Title: A Dark Force for Baryons

Date: Sep 27, 2011 12:30 PM

URL: http://pirsa.org/11090076

Abstract: We suggest the existence of a fundamental connection between baryonic and dark matter. This is motivated by both the stability of these two types of matter as well as the observed similarity of their present-day densities. A unified genesis of baryonic and dark matter arises naturally in models in which proton stability is ensured by promoting the baryon number to a local symmetry. This is illustrated in a specific class of SUSY models using the Affleck-Dine mechanism. The dark matter candidate in these scenarios is charged under the baryon gauge symmetry and is required to have a mass at the weak scale. We discuss the collider constraints from B-factories, LEP, Tevatron, and LHC, as well as direct detection bounds. A baryonic dark force is shown to be consistent with all data for mediators as light as the GeV scale.

Dark & Visible Matter:

- DM and protons are stable (or **very** long lived…)
- DM and baryons have comparable density $\rho_{\rm DM} \approx 5\rho_{\rm B}$

IS THERE A FUNDAMENTAL REASON?

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Logic:

I. There is **a new gauge principle** that forbids proton decay: the baryon number is a local symmetry

II. Any such theory must have **beyond the SM stable particles**: Dark Matter !!!

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Outline

- Why is the proton stable?
  - Baryon number as a gauge symmetry
  - Dark matter
- An example: SUSY with $U(1)_B$
  - The DM is charged under $U(1)_B$
  - Visible and Dark matter (asymmetries) have a common origin
- Asymmetris WIMP Dark Matter
- Experimental constraints
  - B-factories
  - Colliders (LEP, Tevatron, LHC!)
  - Direct Detection

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Why is the proton stable?

The SM has an **accidental** U(1) baryon symmetry of the **renormalizable** formulation: higher dimensional operators consistent with the gauge symmetry generically break it (Ex: $QQQL$).

Hence, generic UV completions (SUSY, extra-D, GUTs,...) are expected to trigger proton decay...

...BUT WE BELIEVE THE SM IS INCOMPLETE...

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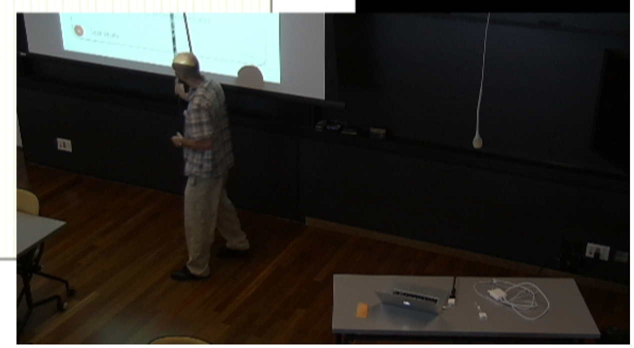

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Local vs Global symmetries:

Carone & Murayama '98,
Fileviez-Perez & Wise '10,…

Model-independent solution: a dynamical principle

We can avoid proton decay at any order in perturbation theory, and beyond the renormalizable level if the baryon number is embedded into a local symmetry that forbids

(see later for examples)

$$\mathcal{L}_{\rm p-decay} = \Psi \mathcal{O}$$

Proton
interp. field

Light fields & the
$U(1)_B$ order parameter

Baryon number as a local symmetry

- The baryon number is anomalous in the SM: we need new fields (e.g. leptons) & new symmetries (e.g. L) to define a gauge symmetry $\mathbf{U(1)_B}$
- Leptons and L do not work: B-L allows $QQQL$
- We need beyond the SM fields, BSM symmetries, **BSM stable particles** (DM)

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Example: SUSY & $U(1)_B$...

(Not exhaustive, not minimal, ...)

- q' do not mix with the SM
(not a standard 4th family)
- The 4th family of quarks is stable **$U(1)_{q'}$**
- The 4th family of leptons mixes with the SM
- L is broken (Majorana neutrinos)
- R-parity is broken
- to break the gauge baryon number $U(1)_B$

	$SU(3)_C$	$SU(2)_W$	$U(1)_Y$	$U(1)_B$
Q'_i	3	2	$+\frac{1}{6}$	$-\frac{1}{N}$
u'_{ci}	$\bar{3}$	1	$-\frac{2}{3}$	$+\frac{1}{N}$
d'_{ci}	$\bar{3}$	1	$+\frac{1}{3}$	$+\frac{1}{N}$
L'_i	1	2	$-\frac{1}{2}$	0
ν'_{ci}	1	1	0	0
e'_{ci}	1	1	$+1$	0
S	1	1	0	$+B(S)$
$\overline{S}$	1	1	0	$-B(S)$

- The DM X is SM singlet and $U(1)_B$ charge B(X)=4/3:
- it facilitates $q' \to qX$ (asymmetry transfer) and is stabilized by $U(1)_{q'}$
- the proton and the DM are stable beyond the ren. level for B(S) integer >1

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Generic Features:

- The DM mass is set by the weak scale (perturbative realizations): the DM is the lightest state of a chiral sector q′
- $U(1)_B$ effectively forces B_q and $B_{q'}$ to be accidental, anomalous global symmetries
- **The DM is charged under the baryonic force**
- If L is not a symmetry the only (if any) accidental nonanomalous symmetries must be of the form $D=B_q+cB_{q'}$ (analog of B-L): **Baryogenesis** ($\eta_{B_q} \neq 0$) **requires** $\eta_{B_{q'}} \neq 0$

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Asymmetric WIMP DM

- Baryogenesis occurs via the generation of a primordial asymmetry for D, which is then transferred between B_q and $B_{q'}$ by the operators mediating q' decay: $\eta_{DM} \sim \eta_B$

Visible and dark matter have a common origin

- In our toy model Affleck-Dine with a flat direction charged under D.

Symmetric case

- When the asymmetry freezes in, one is left with: $x = m/T$

Anti-Particle

$$\frac{dY}{dx} = \frac{d\overline{Y}}{dx} = -\lambda\, g_*^{1/2}\, x^{-n-2}\left(Y\overline{Y} - Y_{eq}\overline{Y}_{eq}\right)$$

Particle

$$\lambda = \sqrt{\frac{\pi}{45}} M_{\rm Pl} m \sigma_0 \qquad \langle \sigma v \rangle = \sigma_0 x^{-n}$$

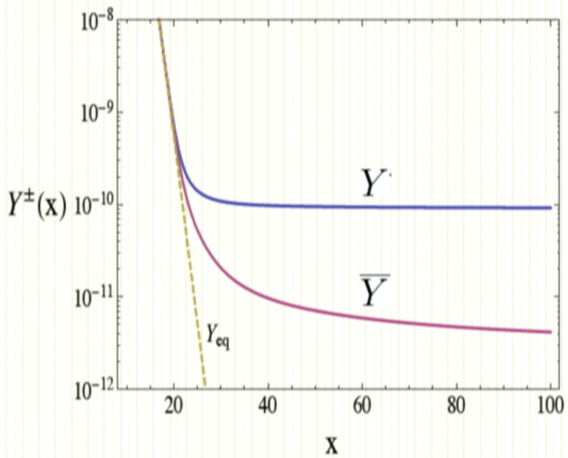
- The symmetric case is well known: $\overline{Y}(x_i) = Y(x_i)$ implies that the populations are the same at any time. In this case, after freeze-out $Y_{eq} \ll Y$ and one finds (**symmetric WIMP**)

$$Y = \overline{Y} \propto \frac{1}{\sigma_0}$$

General case

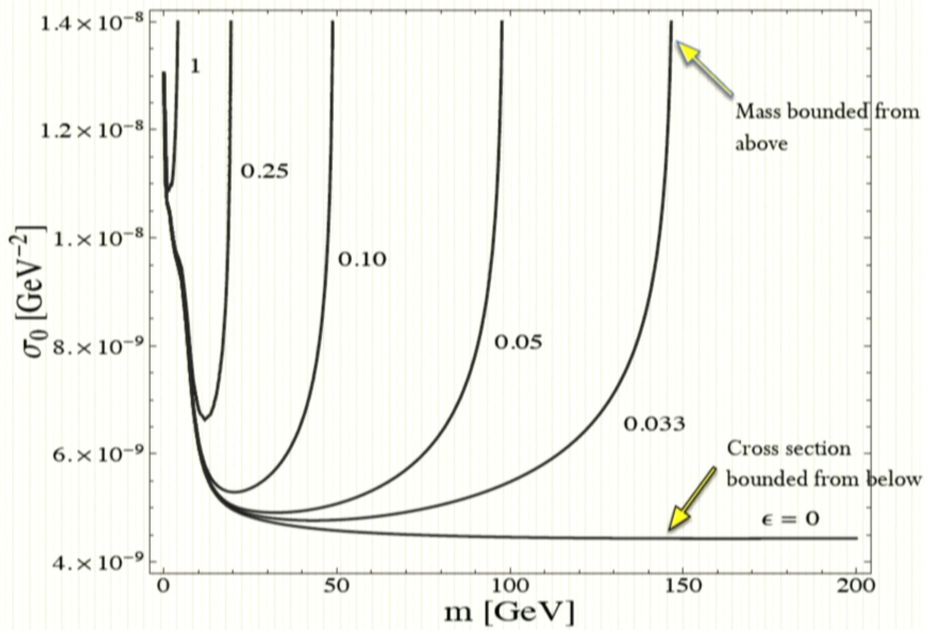
Griest, Seckel '87
M. Graesser, I. Shoemaker, LV '11

- If $\eta \equiv Y - \overline{Y} \neq 0$ then, after freeze-out the less abundant species is depleted further, and further,…



The less abundant population is exponentially sensitive to the cross section

Relic abundance



All curves have the right abundance
for a given asymmetry $\epsilon = \eta_{DM}/\eta_B$

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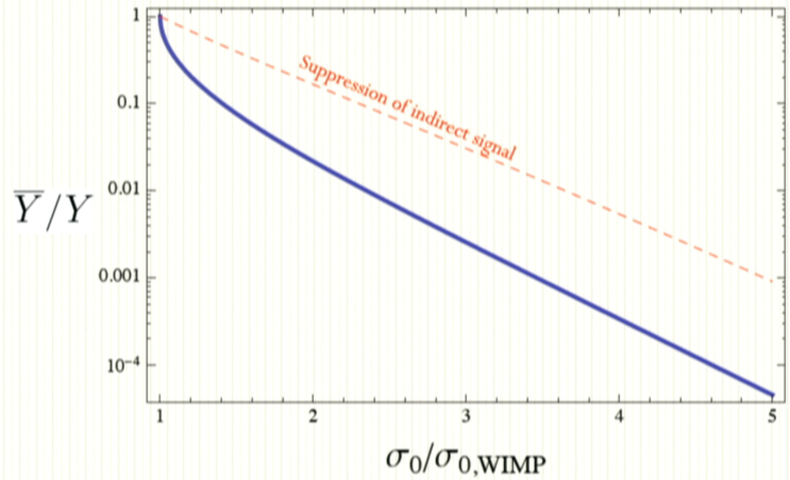
A primordial asymmetry does not necessarily imply absence of antiparticles & indirect signals...
There is a nontrivial dependence on the annihilation cross section:



- You do not need a strong dynamics to deplete the anti-particle population (Asymmetric WIMP)
- If the cross section is small the asymmetry has no effect
- Indirect signals are not completely suppressed

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✓ Asymmetris WIMP Dark Matter

○ Experimental constraints

- B-factories
- Colliders (LEP, Tevatron, LHC!)
- Direct Detection

Phenomenology

At low E these models are described in a model-independent way by:

- **The SM Lagrangian with B(q)=1/3**
- **The dark/baryonic gauge boson Z_B** (mass m_B and coupling g_B)
- **A weak-scale DM field X** (here Dirac) with couplings

$$D^\mu X = \left[\partial^\mu + i g_B (q_V + q_A \gamma^5) Z_B^\mu\right] X$$

- **Kinetic mixing:**
  here models in which the mixing is loop-suppressed $\mathrm{Tr}(BY) = 0$

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Signatures:

- Missing energy at colliders
  - Babar: $\Upsilon \to \text{nothing}$ for light DM
  - LHC/ Tevatron: $pp/p\overline{p} \to jX\overline{X}$

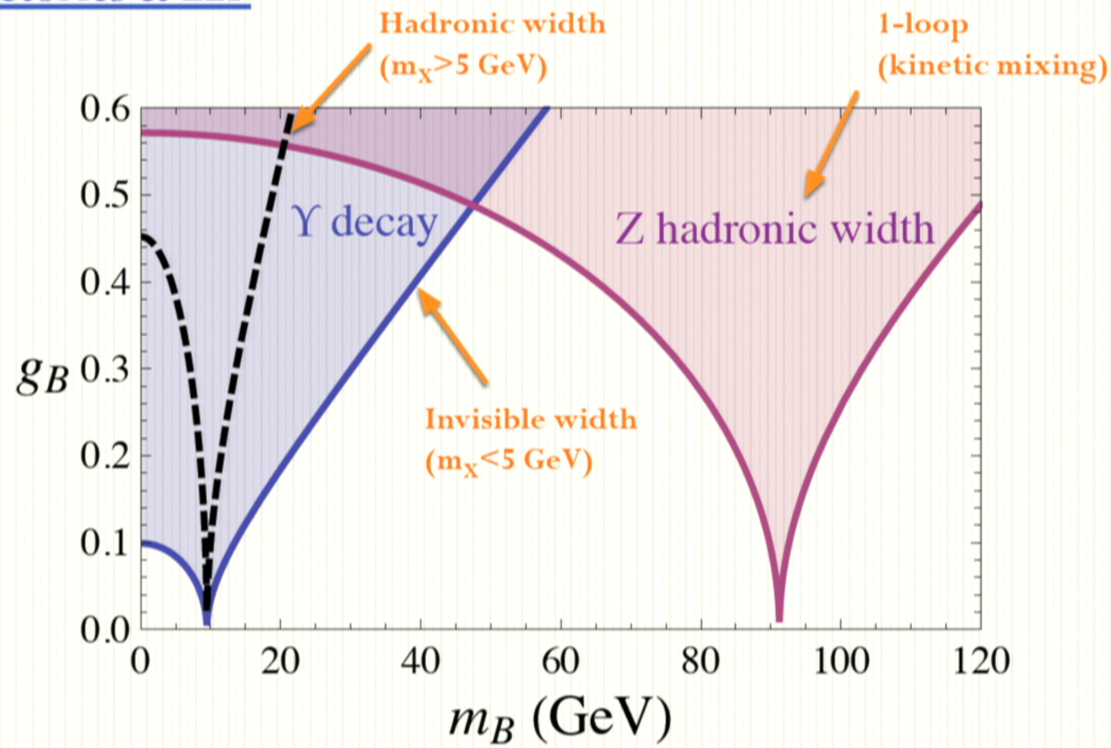
Strong bounds!

- Corrections to hadronic processes
  - Babar: $\Upsilon \to \text{hadrons}$
  - LEP: loop suppressed $Z \to \text{hadrons}$

Carone & Murayama '98,
Burgess et al. '11,...

- Direct detection…

B-factories & LEP



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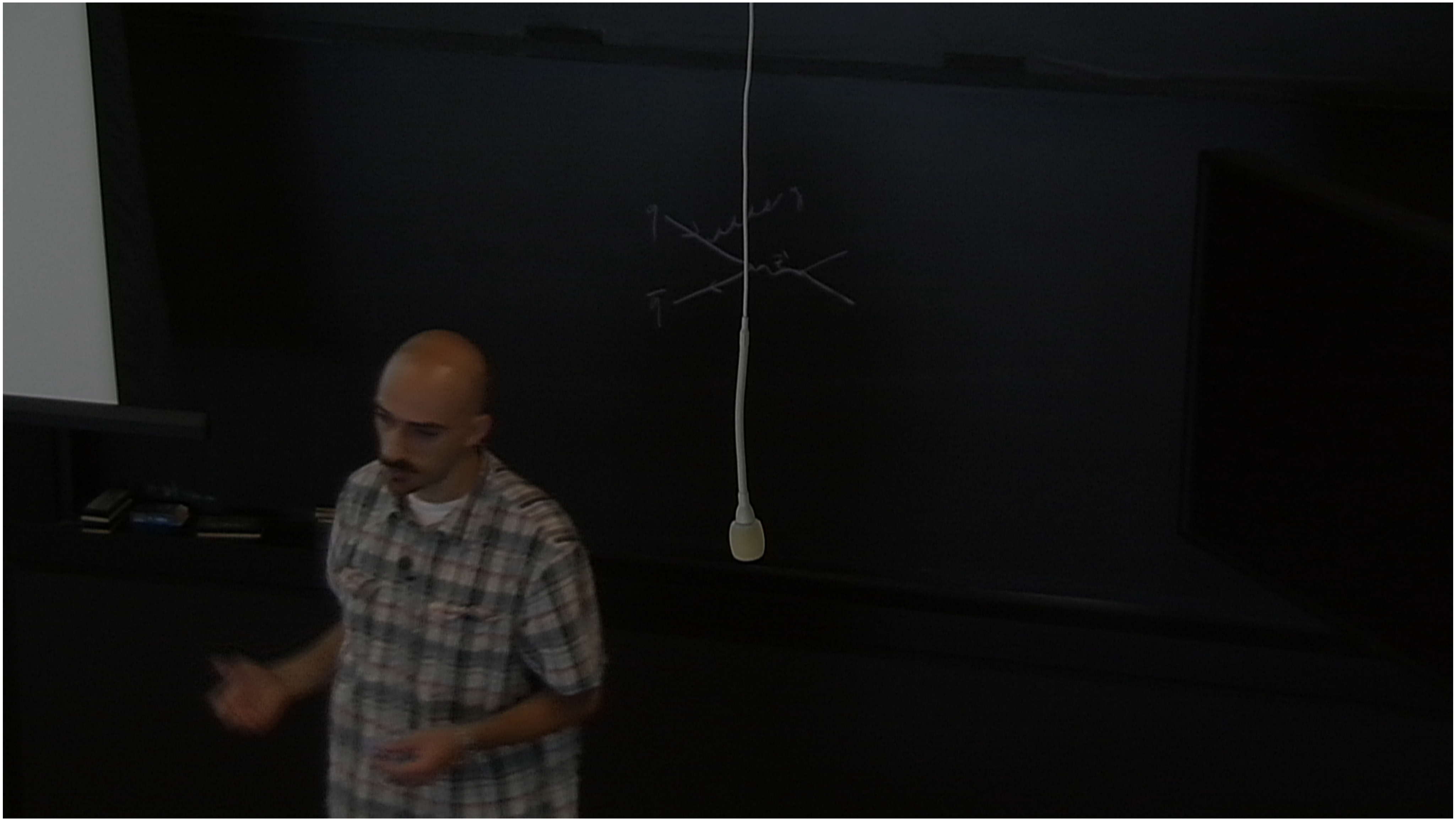
Monojets at Tevatron & LHC

$$pp/p\overline{p} \rightarrow jX\overline{X}$$

- SM background: $jZ \rightarrow j\nu\overline{\nu},\ jW \rightarrow j\nu l$
- Signal: $q\overline{q} \rightarrow gX\overline{X}$ (Tevatron) $qg \rightarrow qX\overline{X}$ (LHC)
- Uncertainty is systematics dominated (QCD):
  monojet is better, there is pT cut that maximizes the signal
- CDF and ATLAS with 1 fb^{-1}: LHC is more constraining (higher pT cut)



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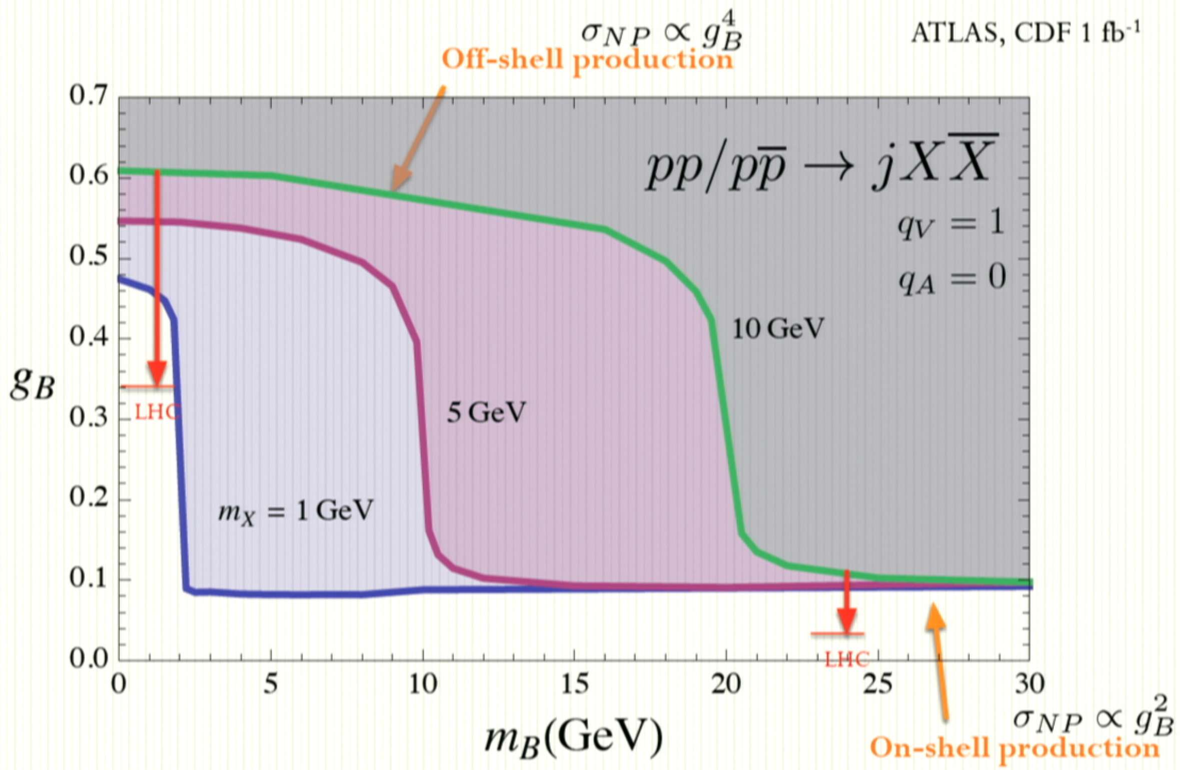
Monojets at Tevatron (LHC)



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Direct detection

$$D^\mu X = \left[\partial^\mu + i g_B (q_V + q_A \gamma^5) Z_B^\mu\right] X$$

- **VECTOR COUPLING**

$$\sigma_{SI} \sim \frac{\mu^2}{\pi}\left(q_V \frac{g_B^2}{m_B^2}\right)^2$$

IF THE BARYONIC GAUGE BOSON DOMINATES ANNIHILATION THEN THE BOUNDS ARE VERY STRONG. ALTERNATIVES:

1. THERE ARE NEW ANNIHILATION CHANNELS
2. THE DM IS LESS THAN 1-2 GEV (BELOW CURRENT SENSITIVITY)
3. ANNIHILATION OCCURS ON-RESONANCE (NOT GENERIC)

- **AXIAL COUPLING**

$$\frac{d\sigma_{SI}}{dE_R} \propto \left(q_A \frac{g_B^2}{m_B^2}\right)^2 \left[O(v^2) + O(q^2/\mu_N^2)\right]$$

THE BOUNDS ARE NOT CONSTRAINING AT THE MOMENT

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If the baryonic gauge boson dominates annihilation then the bounds are very strong. Alternatives:

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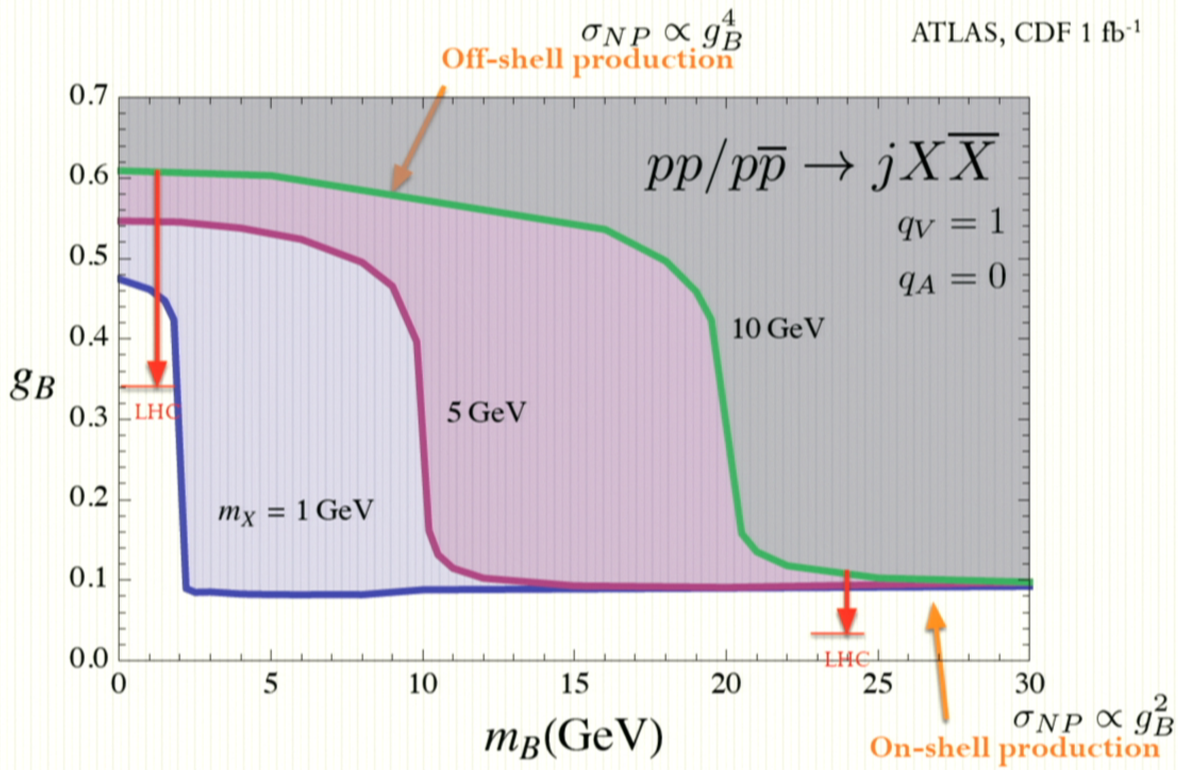
Monojets at Tevatron (LHC)



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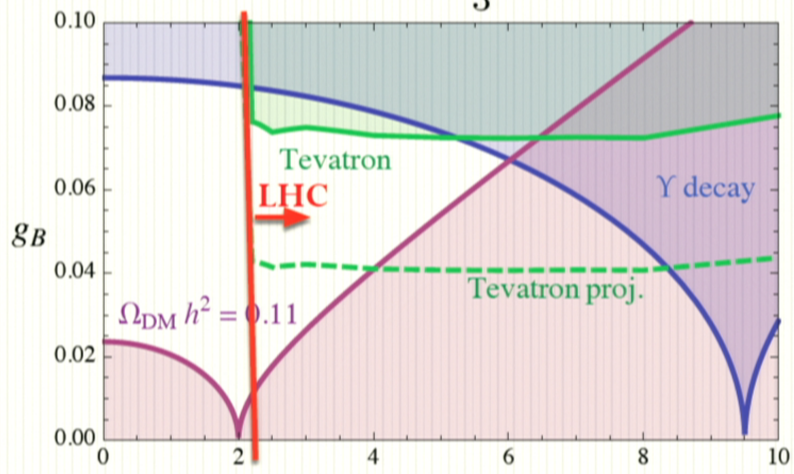
Combined bounds for toy model (I)

$$D^\mu X = [\partial^\mu + i\frac{4}{3}g_B Z_B^\mu]X$$



$m_X = 1$ GeV

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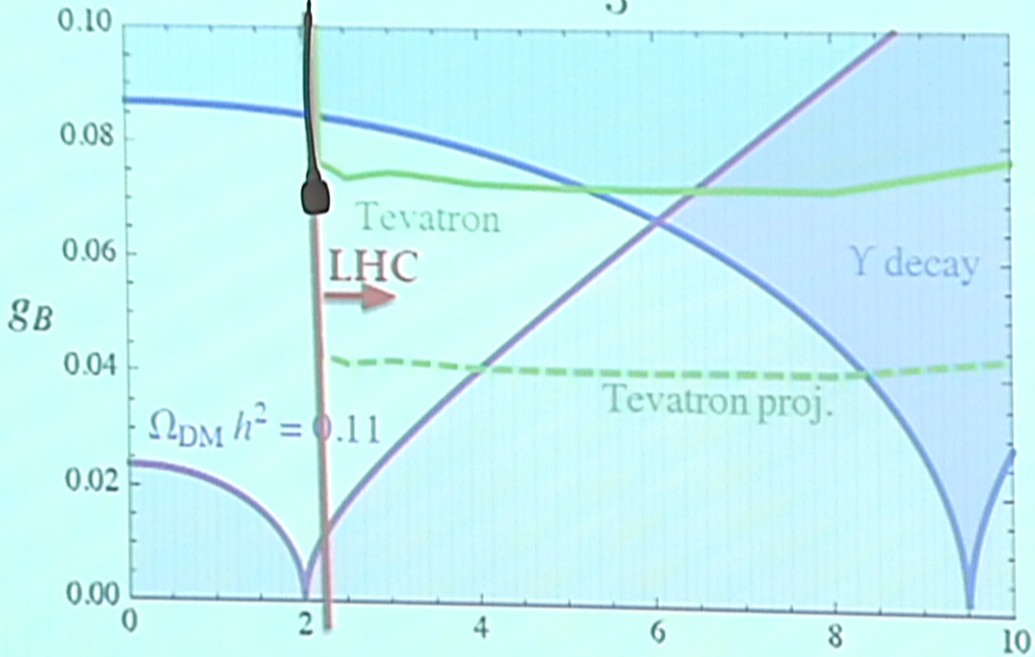
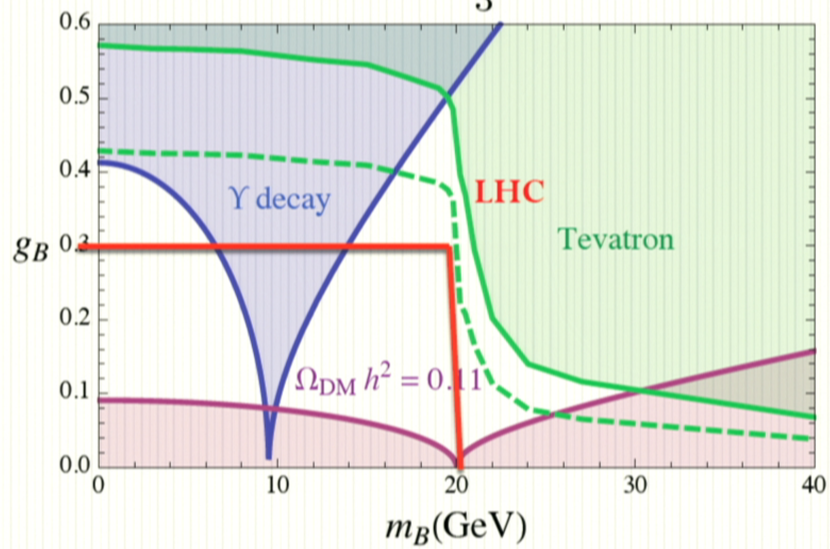


$m_X = 1$ GeV

Combined bounds for toy model (II)

$$D^\mu X = [\partial^\mu + i\frac{4}{3} g_B \gamma^5 Z_B^\mu] X$$



$m_X = 10$ GeV

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A digression…

- Lowest bound on dijet resonance mass is ~100 GeV (UA2…)
- Tevatron and LHC assume no new physics in this range and quote bounds above a few hundred GeV

- But… if there is really new physics at low scales:

  MC simulations would be wrong!

  Is the LHC tuning the MC to the SM+$U(1)_B$?! What about their bounds/signals?

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Conclusions

- The proton can be stabilized in a generic extension of the SM, and beyond the ren. level, by embedding the baryon number into a gauge symmetry [here $U(1)_B$]

- New stable particles generically appear: DM
  - the DM is charged under the baryon gauge force
  - the DM has a weak-scale mass (perturbative models)

- Visible and dark matter are simultaneously generated

- Visible and dark matter have comparable abundances

- Current bounds are weak:
  - hadronic processes overwhelmed by QCD
  - missing energy signals are more constraining

THANK YOU!

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