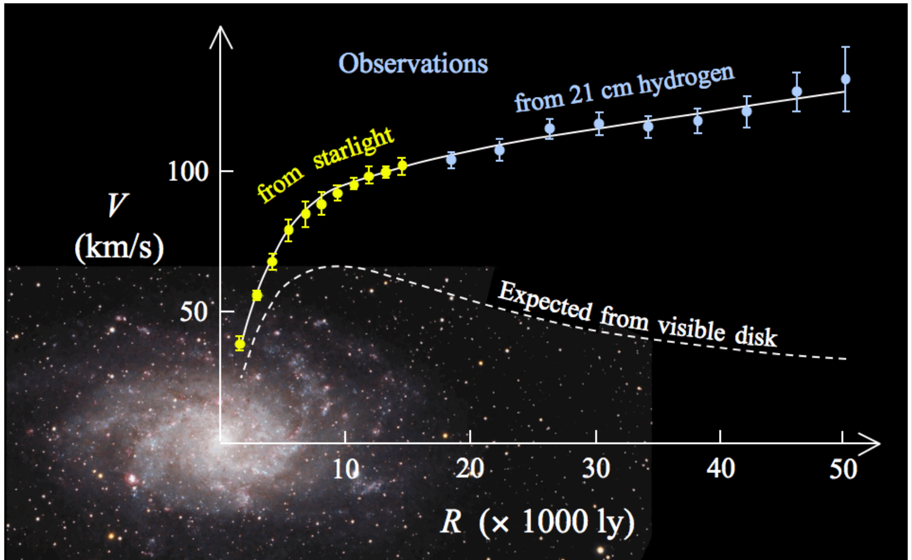
A Simplified Model for Dark Matter Interacting Primarily with Gluons

Free Meson - June 2, 2016

Gaurav Mendiratta

[Kapteyn, Jacobus Cornelius](#) (1922). "First attempt at a theory of the arrangement and motion of the sidereal system".

Astrophysical Journal **55**: 302–327 doi:10.1086/142670."It is incidentally suggested that when the theory is perfected it may be possible to determine the amount of dark matter from its gravitational effect."



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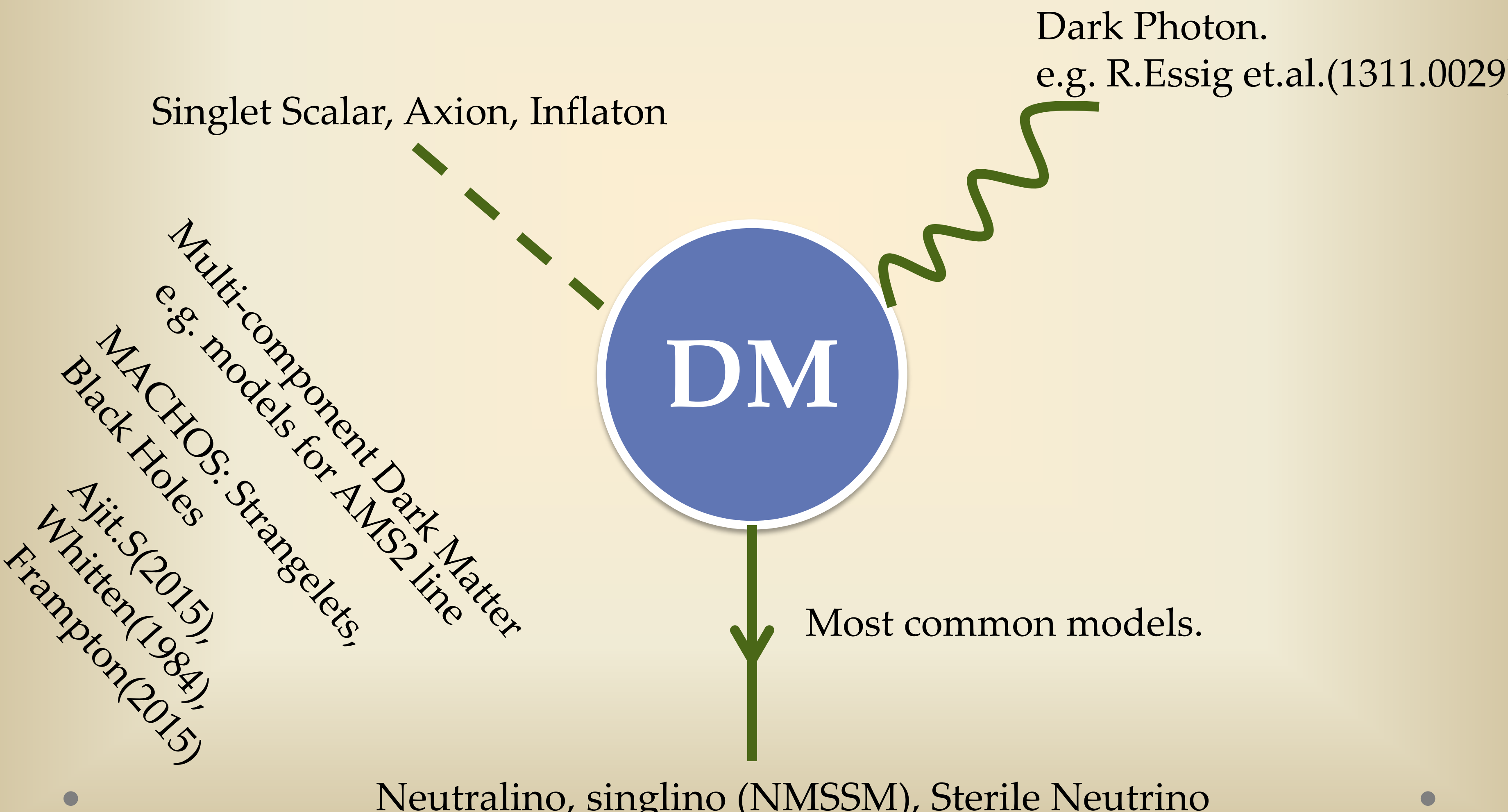
Coma Cluster photographed through 8" Celestron Edge HD in San Diego, CA.

"For the moment we might very well can them DUNNOS (for Dark Unknown Non-reflective Non-detectable Objects Somewhere)." -Bill Bryson

A (incomplete) Review Of DM Models



Outline

- **Scalar Dark Matter**
- **Gluphillic Scalar Dark Matter***
- **Colored Scalar at hadron Colliders#**
- **GDSM at hadron colliders #**

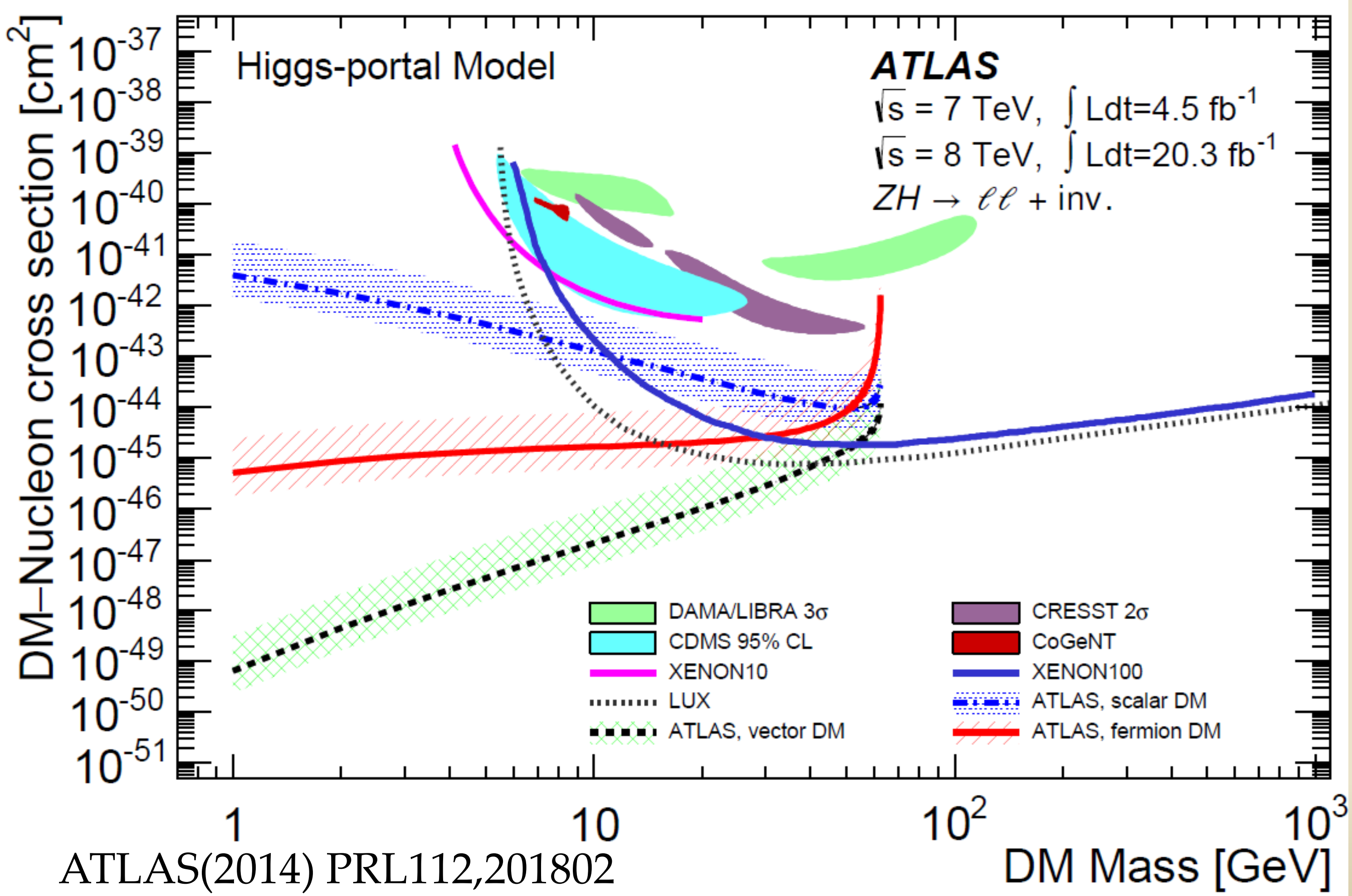
Rohini M. Godbole, G.M. and Tim M.P. Tait [JHEP 08 (2015) 064**]*

*# Rohini M. Godbole, G.M.,Ambresh Shivaji and Tim M.P. Tait [**1605.04756**]*

Simplest DM Model

- SM Singlet WIMP scalar dark matter (χ).
- SM interactions need no additional local symmetries.
- Higgs Portal: $\lambda_p H^\dagger H \chi^\star \chi$

Higgs Portal



ATLAS(2014) PRL112,201802

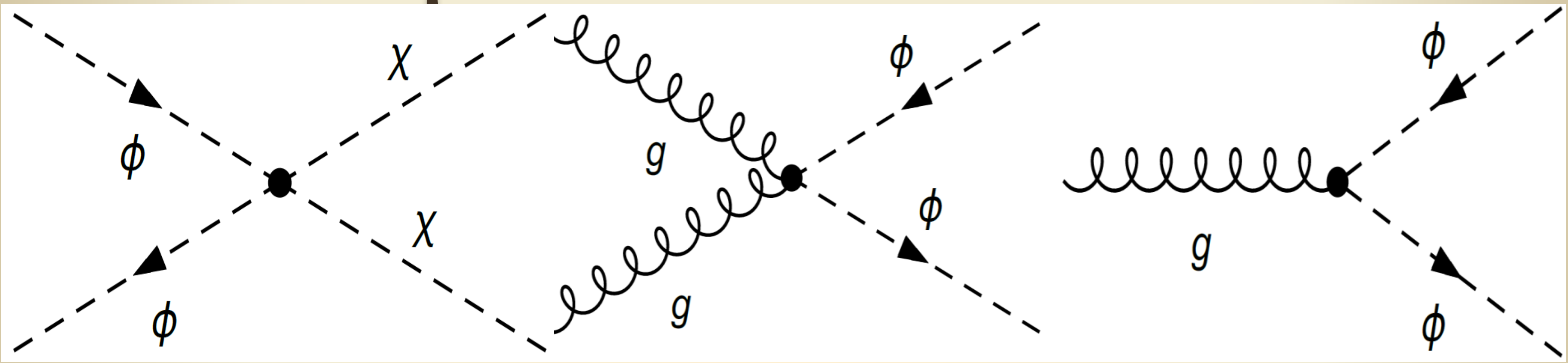
Simplest DM Model

- SM Singlet WIMP scalar dark matter (χ)
- ~~Higgs Portal: $\lambda_p H^\dagger H \chi^\star \chi$~~
- BSM Scalars:
  - ϕ – scalar charged under $SU(3)_C$.
  - χ- SM singlet scalar

$$\lambda_d \phi^\dagger \phi \, \chi^\star \chi$$

- Renormalizable operator allows, the unusual, DM-Gluon coupling.
  - Rich collider Signatures

Gluphillic Scalar DM



$$\mathcal{L}= (\mathcal{D}_\mu\phi)^2 + (\partial_\mu\chi)^2 + \lambda_d\phi^\dagger\phi\chi^\star\chi$$
$$+\eta\epsilon^{\alpha\beta\gamma}\epsilon_{ijk}u^i{}_{R\alpha}u^j{}_{R\beta}\phi^k{}_\gamma + h.c.$$

- MFV formalism with flavor $SU(3)_R$ to avoid flavor constraints on colored scalar-quark couplings. (see for a review: J.Arnold et.al. JHEP 1001, 073 (2010))

Gluphillic DM Model

- A DM model with a colored scalar allows for a rich set of collider signatures.
- The signatures of a colored scalar itself depend on the additional flavor/discrete symmetries.
- DM-scalar and therefore, DM-SM interactions are independent.
- A Z_2 typically invoked to stabilize DM also may apply to ϕ.

Relic Density

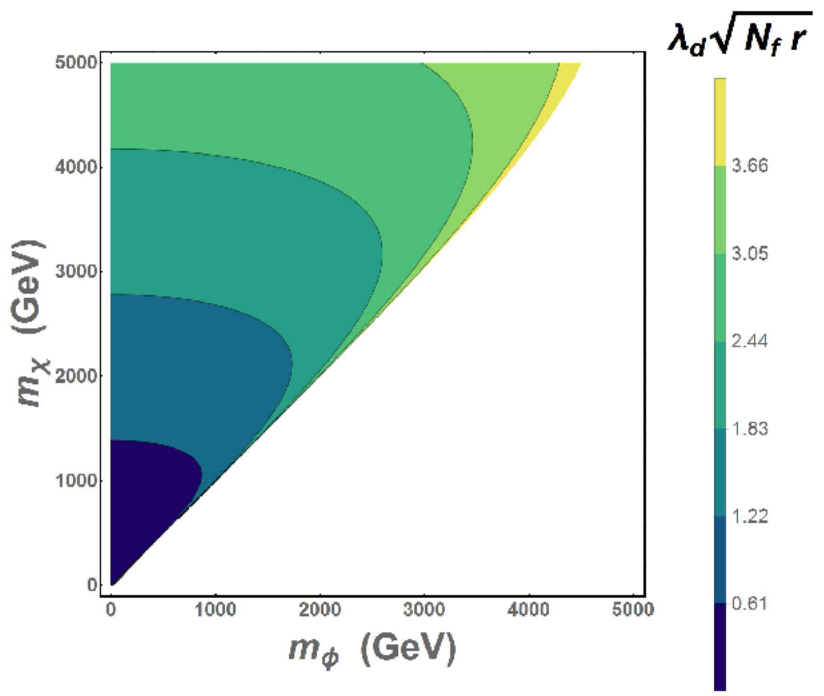
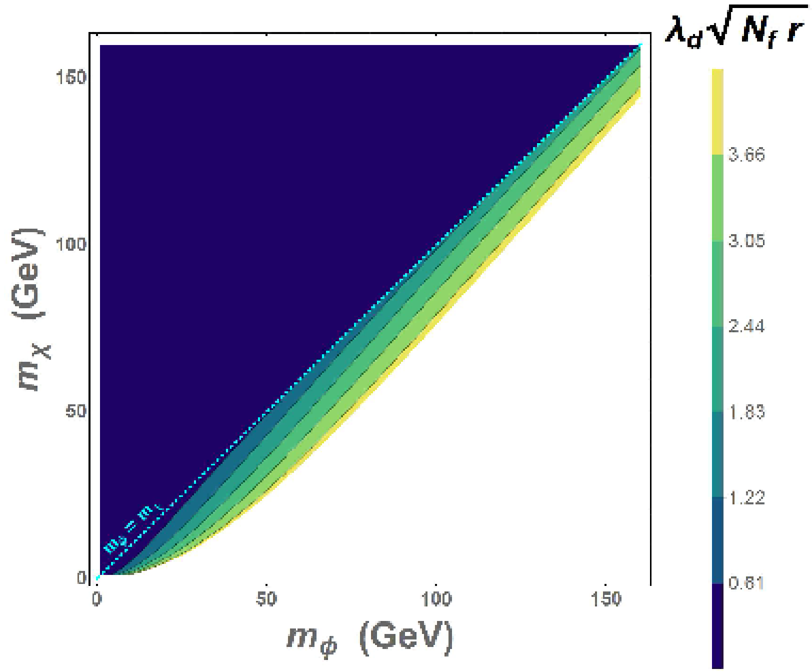


Figure : Constraints on masses of the DM 'χ' and colored scalar 'ϕ'. The color contour represent product of coupling and color factor for a representation r and number of flavors N_f.

Relic Density

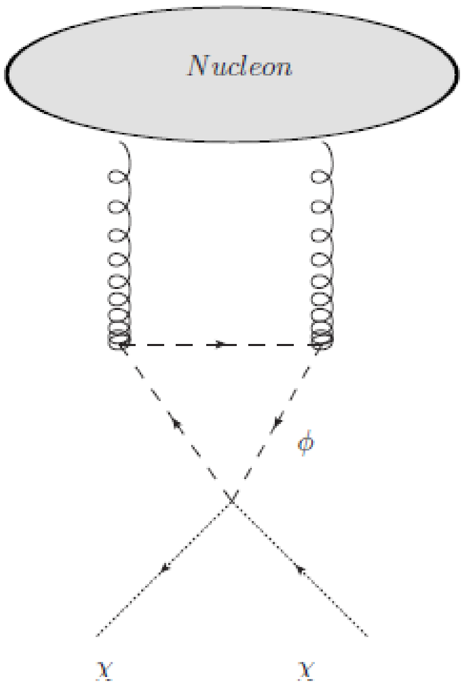


$Dimension\,(r)$	$2T_r$	$2C_{2r}$
3	1	1
6	5	10
8	6	16
10	15	50
15	35	175

Figure : Constraints on masses of the DM 'χ' and colored scalar 'ϕ'.

Direct Detection

- Nucleons interact with DM via loops.



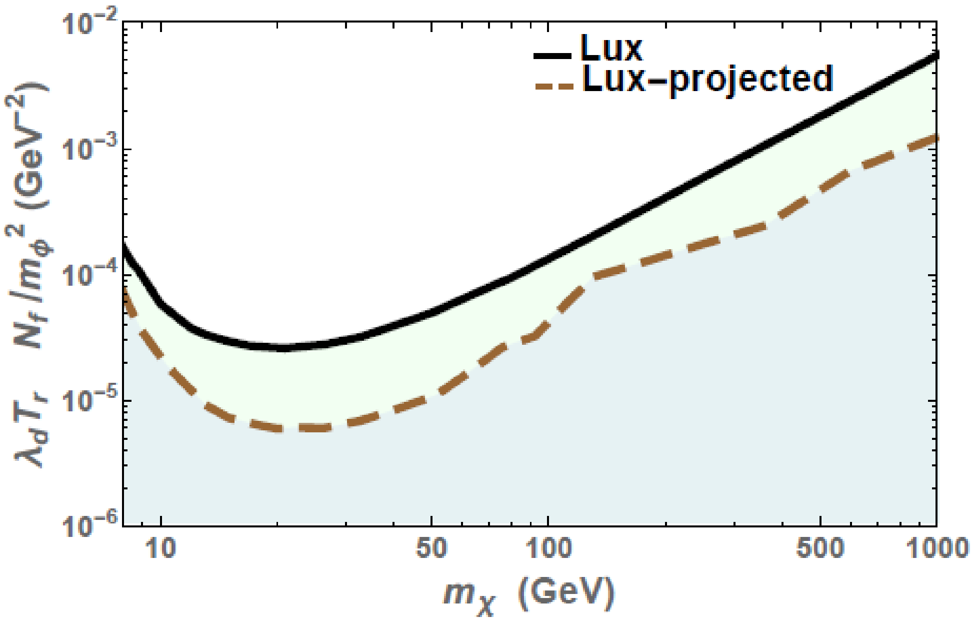
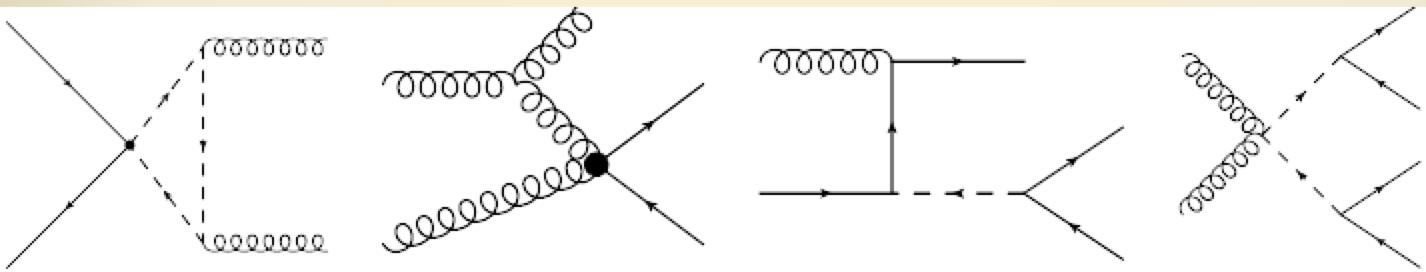


Figure : Constraints from Lux data on $\frac{\lambda_d}{m_\phi^2}$ and m_χ for color representation r and number of flavors N_f.

Colored Scalar

- Representative Feynman diagrams.



(a) Annihilation $\chi^{\star}\chi \to$ gluons at one loop.

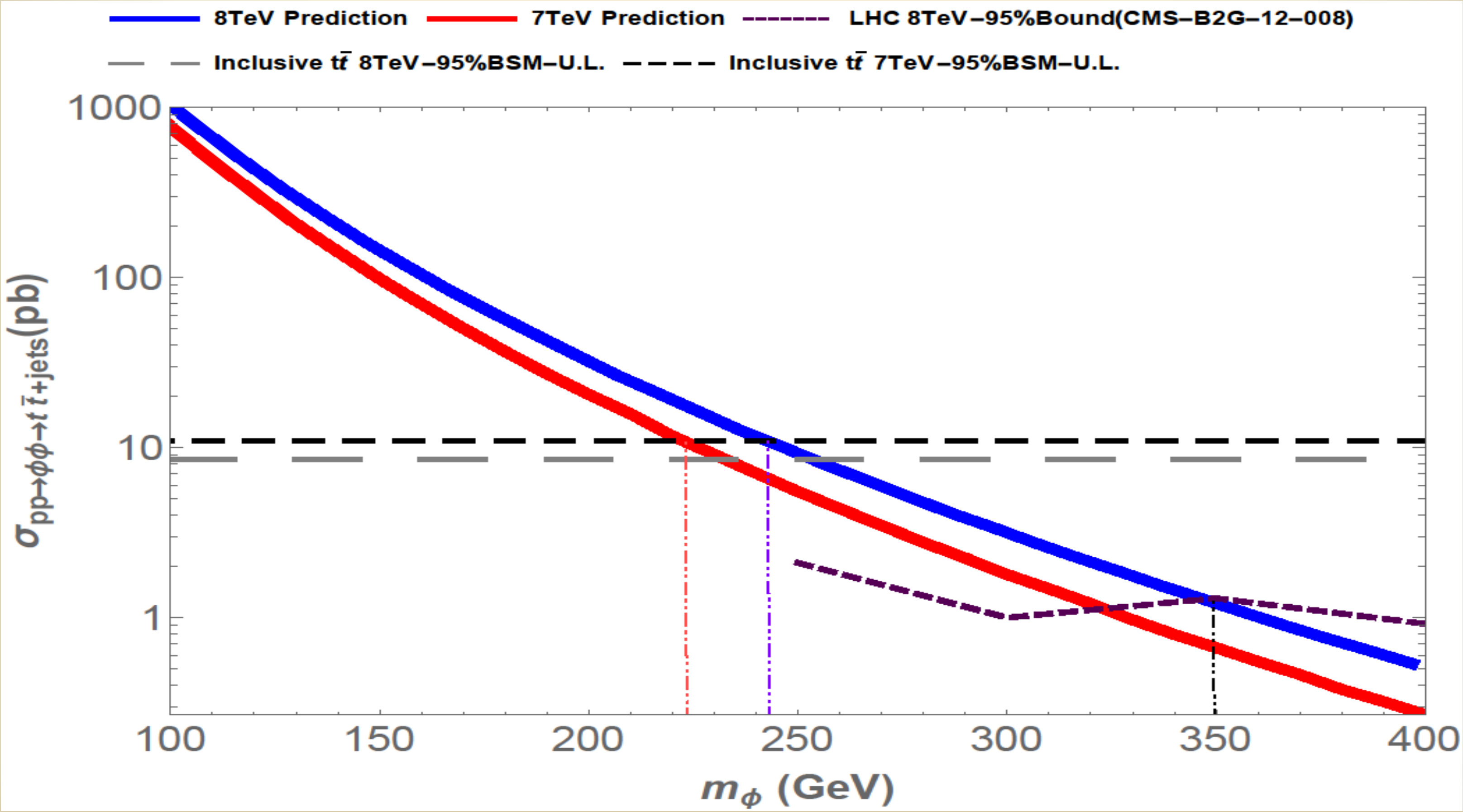
(b) Mono-jet signature.

(c) Mediator + top quark production followed by decay of the mediator into top and an unflavored jet.

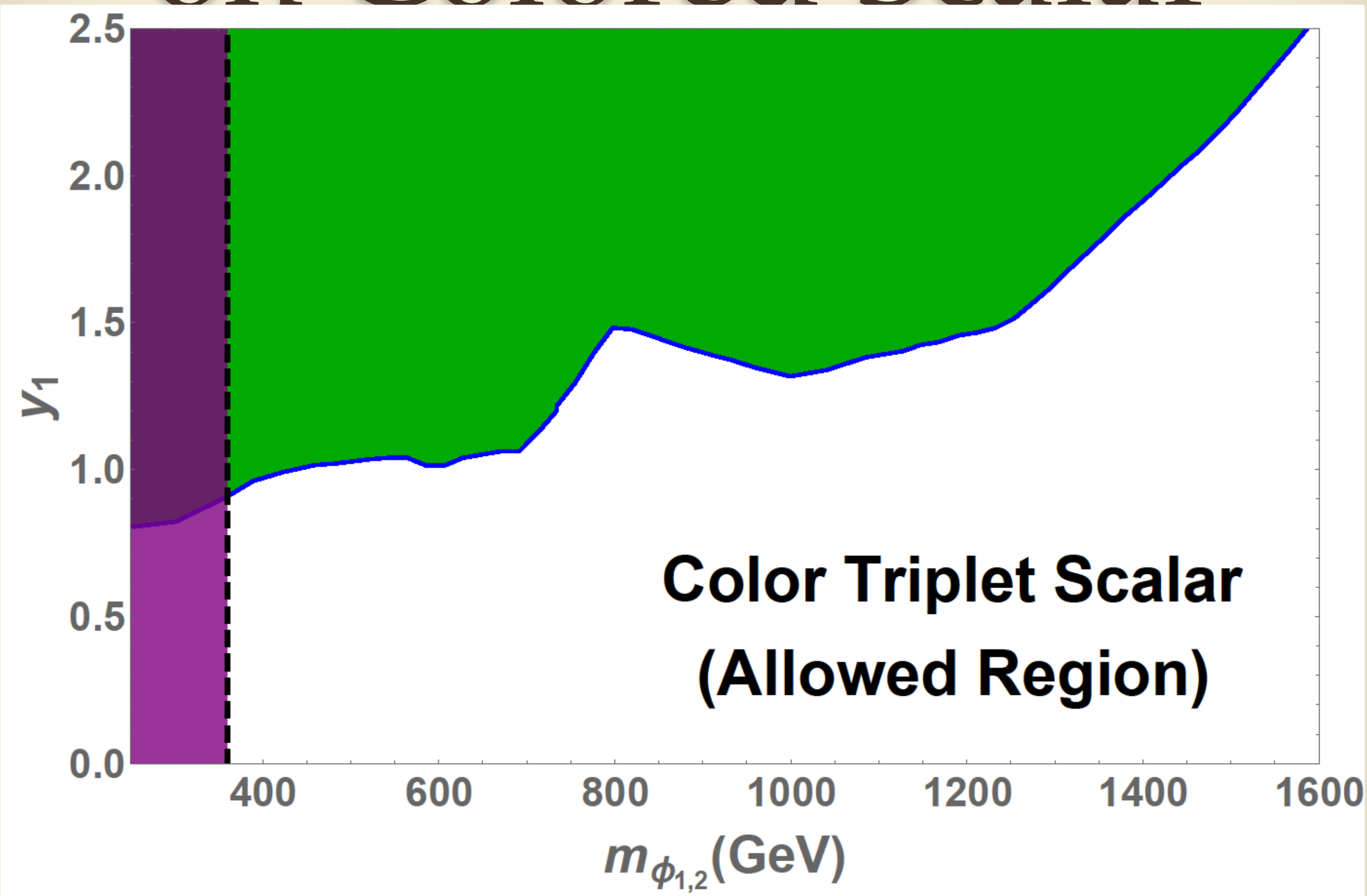
(d) Pair productoin of mediators followed by decay into two fermions.

Collider Constraints on Colored Scalar

- BSM coupling independent bounds on masses of the colored scalar which couples to top quark.
  - The cross-section is calculated with a k-factor of 1.7.



Collider Constraints on Colored Scalar

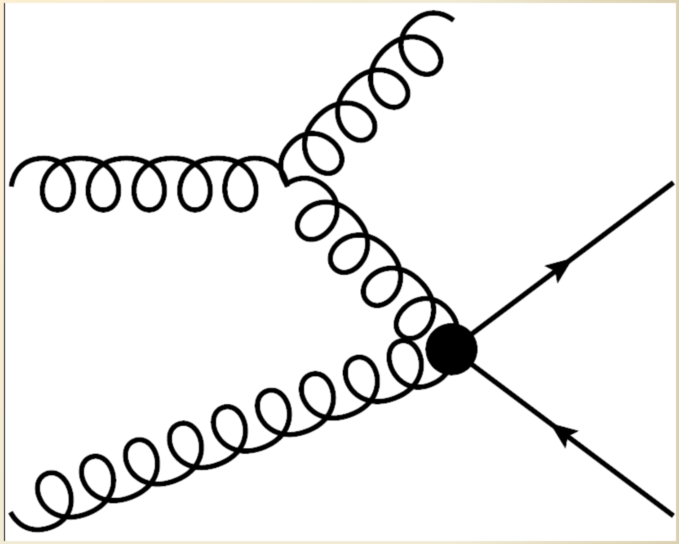


- The constraints are extended by the tt + 1j search[1209.6593,ATLAS] . The purple region is ruled out by pair production of scalars via gluon fusion.

DM Signature at Colliders:Monojet

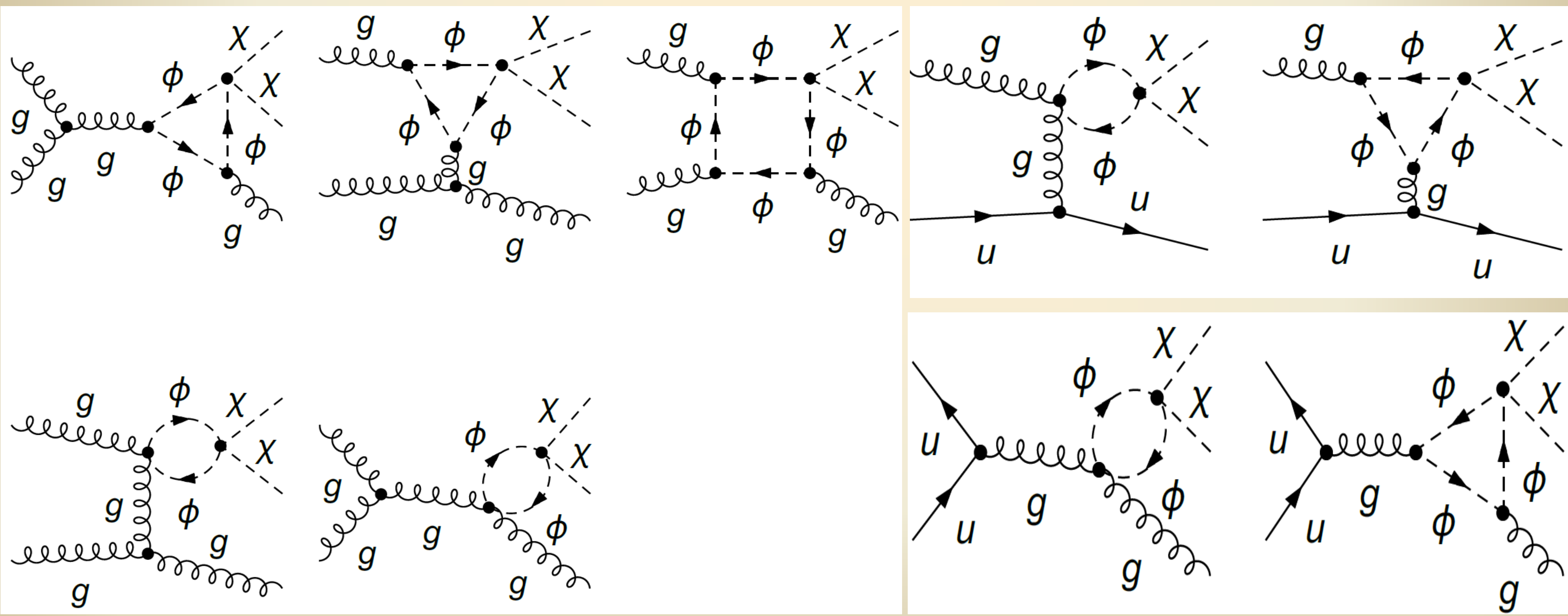
- Effective Field Theory: $\frac{\alpha_s}{M^2} G^{\mu\nu}{}_a G_{\mu\nu}{}^a \chi^\dagger \chi$

- $\frac{\lambda_d T_r}{48\pi M^2} \leq \frac{1}{(207GeV)^2}$



Monojet: EFT

- EFT Fails for small mediator masses and large cuts. Complete loop calculation is necessary.

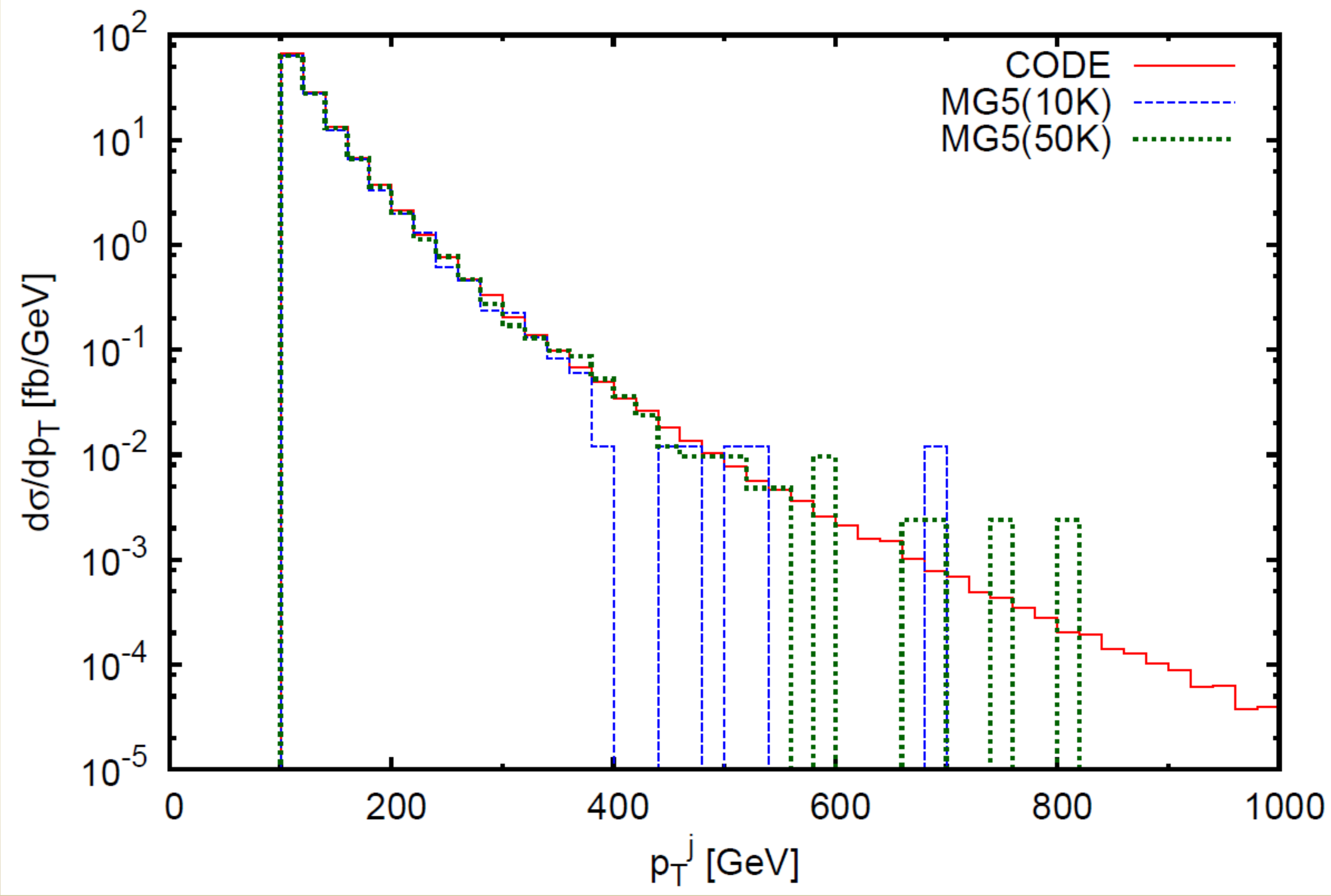


Monojet: Loop Calculation

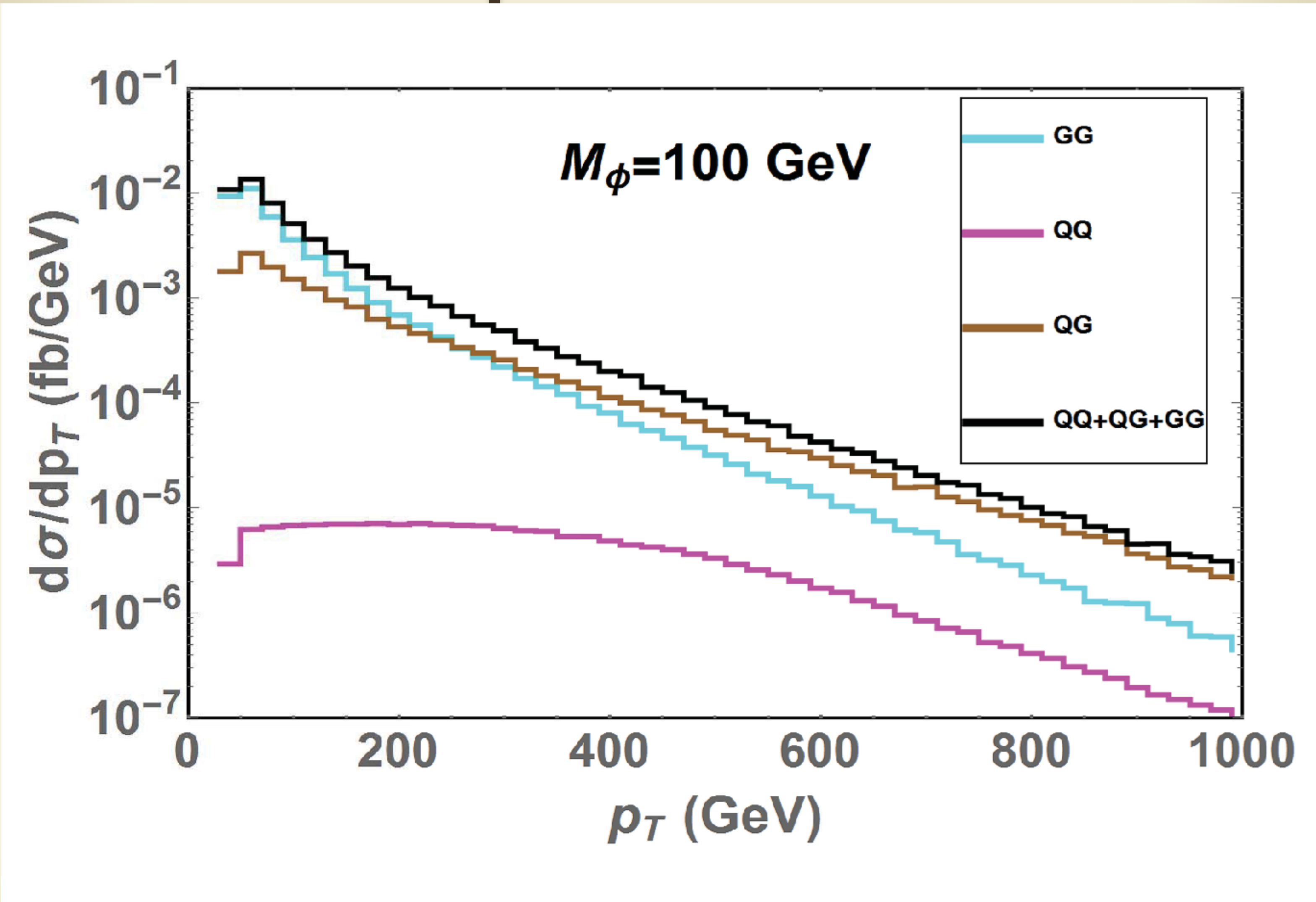
- Monojet amplitude at 1-loop is calculated with 3 methods:
- By hand > Integrated using OneLoop library
- FeynRules > FeynArts > FormCalc > LoopTools
- FeynRules (NLOCT) > Madgraph (NLOCT)

Monojet: Madgraph

- In large p_T regions, Madgraph shows large fluctuations.



Monojet: Initial State Dependence



Monojet: EFT vs Loops

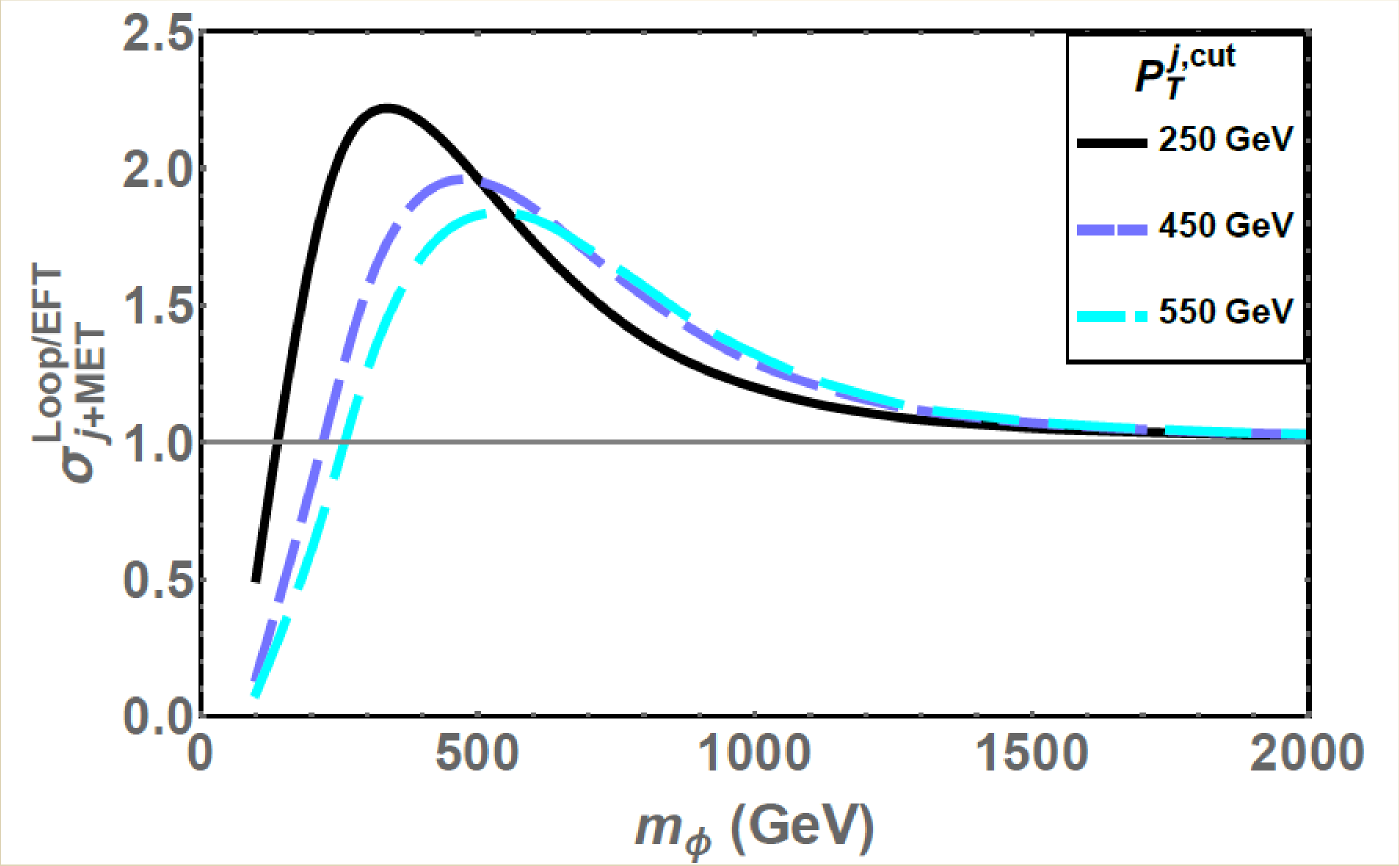
$$\lim_{M_\phi \to Large} iM(\mathrm{gg} \to \chi\chi^\star) \to \lambda_d g_s^2 \delta^{a_1 a_2} \left(\frac{-i}{96\pi^2 M_\phi^2} \right)$$

$$(p_1^{\mu_2} p_2^{\mu_1} - g^{\mu_1 \mu_2} p_1 . p_2)$$

A factor of $\frac{\lambda_d}{96\pi^2}$ is multiplied with the EFT cross section to compare with the loops.

Monojet: EFT vs Loops

- Loop calculation vs EFT ratio at 8 TeV LHC.



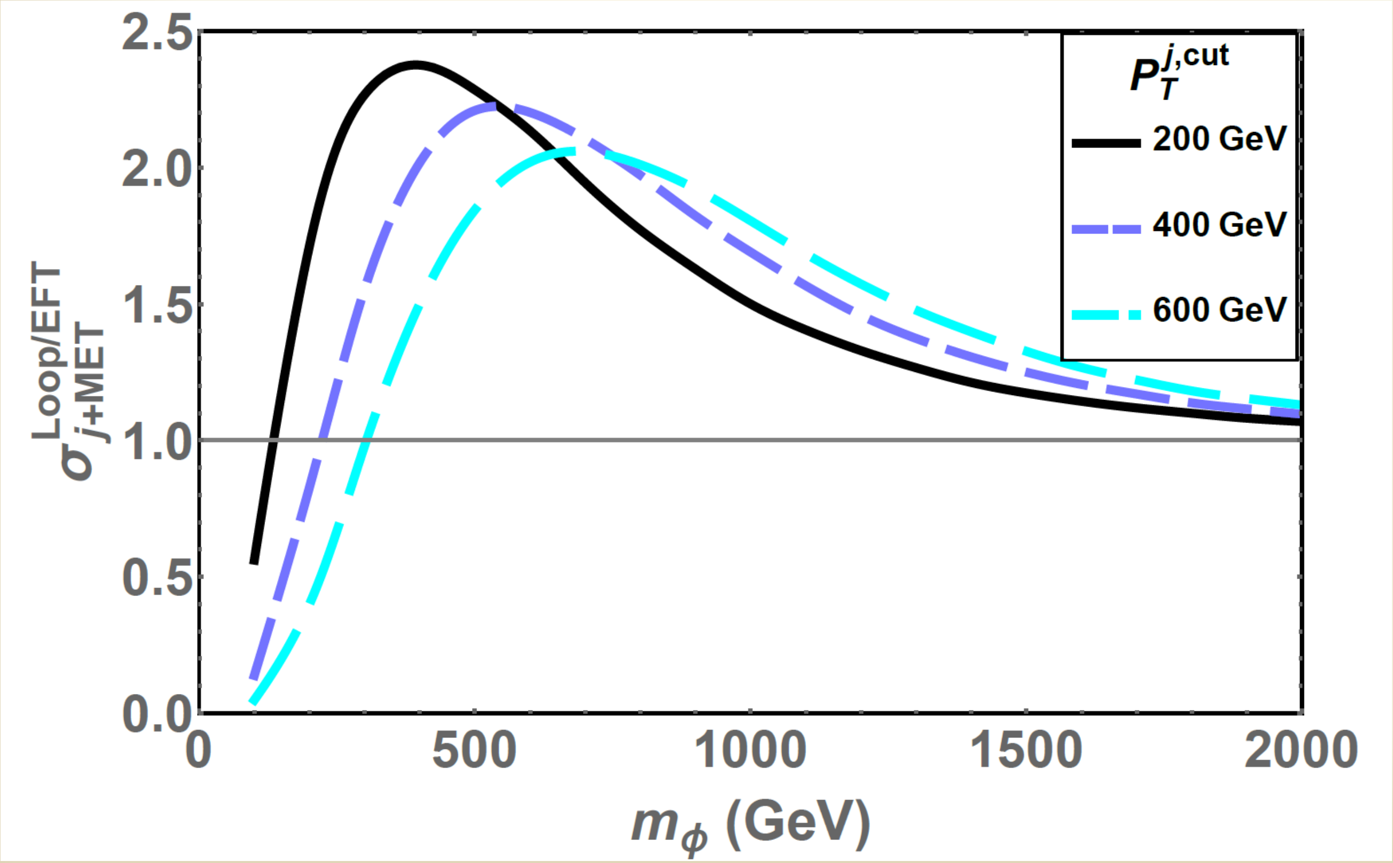
$pp \to \chi\chi^{\star} j$

$m_\chi = 1GeV$

$\lambda = 1$

Monojet: EFT vs Loops

- Loop calculation vs EFT ratio at 13 TeV LHC.



$pp \to \chi\chi^\star j$

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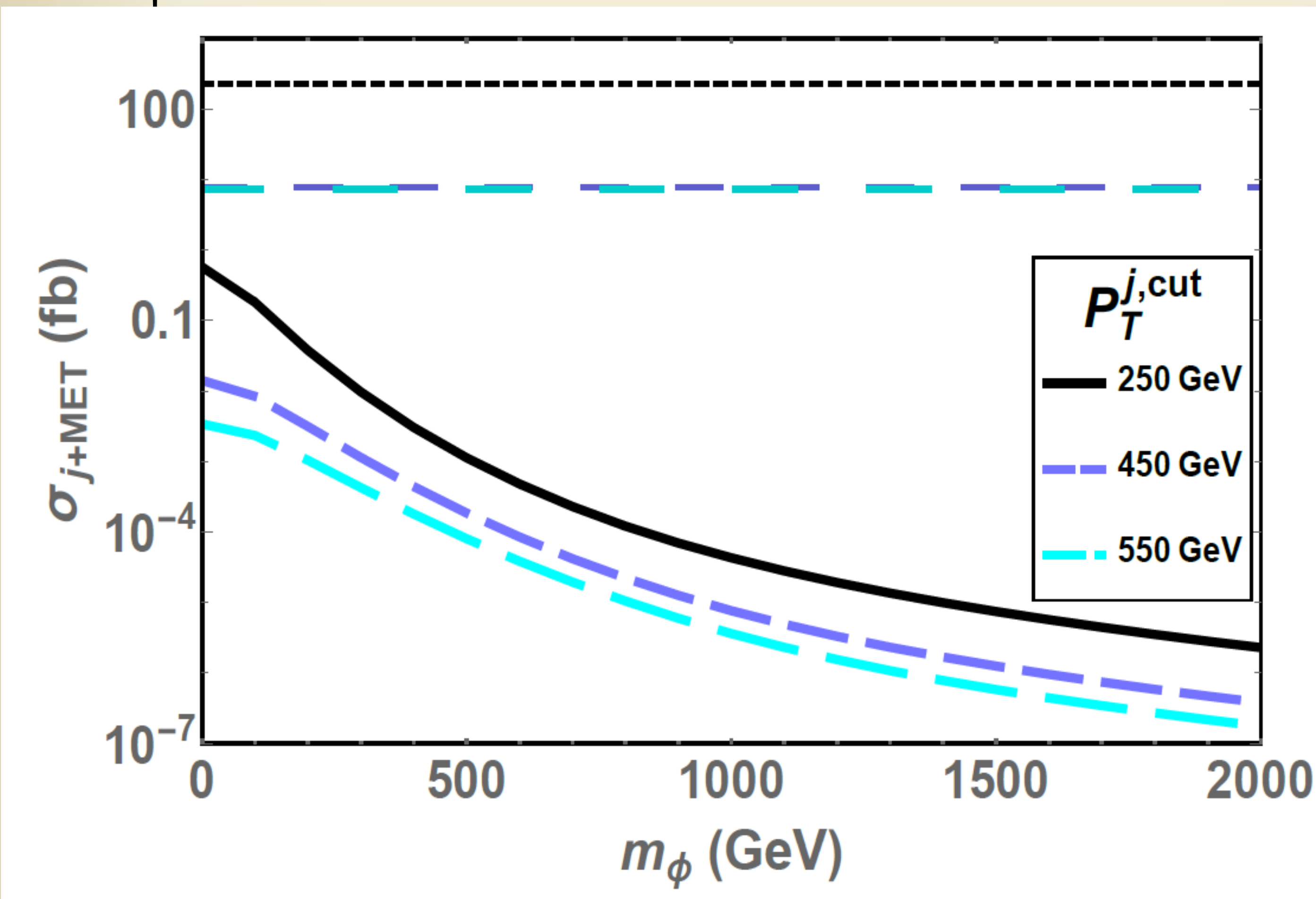
$\lambda = 1$

Monojet: Cross section

- Constraints from CMS [Eur. Phys.J. C75 no. 5, (2015) 235] monojet



$pp \to \chi\chi^{\star} j$

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$\lambda = 1$

r= 3

Monojet: Cross section

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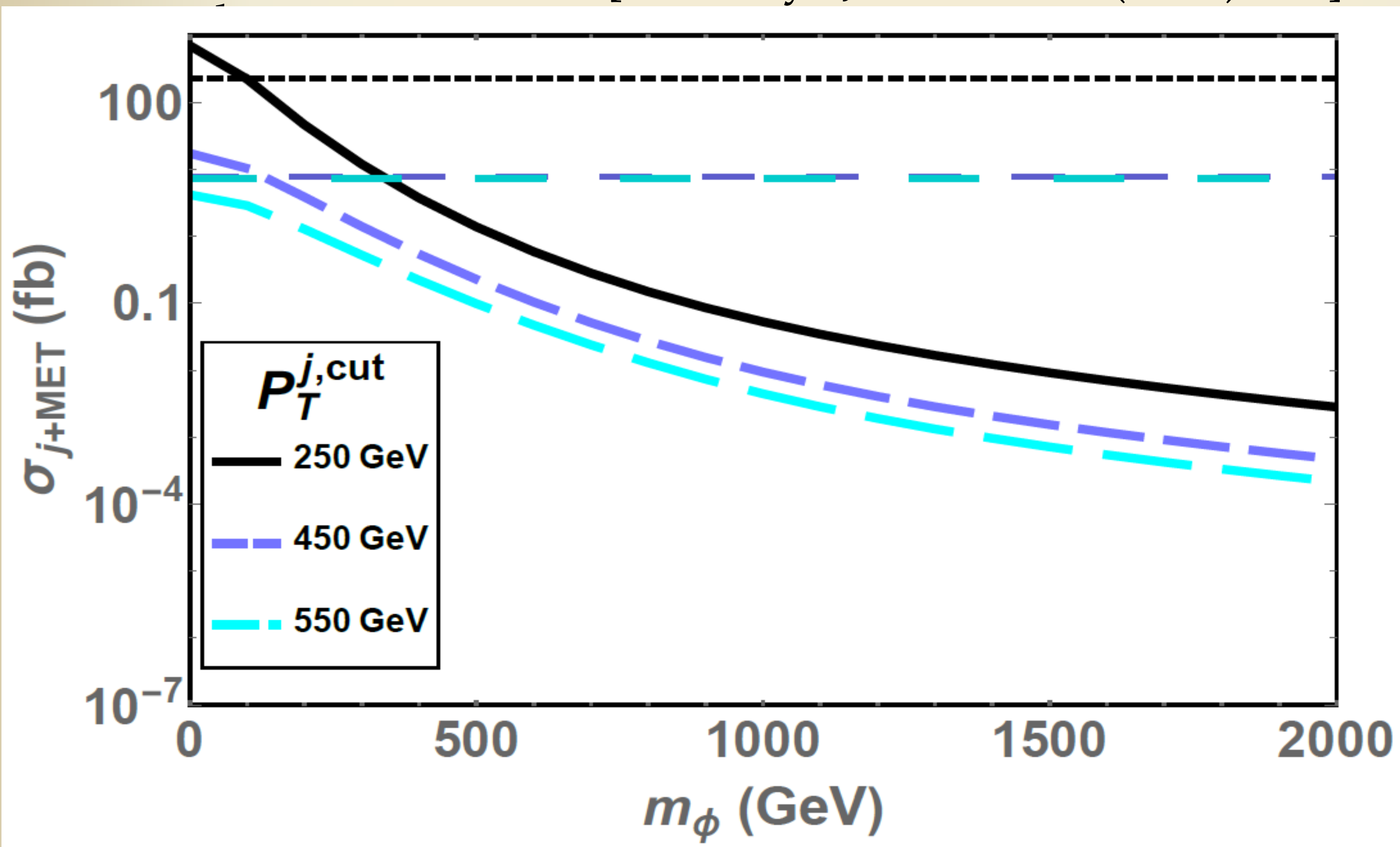

$pp \to \chi\chi^\star j$

$m_\chi = 1GeV$

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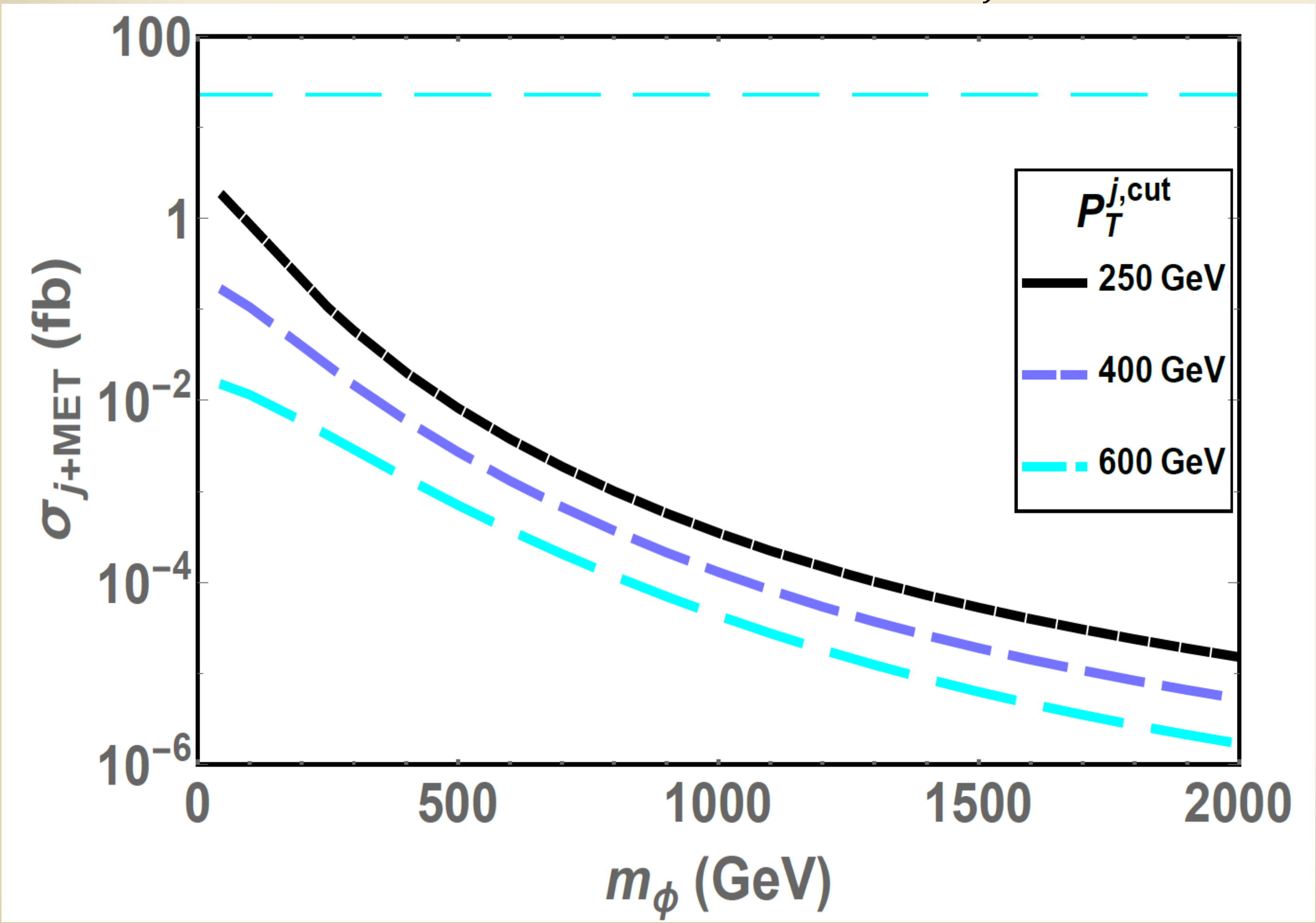
r= 15

Monojet: Cross section

- Constraints from run-II, ATLAS monojet search 1604.07773



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Monojet: Cross section

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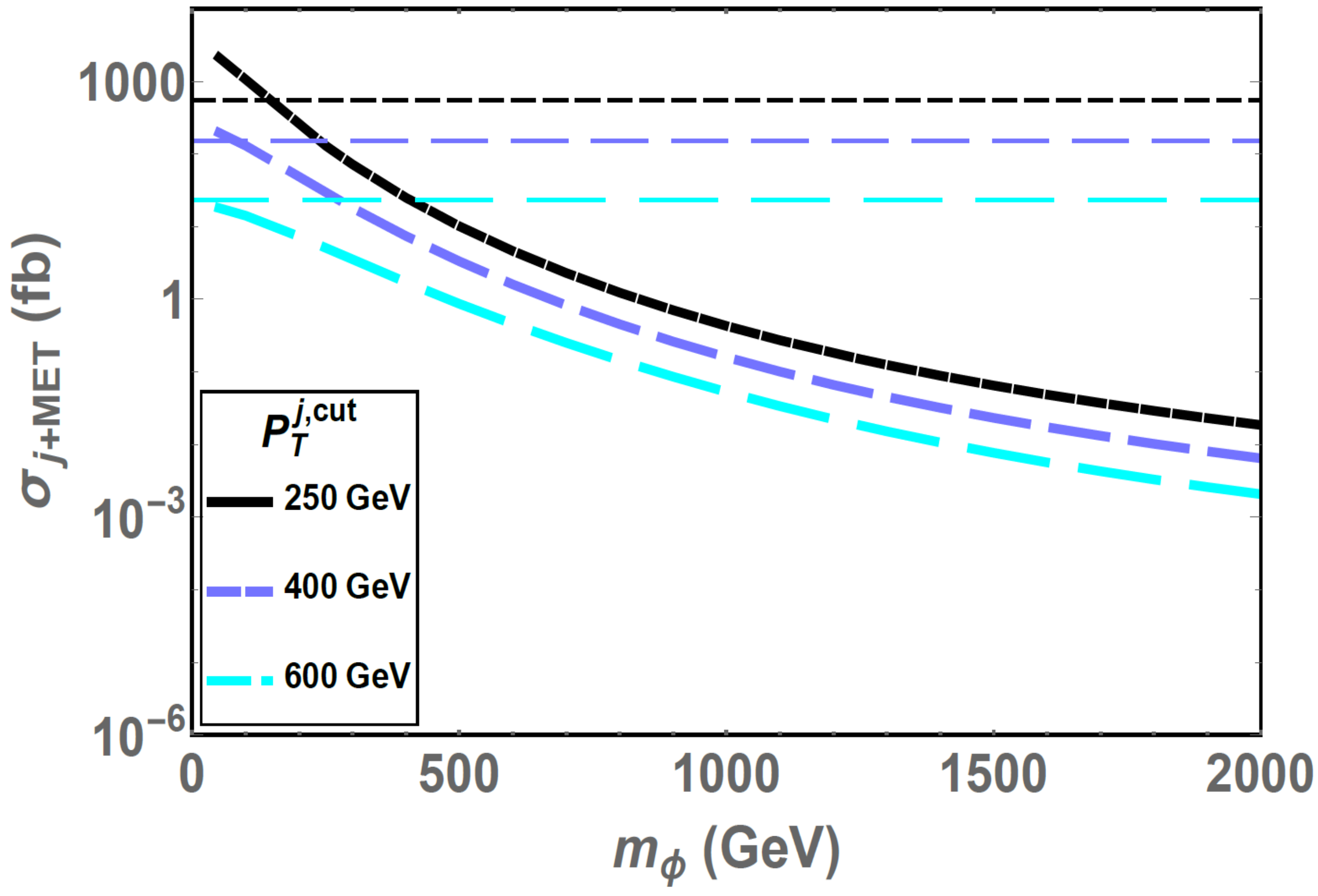

$pp \to \chi\chi^\star j$

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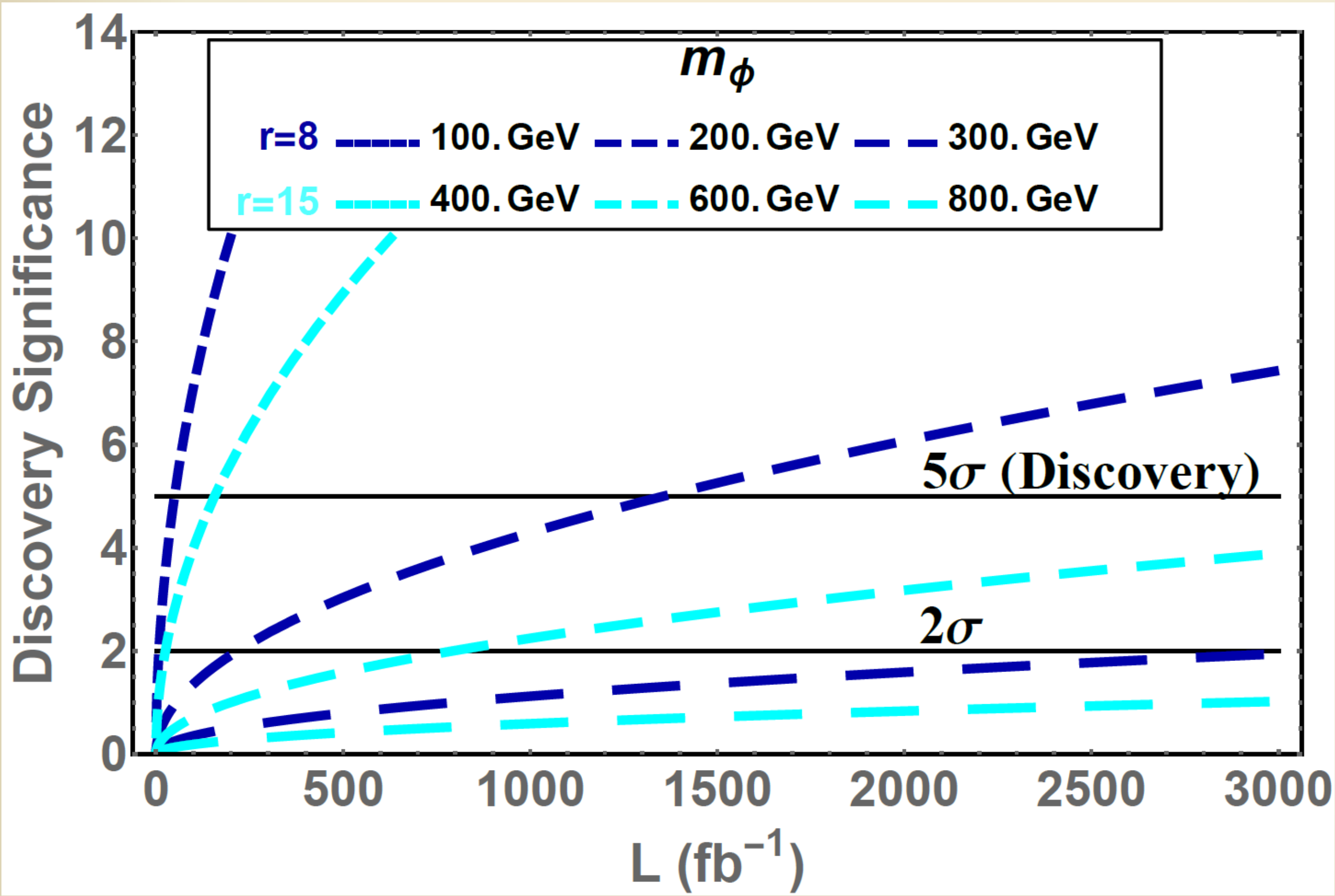
$\lambda = 1$

r= 15

Monojet: Projections

- Reach of LHC-13 in high luminosity limit to constraint GDSM.



$pp \to \chi\chi^{\star}j$

$m_\chi = 1GeV$

$\lambda = 1$

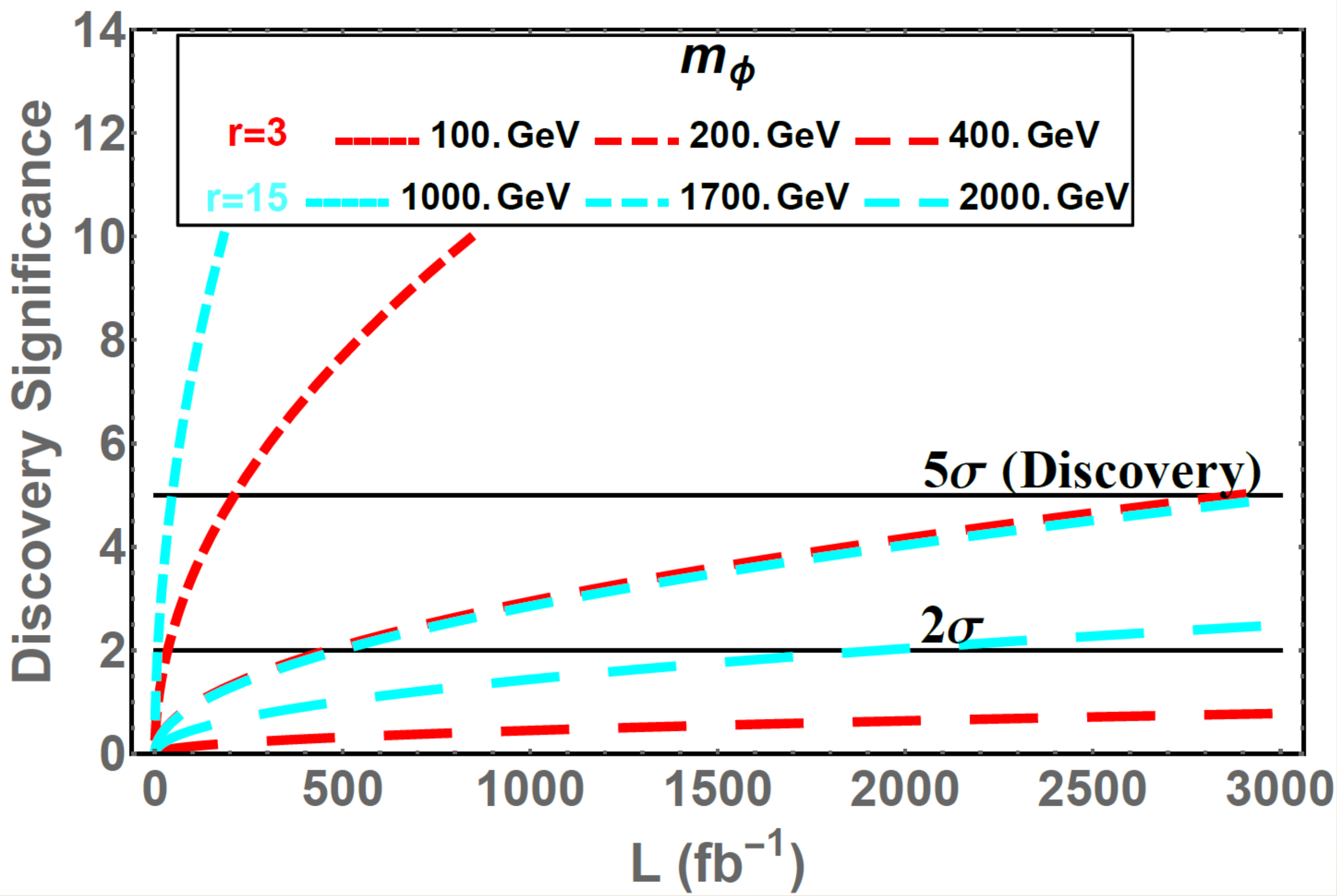
$p_T{}^j > 200GeV$
$|\eta_j| < 2.4$

$Significance = \frac{S}{\sqrt{S+B}}$

Backgrounds: z+j

Monojet: Projections

- Reach of Future Circular (hadron) Collider to constraint GDSM.



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$Significance = \frac{S}{\sqrt{S+B}}$

Backgrounds: z+j

Summary: Gluphillic DM

- We propose a model where a scalar DM preferentially couples with gluons.
- We find that tree-level annihilation gives the correct relic density of DM.
- We calculate the loop-induced monojet process and find that effective field theory underestimates the cross section by a factor of 2 when mediator mass is comparable to the cuts.

Summary: Gluphillic DM

- Colored scalars which can decay give a rich signature at LHC and can be discovered in multi-jet final state searches.

- With the assumption of a light dark matter (1GeV) color triplet scalar can be constrained up to 50 GeV with high luminosity at LHC.

- With 3 inv-ab, LHC can discover a color octet mediator with mass ~200 GeV and dim 15 mediator of mass 500 GeV.

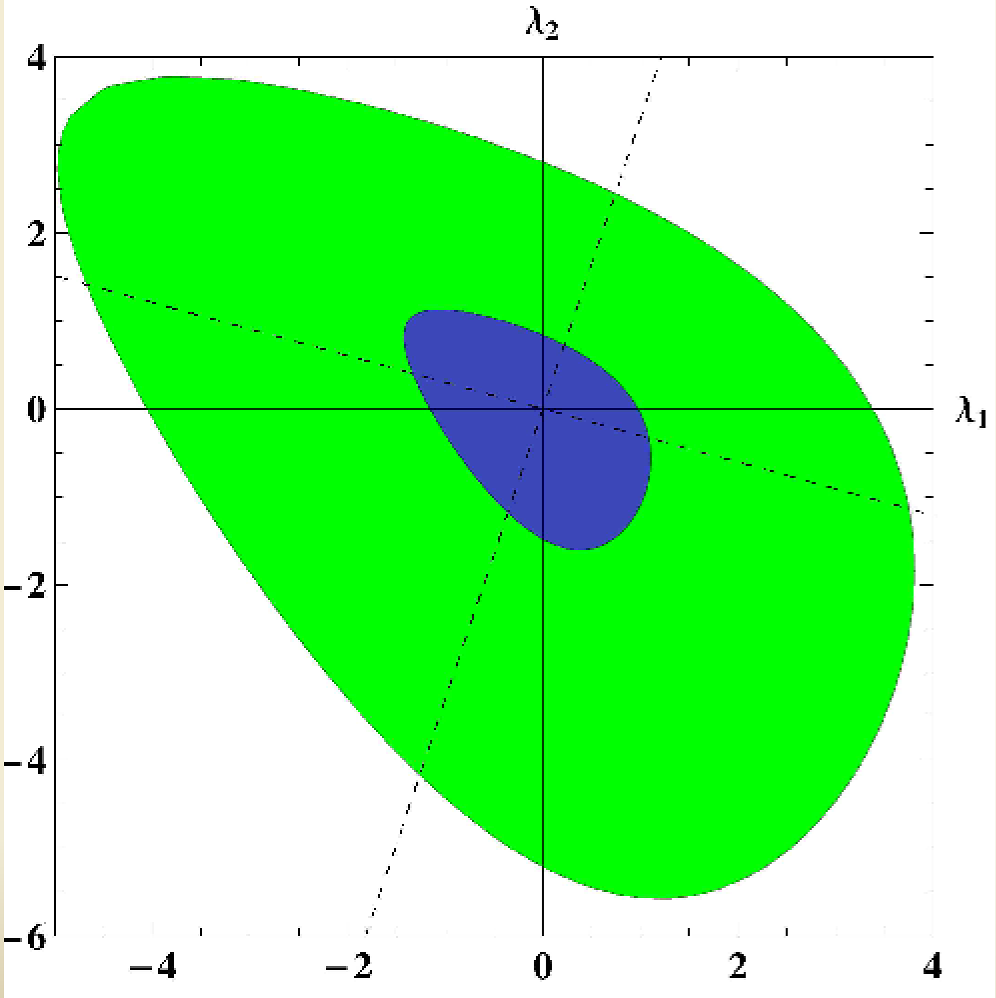
- FCC can probe much larger masses up to TeV scale within a low 300 fb^{-1} luminosity.


Questions & Comments

How dark is DM? Astrophysical Signatures

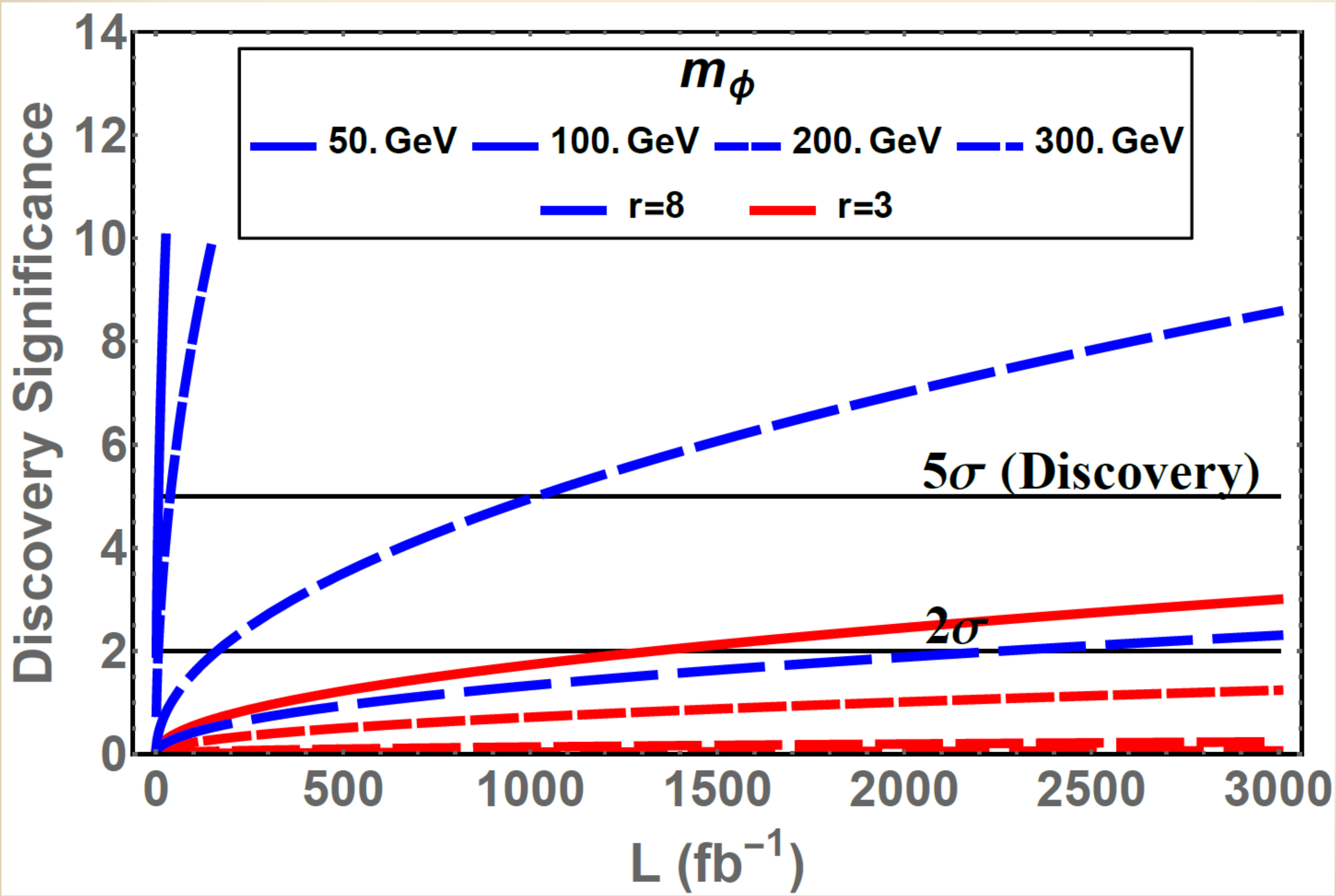
- 3.5 KeV line
- GeV excess
- DM self couplings
  - Abel 3827. (Mon.Not.Roy.Astron.Soc. 449 (2015) 4, 3393-3406)

Unitarity: Color octet scalar



Monojet: Projections

- Reach of LHC-14 in high luminosity limit to constraint GDSM.



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