UHECRs from point sources

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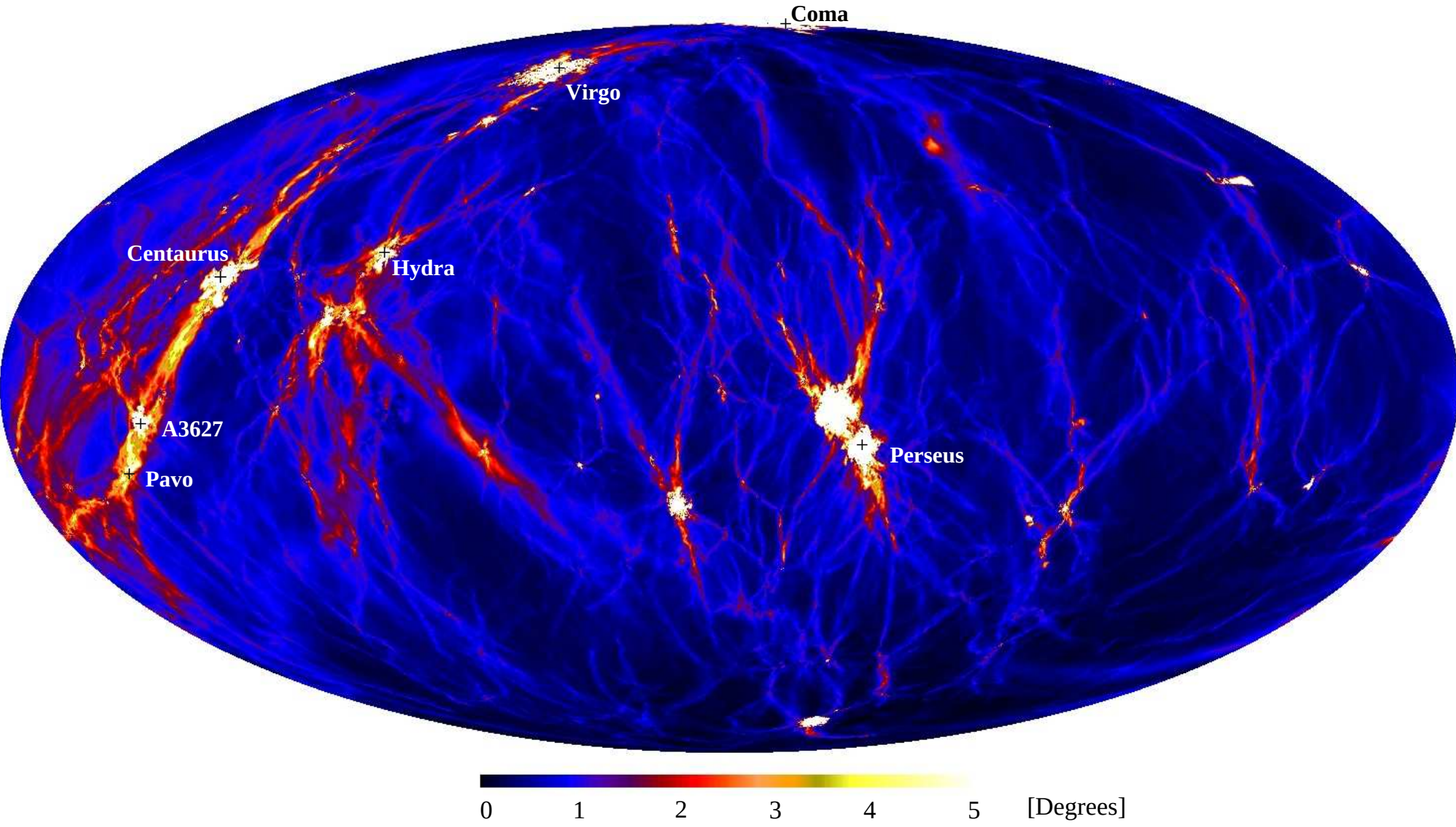
Outline of the talk:

- Introduction
- Uniformly distributed sources:
  - best-fit density n_s
  - fraction of true clusters
  - predictions for PAO
- BL Lacs as proton sources: is there a consistent model possible?
- Summary

Extragalactic magnetic field:



[*Dolag, Grasso, Springel, Tkachev, astro-ph/0310902*]

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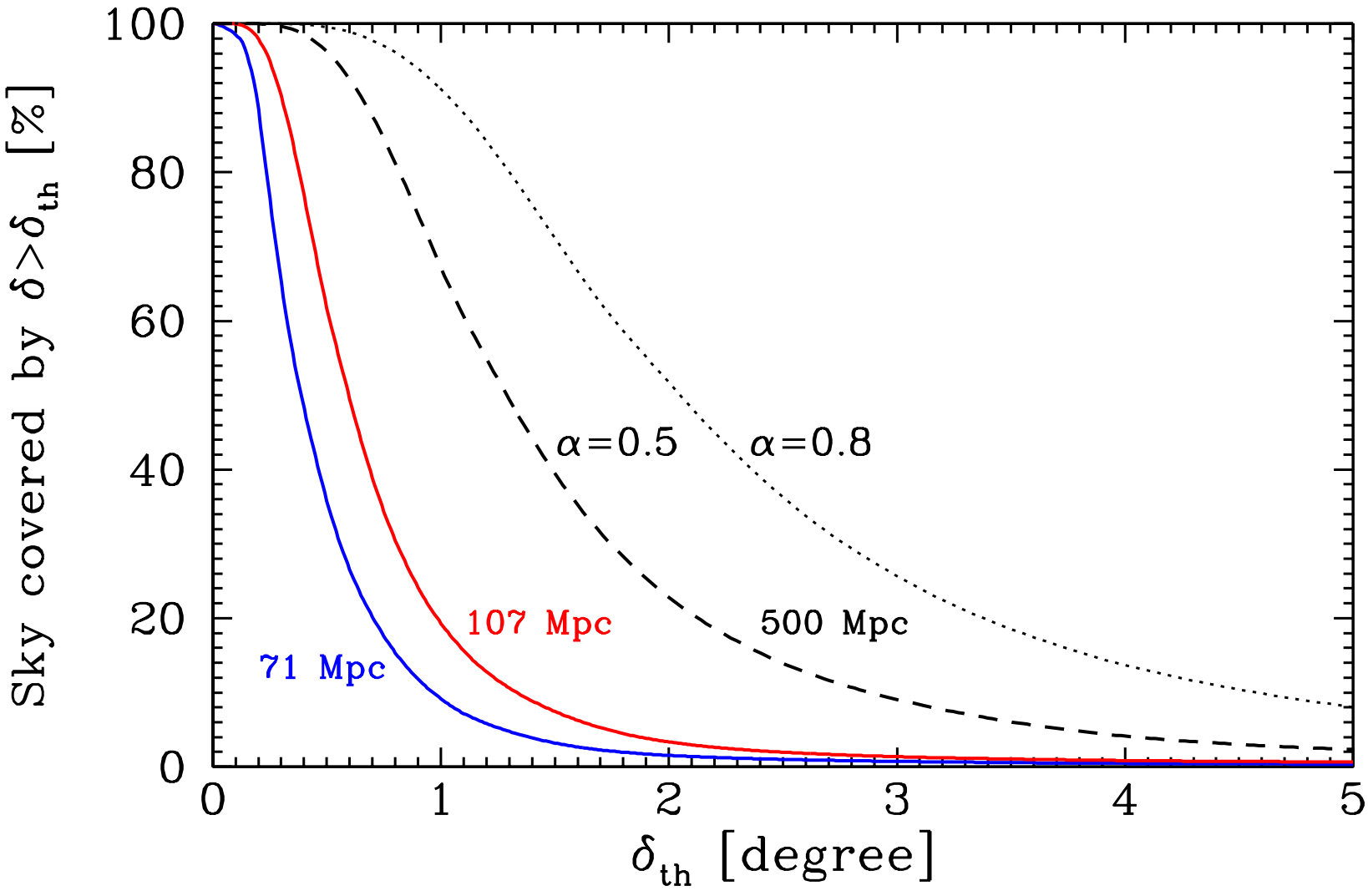

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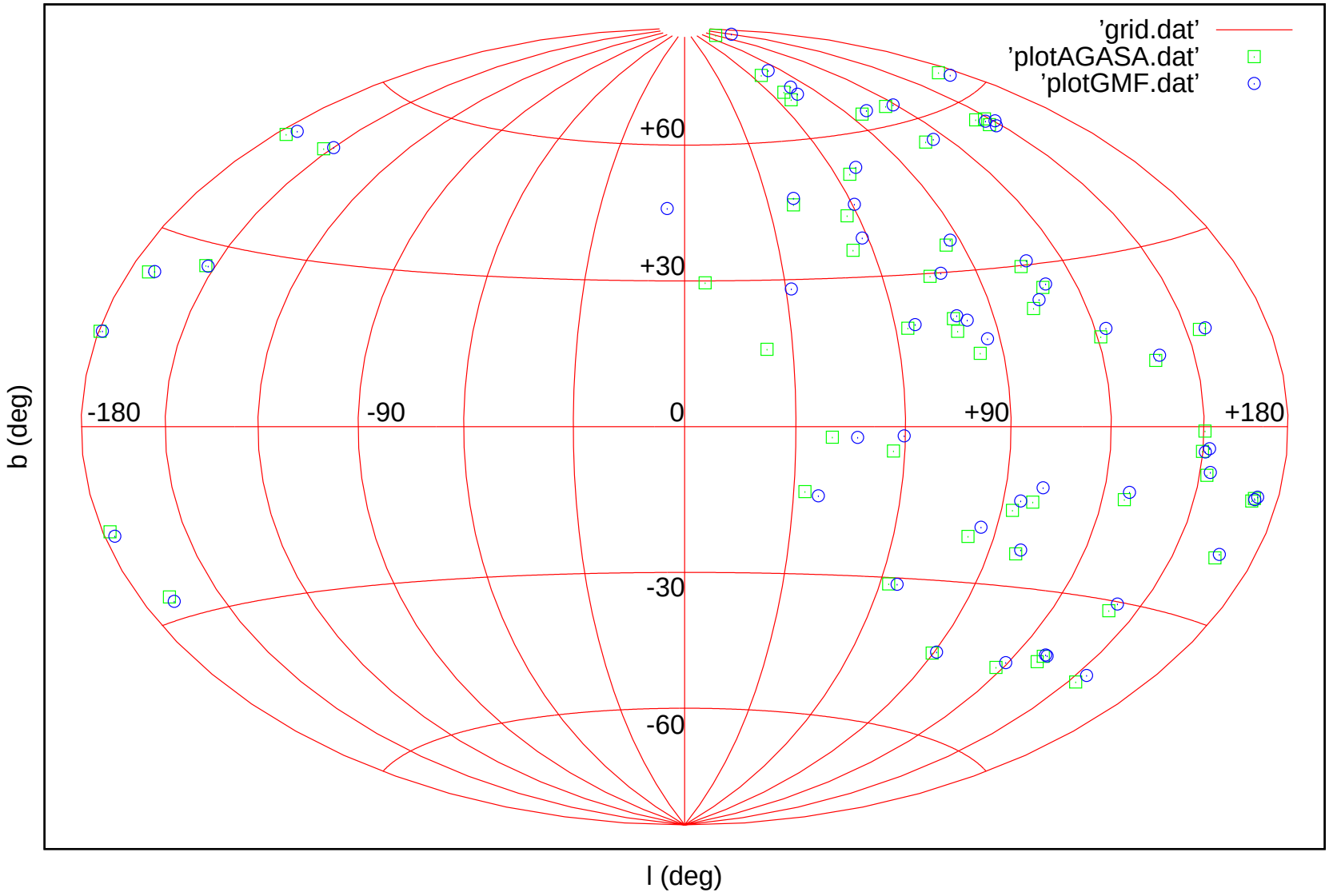
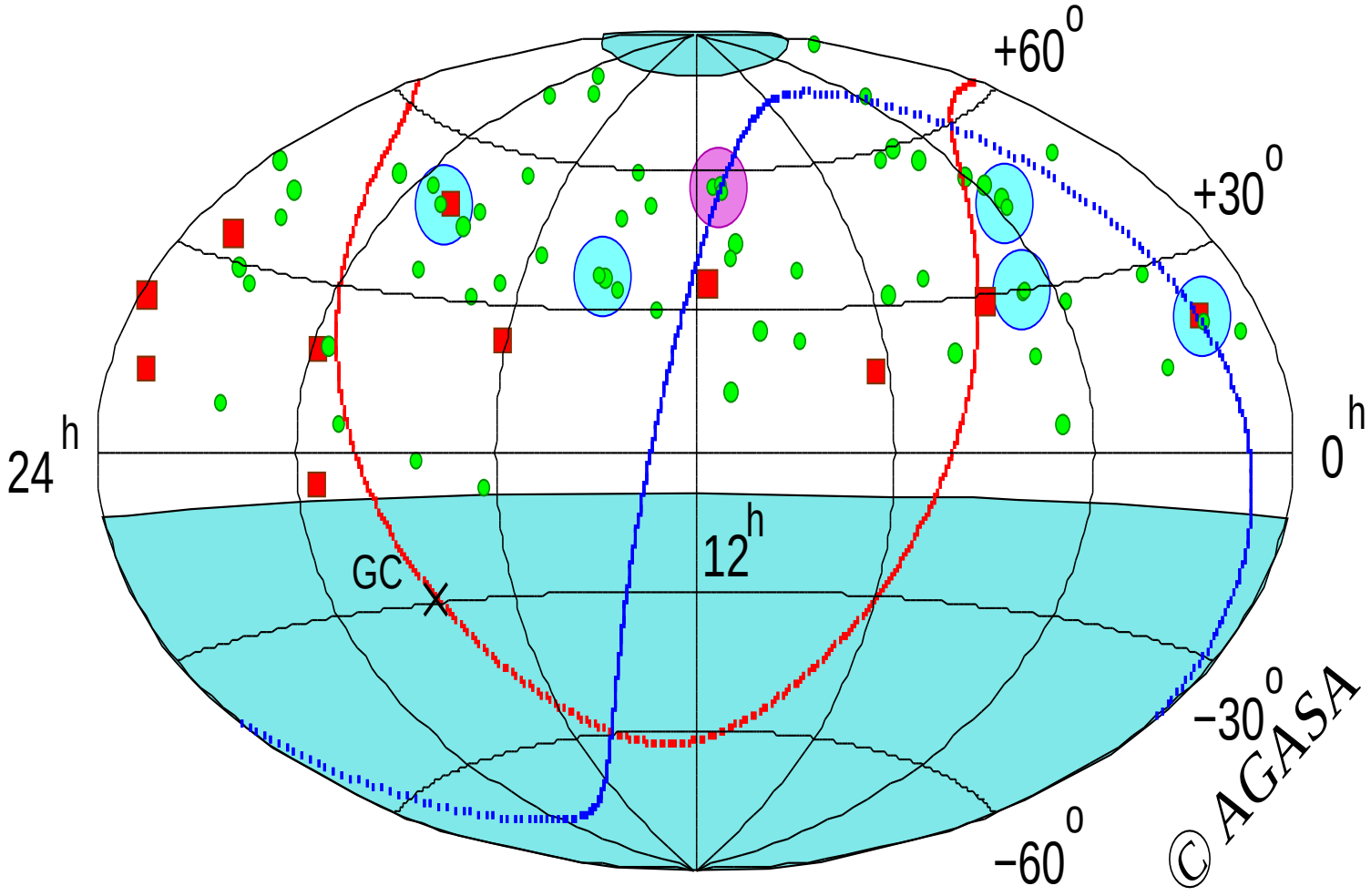
Galactic magnetic field:

Hammer-Aitoff Proj. in Gal. Coord. of the observed and GMF deflected positions of UHECRs in AGASA data



Small-scale clustering in AGASA:



- $E > 10^{20}$ eV
- $E = 4 - 10 \times 10^{19}$ eV

Small-scale clustering:

- How to define statistical significance of clustering?
- autocorrelation function of the data, e.g.

$$w_1 = \sum_{i=1}^{N} \sum_{j=1}^{i-1} \Theta(\ell_1 - \ell_{ij}) \,,$$

  where ℓ_{ij} is the angular distance and ℓ_1 the bin size chosen.
- deviation from expectation for an isotropic distribution

$$r = \frac{w_1^* - \langle w_1^{\rm MC} \rangle}{\sigma^{\rm MC}}$$

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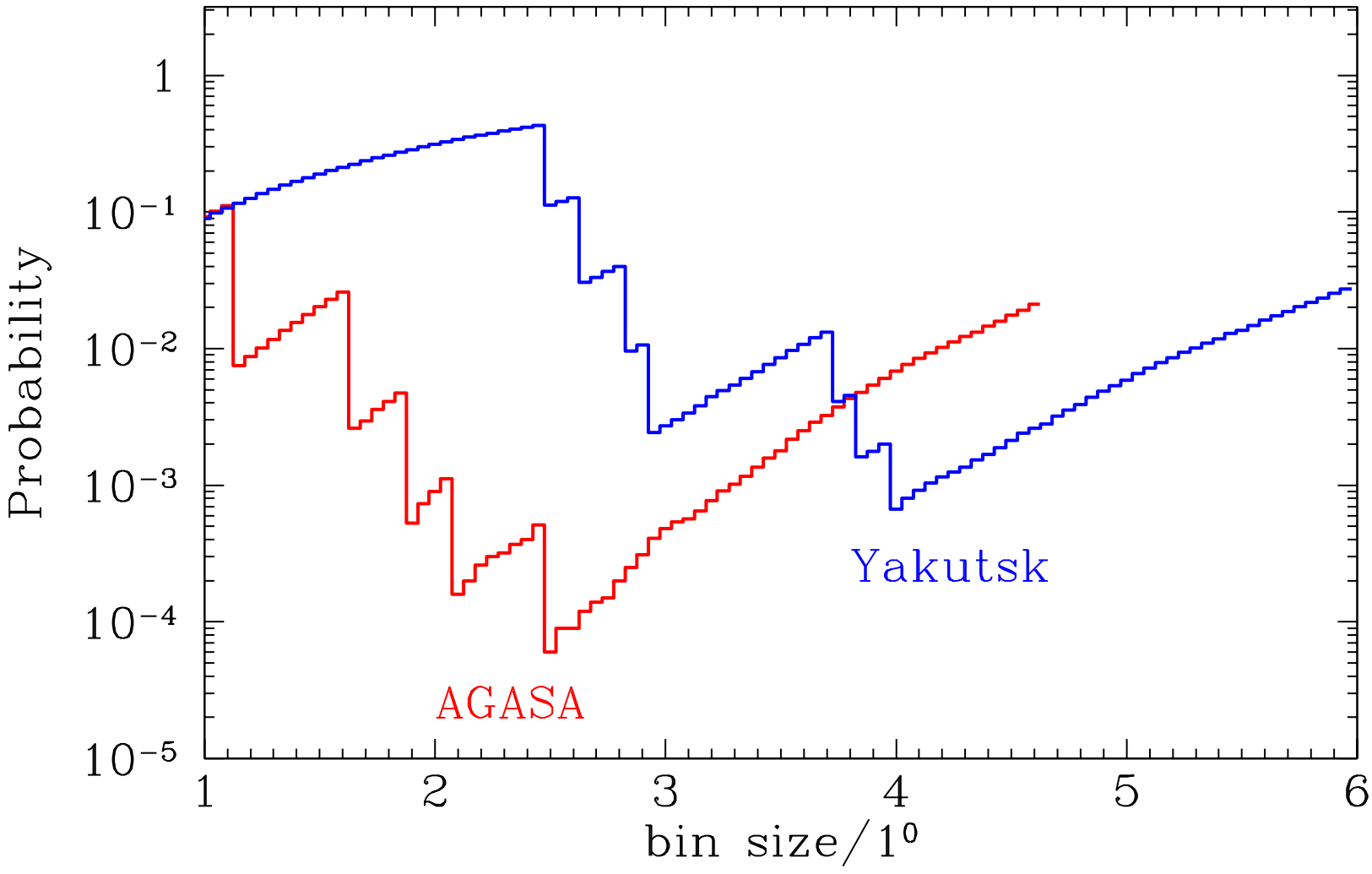
$$r = \frac{w_1^* - \langle w_1^{\mathrm{MC}} \rangle}{\sigma^{\mathrm{MC}}}$$

- test hypothesis: continuous, isotropic distribution on S^2, expectation: lower values of w_1 than measured

$$\Rightarrow P_>(w_1^*; S^2) = \sum_i p_i(w_1; S^2) \Theta\left(w_1 - w_1^*\right) \ .$$

but controversy about cuts and penalty factors:



Finley, Westerhoff, astro-ph/0309159: $p_{ch} = 8\%$.
HiRes Stereo: no clusters astro-ph/0404137

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$\Rightarrow$ optimal bin size for AGASA around 2.5°

Number of sources N_s

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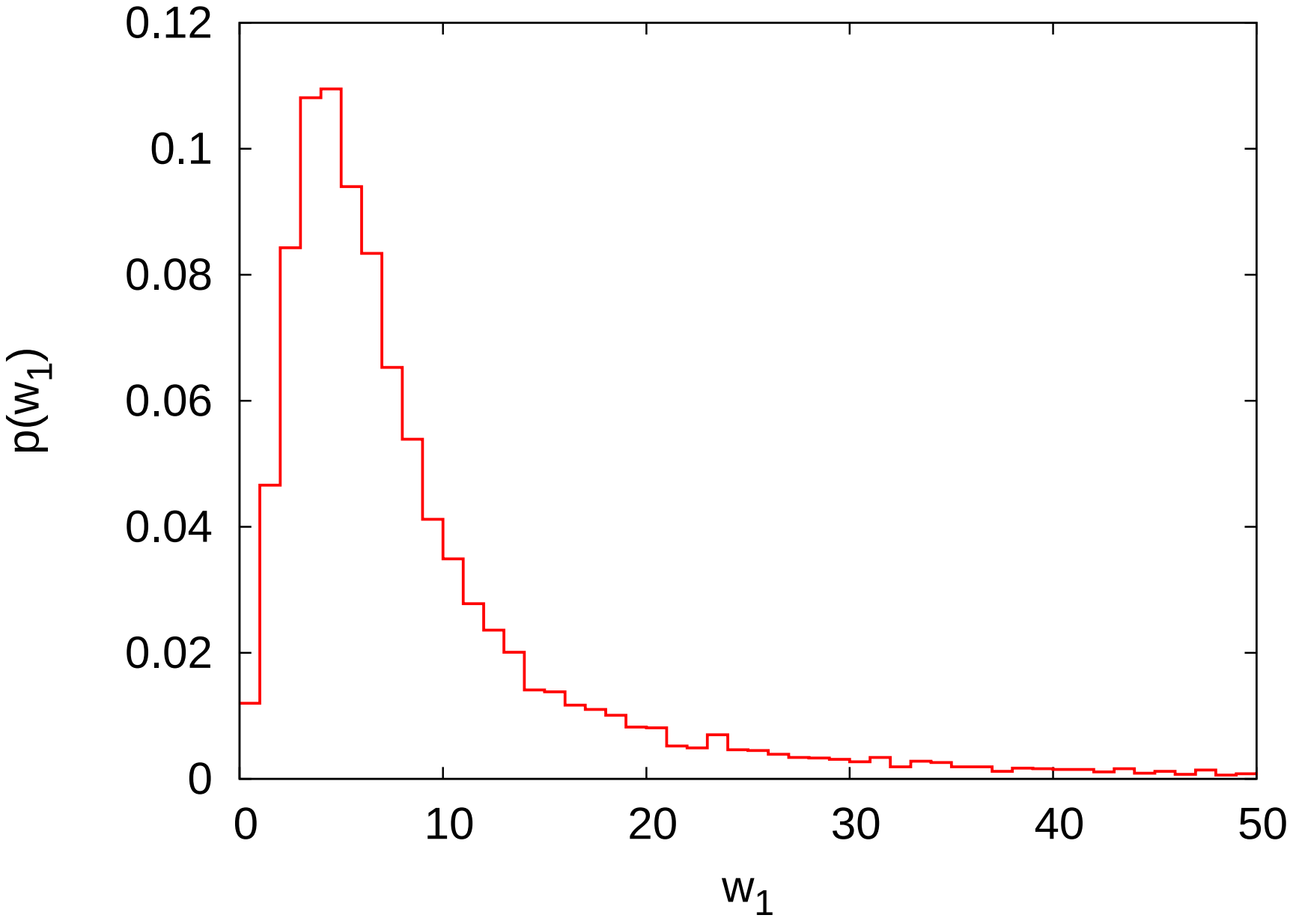
- allows to estimate n_s:
  - ◇ choose finite number of sources according denity n_s
  - ◇ generate CRs according to $dN/dE \propto E^{-\alpha}$
  - ◇ propagate them
  - ◇ calculate w_1 for fixed n_s, α, ℓ_1 ...
  - ◇ determine consistent parameters

Distribution of $p(w_1; n_s)$:



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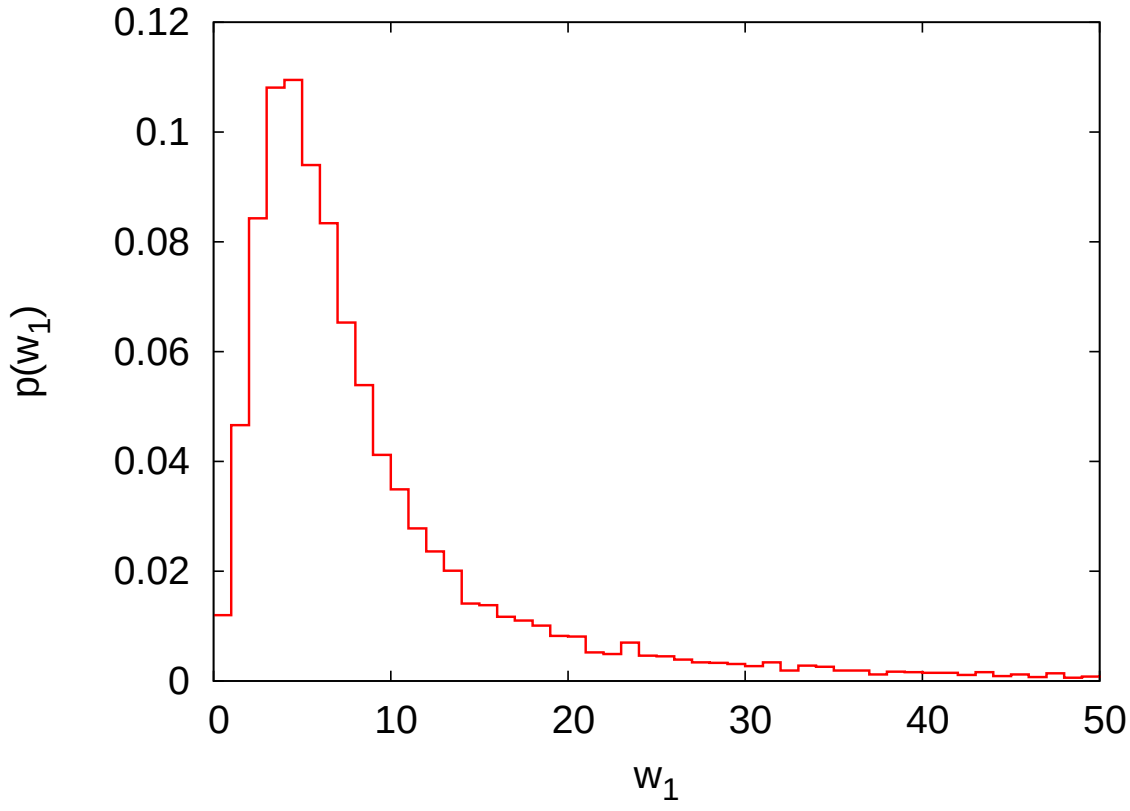
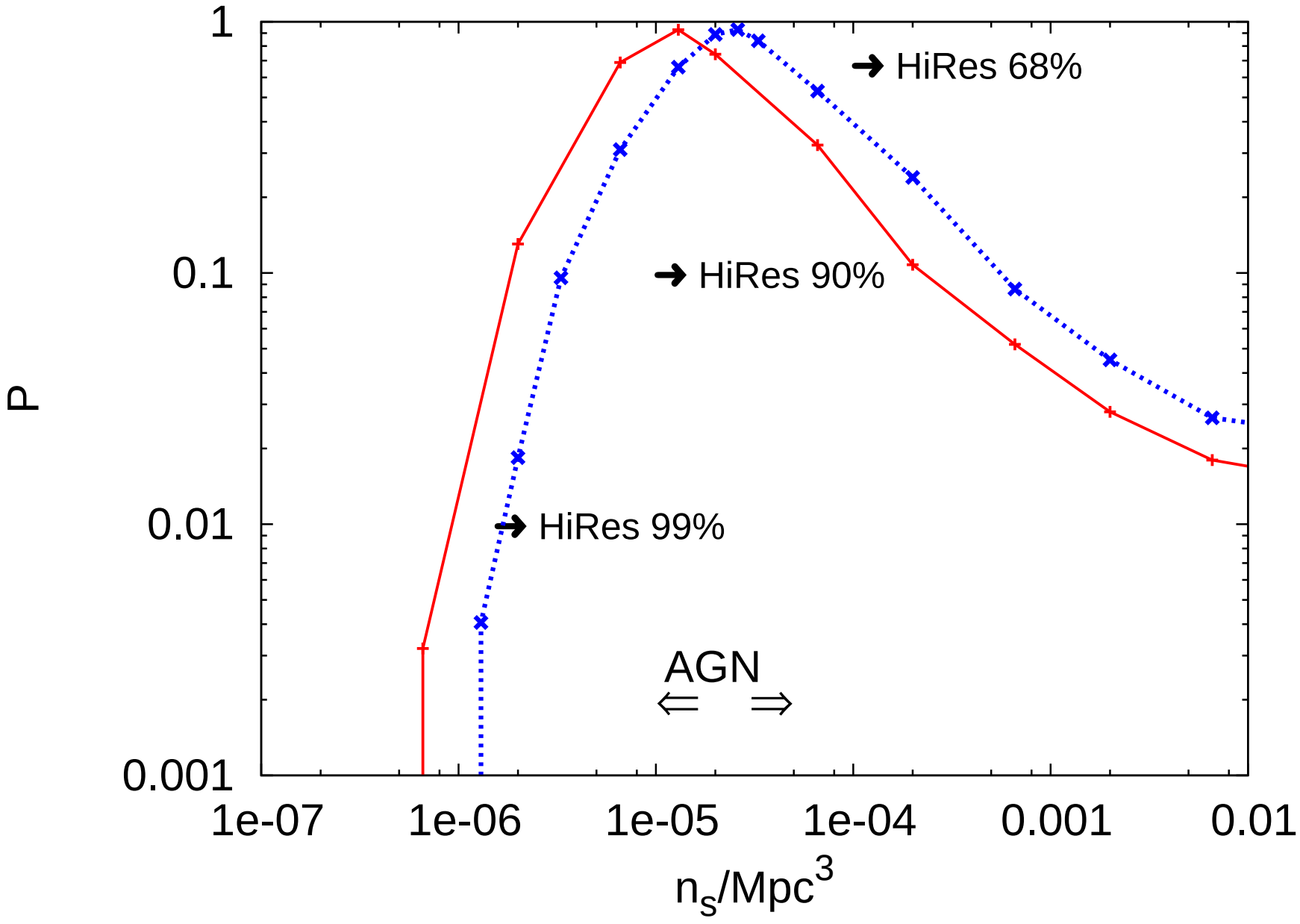


- strongly non-Gaussian, asymmetric
- w_n with $n > 1$ contains essentially no information
- use area between median and observed value as measure

Consistency of $p(w_1; n_s)$ with n_s:



if $n_s < \infty$, main question to address is:

- how many of the clusters seen are true ones?

$\Rightarrow$ if the fraction is large, search for point sources makes sense

How many of the clusters are real?

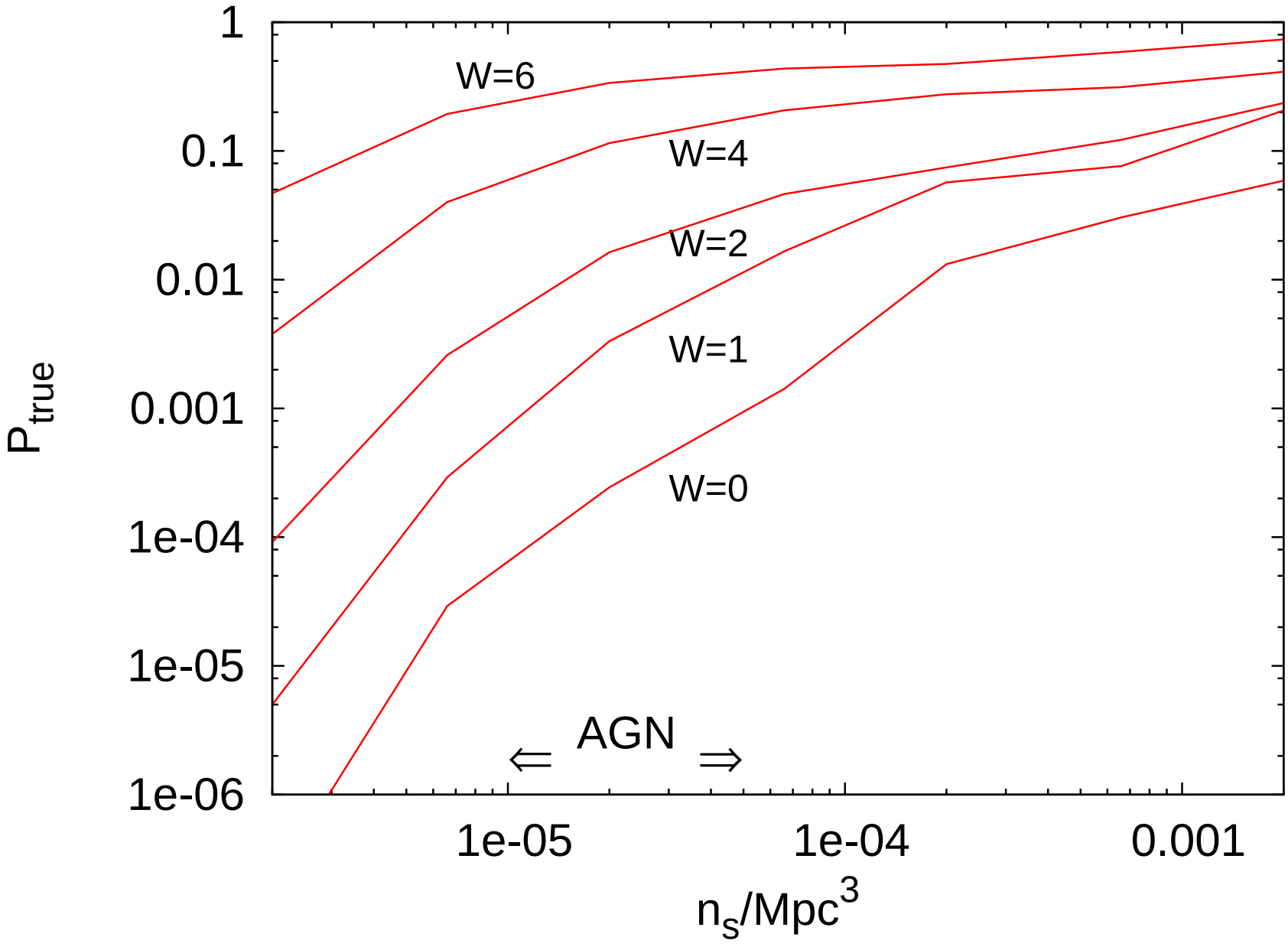
auto-correlation function w of observed event directions,

$$w = \sum_{i<j} \begin{cases} 1, & \text{for} \quad \ell_{ij} < \ell_1 \\ 0, & \text{for} \quad \ell_{ij} > \ell_1 \end{cases}$$

define additionally to "true" or source auto-correlation function W,

$$W = \sum_{i<j} \begin{cases} 1, & \text{for} \quad \ell_{ij} < \ell_1 \text{ and ij from same source} \\ 0, & \text{otherwise} \end{cases}$$

Probability that all clusters are fake if $w_1 = 7$



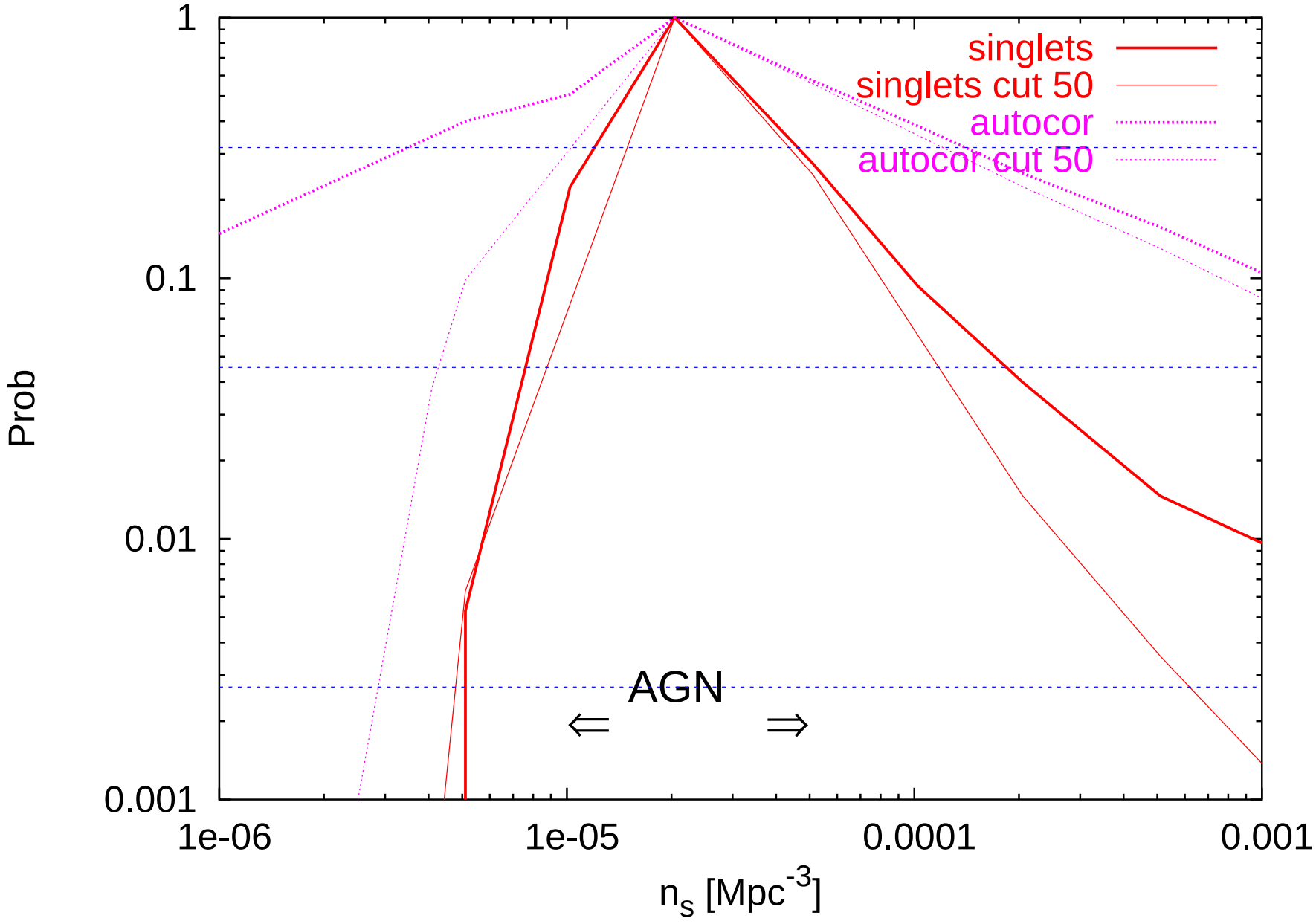
Predictions for PAO:

- for one year, assuming $N = 300$ events above 4×10^{19} eV
- determination of n_s
- establishing finite n_s

if not

- points towards nuclei as primaries

determination of n_s:



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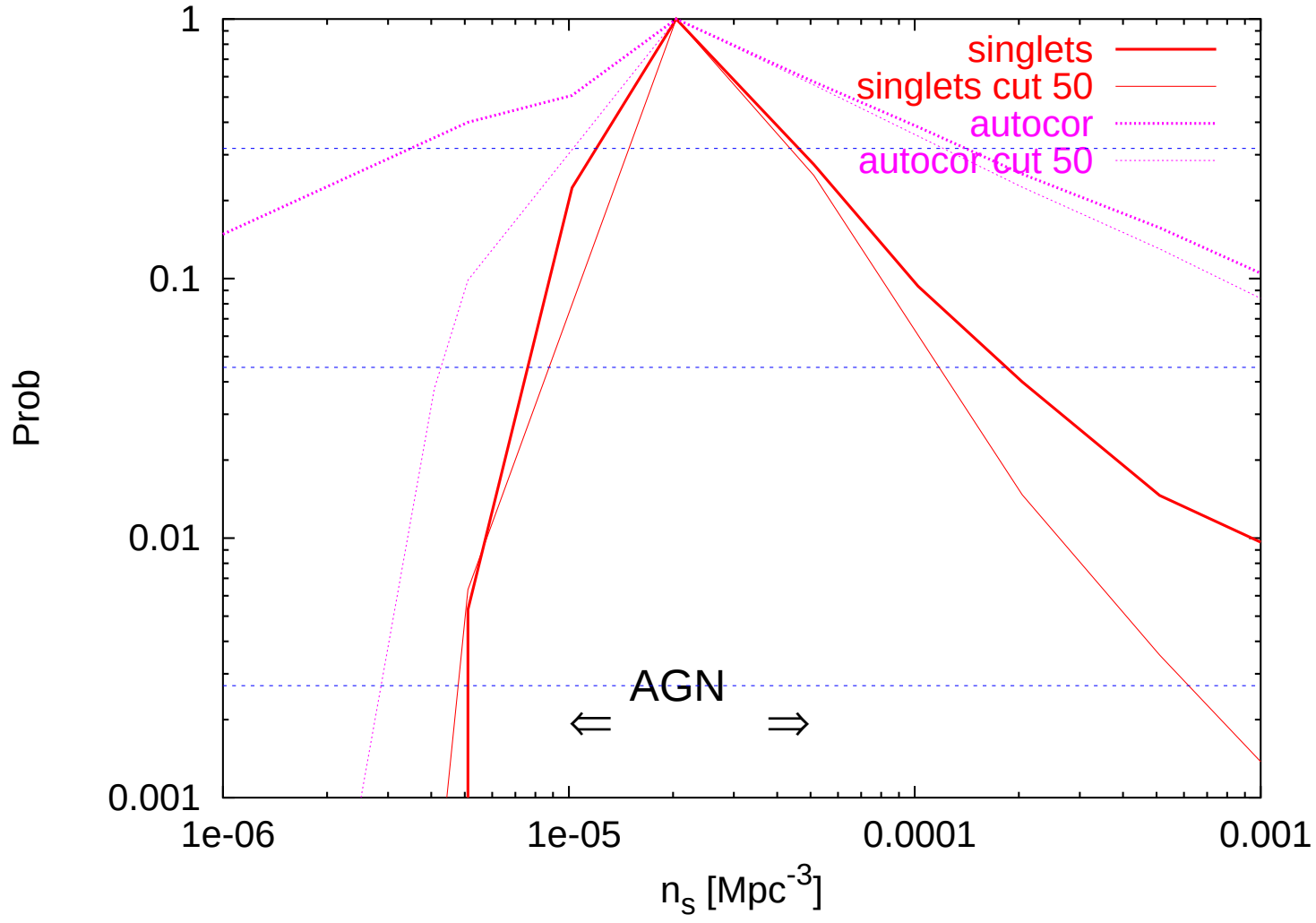
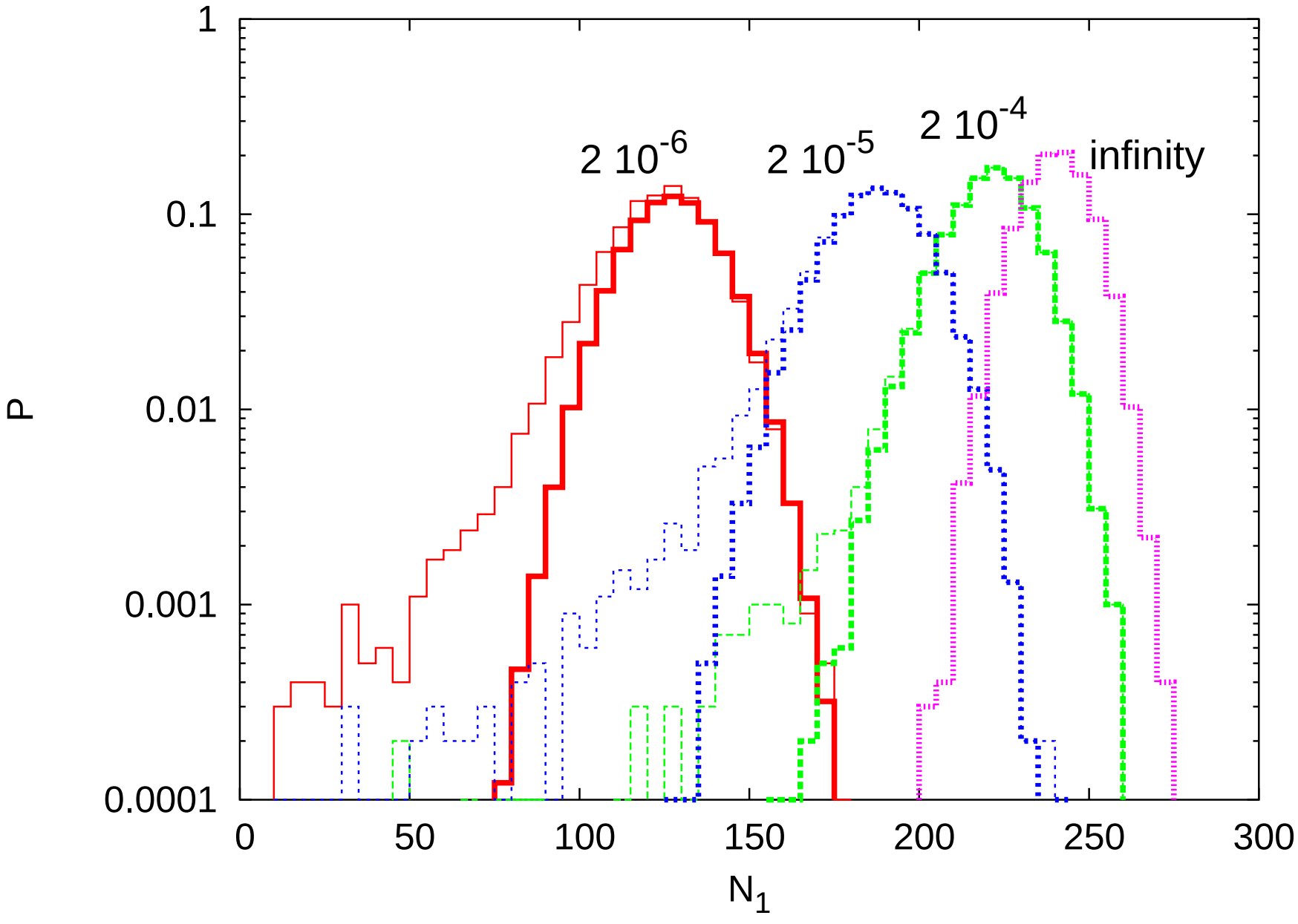


$\Rightarrow$ singlet distribution better than auto-correlation function

singlet distribution:



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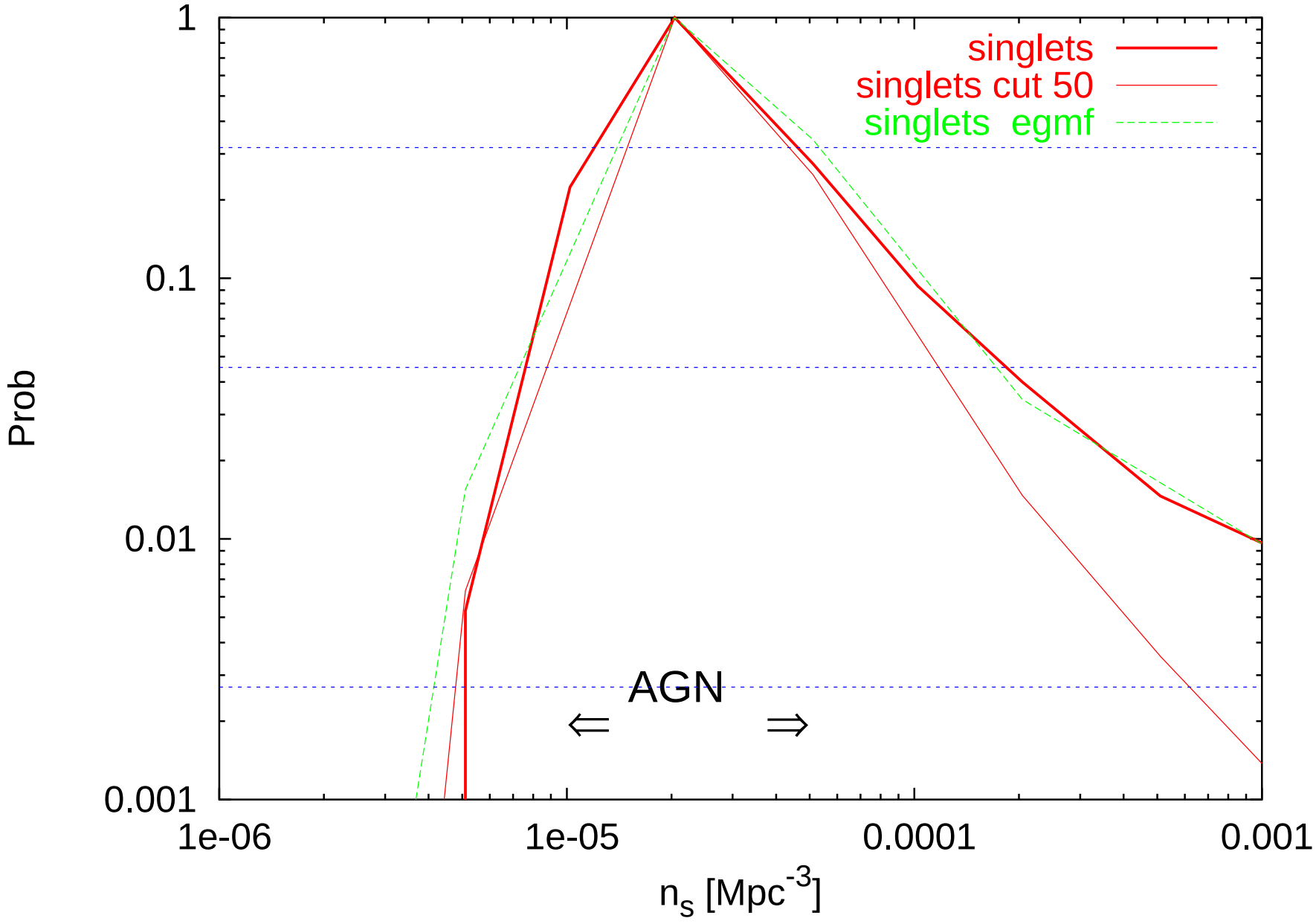

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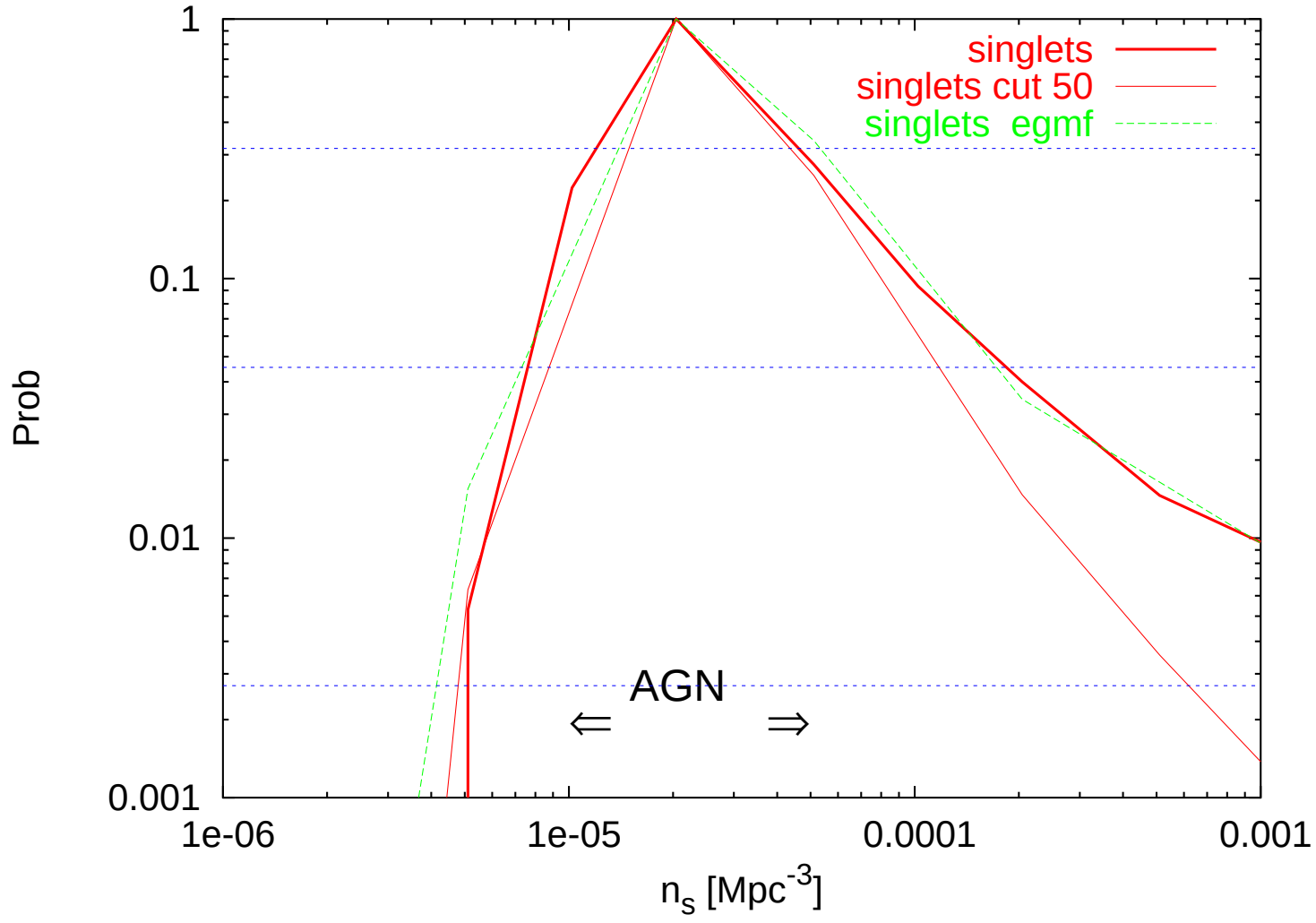
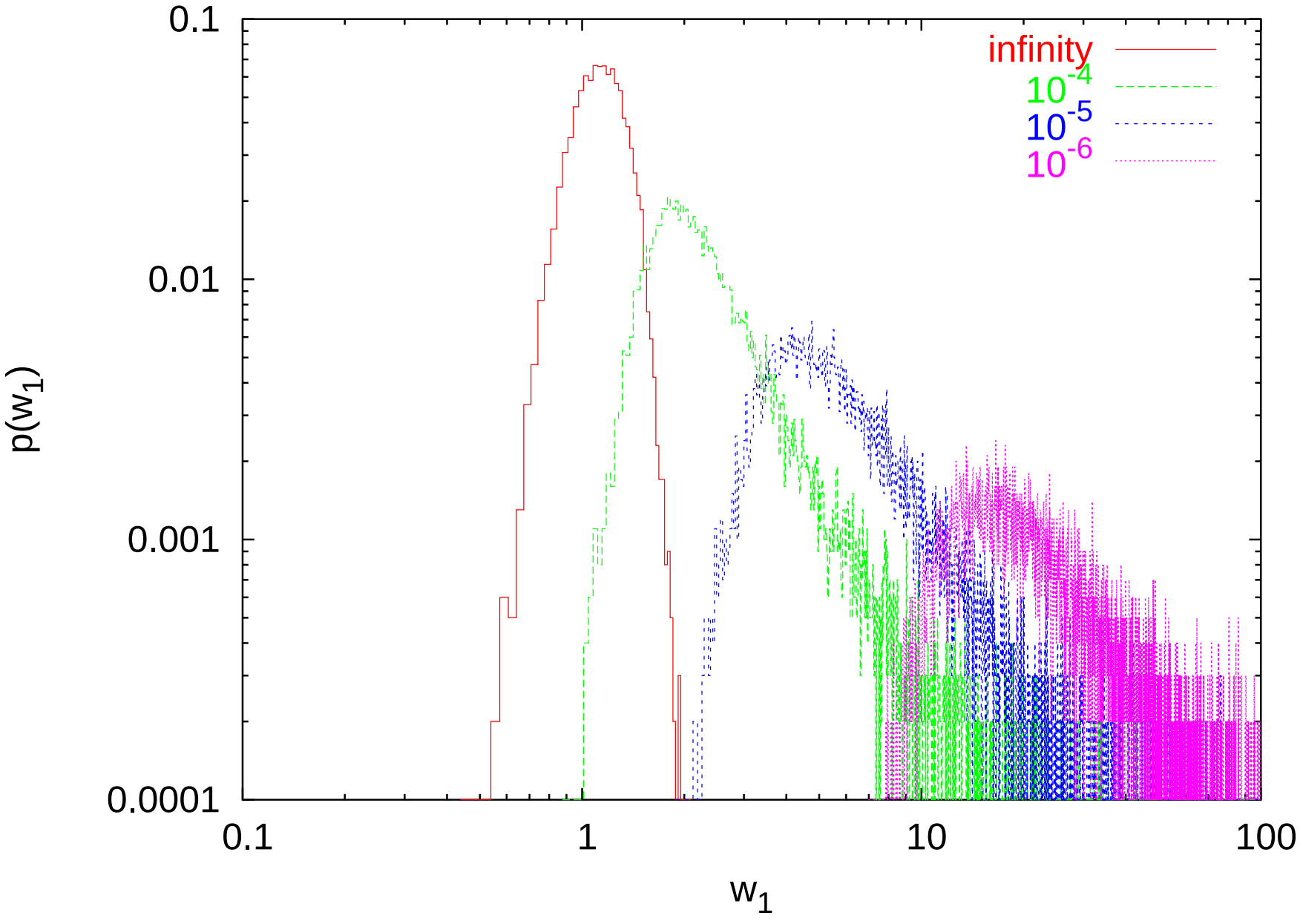


$\Rightarrow$ effect of egmf (à la DGST) not important

establishing $n_s < \infty$:



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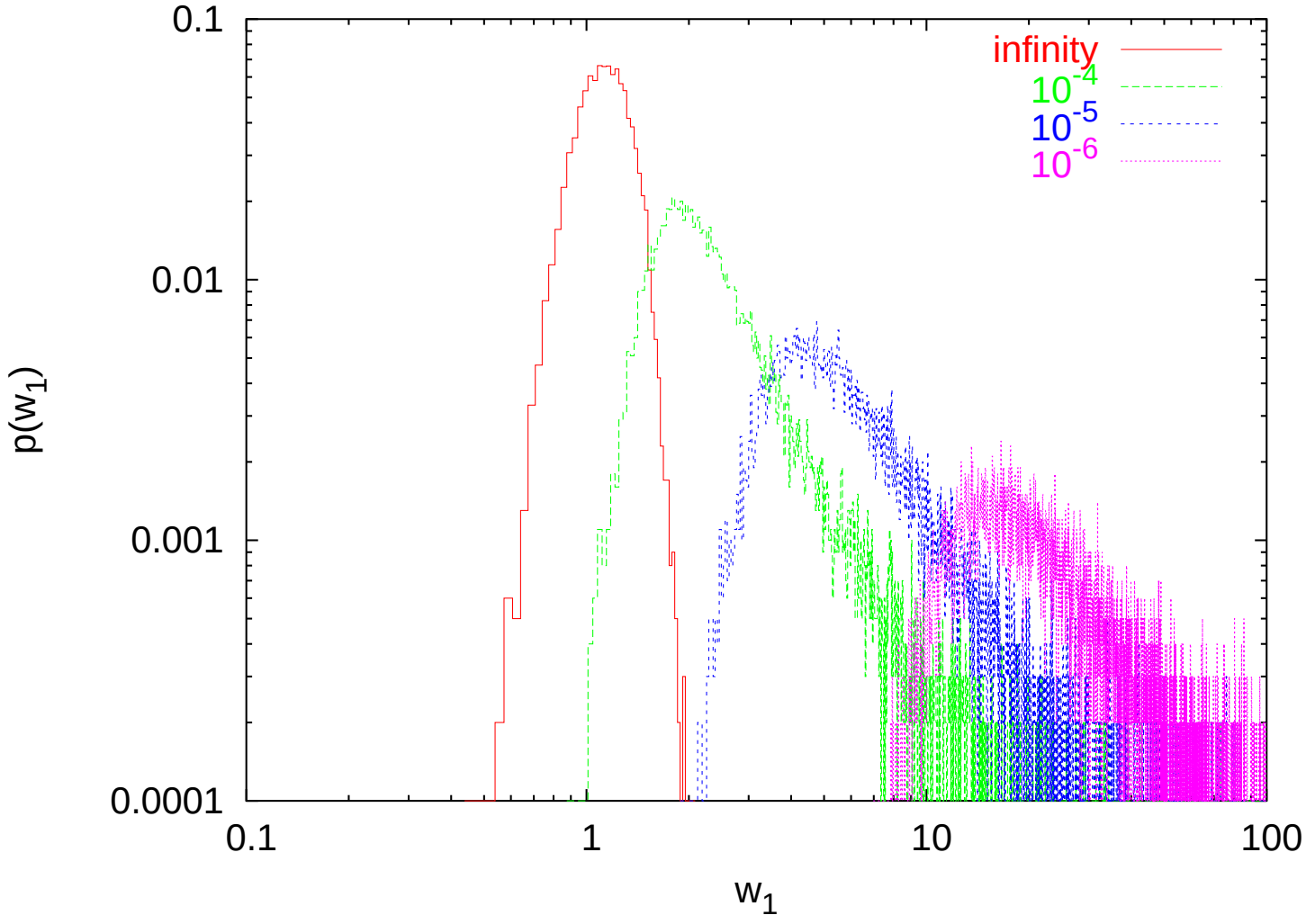
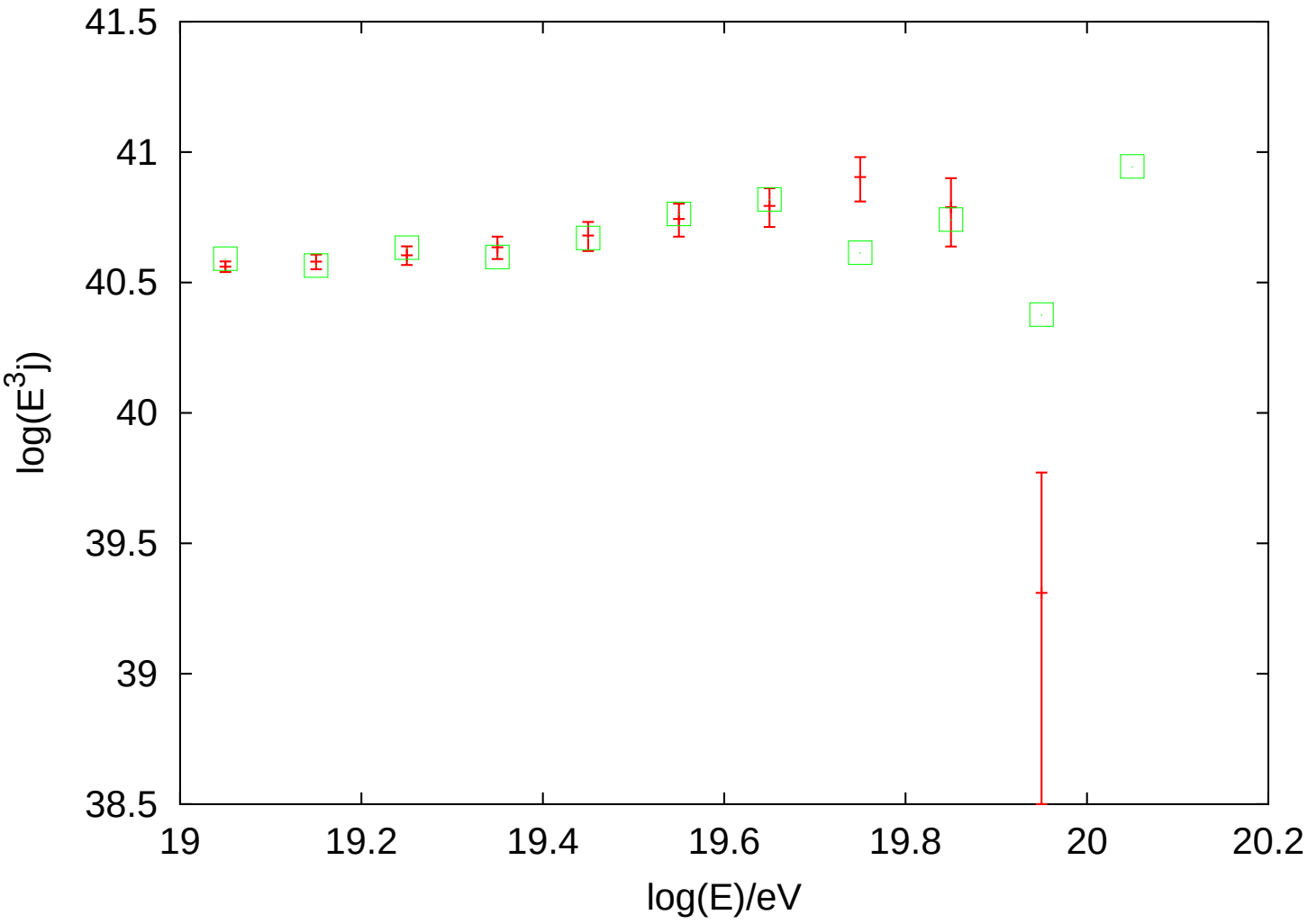


$\Rightarrow$ continuous distribution can be excluded with $< 10^{-5}$ for true densities smaller than $10^{-5}/$ Mpc^3

BL Lacs as sources

small number of BL Lacs results in strong clustering and in strong GZK cutoff, if $z_{\min} > 0$:



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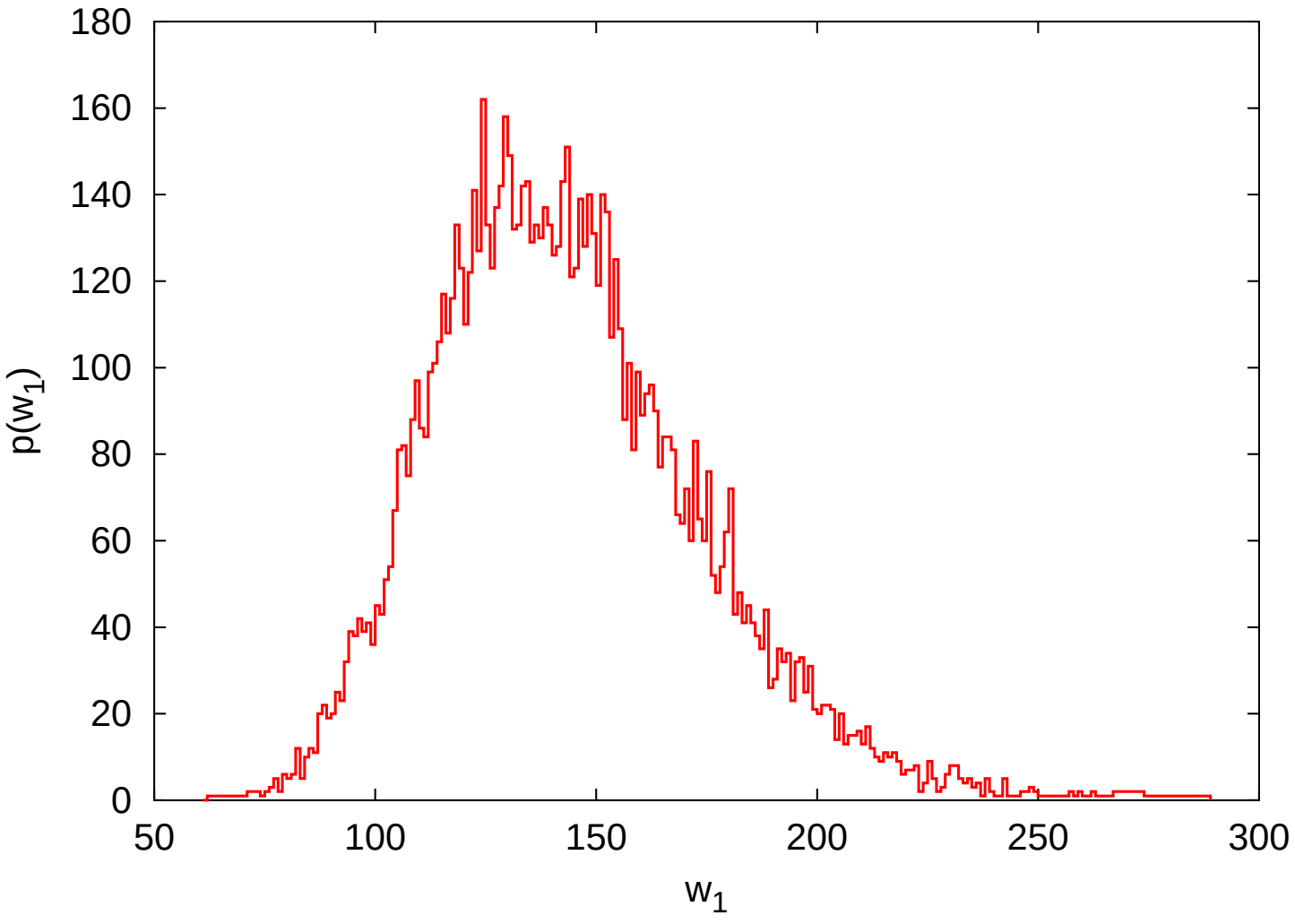
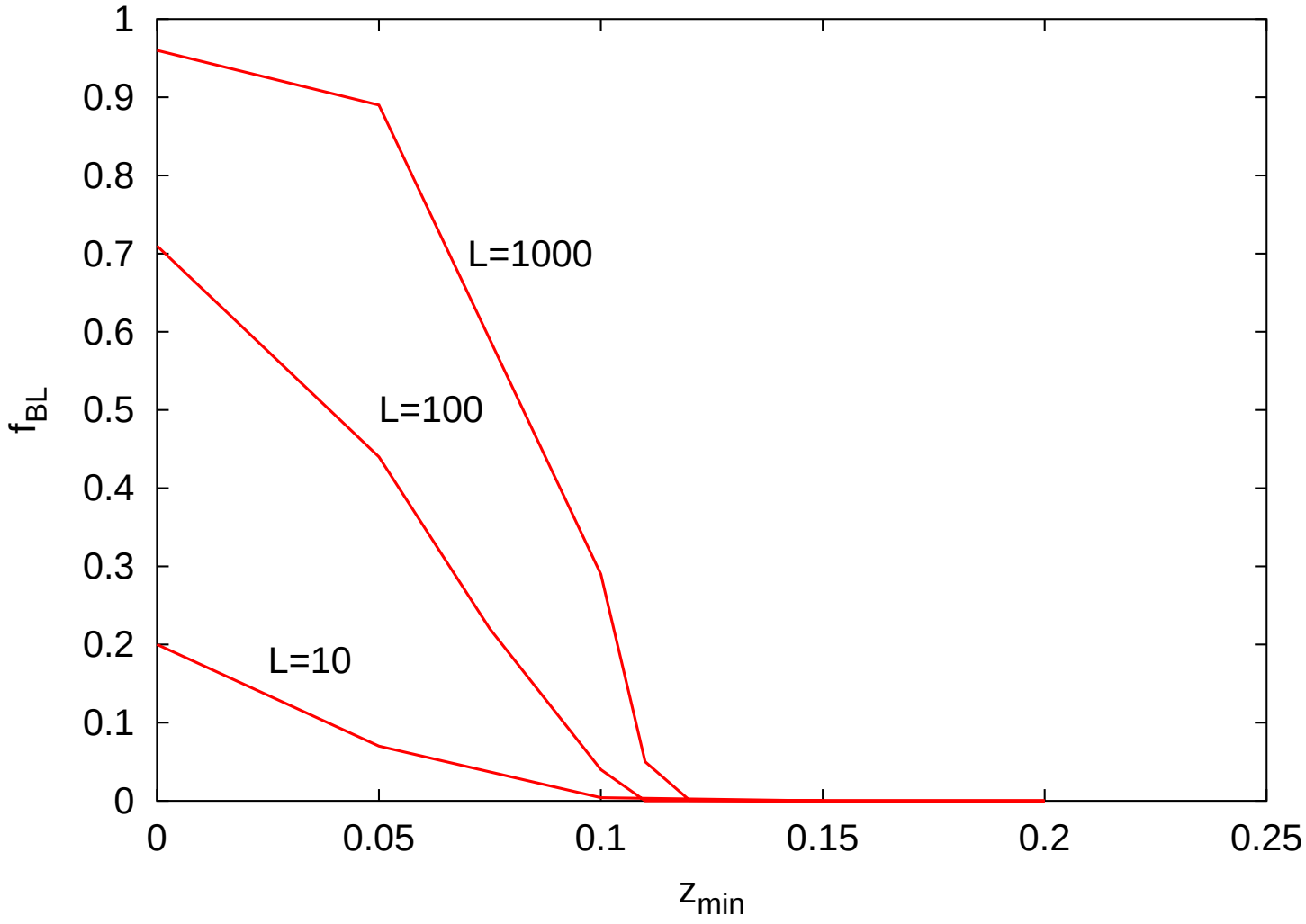


BL Lacs and uniform sources

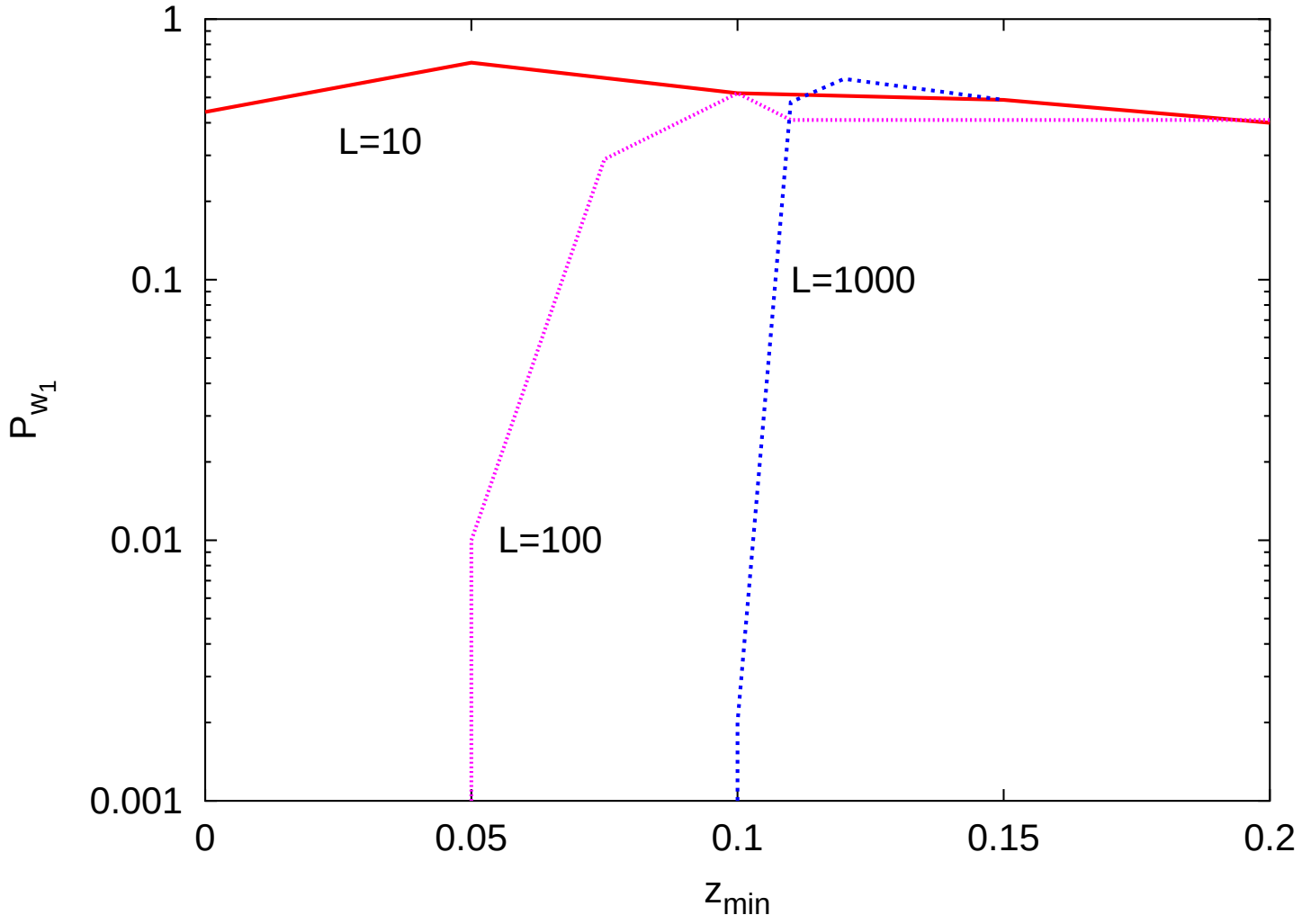
- add to BL Lac distribution an uniform component with smaller luminosity:
- vary parameter L_{BL}/L_u, $z_{\min,BL}$, n_u:
- possible to obtain $f_{BL} = 10$–30% for reasonable parameters?

BL Lacs and uniform sources



$z_{\rm min} \lesssim 0.05$–0.15 necessary for non-negligible contribution of BL Lacs to events above 4×10^{19} eV

BL Lacs and uniform sources



for each L small range in $z_{\min}$ possible with acceptable clustering and non-negligible contribution of BL Lacs

BL Lacs and uniform sources

- BL Lacs can contribute around 20–30% to UHECR flux without contradiction to clustering
- do not improve combined fit of spectra and clustering

Summary:

- if AGNs are sources of UHECRs, clustering is real
- source densities much smaller than AGNs are excluded
- BL Lacs can contribute 20–30% to UHECR events above 4×10^{19} eV
- continuous source distribution can be excluded by PAO for all estimated $n_s < 10^{-4}$/Mpc^3

if not: nuclei as primaries, stronger extragalactic magnetic fields, . . .