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PALAIS DU PHARO
MARSEILLE, FRANCE

ANUBIS : Projected sensitivities and initial results from the proANUBIS demonstrator with Run 3 data

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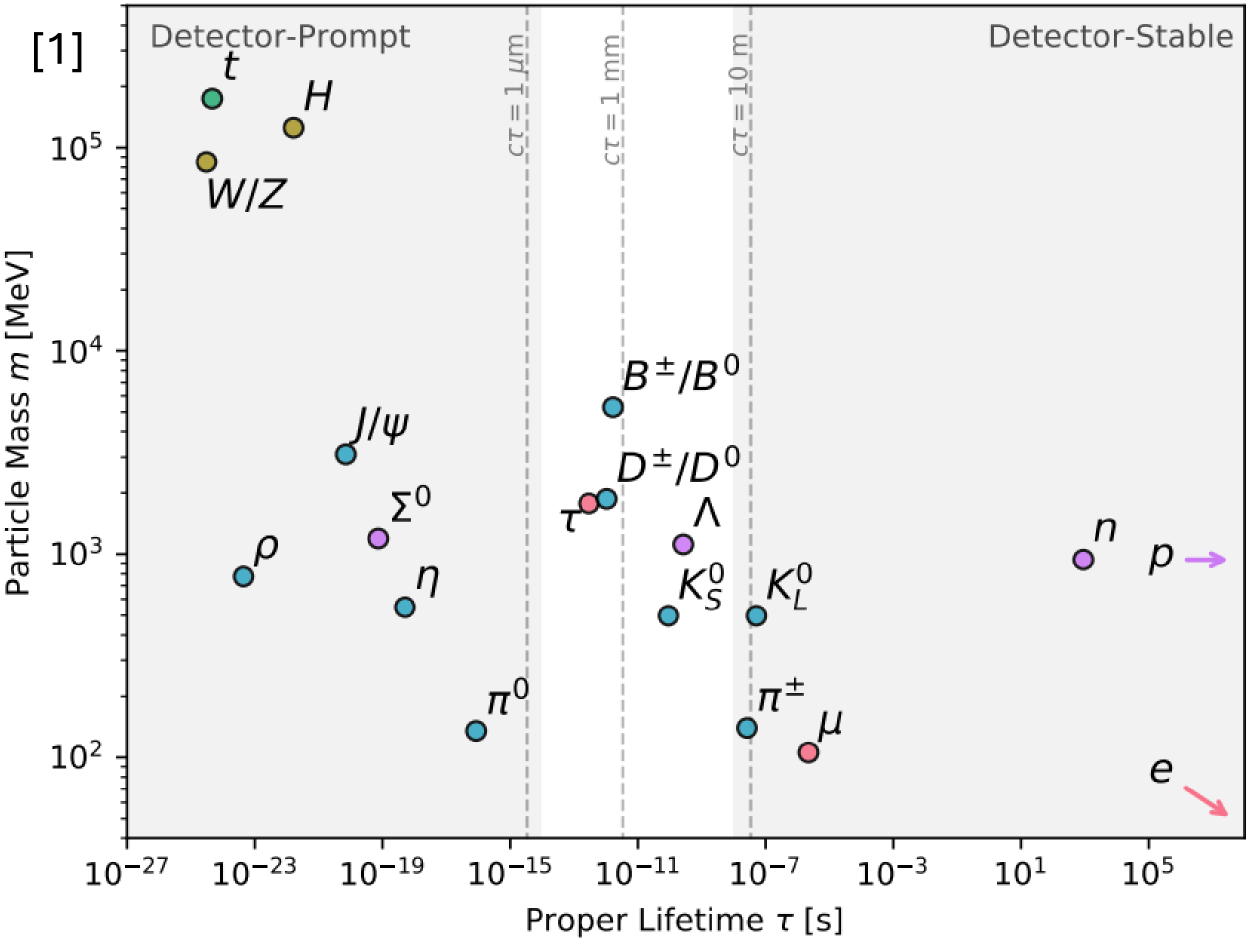
On behalf of the ANUBIS collaboration

09 July 2025

Part I :
Long Lived Particles (LLPs)

Long-Lived particles (LLPs)

[1]



$$\tau^{-1} = \Gamma = \frac{1}{2m_X}\int d\Pi_f |\mathcal{M}(m_X \to \{p_f\})|^2$$

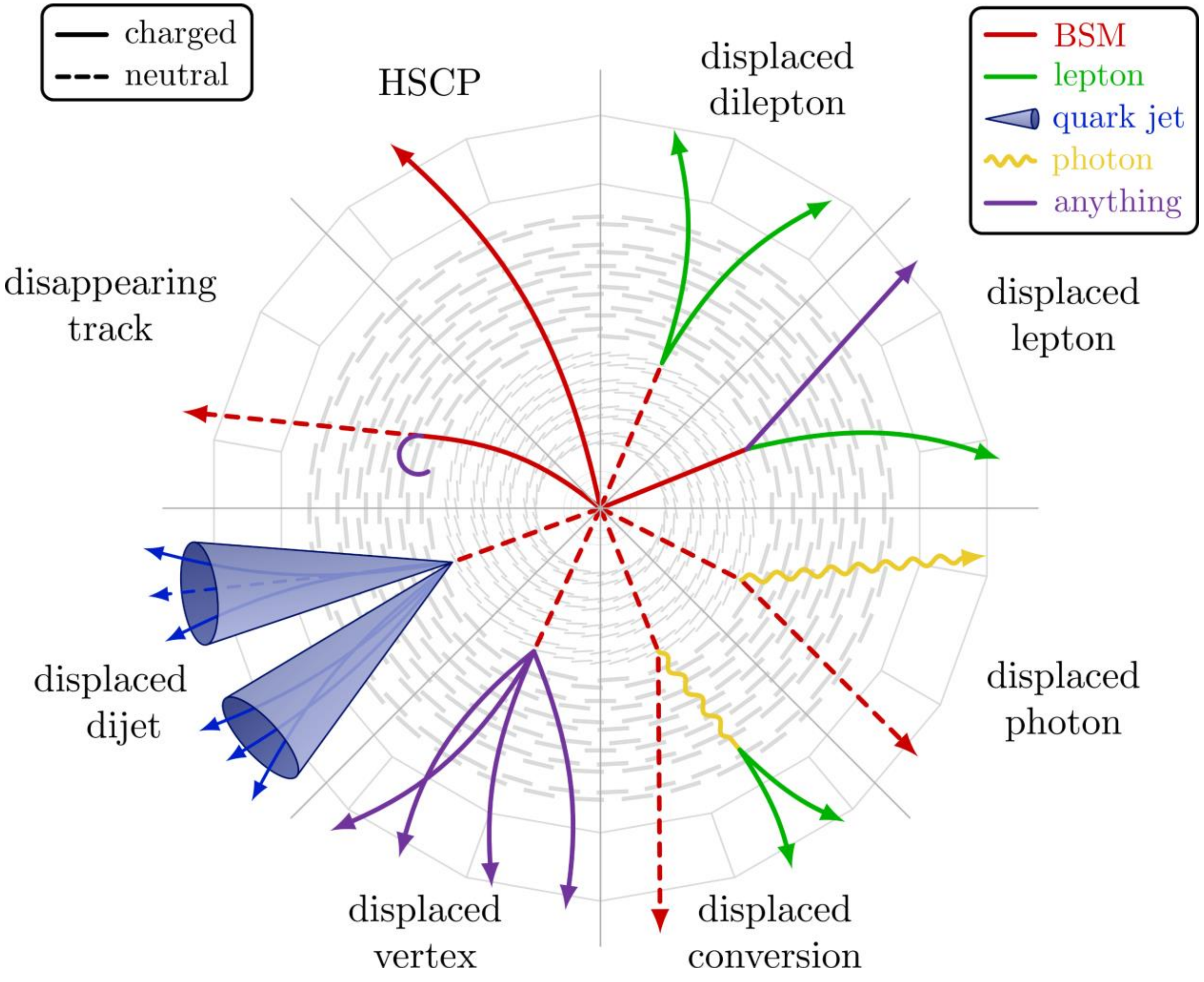
LLPs :

- Have long lifetimes
- Can escape detector if they're neutral
- Are a common feature in many BSM models
  - Can be portal to Dark Matter

[1] arXiv:1810.12602

Long-Lived Particles at the LHC

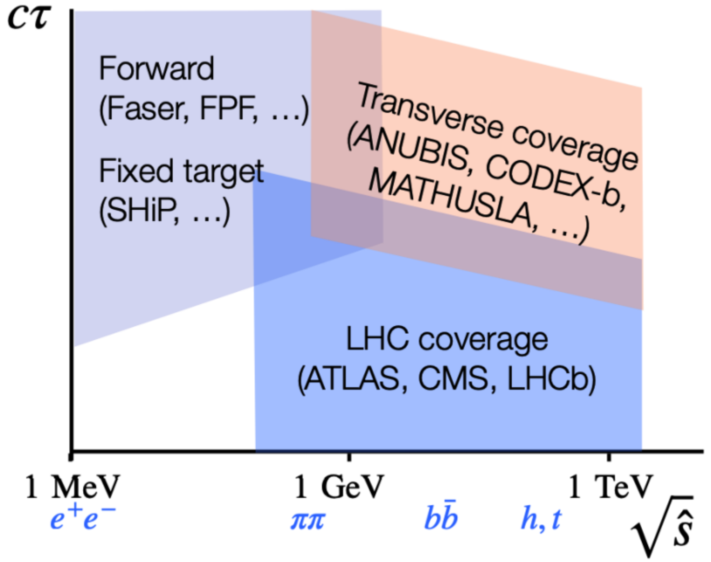
[1]



Limitation of currents detectors for LLPs :

- Difficulty to reach LLPs with lifetime ~ 100m
- Lack of sensitivity for difficult region of lifetime/kinematics/background
- Finite size of General Purpose detectors

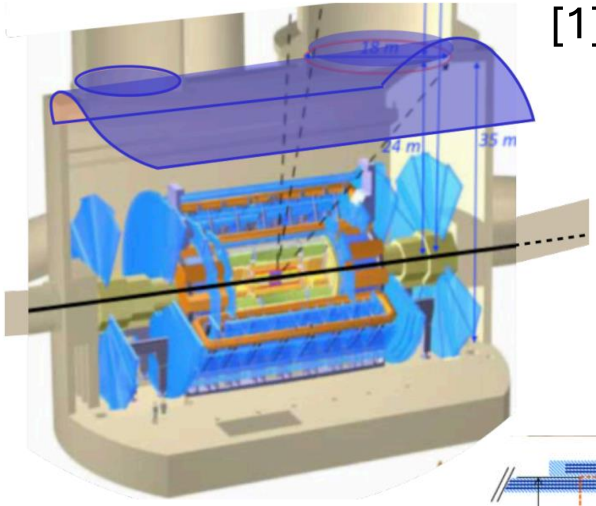
Need for Transverse detector



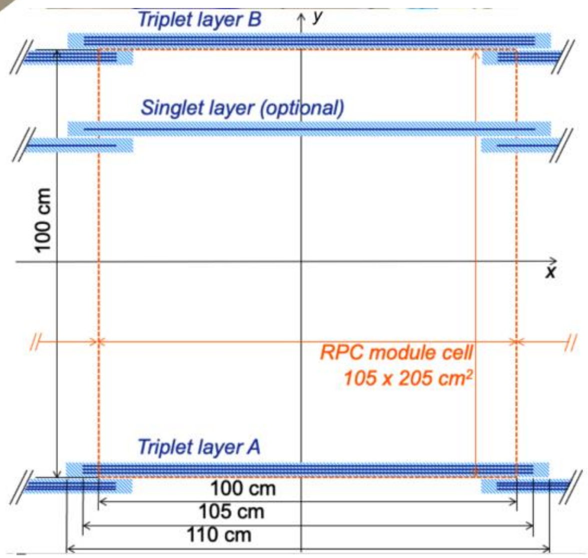
[1] Jamie Antonelli, Searches for long-lived particles at CMS, 2016

Part II :
An overview of ANUBIS

The ANUBIS Detector



[1]



[1]

- Official sub-project of ATLAS.
- Planned to be located in the ATLAS cavern attached to the ceiling.
  - ~ 20+ m from IP.
  - Large solid angle (~2 sr).
- Uses the ATLAS Phase II RPCS as detector technology
- Reduced-scale prototype (**proANUBIS**) in the cavern.
  - Currently taking data since April 2024.
  - 104 fb^{-1} of pp data collected
  - Allows us to perform a background study in situ.

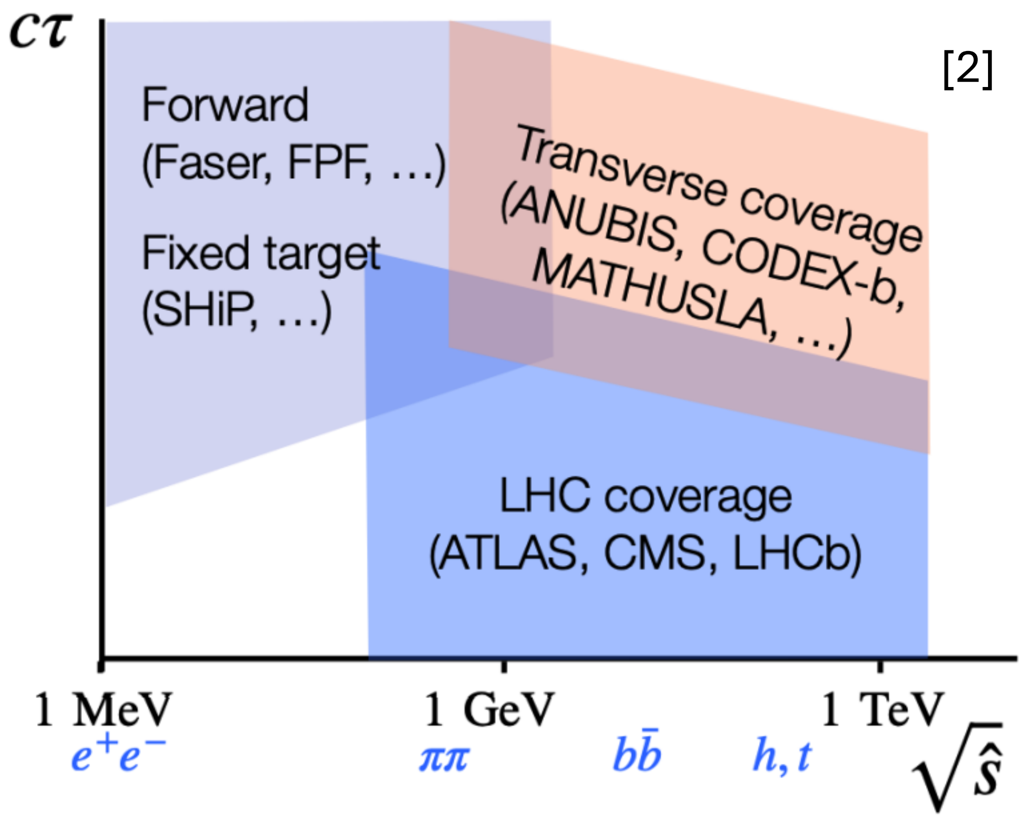
[1] arXiv:2504.03195

The ANUBIS Detector

- Unique sensitivity to Long Lived Particles (LLPs) for Particles with $m_{LLP} > 1\ GeV$ and $c\tau > 100\ m$
- Complementary with other LLP experiments
- Excellent timing resolution of the RPCs allows for timing synchronisation with ATLAS

[1]

Parameter	Specification
Time resolution	$\delta t \lesssim 0.5$ ns
Angular resolution	$\delta\alpha \lesssim 0.01$ rad
Spatial resolution	$\delta x, \delta z \lesssim 0.5$ cm
Per-layer hit efficiency	$\varepsilon \gtrsim 98\%$



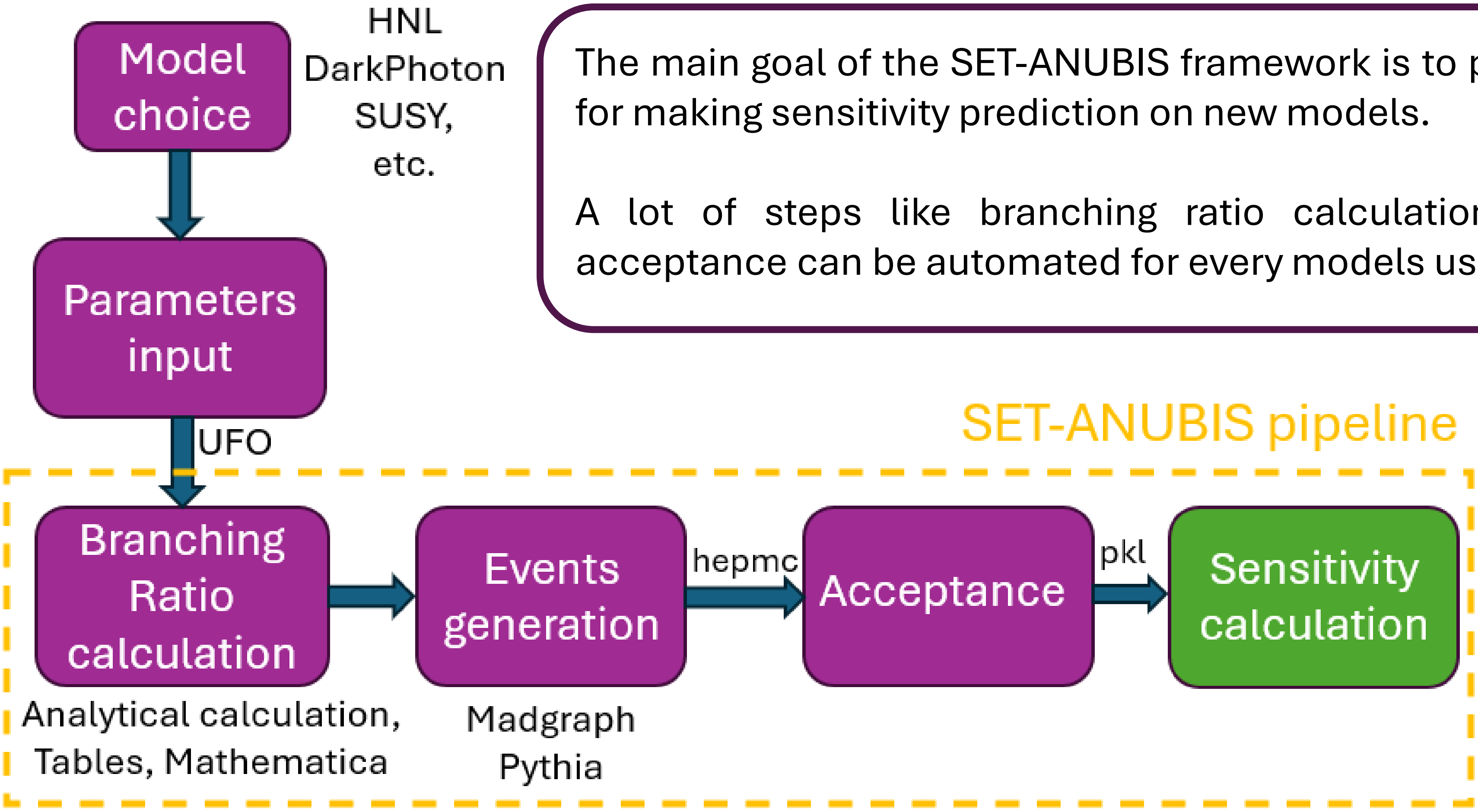
[1] arXiv:1909.13022 [2] arXiv:2504.03195

Part III :
Sensitivity studies

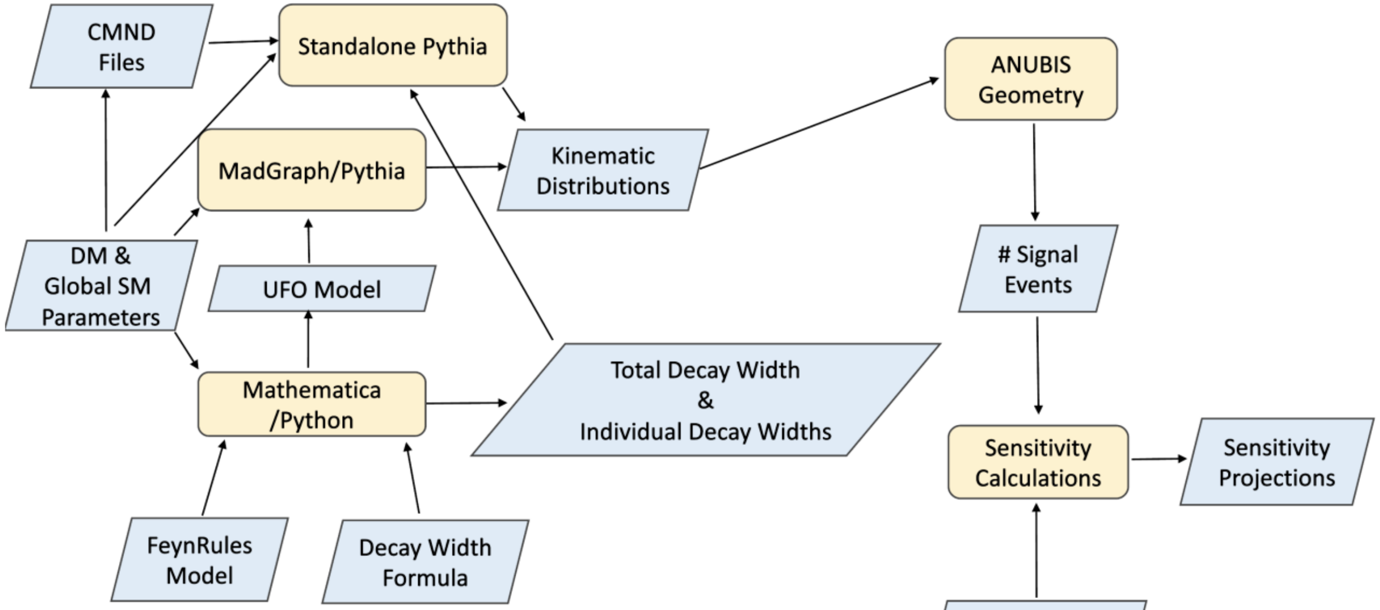
SET-ANUBIS framework

The main goal of the SET-ANUBIS framework is to provide an automated tool for making sensitivity prediction on new models.

A lot of steps like branching ratio calculation, event generation and acceptance can be automated for every models using this framework.



SET-ANUBIS framework



$$N_{LLP} = \mathcal{L}_{HL-LHC} \cdot \sigma_{LLP} \cdot \mathcal{B}(LLP) \cdot \frac{N_{obs}}{N_{gen}}$$

$\mathcal{L}_{HL-LHC}$: LHC luminosity

σ_{LLP} : LLP Production cross section

$\mathcal{B}(HNL)$: LLP Decay Branching Ratio

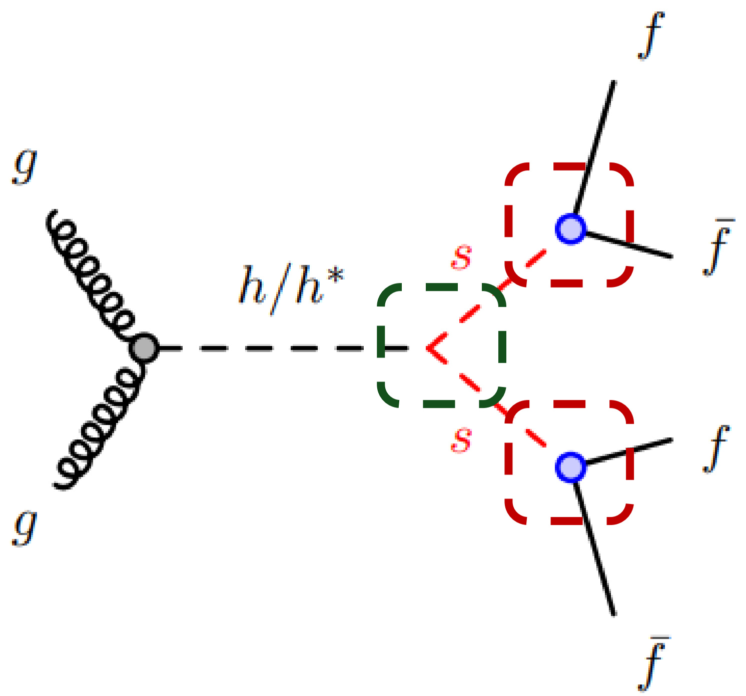
N_{obs} and N_{gen} are the number of LLP passing the cuts and the total number of events generated respectively.

$N_{LLP} \sim 90$ (Conservative data-driven [1] Background estimate)

$N_{LLP} \sim 4$ (0 Background)

[1] arXiv:1811.07370

Higgs Portal Model

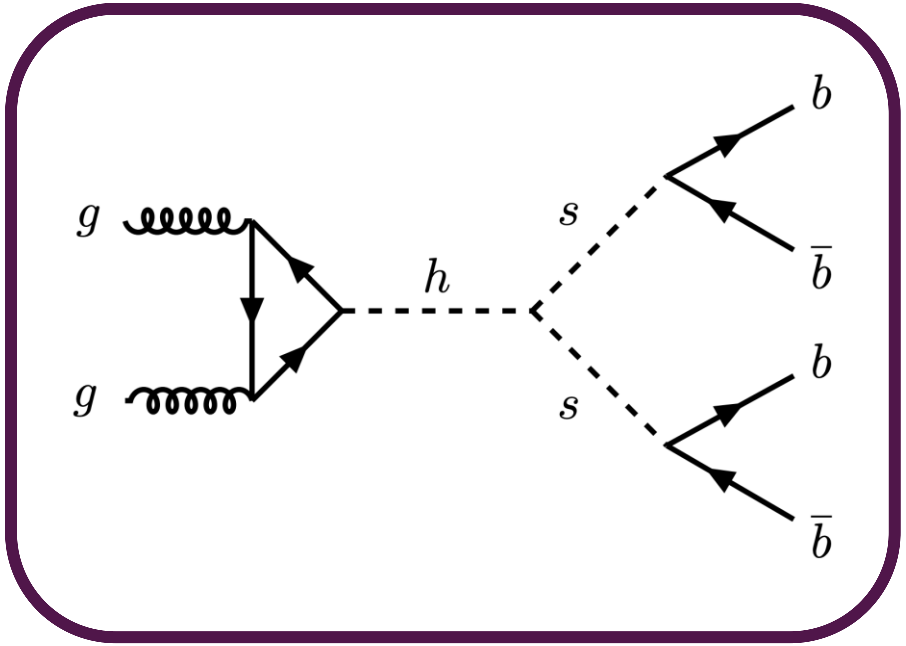


$$\boxed{\mathcal{L} \supset -\frac{\epsilon}{2} S^2 |H|^2} + \frac{\mu_S}{2} S^2 - \frac{\lambda_S}{4!} S^4 + \mu_H^2 |H|^2 - \lambda_H |H|^4,$$

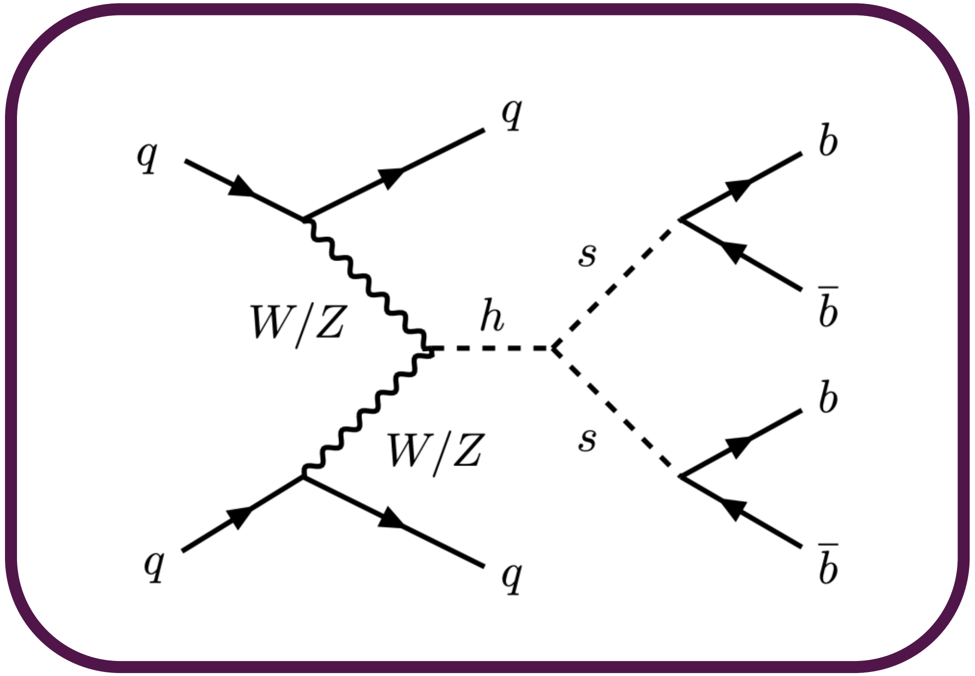
$$\boxed{\mathcal{L} \supset \sin\theta \frac{m_f}{v_h} s f \bar{f}}$$

In the Higgs Portal Model, only the Higgs interact with BSM particles. These BSM particles (S) can be long-lived. S and H can mix which then create an interaction term in the Lagrangian (in red) between SM fermions and scalar.

Higgs production and decay



Gluon-Gluon Fusion, 54.7 pb



Vector-Boson fusion, 4.28 pb

Higgsstrahlung & ttH channels are not considered in this study (neglected compared to ggF and VBF)

Higgs portal simulation

LHE files of Higgs production from ggF and VBF (MC simulation) were provided by ATLAS experiment.

Pythia8 was then used to simulate LLP production from Higgs and decay to $b\bar{b}b\bar{b}$.

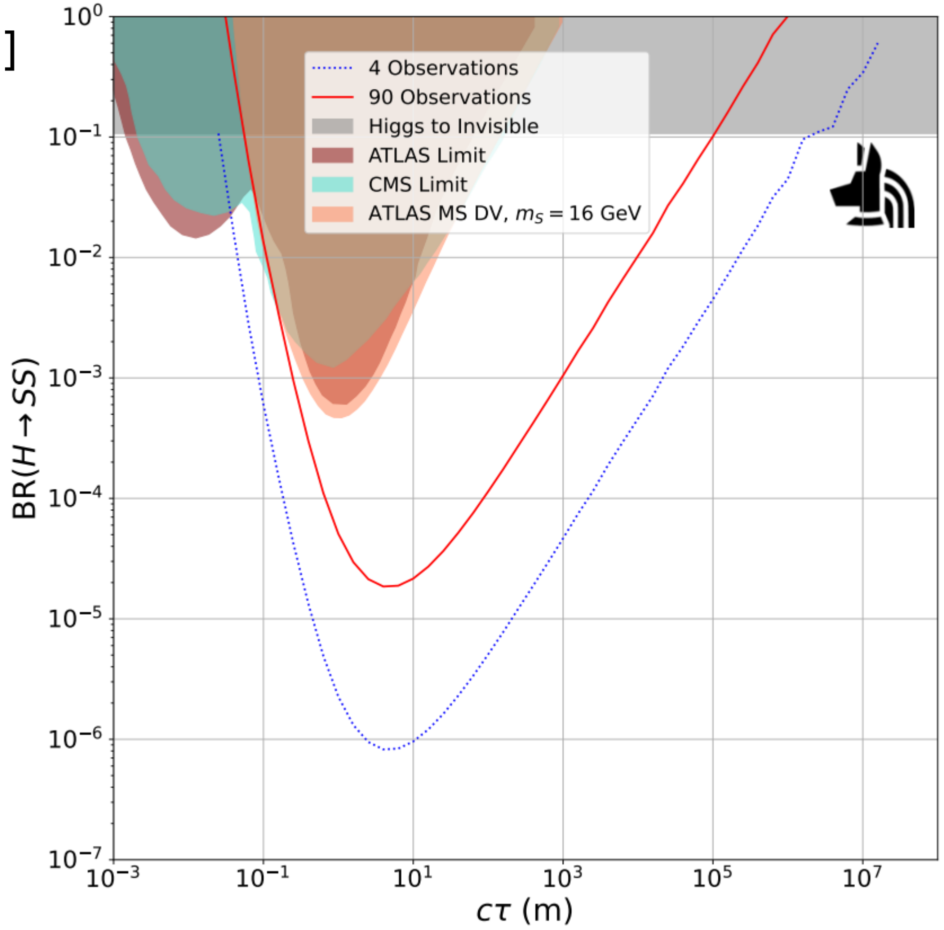
Higgs Production Mechanism	LLP Mass (GeV)	Number of LLPs
ggF	10	76444000
ggF	20	75944000
ggF	30	76112000
ggF	40	76104000
VBF	10	17976000
VBF	20	17916000
VBF	30	17876000
VBF	40	17996000

[1]

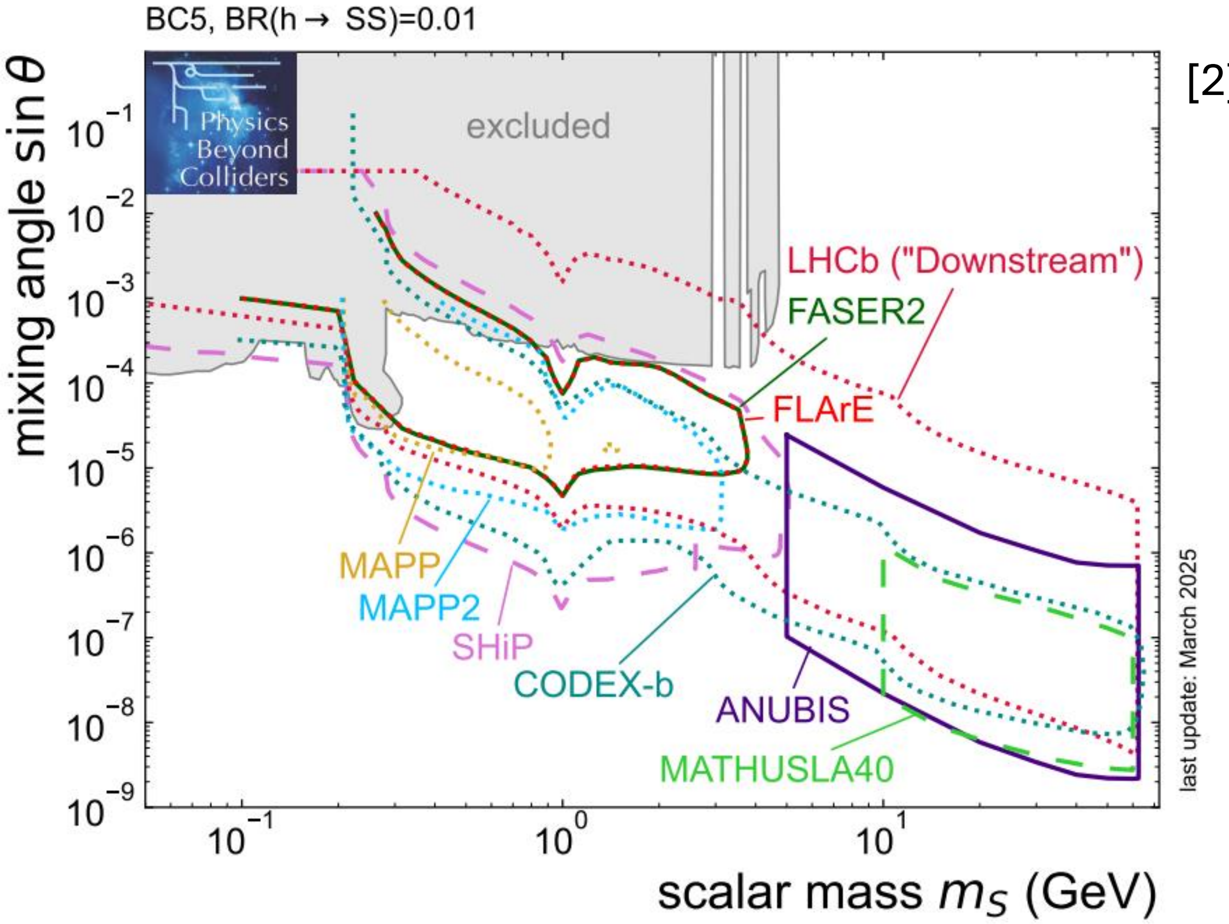
[1] Thomas Peabody Satterthwaite, thesis, 2022

Higgs portal limits

[1]



[2]



[1] arXiv:2504.03195 [2] arXiv:2505.00947

Heavy Neutral Lepton (HNL)

$$\mathcal{L}_{\rm HNL} = \frac{i}{2}\overline{N}_i \not{\partial} N^i - \boxed{\frac{m_{N_i}}{2}}\overline{N}^i N_i^c - \boxed{y_{i\alpha}\overline{N}^i \tilde{\phi} L^\alpha} + h.c$$

$$\begin{pmatrix} 0_{\alpha\beta} & \boxed{\frac{y_{1\alpha}v}{\sqrt{2}}} \\ \boxed{\frac{y_{1\alpha}v}{\sqrt{2}}} & \boxed{m_{N_1}} \end{pmatrix}$$

Seesaw mechanism to generate masses for neutrinos and HNL

Mass basis $\Longleftrightarrow$ **Gauge basis**

$$\nu_l^m = \cos(\theta_{1\alpha})\,\nu_\alpha^L + \sin(\theta_{1\alpha})\,N_1^c$$

$$N_l^m = \cos(\theta_{1\alpha})\,N_1 - \sin(\theta_{1\alpha})\,(\nu_\alpha^L)^c$$

H vertex

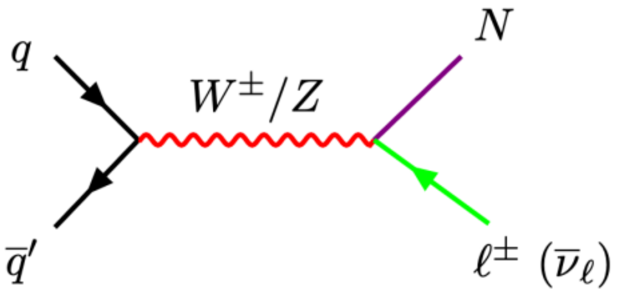
$$\sum_\alpha -|U_{1\alpha}|^2 \frac{m_N}{v} h(\overline{\nu}_{1\alpha}^m (N^m)^{1\alpha} + \overline{N}_{1\alpha}^m (\nu^m)^{1\alpha})$$

Z,W vertex

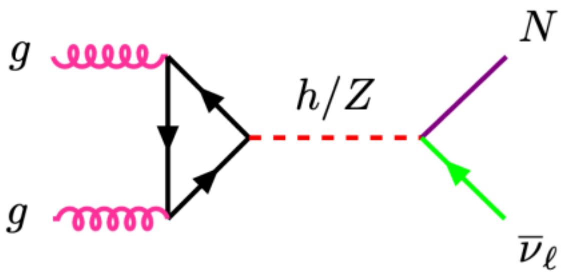
$$\sum_\alpha \frac{g|U_{1\alpha}|^2}{\sqrt{2}} \Big[(W_\mu (\overline{l}_L^m)^{1\alpha} \gamma^\mu N_{1\alpha}^m + h.c) - \frac{\sqrt{g^2 + g'^2}}{\sqrt{2}g} Z_\mu \overline{\nu}_{1\alpha}^m \gamma^\mu (N^m)^{1\alpha} + (\overline{N}^m)^{1\alpha} \gamma^\mu \overline{\nu}_{1\alpha}^m) \Big]$$

HNL Production

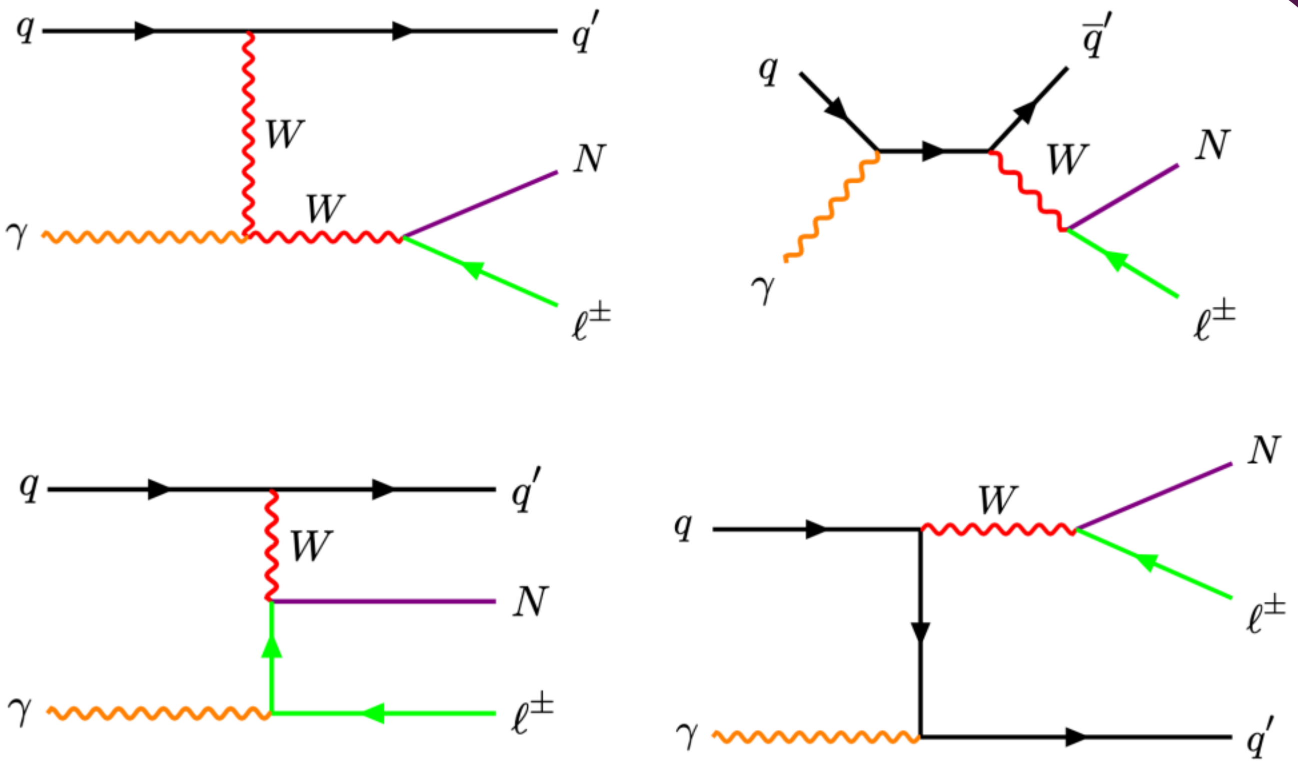
CC & NC Drell-Yan



Gluon-Gluon Fusion

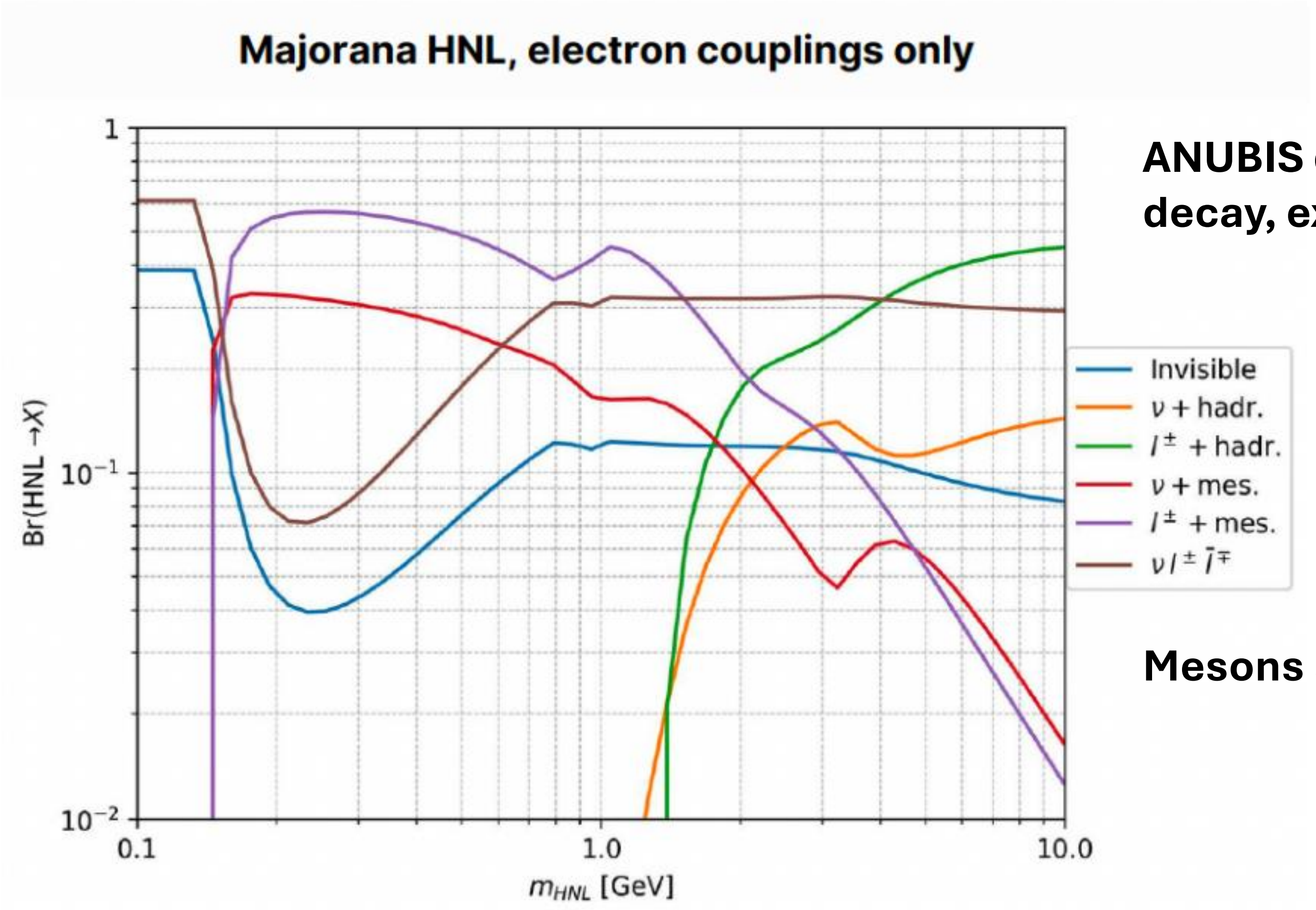


$W\gamma$ fusion



[1] arXiv:2504.03195

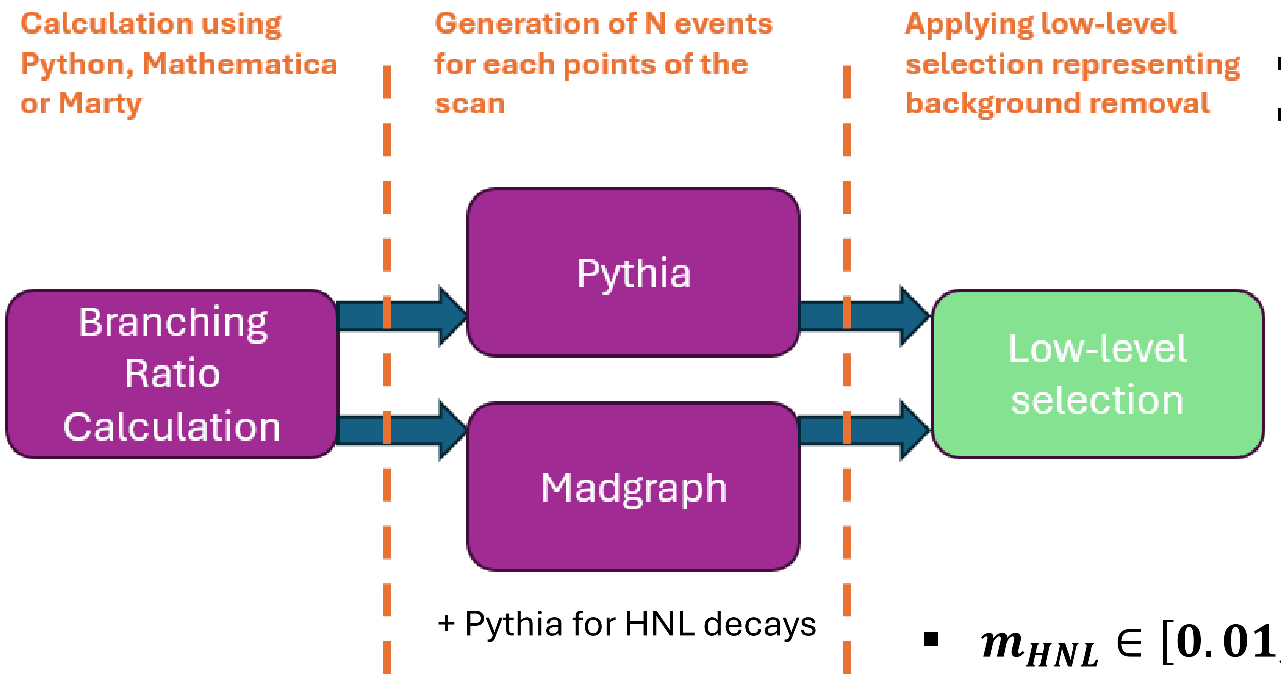
HNL Decays



ANUBIS detector will be sensitive to every HNL decay, except invisible one ($\nu\bar{\nu}\nu$)

Mesons are accessible for larger HNL masses.

HNL Simulation



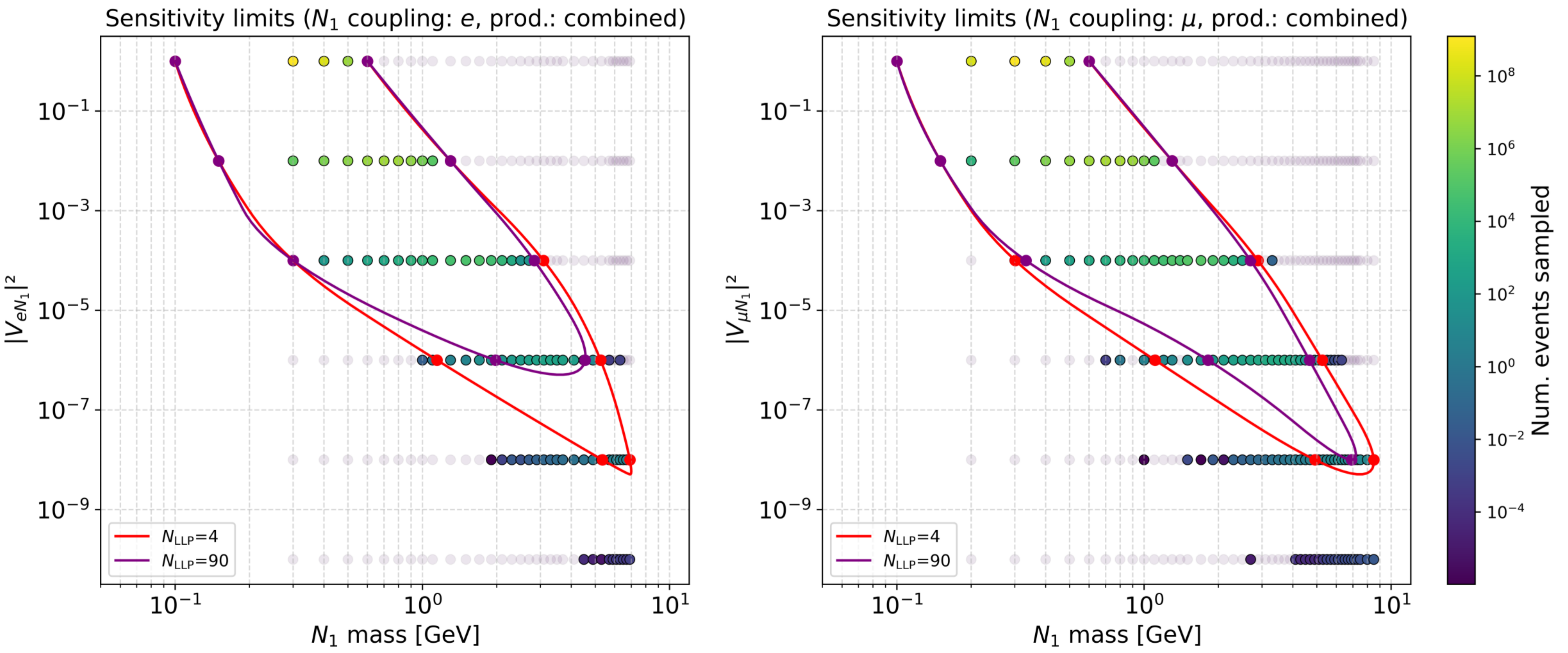
Nominal Selection:

- p > 0.1 GeV, p_T(track) > 5 GeV, p_T(jet) > 15 GeV, E_T^{miss} > 30 GeV, ΔR(LLP, jet/tr) > 0.5.
- Require hits in 2 RPC layers.
- 100% Hit efficiency in RPCs

Scan over a range of masses and couplings for HNL, using different production and coupling (e and μ) :

- $\boldsymbol{m_{HNL} \in [0.01, 10]\ GeV}$
- $\boldsymbol{|V_p|^2_{HNL} = 10^i,\ i \in \{-5, -4, -3, -2, -1, 0\},\ p \in \{e, \mu\}}$

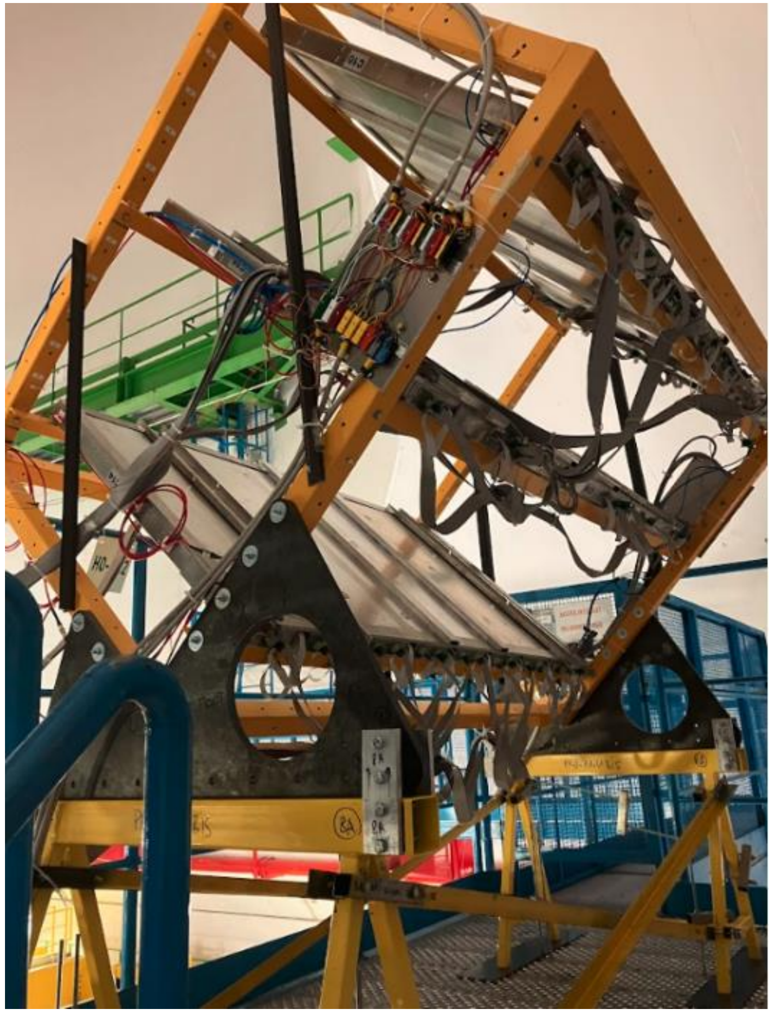
HNL Limits



Sensitivity limits (N_1 coupling: e, prod.: combined)
$|V_{eN_1}|^2$
N_1 mass [GeV]
N_{LLP}=4
N_{LLP}=90
Sensitivity limits (N_1 coupling: μ, prod.: combined)
$|V_{\mu N_1}|^2$
N_1 mass [GeV]
N_{LLP}=4
N_{LLP}=90
Num. events sampled

Part IV :
Data taking/analysis

Current prototype in ATLAS



- Started taking data since 2024
- Ongoing data analysis
  - Track and Vertex reconstruction
  - Timing Corrections
  - Cosmics Study
- Inclined to align with IP
- Three RPC modules (Triplet + Singlet + Doublet)

Four main goals

Proof of concept

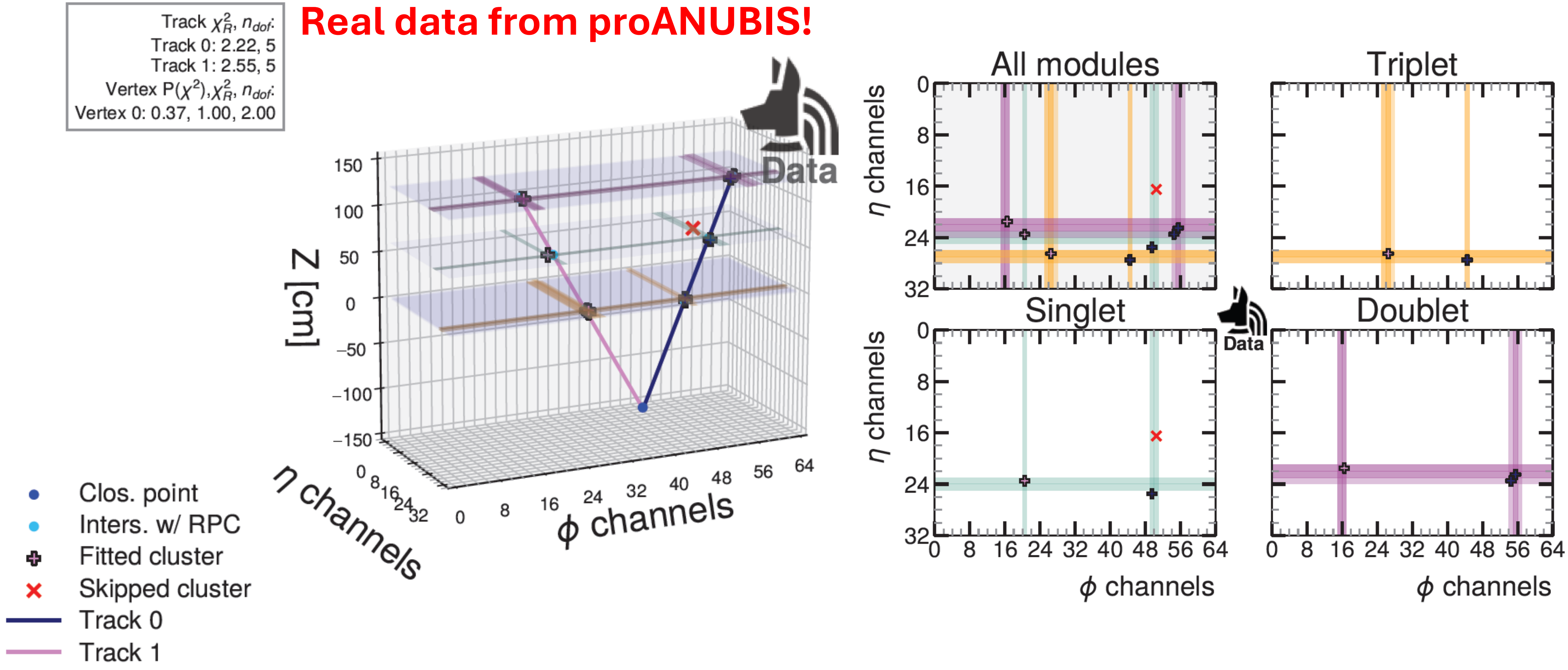
Measure expected background level

Develop analysis pipelines

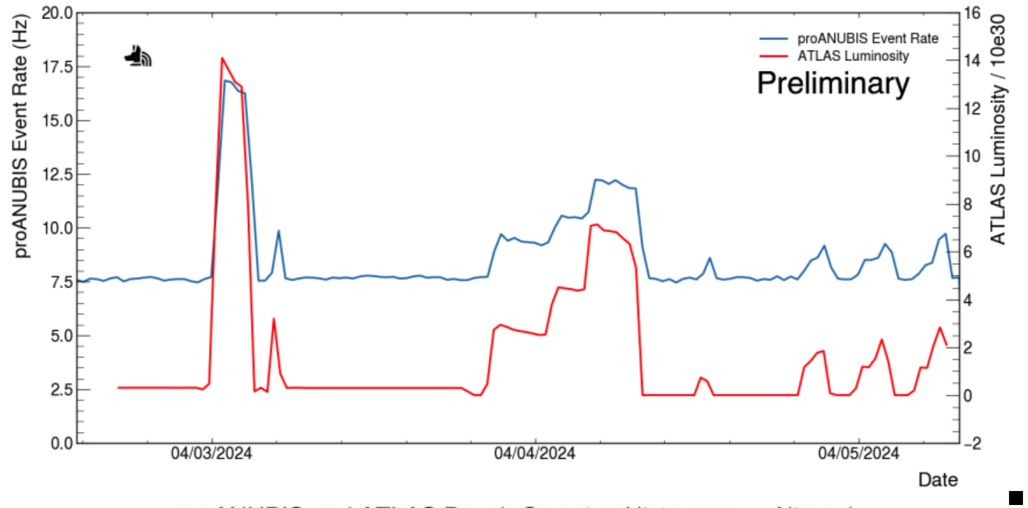
Evaluate detector performance

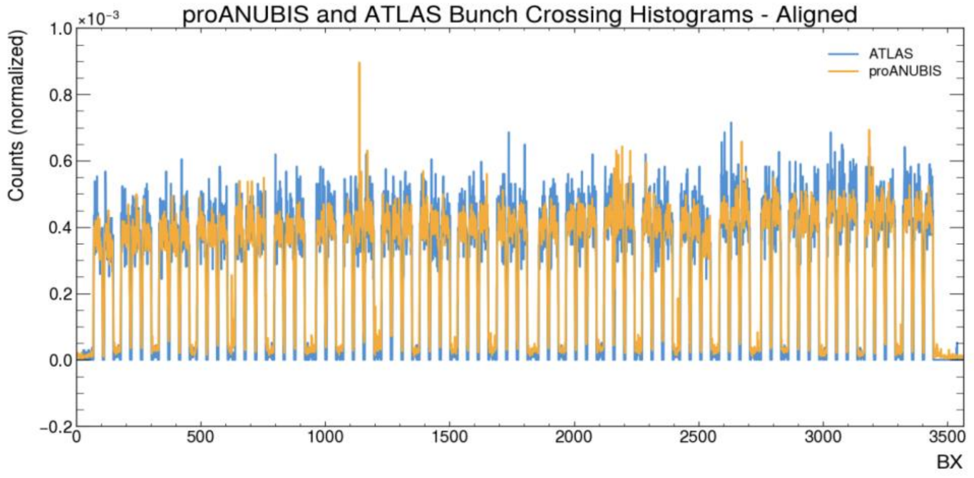
Ongoing Data Analyses

Real data from proANUBIS!



ATLAS Synchronisation



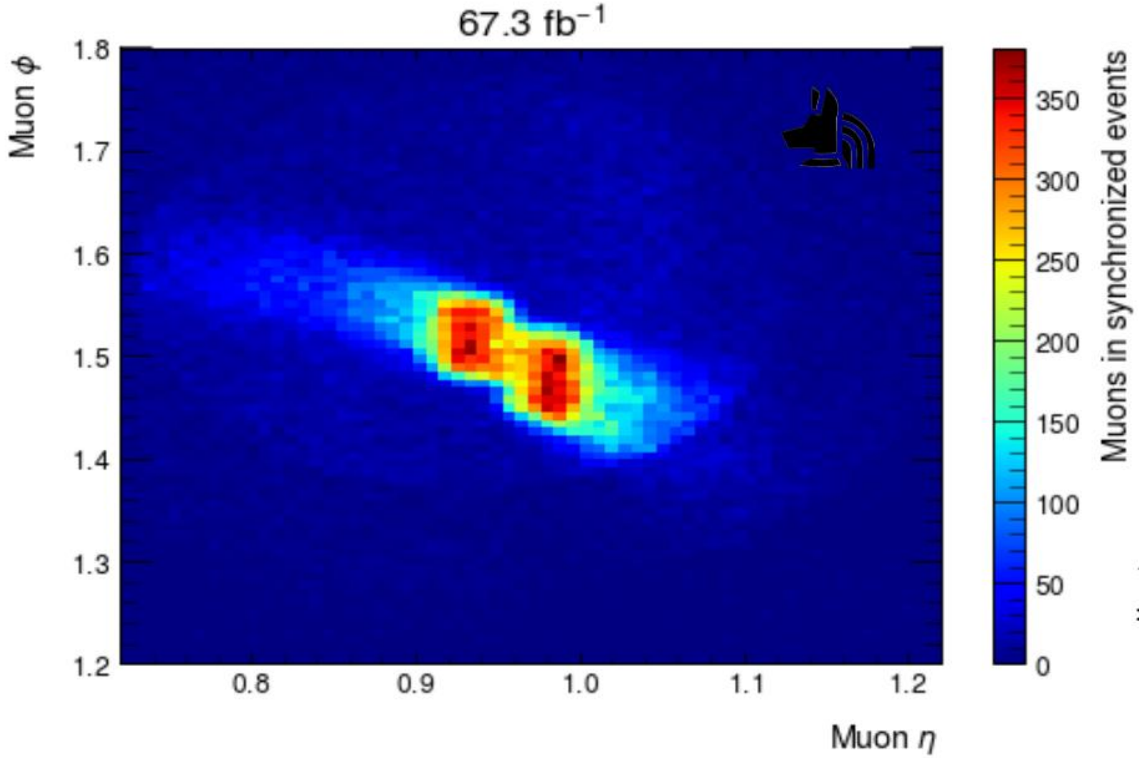


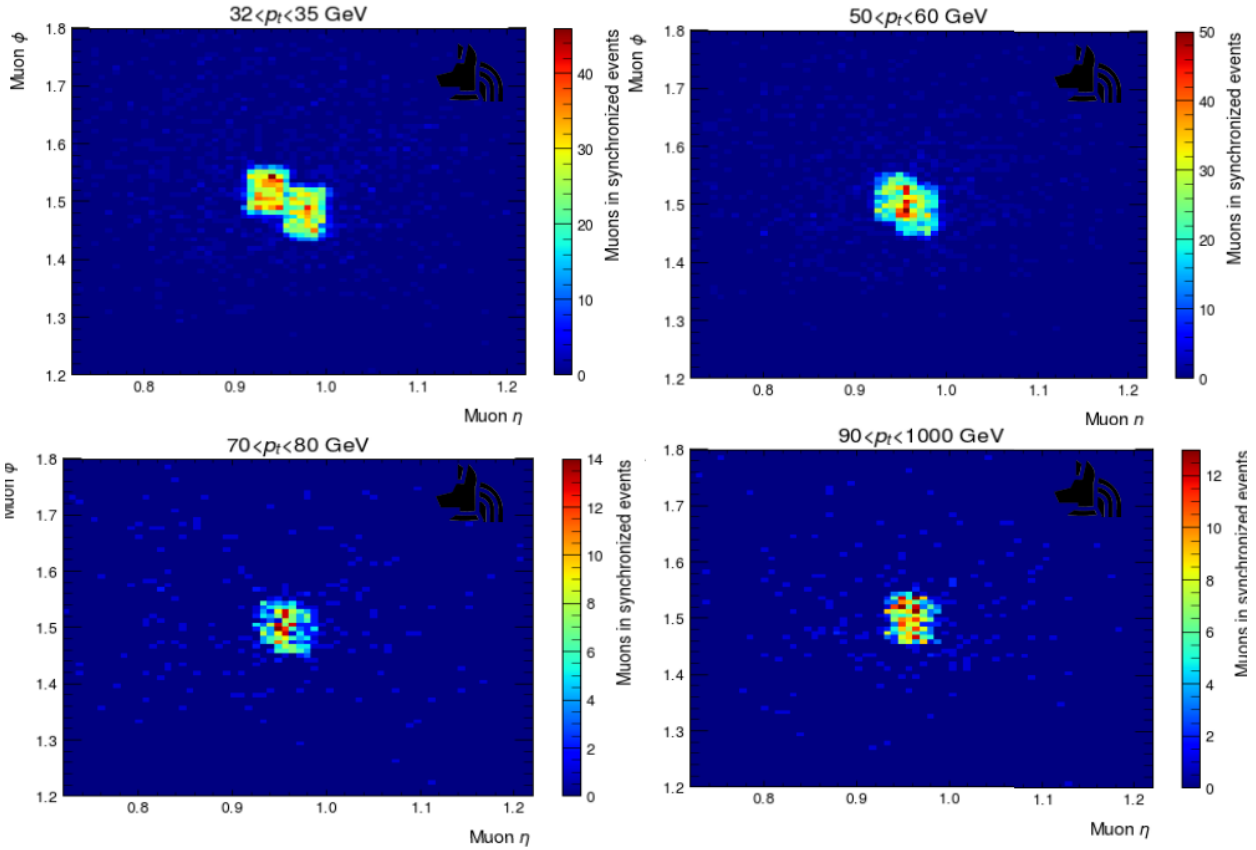
ANUBIS and ATLAS BCR's aligned: Offset ~114 bx = 2850 ns between ATLAS and ANUBIS

Global time + Bunch crossing = Actual event

- Bunch crossing ID matching between **proANUBIS** and ATLAS bunch crossing, and the readout time and ATLAS global time.
- ANUBIS is able to measure the **same muons** as ATLAS.
- Hit-to-Hit synchronisation allows for very precise study on Background, Slow-muon and basic spectroscopy.

Ongoing Data Analyses





Around 100 000 events involving muons has been seen in both **ATLAS** and **proANUBIS** detector. Making cuts on the muons transverse momentum allows for proANUBIS geometry reconstruction

Summary

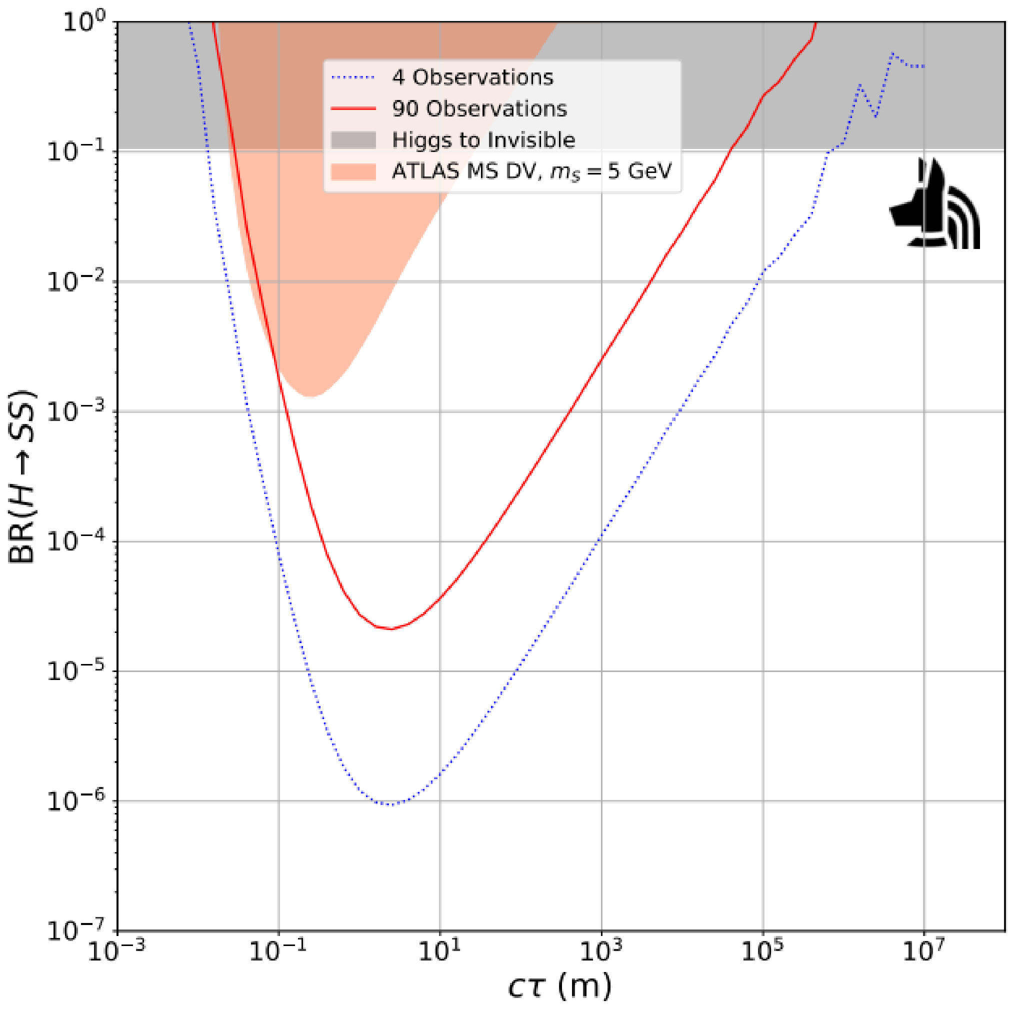
- ANUBIS's potential for LLPs discovery seems excellent, given the last study on HNL and Higgs portal.
- proANUBIS has demonstrated its capacity to take relevant data and synchronise with ATLAS in an event-by-event basis.
- Data analysis is still ongoing and will provide new results on background soon.
- Additional sensitivity studies are ongoing for other BSM models.

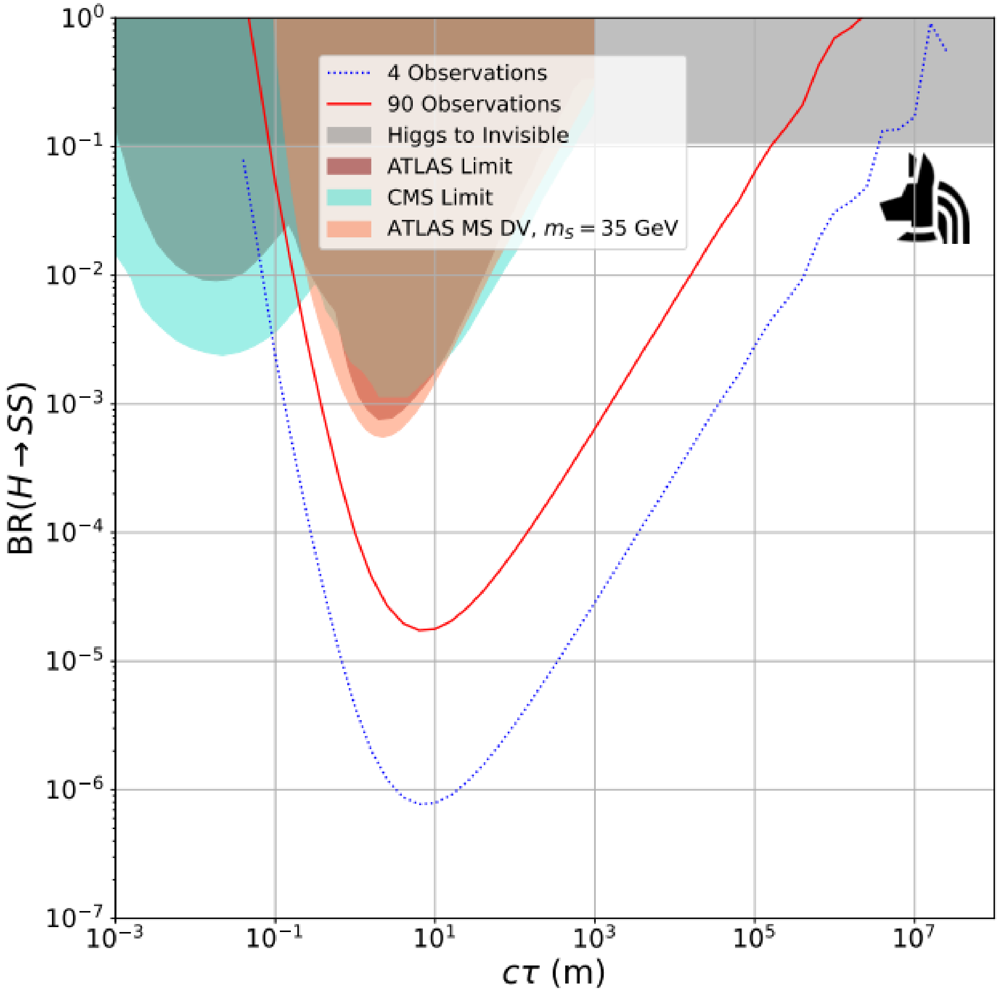
If you're interested and want to get involved, contact one of us !

Thanks for your attention !

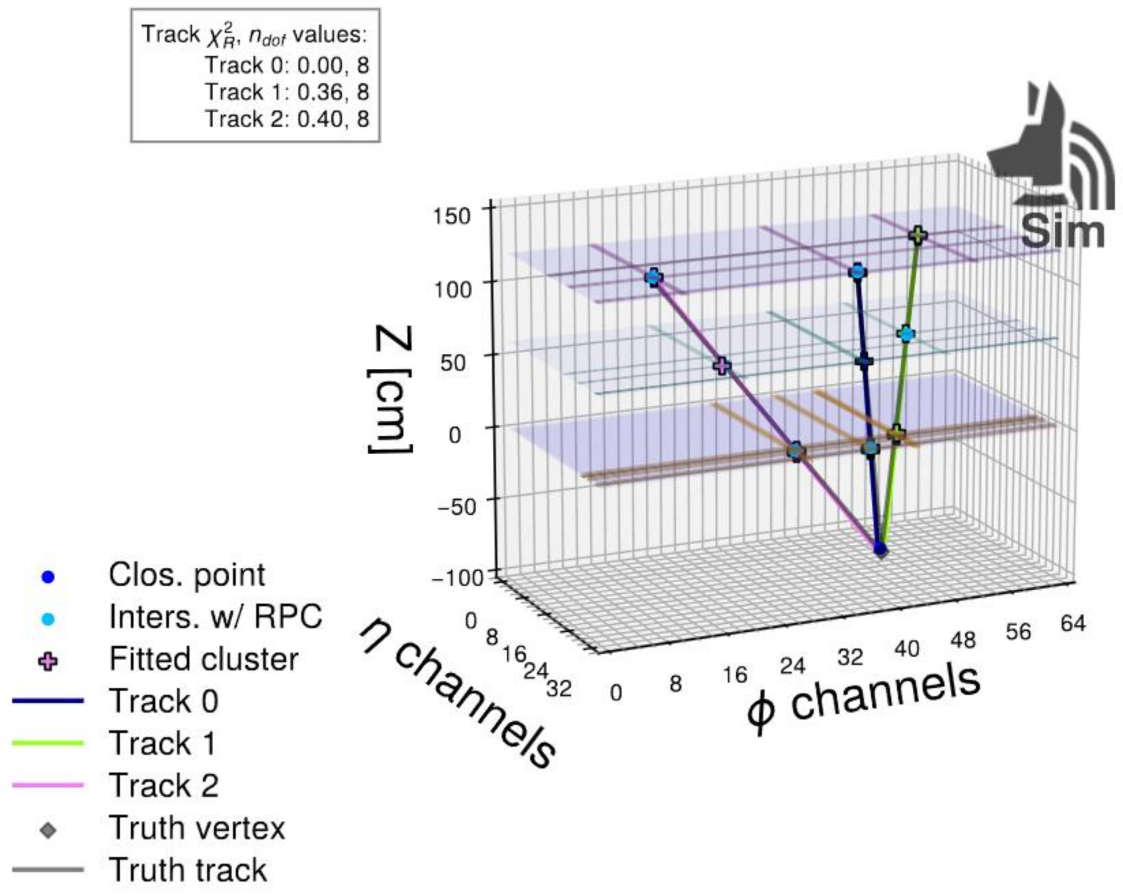
Bonus Part : Backup

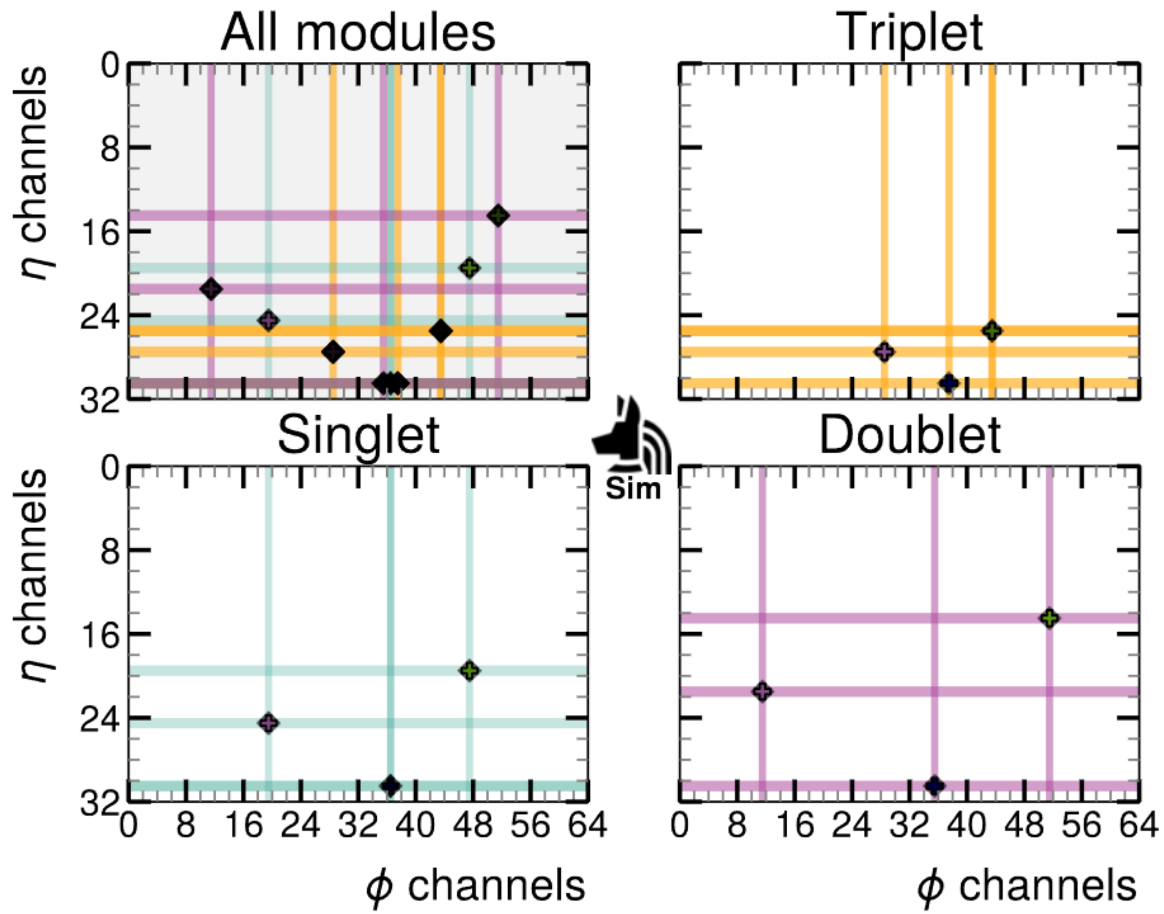
Higgs portal limits (10 + 40 GeV)





Ongoing Data Simulations





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