August Update

Liverpool FASER Meeting

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August 22, 2025

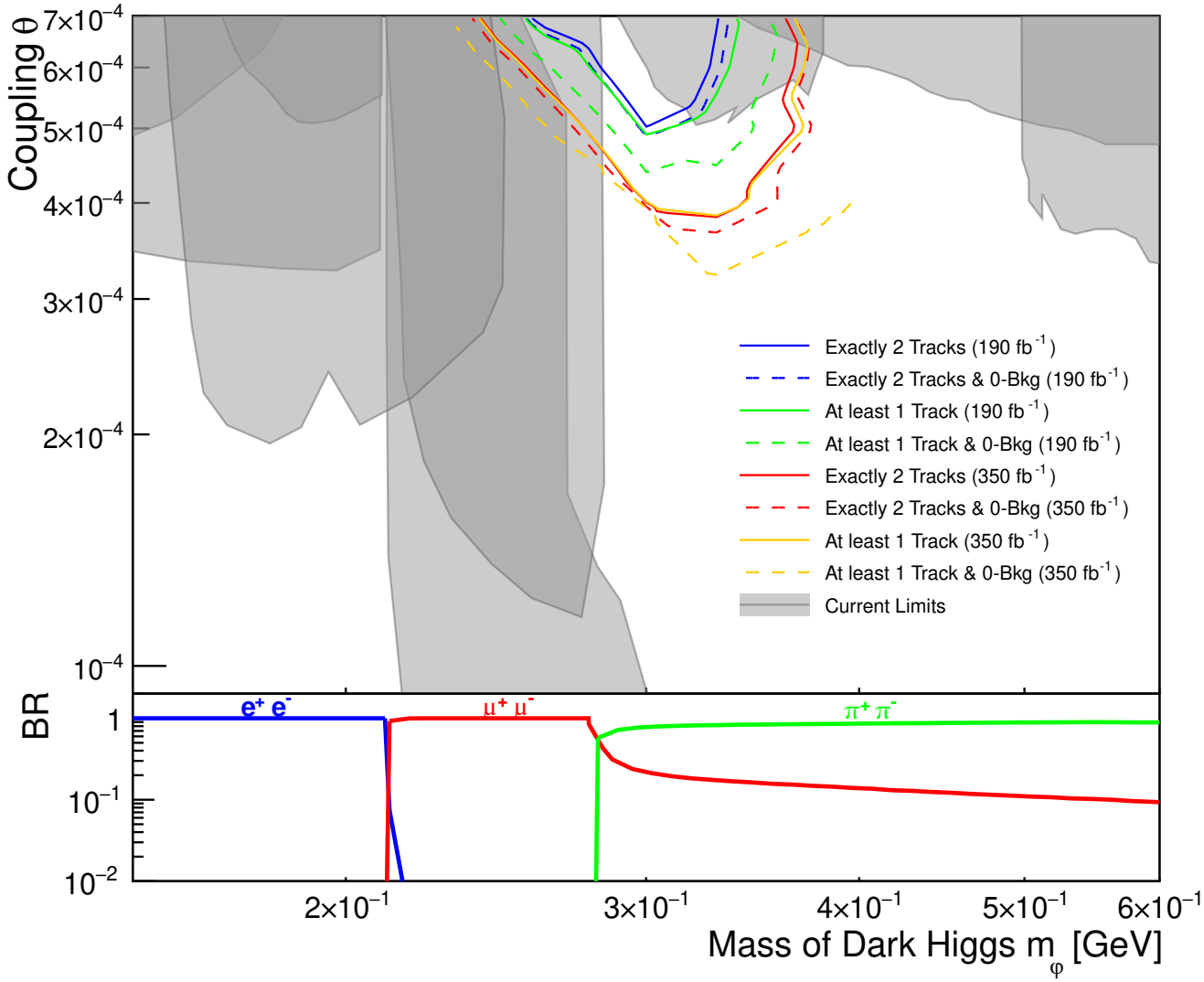
Outline

- Monte Carlo Production
- Current State of Dark Higgs Analysis
- UpPhilic...
- Other Studies

Mone Carlo Production

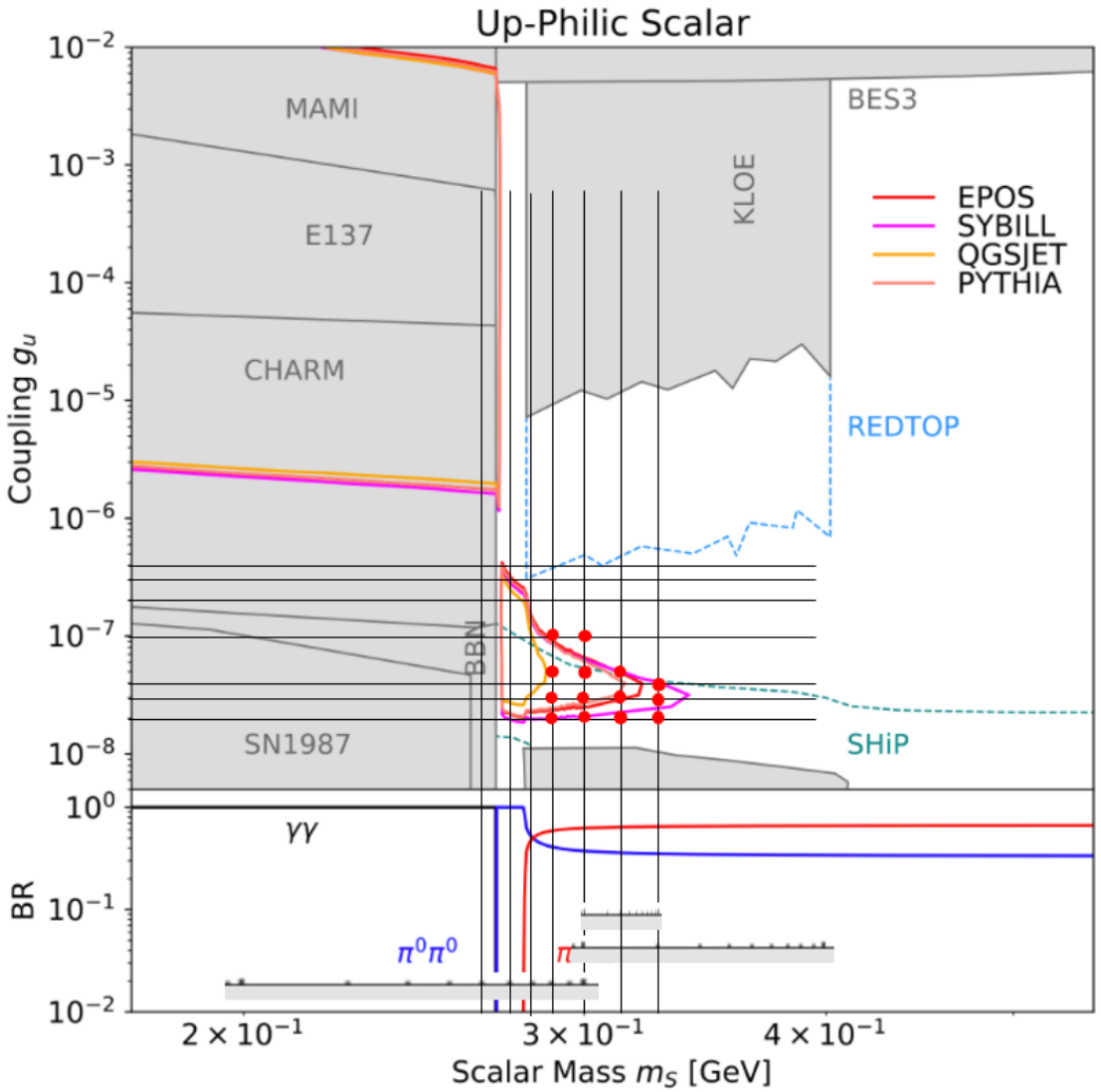
- Alma9 based simulation validated for FORESEE and GENIE
- New Samples Produced
  - ALPs-Flat samples simulated in Alma9
  - UpPhilic samples simulated in Alma9*
- Samples to be produced
  - ALPs-Flat sample with +160 crossing angle
  - Dark Photons with +160 crossing angle
  - Dark Photons in extended grid
  - Flat samples for Dark Photon Analysis
  - Mixed Dark Photon+Higgs samples
- No major issues, minor issues with storage.

State of Dark Higgs



- Waiting for higher luminosity ?

New Model – UpPhilic



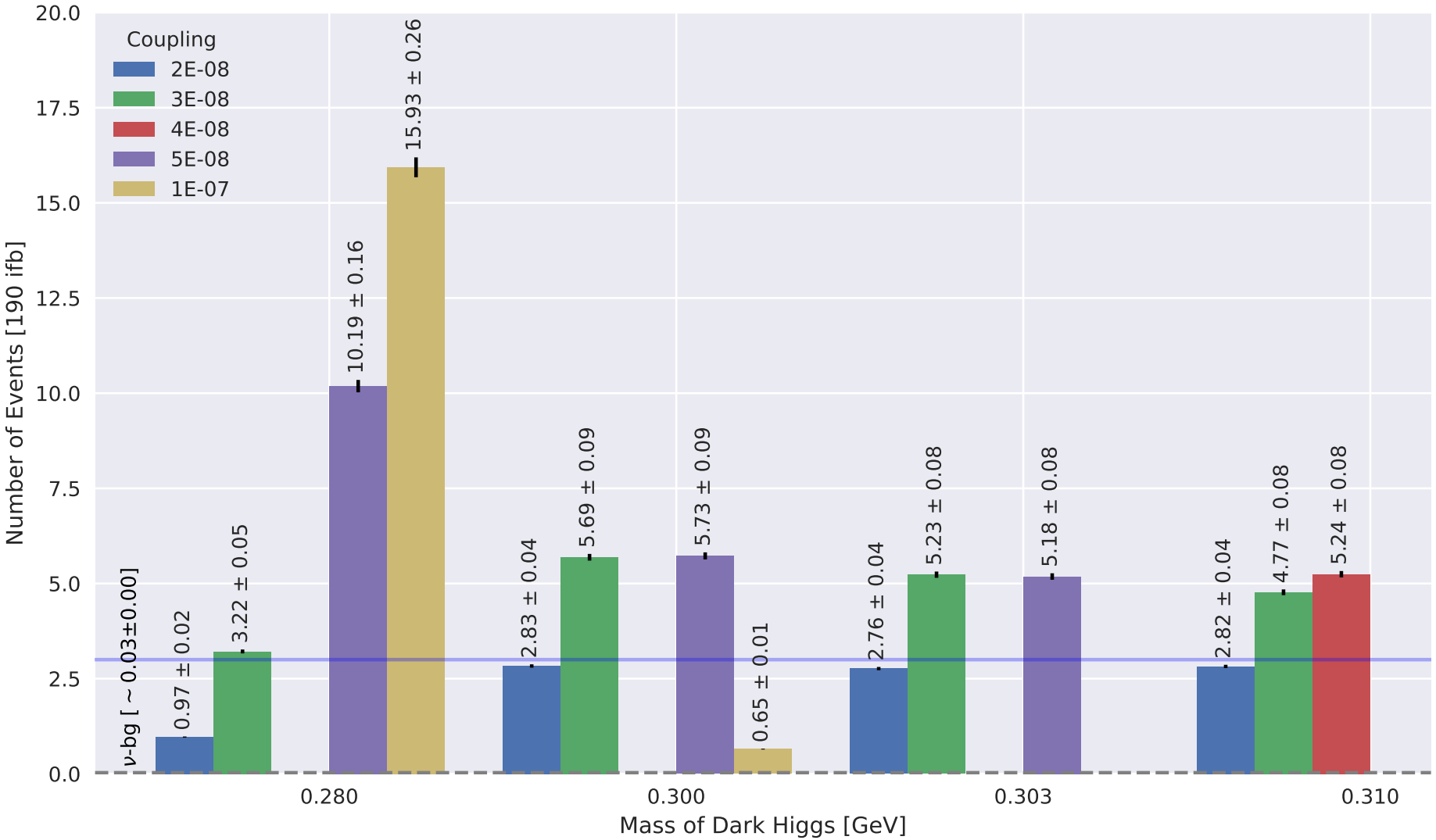
- 14 Mass Coupling points generated with decay into $\pi^+\pi^-$

Cumulative CutFlow

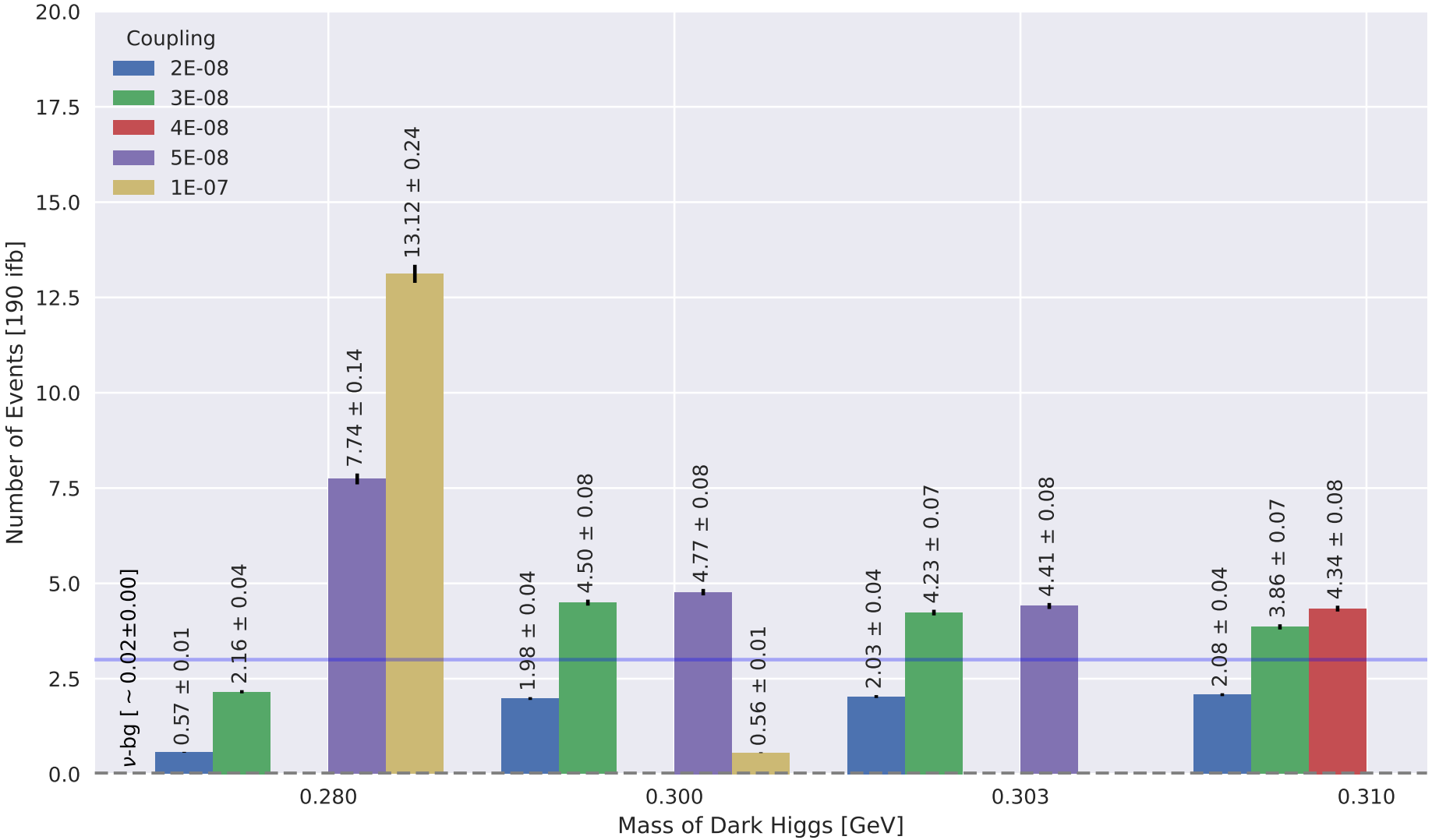
Cut	Cumulative UpPhilic Sample			
	Input	Pass	Eff	CumEff
Colliding BCID	280000	280000	100.000	100.000
Timing Trigger	280000	280000	100.000	100.000
Timing Not Saturated	280000	264673	94.526	94.526
VetoNu_raw_charge $\leq$ 40	264673	264581	99.965	94.493
Veto1_raw_charge $\leq$ 40	264581	263189	99.474	93.996
Timing_raw_charge $>$ 70	263189	94795	36.018	33.855
Preshower_raw_charge $>$ 2.5	94795	94790	99.995	33.854
At least one good track	94790	82278	86.800	29.385
At least two good tracks	82278	73719	89.597	26.328
Exactly two good tracks	73719	62274	84.475	22.241
Track_R $<$ 100	62274	60180	96.637	21.493
Track_R $<$ 95	60180	55317	91.919	19.756
Calo_E_EM_fudged $>$ 0 GeV	55317	55084	99.579	19.673
Calo_E_EM_fudged $>$ 50 GeV	55084	46962	85.255	16.772
Calo_E_EM_fudged $>$ 100 GeV	46962	42537	90.577	15.192
Calo_E_EM_fudged $>$ 250 GeV	42537	29172	68.580	10.419
Calo_E_EM_fudged $>$ 500 GeV	29172	14872	50.980	5.311
Calo_E_EM_fudged $>$ 1 TeV	14872	4259	28.638	1.521

- Surprisingly good efficiency for Tracking cuts.
- Calo Requirement more viable than previous thought..

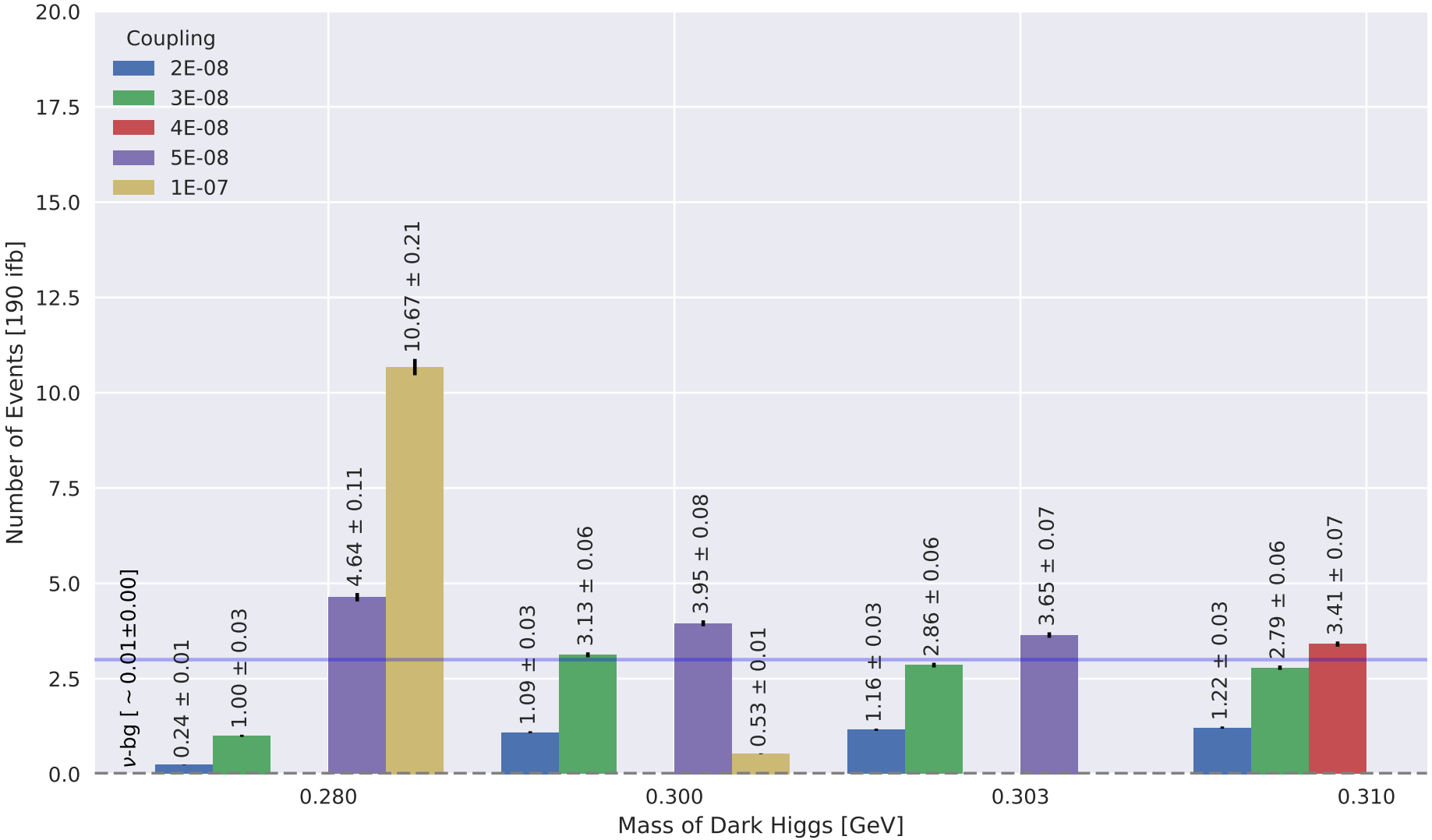
Expected Events @ 2 Good Tracks (w/o Calo)



Expected Events @ 2 Good Tracks+Calo=100 GeV



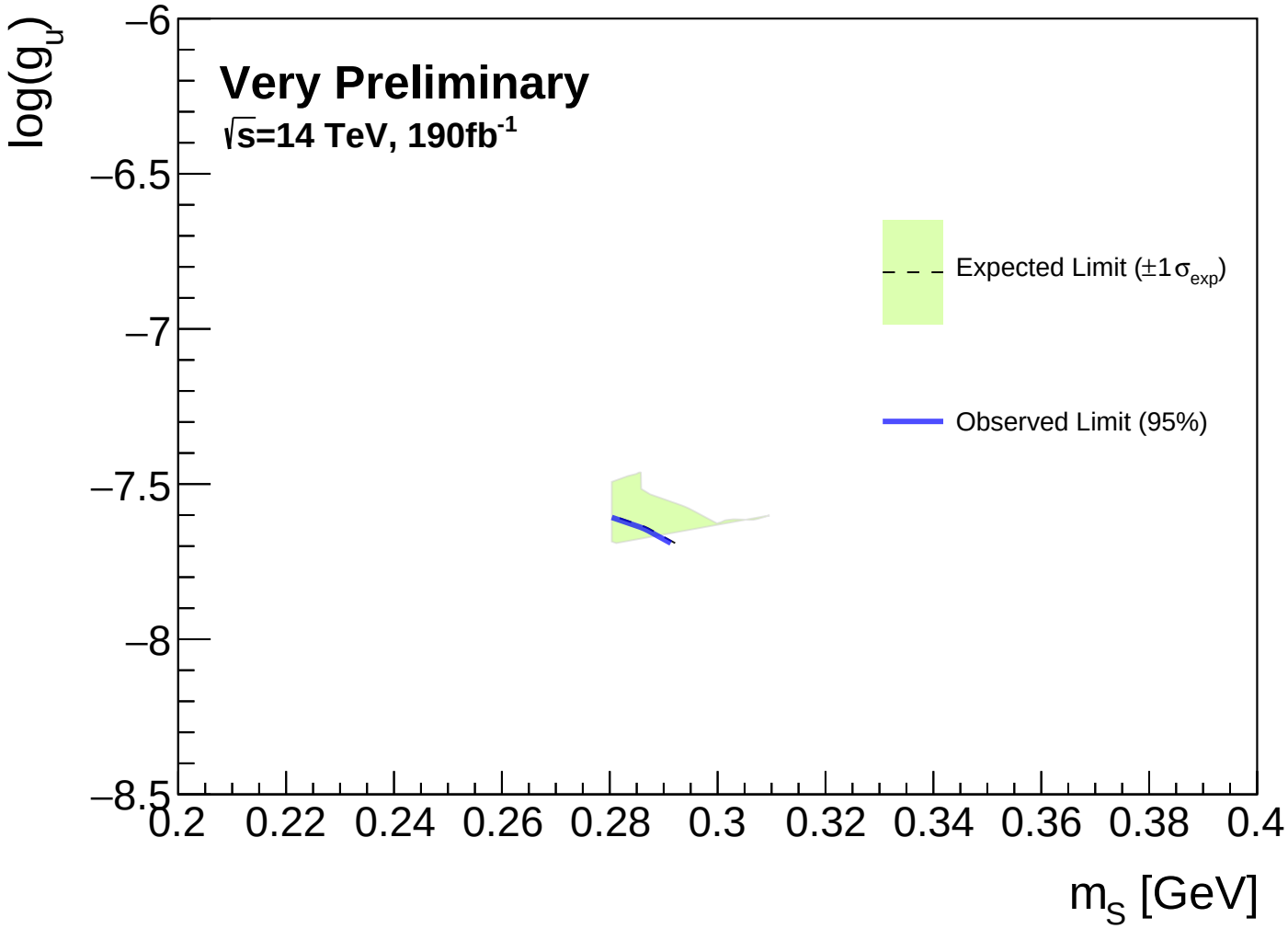
Expected Events @ 2 Good Tracks+Calo=250 GeV



So.

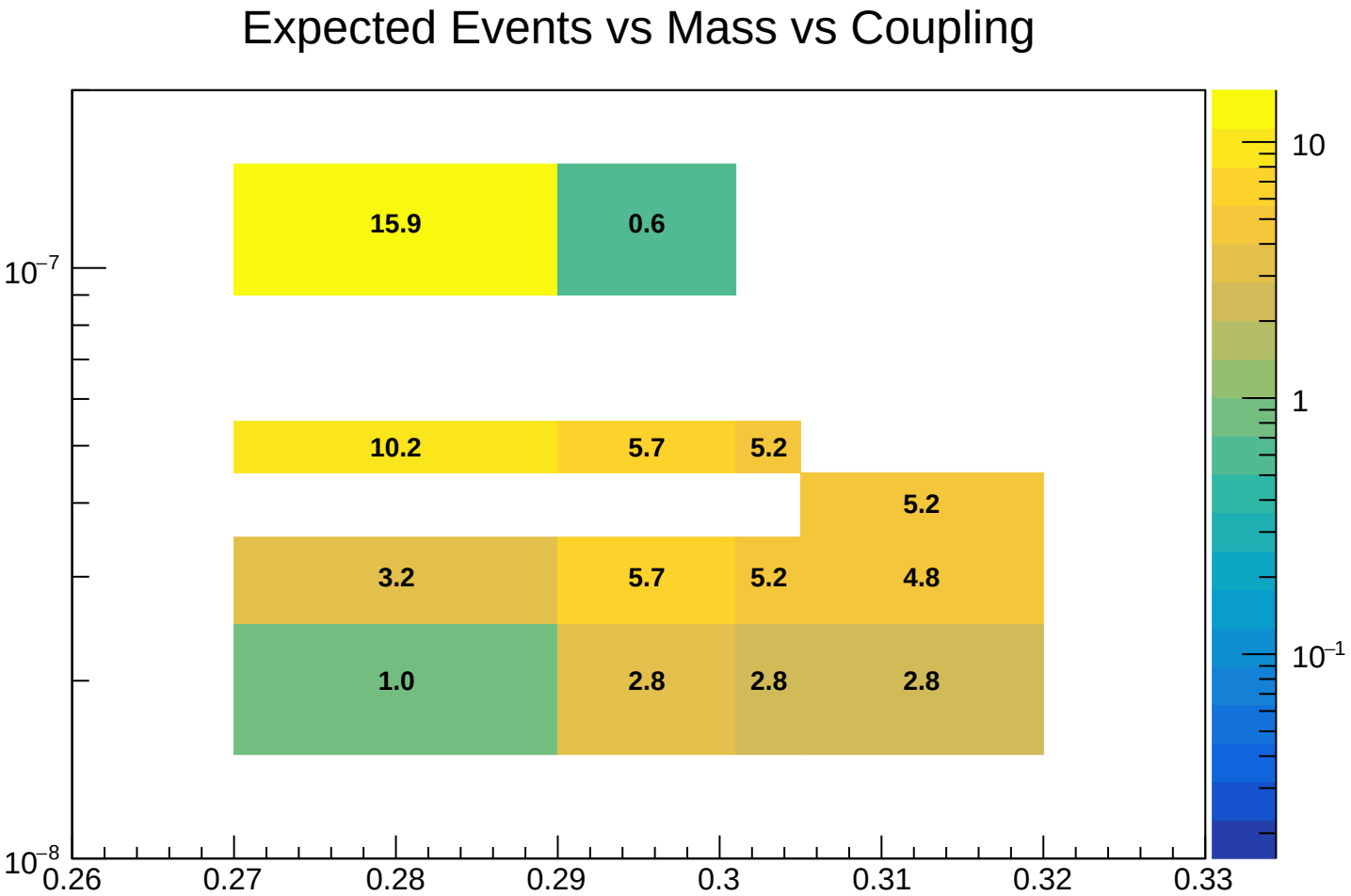
- Surprisingly good Yield from the UpPhilic samples.
- Calo Requirement more viable than previous thought.
- Need to check Calo deposit for each sample individually.
- Should be easy to get an Exclusion limit similar to the Dark Higgs....

Exclusion Contour?



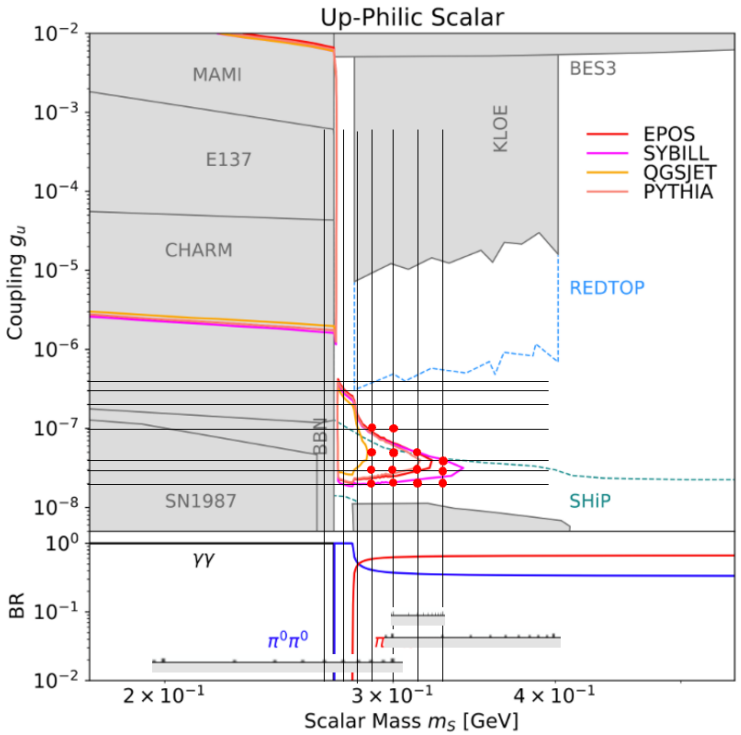
- No contours found....!

What Happened?



- The interpolation algorithm couldn't close off the contours since it didn't have samples on the top/right/left edges.

Stepping Back...



- But, FORESEE suggested that approximate contour location...
  - In the above plot FORESEE was looking at the $\gamma\gamma$ and $\pi^0\pi^0$ reach?
  - It was also done for 60 ifb? – Probably intended for previous ALPs Analysis

Redoing the Plot – Neutral @ 60 ifb

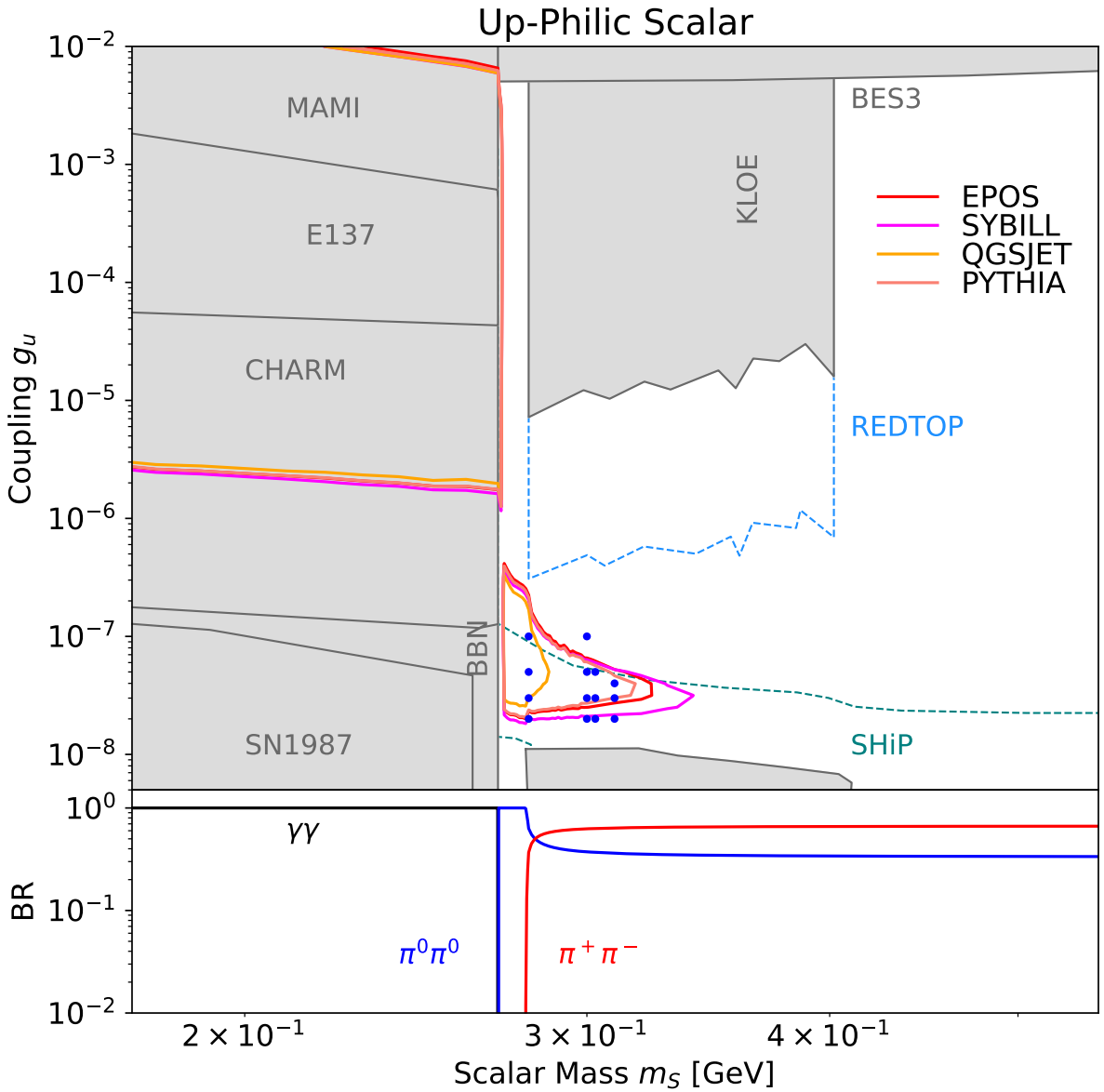


Figure: Expected reach for UpPhilic at 60 ifb in the $\gamma\gamma$ and $\pi^0\pi^0$ channels

Redoing the Plot – Charged @ 60 ifb

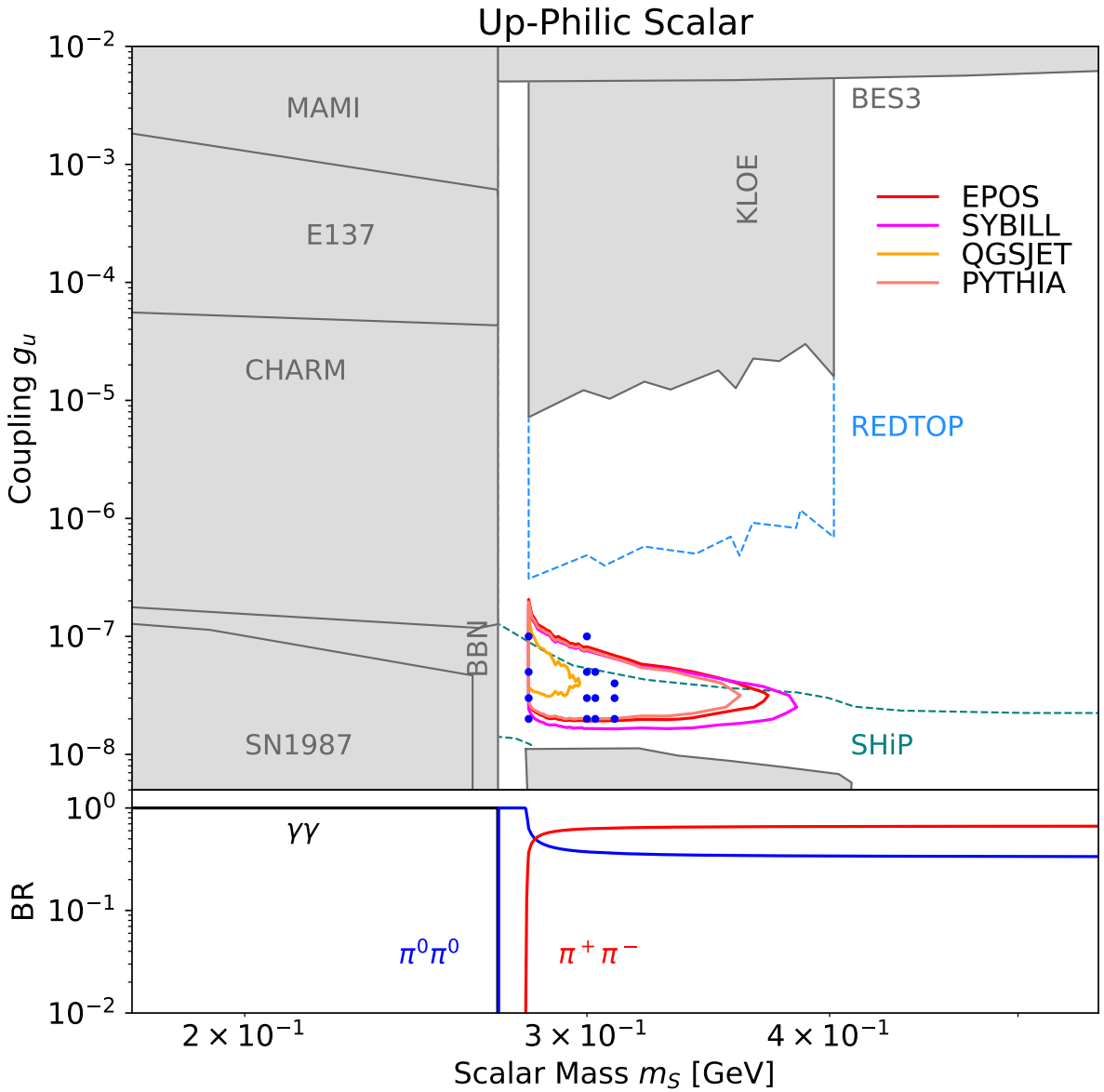


Figure: Expected reach for UpPhilic at 60 ifb in the $\pi^+\pi^-$ channels

Redoing the Plot – Charged @ 190 ifb

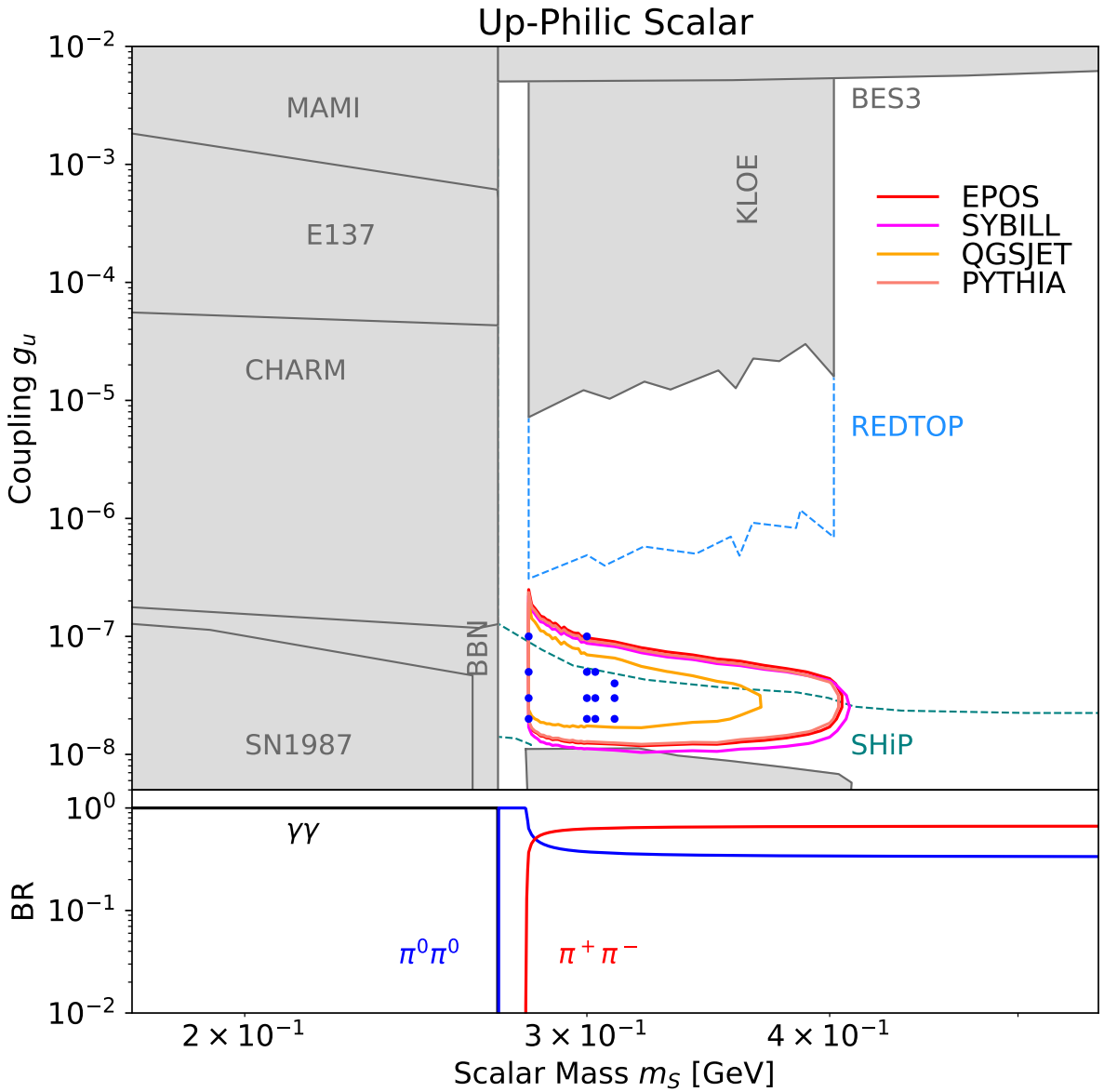


Figure: Expected reach for UpPhilic at 190 ifb in the $\pi^+\pi^-$ channels

Redoing the Plot – Charged+Neutral @ 190 ifb

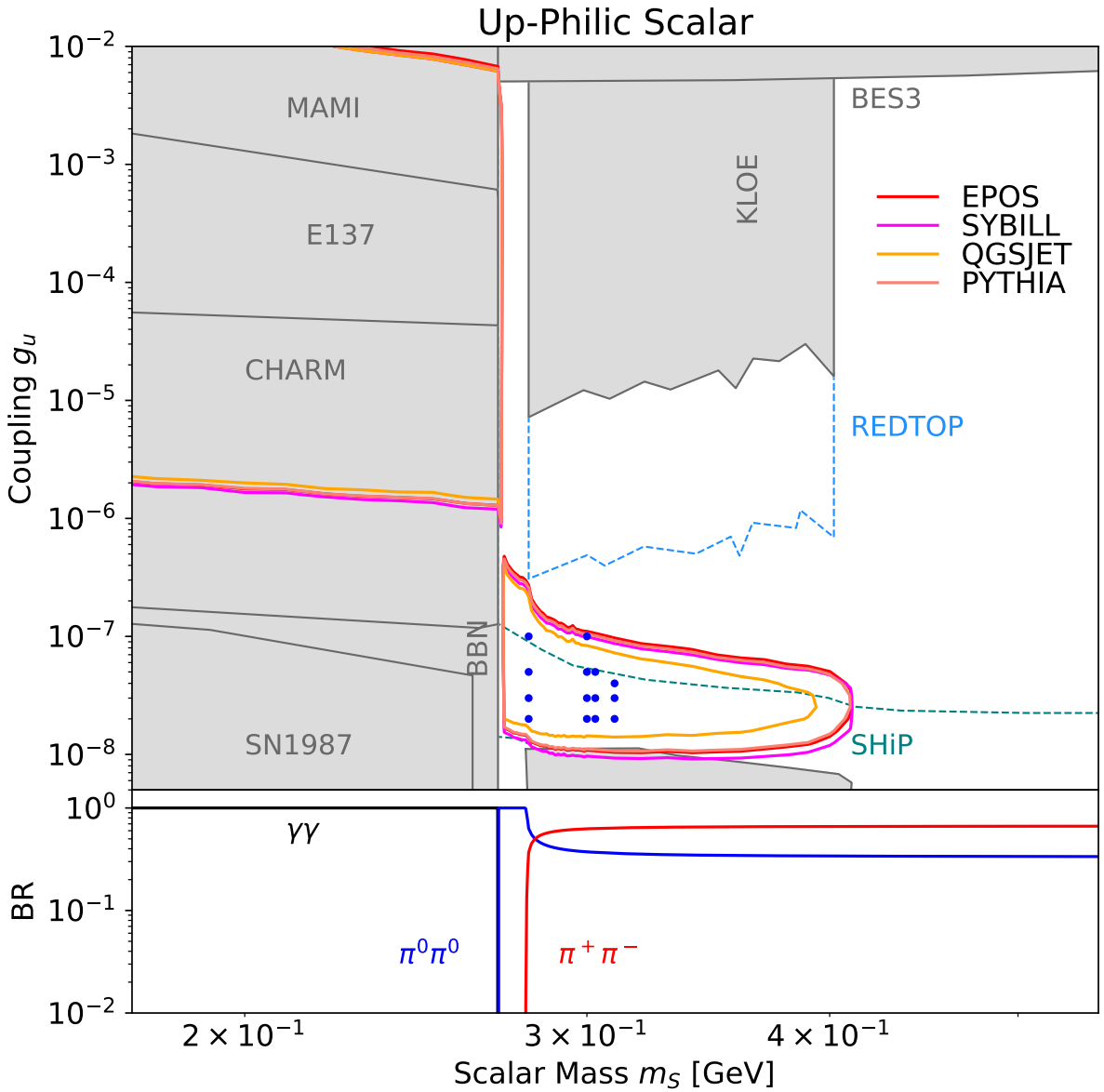


Figure: Expected reach for UpPhilic at 190 ifb in the $\gamma\gamma + \pi^0\pi^0 + \pi^+\pi^-$ channels

Summary on UpPhilics

- So can exclude certain mass points for now...
- But can't seem to get the interpolation into a contour yet.
  - Interpolation can't close off the contours properly at 190 ifb.
  - Naively would expect a certain lower luminosity to work.
  - Did not work yet.
  - Searching for a combination of Lumi+Calo-Cut that works...

In other News

- Data Quality Checks for Track Variables – ongoing
  - To be presented on 26th at Physics Meeting
- Made poster for Durham Summer School
- Summer School from Aug 31 to Sep 12.
- LTA Visa came through.. Tentative plan to leave on Oct 1

Projected Exclusion Limits on Dark Higgs using the FASER Experiment

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Motivation

Dark Matter constitutes approximately 85% of total mass content of the Universe and is theorized to be composed of as yet undiscovered elementary particles and forces.

The DM particles may at least in part obtain their mass in a way similar to electroweak symmetry breaking in the SM -- where the DM particle couples to a complex scalar field.

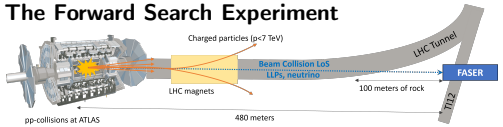
$$\mathcal{L} \supset \mu_H^2|H|^2 - \frac{1}{4}\lambda_H|H|^4 + \mu_\Phi^2|\Phi|^2 - \frac{1}{4}\lambda_\Phi|\Phi|^4 + \lambda_{h\phi}|\phi|^2|H|^2$$

Mixing (θ) between the SM and DM Scalars leads to a Dark Higgs (ϕ)

$$\mathcal{L} \supset -m_\phi\phi^2 - \sin\theta \sum_{\text{fermions}} \frac{m_f}{v}\phi\bar{f}f - \lambda v h\phi\phi$$

This is an example of the few renormalizable interactions allowed between the SM and the Dark Sector (collection of particles and forces that may make up DM). These interactions are often referred to as portals – which result in new mediator particles. These mediators tend to be light, feebly interacting and Long Lived (LLPs).

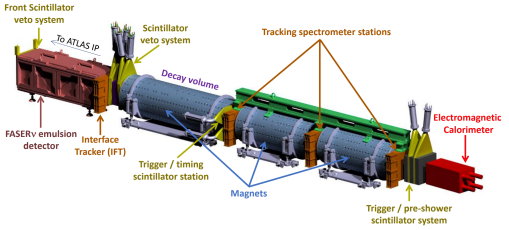
The Forward Search Experiment



Positioned in far-forward direction
- 480 meters downstream of IP-1
- Positioned along Beam Collision LoS
- Shielded by 100 m of rock/concrete
- Low background environment

FASER is sensitive to **light, feebly interacting** and **long lived** particles.

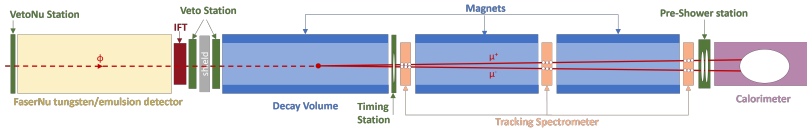
Light = Produced in forward direction
Long Lived = Traverses 480 meters



Dark Higgs at FASER

In FASER, the Dark Higgs is expected to produce a distinctive signature by decaying into a pair of charged particles.

- No Signal in Veto Stations
- Signal in Timing Station
- Two Close-by Tracks
- Calorimeter Deposit – For e+e-



Baseline Selection

- Two Track Selection is used to identify signal events
  - Selection Efficiency is ~50% in Signal MC
  - Cannot reconstruct two tracks at low separation [Fig-1]
  - Potential Improvement: Relax to one-track requirement
- Neutrinos are the dominant background
  - Previous analysis probed the Dark Photon(A') in e^+e^- final state
    - Calorimeter Energy could be used to reject background [Fig-2]
- Projected exclusions consider only the neutrino background [MC]

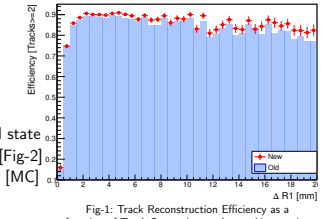


Fig-1: Track Reconstruction Efficiency as a function of Track Separation at the tracking station. Compared between two software versions.

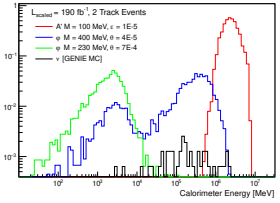
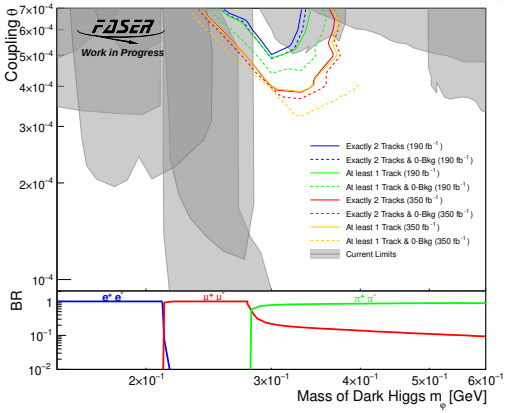


Fig-2: Energy deposited in the Electromagnetic Calorimeter by neutrinos and various signals MC parameterized by their mass/coupling.

Projected Exclusions



Additional Final States

- FASER collected a total of 190 fb^{-1} of data in the 2022-24 period
  - The projected full Run-3 dataset is 350 fb^{-1}.
- The expanded data set allows sensitivity to additional final states
  - Dark Higgs mainly decays to $\mu^+\mu^-$ and $\pi^+\pi^-$ in the parameter space accessible to FASER.

Future Directions

- Promising initial results for Dark Higgs with full Run-3 dataset.
- Further studies on background rejection for the looser 1-Track selection.
- Other promising models – UpPhilic, Combined Dark Photon+Higgs

References

[1] J.L. Feng, I. Galon, F. Kling, and S. Trojanowski, "***Dark Higgs Bosons at FASER***," Phys. Rev. D 97(5), 055034 (2018).
[2] FASER Collaboration, "***The FASER Detector,***" J. Inst. 19(05), P05066 (2024).
[3] FASER Collaboration, "***Search for Dark Photons with the FASER detector...,***" Physics Letters B 848, 138378 (2024).

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Thank You!