



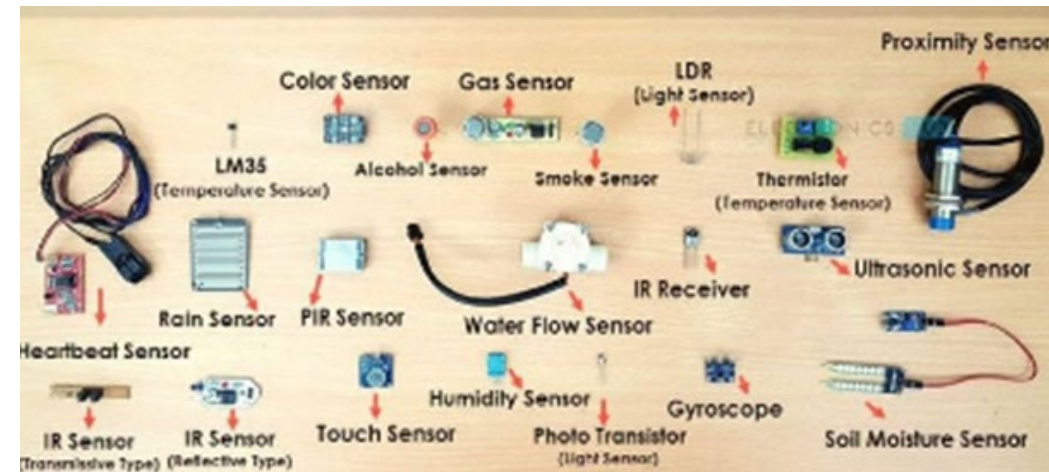
Borehole Muon Radiography of Subsurface Density Variations

COSMIC RAY SENSING

Tancredi Botto, CEO & Co-Founder

tbotto@muonvision.com

- ❑ The mining industry has a data problem
 - Overwhelmed with low-value, hard to integrate data
 - Mostly contact measurements
 - Unable to measure at scale (distance, tonnage)
 - Unable to make accurate predictions
 - Unable to optimally manage its assets



- ❑ Muon Vision mission: boost the efficiency, safety and sustainability of mineral processing



Tancredi Botto (PhD Physics)

CO-FOUNDER & CEO



(1st muon borehole sensor in 2011)



A. Casais (PhD)

Data reconstruction



C. Etcheverry

Mech. Eng.
CHILE



S. Kunwar (PhD)

Data science



T. Salvadores

El. Engineer
CHILE



M. Moussawi (PhD)

3D modelling



N. De Beer

Field Engineer
CHILE

Multiple muon radiography applications identified



COSMIC RAY SENSING

Recover

Optimize

Heap-Leaching

Measure 3D fluid content and porosity to increase productivity and reduce costs.



Mineral processing plants

Optimization & predictive maintenance of refineries, smelters and other critical equipment

Slope Stability

In-situ asset characterization and validation. Prevent catastrophic tailings failures.



Cavity Detection

Tunnel & cavity detection, underground block caving, mine exploration

Alert

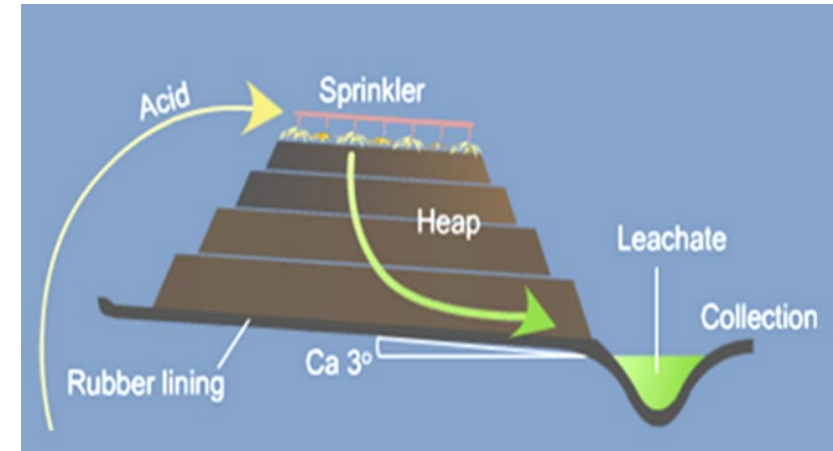
Detect

Muography: a Physical AI platform for high-value physical assets across the mining value chain

(exploration → processing → waste)

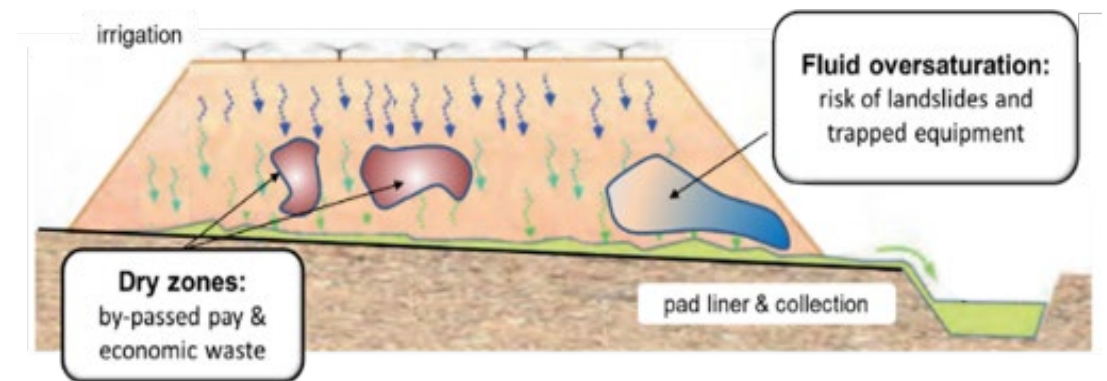
Mineral processing (hydrometallurgy)

- Lowest embedded GHG (no smelting required)
- >20% world Cu supply & growing
- Fastest to mkt supply
- Can be compared to agricultural practices



The fluid distribution inside leaching heaps is critical:

- Too little fluid → poor metal recovery (**up to 60% left behind**)
- Too much fluid → catastrophic landslides (**asset loss**)



Leaching heaps up close



- Static and on/off heaps. Mostly Cu & Au. Mostly in dry climates (Atacama, SW USA)
- May contain few 100's M-tonne of ore (with 0.2-0.4% Copper)

Leaching heaps up close



- Massive plumbing system to manage solution going in and out
- Highly corrosive environment (H_2SO_4 or NaCN)

Leaching heaps up close



- Poorly characterized



- Potentially very dangerous !

Muography is part of the solution



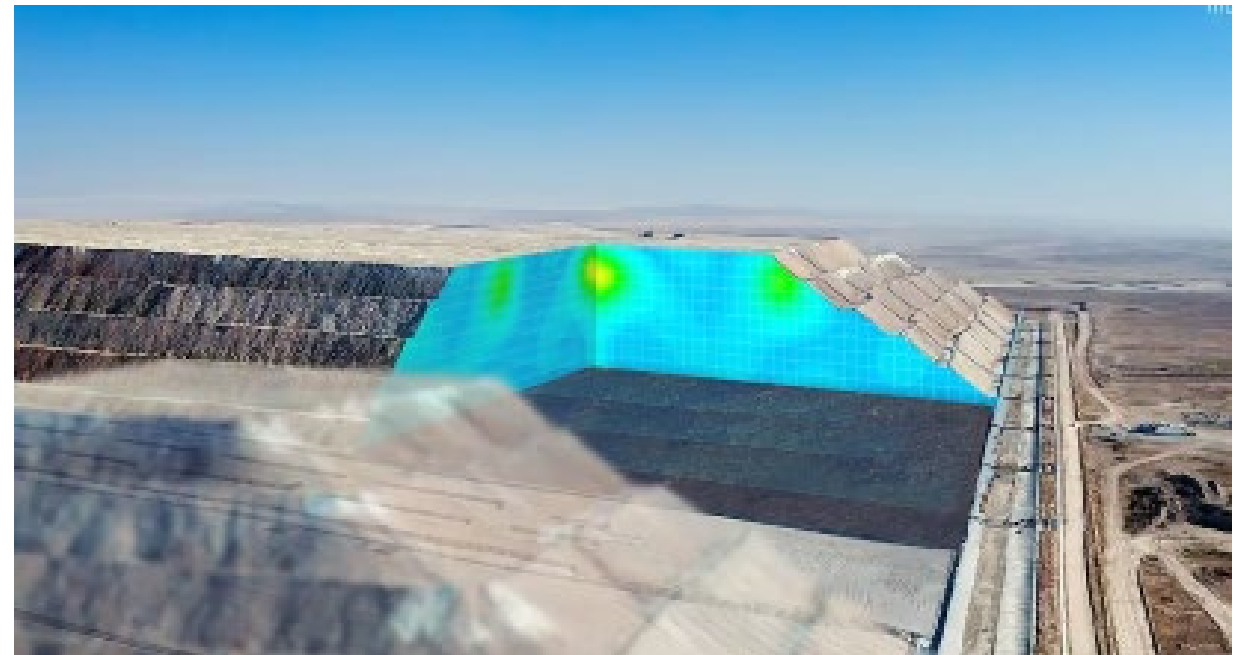
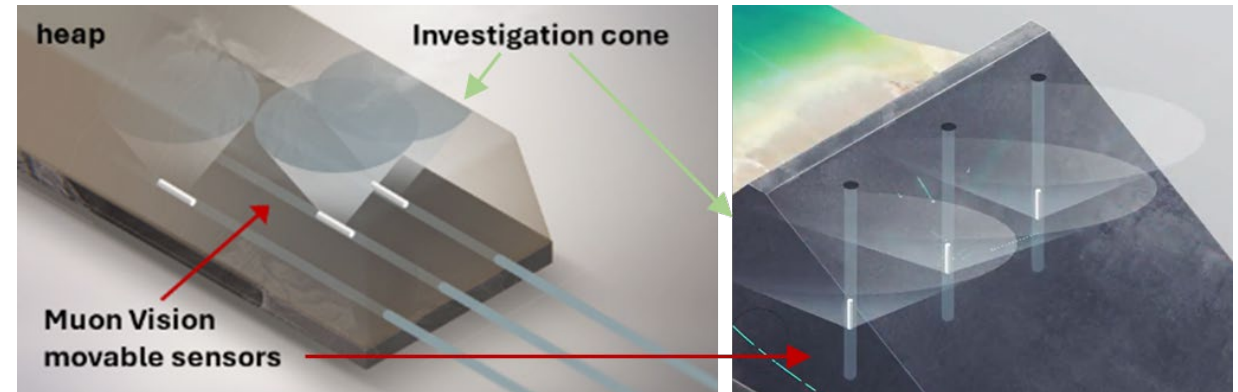
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Pain:

- *Unseeable pockets of overly dry material lead to lost production*
- *Unseeable pockets of overly wet material lead to slope failure*

Solution:

- Contrast Muography density scans can precisely map the actual fluid content distribution
- Quantitative & robust: the observed density change is immediately related to fluid content changes
- Can measure efficiently over large volumes
- Can be fully automated



- 1) Measured muon flux uniquely maps bulk density of the material

$$I(x) = I_0 \exp(-L \rho_b * \text{const})$$

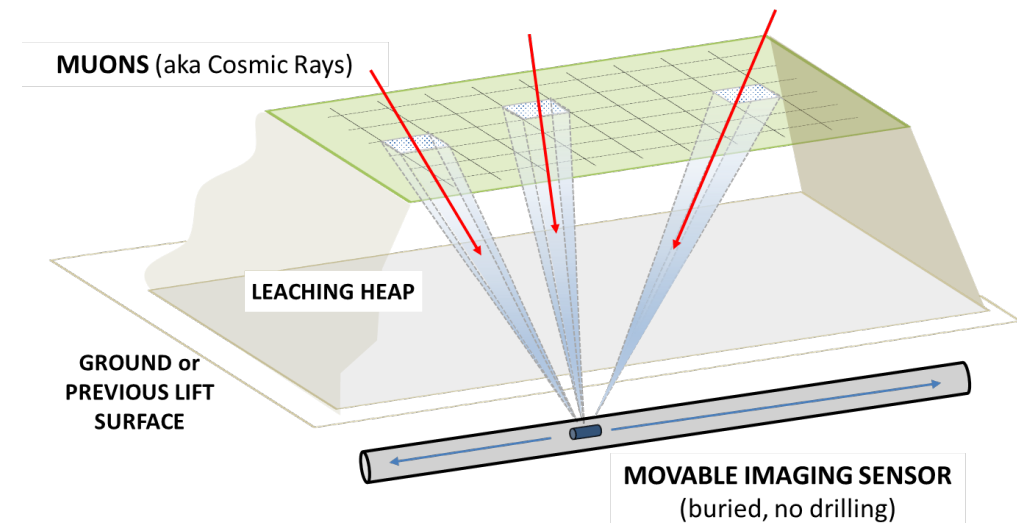
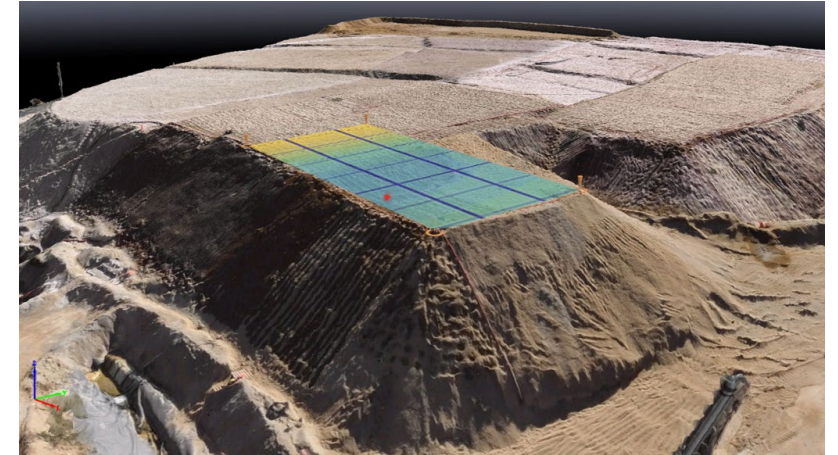
- 2) Dry density = porosity & uniformity of heap materials

$$\rho_{bulk} = \rho_{dry} = \rho_{matrix} * (1 - \Phi_0)$$

- 3) Density differences = access to fluid content /saturation

$$\rho_{bulk} = \rho_{dry} + \Phi_1 (S) \rho_{Fluid}$$

- ❑ Compaction can be measured via drone scans. Needed to apply a correction to porosity ($\Phi_0 \rightarrow \Phi_1$)
- ❑ Fluid content & air filled porosity are key to **productivity** and **slope stability**

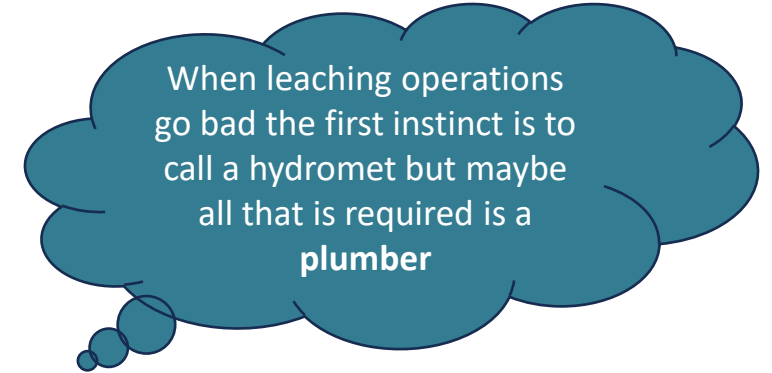


Leaching Value proposition



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- **Up to +20% recovery** from **trapped solution** or **dry spots** in existing operations (*more \$\$\$*)
- **Enable re-mining** and **secondary leaching** (*new reserves*)
- **Reduce costs** for lixiviant & water usage (*sustainability*)
- **Optimize** ore mixing, leach schedule and load variability (*predictable operations*)
- **Eliminate personnel exposure** from routine inspections (*cost saver*)
- **Avoid production loss** from catastrophic landslides (*leads to asset or license loss*)
- **Defer closure** costs (*up to several \$100M's/site*)
- **Speed up** ore removal (*up to months lost time*)



PONDING ISSUES



POOR PERCOLATION



TRAPPED EQUIPMENT



CATASTROPHIC LANDSLIDES

02/13/24: Anagold (Turkey)

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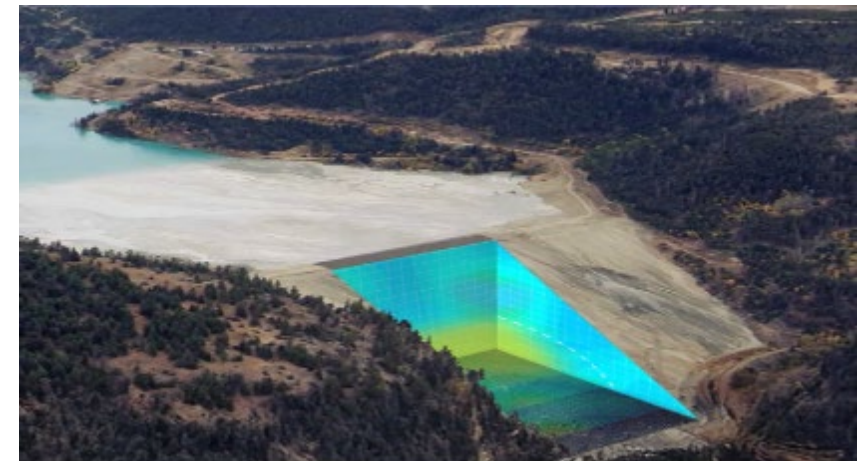
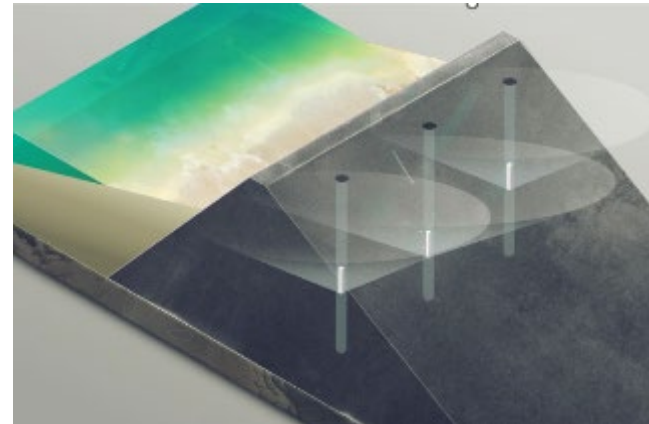
Pain:

- *Point-wise information insufficient*
- *Manual intensive operations too costly*
- *Poor samples are unreliable proxies*
- *Problems apparent when already too late*



Solution:

- *Quantitative asset digitization with (remotely operated) muon radiography*

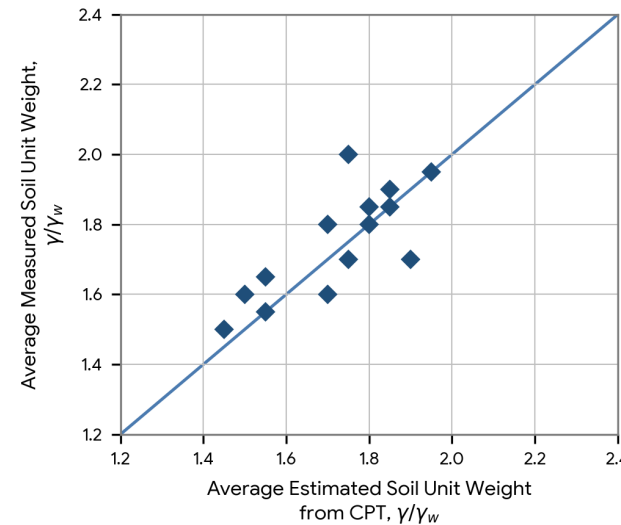
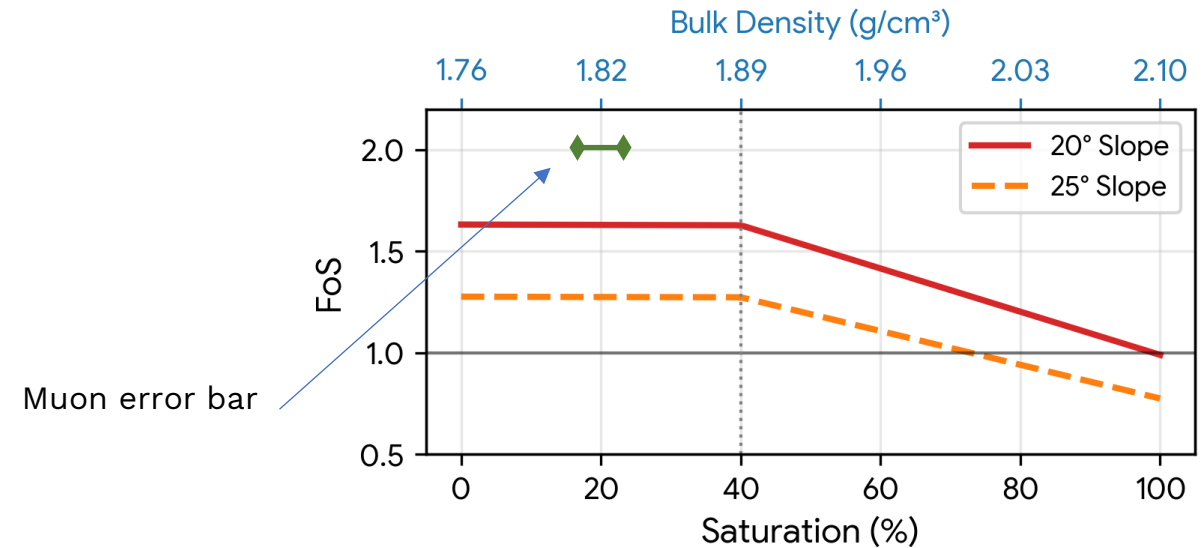


1) Muon Radiography gives better data

- Excellent precision (~ 0.02 g/cc) and high confidence level (2σ) over few weeks even at depth (100-200m)
- Much more robust than “unit weight” inferred from CPT correlation plots or samples. Independent of granulometry
- Direct in-situ measurement – no need for “representative sampling”, “re-moulding” or “blending”



Impact of saturation on FoS & bulk density



Current error bar

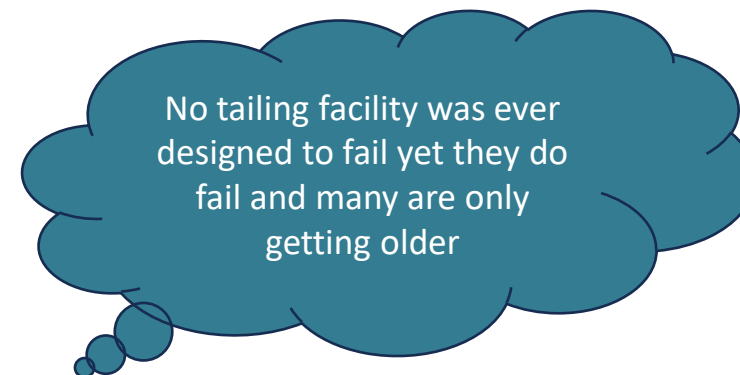
CPT & sample data: $\sim 0.1 - 0.2$ g/cc
inferred estimate versus actual density ([link](#))

Slope stability value proposition



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- **Validate asset models** fill gap between sparse soil sample data
- **Reduce uncertainty** on slope safety factor & run-out calculation
- Build a **continuous record** of the asset over time at low cost
- **Alert** for phreatic changes and **monitor** dewatering actions
- Aid **seasonal slope safety** assessment in rainy, wet regions
- Determine actual **compressive loads** in situ
- **Enhanced transparency**, meet ICMM standards & audits



SAMARCO, BRAZIL (2015)
\$32B SETTLEMENT



BRUMADINHO, BRAZIL (2019)
270 DEAD



KINGSTON, TN (2008)
10x DEEPWATER HORIZON

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Muography competitive advantages



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Feature	Muon bulk density	Aerial Surveys	Electric Resistivity	Ground Radar	Local Sampling
3D volumetric characterization	Yes , full volume	No , only external surface	Indirect , only along E-field lines	No , limited observation cone	No , point-like only
Fluid filled porosity determination	Yes , quantitative, direct & robust	No , indirect & qualitative	No , indirect & qualitative	No , indirect & qualitative	Yes, but point-like only
Air filled porosity determination	Yes , quantitative, direct & robust	NA	NA	NA	NA
Sensitivity to environmental effects	Minimal , can be controlled for	Yes : atmospheric conditions, dust	High : temp, salinity, contact resistance,..	High : temp, salinity...	Low, but sample reliability an issue
Depth of Survey	Up to 100's of m	0 m	< 100m (trade off with spatial res)	~3-5m, depending on saturation	Up to 100's of m
Response time	Days to Weeks	Days	Multi Days	Days	Days
Safe automated operations	Yes , remotely operated	Yes , remotely operated	No , requires slope access	No , requires slope access	No , requires slope access
Service scalability	Yes , movable detectors	Yes , movable detectors	No , manpower intensive & costly	No , manpower intensive & costly	No , manpower intensive & costly
Continuous monitoring	Yes , resolution improves over time	Yes , on dense data grid	No , isolated snapshots only	Possible, if airborne	Yes, but only on sparse grid
Service cost & maintenance	Potentially lowest	Moderate	High	High	Very High



Resistivity: invasive & qualitative



Aerial: surface only



Sampling: expensive

Default solution: do nothing (especially if new or “unproven”)

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Muon Vision Demo Facility – Overview



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Key Features:

Realistic leaching heap mockup (1:3 scale)

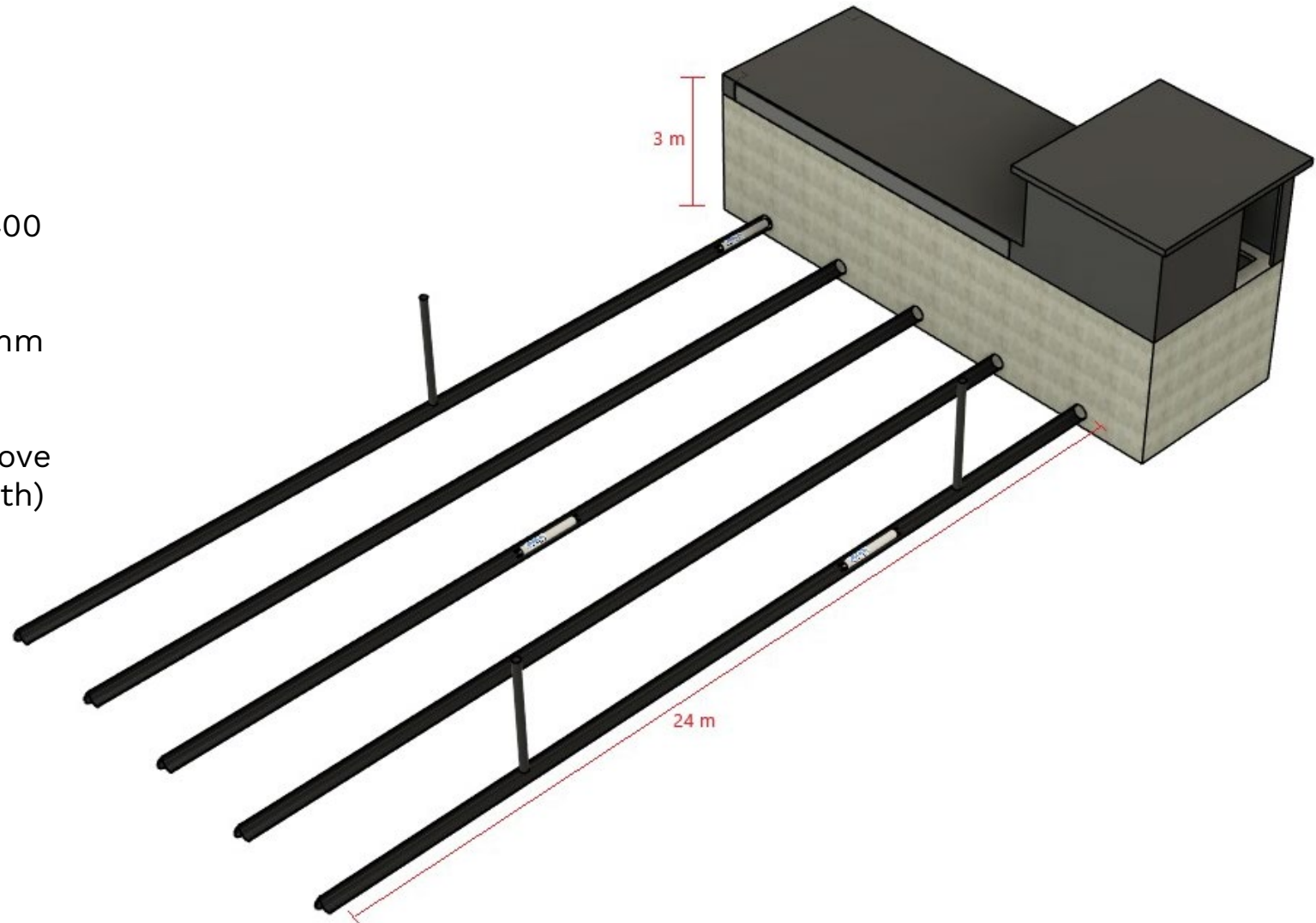
Horizontal wells: Five horizontal HDPE-400 pipes, 24m long, at 3.5 meters depth

Vertical wells: Three vertical wells, 200mm diameter, 3m long

Density configurations: Customizable above surface (up to 6.5m total equivalent depth)

Location:

45mins from Las Condes



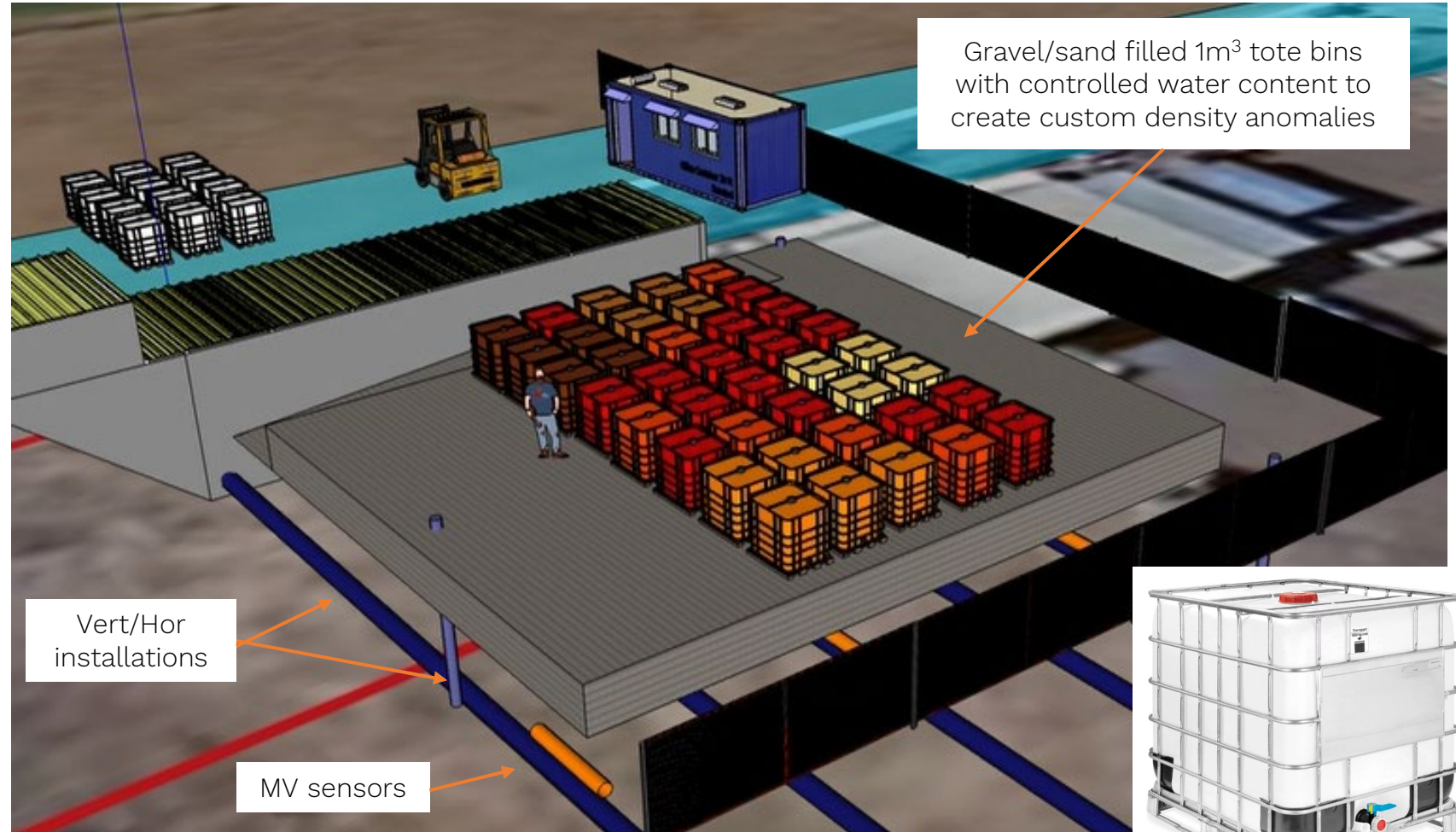
Muon Vision Demo Facility – Overview



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Capabilities:

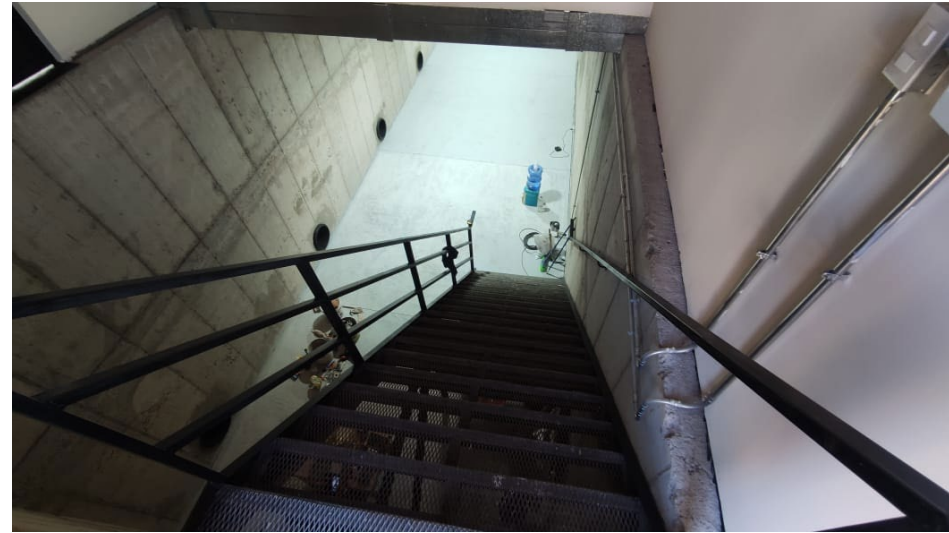
- Validate measurement under controlled conditions against different fluid saturation content
- Validate different scan configurations, station times, detector designs
- Fine tune ML algorithms and fast inversion algorithms
- Perform blind tests
- Perform critical ore characterization studies (e.g. saturation curve) at intermediate scale



Muon Vision Demo Facility – Overview



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Muon Vision Demo Facility – Overview



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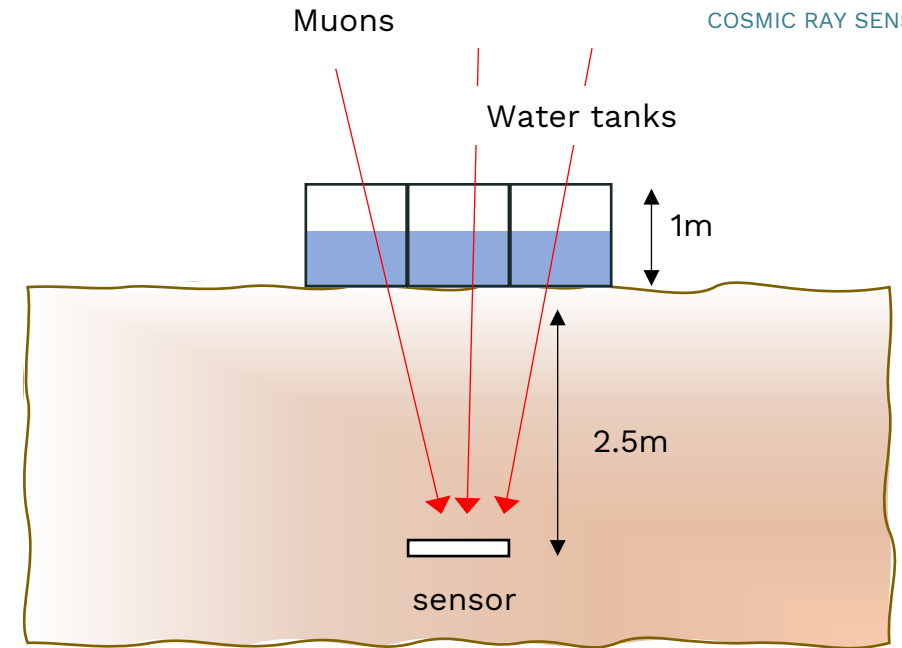
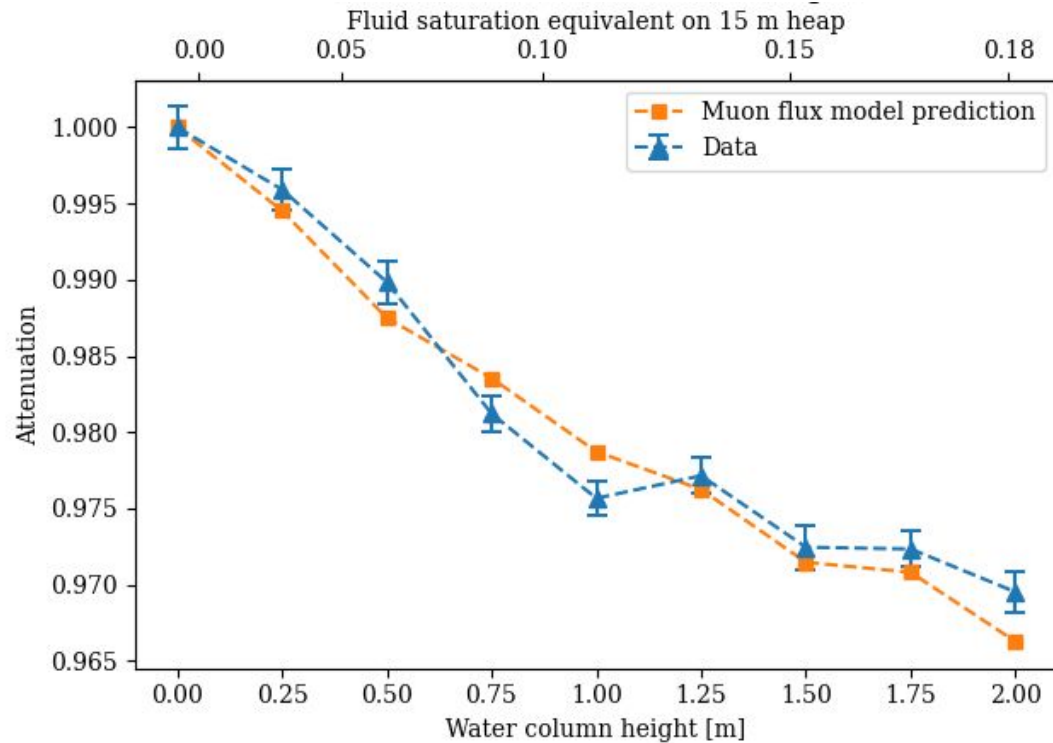
Validation measurements
starting 08/2025

Case study #1: $3 \times 3 \times 1 = 9 \text{ m}^3$
water placed above 2.5m soil
depth



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Fluid content determination



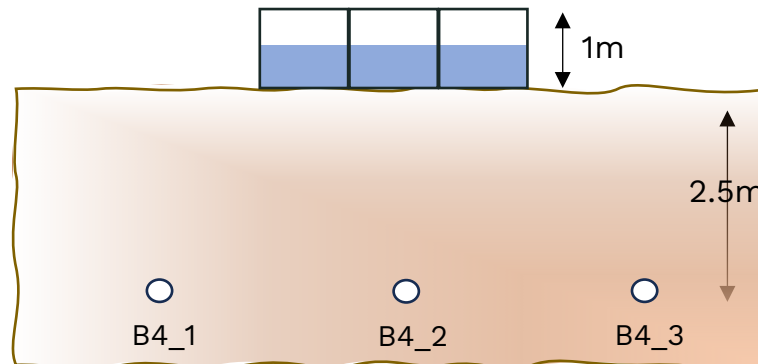
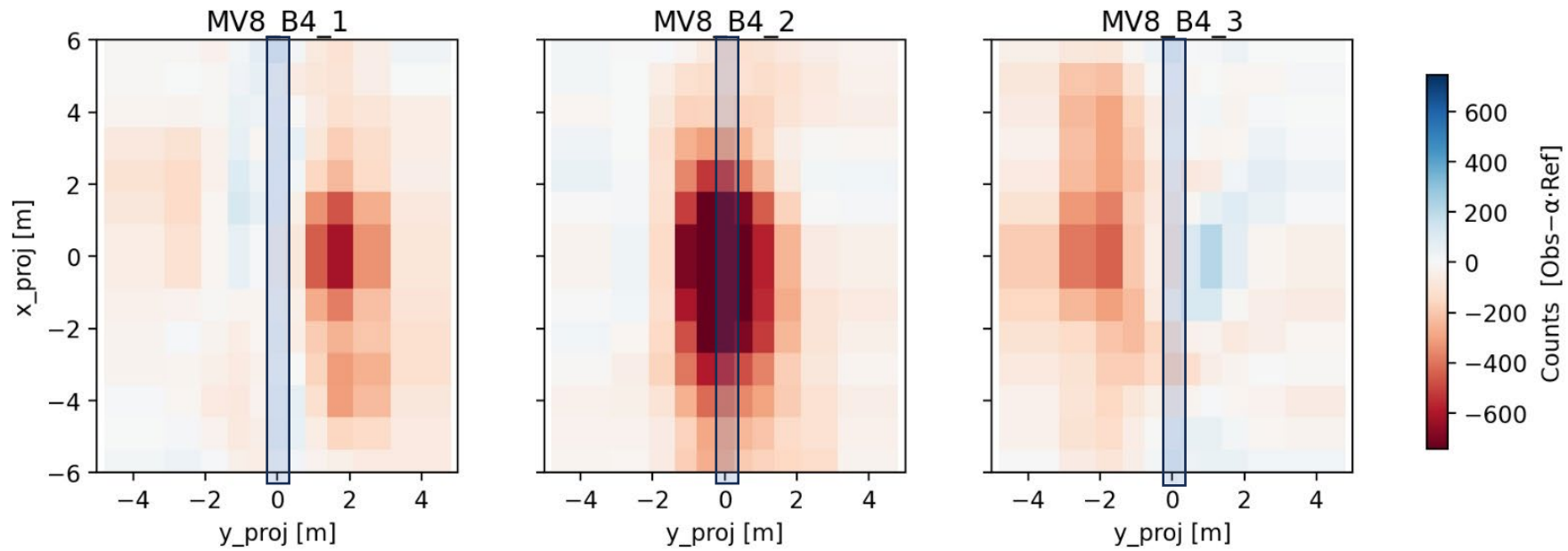
$$\begin{aligned}
 \rho_b &= \rho_{dry} + \Delta\rho \\
 &= \rho_{dry} + \Phi S \rho_{Fluid}
 \end{aligned}$$

Sensors are placed at ~3m depth

Adding fluid to the surface water tanks increases muon attenuation

The measured change in attenuation same as a heap fluid saturation change

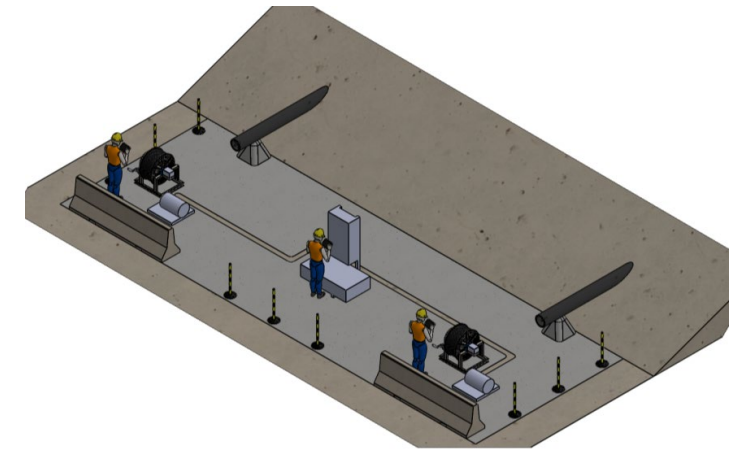
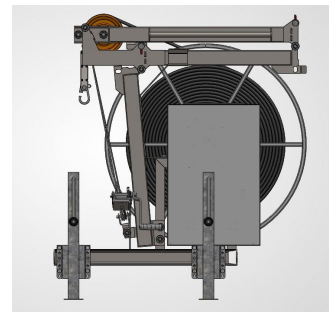
Fluid content determination



Sensor installation: remotization & conveyance



- Staging area:
 - 1x remote control cabinet with battery bank
 - Can serve up to 4 satellite sensors (not co-located)
 - Each winch needs an area ~ 2x3 m²
- Remotization:
 - Connectivity: can use wifi, cellular or (own) Starlink
 - Standalone (solar, solar+generator) or site power
 - Winch remotization later in 2026



Summary and conclusions



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Muon radiography is a mature technique

Achieving product market fit remains very hard

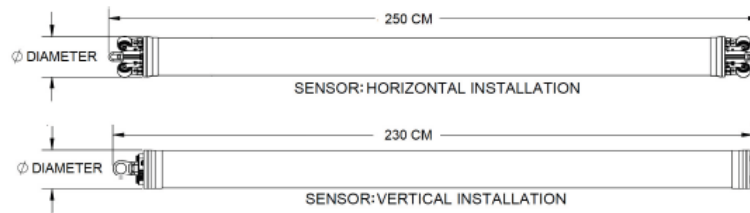
- It's not the detector or how clever/elegant you are: it's the problem you solve
- Customer also needs to see you'll be around for support

Muon Vision first mover in field of minerals processing and slope stability

- We operate commercially in Chile, Australia & Brazil (soon also US)
- We have patented our leaching/slope stability solution internationally
- Robust customer pipeline. Growing the team



3n.com



	Size Designation	Tool OD	Min Tool Length	Min HDPE or well casing ID	Weight
		(cm)	(cm)	(cm)	(kg)
Horizontal	MV6	14.42	250	DN200	20.4
	MV8	19.03	250	DN280	30.4
Vertical	MV4	8.89	255	11.7 (PQ drill)	11.3
	MV6	13.28	230	15.3	15.9
	MV8	17.78	230	19.8	25.9

Thank you!

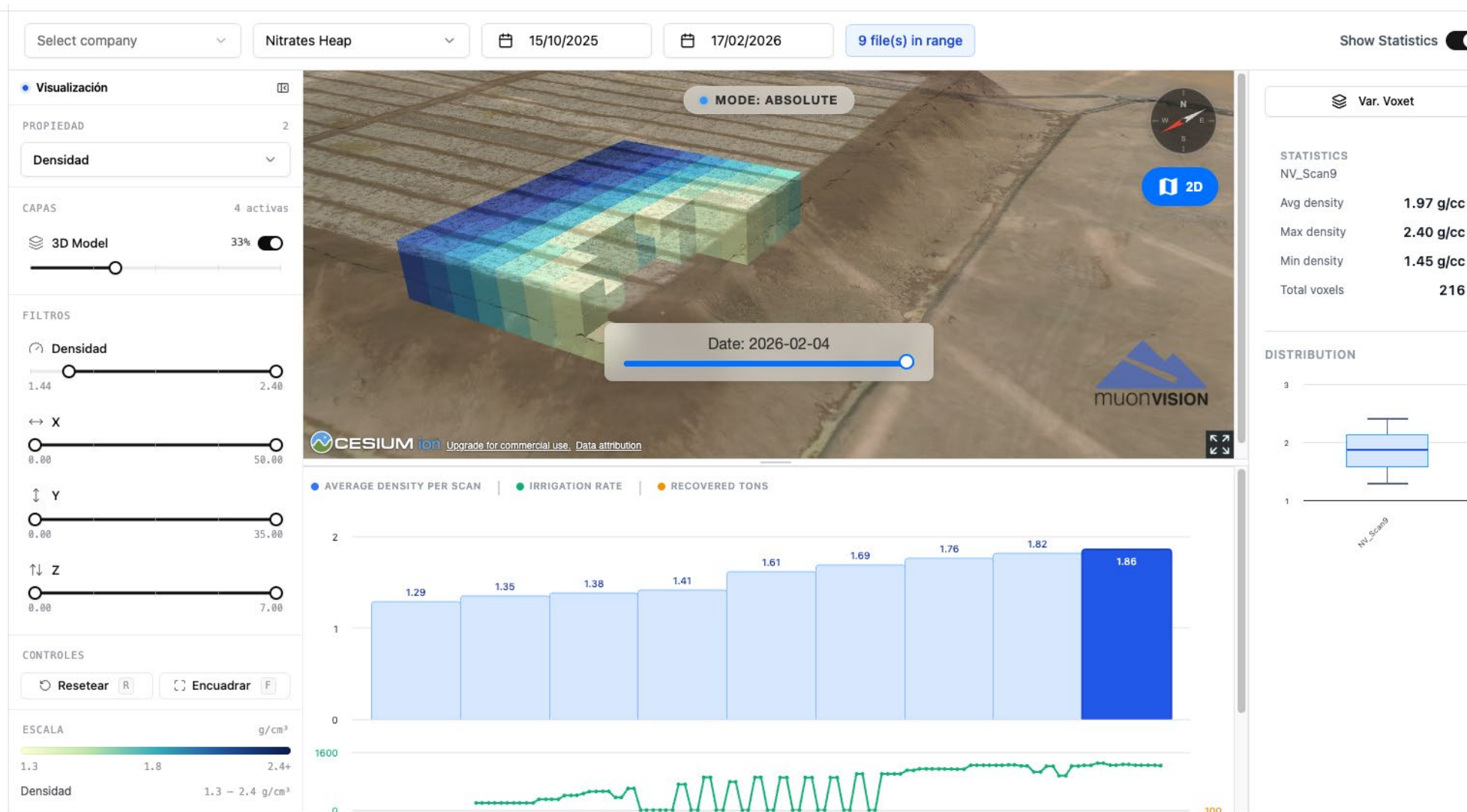




Data Products



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