The constraints on the smallest dark matter halos from the collider and direct dark matter search

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Based on the work with

Paolo Gondolo (Utah) and Junji Hisano (Nagoya)

1205.1914[hep-ph], Phys. Rev. D (2012)

Outline

- Introduction: What is kinetic decoupling?

- Why bother with decoupling: Smallest dark matter halo

Connecting particle physics and cosmology

- Results:

  The upper bound on the smallest dark matter halo

Brief thermal history of Dark Matter (DM)

- In thermal equilibrium.
- Chemical decoupling (Temperature ~ 10 GeV)

DM annihilation rate < expansion rate of the Universe

(DM abundance freezes out)

- Kinetic decoupling (Temperature ~ 10 MeV)

DM scattering rate < expansion rate of the Universe

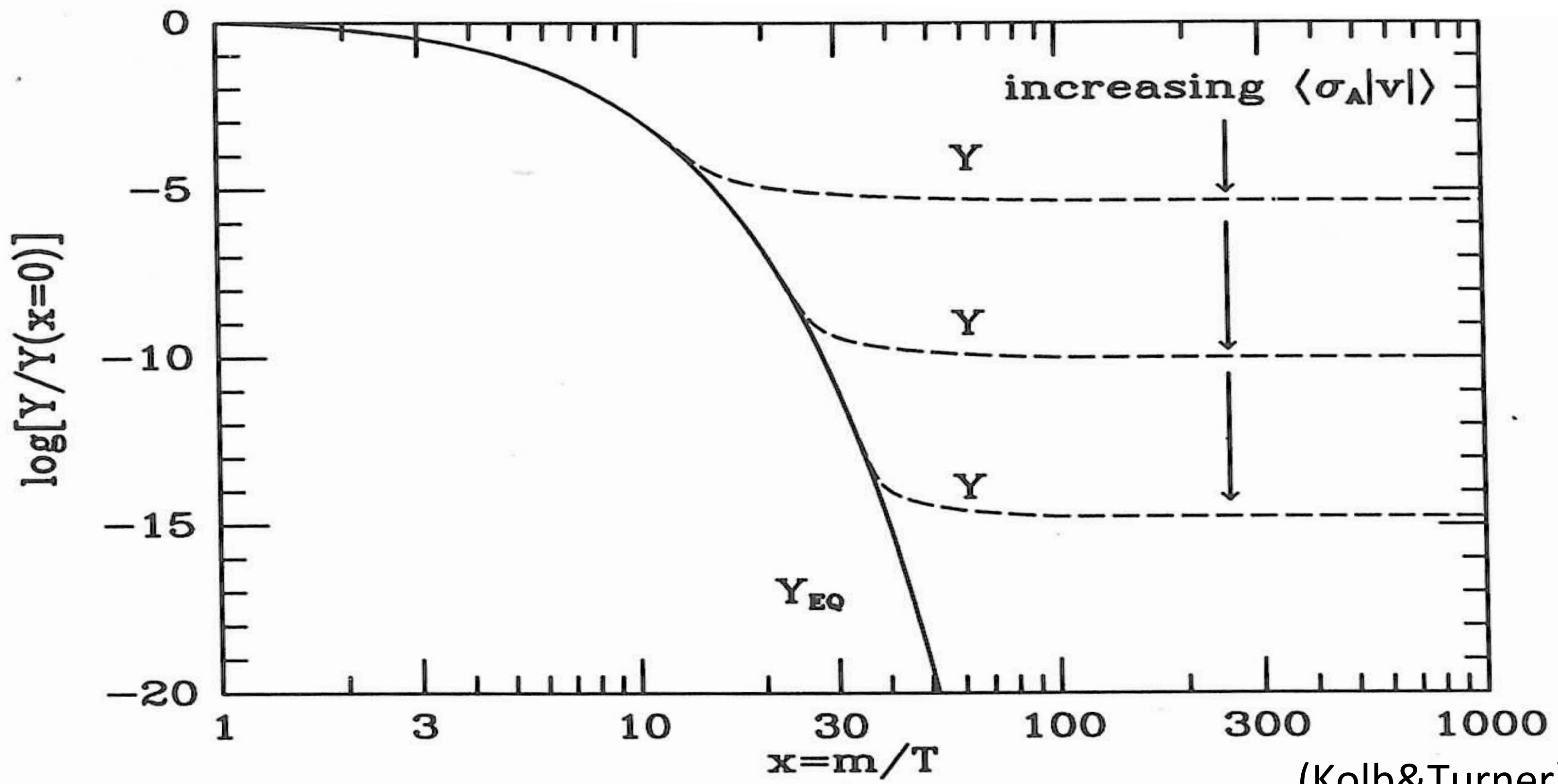
(Structures start forming)

Particle physics and cosmology:

DM abundance, First DM halo

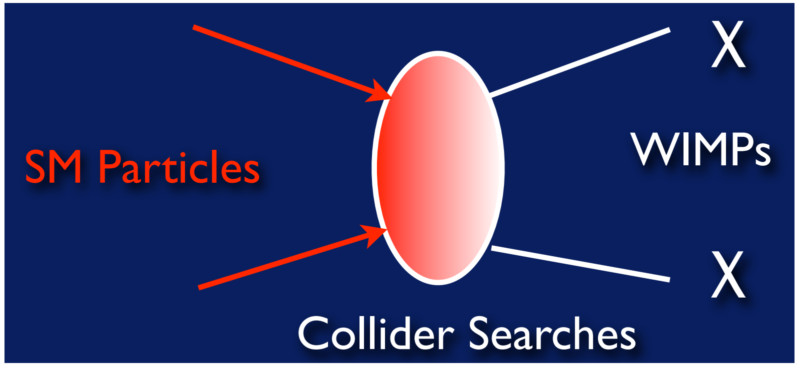
Collider, DM experiments also probe interaction rate between DM and SM

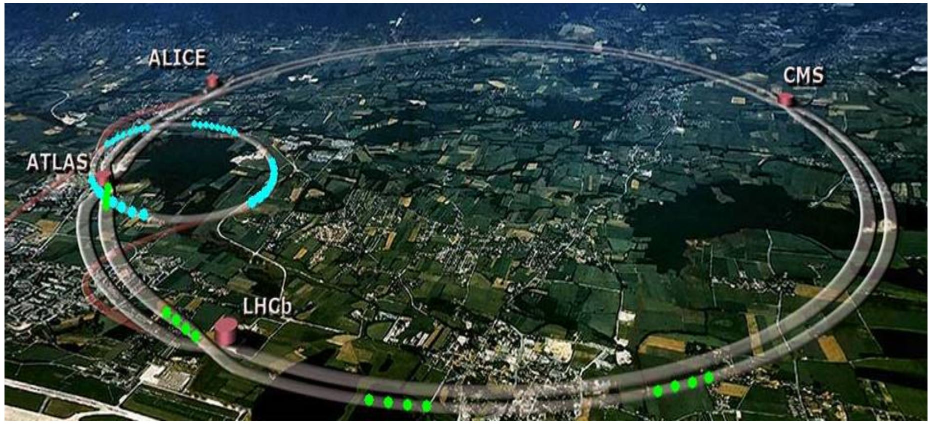
Chemical decoupling and kinetic decoupling

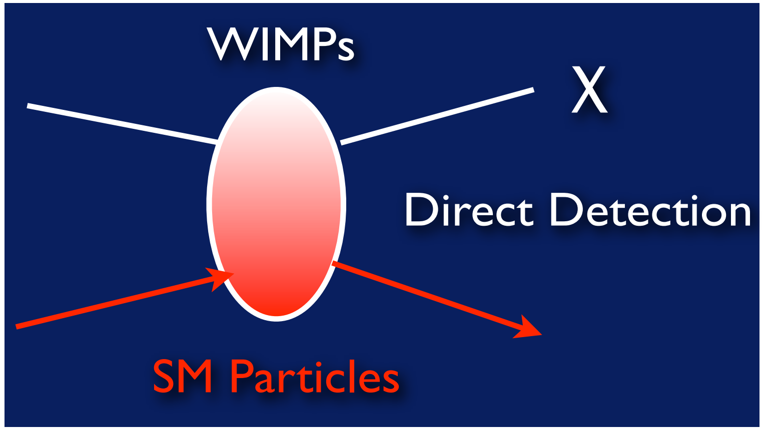


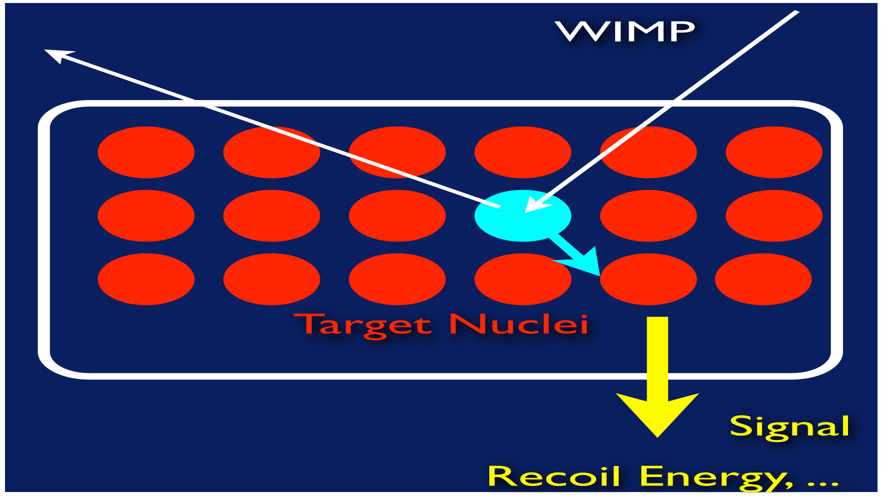
(Kolb&Turner)

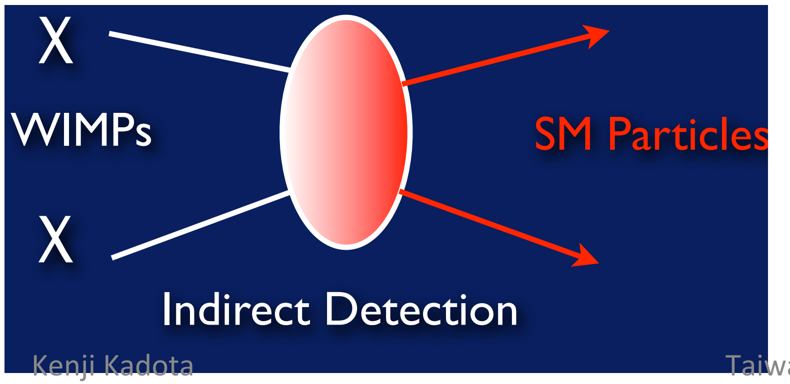
- Chemical decoupling:
  Annihilation < Hubble expansion, T~ $m_\chi/20$
- Kinetic decoupling:
  Elastic scattering < Hubble expansion, T~$m_\chi/2000$

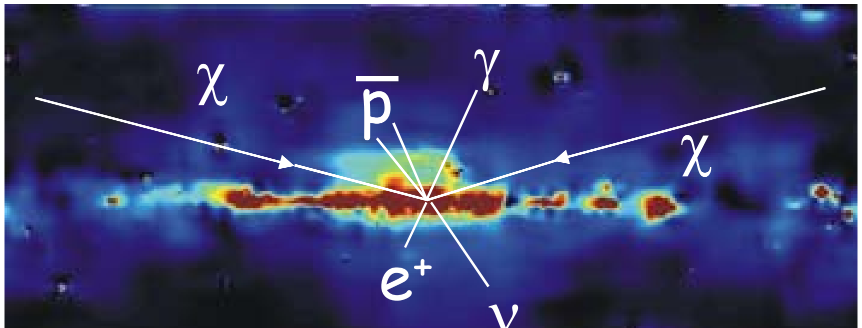




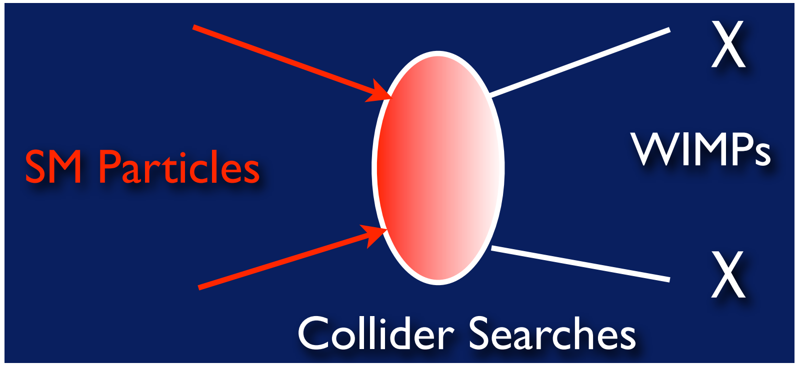


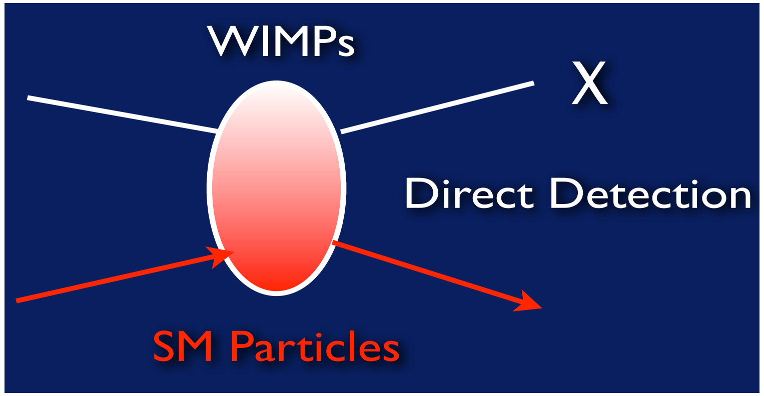




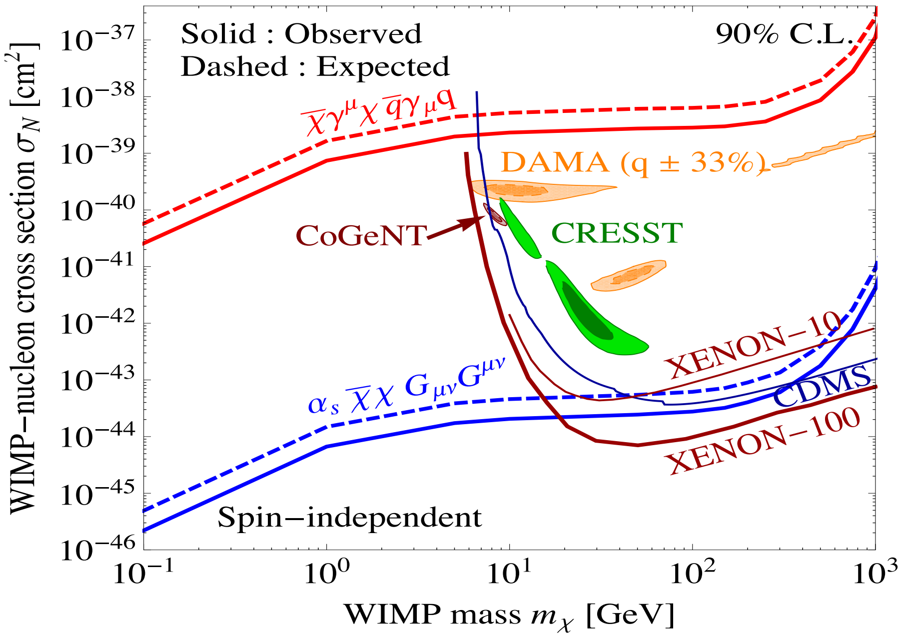


The Milky Way halo in gamma-rays as measured by EGRET (D.Dixon et al, 1997)

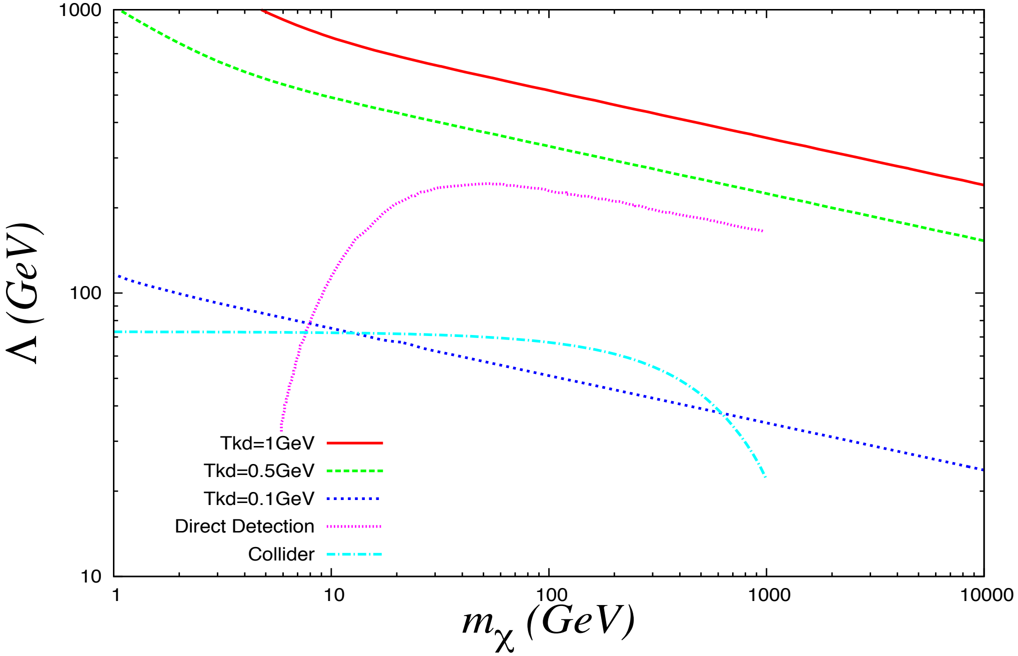




Fox, Harnik, Kopp, Tsai (Phy. Rev. D (2012))



Gondolo, Hisano, KK (Phy. Rev. D (2012))



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Why bother with DM kinetic decoupling?

- Probe on the nature of dark matter (DM) connecting the particle physics and cosmology

An application:

The size of smallest dark matter halo

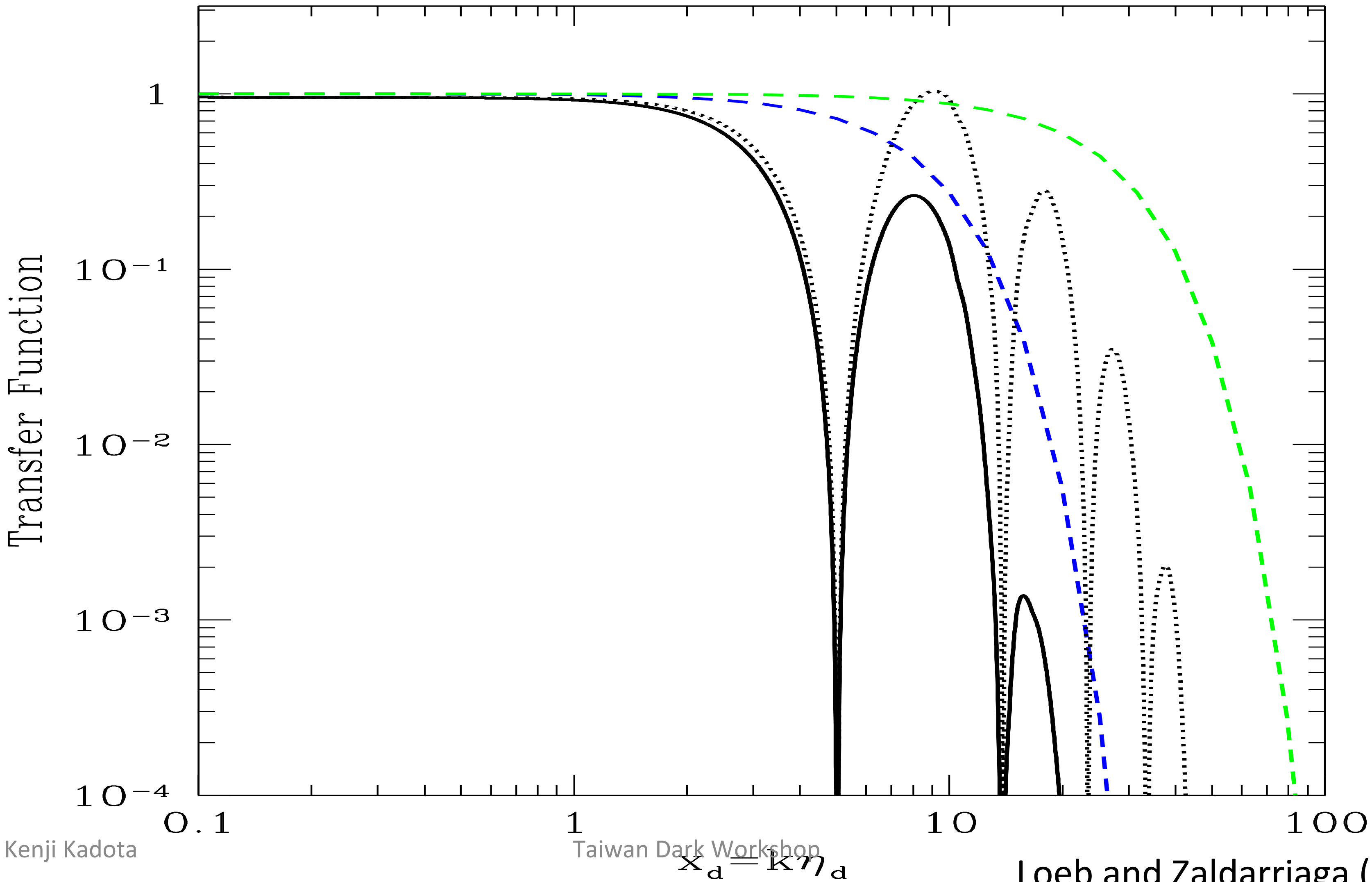
(protohalo or smallest gravitationally bound objects)

- Analogous to:

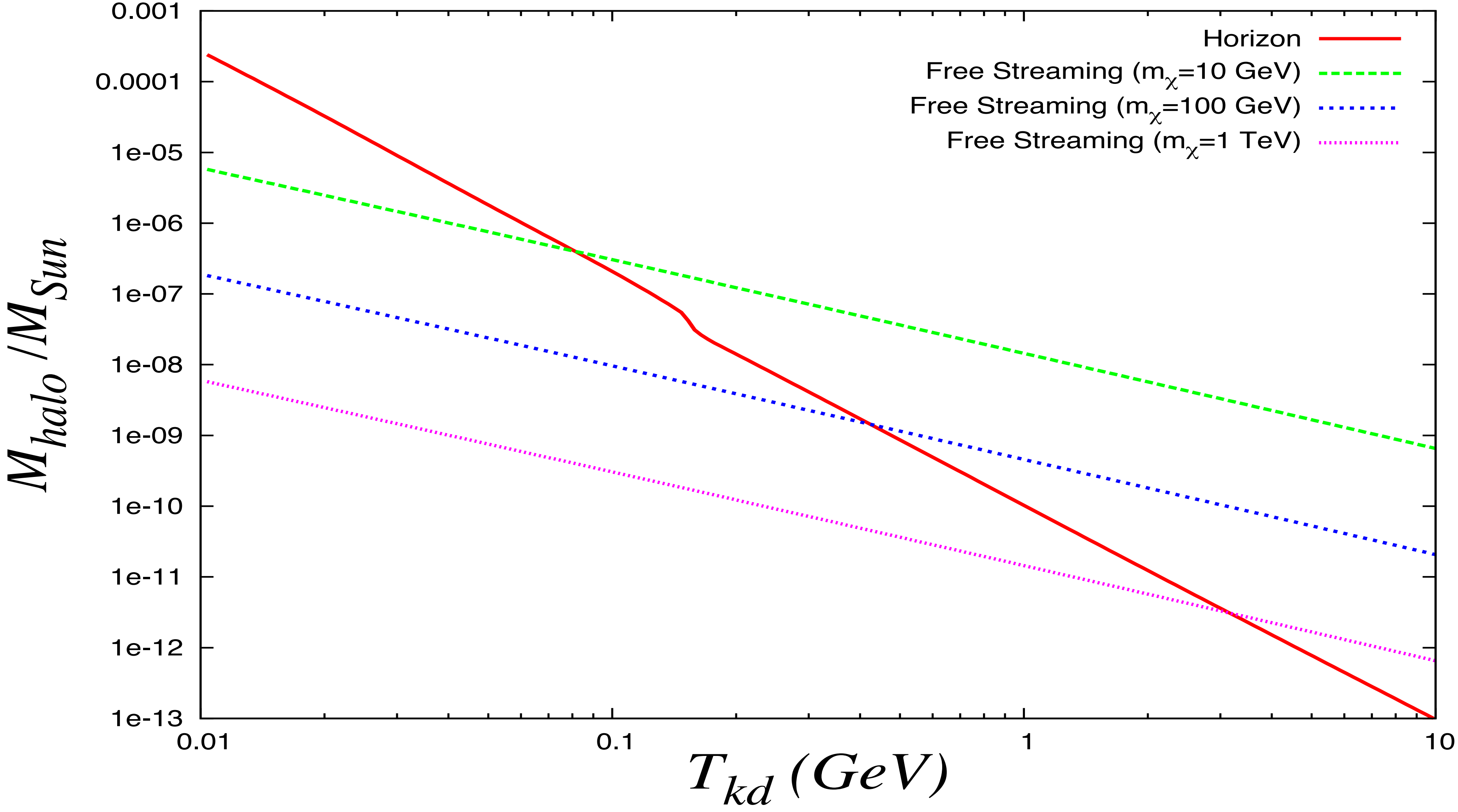
Physics of baryon decoupling

probing the nature of Universe via BAO and CMB

Smallest dark matter halo size:
Max (Free streaming scale, Horizon size)



Loeb and Zaldarriaga (2005)



P. Gondolo, J. Hisano, KK (2012)

$$M_{kd} \sim (\tau_{kd})^3 \sim (T_{kd})^{-3}$$
$$M_{fs} \sim \left(\sqrt{T_{kd}/m_\chi}\,\tau_{kd}\right)^3$$

Comparison with previous works

- DM & lepton-photon fluids

$$T_{kd} : O(10\ \text{MeV} \sim \text{a couple of GeV})$$

Profumo, Sigurdson,Kamionkowski (2006)

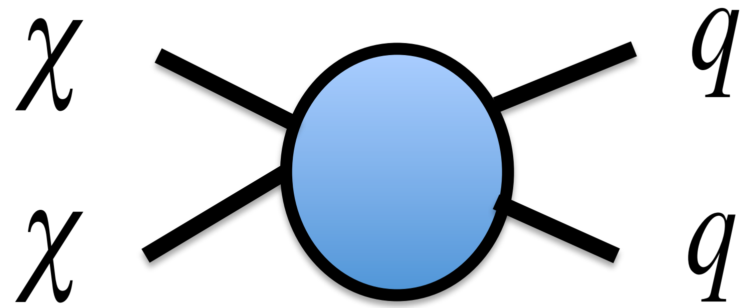
(e.g. Schmid, Shwarz,Widerin,Fayet, Chen,Kamionkowski,

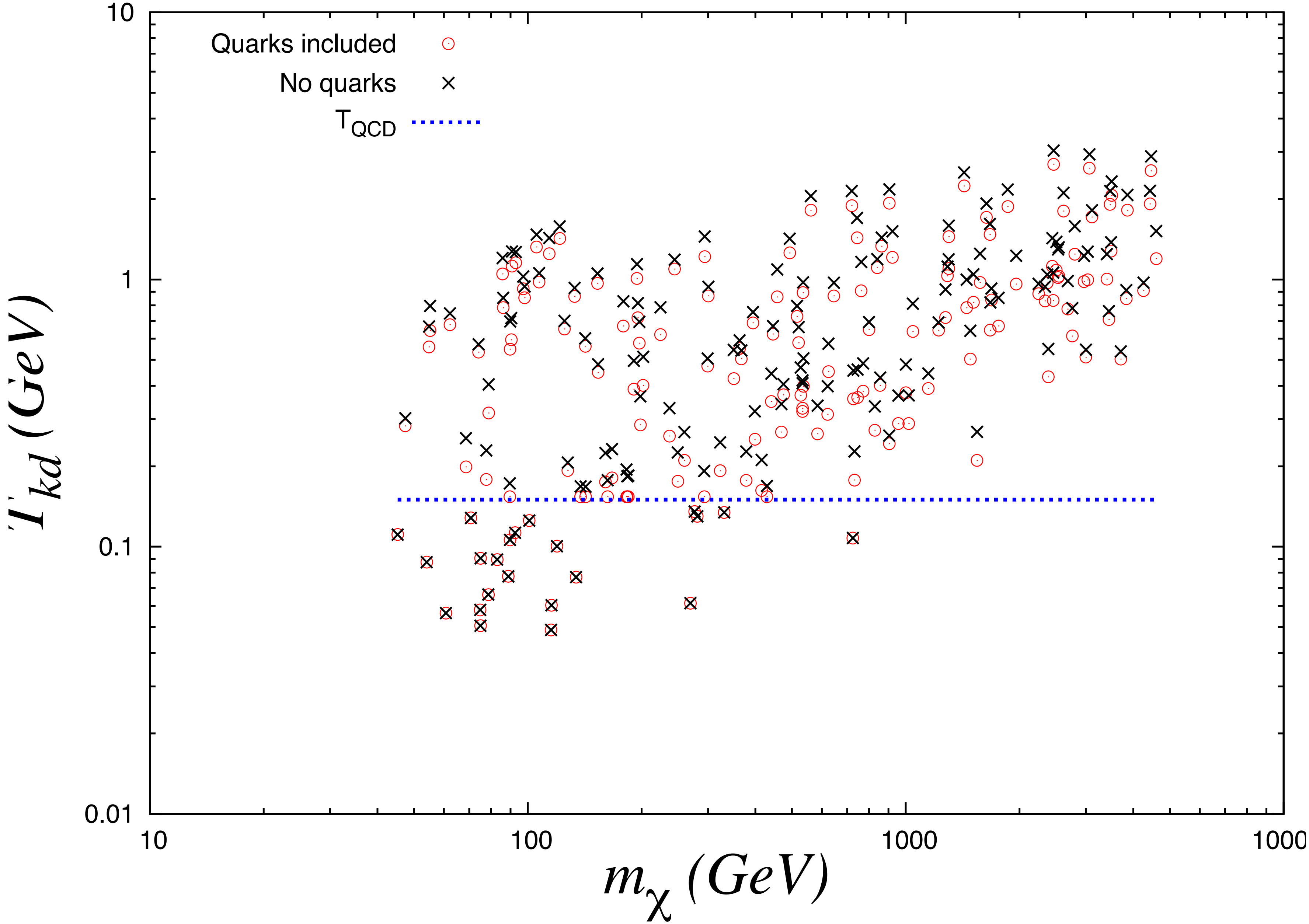
ZhangKasahara,Hoffman,Green, Profumo ,Ullio,,Sigurdson,

Berezinsky,Dokuchaev,Eroshenko, Boehm,
Loeb,Zaldarriaga,Bertchinger,Bringmann, Cornell,…)

- Our work (P. Gondolo, J. Hisano, KK (2012))

Quark-DM interactions
LHC, DM direct detection experiments





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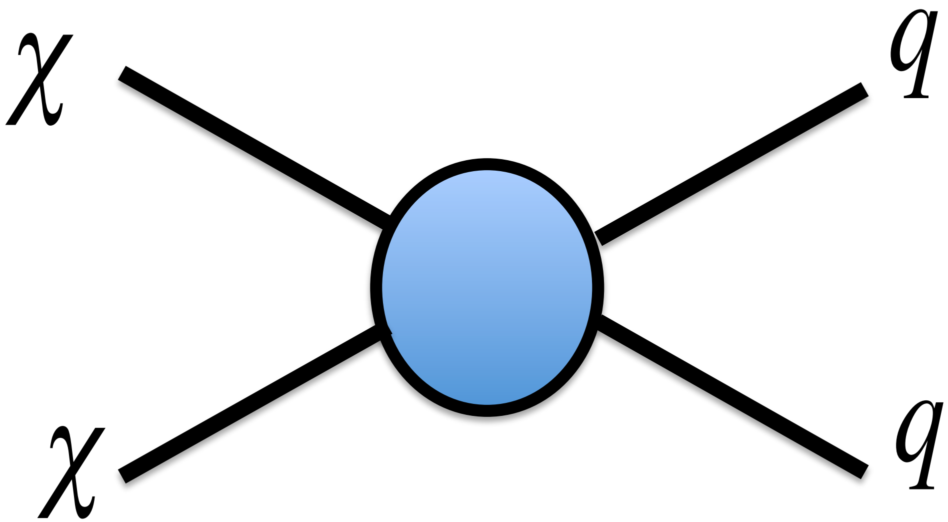
DM-quark interactions: Effective operators

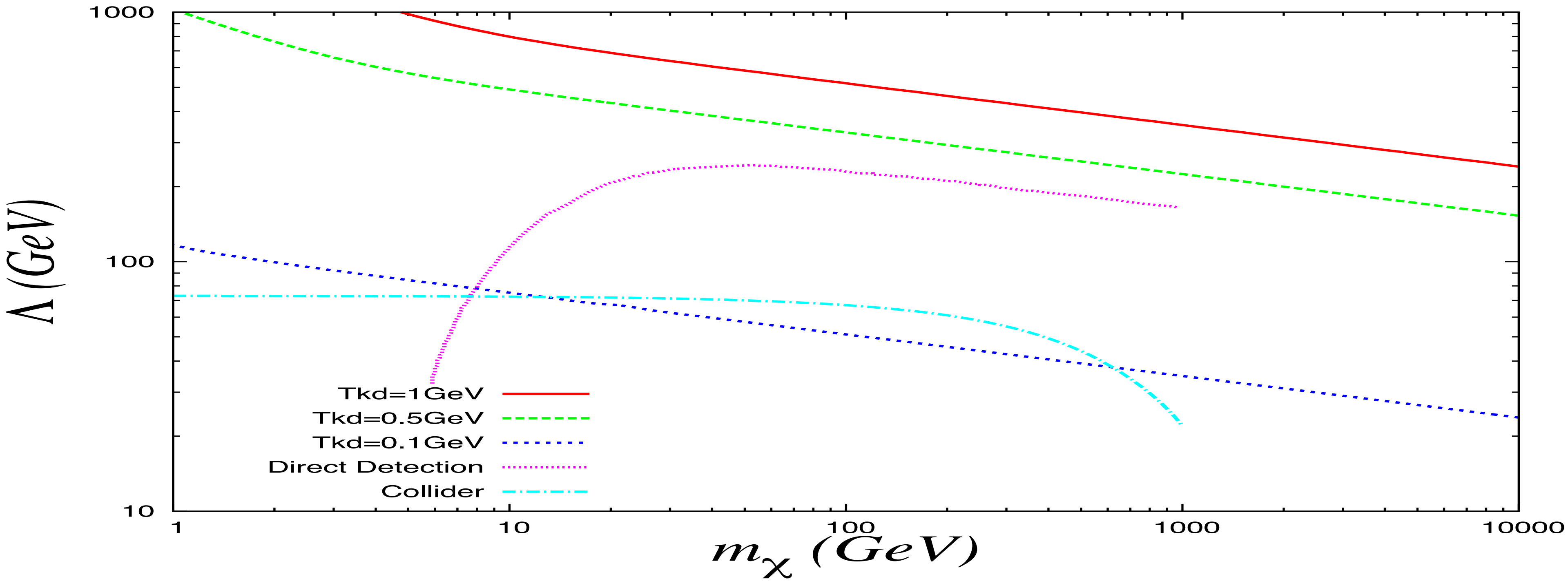


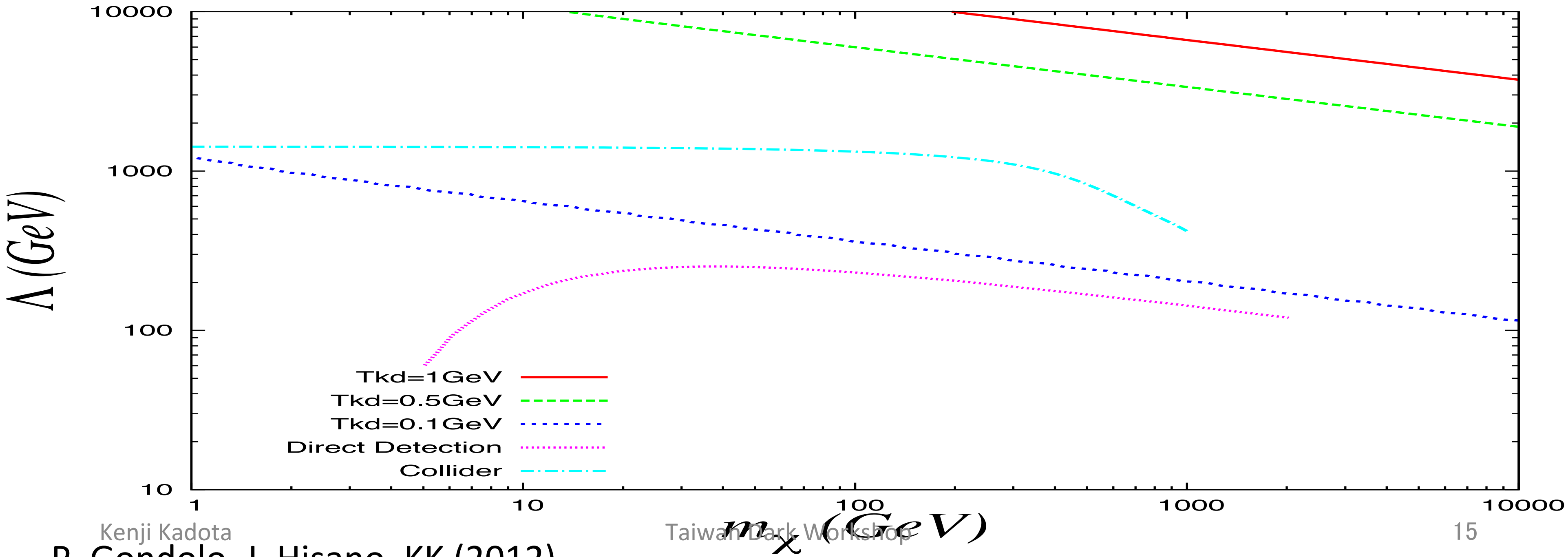
$$O_s = \sum_q \frac{m_q}{\Lambda^3} \bar{\chi}\chi\bar{q}q, \; O_A = \sum_q \frac{1}{\Lambda^2} (\bar{\chi}\gamma^\mu\gamma^5\chi)(\bar{q}\gamma_\mu\gamma^5 q)$$

Mono-jet events by the CMS 4.7/fb @7TeV

Pt>110GeV, |η|<2.4

Missing transverse energy >350GeV





P. Gondolo, J. Hisano, KK (2012)

Conclusion

- Bottom-up effective operator approach: Kinetic decoupling temp > 100 MeV

Smallest dark matter halo: The earth mass

(regardless of the spin and mass of the dark matter)

- Quark interactions important for DM kinetic decoupling