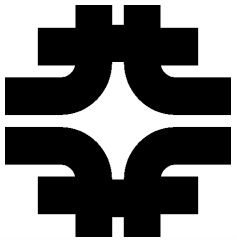
Taking a Razor to Dark Matter Parameter Space at the LHC

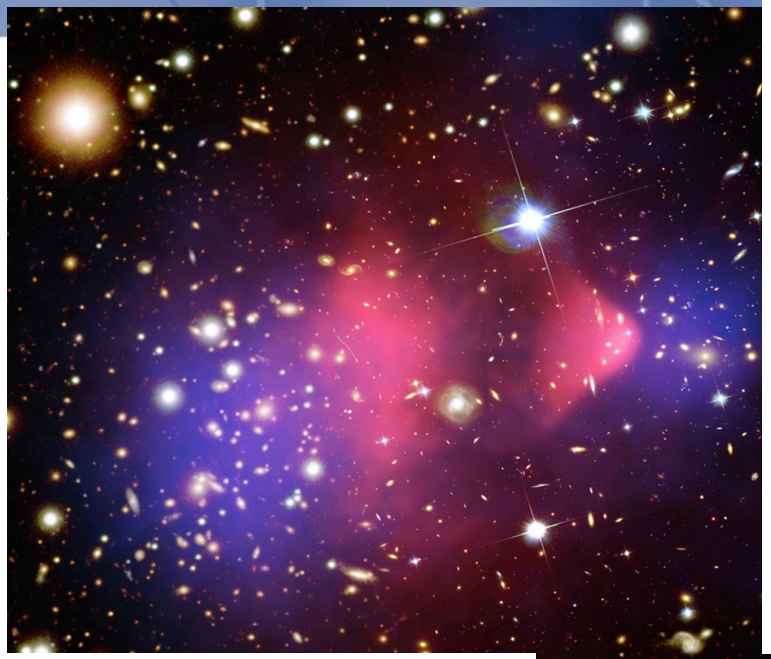
Reinard Primulando

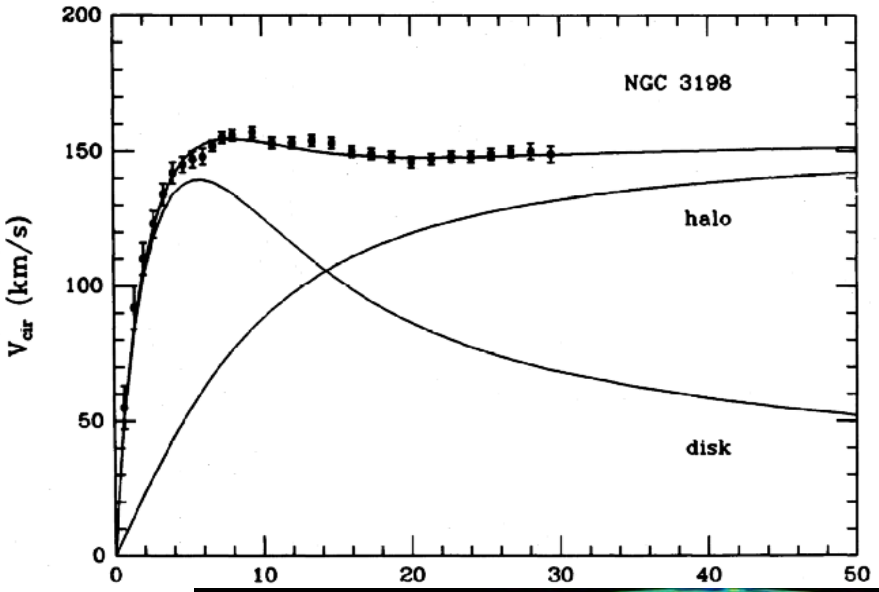
Work with Patrick Fox, Roni Harnik and Chiu-Tien Yu: 1203.1662

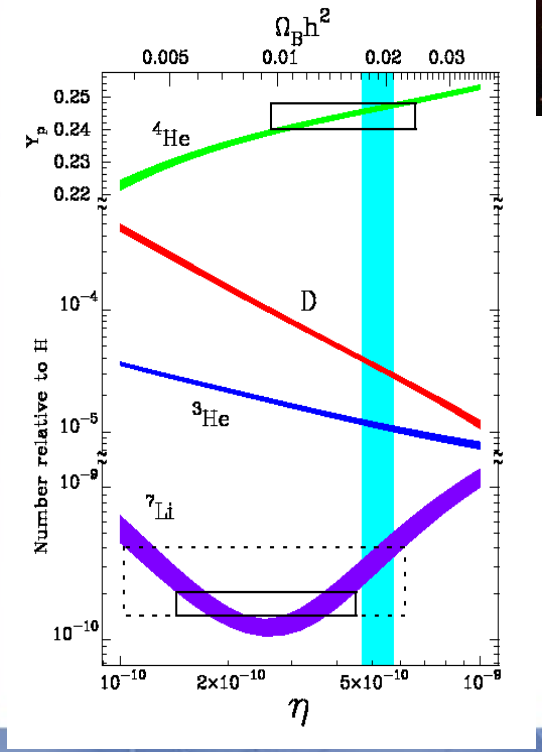


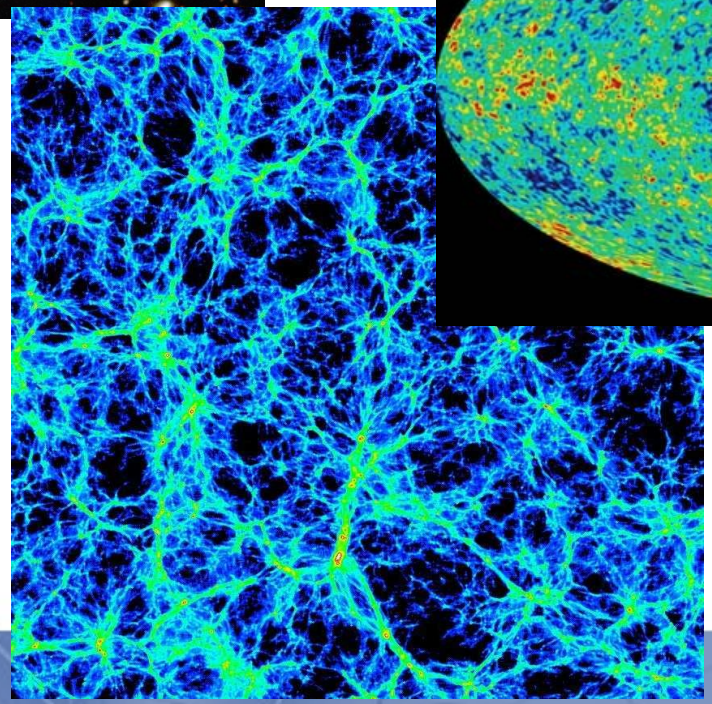
Outline

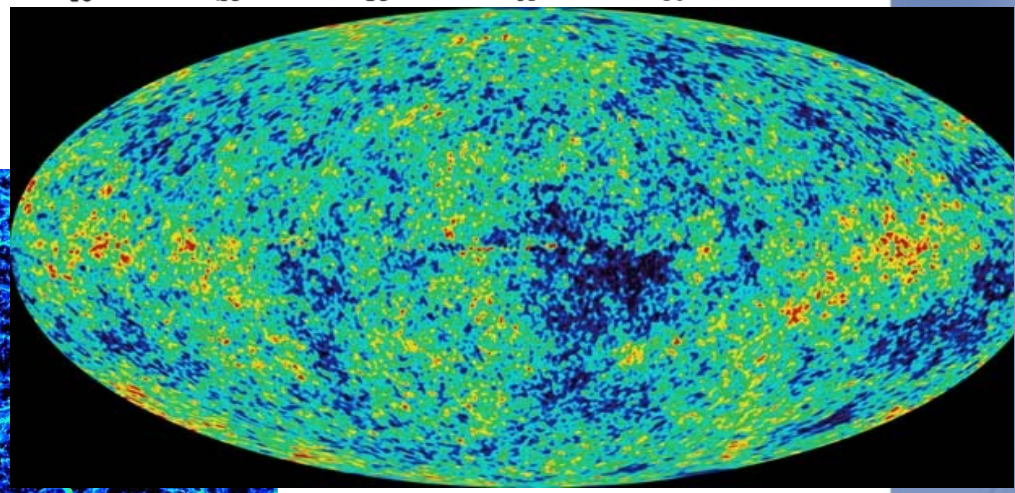
- Dark Matter Direct Detection
- Dark Matter at Collider
- Razor Kinematics
- Light Mediators
- Conclusion



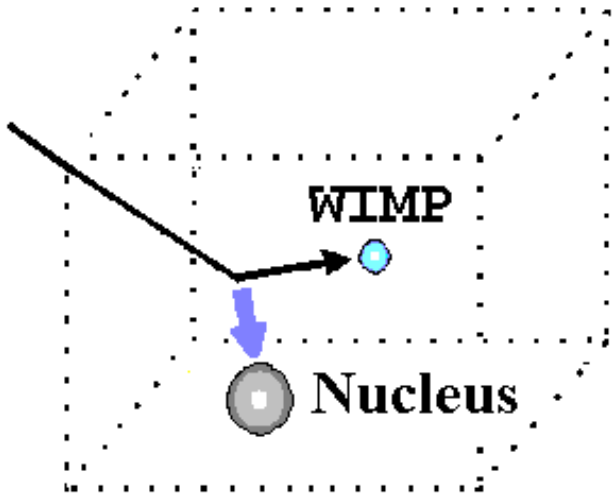

DISTRIBUTION OF DARK MATTER IN NGC 3198
NGC 3198
halo
disk
V_{cir} (km/s)
200
150
100
50
0
0
10
20
30
40
50


$\Omega_B h^2$
0.005
0.01
0.02
0.03
Y_p
0.25
0.24
0.23
0.22
^{4}He
D
^{3}He
^{7}Li
Number relative to H
10^{-4}
10^{-5}
10^{-9}
10^{-10}
10^{-10}
2×10^{-10}
5×10^{-10}
10^{-9}
η





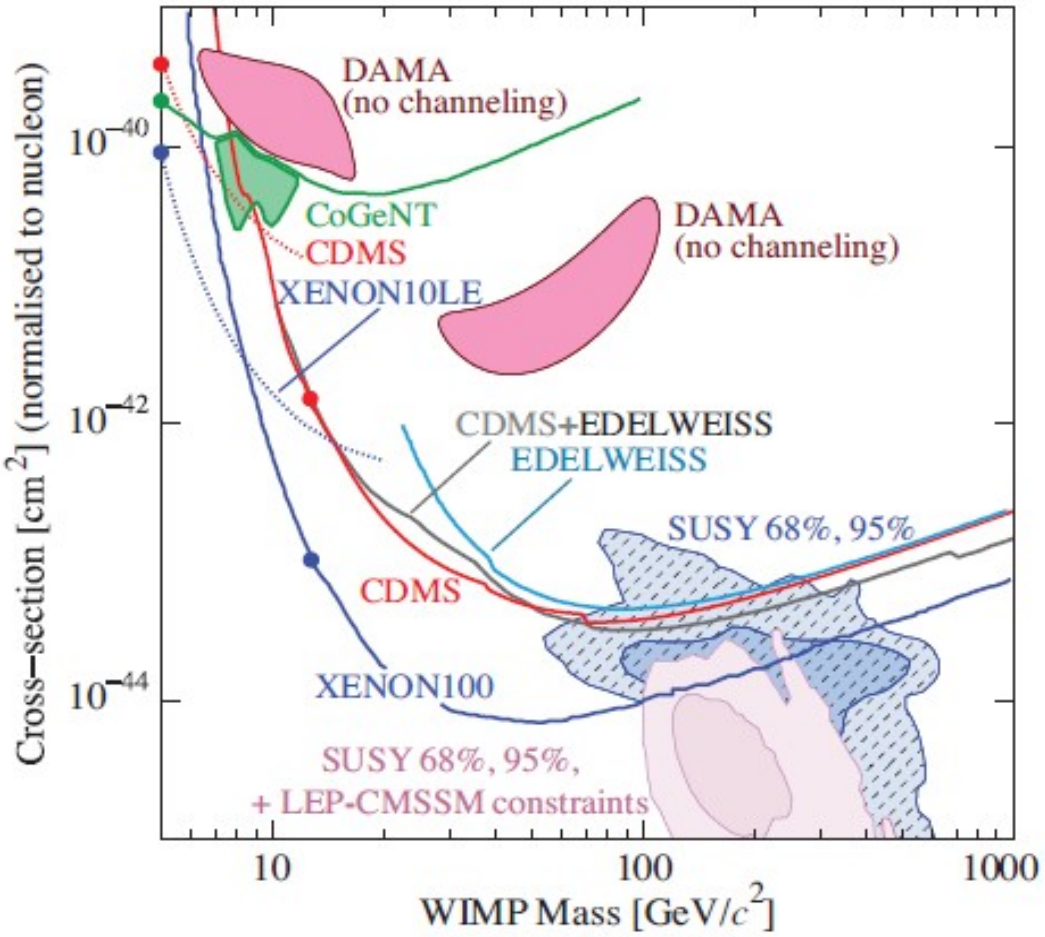
Direct Detection (DD) of DM



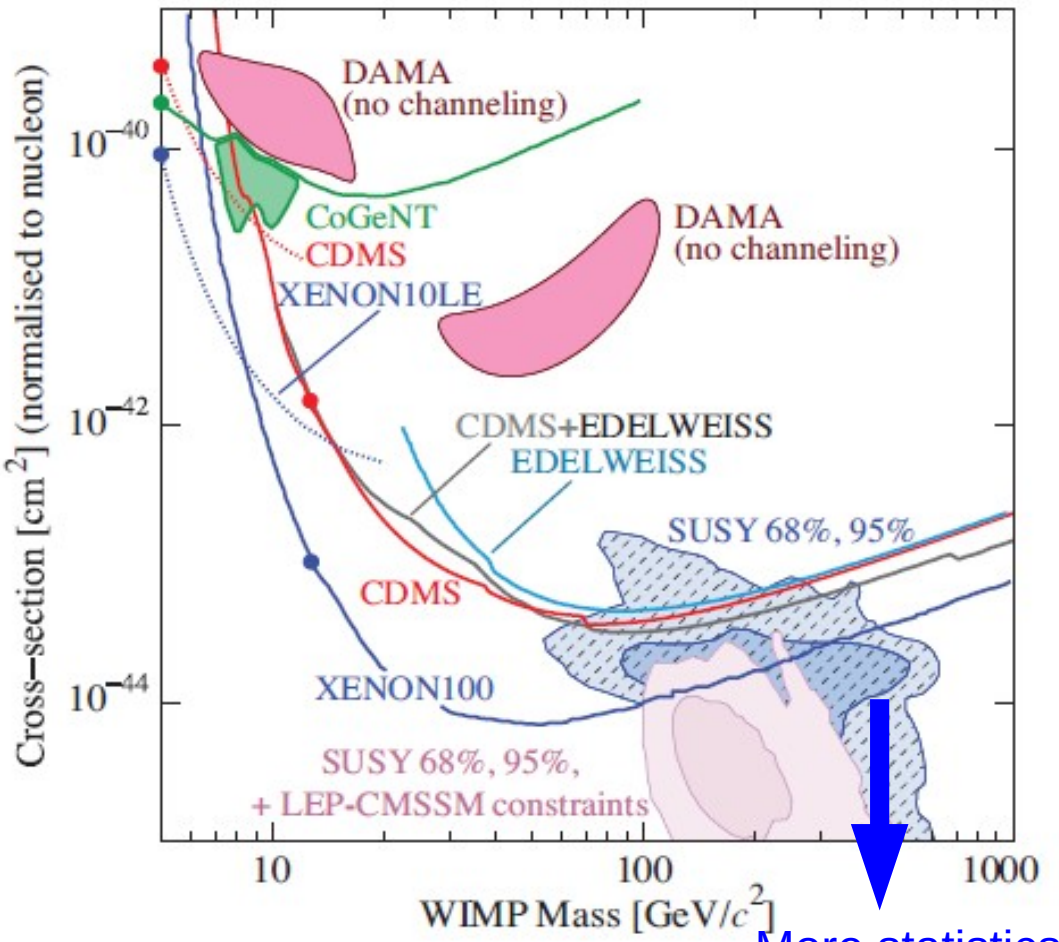
Gives us information about

- Mass
- Interaction with SM

Current State of DD

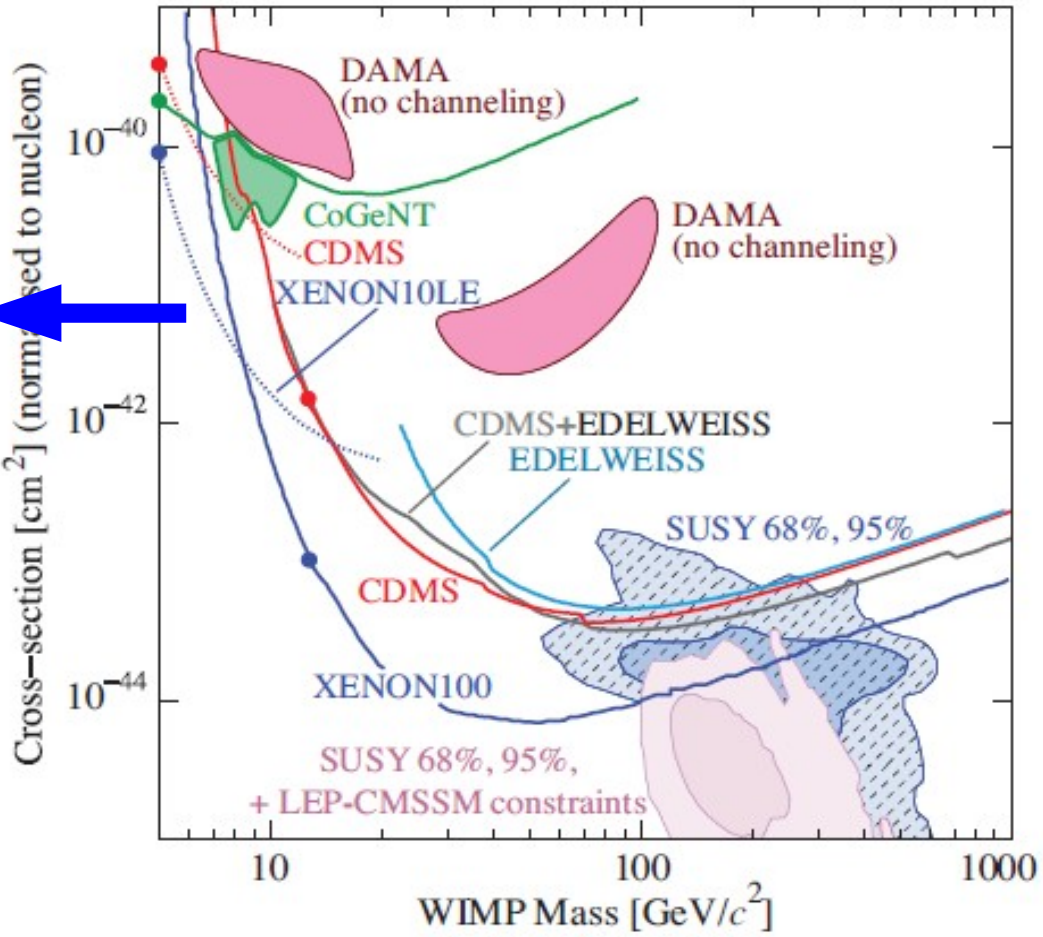


Current State of DD



Current State of DD

- Lower threshold
- Hadron collider



Collider Bounds → DD Bounds

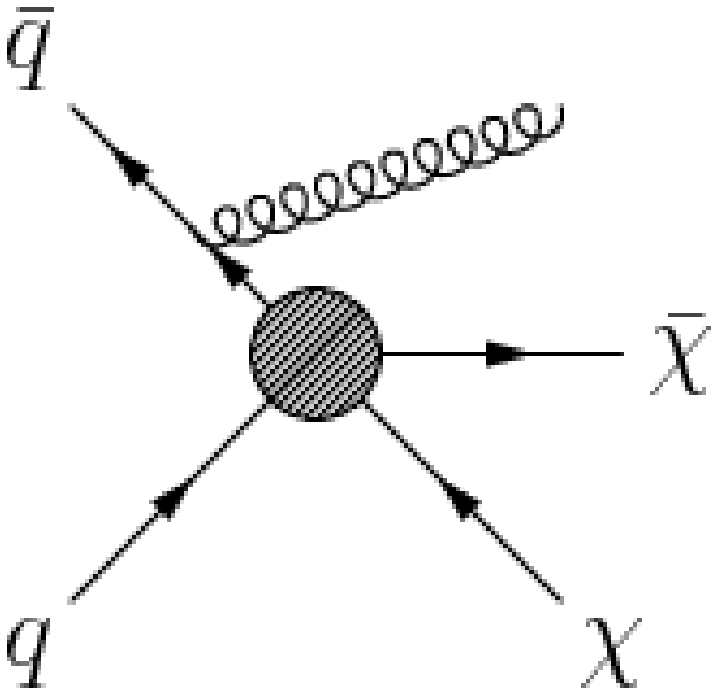
- Need a model independent way to translate collider bounds to DD bounds.
- Assuming contact operators → integrating out heavy mediators
- Two scales left (m_χ and Λ)

$$\mathcal{O}_V = \frac{(\bar{\chi}\gamma_\mu\chi)(\bar{q}\gamma^\mu q)}{\Lambda^2},$$

$$\mathcal{O}_A = \frac{(\bar{\chi}\gamma_\mu\gamma_5\chi)(\bar{q}\gamma^\mu\gamma_5 q)}{\Lambda^2},$$

$$\mathcal{O}_G = \alpha_s\frac{(\bar{\chi}\chi)(G^a_{\mu\nu}G^{a\mu\nu})}{\Lambda^3},$$

LHC Signatures



- Jets + MET
- Photons + MET

Monojet

- Fermilab clan

Bai, Yang et al. JHEP 1012 (2010) 048 arXiv:1005.3797 [hep-ph]; Fox, Patrick J. et al. Phys.Rev. D85 (2012) 056011 arXiv:1109.4398 [hep-ph]; Fox, Patrick J. et al. Phys.Rev. D84 (2011) 014028 arXiv:1103.0240 [hep-ph]; Beltran, Maria et al. JHEP 1009 (2010) 037 arXiv:1002.4137 [hep-ph]

- Irvine clan

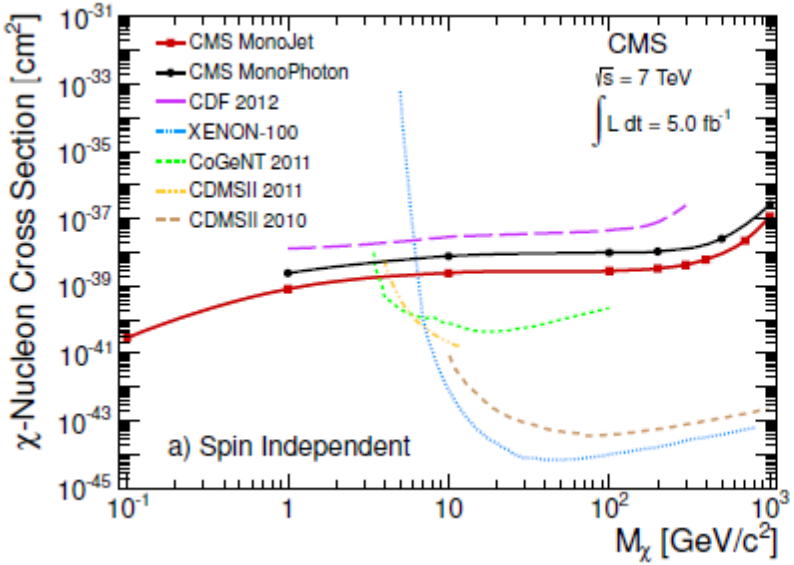
Goodman, Jessica et al. Phys.Lett. B695 (2011) 185-188 arXiv:1005.1286; Goodman, Jessica et al. Phys.Rev. D82 (2010) 116010 arXiv:1008.1783 [hep-ph]; Goodman, Jessica et al. arXiv:1111.2359 [hep-ph]; Rajaraman, Arvind et al. Phys.Rev. D84 (2011) 095013 arXiv:1108.1196 [hep-ph]; Fortin, Jean-Francois et al. Phys.Rev. D85 (2012) 063506 arXiv:1103.3289 [hep-ph]

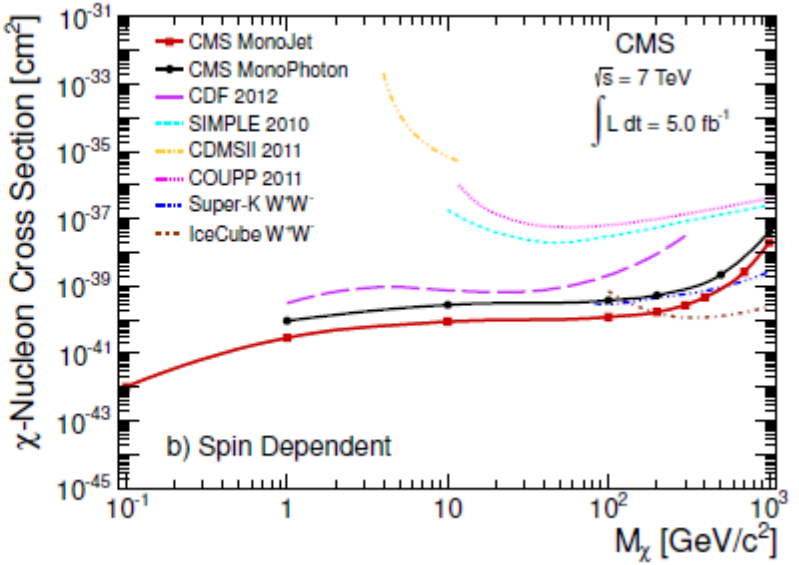
- Los Alamos clan

Shoemaker, Ian M. et al. ArXiv:1112.5457; Friedland, Alexander et al. arXiv:1111.5331 [hep-ph]

Results from Tevatron and LHC

CMS, arXiv:1206.5663





$$\mathcal{O}_V = \frac{(\bar{\chi}\gamma_\mu\chi)(\bar{q}\gamma^\mu q)}{\Lambda^2}$$

$$\mathcal{O}_A = \frac{(\bar{\chi}\gamma_\mu\gamma_5\chi)(\bar{q}\gamma^\mu\gamma_5 q)}{\Lambda^2}$$

Beyond Monojet

- LHC is a jets factory.
- Can we use data with more than one jet?
- Many SUSY analysis require two jets or more + MET.

Razor

- Razor variables was invented for improving SUSY searches. *Rogan, arXiv:1006.2727*
- Inclusive search of two or more jets + MET.
- Data driven approach to estimate the background.
- One can combine the results with monojet analysis (from ATLAS, not CMS).

Razor

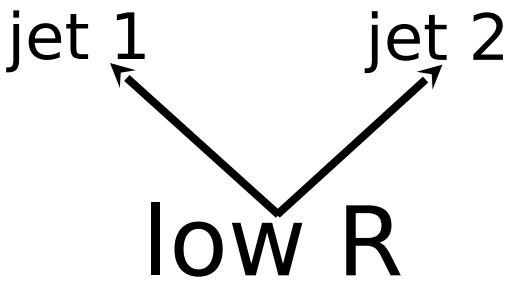
$$M_R = \sqrt{(E_{j_1} + E_{j_2})^2 - (p_z^{j_1} + p_z^{j_2})^2}\ .$$

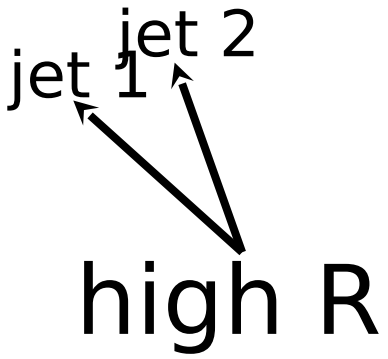
$$M_R^T = \sqrt{\frac{\not{E}_T(p_T^{j_1} + p_T^{j_2}) - \vec{\not{E}}_T \cdot (\vec{p}_T^{j_1} + \vec{p}_T^{j_2})}{2}}\ ,$$

Estimate the scale of the event

$$R = \frac{M_R^T}{M_R}\ ,$$

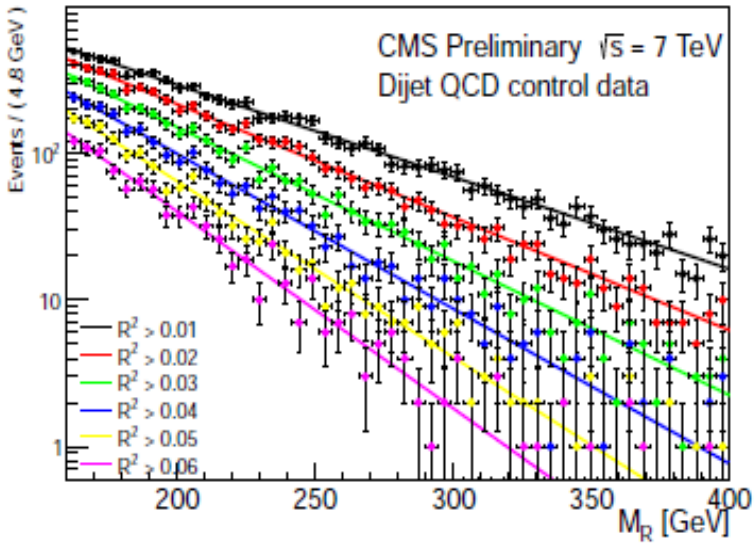
Ratio of MET to visible

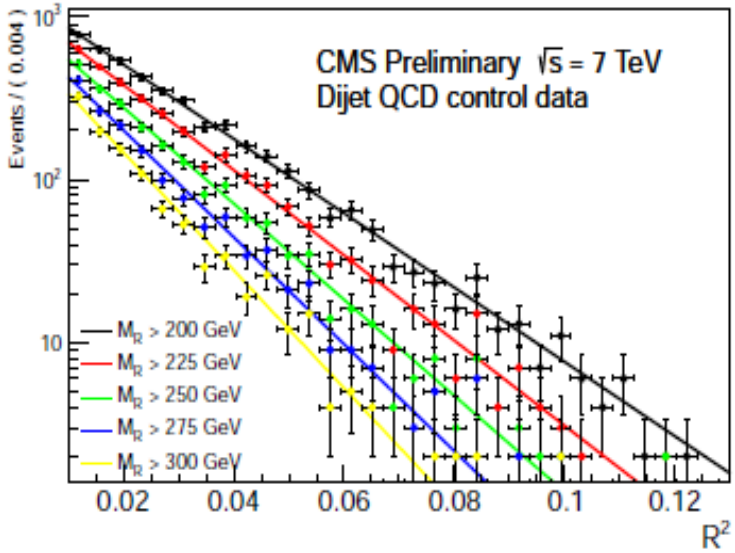




The SM Background

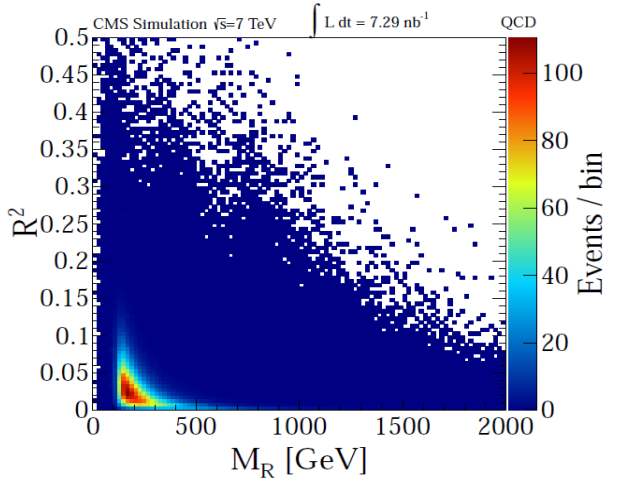
- SM backgrounds fall exponentially.
- Putting cuts on high M_R or R suppress the SM backgrounds.

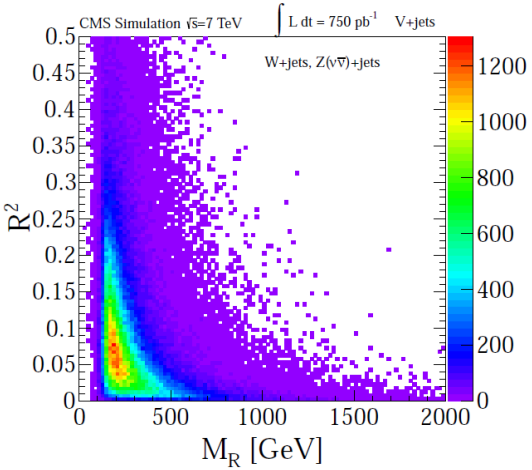


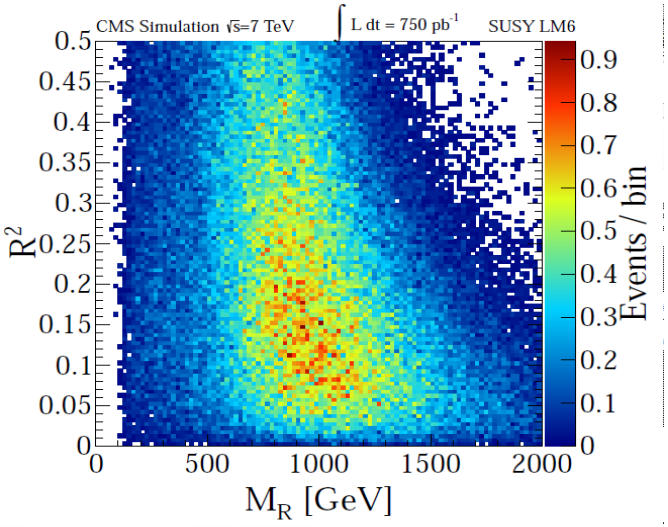


CMS-PAS-SUS-11-008

The SM Background



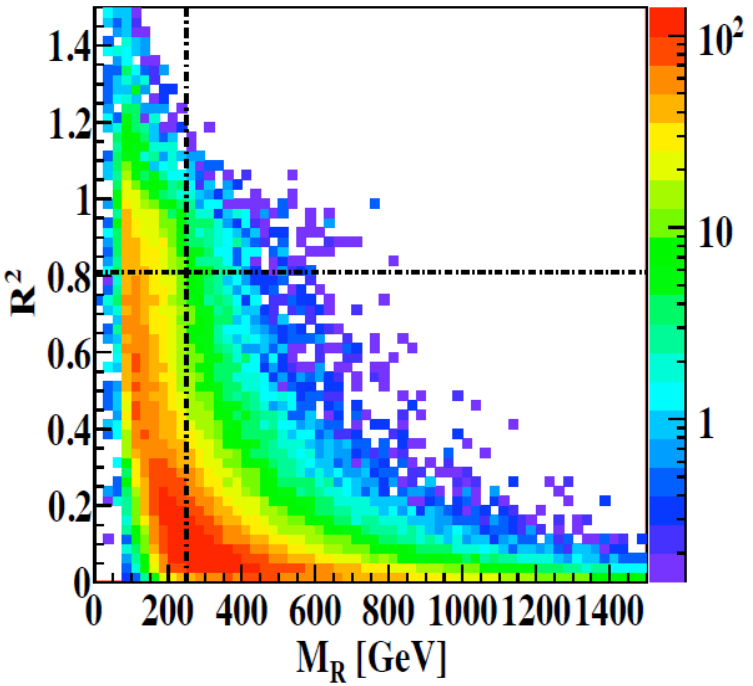




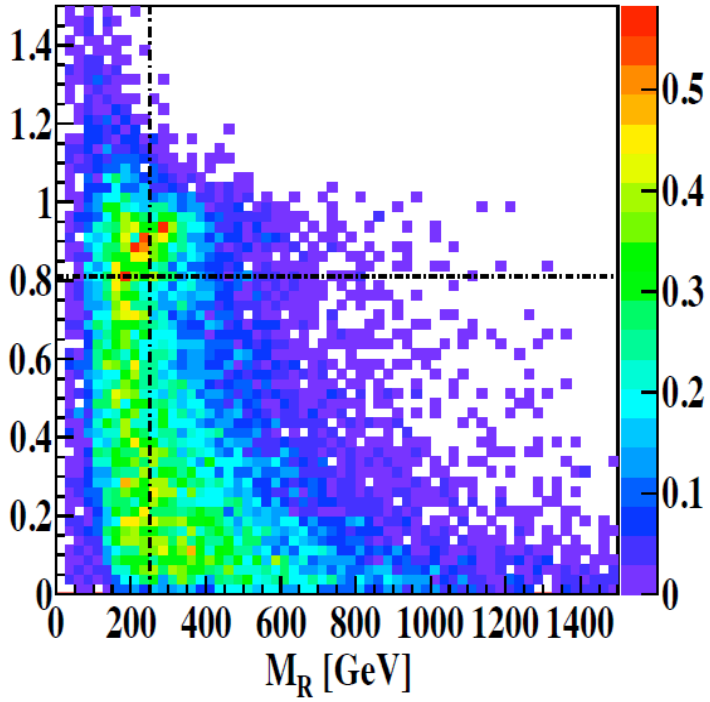
CMS-PAS-SUS-11-008

DM Signal

Z + jets

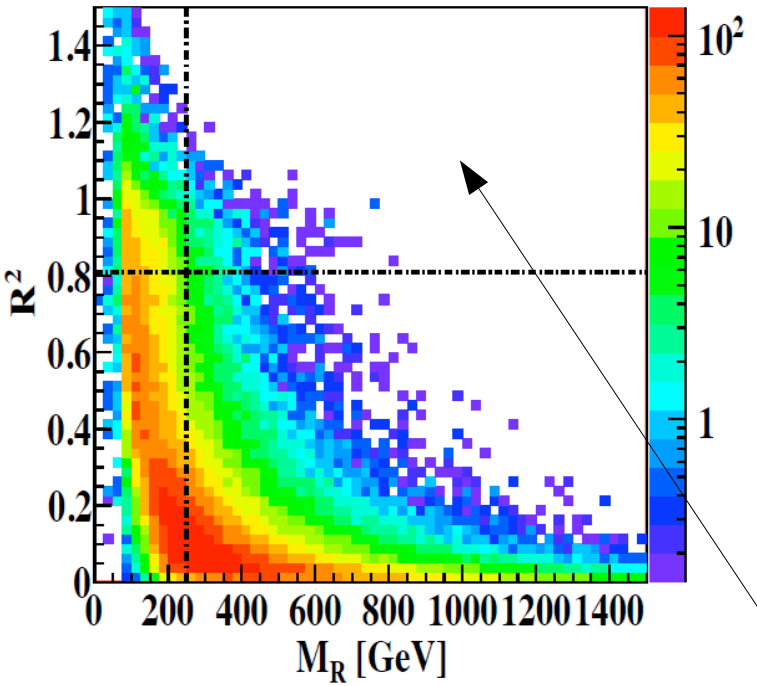


DM Production

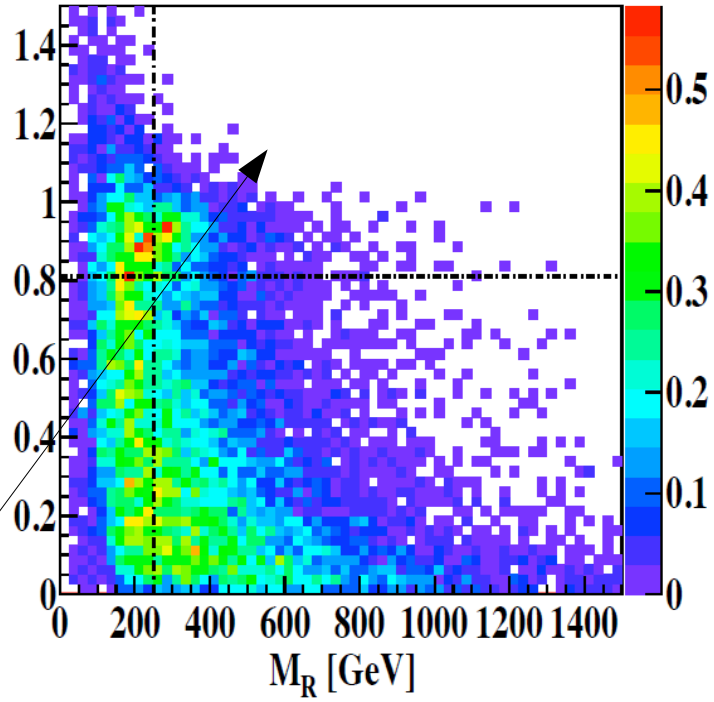


DM Signal

Z + jets

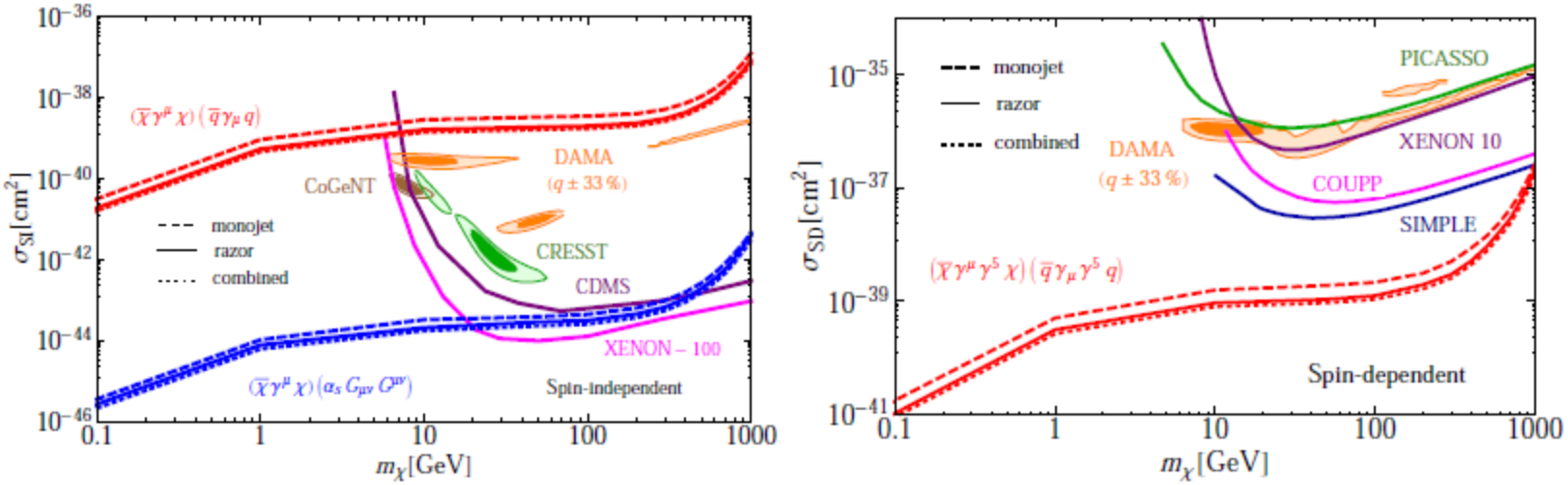


DM Production



Signal region

Results



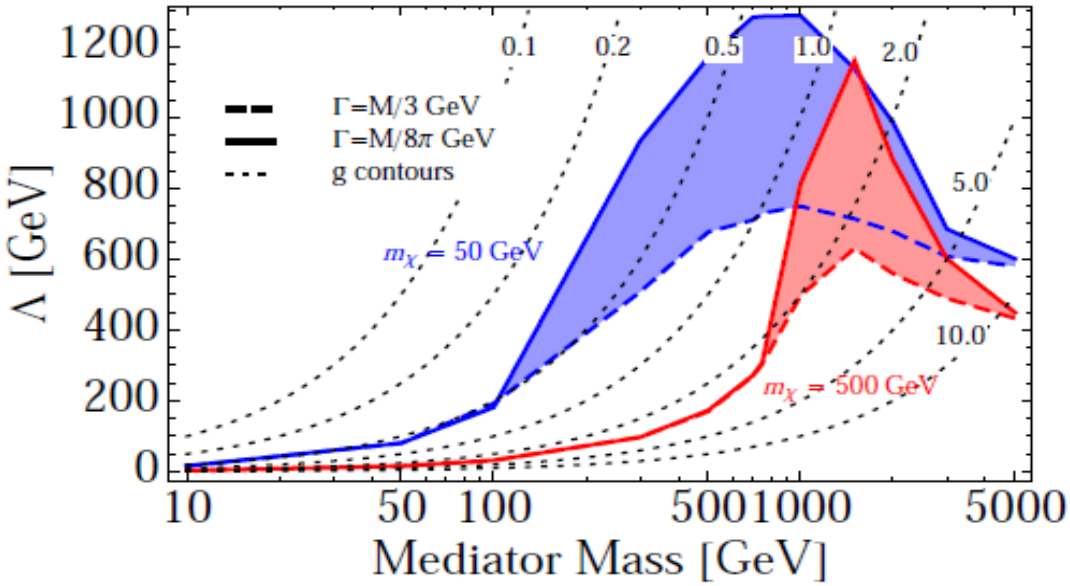
- 50% more sensitivity compared with monojet alone.

Light Mediator

- It is possible that the mediator is accessible at the LHC.
- Unitarity constraint requires the mediator to be less than 7 TeV. *Shoemaker, Vecchi, arXiv:1112.5457*

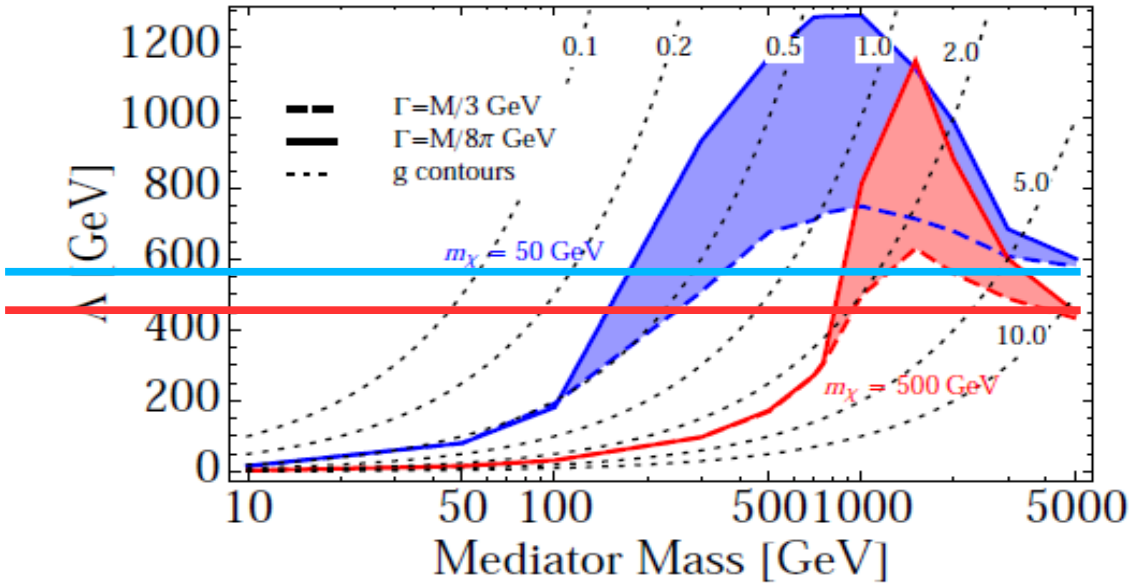
$$\sigma_{\rm DD} \sim g_\chi^2\, g_q^2\, \frac{\mu^2}{M^4} \qquad \sigma_{1j} \sim \begin{cases} \alpha_s\, g_\chi^2\, g_q^2\, \frac{1}{p_T^2} & M \lesssim p_T \\ \alpha_s\, g_\chi^2\, g_q^2\, \frac{p_T^2}{M^4} & M \gtrsim p_T \end{cases}$$

Light Mediator



$$\Lambda \equiv M/\sqrt{g_q g_\chi}$$

Light Mediator



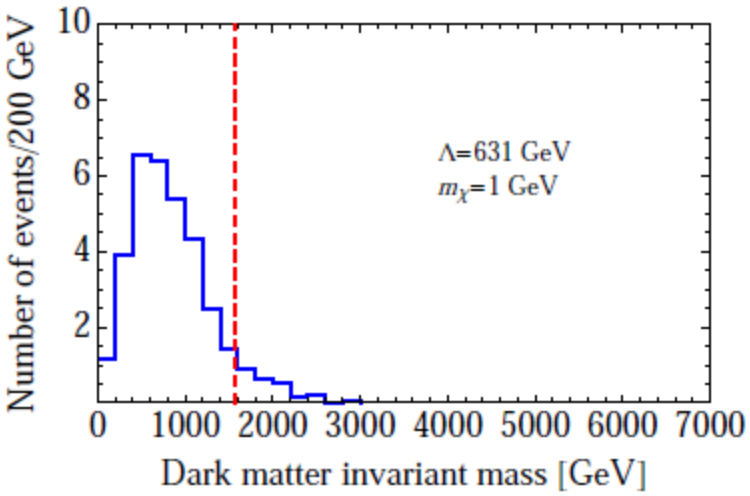
$$\Lambda \equiv M/\sqrt{g_q g_\chi}$$

- Our bound is conservative for most range of mediator mass.
- Very light mediator can be studied by looking at dijet searches. *An, Ji, Wang, arXiv:1202.2894; March-Russell, Unwin, West, arXiv:1203.4854*

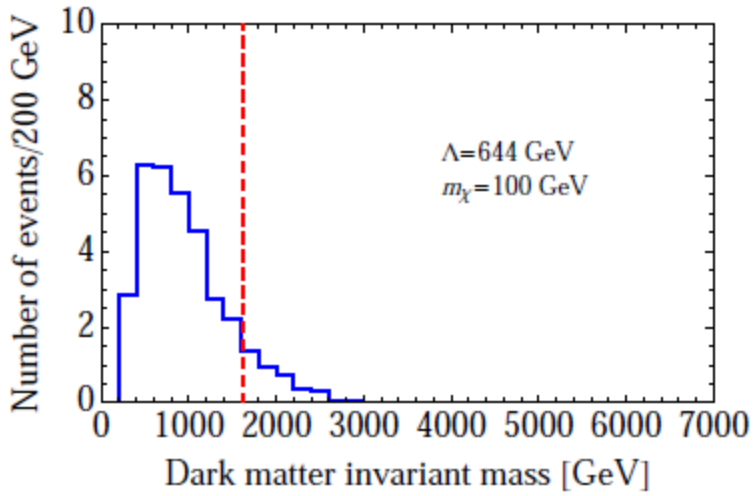
Conclusion

- Dark matter production at hadron colliders can complement searches at direct detection experiments.
- Tevatron and LHC data provide the strongest bounds for light dark matter.
- Using razor kinematics, the collider bounds can be improved.

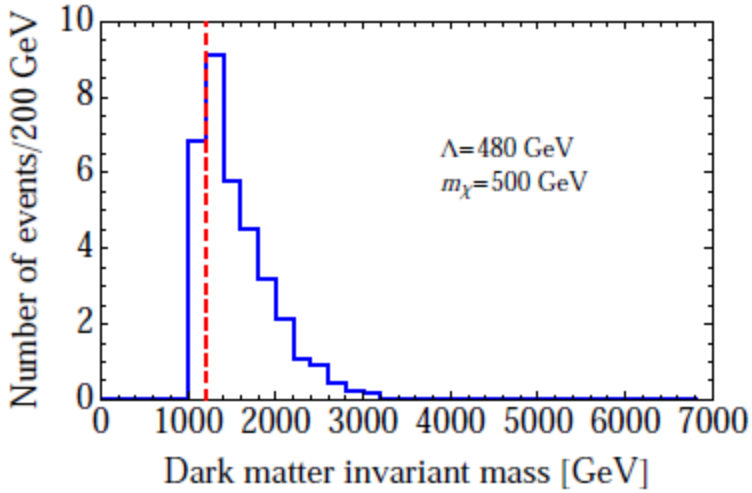
Backup Slides

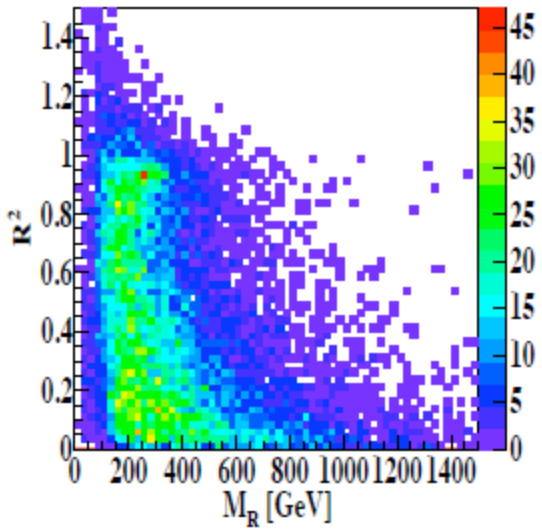


(a) $m_\chi = 1$ GeV

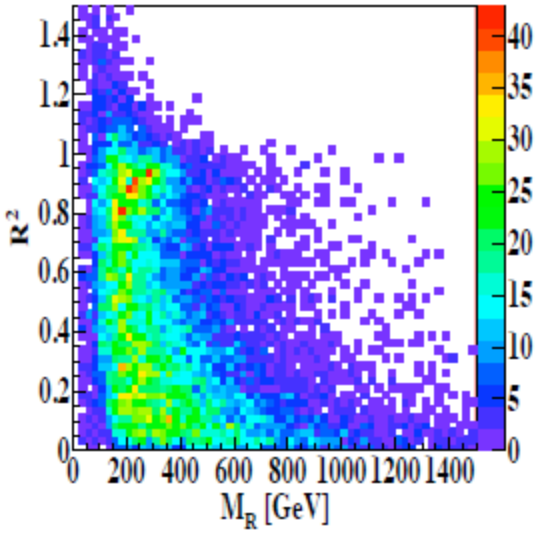


(b) $m_\chi = 100$ GeV

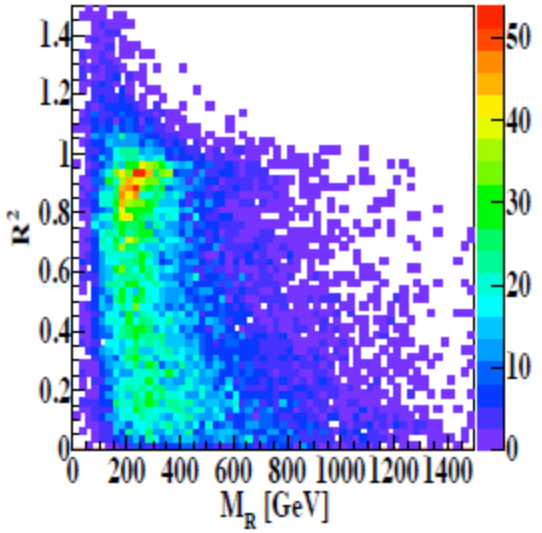


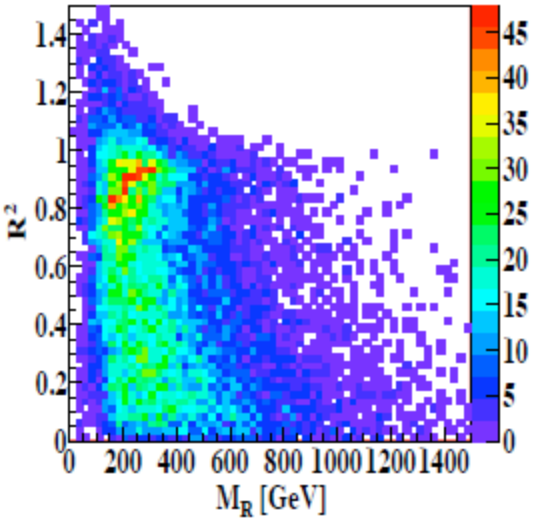


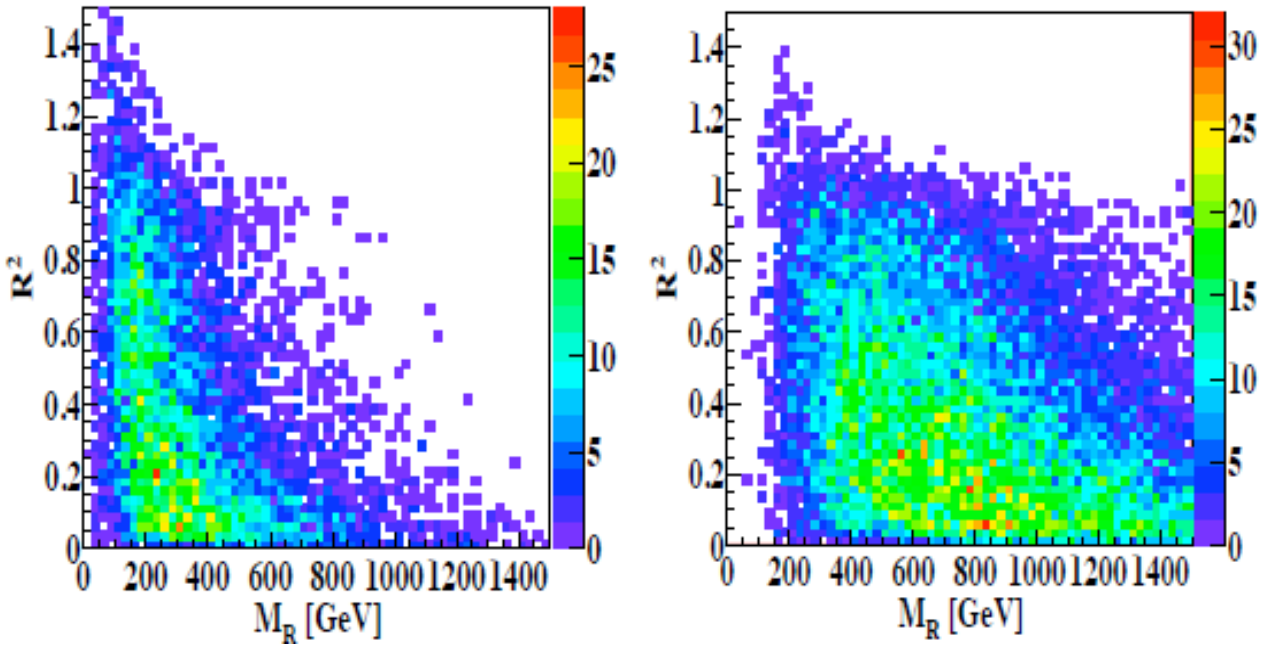
(a) $M_\chi = 0.01$ GeV.



(b) $M_\chi = 100$ GeV.






1.4
1.2
1
0.8
0.6
0.4
0.2
0
R^2
0 200 400 600 800 1000 1200 1400
M_R [GeV]
25
20
15
10
5
0
30
25
20
15
10
5
0