Dark matter beams at the LBNF

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Based on work with:

Pilar Coloma, Claudia Frugiuele, Roni Harnik – 1512.03852

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Direct detection experiments are sensitive to dark matter particles that interact with quarks and have a mass above ~ 5 GeV.

For $m_\chi \lesssim 5$ GeV, monojet and monophoton searches at the LHC impose some constraint on the quark-DM interaction strength.

A promising alternative:

Fixed target experiments $\longrightarrow$ DM beam $\longrightarrow$ signal in ν detectors

B. Batell, M. Pospelov, A. Ritz, arXiv:0906.5614 ; ... ; MiniBoone, 1211.2258

What is the mediator of quark - DM interaction?

Consider a heavy gauge boson: Z' (spin 1, charge 0) which is leptophobic.

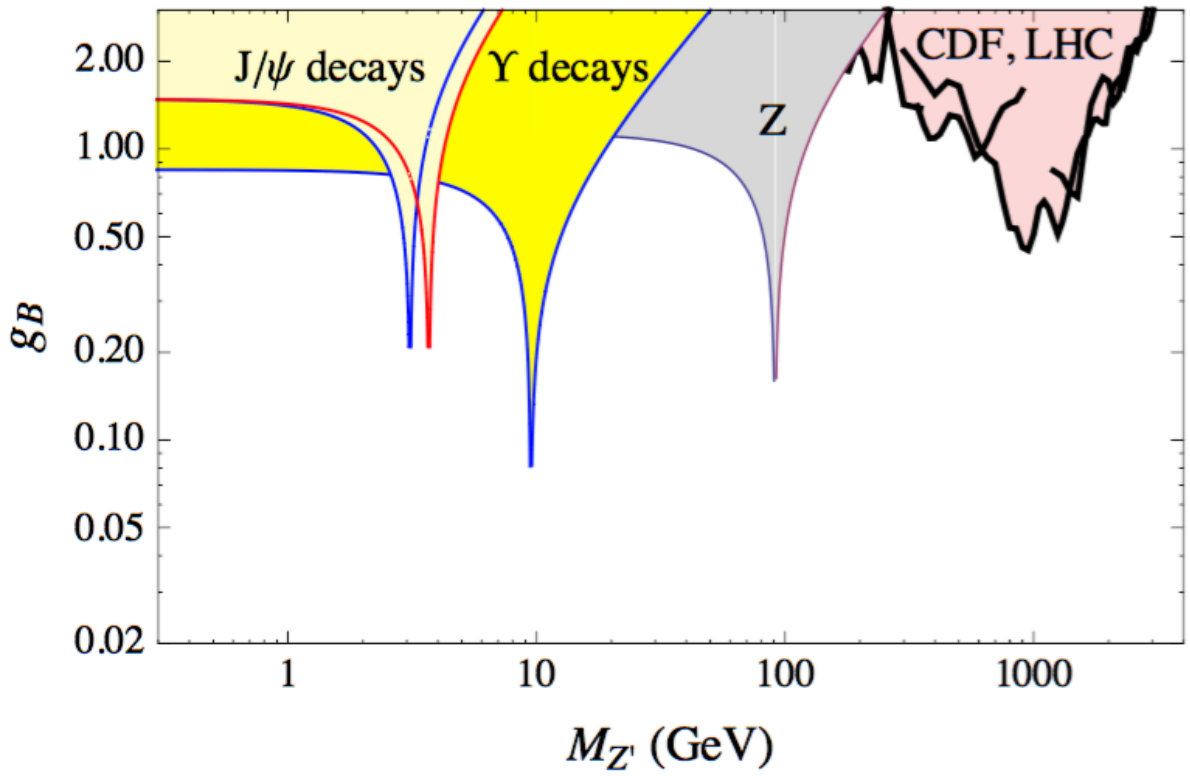
Collider limits on $q\bar{q} \to Z' \to jj$ only for $M_{Z'} \gtrsim 100$ GeV. *(with Felix Yu, 1306.2629).*

Interactions of Z' with quarks are model dependent:

$$\frac{g_z}{2} Z'_\mu \sum_q \left(z_q^L \, \bar{q}_L \gamma^\mu q_L + z_q^R \, \bar{q}_R \gamma^\mu q_R \right)$$

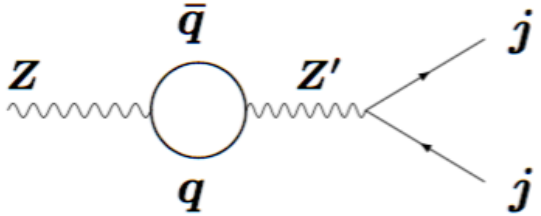
E.g., **"Baryonic" Z': same coupling to all six quark flavors**

$$(z_q^L = z_q^R = 1/3 \ , \ \ g_z \equiv g_B)$$



ARGUS experiment, 1986: limit on $\Upsilon \to Z'^* \to jj$

Small $Z - Z'$ mixing induced at one loop:

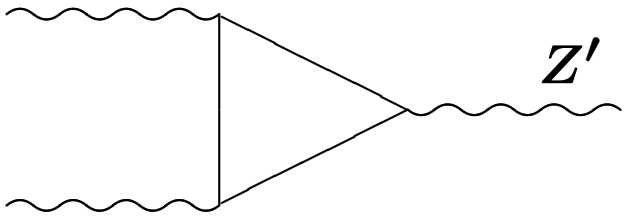


Massive spin-1 particles behave well at high energies only if they are associated with a spontaneously broken gauge symmetry.

Simple gauge extension of the SM: $SU(3)_c \times SU(2)_W \times U(1)_Y \times U(1)_z$

Gauge symmetries may be broken by quantum effects.

Cure: sums over fermion triangle diagrams must vanish.

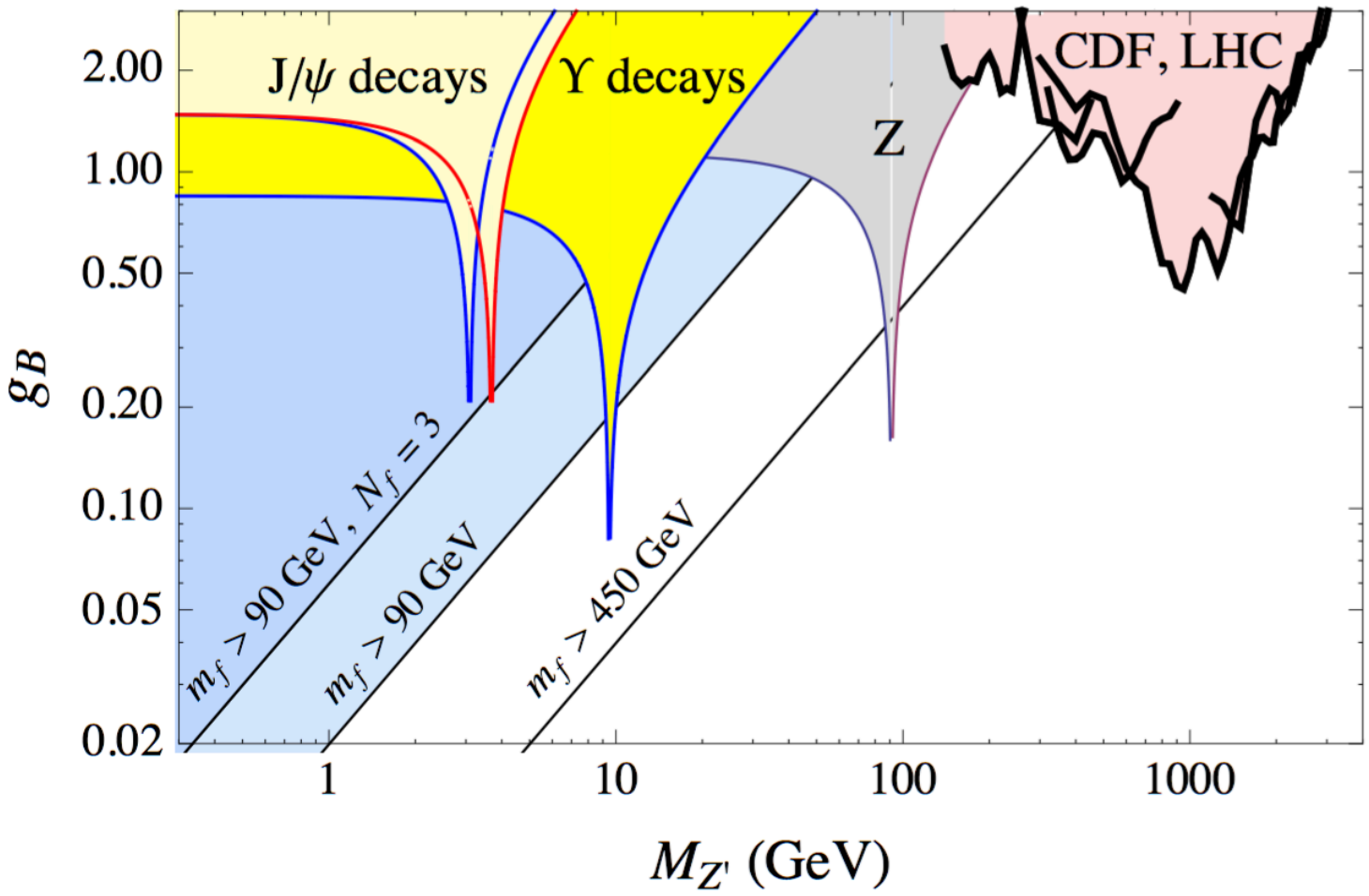


$U(1)_Y[U(1)_z]^2$ **and** $[SU(2)_W]^2 U(1)_z$ **anomaly cancelation require new electrically-charged fermions, of mass** $m_f = \lambda\langle\phi\rangle$.

$$\lambda \lesssim 4\pi/3 \ , \ M_{Z'} = \frac{g_z z_\phi}{2}\langle\phi\rangle$$

$$\longrightarrow \quad g_z = \frac{2\lambda M_{Z'}}{z_\varphi m_f} < \frac{8.4\times 10^{-2}}{z_\varphi}\left(\frac{M_{Z'}}{1\ \mathrm{GeV}}\right)\left(\frac{100\ \mathrm{GeV}}{m_f}\right)$$

Collider limits on the mass of new electrically-charged fermions $\Rightarrow$ limit on g_B:

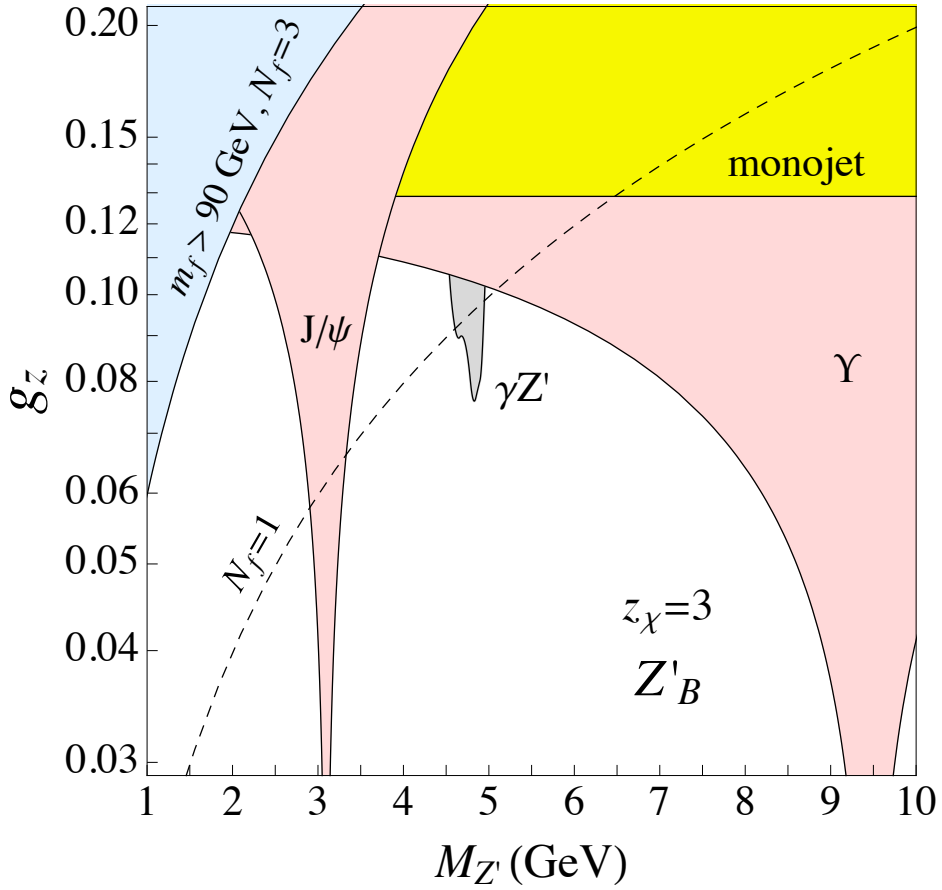


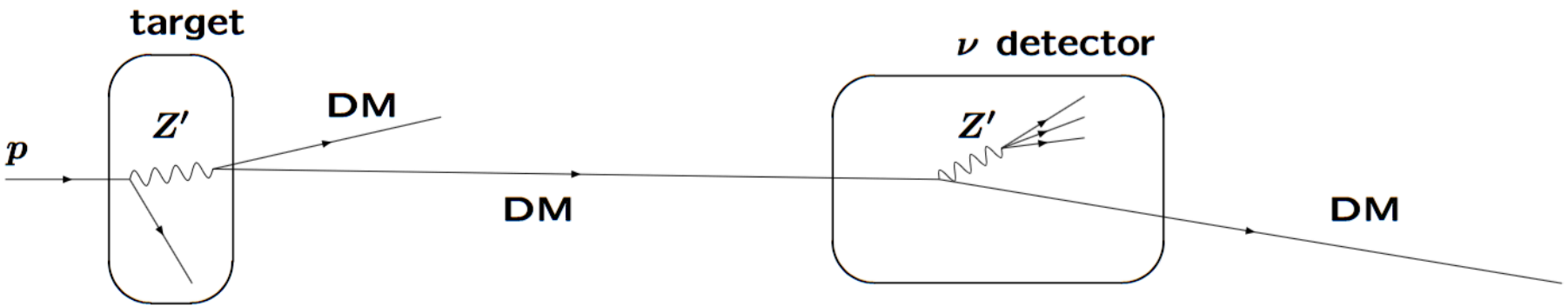
$U(1)_B$ is spontaneously broken by the VEV of a new scalar field φ.

with Claudia Frugiuele:
PRL 113, 061801 (2014)

Let's couple Z'_B to the DM particle: *(with Claudia Frugiuele, 1410.1566)*

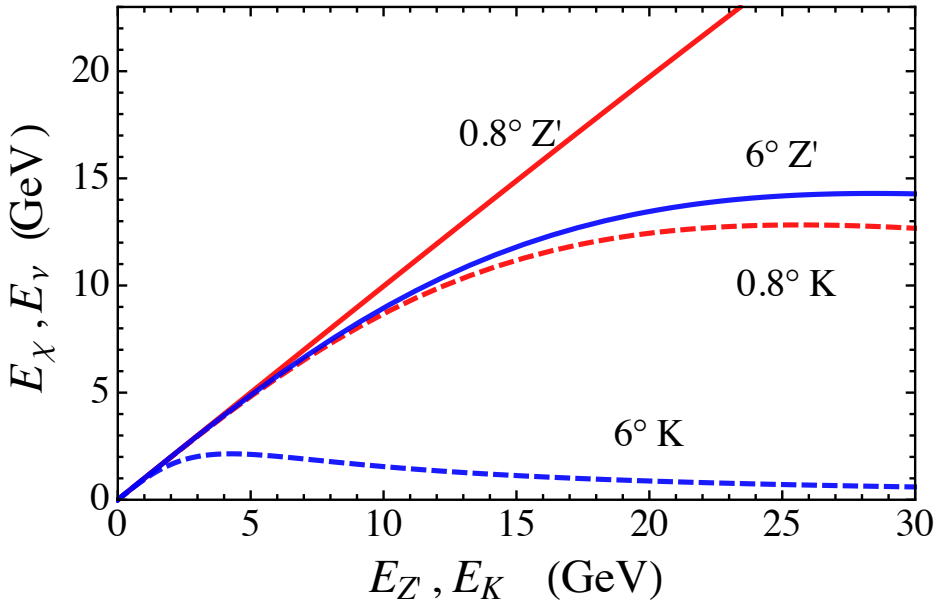
Limits on the gauge coupling:





Neutral-current events $\rightarrow$ background: ν beam!

DM events have higher energy, can separate signal from background.



$\rightarrow$ Place a neutrino near detector at a few degrees off-axis

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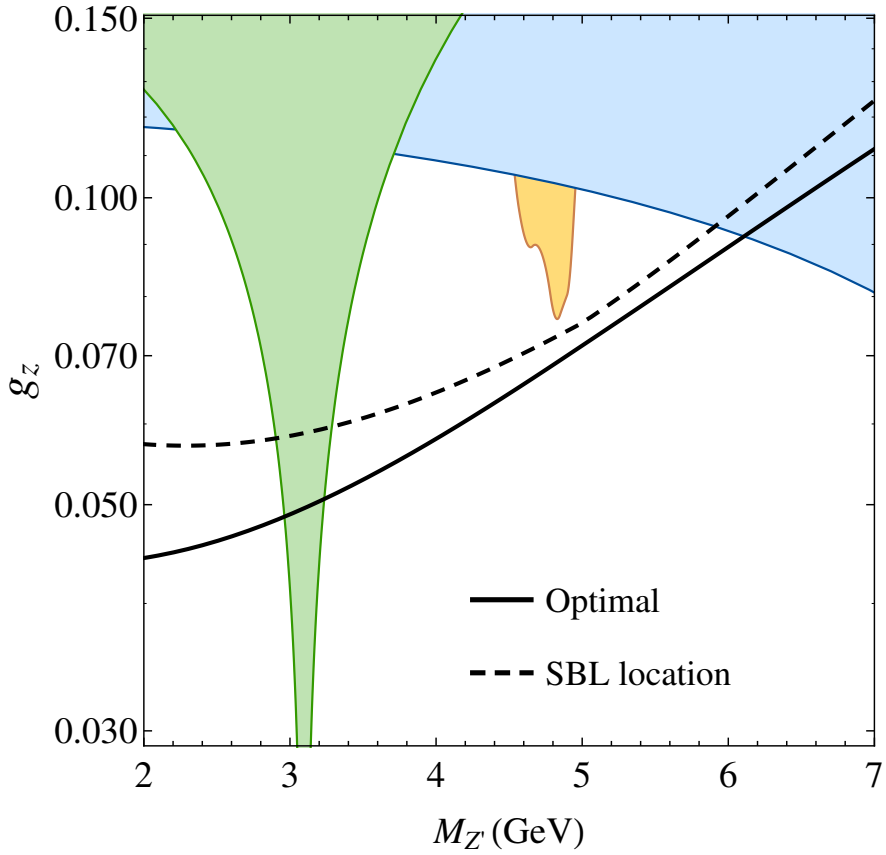
Long-Baseline Neutrino Facility:

$> 10^{21}$ protons of ~ 100 GeV on target.



Region above solid black line can be probed with a near detector placed at $\mathbf{6}^{\circ}$ *off-axis.*

Conclusions:

- Z' bosons of mass at the GeV scale may have relatively strong interactions with quarks and light DM particles ($g_z \lesssim 0.1$).
- Z' bosons produced at the LBNF may generate a beam of light dark matter particles.
- The DM interactions with nucleons in the detector, via Z' exchange, may be probed with a DIS neutral-current signal.
- The optimal location for the near detector is at an off-axis angle of $4^\circ - 6^\circ$ (1512.03852).