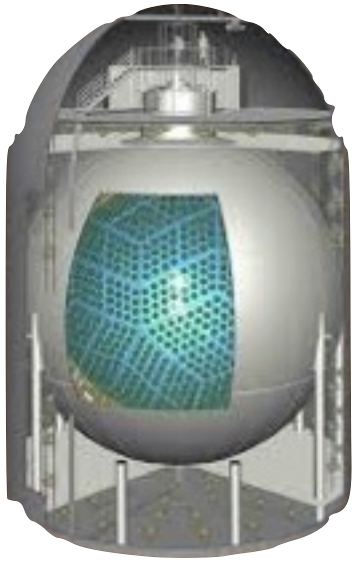
How to build huge detectors in salt domes

Ben Monreal

KamLAND 1kT



Scaling problems all over astroparticle physics

- Large rooms in mines
  - $1000/m^3 (in US/Canada)
  - Roof spans always < 50m

Already maxed out! ☹

- PMTs.
  - SuperK area = 5000m^3
  - PMT cost = $10k/m^3

Not improving fast ☹

- Need to focus on the cheapest materials on Earth.
  - $1000/ton liquid scintillator
  - $100/ton H_2, CH_4, Ar
  - $free: CO_2, N_2, H_2O: cost of purification only

Thin list of options ☹

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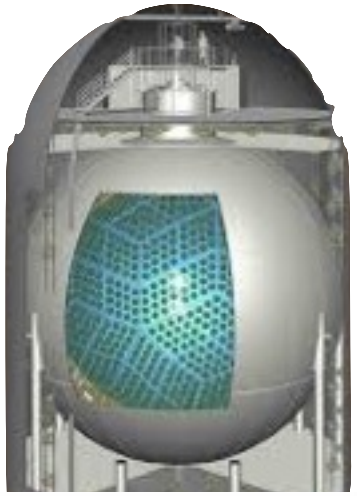
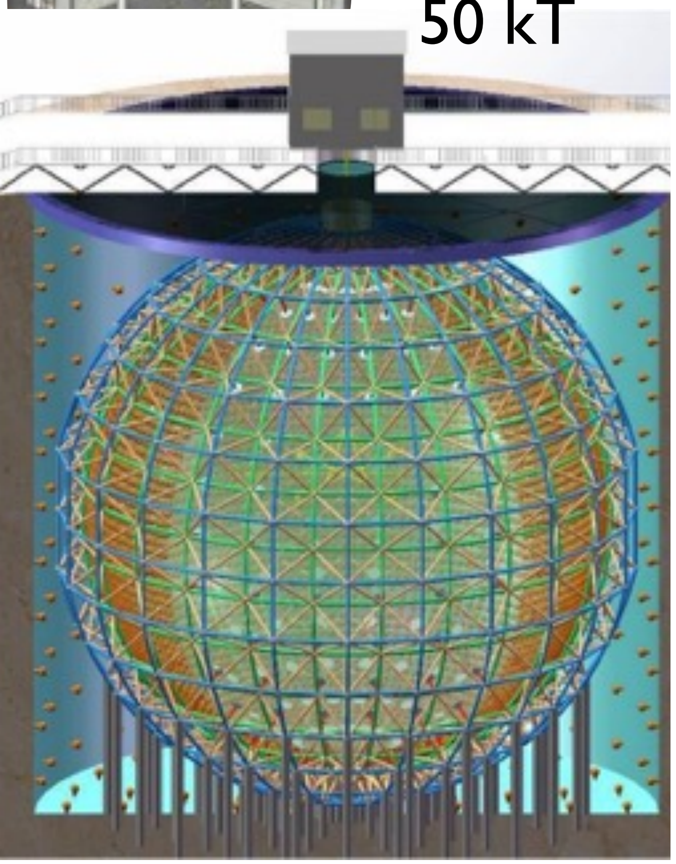


JUNO 50 kT



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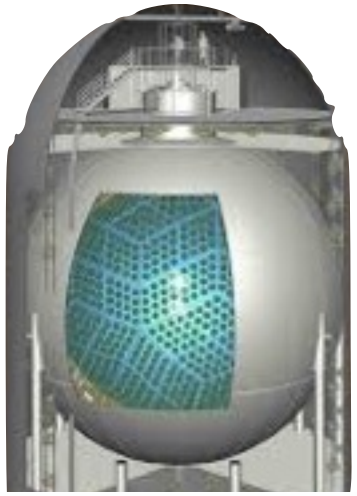

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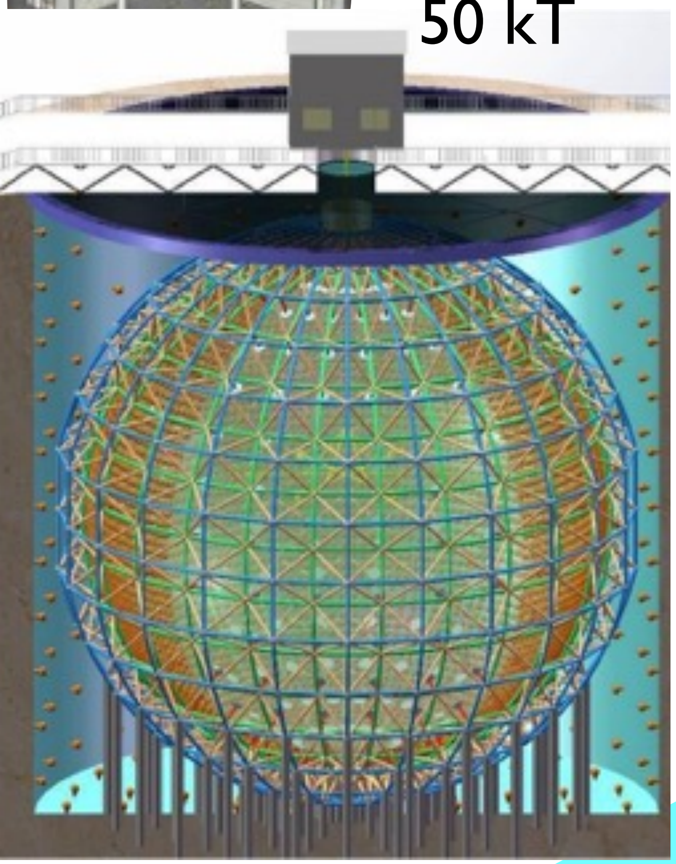

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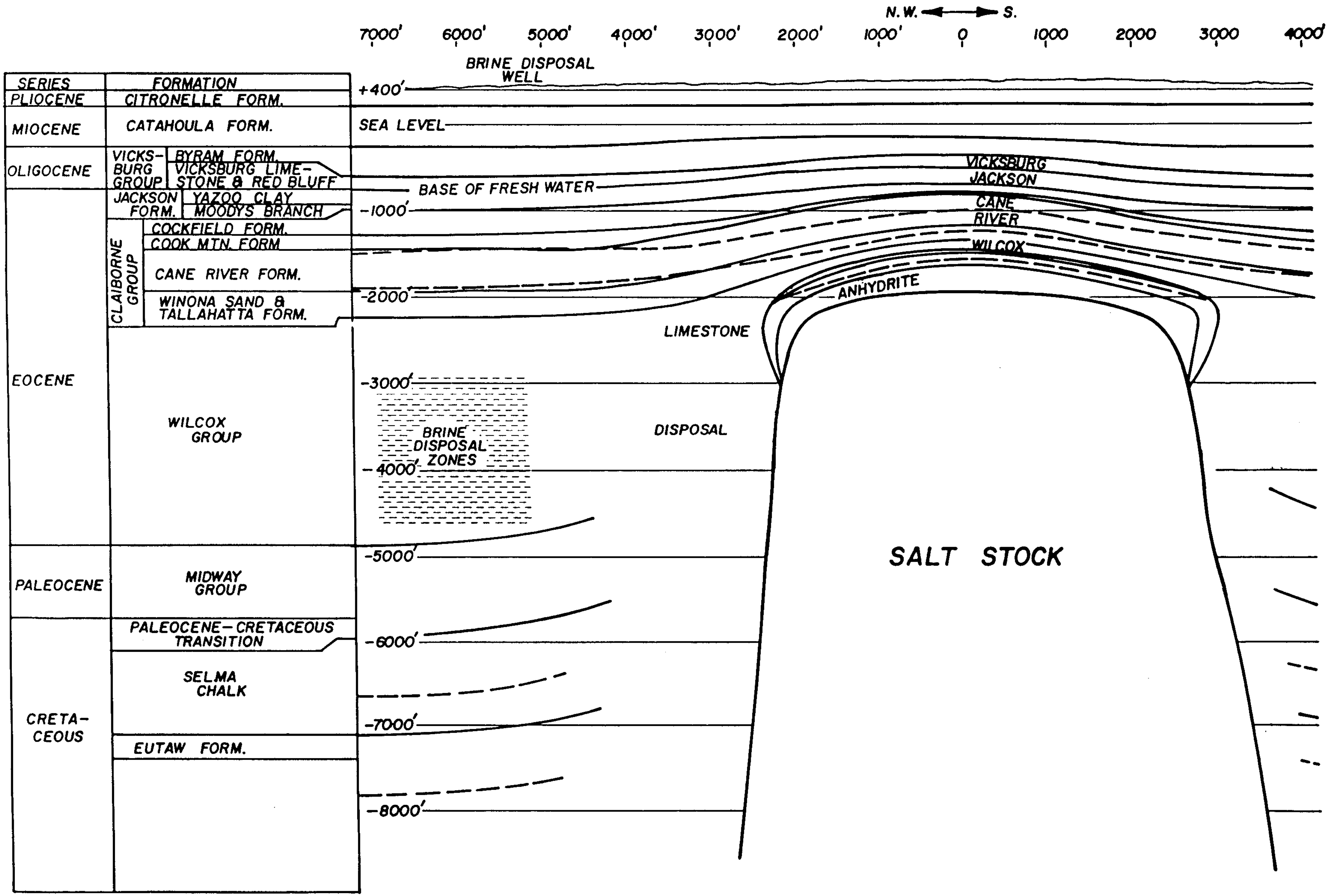
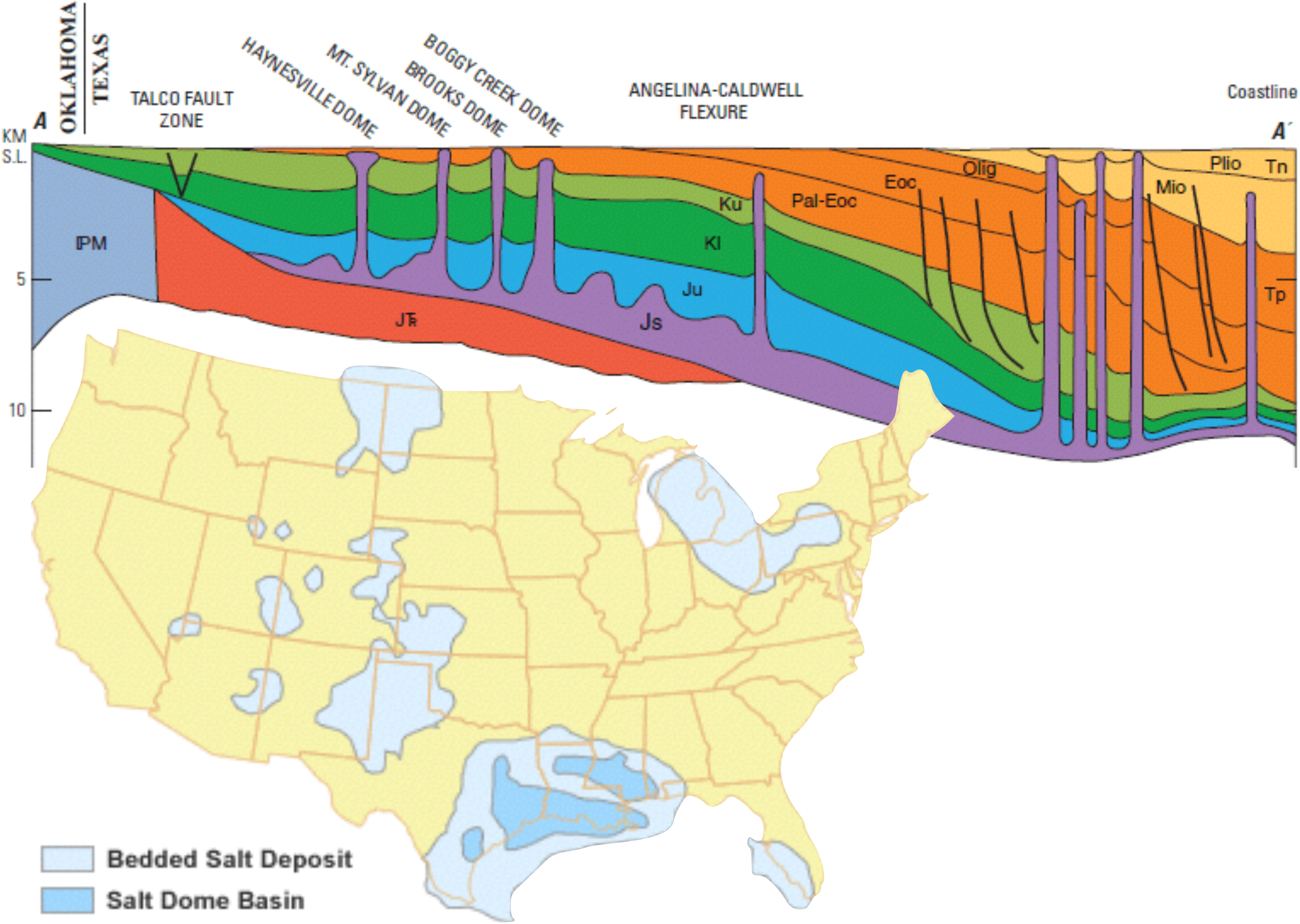
HyperKamiokande
1000 kT



Coates et. al., Proc. 6th Intl Symp. on Salt, 1982

Figure 1. Stratigraphy of Eminence Salt Dome (After Fenix & Scisson, 1980).



A
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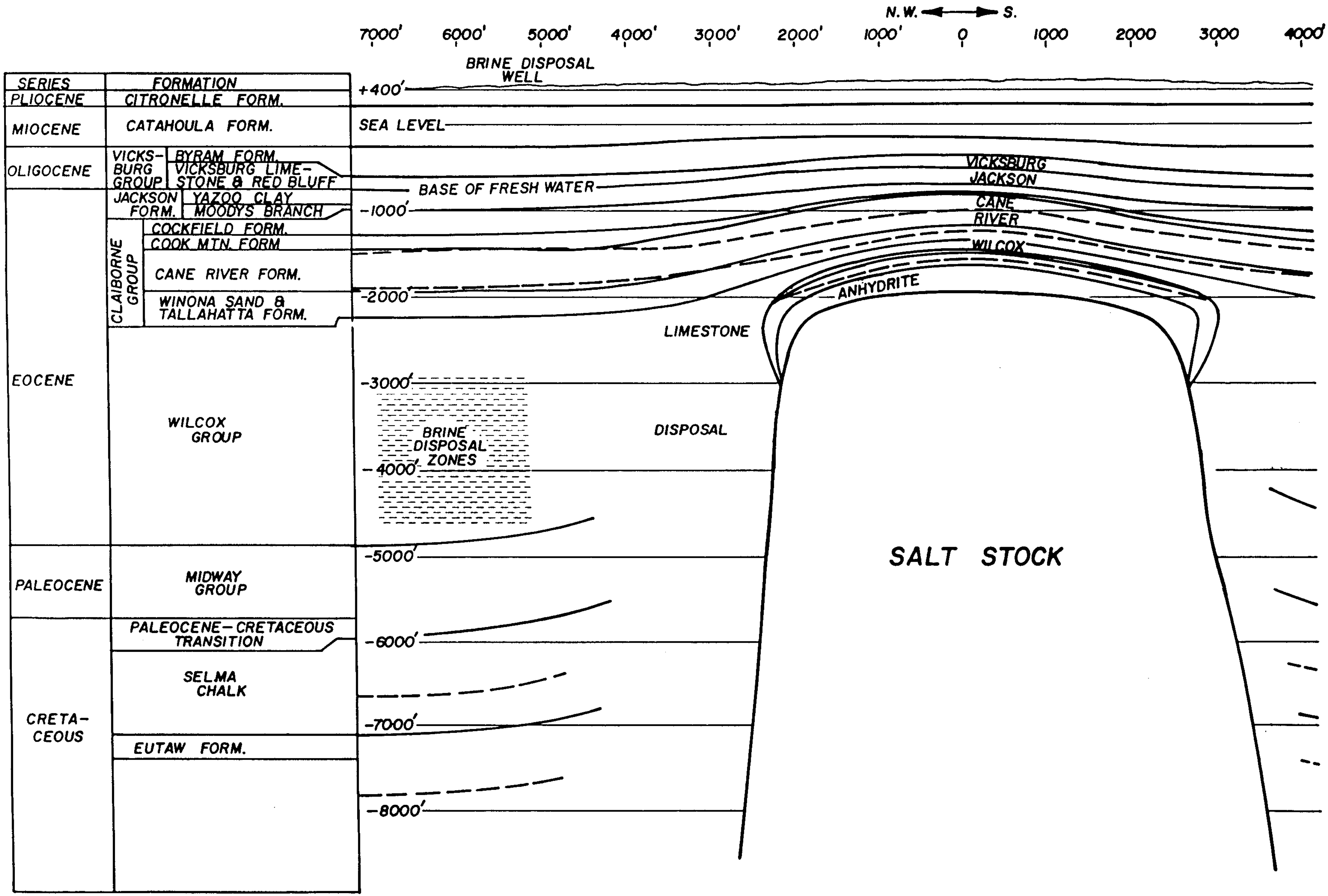

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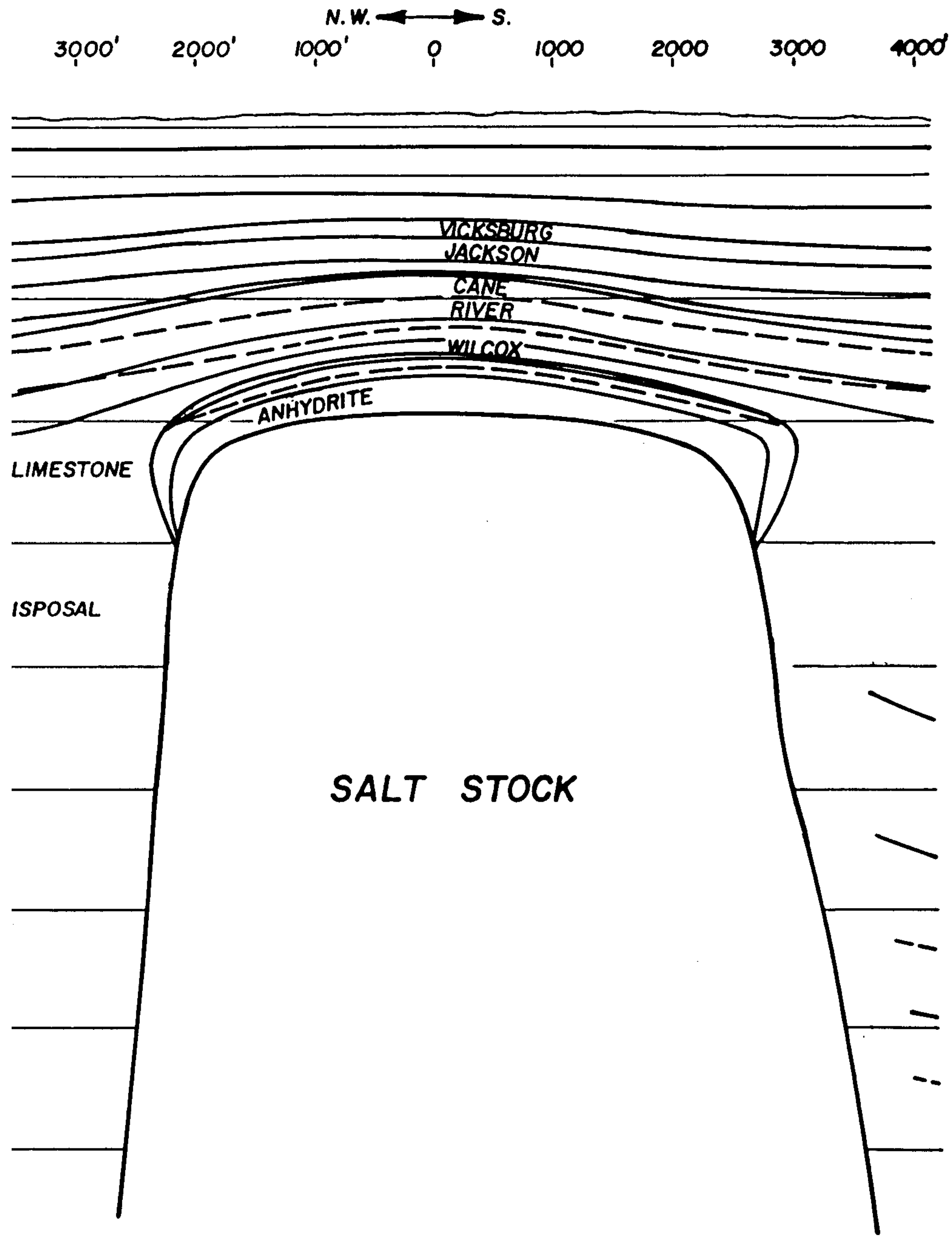
Getting underground cheaply

- "Solution mining"
  - Drill into a salt dome
  - Pump fresh water into well
  - Salt dissolves around injection site
  - Discard brine

DOE Strategic Petroleum Reserve is stored like this. (13Mm^3 mined at \$2/m^3)

Also H2, natural gas, compressed air



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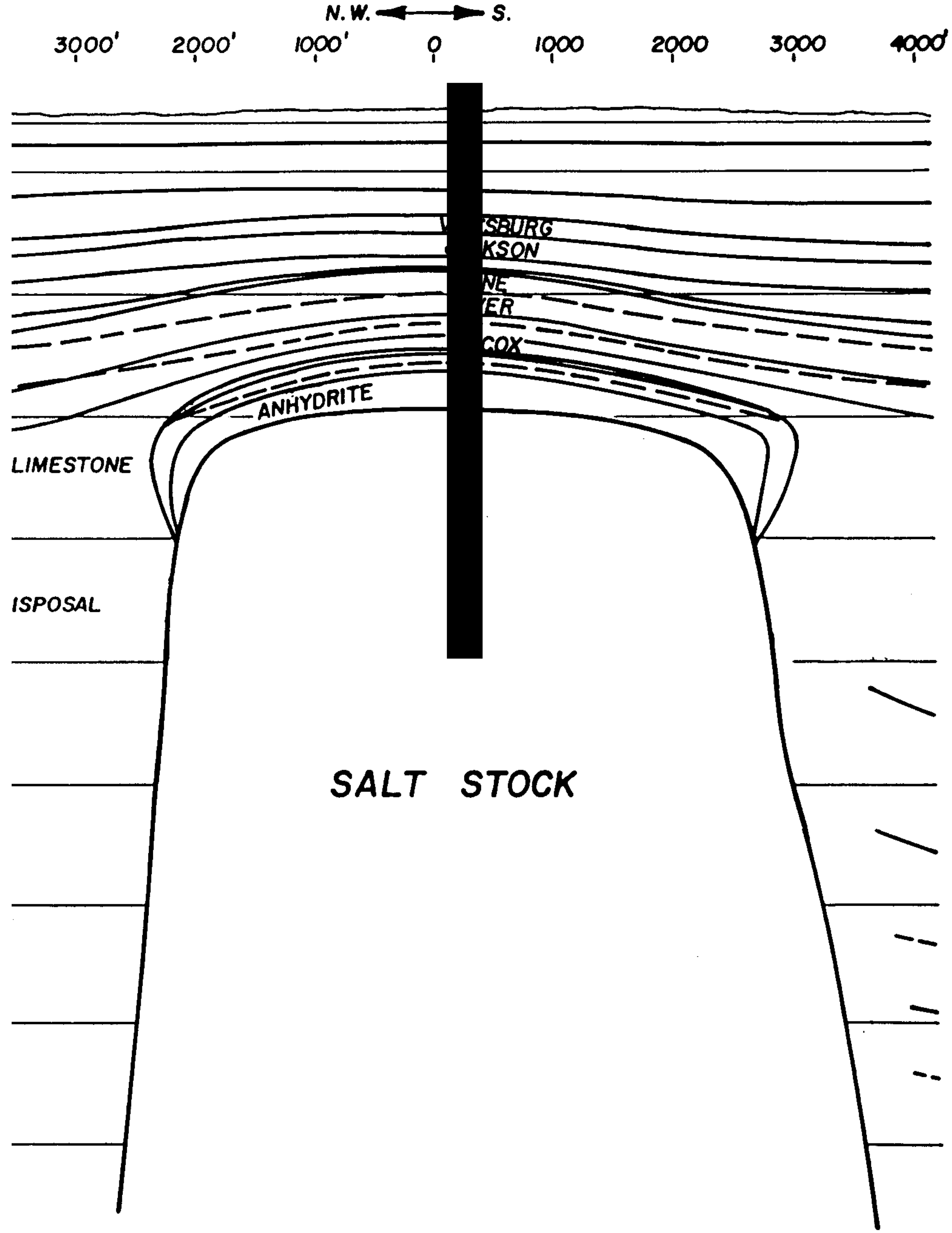

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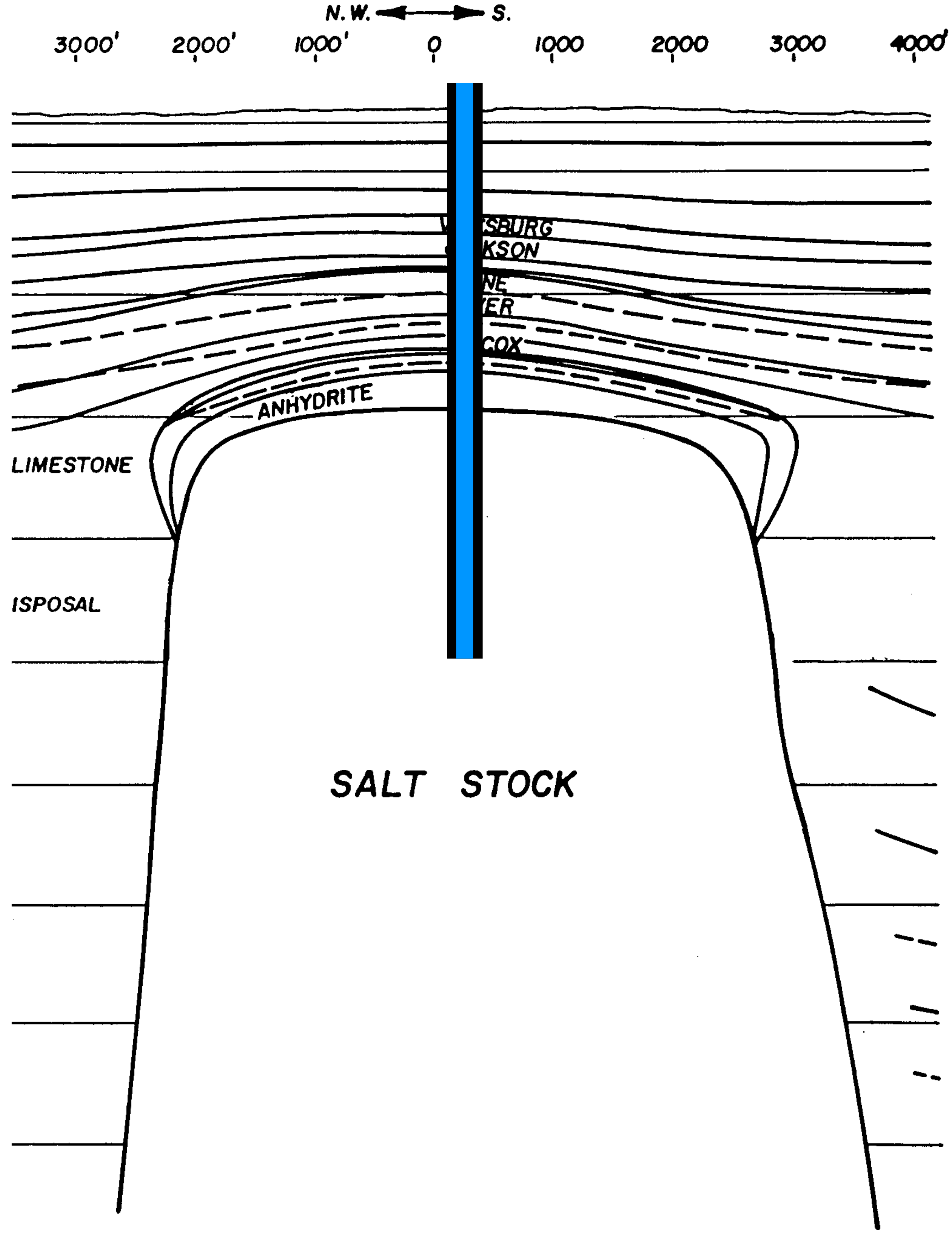

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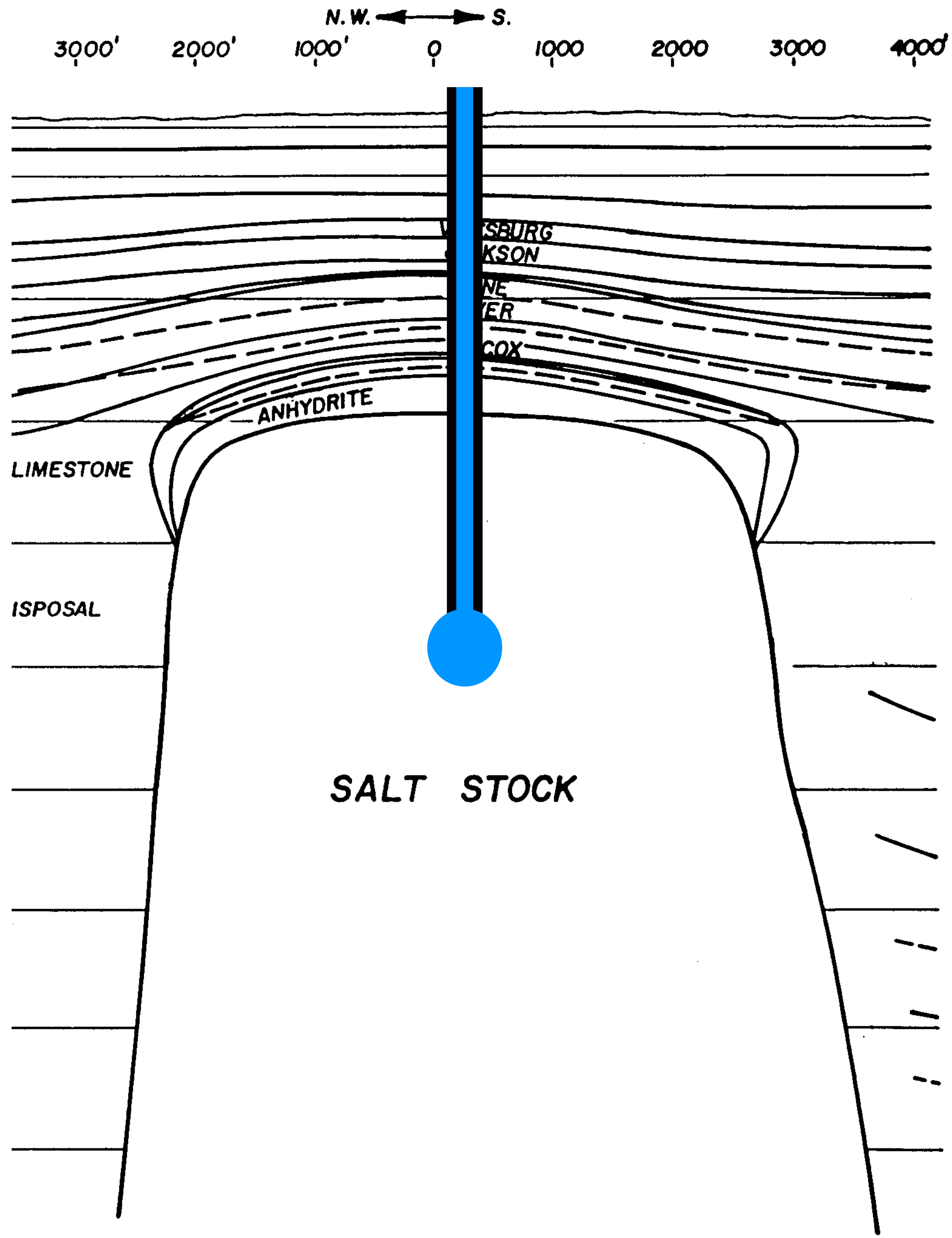

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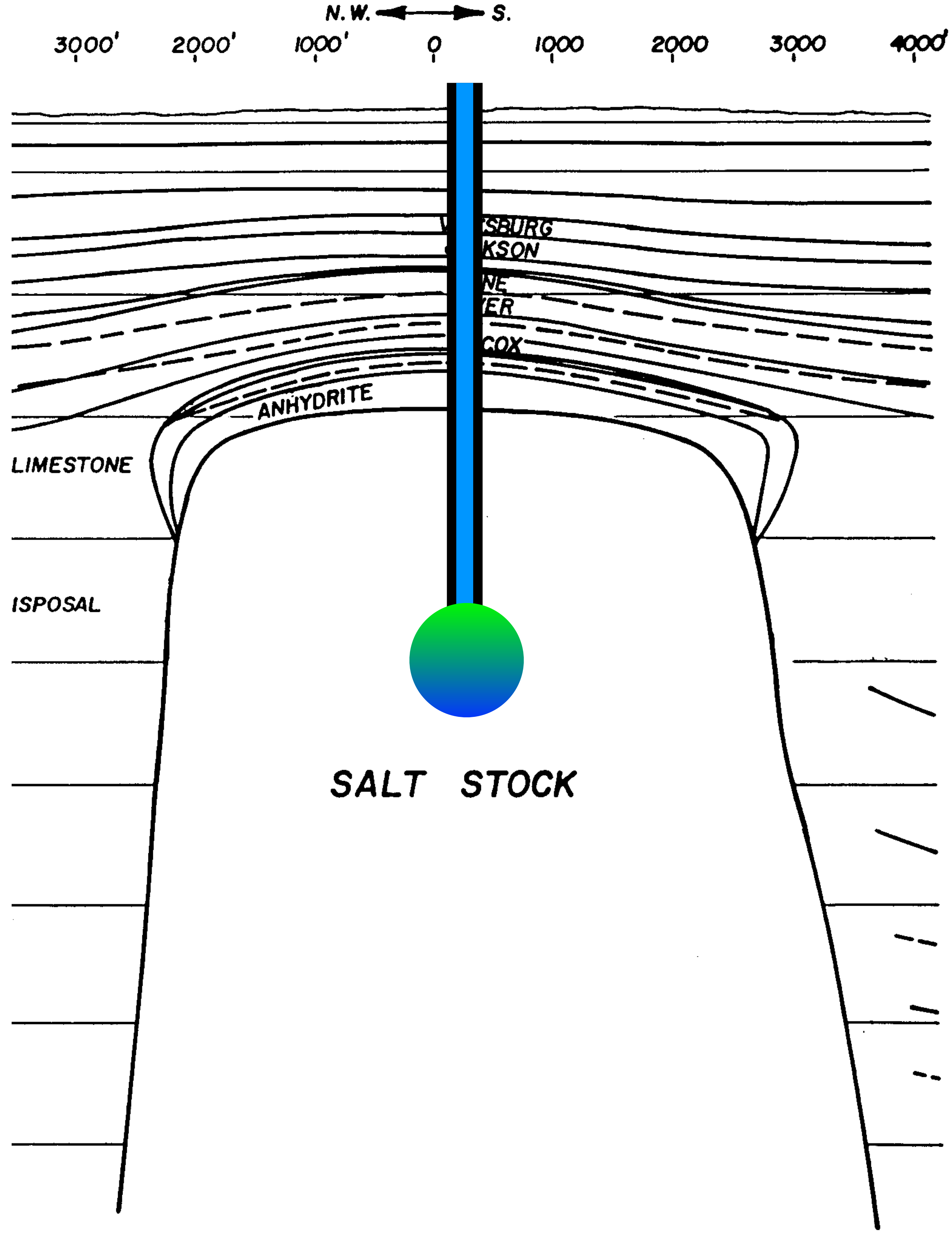

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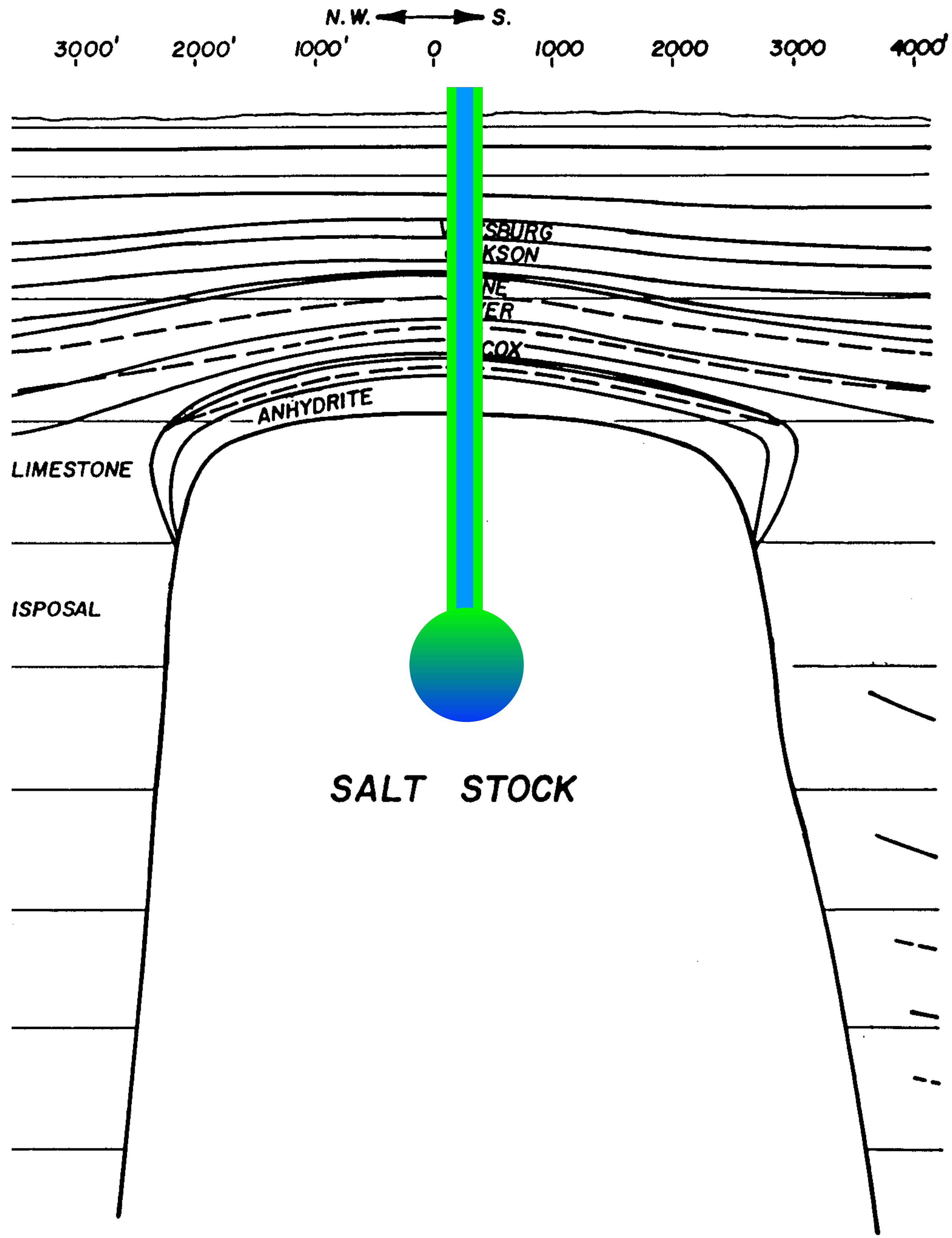

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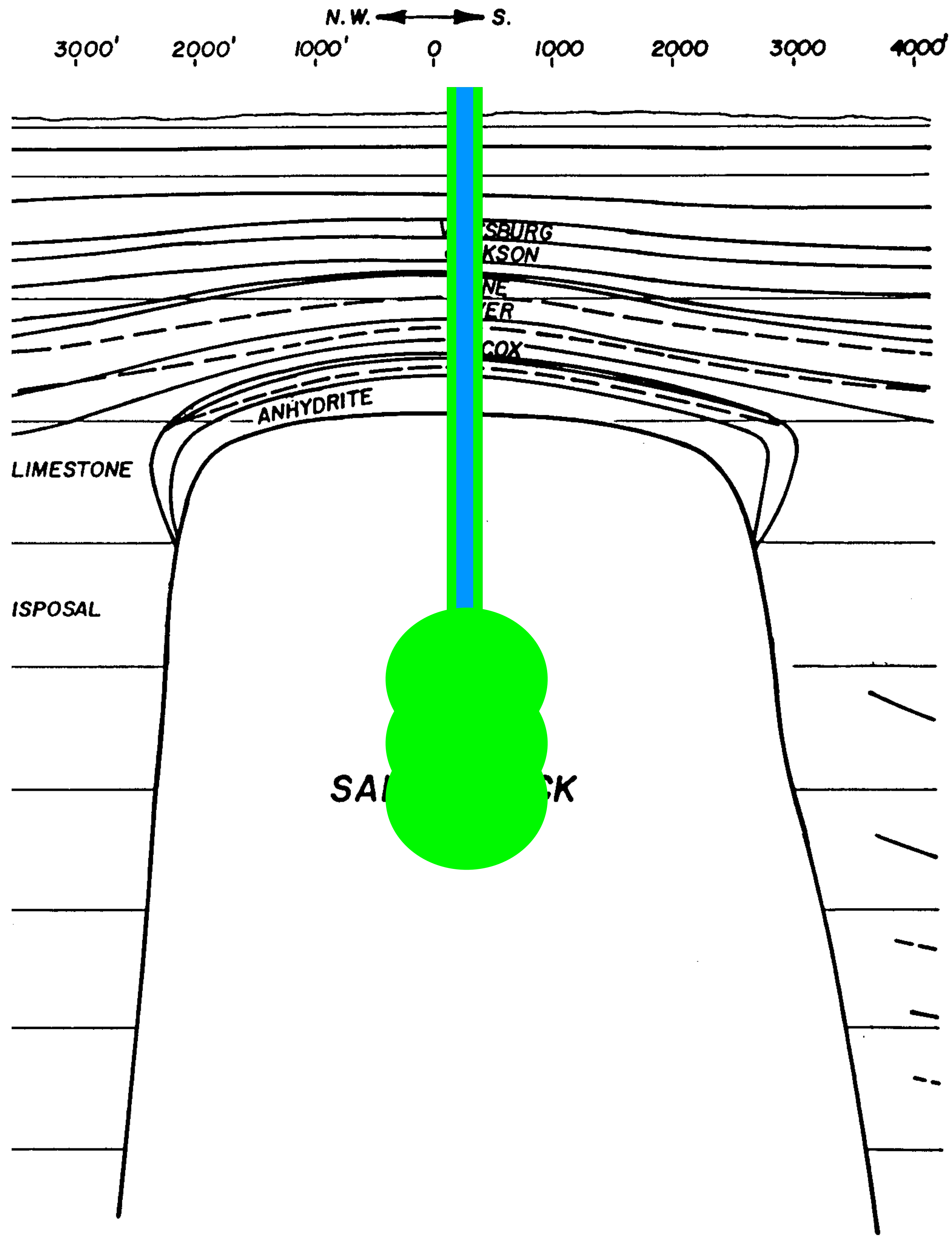

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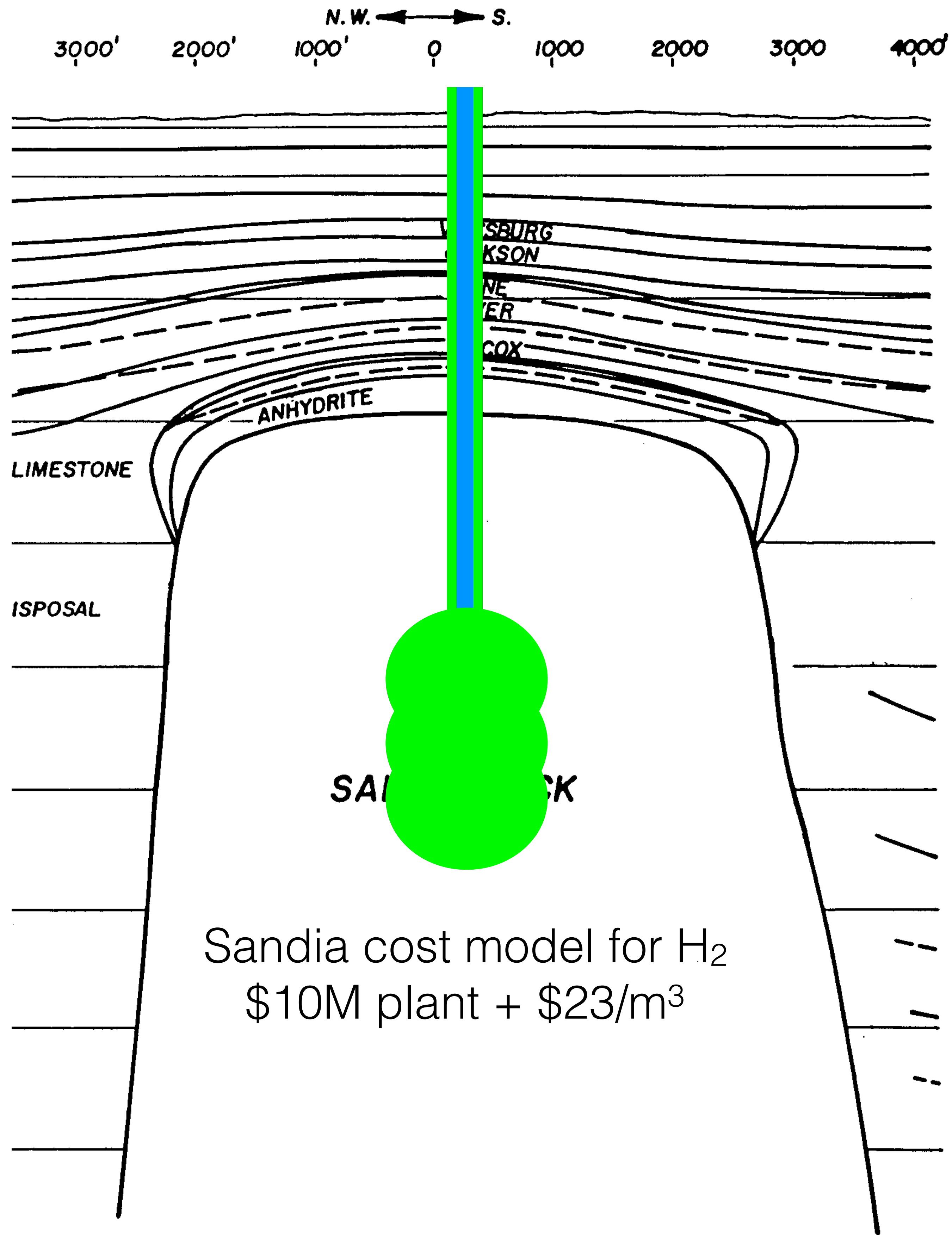

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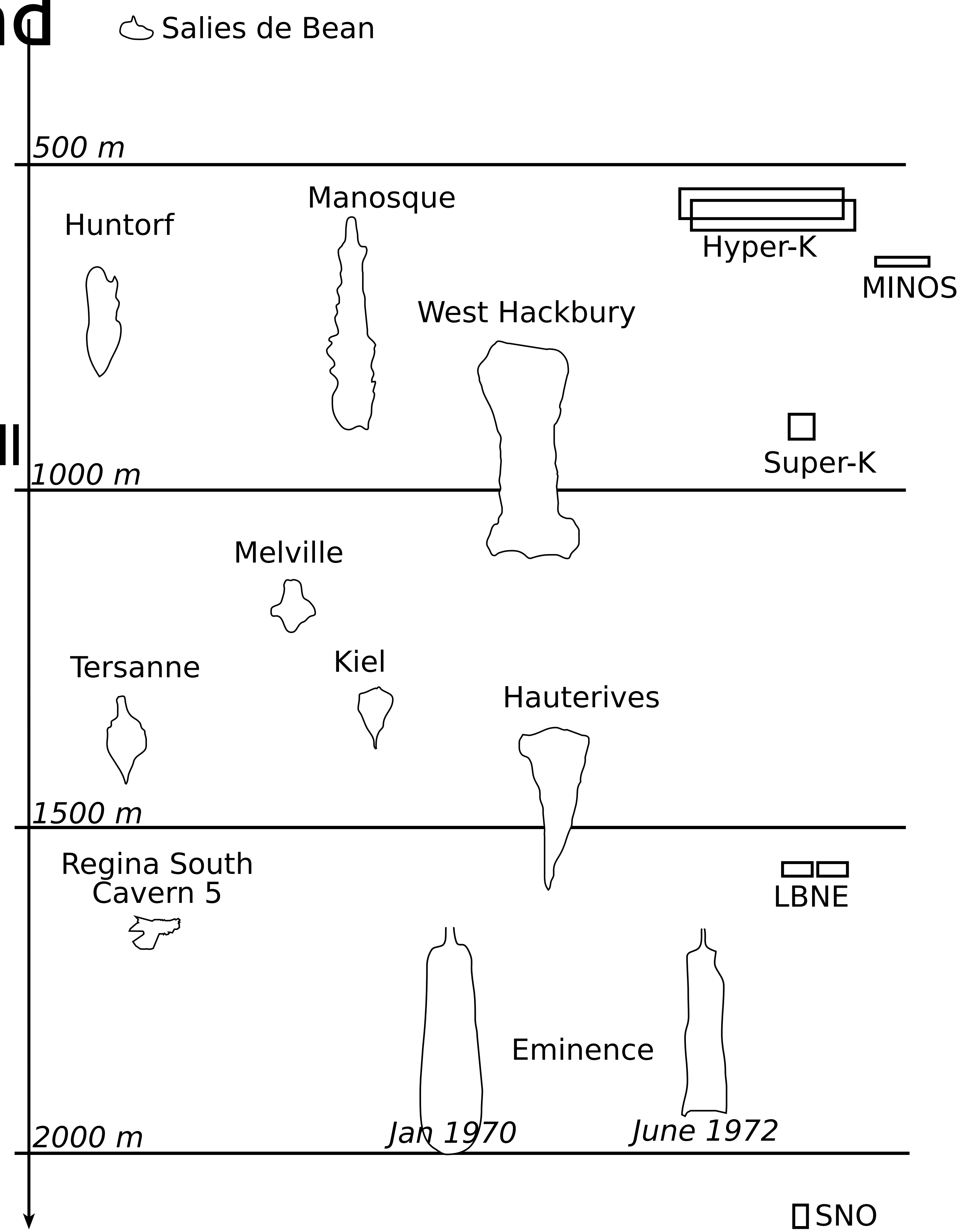
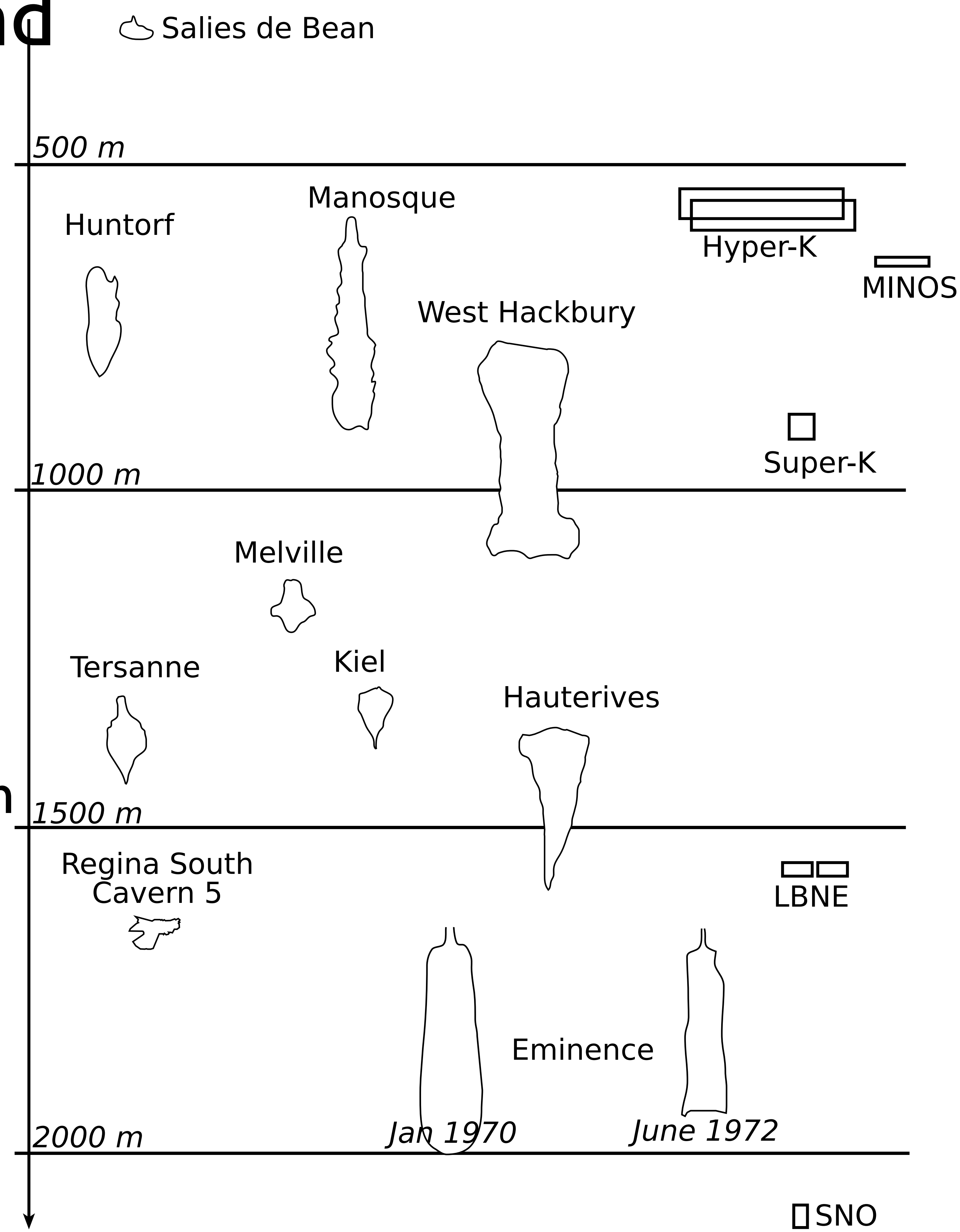
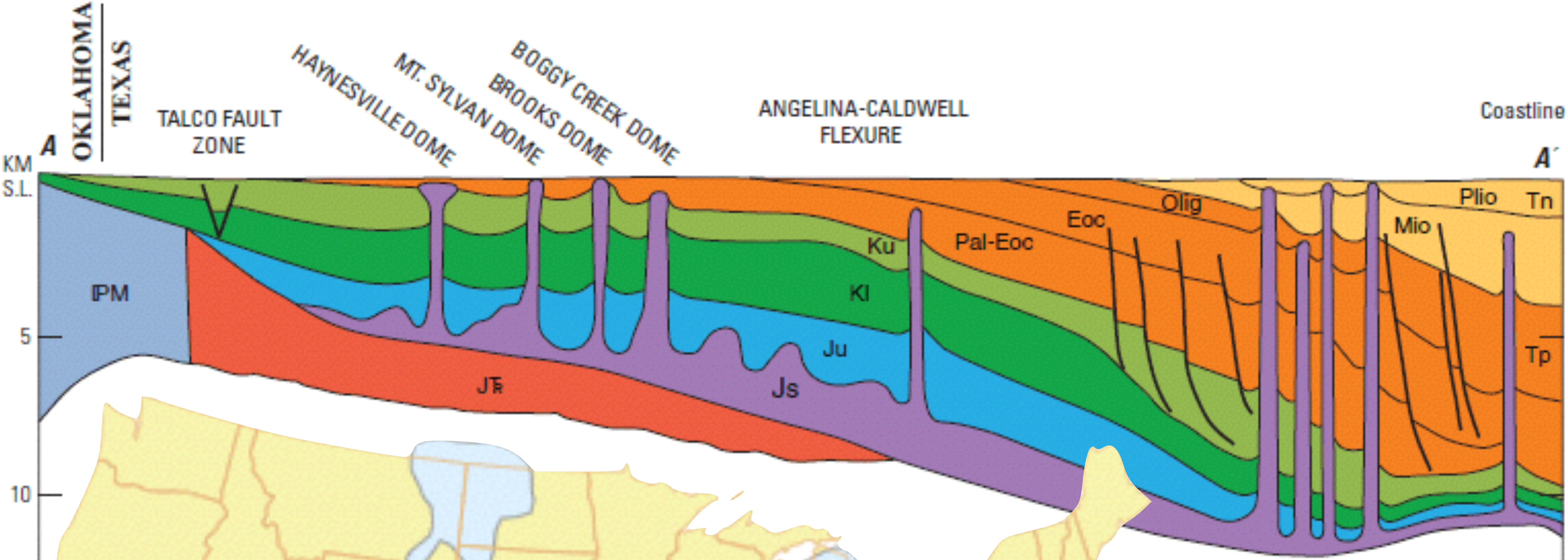
Also H2, natural gas, compressed air



Getting underground cheaply

- These are very strange places.
  - Can be refrigerated!
  - Best kept pressurized:
    - slow creep if d<1 km
    - fast creep if d>1.5 km
    - P > 100bar/km
  - Roof spans of 100—200m
  - NO HUMAN ACCESS. Detector has to deploy down the borehole.





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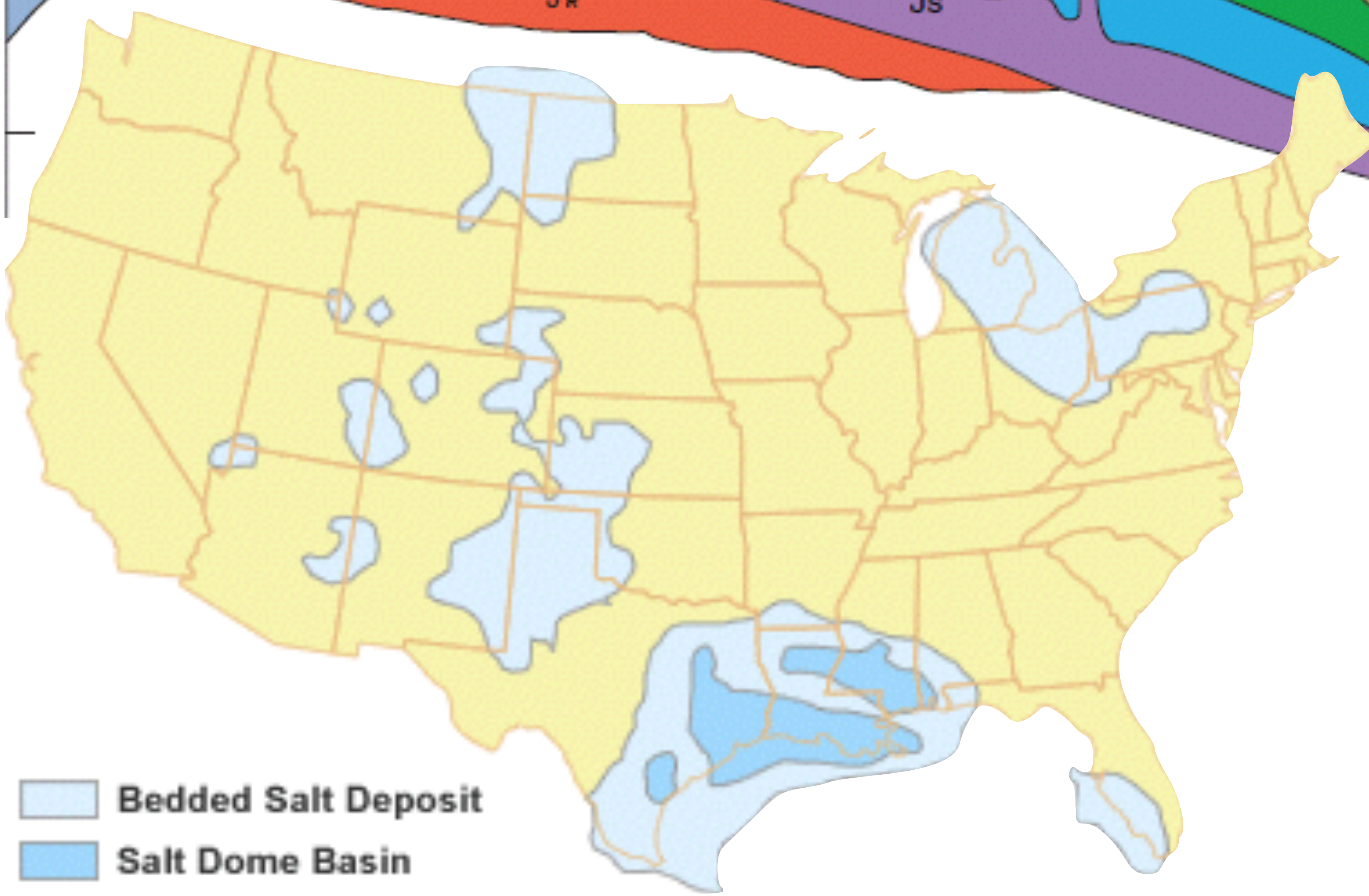
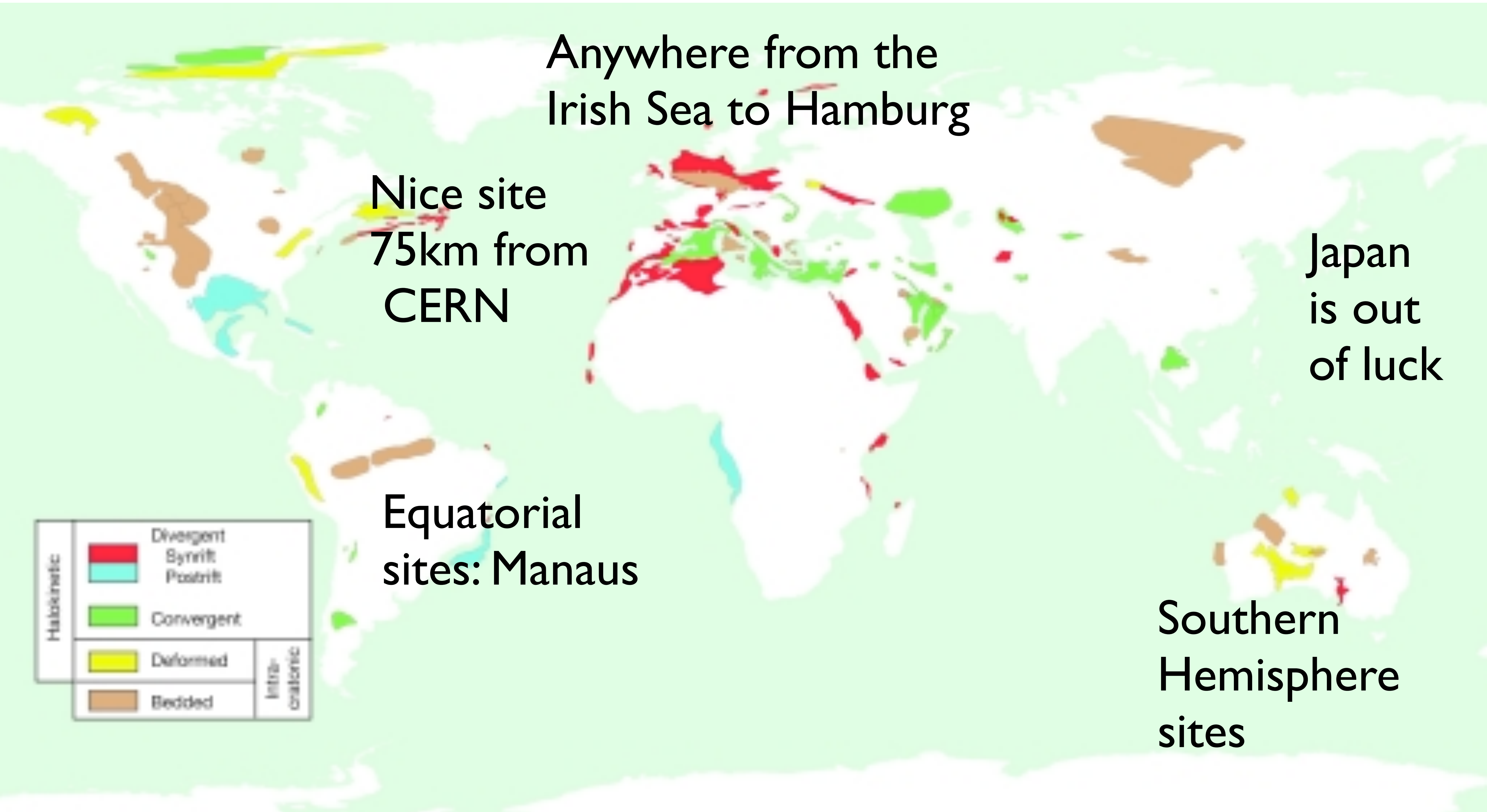


Bedded Salt Deposit
Salt Dome Basin

Global salt bed map



Anywhere from the Irish Sea to Hamburg

Nice site 75km from CERN

Equatorial sites: Manaus

Japan is out of luck

Southern Hemisphere sites

This is a large industry

SOLUTION MINING RESEARCH INSTITUTE

Consultants/engineers

RESPEC

BROUARD CONSULTING

NSAI

ATKINS

GEOSTOCK ENTREPOSE

WSP | PARSONS BRINCKERHOFF

National labs

Sandia National Laboratories

NETL

Argonne NATIONAL LABORATORY

Pacific Northwest NATIONAL LABORATORY

Owners/operators

K+S

DOE National Strategic Petroleum Reserve

AGL Resources

Spectra Energy

MAGNUM Gas Storage

FAIRWAY ENERGY PARTNERS LLC

FREEPORT LNG

Niska Gas Storage

ZECHSTEIN MIDSTREAM

Apex·CAES

TransGas YOUR LINK TO SUCCESS

storengy

e·on

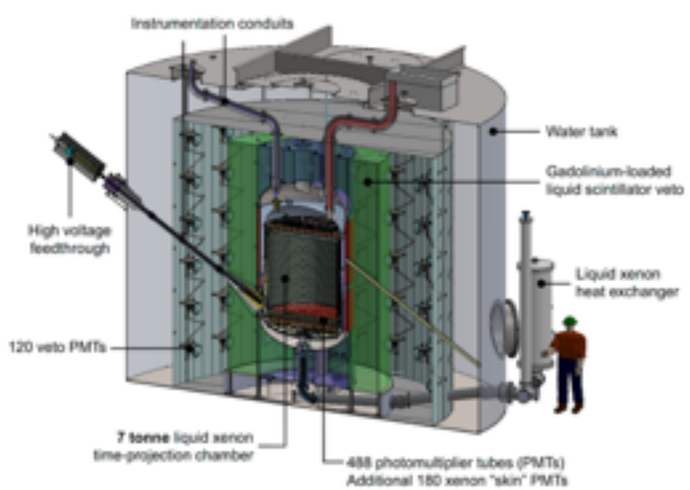
EDF ENERGY

Depth x shielding

The best shielding we can do today:

10m room

6m water tank



high-U/Th/K rock

Brine

Clean salt

Depth x shielding

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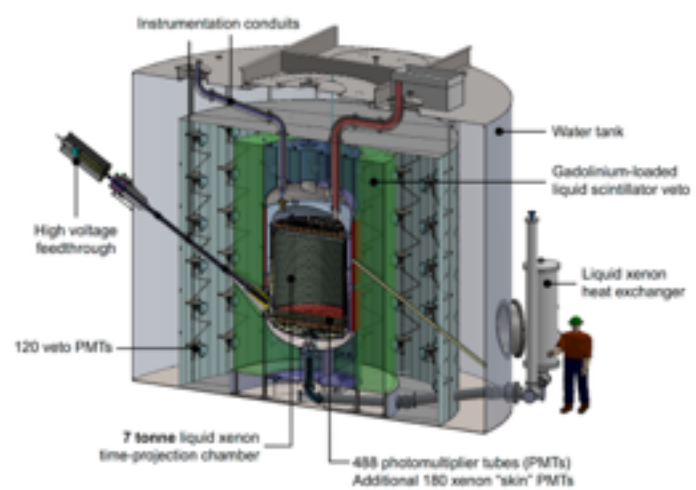

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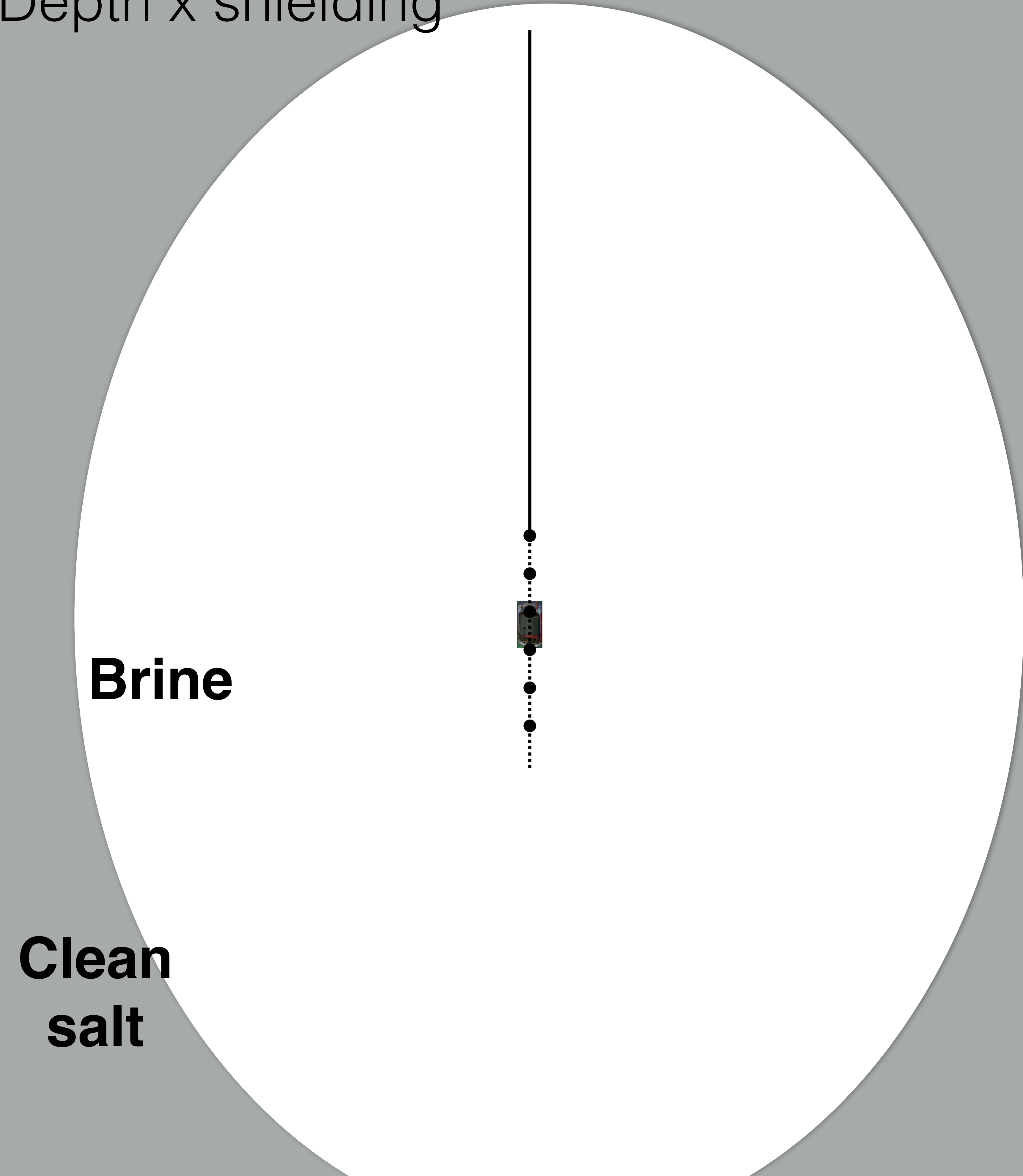

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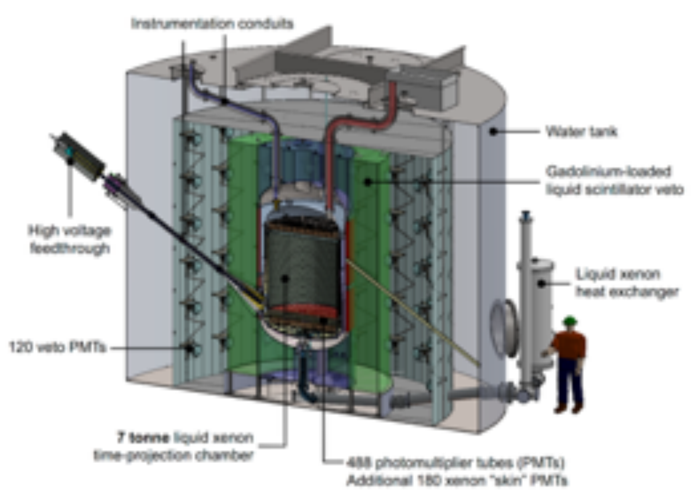

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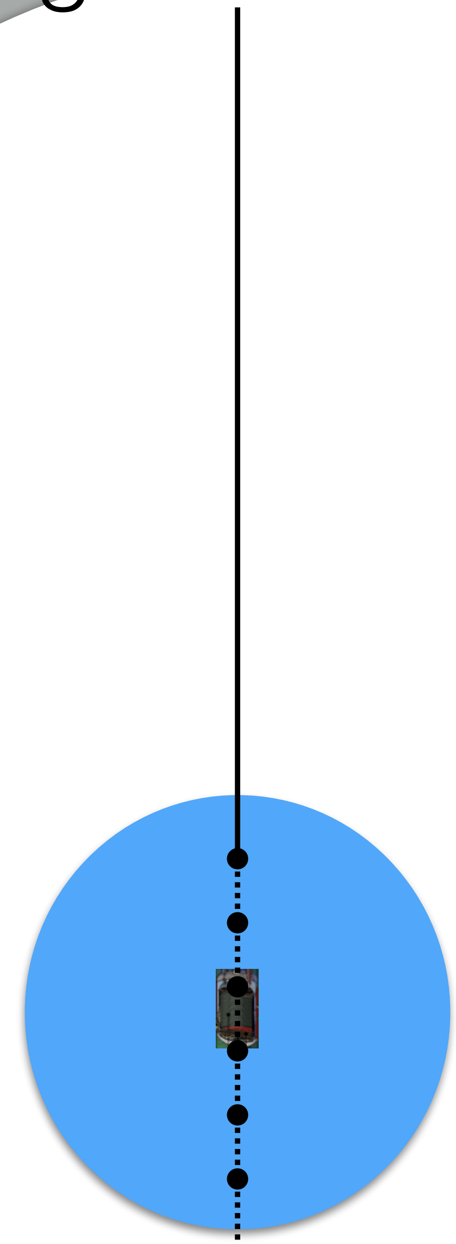

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Any small experiment (DM-ICE)
+clear water balloon
+a few PMTs
= lots of shielding

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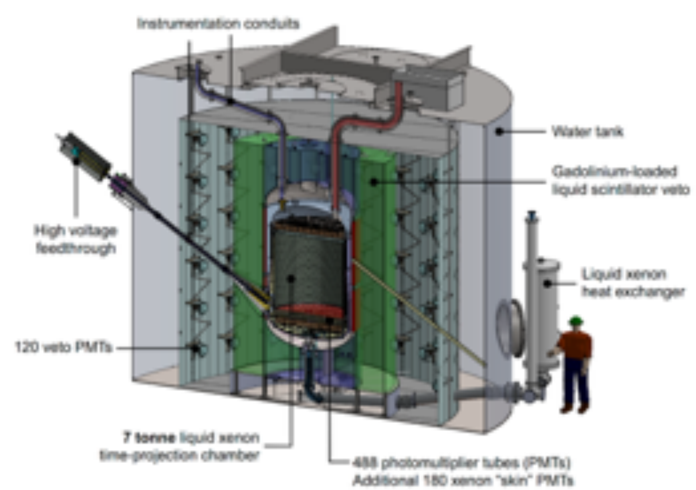

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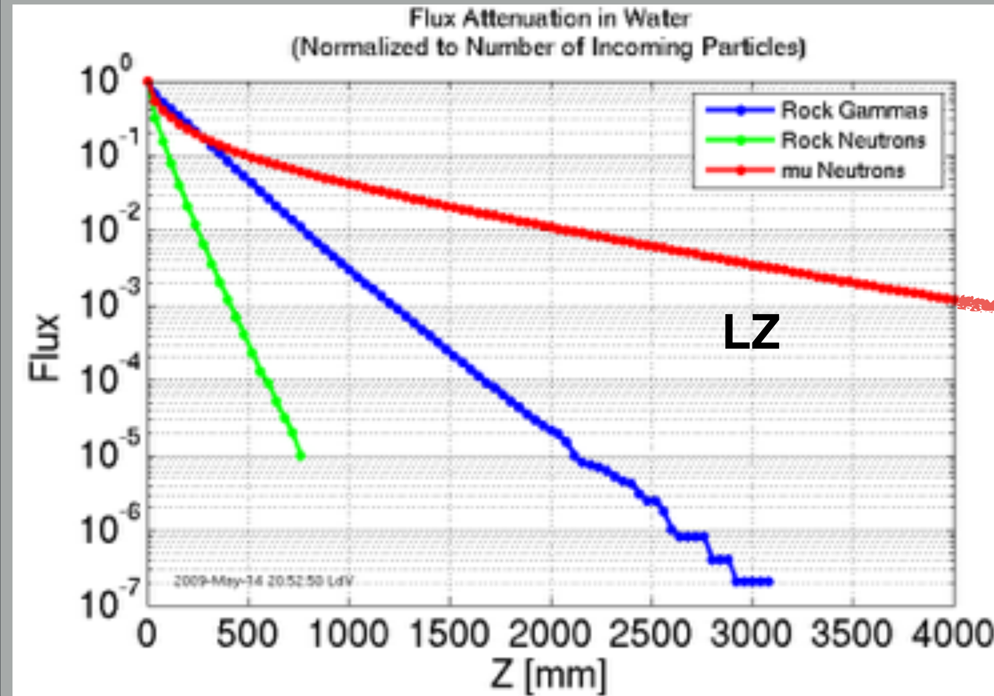
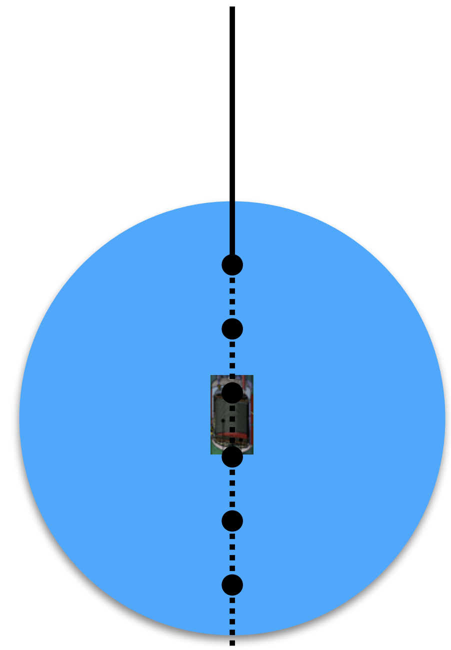


Luiz de Viveiros thesis

10–20m water suppresses μ-induced neutrons by 10^2–10^3 over LZ



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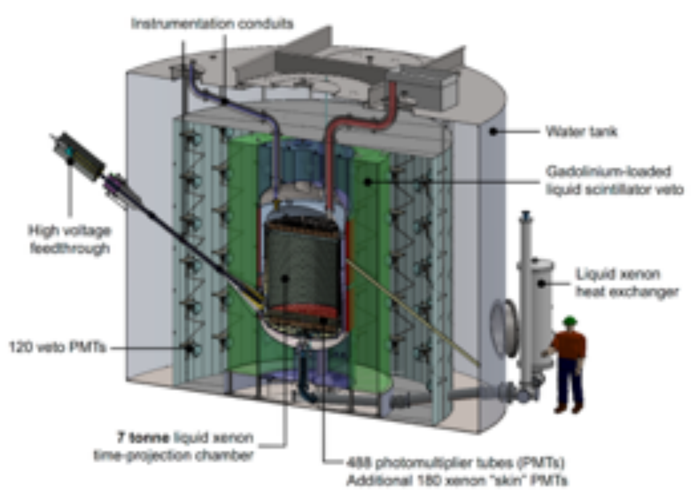

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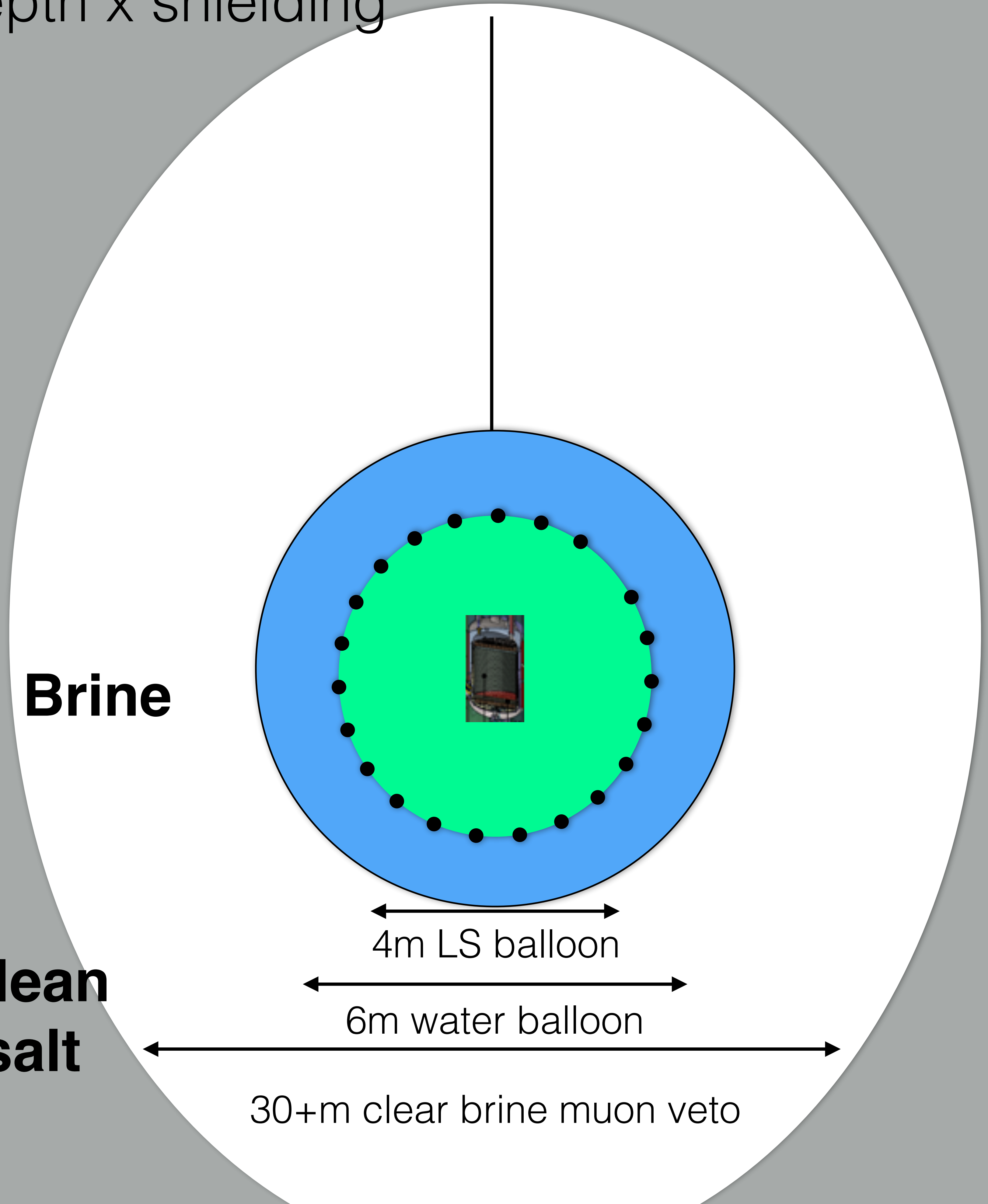


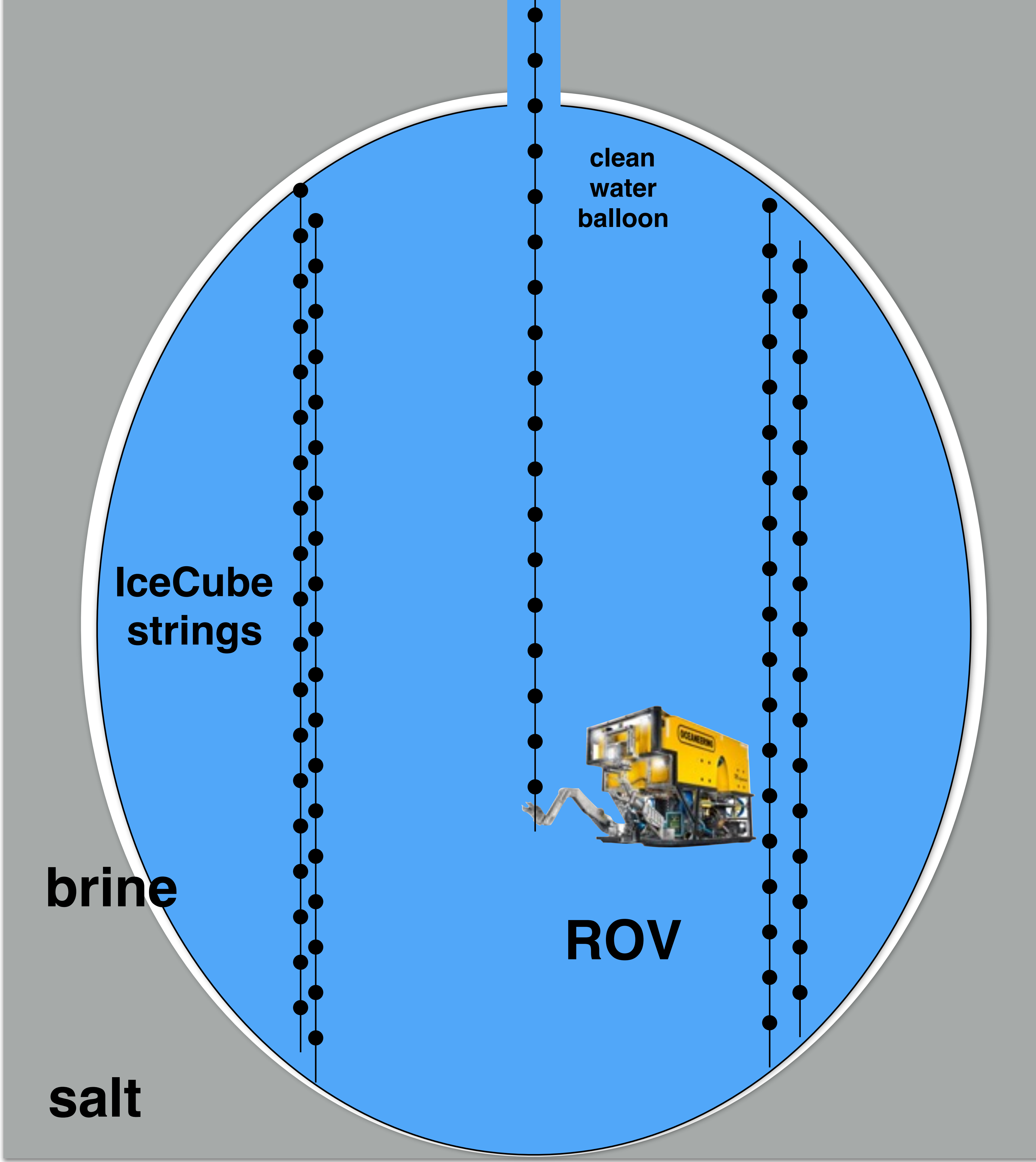
Clean salt

Giant water Cerenkov detector:

80mø x 250m
1.25 MT total

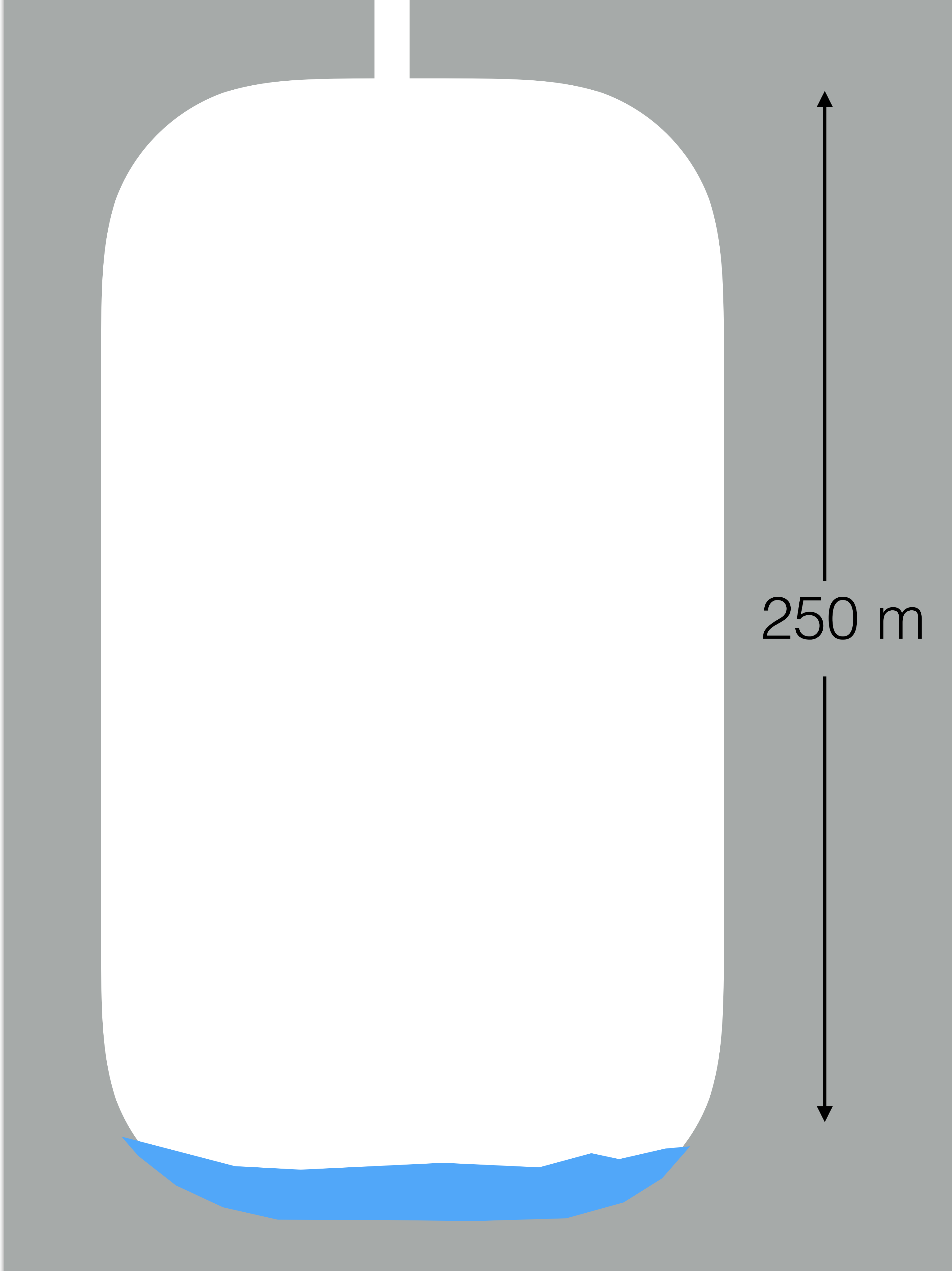
$30M excavation
$5M ROV
lots of 10" PMTs

(HyperK-like PMT coverage would be expensive. Any physics call for a cheap version?)



Giant TPCs

- Complicated electronics, small borehole?
  - "we're already building DUNE in a confined space"
  - Only the anode array is complicated, cathode is simpler
- Solution:
  - Cylindrical drift geometry
  - Inflatable cathode
  - Drift electrons as far as you can manage
- Favorite sketch: 1kT neon in a 16 x 80m balloon
- Sequence of fluids and pressures is tricky



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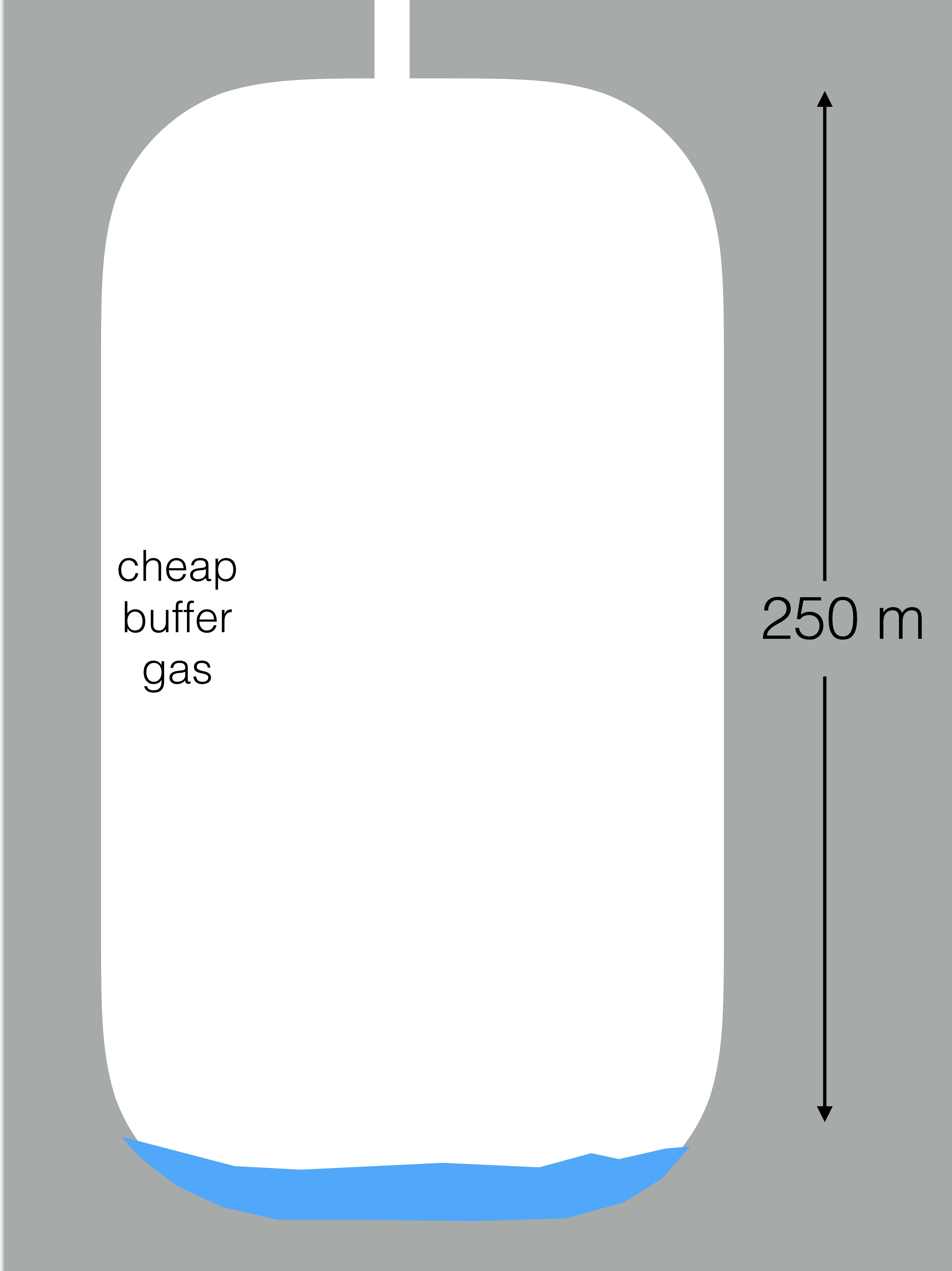

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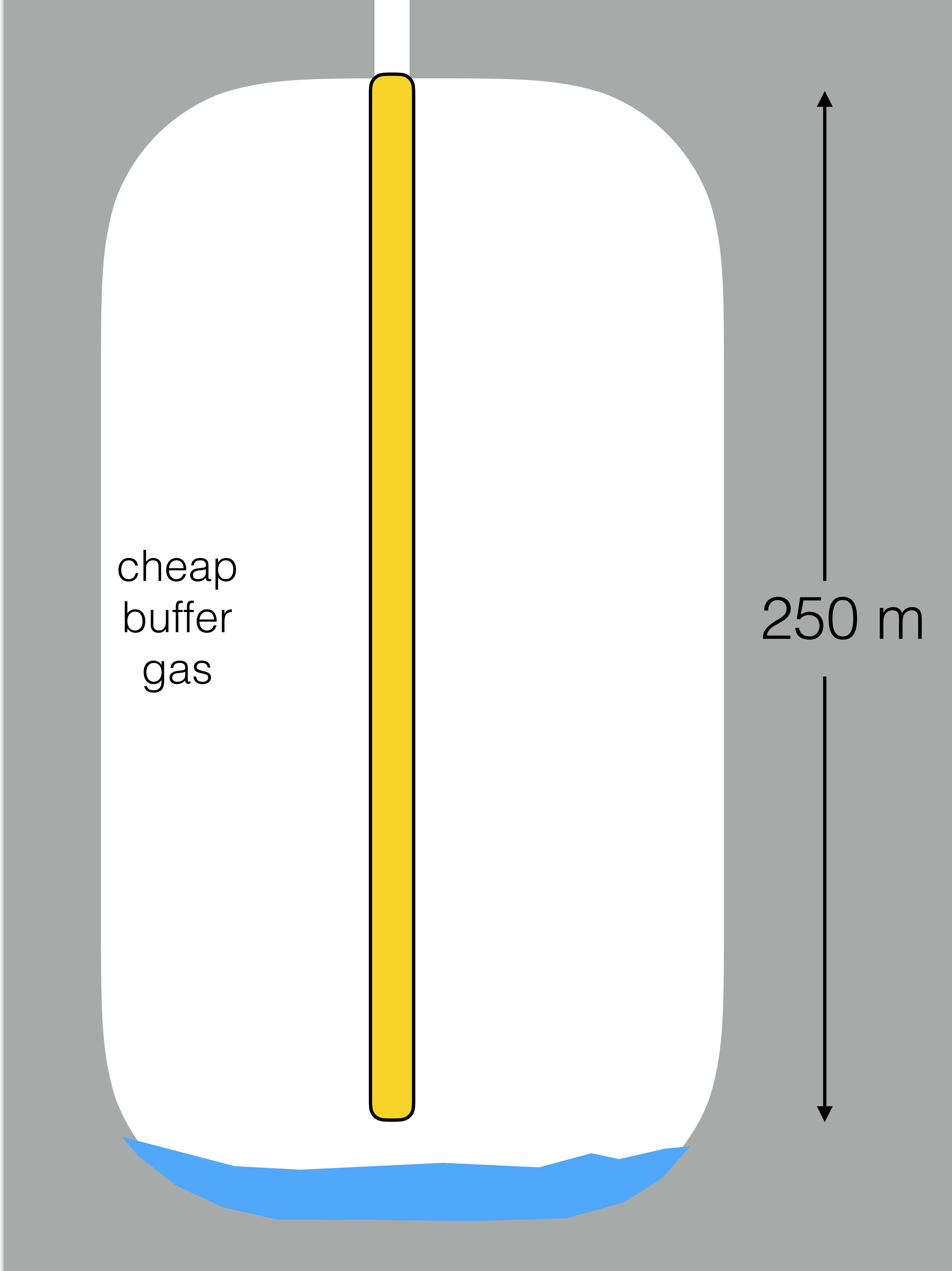

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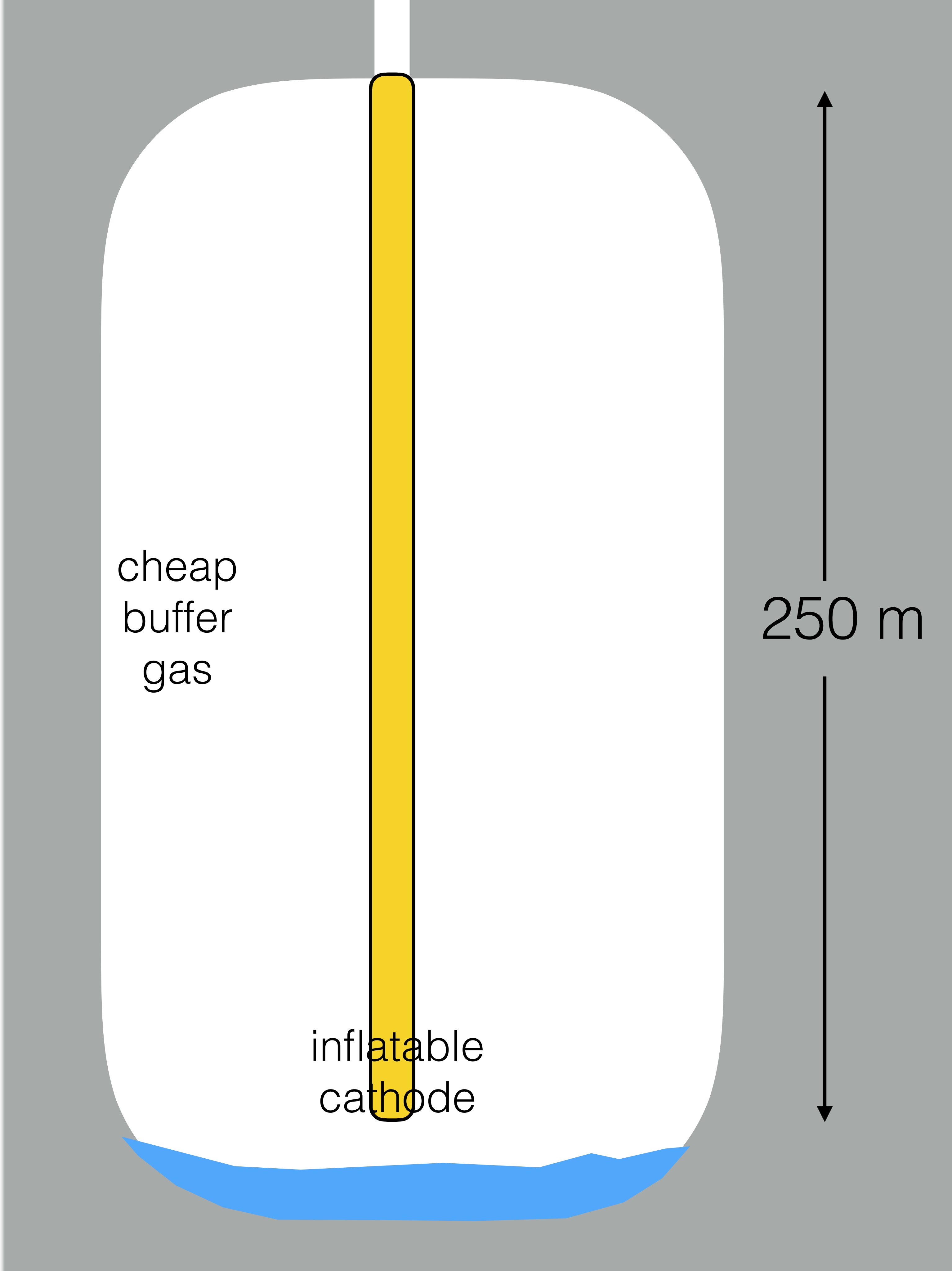

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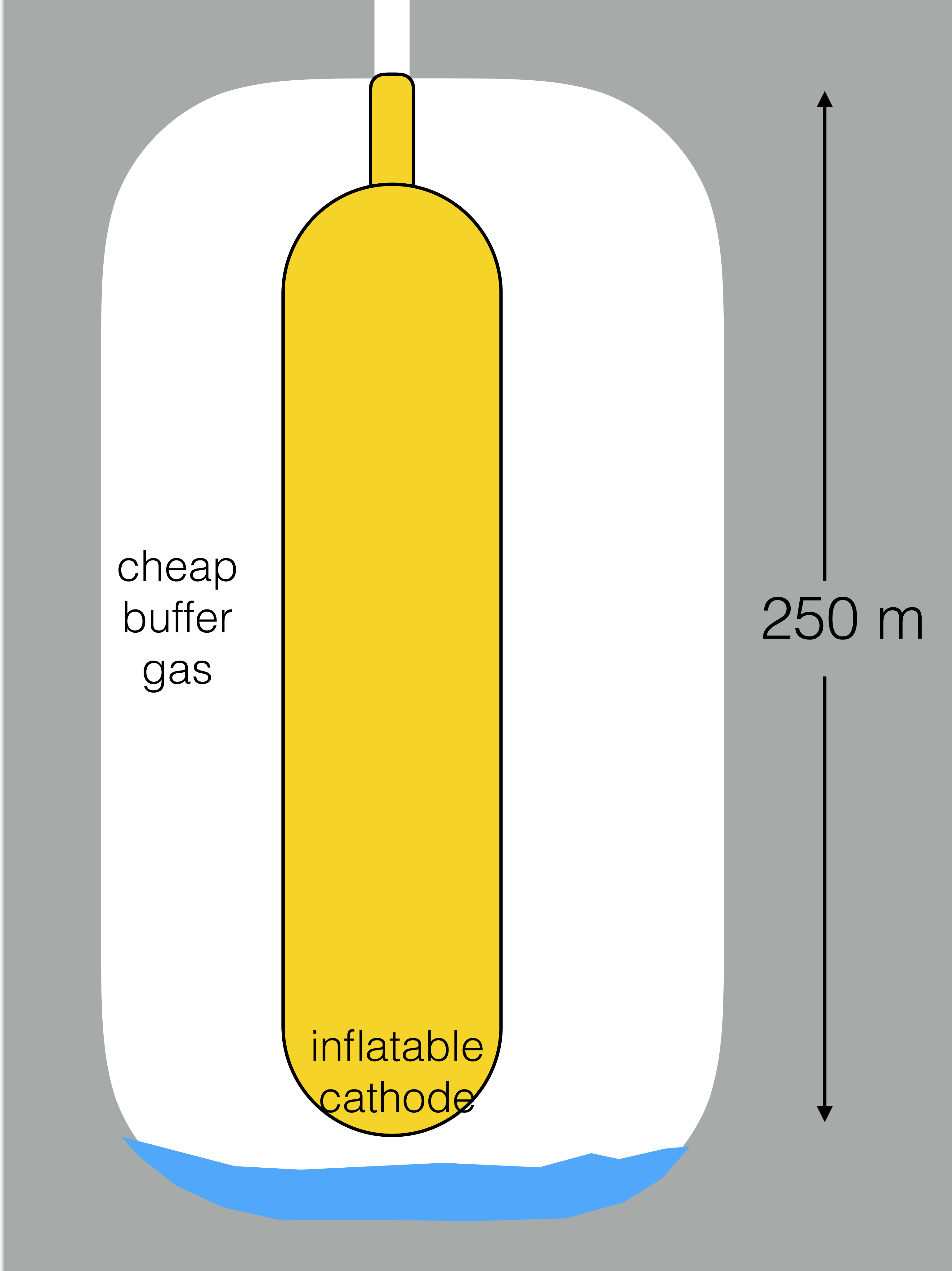

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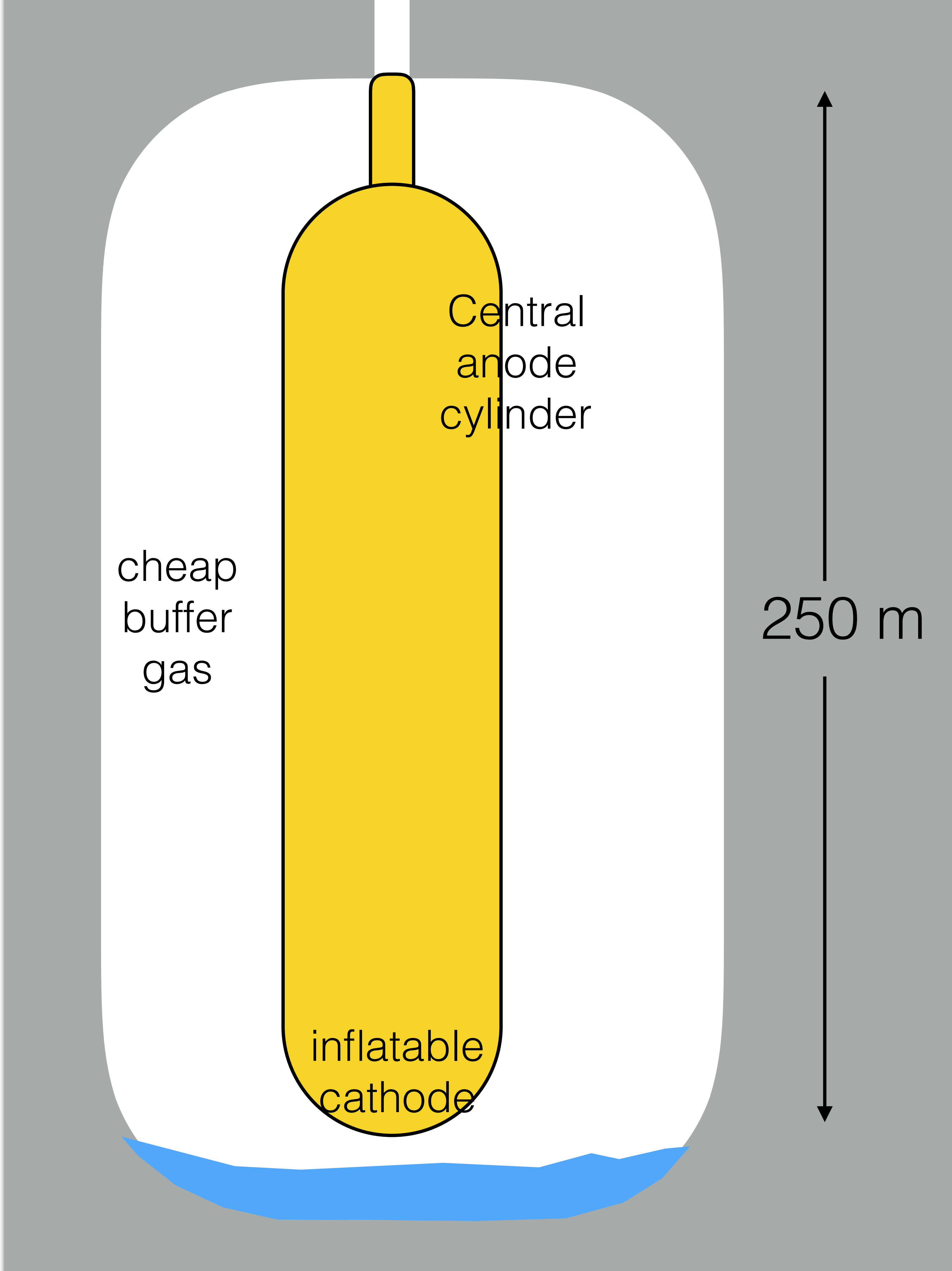

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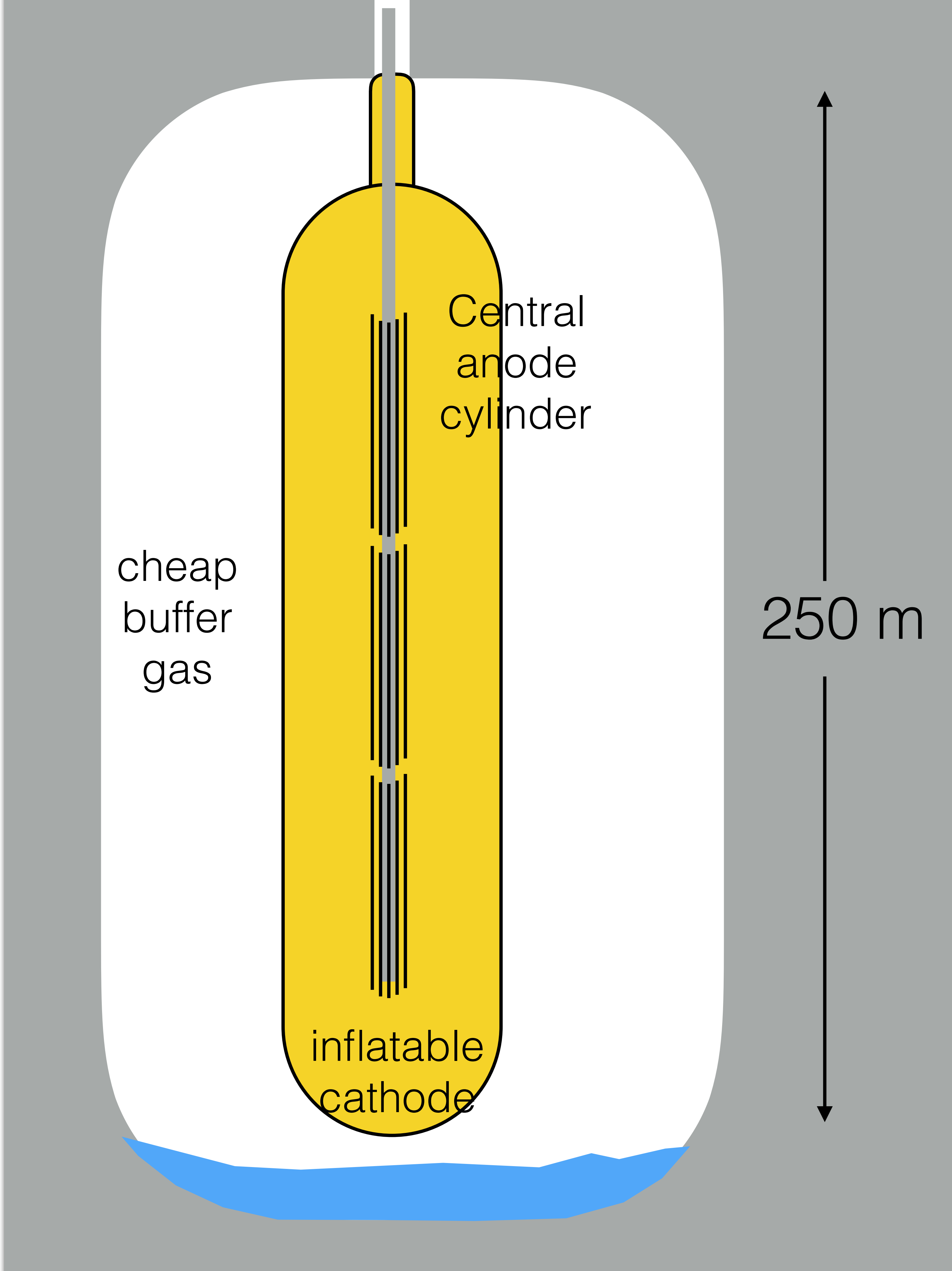
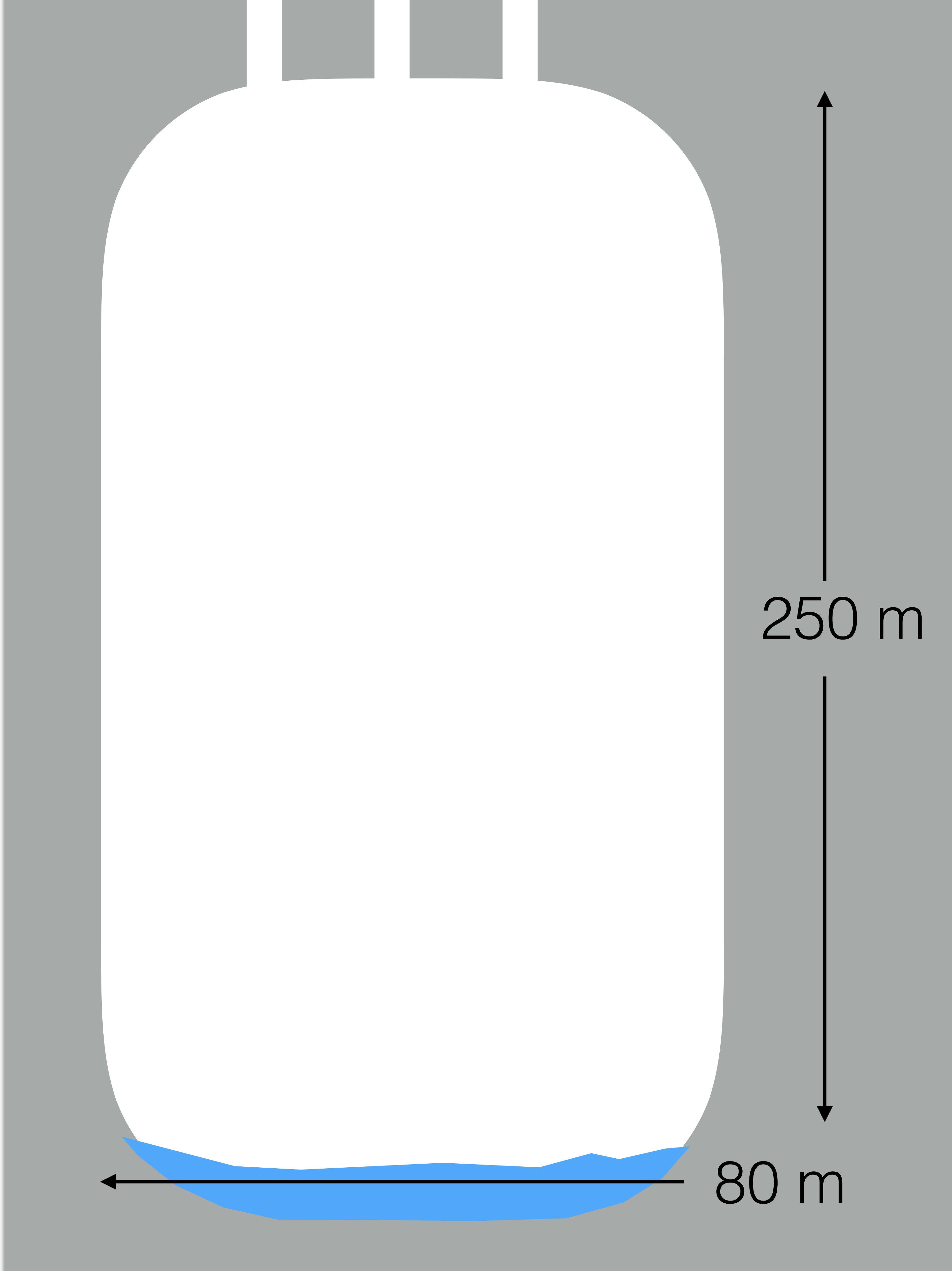


Even bigger TPCs

- Can we get to 500kT scale? (3×10^{35} nucleons)
- CO_2, CH_4, Ar only
- Idea 1: Copy-paste self-contained units
  - (Dead volume between them? Lost gammas?)
  - Drilling isn't free



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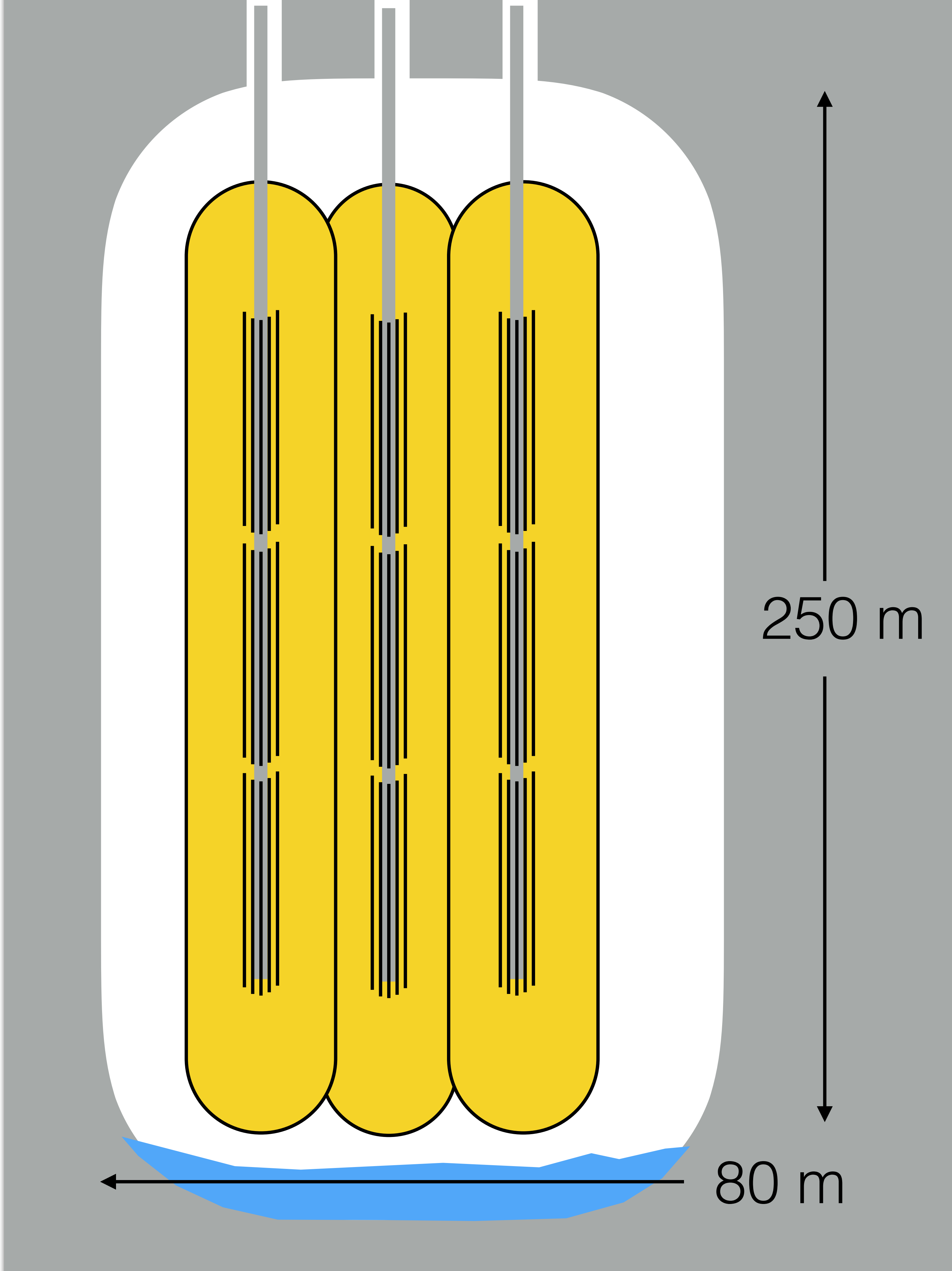

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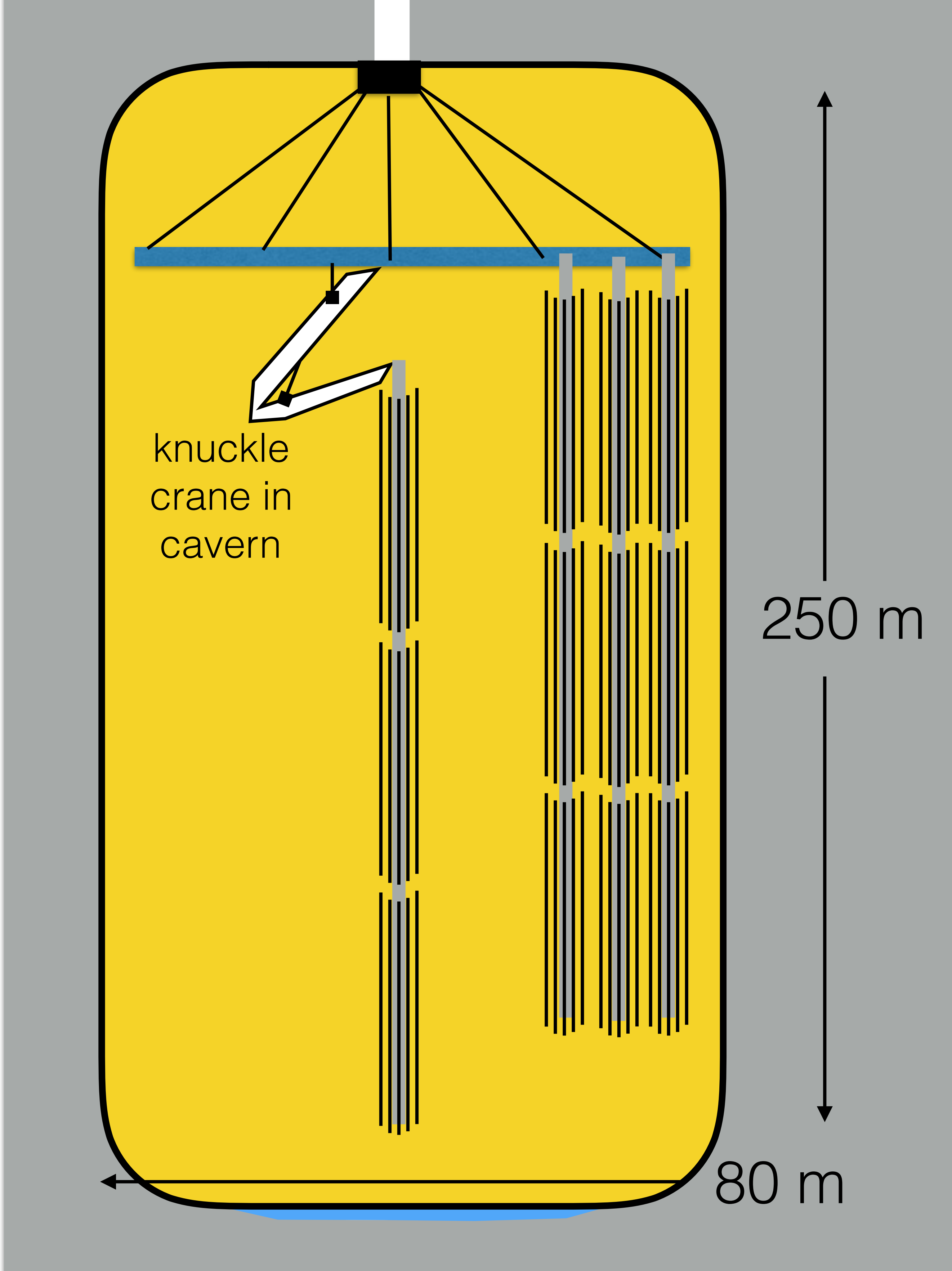
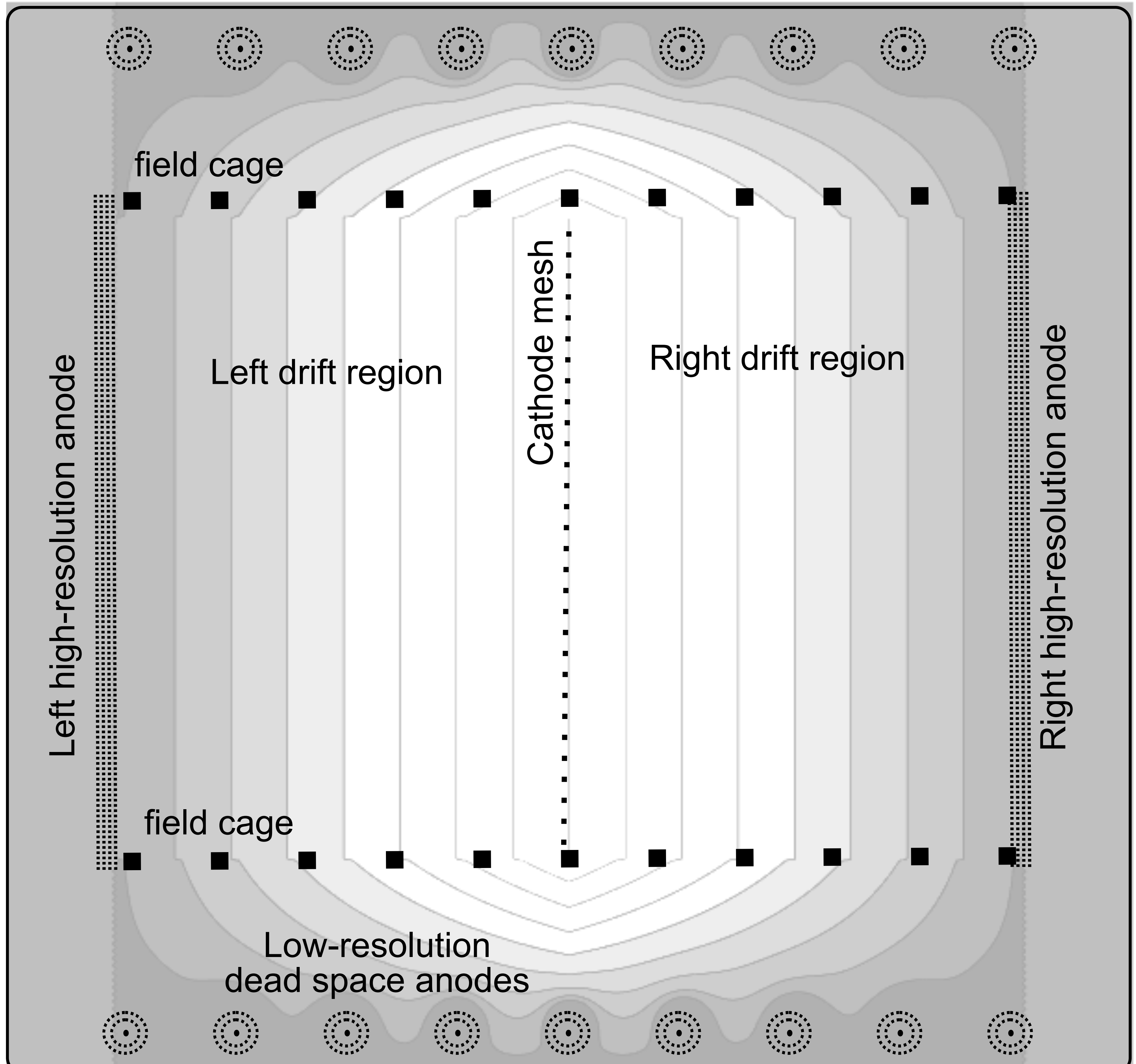
- Idea 2: More elaborate sideways motion inside large single balloon
  - Origami?
  - In-cavern robotic tools?
  - I'll believe it when I see it



Freeing the TPC from the PMT

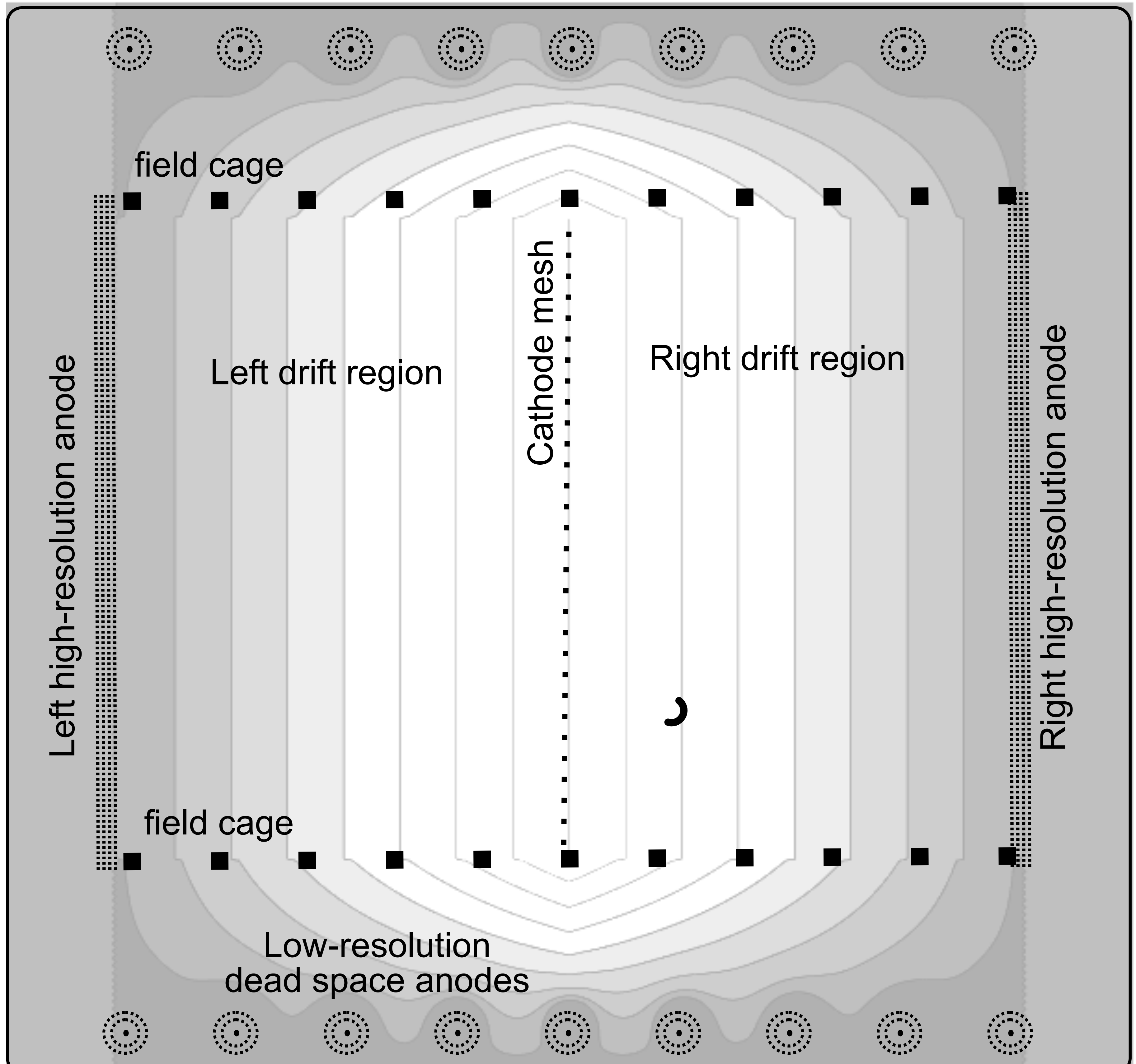
Large gas time projection chamber



arxiv:1512.04926

Large gas time projection chamber

Ionizing event on left. Charge detected on left after $\Delta t = \Delta z/v_{drift}$, but Δz unknown.



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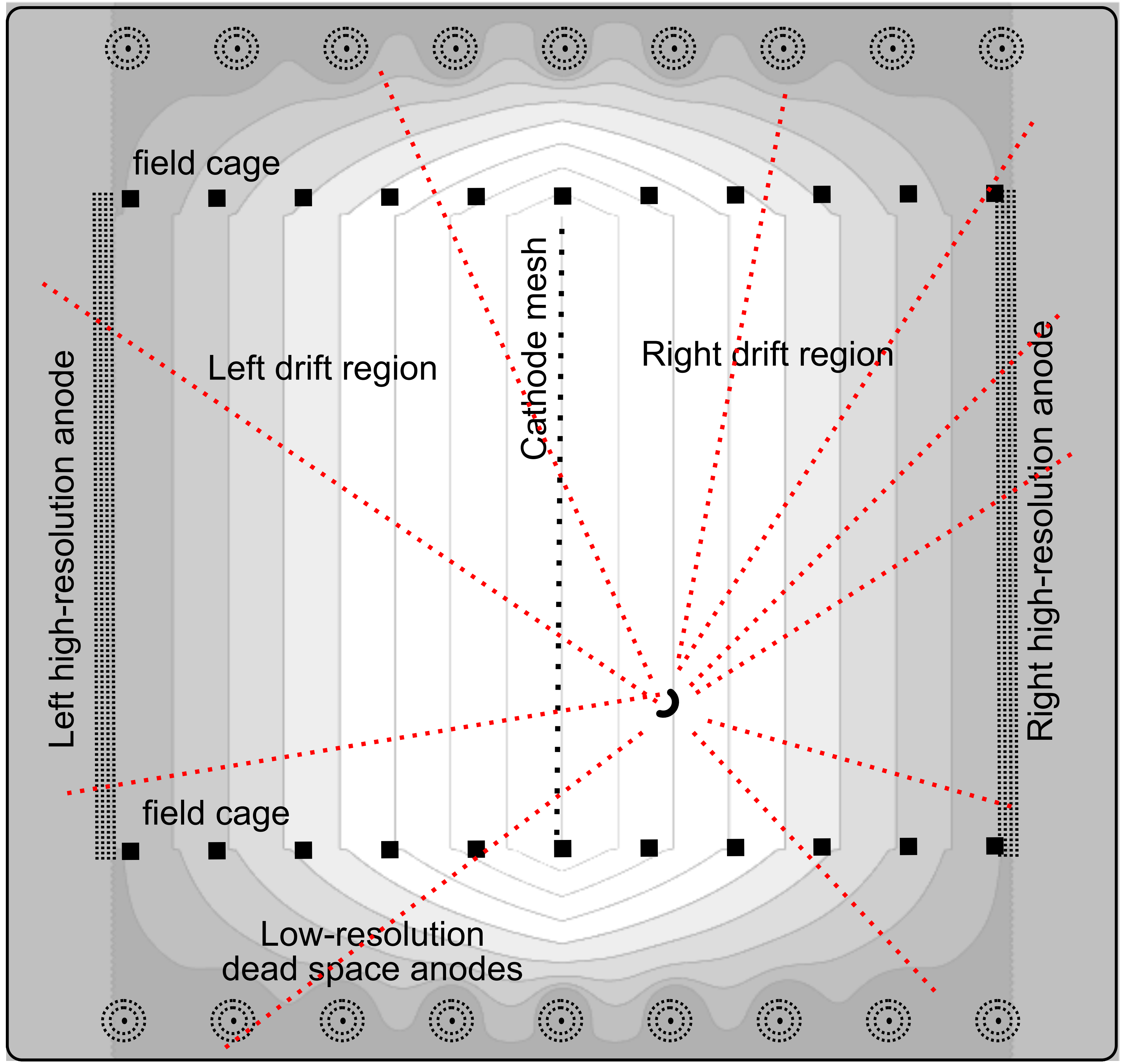
Scintillation light! sets Δt …



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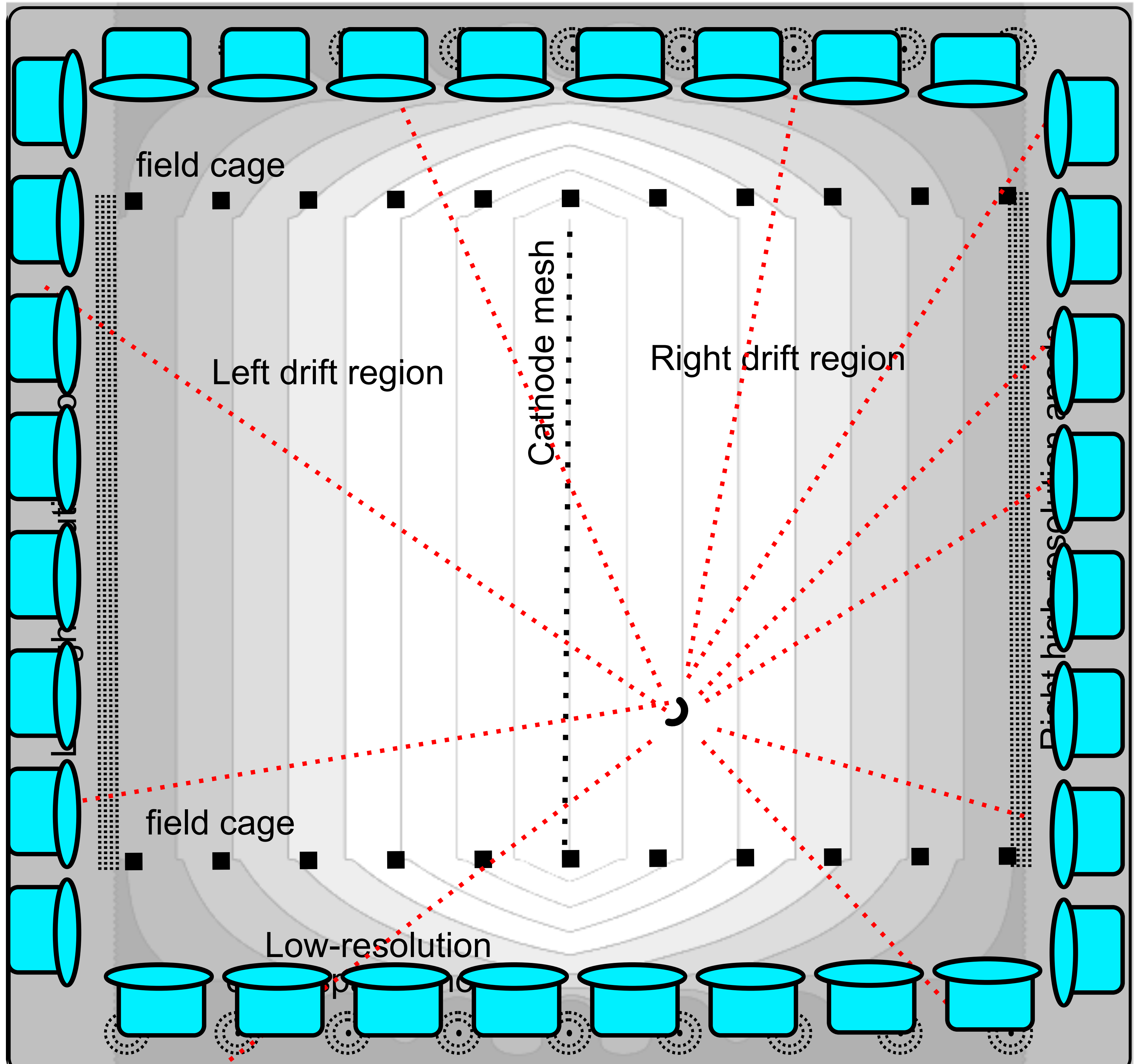

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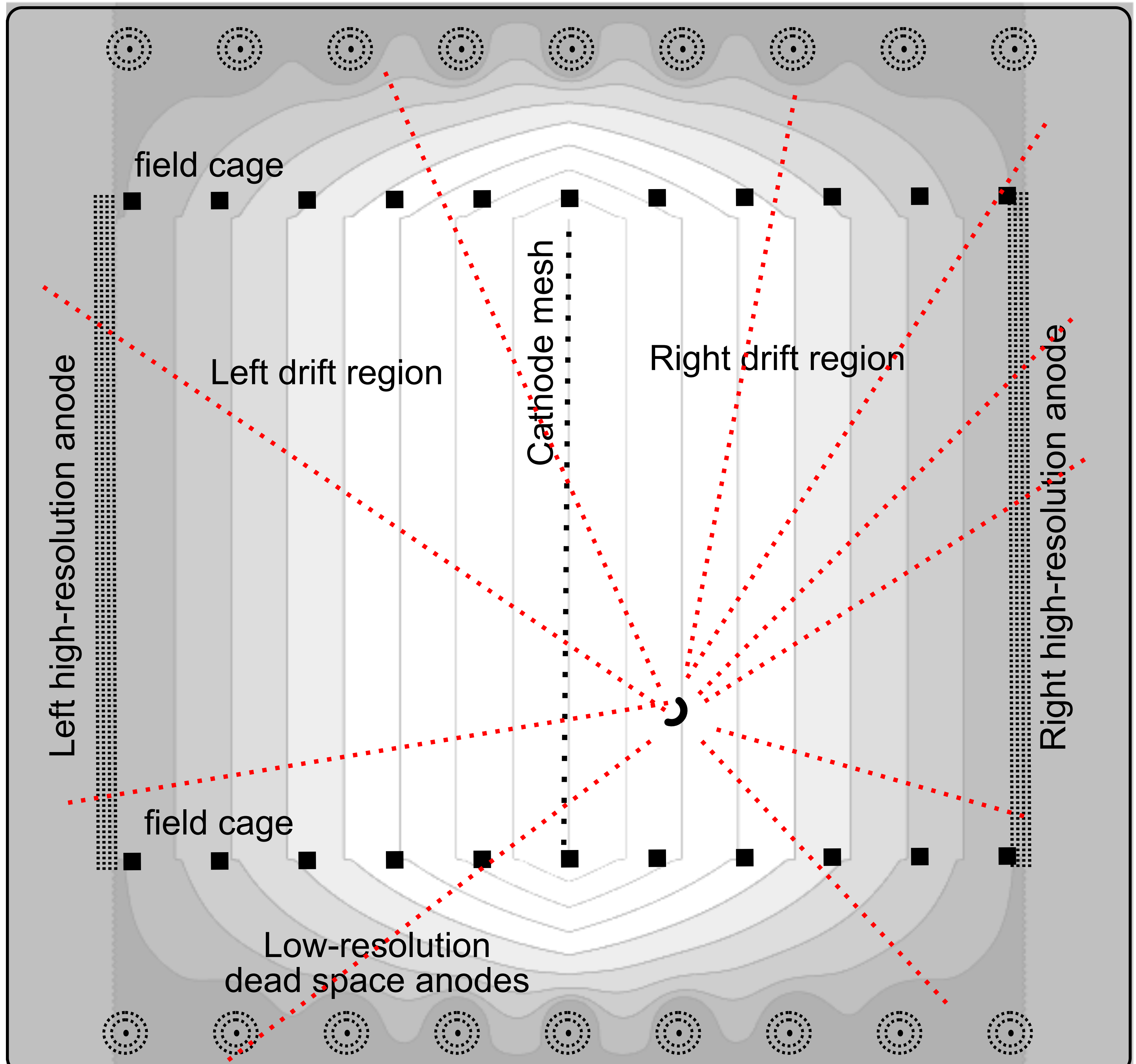

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Ionizing event on left. Charge detected on left after $\Delta t = \Delta z / v_{drift}$, but Δz unknown.

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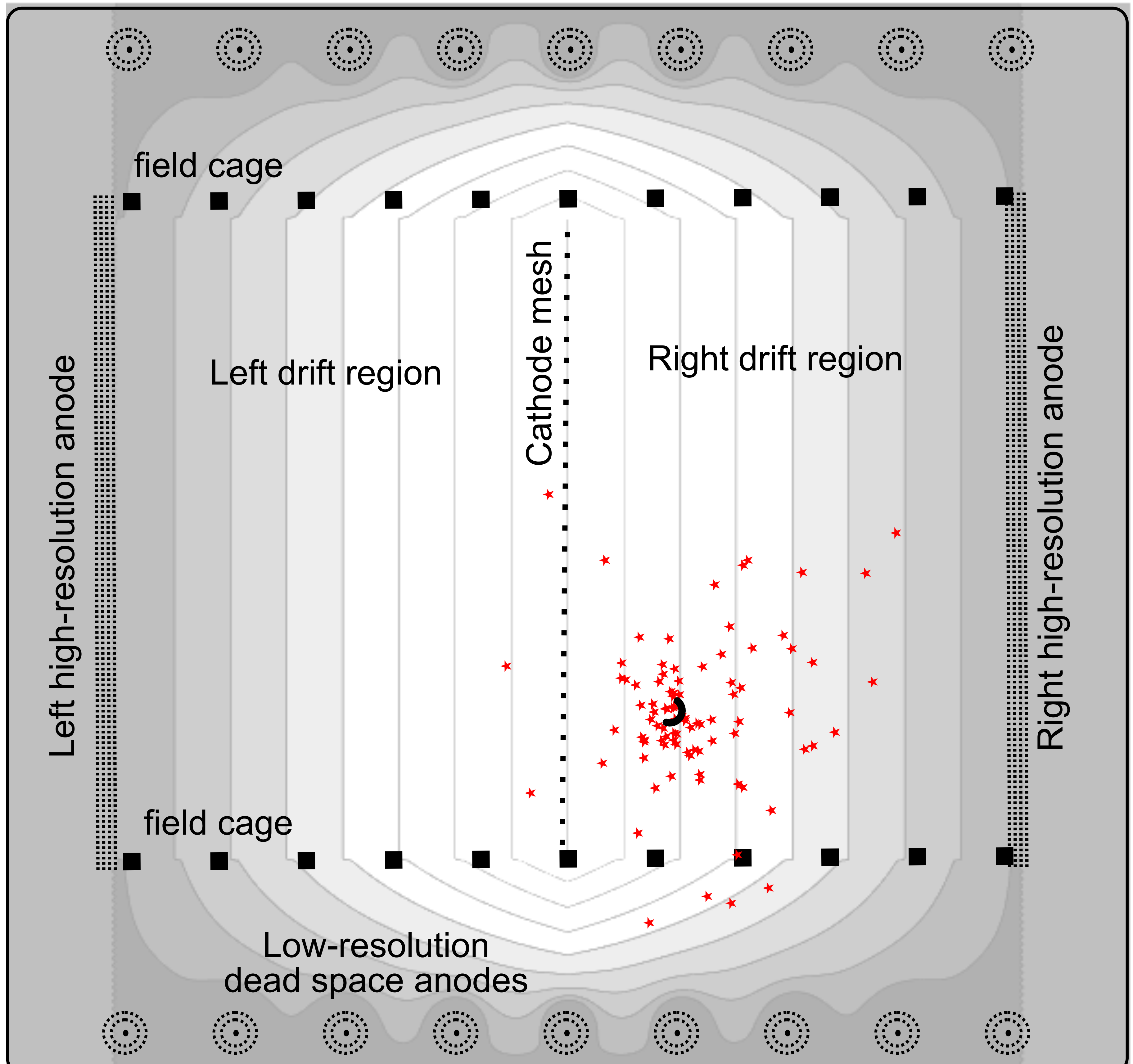
Mix 10^{-7} TMAE into Xe. Converts scintillation photons to photoelectrons.



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right anode

left anode

after $\Delta t = \Delta z / v_{drift}$,
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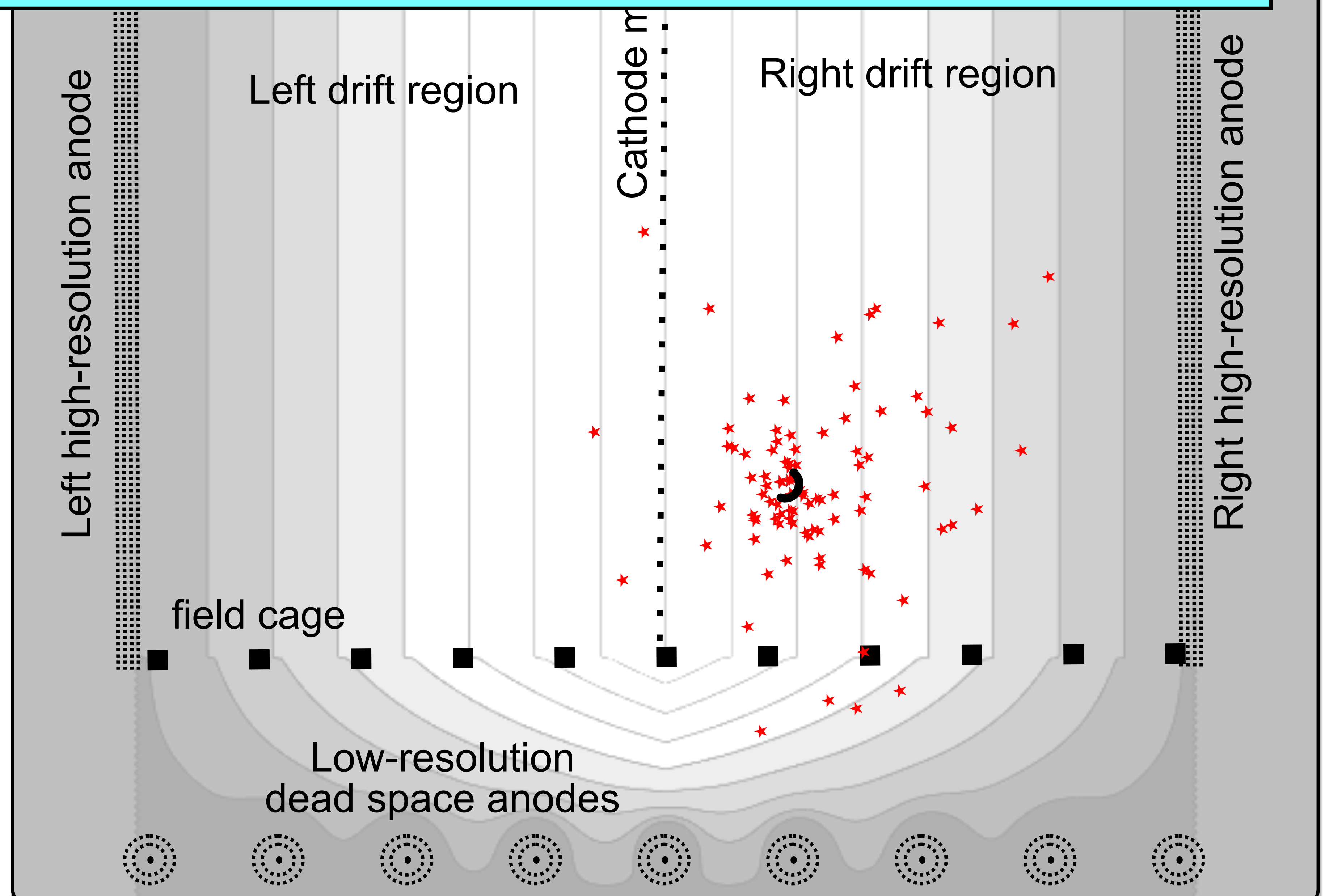

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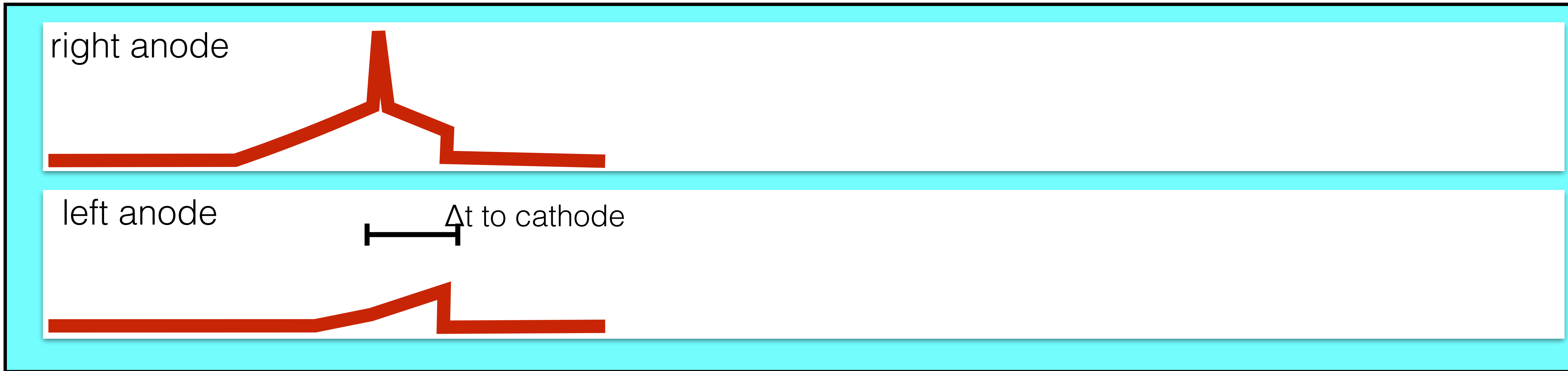

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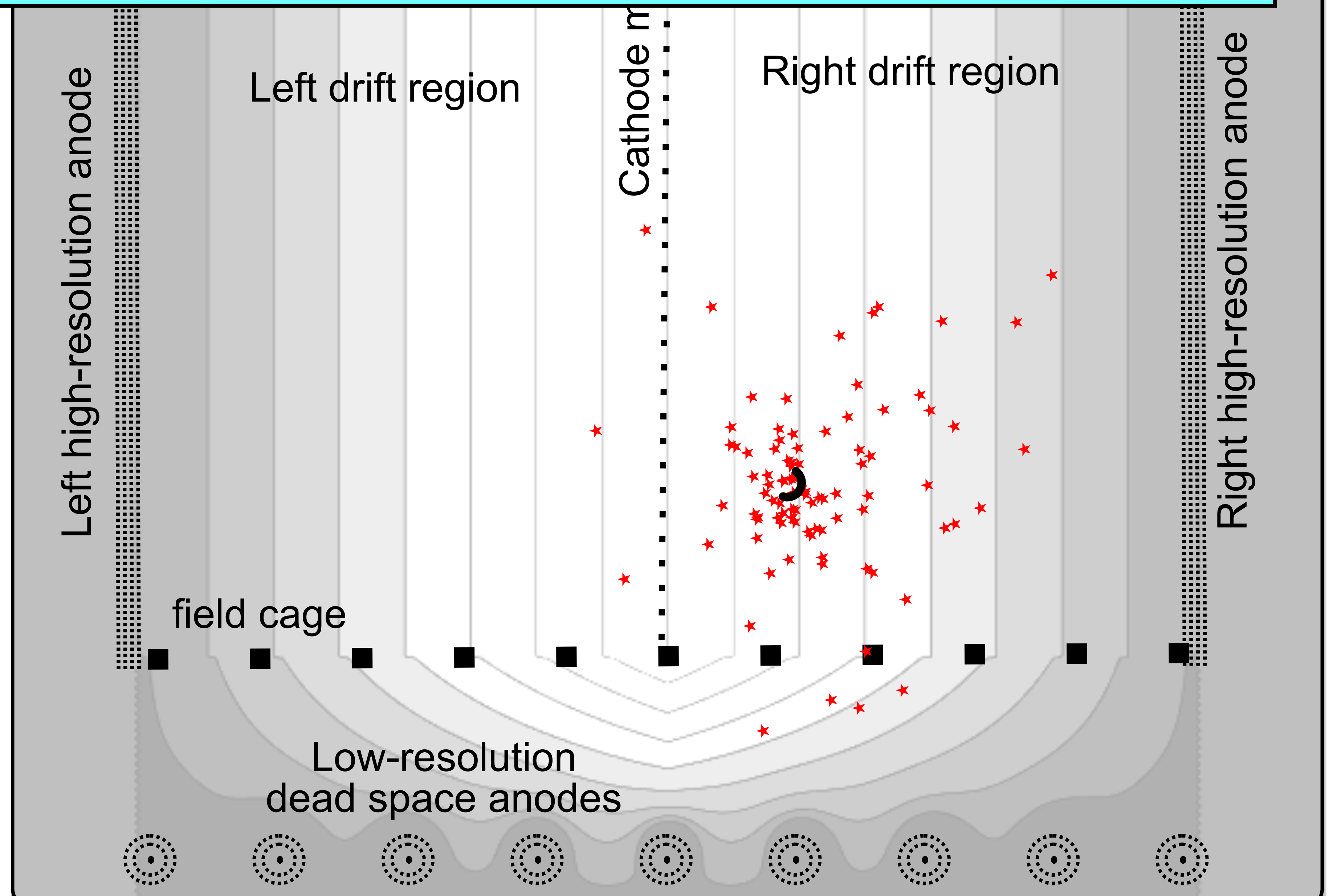

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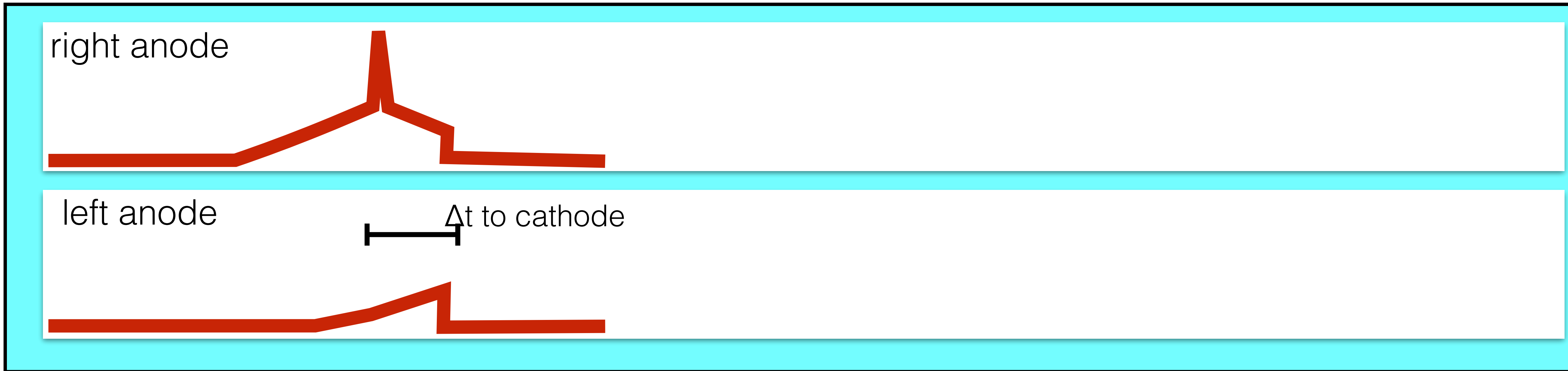

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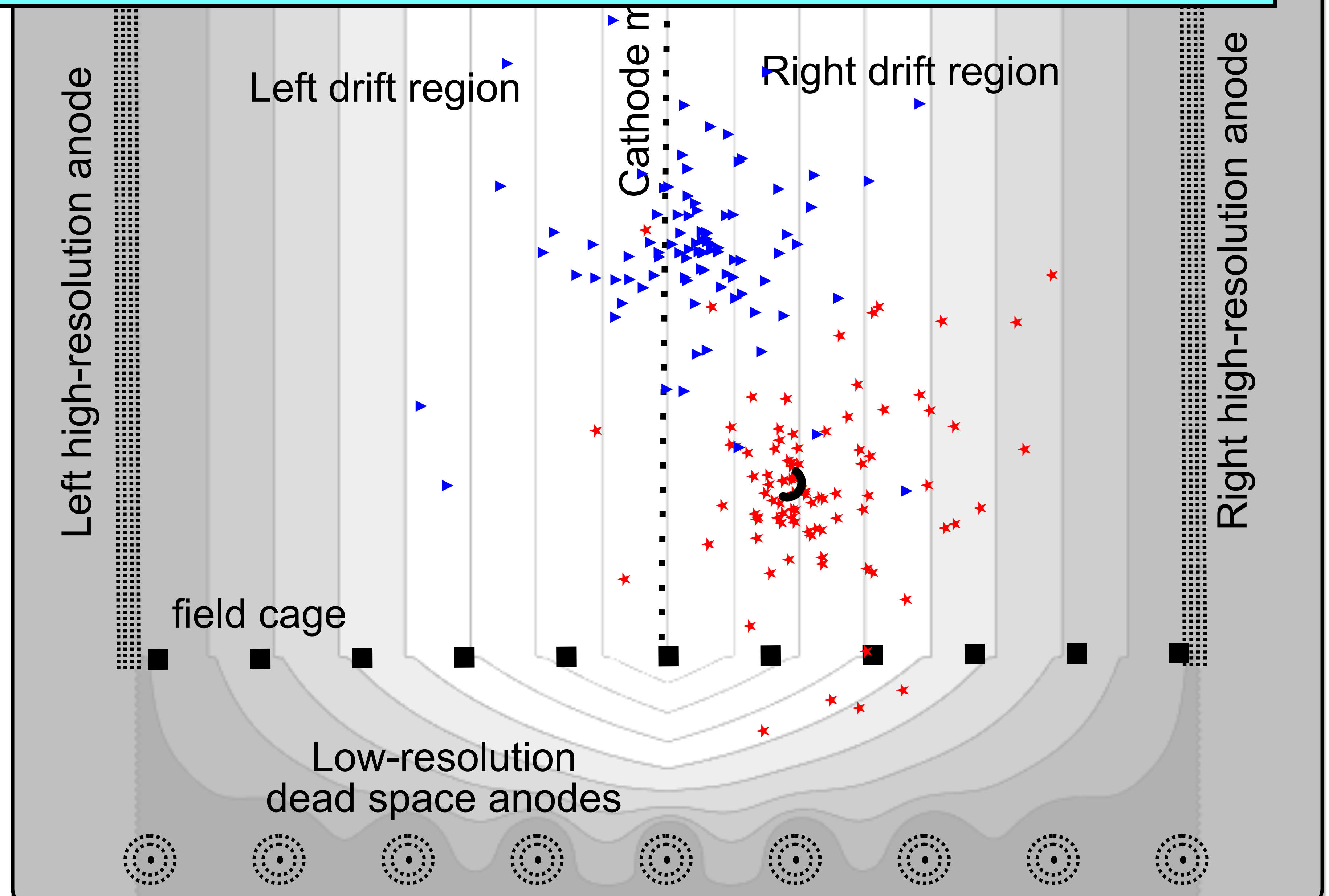

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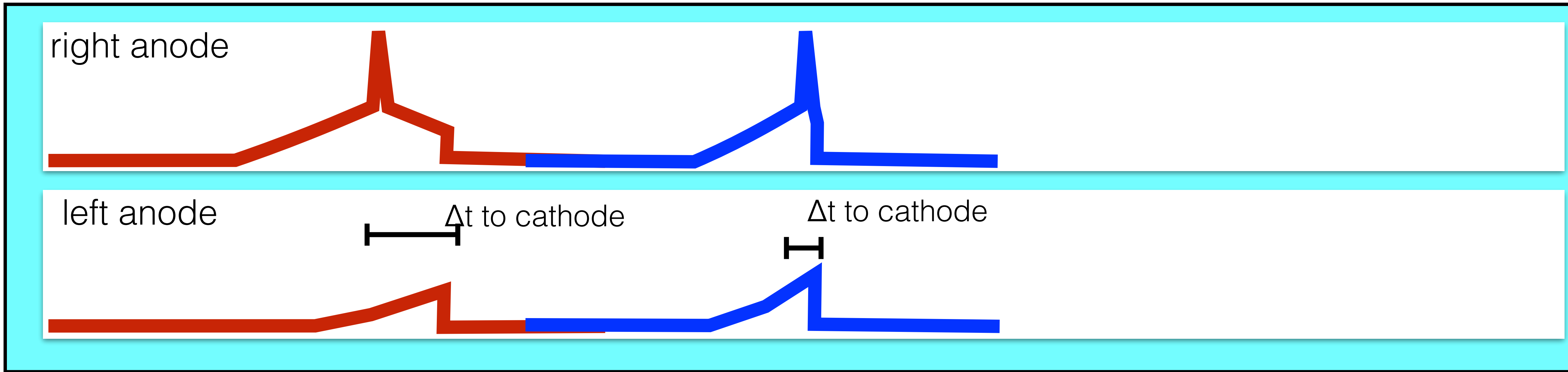

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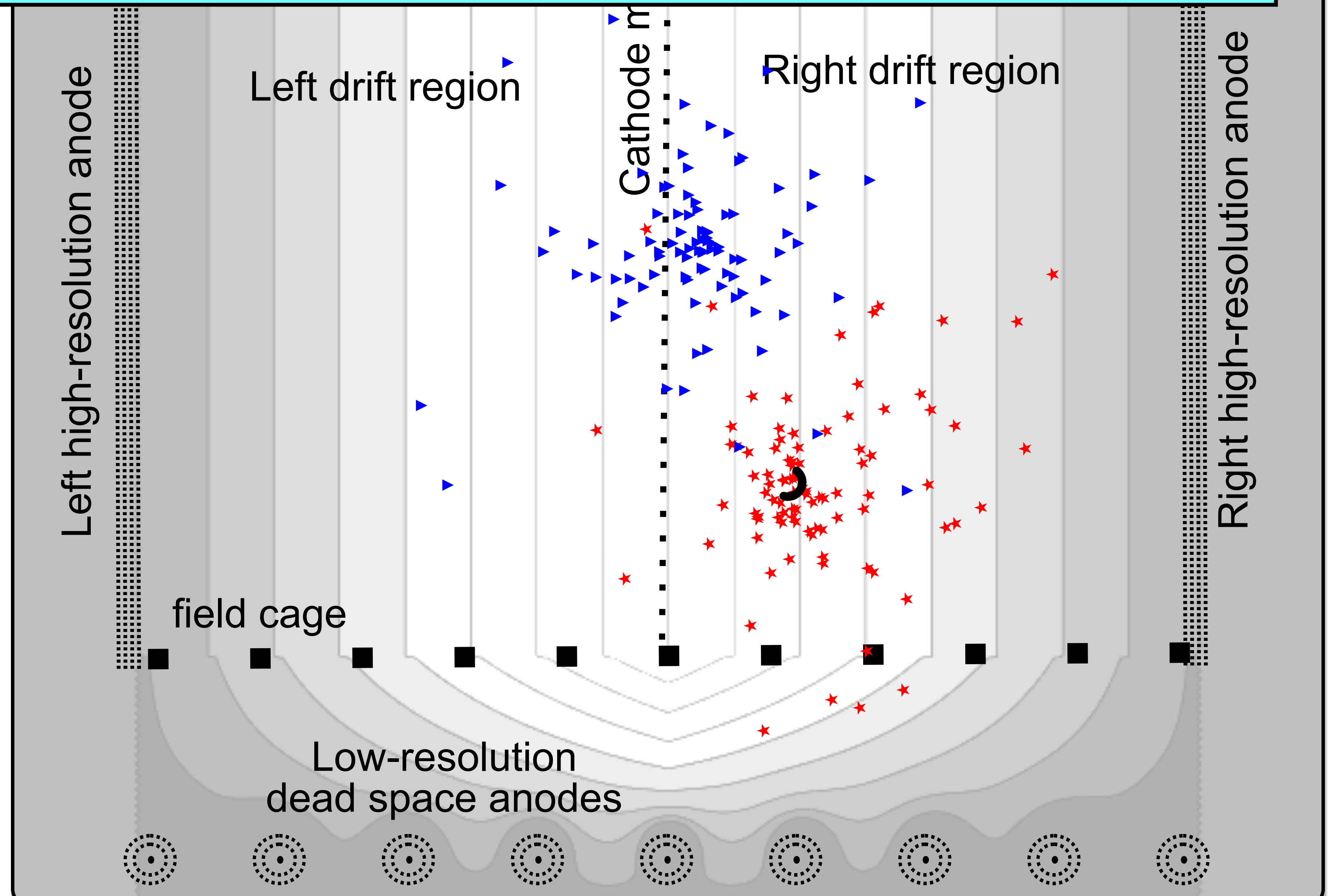

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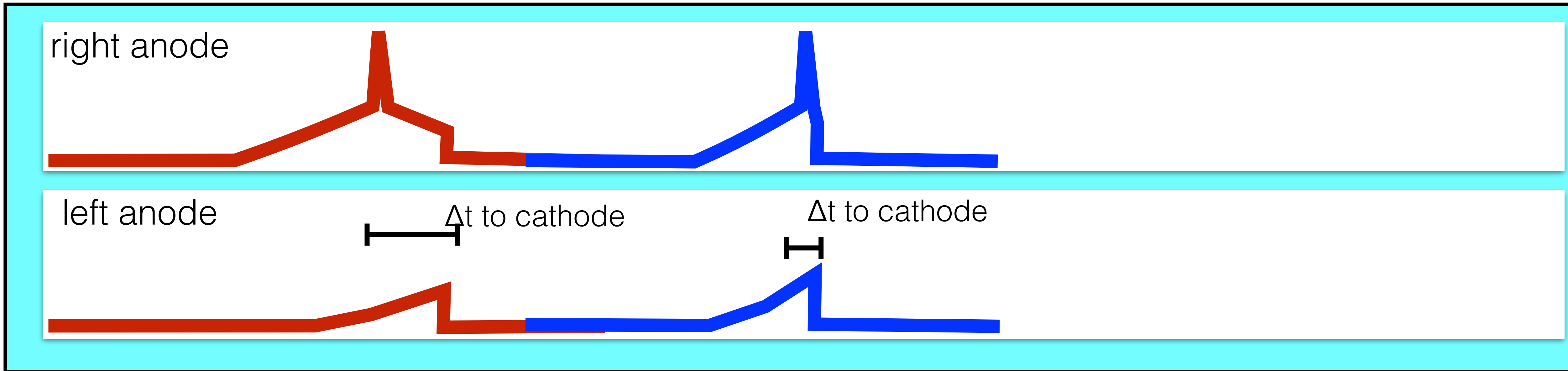

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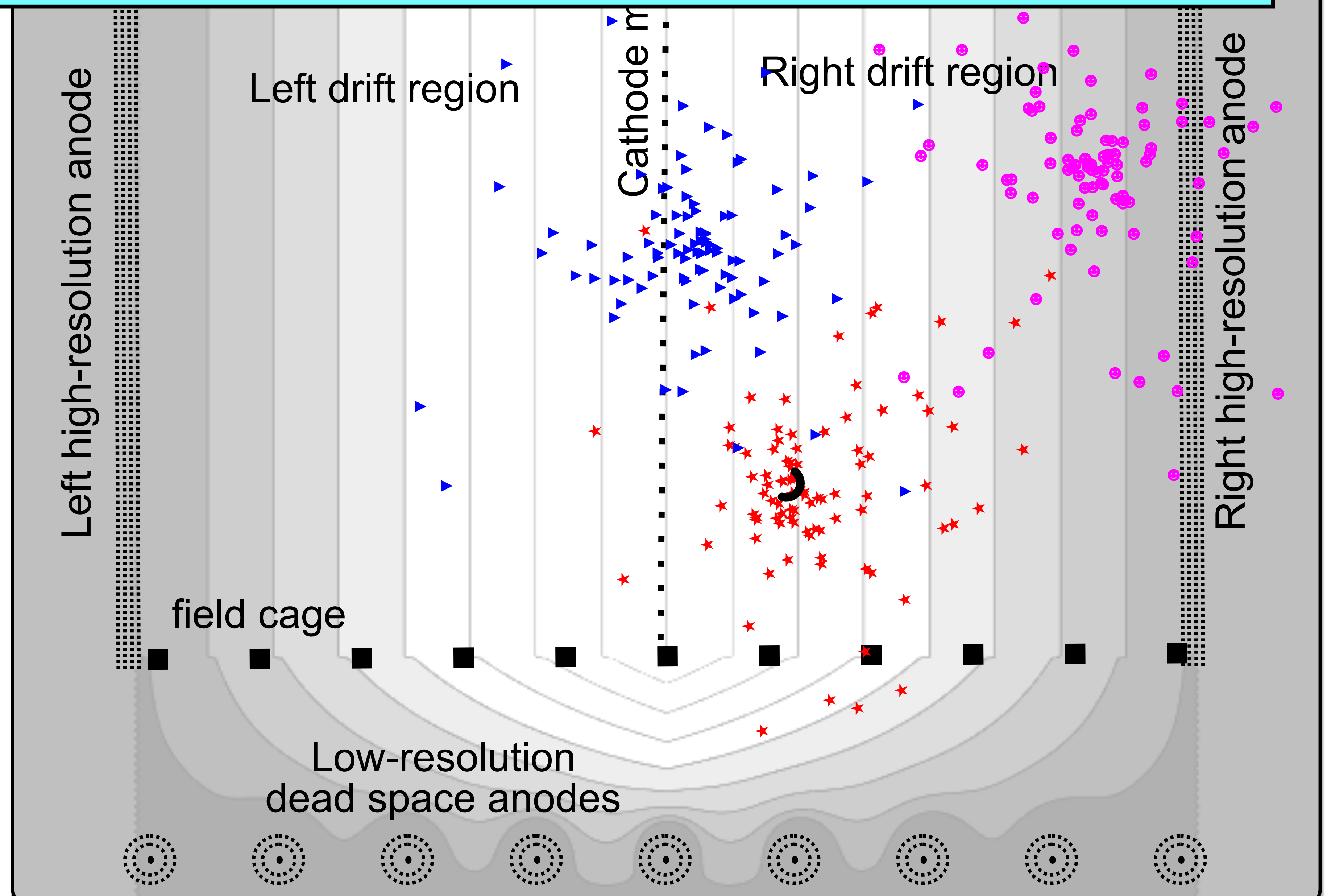

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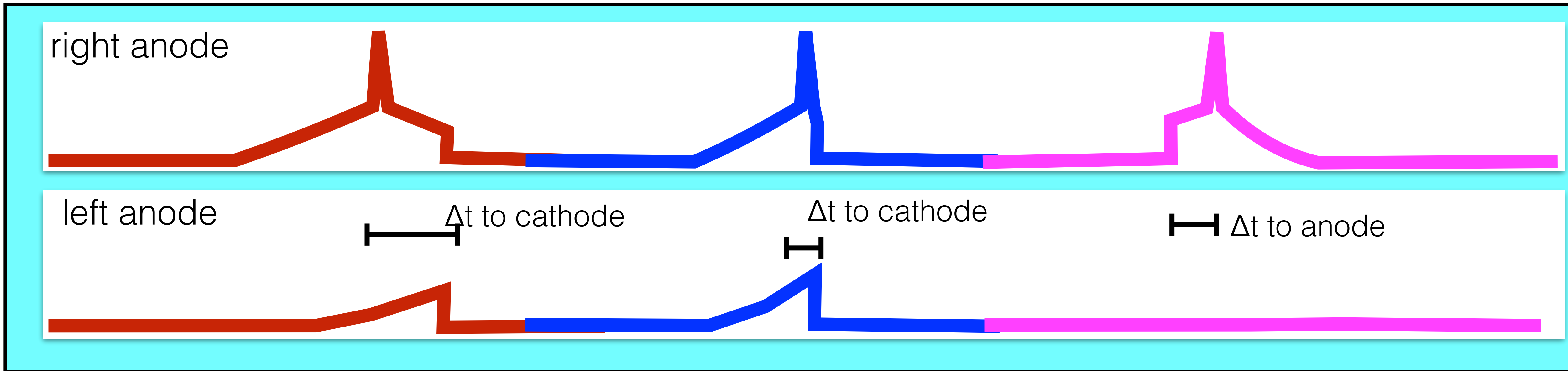

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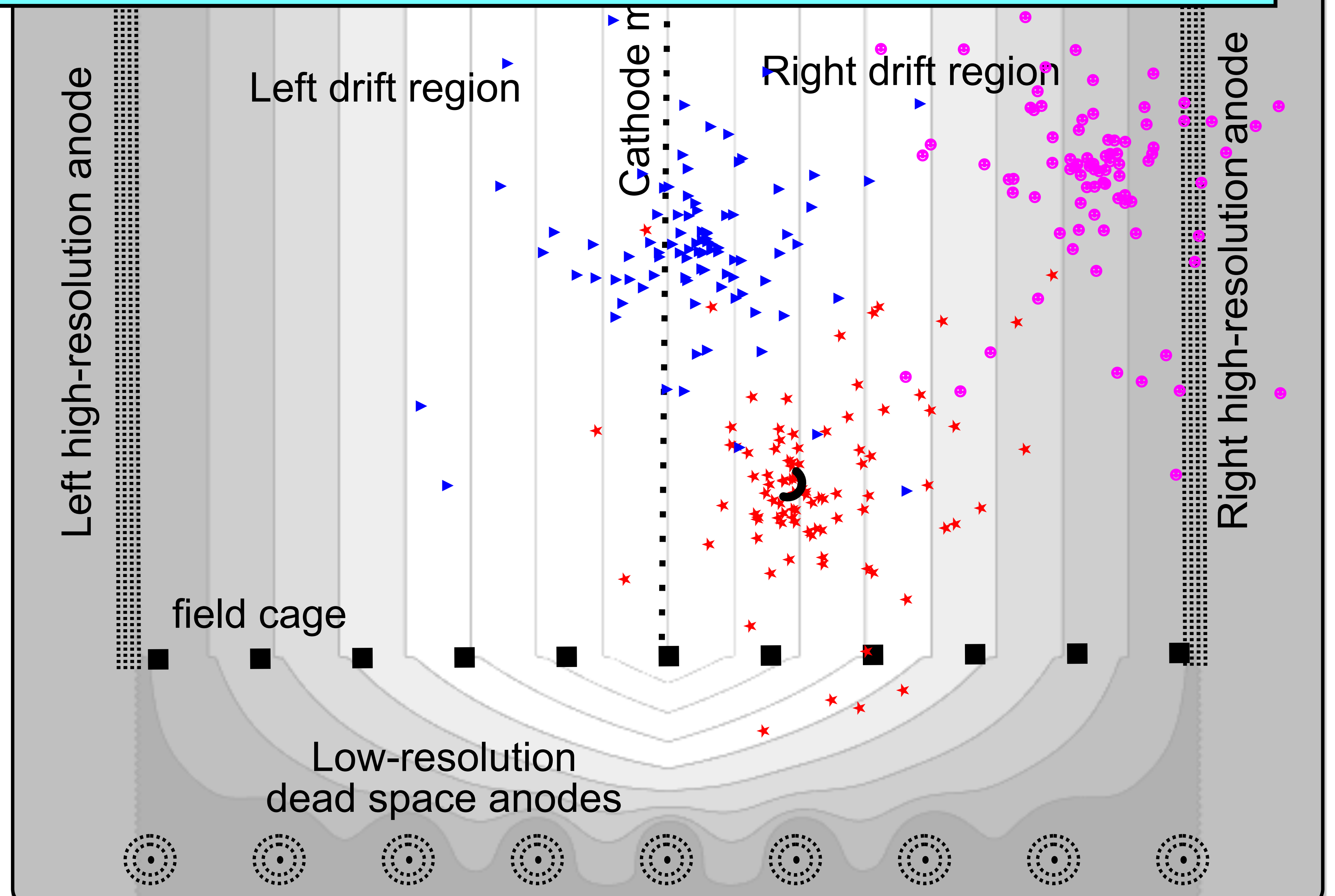

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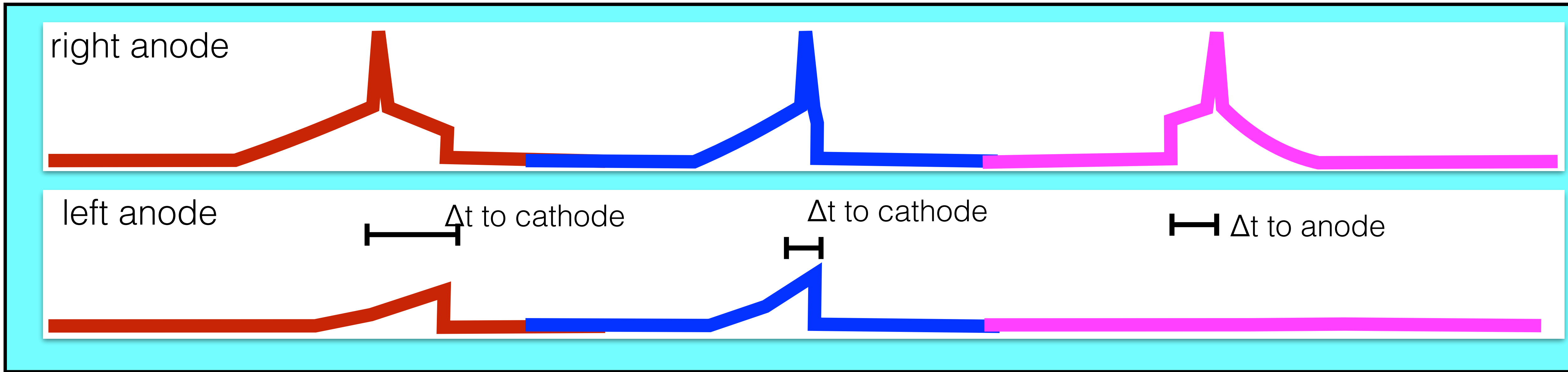

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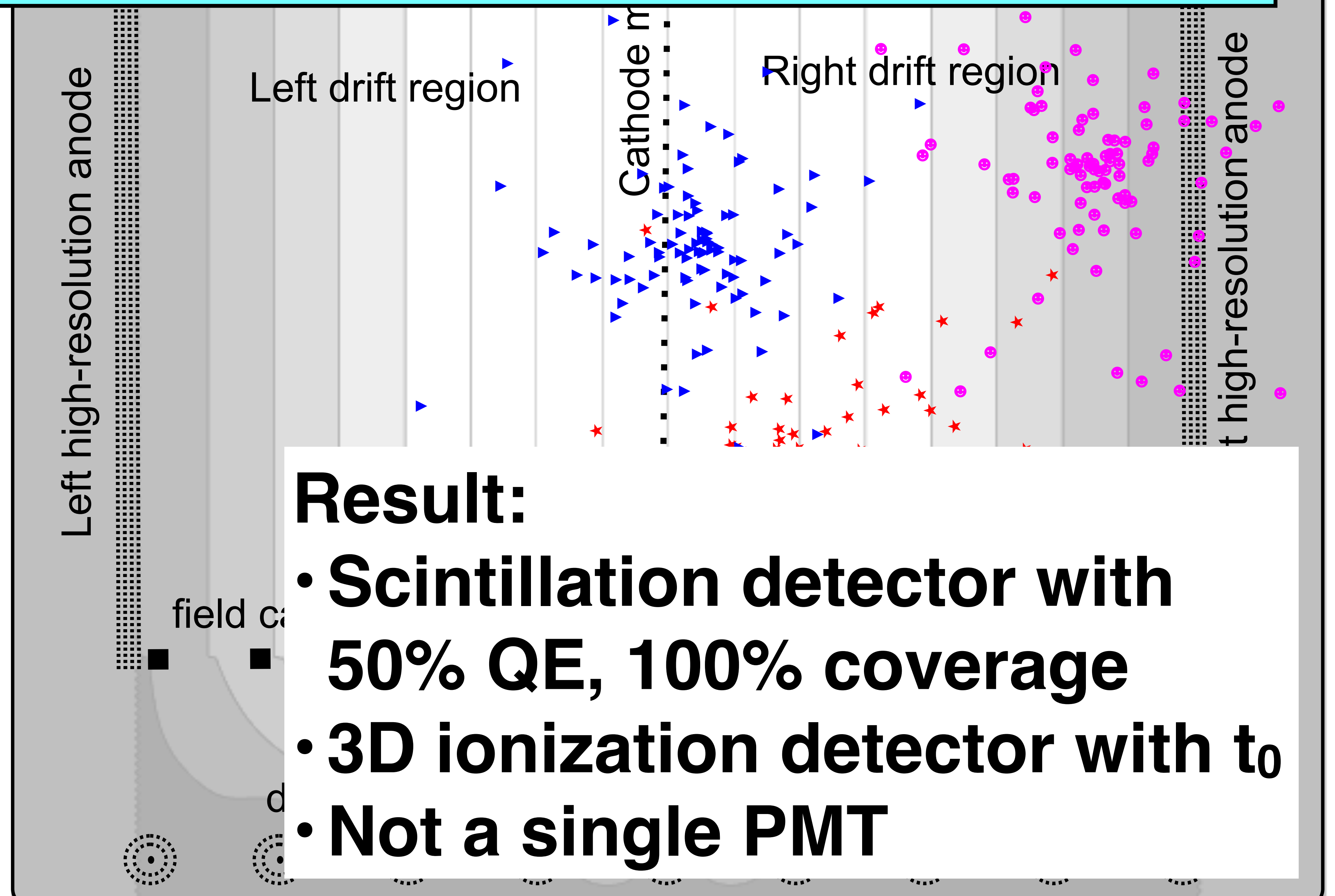
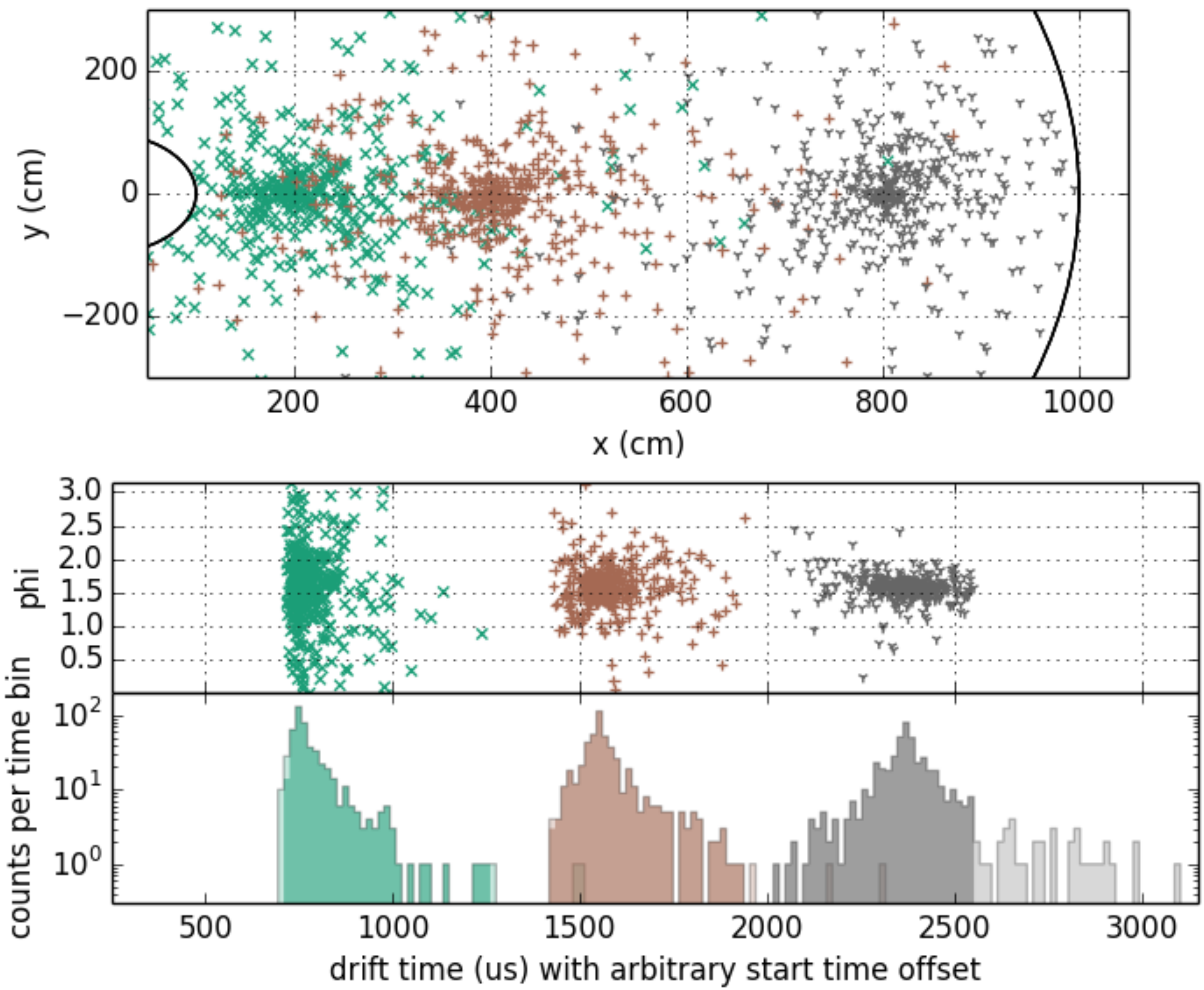


Result:

- **Scintillation detector with 50% QE, 100% coverage**
- **3D ionization detector with t_0**
- **Not a single PMT**

arxiv:1512.04926

Cylindrical drift makes drift-axis resolution easier



Slice of a cylindrical detector with events near center, middle, outside.

Scintillation clouds are symmetric

Symmetric clouds are reshaped by drift fields. r_0 measurable from shape fit.

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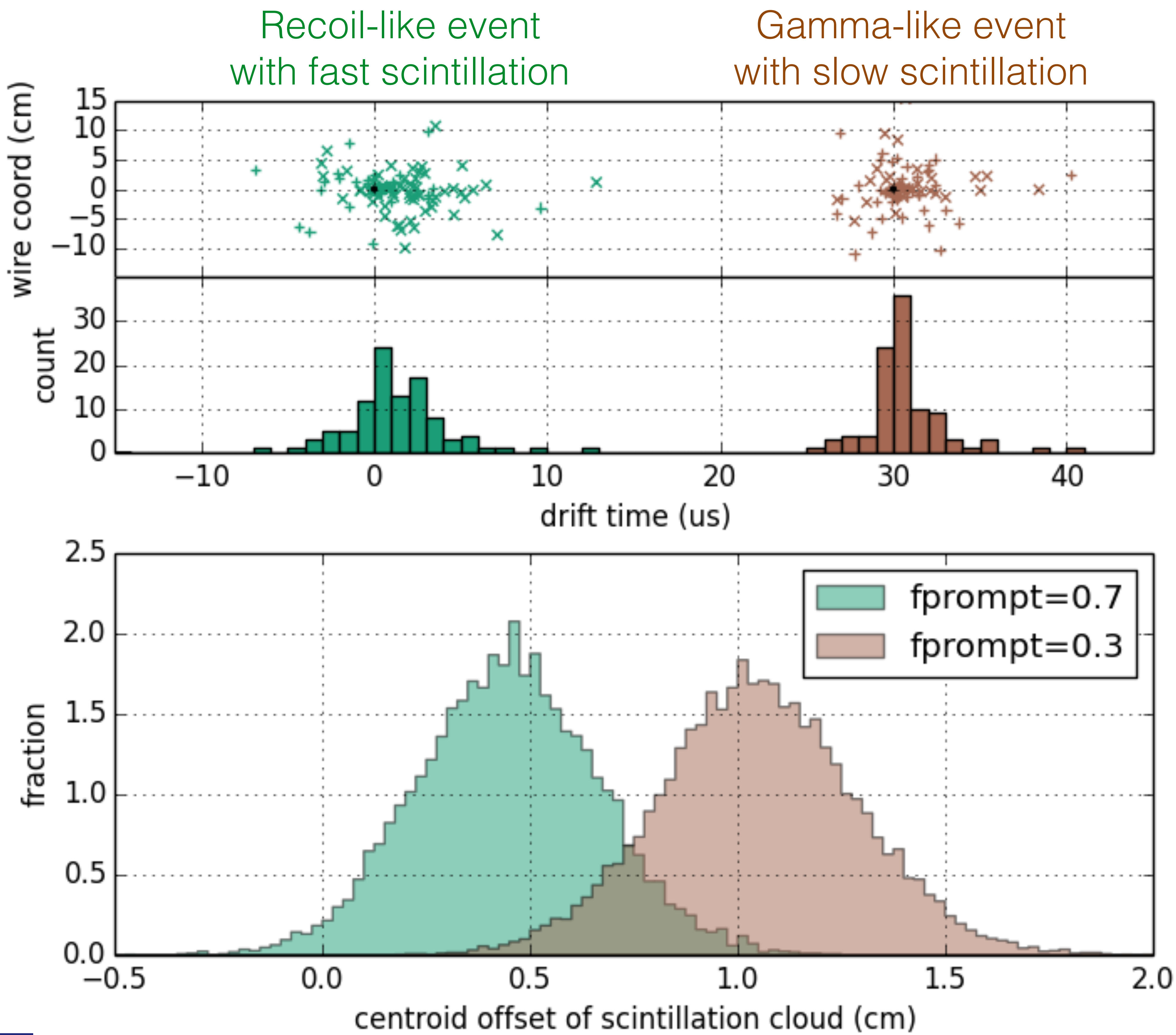
Some sensitivity to slow/fast scintillation for PSD



Liquid argon has good PSD properties: background events lead to slower (10μs) scintillation.

Ionization gets a 1cm head start over photoelectrons.

~99% rejection at 50% efficiency from this alone.

Scintillation/ ionization ratio measured too.

arxiv:1512.04926

Scintillating mixes

Gas : dopant	Scintillation wave-length	Photoabsorption cross section	Ionization quantum yield	Partial pressure for 1 m path
He :Xe	76 nm	1×10^{-17} cm^2	100%	5 mTorr
Ne :H_2	76 nm	5.4×10^{-17} cm^2	$\sim$ 100%	31 mTorr
Ne :Xe	76 nm	1×10^{-17} cm^2	100%	5 mTorr
Ar :TMAE	129 nm	9×10^{-17} cm^2	50%	10 mTorr
Xe :TMAE	178 nm	1.5×10^{-17} cm^2	35%	20 mTorr
H_2 :TMAE	185 nm (?)	Scintillation present but poorly studied		20 mTorr
(CH_4:CF_4):TMAE	210 nm (?)	Presence of scintillation is speculative		20 mTorr

Cherenkov mixes

Gas : dopant	Cherenkov sensitivity range	Photon yield (γ/cm)	photoelectron yield (pe/cm)
(Ar:Xe):TMA	~130–135 nm	60	20
CH_4:TMAE	~155-210 nm	500	150

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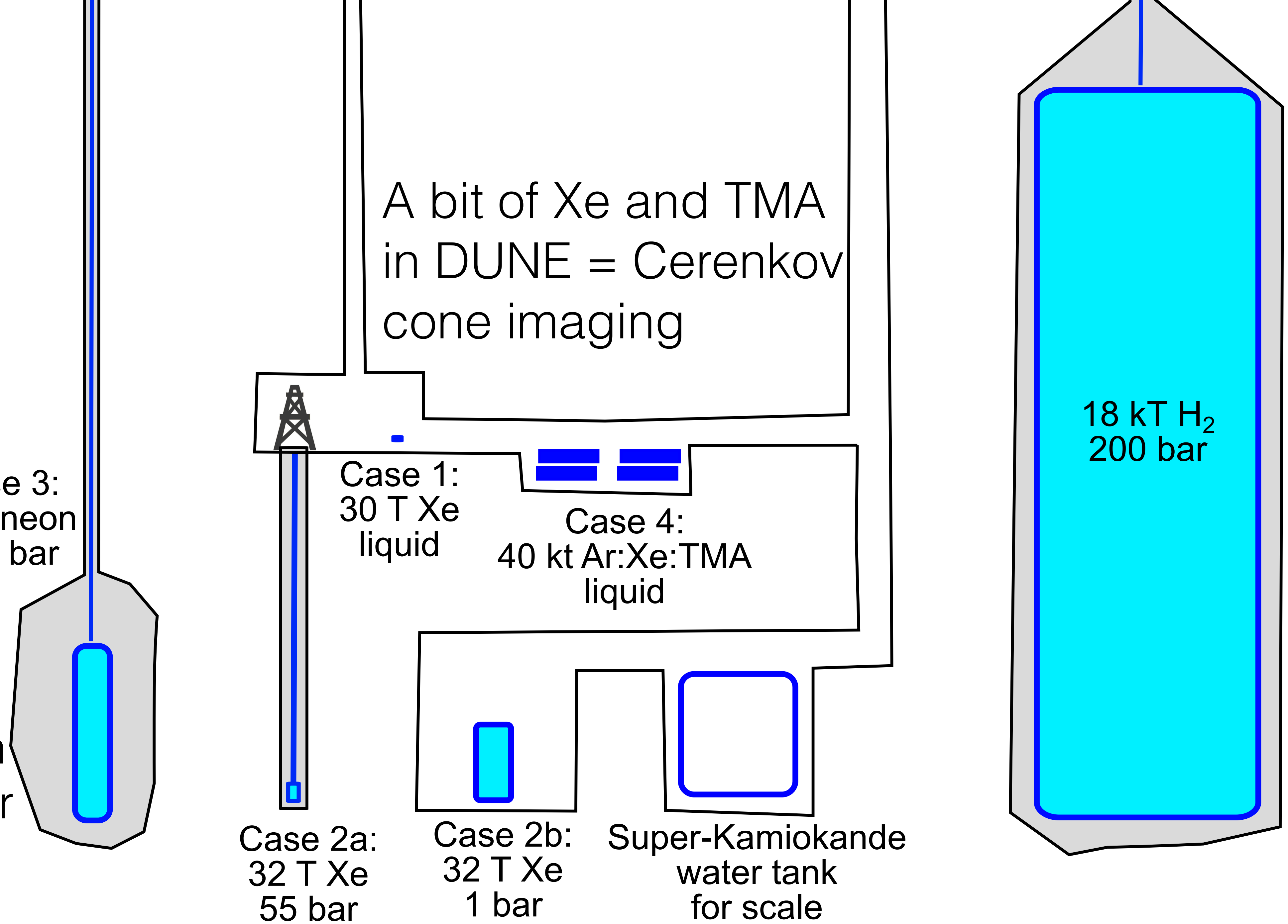

1 kT neon
at 100 bar
in a salt
cavern:
very close to
the dark matter
neutrino floor

18 kT H_2
salt cavern:
Inverse beta
decay signal
from supernova
in Andromeda

30t Xe $\left\{ \begin{array}{l} \text{two phase post-LZ (dark matter)} \\ \text{ambient pressure at Soudan (!)} \\ \text{high pressure at Homestake (0vbb)} \\ \text{(sunk in the \#6 winze)} \end{array} \right.$

H2 scintillates!
at least15 γ/MeV

arxiv:1512.04926

What's next

- For me:
  - Will talk at Solution Mining Research Institute conference (Galveston, 4/2016) and try to meet interested cavern owners & engineers
  - Dark matter sensitivity study of LXe:TMAE
  - Inflatable cylindrical TPC mechanical studies
- For you:
  - Brainstorm up a salt cavern (or a sub-Penning gas TPC) version of your favorite experiment
  - Join our interest group and share ideas
    - http://hep.ucsb.edu/saltcaverns/
    - email scdig_request@hep.ucsb.edu for access to our Basecamp site