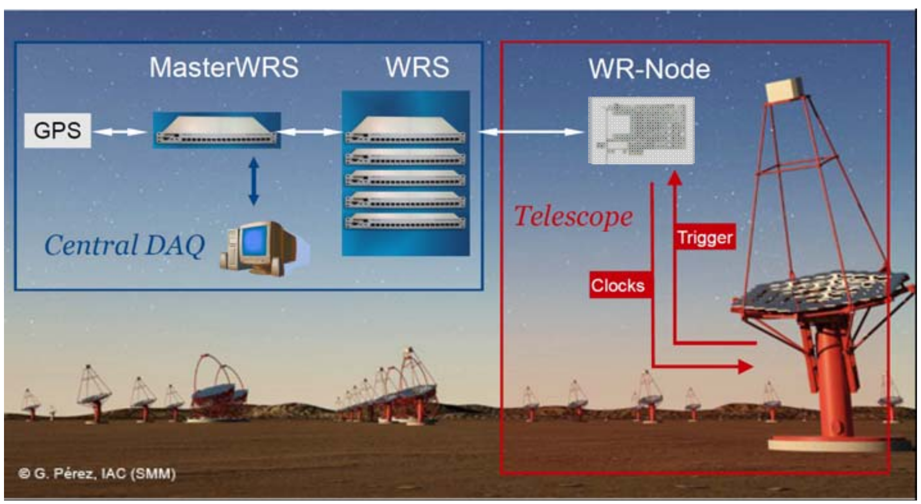
CTA Calibration and the Precision Timing System

Ralf Wischnewski (DESY)

For the ACTL/Timing Group: APC/ DESY/ UVA/ IowaState

CCF-WS, Barcelona, 20151027



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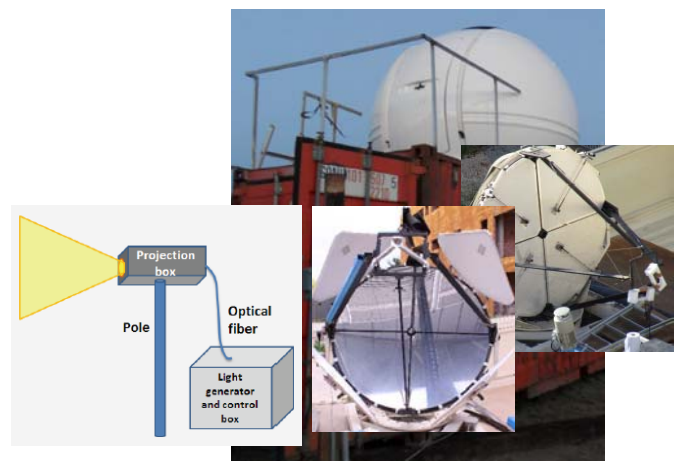


Outline

- **The CTA Timing System**
  - **Basic Design and Operation Modes**
  - **Camera and UCTS Boards**
- **Timing and Array Calibration Sources**
  - **How can Calibration Devices be integrated ? (LIDAR, Illuminator)**
  - **Standard operation: time stamping of CalDev (passive) & SWAT**
  - **(Optional) Synchronous operation of CalDev and Cameras**
- **Summary**

Purpose of this talk:

- Start an active dialog between ACTL/TRIG and Calibration-WP/CCF
- Understand from both sides
  - **Functionality and design**
  - **Which needs and technical possibilities exist ?**

    - We‘re still shaping the hardware/sw – it‘s not too late for (minor) changes on Timing System
    - By now, TRIG was focusing on interaction with Cameras

Abbreviations
- **CalDev = Array Calibration Device (LIDAR, Illuminator …)**
- **WR = White Rabbit; TimSyst = Timing System; UCTS = WR-Node; …**

The CTA Timing System

Covered by ACTL/TRIG-WG = Timing System + SWAT (SoftWareArrayTrigger)

- Task:
  - **guarantee precision timing for triggered camera events → to define array events**
  - **supply precision clocks-signals to cameras and all devices in need (eg. CalDev)**
  - **retrieve deadtime-related information (log events triggered but not readout)…**
  - **… extra-functionalities like interacting w/ CalDev**

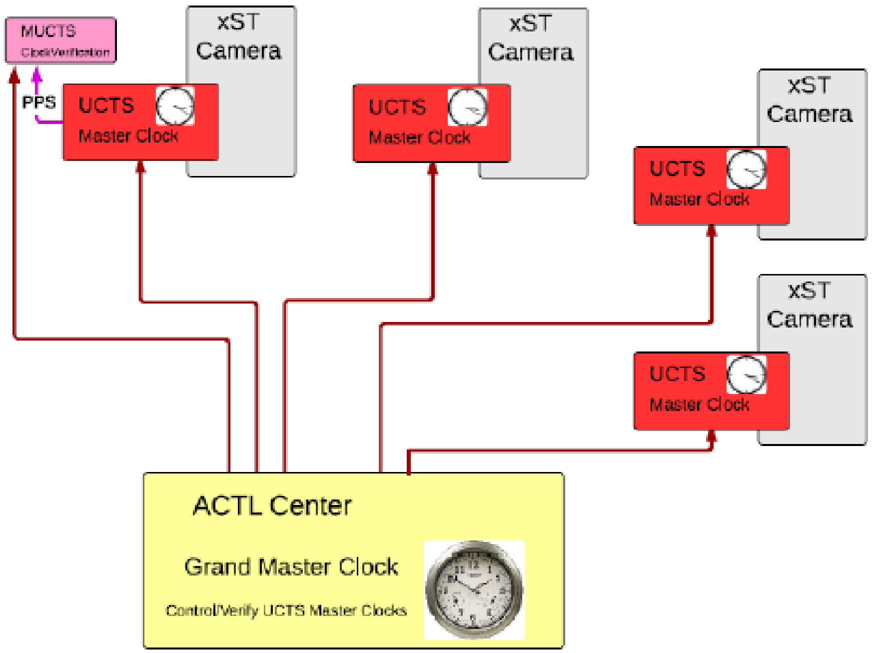
- Method:
  - **Unified Time Cards (UTCS) are located at every Camera**
  - **Each has a local clock (sync'ed to the master) and interacts with the Camera**
    (1ns resolution + sub-ns precision)

- Technical Realization:
  - **Using the WhiteRabbit System**

- Status:
  - **Preparation work: "pre-CTA-like" prototypes were/are evaluated: good performance.**
  - **Final camera-IF agreement is pending (after Heidelberg-Camera-WS May/2015).**
  - **Then: Finalize UCTS hardware production. Time is pressing !**

CTA Timing : Distributed Clocks

- Each Camera has a precision clock, located on a Timing Card (UCTS).
- All clocks are autonomously synchronizing with the GrandMasterClock.
- Inter-Clock deviations are of o(200ps) rms → perfect for CTA-purposes



→ CTA can act like a time machine, ie. is able at each camera to either

(A) measure (timestamp) an "event occuring", or to

(B) generate an event, by issuing a synchronous signal.

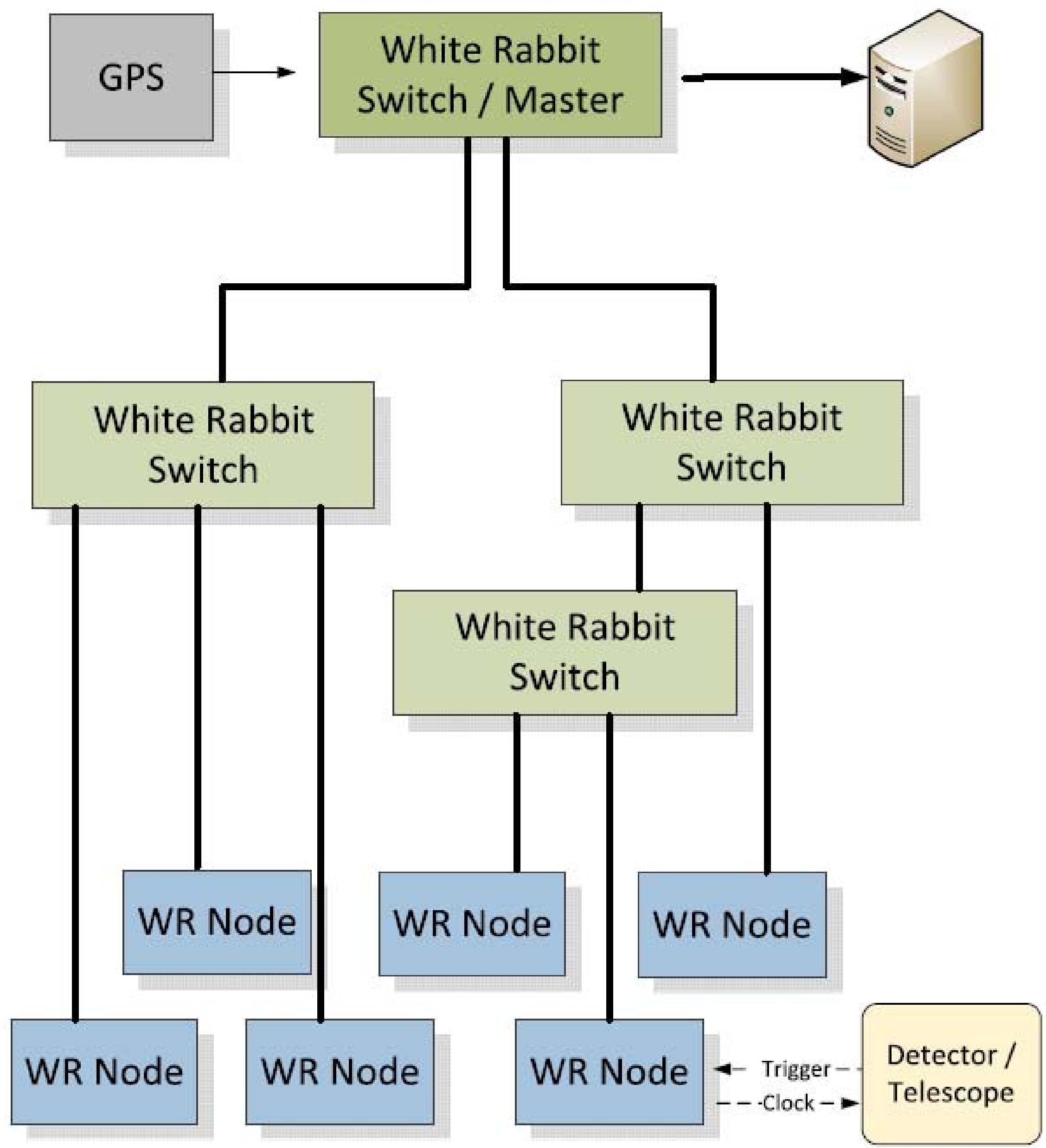
Technical Realization: White Rabbit

WR is a fully deterministic Ethernet based network for data transfer and synchronization. >1000 nodes with sub-ns accuracy over fiber lengths of up to 10 km. A WR network is made of

- ClockMaster(Switch+GPS)
- WR-Switch network
- WR-nodes w/ stable clock
- Base on SyncEthern/PTP

Advantages:

- Open source and open hardware project (CERN/LHC,FAIR,LHAASO)
- Big user community + longterm support
- Commercial support, official ethernet extension
- Low cost; flexibility (Mezzanine, …) …



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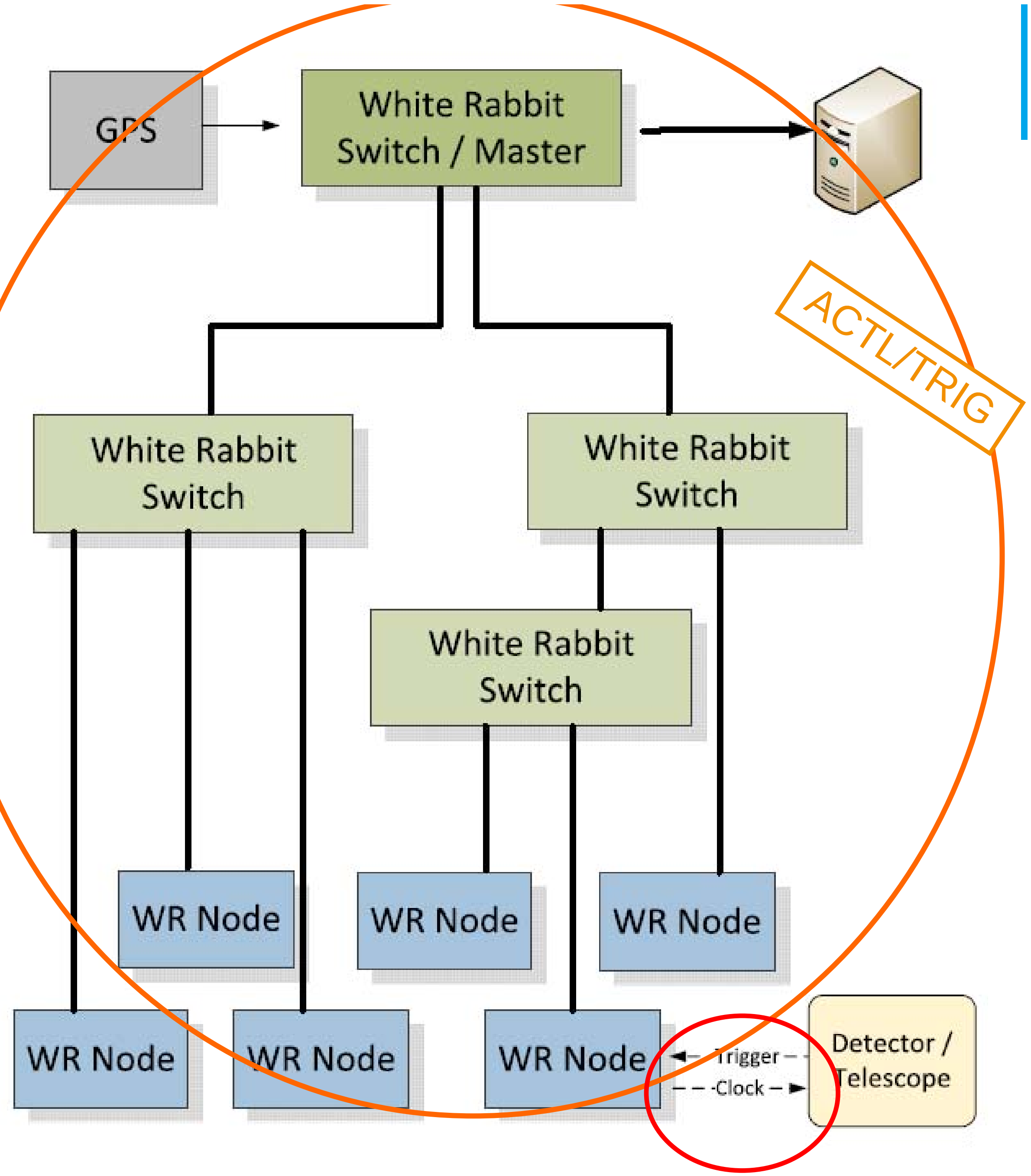
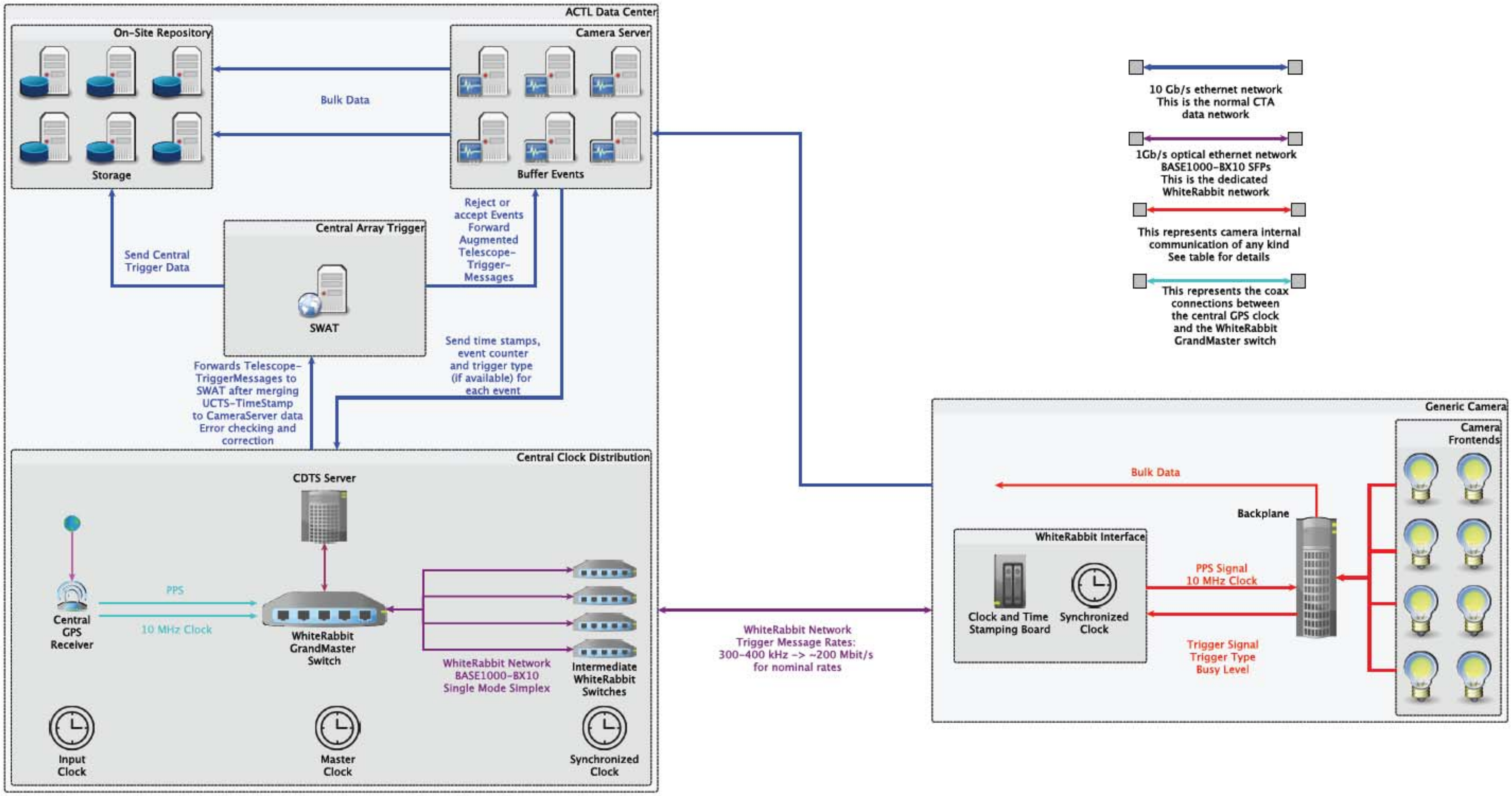


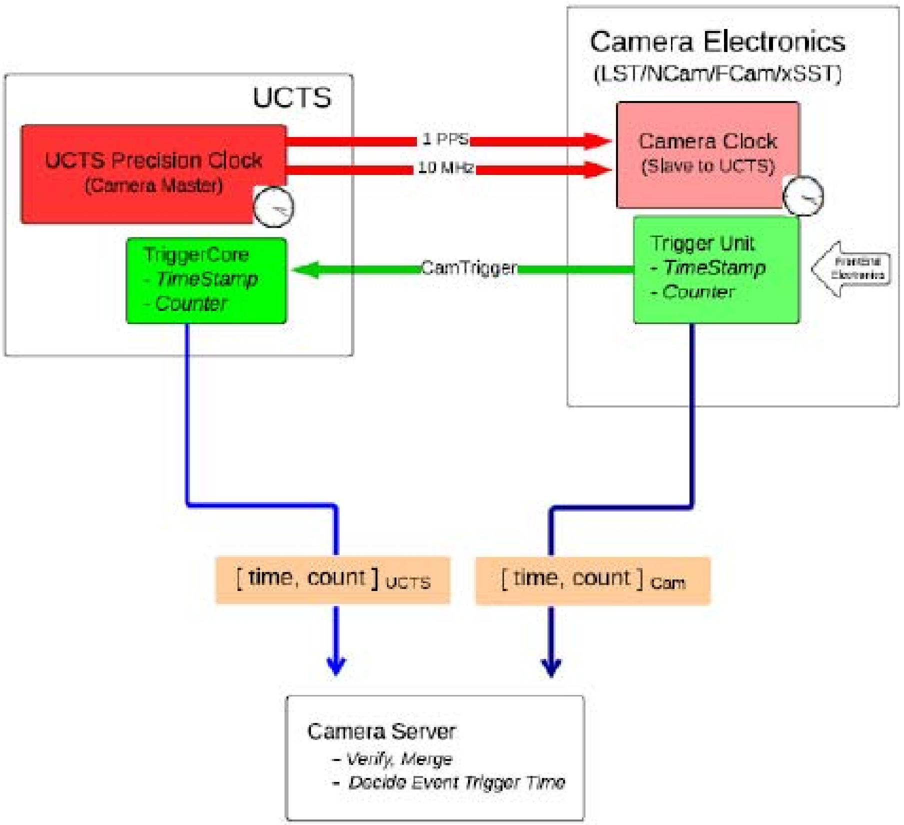
CTA Timing : White Rabbit - Proposed Layout



Note: Details of data flow still to be decided

CTA Timing (zoomed) : UCTS-Card and Cameras

- UCTS = "Unified ClockDistribution & TimeStamping Card" at each Camera



UCTS Interface w/ Camera:

1. **Receive CamTrigger**
2. **Send Clock (PPS/10MHz)**

Figure 1: Layout of the Double-Clock/Double-Timestamping architecture using a generic camera and the UCTS-Board. Both UCTS-Board and camera electronics generate a trigger message [t, count] including a time stamp t and an event counter *count*. The camera server verifies the integrity of event counter and time stamp.

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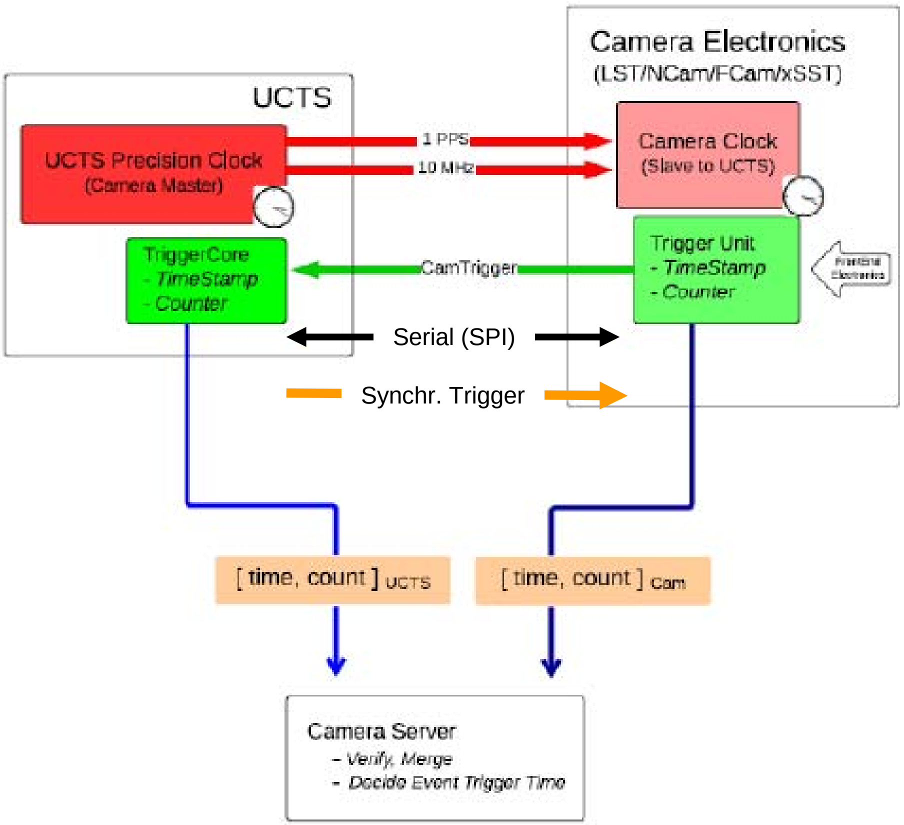

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UCTS Interface w/ Camera:

1. **Receive CamTrigger**
2. **Send Clock (PPS/10MHz)**
3. **Serial line (aux.info // bidir.)**
4. **Send Synchron. Trigger**

Note: A synchronous trigger is pre-programmed, and issued with ns-resolution and 200ps jitter – with respect to all cameras/ devices.

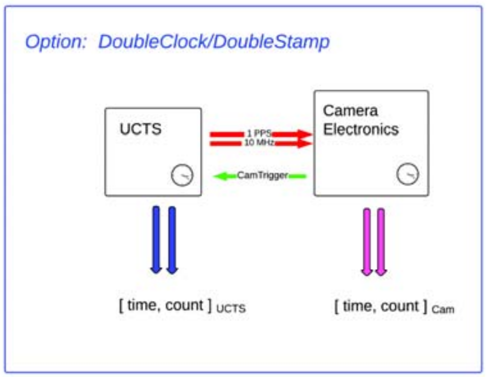
CTA Timing : Redundancy for Verification

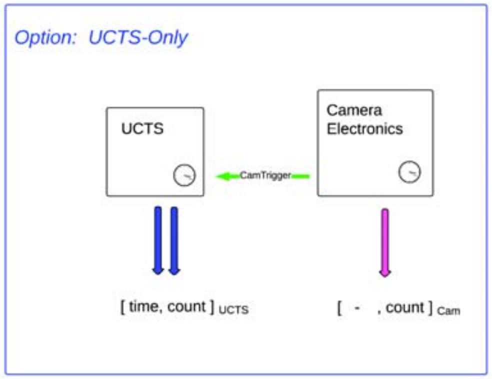
- The Timing System uses a DoubleClock/DoubleTimeStamping Method

  → record trigger times on camera and UCTS side, and compare

  → retrieve information on data and clock-quality (missing events, malfunctioning clocks…)

- Other schemes have no redundancy/recovery potential :





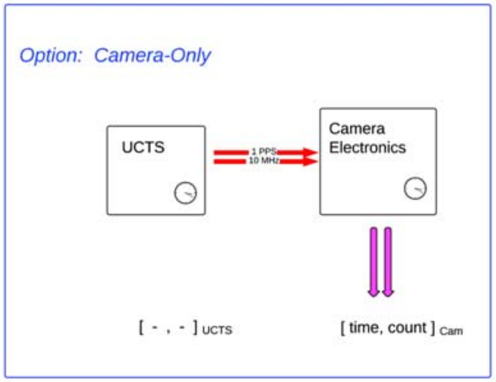


Figure 3: Comparison of the default CDTS scenario "Double-Clock/Double-Timestamp" (upper left) with "UCTS-Only" (upper right) and "Camera-Only" (lower left). The data stream from camera and the UCTS-Board are indicated by blue and purple arrows, respectively. They indicate the disadvantage of the "Camera-Only" scenario - with no redundancy and, correspondingly, with the worst timing reliability.

Put "CalDev" here fpr "Cameras".

Redundancy is a goal.

Array Calibration Devices and UCTS – General Aspects

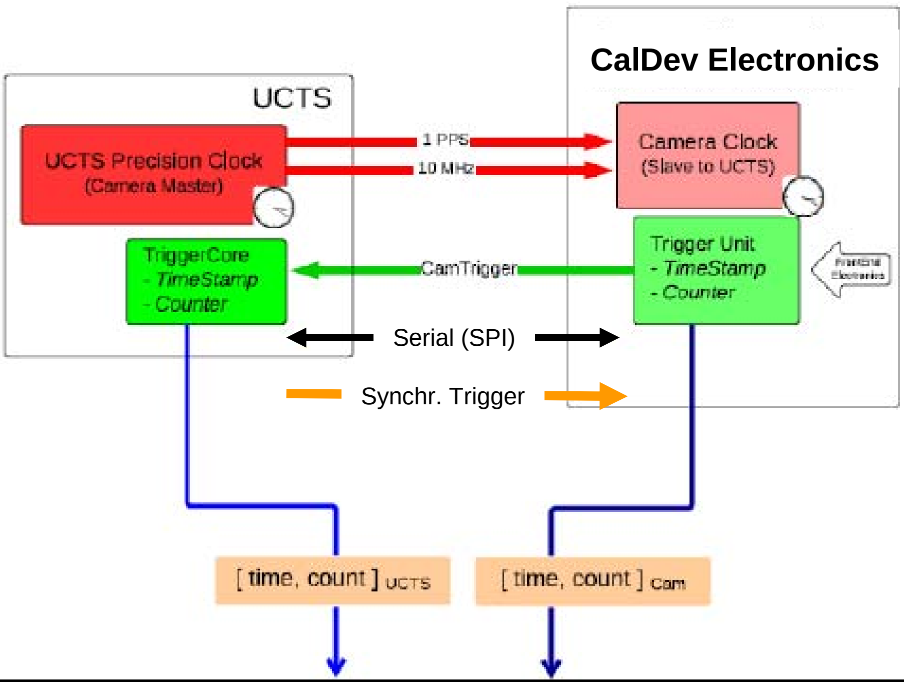
- Assume that Array Calibration Devices (seen by >1 Telescopes) are:
  LIDARs and “Illuminator”; they operate in (short) pulsed mode.
- Unknowns: Operation modes/parameter, repetition rate, …
  CalDev with internal clock, like cameras ? Precision ?
  Space for a “small” UCTS (6x16x3cm^3), or even a larger?

Suggestion/Option:

- Each ArrayCalDev would have a UCTS, and interacts like a generic Camera
  - **<u>Request-1:</u> Send a “Trigger Signal” to UCTS for each individual calibration pulse**
  - **<u>Goal-1:</u> Accept an “External trigger” to launch a calibration pulse**
  - **<u>Request-2:</u> data of pulses should be sent to ACTL (time; parameters; flags). TimeSyst needs it for verification; may be SWAT for array trigger (?)**
  - **Is data exchange with UCTS needed (eg. launch parameter; or status post-fire) ?**
  - **Is the UCTS Clock needed (PPS, 10MHz) ?**

UCTS-Card and Calibration Devices : Baseline Suggestion

- UCTS should be placed at Array CalDevices as well.



UCTS Interface w/ CalDev:

1. **Receive CalDevTrigger**
   - requested -
2. **Send Clock (PPS/10MHz)**
   - optional -
3. **Serial line (aux.info; bidir)**
   - optional – (Ethn helps?)
4. **Send Synchron. Trigger**
   - requested -

UCTS sends TimeStamp to SWAT:

- SWAT can use it as Veto; at least to Flag array/camera events

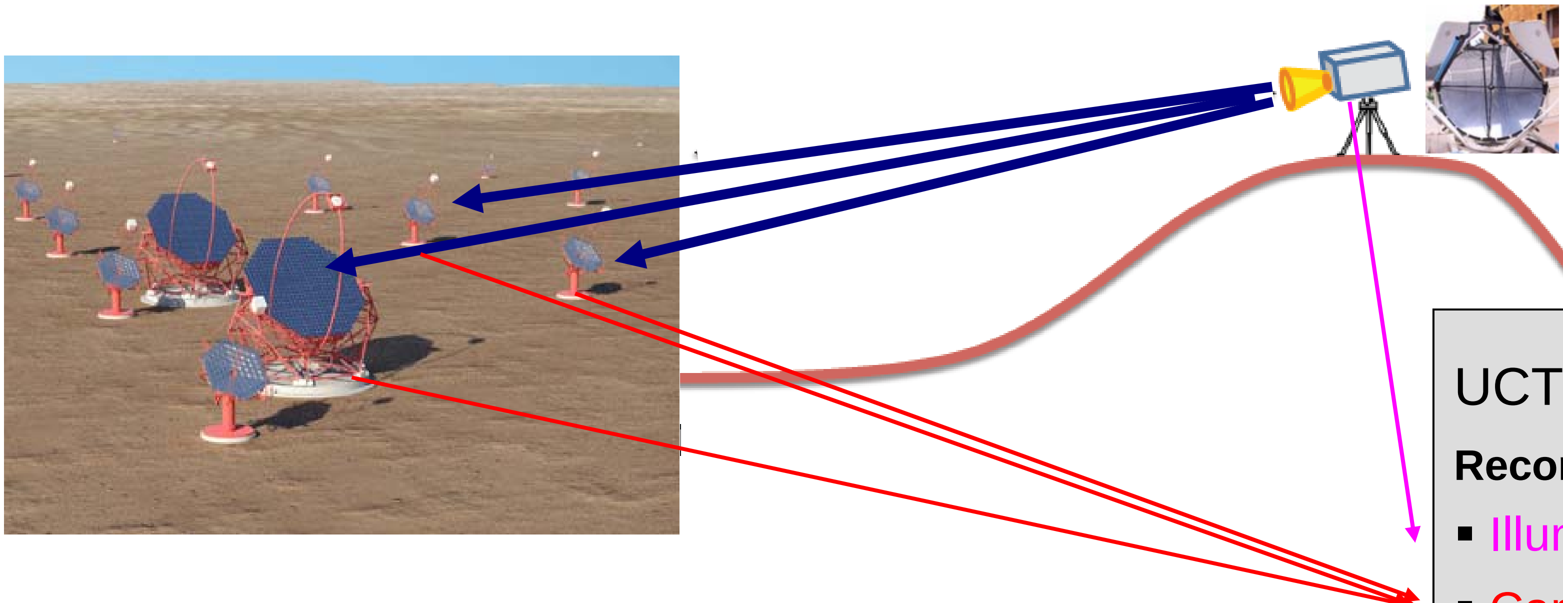
- If CalDev schedule is centrally known, SWAT and also Cameras can be alerted.

Note: A synchronous trigger is pre-programmed, and issued with ns-resolution and 200ps jitter – with respect to all cameras/ devices.

Array Calibration : Default "Passive" Operation with TimingSystem

- Example: Illuminator, LIDAR

(adapted from M.Gaug)



- Suggested a default "Passive" Operation Mode:

(A) Illuminator is self-launching

- sends pulse to UCTS for timestamping; t_{Cal} forwarded to SWAT

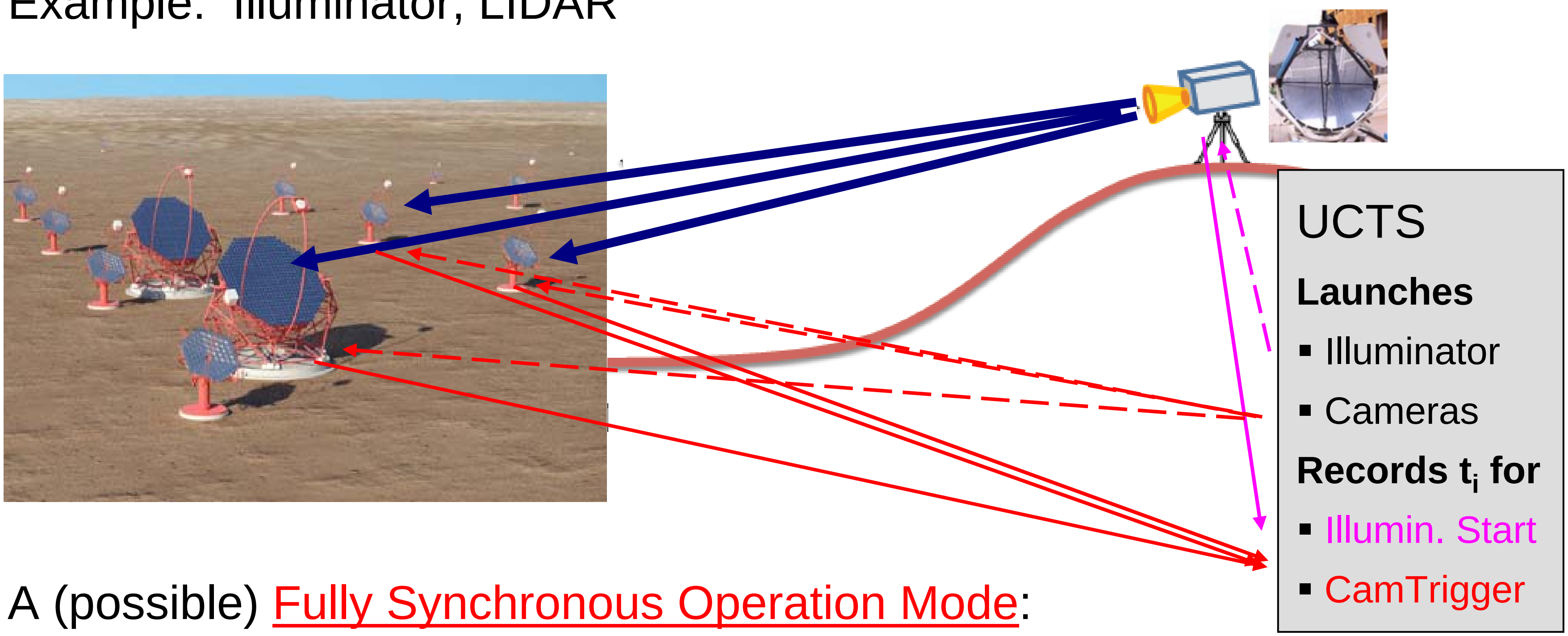
(B) At SWAT:

- Option-1: add CalDev-Flag to array events in a time-window t_{Cal} + DeltaT
- Option-2: use the CalDev times to fully veto array events
- ....-2a: veto only closeby-cameras .... (several options) ....

Array Calibration : Synchronous Operation with TimeSystem

- Example: Illuminator, LIDAR

(adapted from M.Gaug)



- A (possible) Fully Synchronous Operation Mode:

1. Illuminator launched from Timing System at: xx UTC + 0 nsec
2. Cameras launched by TimeSyst (ext.trigger) at: xx UTC + yy nsec

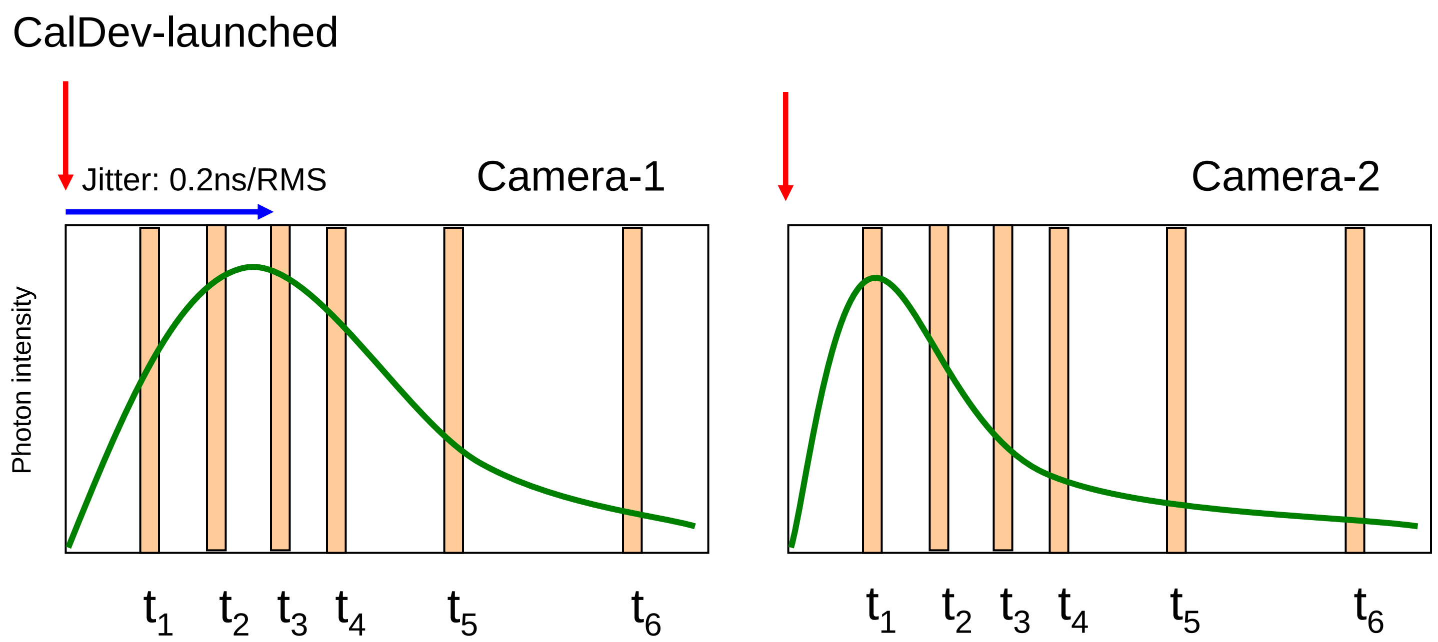
   Every camera is independently launchable; also for 1 Camera only.

   → Scan the photon-field @Cam in time-slices : 0 nsec …yy µs after flash

(Obviously: Launching only the Illuminator is also possible)

Array Calibration: Cameras read Synchronous Time Slices ?

- Time slices for Cameras are wrt. to the CalDev launch. Can be pre-programmed for any time-scale: from nsec to usec/msec,… Always in perfect phase for all Camera and CalDev's.
- Is such an operation mode of CalDev and CTA-array or single telescopes useful ?? Example: Use LIDAR-beam Relative Telescope calibration from ?



- In addition: WR can even generate Waveforms – by using DACs in 100MHz domain (again: in-phase), e.g. to control the CalDev. Useful?

Summary (1)

- The CTA Timing System is made of synchronized UCTS Boards (Unified Timing Boards, to time-stamp camera events and define array events (SWAT)

Timing System and Cameras:

- UCTS cards at each Camera with precision clocks:

  (1) time-stamp camera trigger

  (2) distribute clocks

  (3) generate synchronous trigger for cameras (by Timing System).

Timing System and Calibration Devices:

- The same UCTS cards can also be used, to

  (1) time stamp Calibration pulses

  (2) distribute clocks to CalDev

  (3) launch the CalDev by the TimingSystem externally

Summary (2)

These operation modes of the Timing System for Calibration Devices seem possible:

(1) "Passive / Asynchronous Mode" :

CalDev generates calibration pulses (autonomously). These are sent to the UCTS and there precision time-stamped like for camera trigger.

Times are propagated in real-time, to e.g. veto/ flag the affected Array-Trigger (at SWAT).

(2) "Active / Synchronous Mode":

- CalDev receives a launch-signal by UCTS. CalPulses are time-stamped as for (1).

CalDev Times are available also in real-time, i.e. vetoing/ flagging at SWAT can be done. SWAT can also schedule ahead of time (with "nsec" high precision !).

(2A) "Synchronous Camera Operation":

In addition, the Cameras can be operated synchronously with the CalDev Pulses: Forced CameraTrigger will allow to measure the Telescope response vs. time, with an external trigger (independent on occurence of a camera trigger).

If that is an interesting CTA operation mode, needs investigation. The hardware effort to implement seems not big. (Price/CalDev ~1.5kE + fiber)

Summary (3)

- This presentation intended to start discussion with CCF :
  - **How can the TimSyst interact with CalDevices ?**
  - **What are the relevant Devices, their basic design, data flow ?**
  - **How precise are CalDev internal clocks and the launch-times ?**
  - **Can CalDev send a "CalDev-Trigger Signal " to UCTS; can it be "launched" from UCTS ?**
  - **Main operation modes of CalDev (interleaved, dedicated runs) ?**
  - **Will the array trigger need to be alerted to Veto ?**
  - **...**
- Can the "Passive" and "Synchronous" operation mode be realized ?
- Is "Synchronous operation" of CalDev <u>and</u> Cameras interesting ?
- We need start the dialog now, while not all final decisions are made, on both sides (Timing, CalDevices).

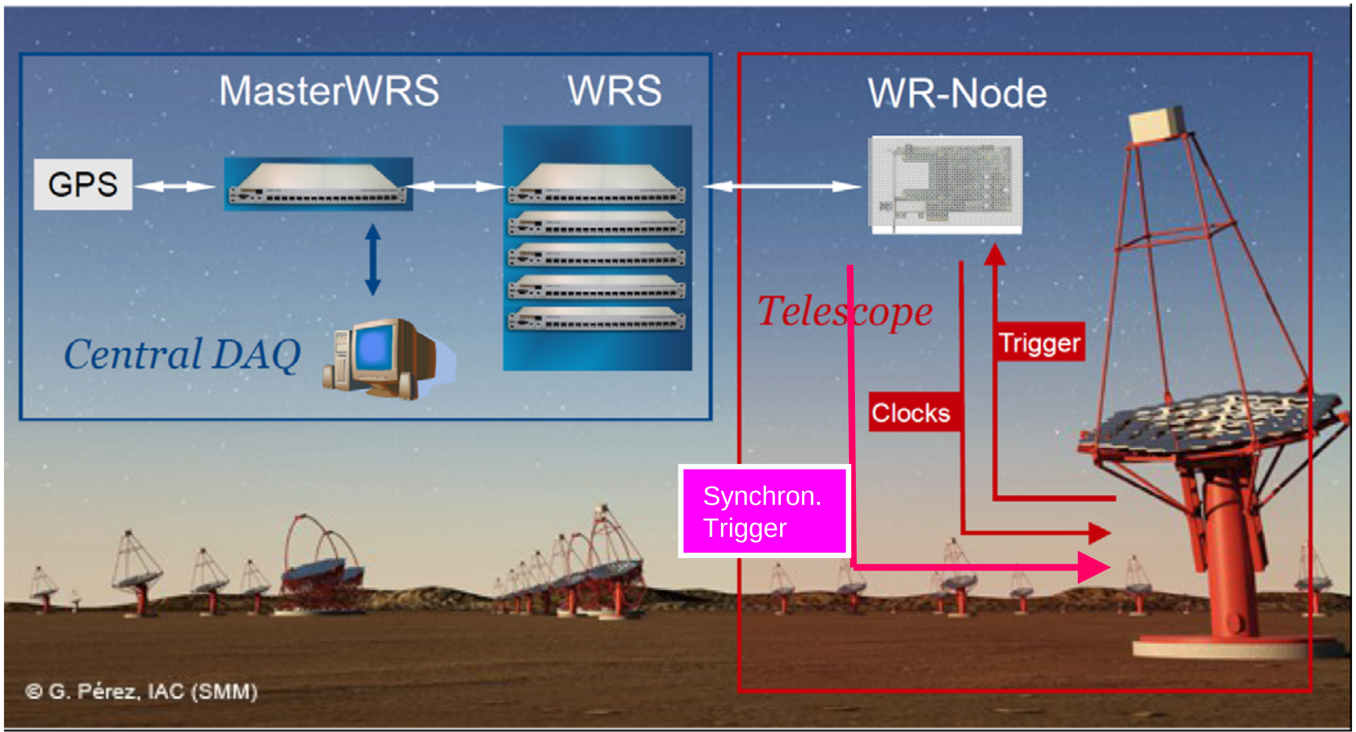
White Rabbit - further documents

More information on CTA & WR: concept, interfaces, tests

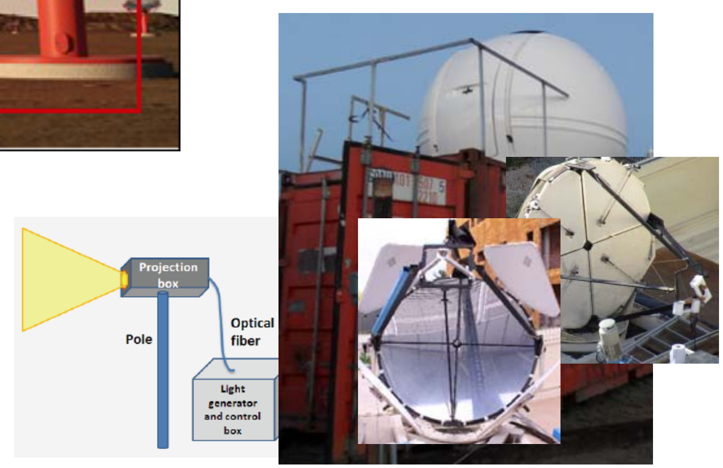
- CTA Interface DataBase (updated 10/2015 !) ← most uptodate on IFs
  - **ACTL-CAM-1000 + ACTL-LST-1000, …**
- 1st ACTL/Camera Workshop (Heidelberg May2015) – CTA-Wiki
  - **“CTA Timing”, “CDTS Camera Interface”, “Verification and Redundancy Concept”**
  - **Summary talk (AW)**
  - **Documents submitted to PC approval (June)**

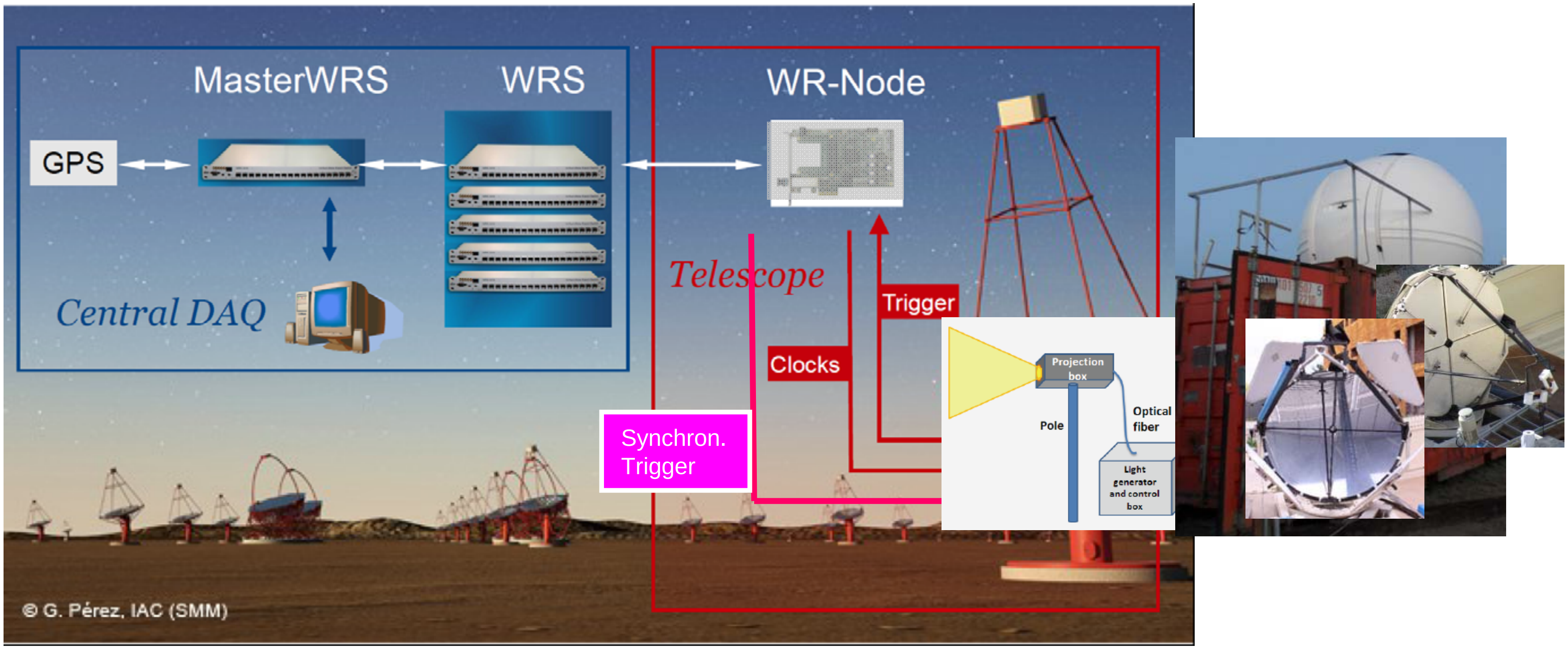
Detailed layout
some parts in discussion

- ACTL/TDR (May-2015), ACTL / Redmine (CamIF Disc)
- WR-Websites / CTA-presentations / Applications:
  - **www.ohwr,org/projects/**
  - **WR-workshops: CERN Oct.2014, …**
  - **CTA Consortium Presentations (Rome/2012 … Liverpool/2015)**
  - **WR tests: (CHEC) - DAQ-workshop**
  - **WR operating in CR-experiments: ICRC2013 / ECRS2014 / ICRC2015 (RW et al)**


MasterWRS
WRS
GPS
WR-Node
Central DAQ
Telescope
Trigger
Clocks
Synchron.
Trigger
© G. Pérez, IAC (SMM)

How ….?


Projection box
Pole
Optical fiber
Light generator and control box



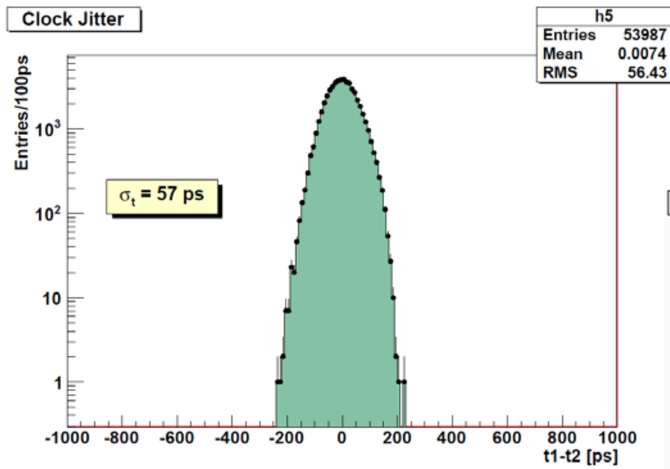
…(try to) use the Timing System.

Thanks…

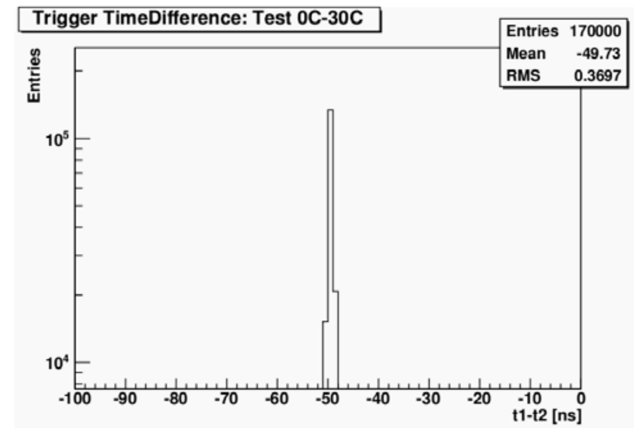
... Backup …

Backup: Extended White Rabbit Tests DESY/APC/UVA

SPEC clock stability (jitter), measure by the PPS pulses: 57ps RMS.



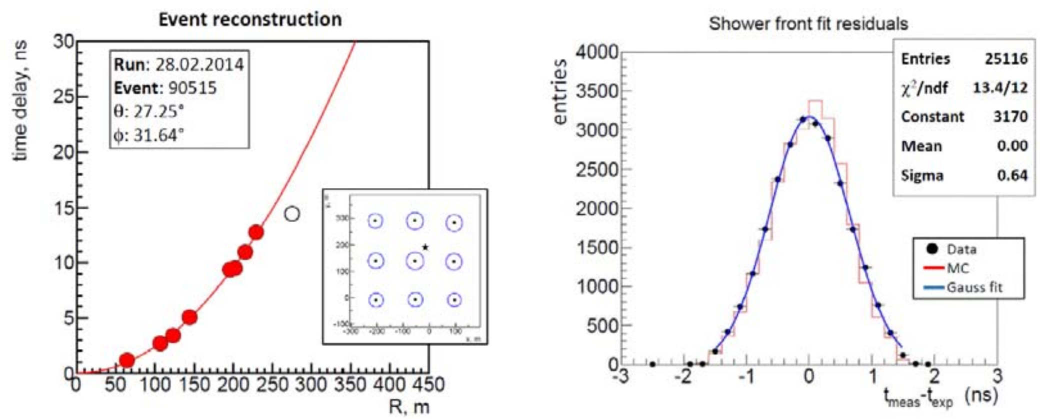
Timestamps, recorded by two SPEC boards (nsec resolution). Climate Chamber.



HiSCORE EAS Shower (2014)

9-Station array, now: 28 stations

(ICRC2015)



(a) (b)

Figure 9: EAS shower reconstruction. (a) Arrival time delay vs distance R from the shower axis; for an event. Red/white dots: stations retained / excluded in the final fit; red line: reconstructed shower profile. Small panel: Reconstructed core position (black star), the area of the circles is