https://wiki.icecube.wisc.edu/index.php/Solar_flare_neutrino_search

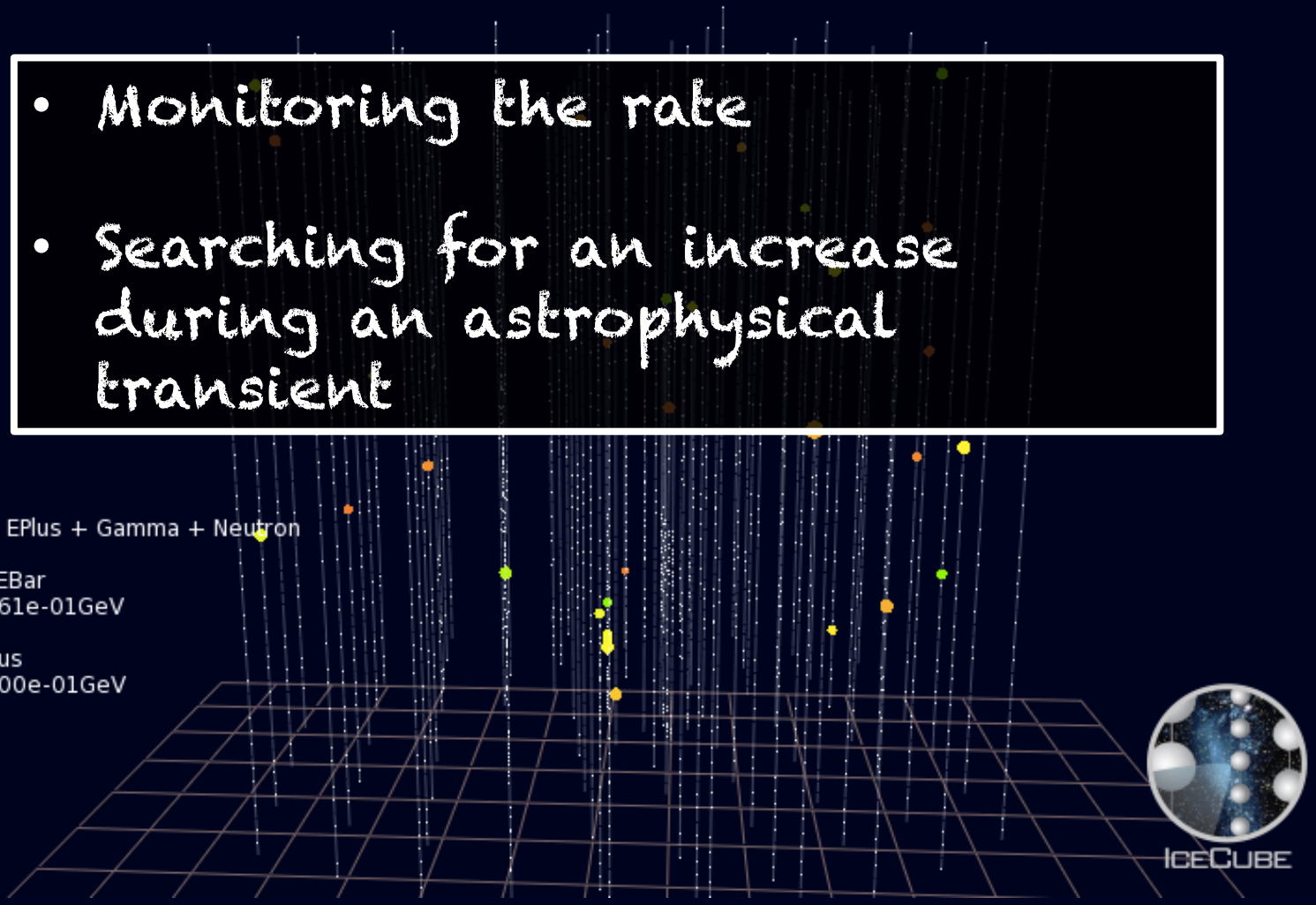
# ELOWEN
## GeV neutrinos from solar flares and LIGO-Virgo events

Gwen de Wasseige

Reviewers: Lutz and Carlos

# GeV neutrinos from astrophysical transients

- Monitoring the rate
- Searching for an increase during an astrophysical transient




IceCube

# Questions:

- From Martin W.:

  *"Why haven't you used the Solar Wimp event selection?"*

  ->According to my simulation of proton-nucleus interactions in solar flares, we expect solar flare neutrinos up to max. 5 GeV, emitted with a soft spectrum. We therefore wanted an event selection optimized for 0.5 - 5 GeV neutrinos, which is not the case of the solar wimp event selection.

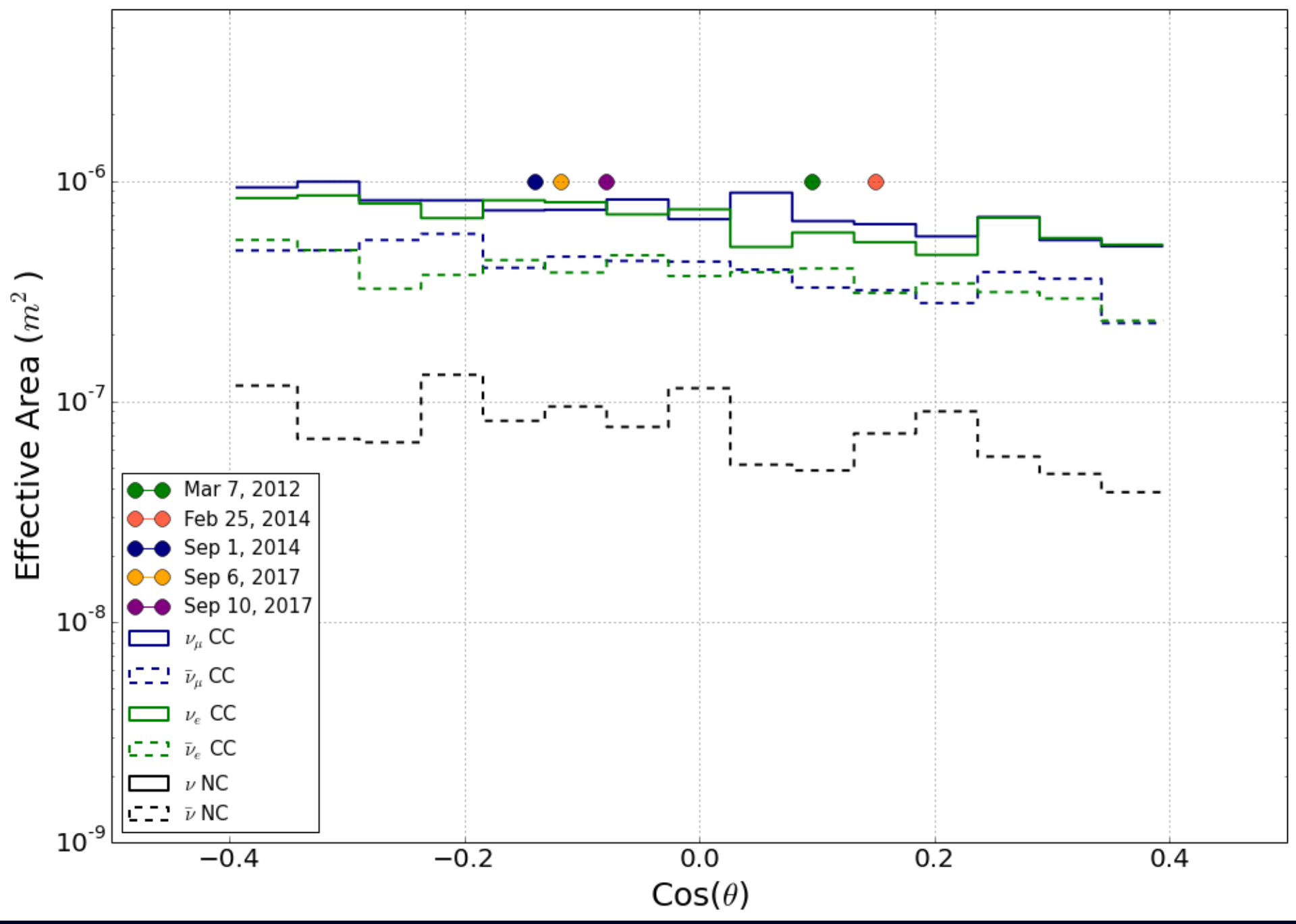
# Questions:

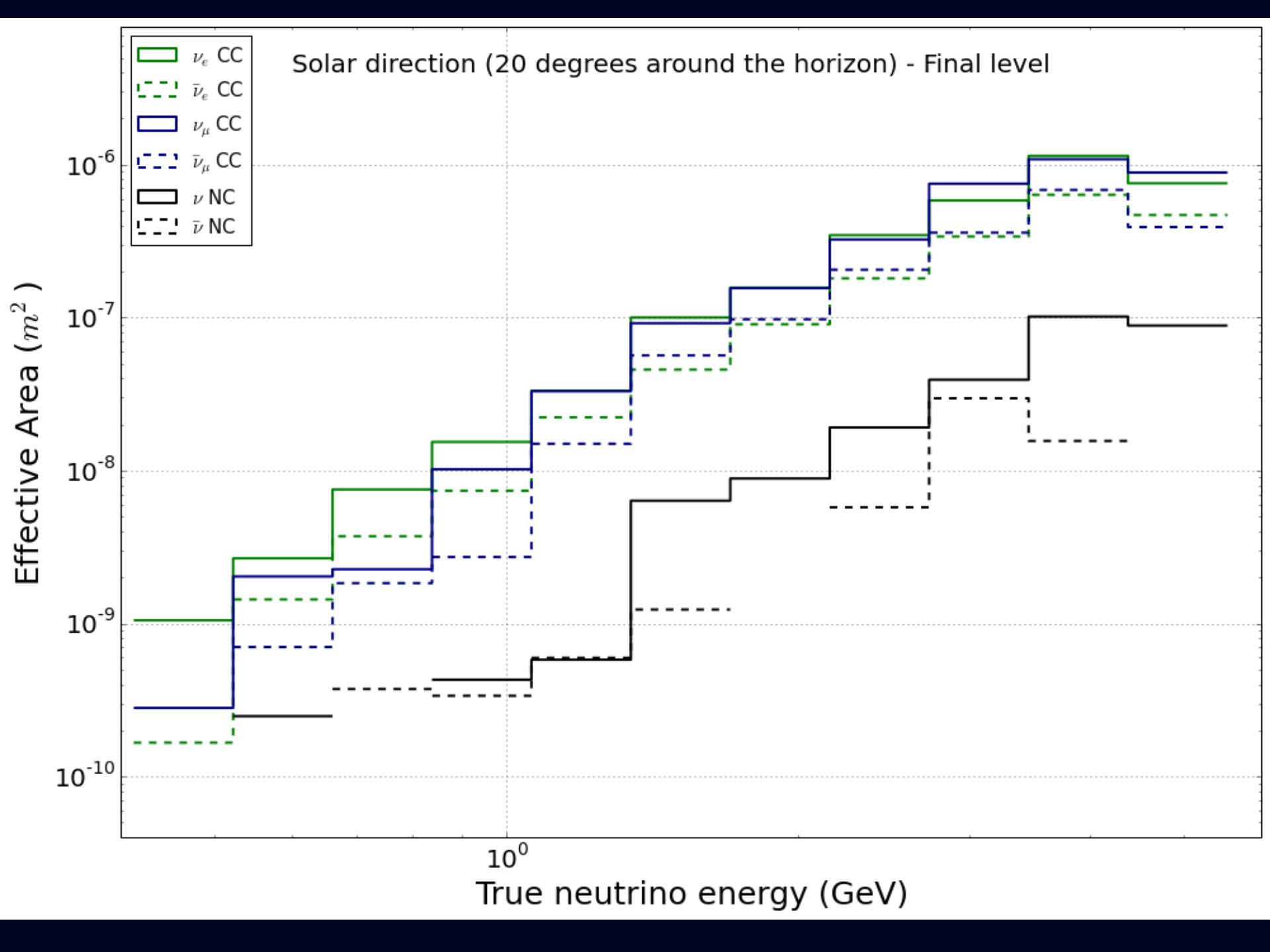
- From Michael L.:

  "*Does your definition of 'solar direction' influence the effective area?*"

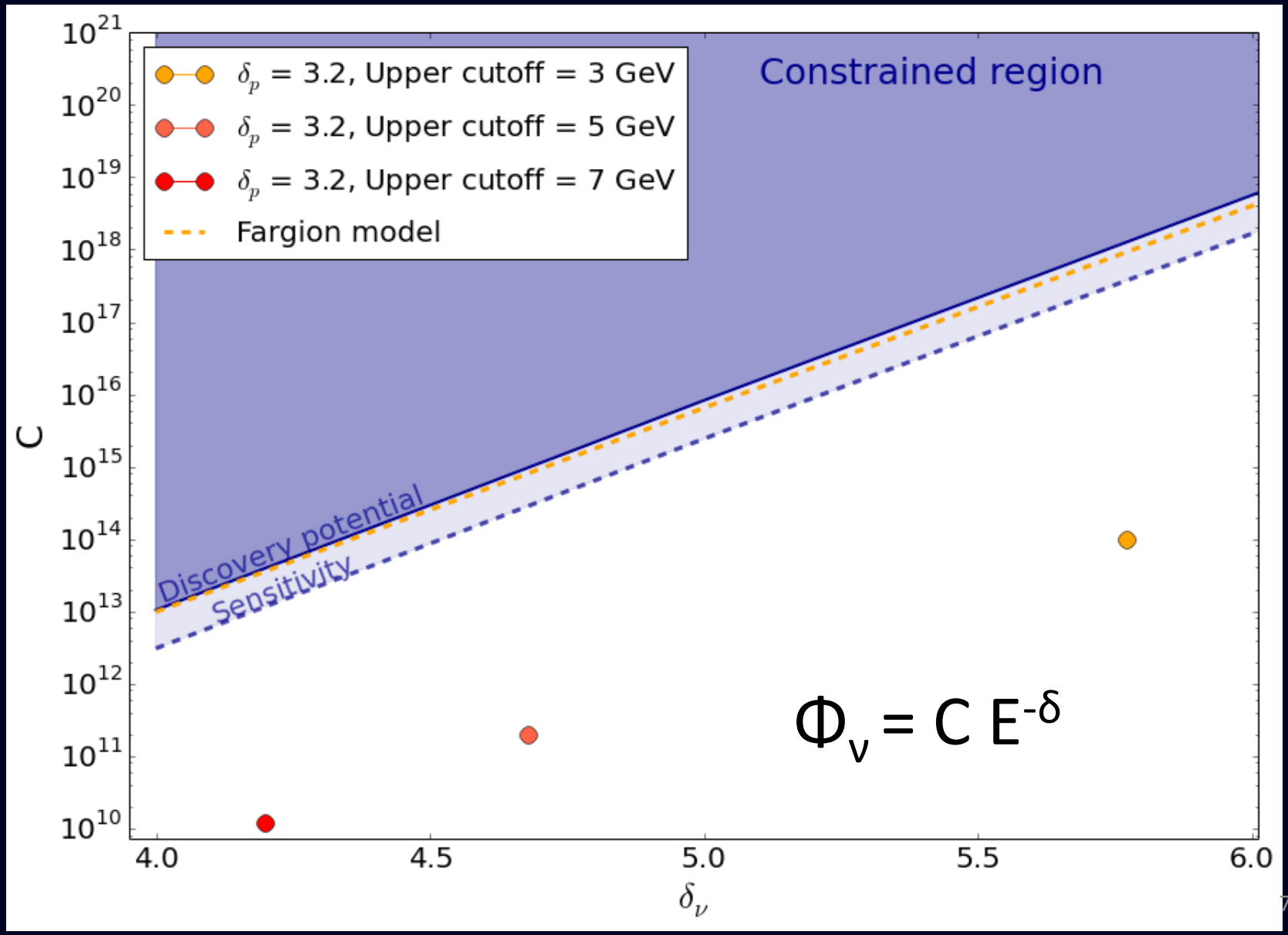
  -> This question makes me find a bug in the code calculating the effective area. Updated effective areas (bigger than previously) are on the next slide.

  In view of answering Michael's question, I restricted the effective areas to ±10 degrees around the horizon, where all the solar flares happened.


Effective Area ($m^2$)
$10^{-6}$
$10^{-7}$
$10^{-8}$
$10^{-9}$
−0.4
−0.2
0.0
0.2
0.4
Cos($\theta$)
Mar 7, 2012
Feb 25, 2014
Sep 1, 2014
Sep 6, 2017
Sep 10, 2017
$\nu_\mu$ CC
$\bar{\nu}_\mu$ CC
$\nu_e$ CC
$\bar{\nu}_e$ CC
$\nu$ NC
$\bar{\nu}$ NC


Solar direction (20 degrees around the horizon) - Final level
$\nu_e$ CC
$\bar{\nu}_e$ CC
$\nu_\mu$ CC
$\bar{\nu}_\mu$ CC
$\nu$ NC
$\bar{\nu}$ NC
Effective Area ($m^2$)
$10^{-6}$
$10^{-7}$
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^{0}$
True neutrino energy (GeV)

# Sensitivity - Solar flare



# Summary of the unblinding proposal

# Unblinding proposal

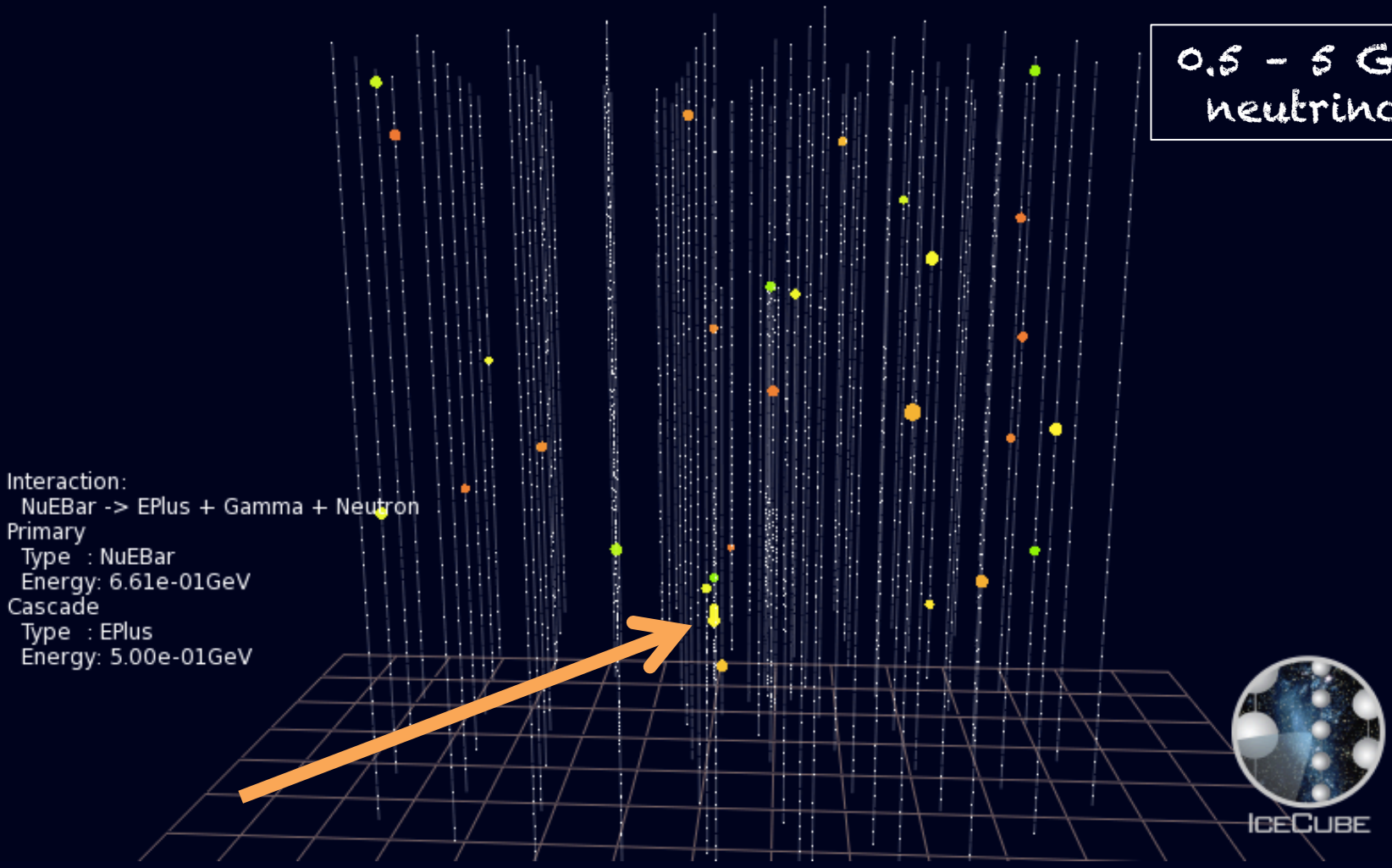
- 5 solar flares: *Li&Ma test*
  - March 7th 2012
  - Feb 25th 2014
  - Sep 1st 2014
  - Sep 6th 2017
  - Sep 10th 2017

- 7 GW events: *Li&Ma test*
  - Sep 14th, 2015
  - Oct 12th, 2015
  - Dec 26th, 2015
  - Jan 4th, 2017
  - June 8th, 2017
  - Aug 14th, 2017
  - *Aug 17th, 2017*

*+ KS for all BBHs stacked*

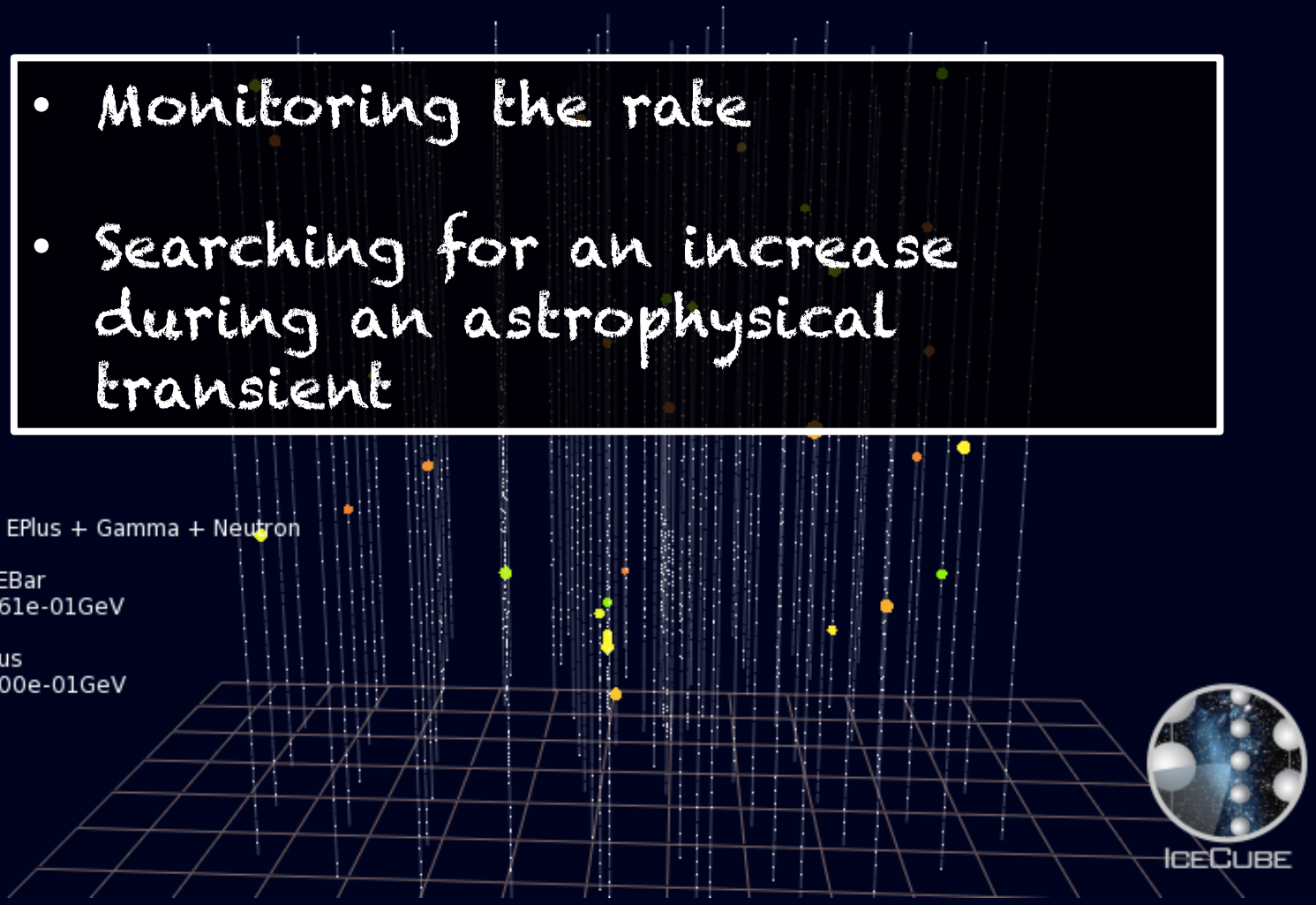
Thanks!

# GeV neutrinos from astrophysical transients



# GeV neutrinos from astrophysical transients

- Monitoring the rate
- Searching for an increase during an astrophysical transient



# Overview

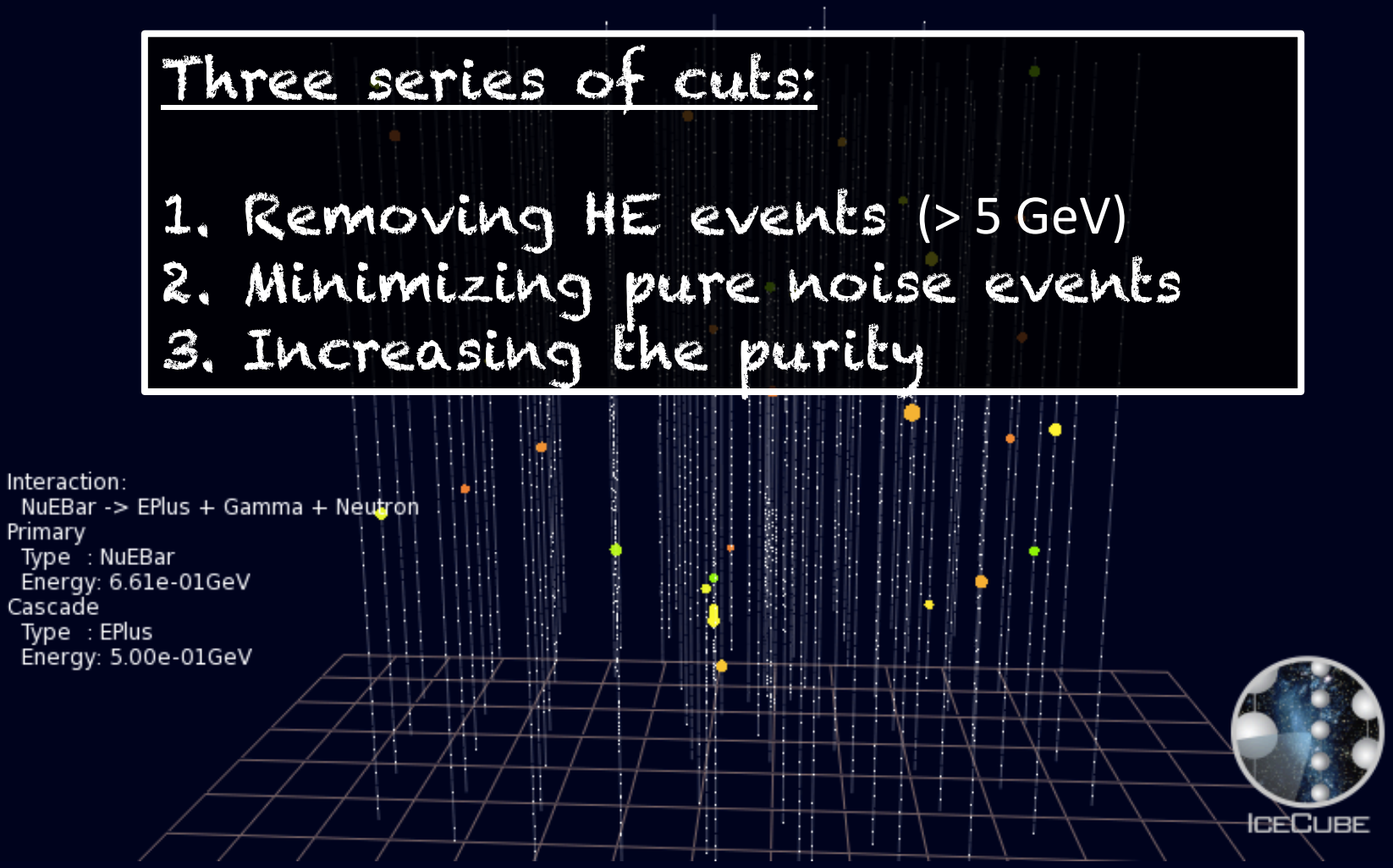
- Description of the event selection
- Rate at final level and effective areas
- Statistical analysis for solar flares
- Statistical analyses for GW events
- Summary of the unblinding proposal

# Event selection

# GeV neutrinos from astrophysical transients

Three series of cuts:

1. Removing HE events (> 5 GeV)
2. Minimizing pure noise events
3. Increasing the purity



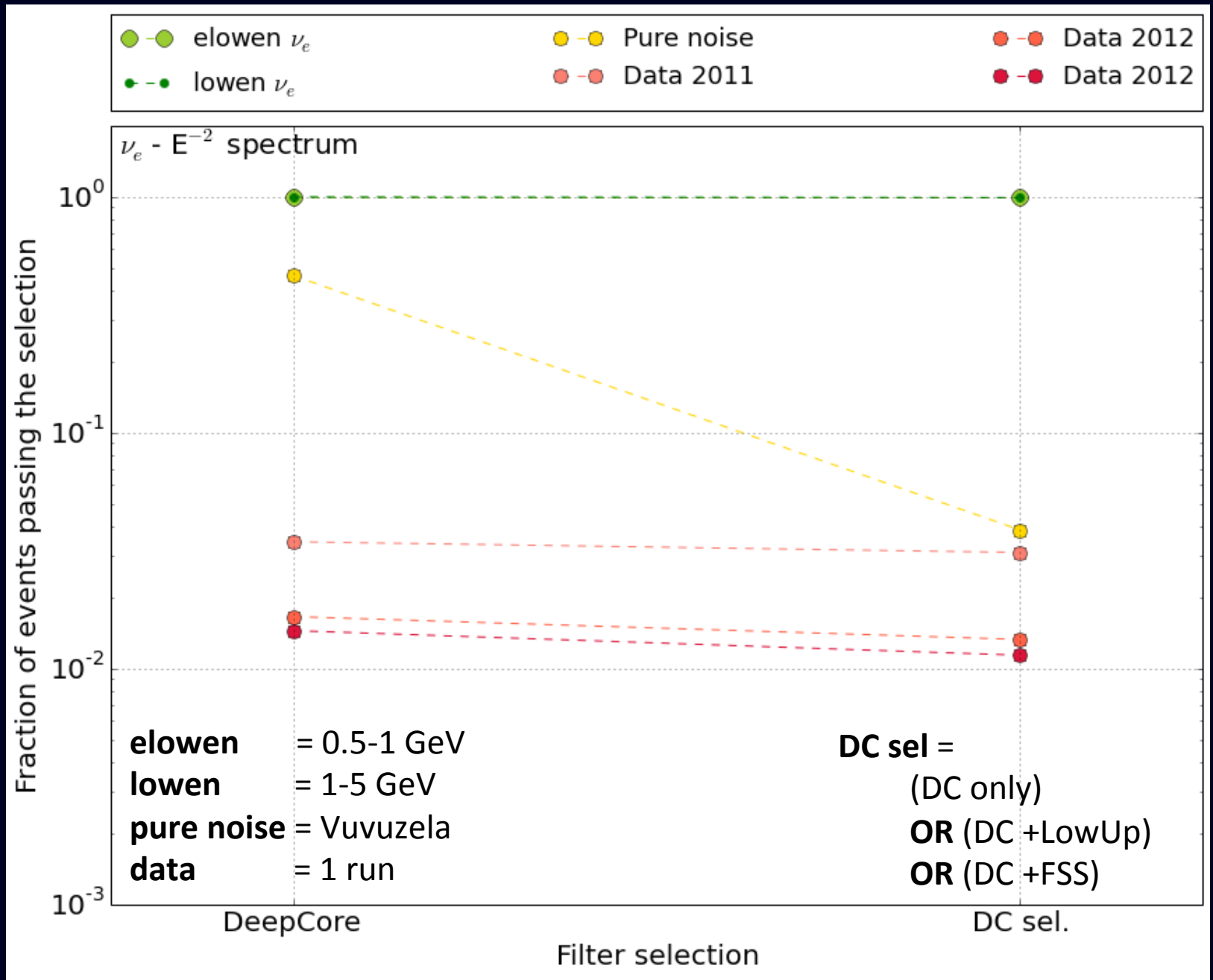
| Variable | Passing conditions |
|---|---|
| 0. Passing filters | DeepCore excluding any other filter aside from LowUp and FSS |
| Number of HLC in IceCube w/o DeepCore (x)<br>Number of HLC in DeepCore (y) | $x \leq 6$ AND $y \leq 7$<br>OR $x = 0$ |
| Number of SRT hits | $\leq 10$ |
| NoiseEngine combination I | NoiseEngine(100, 2, 0.20, 0.90) = True<br><br>NoiseEngine(100, 0, 0.20, 0.90) = True<br>AND NoiseEngine(1000, 0, 0.00, 0.10) = False |
| NoiseEngine combination II | NoiseEngine(300, 2, 0.20, 0.40) = True<br>NoiseEngine(300, 2, 0.10, 0.90) = True<br>AND NoiseEngine(800, 0, 0.00, 0.10) = False<br>NoiseEngine(500, 2, 0.20, 0.30) = True |
| Charge ratio | $> 0.26$ |
| Depth of the first HLC in DeepCore (z) | -2453m $<$ z $<$ -2158 m |
| Distance and delay between 1st and 2nd HLC in DeepCore | $< 70$ m<br>$< 50$ ns |
| Total charge | $< 60$ photoelectrons |
| Number of HLC in DeepCore | $< 10$ |

1. Removing HE events

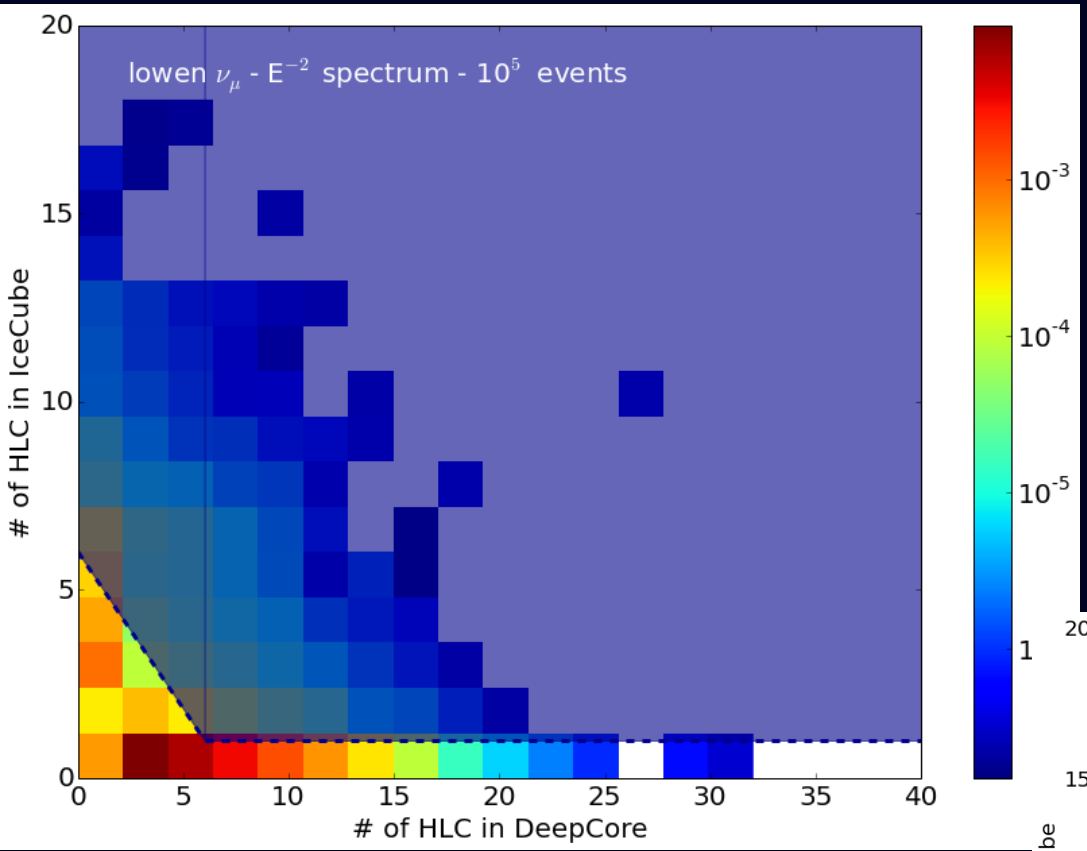
2. Minimizing pure noise events

3. Increasing the purity

# 0. Filter selection

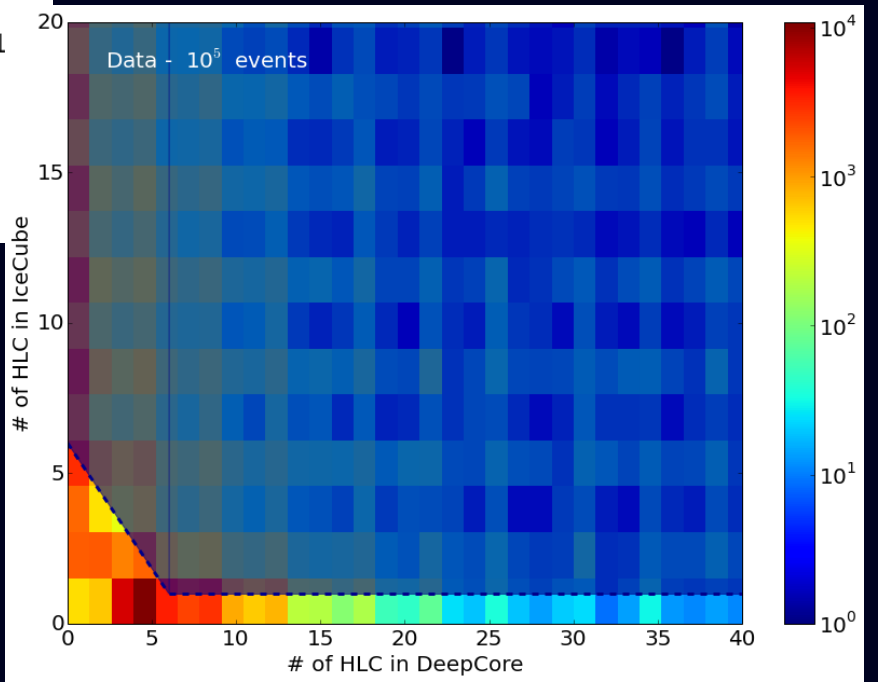


# 1. Removing HE events




Amount of light emitted in the detector

Signal




Data

# 2. Minimizing pure noise events

Use NoiseEngine to remove pure noise events

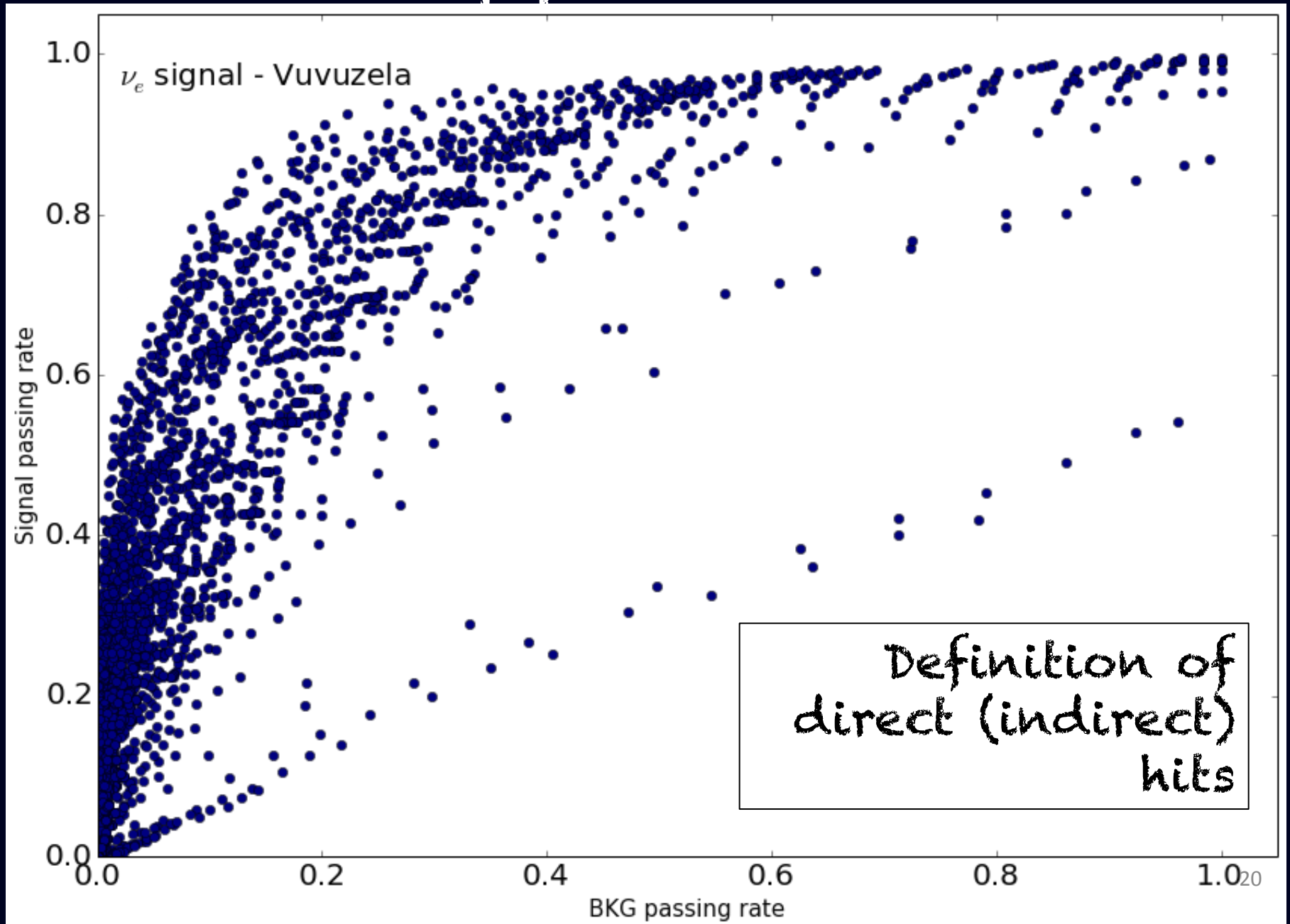
NoiseEngine

4 different variables to select direct/indirect hits :

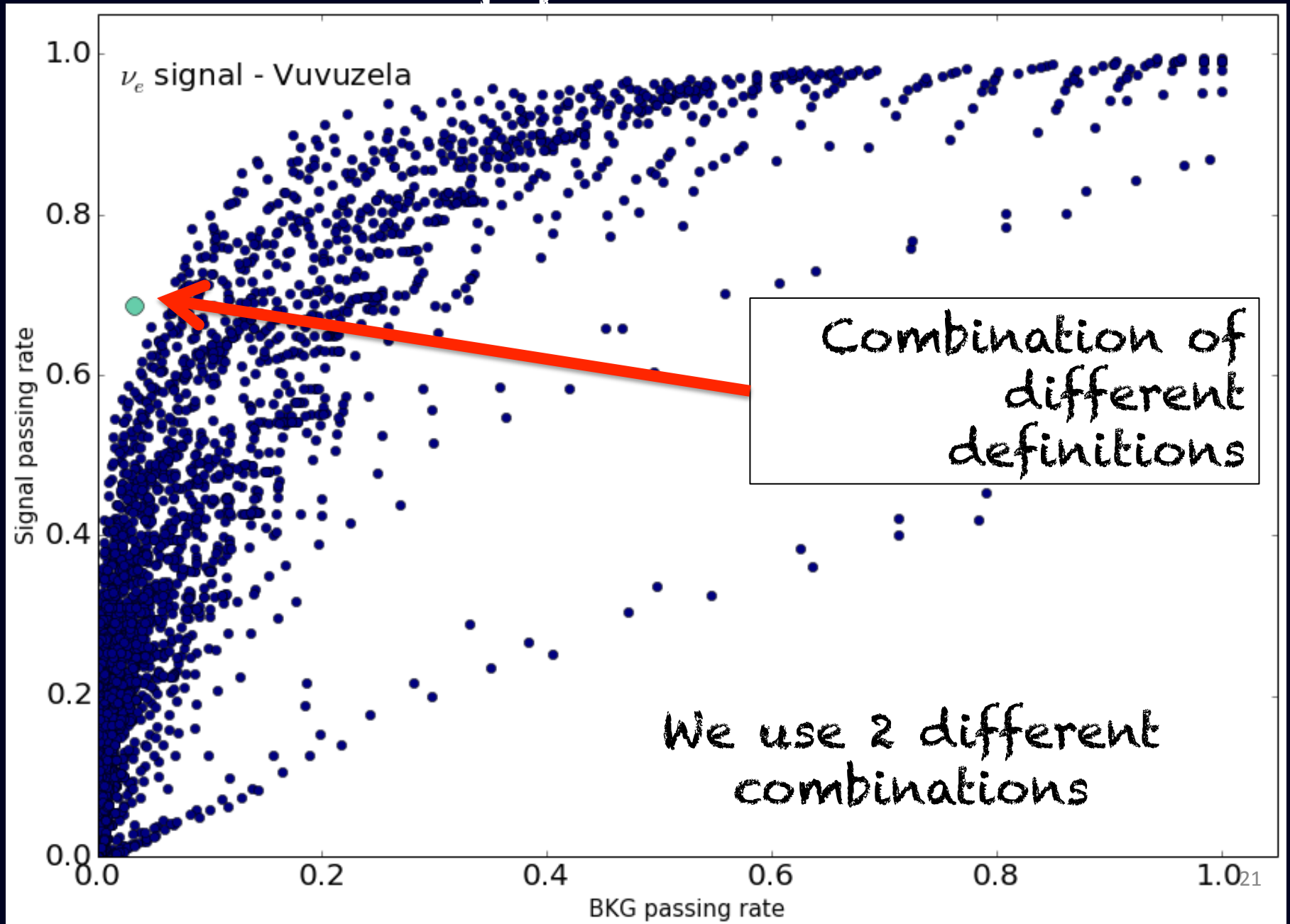
- a time window W (ns)
- a minimal speed X (m/ns)
- a maximal speed Y (m/ns)
- a threshold Z (#of pairs)

We work with the True/False output (not the hit cleaning)

# Minimizing pure noise events



# Minimizing pure noise events

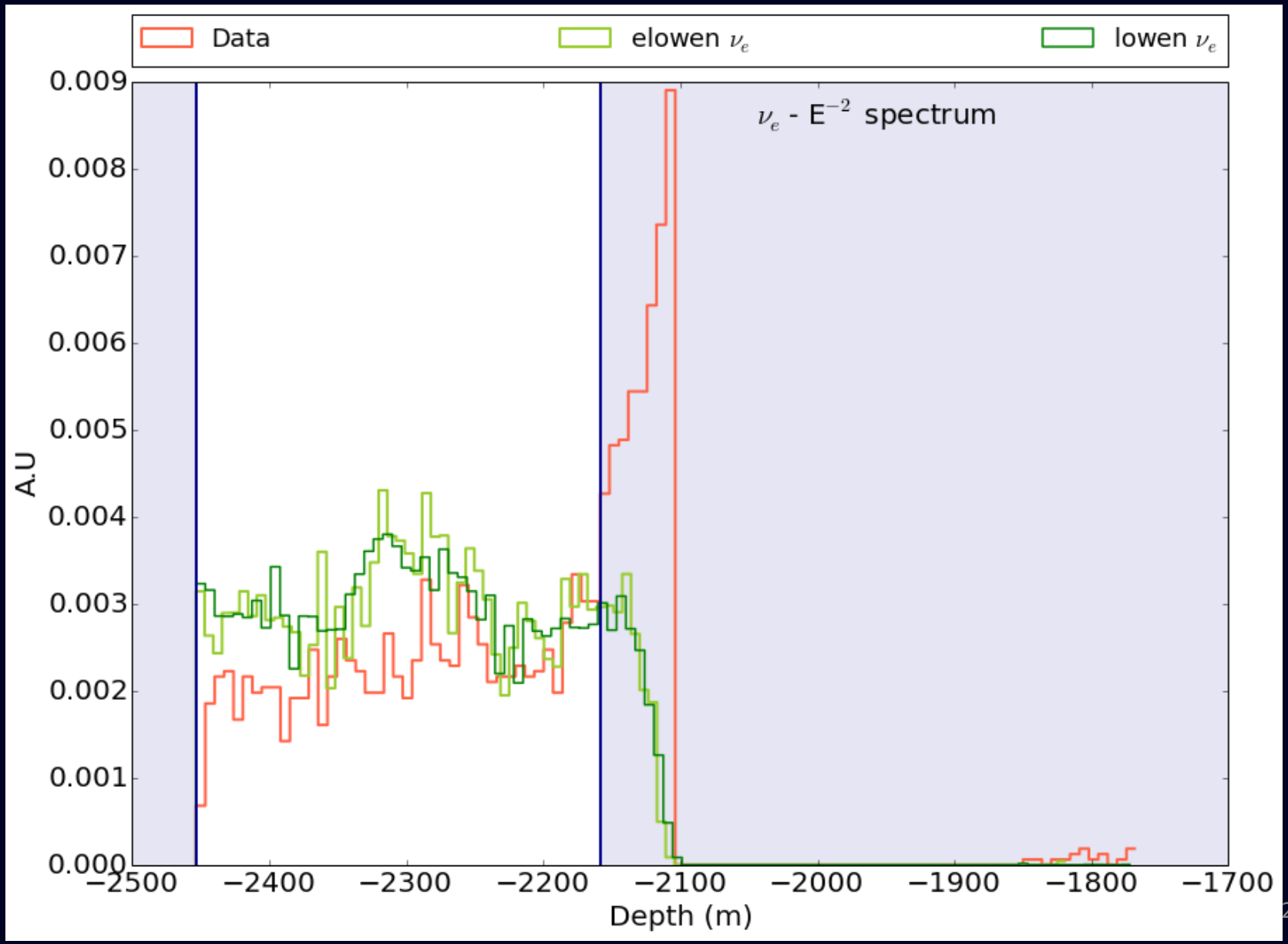


# 3. Increasing the purity

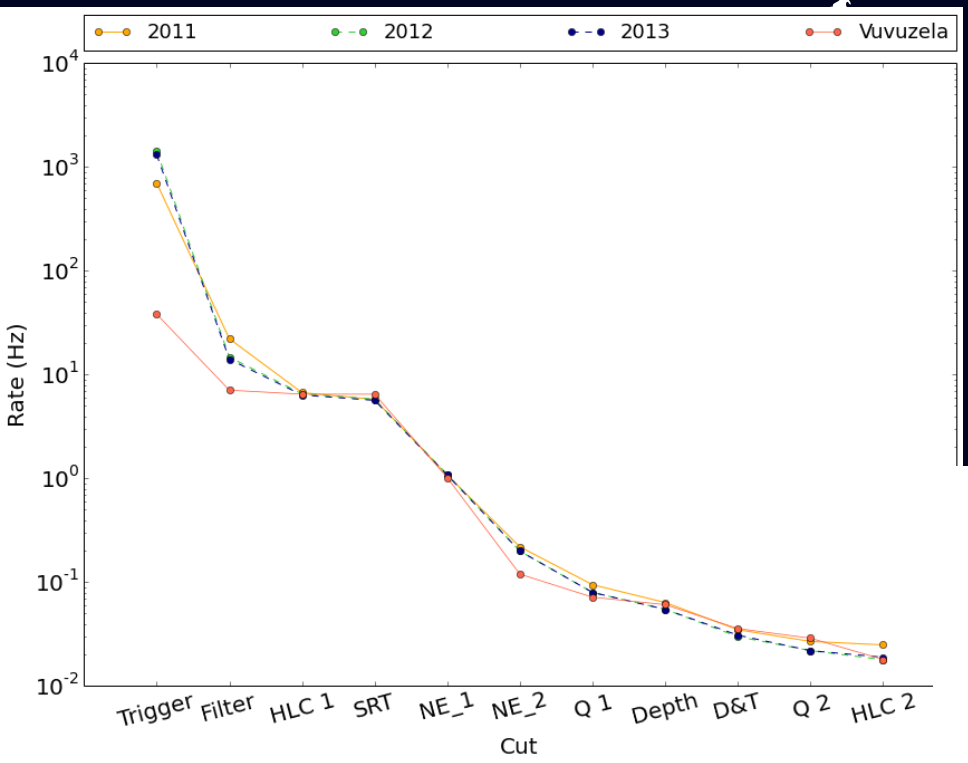
Cut variables used to constrain the 'topology' of the events:

- Charge ratio in 600ns
- Depth of the 1st HLC
- Distance/duration between 1st and 2nd HLC
- Total charge
- Number of HLC in DeepCore

# 3. Increasing the purity

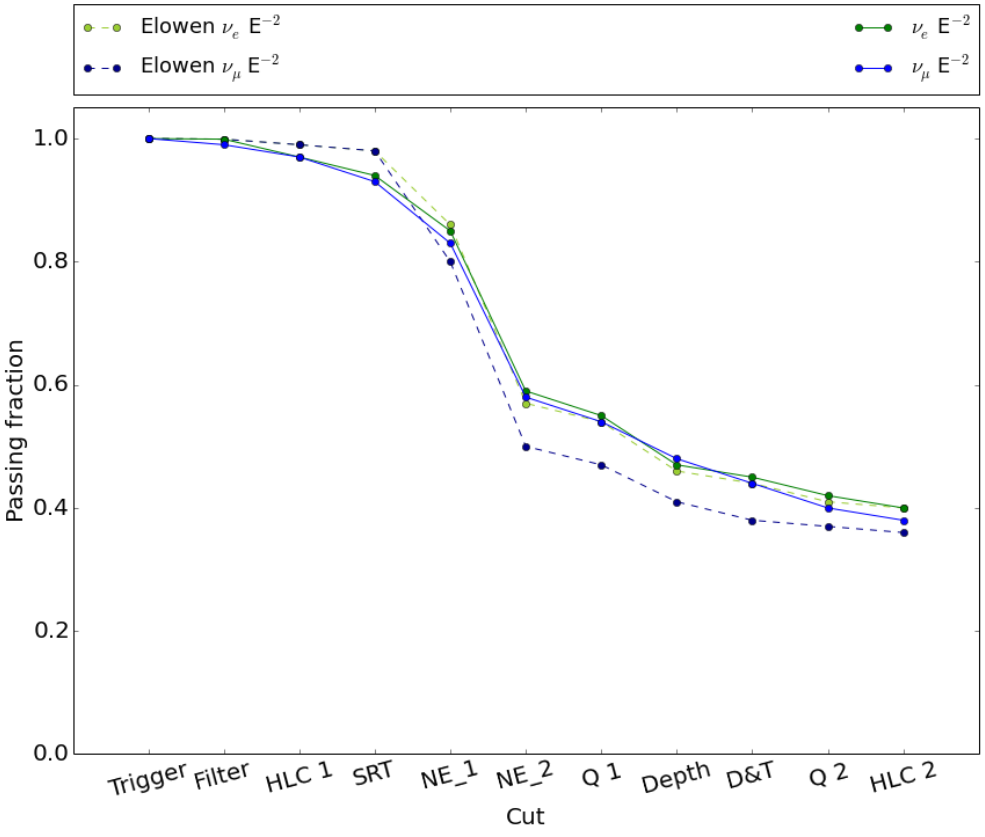


# Summary of the cuts




Data

Signal



# Rate at final level

# Rates at final level

Data

| Sets | | Rate |
|---|---|---|
| Data | 2011 | 0.025 ± 0.003 Hz |
| | 2012 | 0.021 ± 0.003 Hz |
| | 2013 | 0.020 ± 0.003 Hz |
| | 2014 | 0.022 ± 0.003 Hz |
| | 2015 | 0.021 ± 0.003 Hz |
| | 2017 | 0.019 ± 0.003 Hz |

Simulations

| | | |
|---|---|---|
| Vuvuzela | | 0.018 Hz |
| Corsika | | < 0.005 Hz |
| Genie | $\nu_e$ | 0.0003 Hz |
| | $\nu_\mu$ | 0.0008 Hz |

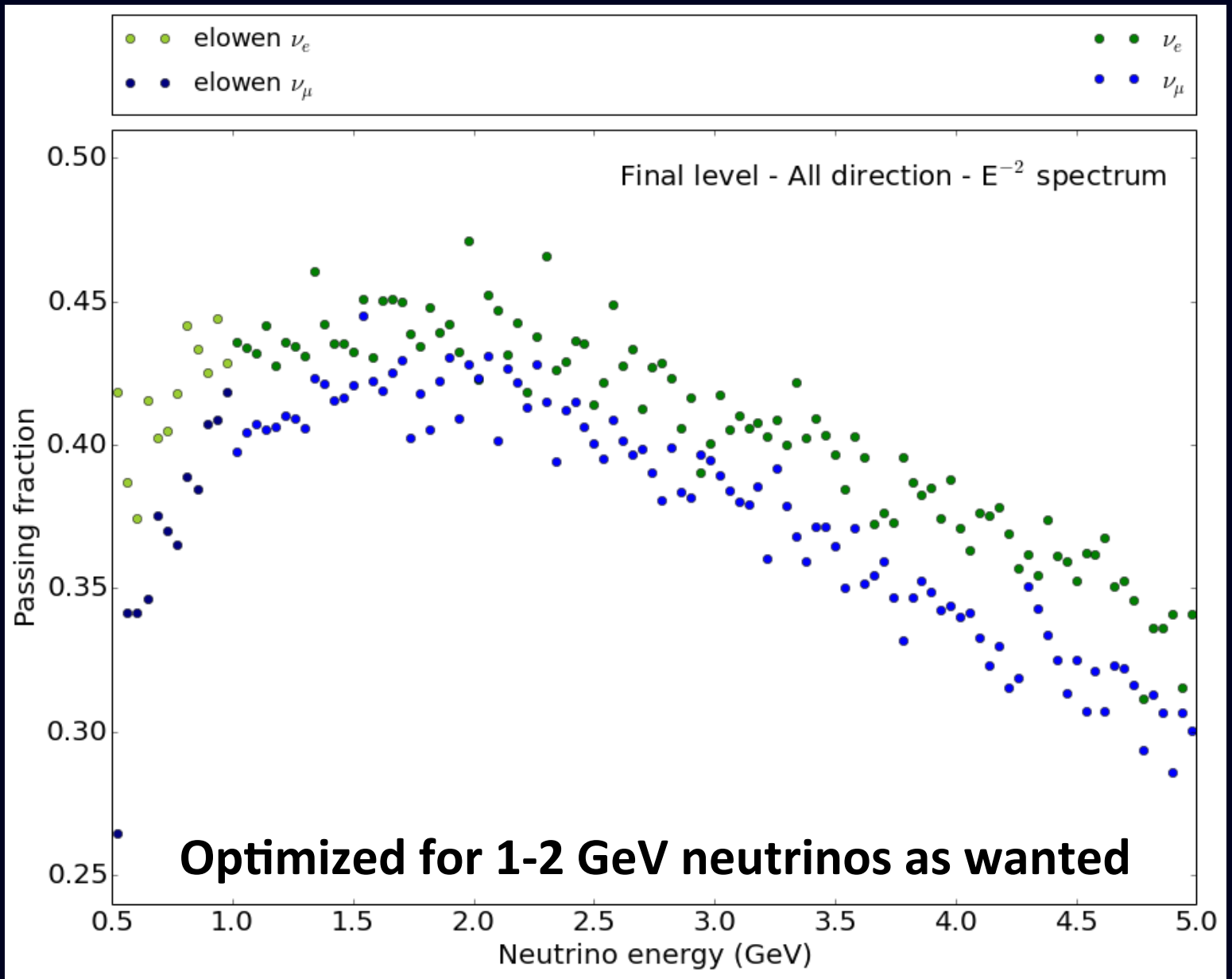
# Rates at final level

Passing fraction for signal events

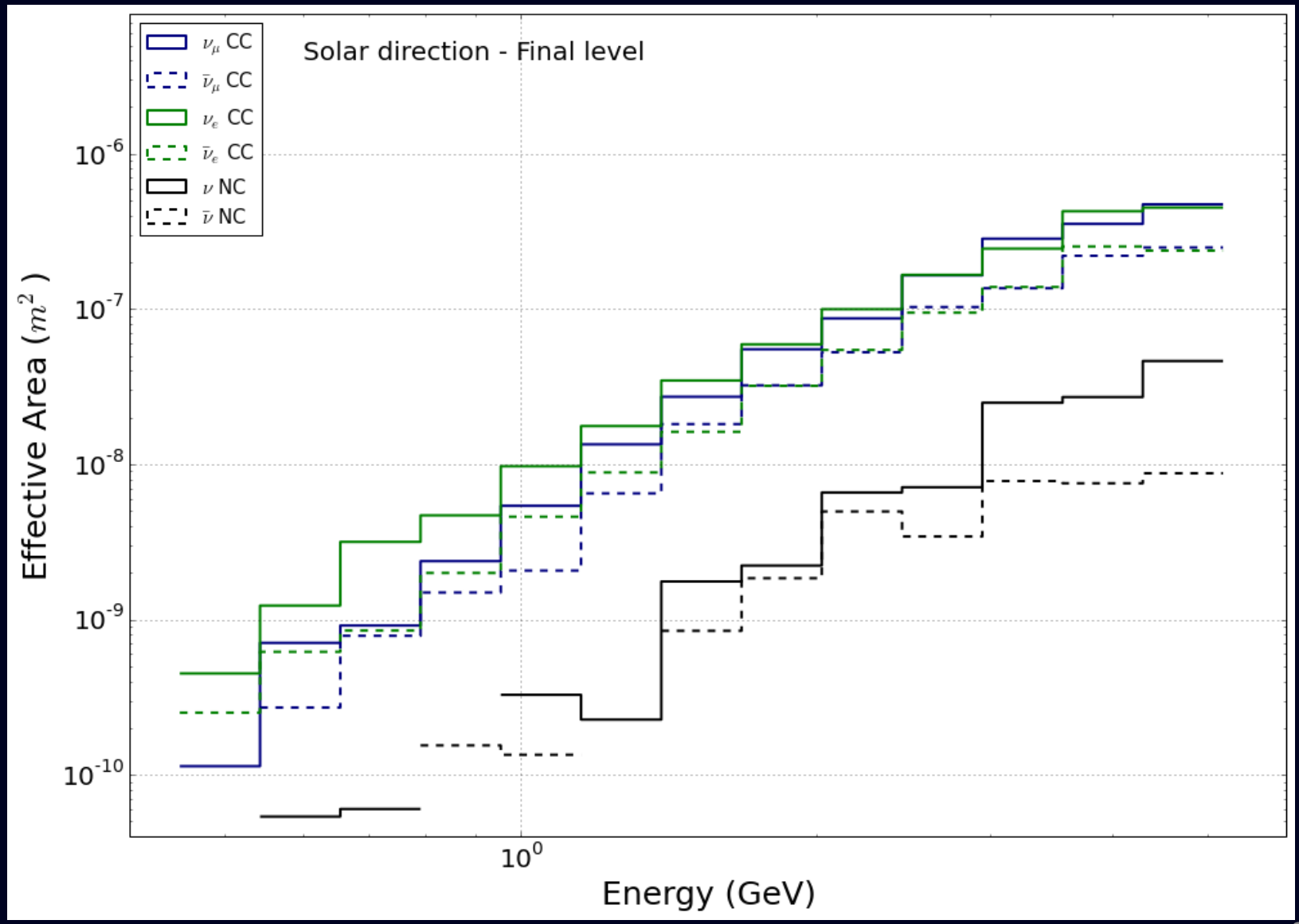
| Sets | Particle type | Energy | Direction | Passing fraction |
|---|---|---|---|---|
| Signal | $\nu_e$ | 1- 5 GeV | Solar | 41 % |
| | | | All sky | 41 % |
| | | 500 MeV - 1 GeV | Solar | 42 % |
| | | | All sky | 43 % |
| | $\nu_\mu$ | 1- 5 GeV | Solar | 39 % |
| | | | All sky | 39 % |
| | | 500 MeV - 1 GeV | Solar | 38 % |
| | | | All sky | 40 % |
| | $\nu_\tau$ | 1- 5 GeV | Solar | 40 % |
| | | | All sky | 40 % |

Similar for $E^{-6}$

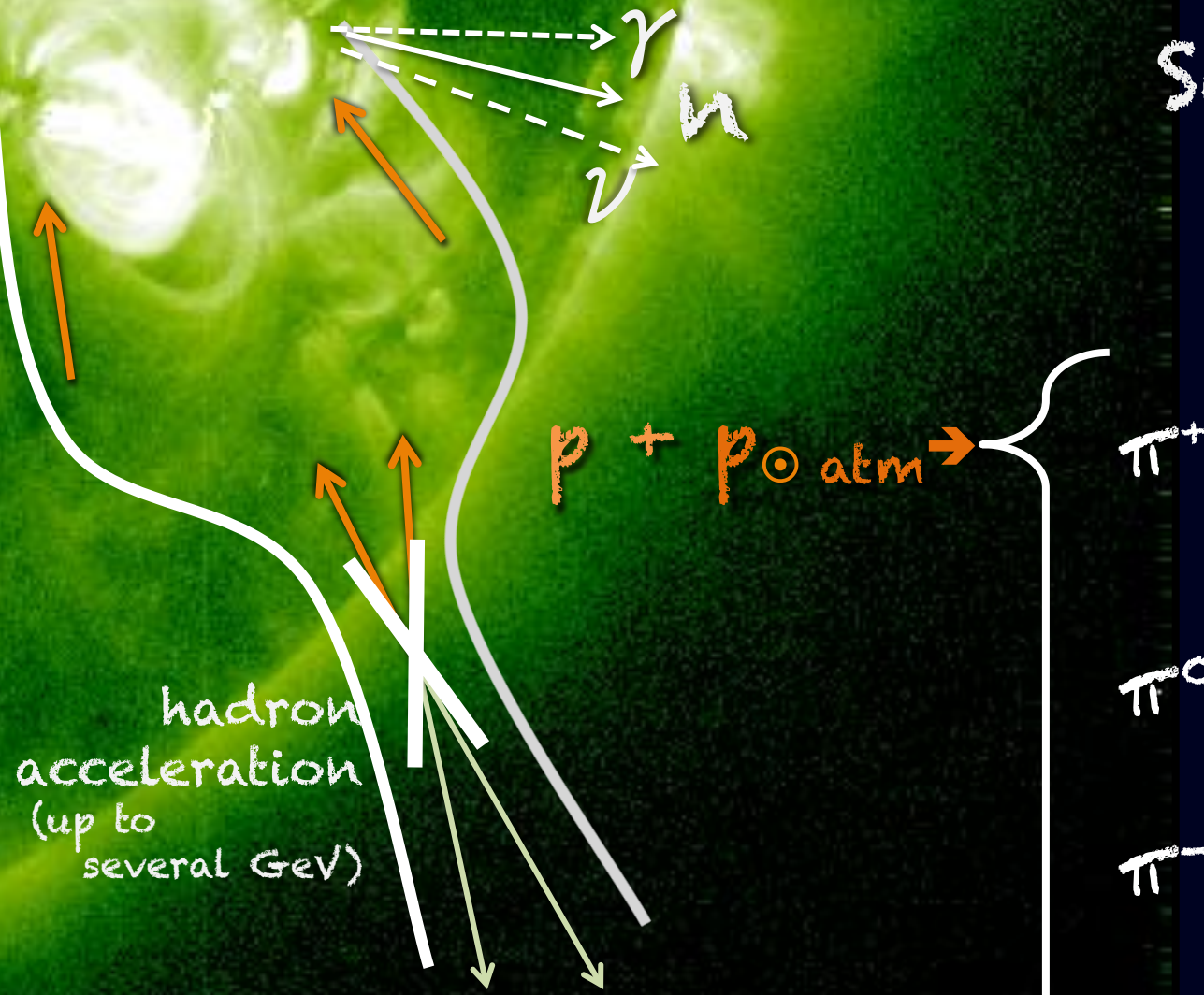
# Passing fraction



# Effective area



# Statistical analysis for Solar Flares




# Solar flare ν

$p + p_{\odot\,atm} \rightarrow$

$\pi^+ \rightarrow \mu^+ + \nu_\mu$

$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$

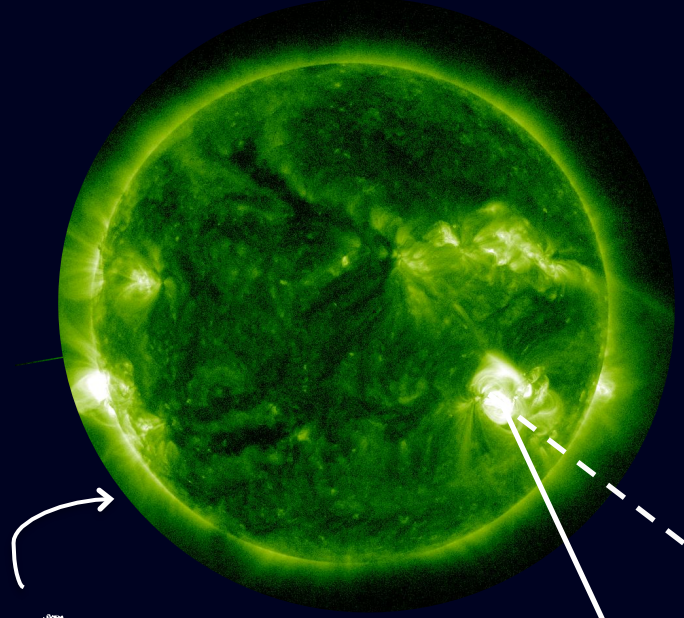
$\pi^0 \rightarrow 2\,\gamma$

$\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$

$\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu$

few MeV
up to a few GeV

# Solar flare $\nu$



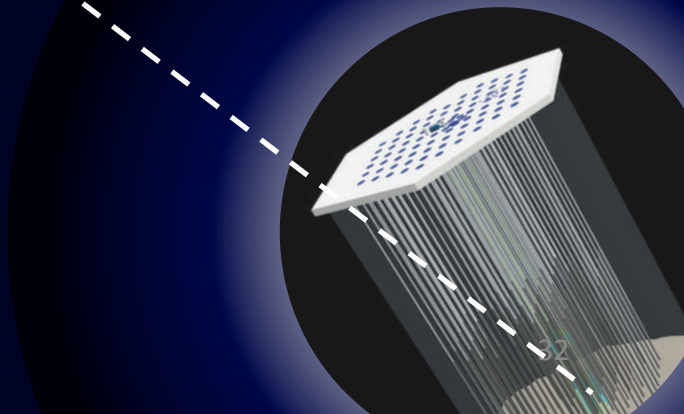
Sun

From Fermi-LAT:

1. Most significant LAT events
2. Optimized time window for neutrino search

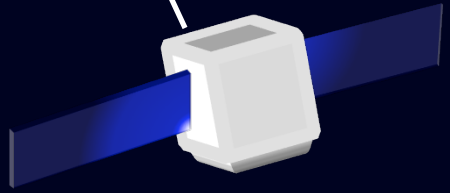
$\nu$

IceCube

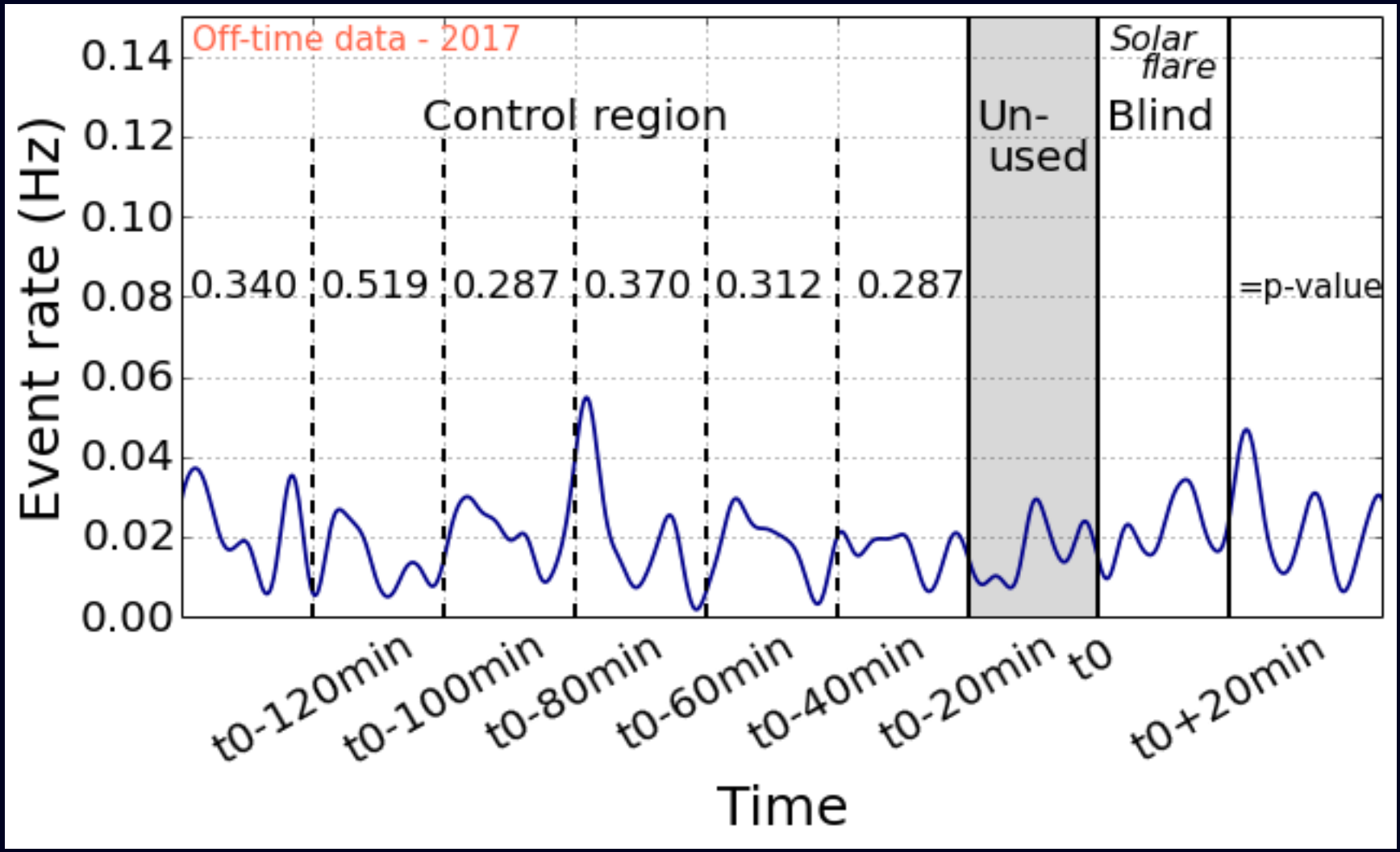


$\gamma$

Fermi

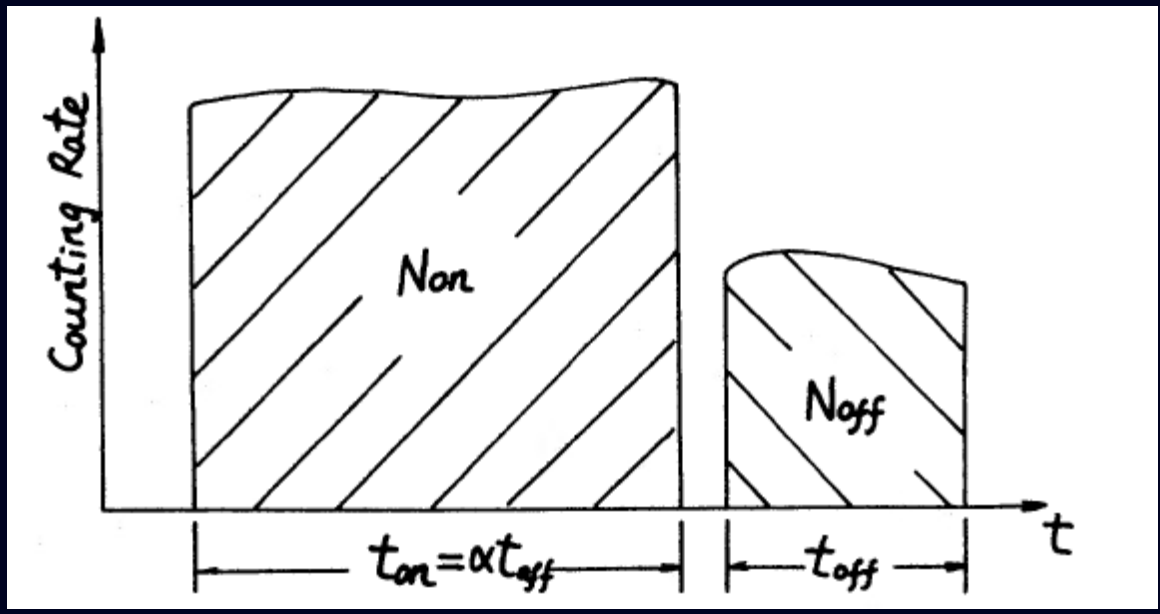


# Rate following a Poisson dist.



# Sensitivity - using Li & Ma

Li&Ma calculates the significance of a counting exp. when both signal and bkg rates are described by a Poisson process

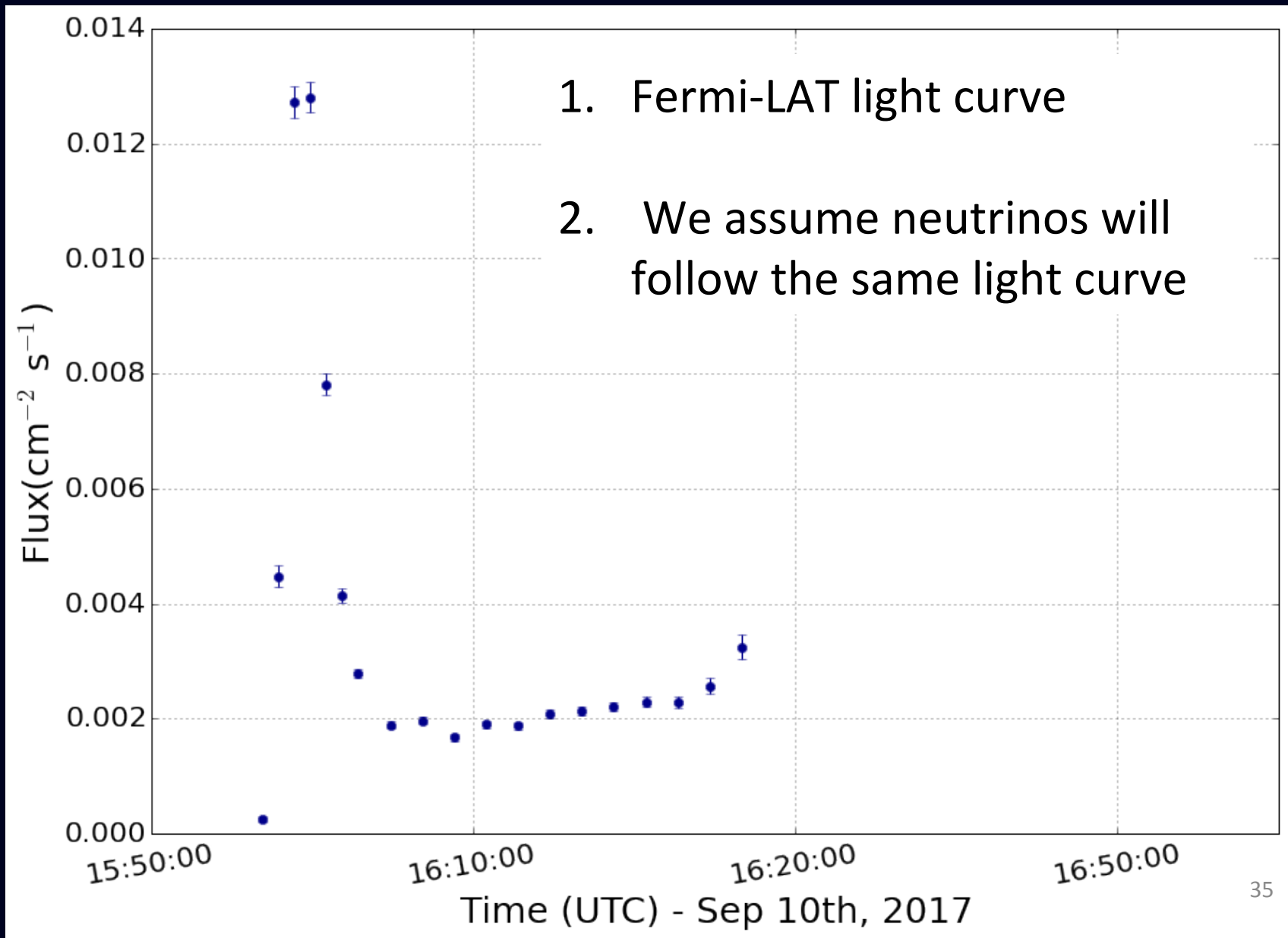



- $t_{on}$ has been optimized for each flare
- $t_{off}$ = 8 hours
- $N_{off}$ = 550 events
- S < 1 for off-time data

$$S = \sqrt{-2 \ln \lambda} = \sqrt{2}\left\{N_{on} \ln\left[\frac{1+\alpha}{\alpha}\left(\frac{N_{on}}{N_{on}+N_{off}}\right)\right] + N_{off} \ln\left[(1+\alpha)\left(\frac{N_{off}}{N_{on}+N_{off}}\right)\right]\right\}^{1/2}$$

http://adsbit.harvard.edu/cgi-bin/nph-iarticle_query?1983ApJ...272..317L&defaultprint=YES&filetype=.pdf

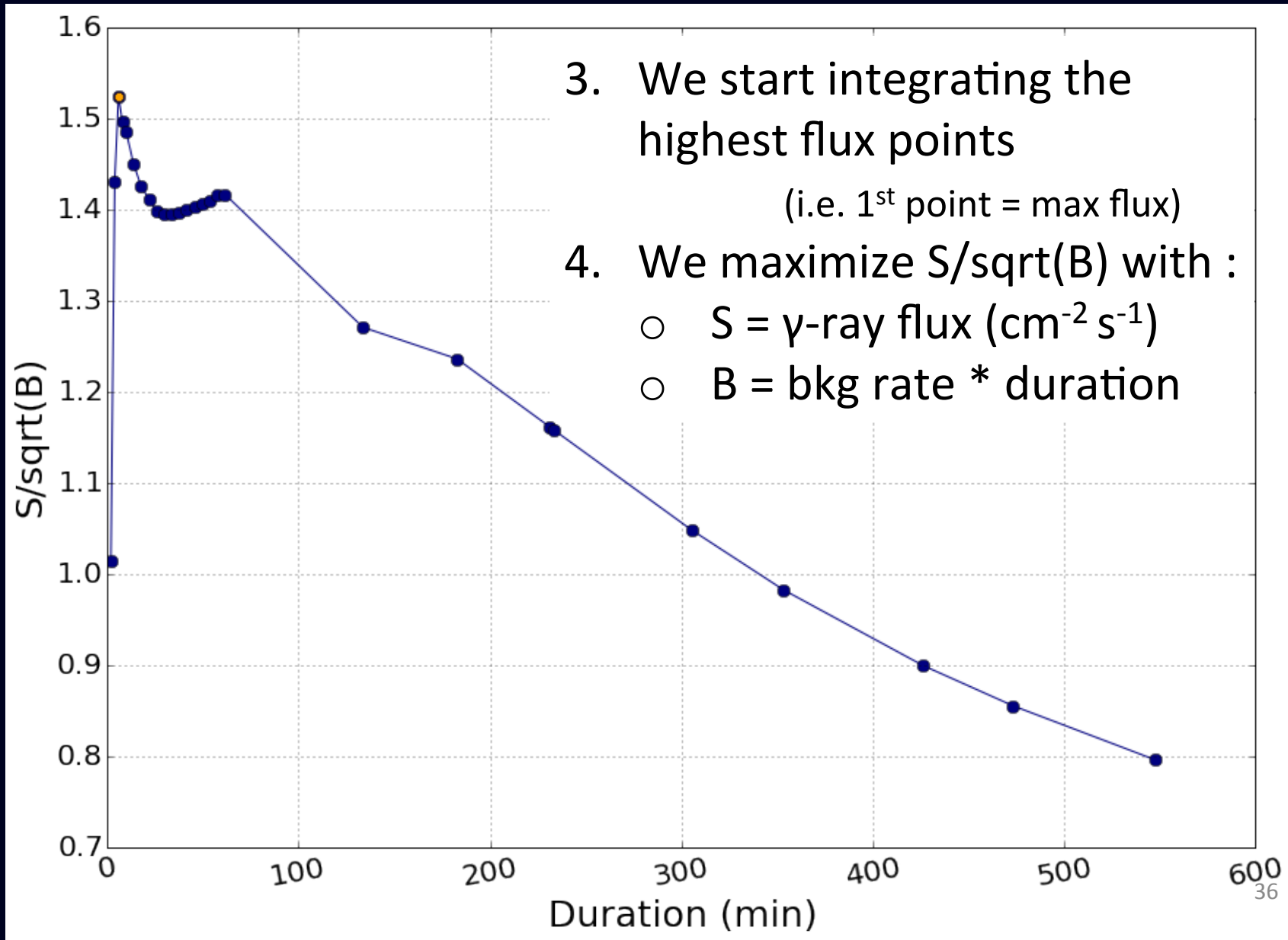
# Definition of $t_{on}$




1. Fermi-LAT light curve

2. We assume neutrinos will follow the same light curve

# Definition of $t_{on}$

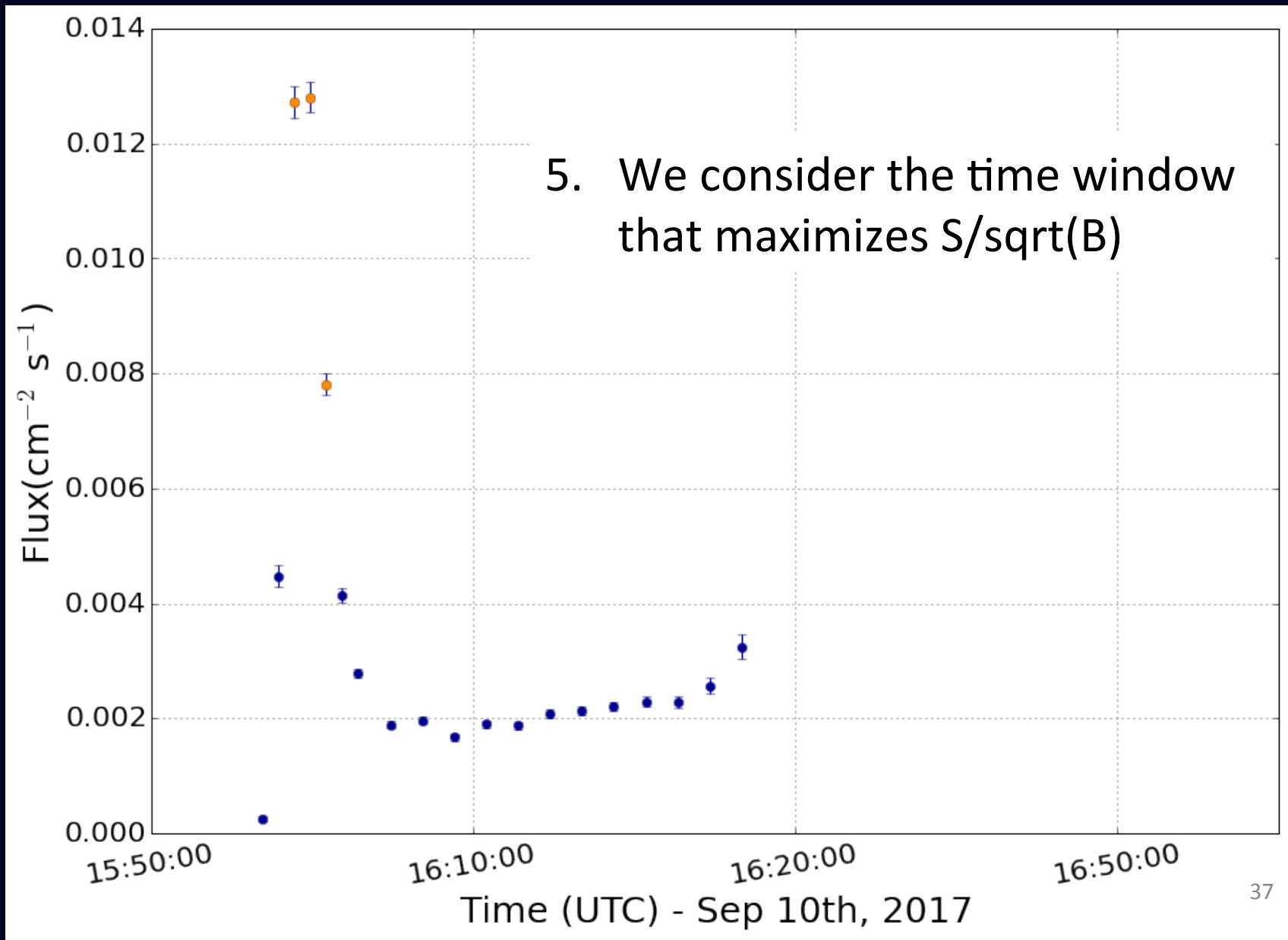



3. We start integrating the highest flux points

   (i.e. 1st point = max flux)

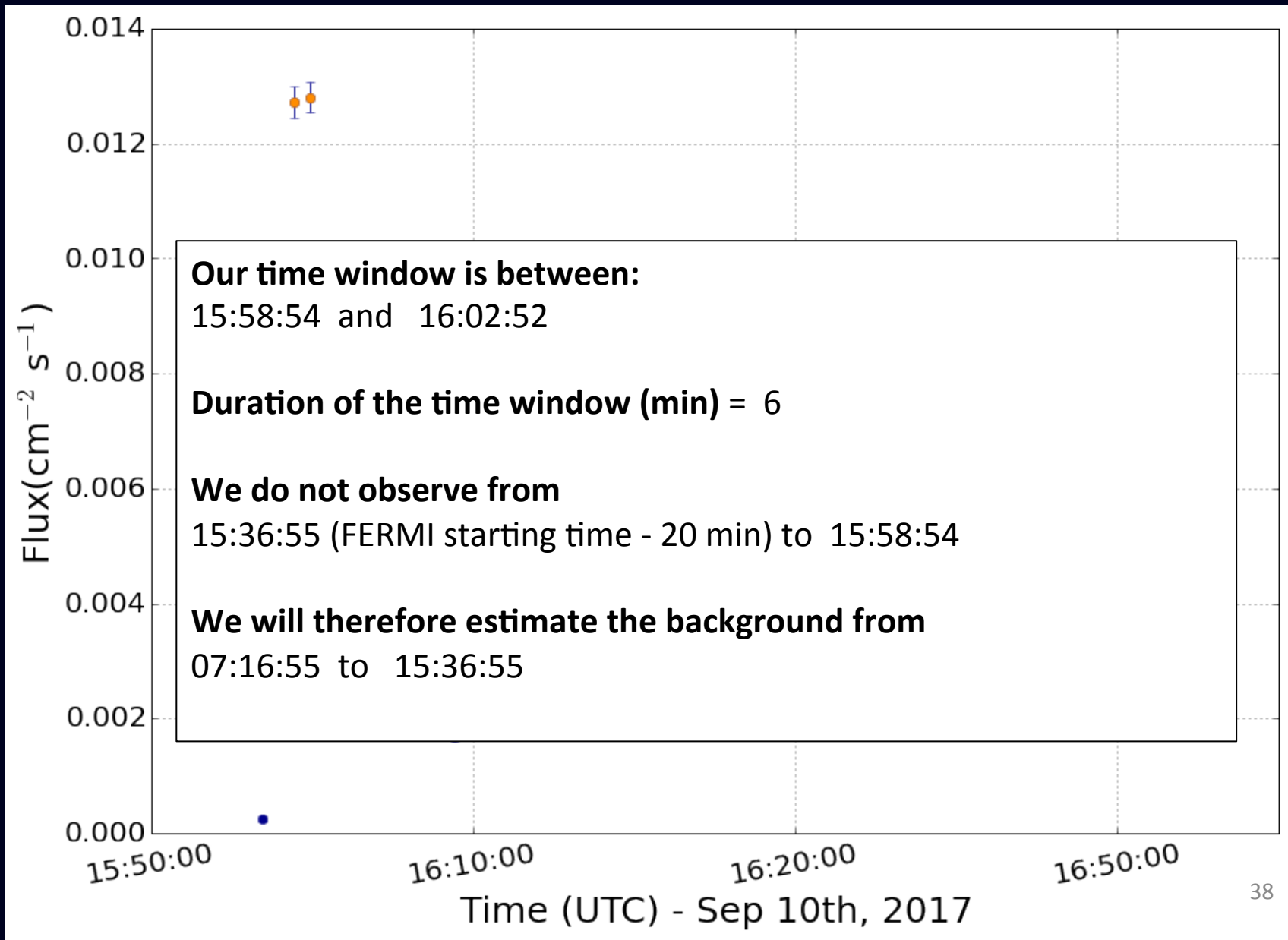
4. We maximize S/sqrt(B) with :
   - S = γ-ray flux ($cm^{-2}\ s^{-1}$)
   - B = bkg rate * duration

# Definition of $t_{on}$




5. We consider the time window that maximizes S/sqrt(B)

# Definition of $t_{on}$



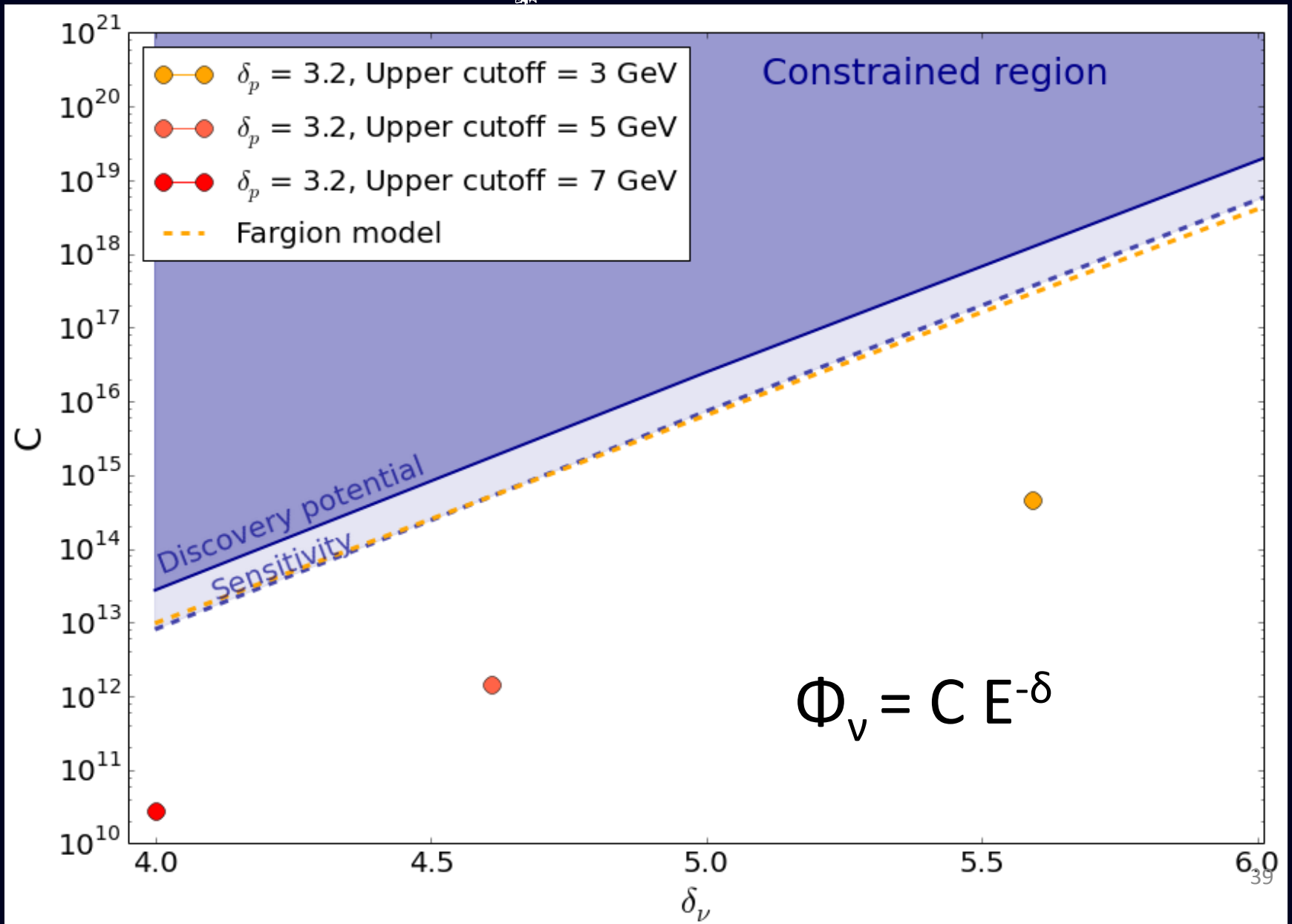

**Our time window is between:**
15:58:54 and 16:02:52

**Duration of the time window (min)** = 6

**We do not observe from**
15:36:55 (FERMI starting time - 20 min) to 15:58:54

**We will therefore estimate the background from**
07:16:55 to 15:36:55

# Sensitivity - Solar flare



# Statistical analysis for GW events

# GW events detected by LIGO and Virgo

## 6 BBH mergers

Sep 14th, 2015

Oct 12th, 2015

Dec 26th, 2015

Jan 4th, 2017

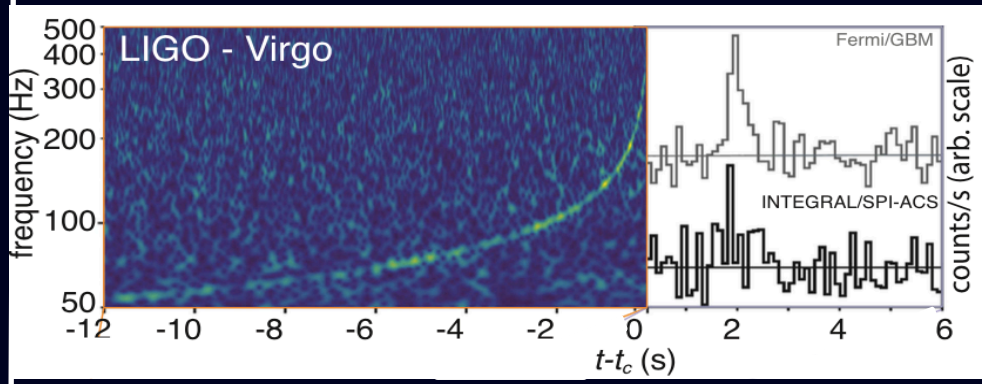
June 8th, 2017

Aug 14th, 2017

Constraint in [-500s,+500s]

## 1 BNS merger

Aug 17th, 2017

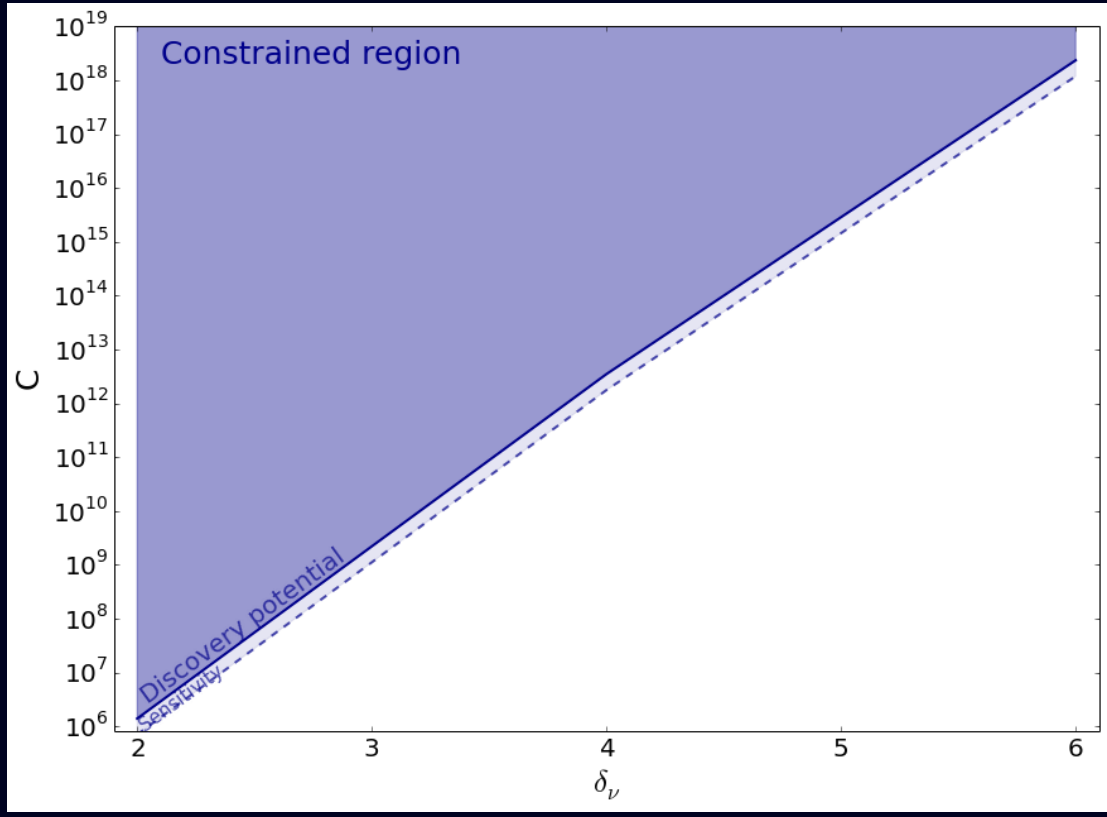



Fermi detection 2s after the merger time

# Sensitivity - using Li & Ma

## Similar to the Solar Flare analysis:

- Same event selection
- Same statistical analysis
  - $t_{on}$ = 3s
  - $t_{off}$ = 8 hours
  - $N_{off}$ = 550 events
  - S < 1 for off-time data



# Sensitivity - Stacking of BBH events

In addition to Li&Ma: Stacking of the 6 BBHs

- Study of the Δt distribution between next-to-neighbor events in [-500s, +500s]
- For off-time data: Δt follow an Erlang distribution
- For on-time data: Measure the deviation from Erlang using Kolmogorov Smirnov test
- Sensitivity: 76 neutrinos $cm^{-2}\ s^{-1}$

assuming $E^{-2}$ injected in 150s

# Summary of the unblinding proposal

# Unblinding proposal

- 5 solar flares: *Li&Ma test*
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  - *Aug 17th, 2017*

*+ KS for all BBHs stacked*

# Lutz and Carlos comments

- Answered in the wikipage:
  https://wiki.icecube.wisc.edu/index.php/Solar_flare_neutrino_search#Sample_properties_at_Final_Level

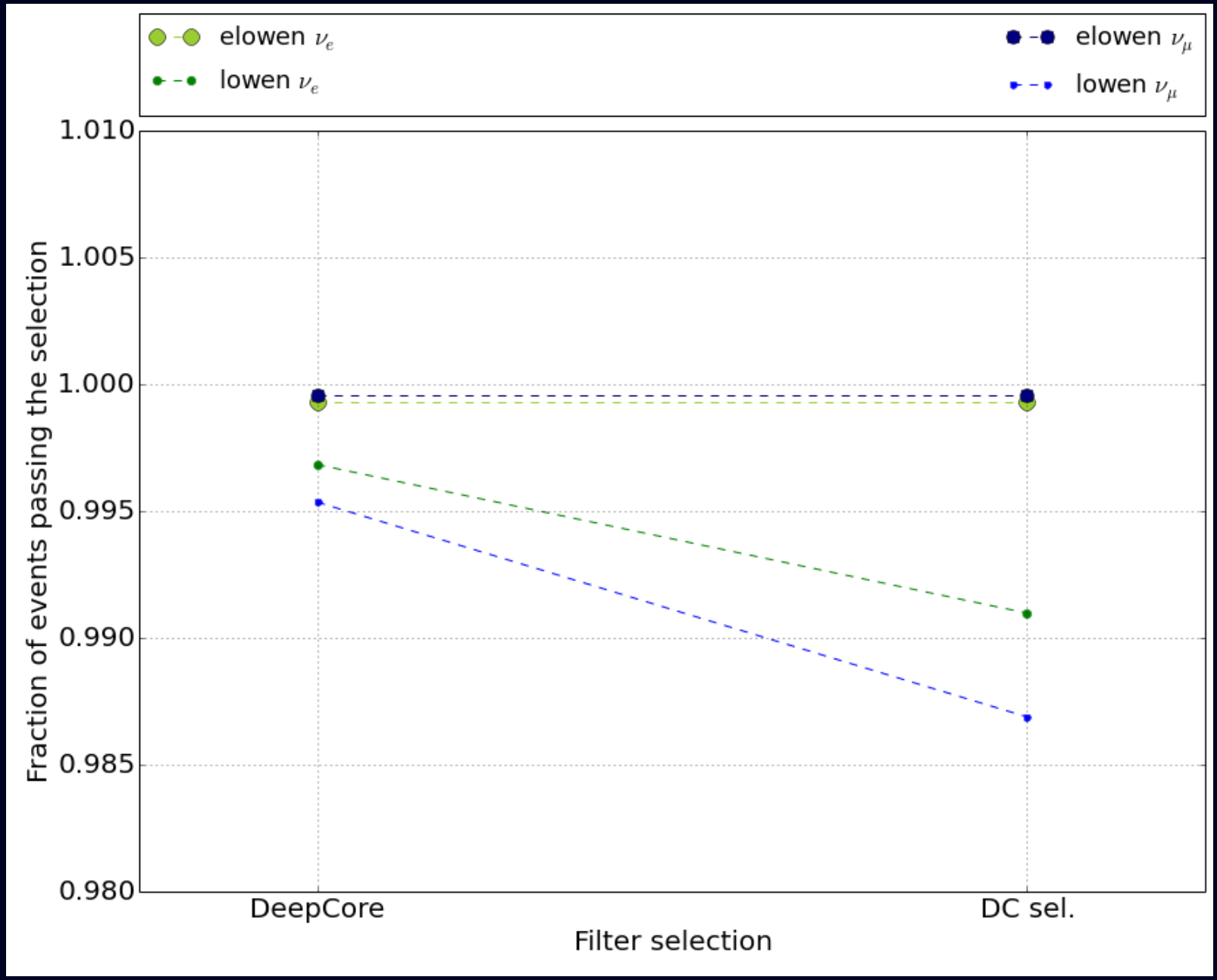
- More comments? Feel free to send me an email with questions!

- More tests, plots, explanations on the wikipage (e.g. asymmetry, energy distribution, systematics, light curves,…)

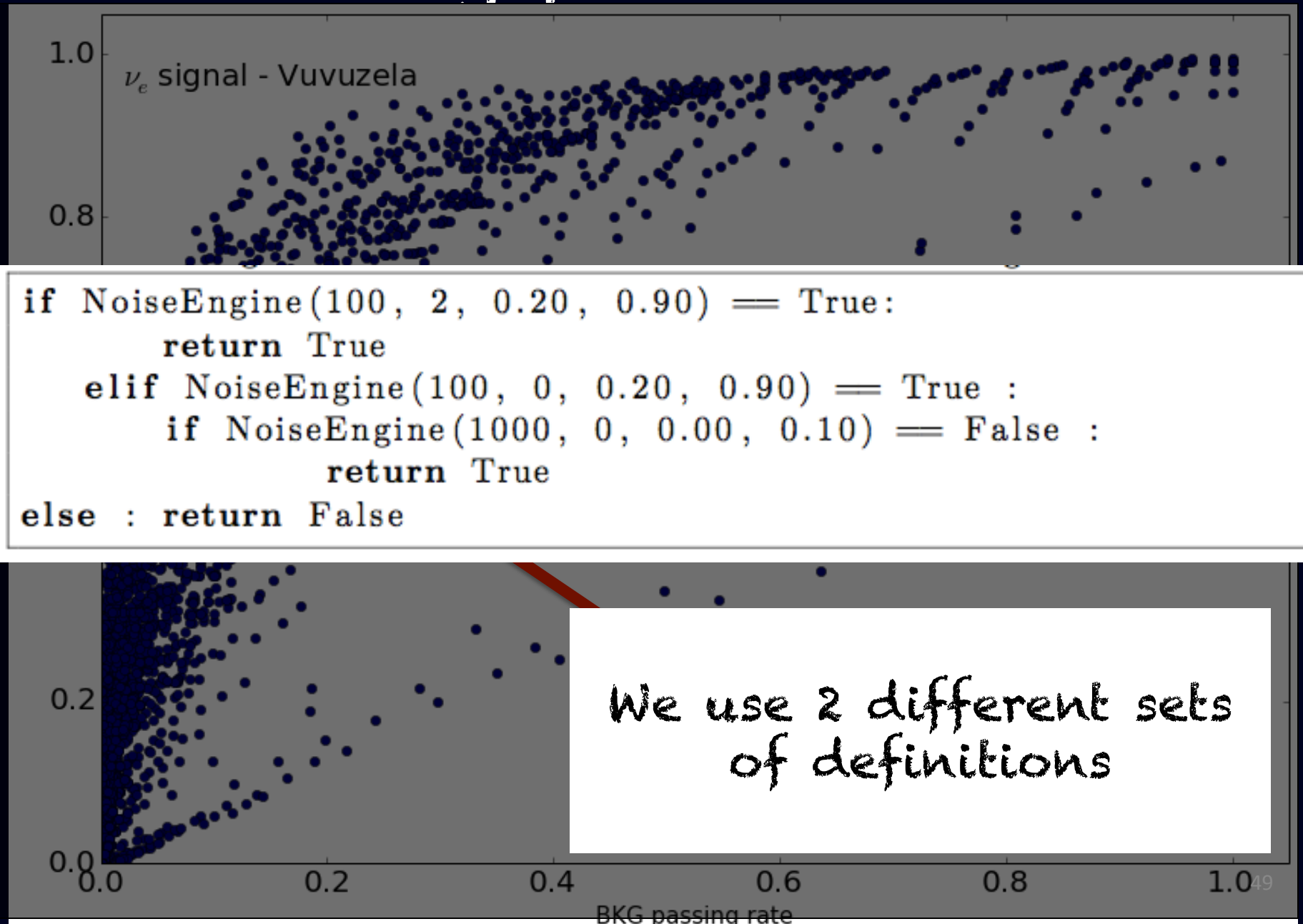
Thanks!

# Back-up slides

# Filter selection



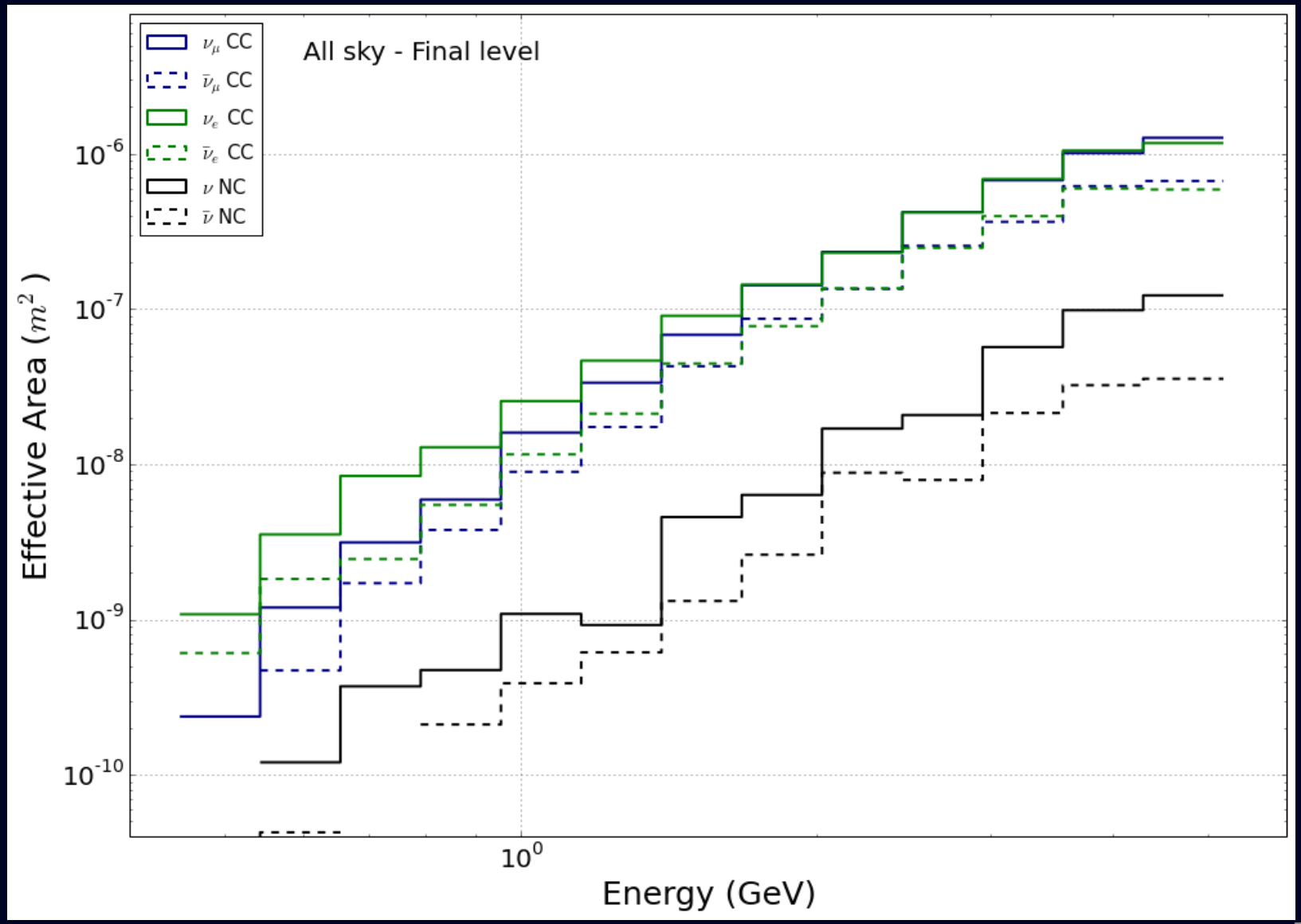
# Minimizing pure noise events




```
if NoiseEngine(100, 2, 0.20, 0.90) == True:
        return True
    elif NoiseEngine(100, 0, 0.20, 0.90) == True :
        if NoiseEngine(1000, 0, 0.00, 0.10) == False :
                return True
else : return False
```

We use 2 different sets of definitions

# Effective area



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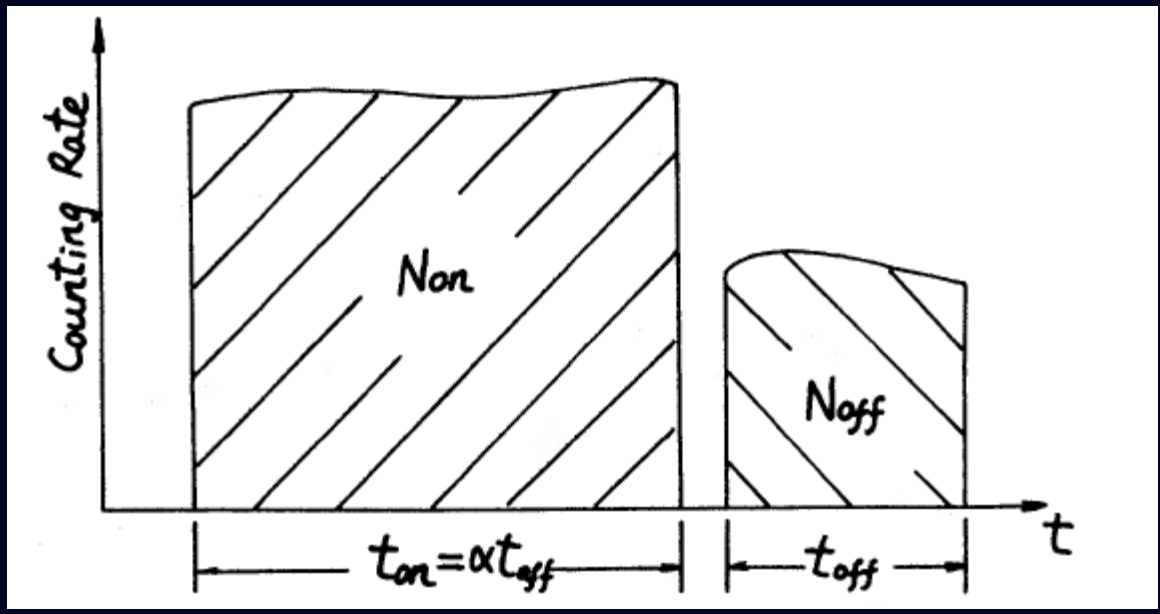


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http://adsbit.harvard.edu/cgi-bin/nph-iarticle_query?1983ApJ...272..317L&defaultprint=YES&filetype=.pdf