Status of coupled-bunch stability studies for PETRA IV

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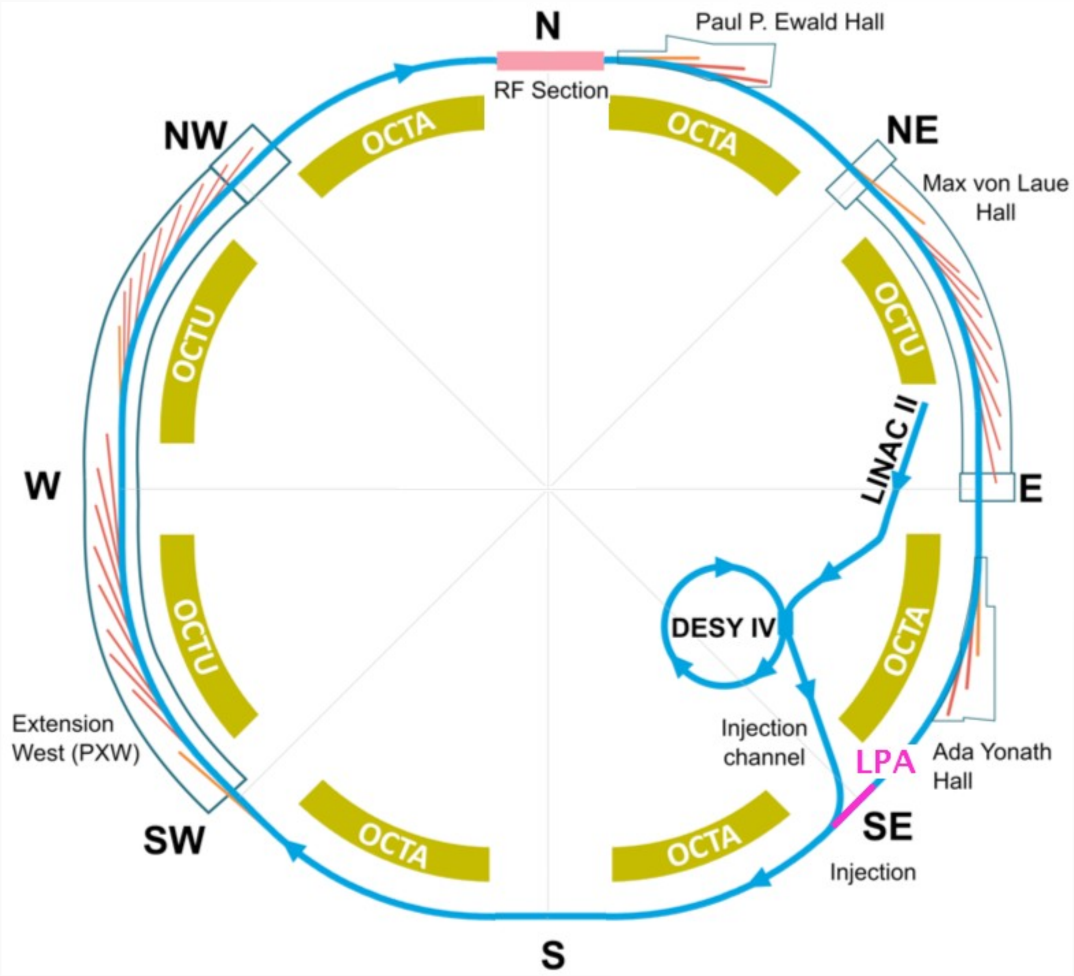
PETRA IV Beam Physics Team

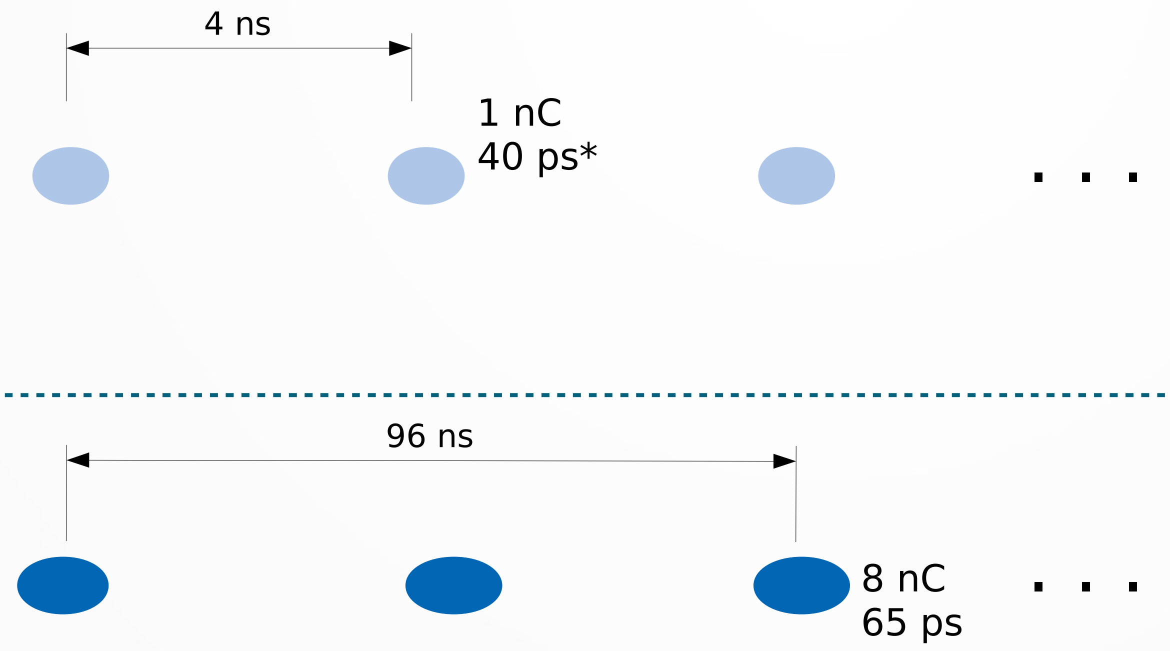
Many thanks M. Dohlus, W. Mueller
DESY-TEMF Collaboration meeting **20.10.22**

PETRA IV light source



Circumference	2304 m
Hor. emittance	20 pm
Coupling	0.2
Energy spread	0.9×10^{-3}
Mom. compaction	3.33×10^{-5}
Nat. bunch length	2.3 mm
Tunes	135.18, 86.27
Energy loss / turn (ID closed)	4.30 MeV
Chromaticity	5, 5
RF voltage (MC)	8 MV
Harmonic number	3840
Max. total current	**200 mA**

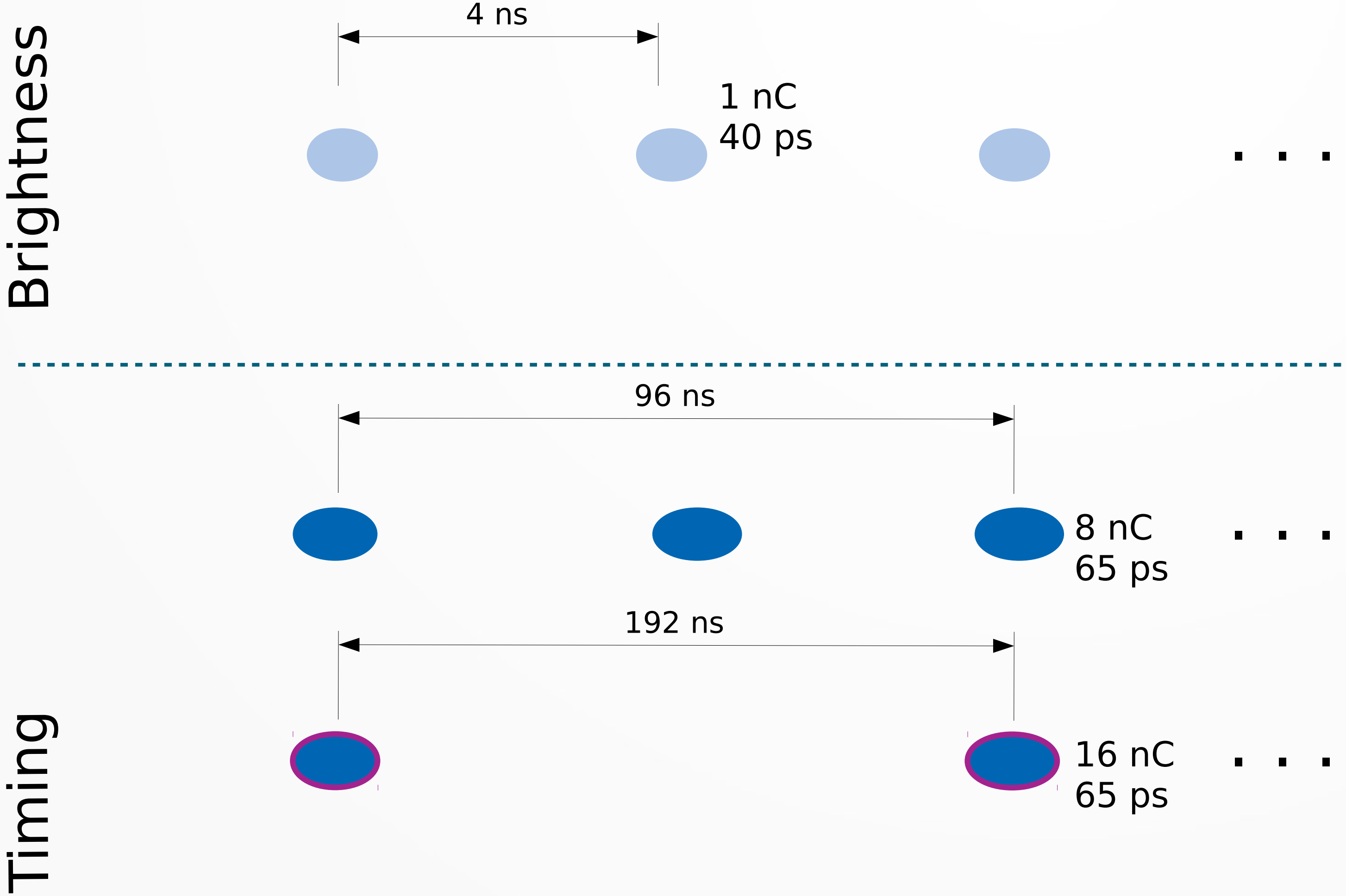
Foreseen filling patterns



	Pattern	Current
Brightness	80 x (20b + 4e) @ 4 ns	200 mA
Timing	80 b @ 96 ns	80 mA

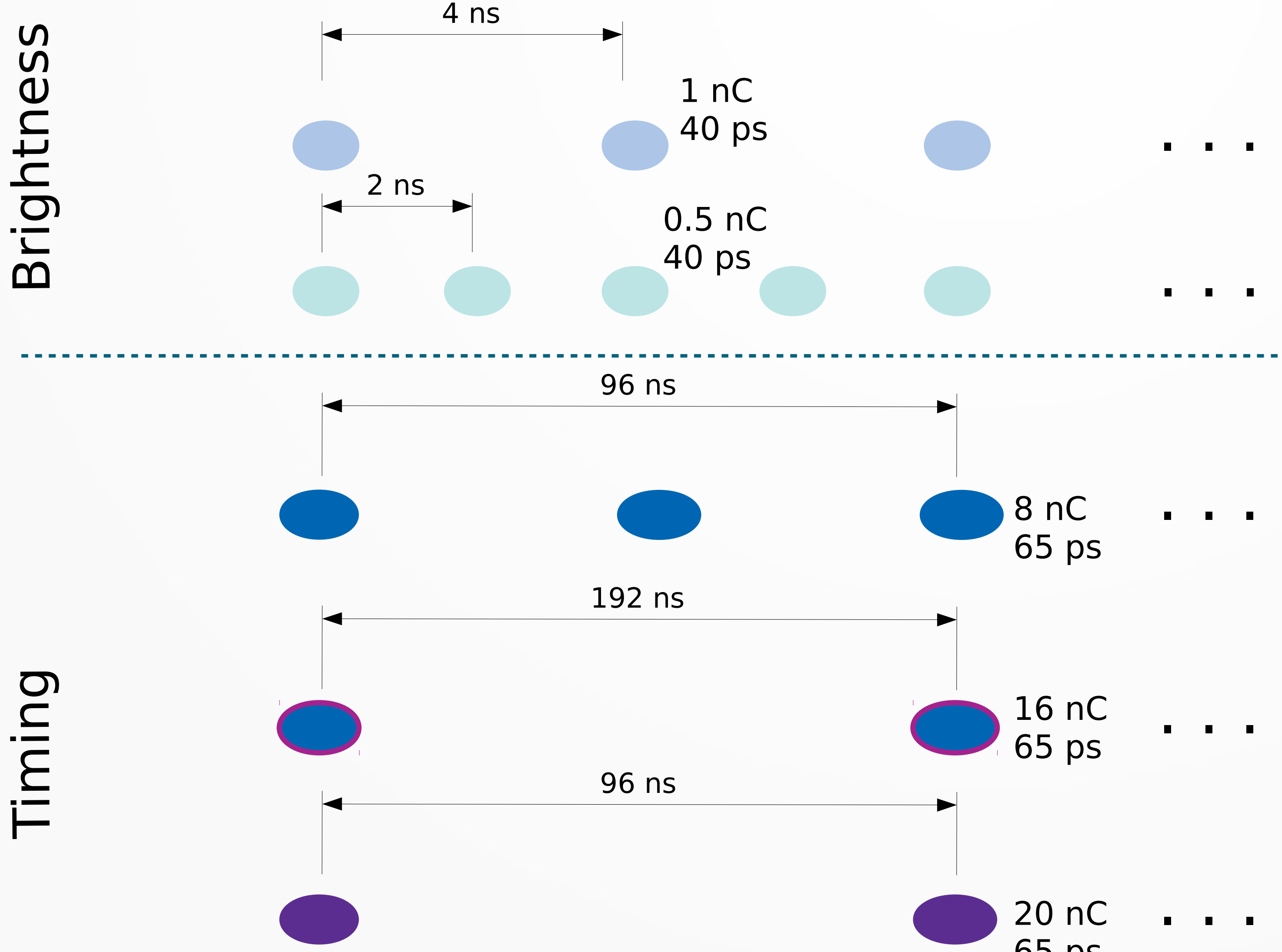
* rms value, includes RF, IBS, Impedance

Foreseen filling patterns



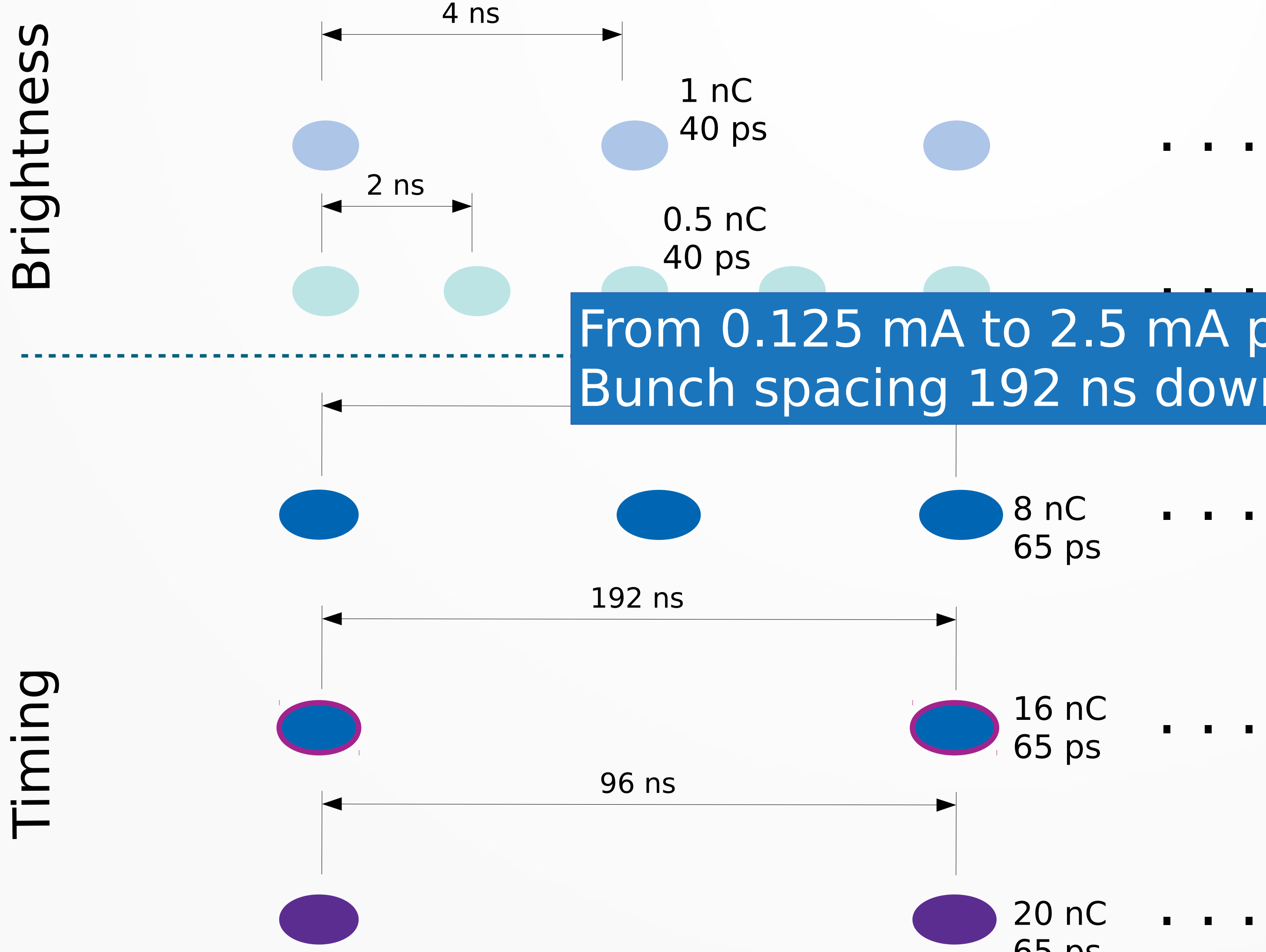
Pattern	Current
80 x (20b + 4e) @ 4 ns	200 mA
80 b @ 96 ns	80 mA
40 b @ 192 ns	80 mA

More exotic filling patterns



Pattern	Current
80 x (20b + 4e) @ 4 ns	200 mA
80 x (40b + 8e) @ 2 ns	200 mA
80 b @ 96 ns	80 mA
40 b @ 192 ns	80 mA
80 b @ 96 ns	200 mA

More exotic filling patterns



Pattern	Current
80 x (20b + 4e) @ 4 ns	200 mA
80 x (40b + 8e) @ 2 ns	200 mA
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40 b @ 192 ns	80 mA
80 b @ 96 ns	200 mA

From 0.125 mA to 2.5 mA per bunch
Bunch spacing 192 ns down to 2 ns

Goal: Ensure sufficient stability margin for all modes of operation

- Main sources of long-range wakes
  - Resistive wall
  - Higher order modes
  - Beam-ion interaction
- Stabilizing mechanisms
  - Chromaticity
  - Multibunch feedback
  - Synch. radiation damping
- Want at least a 100% safety margin at the design stage

Impedance

Working impedance model

- GEO impedance.
  - Wake potential of each element is from GDFIDL (1mm leading bunch)
- RW impedance (ImpedanceWake2D simulation).
  - From ID Chambers
  - From the rest of the ring

Courtesy C. Li

	Element	Number	BetaX/BetaMin/BetaMax	BetaY/BetaMin/BetaMax	Beta Z	Comment
	General components					
p0bpm.stdwake	BPM	788	6.18	7.31	1	Exact BPM locations
CA.stdwake	Absorber	576	3.8	4.73	1	Radiation absorbers at arc BPMs. Exact locations
bellow.stdwake	Bellow	375	2.71	4.25	1	CDR Estimate number, updated betas
flange.stdwake	Flange	375	2.71	4.25	1	CDR Estimate number, updated betas
	ID Arcs (19 x 5 m + 5 x 10 m)					
id6mm.stdwake	ID 6 mm	17	5.04	5.04	1	Average betas over the ID
id5mm.stdwake	ID 5 mm	4	5.04	5.04	1	Exact number of ID with smaller gaps is an estimate. Average betas over the ID
id7mm.stdwake	ID_10 7 mm	5	10.25	10.25	1	Super ID. Average betas over ID
p0bpm.stdwake	ID BPM	0	0	0	0	No small aperture ID BPMs foreseen
CA.stdwake	Absorber	96	5.85	4.4	1	Preliminary locations, sketch from Katharina
bellow.stdwake	Bellow	96	5.7	4.3	1	Preliminary locations, sketch from Katharina
flange.stdwake	Flange	96	5.8	4.4	1	Estimate
	Long straight section					
bessy.stdwake	RF	24	20	20	1	Estimate. RF section was re-optimized to lower average betas
h3cav_hom.stdwake	3V RF	24	20	20	1	Estimate. RF section was re-optimized to lower average betas
fbcav	Long FB	8	averBetax	averBetay	0	No Longitudinal feedback foreseen
fct22mm.stdwake	FCT	6	averBetax	averBetay	1	Fast current monitor
	Short straight section					
feedbackH.stdwake	Tr FB H	4	12.5	15	1	Rough estimate
feedbackV.stdwake	Tr FB V	4	12.5	15	1	Rough estimate
vsrTwo3mm.stdwake	Collimators	4	12.5	15		A few will be needed, exact number to be finalized. Assuming average betas
	Injection straight section					
kicker20mm.stdwake	Inj Kicker	30	10	10	1	Preliminary estimate for 2 ns spacing, top-up stripline kicker
kicker20mm.stdwake	Ext Kicker	0	0	0	0	No extraction foreseen
				final Geo impedance is given to GeoImp.sdds		
					ID Chamber RW impedance	
SuperID_Chamber.sdds	SuperID	5	6.08/4/10.25	6.08/4/10.25		10m long for each
5mmID_Chamber.sdds	5mmID	4	3.14/2.2/5.04	3.14/2.2/5.04		5m long for each
6mmID_Chamber.sdds	6mmID	17	3.14/2.2/5.04	3.14/2.2/5.04		5m long for each
					Ring Round chamber RW impedance	
RW_Ring.sdds		1	averBetax	averBetay		2304

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id7mm.stdwake	ID_10 7 mm	5	10.25			
p0bpm.stdwake	ID BPM	0	0			
CA.stdwake	Absorber	96	5.85			rina
bellow.stdwake	Bellow	96	5.7			rina
flange.stdwake	Flange	96	5.8			
	Long straight section					
bessy.stdwake	RF	24	20			lower average betas
h3cav_hom.stdwake	3V RF	24	20			lower average betas
fbcav	Long FB	8	averB			
fct22mm.stdwake	FCT	6	averB			
	Short straight section					
feedbackH.stdwake	Tr FB H	4	12.5			
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					Ring Round chamber RW impedance	
RW_Ring.sdds		1	averBetax	averBetay		2304

TABLE III. Impedance contributions at chromaticity 5

Impedance contribution	Value (MΩ/m)	Share (%)
RW round chambers	0.32	23
RW ID chambers	0.64	46
Geometric impedance	≤ 0.4	≤ 30

Airbag model gives a simple analytical estimate

Growth rate — Norm. beam cur. — Impedance — Chromaticity

Low intensity: $$\Omega^l - \omega_\beta - l\omega_s \sim -i \frac{M N_b r_0 c}{2\gamma T_0^2 \omega_\beta} \sum_p Z(\omega') J_l^2(\omega'\tau - \chi) \qquad \omega' = (pM + \mu)\,\omega_0 + \Omega$$

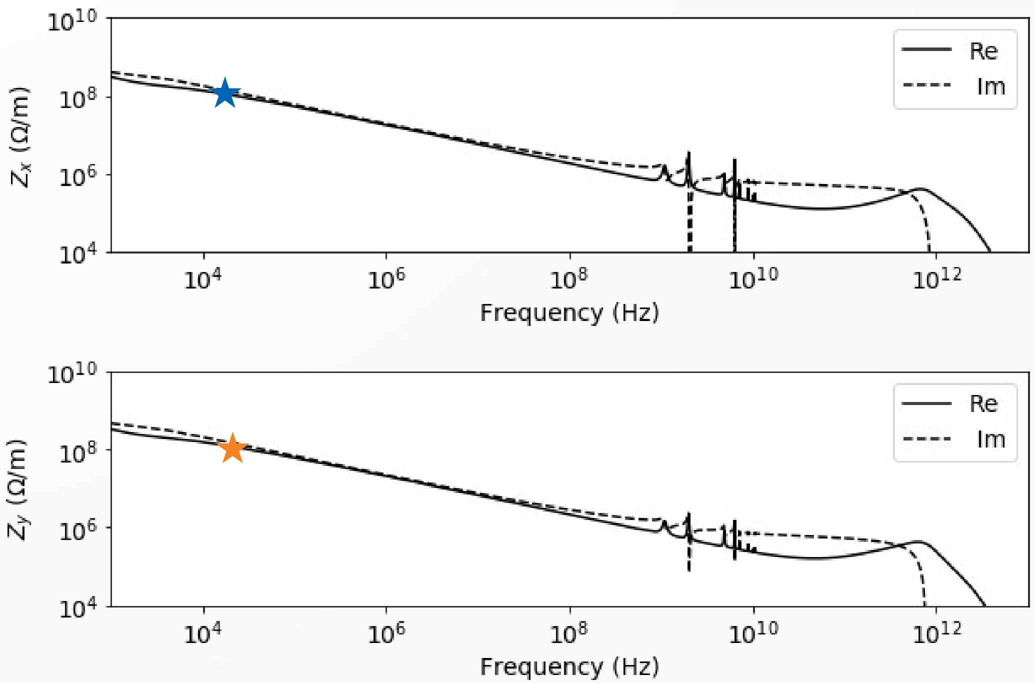
Simple analytical estimate: Air-bag model

Growth rate — Norm. beam cur. — Impedance — Chromaticity

Low intensity: $\Omega^l - \omega_\beta - l\omega_s \sim -i \dfrac{MN_b r_0 c}{2\gamma T_0^2 \omega_\beta} \sum_p Z(\omega') J_l^2(\omega'\tau - \chi)$ $\qquad \omega' = (pM + \mu)\,\omega_0 + \Omega$

- At chromaticity 0: $\Gamma = \dfrac{M N_b r_0 c}{2\gamma T_0^2 \omega_\beta} \Re Z(\omega')$
  - Lowest betatron sidebands: (23.4, 35.1 kHz)
  - Growth times for full machine (M = 1920):

    (140, 80) revolutions
  - Note: this is an upper bound



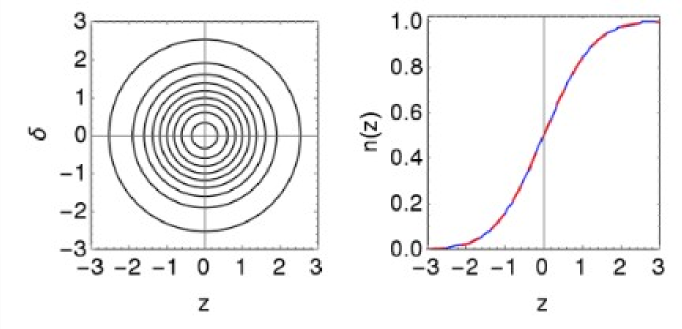
NHT Vlasov solver

- Physics:
  - Impedance: Single-bunch + couple-bunch modes
  - Chromaticity
  - Transverse feedback system (assumed ideal)

RF well, Imp, Damp, CB

$$\frac{\Delta\omega}{\omega_s} X = SX - iZX - igFX + CX,$$

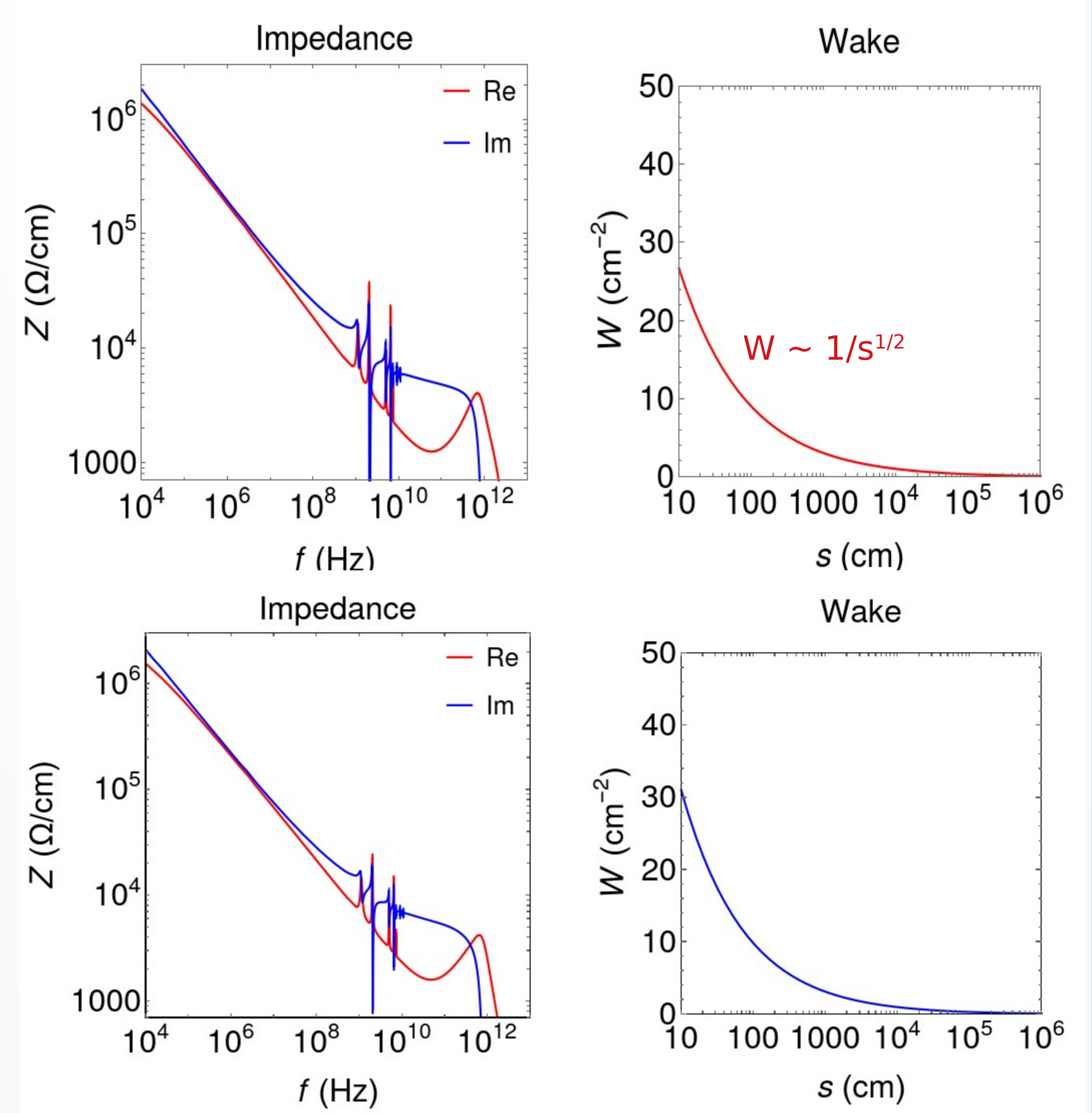
- Discretizing the longitudinal distribution on a set of air-bags



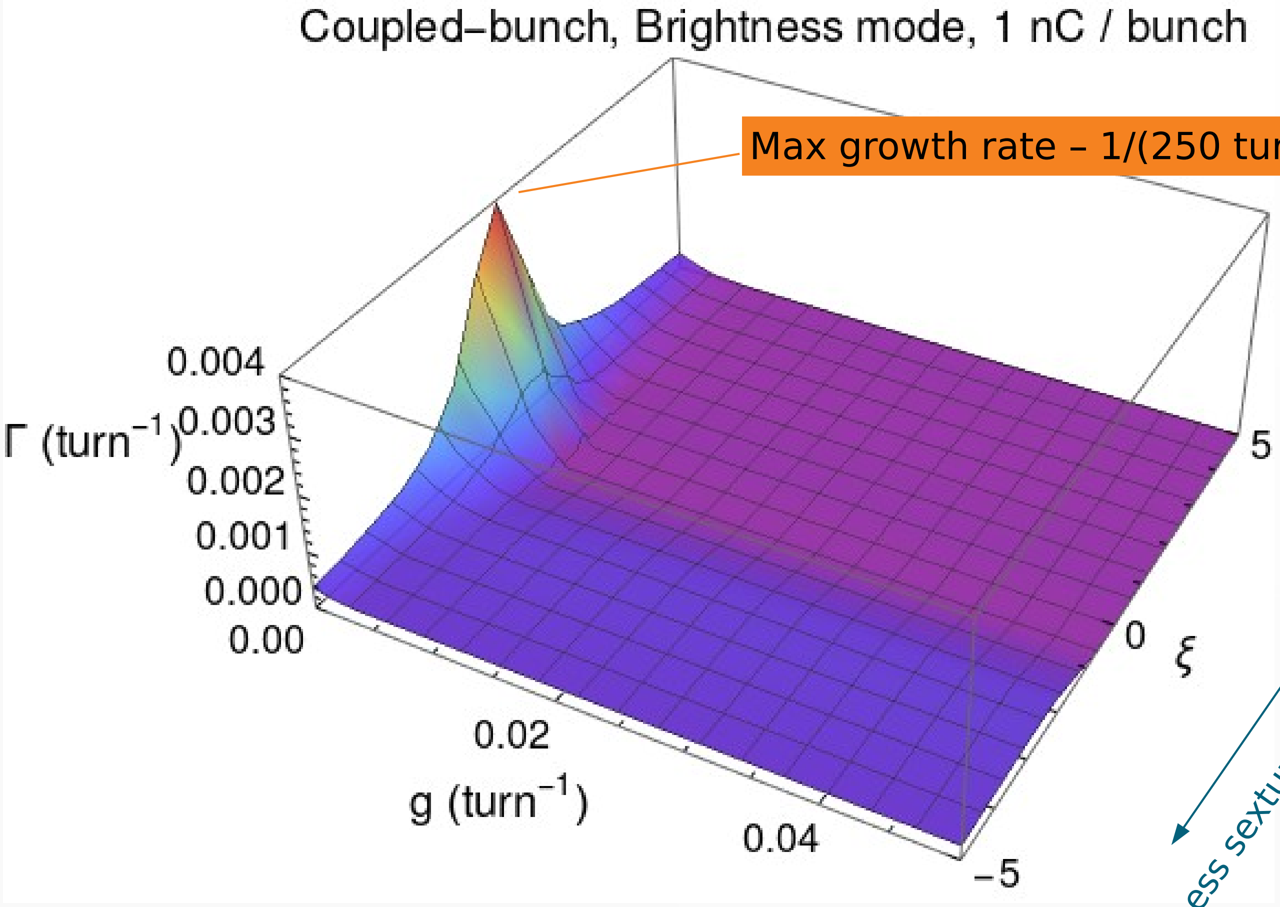
Impedance and long-range resistive wall wakes

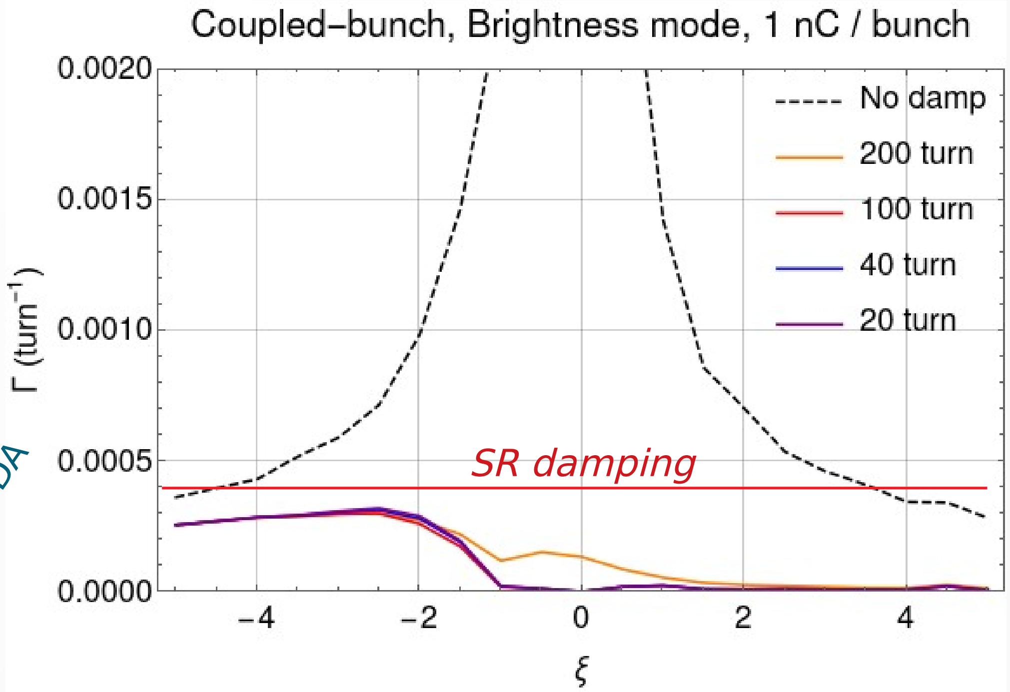
Horizontal plane

Vertical plane



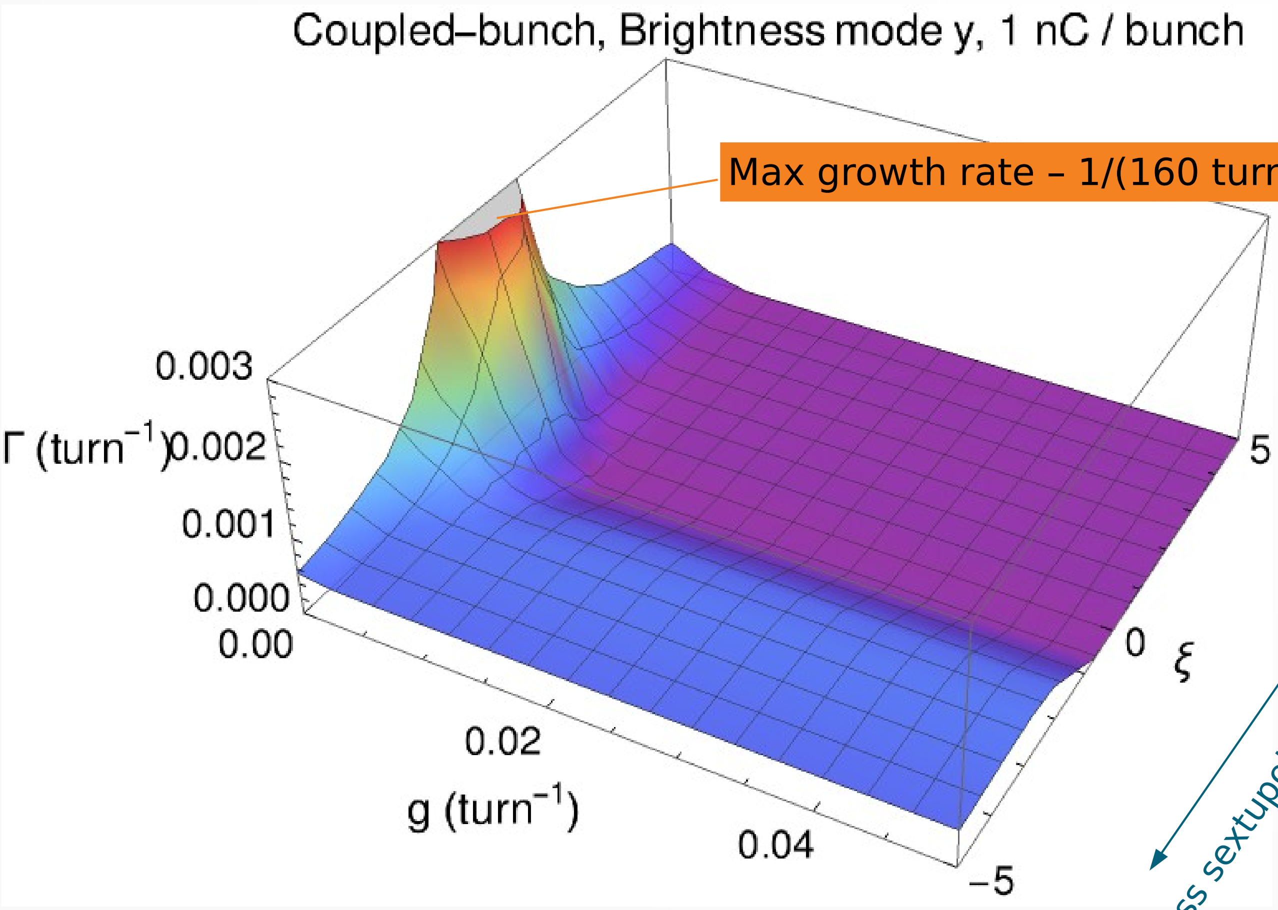
Brightness mode: Horizontal plane

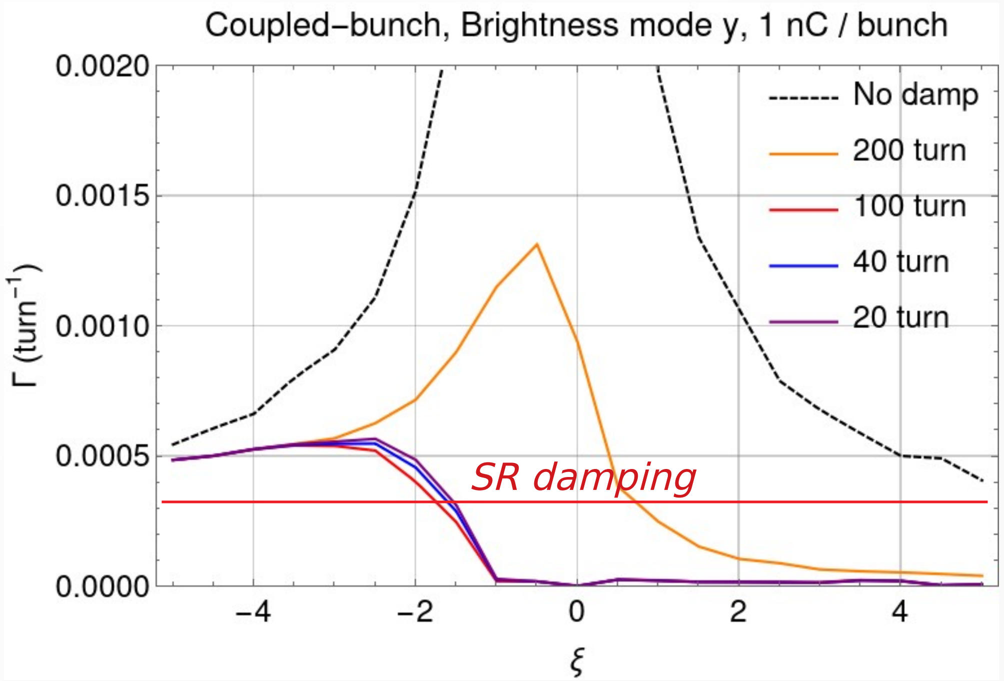




 Transverse feedback is essential for the feasibility of the 200 mA Brightness mode

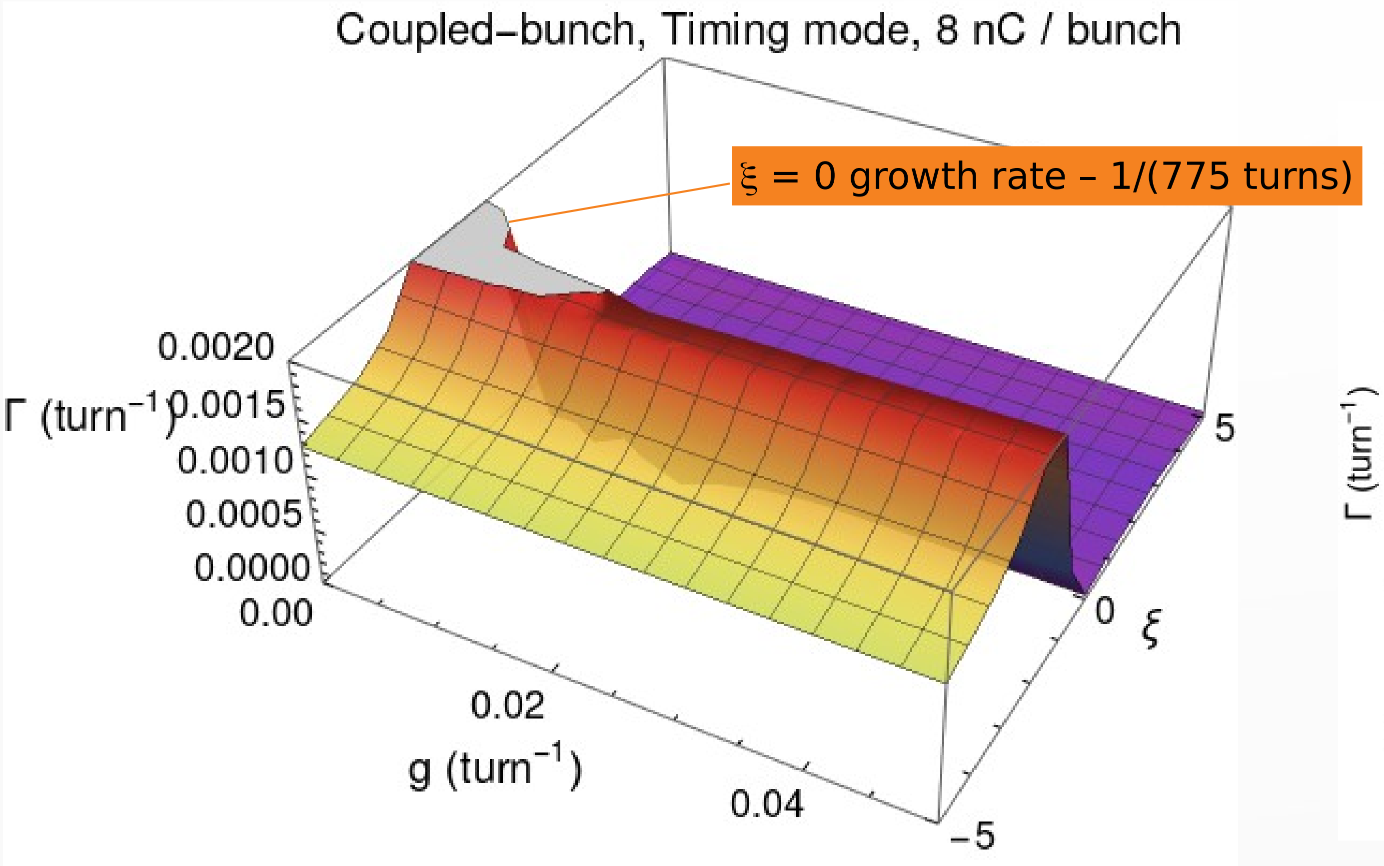
Brightness mode: Vertical plane

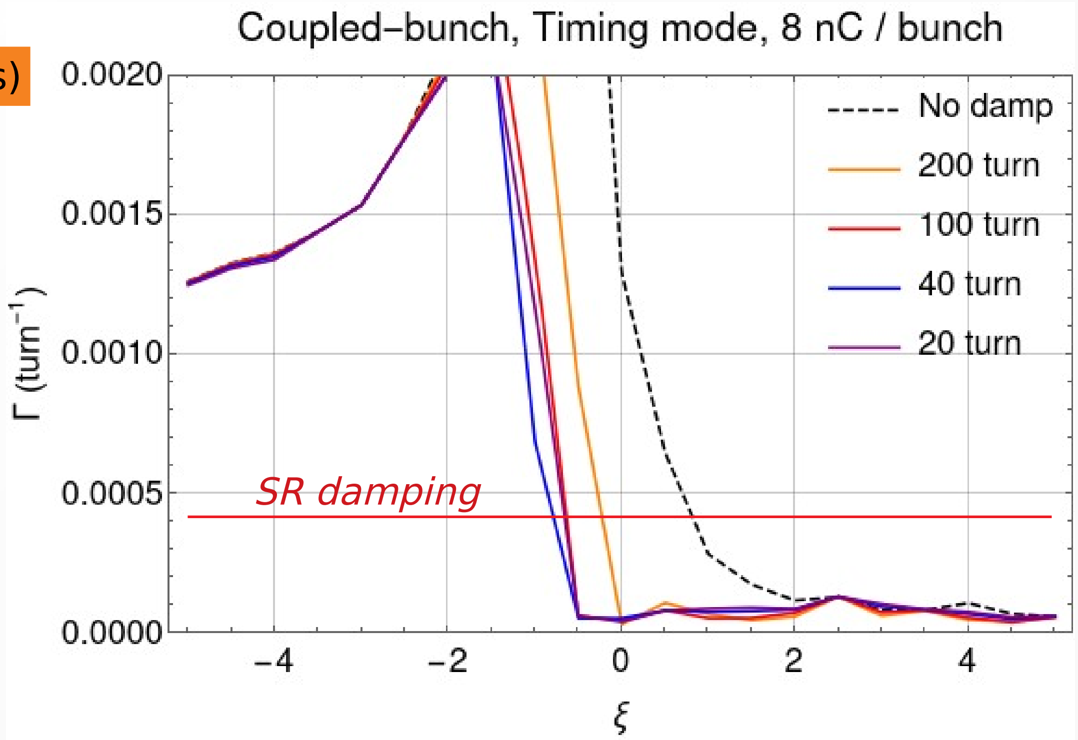




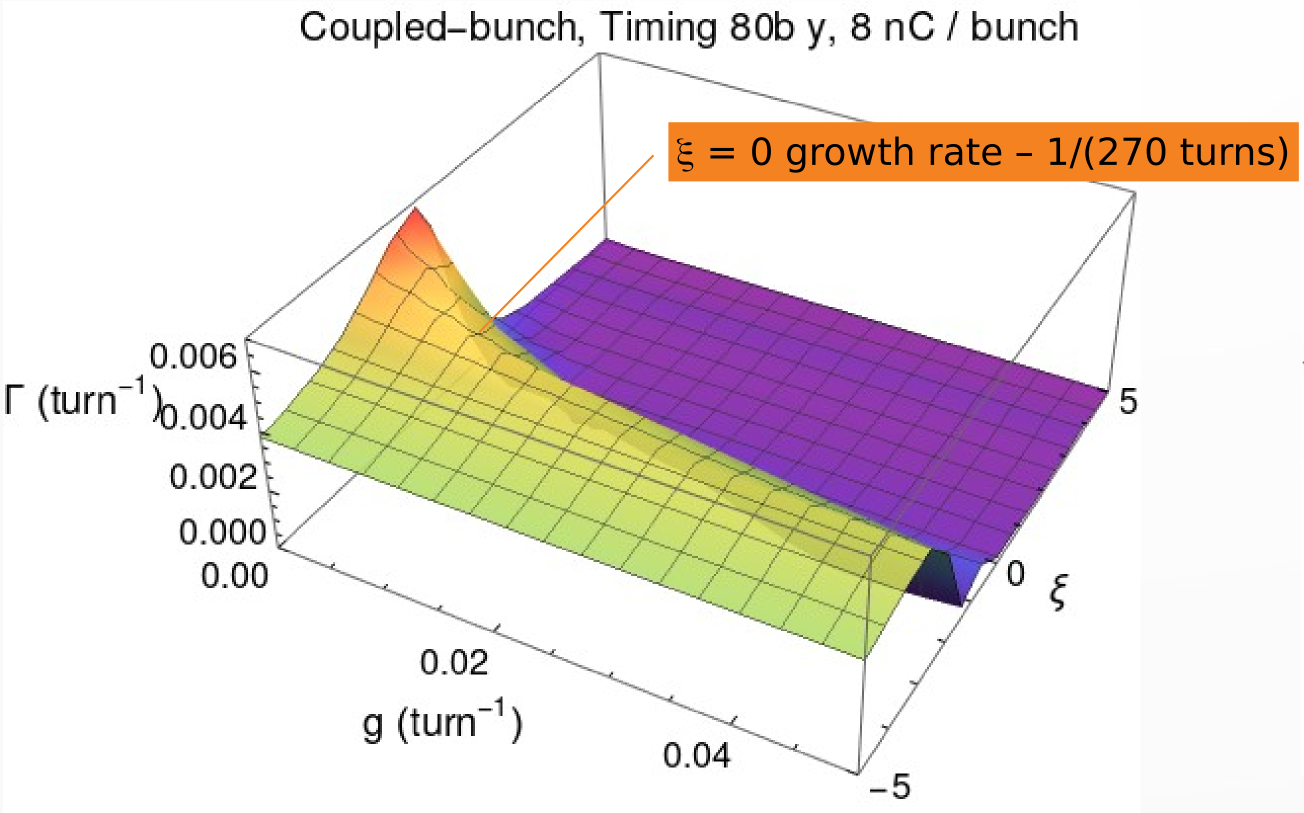
S. Antipov, **Transverse feedback is essential for the feasibility of the 200 mA Brightness mode**

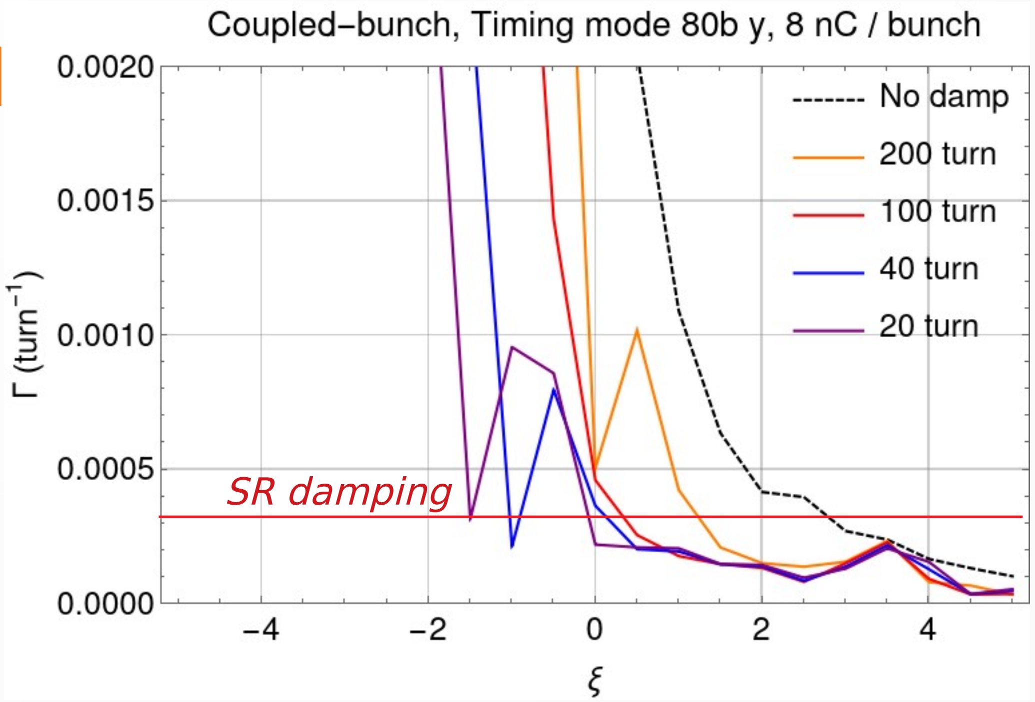
Timing mode: Horizontal plane





Timing mode: Vertical plane





Couple-bunch growth times for different operation modes: no feedback, no synchrotron damping

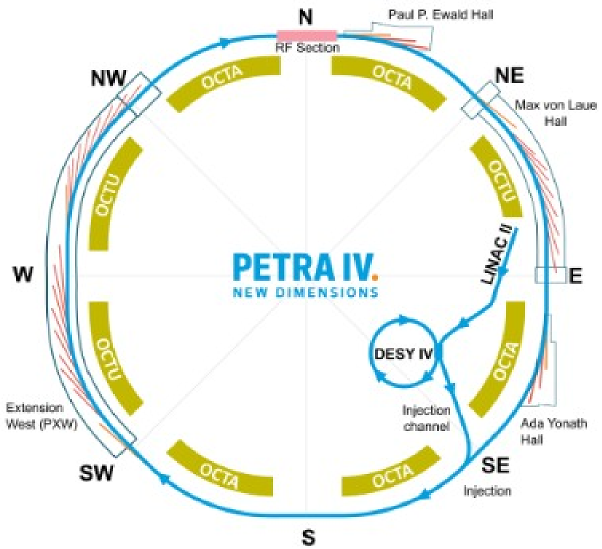
Growth rates in horizontal (vertical) planes

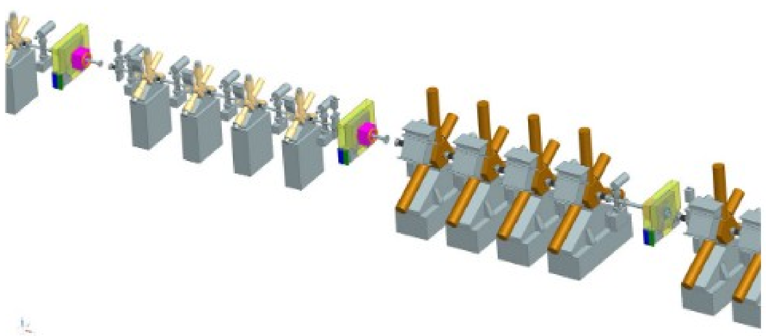
Filling scheme	Q' = 0	Q' = 5
Brightness 4 ns, 200 mA	250 (160) turns	3 530 (2080) turns
Brightness 2 ns, 200 mA	250 (160) turns	3 130 (2050) turns
Timing 80 b., 80 mA	770 (270) turns	17 150 (9370) turns
Timing 40 b., 80 mA	640 (110) turns	8 720 (5310) turns
Timing 80 b. 200 mA	160 (100) turns	5 510 (2360) turns

SR damping
~3 000 turns

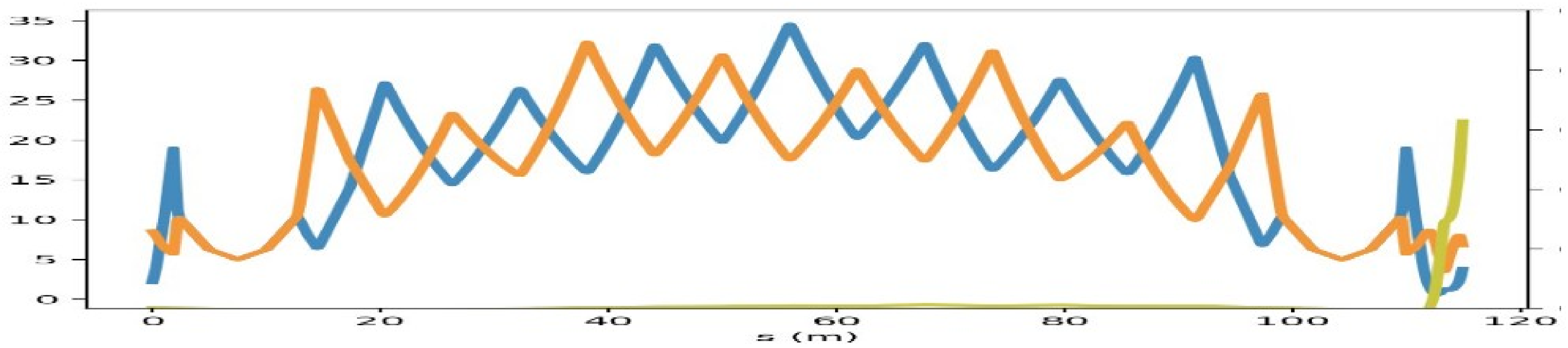
Higher Order Modes

RF straight section: Layout optimized to reduce the β-functions, # aperture transitions





- Optics was readjusted to accommodate insertion device simultaneously keeping the average beta function possibly low
- Cavity placement done



Courtesy I. Agapov

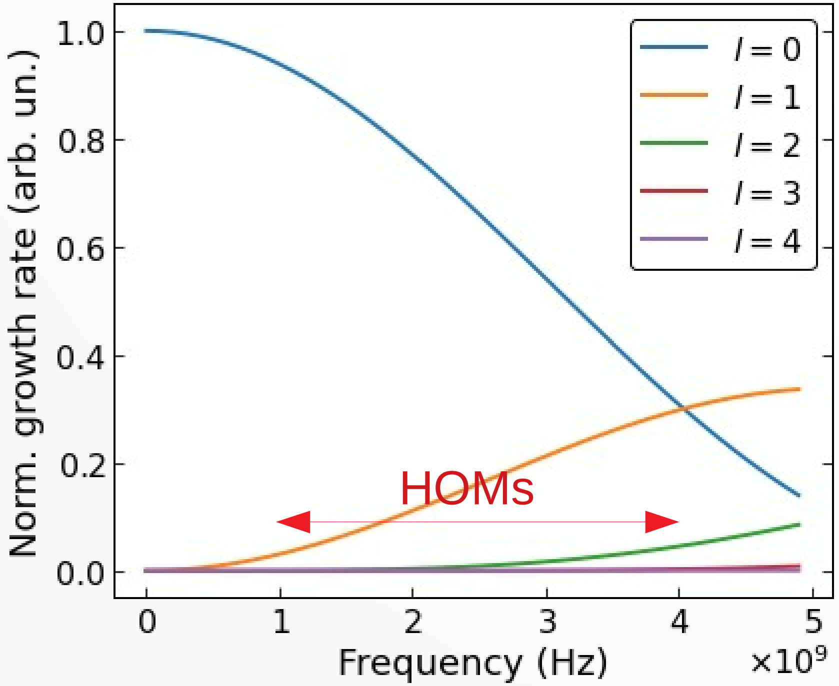
500 MHz 500 MHz 500 MHz

1500 MHz 1500 MHz 1500 MHz 1500 MHz

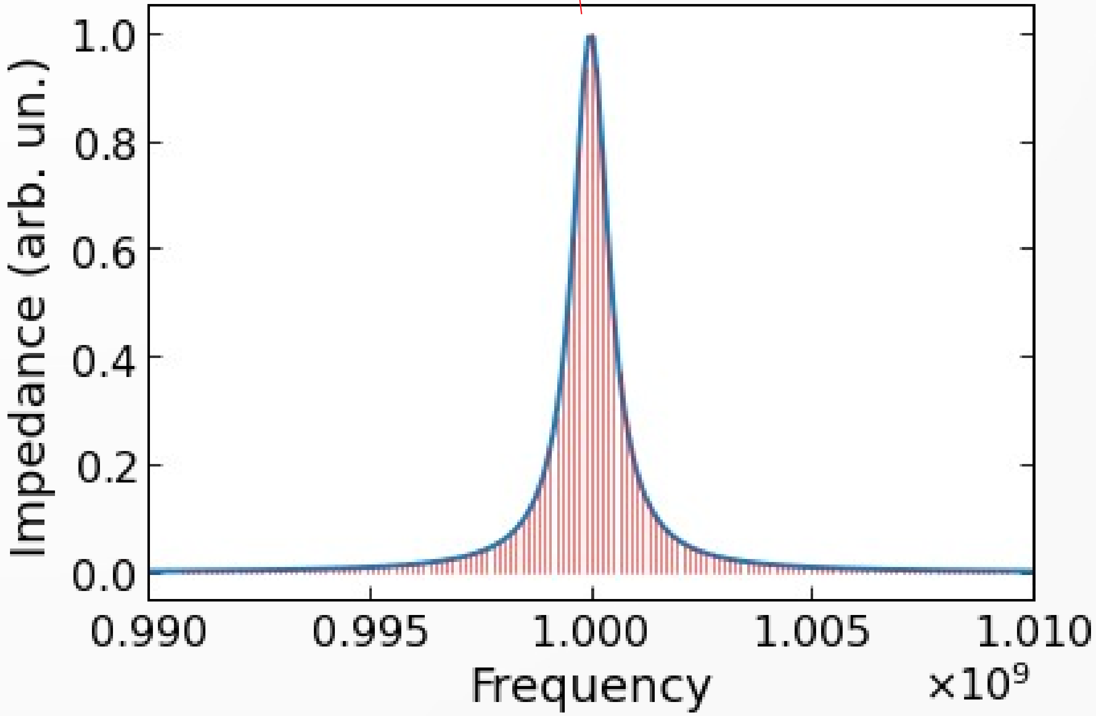
Several CB modes are excited

Low intensity: $\Omega^l - \omega_\beta - l\omega_s \sim -i\dfrac{MN_b r_0 c}{2\gamma T_0^2 \omega_\beta}\sum_p Z(\omega')J_l^2(\omega'\tau - \chi)$ $\omega' = (pM + \mu)\,\omega_0 + \Omega$

Chromaticity 0



Not only the dipole ($l = 0$) head-tail mode excited

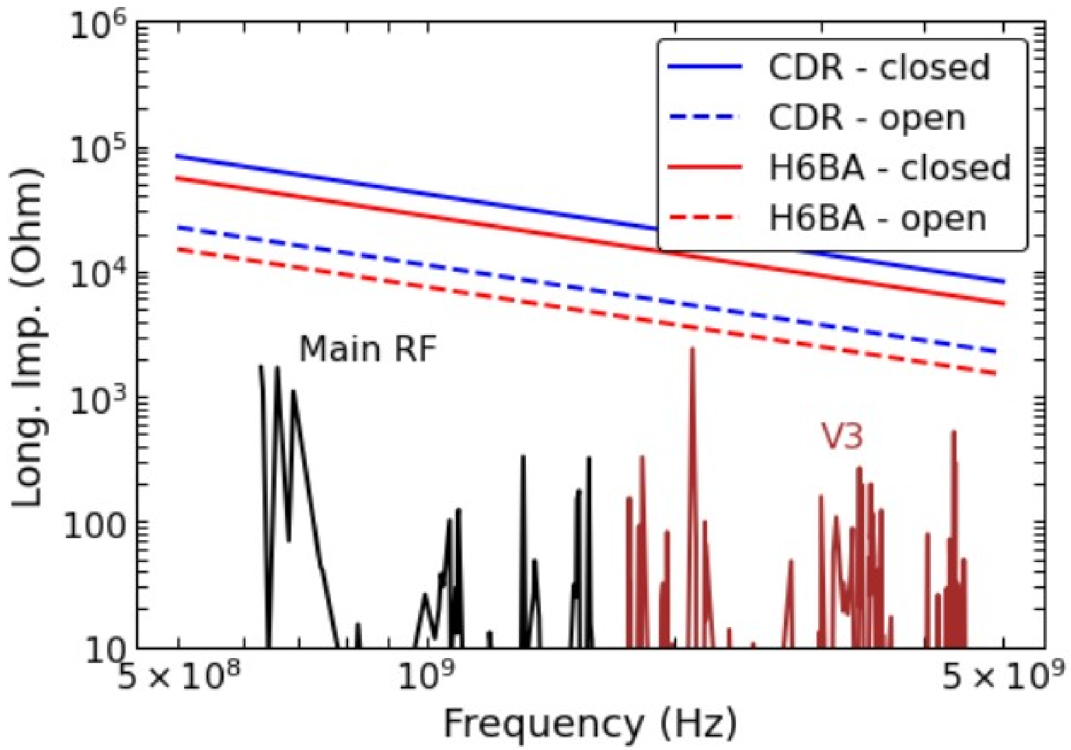


Example: $Q = 1000$ HOM at 1 GHz

Conservative limits:
All HOMs have the same frequencies

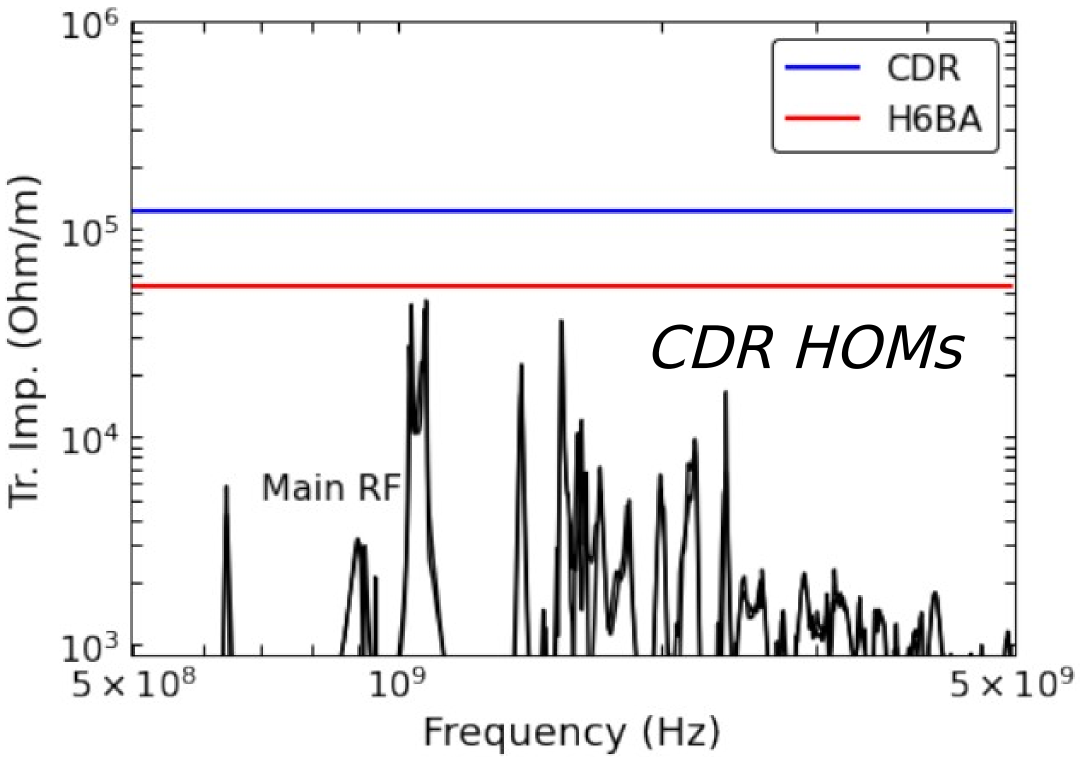
- Longitudinal stability

$$Z_{||}^{thresh}(f) = \frac{1}{f}\frac{1}{N_C}\frac{2EQ_s}{I_B \alpha_C \tau_s}$$



- Transverse stability

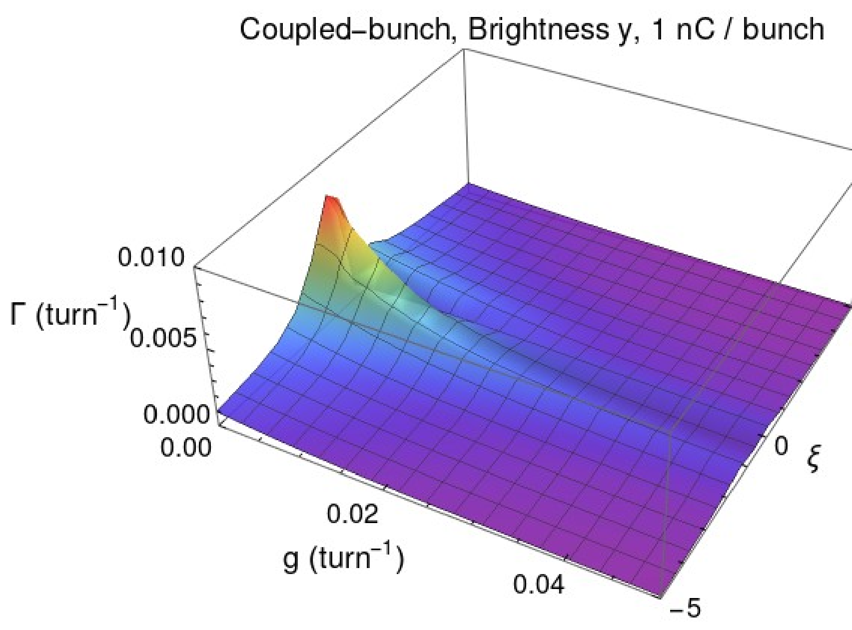
$$Z_{x,y}^{thresh}(f) = \frac{1}{f_{rev}}\frac{1}{N_C}\frac{2E}{\beta_{x,y} I_B \tau_{x,y}}$$



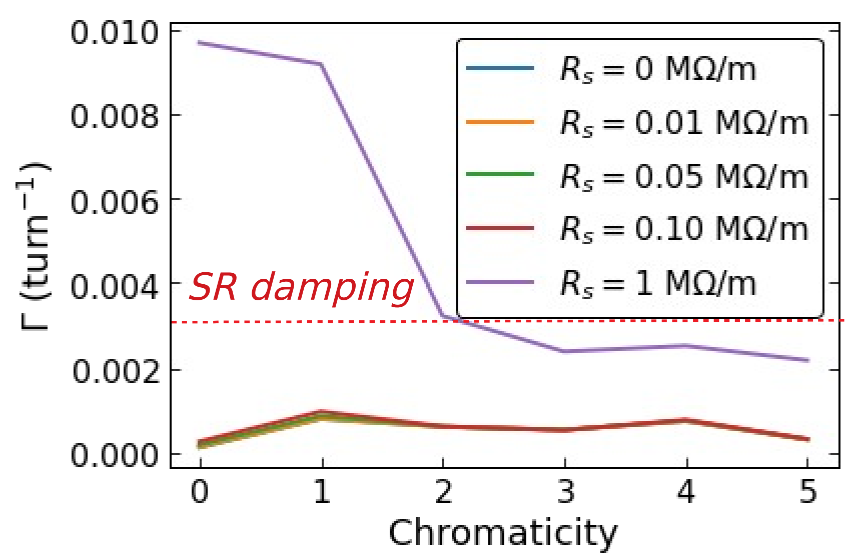
Example: HOM at 1 GHz

- 24 cavities, β = 20 m, vertical plane, M = 1920, Q_b = 1 nC
- FB and chromaticity might be insufficient to stabilize

R_s = 1 MΩ/m, no other source of impedance



With FB and chroma, full impedance model



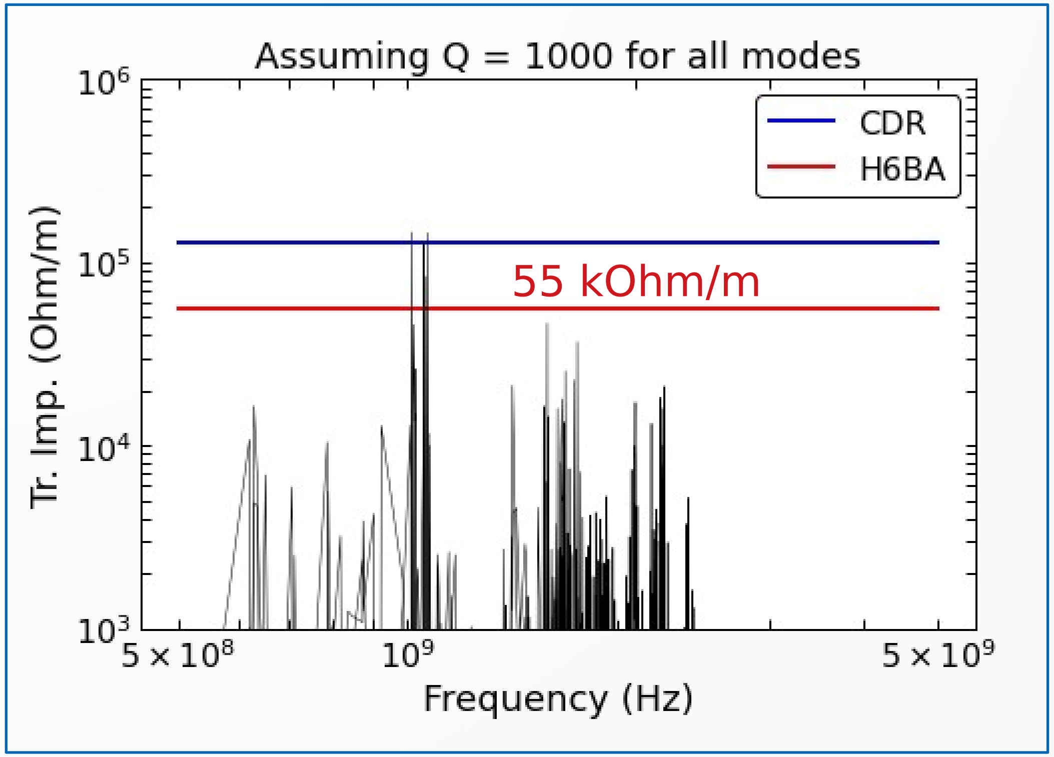
Must make sure the modes are well damped

Transverse plane: need to make sure R_s < 55 kΩ/m

- Computed without losses, assuming Q < 1000
- Have to be verified with wall losses

Nr	f [GHz]	Qext = QL	R/Q (with TT) [Ohm]	Energy [J]	Voltage [V] x0y0	Voltage [V] x5y0	Voltage [V] x0y5	Voltage/r [V/m]	Rtx/Q/rho [Ohm/m]	Rty/Q/rho [Ohm/m]	Rt/Q [Ohm]
1	0.49955279024069	2887.6248476858	225.65056728295	1.000297066811	8.4171165577659E+05	8.41855699204031E+05	8.41288917178699E+05	89321.0907089248	0.0126240006234268	0.108731134453783	10.7764769690762
2	0.62050293522244	525.11987823031	1.7010372397118	0.99884198403287	8.13892711477911E+04	7.61713522298945E+04	8.2983858579844E+04	1091226.59264159	10.75256485862560	1.00418583749811	0.06540210788765
3	0.62162739508796	222.25862602368	2.2995651610279	0.99855846788505	9.47031918470079E+04	9.66248608302338E+04	9.56682302177656E+04	430074.91152715	1.45353421235784	0.36657028796444	0.08825459763871
4	0.62357569999324	96.573761956449	1.670781087987	0.99854949240183	8.08498276816566E+04	8.11199546305649E+04	8.02518154435628E+04	131238.287924898	0.02854235167825	0.13988594140605	0.06392226162785
5	0.62923728675441	70.085061853441	1.108485558341	0.99940629355153	6.61809837910445E+04	5.96436173812815E+04	6.97395039940552E+04	1488626.55640336	16.40350149112820	4.86037501449507	0.04202786747461
6	0.63566729606325	77.513230787534	1.2611248092123	0.99939862659687	7.09501433343034E+04	7.51169684525662E+04	7.44552175977522E+04	1088999.12136745	6.53001155068232	4.62059443219561	0.04733146702356
7	0.64077260118994	28.745716582463	19.472030900917	0.99905631702567	2.79861083404747E+05	2.80382689049699E+05	2.78050902606652E+05	376766.610550226	0.10073690785134	1.21324345670992	0.72498510021836
8	0.65145469663379	21.966030850412	0.43820243953686	0.99895712929329	4.23294733109839E+04	3.79412125691126E+04	4.14911979052567E+04	893521.974984297	6.89876652027058	0.25174453237738	0.01604768296962
9	0.65579023518499	20.086427878144	2.0776135697515	0.99886957726585	9.24717734185989E+04	9.35596031832585E+04	9.24439401223539E+04	217637.155767045	0.41839365074062	0.00027390029139	0.07558255904525
10	0.67067894408684	30.429109022162	49.68684830708	0.99979520972181	4.57534156143391E+05	4.59052005371437E+05	4.56408562479928E+05	377932.659308925	0.77807016059151	0.42788274292595	1.76745572066802
11	0.68896589761329	130.27891027686	5.3243528858353	1.0012535978178	1.51912761249237E+05	1.50950672154867E+05	1.52277192909071E+05	205759.652040438	0.295796431173091	0.042441873289005	0.18437026101571
12	0.70633847240895	11.53687282659	0.0048272768192108	0.99900347247156	4626.2698975465	9036.0258824315	4468.9246784792	882512.444426534	5.92568119846443	0.00754425342884163	0.000163046359669512
13	0.71130537619209	11.769430386003	5.6852143514389	0.999067172889	1.59326767939542E+05	1.59371759396534E+05	1.56450344379259E+05	575355.080949265	0.000608212204818064	2.48599751655146	0.190683237507245
14	0.71534299214279	11.308472918786	13.998234022621	0.99914296455267	2.50724942198735E+05	2.50899627166139E+05	2.51851854325381E+05	228074.179075032	0.00906476741270	0.37724692077746	0.46685357338064
15	0.78545059973889	390.10197837964	0.010272335436882	0.99924049897896	7117.3608004266	1.36167754055791E+04	6702.8322383355	1302524.07484021	10.4074082902858	0.0423353377059837	0.000312012563319627
16	0.78820981148631	9.2130919924043	0.6717744881112	0.99923186531314	5.76574914650711E+04	5.75332956870913E+04	5.28789831923689E+04	956024.390976535	0.00377368463665	5.58645910054501	0.02033309241688
17	0.79312305070041	8.9264284216597	2.1014350450912	0.99929209251399	1.02297361164481E+05	1.01517196182974E+05	1.04211674378472E+05	413436.934955278	0.14706224716853	0.88543011069334	0.06321165527864
18	0.79952348905802	8.6346663272222	0.57263653661066	0.99939228336819	5.36183037812536E+04	5.54289339405638E+04	5.57241120782065E+04	555438.931200158	0.77940455777117	1.05424392228170	0.01708714841142
19	0.81816528985885	776.01509738588	0.023485138139209	0.99974432329527	1.09863009749497E+04	1.4737511136098E+04	9702.9108941142	792935.50236294	3.19354934577486	0.37380765911009	0.00068481589597
20	0.82049170983973	8.3485985945131	0.067121396346512	0.99963318804607	1.85984973583886E+04	1.73045647247662E+04	1.73440181568635E+04	360443.045565429	0.37786455773664	0.35517284752614	0.00195167972200
21	0.83708792104343	119.38276956106	0.0076802306449062	1.0000829337306	6355.9520346365	8744.4263562332	8182.4004705019	601355.91703423	1.23641673309231	0.723000424634369	0.000218889511376395
22	0.84701452246219	19.77558446317	0.030877376555274	1.0028914194256	1.28375609136695E+04	1.04861662664239E+04	1.09734601477417E+04	600130.934134473	1.16712483168588	0.733508293354941	0.000869703668621882
23	0.87444682108517	22.414503189007	0.22472642360261	0.99979401706344	3.51349203006937E+04	3.7466267207051E+04	3.85760471879619E+04	831300.972020649	1.07978763715464	2.35247989949300	0.00613115790757
24	0.87597264750135	434.34349381081	0.069220671911441	0.99974358388058	1.95162972866946E+04	2.39287954933409E+04	2.20184294196288E+04	1014510.83058425	3.85479471425165	1.23951746811417	0.00188524166631
25	0.90459879912	7.3921805478413	0.14350136255882	0.99941346004231	2.85508174415767E+04	2.8406953362686E+04	3.33191121599554E+04	954092.896829513	0.00384369942158868	4.22251168738295	0.00378461566272247
26	0.91325822233152	7.3152233422991	0.00013759744087886	0.99916646445888	888.20013040537	3098.4826753156	910.5379571134	442079.08373217	0.890373948150096	0.0000909407834361191	0.00000359450034978277
27	0.92330538654101	8.1369559728984	0.34904847658722	0.99965384171074	4.4991483349901E+04	4.57240659570792E+04	4.55961093779572E+04	189973.672927911	0.0956477408565096	0.0651531154452495	0.00901907798489829
28	0.92570195254091	8.0497401840095	0.0053459153806392	0.99964569269353	5575.1892438846	1.40715529881606E+04	5078.2898204443	1702176.32355832	12.7991056215042	0.0437774453506968	0.000137775712248488
29	0.98815006929656	140.76999604246	0.14310672943767	0.99908960392881	2.97943307833013E+04	3.32279531096032E+04	2.68734690464294E+04	901580.735499627	1.83550970469123	1.32823107198925	0.00345508642736
30	1.0118779520743	806.71270297987	0.56609188914782	0.999695026294	5.99834212298152E+04	6.00698716860282E+04	6.93161945262572E+04	1866634.73753341	0.00110895179631052	12.9240765805744	0.0133469048321386
31	1.0151299745999	967.17427588105	0.0035499137110798	0.99970419899101	4757.6820630384	3.61653308767779E+04	5349.5296796267	6282644.94495257	145.431311335242	0.0516424542868616	0.0000834291673853082
32	1.0202599586335	1.36380666479908E+05	0.30496649997718	0.99896951259138	4.4192395164296E+04	4.30922059783936E+04	6.18383820943508E+04	3536050.17487276	0.17679204185714	45.4799391048329	0.0071312072361153
33	1.0252205468235	2428.3660896045	0.3919842522981	0.99870928911927	5.02171937279964E+04	6.36439355289247E+04	4.0506198615201E+04	3314096.08472375	26.0837164275196	13.6444384429261	0.00912164325125142
34	1.0267187842884	615.39905533088	0.37891600414094	0.99850375224902	4.94039886251899E+04	4.25519896340565E+04	3.92868713713474E+04	2443816.29180666	6.77460146192126	14.7693960835034	0.00880467248108941
35	1.0292843198046	1942.2877622189	0.00025043564714257	0.99769164084561	1271.1706374631	993.62021721565	1575.1926723887	82331.9217557416	0.0110692607766722	0.0132814338513705	0.00000580473709090539
36	1.0311688236709	7.6634707545148	0.18461593738993	0.99809426939553	3.45521596041196E+04	3.80281308774124E+04	3.34921568694996E+04	726800.717945673	1.72911203837158	0.160799520193423	0.00427131086235933
37	1.0334935948892	7.3983617228074	0.045228901628169	0.99840342196989	1.71239866227505E+04	2.09840846083499E+04	1.60032808267922E+04	803898.947368961	2.12215404570294	0.178880699187906	0.00104407095962726
38	1.0370178017705	7.6172783700508	0.010437715083572	0.99970280280075	8245.5800788088	1.11077775454883E+04	7082.0050844879	617934.66015997	1.15733141082823	0.19127020062744	0.000240126997530939
39	1.053375214945	7.2913731503846	0.51686947905678	0.99845896680551	5.84436103691082E+04	5.89271753036442E+04	6.87864950582747E+04	2070836.53376415	0.0320564241789221	14.6652287137756	0.0117062975002451
40	1.0543641033233	7.509022434096	0.0067705343069623	0.99852202612695	6692.3020806762	3.72532959486397E+04	9489.3406072341	6137744.76731235	127.790321409032	1.07043404123326	0.000153198352864627
41	1.0563379104689	1.36688154854062E+04	0.0011081748559951	0.99793372736059	2709.2330423937	3609.828782878	4342.3260047626	372991.437516589	0.110625241353176	0.363761111838639	0.0000250280601582472
42	1.0612327443719	29.398818973604	0.02306704886768	0.99901543742206	1.23958802614016E+04	1.35693734813439E+04	3.72722293008082E+04	4980802.45690445	0.185895798518195	83.5375412014306	0.00051856494902611
43	1.0641131070435	711.76385574442	0.00036077204061208	0.99866391894792	1552.0651471946	3.43298698984767E+04	1873.7656370876	6555876.67827383	144.300112861347	0.0138998587639582	0.00000808847867447962

Courtesy W. Mueller

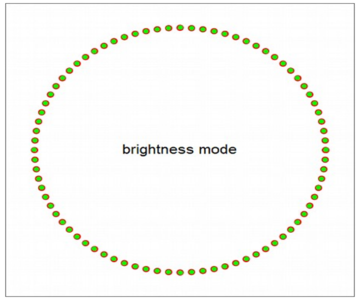


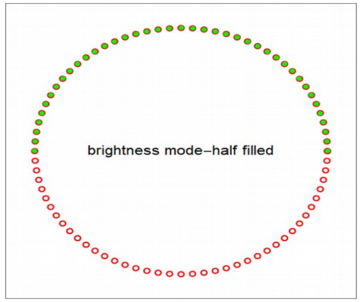
Beam-ion effects

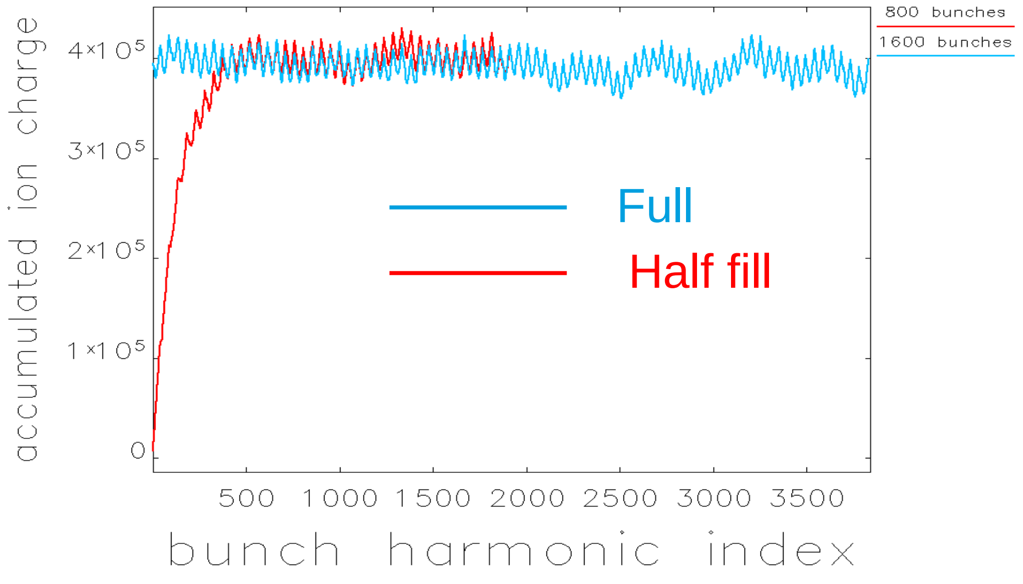
Beam-ion effect @ brightness mode

- **Nominal brightness filling patter: 3840 = 80 * (20*2 +8)**
- **Half-fill filling pattern: 3840 = 40 * (40 +8) + 1600**

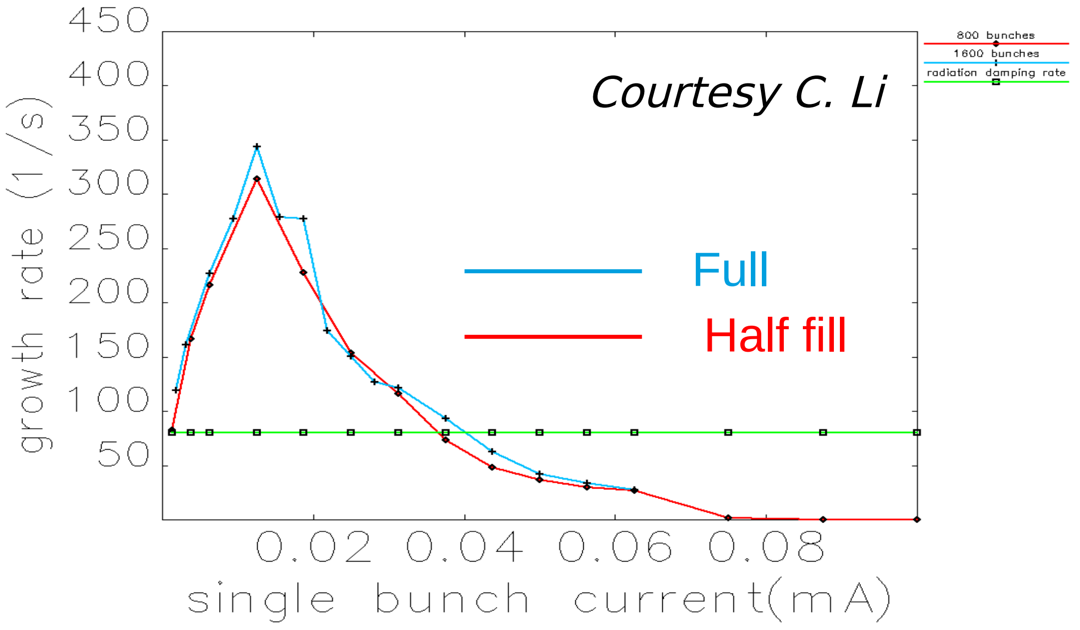
- **We verified that the long gap can clean ions.**
- **Maximum number of accumulated ion within one turn is comparable.**
- **The beam ion growth rate are almost the same ("fast-ion" mechanism within one turn)**
- **Long gap does not help too much to mitigate the ion effects in our case.**







macro-ions charge in the second last turn @20mA



Beam-ion instability growth rate Vs beam current

Transient beam loading @ brightness mode

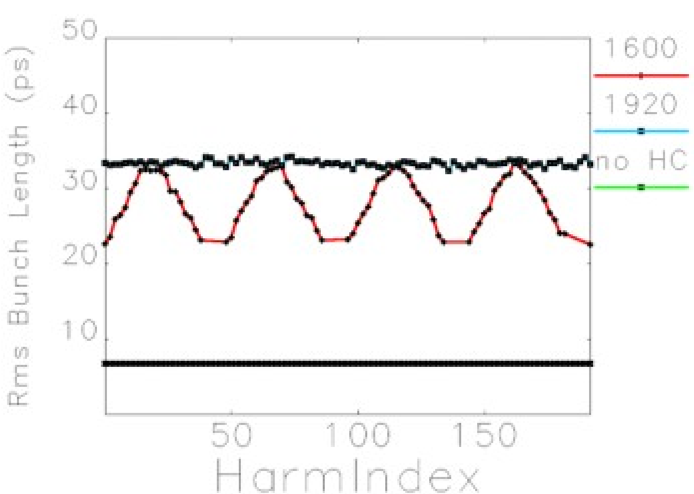
Courtesy C. Li

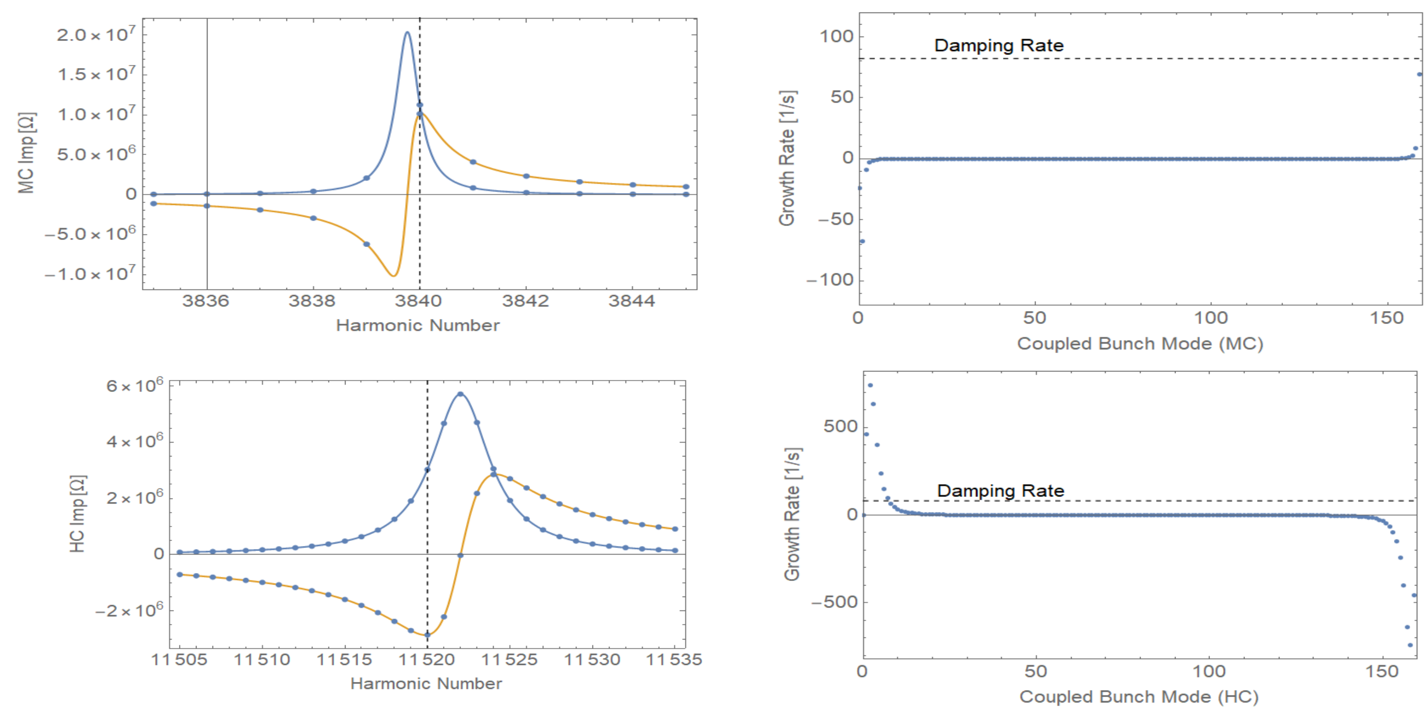
- **A strong transient beam loading due to non-uniform filling scheme and coupled bunch instability is foreseen due to the cavity fundamental mode.**

- **Double active RF system.**
- **However, if the low lever RF control loop can be applied appropriately, the impedance of the fundamental mode beam can sample will be significantly reduced.**

- **we show how bunch length is affected by the transient beam loading effect in spite of the coupled bunch instability.**

	Main cavity	3rd Harmonic Cavity
[illegible]	29600	17000
[illegible]	7400	2700
[illegible]	3	5.3
Shunt impedance (Ohm)	8.16E+6	36E+6
200 mA		
Opt. Tune Psi	-0.747	0.697
Cavity Vol. (V)	8E+6	2.391E+6
Cavity Phase(rad)	1.08	-1.746
Beam Induced Vol. (V)	5.983E+6	1.7418E+6
Beam Induced Phase (rad)	2.393	-2.442
Generator Vol. (V)	8.67e+8	1.535E+6
Generator Phase	0.3523	-0.928





Growth rate 200mA

Conclusion

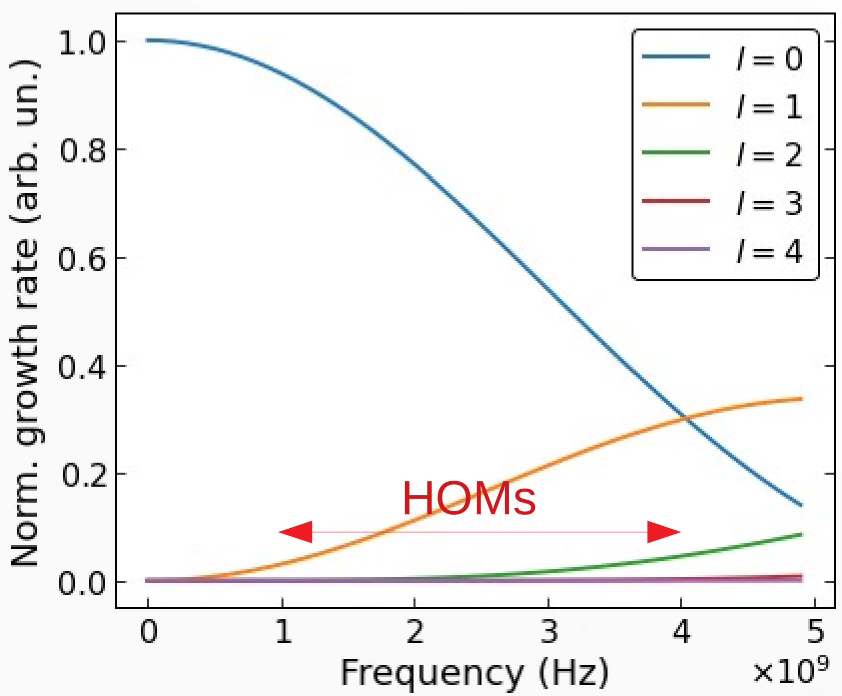
- Baseline scenarios are stable when using both feedback and chromaticity
  - Gain of ~1/20 turns seems to be sufficient with significant safety margin
  - Both resistive wall and ion effects
  - Beam can be stabilized at 0 chromaticity – beneficial for machine studies
- To guarantee transverse stability HOMs shall be damped below **55 kΩ/m**
  - Otherwise, need to be carefully examined separately
- Ongoing work:
  - Refining the impedance model (see talk of *A. Rajabi*)
  - Studying non-uniform filling patterns
  - Developing an in-house code for transient beam loading and longitudinal stability due to fundamental mode (see *C. Li, eeFACT2022*)

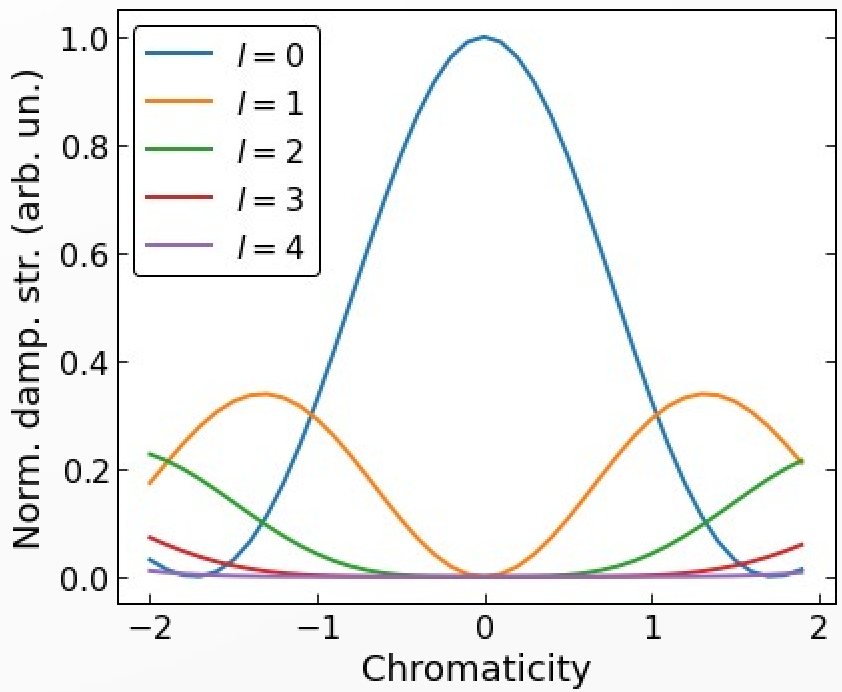
Transverse feedback might not be efficient

Low intensity: $\Omega^l - \omega_\beta - l\omega_s \sim -i\frac{MN_b r_0 c}{2\gamma T_0^2 \omega_\beta}\sum_p Z(\omega')J_l^2(\omega'\tau - \chi)$ $\omega' = (pM + \mu)\,\omega_0 + \Omega$

$\xi = 0$

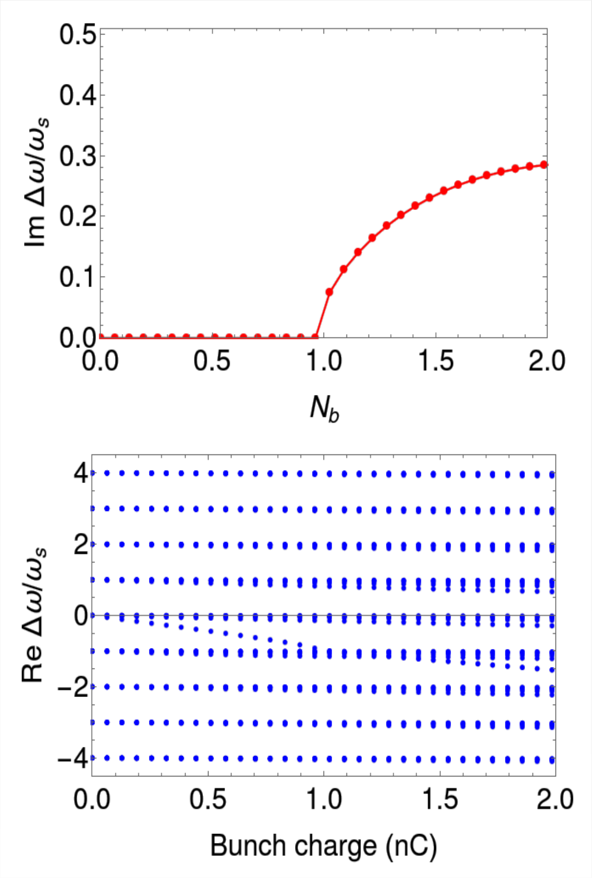
$R \in [a;b]$



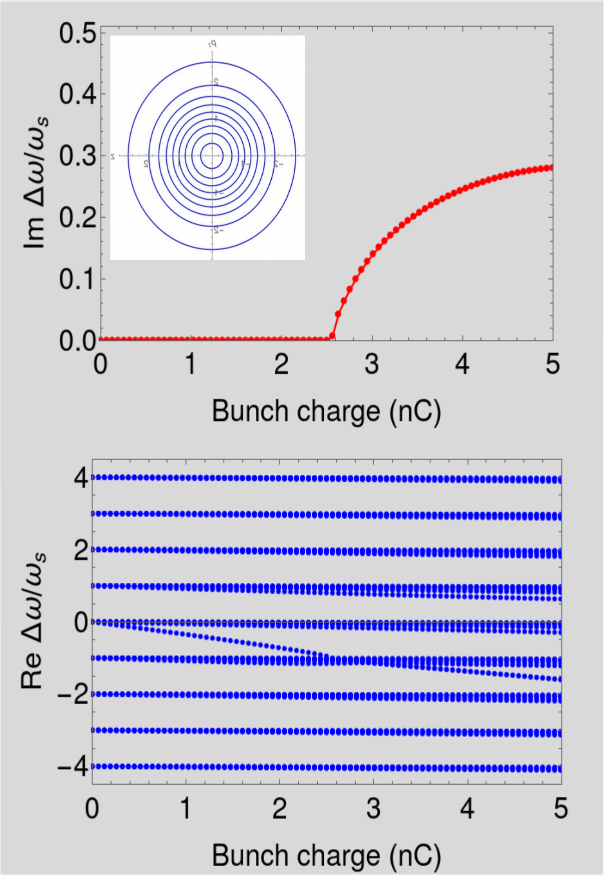


PETRA IV Case: Single Bunch

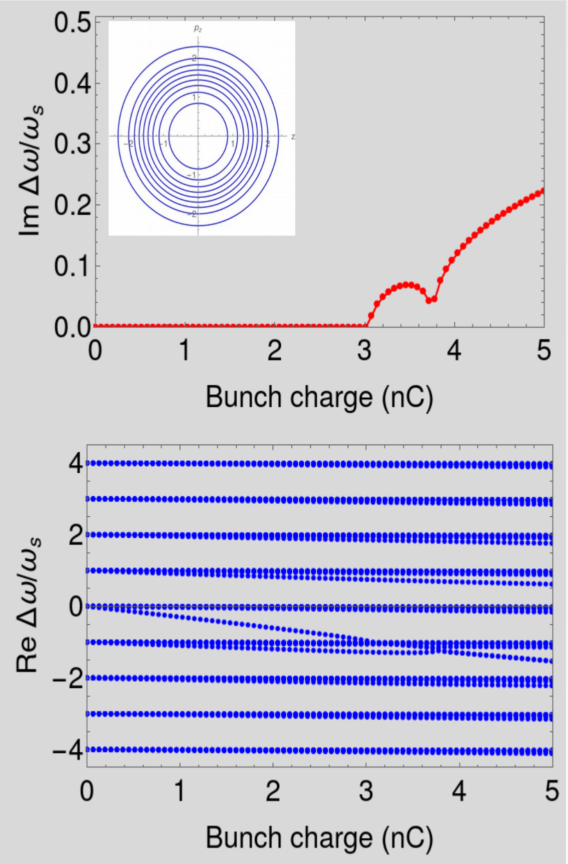
No V3, σ_z = 2.5 mm



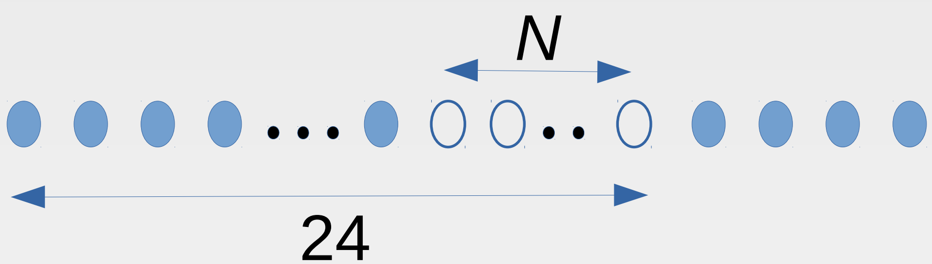
V3, σ_z = 11.4 mm,
Gaussian

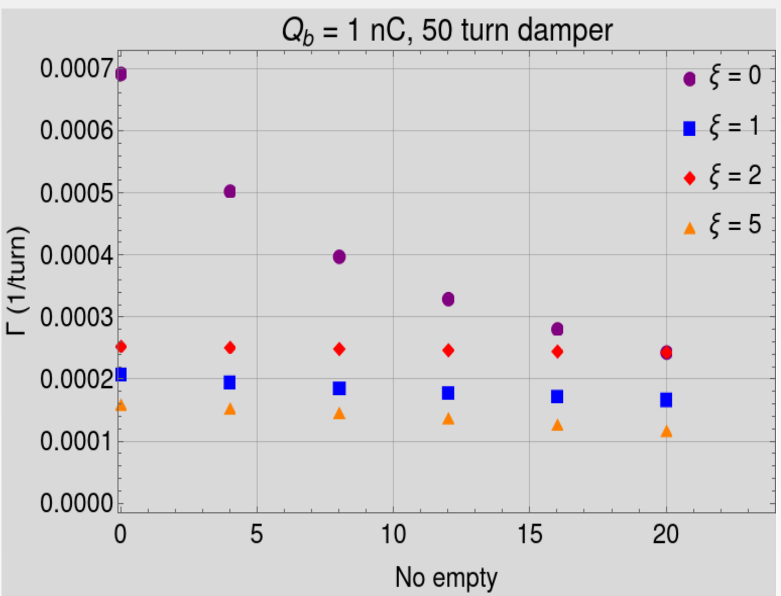


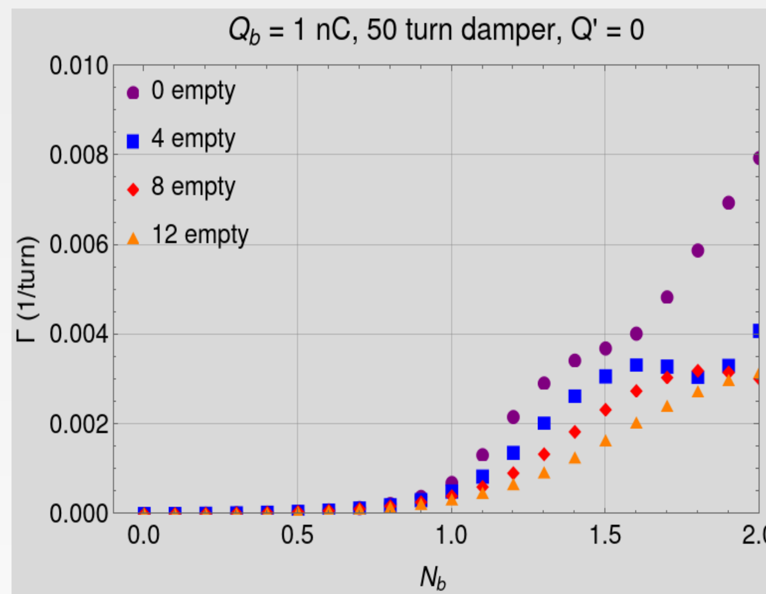
V3, σ_z = 11.4 mm,
"Flat", U ~ z^4

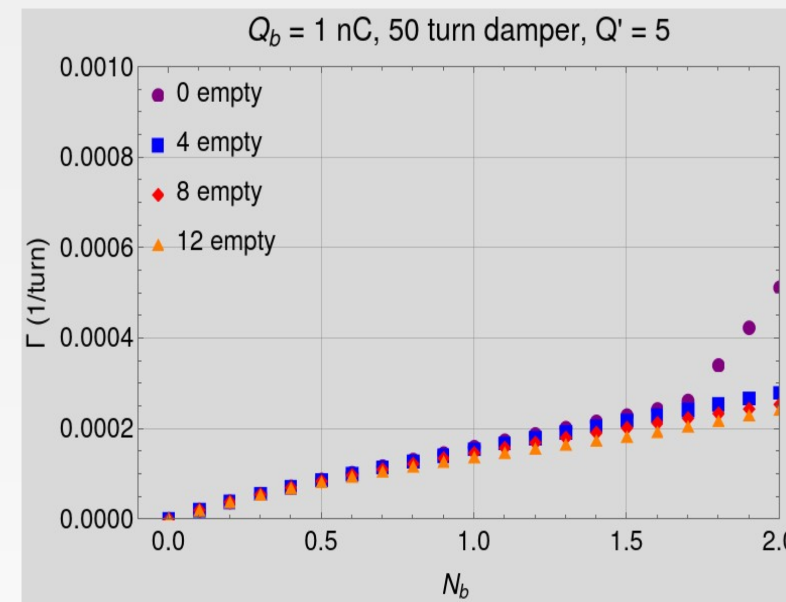


PETRA IV Case: 50-turn FB



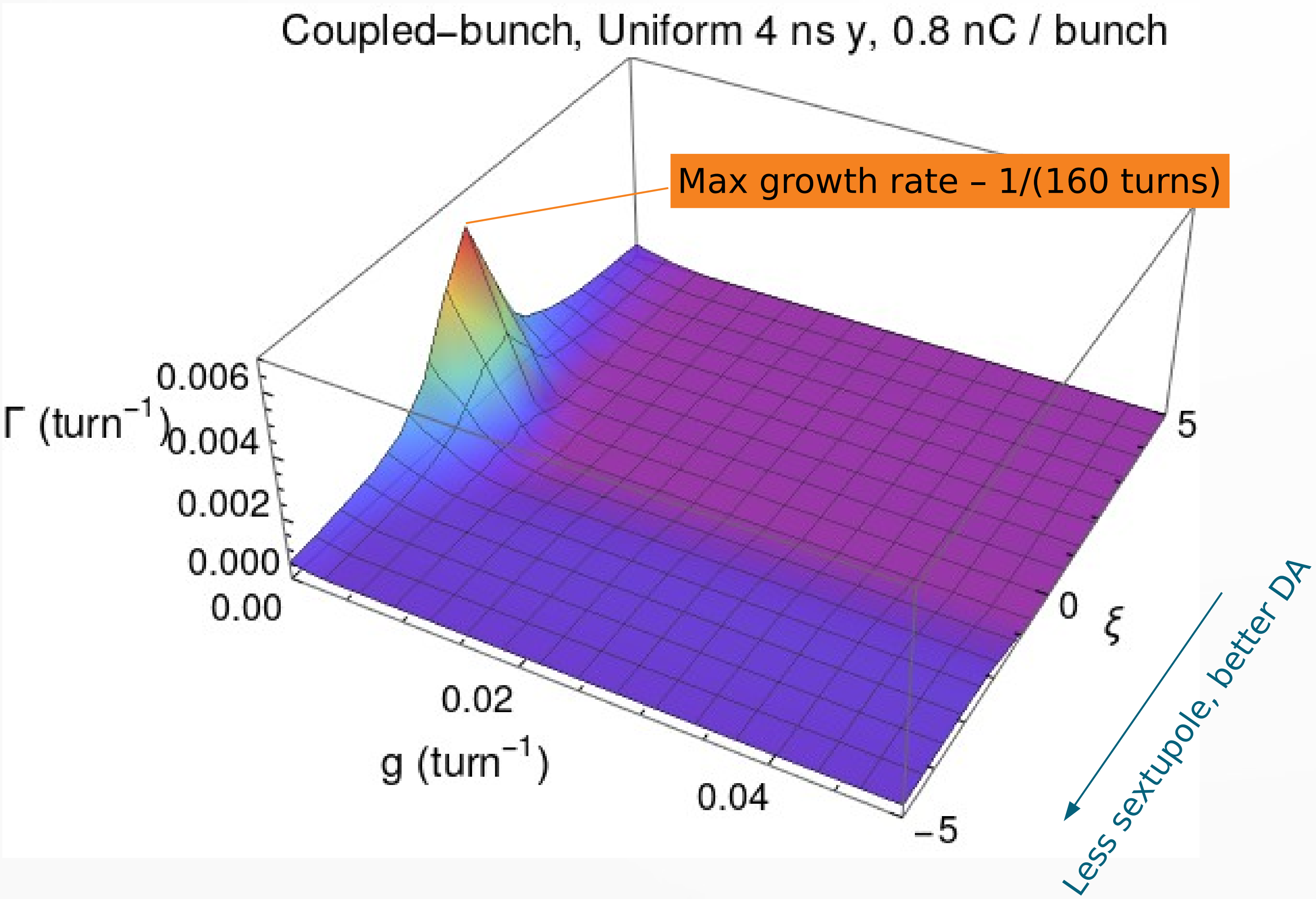






No significant difference for different fillings schemes with damper

Brightness mode with uniform 4ns filling: Vertical plane



S. Antipov, Transverse feedback is essential for the feasibility of the 200 mA Brightness mode

Bunch lengthening due to 3rd harmonic RF and impedance

- Tracking in ELEGANT
  - 10^5 macroparticles