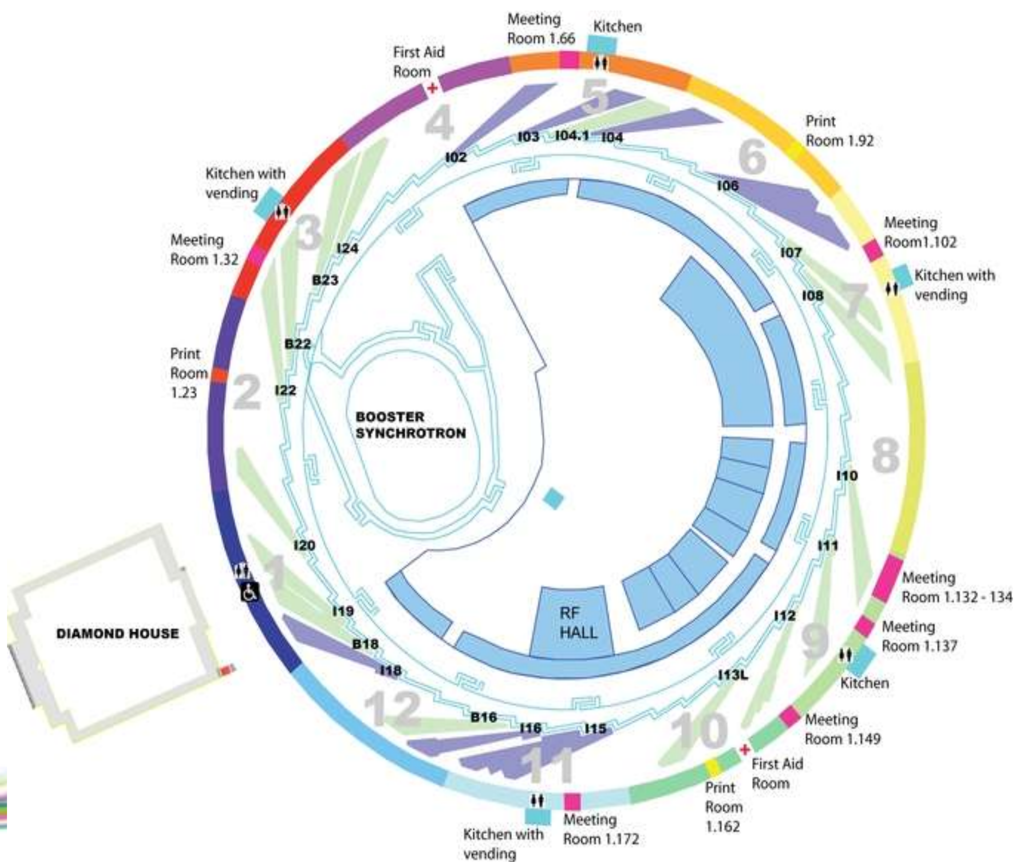
Review of the Diamond Light Source Timing System

Y. Chernousko, P. Hamadyk, M. T. Heron,
Diamond Light Source, United Kingdom

About Diamond



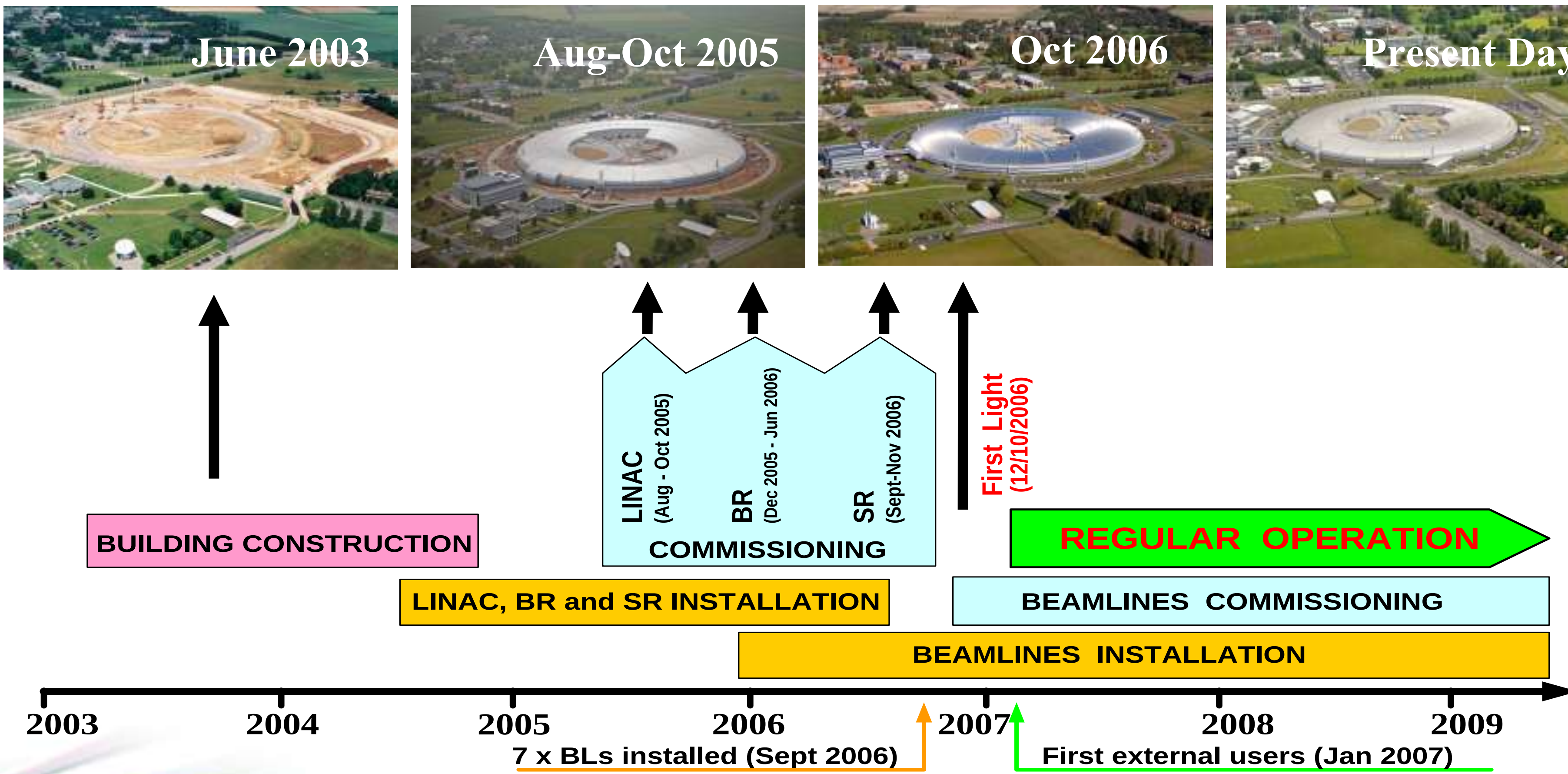
Diamond Light Source is a 3 GeV third-generation light source based on:

- **a storage ring (SR),**
- **a full-energy booster (BR),**
- **a 100 MeV pre-injector Linac**

Diamond key machine parameters

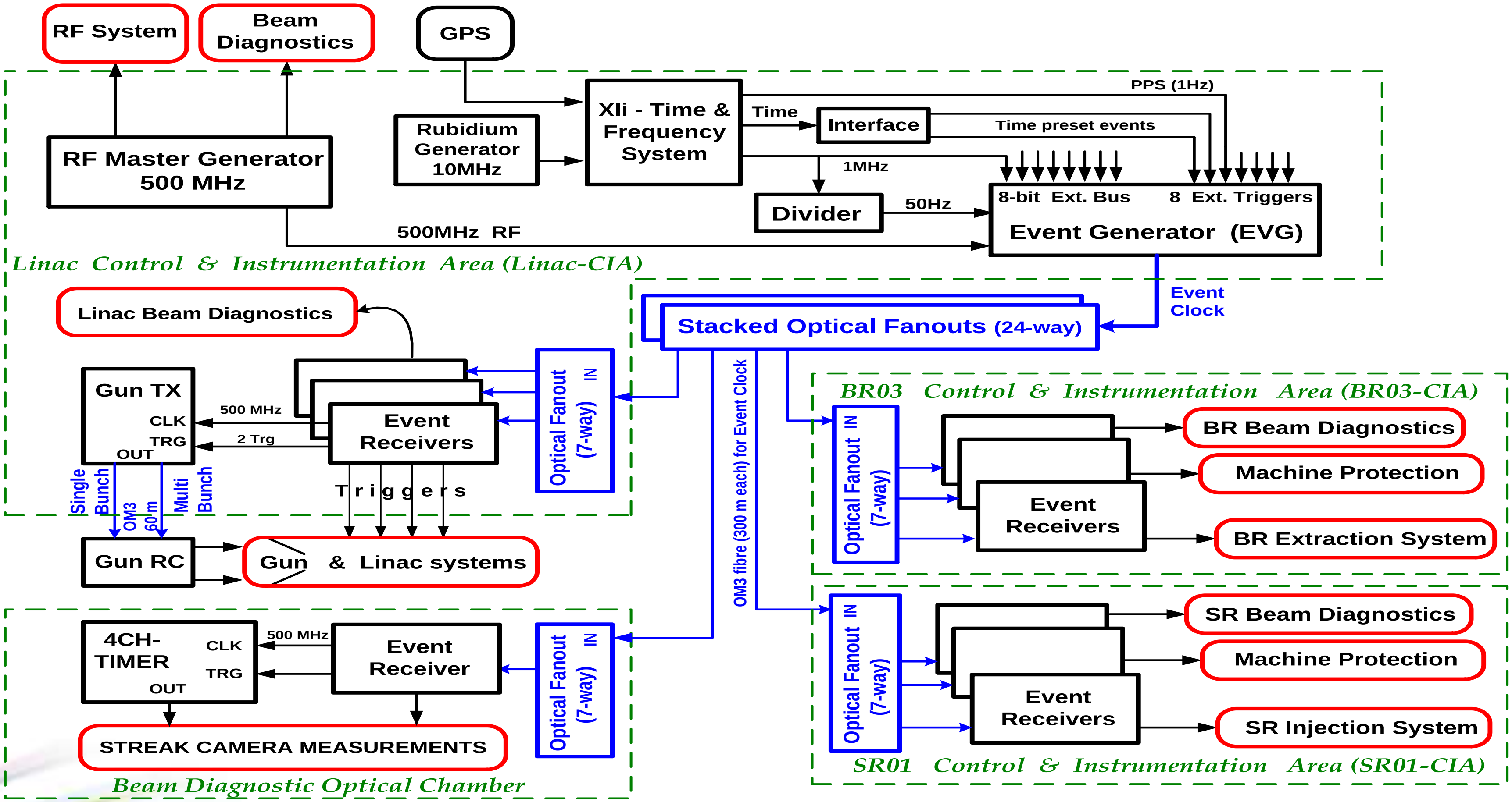
Electron Beam Energy	3 GeV
SR Circumference	561.6 m
Number of cells	24 double-bend achromatic
Insertion devices straights	4 x 8 m and 18 x 5 m
Electron beam current	300 mA (500 mA)
Beam life time	> 10 h
Beamline capacity	40 max
Number of Beamlines	22 BLs over the period 2007-2012 (3 are still in construction)

About Diamond (Milestones)



19/10/2007 – Official Opening

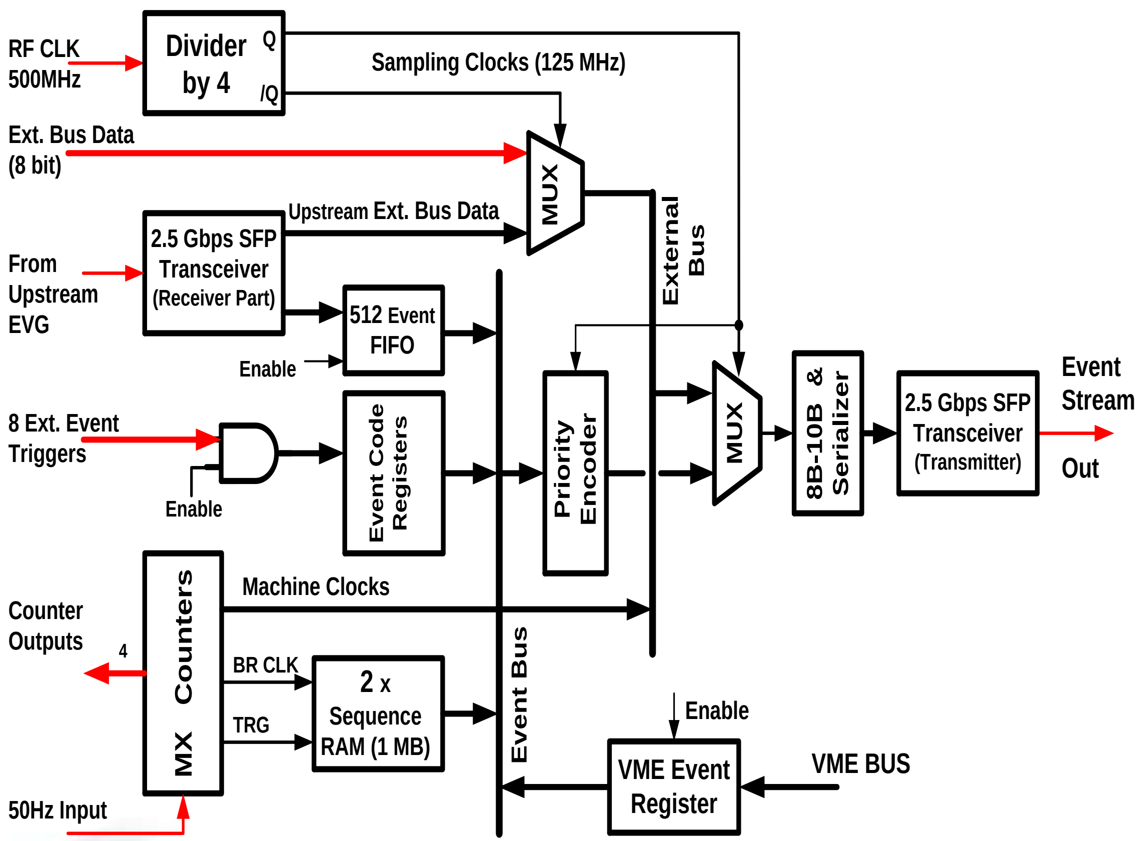
Diamond Timing System Structure



Main features of the System

- RF 500 MHz is a single time scale for providing synchronization with both accelerator cycles and their beam structures
- The same functional modules are used for both types of synchronization
- 500 MHz is recovered from the Event Clock at destination points
- Time stamping is provided for collected data and performed actions along accelerators and beamlines

Event Generator



Event clock format:
Event code byte
\+ External bus byte

Input-Output Ports:
Optical (SFP transceiver):
- Event stream: 125 M-Events/sec
- Bit rate: 2.5 Gbps

Electrical:
- RF 500 MHz Input (PECL)
- 50 Hz Input (TTL, cycle triggering)
- 8 External event triggers (TTL)
- 8 External bus inputs (TTL)
- 4 outputs from 6 x Counters

Event sources:
- 8 External triggers
- 2 Internal sequence RAMs (1MB)
- VME bus triggers
- Upstream EVG

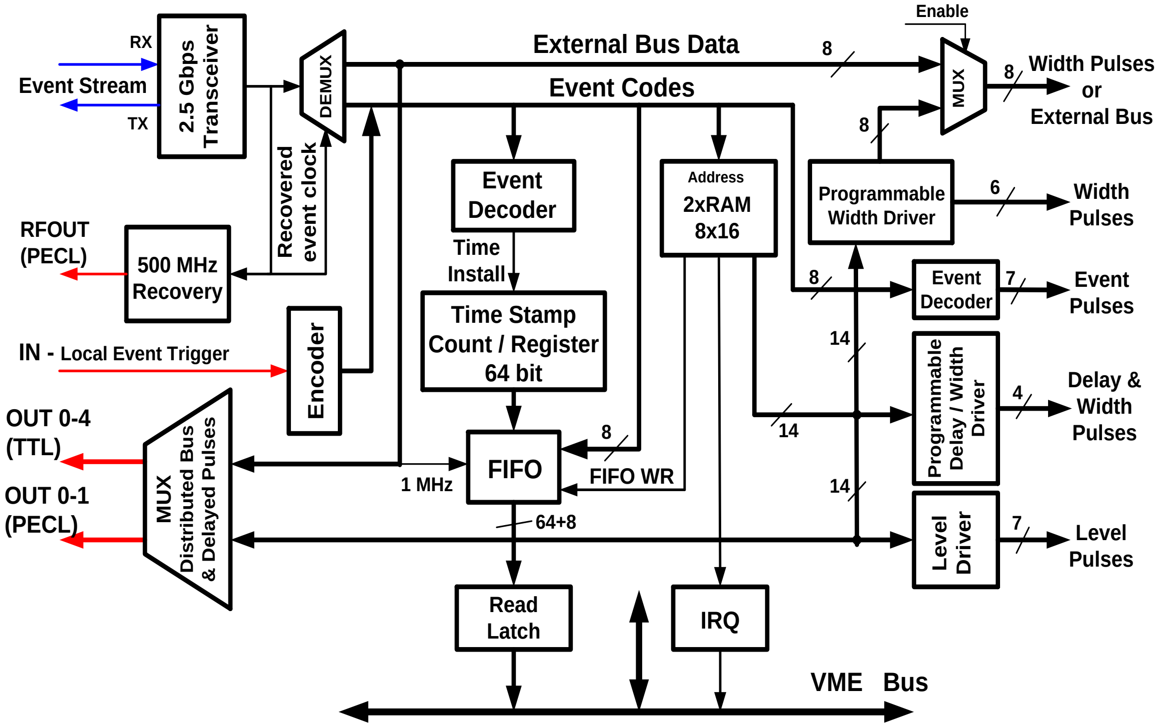
External bus sources:
- 8 External Inputs (TTL)
- 6 Internal from counters

Event clock is always synchronized to RF 500MHz!!!

Data transmitted in "event byte":
- 19 functional events (3 from external sources, 16 generated internally)
- 6 service events (basically for time stamping)

Data transmitted in "external bus byte":
- 1 MHz clock for time stamping (external)
- Machine clocks – BR-CLK, SR-CLK and COINC-CLK (internally generated by counters)

Event Receiver



EVR Functions:

- Retransmitting Event Clock (for cascading)
- Recovering 500 MHz clock
- Decoding and output of External bus bits to output ports
- Decoding Event byte and providing:
  - event pulses (8 ns)
  - delayed pulses
  - flip-flop signals (from 2 events)
  - system bus interrupts
  - time stamping
- Processing external local signal as an incoming event

Front panel connectors:

- 6 outputs for any signals on P2 connector
- 1 local “event” trigger
- RFOUT 500 MHz (PECL)

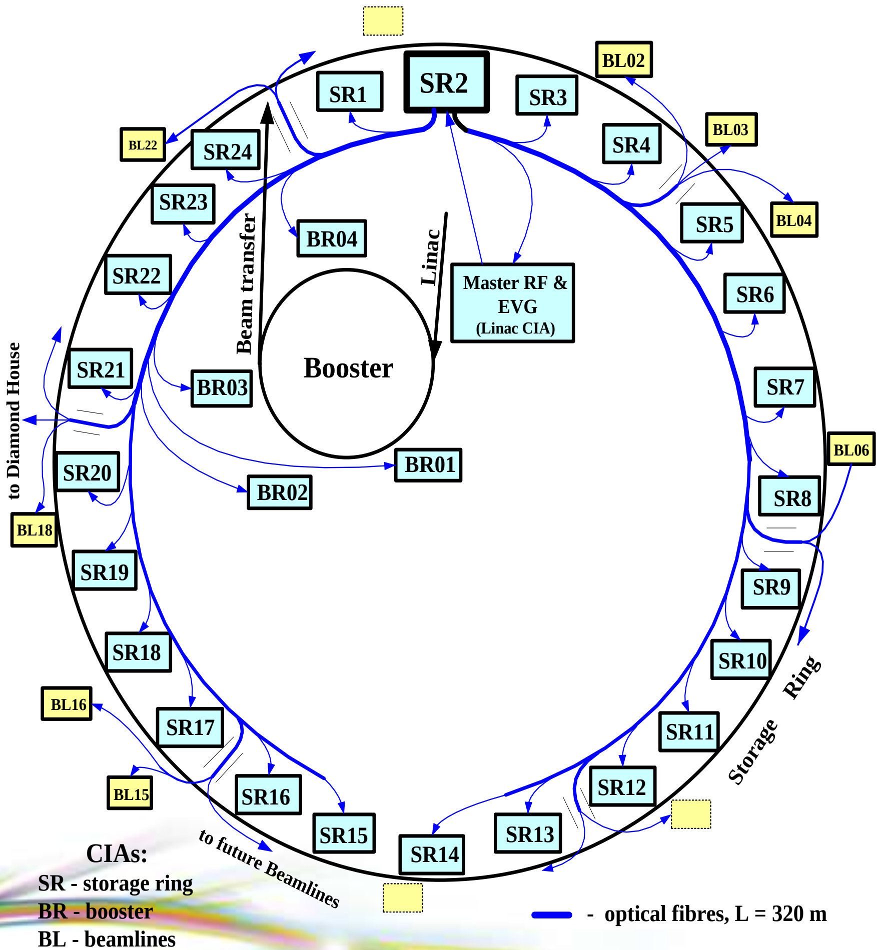
VME P2 connector ports:

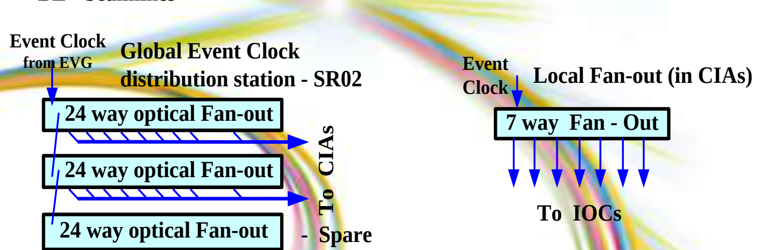
- 7 (EVNT) decoded events
- 18 delay-width modulated outputs
- 7 (LVL) outputs

Time parameters:

- 8 ns event message length
- 8 ns delay/width resolution for output pulses
- less than 8 ps RMS jitter of output pulses (PECL)
- 5 ps RMS jitter of restored RF 500 MHz (PECL)

Timing System Network

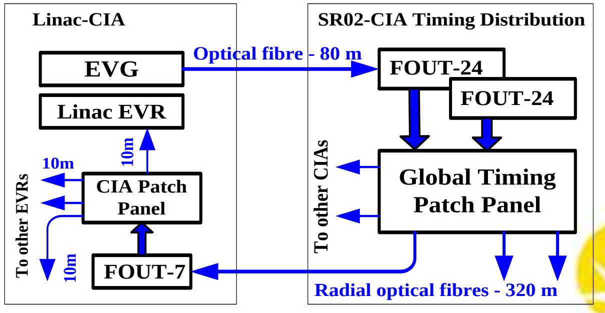




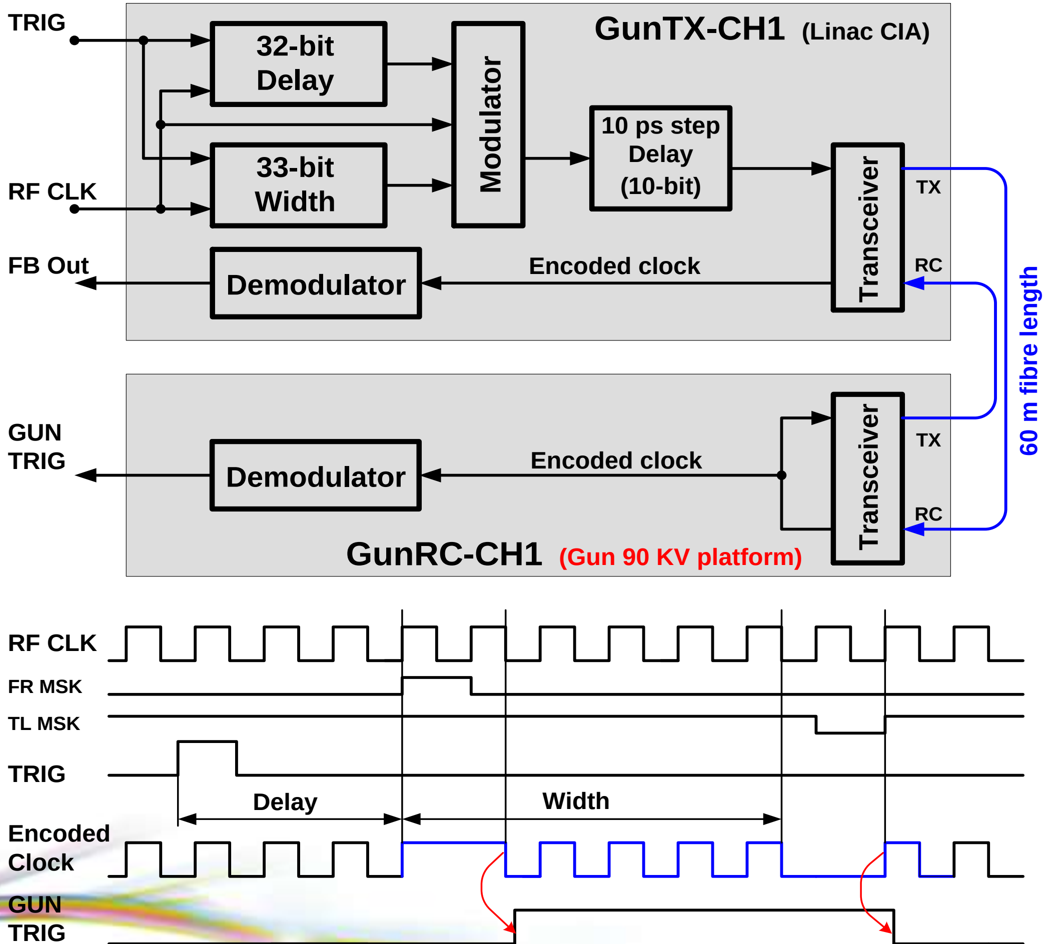
Network Features

1. Multi-star topology:
   - Global distribution layer (3x24-way fanout modules with fibres of equal length 320 m)
   - Local distribution layers in each CIAs (through 7-way fanout modules to IOCs)
2. Transmission media - OM3 MM fibre which provides 10 Gbps for 300 m length
3. Time error of decoding the same events in all CIAs is +/-1 ns (due to difference of fibre lengths +/- 20 cm).
4. System stability due to distribution network:
   - seasonal delay drift is within 25–30 ps
   - 24 h delay drift does not exceed 10 ps

   Temperature stability is a dominant factor
5. The timing system response time is ~2.4 us (2.1 us is time delay through network fibres)



Gun Driver Set



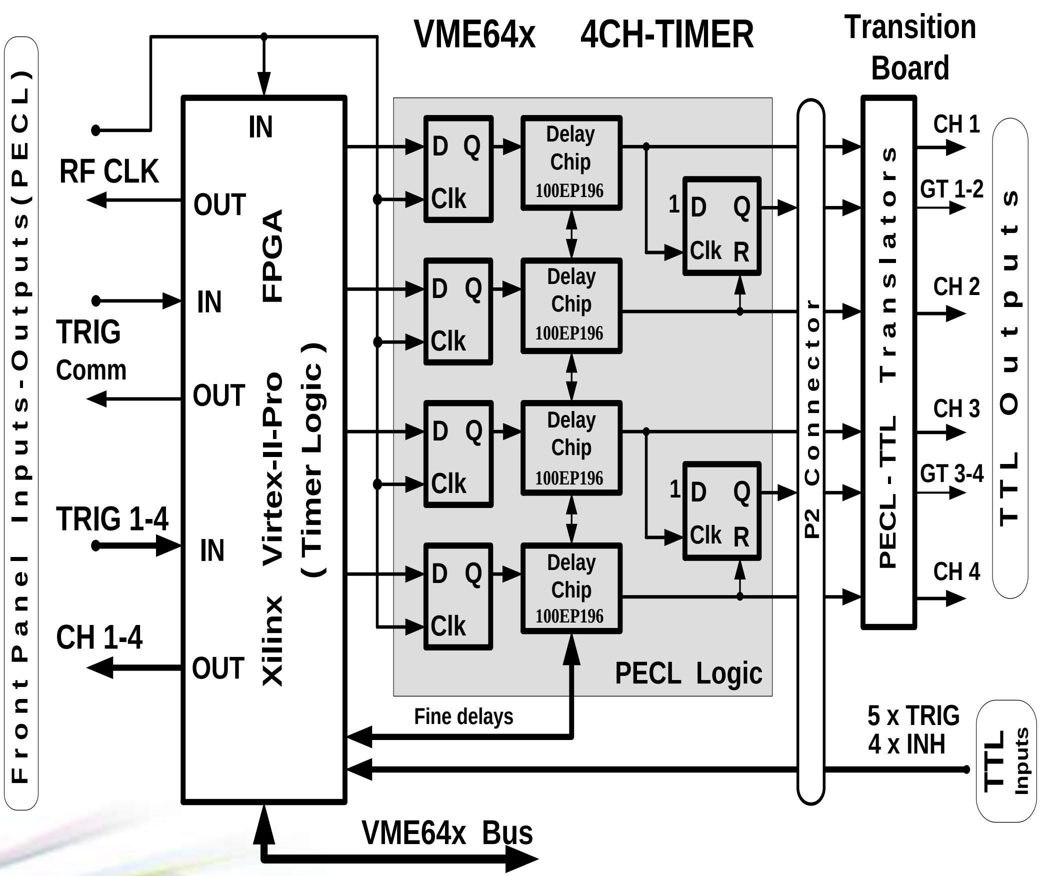
Features:

- Two modules - GunTX and GunRC
- Two channels for single and multi bunch injections which are triggred from an EVR system
- Connected by OM3 fibre with an encoded 500 MHz clock passed through it
- Method of coding - masking a pulse sequence in specific points by pulses of a one period length
- Delay & width pulse parameters are defined in GunTX
- GunRC recovers required Gun trigger pulse and returns it back to GunTX the encoded clock (for monitoring)

Time parameters:

- “Rough” resolution of 2 ns is provided for pulse delay in range of ~8.2 s
- “Fine” resolution in range of 10 ns is less then 10 ps
- Minimum pulse width time is 8 ns (4 periods of clock)
- RMS jitter of output trigger pulse (TTL) is 4 ps (in respect to RF clock 500MHz)

Four Channel Timer



Features:

- Four independent timer channels with programmable delay and pulse width
- Individual and common channel triggers
- Used for synchronization with SR RF structure every turn, every second turn and so on, i.e. it works like divider of trigger clocks
- FPGA and PECL technology used (for increasing precision and stability)
- Implemented with a transition board (TTL) and without – connection to front panel connectors (PECL)

Time parameters:

- Maximum frequency of counting clock is up to 800 MHz
- “Rough” resolution of pulse delay/width is 2 ns in range of 8.2 s
- “Fine” resolution in range of 10 ns is less then 10 ps
- RMS jitter of output trigger pulse (PECL) < 2.5 ps (in respect to RF clock)

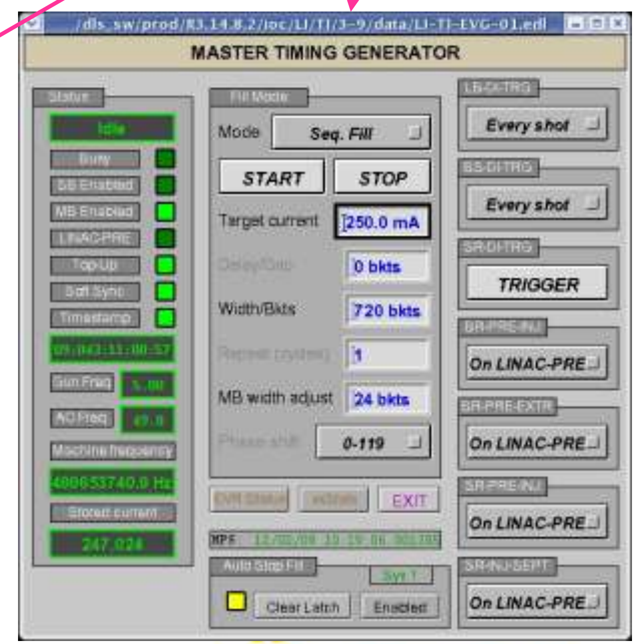
diamond

Software

- The Timing system is integrated into the Diamond control system (based on **EPICS** - **E**xperimental **P**hysics and **I**ndustrial **C**ontrol **S**ystem) through a number of EPICS records.
- The **EG record** configures and defines the options of the EVG module (EVG operation mode, internal clocks, SW events, external triggers enable).
- The **EGEVENT** record specifies a single event to be placed into the sequence RAM
- The **ER record** configures the options for the EVR module (pulse delay, width and polarity, front panel output assignments and distributed bus enable)
- The **EREVENT** record specifies the desired actions to be performed upon receipt of a specific event code
- Applications for the timing system are built with the usual EPICS tools for databases and **EDM** for display panels.
- EPICS is open system for all users. In the beginning we used drivers for EVG and EVR developed in SLS, then - its modernized version from Los Alamos

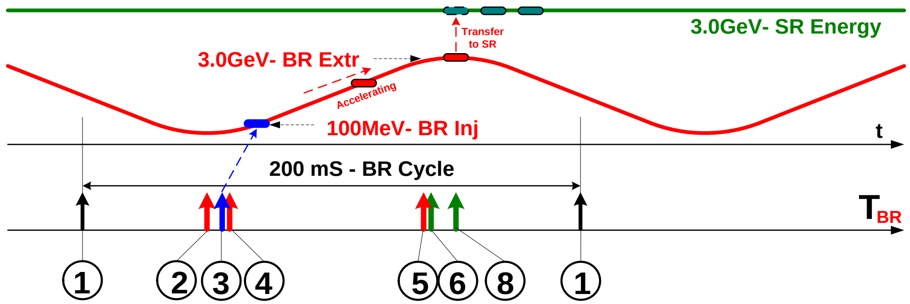
```
Record (egevent, "LI-TI-EVG-01:T-ZERO")
{
field (DTYP, "MRF Event Generator")
field (OUT,  "#C4 S0 @")
field (ENM,  "0x20")
field (RAM,  "0")
field (DELY, "0")
field (SCAN, "Passive")
field (UNIT, "Clock Ticks")
field (PINI, "YES")
field (VAL,  "0")
}
```

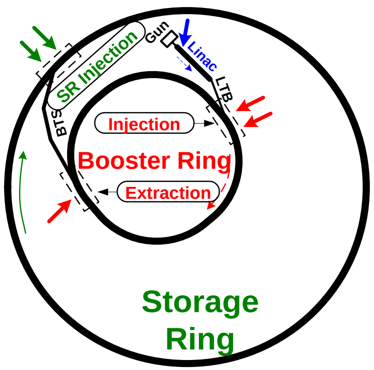
```
Record (erevent, "LI-TI-EVR-01:T-ZERO")
{
field (DTYP, "MRF Event Receiver")
field (OUT,  "#C3 S0 @")
field (ENAB, "Enabled")
field (ENM,  "0x20")
field (PINI, "YES")
field (PRIO, "LOW")
field (SCAN, "Passive")
field (VME,  "Enabled")
}
```



Event Generation

Superposition of main technological events

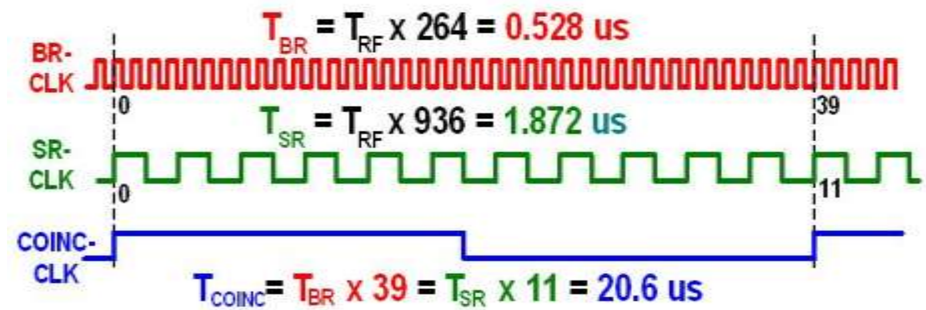




1. T-ZERO at 0*T_{BR}
2. BR-HW-TRG at 85168*T_{BR}
3. LINAC-PRE at 94536*T_{BR}
4. BR-PRE-INJ at 94537*T_{BR}
5. BR-PRE-EXTR at 282000*T_{BR}
6. SR-INJ-SEPT at 282001*T_{BR}
7. SR-PRE-INJ at 282003*T_{BR}
8. SR-INJ at 283895*T_{BR}

Diamond Time Related Parameters

Parameter	Booster Ring	Storage Ring
Accelerating Frequency / Period	RF-CLK = 500 MHz / 2 ns	
Bunches	264 = 2 x 2 x 2 x 3 x 11	936 = 2 x 2 x 2 x 3 x 3 x 13
Coincidence factor	10296 = 11 x 936	
Coincidence Frequency / Period	COINC-CLK = 500000 kHz : 10296 = 48.563 kHz / 20.592 us	
Orbit Frequency / Period	SR-CLK = 1893.4 kHz / 528 ns	BR-CLK = 534.2 kHz / 1872 ns
Coincidence / Machine Period Ratio	20592 ns : 528 ns = 39	20592 ns : 1872 ns = 11



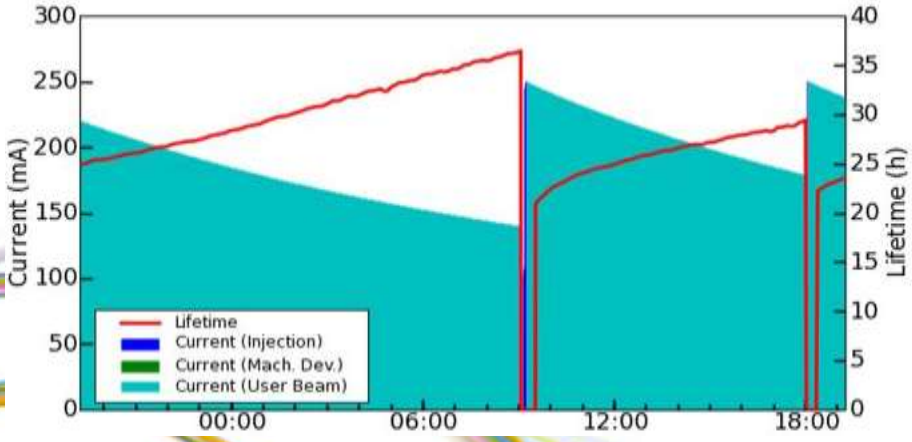
- These events are references for providing system triggers to accelerate electrons through the Linac and the BR into the SR
- Supplementary events are produced to provide control of the diagnostics in each of the accelerators and transfer lines, gating signals during Top-up, and beam lost post mortem

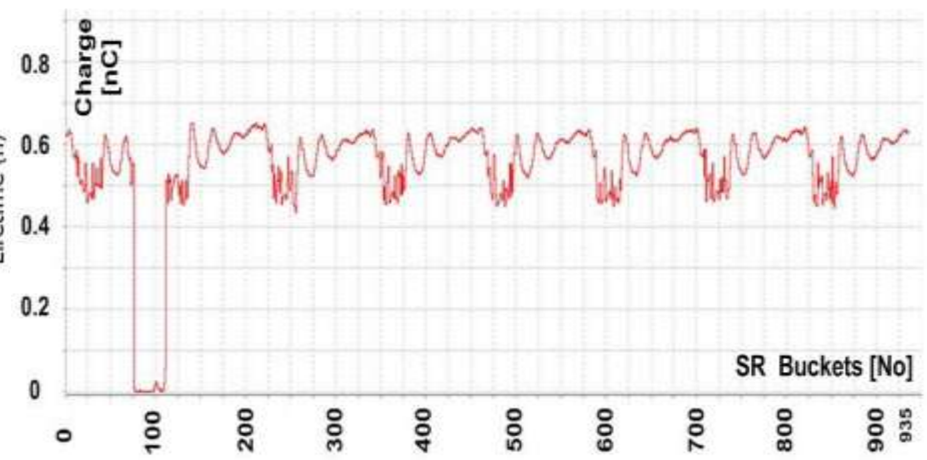
- Every 20.6 us machine beams are in coincidence
- COINC-CLK is used for synchronizing 200 ms booster cycle (i.e. triggering sequence RAM)
- Events are placed in the RAM in ascending order of their time settings.
- The BR-CLK is used for scanning the RAM and generating required events.

Diamond operational modes: Decay mode

During the first two years Diamond worked in "decay mode".
This mode is characterized by:

- **Multi-bunch injection (up to 120 bunches during few minutes and with repetition every 4-8 hrs)**
- **Changing values of beam current and lifetime**
- **Irregular distribution of beam in the buckets**
- **Closed Beamline shutters for injection**





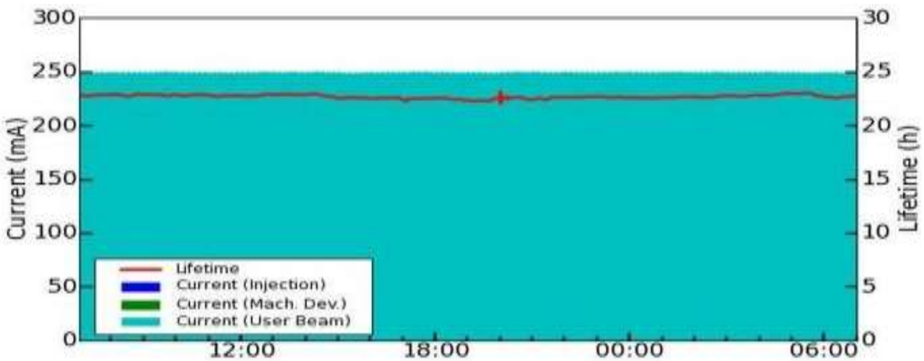
Diamond operational modes: Top-up mode

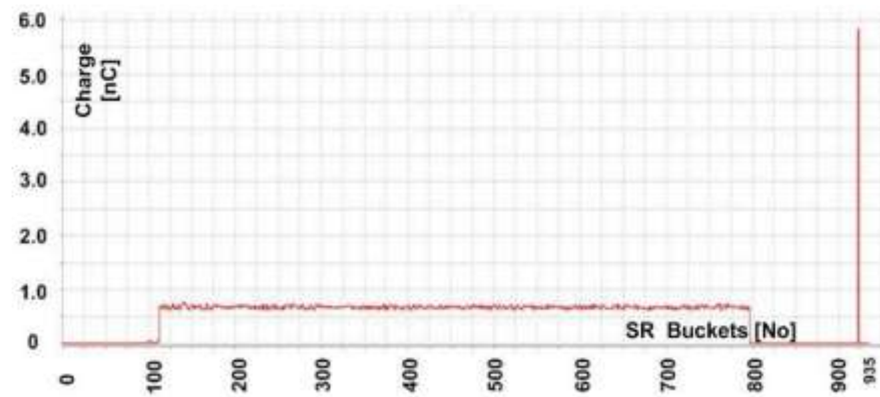
Since October 2008 Diamond mastered "Top-up mode".

Top-up is when beam current is maintained close to a constant level by periodic small injections of charge.

Advantages of Top-up:

- Higher average brightness defined by higher average current and constant flux on samples.
- Improved stability provides a constant heat load of machine components and beamline optics
- Operation modes with bunches of different charge (Hybrid)
- Beamline shutters remain open during injections





This is realized by:

- **Series of single bunches are injected every ~10 minutes**
- **Bunches with "low charge" are targets for such injections**
- **Top-up supercycle includes following phases:**

10 min delay

- Test of Injector (SBs, from Linac through BTS to Faraday cup – efficiency check)
- Gun off / BTS switch on
- Preheating SR pulsed magnets
- Identifying low-charge bunches from fill-pattern (up to 20 bunches)
- Injection to target bunches (up to 20 cycles – 4 seconds)
- Turn off injector and BTS dipole

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Timing system developments for Top-up

A number of changes and additions have been made in the timing system to support the operation of the accelerators in Top-up mode.

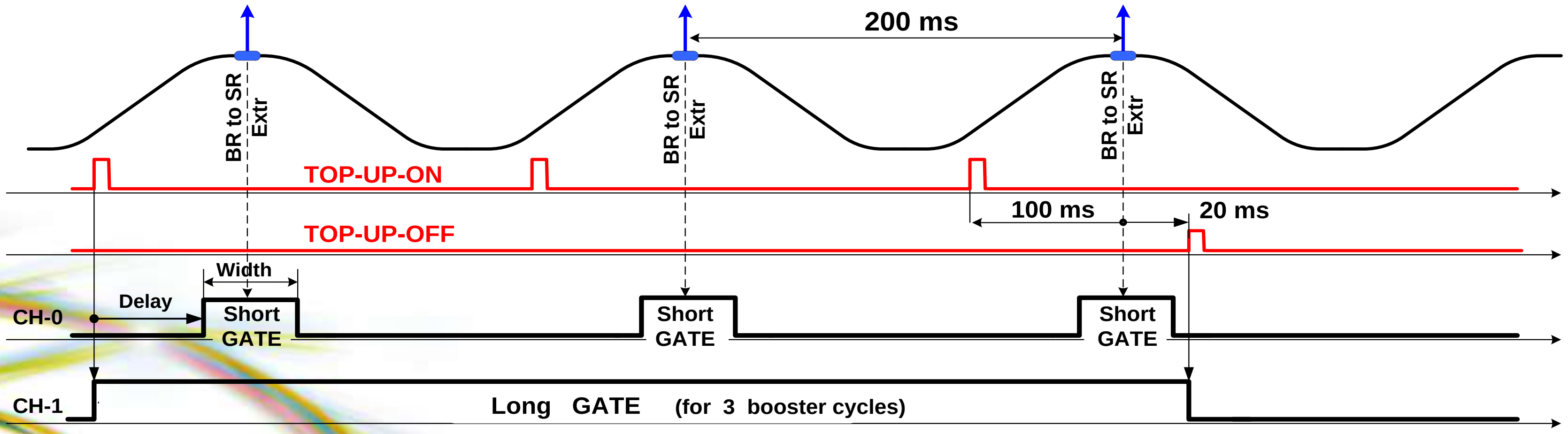
1. **Software part of EVG (MTEVG) was upgraded and integrated into a top-level program of Top-up mode. This allowed us easily to change the parameters of Top-up mode (frequency and number of injections, fill patterns, etc.)**

2. **Originally the SR kickers and septum used a common event, however the septum power supply required a number of cycles before it achieved the required field. By assigning the septum to a separate event (SR-INJ-SEPT) a number of pre-cycles of the septum can take place, as part of the Top-up cycle, without triggering the kickers and so without disturbing the stored beam.**

3. **The four hour periodic event (4HR-RST) was introduced into the system to reset the integrators on all radiation monitors, which provide an interlock based on the integrated dose over that time period. This event is initiated by an EVR close to the EVG. The event is distributed through network and decoded by local EVRs for resetting. To increase the reliability of this, an interface module was developed which can continue producing the reset, every four hours, when the event from the timing systems isn't produced. Any failures with this event do not result in false alarms from radiation monitors.**

Timing system developments for Top-up

4. **Pulse asymmetry of SR kicker magnets results in beam disturbance which lasts up to 12 ms. This affects the brightness of the photon beam and hence some of the beamline experiments. Two additional events were introduced for top-up operation (TOP-UP-ON and -OFF) to enable the beamlines to mask the periods when the injection takes place. These events are decoded as “Short” and “Long” gate signals from the EVRs, and mask either each injection shot, or all of the multiple injections of a top-up cycle, and so are provided on each photon beamline.**



Operational Experience

The Diamond timing system has demonstrated a relatively high level of reliability. In all cases, the failures that have occurred have not led to the loss of stored beam in the SR.

These failures have been associated with:

- non-optimal driving current of optical transmitters in EVR transition modules
- defective transceivers in fan-out modules
- connection loss in optical fibres

In two cases individual EVRs lost their functionality and "refused" processing incoming events. Their functionality was restored after reflashing the Xilinx FPGA

Conclusion

- The installed timing system has functionally met the requirements for the initial operation of the accelerator and beamlines on Diamond Light Source.

- The system has further proved to be very reliable and precise in operation and has proved to be flexible to accommodate additional functionality for Top- up operation.

http://www.mrf.fi/

Questions - ?