

About “CSR” Effects

some remarks

FLASH BC3

Idealized Gaussian Input Distribution

Calculation with CSRtrack “projected method”

Split Calculations

Two (of many) CSR effects

Very Rough Estimation of Growth of Projected Emittance

An Effect causing Growth of Slice Emittance
and an other estimation

for DESY-PSI-CANDLE collaboration workshop 2010



(very) high compression in last bunch compression stage
rf tolerances (in particular for low bunch charges)
space charge effects (in particular for high bunch charges)

longitudinal dynamics (in BC)

extremely sensitive to self effects

can be compensated to some extent (and has to be) in advance
by the energy profile before the compressor

transverse dynamics (in BC)

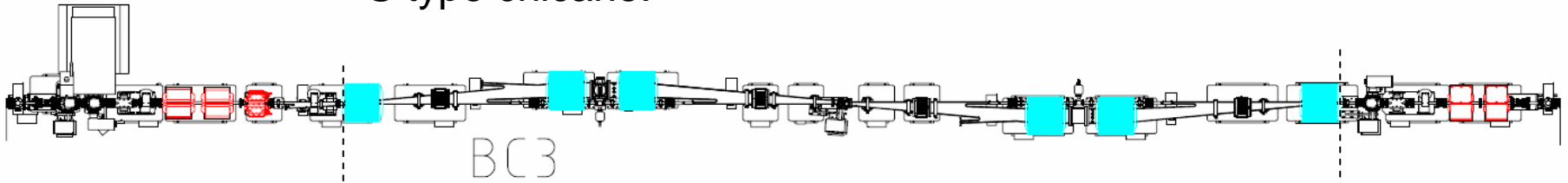
most important things happen in the last dipole (of the chicane)
and on the drift before)

this statement is investigated in the following for an particular
example (= S-type bc of FLASH)

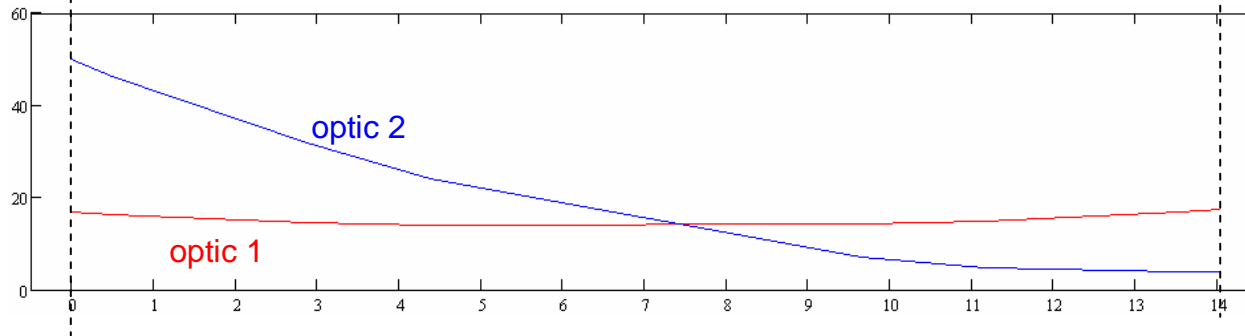


FLASH BC3

S type chicane:



horizontal beta function:



at FLASH: energy ≈ 500 MeV

here: calculations for 500 MeV and 2 GeV
as well as for both optics

$r_{56} \approx 56.4$ mm

~ BC2 of XFEL



Idealized Gaussian Input Distribution

Gaussian in all 6 phase space components
+ z-correlated correlated (nonlinear) energy chirp
to achieve (without self effects) ideal linear compression

bunch charge: scan $q = 25 \text{ pC} \dots 1 \text{ nC}$

bunch length: $100 \text{ } \mu\text{m}$

initial transverse emittance: $\varepsilon = \frac{1.2 \text{ } \mu\text{m}}{\gamma} \sqrt{\frac{q}{1 \text{ nC}}}$

transverse twiss parameters: according to optic given above

chirp: ideal linear compression (in given S type chicane) to $\hat{I} = 2.5 \text{ kA}$

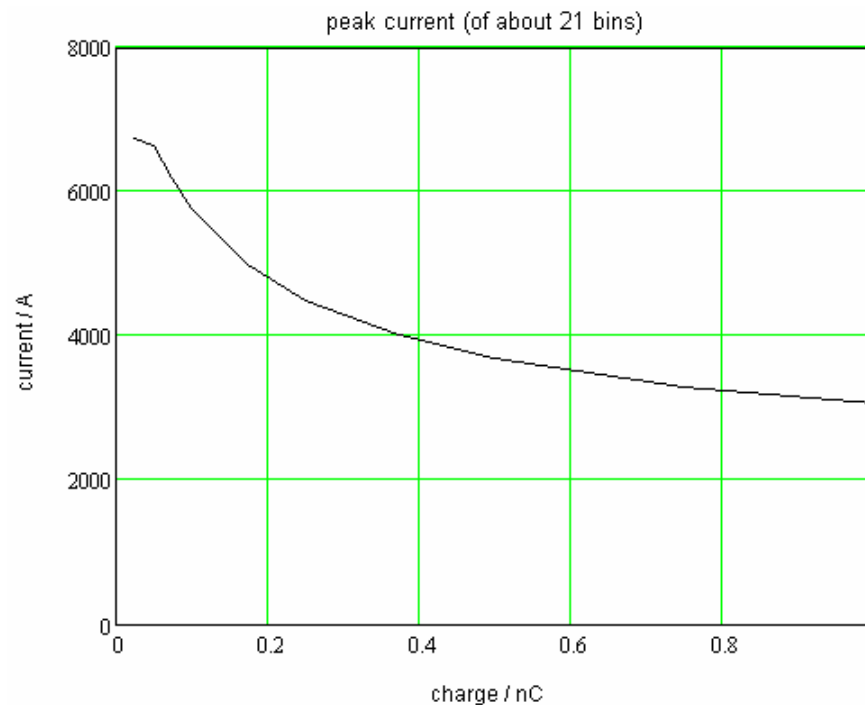
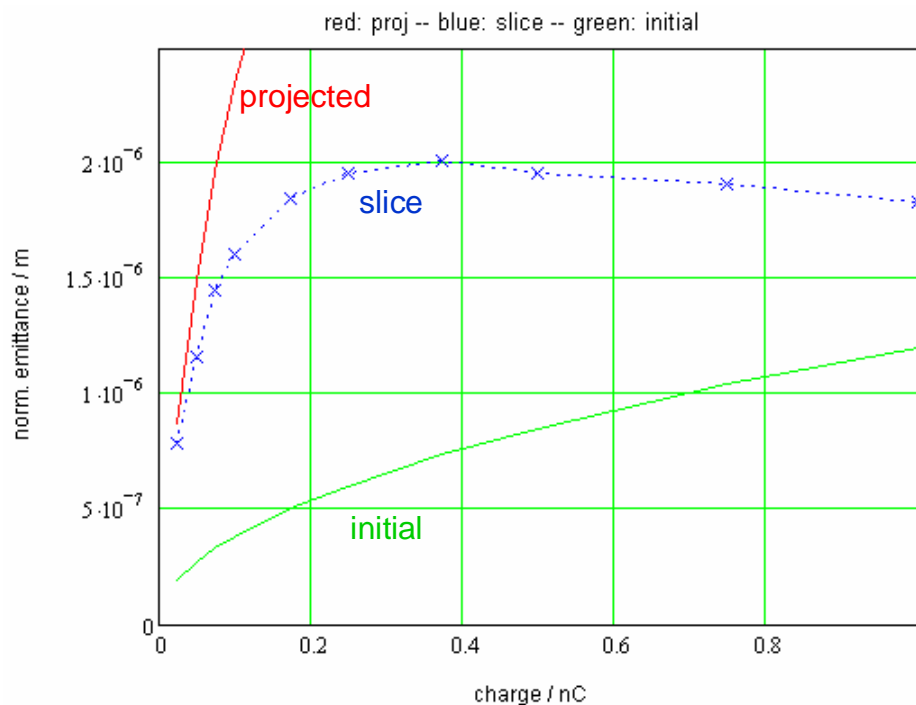
uncorrelated energy spread: small



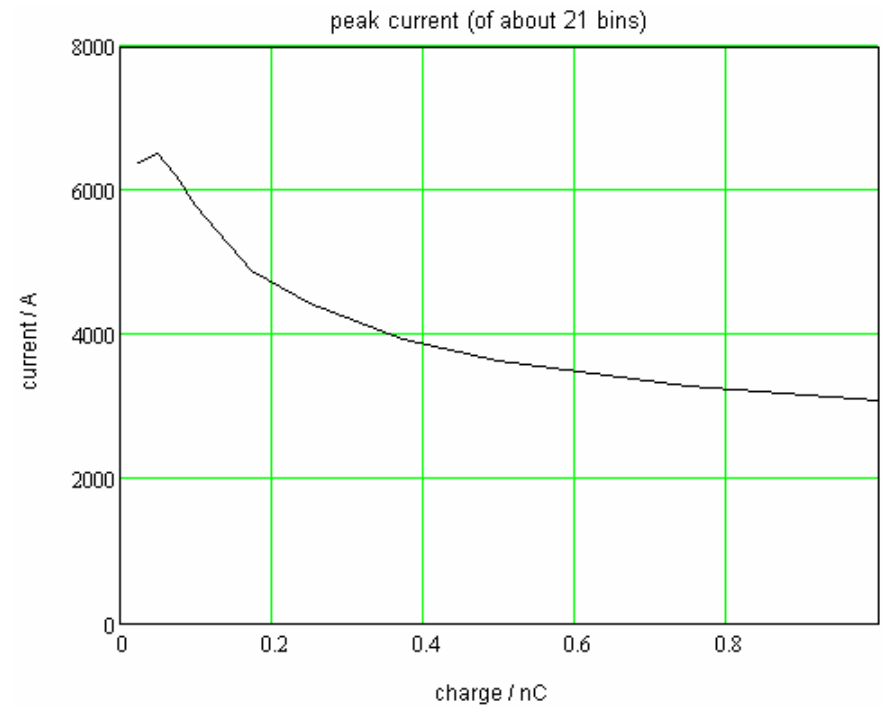
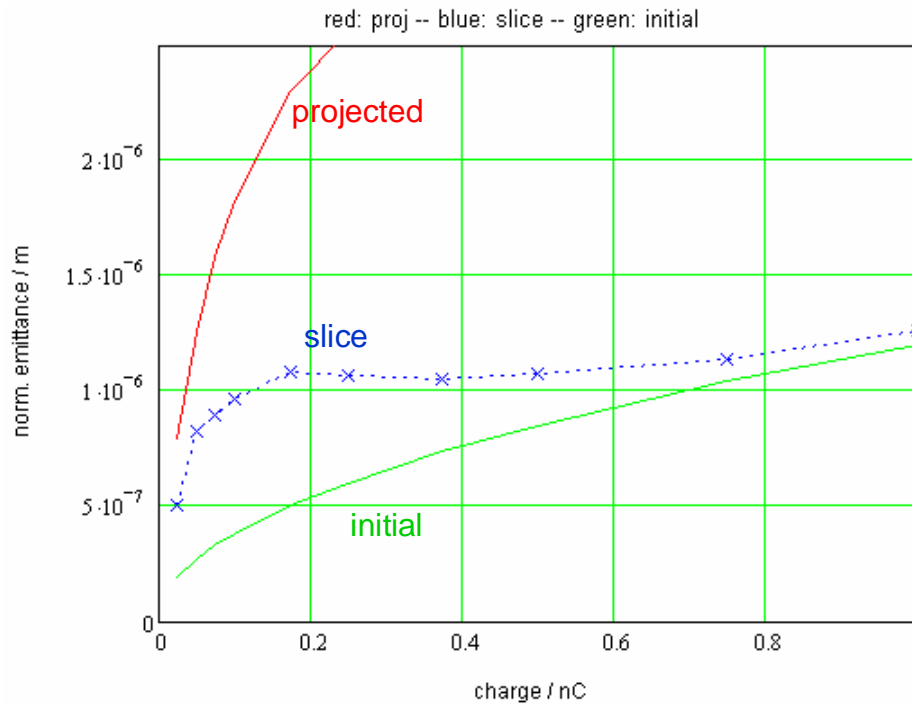
Calculations with CSRtrack “projected method”

S-type BC3 (FLASH) 500MeV optic 1

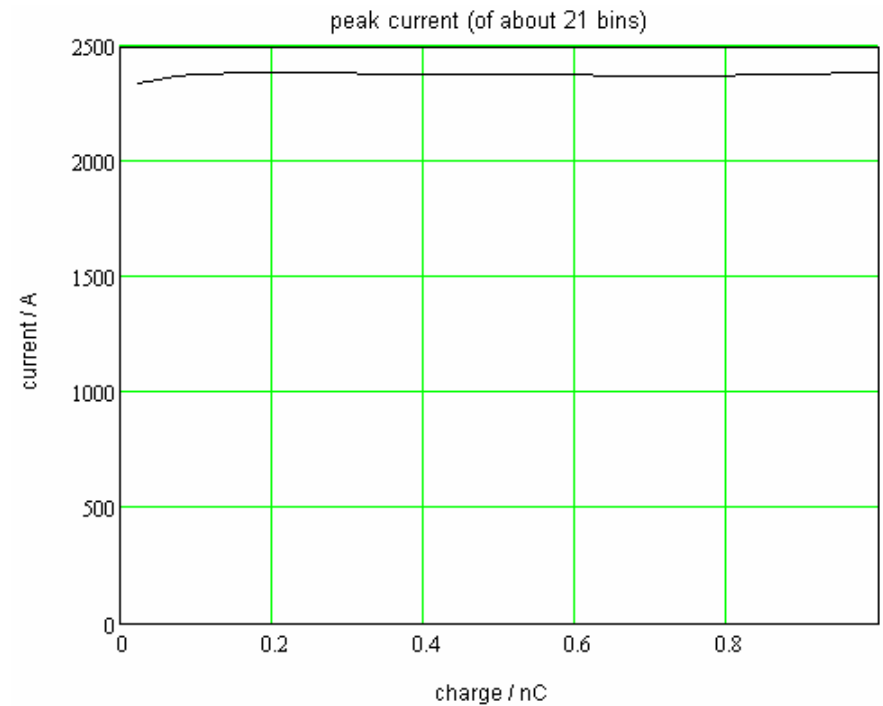
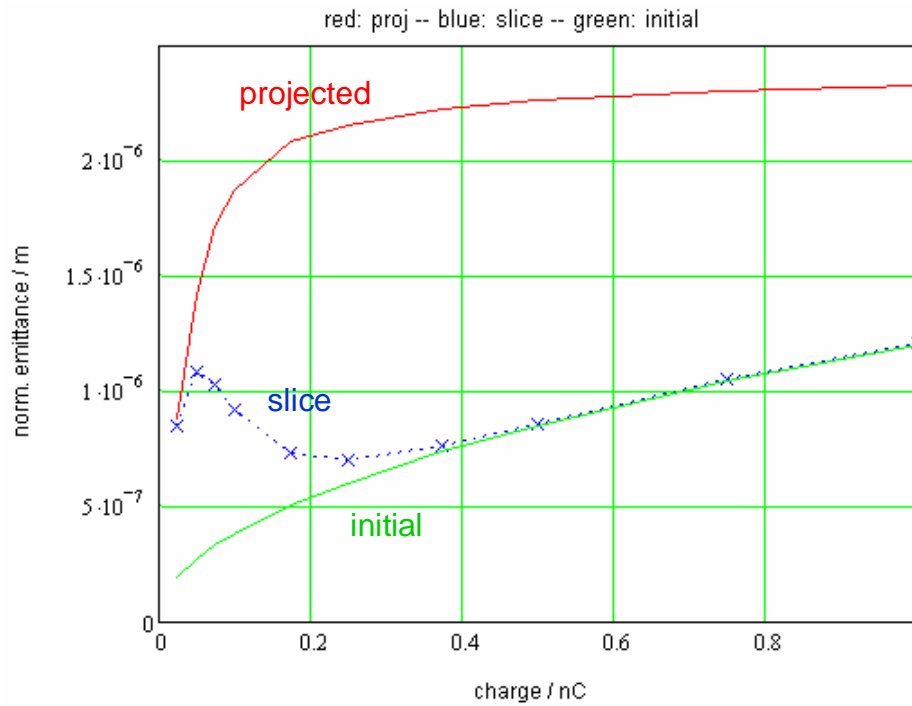
slice emittance
for
slice with peak current



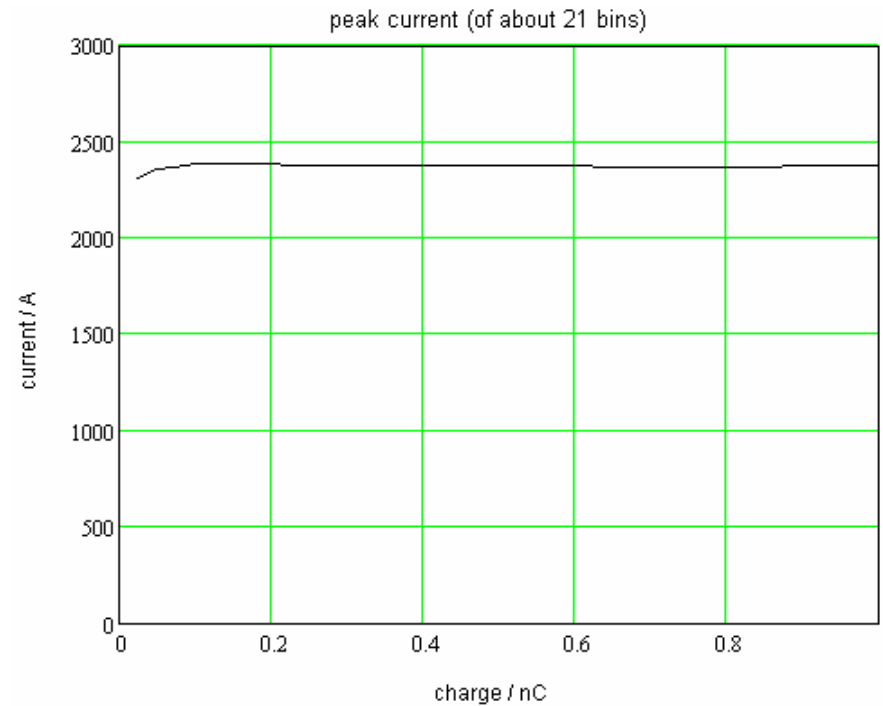
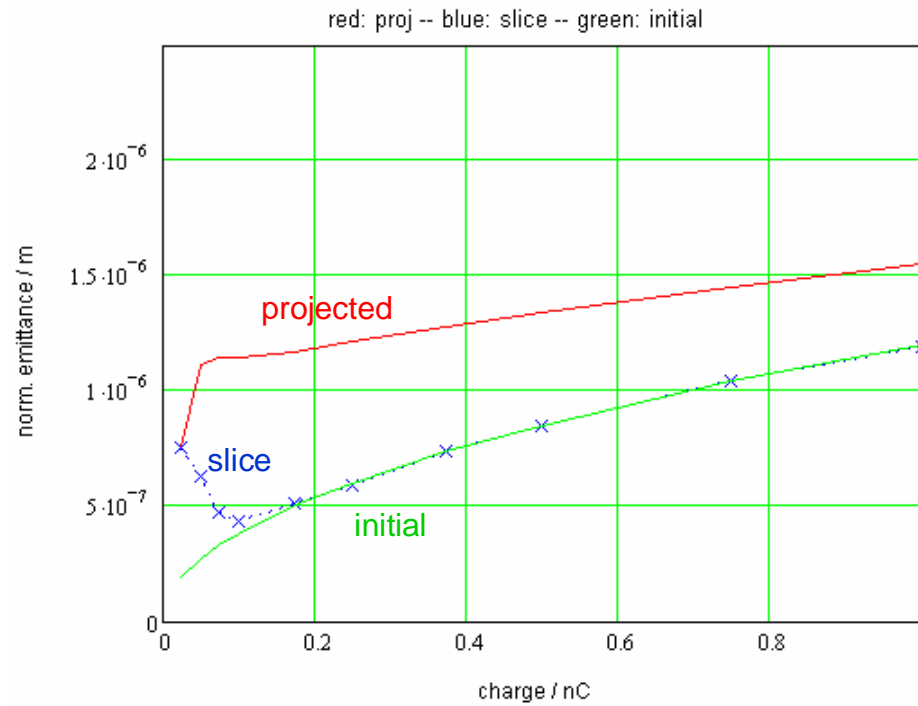
S-type BC3 (FLASH) 500MeV optic 2



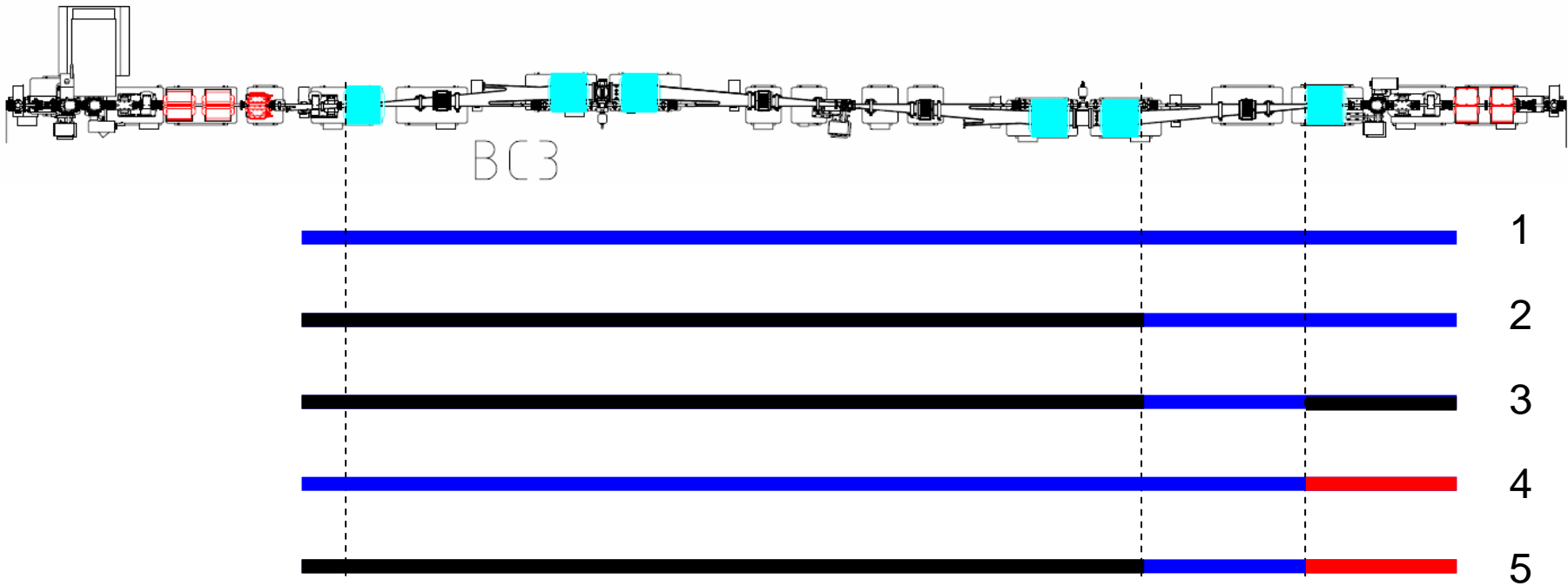
S-type BC3 2GeV optic 1






S-type BC3 2GeV optic 2



Split Calculations

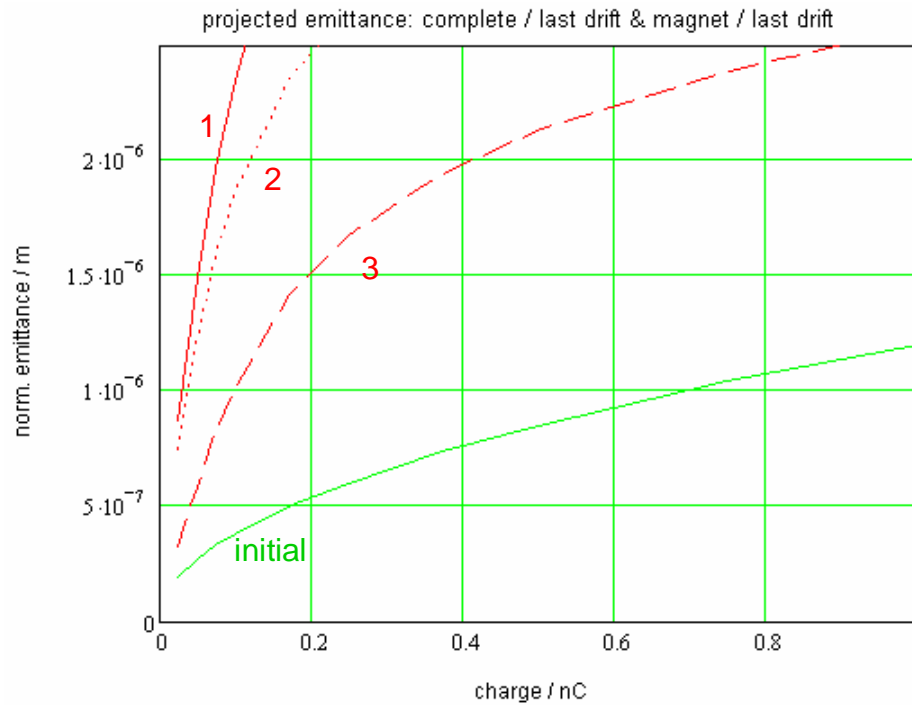
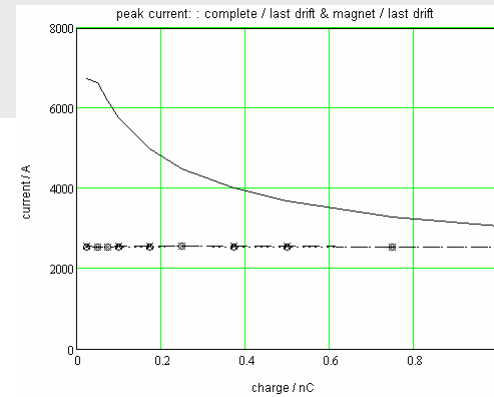


-  no self forces
-  CSR projected method
-  CSR "Greens function method"

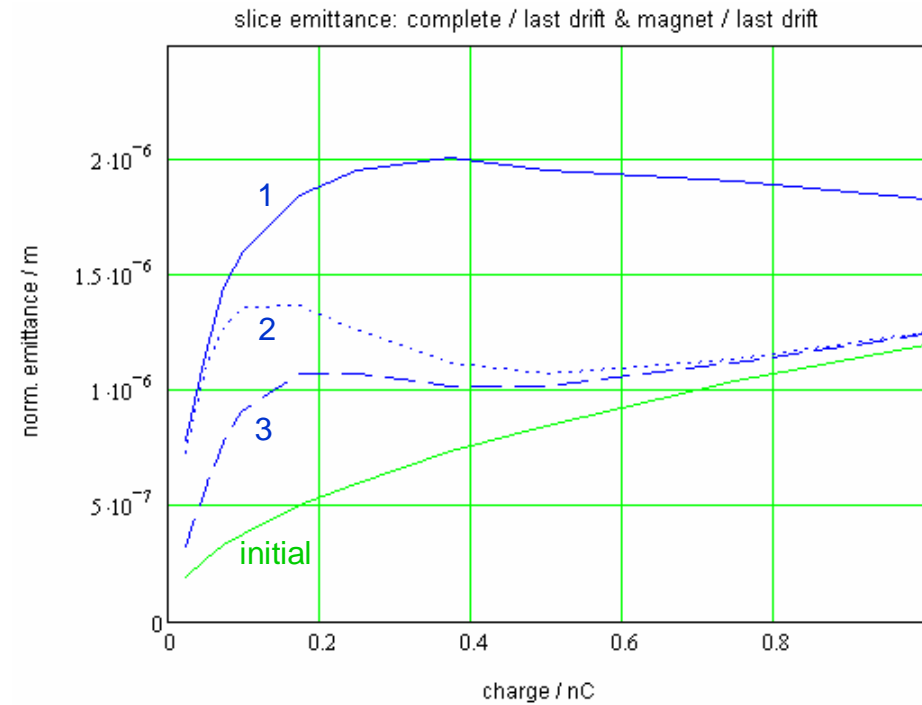


Split Calculations

S-type BC3 (FLASH) 500MeV optic 1



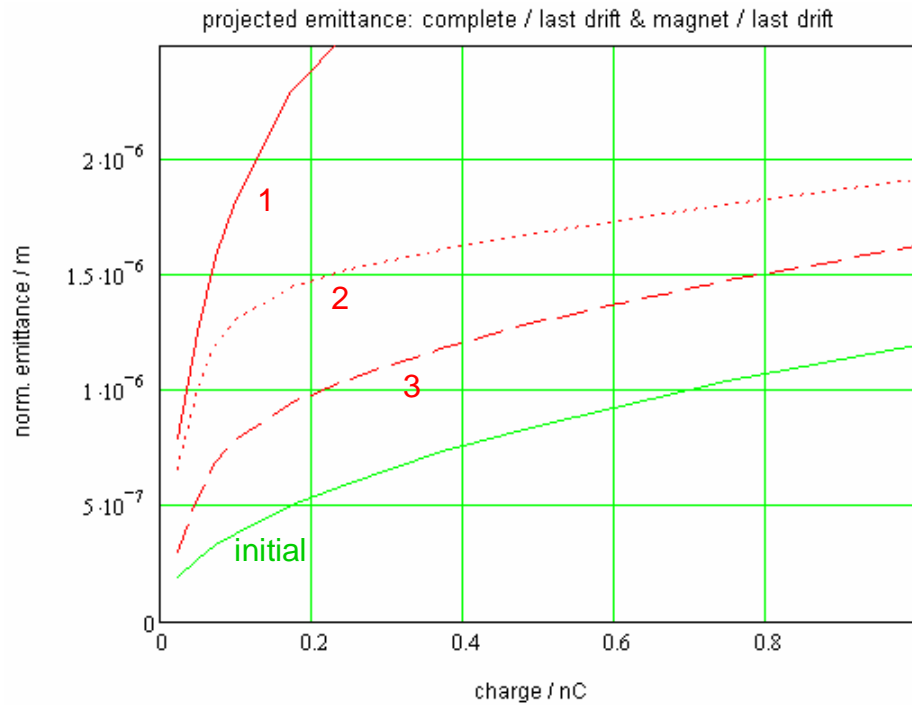
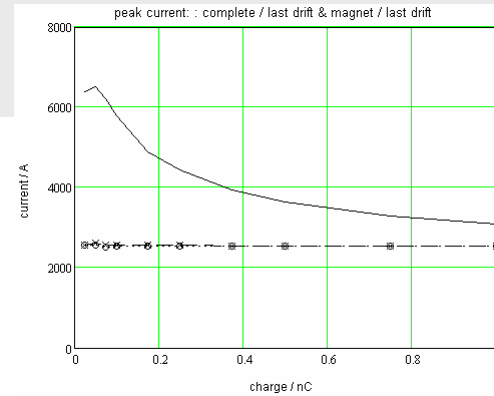
- 1 projected complete
- 2 projected only drift & magnet
- 3 projected only drift



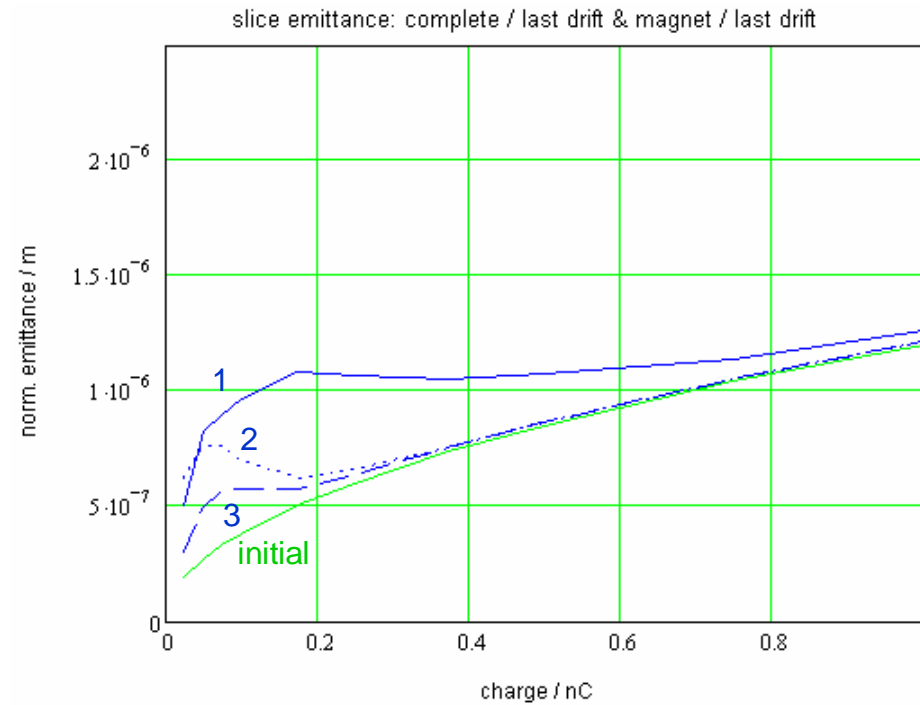
- 1 slice complete
- 2 slice only drift & magnet
- 3 slice only drift



S-type BC3 (FLASH) 500MeV optic 2



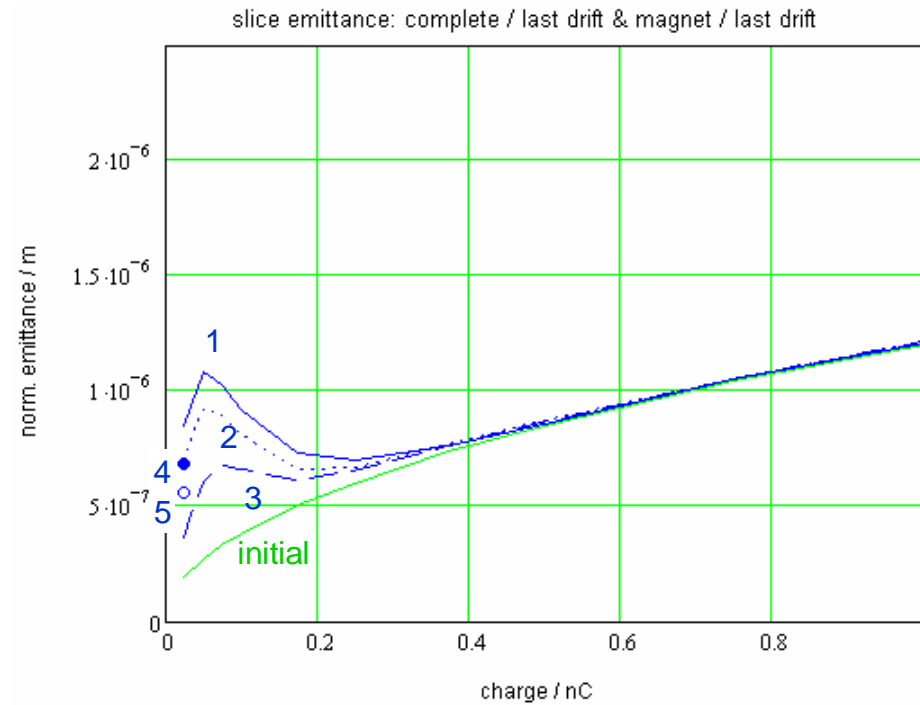
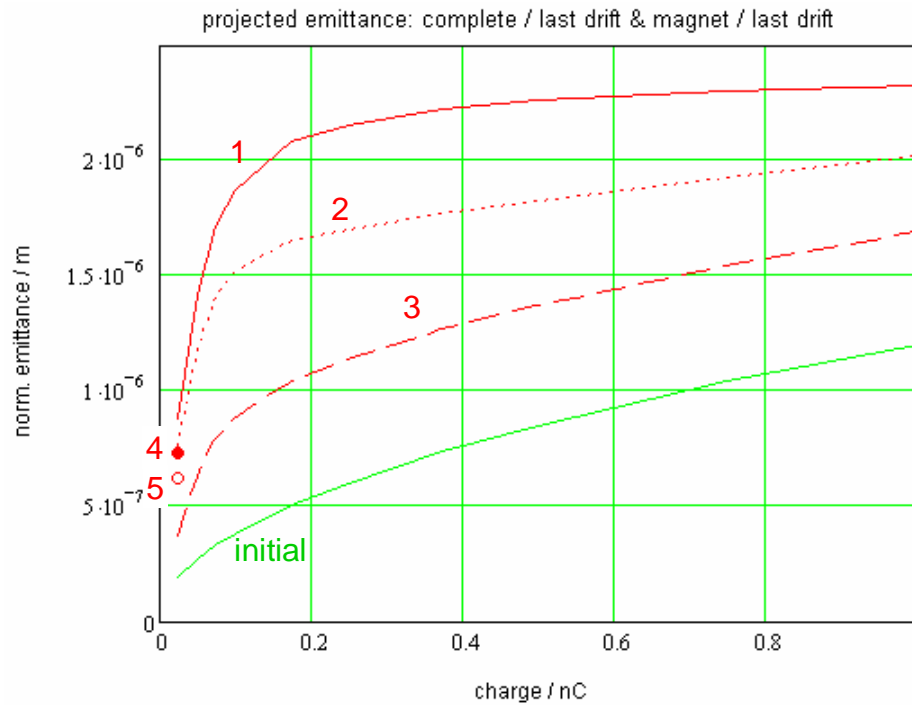
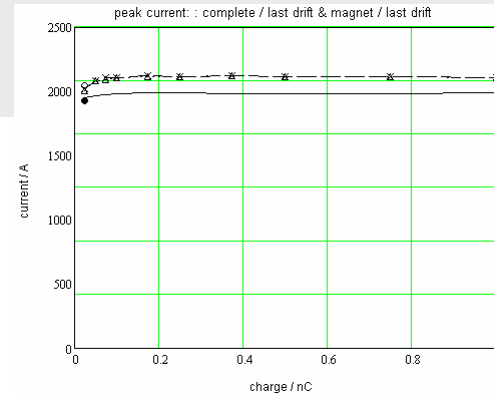
- 1 projected complete
- 2 projected only drift & magnet
- 3 projected only drift



- 1 slice complete
- 2 slice only drift & magnet
- 3 slice only drift



S-type BC3 2GeV optic 1

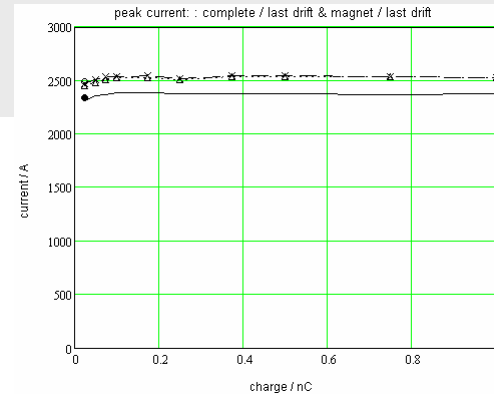


- 1 projected complete
- 2 projected only drift & magnet
- 3 projected only drift
- 4 projected & greens in last magnet
- 5 projected only drift & greens in last magnet

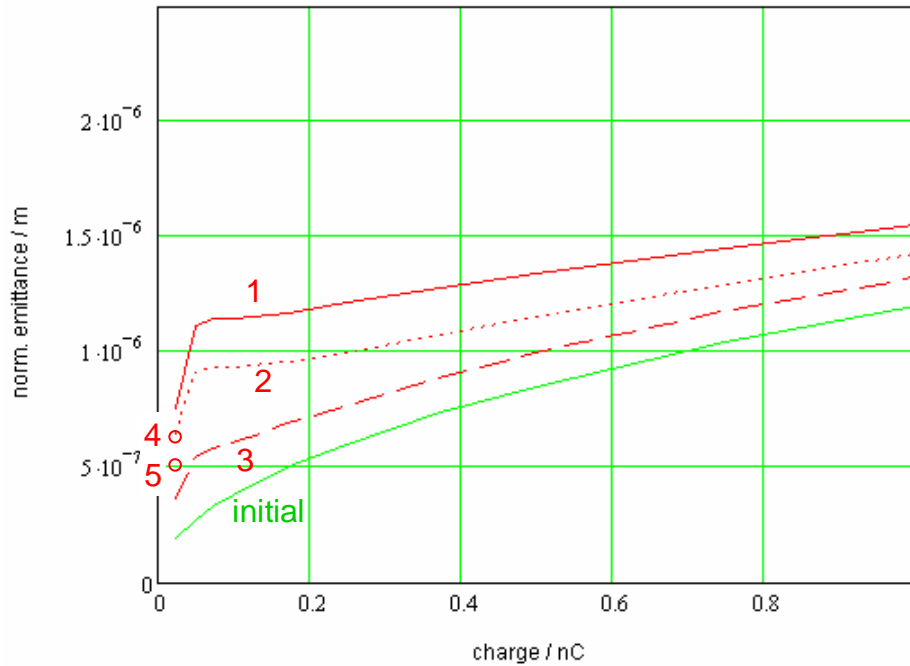
- 1 slice complete
- 2 slice only drift & magnet
- 3 slice only drift
- 4 slice & greens in last magnet
- 5 slice only drift & greens in last magnet



S-type BC3 2GeV optic 2

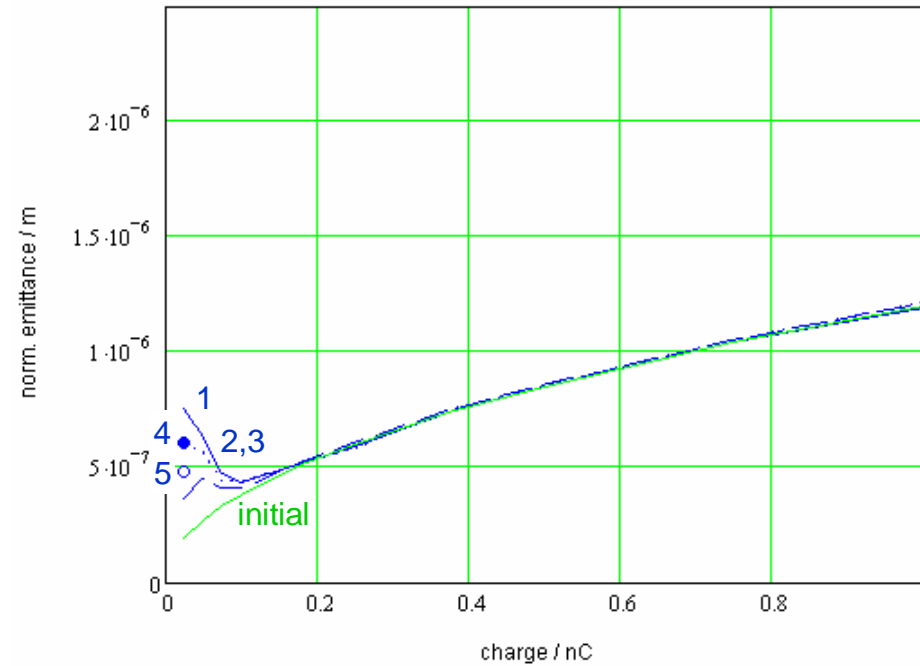


projected emittance: complete / last drift & magnet / last drift



- 1 projected complete
- 2 projected only drift & magnet
- 3 projected only drift
- 4 projected & greens in last magnet
- 5 projected only drift & greens in last magnet

slice emittance: complete / last drift & magnet / last drift

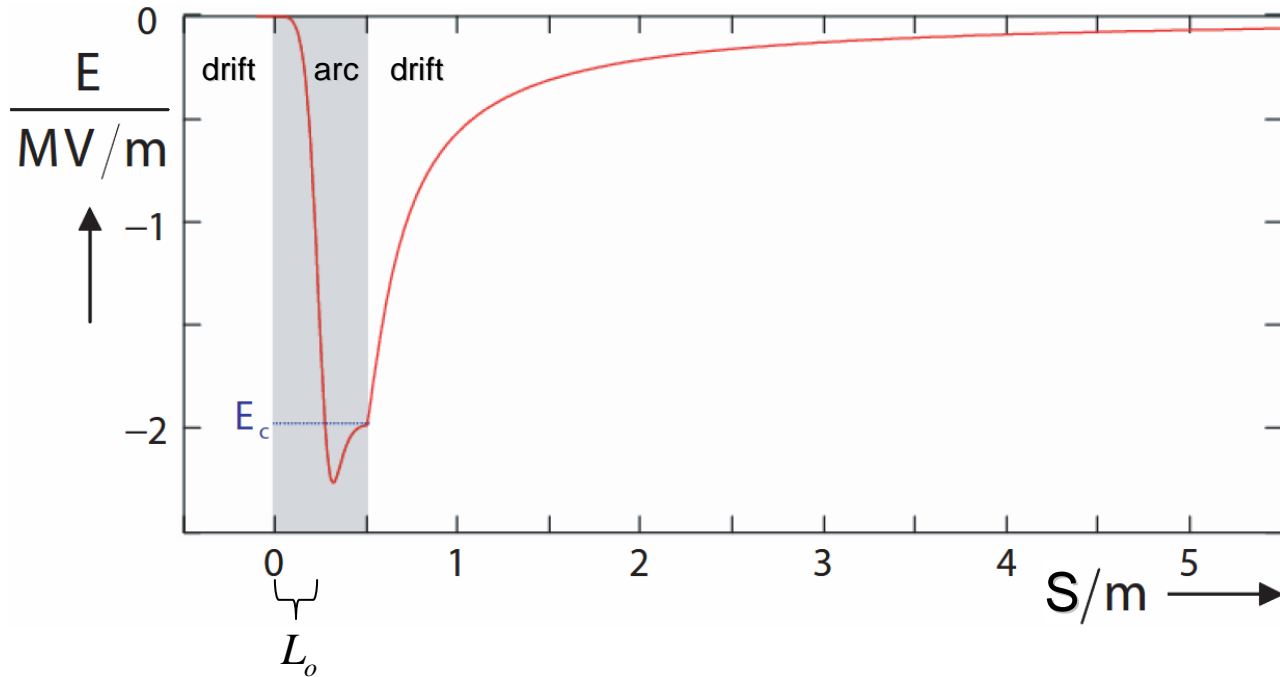


- 1 slice complete
- 2 slice only drift & magnet
- 3 slice only drift
- 4 slice & greens in last magnet
- 5 slice only drift & greens in last magnet



Two (of many) CSR Effects

steady state and transient longitudinal CSR field



$$L_o = \sqrt[3]{24R_{\text{bend}}^2 \sigma}$$



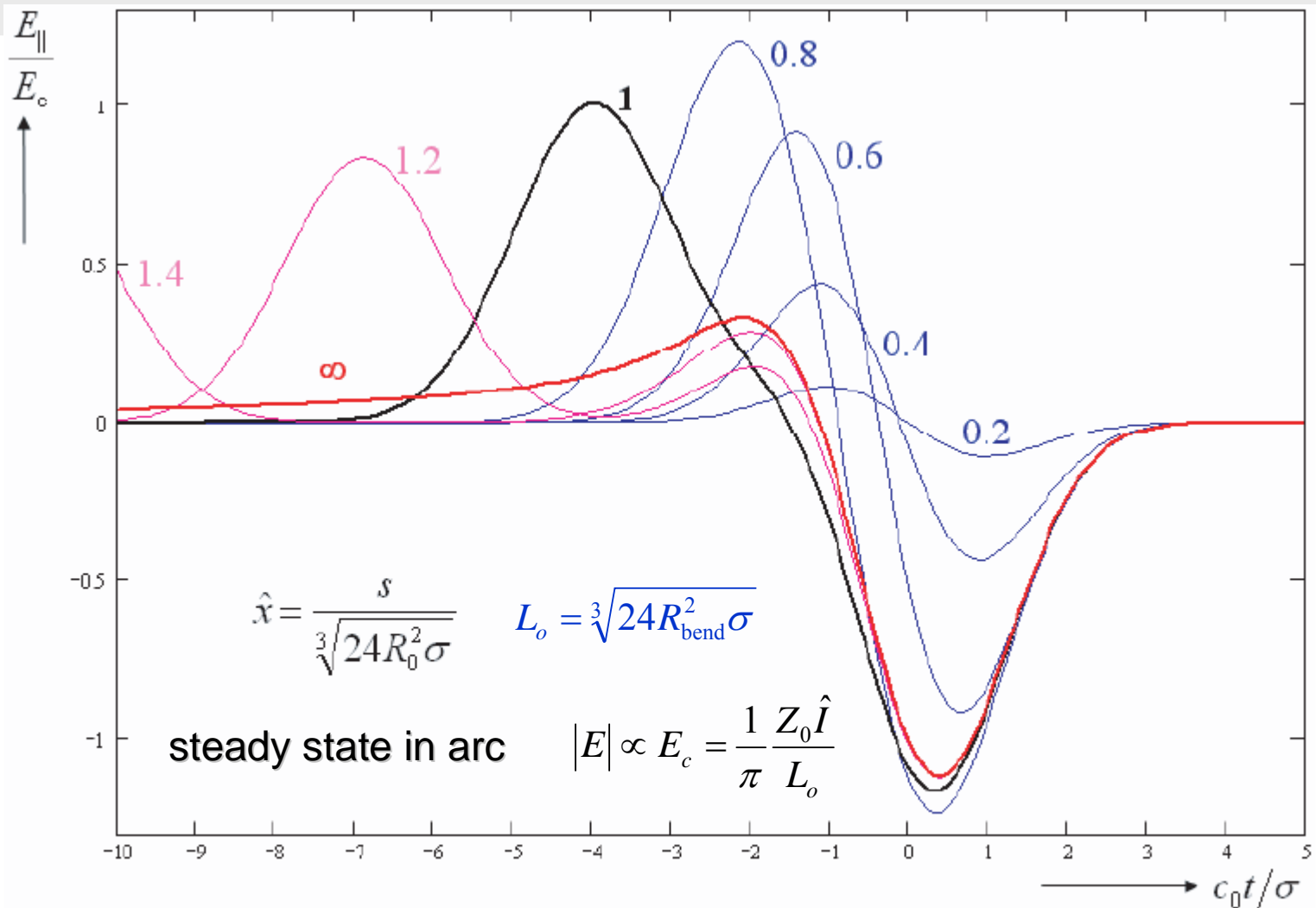


Figure 8: Transient CSR field: Injection



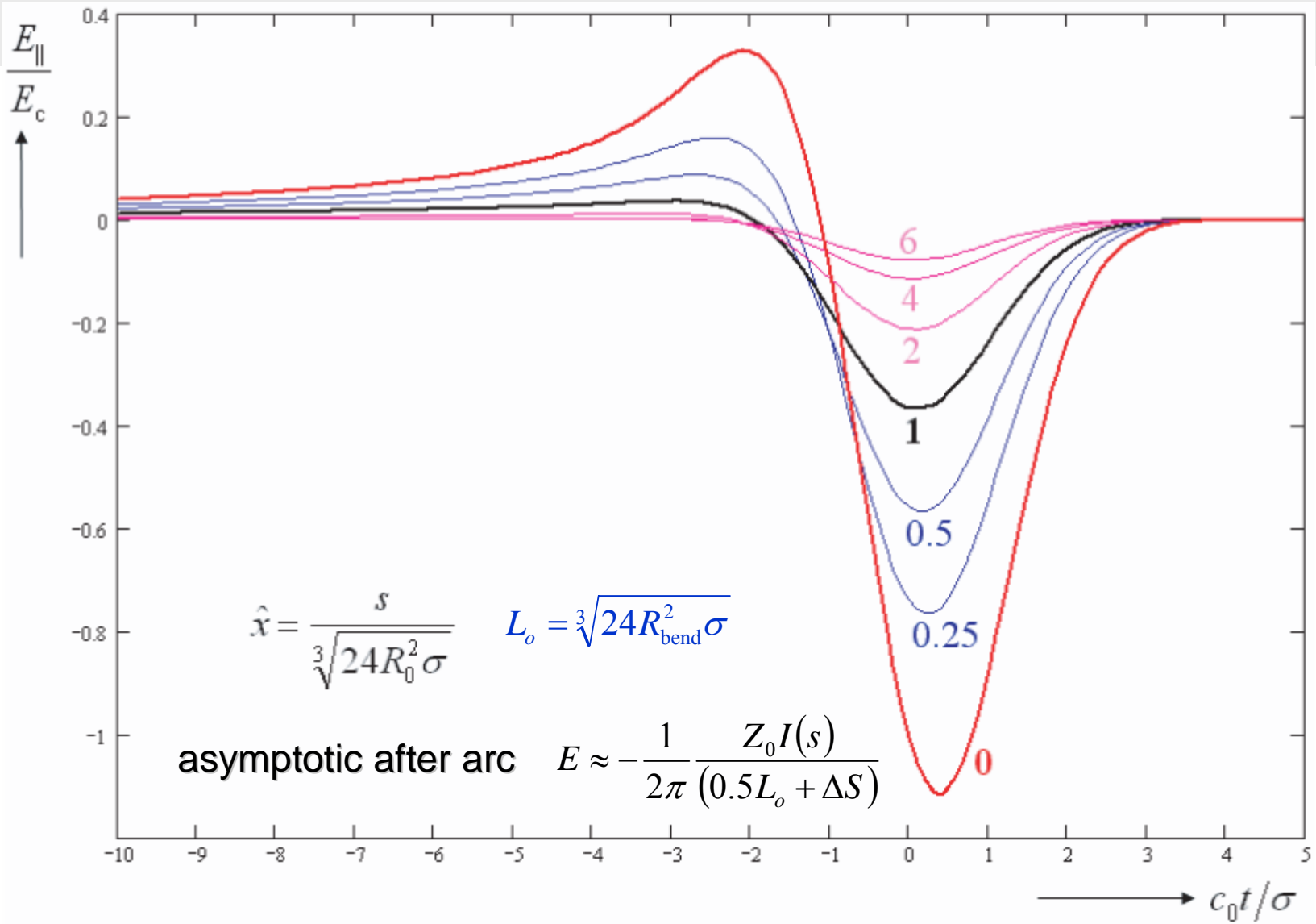


Figure 9: Transient CSR field: Ejection



Rough Estimation of Projected Emittance Growth

estimation 1:

idea: everything is ok to the entrance of last magnet

estimate additional energy spread by steady state CSR in last magnet

estimate additional kick for short magnet

→

$$E_c = \frac{1}{\pi} \frac{Z_0 \hat{I}}{L_o}$$

magnet length L_m

$$E_{\text{rms}} \approx 0.444 E_c L_m$$

$$\phi_{\text{rms},1} \approx \phi_{\text{bend}} \frac{E_{\text{rms}}}{E_{\text{ref}}}$$

$$\tilde{\varepsilon}_1 \approx \varepsilon \sqrt{1 + \frac{\beta}{\varepsilon} \phi_{\text{rms},1}^2}$$



estimation 2:

idea: everything is ok to the entrance of last magnet

...

but: steady state field **in** last magnet

$$\phi_{\text{rms},2} \approx \phi_{\text{bend}} \frac{\int \delta E_{\text{rms}}(\phi)}{E_{\text{ref}}}$$

$$\phi_{\text{rms},2} \approx \frac{1}{2} \phi_{\text{bend}} \frac{E_{\text{rms}}}{E_{\text{ref}}}$$

$$\tilde{\mathcal{E}}_2 \approx \varepsilon \sqrt{1 + \frac{\beta}{\varepsilon} \phi_{\text{rms},2}^2}$$



estimation 3:

idea: everything is ok to the exit of magnet before last magnet
effects in last magnet neglected
energy spread due to csr field in drift

$$E \approx -\frac{1}{2\pi} \frac{Z_0 I(s)}{(0.5L_o + \Delta S)} \quad V(s) = \int_0^{\text{drift}} E dS \propto \frac{Z_0 I(s)}{2\pi} \ln\left(1 + \frac{\text{drift}}{0.5L_o}\right) \quad V_{\text{rms}} = \frac{V(0)}{2\sqrt{\pi}}$$

$$\phi_{\text{rms},3} \approx \phi_{\text{bend}} \frac{qV_{\text{rms}}}{E_{\text{ref}}}$$

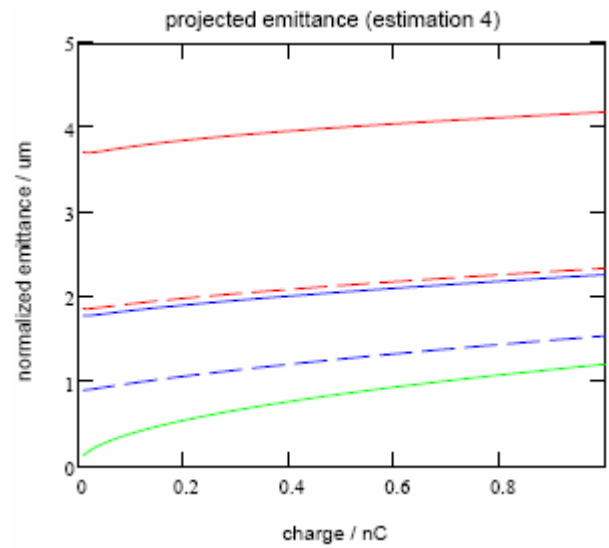
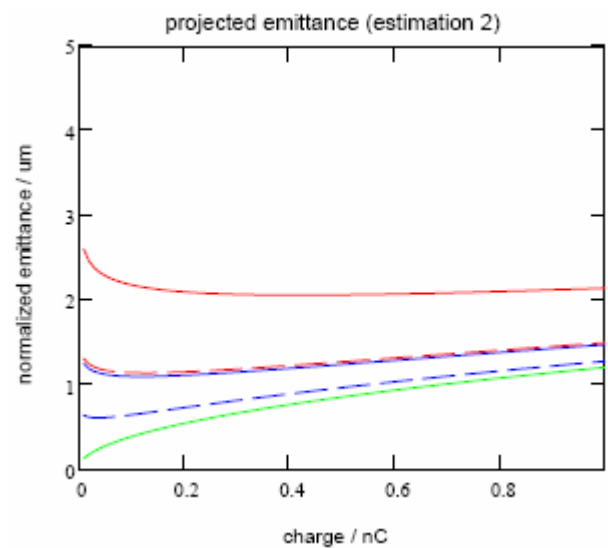
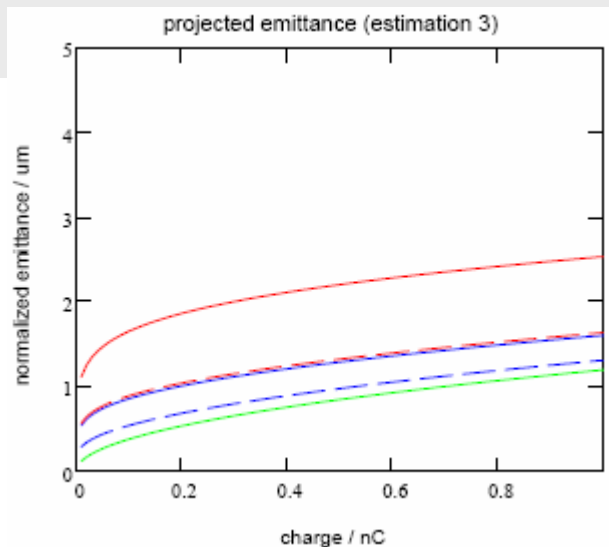
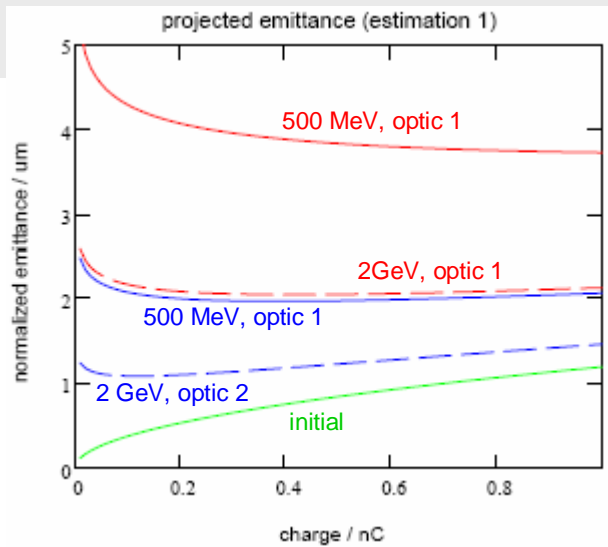
$$\tilde{\varepsilon}_3 \approx \varepsilon \sqrt{1 + \frac{\beta}{\varepsilon} \phi_{\text{rms},3}^2}$$

estimation 4:

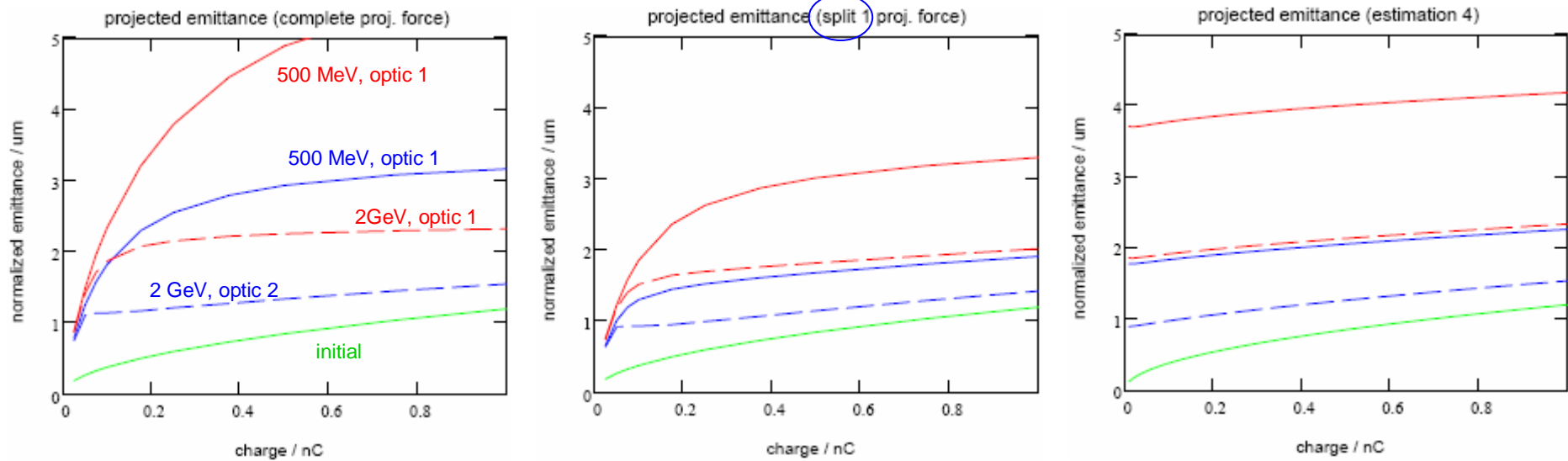
$$\phi_{\text{rms},4} \approx \phi_{\text{rms},2} + \phi_{\text{rms},3}$$

$$\tilde{\varepsilon}_4 \approx \varepsilon \sqrt{1 + \frac{\beta}{\varepsilon} \phi_{\text{rms},4}^2}$$

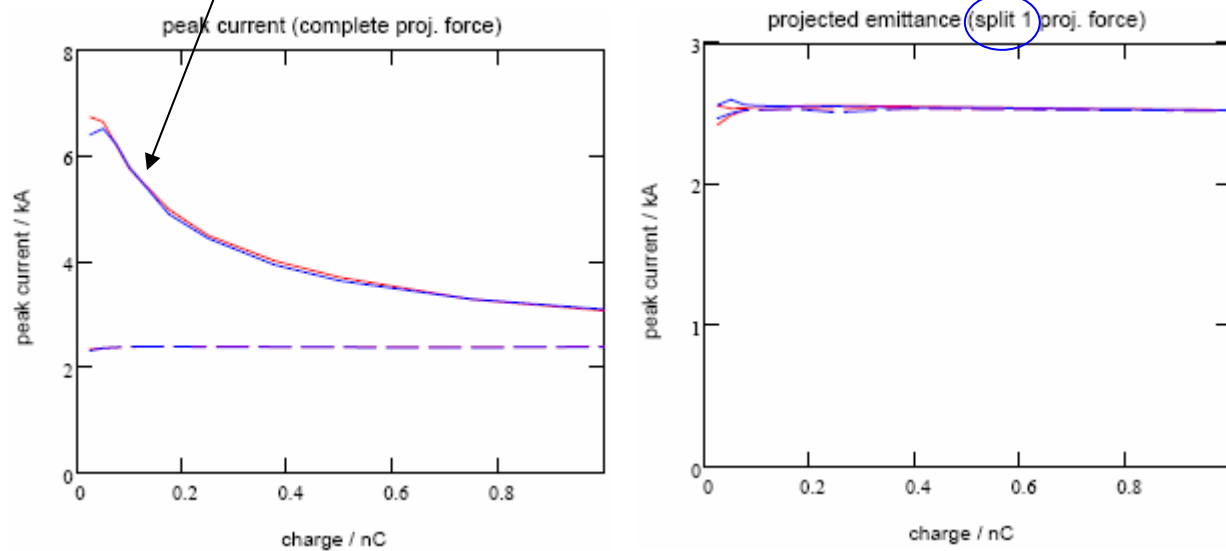




comparison for projected emittance: complete <---> splitted <---> estimation 4

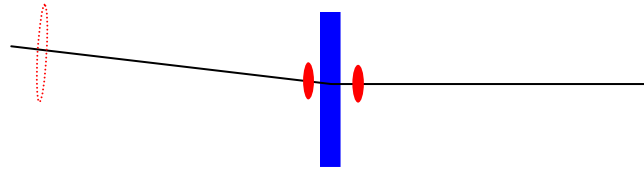


even weak effects in the first part of the compression process
change the longitudinal dynamics significantly (@500 MeV)

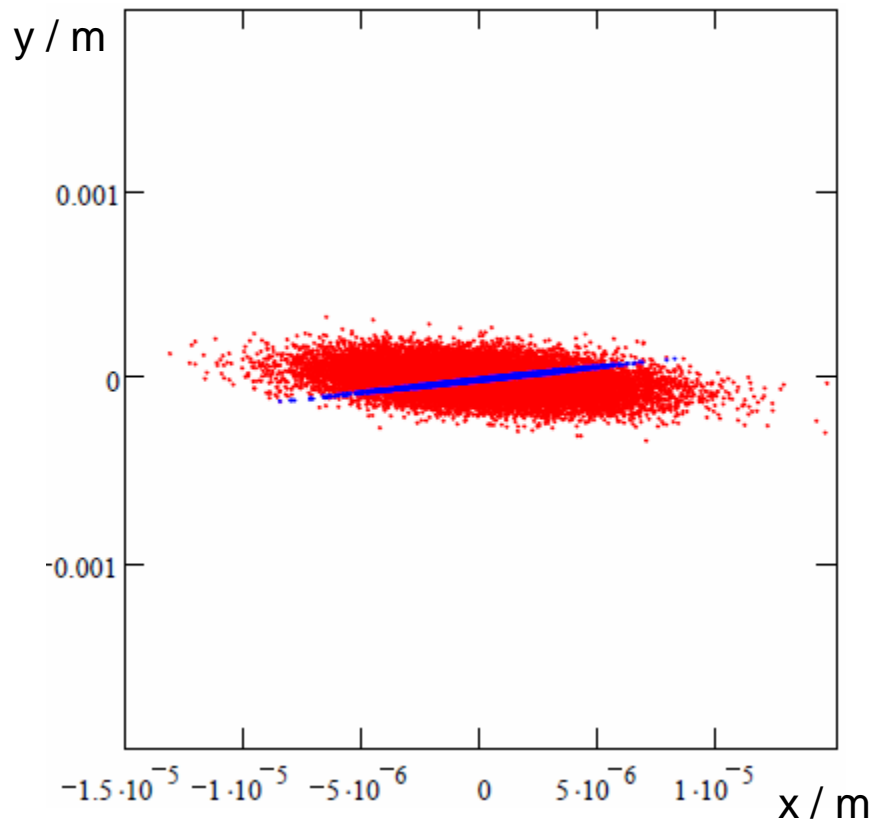


An Effect causing Growth of Slice Emittance

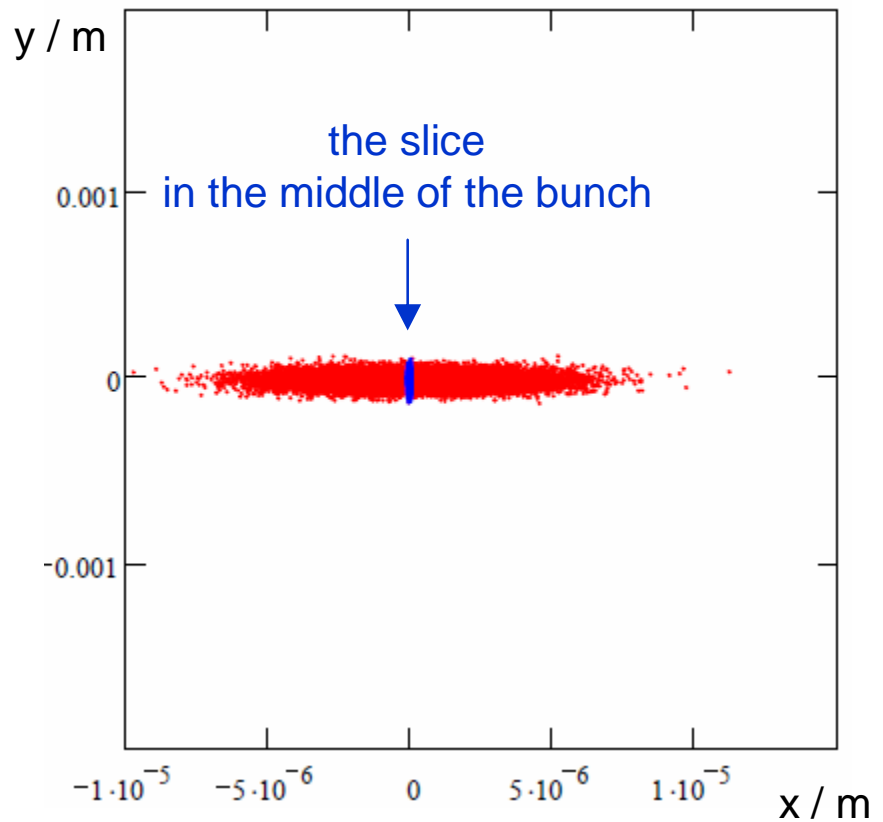
simplification: last magnet is discrete = no length but same deflection



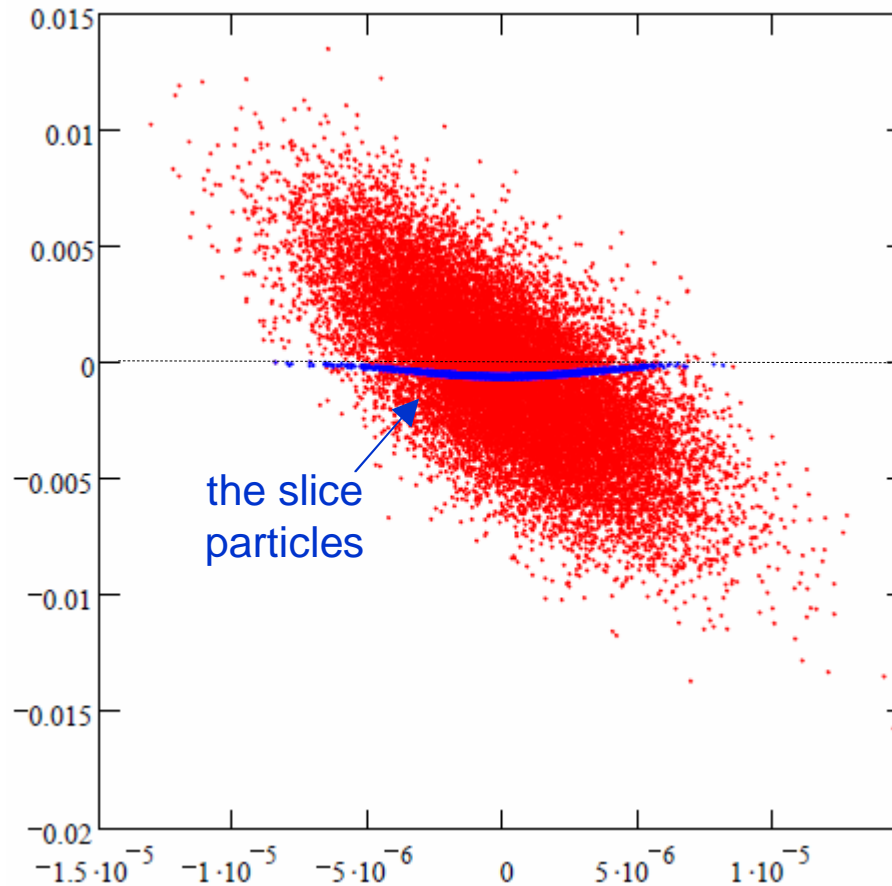
top view: a bit before last magnet



directly after last magnet



longitudinal phase space short before last (discrete) magnet

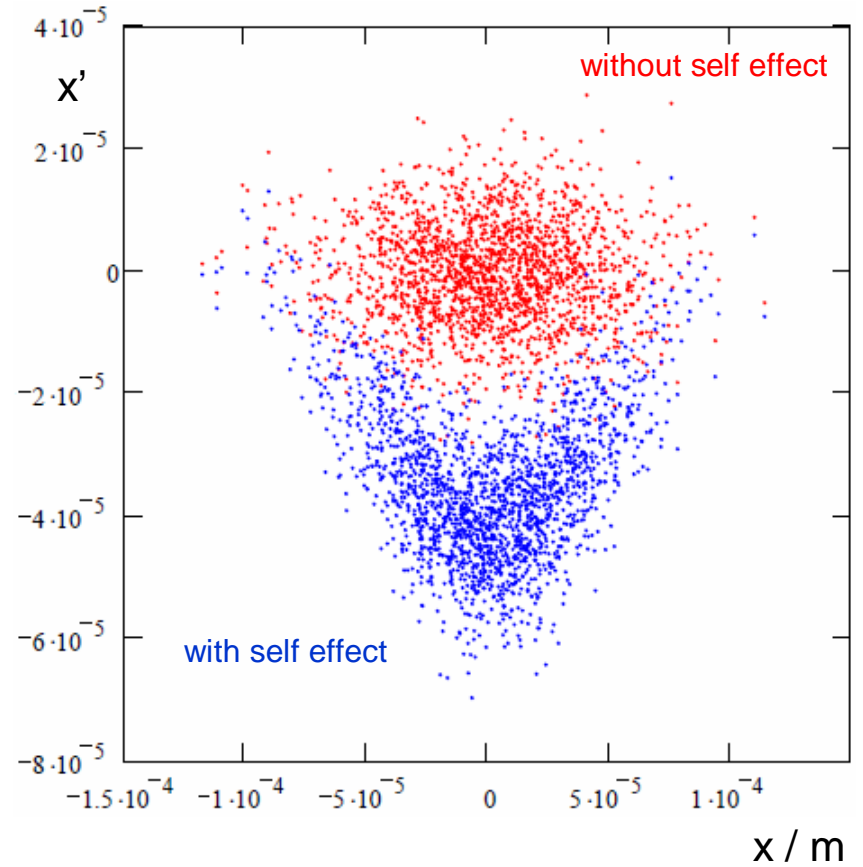
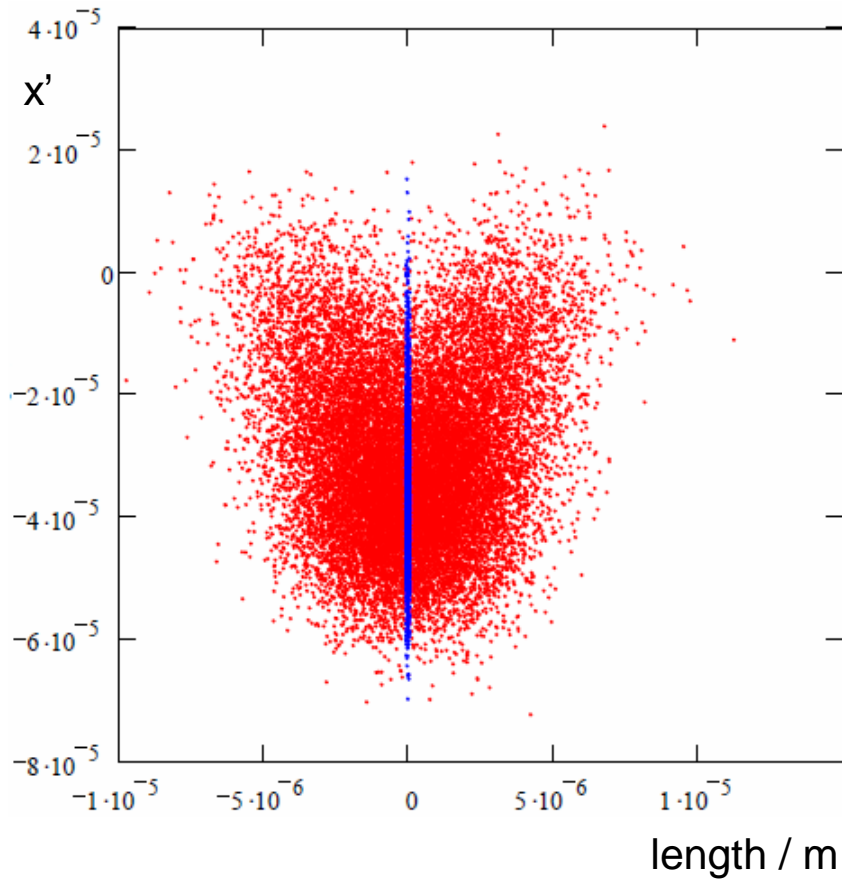


energy loss estimated by asymptotic “csr-field” on drift $E \approx -\frac{1}{2\pi} \frac{Z_0 I(s)}{(0.5L_o + \Delta S)}$



after (discrete) magnet

only the slice



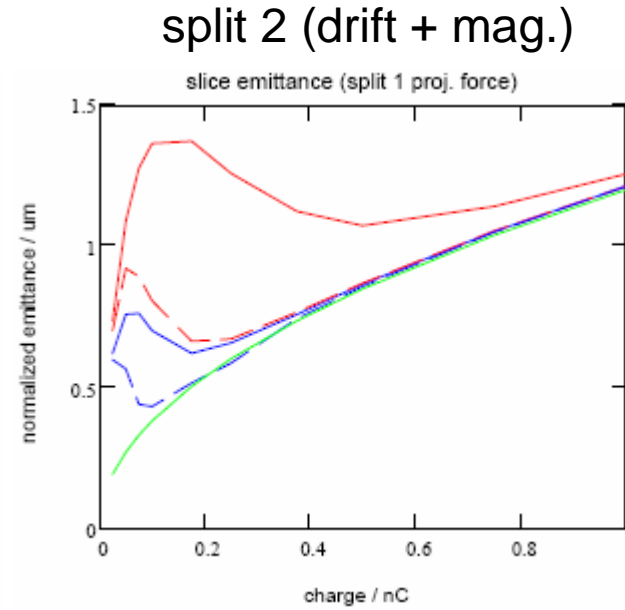
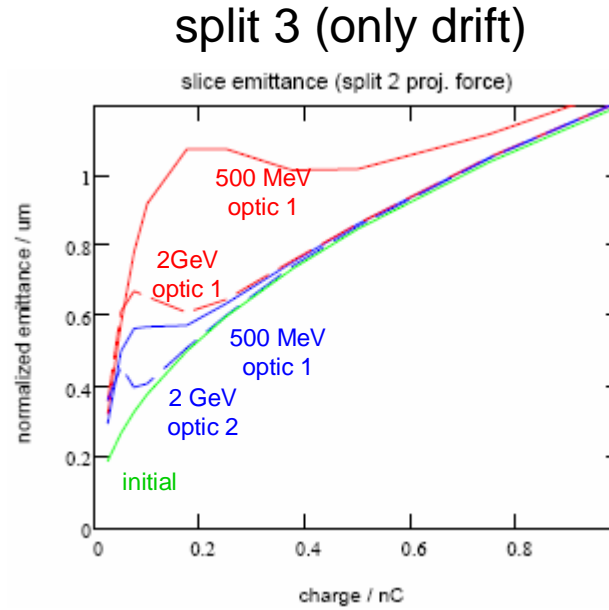
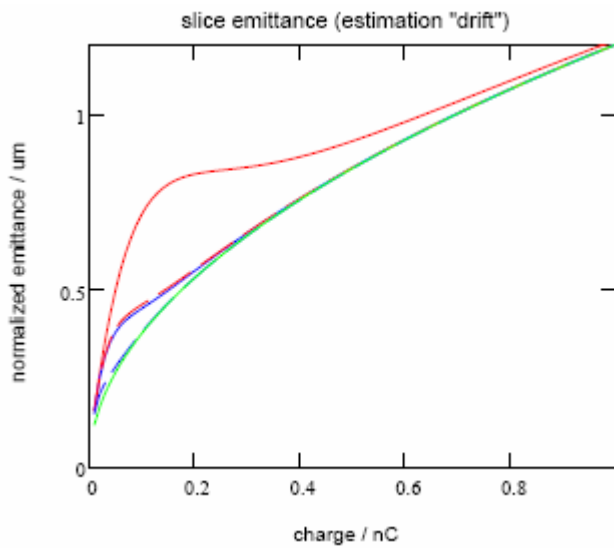
growth of slice emittance!



this can be solved analytically



numerical calculation with
projected method:

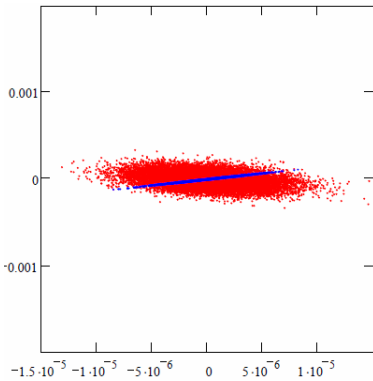


this difference is essentially caused
by the discrete magnet approach



only optics:

“length of slice”
determines bunch length
before magnet

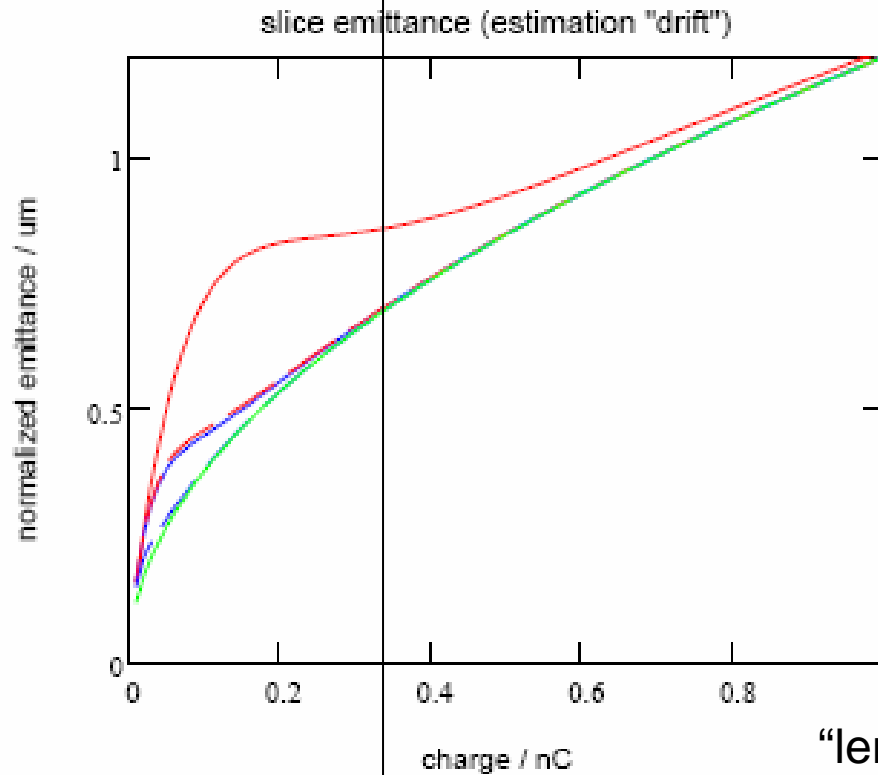


(it is an
emittance effect)

growth of slice emittance

case 1

case 2



“length of slice”
is short before bunch length
before magnet $\approx \sigma / C$

no growth of slice emittance
by that effect

