Unbinned search for dark matter in the Sun and the galactic center with ANTARES

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Method

- A "Binning" method has been adapted from Guillaume Lambard (I am very grateful for that)
- For every event of a measurement period a number of randomly chosen source positions from the amount of 5000 source positions during the measurement period has been used for the background estimation
- Every so produced source position and event combination is inserted in a histogram displaying the angular difference to the random source position vs. the fit quality parameter of the event
- The data from 2007 to 2012 have been used

Setup and comparison

AAFit recons. BBFit recons.	X	Single line (BBFit only) Multiline	X	Sun Galactic Center

- Comparison has been made to Guillaume's limits for the 2007 to 2012 data only for the Sun using a "binning" estimation method
- Both the flux and the cross section limits show great agreement with Guillaume's results in every annihilation channel

Example: AAFit Sun

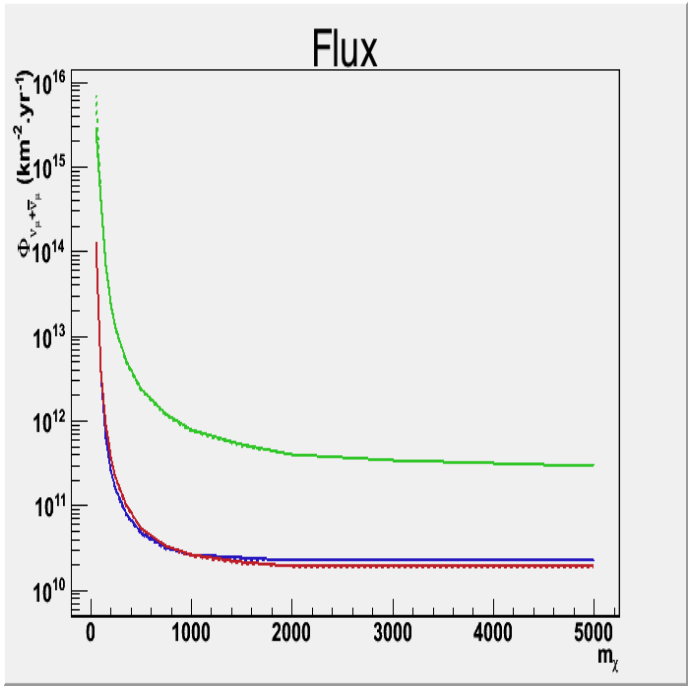


Figure : Dashed: my limits, Solid: Guillaume's
Green: $b\bar{b}$, Blue: W^+W^-
Red: $\tau^+\tau^-$

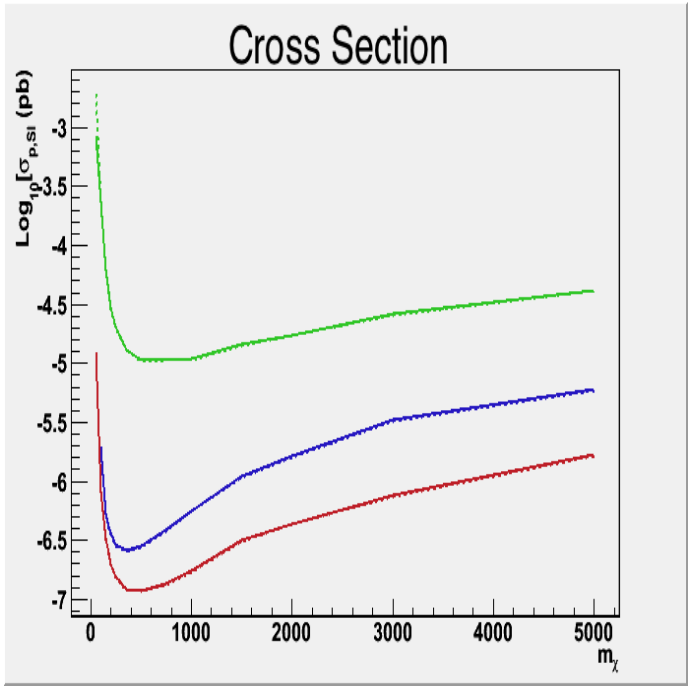
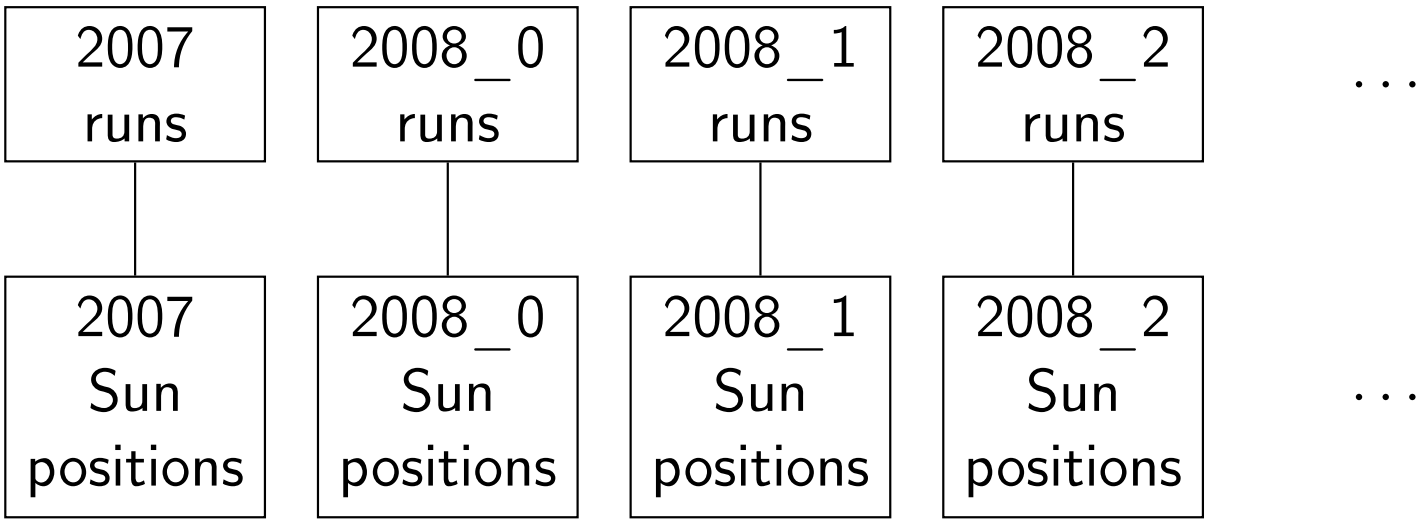


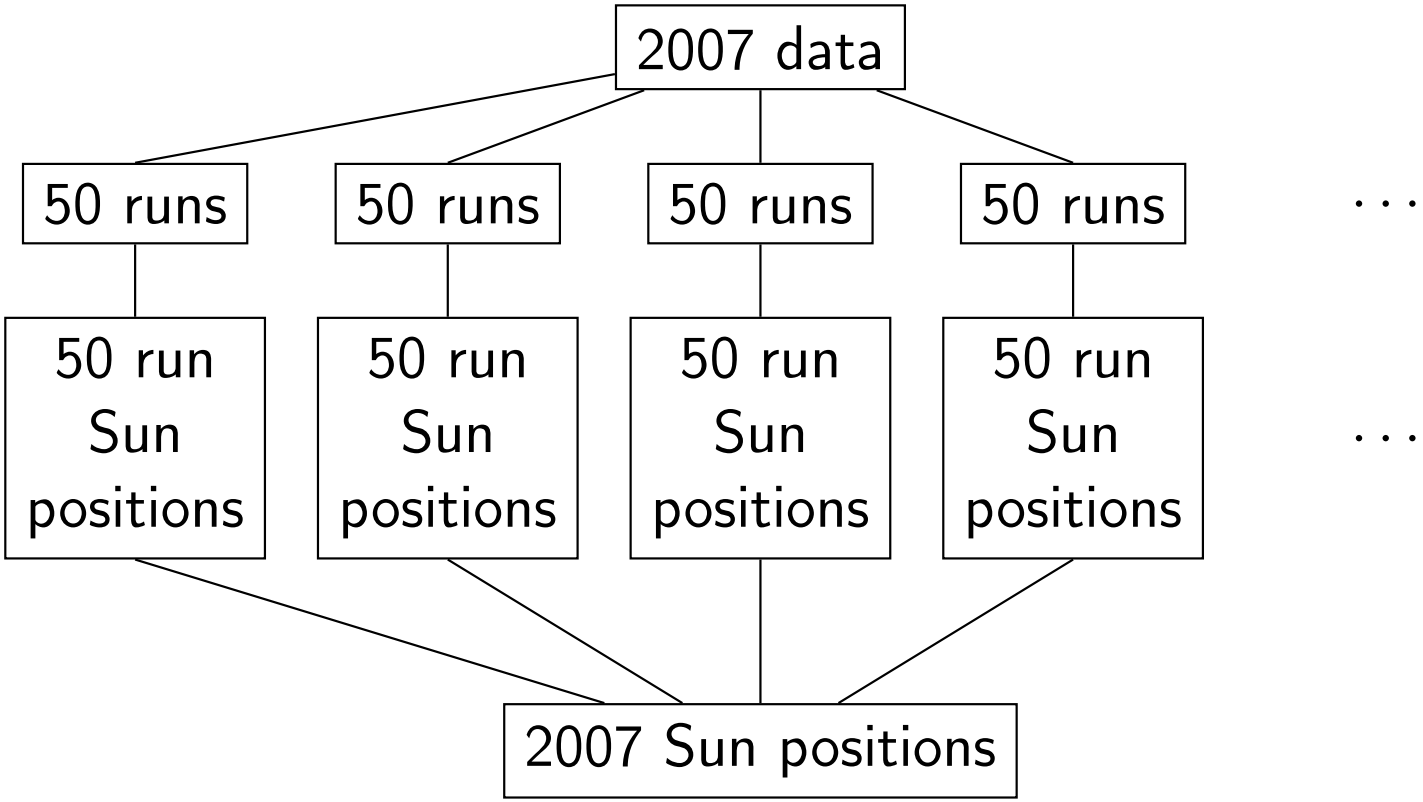
Figure : Dashed: my limits, Solid: Guillaume's
Green: $b\bar{b}$, Blue: W^+W^-
Red: $\tau^+\tau^-$

No splitting



Take all source positions of a detector configuration period for all the data of a detector configuration period

Splitting



Split both the source poitions and the data and use for a data bunch only the encompassing source position bunch

Unbinning method

- It is possible to apply the "unbinned" method of the point source analysis of ANTARES to the Dark Matter analysis for the sun and the galactic center. A change from a "binning" to a "unbinning" method improves the produced limits typically about 30% .
- The first step is to produce several random skies with a varying number of fake signal events
- For the produced background one uses the statistics of the measured data, for the fake signal one uses the detector PSF and statistics obtained from the monte carlo data and simulated signal spectra

Likelihood function

- For each produced random sky one then evaluates a likelihood function

$$\log(L) = \log\left(\prod_i P_i\right) = \sum_i \log\left(\frac{n_s}{N} S_i + \left(1 - \frac{n_s}{N}\right) B_i\right)$$

- B_i is the likelihood density for the ith event to be Background as produced from the monte carlo data, S_i the corresponding likelihood density for the ith event to be signal
- N is the total number of events and n_s is the assumed number of signal events
- This function expresses the likelihood of a random sky to contain n_s signal events

Example: likelihood function

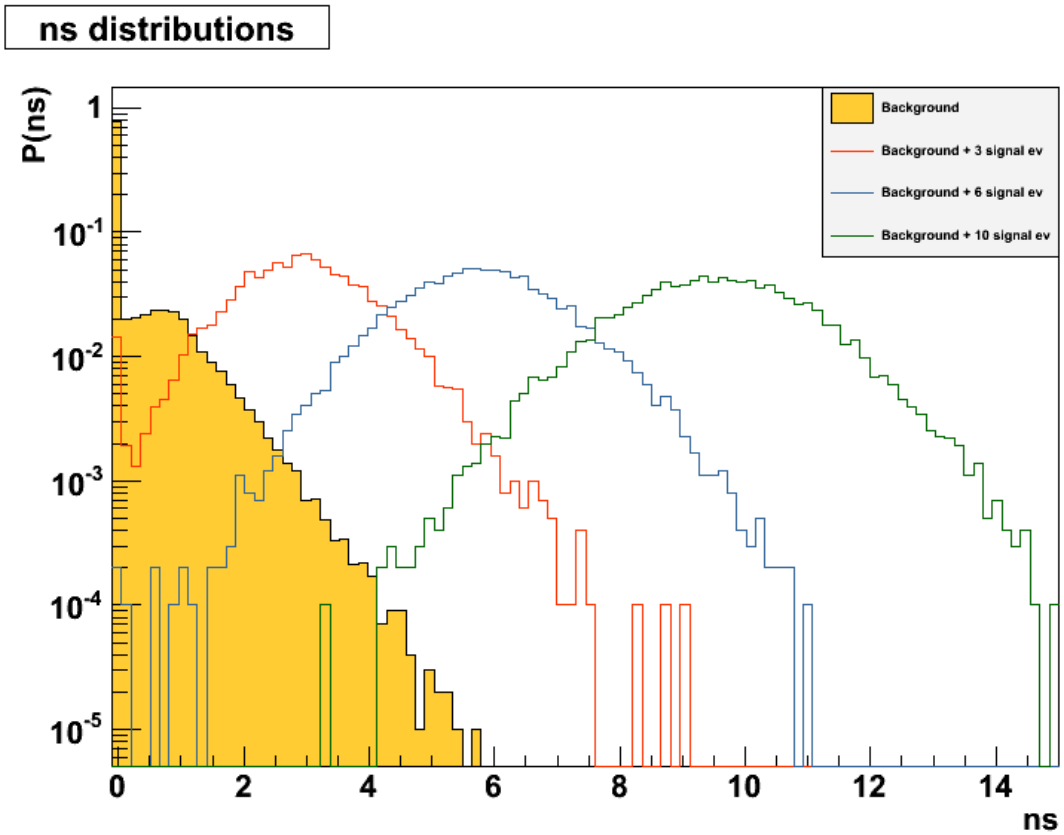


Figure : A example for histogram of the number of psuedo experiments vs. the optimum n_s value in the likelihood function, plot by Javier Barrios Marti

Test statistics and limits

- Once the likelihood function maximized with respect to n_s one creates the test statistics:

$$TS = \log\left[L^{max}\right] - \log\left[L(n_s = 0)\right]$$

- The maximum number of signal events in one pseudo experiment is considered to be n_s^{max} for the test statistic
- The total upper limit is then calculated with the statistics of n_s^{max} using the Neyman method
- This limit is then converted using a acceptance calculated from the Monte Carlo data

Example plot: test statistics

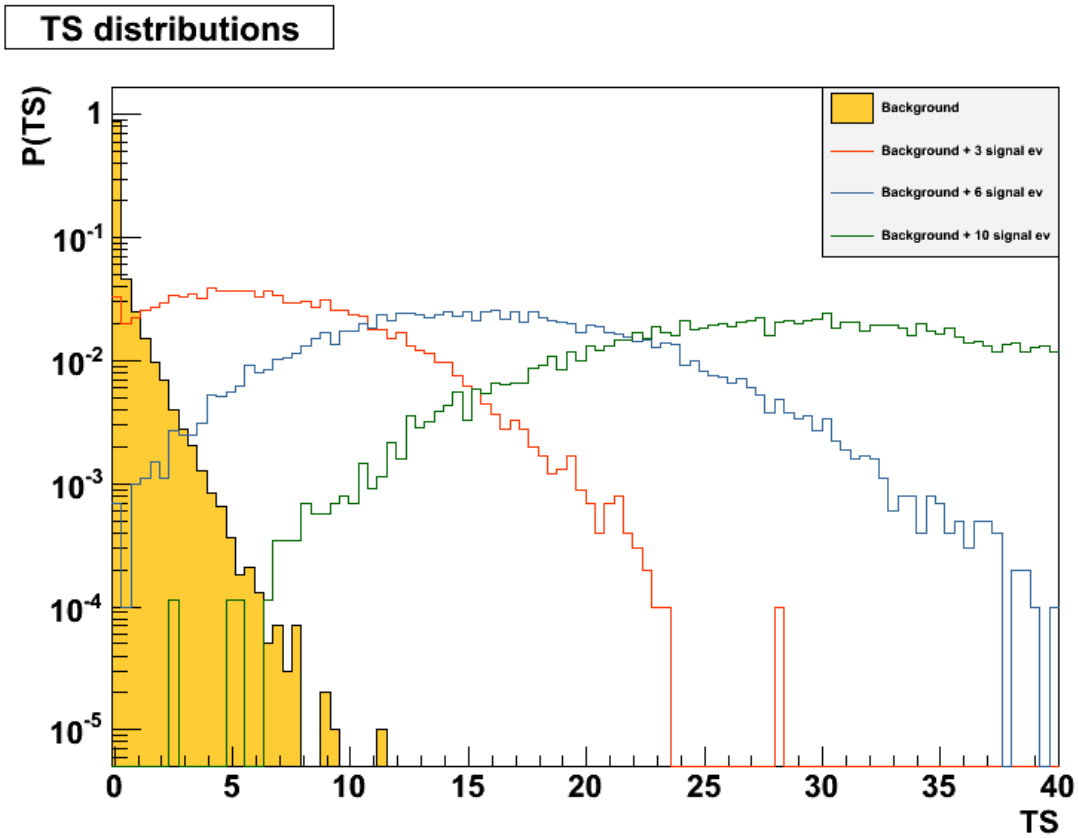


Figure : A example for histogram of the number of psuedo experiments vs. the TS value, plot by Javier Barrios Marti

Example plot: discovery power

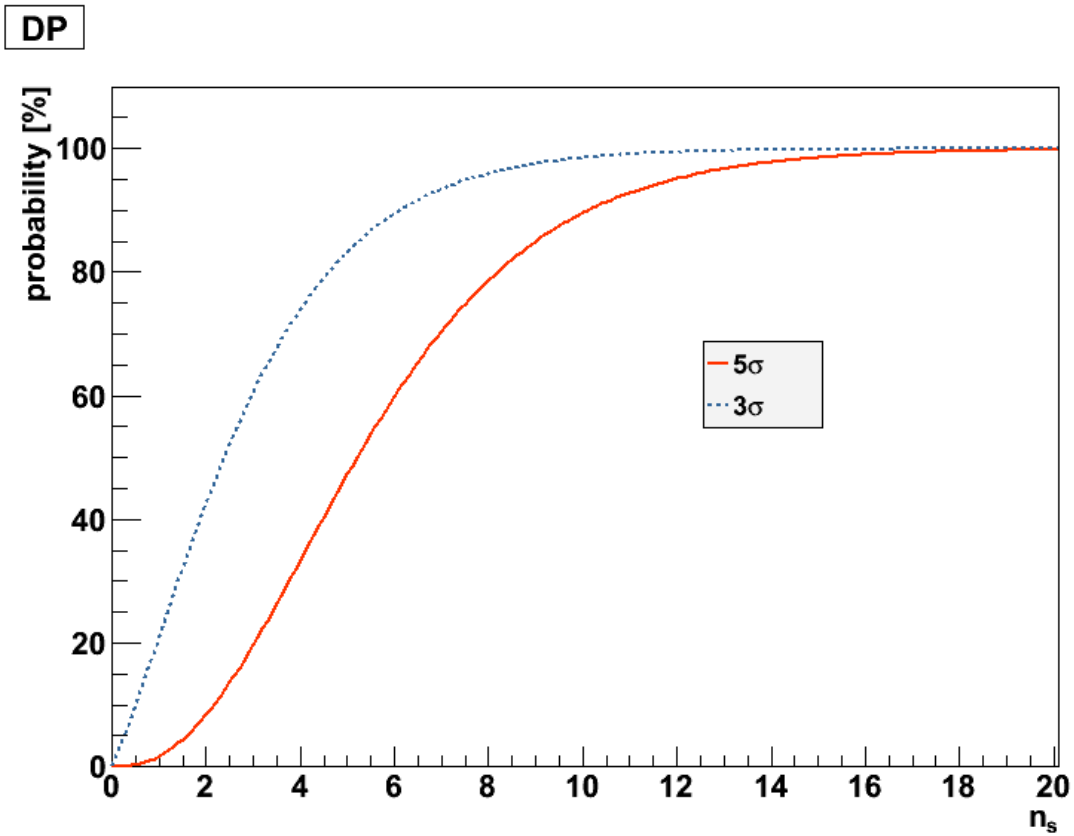


Figure : A example for the discovery likelihood vs. the number of signal events for different discovery powers, plot by Javier Barrios Marti

Unbinned method: Galactic Center

- The major difference to the conventional point source analysis lies in the acceptance used to convert the statistics of detected events into a neutrino flux and in the statistics used to produce the fake signal events in the random skies
- For the acceptance and the signal statistics one has to use a expected dark matter neutrino signal, which can be produced by the program DarkSusy
- The different annihilation channels and possible WIMP masses have to be taken into account, leading to the same types of limits as in the "binning" analysis

The Sun

- In addition to the dark matter neutrino signal spectrum one has to care for the movement of the source in declination in the case of the Sun
- The most direct way to take care of this issue is to add the Sun position at the time of the event (first attempt)
- Alternatively one can also use a set of random Sun positions from the detector configuration period (probably a very slow method, but with better statistics)
- Another way would be a splitting similar to the splitting in the "Binning" method (most likely a bit faster than the previous method with also slightly better statistics, but one could end up with stronger systematics)

Summary

- The "binned" analysis of Guillaume Lambard (Thank you) could be successfully reproduced in the case of the multiline events
- Some methods to accelerate the analysis have been implemented and tested
- The application of point source analysis methods to the dark matter analysis is planned