# Metodologie di Calcolo in Auger

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# Pierre Auger Observatory

Studio della radiazione cosmica di altissima energia ($10^{17}$-$10^{21}$ eV)

- Spettro di Energia
- Composizione
- Direzione di Arrivo

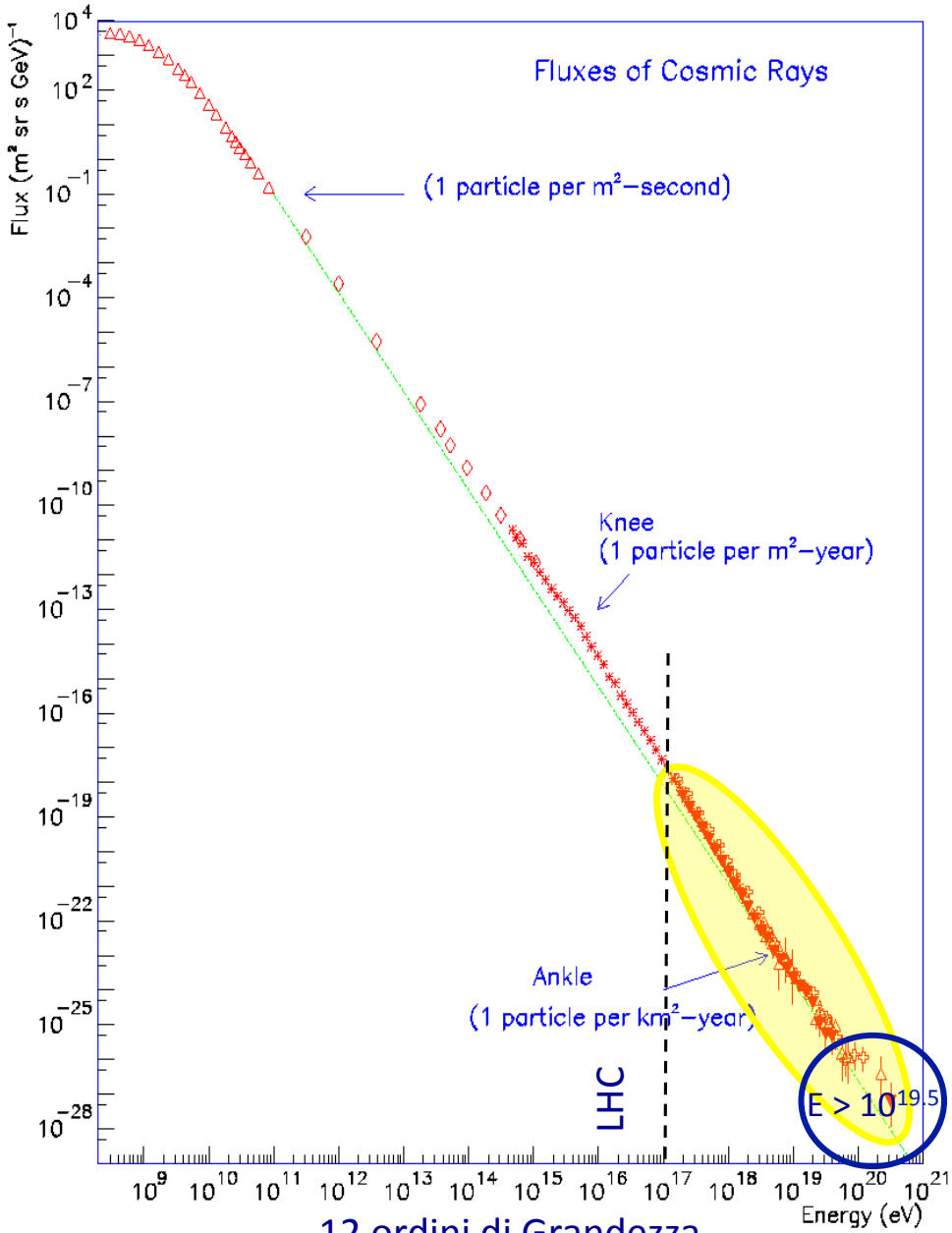
Flusso a E > $10^{19.5}$ eV estremamente basso

1 particella/(Km$^2$ sr secolo)

Apparato di grandi dimensioni:

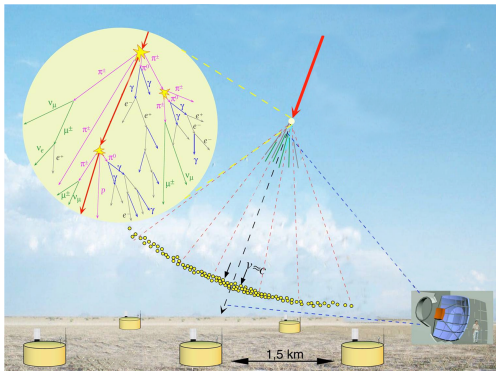
Pierre Auger 3000 Km$^2$

30 Eventi/Anno



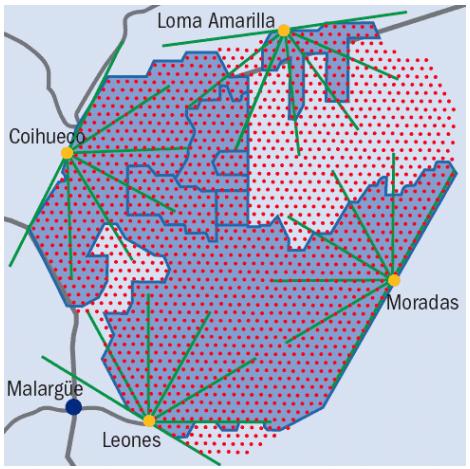

12 ordini di Grandezza

# Pierre Auger Observatory




The Auger Observatory is a hybrid detector, with two independent methods to detect HE cosmic rays. One technique detects particles in interaction with water in surface detector tanks. The other tracks the air showers development by observing ultraviolet light emitted high in atmosphere. The hybrid nature provides for two complementary ways to see cosmic rays.

- Surface Detectors
  - 1660 rivelatori Cherenkov (12000 l di acqua).
    Area di 3000 $Km^2$ su griglia esagonale (passo 1.6 Km).
  - 85 rivelatori Cherenkov + Contatori a scintillazione per muoni.
    Area di 24 $Km^2$ su griglia esagonale (passo 0.4 e 0.7 Km) infilled nella griglia principale.
  - AugerPrime. Aggiunta di uno scintillatore plastico di 4 $m^2$ sopra I 1660 rivelatori Cherenkov




- Fluorescence Detectors
  - 24 telescopi a Fluorescenza organizzati in 4 siti.
    10560 Pmts (440 x 6), 6 telescopi per sito.
  - 3 telescopi a Fluorescenza, inclinazione 0 e 60 gradi, un sito.
    1320 Pmts (440 x 3).
- AERA radio stations
  - 124 LPDA logarithmic-periodic dipole antennas
    Area di 6 $Km^2$ su griglia quadrata (passo 150 metri)

# Pierre Auger Observatory

The Observatory makes use of the atmosphere as a giant calorimeter.

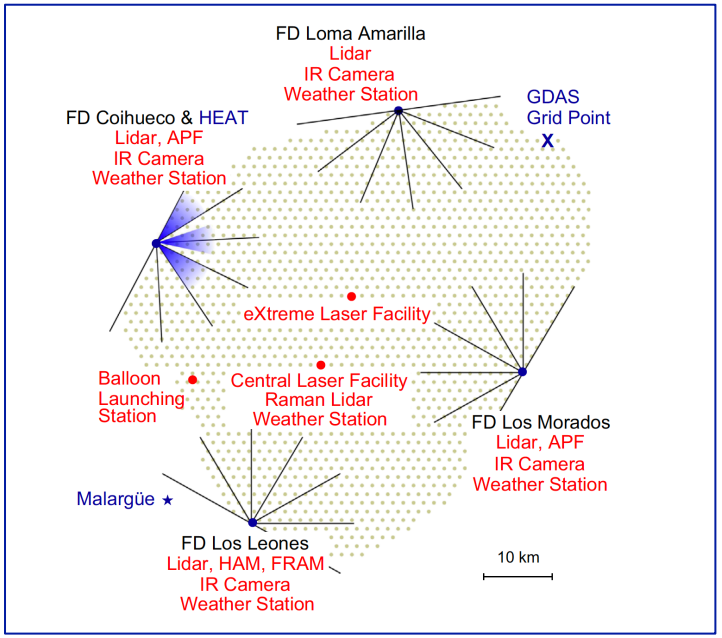
The atmospheric state variables, i.e. temperature, pressure and humidity, are needed to assess the longitudinal development of extensive air showers as well as the amount of the isotropically emitted fluorescence light induced.

The SD observations are altered by different atmospheric conditions.

Aerosols and clouds represent the most dynamic monitoring and calibration challenges at the Observatory.

Atmospheric measurements performed and the instruments that are used.

| Category | Variable | Frequency | Instrument(s) |
|---|---|---|---|
| State | At ground: pressure, temp., wind, humidity | 5 min | Weather stations |
| | Profile: pressure, temp., humidity | 3 h | GDAS[a] |
| Aerosols | Vert. optical depth ($z$) | Hourly | CLF, XLF + FD |
| | Phase function | Hourly | 2 APF units |
| | Ångström coefficient | Hourly | FRAM (HAM) |
| Clouds | Presence in FD pixels | 15 min | 4 cloud cameras |
| | Behind FD sites | 15 min | 4 lidar stations |
| | Along select tracks | Avg. 1/night | FRAM, lidar |
| | Above CLF/XLF | Hourly | CLF, XLF + FD |




**Involvement of Atmospheric monitoring in analyses**

preliminary

**Hybrid spectrum**
cloud coverage (Lidar database), Aerosol DB (CLF and RAMAN), Molecular DB (related instruments)

**FD/SD Calibration**
the same as for the hybrid spectrum

**Xmax, Cross Section, Muon Excess**
the same as for the hybrid spectrum plus Cloud Cameras and GOES

**hybrid photon search**
the same as before plus cloud camera in case the Lidar DB is missing and for checking the candidates

**SD spectra**
weather stations

**weather effect**
CLF weather station

**Muon production depth**
Molecular DB (related instruments)

Horizontal uniformity: Lidar

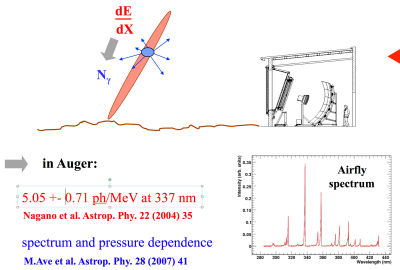
Double bump showers: FRAM

Side scattering correction: APF

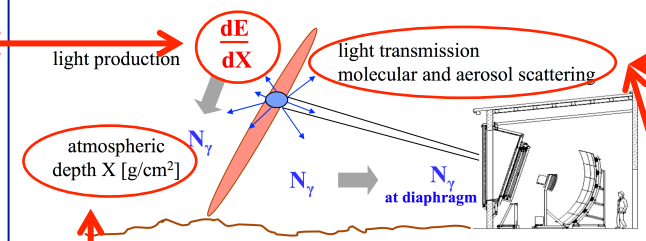
→ Specific analyses

# Ricostruzione di un evento FD.

## FLUORESCENCE YIELD




## ATMOSPHERIC MONITORING




**Atmospheric monitoring**

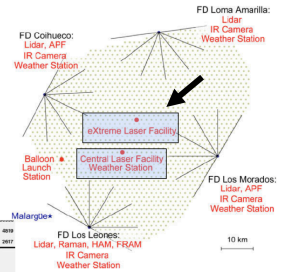
pressure, temperature and umidity

aerosols (clouds, dust, smoke, …)

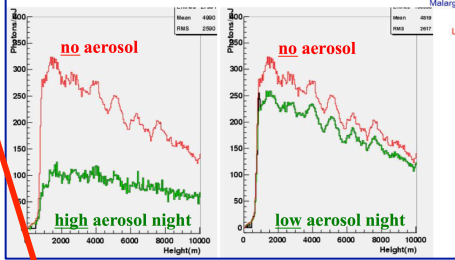
## ATMOSPHERIC MONITORING

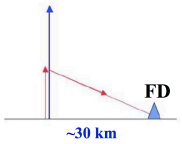
**355 nm steerable laser**

**50 shots every 15 min**

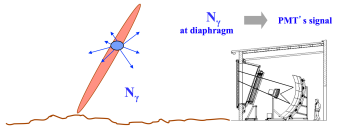



Laser profiles measured by FD



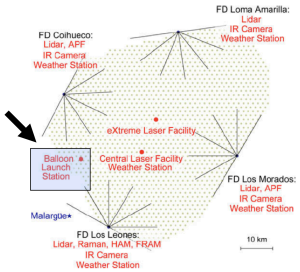

## FD CALIBRATION



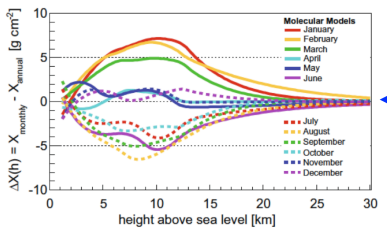

**We need to know the number of photons at diaphragm per ADC count detected by each pixel**

## ATMOSPHERIC MONITORING

Radio soundes to provide atmospheric profiles (pressure, temperature, …) vs altitude

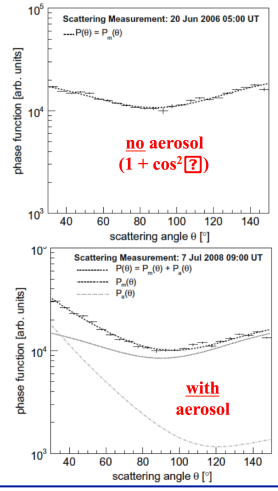


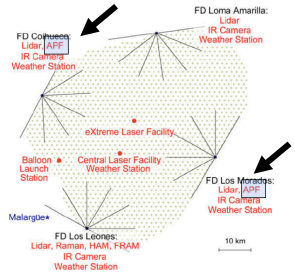

**Montly Malargue average model**



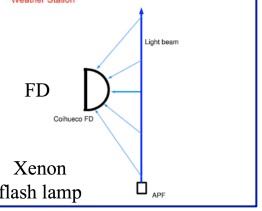

atmospheric depth X(h): deviation of montly mean values from the yearly average

## ATMOSPHERIC MONITORING




**Aerosol phase function monitors**




Xenon flash lamp

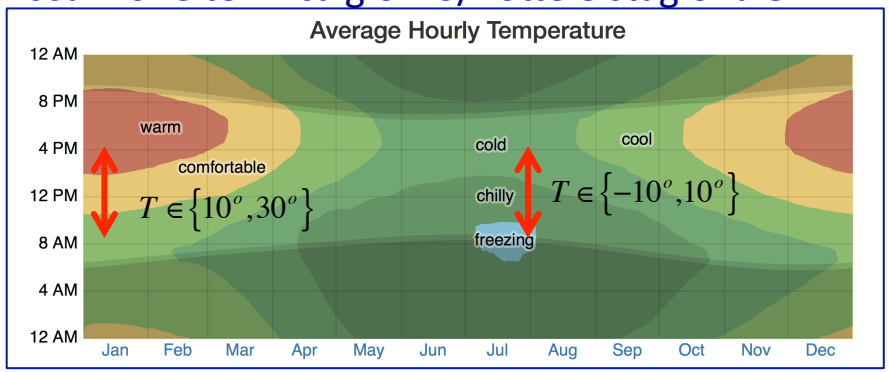
# Pierre Auger Observatory

Le osservabili ambientali influenzano anche il comportamento dei rivelatori

Polvere sui filtri dei telescopi FD

Animali al pascolo

Escurzione termica giorno/notte e stagionale




Neve

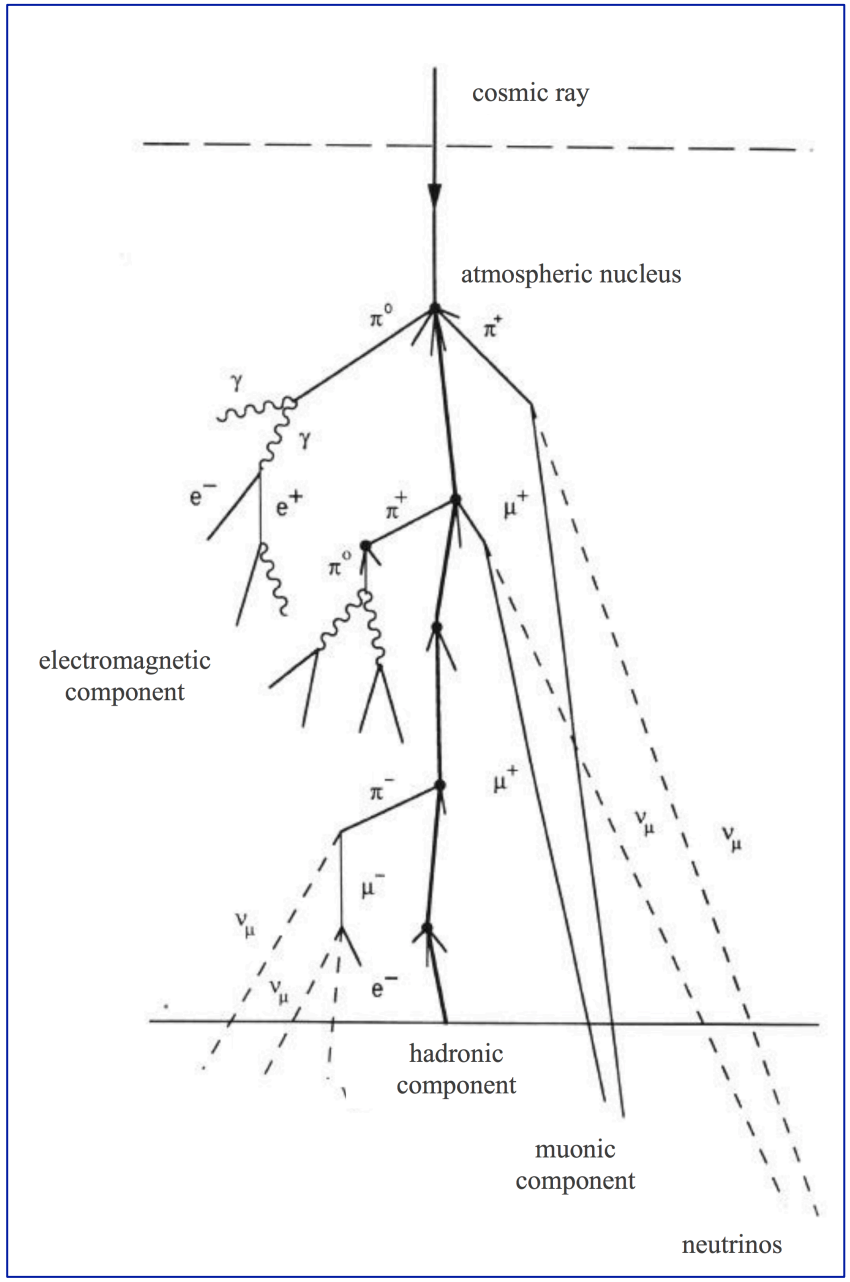
# Pierre Auger Observatory

The Extensive Air Shower (EAS) occurs when high energy cosmic ray primaries, protons or heavy nuclei, are incident on the atmosphere. The primaries in interaction with air nuclei produce a huge numbers of secondary particles which interact with the atmospheric constituents or decays to give other particles.

Numerical simulation of the shower development in the atmosphere is a powerful approach to link the properties of the measured shower to those of the primary particle.
Corsika, Conex & Aires

The main uncertainties of the shower simulation come from the hadronic and nuclear interaction, where there are still large uncertainties.

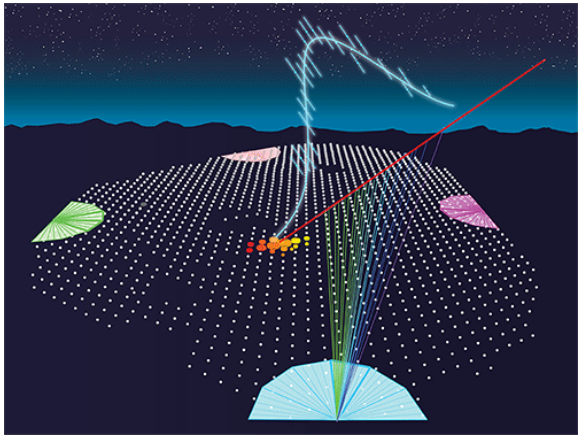
Different Model for hadronic and nuclear interaction are used.



# Pierre Auger Observatory

Metodi di simulazione numerica sono anche usati per la caratterizzazione dello stato del rivelatore.

Lo studio dettagliato delle sistematiche richiede simulazioni e ricostruzioni diverse.



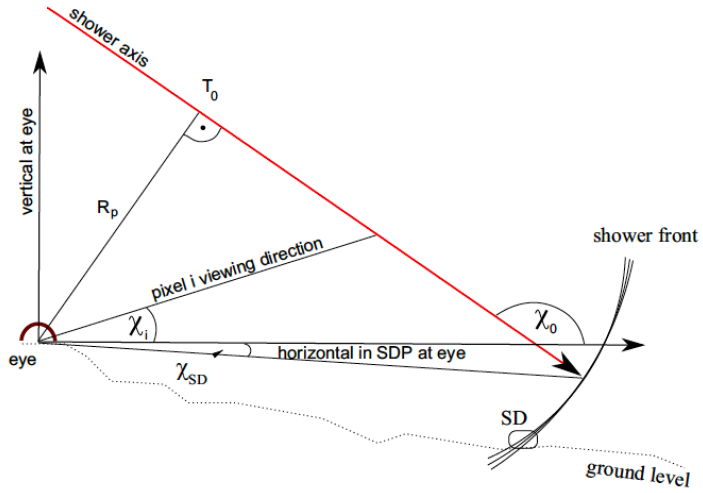



**Fig. 32.** Geometry of an air shower within the shower detector plane.

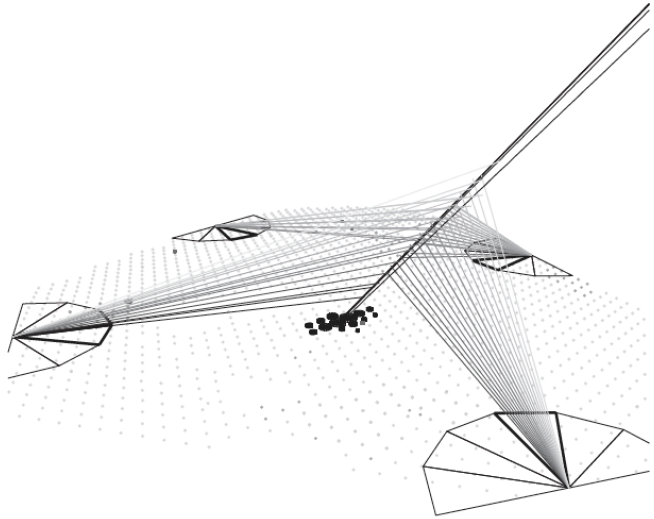


**Fig. 33.** Geometry reconstruction of an event observed by four telescopes and the surface detector.

# Pierre Auger Observatory

Sistema fisico complesso e *poco* compreso

| | |
|---|---|
| Absolute fluorescence yield | 3.4% |
| Fluores. spectrum and quenching param. | 1.1% |
| **Sub total (Fluorescence Yield)** | **3.6%** |
| Aerosol optical depth | 3% ÷ 6% |
| Aerosol phase function | 1% |
| Wavelength dependence of aerosol scattering | 0.5% |
| Atmospheric density profile | 1% |
| **Sub total (Atmosphere)** | **3.4% ÷ 6.2%** |
| Absolute FD calibration | 9% |
| Nightly relative calibration | 2% |
| Optical efficiency | 3.5% |
| **Sub total (FD calibration)** | **9.9%** |
| Folding with point spread function | 5% |
| Multiple scattering model | 1% |
| Simulation bias | 2% |
| Constraints in the Gaisser-Hillas fit | 3.5% ÷ 1% |
| **Sub total (FD profile rec.)** | **6.5% ÷ 5.6%** |
| **Invisible energy** | **3% ÷ 1.5%** |
| **Statistical error of the SD calib. fit** | **0.7% ÷ 1.8%** |
| **Stability of the energy scale** | **5%** |
| **TOTAL** | **14%** |

**Update the uncertainties in the energy scale?**

to be checked with the 54 dbs

octocopter

see next slide

FAL paper ?

$k^c$ cons. GH fit
(it affects also the resolution – 'uncorrel.' unc.)

$E_{inv}(N_{19})$ – to be done

to be checked

22% nel 2013

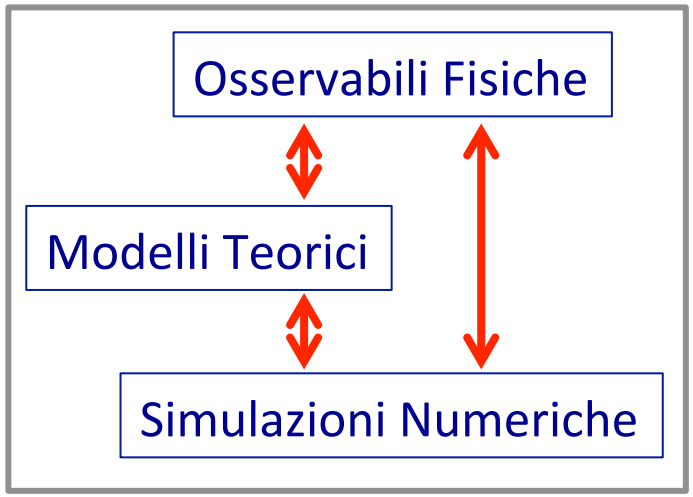
# Computational Model for Pierre Auger Observatory

## Tre caratteristiche

Estrema variabilita' sintattica e semantica dei datasets.

Datasets fortemente correlati

Miglioramento continuo dei Modelli Teorici, i.e. il modello di atmosfera e i modelli di Interazione adronica.




## e la ampia tassonomia degli eventi

Golden, GoldenAERAlet, GoldenHAS & GoldenInfill

Hybrid

SD, SDAERAlet, SDHAS & SDInfill

## vincolano fortemente le scelte fatte per il modello computazionale.

# Computational Model for Pierre Auger Observatory

## Livello Atomico

Ogni evento, fisico, di calibrazione o di *misura*, nei diversi rivelatori viene storato su files. (Tempo e Conteggi ADC)

Gli osservabili ambientali e atmosferici e i gli interventi di manutenzione ordinaria e straordinaria sono storati su DataBase.

## Data Reduction

Gli eventi fisici dei vari rivelatori vengono sincronizzati ed etichettati in macro-classi.

Dagli eventi di calibrazione e di misura si derivano le costanti di calibrazione dei rivelatori e le osservabili fisiche descriventi l'atmosfera e storati su DB.

Produzione *quasi* statica

Dall'analisi delle calibrazioni e dal DB della manutenzione sono determinati i Bad Period e storati su DB.

## Data Analisi

Ogni nuova analisi puo' comportare il processamento dell'intero dataset degli eventi fisici e la generazione delle simulazioni numeriche per la fisica dello sciame e la caratterizzazione del rivelatore (estremamente CPU demanding).

# Computational Model for Pierre Auger Observatory

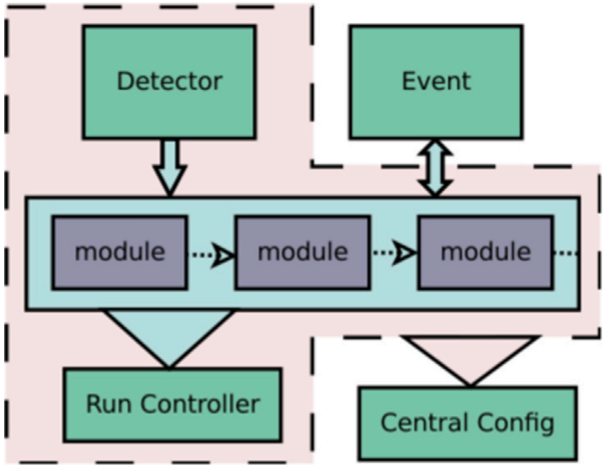
≈ 50 TeraBytes

Un sottoinsieme dei dati sincronizzati e' copiato nelle Sedi Regionali

La produzione dei dati RAW degli eventi (sincronizzazione) avviene nel Tier1 di Lione.
A Lione è anche archiviata una copia dei dati RAW su nastro.

CNAF
Clone di Lione

# The Offline Software




Simulation and reconstruction tasks are encased in modules.

Each module is able to read information from the detector description and/or the event, process the information, and write the results back into the event under command of a Run Controller.

A Central Config object is responsible for handing modules and framework components their configuration data and for tracking provenance.

The Offline software comprises over 350,000 lines of code, corresponding to some 95 person years of effort, according to the Constructive Cost Model.

Nucl. Inst. and Meth. A 580 (2007) 1485

# The Offline Software

## Organization

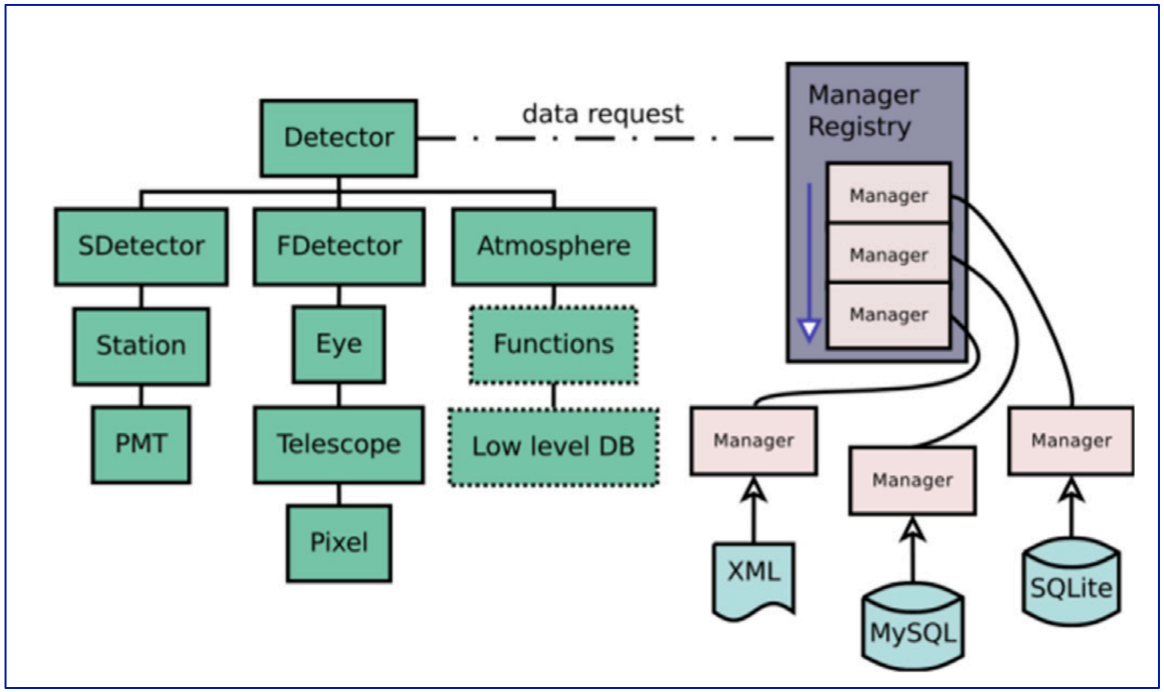
- Framework
  event, detector and atmosphere class, central configuration, coordinate system registry , data source managers
- Event I/O
  object persistence, raw event, external simulation files
- ADST
  alternative data summary, event detector and reconstruction viewer
- Modules
  reading/writing, calibration, physics, reconstruction, simulation
- Validation
  event structure and modules
- Utilities
  helpers, Geometry, etc
- Build system
  libtool ->CMake, APE, Buildbot

# The Offline Software

## Framework

- Event structures
- Detector description
- Strict separation os framework classes from physics ones
- one class per header file
- Non deletable, processing only adds things: implemented Has/Make/Get interfaces
- prevent the accidental processing of a copy
- data source Managers: easy source replecement and wrappers for MySQL, SQLite, Xerces
- central configuration: Detector, Managers, Modules
- Registry of Random number streams

# The Offline Software




Framework Managers

Machinery of the detector description.

The user interface (left) comprises a hierarchy of objects describing the various components of the Observatory.

These objects relay requests for data to a registry of managers (right) which handle multiple data sources and formats.

# The Offline Software

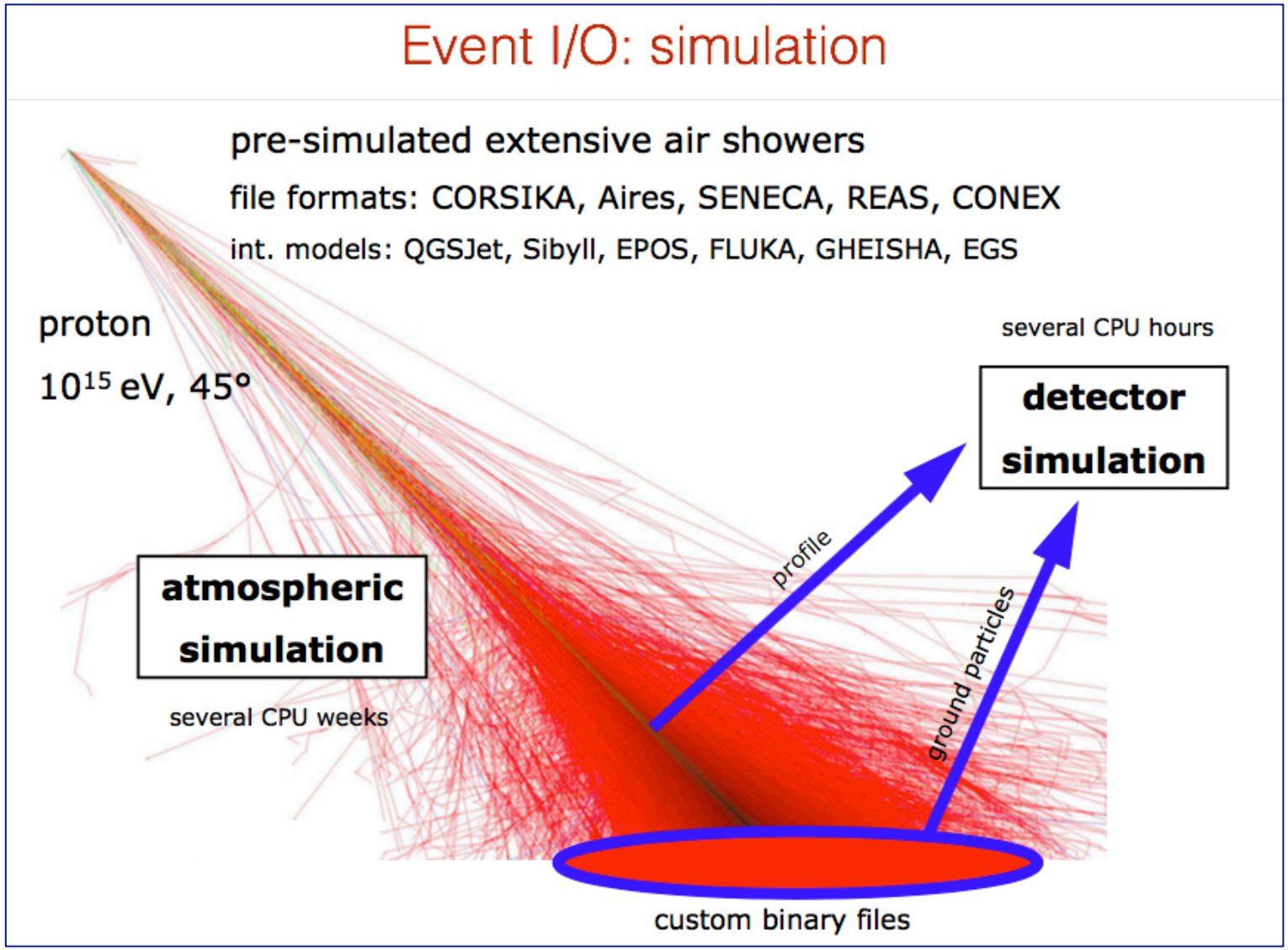
## Framework Config

- XML
- Run-time XML Schema validation: XSD
- automatic conversion of physical quantities into internal units

```
<energy unit="GeV"> 137.23 </energy>
<height unit="km"> 14.3 </height>
```

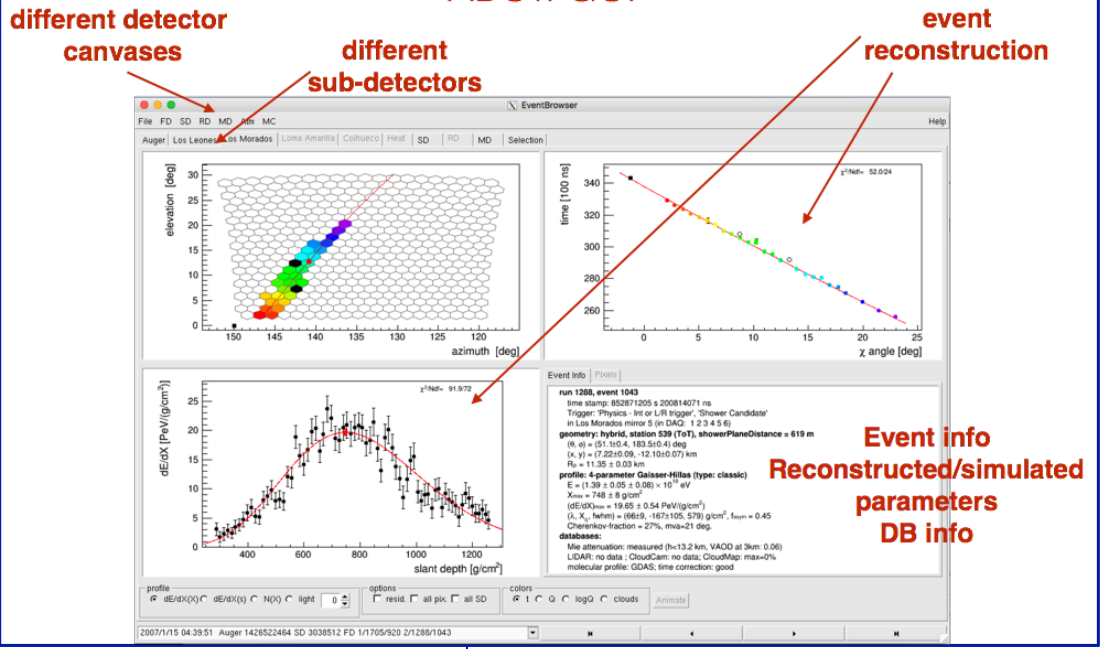
- Default configuration checksummed, modifications are reported in run logs
- full configuration is saved in ADST

# The Offline Software



# The Offline Software

## ADST: GUI




## ADST

- Summary files (ROOT)
- GUI: event/detector browser, run configuration inspector, basic selection tools
- micro/extended ADST format: reconstruction results only, simulation information included, specialized analysis for sub-detectors
- Produced on regular basis with production releases

# The Offline Software

## Modules

- Fluorescence Detector, Surface Detector, Radio Detector
- calibration, reconstruction, simulation(Geant4)
- readers/writers: native event/detector, ADST
- modules are easily replaceable: implementing several alternatives or competing approaches ( e.g. Auger Prime)
- Modules can communicate **ONLY** through the Event structure
- Currently about 200 modules

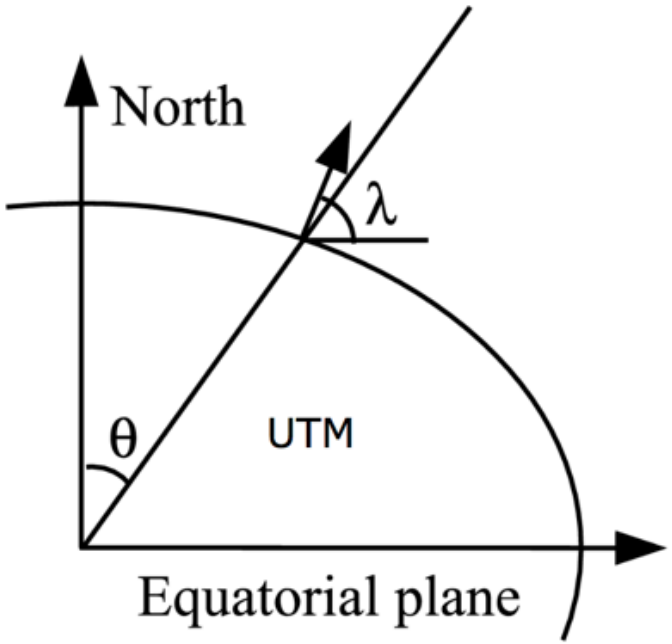
## Utilities

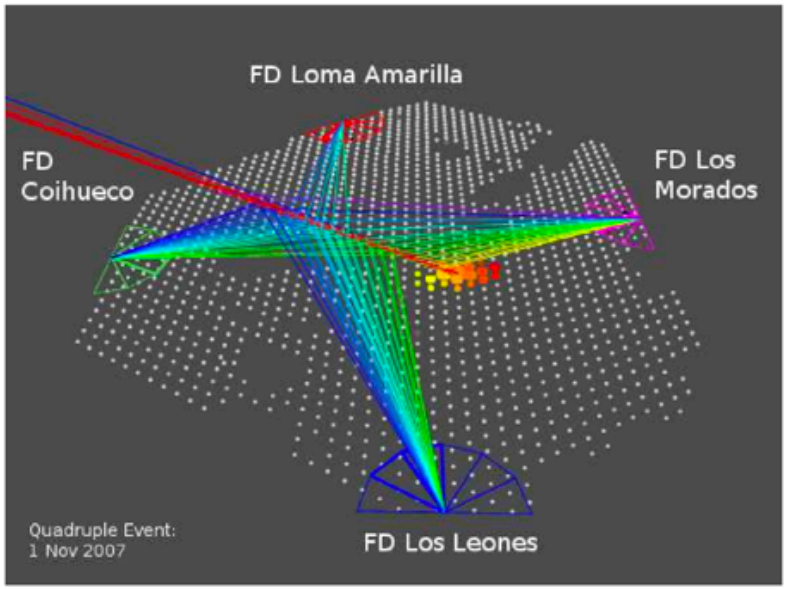
- XML Reader (Xerces wrapper)
- SI units, internal units definition
- Mathematics, Statistics and Physics functions
- Trace, trace algorithms
- Linear Algebra, Geometry
- Fourier transform wrapper (FFT)
- MD5 for configuration checksum
- custom exceptions
- special template library: specialised event and detector containers, shadow pointer, Meyers singleton, counted objects, safe bool cast

# The Offline Software

## Utilities: Geometry

Impossible to find one privileged coordinate system
it depends on the problem




70 km

curved, non-Cartesian coordinates

# Un Esempio: lo spettro ibrido

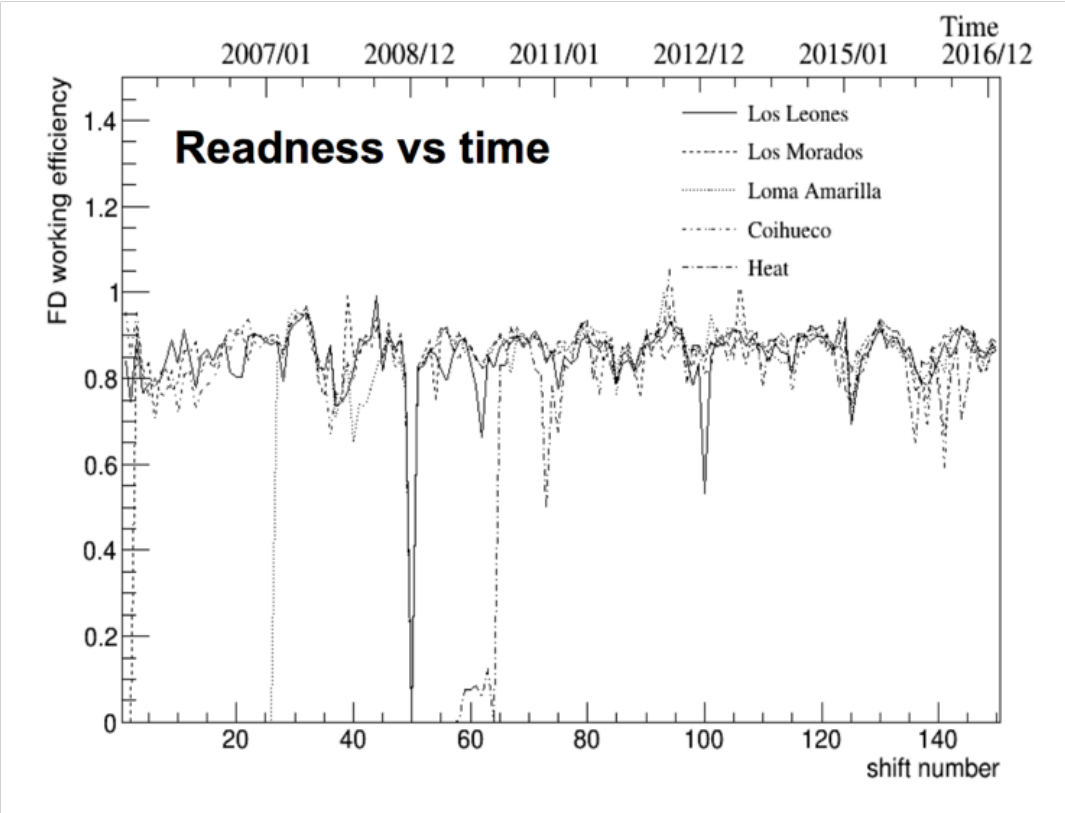
$$J(E) = \frac{\Delta N_{\mathrm{sel}}(E)}{\Delta E} \frac{1}{\mathcal{E}(E)}$$

$$\mathcal{E}(E) = \int_T \int_\Omega \int_{S_{gen}} \varepsilon(E, t, \theta, \phi, x, y) \ \cos\theta \ \mathrm{d}S \ \mathrm{d}\Omega \ \mathrm{d}t = \int_T \mathcal{A}(E, t) \ \mathrm{d}t$$

- Per determinare lo spettro occorre stimare l'esposizione del rivelatore.
- Per il rivelatore di Fluorescenza l'esposizione dipende dal tempo:
  - Stato di funzionamento dei singoli telescopi (24)
  - condizioni atmosferiche,
  - veti vari provenienti dai sistemi laser di monitoraggio atmosferico
  - stato di funzionamento delle tank SD nella zona del core
- Dunque la determinazione dell'esposizione è una operazione complessa

# Un Esempio: lo spettro ibrido

## Hybrid on-time

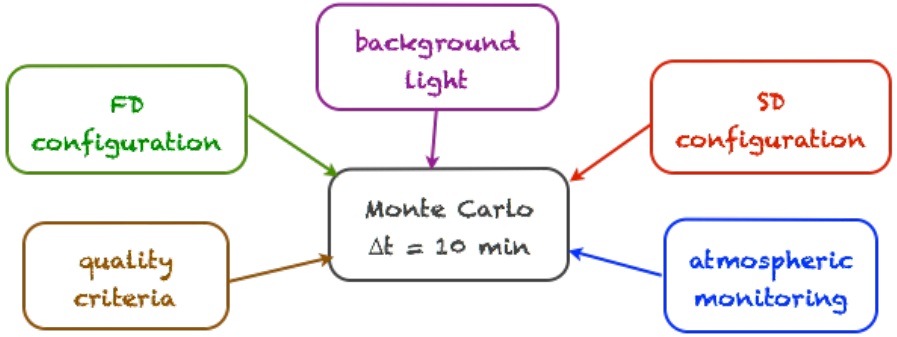



On-time per i diversi occhi di fluorescenza in funzione del tempo

# Un Esempio: lo spettro ibrido

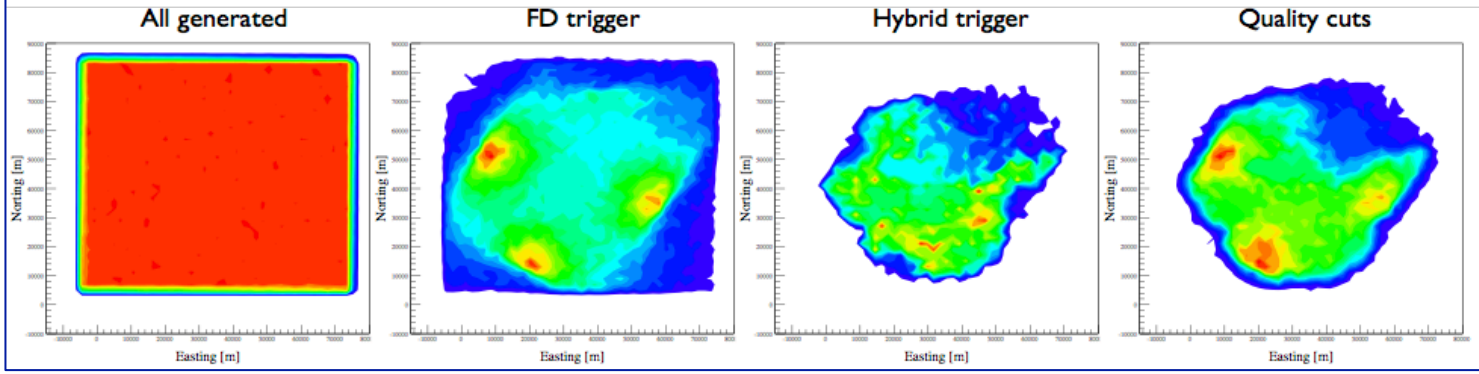
## Time Dependent MC simulation

Per stimare l'esposizione viene utilizzato un Time Dependent MC che simula sciami nelle condizioni in cui i dati reali sono stati raccolti. Tutti i parametri di funzionamento del rivelatore sono salvati DataBase MySQL e files root che vengono da analisi intermedie (e.g Ontime)




Very Requiring dal punto di vista di risorse di calcolo:

- simulazione sciami
- accesso al database
- ricostruzione



# Conclusioni

È stata descritta la problematica di calcolo legato alla mistura dei raggi cosmici di altissima energia

Dopo aver illustrato brevemente il modello di calcolo di Auger sono state introdotte le principali caratteristiche del software proprietario della collaborazione (i.e OFFLINE) utilizzato sia per la simulazione che per la ricostruzione degli eventi di Raggi Cosmici di altissima energia

Infine è stata mostrata una particolare applicazione del calcolo alla misura dello spettro in energia utilizzando gli eventi ibridi (FD + SD) dell 'Osservatorio Pierre Auger