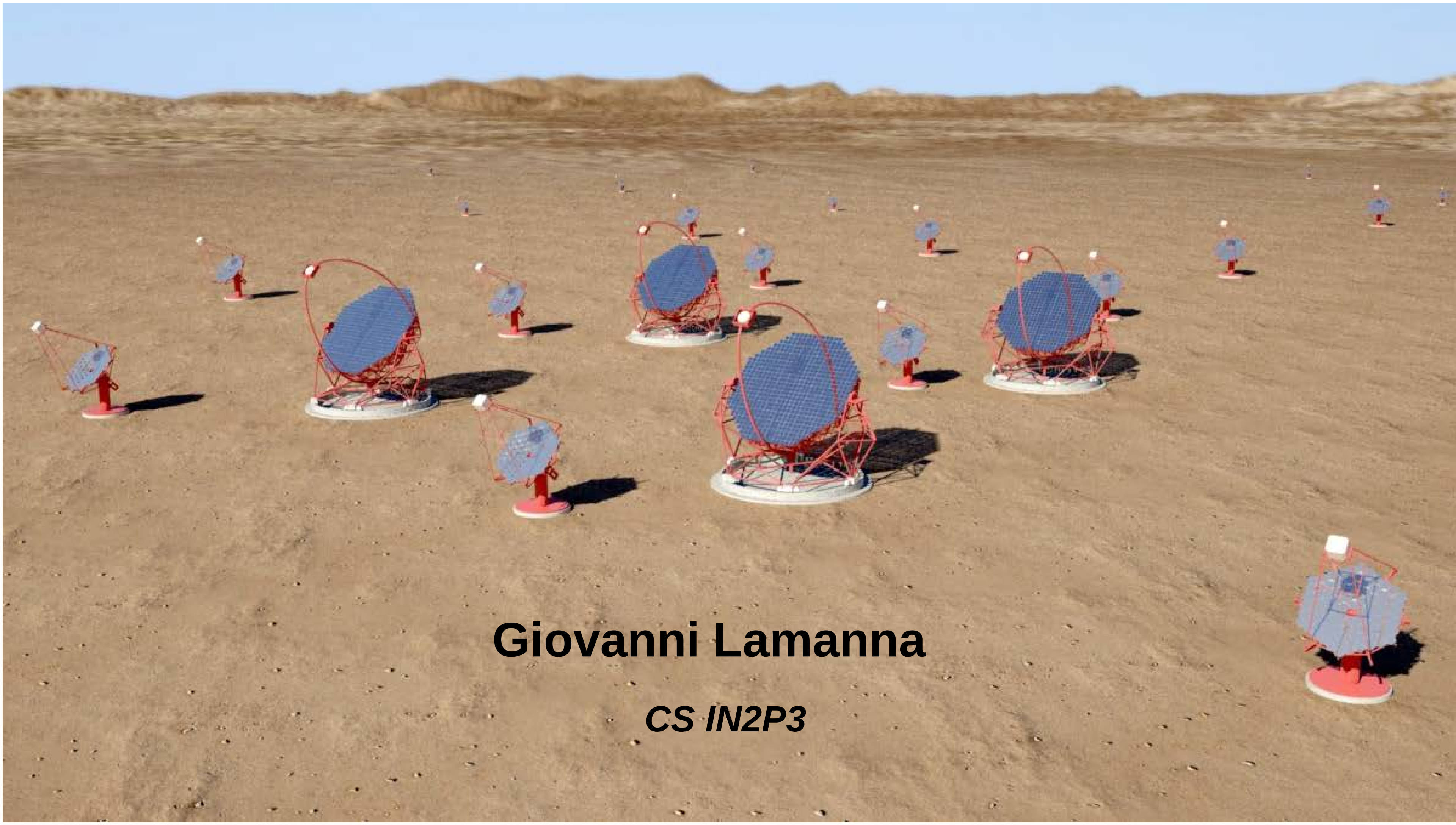
CTA - Cherenkov Telescope Array



Giovanni Lamanna

CS IN2P3

Data Management

CTA Data Management

"DATA MANAGEMENT" international "first" level sub-project led by FRANCE (IN2P3-LAPP):
G. Lamanna (LAPP) – scientific coordinator
N. Neyroud (LAPP) – technical and system engineer.

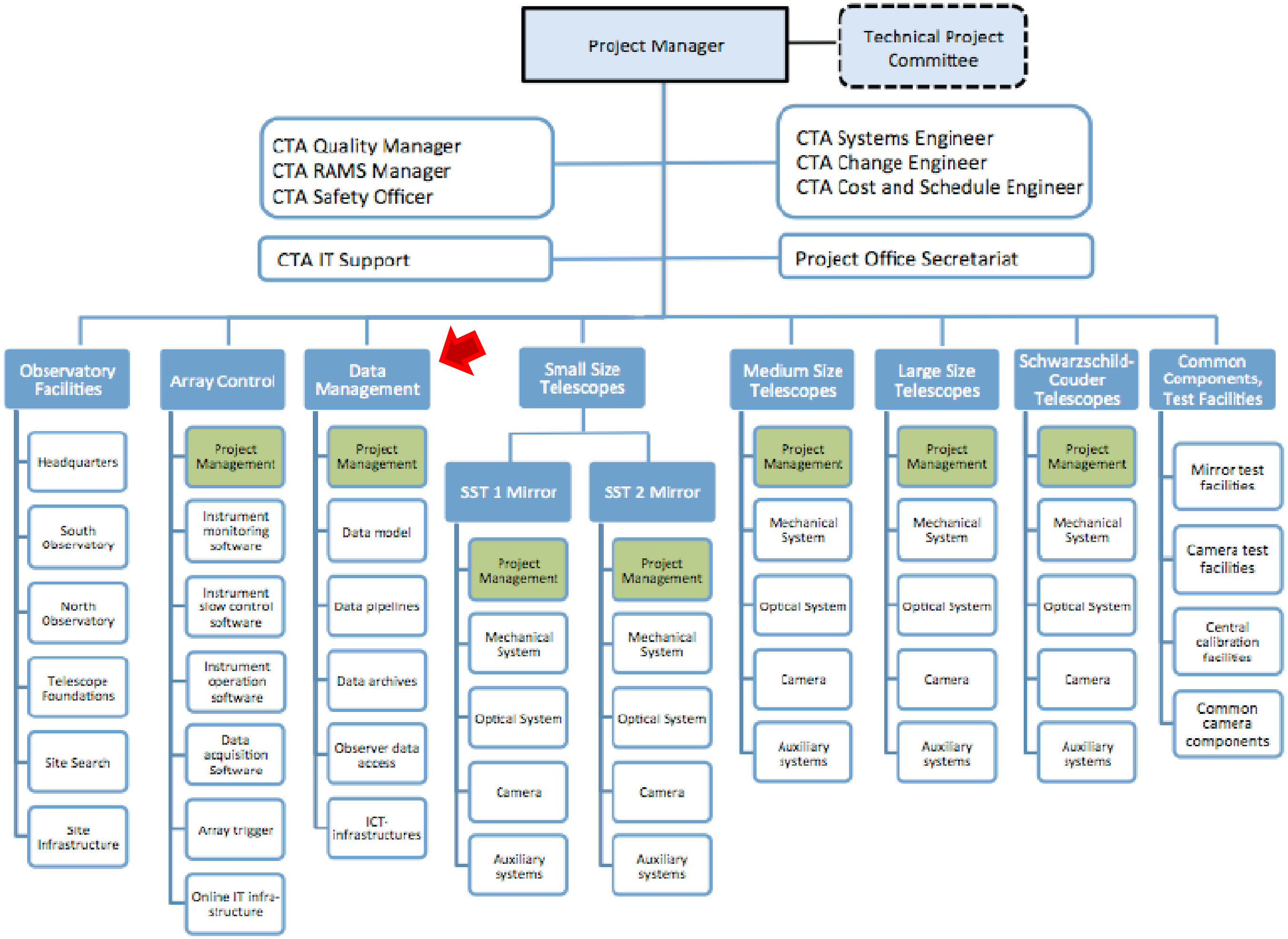
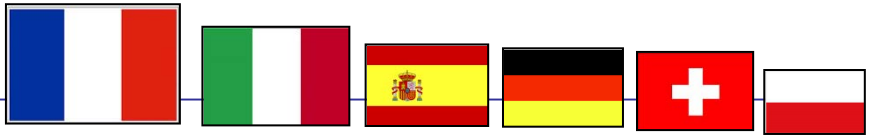


Figure 3 : Organigram of the Project Management.

Product Breakdown structures and Institutes

Product	Code	Research team
Data management	3	**Project management: IN2P3 (LAPP)**
Data model	3.1	
Low level	3.1.1	Uni PD, **LUTH, LPNHE**, ISDC, **IRFU**
Mid level	3.1.2	Uni PD, **LUTH**, DESY, **IRFU**
High level (FITS)	3.1.3	INAF-IASF Mi, INAF-OAR, **LUTH**, ISDC, **IRFU**
Instrument resp.	3.1.4	**LUTH, LAPP**, DESY, **IRFU**
VO compatible	3.1.5	INAF-OATs, INAF-OAR, **LUTH, LUPM, IRFU**
Data archive str.	3.1.6	INAF-OATs, INAF-OAR, **LUTH**, IFAE, **IRFU**
Data pipelines	3.2	
Reconstruction	3.2.1	INAF-OAR, Univ. PD, **LAPP, LLR, LPNHE, IRFU, APC, LUTH**
Analysis	3.2.2	INAF-IBo,OAR, Univ.PD, **LUTH, LLR, LPNHE, IRFU, APC**, UCM, DESY
Monte Carlo	3.2.3	**LAPP, LLR, LUPM, APC,** DESY
Data archives	3.3	
Raw data	3.3.1	INAF-OAR, INAF-OATS, DESY, **LAPP**, ISDC, **IRFU**
Science data	3.3.2	INAF-OAR, INAF-OATS, **LUTH, LAPP, IRFU, IFAE**
Engineering data	3.3.3	INAF-OAR, INAF-OATS, **LUTH, LAPP, IRFU**
VO data	3.3.4	INAF-OAR, INAF-OATS, **LUTH, IRFU**
Data access	3.4	
User support	3.4.1	INAF-OATs, INAF-OACt, **LAPP, IRAP, LLR, LUPM, IRFU**
User gateway	3.4.2	INAF-OATs,OACt,OAR,**LAPP, IRAP, LLR, LUPM, IRFU, APC**, CYF, U.Barc.
Science tools	3.4.3	INAF-OAR, **IRAP, LUTH, APC, IRFU**
ICT-infrastructures	3.5	
Data management services	3.5.1	INAF-OATS, **LAPP, LLR, LUPM**, Uni. Barc.
Offline computing	3.5.2	INAF-OATS, INAF-OAR, **LAPP**
Network infrastructures	3.5.3	INAF-OATS, **LAPP**
Operational framework	3.5.4	INAF-OATS, **LAPP**

Status in 2013



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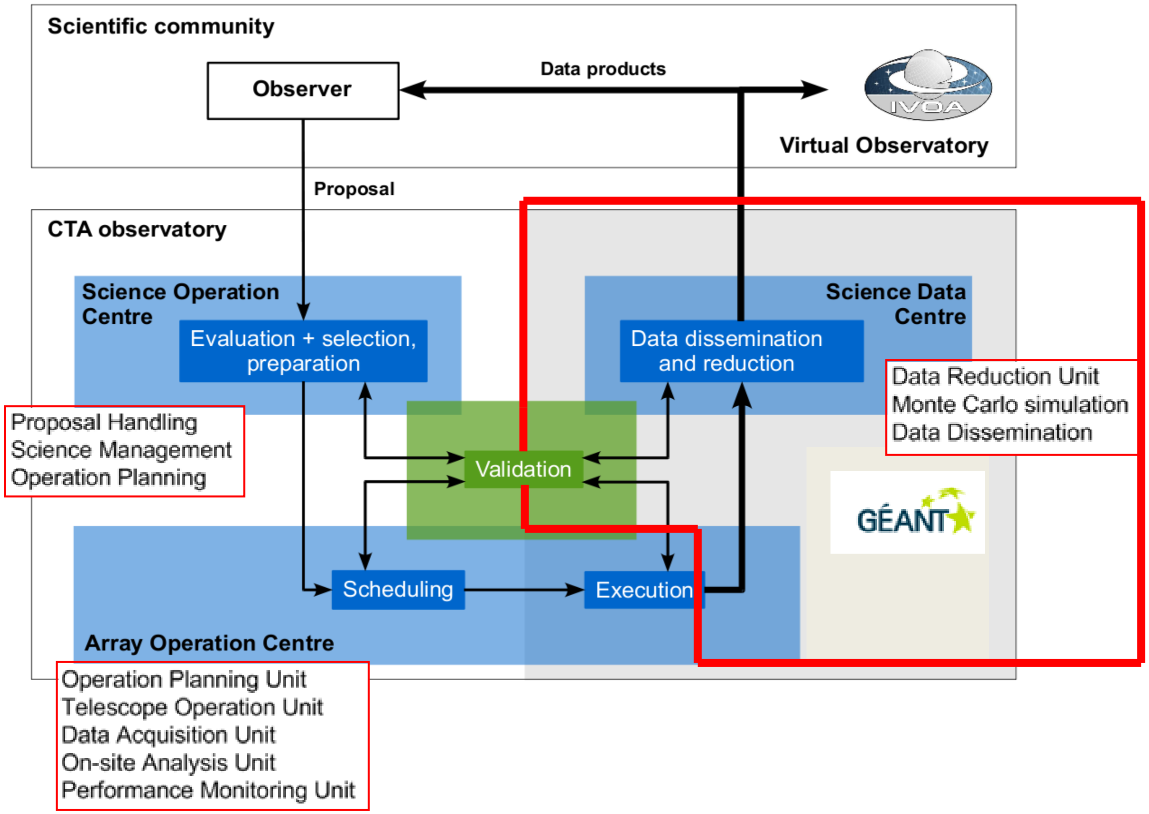
CTA Data Management



CTA-FRANCE
main “final” goal is the
“SCIENCE DATA CENTER”

Distribution des données

- accès aux données
- logiciels d’analyse scientifique
- support utilisateurs

Traitement des données

- infrastructure : CC IN2P3
- collection, traitement, archivage de toutes les données
- gestion des ressources
- interface utilisateurs internes

SAp, SPP, Sedi

Some specifications and main issues

(*e.g. data rate, computing, storage*)

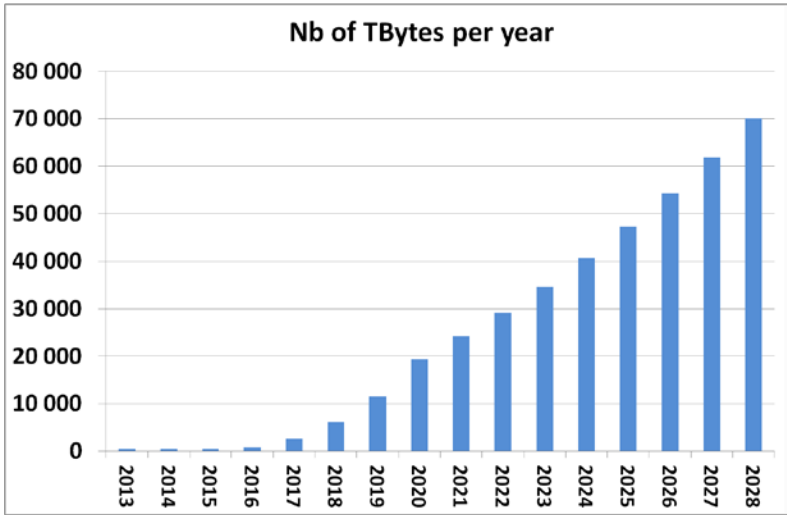
CTA Big Data: PByte Scale

The total expected data rate: 0.4 - 5.3 GB/s:
From 0.3 to 4.0 GB/s for the South Array (70 telescopes) and from 0.1 to 1.3 GB/s for the North Array (20 telescopes)

A per-year volume of data between 2 and 25 PB
(assuming a 15% of observation time per year)

In the following we consider a close-to-minimum case rate: **~ 3 PB/year**

(PRELIMINARY)



Storage assumptions

Year	2013	2014	2015	2016	2017	2018	2019	2020	2021
Raw data flow per year (TB)				260	781	1 301	1 821	2 602	2 602
Cumulated raw data (TB)				260	1 041	2 342	4 163	6 764	9 366
Processing and Reprocessing on previous raw data (TB)				52	208	468	833	1 353	1 873
Total new data per year (TB)				312	989	1 769	2 654	3 955	4 475
Cumulated data(TB)	0	0	0	312	1 301	3 070	5 724	9 678	14 153
Monte-Carlo data flow per year (TB)	500	500	500	500	1 301	3 070	5 724	9 678	10 000
Cumulated volume (TB)	**500**	**500**	**500**	**812**	**2 602**	**6 140**	**11 448**	**19 357**	**24 153**

Reminder 1: total current storage capacity @ CCIN2P3 is ~ 30 PB
Reminder 2: total raw data of four LHC experiments is ~ 15 PB/year

After 2020 constant yearly raw data rate
~ 4-5 PB per year of new data

CPU estimation

based on some assumptions, not (yet) corresponding to specifications:

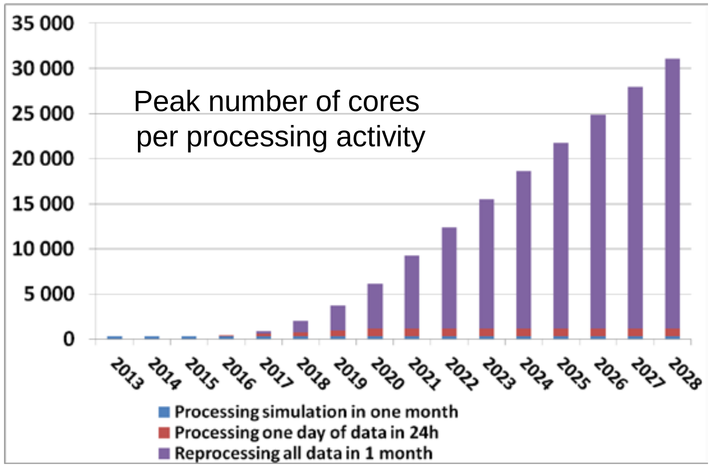
(PRELIMINARY)

Data reprocessing year N = Data reprocessing year N-1 + Data pipeline year N

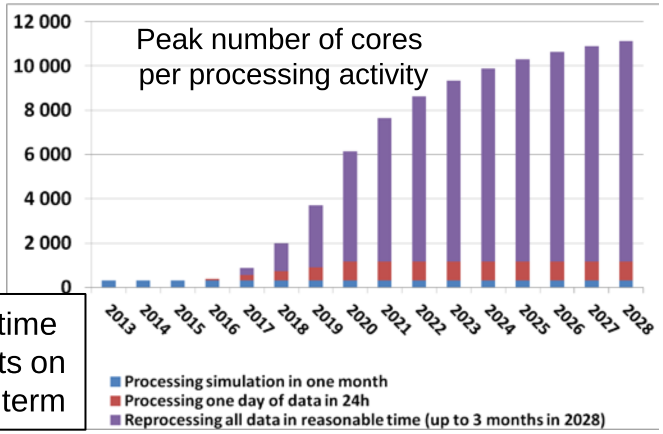
Peak number of cores= Number of cores to be able to process one day of data acquisition in **one day** in parallel with all data reprocessing in **less than 1 month**.

Year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Annual wall time for simulation (HS06)	8 071 714 286	8 071 714 286	8 071 714 286	8 071 714 286	8 071 714 286	8 071 714 286	8 071 714 286	8 071 714 286	8 071 714 286	8 071 714 286
Annual wall time for Data pipeline (HS06)				8 071 714 286	24 215 142 857	40 358 571 429	56 502 000 000	80 717 142 857	80 717 142 857	80 717 142 857
Annual wall time for data reprocessing - one per year (HS06)					8 071 714 286	32 286 857 143	72 645 428 571	129 147 428 571	209 864 571 429	290 581 714 286
Total KHS06	8 071 714	8 071 714	8 071 714	16 143 429	40 358 571	80 717 143	137 219 143	217 936 286	298 653 429	379 370 571
Average number of cores per year	26	26	26	51	128	256	435	691	947	1 203
Peak number of cores for processing simulation in one month	311	311	311	311	311	311	311	311	311	311
Peak number of cores to process one day of data in 24h				85	256	427	597	853	853	853
Peak number of cores for reprocessing all previous years in one month				0	311	1 246	2 803	4 983	8 097	11 211

From 2022, there are 11000 physical cores @ peak (during a full month)



Less tight time constraints on long term



Reminder 3: total current number of physical cores @ CCIN2P3 is ~ 16000

(PRELIMINARY)

Network assumptions and requirements.

To be able to transfer all raw data from site to one Data Center in one day:

Medium requirements			
	Data storage per day in Gbits	**Timescale (h)**	**Throughput (Gbps)**
South site	138 240	24	1,60
North site	51 840	24	0,60

(Reminder: Final data rate can be even 10 times larger than considered here….;
Nominal bandwidth not corresponds to the effective one. It depends on reliability and quality of the I infrastructures.

Some major CTA scientific challenges in ICT and e-Science @ IN2P3

Software

Know-how of IN2P3-HESS teams (with important and sometime unique contributions in the Cherenkov field) and more general of particle physicists at IN2P3:

- Data calibration and event reconstruction of Cherenkov telescopes.
- Monte Carlo simulation of detector response and radiation-matter interactions.
- Scientific data analysis systems.

Complemented within CTA-FRANCE by the Astrophysics tradition and know-how:

- Astronomical standards for multi-wavelength and multi-experiment data mining, data analysis in open access (e.g. Virtual Observatory).
- Science tools for high level data products for archive users.

Software

About "Calibrations":
- the full set of procedures are applied per each camera at pixel level and at array level.

About "Reconstruction":
- The most sophisticated statistical approaches are based on Likelihood, Boost Decision Tree, multi-Probability Density Functions, Neural Networks and detailed comparison data/MC.
- The event is build based on stereoscopy and telescopes combinatory (depending on observations).

Some development paths to be explored in CTA Data Management:

a) Calibration optimization through parallelization. Parallelization of reconstruction processing at camera level before stereo convergence ?
(*requiring new data structure conception, avoiding tails effect in multithread…)*

b) Software to be conceived/designed to be able to scale to "manycore" computing.
(Lack of standards, code generation not well understood)

c) GPUs parallel computing faster and at a tenth of the cost of conventional systems.
(translating algorithms into Graphics processing, !)

Monte Carlo Simulations

Two software packages:
1) CORSIKA for the air showers;
2) SIM_TELARRAY for the array, the telescope and the detector response.

Monte Carlo simulations are an essential tool:
- to optimize the best configuration and performance of CTA and for data analysis
- to discriminate between gamma and hadron showers (reconstruction)
- to calibrate the scientific data

Huge numbers of background showers have to be simulated.

Processing, access and analysis of Monte Carlo data demand massive computing, storage resources as well as an efficient worldwide access of the scientific community.

Monte Carlo and GRID

CTACG (CTA Computing Grid) , an IN2P3 initiative started in 2008 during the CTA design study phase: a feasibility study but also the infrastructures for CTA MC production.

-> Since 2008 CTACG is a "Grid success story"; today it counts **7** countries and **18** EGI sites supporting a dedicated EGI CTA Virtual Organization (VO) (>600 TB and >2000 cores).

-> EGI-Grid infrastructures and EGI-Grid middleware for distributed data Storage, data processing and data access : one potential solution for CTA data management ?

Other correlated IN2P3 initiatives :

-> EGI – CTA Virtual Team (France Grilles + NGI Italy, Spain and Poland) prototyping of SSO system and Gateway for a worldwide community.

-> Promotion of the LHCb DIRAC management system: feasibility study through management system of MC production and analysis and MC metadata catalogue for archive model.

Archives

While the Archive Management System would rely on astronomical standards and will be developed based on existing software (e.g. from ESO), the Archive and its Data Base systems deserve investigation.

In-line with similar efforts in general in Science and also at IN2P3 to match:
a) Big Data issue (O(PB), millions of files)
b) Relational data model not a good fit for most science data sets.

NoSQL databases:

- SciDB: o.s. DB for science inspired by LSST needs.

- Hadoop: o.s. DB specialized for a Write-once-read-many pattern plus tools that are optimized for batch processing ("event storage" oriented)

N.B.: CTA data are reduced of one order of magnitude at first level and two at second. Furthermore is an event-base experiment; not to be confused with LSST spec.

Access and dissemination

H.E.S.S., MAGIC and VERITAS partial data-sets provided (to the CTA community) to enable an international but also IN2P3, INSU and IRFU inter-collaboration towards:

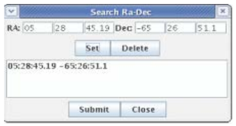
- a common study of software science data analysis tools (Science Tools) which enable scientists to move from lists of selected gamma-events to high level products;

- adopting and respecting standard astronomical data formats (e.g. FITS, Virtual Observatory archive model) for archive purpose;

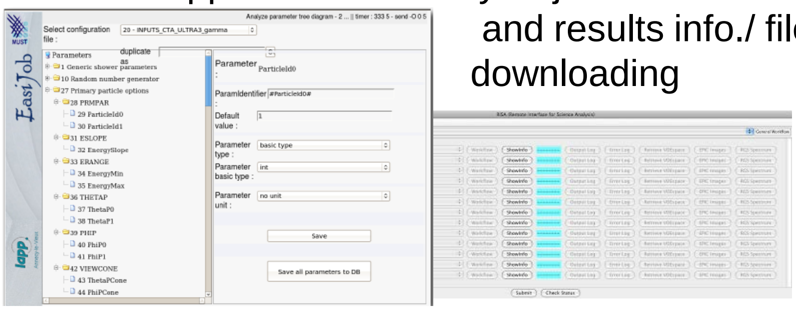
- assuring complete compliancy with combined multi-mission scientific analysis. (i.e. spectra, brightness maps, etc.)

The Scientific Analysis System model under study in CTACG for MC simulations

User Web Client and/or VM for data searching



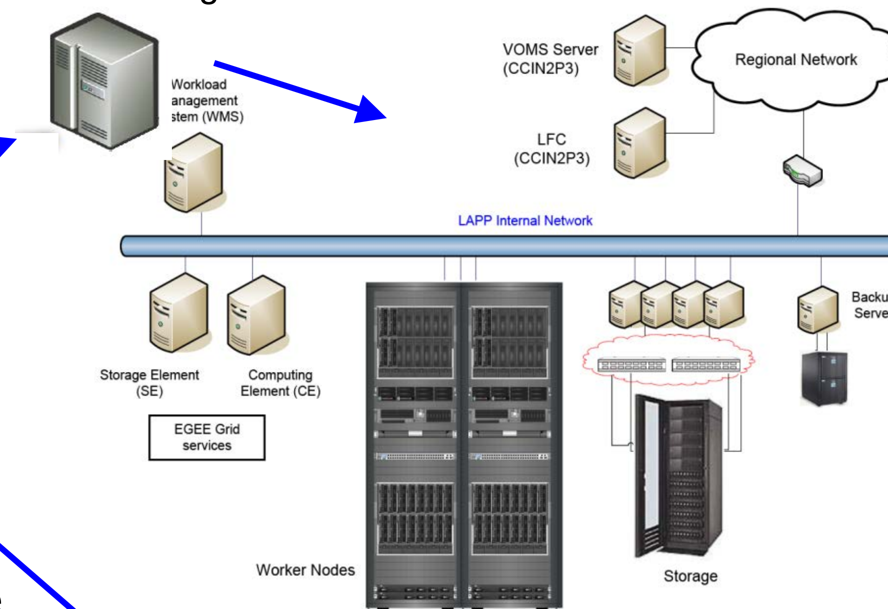
Client application for analysis job submission and results info./ file downloading

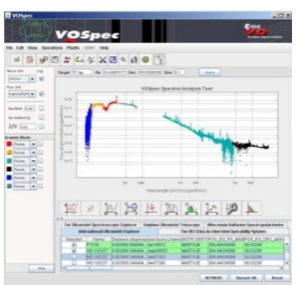


High-level data request

Web Server workload management

Grid jobs management





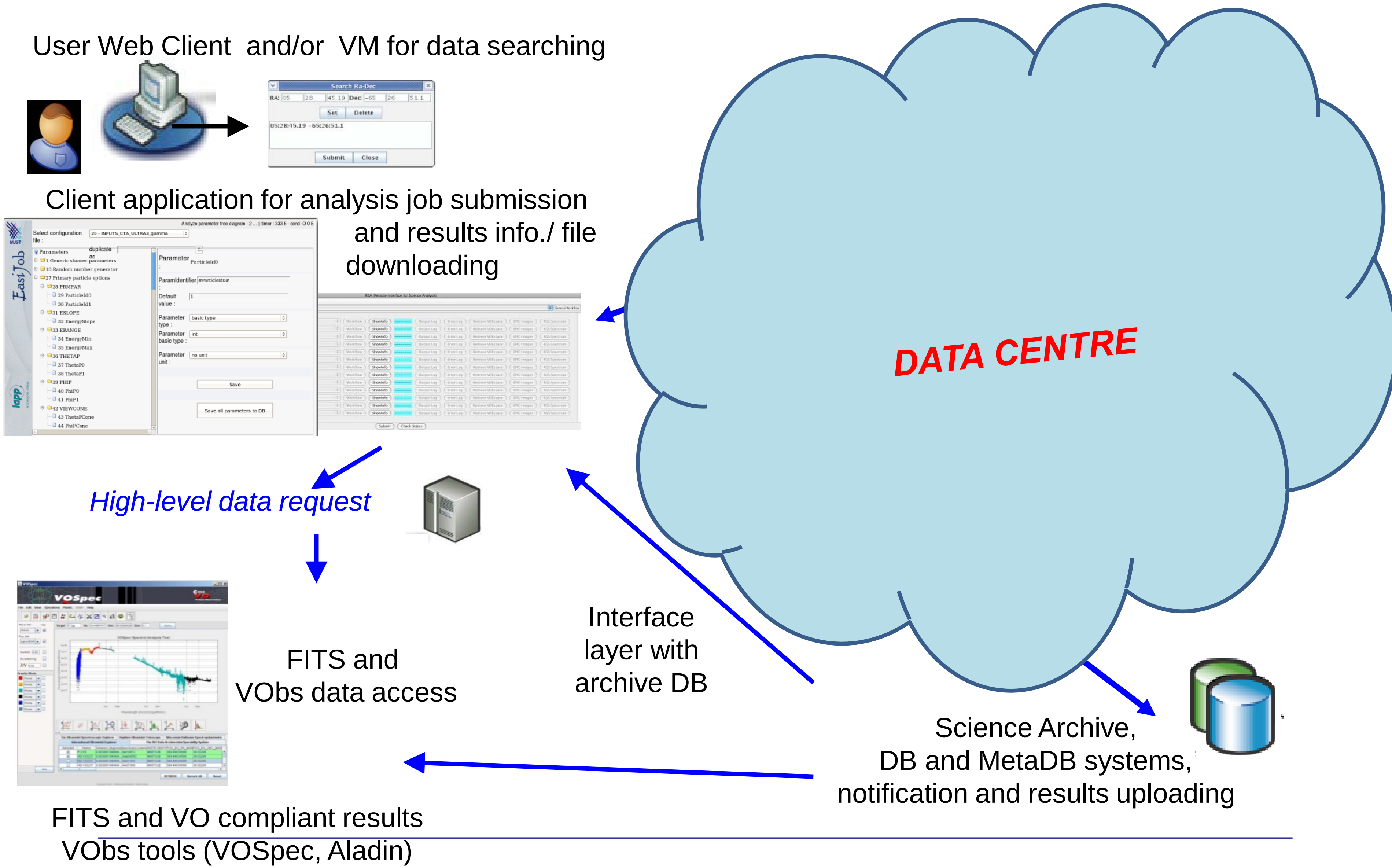
FITS and VObs data access

Interface layer with archive DB

Science Archive,
DB and MetaDB systems,
notification and results uploading

FITS and VO compliant results
VObs tools (VOSpec, Aladin)

The Scientific Analysis System without any computing model specification



Gateway and Virtualization

- Generalize the web-services and the web-environment at any level of the user interface to the SAS.
- Follow-up the modern tendency (biased by vendors) to keep user (of any level) connected by low-memory modern devices (Smartphone, pads…)

Towards a virtual web-oriented **Gateway** where a larger community will be uploaded and further cooperate.

-> Cloud (for science) @ IN2P3

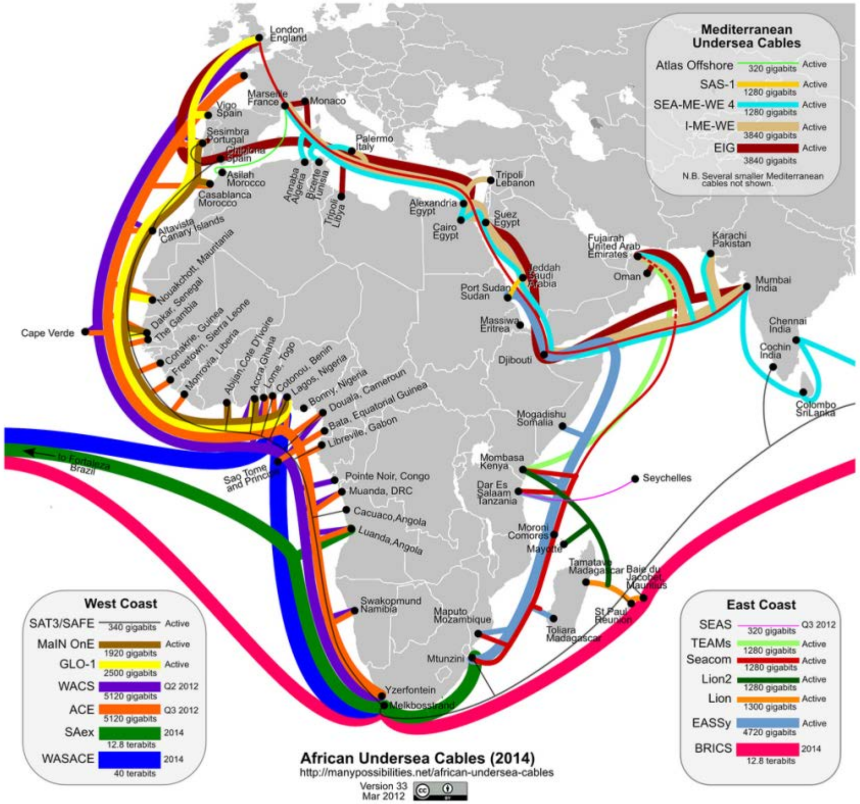
- 1) IaaS on demand of CTA consortium users
  (secure and cooperative approach for analysis workload management)
  Evolution of Data Center (in progress @ CCIN2P3)

- 2) SaaS on demand of any user (+ guest observers and archive users)
  (configuring his/her own dedicated dashboard and consuming software on demand)
  "Liferay" technology is currently explored

Data transmission (pipeline)

The new and powerful intercontinental oceanic networks open new perspectives for the computing, data management and operational models of CTA, e.g :

-ACE/WACS (5.1 Tb/s) South Africa-Namibia-
-Canaries-Europe is under tests.
- WASACE (40 Tb/s) South Africa-South America
-Brazil-USA-Europe in 2014.



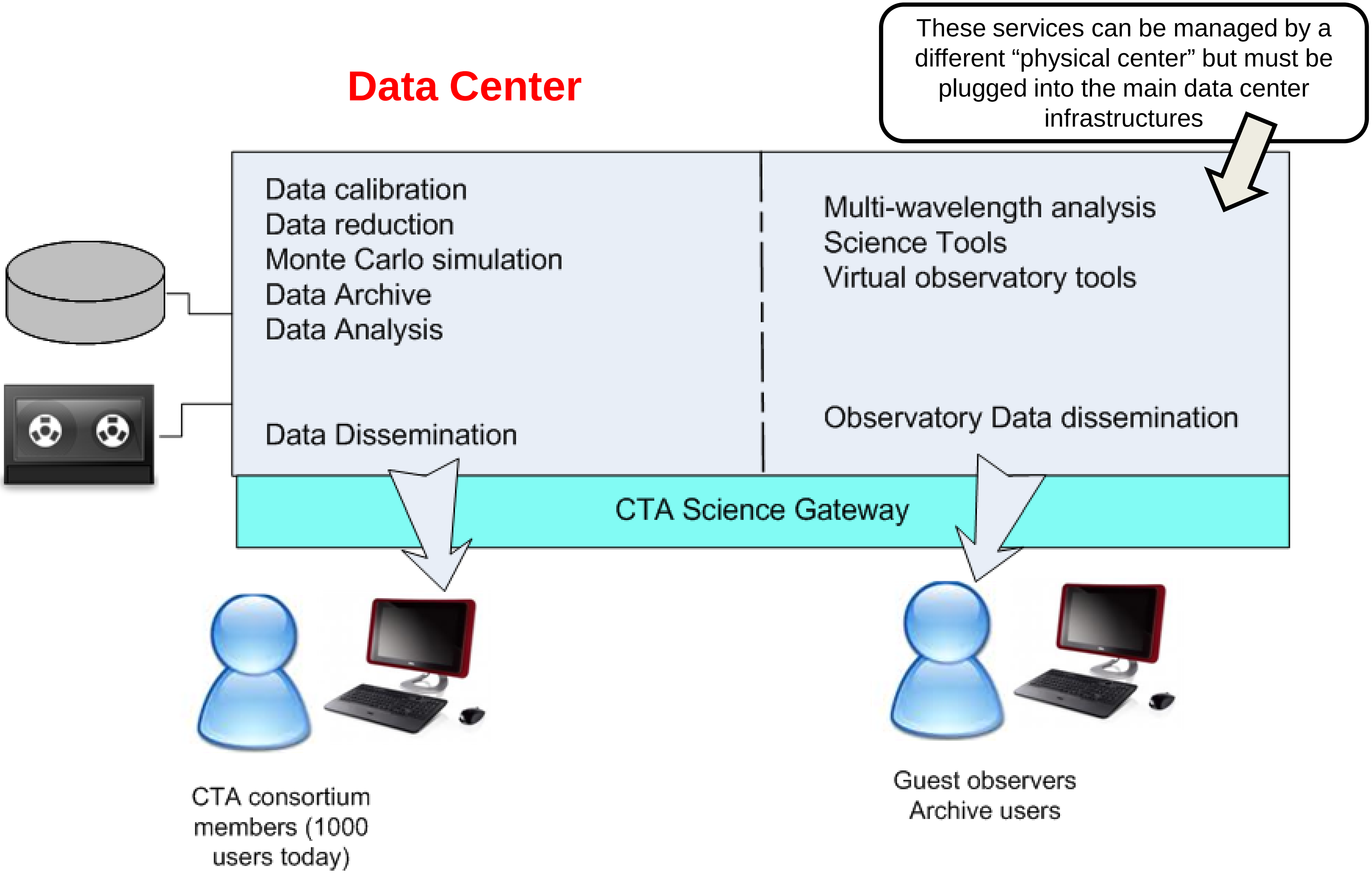
High-bandwidth and reliable network.
data transmission enables :

- Real time <u>remote</u> data processing.
- Remote quick look, monitoring and control
- Interdisciplinary (atmosphere , geo-studies) ?
- Societal benefit

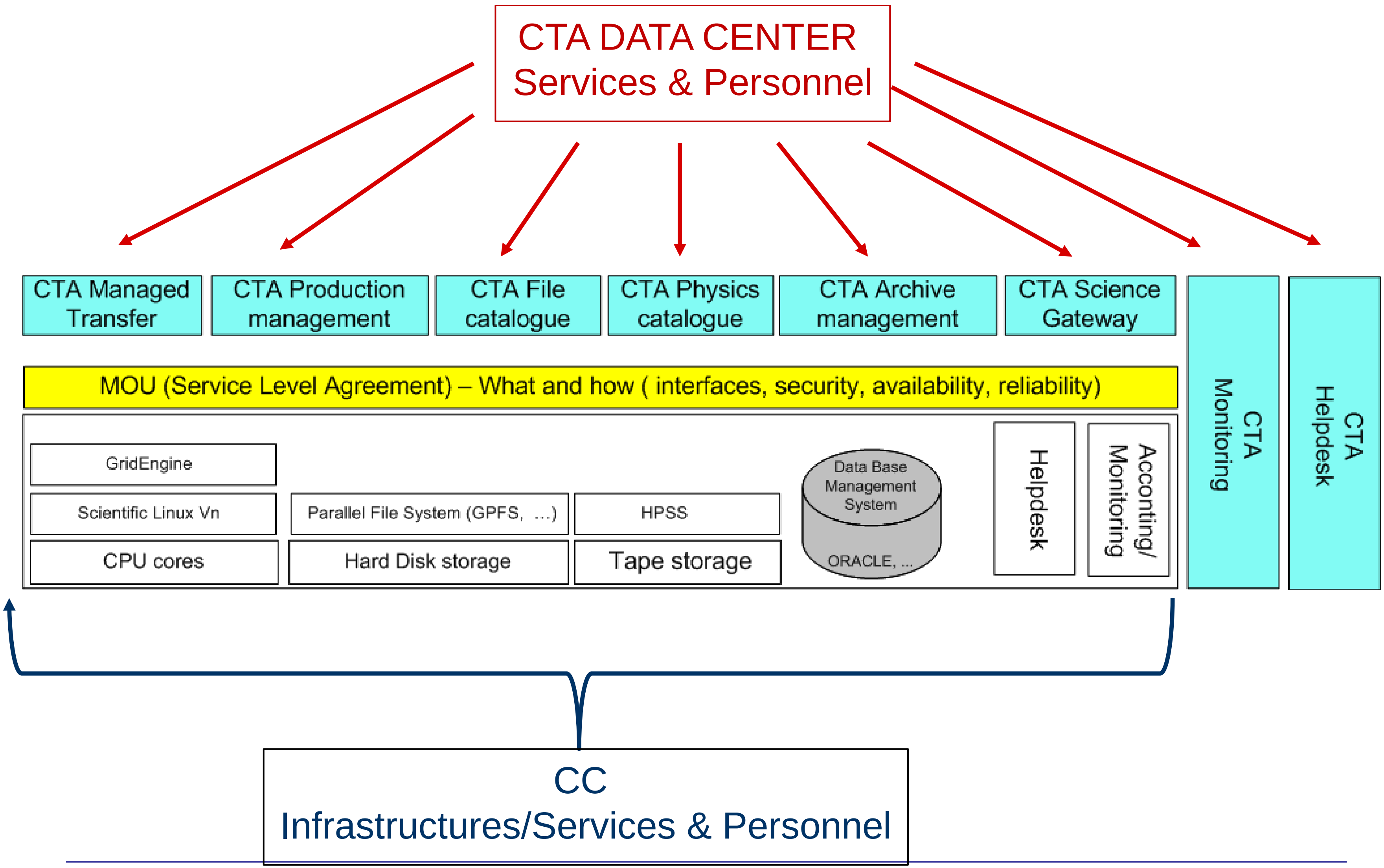
Proposed scenario: EC-contract among IN2P3 (and French NREN Renater), CTA host countries & GEANT in order to provide the bandwidth between the CTA sites and Europe.

Studying a Computing Model for CTA
(and the computing @ IN2P3)

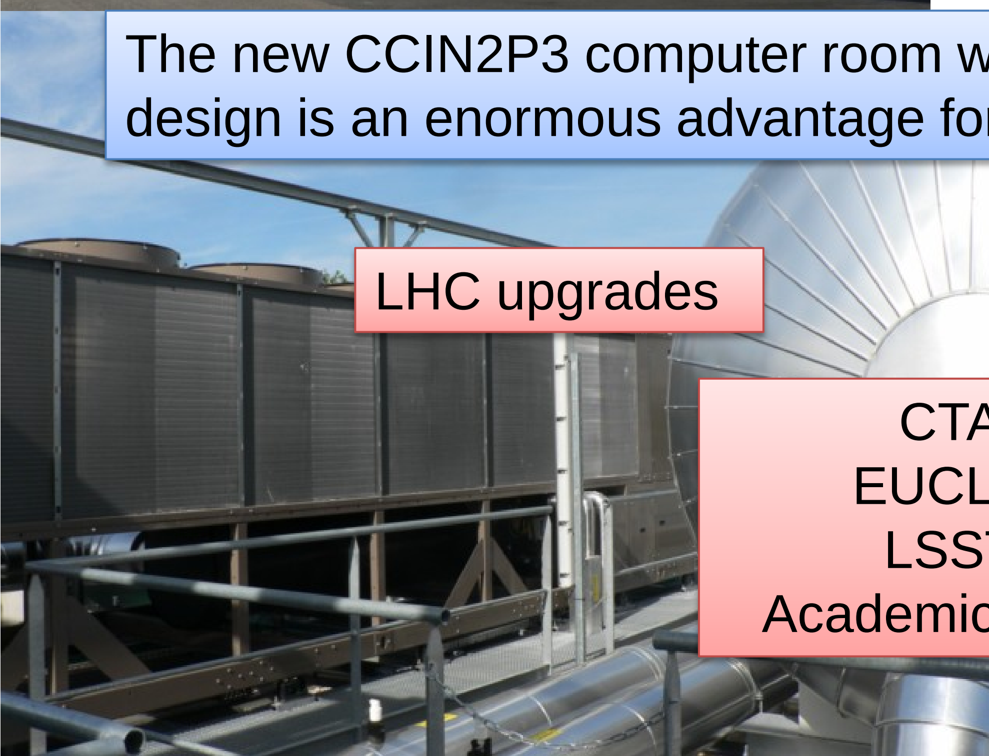
Data Center operational concept

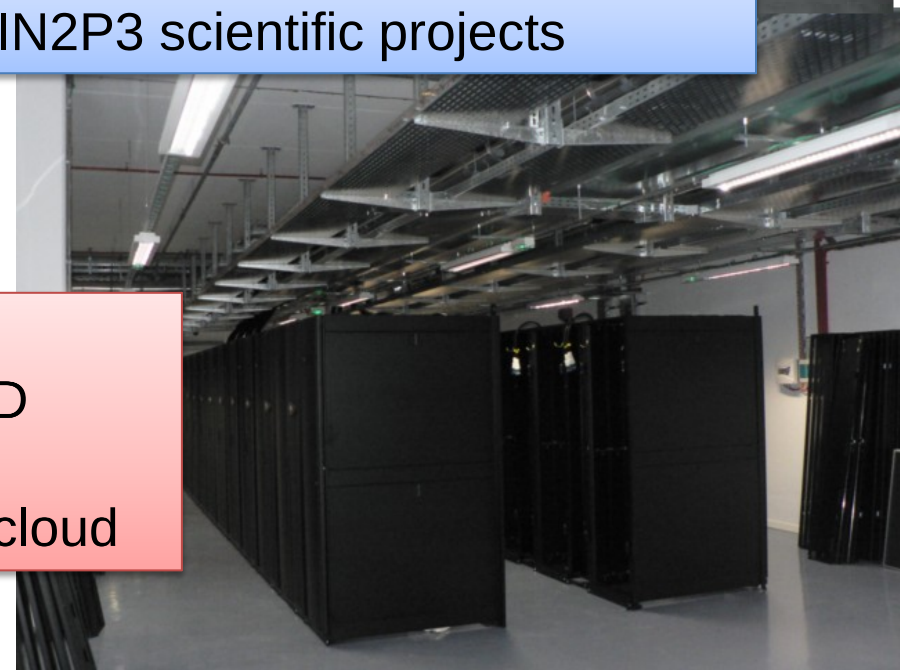


Data center concept



The new CCIN2P3 computer room with its innovative and modular design is an enormous advantage for IN2P3 scientific projects





LHC upgrades

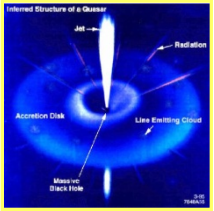
CTA
EUCLID
LSST
Academic cloud

Large **S**ize **T**elescope

LST: the scientific cases

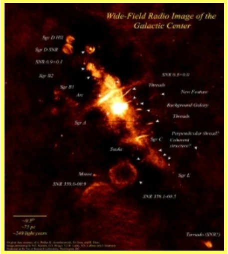
The Sub-array of **Large Size Telescopes** optimized for the energy range **20-200 GeV**


Binaries and transients



High-redshift AGNs (z<2)

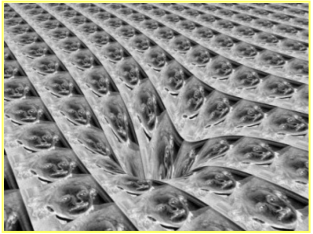

GRBs (z<4)

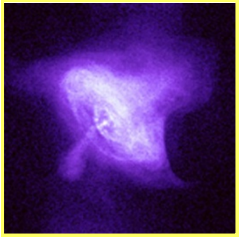


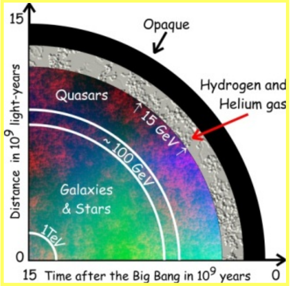
Dark matter

For all key Astroparticle Physics cases:

- ✓ High-redshift AGNs and GRBs, *Expand the Gamma-Ray Horizon*
- ✓ Dark Matter, Cosmology and fundamental physics
- ✓ Binaries, Pulsars and other type of transients at low energy.


Space-time & relativity


Pulsars and PWN



Cosmology

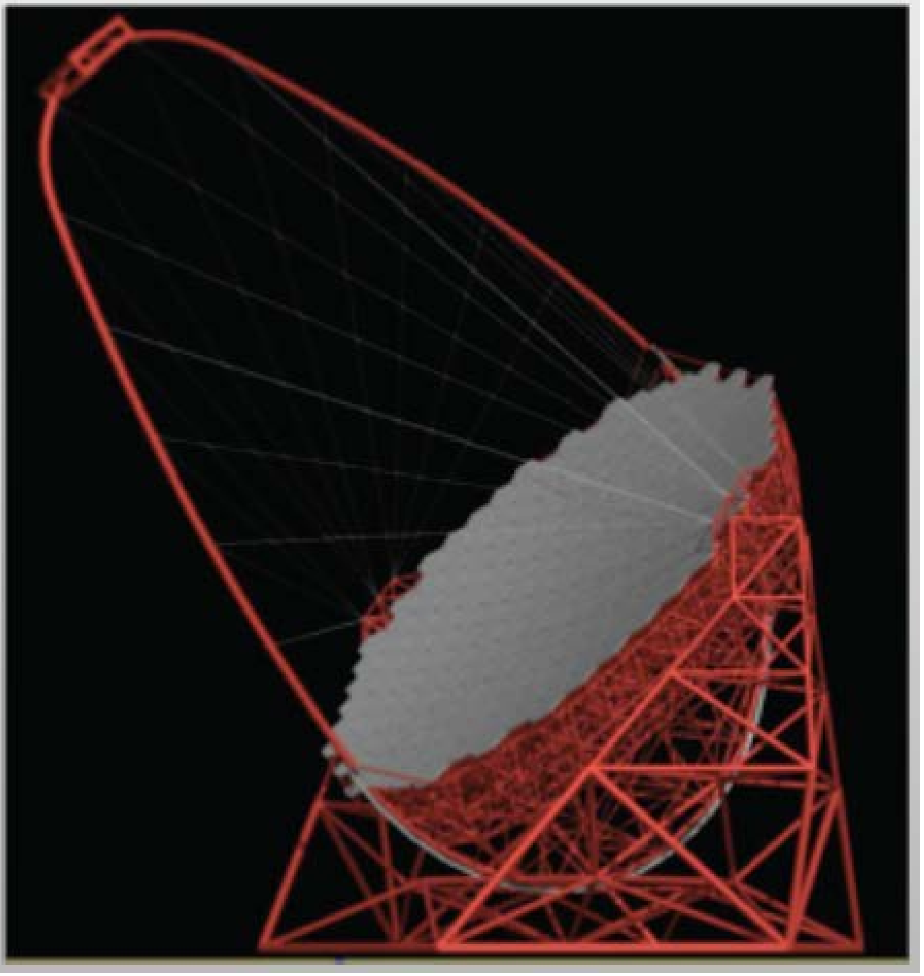
LST specifications

- Diameter: 23m
- Dish area: 407 m^2
- F/D = 1.2, F=28m
- Dish profile: Parabolic
- Permanent Active Mirror Control

- FOV = 4.5 degrees, Pixel size = 0.1 degrees (1855ch camera)

- Total weight ~ 60 tons
- Fast rotation: <180 deg/20 sec

- Dish profile: parabolic ➔ isochronicity: <0.6 ns RMS
- Camera sagging: < 1 pixels
- Camera oscillation in wind gust: <8mm



CTA LST project

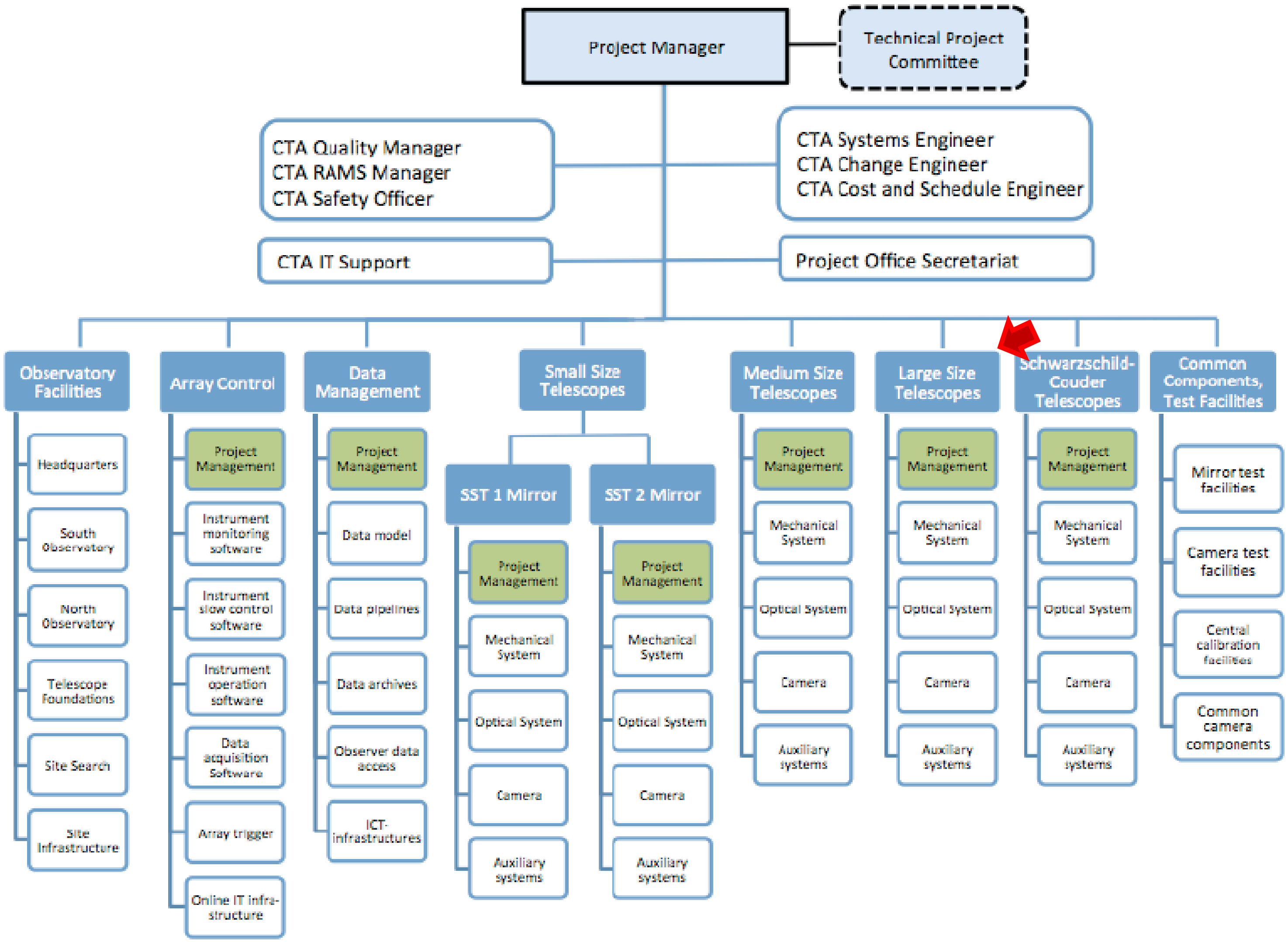
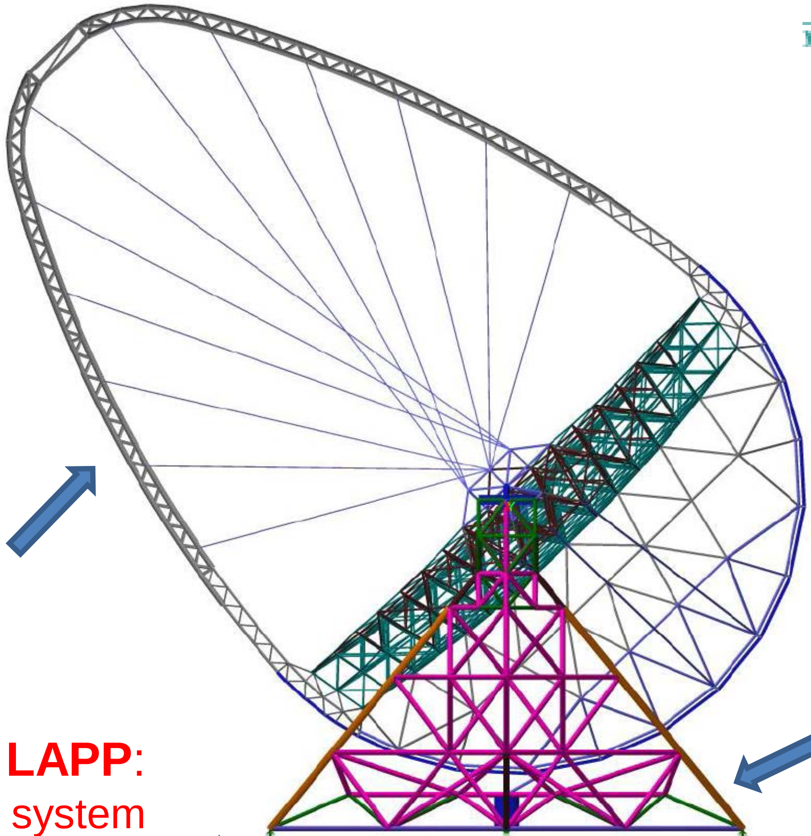


Figure 3 : Organigram of the Project Management.

LST design of the mechanical structures.

CIEMAT:
Inner camera mechanics

LAPP:
Camera mast (arch), camera housing and and active mast control.



MPI-M: mount, dish, mirror mounts, global structure.

IFAE:
Lower structures, rails and bogies

LAPP:
Drive system

LST arch + camera frame

Light (< 2.5 tons) and strong design (28 m focal length for 2 tons camera weight), minimal shadow on the dish, fast (GRB) repointing of ~5 m/s: conception, design, simulation, calculations, prototypes, tests and production.

Conception and design:

Hybrid discrete components (tubes) in Carbon Fibers tightened on interface components (industrial partnership).

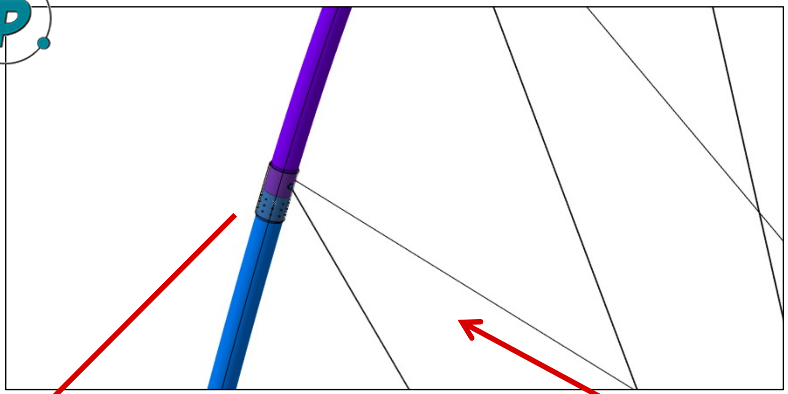
Pre-peg ("Epoxy pre-impregnated into the fibers") technology

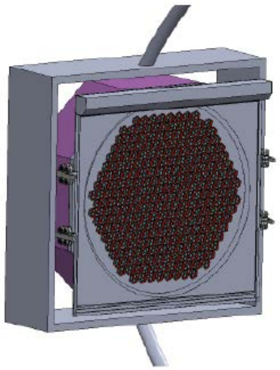
Pre-peg technology :

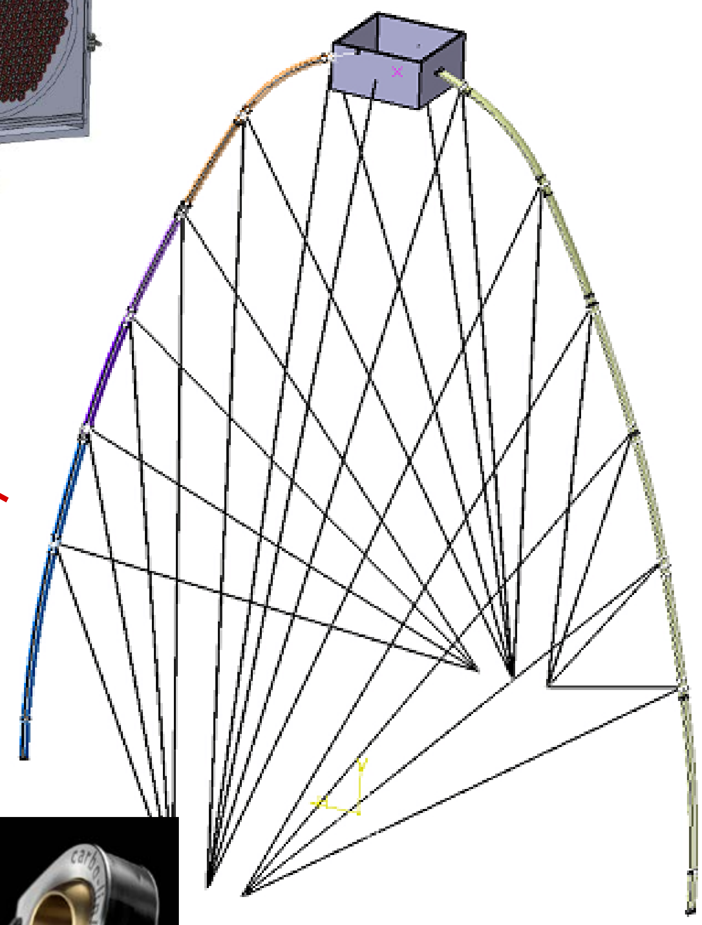
Fiber orientation flexibility (0°)
Better & well known resin / fiber volumic ratio
Glass transition temperature higher
Local reinforcement possible
Mechanical dedicated simulation tools

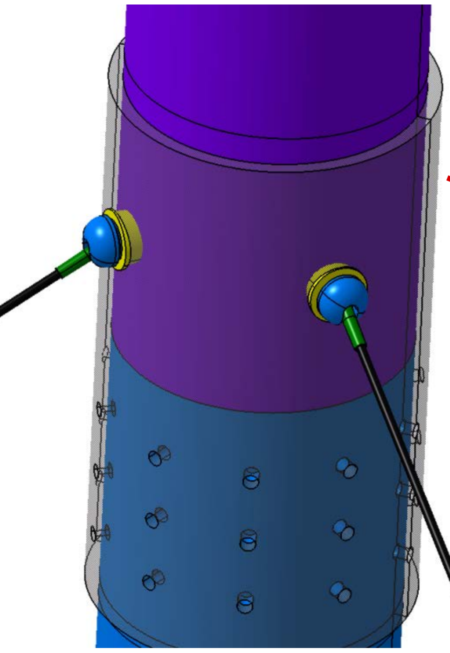
Simulations and calculations (READY by December 2012).
International Readiness Review (14-15 March 2013)
Prototypes and test (during 2013)
LST production and safety review (2014)

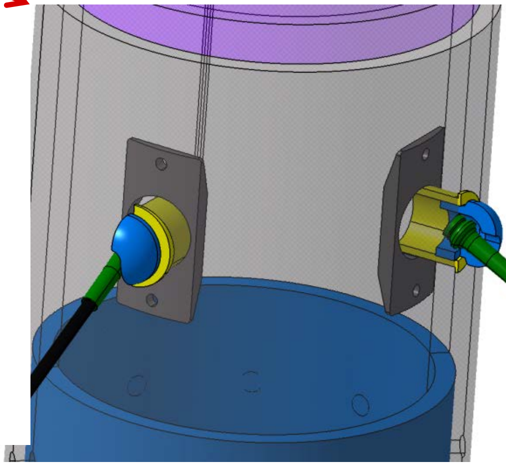
LST arch + camera frame

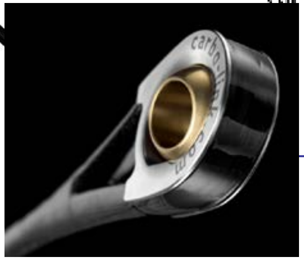






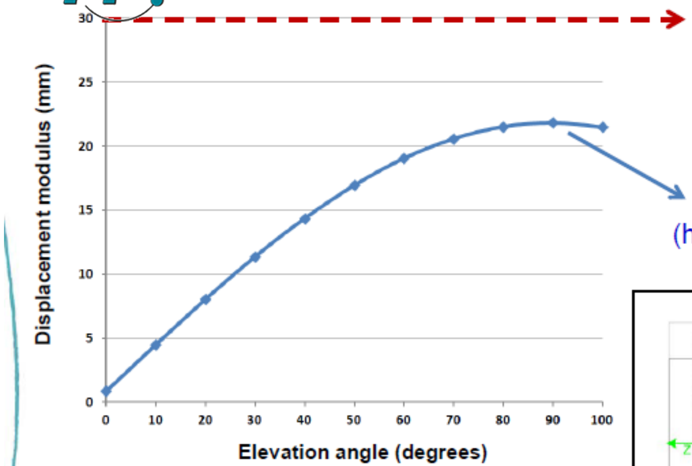


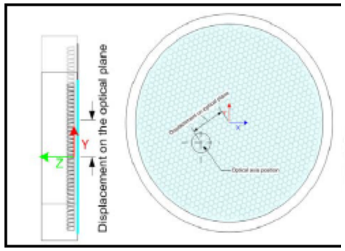




Simulations: static and dynamic load cases

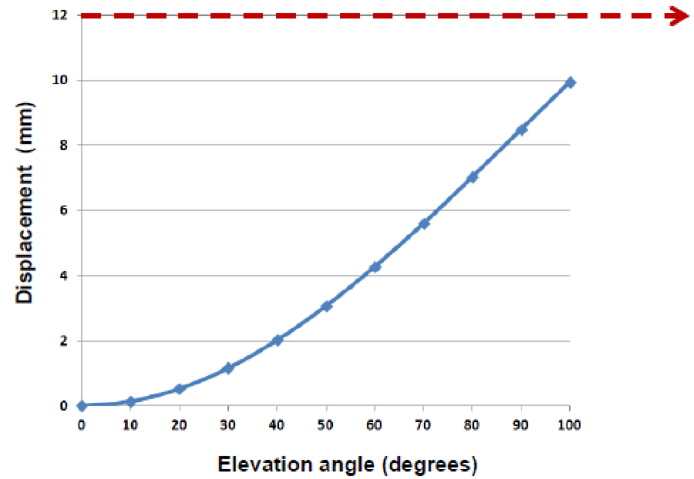
Static displacements in the focal plane as a function of elevation





Same results, with 0° as a reference for better understanding

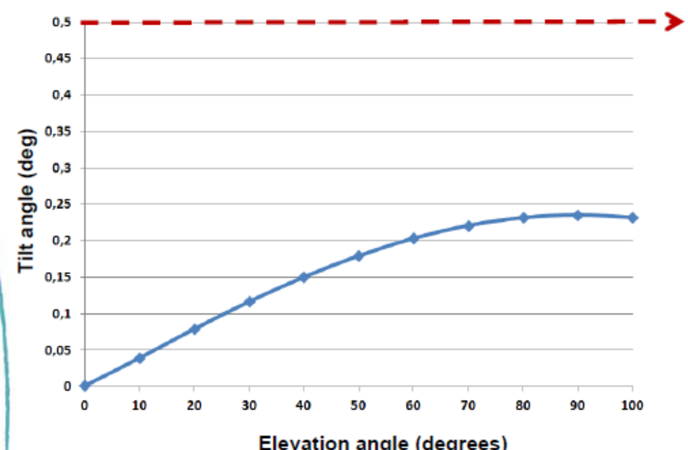
Evolution of the focal distance as a function of elevation

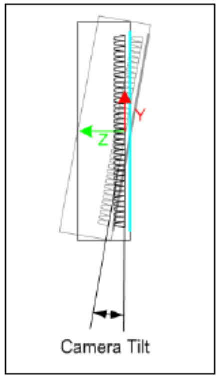


Preliminary achievements vs specifications (under some modeling assumptions)

- A series of acceleration cases examined, e.g. the fast pointing for GRB follow-up:
  2 tons camera moving at a mean speed of ~5 m/s

Evolution of the tilt as a function of elevation





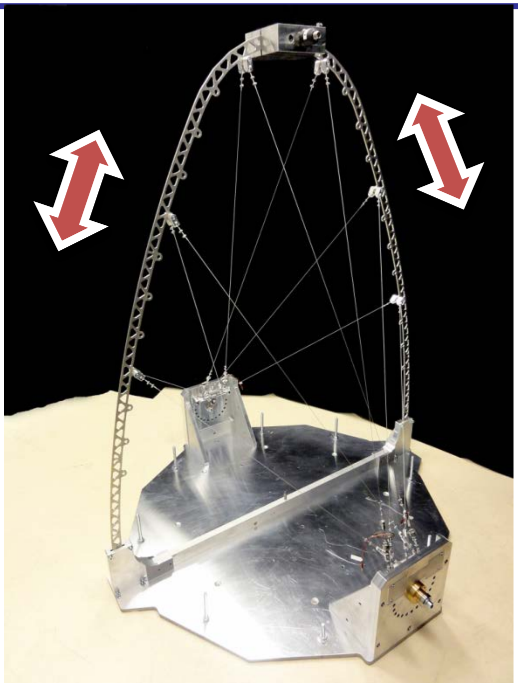
NB : tilt = 3D angle and not in-plane angle

LST mechatronics (R&D)

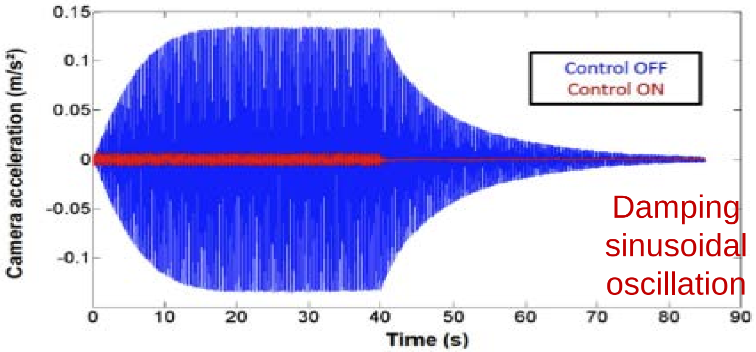
To add the stabilization of the camera an R&D project started in 2010: Active camera damping and control system

-> R&D: Mock-up prototype designed and tested (DONE !)
-> Real size detailed design study (READY by 2013).

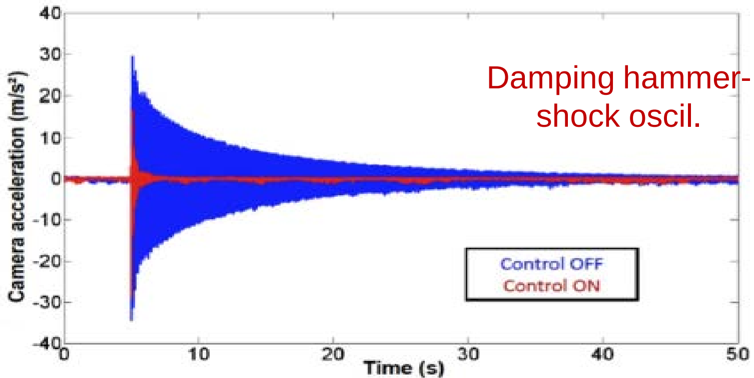
A mechatronic damping device stabilizing the camera and fast position control



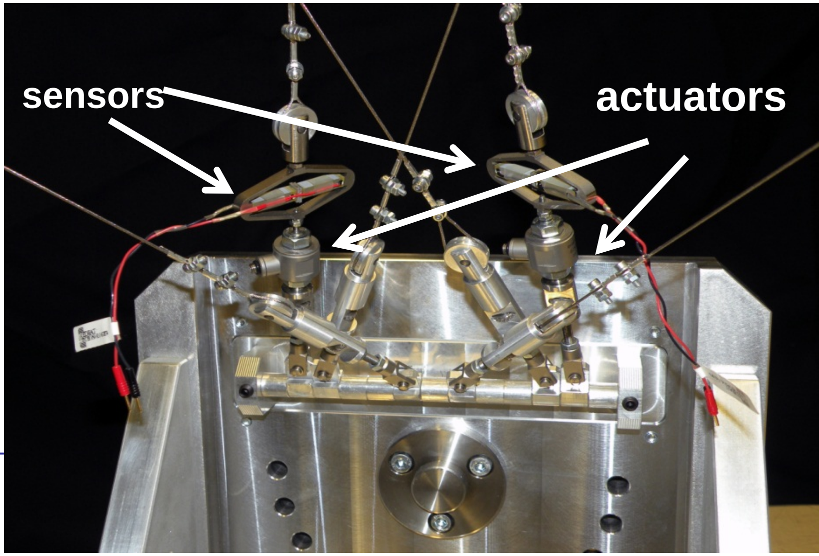
Ropes instrumented with sensors and actuators



Damping sinusoidal oscillation



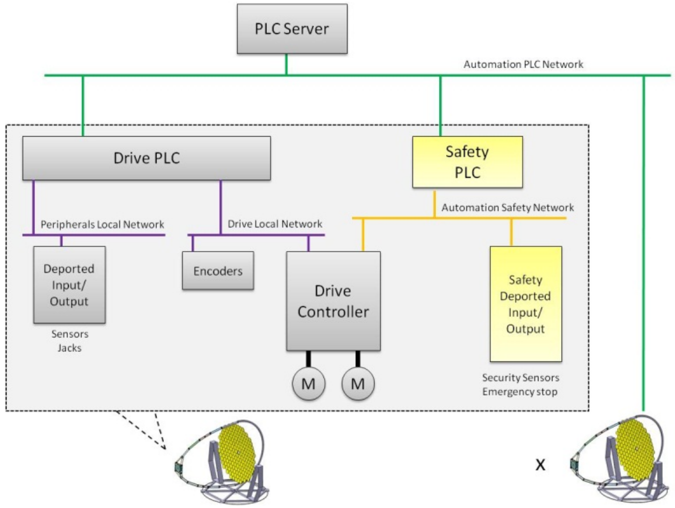
Damping hammer-shock oscil.



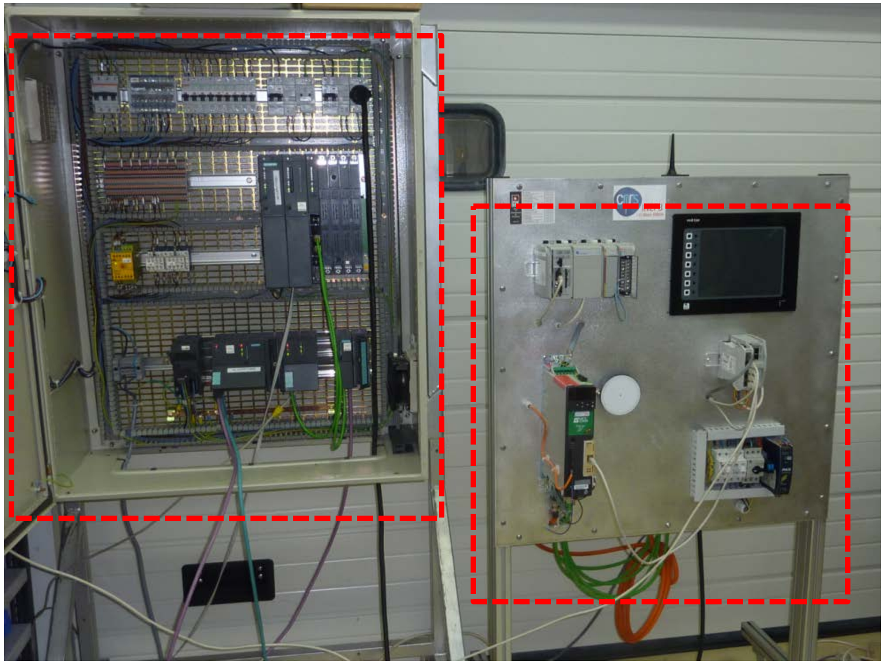
- *CS IN2P3*

LST mechatronics: Drive system / Array control

The **LSTs array control** interfaces the "**Drive System**" (control, command and safety of the telescope motions as well as other auxiliary systems, including the cameras:



Automation architecture



Test bench and prototype based on PLC and OPC-UA technology:

-> Control of LST telescope-drive

-> Design study and validation of communications, safety and control of components

-> Integration of heterogeneous equipment using OPC UA Server

LAPP test bench

_ 1 PLC server
_ 1 Drive PLC
_ 1 Safety PLC

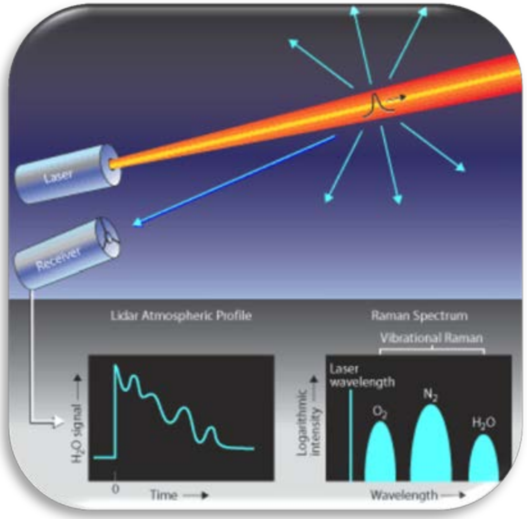
LUPM - LIDAR test bench

_ 1 PLC
_ 1 Motor
_ 1 Variator

LIDAR

RAMAN LIDAR PROJECT

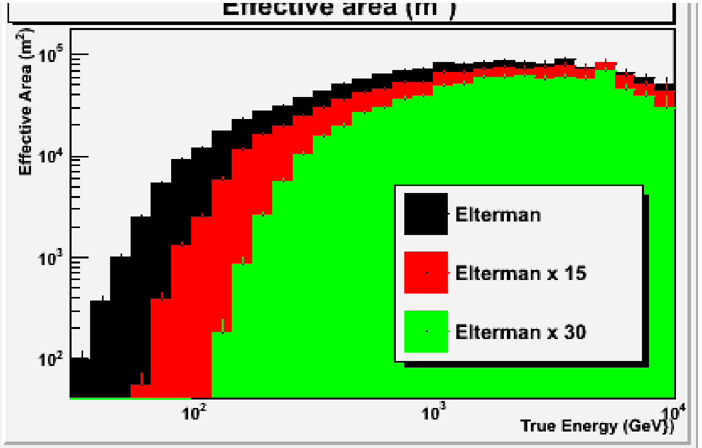
- Atmosphere acts as calorimeter for IACTs, need to understand its properties to correct for :
  - Energy bias and resolution
  - Reconstructed spectral index and flux
  - Energy threshold
  - Angular bias and resolution?



Light propagation in the atmosphere is affected by:

- Absorption and scattering from molecules → Rayleigh-theory → quite easy
- Absorption and scattering from aerosols→ Mie or other theories→ complex

Model	$\log_{10}(dN/dE)\|_{100\ \mathrm{GeV}}$ [$\mathrm{GeV}^{-1}\ \mathrm{m}^{-2}$]	Spectral Index
Elt-1	-1.483 ± 0.011	1.985 ± 0.015
Cl-6	$-1.476 \pm 0.015\ (0.3\,\sigma)$	$1.991 \pm 0.018\ (0.3\,\sigma)$
Cl-6 (wrong MC)	$-1.589 \pm 0.019\ (5\,\sigma)$	$2.044 \pm 0.016\ (2.7\,\sigma)$
Cl-10	$-1.478 \pm 0.015\ (0.3\,\sigma)$	$1.993 \pm 0.018\ (0.3\,\sigma)$
Cl-10 (wrong MC)	$-1.646 \pm 0.012\ (10\,\sigma)$	$1.966 \pm 0.016\ (0.8\,\sigma)$
Cl-14	$-1.475 \pm 0.013\ (0.5\,\sigma)$	$1.993 \pm 0.016\ (0.4\,\sigma)$
Cl-14 (wrong MC)	$-1.548 \pm 0.016\ (3.3\,\sigma)$	$1.958 \pm 0.015\ (1.3\,\sigma)$



LUPM RAMAN LIDAR

- Project within the Calibration Central Facilities WP
  - (ex-ATAC WP/Coord LUPM)

- International Coll. (IFAE/UAB/CIEMAT/LUPM)
  - Similar Hardware Base (CLUE Exp Container)
  - Common Mechanical Components
  - Simulation Studies (MC and Optical ZEMAX on)

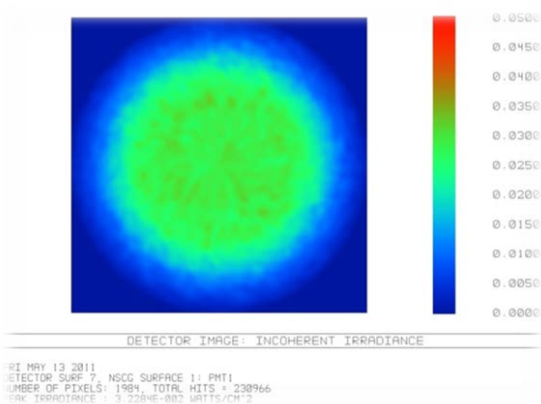
- No prototyping; All LIDARS will be build and tested beginning 2014 and installed at the final CTA sites

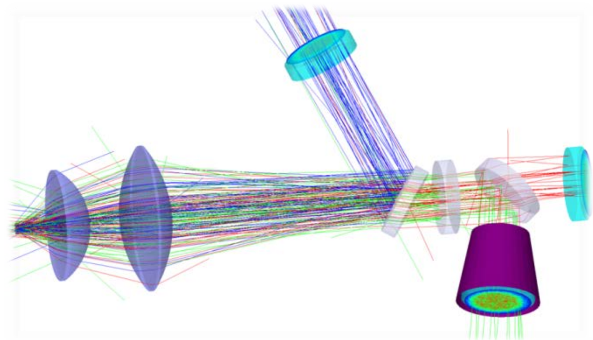
- Three LIDAR to be build

  North CTA Site (IFAE/UAB)
  South CTA Site (LUPM & CIEMAT)

Project Status

- Initial Optical Simulations as of the optimization of the Raman Optical Bench Completed.





- Currently finalizing the mechanical integration and dish reinforcement.
- Test the ACTL-CTA compatible daq automated system.
- Test and assembly of the Raman Optical test bench
- Final assembly and first tests to be performed at LUPM by the end of 2013.

CLOCK and ARRAY TRIGGER

Clock Distribution and Array Trigger

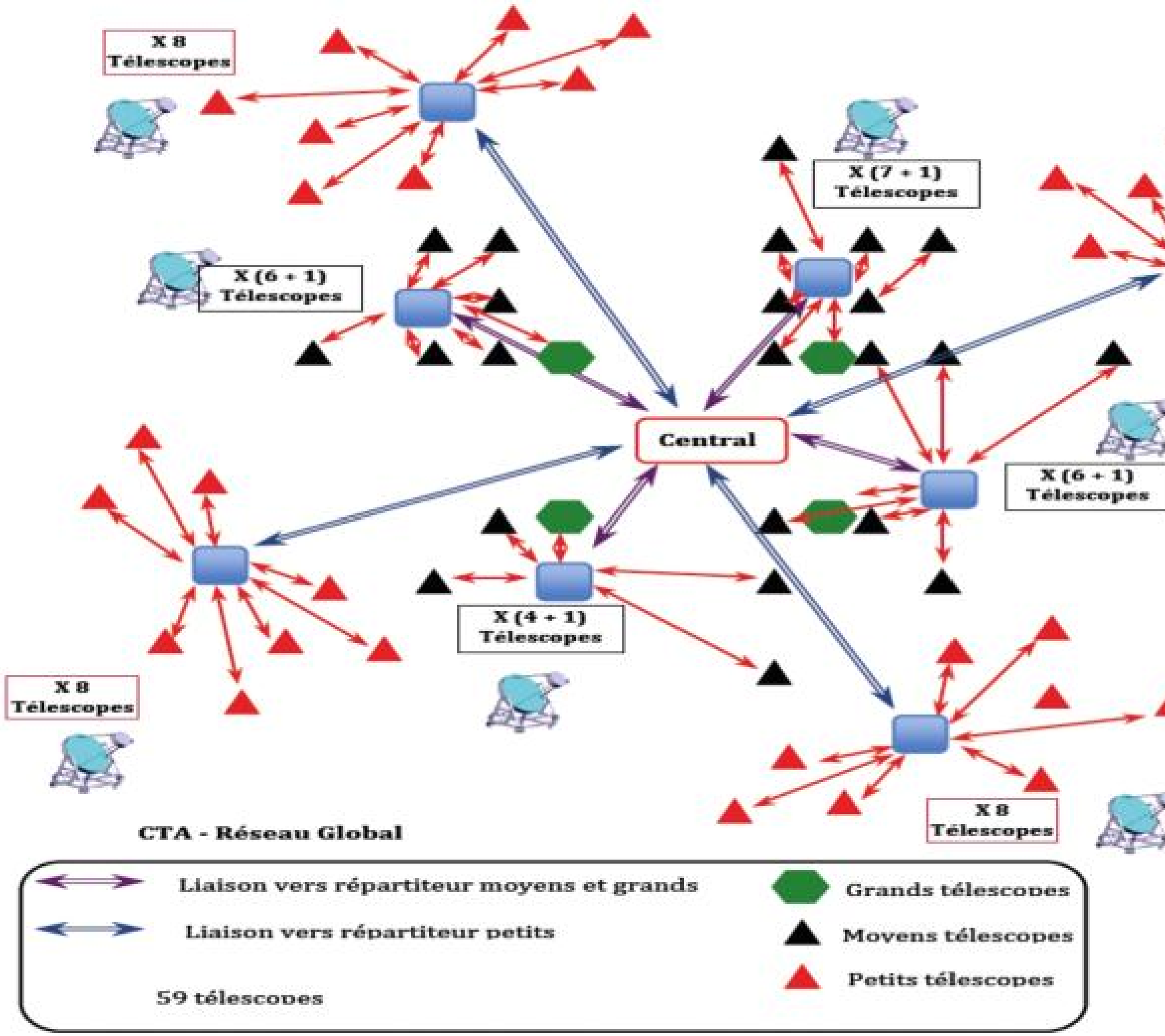
For the stereoscopic triggering of the telescopes in CTA,

APC is working on an approach based on :

- Distribution of a high-precision clock from a central location (star-distribution)
- Time-tagging camera events (or partial events) using this clock
- Collecting streams of time-tags in a central trigger crate
  and checking for coincidence in software
- Then sending the streams of coincident time-tags *either*
  (depending on bottleneck):
  - to relevant cameras, to ask for data
    to be sent to central
  - to central farm of processors which hold events
    in memory, identify events to be written to disk

Clock Distribution and Array Trigger

Distribution d'horloge (haute précision)



Array Trigger: For What? How?

Why an Array trigger?

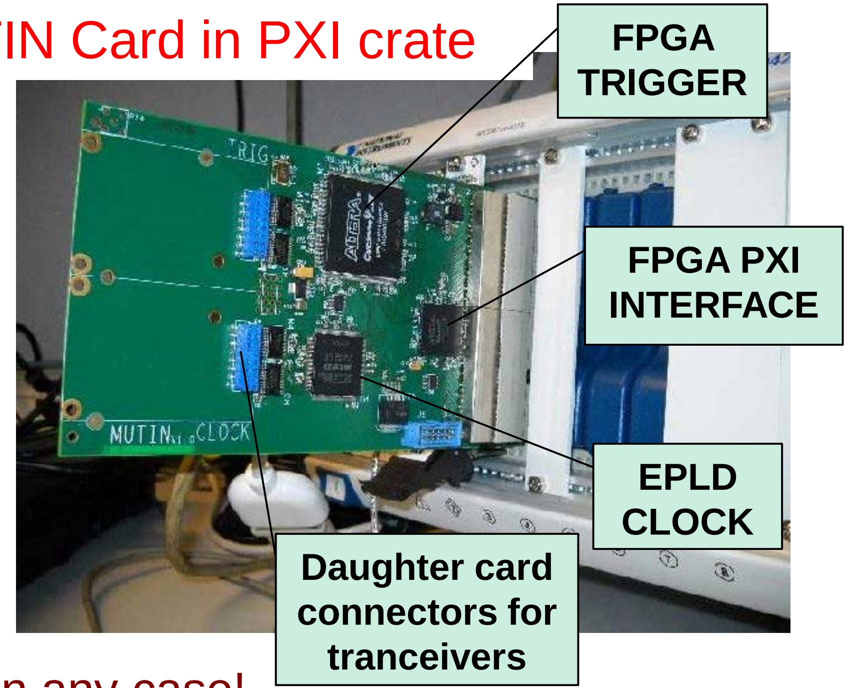
- Reducing the amount of data to transfer over ethernet or to be written to disks (up to 50%)
- Reducing amount of data to be searched
- Detecting telescope failures : if participation rate of a telescope in stereo triggers drops or rises

How an Array trigger?

- Distribution (Clock & Time-stamps) over optical fibres using SerDes and commercial off-the-shelf (COTS) components
- Functionality implemented on custom-built MUTIN boards (Multi-use Telescope interface) for testing to adapted for final use-cases

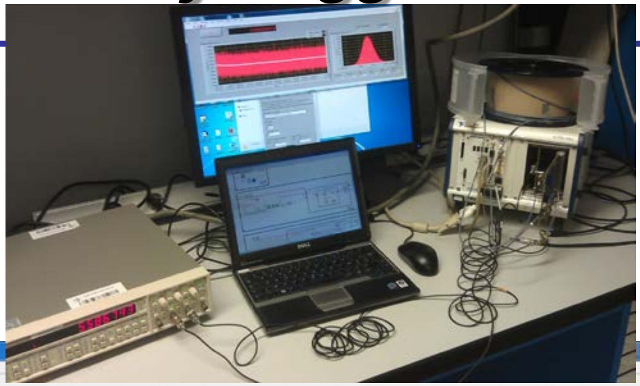
Commercial bidirectional tranceivers

MUTIN Card in PXI crate



Note!! Clock Distribution to 1-2ns is needed in any case!

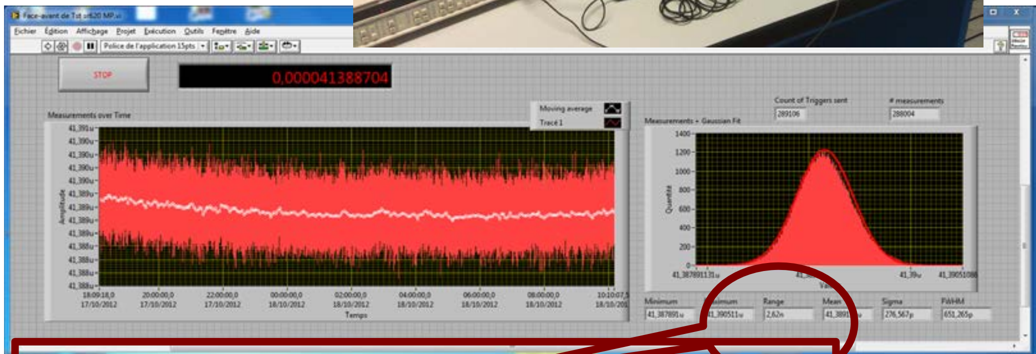
Clock distribution & Array Trigger Status



- Currently, test-bench confirms that measurement of time-calibration (jitter) achievable to ~1ns
- Time-stamping to ~2ns implemented on MUTIN FPGA
- Tests to commence on time-stamp

  e.g. Test jitter over the return journey, 2 x 4 km fibre

  (including 5 optical connectors)



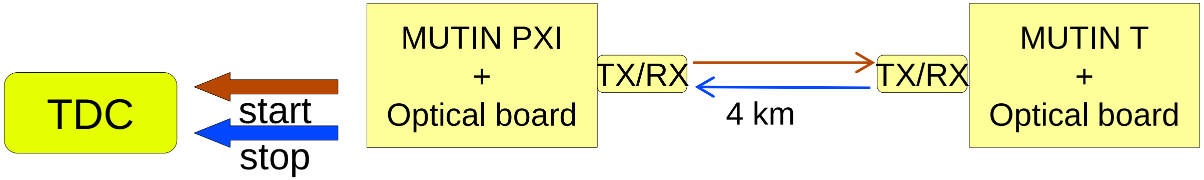
σ = 276 ps

Reliable Clock Distribution

(some temp. drift over 16h to be corrected)

- Building demonstrator

  (array of scintillators,
  for particle-shower coincidences)



- *Context/competition:* More costly scheme investigated @ DESY (using White Rabbit), or no array trigger (“software coincidences”) requiring all data stored, no monitoring

MERCI