NIDays

ENGINEER NEXT


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Ground Vibration Monitoring at CERN as Part of the International Seismic Network

Kevin Develle

LabVIEW Developer

CERN

Contents

- CERN
- Challenge
- Technical proposal
- Solution implemented
- Performances
- Conclusion

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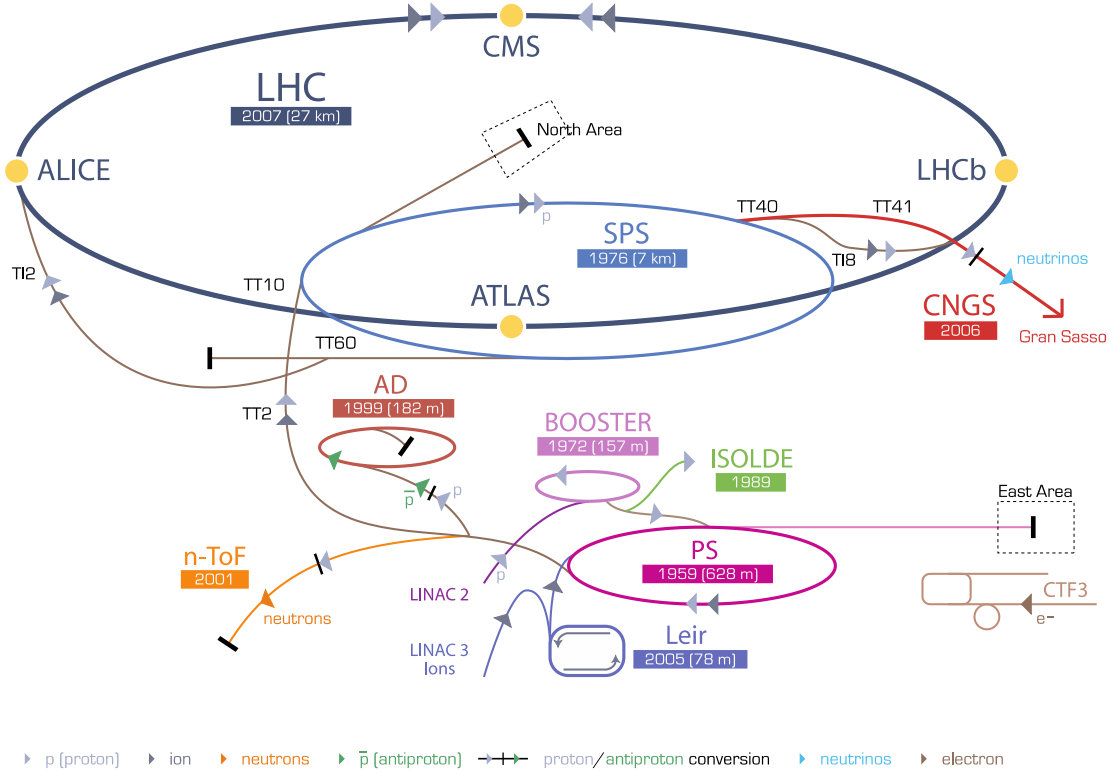

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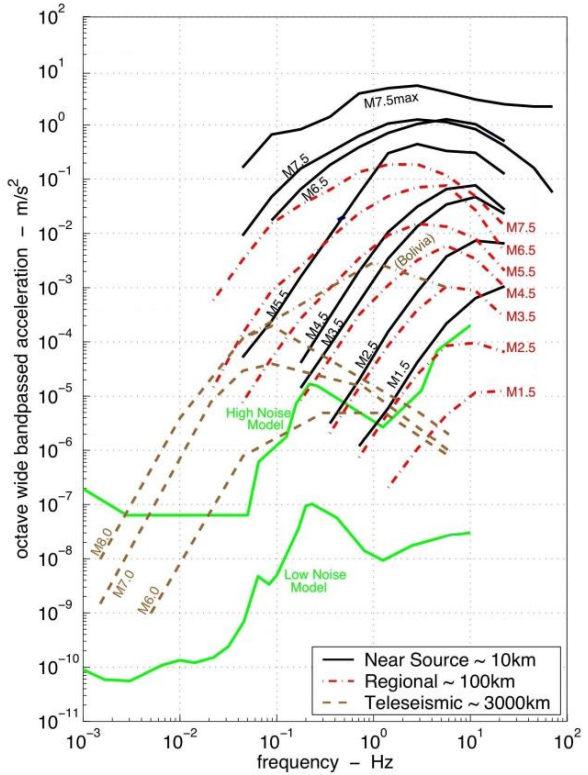
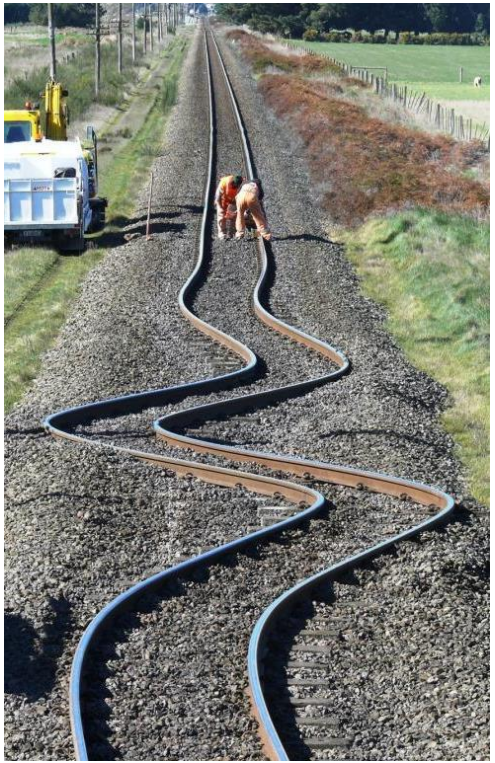
Challenge :

- Monitor impact of seismic waves on CERN accelerators complex





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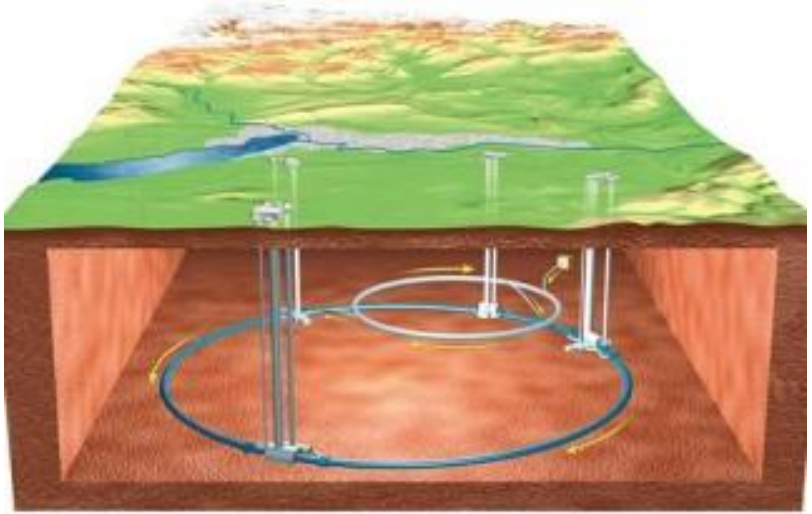
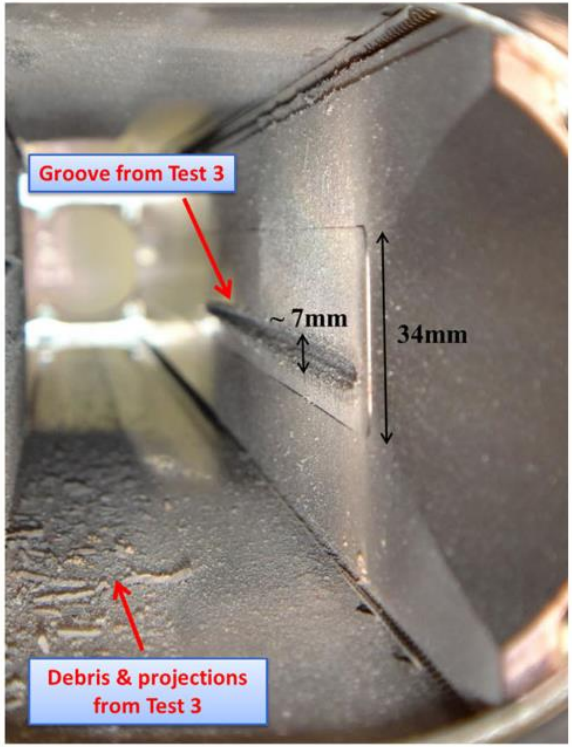
The Large Hadron Collider (LHC) : A 27km ring





The energy of 360 MJ stored in one LHC beam corresponds to the energy of a 200m long fast train at 155 km/hour.

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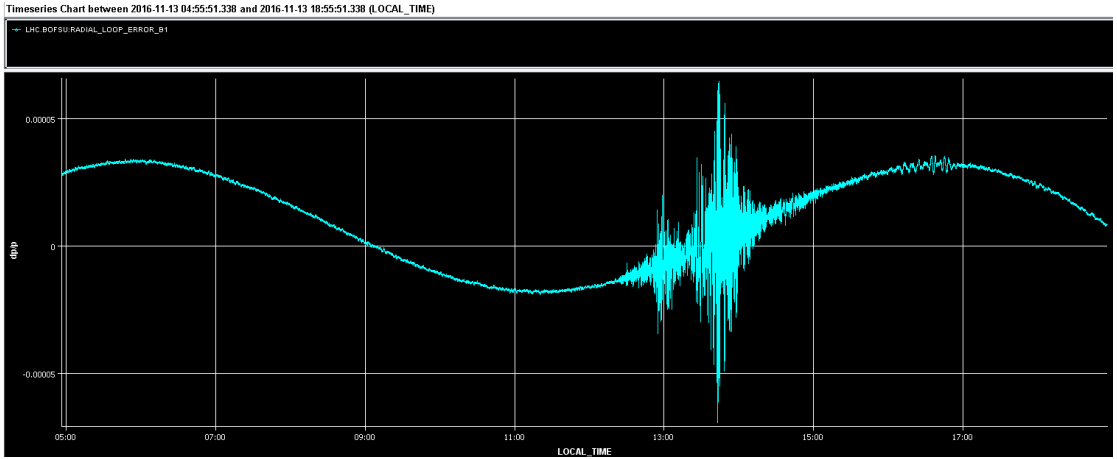
Motivations

- Continuous LHC monitoring
  - Beam sizes around 1 mm during injection, 0,25 mm at top energy
  - Stability of the magnetic field center
    - Optimal conditions : < 5 µm
    - Non-optimal conditions : 5 to 50 µm

Influence of the moon and an earthquake in New Zealand on LHC orbit



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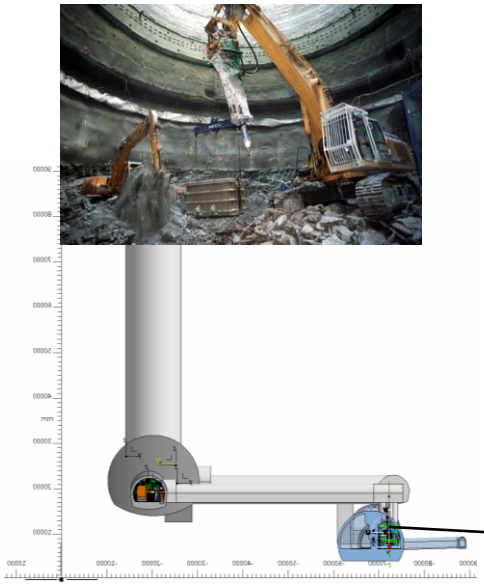
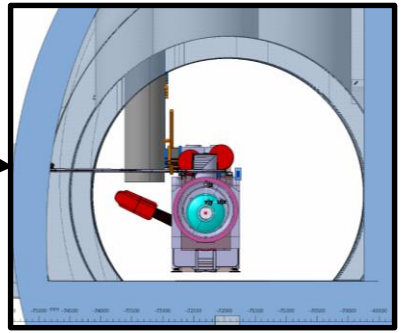
Motivations

- HL-LHC Civil engineering activities



- Monitor our installation to anticipate some risks on the beam stability generated by civil engineering activities.
- Study ongoing to determine the best excavation technique.



Motivations

- Geneva Program “Géothermie 2020”
  - Evaluate effects of the micro-seismicity induced by the geo-thermal exploitation on CERN installations.
  - Study by the engineering company Resonance mandated by SIG (Services Industriels de Genève)

Expected earthquakes	During the stimulation period	During the stationary phase	Expected magnets movements
Magnitude 2	Several per week	A few per month	~1-10 µm
Magnitude 3	A few per month	2 to 3 per year	~10-100 µm

- Need for a seismic network
  - Measuring near source earthquakes to better know the region seismicity
  - Integrated into the worldwide seismic network

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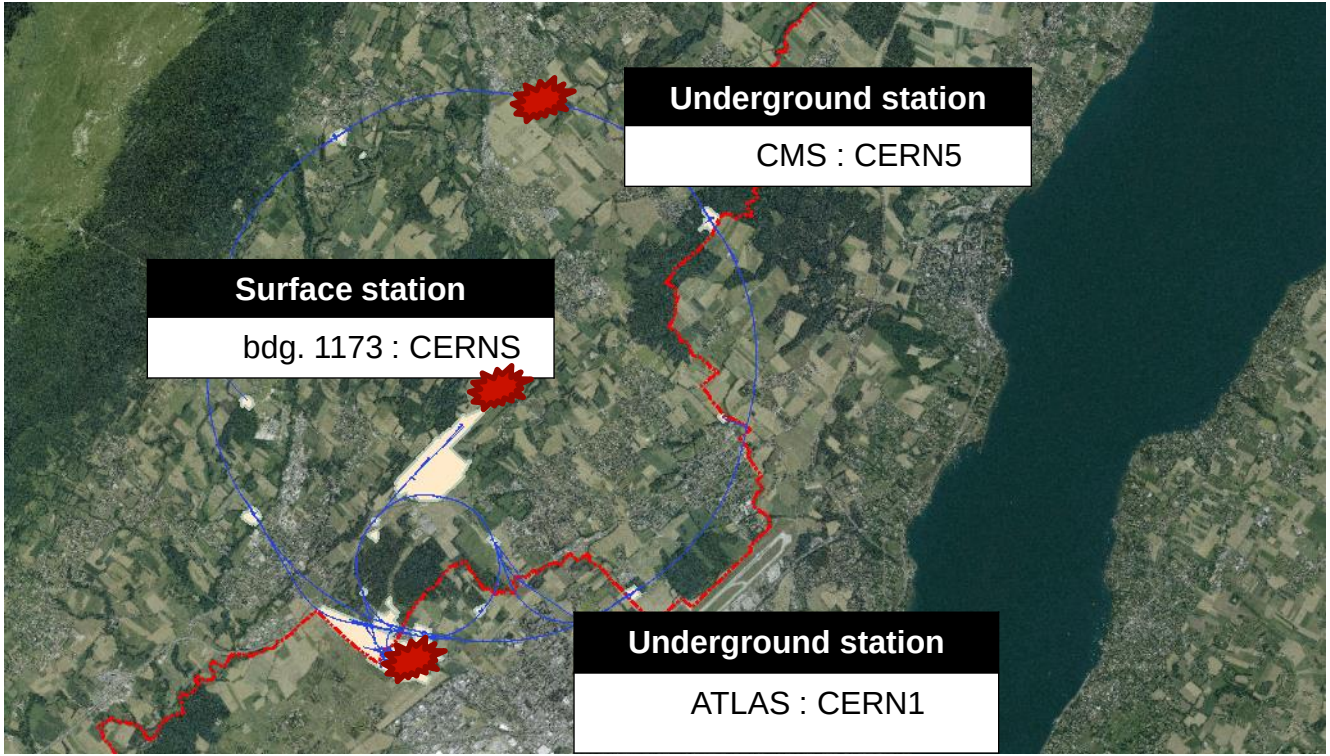
Schweizerischer Erdbebendienst
Service Sismologique Suisse
Servizio Sismico Svizzero
Swiss Seismological Service

Best monitoring point



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Requirements

	Needs for a common station	Specific needs for CERN
	Geothermal exploitation, SED	HL-LHC excavation
Min amplitude	LHC ground motion	LHC ground motion
Max amplitude	20 m/s^2	20 m/s^2
Min frequency	1/30 Hz	1 Hz
Max frequency	20 Hz	100 Hz
Timestamp precision	~ 1 ms	~ 10 ms
Data latency	10 s	60 s
Data format	MiniSEED	ASCII
Data transmitted to	SED servers	CERN servers, LHC database
Other needs	Available 24/7	Independent systems with same software and hardware

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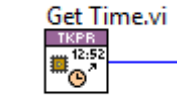
Custom Solution

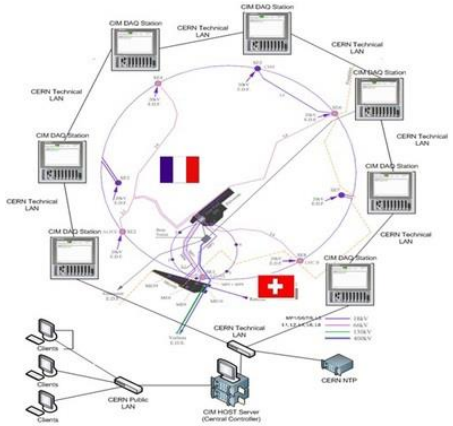
Advantages

- CERN is a LabVIEW Center of excellence
- Huge experience with CompactRIO at CERN
- Timekeeper API
- Sounds and Vibration, HTTP, WebDAV palette from NI
- RADE palette from MTA Team to communicate with CERN infrastructure
- Distributed architecture
- System fulfilling the requirements



Challenges

- Manpower cost more important for the development
- MiniSEED converter to be develop
- Quality of the streaming to SED to be proven
- Non-standard seismic station



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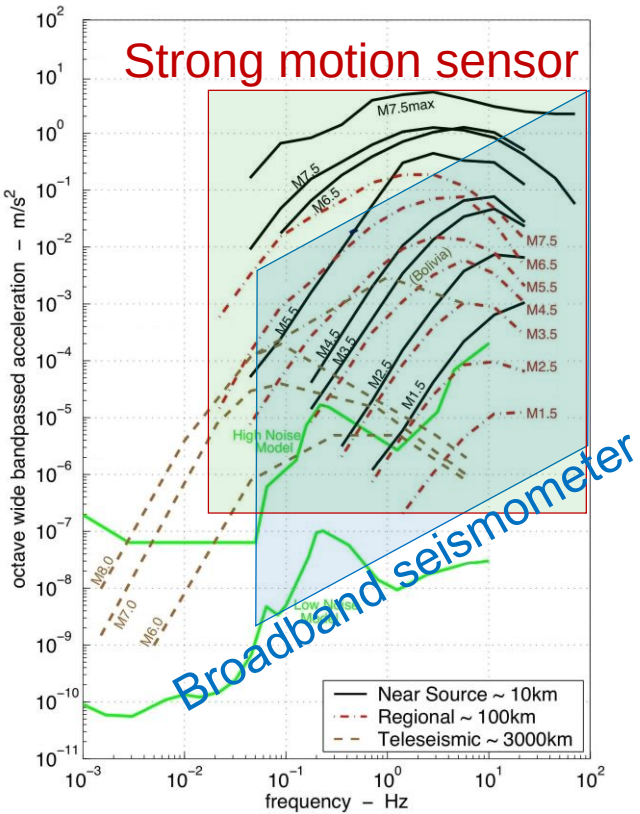
Hardware proposal

Model	Guralp 6T	Guralp 40T	Kinemetrics EpiSensor ES-T
Output	Velocity	Velocity	Acceleration
Triaxial	Yes	Yes	Yes
Frequency range	30s to 100Hz	60s to 100Hz	DC to 200Hz
Sensitivity	2000 V/(m/s)	800 V/(m/s)	2,5 V/g
Analog/digital	both	both	Analog +-5V differential
Noise	172 dB	172 dB	155 dB
Power supply [V]	10 to 36V	10 to 36V	12V
LHC Ground motion level	Yes	Yes	No
Threshold level for earthquake	≈ M3 @10km	≈ M3,5 @10km	M 7,5 @10km



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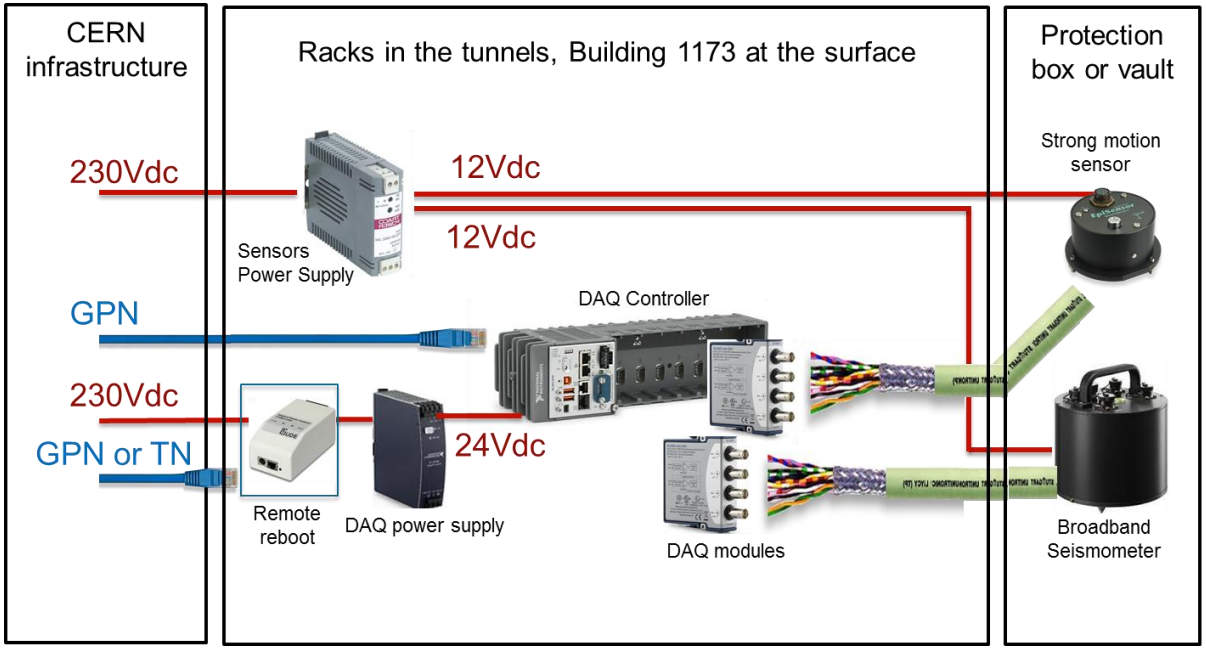
With a 10V, 24 bits ADC

Hardware proposal



- NI CompactRIO 9035
- 2 NI C-series 9239
- Linux Real Time
- NTP timing source at CERN (<1ms accuracy)
- GPN connection
- Remote reboot: GUDE Expert power control 1103

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Software proposal

Raw data

CERN Experts

Mechanical Measurement Laboratory

Raw data (time domain)
Power Spectral Density (frequency domain)
Sum Level (time domain)

CERN Users

timber
The LHC Logging System
TIMBER
browsing & data extraction

Power Spectral Density : Ground motion monitoring (frequency domain)

SED and worldwide seismic databases

Schweizerischer Erdbebendienst
Service Sismologique Suisse
Servizio Sismico Svizzero
Swiss Seismological Service

MiniSEED Files : Standard for Exchange of Earthquake Data (time domain)

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System architecture

Settings

Program

1173 Station

UL16 Station

UP53 Station

WEBDAV

CMW GPN

CMW TN

HTTPS

CERN Experts

Mechanical Measurement Laboratory

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timber
The LHC Logging System

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browsing & data extraction

46

SED and worldwide seismic databases

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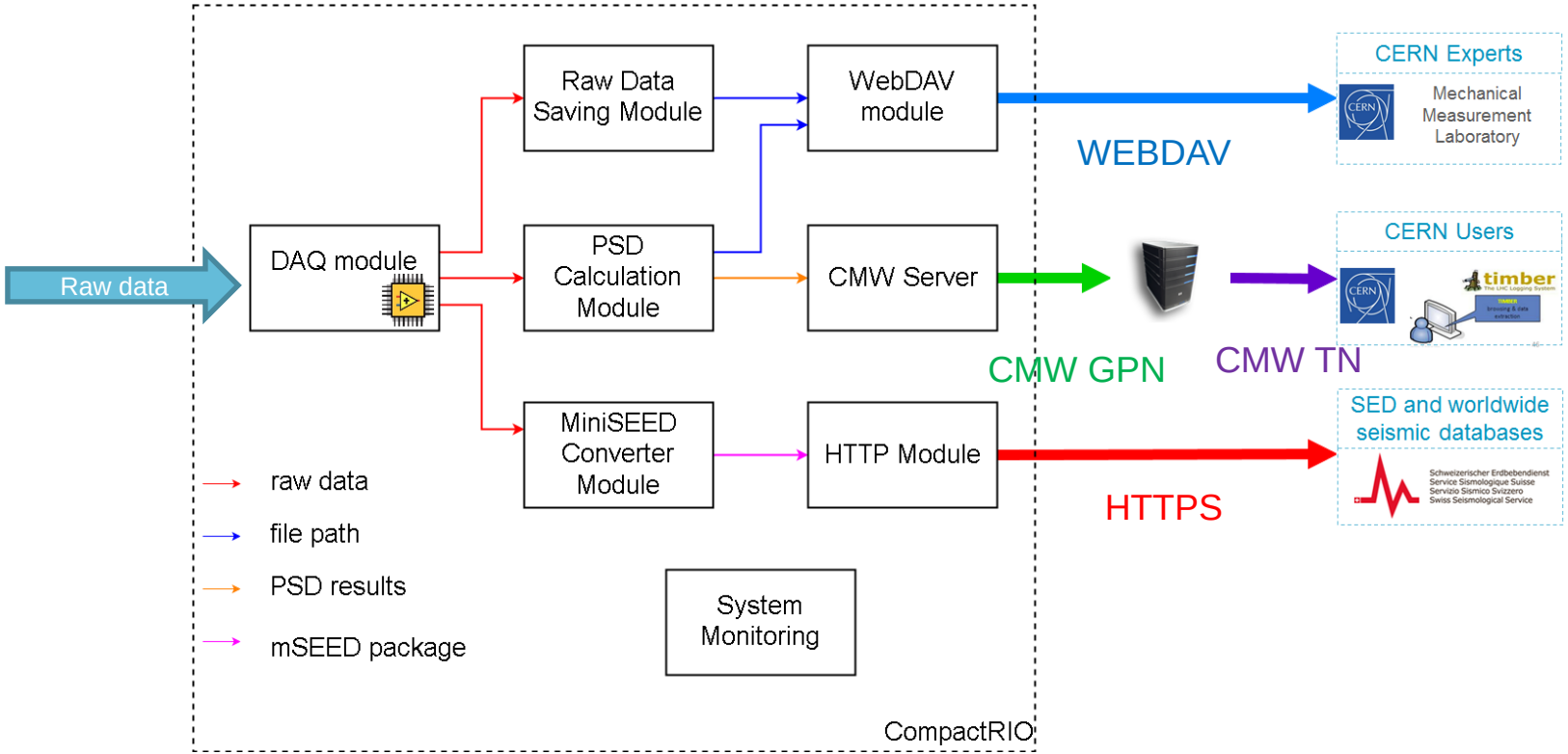
Software architecture



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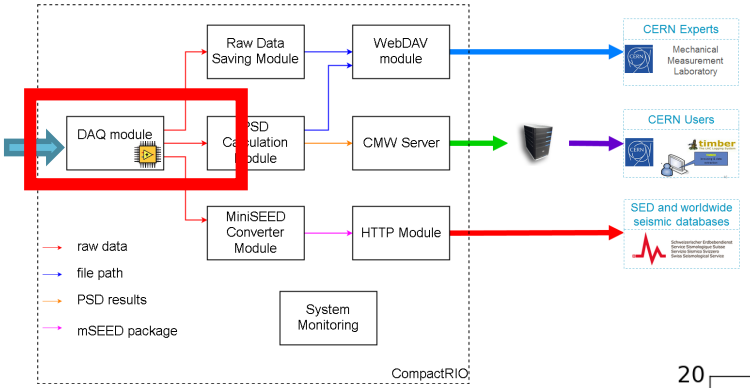
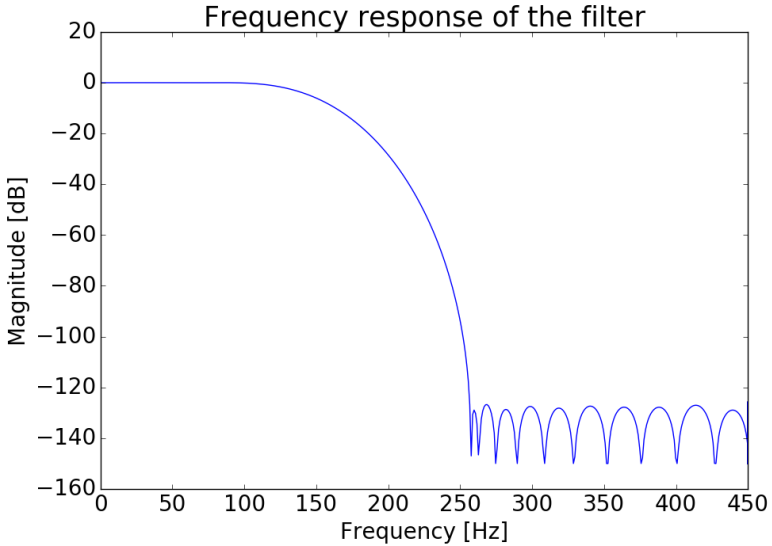
Data Acquisition Module



- Read data from DMA
- Keep Timekeeper synchronized
- Down sample and filter from 2kHz to 250Hz
- Sinc filter with Blackman window



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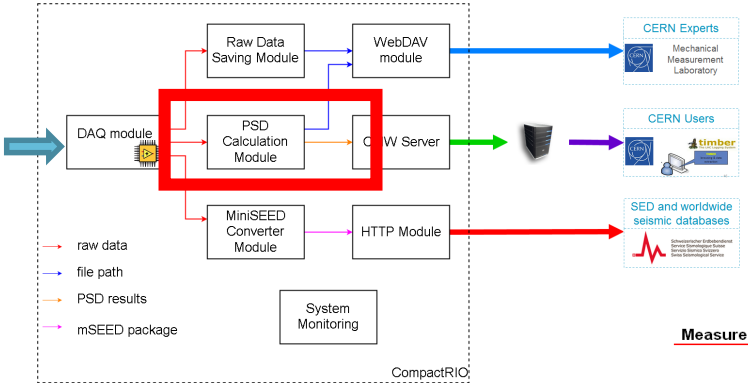
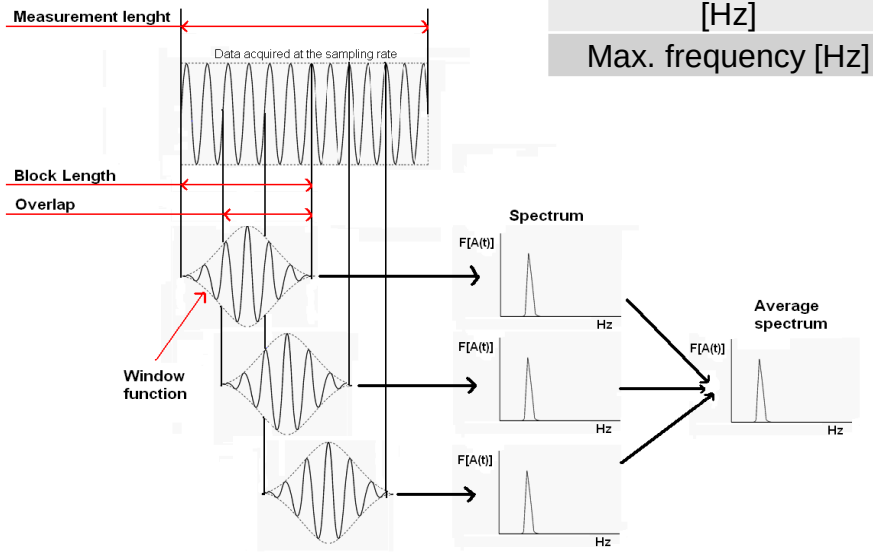
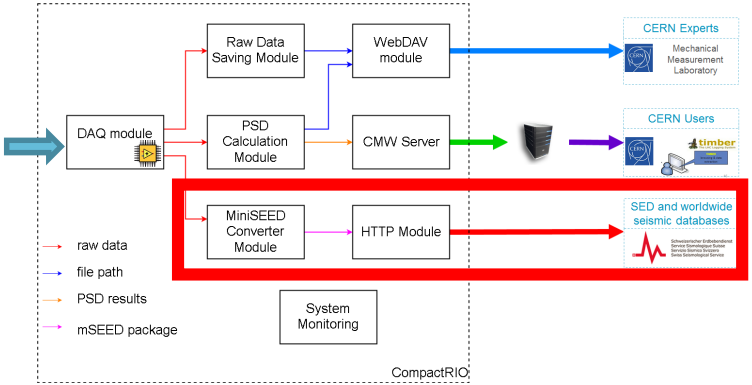
Power Spectral Density Module



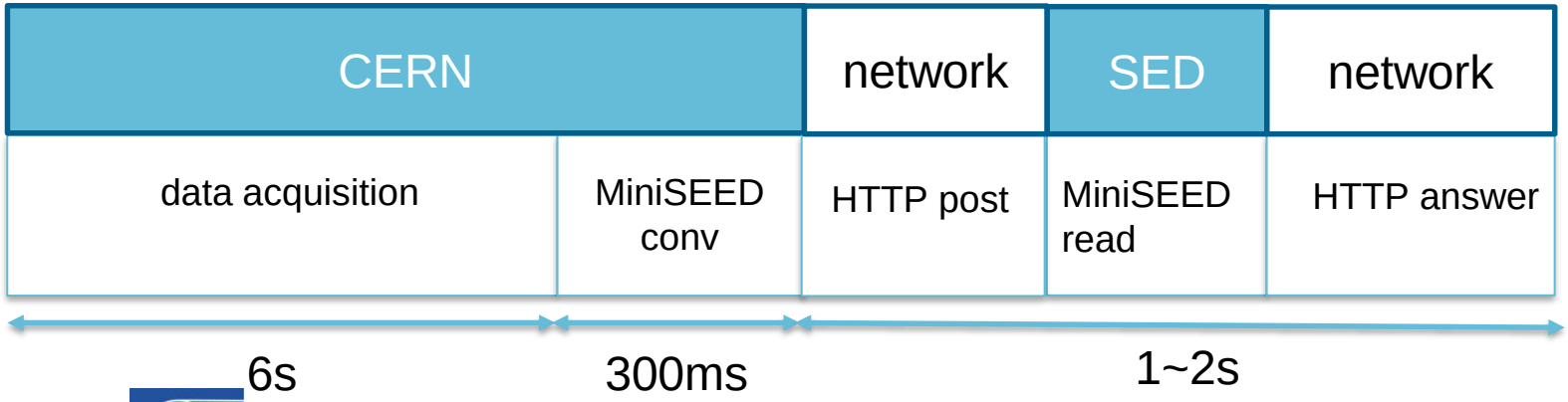
Parameter [unit]	Value
Representation	Quadratic RMS [m^2/Hz]
Window	Hanning
Block length	64s
Overlap	66.60%
Frequency resolution fr [Hz]	0.015625
Max. frequency [Hz]	97.7



MiniSEED Converter & HTTP Module



- Build MiniSEED header (timestamp, sequence number, station name…)
- Send package to SED
- Handle SED server respnse, network disconnection
- Objective: 10s latency



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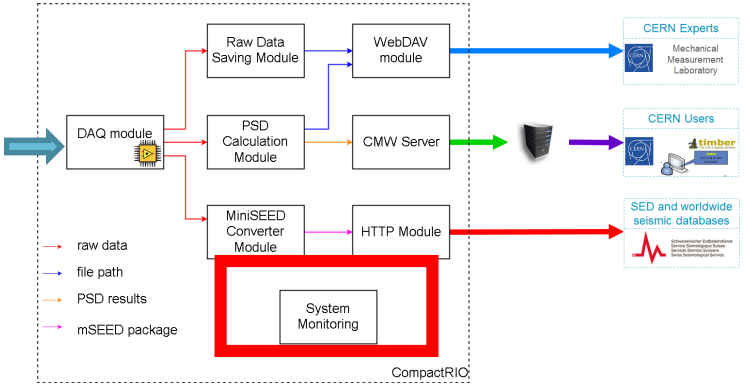
System Monitoring Module



- Monitor CPU/RAM usage
  - Maximum CPU peak at 50%
    Average CPU ~ 10%
  - About 50% of the 1GB RAM available
- Monitor VI states
- Monitor number of elements in queue and RT fifo
- Send “alive” message to an other machine
- Monitor NTP synchronization

```
NTP report :

     remote           refid      st t when poll reach   delay   offset  jitter
==============================================================================
*[redacted]      2 u  556 1024  377    0.301   -0.071   0.025
+[redacted]      2 u  397 1024  377    0.302   -0.091   0.038
+[redacted]      3 u   47 1024  377    0.335   -0.062   0.038
```

NTP server

seconds

Octal code

milliseconds

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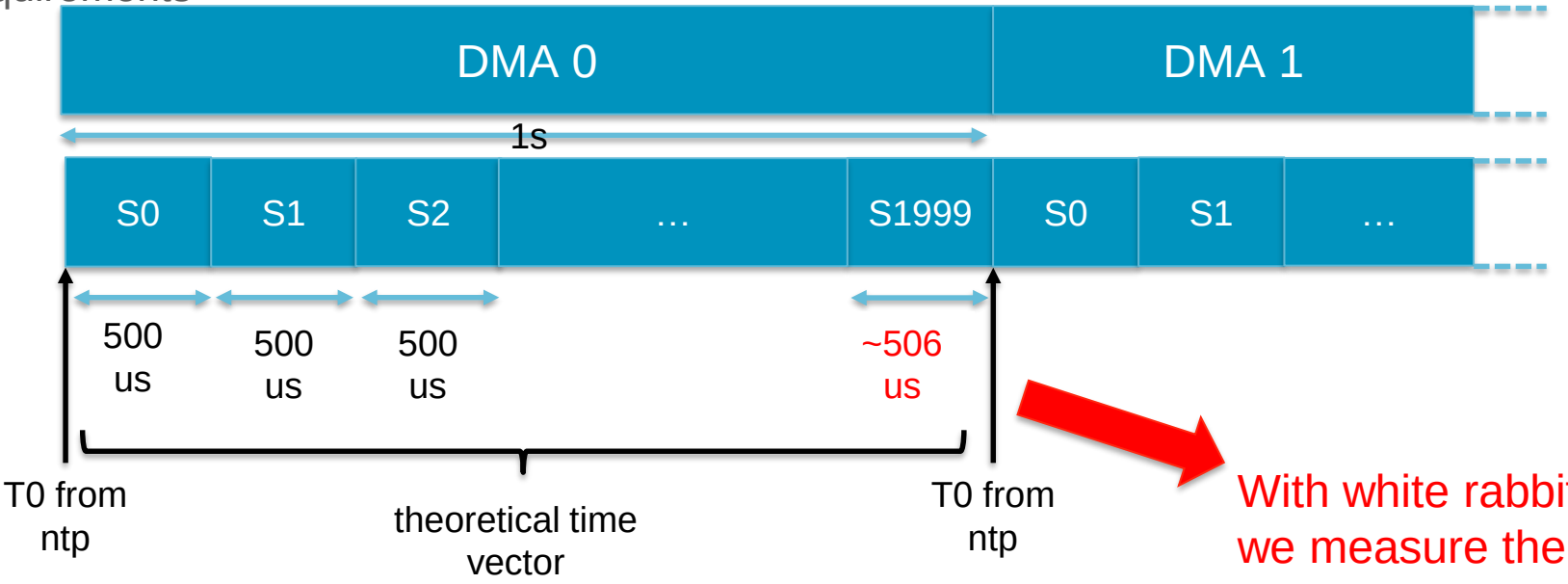
The Timing Challenge

- Problem with SED :

The 2kHz on-board clock is not perfect. The gap between the timestamp of sample 1999 of DMA 0 and sample 0 of DMA 1 had to be reduced below 1us to fulfil SED requirements



With white rabbit, we measure the loop speed at ~500.003 us

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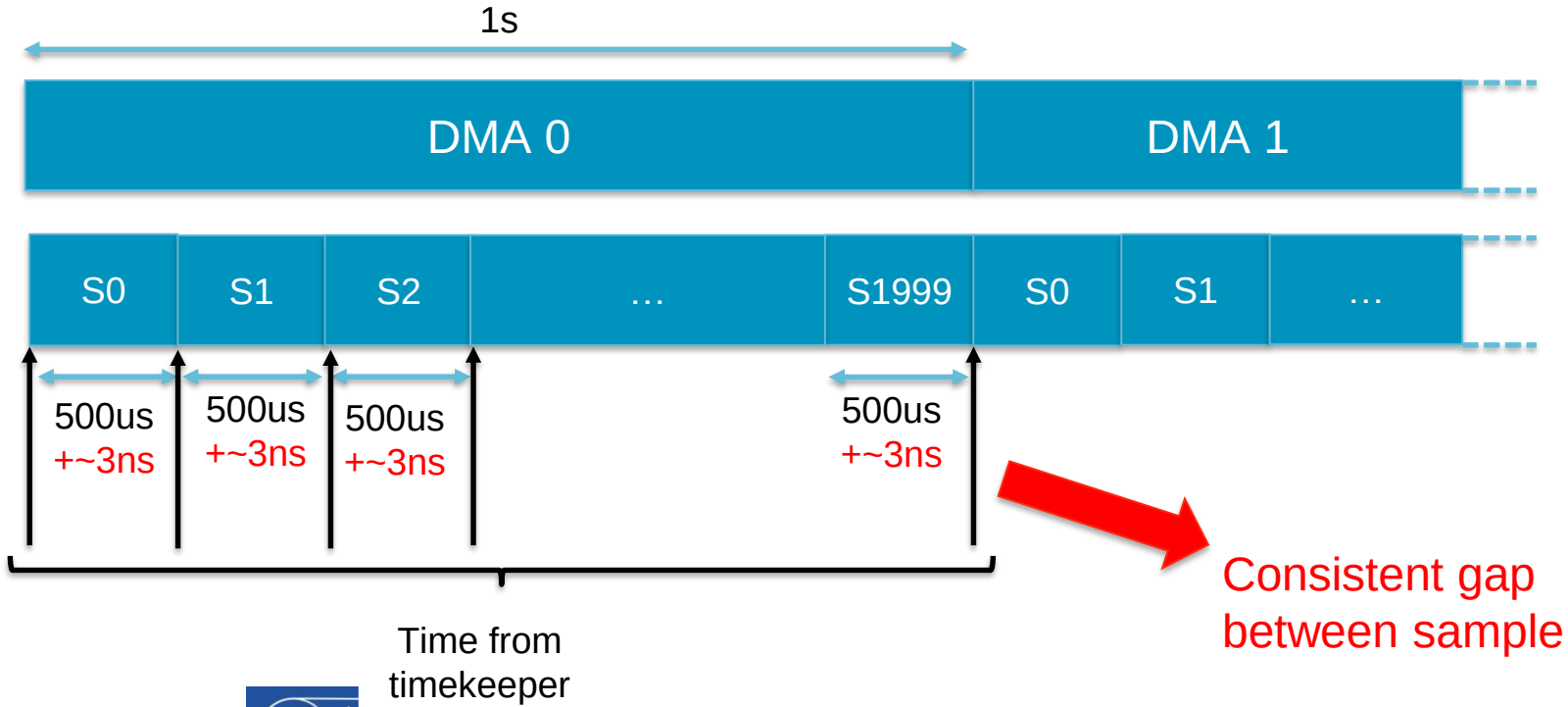
http://www.ohwr.org/projects/white-rabbit/wiki

The Timing Challenge

- Solution :

  The timekeeper API to timestamp every sample on the FPGA



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System Robustness

Problem	CompactRIO reaction
CERN Users	Sends warning and keeps streaming
SED and worldwide seismic databases	Stores MiniSEED files on USB drive, sends it when SED is back
CERN Experts	Stores experts files on USB drive
Mechanical Measurement Laboratory	Stores everything on USB drive
	Automatic restart

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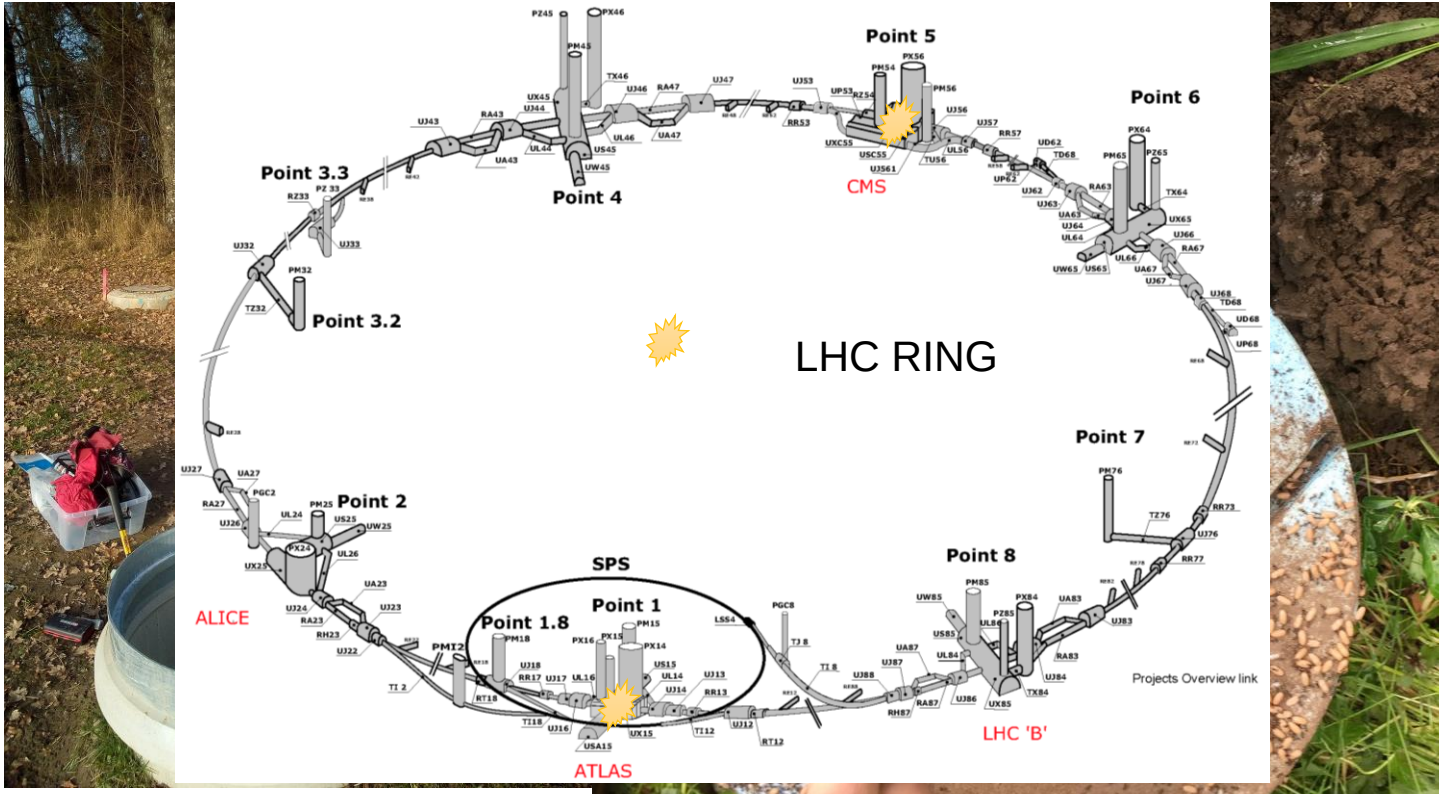
Installation



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Stations performance

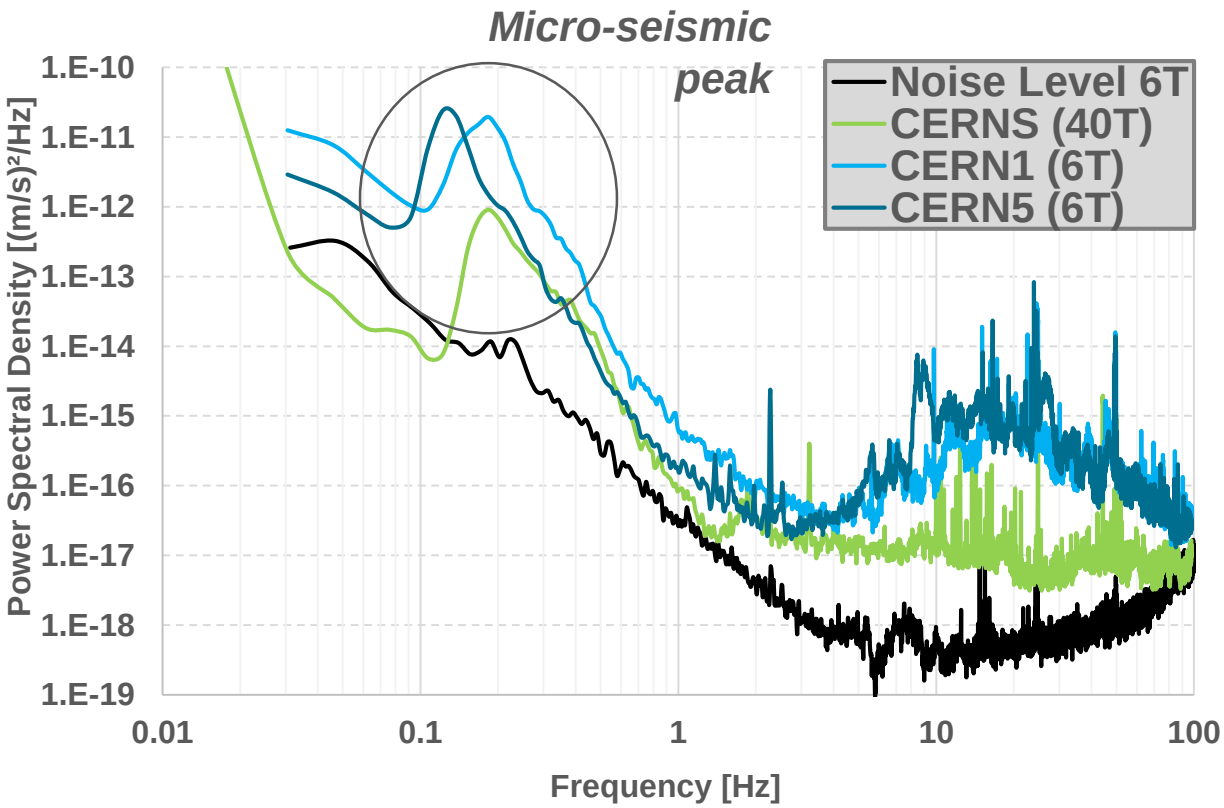
PSD

Power Spectral Density

$$\phi_w = \frac{\left(\overline{S_w^2}\right)}{fr}$$

$\overline{S_w}$: average magnitude of FFT spectrum [rms]

fr: *Frequency resolution*



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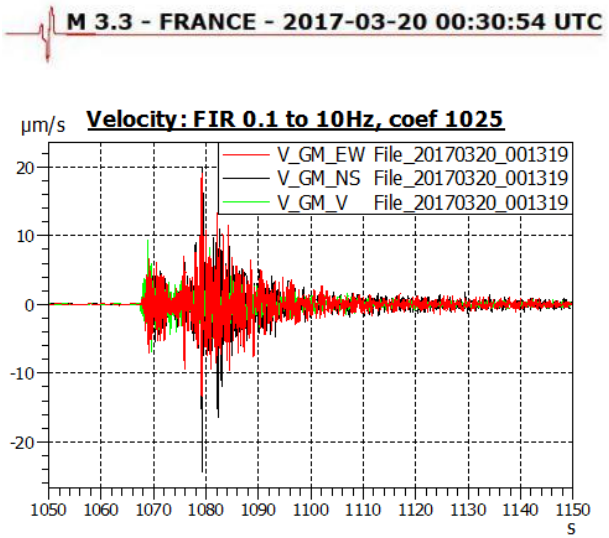
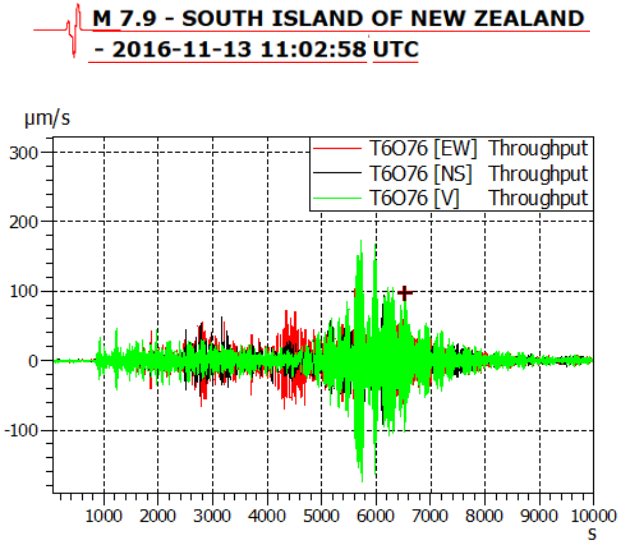
Stations performance

- Recorded earthquakes





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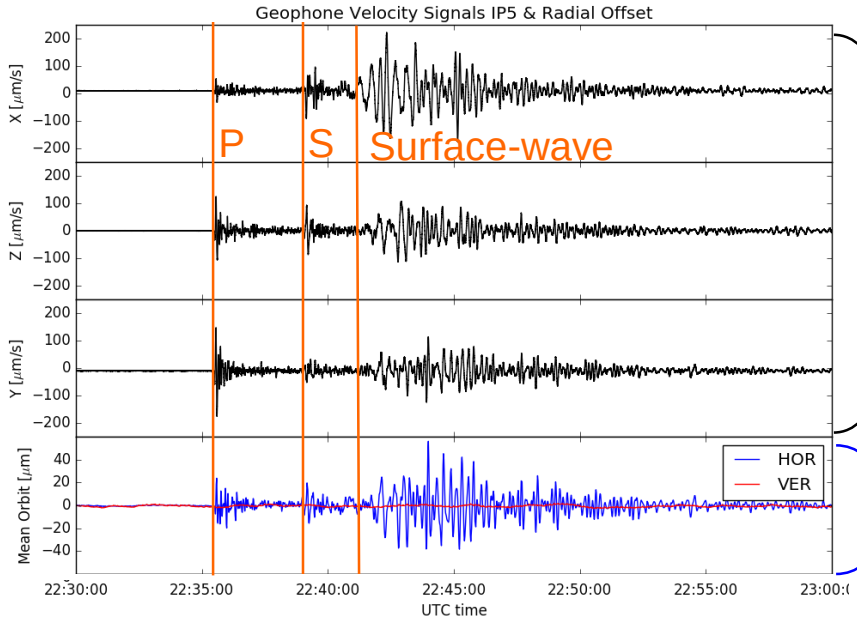
Stations performance

- Correlation on LHC stable Beam

P = compressional wave
S = shear wave

Geophone Signal IP5 & Beam Radial Offset



Geophone Signal IP5

LHC B1 Orbit measurement:

±40μm radial shift

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Conclusion

- The CERN seismic network already permits to:
  - Monitor the LHC ground motion
  - Track earthquakes on a wide range of amplitudes

- It satisfied successfully the needs of SED and CERN
  - System compliant with LHC tunnel and CERN network
  - Standard format files for seismologists

- SED is doing checking on CERN stations as for their own stations, CERN is also monitoring the stations and do the maintenance

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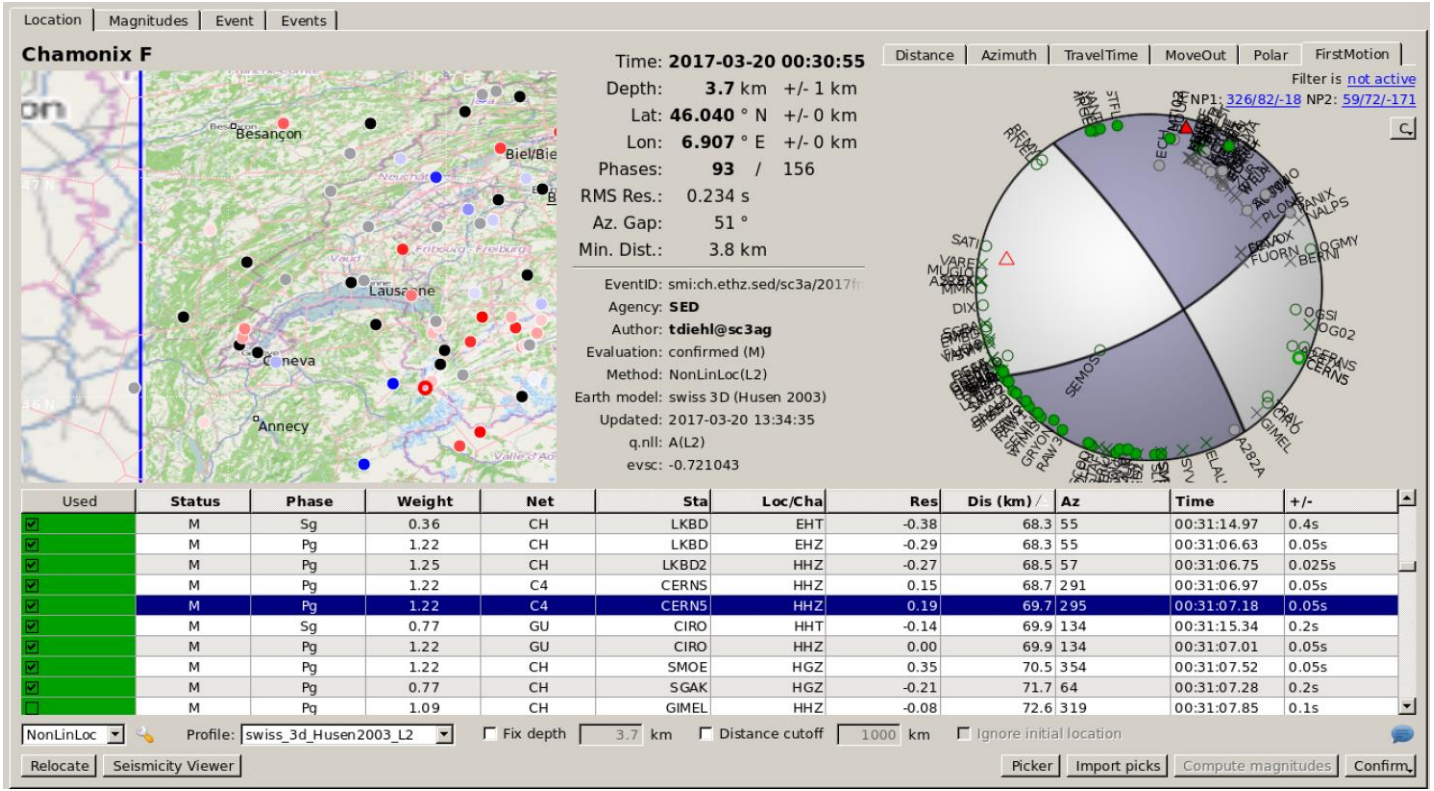
Conclusion



"CERN stations fully integrated in network, expect to operate like any other SED station, and included permanent archive"

"CERN stations now used in all earthquake related products"

Dr. John Clinton, Director of Seismic Networks and Head of the Earthquake Monitoring section at the SED

http://stations.seddbd.ethz.ch/fr/networks/c4/

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Next Steps

- Calculations will be implemented to set a warning trigger during the excavation
- Collaboration with SED to get a warning in case of large earthquake
- Streaming latency to SED reduce to 2s
- Slots, CPU, FPGA and RAM are not fully used : new features can be implemented
- Installation of new stations

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Thank you!

Questions

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