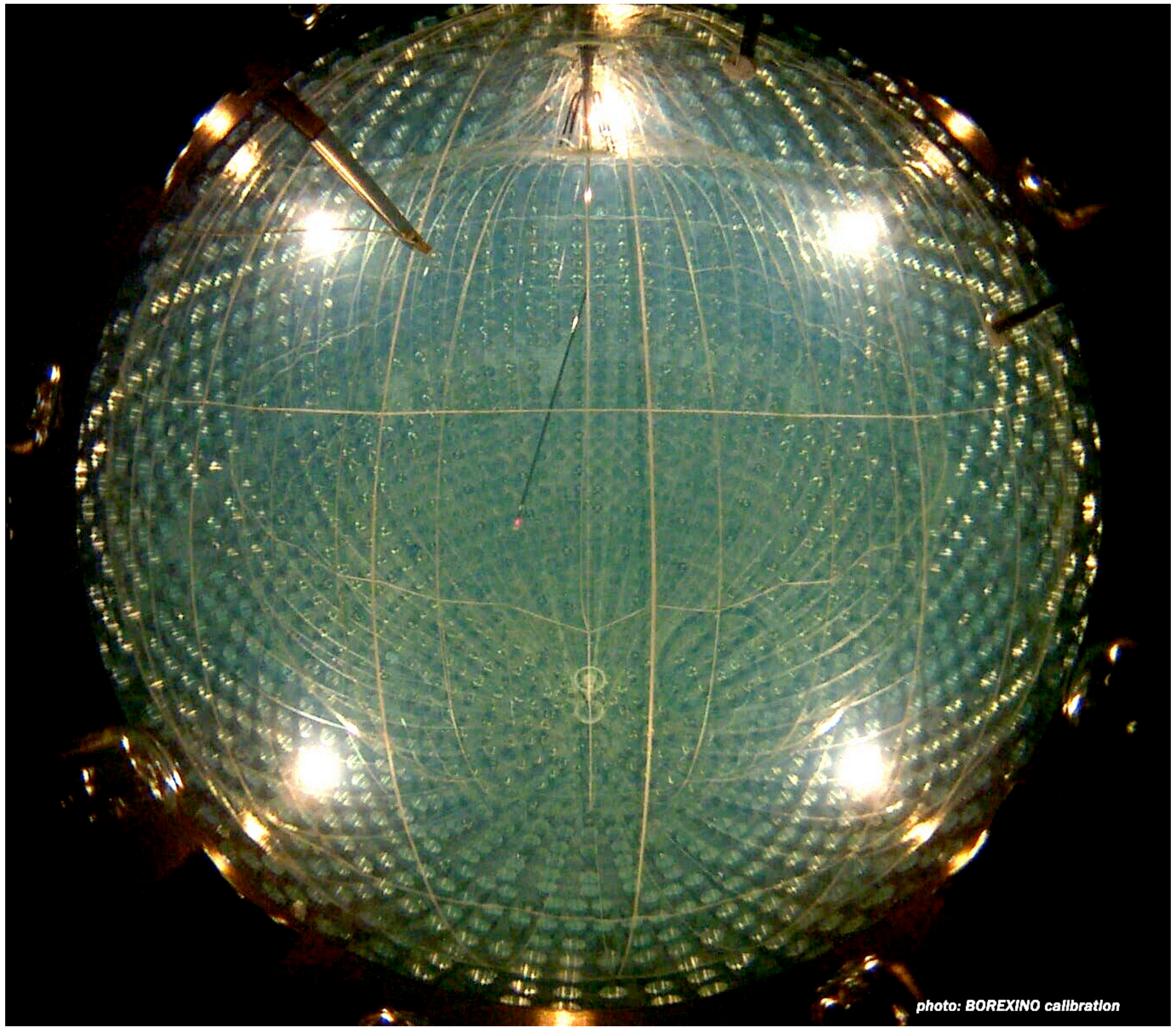


Toward a high precision neutrino speed measurement with Borexino

LNGS - March 28th, 2012

Marco Pallavicini
on behalf of the Borexino Collaboration

Dipartimento di Fisica - Università di Genova e
Istituto Nazionale di Fisica Nucleare (INFN)- Genova

Overview

- **Speed** measurement in Borexino
  - Signal with scintillator and water detectors
  - Old system limitations
  - Work in progress on 2011 data
- Toward a **high precision measurement**
  - **New hardware**
    - **Trigger**
    - **GPS-based time measurement**
  - Plans for a new **geodesy** measurement
- Conclusions

The Borexino detector

Scintillator:

270 t PC+PPO (1.5 g/l)
in a 150 µm thick
inner nylon vessel (R = 4.25 m)

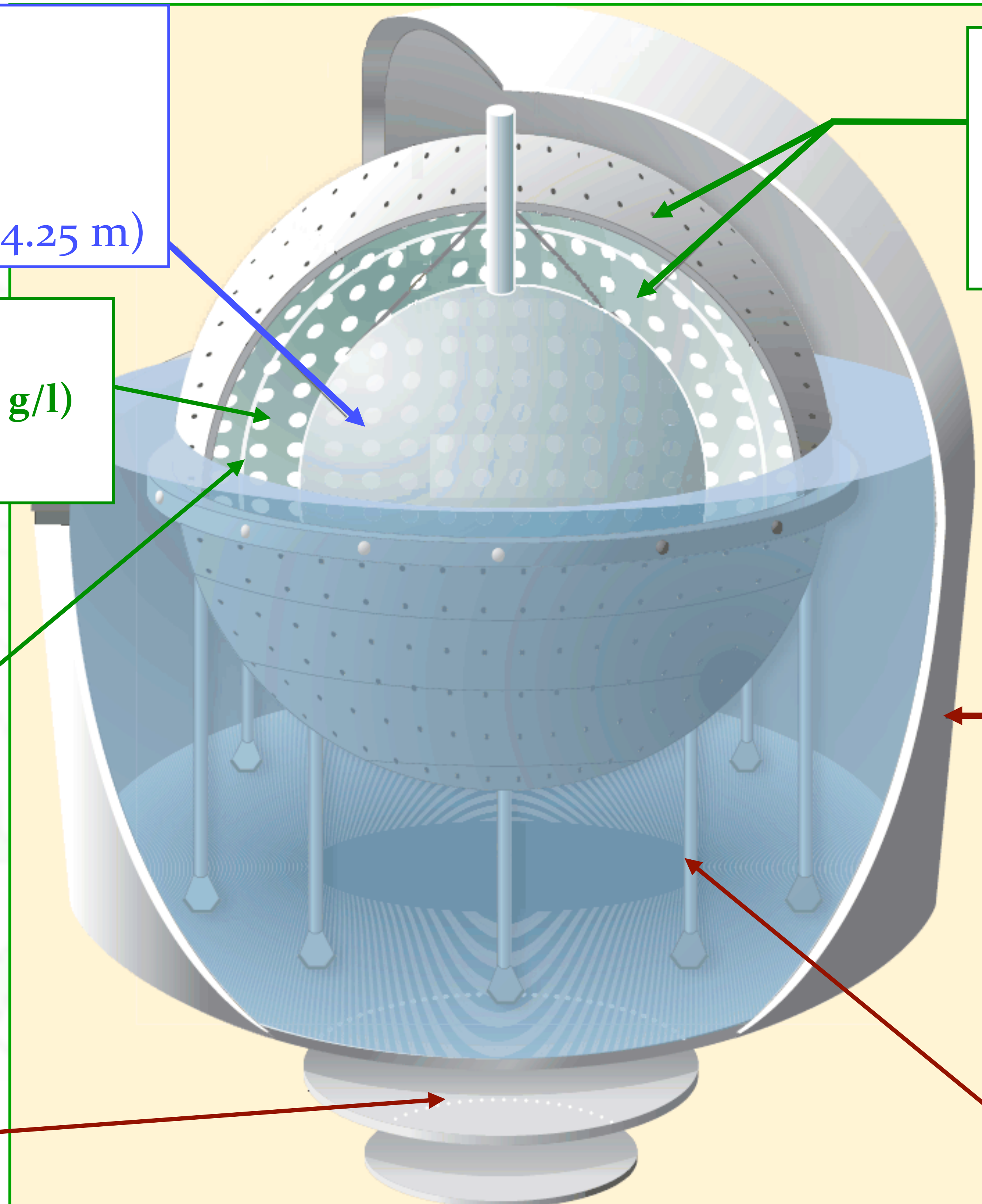
Buffer region:

PC+DMP quencher (5 g/l)
4.25 m < R < 6.75 m

Outer nylon vessel:

R = 5.50 m
(^{222}Rn barrier)

Carbon steel plates



Stainless Steel Sphere:

R = 6.75 m
2212 PMTs
1350 m^3

Water Tank:

γ and n shield
μ water Č detector
208 PMTs in water
2100 m^3

20 steel legs

CNGS events detection

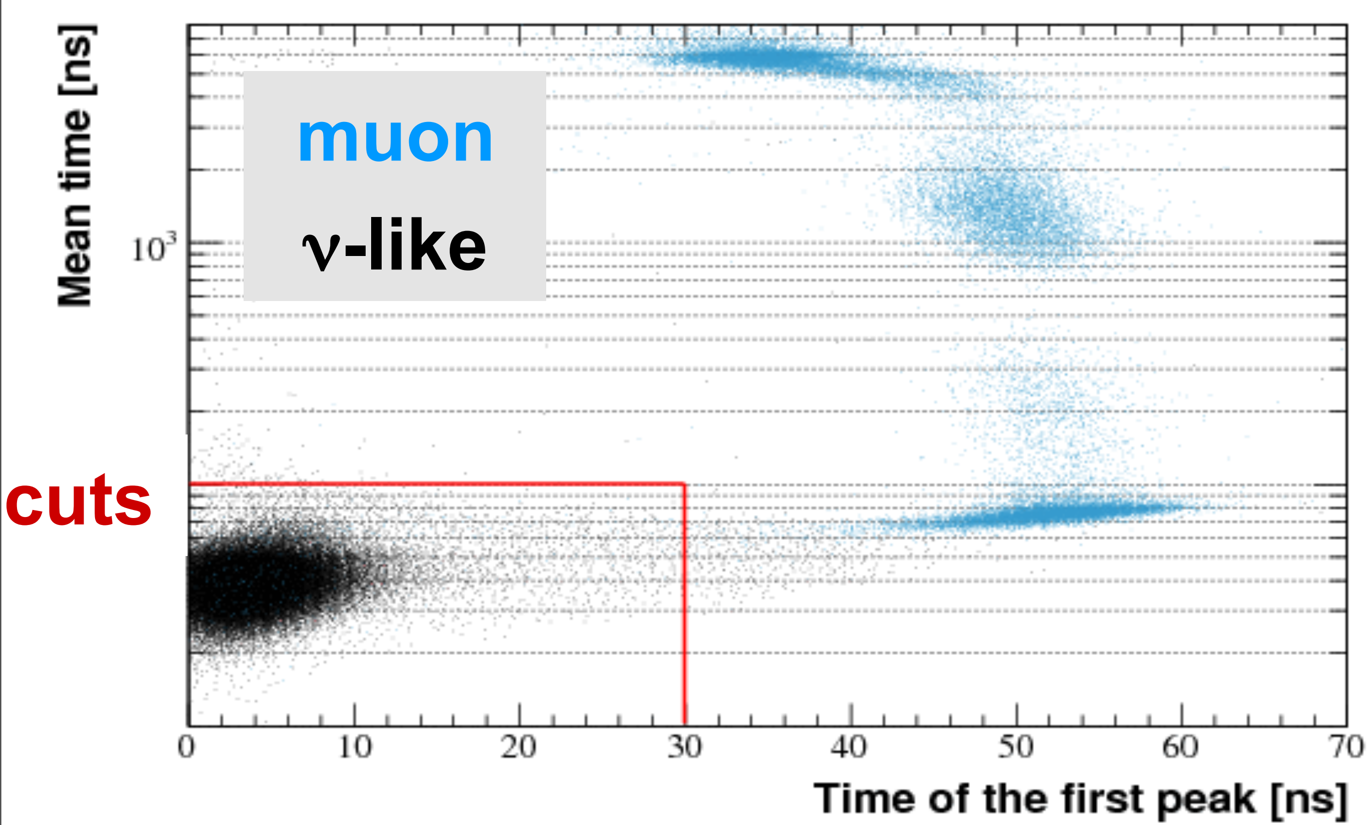
- **CNGS** muons (neutrinos) are detected by Borexino in two ways:
  - **Scintillation** for muons crossing the SSS
  - **Cerenkov light** in water
- As for other experiments, most of the events are due to neutrinos interacting in the rock upstream
  - Internal events exist, but are very **difficult to tag**
  - Simple kinematics tells that there is no crucial difference between the two classes of events

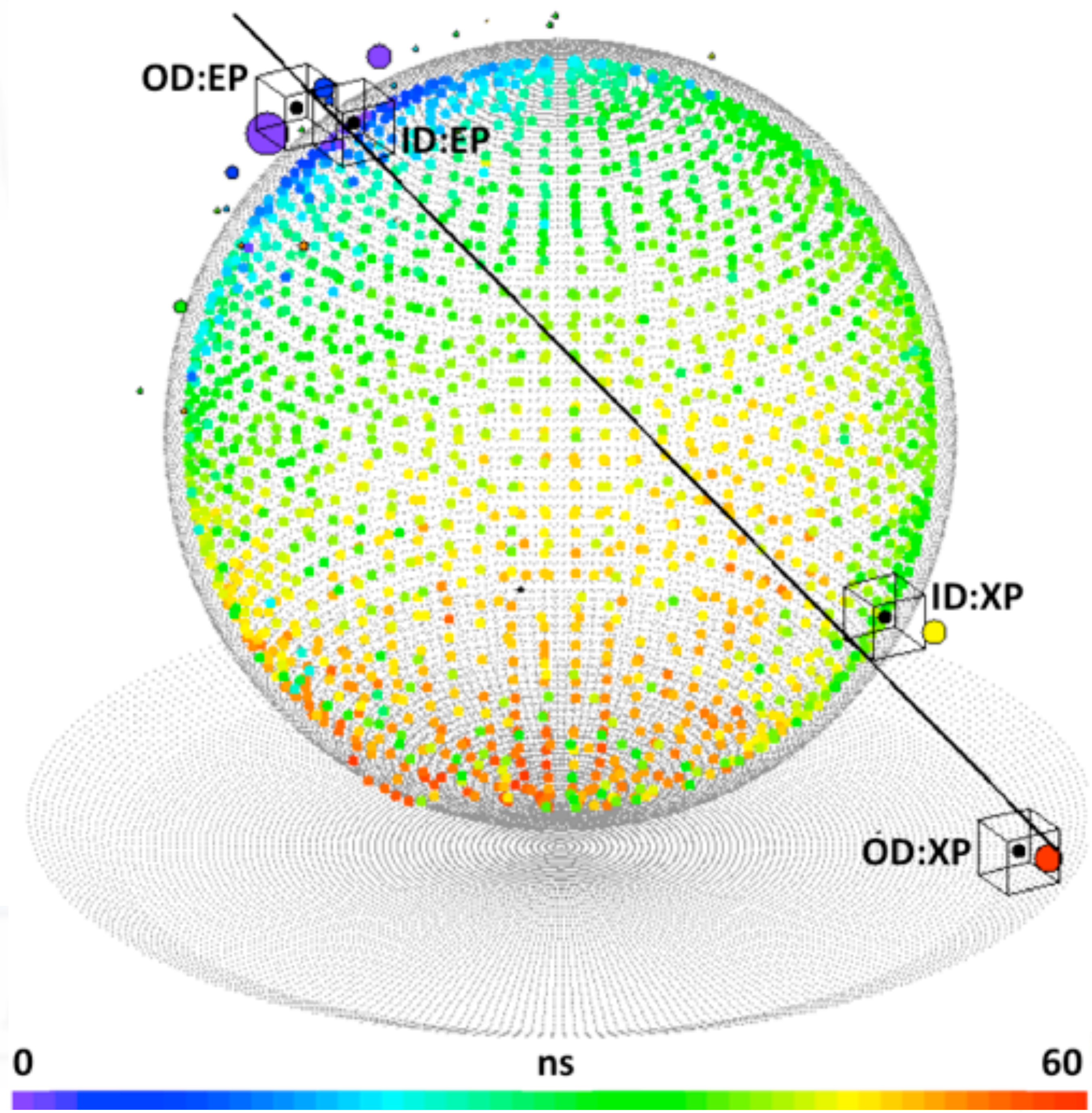
$$\Delta t = \tau_\mu - \frac{L_\mu}{c} = \frac{L_\mu}{c}\left(\frac{1-\beta}{\beta}\right) \approx \frac{L_\mu}{2\gamma^2 c} \approx 0.1 \cdot 10^{-9} s$$

    - Actually, a Monte Carlo evaluation of the effects related to **multiple scattering** is foreseen. **Probably small.**

Muon detection capability

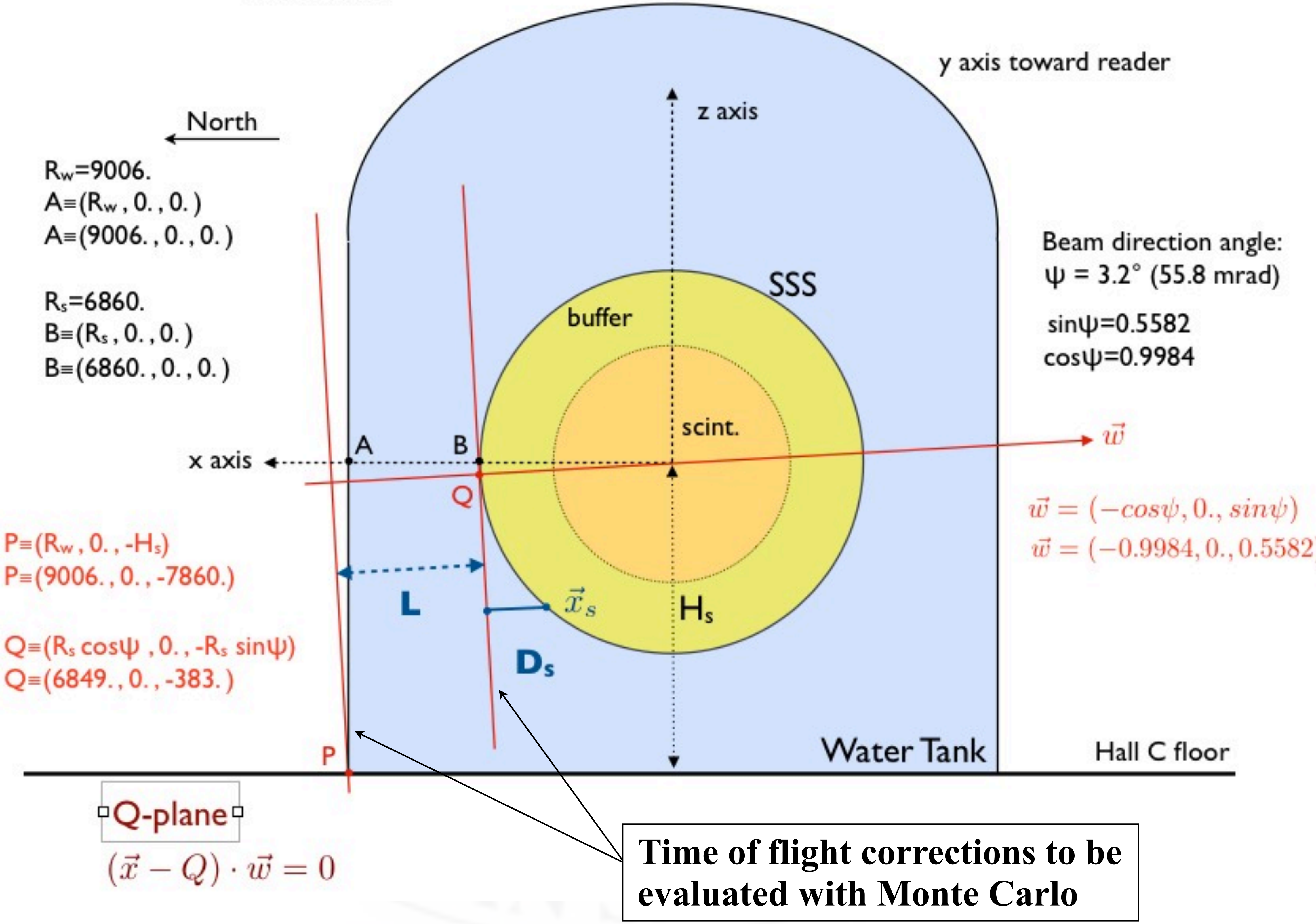
- CNGS events are **well tagged by time coincidence only**
  - However, we have also a well developed **muon identification capability**
  - Expected background close to zero
  - Muon detection is efficient at all angles





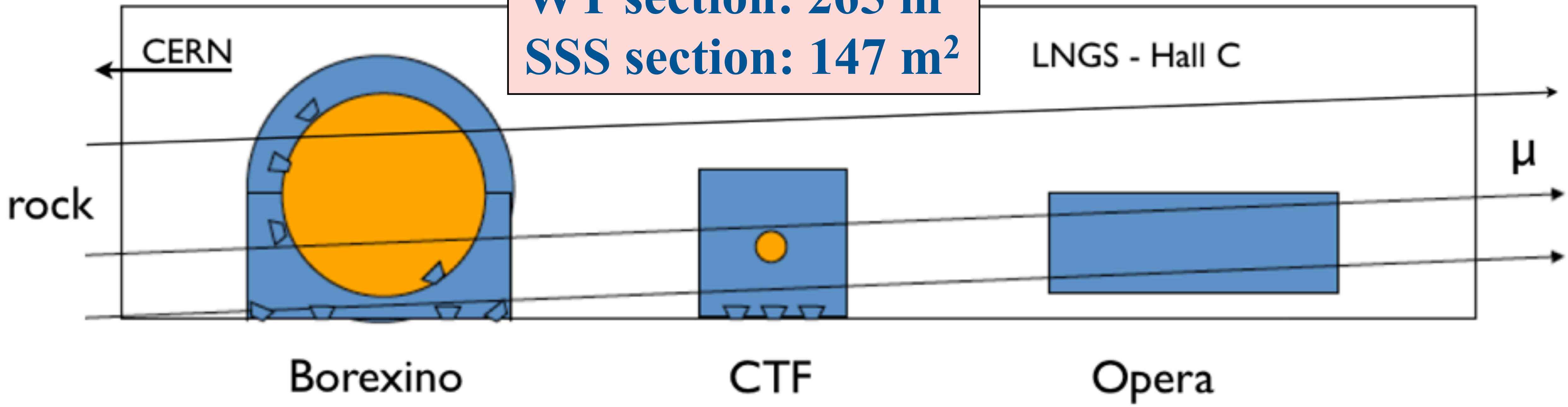
Internal geometry

Units: mm



2009–2011 data: statistics

WT section: 265 m²
SSS section: 147 m²



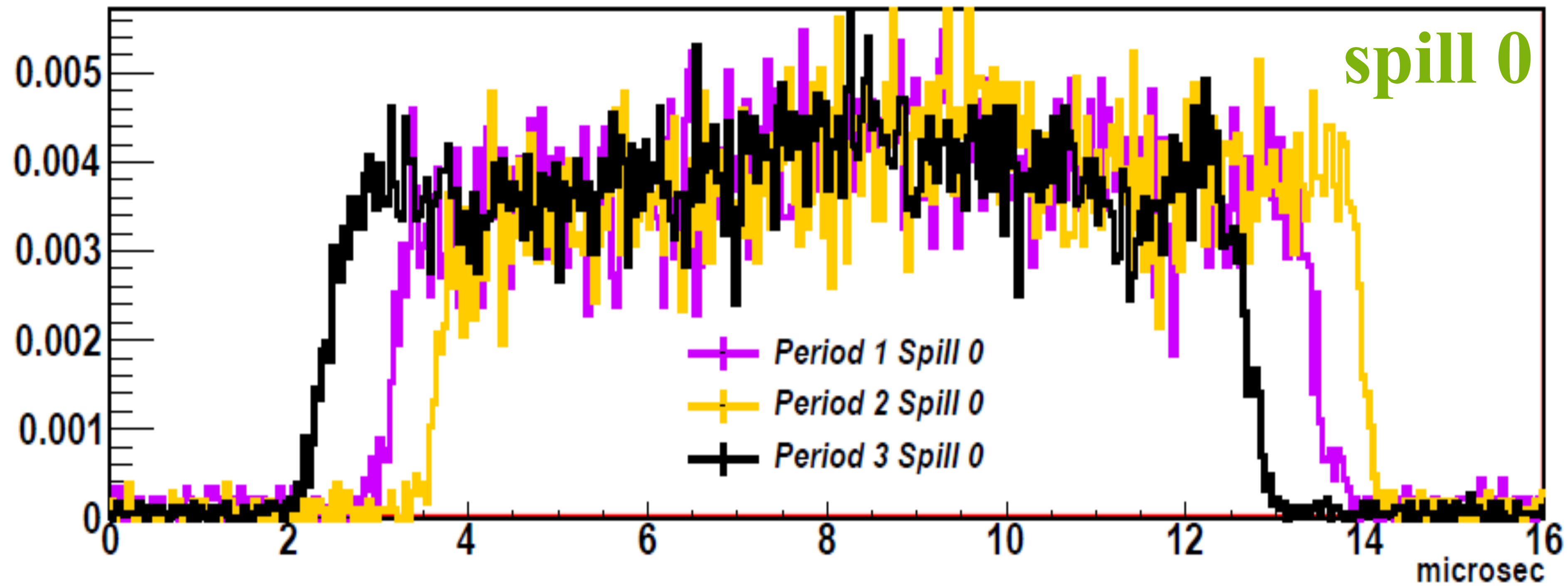
- Standard beam (2007-2011)
  - ~140 events / 10^{17} p.o.t. in total
    - ~ 50% through inner detector,
      ~ 50% through water detector only
    - Water Detector events are less precise, probably

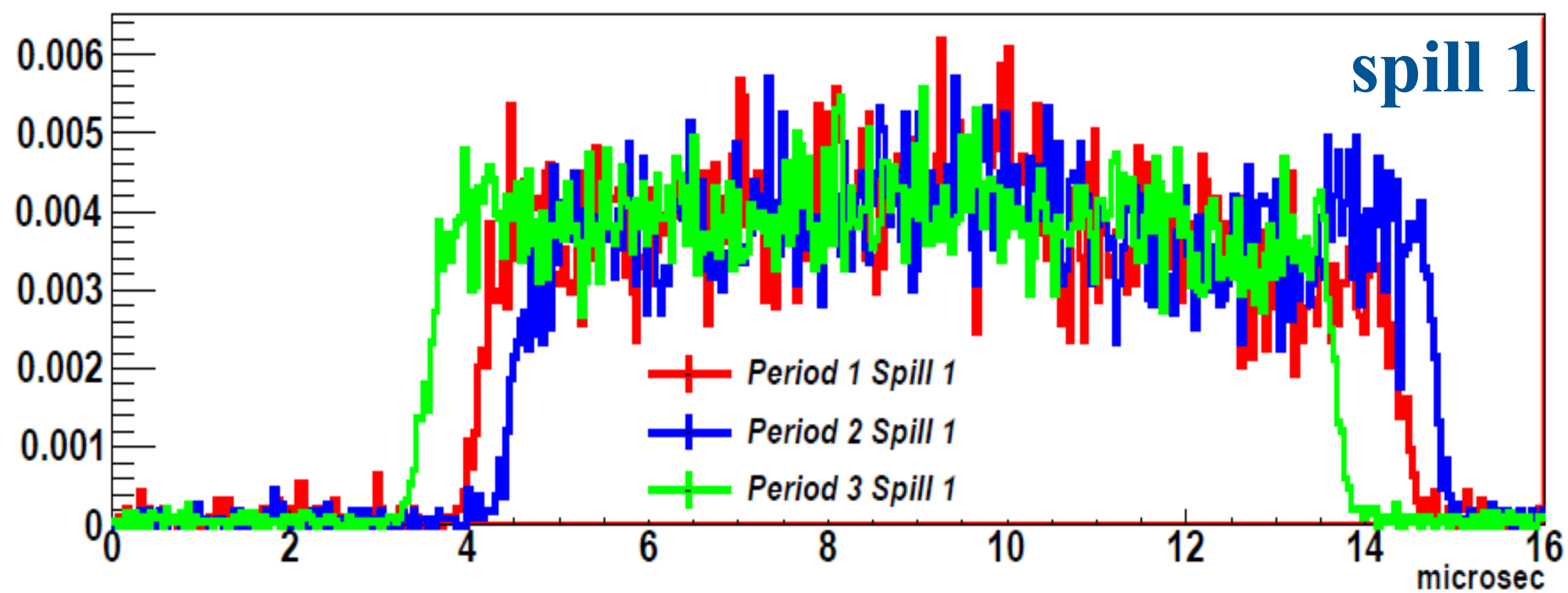
Year	Run	p.o.t (10^{19})	Events
2007	5972-6132	0.06	883
2008	8013-9052	1.31	19079
2009	10201-11685	2.34	33730
2010	12833-14620	3.25	47221
2011 OB	15509-16938	4.37	61138
			162051

- Short bunch beam 2011
  - 74 events in total
  - **38** detected events with inner detector

2009–2011 data: different trigger periods

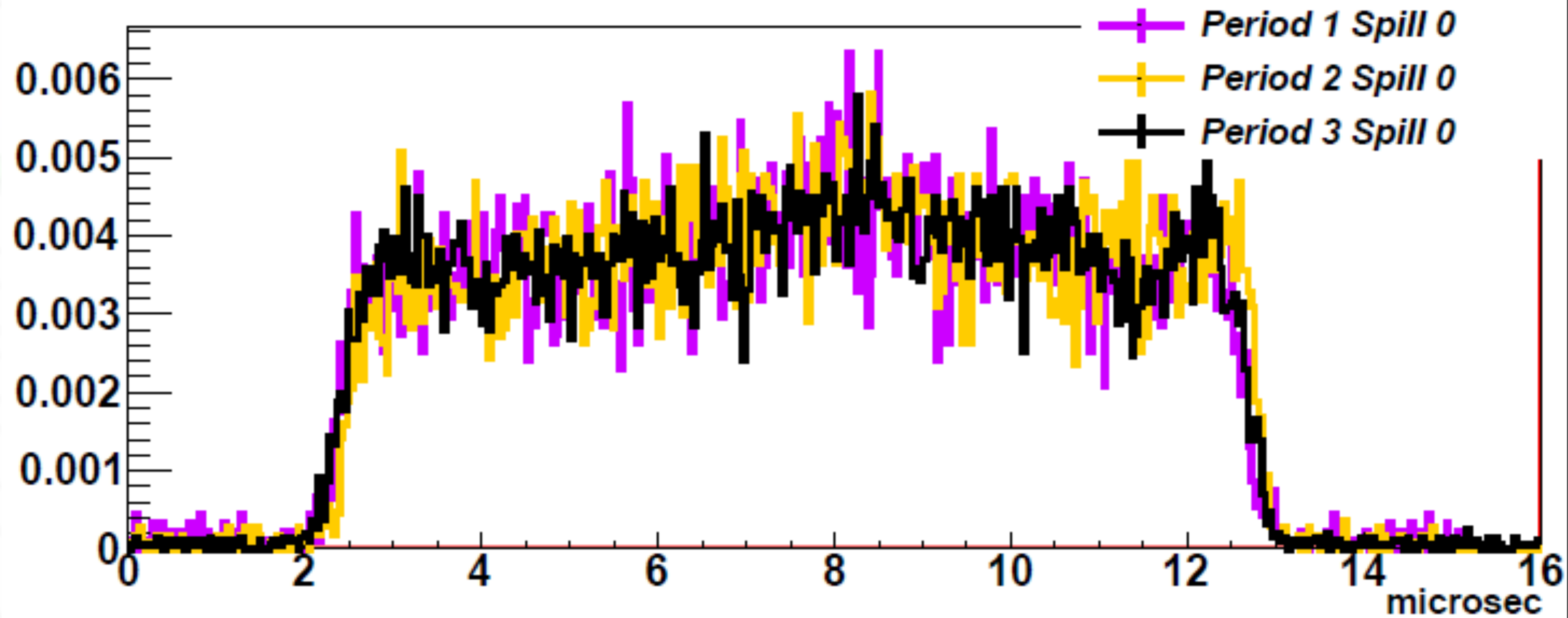
- 3 periods
  - change in trigger make delays different
- consistent results
  - shifts are understood
- very high statistics

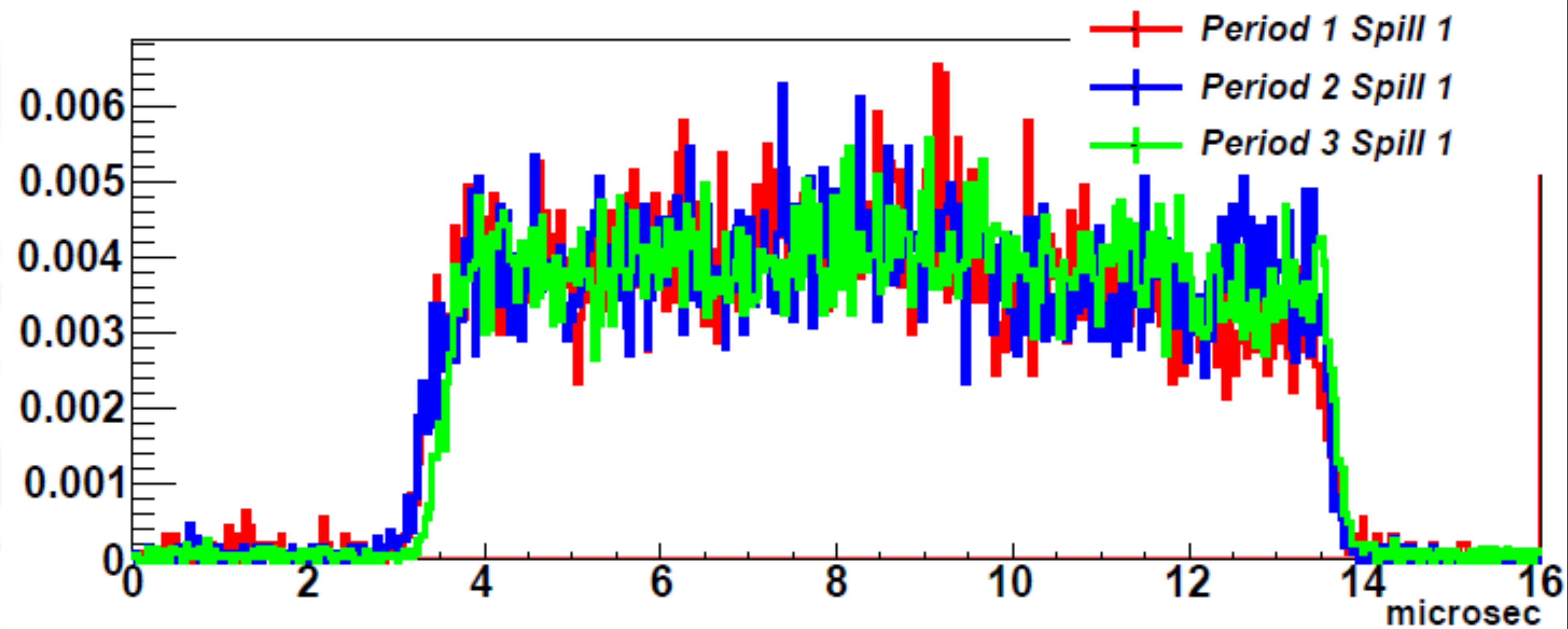




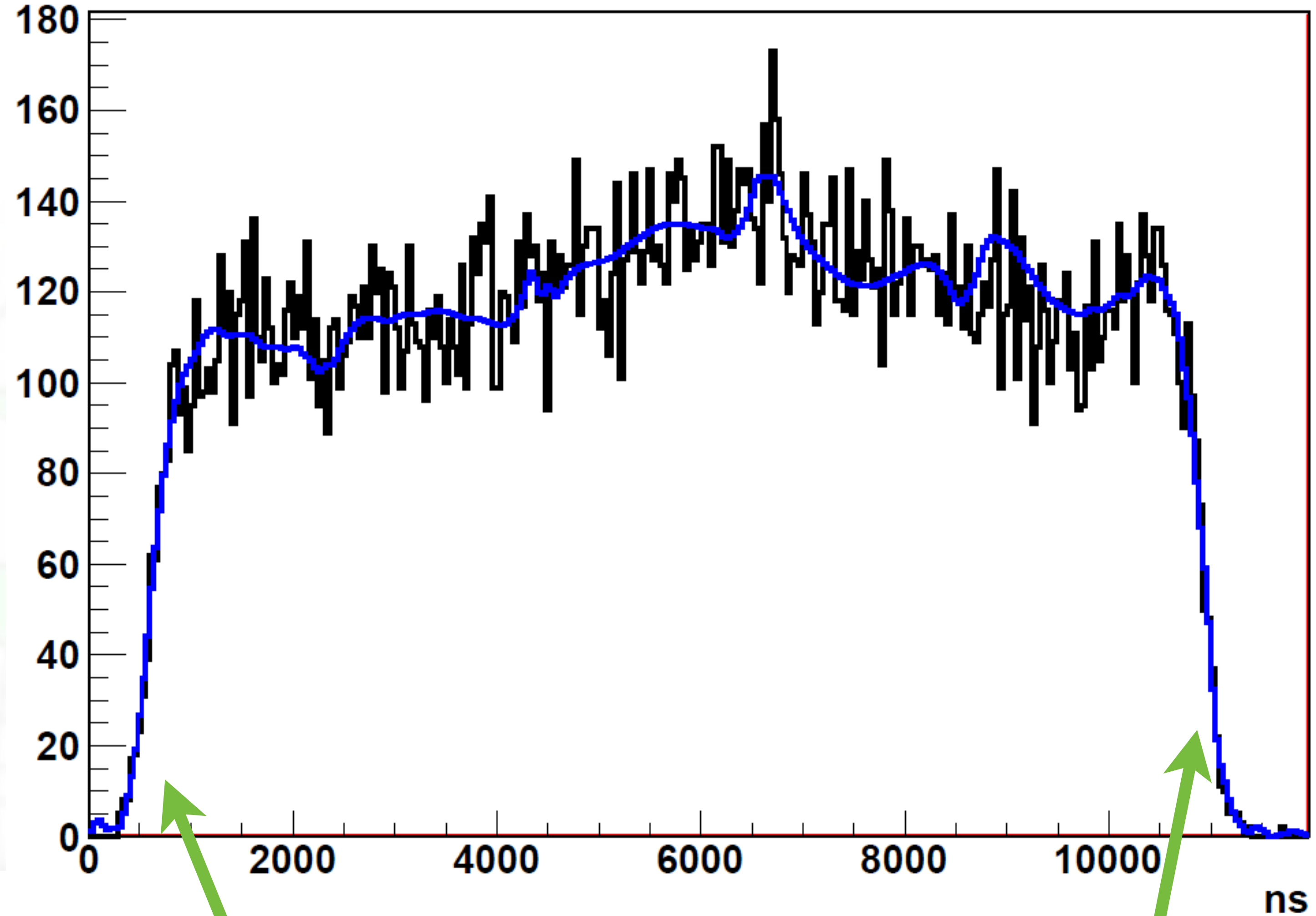
2009-2011 data: after trigger corrections

- same plot after Borexino trigger correction
- small shift still present in CERN waveforms as well
- known problem, already noticed and corrected for by Opera



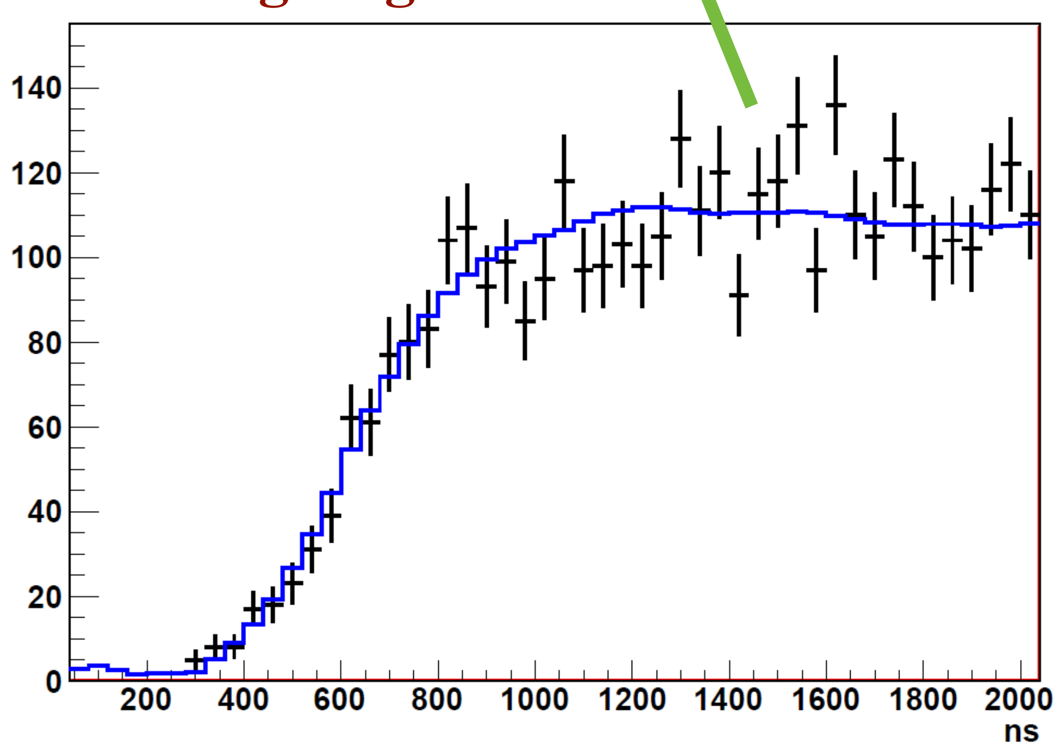


Fitting 2009–2011 data

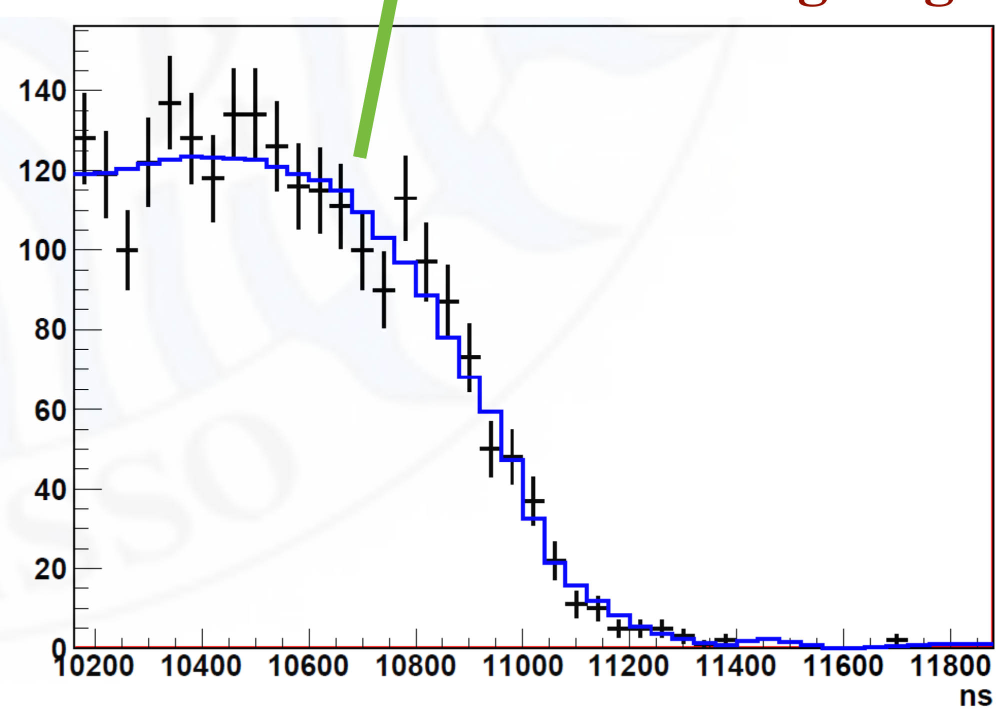


Digital filter developed and applied to waveforms to remove high frequency noise

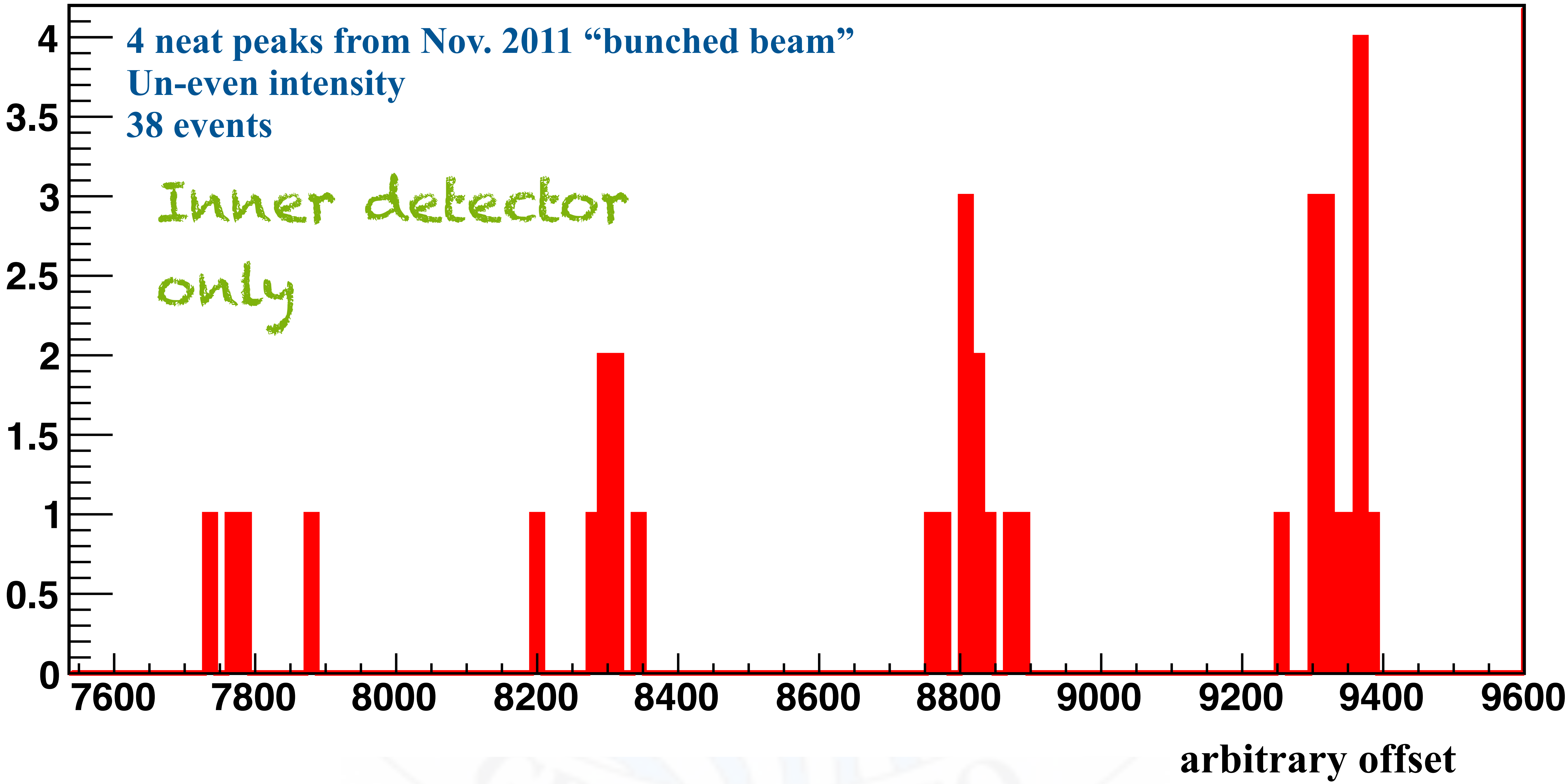
Leading Edge



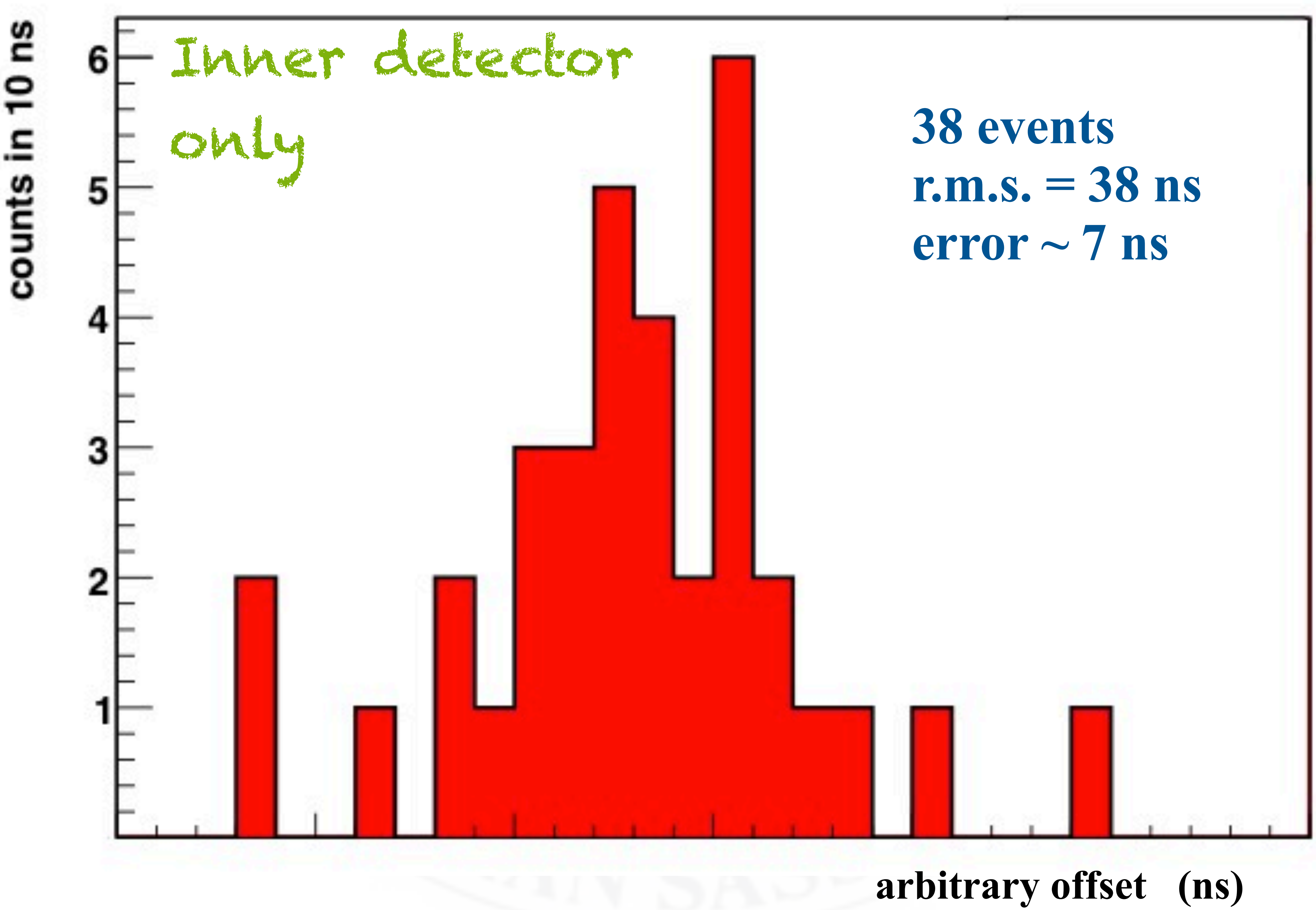
Trailing Edge



Nov. 2011 data

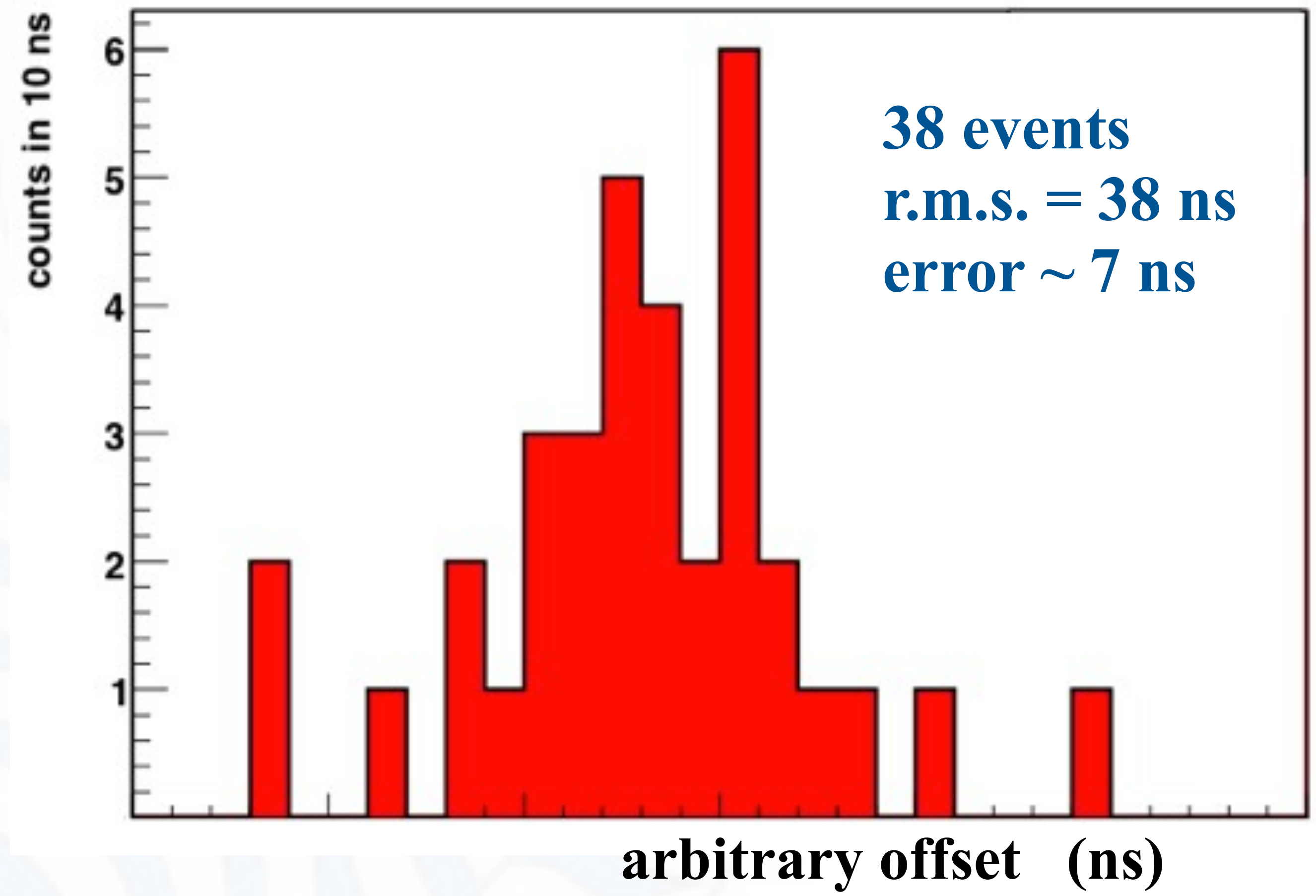


Nov. 2011 data: folding



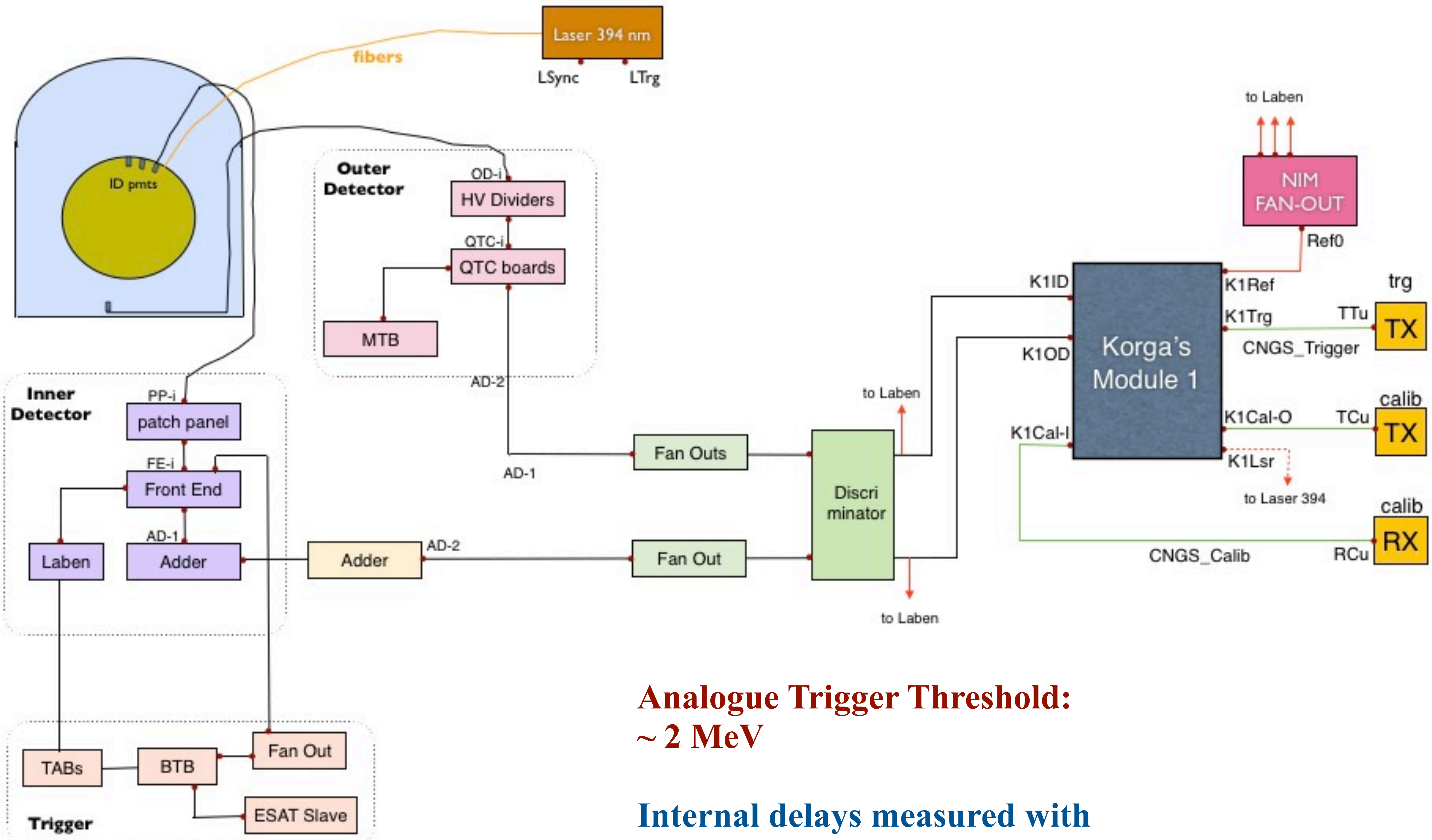
Comments on 2011 data

- The **policy** of the Borexino Collaboration has been since the very beginning to release results only when:
  - Data analysis has been completed by at least two independent groups
  - The work is complete and throughly checked by the Data Validation Committee



- This process is still in progress
  - **We make no exception** for the **neutrino speed** measurement
  - Our goal is a paper soon after the “short bunch beam” in May

New trigger: no digital clocks

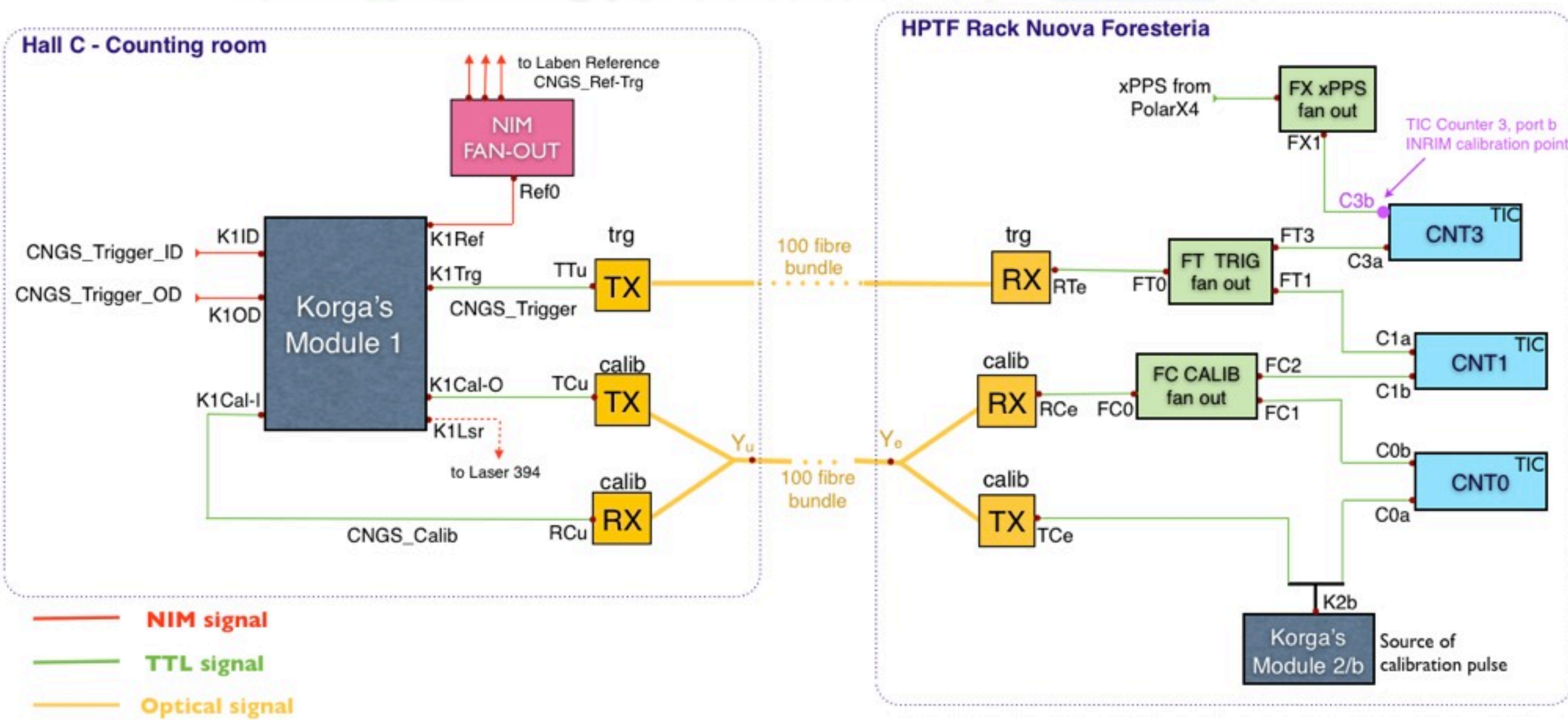


Analogue Trigger Threshold: ~ 2 MeV

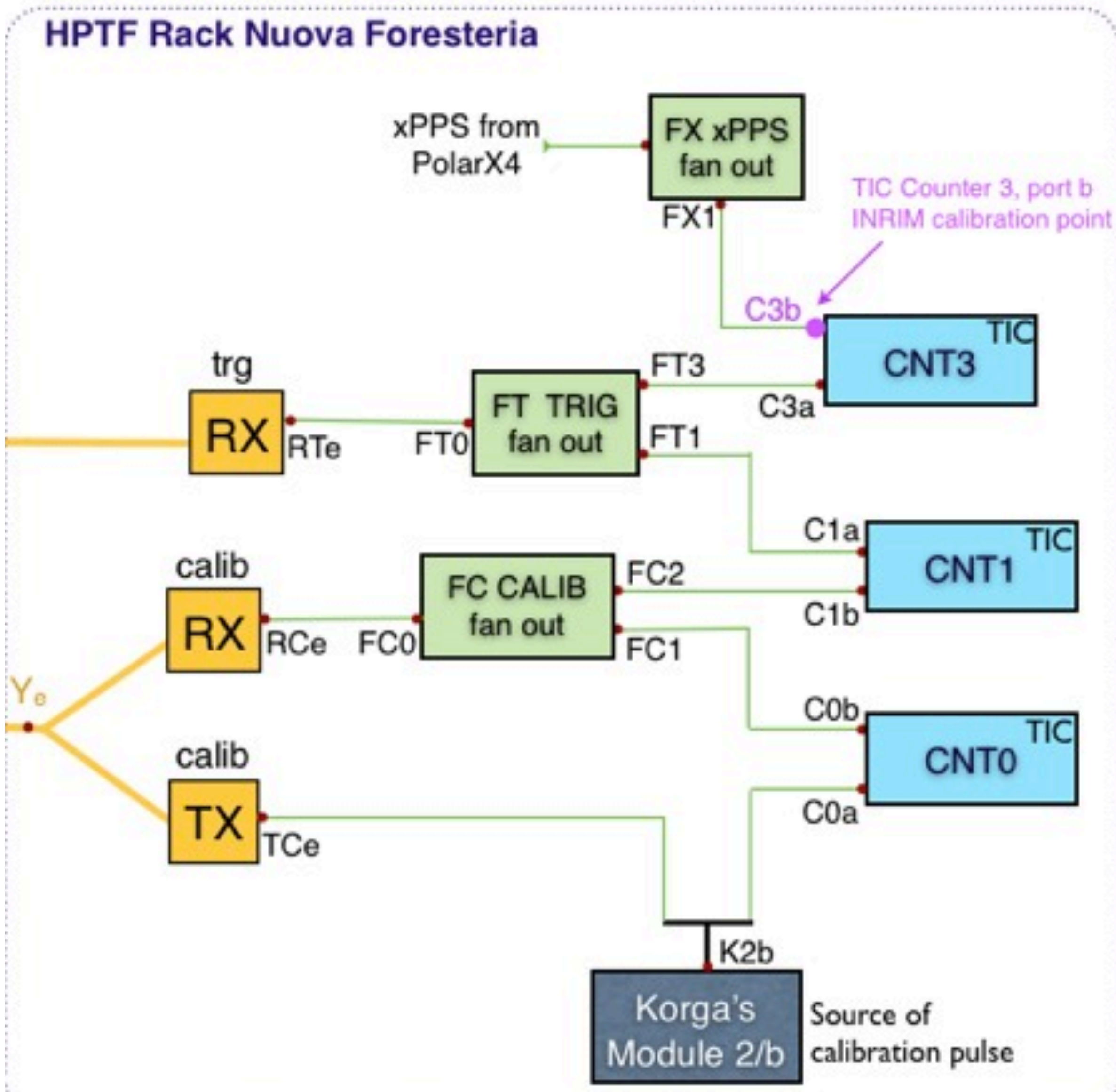
Internal delays measured with 0.1 ns accuracy

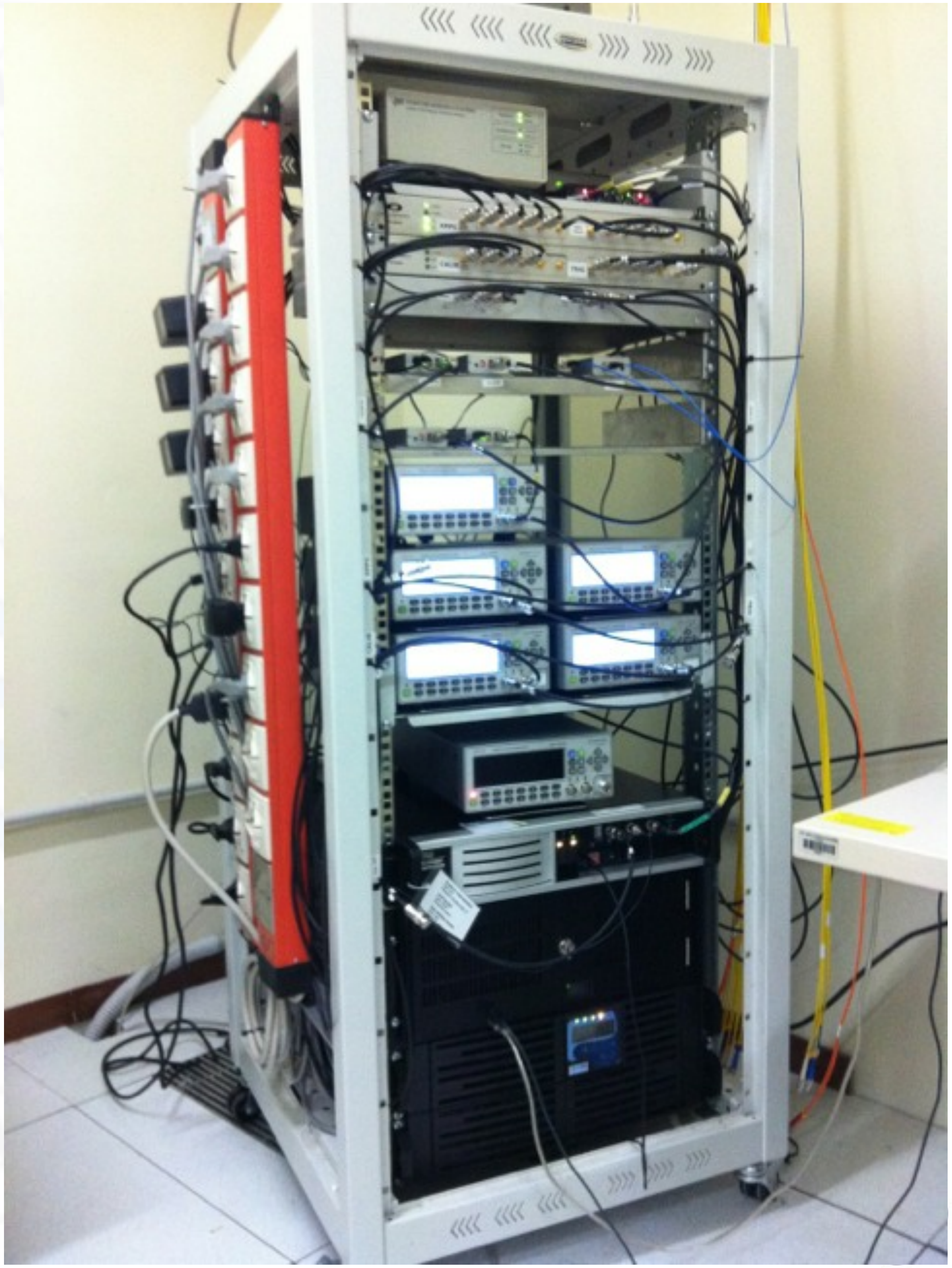
New system design: HPTF

- Main features:
  - Trigger delivered outside with optical fiber
  - No digital parts (low jitter)
  - Real time monitoring of fiber lengths and internal delays

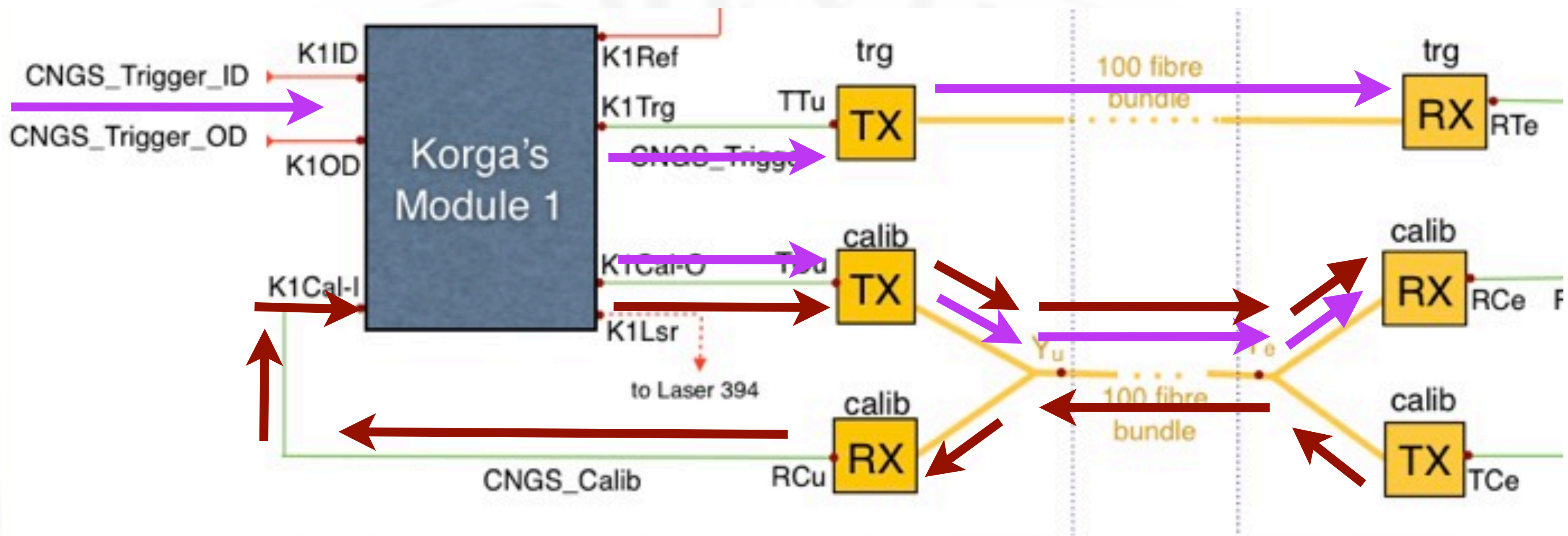


New design: High Precision Timing Facility



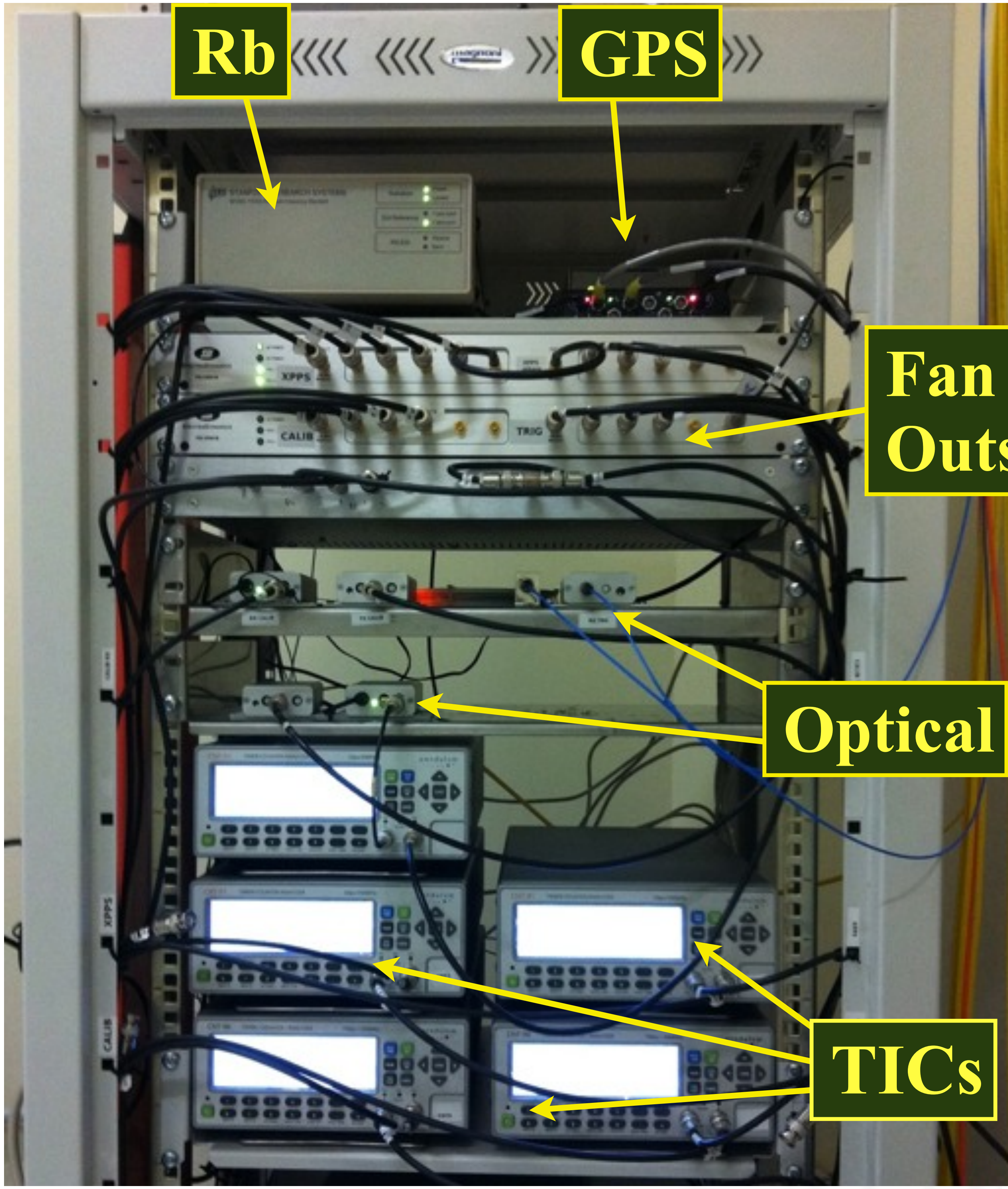


Online monitoring of detector delays



- The connection between the detector in Hall C and the GPS receiver outside is **monitored real time**
  - **Physics triggers** are split in two signal that **travel along both fibers**
  - **Calibration pulses** go **back and forth along the calibration fiber**
- We measure every **10 s** the length of both paths (up to small constant delays)

GPS



RELAZIONE

I.N.RI.M.
ISTITUTO NAZIONALE DI RICERCA METROLOGICA

N. 12-xxxx-xx emessa il 2012-03-19 - pag. 12/12

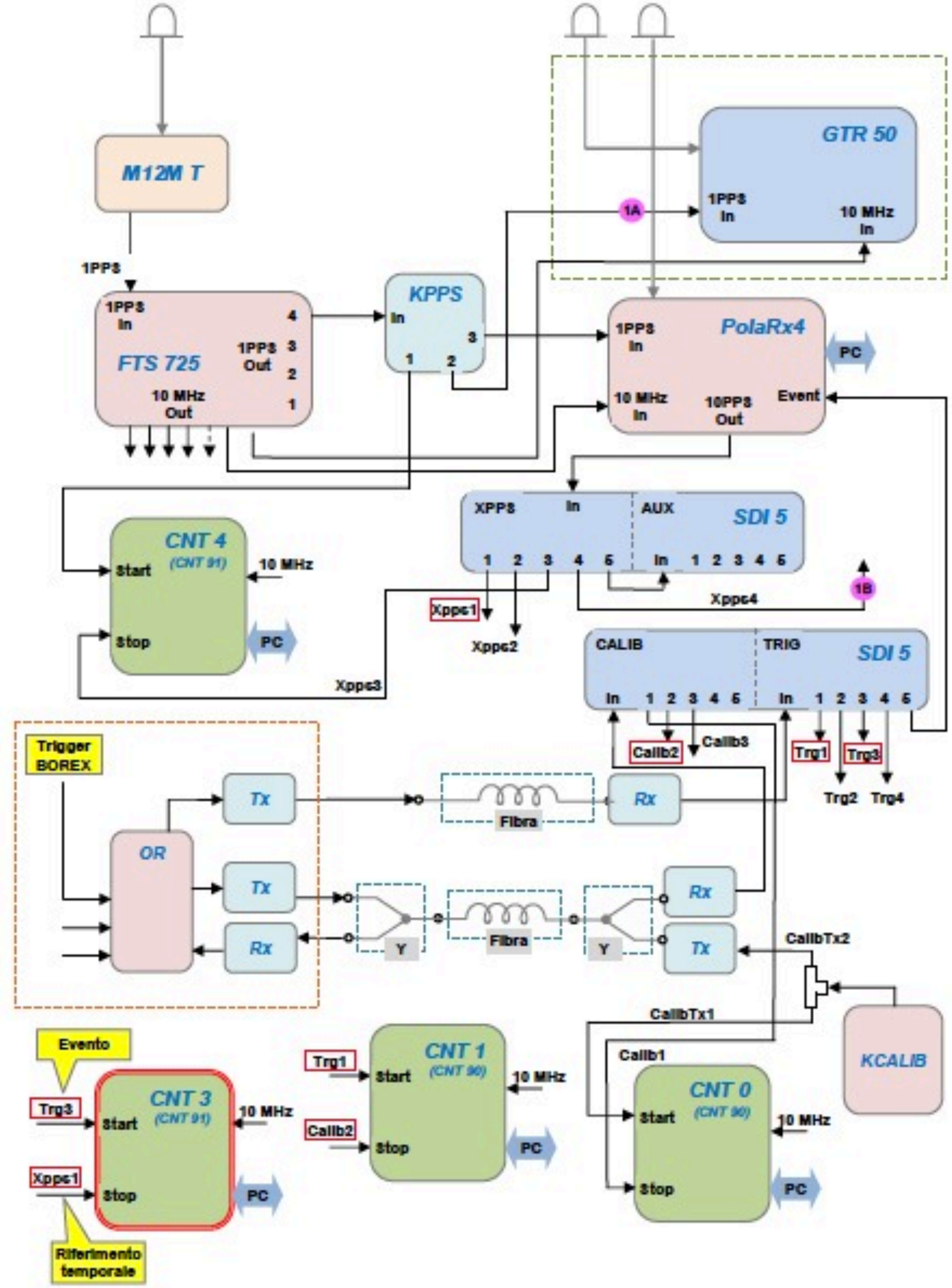
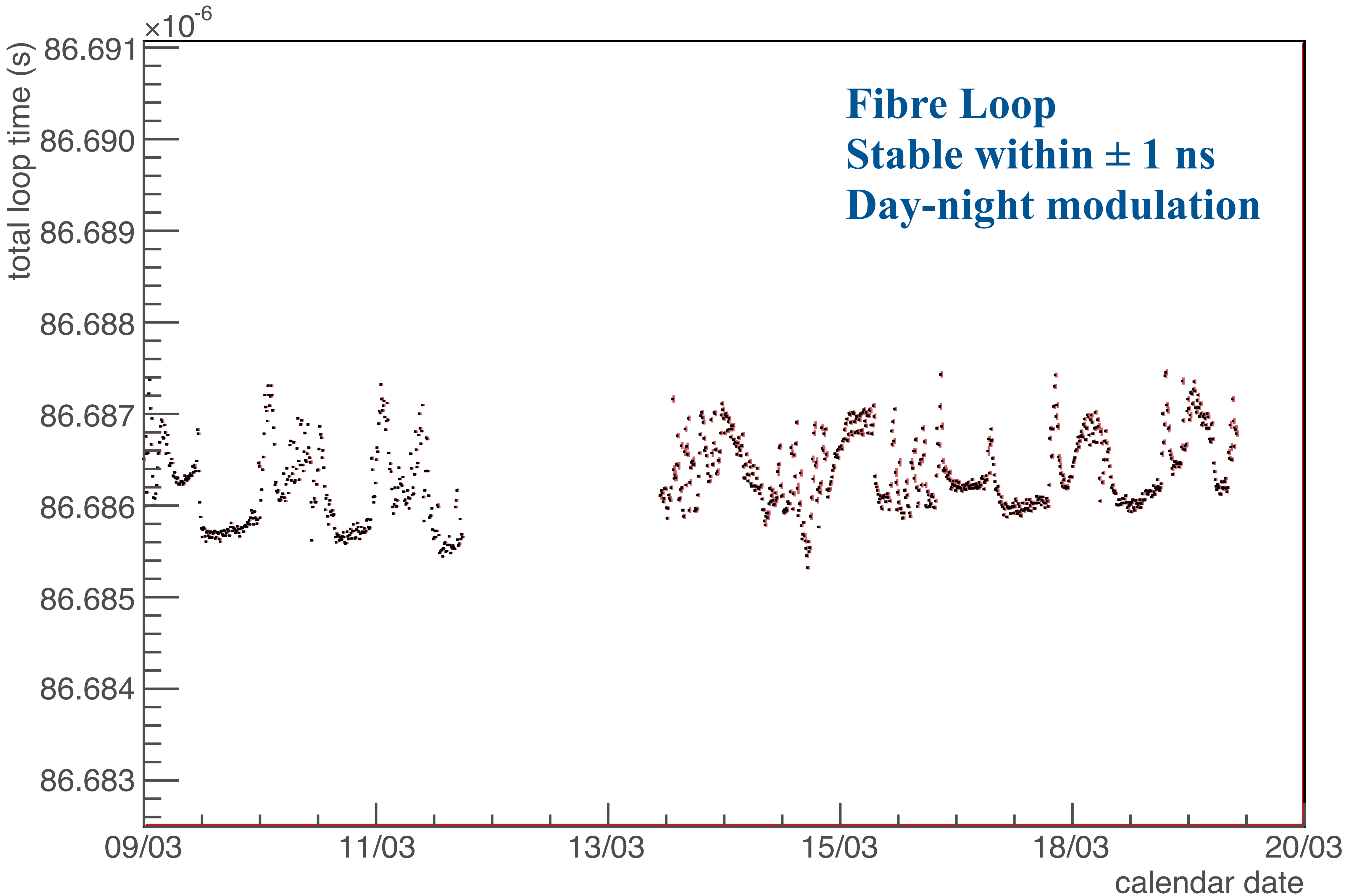


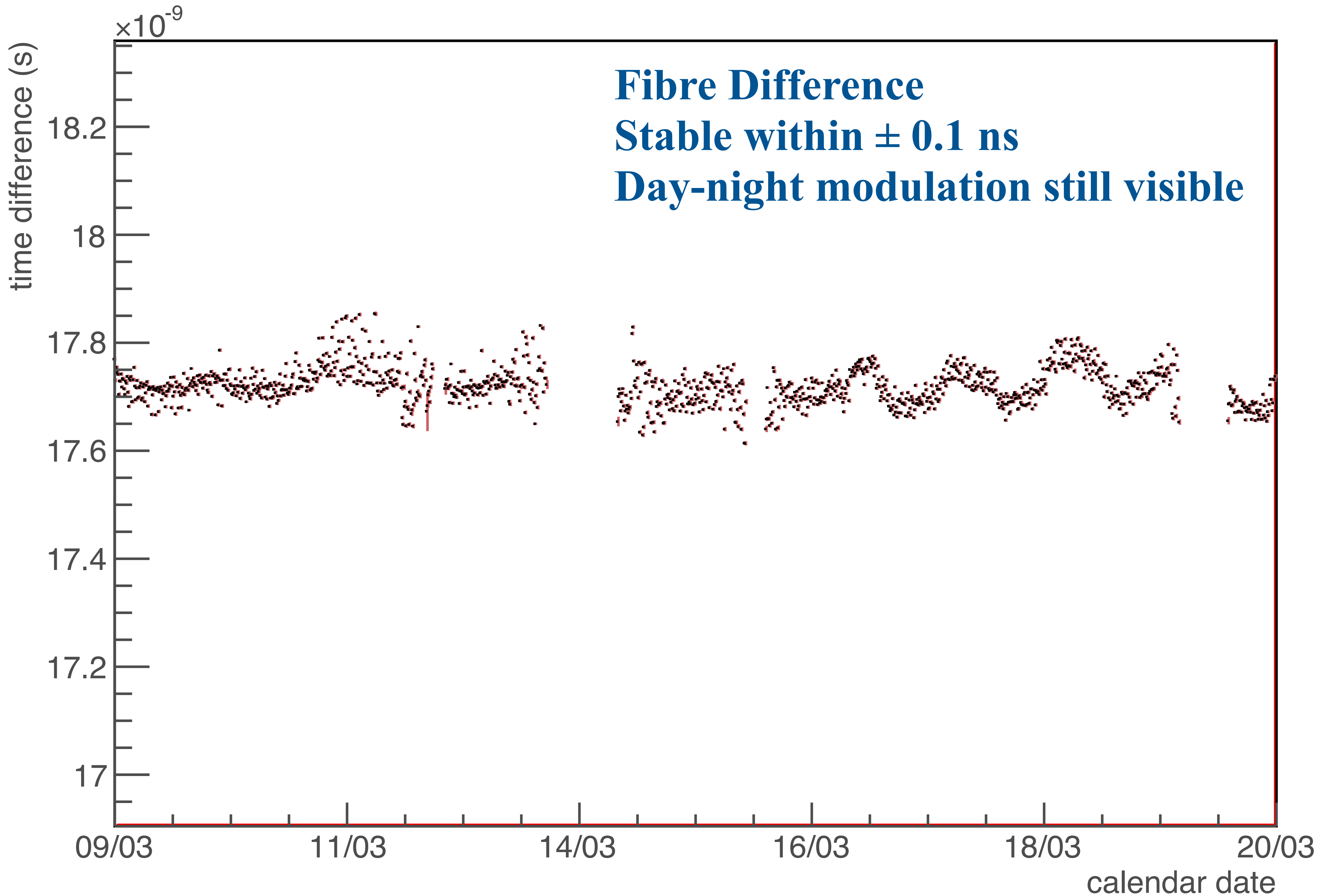
Fig. 7.1 – Schema a blocchi della catena di misura presso i LNGS

Controllato: ____________
(Valerio Pettiti)

Online monitoring of detector delays

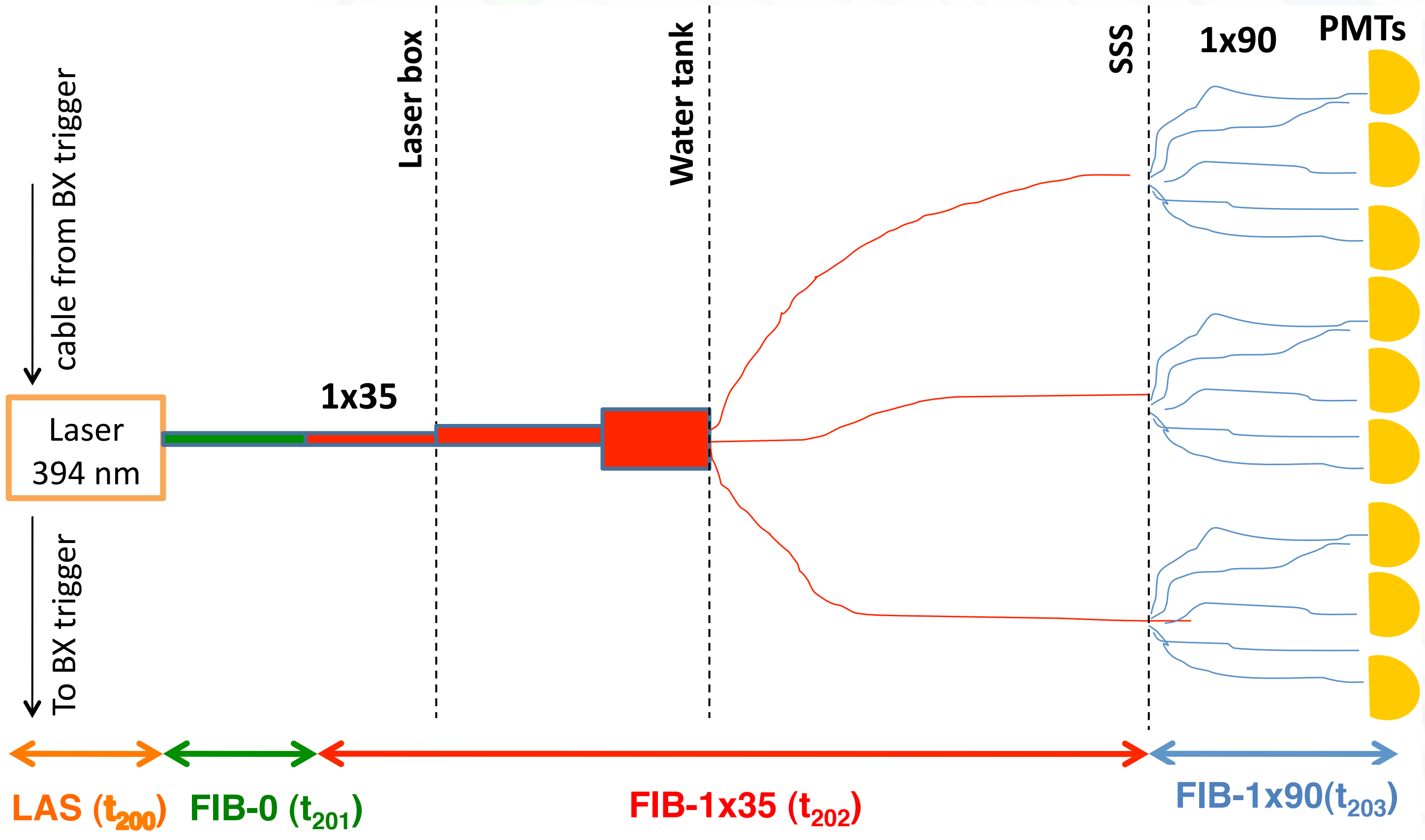


Online monitoring of detector delays



Timing laser system

- Borexino is equipped with a calibration system designed for high precision timing
  - A laser pulse, 394 nm, a few tens of ps long, is distributed to all PMTs through a set of optical splitters (passive) and optical fibers
  - By means of OTDRs we have measured the length of the fibers with 100 ps accuracy (@ 394 nm)
    - We can also pulse the Outer Detector, but with less precision

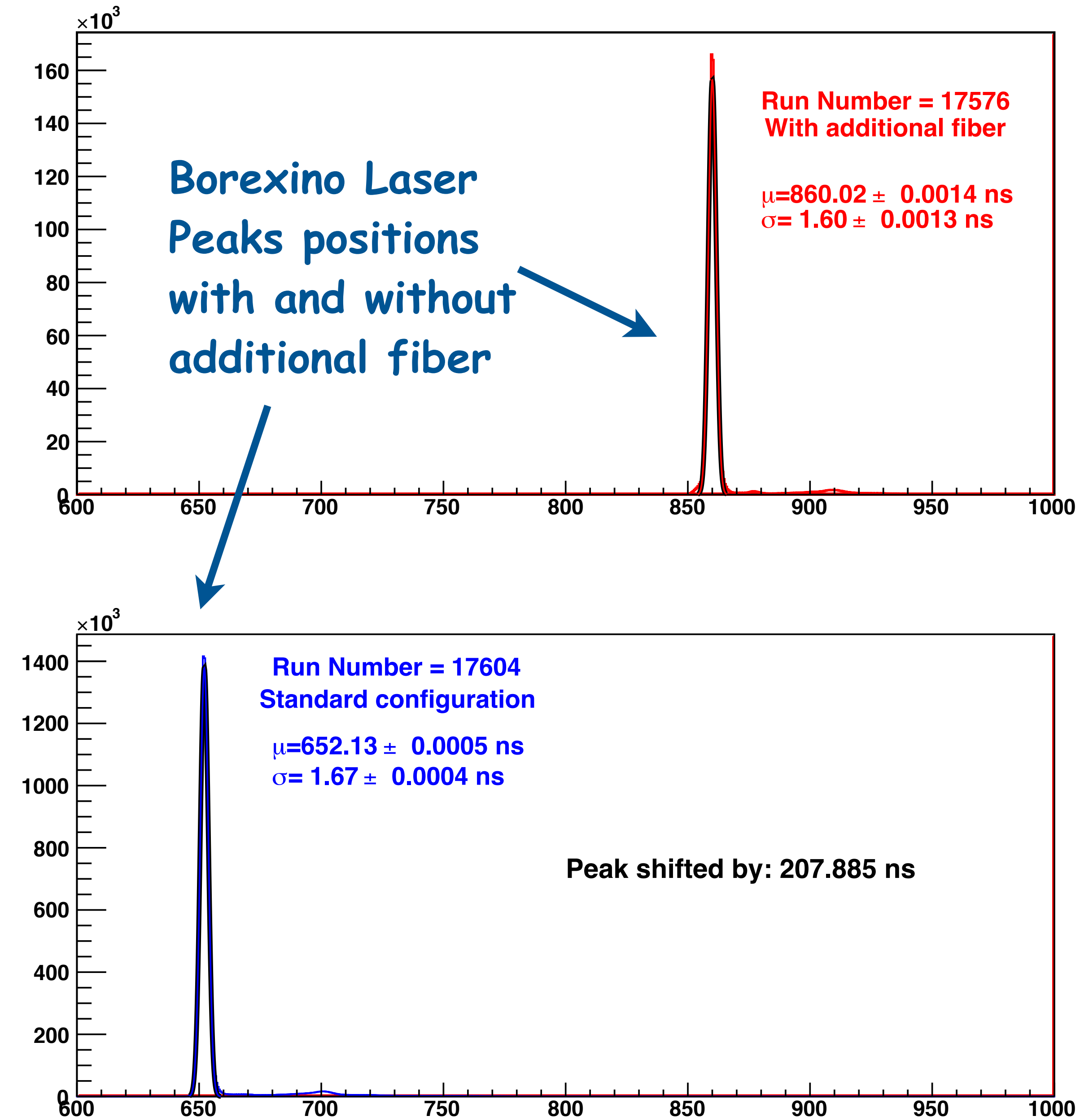


Distribution of light pulse in the detector

- Accurate and safe internal delays measurements possible through laser pulses
  - The delay from the PMTs photocathode up to the main TIC input is possible by summing just 2 contributions, both known with ~ 0.2 ns precision

Calibration of the calibration system

- In order to use the Timing Laser to measure the detector delays accurately, we must know the exact length of the fibers
  - We have used an OTDR (Optical Time Domain Reflectometer) to measure the length of all fibers at 850 nm
  - We have inserted a known fiber in the path made by the very same batch and used Borexino data to rescale the delay at 394 nm
  - Final precision: < 100 ps
    - Dominated by measurement of fiber physical length (~ few cm)



Collaboration with INRIM, ROA and CERN

- The preparation of a high precision GPS system requires knowledge and skills that do not belong to INFN
  - We have activated a cooperation and a “convenzione” with INRIM - Istituto Nazionale di Ricerca Metrologica, the italian institute of metrology
    - We have also an indirect collaboration with ROA, Real Observatorio de l’Armada, the spanish equivalent
  - The HPTF have been throughly tested and calibrated in Torino at INRIM
  - INRIM personnel is working with CERN Timing and CNGS groups in order to perform the complete calibration of the time link between CERN and HPTF
    - THANKS TO ALL

Expected error budget (estimate)

- Errors on a **single event**
  - **Statistical**
    - Uncertainty in the muon entrance point: ~ 0.7 m --> ~ 3 ns
    - Uncertainty in the light propagation and trigger formation jitter --> ~ 5 ns
    - GPS measurement --> ~2 ns

total r.m.s. ~ 6 ns

  - **Systematic**
    - Internal delays --> ~ 0.5 ns
    - Geodesy ~15 cm --> ~0.5 ns
    - GPS systematic --> ~ 1.5 ns
    - Muon entrance point --> ~ 0.5 ns
  - With **~200** events, we expect:

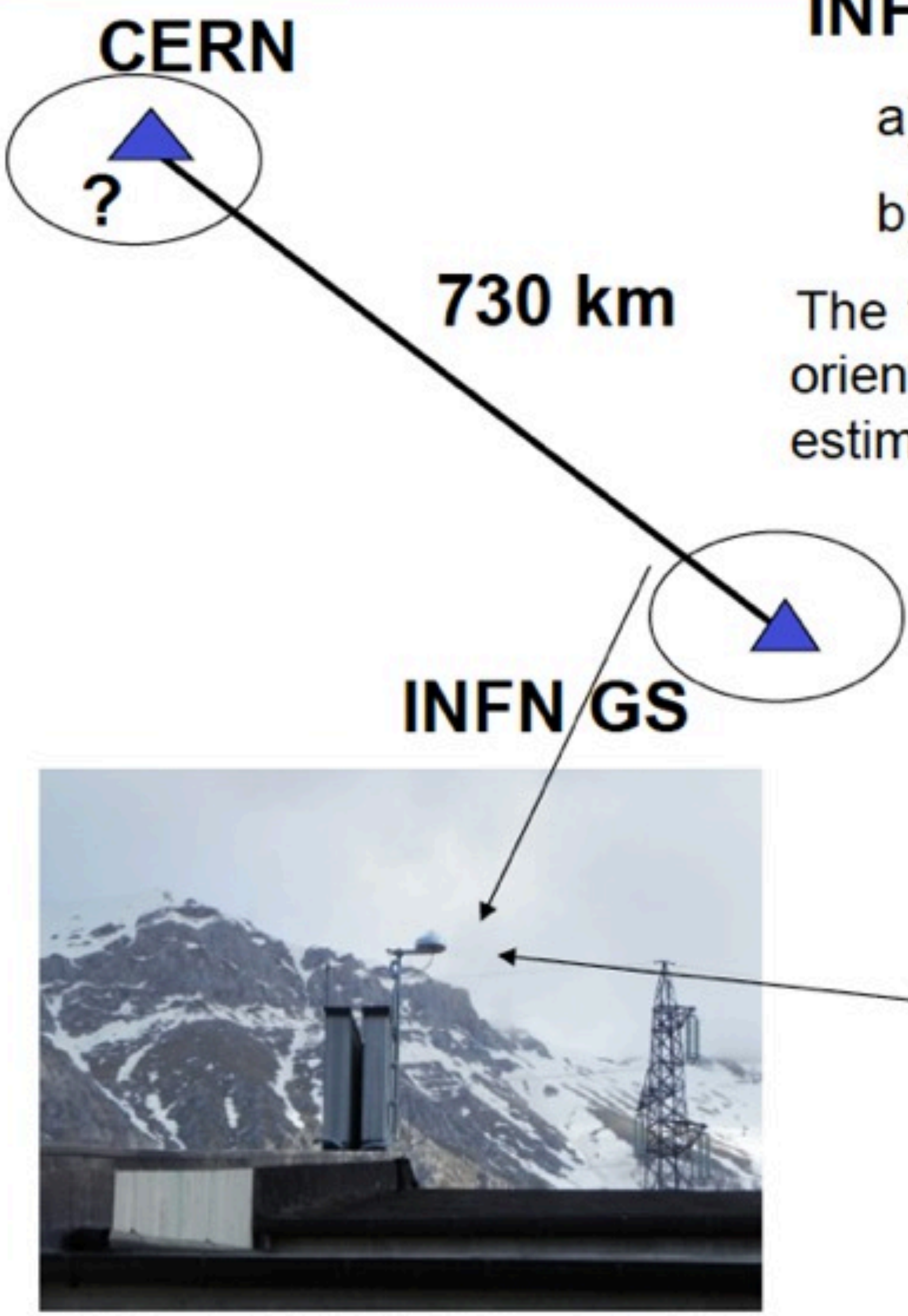
statistical ~ 0.5 ns **systematic ~ 2 ns**

- **NOTE: Estimates! Only data will tell which will be the final precision.**

Geodesy

- We are in contact with Prof. R. Barzaghi and his group of **Politecnico di Milano**
  - Experts in **geodesy measurement**
- In **agreement** with **LVD** and **Icarus** collaborations, and in strict coordination with the **Laboratory,** we will re-do the geodesic measurement of the position of the Underground Laboratory and of the three detectors
  - First inspections already done
  - The activity is foreseen for May, when, luckily enough, the highway is already scheduled to close at night for other works

Geodesic measurements

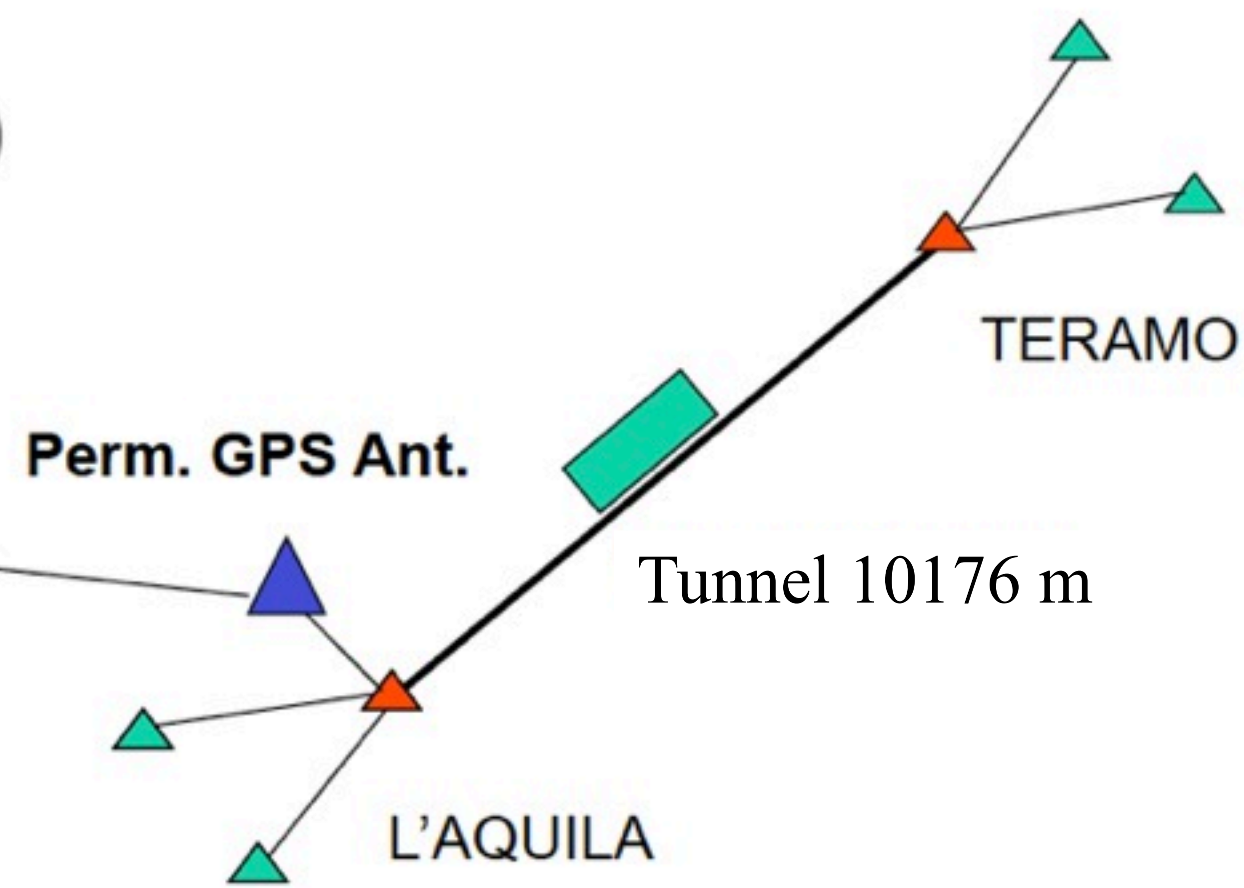


INFN GS:- 2 semi-permanent GPS Networks

a) Tunnel entrance (L'Aquila)

b) Tunnel entrance (Teramo)

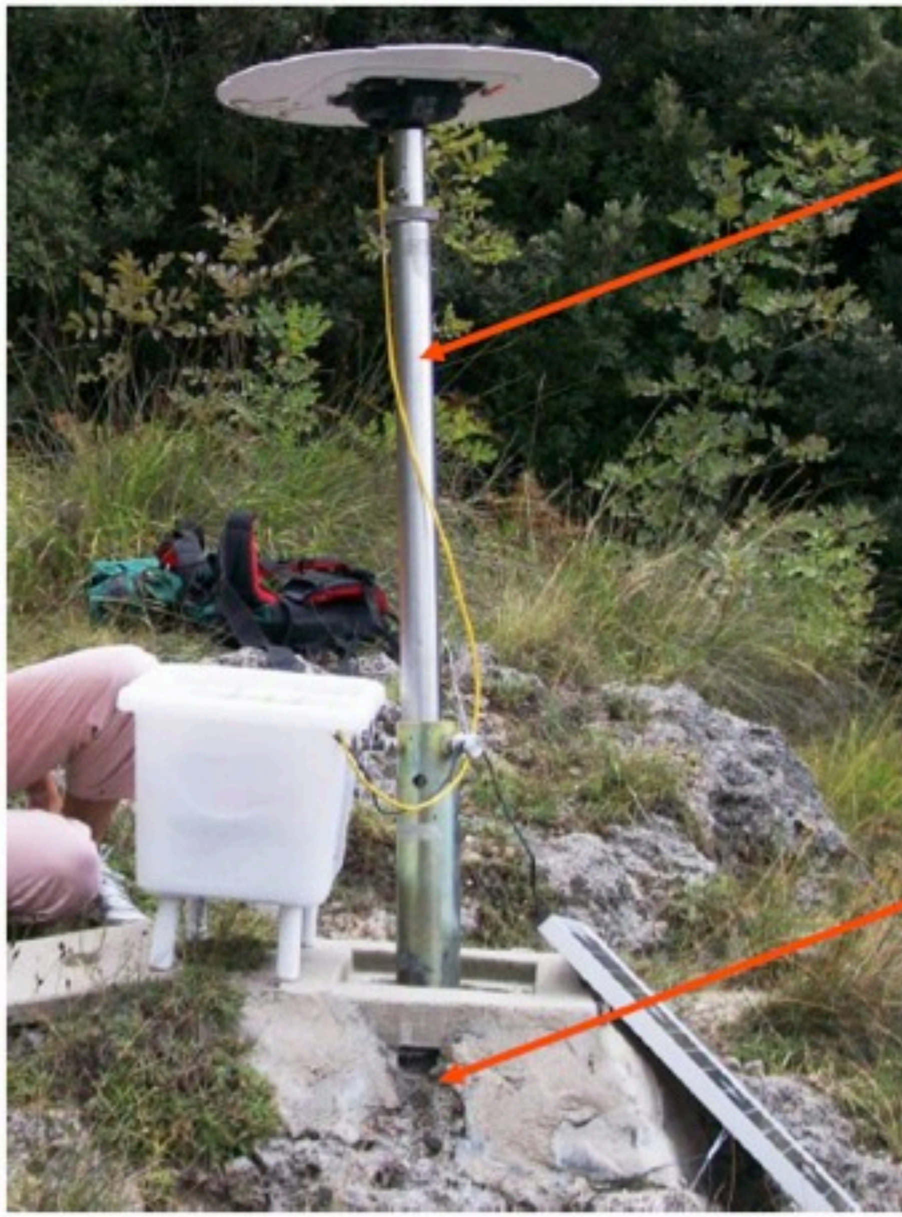
The two entry point coordinates ▲ and the two orientation points △ are needed in order to estimate the coordinates inside the GS Lab



credit: Prof. R. Barzaghi

Geodesic measurement

Monumentation of the GPS points



Steel pillar

Semi permanent GPS networks

Four day static measurements h24, L1/L2 receivers (solar powered).

- 4 Trimble 4700 receivers

- 2 Trimble 5700 receivers

Marker
On rock
(if possible)

credit: Prof. R. Barzaghi

Geodesic measurement

Tunnel measurements

Theodolite TS 30 Leica

Angular rms = 0.5”

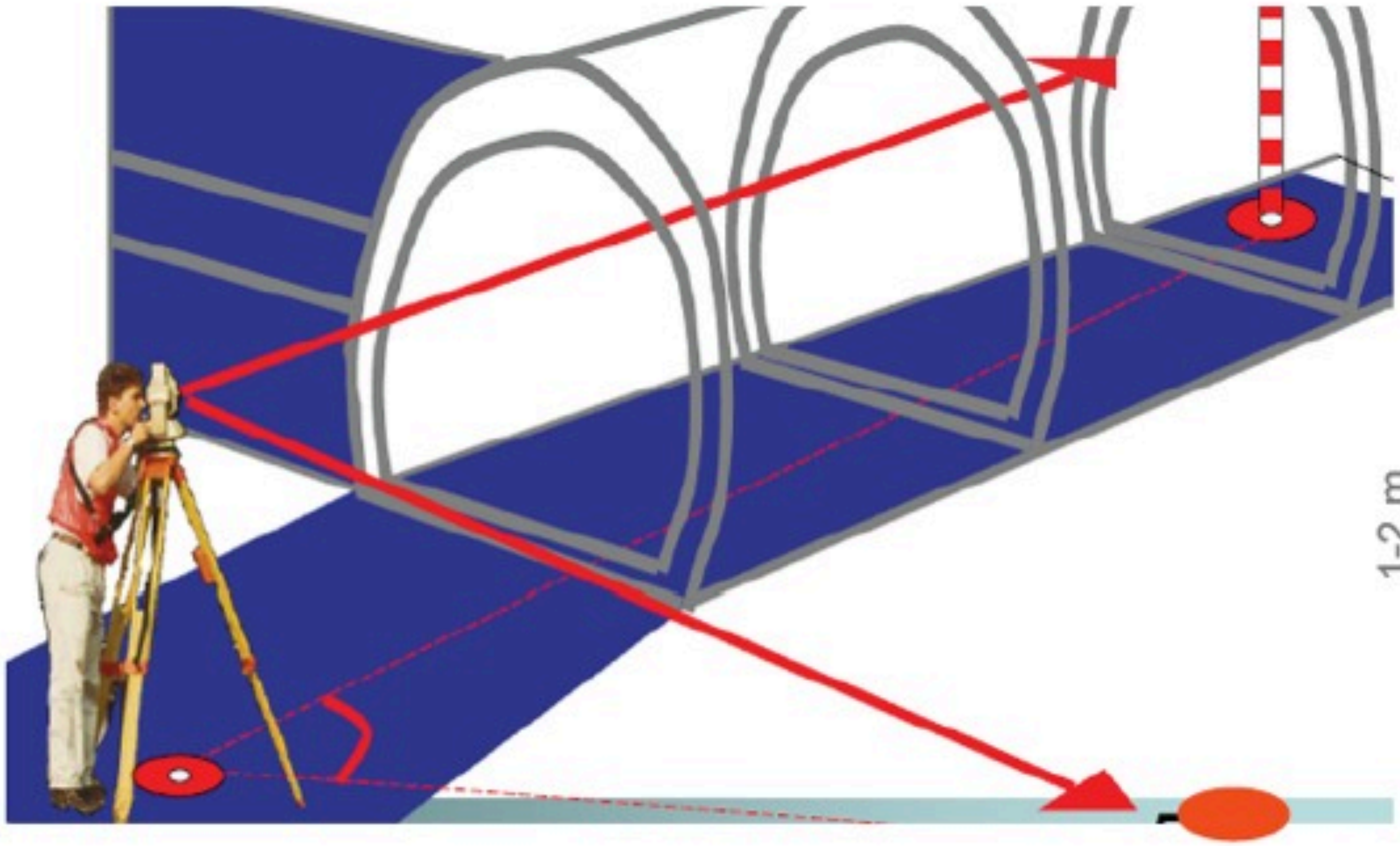
Distance rms = 0.5 mm + 0.5 ppm

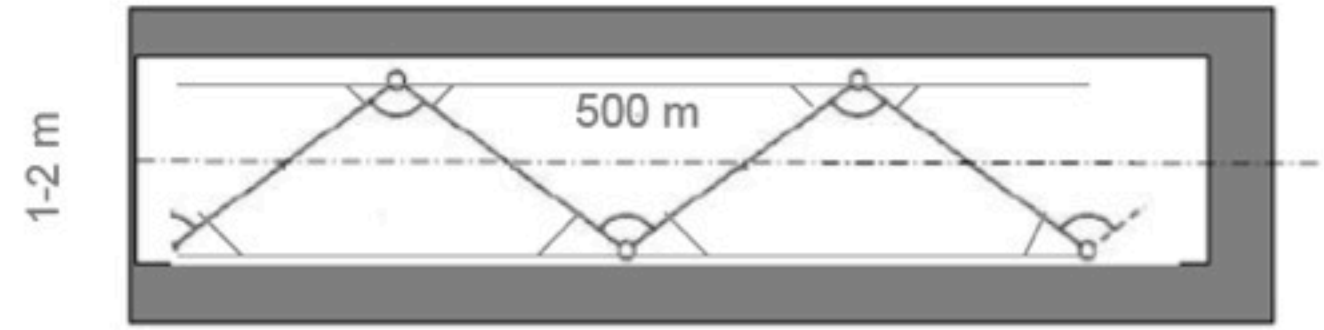
DATUM WGS84

3D Coordinates

Traverse survey

Trellis pattern: 250/500 m distance between points.





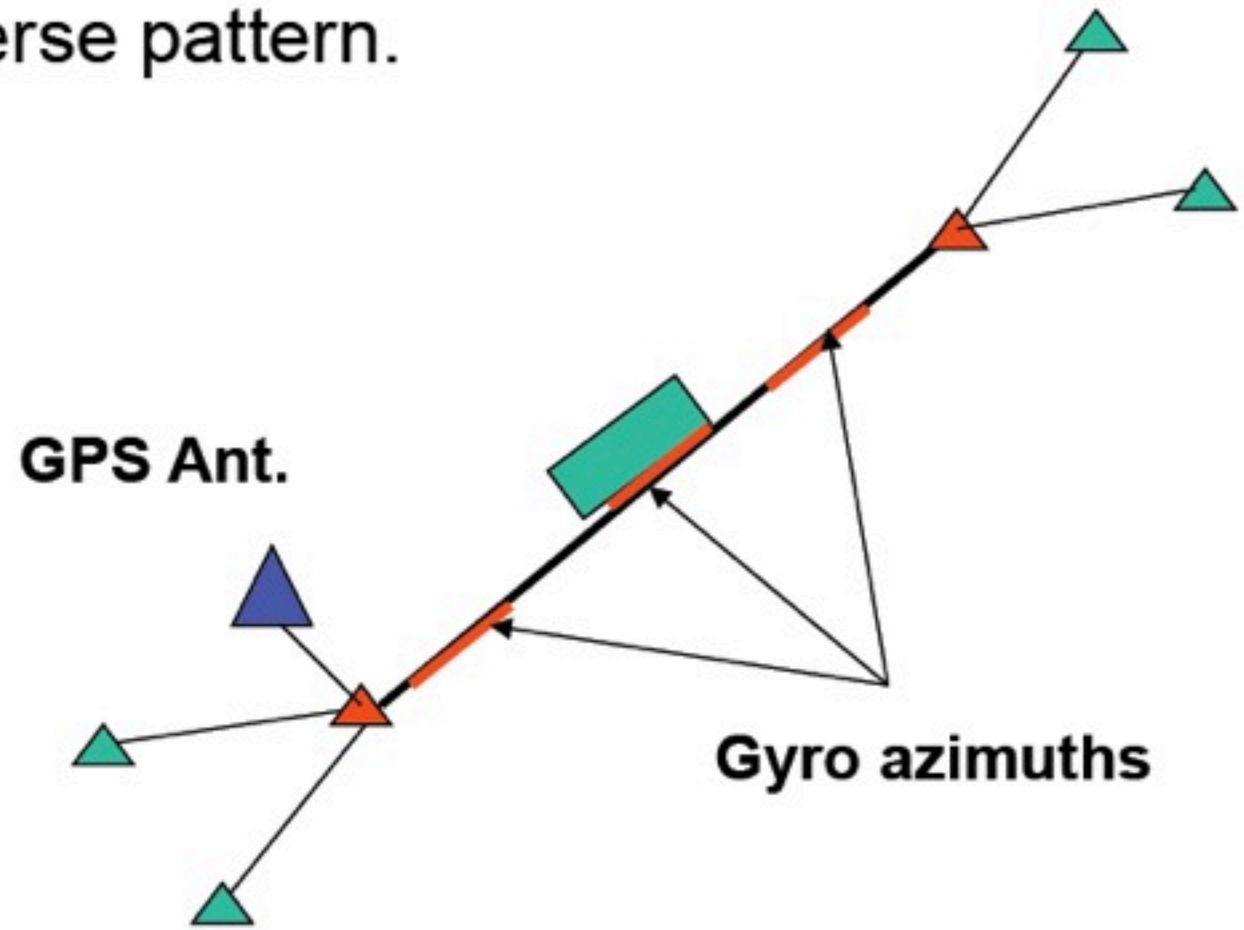
credit: Prof. R. Barzaghi

Geodesic measurement

Tunnel measurements

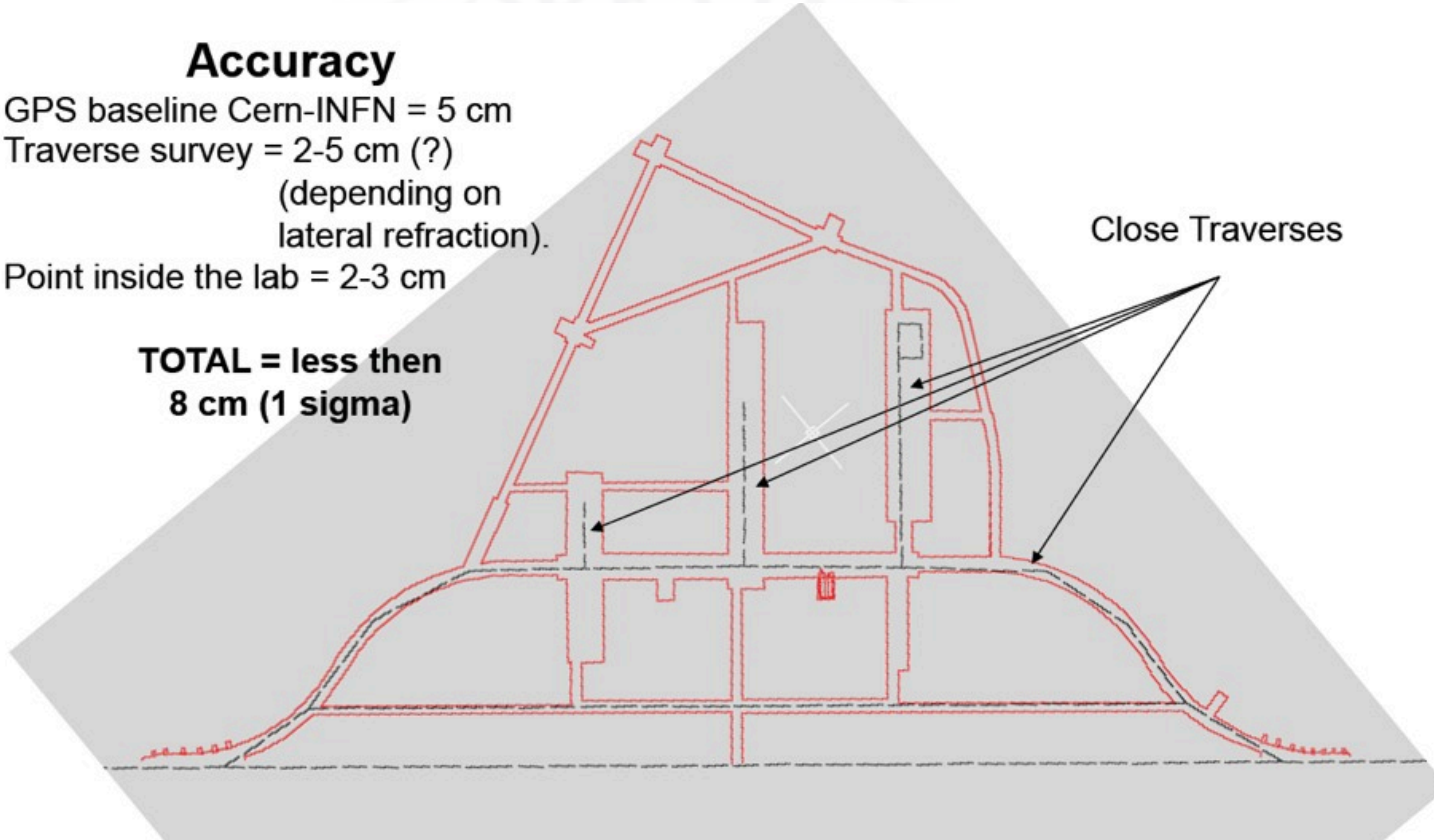
Azimuth measurements

Three Azimuths will be measured inside the tunnel with Gyro theodolite (DMT Gyromat), to constrain the traverse pattern.



credit: Prof. R. Barzaghi

Geodesic measurement



credit: Prof. R. Barzaghi

Conclusions

Borexino Investment	
INFN-2	35 k€
USA	10 k€
France	10 k€
Poland	5 k€
Total	60 k€
LVD	8 k€
Geodesy: ~40 k€ Icarus + LVD	

- None, a lot of work in progress
  - We have a good understanding of 2007-2011 data
  - We have a brand new trigger and GPS facility up and running
    - Turned on 1 week ago. Debugging and testing still in progress.
  - We have strong support from INRIM on timing, and from Politecnico di Milano on Geodesy (in agreement with Icarus and LVD)
  - We are **ready for May run**
    - We aim at **2 periods: 1 week** with 532 ns period **(4 bunches)**, and **1 week** with 100 ns period **(16 bunches)**
  - We plan to release results soon after the run in May 2012