The RICH detector of the NA62 experiment at CERN

basic performance and aging effects

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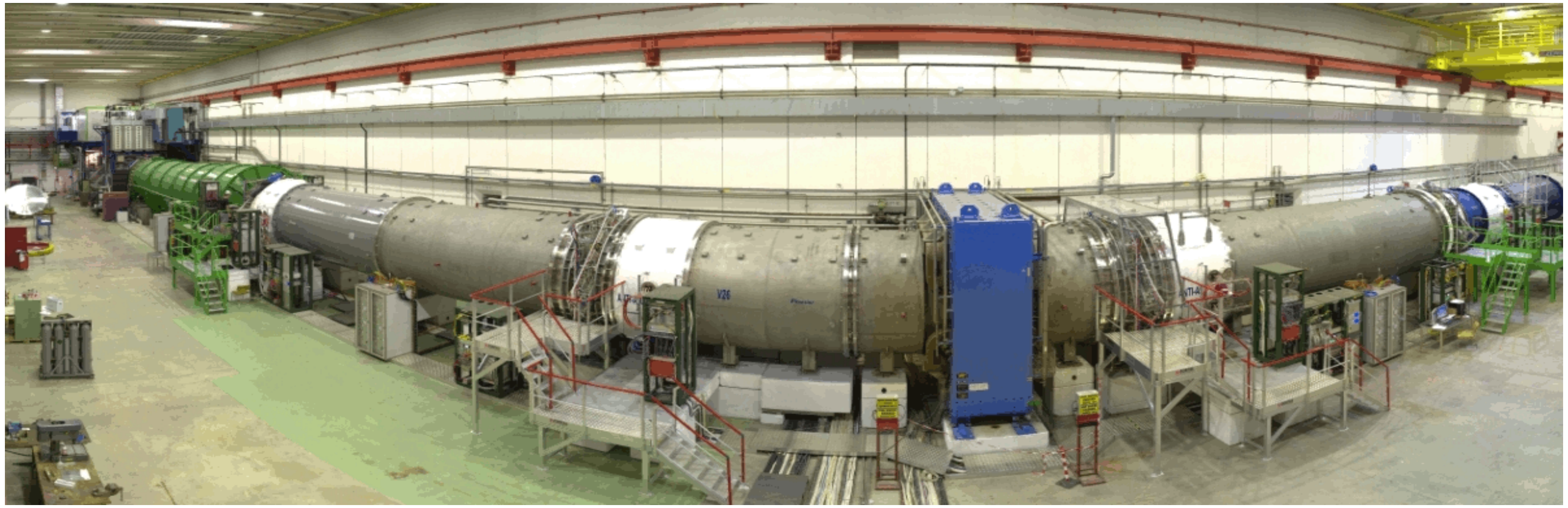
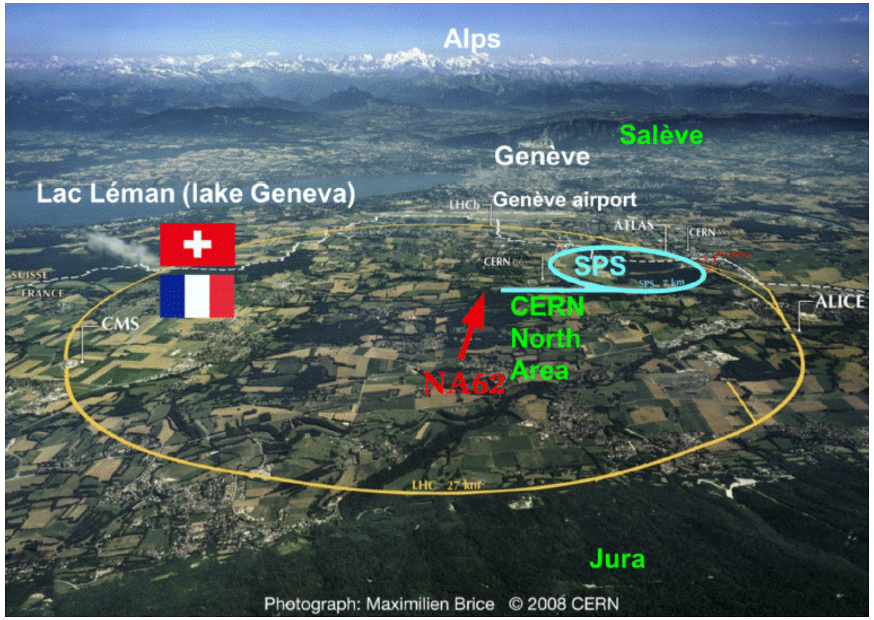
on behalf of the NA62 RICH working group

NA62 Experiment





- Fixed target experiment installed in the North Area of the CERN SPS
- Main goal: measure the BR of the ultra-rare $K^+ \to \pi^+ \nu\bar{\nu}$ decay

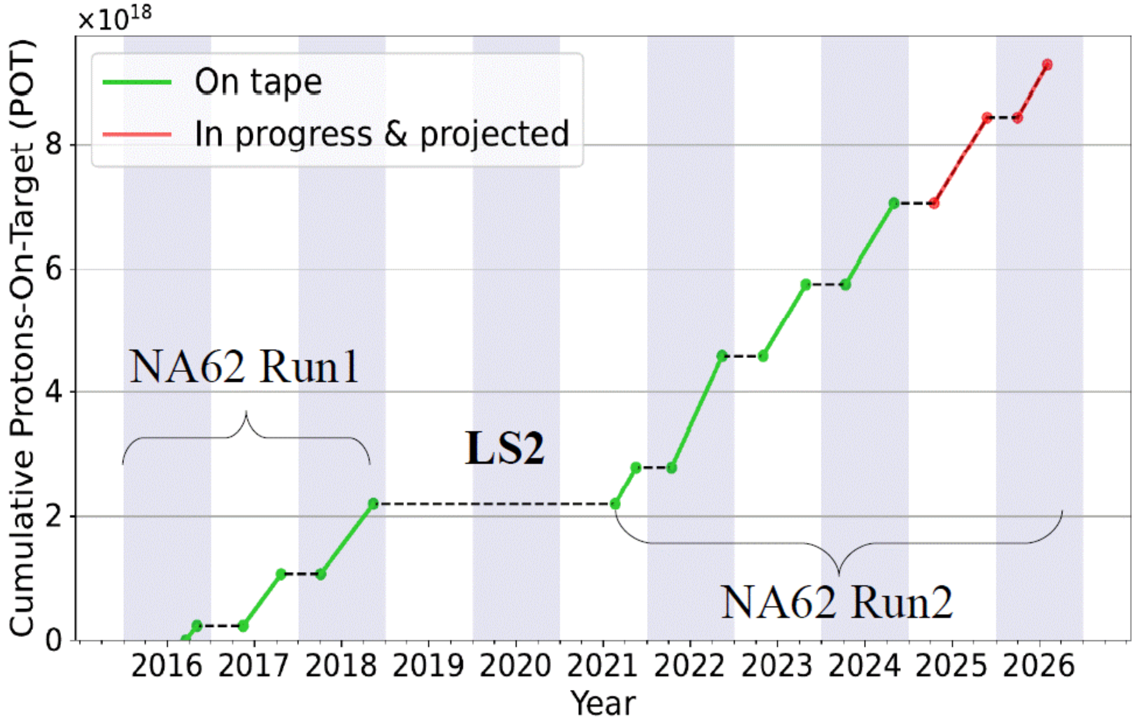
  $BR_{SM}(K^+ \to \pi^+ \nu\bar{\nu}) = (8.60 \pm 0.42) \times 10^{-11}$ Buras et al. EPJC 82 (2022) 7, 615

  $BR_{NA62}(K^+ \to \pi^+ \nu\bar{\nu}) = (13.0^{+3.3}_{-3.0}) \times 10^{-11}$ JHEP 02 (2025) 191

  First observation of $K^+ \to \pi^+ \nu\bar{\nu}$ decay. BR consistent with SM prediction within 1.7 σ
- Also covering a broad kaon and beam-dump physics programme

NA62 Timeline

- NA62 approval: 2008
- Detector R&D and installation: 2009 → 2015
- Commissioning: 2015
- Run1: 2016, 2017 and 2018
- Run2: 2021, 2022, 2023, 2024, 2025 (on going)
- Approved till LS3

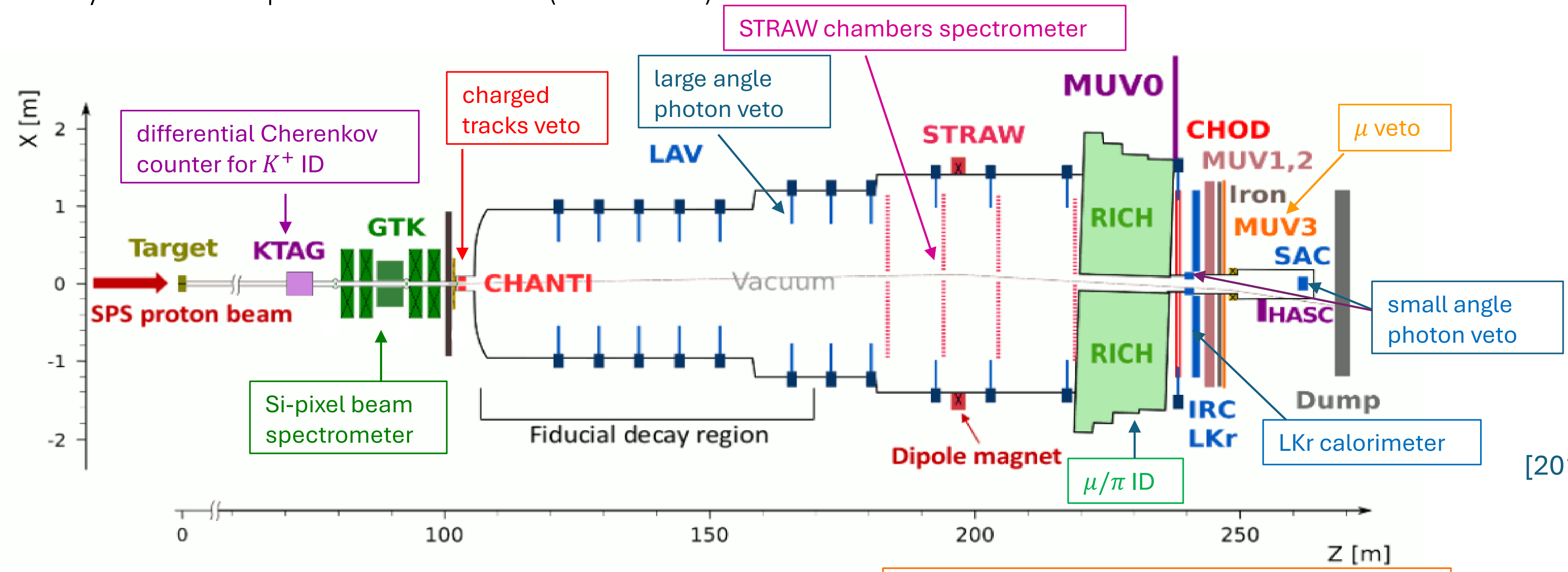


400 GeV/c protons from SPS hitting a beryllium target

Secondary hadron 75 GeV/c beam:
70% pions, 24% protons, 6% kaons

Detector Layout and RICH Requirement

Key detector improvements in Run2 (2021-2026)



[2017 JINST 12 P05025]

NA62 requirements

- Time coincidence: $O(100\ ps)$
- Kinematic rejection: $O(10^4)$
- Muon rejection: > $O(10^7)$
- π^0 rejection: >10^7

RICH requirements

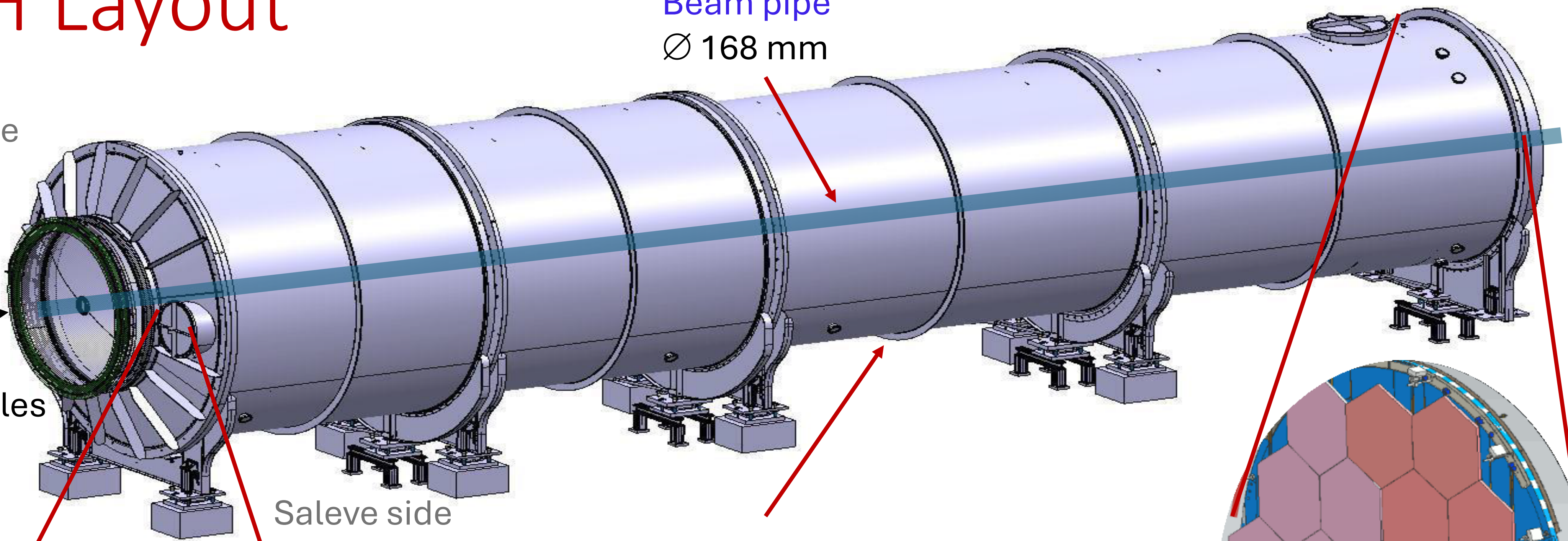
- Time resolution: $O(100\ \mathrm{ps})$
- μ^+mis-ID <1%

  (15 < $\mathrm{p_{track}}$ < 35 GeV/c)
- Provide L0 trigger for charged tracks

RICH Layout

Beam pipe
∅ 168 mm

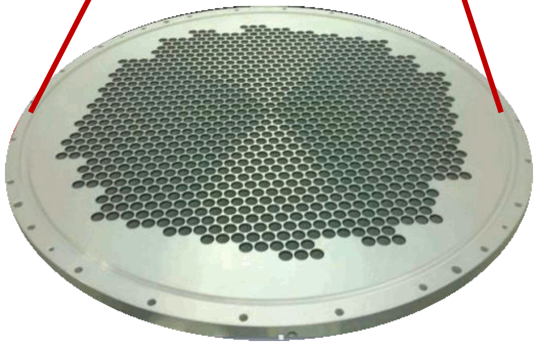
Jura side



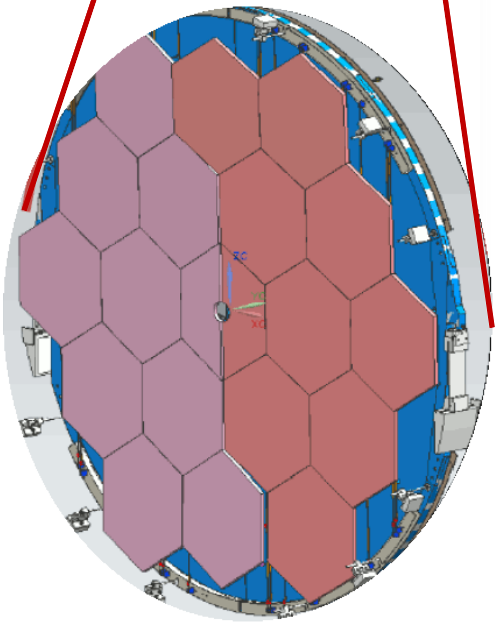
Residual beam of
undecayed particles

Saleve side

Vessel
~ 17 m long
filled with neon at p = 1 atm



PMTs disks
2 disks × 976 PMTs
$R_{disk} \sim 300$ mm



Mirror mosaic
(17 m focal length)

RICH Vessel and Radiator

Vessel:

- Vacuum proof tank
- 17 m long made of structural steel
- Beam pipe ∅ 168 mm passing through

Radiator:

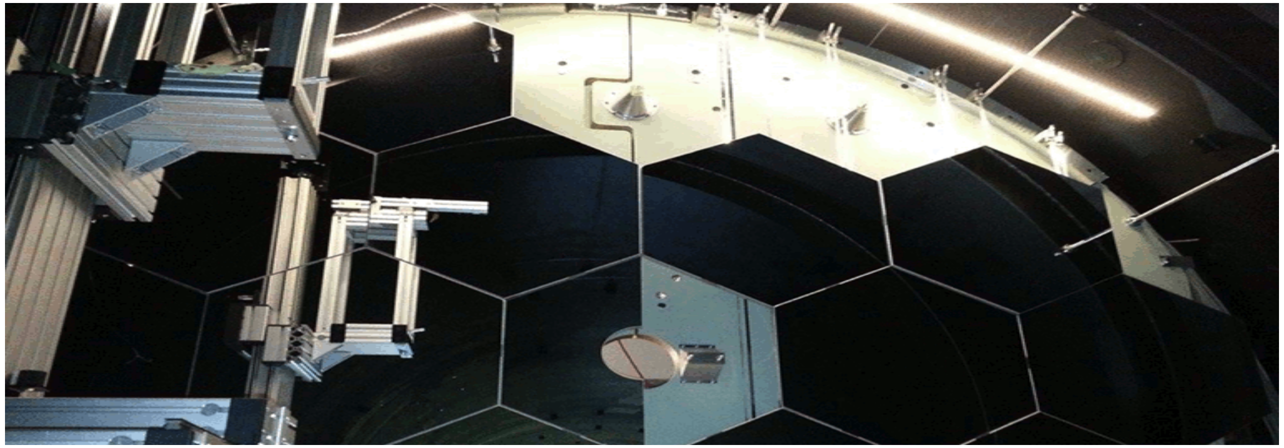
- Neon gas at ~ atmospheric pressure
- Refractive index (n-1) = 61.8 ×10^{-6} (λ = 300 nm, 1atm, t=25°C)
- Cherenkov threshold p_{th} =12.5 GeV/c for π^+
- Low chromatic dispersion ($\Delta n = 1.3 \times 10^{-6}$ for R7400U-03 PMT)
- Low atomic number
- Good light transparency in visible and near-UV

No purification/recirculation system:

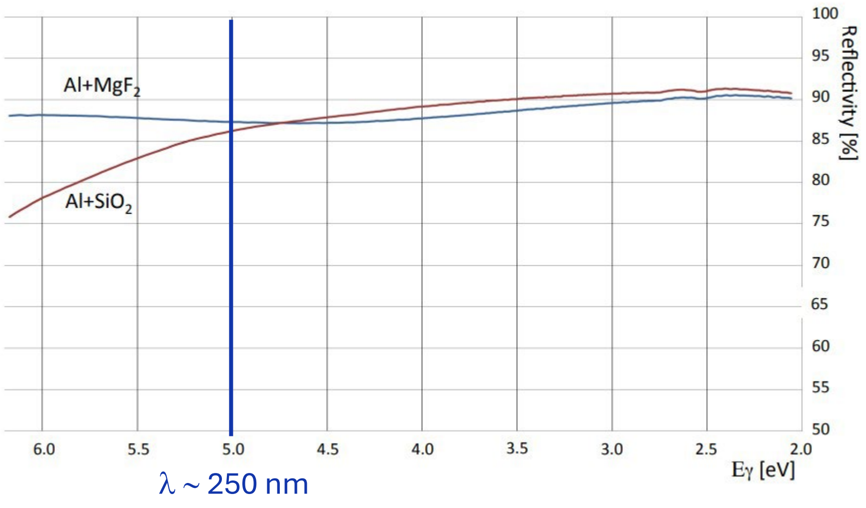
- fresh neon injected after emptying the vessel
- first fill in 2014, a second fill in 2016 after maintenance

RICH Mirrors System

- Mosaic of 20 spherical mirrors: 18 hexagons (35 cm side dimension) + 2 semi-hexagons
- Radius of curvature (34.0 ± 0.2) m, D_0<4 mm
- 2.5 cm thick glass, Al + thin MgF_2 dielectric film
- Reflectivity between 85 and 90% in the range 195 < λ <650 nm



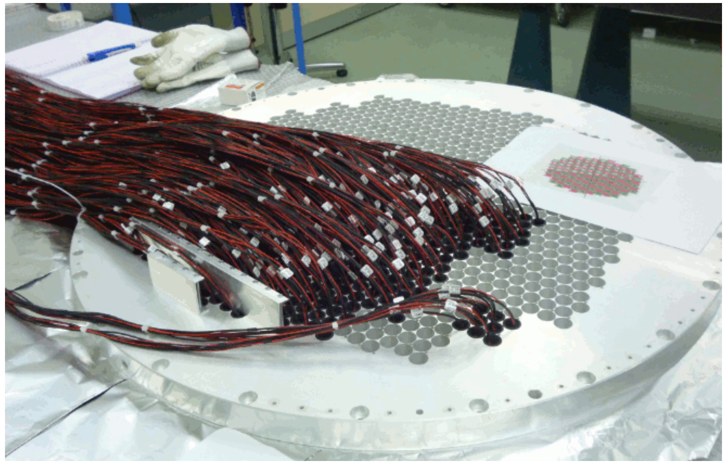
- Mirrors individually supported by a back dowel
- Two thin Al ribbons keep each mirror in equilibrium allowing its orientation. The half-hexagonal mirrors are fixed.
- Remote control of mirror orientation through piezo motor actuators

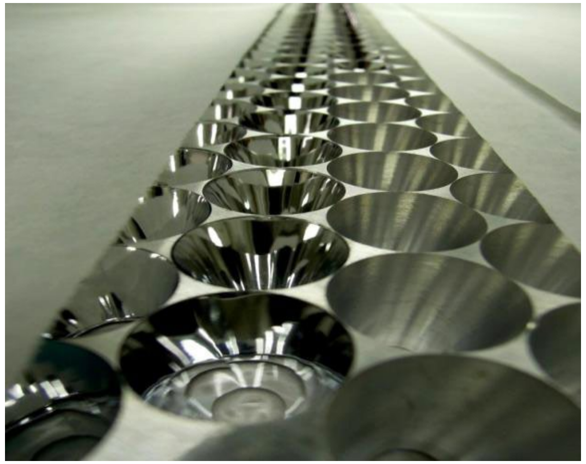


Total reflectivity for two different coating as a function of the photon energy

RICH Photodetection System

- Hamamatsu R7400U-03 PMTs
- Compact hexagonal packing, 18 mm pixel size
- Light collected by means of Winston cones with Al mylar
- 1 mm thick quartz window to separate neon from PMTs
- Custom made HV dividers to reach best compromise between signal quality (time resolution) and resistance values (heat dissipation)





Hamamatsu R7400-03 PMTs
Sensitivity range 185-650 nm (420 nm peak)
Gain 1.5×10^6 at 900 V
UV glass window, 16 mm ∅ (8 mm active ∅)
Q.E. ~ 20% at peak
280 ps time jitter (FWHM)

RICH Basic Performance

Basic performance

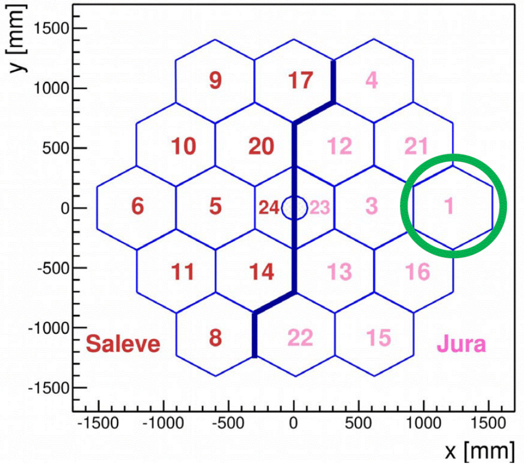
- Mirrors alignment
- Average number of hits: $\langle N_{hits} \rangle$
- Average electron ring radius and ring radius resolution: $\langle R_e \rangle$, σ_{R_e}
- Single hit space resolution
- Single hit time resolution

- RICH basic performance measured with a clean sample of e^+ from $K^+ \rightarrow \pi^0 e^+ \nu_e$
- Unbiased sample: ring radius and number of hits do not depend on the momentum $(\beta = 1)$
- Require positron rings fully contained within RICH acceptance

RICH Mirrors Alignment

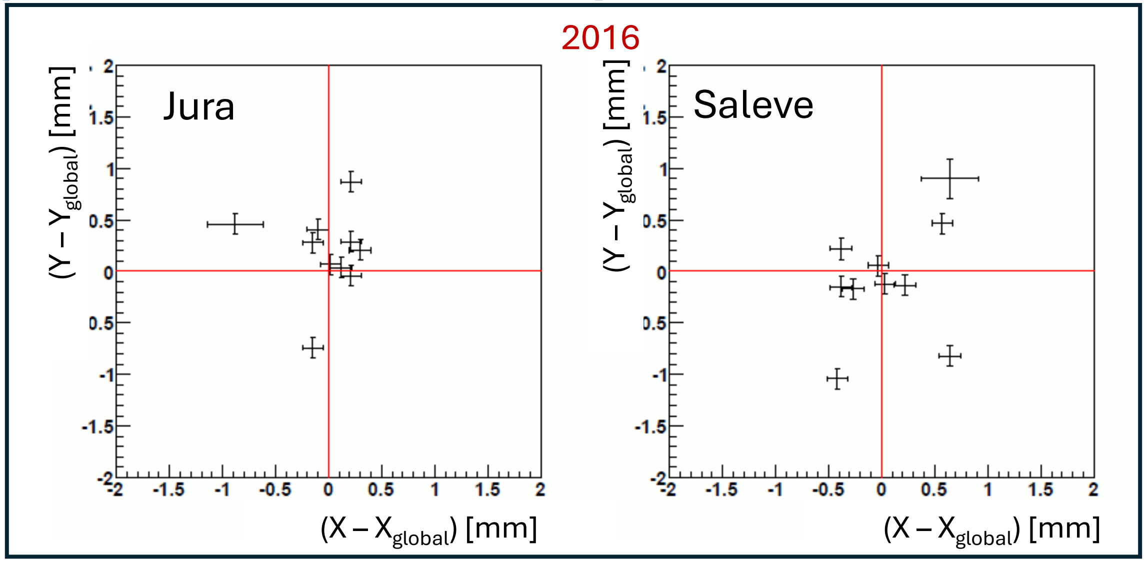
At the beginning of each data taking periods

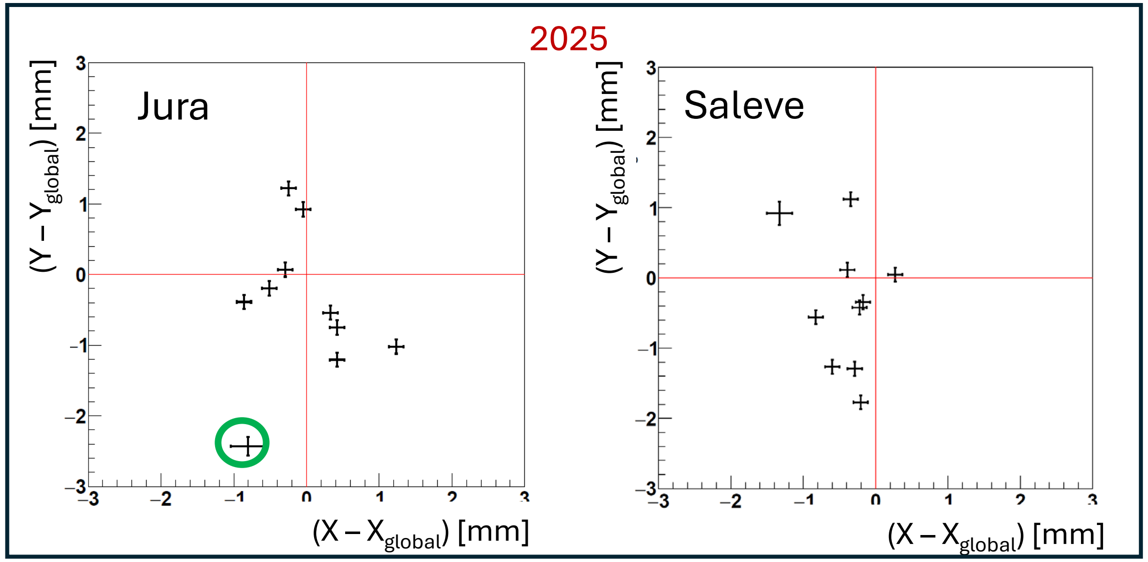
- Mirrors relative alignment measured with reconstructed tracks
- Mirrors movements performed if needed



Residual misalignment with respect to global offset

[Anzivino et al. 2018_JINST13 P07012]

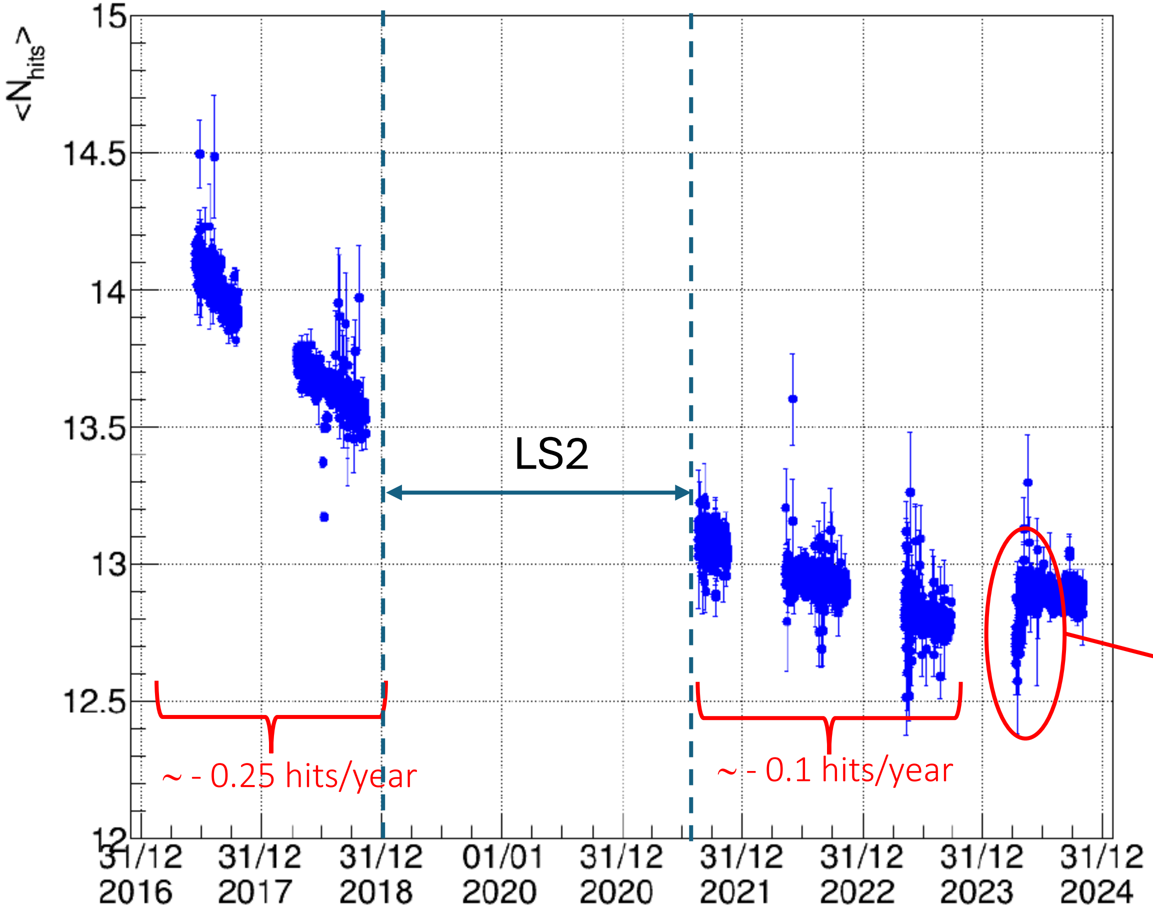




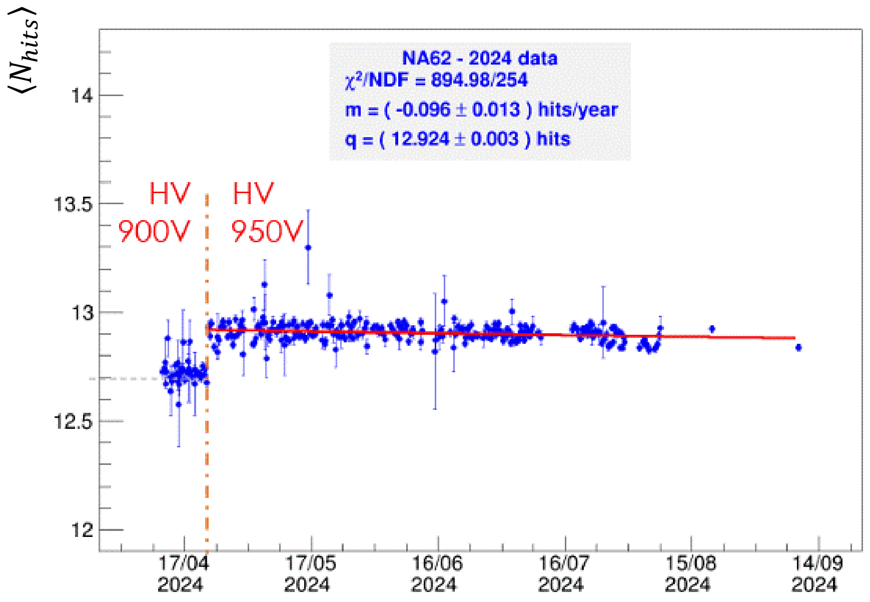
In 2025 Mirrors (except #1) are aligned within 1.5 mm

Slightly larger spread with respect to 2016 but negligible effect on PID performance

Number of Hits

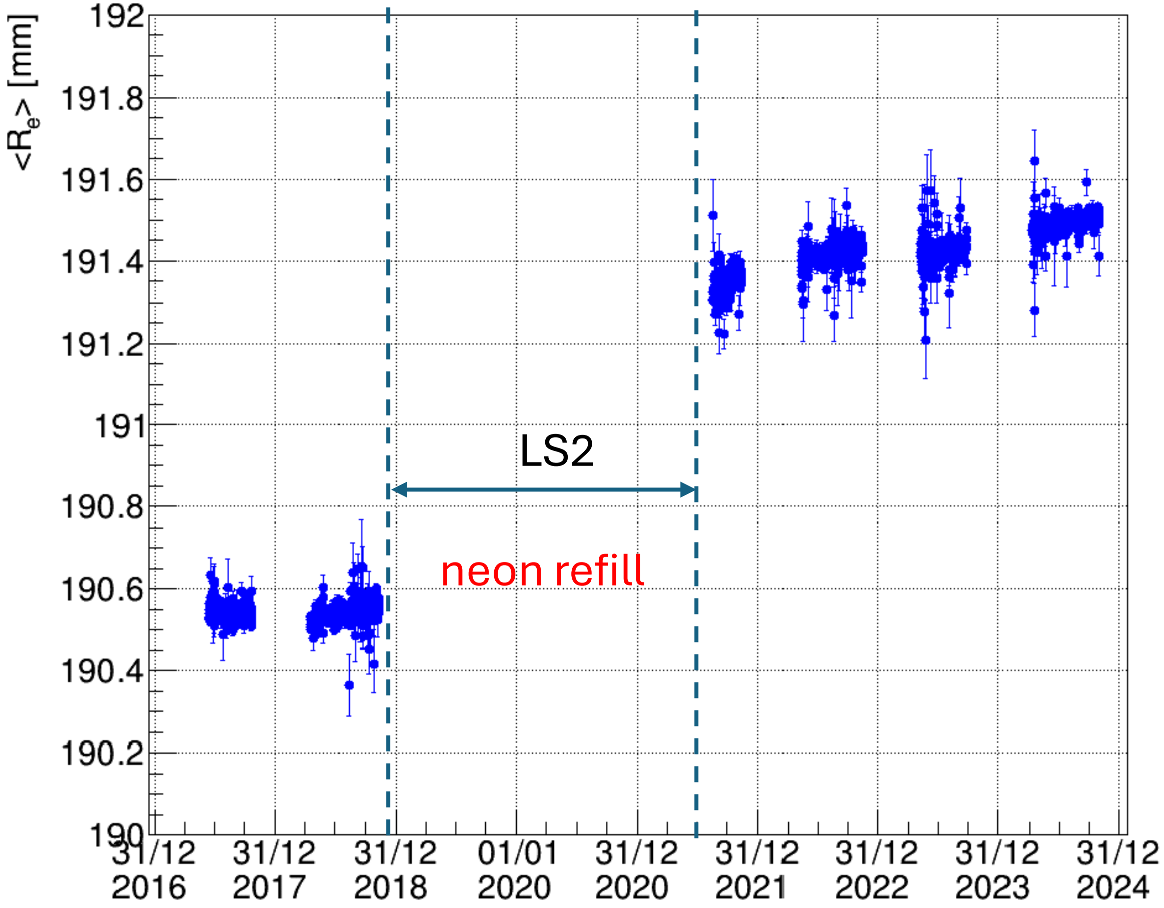


	m[hits/year]	q[hits]
2017	-0.64 ± 0.01	14.143 ± 0.003
2018	-0.354 ± 0.006	13.759 ± 0.002
2021	-0.14 ± 0.03	13.089 ± 0.004
2022	-0.116 ± 0.008	12.2974 ± 0.03
2023	-0.13 ± 0.01	12.828 ± 0.003
	PMTs HV change	
2024	-0.053 ± 0.006	12.916 ± 0.002



~ 0.2 increase in $\langle N_{hits} \rangle$ due to PMTs HV change

Electron Ring Radius

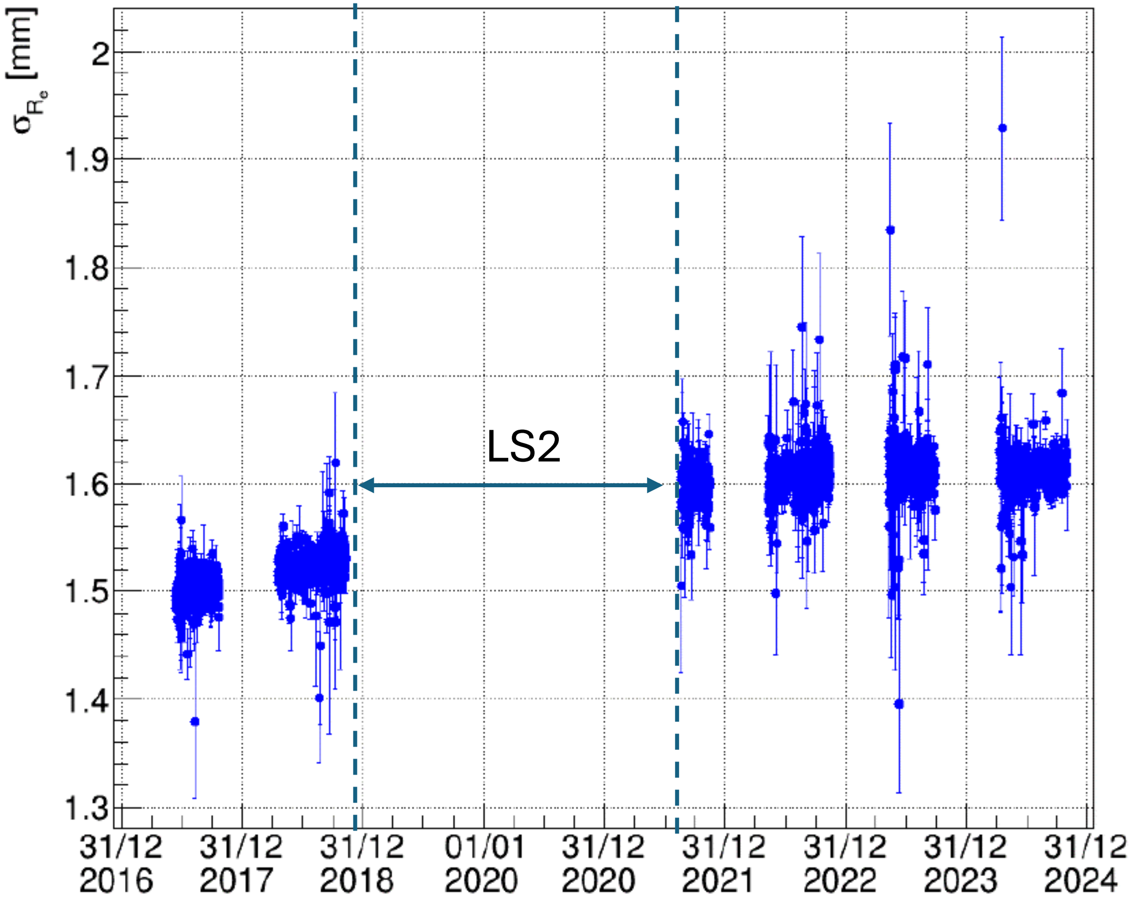


	m[mm/year]	q[mm]
2017	-0.017 ± 0.05	190.543 ± 0.001
2018	0.070 ± 0.002	190.518 ± 0.001
	neon refill	
2021	0.163 ± 0.013	191.317 ± 0.002
2022	0.064 ± 0.004	191.395 ± 0.001
2023	0.067 ± 0.005	191.402 ± 0.001
2024	0.058 ± 0.003	191.472 ± 0.001

$\langle R_e \rangle$ value at the beginning of 2021 data taking consistent with the expected value taking into account :

- the neon refill (+0.28%)
- the radius increase during the shutdown (+0.1%) due to the measured trend

Electron Ring Radius Resolution



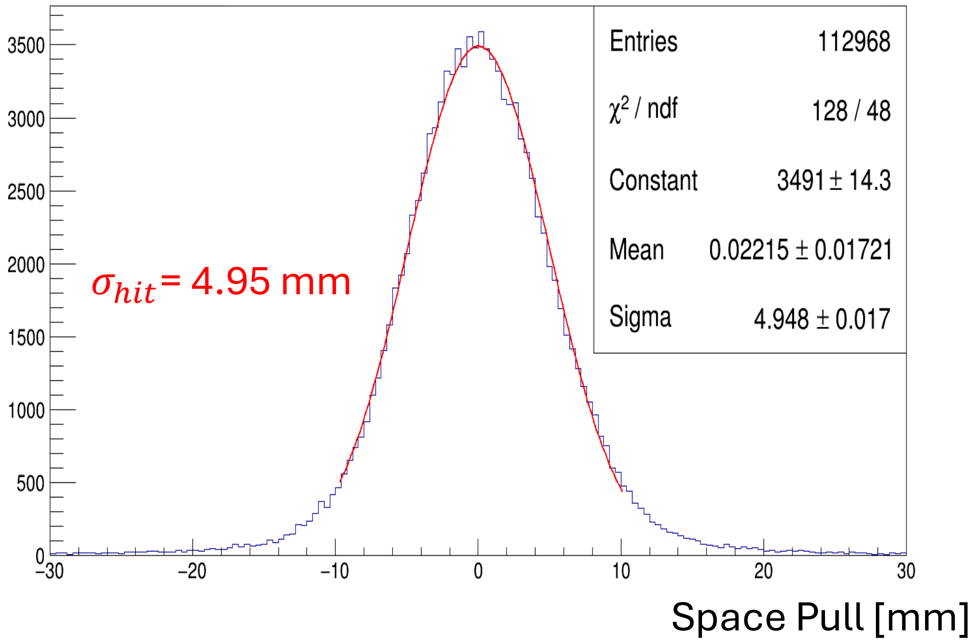
	m[mm/year]	q[mm]
2017	-0.014 ± 0.005	1.498 ± 0.001
2018	0.020 ± 0.002	1.517 ± 0.001
	neon refill	
2021	-0.02 ± 0.01	1.602 ± 0.002
2022	0.019 ± 0.003	1.600 ± 0.001
2023	-0.008 ± 0.004	1.612 ± 0.001
2024	0.008 ± 0.003	1.607 ± 0.001

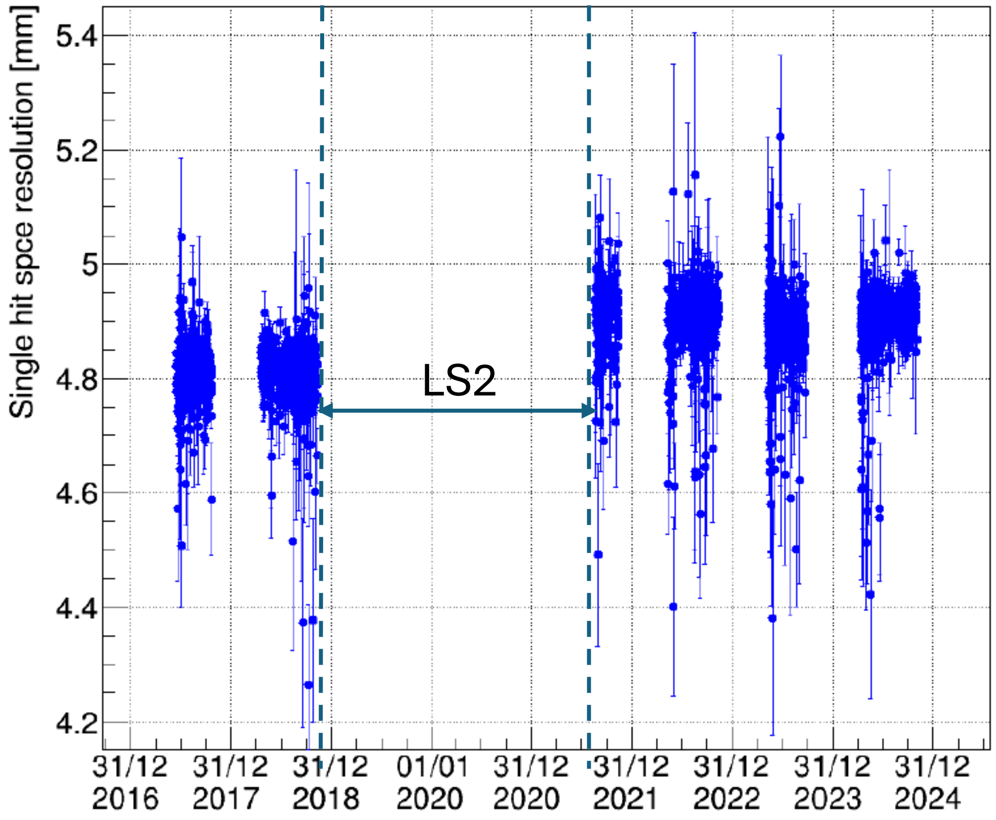
The angular resolution per detected photon is
$\sigma_{\theta_c} = \sigma_R / f \sim 90\ \mu rad$
with $f \sim 17\ m$ focal distance

Single Hit Space Resolution

- Compute the Space Pull = $(R - R_{exp})\sqrt{N_{hits} - 3}$, where R is the ring radius as obtained by the fit and R_{exp} the radius calculated from the momentum assuming the electron mass
- The single hit spatial resolution $\sigma_{hit} = \sigma_{Space\ Pull}$

2022 Data – positron selection

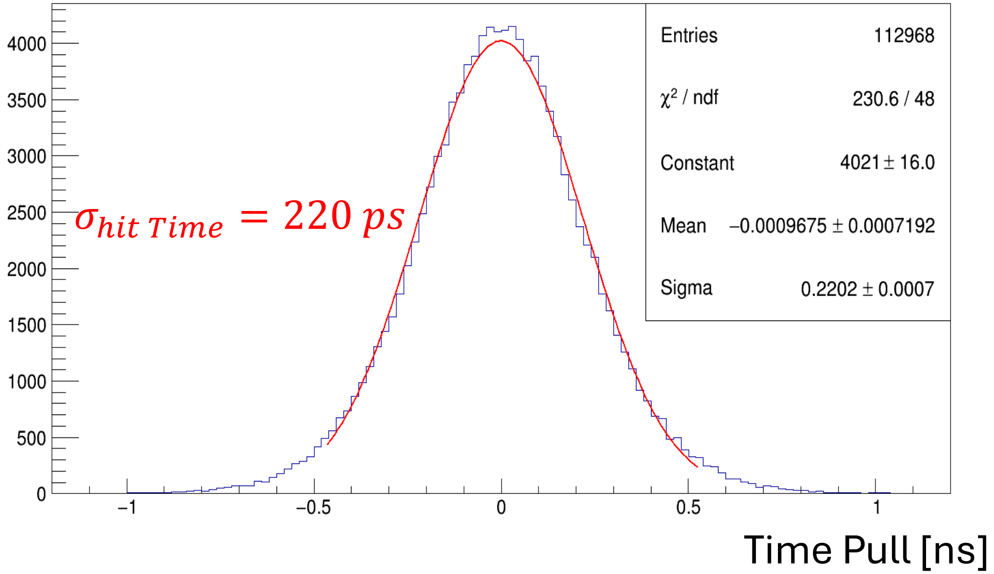


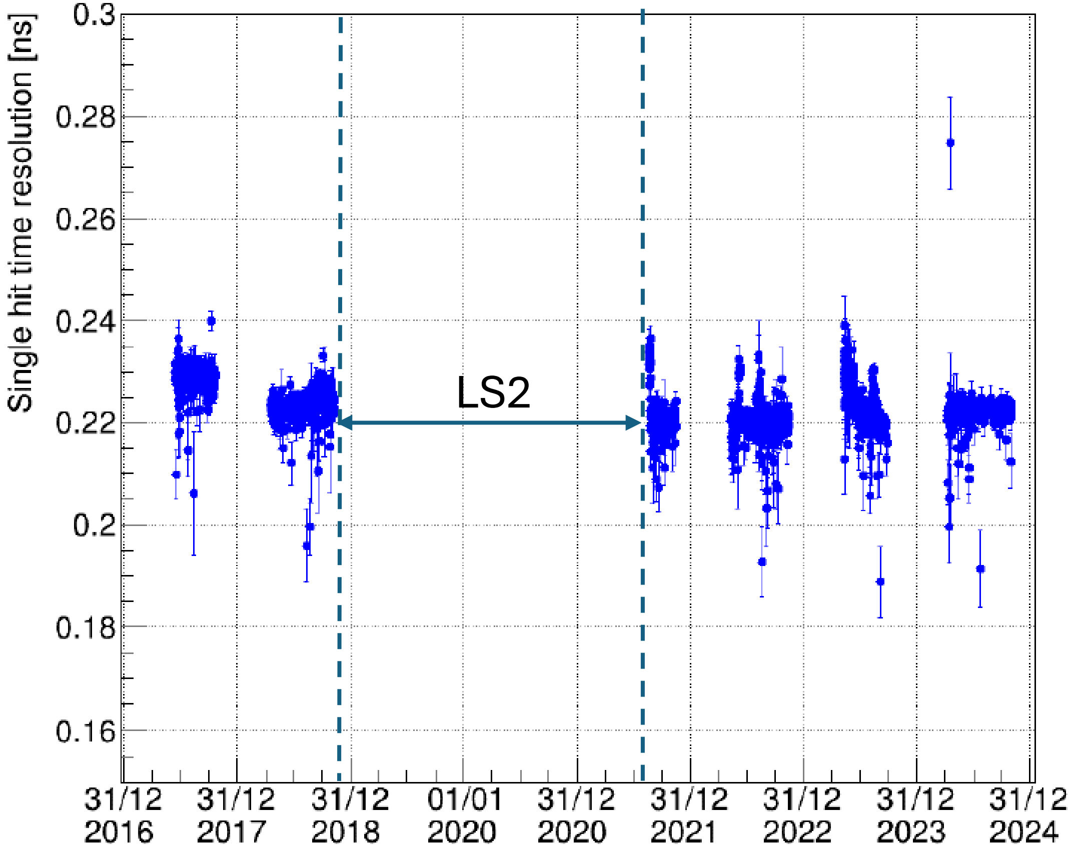


Single Hit Time Resolution

- For each event the RICH hits are randomly split in 2 groups
- The average time of each group, T_1 and T_2, is computed
- Compute the Time Pull = $\frac{(T_1 - T_2)}{2}\sqrt{N_{hits}}$
- The single hit time resolution $\sigma_{hit\ Time} \simeq \sigma_{TimePull}$

2022 Data – positron selection

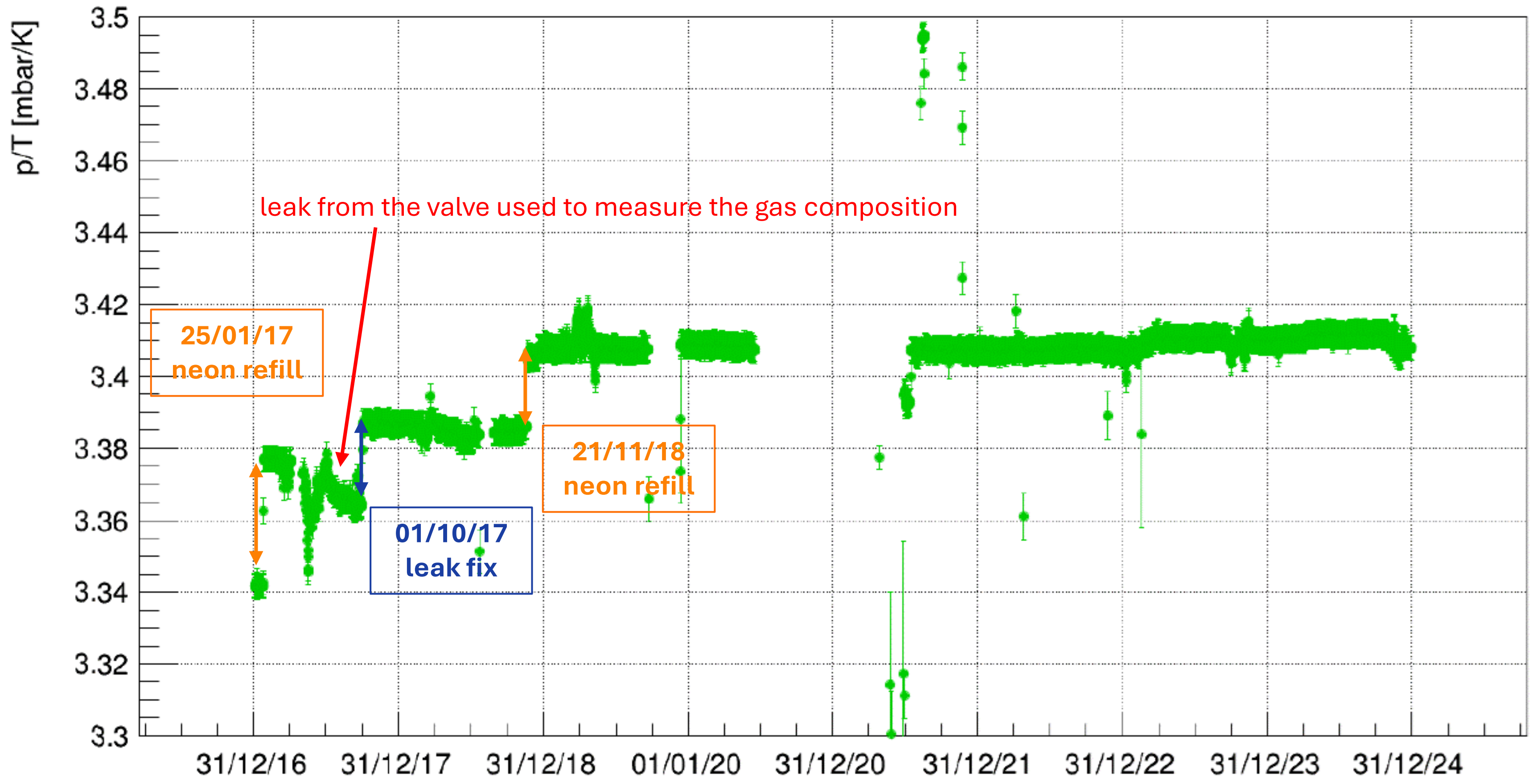




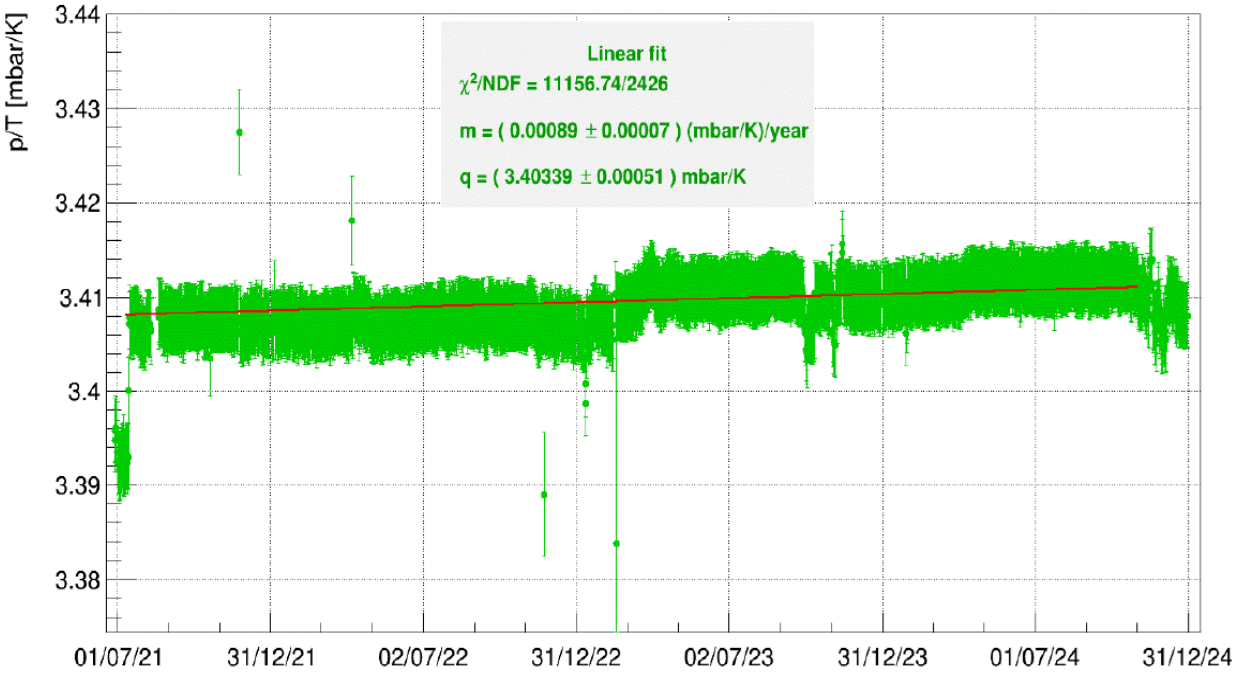
$\sigma_{hit\ Time}$ is stable in time, but with fluctuations at the level of few %

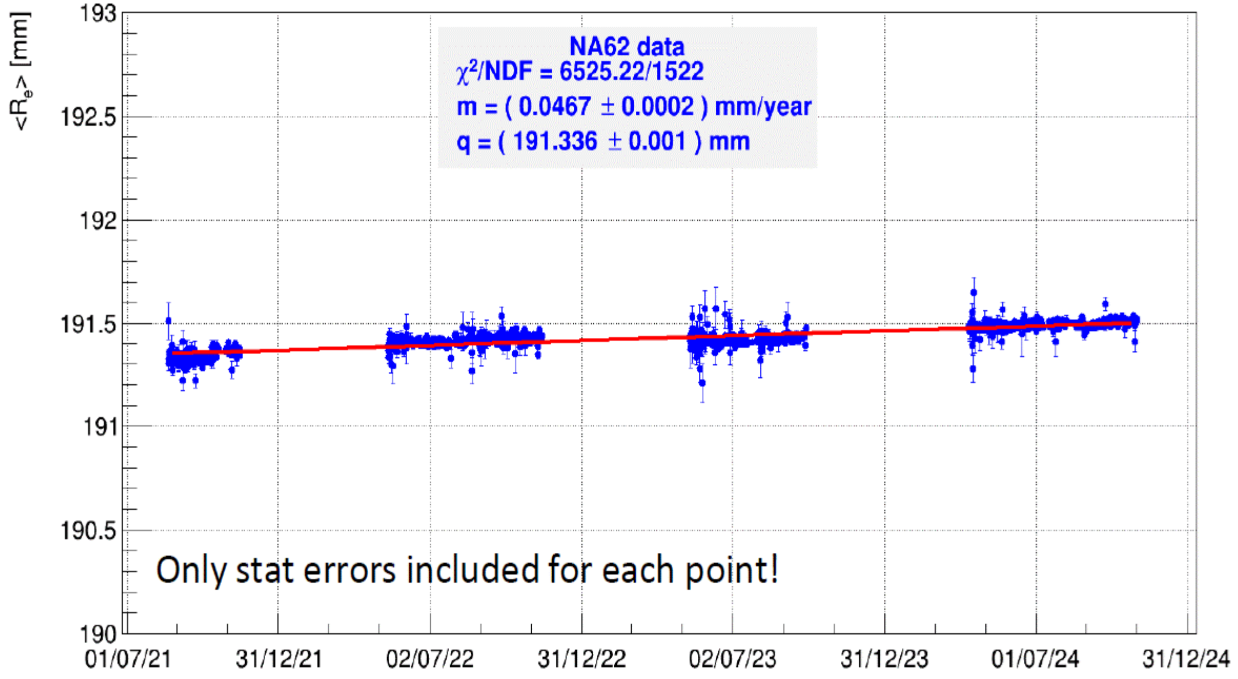
Pressure over Temperature

The pressure p inside the RICH vessel measured by one sensor
The temperature T is the mean of 12 measurements provided by probes placed along the RICH vessel



p/T and $\langle R_e \rangle$ Variation in Time





$\frac{\Delta\left(\frac{p}{T}\right)}{\frac{p}{T}} \sim 0.026\%$ per year

$\frac{\Delta(R_e)}{R_e} \sim 0.024\%$ per year

$\langle R_e \rangle$ variation seems to follow the p/T trend, even if we expected $\frac{\Delta(R_e)}{R_e} = \frac{1}{2}\frac{\Delta\left(\frac{p}{T}\right)}{\frac{p}{T}}$ if $\langle R_e \rangle \propto \sqrt{\frac{p}{T}}$

Conclusions

NA62 RICH is a detector with very stringent requirements that, even after 9 years of data taking and without any intervention, continues to meet the design criteria:

- Observed trends of some of the basic quantities do not affect PID performance

  (see talk by V. Duk tomorrow)

- The analysis of collected data and the search for possible correlations with environmental variables and performed interventions carried out to understand the observed trends and advance our knowledge for the design of future Cherenkov detectors