New MPGD-based muon telescopes for ScanPyramids and gas R&D

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• Starting point
• New telescopes
• Gas R&D
• Maintenance & data taking
• Perspectives
Development of telescopes for HD muon imaging

Genetic multiplexing on MM   Resistive strips, reverse grounding   2D readout

$$\Rightarrow \sigma \cong \frac{p'}{40}$$  $$\Rightarrow \text{large & stable gain}$$  $$\Rightarrow \text{less detectors}$$

Miniaturized equipment

$$\Rightarrow \text{low consumption}$$
STARTING POINT (1/2)
Development of telescopes for HD muon imaging

Genetic multiplexing on MM
Resistive strips, reverse grounding

⇒ $σ \approx \frac{p'}{40}$
⇒ large & stable gain
⇒ less detectors

Miniaturized equipment

⇒ low consumption
Discovery of the ScanPyramids Big Void in 2017

Nagoya  KEK  CEA

⇒ Best place to study it in more details is the Grand Gallery…
NEW MISSION – NEW TELESCOPES

Bigger telescopes, to be competitive with other teams (Nagoya)

• Surface doubled (1/2 m²): 4 → 8 detectors
• 2 telescopes → 16 detectors

Have to be compatible with operation in Grand Gallery

• Gas? (high pressure bottle, evacuation, autonomy)
• Small corridors…
• Tourists…
• Network / remote access…

⇒ Gas R&D to reduce consumption
… btw, why do we flush MPGDs with gas?

• A priori combination of leakage & outgasing
• Measured leak < 1 mL/h for most of the detectors

Effects easy to observe: just reduce the gas flow 😊

T2K gas: Ar-iC₄H₁₀-CF₄ (95-2-3)

Flowmeter OUT

IN: 0.4 L/h

Flowmeter IN

NB: HV automatically adjusted to keep constant gain

⇒ Large HV gradient between detectors

⇒ Accompanied by signal degradation & efficiency loss

• If flow is stopped: ~+1V/h to maintain the same gain

→ Problem: small injection rate = small circulation rate…
Can we reduce injection and keep circulation rate high (at small cost & low consumption)?

- make use of a turbine developed for HARPO (D. Attié & P. Magnier)
- Introduce a *semi-sealed* setup

**NB: HV automatically adjusted to keep constant gain**

⇒ Better homogeneity and efficiency by « mixing the shit »

⇒ Similar HV for all, but quite high

→ By how much is the circulation rate increased?

T2K gas: Ar-iC₄H₁₀-CF₄ (95-2-3)
Not easy to measure the flow without a flowmeter…

- Solution to measure the pressure drop in a circuit, via the Darcy-Weisbach equation:

\[ \Delta P = f \frac{L \rho v^2}{D} \]

\[ \Rightarrow \]

\[ \Delta P = \frac{8}{\pi^2} f \frac{L}{D^5} \rho F^2 \]

- Typical Reynolds number below ~ 10 F [L/h]

\[ \frac{8}{\pi^2} f = \frac{64}{Re} \]

\[ \Rightarrow \]

\[ \Delta P = \frac{128 \mu L F}{\pi D^4} \]

⇒ Measuring \( \Delta P \) in a given setup with the turbine gives the corresponding flow:

\[ \begin{array}{cccccccccc}
 F & [L/h] & 0.1 & 0.2 & 0.3 & 0.5 & 1.0 & 2.0 & 3.0 & 4.0 & 5.0 \\
 \Delta P_{\text{calc}} & [\text{mbar}] & 0.10 & 0.19 & 0.29 & 0.48 & 0.96 & 1.92 & 2.88 & 3.84 & 4.80 \\
 \Delta P_{\text{mes}} & [\text{mbar}] & 0.09 & 0.20 & 0.32 & 0.50 & 0.93 & 1.94 & 2.91 & 3.88 & 5.01 \\
\end{array} \]
Effect of Humidity (1/2)

Measured with T,P,H probes (Yocto-Meteo) used since 2016 in ScanPyramids

- Relative humidity around 10-40% routinely measured in telescopes

  ![Image of humidity probe](image)

  yields less than 1% of H$_2$O in volume (only)

  Ex: 4.5 g/m$^3$ of water yields 0.6% of H$_2$O in the gas

- Humidity goes essentially with 1/F (gas injection flow)

  \[ \Rightarrow \text{Good candidate to explain gain drop and HV gradient} \]
Tests with H2O absorbers

- As before, HV adjust automatically to keep constant gain (see pressure effect!)

![Graphs showing the effect of humidity on different detectors and related parameters over time.](image_url)
Tests with H2O absorbers

- As before, HV adjust automatically to keep constant gain (see pressure effect!)

⇒ Reduces humidity by a factor 4 in a few hours

⇒ HV drop by 18V!

⇒ Much better gas quality

• What about Oxygen?
Effect of Oxygen (1/2)

Measured with Yocto-serial coupled with Luminox sensor (SST sensing)

- Price: 120 euros for Yocto+Luminox

- Tests of the sensitivity:

  ⇒ (relative) accuracy of 100 ppm, but can reach better than 10 ppm by time integration
Test with O2 absorbers

- As before, HV adjust automatically to keep constant gain (see pressure effect!)

⇒ Typical O$_2$ around 1%
(largely depends on leak rate)
Test with O2 absorbers

- As before, HV adjust automatically to keep constant gain (see pressure effect!)

⇒ Another ~18V drop by Oxygen absorption!
Test with O2 absorbers

- As before, HV adjust automatically to keep constant gain (see pressure effect!)

⇒ Another ~18V drop by Oxygen absorption!
⇒ HV correlate maximally with $O_2$ concentration
Effect of Gas Pipes

Pure argon flushed in 1 m pipes during 1 hour (80 volume flushes)

All pipes equivalent?
Effect of Gas Pipes

Pure argon flushed in 1 m pipes during 1 hour (80 volume flushes)

\[ \text{O}_2 \text{ (ppm)} \]

<table>
<thead>
<tr>
<th>pipe</th>
<th>PA (nylon,1)</th>
<th>PTFE (teflon)</th>
<th>PUN (1)</th>
<th>PA (nylon,2)</th>
<th>PUN (2)</th>
<th>Aluminum</th>
</tr>
</thead>
</table>

\[ \text{H}_2\text{O} \text{ (g/m}^3) \]

⇒ Definitely not!
TELESCOPES IN THE PYRAMID

All gas improvements implemented

- Better gas tightness
- Semi-sealed mode
- Change of gas pipes & elements

⇒ *1 L/h for 4 detectors (15L) in 2016, 0.5 L/h for 16 detectors (50L) in 2019*

1st installation in July 2018

- Data taking from July ‘18 to January ‘19
- Some strange issues with detectors and probes…
Another mission in March ‘19 for maintenance and new bottle…
TELESCOPES IN THE PYRAMID

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DATA TAKING

Accumulated ~ 25 millions of reconstructed muons so far

Real muography (9 days)  simulation  Tan(\phi) direction for di-muon events
CONCLUSION & PERSPECTIVES

MPGDs validated in more and more difficult conditions

- Dust, storms, large temperature variations, humidity, mice

Successful gas R&D to lower gas consumption by a factor close to 10

- Be careful with gas pipes you use!
- Still a lot to understand (gas spectrometer to be purchased)
- T2K gas extremely sensitive to pollutants

More telescopes & detectors currently under test

- Plug & play, 1m² telescope (used on Gbar)
- See Hector’s poster on multiplexed TPC
THANK YOU!