

UHECRs from point sources

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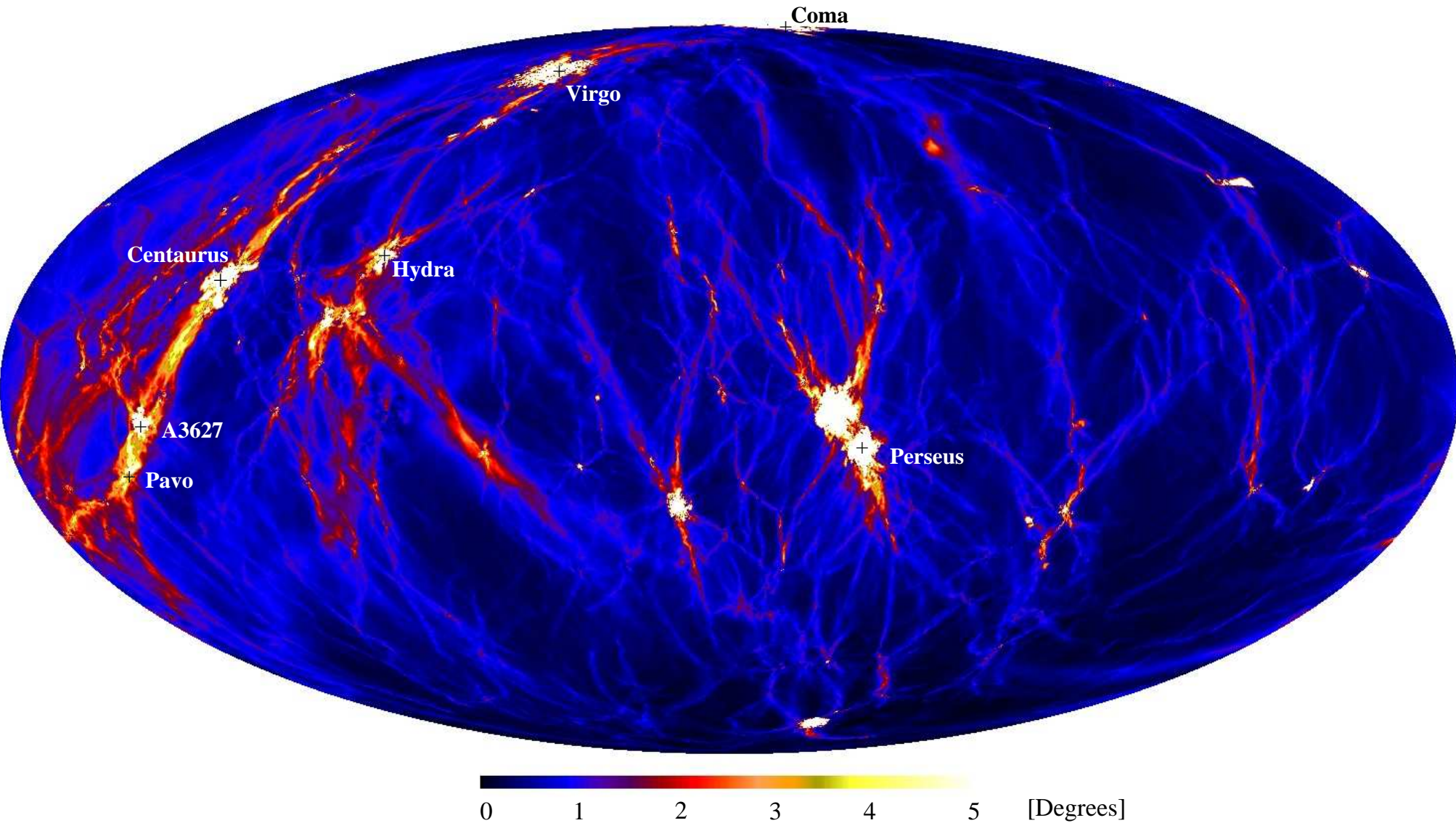


in collaboration with Dima Semikoz

Outline of the talk:

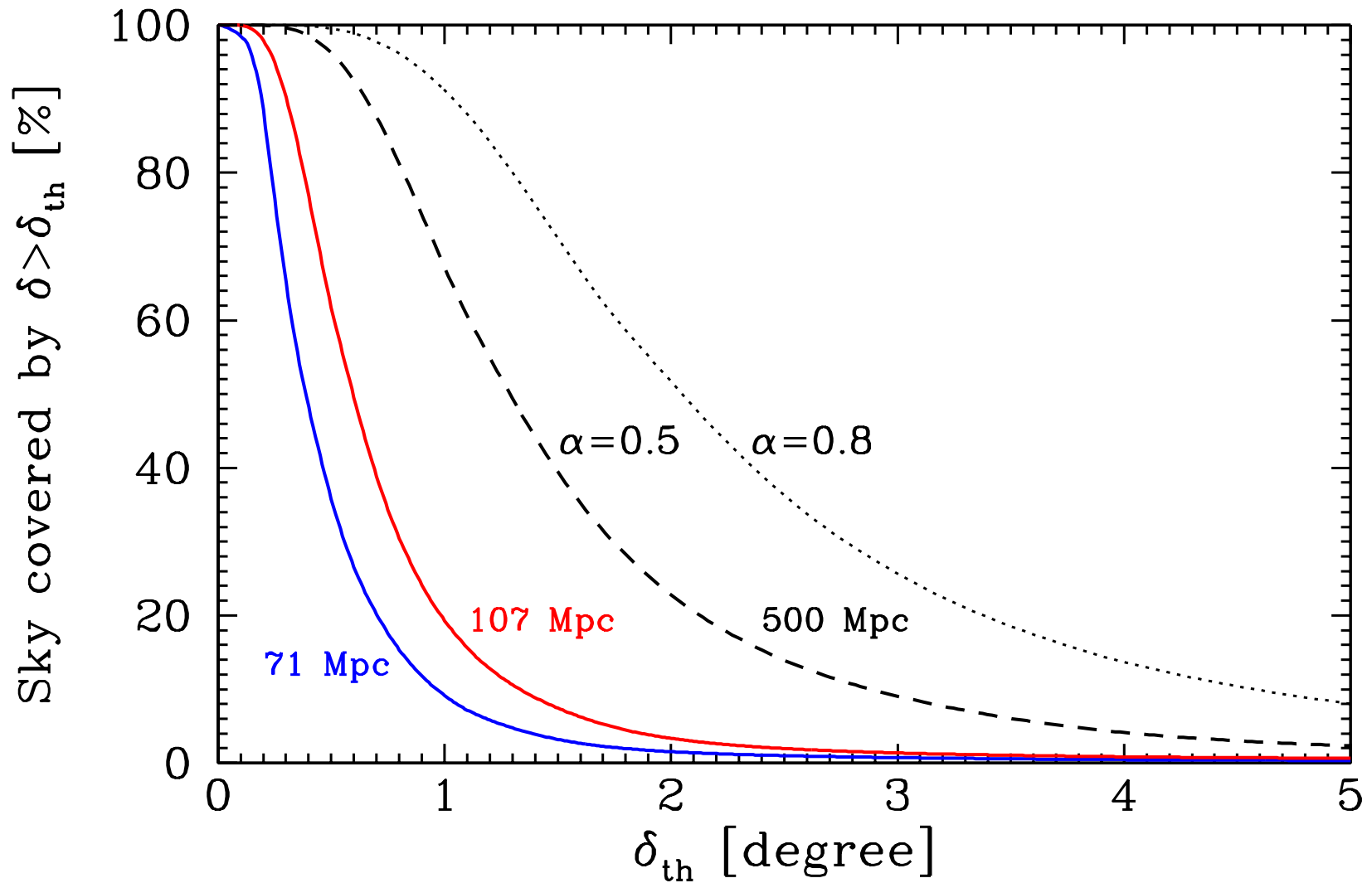
- Introduction
- Uniformly distributed sources:
 - ◇ best-fit density n_s
 - ◇ fraction of true clusters
 - ◇ predictions for PAO
- BL Lacs as proton sources: is there a consistent model possible?
- Summary

Extragalactic magnetic field:



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

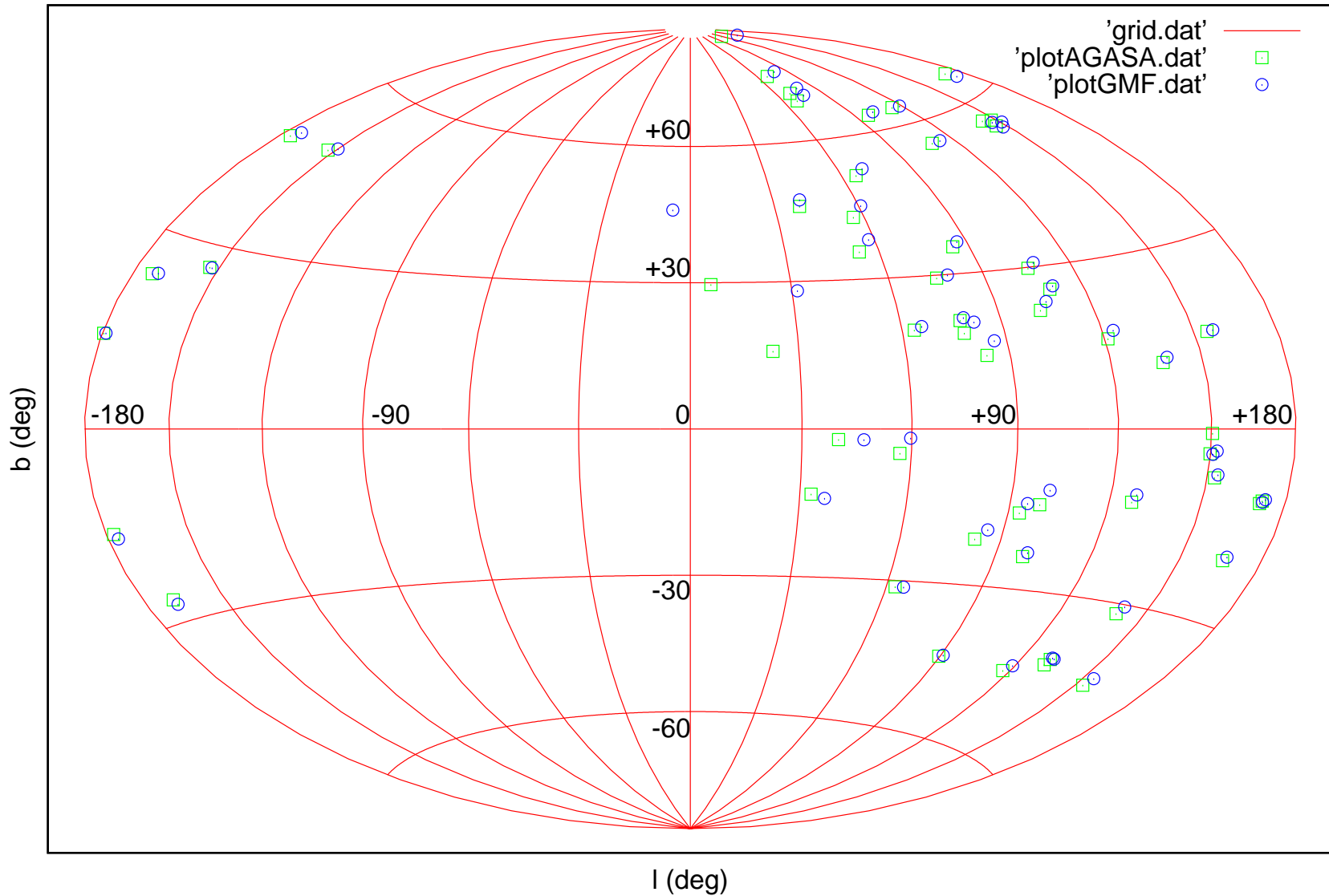
Extragalactic magnetic field:



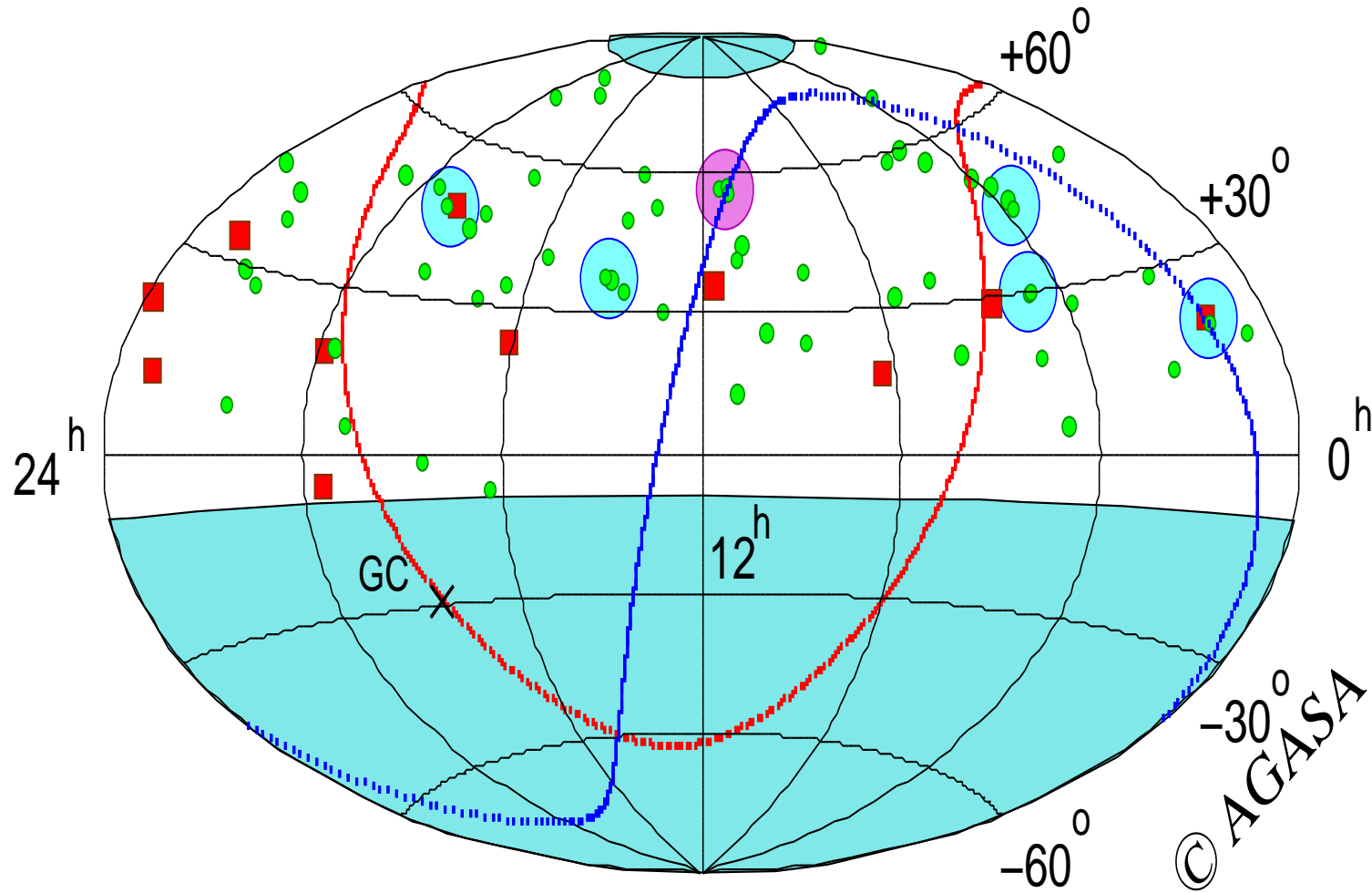
[Dolag, Grasso, Springel, Tkachev, astro-ph/0310902]

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

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

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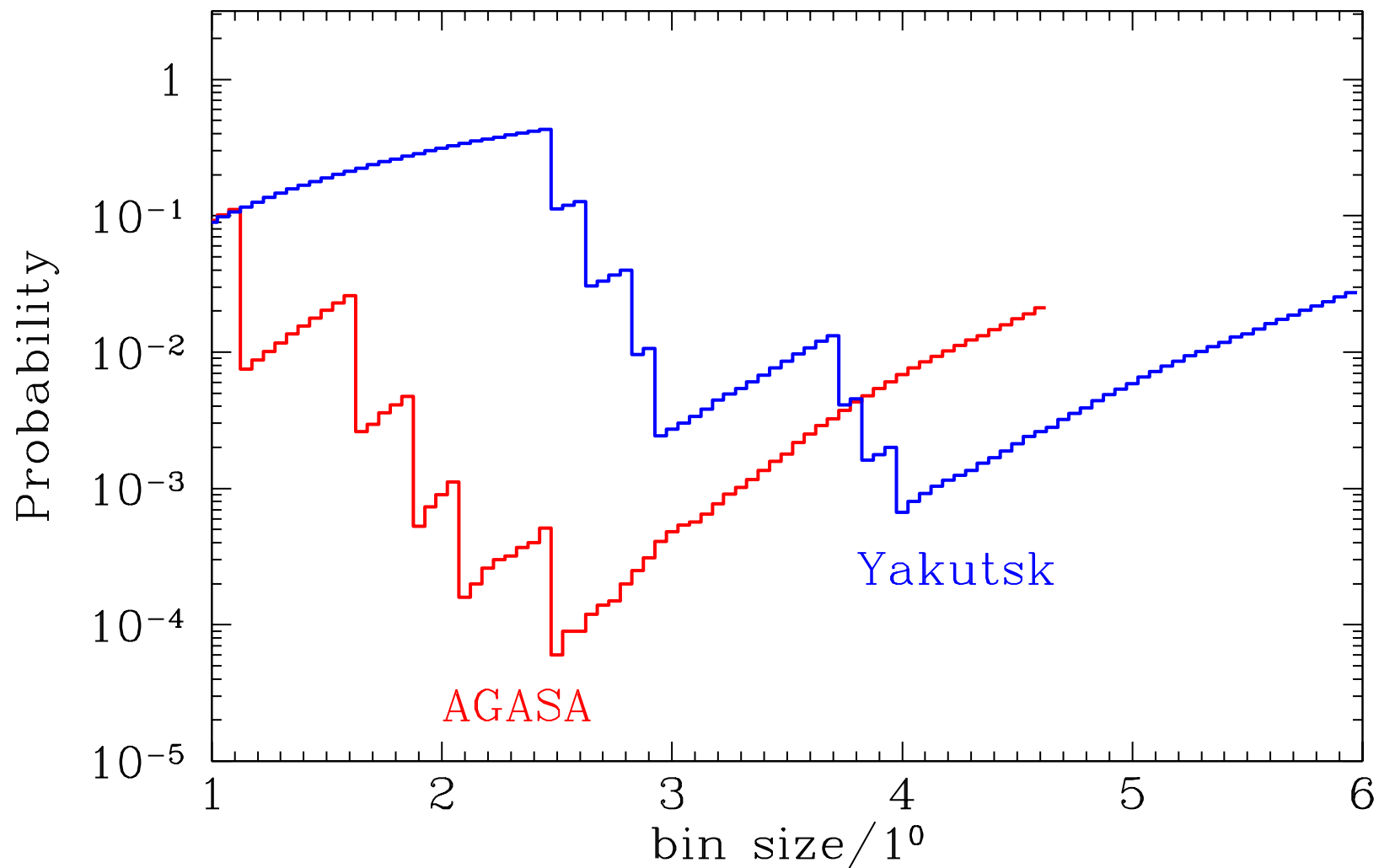
- deviation from expectation for an isotropic distribution

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

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

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

but controversy about cuts and penalty factors:



Finley, Westerhoff, astro-ph/0309159: $p_{ch} = 8\%$.

HiRes Stereo: no clusters astro-ph/0404137

how to choose estimators and cuts

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- instead: MC data sets for your test hypothesis:

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 - ◇ optimize normalized auto-correlation function as function of bin size (including magnetic field, detector resolution)

how to choose estimators and cuts

- **do not use data!**
- instead: MC data sets for your test hypothesis:
 - ◇ Ex.: choose single source
 - ◇ optimize normalized auto-correlation function as function of bin size (including magnetic field, detector resolution)

⇒ **optimal bin size** for AGASA around 2.5°

Number of sources N_s

- As N_s decreases, sources become brighter for fixed flux \Rightarrow probability for clustering increases.

[Waxman, Fisher, Piran '96]

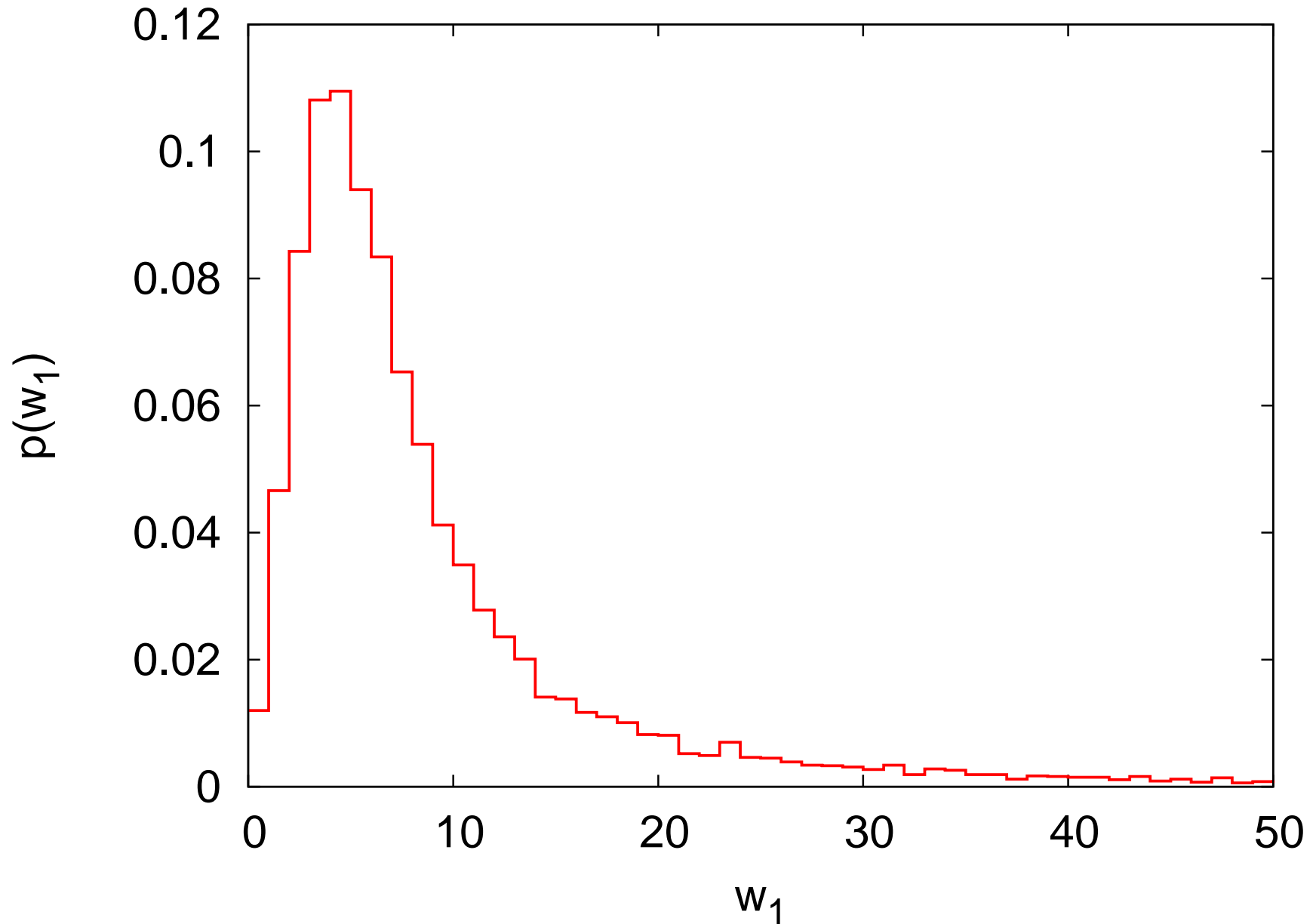
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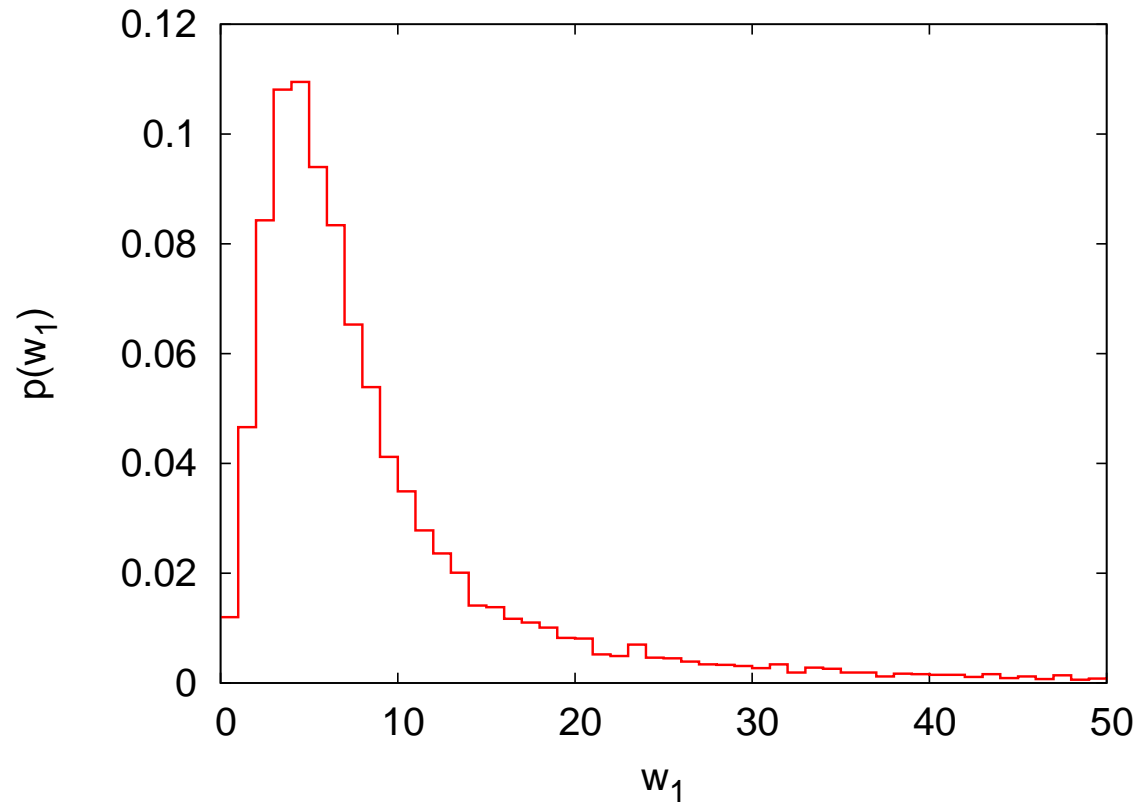
Number of sources N_s

- As N_s decreases, sources become brighter for fixed flux \Rightarrow probability for clustering increases. [Waxman, Fisher, Piran '96]
- allows to estimate n_s :
 - ◇ choose finite number of sources according density n_s
 - ◇ generate CRs according to $dN/dE \propto E^{-\alpha}$
 - ◇ propagate them
 - ◇ calculate w_1 for fixed $n_s, \alpha, \ell_1 \dots$
 - ◇ determine consistent parameters

Distribution of $p(w_1; n_s)$:

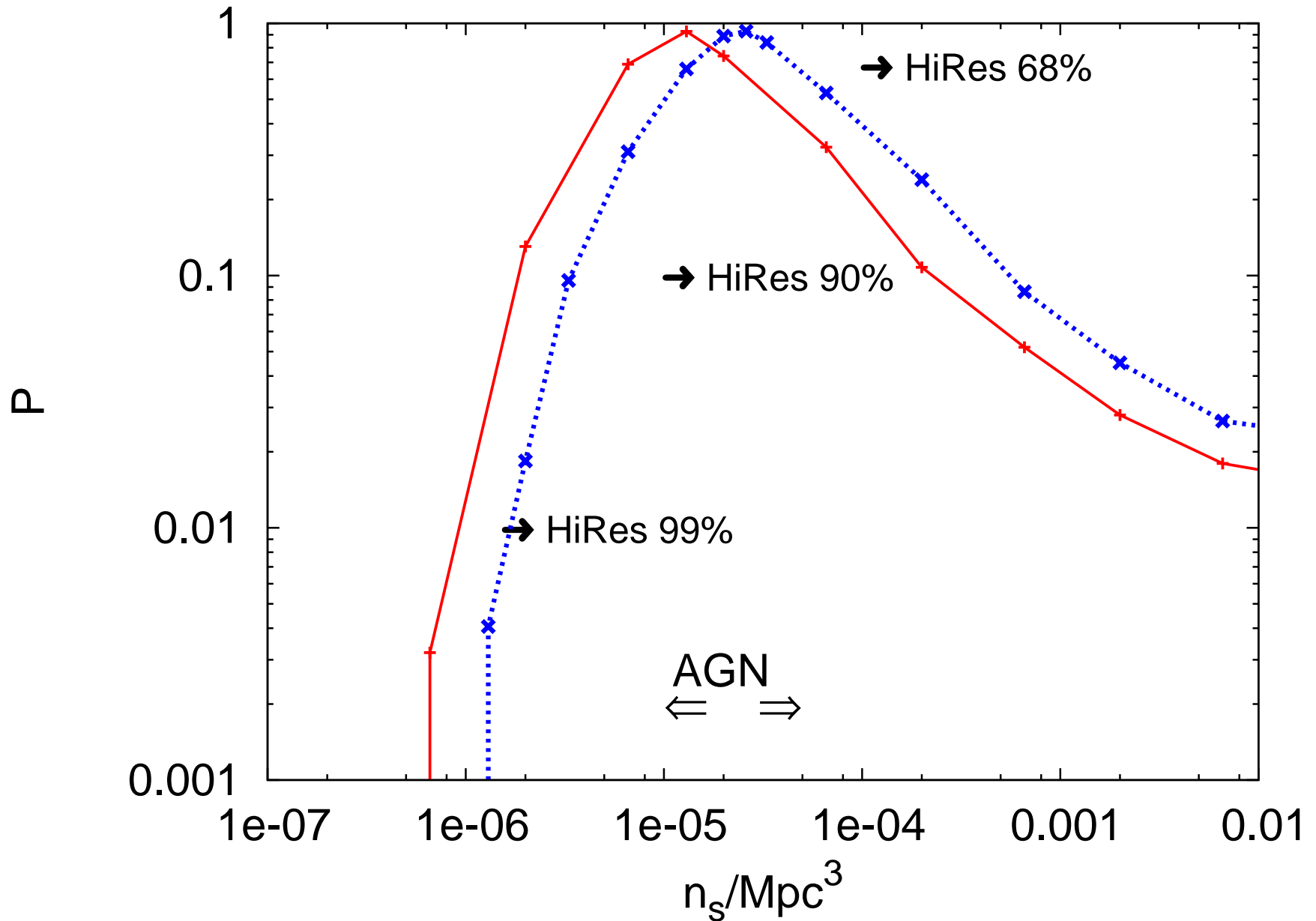


Distribution of $p(w_1; n_s)$:



- 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?

⇒ if the fraction is large, search for point sources makes sense

How many of the clusters are real?

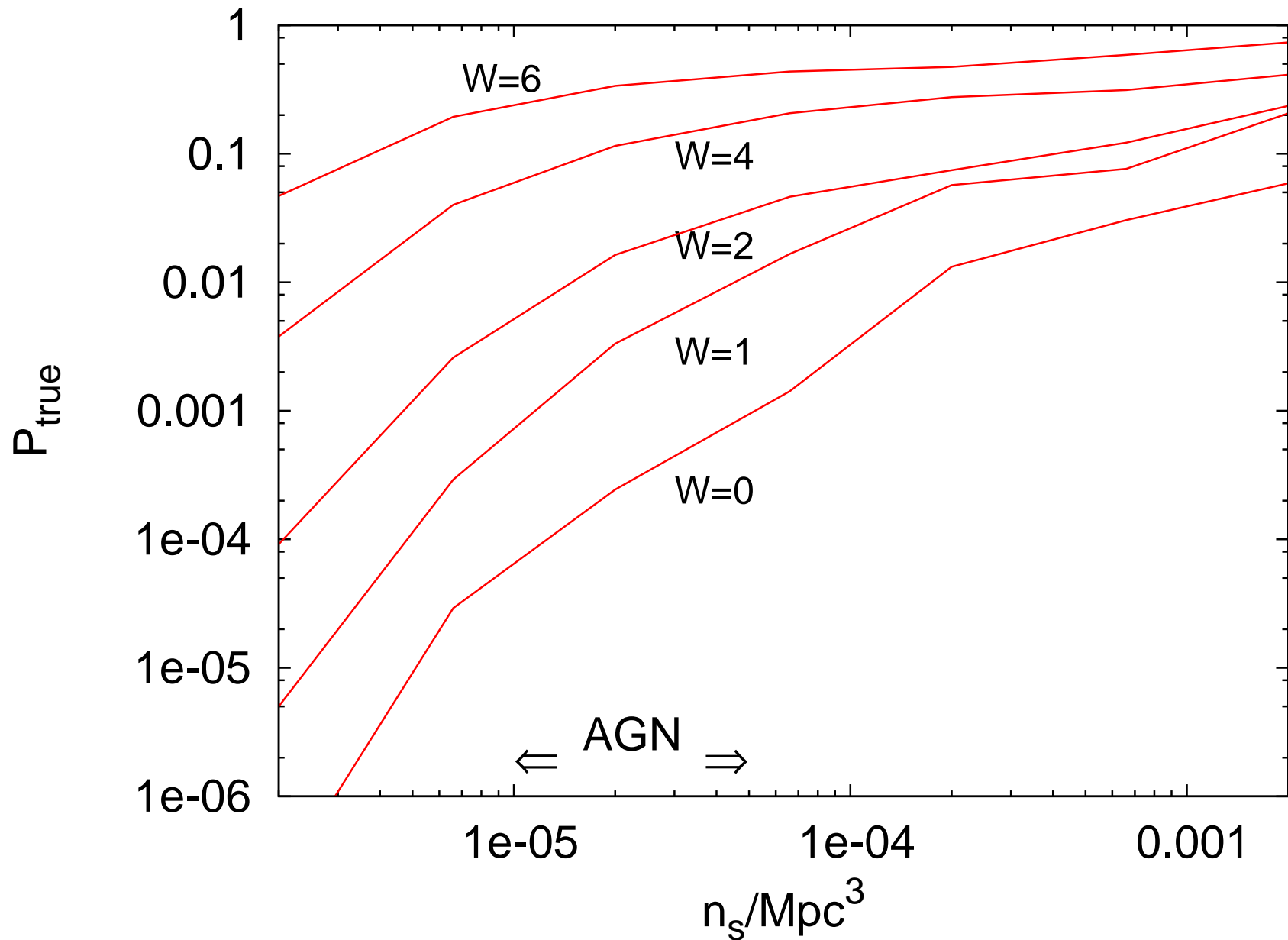
auto-correlation function w of **observed event directions**,

$$w = \sum_{i < j} \begin{cases} 1, & \text{for } l_{ij} < l_1 \\ 0, & \text{for } l_{ij} > l_1 \end{cases}$$

define additionally to “true” or **source auto-correlation function** W ,

$$W = \sum_{i < j} \begin{cases} 1, & \text{for } l_{ij} < l_1 \text{ and } ij \text{ from same source} \\ 0, & \text{otherwise} \end{cases}$$

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



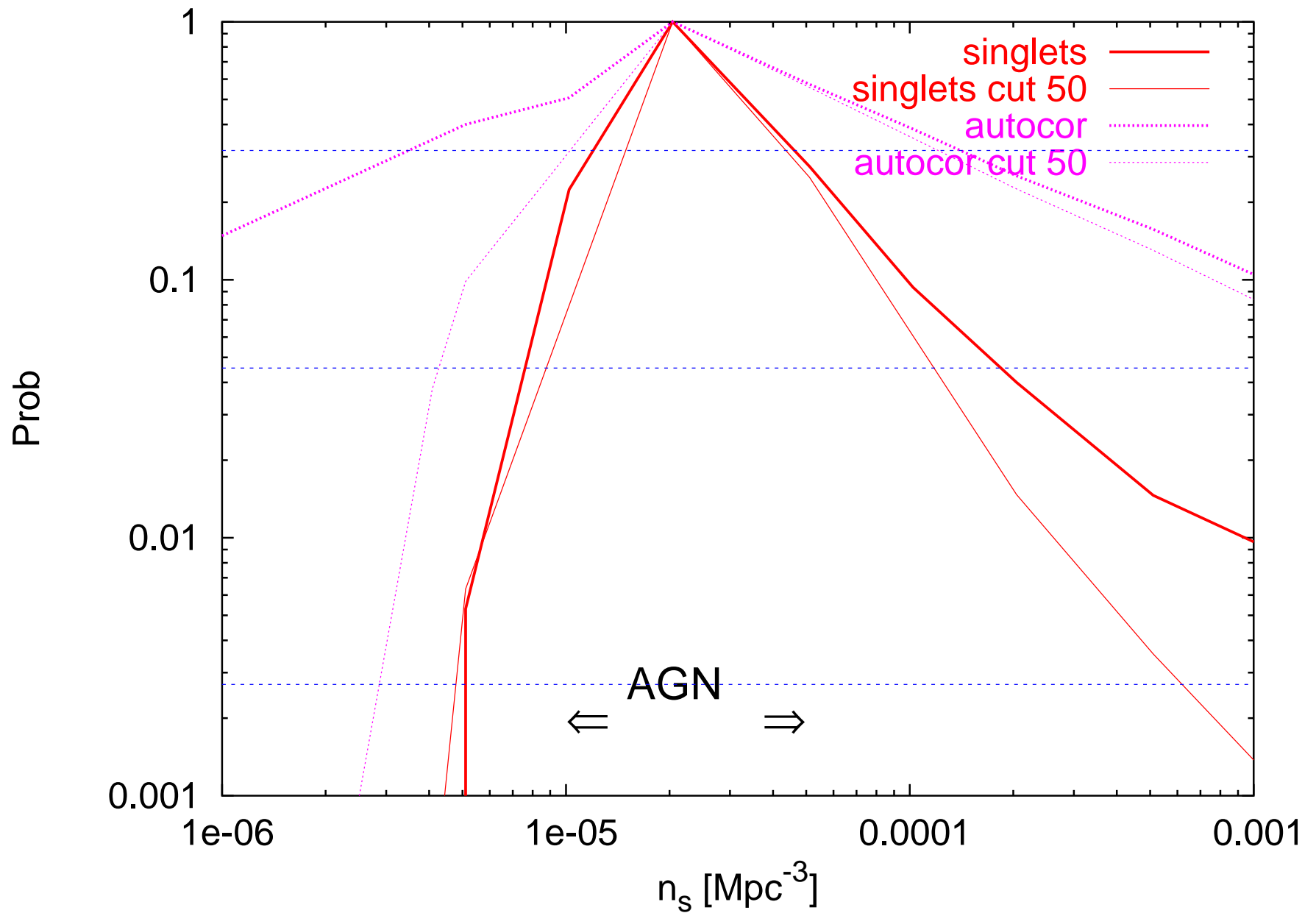
Predictions for PAO:

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

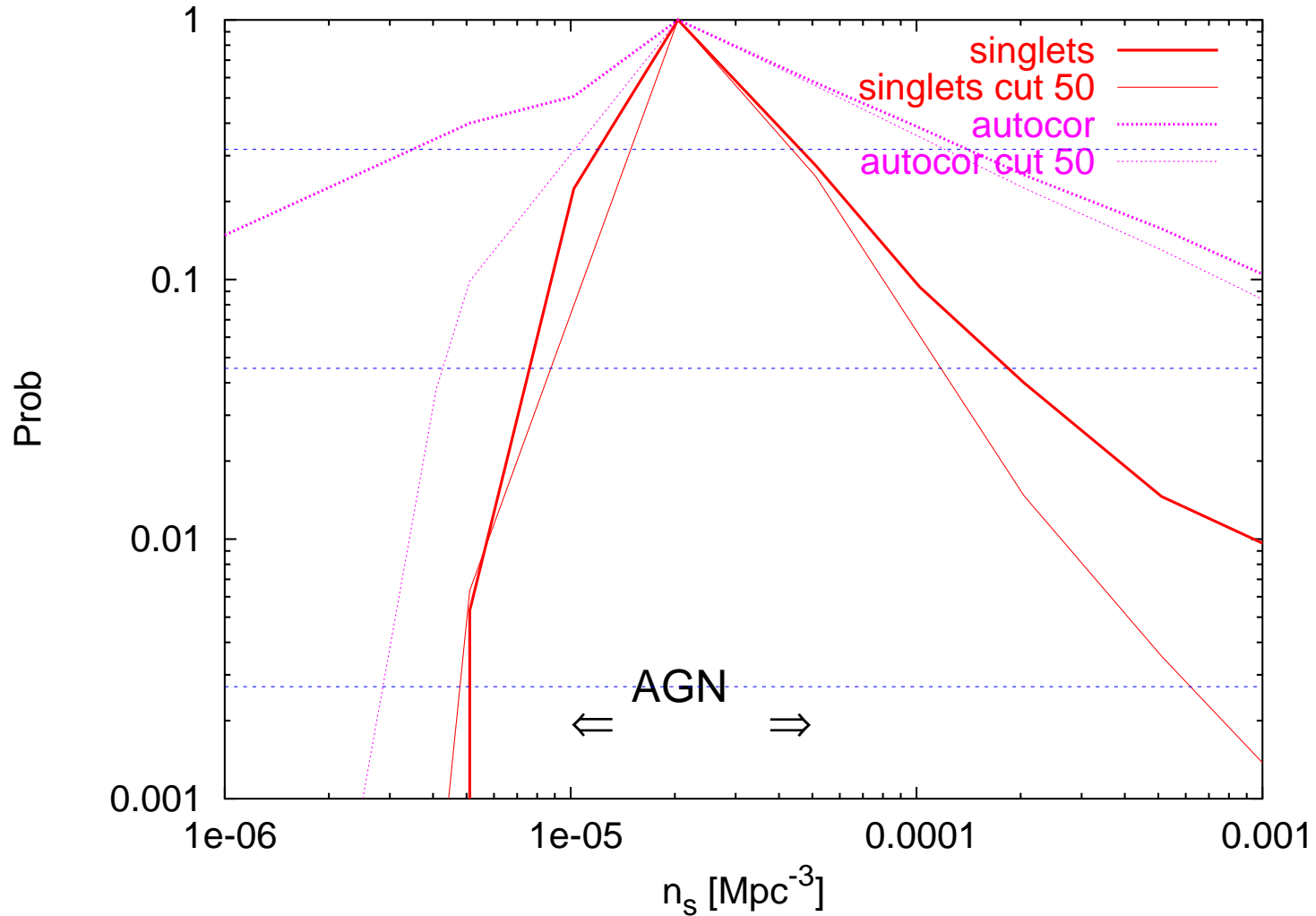
if not

- points towards nuclei as primaries

determination of n_s :

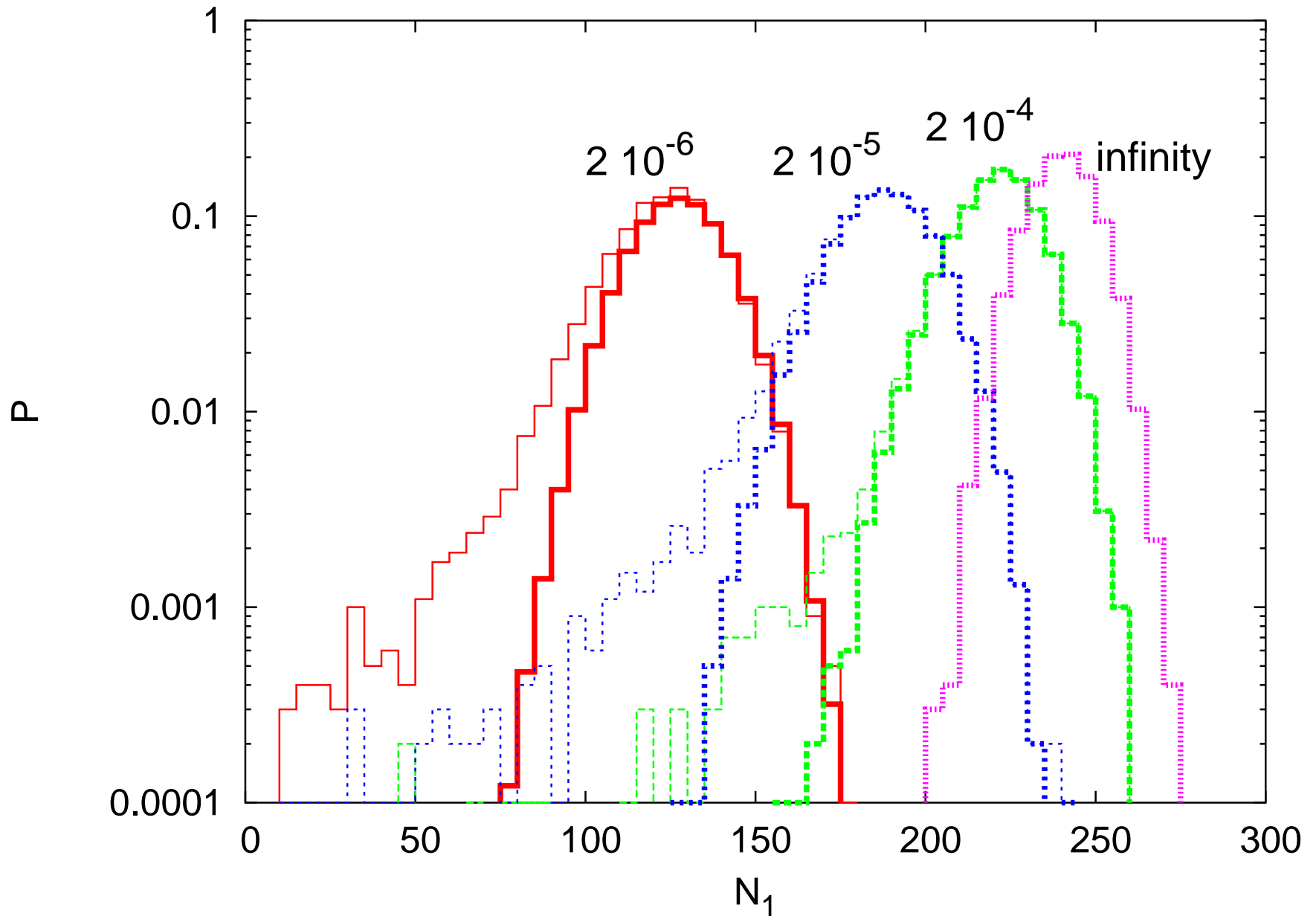


determination of n_s :

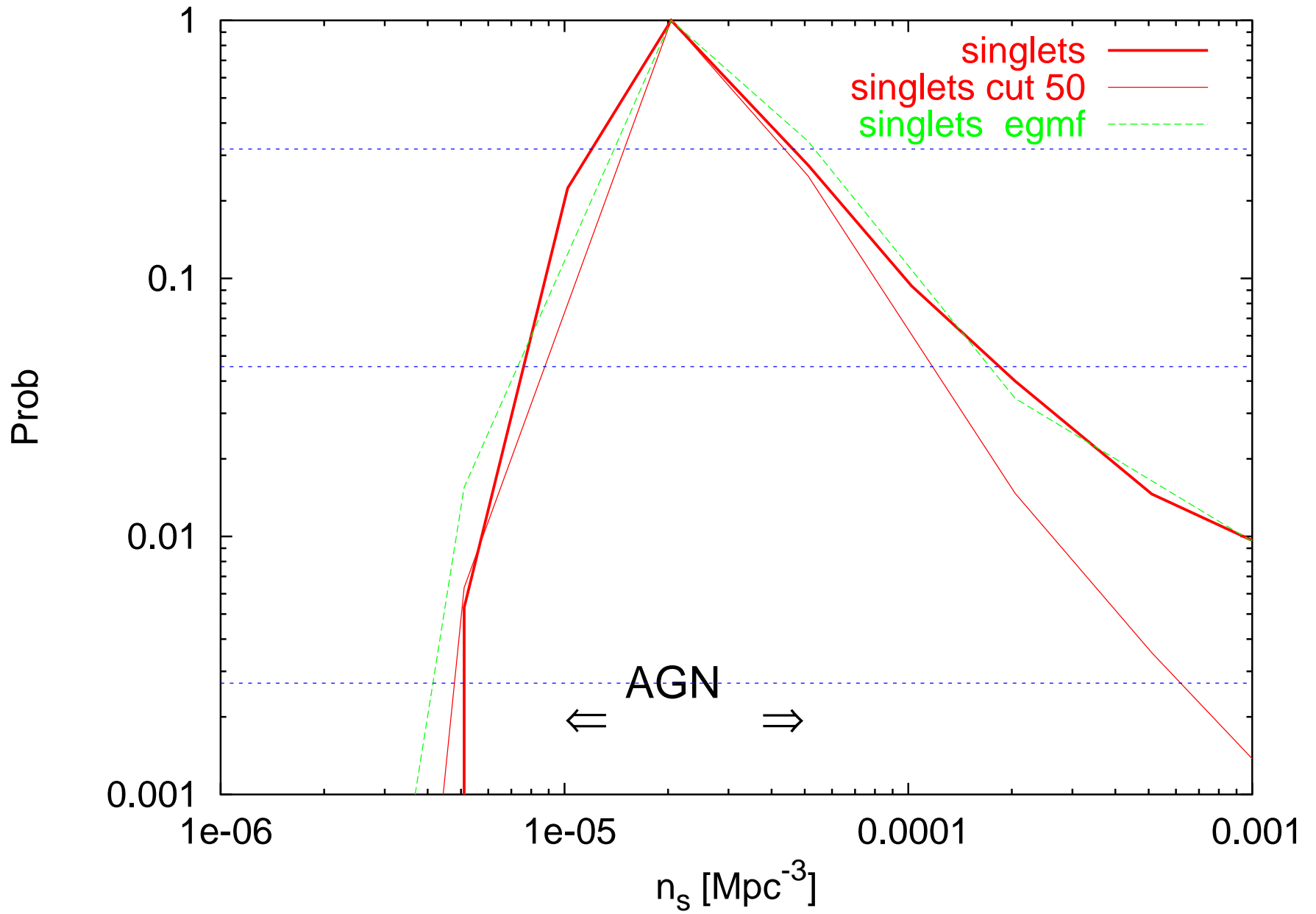


⇒ singlet distribution better than auto-correlation function

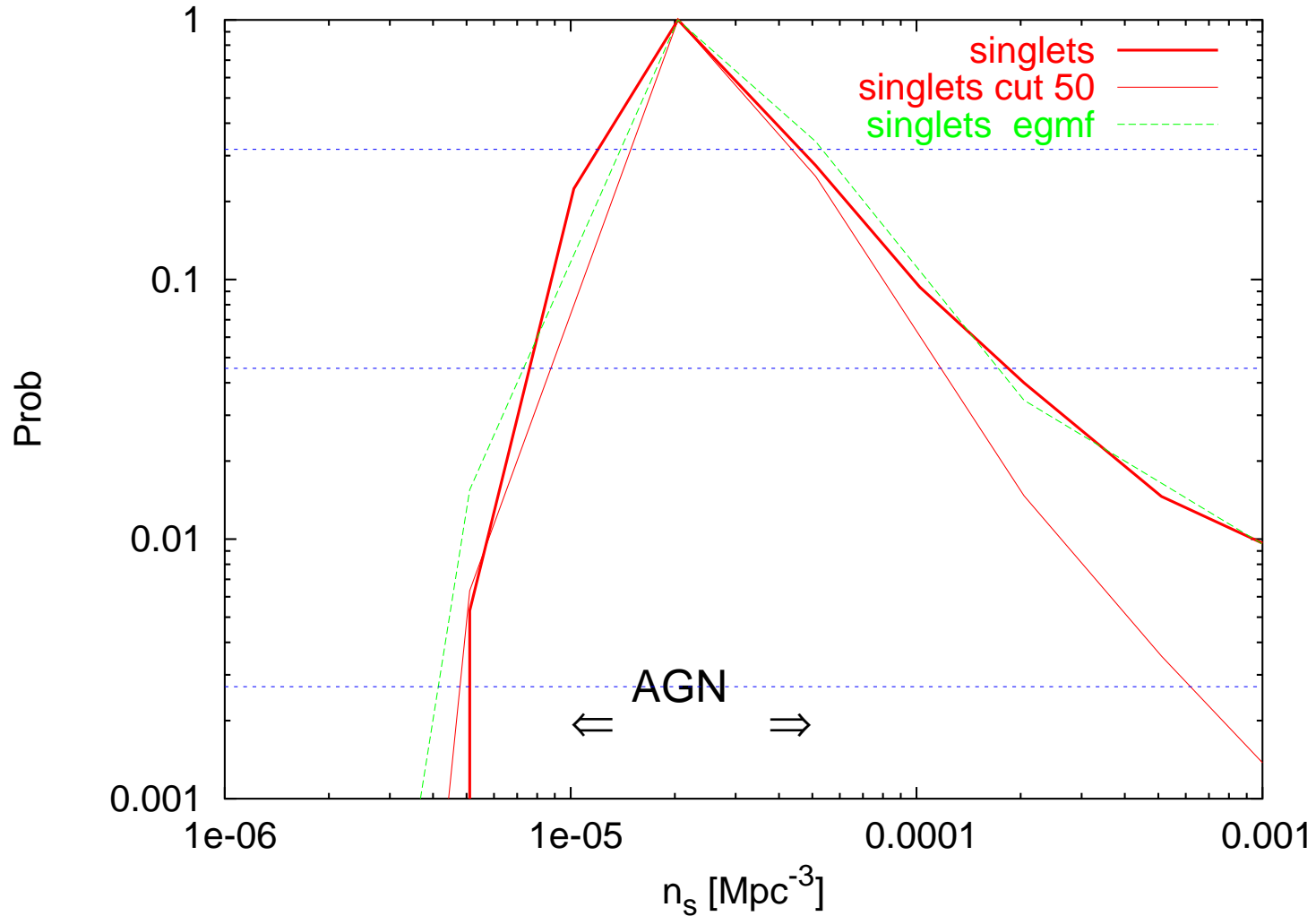
singlet distribution:



determination of n_s :

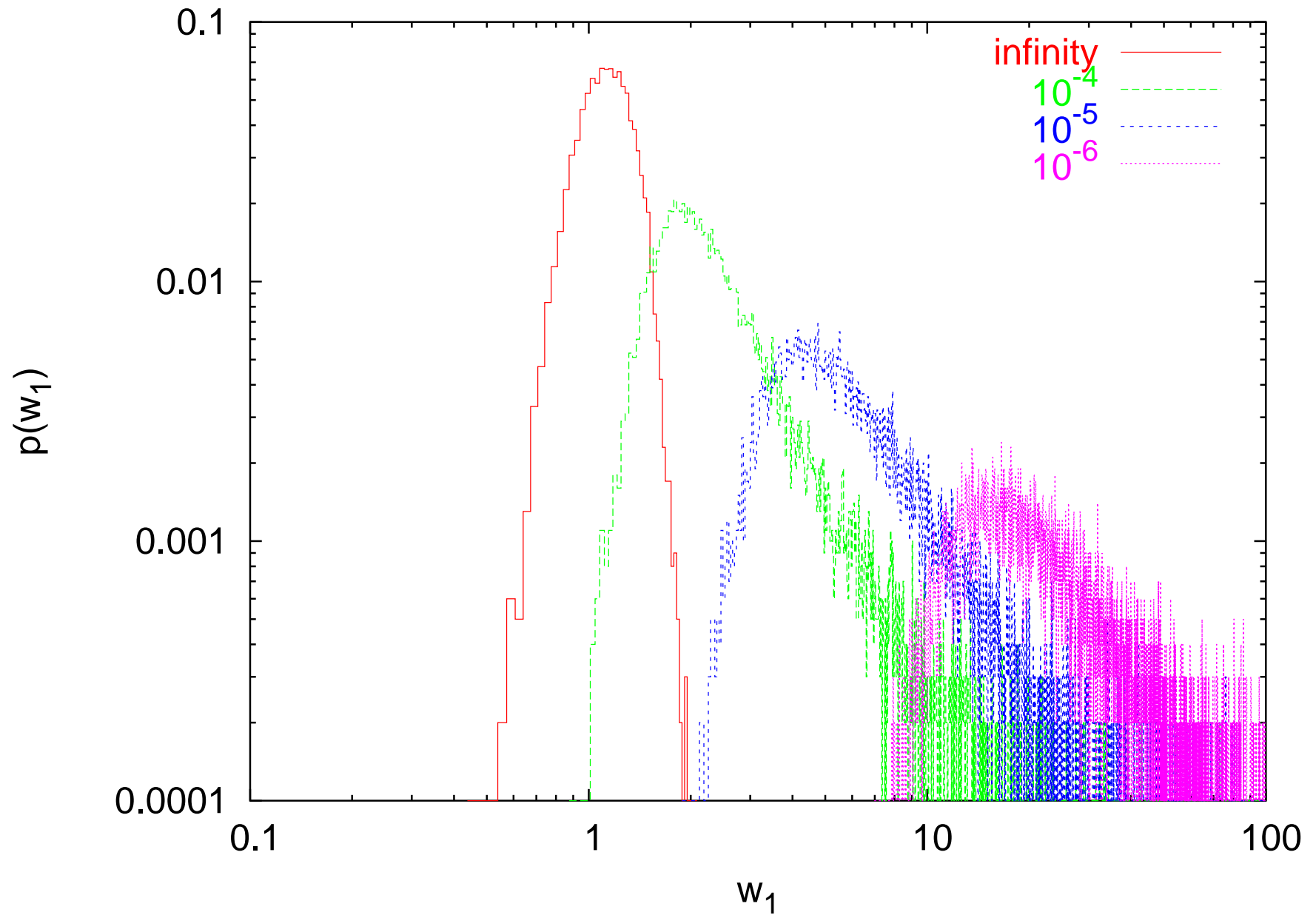


determination of n_s :

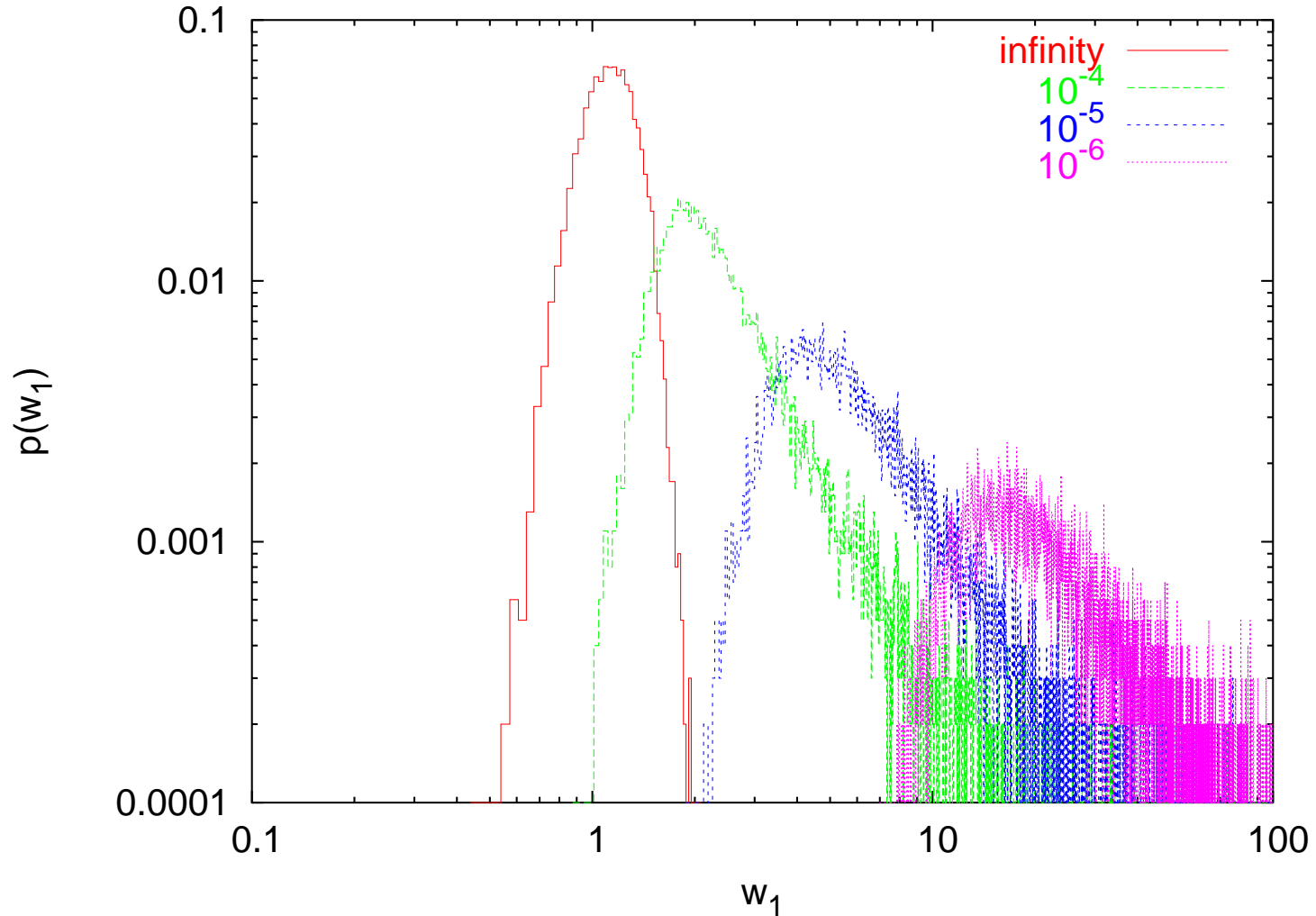


\Rightarrow effect of egmf (à la DGST) not important

establishing $n_s < \infty$:



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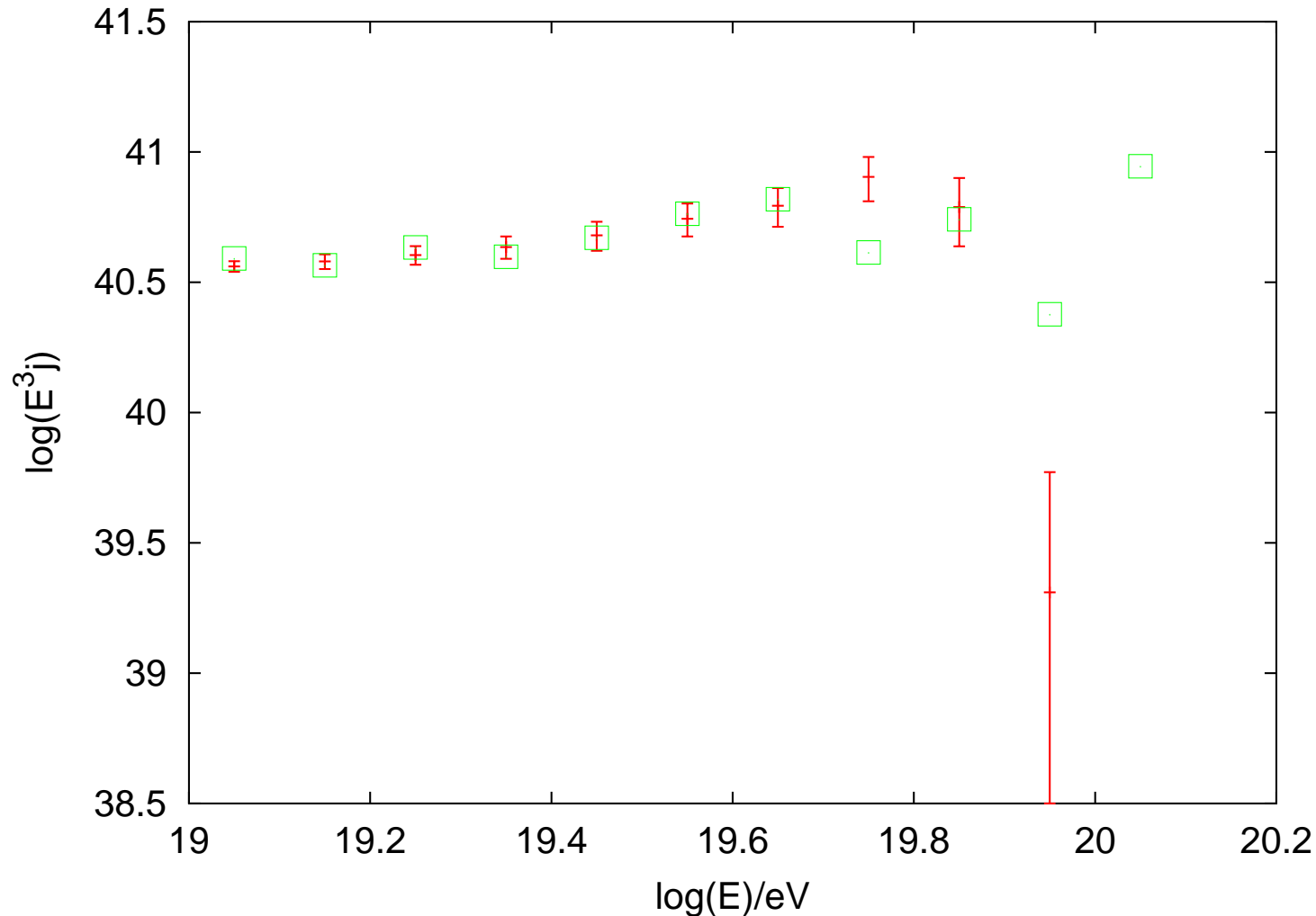


\Rightarrow continuous distribution can be excluded with $< 10^{-5}$ for true densities smaller than $10^{-5} / \text{Mpc}^3$



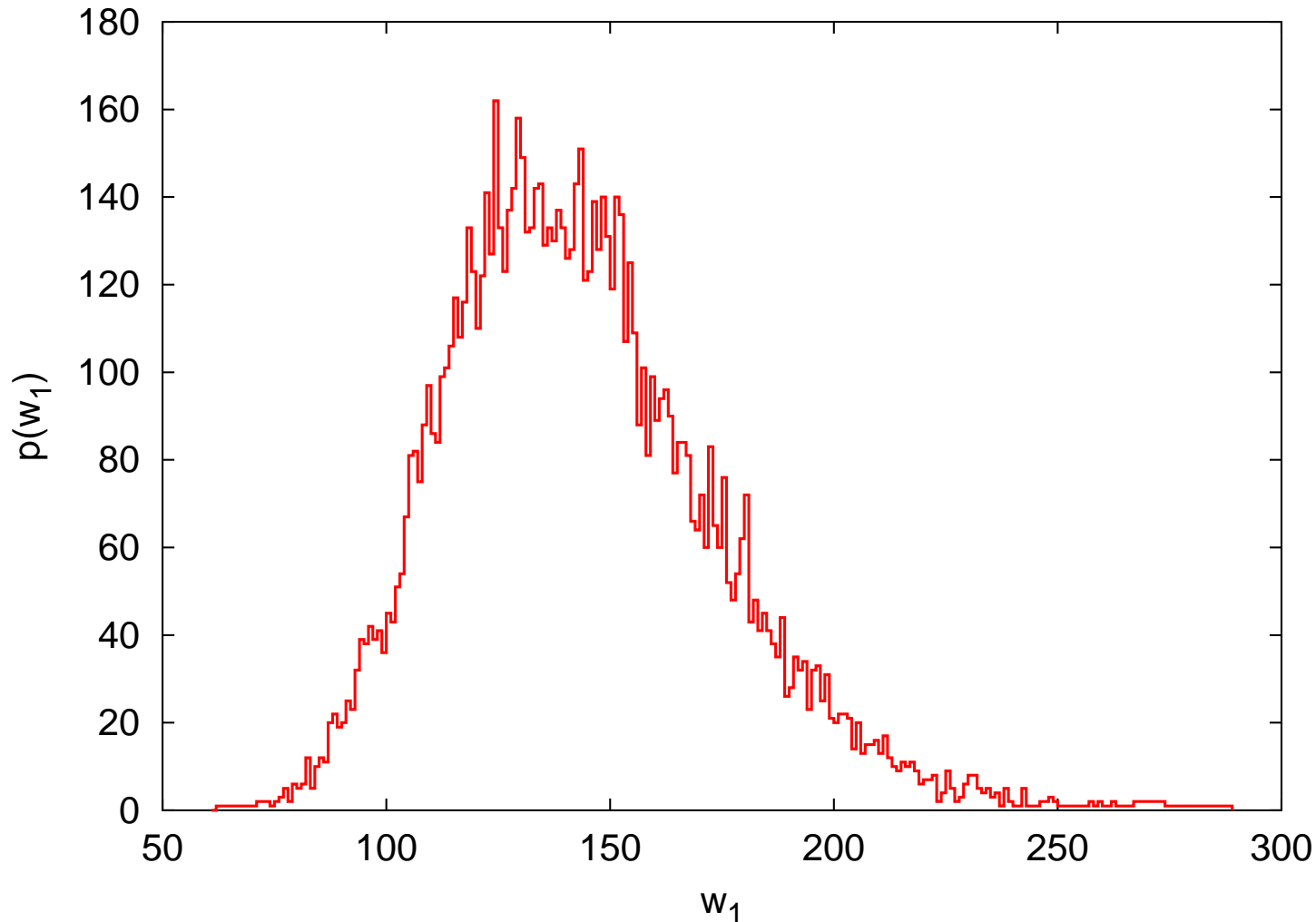
BL Lacs as sources

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



BL Lacs as sources

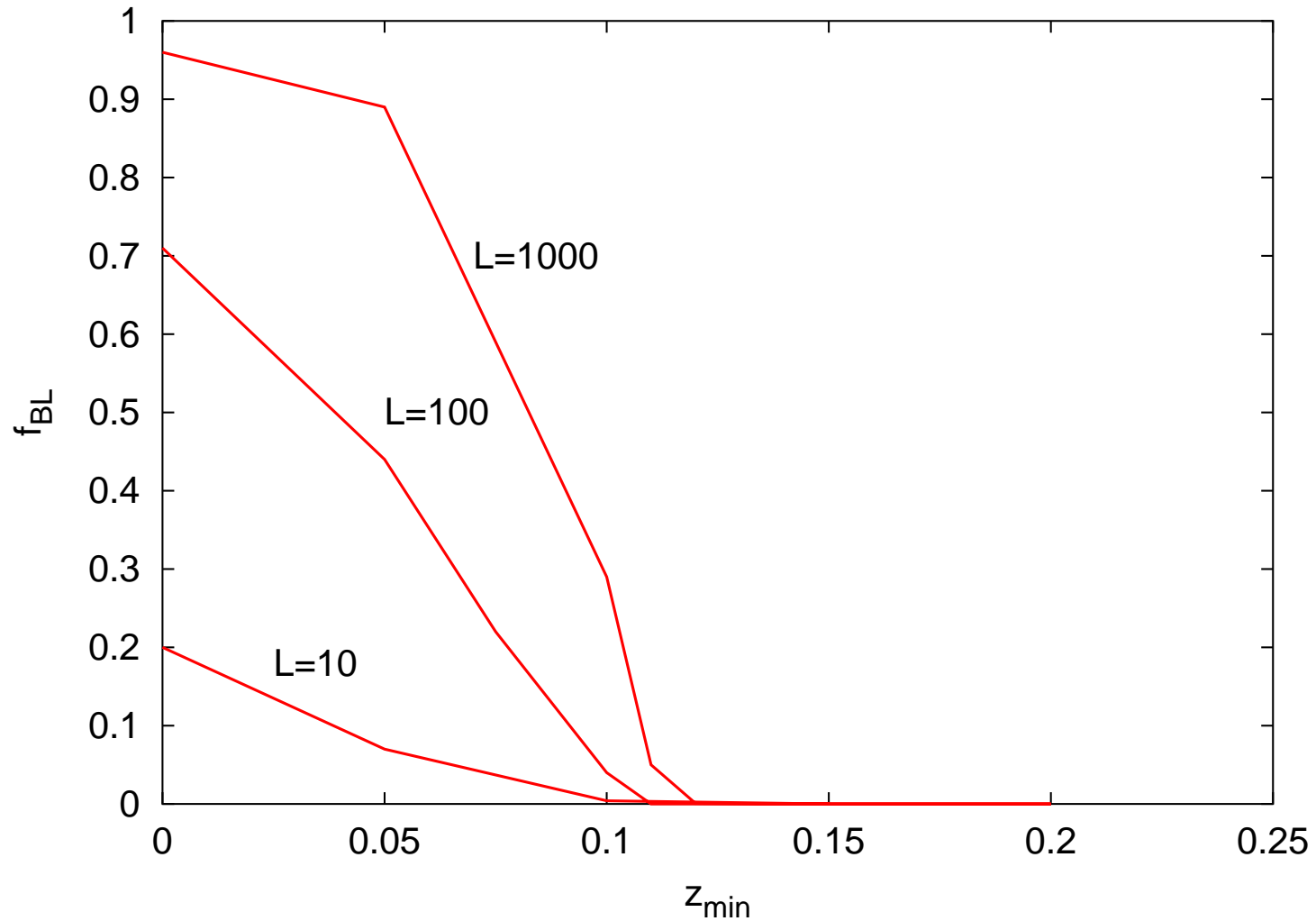
small number of BL Lacs results in strong clustering and in strong GZK cutoff, if $z_{\min} > 0$:



BL Lacs and uniform sources

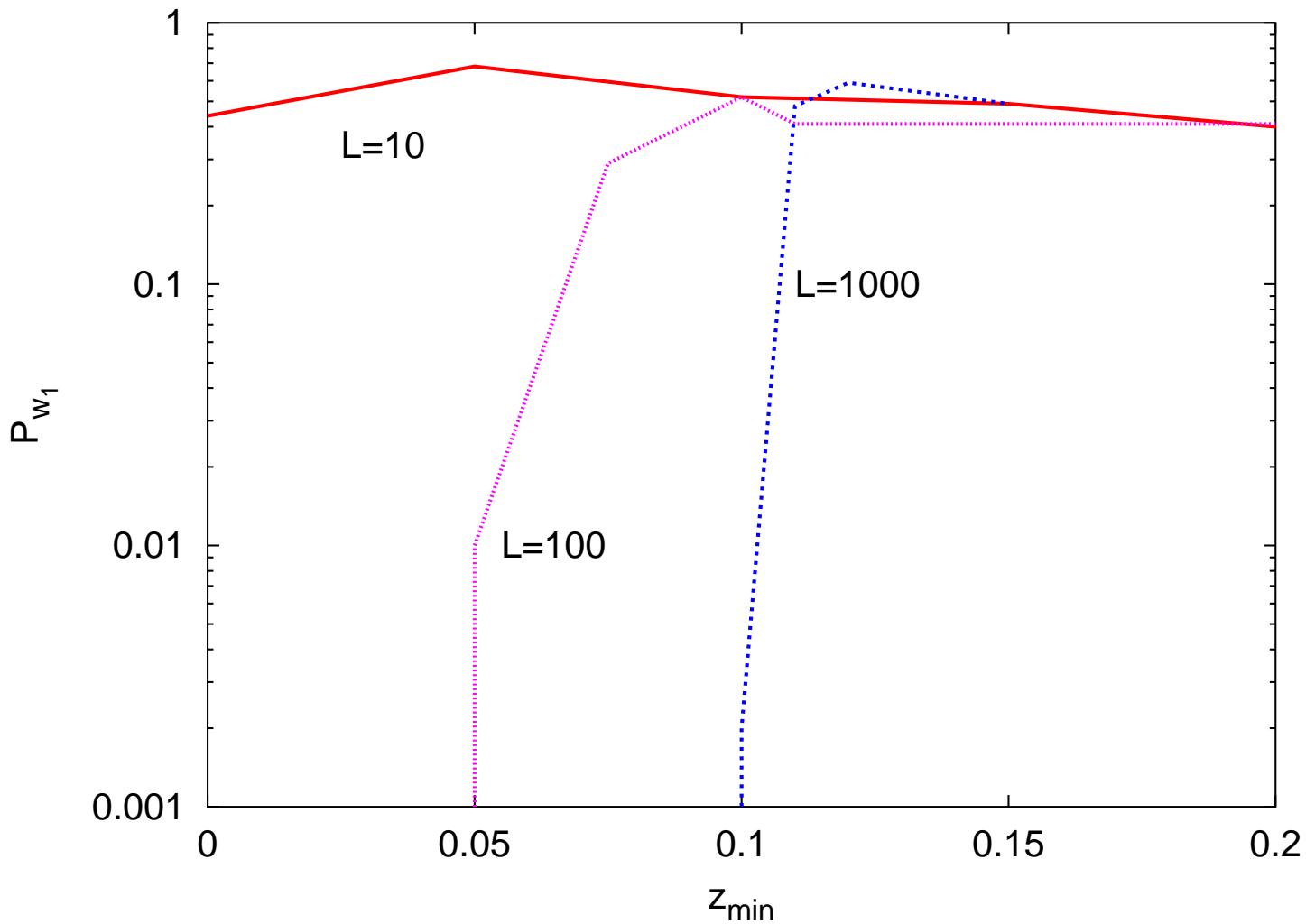
- **add** to BL Lac distribution an **uniform component** with smaller luminosity:
- vary parameter L_{BL}/L_u , $z_{\min,BL}$, n_u :
- **possible** to obtain $f_{BL} = 10\text{--}30\%$ for reasonable parameters?

BL Lacs and uniform sources



$z_{min} \lesssim 0.05-0.15$ 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 $n_s < 10^{-4}/\text{Mpc}^3$

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