Timing Constraints.

How timing issues constrain the ILC parameters

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Overview

- The two timing problems
- The Damping Ring harmonic problem
- The global timing problem

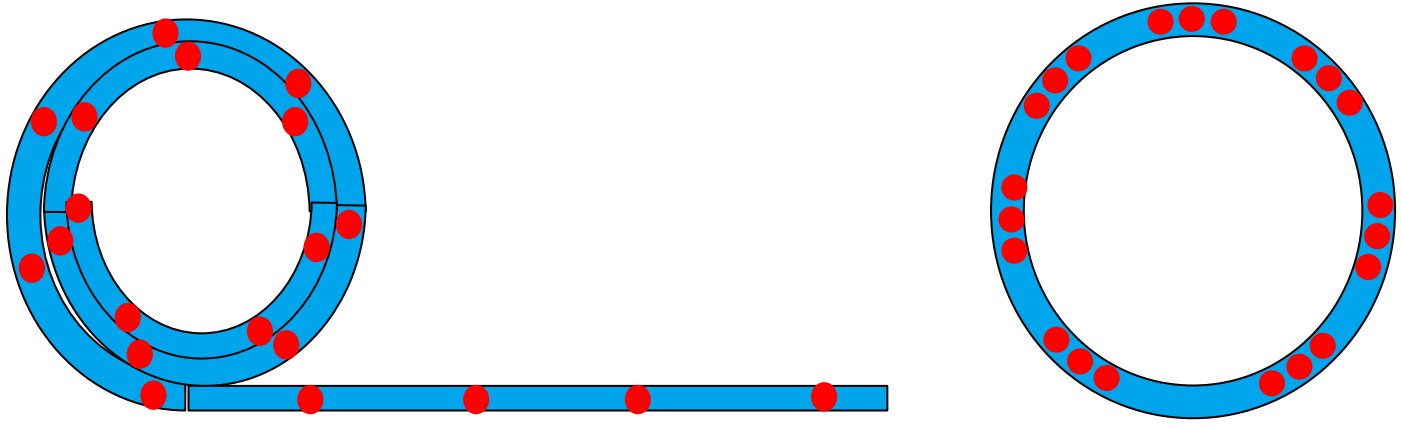
Two timing problems

- The “local” timing problem: How to fit a 300km long bunch train into a 3km damping ring
- Constrains the damping ring “harmonic number” (number of RF buckets) -> DR circumference
- Constrains also the bunch spacing in the Main Linac -> beam current -> RF power

- The “global” timing problem: Find an empty RF bucket in the DR for a new positron bunch
- Reason: Positrons are generated from main electron beam
- Constrains the ratio of (RTML+Main Linac+BDS)/DR to an integer number
- -> Constrains the Main Linac Length -> beam energy

The Damping Ring timing constraint

- Basic problem: Fit a 1ms bunch train of 300km length into a 3km damping ring
- Imagine a thread with beads, wound around a roll
- Each bunch has to have its own bucket
- Bunches have to have a >3ns separation (kicker rise time)
- Bunches have to form “minitrains” with 40ns gaps in between to allow clearing pulse for ion / electron clouds
- Minitrains should not be more than 50 bunches long



The formal constraints

- Bunches are ejected from back of DR trains: avoid disturbance of damped bunches by kicker field
- Bunch spacing in DR at least n_b=2 RF buckets at 650MHz (3ns): limited by kicker speed
- Gap size g between trains at least 25 buckets (40ns): needed for fast ion / electron cloud clearing
- ML bunch spacing is multiple of 4 or 6ML RF buckets: required by electron source subharmonic buncher
- DR trains must be at most 50 bunches long: from fast ion instabilities
- ML bunch spacing should be close to SB2009 value (tb=534ns), and RDR value (tb=356ns) should be viable for lumi upgrade: factor ~1.5 -> difficult!
- Pulse must be less than 700us / 1000us long for baseline / full power
- Current must be close to 6mA / 9mA for baseline / full power

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- ML bunch spacing is multiple of 4 or subharmonic buncher

Minimum for 2625 bunches:	
53 trains at 50 bunches x 2 buckets:	5300
+ 53 gaps at 25 buckets:	1325
Minimum size:	6625 buckets

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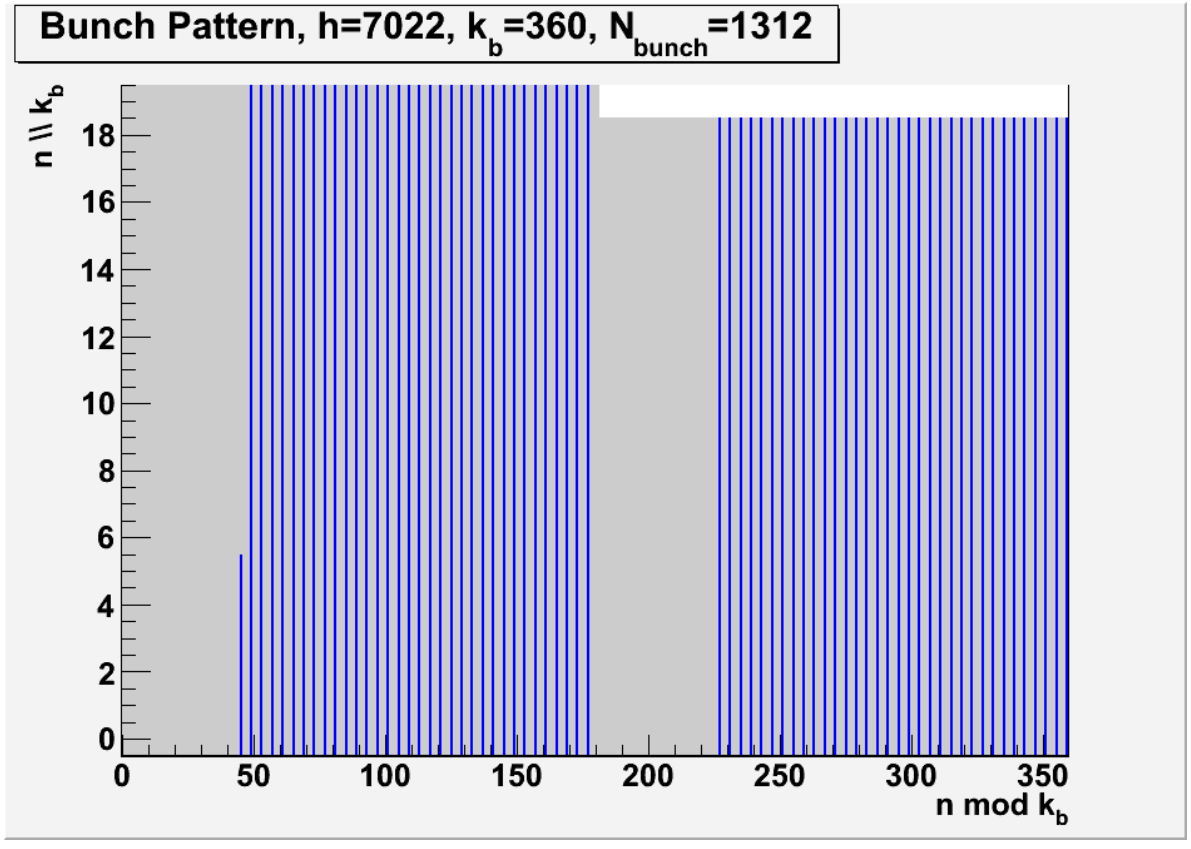
The baseline solution

DR harmonic number: h=7022
DR circumference: 3238.681m

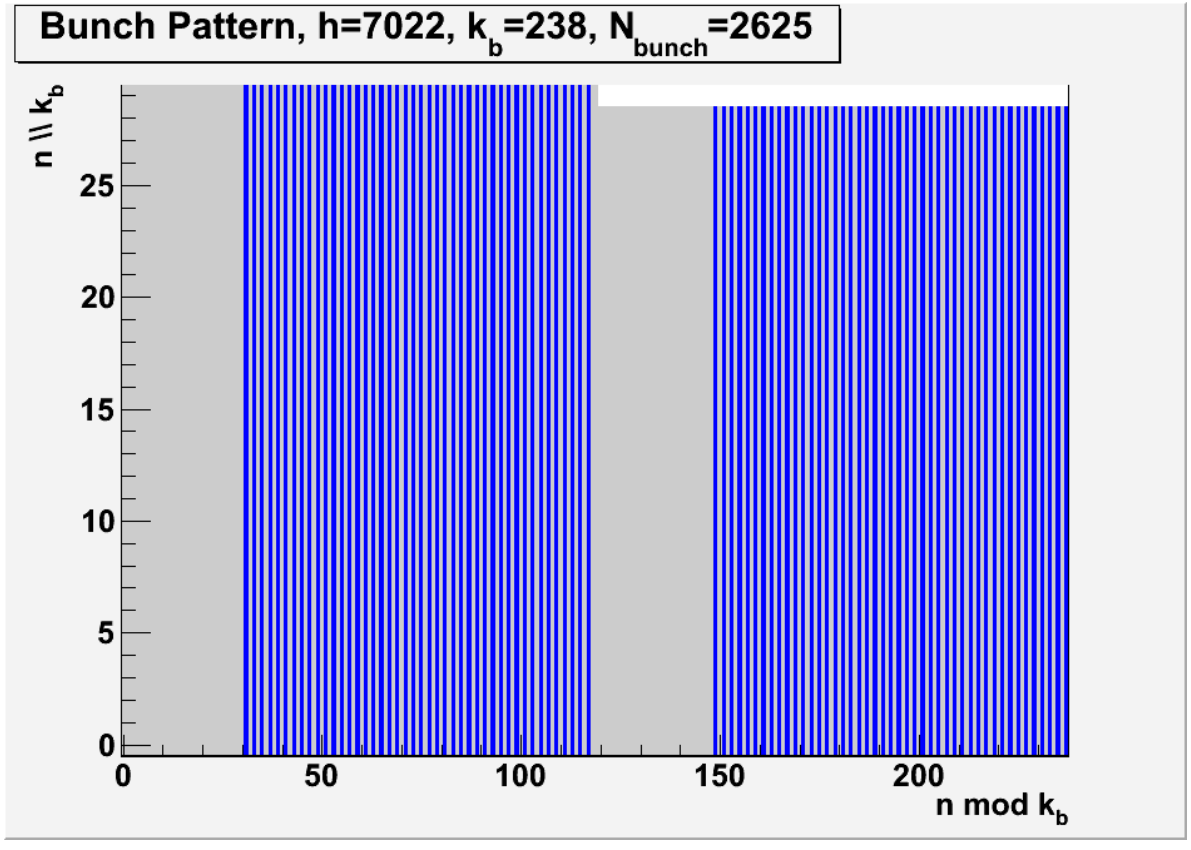
Parameter	Nominal	Lumi upgrade	Short
ML bunch spacing tb [ns]	554	366	277
- In DR RF buckets kb*	360	238	180
DR bunch spacing (e-/e+)*	4	2 / 4	2 / 4
Gap size*	45	31	45
Bunches per train	34	45 / 23	68 / 34
Total bunches	1312	2625 / 1312	2625 / 1312
Bunch charge [1E10]	2.0	2.0	1.74
ML Current [mA]	5.8	8.8	10.0

*: measured in DR RF buckets (650MHz)

Bunch Pattern, Baseline configuration



Bunch Pattern, full power



Some other solutions

		Baseline				Full Power			
Harmonic number h	Circumf. (m)	DR bucket spacing kb	ML bunch spacing (ns)	ML current (mA)	Max bunches	DR bucket spacing kb	ML bunch spacing (ns)	ML current (mA)	Max bunches
7022	**3238.7**	**360**	**553.8**	**5.79**	**1263**	**238**	**366.2**	**8.75**	**2731**
7126	3286.6	380	584.6	5.48	1197	250	384.6	8.33	2600
7240	3339.2	356	547.7	5.85	1278	254	390.8	8.20	2559
7372	3400.1	364	560.0	5.72	1250	234	360.0	8.90	2777
7382	3404.7	360	553.8	5.79	1263	242	372.3	8.61	2685
7498	3458.2	346	532.3	6.02	1315	238	366.2	8.75	2731
7606	3508.0	374	575.4	5.57	1216	234	360.0	8.90	2777
						248	381.5	8.40	2620
7736	3568.0	340	523.1	6.13	1338	238	366.2	8.75	2731
		364	560.0	5.72	1250				
7906	3646.4	340	523.1	6.13	1338	242	372.3	8.61	2685
		372	572.3	5.60	1223				
8005	3692.1	368	566.2	5.66	1236	232	356.9	8.98	2801
8102	3736.8	360	553.8	5.79	1263	248	381.5	8.40	2620
8108	3739.6	380	584.6	5.48	1197	242	372.3	8.61	2685
8126	3747.9	366	563.1	5.69	1243	250	384.6	8.33	2600
8148	3758.0	376	578.5	5.54	1210	242	372.3	8.61	2685
8172	3769.1	380	584.6	5.48	1197	238	366.2	8.75	2731
8182	3773.7	362	556.9	5.75	1256	236	363.1	8.83	2754
8191	3777.8	360	553.8	5.79	1263	252	387.7	8.27	2579
8237	3799.1	366	563.1	5.69	1243	232	356.9	8.98	2801
8308	3831.8	352	541.5	5.92	1292	234	360.0	8.90	2777
		356	547.7	5.85	1278				
8378	3864.1	358	550.8	5.82	1270	244	375.4	8.54	2663

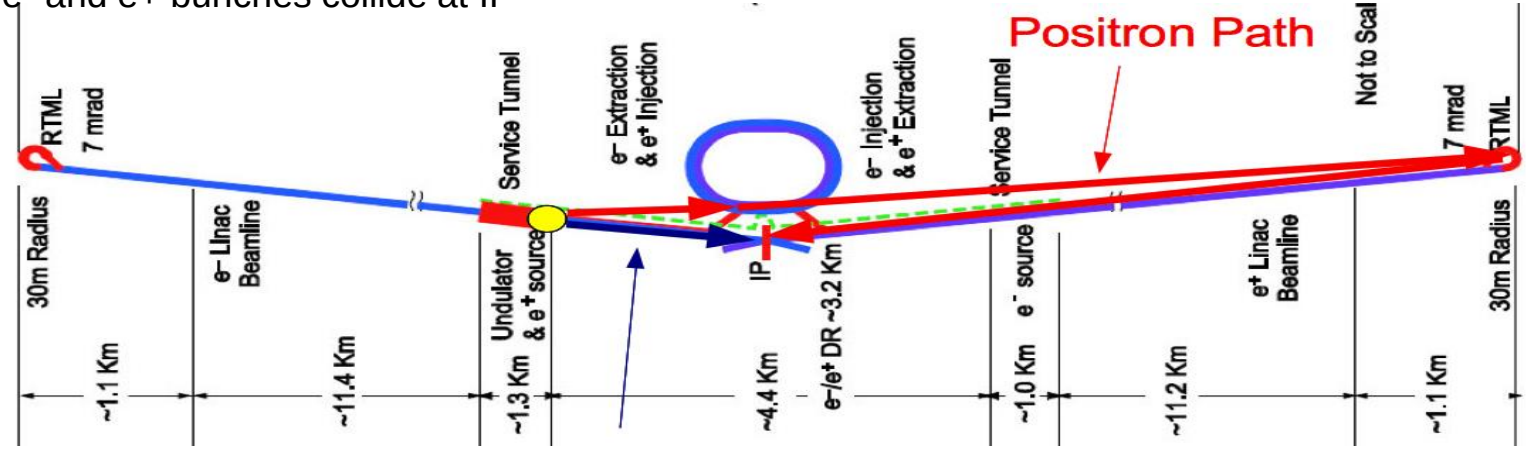
Consequence of an increased bunch spacing

- Nominal bunch spacing: 554ns -> 5.8mA at 3.2nC bunch charge
- Increase bunch spacing by 5%:
- -> current down by 5%, RF power down by 5%
  -> moreRF margin (e.g. for higher gradient)
- Bunches in 700us pulse: down by 5% -> lumi down by 5%
- Cavity fill time up by 5% -> need to reduce pulse time -> lumi further down
- 5% lumi loss can be compensated by increase of 2.5% bunch charge increase

- Changing the bunch spacing by more than 1-2% reduces luminosity

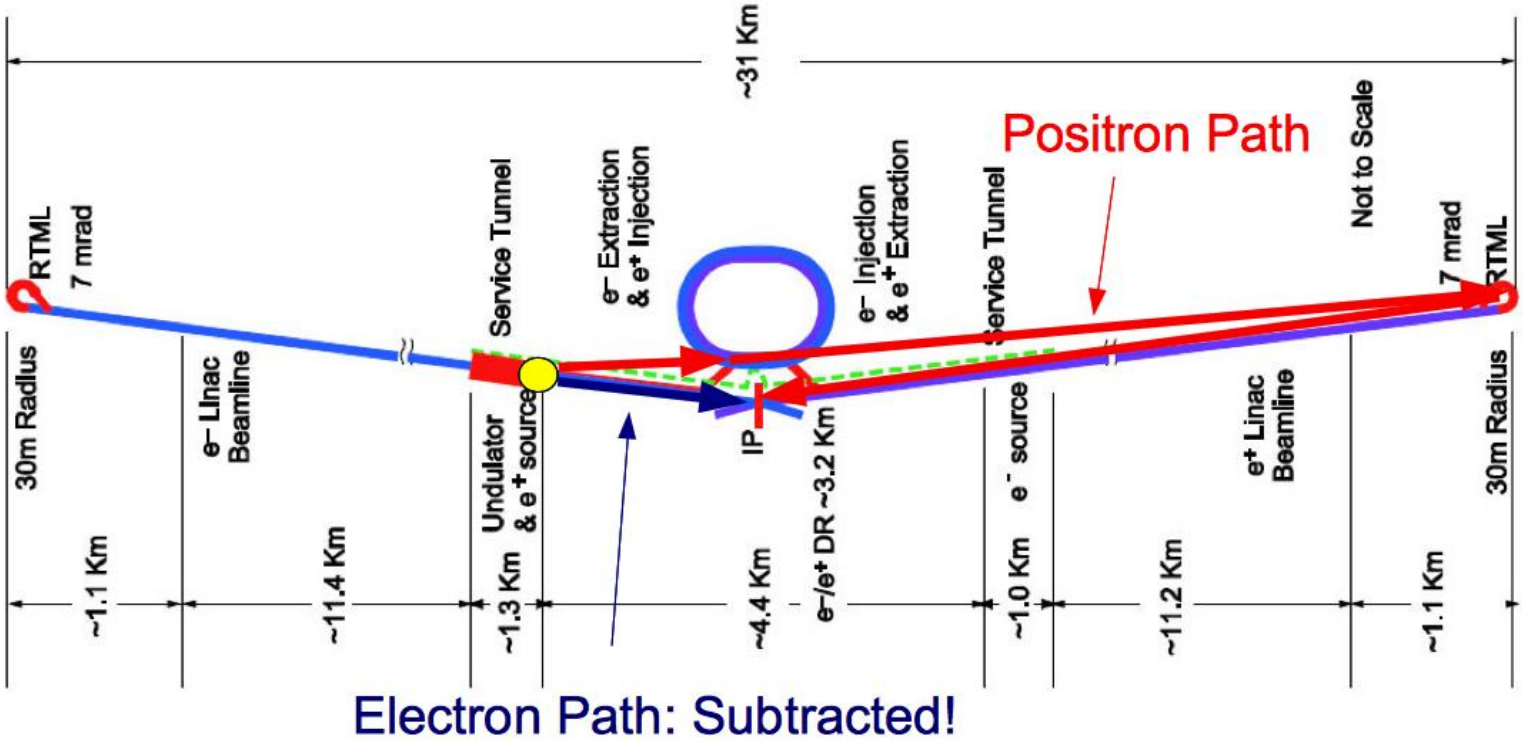
The Global timing constraint

- Positron bunches are produced from their “partner” electron bunches
- -> new positron bunches are injected into DR while old (damped) positrons are still in
- Simplest solution: each e+ bunch goes into exactly the same bucket that was occupied by colliding e+ bunch
  - e+ bunch is ejected from DR, travels down RTML and Main Linac, while
  - empty bucket left by e+ bunch rotates around DR several times
  - Partner e- bunch creates new e+ bunch
  - e+ arrives exactly at DR in time to fill rotating void bucket, while
  - e- and e+ bunches collide at IP



The numerical condition

- Length (DR ejection -> IP) – length (target -> IP) + length (target -> DR injection) = n * DR circumference
- For a given DR circumference:
  ML length is quantized by ½ DR circumference (~1.5km: 35GeV)



The calculation for the TDR baseline design (Asian site)

Undulator Photon Transport UPT (BEGEDOGL -> PTARGET)	372.0		
Positron to DR injection PTARGET -> MPDRINJ	2232.4		
INJ straight	89.3		
Photons/positrons to z=0		**2693.7**	
Electron dogleg EDOGL (BEGDOGL -> TPS2BDS)	-423.6		
Electron BDS to IP	-2253.5		
Electrons to z=0, i.e. IP		**-2677.1**	
Difference Positrons-Electrons to z=0:			**16.6**
Positrons to DR extraction	107.9		
Positron RTML (DKS version)	15993.0		
ML length (DKS)	11071.7		
Positron BDS to IP	2252.6		
Positron Path			**29425.2**
Total Sum			29441.8
9 / 10*DR circumference	3238.7	29148.1	32386.8
Mismatch		**-293.6**	**2945.0**

What needs to be changed

- Reduce ML and/or BDS length by 147m
  (can probably be done in BDS)
- Or increase ML length by 1473m:
  room for 12 more cryostrings a 2.54GeV / 116m: 250 -> 280.5 GeV beam energy
- Or change DR circumference -> Try different viable DR circumferences

Possible Solutions

h	Circumference (m)	n	N*circumference (m)	Mismatch (m)	Beam energy (GeV)	CM energy (GeV)
7022	3238.7	**9**	**29148.1**	**-293.6**	244.9	489.8
7906	3646.4	8	29171.2	-270.6	244.9	489.8
8005	3692.1	8	29536.5	94.7	250.0	500.0
7126	3286.6	9	29579.8	138.1	250.0	500.0
8102	3736.8	8	29894.4	452.6	252.5	505.1
8108	3739.6	8	29916.5	474.8	255.1	510.2
8126	3747.9	8	29982.9	541.2	255.1	510.2
7240	3339.2	9	30053.0	611.3	255.1	510.2
8148	3758.0	8	30064.1	622.3	255.1	510.2
8172	3769.1	8	30152.7	710.9	257.6	515.2
8182	3773.7	8	30189.6	747.8	257.6	515.2
8191	3777.8	8	30222.8	781.0	257.6	515.2
8237	3799.1	8	30392.5	950.7	260.2	520.3
7372	3400.1	9	30601.0	1159.2	260.2	520.3
7382	3404.7	9	30642.5	1200.7	262.7	525.4
8308	3831.8	8	30654.5	1212.7	262.7	525.4
8378	3864.1	8	30912.8	1471.0	265.2	530.5
7498	3458.2	9	31124.0	1682.2	267.8	535.6
7606	3508.0	9	31572.3	2130.5	272.9	545.7
7736	3568.0	9	32111.9	2670.2	277.9	555.9
7022	**3238.7**	**10**	**32386.8**	**2945.0**	280.5	561.0

Conclusion

- A number of possible DR harmonic numbers / circumferences exist, with different tradeoffs -> needs more checking
- Solutions for ML length exist with a few 100m spacing

- To fulfill global timing constraint requires change of ML length and/or DR circumference
- Many solutions are viable -> choose the required CM energy and energy reserve first, then fix DR and ML lengths