



DR Harmonic Number



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*Joint Session:
Sources and
Damping Rings
26.9.2011*

- Constraints
- Result



Harmonic Number: Introduction

- Bunch pattern in DR consists of trains, with gaps for clearing of fast ions and electron cloud
- Bunch spacing in ML (kb) and DR (nb) and DR harmonic number (h) are interrelated to get a viable DR fill pattern
 - it is not possible to pick a ML bunch spacing or the DR harmonic number at will
- → **The choice of the DR harmonic number constrains / fixes the ML bunch spacing**
 - Consequences for global ILC layout
- Viable solutions are limited

- [1] H. Ehrlichmann et al., “Recommendations for ILC configuration satisfying timing constraints,” unpublished report (2006).
DESY EDMS ID: D00000000829945
- [2] H. Ehrlichmann, “Bunch timing aspects for the ILC,” DESY-M-06-01 (2006).
DESY EDMS ID: D00000000951925
- [3] G. Penn, “Timing issues for the ILC damping rings,” unpublished report (2007).
DESY EDMS ID: D00000000951965
- [4] B. List, „Harmonic number for the ILC Damping Rings“, unpublished report (2011).
DESY EDMS ID: D00000000960865



Constraints Considered in Optimization

- Bunches are ejected from back of DR minitrains:
avoid disturbance of damped bunches by kicker field
- Bunch spacing in DR at least $n_b=2$ RF buckets (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 ~~24~~ ^{4 or 6} ML RF buckets:
required by electron source subharmonic buncher
- DR trains must be at most 50 bunches long:
from fast ion instabilities
- DR must accomodate ML bunch spacings for SB2009
baseline and full power upgrade timing

~~hard!~~



The Electron Source Constraint

- G. Penn [3] mentions that subharmonic buncher needs ML bunch spacing to be multiple of 24 RF buckets.
- This is really hard
- John Sheppard: ES operates at 6th harmonic, 4th harmonic is feasible → relaxes constraint considerably
- Assumption: ES produces bunches with the same spacing as used in ML

CONSTRAINTS

The main constraints required for proper timing of bunches are given in Ref. [3], and are summarized below. A newly considered constraint not included in this document is imposed by the subharmonic buncher of the electron source. This works best when the ratio of bunch spacing to the linac RF period is divisible by powers of 2 and 3. One factor of two arises automatically because the linac RF period is half of the damping ring RF period. The nominal constraint is that this ratio must be divisible by 24, although additional factors of 3 would be desirable. This report will



Nominal ML Bunch Spacings

- SB2009:
 - **tb = 712ns (kb = 463) for DRFS RF scheme**
 - **tb = 534ns (kb = 347) for KCS RF scheme**
 - **tb = 356ns (kb = 231.5) for full power (FP) upgrade**
- None of these values are viable for electron source, slight adjustment is needed.
- ML bunch spacing may have to change by ~2-3 %
- Upgradeability: Need to run at least at 2 bunch spacings:
 - **either DRFS + FP (trivial, because of factor 2)**
 - **or KCS + FP (hard because of factor 1.5)**
- General observation: A ring that can run in KCS and FP configuration also works for DRFS
- → Search for harmonic numbers that fit for all three spacings
- If only DRFS is considered, more harmonic numbers are viable

One ~~Three~~ Solutions

- Solution 1: $h=7022$, circumference 3239m
 - + – Only solution with 4 buckets bunch spacing for KCS
 - – ML bunch spacings get longer by 3-4%
→ 4% longer RF pulses or 2% bunch charge increase or 4% loss of lumi
 - – Electron Source RF has to operate at 4th harmonic (325MHz)
- Solution 2: $h=7077$, circumference 3264m
 - + – ML bunch spacing within 0.3% of SB2009 values
 - – for KCS, DR bunch spacing is 3, not 4 RF buckets
→ not possible as baseline right now (M. Palmer)
 - – ES at 4th harmonic
- Solution 3: $h = 7081$, circumference 3266m
 - + – ES runs at 6th harmonic
 - – KCS bunch spacing is 3
 - – ML bunch spacings increased by 3-4%



Solution 1

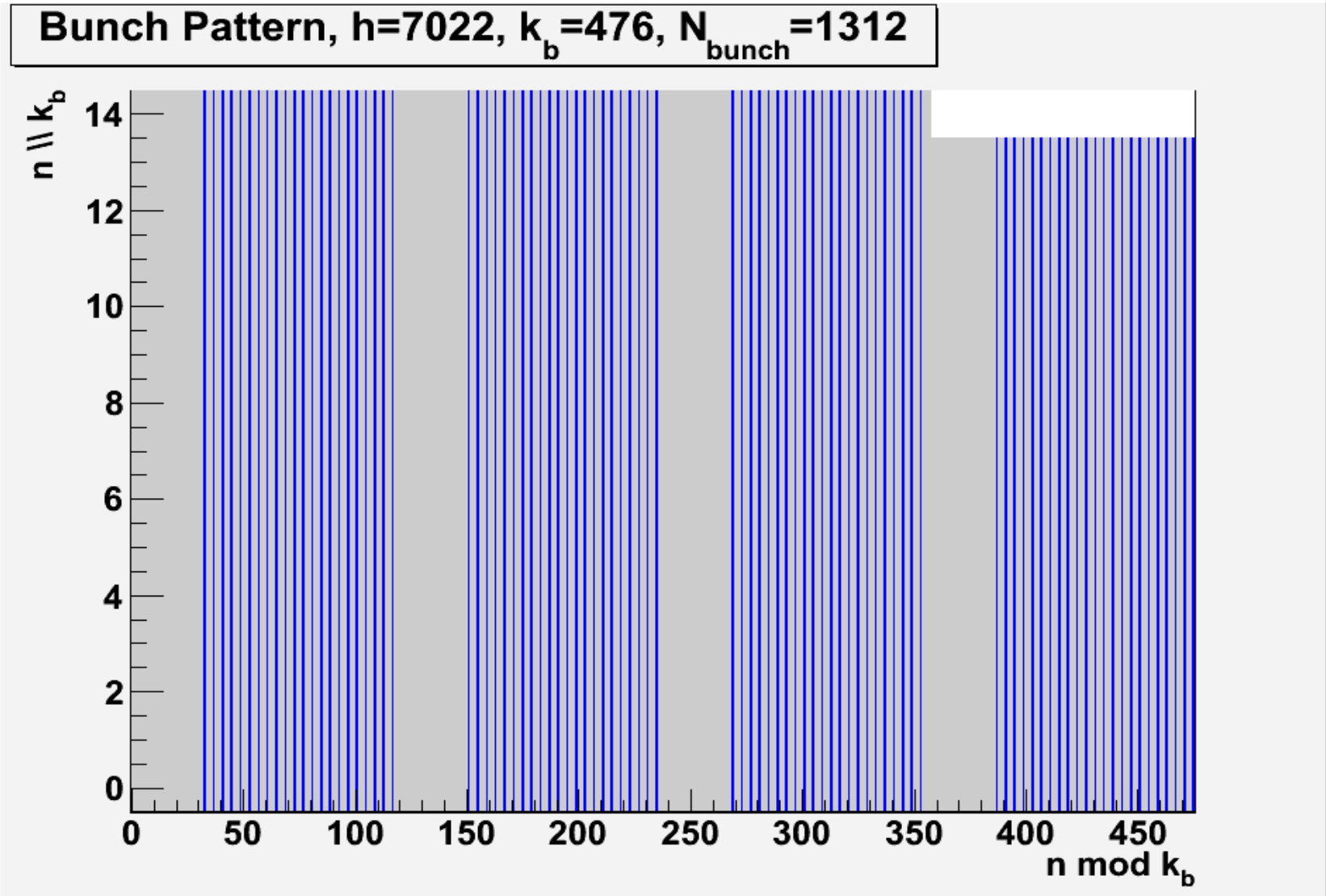
- Increased ML pulse length
- ES RF needs to operate on 4th harmonic (325 MHz)
- All DR criteria (bunch spacing, gap sizes, train lengths) OK

h: Harmonic number in DR RF buckets
 kb: ML bunch spacing in DR RF buckets
 nb: DR Bunch spacing in DR RF buckets
 g: Gap size in DR RF buckets
 nt: Filled bunches per DR train
 Nt: Number of trains in DR
 Qb: Single bunch charge
 tb: ML bunch spacing
 IML: ML current in pulse
 tpulse: ML pulse length

type	h	k_b	N_{bunch}	n_b	g	n_t	N_t	Q_b [$10^{10}e$]	t_b [ns]	I_{ML} [mA]	t_{pulse} [μs]
SB2009 nominal values								$c = 3248 \text{ m}$			
DRFS	7042	463	1312	–	–	–	–	2.00	712	4.5	935
KCS	7042	347	1312	–	–	–	–	2.00	534	6.0	700
FP(e^-)	7042	231.5	2625	–	–	–	–	2.00	356	9.0	935
FP(e^+)	7042	231.5	1312	–	–	–	–	2.00	356	9.0	935
Solution 1								$c = 3238.68/3239.14 \text{ m}$			
DRFS	7022	476	1312	4	33	23	59	2.00	732	4.4	961
KCS	7022	360	1312	4	45	34	39	2.00	554	5.8	727
FP(e^-)	7022	238	2625	2	31	45	59	2.00	366	8.8	961
FP(e^+)	7022	238	1312	4	75	23	59	2.00	366	8.8	961
FP(e^+)	7022	238	1312	4	32	23	59	2.00	366	8.8	961



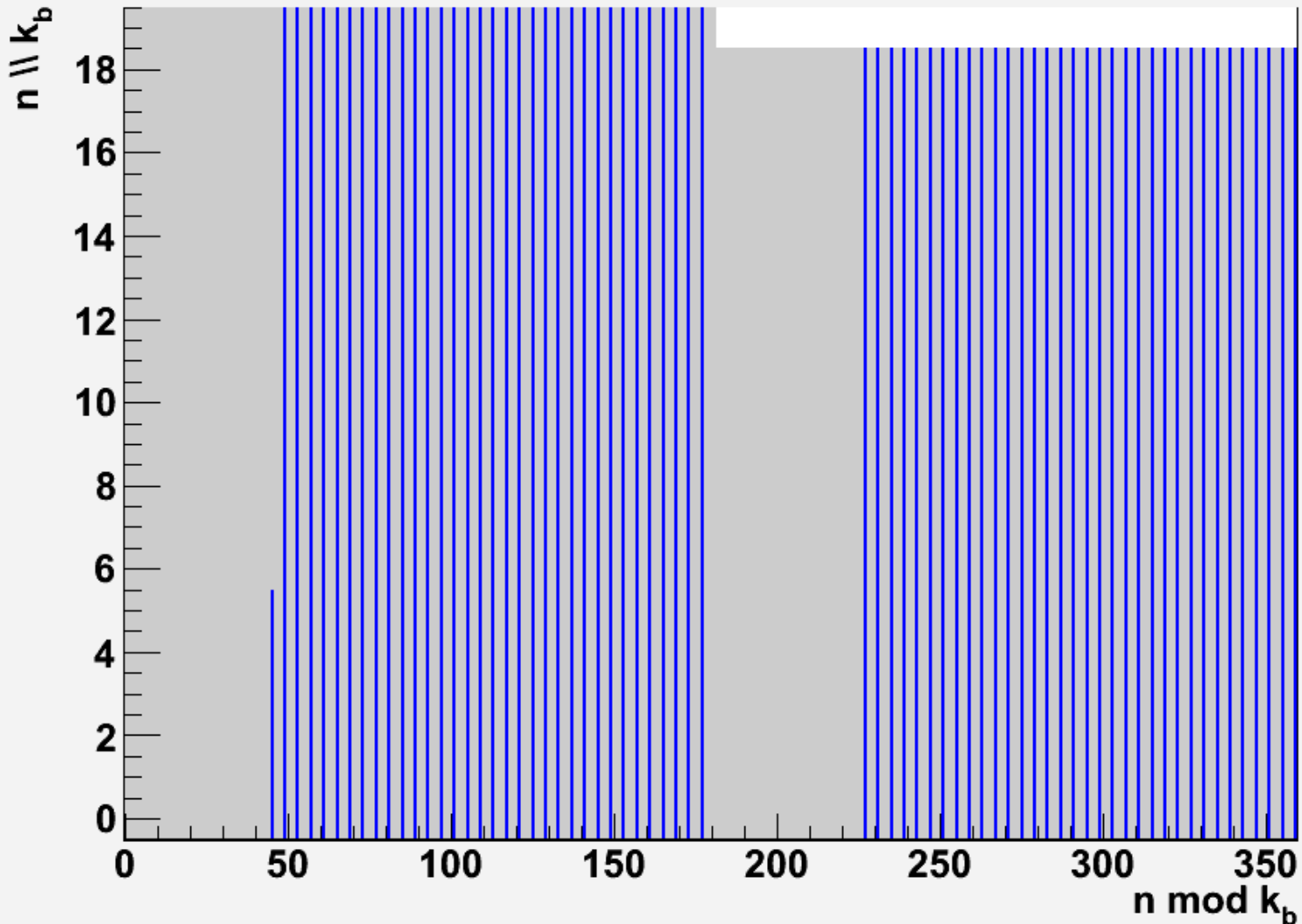
Bunch Pattern DRFS





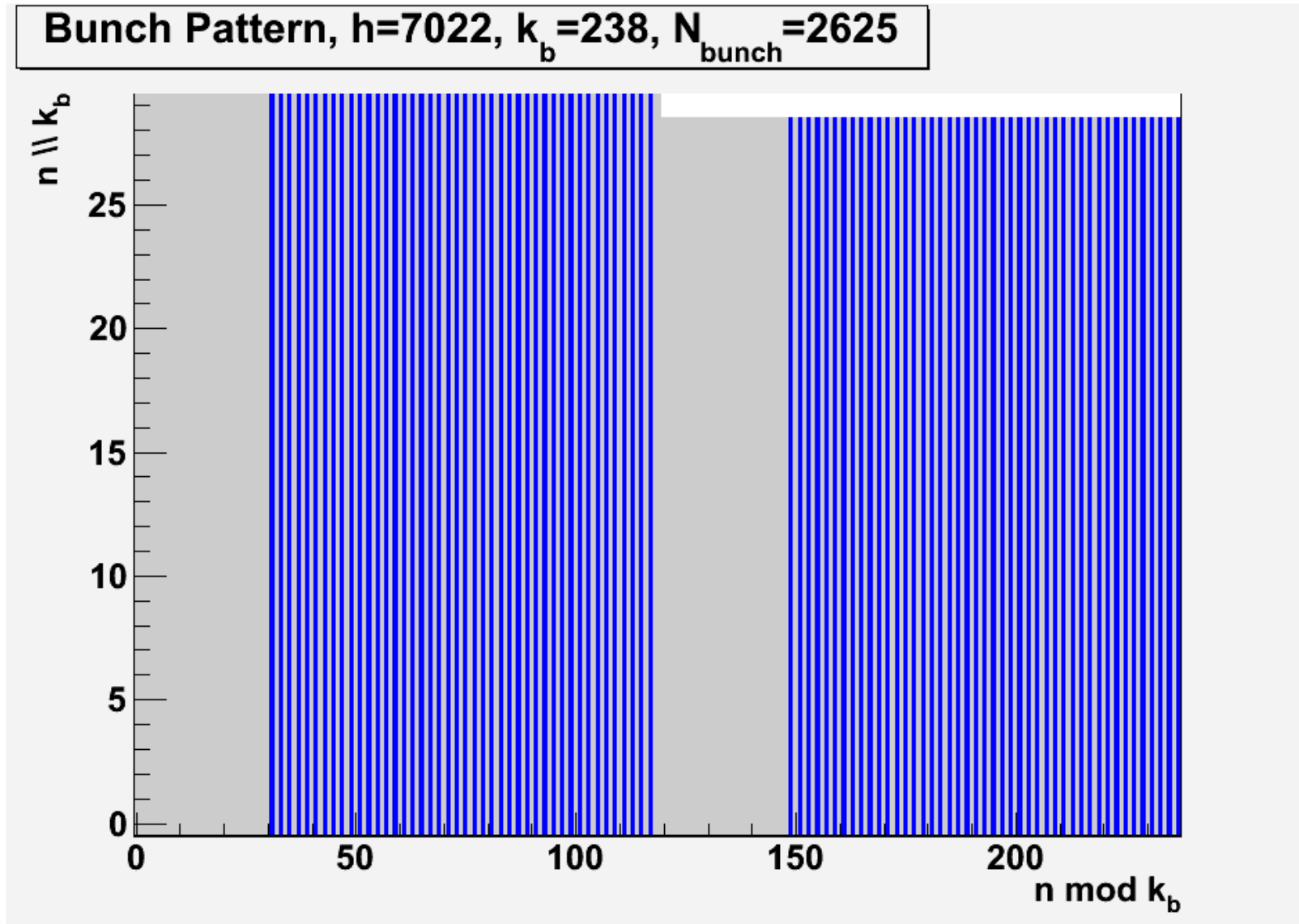
Bunch Pattern KCS

Bunch Pattern, $h=7022$, $k_b=360$, $N_{\text{bunch}}=1312$



Bunch Pattern e-, Full Power

Bunch Pattern, $h=7022$, $k_b=238$, $N_{\text{bunch}}=2625$



Bunch Pattern e+, FP

- Same as for e- Ring, but:
- 28/29 consecutive bunches extracted from Ring 1, then from Ring 2
- Result: 4 instead of 2 buckets bunch spacing in positron ring, ~ half the number of bunches per ring
- Requires 44 switches between rings 1 and 2 within a 1ms bunch train, switching time is 366ns

Mitigation of increased t_b

ML current: $I_{ML} = Q_b / t_b$

Lumi: $L \sim Q_b^2 * N_{bunch}$

ML pulse length: $T_{pulse} = t_b * N_{bunch}$

- A change of +4% in t_b means
 - N_{bunch} down by 4%, Lumi down by 4%, I_{ML} down by 4%
 - T_{pulse} up by 4%, I_{ML} down by 4%
 - N_{bunch} down by 4%, Q_b up by 2%, I_{ML} down by 2%
 - N_{bunch} down by 2%, Q_b up by 1%, T_{pulse} up by 2%, I_{ML} down by 3%
 - or any middle ground
- A slight increase of t_b is more attractive than a reduction, because at least it saves RF power, so increased demands on pulse length and/or source pay some dividends



Solution 1a: fewer bunches

type	h	k_b	N_{bunch}	n_b	g	n_t	N_t	Q_b [$10^{10}e$]	t_b [ns]	I_{ML} [mA]	t_{pulse} [μs]
Solution 1								$c = 3238.68/3239.14 \text{ m}$			
DRFS	7022	476	1312	4	33	23	59	2.00	732	4.4	961
KCS	7022	360	1312	4	45	34	39	2.00	554	5.8	727
FP(e^-)	7022	238	2625	2	31	45	59	2.00	366	8.8	961
FP(e^+)	7022	238	1312	2	75	23	59	2.00	366	8.8	961
FP(e^+)	7023	238	1312	4	32	23	59	2.00	366	8.8	961
Solution 1a: fewer bunches, larger bunch charge											
DRFS	7022	476	1276	4	33	22	59	2.03	732	4.4	934
KCS	7022	360	1263	4	53	33	39	2.04	554	5.9	700
FP(e^-)	7022	238	2554	2	33	44	59	2.03	366	8.9	934
FP(e^+)	7022	238	1276	2	75	22	59	2.03	366	8.9	934
FP(e^+)	7023	238	1276	4	32	22	59	2.03	366	8.9	934

Conclusions

- Proposal to set DR harmonic number to $h=7022$ as baseline
- ML parameters need to be adjusted
- Needs Electron Source to run at 4th harmonic
- The KCS timing poses a real challenge to DR, if upgradeability to FP option is needed
- Final Remark: I have looked for bunch patterns that are close to the SB2009 parameters. The DR can accommodate many more bunch patterns for commissioning with larger bunch spacing in ML or DR, at reduced luminosity

Additional Material



Solution 4 (Getting Desperate)

- If $nb=4$ is mandatory for KCS,
- and ES needs to operate at 6th harmonic:
- $h=7606$ ($\text{circ}=3508\text{m}$) is the first solution
- Rather unusual: Has $nb=5$ for KCS
- t_b increased by 18.4% for KCS (IML=5.1mA!),
1.1% for DRFS / FP
- → makes KCS very „DRFS-like“,
needs big increase of pulse length
- DR circumference increased by 260m!

Solution 5

- If $nb=4$ is mandatory for KCS,
- and ES needs to operate at 6th harmonic:
- $h=7867$ (circ=3628m) is a first solution
- Rather unusual: Has $nb=5$ for KCS
- tb reduced by 7.5% for KCS (IML=6.5mA!),
1.5% for DRFS / FP
→ makes KCS more „FP-like“
- DR circumference increased by 380m!



Mitigation of reduced bunch distance

- ML current: $IML = Q_b / t_b$
- Lumi: $L \sim Q_b^2 * N_{bunch}$
- ML pulse length: $T_{pulse} = t_b * N_{bunch}$
- A change of -8% of t_b means:
 - **Q_b down by 8%, N_{bunch} up by 8%: Lumi down by 8%**
 - **Q_b down by 4%, N_{bunch} up by 8%: IML and IDR up by 4%**
 - **Q_b down by 8%, N_{bunch} up by 8%: T_{pulse} up by 8%**
 - **or any middle ground**
- Changes of t_b by more than minimal ~4% can cost serious money
- No matter what, one gets less lumi per buck



Circumference change by $\Delta h=1$

- Full power option means
 - 1 e- ring with 2625 bunches
 - and 2 e+ rings with 1312 bunches each
- Question: how are the bunches from the 2 e+ rings combined into a single train?
 - all bunches from ring 1, then all from ring 2
 - 1 DR revolution (~ 19 bunches) from ring 1, then 19 from ring 2