Jelena Celic

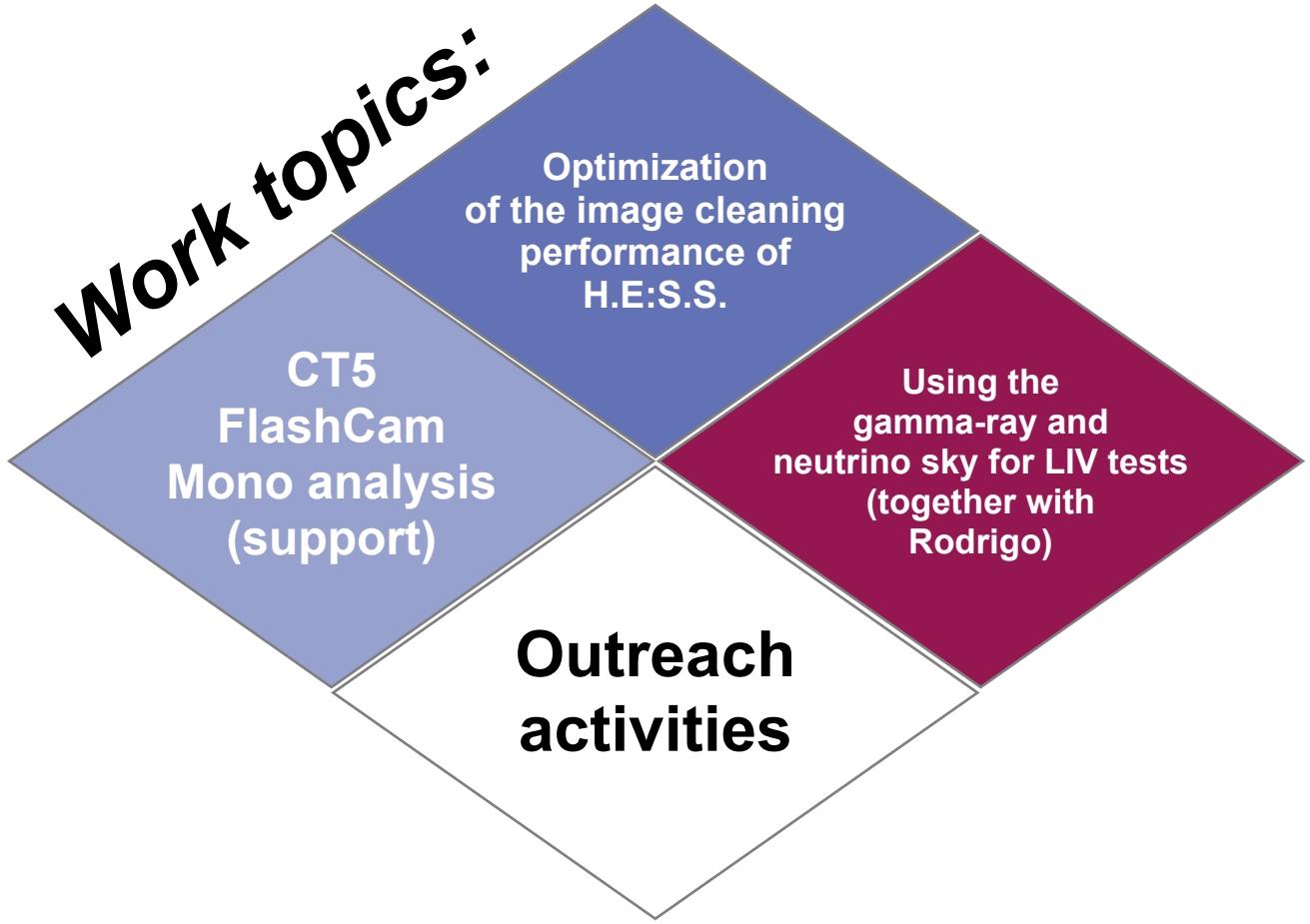
Bachelor thesis

Unsupervised learning for identification of event topologies with ORCA

Master thesis

Further studies with DesertAct and performance analysis of a new type of tiny sized telescope

PhD Student since October 2021



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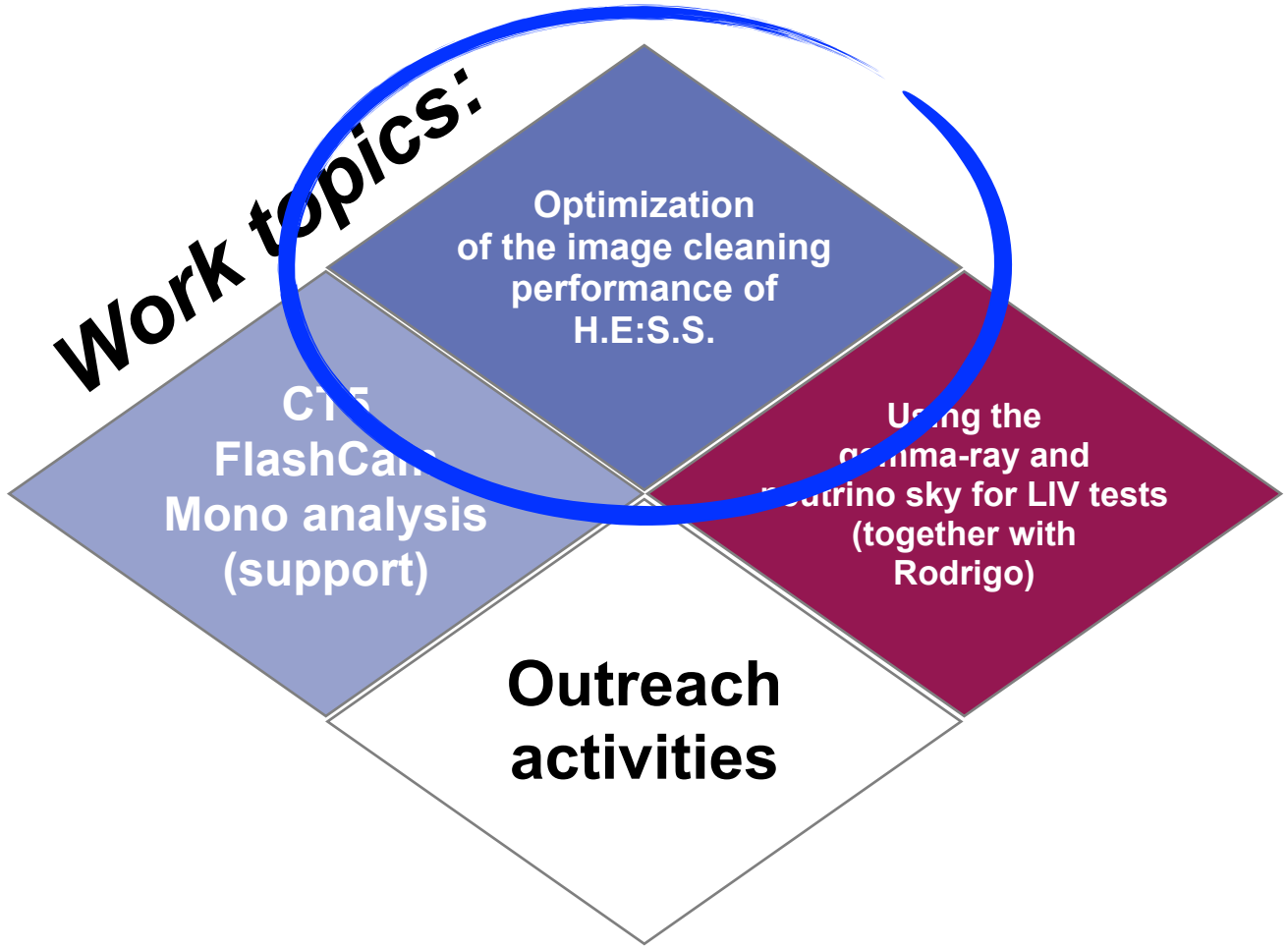
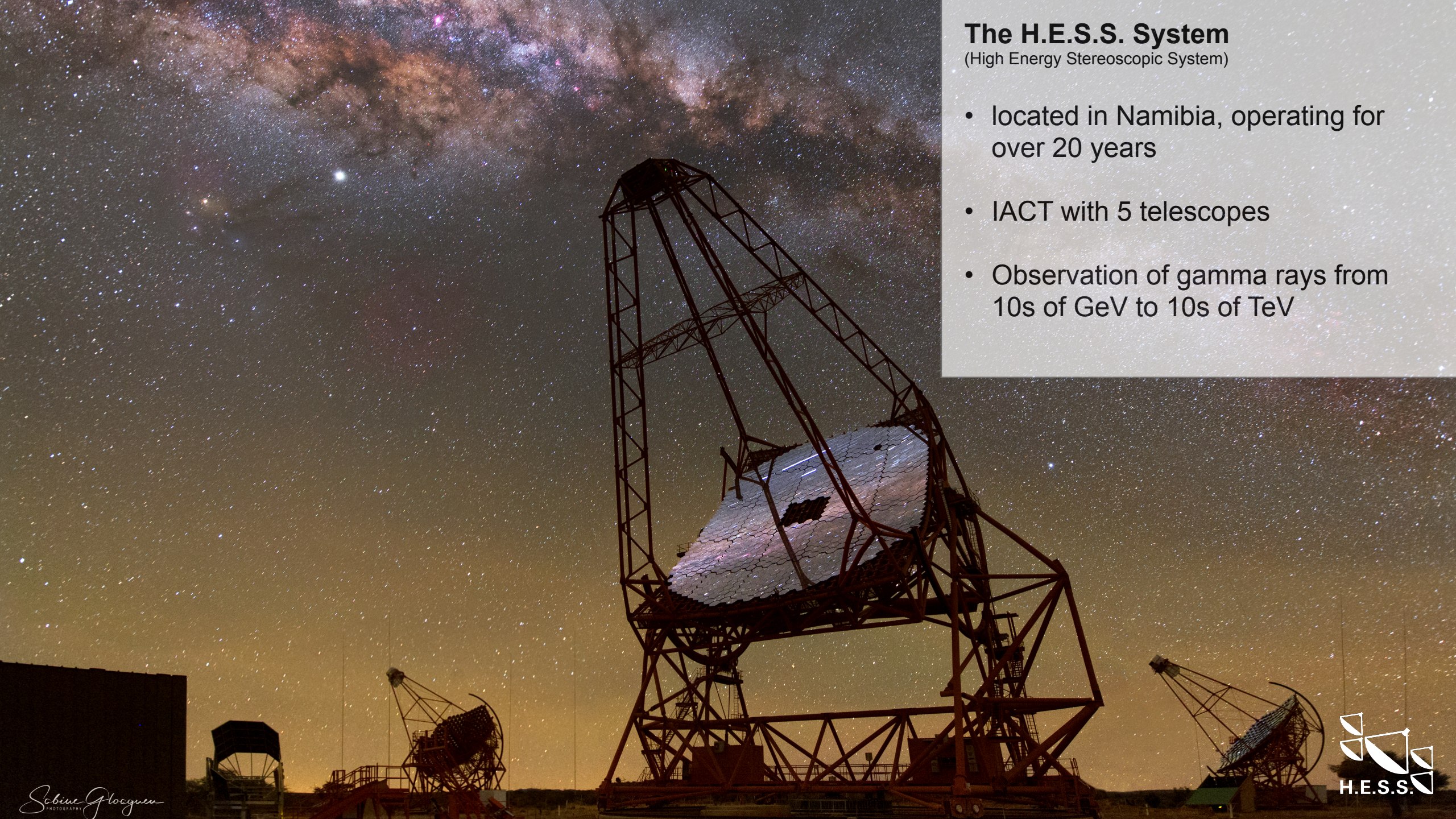


Friedrich-Alexander-Universität
Erlangen-Nürnberg

Optimization of the image cleaning performance of H.E.S.S. telescopes

Jelena Celic

High-energy astrophysics in the multi-messenger era
08.04.2024



The H.E.S.S. System

(High Energy Stereoscopic System)

- located in Namibia, operating for over 20 years
- IACT with 5 telescopes
- Observation of gamma rays from 10s of GeV to 10s of TeV

Detection principle of IACTs

- Gamma ray enters atmosphere
  -> Particle cascade showers
- Cherenkov radiation

Sabine Glocquen PHOTOGRAPHY

H.E.S.S.

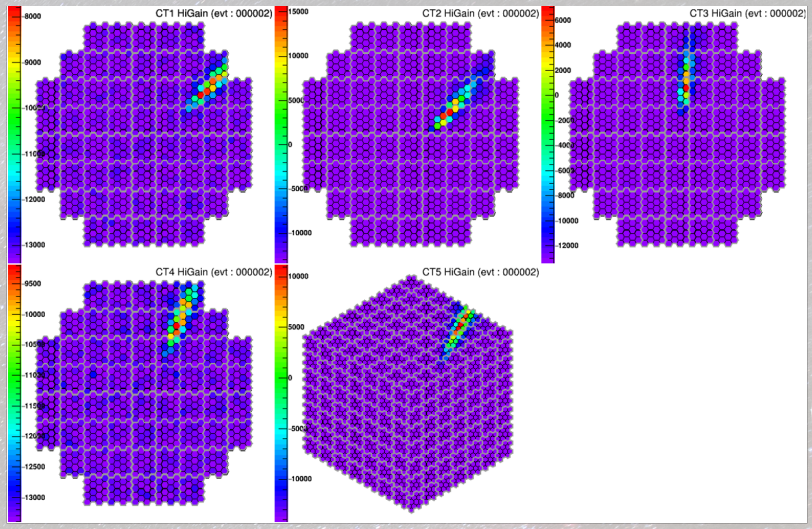
Detection principle of IACTs

- Gamma ray enters atmosphere
  -> Particle cascade showers
- Cherenkov radiation

Sabine Glocquen PHOTOGRAPHY

H.E.S.S.

H.E.S.S. control room



Let's take a closer look

Detection principle of IACTs

- Gamma ray enters atmosphere
  -> Particle cascade showers
- Cherenkov radiation

Sabine Glosguen PHOTOGRAPHY

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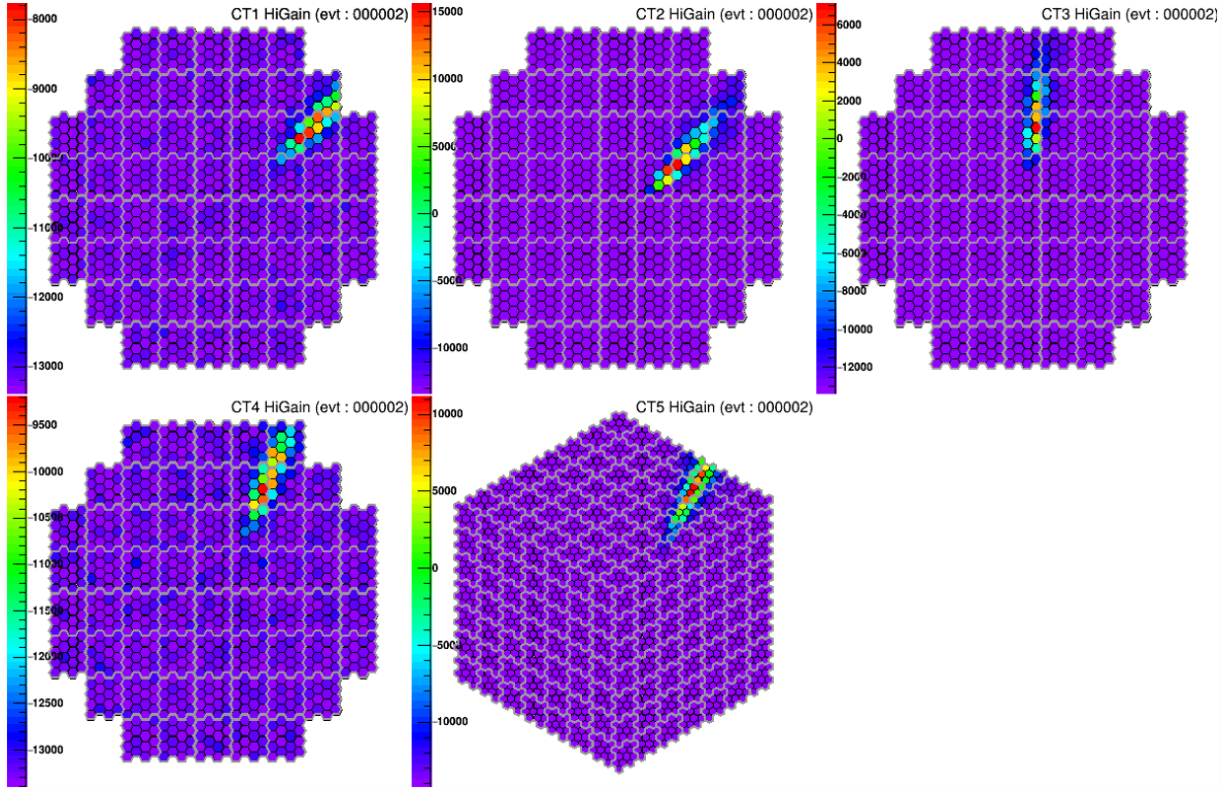
The H.E.S.S. System

Image cleaning technique (done for over 20 years)

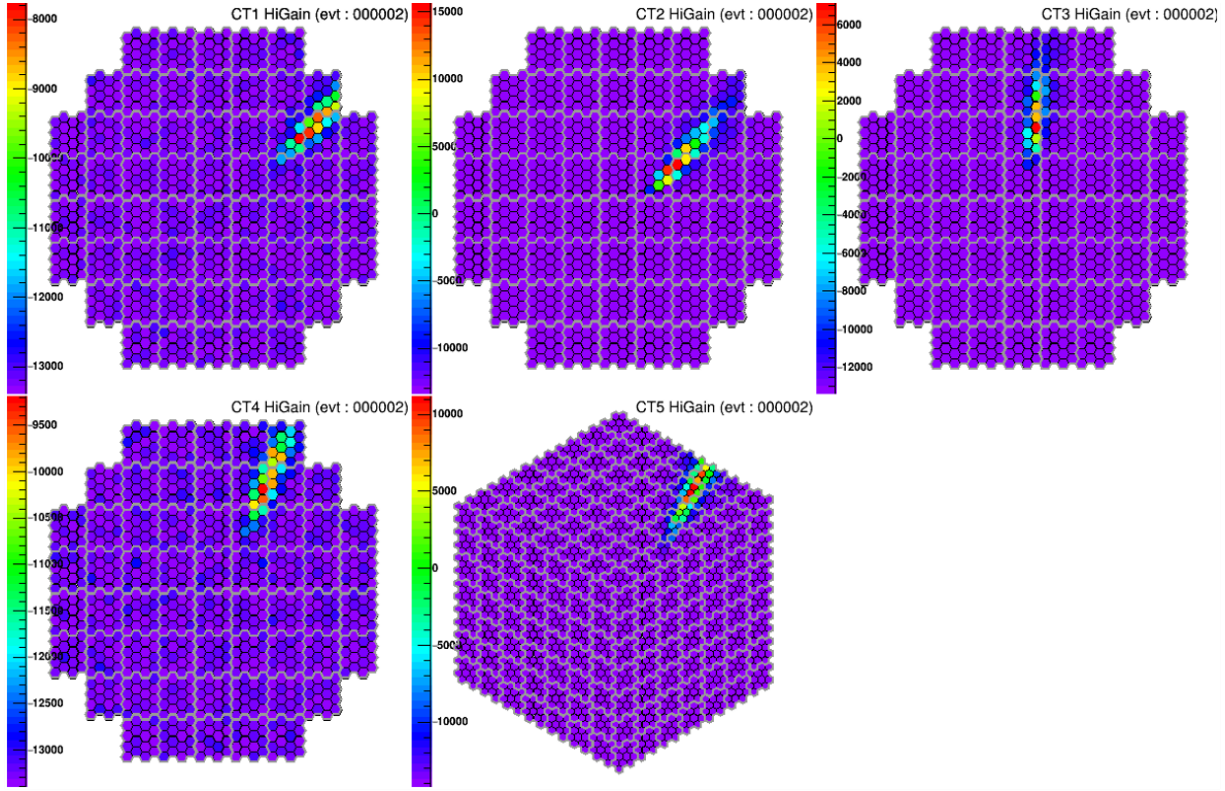
Raw Image = Signal + Noise due to Night Sky Background (NSB)

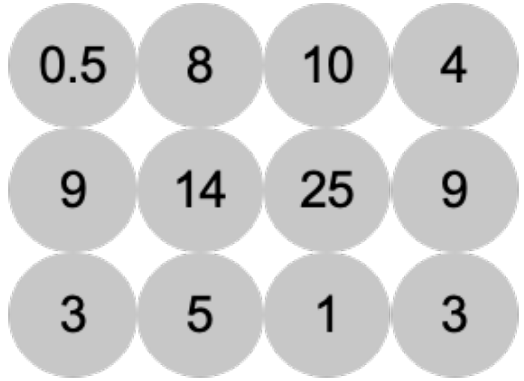


The H.E.S.S. System

Image cleaning technique (done for over 20 years)

Raw Image = Signal + Noise due to Night Sky Background (NSB) → **Tailcut cleaning** = Two threshold cleaning





1. Threshold: 10
2. Threshold: 5

The H.E.S.S. System

Image cleaning technique (done for over 20 years)

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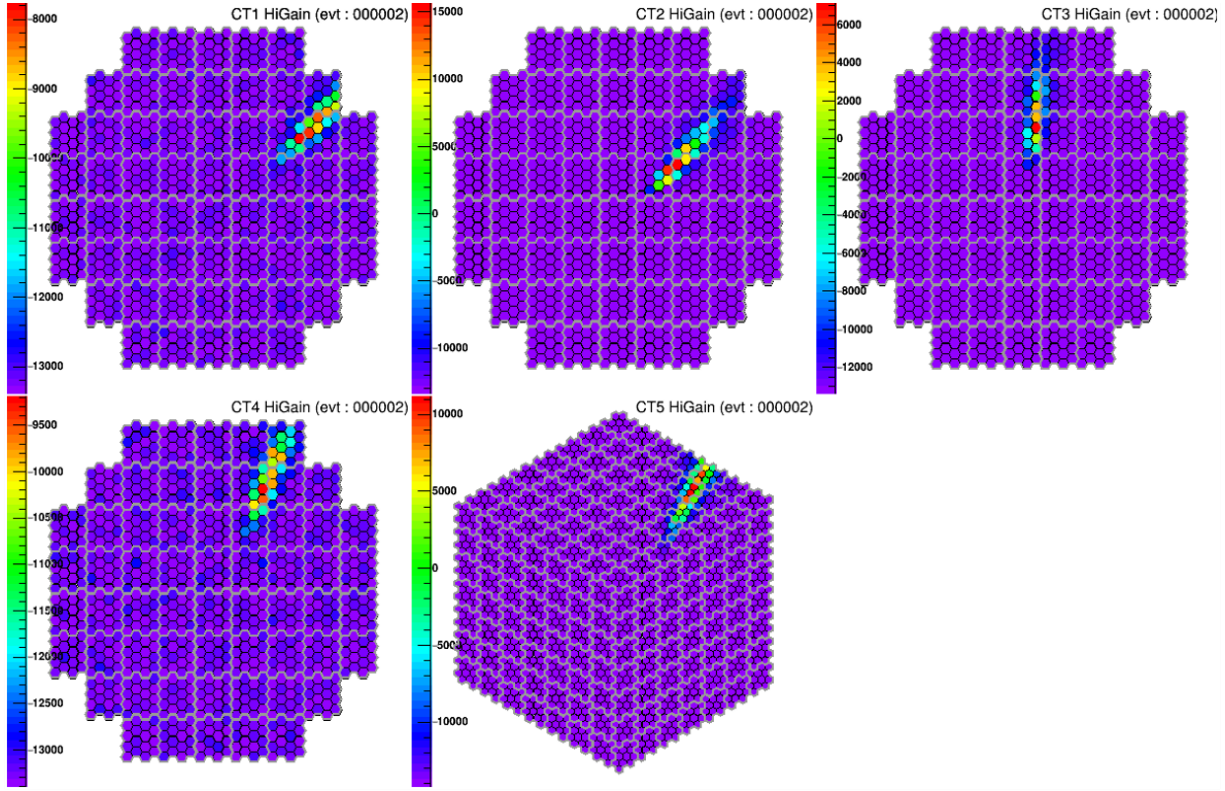

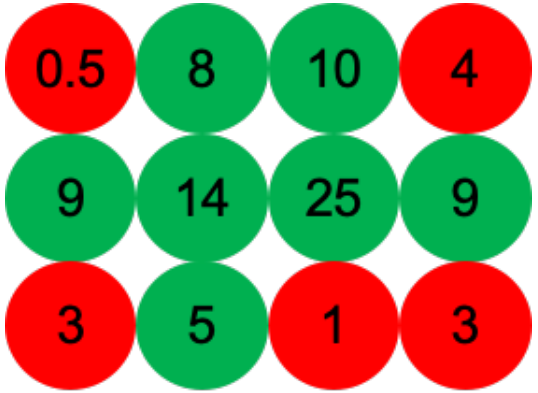

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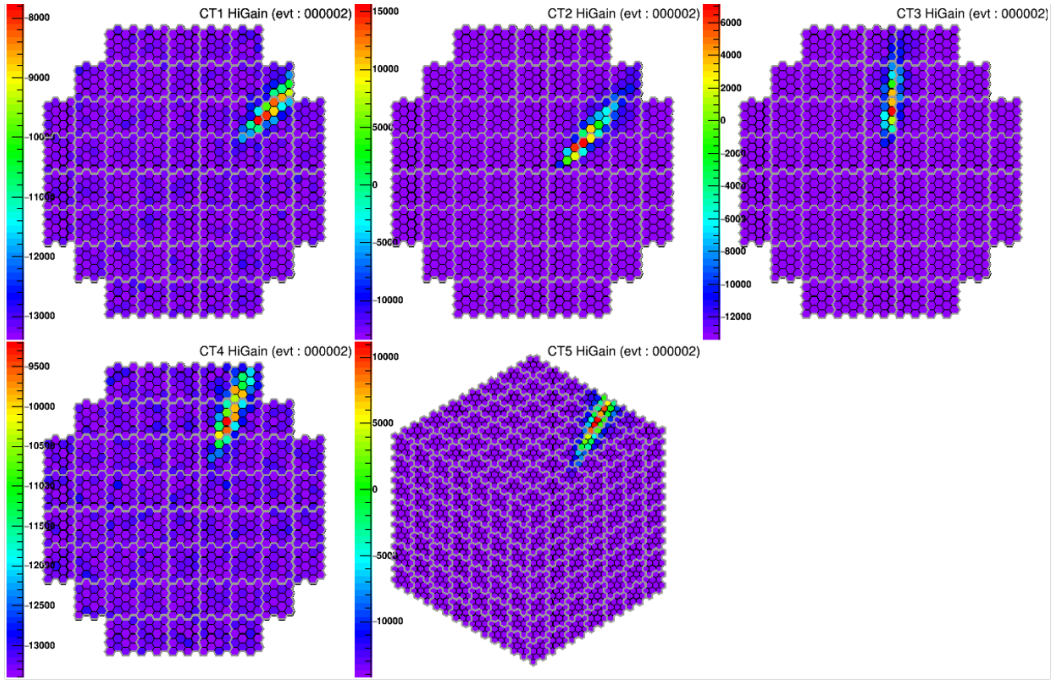
The H.E.S.S. System

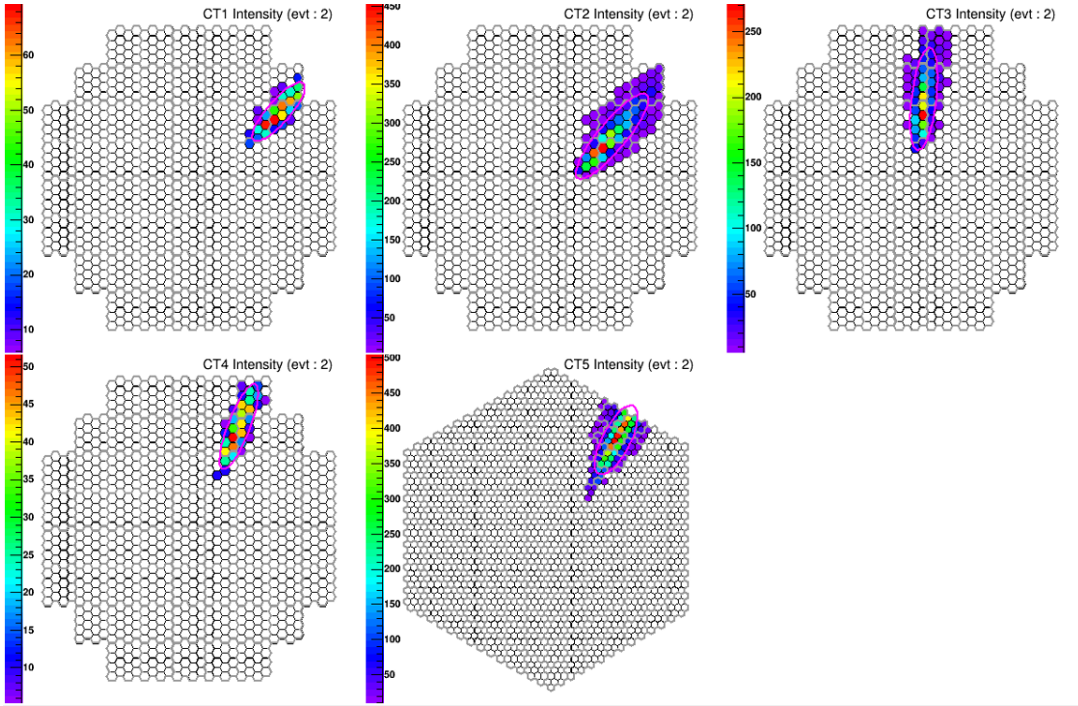
Image cleaning technique (done for over 20 years)

Image Cleaning

Raw images



Cleaned images



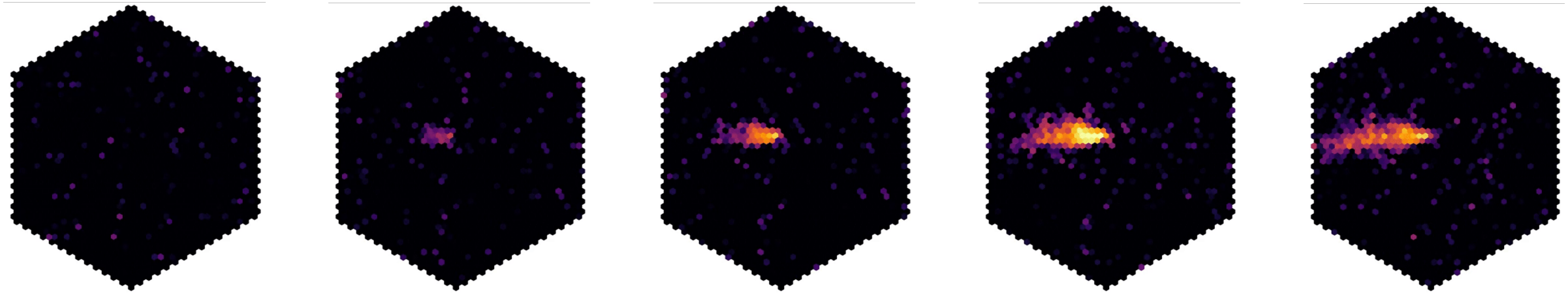
Time-based cleaning

In theory

- Standard cleaning: Not suitable for faint showers / low size events (~ low energetic events)

- **Novel approach:** Including the pixel time information → **Time-based cleaning**

Aim: Improvement in low shower size range → Lower the energy threshold



Taken from HESS

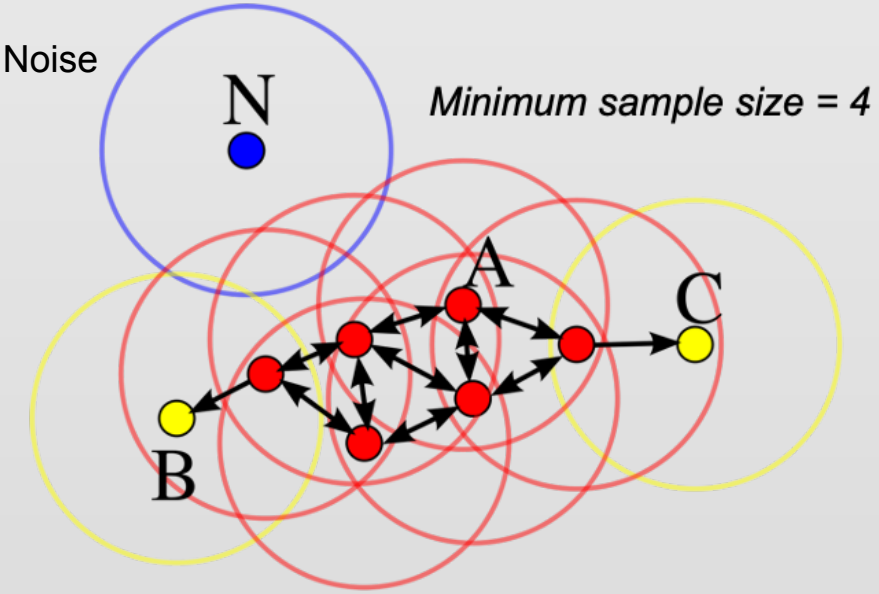
Time t

Time-based cleaning

Working principle of the algorithm

Our tool: **DBScan** = Density-Based Spatial Clustering of Applications with Noise

⟶ 2 parameters: minimum sample size and distance ϵ



- Our implementation requires 4 parameters:
  - Noise cut (=Precleaning step)
  - **Time scale**
  - **Spatial scale**
  - **Cluster size**

  } **3D DB Scan**

Time-based cleaning

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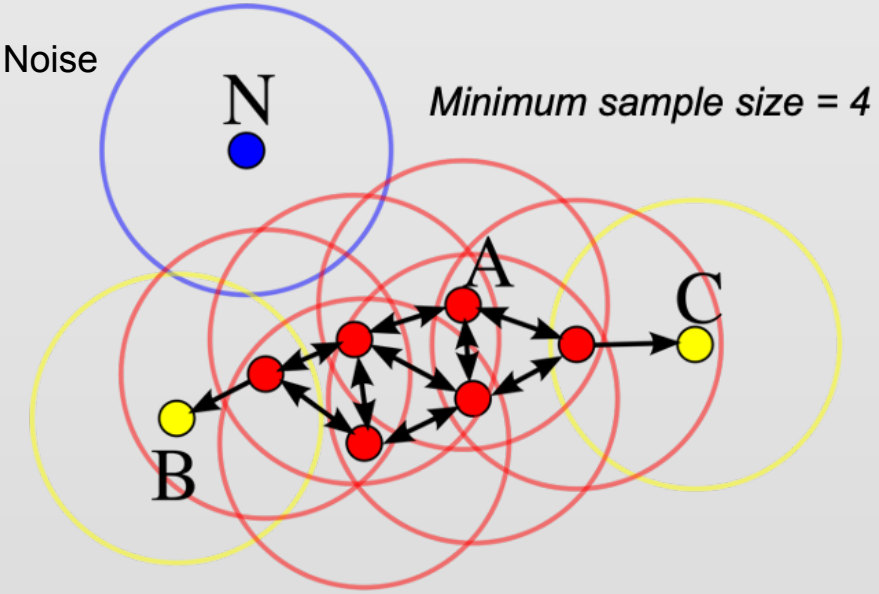

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  } **3D DB Scan**

- **Optimization of sensitivity not trivial**
  - Image cleaning > Sensitivity

Time-based cleaning

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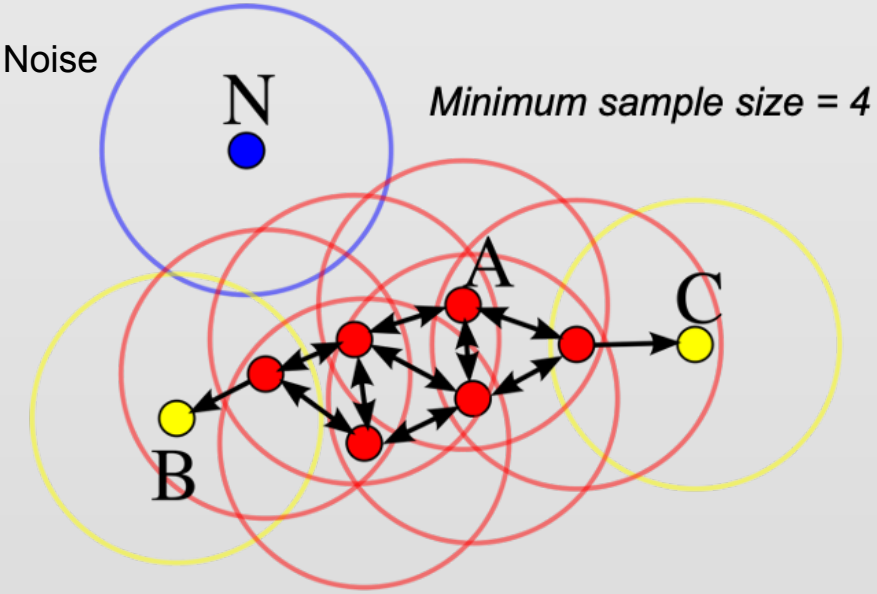

- Our implementation requires 4 parameters:
  - Noise cut (=Precleaning step)
  - **Time scale**
  - **Spatial scale**
  - **Cluster size**

  } **3D DB Scan**

- **Optimization of sensitivity not trivial**
  - Image cleaning (> Angular reconstruction > Energy reconstruction > Gamma-Hadron-Separation > Instrument Response Functions) > Sensitivity
    - Very CPU time intensive → Image cleaning study pipeline is needed

Image cleaning study pipeline

My approach to study image cleaning performance

Only tested for CT5

H.E.S.S.

H.E.S.S. ecap Erlangen Centre for Astroparticle Physics FAU

Image Cleaning Study

Goals of image cleaning

- Keeping as much light of the shower as possible (Size retainment)
- Cleaning NSB as well as possible away (NSB survival rate)

Parameter Space

Image Cleaning Study

- Size retainment
- NSB survival rate

Final estimate

Optimization pipeline

Image cleaning study pipeline

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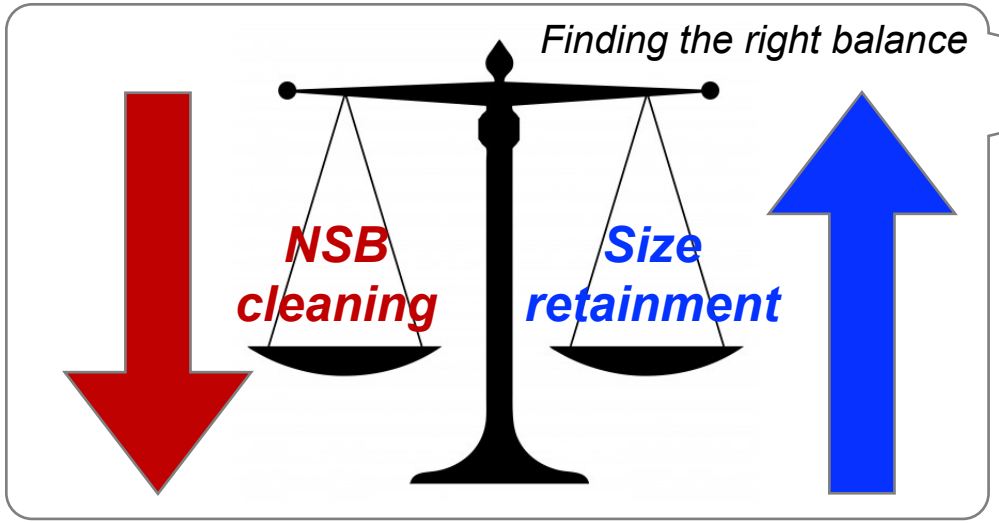

Parameter Space

Image Cleaning Study

- Size retainment
- NSB survival rate

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Image cleaning study pipeline

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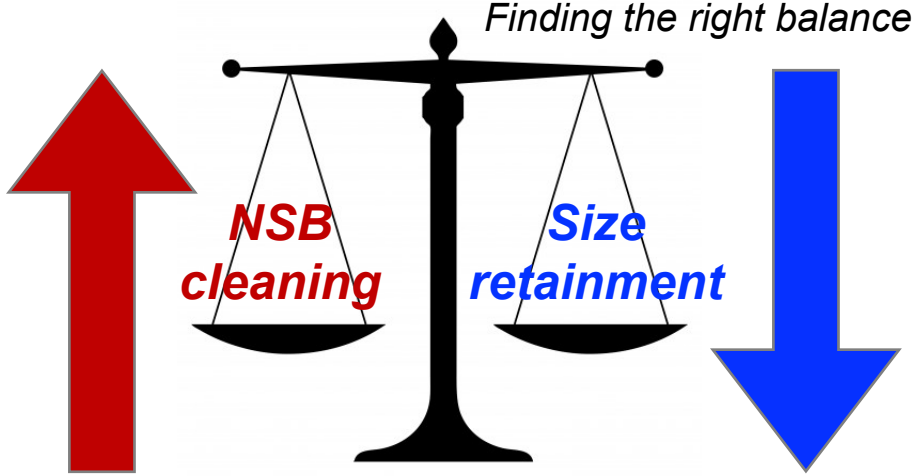
Image Cleaning Study

Goals of image cleaning

- Keeping as much light of the shower as possible (Size retainment)
- Cleaning NSB as well as possible away (NSB survival rate)

Finding the right balance



Parameter Space

Image Cleaning Study

- Size retainment
- NSB survival rate

Final estimate

Optimization pipeline

Image cleaning study pipeline

My approach to study image cleaning performance

Only tested for CT5

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Image Cleaning Study

Goals of image cleaning
- Keeping as much light of the shower as possible (Size retainment)
- Cleaning NSB as well as possible away (NSB survival rate)

+

Distinguish Gammas from Hadrons
And
Less susceptible of NSB rate fluctuations

Parameter Space

Image Cleaning Study
- Size retainment
- NSB survival rate
- ***Background rejection power***
- ***NSB susceptibility***

Final estimate

Optimization pipeline

Image cleaning study pipeline

My approach to study image cleaning performance

Only tested for CT5

H.E.S.S.

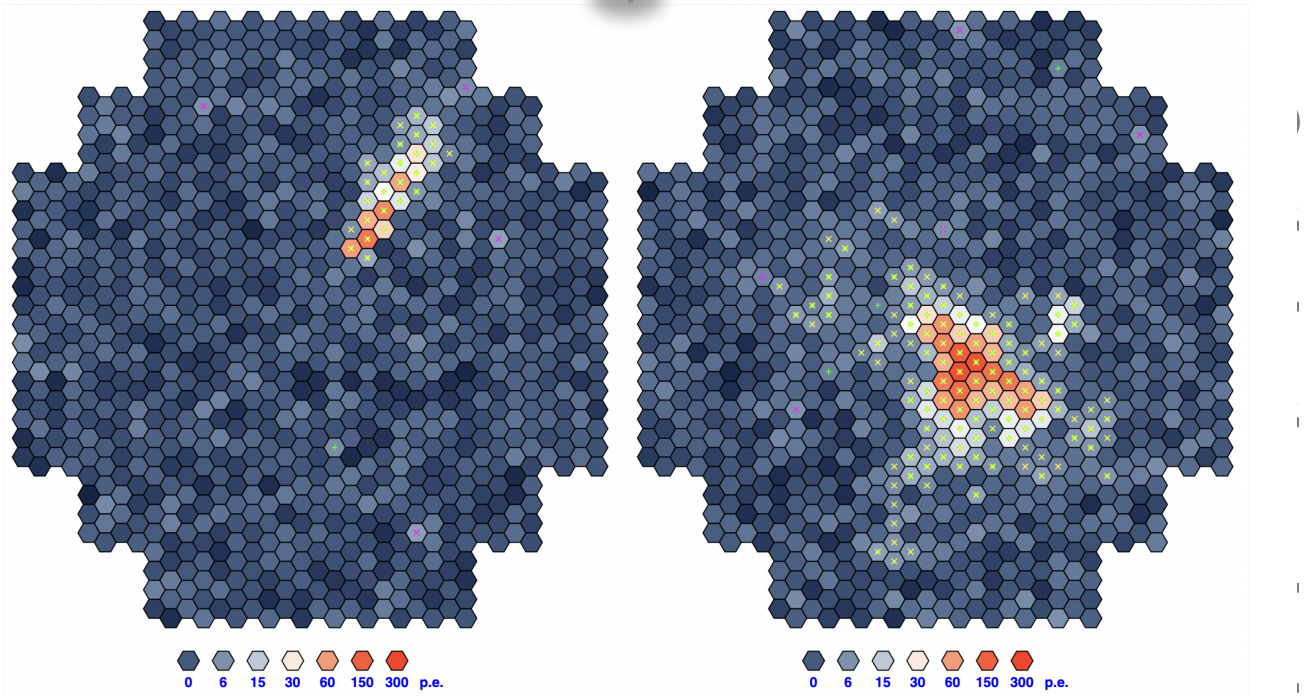
Image Cleaning Study

Goals of image cleaning

- Keeping as much light of the shower as poss (Size retainment)
- Cleaning NSB as well as possible away (NSE survival rate)

+

Distinguish Gammas from Hadron And Less susceptible of NSB rate fluctuations



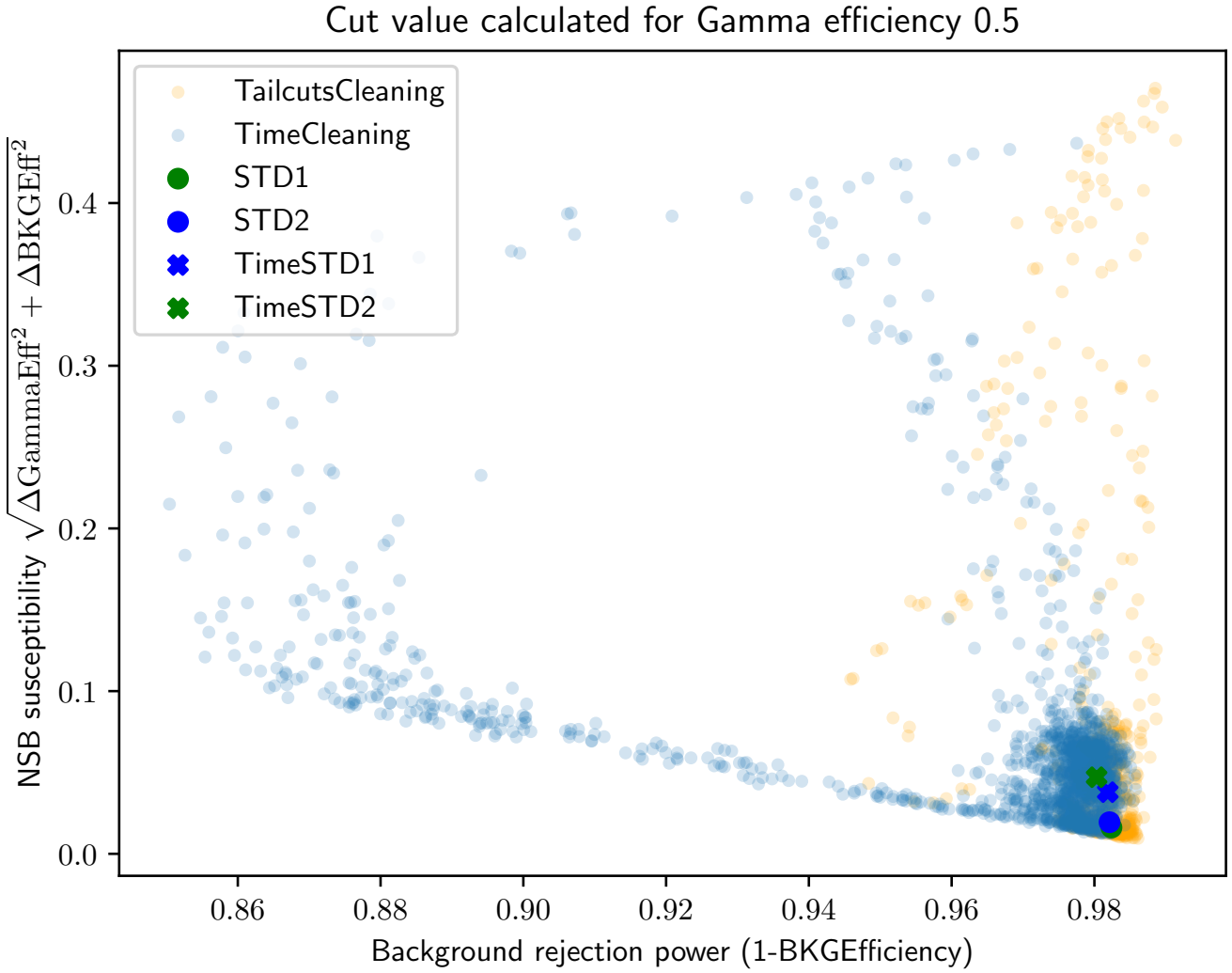
1.0 TeV gamma shower

2.6 TeV proton shower

HJ Völk, K Bernlöhr, 2009

The metric plot

Background rejection power vs. NSB susceptibility



Tailcut Cleanings

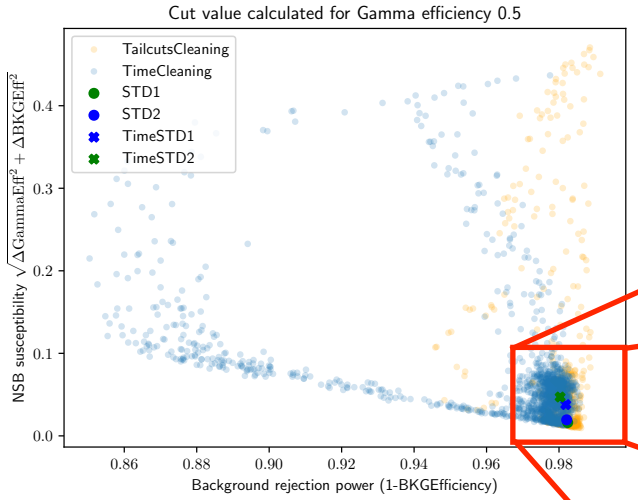
- STD1: Hillas0916NN2
- STD2: Hillas0714NN2

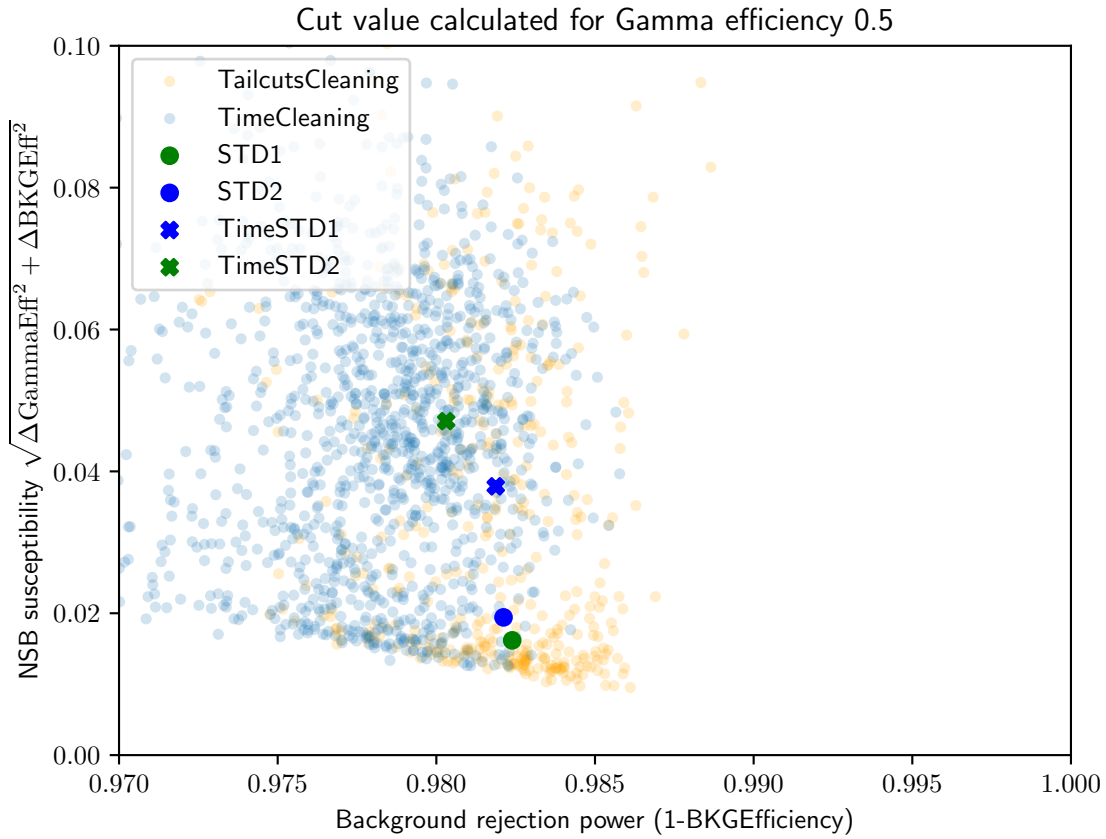
Time Cleanings

- TimeSTD1:HillasTimingN5
- TimeSTD2:HillasTimingN3

The metric plot (zoomed in)

Background rejection power vs. NSB susceptibility





Tailcut Cleanings

- STD1: Hillas0916NN2
- STD2: Hillas0714NN2

Time Cleanings

- TimeSTD1:HillasTimingN5
- TimeSTD2:HillasTimingN3

The metric plot with new time-based cleaning algorithm

Background rejection power vs. NSB susceptibility

Four dimensional DBscan

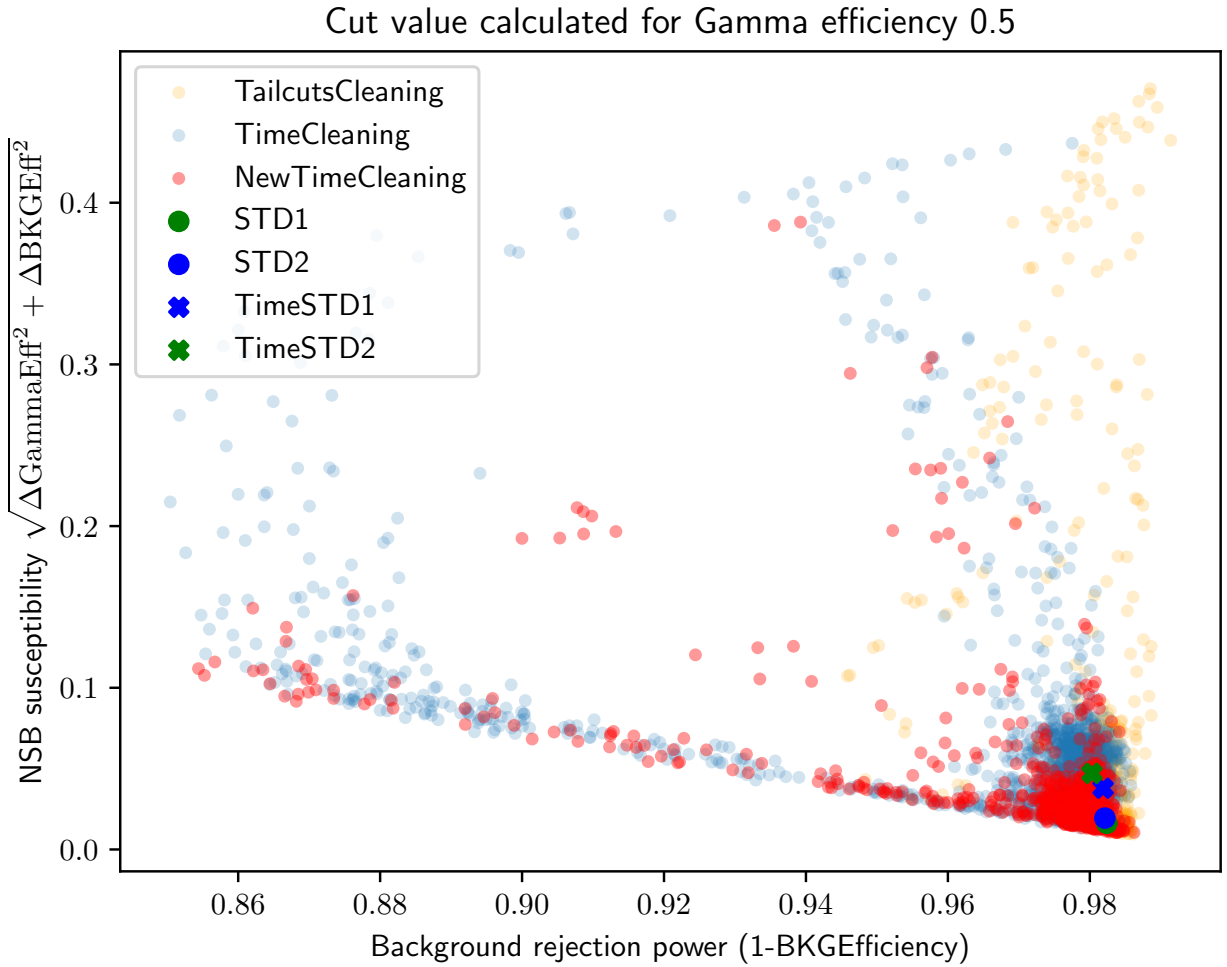
DBscan in NSBTimingCleaner.C

- TimeScale
- SpatialScale
- Clustersize

3D

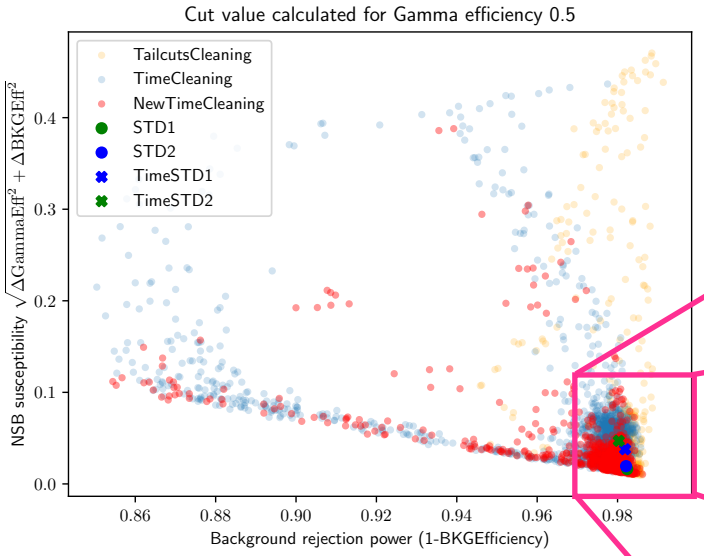
+

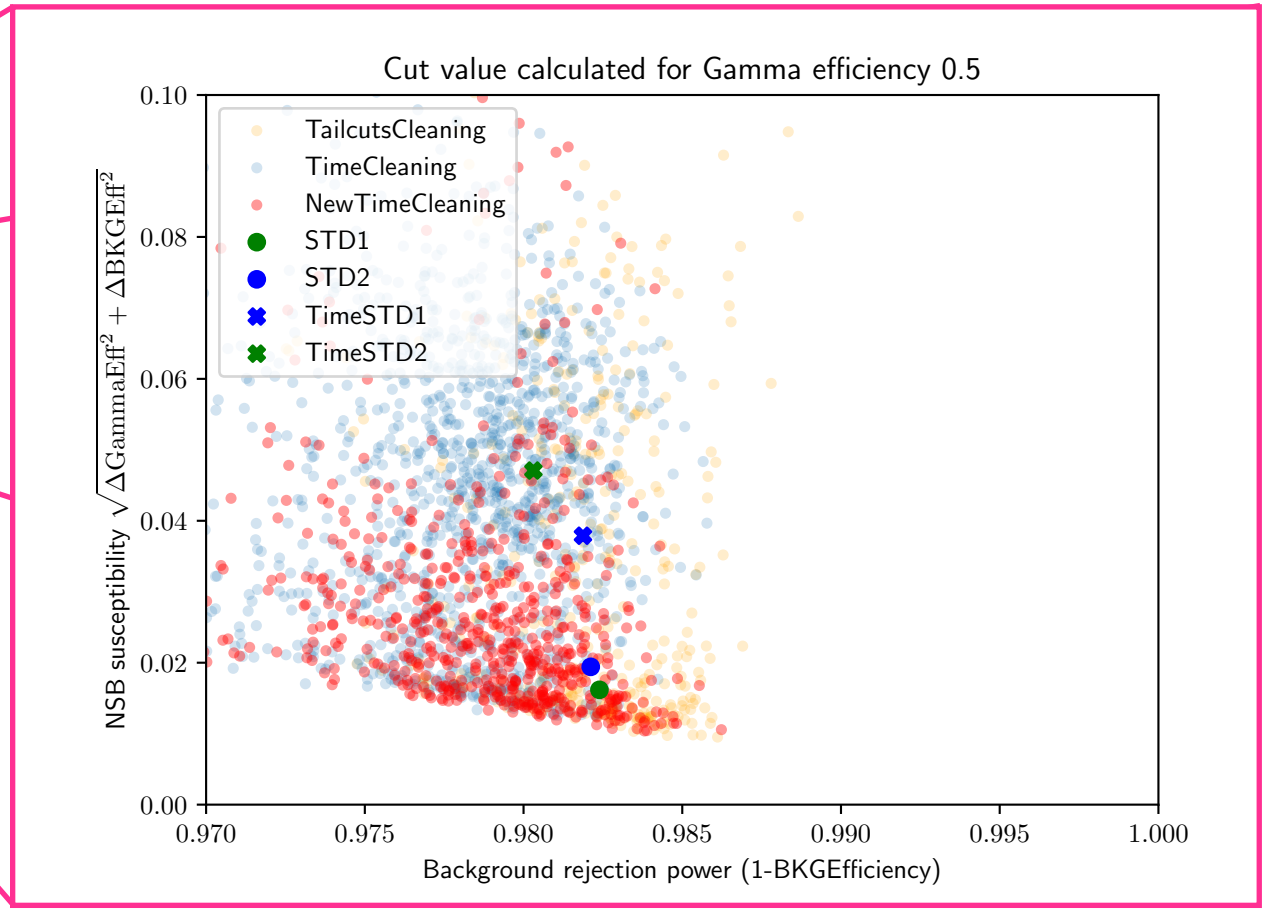
Scale factor that also considers the **PixelAmplitude**



The metric plot with new time-based cleaning algorithm

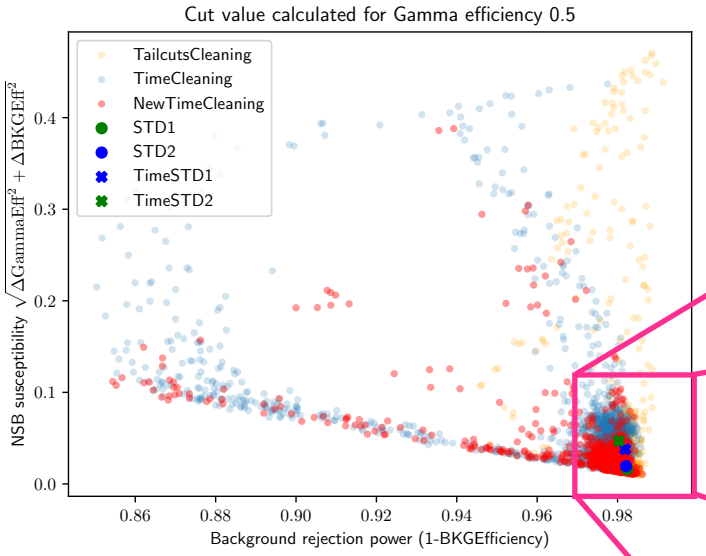
Background rejection power vs. NSB susceptibility

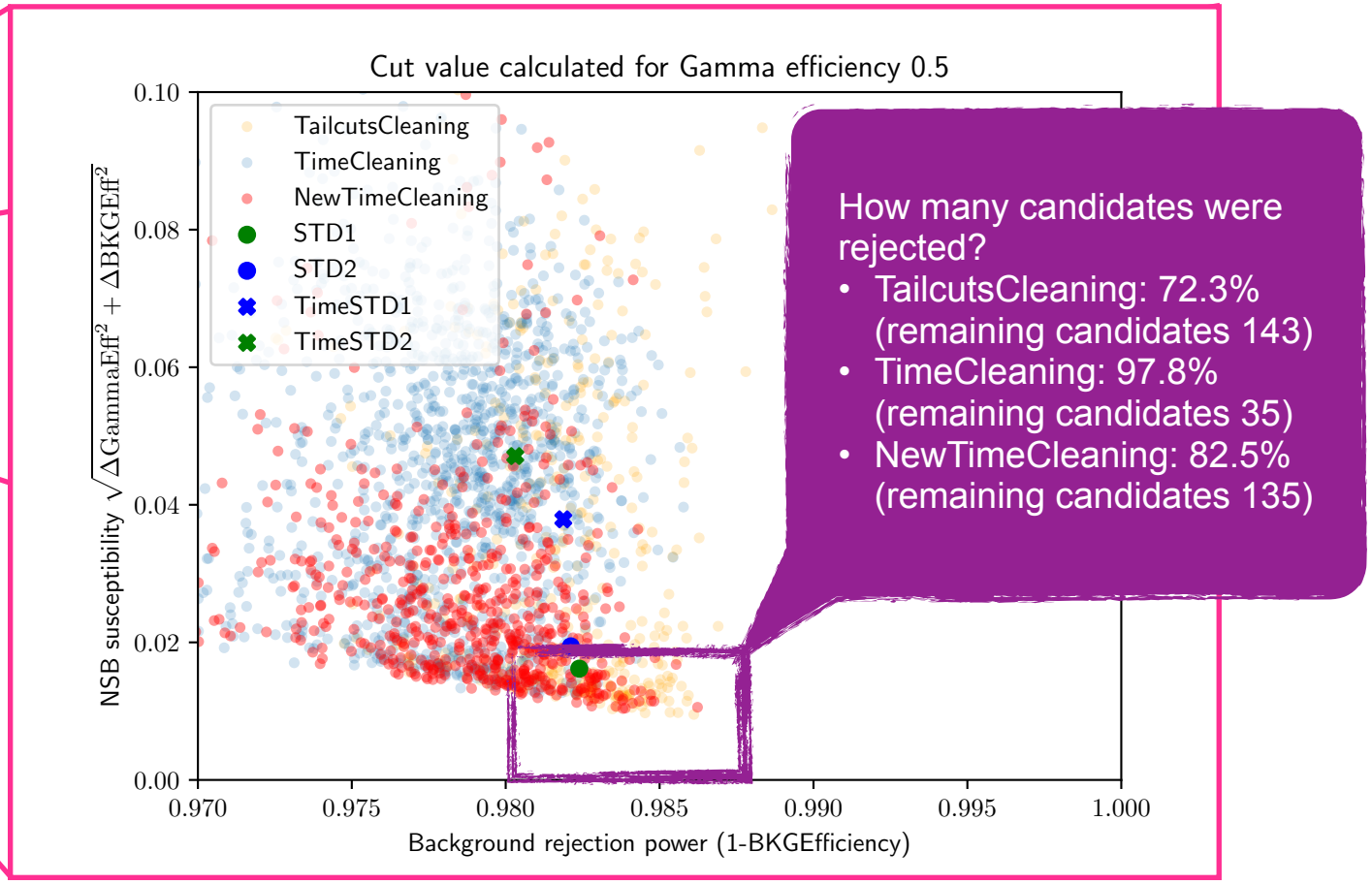




The metric plot with new time-based cleaning algorithm

Background rejection power vs. NSB susceptibility





Summary and Outlook

You almost survived a talk about cleaning

Summary:

- Optimization of the image cleaning performance is **not** a trivial task
- Pipeline focuses on **gamma-hadron separation and NSB susceptibility**
  - Currently implemented time-based cleaning algorithm apparently does not outperform tailcut
  - Adding a new dimension in DBscan: **some candidates outperform tailcuts**

Outlook:

- Testing **some modified time-based cleaning** algorithm that also cluster pixels according to their pixel value
- Run Optimization pipeline for HESS-IUs:
  - How to deal with stereo reconstruction?
  - Do we even need different cleanings for different configurations?
- Testing on some sources like Crab Nebula, RS Oph

Friedrich-Alexander-Universität
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ecap Erlangen Centre for Astroparticle Physics

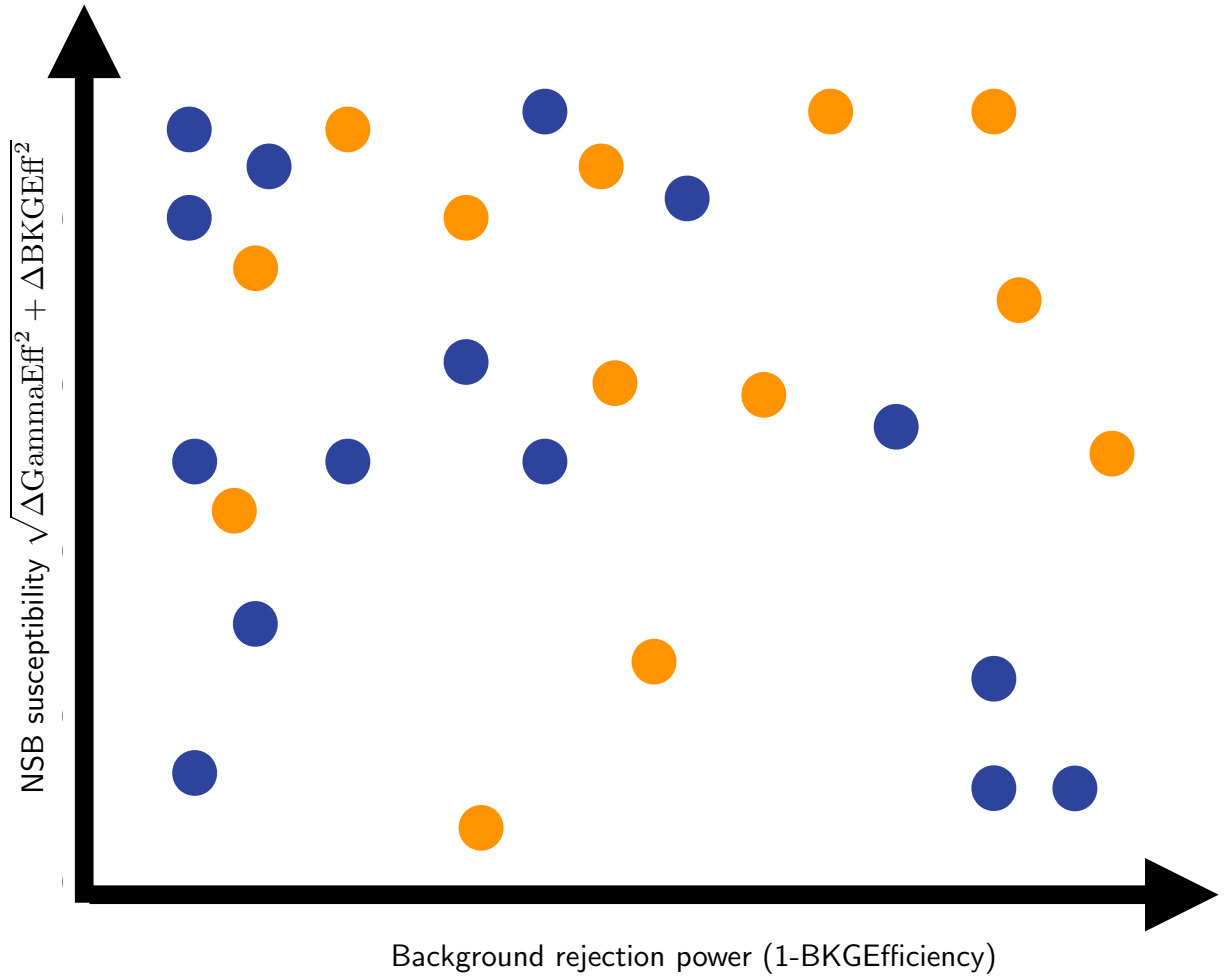
FAU

Thanks for your attention!
Any Questions?

What has changed since the last meeting?

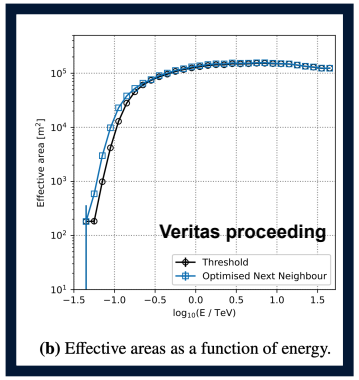
Properties of Interest for Image Cleaning Study

New metric plot

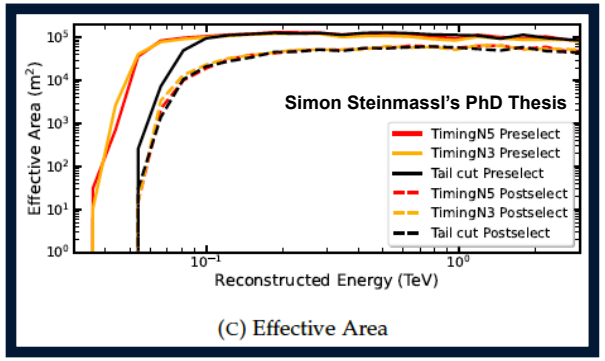


Metric is calculated for each cleaning
at a fixed gamma efficiency after preselect

- **Old optimization of time-based cleaning parameters (or how everyone else has approached this topic)**



(b) Effective areas as a function of energy.



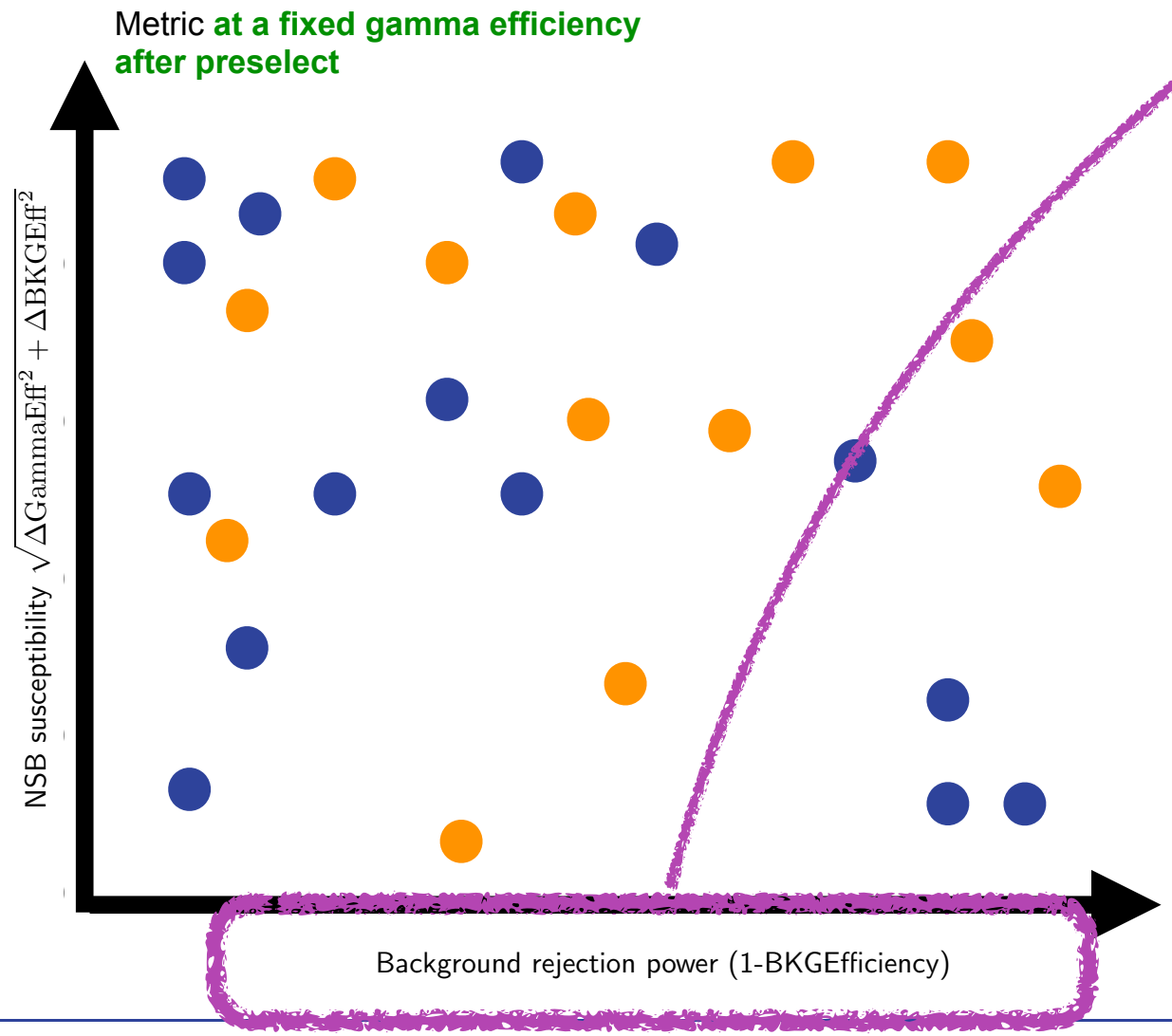
(C) Effective Area

My question:
Does time-based cleaning outperform tailcuts cleaning on a same event comparison?

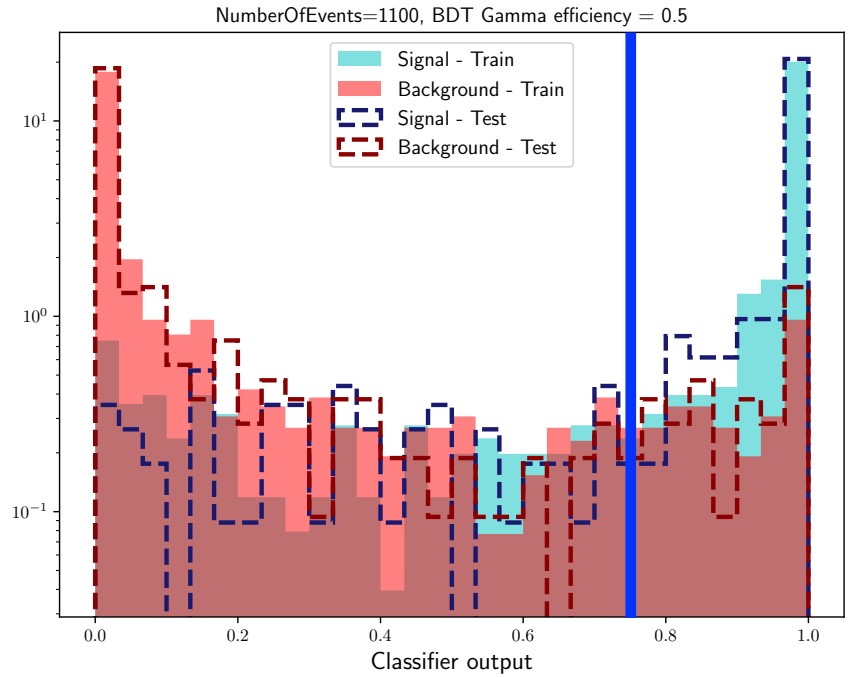
What has changed since the last meeting?

Properties of Interest for Image Cleaning Study

New metric plot



How high is the background rejection power at a fixed BDT gamma efficiency?



Note: line is completely arbitrary and only for simplicity reasons there

- Train BDT model for each cleaning (Gamma NSB1.0 vs. Offrun)
- Let BDT model predict test data
- Evaluate BDT classifier output where Signal = BDT Gamma efficiency

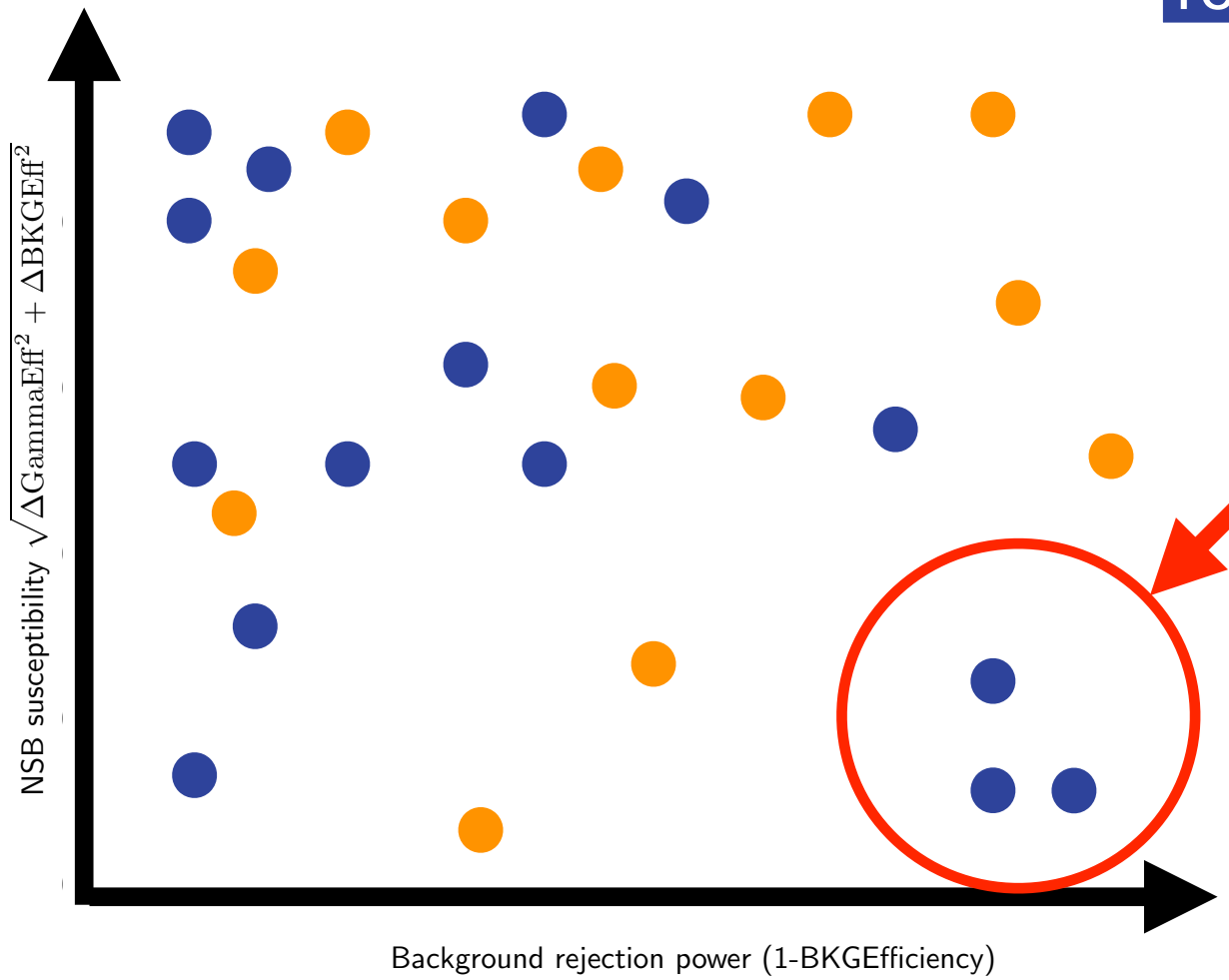
⟶ **Calculate how many background events got rejected**

What has changed since the last meeting?

Properties of Interest for Image Cleaning Study

New metric plot

Metric **at a fixed gamma efficiency**



Yeah cool, but how do I read the plot now?

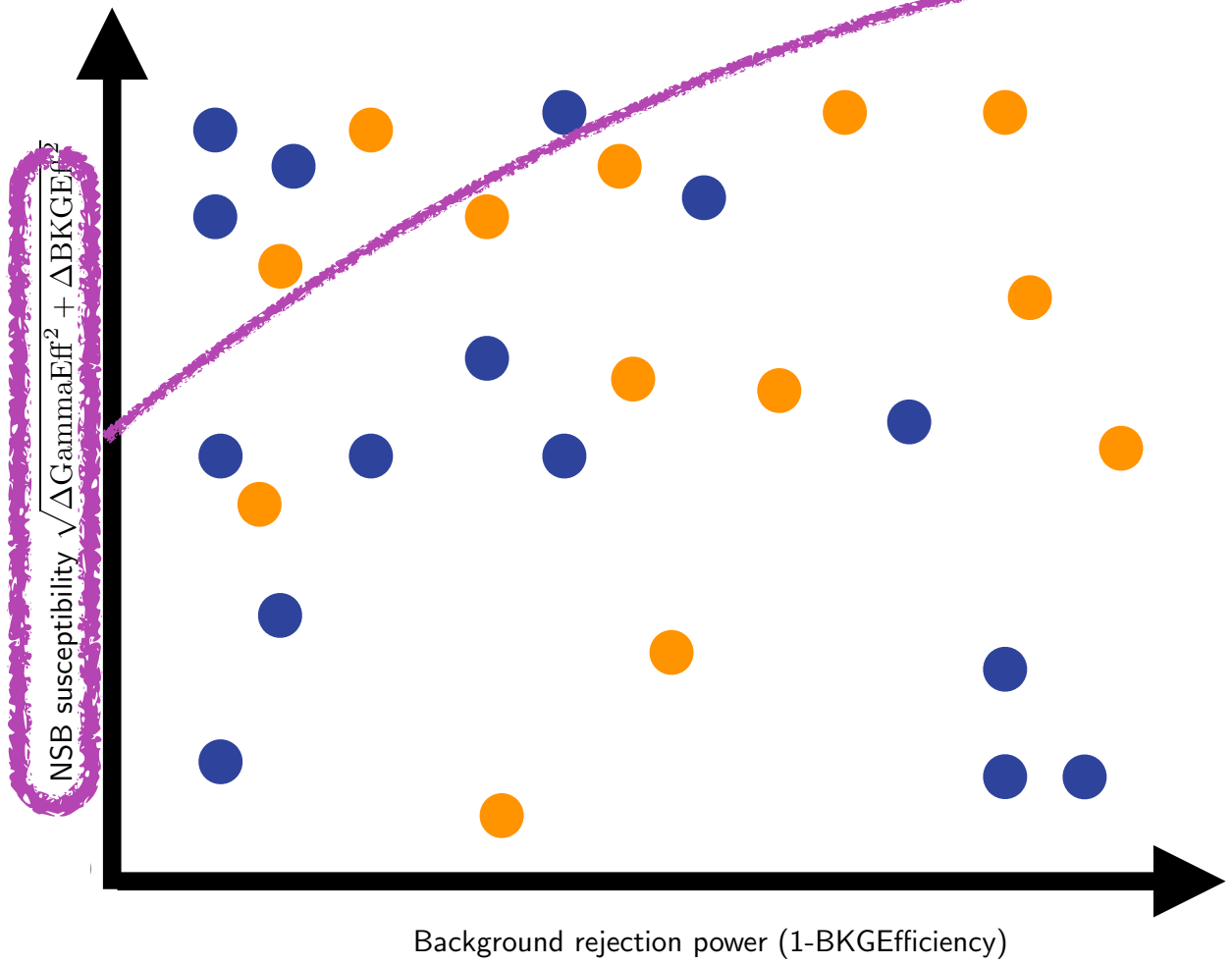
We are interested in this region
- Good Separation
- NSB independent cleaning

What has changed since the last meeting?

Properties of Interest for Image Cleaning Study

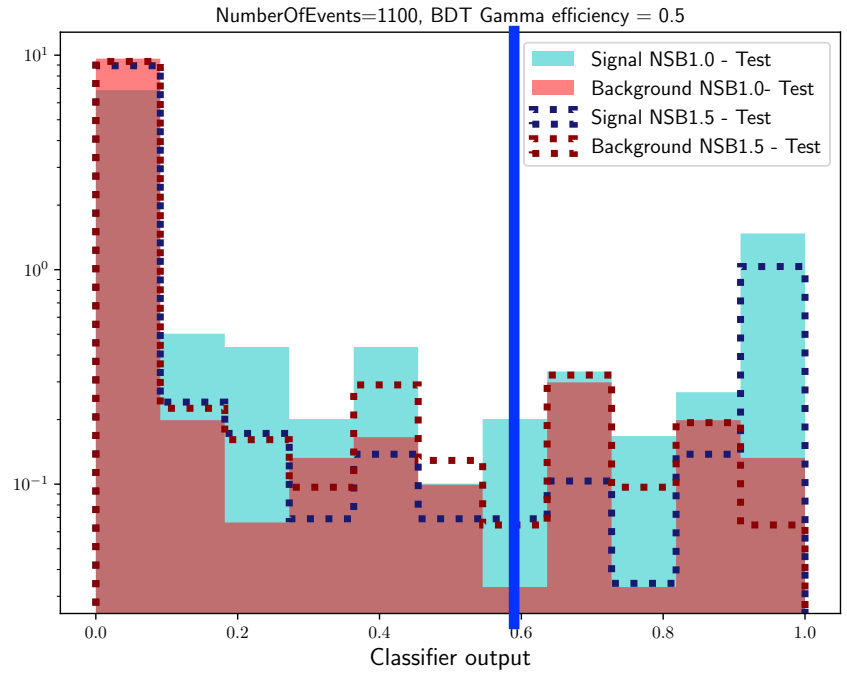
New metric plot

Metric **at a fixed gamma efficiency**



How NSB robust is our cleaning?

⟶ Do we keep more NSB pixels at a higher NSB rate



Note: line is completely arbitrary and only for simplicity reasons there

- Use BDT cut value from Background rejection power
- Calculate differences in gamma efficiency and background efficiency:

$$\text{NSB susceptibility} = \sqrt{(\Delta\gamma_{eff})^2 + (\Delta\text{BKG}_{eff})^2}$$

Modified time-based cleaning algorithm

Added dimension in DBscan

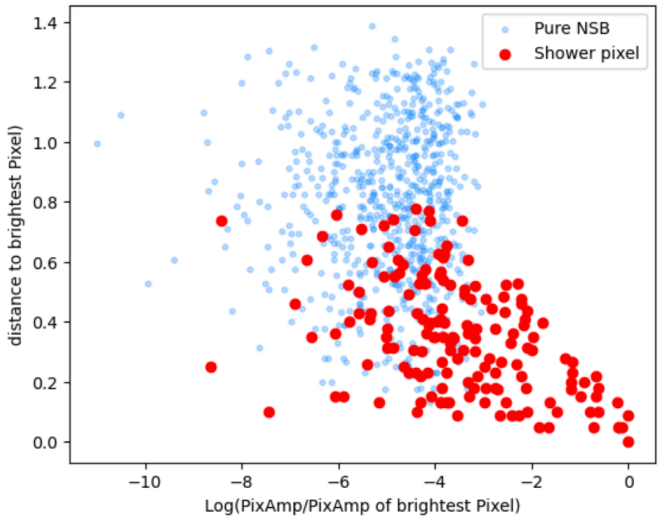
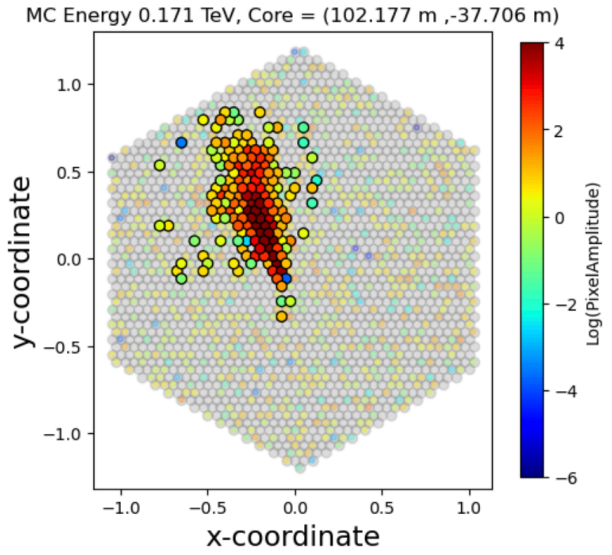
Four dimensional DBscan

DBscan in NSBTimingCleaner.C

- TimeScale
- SpatialScale
- Clustersize

3D

+

Scale factor that also considers the **PixelAmplitude**

My approach (at least for now): How much does the PixelAmplitude deviate from brightest one?