How to build huge detectors in salt domes

Ben Monreal, UCSB (—> Case Western)

"I can afford the fluid and instruments but not the cavern/cryo/vessel … "

20 kT H_2 for antineutrinos
500 kT Ar for proton decay
1.5 MT water for [???]
1 kT Ne for solar neutrinos
[???]T Xe for WIMP/0vbb

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generic, high-risk, high-impact blue sky detector R&D

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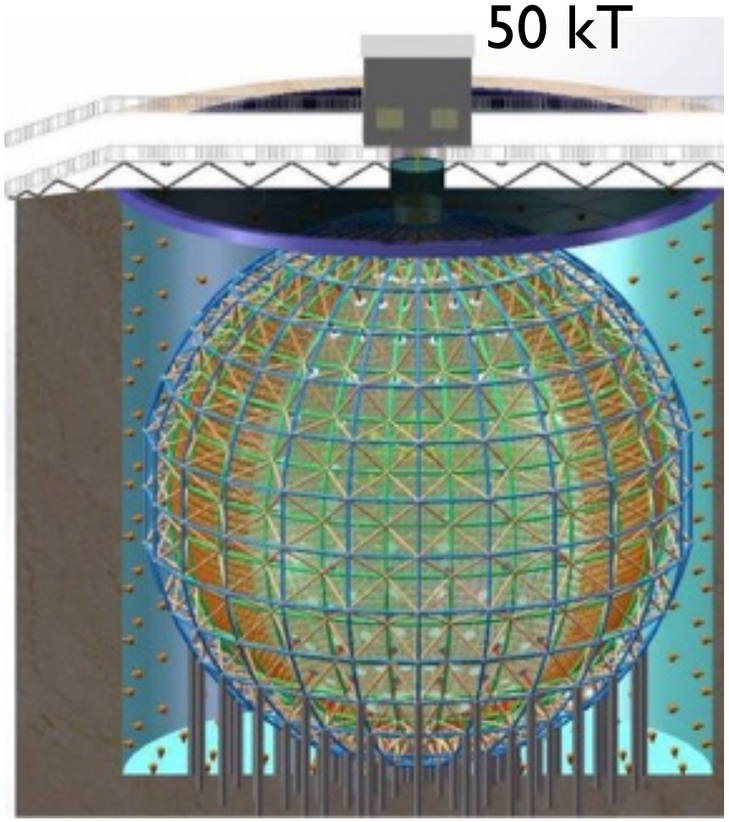
Are we at the end of the "target mass frontier"?



- $1000/ton liquid scintillator
- $100/ton H2, CH4, Ar
- $free: CO2, N2, H2O

Still have budget room for medium itself 😀

- PMT arrays $10k/m3
- TPC wire planes $10k/m3

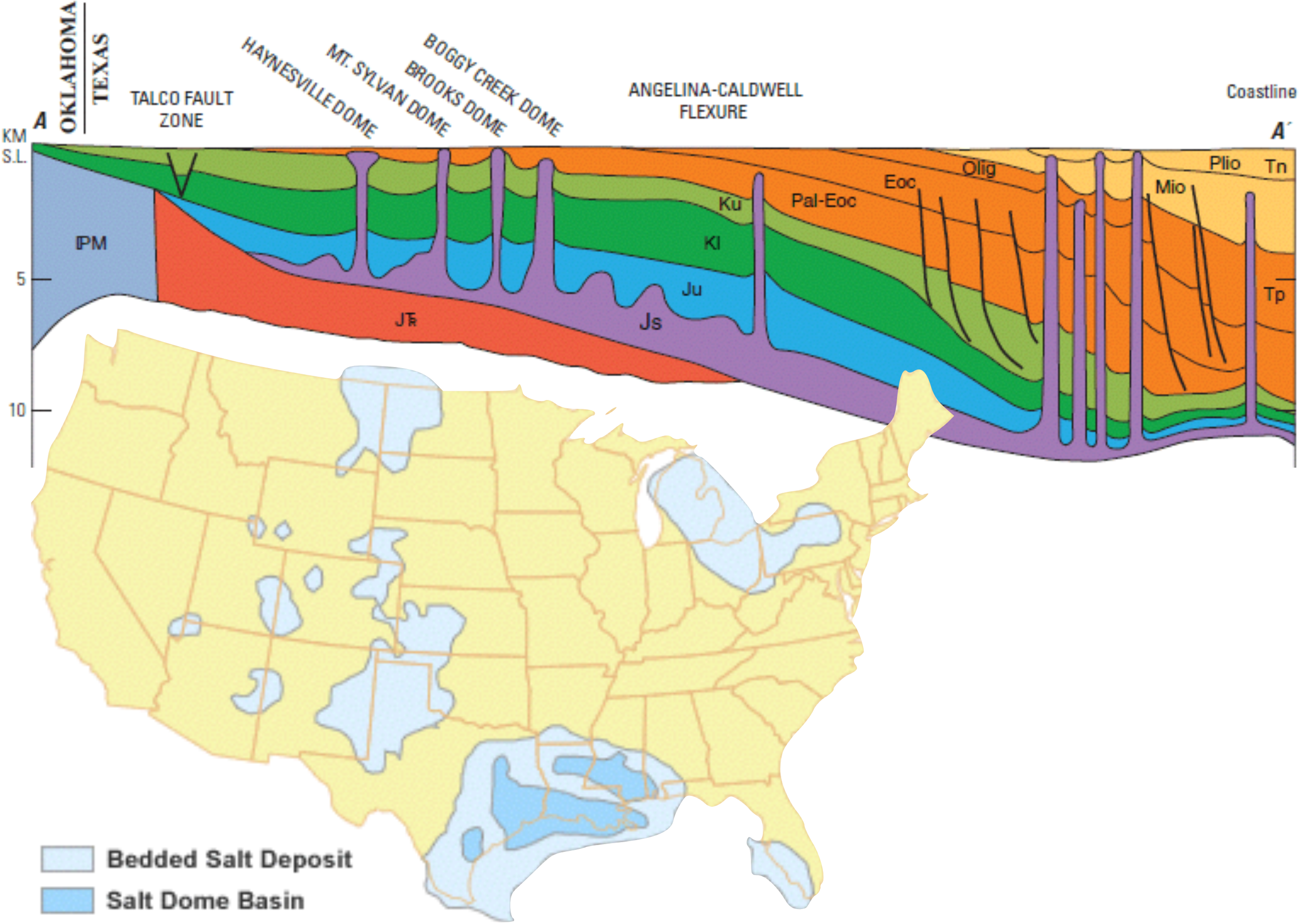
Another generation still affordable 😐

HyperKamiokande
(2011 shape)

1000 kT

- Large rooms in rock mines
  - $1000/m3 (in US/Canada)
  - Roof spans 50–70 m

HyperK maxes out! ☹️


OKLAHOMA
TEXAS
A
TALCO FAULT ZONE
HAYNESVILLE DOME
MT. SYLVAN DOME
BROOKS DOME
BOGGY CREEK DOME
ANGELINA-CALDWELL FLEXURE
Coastline
A´
KM S.L.
5
10
IPM
JTr
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Kl
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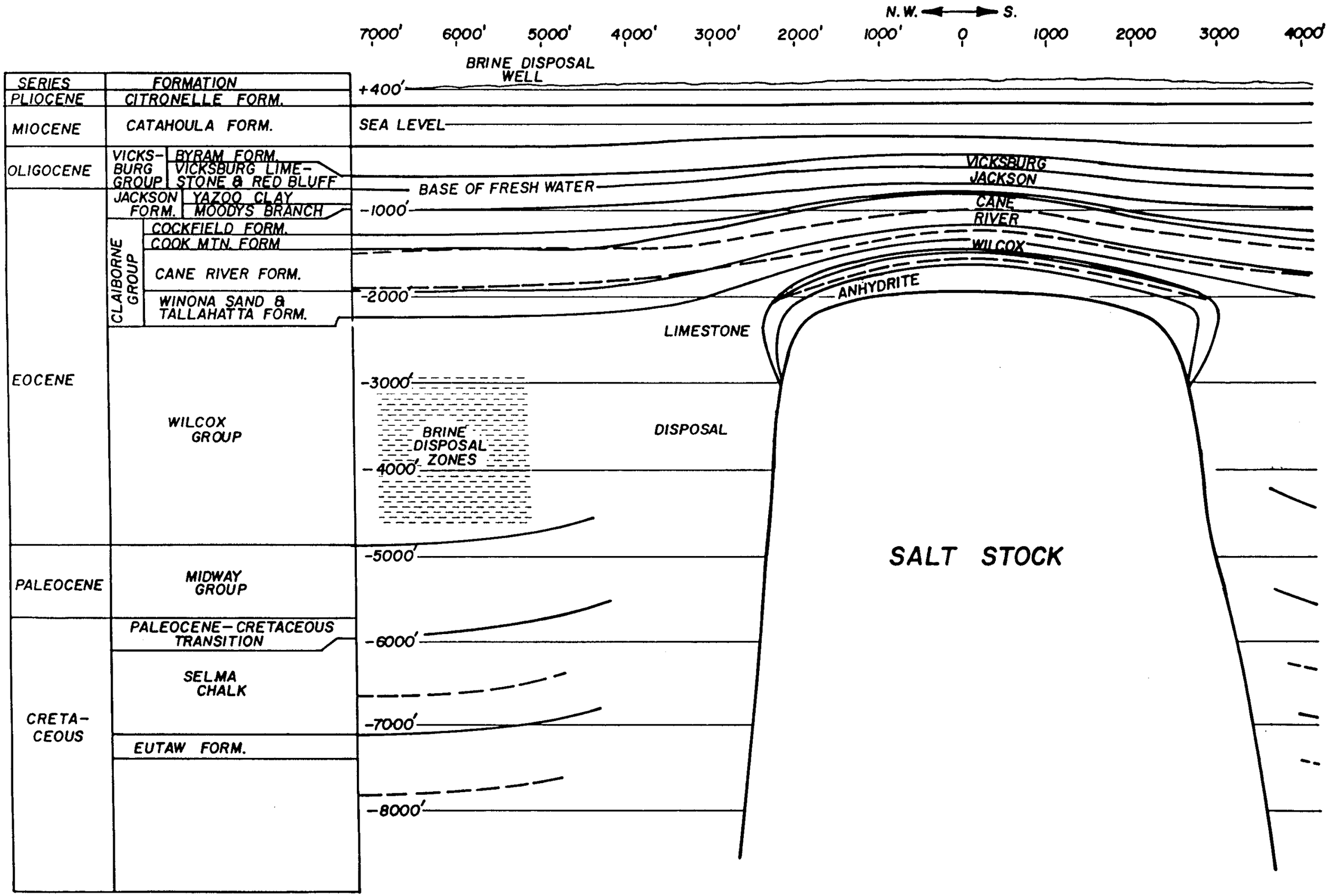
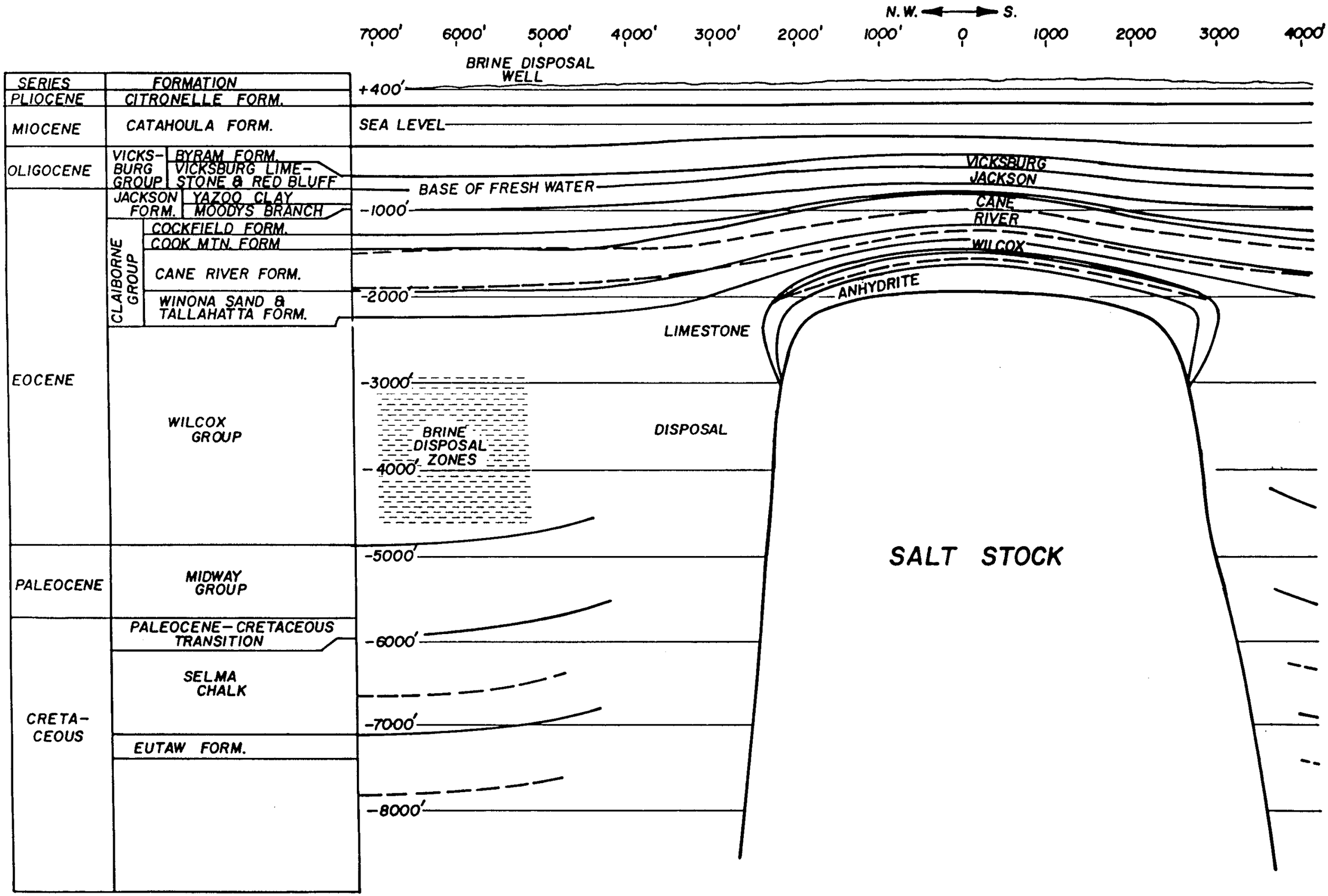
Eoc
Olig
Mio
Plio
Tn
Tp
Bedded Salt Deposit
Salt Dome Basin



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

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



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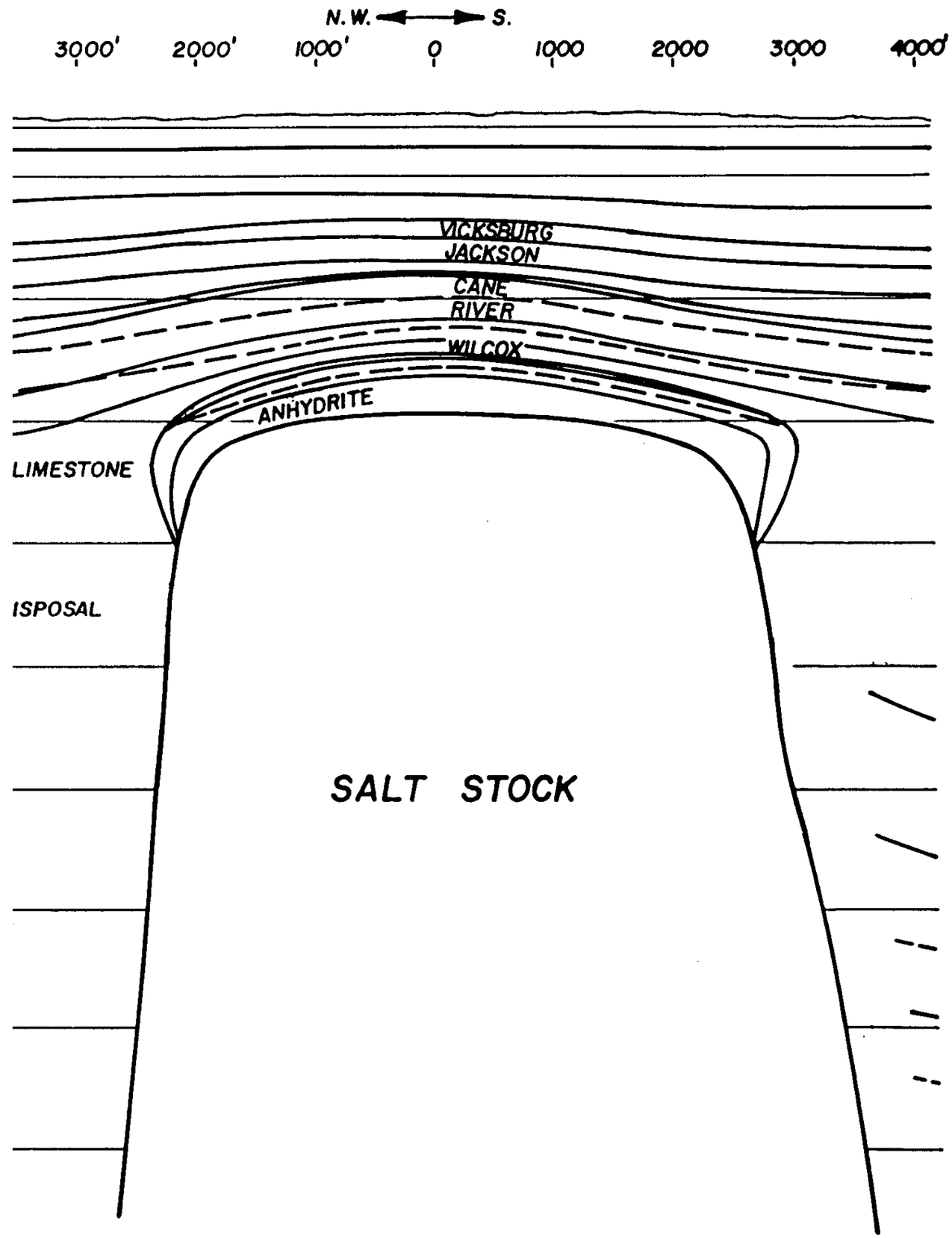
Getting underground cheaply

- "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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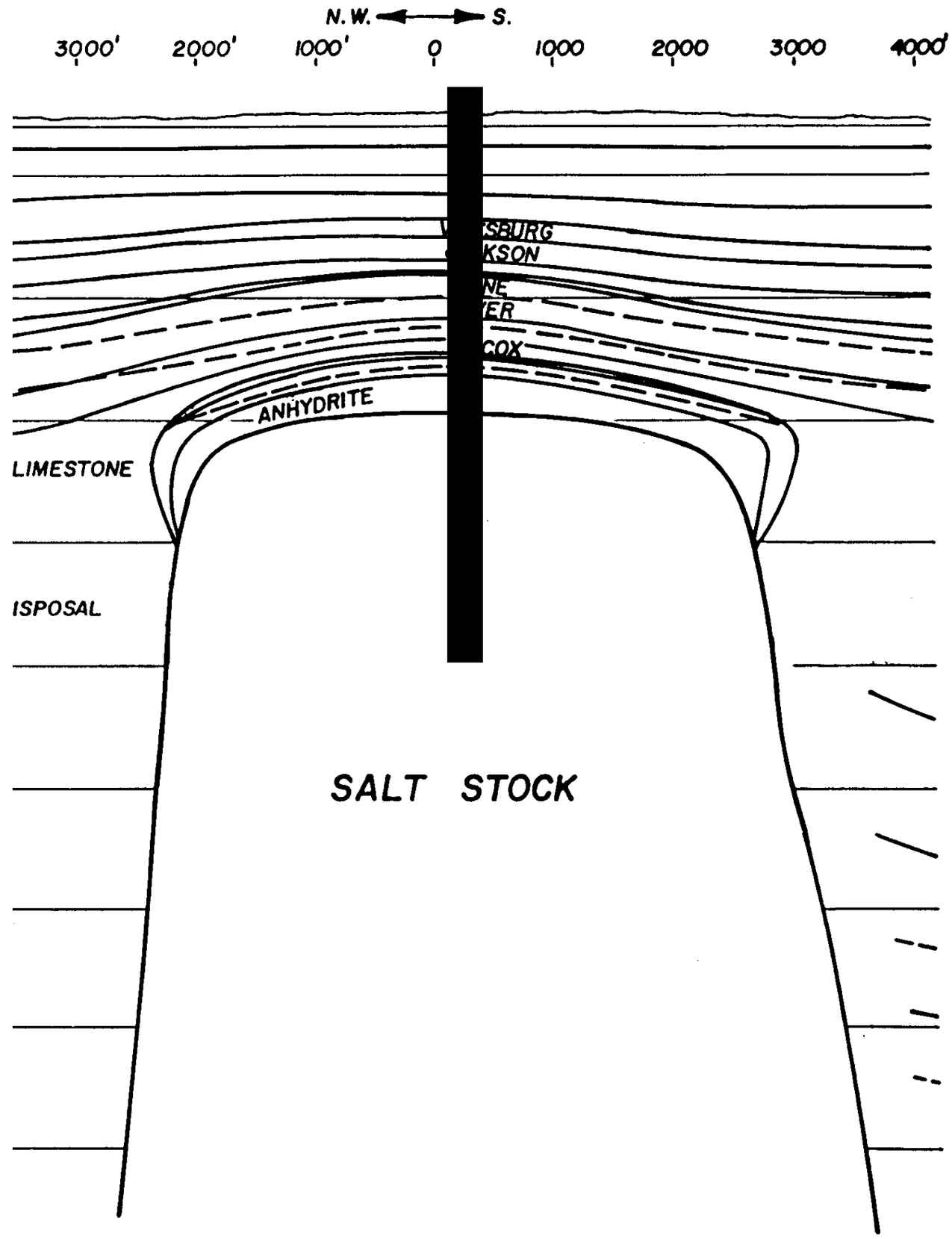

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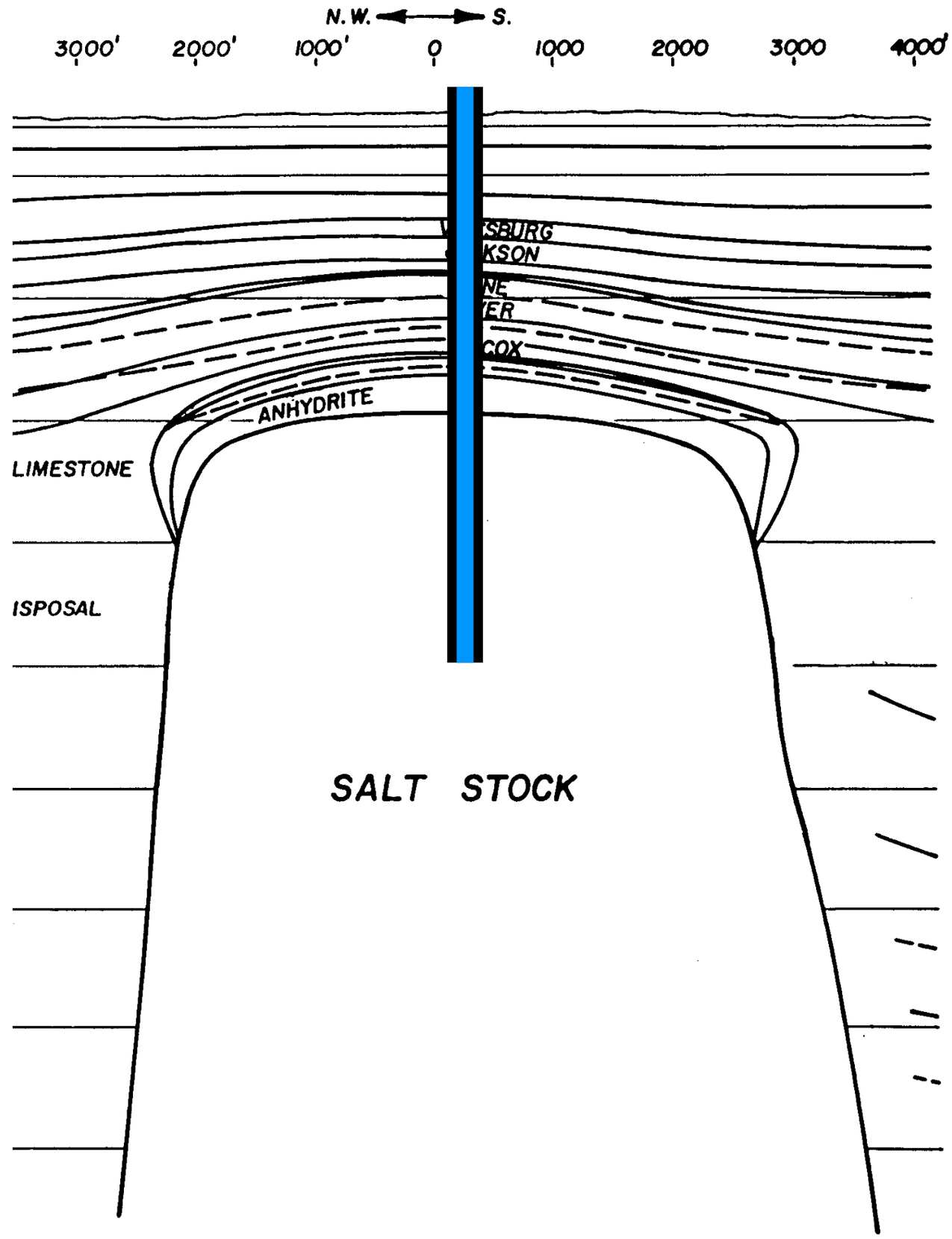

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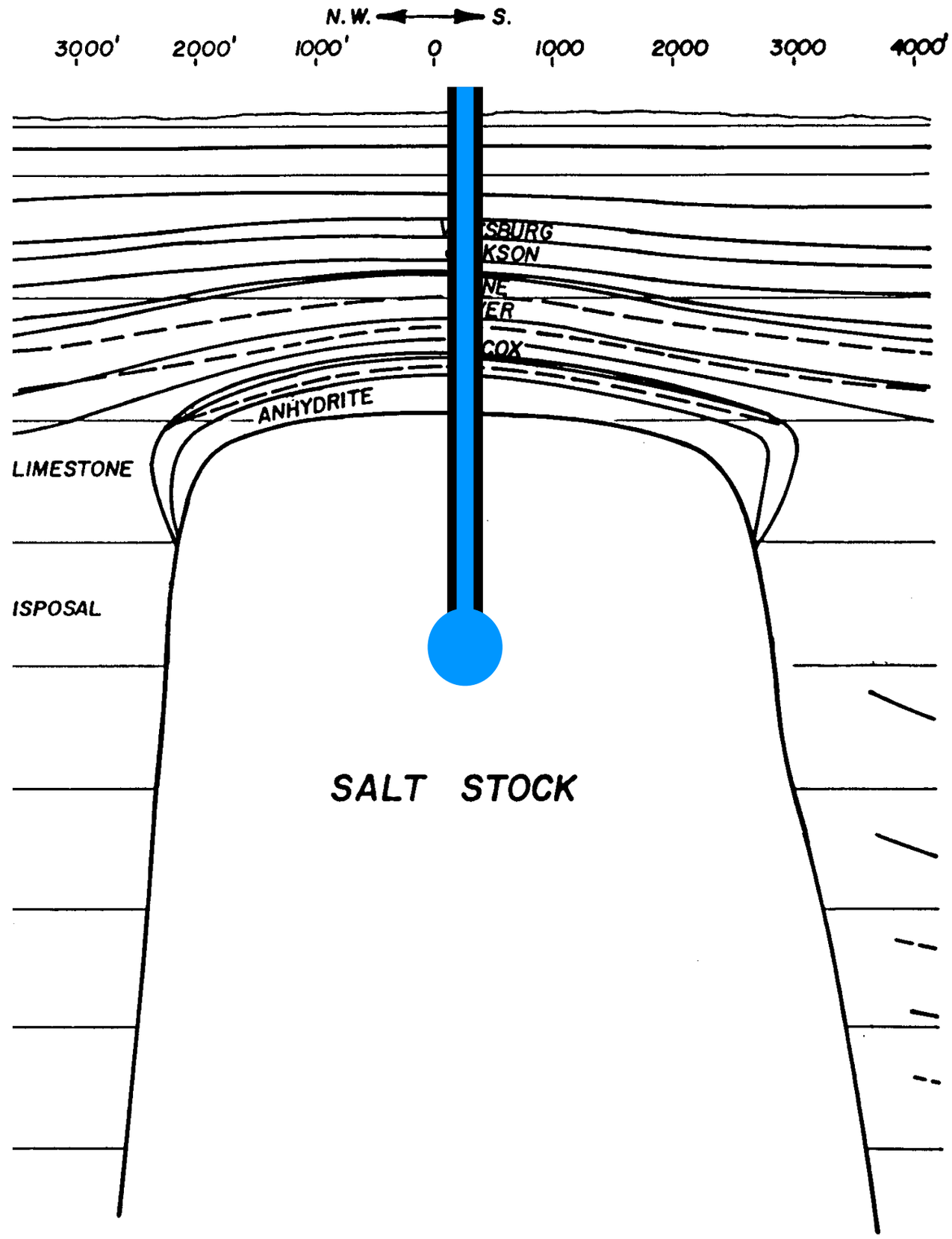

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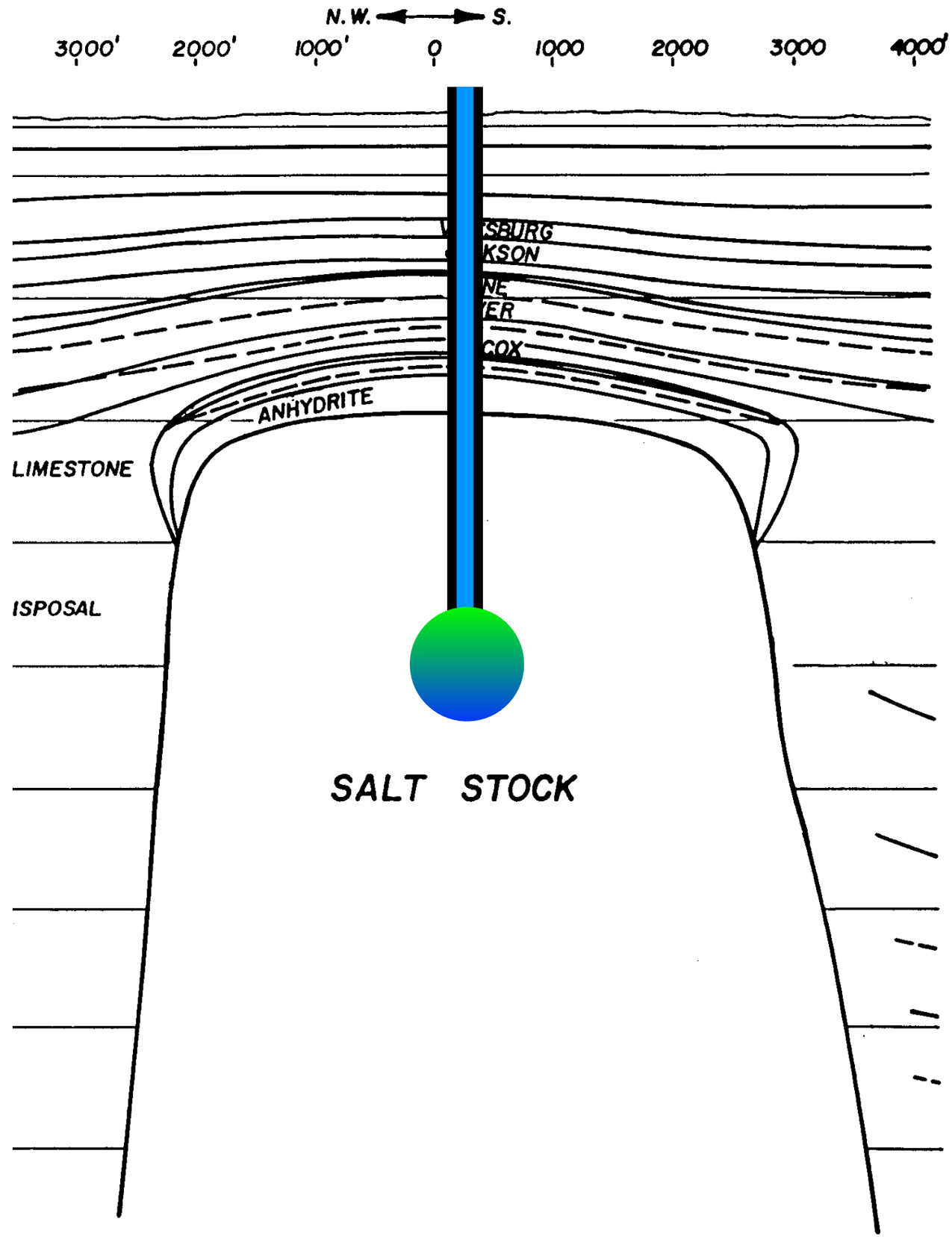

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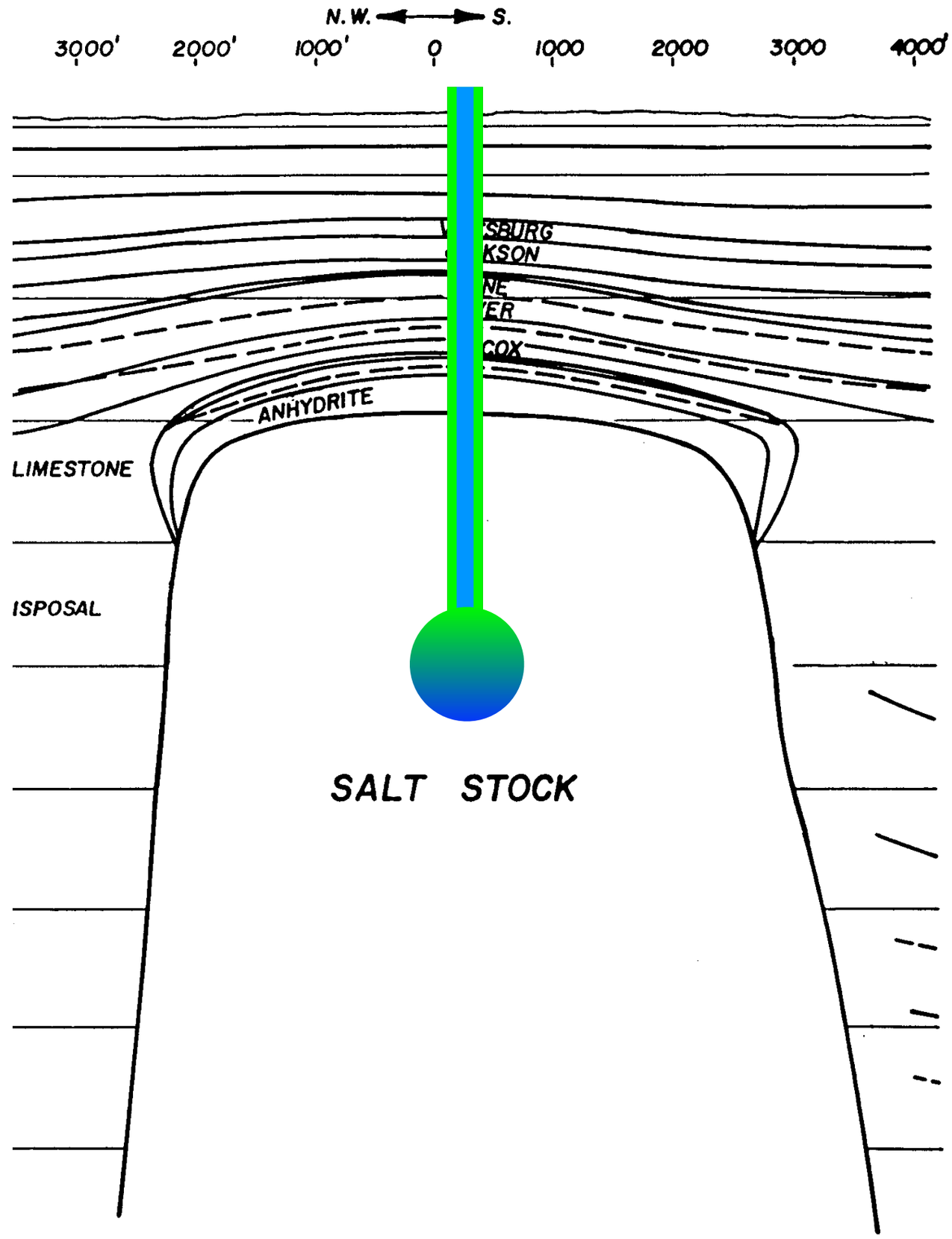

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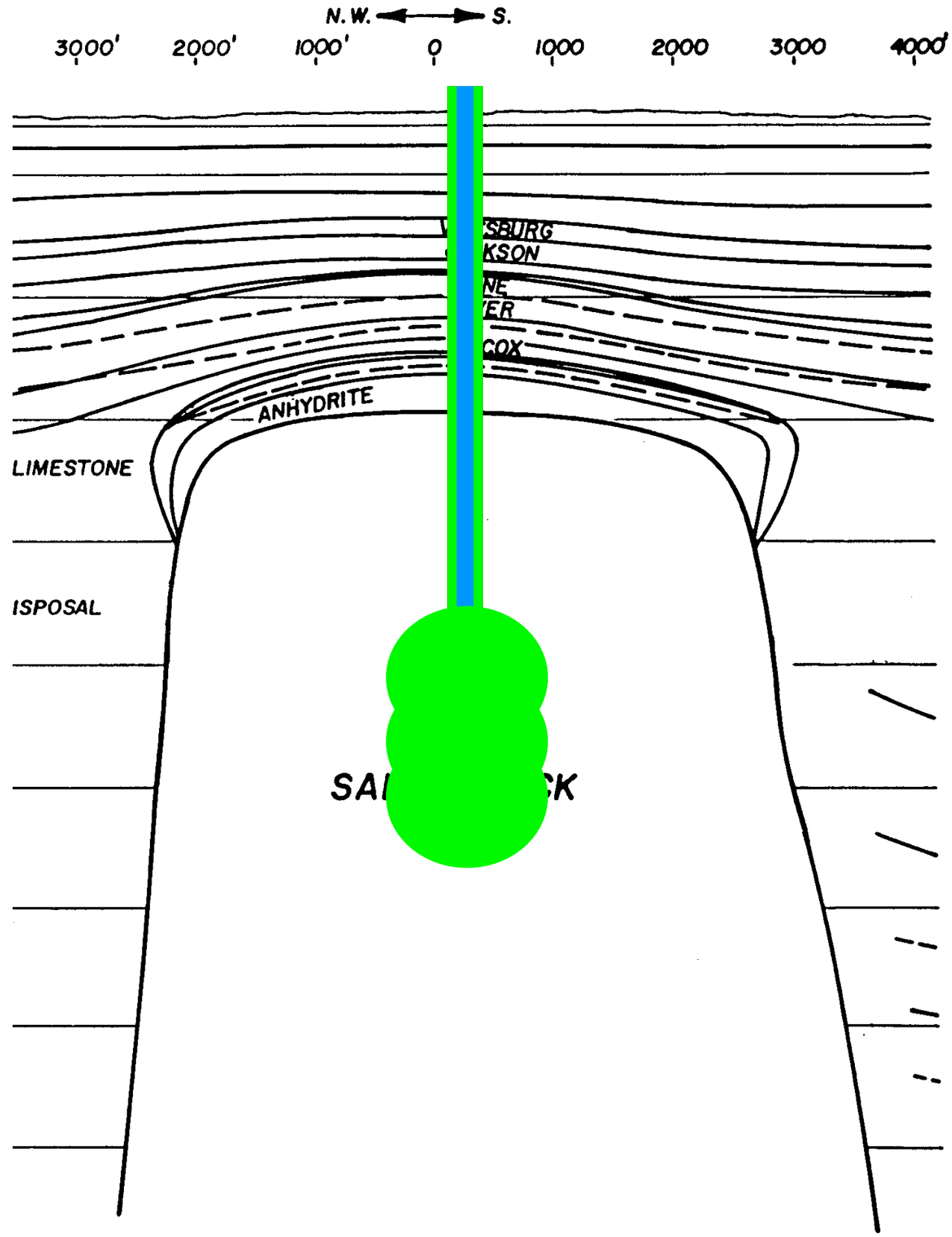

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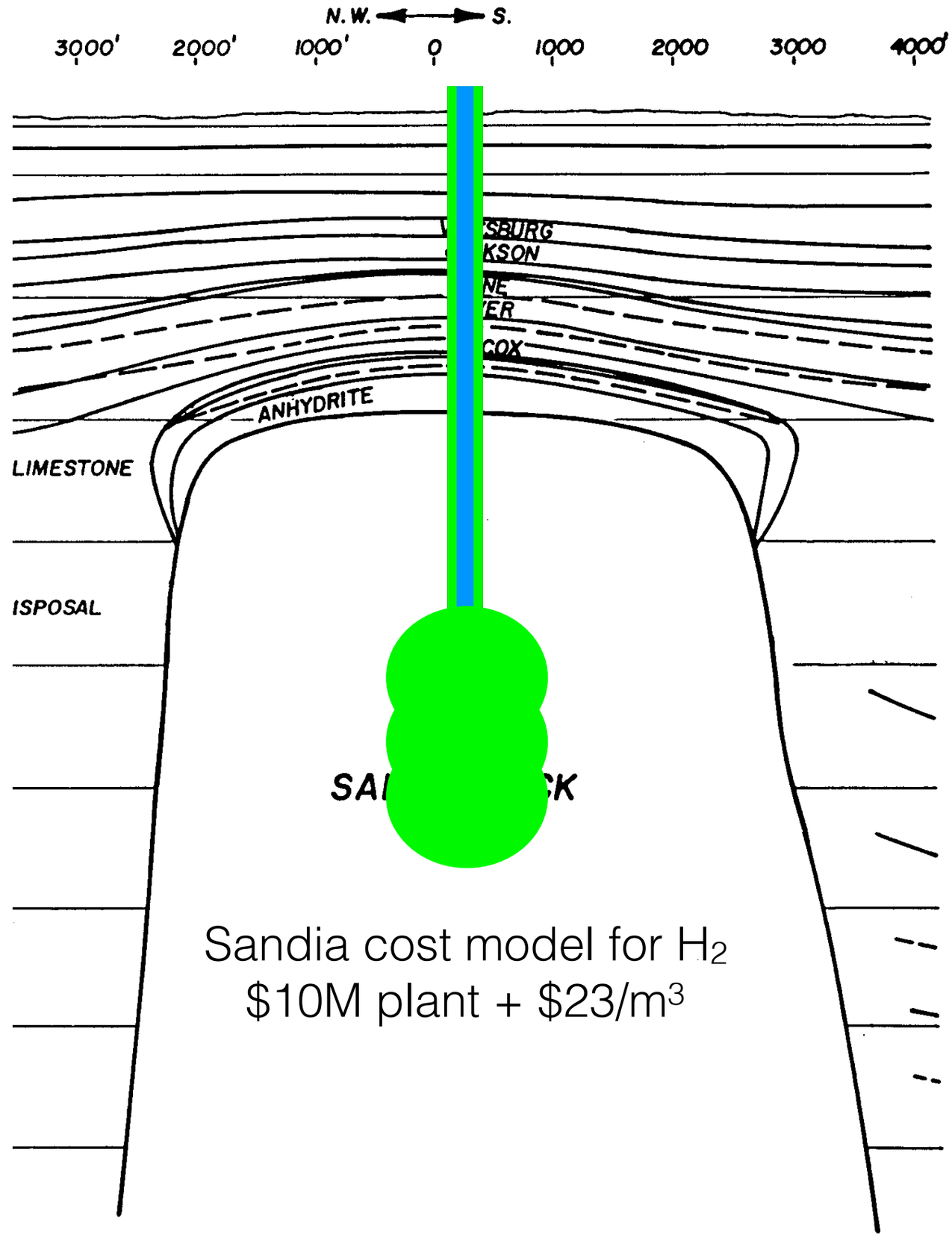

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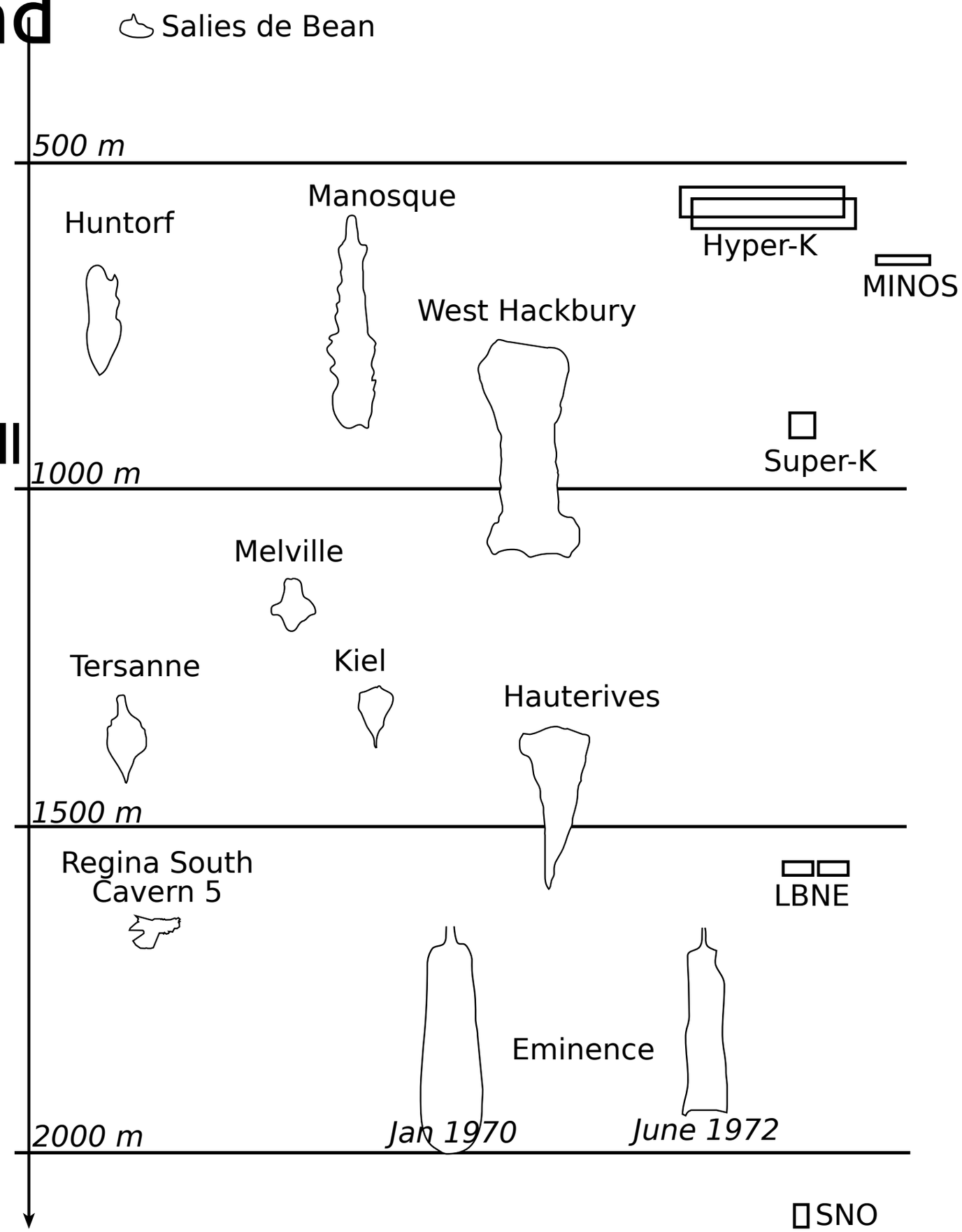
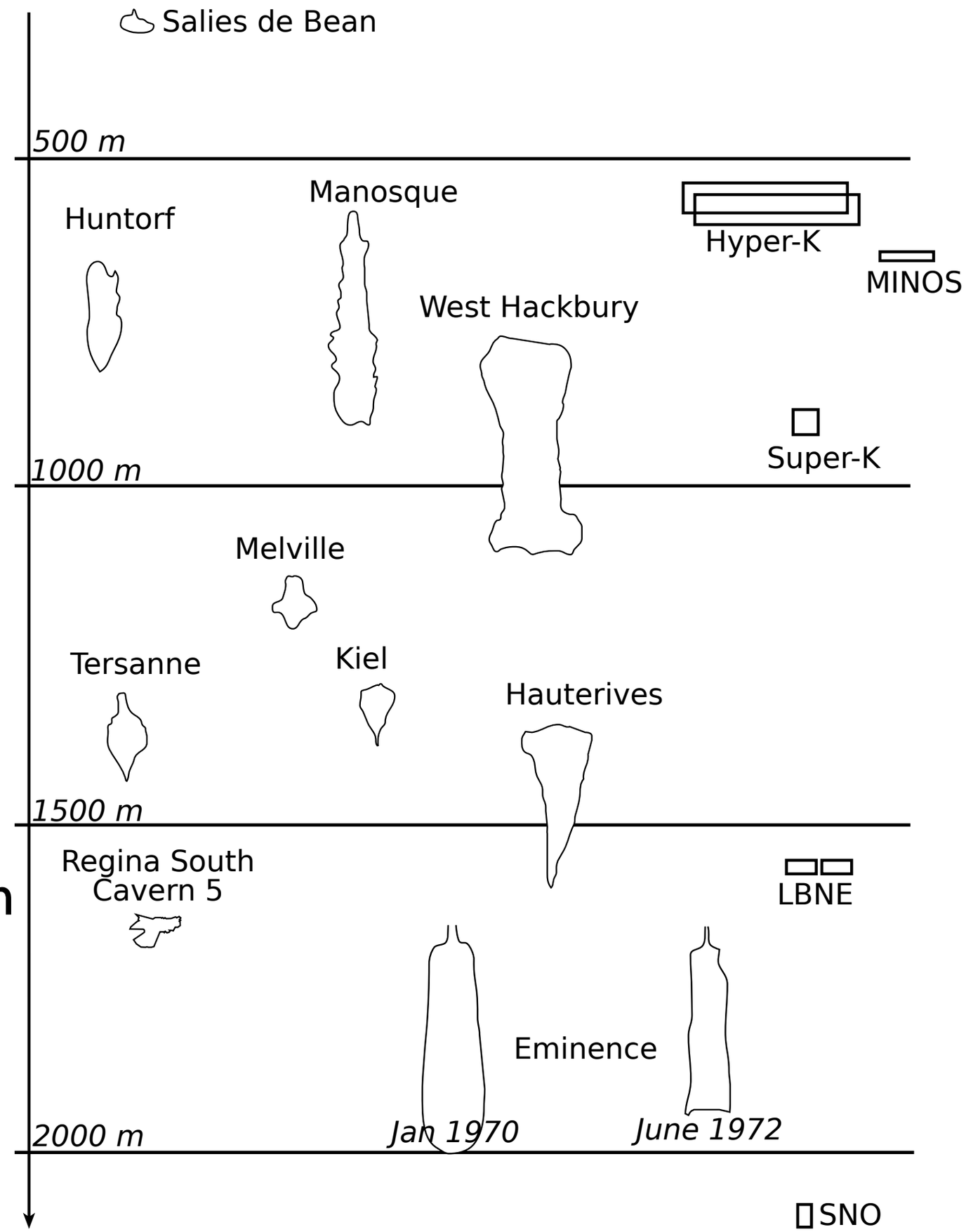


Getting underground cheaply

- 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 deploys down the borehole.



This is a large industry

SOLUTION MINING RESEARCH INSTITUTE

Consultants/engineers

RESPEC

BROUARD CONSULTING

NSAI

ATKINS

GEOSTOCK ENTREPOSE

WSP | PARSONS BRINCKERHOFF

Owners/operators

K+S

DOE National Strategic Petroleum Reserve

AGL Resources

Spectra Energy

MAGNUM Gas Storage

FAIRWAY ENERGY PARTNERS LLC

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TransGas YOUR LINK TO SUCCESS

storengy

e·on

EDF ENERGY

National labs!

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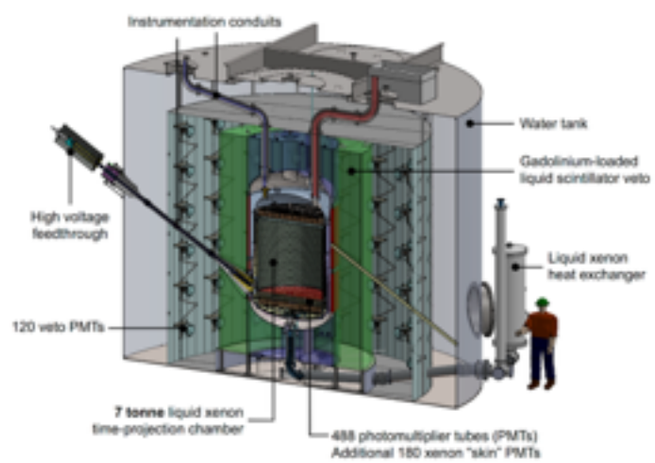
Depth x shielding

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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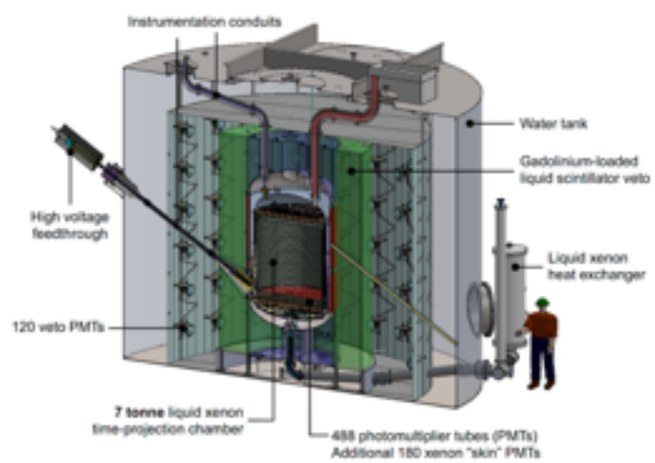
6m water tank



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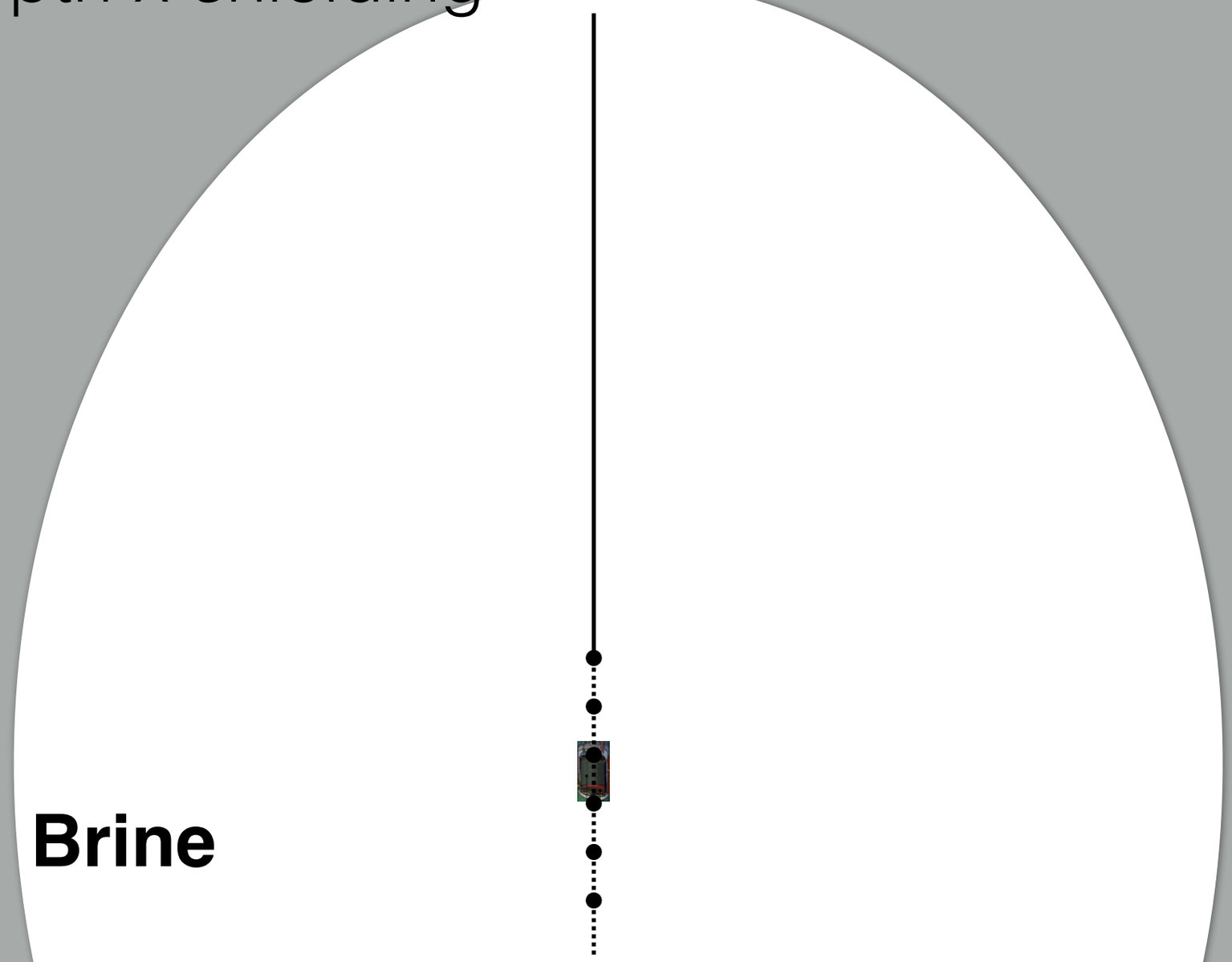

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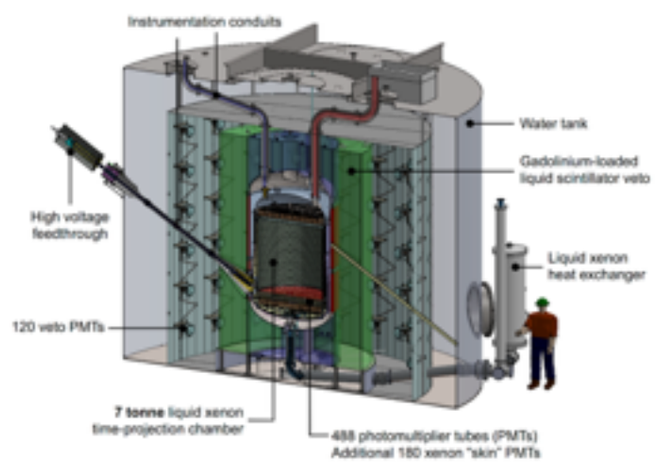

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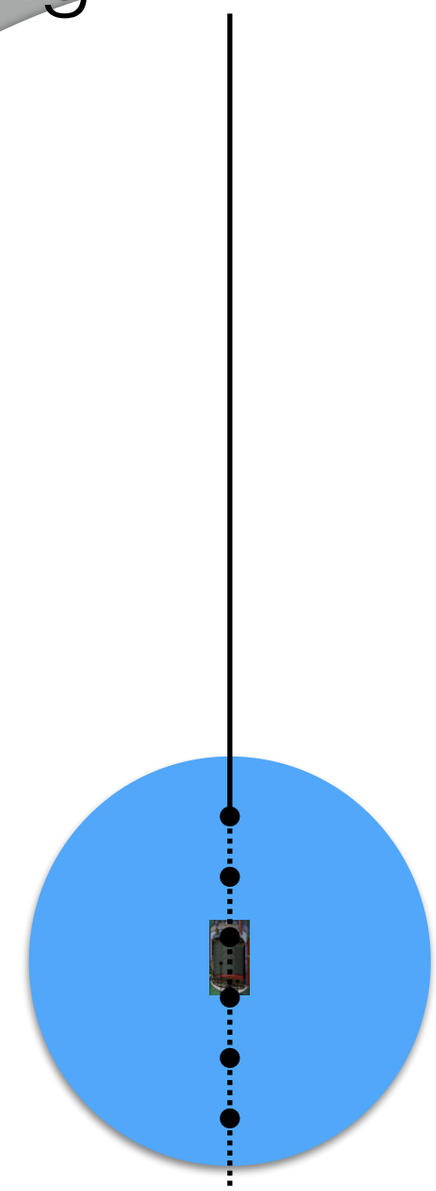


Clean salt

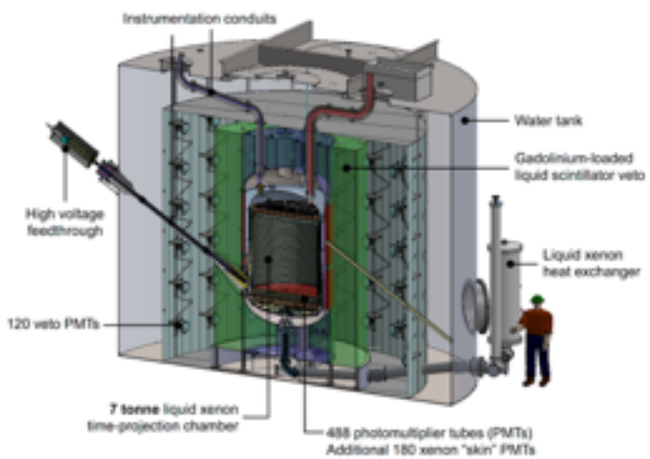
Any small experiment (DM-ICE)
+clear water balloon
+a few PMTs
= lots of shielding

Depth x shielding

The best shielding we can do today:

10m room

6m water tank



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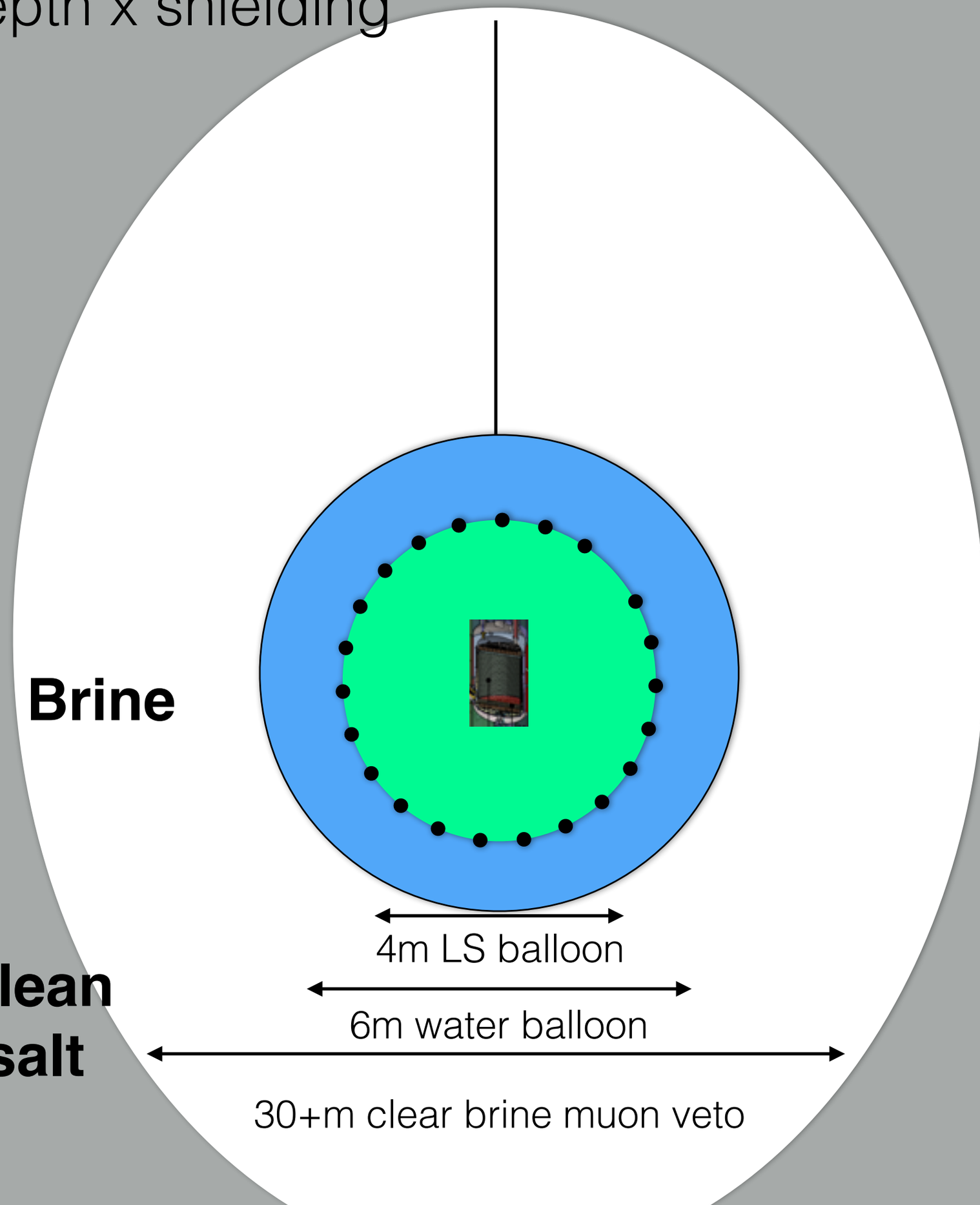
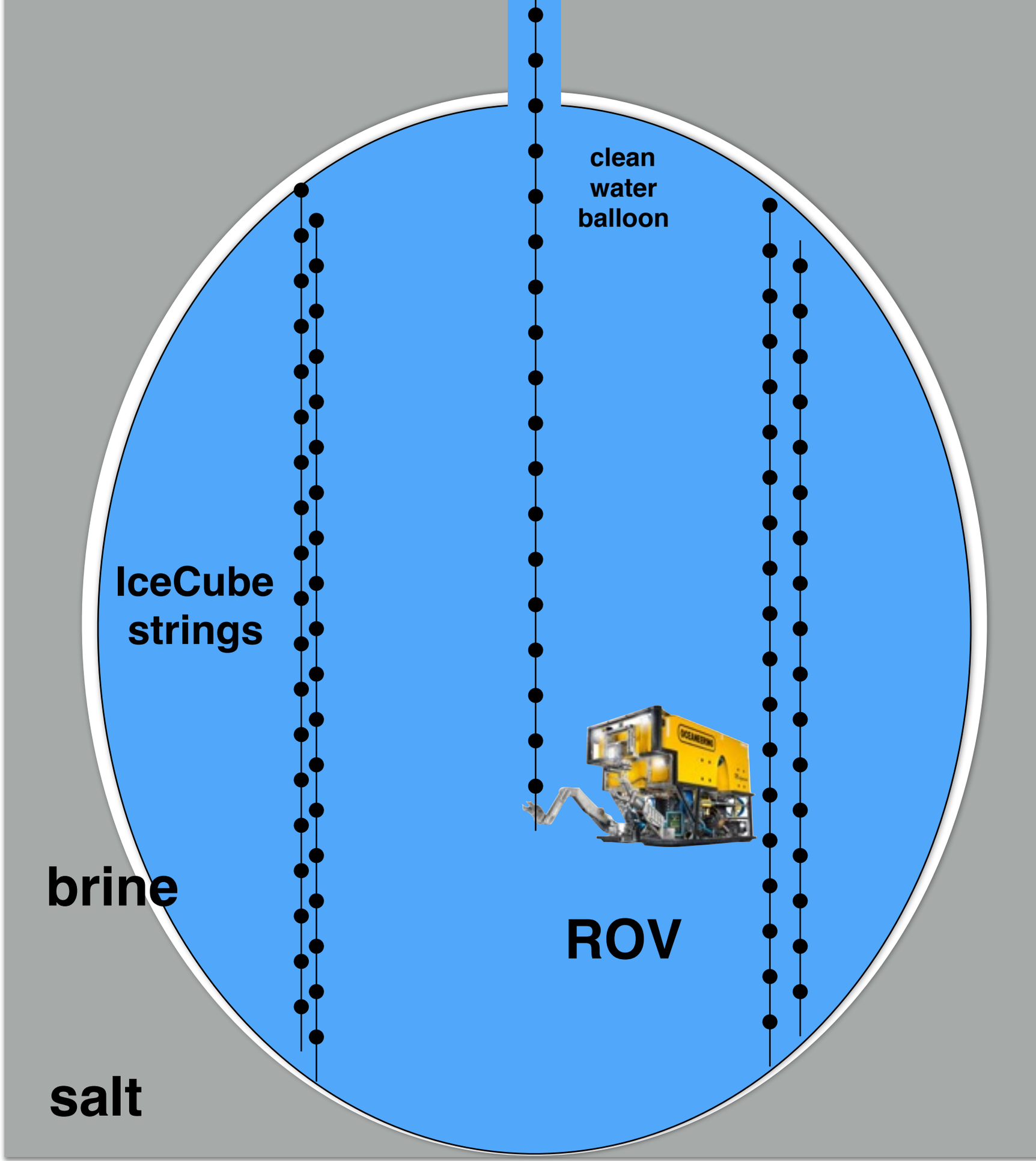


Giant water Cerenkov detector:

80mø x 250m
1.25 MT total

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



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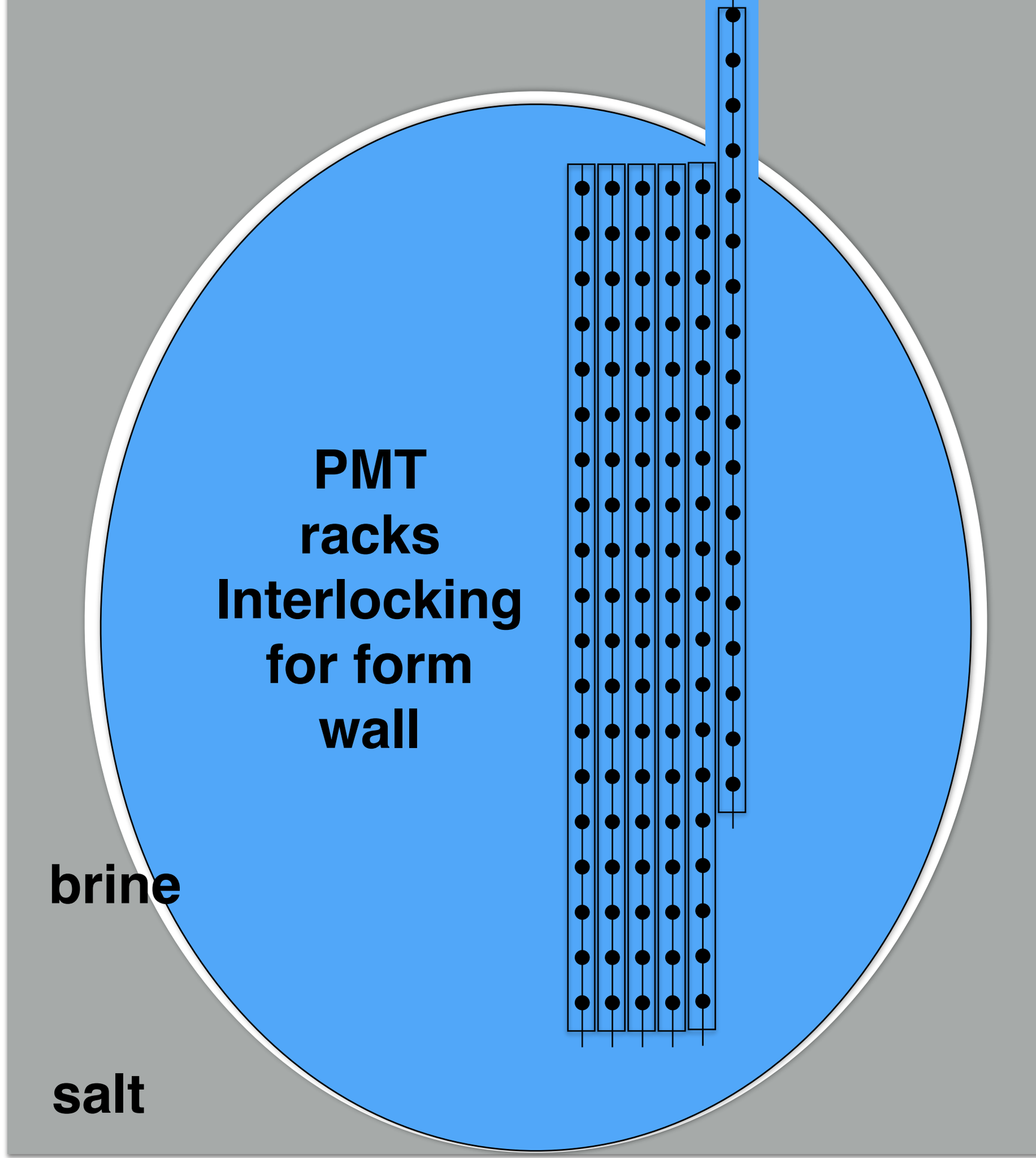
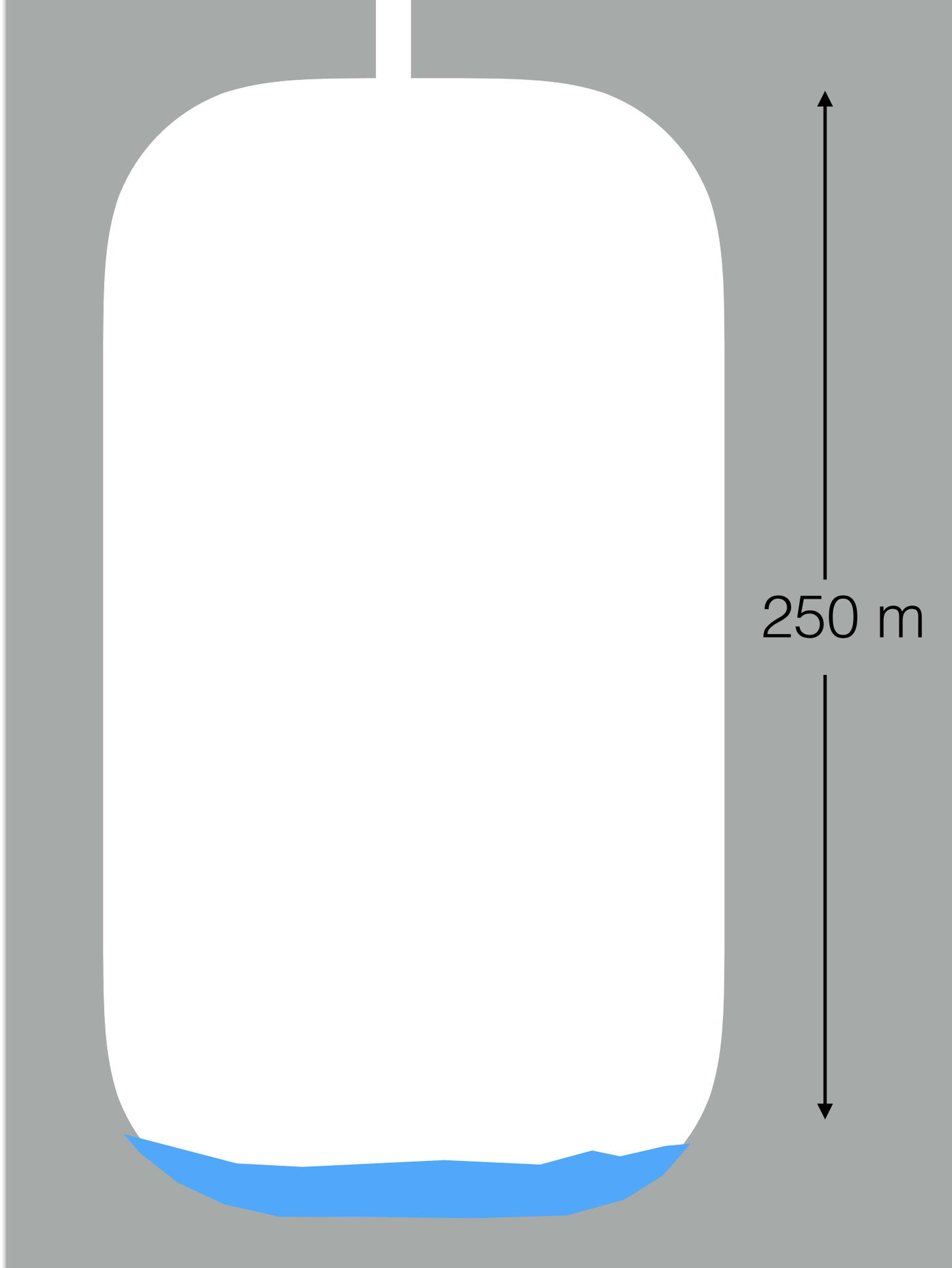
excavation = $30M
10" or 17" DOMs = rest of budget



Giant TPCs

- Easiest place to start:
  - Cylindrical drift geometry
  - Inflatable cathode
  - Drift electrons as far as you can manage
- Favorite sketch: 1kT neon in a 16 x 80m balloon
- Linear-drift TPC needs fancier (unfolding?) mechanicals.



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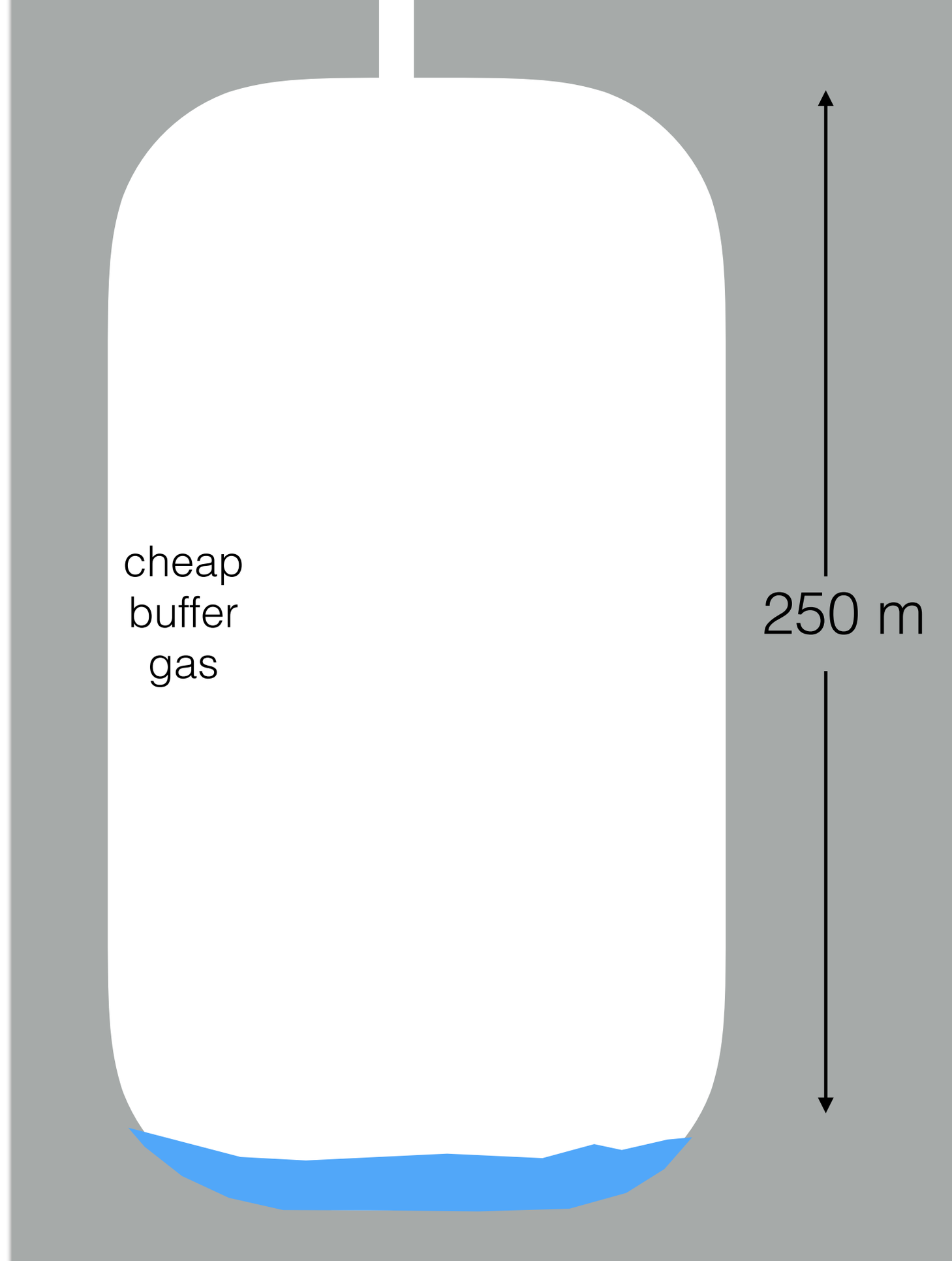

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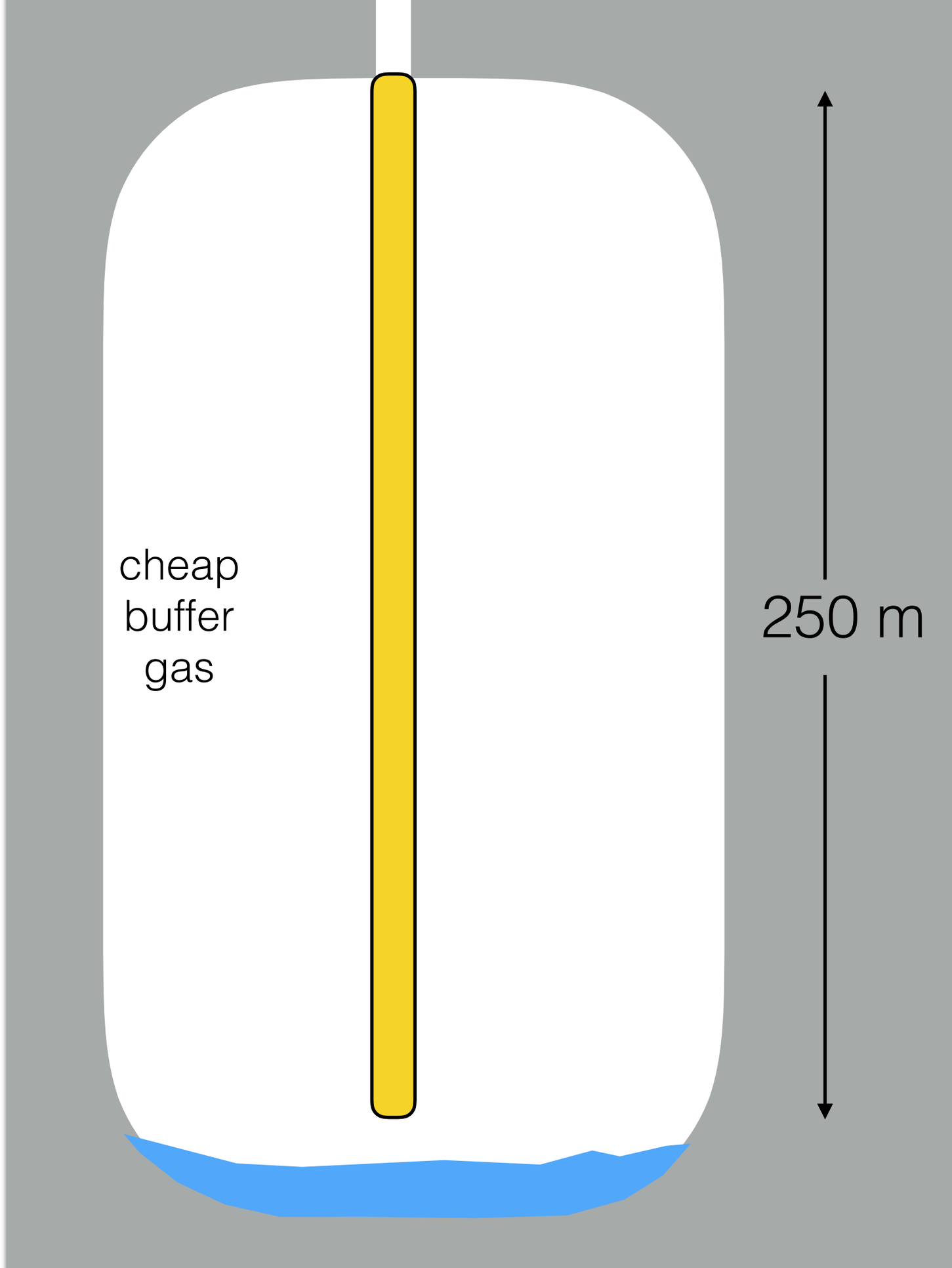

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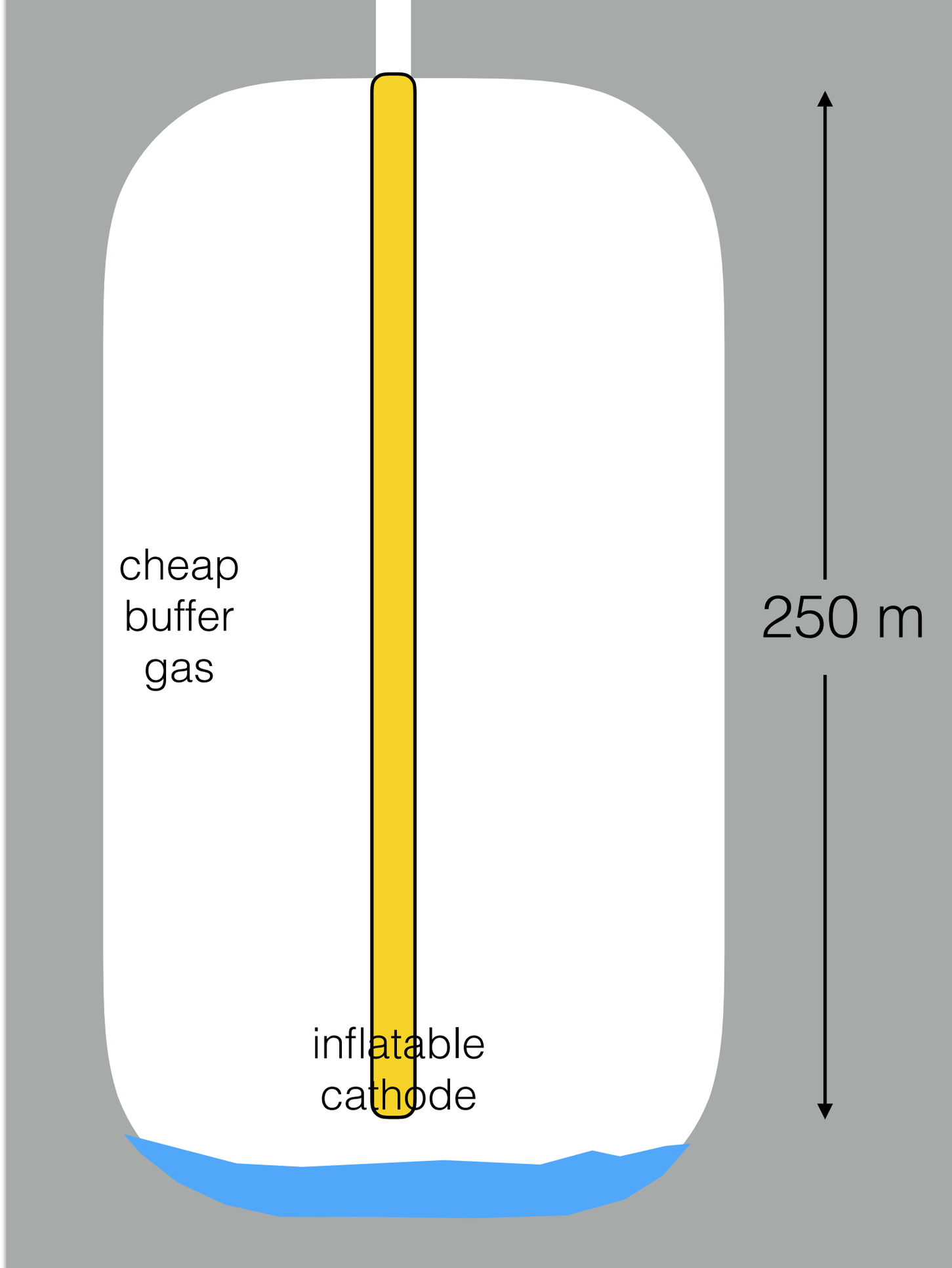

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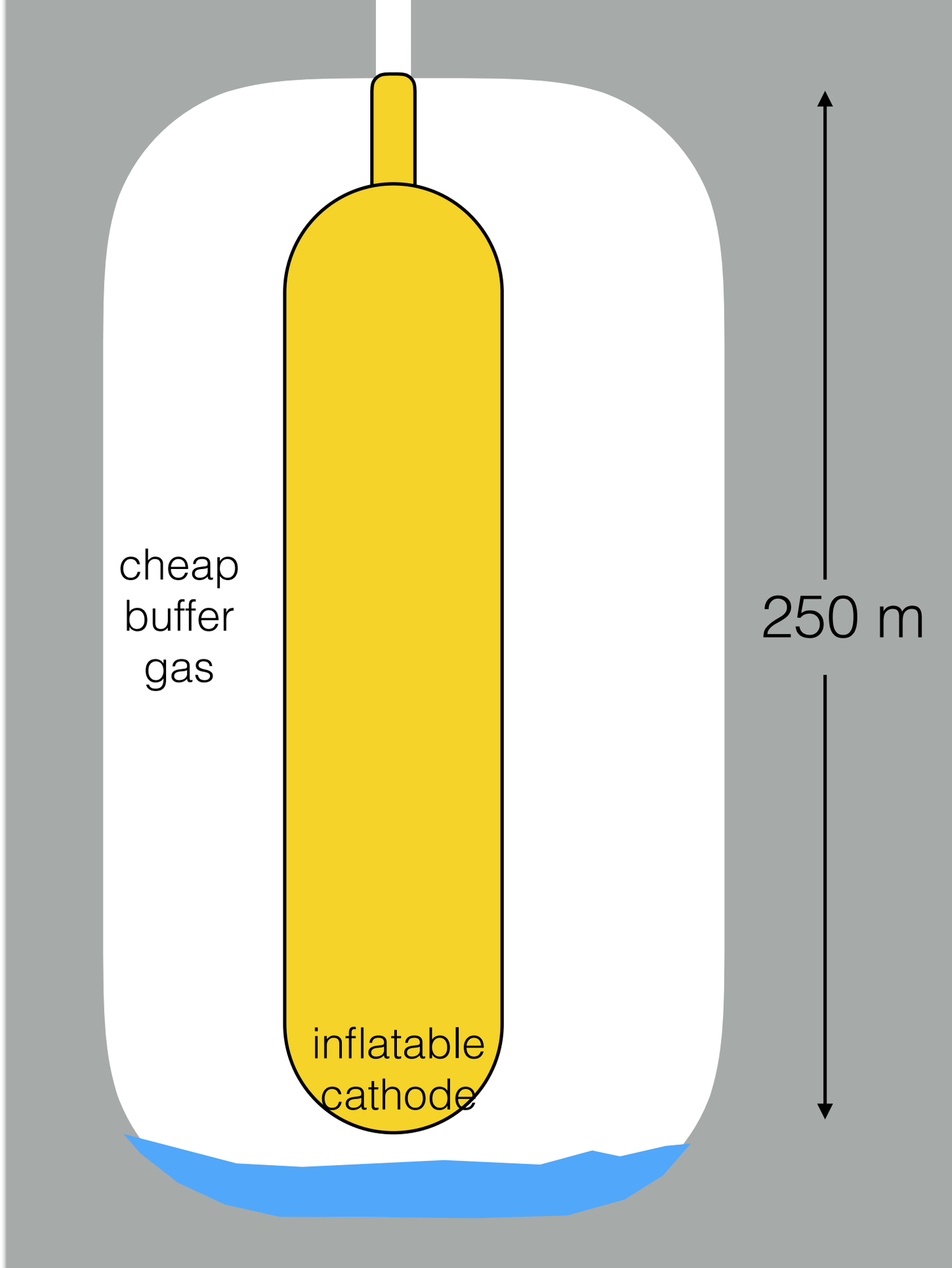

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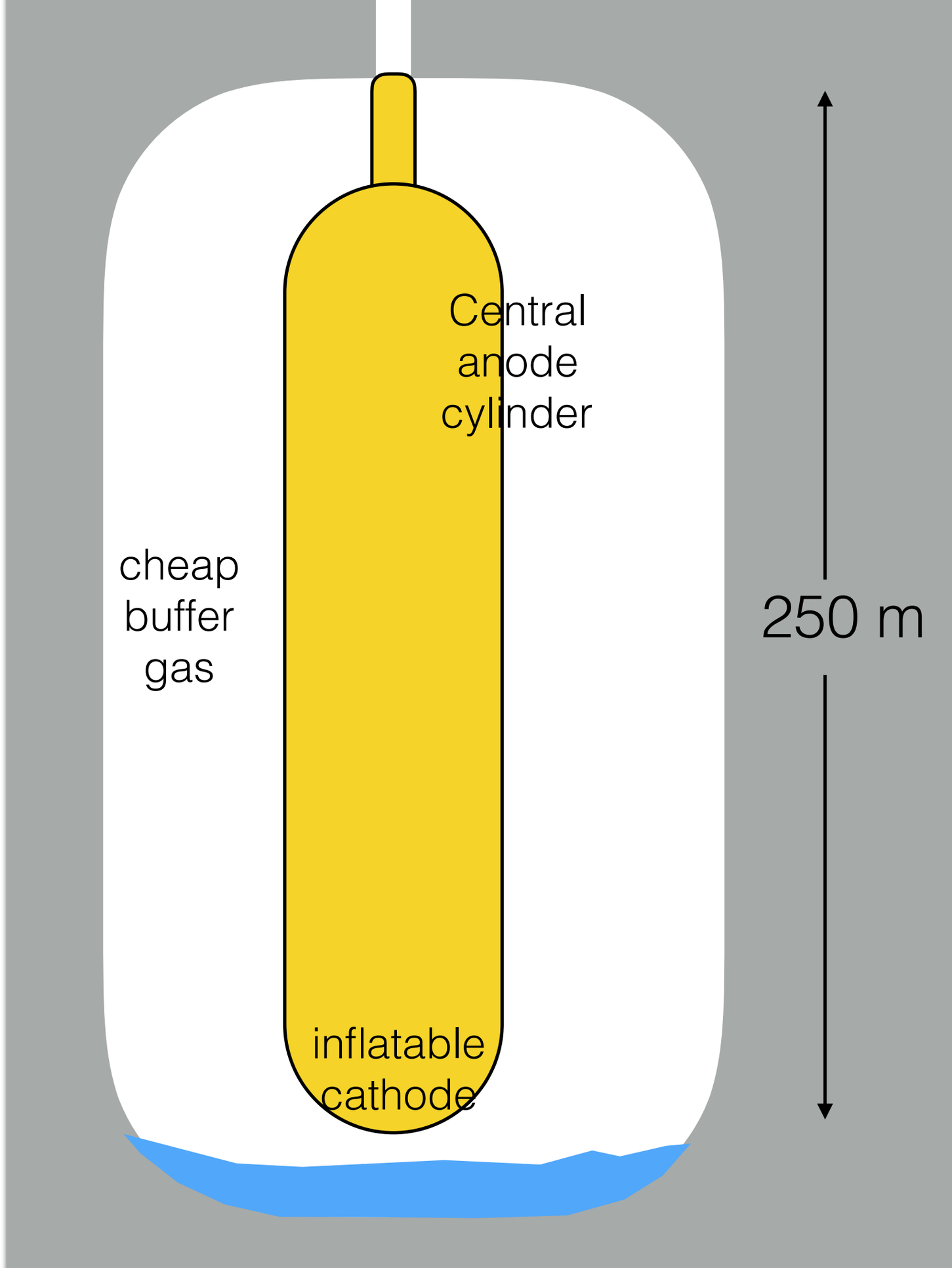

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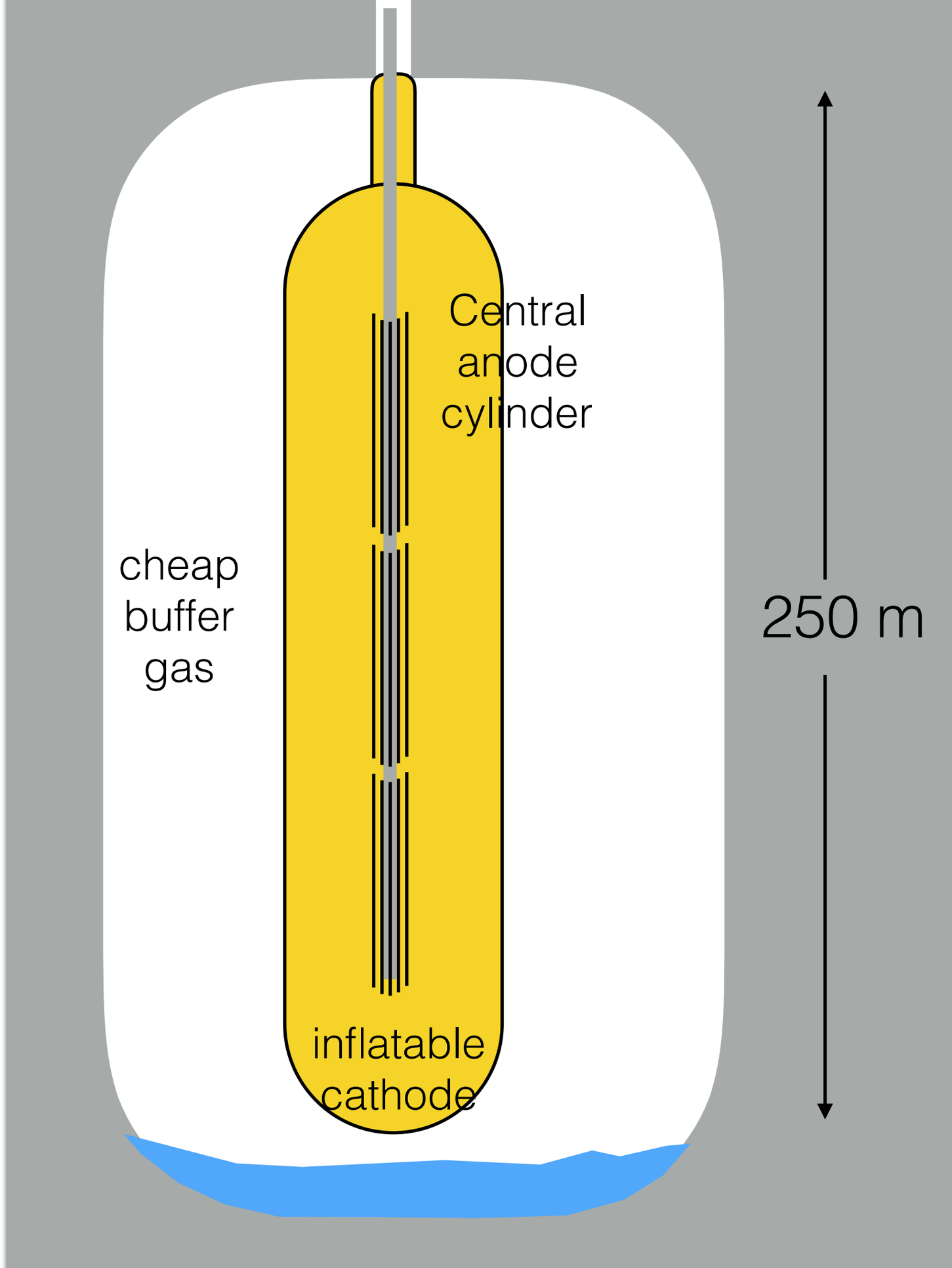
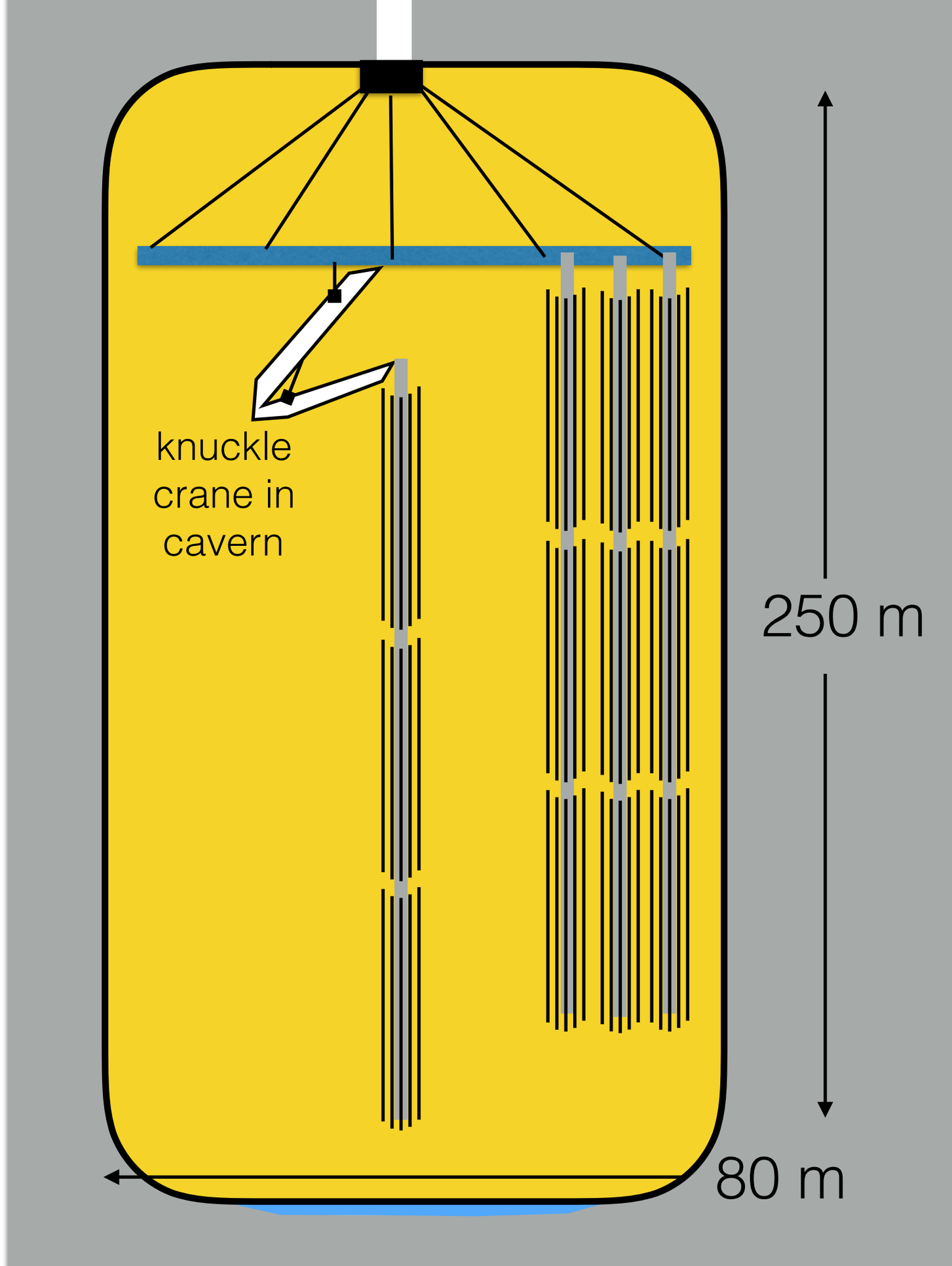


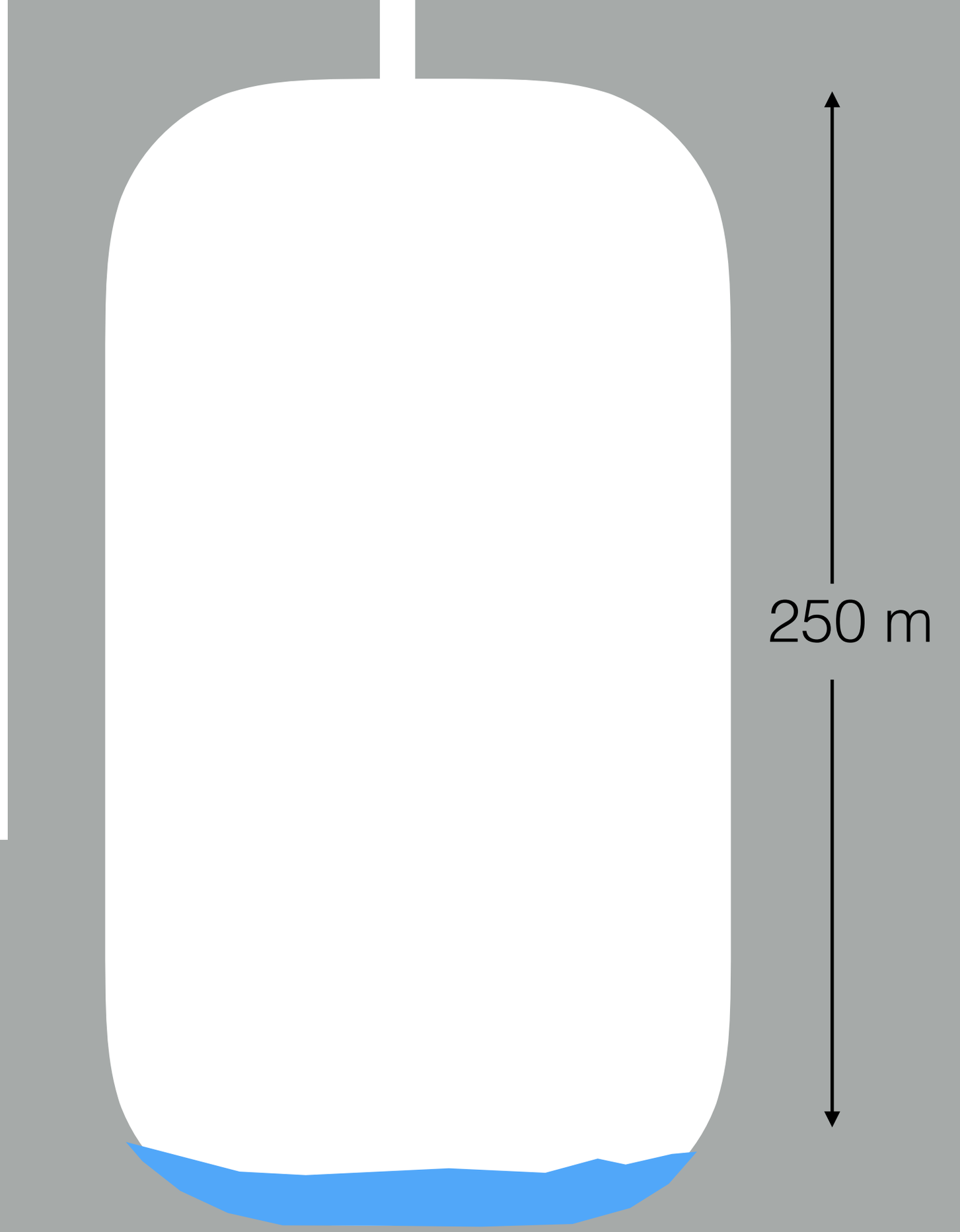
Even bigger TPCs

- Can we get to 500kT scale? ($3x10^{35}$ nucleons)
- CO_2, CH_4, Ar only
- Idea 1: Copy-paste self-contained units
  - (Dead volume between them? Lost gammas?)
  - Drilling isn't free
- Idea 2: More elaborate construction inside large single balloon
  - Origami?
  - In-cavern robotic tools?
  - I'll believe it when I see it



Conventional construction might work too

- Solution mine cavern
- Conventional access drift
- Construct detector
- Retreat and seal drift
- Fill and operate
  - Suggested by cavern engineers
  - "Has that ever been done?" "No"



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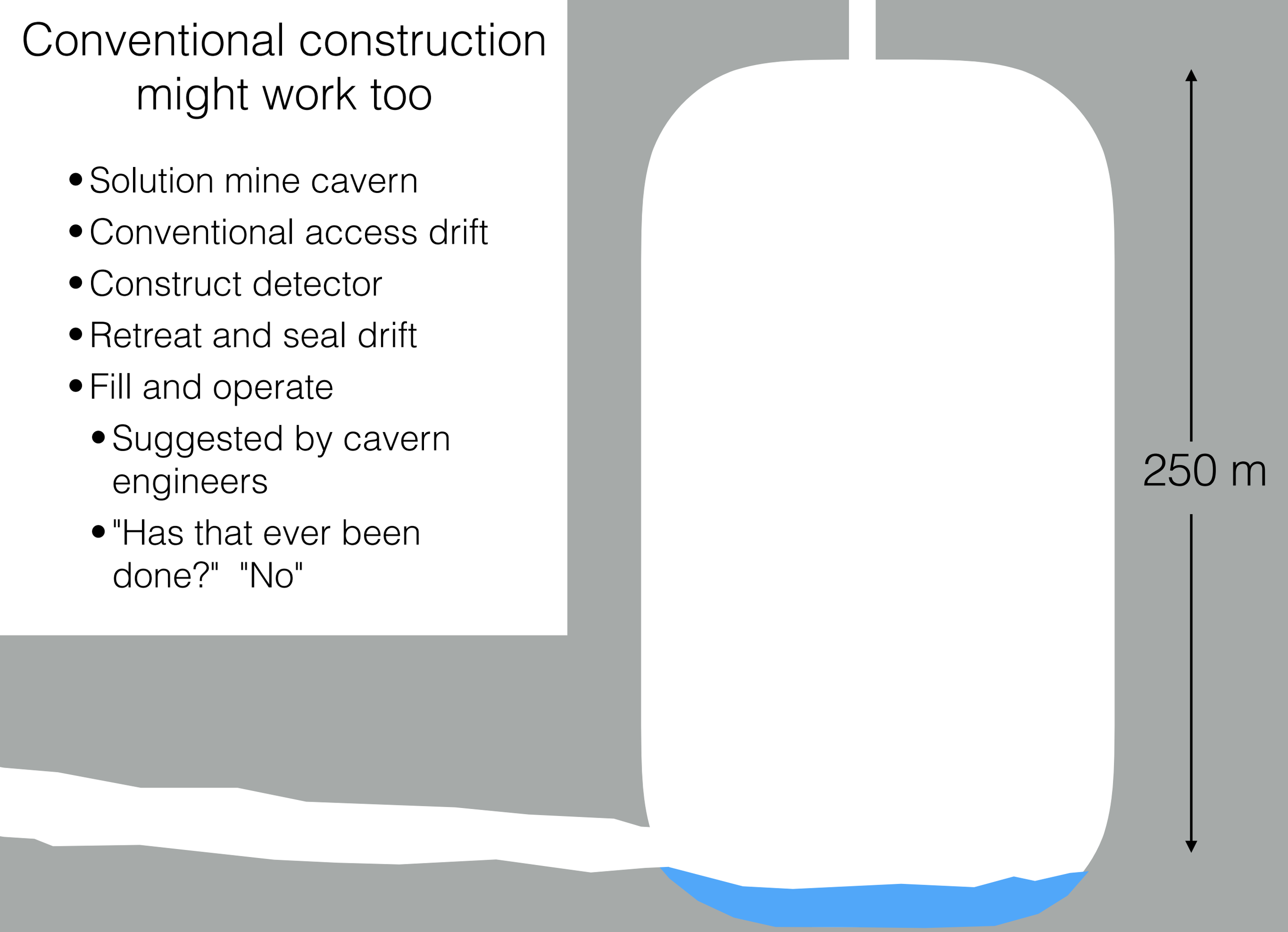

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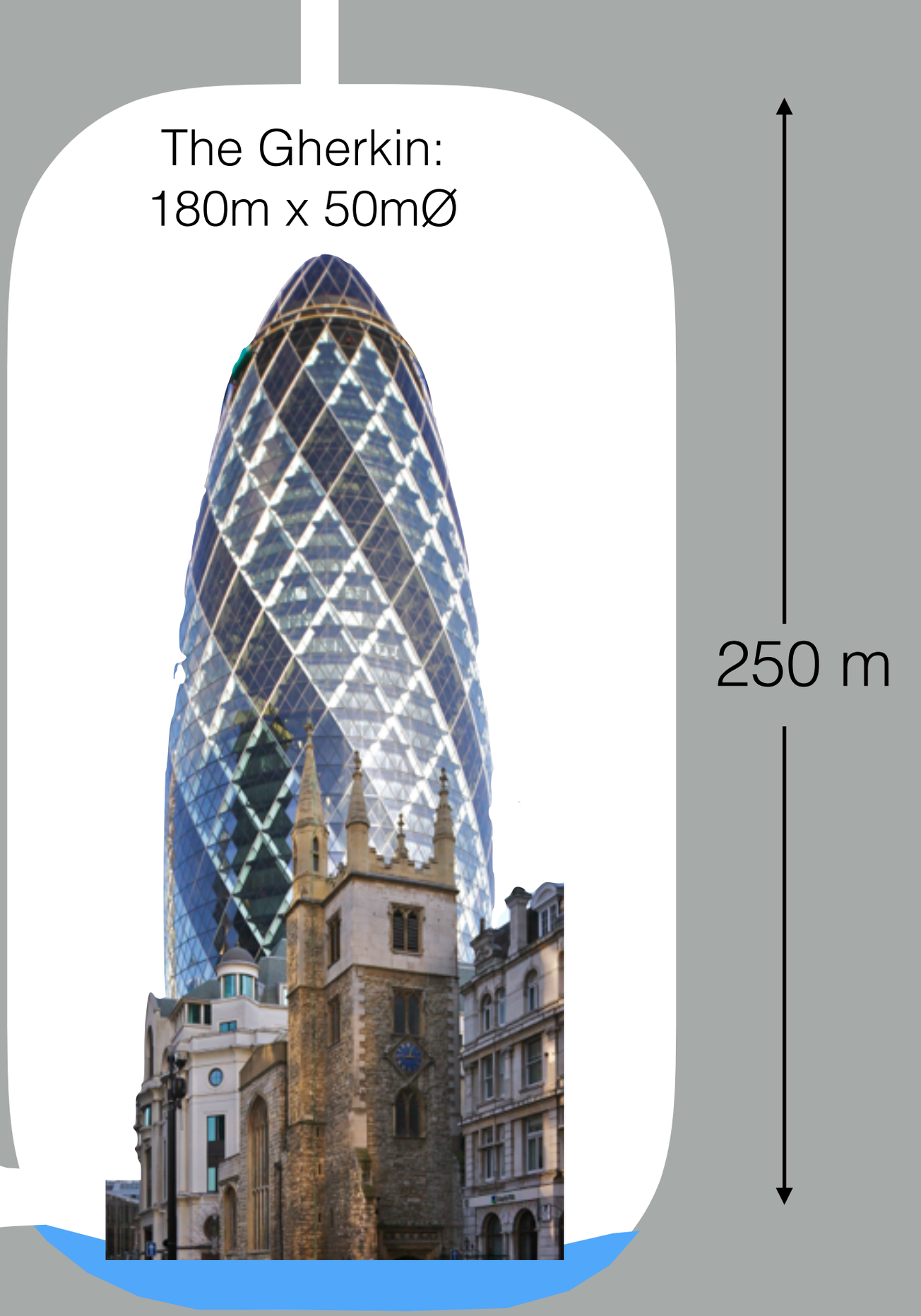
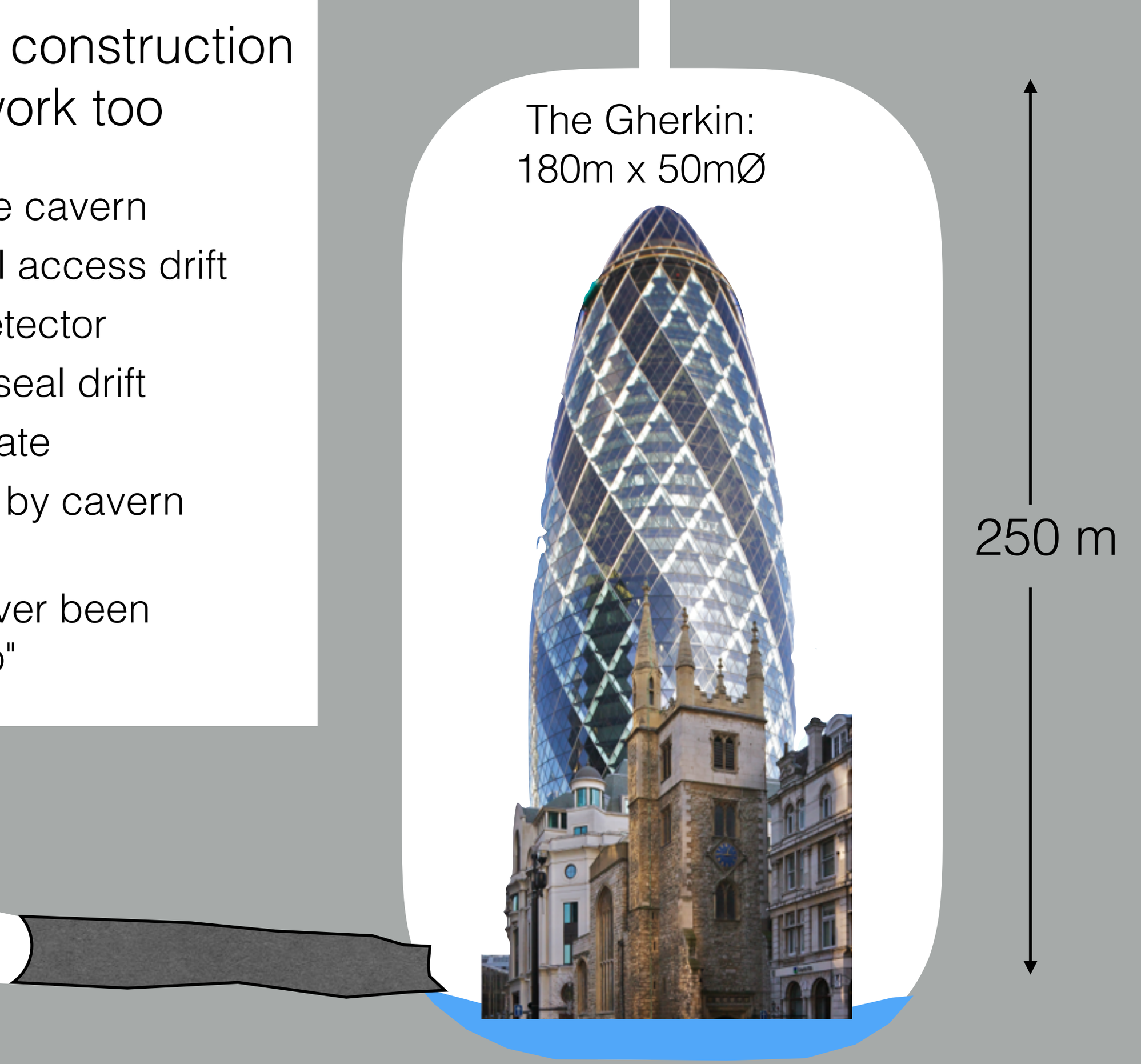


Conventional construction might work too

- Solution mine cavern
- Conventional access drift
- Construct detector
- Retreat and seal drift
- Fill and operate
  - Suggested by cavern engineers
  - "Has that ever been done?" "No"



Salt cavern options for the whole G3/G4 program

16ø x 80m
P = 100 bar
1 kT Neon
solar ν, DM

P = 0.1 bar
8 T Xe
directional
dark matter

MSU, UMich, CWRU, LSU: could have a small deep lab on campus

3.5ø x 6m
32t Xe
P = 55 bar
0νββ, DM

20+ meters clean water for veto + shielding

SuperK tank for scale

39ø x 42m

40 kT Ar
50ø x 120m
P = 100 bar

a) There is bedded salt 1.5° N of DUNE beam

b) Louisiana salt domes are 1300 km from FNAL

The largest caverns in routine use are 80ø x 250m

1.25 MT H_2O

at 200 bar:

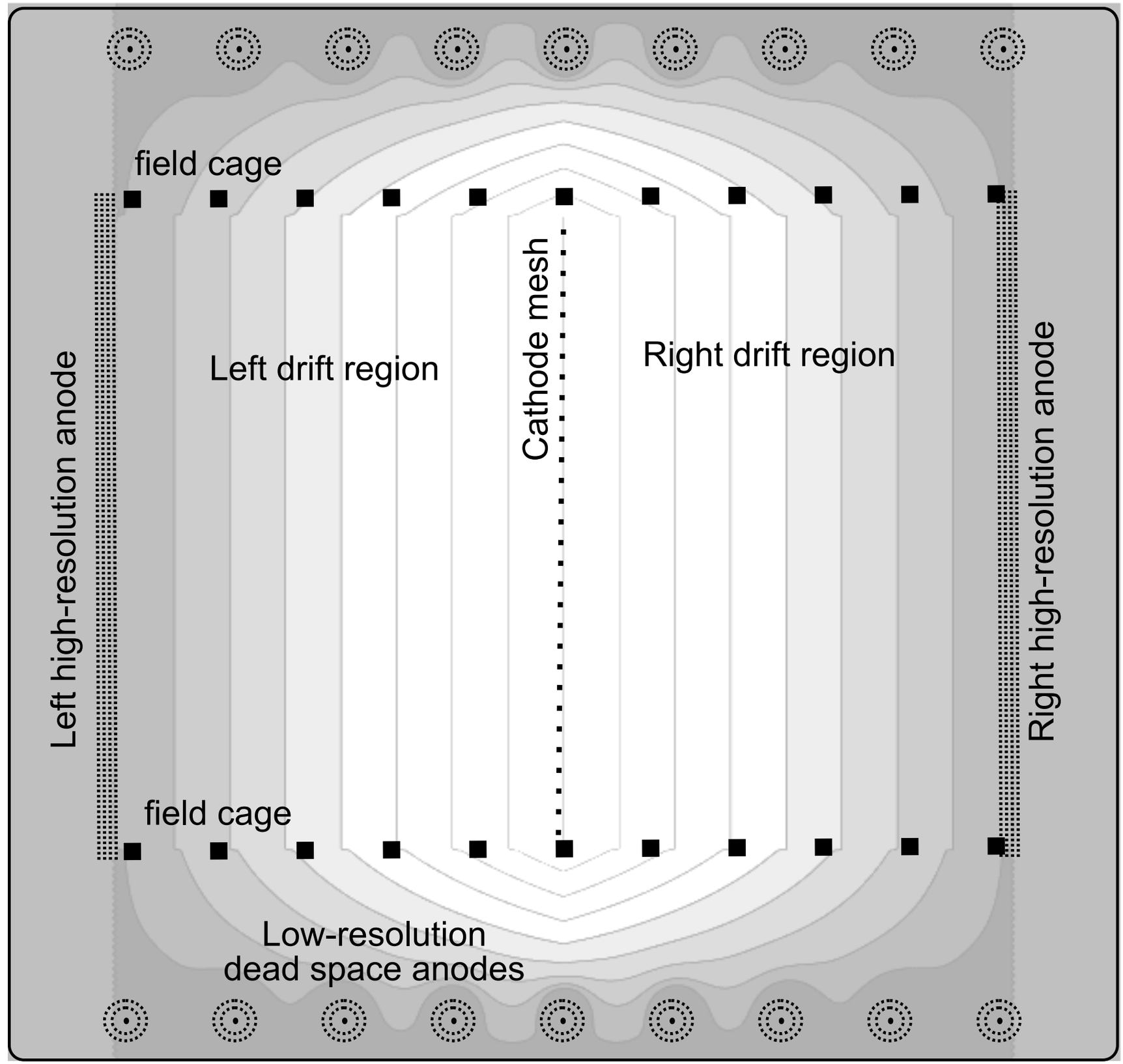
0.4 MT Ar
200 kT CH_4
18 kT H_2

What's next

- For me:
  - Moving to Case Western and looking for local well access to play with
  - Dark matter sensitivity study of LXe:TMAE
  - Inflatable cylindrical TPC mechanical studies
- For you:
  - Brainstorm up applications, identify problems
  - Join interest group and share ideas
    - http://hep.ucsb.edu/saltcaverns/
  - email scdig_request@hep.ucsb.edu for access to our Basecamp site
  - How to get from brainstorming to funded R&D?

Giant TPCs without PMTs

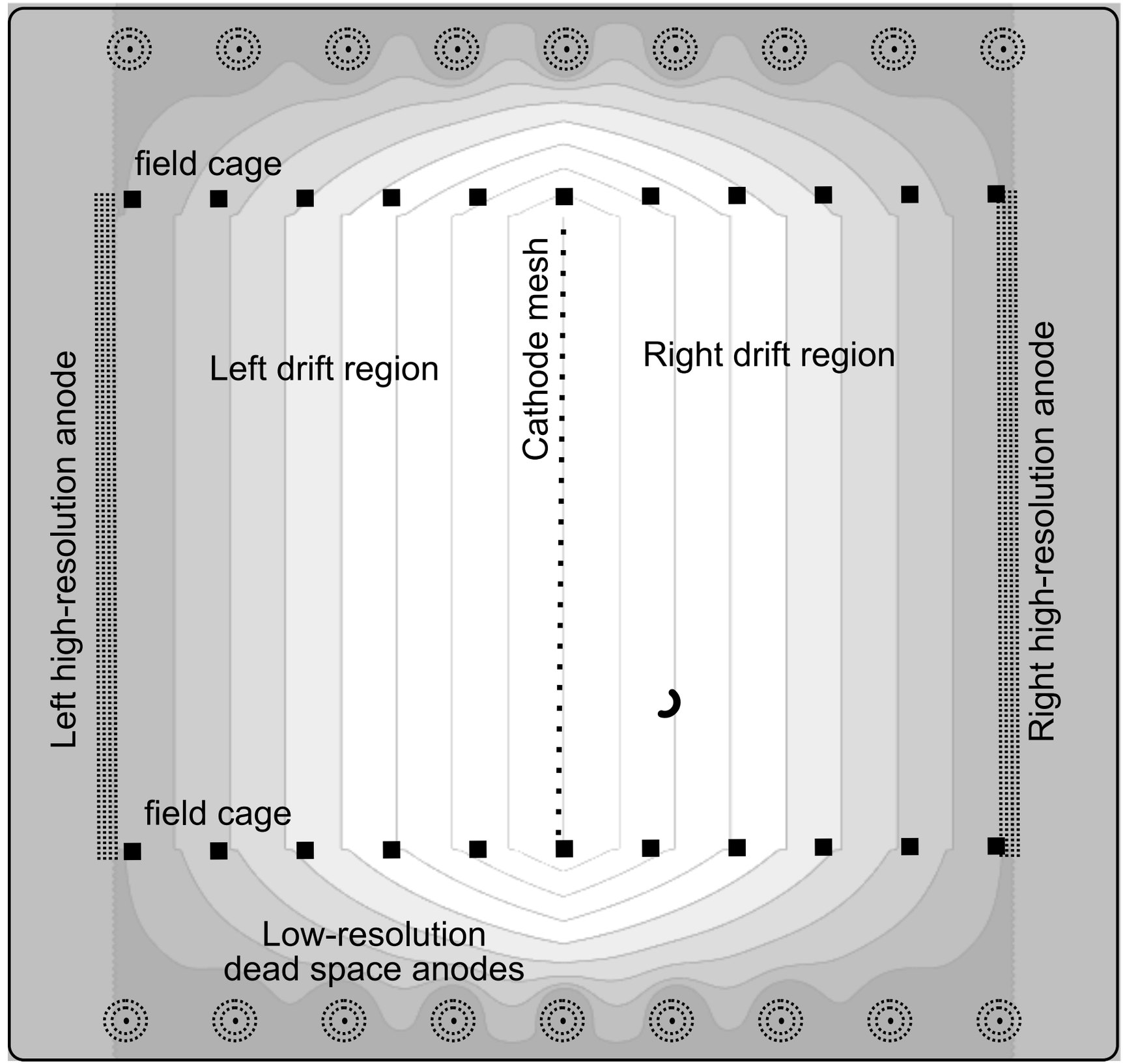
Large gas time projection chamber



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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Large gas time projection chamber

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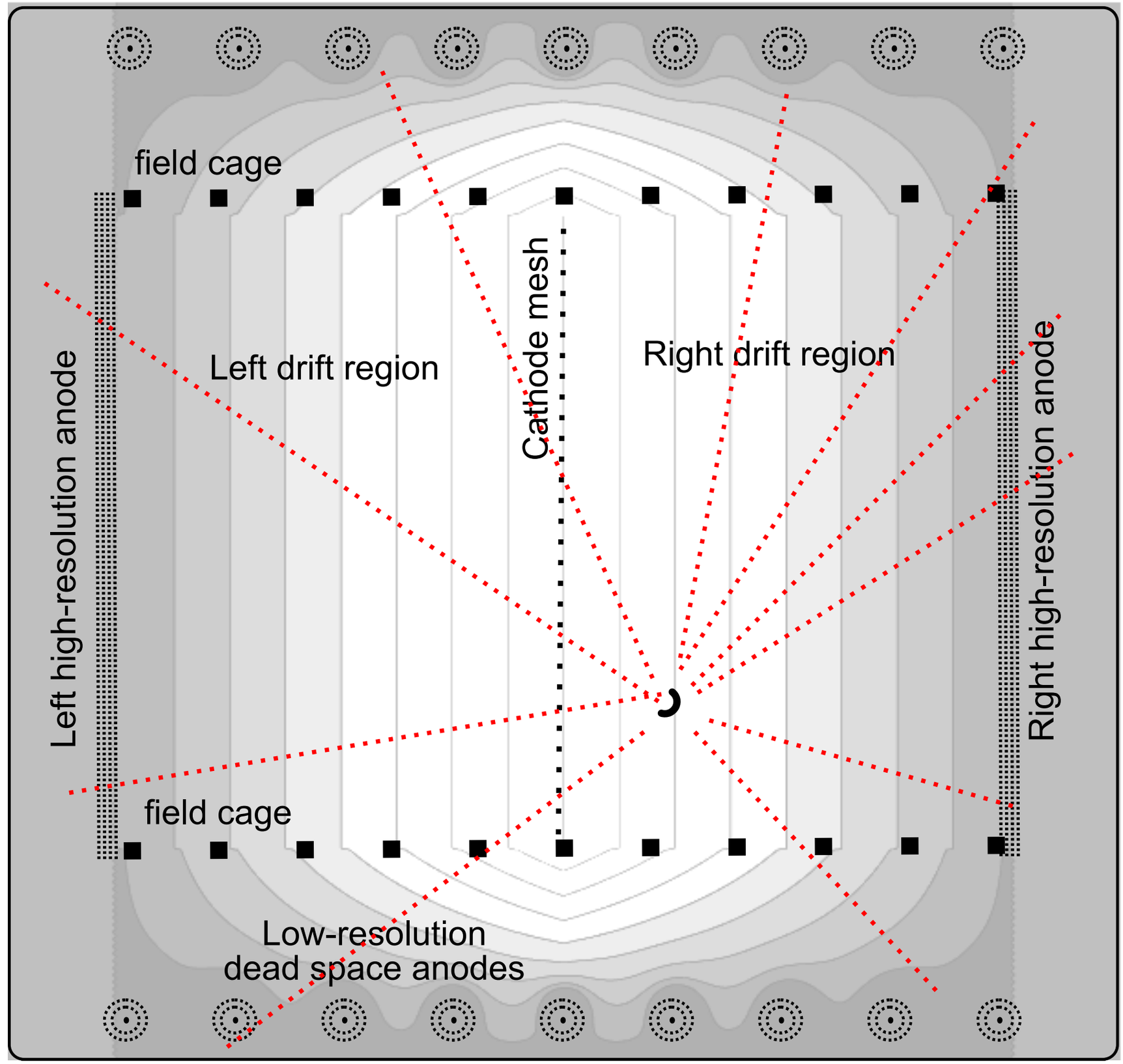
Scintillation light! sets Δt …



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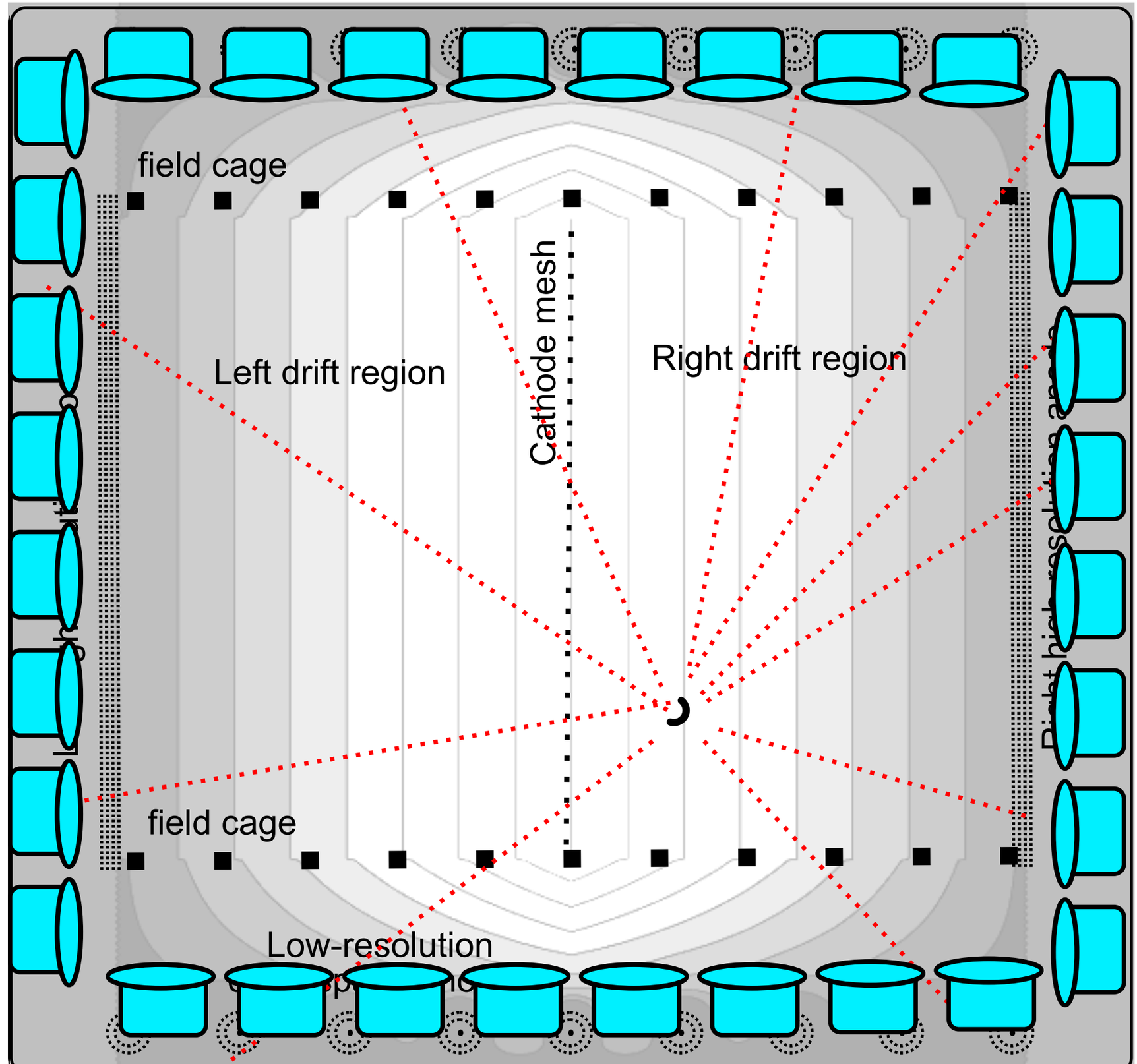

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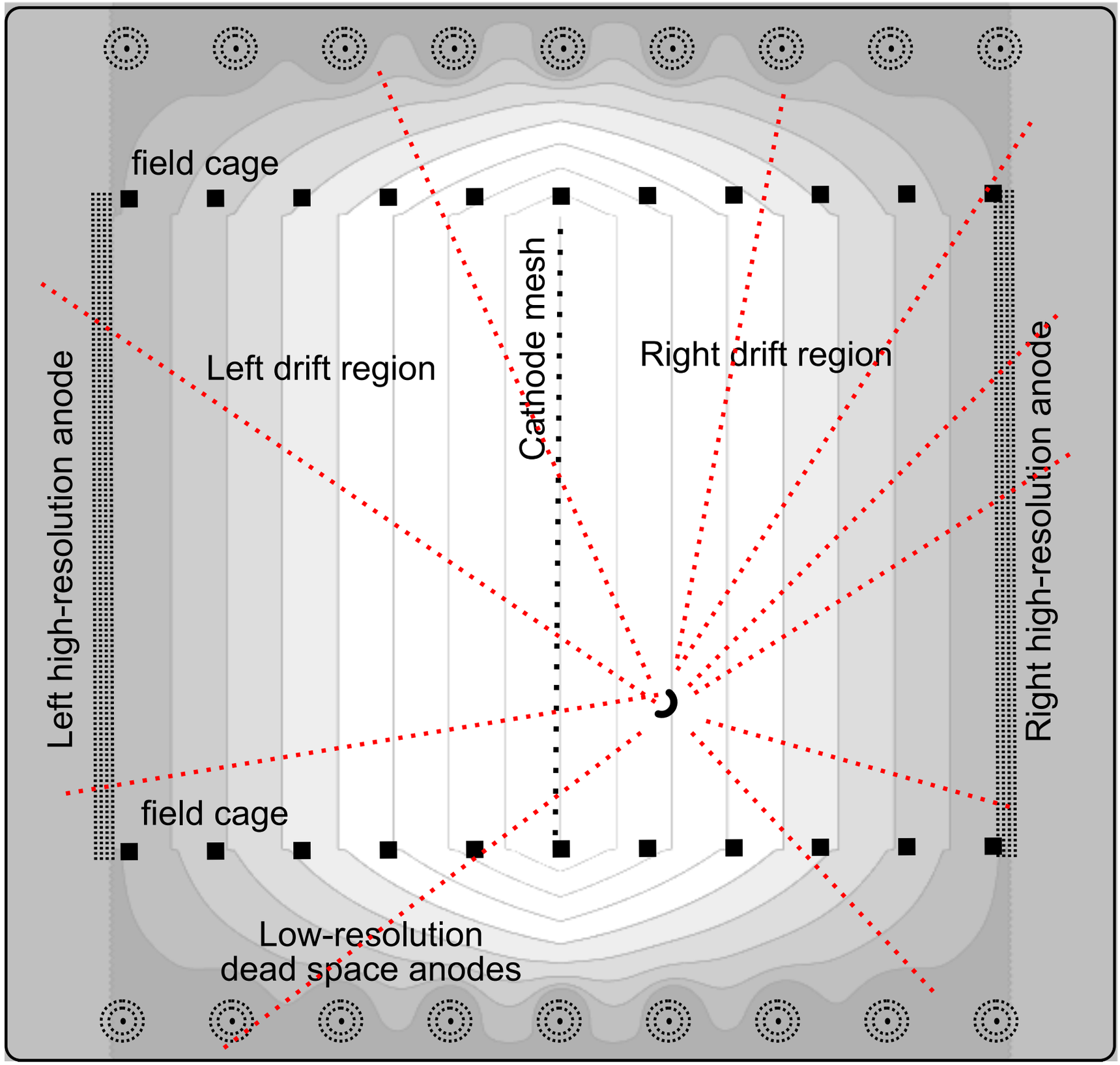

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Large gas time projection chamber

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Scintillation light! sets Δt …

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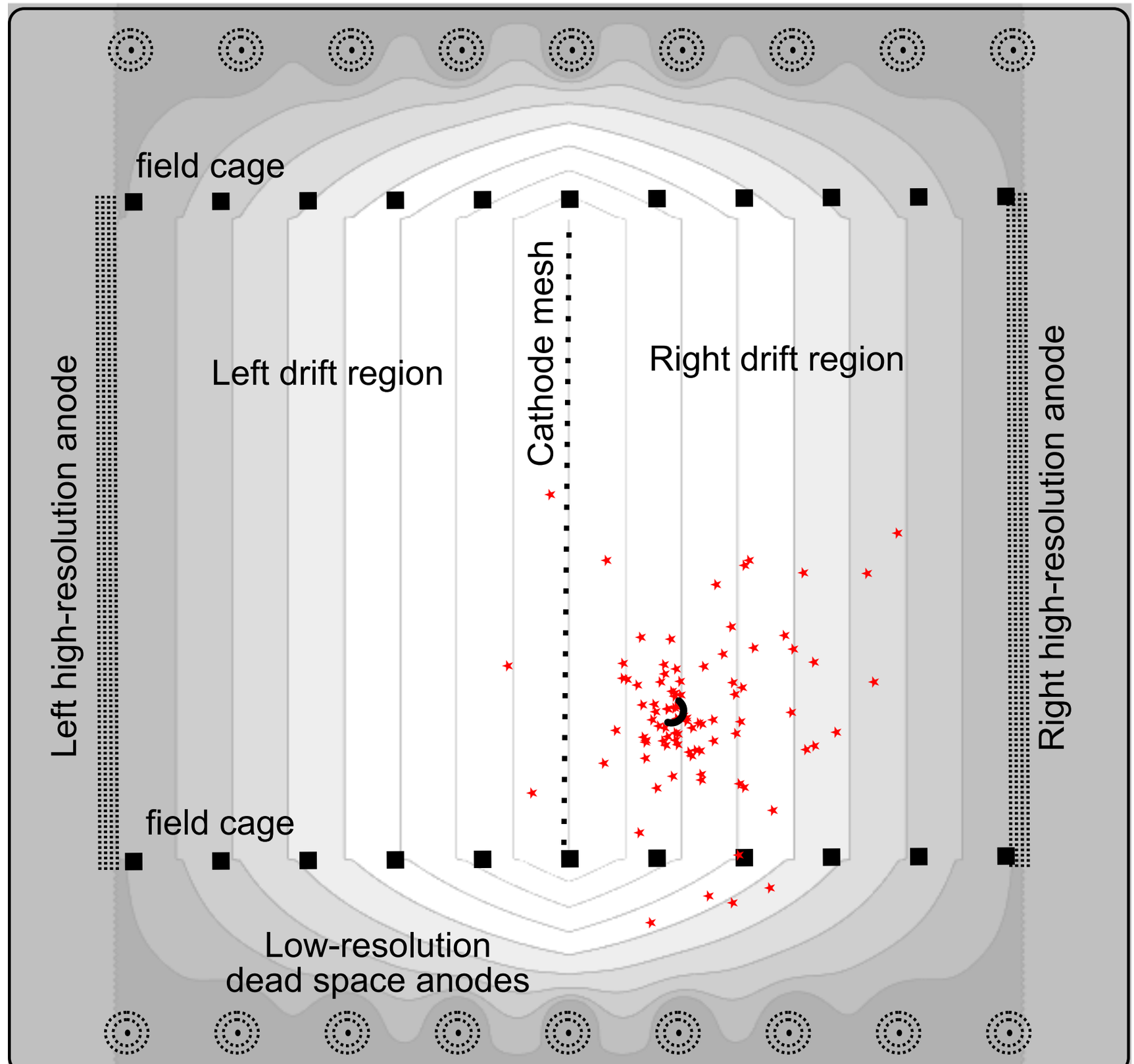
Mix 10^{-7} TMAE into Xe. Converts scintillation photons to photoelectrons.



arxiv:1512.04926

right anode

left anode

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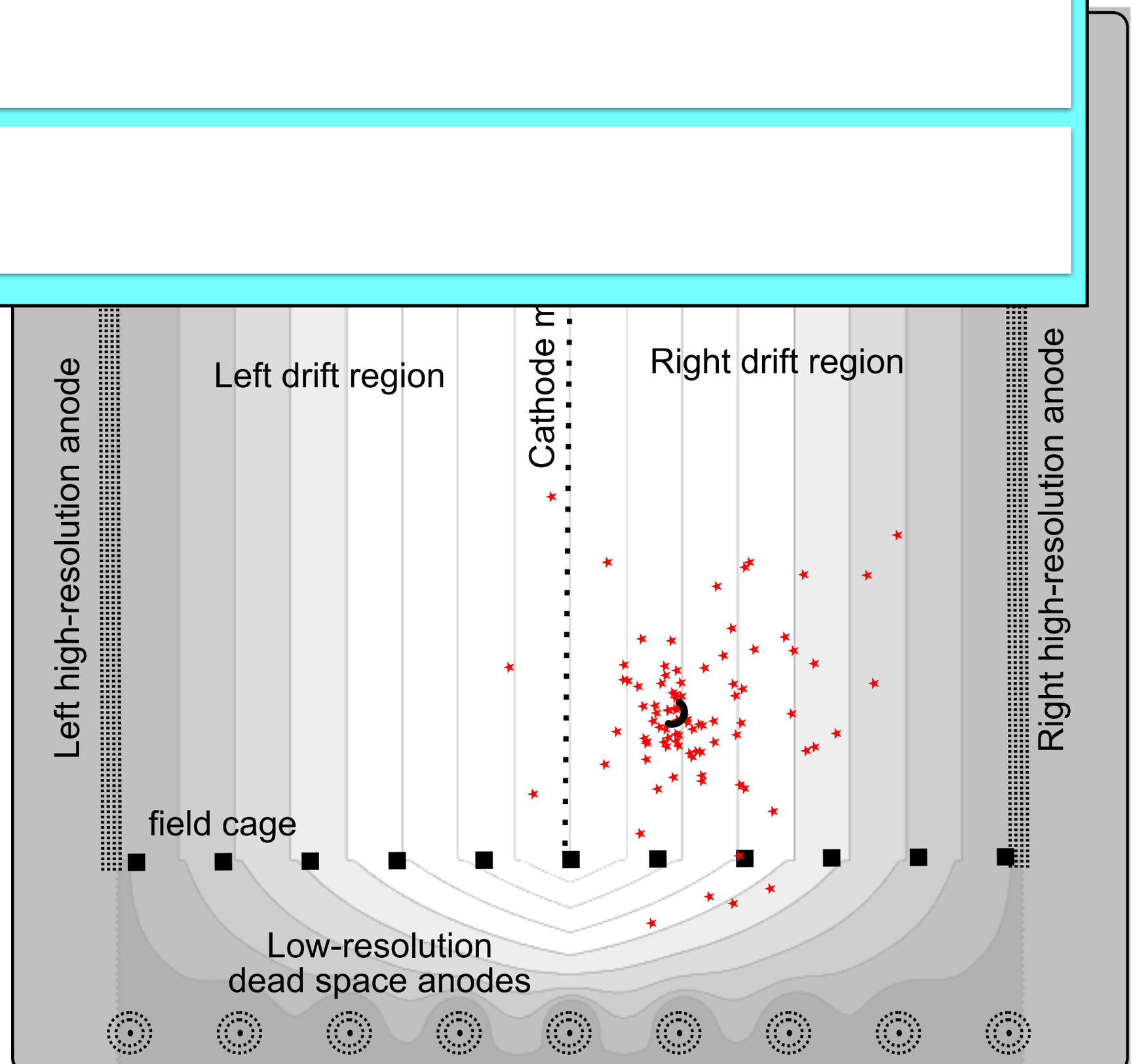

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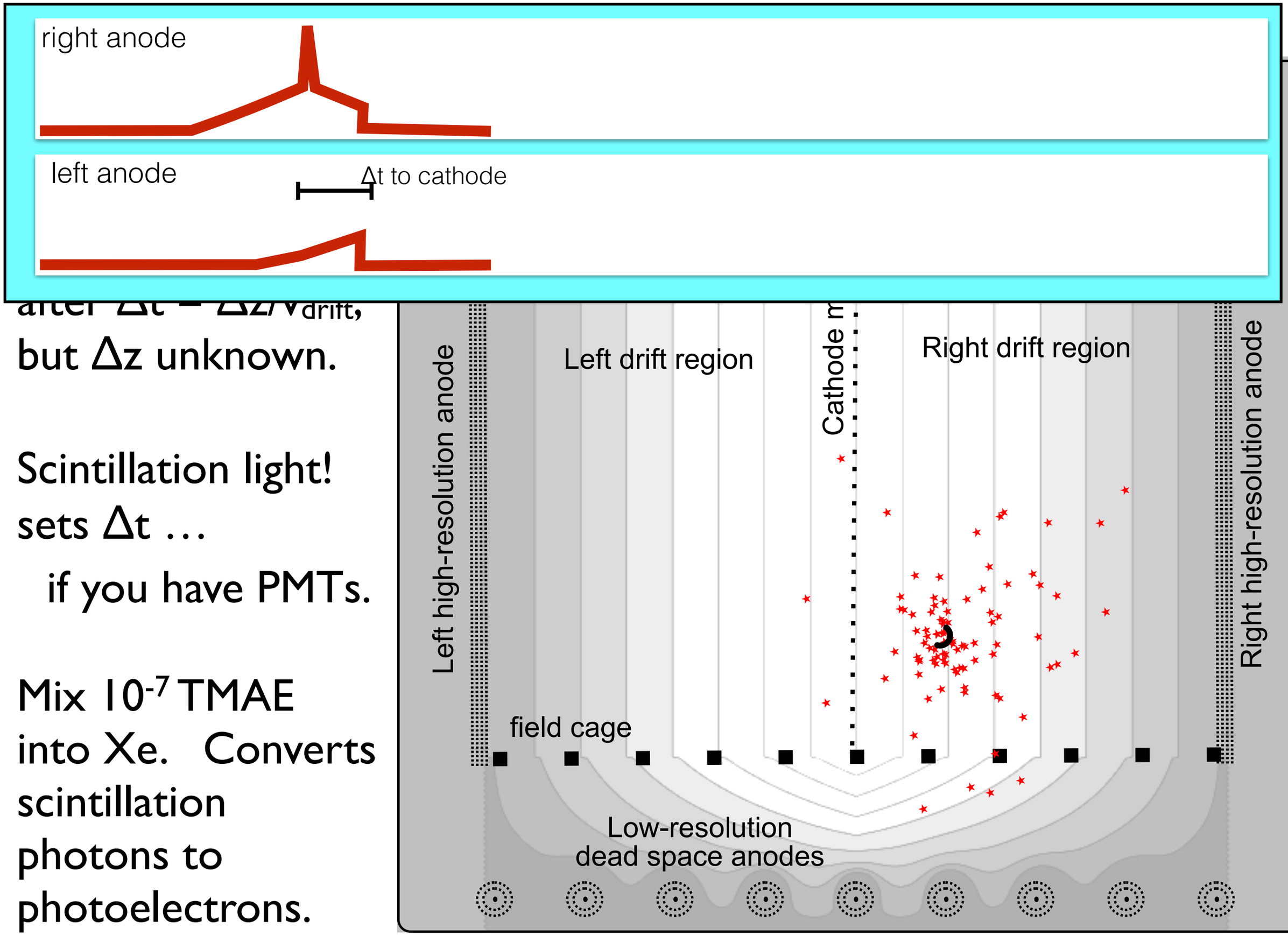

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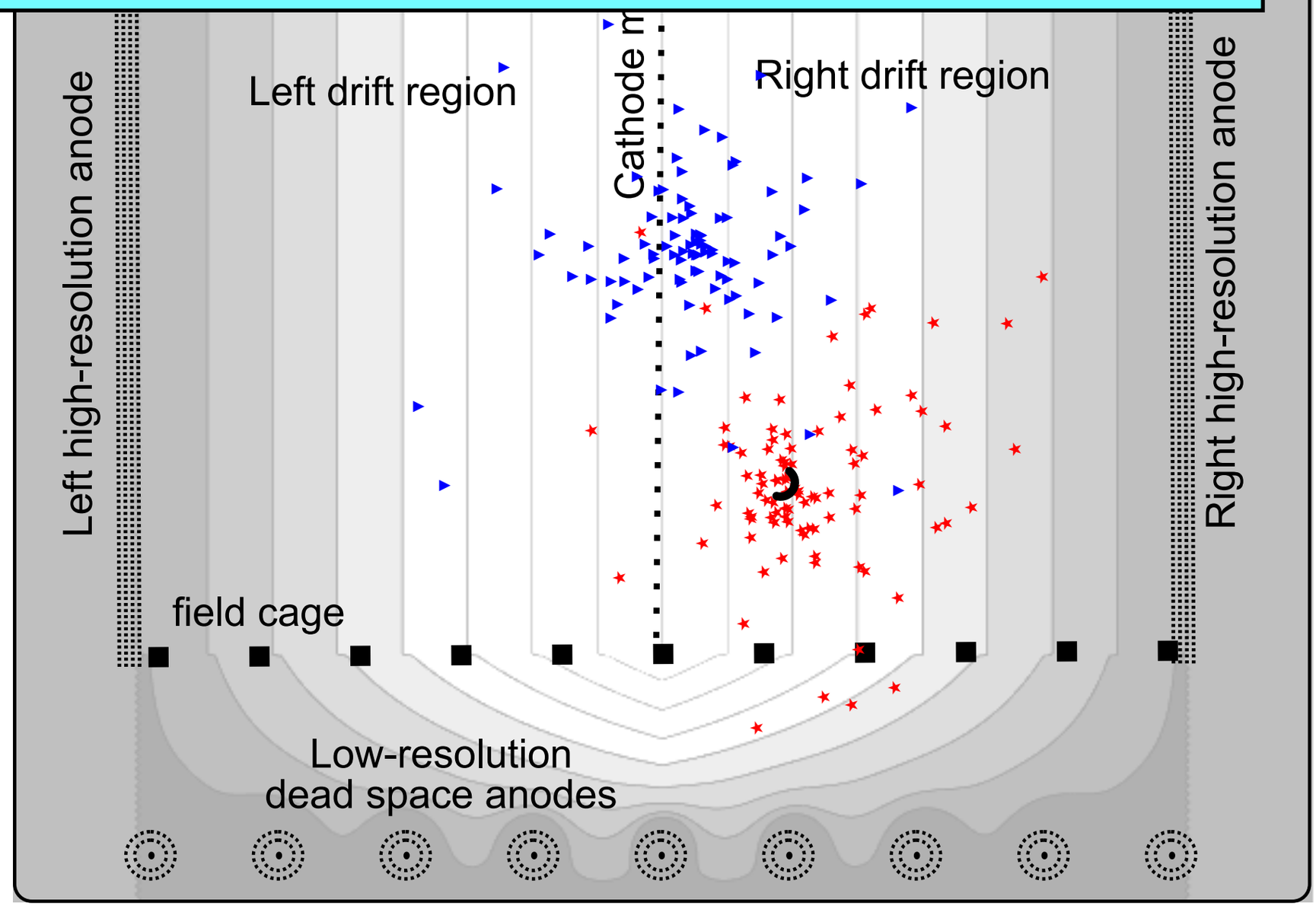

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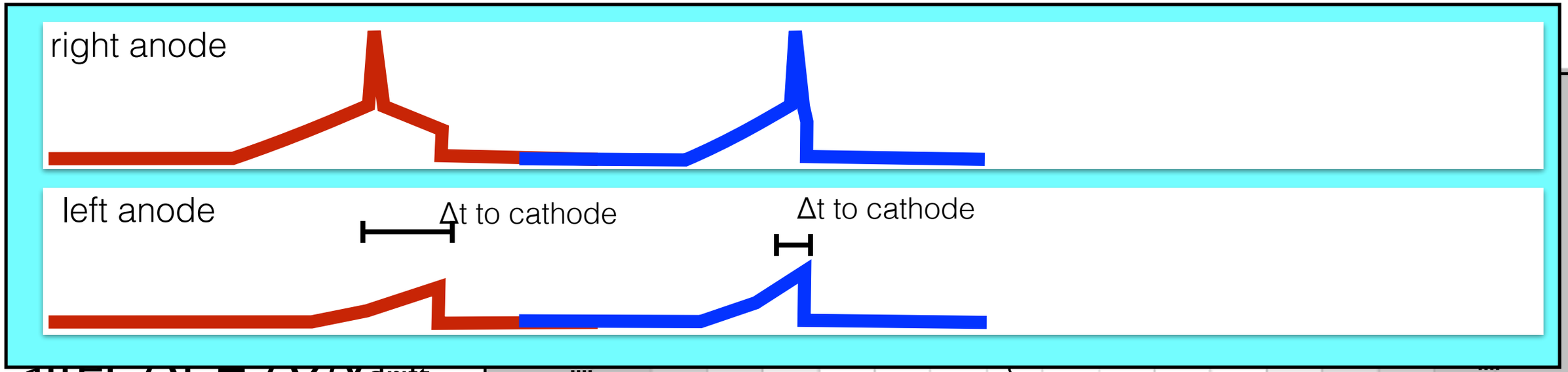

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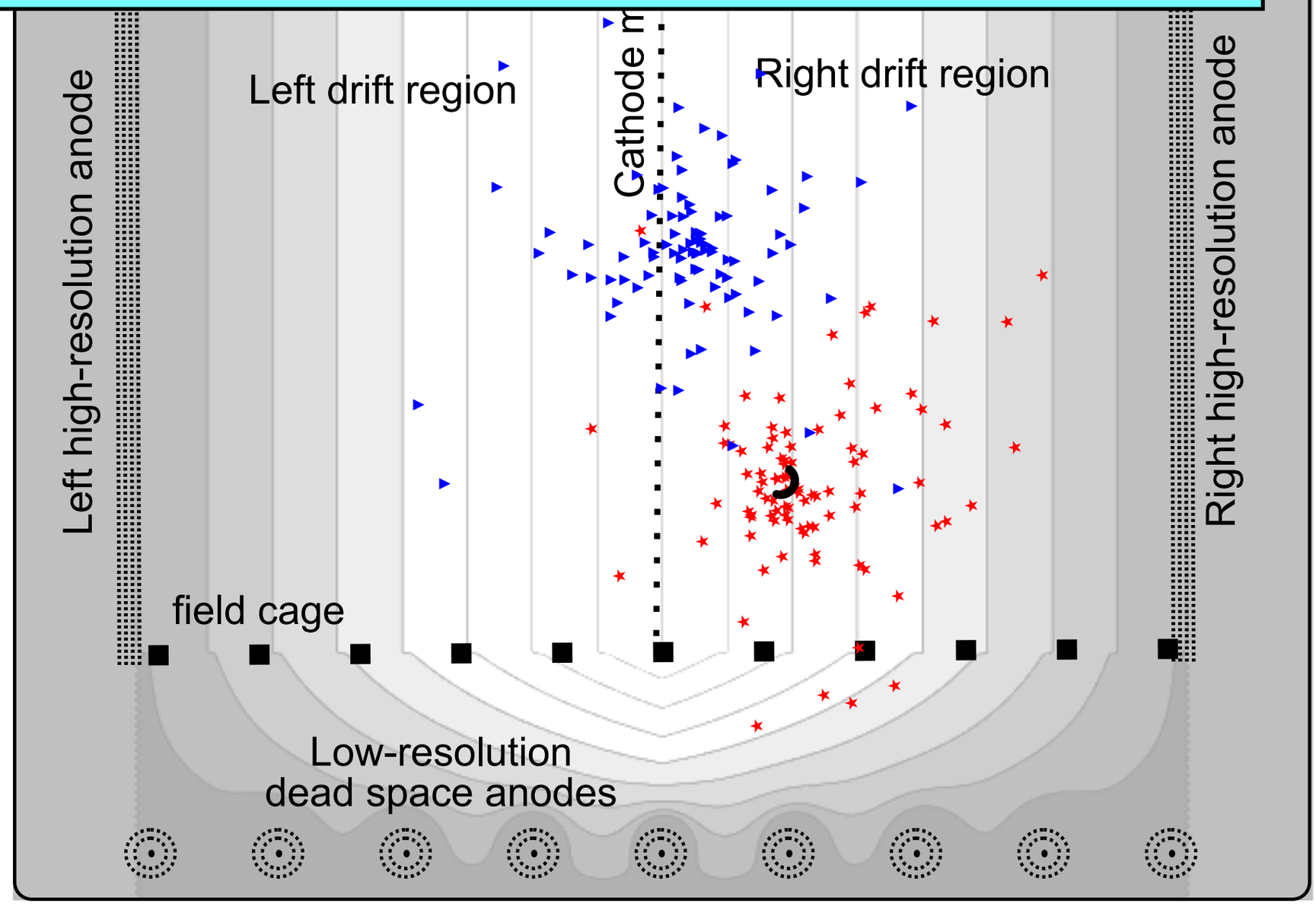

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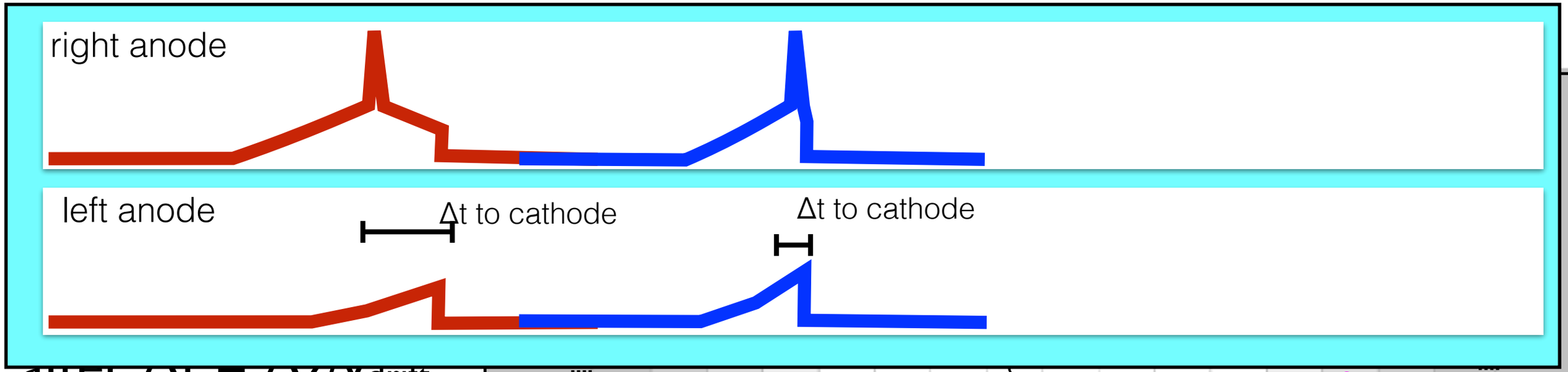

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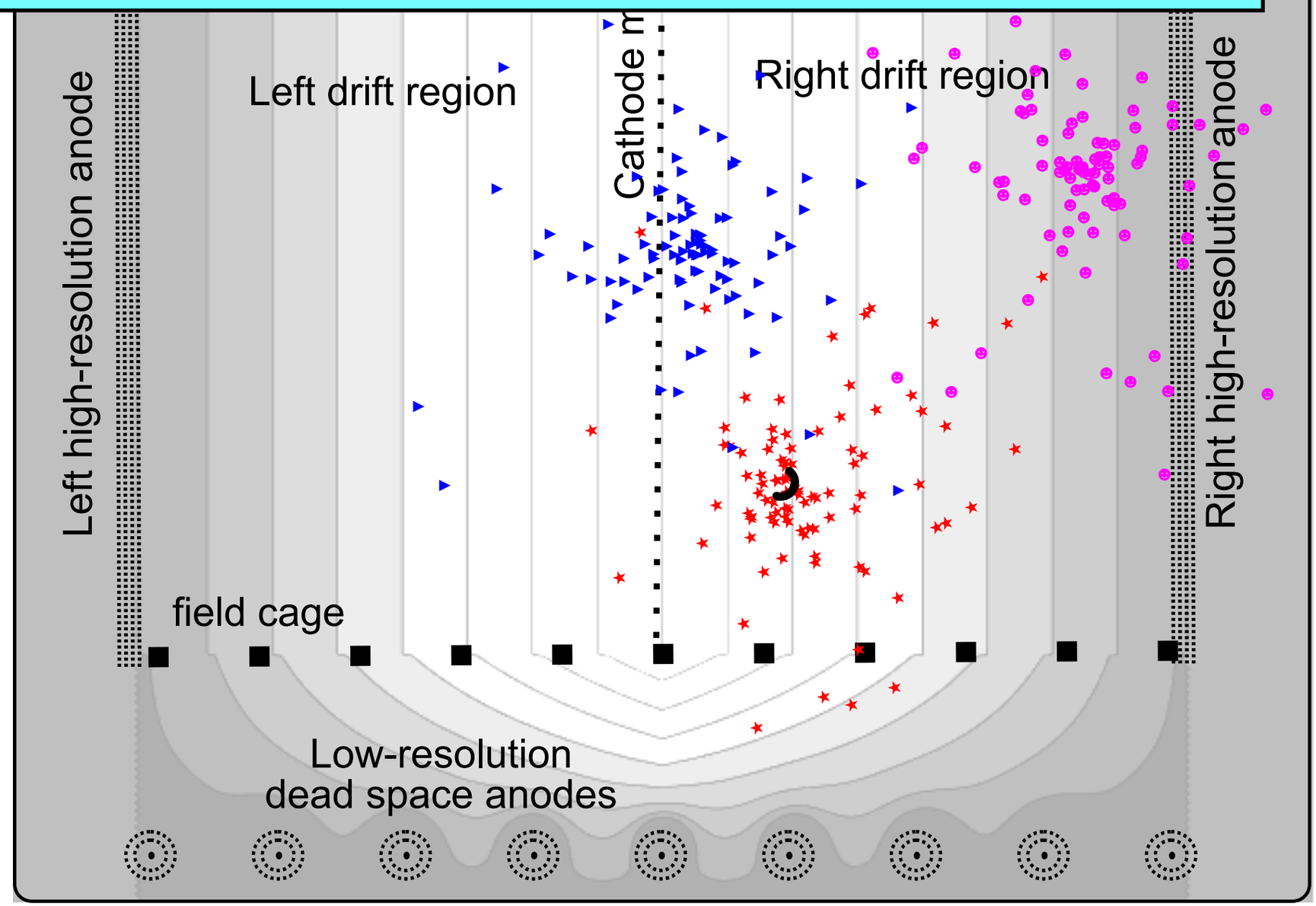

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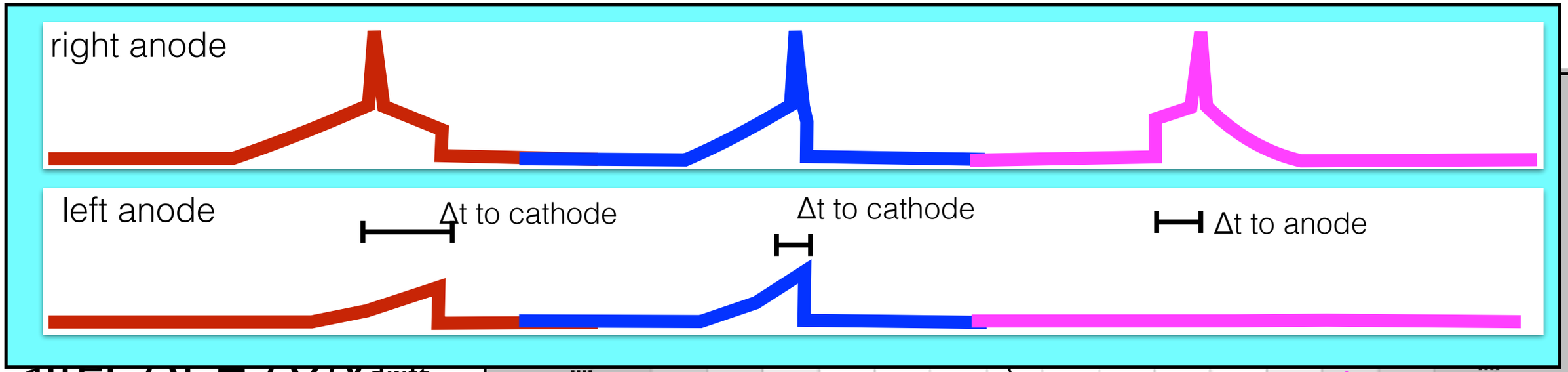

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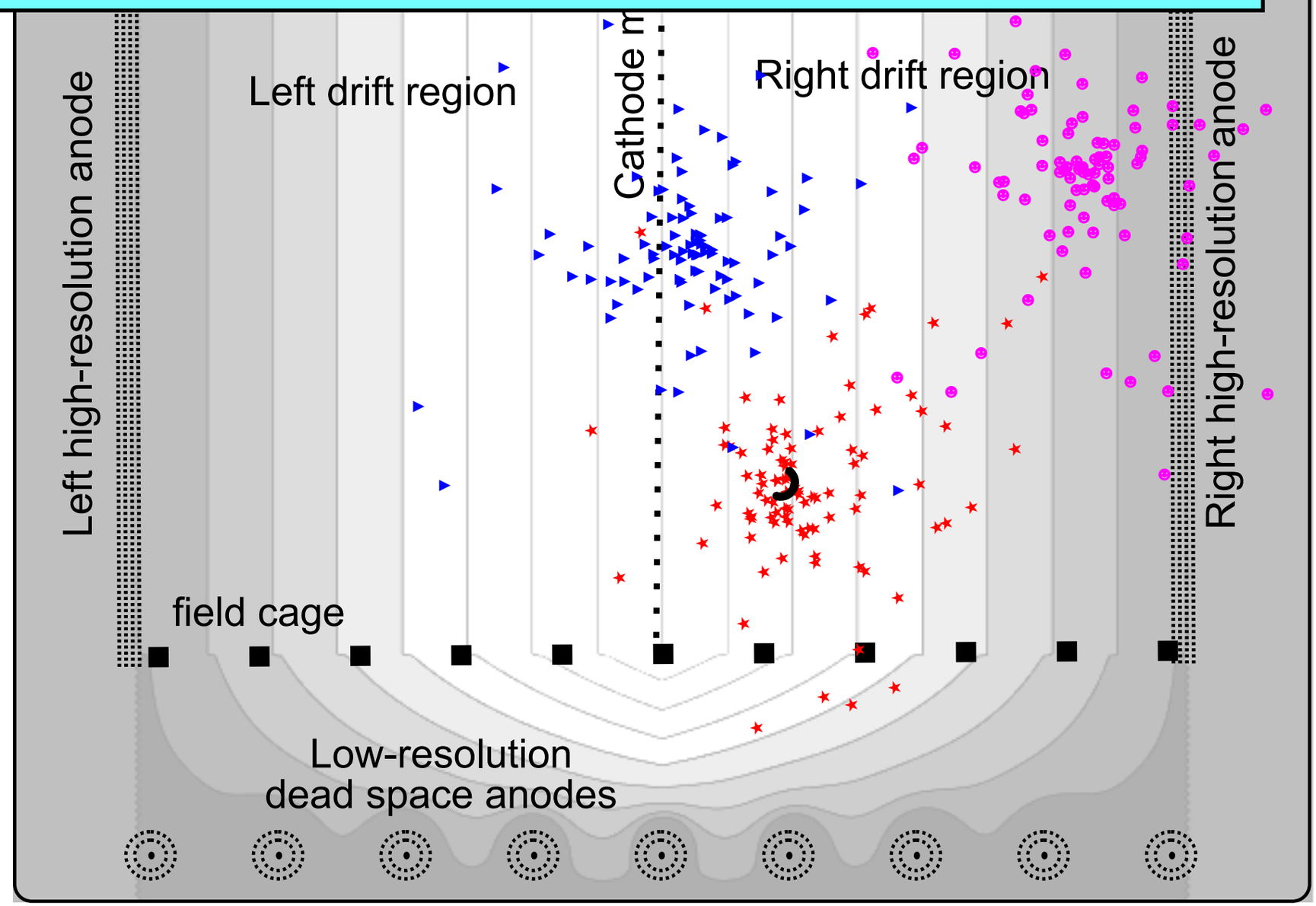

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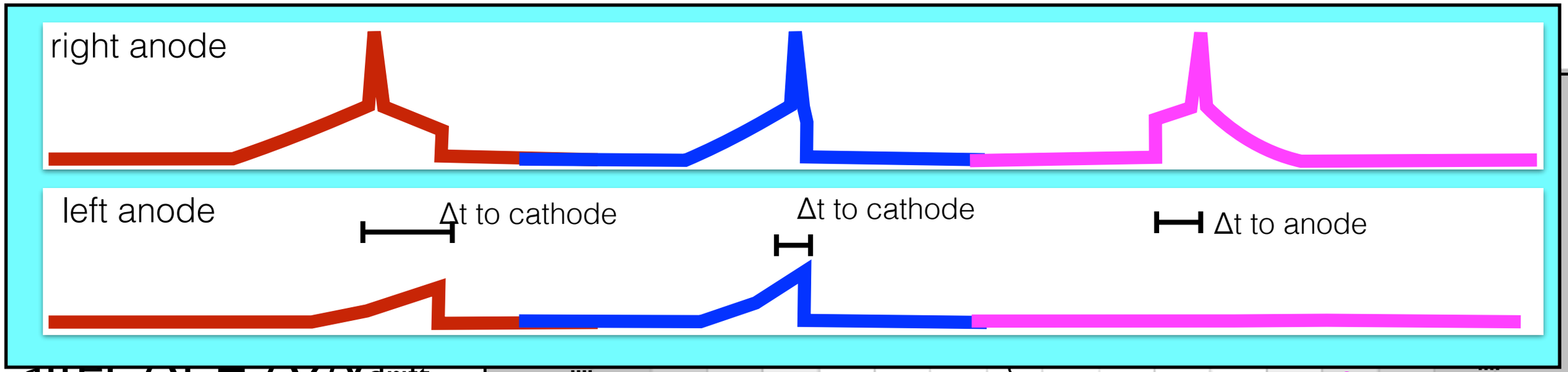

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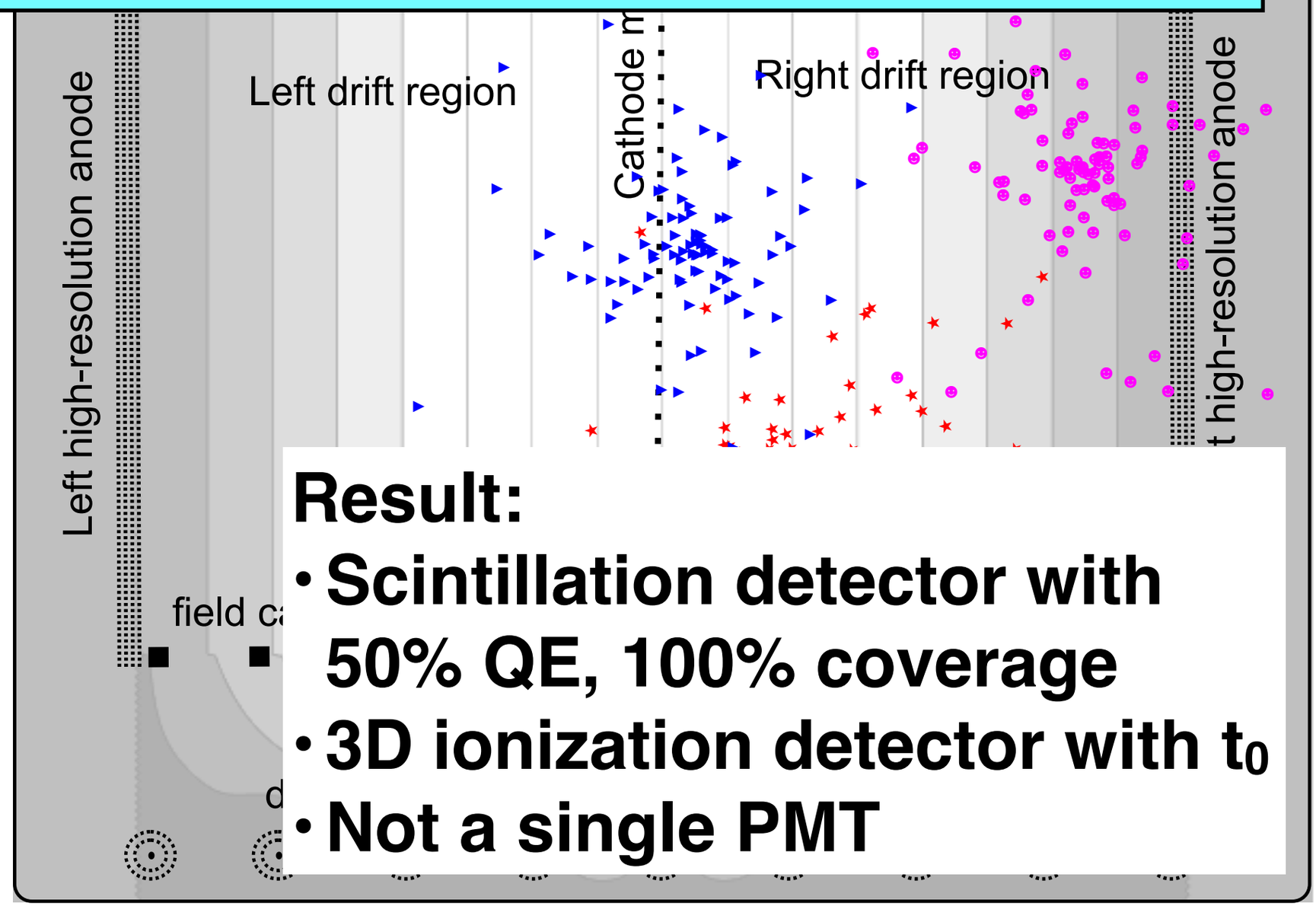
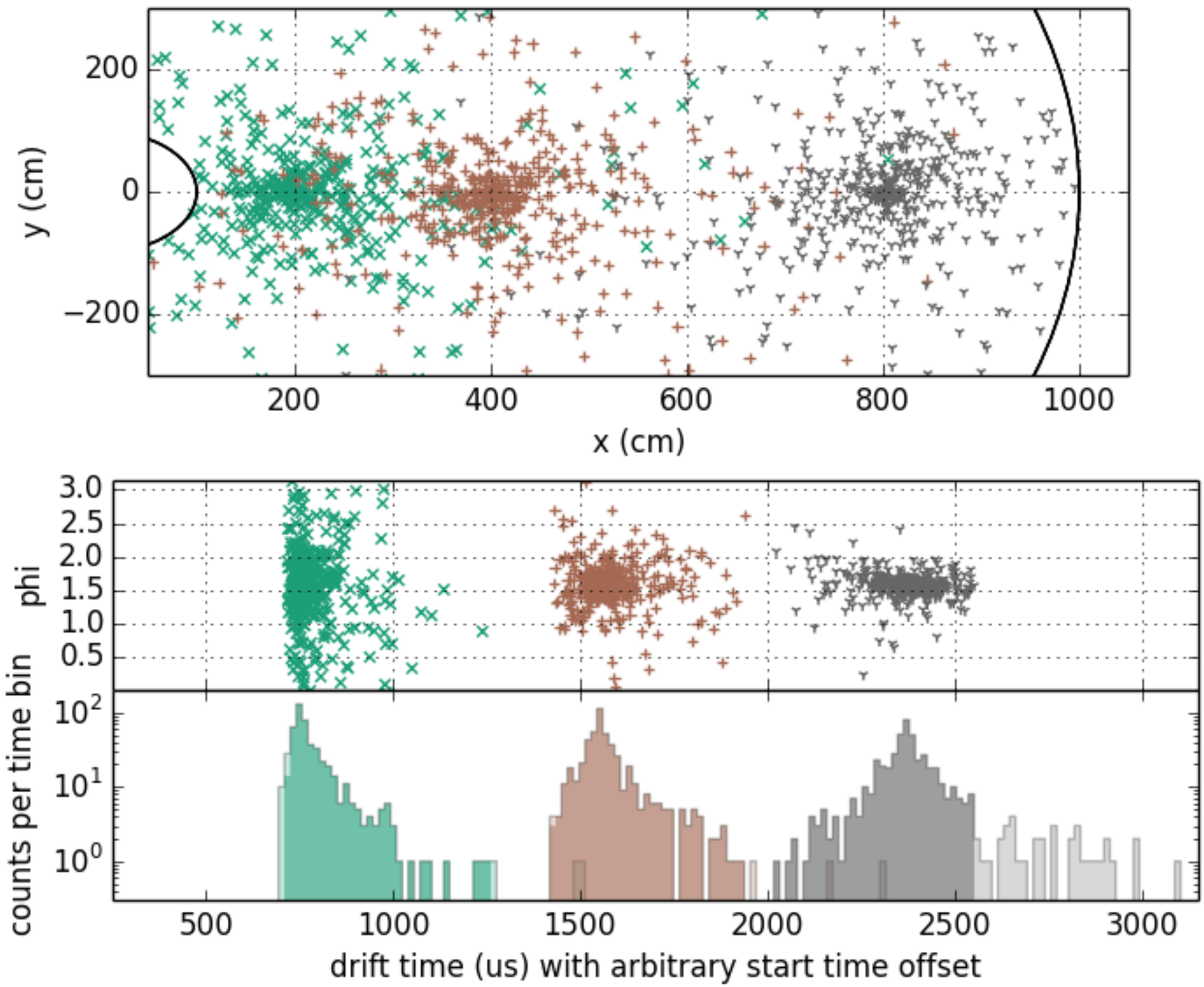


Result:

- **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



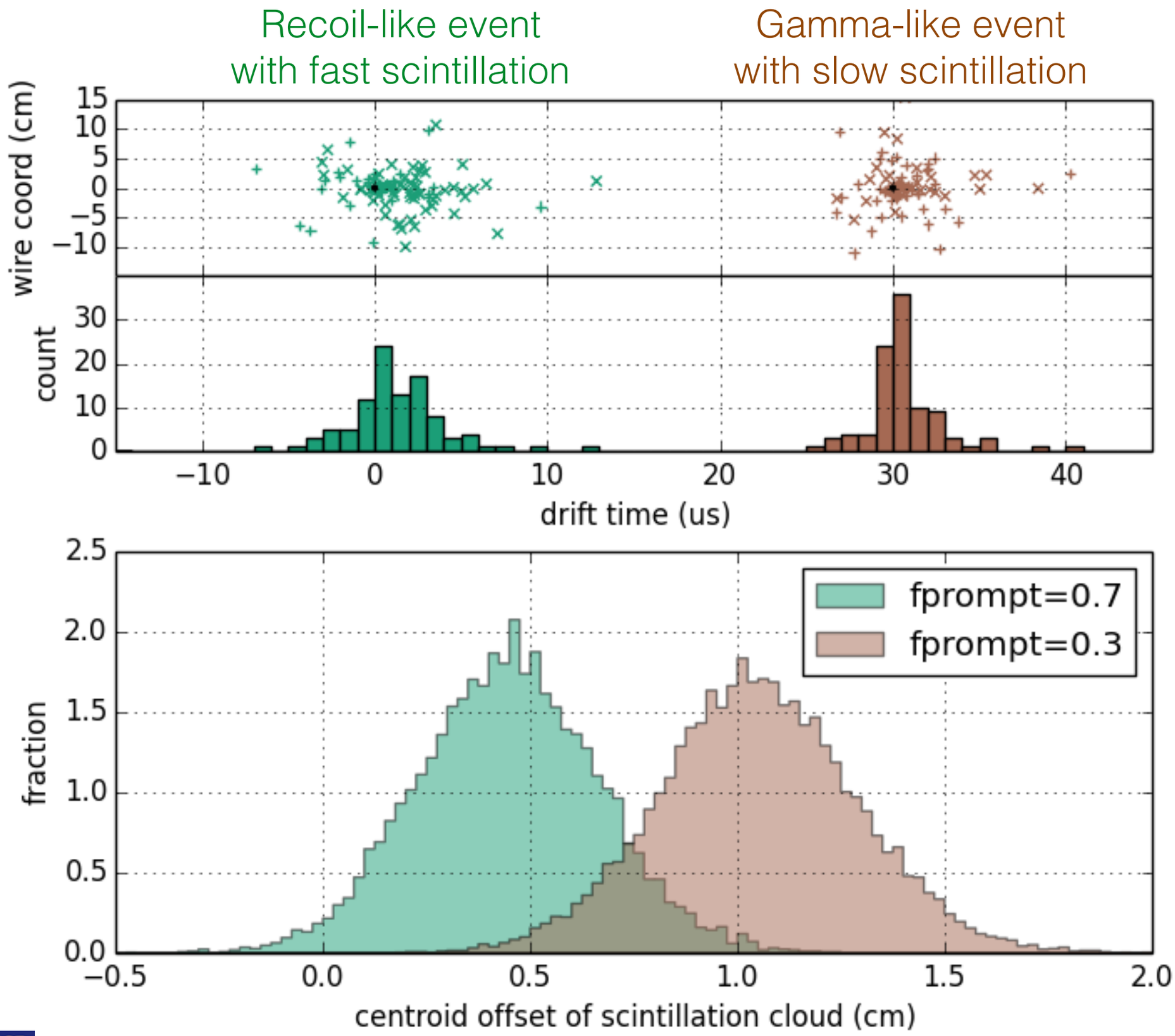
Slice of a cylindrical detector with events near center, middle, outside.

Scintillation clouds are symmetric

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

arxiv:1512.04926

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

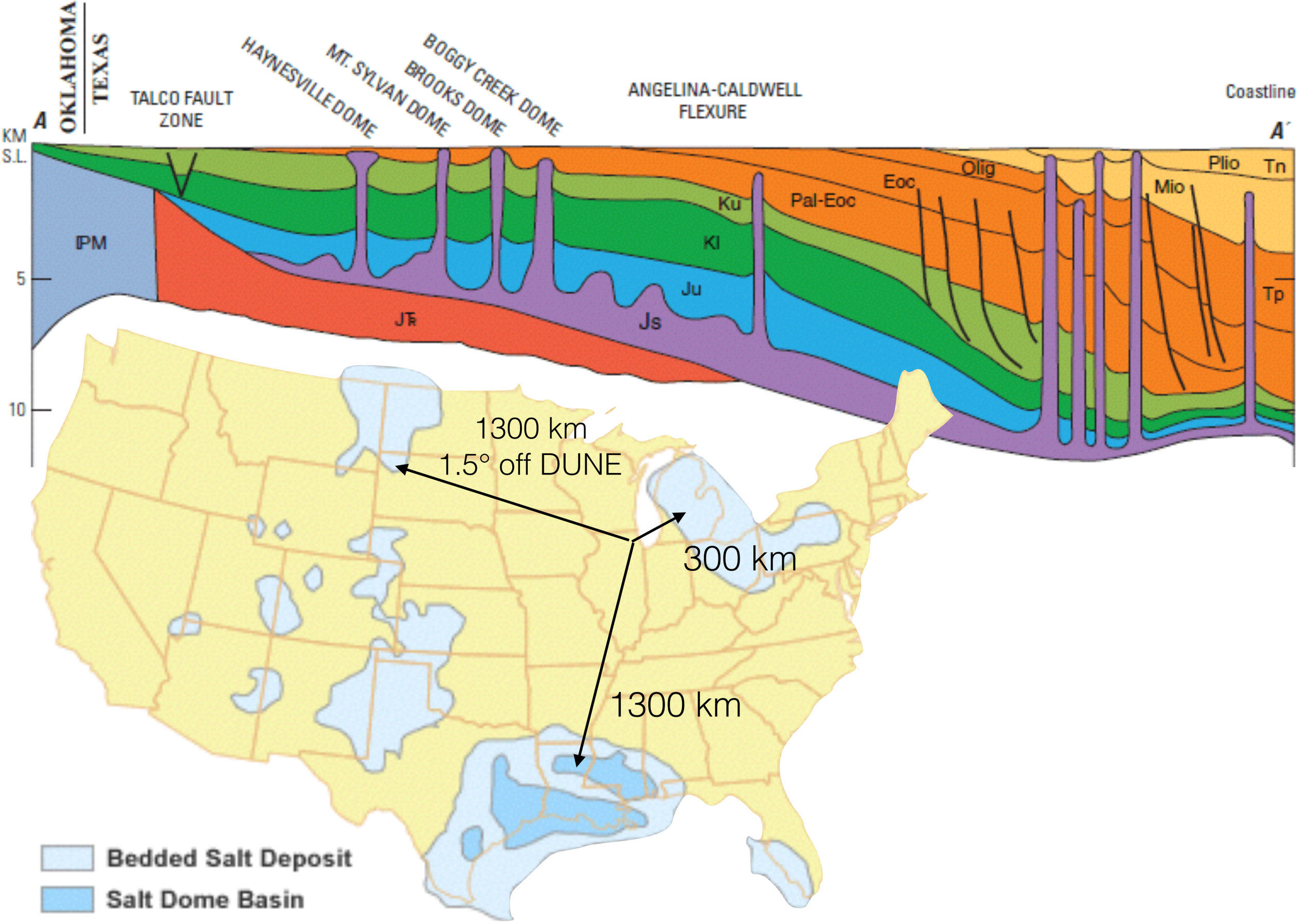
Scintillating mixes

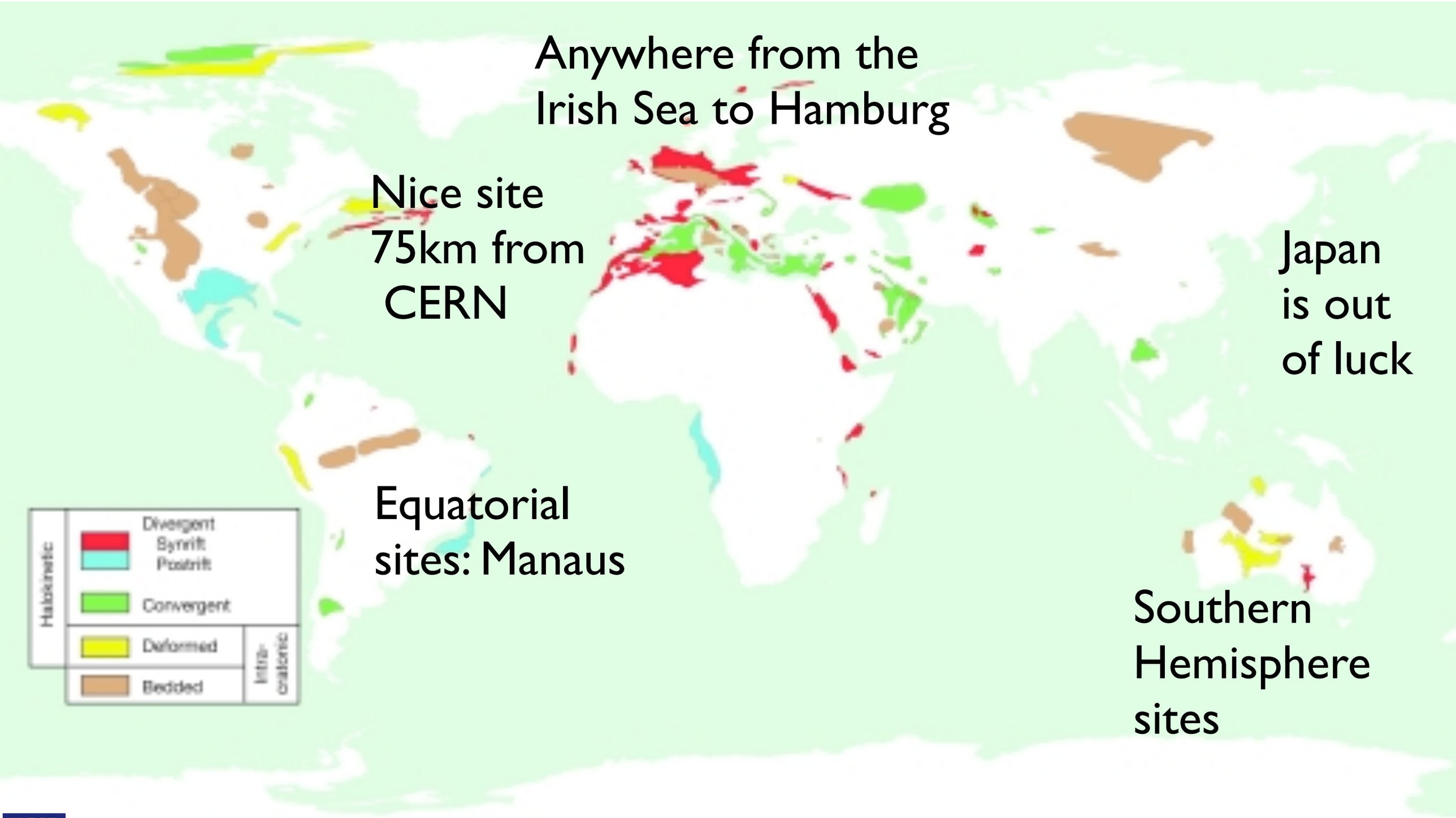
Gas : dopant	Scintillation wave-length	Photoabsorption cross section	Ionization quantum yield	Partial pressure for 1 m path
He :Xe	76 nm	1×10^{-17} cm^2	100%	5 mTorr
Ne :H_2	76 nm	5.4×10^{-17} cm^2	$\sim$ 100%	31 mTorr
Ne :Xe	76 nm	1×10^{-17} cm^2	100%	5 mTorr
Ar :TMAE	129 nm	9×10^{-17} cm^2	50%	10 mTorr
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

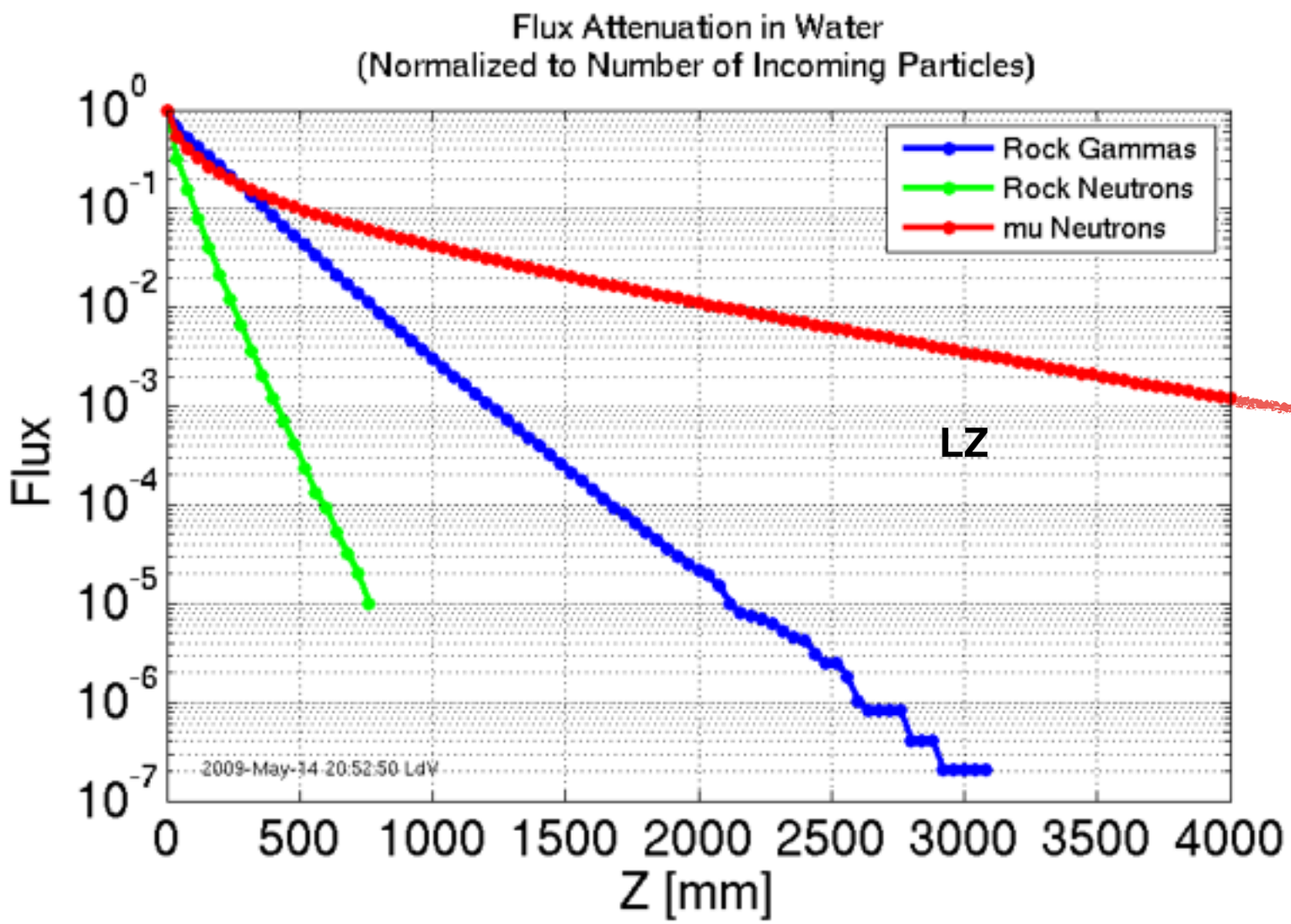
Cherenkov mixes

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

arxiv:1512.04926


OKLAHOMA
TEXAS
A
TALCO FAULT ZONE
HAYNESVILLE DOME
MT. SYLVAN DOME
BROOKS DOME
BOGGY CREEK DOME
ANGELINA-CALDWELL FLEXURE
Coastline
A´
KM S.L.
5
10
IPM
JTR
Js
Ju
Kl
Ku
Pal-Eoc
Eoc
Olig
Mio
Plio
Tn
Tp
1300 km
1.5° off DUNE
300 km
1300 km
Bedded Salt Deposit
Salt Dome Basin


Anywhere from the
Irish Sea to Hamburg
Nice site
75km from
CERN
Japan
is out
of luck
Equatorial
sites: Manaus
Southern
Hemisphere
sites
Divergent
Synrift
Postrift
Convergent
Deformed
Bedded



Luiz de Viveiros thesis

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