\right)+r^2\left(\frac{\partial^2 \overline{E}_r}{\partial r^2}+\frac{\partial^2 \overline{E}_r}{\partial y^2}\right)\right]$$

✳ Further Approximation is possible as Agoh-Yokoya did, but not done here.

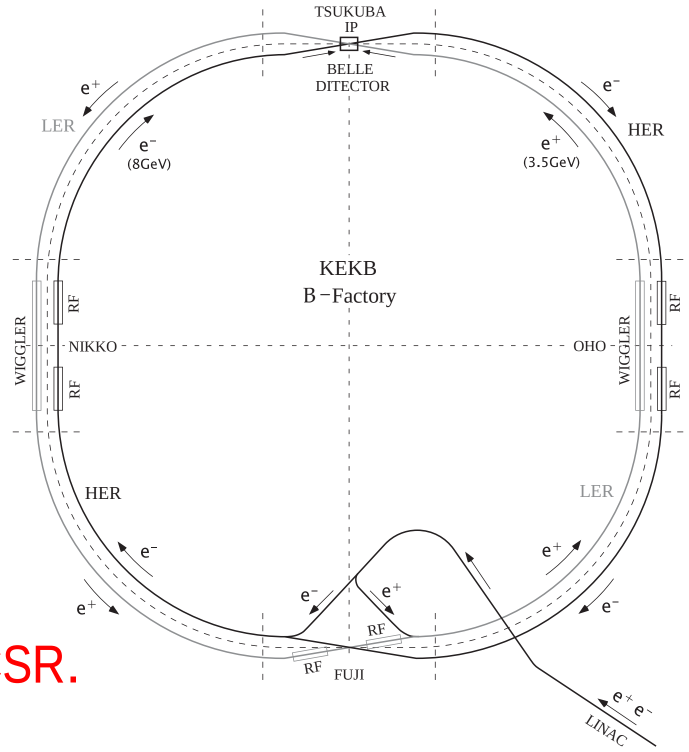
CSR in SuperKEKB

	KEKB LER	SuperKEKB LER
Bunch length	6 mm	3 mm
Bunch current (charge)	1.4 mA (~14 nC)	1.9 mA (~19 nC)

We will keep using present magnets to save money and R&D time.

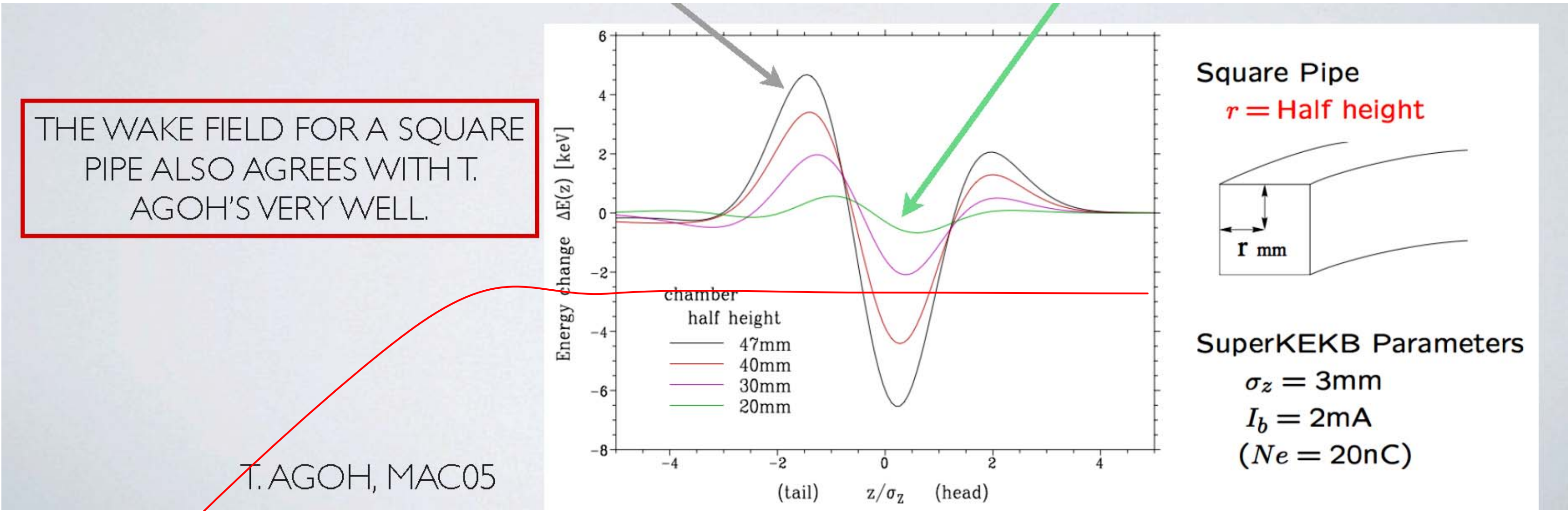
Bending radius

LER (positron): R=16.31m
HER (electron): R=104.5m



Positron bunch will be affected with CSR.

Energy change due to CSR (Longitudinal wakefield for a single bend)



Approximation formula gives 2.4 kV/magnet (150 magnets)

- Good agreement for large CRS effect
- Not so good agreement for stronger shielding
- PEP-II and Super-B factory have smaller size of the vacuum chamber.
- The CSR effect is almost dammed for Super-B.
- However more analyses are needed.

What to do next

- Choose an algorithm for more careful analyses of CSR.
- There are several possibilities.
- Use existing codes. (Argone, DESY, KEK) to calculate the CSR wake potential
- Or write a new code, which can be used also for other applications (for example LCLS)