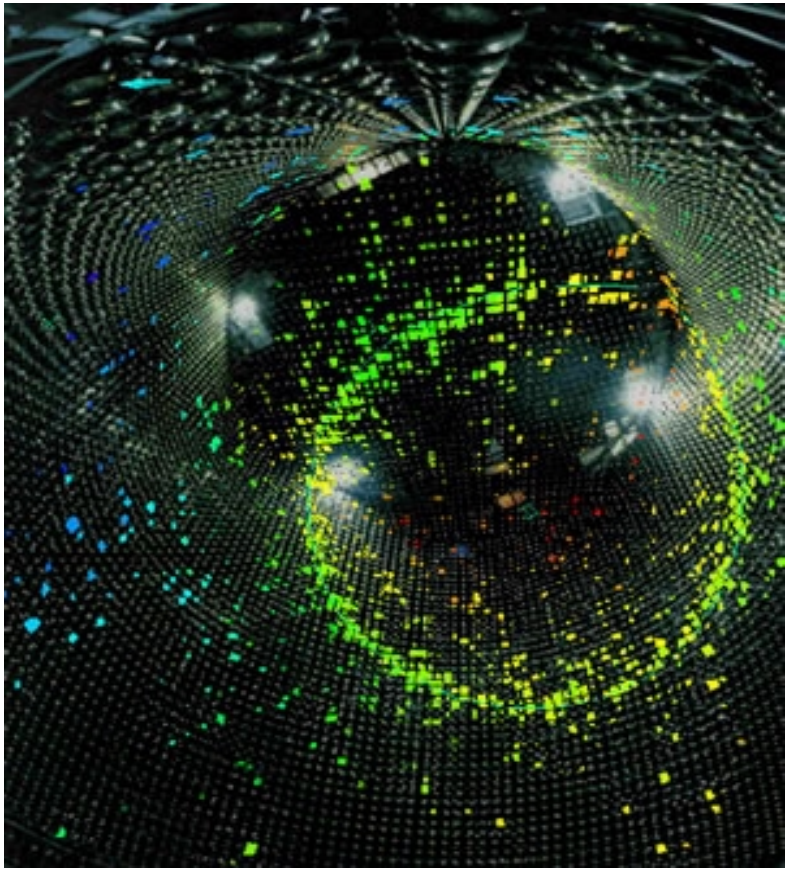
Les Rencontres de Physique de la Vallée d'Aoste, 1–7 III 2015

Indirect searches for dark matter particles with the Super–Kamiokande detector

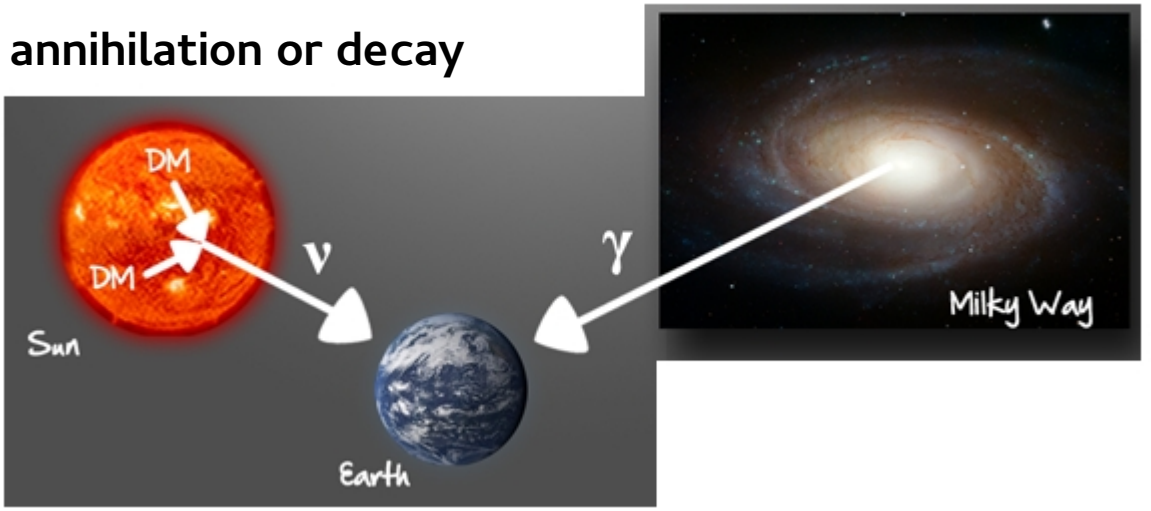


Katarzyna Frankiewicz
National Center For Nuclear Research

Indirect dark matter detection

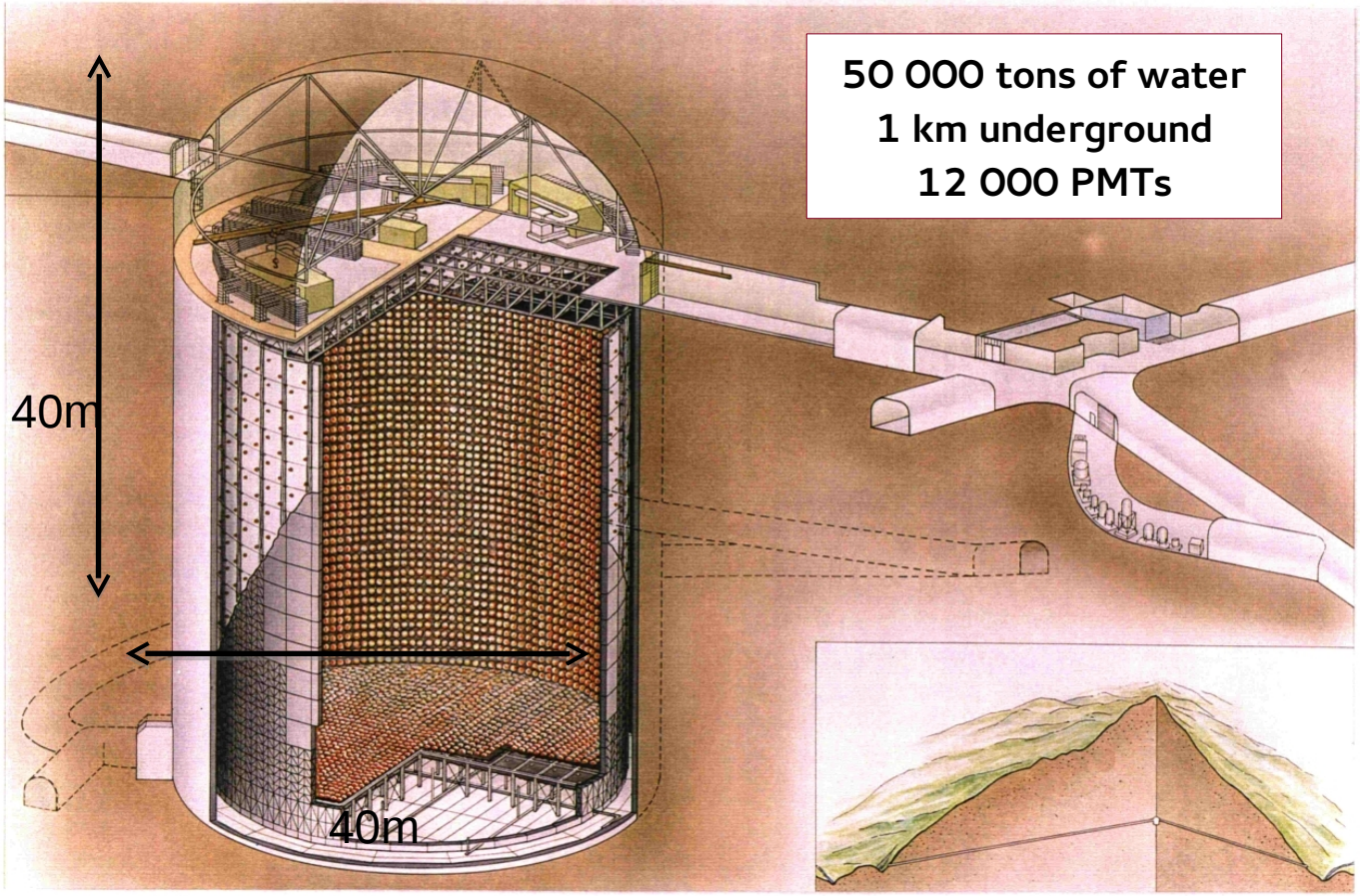
– Search for the products of WIMP annihilation or decay

$$\chi\chi \rightarrow \begin{matrix} q\bar{q}\left(c\bar{c}, b\bar{b}, t\bar{t}, \ldots\right) \\ l\bar{l} \\ W^{\pm}, Z, H \end{matrix} \rightarrow \ldots\ldots \rightarrow \nu, \gamma, \bar{e}, \bar{p}, \bar{H}_2$$



Super-Kamiokande

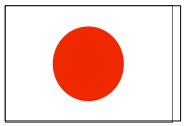
Water Cherenkov detector

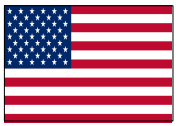


Kamioka Observatory, Japan

Detector measures solar, atmospheric, cosmic and accelerator neutrinos

Super-Kamiokande collaboration


~60%


~25%

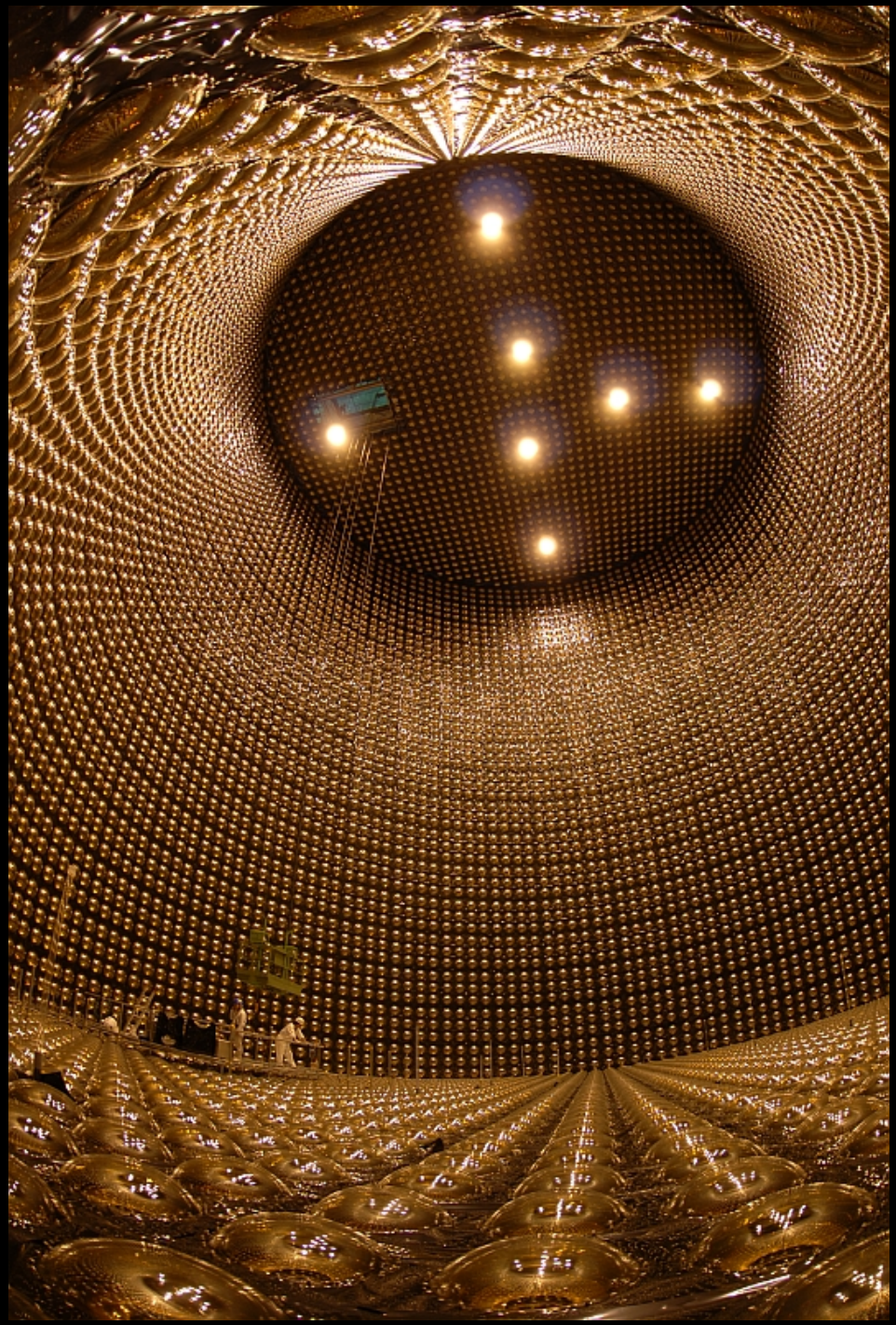

~6%

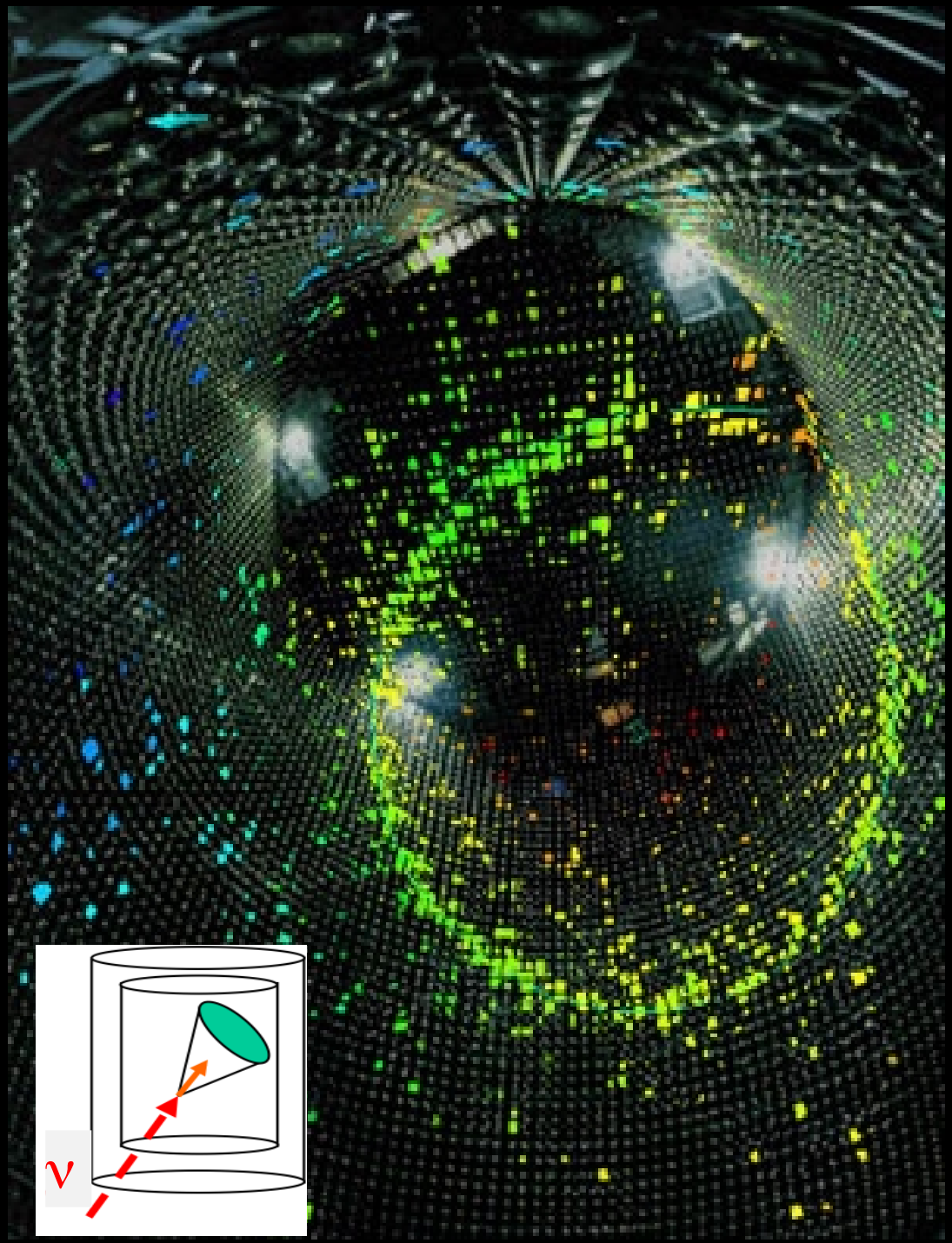

~3%


~5%


<1%

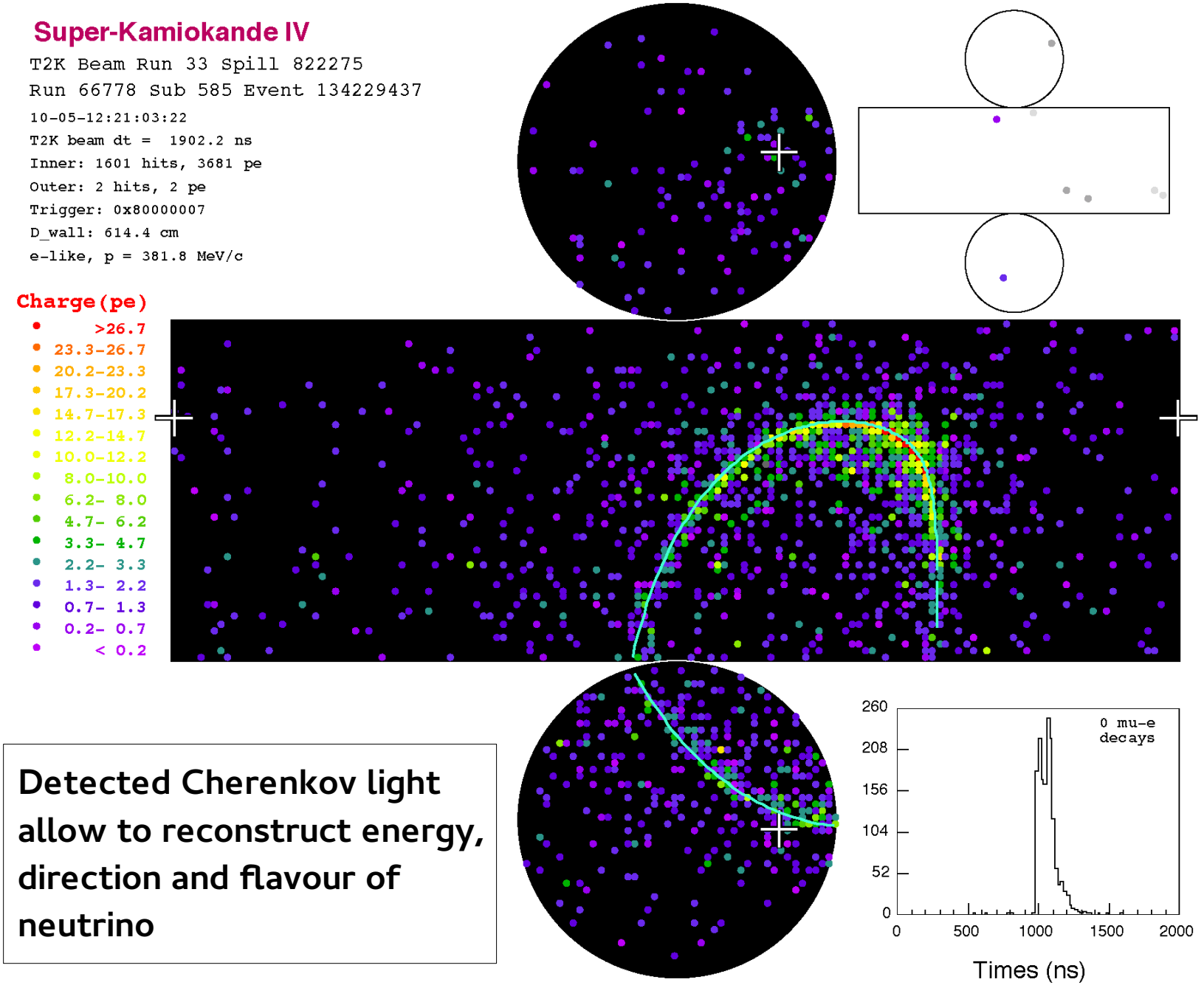

<1%





Super-Kamiokande IV

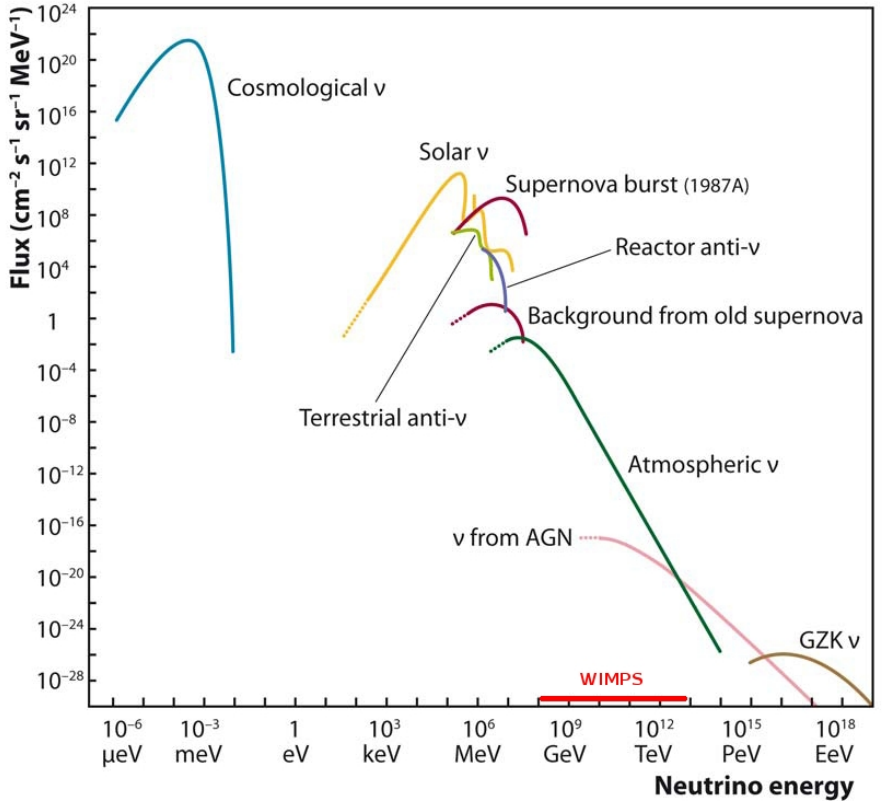
T2K Beam Run 33 Spill 822275
Run 66778 Sub 585 Event 134229437
10-05-12:21:03:22
T2K beam dt = 1902.2 ns
Inner: 1601 hits, 3681 pe
Outer: 2 hits, 2 pe
Trigger: 0x80000007
D_wall: 614.4 cm
e-like, p = 381.8 MeV/c

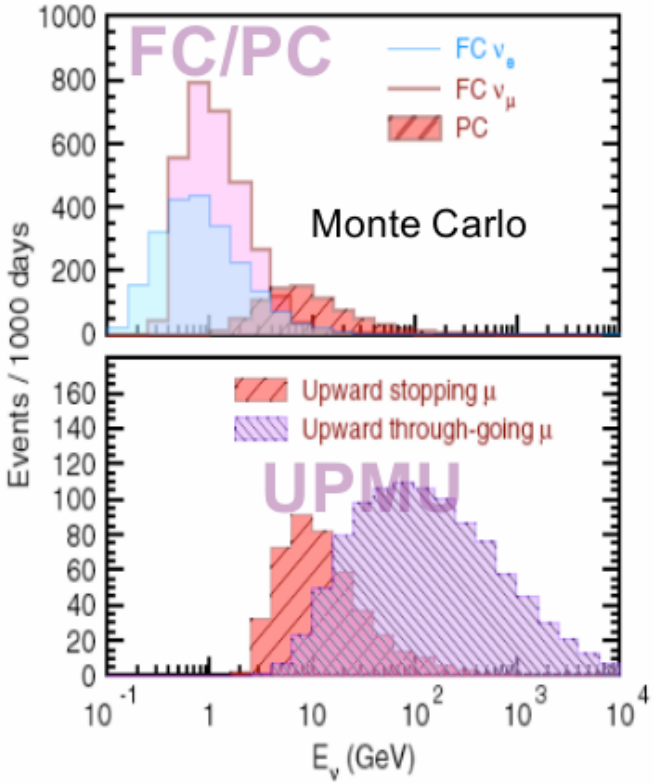


Detected Cherenkov light allow to reconstruct energy, direction and flavour of neutrino

Neutrinos at Super-Kamiokande

Neutrino sources





FC = ~8.3 evts/day

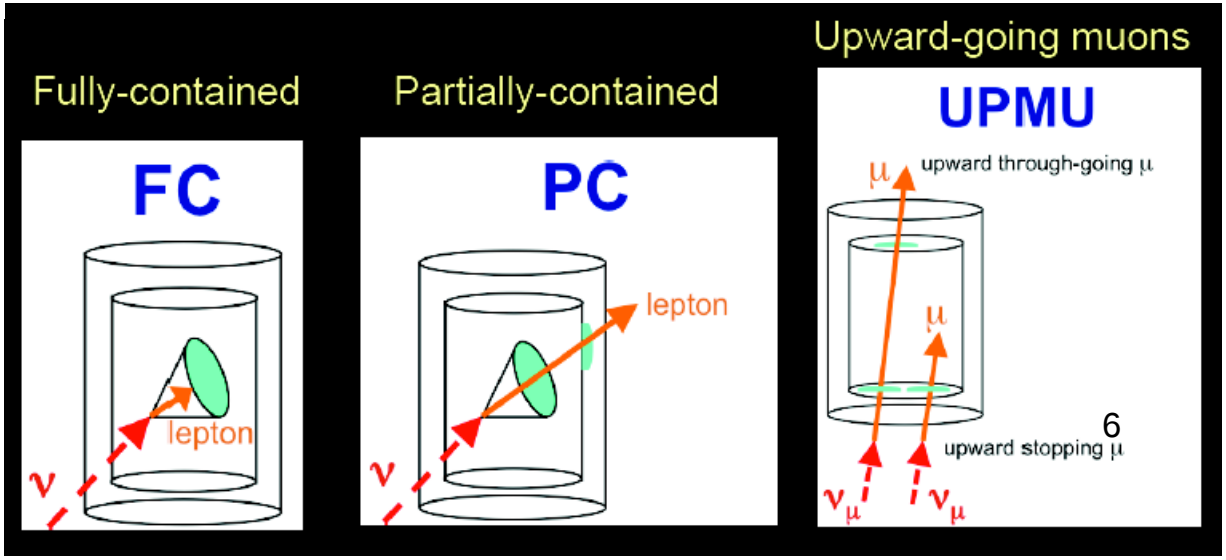
PC = ~0.7 evts/day

UPMU = ~1.5 evts/day

= ~10 /day

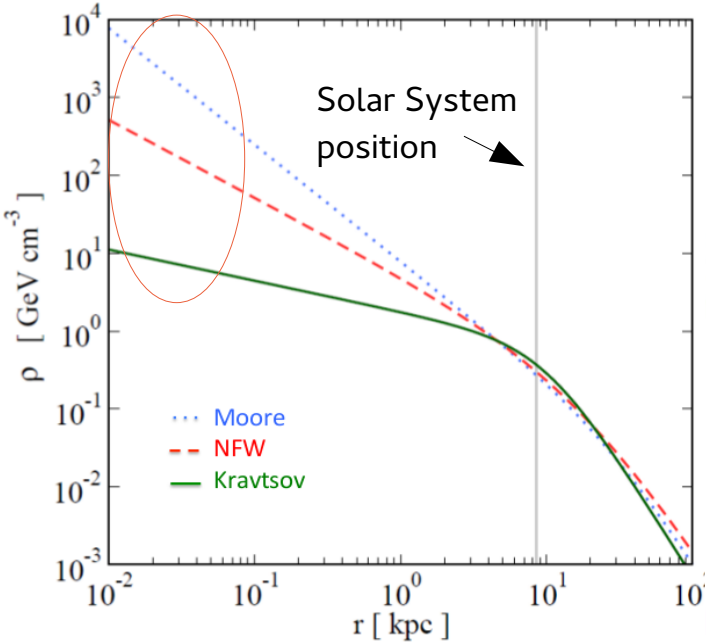
Main backgound for DM searches:

Atmospheric neutrinos

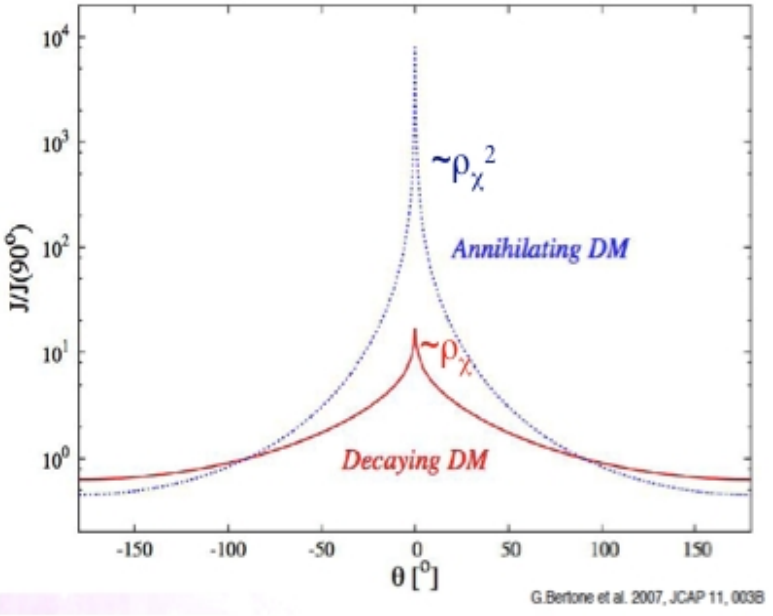


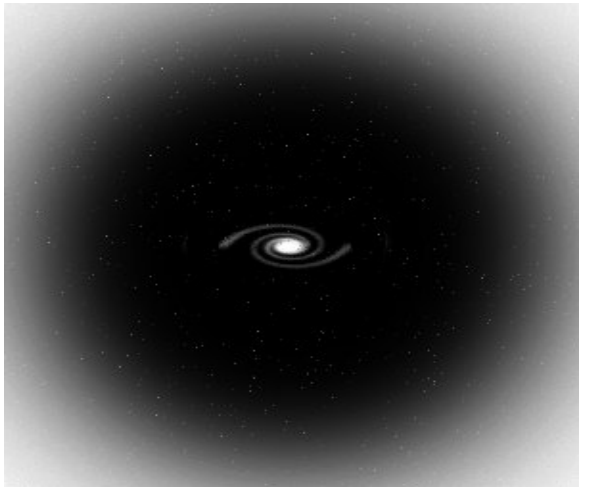
Dark Matter halo models

Dark Matter density



Expected DM intensity





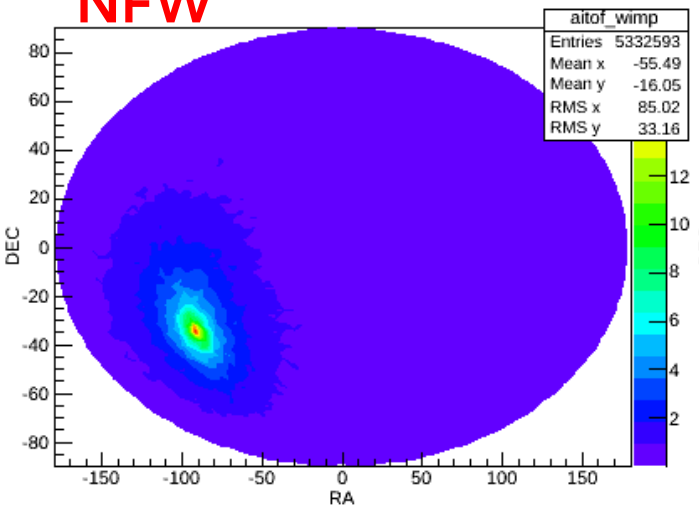
Local DM density

$$\rho_\chi \approx 0.389 \pm 0.025\ \mathrm{GeV\ cm^{-3}}$$

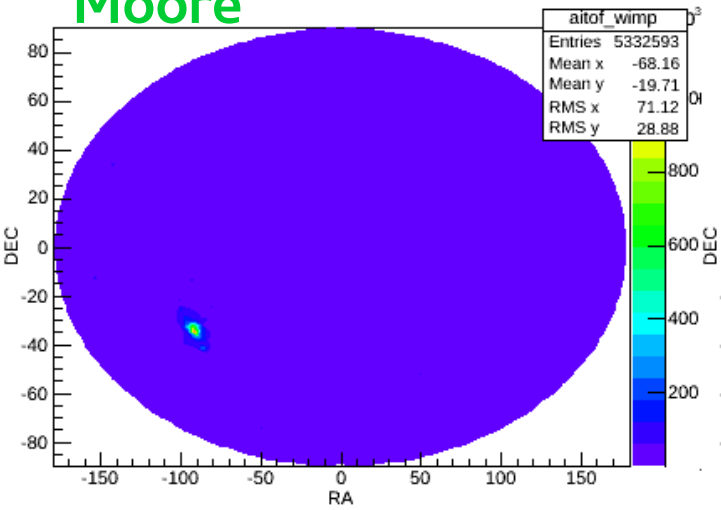
Expected local DM flux

$$\phi_\chi \sim 10^5\ \mathrm{cm^{-2} s^{-1}} \left(\frac{100\ \mathrm{GeV}}{m_\chi}\right)$$

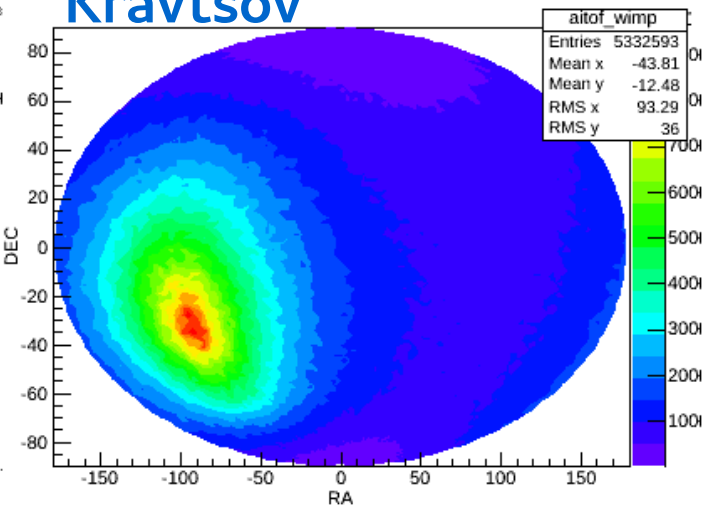
NFW



Moore



Kravtsov



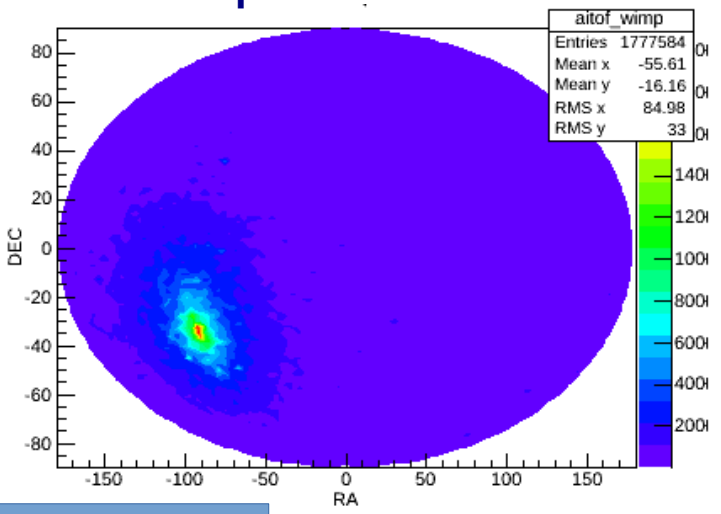
NFW – benchmark model

Moore & **Kravtsov** – extreme cases (to estimate the impact of halo model choice on the results)

Analysis idea

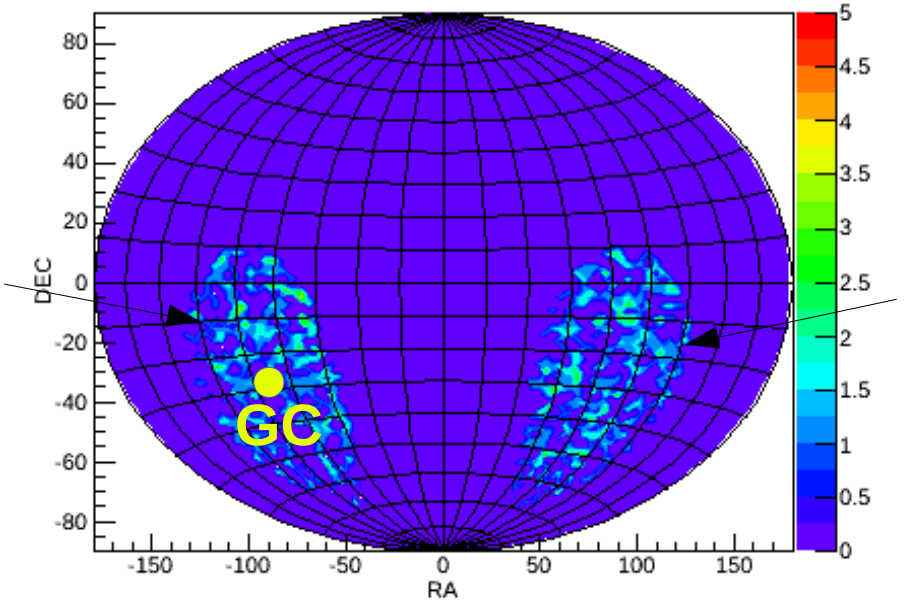
Search for a large-scale anisotropy due to DM-induced ν's from Milky Way

Expectations:



on-source

$$N_{on}^{bkg} + N_{on}^{sig}$$



off-source

$$N_{off}^{bkg} + N_{off}^{sig}$$

$$\Delta N \approx N_{on}^{sig} - N_{off}^{sig} = \Delta N^{sig} \propto \langle \sigma_A v \rangle$$

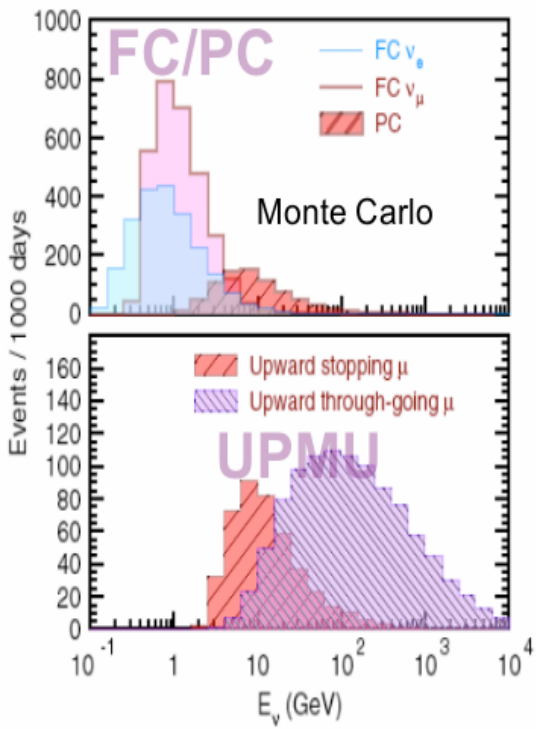
- Analysis uses on-soufce/off-source method to estimate the background directly from the data
  - method independent of MC simulations and related systematic uncertainties
- DM simulation is used only to optimize analysis

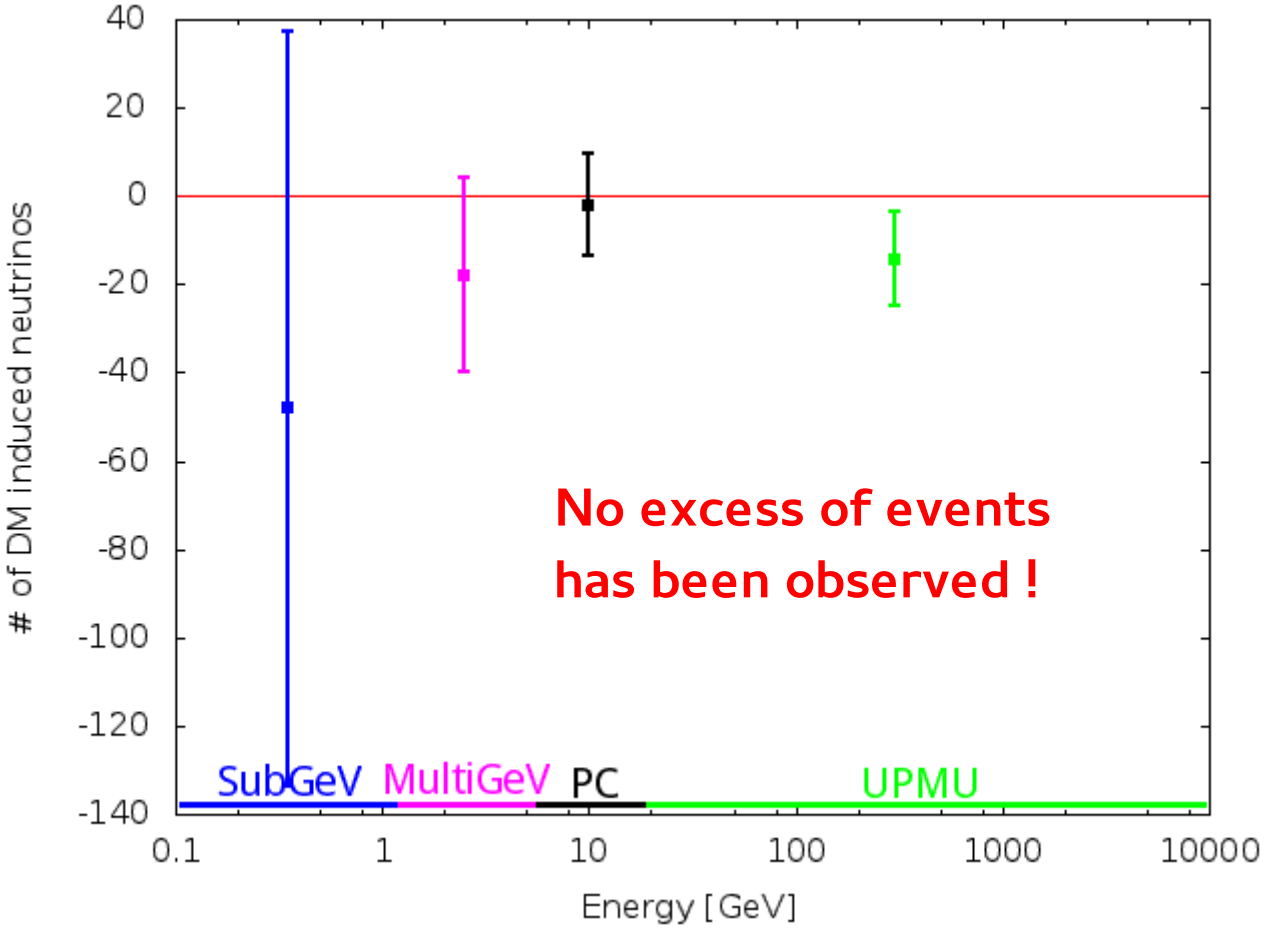
Analysis results:
DM annihilation

Main result: Upper limits on allowed number of DM-induced events

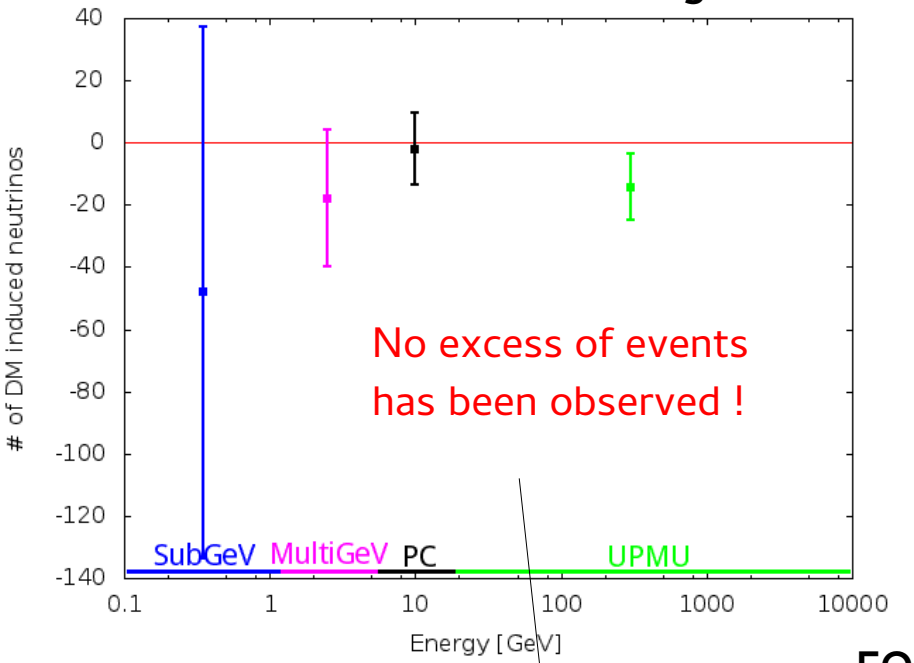
Based on SK 1-4 data (1996-2014)

	Sample	Size	On−source	Off−source	ΔN sig	90% CL ΔN sig
$\nu\bar{\nu}$	FC Sub GeV	80	3628	3676	-48 ± 85.5	114.4
	FC Multi GeV	30	233	251	-18±22	26.9
	PC	20	65	67	-2 ± 11.5	17.7
$b\bar{b}$, W^+W^- , $\mu^+\mu^-$	UPMU	10	49.2	63.5	-14.3 ± 10.6	10.8
	ALL	35	2010.4	2161.1	-150.7±64.6	49.3

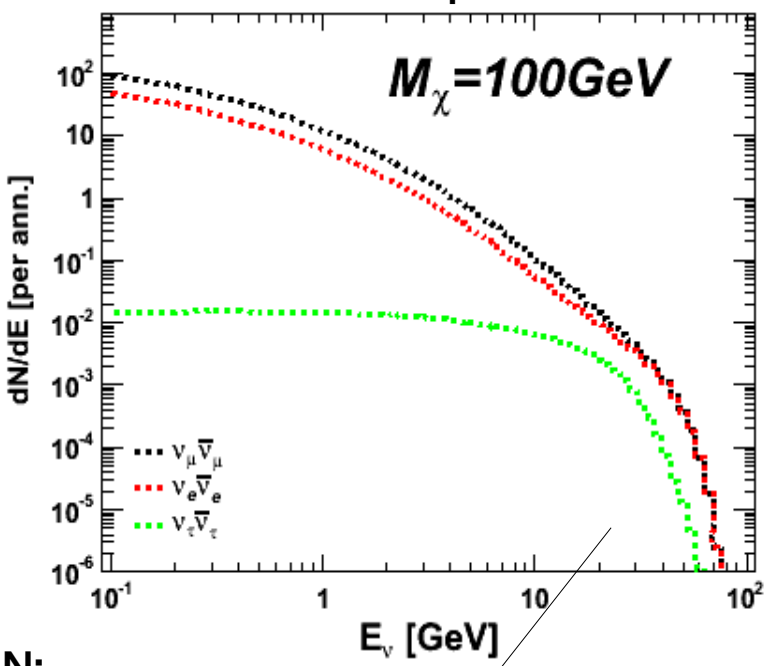




Based on SK 1–4 data: ΔNsig → ∅



DarkSUSY: Example for $b\bar{b}$:

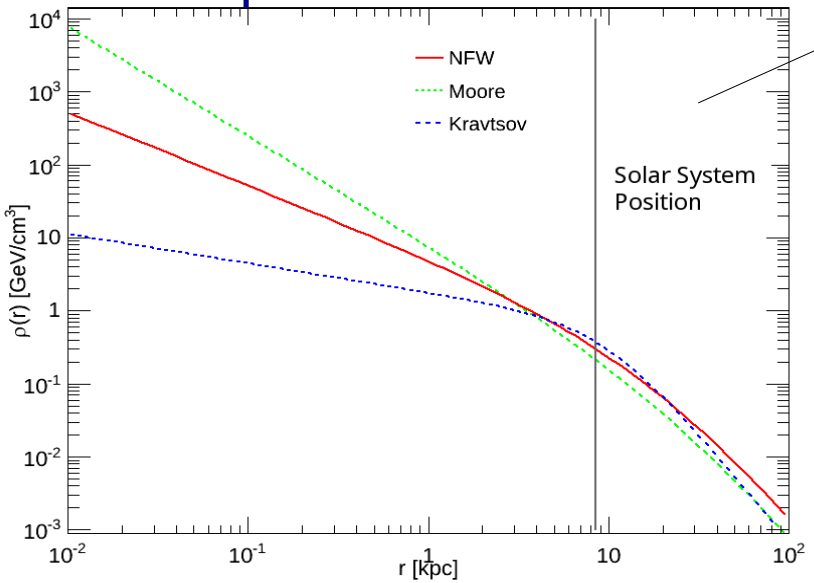


FOR ANNIHILATION:

$$\frac{d\Phi_{\Delta\Omega on}}{dE} - \frac{d\Phi_{\Delta\Omega off}}{dE} = \frac{\langle \sigma_A \upsilon \rangle}{2} \left(J_{\Delta\Omega on} - J_{\Delta\Omega off} \right) \frac{R_{sc}\rho_{sc}^2}{4\pi m_\chi^2} \frac{dN}{dE}$$

$\nu\bar{\nu}$, $b\bar{b}$, W^+W^-, $\mu^+\mu^-$ channels considered

DM halo profiles



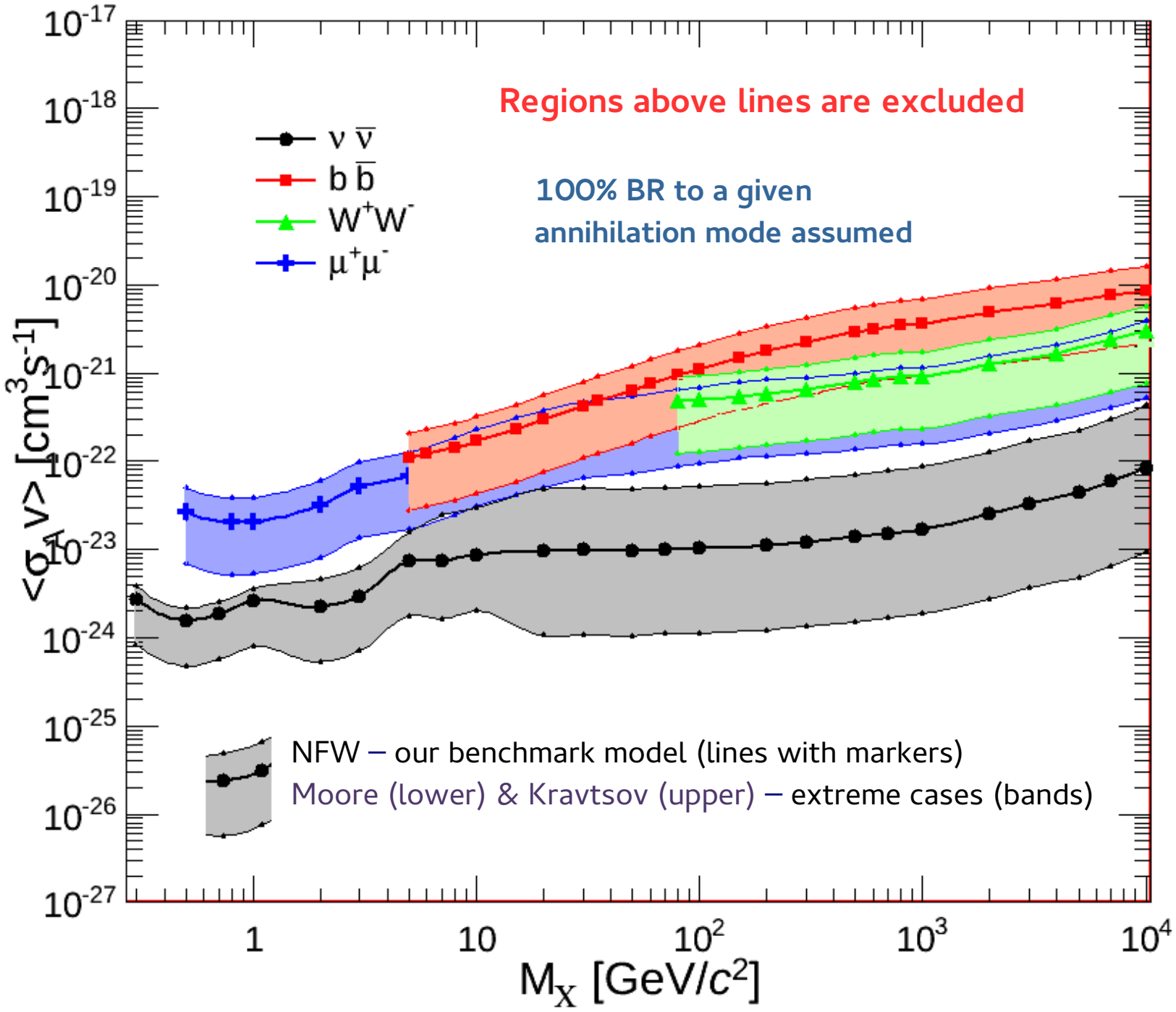
Futher interpretation:

For assumed m_χ
we can calculate $\langle \sigma_A \nu \rangle$

The same procedure
for DM decay analysis

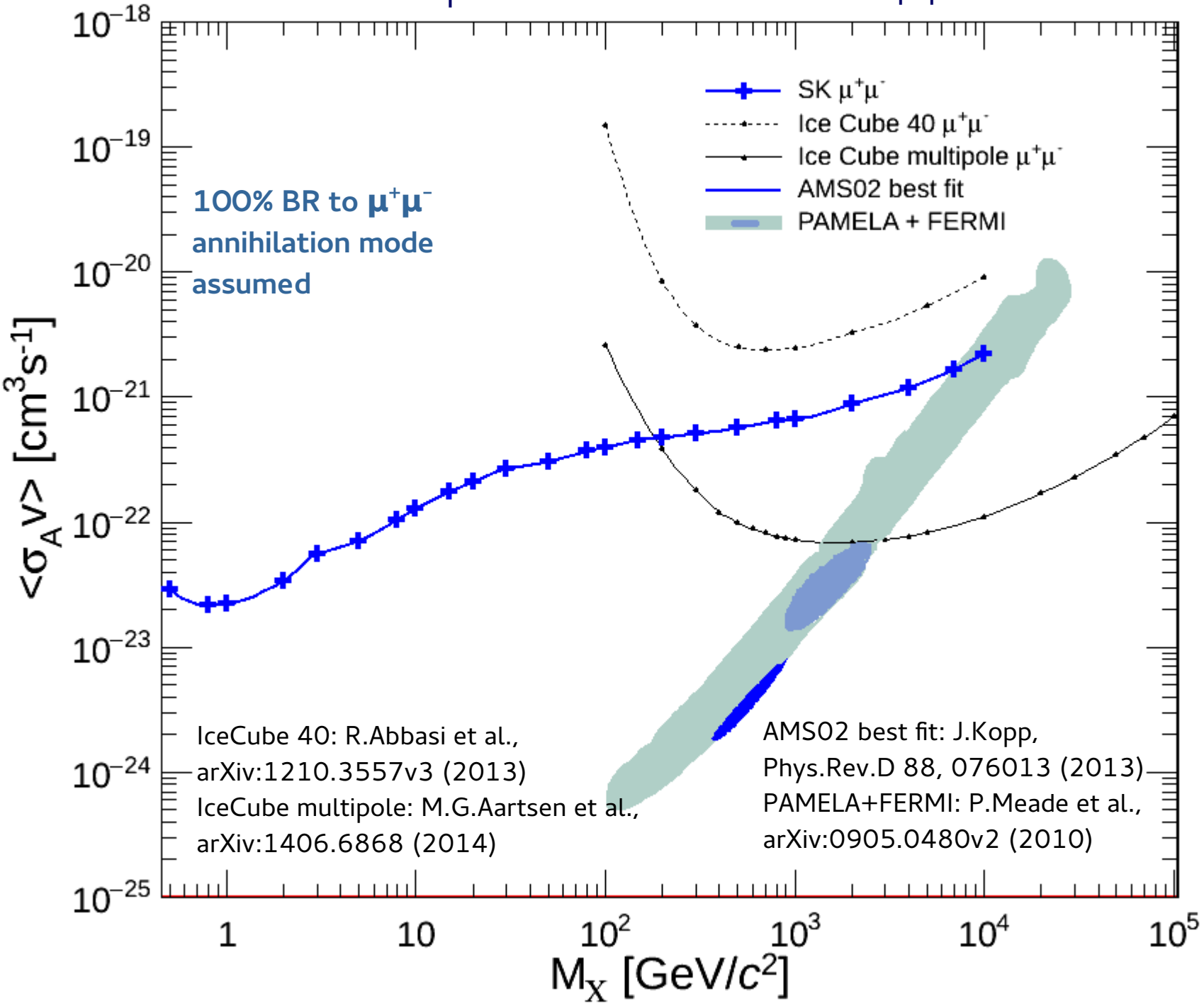
90% CL upper limits on $\langle\sigma_A v\rangle$

+ halo model choice influence



90% CL upper limits on $\langle\sigma_A v\rangle$

- comparison with other results for $\mu^+\mu^-$



Analysis results:
DM decay

Upper limits on allowed number of DM-induced events

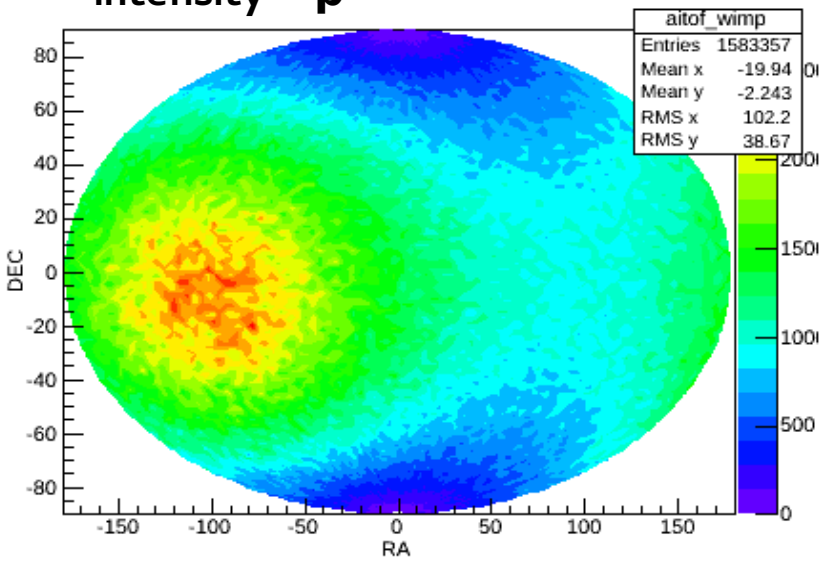
Based on SK 1-4 data (1996-2013)

	Sample	Size	On-source	Off-source	ΔN sig	90% CL ΔN sig
$\nu\bar{\nu}$	FC Sub GeV	80	3628	3676	-48±85.5	114.4
	FC Multi GeV	80	1490	1415	75±53.9	146.7
	PC	80	1049	978	71±45.0	130.2
	UPMU	80	3143.6	3214.6	-71.0±79.7	94.9
$b\bar{b}$, W^+W^- , $\mu^+\mu^-$	ALL	80	9310.6	9283.6	27.0±136.4	241.6

Expected WIMP signal shape for NFW profile:

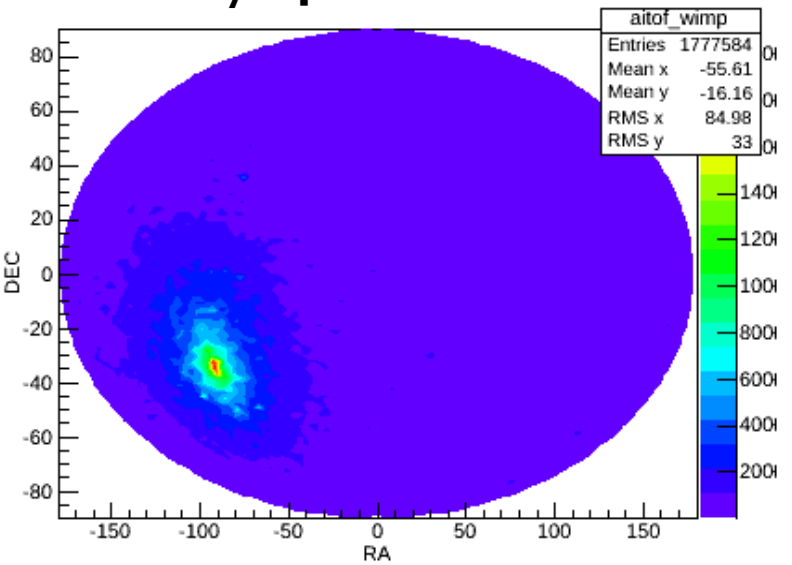
Decay

intensity ~ ρ

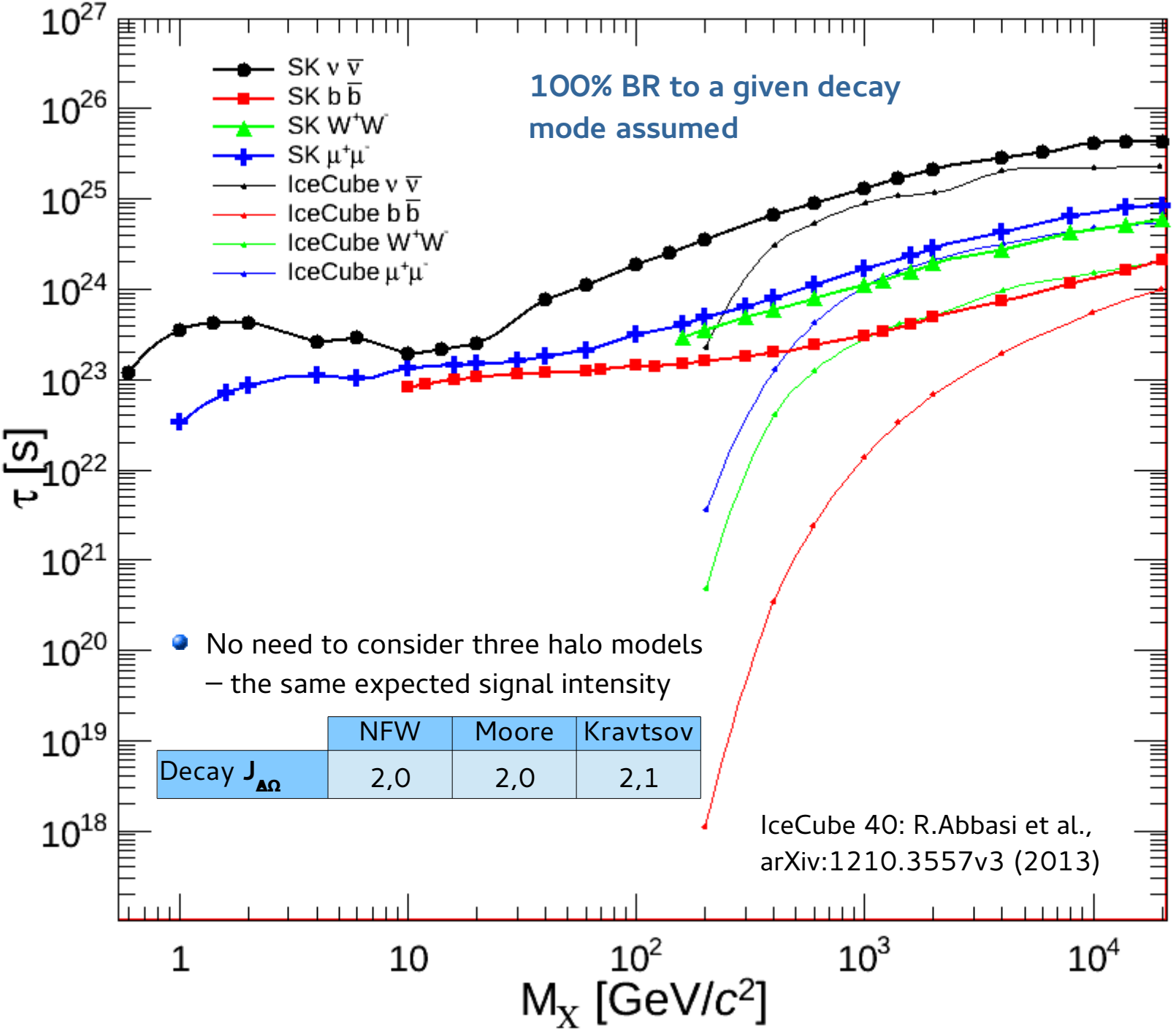


Annihilation

intensity ~ ρ^2



90% CL lower limits on τ



	NFW	Moore	Kravtsov
Decay $J_{\Delta\Omega}$	2,0	2,0	2,1

Summary

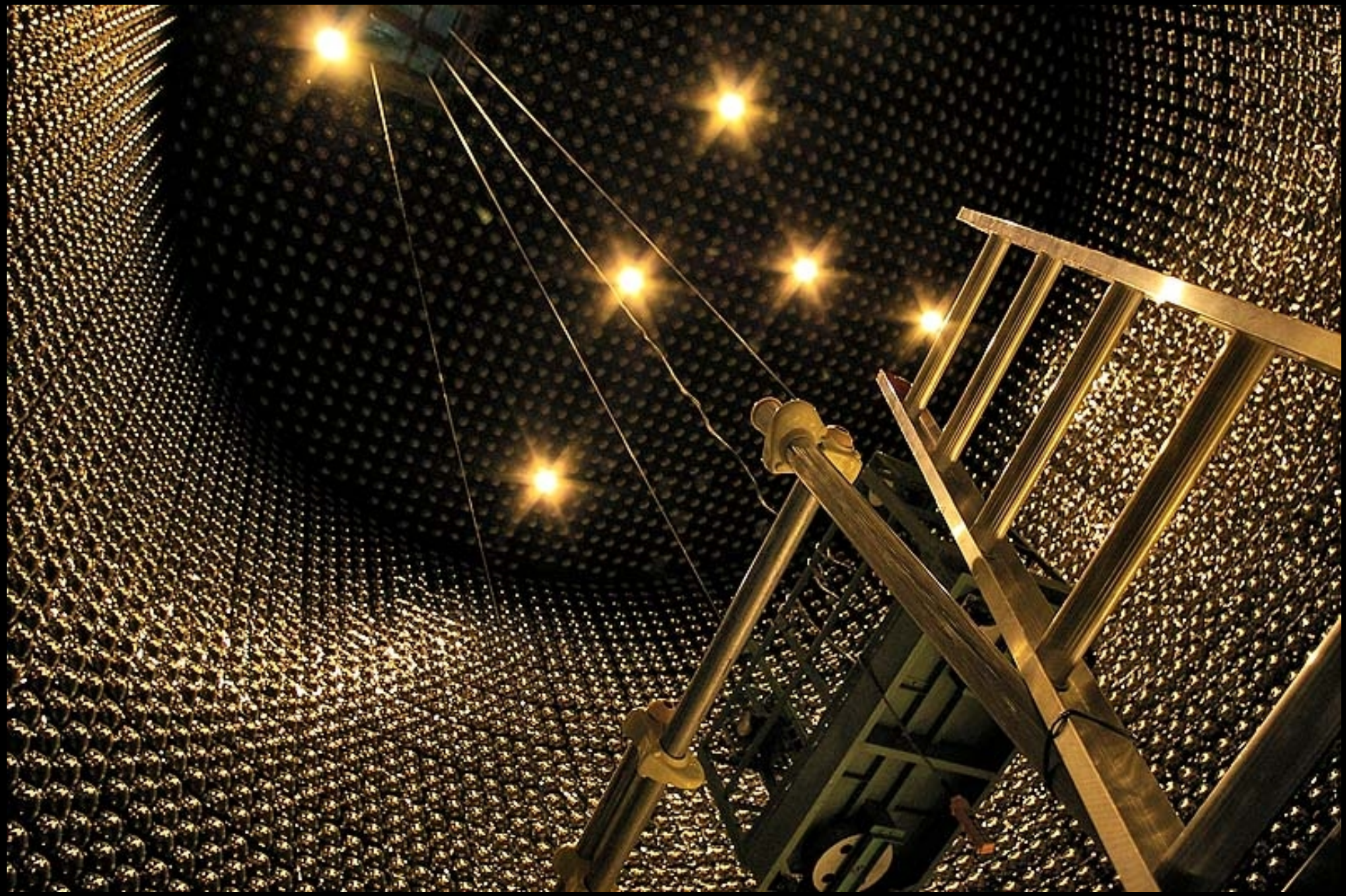
- Dark Matter search is highly challenging field, the existing results are not conclusive, multi-messenger approach is very important

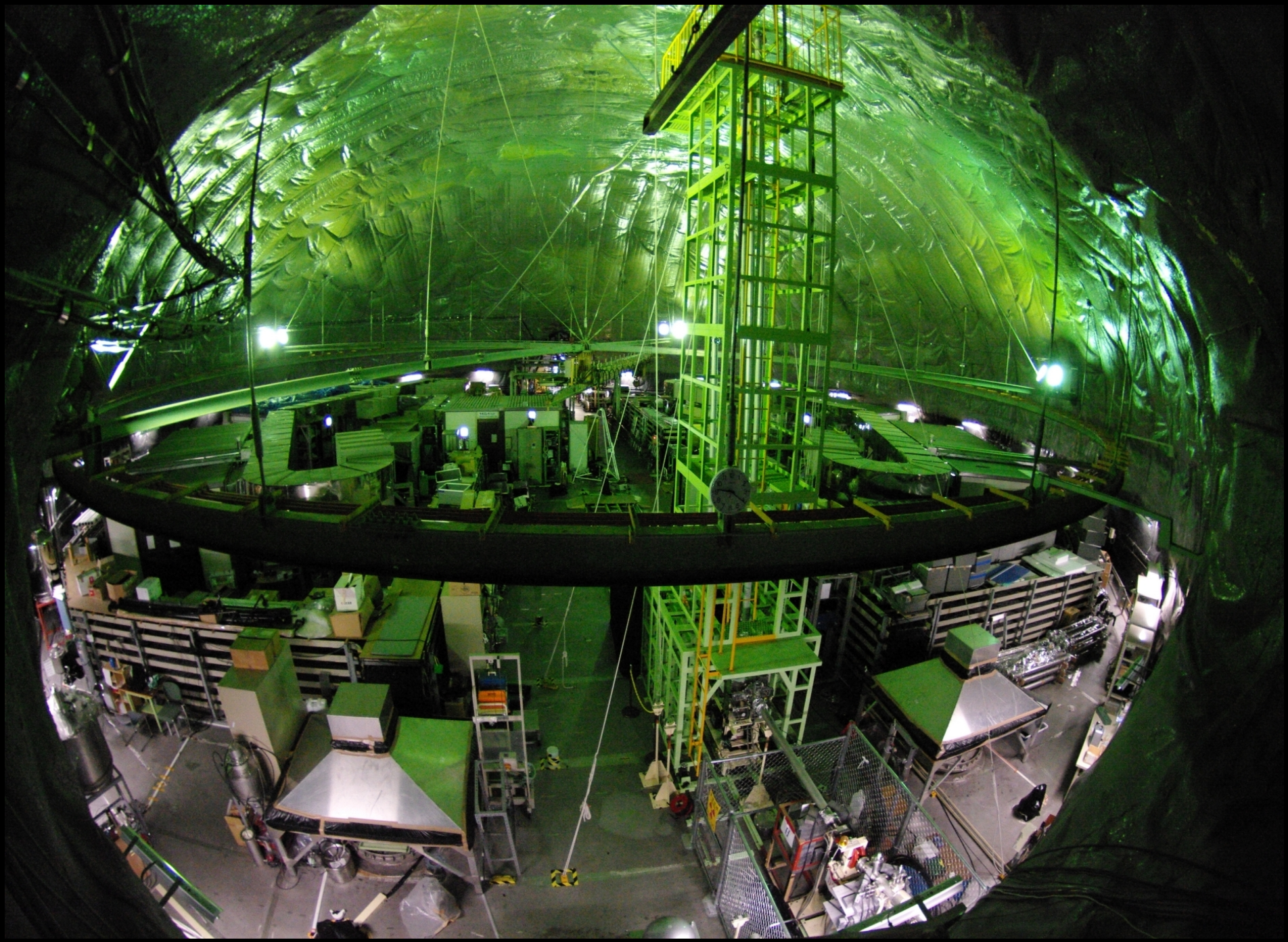
My analysis:

- Limits on WIMP induced neutrinos based on difference in number of events between on-source and off-source regions:
  - background is estimated directly from the data

- The optimal conditions (size of on-source region) for analysis are determined based on performed DM simulation

  - SK 1-4 data samples are used
  - Main result is model independent
  - Four annihilation/decay channels are investigated: $\chi\chi \rightarrow \nu\bar{\nu}$, $b\bar{b}$, W^+W^-, $\mu^+\mu^-$
  - NFW, Moore and Kravtsov DM halo models are considered





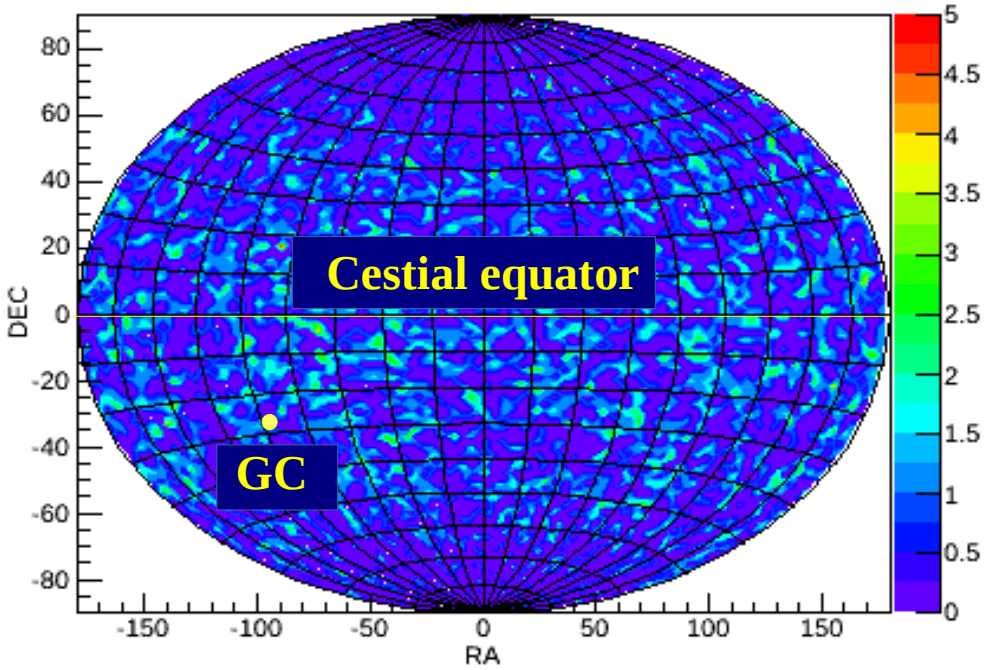
Equatorial coordinate system

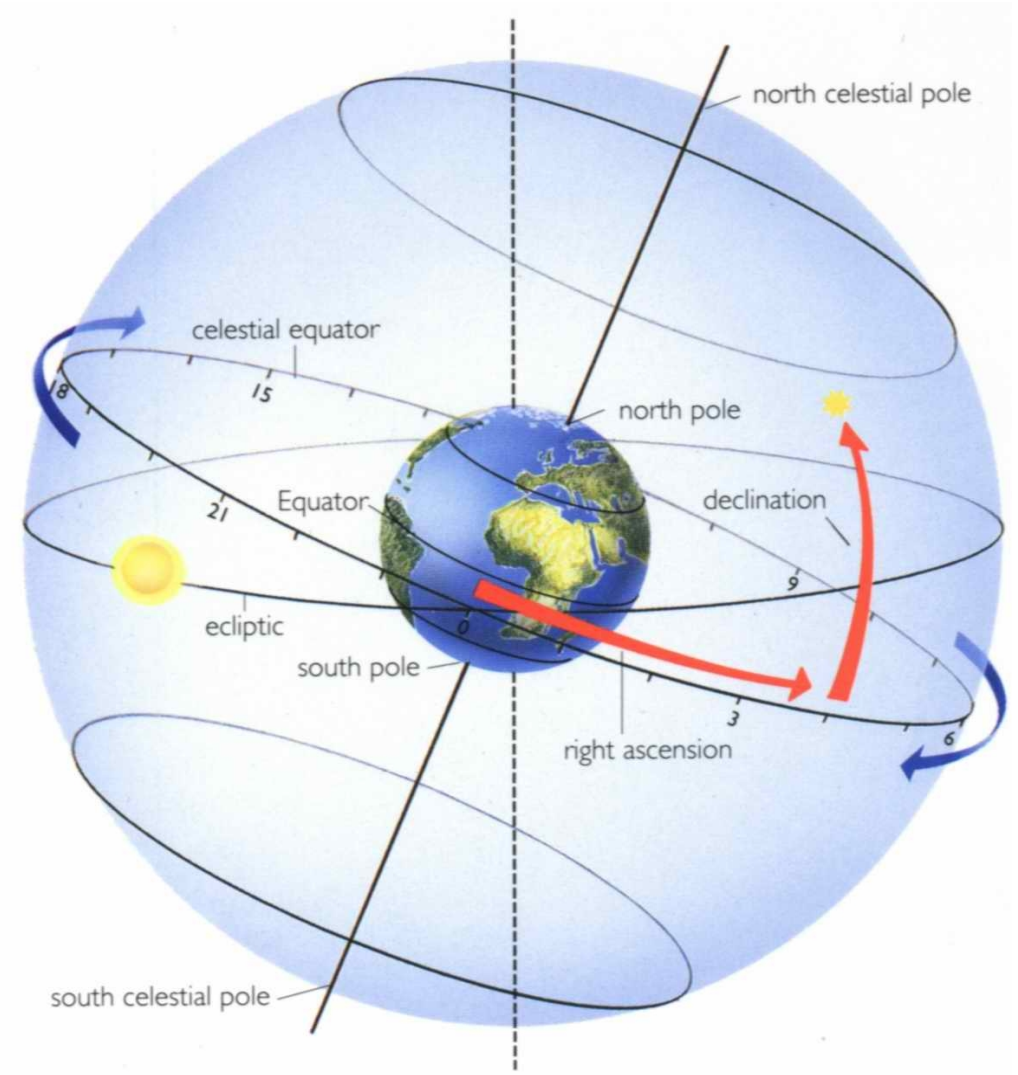
- **Declination (DEC)**

  angular distance of an object perpendicular to the celestial equator

- **Right ascension (RA)**

  angular distance of an object eastward along the celestial equator from the vernal equinox to the hour circle passing through the object



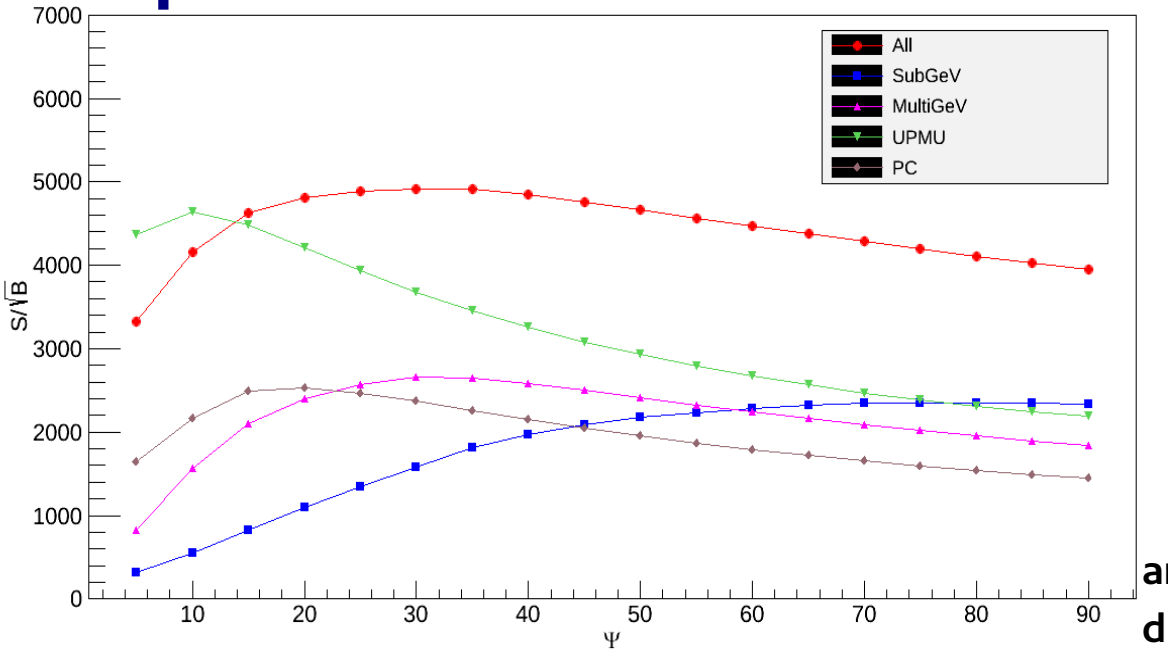


- **Image of the sky in equatorial coordinate system**
- **This coordinate system does not rotate with the Earth, but remains fixed against the background stars**

Determination of the optimal size of the on-source region

For NFW Profile :

Optimization of the S/√B ratio as a function of the distance from the GC



angular distance from GC

Angular resolution differs between various Event classes

Difference between true and reconstructed angular distance from GC