MAX-PLANCK-INSTITUT
FÜR PHYSIK

# NEW DEVELOPMENTS IN TIMING RPCS

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15$^{th}$ Terascale Detector Workhop
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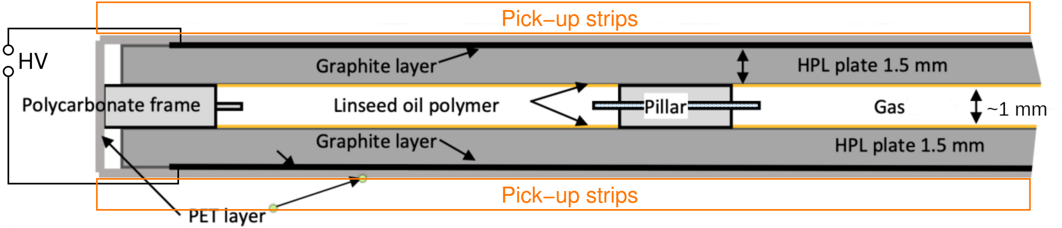
# Resistive Plate Chamber concept

RPC as proposed by Cardarelli and Santonico in 1981 (NIM 187 (1981)377-380)




- Parallel plate geometry with resistive electrodes to prevent shorts between the electrodes at high gas gains.
- Smooth inner surface of the electrode required to prevent point discharges.
- Fast response $\sim$ns and excellent time resolution $\ll$ 1 ns.
- High-rate capability defined by the resisitivity of the electrodes.
- Spatial resolution defined by the granularity of the pick-up strips.
- Ideal for the cost-effective instrumentation of large area where decent spatial and excellent temporal resolution is required.

# Current German involvement in the RPC development

## Institutes with RPC developments

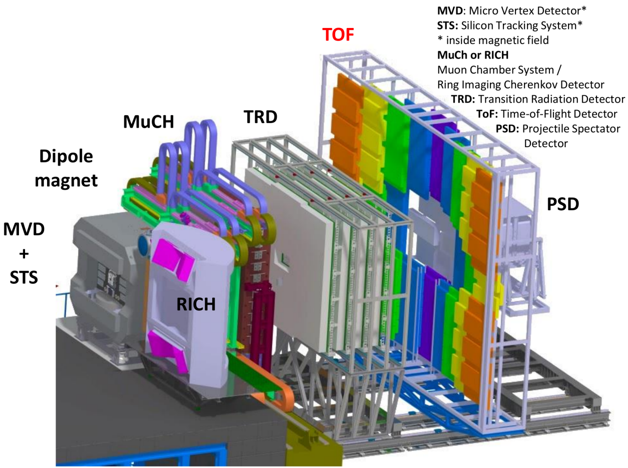
- Helmholtz-Zentrum Dresden-Rossendorf
- University of Heidelberg
- Max-Planck Institute for Physics Munich

## German involvement in RPC R&D

- TOF systems for experiments at FAIR (Dresden, Heidelberg).
- Thin-gap RPCs for the ATLAS phase-I and phase-II muon spectrometer upgrades (MPI Munich).
- Topics followed by all three institutes:
  - Search for alternative gas mixtures.
  - Search for alternative electrode materials.
  - Aging studies.

# Time-of-Flight system for CBM

**Compressed Baryonic Matter (CBM) Experiment**



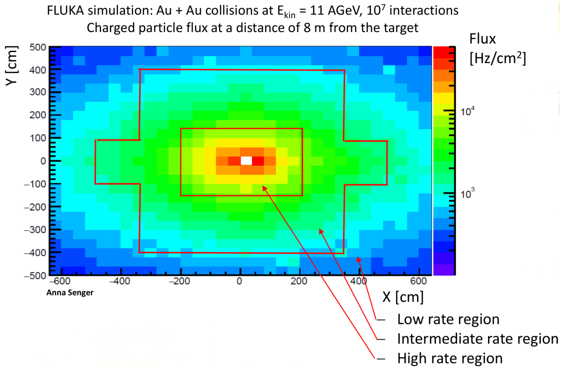

## CBM-TOF requirements

- Time resolution $\sim$80 ps.
- Efficiency $>$ 95%.
- Rate capability $\leq$ 50 kHz/cm$^2$.
- Active area of 120 m$^2$.

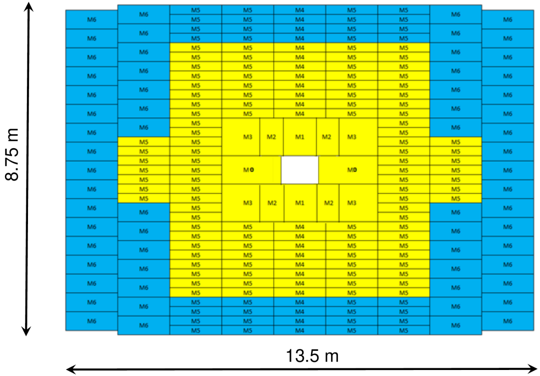
https://indico.cern.ch/event/1123140/contributions/5010232/attachments/2516082/4325787/deppner_RPC2022.pdf

# Charged particle fluxes in CBM-TOF

## Particle flux

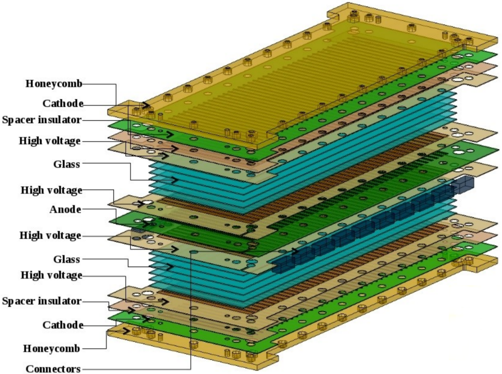



## Structure of the TOF

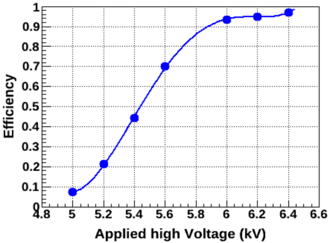


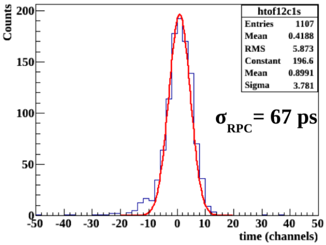

- In order to cope with the high particle fluxes in the central yellow region electrodes of low resistivity glass, $\rho \approx 10^{10}\ \Omega\,\text{cm}$ are used.
- Counters with higher-resistivity thin float glass, $\rho = 10^{12}\ \Omega\,\text{cm}$ are used.

# Multigap RPC prototype for CBM-TOF



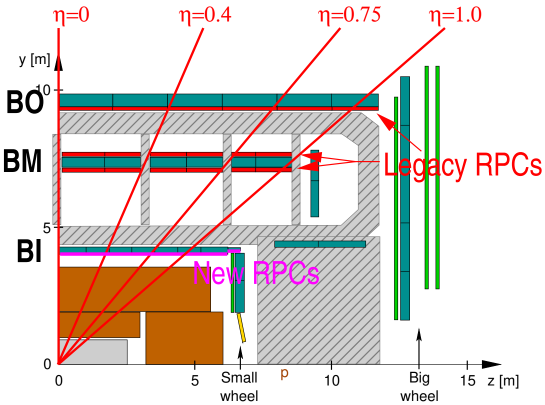

- Symmetric structure: 5 gaps$\times$2 stacks.
- Gas gap thickness: 200 $\mu$m.
- Active area 60/100/200 mm$\times$300 mm.
- Electrode: $\rho = 10^{10}\ \Omega$ cm. 0.7 mm thick glass.
- Gas mixture: $C_2H_2F_4$:$SF_6$(97.5:2.5).

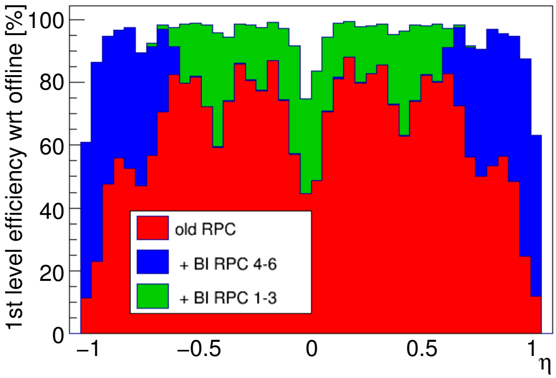



- Required efficiency and time resolution was achieved.
- Aging caused by F ion deposition on the electrodes.
- Strategy to solve this problem: improve/increase gas flow.

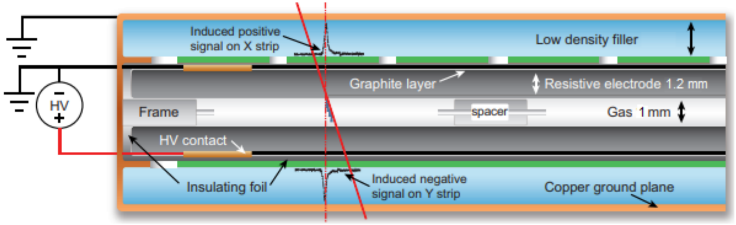
# Upgrade of the ATLAS muon spectrometer




Installation of additional RPCs with increased high-rate capability in the inner barrel layer to recuperate muon trigger efficiency.

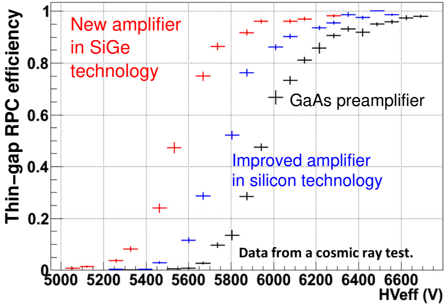
# ATLAS thin-gap RPC



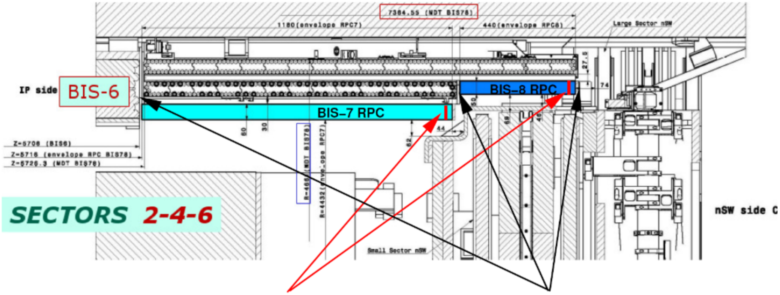

- Electrode material: phenolic high-pressure laminate ($\rho = 10^{10}\ \Omega$cm).
- Gas mixture: $C_2H_2F_4$/iso-$C_4H_{10}$/$SF_6$ (94.7/5/0.3)

| Detector parameter | Legacy RPC | New thin-gap RPC |
|---|---|---|
| Gas gap width | 2 mm | 1 mm |
| Electrode thickness | 1.8 mm | 1.4 mm |
| FE technology | GaAs | Si&Si-Ge |
| FE effective threshold | 2-3 mV | 0.2-0.3 mV |
| FE power consumption | 30 mW/ch | 12 mV/ch |

- Rate capability and longevity: up to 10 kHz/cm$^2$ for ten years of HL-LHC operations.



# CHALLENGES FOR THE BI RPC UPGRADE




**Limited space in radial direction** **Limited space for RPC support structure in z direction**

## Challenging requirement

- Very compact mechanical structure needed to fit into the limited available space.
- Very rigid mechanical structure required in order to avoid conflicts with the sMDT chamber.
- RPC gaps must be produced within tight mechanical tolerances.

## Phase-I pilot project “BIS78”

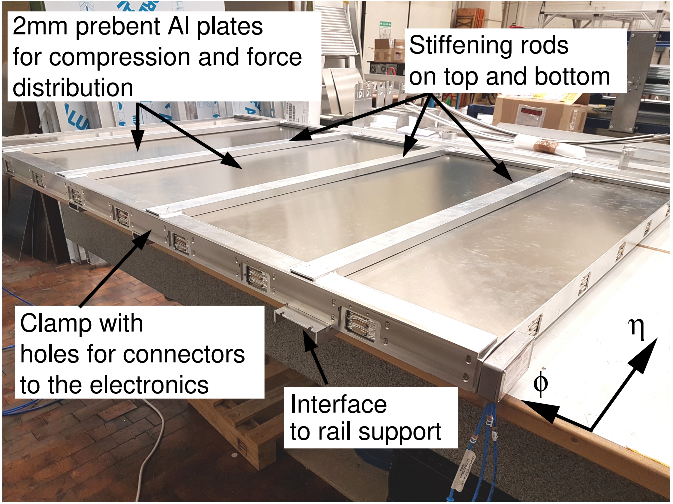
Installation of thin-gap RPCs in the barrel end-cap transition region.

# Mechanical structure for BIS-78 RPC triplets

- Rigidity of present RPCs achieved by 5 cm thick honeycomb plates.

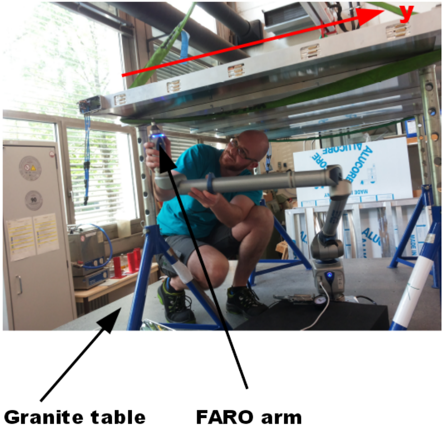
$\Rightarrow$ Impossible within 6 cm envelope of BIS-78.

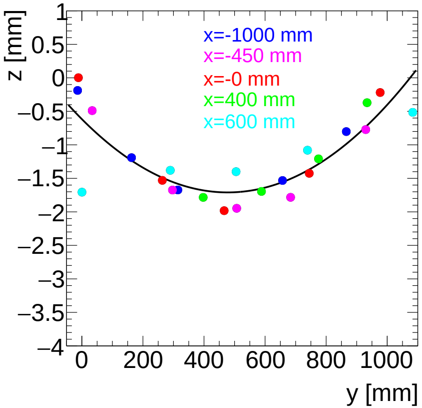
### Solution for BIS-78



# Measurement of the rigidity of the BIS-7 mechanics

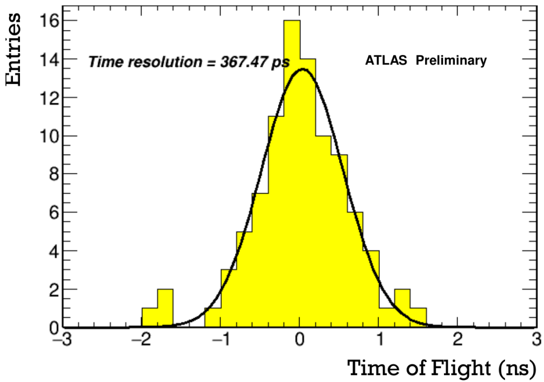
Measurement of the height of the bottom of the mechanical structure under the load of an RPC triplet

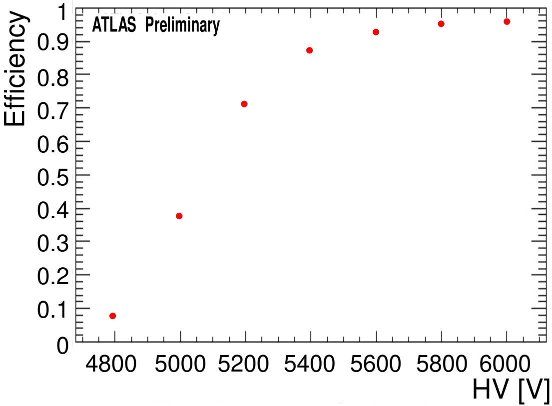



Sag of the stiffening rods <2 mm.

# Performance of theinstalled BIS78 thin-gap RPCs



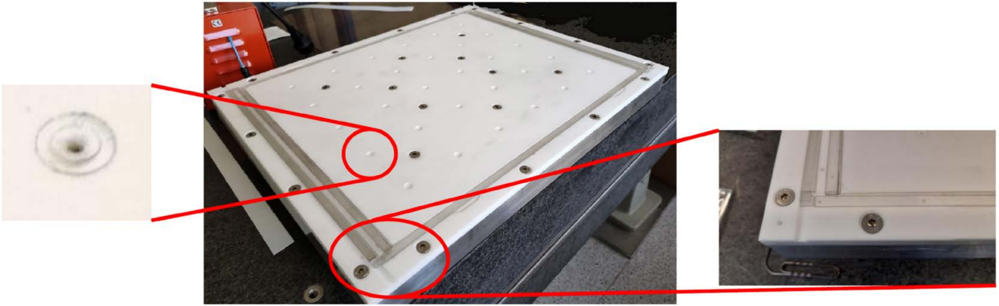



# Establishing a new thin-gap RPC manufacturer

- Huge demand for thin-gap RPCs in the future (ATLAS upgrade, ANUBIS, ecc.)
- Need for a production fulfilling the tight mechanical requirements on the gas gaps.
- Supported by the Tor Vergata RPC group, the ATLAS group at the MPI for Physics has therefore started to establish two additional manufacturers: PTS Maschinenbau, Mirion Technologies:
  - 2021: Adaption of the gas gap production procedure to industrial standards.
  - 2022: Production of small-size $40 \times 50$ cm$^2$ test sample RPCs at the two companies.
  - Spring 2023: Production of 18 full-size ATLAS RPC gaps at the two companies.
  - May 2023-April 2024: Aging test of the 18 RPC gaps for certification of the production.

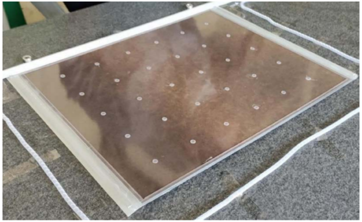
# A FEW PHOTOS FROM THE TEST SAMPLE PRODUCTION

## Gluing template



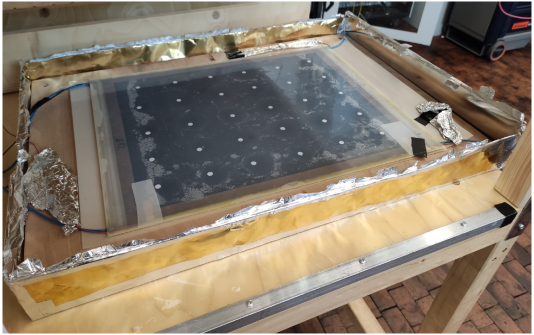
## Electrode in the template

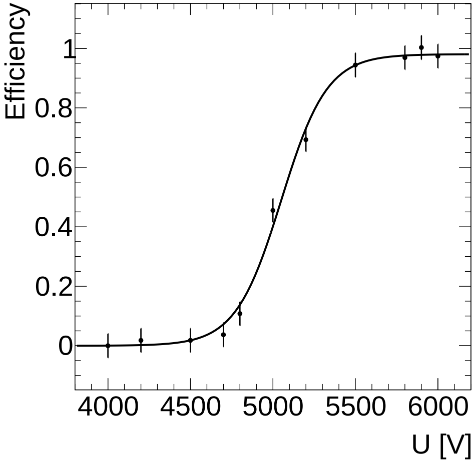
## Electrode after first gluing step



# A few photos from the test sample production

## Functional tests of the test sample RPCs





# Search for eco-gas mixtures

**Standard gas mixture:** $C_2H_2F_4/i-C_4H_{10}/SF_6$.

- High gas density ensuring sufficient primary ionization even for gas gaps in the millimeter range size.
- Prompt charge slowly increasing with the applied voltage and high enough to overcome the FE threshold.
- Total delivered charge low enough to ensure modest working current and good rate capability.
- Large separation of avalanche and streamer mode.
- Non-flammable.

**Disadvantages of the standard gas mixture**

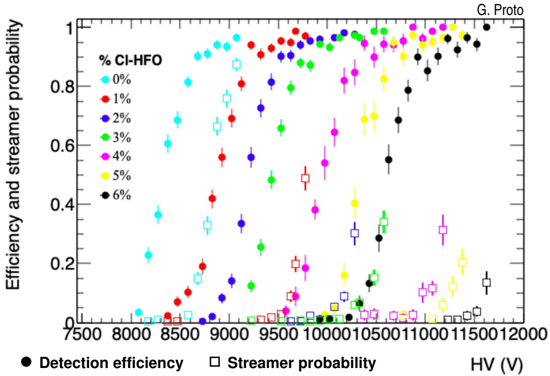
- High global warming potential (GWP): 1450.
- Use of $C_2H_2F_4$ forbidden by the EU since 2011. $\Rightarrow$ Future availability of $C_2H_2F_4$ unclear.

# Strategy for new eco-gas mixtures

- Reduction of the GWP to 200 by replacing the tetrafluorethane by $CO_2/C_3H_2F_4$.
- Further reduction of the GWP to $\sim$10 by replacing $SF_6$ by chlortrifluorpropene $C_3H_2ClF_3$.
- The candidate eco-gas mixture $CO_2/C_3H_2F_4 + i - C_3H_{10} + C_3H_2ClF_3$ must have similar physical properties like the standard gas in terms of
  - Detection efficiency.
  - Avalanche and streamer mode separation.
  - Total charge delivered inside the gas.
  - Time resolution.
- The new mixture must be possible to operate the legacy RPCs which are installed in ATLAS and CMS.

# Selection of the mixing ratio of the new components

Performance of a legacy RPC



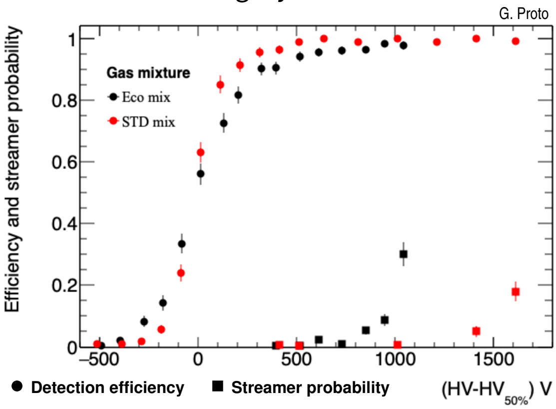

- Efficiecny turn-on moves to large operating voltages with increasing $C_3H_2ClF_3$ fraction.
- No separation of avalanche and streamer mode without $C_3H_2ClF_3$.
- Separation between avalanche and streamer mode $\sim$ 400! V for all gas mixtures containing $C_3H_2ClF_3$.

Candidate gas mixture (with the lowest ionic charge):

$$CO_2/C_3H_2F_4 + i - C_3H_{10} + C_3H_2ClF_3\ (76/15/7/2)$$

# Comparison of the new and the standard gas mixture

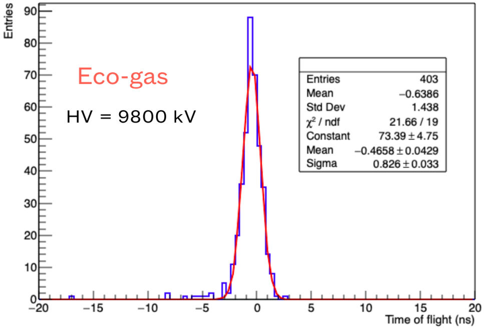
Performance of a legacy RPC

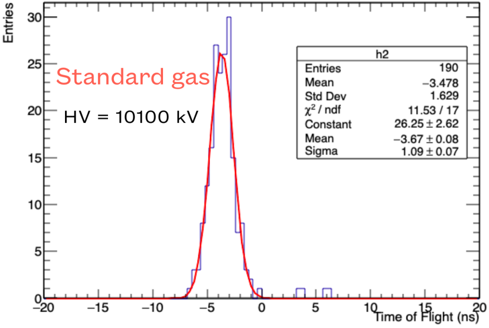



- Similar operating voltages of the new and standard mixtures.
- Steeper efficiency turn-on for the standard mixture.
- Singificantly larger avalanche-streamer separation of the standard gas than of the new gas.
- Avalanche-streamer separation of the new gas still acceptable.

# Time resolution with the new gas mixture

Legacy RPC



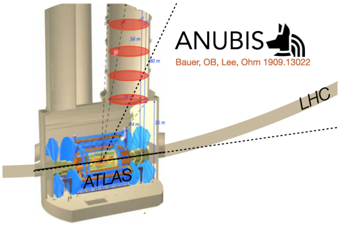

https://indico.cern.ch/event/1123140/contributions/5000800/attachments/2517497/4328395/RPC_2022_3.pdf

- $\sigma_t^{ECO} = (0.83 \pm 0.03)$ ns$<$ $\sigma_t^{standard} = (1.09 \pm 0.07)$ ns!
- Final qualification of the new mixture requires a successful aging test which is ongoing in the GIF++ at CERN.

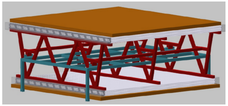
# RPCs AT FUTURE EXPERIMENTS

RPCs are considered for several future experiments like:

- Search for long-lived particles with ANUBIS.
  - $\sim$1200 RPC gas gaps needed per access shaft.
  - Industrialization of the gas gap production crucial for a timely production of all the required gaps (eventually split over different countries).




- Myon system of the CLD detector can use current thin-gap RPC technology, will have to operate with an eco-friendly gas mixture.
- The Fe-DHCAL option for the CALICE digital hadron calorimeter with RPCs will need low-resistivity electrodes and an eco-friendly gas mixture offering the required high-rate capability and longevity.
- Stations of thin-gap RPCs and sMDT chambers used in the muon system of the baseline FCC-hh detector. Thin-gap RPCs with sufficient longevity for $\gamma$ background rates of up to 30 kHz/cm$^2$ needed.



# Summary

- RPCs are ideal for the instrumentation of large areas where decent spatial resolution ($\sim$mm) and excellent time resolution ($\sim$10-100 ps) are required.
- The limitation of the high-rate capability of glass RPCs can be overcome by the availability of affordable low-resistivity glasses.
- The new thin-gap RPCs with phenolic HPL electrodes are suitable for 10 years of HL-LHC operation at a $\gamma$ background hit rate of up to 10 kHz/cm$^2$.
- The certification of two new manufacturers of thin-gap RPCs is ongoing and will provide the required production capacities for thin-gap RPCs for future experiments.
- There is a lot of progress in the search for eco-friendly RPC gas mixtures with aging tests ongoing.