Main advantages of 56 MHz SRF cavity for High Luminosity in RHIC

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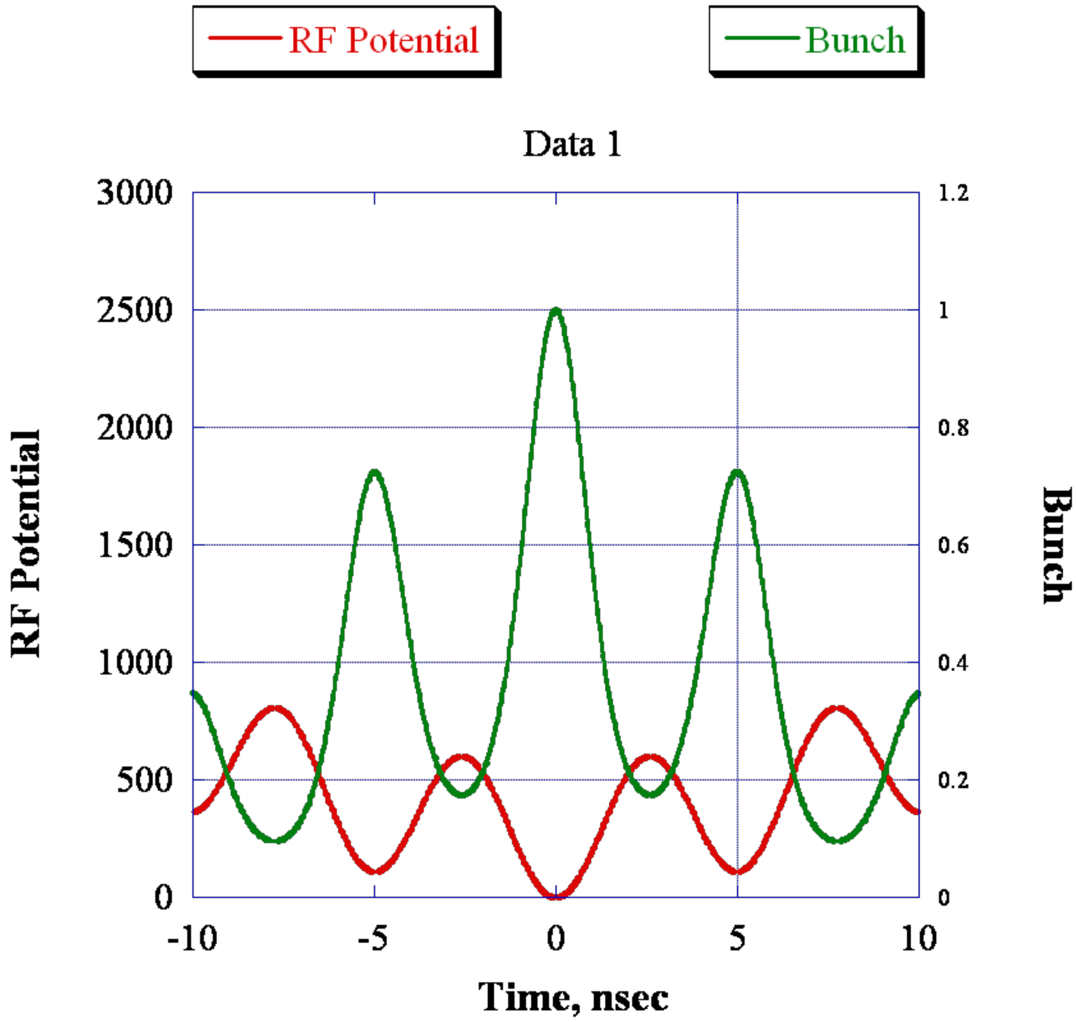
Summary
Main advantages of 56 MHz SRF cavity

- Large bucket - 5 times larger than 197 MHz cavities - no spill of ions
- Adiabatic re-capturing into 56 MHz does not increase longitudinal emittance in contrast with Rf-gymnastics with re-bucketing into the 197 MHz system
- Increased luminosity with and without stochastic cooling
- Improved luminosity in vertex for protons
- Perfect addition to the stochastic cooling

$$\delta_{acc} = \pm\sqrt{\frac{Z}{A}\frac{2}{\pi}\frac{E_{on}eV_{rf}}{\eta h_{rf}}};\ \tau_{acc} = \pm\frac{1}{2h_{rf} f_o}$$

RF system		28 MHz	56 MHz	197 MHz
hrf		360	720	2520
Vrf	V	3.00E+05	2.50E+06	5.00E+06
sqrt	eV	1.38E+08	2.82E+08	2.14E+08
phi_tau	1/sec	1.77E+08	3.54E+08	1.24E+09
E acc	eV	1.38E+08	2.82E+08	2.14E+08
E acc rel		1.38E-03	2.82E-03	2.14E-03
Separatrix	sec	3.55E-08	1.77E-08	5.07E-09
Acceptance	**eV sec**	**6.25E+00**	**6.38E+00**	**1.38E+00**

V_{28MHz}= 0.3MV; $V_{56\ MHz}$= OFF; V_{197MHz}= 2 MV



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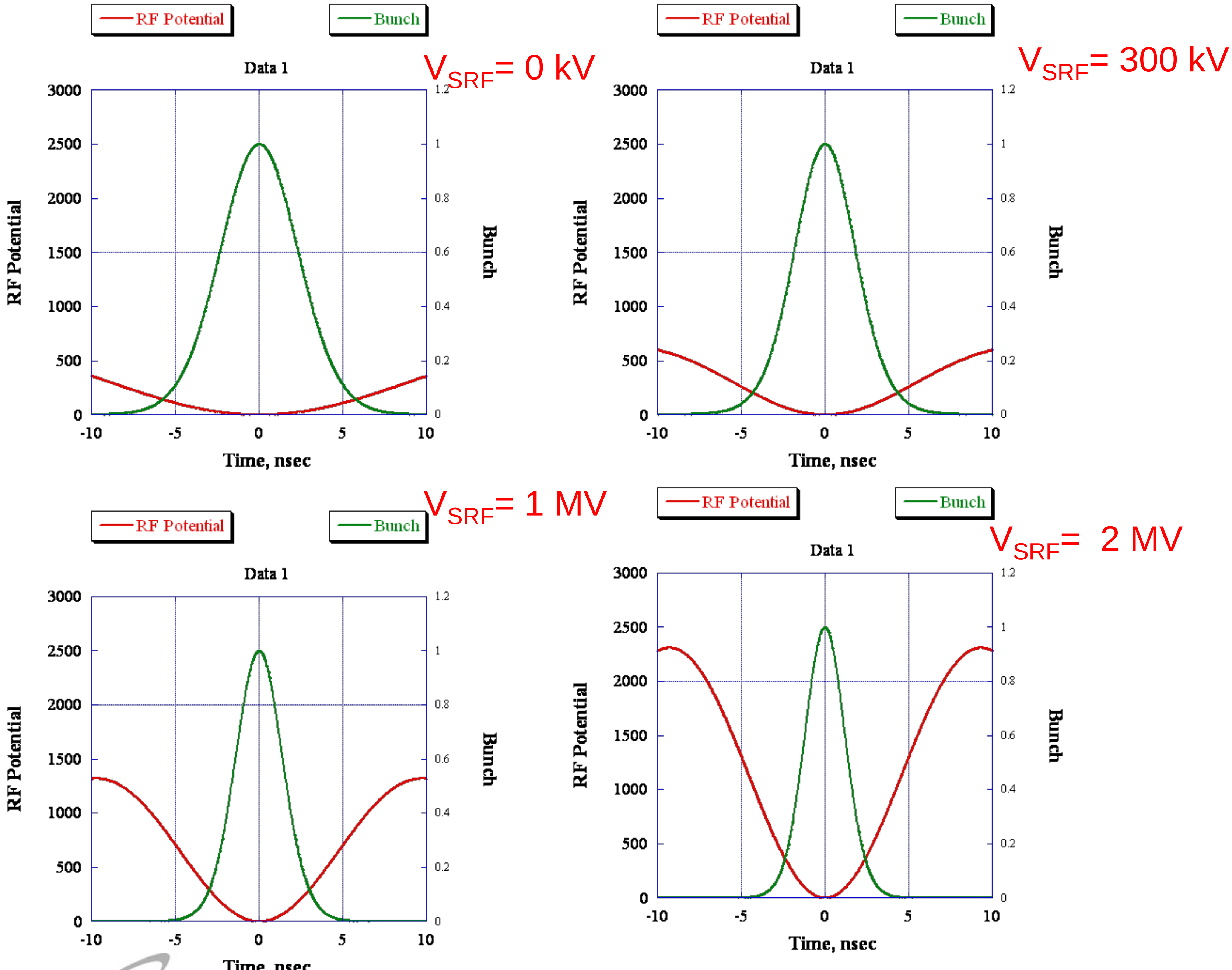
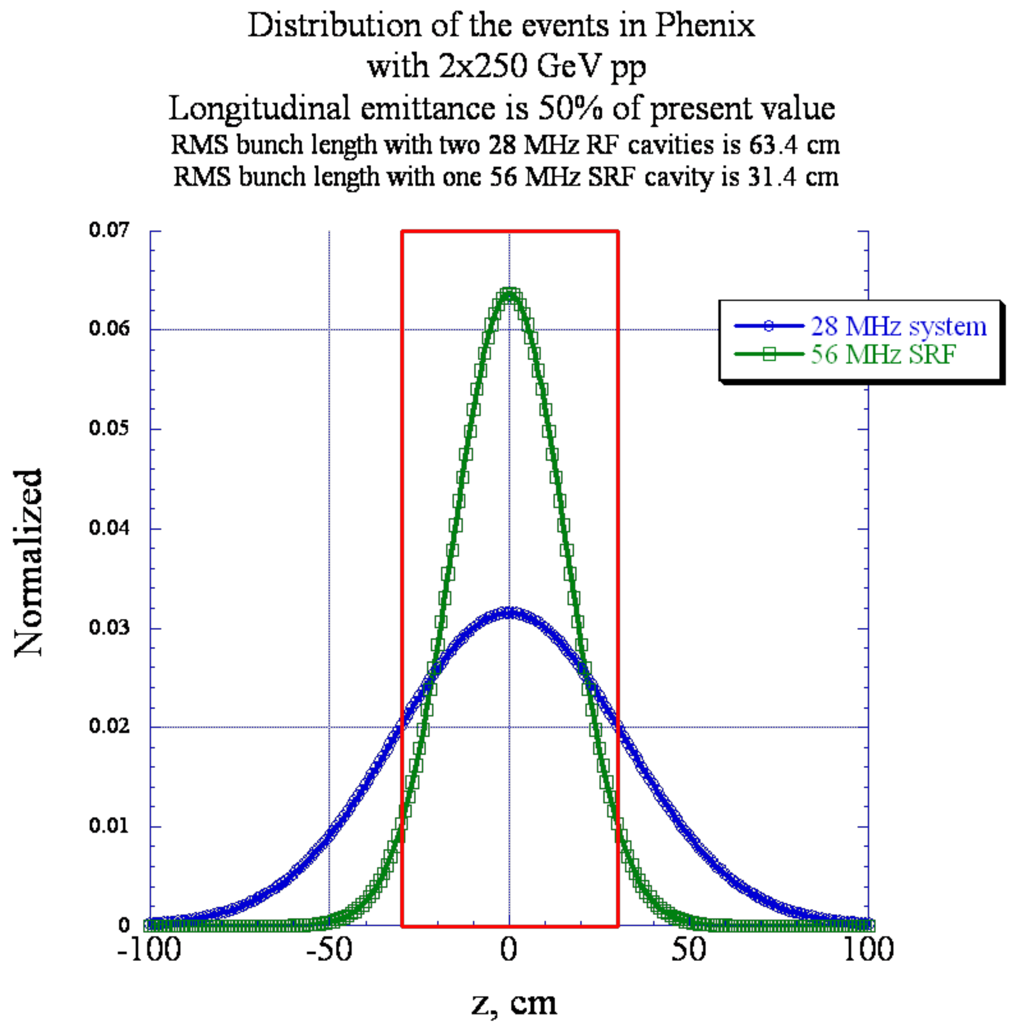
Re-capturing from V_{28MHz} is 300 kV



56 MHz SRF system will increase useful luminosity for 2x250 GeV pp collisions in Phenix by 66.6% with β^*=1 m and by 68.6% with β^*= =0.5 m

Using of two SRF cavities per ring will increase this improvements to 81% and 84.2% correspondently.



Parameters of the ion beam

56 MHz RF: 2.5MV

Rms momentum spread sigma_p=6e-4

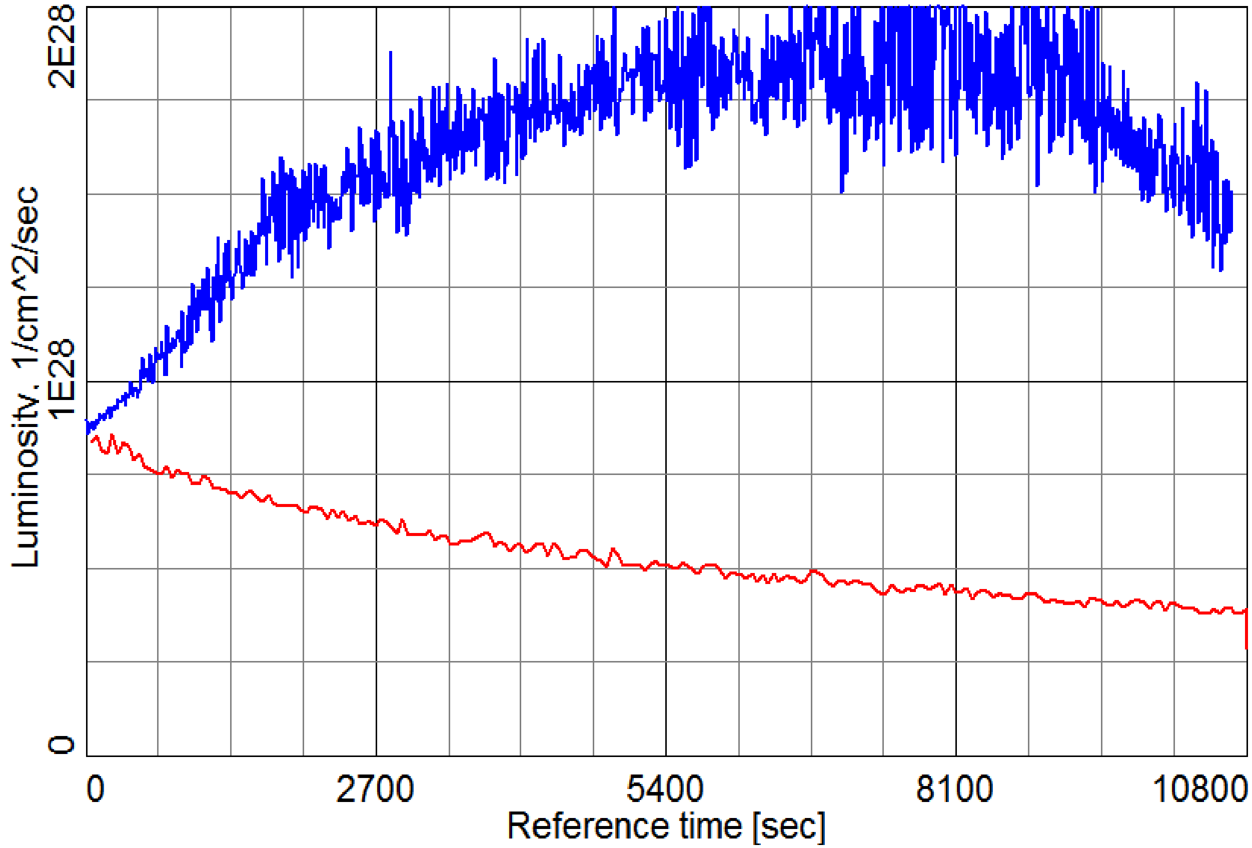
Rms bunch length sigma_s=40cm

Longitudinal emittance S_rms=0.25 eV-s; S_95%=1.5 eV-s

Transverse emittance, 95%, normalized: 15 mm mrad

IBS-suppression lattice from Run-8: "dAu82"

N=1.5e9; red – no cooling; blue – with cooling
(same as previous slide, just different scale)



Run-7: <L>=1.2e27

56 MHz, no cooling, no vertex cut: <L>=5.4e27

56 MHz, with cooling: <L>=1.6e28

Average luminosity per store (for beta*=0.8m), without vertex cut

	<L> @ 2h	3h	4h	5h
IBS (1e9)	2.9e27	2.7e27	2.5e27	2.3e27
IBS (1.5e9)	6e27	5.4e27	4.9e27	4.5e27
IBS (2e9)	**1e28**	**8.9e27**	**8e27**	**7.4e27**
COOL (1e9)	8.9e27	9.7e27	9e27	
COOL (1.5e9)	1.6e28	1.6e28	More than half of the beam is already burned-off	
COOL (2e9)	2.3e28	2.3e28		
With Stochastic Cooling (1.5e9, beta*=0.5m, 2PUs, 5-12 GHz), M. Blaskiewicz, MAC08			**~8e27**	**~7e27**
Run-7 (1.1e9, achieved)				**1.2e27**

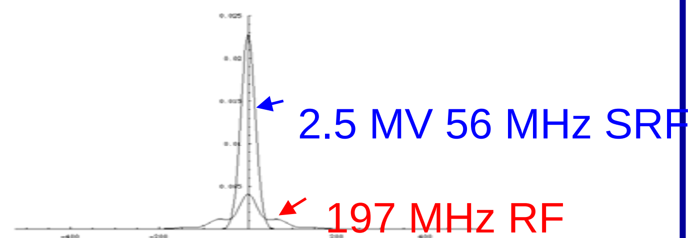
Main point

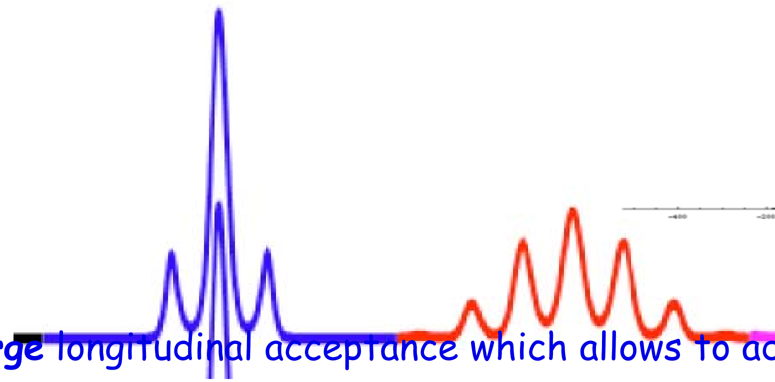
$$L = \frac{1}{4\pi\beta^{*}\varepsilon} f_b N^2{}_{per\ \ bunch} = \frac{1}{4\pi\beta^{*}\varepsilon}\frac{N^2{}_{total}}{f_b}$$

With given beam intensity ($N_{total}=f_b{}^{*}N_{bunch}$) splitting bunches in about three

this what happens with stochastic cooling in the presence of 197 MHz RF -

reduces luminosity by a factor ~ 3





56 MHz SRF cavity creates **large** longitudinal acceptance which allows to adiabatically compress ion/proton bunches with full preservation of longitudinal emittance.

Cooling such beam makes the advantages of the 56 MHz SRF shine.

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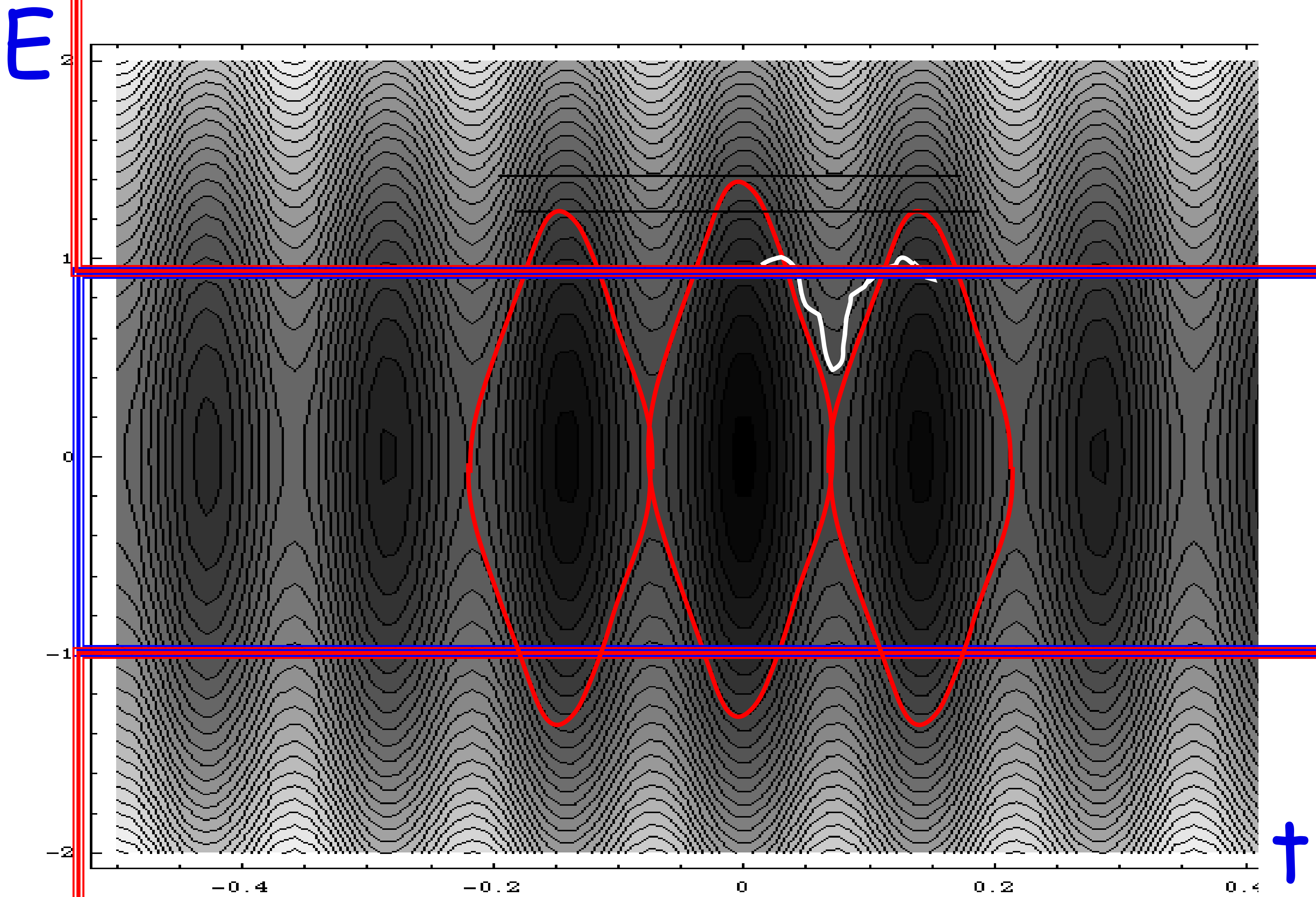

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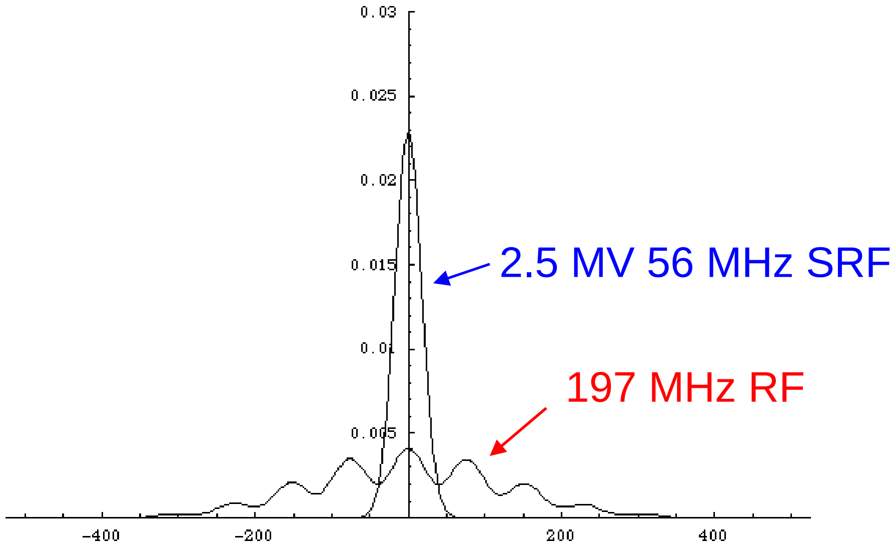
Luminosity

$$L(z) = \frac{L_0}{1+\left(z/\beta^*\right)^2} \int_{-\tau v/2}^{-\tau v/2} f_{1l}(z+\xi)\, f_{1l}(z-\xi) \cdot d\xi$$

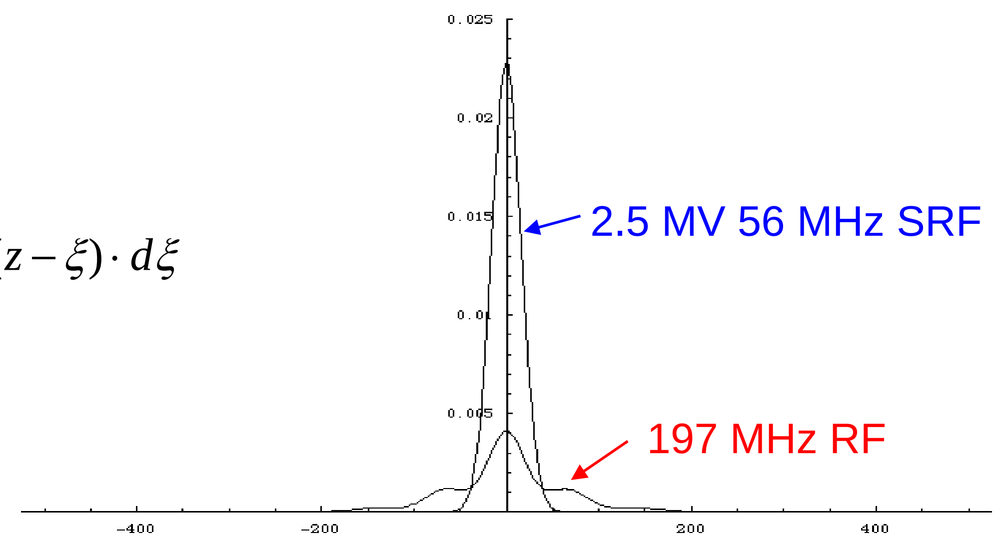
$$L_o = \frac{f_{col} N_1 N_2}{4\pi\varepsilon\beta^*}; \quad L_{tot} = L_o \int_{\text{detector}} \frac{dz}{1+\left(z/\beta^*\right)^2} \int_{-\tau v/2}^{-\tau v/2} f_{1l}(z+\xi)\, f_{1l}(z-\xi) \cdot 2d\xi$$

$$c_{eff} = \frac{L_{tot}}{L_o} = \int_{-1}^{1} \frac{dz}{1+\left(z/\beta^*\right)^2} \int_{-\tau v/2}^{-\tau v/2} f_{1l}(z+\xi)\, f_{1l}(z-\xi) \cdot d\xi$$



$$\int_{-\tau\nu/2}^{-\tau\nu/2} f_{1l}(z+\xi)\, f_{1l}(z-\xi)\cdot d\xi$$

$$L(z) = \frac{L_0}{1+\left(z/\beta^*\right)^2} \int_{-\tau\nu/2}^{-\tau\nu/2} f_{1l}(z+\xi)\, f_{1l}(z-\xi)\cdot d\xi$$



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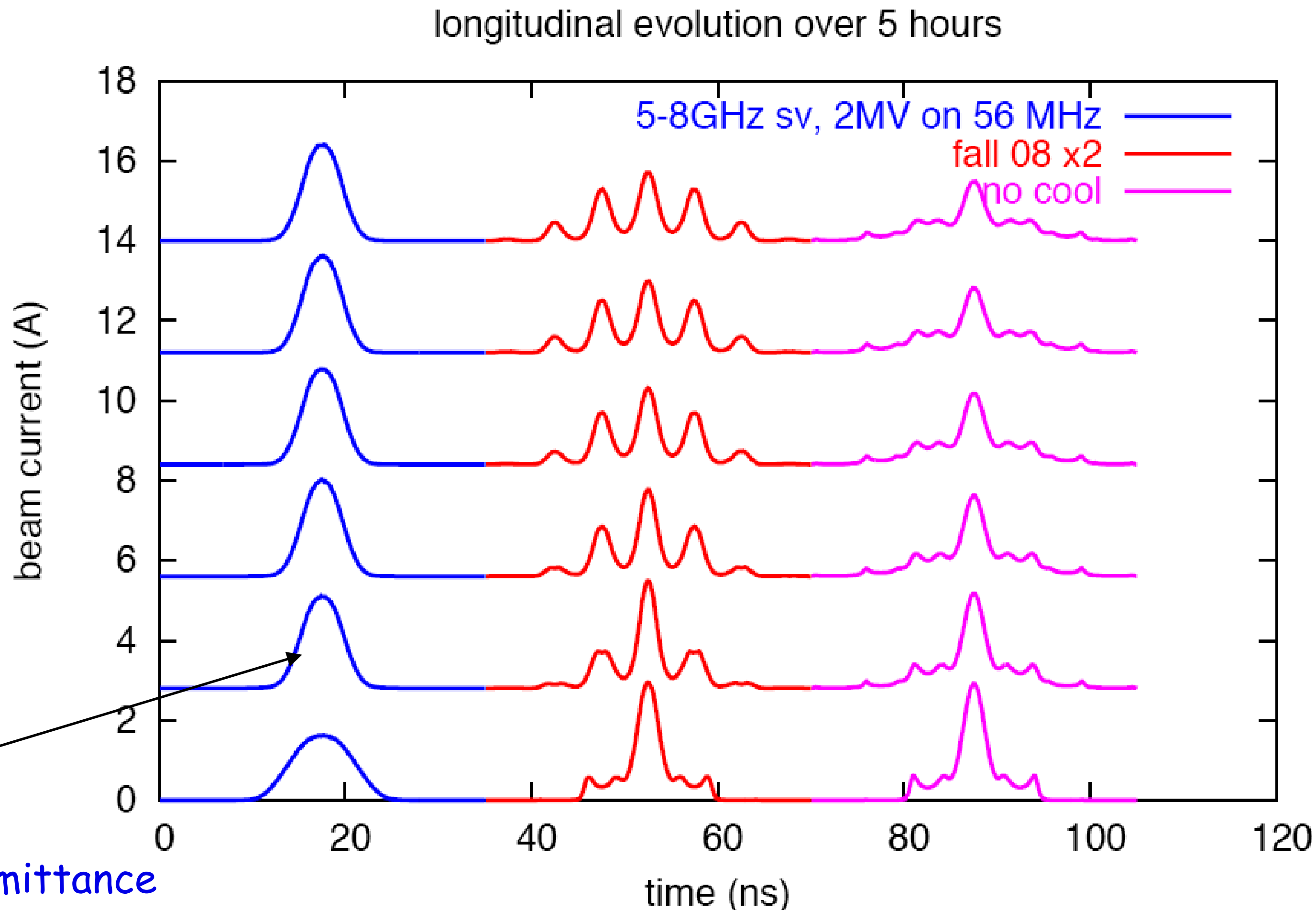
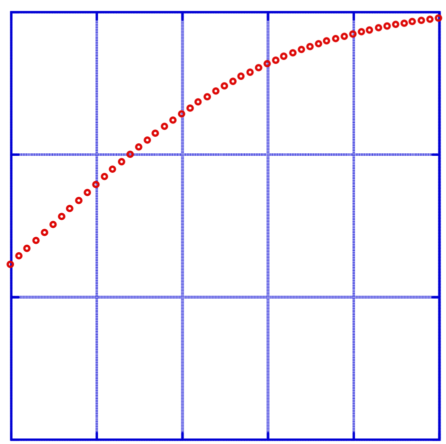


7 time larger longitudinal emittance used for 56 MHz

Mike Blaskiewicz

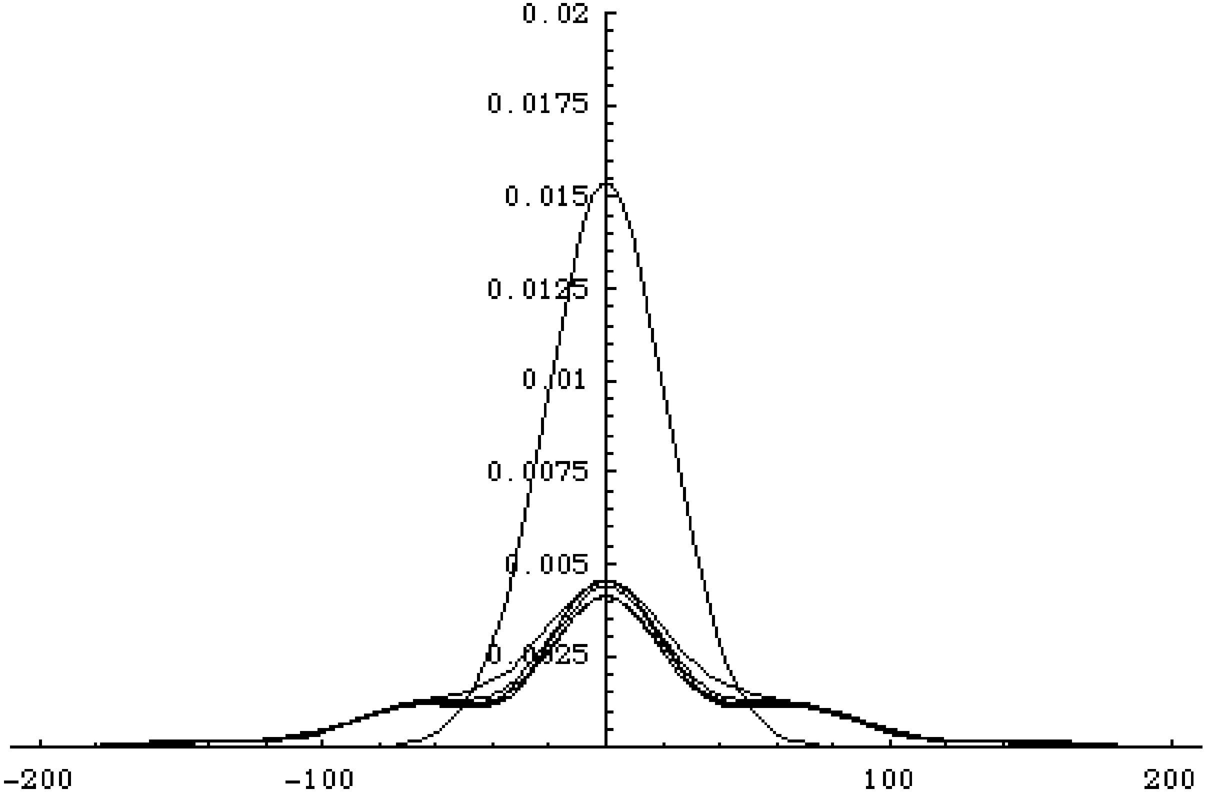
QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Longitudinal profiles from Mike Blaskiewicz simulations overlapped with analytical profiles (black thin lines). Integrals under the curves are constant (no burn-off was assumed by Mike).



$$L(z) = \frac{L_0}{1 + \left(z/\beta^*\right)^2} \int_{-\tau v/2}^{-\tau v/2} f_{1l}(z+\xi)\, f_{1l}(z-\xi) \cdot d\xi$$

Stochastic cooling with 197 MHz



Luminosity distribution in the IR (horizontal scale is in cm): top curve is for 56 MHz case, six the curves show evolution in the 197 MHz case.

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Stochastic cooling with and without 56 MHz

Stochastic cooling with197 MHz RF

c_{eff}(197 MHz)	Initial, t=0	1 hour	2 hours	3 hours	4 hours	5 hours
Total (no cut)	0.437	.407	0.398	0.388	0.370	0.369
In STAR ±70 cm cut	0.351	0.319	.310	.299	.283	.281
In PHENIX ±30 cm cut	0.220	0.207	.204	.196	0.185	0.183

Stochastic cooling with 56 MHz 2.5 MV SRF

c_{eff}(56 MHz)	all the way
Total (no cut)	0.835
In STAR ±70 cm cut	0.833
In PHENIX ±30 cm cut	0.689

Advantage of the 56 MHZ 2.5 MV SRF vs. 197 MHz RF with stochastic cooling defined as c_{eff}(56 MHz)/c_{eff}(197 MHz)

Advantage	Initial, t=0	1 hour	2 hours	3 hours	4 hours	5 hours
Total (no cut)	1.91	2.05	2.09	2.15	2.25	2.26
In STAR ±70 cm cut	2.38	2.61	2.69	2.78	2.94	2.95
In PHENIX ±30 cm cut	3.13	3.32	3.38	3.51	3.72	3.75

Conclusions

- 56 MHz SRF cavity gives advantages with and without stochastic cooling
- The combination of stochastic cooling and 56 MHz cavity is very natural and makes the best of both systems

Average luminosity per store (for beta*=0.8m) without/with vertex cut

	<L> @ 2h	3h	4h	5h
IBS (1e9)	2.9e27	2.7e27/2	2.5e27/2	2.3e27/2
IBS (1.5e9)	**6e27**	**5.4e27/2**	**4.9e27/2**	**4.5e27/2**
IBS (2e9)	**1e28**	**8.9e27/2**	**8e27/2**	**7.4e27/2**
COOL (1e9)	8.9e27	9.7e27	9e27	
COOL (1.5e9)	1.6e28	1.6e28	More than half of the beam is already burned-off	
COOL (2e9)	2.3e28	2.3e28		

Main points: true for both ions and protons

- Adiabatic bunch compression vs. RF gymnastics
- Large acceptance (6 times that of 197 MHz)
- No splitting bunch into 3 and no lowering of luminosity
- With 1.5e9 ions per bunch the luminosity without cooling is at the same level as with the stochastic cooling and 197 MHz (most of the loss comes from splitting the bunch is about 3 bunches)
- Hour-glass effect
- Vertex cut