Diffuse flux sensitivity studies for KM3NeT

Luigi Antonio Fusco
University of Bologna and INFN – Sezione di Bologna

MANTS-GNN Collaboration, CERN, 20-21 September 2014

Outline

- Estimation of KM3NeT Phase1.5 capabilities to **detect** 'the' IceCube flux
  - **Muon channel**
  - **Cascade events**

KM3NetT Phase1.5
→ 2 building blocks, for a total volume of ~1km^3

- Tracks
  - Max-likelihood method:
    - Angular selection and quality cuts applied to improve signal/backgroung ratio and likelihood maximization.
- Showers
  - Cut-and-count procedure:
    - Sequence of 4 cuts to reduce the atmospheric background (both ν and μ) and MRF minimization.

Signal and background definition

- Atmospheric (background) neutrino flux
  - Honda (conventional) with knee correction + Enberg (prompt)
  - Taken from the *neutrinoflux* package
- Atmospheric (background) muon bundles
  - Parametrized flux from mupage

BKG

- Isotropic diffuse cosmic flux
  - IceCube signal*
  - ν_e and ν_μ directly from the simulations
  - ν_τ contribution estimated from other flavours

SIGNAL

*Here 1.2 10^{-8} usual units; per flavour, with cutoff at 3 PeV

Tracks: max-likelihood method

- Rejection of atmospheric muons:
  - Angular selection up to 10° above the horizon
  - Cut on the reconstruction quality parameter ($\Lambda > -5.8$, $\beta < 1.2°$)
- Unbinned max. likelihood method* to evaluate the significance.

$$LR = \sum_{i=1}^{n} \log \frac{\frac{n_{sign}}{n} \times P_{sig}(E_i^{\mu_{rec}}) + \left(1 - \frac{n_{sign}}{n}\right) \times P_{back}(E_i^{\mu_{rec}})}{P_{back}(E_i^{\mu_{rec}})}$$

- No separate fit for conventional and prompt
- Background normalization allowed to vary in the likelihood fit

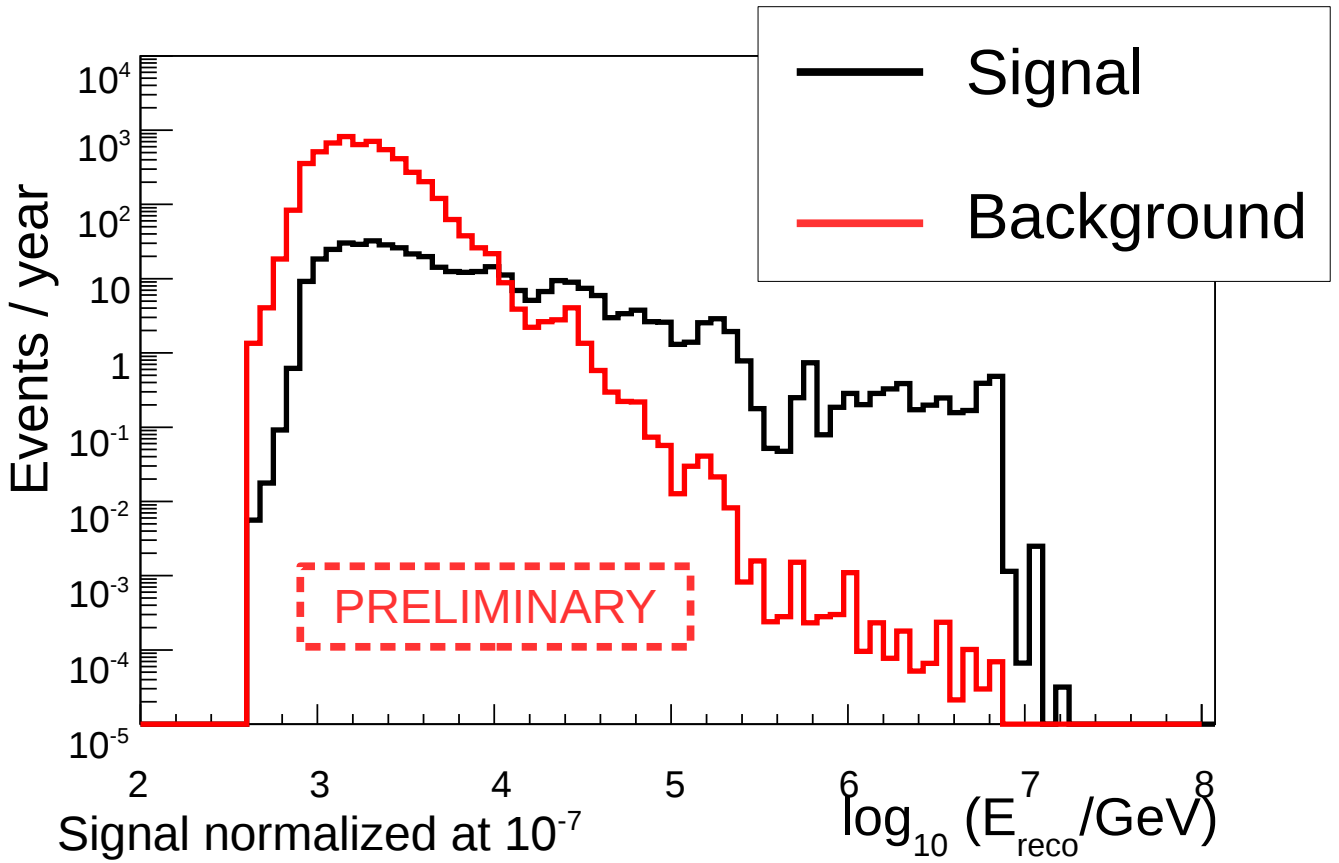
*Talk by Agata with some more detail on the method

Tracks: max-likelihood method

- Max likelihood method to evaluate the significance.

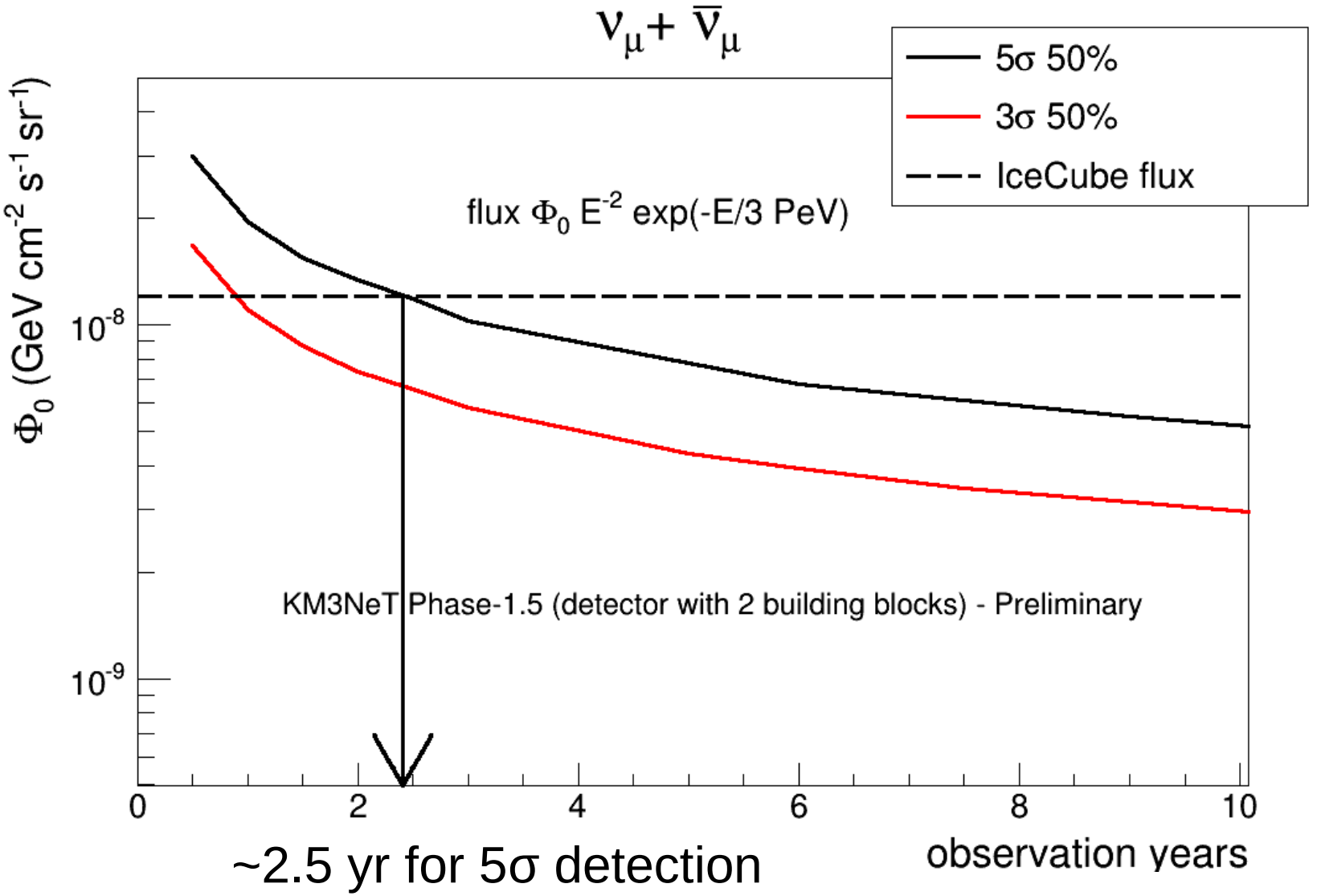
$$LR = \sum_{i=1}^{n} \log \frac{\frac{n_{sign}}{n} \times P_{sig}(E_i^{\mu_{rec}}) + \left(1 - \frac{n_{sign}}{n}\right) \times P_{back}(E_i^{\mu_{rec}})}{P_{back}(E_i^{\mu_{rec}})}$$

Only the reconstructed energy enters the likelihood.



Work in progress:
2D likelihood

Tracks: max-likelihood method



~2.5 yr for 5σ detection

Cascades: cut-and-count

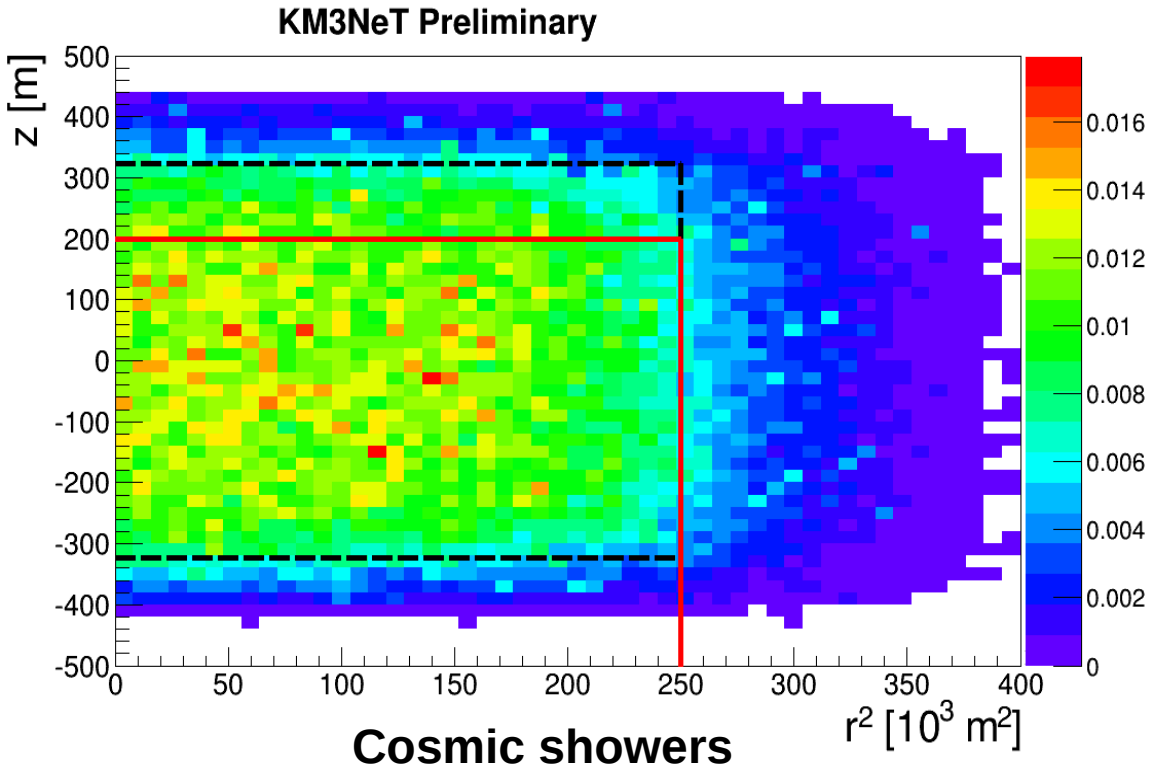
1. First level cut – Nhit2k
   - Events below 2000 PMT pulses are dominated by background
   - Dusj and Q-strategy* ~100% efficient on showers (above 10TeV)
     - Use both reconstruction informations

*Aart's talk yesterday, algorithm 2 and 1 respectively

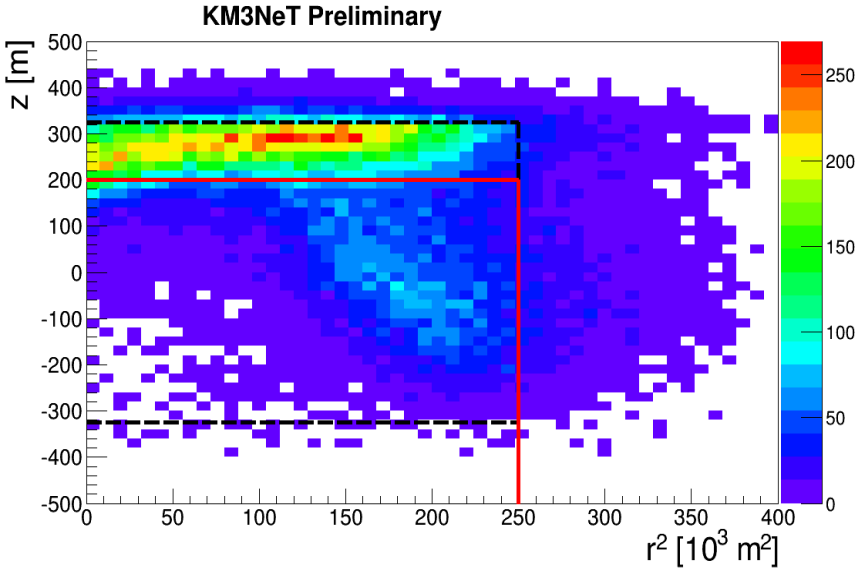
2. Geometrical cut
   - Q-strategy shower vertex containment
3. ToT cut
   - Total Time over Threshold of hits selected to be causally connected with the reconstructed shower vertex
4. Boosted Decision Tree for background suppression
   - Multivariate algorithm using both Dusj and Q information content
   - Simultaneous 2D-MRF minimization with ρ for the final selection

Cut-and-count procedure: containment

- Different distribution of the (pseudo)vertex for neutrinos and atmospheric muons.



Cosmic showers



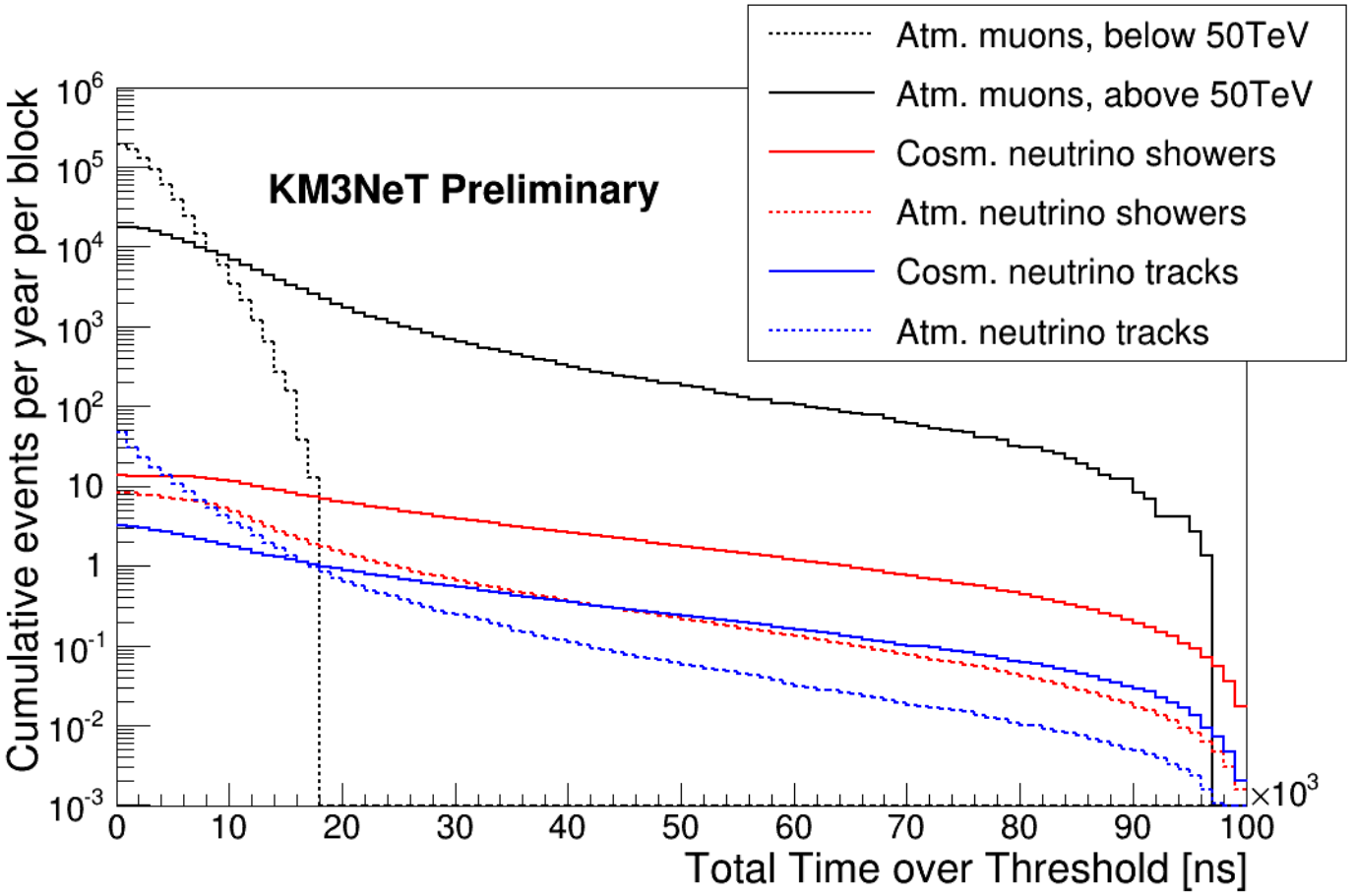
Muon bundles

The chosen cut is
r < 500 m, z < 200 m

selected
V_{instr} ~ 0.4 Gton

Cut-and-count procedure: ToT

- Total Time over Threshold of hits causally connected with a cascade event at the reconstructed vertex from Q-strategy
- Cuts on both event energy and topology

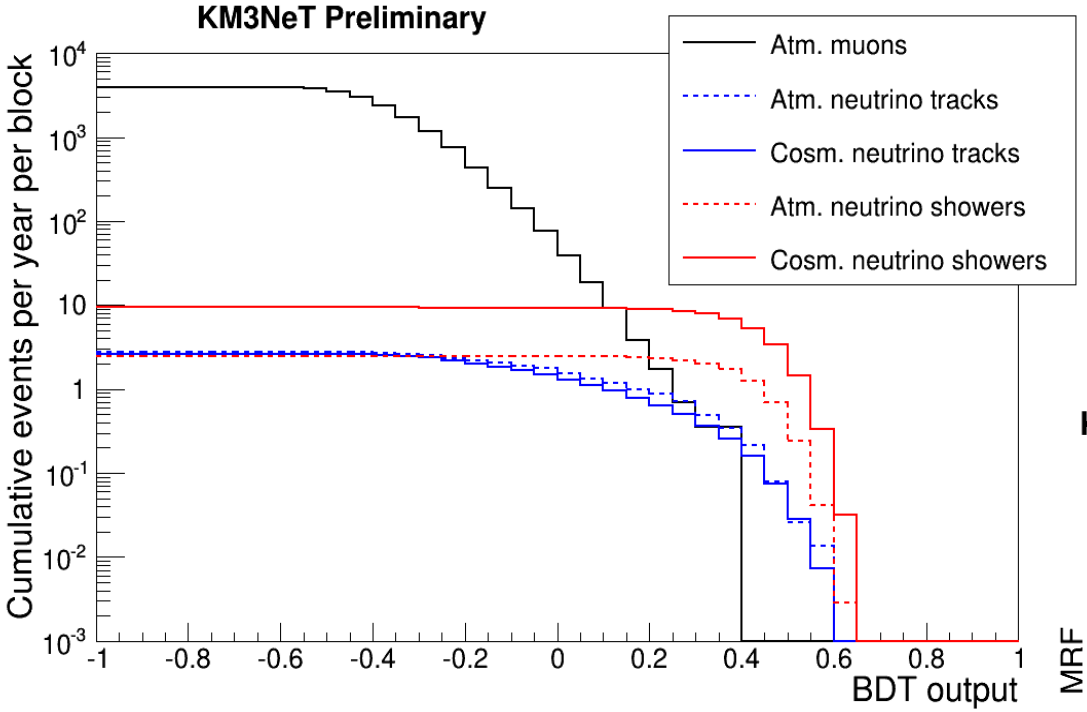


Cut at **15 10^3 ns**, corresponding to ~20TeV.

Strong suppression of low energy μ bundles and atmospheric neutrino tracks

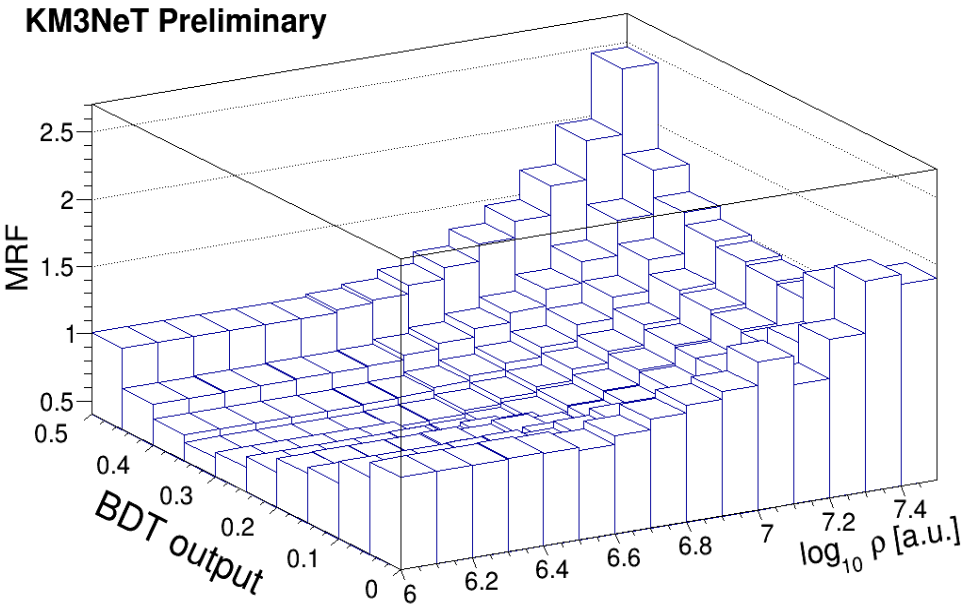
Cut-and-count procedure: BDT

- Multivariate algorithm, using both Q-strategy and Dusj quality parameters



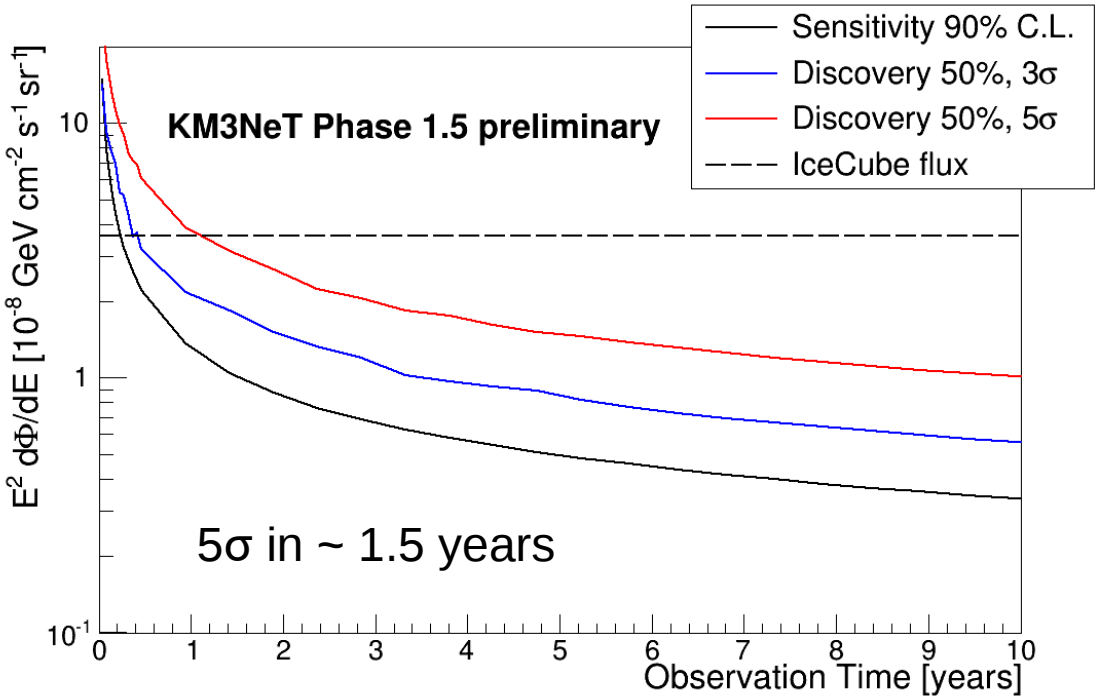
MRF minimization: energy estimator **ρ** and the BDT

$\rho > 10^6$ and BDT > 0.35

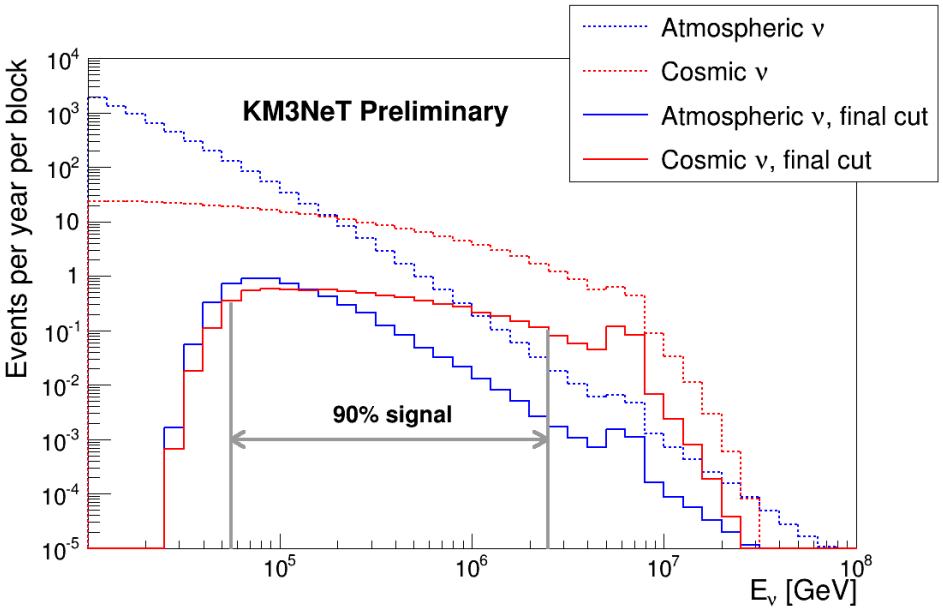


Strong rejection of the surviving atmospheric muons (< 1 ev per year)

Sensitivity estimation



90% signal in 56TeV – 2.5 PeV



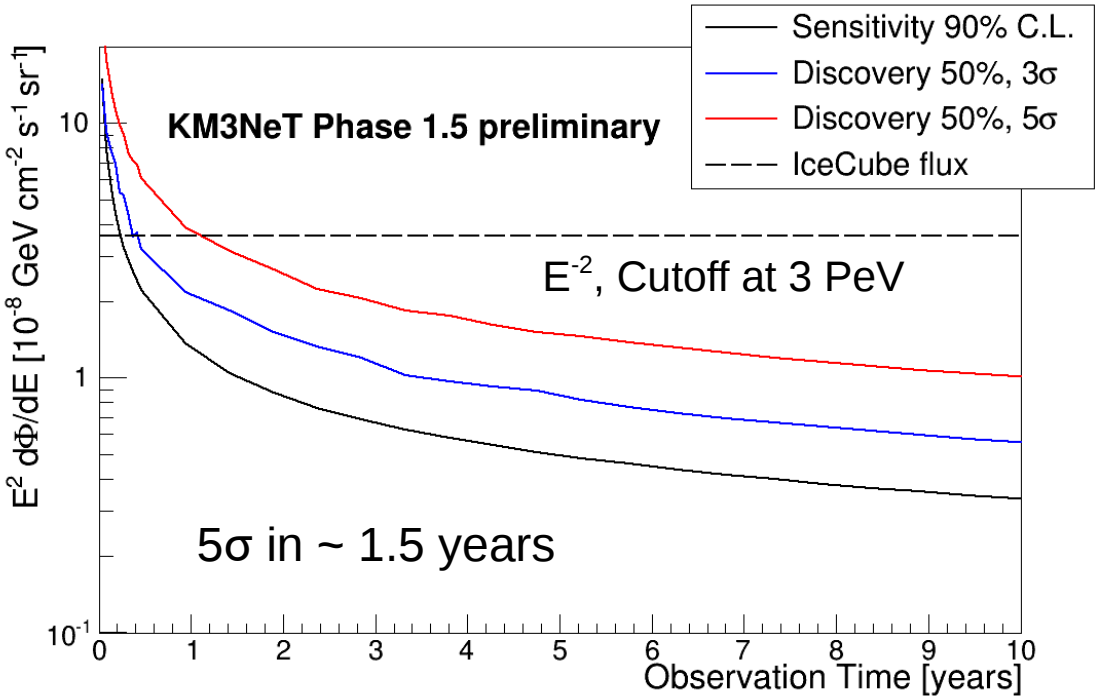
Per year per block

	Signal	Bkg
ν_e	3.6	1.4
ν_μ	0.4	0.7
ν_τ	2.7	-
total ν	6.7	2.1
atm μ	-	0.1

E^{-2} spectrum with cutoff at 3 PeV – 1yr with 2 blocks:

90% Sens.	**1.37 10^{-8}**
3σ Disc 50%	**2.5 10^{-8}**
5σ Disc 50%	**4.1 10^{-8}**

Sensitivity estimation



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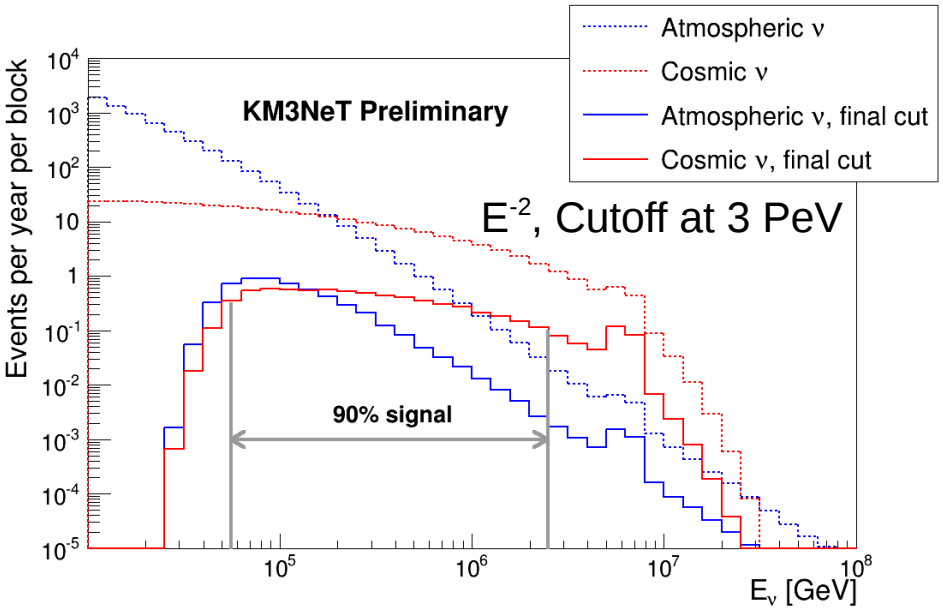


Per year per block

E^{-2}, with cutoff	Signal	Bkg
ν_e	3.6	1.4
ν_μ	0.4	0.7
ν_τ	2.7	-
total ν	6.7	2.1
atm μ	-	0.1

Other possible spectra studied (1yr)
All flavour sensitivity/discovery flux

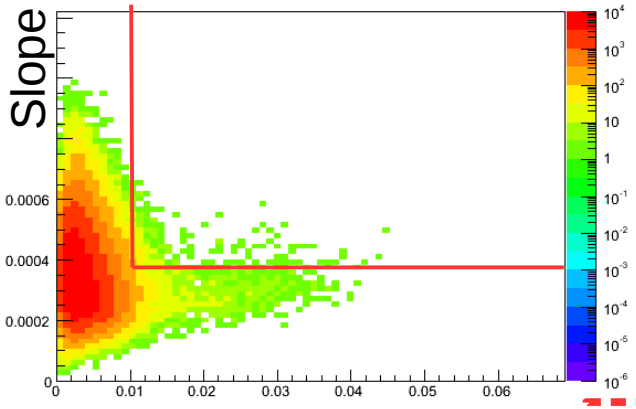
Spectrum	$\Phi = K E^{-2}$	$E^2\Phi \approx K (E/100TeV)^{-0.3}$
90% Sens	**$1.05\ 10^{-8}$**	**$1.37\ 10^{-8}$**
3σ Disc 50%	**$1.9\ 10^{-8}$**	**$2.4\ 10^{-8}$**
5σ Disc 50%	**$3.2\ 10^{-8}$**	**$4.1\ 10^{-8}$**

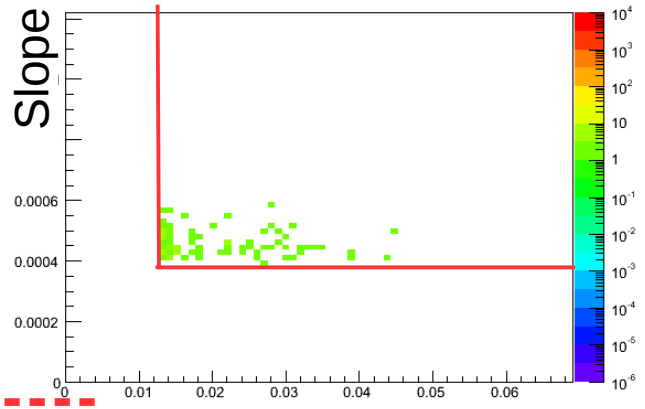
Cascades: independent analysis (D.Stransky)

- Cutting away muons in 2 steps

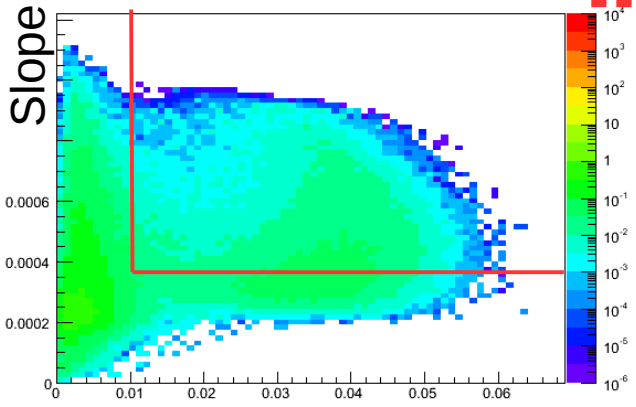
  1 – 2D distribution of dusj strategy shower-id parameters

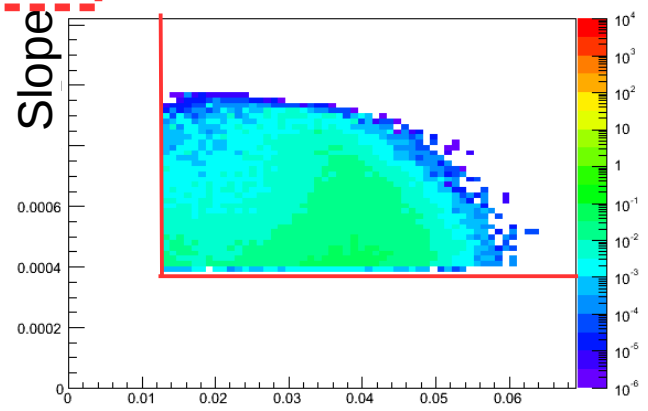
GoldParameter: shower χ^2
Slope: fraction of hits on light cone





PRELIMINARY



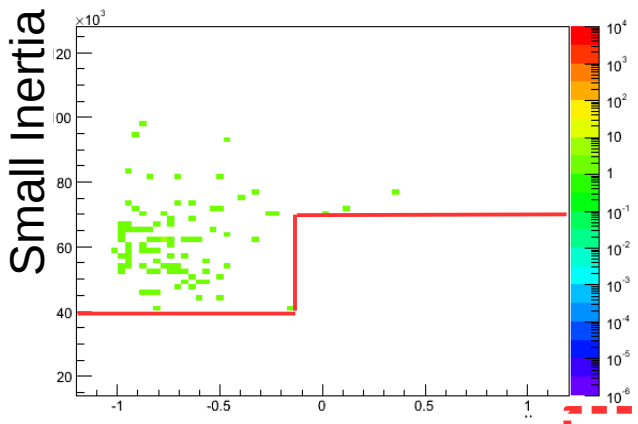


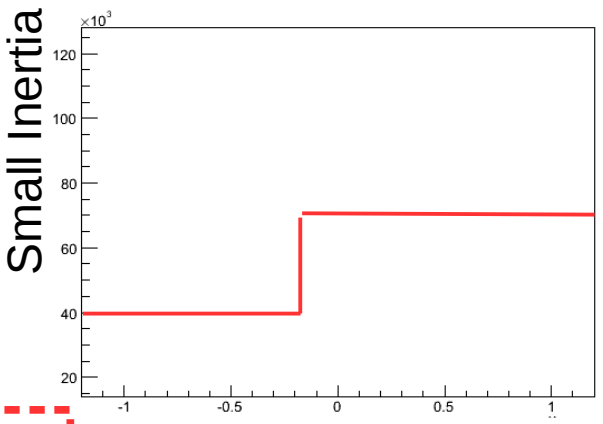
Out of some hunderds of possible combinations

Cascades: independent analysis (D.Stransky)

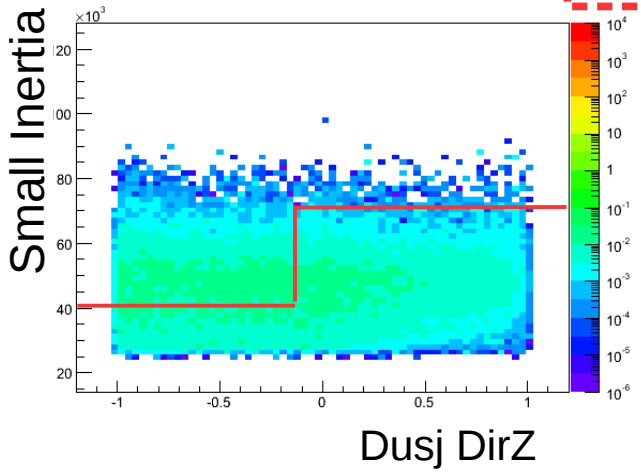
- Cutting away muons in 2 steps

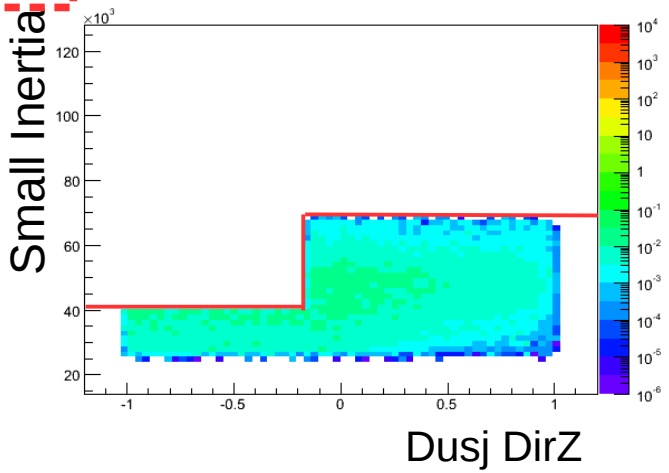
  2 – 2D distribution of a dusj strategy shower-id parameters and direction





PRELIMINARY

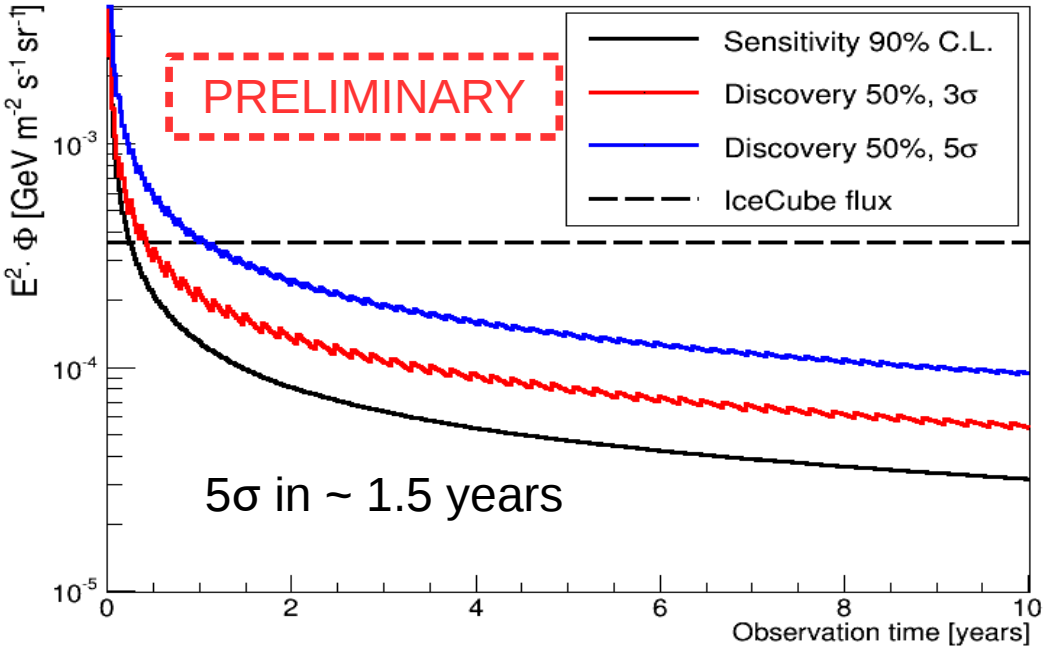


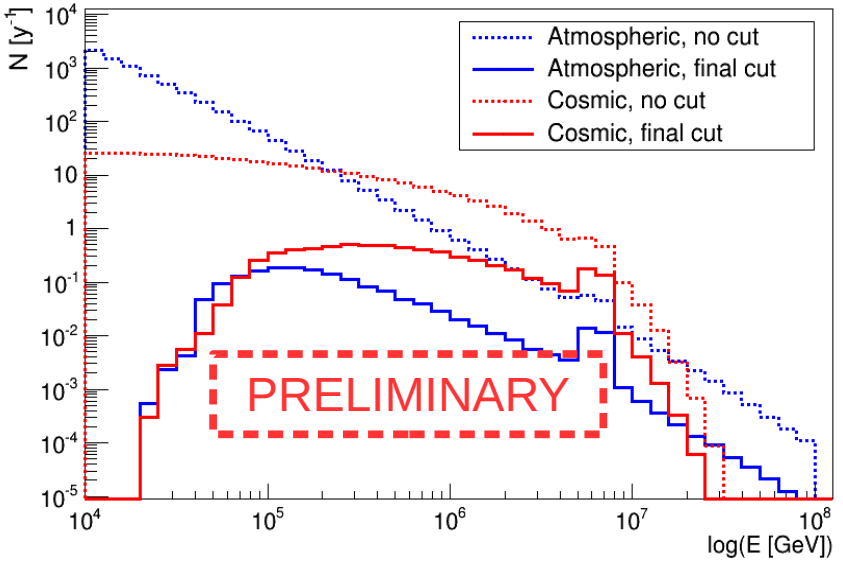


Inertia: how spherical the light distribution is

Out of some hunderds of possible combinations

Sensitivity estimation





Per year per block

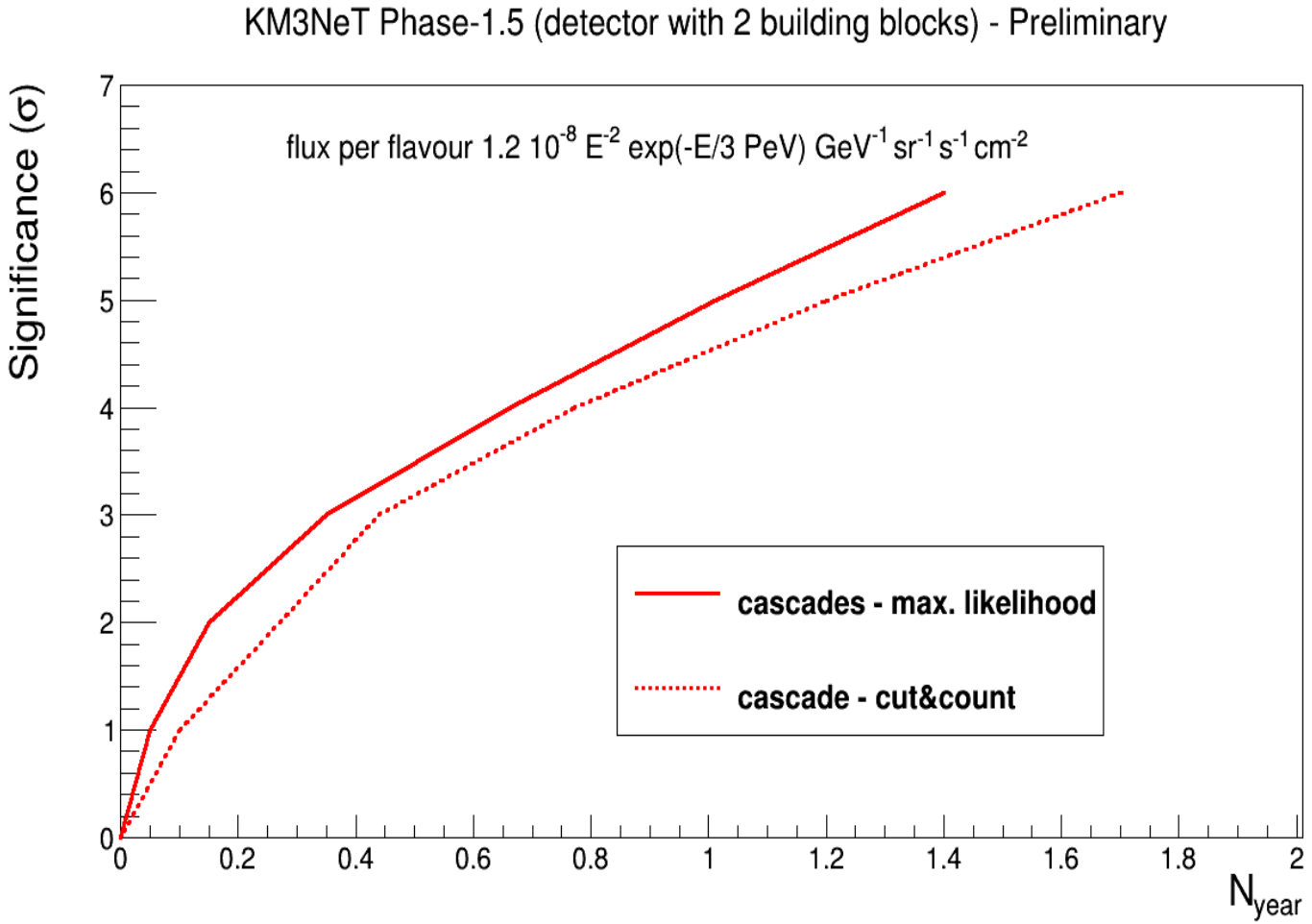
Flavour	Signal	Bkg
ν_e	3.2	0.8
ν_μ	0.6	0.8
ν_τ	2.5	-
total ν	6.3	1.6
atm μ	-	~0

Completely analogous results to the first cut-and-count procedure

90% Sens.	**$1.35\ 10^{-8}$**
3σ Disc 50%	**$2.4\ 10^{-8}$**
5σ Disc 50%	**$4.1\ 10^{-8}$**

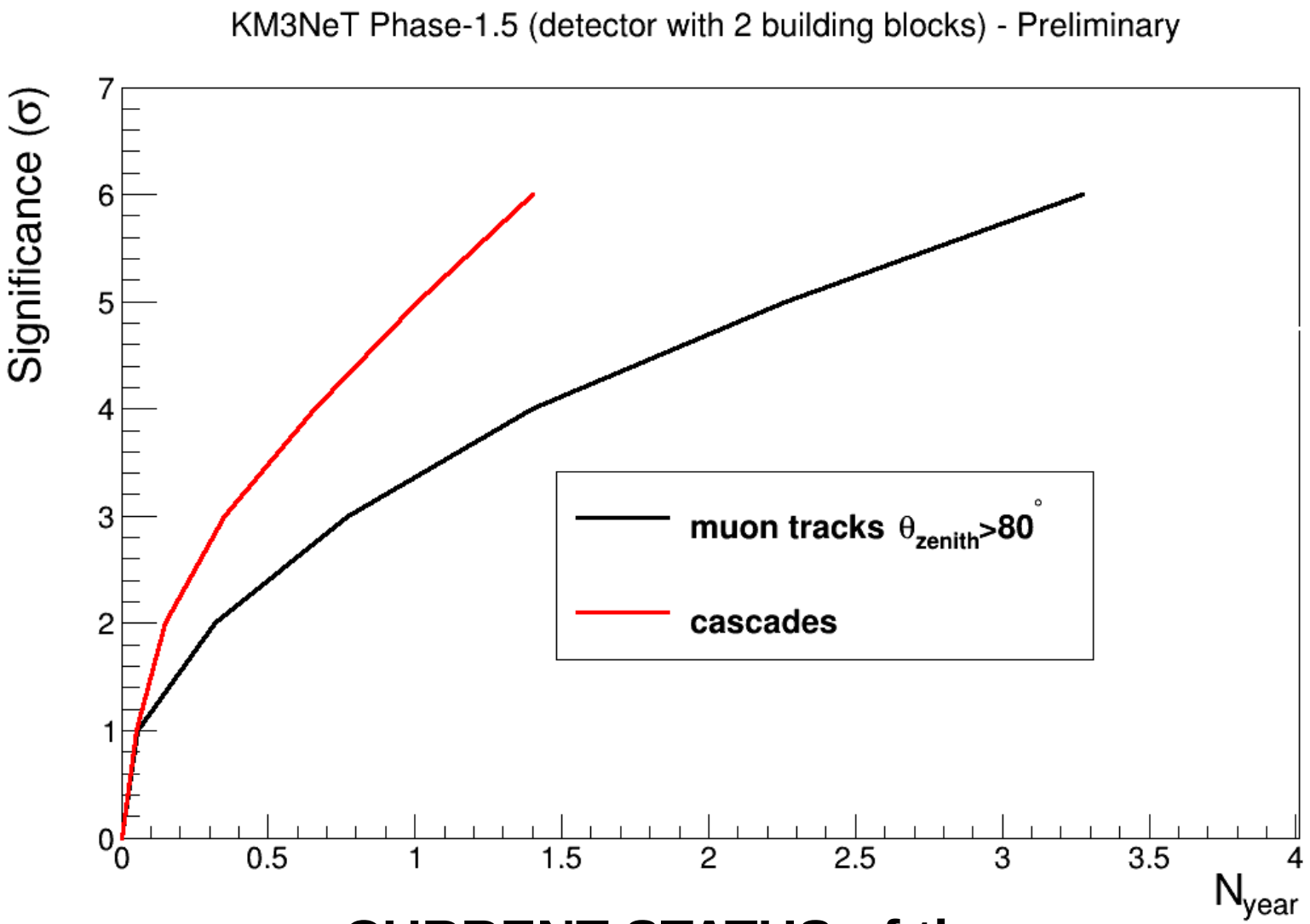
Diffuse fluxes – maximum likelihood

- Same as for track analysis, improvement expected (and first application is encouraging)



Prelim. cuts for the first cut&count

Diffuse fluxes – maximum likelihood



CURRENT STATUS of the analyses: max. likelihood

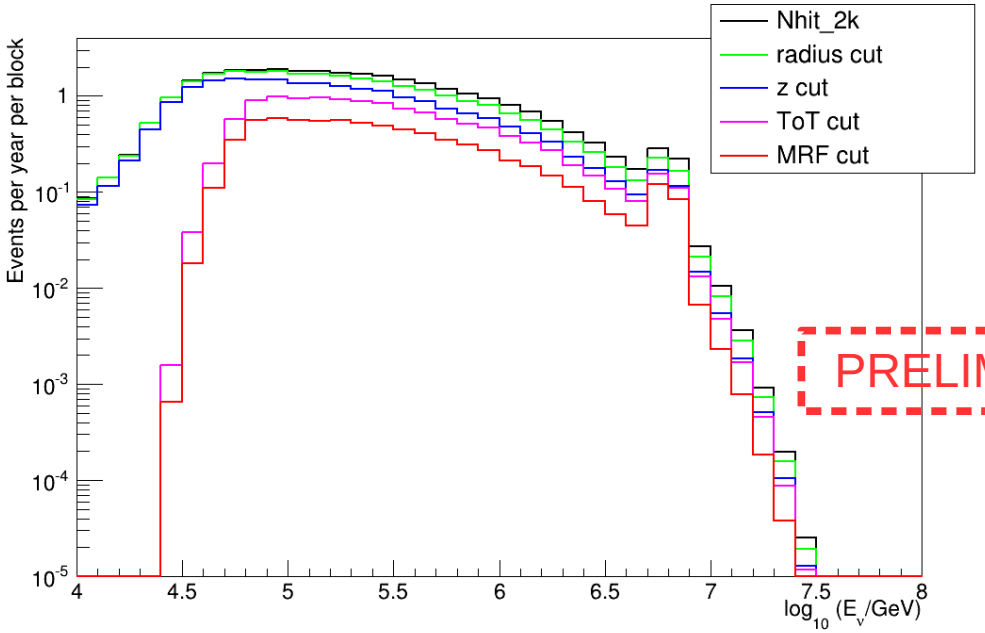
Conclusions and outlook

- Sensitivity studies in both the muon and the cascade channel
  - Good atmospheric muon background rejection feasible
  - Good performances for KM3NeT Phase 1.5 in the detection of 'the' IceCube signal:
    - Studying it (composition, fitting spectral shape, etc.) still to be done.
  - Also studied the 120 m behavior (see backup)
- Improvements to come soon
  - Optimized maximum likelihood calculation also for cascades (first insight showing ~20% improvements)
  - More advanced ToT and trigger simulations to be applied in the simulation chain
  - Improved shower reconstruction to be applied
  - Systematic studies

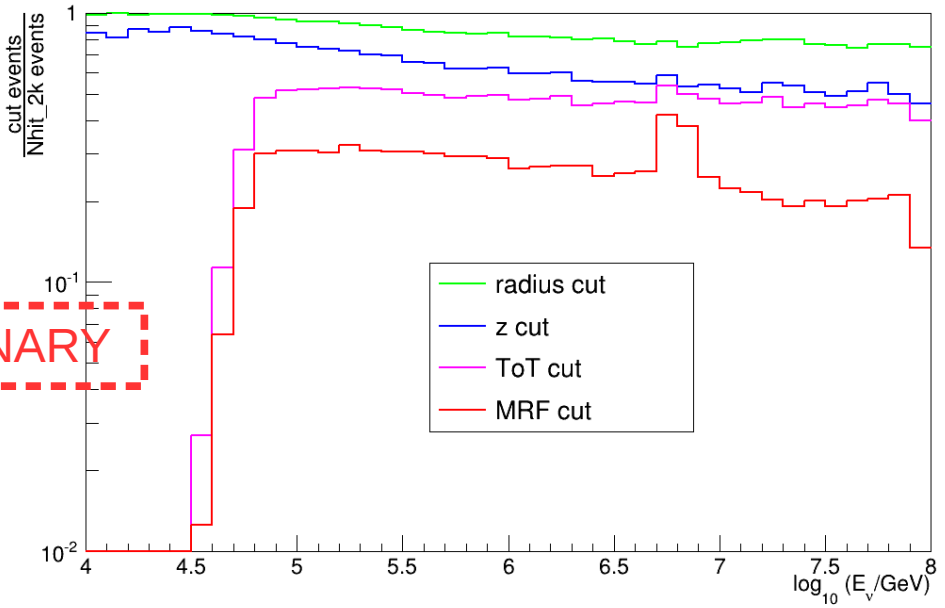
Backup

Cut-and-count procedure: efficiency on the signal

Cosmic neutrinos, event rates at each cut level



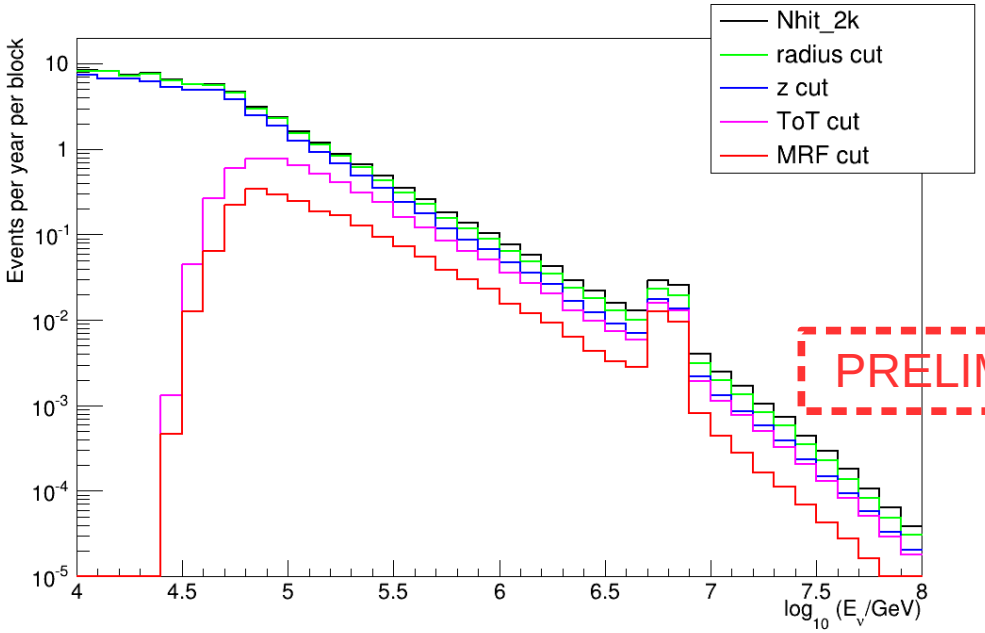
Cosmic neutrinos, event rates/Nhit_2k rates



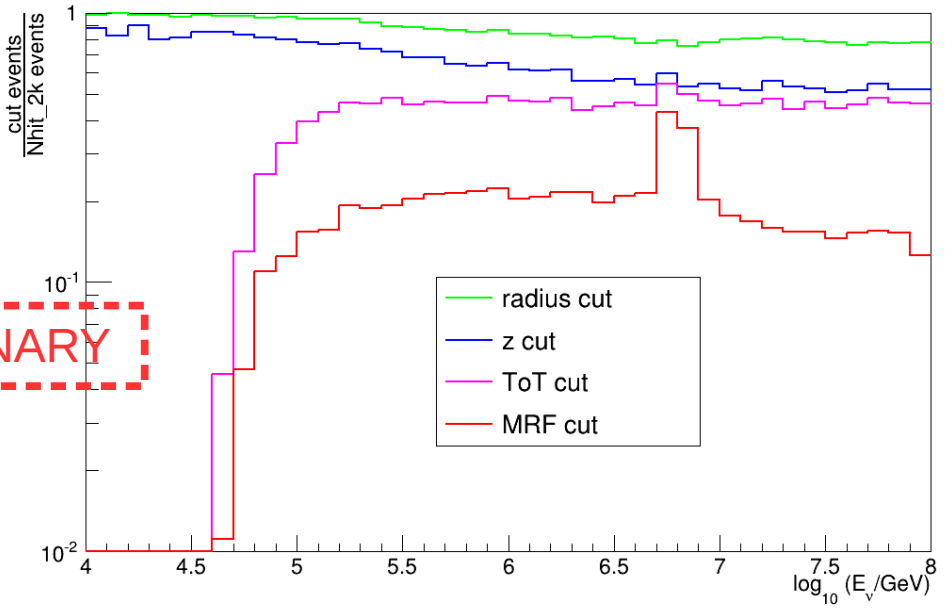
PRELIMINARY

Cut-and-count procedure: efficiency on the neutrino background

Atmospheric neutrinos, event rates at each cut level



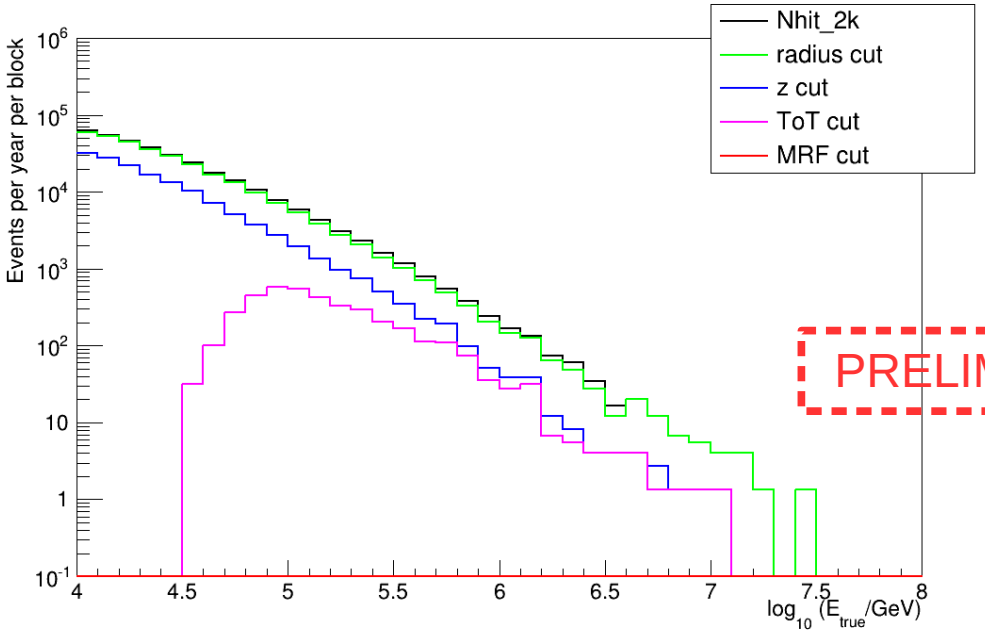
Atmospheric neutrinos, event rates/Nhit_2k rates



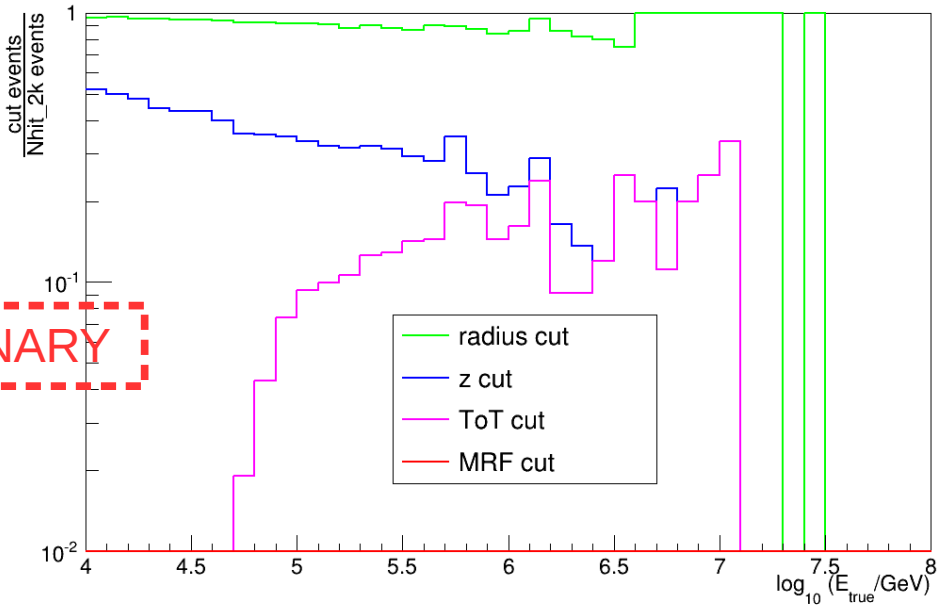
PRELIMINARY

Cut-and-count procedure: efficiency on the atmospheric muons background

Atmospheric muons, event rates at each cut level

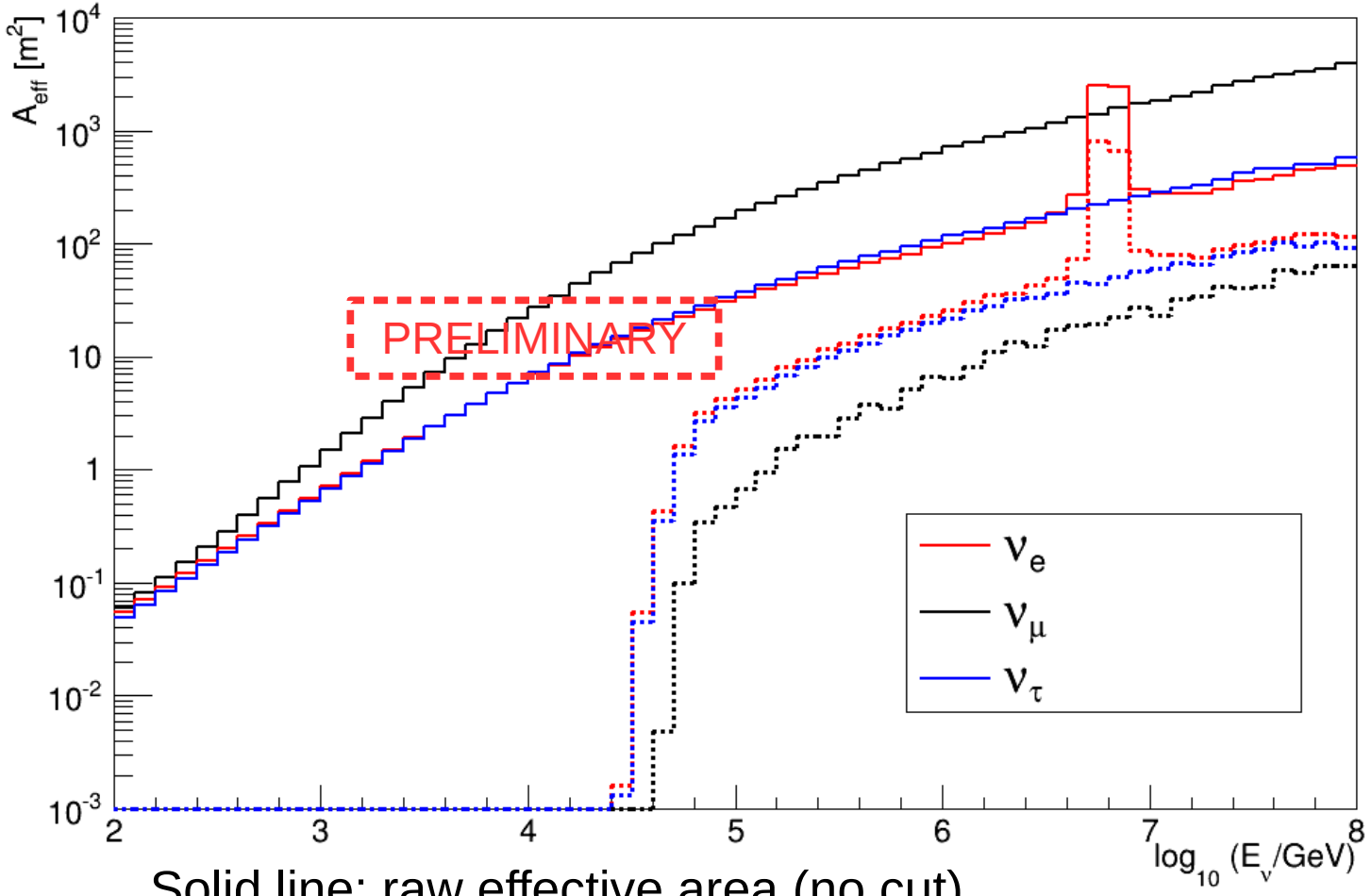


Atmospheric muons, event rates/Nhit_2k rates



PRELIMINARY

Resulting effective area for cascade analysis



Solid line: raw effective area (no cut)
Dashed: final effective area (after cuts)

Boosted decision tree inputs

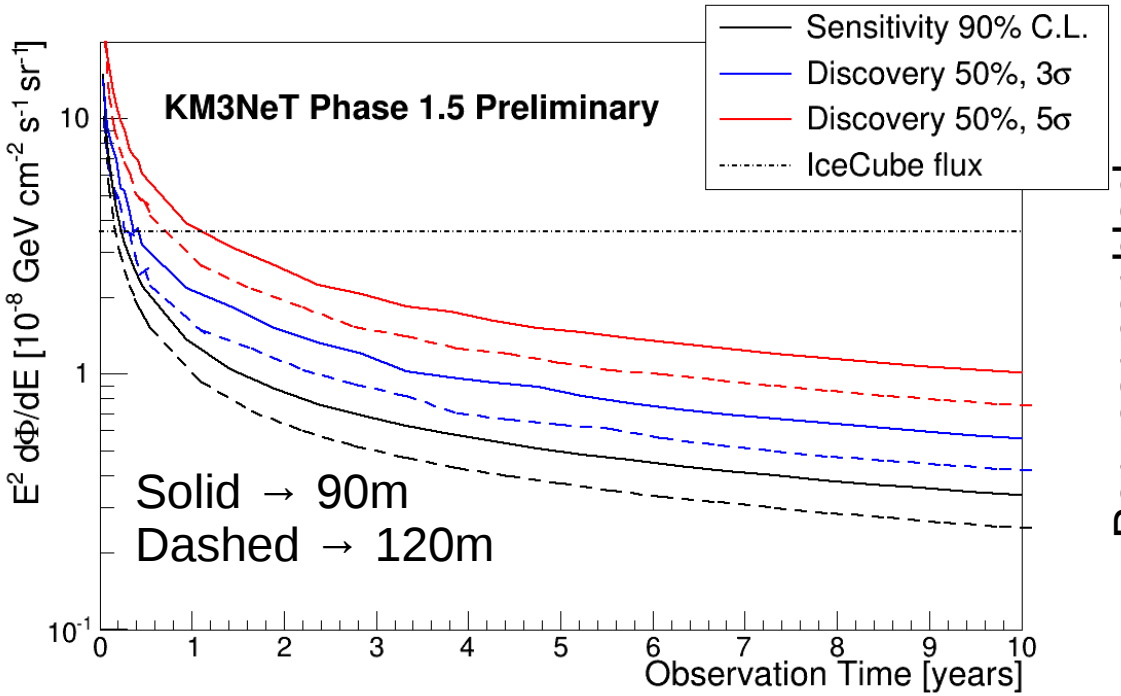
- From Q-strategy:
  - Vertex position;
  - Reconstructed θ;
  - M estimator;
  - R estimator;
  - Inertia ratio;
  - Aph parameter:
    - Correlated with the highest pulse position;
  - Distance parameter:
    - Correlated with the highest pulse position;

- From dusj
  - Vertex position;
  - Reconstructed θ;
  - Vertex distance;
  - FinalFitLogLikelihood:
    - and reduced value;
  - VertexFitLogLikelihood:
    - and reduced value;
  - Inertia;
  - Gold parameter;
  - Y intersect;
  - Residuals FWHM.

In blue, discriminating variable developed specifically for KM3NeT

120 m spacing – diffuse cascades

- Tested an “expanded” block, with 120 m spacing between the strings
  - Same cut-and-count steps, different selection cuts
- Improvements in the FOM for diffuse searches...



Per year per block

	signal	bkg
ν_e	4.5	1.3
ν_μ	1.0	0.7
ν_τ	3.6	-
total ν	9.1	2.0
atm μ	-	0.1