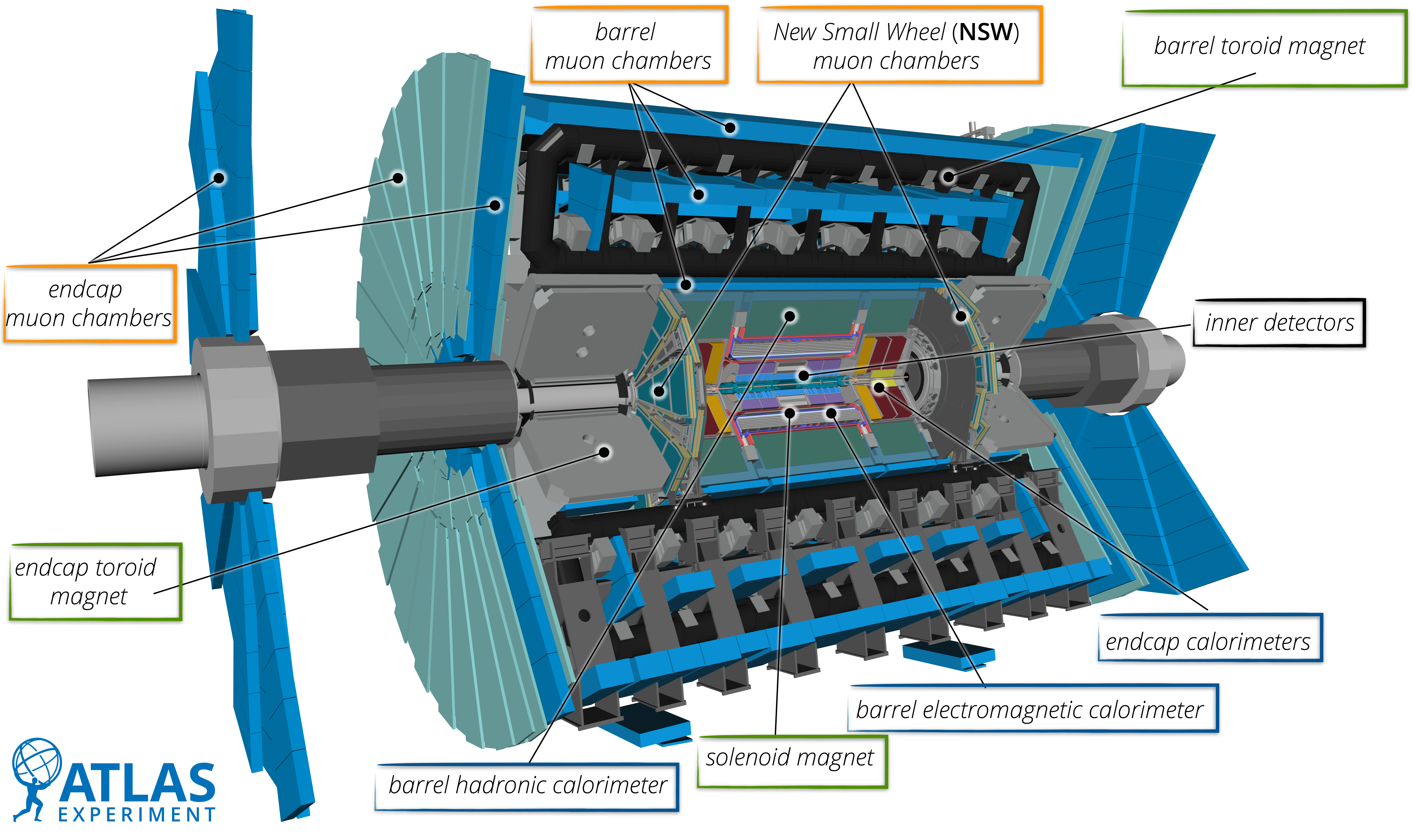
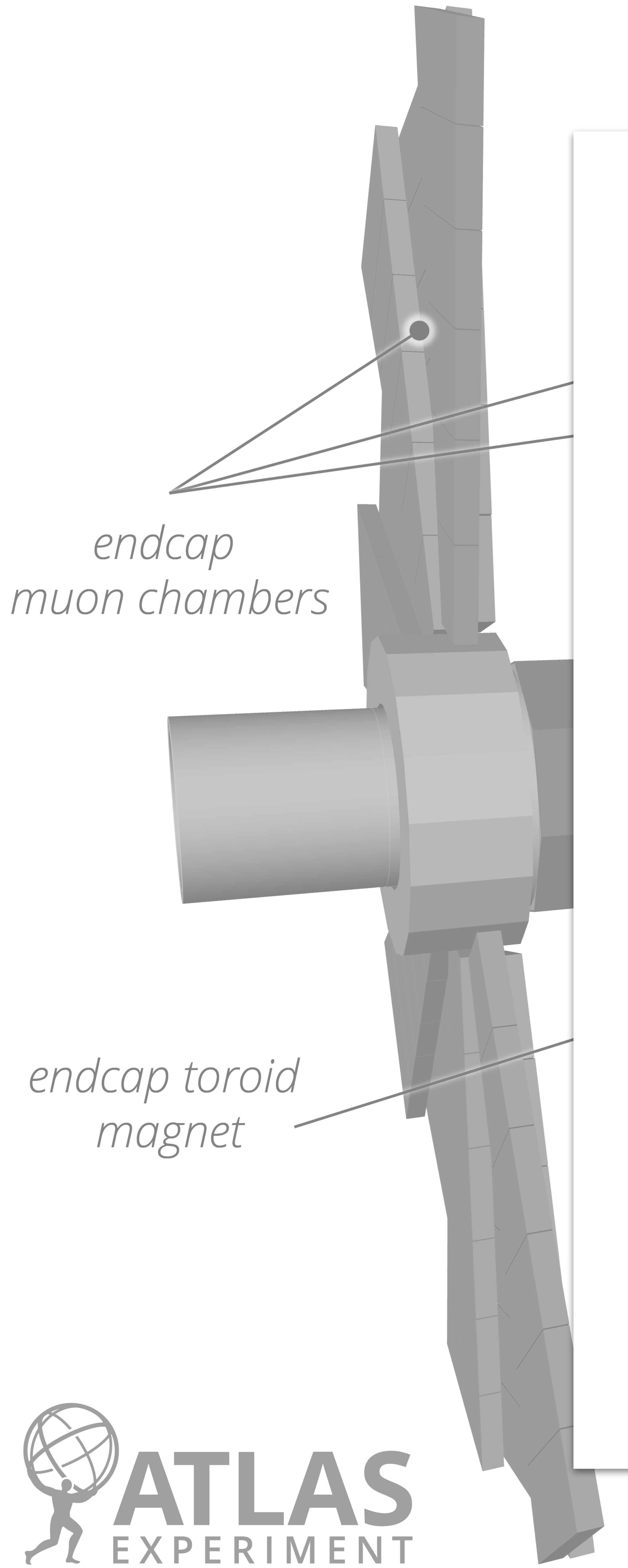
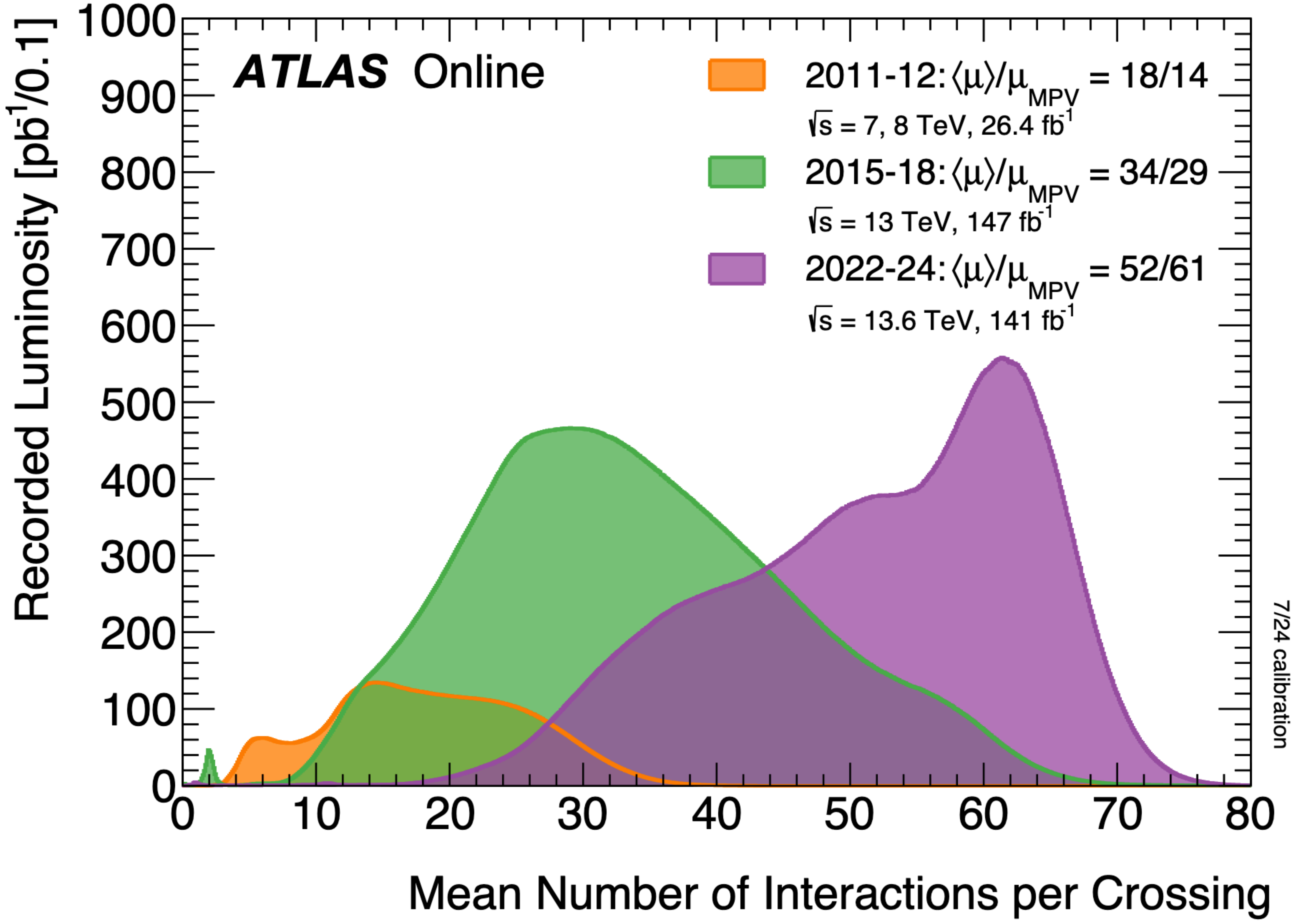
Recent Highlights from the ATLAS experiment

Matthias Danninger for the ATLAS Collaboration
PPC 2024, Hyderabad, India

SIMON FRASER UNIVERSITY


barrel muon chambers
New Small Wheel (**NSW**) muon chambers
barrel toroid magnet
endcap muon chambers
inner detectors
endcap toroid magnet
endcap calorimeters
barrel electromagnetic calorimeter
solenoid magnet
barrel hadronic calorimeter
ATLAS
EXPERIMENT





- Well into Run-3
- LHC is currently levelling at μ=63
- ATLAS is running at 94% recording efficiency

ATLAS EXPERIMENT

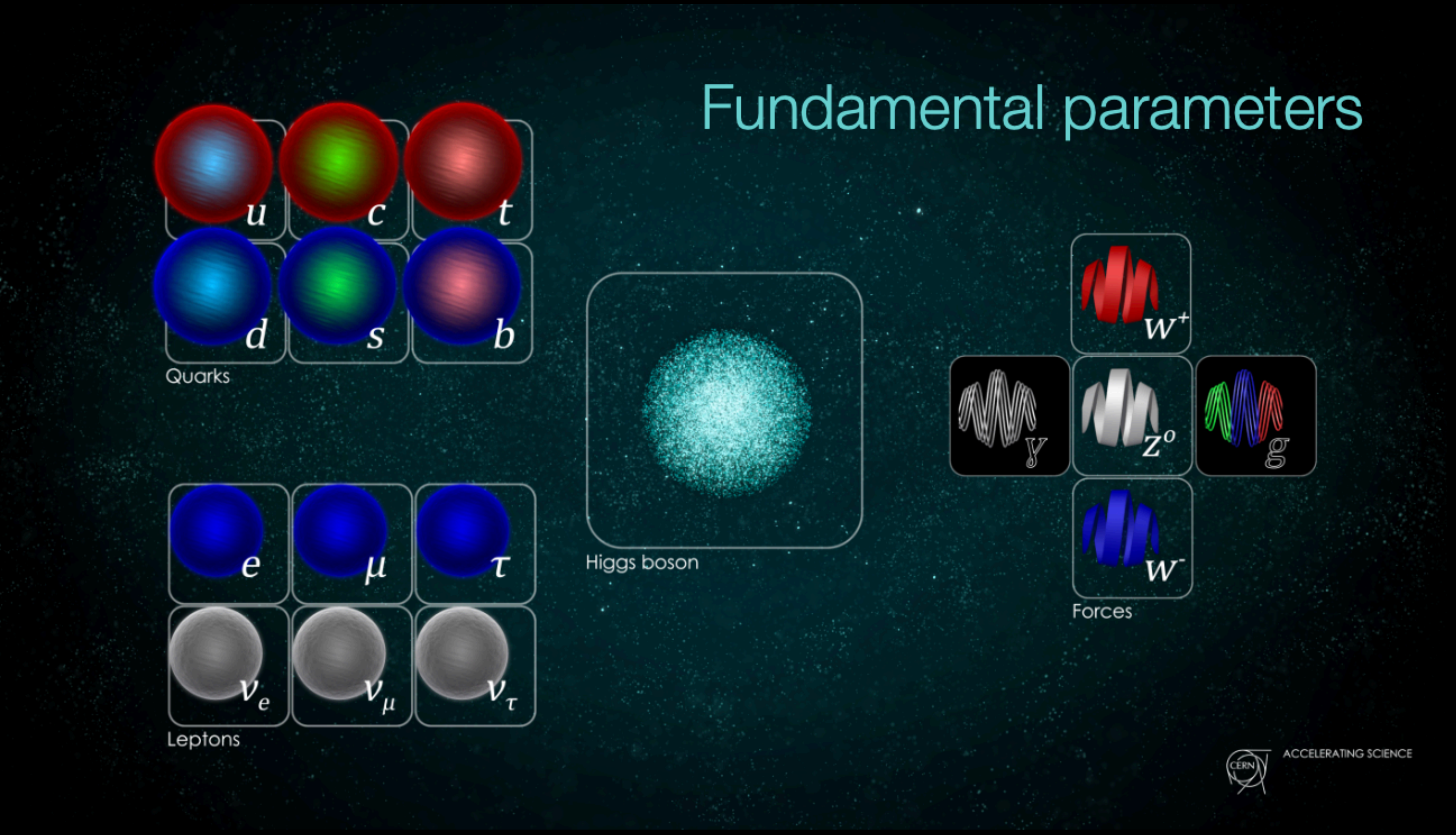
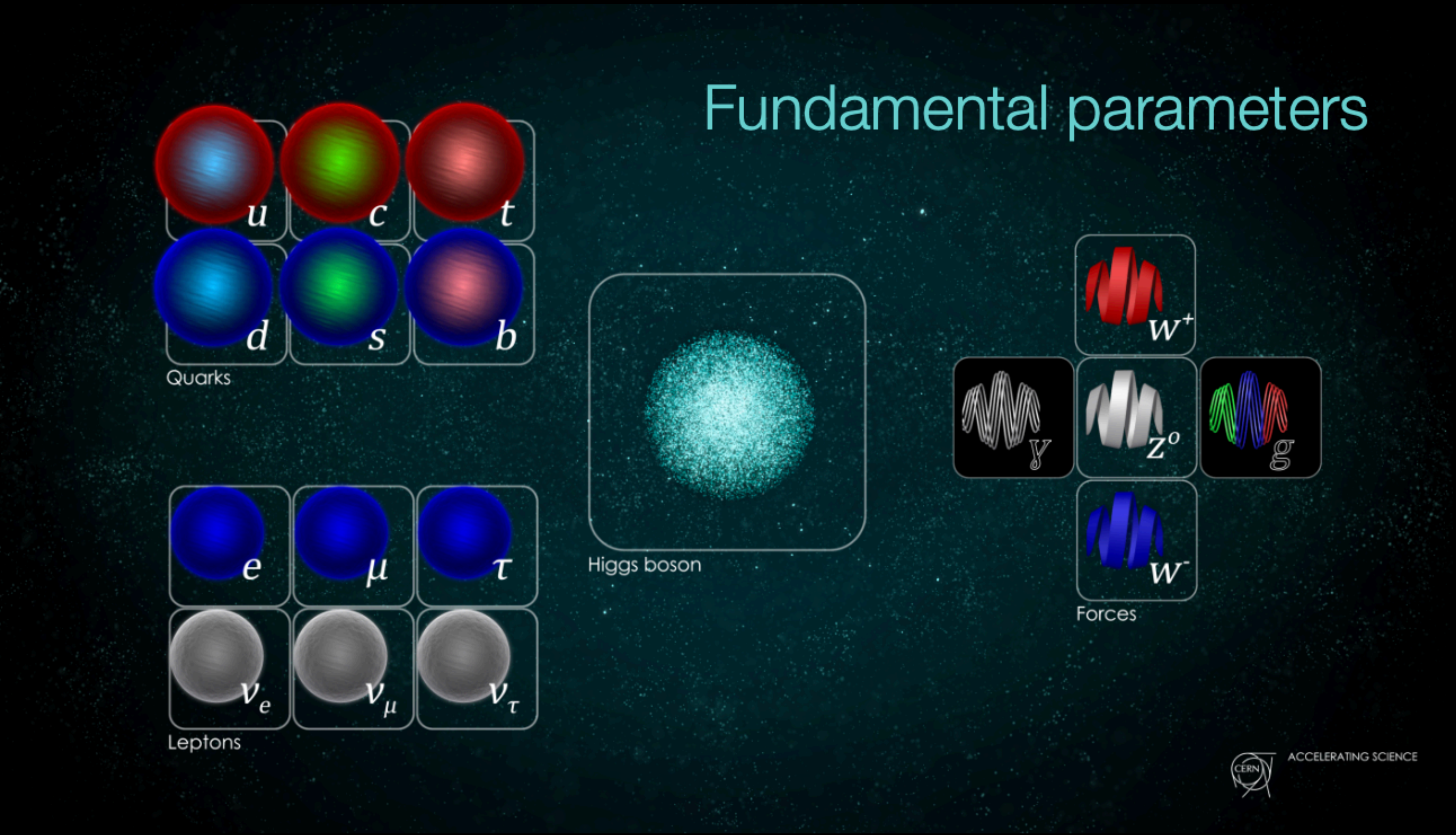
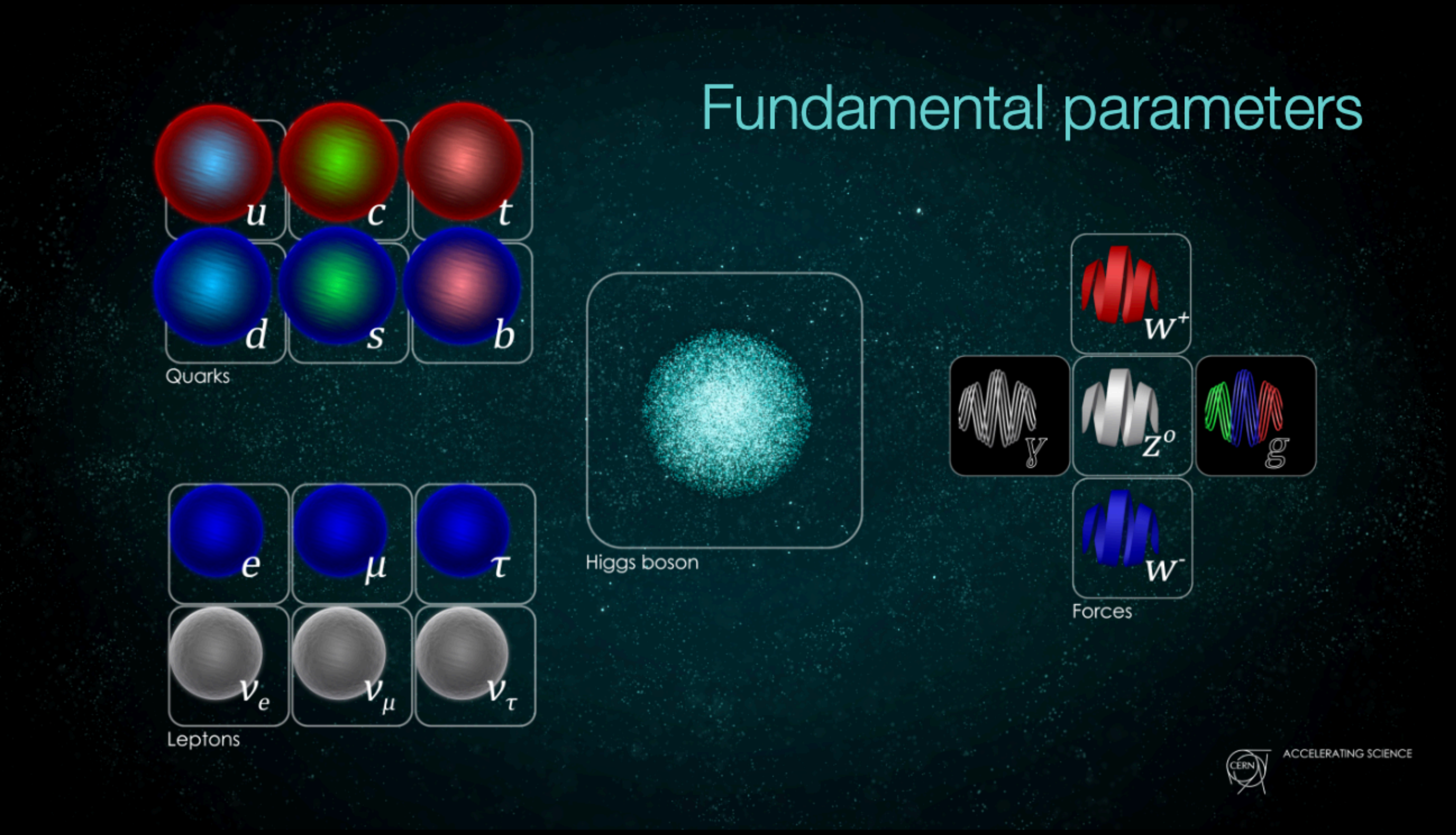


image credit CERN & M. Dunford



Where are the Interconnection between Particle Physics and Cosmology in the context of ATLAS?

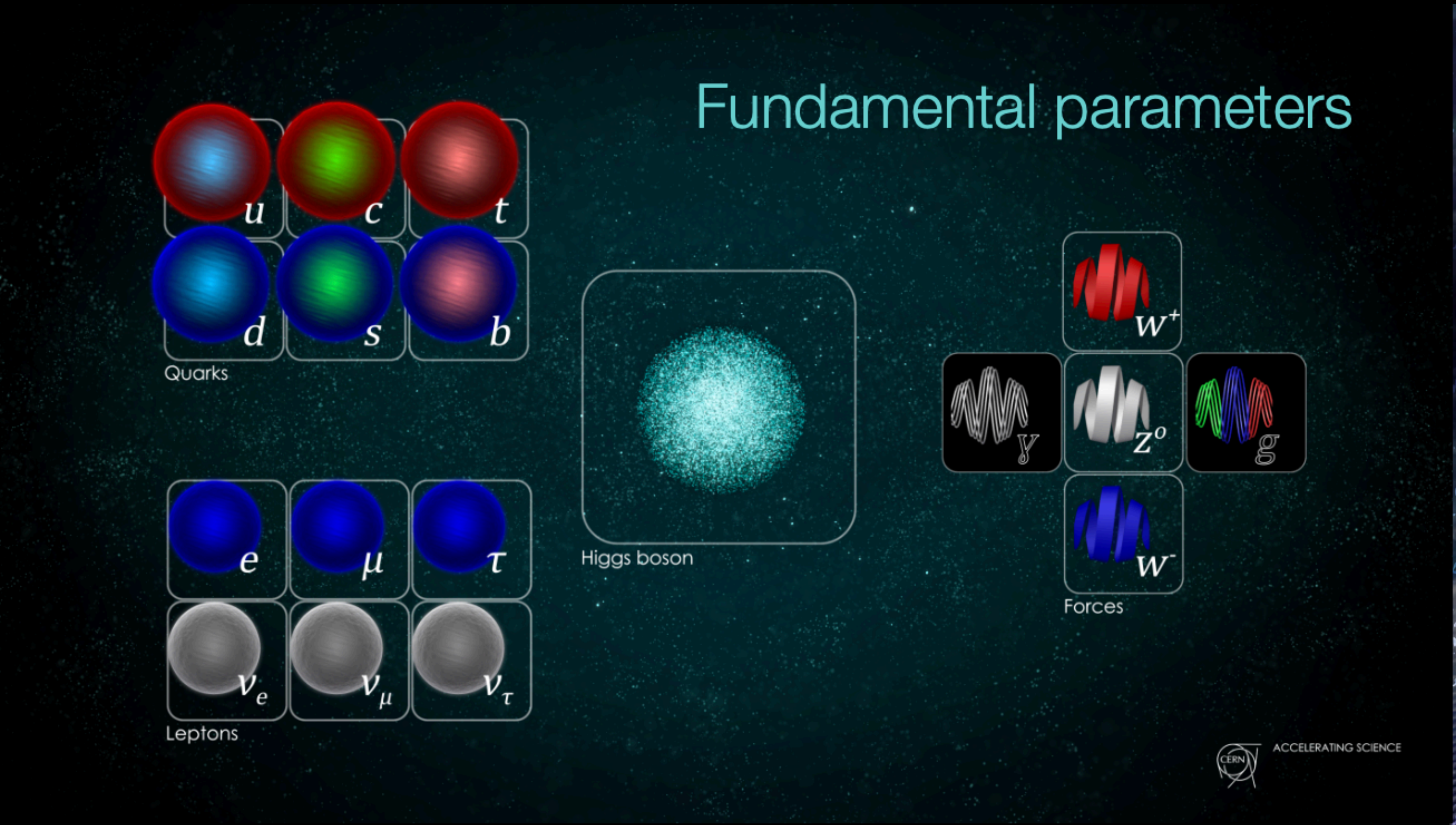
image credit CERN & M. Dunford

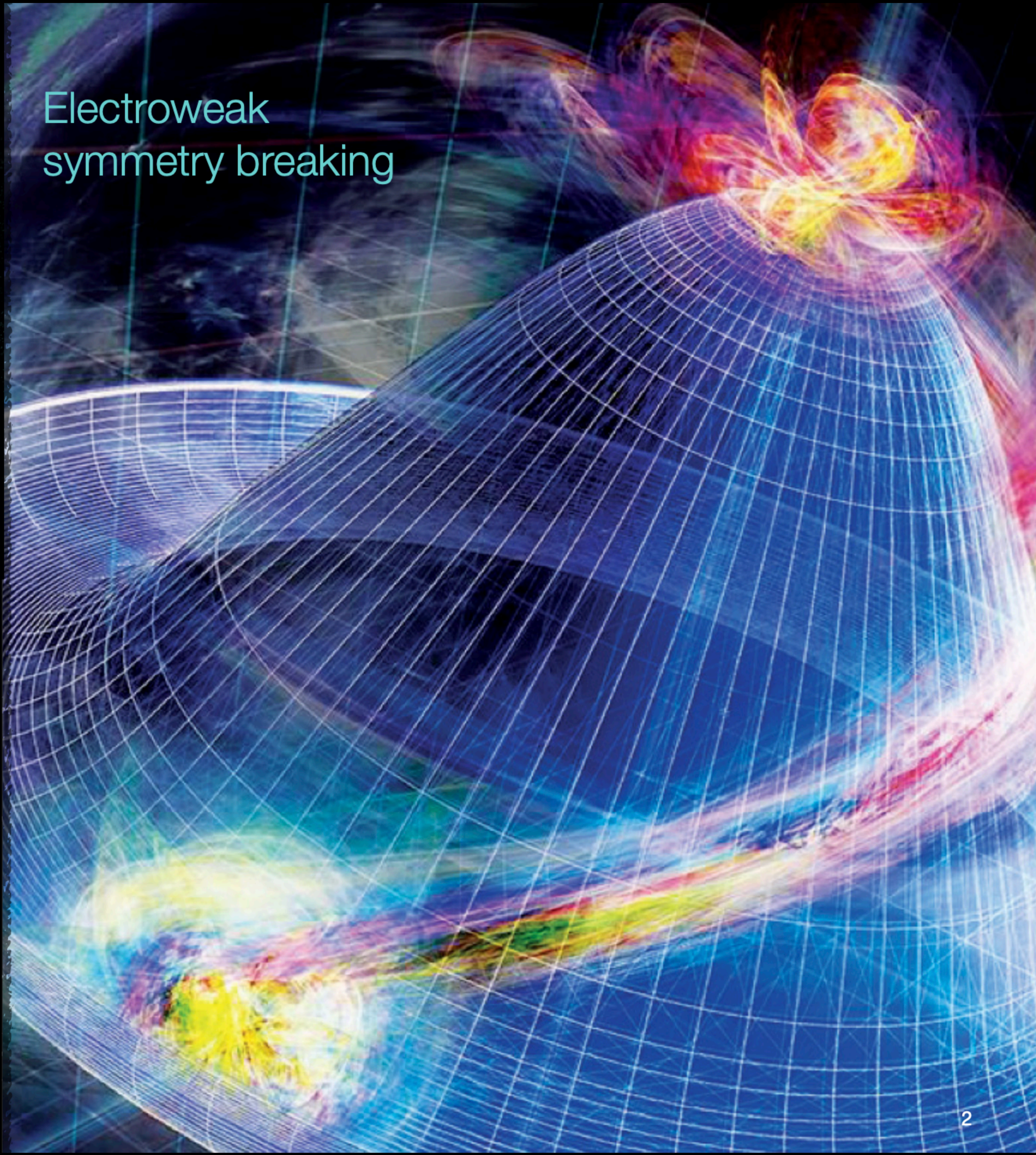


Where are the Interconnection between Particle Physics and Cosmology in the context of ATLAS?

1) Testing all details of the Standard Model!

image credit CERN & M. Dunford





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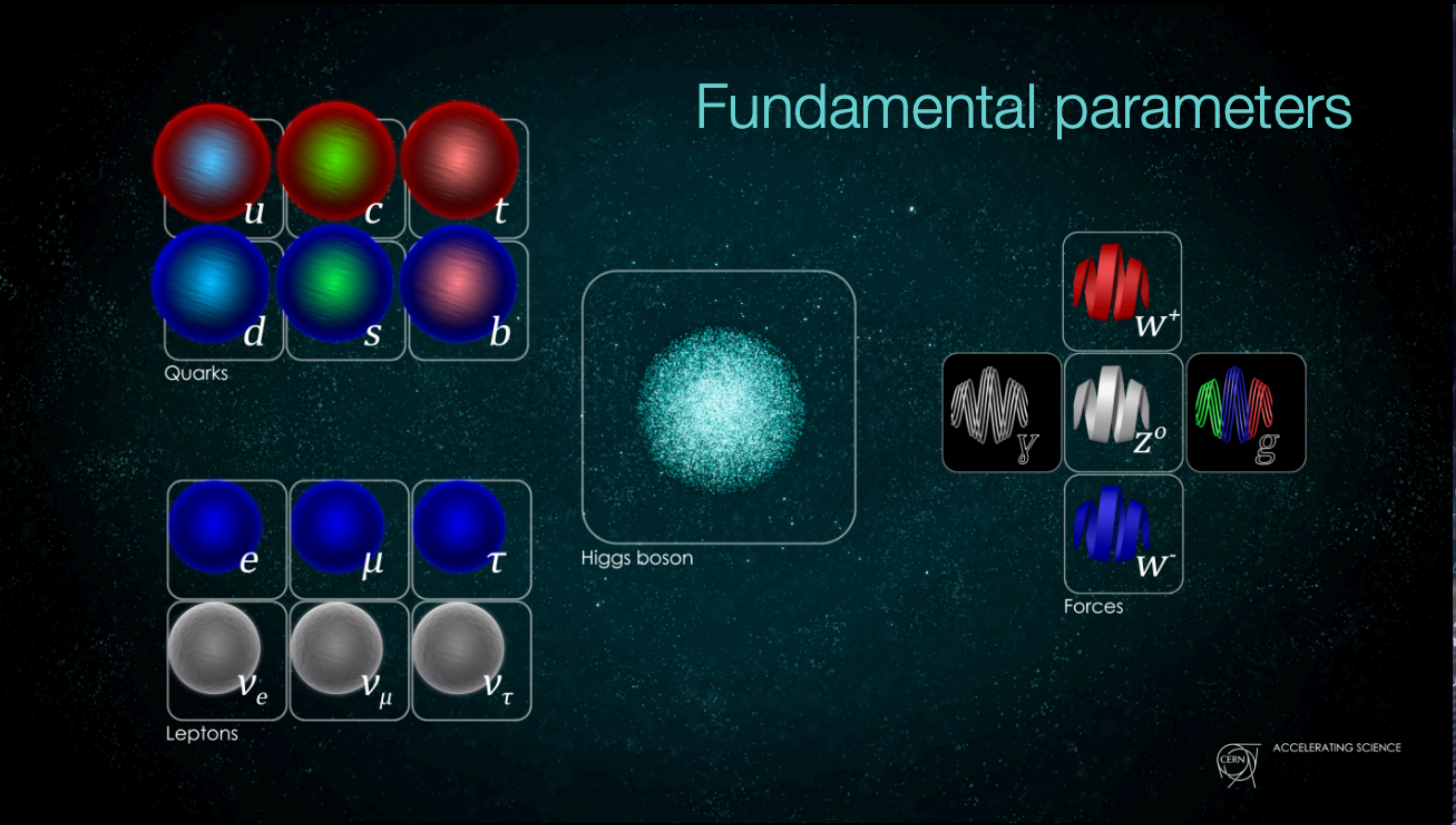

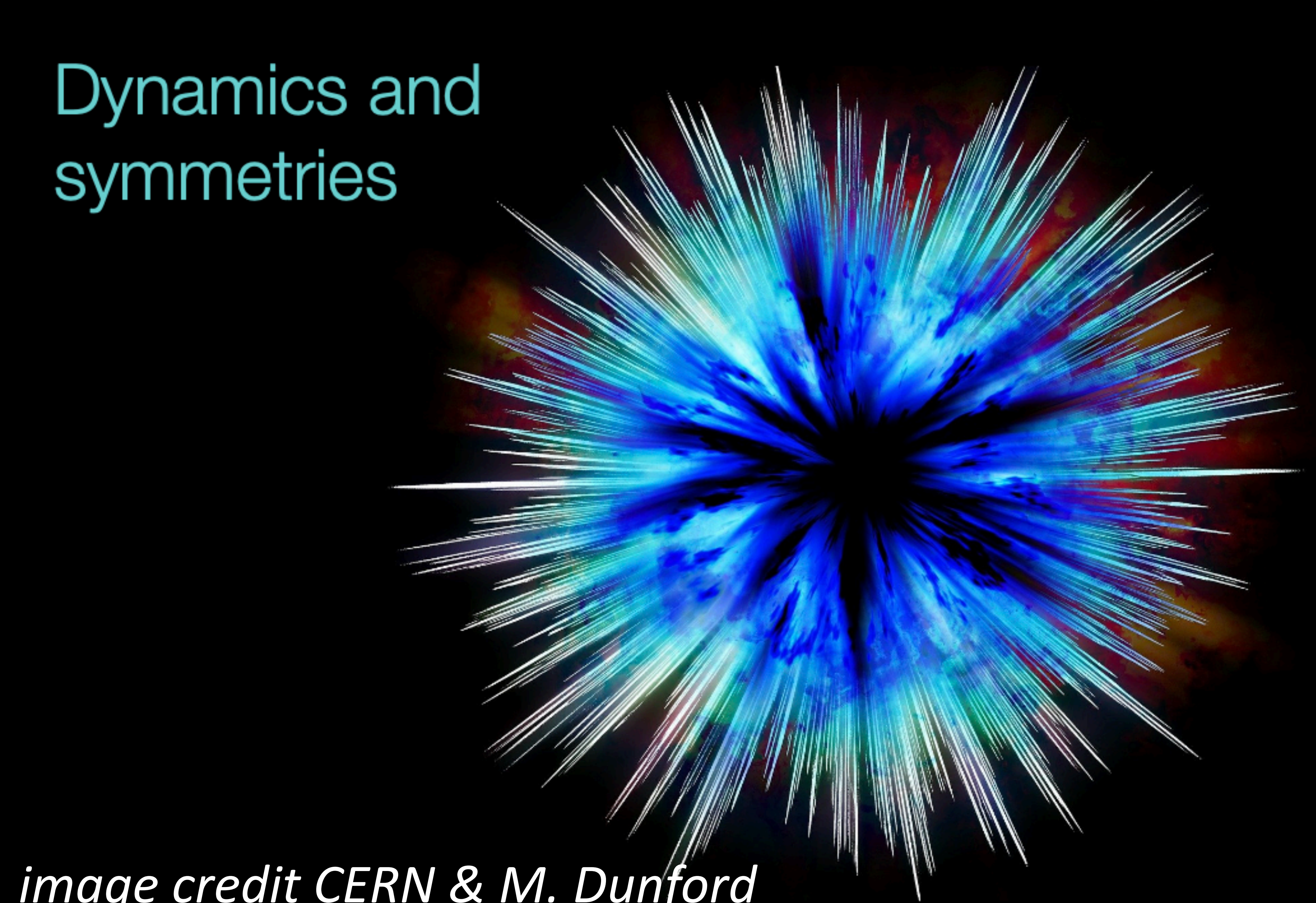

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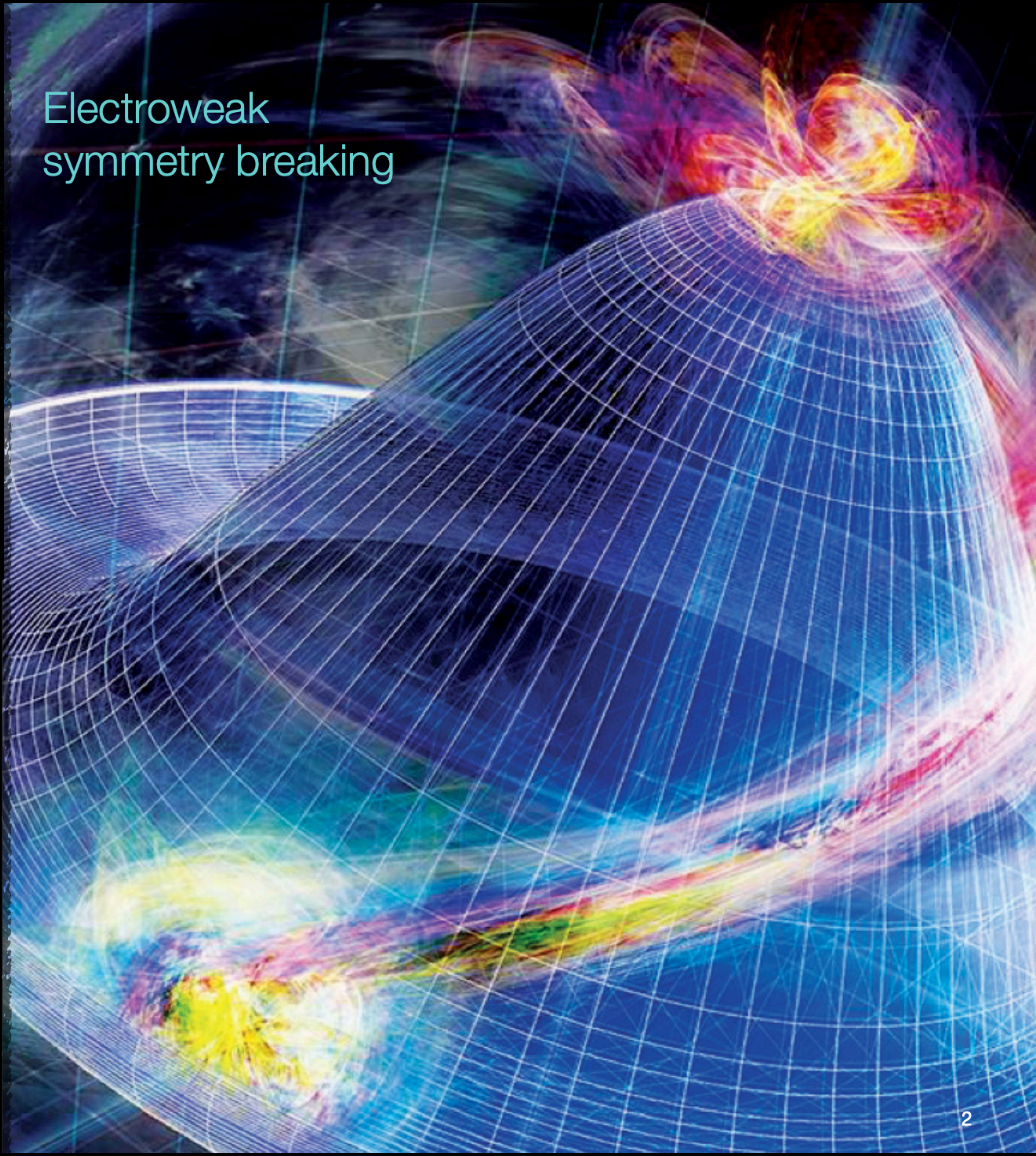
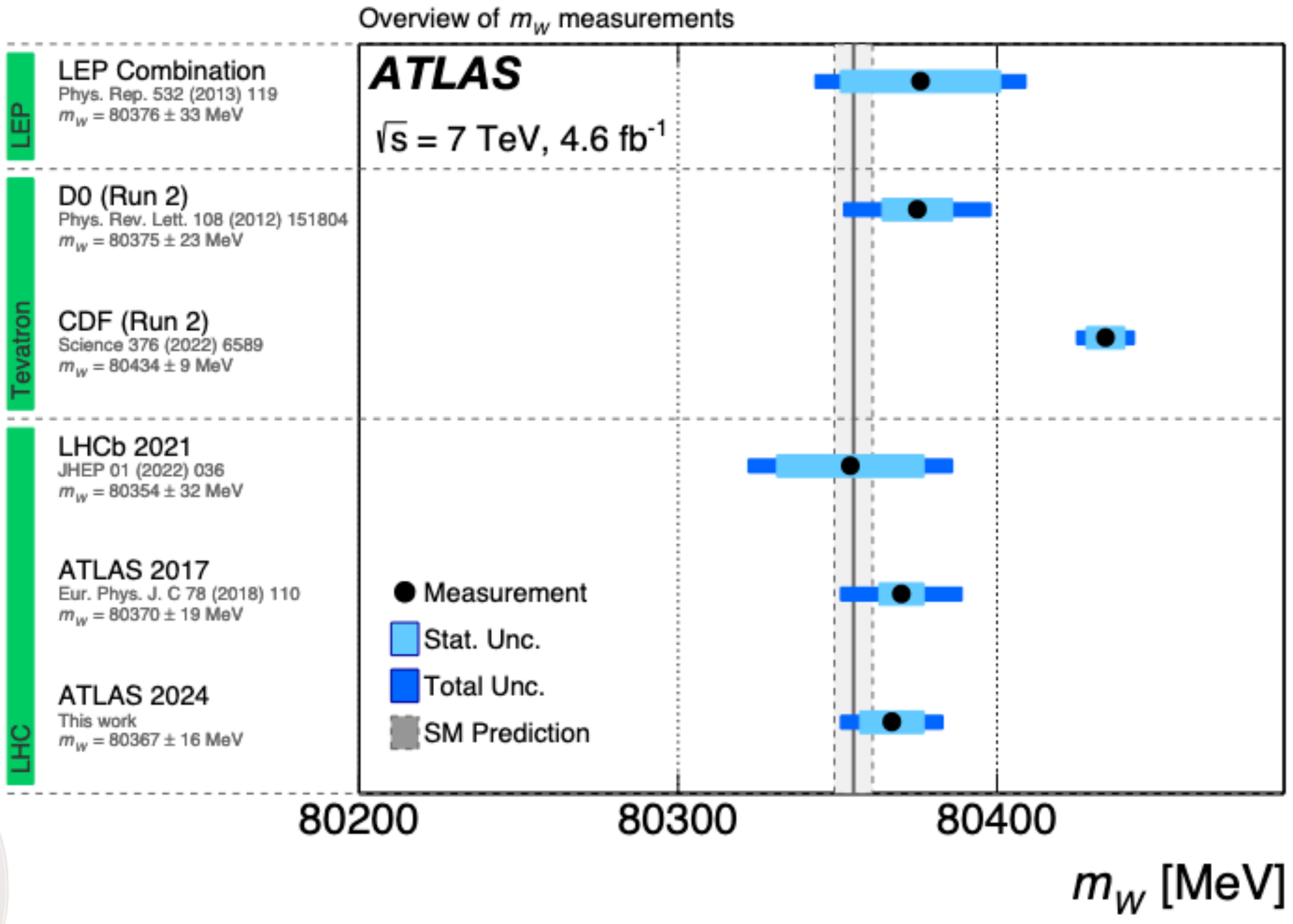


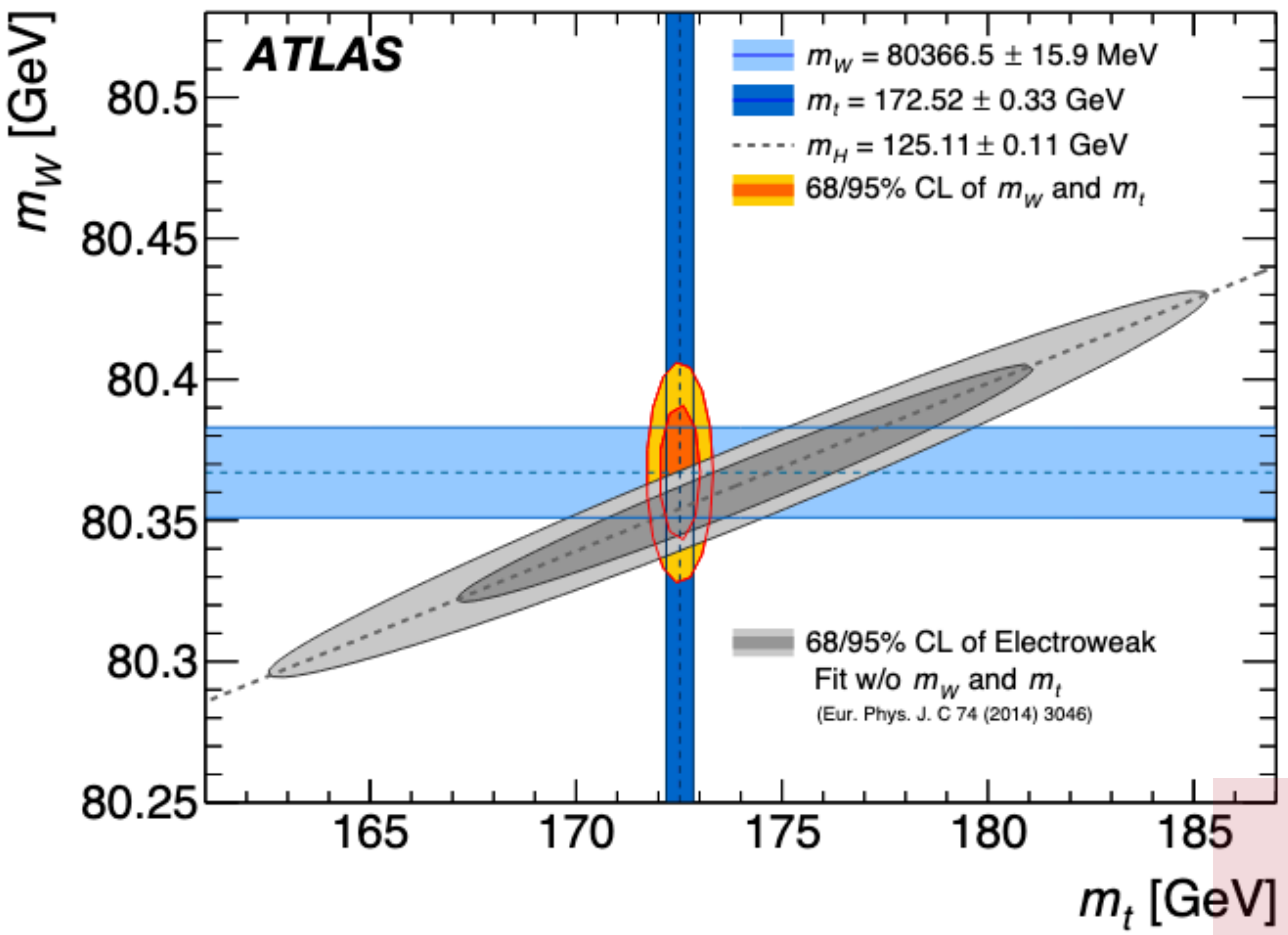
Understanding fundamental parameters

PRL 131 (2023) 251802
arxiv:2403.15085

Mass measurement precisions:

- 0.02% on W mass
- 0.2%   on top mass
- 0.09% on Higgs mass





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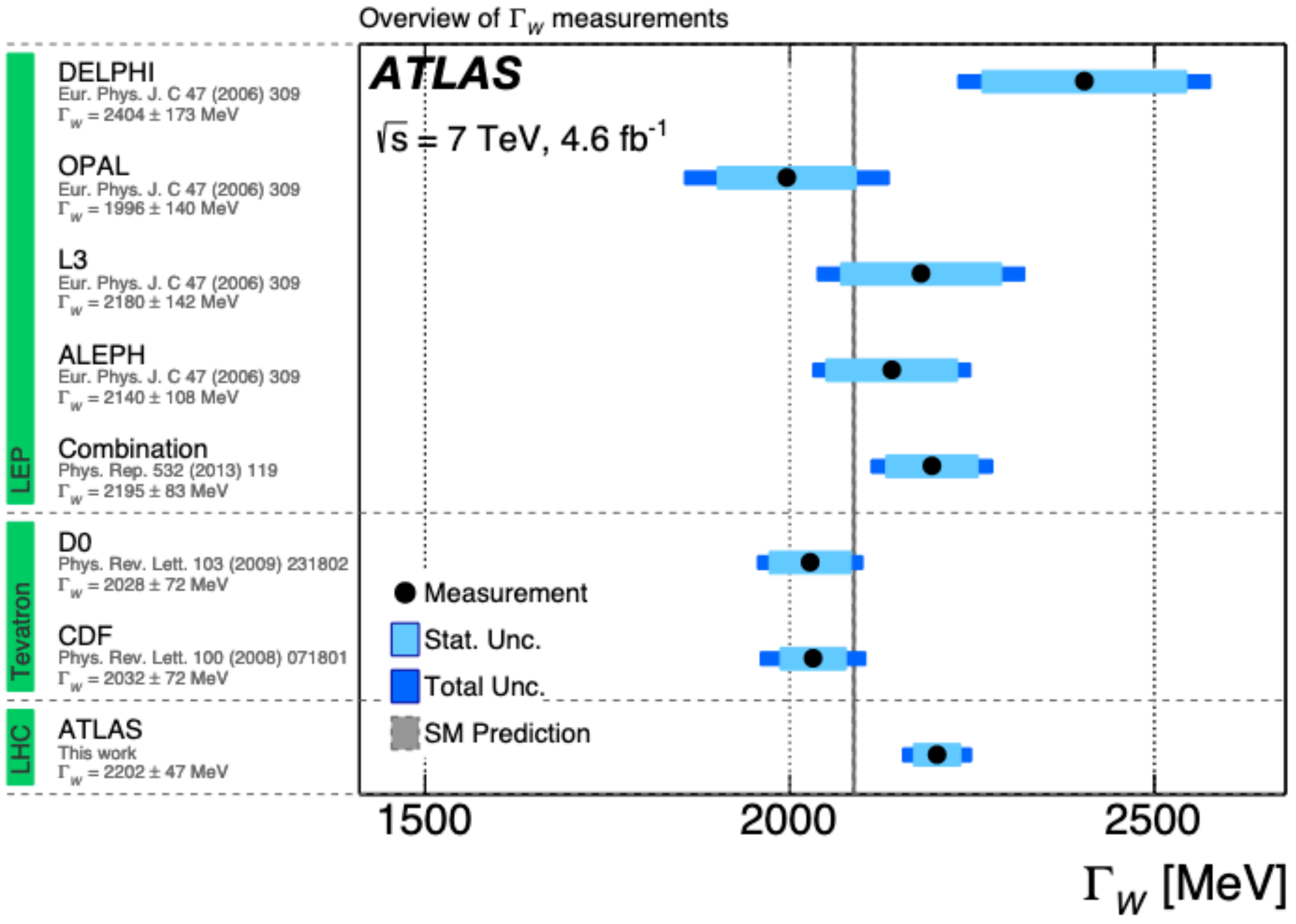
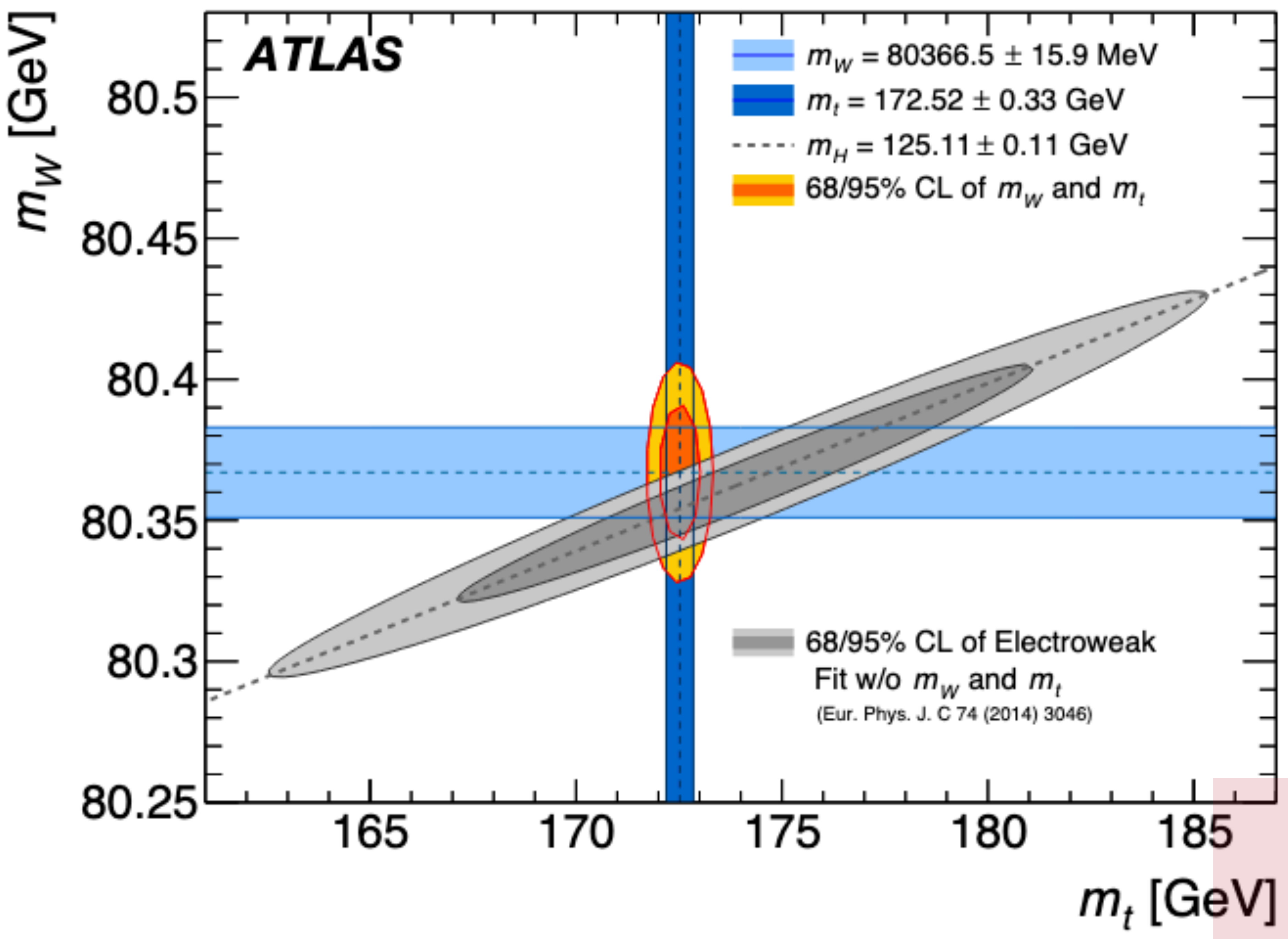


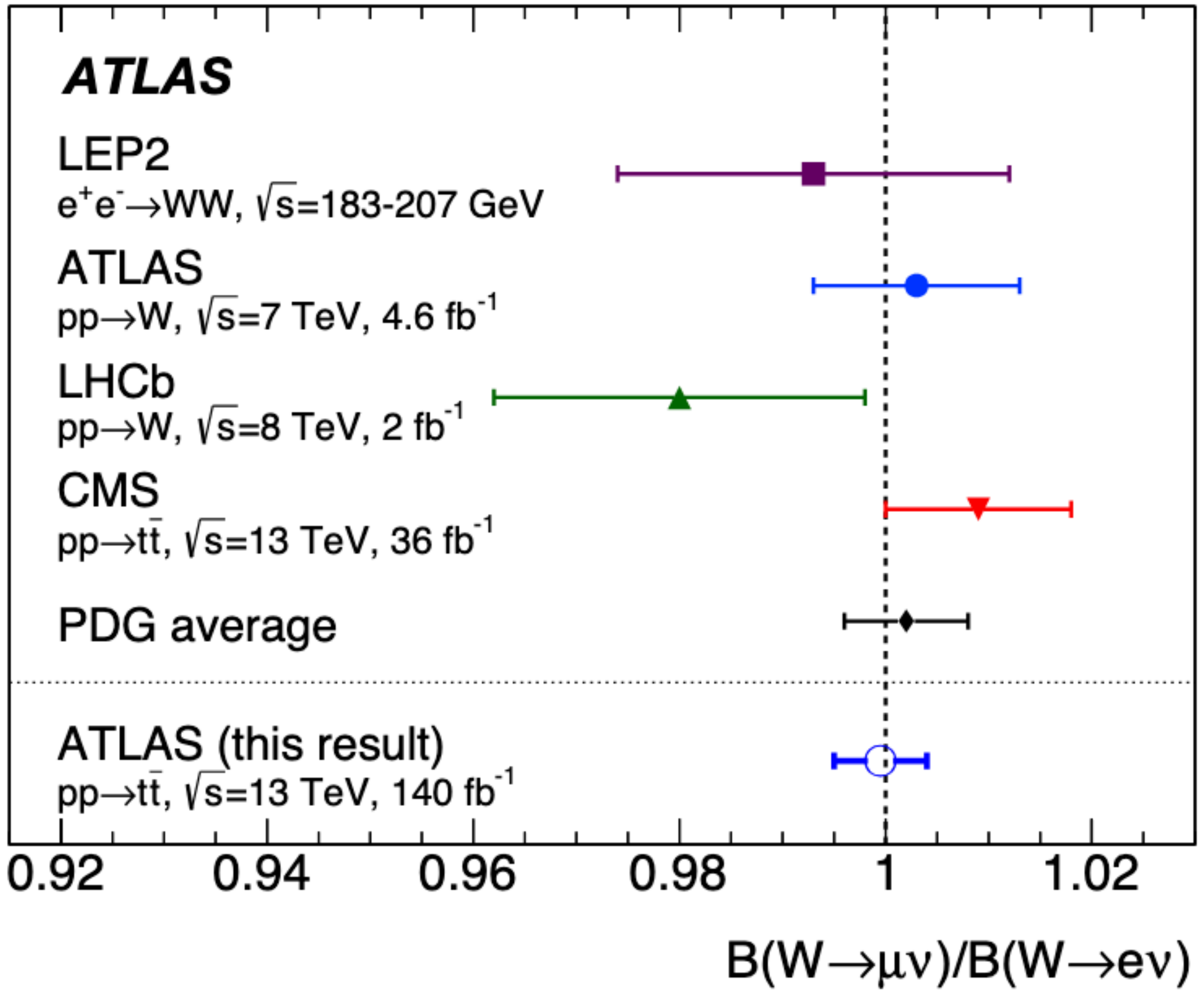


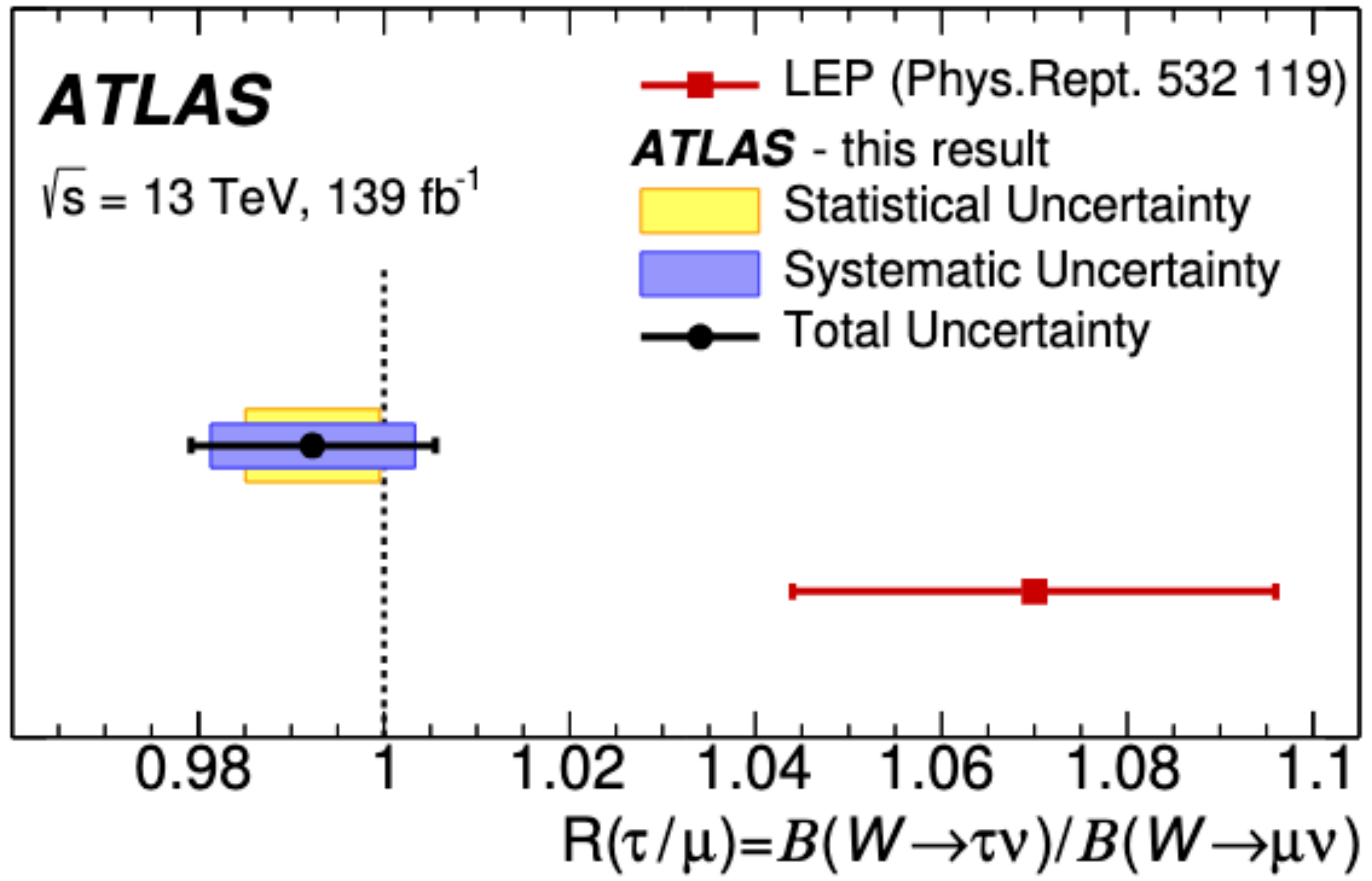
Understanding fundamental parameters

(EPJ C 84 (2024) 993)
(Nature 17 (2021) 7)

Lepton universality:

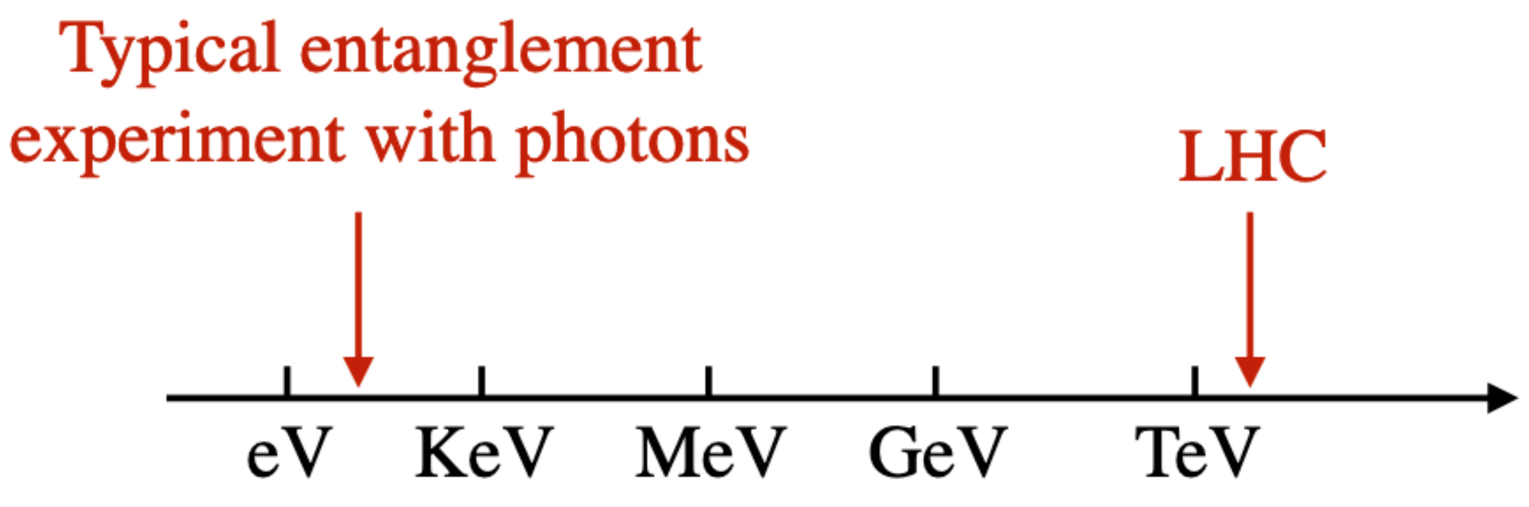
- Probed in W decays to electrons and muons from top-pairs
- 0.45% precision —> more precise than current world average $R_W^{\mu/e} = 0.9995 \pm 0.0045$
- This complements previous result with taus $R(\tau/\mu)$





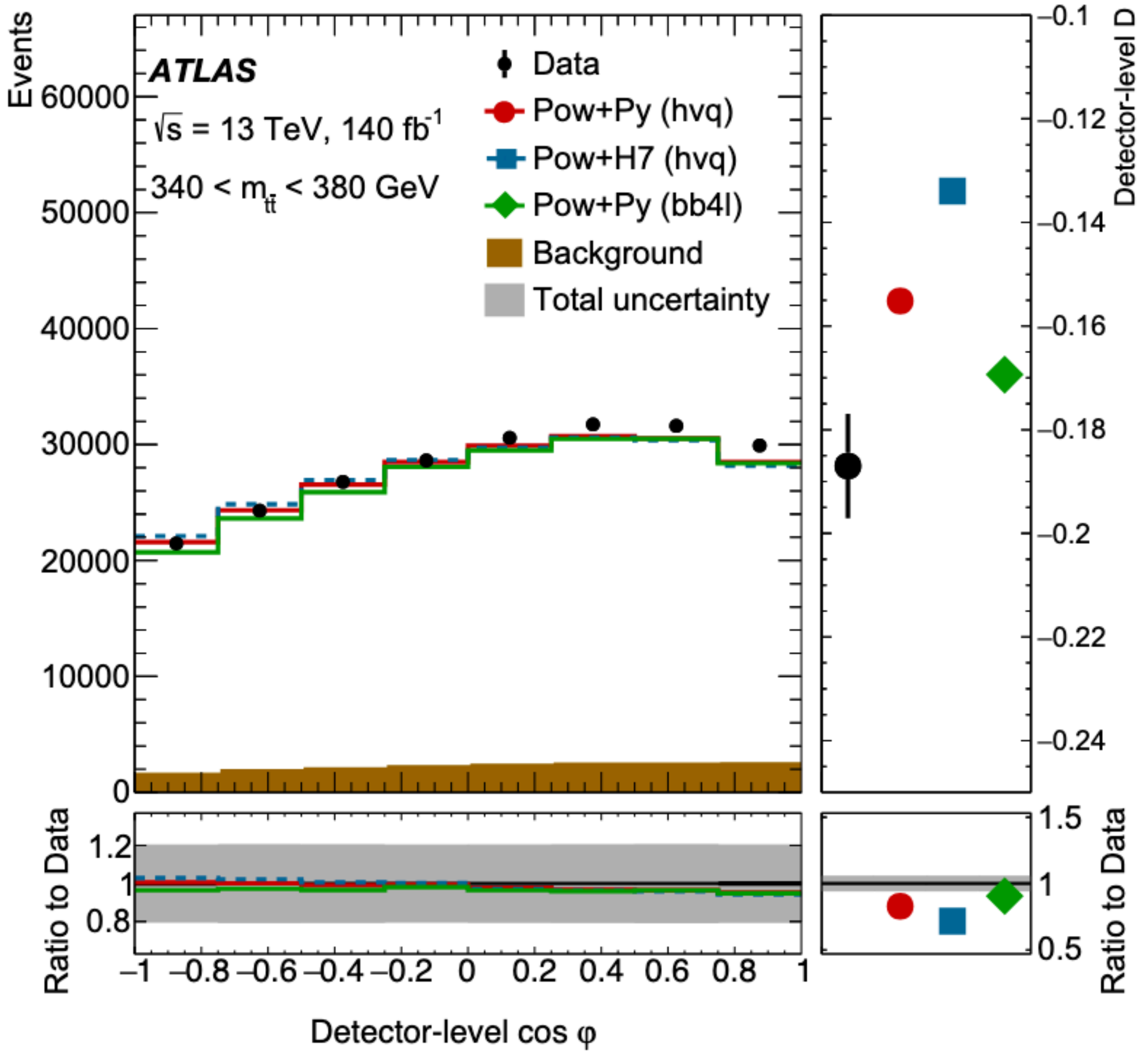
Understanding fundamental parameters

First observation of quantum entanglement at high-energy:

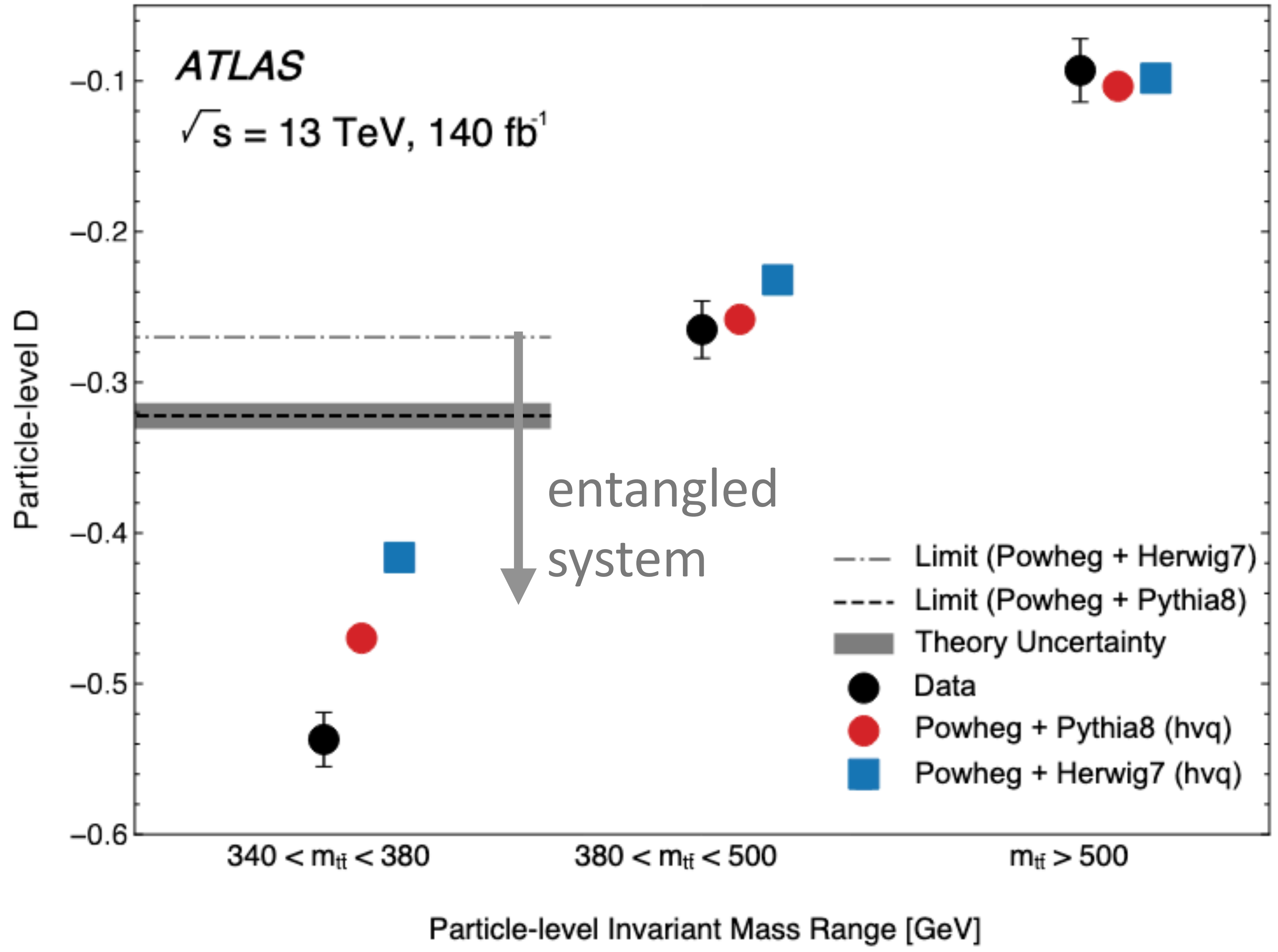


- Probed via spin correlations in top-pair events (two-qubit system)
- A correlation marker is inferred from the angle between the charged leptons in their parent top- and antitop-quark rest frames $D = -3 \cdot \langle \cos\varphi \rangle$

(Nature 633, 542–547, 2024)



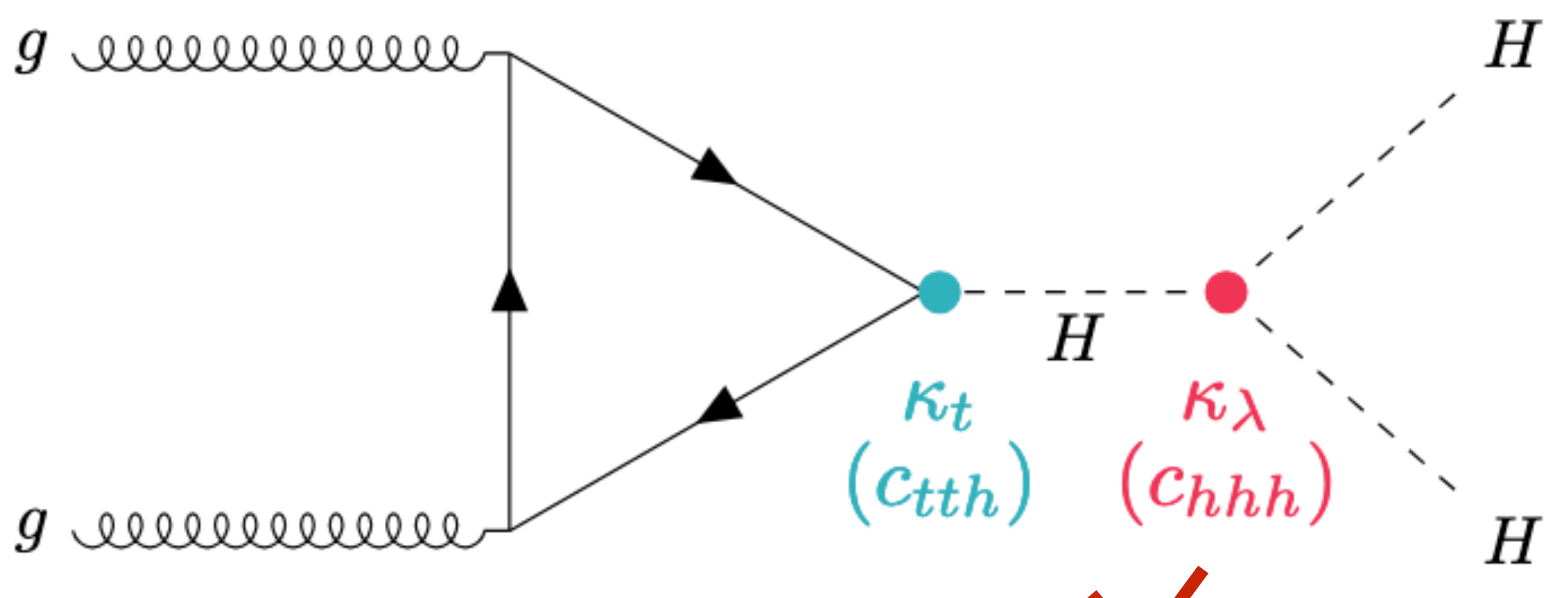
detector to particle level correction



Understanding fundamental parameters

Higgs couplings and self-coupling

- Learn about electroweak phase transition & vacuum stability!
- Self coupling allows us to trace the shape of the potential away from the Higgs mass



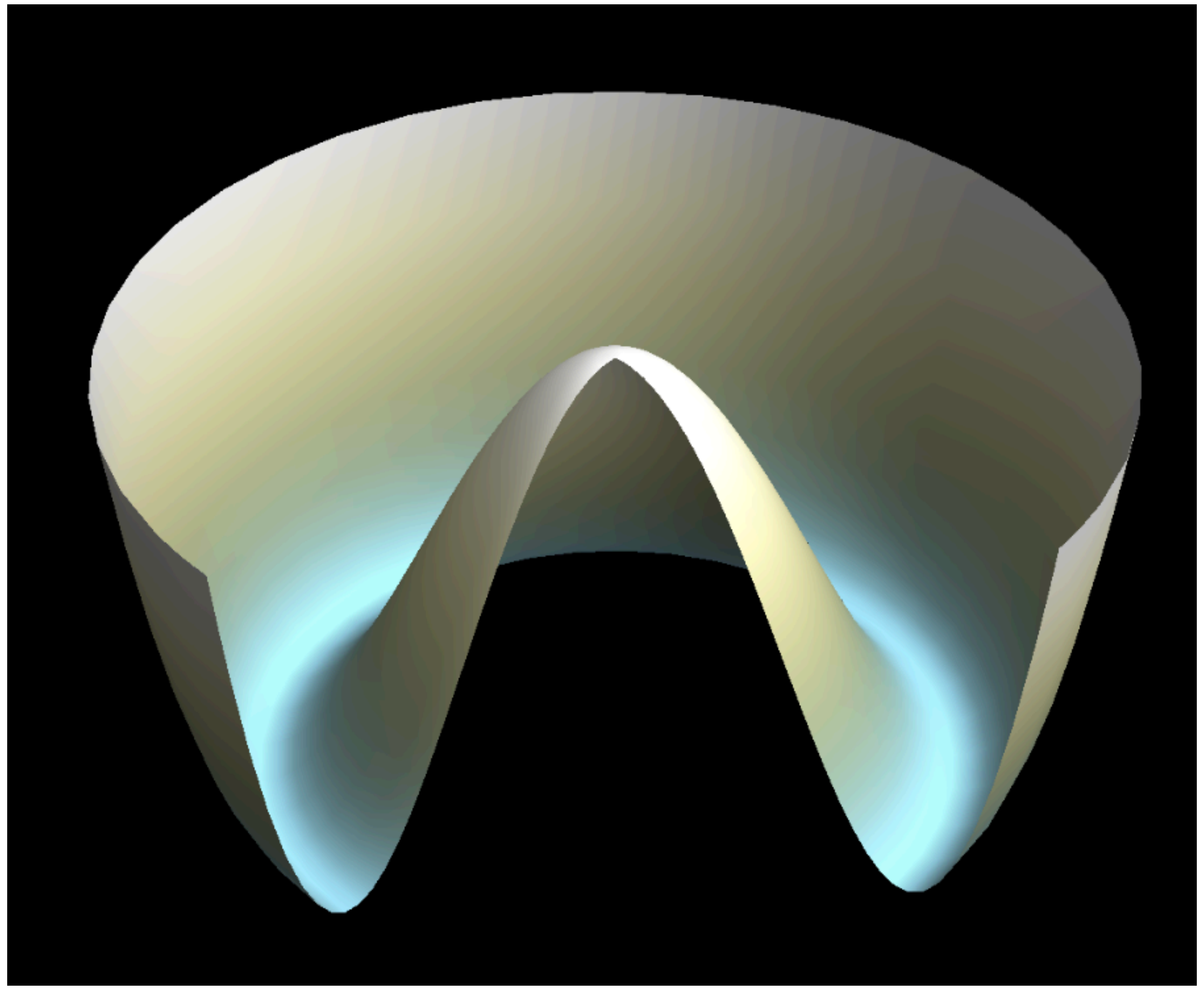
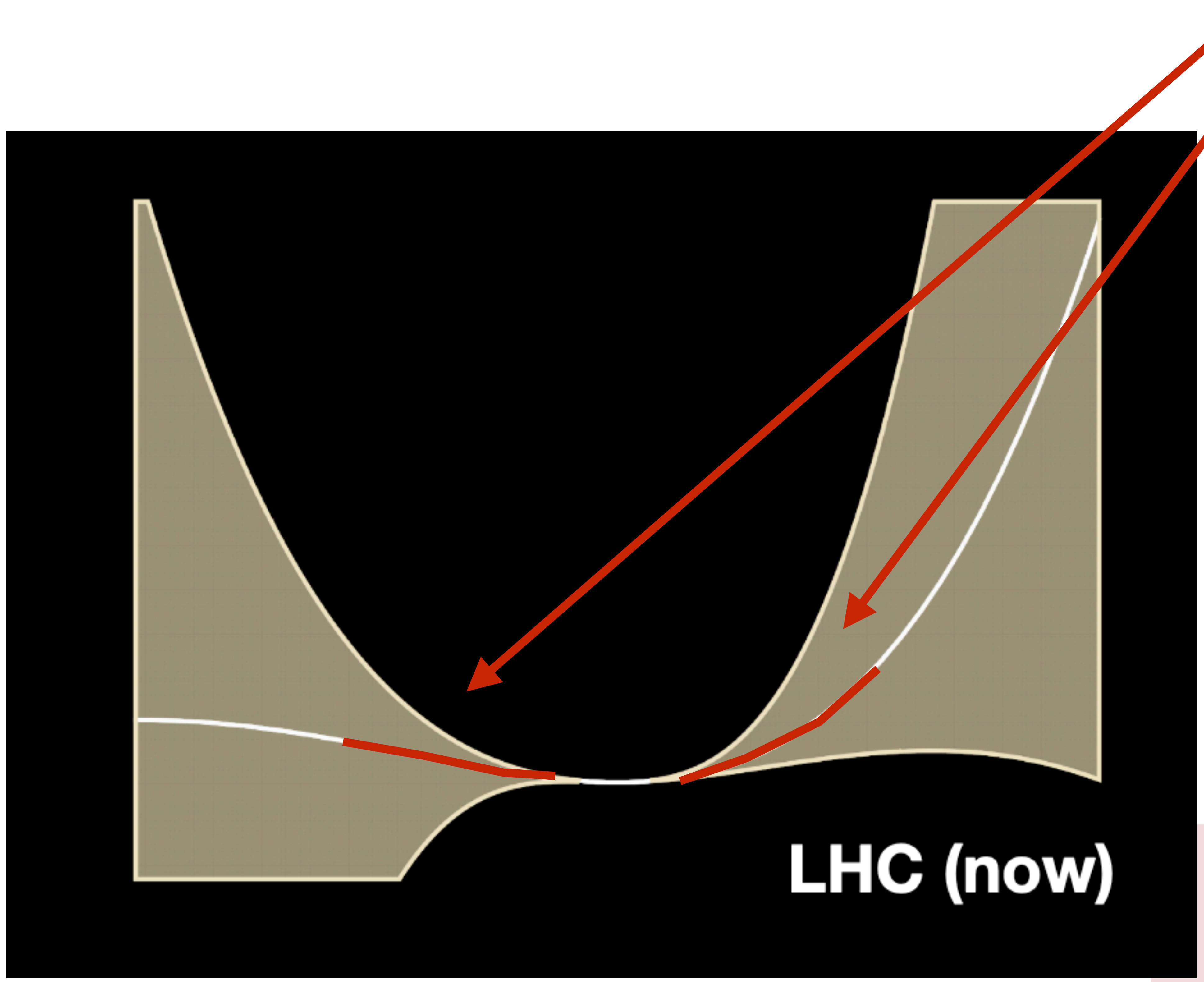


image credit N. Craig

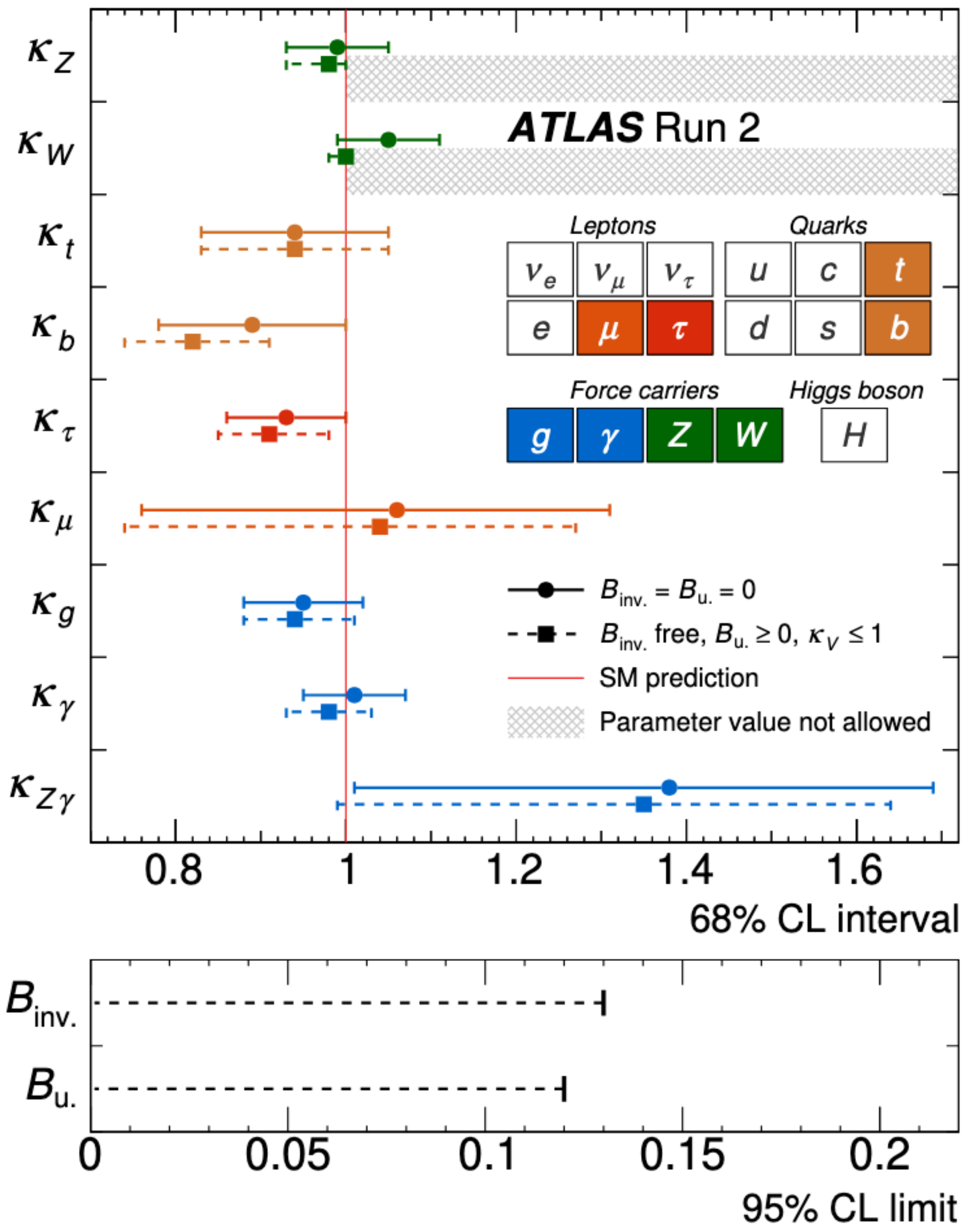


Understanding fundamental parameters

(PRL 133 (2024) 101801)
Nature 607, 52–59 (2022)

Higgs couplings and self-coupling

- Higgs coupling to SM particles



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Understanding fundamental parameters

(PRL 133 (2024) 101801)
Nature 607, 52–59 (2022)

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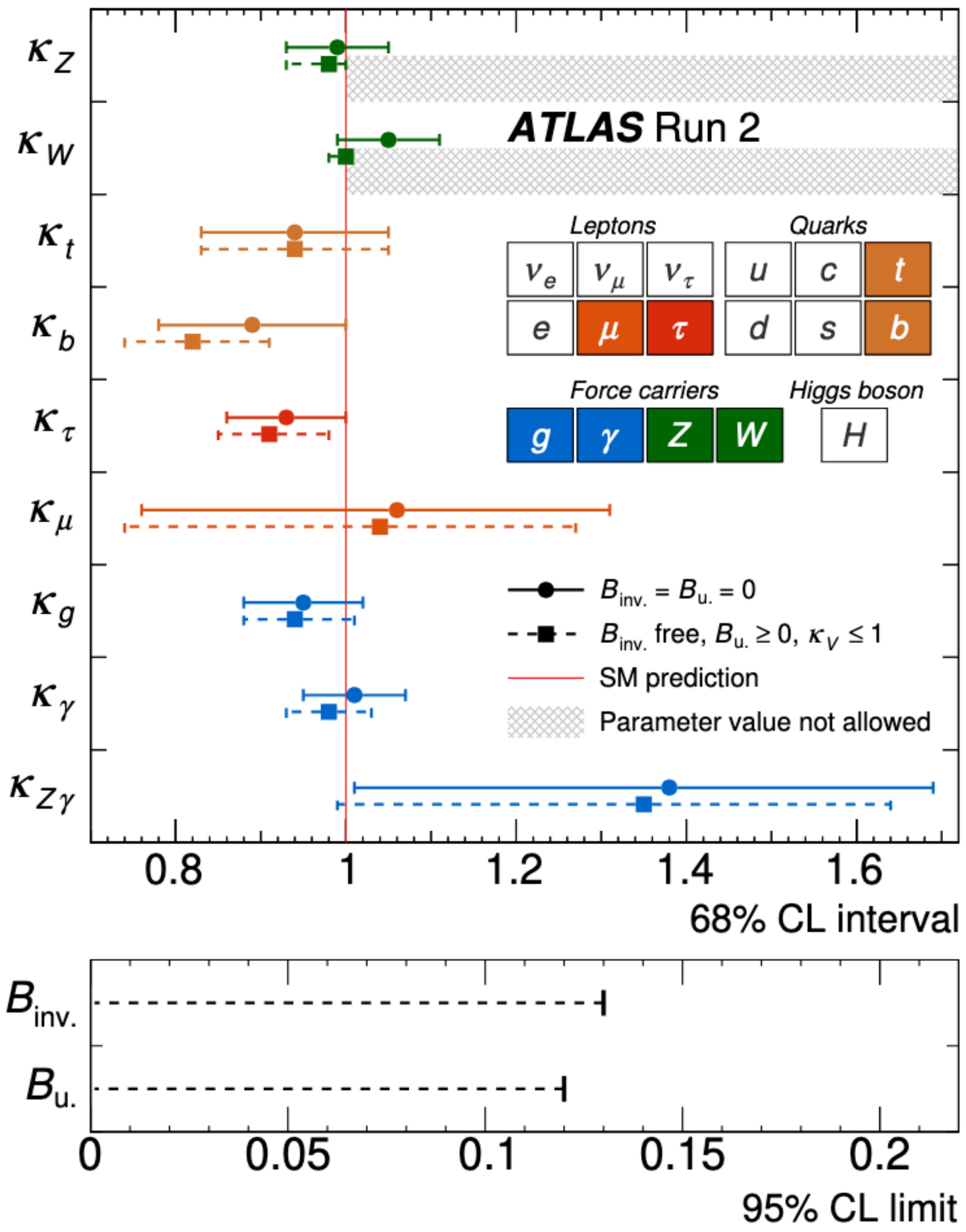
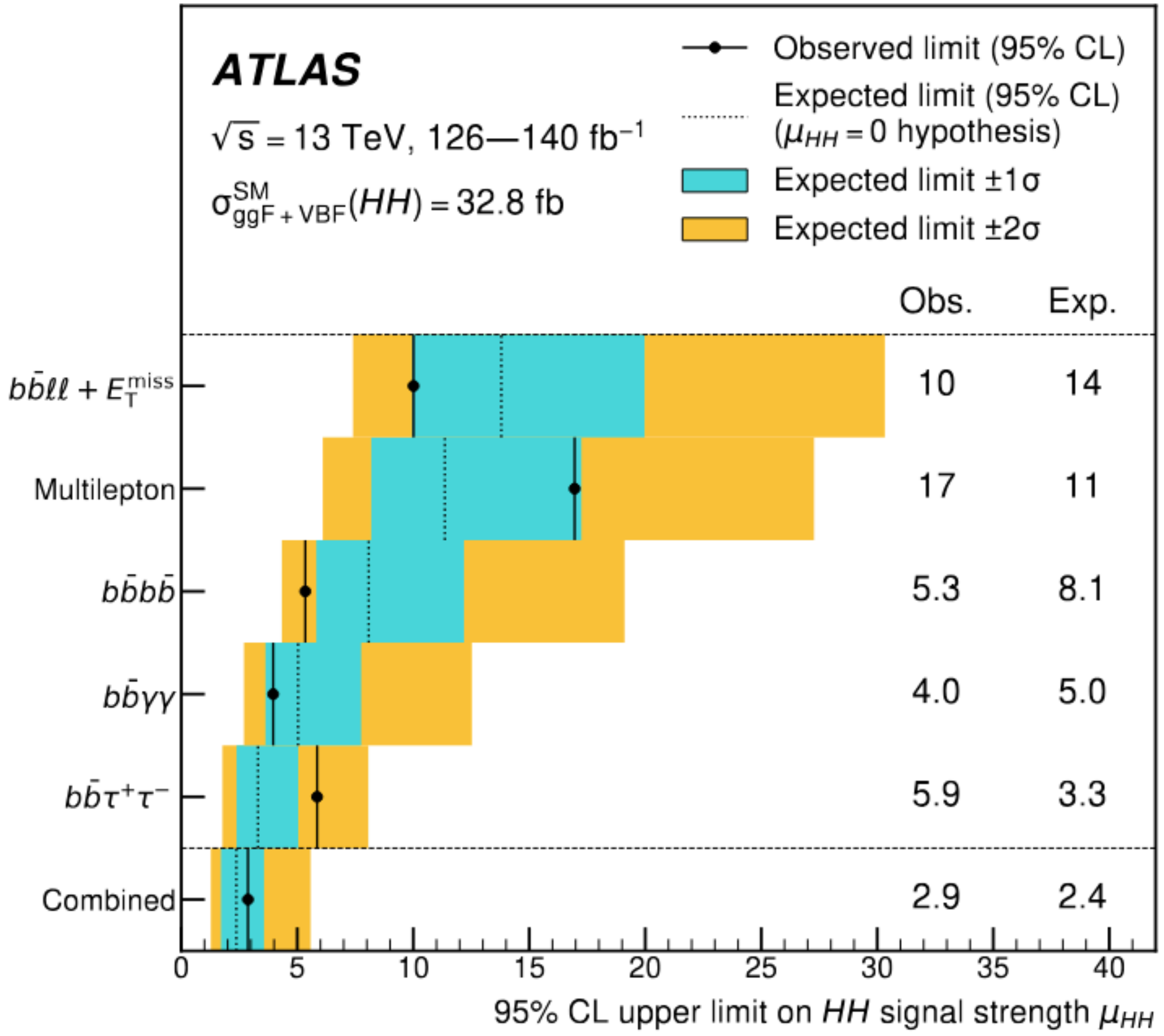


- Upper limit on Di-Higgs coupling

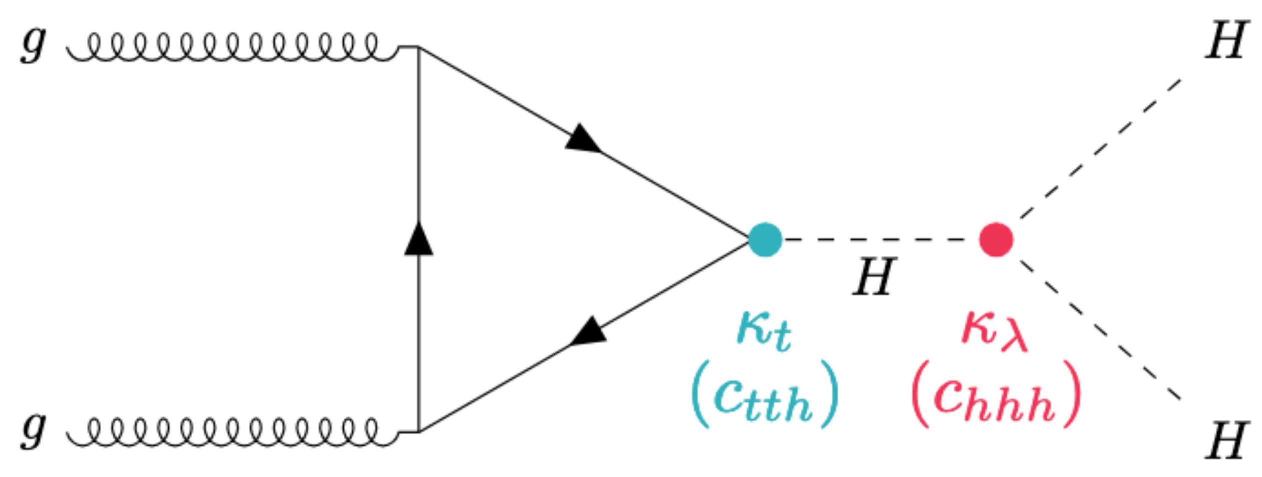
$\mu_{HH} < 2.9$ **(obs)** and 2.4 (exp) at 95%



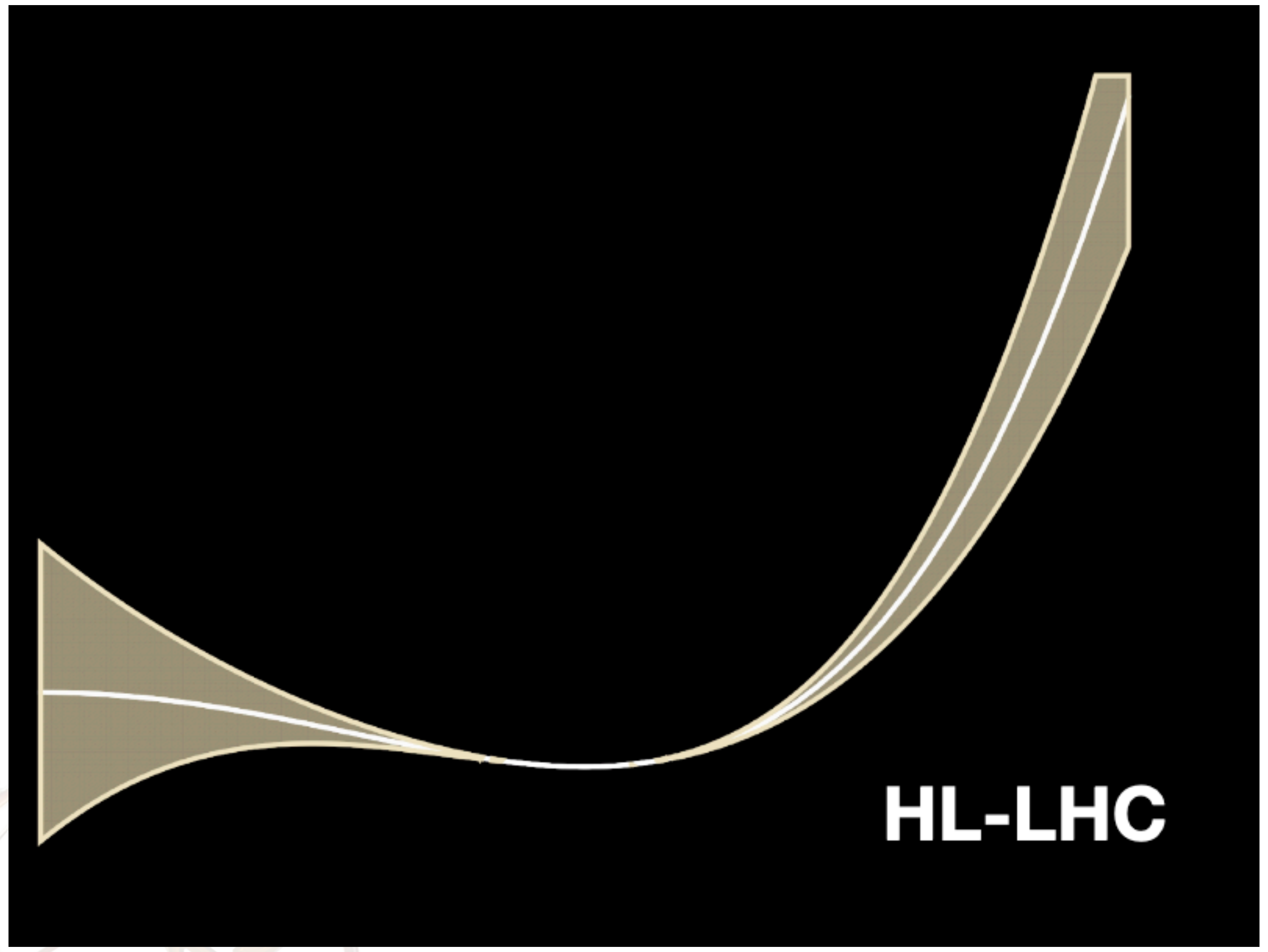
Understanding fundamental parameters

Higgs couplings and self-coupling

- HL-LHC goal — Observation of Higgs self-coupling
- B-tagging plays a crucial role



Improvements to identification yielding impressive gains to boost precision on top of (& until) HL-LHC!!



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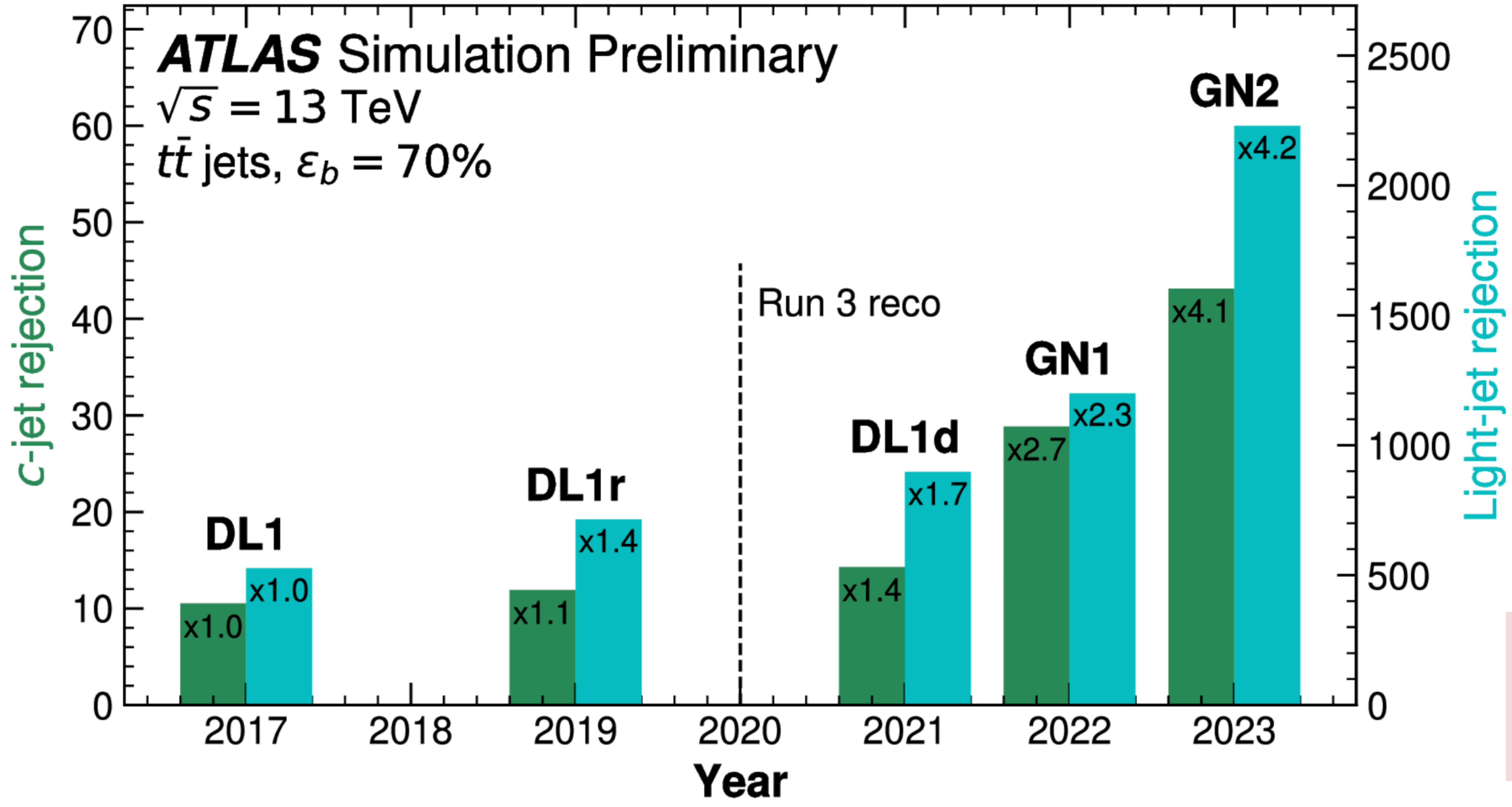
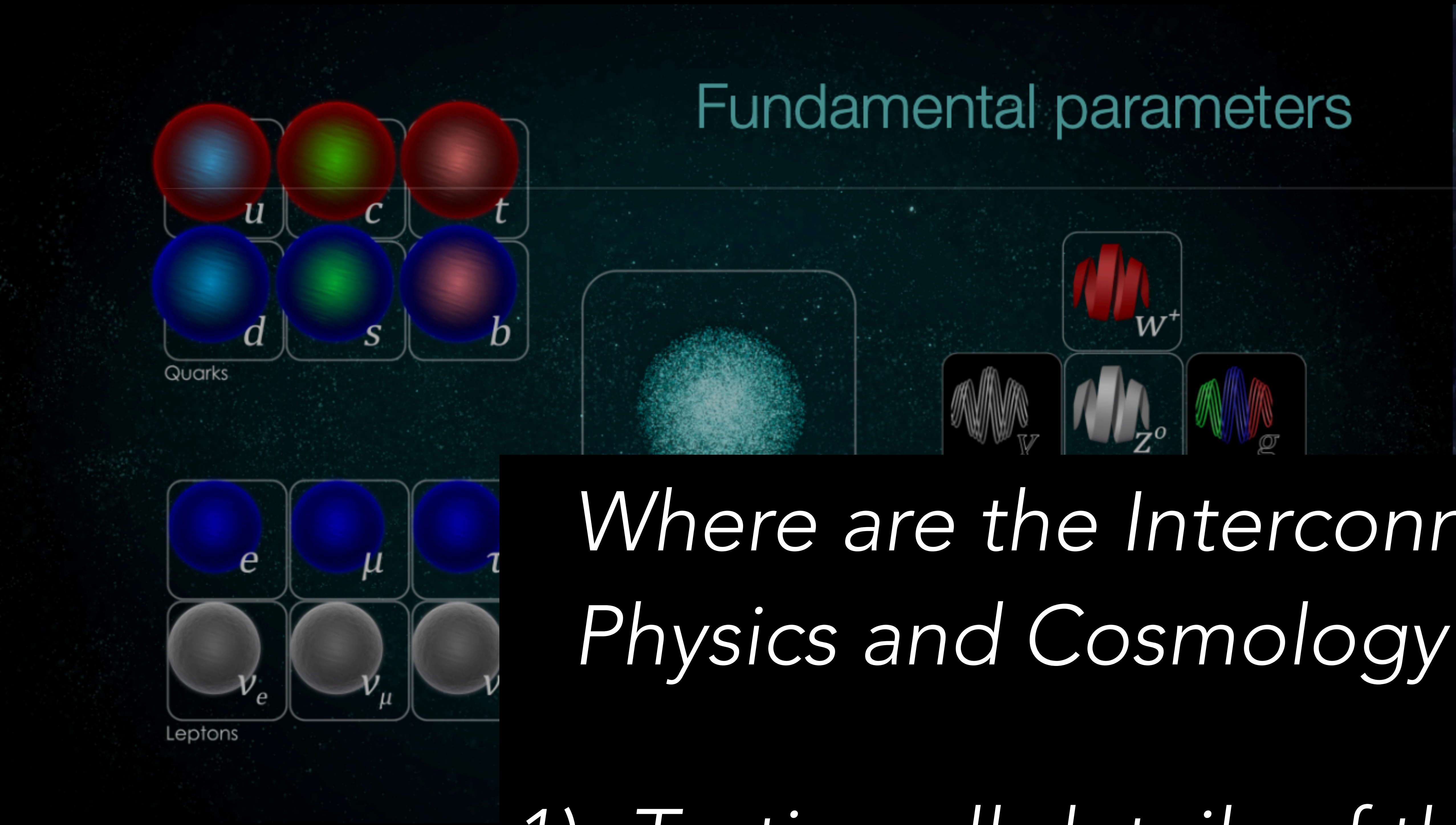
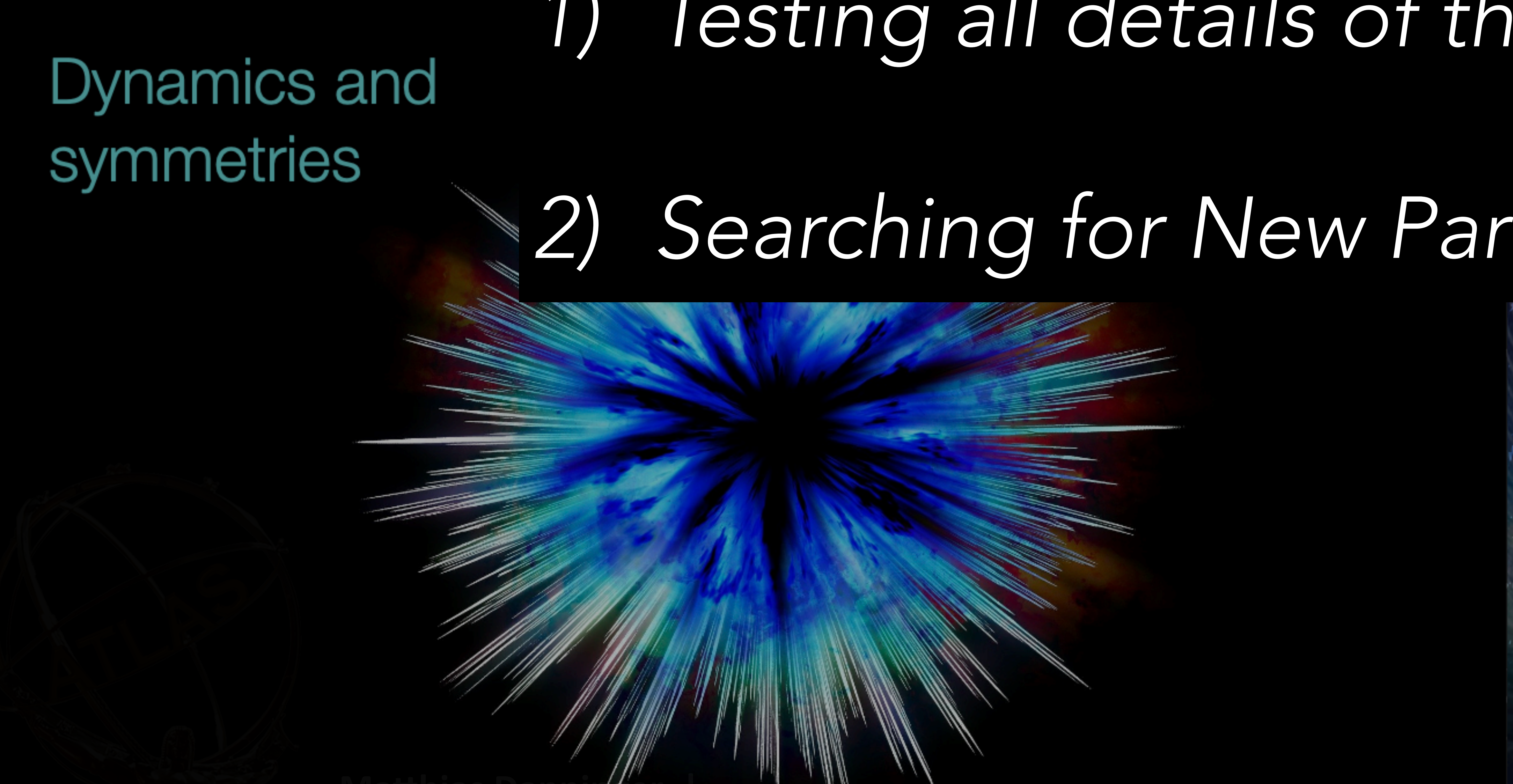
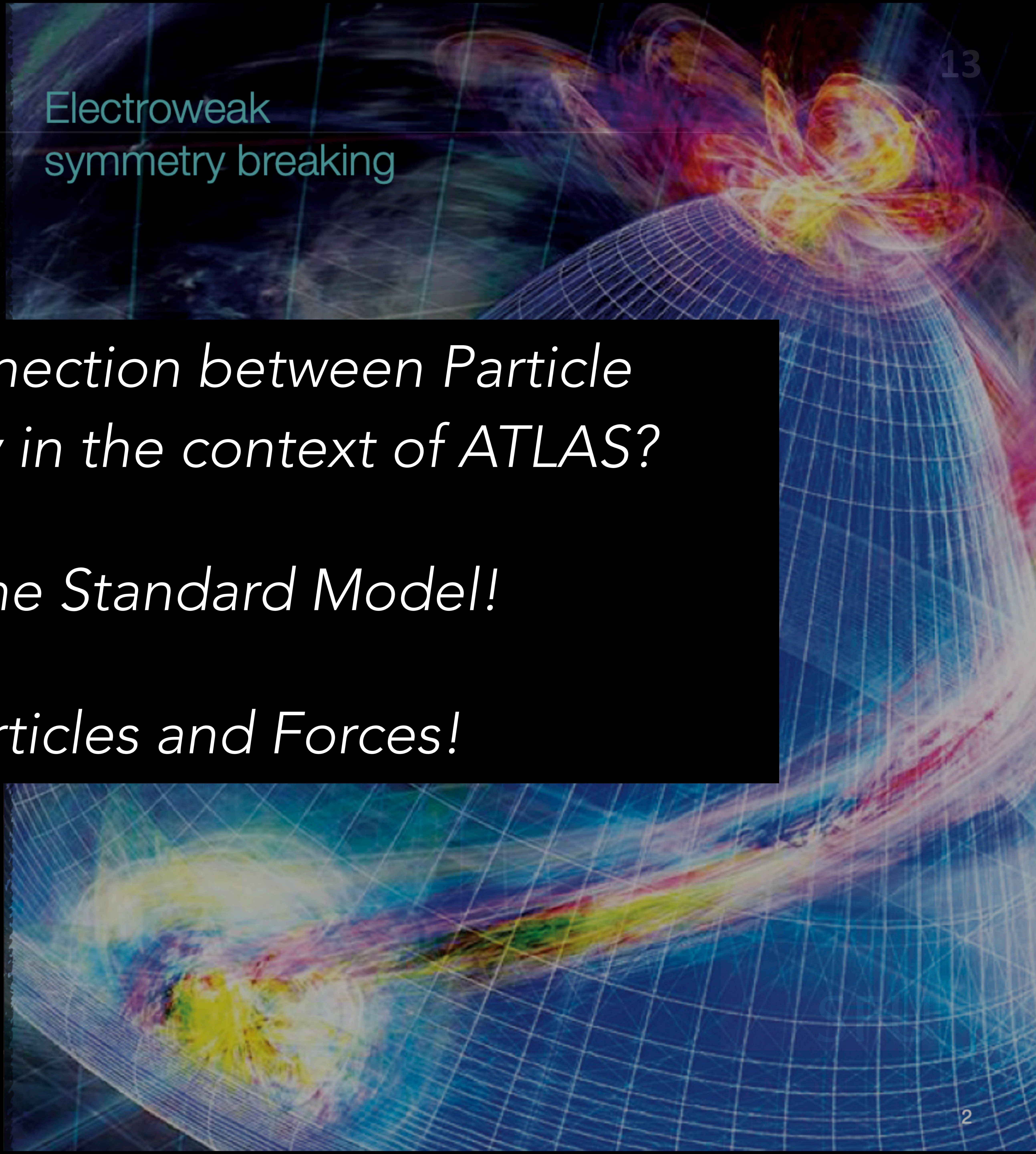


FTAG-2023-01 note (Flag)







Where are the Interconnection between Particle Physics and Cosmology in the context of ATLAS?

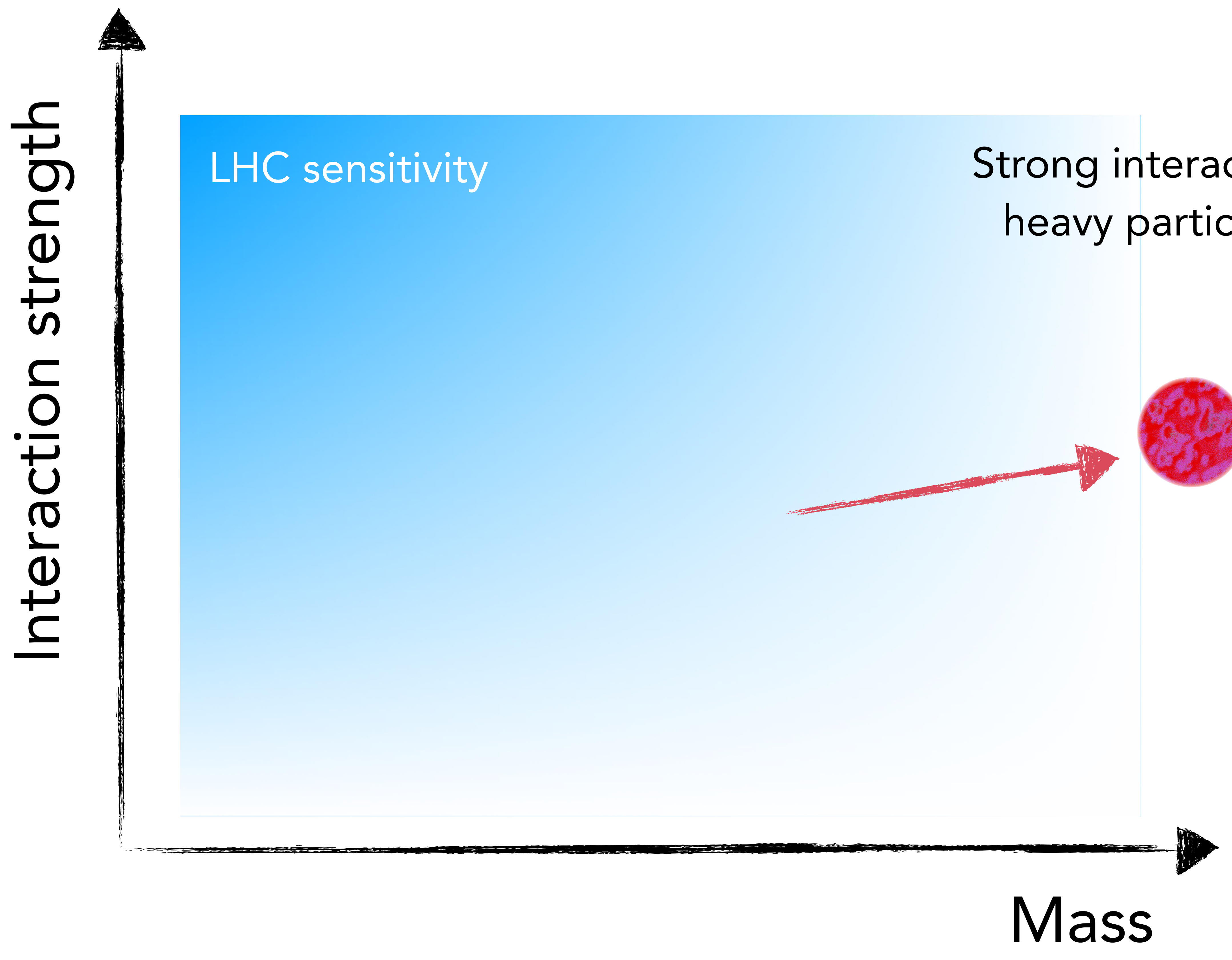
1) *Testing all details of the Standard Model!*

2) *Searching for New Particles and Forces!*

image credit CERN & M. Dunford

Where is the New Physics?

1. Is new physics out of reach?



Where is the New Physics?

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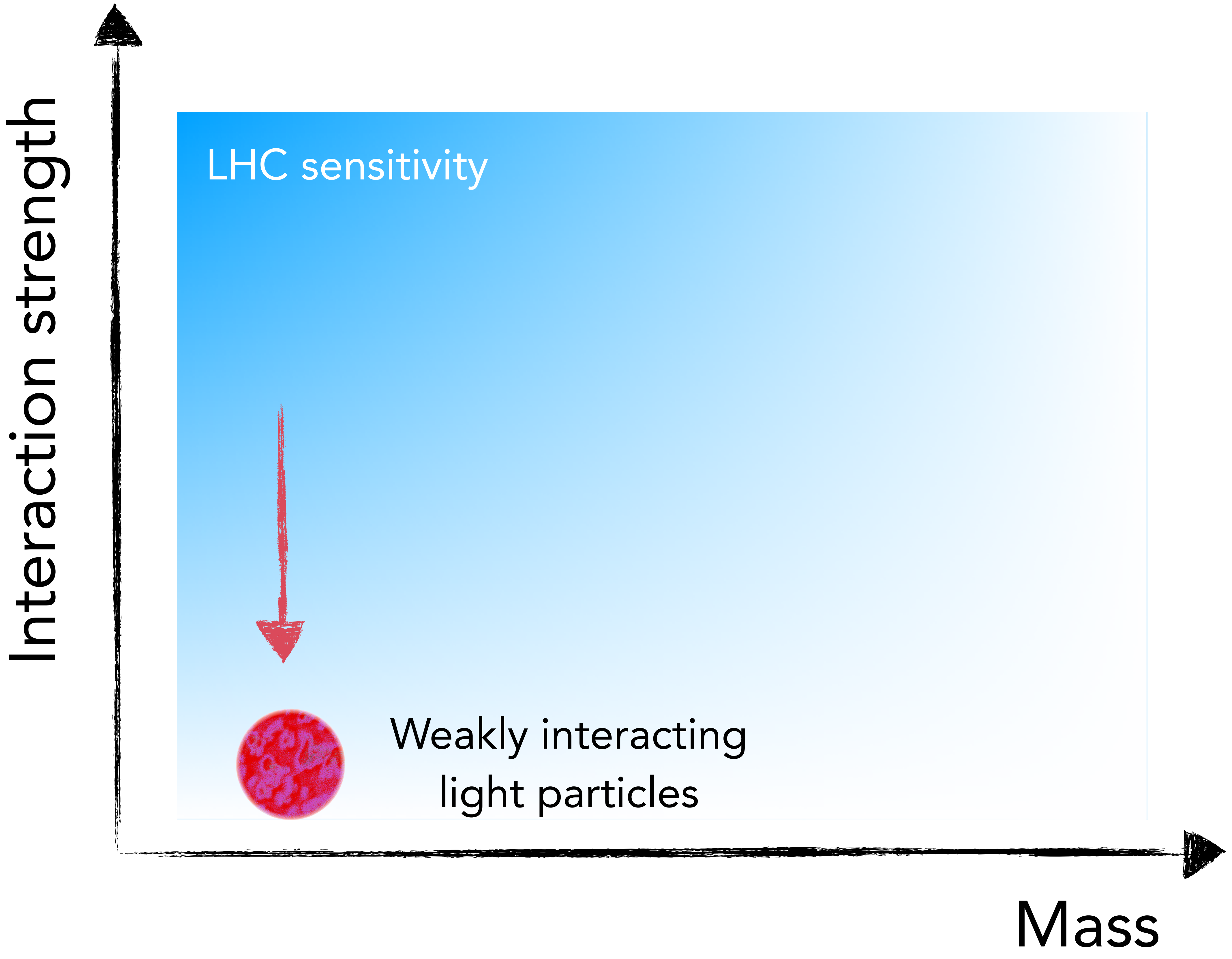
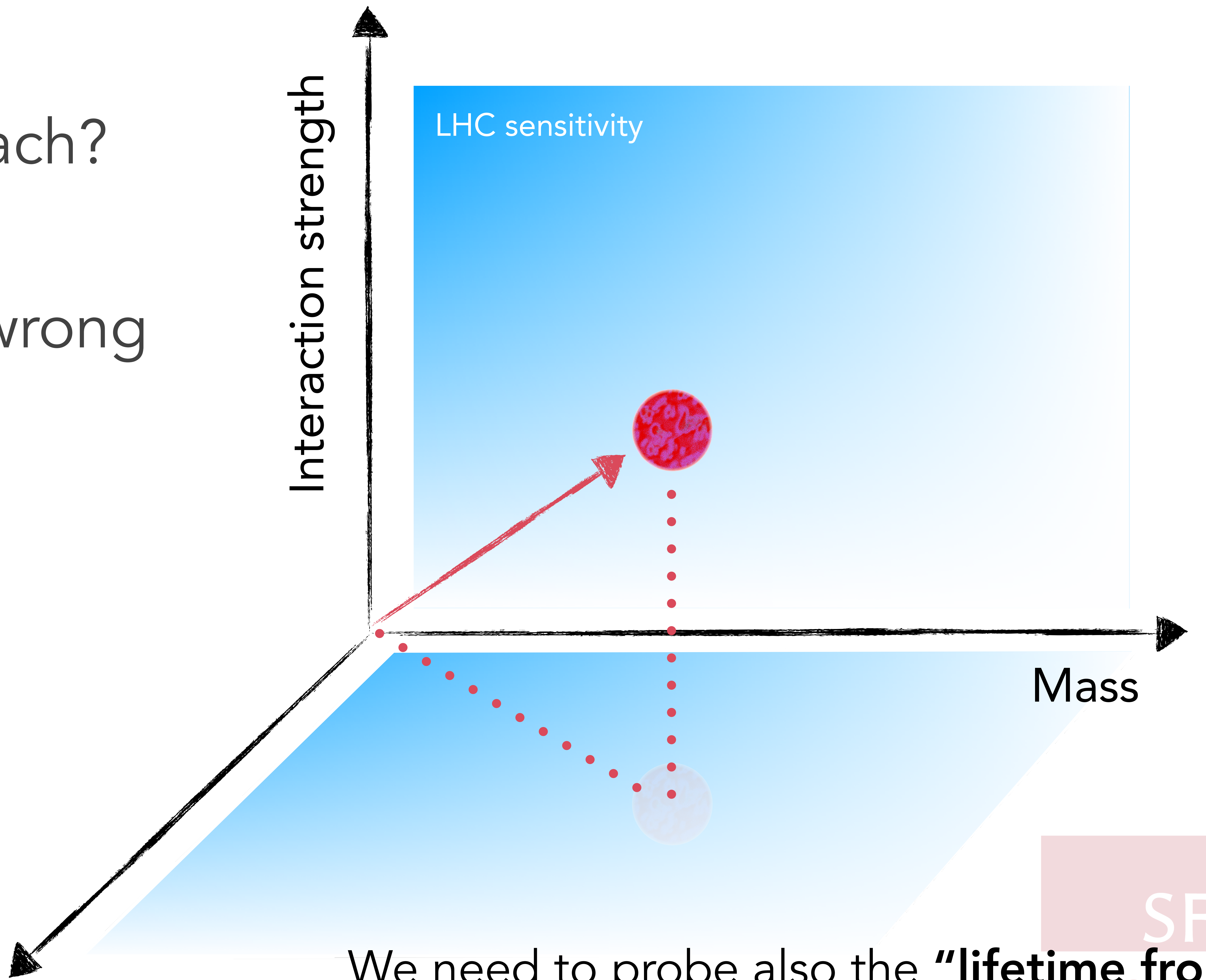


Where is the New Physics?

1. Is new physics out of reach?

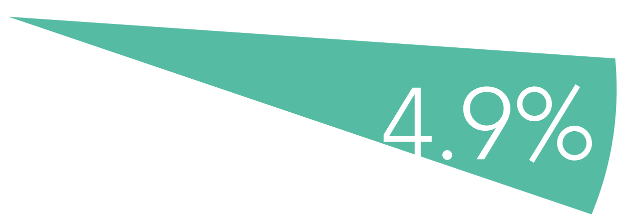
2. Have we looked in the wrong place so far?



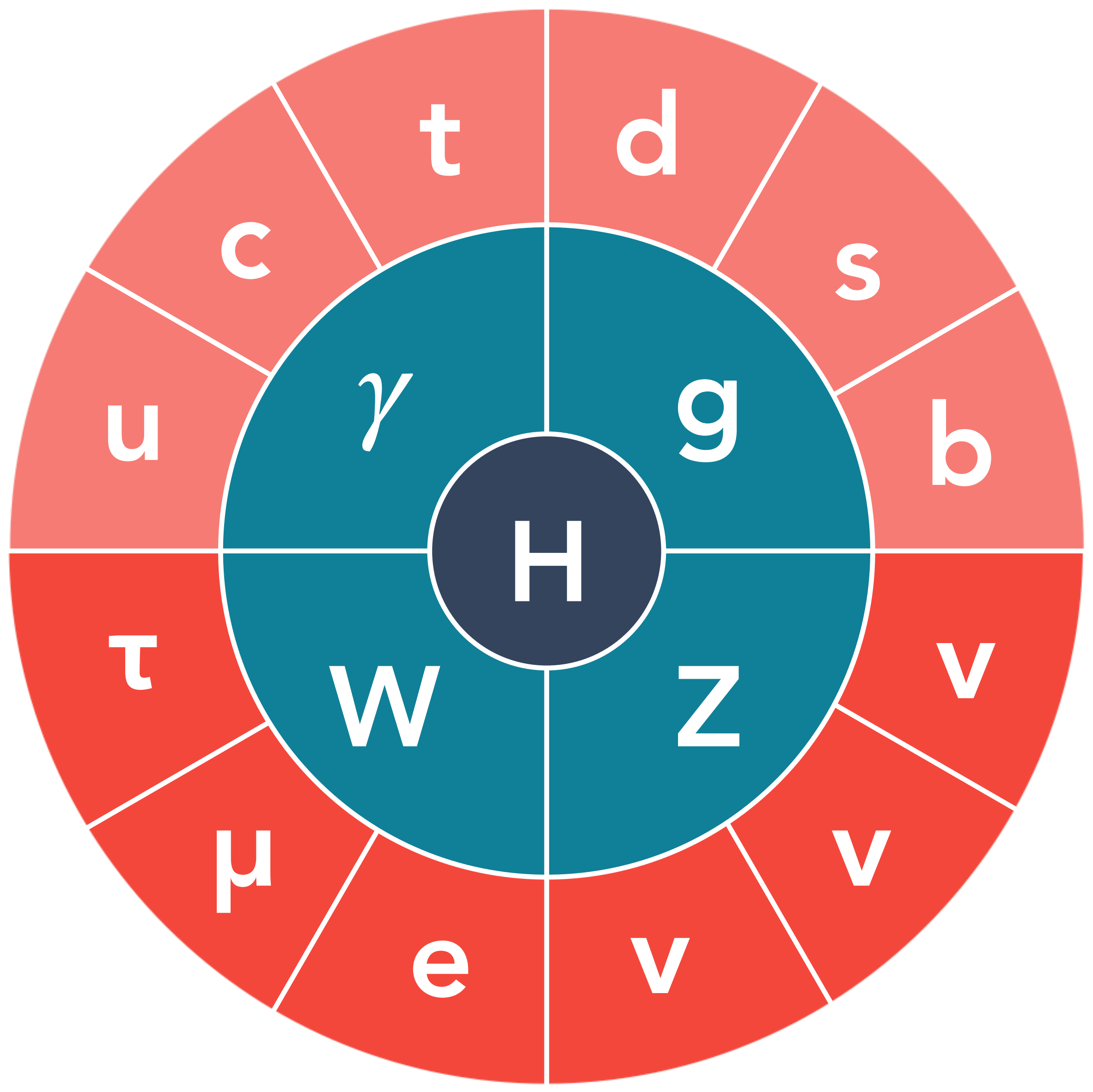
We need to probe also the **"lifetime frontier"**

New long-lived particles candidates

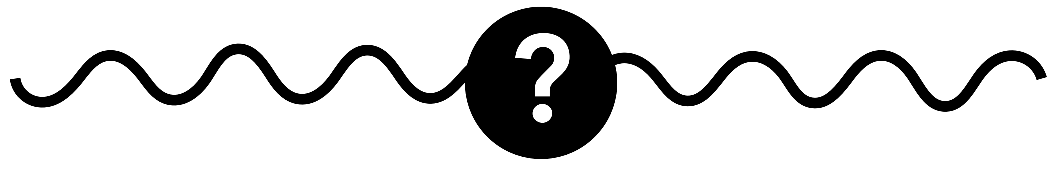
Visible Sector



Ordinary Matter



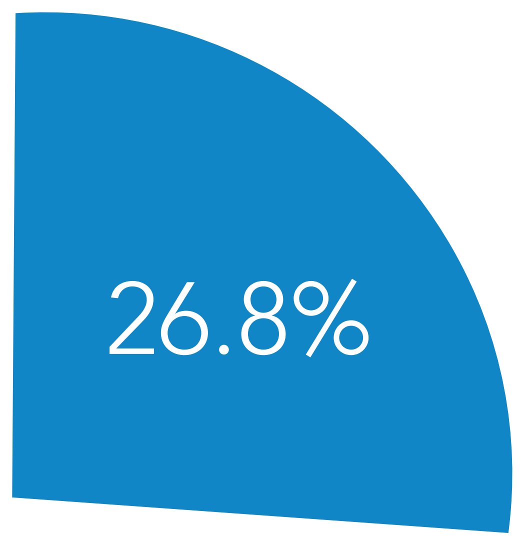
Mediator particle



"Scalar portal"

$$h^\dagger h \phi_D^\dagger \phi_D$$

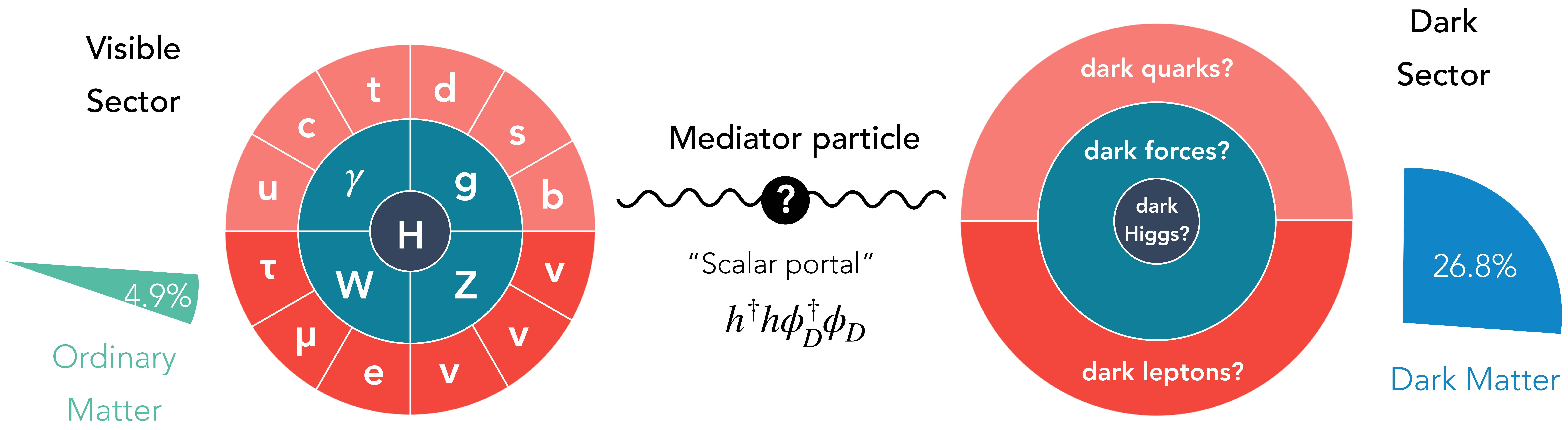
Dark Sector



Dark Matter

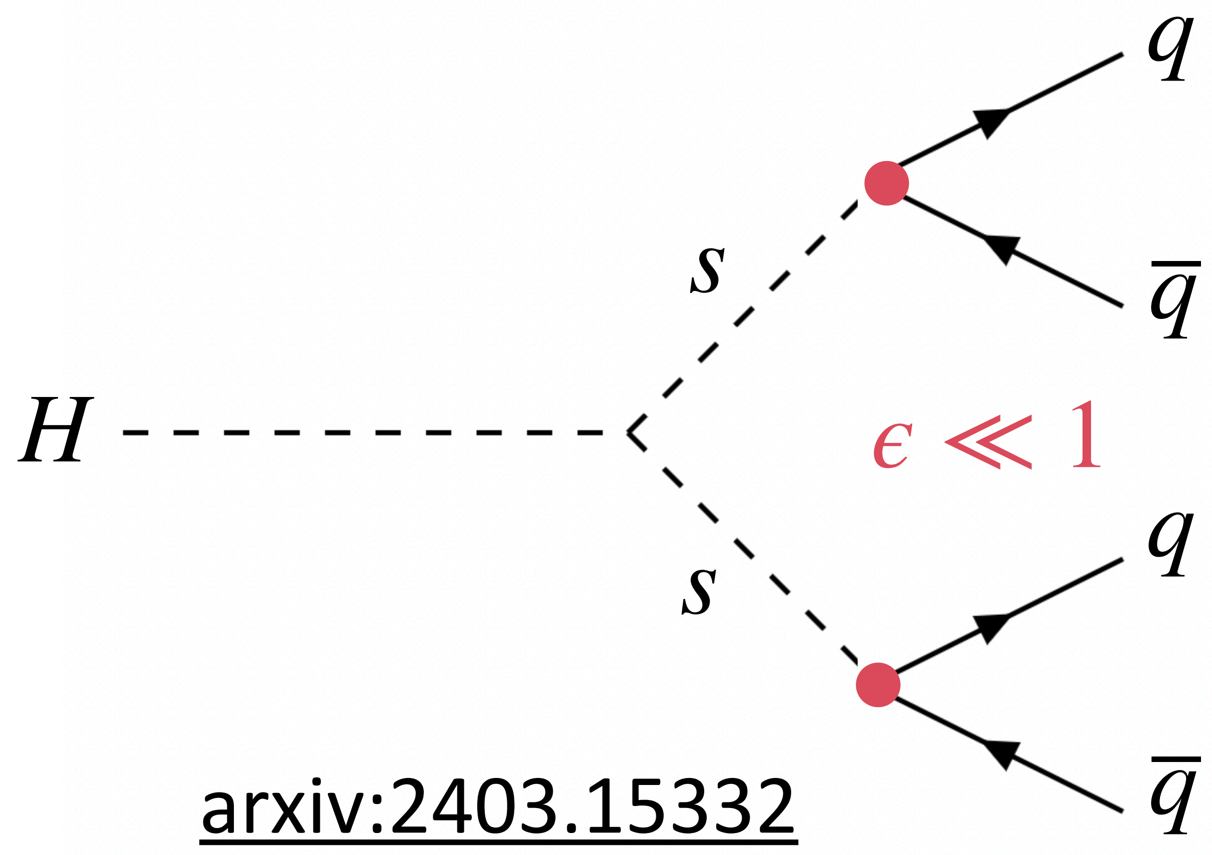
arxiv:2403.15332

New long-lived particles candidates



Hidden Sector portal — A portal to the Higgs Boson

—> Scalar becomes long lived if couplings to SM particles is very small

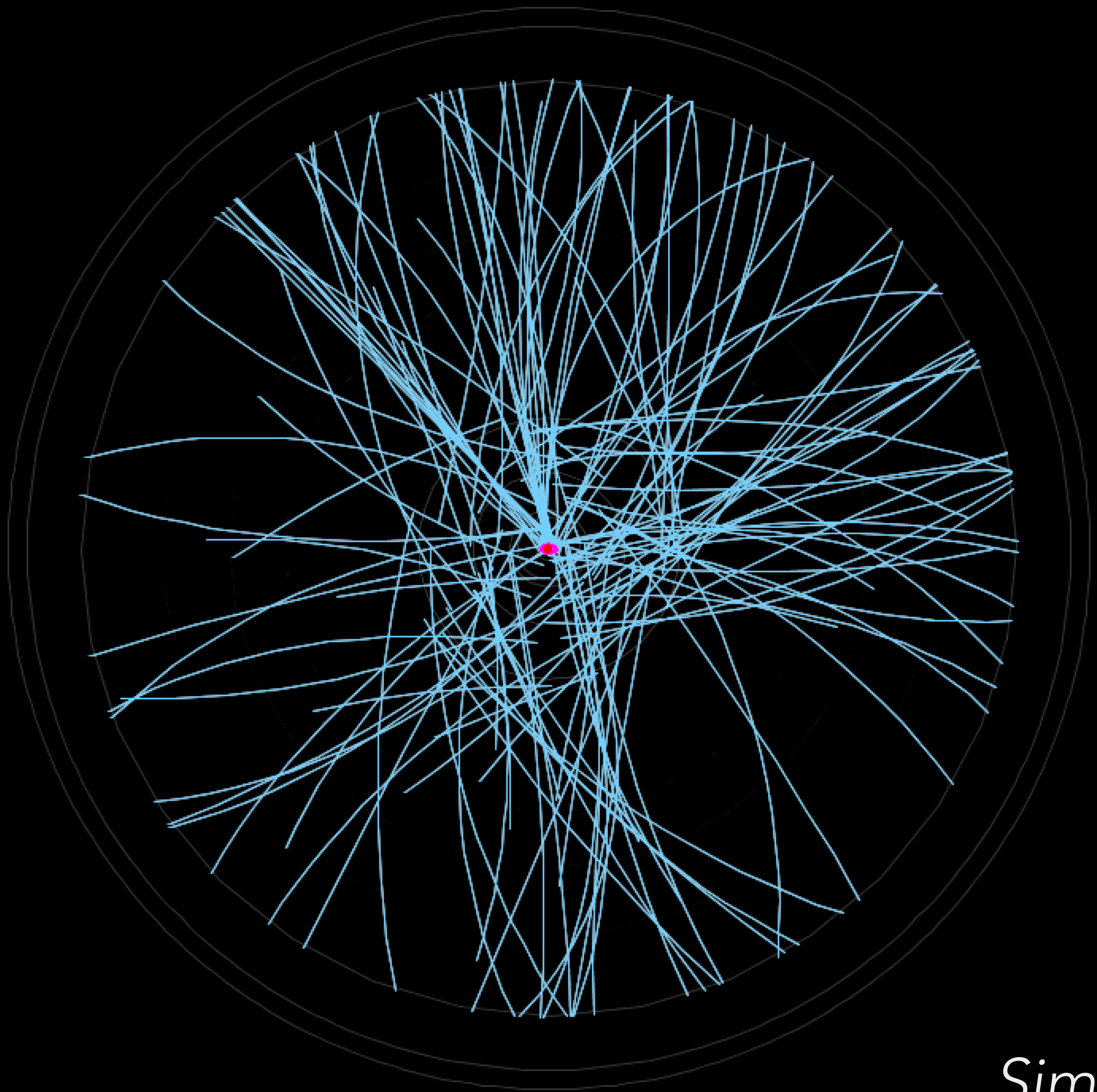


arxiv:2403.15332

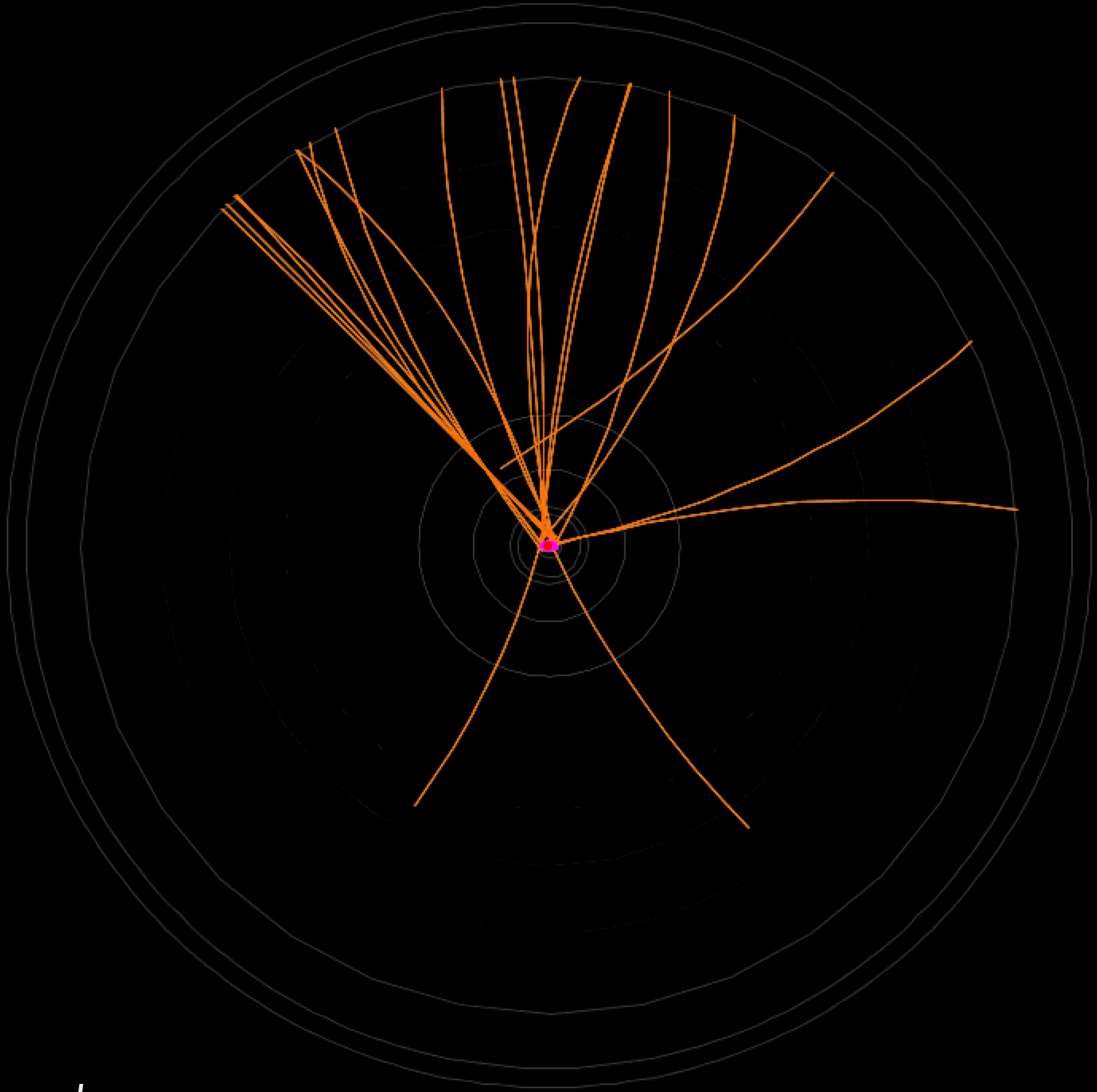
New improved Reconstruction

EPJ C 83 (2023) 1081

Old



New



Simulated signal event

New improved Reconstruction

EPJ C 83 (2023) 1081

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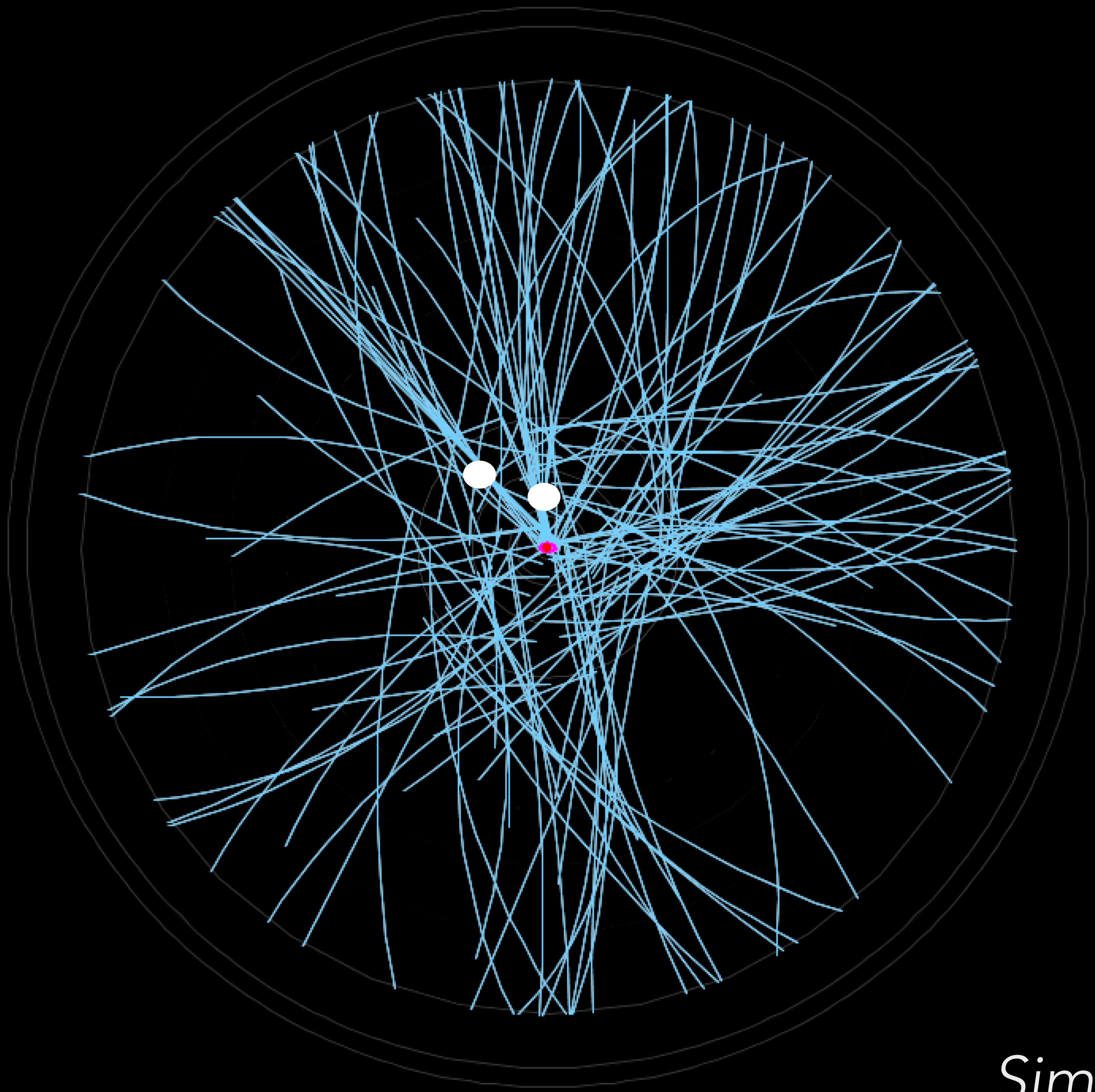

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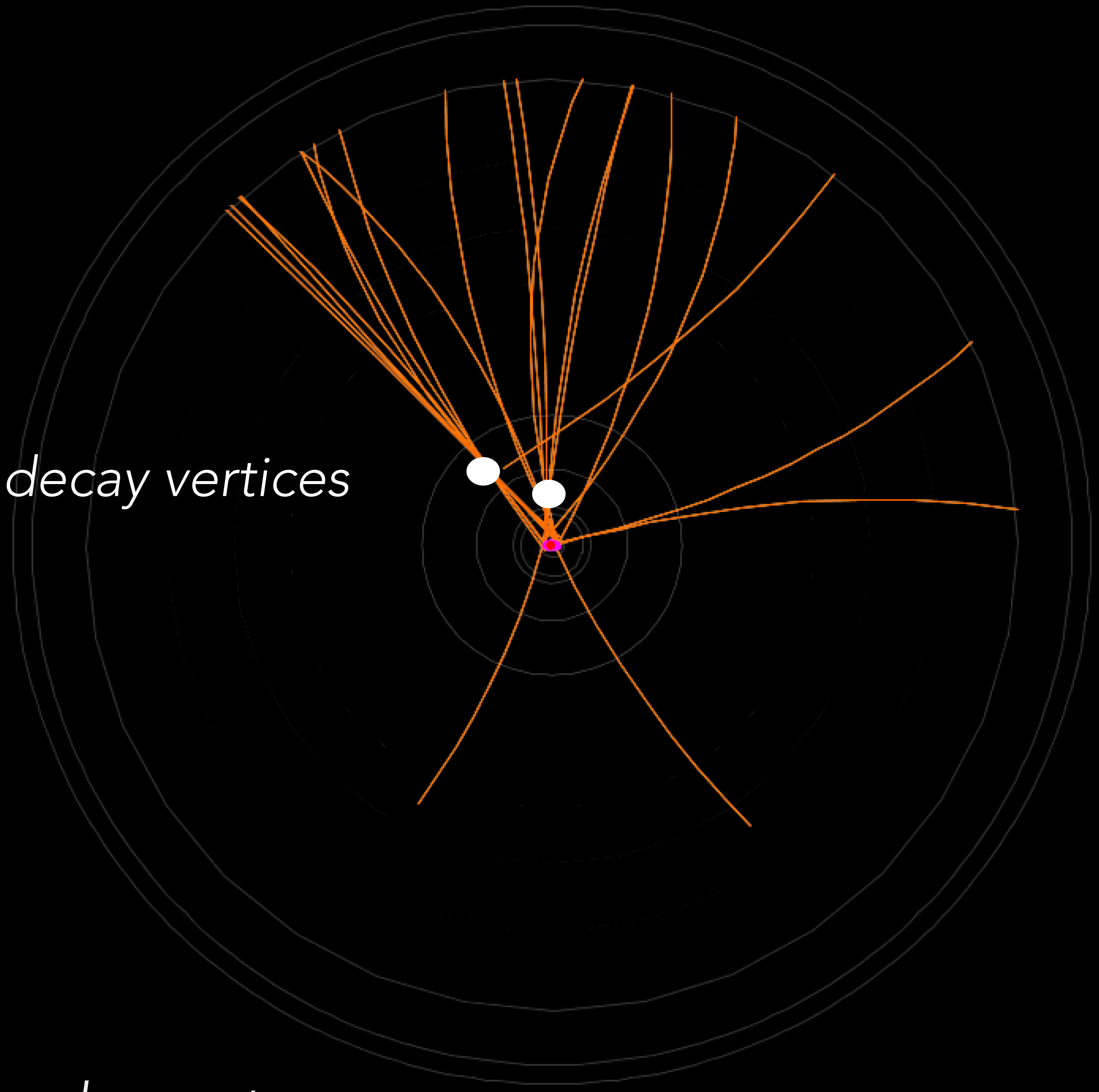

LLP decay vertices

Simulated signal event

New improved Reconstruction

EPJ C 83 (2023) 1081

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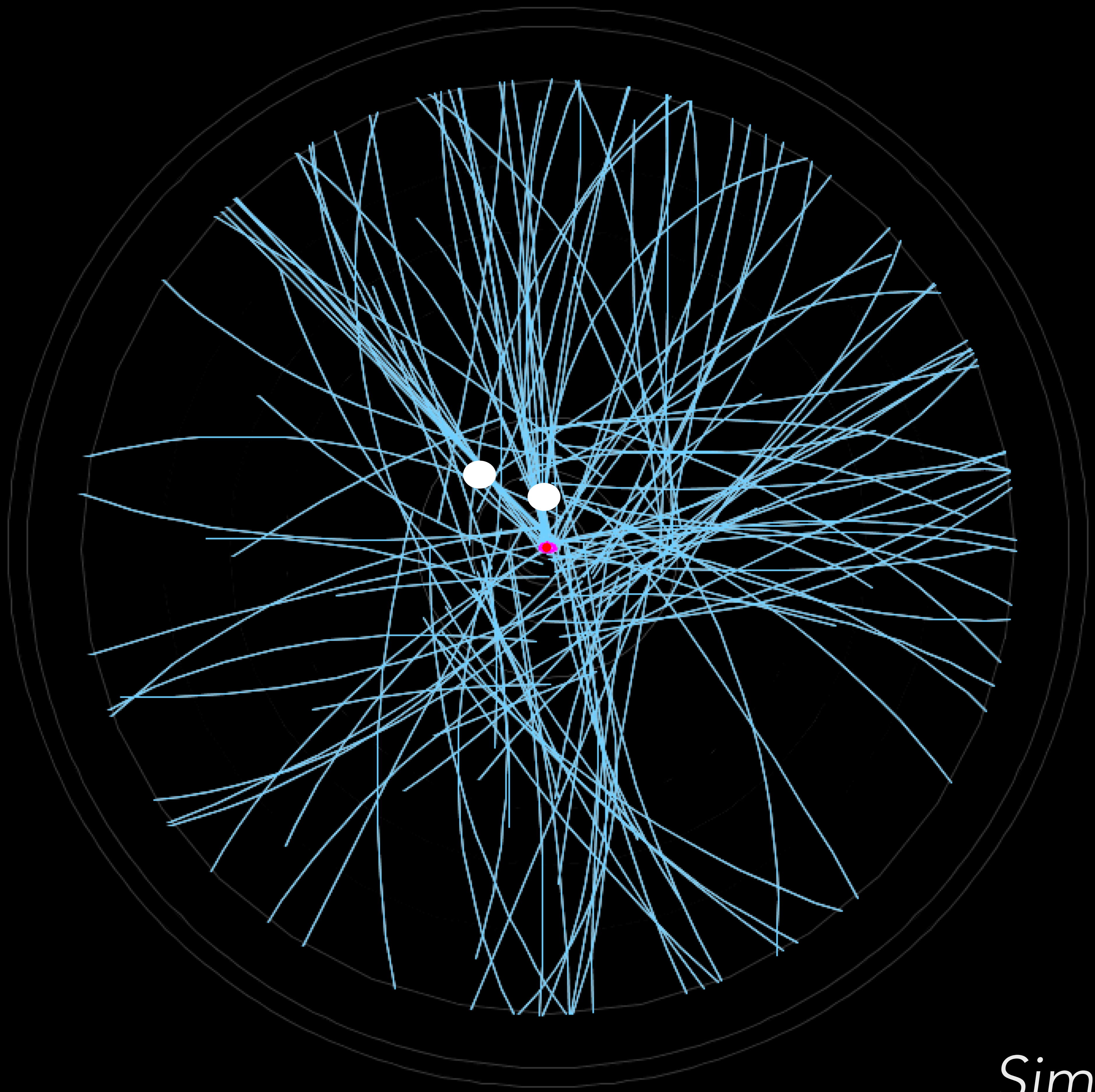
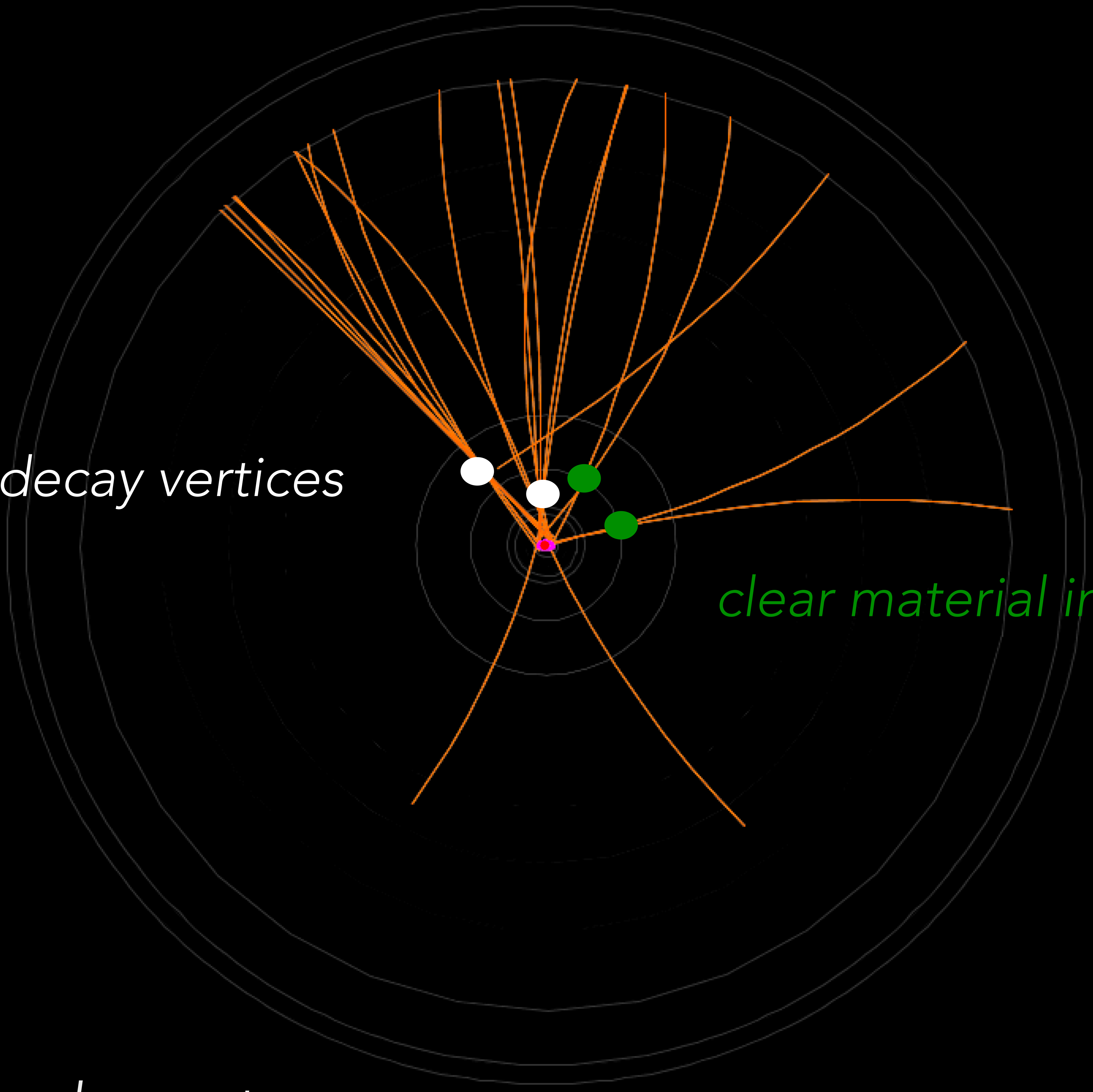


New



LLP decay vertices

clear material interaction

Simulated signal event

New improved Reconstruction

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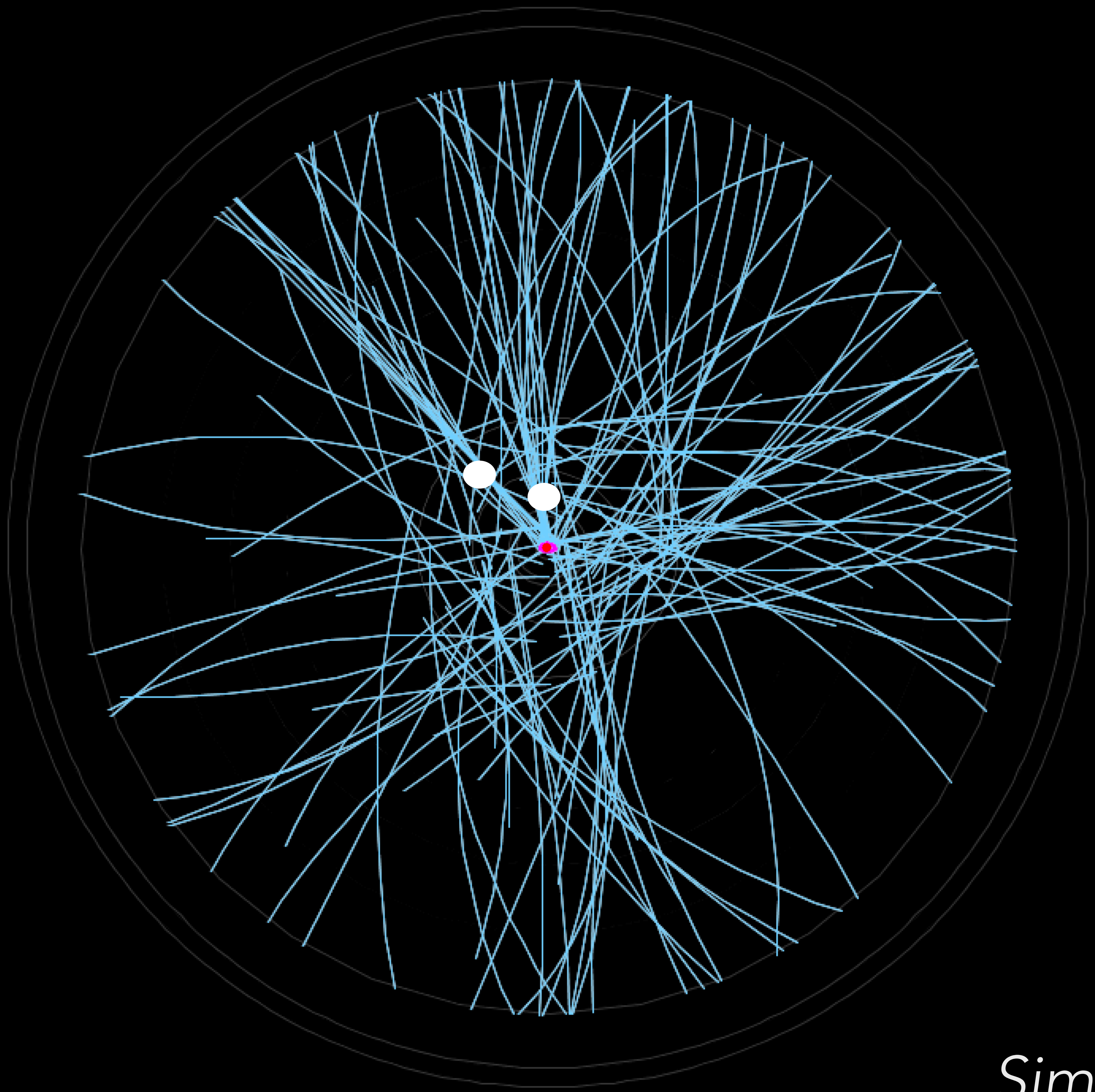

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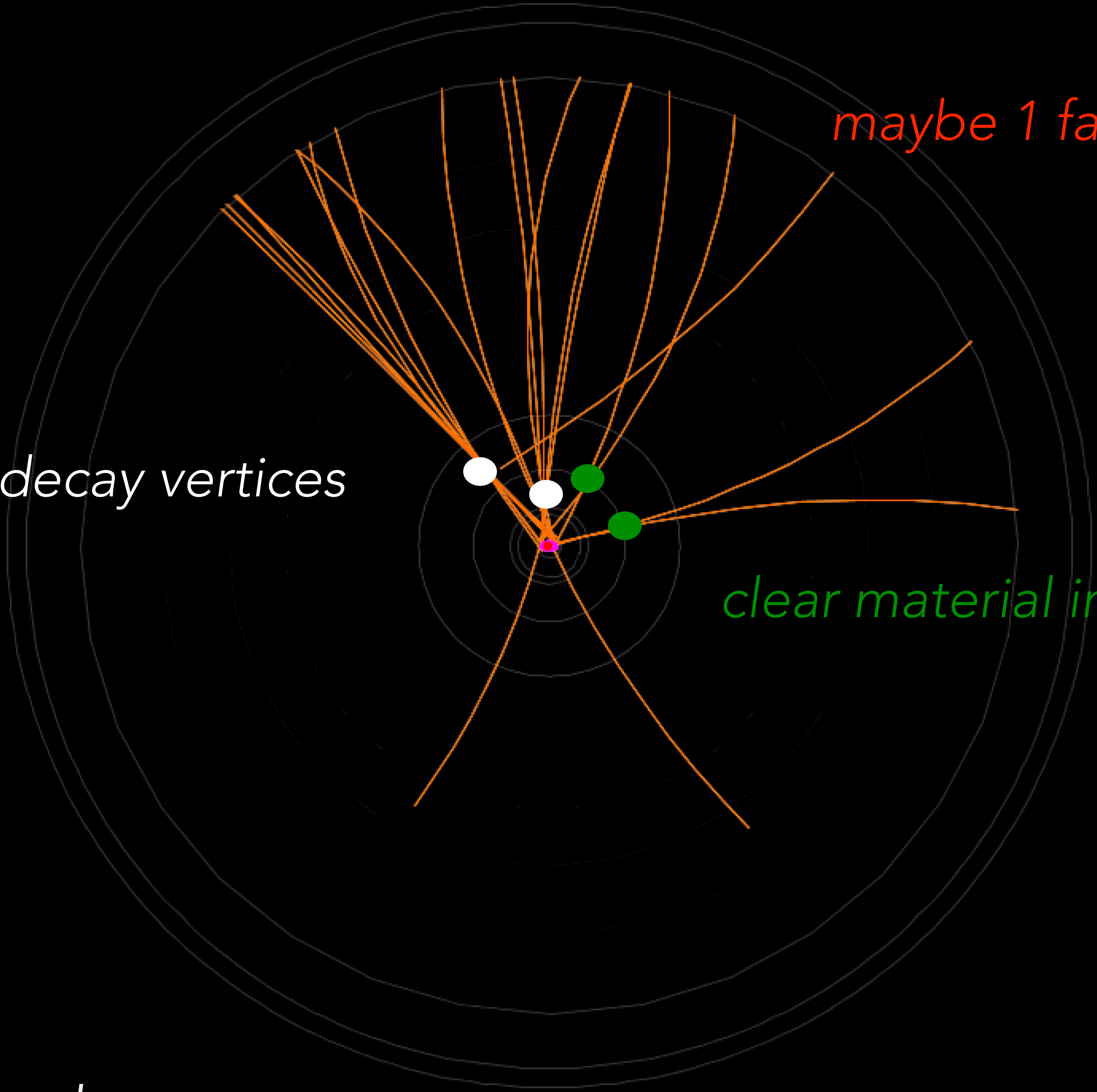

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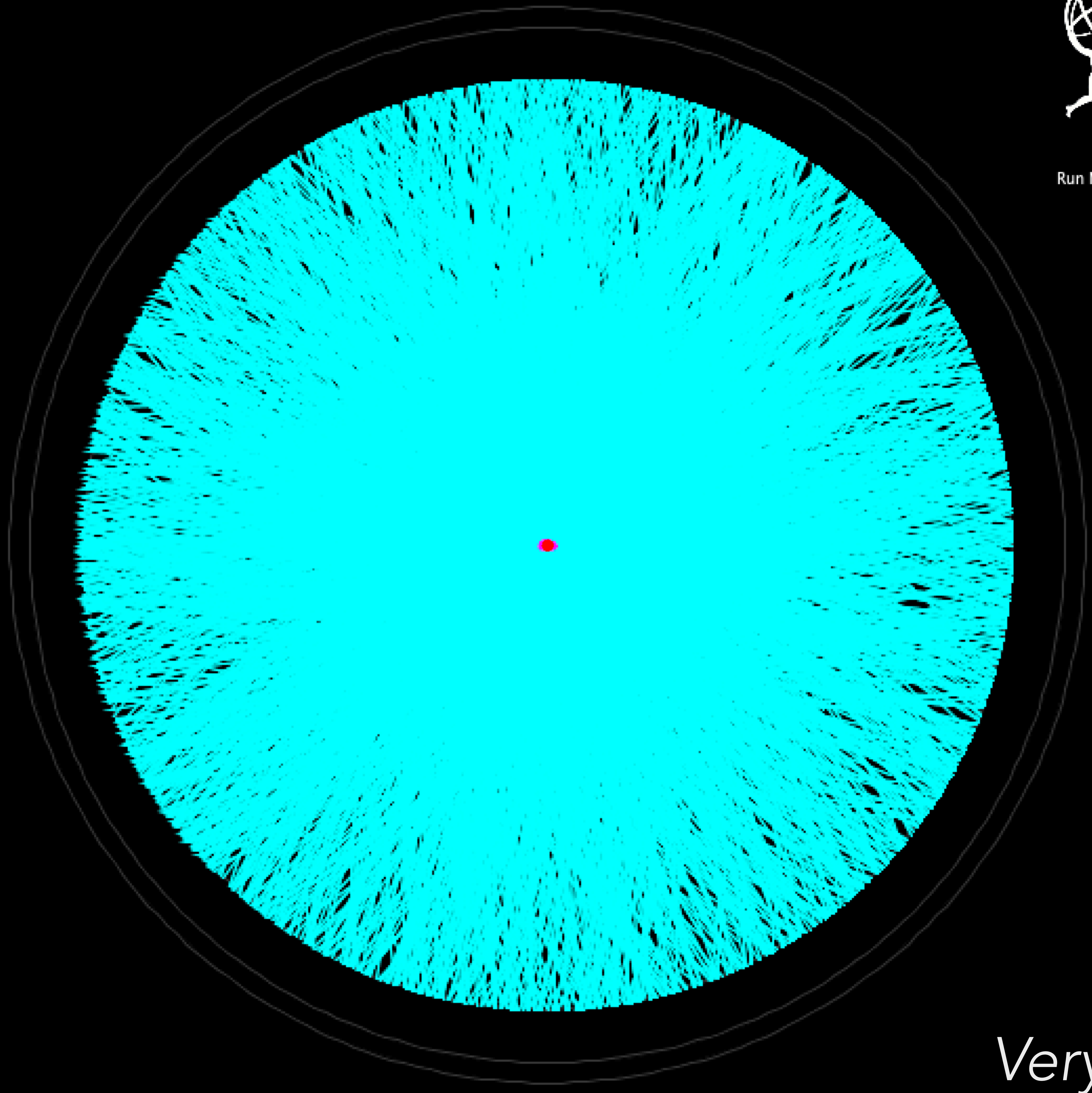

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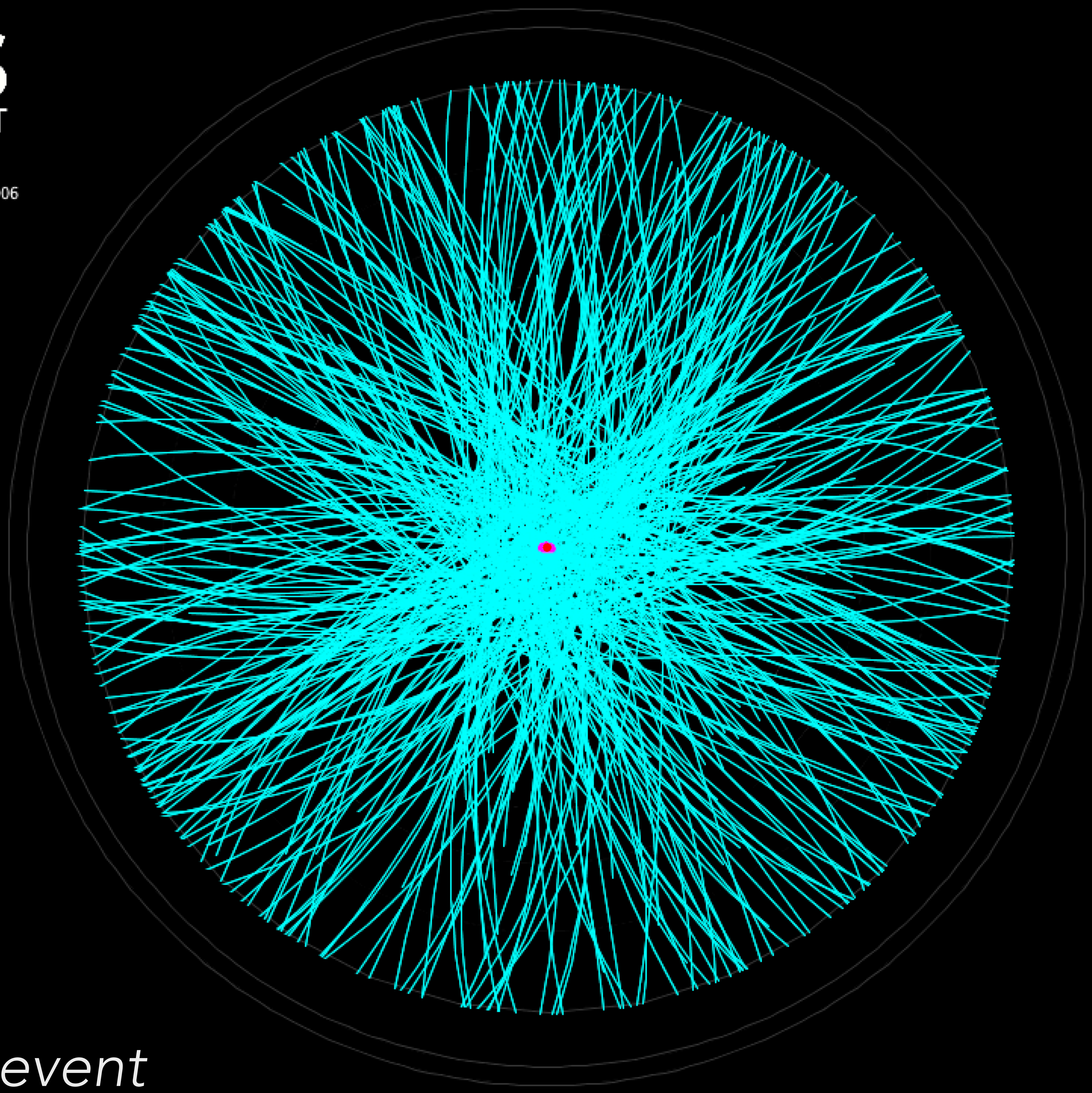


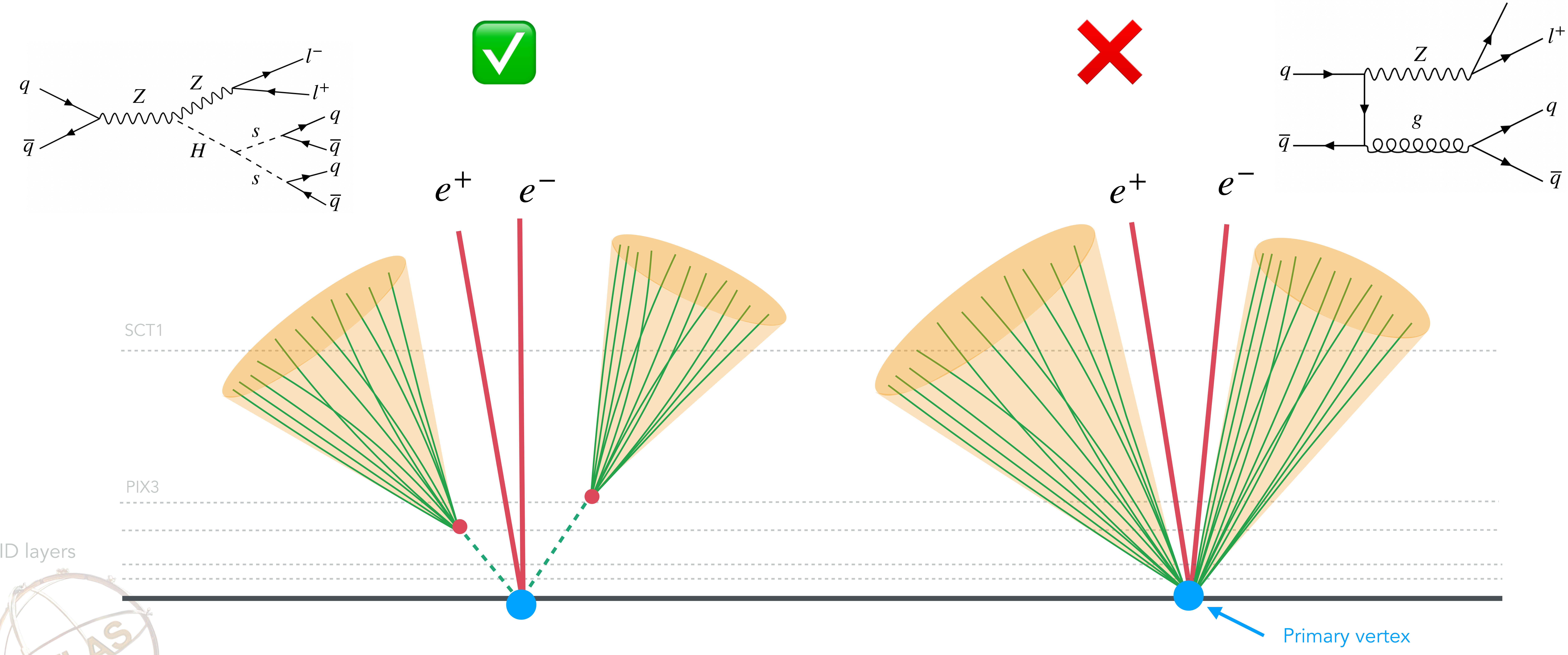
ATLAS EXPERIMENT

Run Number: 364485, Event Number: 2897469006

Date: 2018-10-26 08:35:18 CEST

Very busy data event

What can we expect?



What can we expect?

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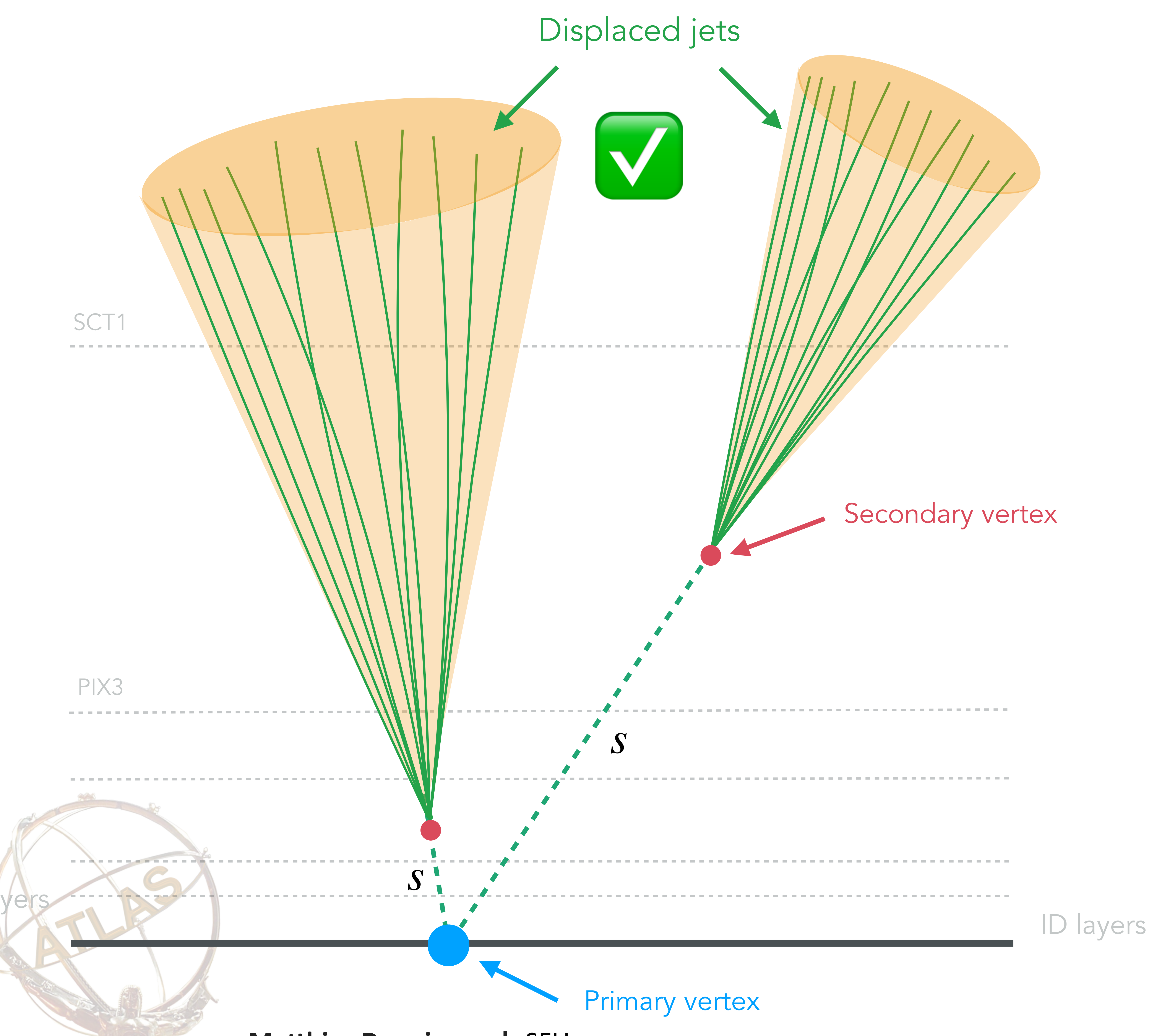

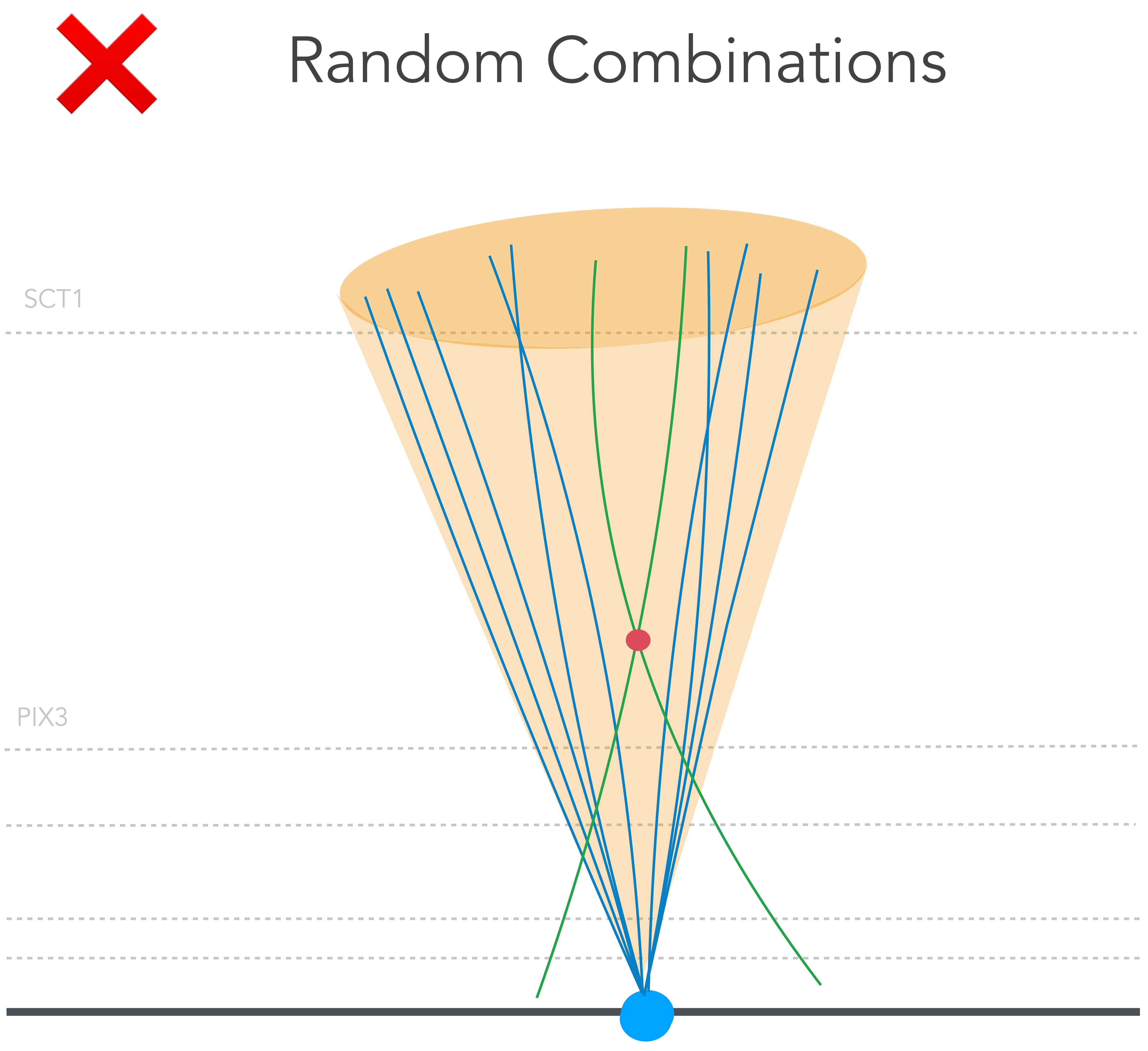

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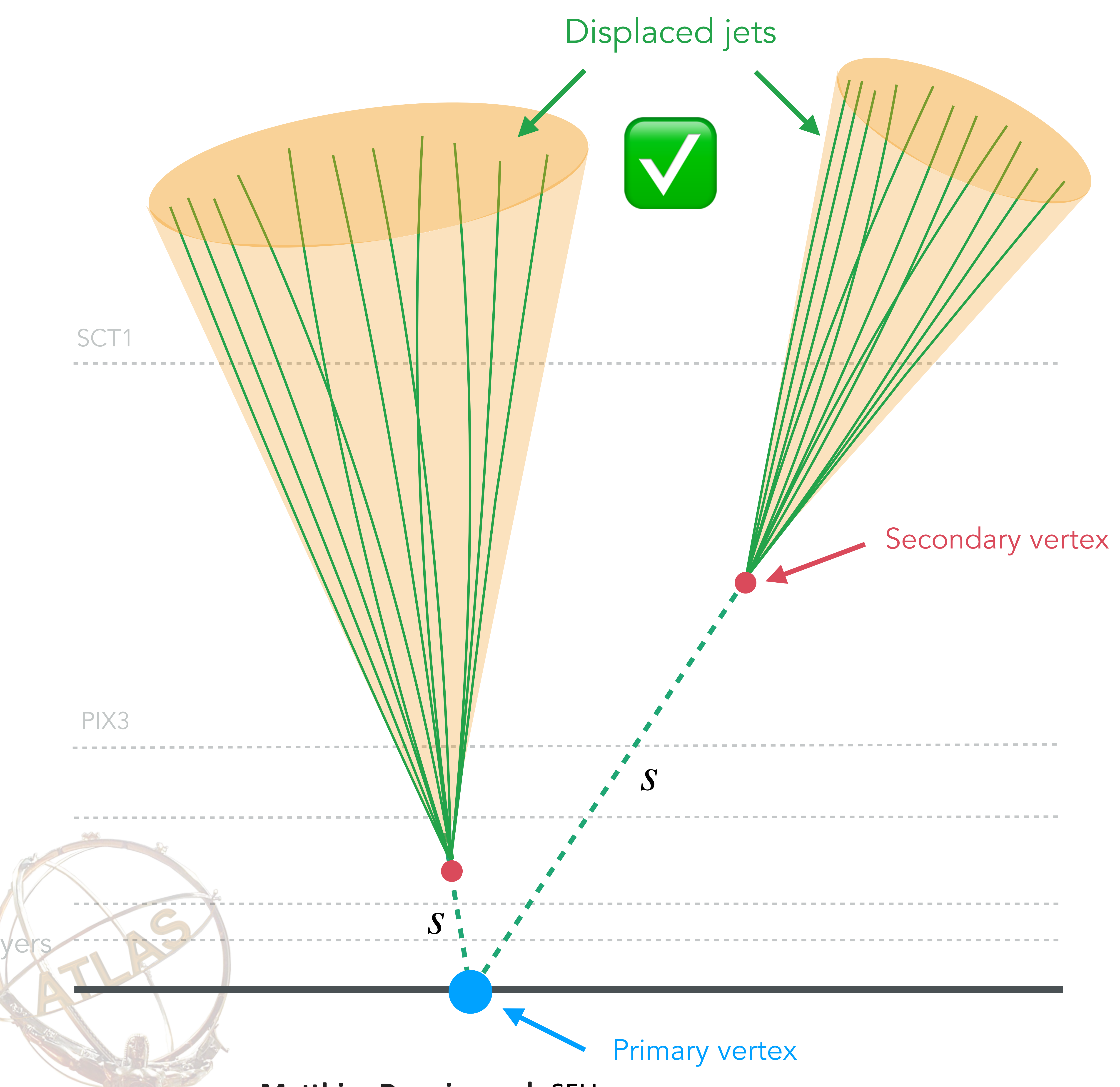
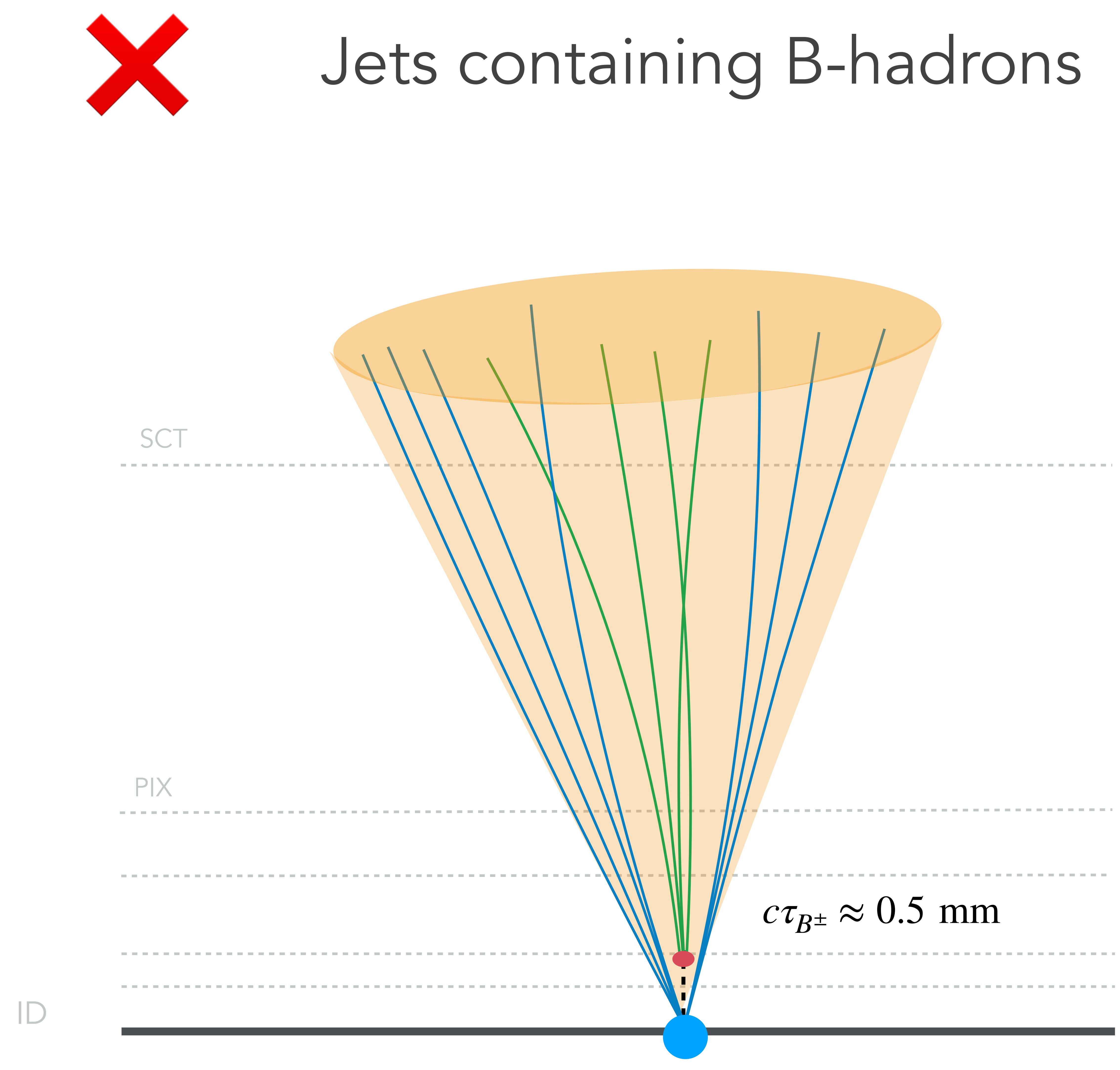
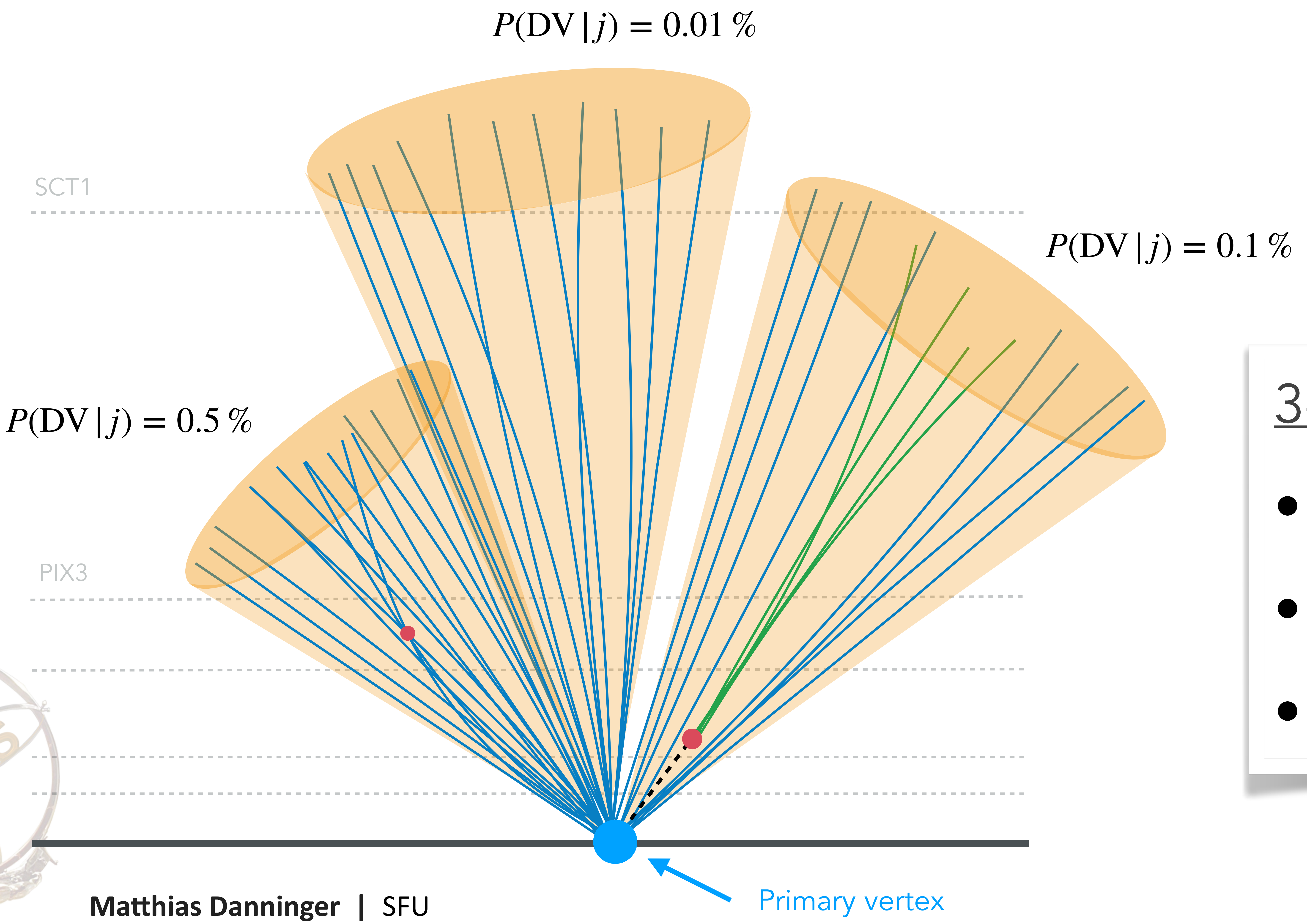




What can we expect?

Simulation not reliable for estimating unconventional backgrounds → need a **data-driven** approach

Strategy: measure the probability in data for a given jet to be matched to a displaced vertex

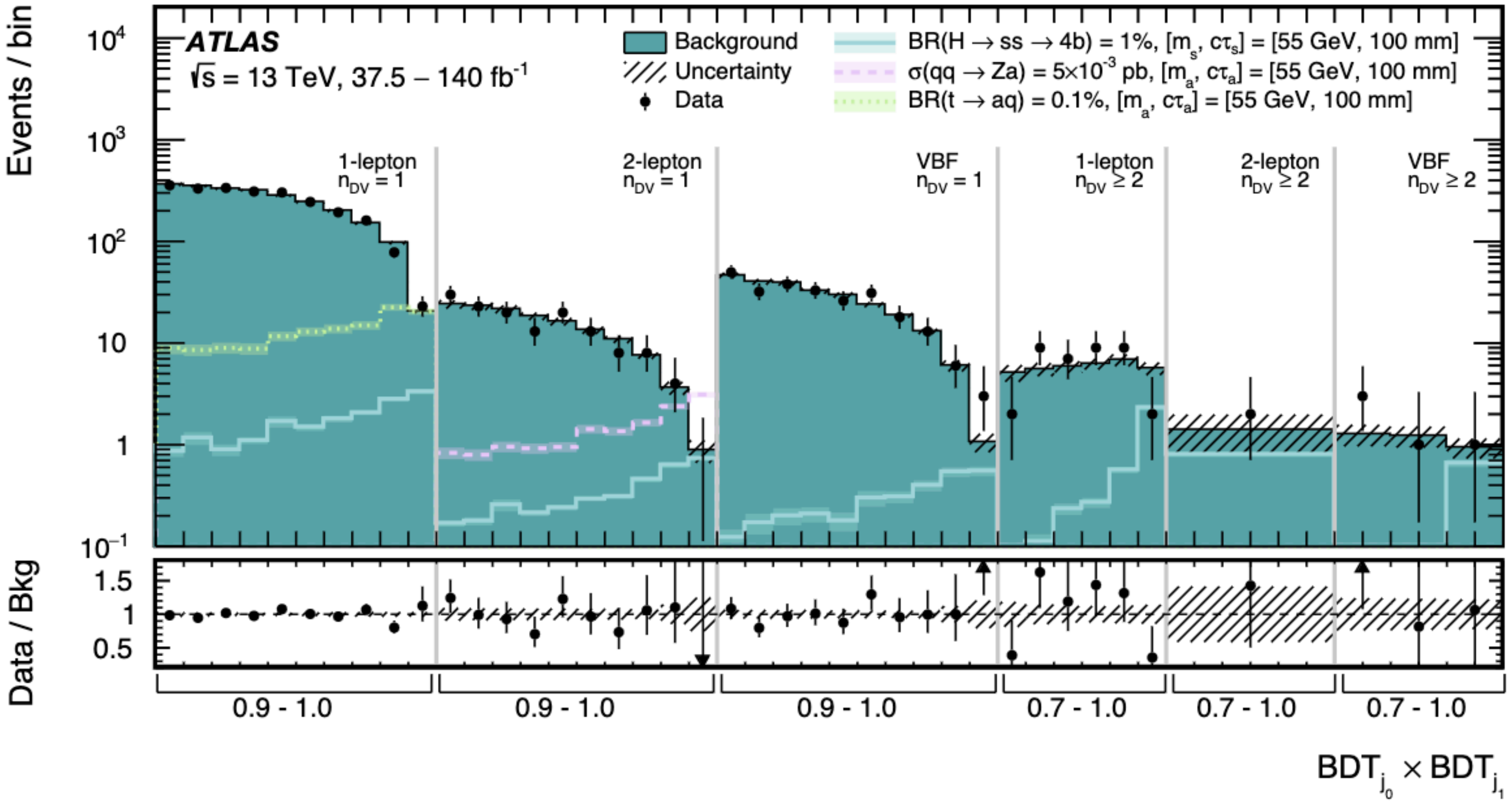


3-dimensional parameterization:

- LLP jet classification
- B-jet classification
- Jet Momentum

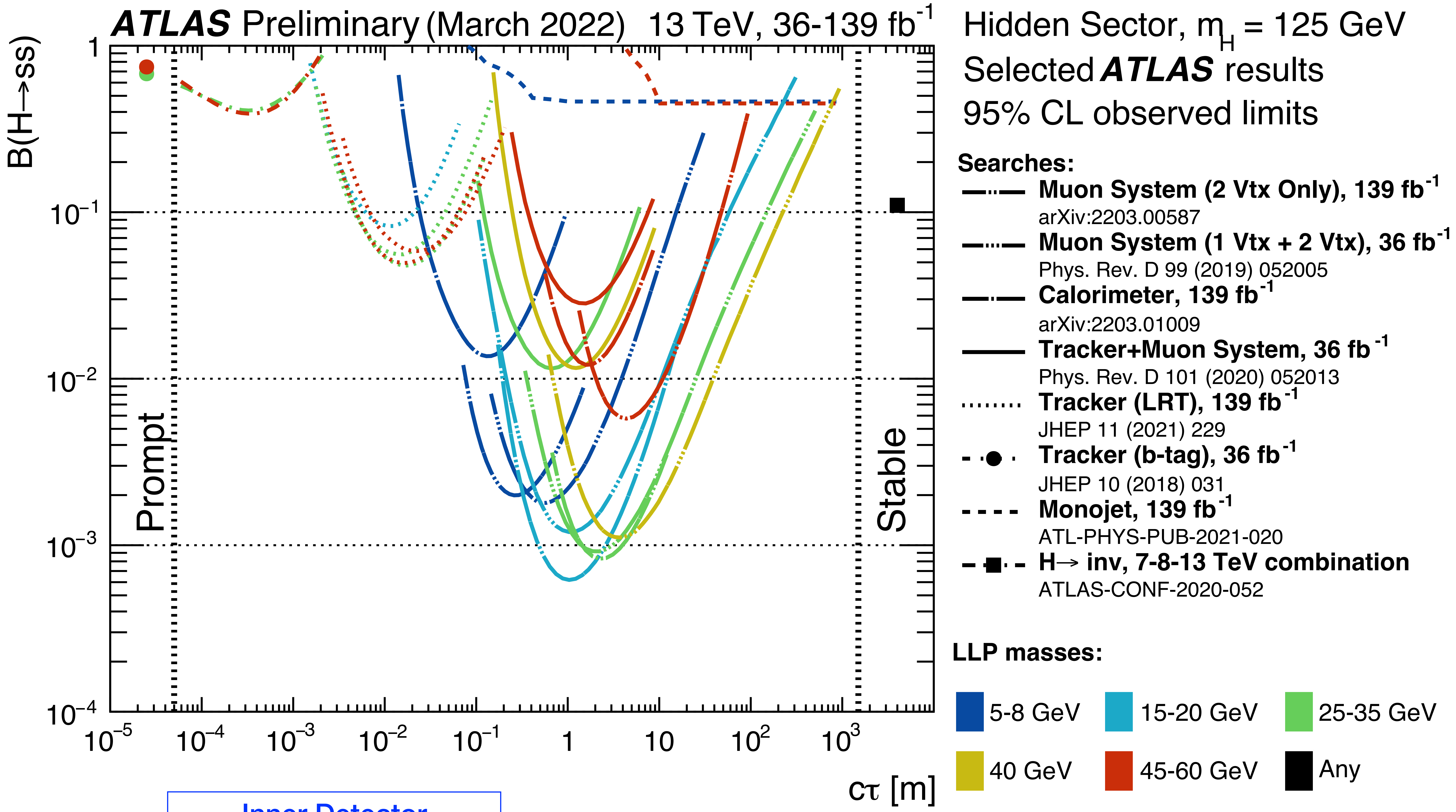
Long Lived Hidden Sector Searches

arxiv:2403.15332



- Excellent data-driven modelling of SM background
- No significant excess observed

Long Lived Hidden Sector Searches



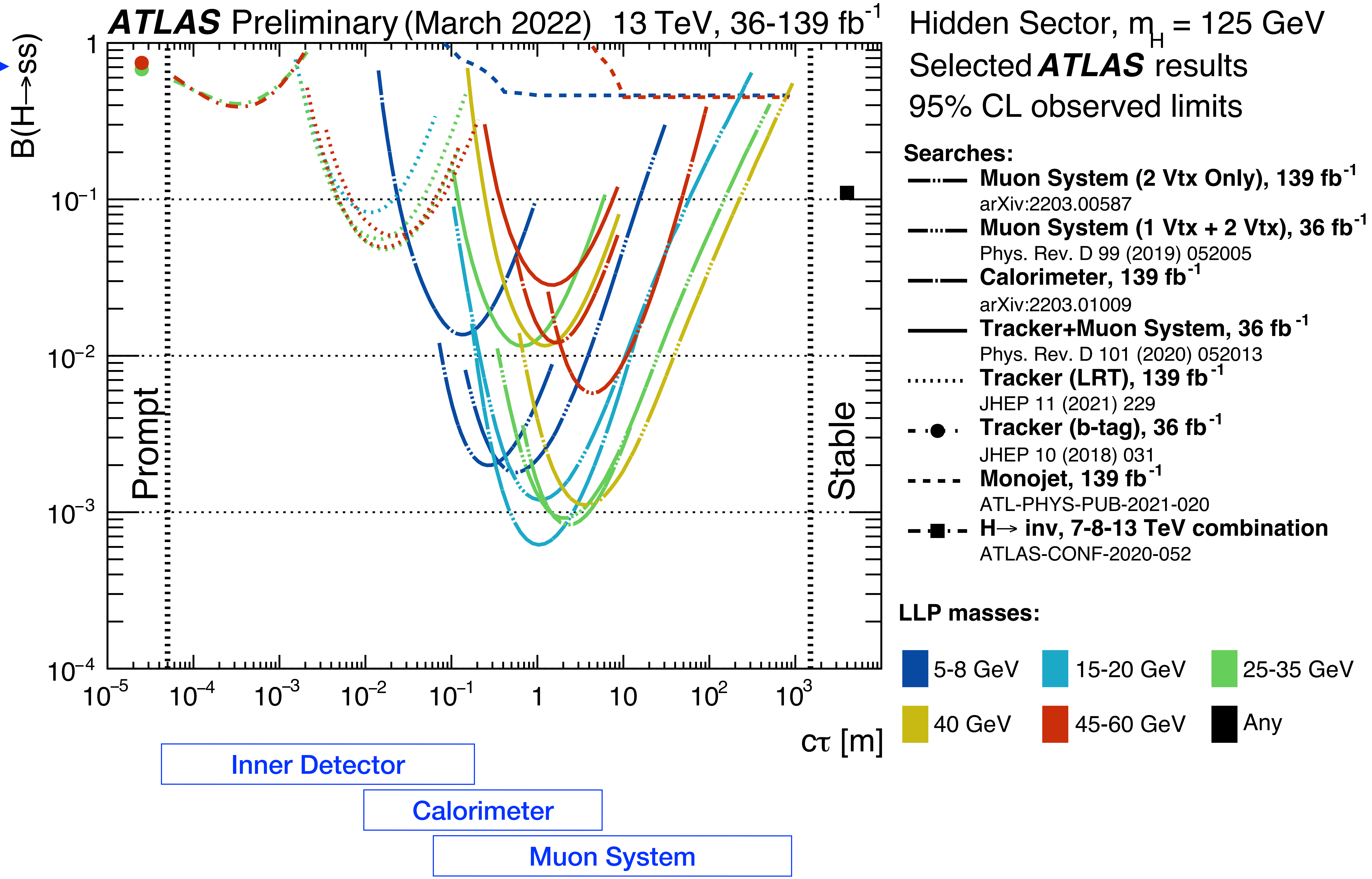
Inner Detector

Calorimeter

Muon System

Long Lived Hidden Sector Searches

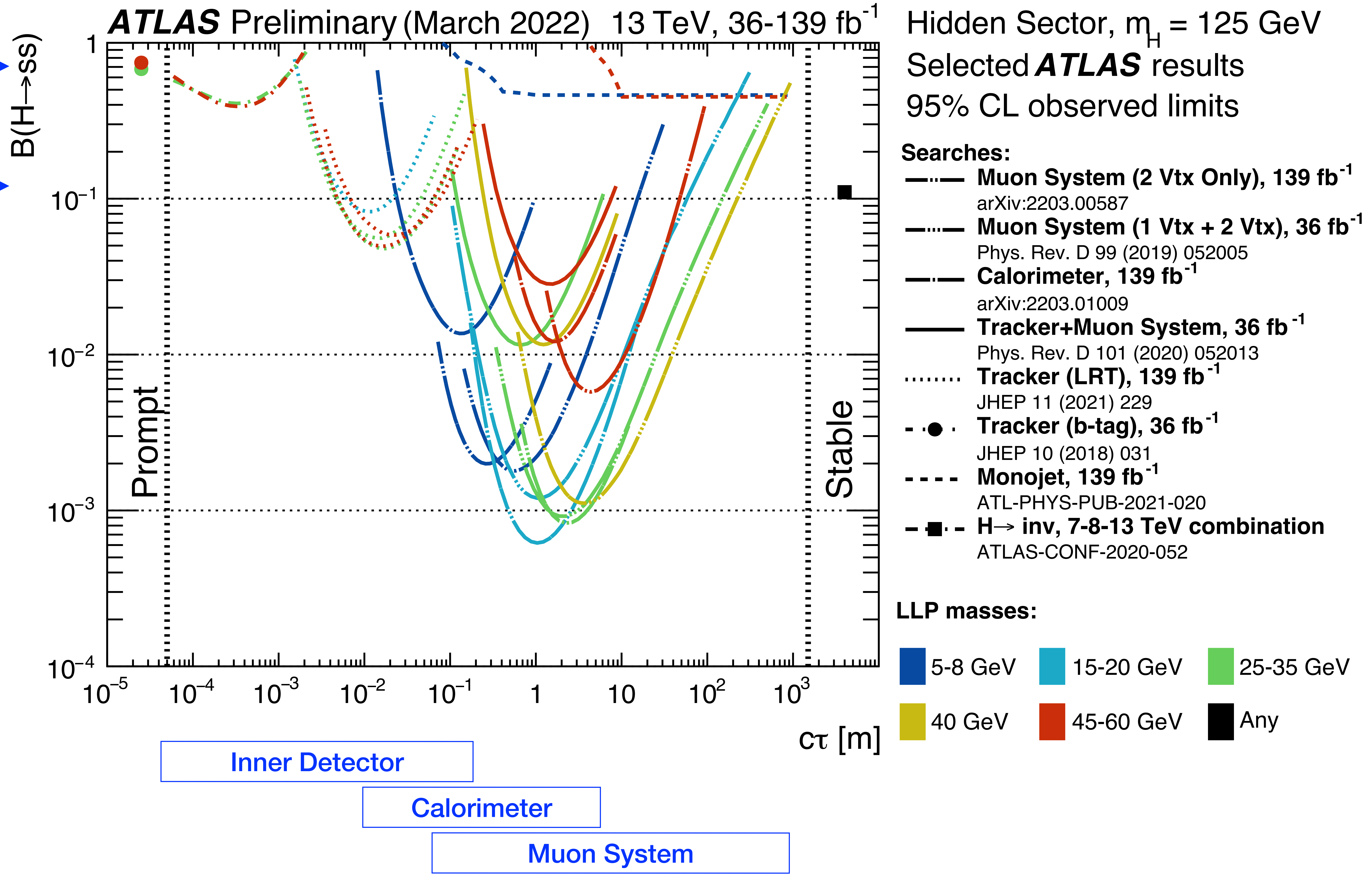
Prompt search



Long Lived Hidden Sector Searches

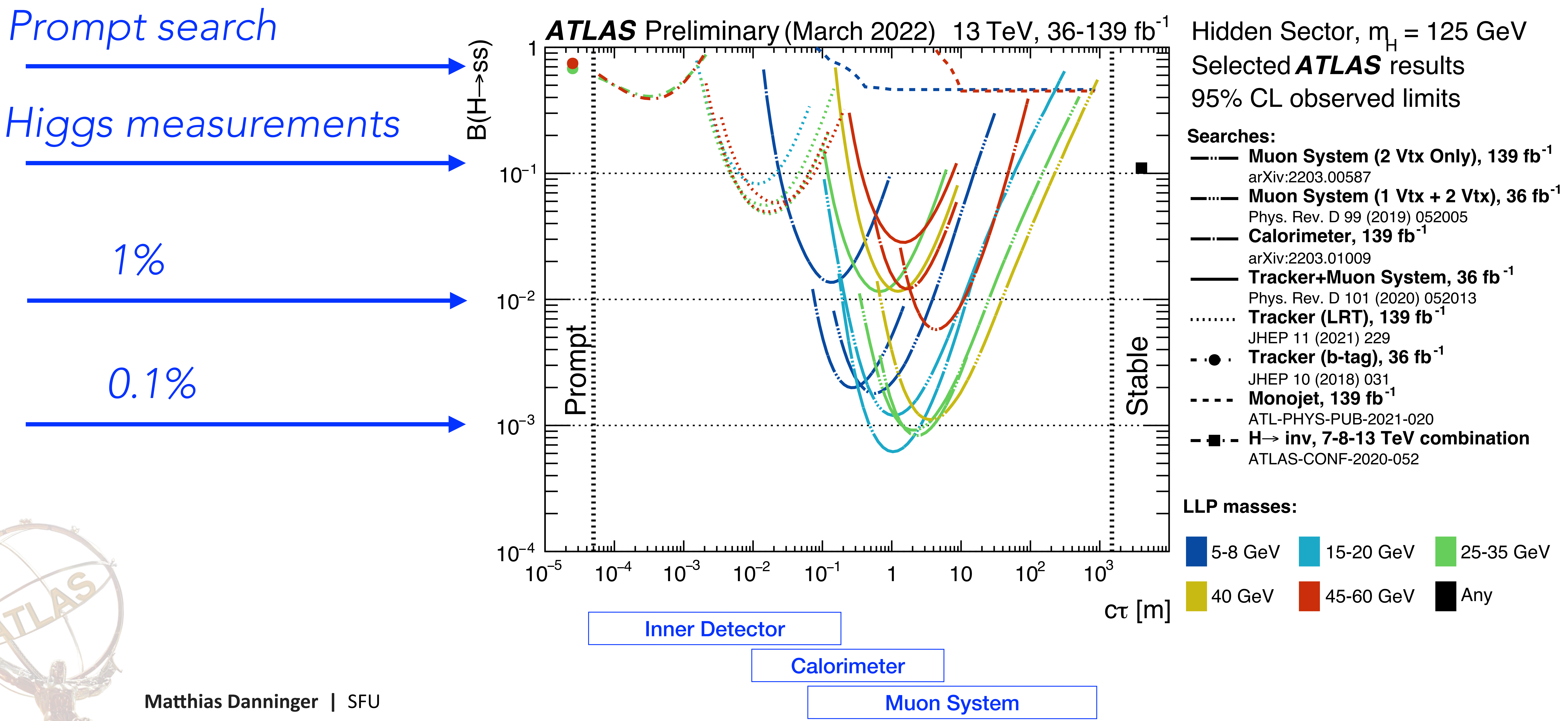
Prompt search

Higgs measurements



Long Lived Hidden Sector Searches

- Results prior to latest search with Inner Detector



Long Lived Hidden Sector Searches

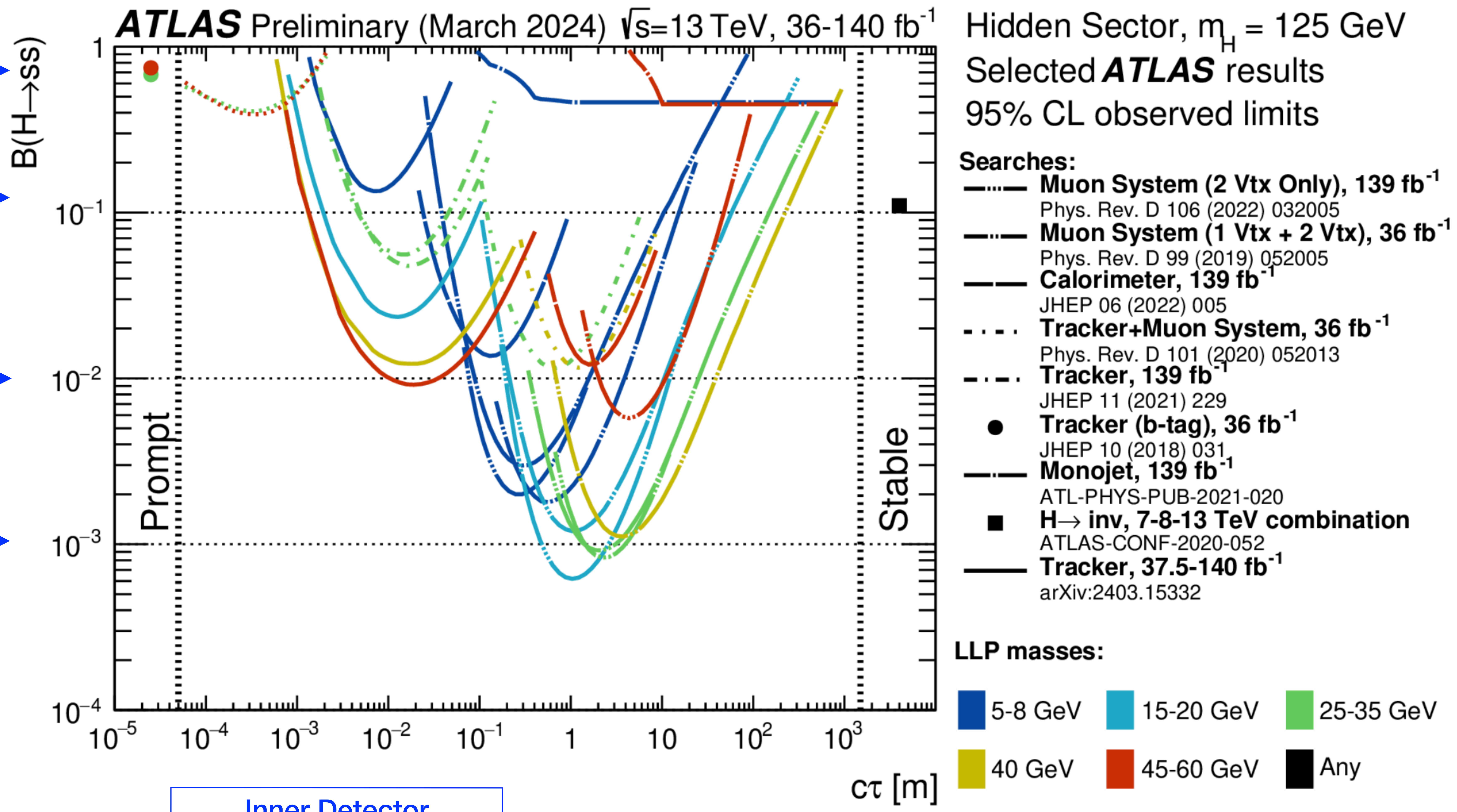
- 10-40x more sensitive than previous results using the **same dataset**

Prompt search

Higgs measurements

1%

0.1%



Inner Detector

Calorimeter

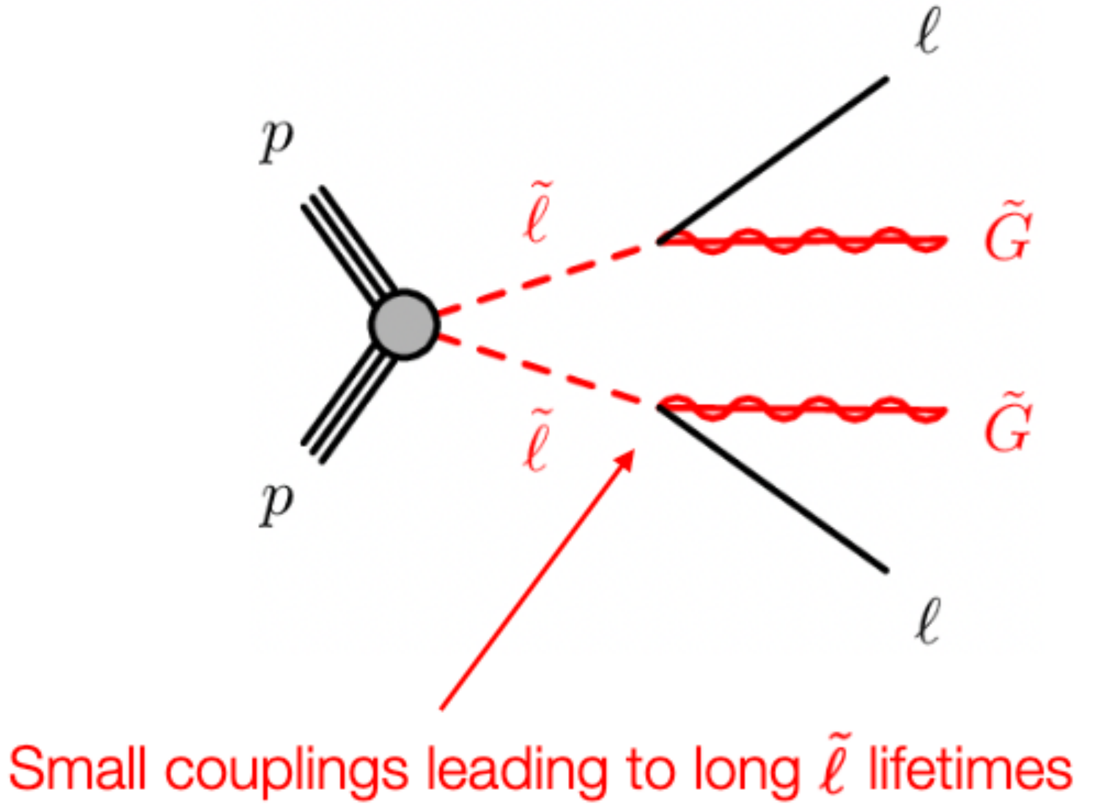
Muon System

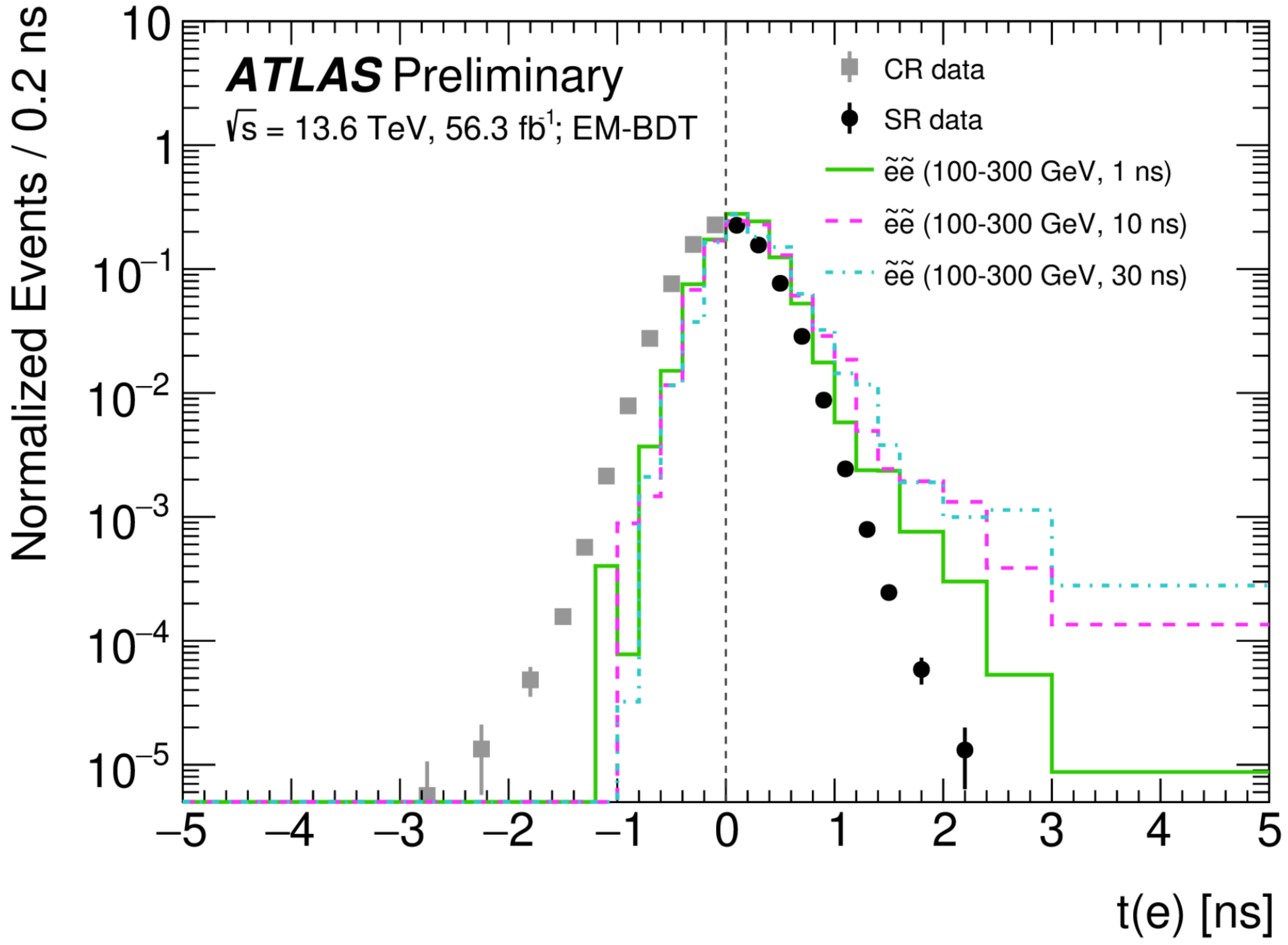
Long-lived sleptons search

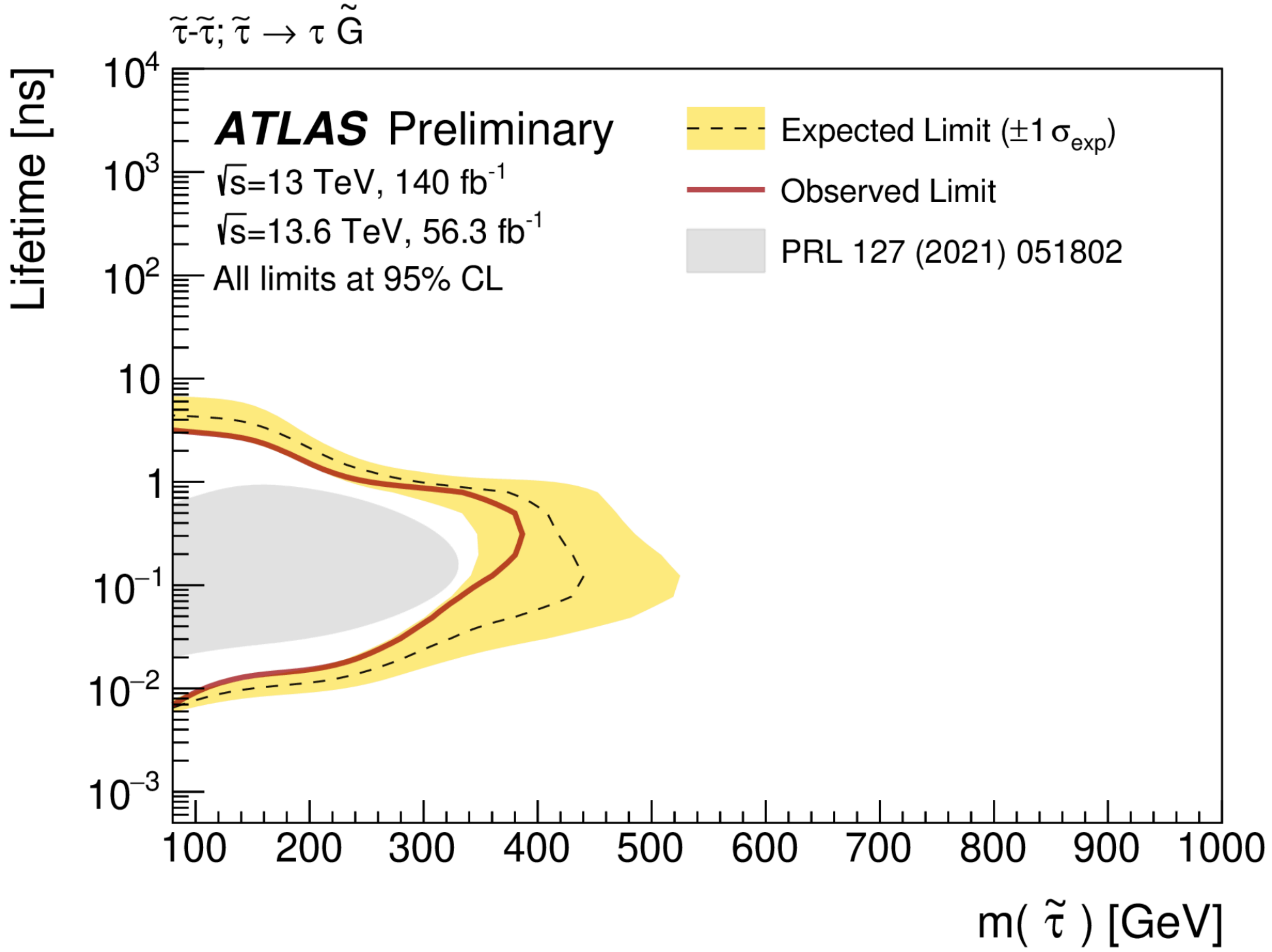
ATLAS-CONF-2024-011

Displaced lepton search:

- Run 3 search using new LLP reconstruction (also in the trigger!)
- Precision timing information from calorimeter is used to complement tracking information
- New improved limits also for electron and muon channels



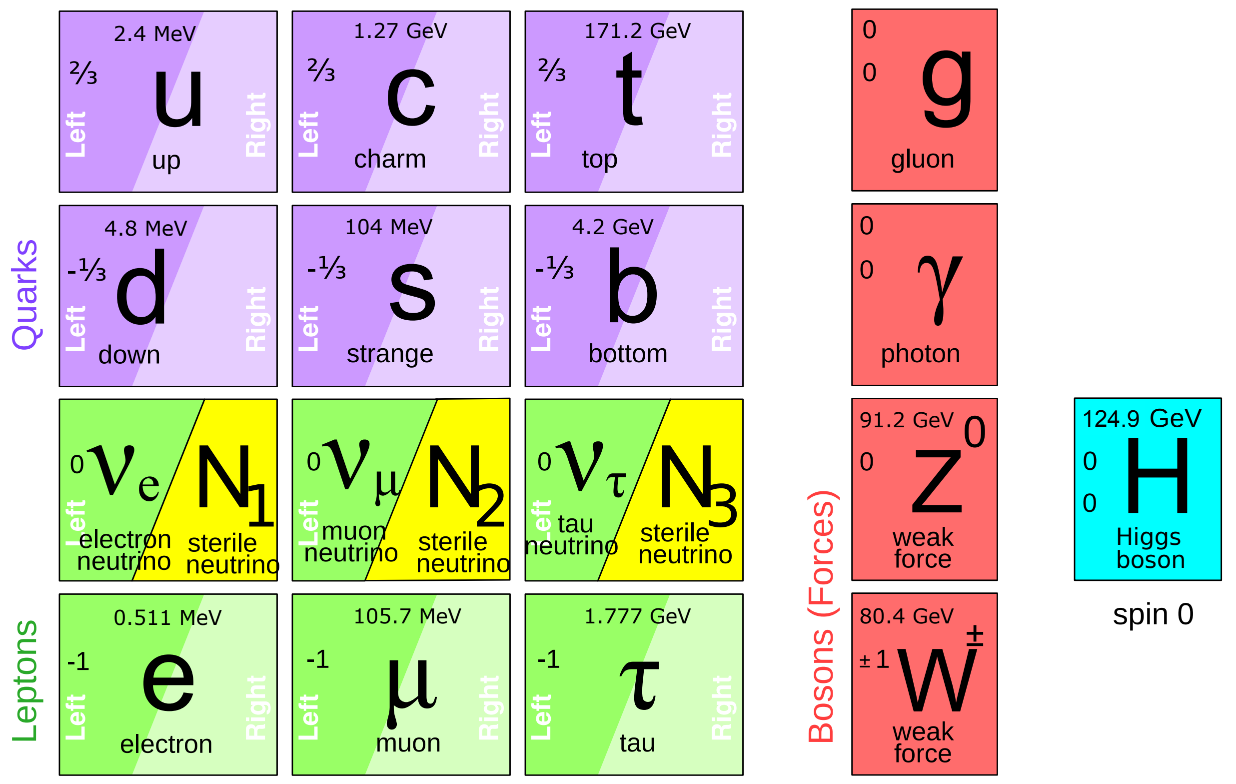


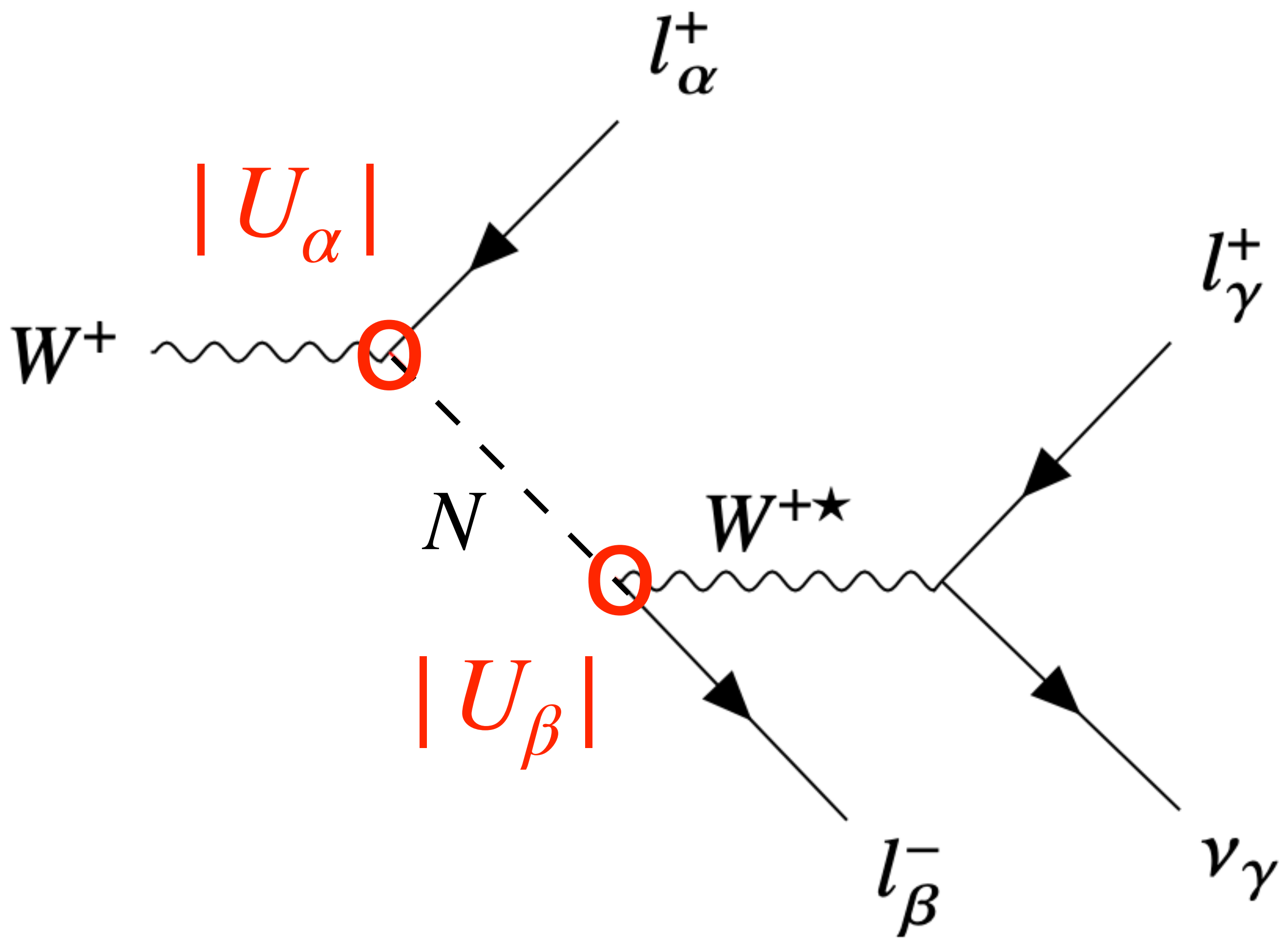


Heavy Neutrinos — Sterile Neutrinos

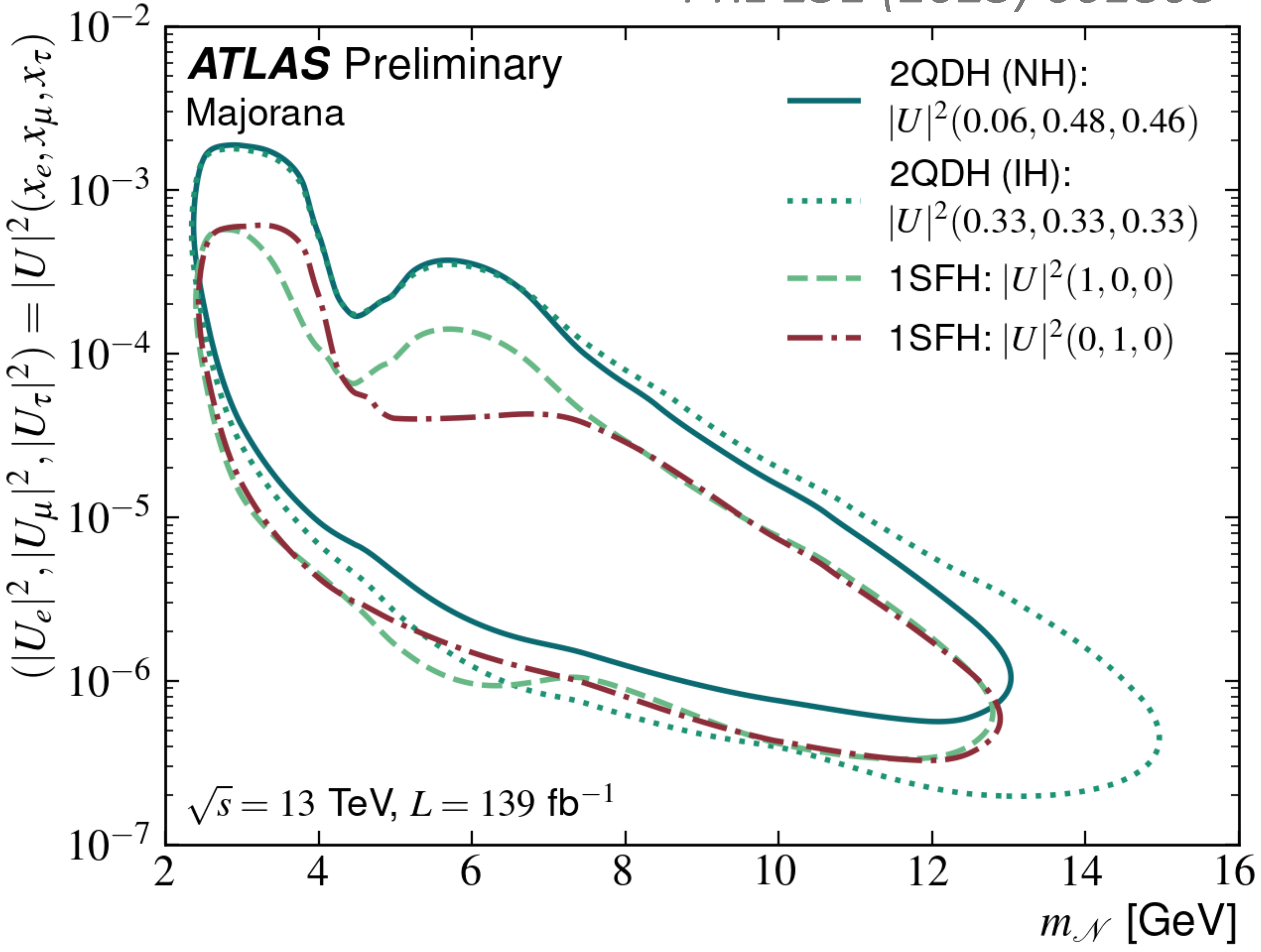
—> Sterile neutrino becomes long lived due to off-shell W-decay

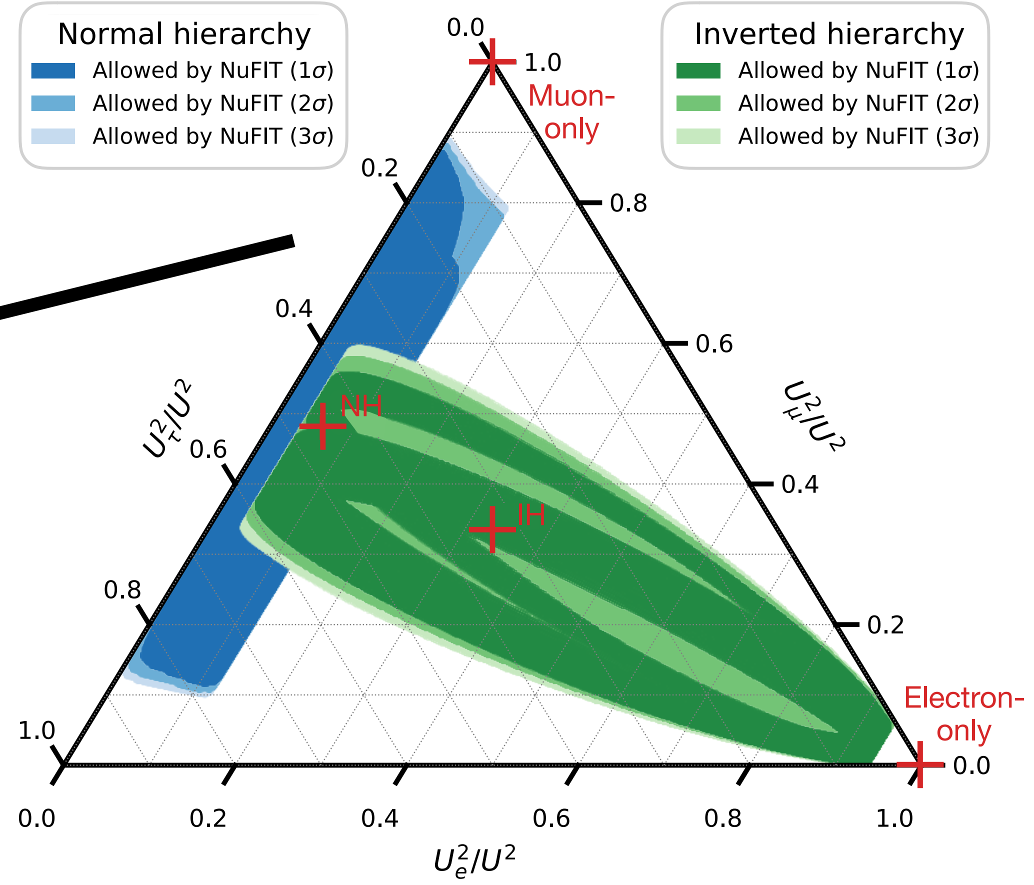
arxiv:1301.5516





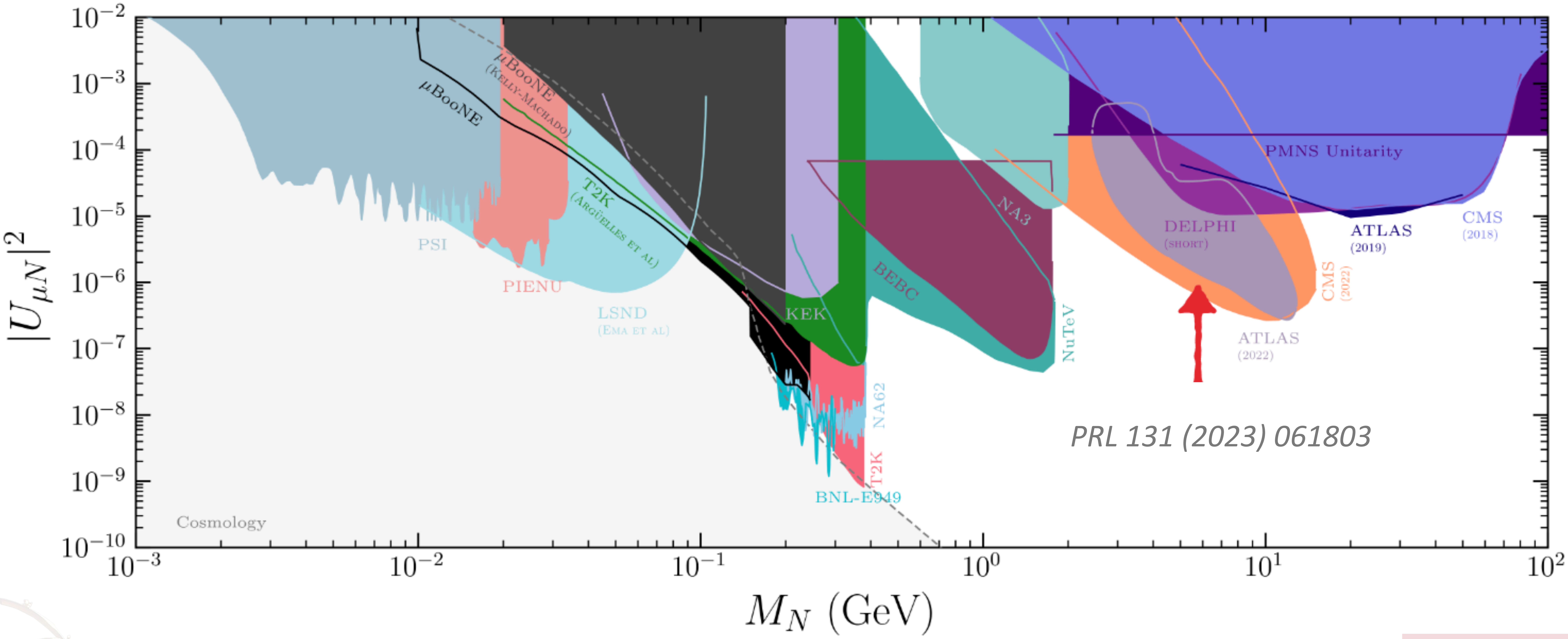
PRL 131 (2023) 061803





"Realistic" multi-flavour mixing models consistent with neutrino oscillations data

Heavy Neutrinos — Sterile Neutrinos



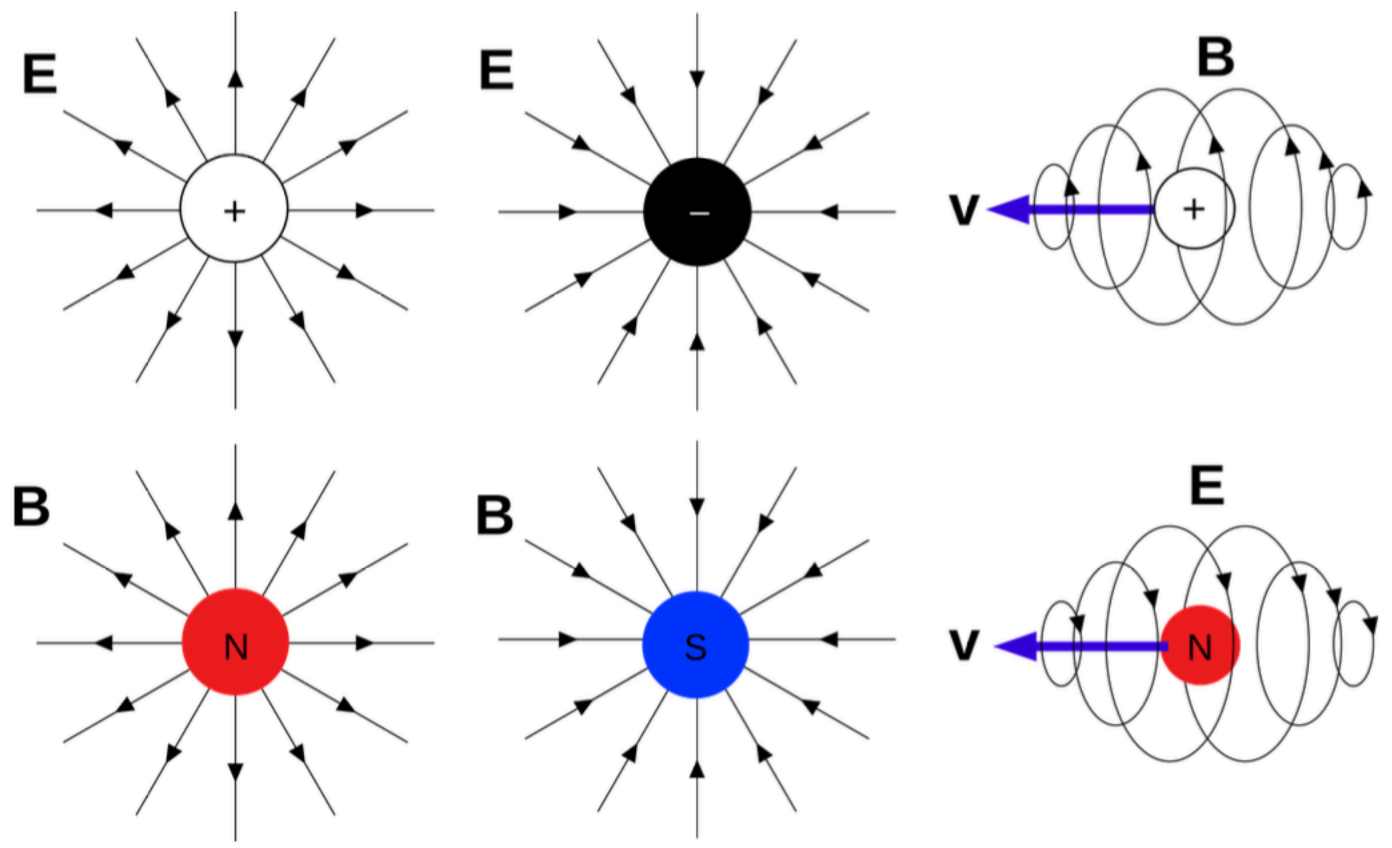
—> Complementarity also to neutrino-less double-beta decay experiments

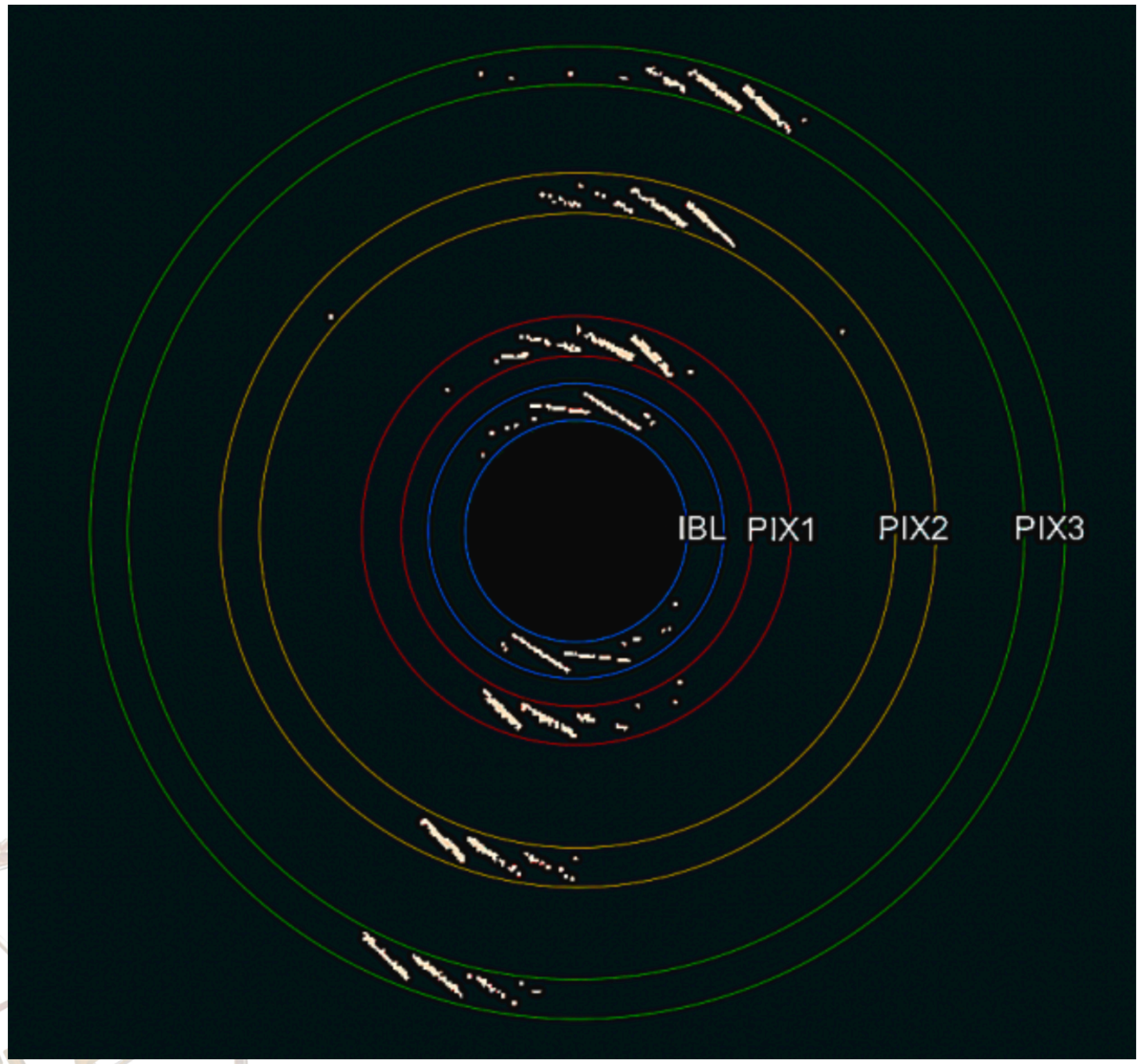
Unconventional Heavy Ion Searches

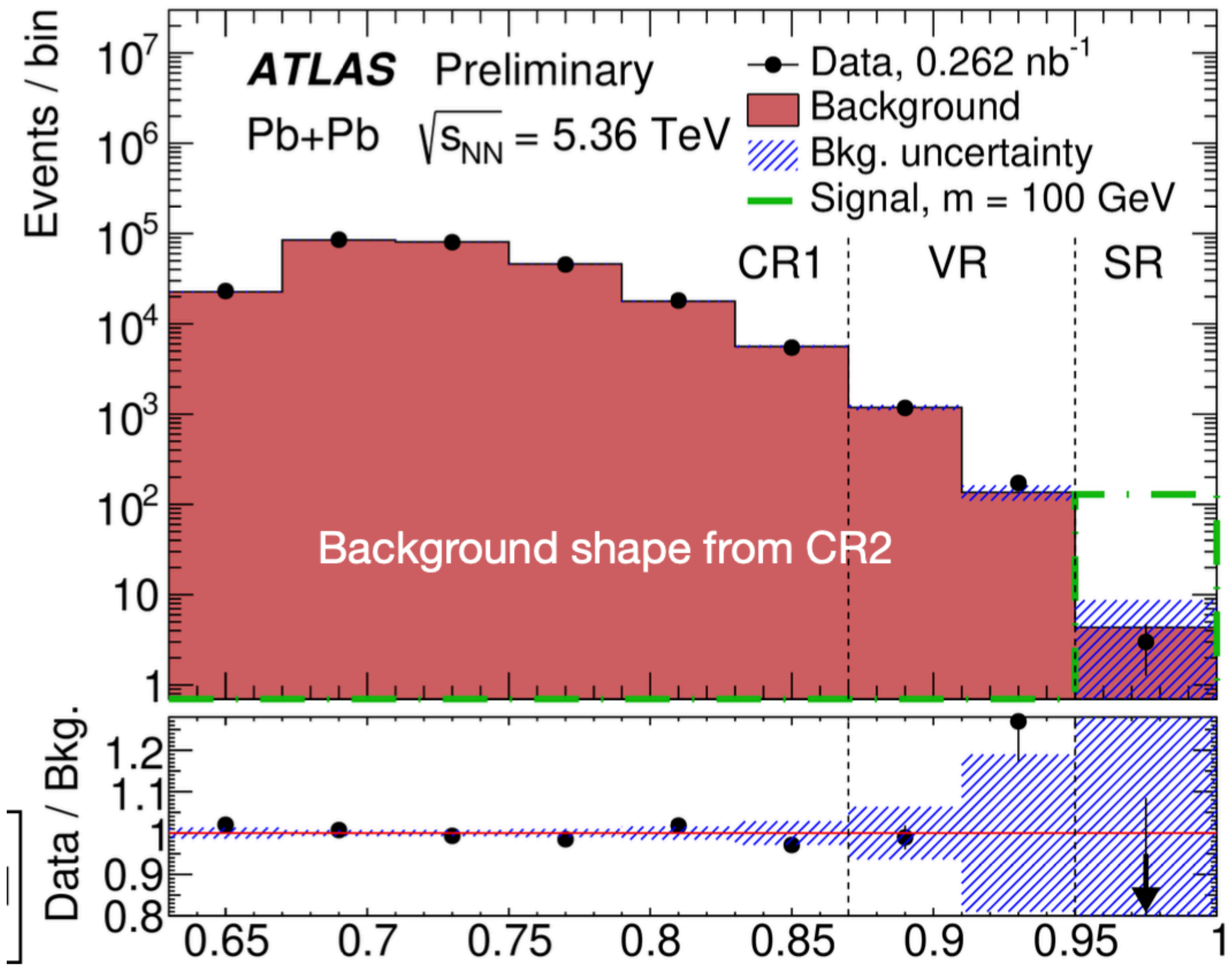
arXiv:2408.11035

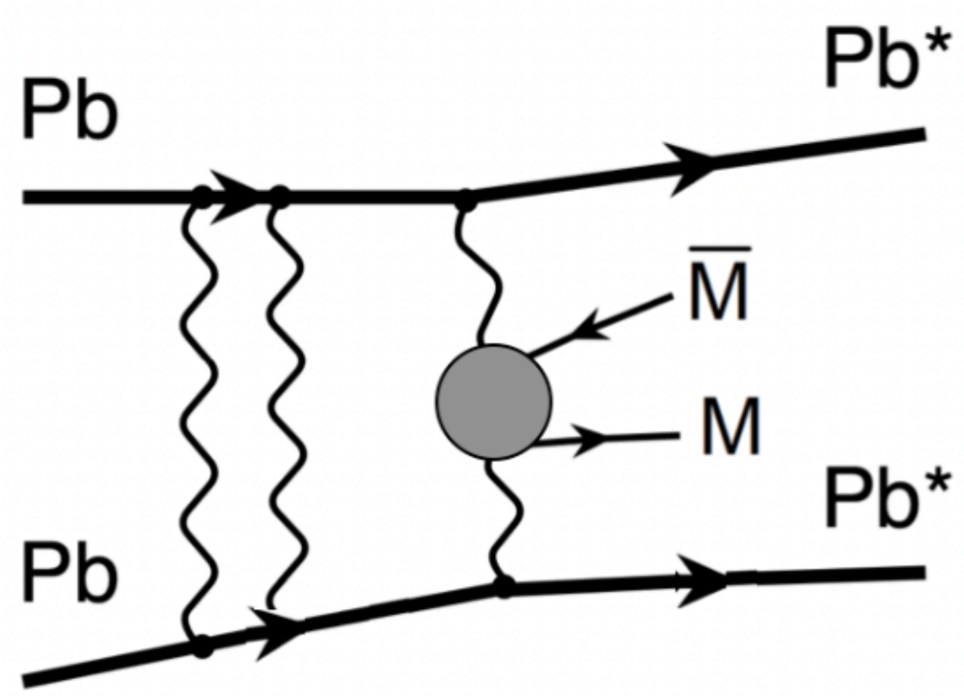
Magnetic Monopole Search:

- Using ultra peripheral lead collisions in Run 3 (new triggers)
- Production via the **Schwinger mechanism** in strong magnetic fields
- Striking experimental signature (Huge ionization loss)









Unconventional Heavy Ion Searches

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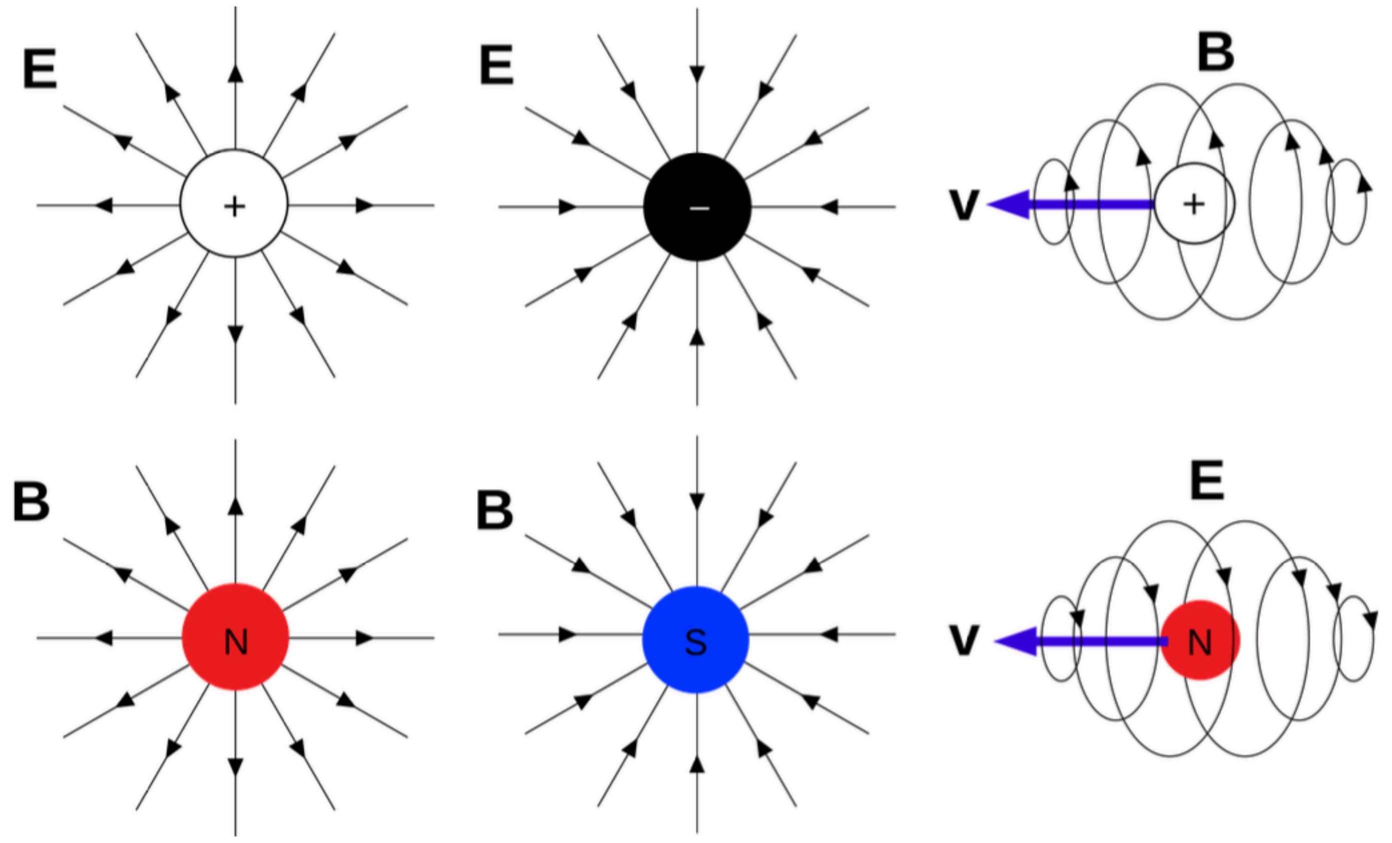
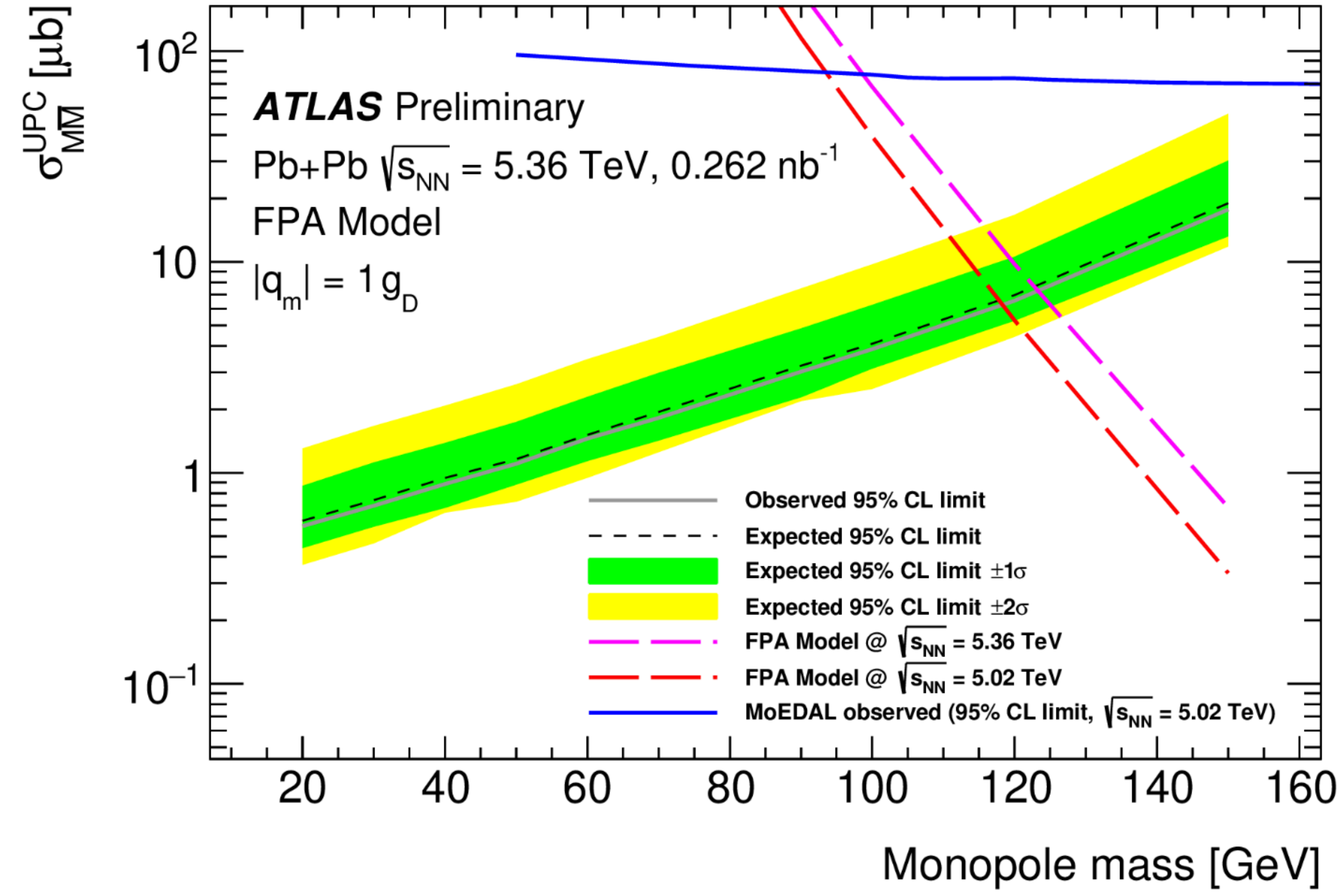
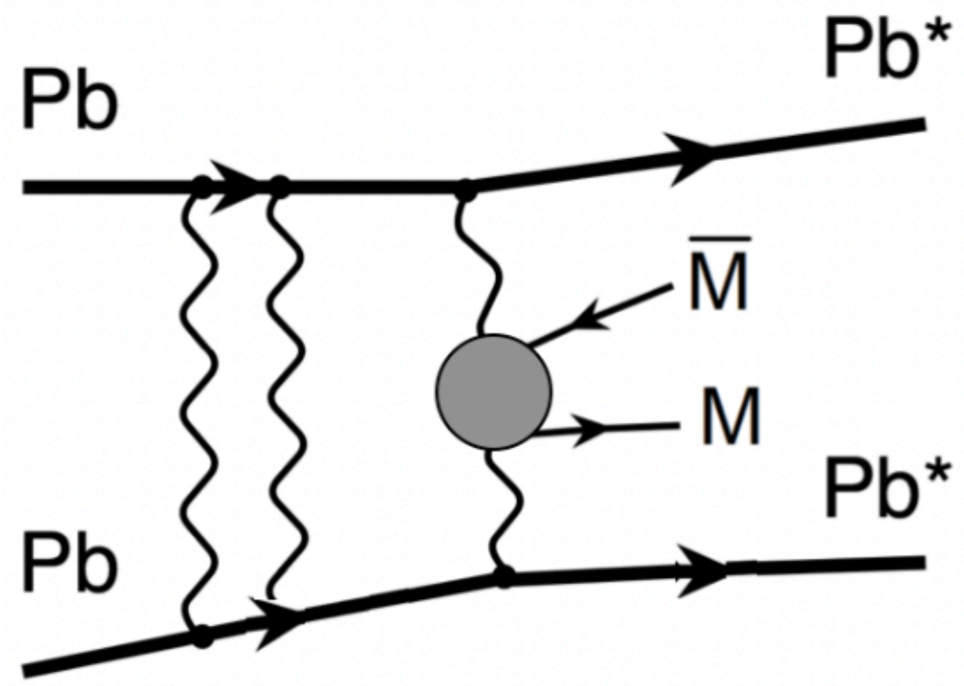
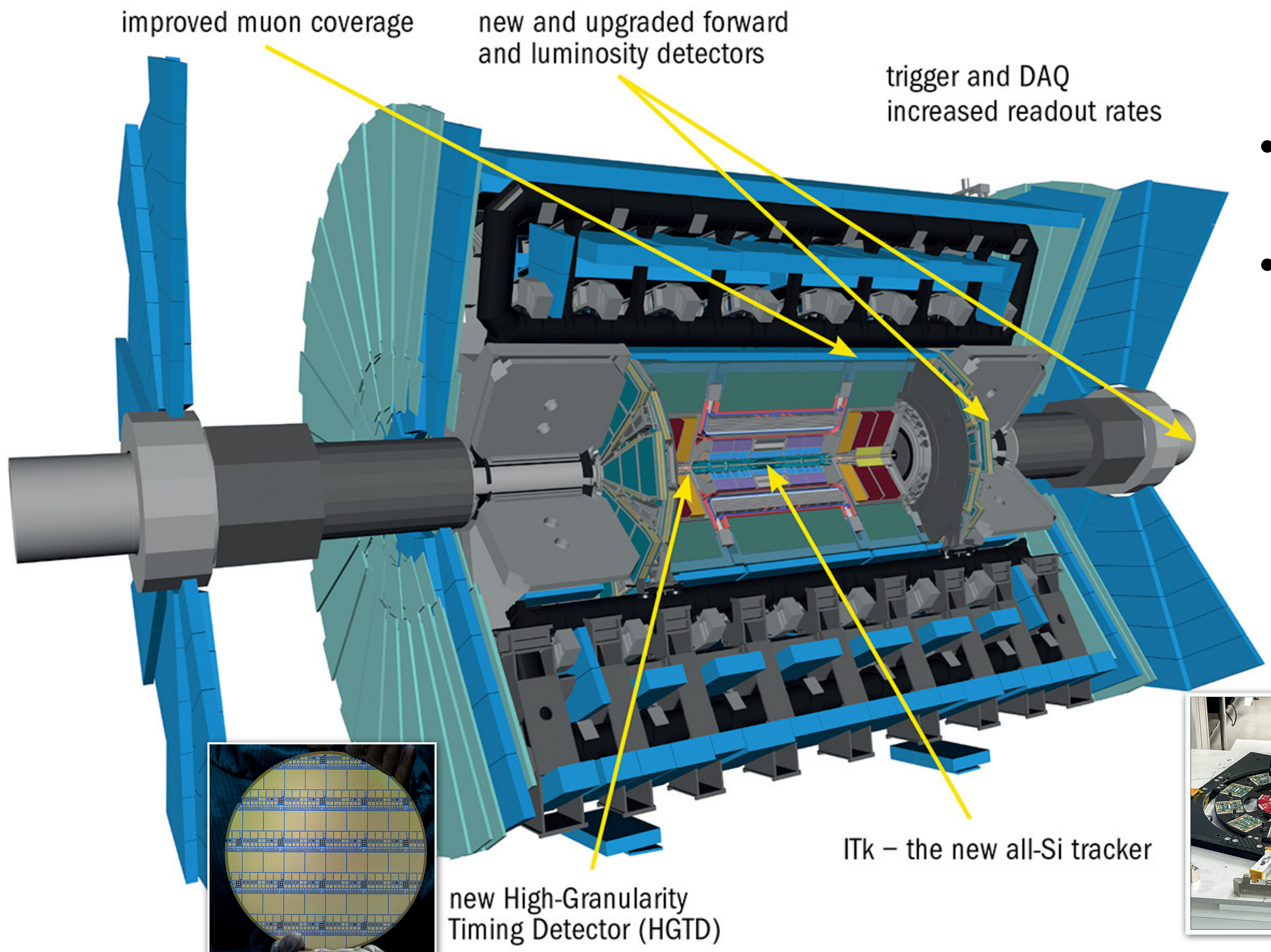




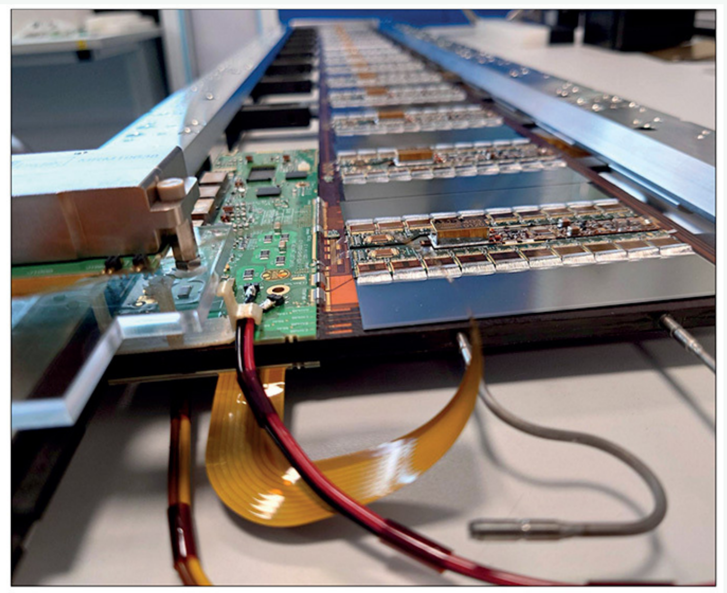


HION-2023-01

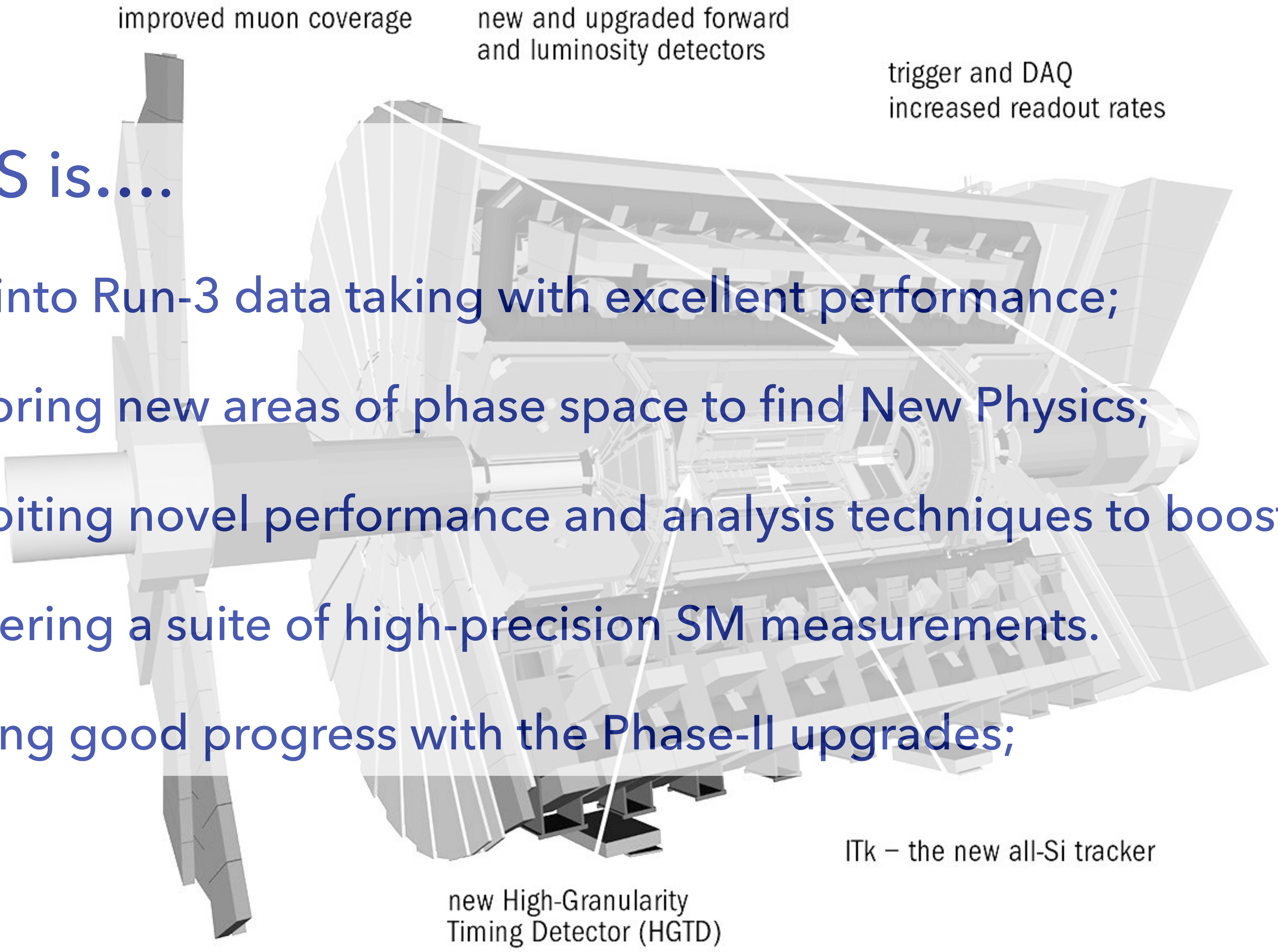
The future ATLAS detector for HL-LHC



- Expected HL-LHC int. luminosity is $3000 fb^{-1}$ (~$300 fb^{-1}$ end of Run 3)
- Pileup will increase to μ=200



Summary



ATLAS is….

- well into Run-3 data taking with excellent performance;
- exploring new areas of phase space to find New Physics;
- exploiting novel performance and analysis techniques to boost performance;
- delivering a suite of high-precision SM measurements.
- making good progress with the Phase-II upgrades;

Backup

ATLAS EXPERIMENT

Where can we go ATLAS and the HL-LHC

A Higgs factory:

400M Higgs bosons in ATLAS & CMS for precise Higgs coupling measurements, access to Higgs self interaction and longitudinal vector boson scattering

Plus significantly increased overall rare & new physics sensitivity

An upgraded ATLAS:

New detectors: high-granularity, high-coverage tracker, high-granularity timing detector, muon chambers

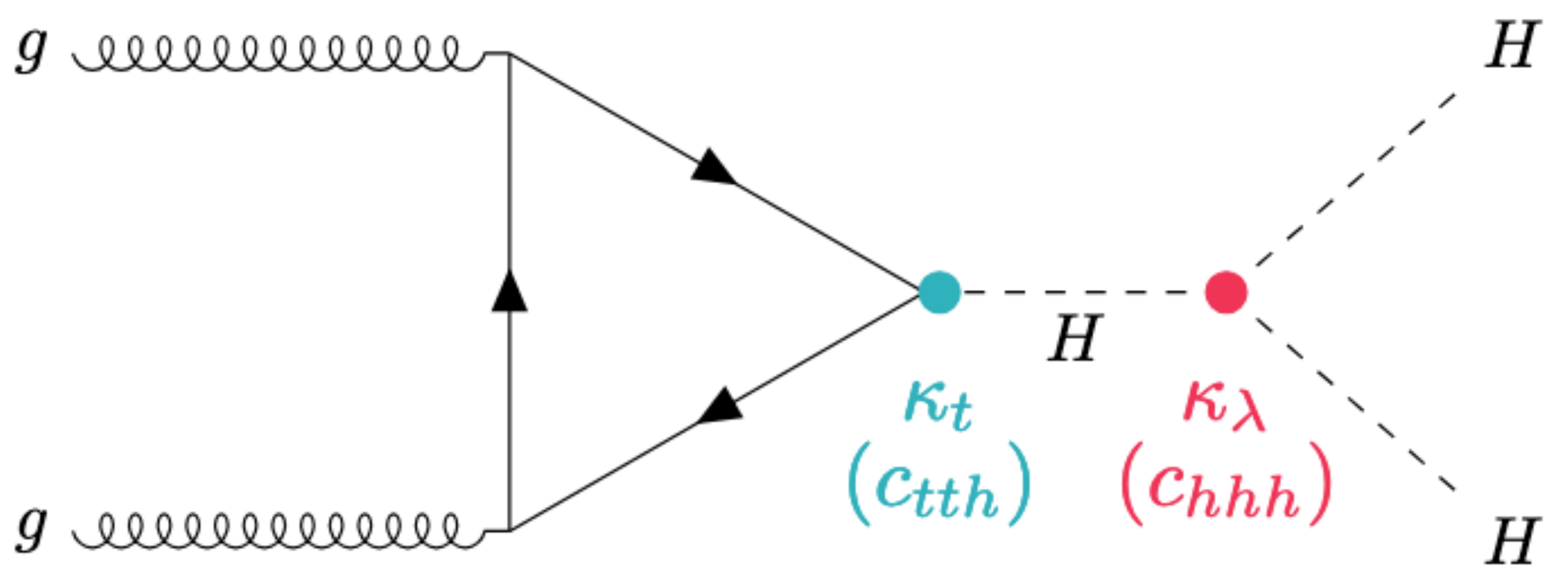
Improved trigger, high-performance software & computing, deeply embedded machine learning

slide from M. Dunford

Understanding fundamental parameters

Higgs couplings and self-coupling

- Learn about electroweak phase transition & vacuum stability!
- Self coupling allows us to trace the shape of the potential away from the Higgs mass



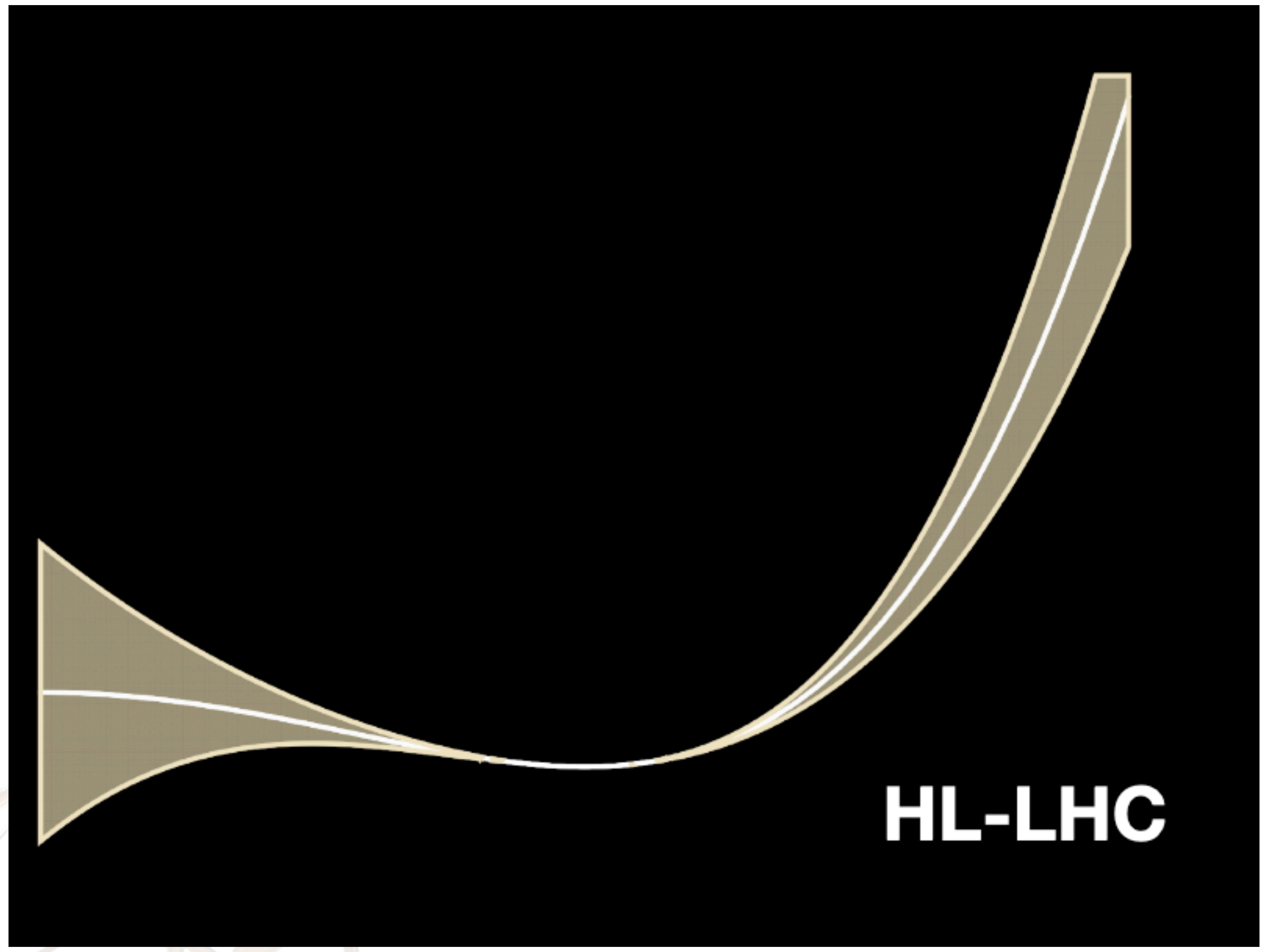
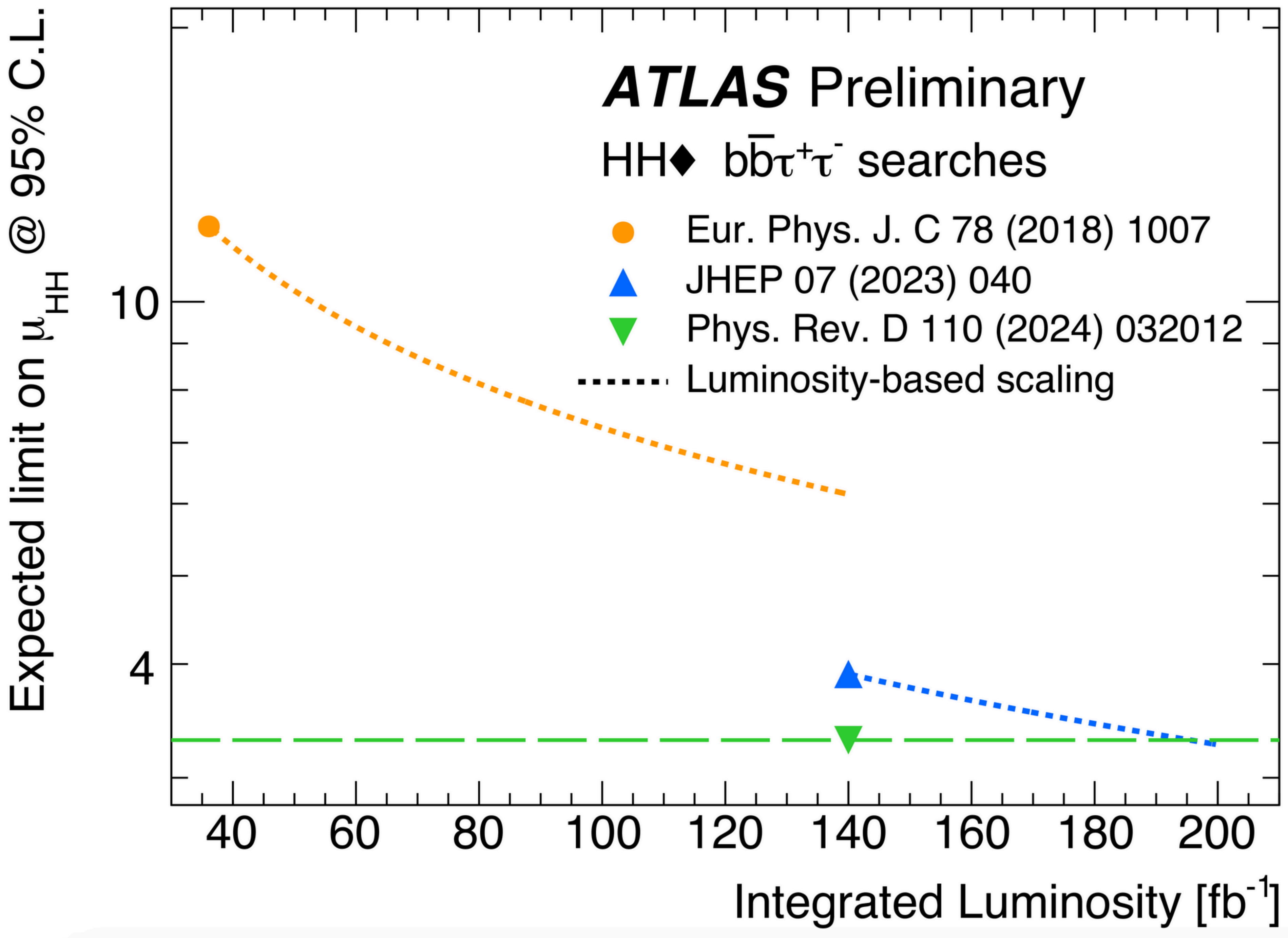


image credit N. Craig

ATL-PHYS-PUB-2024-016

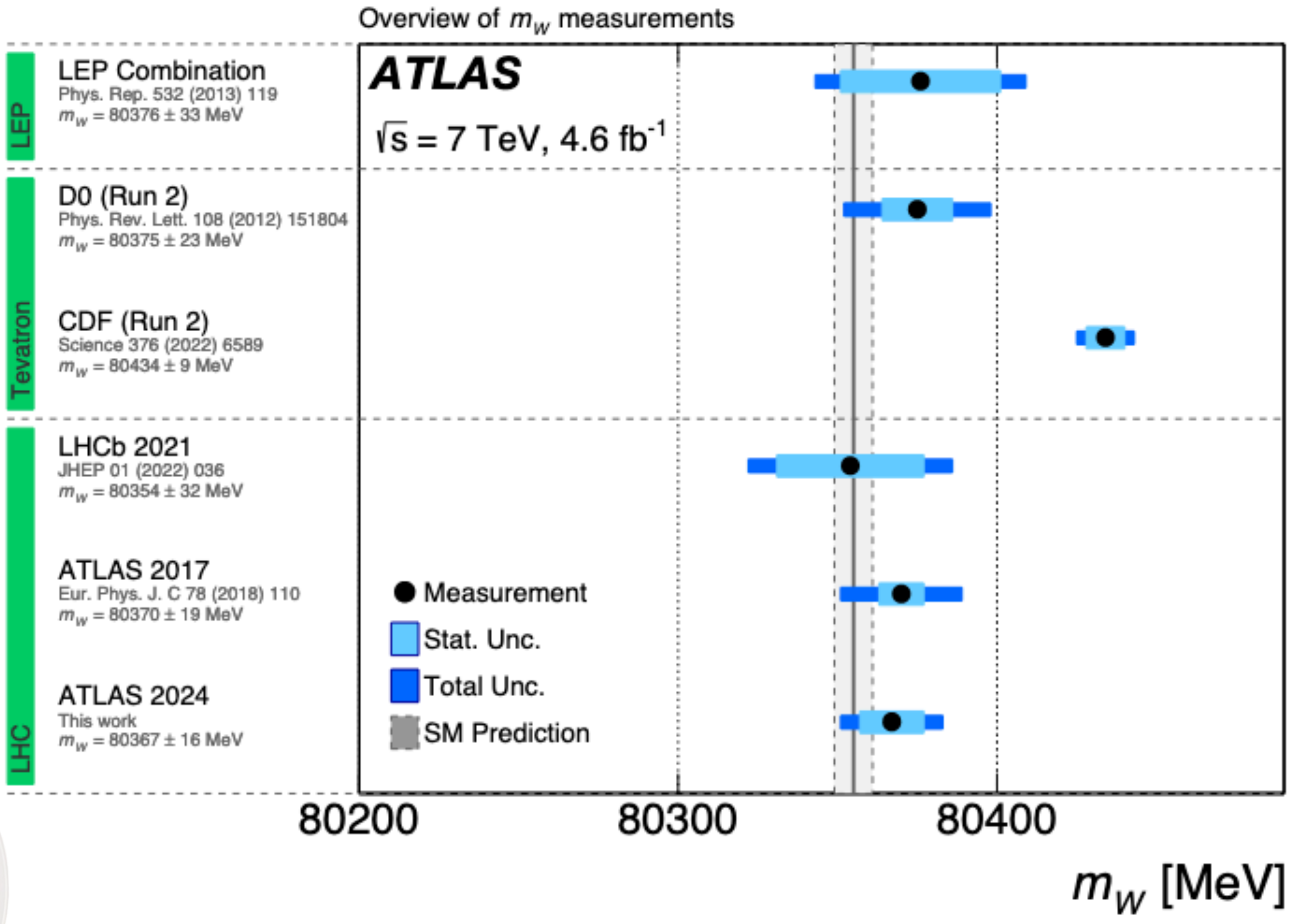


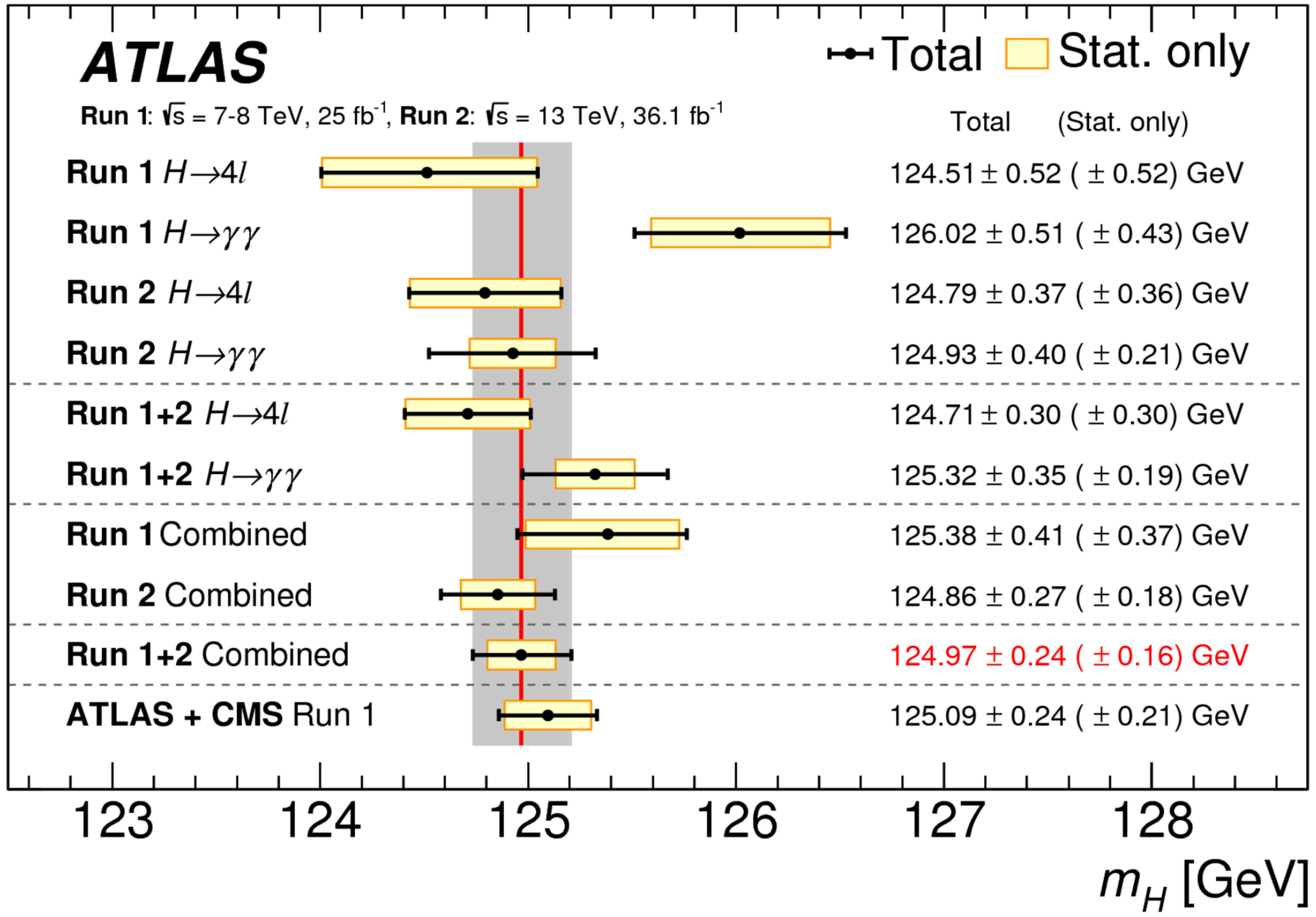
FTAG-2023-01 note (Flag)

Understanding fundamental parameters

Mass measurement precisions:

- 0.02% on W mass
- 0.2% on top mass
- 0.09% on Higgs mass

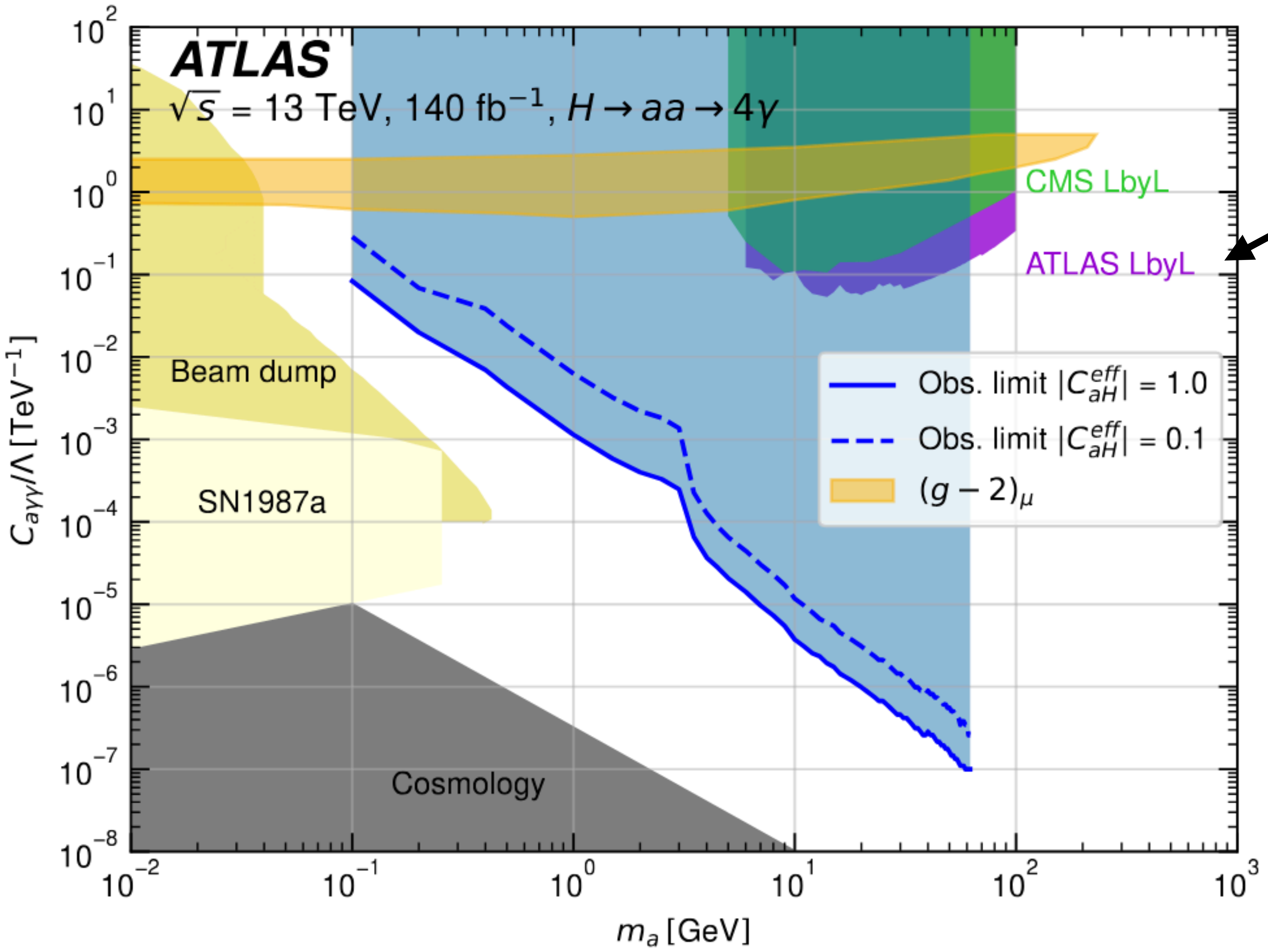


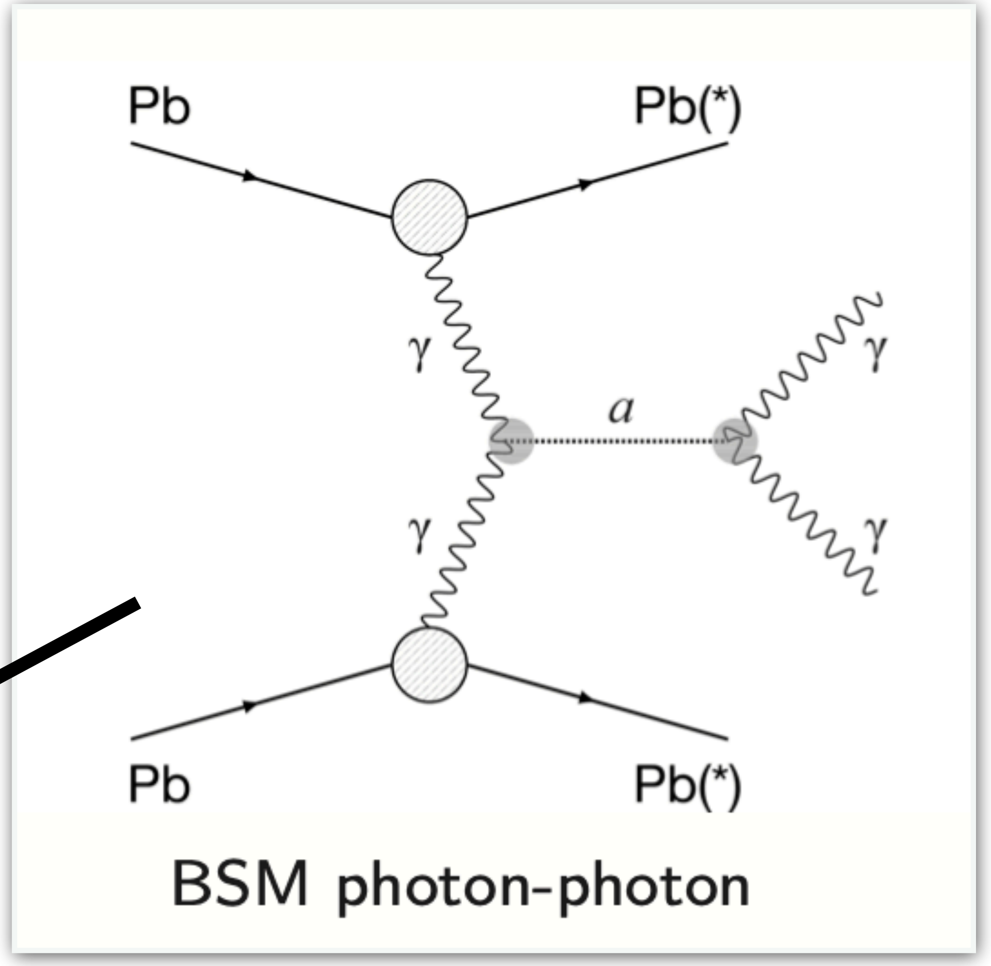


Axion-like Particles

- Search for anomalous Higgs boson decays into two axion-like particles (ALPs) $H \rightarrow aa \rightarrow 4\gamma$
- 4 photon invariant mass system is reconstructed
- Search is sensitive to long and short lived ALPs
- Complementarity to light-by-light heavy ion search

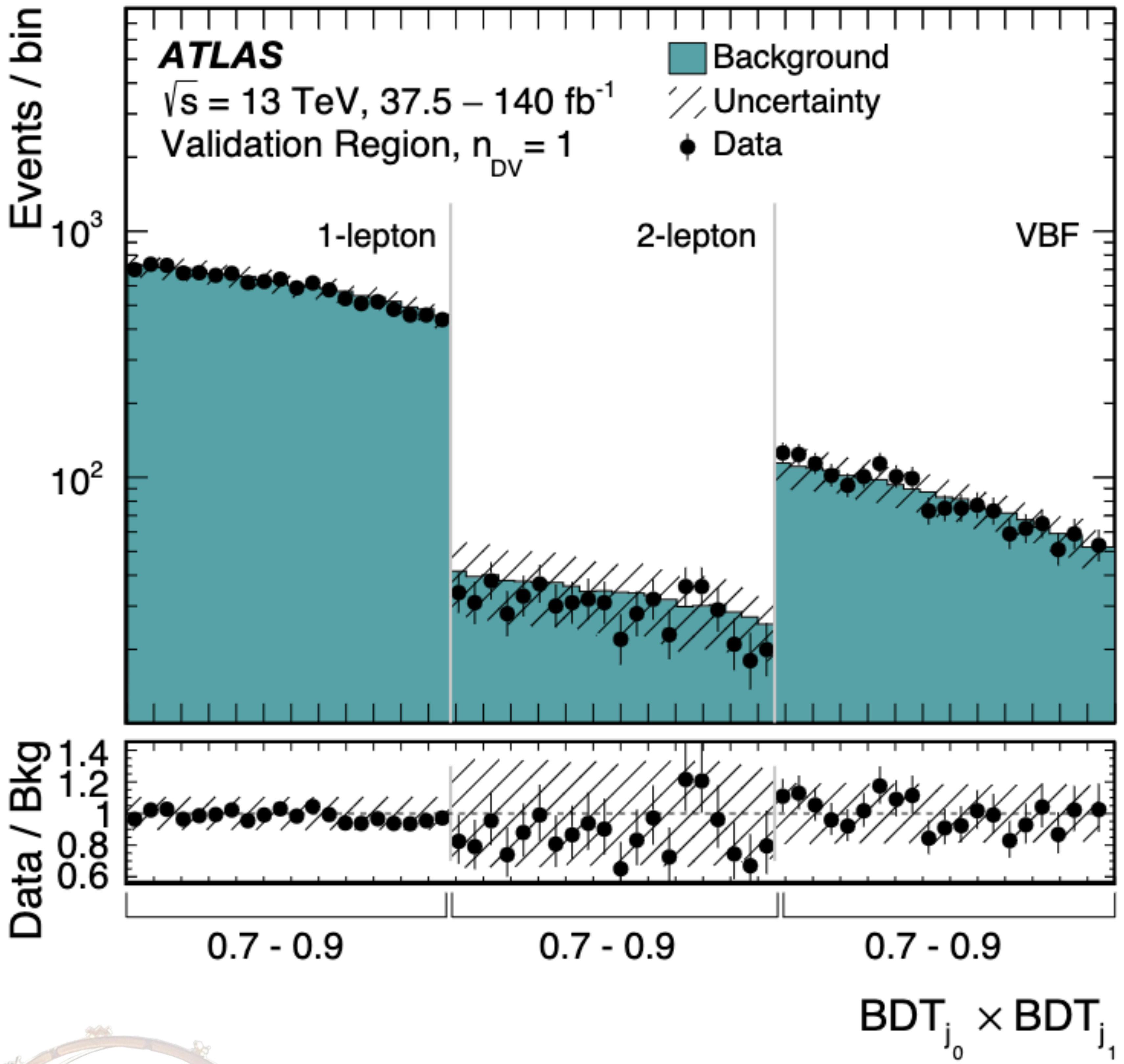
arxiv:2312.03306





What can we expect?

arxiv:2403.15332



What can we expect?

arxiv:2403.15332