New developments in timing RPCs

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On behalf of the RPC R&D group @ LIP

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Outlook

- timing RPCs (tRPCs)

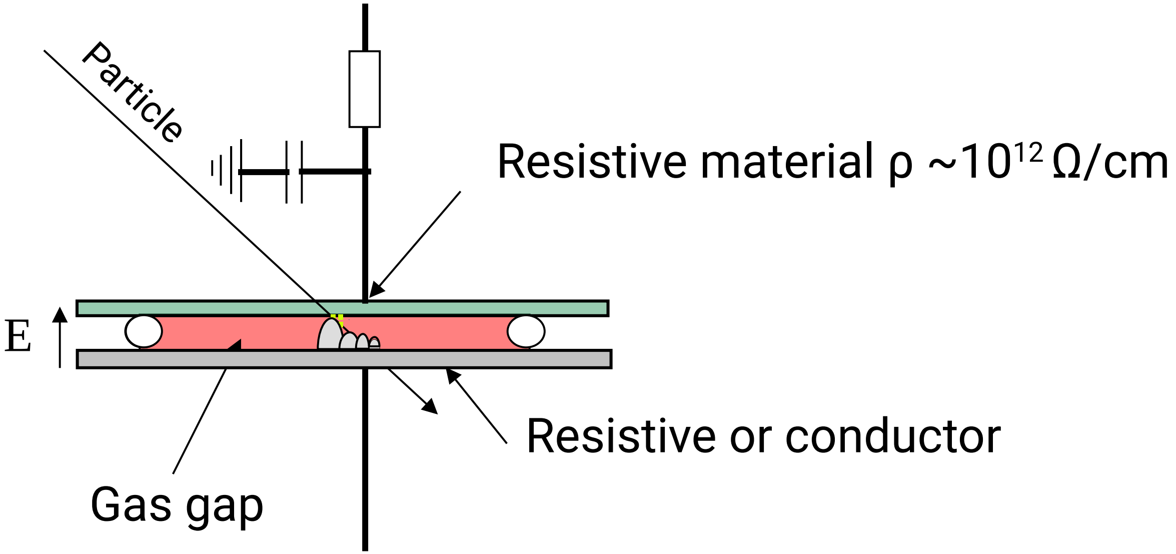
- **Large area timing RPCs**. SHiP and R^3B timing detectors.

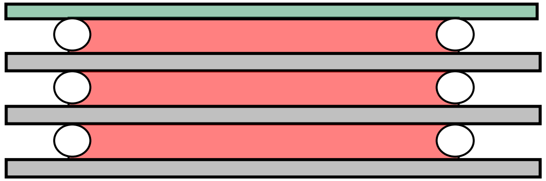
- Timing RPCs with precise **2D spatial resolution.**

- **Sealed (no gas flux)** RPCs.

- Increase the rate capability of timing RPCs by **increasing the operational temperature**. HADES.

Timing RPCs





[Davies and Evans, 1973]

Evolution of the number of electrons

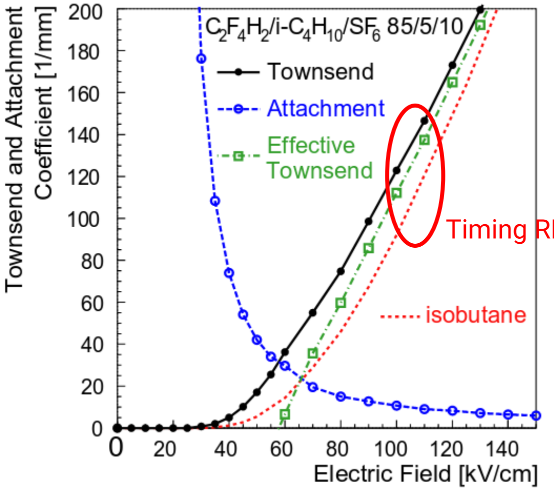
$$\frac{\delta n_e(x,y,z,t)}{\delta t} = \alpha n_e |v_e| - \nabla (n_e v_e) + D_e \nabla^2 n_e$$

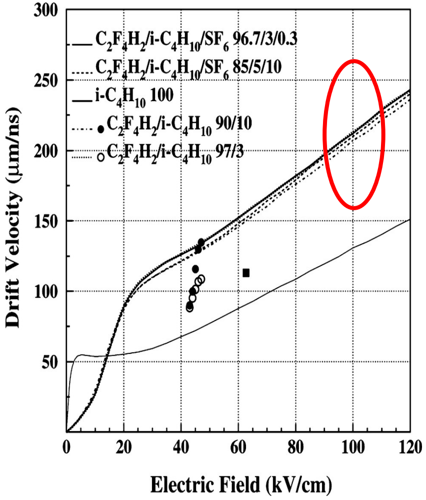
α = 1/λ, first Townsend coefficient
n_e = number of electrons
v_e = electron drift velocity
$v_e(E/N)$
E = electric field
N = density of the gas
D_e = diffusion coefficient of electrons

$$n_e(x,y,z,t) = n_o e^{\alpha v_e t} \frac{1}{(4\pi D_e t)^{3/2}} \exp\left(\frac{x^2+y^2+(z-v_e t)^2}{4 D_e t}\right)$$

* Equal longitudinal and transverse diffusion
V_e and α constant during amplification

[Lippmann and Riegler, 2004]





Timing RPC

[Davies and Evans, 1973]

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* Equal longitudinal and transverse diffusion
V_e and α constant during amplification

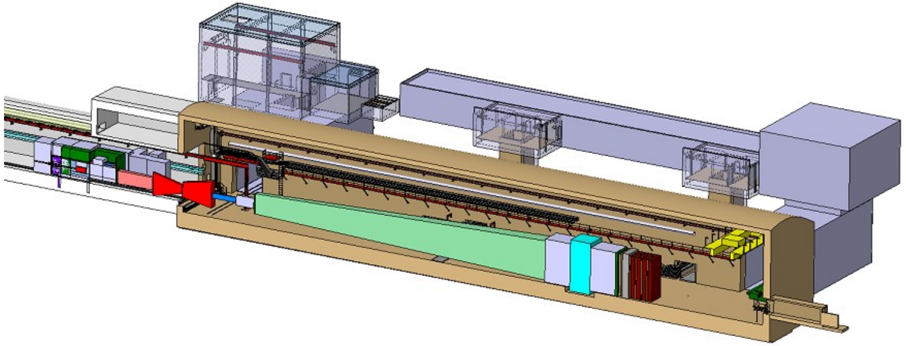
Large area timing RPCs. SHiP and R^{3}B timing detectors

Objective: develop tRPC of **large area > 1 m²** with **excellent timing precision ~50 ps** and **efficiency > 95 %** at **very low cost** (driven basically by the FEE and DAQ price).

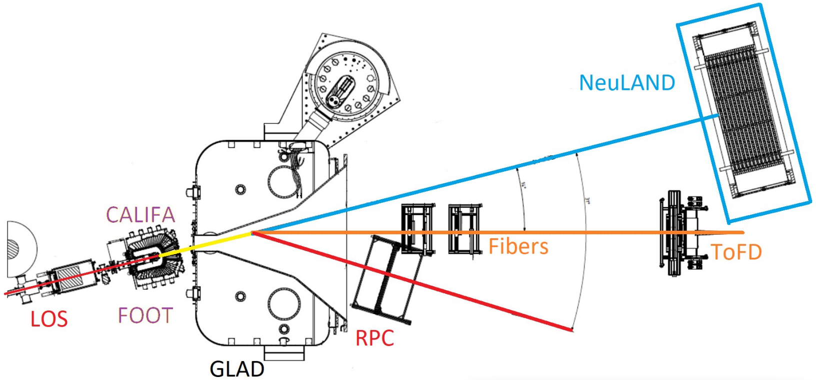
Target applications (currently)

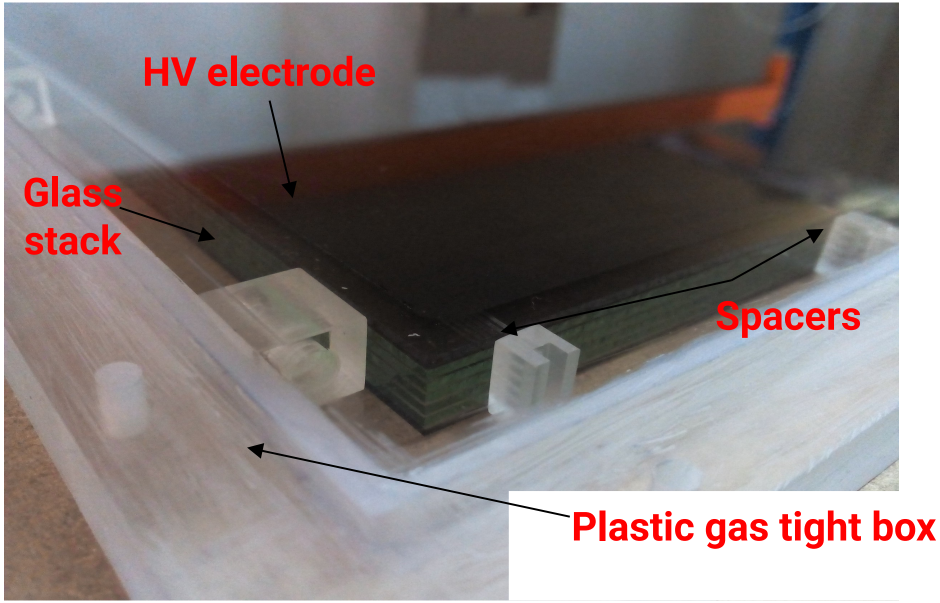
- **Future SHiP timing detector.**

SHiP
Search for Hidden Particles



- **TOF proton arm of R^{3}B collaboration.**





Novel construction

A **glass stack** contains the glass and HV electrodes enclosed in a plastic gas tight box with feed-throughs for gas and High Voltage.

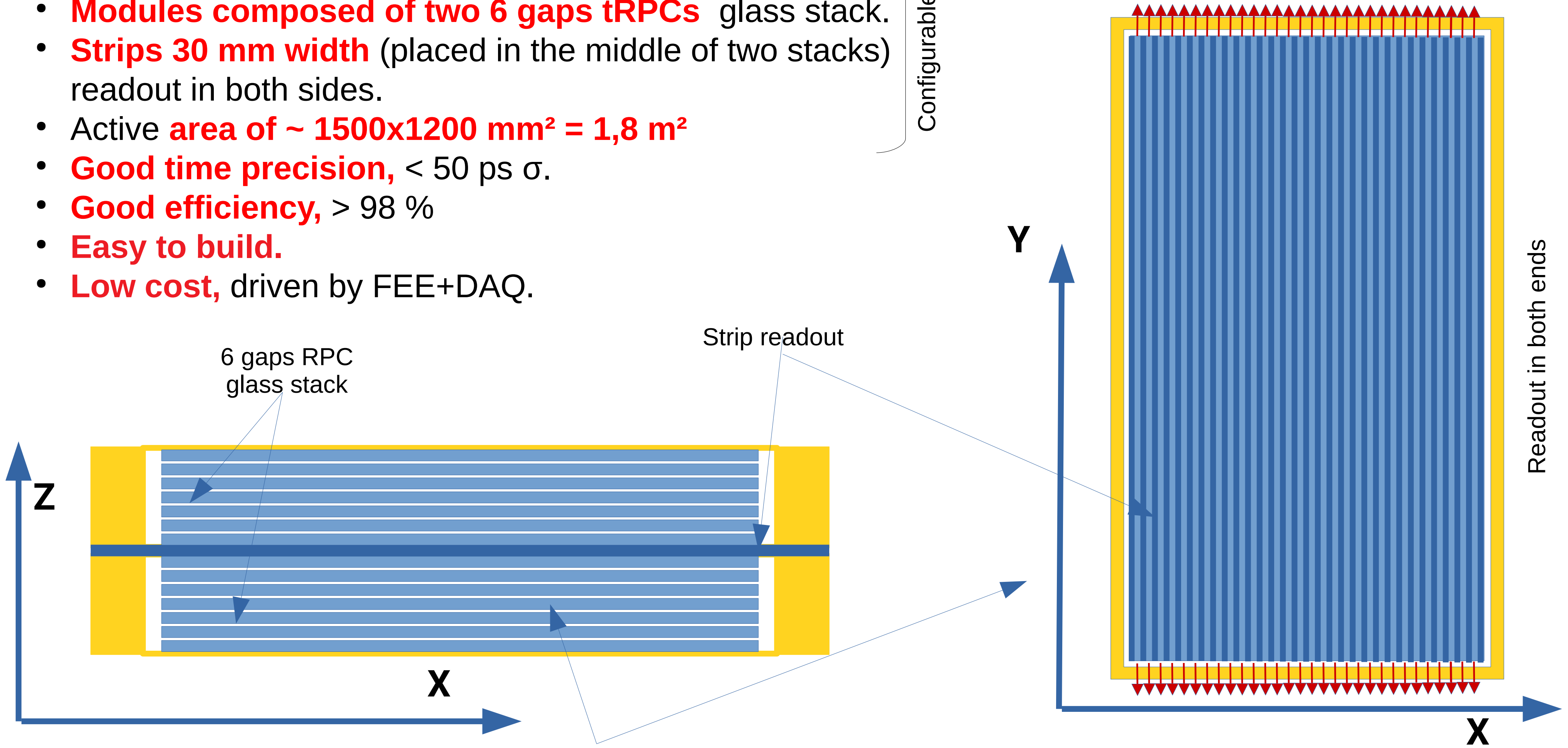
Easy to build
completely gas tight,
no gas leaks, robust.

Decouples the gas and HV from the rest.

Large area timing RPCs. SHiP and R³B timing detectors

- **Modules composed of two 6 gaps tRPCs** glass stack.
- **Strips 30 mm width** (placed in the middle of two stacks) readout in both sides.
- Active **area of ~ 1500x1200 mm² = 1,8 m²**
- **Good time precision,** < 50 ps σ.
- **Good efficiency,** > 98 %
- **Easy to build.**
- **Low cost,** driven by FEE+DAQ.

Configurable



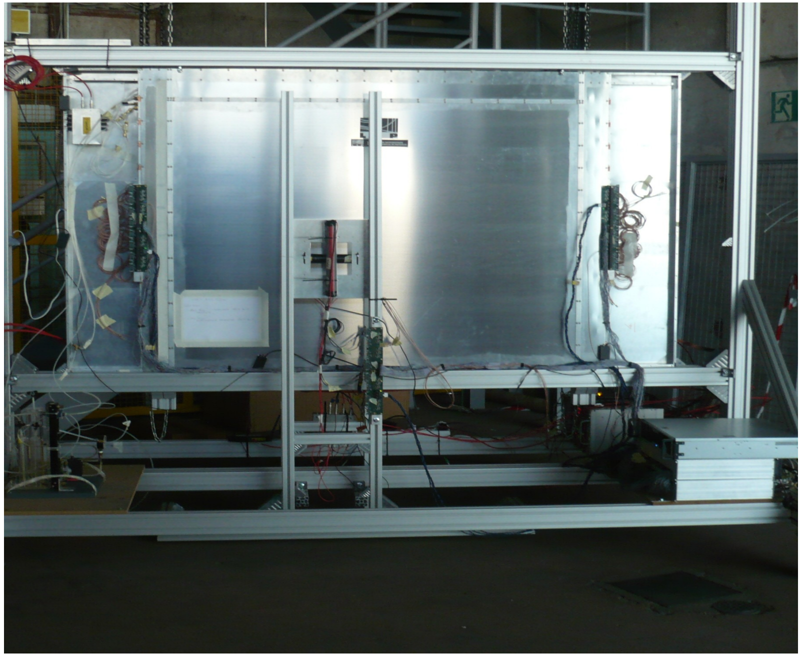
RPC cross-section

RPC top View

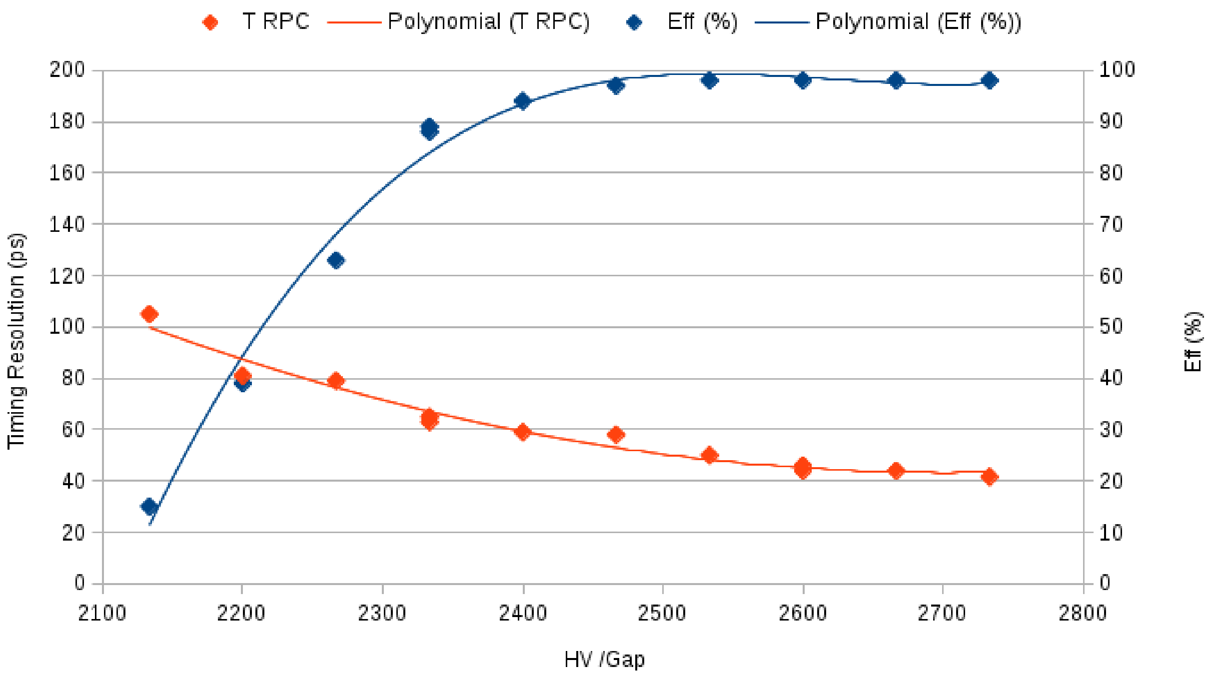
Large area timing RPCs. SHiP and R^{3}B timing detectors

A. Blanco et al 2020 JINST 15 C10017
doi.org/10.1088/1748-0221/15/10/C10017

RPC @ SHiP test beam, CERN.



High voltage scan
Timing accuracy < **50 ps**
Efficiency > **98 %**



Large area timing RPCs. SHiP and R^3B timing detectors

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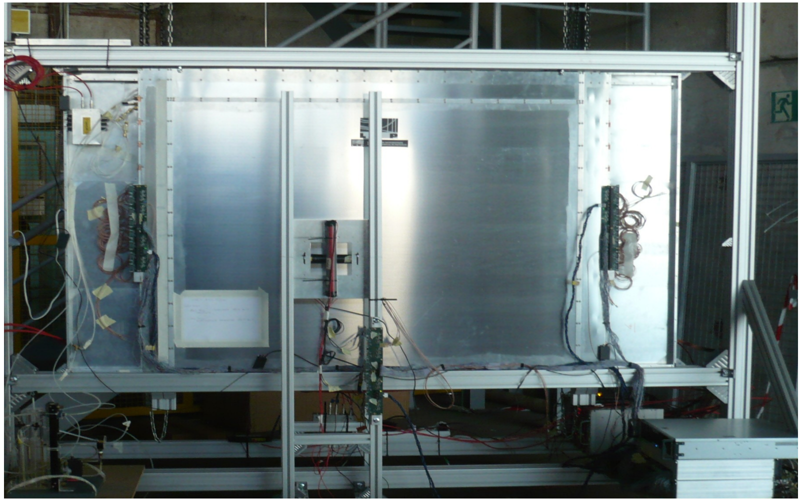
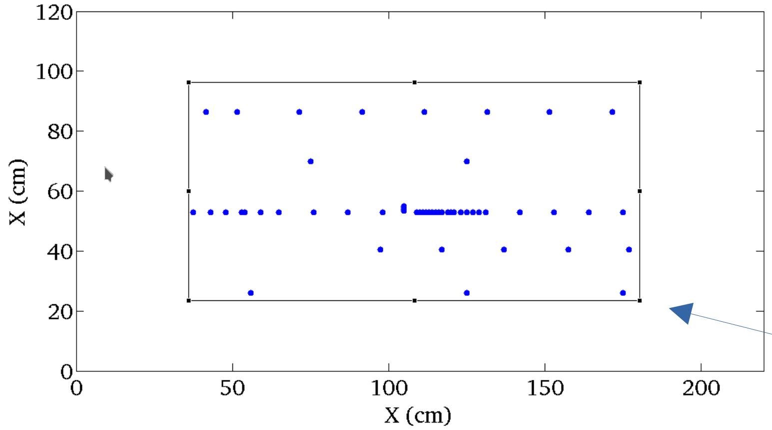
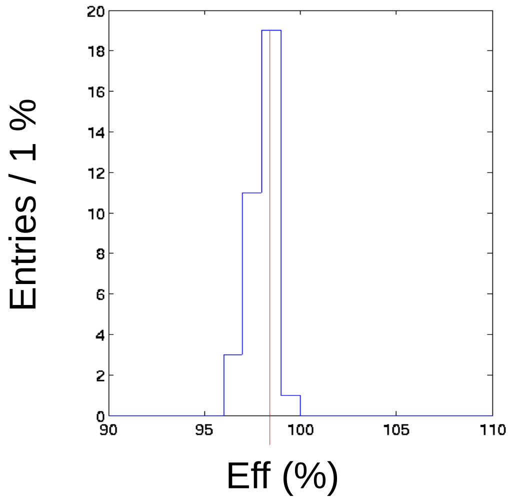
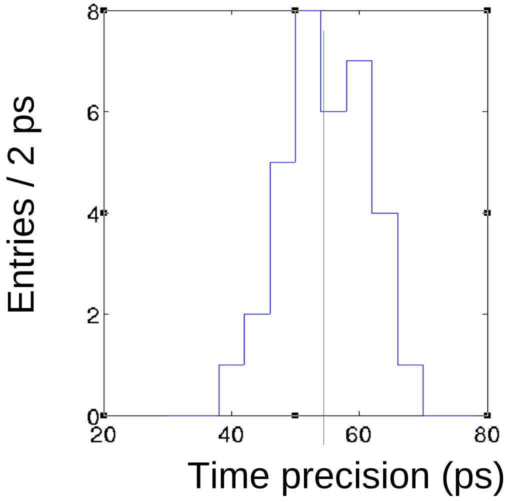




2D Scan
in multiple positions

All positions

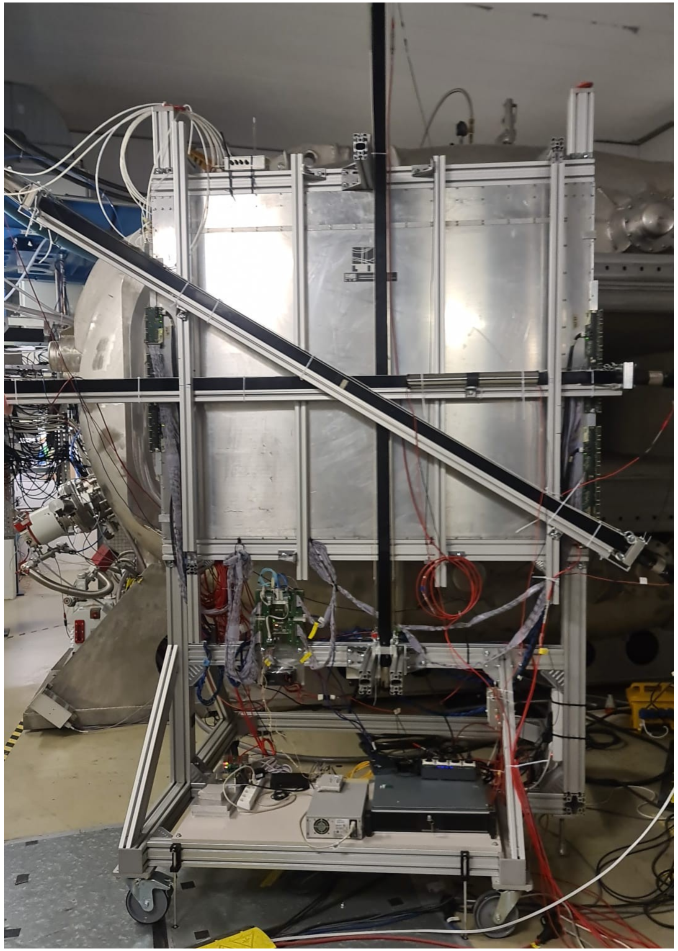




<98 %>

<54 ps>

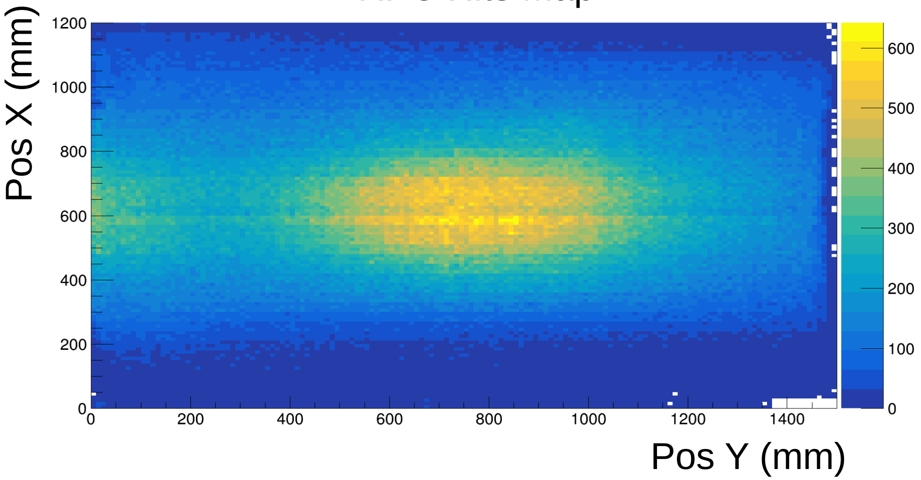
Large area timing RPCs. SHiP and R³B timing detectors

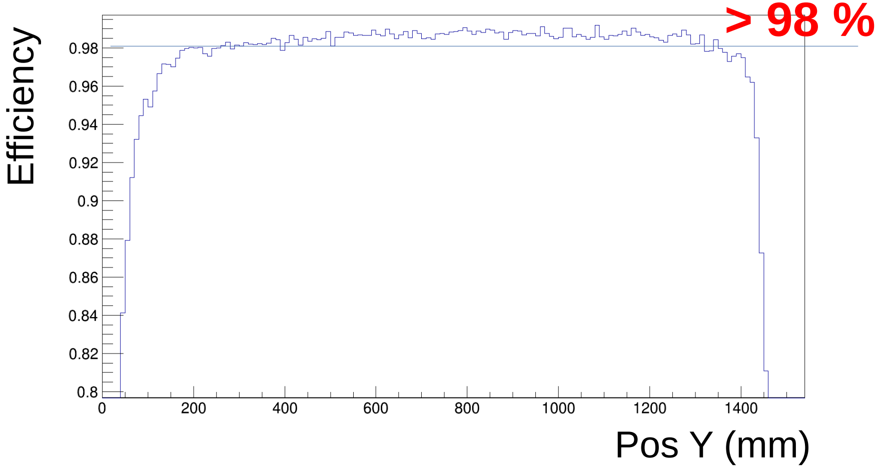


RPC @ R3B, GSI/FAIR, the crossing bars are Scintillators for calibration and efficiency

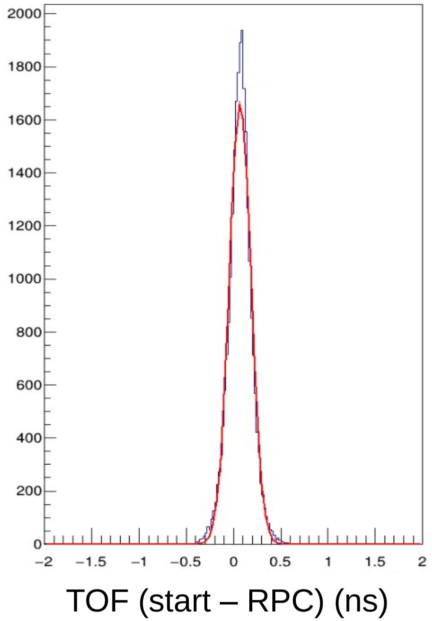
M. Xarepe et al 2023 NIMA 1055, 168445
doi.org/10.1016/j.nima.2023.168445

RPC Hits Map





RPC contribution
98 ps
HV not optimal



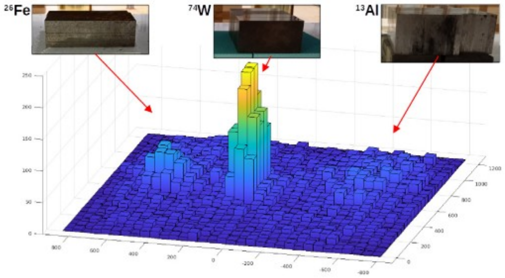
Timing RPCs with precise 2D spatial resolution

Objective: develop RPCs with **excellent timing precision ~ 100 ps** and **efficiency > 95 %** (MIPS) with **sub-millimeter 2D position precision.**

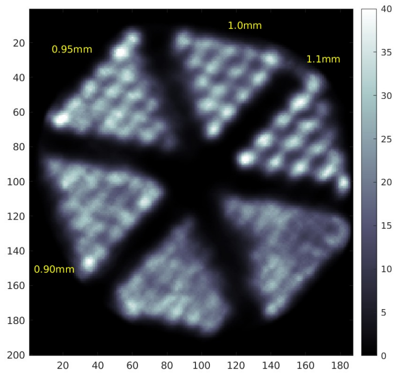
Target applications

- PID in **HEP experiment.**
- **Muon tomography.**

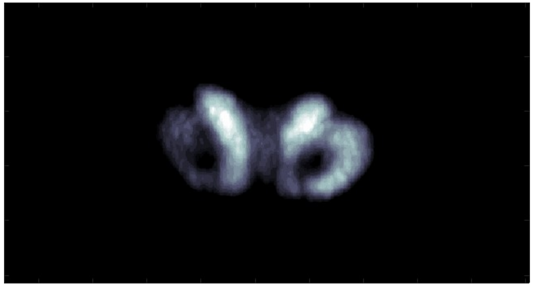
J. Saraiva et al. 2023 NIMA, 1050, 168183
doi.org/10.1016/j.nima.2023.168183



- **Medical application RPC-PET**



P Fonte et al., 2023 NIMA, 1051, 168236
doi.org/10.1016/j.nima.2023.168236

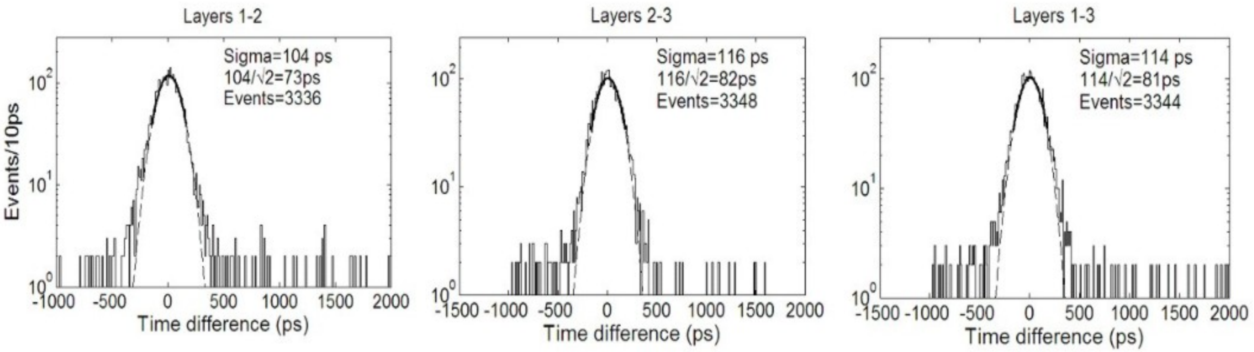


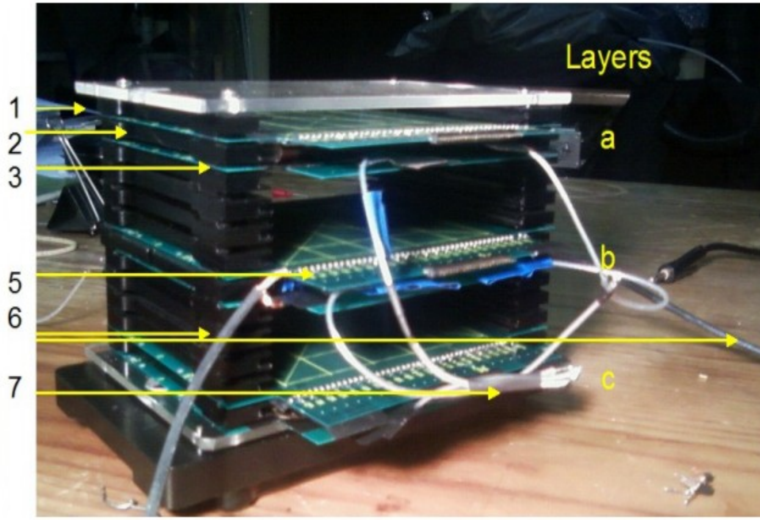
Timing RPCs with precise 2D spatial resolution

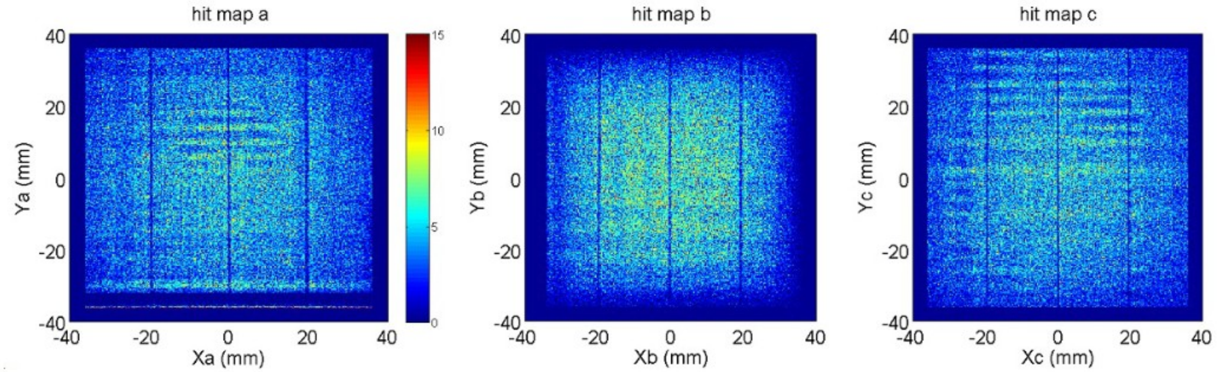
Readout optimized for precision
Number of channels scale with readout area
80x80 mm²

A Blanco et al 2012 JINST 7 P11012
doi.org/10.1088/1748-0221/7/11/P11012

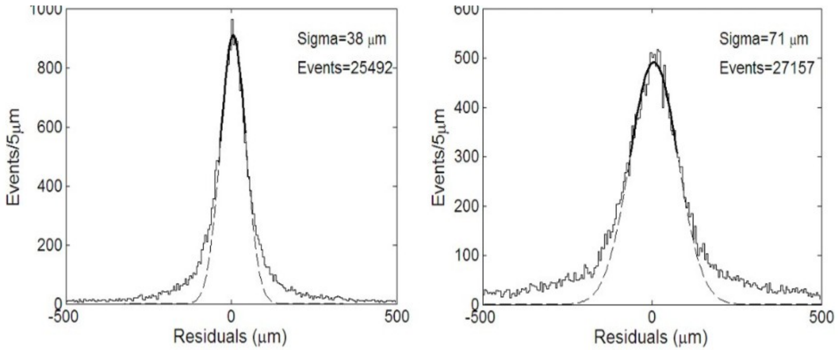
Timing precision ~80 ps



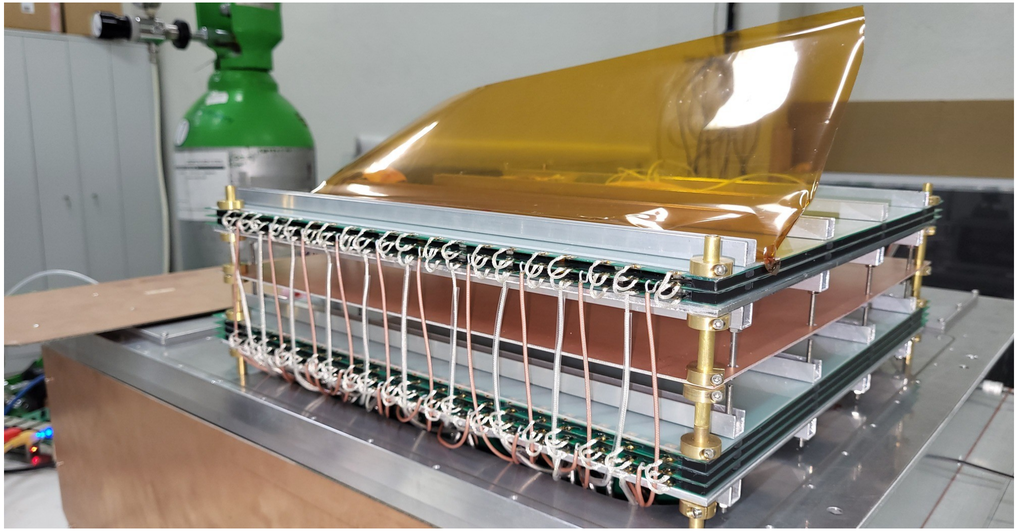




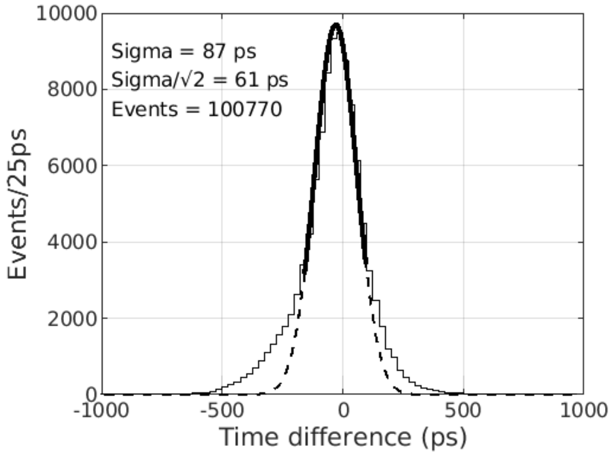
2D spatial precision ~50 um



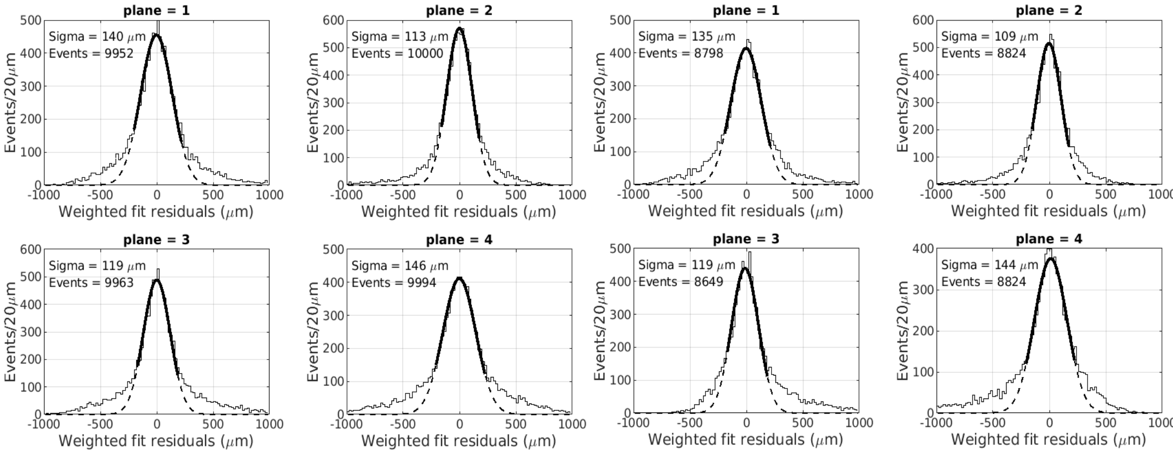
Readout optimized for precision
Number of channels scale with readout area
300x300 mm²



Timing precision ~60 ps



2D spatial precision ~130 um



Timing RPCs with precise 2D spatial resolution

Readout optimized for large area > 1 m², number of channels do not depend on readout area.

24 X, 24Y + 10 timing. X, Y readout in parallel sub-groups, group disentanglement via raw position from time.

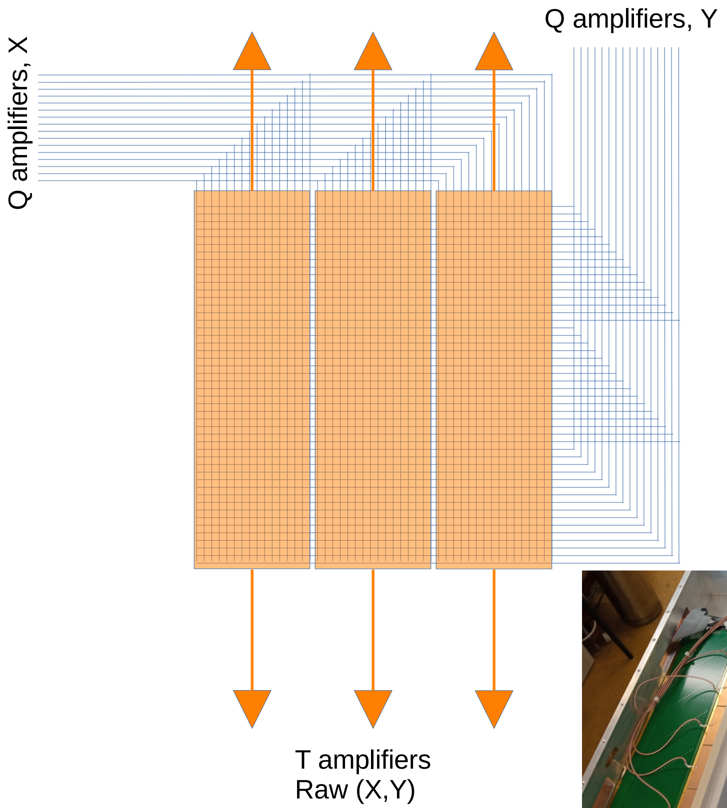
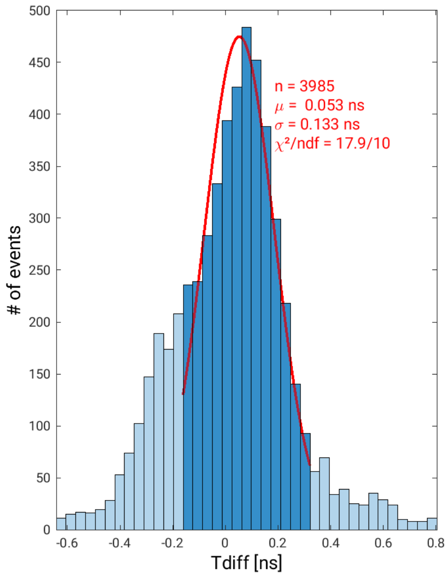
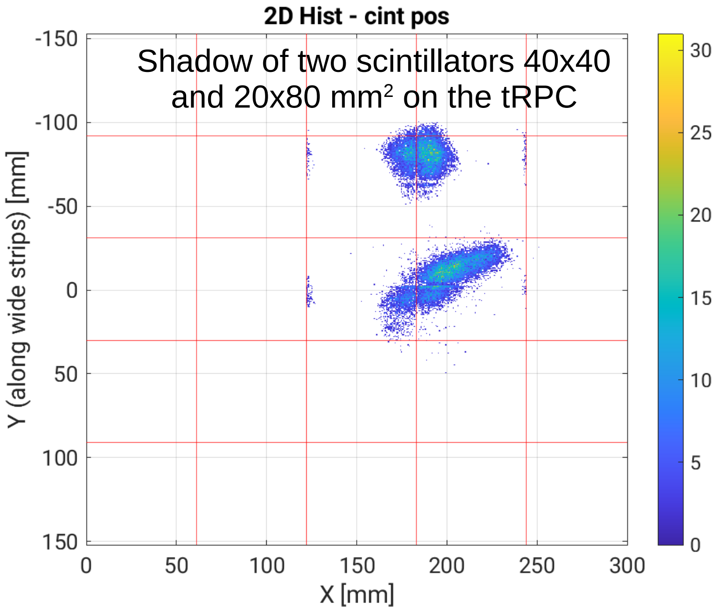


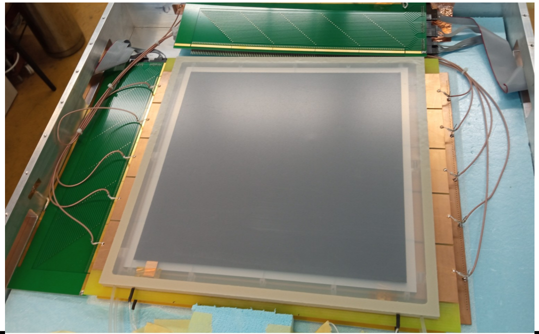
illustration (partial) of readout

Timing precision ~90 ps





Sub-millimeter 2D spatial precision



300x300 mm² prototype to be extended to 1 m²

Sealed (no gas flux) RPCs

Objective: develop **tRPCs requiring no gas flow for its operation**

Target applications

- Mitigate the **HFCs phaseout.**

- Installation in **remote locations** for Cosmic Rays experiments or muon tomography.

L. Lopes et al 2019 JINST 14 C07002
10.1088/1748-0221/14/07/C07002

RPC under AUGER tank

RPC telescope
for mine tomography

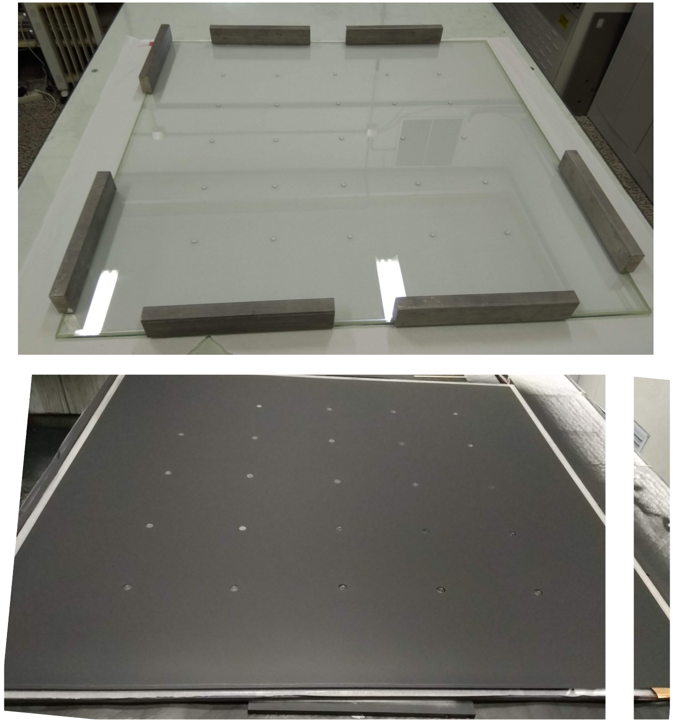
RPC 2022 - XVI Workshop
on Resistive Plate Chambers
and Related Detectors,
CERN, Geneva, Switzerland

- In general **new world of opportunities**.

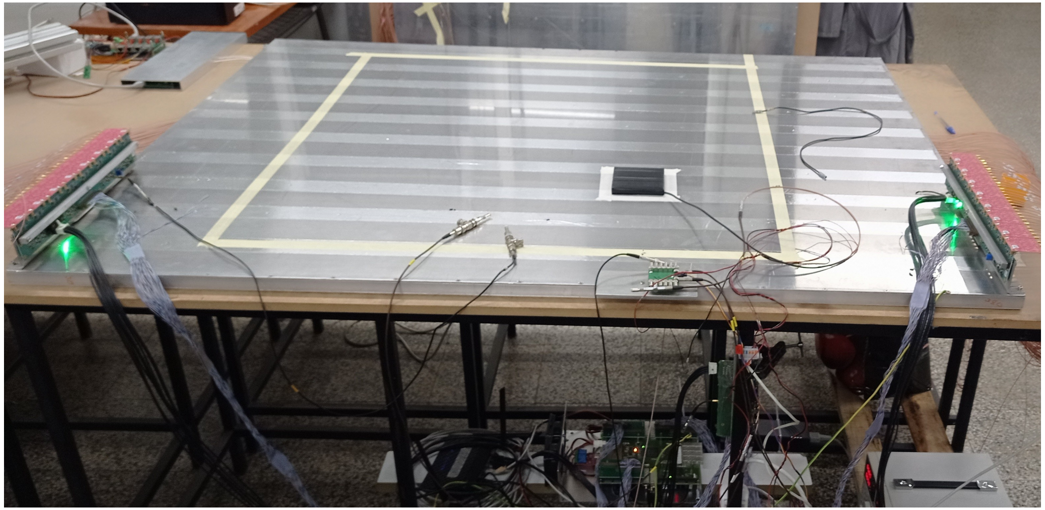
Sealed (no gas flux) RPCs

Acepted for publication
EPJP-D-23-02672

Sealed RPC operated without gas flux. 1 m² 2x1 mm gaps. In operation for **more than one year**.
Not yet a timing RPC, next step



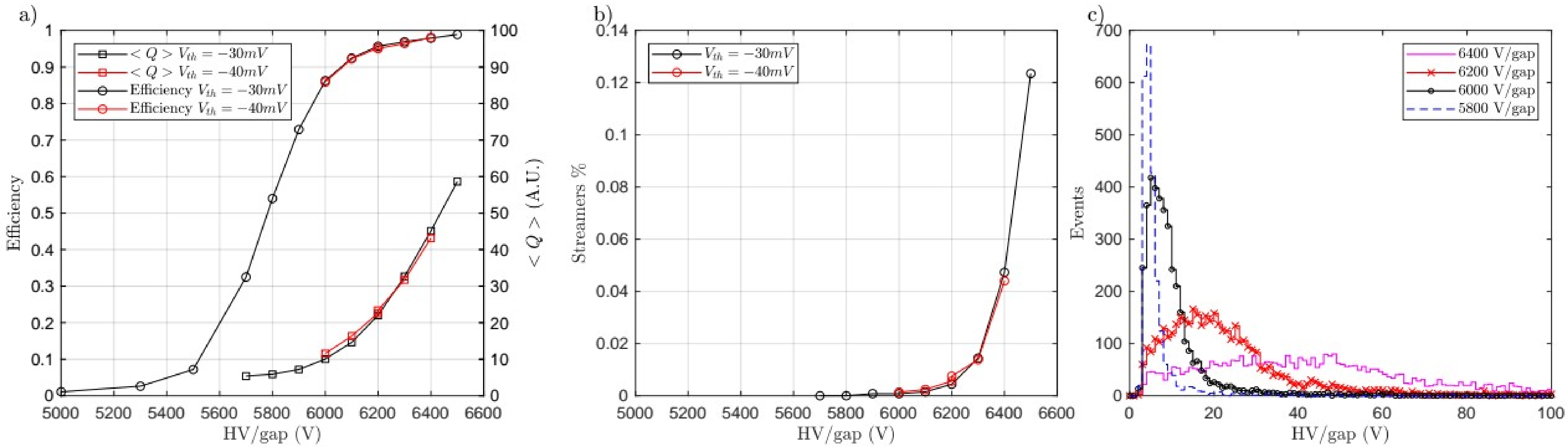
Assemble process



Experimental setup

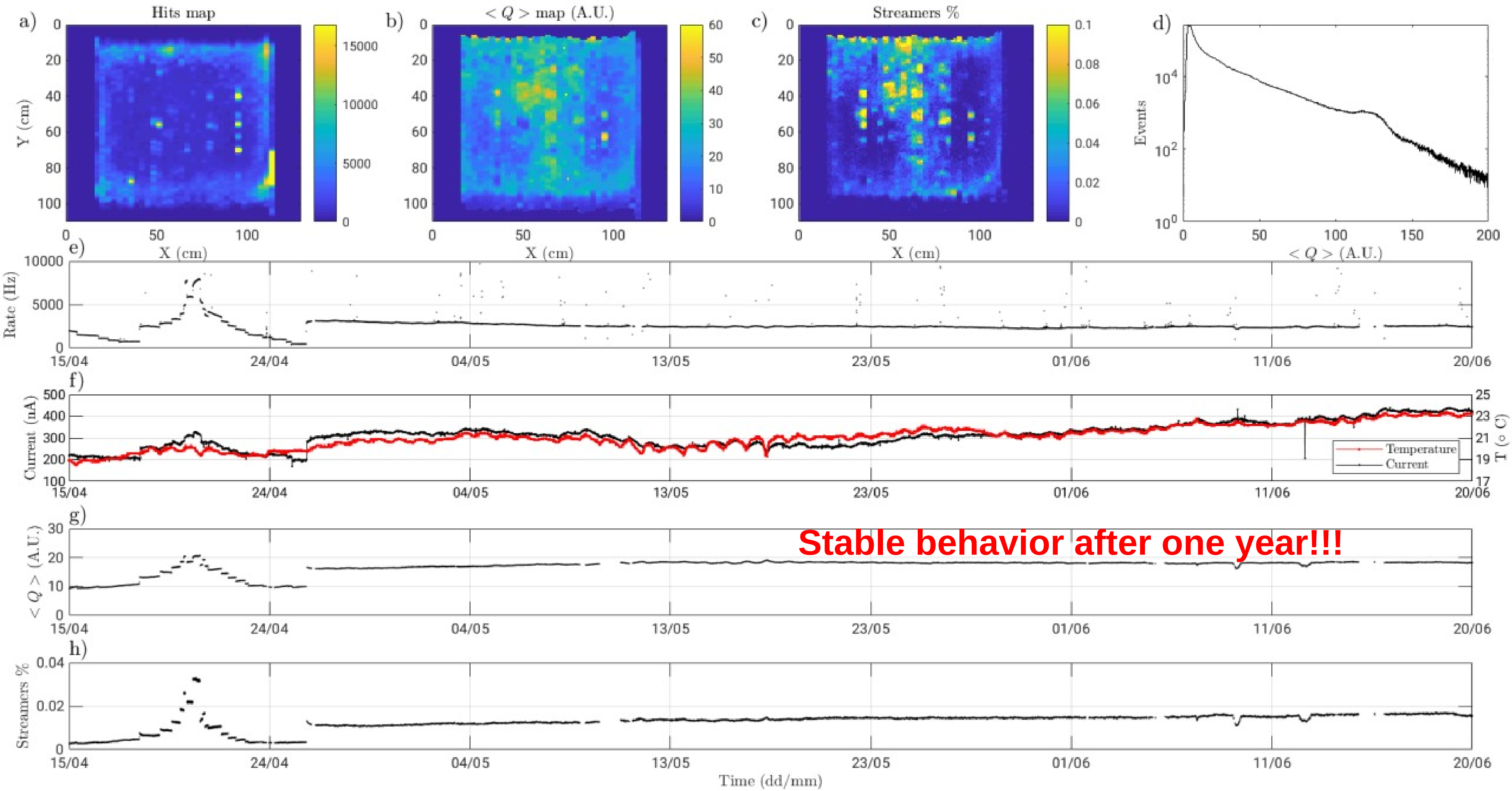
Acepted for publication
EPJP-D-23-02672

Performance similar to what could be expected from such a detector operated in a continuous gas flow, efficiency higher than 95 % and streamer percentage below 1 %



Sealed (no gas flux) RPCs

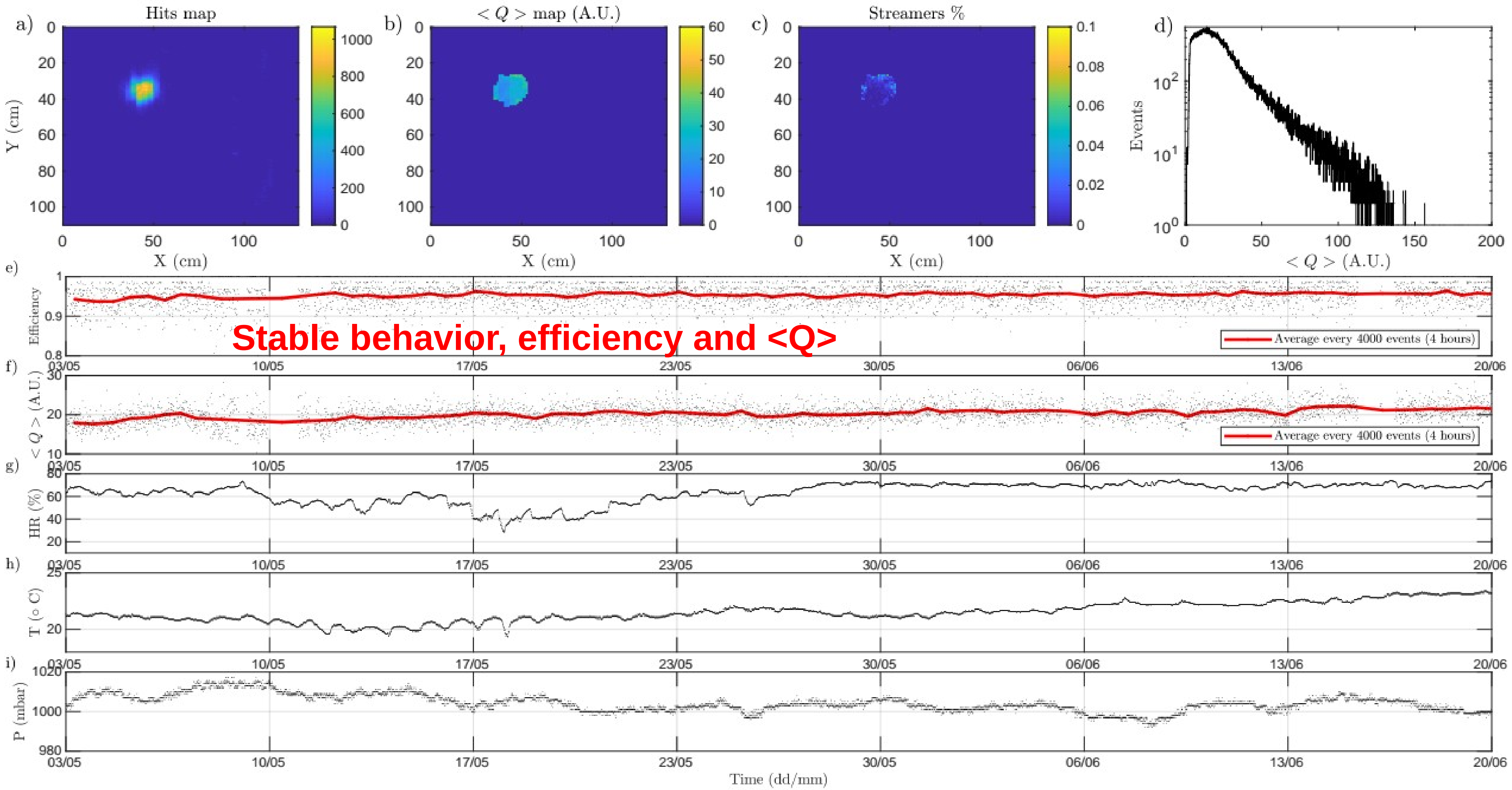
Acepted for publication
EPJP-D-23-02672



Self trigger operation

Sealed (no gas flux) RPCs

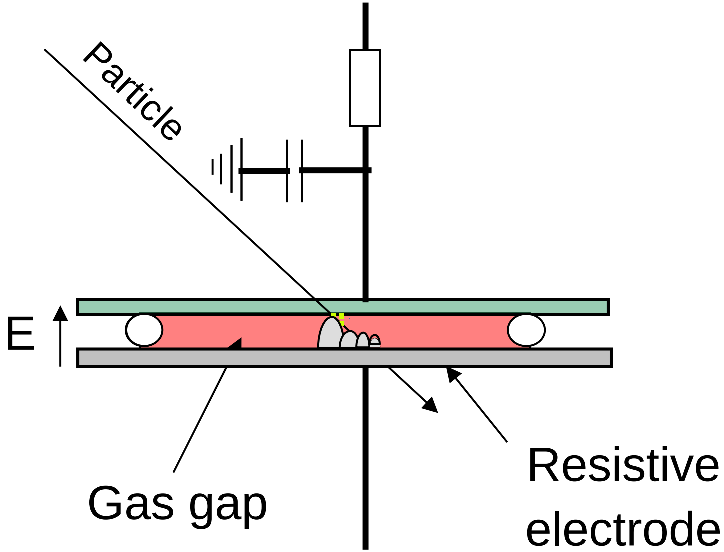
Acepted for publication
EPJP-D-23-02672



Operation with Cosmic muons (external scintillator trigger)

Increase the rate capability of tRPCs by increasing the operational temperature. HADES.

The **idea** to **decrease the resistivity** of the electrode **by increasing** the working **temperature** is **not new** => NIMA 555(1):72-79, 2005 and eventually others



$$\phi_{max} \leq \frac{\Delta V}{\rho d \bar{q}}$$

Φ_{max} = maximum particulate flux
ΔV = allowable voltage drop at the resistive electrode, which do not compromise performance.
ρ = electrode resistivity
d = electrode thickness
q = average charge per avalanche

Φ_{max} can be increased by decreasing ρ
ρ can be decreased by increasing temperature

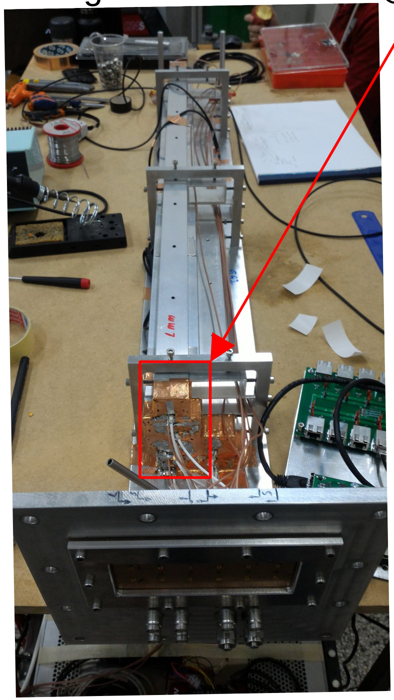
factor 10 every 25 ºC at least in glass

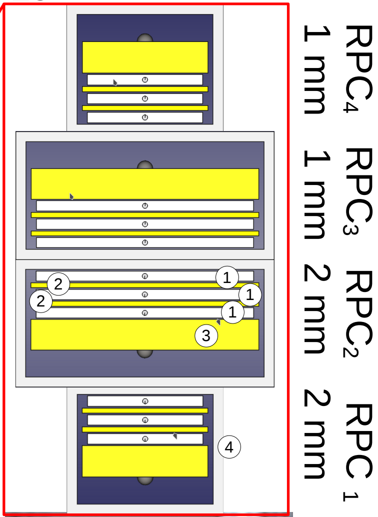
Increase the rate capability of tRPCs by increasing the operational temperature. HADES.

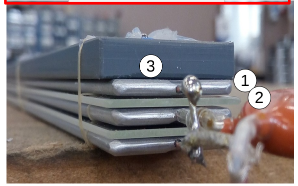
Test beam

4x **individually shielded RPC cells** (**750 mm long**) with **4 x 0.28 µm gap** width. Two **widths (22 and 44 mm)** and two **glass (1 and 2 mm)** thickness and resistivities

1 mm glass ~4.10^{12} Ωcm
2 mm glass ~1.10^{13} Ωcm @ 25º





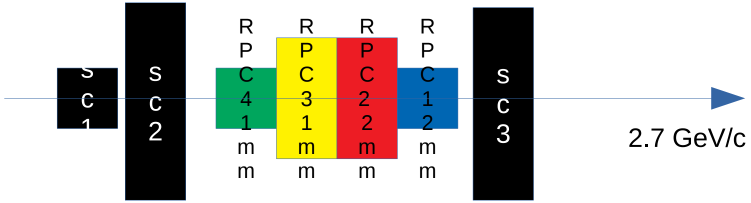


1 aluminum electrodes
2 glass electrodes
3 plastic support bar
4 aluminum tube.

RPC + heating system for count rate improvement

Reference scintillators

Beam line order (transverse view)

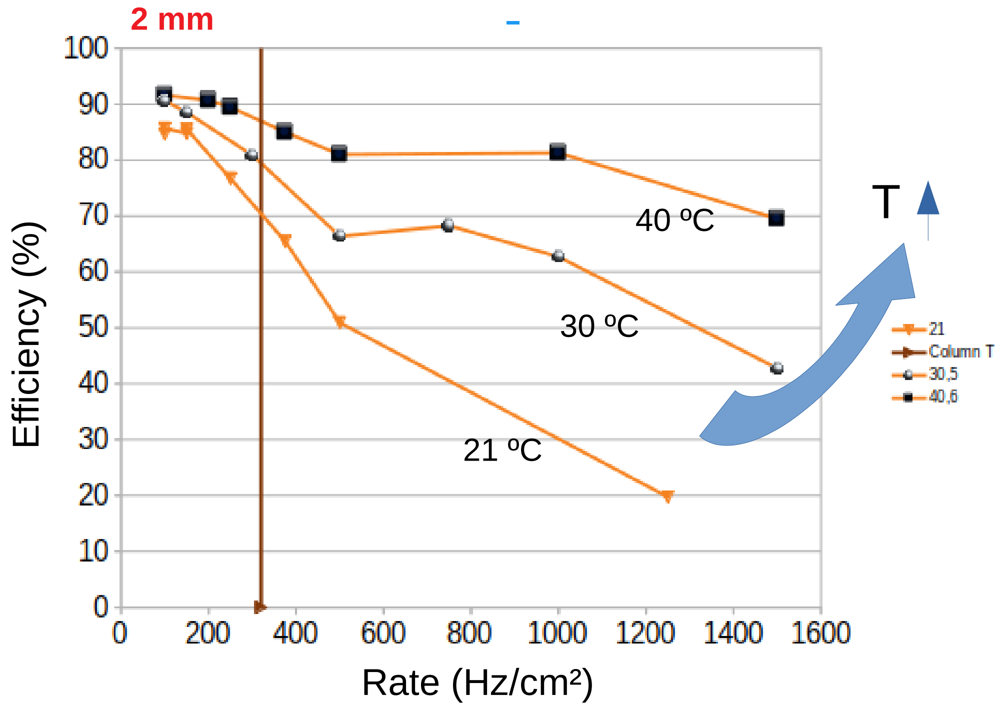


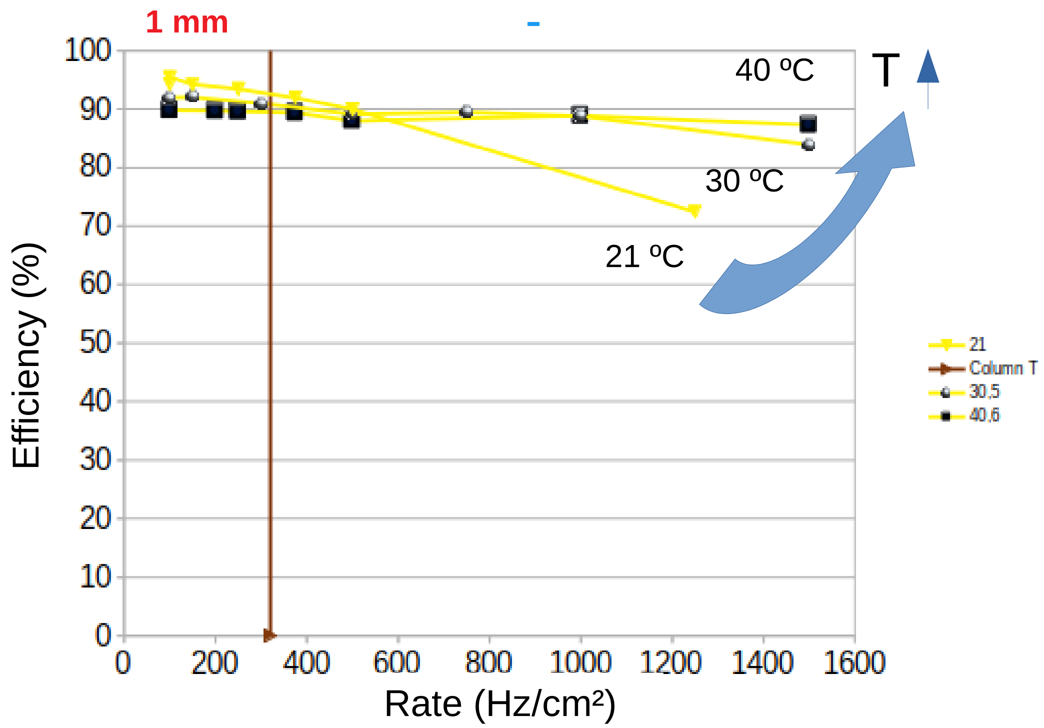
Increase the rate capability of tRPCs by increasing the operational temperature. HADES.

Test beam results

A. Blanco et al 2023 NIMA 1045, 167652
doi.org/10.1016/j.nima.2022.167652

- Increase of **working temperature extent the count rate capability.**
- 1 mm glass, **efficiency above 90 % under 1000 Hz/cm² at 30, 40 ºC.**
- 2 mm glass, **huge recovery but not totally.**



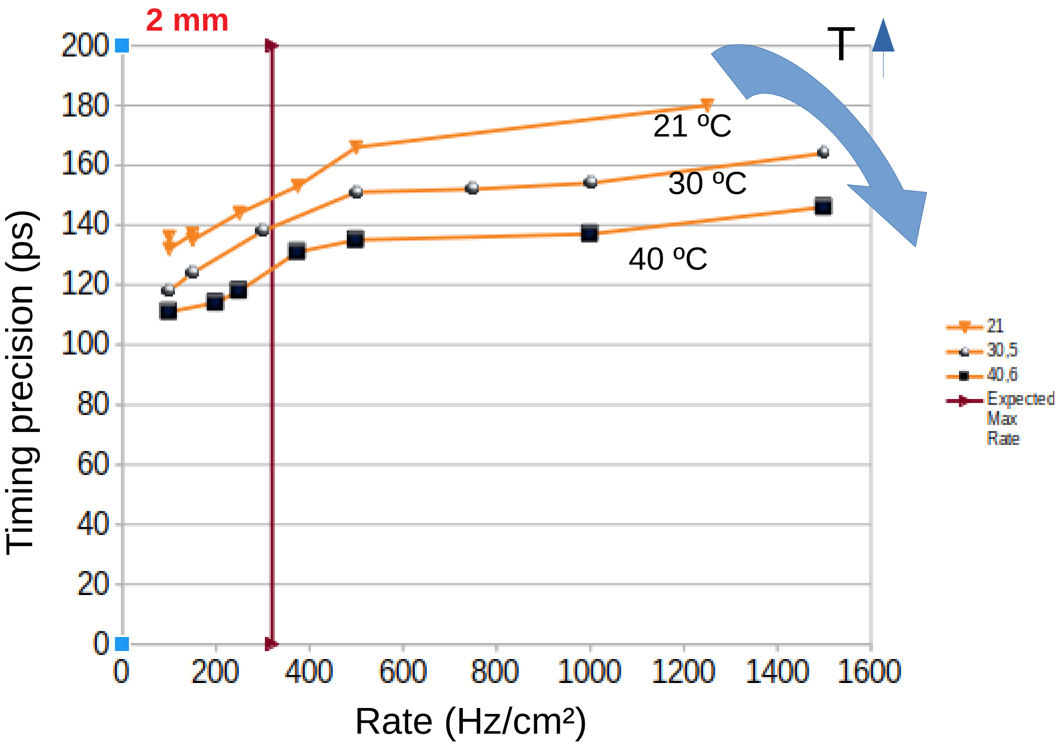


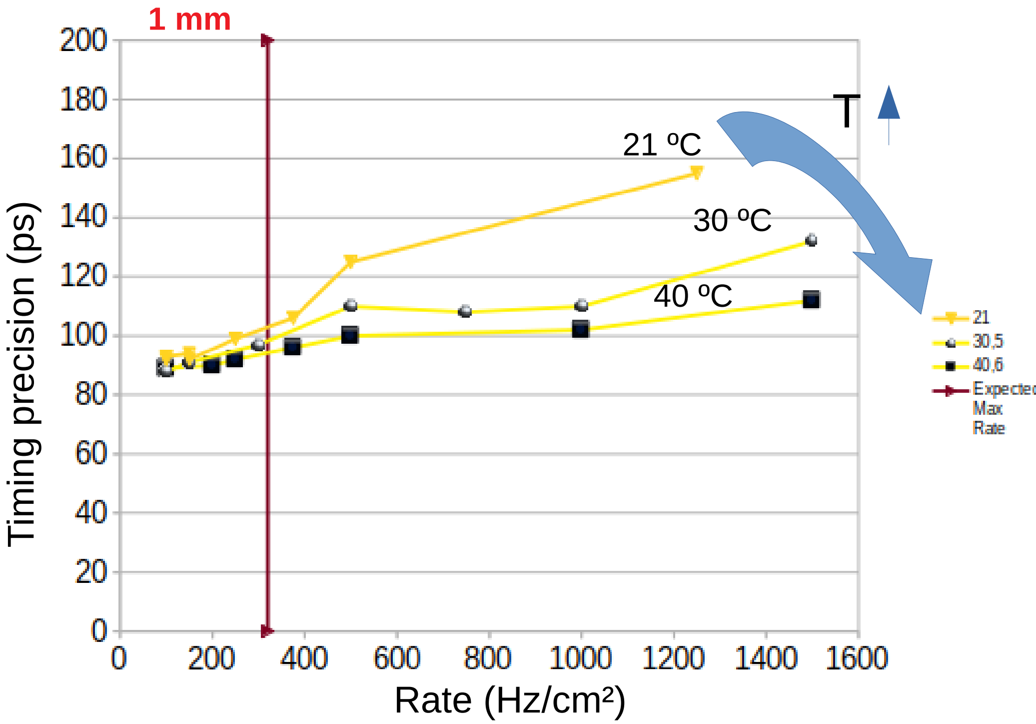
Increase the rate capability of tRPCs by increasing the operational temperature. HADES.

Test beam results

A. Blanco et al 2023 NIMA 1045, 167652
doi.org/10.1016/j.nima.2022.167652

- Increase of **working temperature extent the count rate capability.**
  - 1 mm glass, **timing precision ~ 100 ps under 1000 Hz/cm².**





Increase the rate capability of tRPCs by increasing the operational temperature. HADES.

HADES upgrade to increase the forward region acceptance and measure the **electromagnetic decays of the hyperon resonances** Σ(1385), Λ(1405) and Λ(1520) as well as the production of **double strange baryon systems** Ξ− and ΛΛ in p + p reactions at a beam kinetic energy of 4.5 GeV.

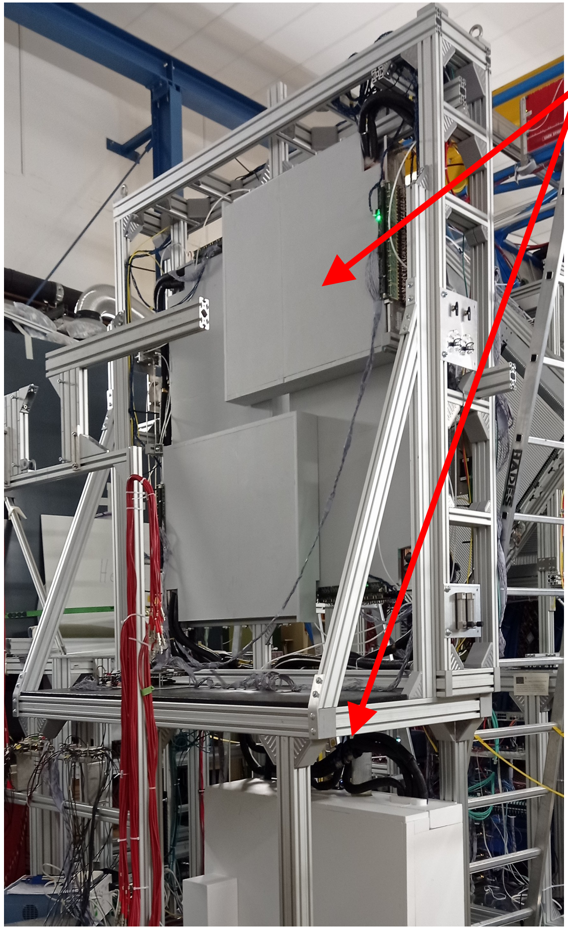
doi.org/10.1140/epja/s10050-021-00388-w
doi.org/10.5506/APhysPolB.51.239

Heating distribution copper pipes

64 I²C temperature sensors

REAR

Heating element + pumps

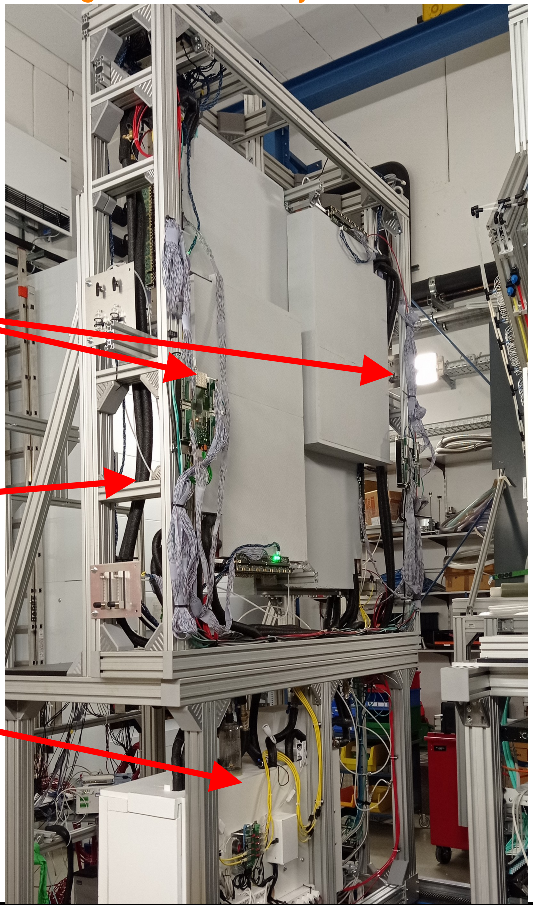


XPS insulation

TRBs

Water pipes

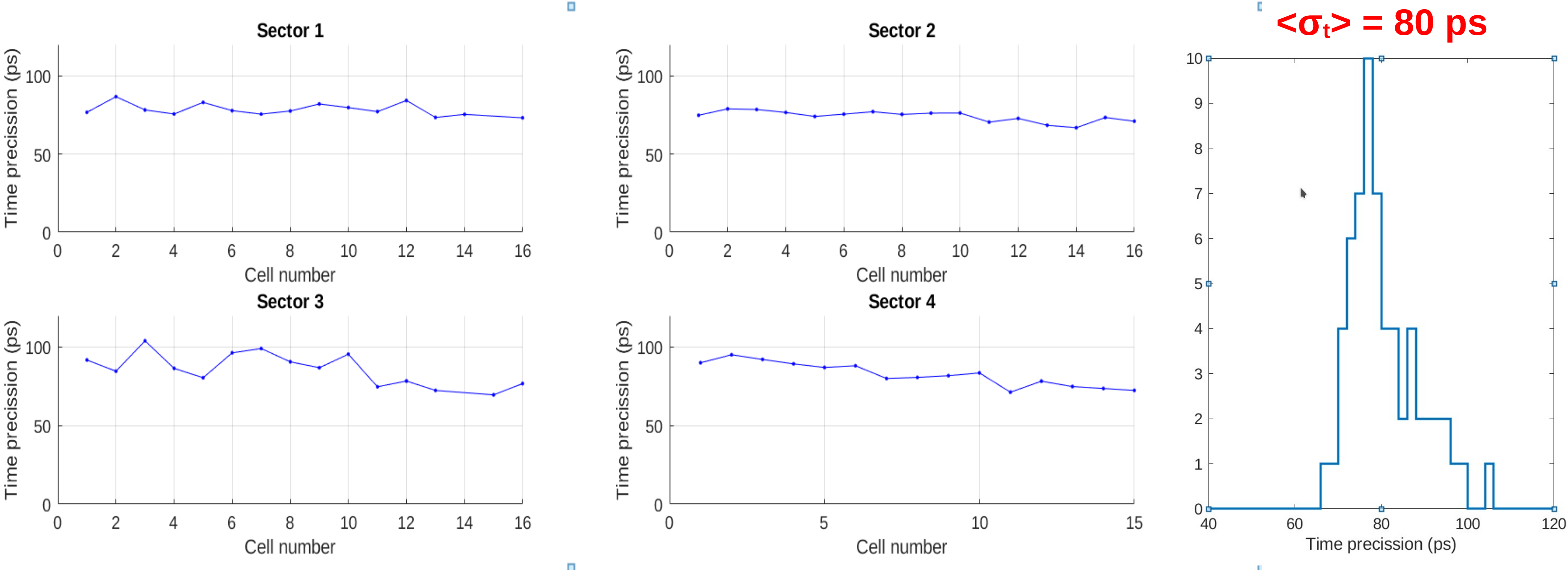
PID control + I²C distribution



FRONT

Increase the rate capability of tRPCs by increasing the operational temperature. HADES.

A. Blanco et al 2023 NIM, 1050, 168182
doi.org/10.1016/j.nima.2023.168182



An alternative way to increase the count rate capability of an standard RPC

Conclusions

Many possibilities for tRPC from HEP, Nuclear Physics, and applications: Tomography and Medical Physics.

Excellent timing < 100 ps and position resolution (sub-millimeter) over large areas (at low cost).