Progress of longitudinal dynamics

CEPC-SppC workshop

2016-4-8

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Outline

- IBS effect
- My understanding on LHC RF choice
- The RF choice in SPPC
- Future work

IBS growth time (J. Wei's IBS formalism , round beam)

$$\alpha_{\mathrm{IBS},x,y} = \frac{C_1 N_b}{\sigma_s \epsilon^2 \sqrt{\epsilon + C_2 \sigma_p^2}}$$

$$\alpha_{\mathrm{IBS},s} = \frac{C_3 \epsilon}{\sigma_p^2} \alpha_{\mathrm{IBS},x,y},$$

where C_1, C_2, and C_3 are constant during operation:

$$C_1 = \frac{5\sqrt{2} c Z^4 r_{p0}^2}{8 A_{\mathrm{ion}}^2 \gamma^5 \beta_{\mathrm{rel}}^3} \frac{2D_x^2\gamma^2 - \beta_x(\beta_x + \beta_y)}{\beta_x \sqrt{\beta_x + \beta_y}}$$

$$C_2 = \frac{D_x^2}{\beta_x}$$

$$C_3 = \frac{4\gamma^2 \beta_x}{2D_x^2\gamma^2 - \beta_x(\beta_x + \beta_y)}.$$

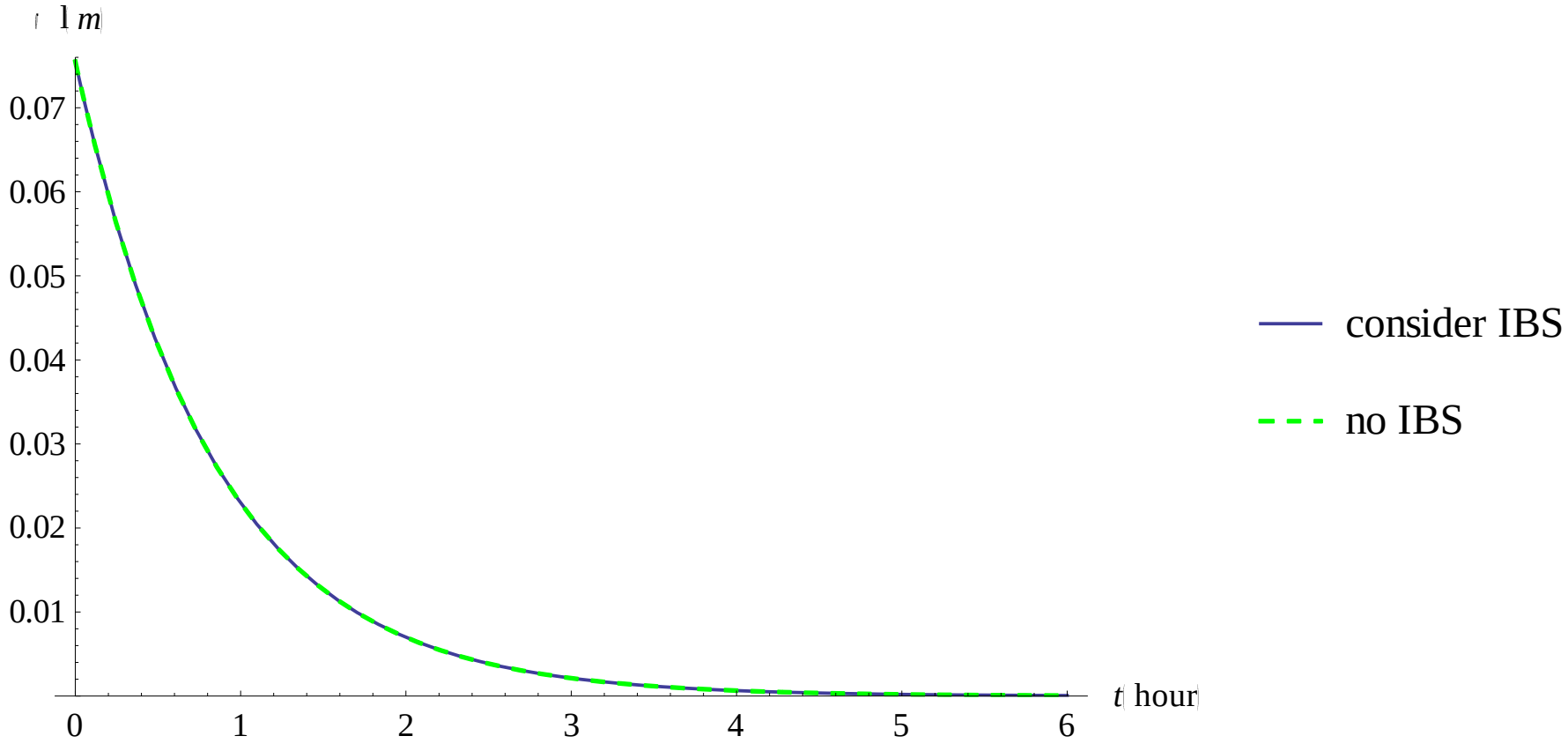
cell length =106.9m
Emittance=4.1μm
Bunch number=5835
Particle number=2E11
Frequency of RF=400MHz

Horizontal IBS emittance growth time
218h(injection)
1102h(collision)

Longitudinal IBS emittance growth time
18h(injection)
459h(collision)

Reference: PRST-AB 18, 091002 (2015)

With /without IBS the change of bunch length



IBS effect needn’t consider in our design!

parameters	LHC injection[1]	LHC(HL-LHC)[1]	HE-LHC[2]	FCC-hh[3]
Proton energy [TeV]	0.45	7	16.5	50
Ring circumference [km]	26.7	26.7	26.7	83
Dipole field	0.535	8.33	20	20
Longitudinal emittance (4σ) [eVs]	1	2.5	4.0	23
RMS bunch length [cm]	11.24	7.55	6.5	10
Energy loss per turn[keV]	1.15×10^{-4}	6.71	201.332	5.86×10^{3}
Longitudinal emittance damping time [hours]	48498.1	12.9	1	0.32
Momentum compaction	3.225×10^{-4}	3.225×10^{-4}	3.225×10^{-4}	3.62×10^{-5}
Energy spread	$4.4(3.06) \times 10^{-4}$?	1.13×10^{-4}	0.9×10^{-4}	1.1×10^{-4}
Revolution frequency[kHz]	11.245	11.245	11.245	3.614
RF frequency[MHz]	400	400	400	400
Harmonic number	35640	35640	35640	106740
Synchrotron frequency[Hz]	61.8	23		1.9
Total RF voltage[MV]	8	16	32	22
Bucket area[eVs]	1.46	8.7		
Bucket half height (ΔE/E)	1×10^{-3}	0.36×10^{-3}	0.33×10^{-3}	2.1×10^{-4}

[1]:LHC design report
[2]:cern-2011-003
[3]:A first look at the performance for pb-pb and p-pb collisions in FCC-hh

LHC RF considerations

- 400MHz (main) + 200MHz(capture)
- At injection into the LHC： a 200 MHz RF system was proposed, to be used only for capture, in addition to the main 400 MHz RF system .For capture the operational total voltage at 200 MHz is 3 MV .
- After capture the voltage of the 400 MHz RF system is adiabatically increased up to 8 MV and the voltage of the200 MHz RF system is decreased to zero.
- On the flat top the emittance is required to be 2.5 eVs. To have the shortest possible bunch length during collision the maximum available voltage (16 MV) at 400 MHz will be applied producing ~1 ns long bunches.

LHC RF choice

The RFC frequency determines the bucket size, which in turn determines the bunch length that can be effectively captured. We want as long a bucket as possible but there are limitations because a lower frequency means a larger RF cavity which leads to greater challenges with applying superconducting technology.

The possible bunch space in the LHC of integer multiples of 25 ns, possible frequencies for LHC are harmonics h of 40.079 MHz, h>3.

Bucket height: $\left(\frac{\Delta p}{P}\right) = \sqrt{\frac{2eV_{rf}}{\pi h \alpha_p E \beta_{rel}}}$

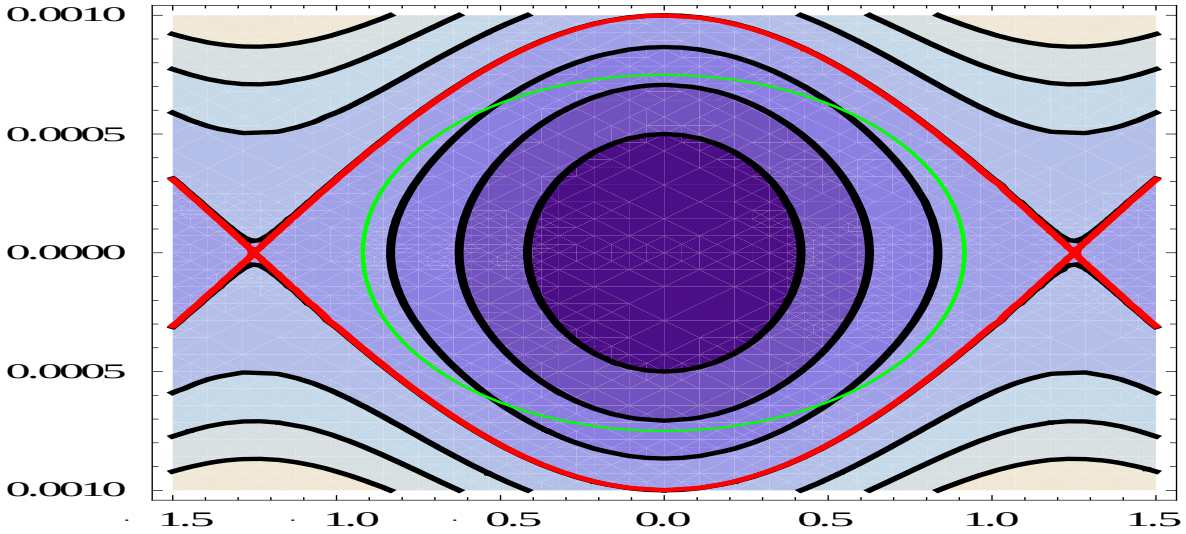
Bucket area: $A_b = \frac{8C_{ring}}{h\pi c}\sqrt{\frac{eV_{rf}E}{2\pi h\alpha_p}}$

The bucket height is at least $\sqrt{6}\sigma_\epsilon$, bucket area is at least equals 95% longitudinal emittance. From these considers, 400MHz is a good choice.

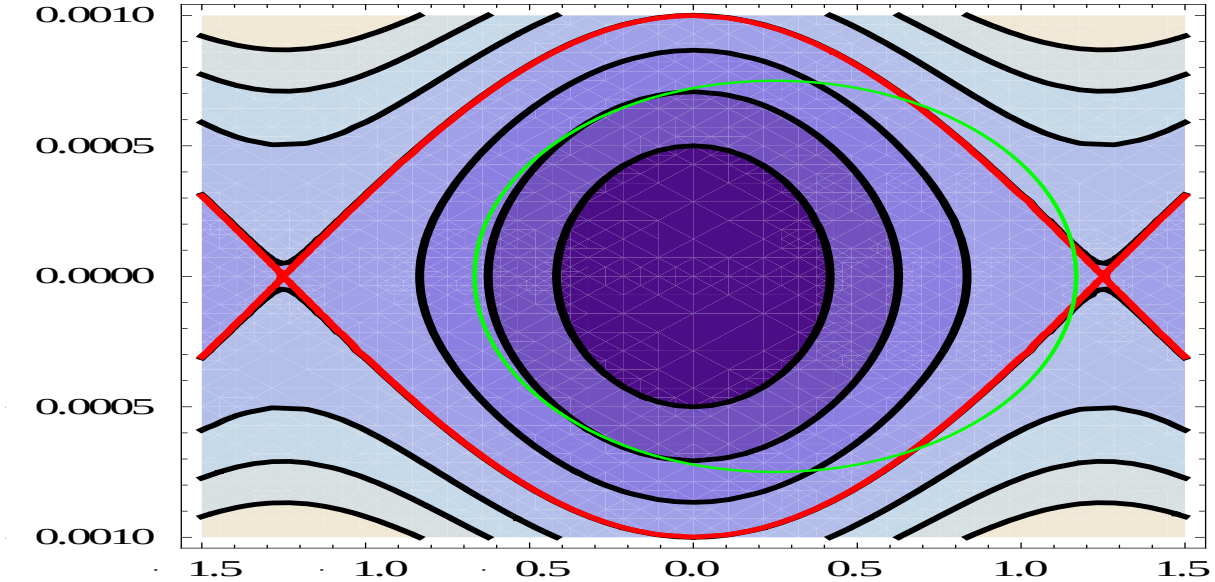
Reference :Choice of the RF Frequency, Erk JENSEN

400MHz 8MV

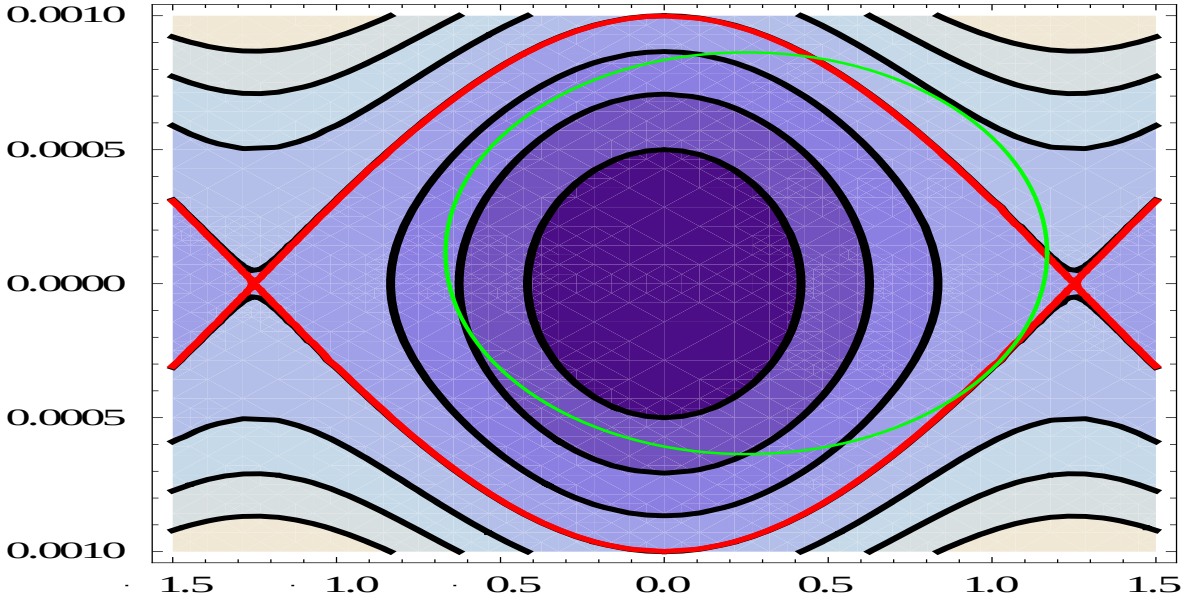
The Green ellipse is 95% longitudinal emittance



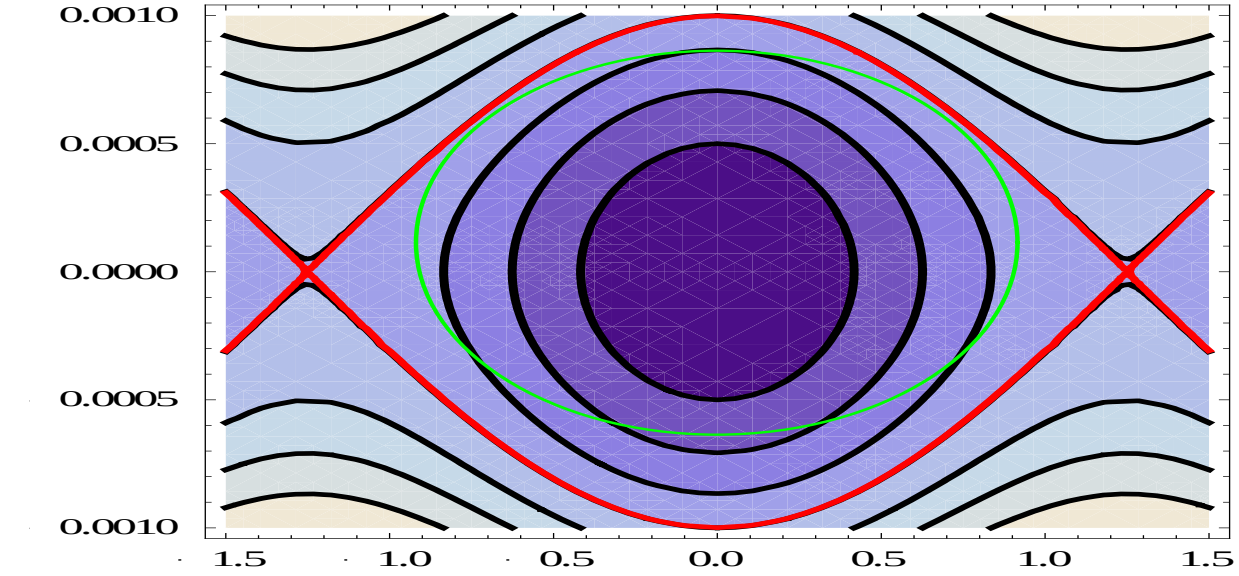
no error



250ps error

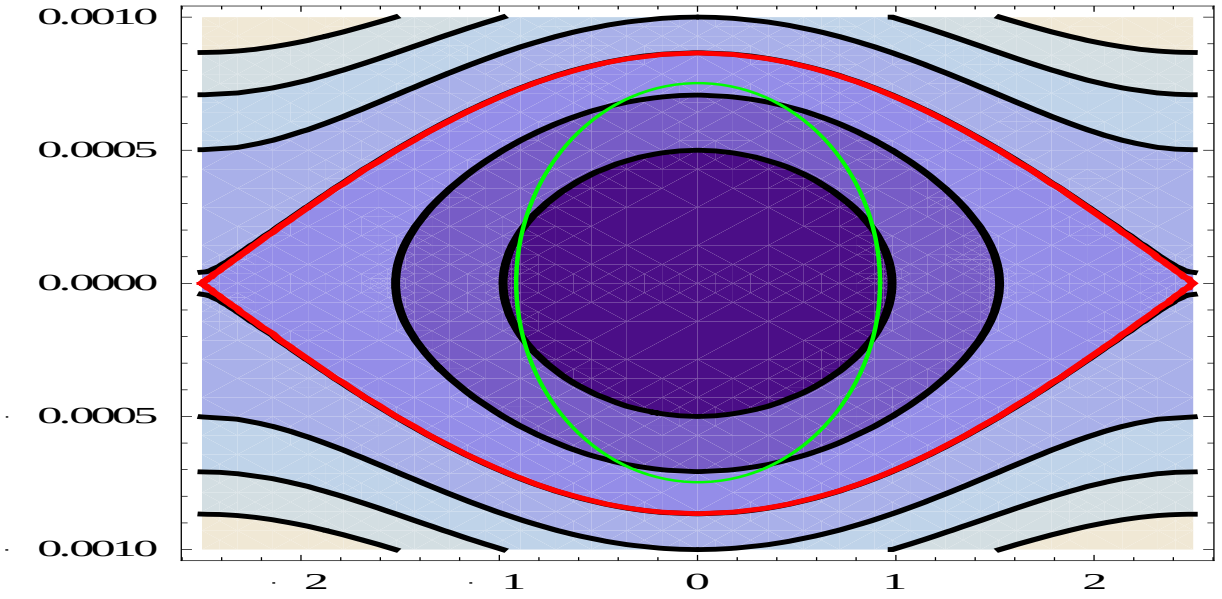


250ps and 50MeV error



50MeV error

200MHz 3MV



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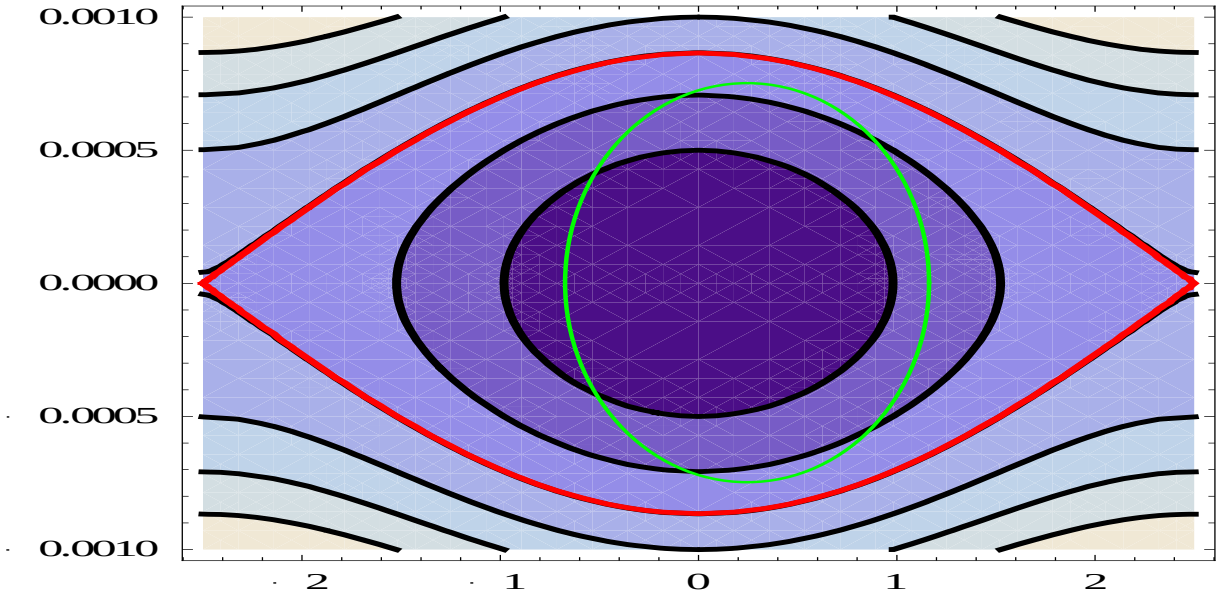
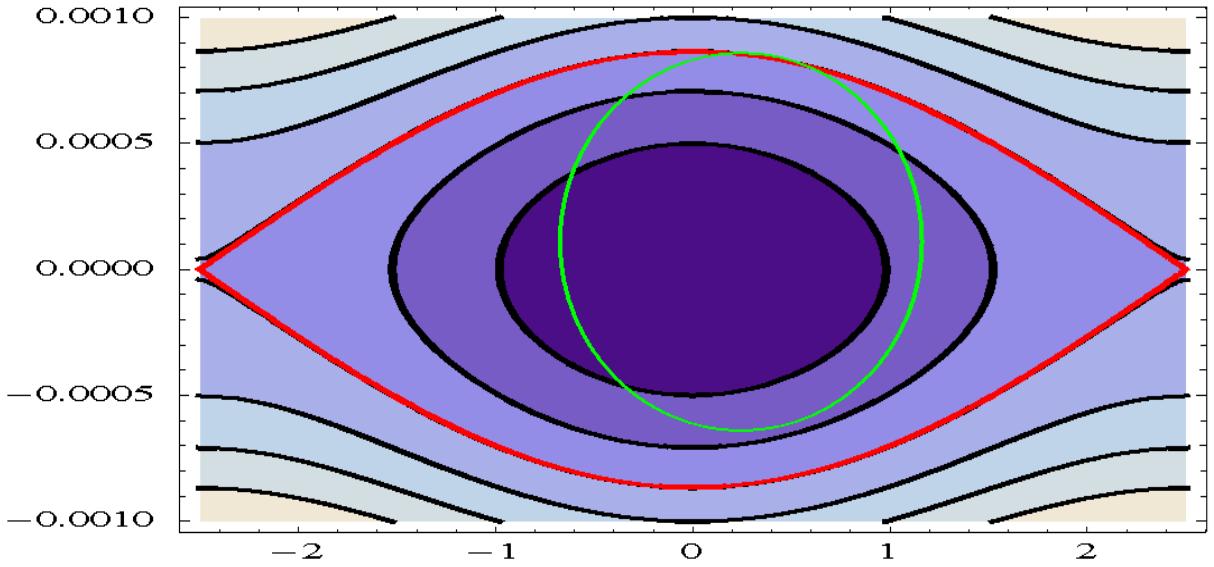
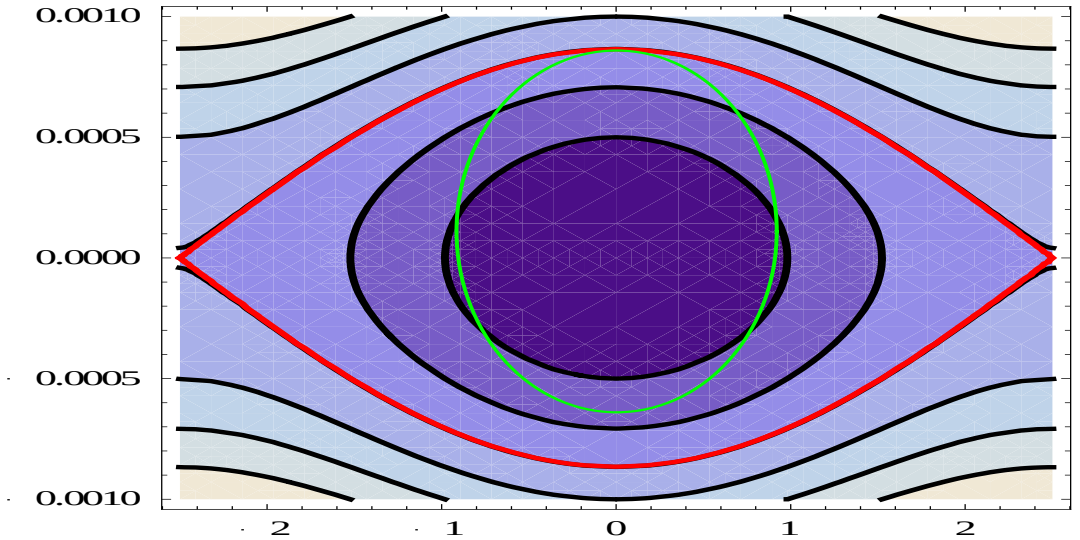


250ps error



250ps and 50MeV error



50MeV error

Why we choose 400MHz RFC as main RFC?

200MHz seems better than 400MHz in injection : less capture loss, low RF voltage and so on. why don't we choose 200MHz RFC as main RFC?

But in collision, we need short bunch length to get high luminosity. Getting the same bunch length, the RF frequency is lower, the RF voltage is higher and RFC size is bigger.

At LHC collision energy, if we want to obtain 7.55cm bunch length, we need 16MV RF voltage with 400MHz, and 32MV with 200MHz.

Why not 800MHz?

The bucket height and bucket area restriction. Main depends on the beam energy spread.

Longitudinal beam parameters of SppC

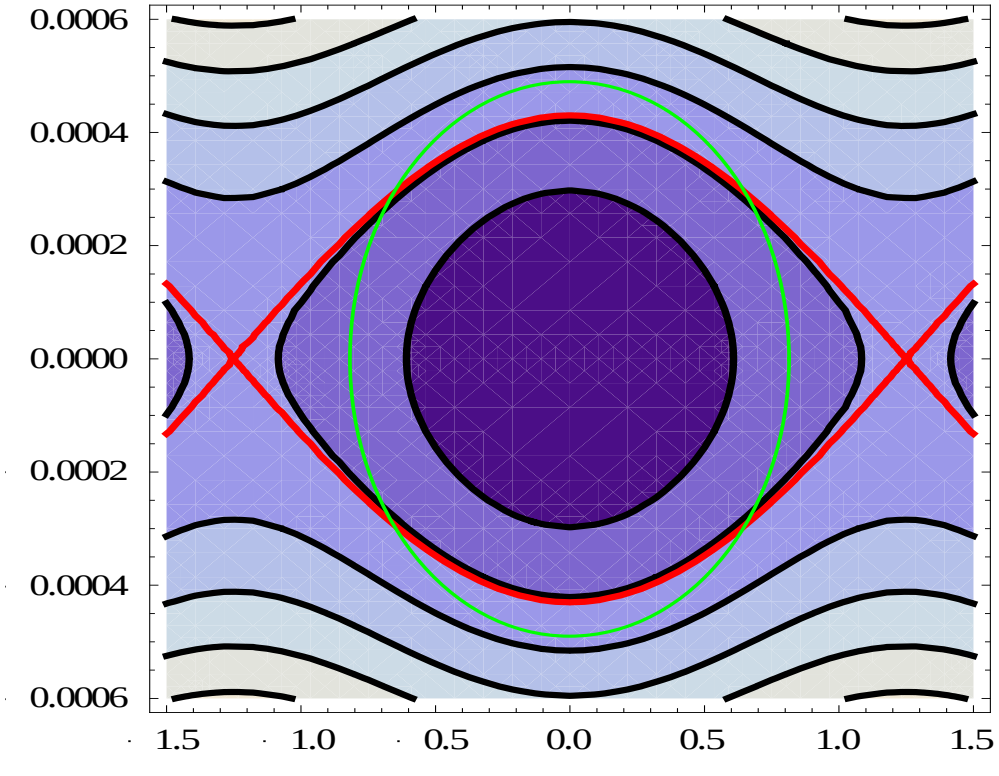
parameters	injection	collision
Proton energy [TeV]	2.1	35.3
Ring circumference [km]	54.7	54.7
Dipole field	1.18	20
Longitudinal emittance (4σ) [eVs]	1.8	11.9
Dipole curvature radius	5885	5885
RMS bunch length [cm]	10	7.55
Energy loss per turn[keV]	0.025	2.06×10^{3}
Momentum compaction	9×10^{-5}	9×10^{-5}
Energy spread	2×10^{-4}	1.1×10^{-4}
Revolution frequency[kHz]	5.48	5.48
Harmonic number	72930	72930
Synchrotron frequency[Hz]	10.1	5.7

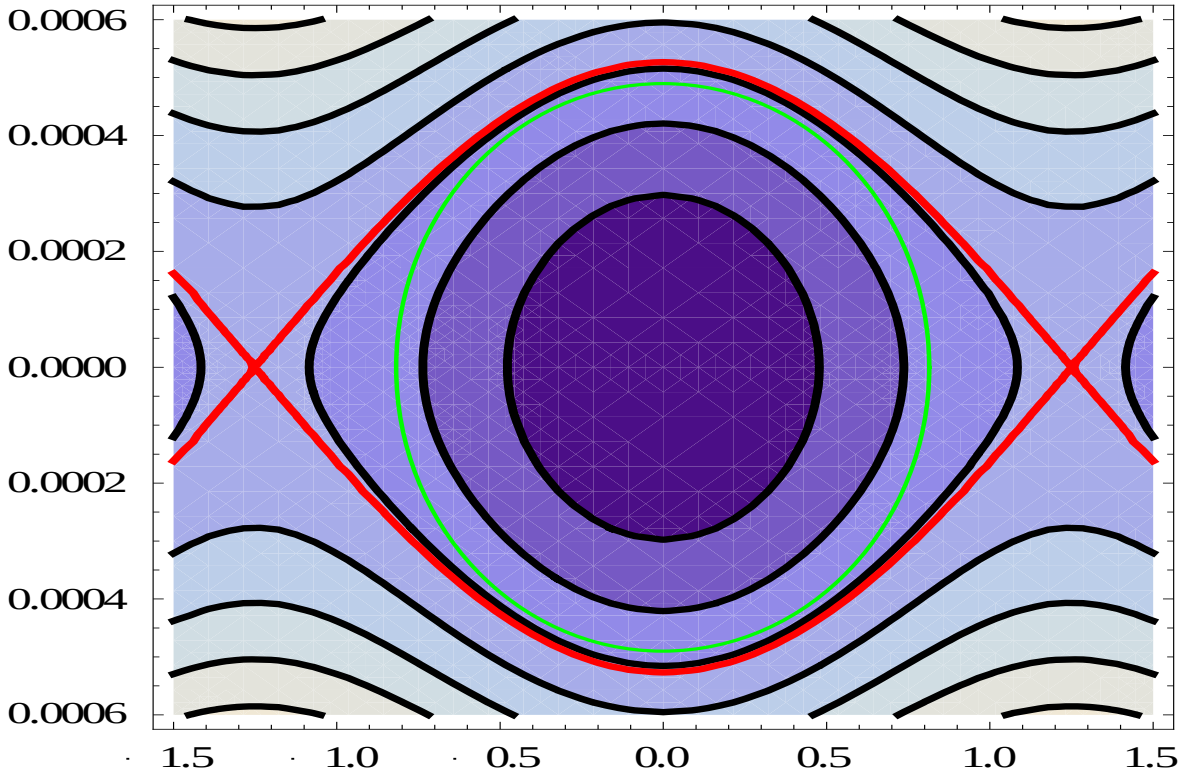
SPPC RF chioce

95% longitudinal emittance = 2.64 eV.s,

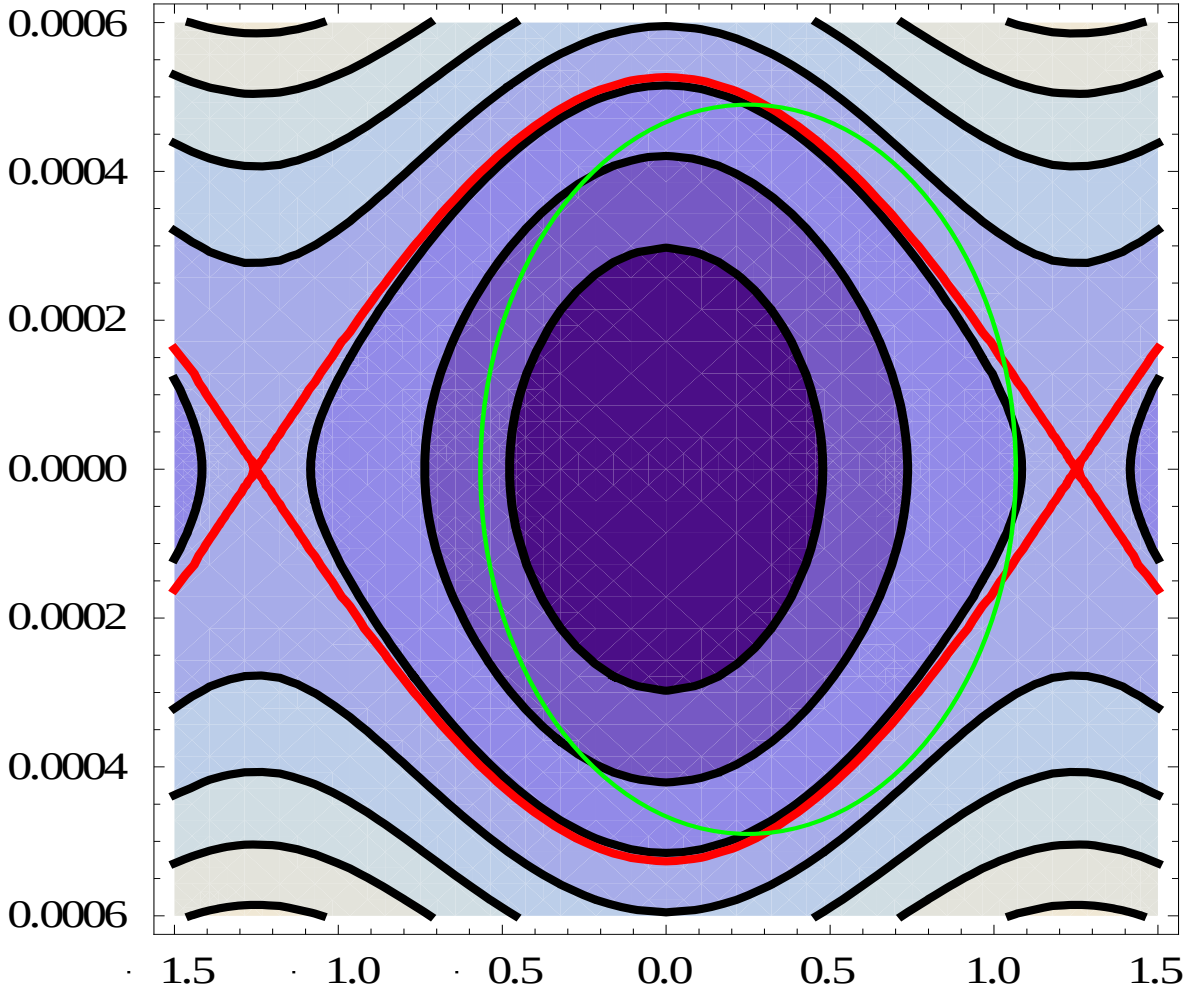
we need the voltage of 400MHz RFC is 4MV

For satisfy bucket height requirements, we ,need the RF voltage is 6MV.

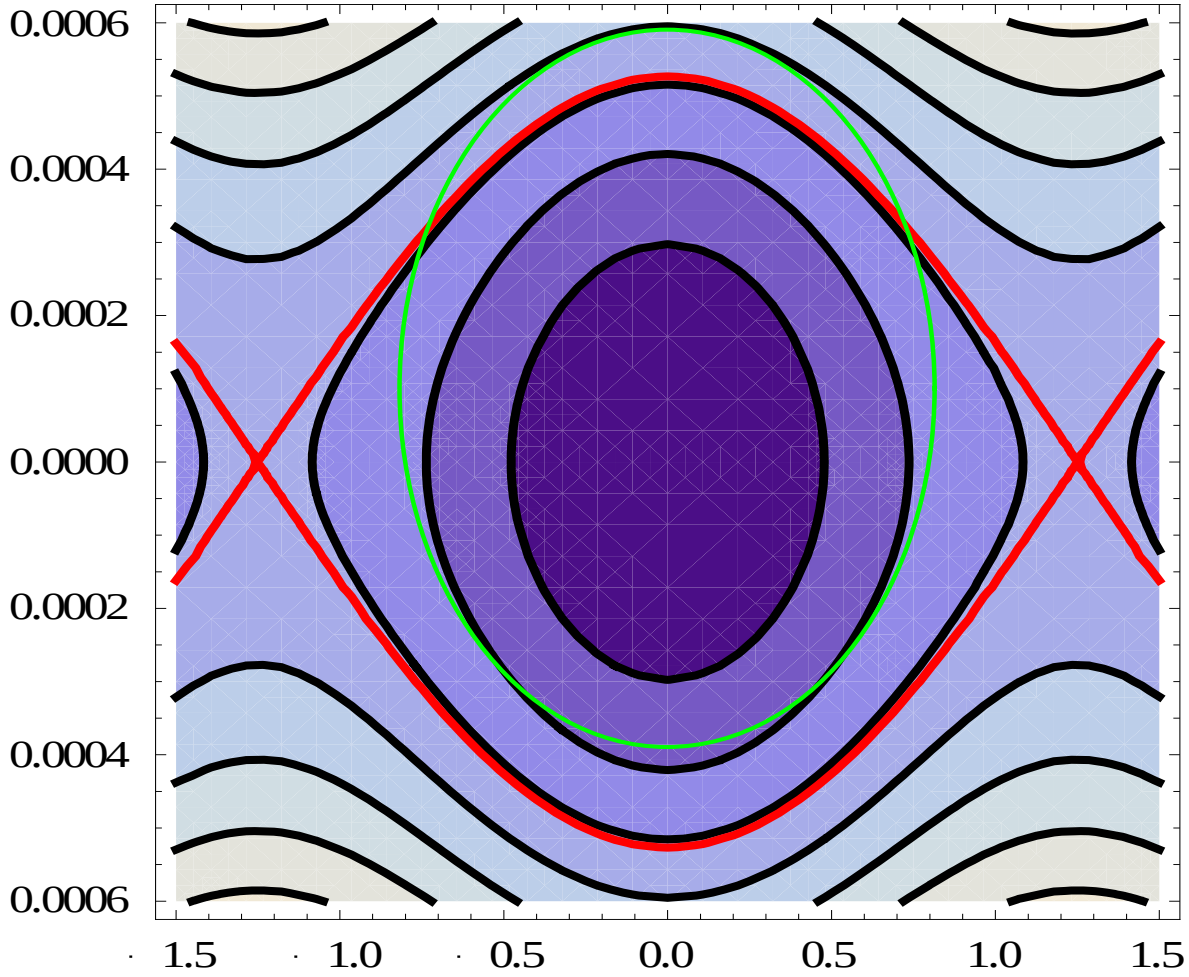




400MHz 6MV

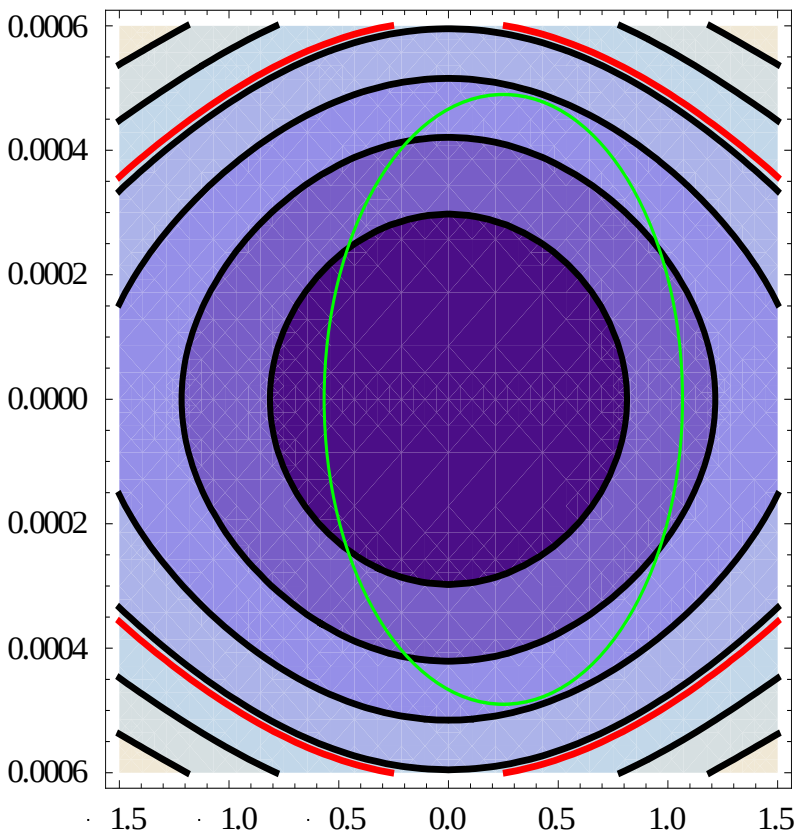


50ps error

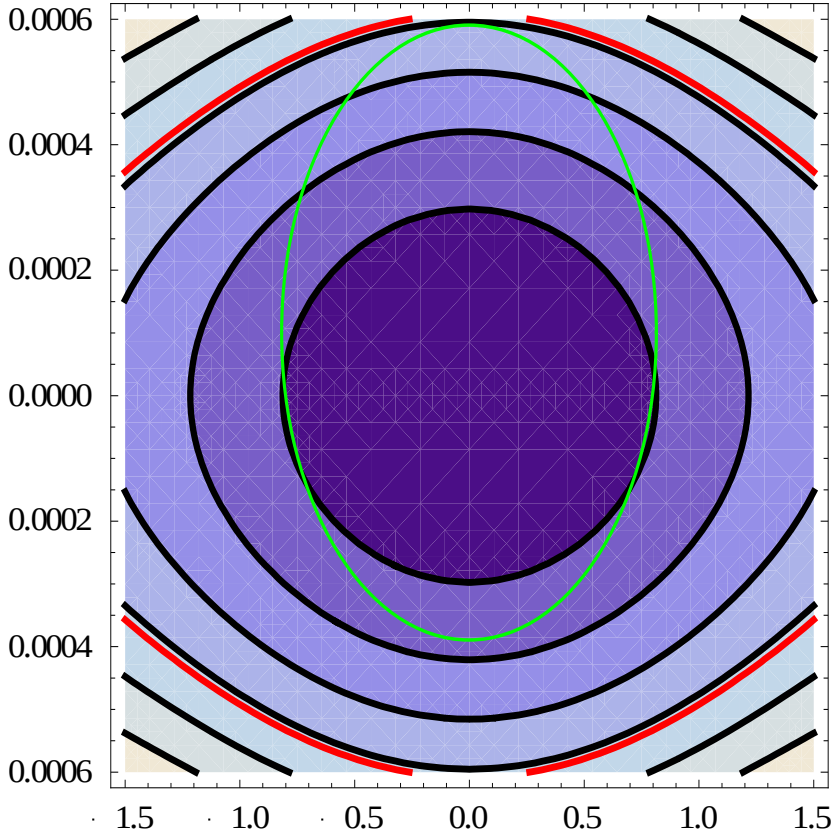


1E-4 energy error

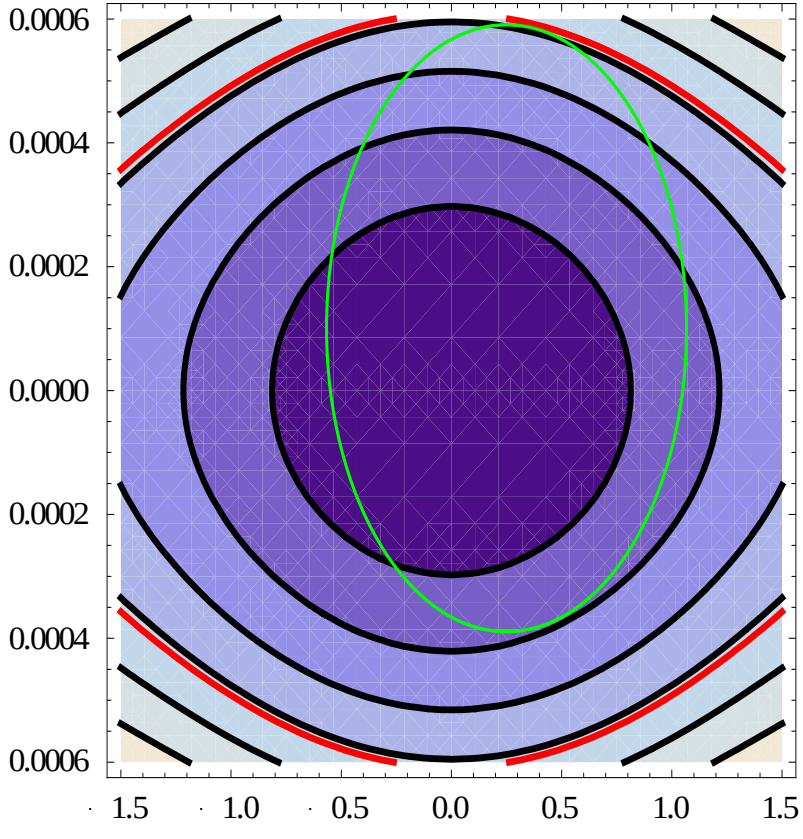
For satisfy 95% longitudinal emittance and bucket height requirement，
The voltage of 200MHz RFC is 4MV.



50ps error

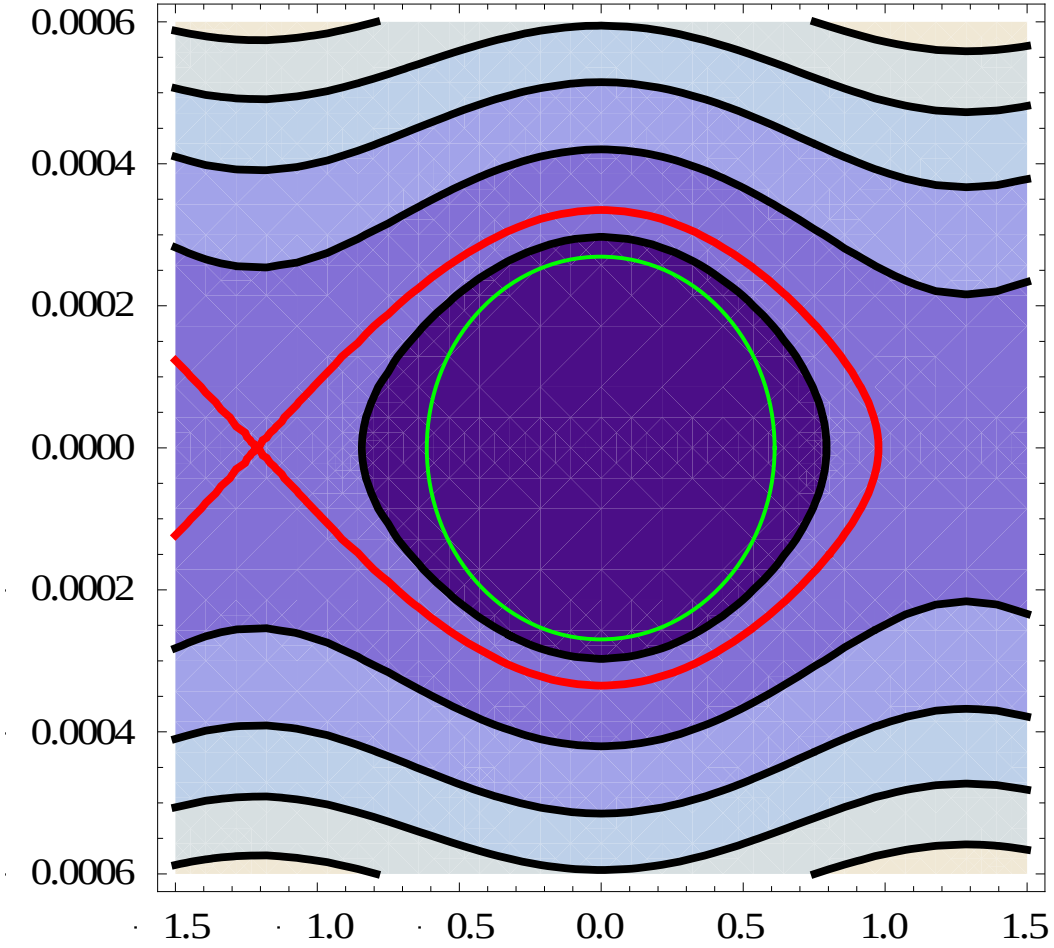


1E-4 energy error

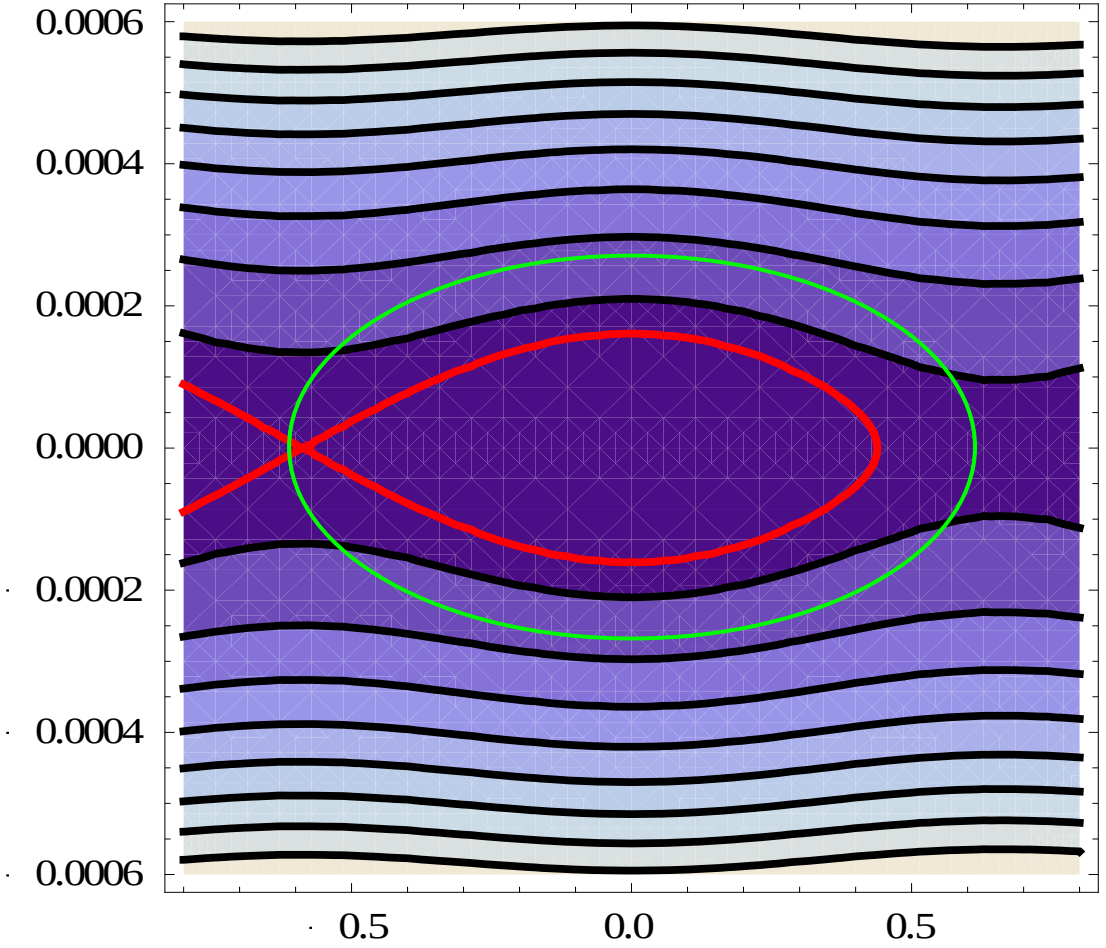


both error

Collision energy



400MHZ 44MV



800MHZ 22MV

SPPC RF

- At injection： a 200 MHz RF system was proposed, to be used only for capture, in addition to the main 400 MHz RF system .For capture the operational total voltage at 200 MHz is 4MV .
- After capture the voltage of the 400 MHz RF system is adiabatically increased up to 6MV and the voltage of the200 MHz RF system is decreased to zero
- On the flat top the emittance is required to be 11.9 eVs. To have the shortest possible bunch length during collision the maximum available voltage (44 MV) at 400 MHz will be applied.

Future work

- Threshold calculation of longitudinal instability
- Energy ramp process simulation and analysis
- ……

Thank you!