CMS Non-thermal DM Model Interpretation

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Contents

Introduction

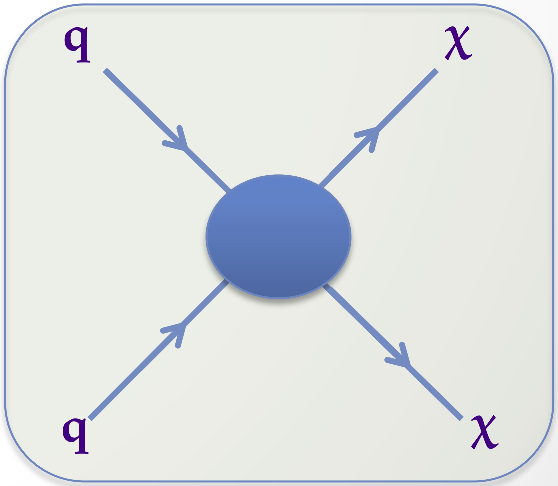
Dark Matter Production at LHC

- Dark matter (DM) outweighs visible matter roughly six to one, making up about 27% of the universe.

- Several theories to predict its nature – i.e. DM could contain "supersymmetric particles"… etc

- Experiments at the **L**arge **H**adron **C**ollider may provide more direct clues.
  - DM would be light enough to be produced at the LHC.
  - Escape through the detector unnoticed.
  - Carries away energy and momentum so that its existence can be inferred through "missing" information.

$$q + q \rightarrow \chi + \chi$$

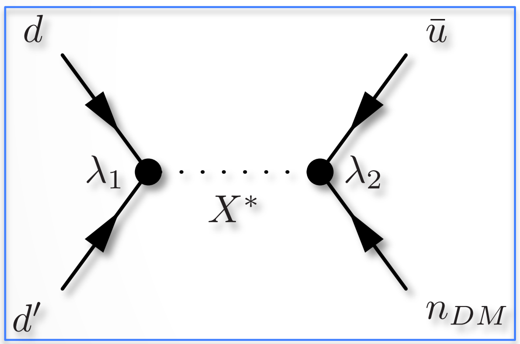


Light Non-Thermal DM Model

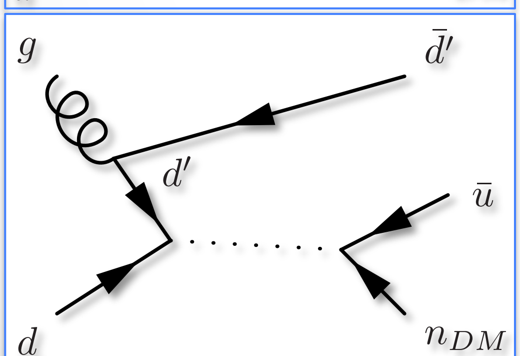
Simplified Model –

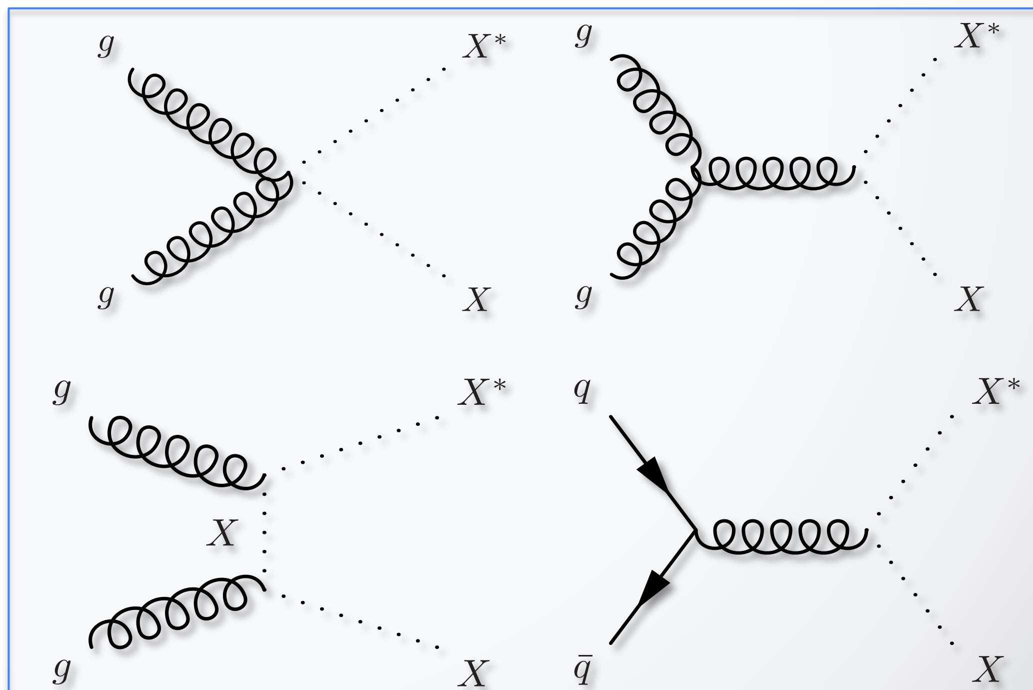
- predicts "light" dark matter ($M_{DM} \approx M_{Proton}$).
- Mediator -- Heavy scalar color triplet(s) (~TeV)
- Not parity protected – can be singly produced at the LHC
- **Large missing energy** associated with an **energetic jet** – transverse momentum distribution shows jacobian-like shape.
- Parameters of the model are: λ_1, λ_2 (couplings) , M_X , M_{DM}(Masses) and Width of mediator.

Monojet



ISGS





Pair Production of *X*

http://arxiv.org/abs/1401.1825 Bhaskar Dutta, Yu Gao and Teruki Kamon

Sample Production

- The Non-thermal DM model is implemented in the **MADGRAPH5 aMC@NLO** framework and are simulated at LO in QCD.
- The mass of the DM particle is fixed to the proton mass to assure the stability of both the proton and the DM particle.
- Out of two mediator X_1 and X_2, we fixed mass of X_2 at fairly large value compared to X_1 i.e. X_2 =8TeV. (to avoid interference terms)
- Several M_{X1} are considered --- M_{X1} ={1000 1500 2000}
- 16x16 coupling grid is covered ---

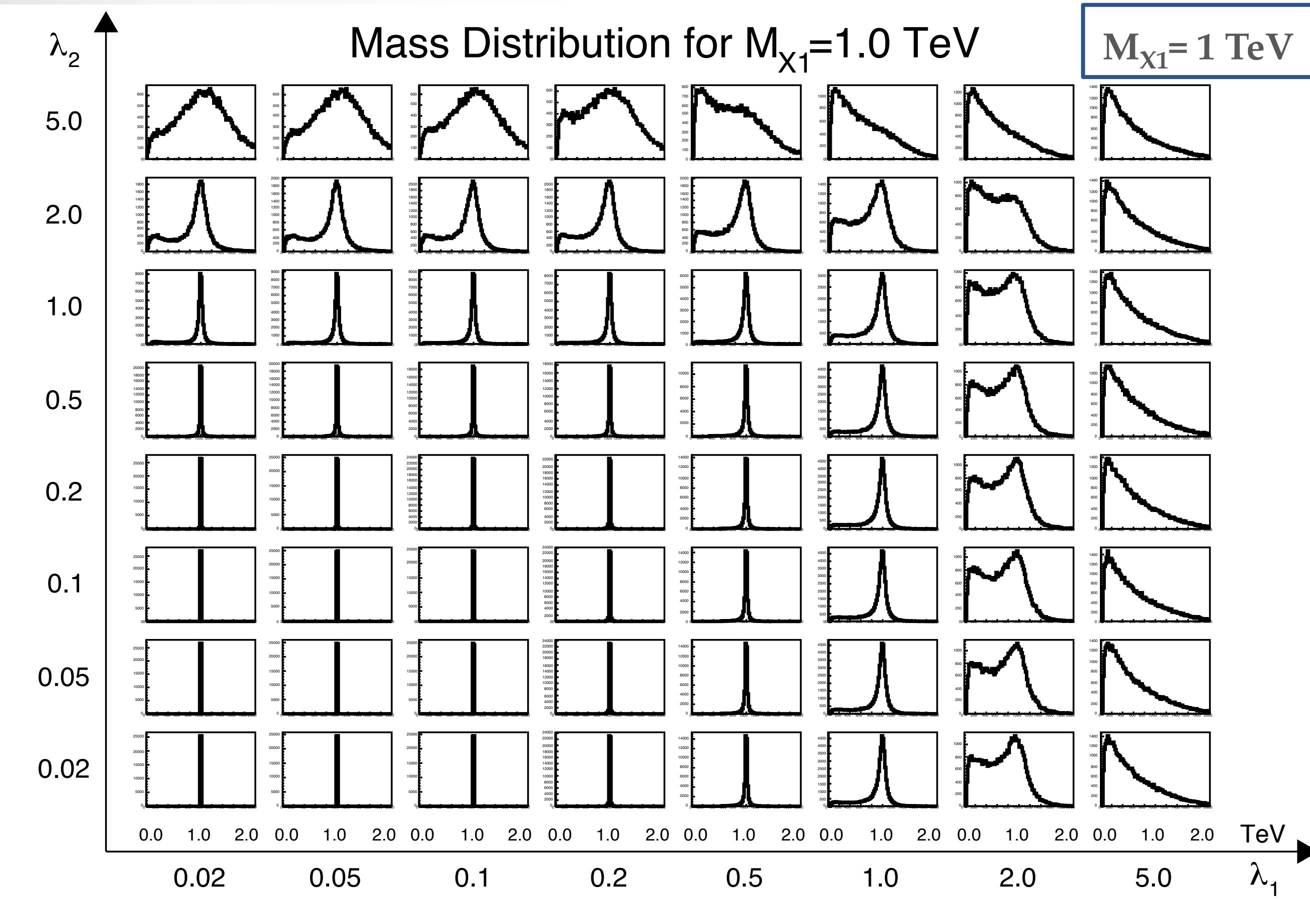
$$\lambda_1 = \{0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09, 0.1, 0.2, 0.5, 1.0, 2.0, 5.0, 10.0\}$$
$$\lambda_2 = \{0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09, 0.1, 0.2, 0.5, 1.0, 2.0, 5.0, 10.0\}$$

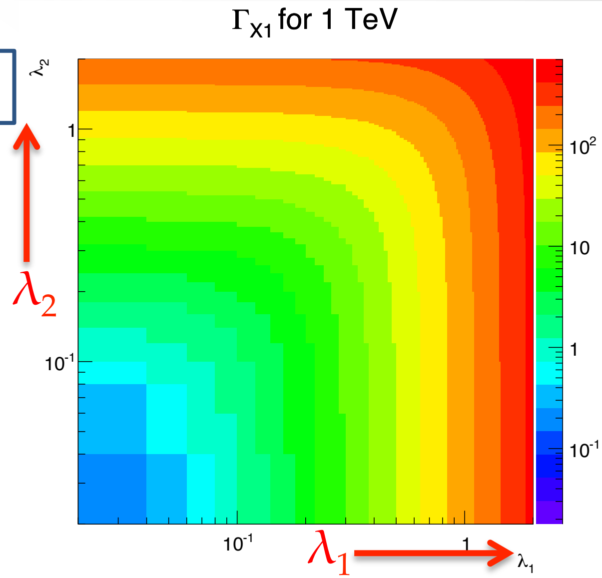
- For each M_{X1} the width is calculated as a function of couplings using following formula

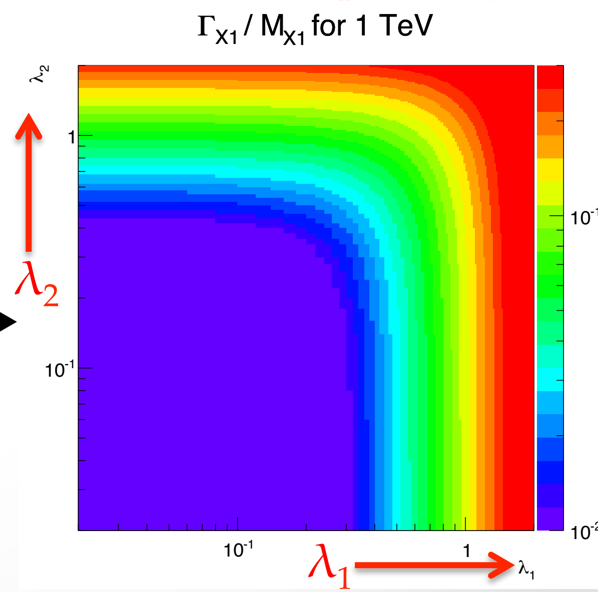
$$\Gamma_X = \frac{1}{8\pi M_X^2}\left[2|\lambda_1|^2 \sum_{i\neq j} |\overrightarrow{p}_{ij}(M_X^2 - M_{d_i}^2 - M_{d_j}^2) + |\lambda_2|^2 \sum_i |\overrightarrow{p}_i(M_X^2 - M_{u_i}^2 - M_{n_{DM}}^2)\right]$$

Generator Level Studies

Generator Level Studies – M_{X1}



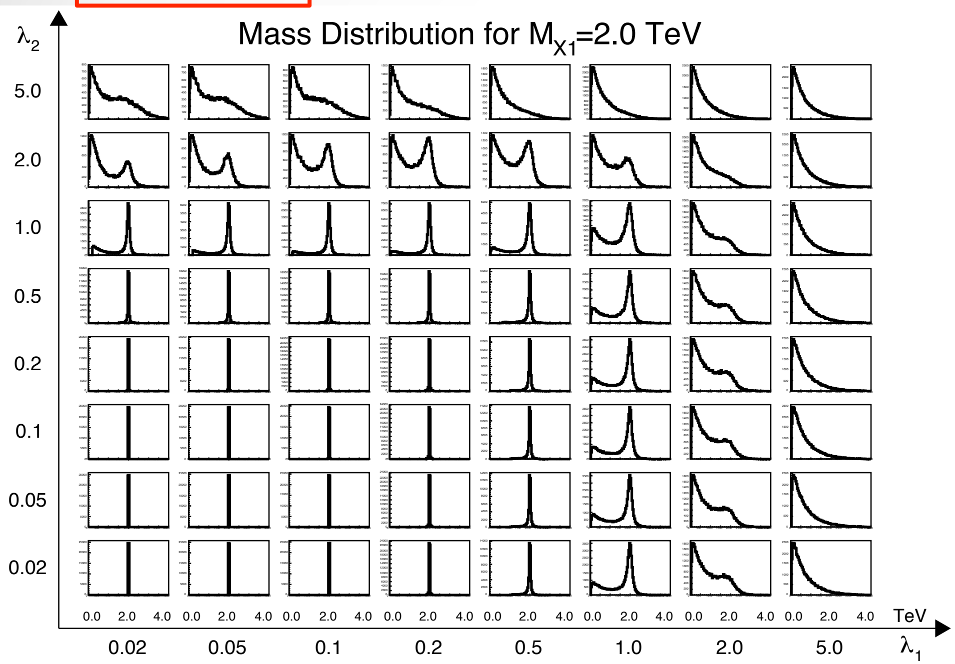




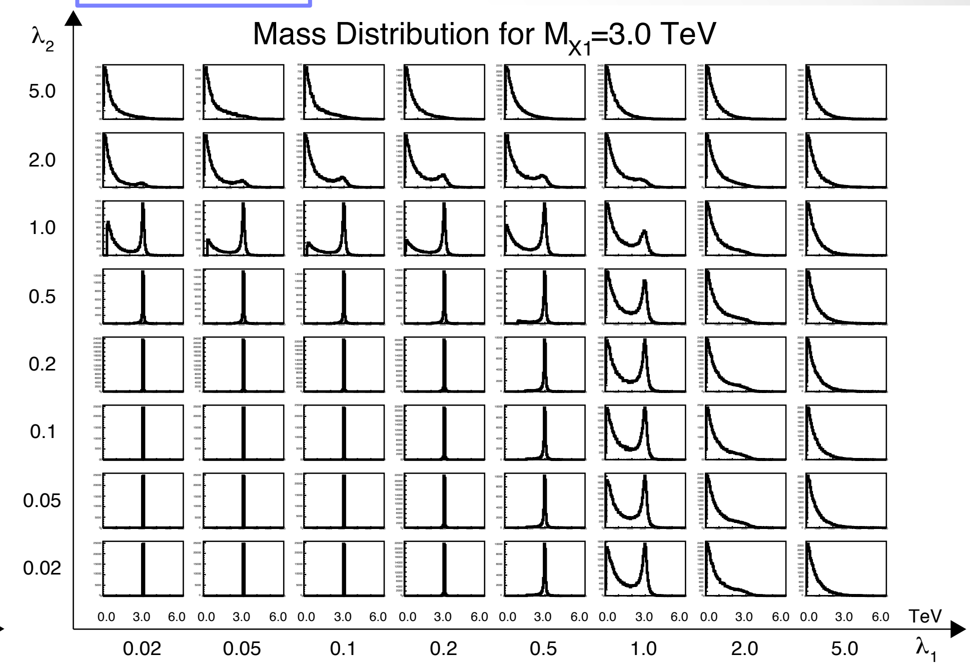
For λ_1 =[0.01-1.5] & λ_2=[0.01-2.0] mediator width is less than about 30% of its mass

Generator Level Studies – M_{X1}

M_{X1}= 2 TeV

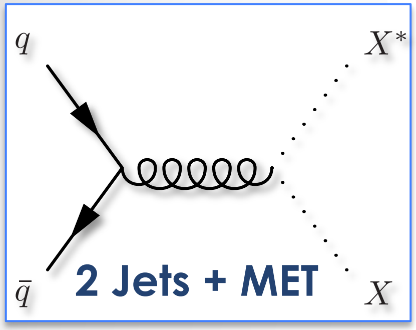


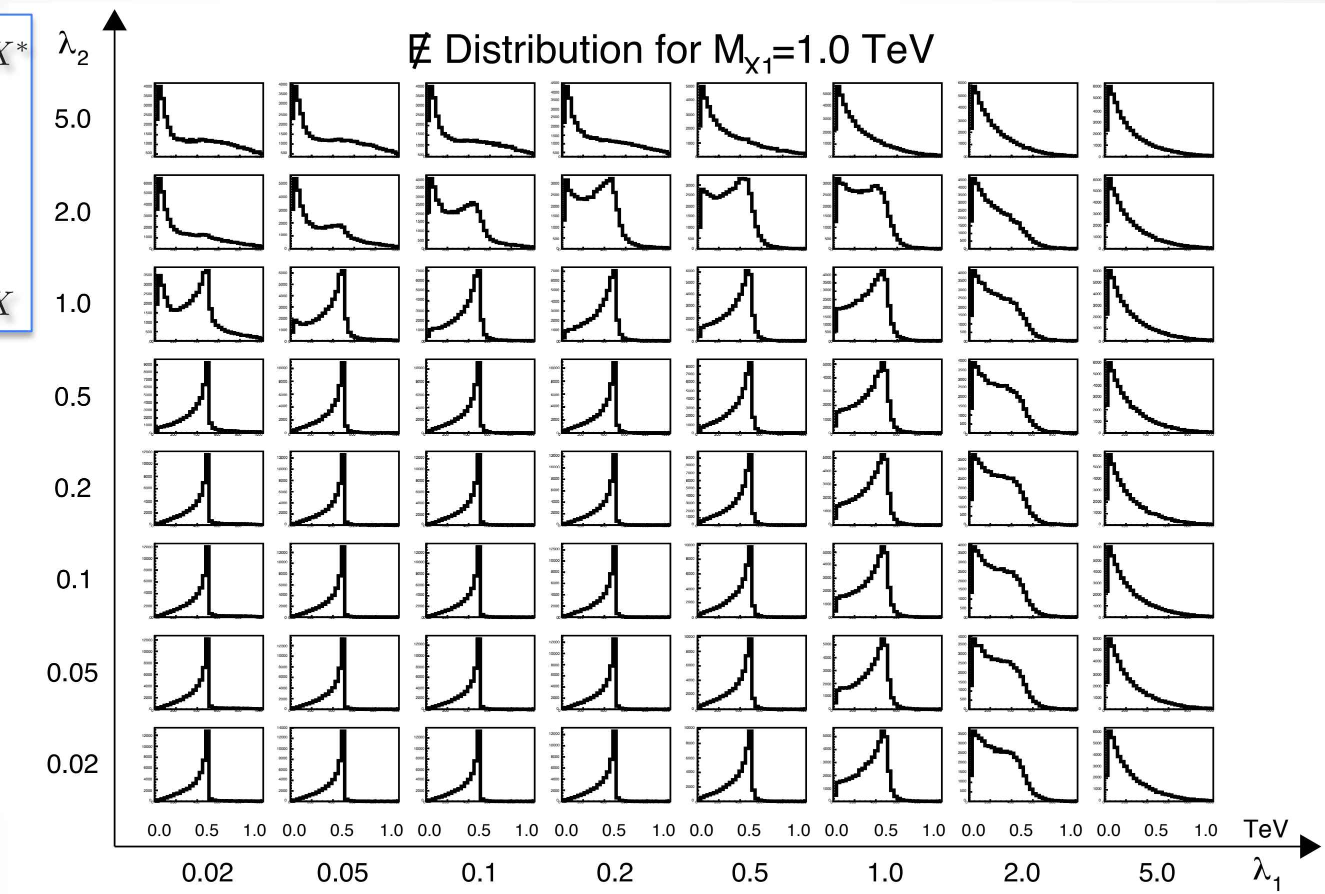
M_{X1}= 3 TeV

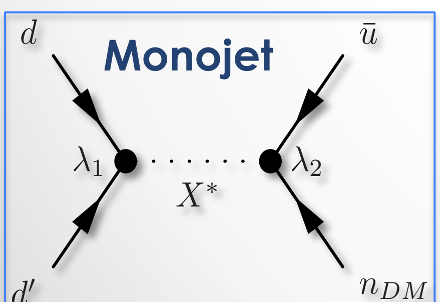


Generator level mediator masses for M_{X1} = 2 & 3 TeV

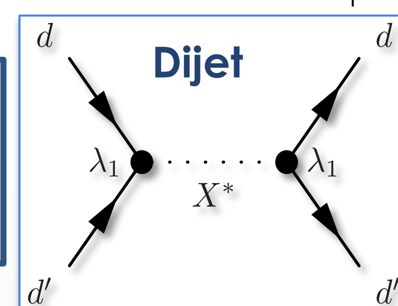
Generator Level Studies – MET



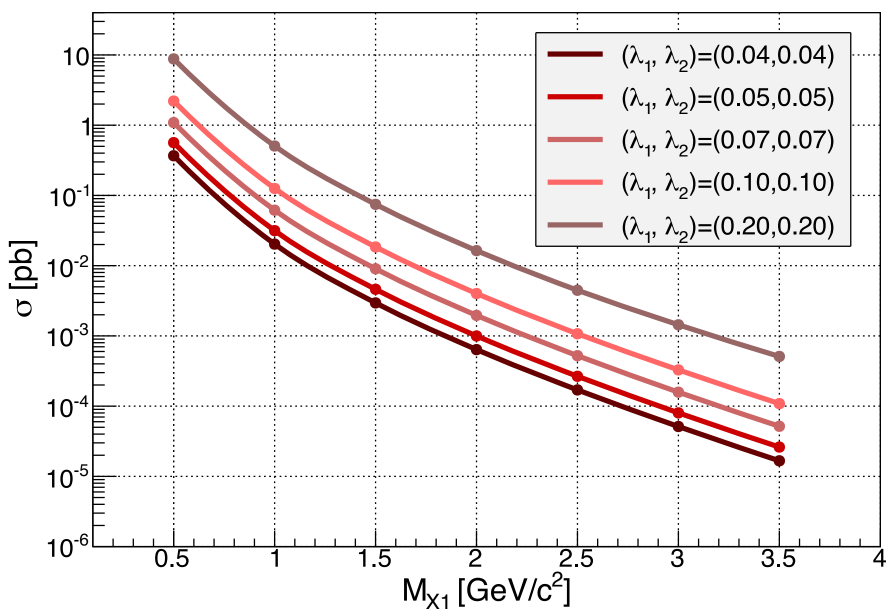


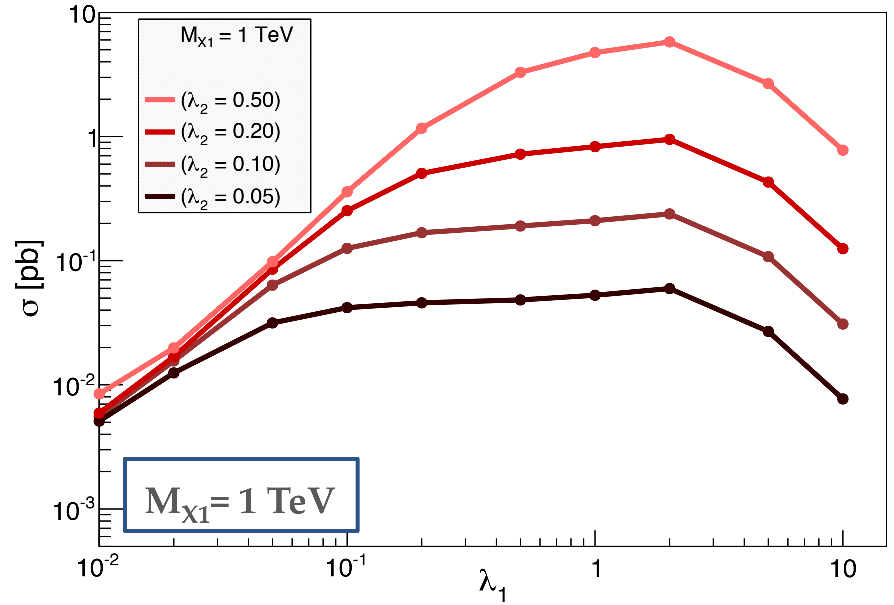


- Jacobian peak appears in most of coupling parameter space.
- Peaks at half of the mediator mass.



Generator Level Studies – Cross Section vs model's parameters





Cross Section vs Mediator Mass $\mathbf{M_{X1}}$

Cross Section vs Coupling λ_1 for fixed λ_2

Analysis Strategy

Backgrounds

Dominant Backgrounds:

- $Z(\nu\nu)$+Jets
- $W(l\nu)$+Jets

Together make up about 95% of total.

Subdominant Backgrounds:

- Z(ll)+Jets
- γ+ Jets (Serves as Control Region for background estimation)
- Top
- Diboson
- QCD

Event Selection

- The data is 35.9 fb^{-1} with $\sqrt{s}$=13 TeV

Baseline Selection:

- E_t^{miss} >250 GeV (consistent with trigger turn-on).
- Leading Jet (AK4) p_T > 100 GeV with $|\eta|<2.5$
- $\min\Delta\phi(E_t^{miss}, \text{jets}) > 0.5$
- $|E_t^{miss}{}_{calo} - E_t^{miss}{}_{PF}| / E_t^{miss}{}_{calo} < 0.5$

✓ Signal ← NO ←

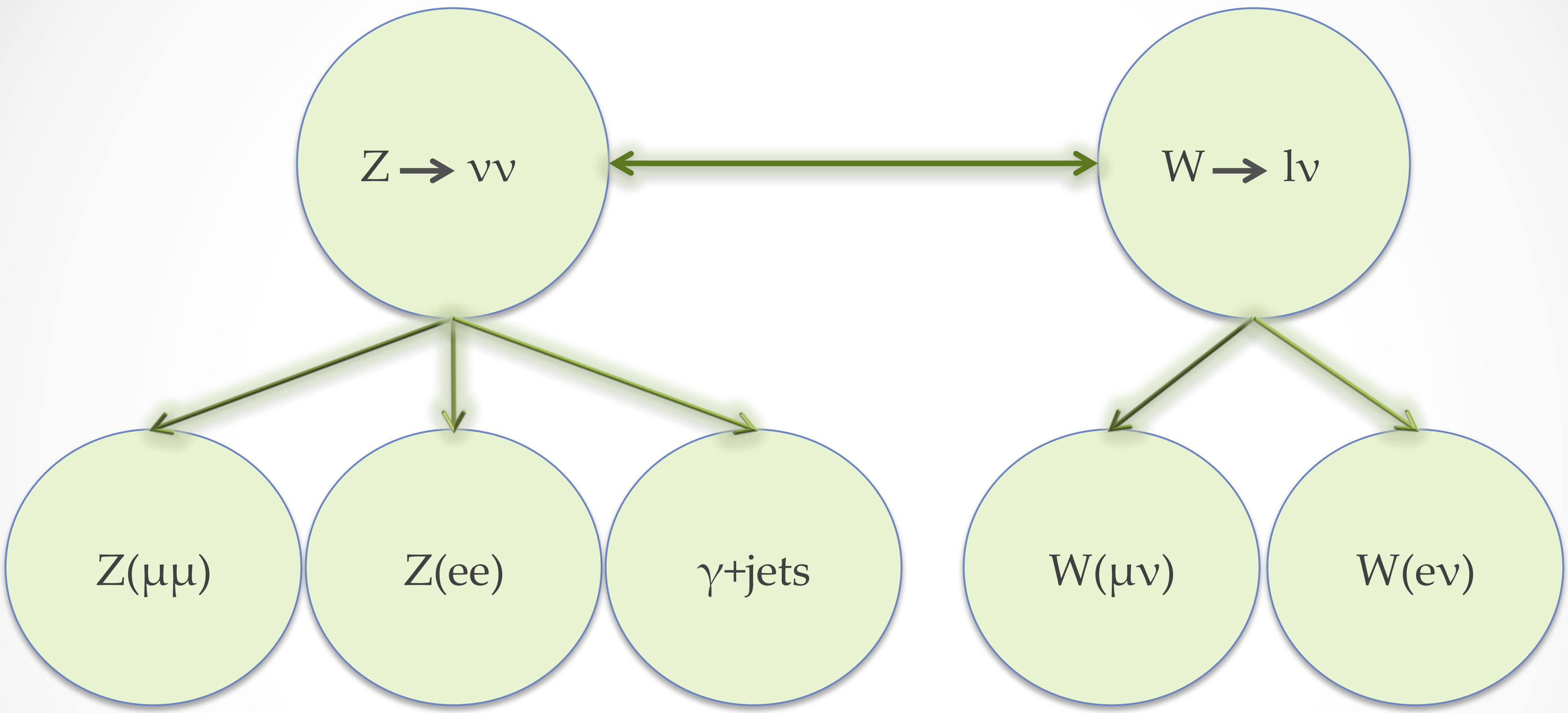
- Leptons
- B-jets
- Photons

→ YES → ✓ Background (Control Region)

Background Estimation

- Leading Electroweak backgrounds are estimated using combined maximum likelihood fit of 5 Control Regions (CR).
- This fit takes into account for
  - All sources of systematic uncertainties.
  - Normalized uncertainties:
    - *Luminosity and cross section uncertainties in MC-driven backgrounds,*
    - *lepton, photon reconstruction uncertainties in CR and bjet veto.*
  - Shape uncertainties:
    - *Theory uncertainties (QCD scale, PDF, NLO-EW correction)*
    - *Jet energy scale and jet energy resolution.*

Background Estimation

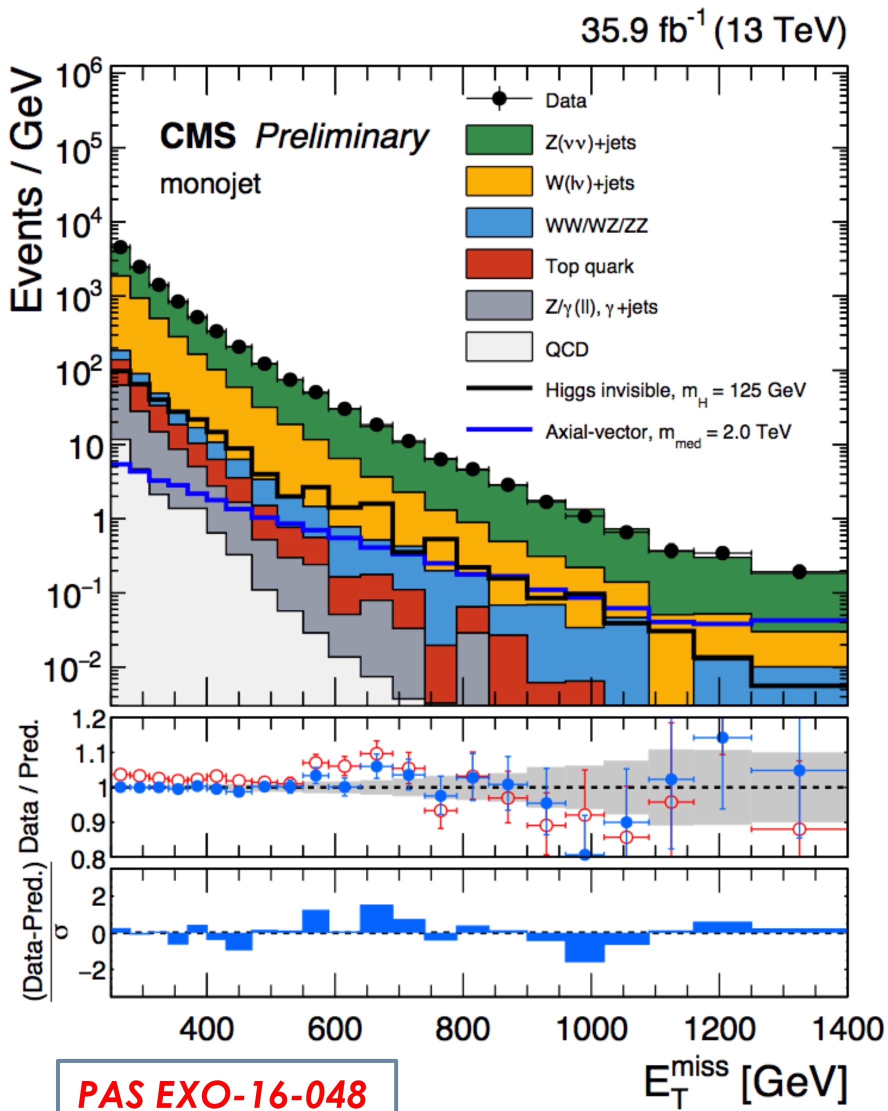


- **Transfer factors (TF)** are used to translate yields from control regions to signal region.
- **TF** are derived through **binned MC**.

Results

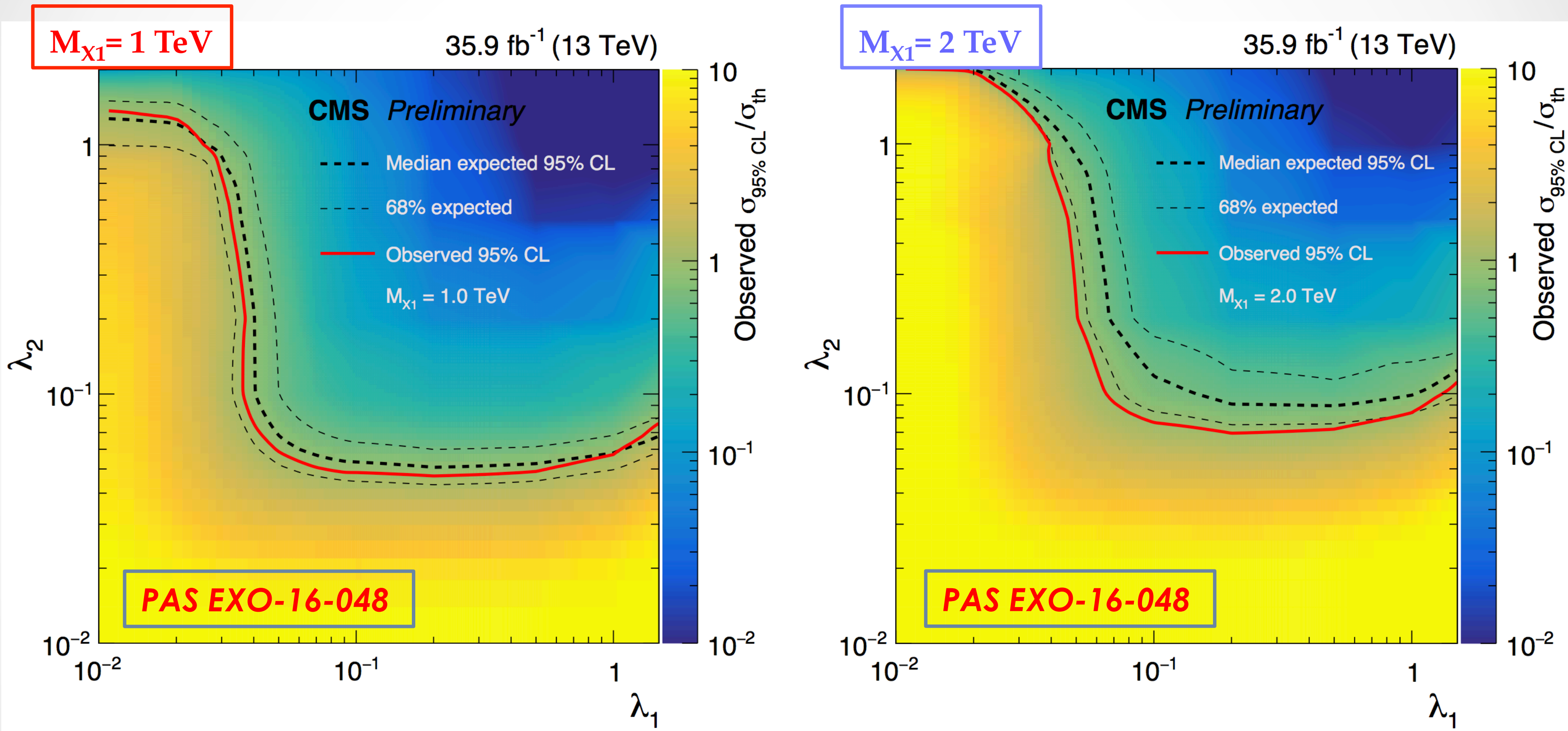
Signal Region Result

- Observed MET distribution in the signal regions compared with the post-fit background expectations for various SM processes.
- The last bin includes all events with MET > 1250 GeV



PAS EXO-16-048

Non-thermal DM Interpretation



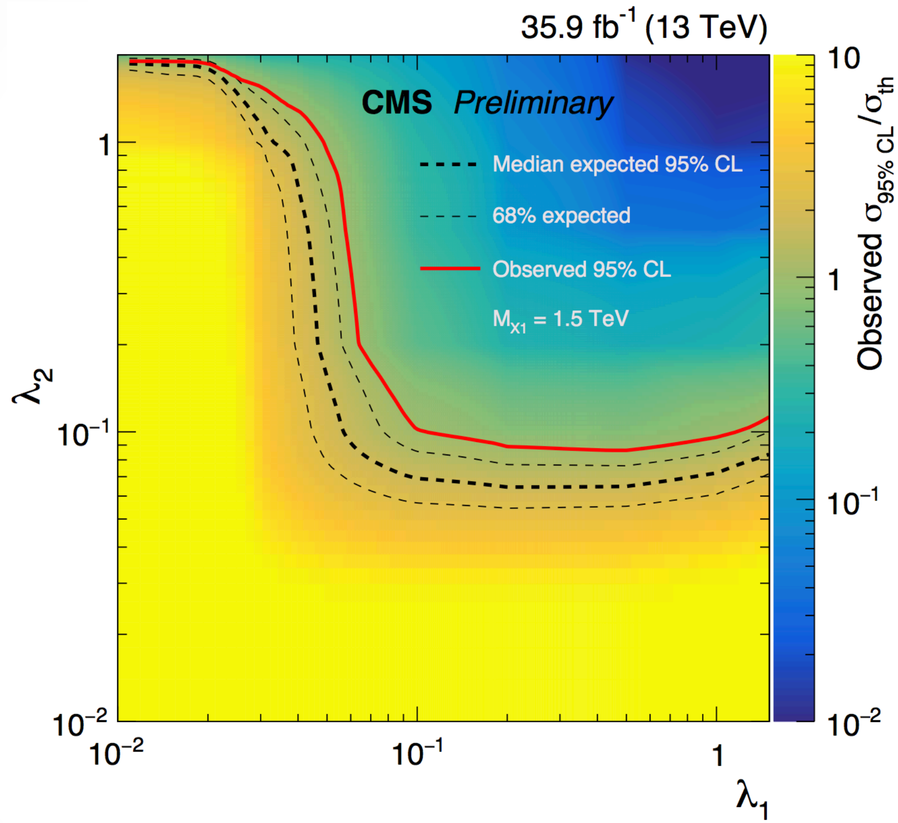
95% CL expected (black dashed line) and observed (red solid line) upper limits on $\mu = \sigma/\sigma_{th}$ for a nonthermal DM particle for mediator masses $M_{X1}$of 1 and 2 TeV, in the $\lambda_1 - \lambda_2$ plane.

Summary

- We do not see signal (excess of data) in our analysis so we set limit on the production of dark matter in Non-thermal DM model.
- The limit is improved by roughly a factor of 2 or so (8 TeV vs 13 TeV).
- We look forward to 2017 data for further study of this model.

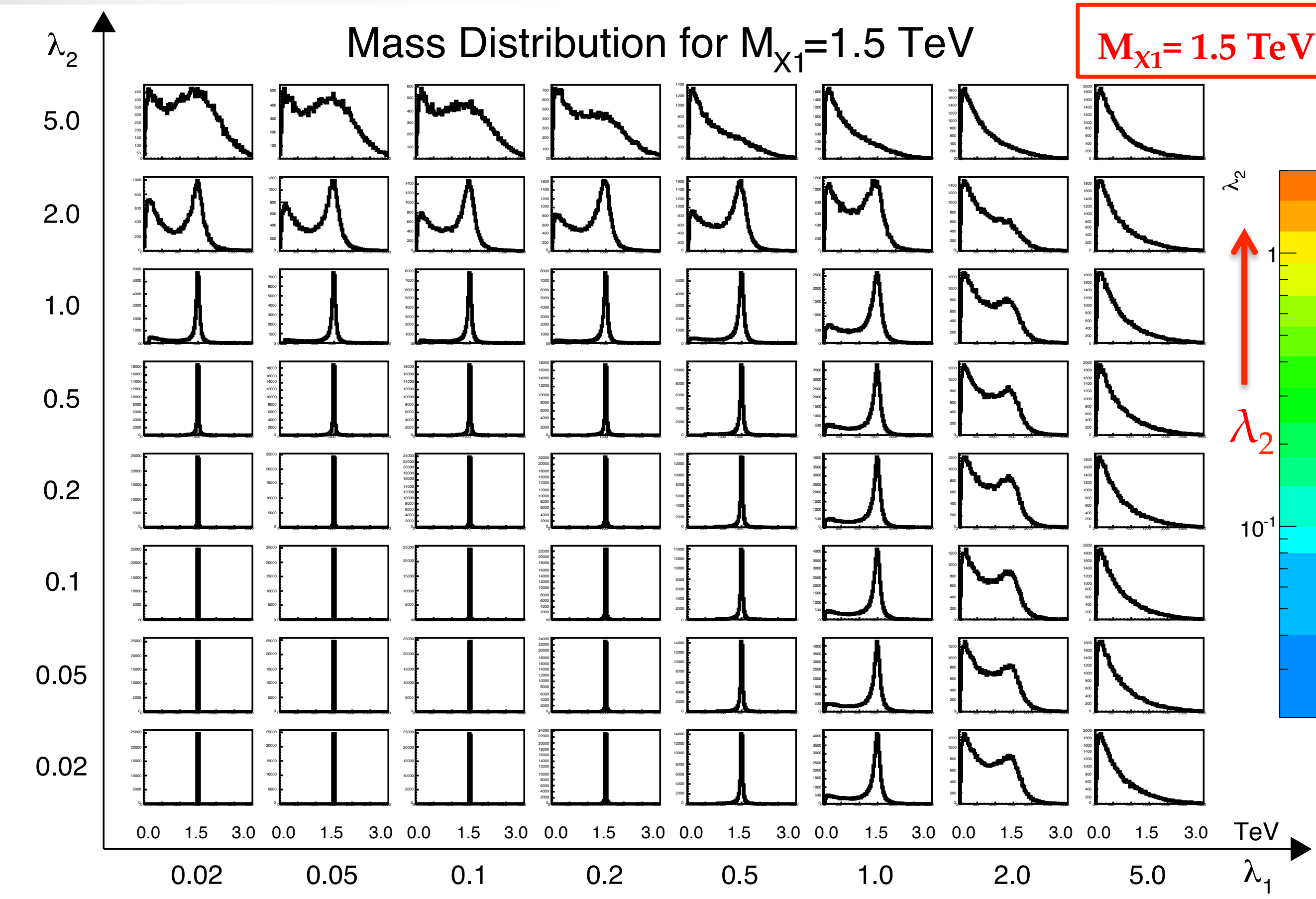
Backup

Non-thermal DM Interpretation

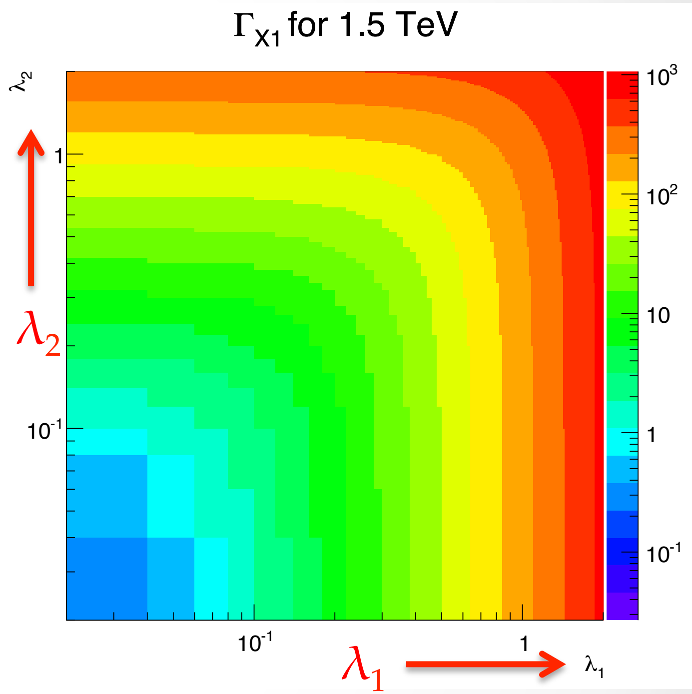


95% CL expected (black dashed line) and observed (red solid line) upper limits on $\mu = \sigma/\sigma_{\text{th}}$ for a nonthermal DM particle for mediator mass M_{X1}=1.5 TeV, in the $\lambda_1 - \lambda_2$ plane.

Generator Level Studies – M_{X1}



M_{X1}= 1.5 TeV



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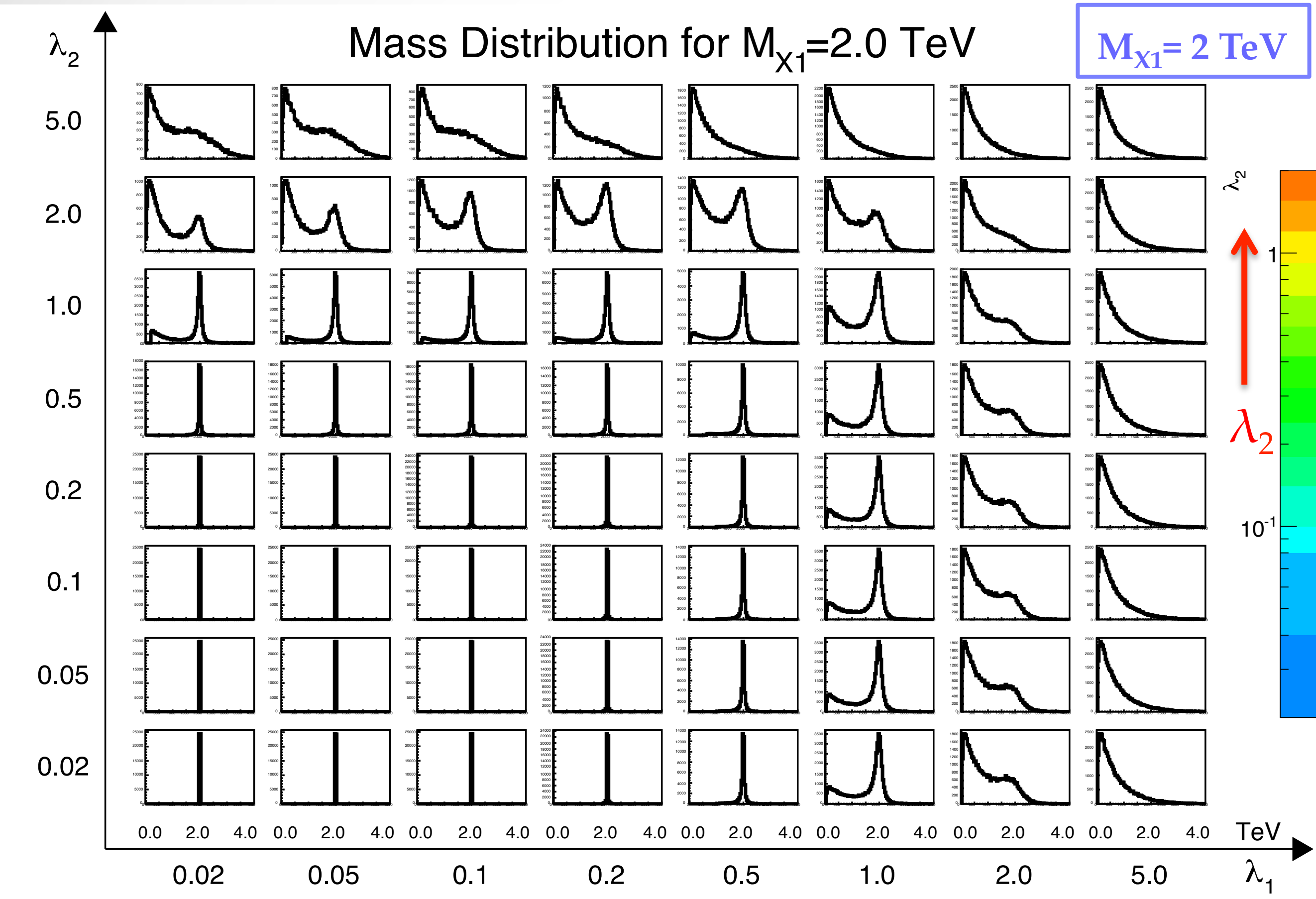
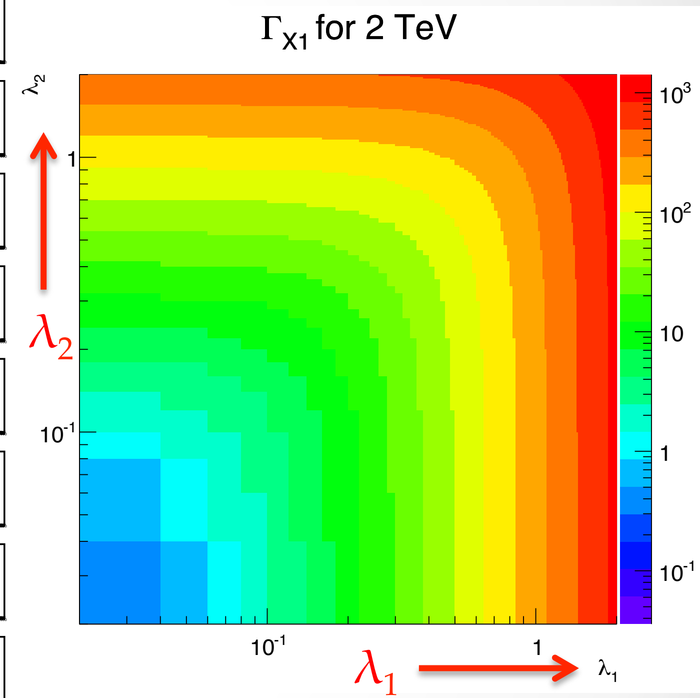


M_{X1}= 2 TeV



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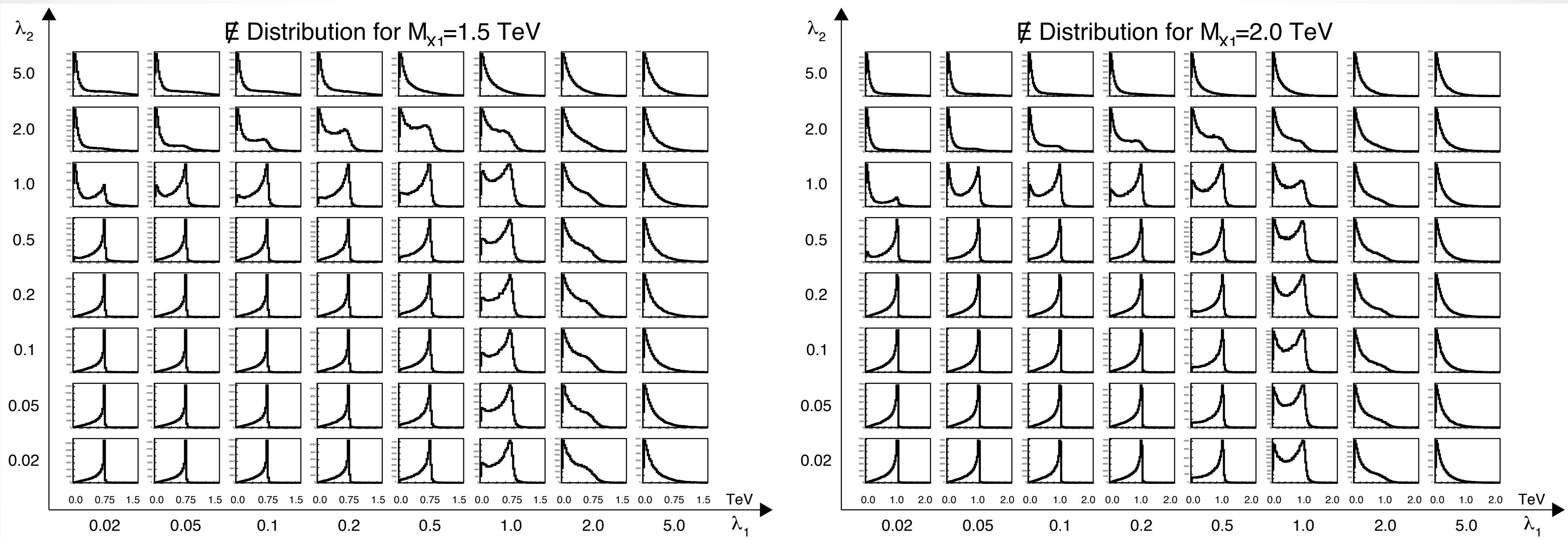
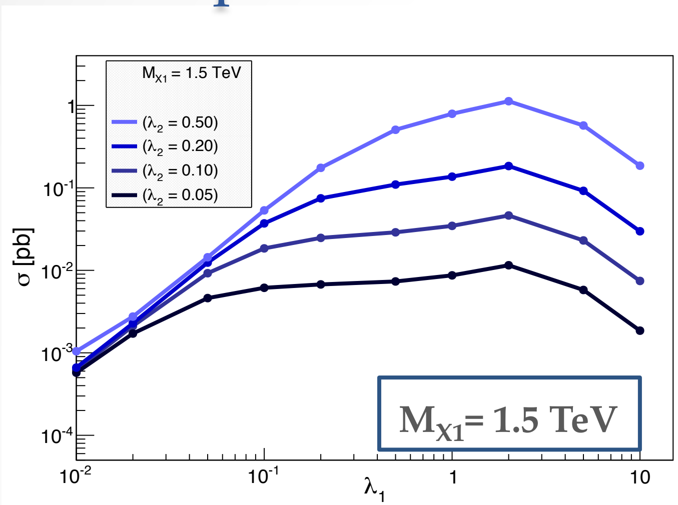
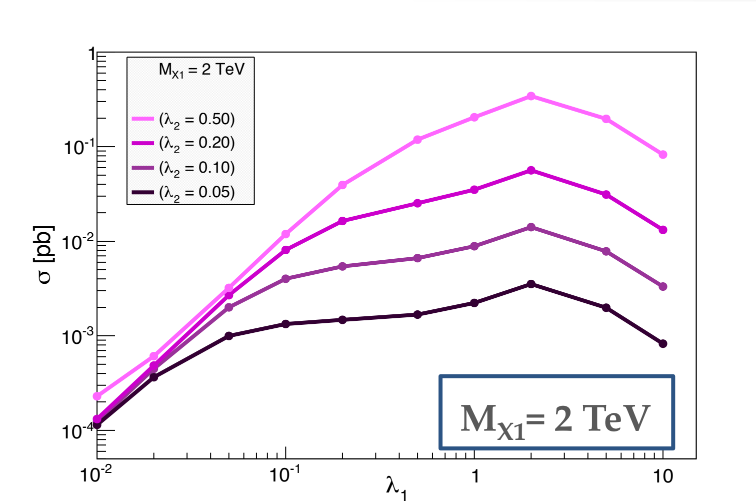
Generator Level Studies – MET

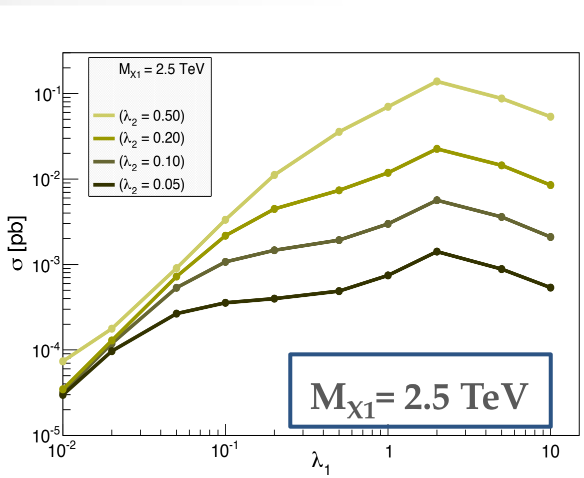


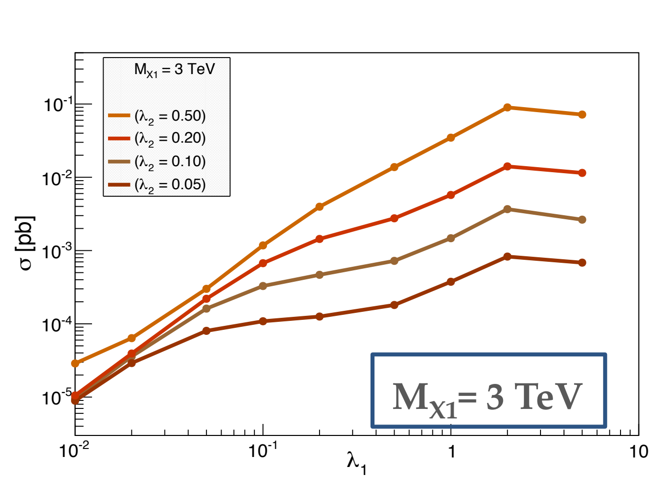
MET distribution for $\mathbf{M}_{X1}$ = 1.5 and 2 TeV

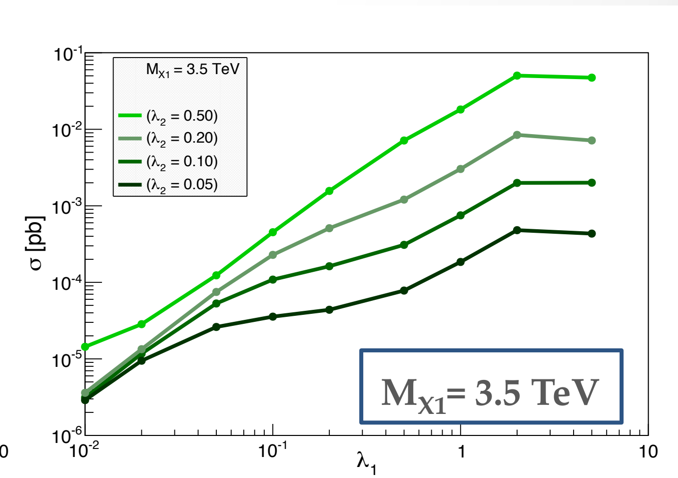
Generator Level Studies – Cross Section vs model's parameters











Cross Section vs Coupling λ_1 for several $\mathbf{M}_{X1}$ keeping λ_2 fixed

Run 1 vs Run 2 Results

Non-thermal DM Results -- Run 1 vs Run 2

Our Run 2 (13 TeV) limit poses stronger Behavior compared to Run 1 (8 TeV) results as expected.