New Physics beyond the Standard Model

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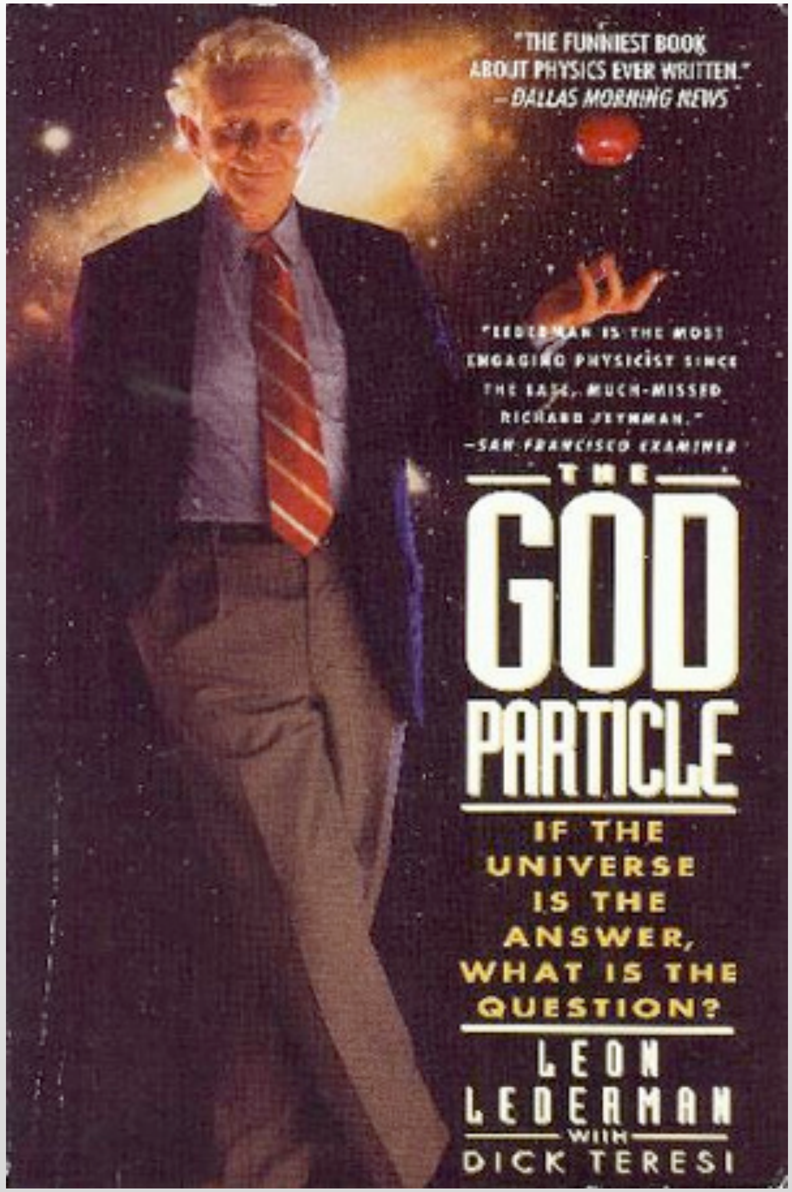
What is new physics BSM ?

Based on theoretic argument or experimental evidence, speculated new particle or new dynamics that is not covered in the existing Standard Model

What is the next "God Particle"?

God Particle



We know that the Higgs field is everywhere including SJTU.

Which Xian (仙: God in Chinese) the Higgs boson is ?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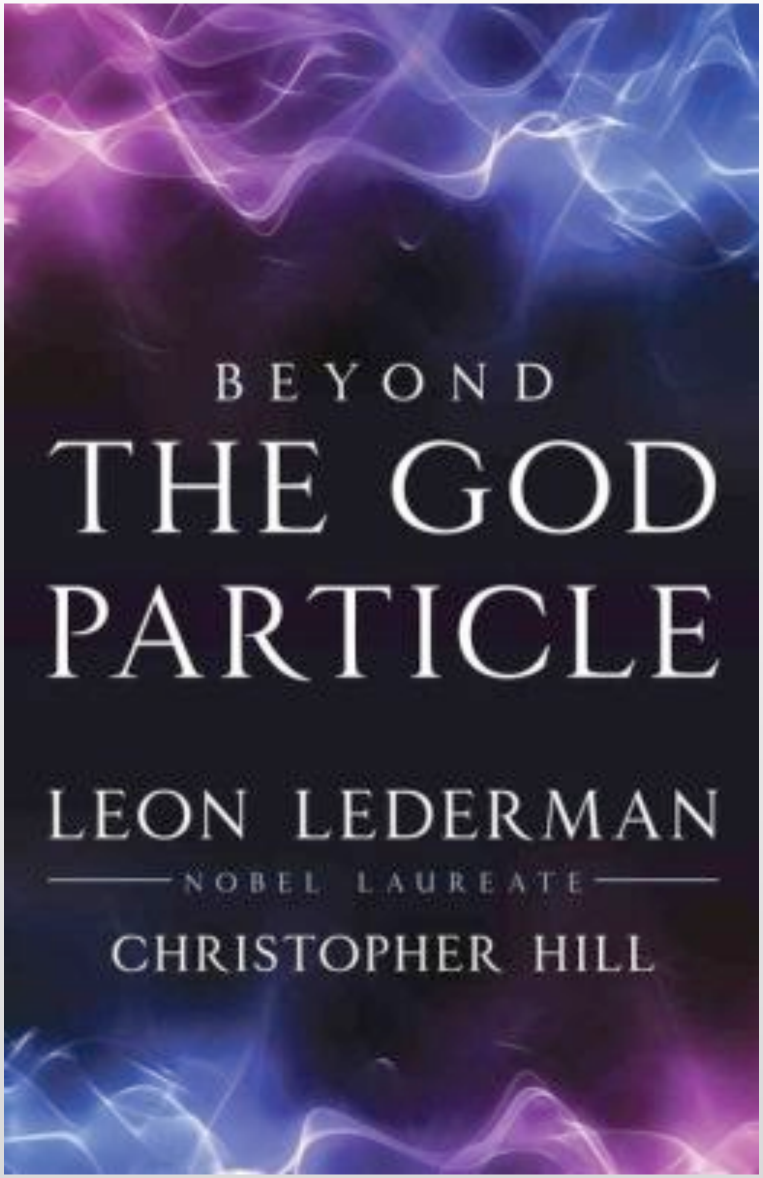
My Choice

Higs: →

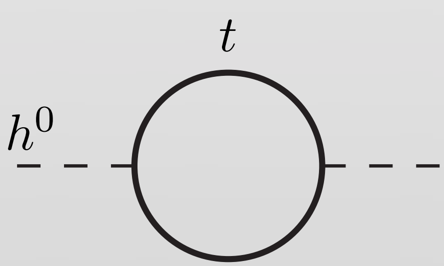
It can give masses to 12 particles or 93 degrees of freedom

$$12 < 72 < 93$$

Beyond the God Particle



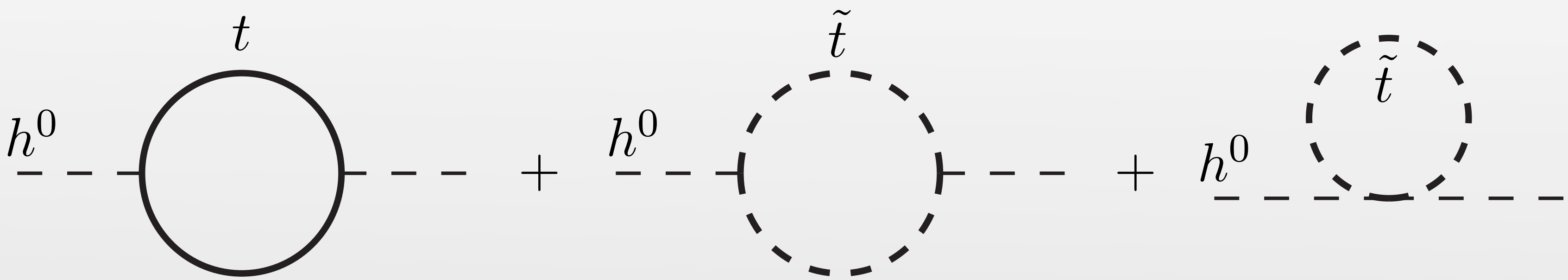
Who is Master Tang ?



$$-\frac{\lambda_t^2}{8\,\pi^2}\,\Lambda_{\mathrm{UV}}^2$$

Natural SUSY Spectrum

Dimopoulos and Giudice, 1995
Cohen, Kaplan and Nelson, 1996



"Stop" (or the "top partner" in other models) is an important particle to cancel the SM particle radiative corrections to the Higgs boson mass

It could be lighter than other particles in the MSSM and could be "Master Tang"

Direct Production of Stops

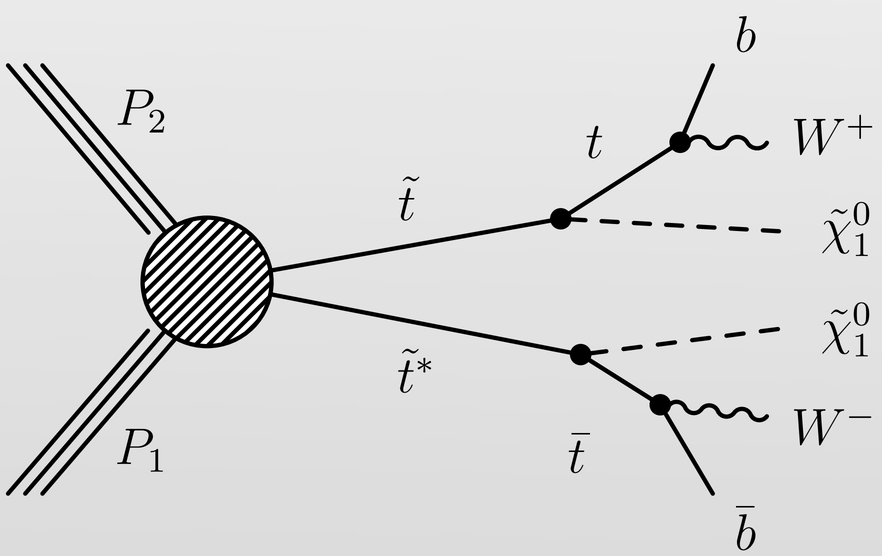
The signal is ttbar+MET

Early work:	......
	Meade and Reece, hep-ph/0601124
	Kong and Park, hep-ph/0703057
	Han, Mahbubani, Walker, Wang, 0803.3820
	......
Endpoints:	YB, Cheng, Gallichio, Gu, 1203.4813
	Killic and Tweedie, 1211.6106
Spin-correlations:	Han, Katz, Krohn, Reece, 1205.5808
Top-tagging:	Plehn, Spannowsky, Takeuchi, 1205.2696
	Kaplan, Rehermann, Stolarski, 1205.5816
	Dutta, Kamon, Kolev, Sinha, Wang, 1207.1893
Shapes of missing Et:	Alves, Buckley, Fox, Lykken, Yu, 1205.5805
Topness:	Graesser and Shelton, 1212.4495
	......

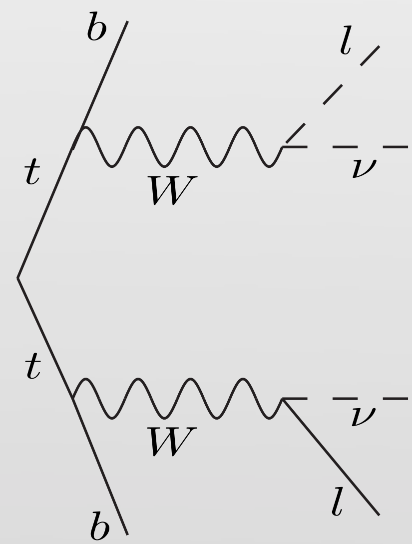
Search for Vanilla Stops

$$m_{\tilde{t}_1} \gg m_t + m_{\tilde{\chi}_1^0}$$

Signal: ttbar+MET (one lepton + jets + MET)



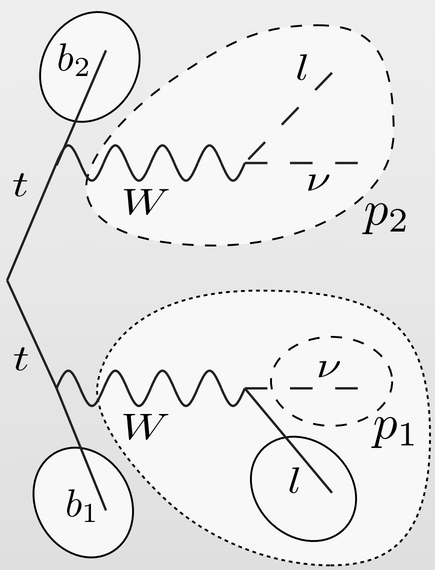
Background: ttbar in the dileptonic channel

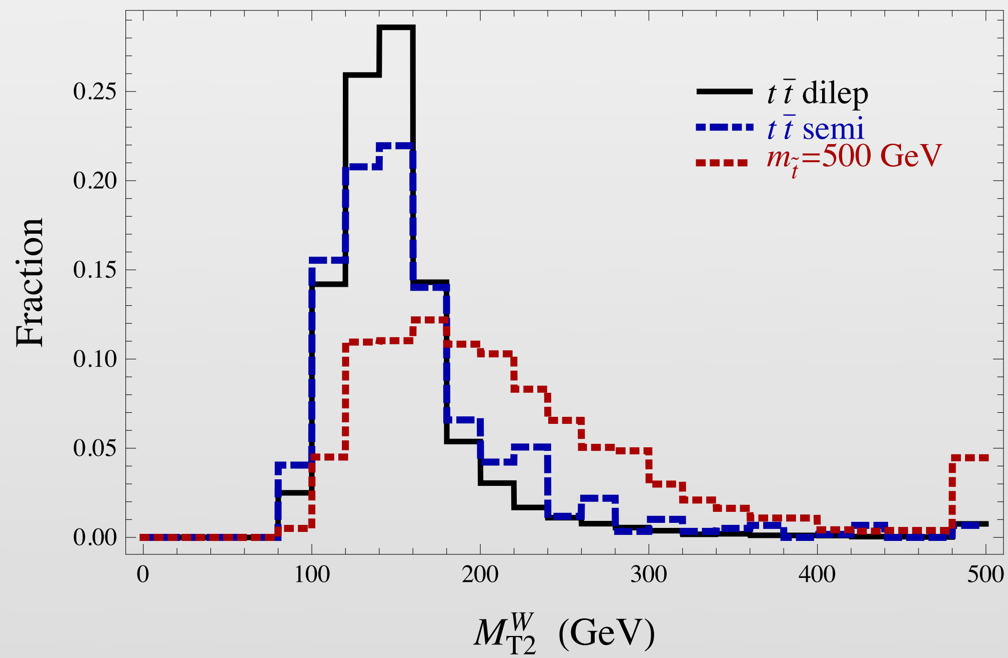


Reduce the ttbar Background

YB, Cheng, Gallichhio, Gu, 1203.4813, JHEP 1207 (2012) 110

$$M_{T2}^{W} = \min\left\{ m_y \text{ consistent with: } \left[\begin{array}{r} \vec{p}_1^{\,T} + \vec{p}_2^{\,T} = \vec{E}_T^{\text{miss}}\,,\; p_1^2 = 0\,,\; (p_1 + p_\ell)^2 = p_2^2 = M_W^2\,, \\ (p_1 + p_\ell + p_{b_1})^2 = (p_2 + p_{b_2})^2 = m_y^2 \end{array} \right] \right\}$$





Concentrating on background

Reduce the ttbar Background

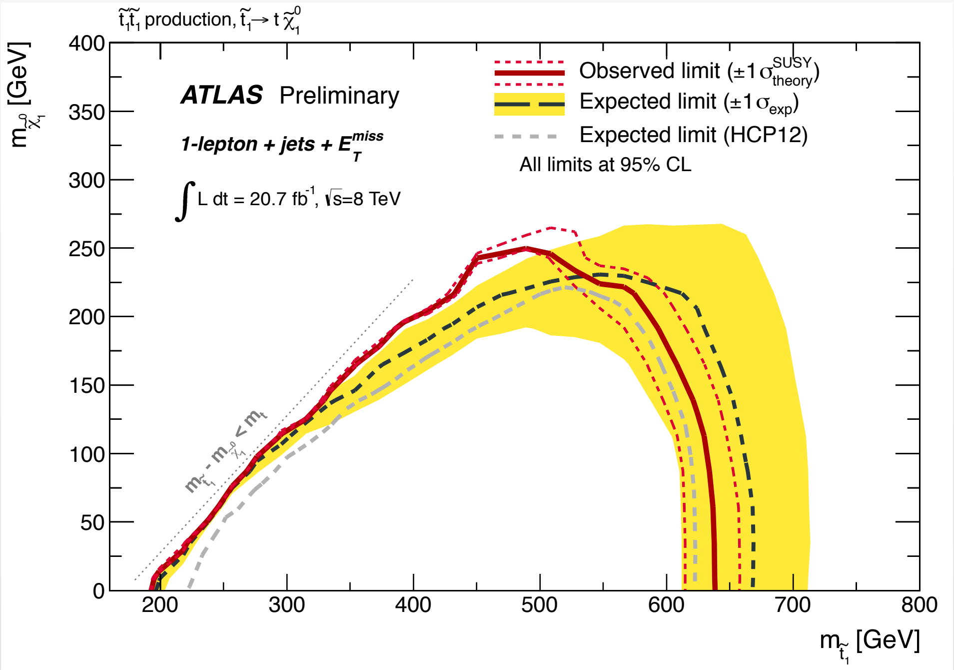
YB, Cheng, Gallichhio, Gu, 1203.4813, JHEP 1207 (2012) 110

Minimum Cuts					$m_{\rm stop} = 600\,{\rm GeV}$			
$E_T^{\rm miss}$	$m_{\rm eff}$	M_{T2}^W	M_{T2}^b	M_{T2}^{bl}	$S_{20fb^{-1}}$	$B_{20fb^{-1}}$	S/B	σ
(150)	-	-	-	-	16.7	738.4	0.02	0.60
377	-	-	-	-	4.5	3.0	1.49	2.04
345	696	-	-	-	6.1	6.3	0.97	$\boxed{2.05}$
337	727	168	-	-	5.9	3.0	2.01	2.66
337	726	-	-	168	5.8	2.7	2.17	2.69
333	740	-	157	-	5.3	2.1	2.59	2.73
332	741	168	148	91	5.5	2.1	2.67	$\boxed{2.81}$

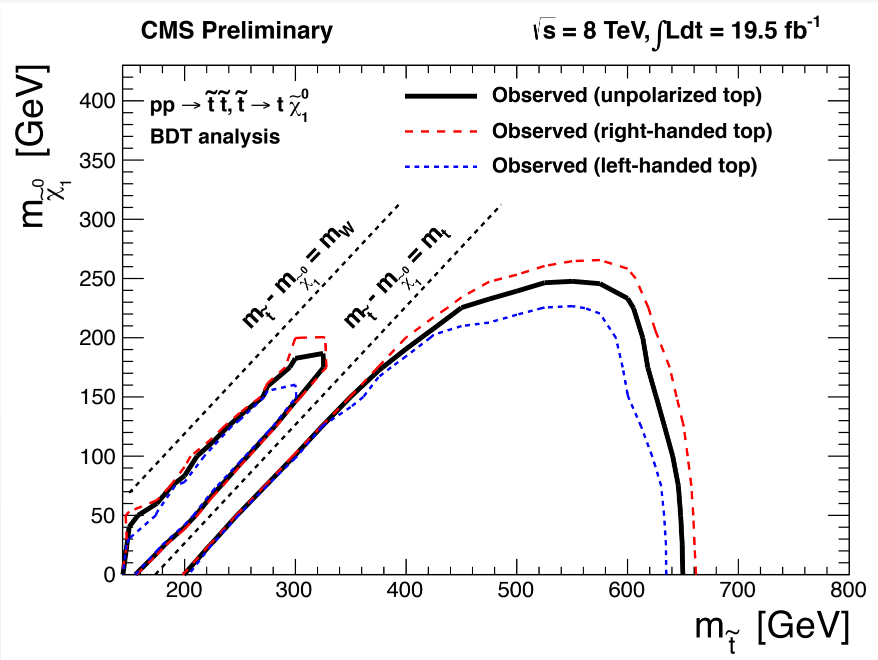
Both ATLAS and CMS have obtained our c++ code of variables and performed a search using our method

Used in ATLAS and CMS Searches

ATLAS-CONF-2013-037



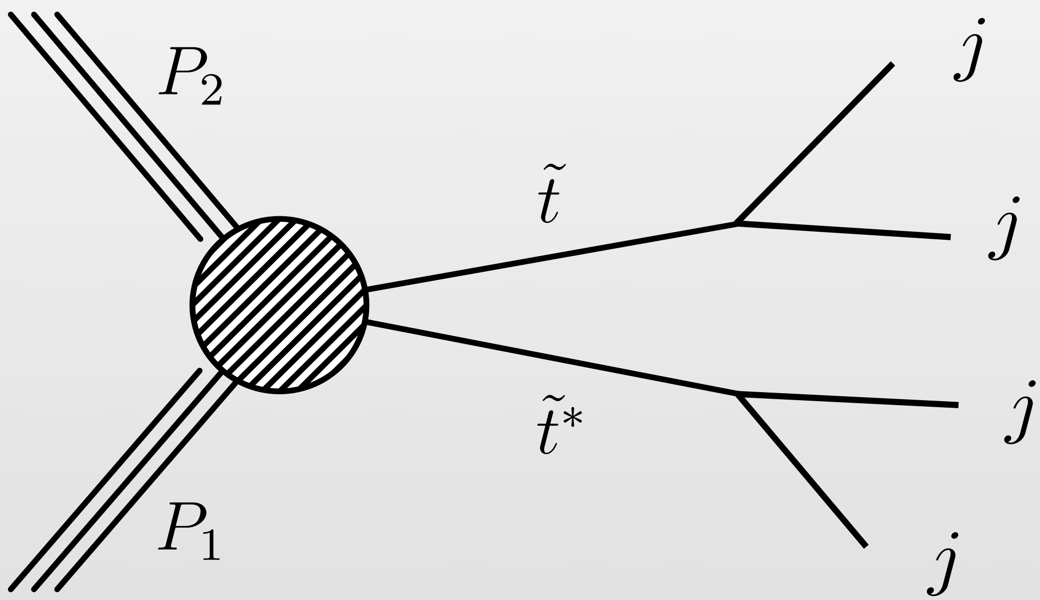
CMS PAS SUS-13-011



We can wait for the 14 TeV LHC results or explore other alternative options

R-parity Violation

No missing energy. The current experimental constraints are much weaker.

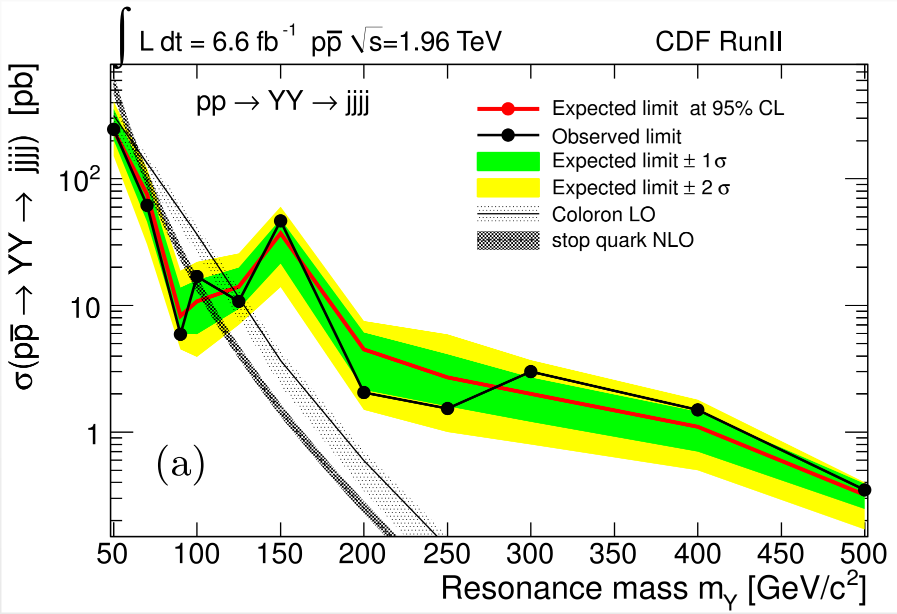


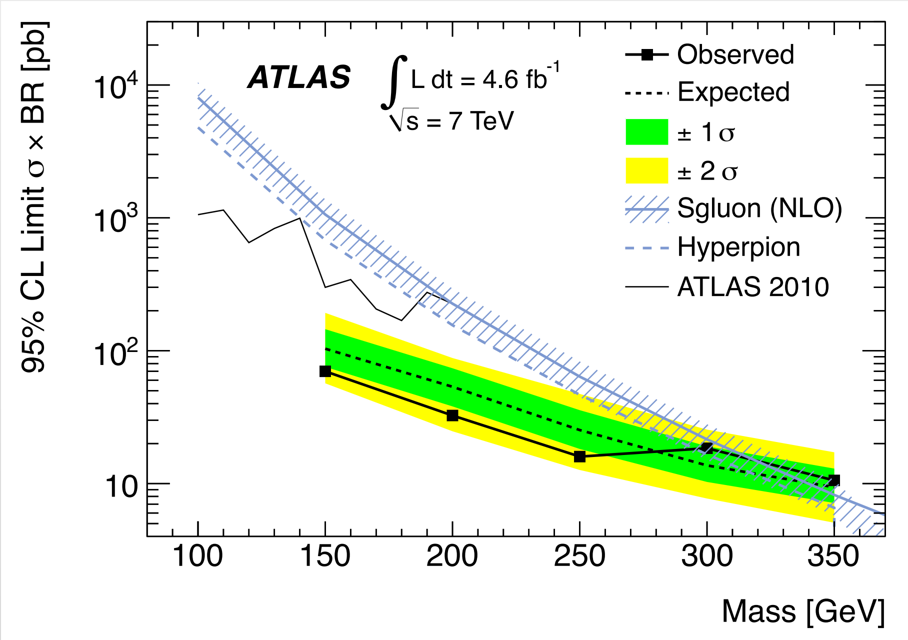
Behave as a pair of dijet resonances

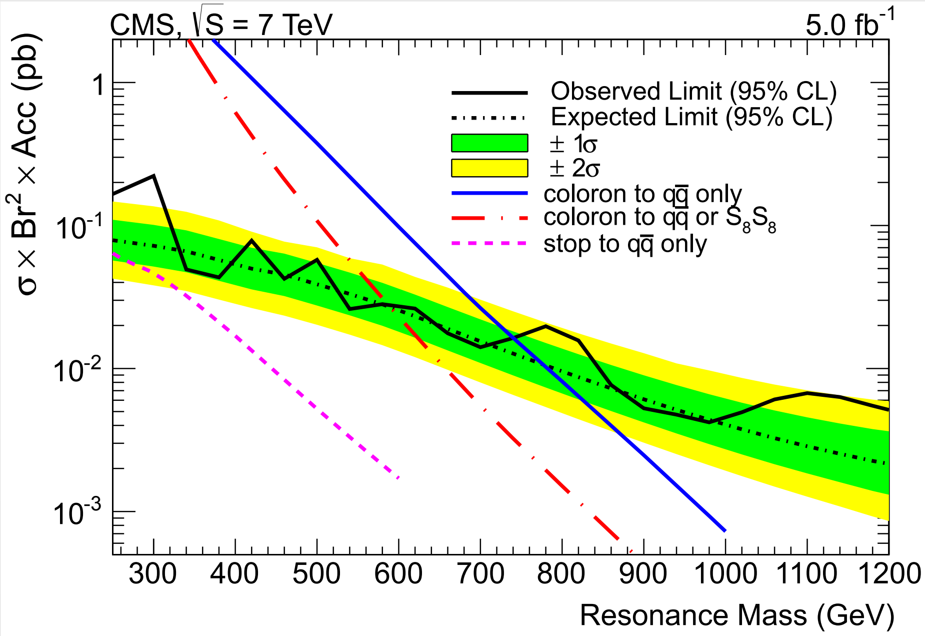
Color Octet Particles

- Technipions or Technirho mesons — Eichten, Hinchliffe, Lane, Quigg ‘1984
- Partners of the QCD gluon:
  - Coloron in the top-color models — Hill ‘1991, Chivukula, Cohen, Simmons, ‘1996
  - KK-gluon in the extra-dimension models — Randall, Sundrum ‘1998; Appelquist, Cheng, Dobrescu ‘2000
- New vector-like confining gauge group: — Killic, Okui, Sundrum ‘2008; YB, Martin, 1003.3006
- Model-independent studies: — Manohar, Wise, ‘2006; Dobrescu, Kong, Mahbubani, ‘2007; YB, Dobrescu, 1012.5814
- The famous gluino particle — SUSY fans

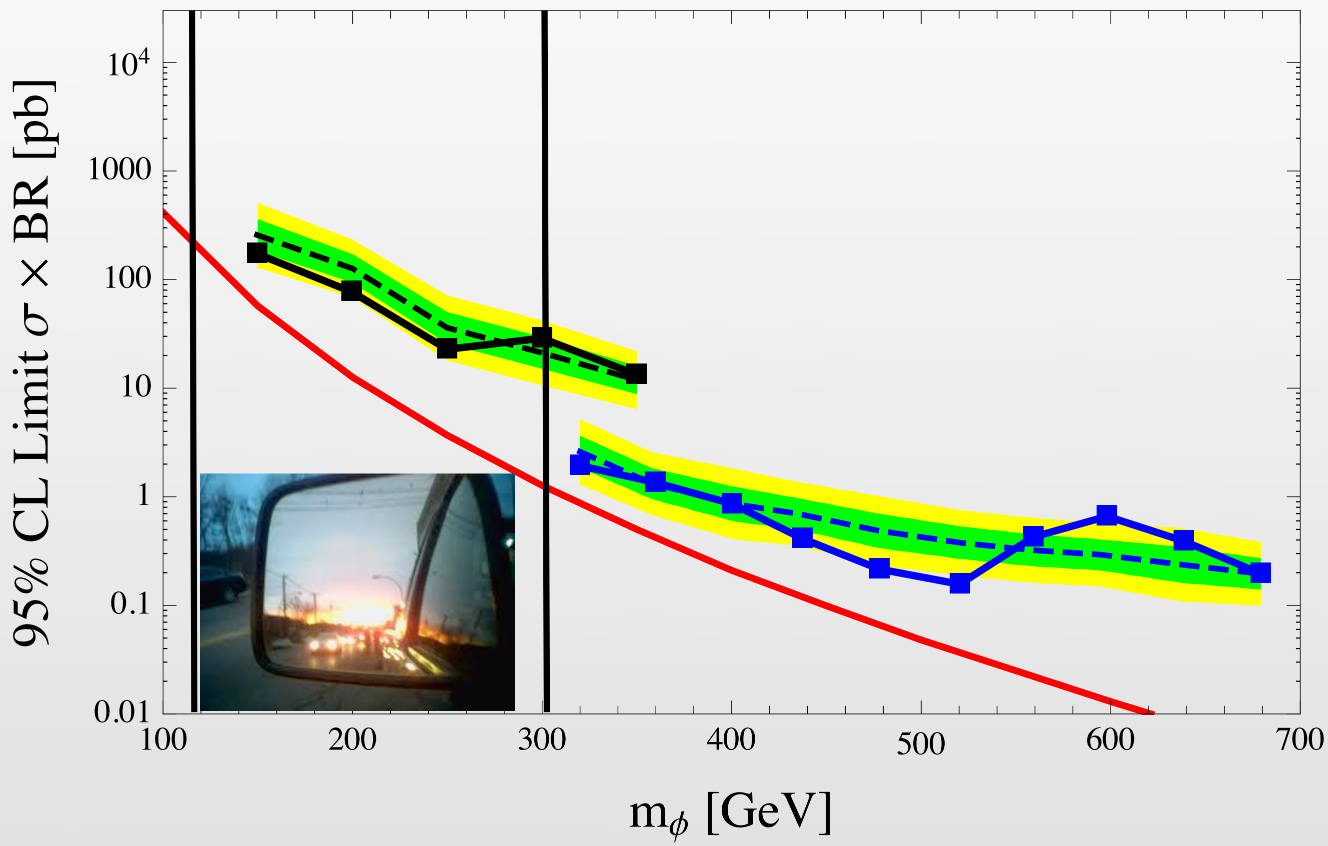
Current Searches







Blind Spot



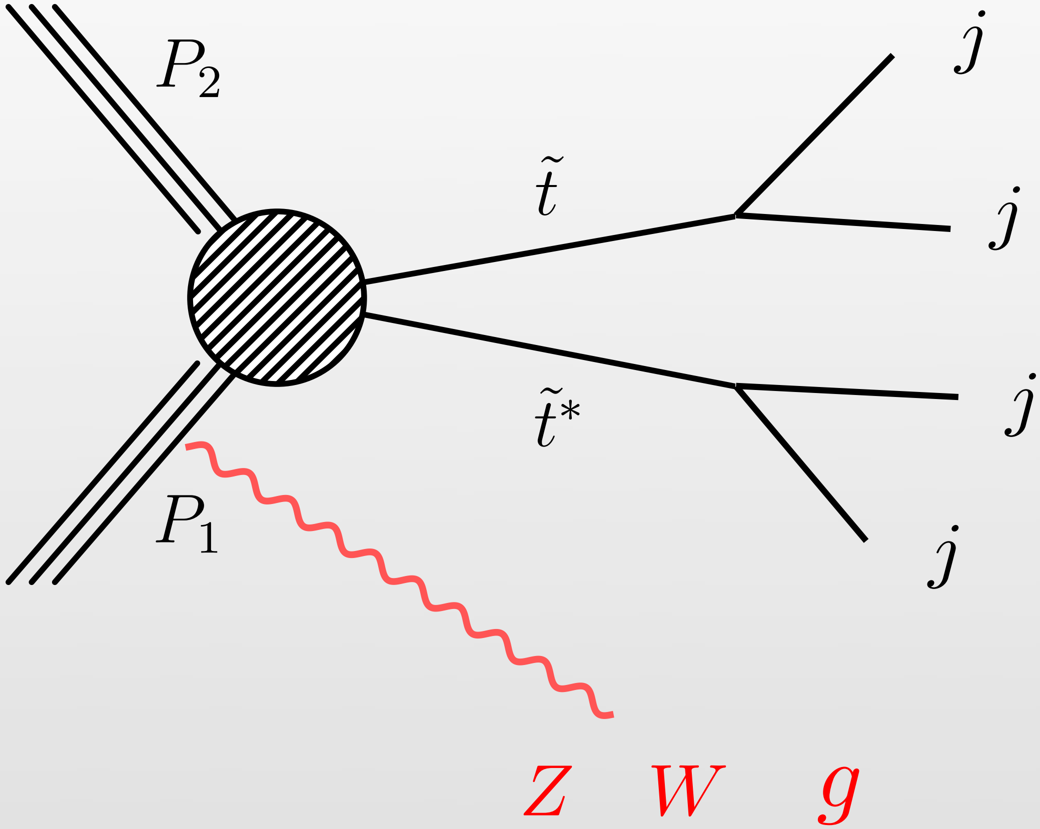
Full hadronic final state; trigger is an issue

Trigger Menu

(Unprescaled) Object	Trigger Threshold (GeV)	Rate (Hz)	Physics
Single Muon	40	21	Searches
Single Isolated muon	24	43	Standard Model
Double muon	(17, 8) [13, 8 for parked data]	20 [30]	Standard Model / Higgs
Single Electron	80	8	Searches
Single Isolated Electron	27	59	Standard Model
Double Electron	(17, 8)	8	Standard Model / Higgs
Single Photon	150	5	Searches
Double Photon	(36, 22)	7	Higgs
Muon + Ele x-trigger	(17, 8), (5, 5, 8), (8, 8, 8)	3	Standard Model / Higgs
Single PFJet	320	9	Standard Model
QuadJet	80 [50 for parked data]	8[100]	Standard Model /Searches
Six Jet	(6 x 45), (4 x 60, 2 x 20)	3	Searches
MET	120	4	Searches
HT	750	6	Searches

S. Beauceron, CMS, ICHEP2012

Initial State Radiation



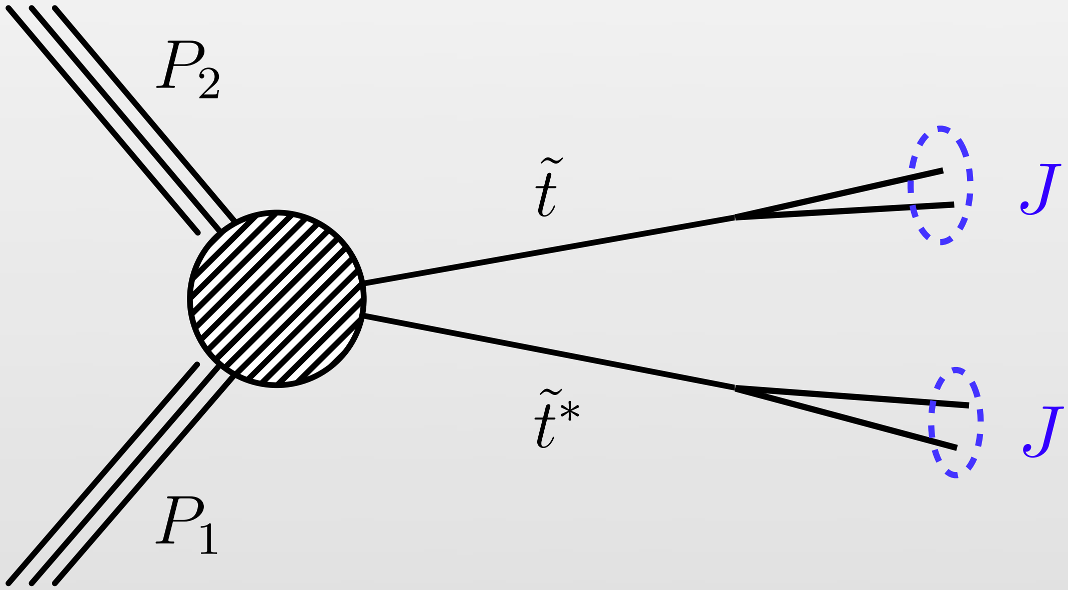
The reduction on signal events is too much

Not the way to go !

“Stop Jet”

For a large center-of-mass energy, stops are boosted

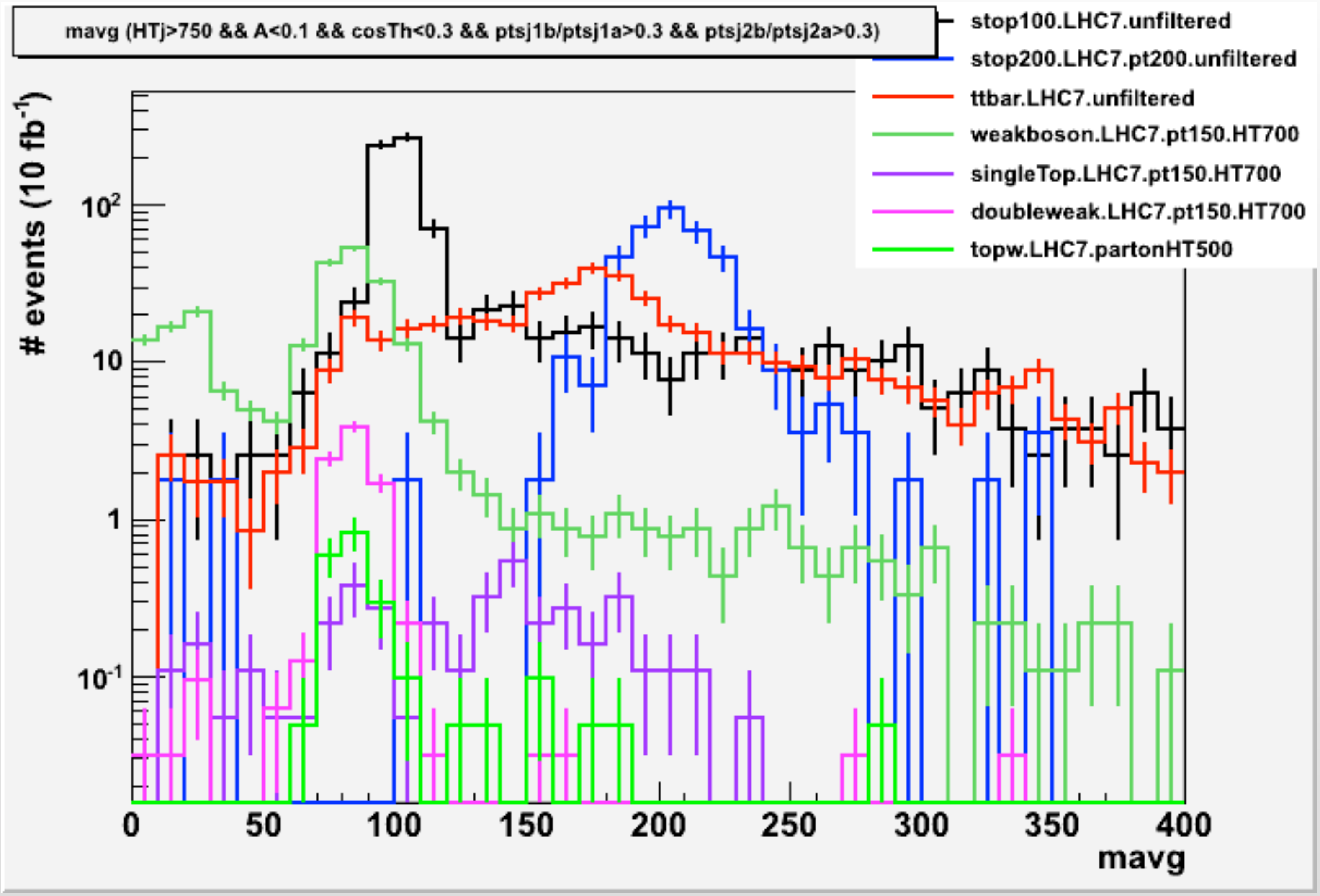
The two jets from its decay are collimated



We can use the high H_T trigger

The way to go !

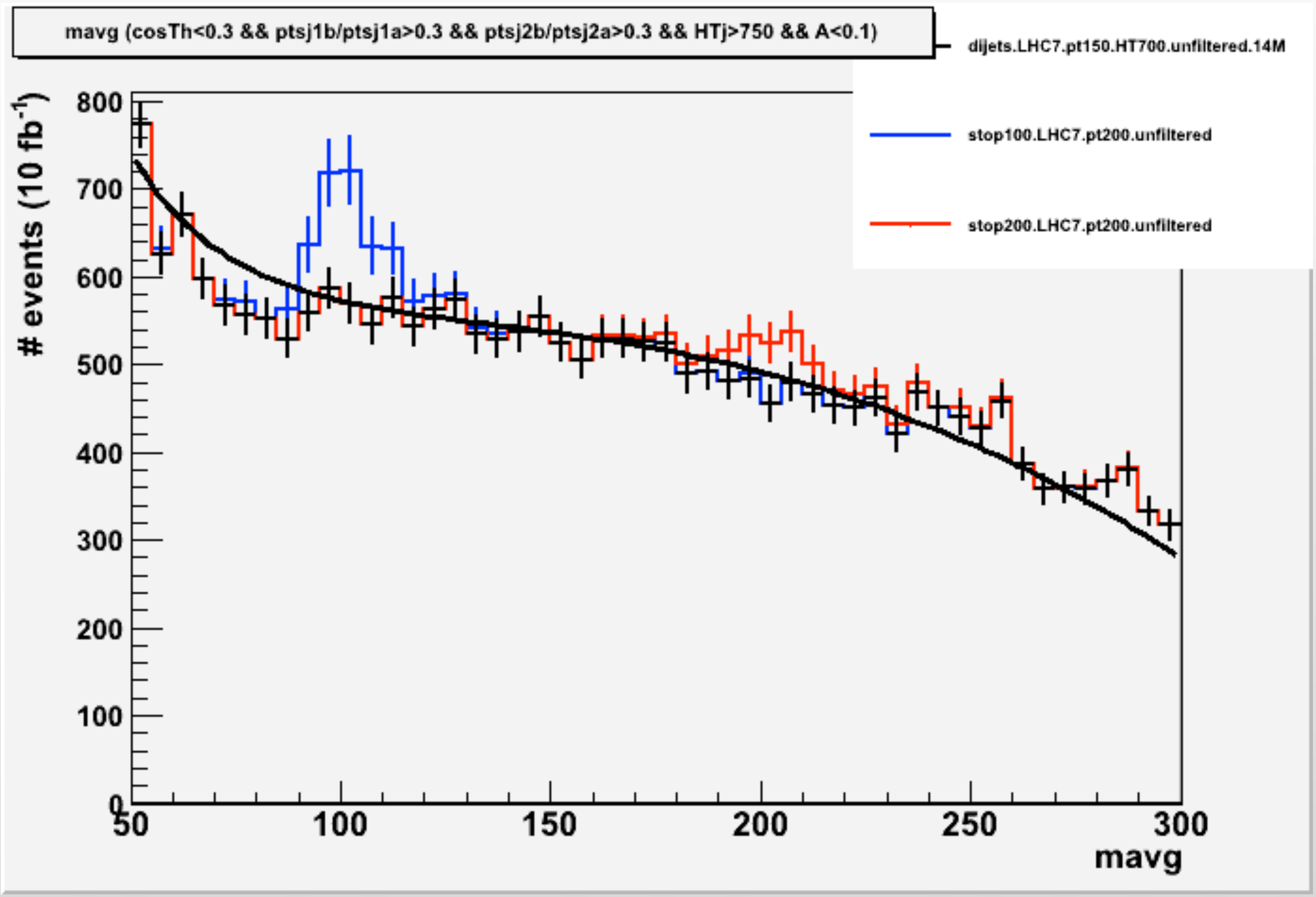
Preliminary Results



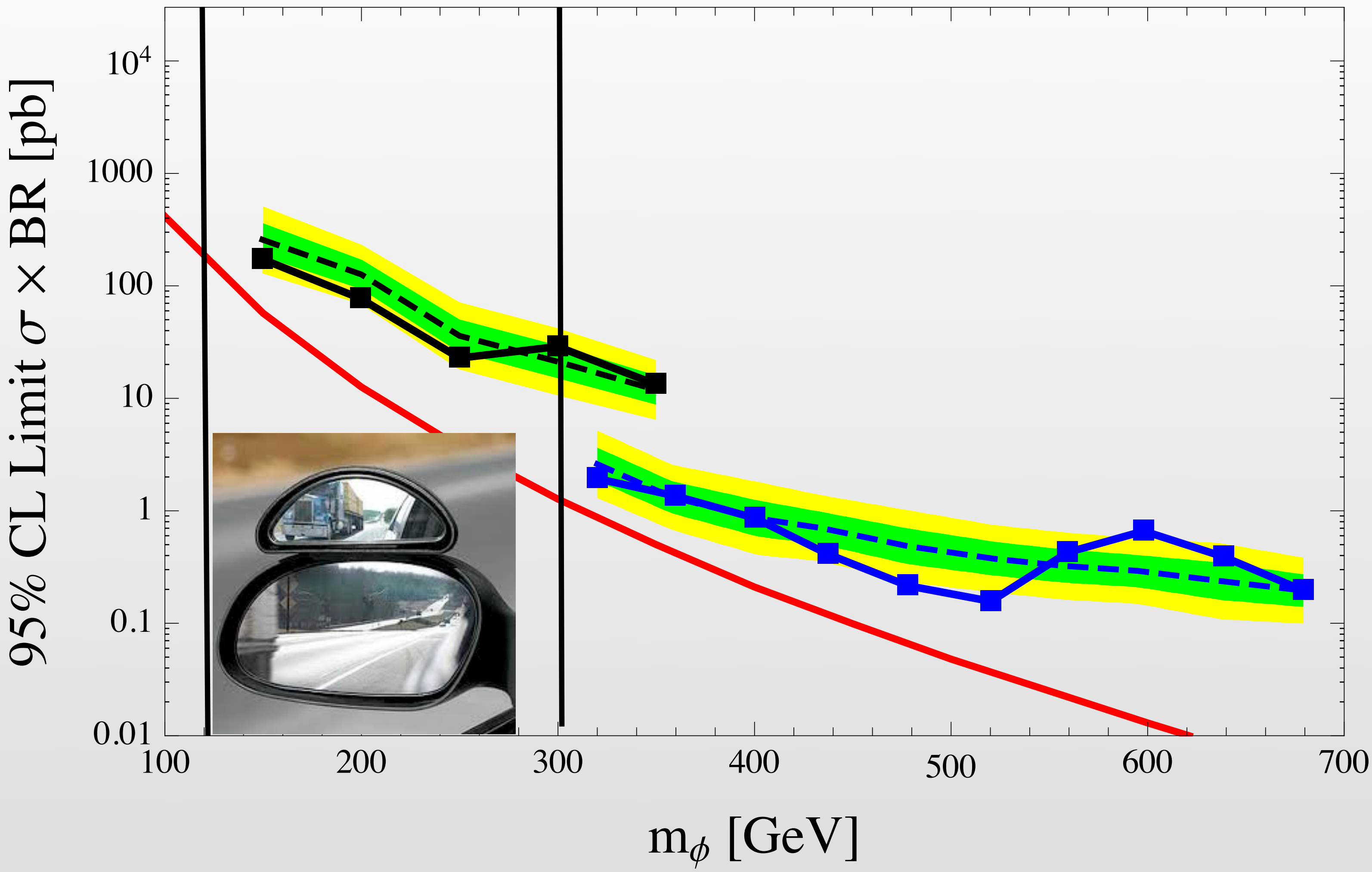
YB, Katz, Tweedie; work in progress

Preliminary Results

YB, Katz, Tweedie; work in progress



Blind Spot: not anymore



Our strategy can be used to cover this mass region

What are other “Xian Particles”

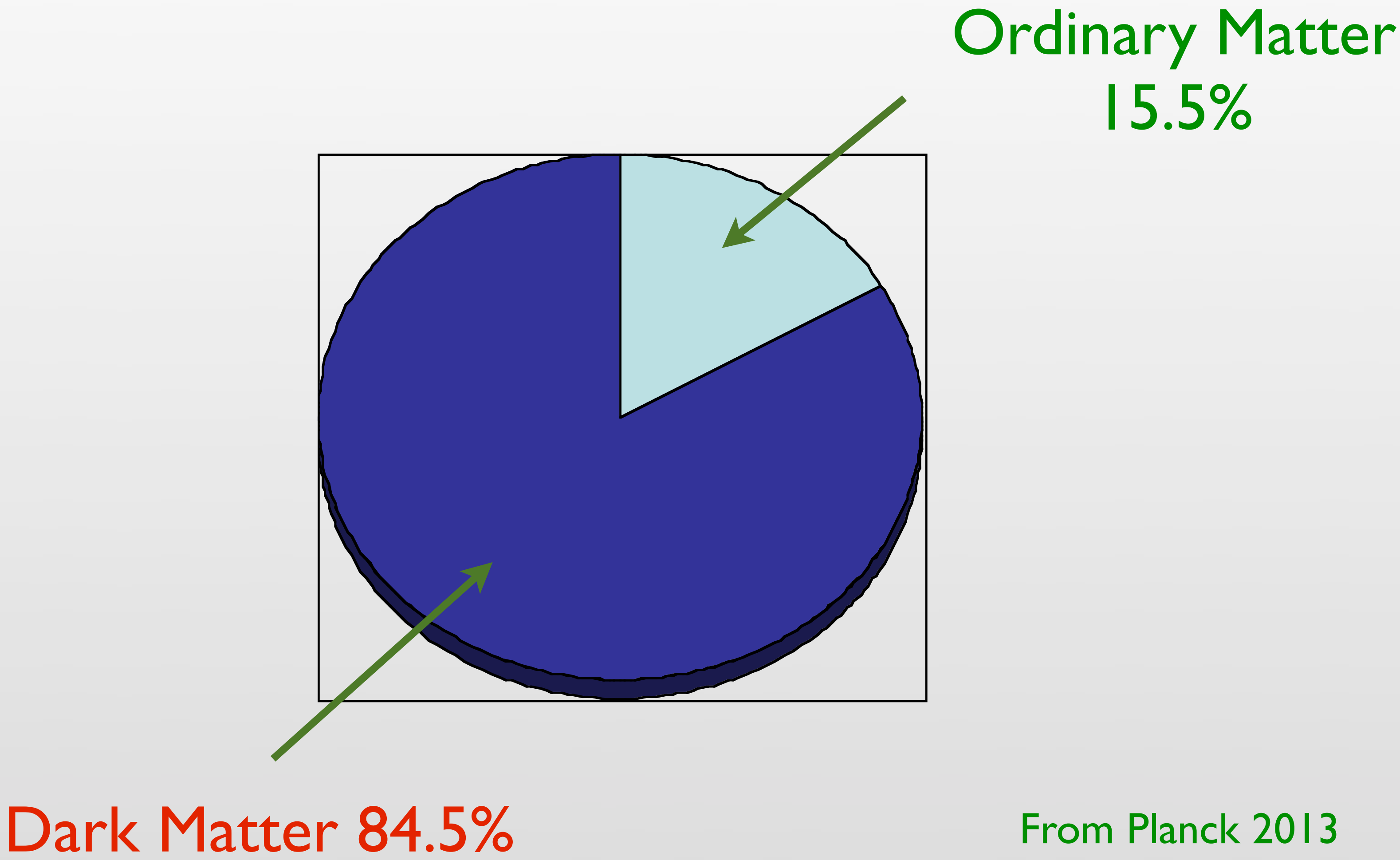
Dark Matter

“Jade Emperor Particle”

What are other "Xian"

Dark Energy →

The Jade Emperor Particle



From Planck 2013

One Number to Explain

$$\frac{\Omega_{\rm DM}}{\Omega_{\rm Baryon}} = \frac{m_{\rm DM} n_{\rm DM}}{m_{\rm p} n_p} \approx 5 \sim 6$$

Most popular models: “WIMP miracle”

$$\Omega_{\rm DM} = \frac{s_0}{\rho_c}\left(\frac{45}{\pi g_*}\right)^{1/2} \frac{x_f}{m_{\rm pl}} \frac{1}{\langle \sigma v\rangle} \qquad \langle \sigma v\rangle \approx 1 \text{ pb} \approx \frac{\pi \alpha^2}{8 m_{\rm DM}^2}$$

$$\text{for } m_{\rm DM} = 100 \text{ GeV}$$

This could be just one option:

dark matter is related to the electroweak scale

The Second Option

$$\frac{\Omega_{\rm DM}}{\Omega_{\rm Baryon}} = \frac{m_{\rm DM} n_{\rm DM}}{m_{\rm p} n_p} \approx 5 \sim 6$$

$$n_{\rm DM} \sim n_p \qquad\qquad m_{\rm DM} \sim m_p$$

The first condition can be satisfied by introducing some non-trivial number density history

The dark matter could be like baryon from an asymmetry mechanism

The dark matter mass is related to the QCD scale

If dark matter is a “dark baryon” from a new QCD-like strong dynamics in the dark matter sector

$$\Lambda_{\mathrm{dQCD}} \sim \Lambda_{\mathrm{QCD}} \quad ?$$

Need to have QCD and dQCD gauge couplings related to each other

Matter Content

$$G_{\text{gauge}} = SU(N_c)_{\text{QCD}} \times SU(N_d)_{\text{dQCD}}$$

Field	$SU(N_c)_{\text{QCD}}$	$SU(N_d)_{\text{darkQCD}}$	multiplicity
SM fermion	N_c	1	n_{f_c}
SM scalar	N_c	1	n_{s_c}
DM fermion	1	N_d	n_{f_d}
DM scalar	1	N_d	n_{s_d}
joint fermion	N_c	N_d	n_{f_j}
joint scalar	N_c	N_d	n_{s_j}

Gauge Coupling Running

$$\frac{dg_c}{d(\log\mu)} = \beta_c(g_c, g_d)\,, \qquad\qquad \frac{dg_d}{d(\log\mu)} = \beta_d(g_c, g_d)$$

$$\begin{aligned}
\beta_c(g_c, g_d) \;=\;& \frac{g_c^3}{16\pi^2}\left[\frac{2}{3}\,T(R_f)\,2(n_{f_c} + N_d\,n_{f_j}) + \frac{1}{3}\,T(R_s)\,(n_{s_c} + N_d\,n_{s_j}) - \frac{11}{3}\,C_2(G_c)\right] \\
&+ \frac{g_1^5}{(16\pi^2)^2}\left[\left(\frac{10}{3}C_2(G_c) + 2C_2(R_f)\right)\,T(R_f)\,2\,(n_{f_c} + N_d\,n_{f_j})\right. \\
&\qquad \left. + \left(\frac{2}{3}C_2(G_c) + 4C_2(R_s)\right)\,T(R_s)\,(n_{s_c} + N_d\,n_{s_j}) \,-\, \frac{34}{3}\,C_2^2(G_c)\right] \\
&+ \frac{g_c^3\,g_d^2}{(16\pi^2)^2}\left[2C_2(R_f)\,T(R_f)\,2\,N_d\,n_{f_j} \,+\, 4C_2(R_s)\,T(R_s)\,N_d\,n_{s_j}\right]\,.
\end{aligned}$$

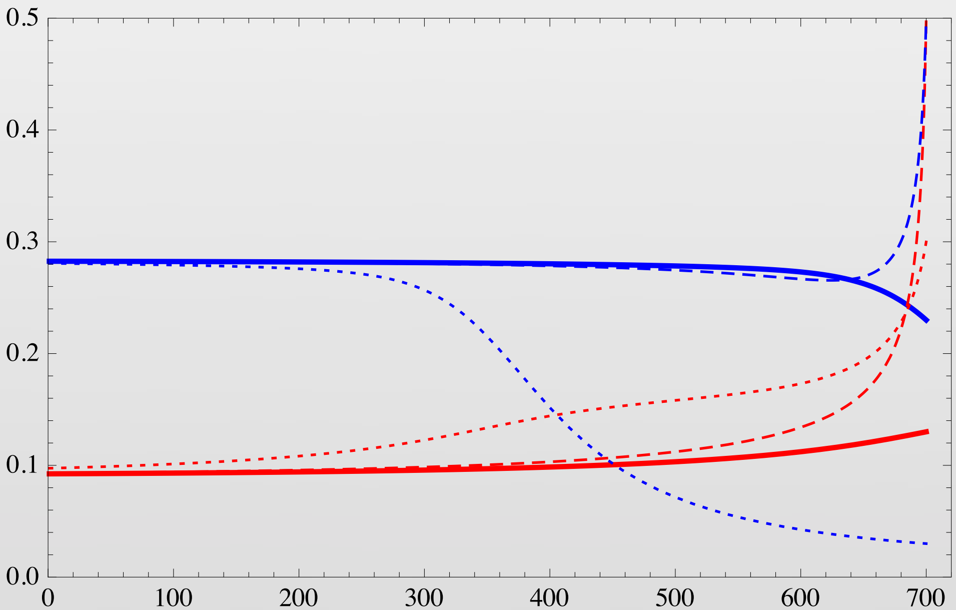
$$c \leftrightarrow d \qquad \text{for} \qquad \beta_d(g_c, g_d)$$

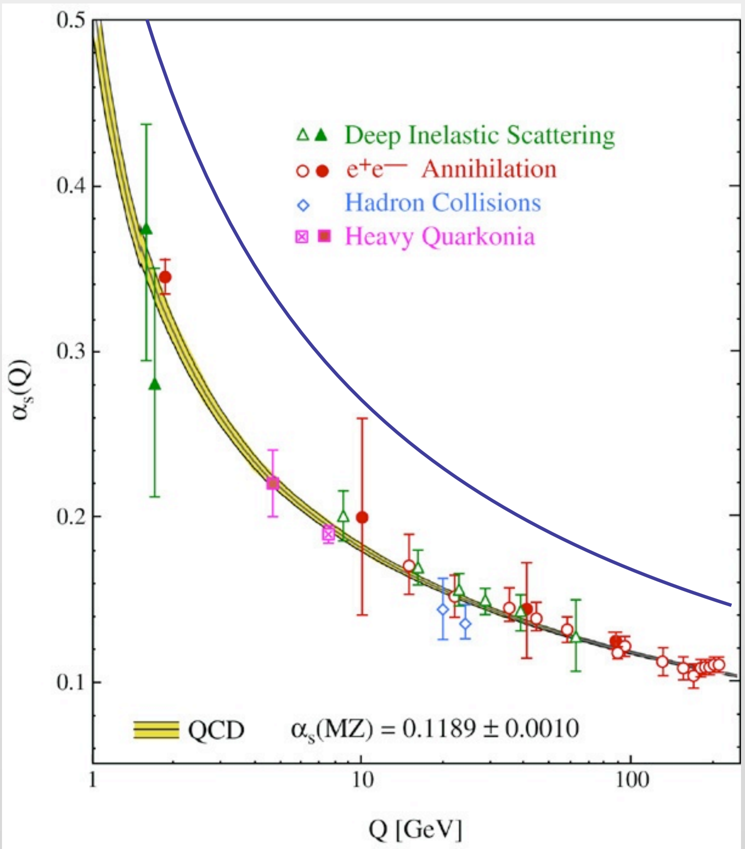
Infrared Fixed Point

$$\beta_c(g_c, g_d) = \beta_d(g_c, g_d) = 0$$

$$\begin{aligned} \alpha_s^0 &\equiv \alpha_s^0(n_{f_c}, n_{s_c}, n_{f_d}, n_{s_d}, n_{f_j}, n_{s_j}) \\ \alpha_d^0 &\equiv \alpha_d^0(n_{f_c}, n_{s_c}, n_{f_d}, n_{s_d}, n_{f_j}, n_{s_j}) \end{aligned}$$

decouple at a scale M





A Sample of Representations

n_{f_c}	n_{f_d}	n_{f_j}	n_{s_c}	n_{s_d}	n_{s_j}	α_s^0	α_d^0	M (GeV)	m_D (GeV)
6	6	3	1	0	0	0.083	0.120	1973	8.2
6	6	3	1	1	0	0.091	0.091	781	0.32
6	7	3	2	0	0	0.082	0.022	2244	≈ 0
8	8	2	2	1	1	0.082	0.118	2244	1.2
9	9	2	1	0	0	0.092	0.126	704	0.15
9	9	2	1	1	0	0.097	0.097	431	0.0044
9	10	2	2	0	0	0.083	0.028	1973	≈ 0
9	10	2	2	1	0	0.087	0.0068	1215	≈ 0
6	6	2	3	3	3	0.094	0.094	575	0.32
7	7	2	2	1	2	0.090	0.133	869	3.5
8	8	2	2	1	1	0.0816	0.118	2365	1.23

$$0.08 < \alpha_s < 0.10$$

Example Model

$$\Phi : \ (\bar{3}, 3)_{1/3} \qquad Y_1 : \ (\bar{3}, 3)_{1/3} \qquad Y_2 : \ (\bar{3}, 3)_{-2/3}$$

$$\mathcal{L} \supset k_i \bar{Y}_1 \Phi N_i + \text{h.c.}.$$

Generate number asymmetries for $\Delta n_\Phi = -\Delta n_{Y_1}$

$$\mathcal{L} \supset \kappa_1 \Phi \bar{Y}_1^c Y_2 + \kappa_2 \Phi \bar{Y}_2 e_R + \kappa_3 \Phi \bar{X}_L d_R + \text{h.c.},$$

$$Y_1 \to \bar{Y}_2 \Phi^\dagger \qquad Y_2 \to \Phi e_R \qquad \Phi \to X_L \bar{d}_R$$

$$\Delta n_{d_R} \equiv 3 n_B = 3 \Delta n_{Y_1} \,,$$

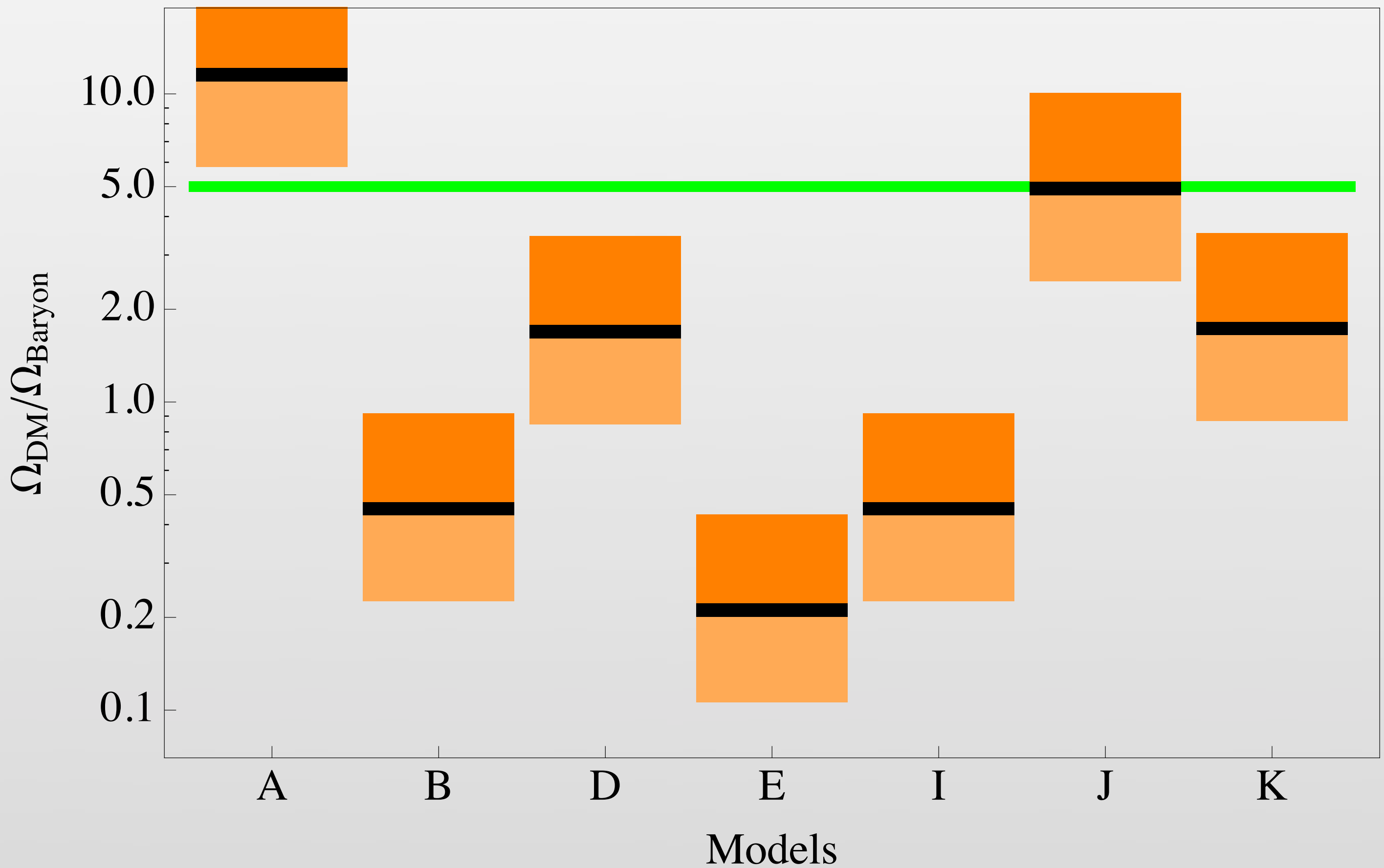
$$\Delta n_{e_R} \equiv n_L = -\Delta n_{Y_1} \,,$$

$$\Delta n_X \equiv 3 n_D = -3 \Delta n_{Y_1} \,,$$

$$\frac{n_D}{n_B} = \frac{79}{56}$$

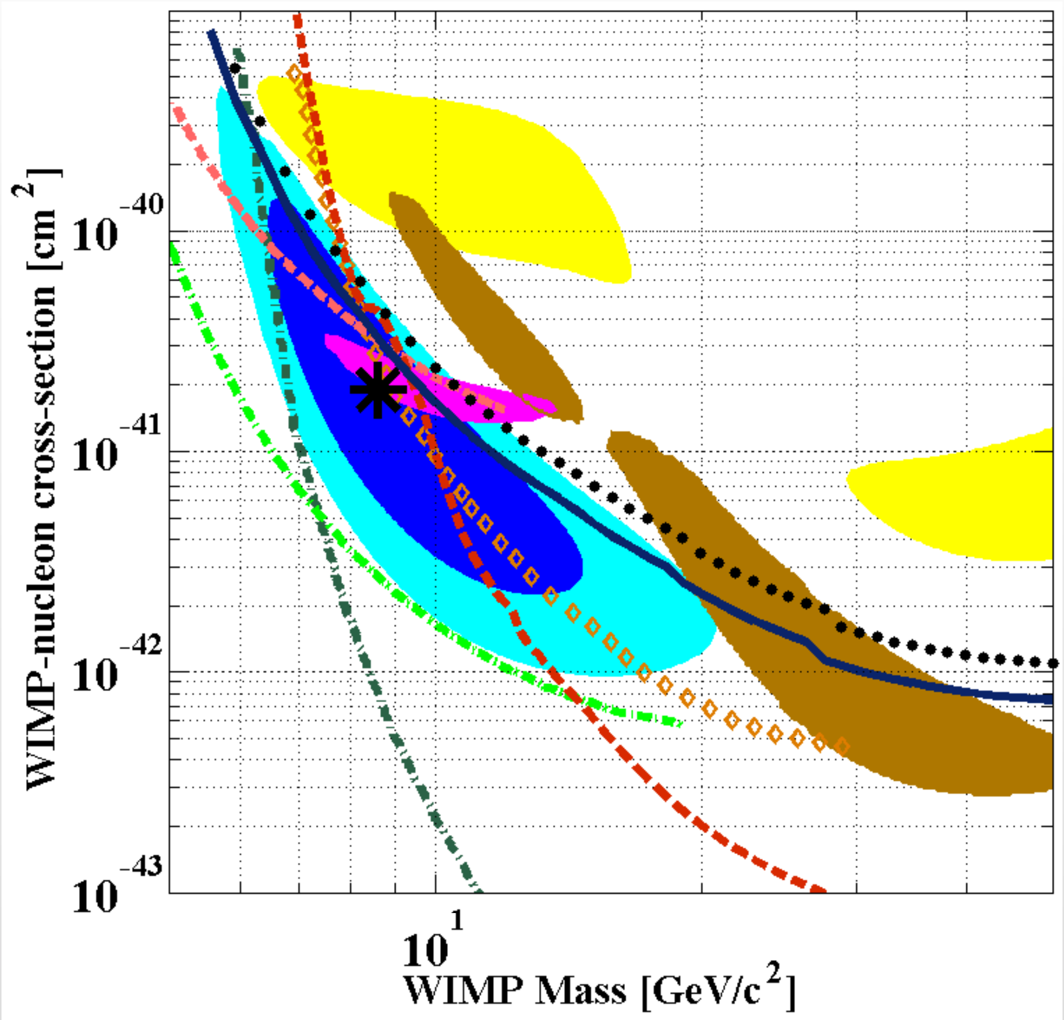
Ratios of Energy Densities

$$\frac{\Omega_{\rm DM}}{\Omega_{\rm Baryon}} = \frac{n_D m_D}{n_B m_p} \approx \frac{79}{56}\frac{m_D}{m_p}$$



YB, Schwaller; work in progress

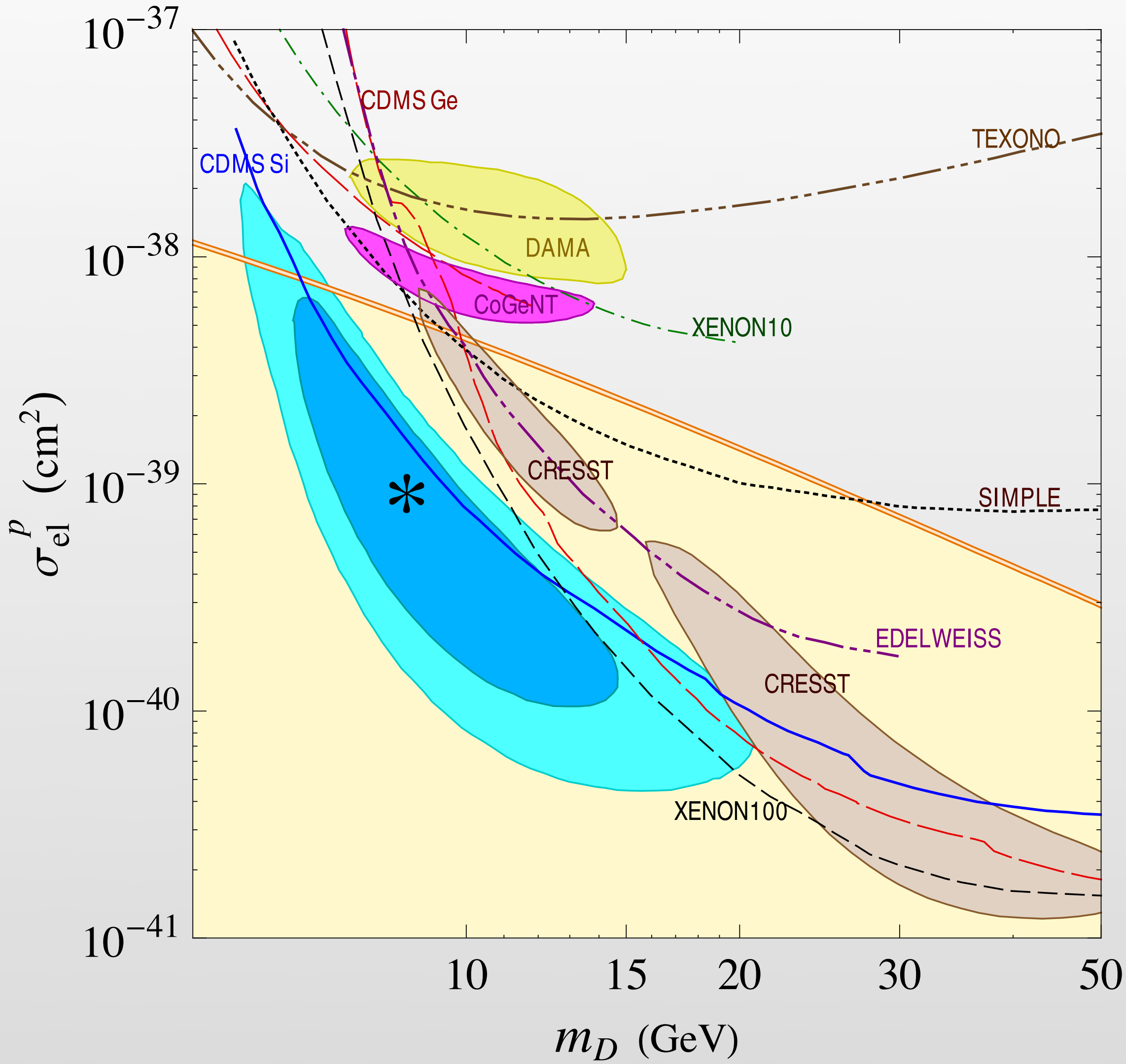
Evidence of Light Dark Matter



CDMS, 1304.4279

$$\sigma_{\chi N}^{\mathrm{SI}} \propto A^2 \qquad\qquad f_p = f_n$$

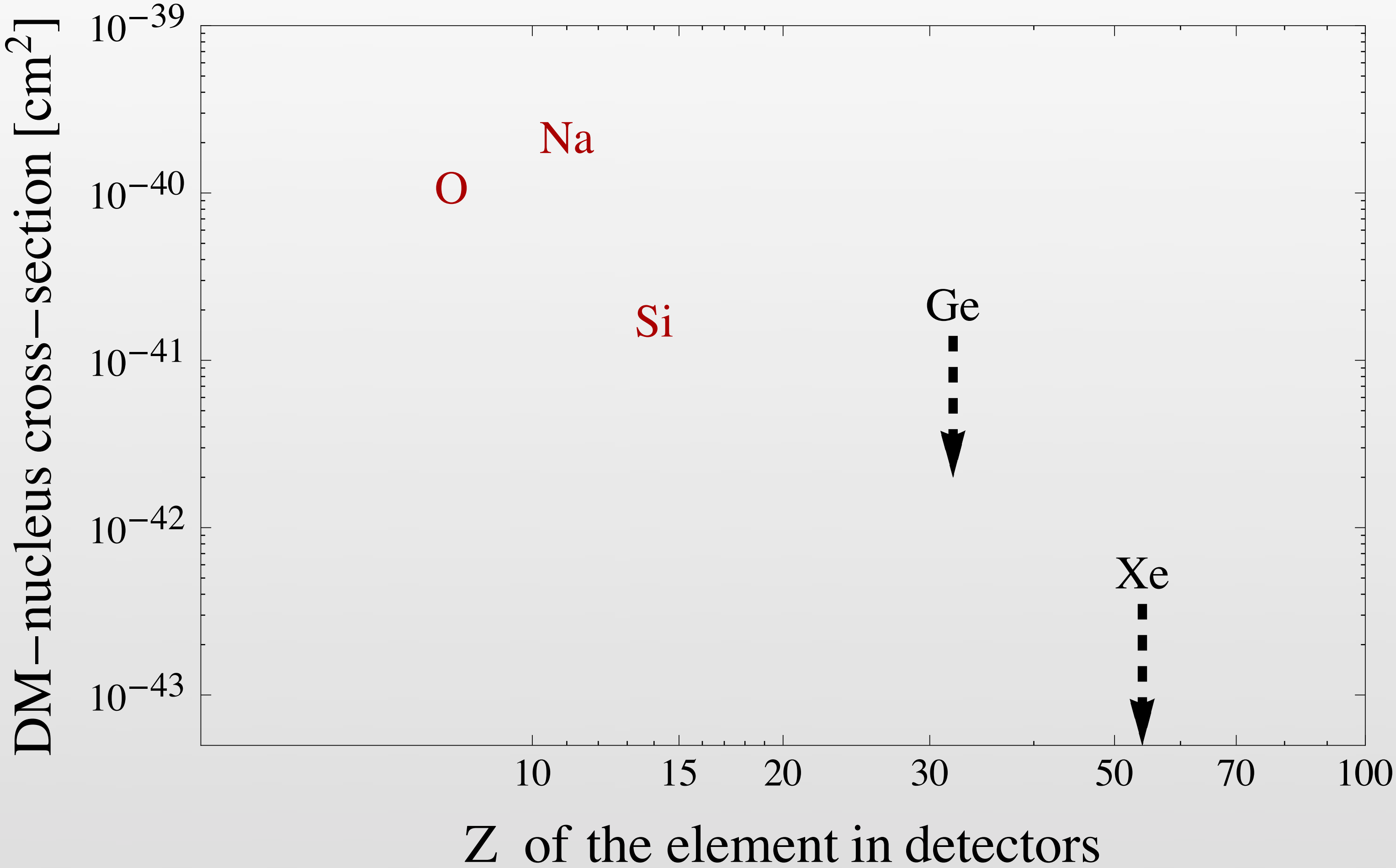
Isospin Violation Dark Matter



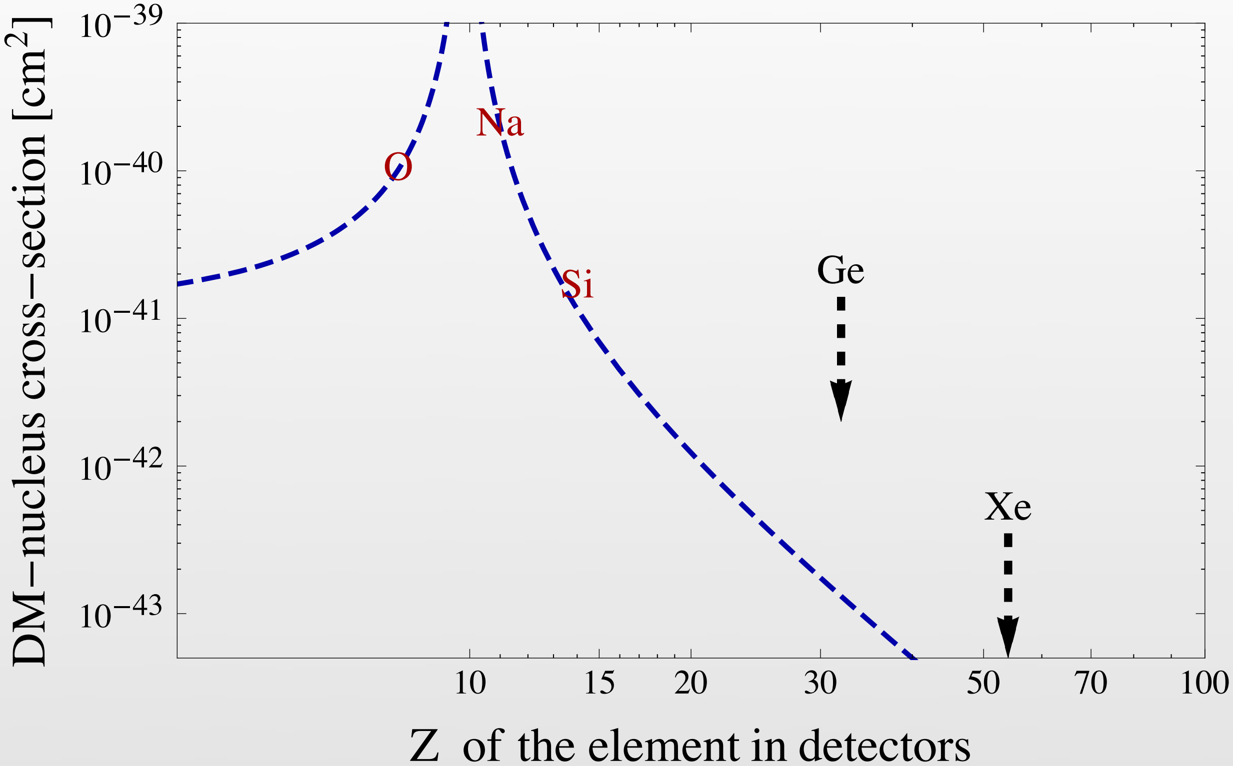
He and Tandean, 1304.6058

$$f_n = -0.7 f_p$$

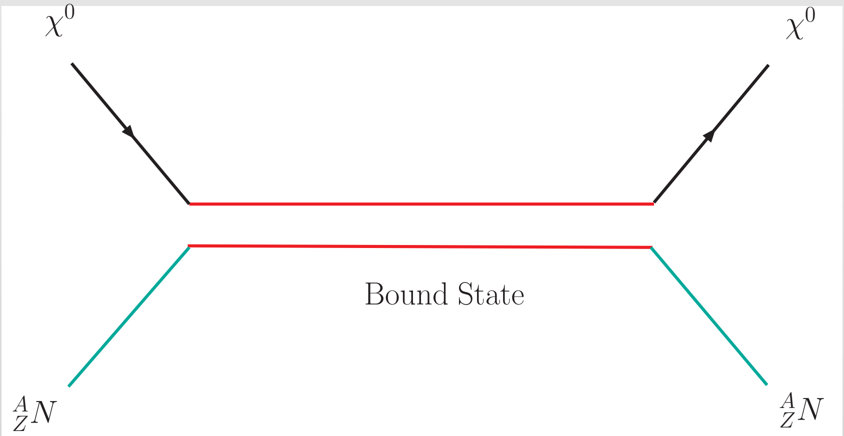
Interpreting the Current Data



Phenomenological Fit



$$\sigma_{\chi N} \propto \frac{\sigma_0}{(a - Z^2)^2}$$



Resonant Dark Matter

YB, Fox; arXiv:0909.2900

Episode 2 is coming

Thanks