Title: Are the recent IceCube events hinting at O(100) TeV decaying dark matter?

Date: May 22, 2014 01:00 PM

URL: http://pirsa.org/14050118

Abstract: The IceCube detector has recently reported the observation of 28 events at previously unexplored energies. While the statistics of the observed events are still low, these events hint at the existence of a neutrino flux over and above the atmospheric neutrino background. We investigate the possibility that a significant component of the additional neutrino flux originates due to the decay of a very heavy dark matter (VHDM) particle via several possible channels into standard model particles. We show that a combination of a power law astrophysical neutrino spectrum and the neutrino flux from the decay of a DM species of mass in the range 150-400 TeV improves the fit to the observed neutrino events than that obtained from a best-fit astrophysical flux alone. Assuming the existence of an astrophysical background described by the IC best-fit, we also show that, for the decay of even heavier DM particles ($m_{\text{DM}} \sim 1$ PeV), the same observations impose significant constraints on the decay lifetimes. Allowing the astrophysical flux normalization to vary leads to modifications of these limits; however, there is still a range of dark matter mass and lifetime that is excluded by the IC results.

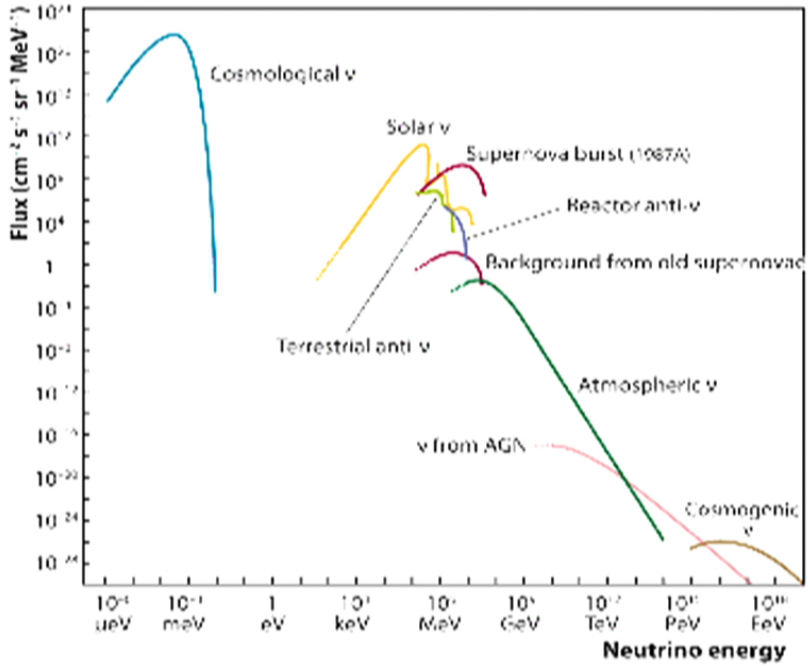
Are the recent IceCube events hinting at O(100) TeV decaying dark matter?

Atri Bhattacharya

Talk at **Perimeter Institute**

22 May 2014

THE NEUTRINO SKY... TO THE HIGHEST ENERGIES



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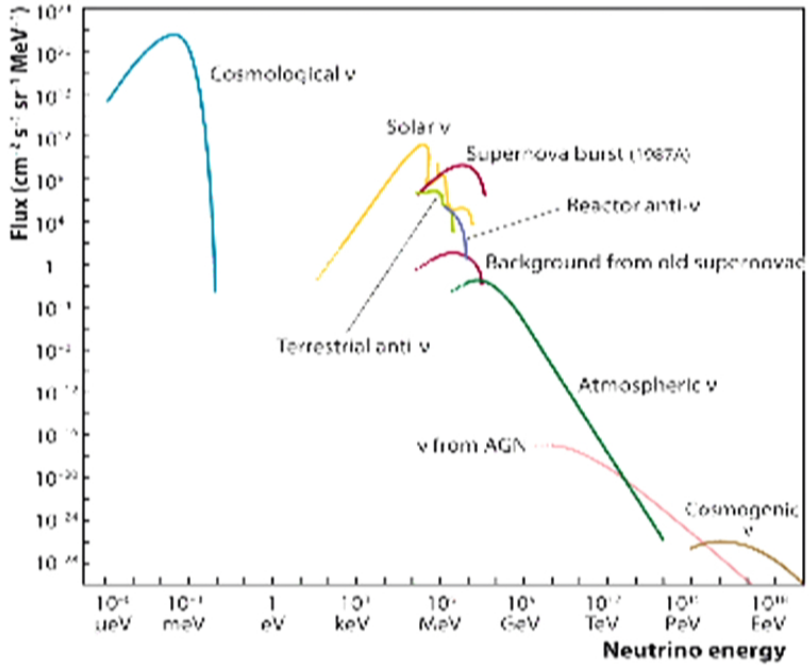

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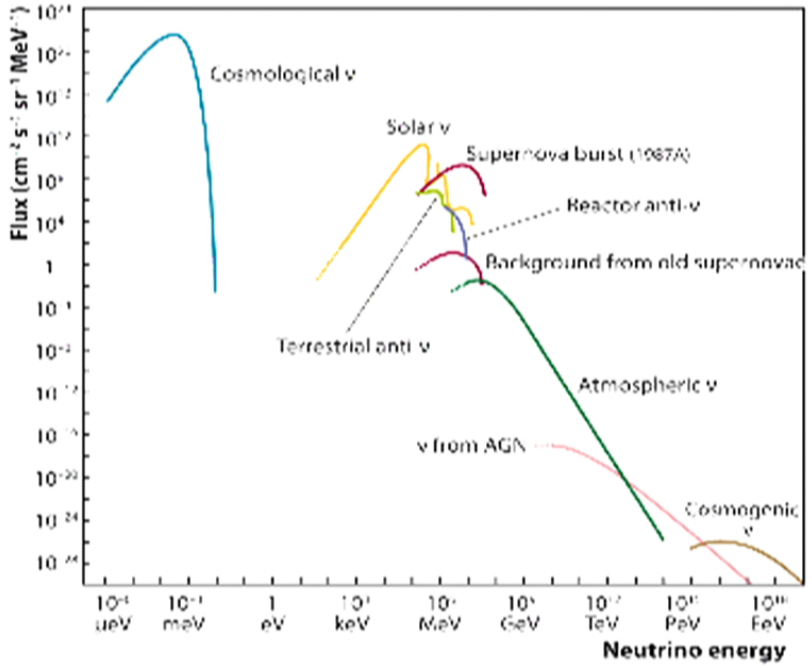

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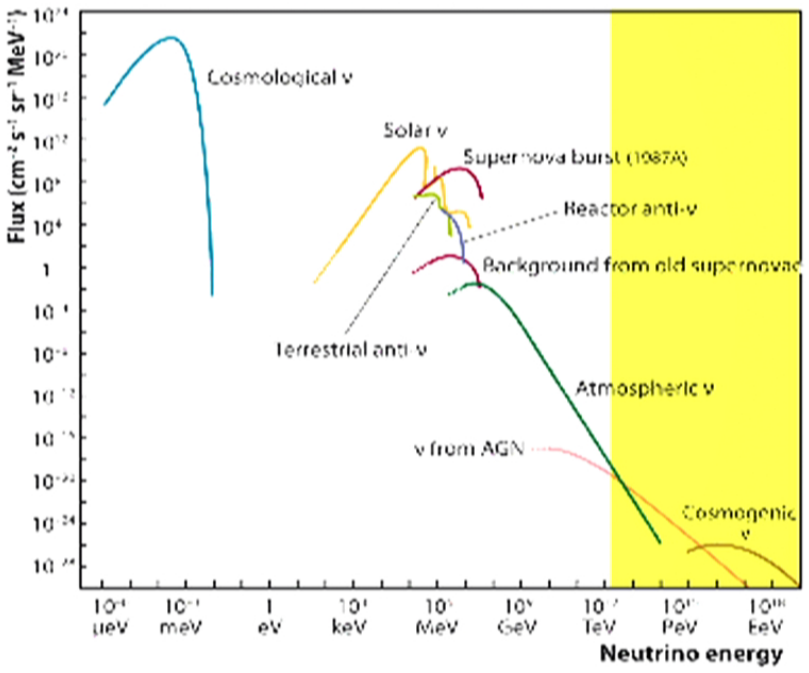
Probe highest energy neutrino production mechanisms

Existence of tiny non-std physical effects (LV, etc.)

Hunting for astrophysical point objects (AGN, etc.) using neutrinos



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DM annihilation at the galactic centre

Indirect search for very heavy DM decay

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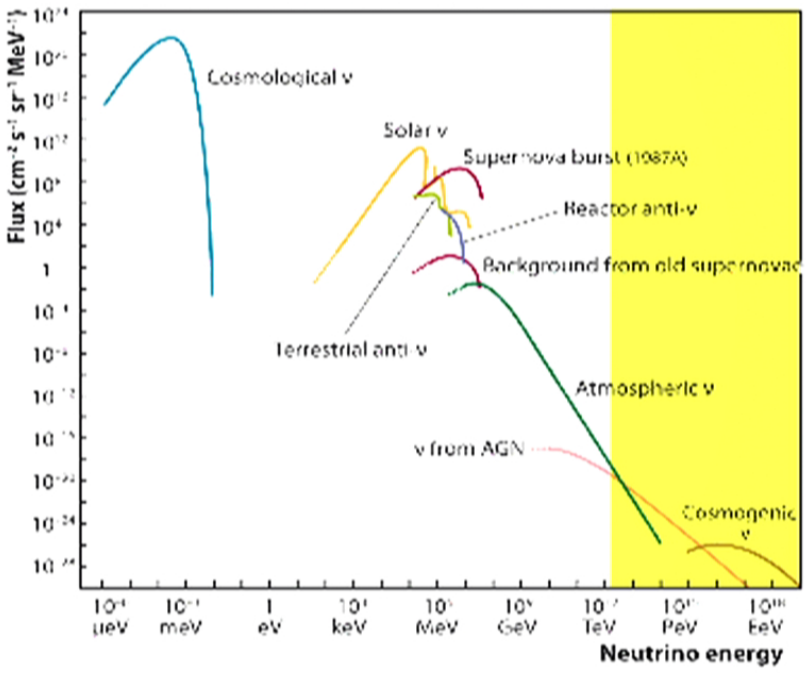

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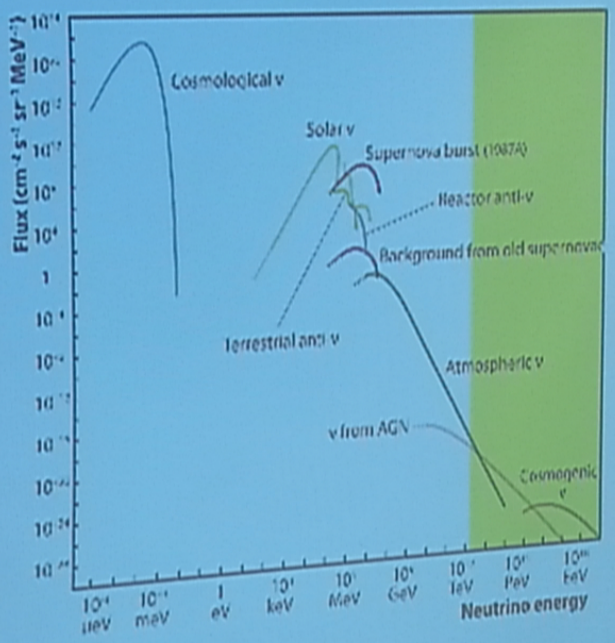

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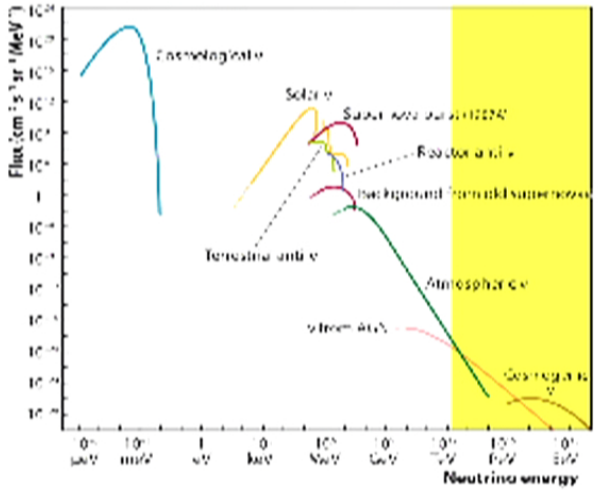
Neutrinos @ highest energies: HowCatch'em



Main issues with detection

- Extremely low incident fluxes
- Huge incident energies – reconstruction requires voluminous detectors
- Flavour discrimination?

Solution?
Km³ Detectors

Km³ detectors

- Trap high fraction of incident neutrino fluxes
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  - Big enough to contain hadronic/em cascades
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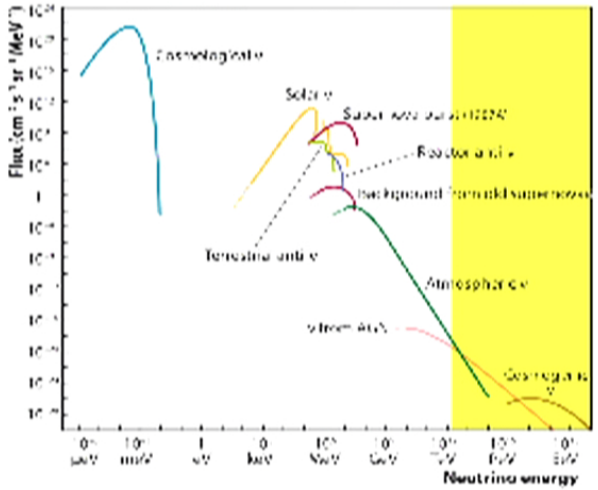

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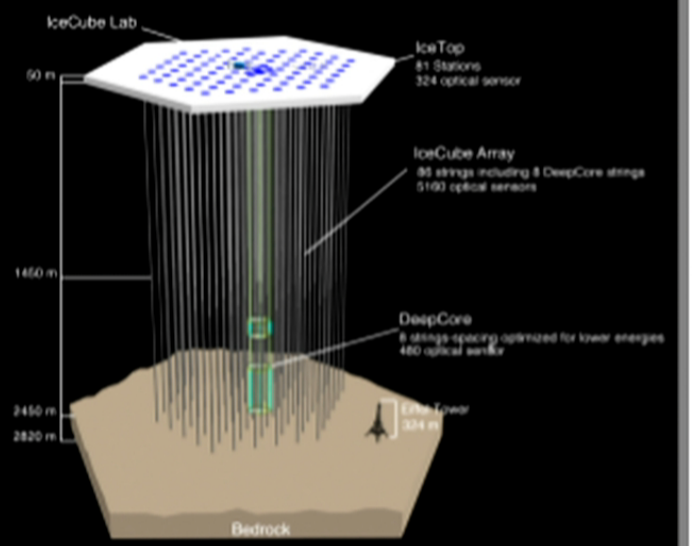

IceCube

- Operational since 2010
  - Full exposure since Dec. 2011
- Capable of flavour discrimination
  - Limited to detection of three distinct event signatures
- Excellent energy reconstruction
  - < 10% for contained cascades
  - ~ 30% for tracks with contained vertices
- Good direction reconstruction
  - Up to 1° for tracks
  - ~30° for cascades
- Designed to run (minimal op. cost) for 10+ yrs
- Collected 28 UHE events in 662 days of run-time
  - 2 events at PeV+ energies
  - Recently reported 9 more events, making total event number 37 over 988 days

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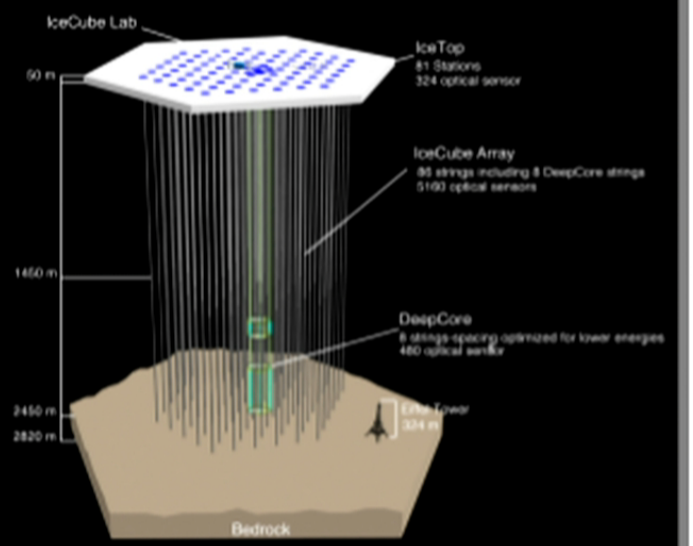

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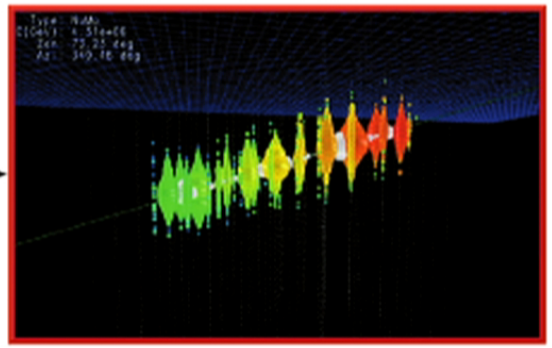
Flavour @ IC

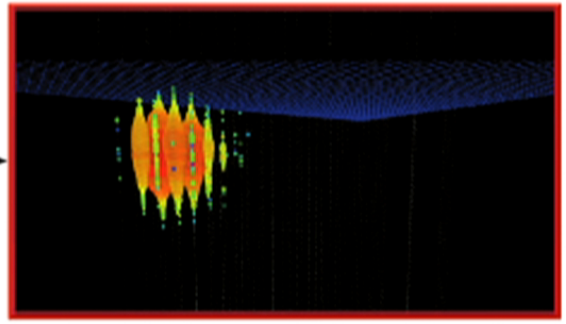
Muon Track

$\nu_\mu N\ CC$



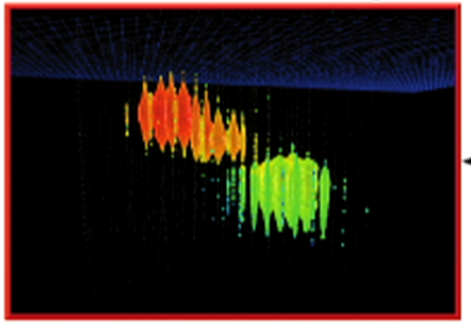
$\nu_{e,\tau} N\ CC$
$\nu N\ NC$

Cascades

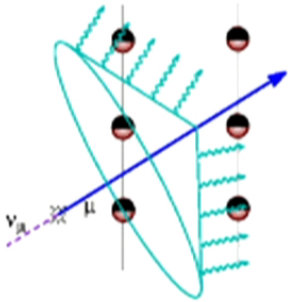


$\nu_\tau N\ CC (\geqslant 1\ \mathrm{PeV})$

Double Bang



Reconstructing events @ IceCube

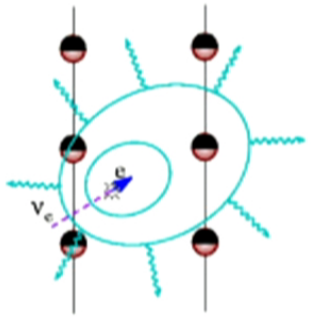


Muon Tracks

Charged current interaction of the muon-neutrino

Clear tracks and excellent direction reconstruction

Energy reconstruction is indirect – energy loss along track



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Neutral current interactions of all flavours

Excellent energy but poorer direction reconstruction

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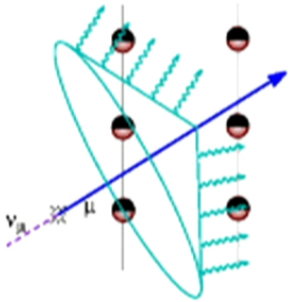

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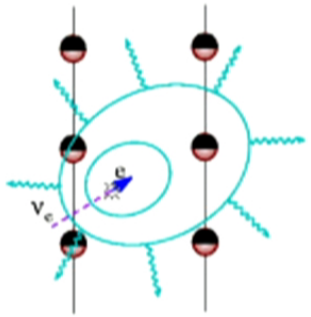

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- Diffuse flux from all-sky astrophysical sources
  - Expected to follow a power-law spectrum
    - Fermi 1st order shocks → α = 2.0
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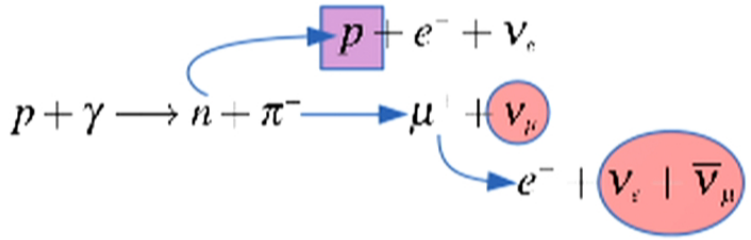

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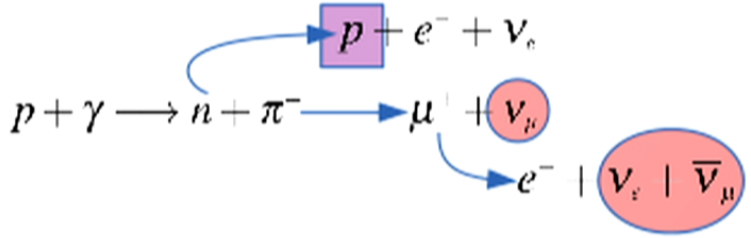
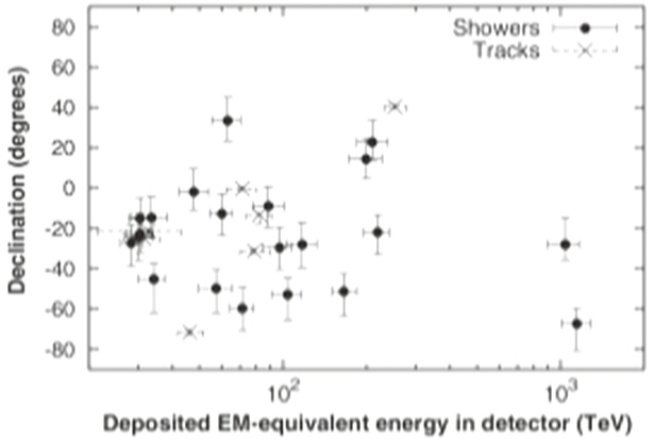


Observations @ IC [662 days]



27 total events

- Two PeV+ cascades
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- Additional 18 lower energy cascades
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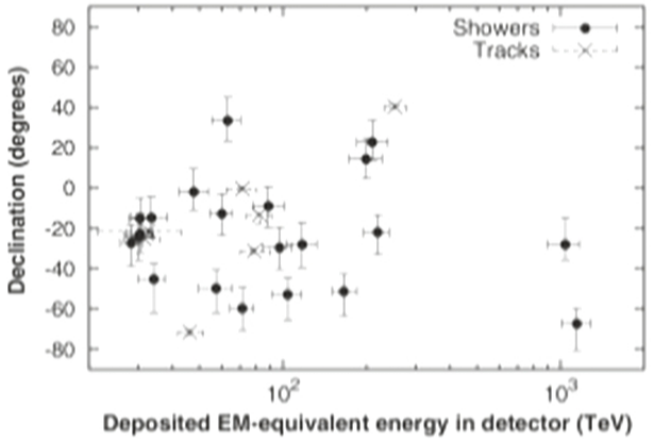

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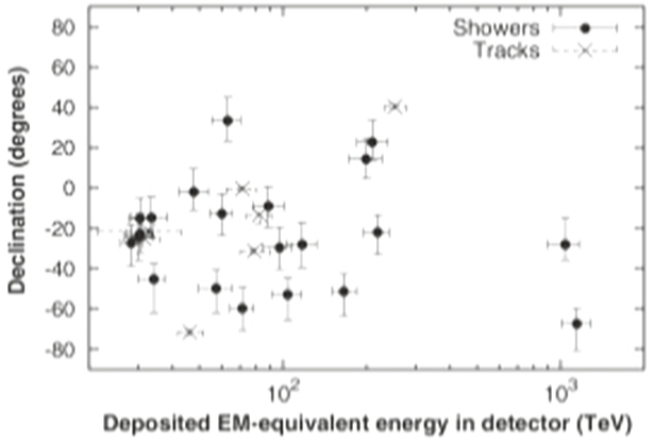

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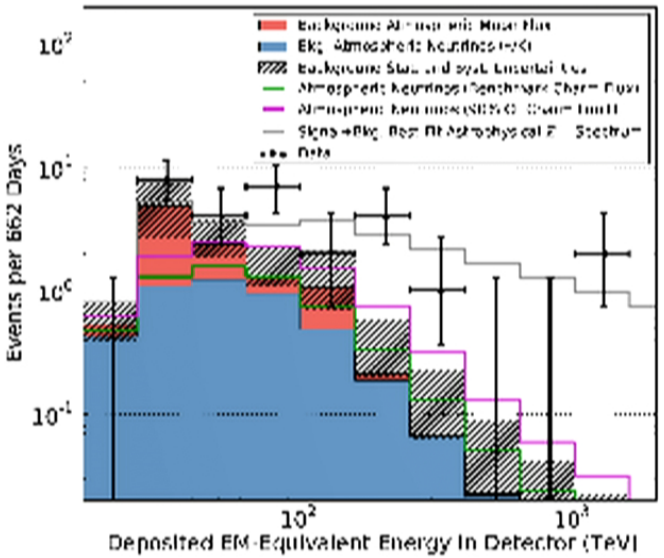

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Best-fit largely consistent with E^{-2} power flux up to 1.1 PeV...

$$E^2\Phi = 1.2^{1.6}_{0.8} \times 10^{-8}\ \mathrm{GeV\ cm^{-2}\ s^{-1}\ sr^{-1}}$$

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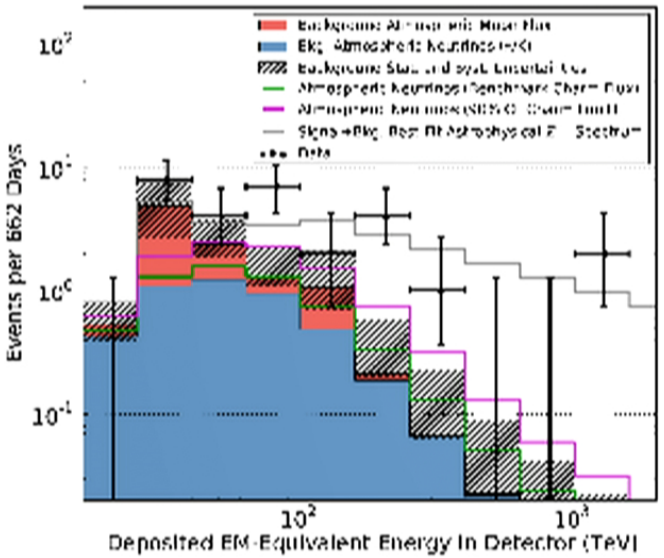

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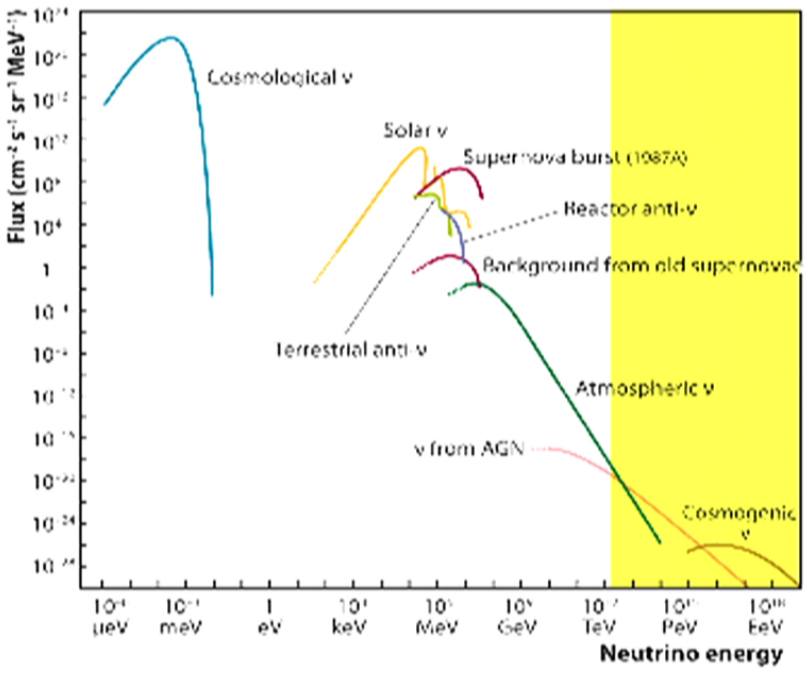

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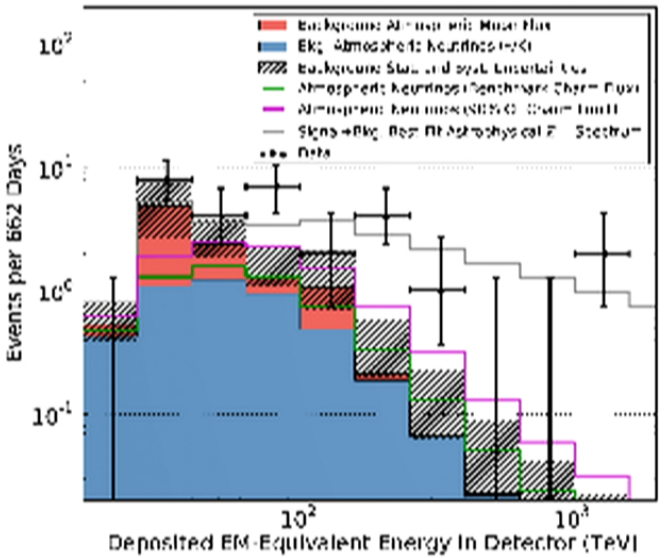

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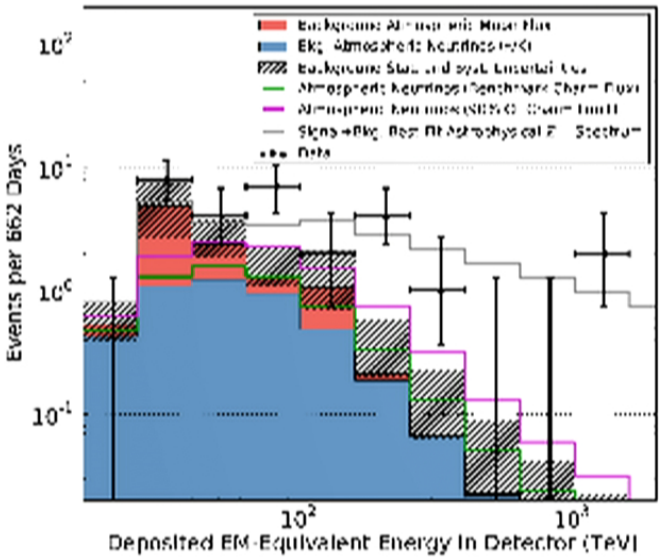

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Possible sources

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  - For WIMP-like $\langle \sigma v \rangle^{\dagger}$, expected IC signal too low
    - 1 event in 50 yrs
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† For WIMP's, $\langle \sigma v \rangle \approx 10^{-27}$ cm^3 s^{-1}

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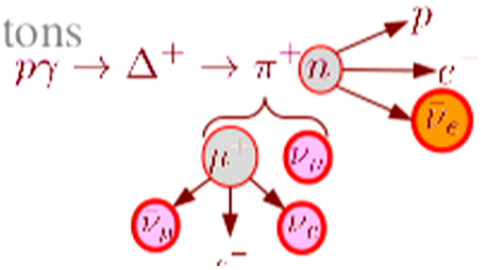
  - Cosmic rays interacting with CMBR photons



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Heavy DM decay: Features

- Same OoM contribution from galactic and extra-galactic source
  - Diffuse flux from 4π sky
  - Observable event rates predicted (comparable to IC b.f.)
    - Contrary to DM annihilation scenarios
  - Reasonable lifetimes for DM relic particles: $O(10^{27})$ s
    - Explains relic abundance, 27% of universe's energy content
  - Possible decay channels: ZZ, WW, $\tau^+\tau^-$, $\mu^+\mu^-$, $\nu\bar{\nu}$, $q\bar{q}$...

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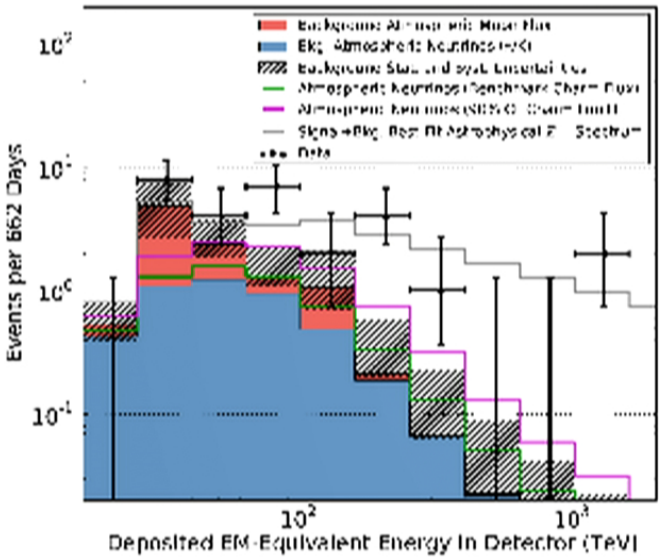

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DM decay: Considerations

- Simplicity:
  - Single DM species decaying with lifetimes ~ $O(10^{27})$s
  - Limit to study of scalar DM
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  - Decays to std. model particle pairs
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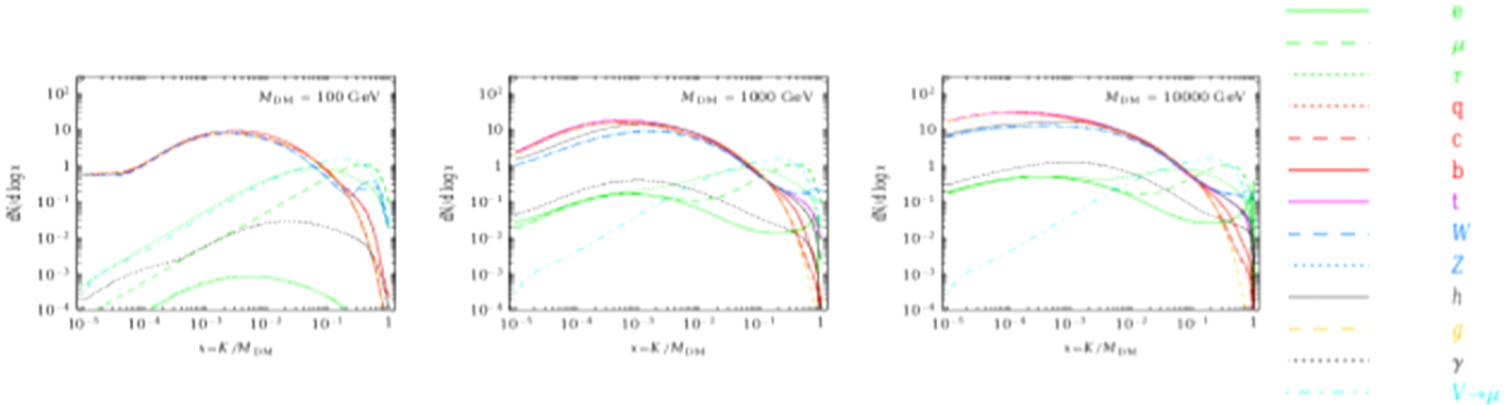
DM decay: Spectrum



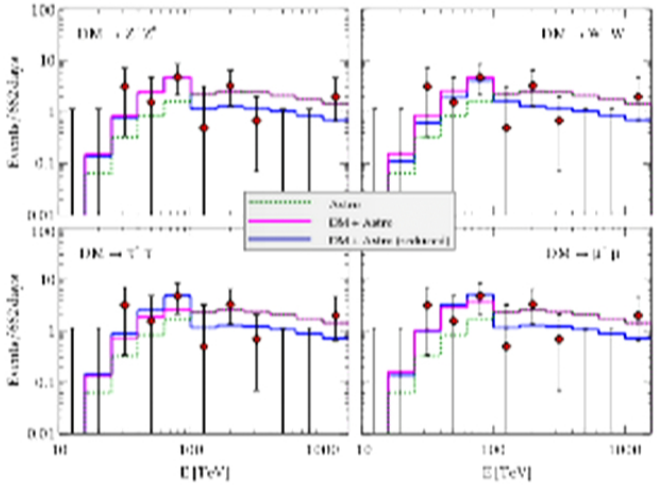
All flavour neutrino flux at source from different DM decay/annihilation channels

Fluxes from heavy DM decay

Total Flux = Galactic Flux + Extra-Galactic Flux

- Galactic
  - $$\frac{\mathrm{d}\Phi^{\mathrm{G}}}{\mathrm{d}E_\nu} = \frac{1}{4\pi\, m_{\mathrm{DM}}\, \tau_{\mathrm{DM}}} \frac{\mathrm{d}N_\nu}{\mathrm{d}E_\nu} \int_0^\infty \rho(r(s,l,b))\, \mathrm{d}s$$
- Extragalactic
  - $$\frac{\mathrm{d}\Phi^{\mathrm{EG}}}{\mathrm{d}E} = \frac{\Omega_{\mathrm{DM}}\, \rho_c}{4\pi\, m_{\mathrm{DM}}\, \tau_{\mathrm{DM}}} \int_0^\infty \frac{1}{H(z)} \frac{\mathrm{d}N_\nu}{\mathrm{d}E'_\nu} \left|(1+z)E'_\nu\right| \mathrm{d}z$$
- Comparable contributions from G and EG fluxes, flux obtained from 4π sky
  - High energy neutrinos attenuated by earth => more downgoing neutrinos than up-going

"Hidden" component: ν from DM decay?



- Presence of Astrophysical power-law flux alongwith ν's from heavy DM decay
- DM of mass $O(100)$ TeV could decay to SM particles
  - W^+W^-, Z^0Z^0, $\tau^+\tau^-\mu^+\mu^-$
  - Secondary neutrinos @ 10 TeV – $m_{DM}/2$
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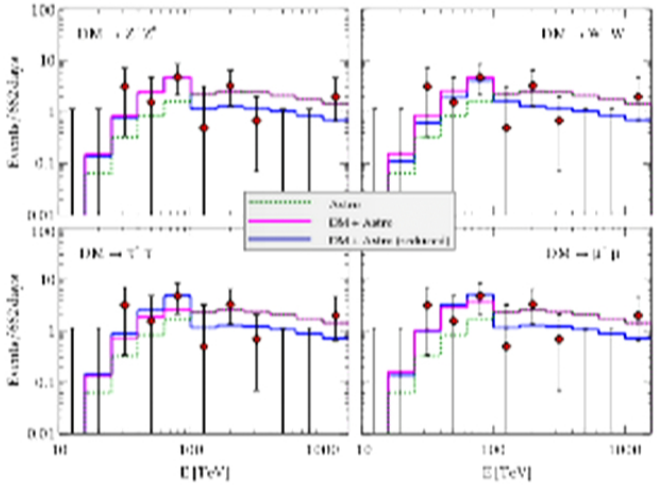

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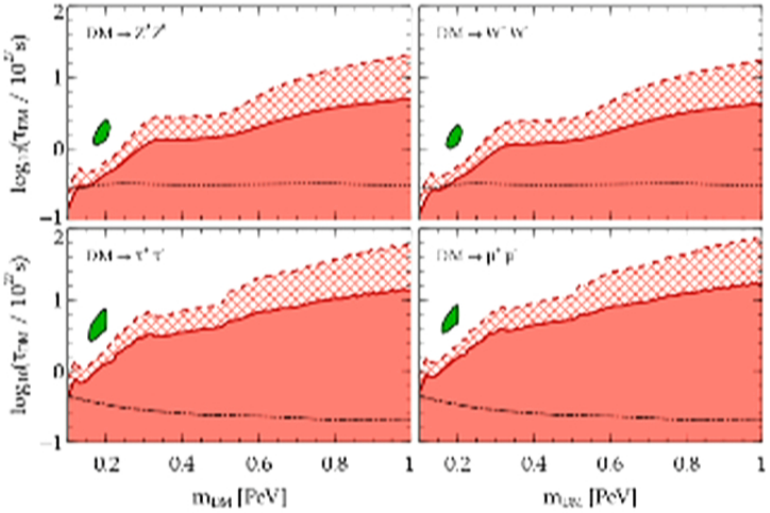
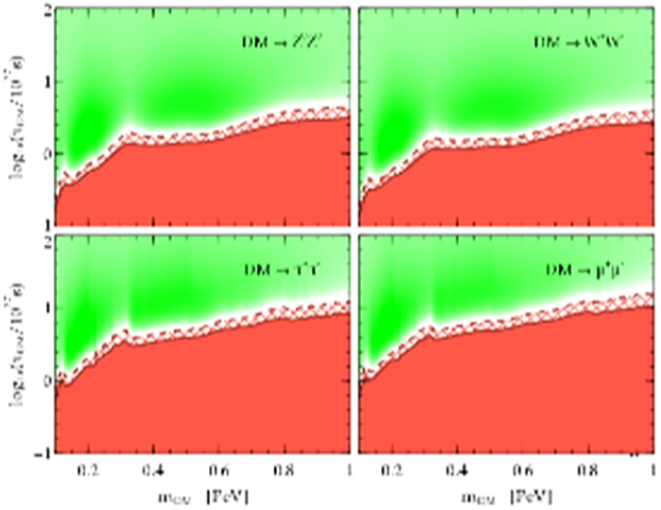
Constraints on DM parameter space

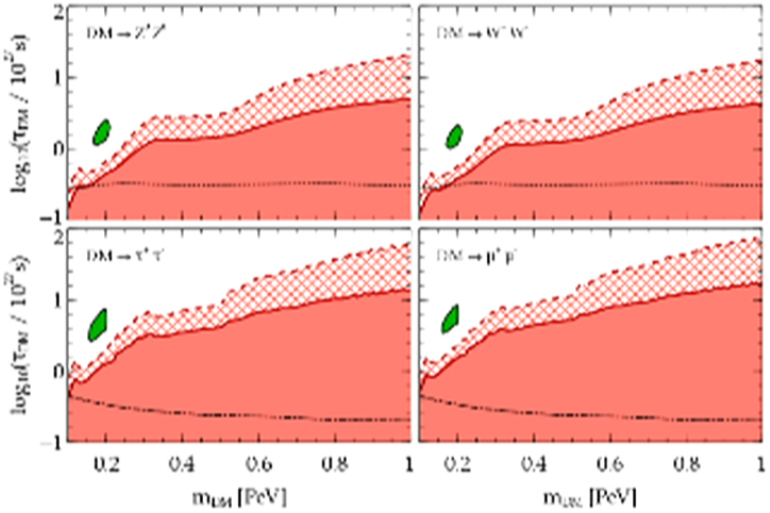


Astro flux at IC b.f.



Astro flux normalisation as free parameter

Constraints on DM parameter space



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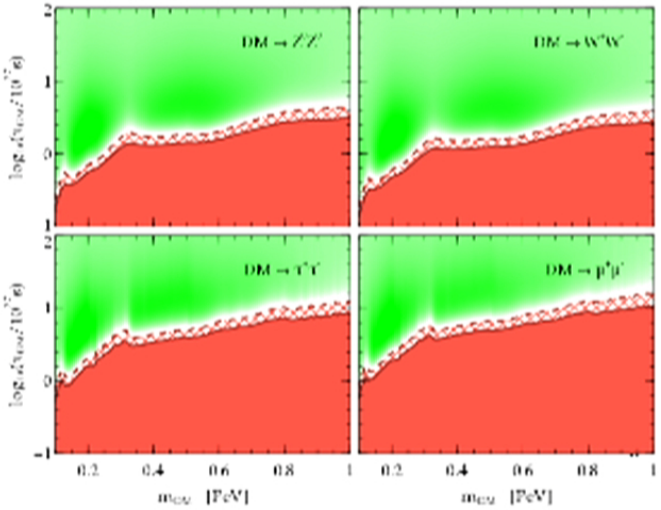

Astro flux normalisation as free parameter

IC events as DM + Astro

- **MORE DATA REQUIRED**
- Within the purview of limited statistics, reduced astrophysical flux + low energy neutrinos from DM decay fits observed data significantly better than the IC best-fit with a power-law astrophysical flux alone
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Remarks

- Other efforts
  - Esmaili, Serpico JCAP 1311 (2013) 054
    - No astrophysical neutrinos, only DM decay
    - DM $\rightarrow \nu_e\nu_e$ (12%), $q\bar{q}$ (88%)
    - Also explains lack of events in the 300 TeV – 1 PeV bins
    - In some tension with lower energy events
- Updated background estimates for the neutrino fluxes from charm decay in the low TeV energies will help
  - Present calculations (Enberg et al, 2008) based on outdated pdf's

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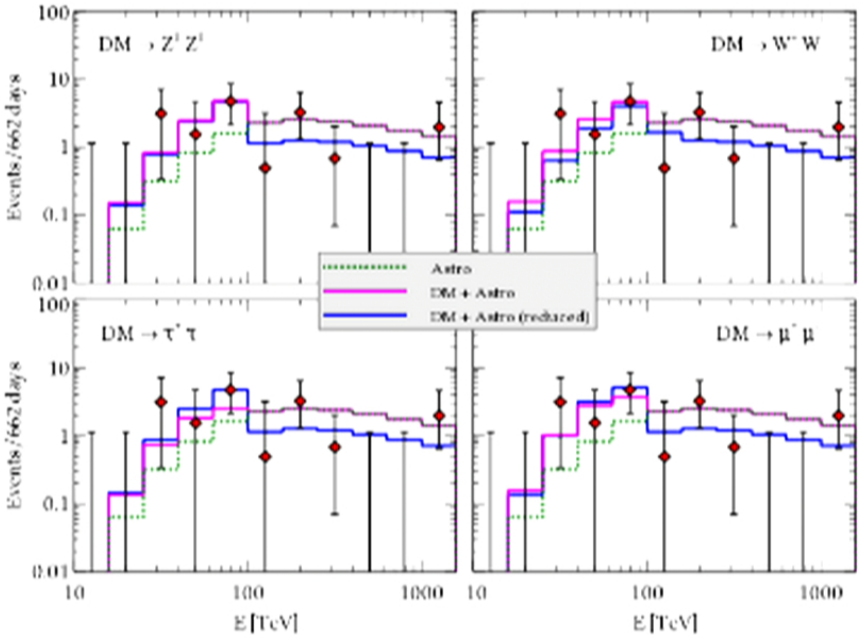
$\chi^2 = 4.209$
p-value = 0.061



$\chi^2 = 4.209$
p-value = 0.061

$\chi^2 = 4.188$
p-value = 0.060

$\chi^2 = 4.445$
p-value = 0.072

Compare with IC best-fit
$\chi^2_{IC} = 10.7$

Addendum: More recent events @ IC

- 9 more events since Dec. 2013, 37 in total
- One event at 370 TeV, none from 400 TeV – 1 PeV
- One more PeV+ event at ~ 2.1 PeV
  - Total of three PeV+ events
- E^{-2} best fit now at 0.95e-8 GeV cm^{-2} s^{-1} sr^{-1}

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Additional neutrino flux component?

Possible sources

- **NOT**
  - Atmospheric
  - Cosmogenic
- Heavy DM – $m_{DM} = O(100)$ TeV – annihilation?
  - Predominance of signal from galactic centre
    - Slight excess towards GC seen
  - For WIMP-like $\langle \sigma v \rangle^{\dagger}$, expected IC signal too low
    - 1 event in 50 yrs
- Heavy DM decay...

† For WIMP's, $\langle \sigma v \rangle \approx 10^{-27}$ cm^3 s^{-1}