VBS

MSC SEMINAR

Alexi Stadnitski

19 March 2024

OUTLINE

- Motivation for the research
- Basics of the Standard Model
- Properties of vector bosons
- Scattering & decay channels
- CMS event processing chain
- Discussion of results
- Current challenges
- Future of the project
- Conclusions

MOTIVATION

- Search for new physics with Run-2 and Run-3 data, probing evidence of effects beyond the standard model
- Analyze a relatively unexplored sector of the phase space (all-hadronic VBS)
- Set up the analysis to study VBS event topology; analyze events from scratch
- Guide selection: signal from background

HENNING KIRSCHENMANN
NURFIKRI NORJOHARUDEEN
NICO TOIKKA
ALEXI STADNITSKI

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W AND Z BOSONS

- Massive bosons with spin 1
  - W: 80.377±0.012 GeV
  - Z: 91.1876±0.0021 GeV
- Both weakly interacting
  - W^+ and W^- charged
  - Z^0 neutral
- Decay into fermions
  - Γ_W = 2.085±0.042 GeV
  - Γ_Z = 2.4955±0.0023 GeV

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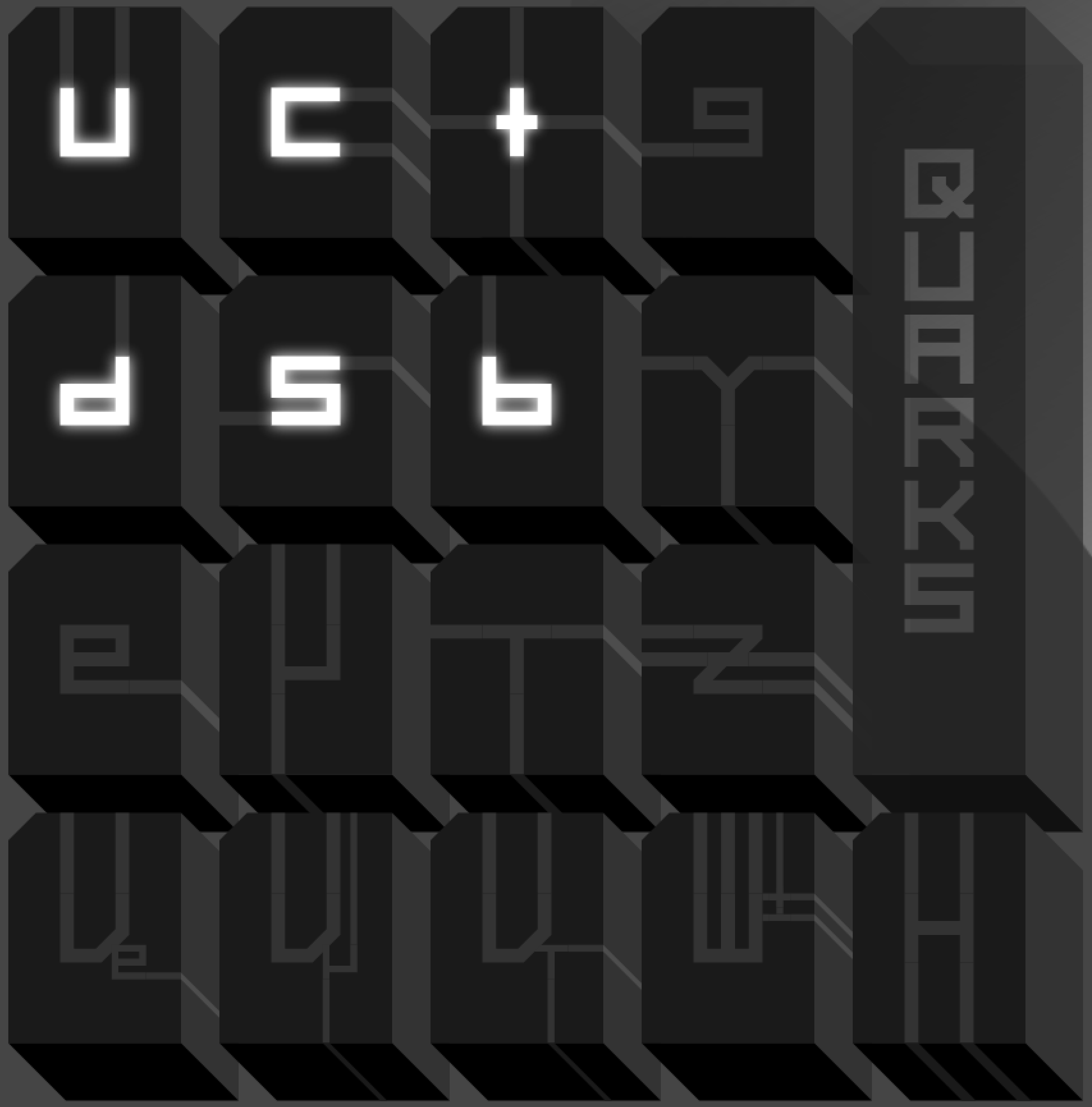

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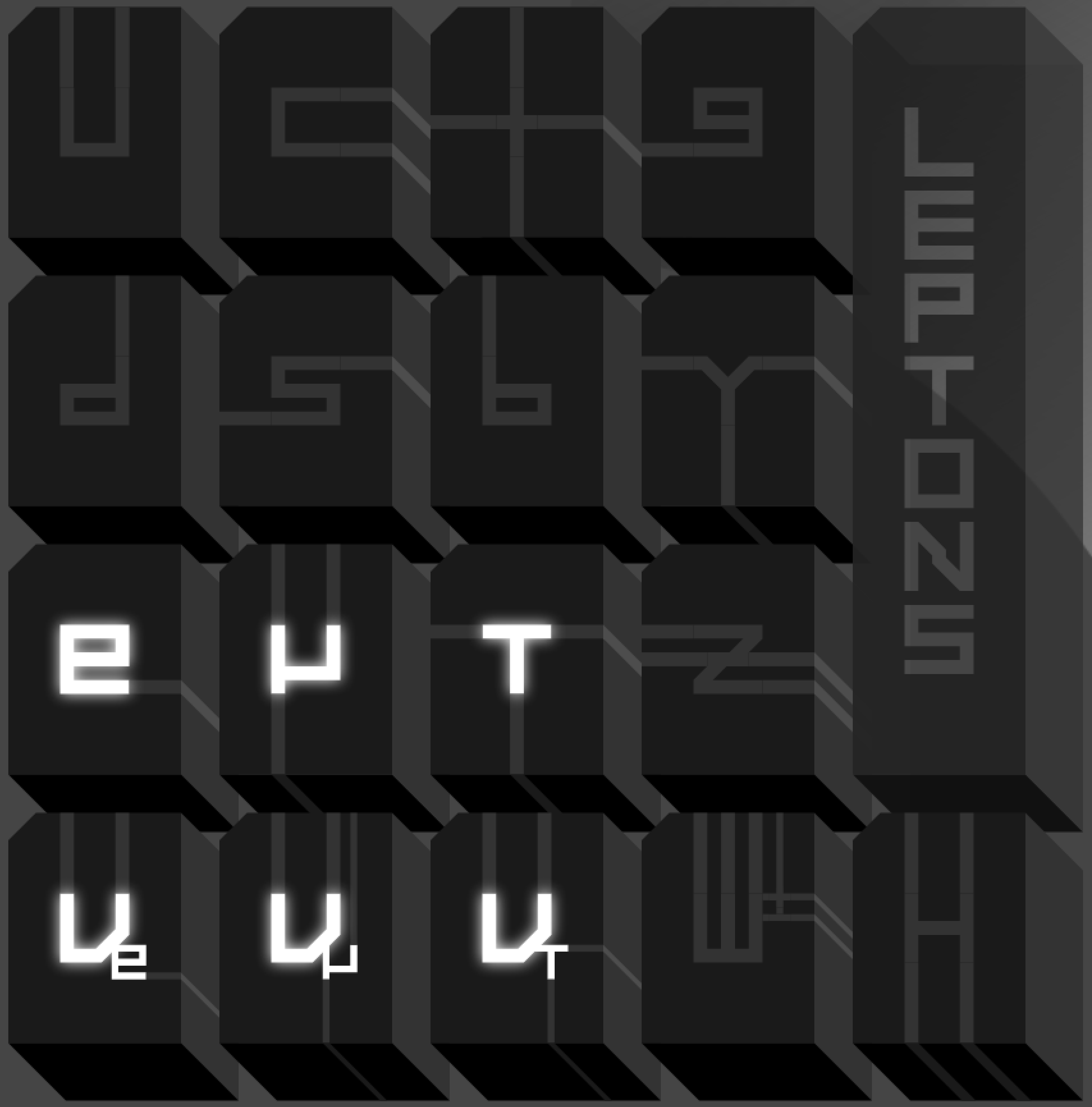

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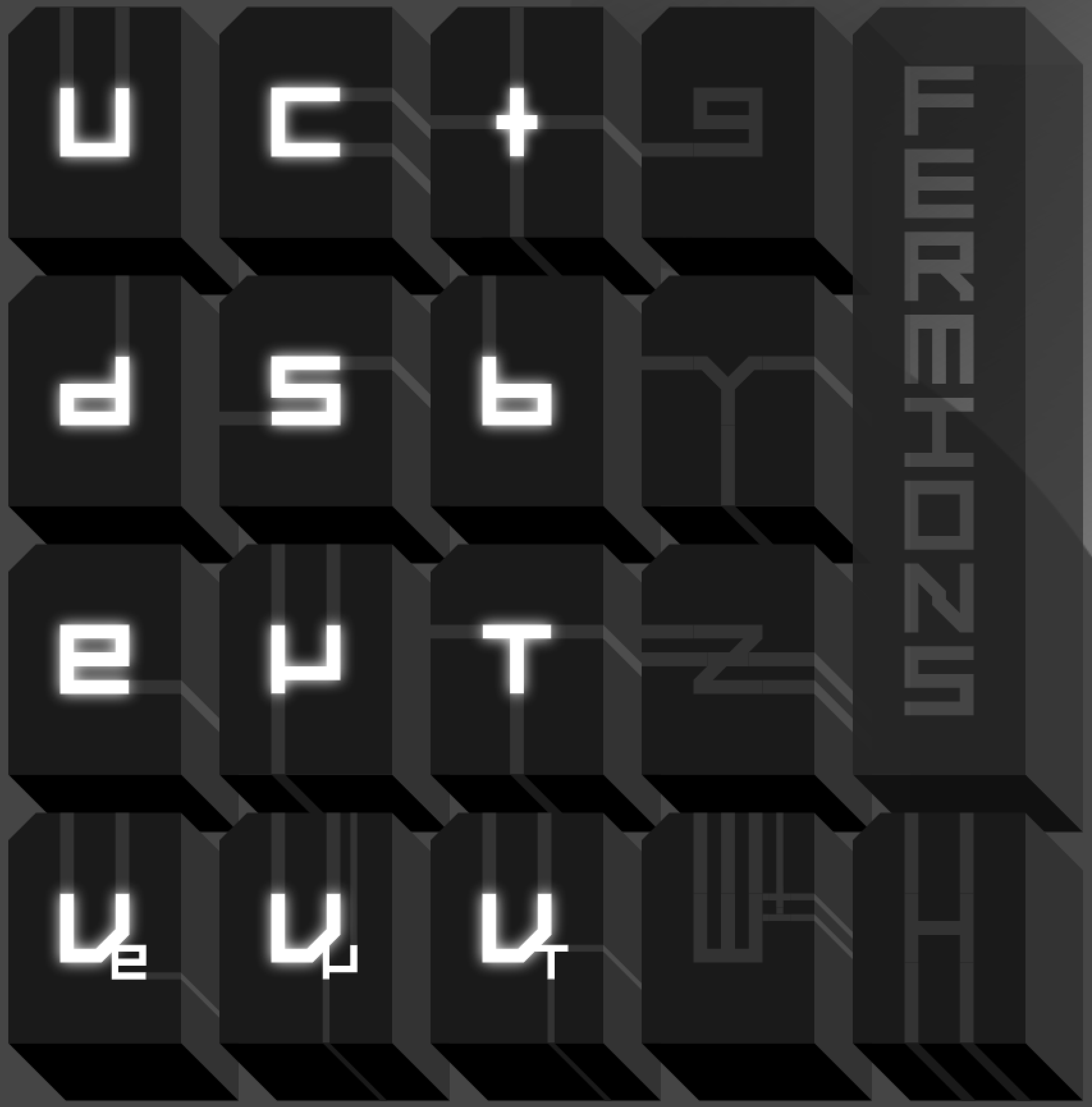

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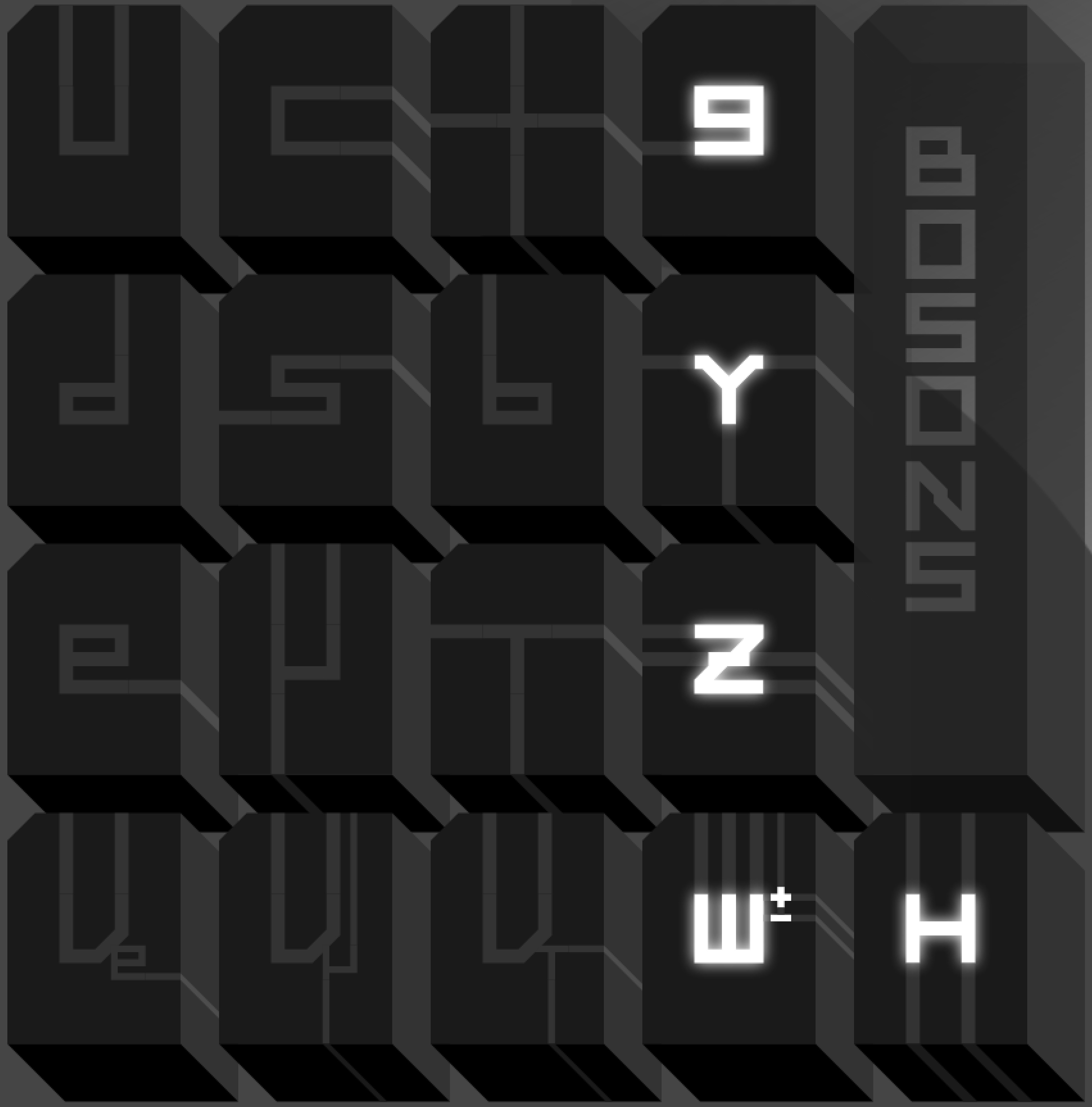

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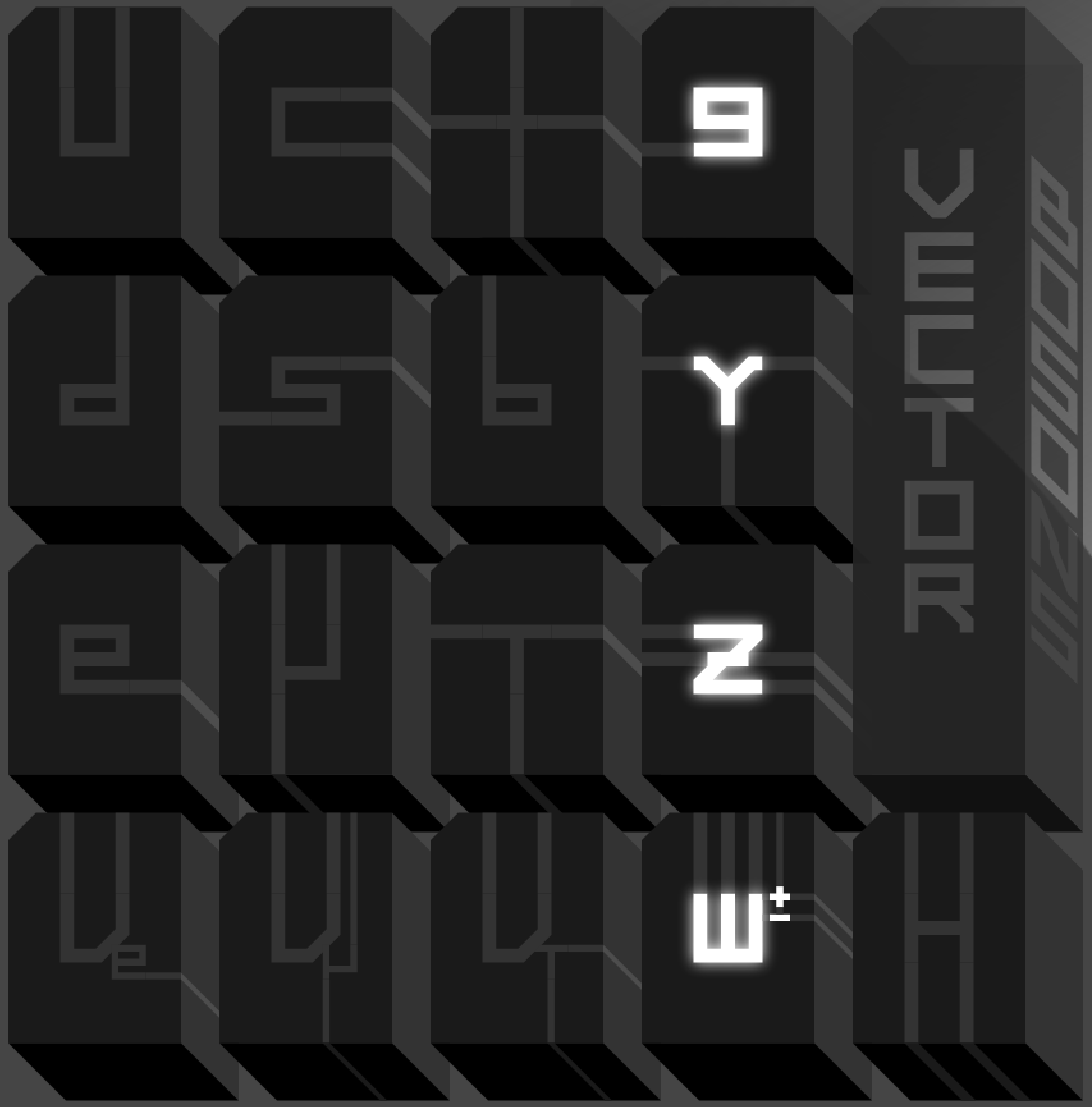

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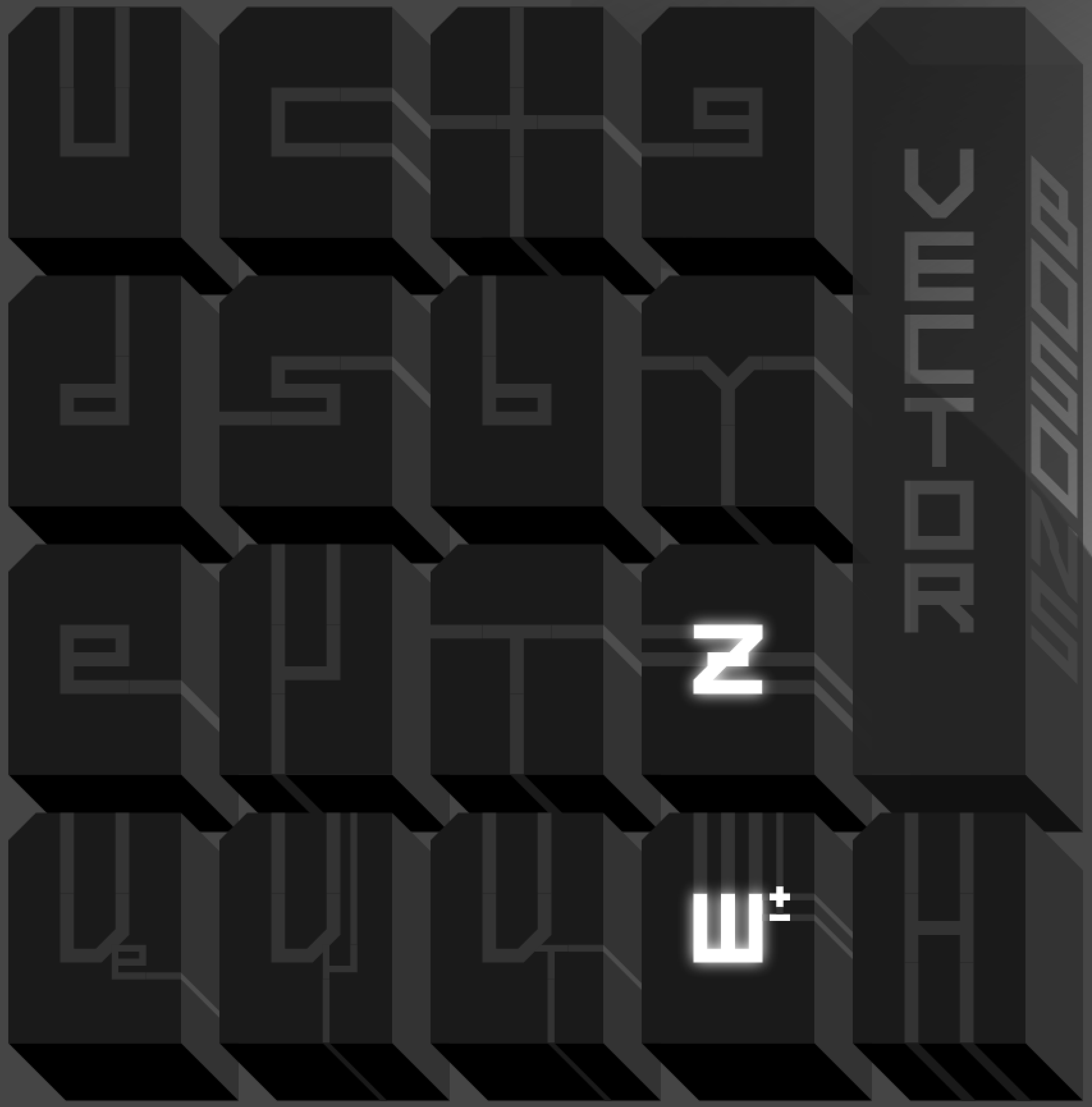
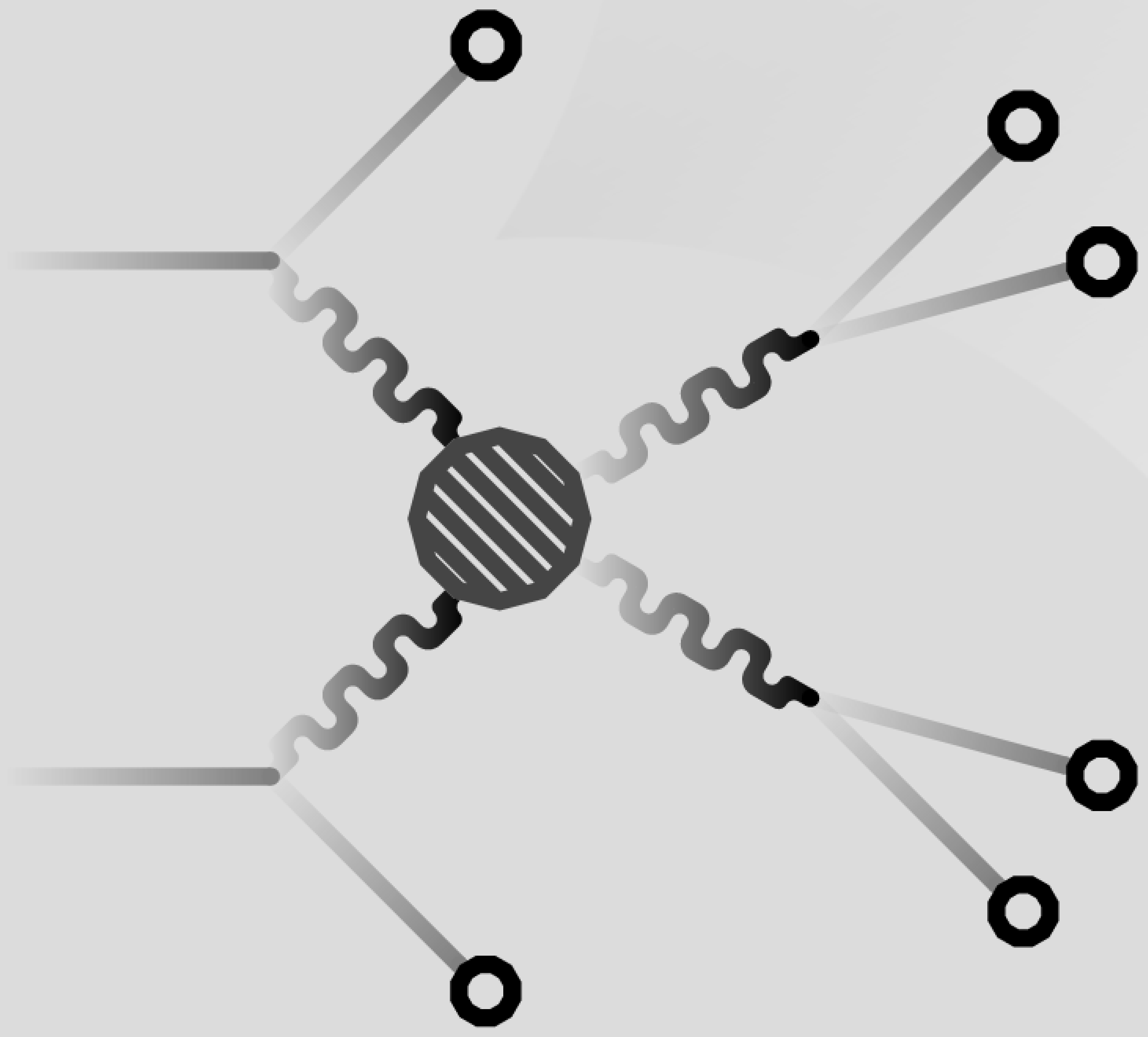


SCATTERING

- Incoming quarks scatter off each other
- Momentum exchange by weak boson
- W/Z decay to one of multiple states:
  - Fully leptonic
  - Semi-leptonic
  - All-hadronic
- ZZ production rarer than WZ and WW
- Probes the quartic gauge coupling
- Same- and opposite-sign behavior



QUARTIC COUPLING

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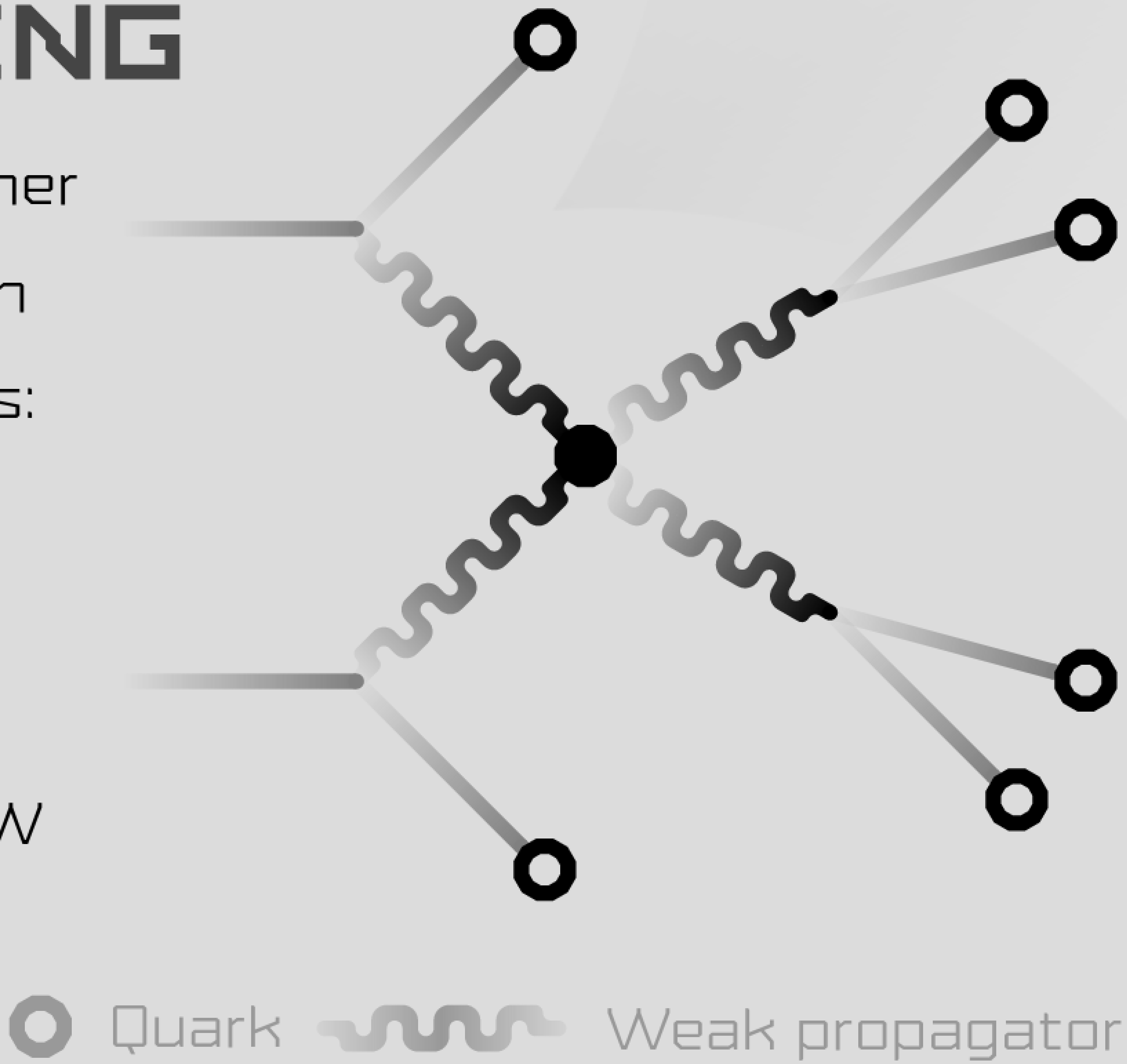

HIGGS T-CHANNEL

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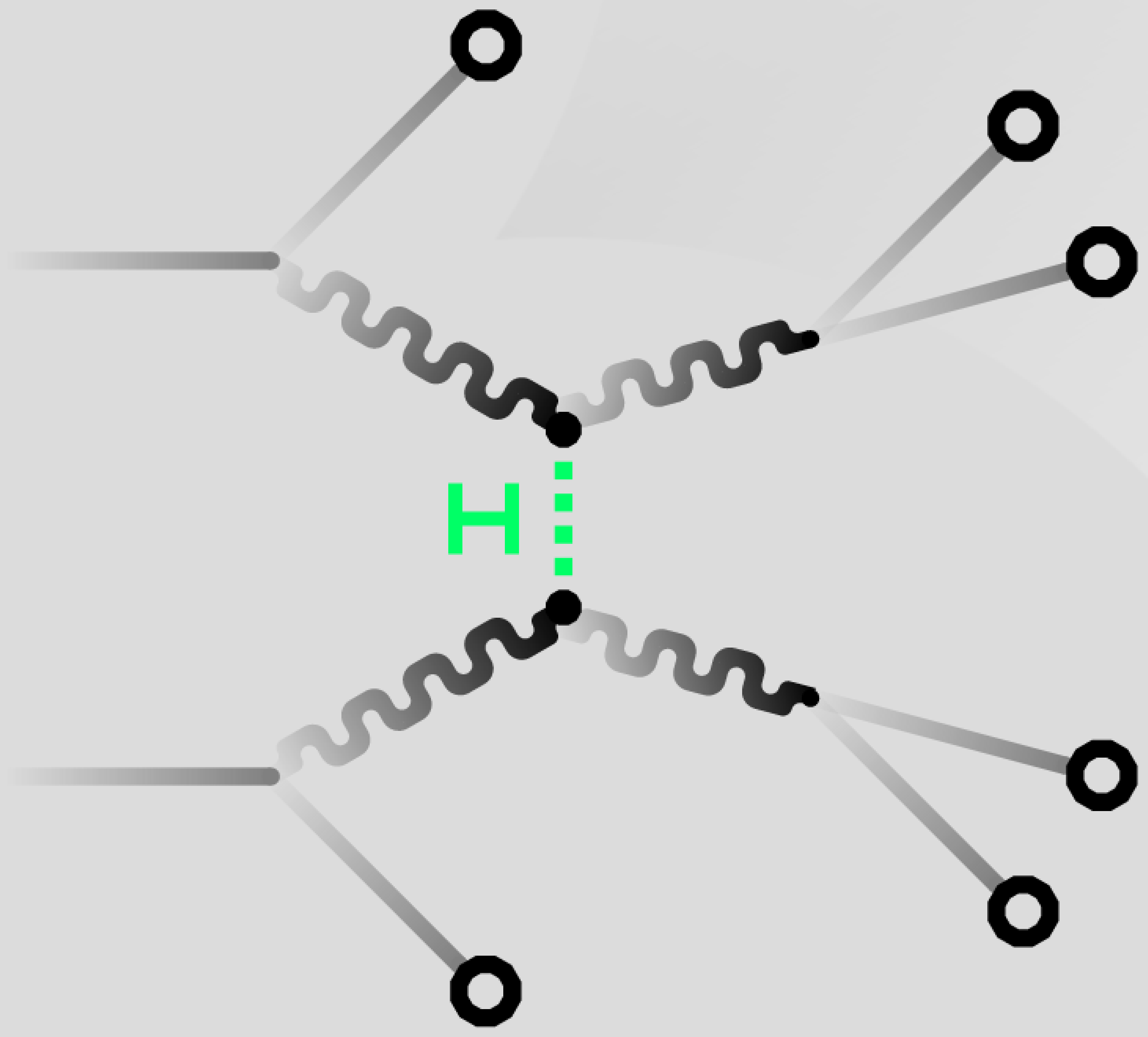

FUSION

- Incoming quarks scatter off each other
- Momentum exchange by weak boson
- W/Z decay to one of multiple states:
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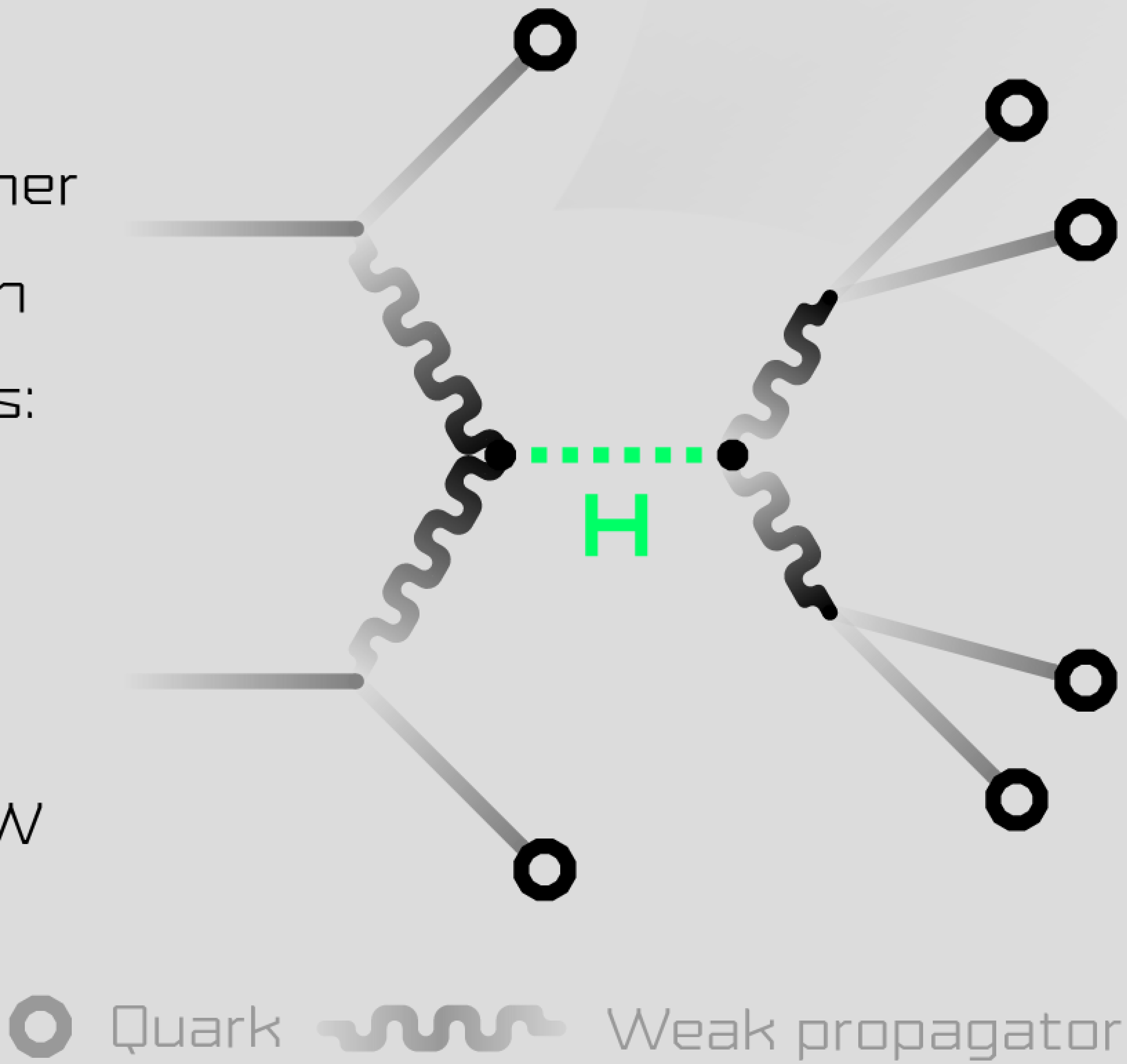
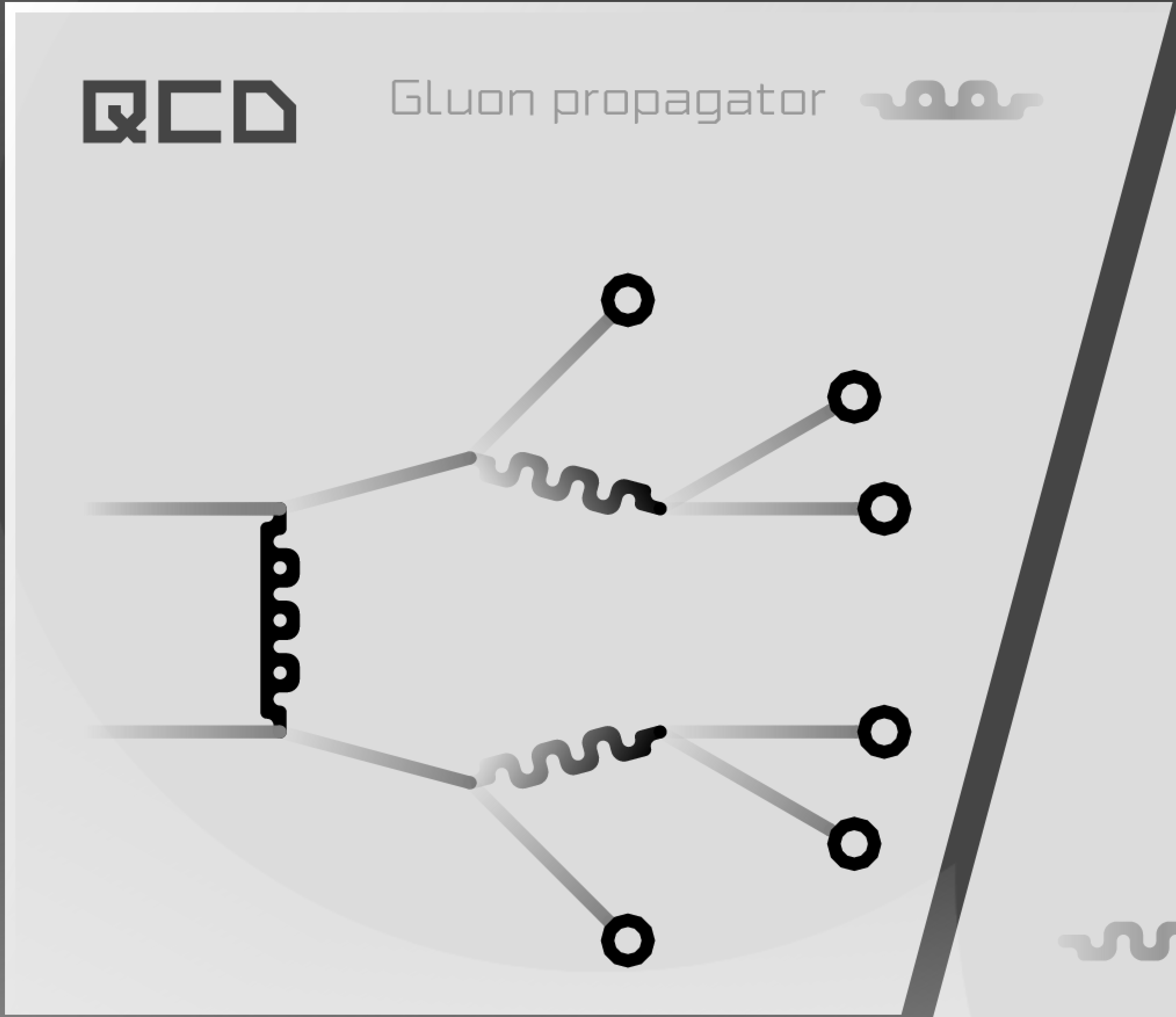
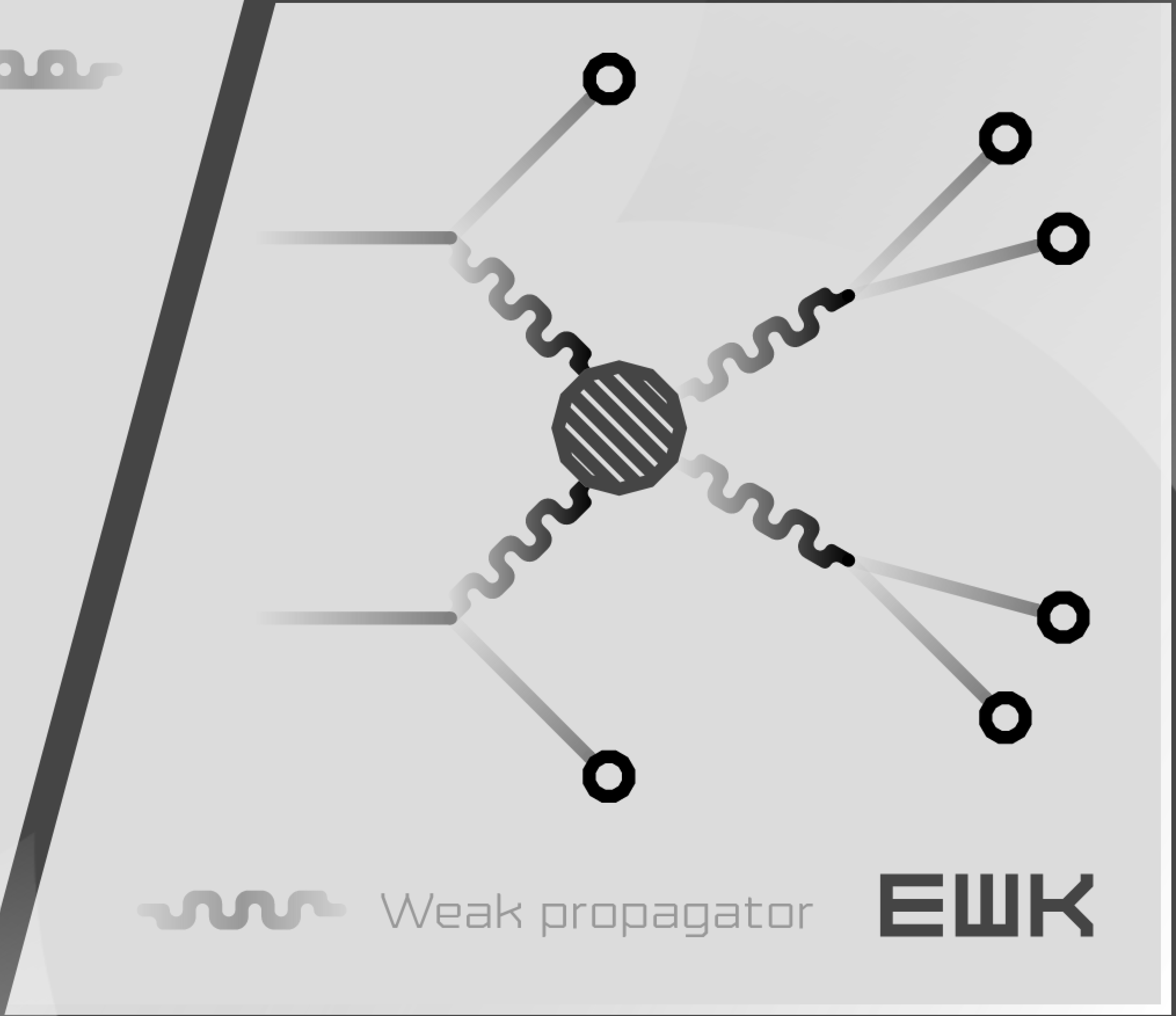
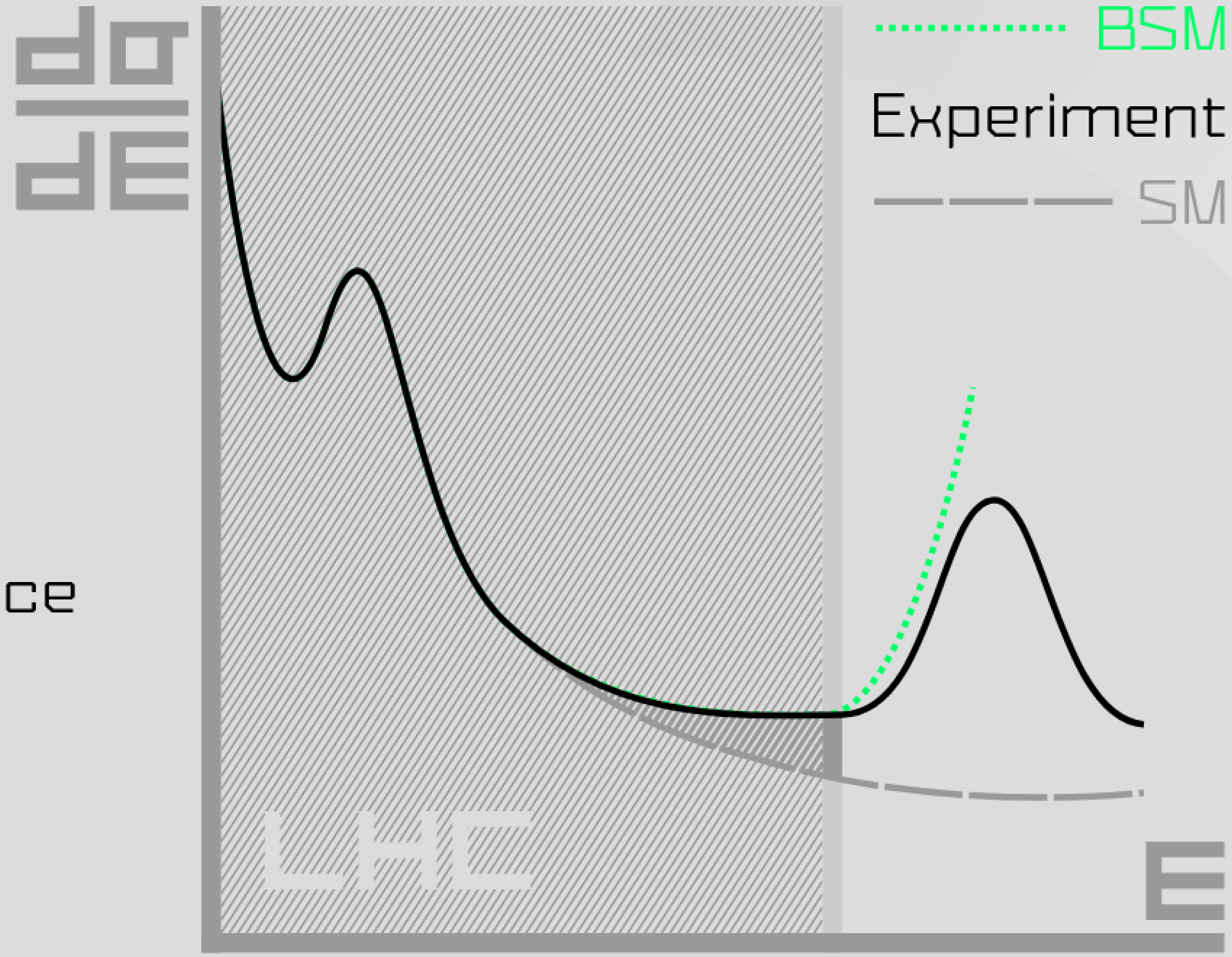



QCD
Gluon propagator


Weak propagator
EWK

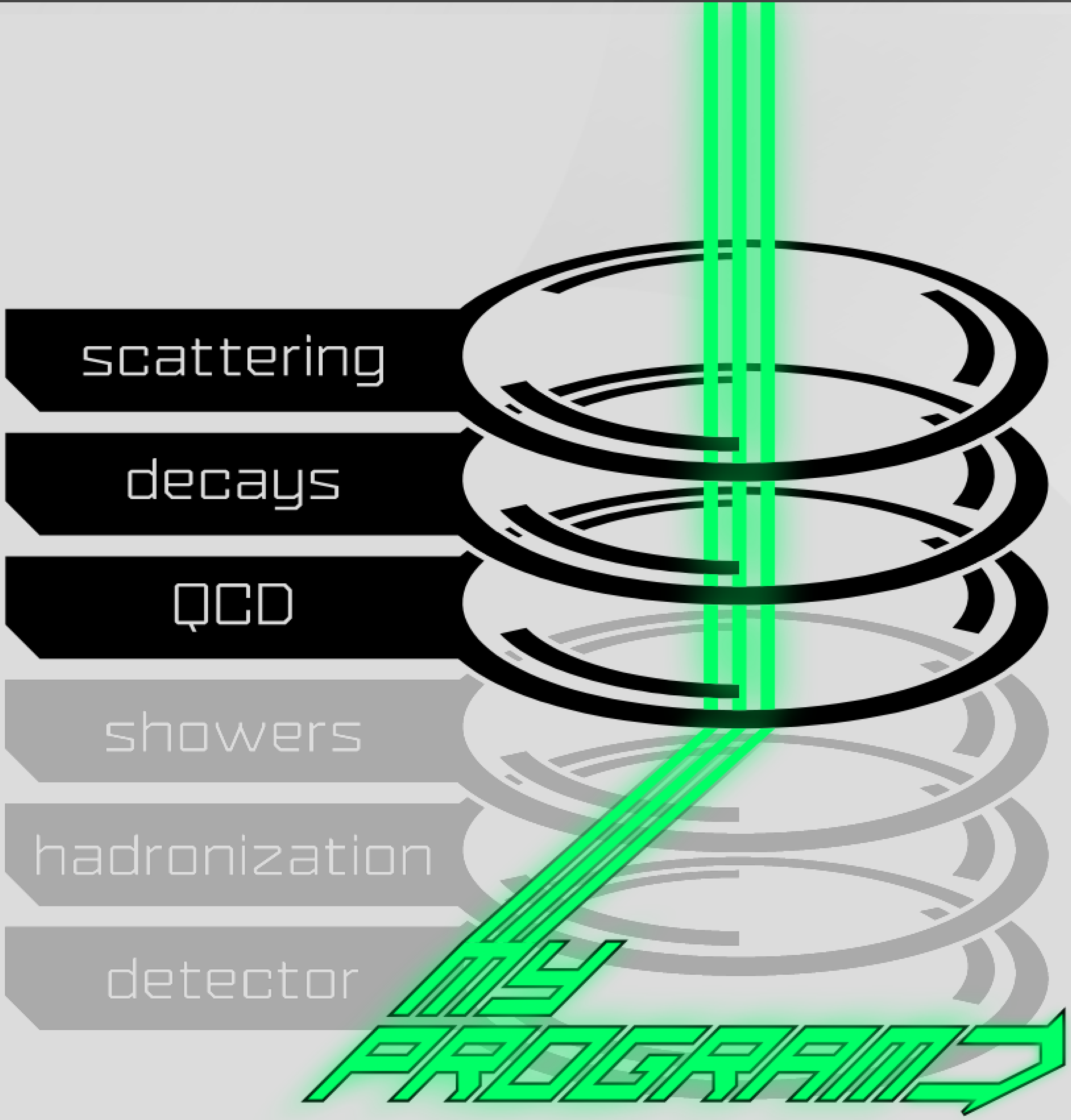
NEW PHYSICS

- Beyond the standard model
  - Consistent with observations
  - Enable new predictions
- Effects noticeable at TeV scale
  - Limited by reach of the LHC
  - Tail behavior may provide evidence
- SM unitarity cancellations
- Resonances
- Axions



EVENT CHAIN

- Monte-Carlo bootstrapping
- Pythia, HERWIG, MadGraph
- Generator-level analysis
  - Underlying physics
- Read ROOT files, saving:
  - Transverse momentum p_T
  - Azimuthal angle ϕ
  - Pseudorapidity η
  - Mass M



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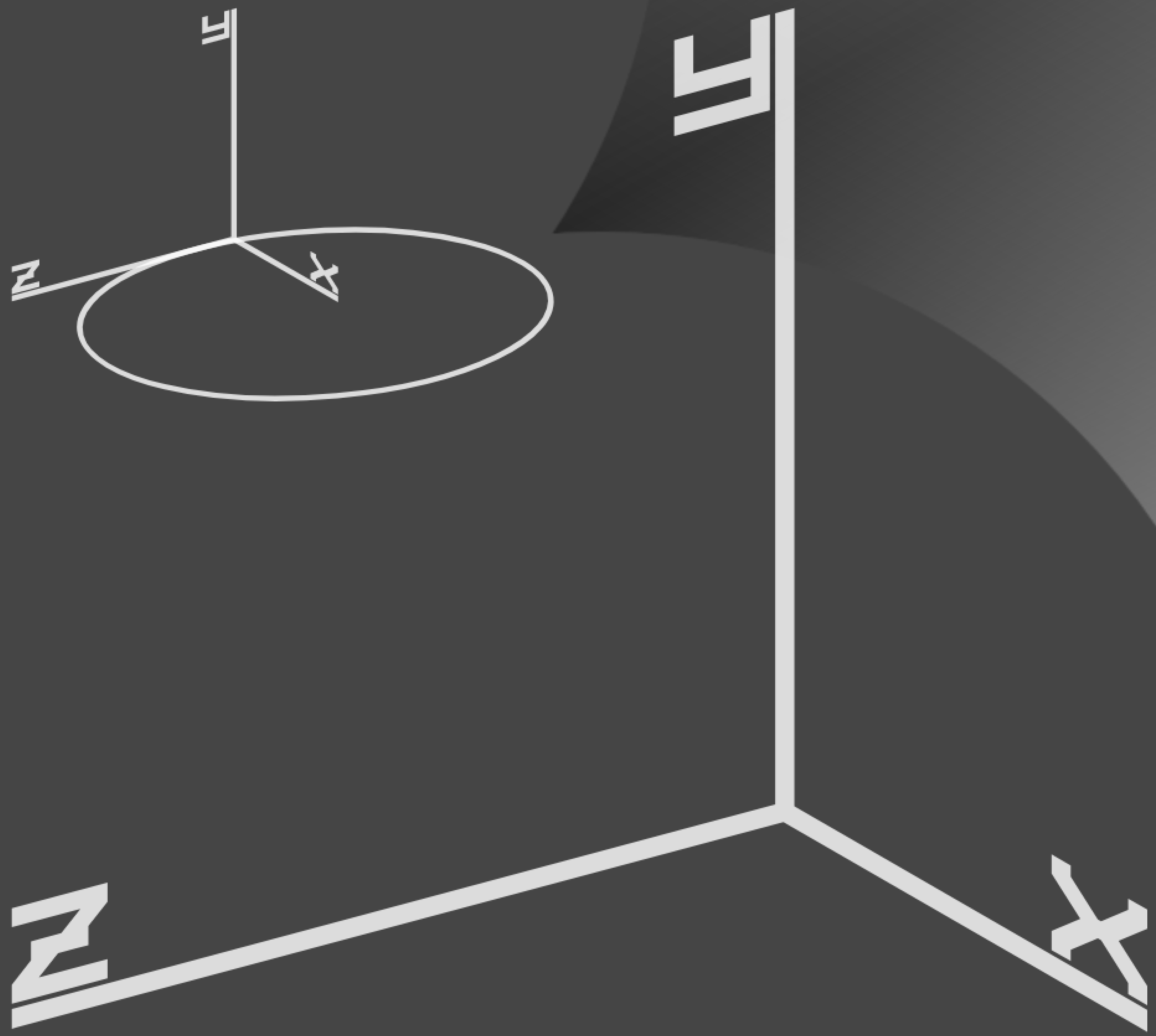

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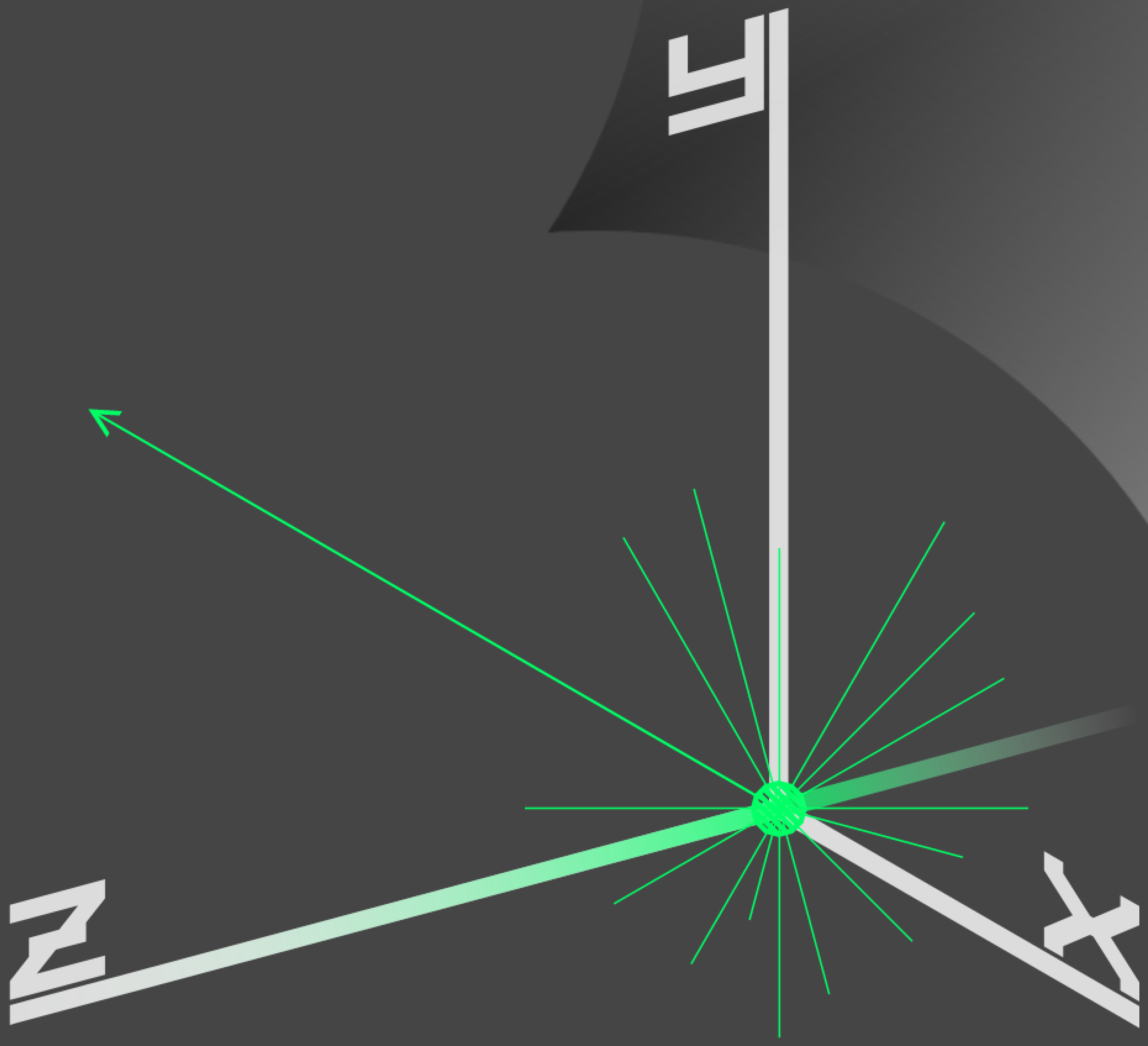

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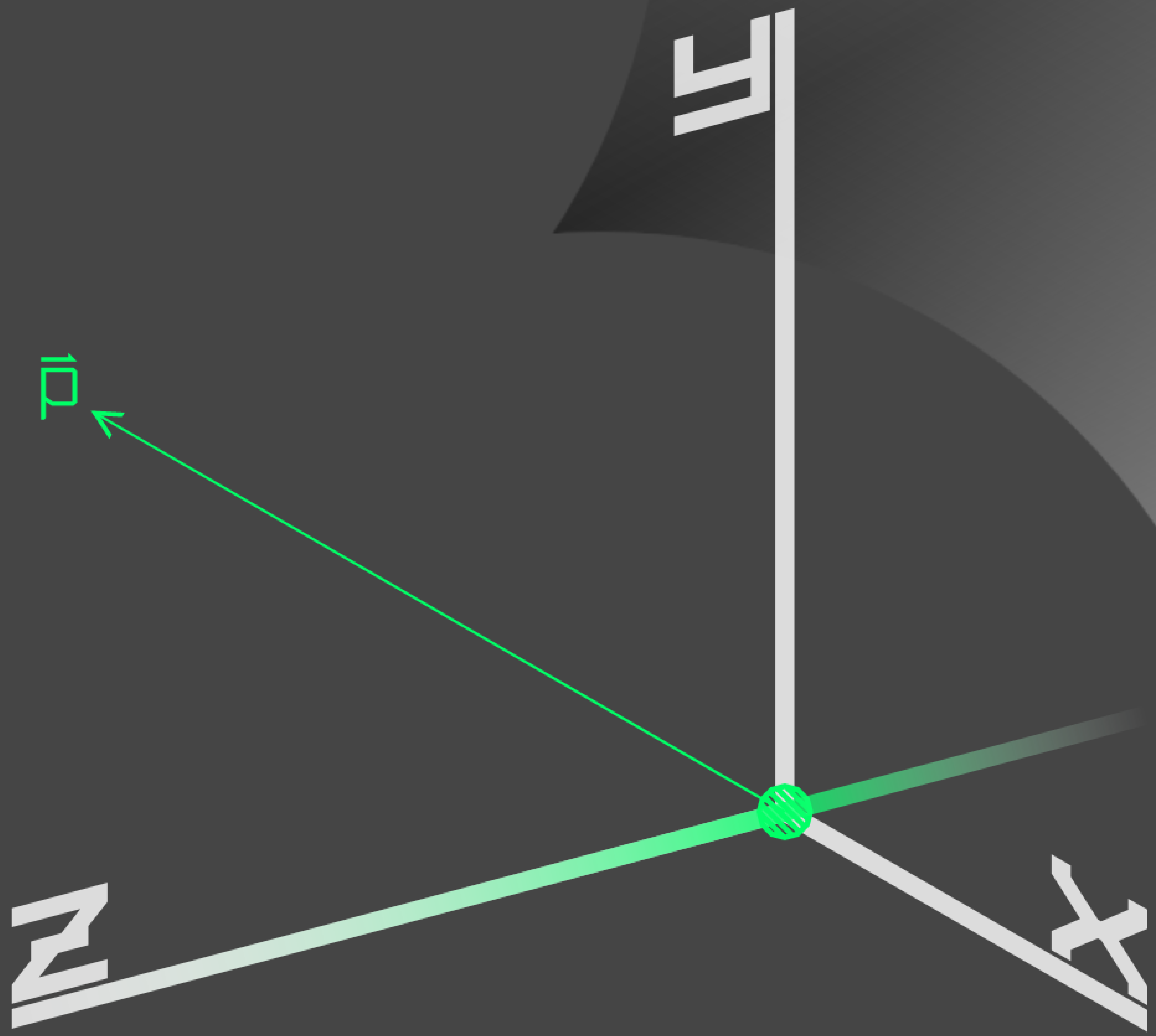

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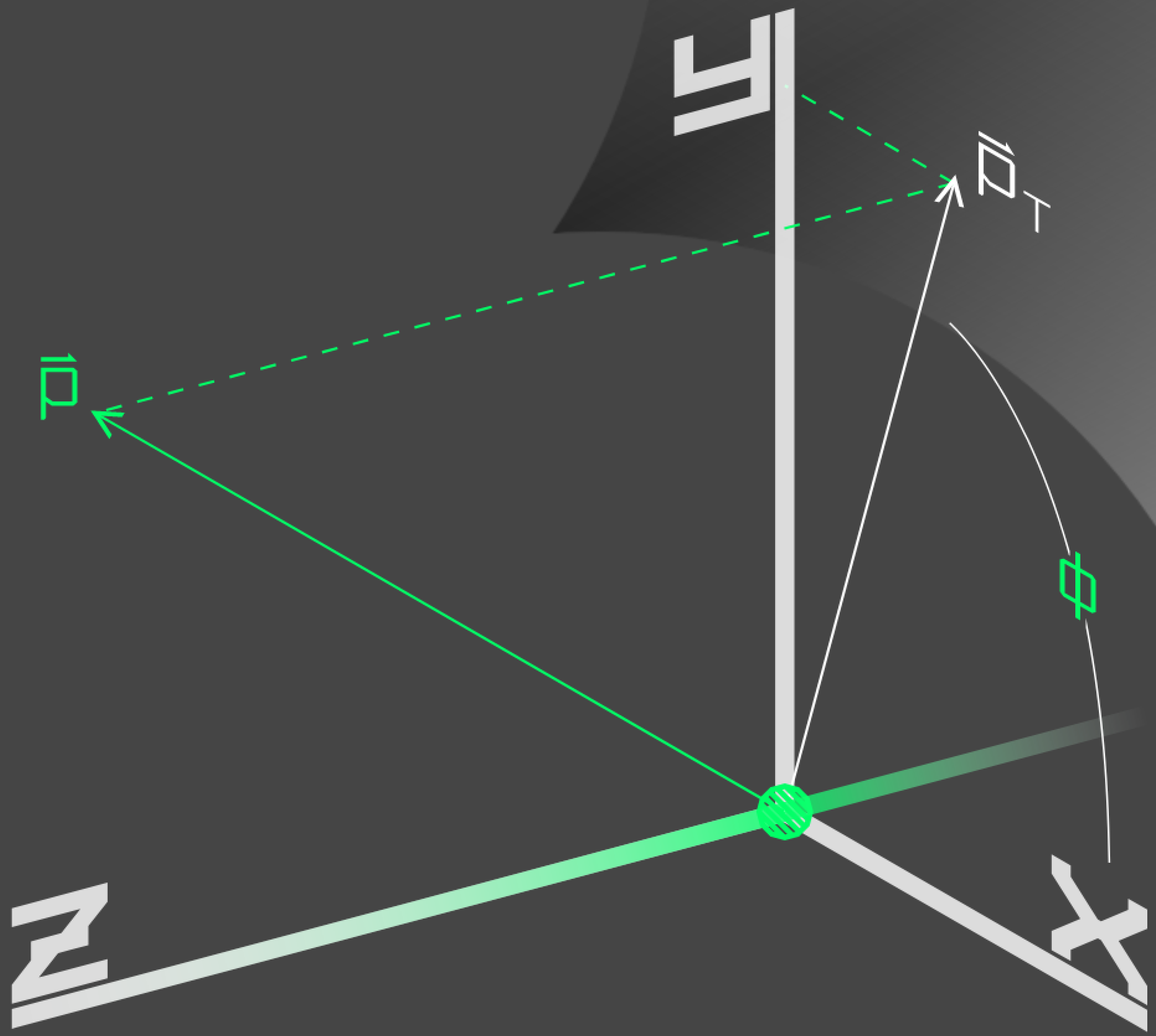

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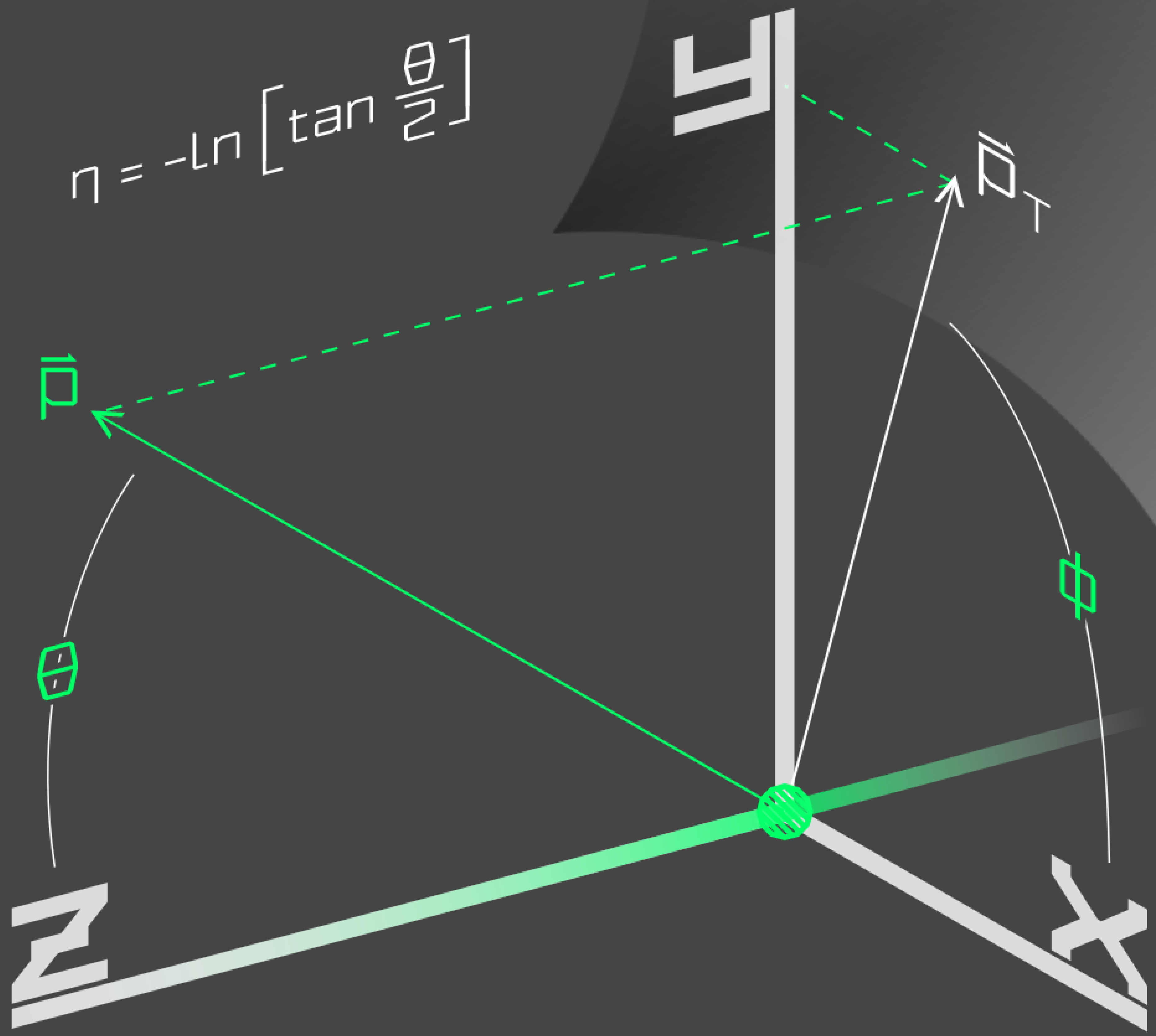
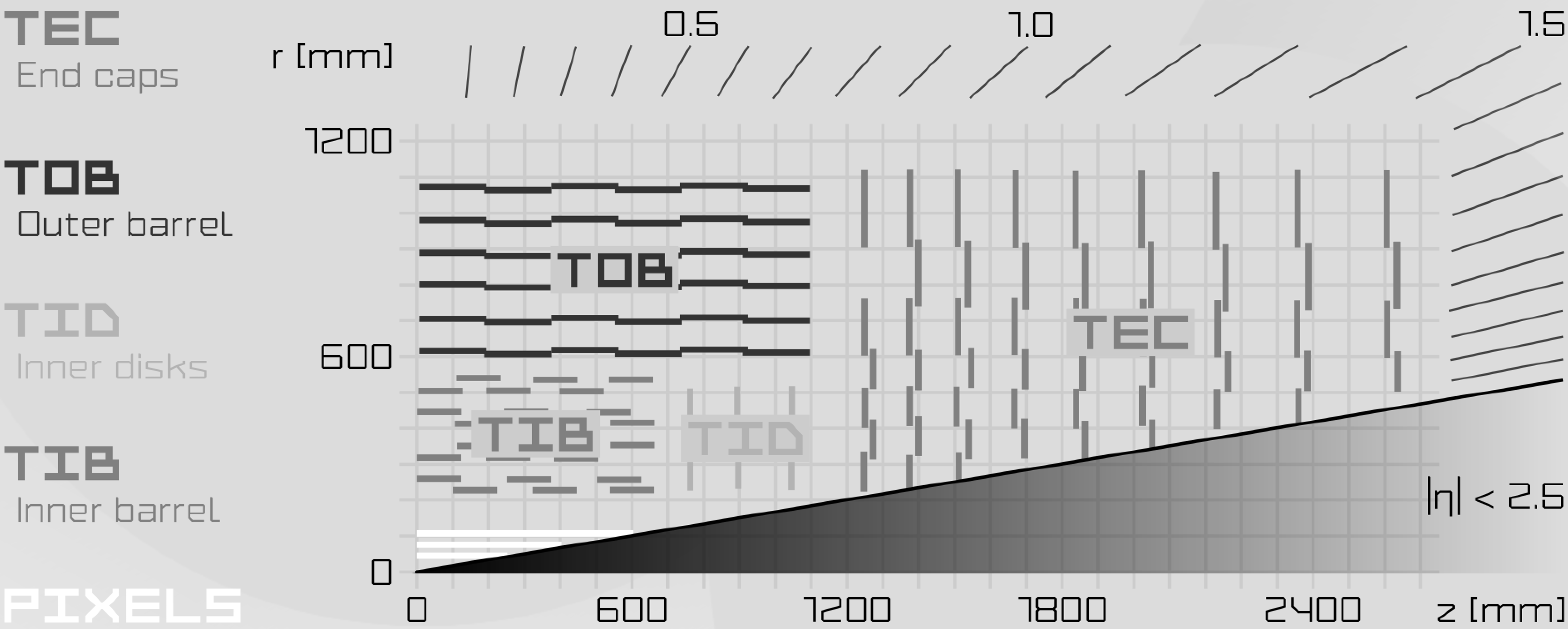
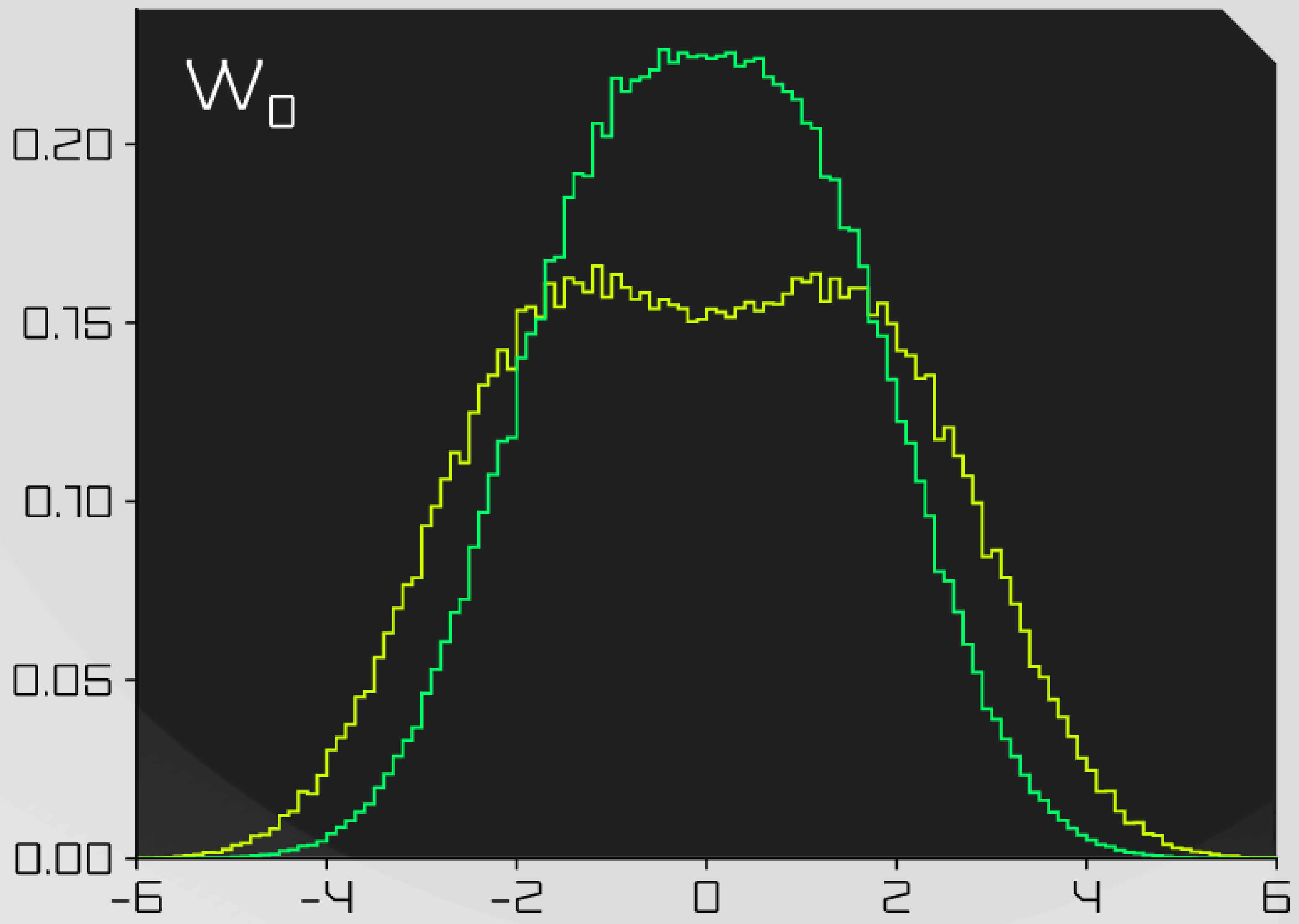


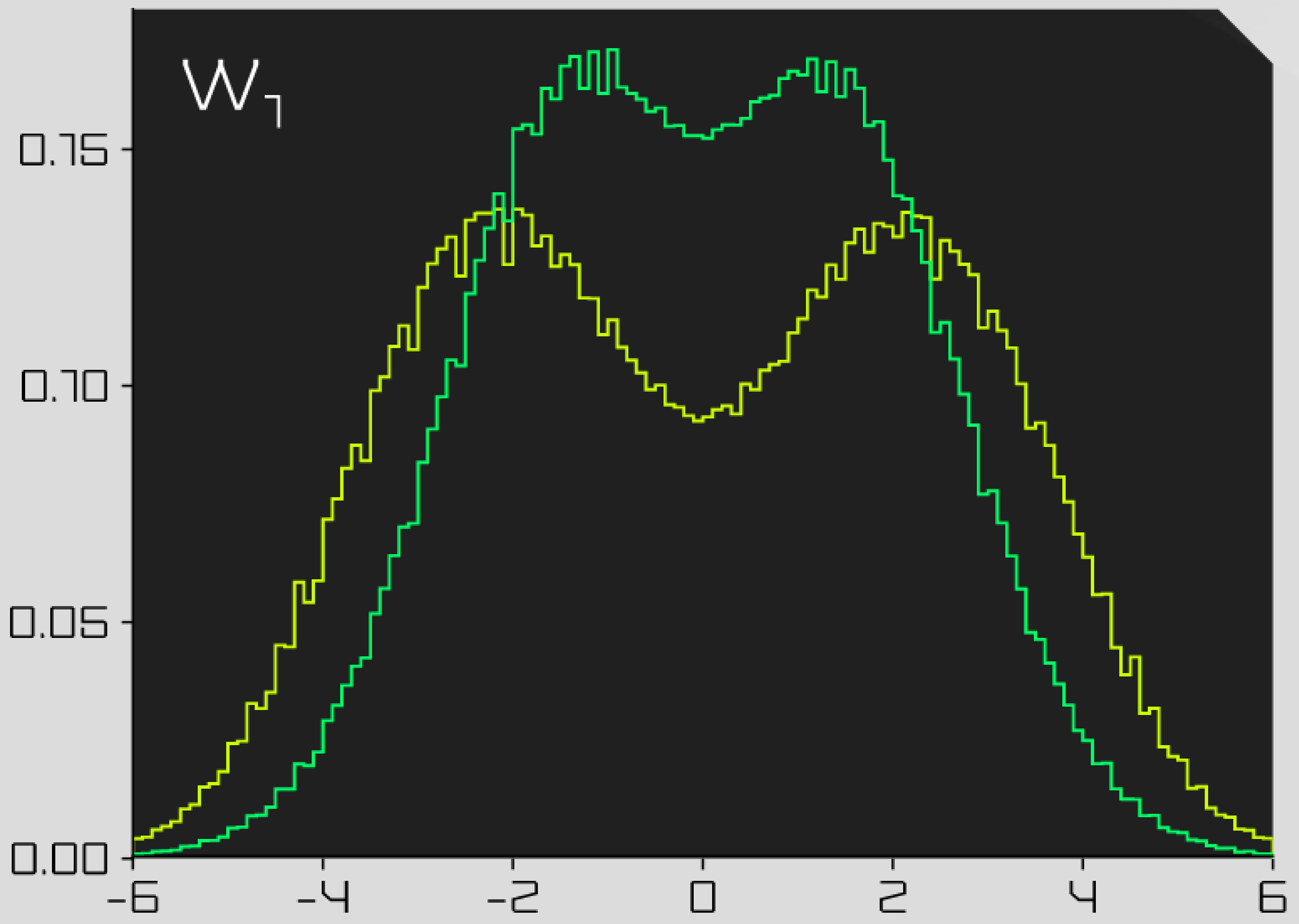
TRACKER LIMITATIONS



PSEUDORAPIDITY

EWK QCD

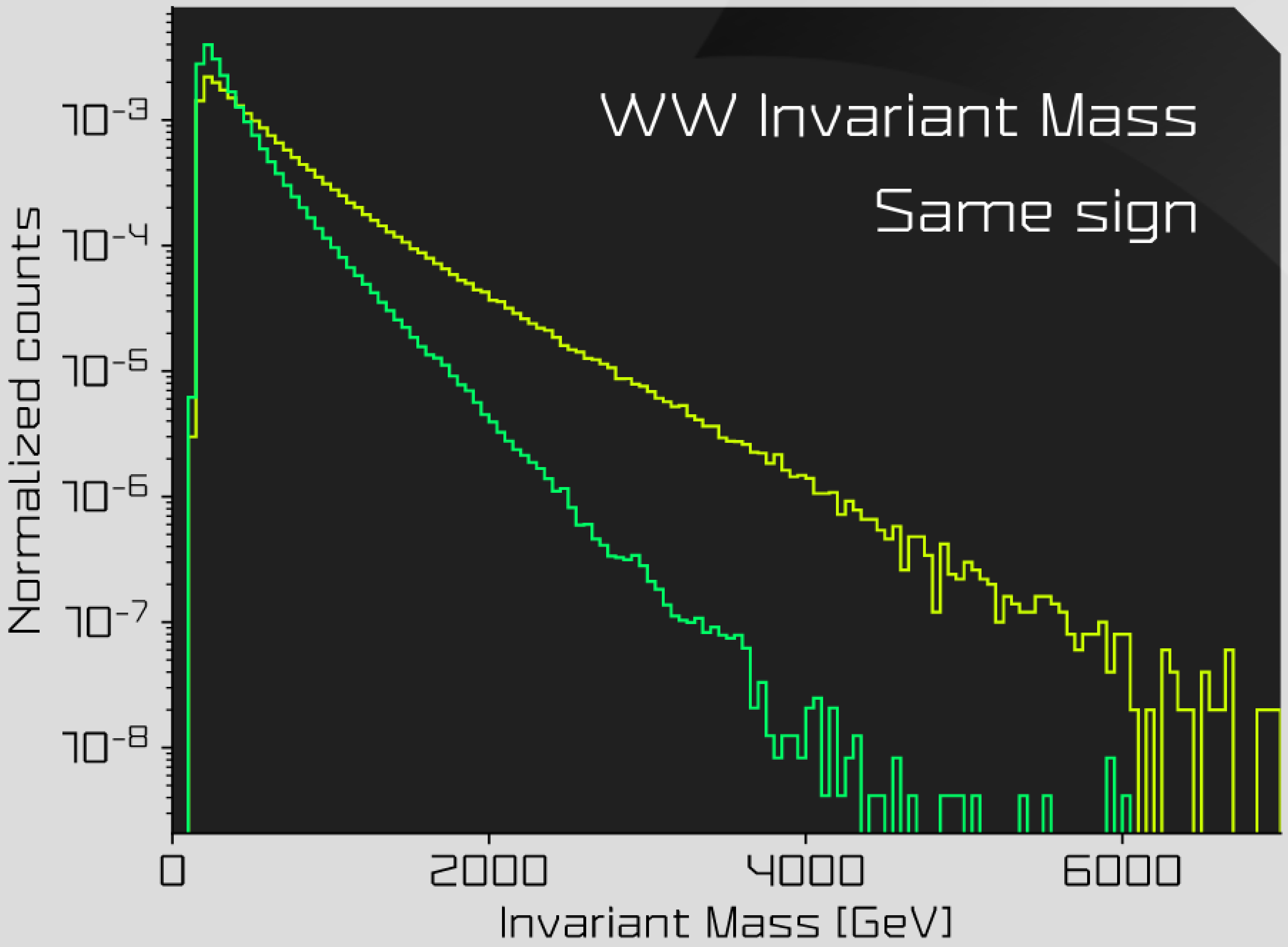




INVARIANT MASS

EWK QCD

- Sensitivity to BSM at TeV scale
- Computed as ROOT 4-vector
- Different shapes allow to discriminate EWK and QCD
- VBS identified by looking at event record
- Target pipeline:
  - Cut with dijet mass m_{jj}
  - Measure diboson mass m_{VV}



CHALLENGES

- Incredibly small cross section
  - On the order 10^{-15} b (10^{-43} m^2)
  - Only 140 or so events in Run 2
  - Need to be precise with cuts
- Low signal-to-background ratio
  - Leptonic VBS 'golden channel'
- Forward region difficult to study
  - How to trigger for VBS events
  - How to suppress pileup events

FUTURE

- Investigate opposite-sign samples
- Modify code to process Z samples
- Identify jet quarks from event record
- Determine optimal cuts
- Apply to physical data
- Compare results with ATLAS
- $W^{\pm}W^{\pm}$ a priority for HL-LHC
- Applications to Higgs sector
- Machine learning with deep neural networks

CONCLUSIONS

- VBS has high sensitivity to potential new physics
- All-hadronic channel has the highest cross section
- Loses to leptonic by low signal-to-background ratio
- We are developing a new analysis in unexplored territory
- Goal is to have an understanding of VBS event topology
- Data analysis on Monte Carlo to be applied to real data
- Need a precise cut due to high all-hadronic background

THANK YOU

BACKUP

REFERENCES

- Outline
  - Izaak Neutelings – CMS coordinate system
- Motivation
  - Henning Kirschenmann – Overview of the ForVVard project
  - Nurfikri Norjoharudeen – Fully hadronic VBS and wide-cone jets
- W and Z bosons
  - Particle Data Group – 2023: Summary Tables
- Scattering
  - Franzosi et.al. – VBS Processes: Status and Prospects

REFERENCES

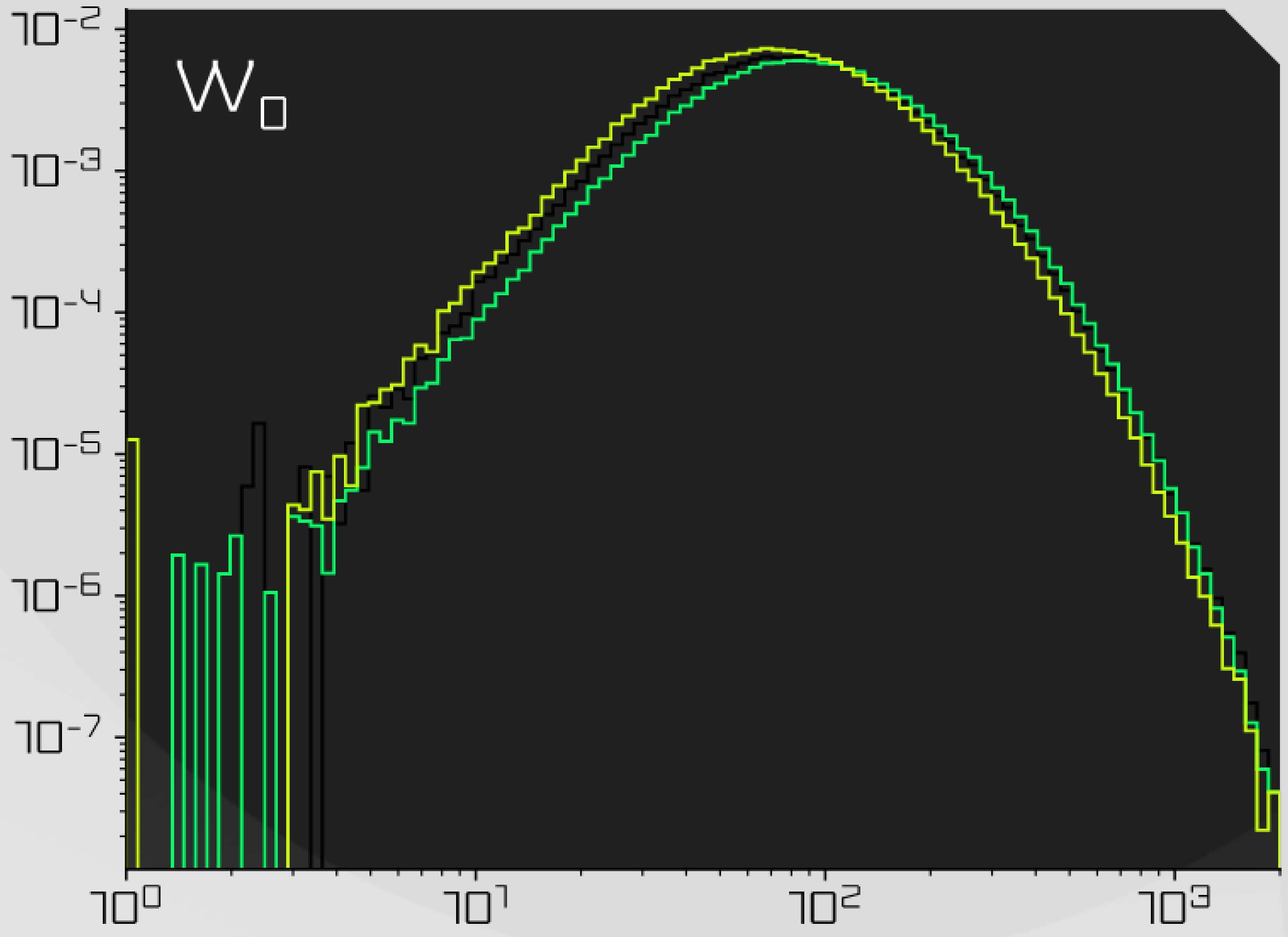
- Quartic coupling
  - Dan Green – Vector Boson Fusion and Quartic Boson Couplings
- New physics
  - Talk by C. Severi, M, Thomas, and E. Vryonidou
  - Bonilla et. al. – Nonresonant Searches for Axion-Like Particles in Vector Boson Scattering Processes at the LHC
- Event chain
  - Nico Toikka – Flavor response
  - Tilman Plehn – Machine Learning for the LHC

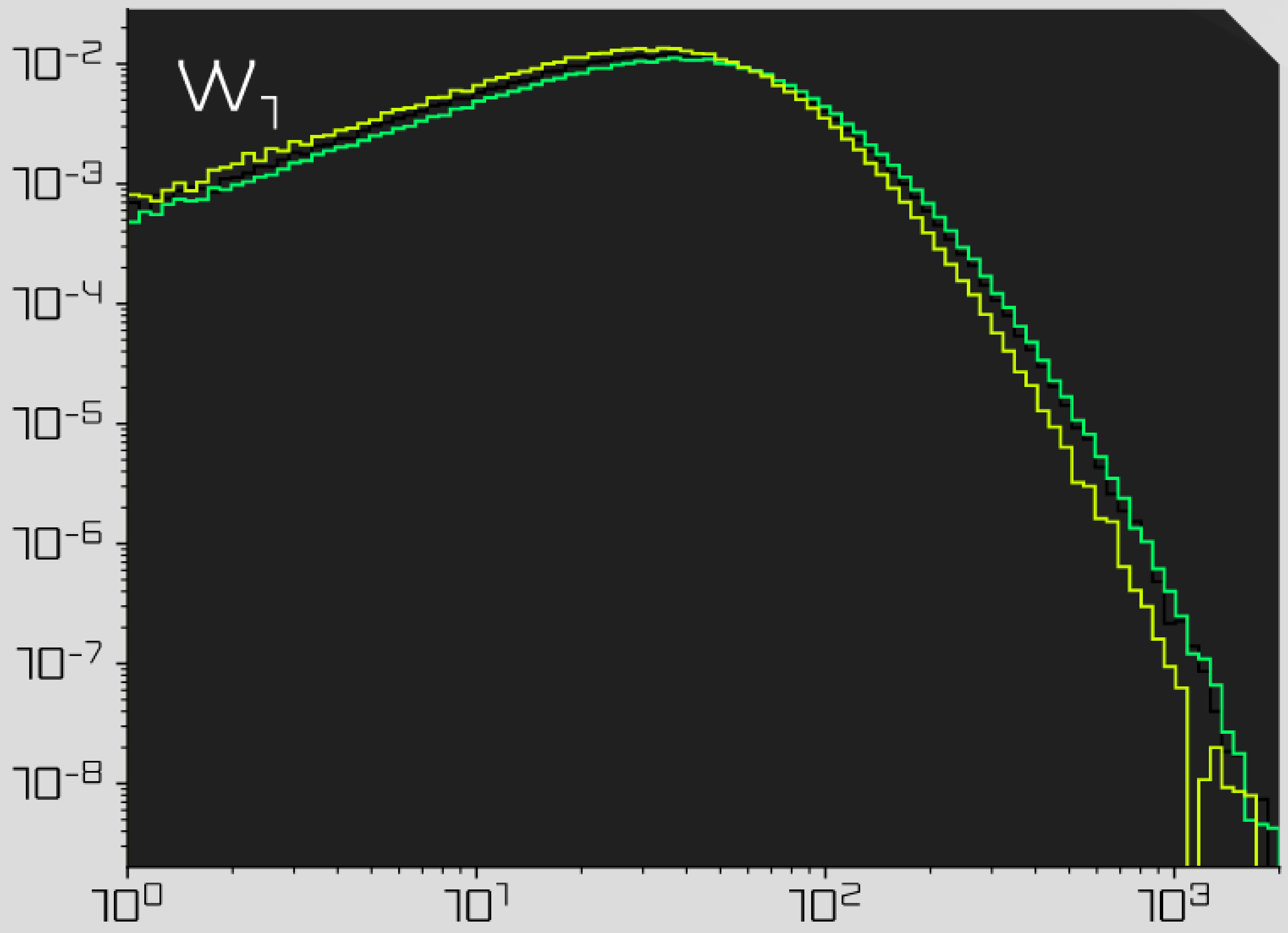
REFERENCES

- Tracker limitations
  - CMS Experiment – Silicon Strips
  - Paolo Azzurri – The CMS Silicon Strip Tracker
- Invariant mass
  - ROOT – TLorentzVector Class Reference
- Challenges
  - ATLAS – Standard Model Results
- Future
  - CERN Courier – Vector-boson scattering probes quartic coupling

TRANSVERSE MOMENTUM

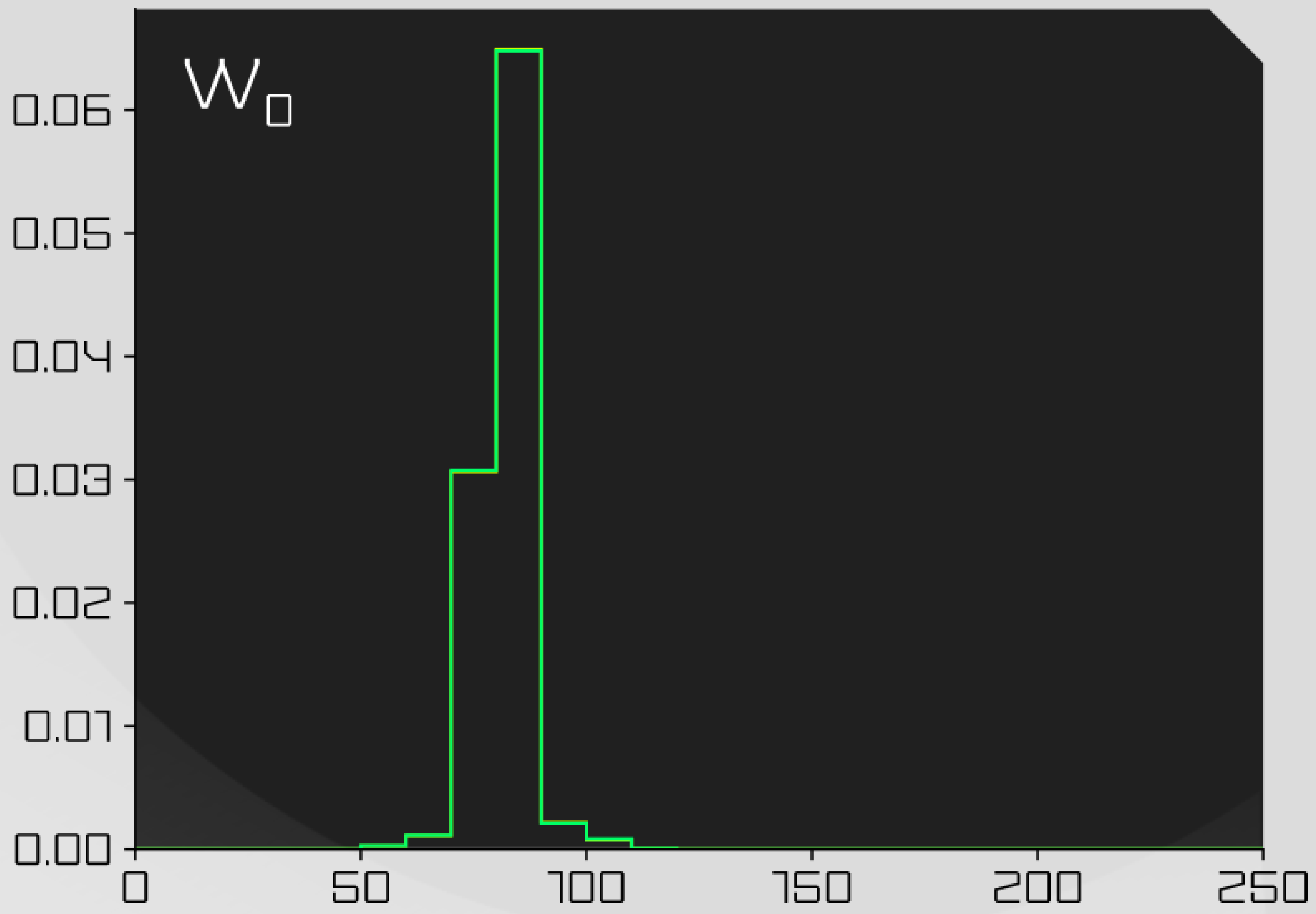
EWK QCD



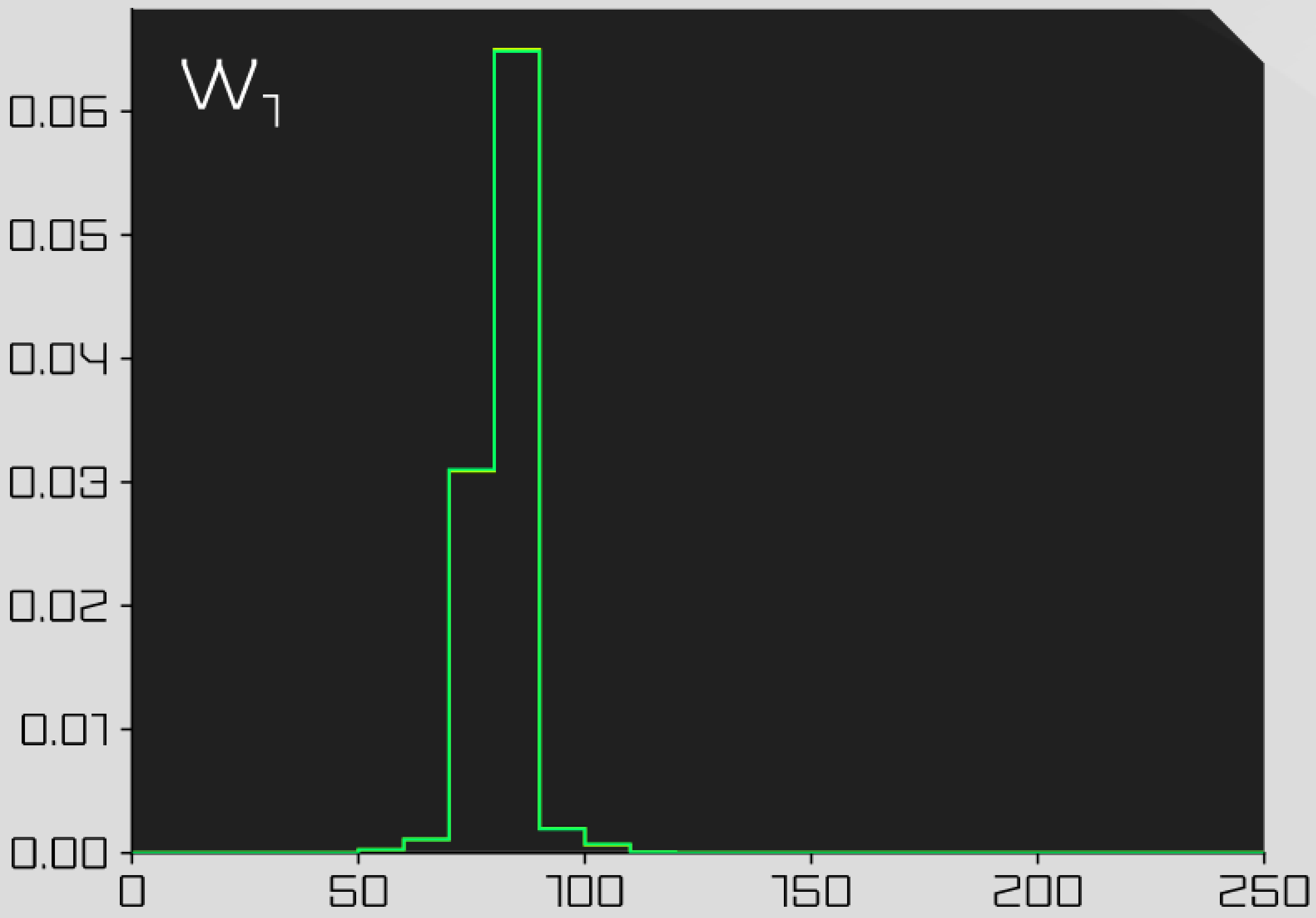


MASS

EWK QCD



W0
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0
50
100
150
200
250



W1
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SCATTERING ANGLE

EWK QCD