Detecting *Boosted* Dark Matter with Neutrino Experiments

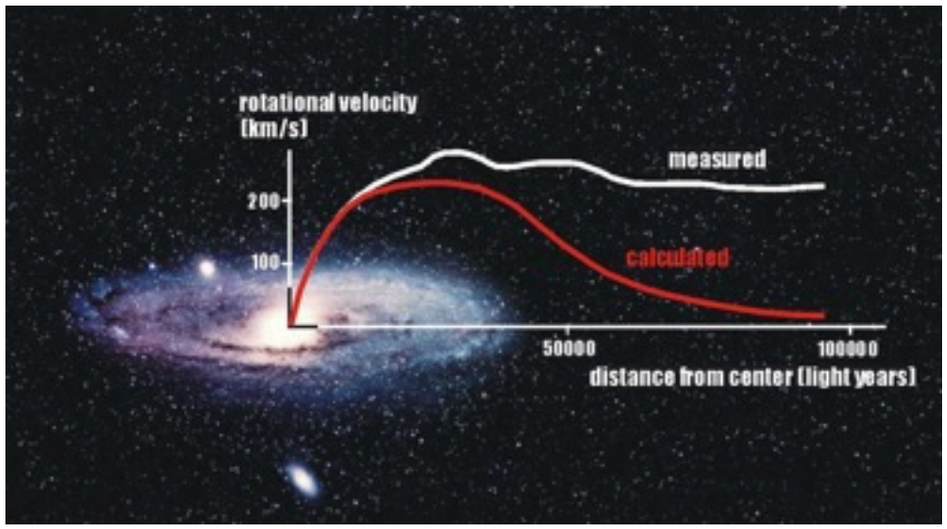
Yanou Cui

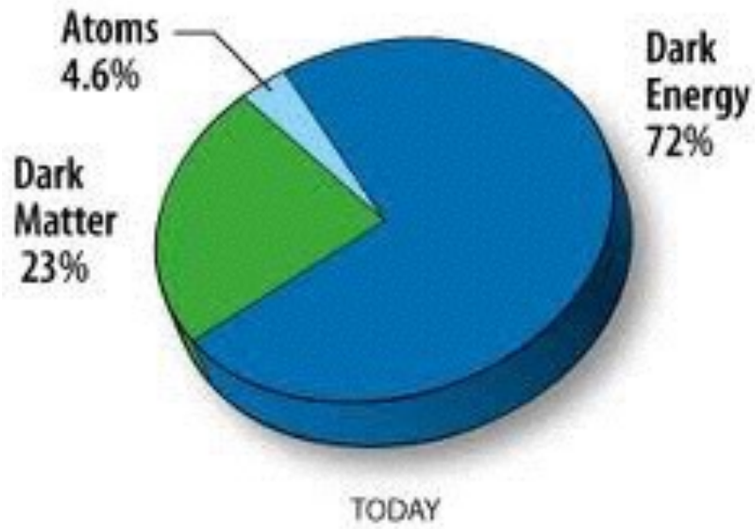
Perimeter Institute for Theoretical Physics

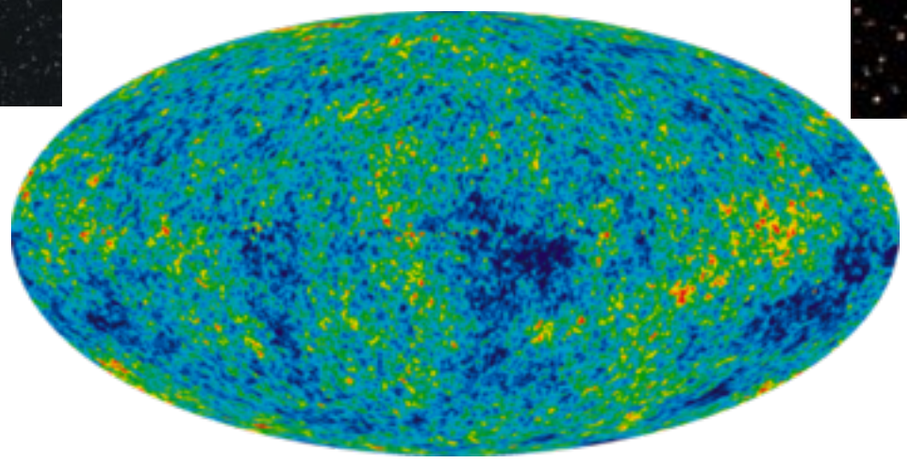
What is Dark Matter ?

- **Dark Matter: 85%** of cosmic matter abundance!

  Cold, non-relativistic



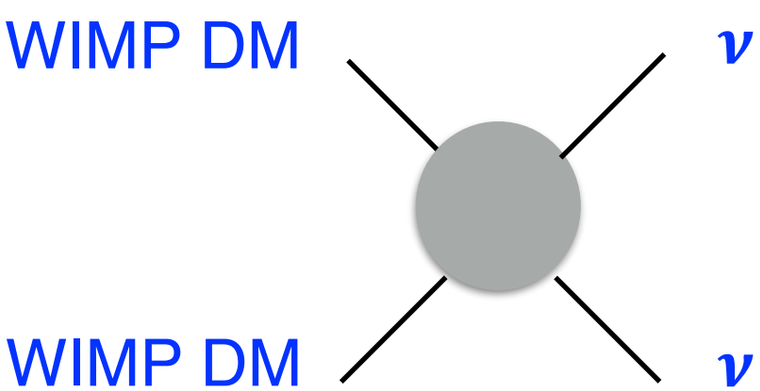




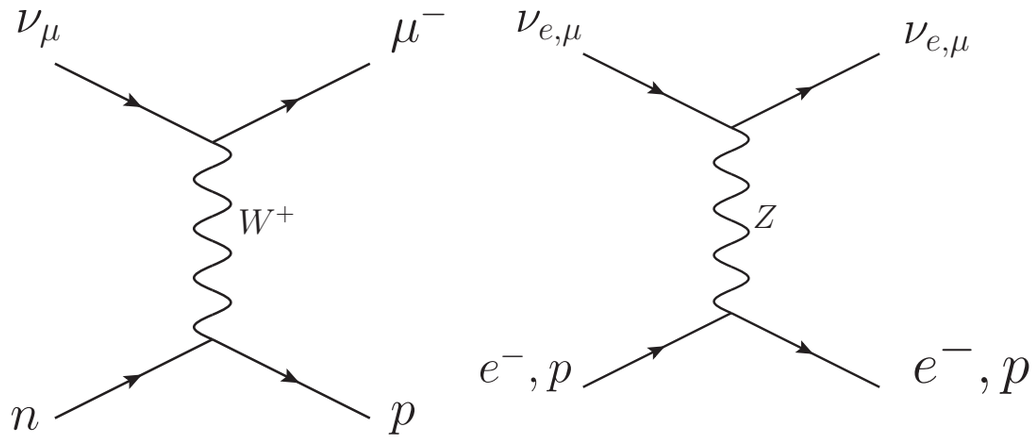
Big mystery! Demand new particle physics beyond the Standard Model !

A New Opportunity of Probing Dark Matter with Neutrino Experiments

- It ***is NOT*** the familiar ***indirect*** detection



ν ----------->



Galactic center, Sun

Neutrino detector on earth

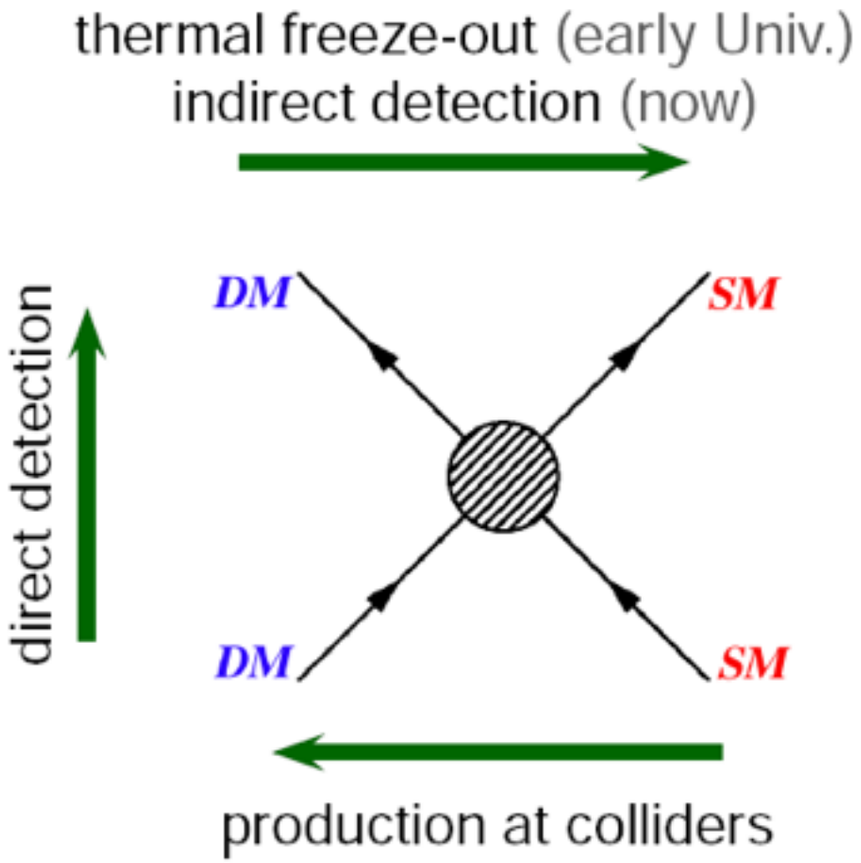
- It **IS**: **direct** detection of a (small) **relativistic** component of dark matter
  — **Boosted Dark Matter!** (NEW)

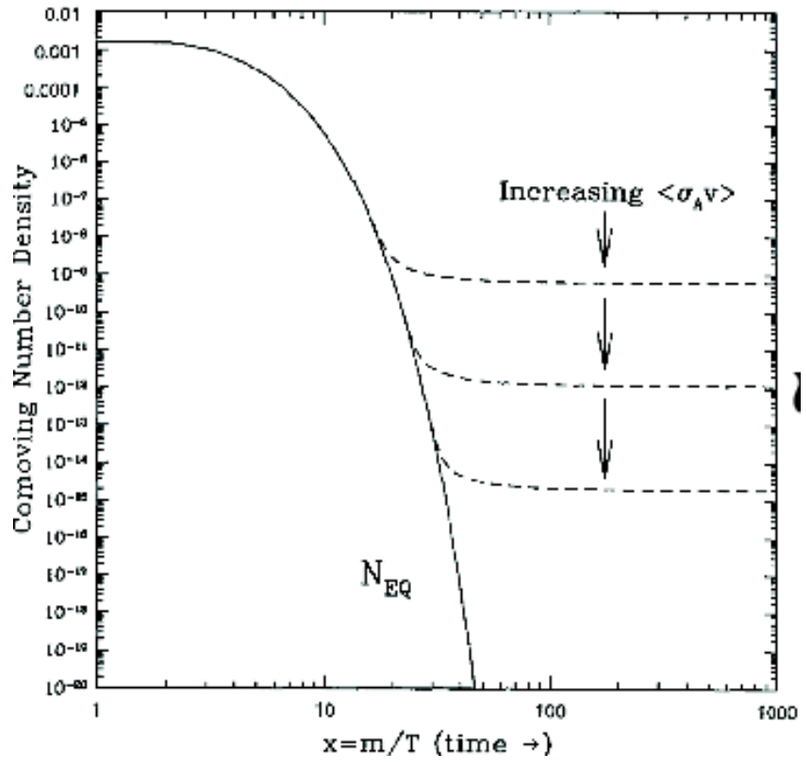
May be the smoking gun signal for DM!

Motivations of Boosted Dark Matter:

e.g. Hidden dark matter sector with multiple components

WIMP DM miracle: merits and challenges





$$\Omega_\chi \propto \langle \sigma_{\rm ann} v \rangle^{-1} \sim 0.1 \left(\frac{G_{\rm Fermi}}{G_\chi} \right)^2 \left(\frac{M_{\rm weak}}{m_\chi} \right)^2$$

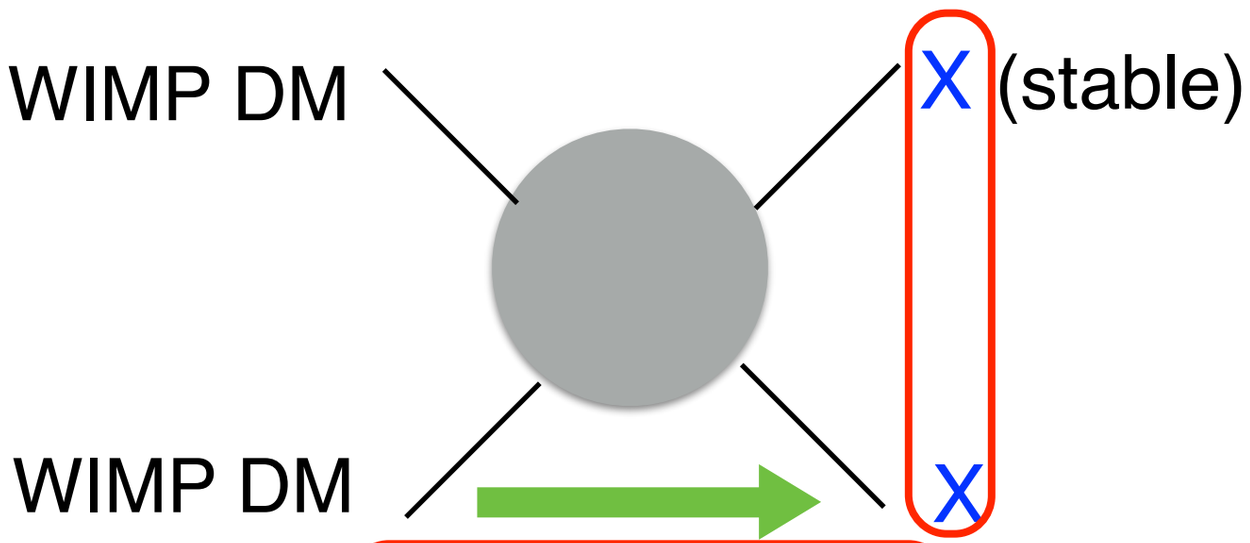
- But no convincing signal yet: many years, many experiments…

Not looking at the right signal channel(s)?

Motivations of Boosted Dark Matter:

e.g. Extended dark matter sector with multiple components

A New Realization of WIMP Miracle

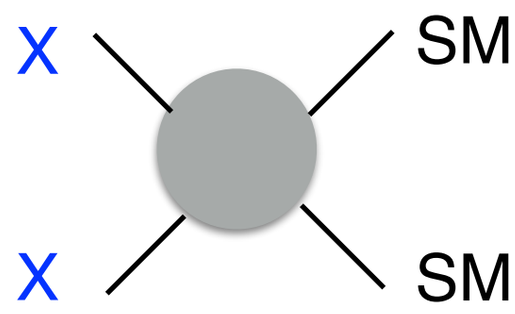


- **Determines Ω_{DM}!**
- Conventional signals absent/suppressed

Boosted X: $\gamma_X = m_{\rm WIMP}/m_X$

- Massive X ($m_X \gtrsim$eV): $\Omega_X > 1$

☞ deplete X via annihilation→SM



- **Novel signal: Boosted DM (X)** (Vs. "slow" DM) !

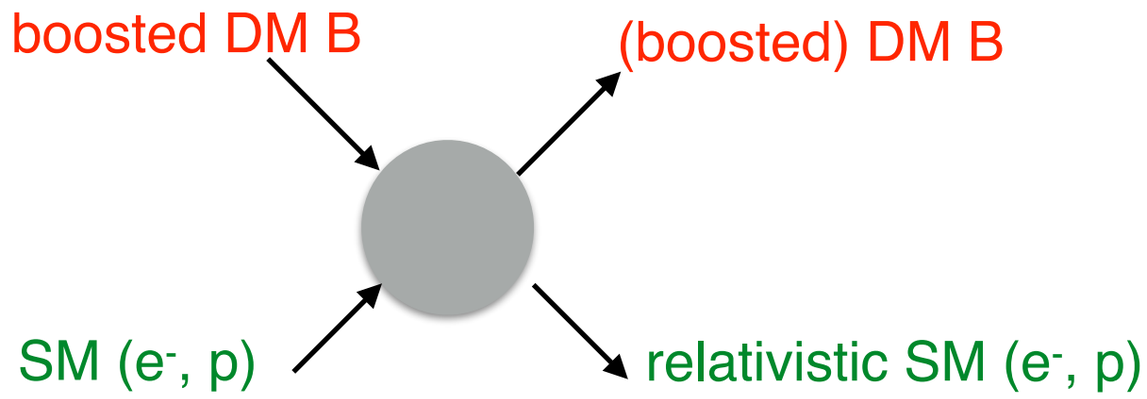
  JCAP 1410 (2014) 062, **YC** w/Agashe, Necib, Thaler;
  JCAP 1502 (2015) , **YC** w/Berger, Zhao

- **Dark matter lives in a hidden sector!** (DM (A), X (B), +…)

How to Search for Boosted DM?

- Small flux $\propto n^2_{\mathrm{DM-A}}$
- Boosted incoming B

  $\Rightarrow$ Relativistic outgoing e^-, p



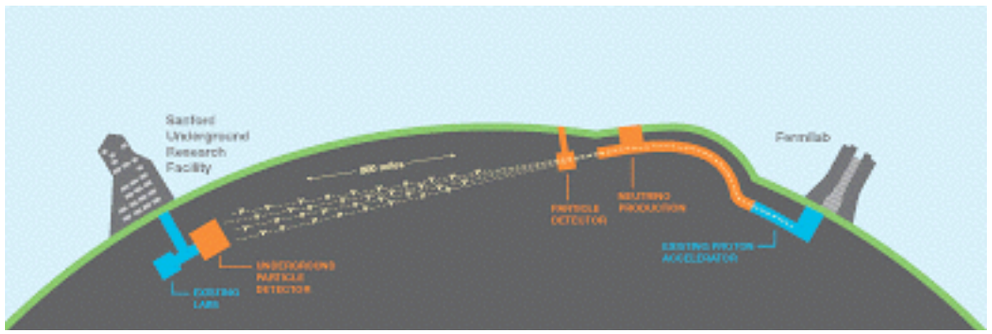
What experiments?

☞ Large volume detector + sensitive to energetic e^-, p

(Conventional DM direct detection ☹)

Experiments for neutrinos or proton decay!

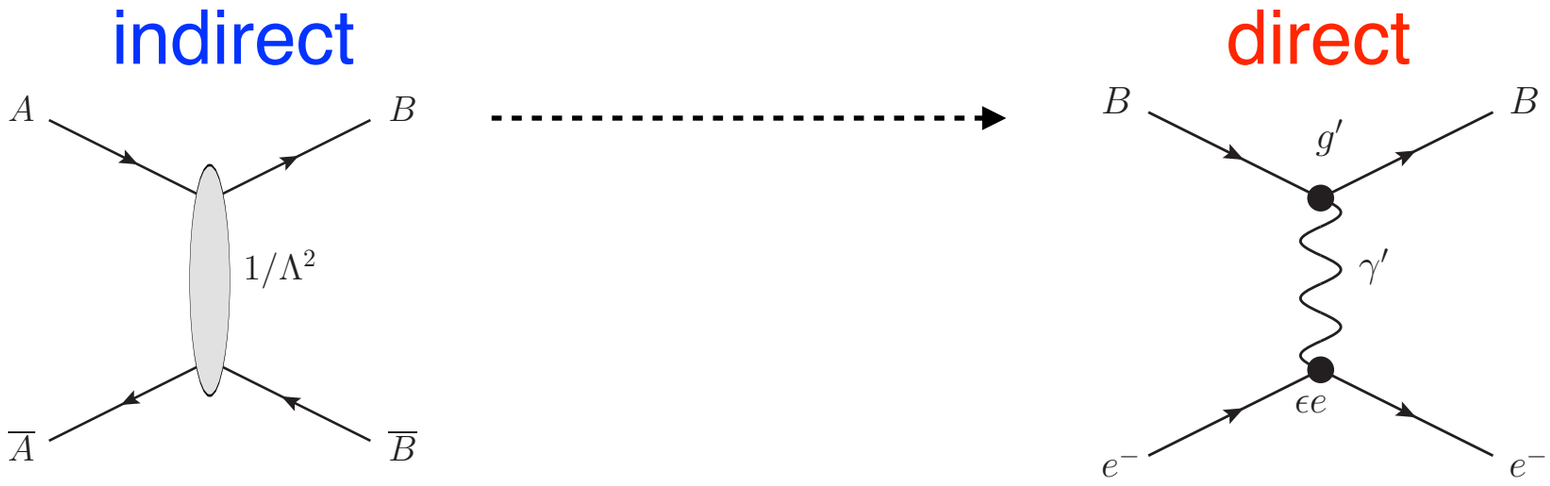
- Cherenkov-radiation: *SuperK/HyperK, IceCube/PINGU…*
- Liquid scintillator: *Borexino, JUNO…*
- Liquid Argon: *DUNE/LBNF!*



Search Strategies for Boosted DM

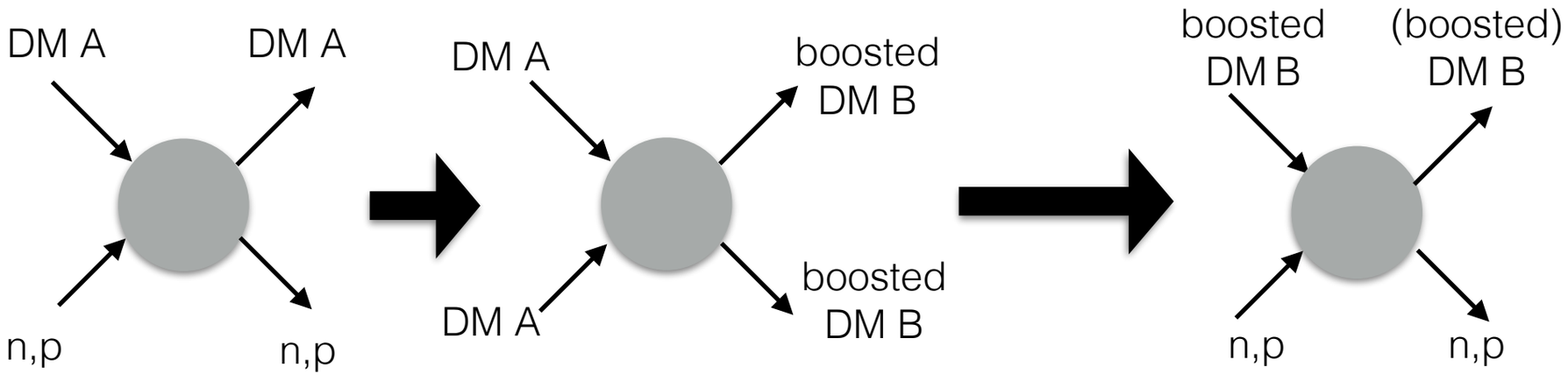
-A <u>combination</u> of conventional DM indirect & direct detections

- **Signals from the galactic center:**



With neutrino detectors!

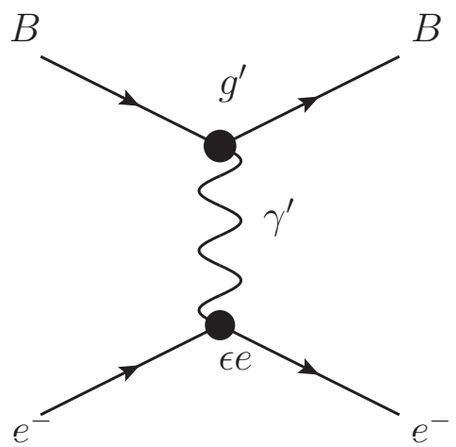
- **Signals from the Sun:**

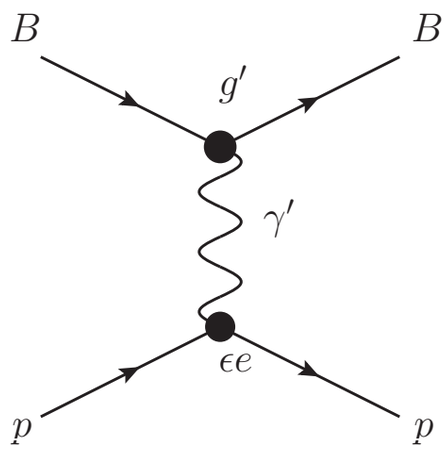


Capture in the sun **Annihilation in the sun**

Signals for Boosted DM

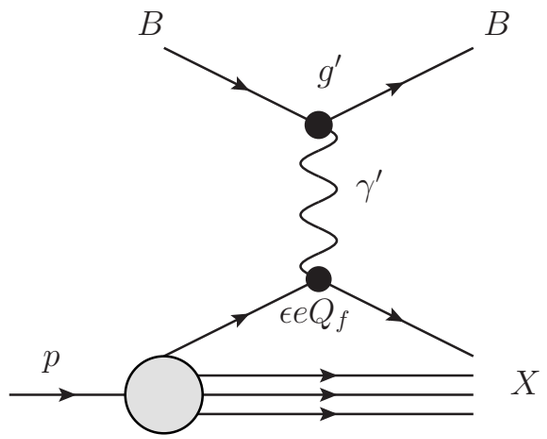
- Single e^- and/or single proton track (model dependence)





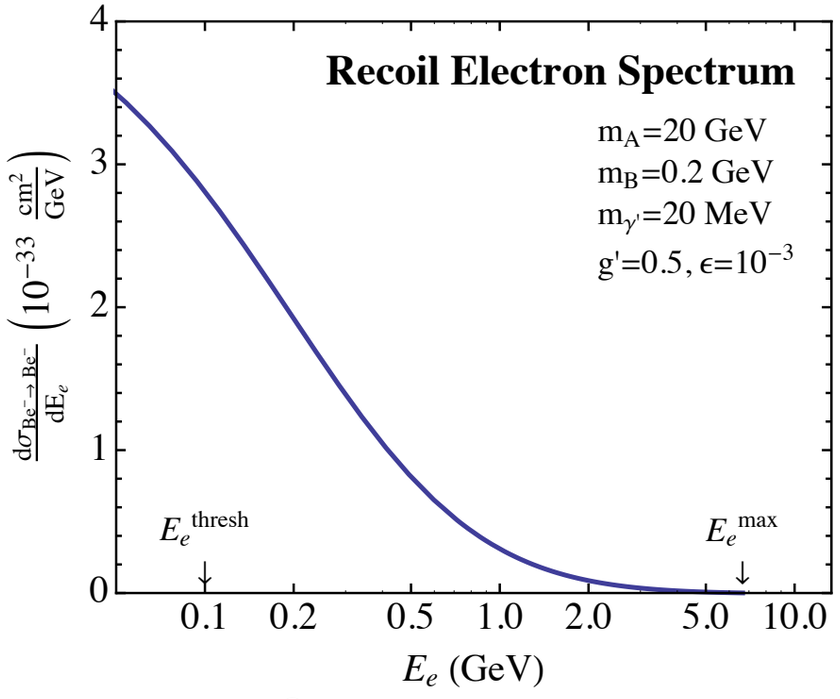
May only interact w/baryons!

Motivated, studied!



inelastic channel:
lack directionality…

- Signal spectrum may peak at low E ($m_{\gamma'} \ll E_B$)



low E threshold desirable (both e^- and p)!

How to Distinguish Boosted DM from Neutrinos?

- **Directionality:**

  Boosted DM: from DM concentrated region,

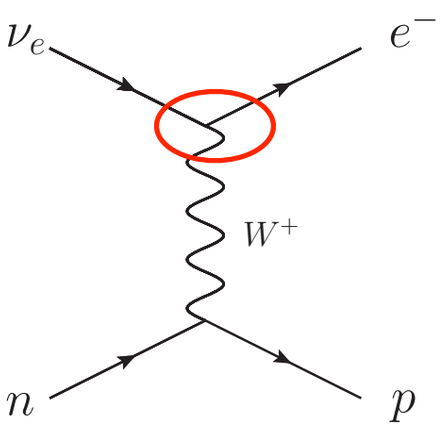
  e.g. GC, Sun…

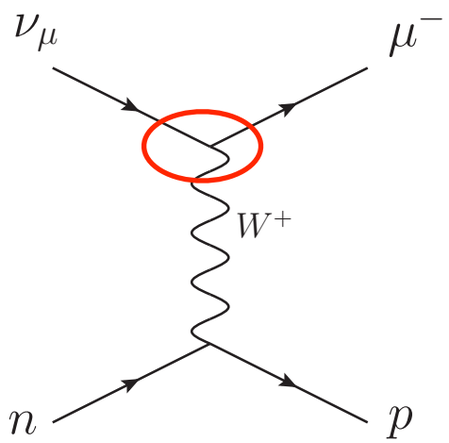
  Vs. (atmospheric) neutrino: isotropic

- **Interaction:**

  Boosted DM interaction: neutral current-like only,

  Vs. Neutrino: neutral current + charged current





No correlated muon, muon veto

Outlook
- Great Opportunity at DUNE

Desirable Factors

- **Large volume detector**
- **Good angular resolution** *(directionality)*
- **Low energy threshold:** $E_k \sim O(MeV)$ for both e^- and p ?
  - Spectrum peaks at low E: light γ'
  - Low mass dark matter (sub-GeV)

    (work in progress: YC w/Pappadopulo, Ruderman, YC w/Pospelov, Pradler)
  - Benefit Supernova-, solar- neutrino studies as well!

    (Super-K, IceCube: limited by Cherenkov threshold;
    Borexino, JUNO: sensitive to *E~MeV; DUNE?)*

We look forward to interactions with neutrino physicists at DUNE!

(Already substantial interests from experimentalists at Super-K, Microboone)

Thank you!

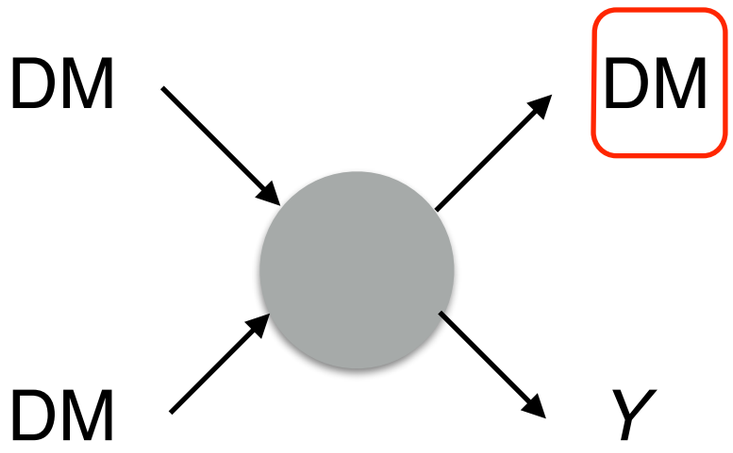
My email: ycui@perimeterinstitute.ca

Backup slides

Motivation of Boosted Dark Matter

2. Other motivations

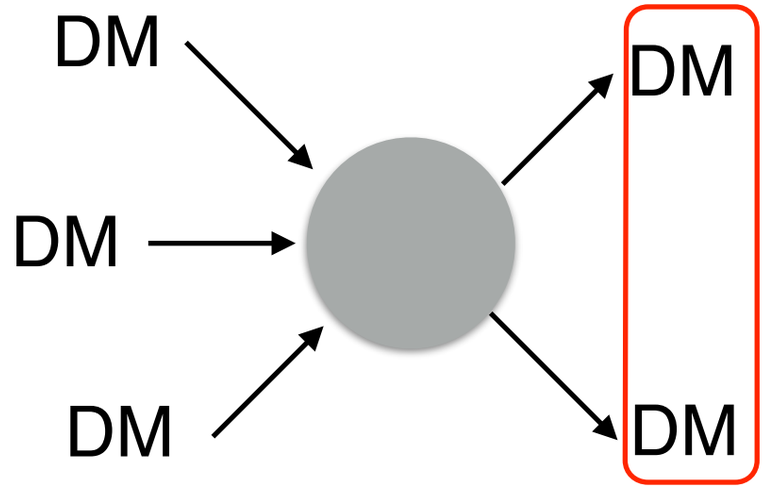
- Z_3 semi-annihilating dark matter:



$m_Y < m_{\rm DM}$

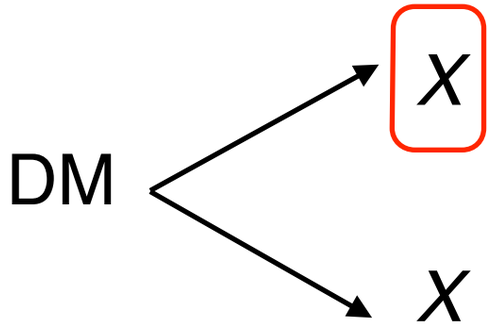
$\gamma_{\rm DM} \approx 1.25$

- Self-annihilating dark matter:



$\gamma_{\rm DM} = 1.5$

- Decaying dark matter:



$\gamma_X = m_{\rm DM}/2m_X$