Performance and aging of OPERA bakelite RPCs

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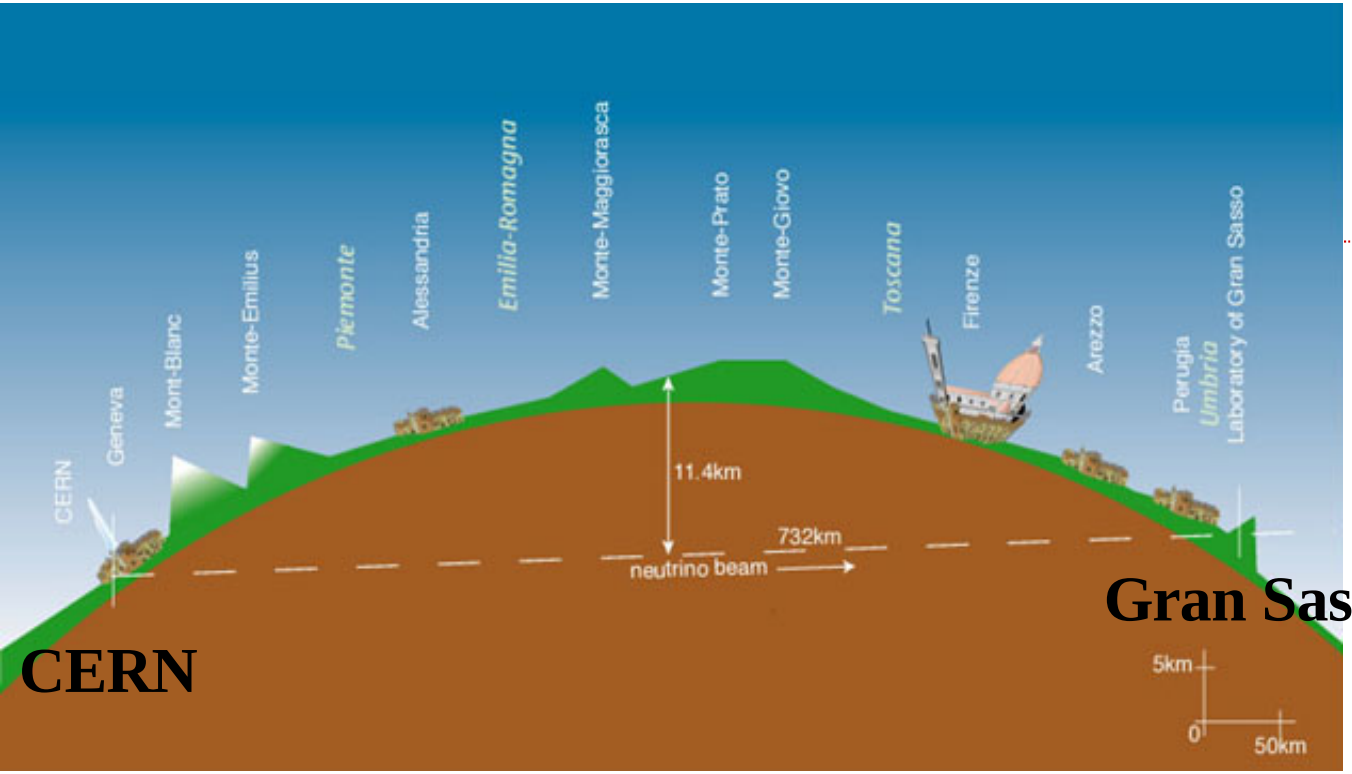
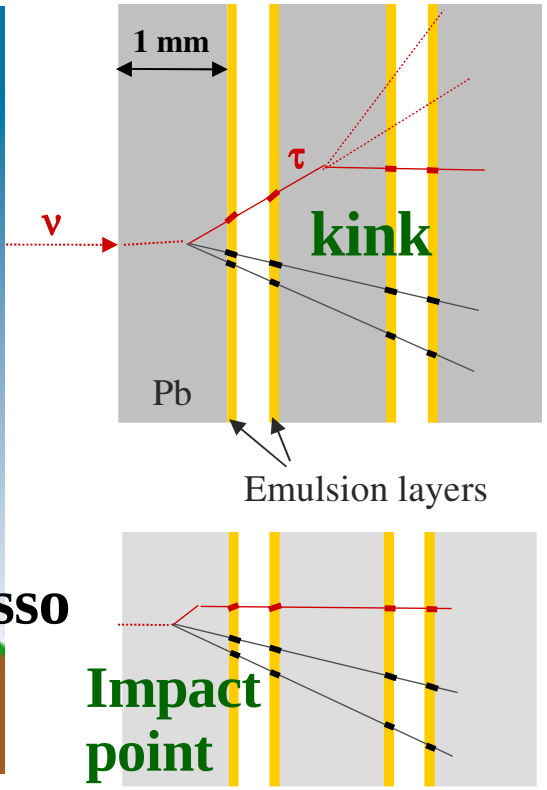
OPERA and RPC system description

The OPERA experiment

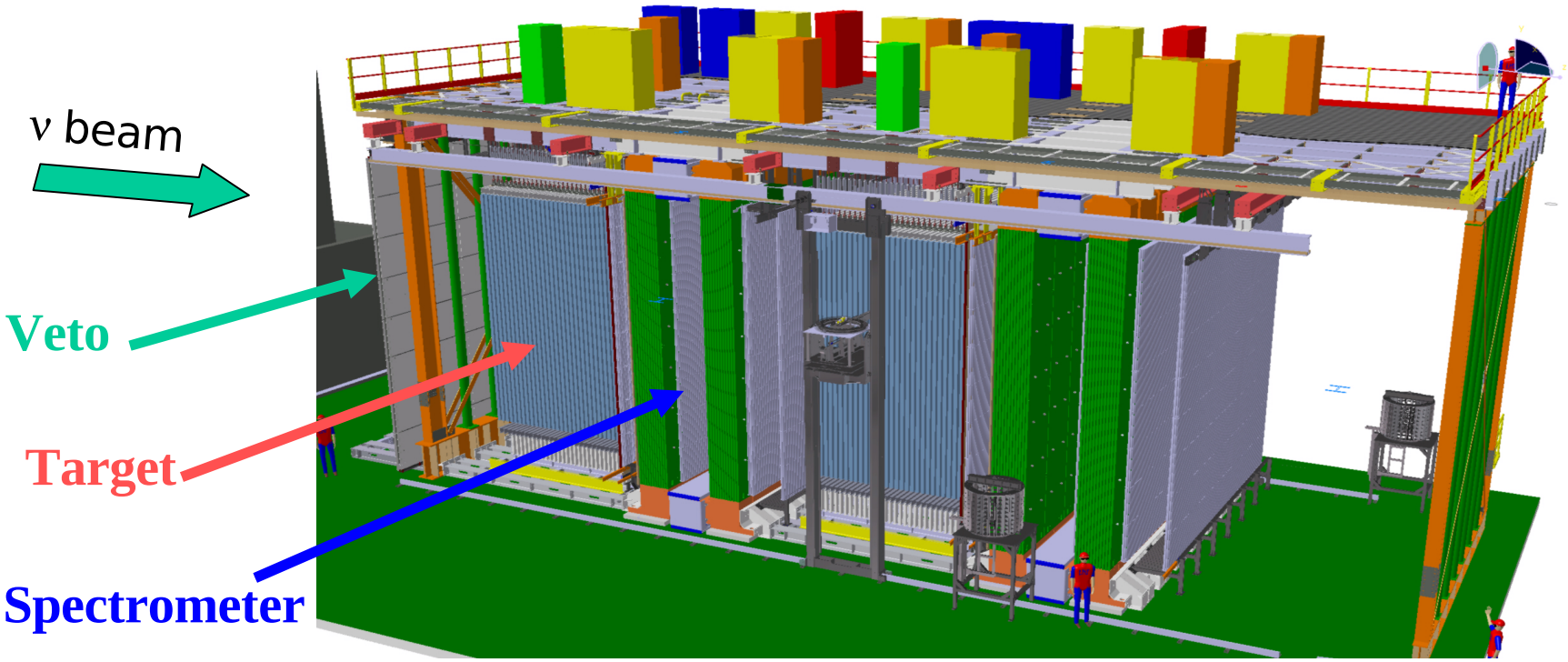
• OPERA (CNGS) is a dedicated experiment for the detection of $\nu_\mu \rightarrow \nu_\tau$ through τ appearance (baseline=730 km)

• τ selection based upon topological criteria: decay vertex reconstruction with μm precision using emulsion layers alternated to 1 mm thick Pb sheets (target section)



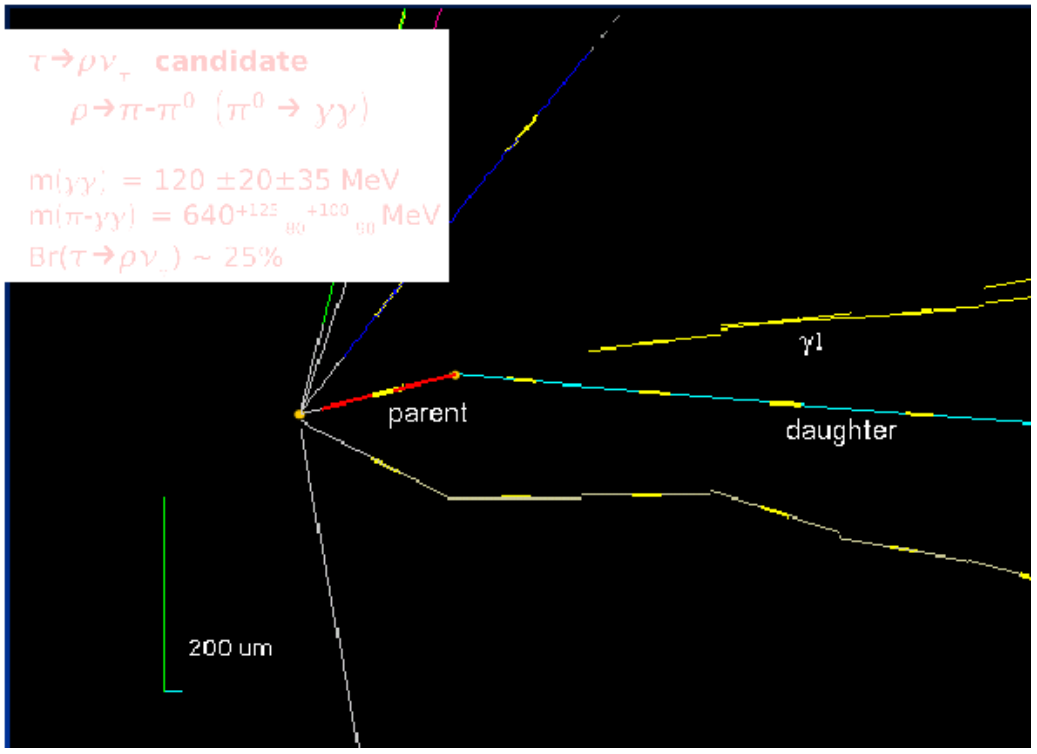


OPERA (Oscillation Project with Emulsion tRacking Apparatus)



- 2 Supermodules (1 Supermodule = 1 target section + 1 spectrometer)
- 2 Target sections with 154000 bricks arranged into walls
- 1 Brick= 56 lead sheets (target) alternated to 57 nuclear emulsions (vertex reconstruction)
- Target sect.=31 Target Walls/Target Tracker (xy scintillator strips)
- Total target mass (1350 tons of lead)
- Spectrometer: 1 kton dipolar magnet equipped with drift tubes and RPCs
- Veto system to tag external neutrino interactions (glass RPCs)

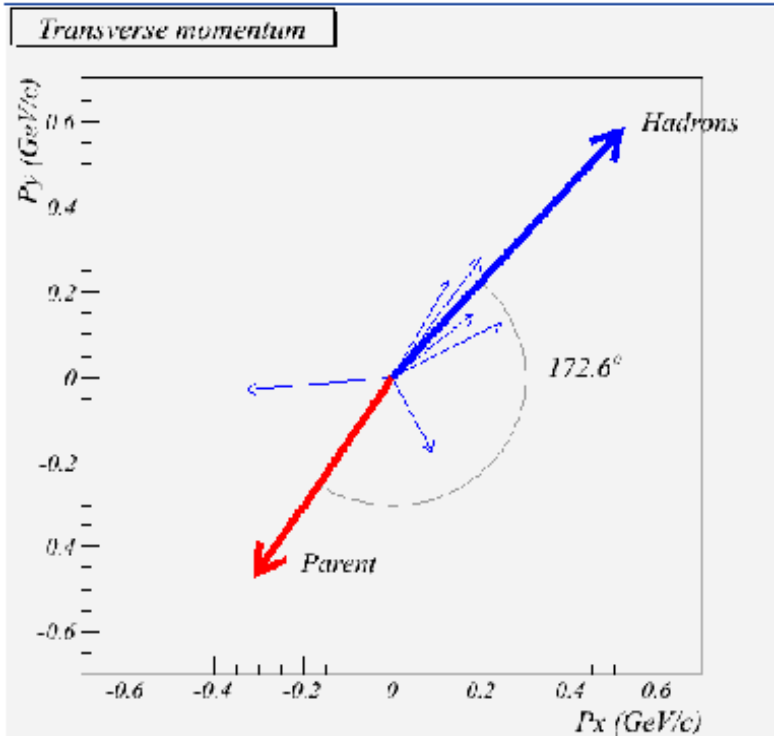
OPERA results about neutrino oscillations



2008+2009 ($4.8*10^{19}$ pot) data analysis completed.

One ν_τ candidate observed with 1.65 expected signal and 0.16 estimated background events (95% statistical significance).

~20 ν_e events observed (compatible with beam background).



Event topological features

Variable	Value	Selection criteria
kink (mrad)	41±2	> 20
decay lenght (μm)	1335±35	≤ 2 Pb plates
P daughter (GeV/c)	12+6-3	> 2
Pt (MeV/c)	470+230-120	> 300
missing Pt (MeV/c)	570+320-170	< 1000
Azimuth angle (deg)	173±2	> 90

The magnetic spectrometer

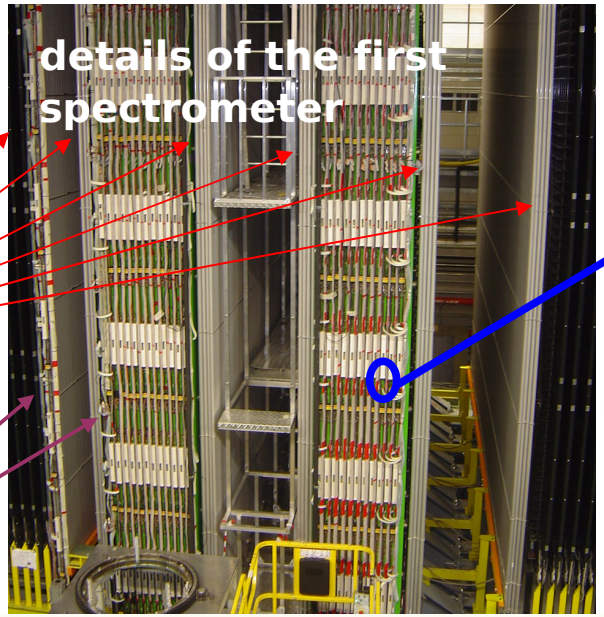
One spectrometer is composed by:

1 dipolar magnet (1.52 T)

22 RPC layers as inner tracker inside magnetized iron

6 drift tubes stations (PT stations)

2 external XPC stations (RPCs with strips at ±43º)



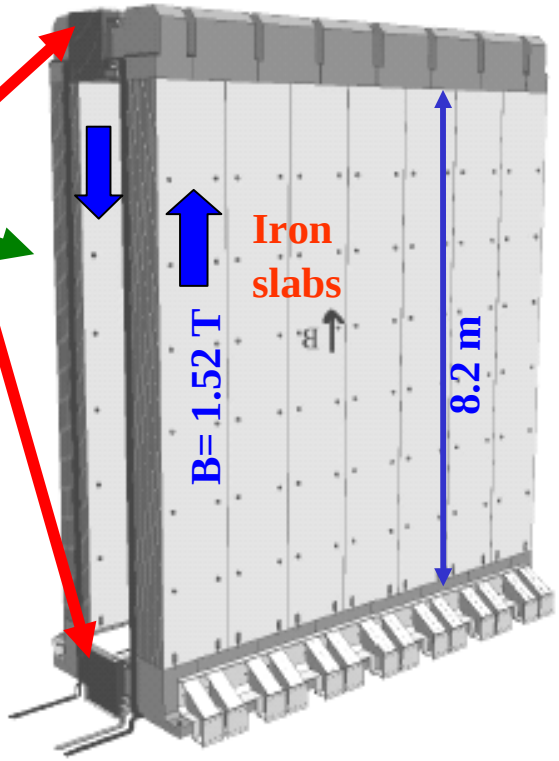
Precision Trackers (drift tubes)

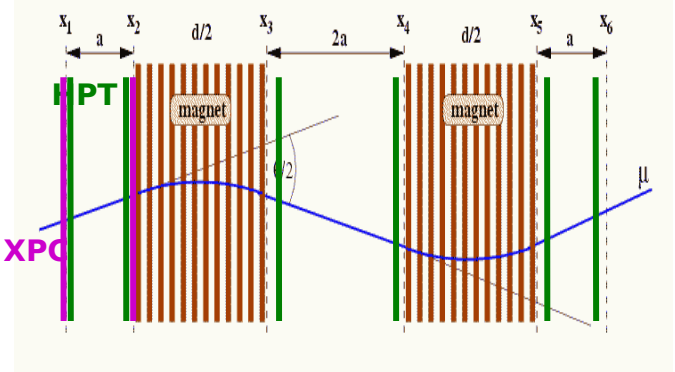
XPCs

12 Fe slabs per magnet side

Fe (5 cm)

RPC





Charm bkg rejection in ν_μ CC events

Muon identification (with TT) >95%

$\Delta p/p$ < 20% for p<30 GeV

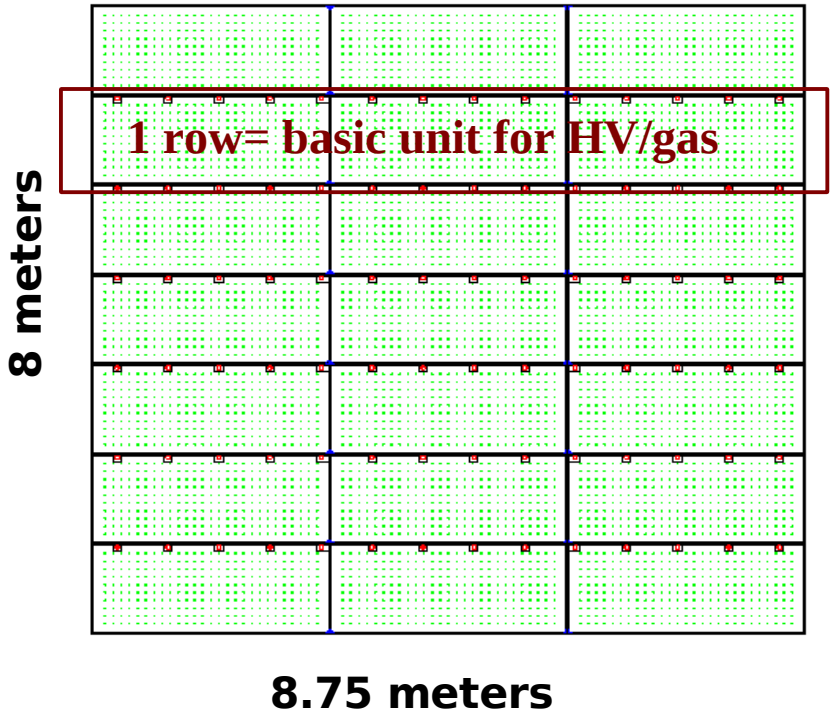
Charge misidentification < 0.3%

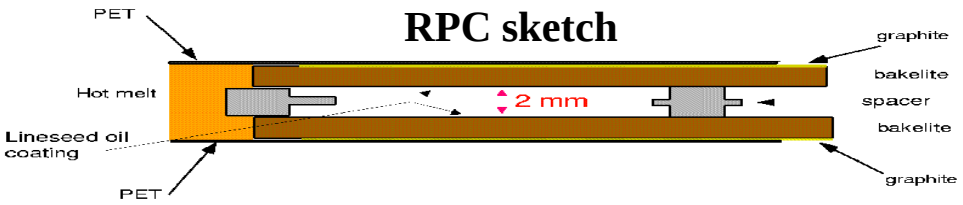
OPERA RPCs

Inside 2 cm gaps between iron slabs:
- **Track reconstruction inside magnet**
- **Showers leakage measurement**
- **Trigger & Timing for the drift tubes**

1 layer = 21 RPCs of size (2.9*1.1) m²
1 spectrometer = 504 RPCs/XPCs

- **High resistivity bakelite electrodes (low rate expected): $\rho > 5*10^{11}$ Ω cm @20°C**
- **Special curved contour chambers**
- **Streamer mode operation (large signals)**
- **Read-out by means of ~8 m strips with 2.6 (3.5) cm pitch for bending (orthogonal) view**



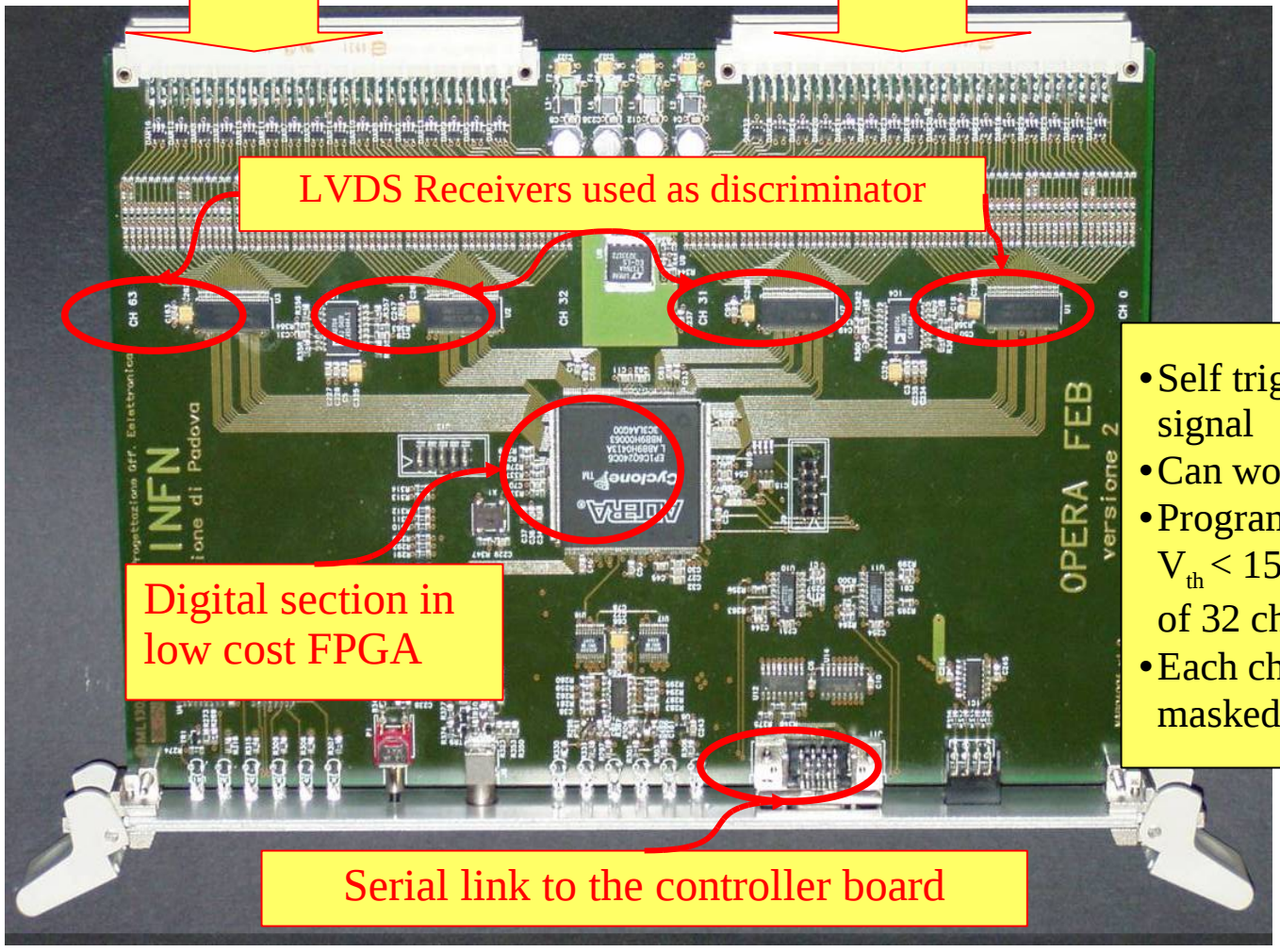


Total surface of the system ~ 3200 m²
Number of digital electronics channels ~ 28000
Streamer operation with $Ar/C_2H_2F_4/isoC_4H_{10}/SF_6$=75.4/20/4/0.6 (5 refills/day, open-flow system).

RPC Front End Card

Located on top platform and connected to the read-out strips through twisted-pair flat cables as long as 13 m.

64 channels inputs

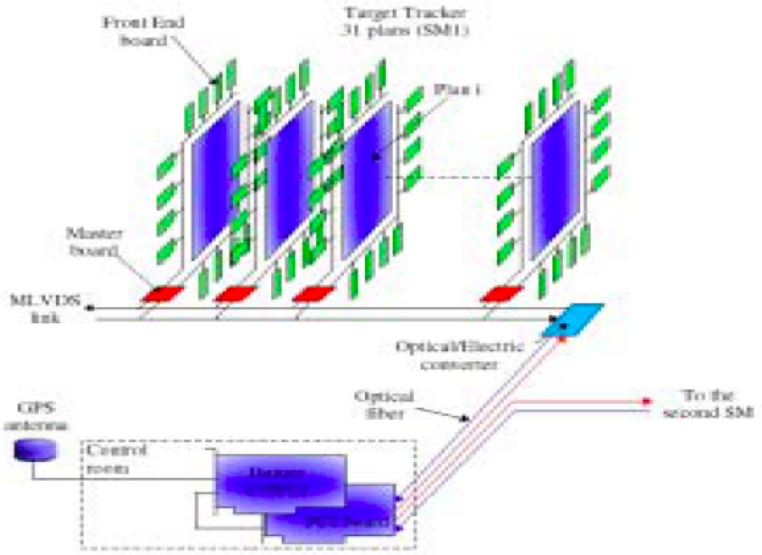


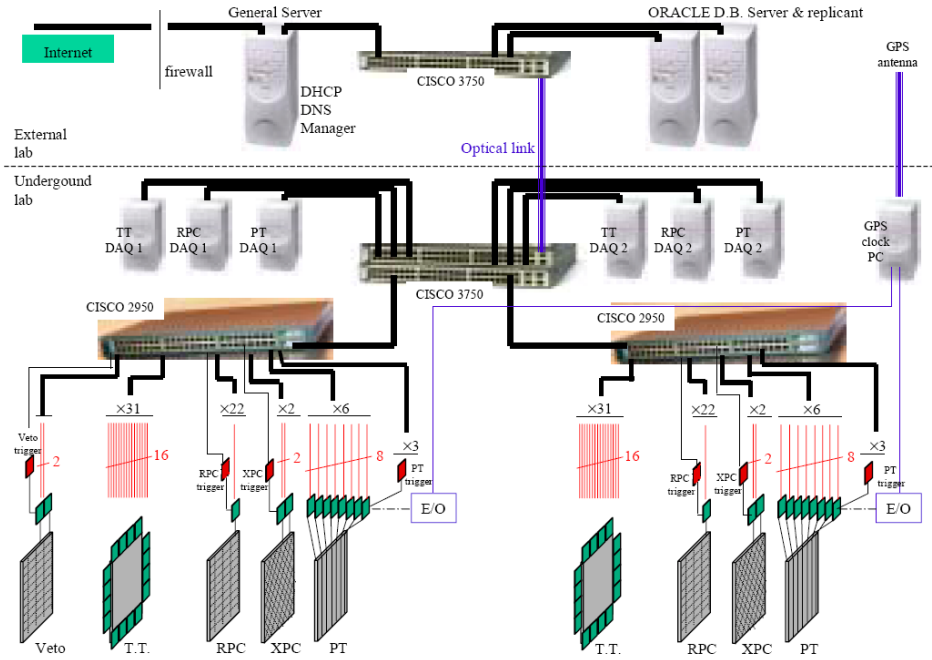
- Self trigger able on 32 ch. FastOR signal
- Can work with external trigger
- Programmable threshold (-150mV < V_{th} < 150mV) and polarity in groups of 32 ch
- Each channel can be individually masked

DAQ

DAQ structure based on a Gigabit Ethernet network (1200 nodes)

A node of the network is:
- Target Tracker, FEB (64 PMT)
- Drift Tubes, TDC Board (96 ch)
- RPC, Controller Board (9 FEB = 1 RPC plane, ½ XPC plane)

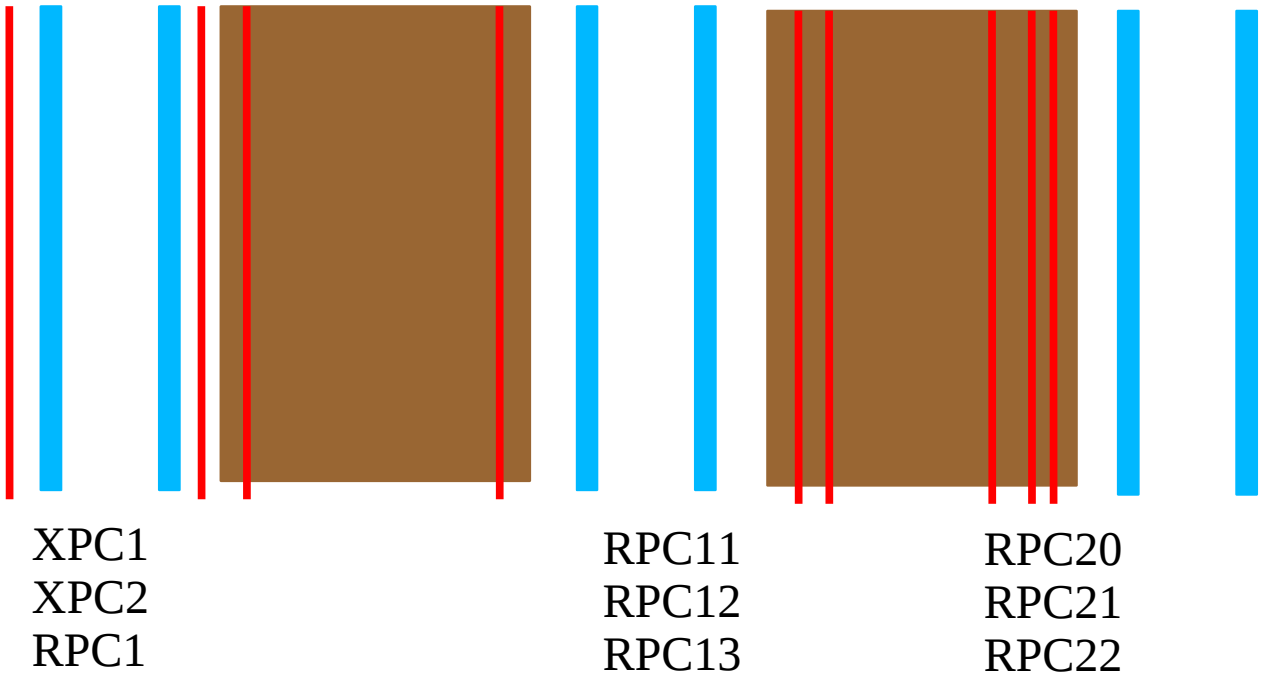




The nodes can auto trigger and time stamp (10ns resolution) the data
A clock is distributed to each node to synchronize the time stamp with GPS clock
Trigger performed at computer level (3/24 RPC/XPC layers majority for each spectrometer)

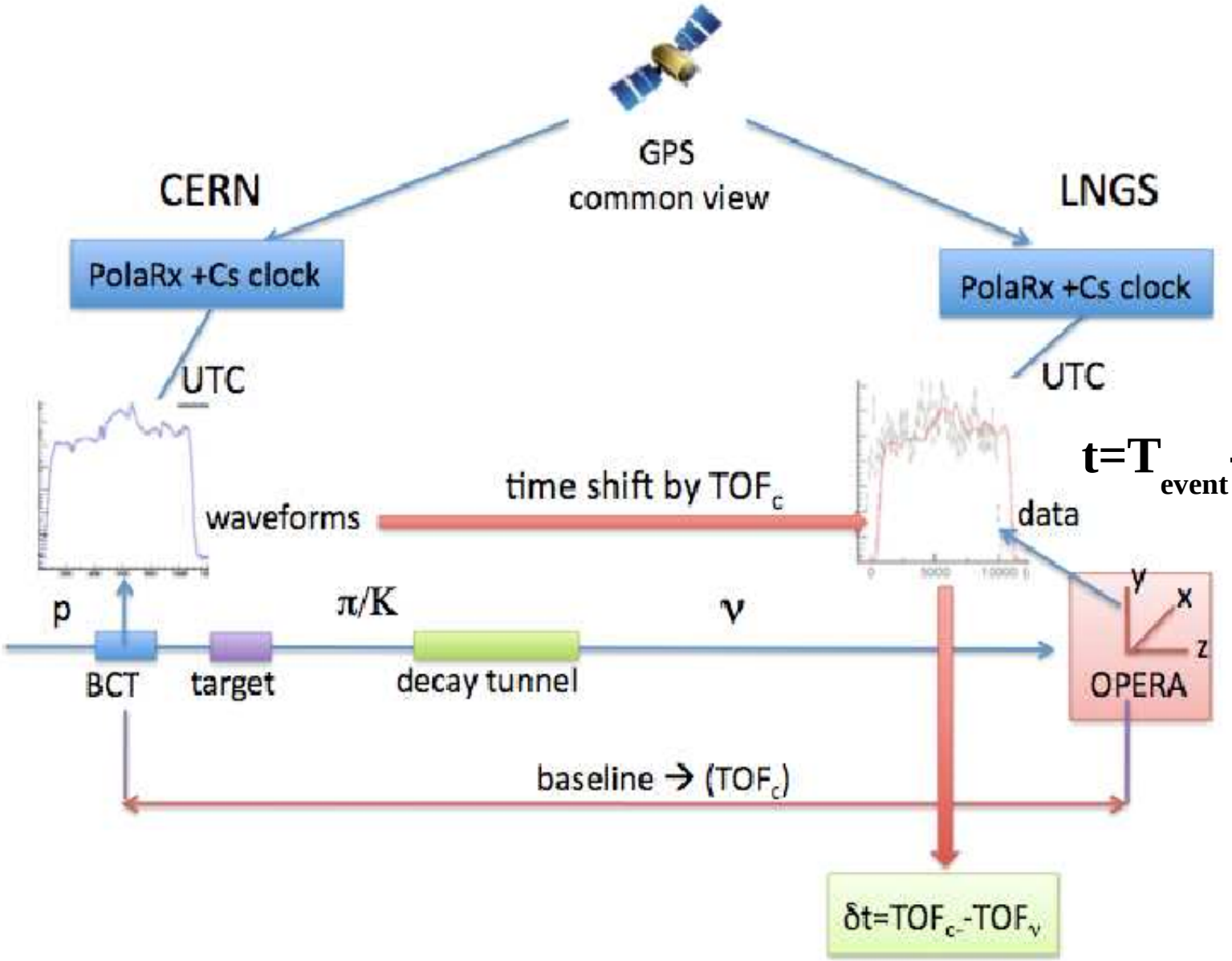
Drift Tubes Trigger / Timing system

9 XPC/RPC layers instrumented with Timing Boards (TBs)
TBs are high impedance low threshold discriminators located on strip panels
1 TB discriminates 16 strips and performs also the OR of the digital signals



2/3 majorities in each station; global OR of the majorities as trigger
Also the timing board signals are read-out with the TDCs (TOF measurement)
TB threshold=20 mV, lower than the digital read-out of single strips
Trigger given by 2/3 majorities, but TDC stop by the OR of the majority inputs

Neutrino velocity measurement description



$$t = T_{event} - T_{kicker} - TOF_c$$

Neutrino velocity measurement results

During September 2011, the experiment reported an evidence for a neutrino arrival time anticipation of

$$\delta t = TOFc - TOFv = (57.8 \pm 7.8\ (stat.)\ ^{+8.3}_{-5.9}\ (sys.))\ ns$$

Corresponding to

$$(v-c)/c = \delta t / (TOFc - \delta t) = (2.37 \pm 0.32\ (stat.)\ ^{+0.34}_{-0.24}\ (sys.)) \times 10^{-5}$$

with an overall significance of 6.2 σ.

The analysis is based on Target Tracker scintillator data from 2009 to 2011.

We are in the process of performing a similar (1 ns level) time calibration of the RPC system before the start of the next run (March 2012).

OPERA RPC system performances

OPERA RPC system CNGS run history

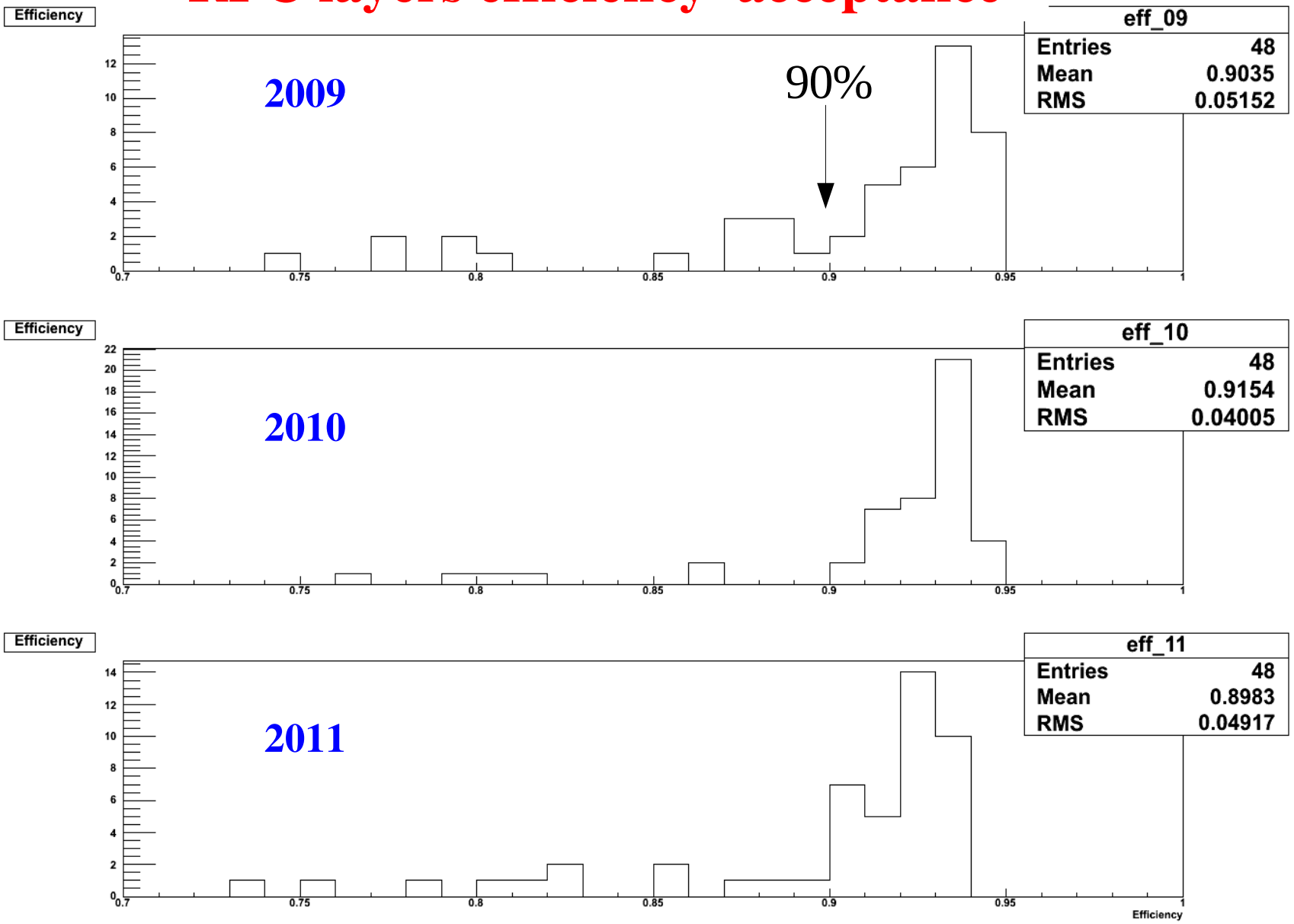
August 2006
No bricks inside OPERA target
Operating voltage V=5.8 kV (no pressure correction applied)
Discriminator thresholds Thr-=Thr+=40 mV

September-October 2007
Operating voltage V=5.8 kV (no pressure correction applied)
Discriminator threshold Thr-=Thr+=40 mV

June-November 2008
Operating voltage V=5.8 kV @900 mbar (pressure correction applied)
Discriminator threshold Thr-=Thr+=40 mV

June-November 2009 + April-November 2010 + March-November 2011
Acquisition software improved
Operating voltage V=5.7 kV @900 mbar (pressure correction applied)
Threshold equalization: Thr-=40 mV; Thr+=26 mV
(correction for different impedance matching between strips and cables)

RPC layers efficiency*acceptance

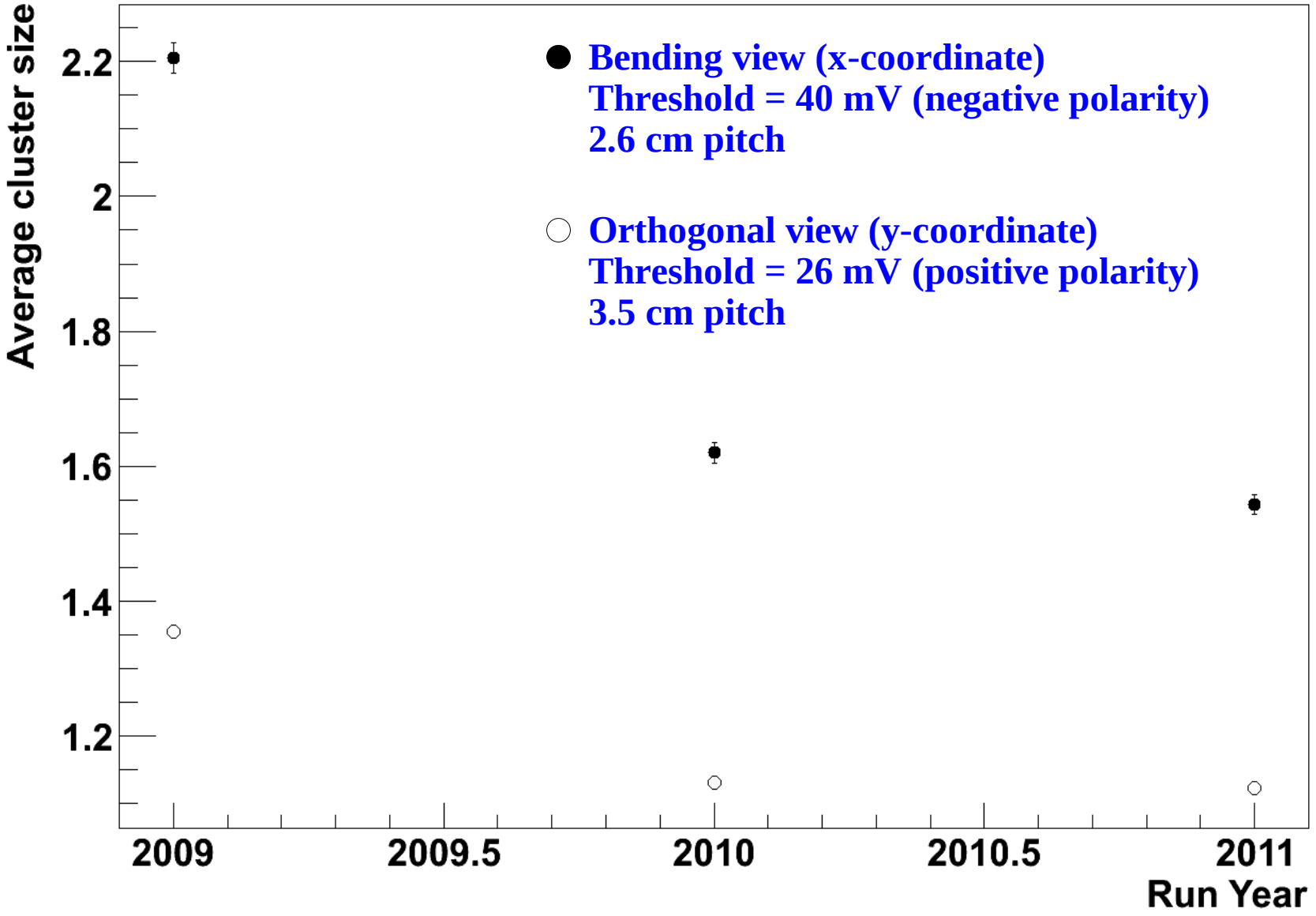


RPC layers with efficiency values lower than 90% due to HV and gas distribution failures (maintenance possible only at the end of the year, during BMS maintenance).

RPC Cluster Size

Average cluster size on rock muons

HV=5.7 kV
@T~15°C, P~900 mbar



Time resolution

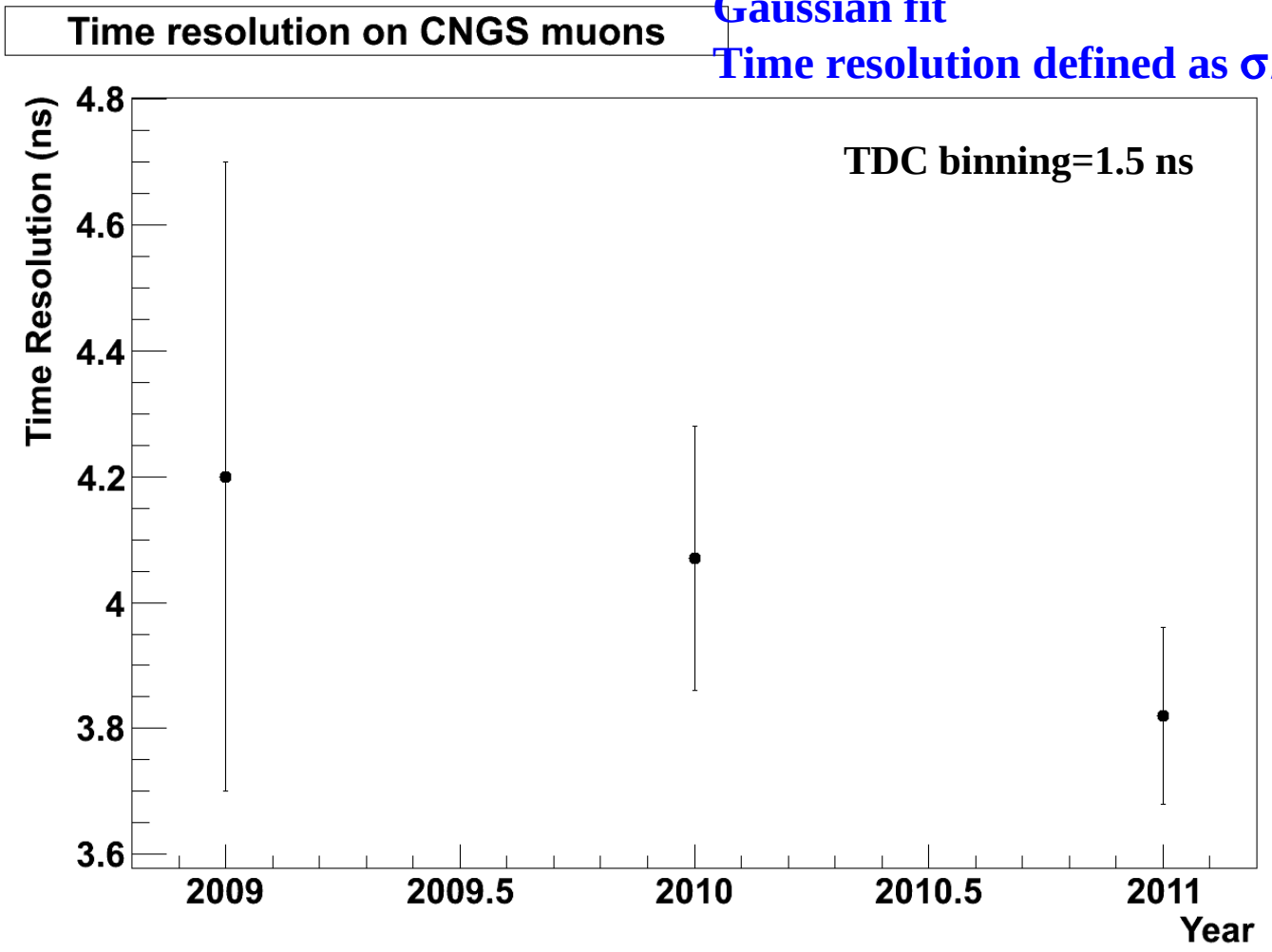
Measurement method:

Time difference between consecutive layers

Muon TOF and the strip propagation delay corrections

Gaussian fit

Time resolution defined as $\sigma/\sqrt{2}$



Measured Drift Tubes space-resolution within specifications (~300 μm).

Aging effects on OPERA RPCs

RPC Currents at the end of 2011 run – first spectrometer

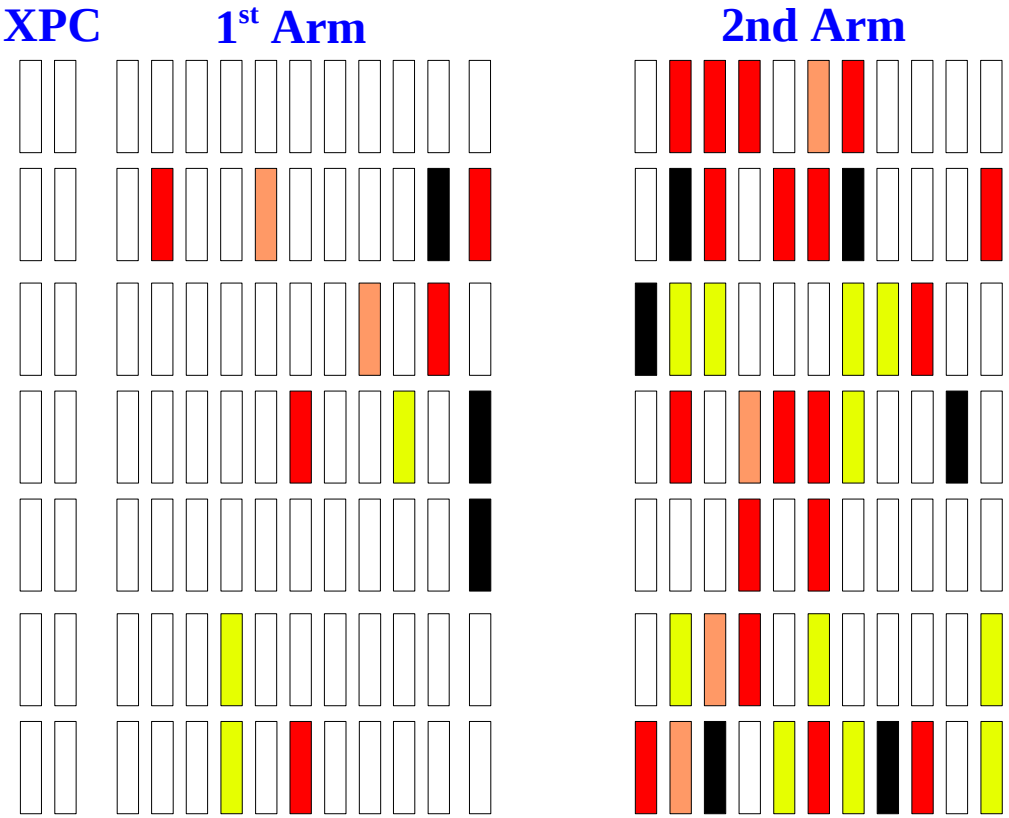
1 RPC row:
3 chambers in a series (~9 m^2)
Basic unit of gas flow and HV

I > 1000 nA

I > 1500 nA

I > 2000 nA

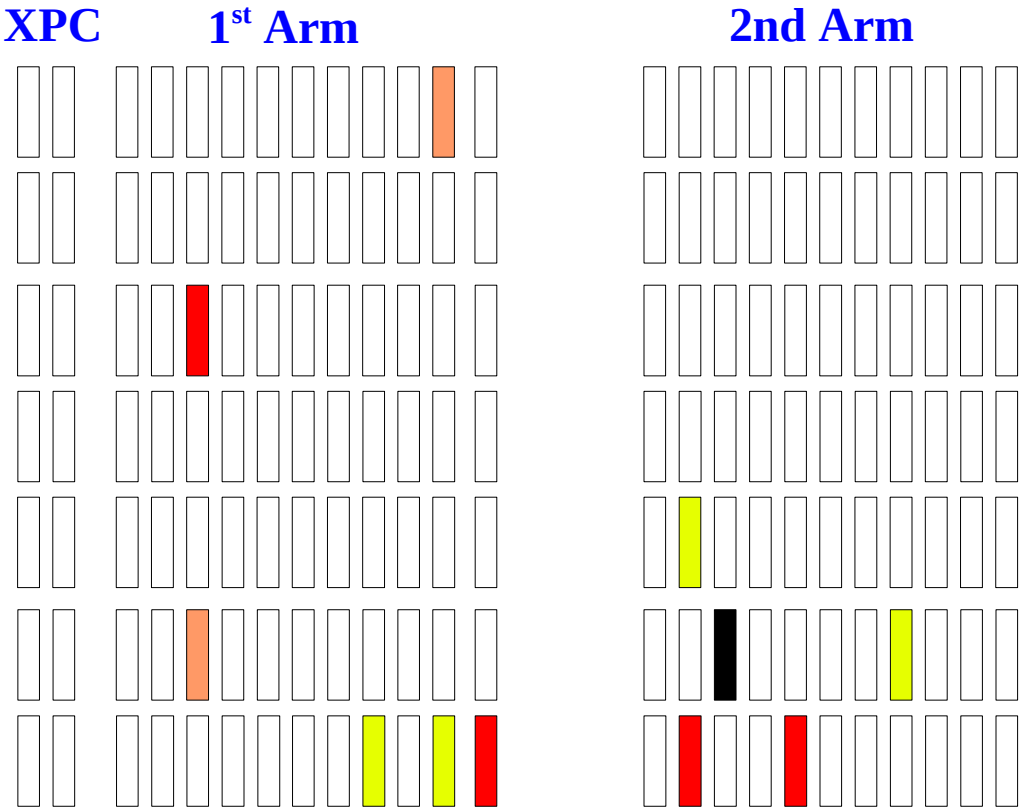
HV failure (cable insulator: 1 trip/month of run)



9 RPC row with I > 4000 nA
1 RPC row with I > 10000 nA
High currents show also a consistent ohmic component

RPC Currents at the end of 2011 run– second spectrometer

1 RPC row:
3 chambers in a series (~9 m^2)
Basic unit of gas flow and HV



I > 1000 nA

I > 1500 nA

I > 2000 nA

HV failure (cable insulator: 1 trip/month of run)

2 RPC row with I > 4000 nA

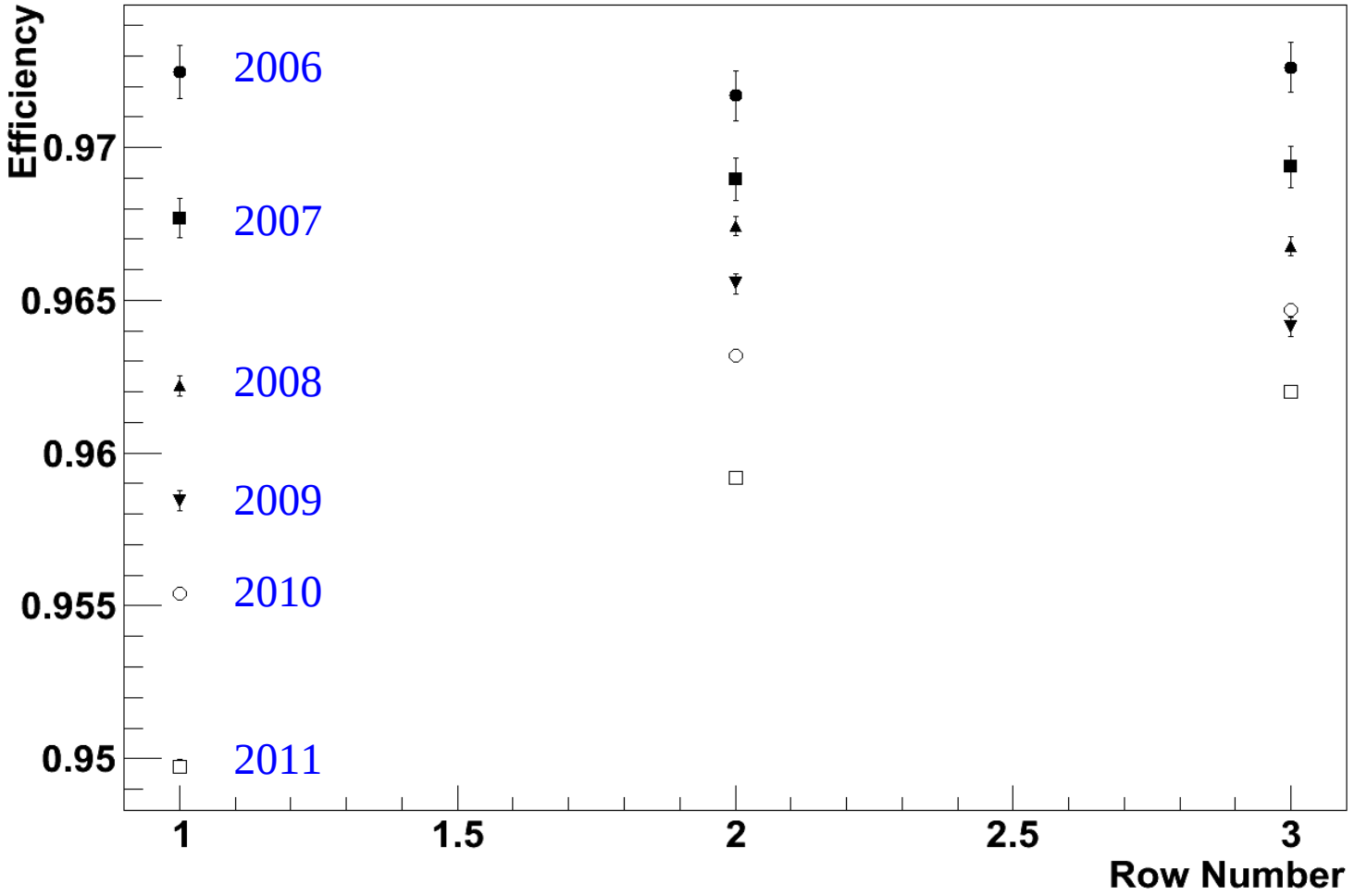
March-November 2011 run:

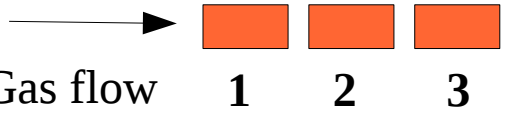
10 RPC rows off because of HV failures (3% of the system).
Most of the failures in the first spectrometer.
Repaired during December BMS stop.

Bakelite electrodes progressive drying

Unique gas system for spectrometer (bakelite) and VETO (glass) RPC → dry mixture

Efficiency vs Row Number (acceptance corrected)





Conclusions

The OPERA RPC system completed its 5th year of operation.

About 1% of RPC rows show high current (>4 μA), located mostly in the first spectrometer (lower quality of gas distribution during the first three years of operation).

Progressive electrode drying (dry gas mixture flow) is under control and the detector performances are still within specifications.

Timing calibration at 1 ns level is under way to use RPC data for the neutrino velocity measurement.