Collider Constraints on Low Mass Dark Matter

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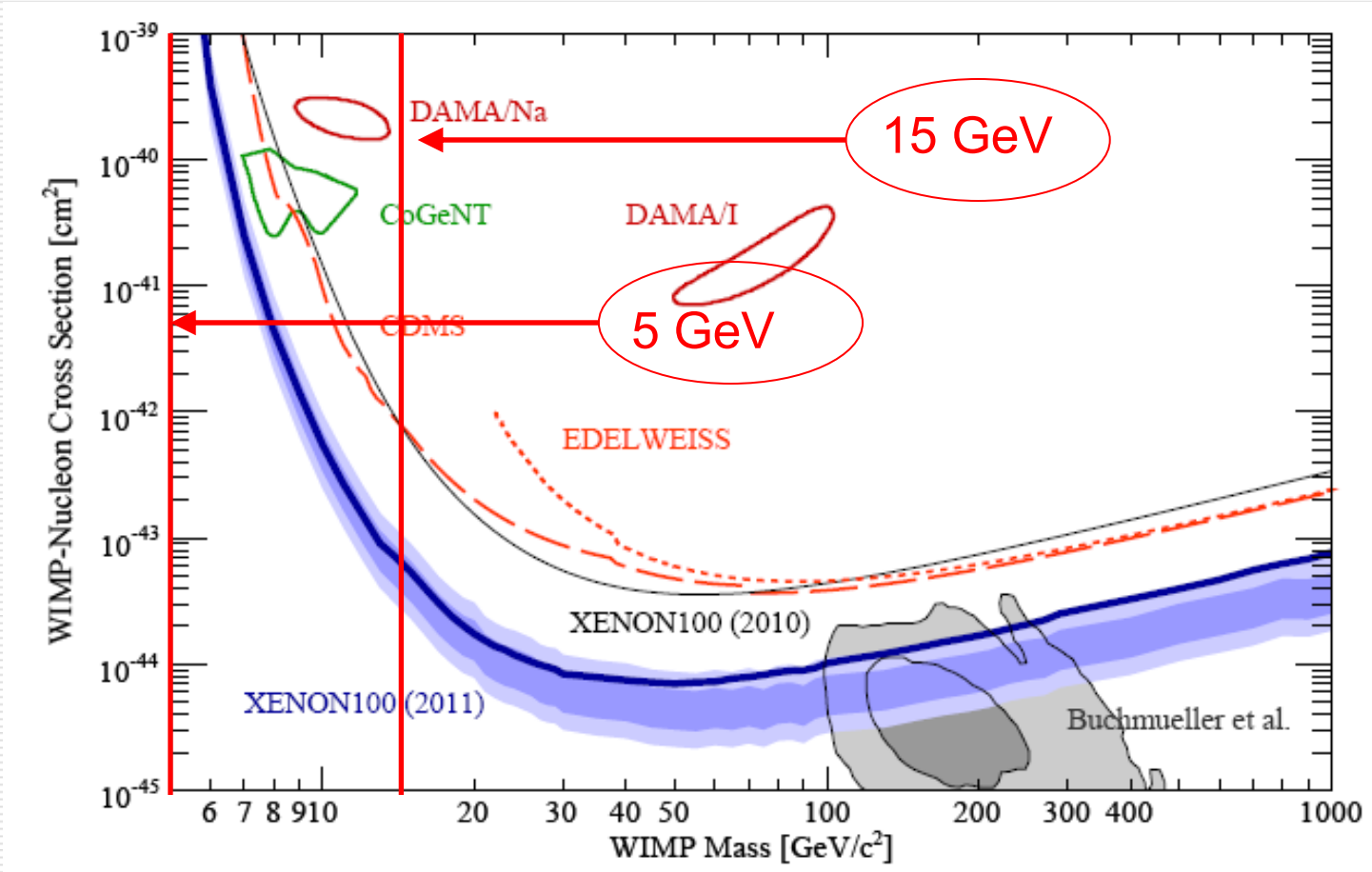
In collaboration with Xiangdong Ji and Liantao Wang

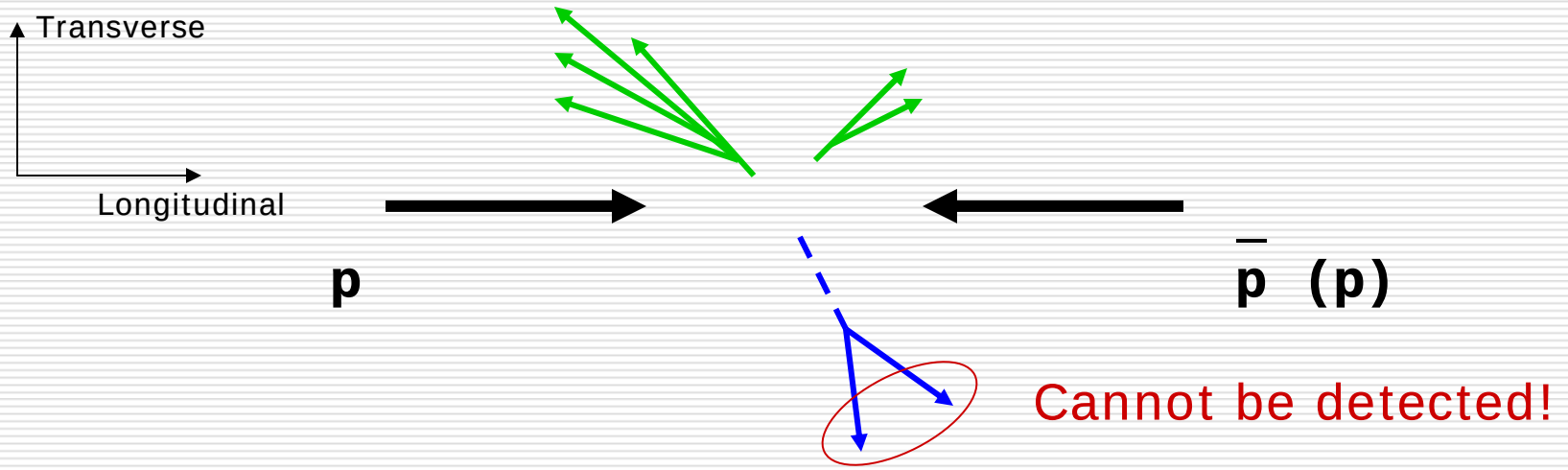
Outline

- Motivation
- From Mediator to Contact Interaction
- Current Collider Constraint
- LHC Reach
- Summary

Dark Matter Direct Detection Experiments



Observable



The transverse momentum (p_T) is conserved.

The signal is missing transverse momentum (MET).

Relevant searches with MET

- Tevatron Constraints

$p\,\bar{p} \longrightarrow$ MET + Mono-jet

CDF Collaboration, PRL 101, 181602, 2008.

Yang Bai, Patrick Fox, Roni Harnik 1005.3797.
Goodman, Ibe, Rajaraman,
Shepherd, Tait, Yu 1005.1286, 1008.1783;

- LEP constraints

$e^+ e^- \longrightarrow$ MET + Mono-photon

L3 Collaboration, Phys. Lett. B 587, 16, 2004.

Patrick J. Fox, Roni Harnik,
Joachim Kopp, Yuhsin Tsai 1103.0240

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Collider Constraints

Yang Bai, Patrick Fox, Roni Harnik 1005.3797.
Goodman, Ibe, Rajaraman,
Shepherd, Tait, Yu 1005.1286, 1008.1783;
Patrick J. Fox, Roni Harnik,
Joachim Kopp, Yuhsin Tsai 1103.0240
Jean-Francois Fortin, Tim M.P. Tait 1103.3289

Effective operator

If the mass of the intermediate particle is around a few hundred GeV, the interaction cannot be described by a contact local operator.

Mediator: vector boson, scalar boson, ...

Dark matter: spinor, scalar, ...

Interaction: vector-like, dipole-like, ...

Z' model

1. Leptophobic vector boson (Z') couples to SM quarks universally and dark matter particle.
2. Dark Matter particle is a Dirac spinor.
3. The coupling between Z' and dark matter can be either vector-like.

$$L = Z'_{\mu}[\bar{q}(g_{Z'}\gamma^{\mu} + g_{Z'5}\gamma^{\mu}\gamma_5)q + \bar{\chi}(g_D\gamma^{\mu} + g_{D5}\gamma^{\mu}\gamma_5)\chi].$$

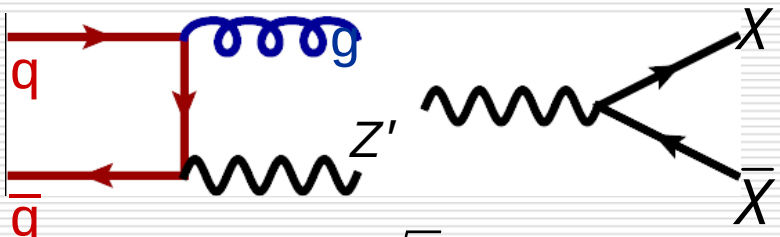
$$g_{Z'},\ g_{Z'5} \to 0,\ g_D,\ g_{D5} \to 0,\ M_{Z'},\ M_D$$

$$\sigma_{SI} = \frac{3^2 g_{Z'}^2 g_D^2 M_N^2 M_D^2}{\pi M_{Z'}^4 (M_N + M_D)^2}$$

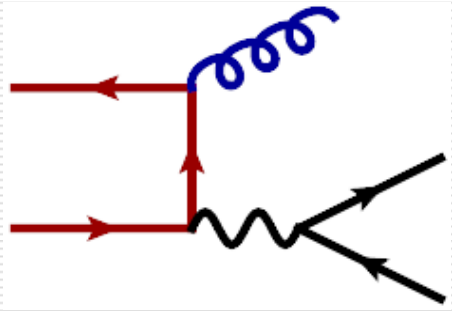
From Mediator to Contact Interaction

p $\bar{p}$ ⟶ MET + Mono-jet

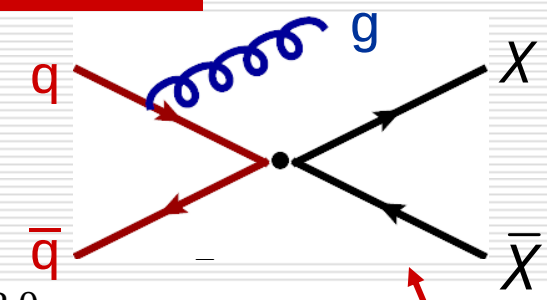
$g_{Z'}=g_D$, $g_{Z'}/M_{Z'}$ = 400 GeV



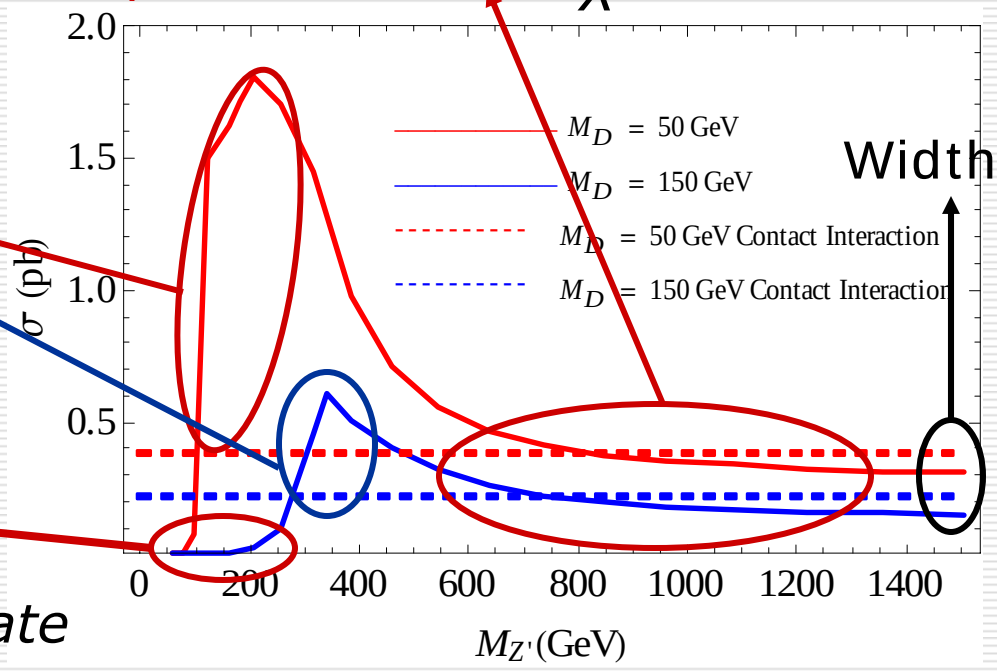
$2M_D < M_{Z'} < \sqrt{\hat{s}}$, 2-body



$M_{Z'} < 2M_D$, 3-body final state



Contact interaction



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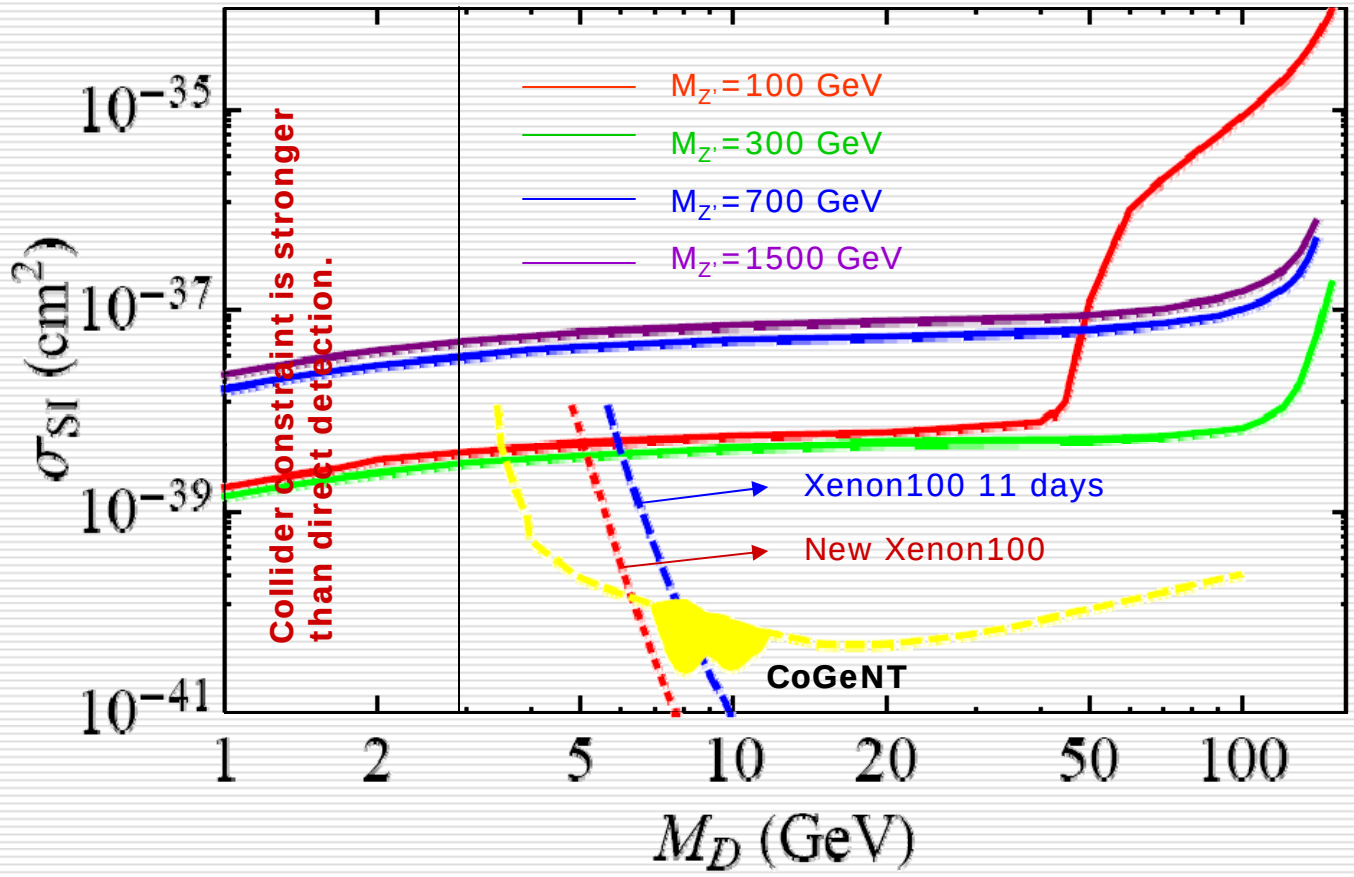
Tevatron Constraint



No axial couplings;

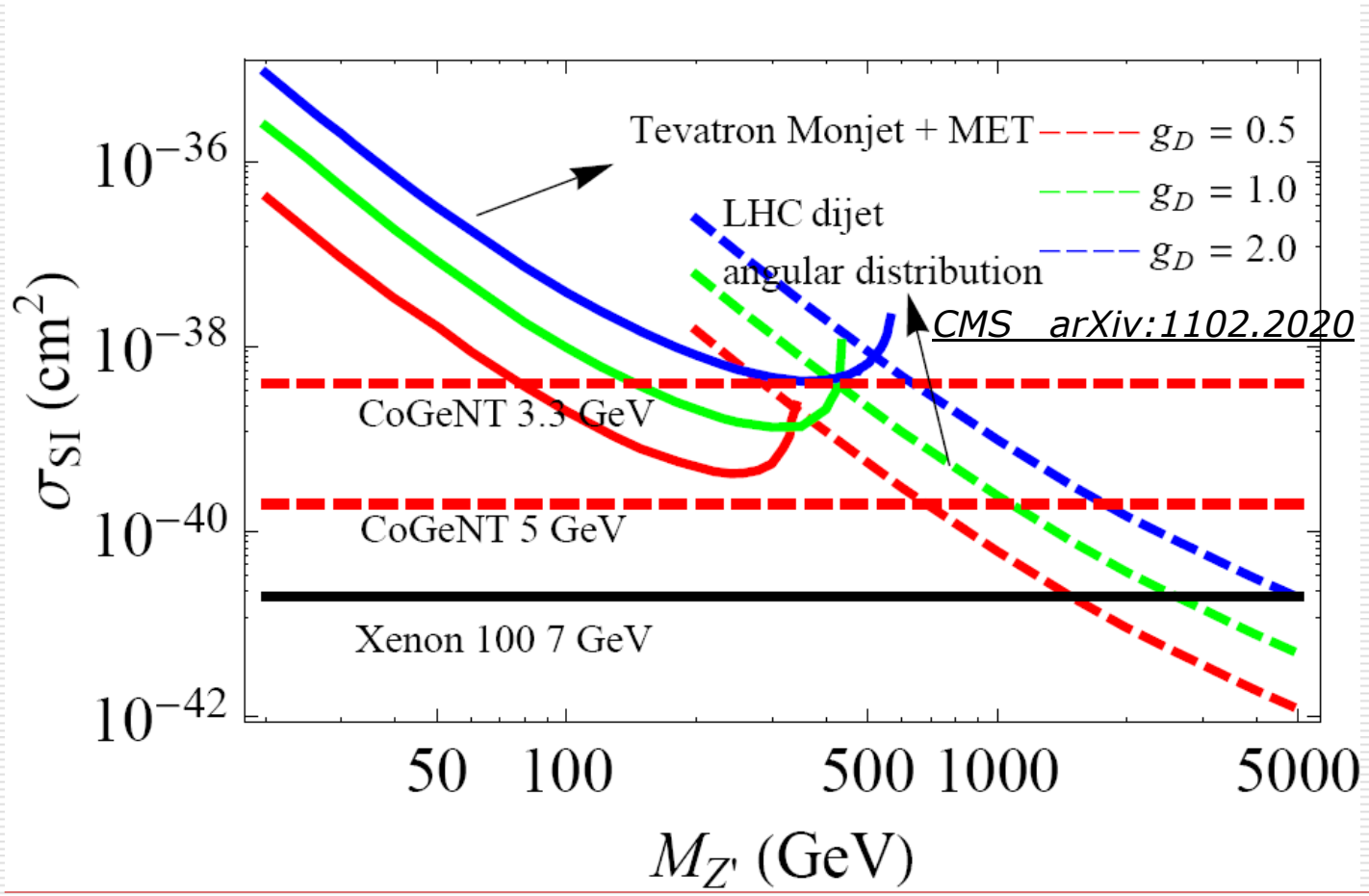
$g_{Z'} = g_D$;

$g_{Z'5} = 0$;

$g_{D5} = 0$.

CalcHEP2.5.7

Tevatron + LHC



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LHC Reach

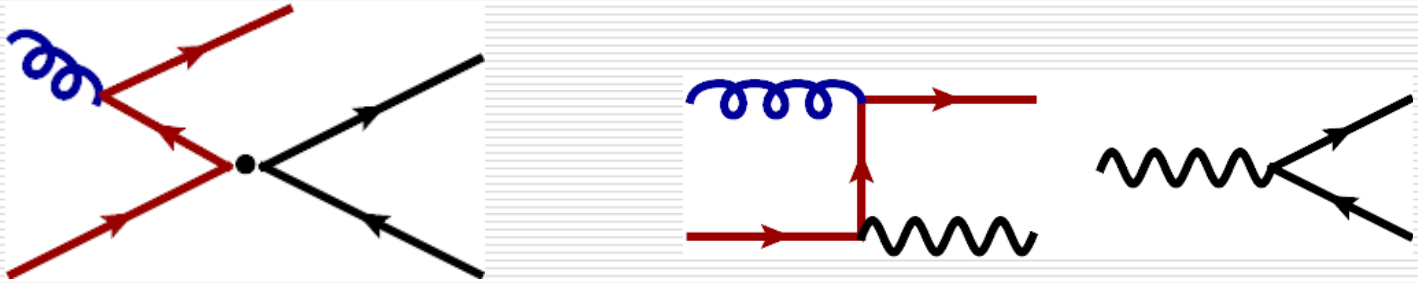
p p ⟶ Missing ET + Monojet

Missing E_T > 500 GeV, 100 fb^{-1} luminosity.

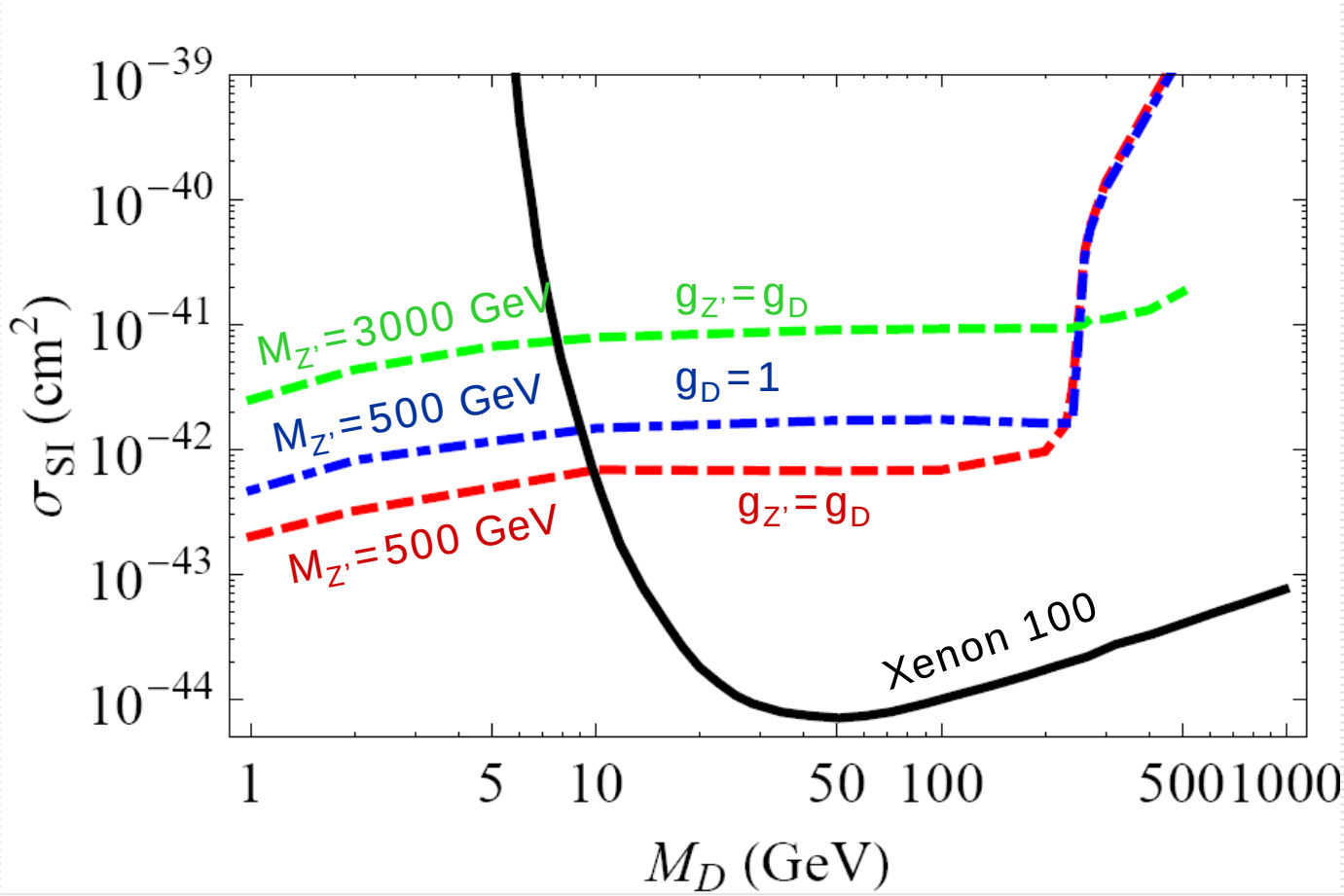
Vacavant and Hinchliffe, J. Phys. G 27 (2001) 1839-1850

SM background ≈ 20000. $S > 5\sqrt{B}$

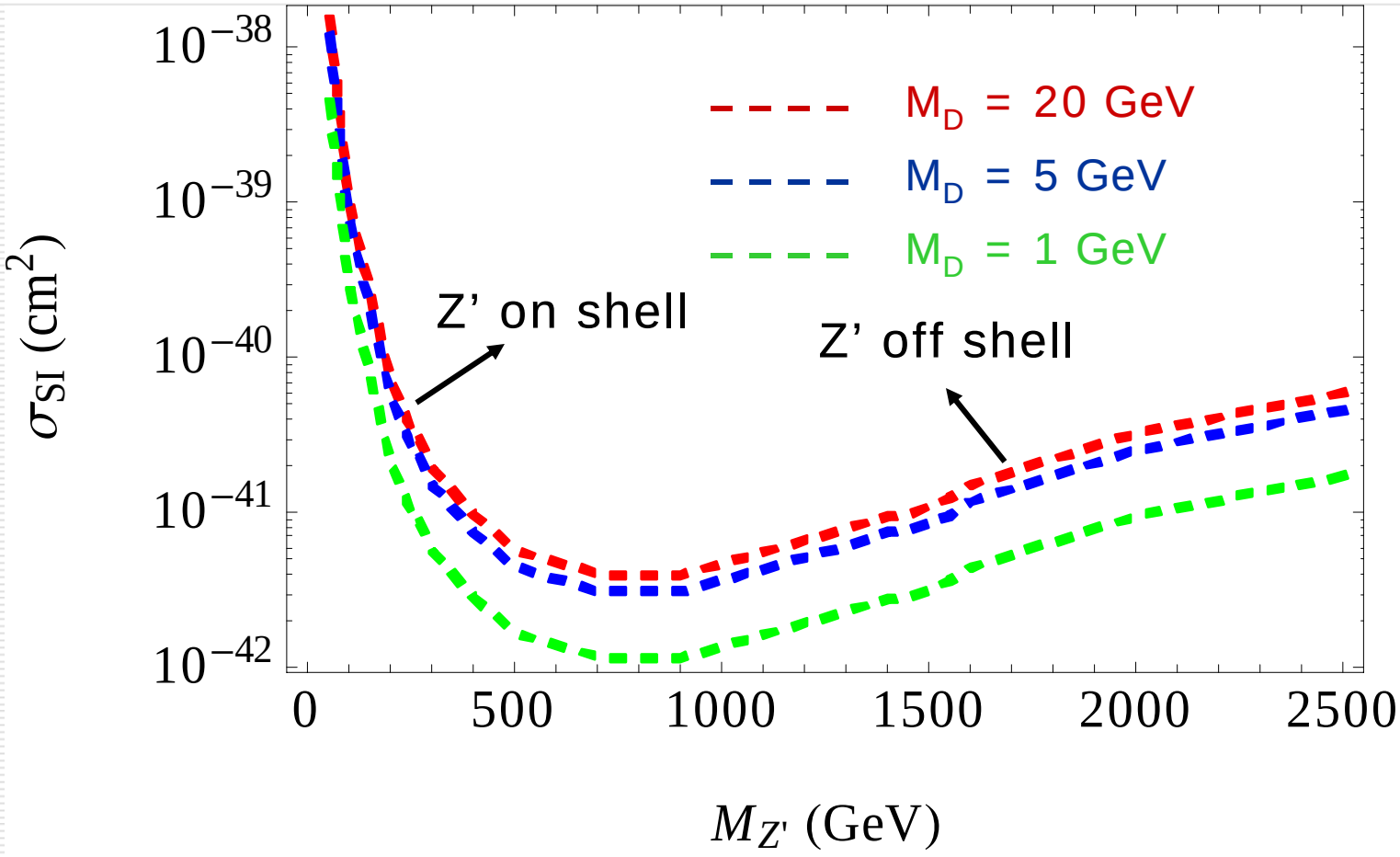
Shepherd, Tait, Yu 1005.1286, 1008.1783



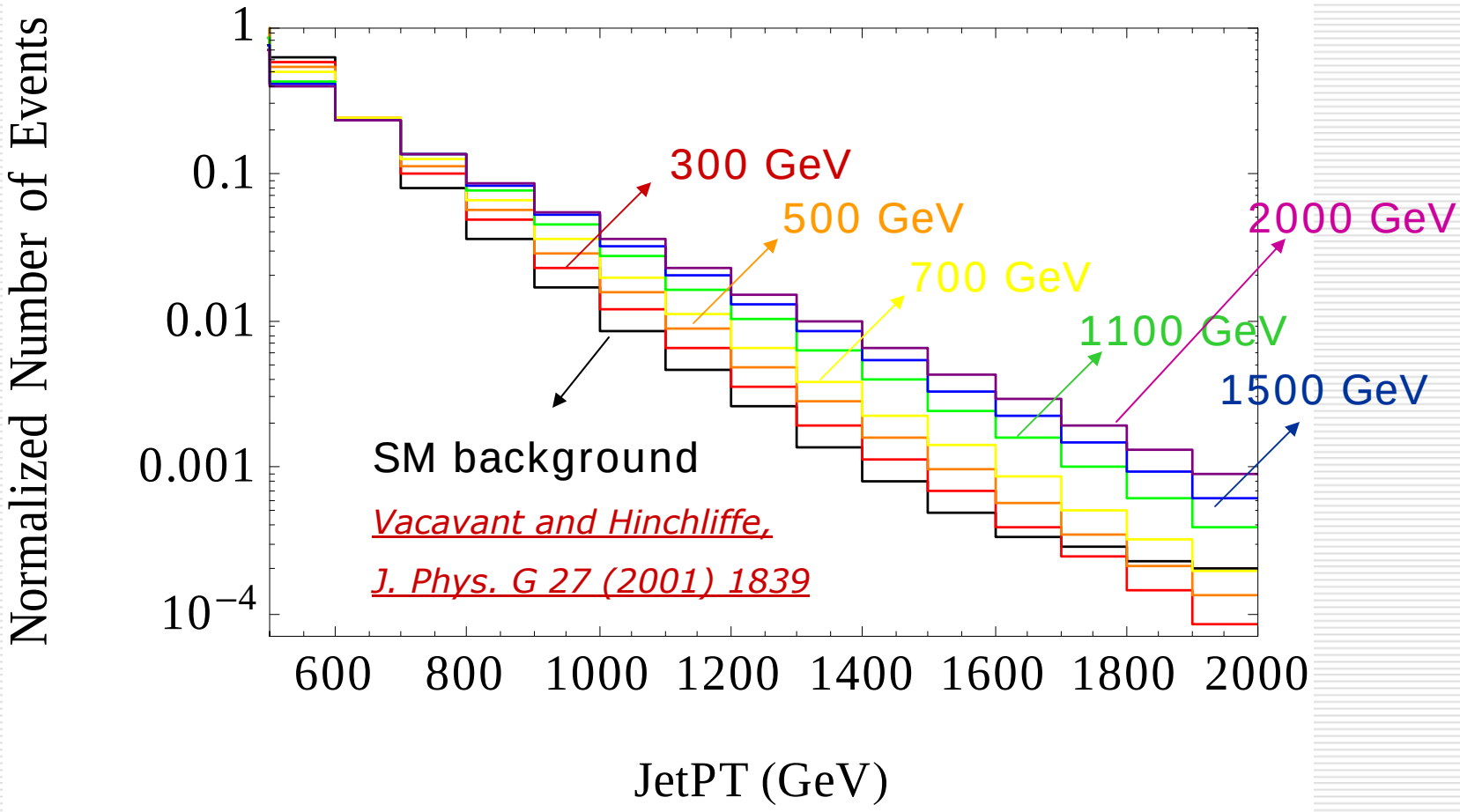
LHC Reach


10^{-39}
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
σ_{SI} (cm^2)
$M_{Z'}$=3000 GeV
$g_{Z'}=g_D$
$M_{Z'}$=500 GeV
g_D=1
$M_{Z'}$=500 GeV
$g_{Z'}=g_D$
Xenon 100
1
5
10
50
100
500
1000
M_D (GeV)

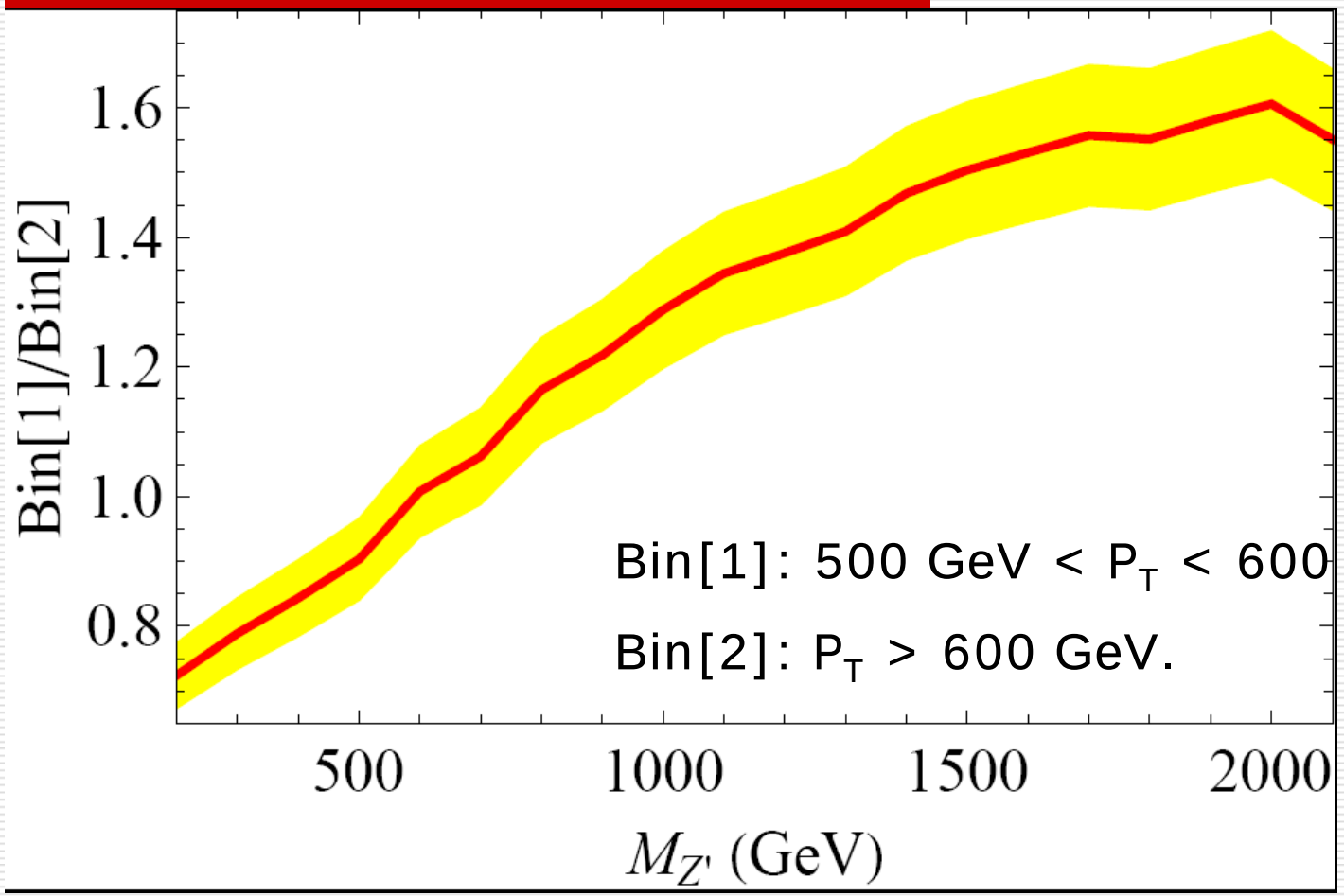
LHC Reach


10^{-38}
10^{-39}
10^{-40}
10^{-41}
10^{-42}
σ_{SI} (cm^2)
0
500
1000
1500
2000
2500
$M_{Z'}$ (GeV)
M_D = 20 GeV
M_D = 5 GeV
M_D = 1 GeV
Z' on shell
Z' off shell

Determine the Mass of Z'



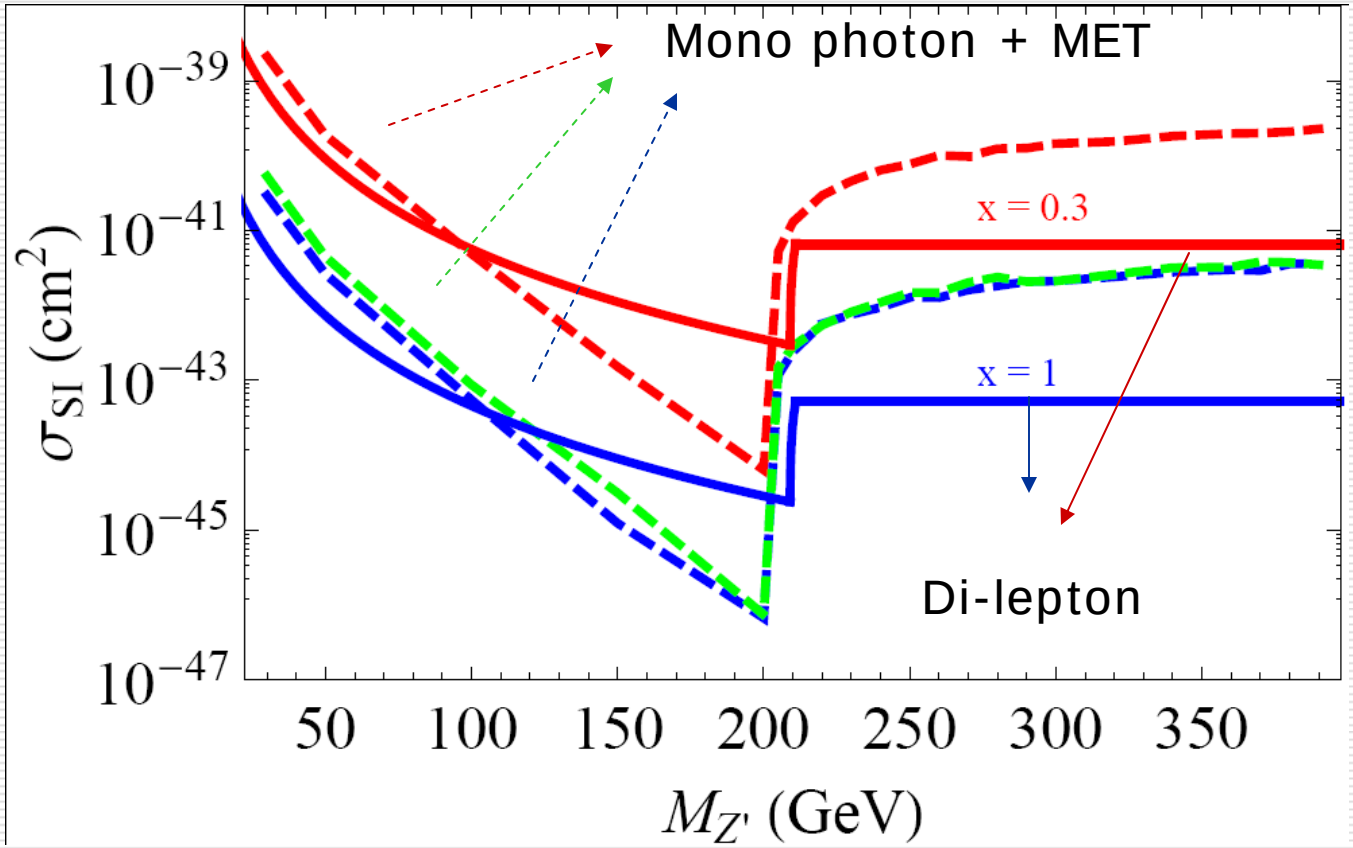
Determine the Mass of Z'



Summary

- Collider constraints are very important in the case of low mass dark matter;
- Tevatron constraints and LHC reach strongly depends on the mass of Z';
- The mass of Z' can be determined from the distribution of jet transverse momentum.

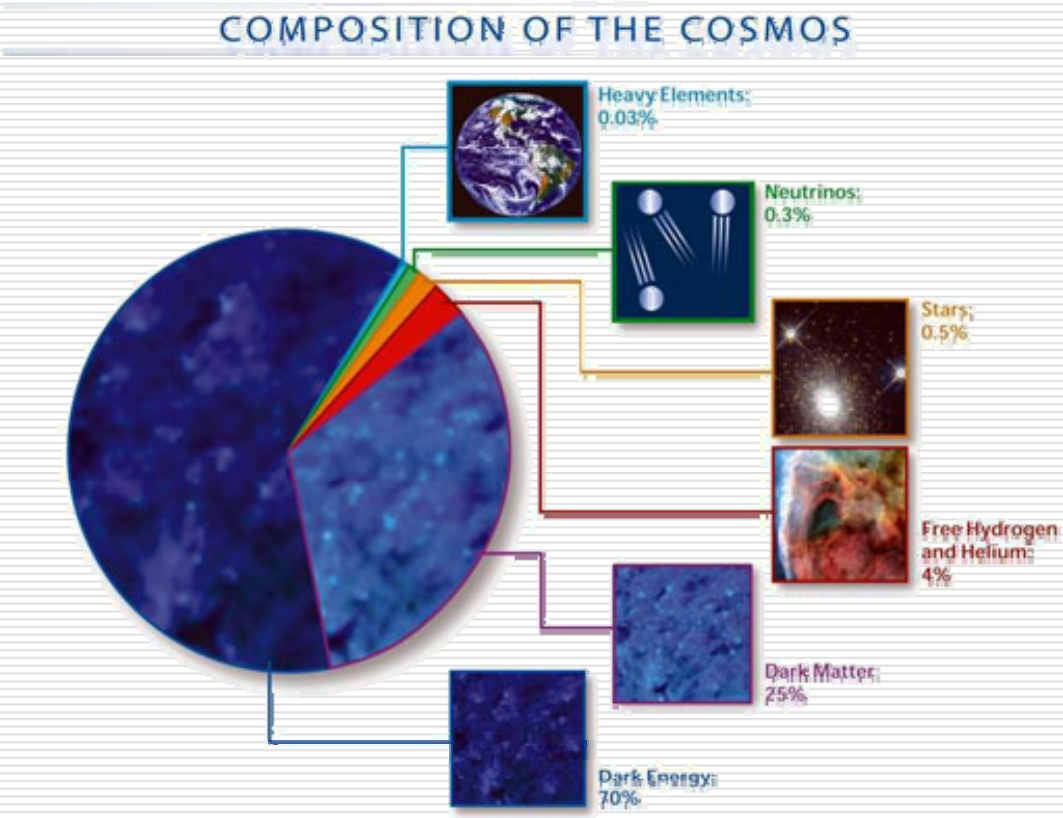
Backup: LEP constraint



B-xL model

$g_{Z'} = g_D$

Overview



- Existence;
- Dark;
- Massive;
- Stable;
- Relic abundance
  ~ 25%;
- Not identified yet.

Tevatron Constraints on Direct Detection Cross section