Neutrino Signals from Unstable Dark Matter

Ongoing Project in Collaboration with Laura Covi, Alejandro Ibarra and David Tran

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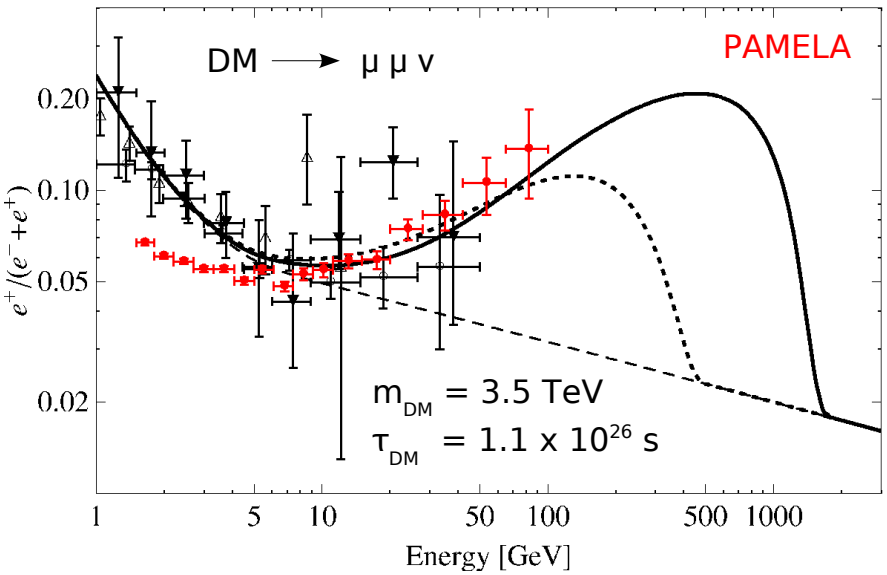
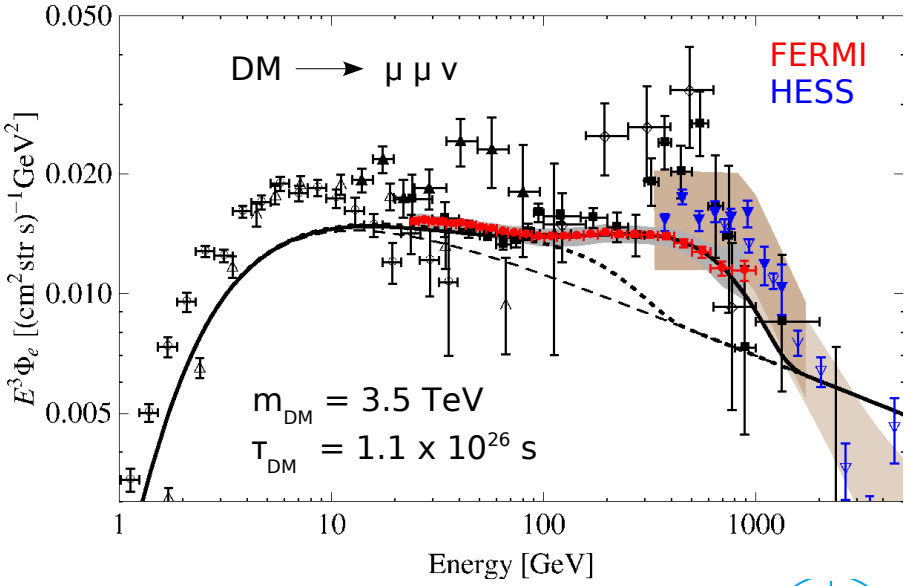
HELMHOLTZ ASSOCIATION

DESY

Motivation

- Recent cosmic ray experiments show anomalies in the 10 GeV up to TeV range (PAMELA, FERMI, HESS, ...)
- Can be explained by astrophysical sources: pulsars
- But: could also be a signal of dark matter annihilation or decay!
- Need further observations to discriminate between scenarios





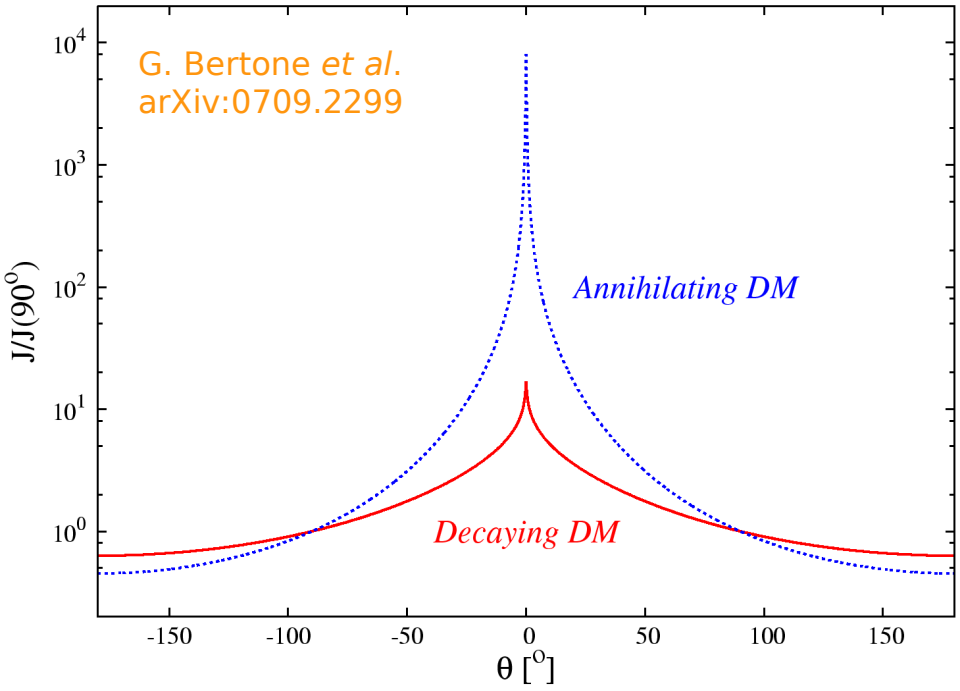
A. Ibarra, D. Tran and C. Weniger, arXiv:0906.1571

Annihilating vs Decaying Dark Matter

- Flux from galactic halo:

$$\frac{dJ}{dE} = \frac{1}{4\pi} \underbrace{\frac{\langle \sigma v \rangle}{2 m_{DM}^2} \frac{dN}{dE}}_{\text{particle physics}} \underbrace{\int \varrho_{halo}^2(\vec{x})\, ds}_{\text{astrophysics}}$$

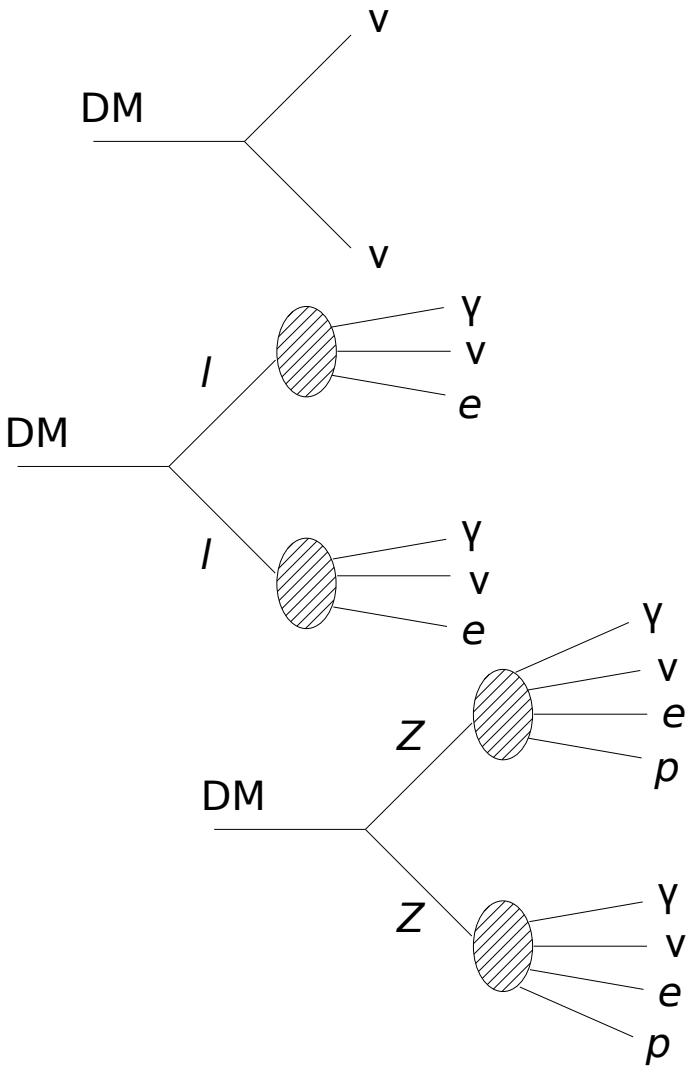
- Annihilation
  - $\propto \frac{\langle \sigma v \rangle}{2 m_{DM}^2} \varrho^2$
  - Look towards galactic center, halo substructures or DM accumulation
- Decay
  - $\propto \frac{1}{m_{DM} \tau_{DM}} \varrho$
  - Look for diffuse signal

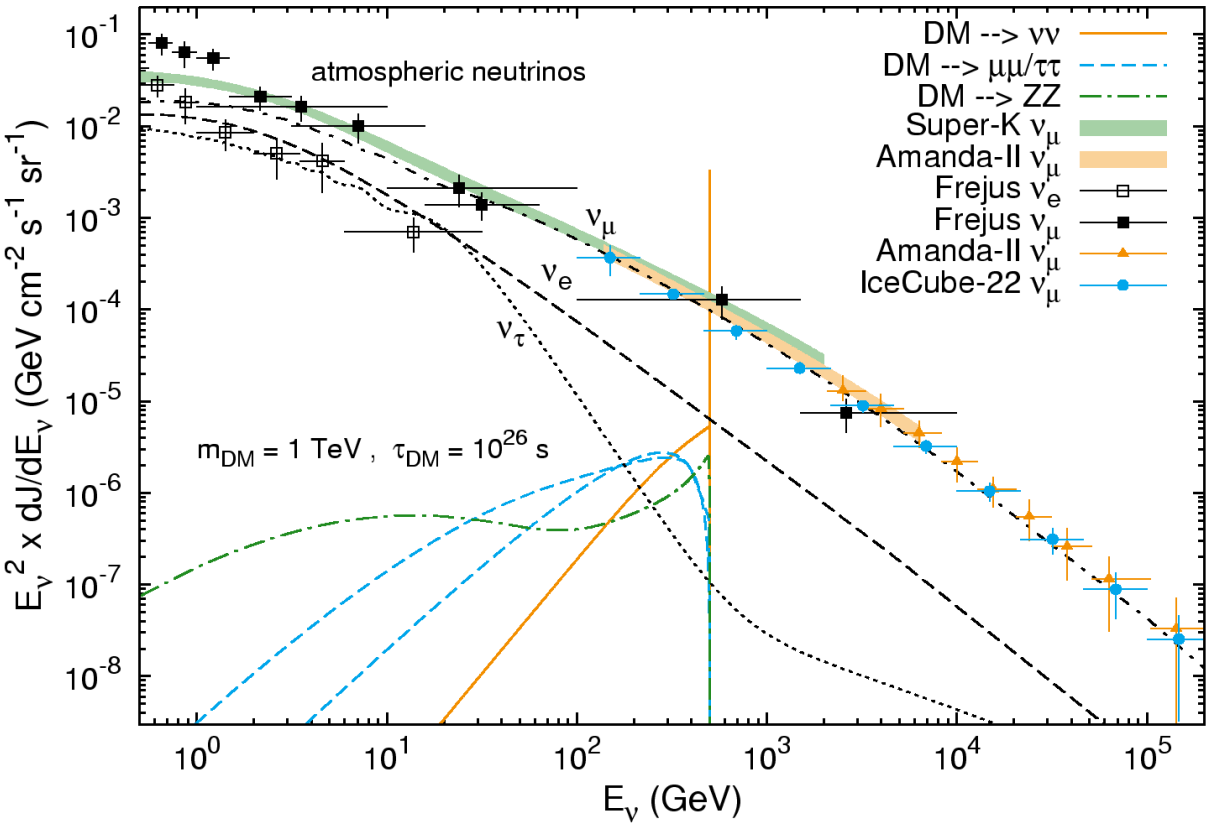


- Directionality can discriminate annihilation and decay
- Gamma-rays and neutrinos are messengers that provide directional observations
- In addition to halo flux isotropic (but subdominant) flux from cosmological dark matter density

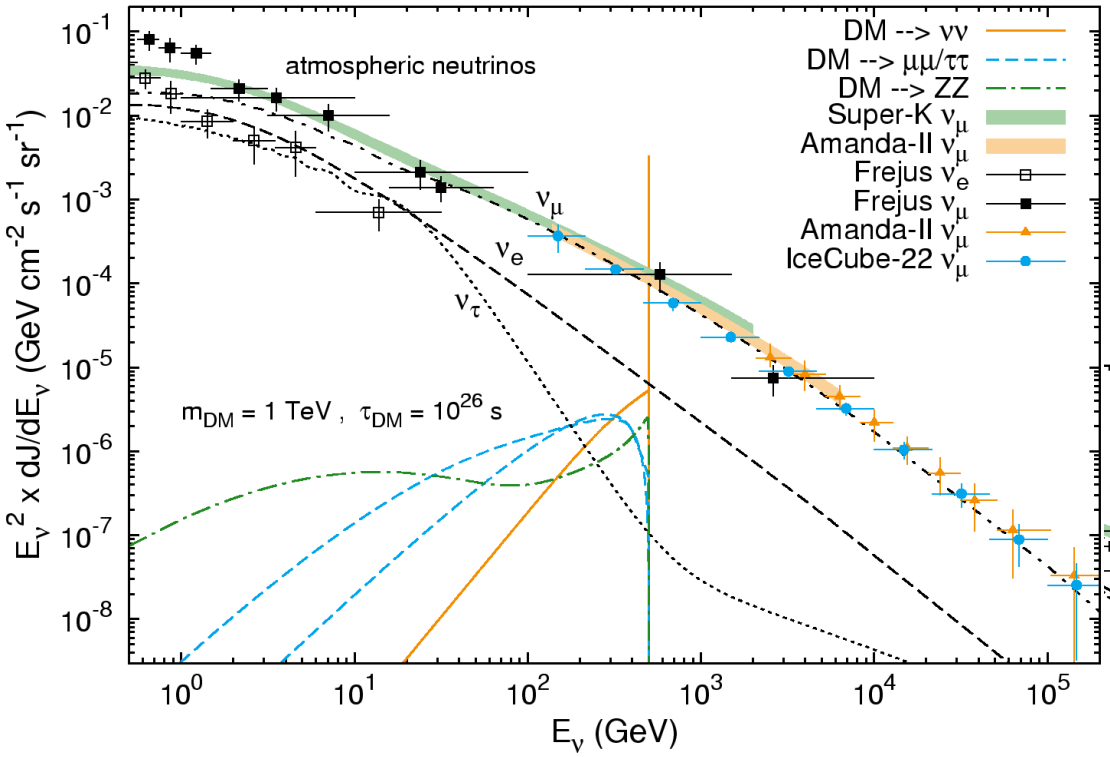
Scalar DM Decay Channels and Neutrino Flux

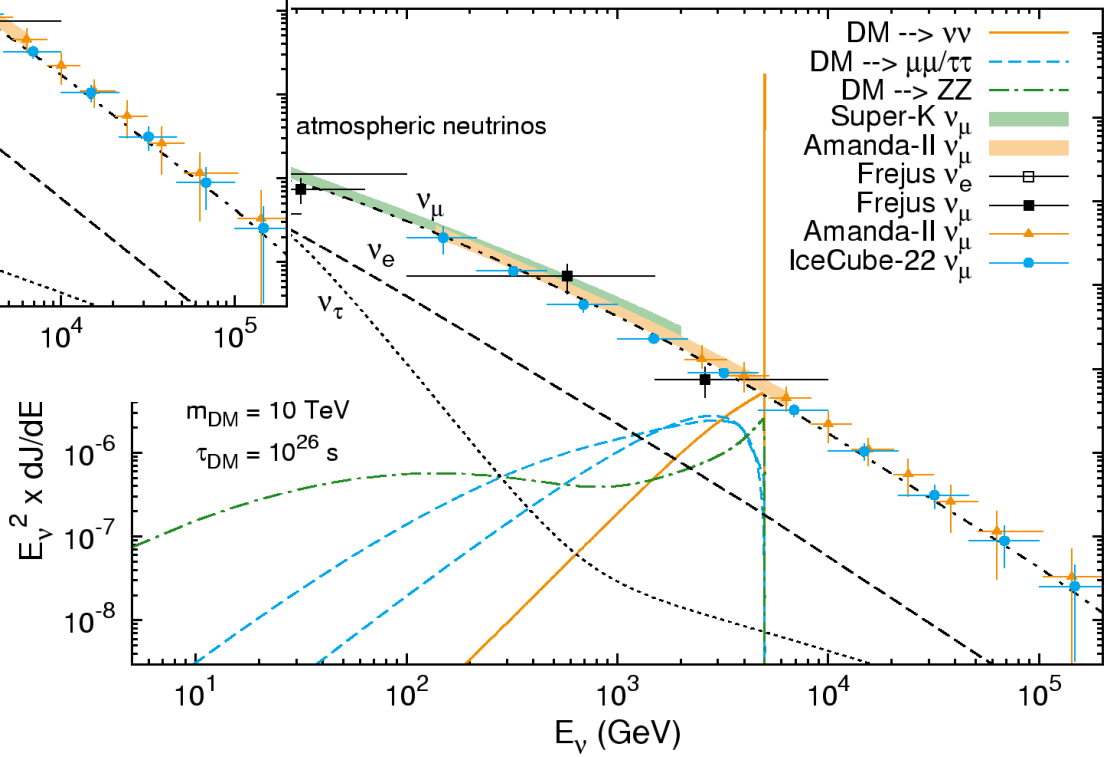
- Neutrino oscillations distribute the flux equally into all flavors
- Atmospheric neutrinos are the dominant background





Dark Matter Decay Channels and Neutrino Flux

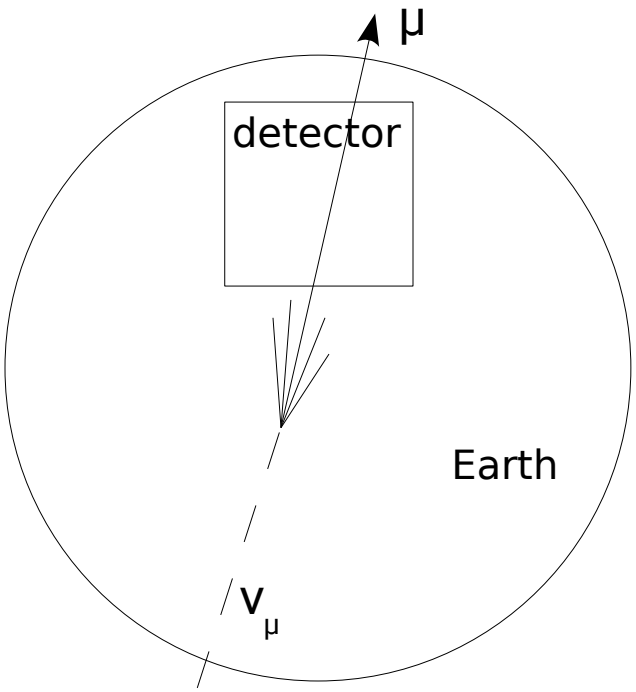


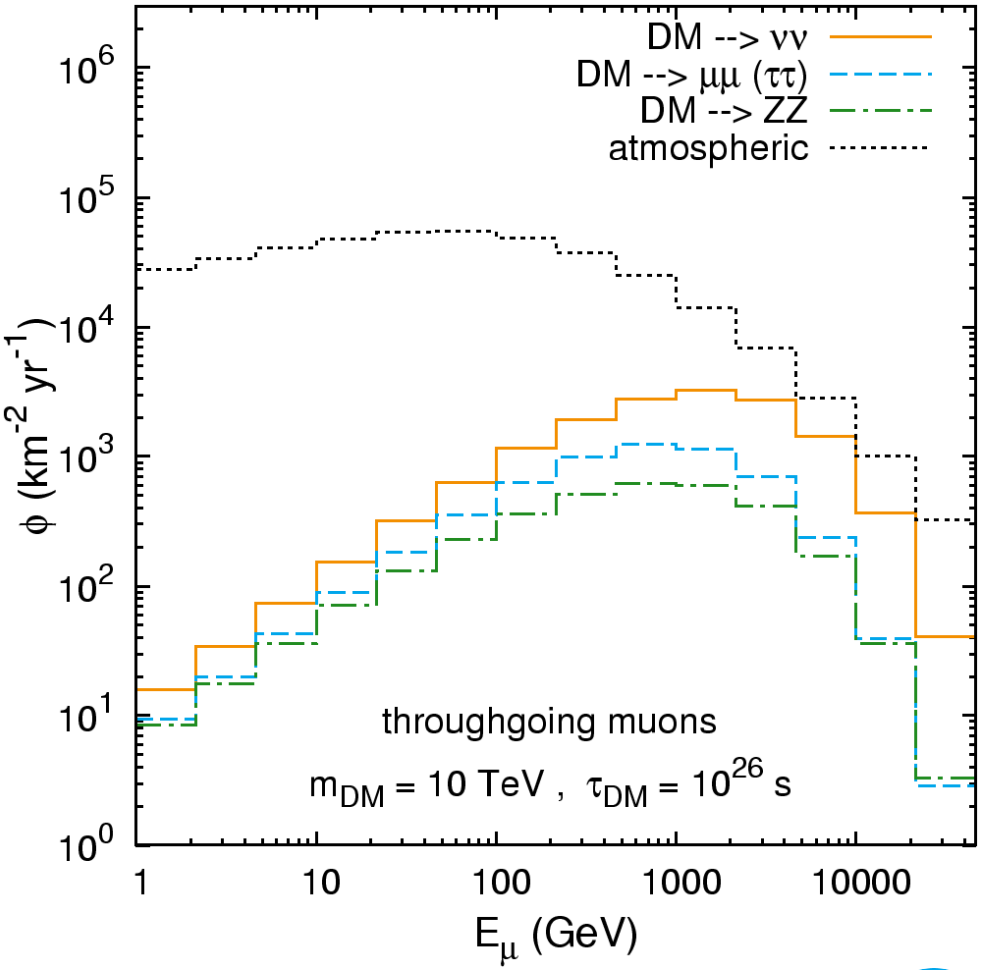


- Larger dark matter mass:
  - Spectrum shifts to higher energies
  - Signal-to-background ratio increases

Upgoing-Throughgoing Muon Events

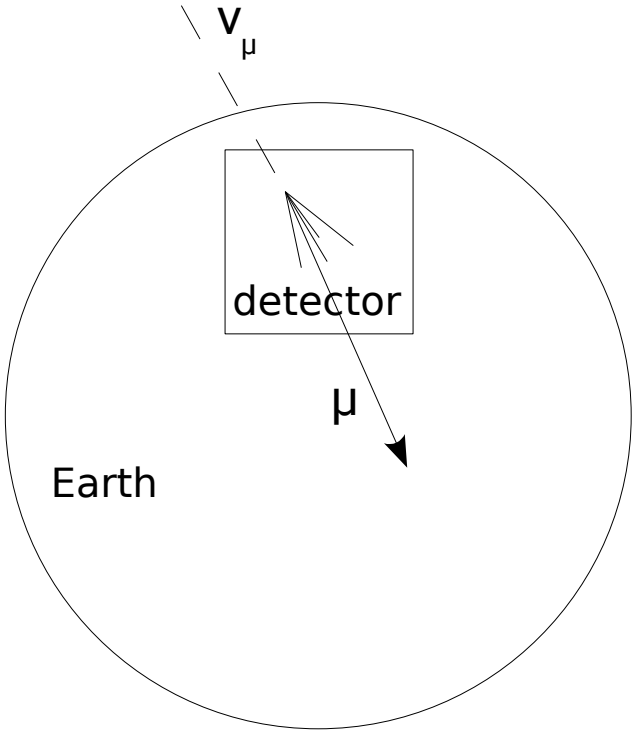
- Downgoing muon signal is dominated by atmospheric muons (only upgoing events can be used → 2π sensitivity)
- Muon energy loss shifts spectrum to lower energies and initial neutrino energy cannot be reconstructed

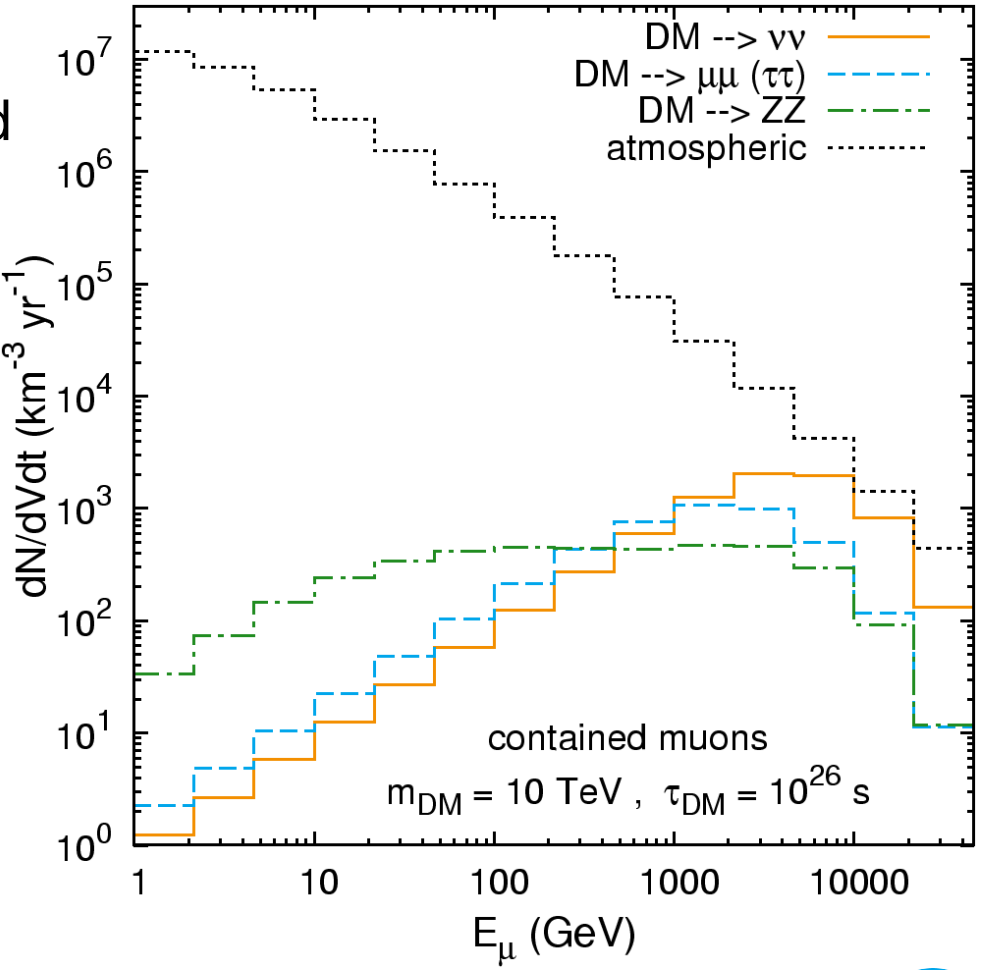




(Partially) Contained Muon Events

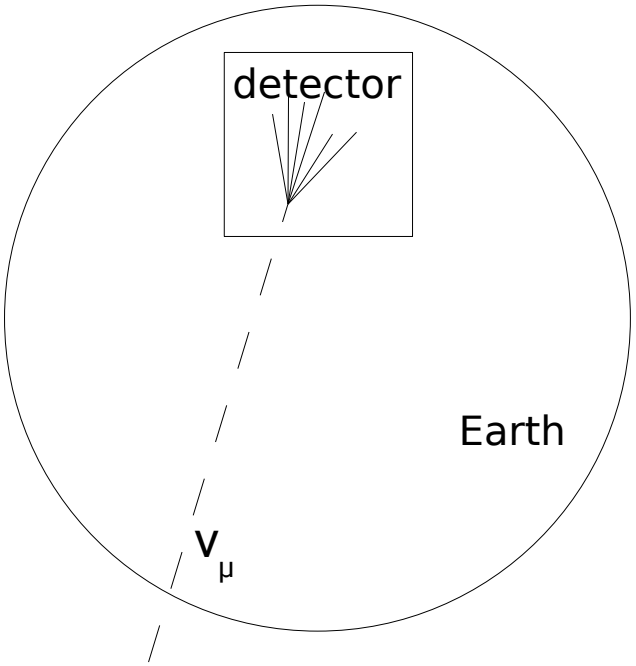
- A muon veto allows to discriminate starting from throughgoing tracks (→ 4π sensitivity, e.g. Super-Kamiokande, IceCube +DeepCore)
- If the shower is also detected reconstruction of initial neutrino energy possible

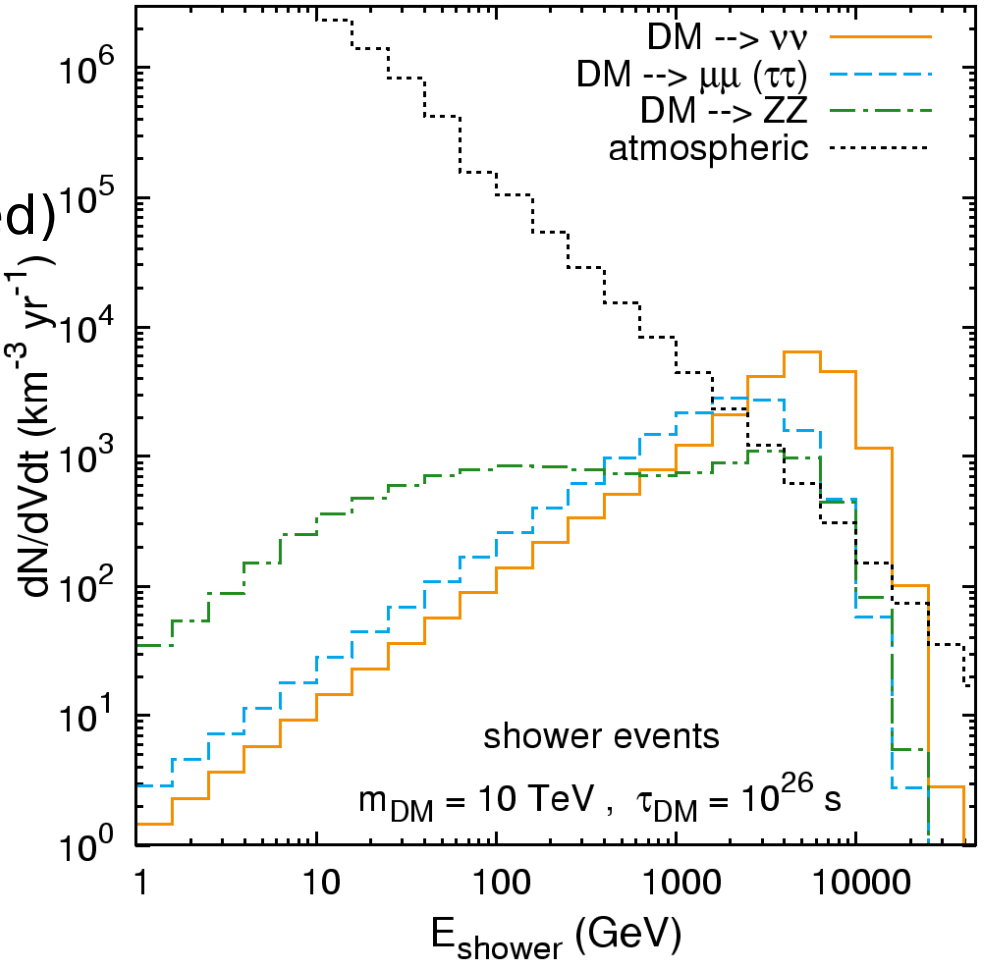




Shower Events

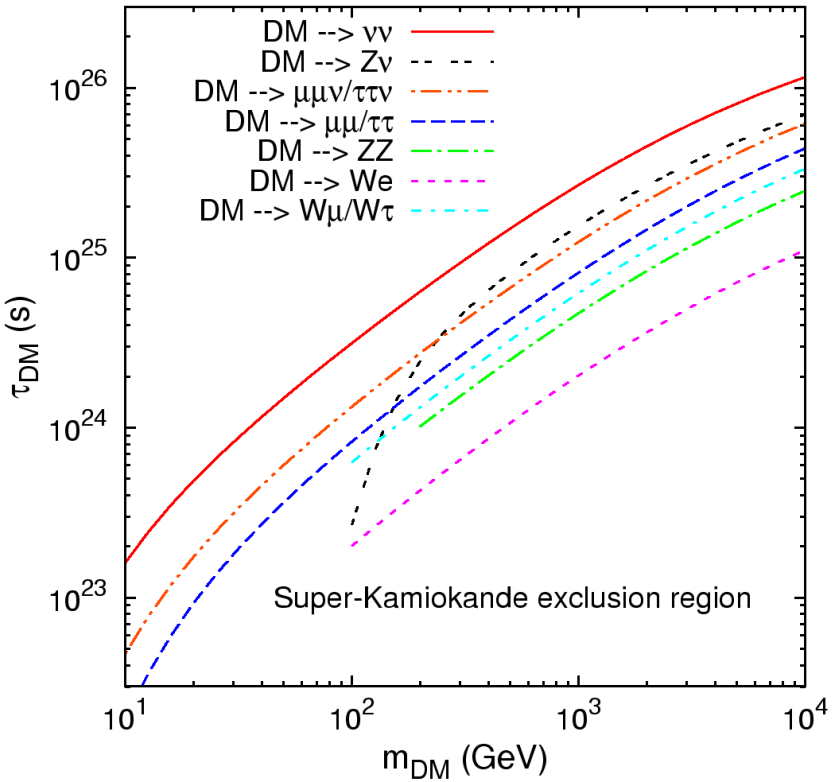
- Energy of initial neutrino can be reconstructed for charged current events
- Larger signal and lower atmospheric background
- 4π sensitivity (no veto needed)

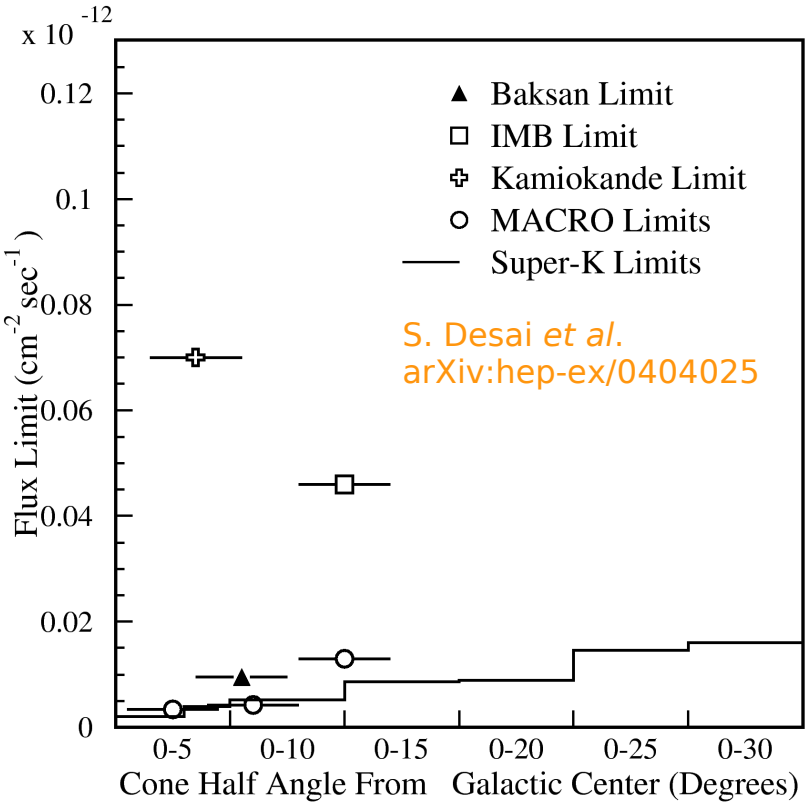




Limits on the Dark Matter Parameter Space

- Super-Kamiokande:
  - Limit on (integrated) flux of upgoing-throughgoing muons
  - Strongest limit from 30° cone around galactic center
  - Stronger limits for larger masses





- Super-K limit on diffuse muon flux could slightly improve the limit
- PAMELA inspired decaying dark matter scenarios are not in conflict with Super-K results

Neutrino Telescopes

- Large-scale neutrino telescopes like Amanda, Antares or IceCube have much larger event rates
- Upgoing muon rates for dark matter with lifetime of 10^{26} s (scales with τ_{DM}^{-1}):

		DM → ν ν		DM → W e		Atmospheric
		1 TeV	10 TeV	1 TeV	10 TeV	
Super-Kamiokande	Rate (yr^{-1})	4.1	17	0.31	1.7	430
Antares (~ Amanda)	Rate (yr^{-1})	28	170	1.6	14	1,600
IceCube80	Rate (yr^{-1})	3,600	14,000	220	1,400	200,000
IceCube80 + DeepCore	Rate (yr^{-1})	6,400	14,000	450	1,600	400,000

- Much stronger limits or even detection seem possible

Conclusion

- Indirect dark matter searches possibly play an important role to unveil the nature of the dark matter in the near future
- Decaying dark matter will need different search strategies than the well-established strategies for annihilating WIMPs
- Neutrinos are a tool complementary to charged cosmic rays and gamma rays that can help to discriminate between annihilating and decaying dark matter
- Forthcoming neutrino telescopes will be able to set constraints on dark matter parameters that are competitive with those from other cosmic ray species
- Even the detection of a neutrino signal seems possible