A Proposal to Obtain 1 kA @ 1 GeV in the APS Storage Ring

G. Decker 1/8/99

I) Use energy, RF voltage only as variables to obtain high peak current for a small number of turns

II) Inject 1 mA (3.68 nC) on axis, full coupling, standard lattice, allow to damp (τ = 3 seconds), using very low rf voltage (two klystrons, full power, backphased). Obtain nearly mono-chromatic beam (σ_E / E = 1.4e-4), moderate bunch length (σ_t = 20 to 30 ps). Rad. loss / turn is 2.3 kV. V_{RF0} = 10 kV sufficient.

III) Apply step change in rf phases in less than one turn to apply full rf voltage, without changing relation between ϕ_s and P_0 .

IV) Wait one-fourth of a synchrotron oscillation (f_s = 6 kHz, @ 10 MV so a quarter oscillation is approx. ten turns).

V) Bunch length collapses by ratio of square roots of RF voltages, energy spread increases by reciprocal amount, i.e. obtain “equilibrium” bunch length with energy spread larger than “equilibrium” by { V_{RF} / V_{RF0} } .

GeV x kA cont'd

Advantages:

I) Boneheaded, easy to try.

II) Millions of dollars of electroptics available to analyze in detail the dynamics of phase space rotation (still difficult).

Disadvantages:

I) Intrabeam scattering guaranteed nasty, but equilibrium emittance is so low that artificial emittance blowup, (e.g. pinger driven at β-tron tune (only one tune on coupling resonance) probably wouldn't hurt.) Intrabeam scattering growth rates need to be determined via simulation -> choose optimal energy (2GeV?).

II) What is minimum bunch length from IBS, etc. -> determine largest value for low RF voltage value, i.e. you'd like a small beginning bunch length but a large voltage step, so there's no sense starting out with more RF voltage than absolutely necessary. Simulations to show dependence on beam current, energy would be helpful. ESRF saw 10 ps @ 2GeV at "lowest currents allowing streak camera measurements".

III) Microwave instability advertised as fundamental limit on bunch length in storage rings. Question is how much damage can it do in ten turns or less. Also how does it scale with energy, and what is the Haissinski equation anyway? Does it impact the bunch length at 1 GeV at the 20 ps scale?

Derivation of relevant bunch compression formula

Harmonic Oscillator Hamiltonian (ref. Wiedemann)

$$H = \alpha^2 \delta^2 + \Omega_s^2 \tau^2$$

where

α = Momentum compaction

δ = Energy variable

Ω_s = Angular synchrotron frequency $2 \pi f_s$

$= \{ \alpha \omega_{RF} \cos \phi_s e V_{RF} / T_0 E \}^{1/2}$

τ = Time variable

For reference, equilibrium fractional energy spread, bunch length :

$$\sigma_E^2 = C_q I_3 \gamma^2 /(2 I_2 + I_4)$$

$$\sigma_\tau = \{ 2 \pi \alpha h E / \omega_{RF}^2 \cos \phi_s e V_{RF} \}^{1/2} \sigma_E$$

So, effects of phase rotation are easy to infer:

$$\sigma_E = (\Omega_s / \alpha) \sigma_\tau^0 = \{ V_{RF} / V_{RF}^0 \}^{1/2} \sigma_E^0$$

$$\sigma_\tau = (\alpha / \Omega_s) \sigma_E^0 = \{ V_{RF}^0 / V_{RF} \}^{1/2} \sigma_\tau^0$$

E (V)	7.00E+09	alpha	2.2799E-04
rho (m)	38.954	alpha2	4.5598E-03
Vrf (V)	8.00E+06	chsi	0.0000E+00
L (m)	1104	DELTA	7.7358E-03
Cq (m-rad)	3.84E-13		
h	1296	U0 (V)	5.4549E+06
I1(m)	0.2517	sigE/E	9.6173E-04
I2 (1/m)	0.7276	eps(m-rad)	8.2183E-09
I3 (1/m^2)	1.868E-02	taux (S)	9.50E-03
I4 (1/m)	0	tauy (S)	9.50E-03
I5 (rad?)	8.30E-05	tauE (S)	4.75E-03
Jx	1	phis	0.7503
Jy	1	epsRF	2.1E-02
Je	2	nuS	6.27E-03
gamma	1.3699E+04	fs (Hz)	1703
OverV q	1.47E+00	sigT (S)	2.05E-11
c (m/s)	3.00E+08	Ipeak (A)	71.6791
Iave (A)	1.00E-03	deltaMax	0.0500
Frf (Hz)	3.51927E+08	deltaDelta	0.0020
T0 (sec)	3.68E-06	psiMax	0.0200
Q (C)	3.68E-09	deltaPsi	0.0008

E (V)	1.00E+09	alpha	2.2799E-04
rho (m)	38.954	alpha2	4.5598E-03
Vrf (V)	1.00E+04	chsi	0.0000E+00
L (m)	1104	DELTA	6.7688E-05
Cq (m-rad)	3.84E-13		
h	1296	U0 (V)	2.2719E+03
I1(m)	0.2517	sigE/E	1.3739E-04
I2 (1/m)	0.7276	eps(m-rad)	1.6772E-10
I3 (1/m^2)	1.868E-02	taux (S)	3.26E+00
I4 (1/m)	0	tauy (S)	3.26E+00
I5 (rad?)	8.30E-05	tauE (S)	1.63E+00
Jx	1	phis	0.2292
Jy	1	epsRF	3.8E-03
Je	2	nuS	6.77E-04
gamma	1.9569E+03	fs (Hz)	184
OverV q	4.40E+00	sigT (S)	2.71E-11
c (m/s)	3.00E+08	Ipeak (A)	54.1549
Iave (A)	1.00E-03	deltaMax	0.0500
Frf (Hz)	3.51927E+08	deltaDelta	0.0020
T0 (sec)	3.68E-06	psiMax	0.0200
Q (C)	3.68E-09	deltaPsi	0.0008

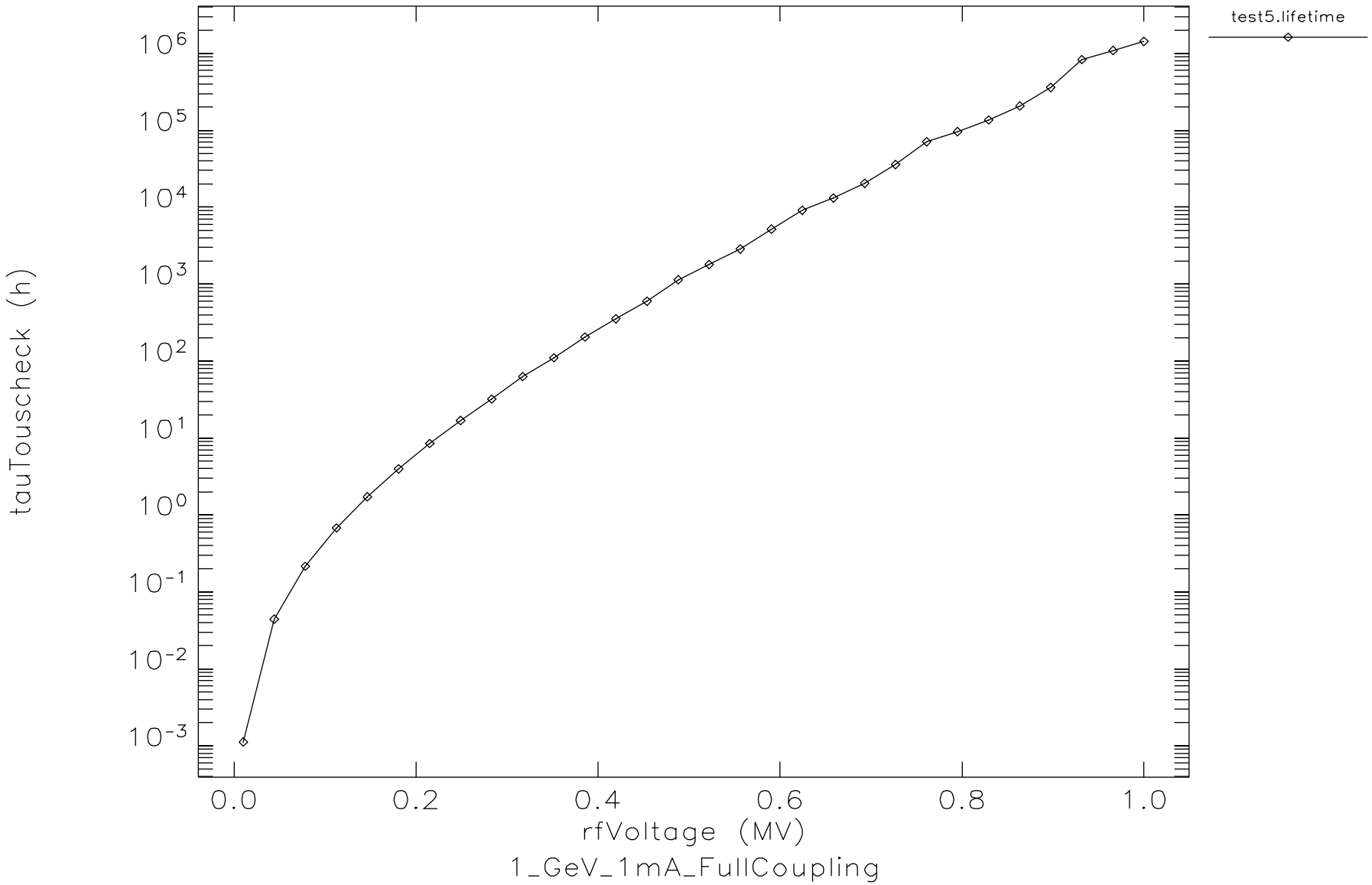
E (V)	1.00E+09	alpha	2.2799E-04
rho (m)	38.954	alpha2	4.5598E-03
Vrf (V)	1.00E+05	chsi	0.0000E+00
L (m)	1104	DELTA	6.7688E-04
Cq (m-rad)	3.84E-13		
h	1296	U0 (V)	2.2719E+03
I1(m)	0.2517	sigE/E	1.3739E-04
I2 (1/m)	0.7276	eps(m-rad)	1.6772E-10
I3 (1/m^2)	1.868E-02	taux (S)	3.26E+00
I4 (1/m)	0	tauy (S)	3.26E+00
I5 (rad?)	8.30E-05	tauE (S)	1.63E+00
Jx	1	phis	0.0227
Jy	1	epsRF	1.4E-02
Je	2	nuS	2.17E-03
gamma	1.9569E+03	fs (Hz)	589
OverV q	4.40E+01	sigT (S)	8.47E-12
c (m/s)	3.00E+08	Ipeak (A)	173.5145
Iave (A)	1.00E-03	deltaMax	0.0500
Frf (Hz)	3.51927E+08	deltaDelta	0.0020
T0 (sec)	3.68E-06	psiMax	0.0200
Q (C)	3.68E-09	deltaPsi	0.0008

E (V)	1.00E+09	alpha	2.2799E-04
rho (m)	38.954	alpha2	4.5598E-03
Vrf (V)	1.00E+06	chsi	0.0000E+00
L (m)	1104	DELTA	6.7688E-03
Cq (m-rad)	3.84E-13		
h	1296	U0 (V)	2.2719E+03
I1(m)	0.2517	sigE/E	1.3739E-04
I2 (1/m)	0.7276	eps(m-rad)	1.6772E-10
I3 (1/m^2)	1.868E-02	taux (S)	3.26E+00
I4 (1/m)	0	tauy (S)	3.26E+00
I5 (rad?)	8.30E-05	tauE (S)	1.63E+00
Jx	1	phis	0.0023
Jy	1	epsRF	4.6E-02
Je	2	nuS	6.86E-03
gamma	1.9569E+03	fs (Hz)	1862
OverV q	4.40E+02	sigT (S)	2.68E-12
c (m/s)	3.00E+08	Ipeak (A)	548.7710
Iave (A)	1.00E-03	deltaMax	0.0500
Frf (Hz)	3.51927E+08	deltaDelta	0.0020
T0 (sec)	3.68E-06	psiMax	0.0200
Q (C)	3.68E-09	deltaPsi	0.0008

E (V)	1.00E+09	alpha	2.2799E-04
rho (m)	38.954	alpha2	4.5598E-03
Vrf (V)	1.00E+07	chsi	0.0000E+00
L (m)	1104	DELTA	6.7688E-02
Cq (m-rad)	3.84E-13		
h	1296	U0 (V)	2.2719E+03
I1(m)	0.2517	sigE/E	1.3739E-04
I2 (1/m)	0.7276	eps(m-rad)	1.6772E-10
I3 (1/m^2)	1.868E-02	taux (S)	3.26E+00
I4 (1/m)	0	tauy (S)	3.26E+00
I5 (rad?)	8.30E-05	tauE (S)	1.63E+00
Jx	1	phis	0.0002
Jy	1	epsRF	1.5E-01
Je	2	nuS	2.17E-02
gamma	1.9569E+03	fs (Hz)	5889
OverV q	4.40E+03	sigT (S)	8.47E-13
c (m/s)	3.00E+08	Ipeak (A)	1735.3686
Iave (A)	1.00E-03	deltaMax	0.0500
Frf (Hz)	3.51927E+08	deltaDelta	0.0020
T0 (sec)	3.68E-06	psiMax	0.0200
Q (C)	3.68E-09	deltaPsi	0.0008

E (V)	2.00E+09	alpha	2.2799E-04
rho (m)	38.954	alpha2	0.0000E+00
Vrf (V)	1.00E+05	chsi	0.0000E+00
L (m)	1104	DELTA	3.3844E-04
Cq (m-rad)	3.84E-13		
h	1296	U0 (V)	3.6351E+04
I1(m)	0.2517	sigE/E	2.7478E-04
I2 (1/m)	0.7276	eps(m-rad)	6.7088E-10
I3 (1/m^2)	1.868E-02	taux (S)	4.07E-01
I4 (1/m)	0	tauy (S)	4.07E-01
I5 (rad?)	8.30E-05	tauE (S)	2.04E-01
Jx	1	phis	0.3720
Jy	1	epsRF	7.3E-03
Je	2	nuS	1.48E-03
gamma	3.9139E+03	fs (Hz)	402
OverV q	2.75E+00	sigT (S)	2.48E-11
c (m/s)	3.00E+08	Ipeak (A)	296.0940
Iave (A)	5.00E-03	deltaMax	0.0500
Frf (Hz)	3.51927E+08	deltaDelta	0.0020
T0 (sec)	3.68E-06	psiMax	0.0200
Q (C)	1.84E-08	deltaPsi	0.0008

E (V)	2.00E+09	alpha	2.2799E-04
rho (m)	38.954	alpha2	0.0000E+00
Vrf (V)	1.00E+07	chsi	0.0000E+00
L (m)	1104	DELTA	3.3844E-02
Cq (m-rad)	3.84E-13		
h	1296	U0 (V)	3.6351E+04
I1(m)	0.2517	sigE/E	2.7478E-04
I2 (1/m)	0.7276	eps(m-rad)	6.7088E-10
I3 (1/m^2)	1.868E-02	taux (S)	4.07E-01
I4 (1/m)	0	tauy (S)	4.07E-01
I5 (rad?)	8.30E-05	tauE (S)	2.04E-01
Jx	1	phis	0.0036
Jy	1	epsRF	1.0E-01
Je	2	nuS	1.53E-02
gamma	3.9139E+03	fs (Hz)	4164
OverV q	2.75E+02	sigT (S)	2.39E-12
c (m/s)	3.00E+08	Ipeak (A)	3067.7172
Iave (A)	5.00E-03	deltaMax	0.0500
Frf (Hz)	3.51927E+08	deltaDelta	0.0020
T0 (sec)	3.68E-06	psiMax	0.0200
Q (C)	1.84E-08	deltaPsi	0.0008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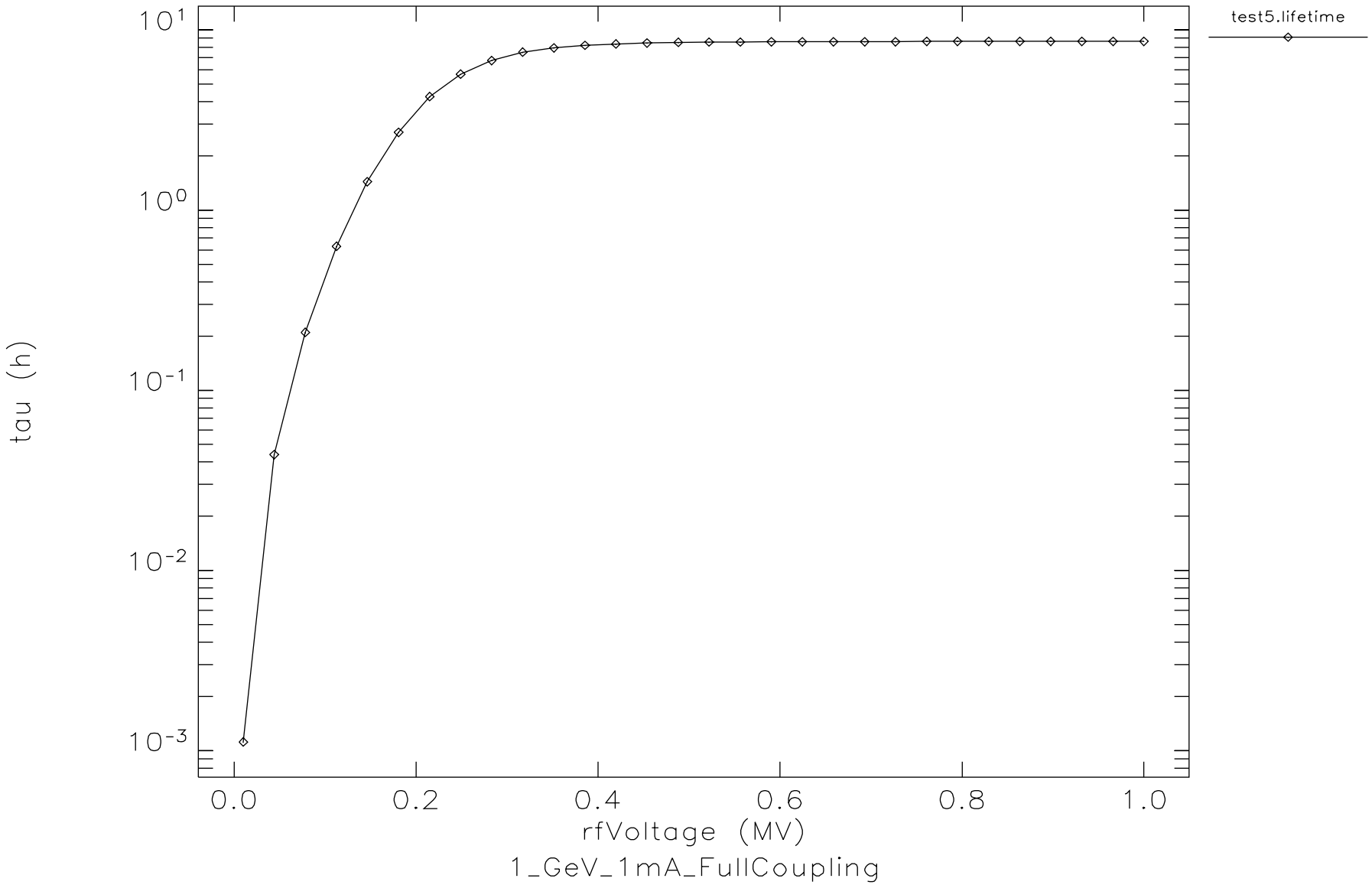
rfVoltage (MV)
1_GeV_1mA_FullCoupling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0.8
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rfVoltage (MV)
1_GeV_1mA_FullCoupling