Timepix3 in the AEgIS experiment

Helga Holmestad

University of Oslo

26/10-2018

AEgIS experiment

Measure the gravitational acceleration of antimatter

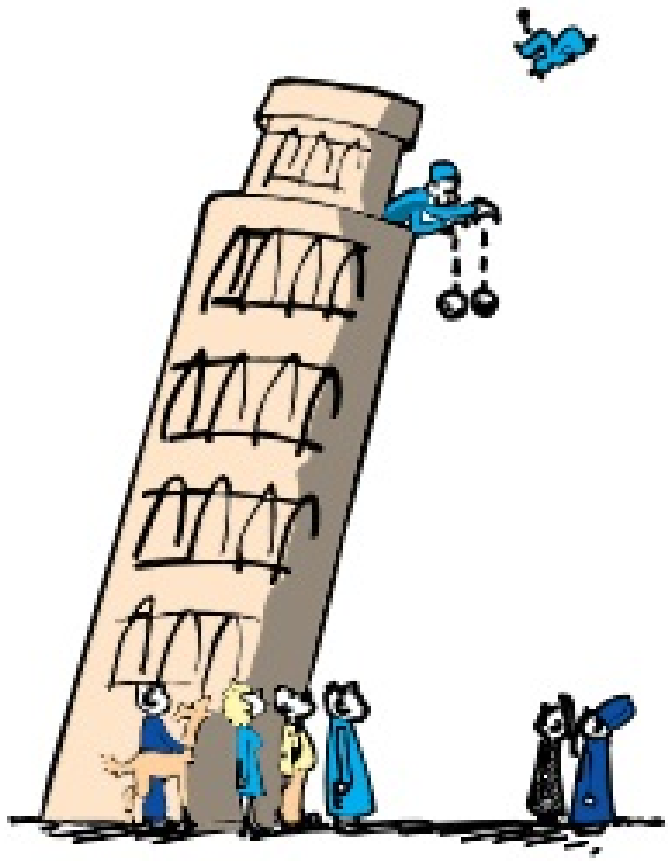

Figure by Markus Poessel

AEgIS experiment

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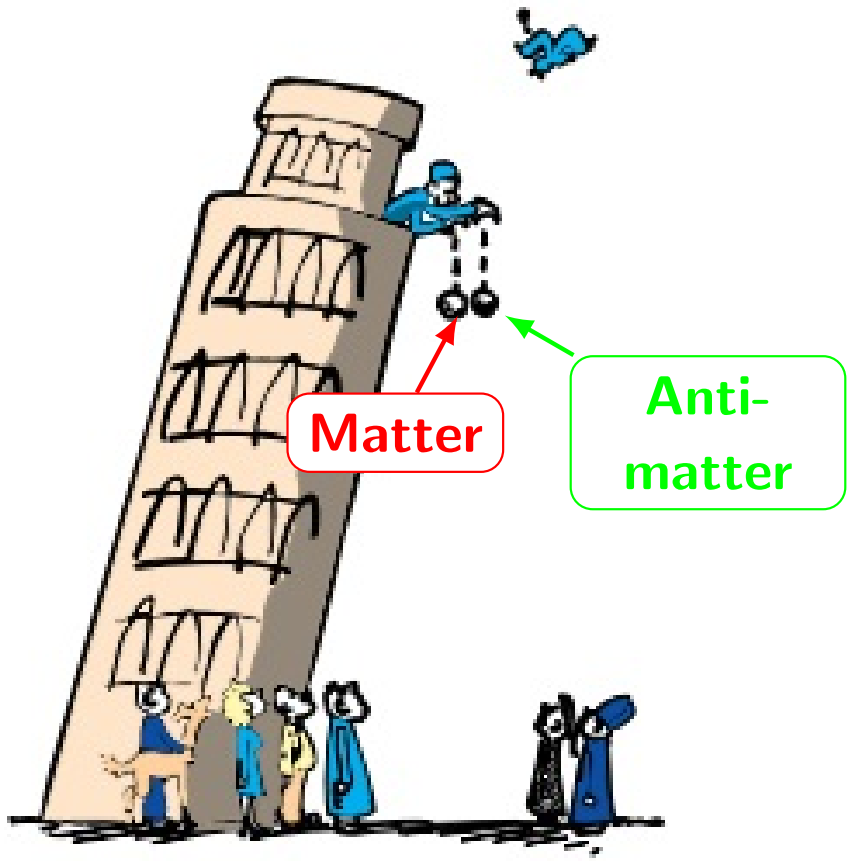
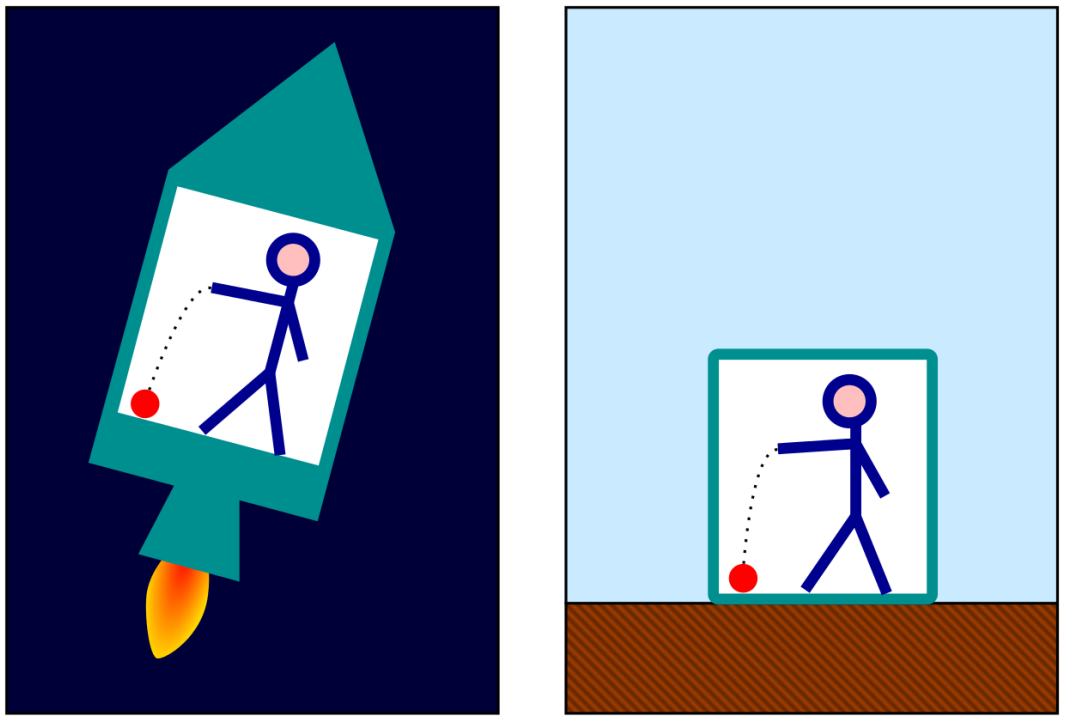


Figure by Markus Poessel

The equivalence principle

- Predicts: $\bar{g} = g$
  - Never been tested before
- Building block of general relativity
- Matter-antimatter asymmetry



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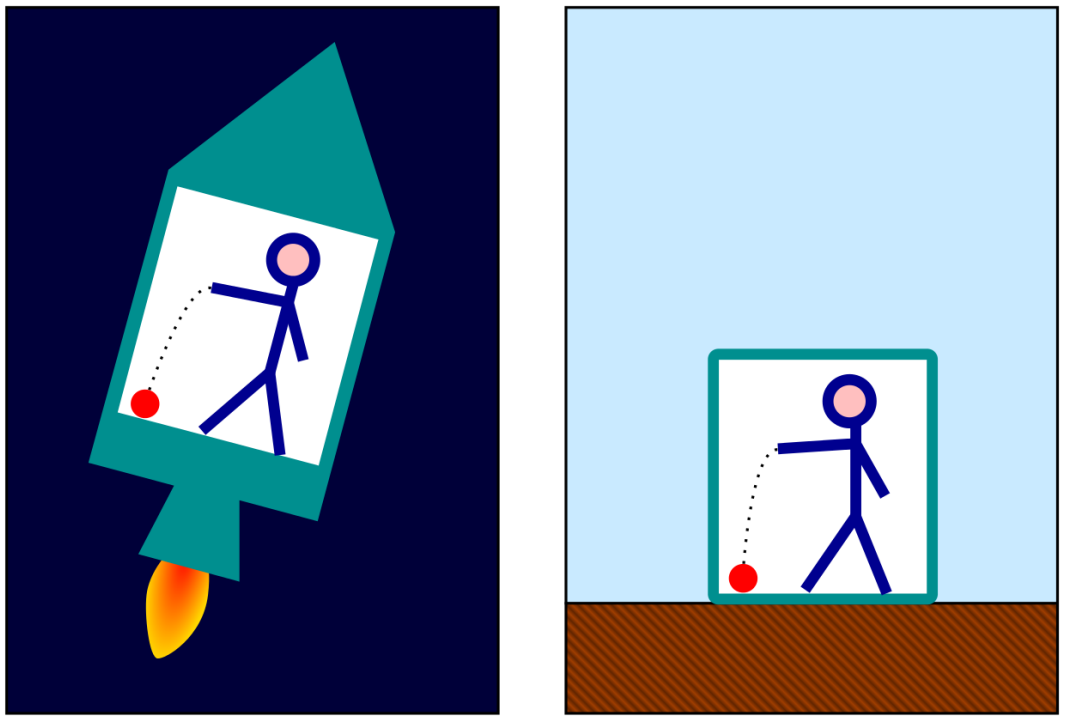

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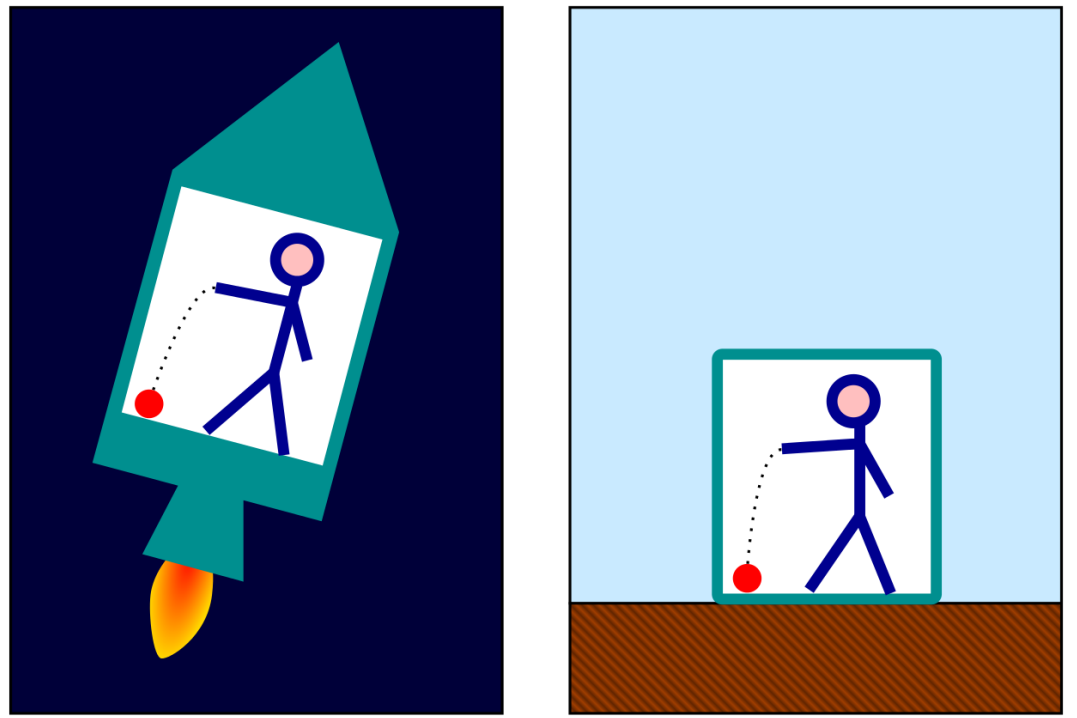
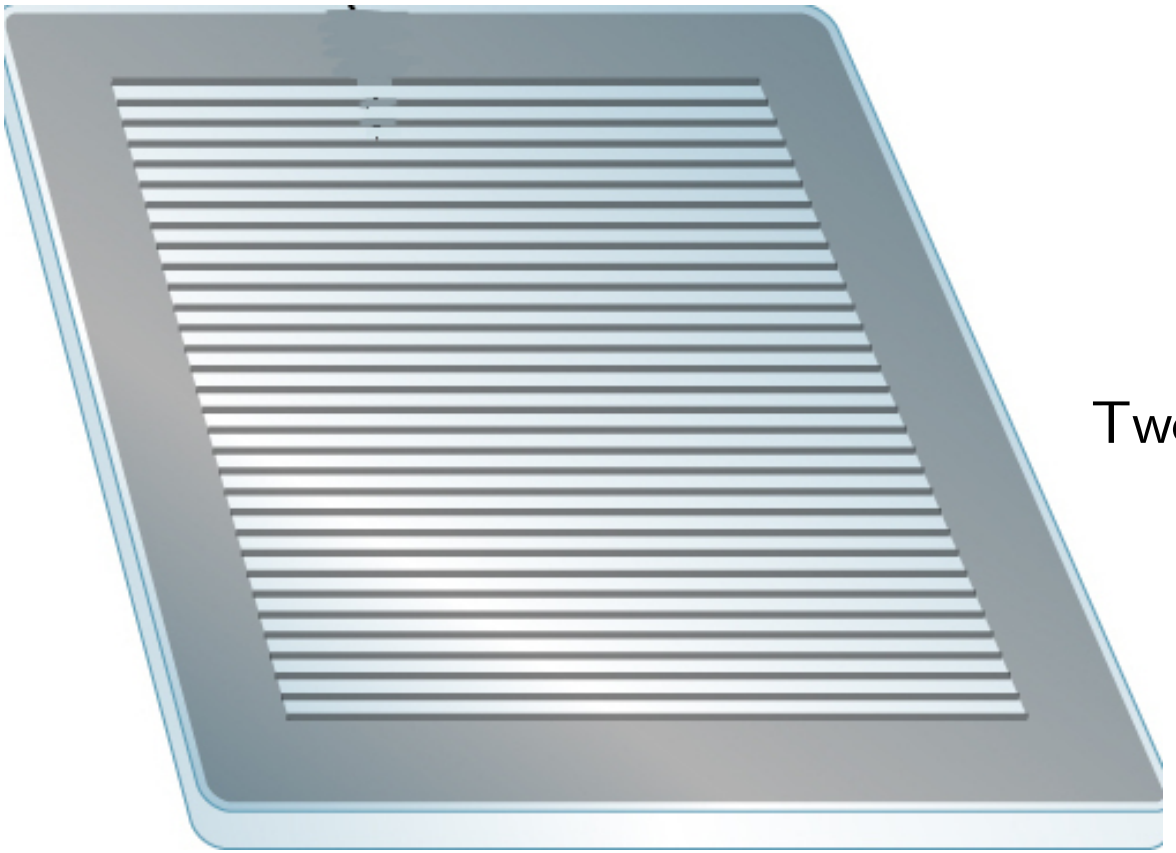


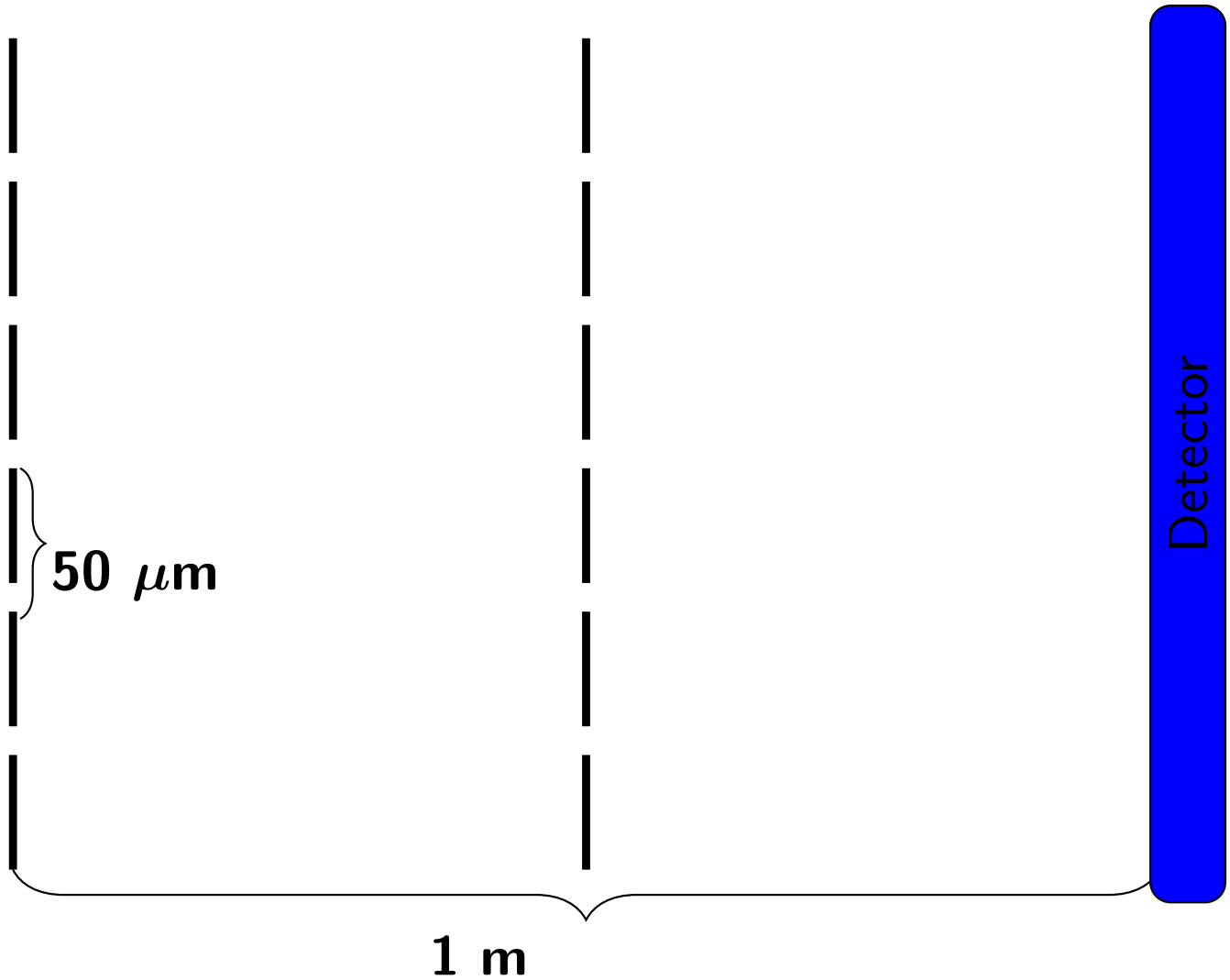
Figure by Markus Poessel

A classical moiré deflectometer



Two of these gratings

A classical moiré deflectometer



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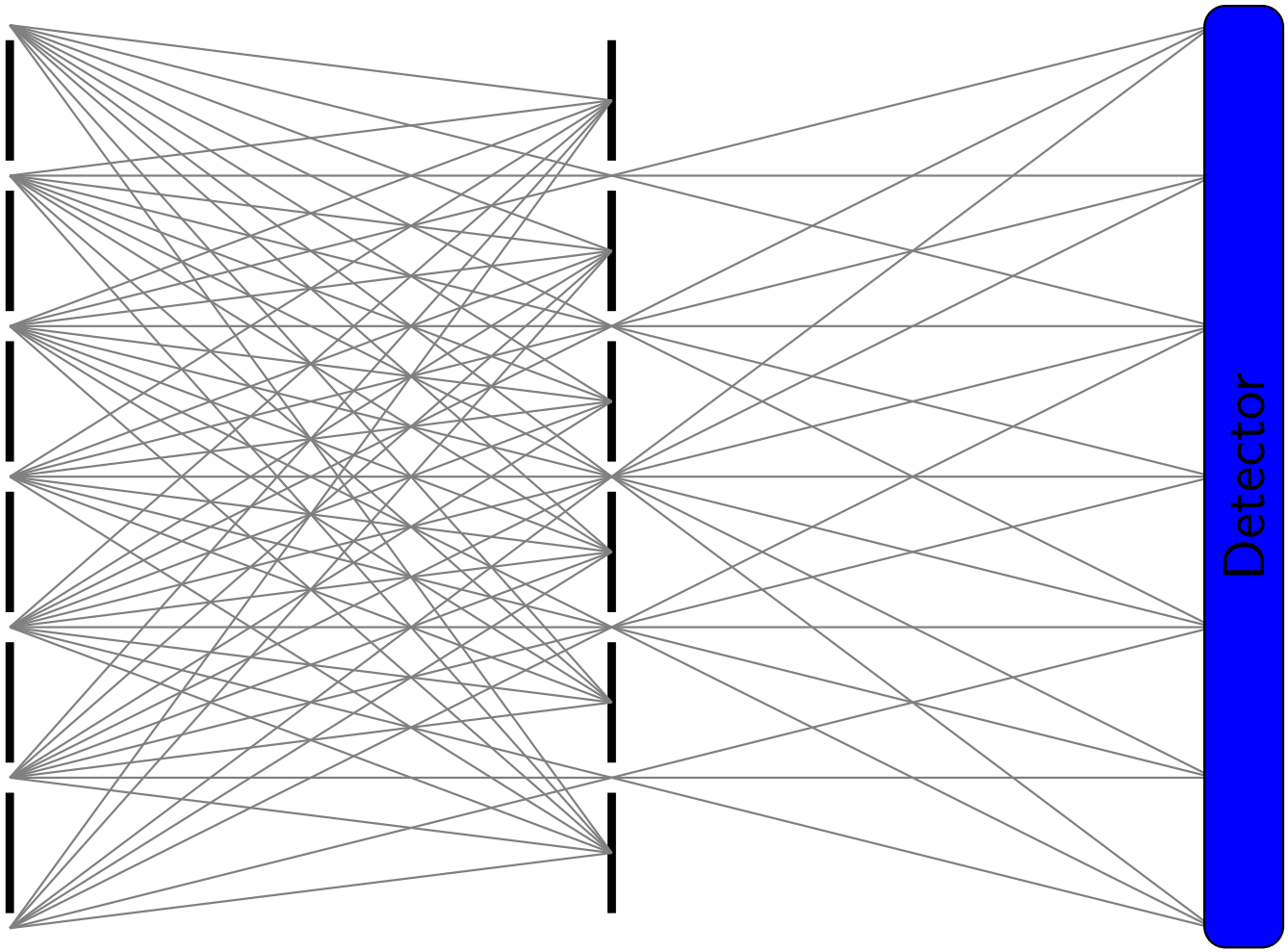

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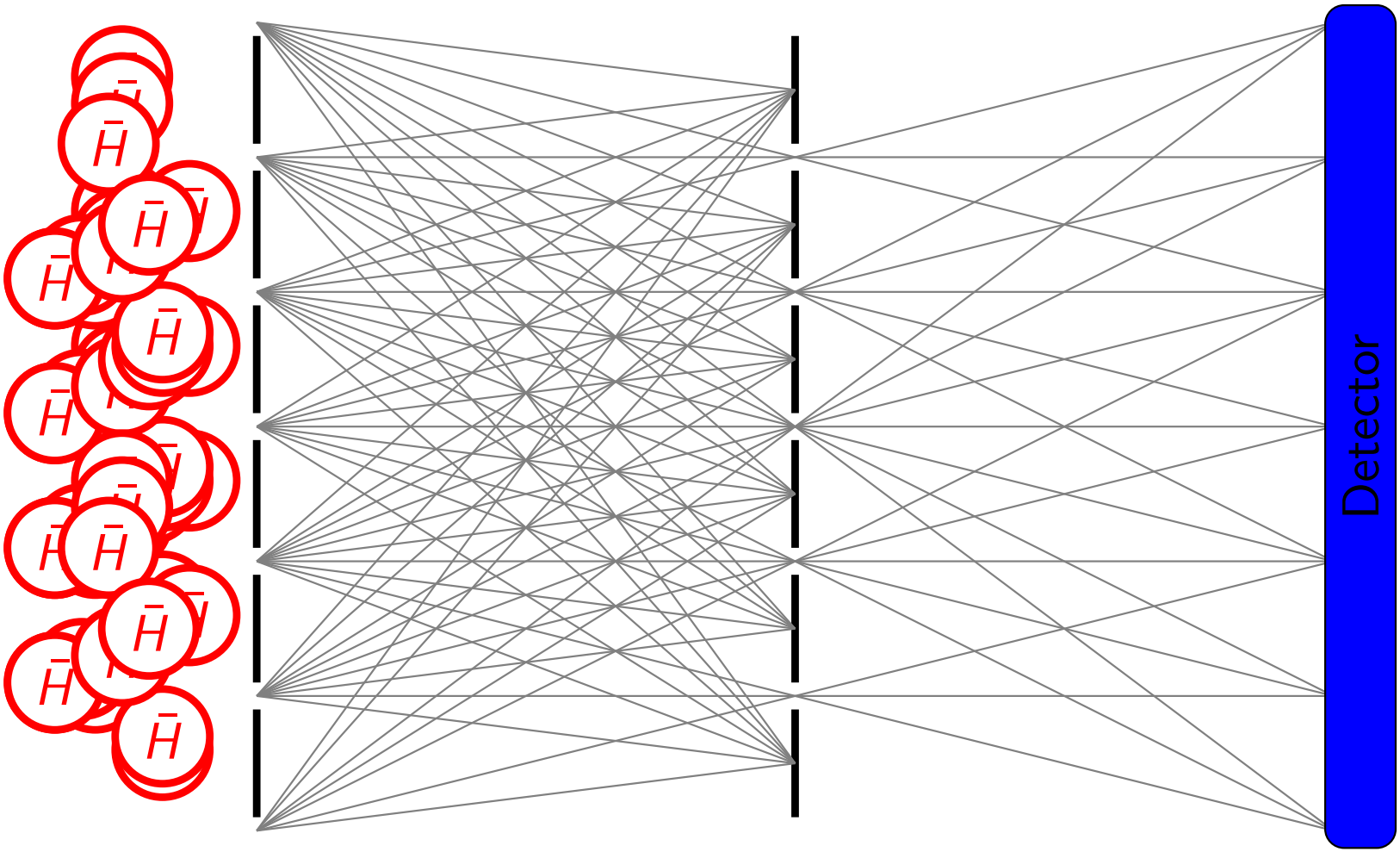

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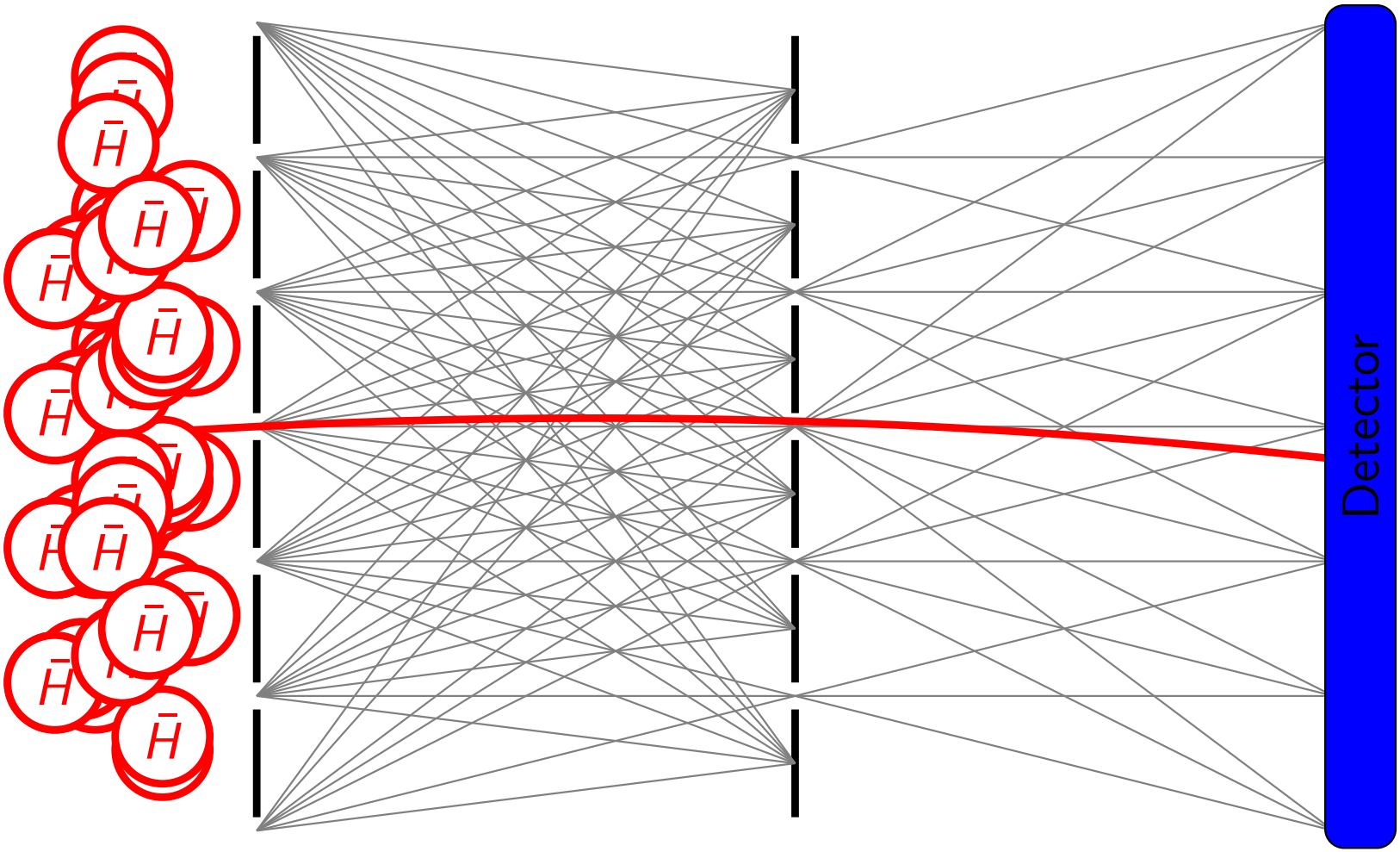

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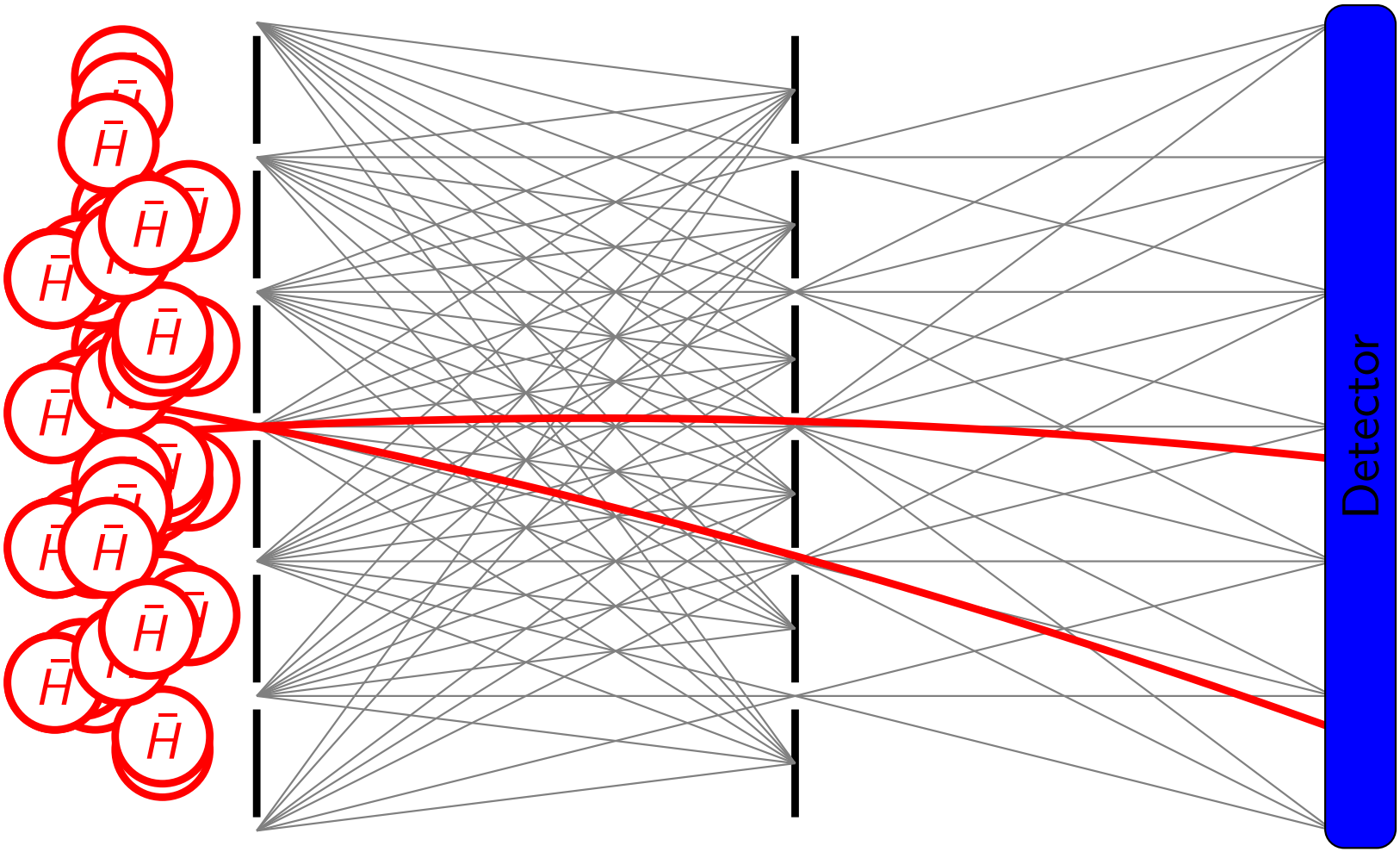

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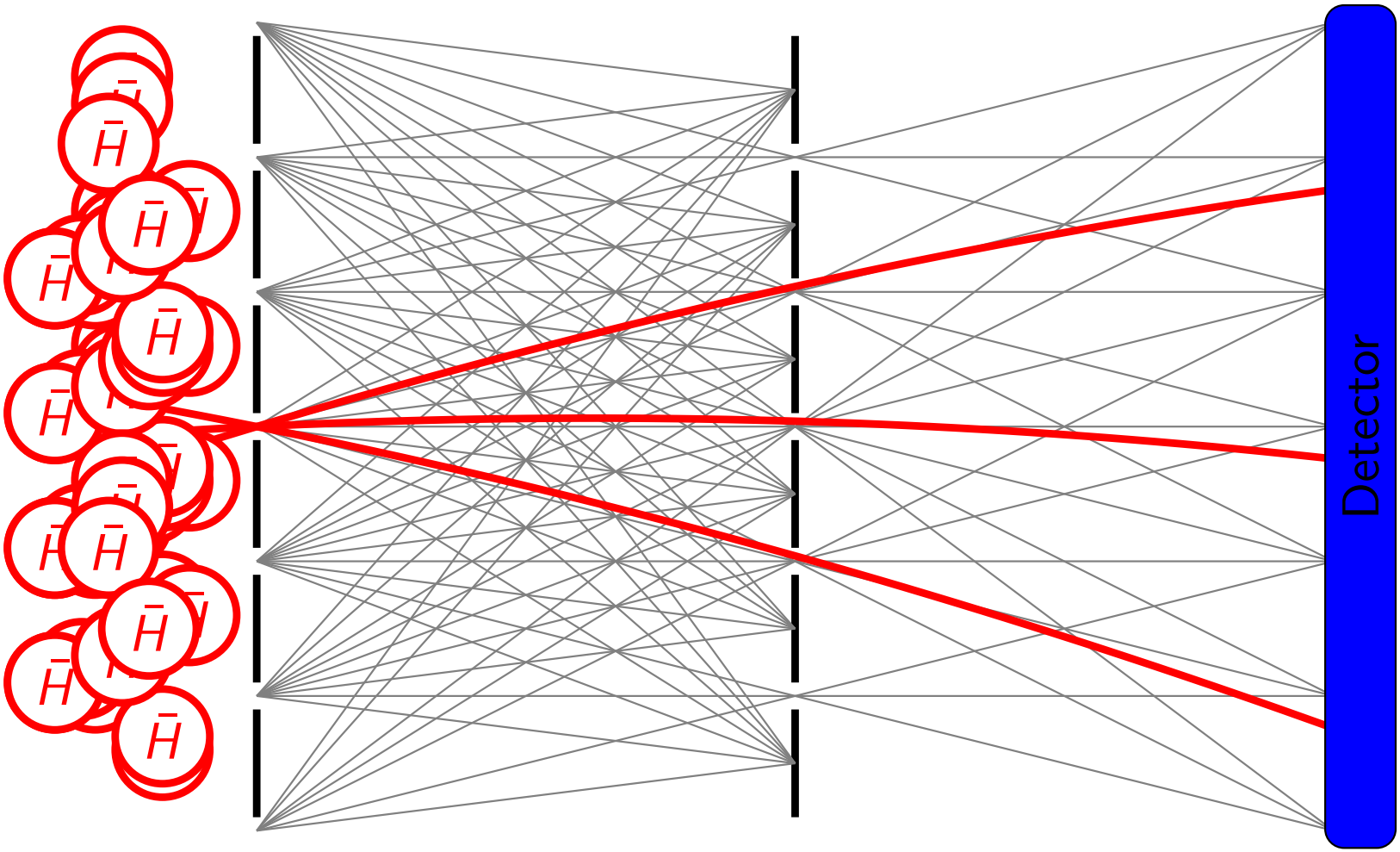

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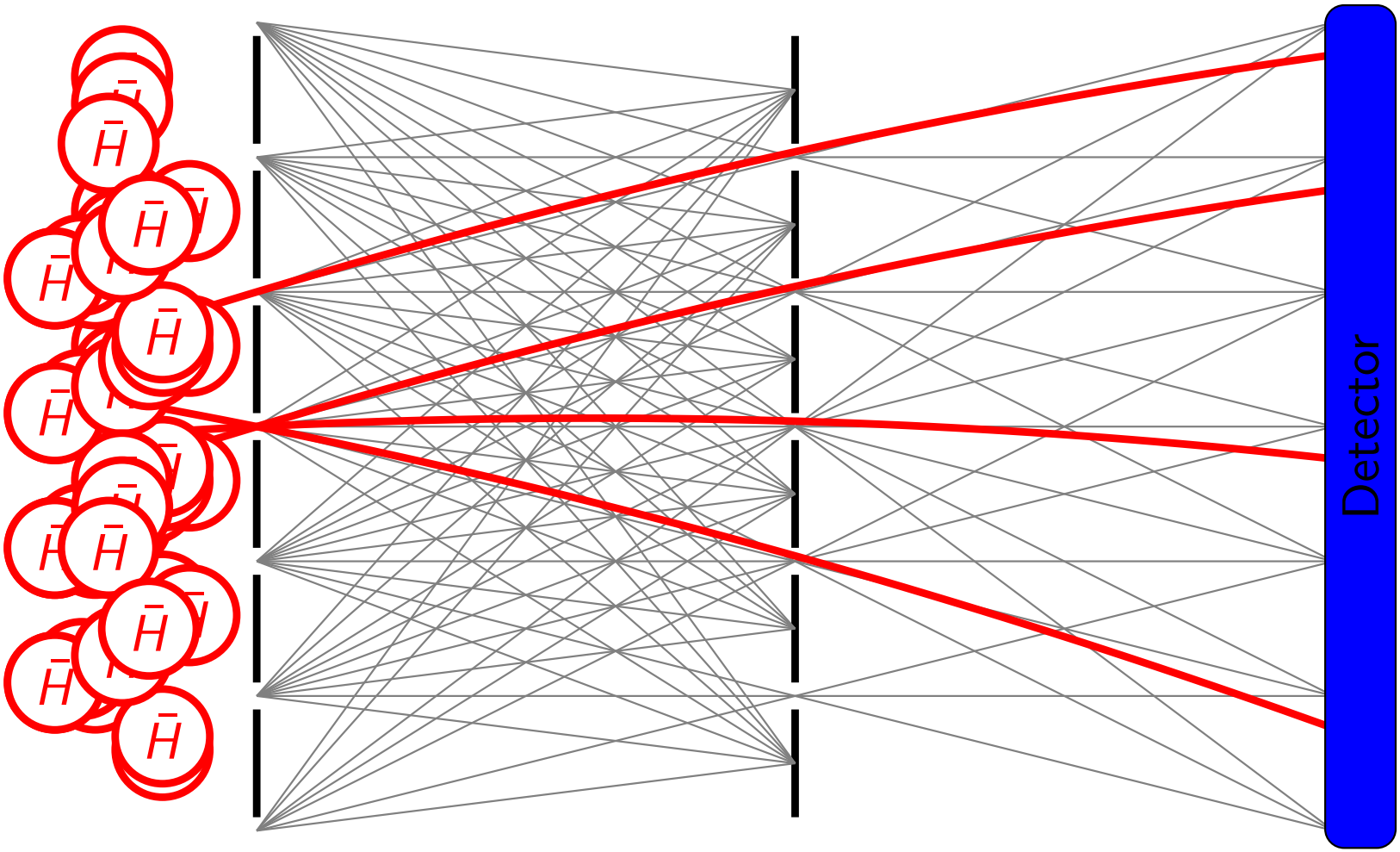

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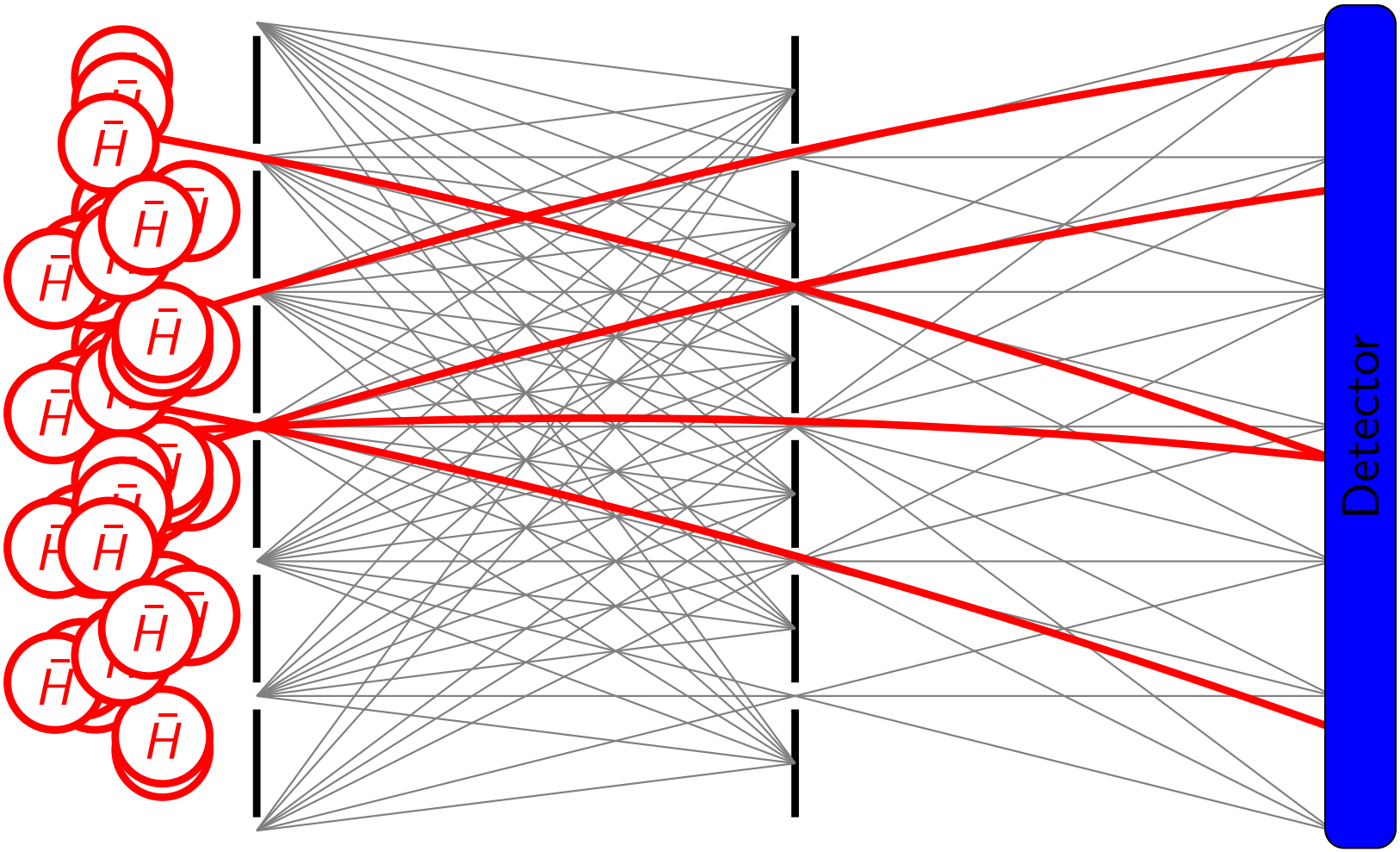

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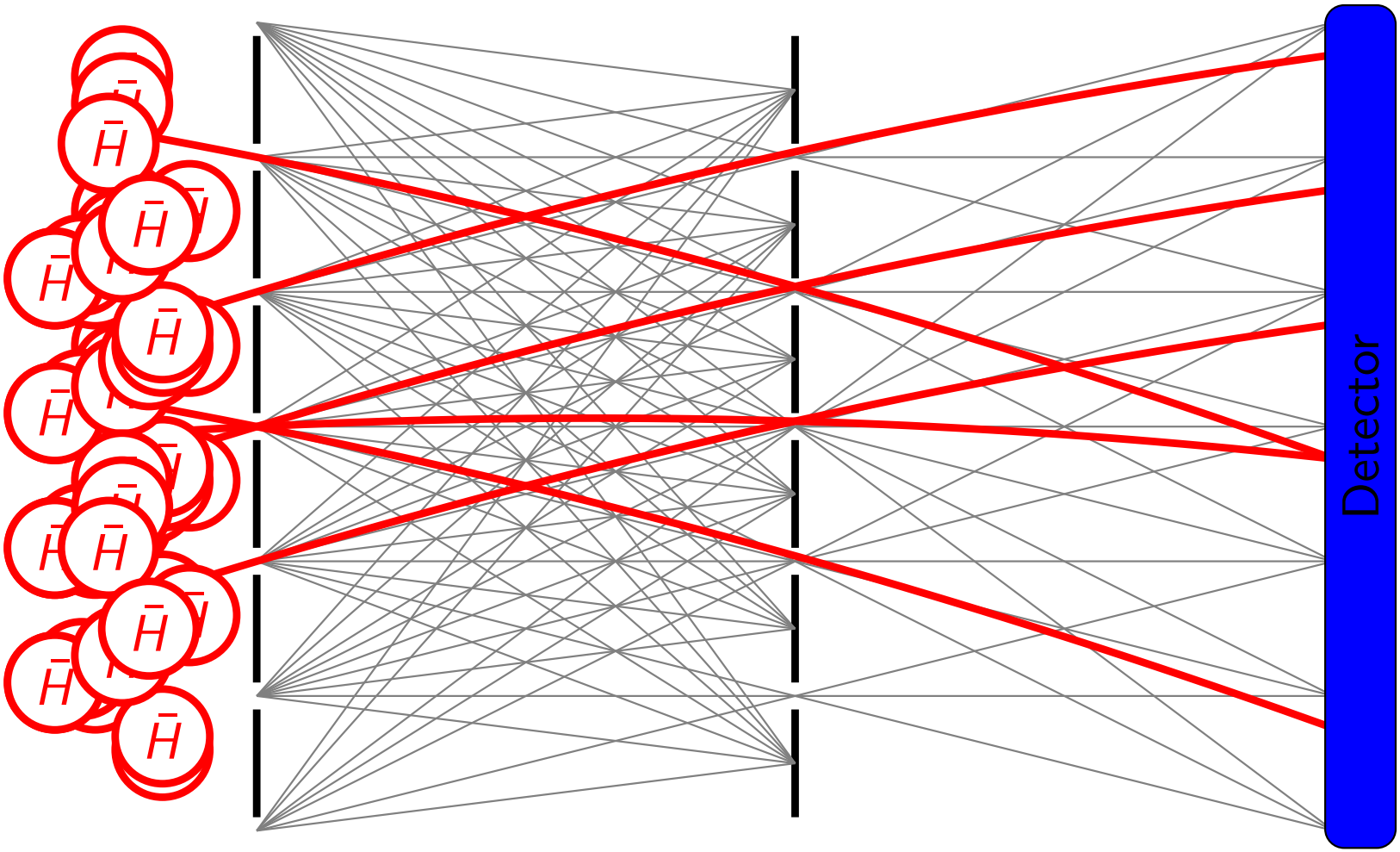

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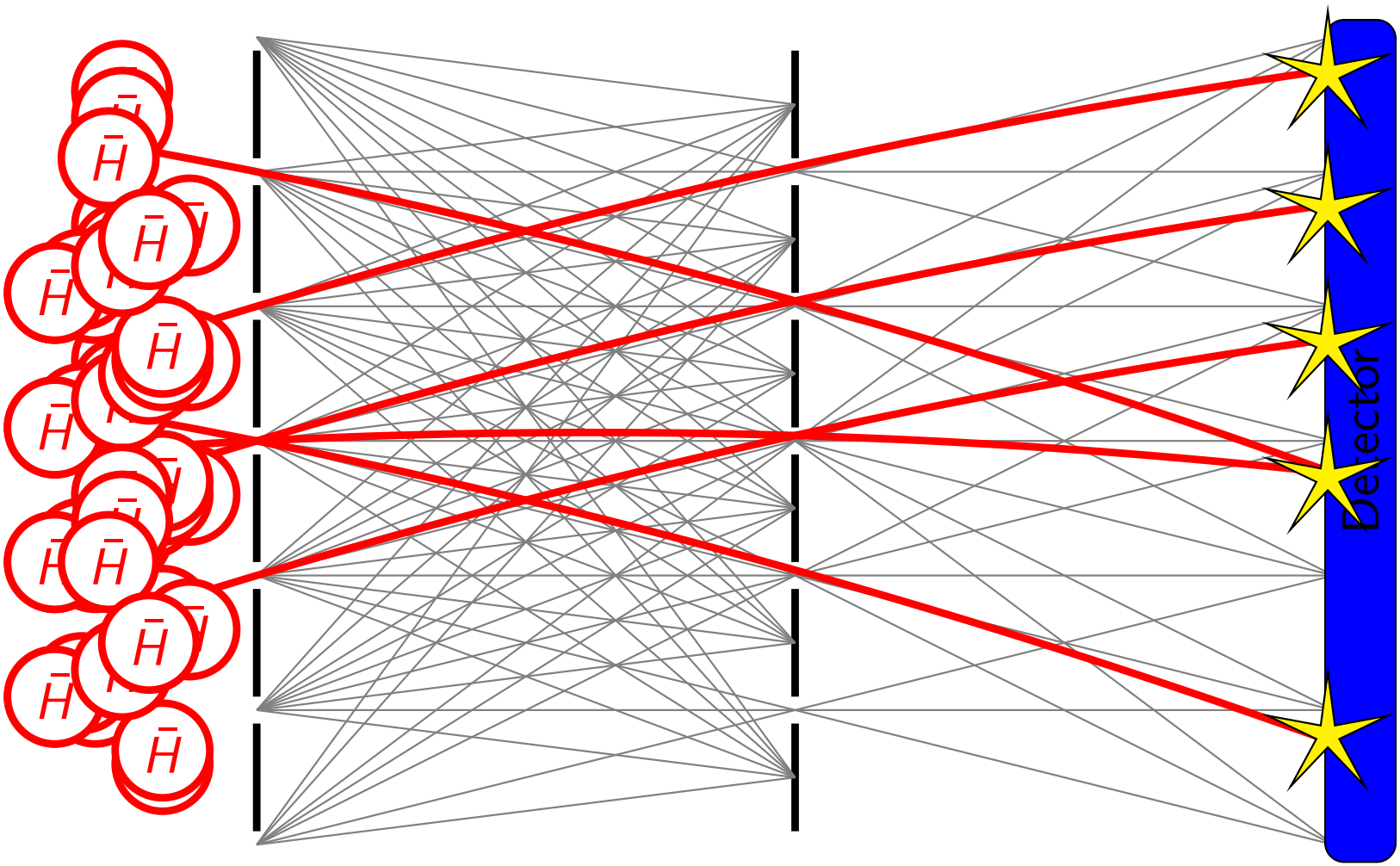

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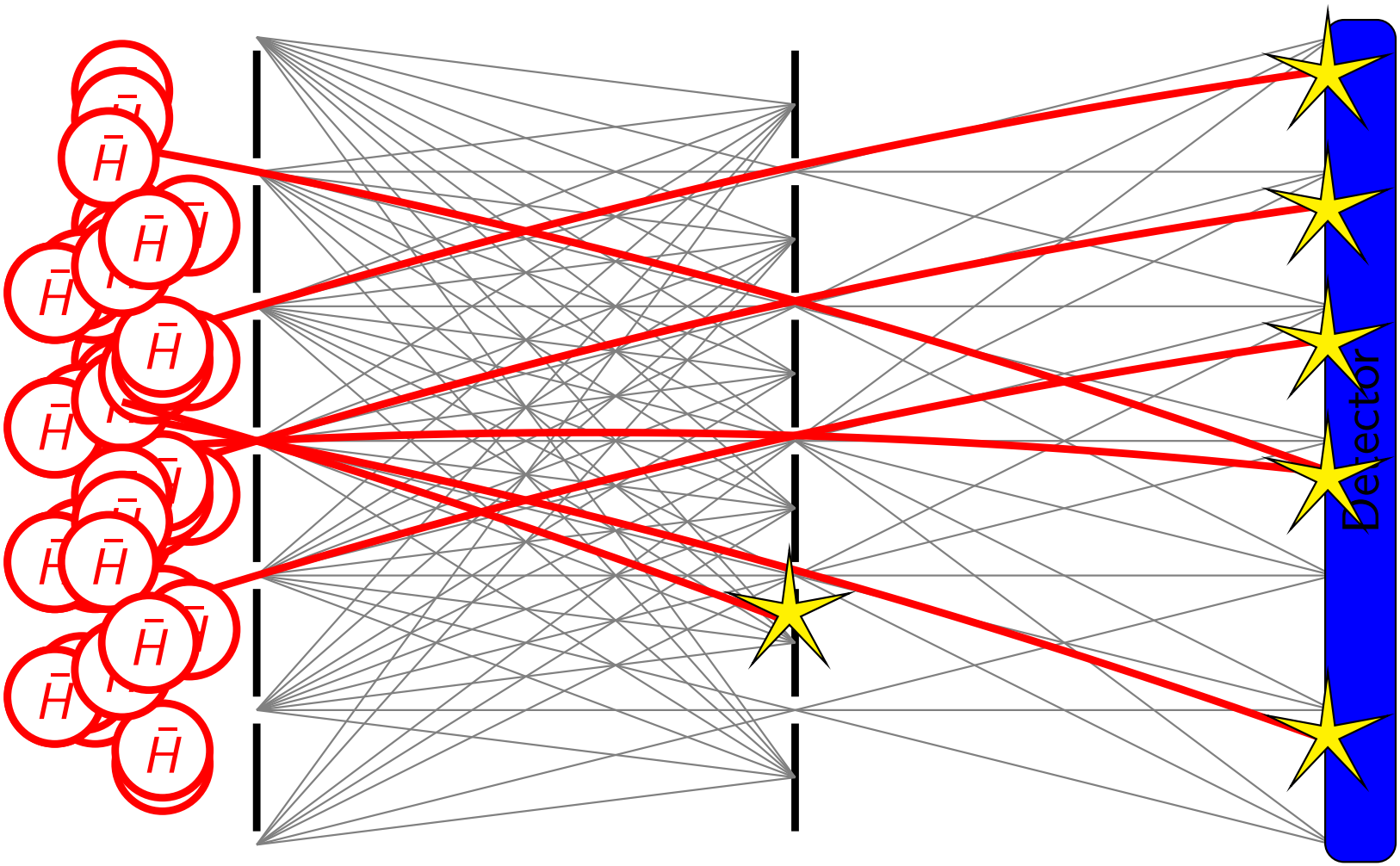

Requirements for the detector

- Tag antihydrogen
  - Fragments from annihilations outside the detector
- Measure time of flight
  - Energy of antihydrogen beam will not be completely uniform
  - Transit time through the moirè deflectometer is around 2ms
- Reconstruct the annihilation point
  - The periodicity of the moire deflectometer is around 50 μm
  - Vertical fall around 10 μm
  - Around 10 μm resolution needed to achieve 1% precision on $\bar{g}$
- Does a detector fulfilling these requirements already exist?

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Silicon pixel detector using the Timepix3 readout system

- 55 μm$\times$55 μm pixels
- Measure both time of arrival and deposited energy
- Time resolution 1–2 ns
- 670 μm thick
- Expose the Timepix3 detector to antiprotons as the annihilation process is the same

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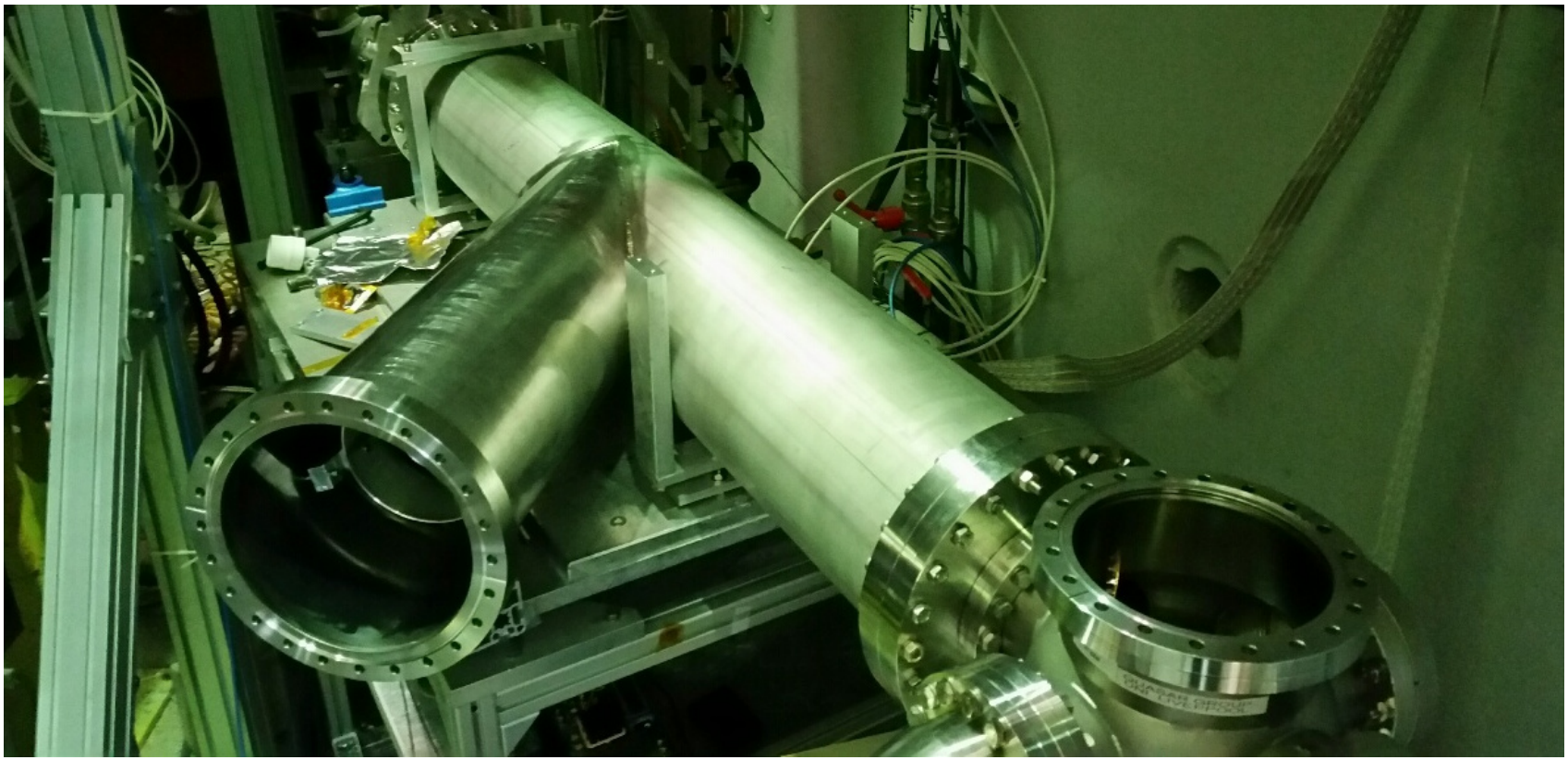
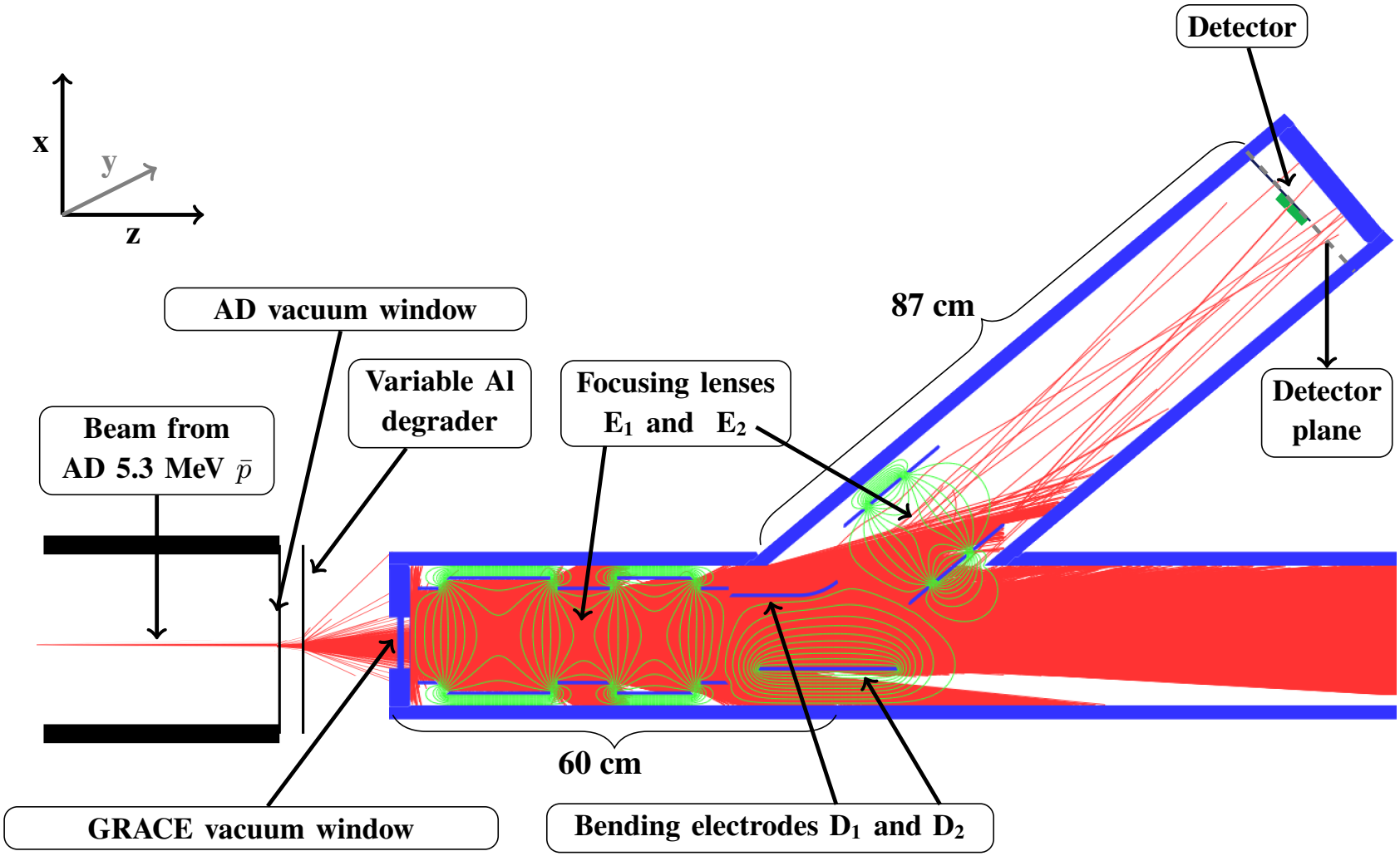
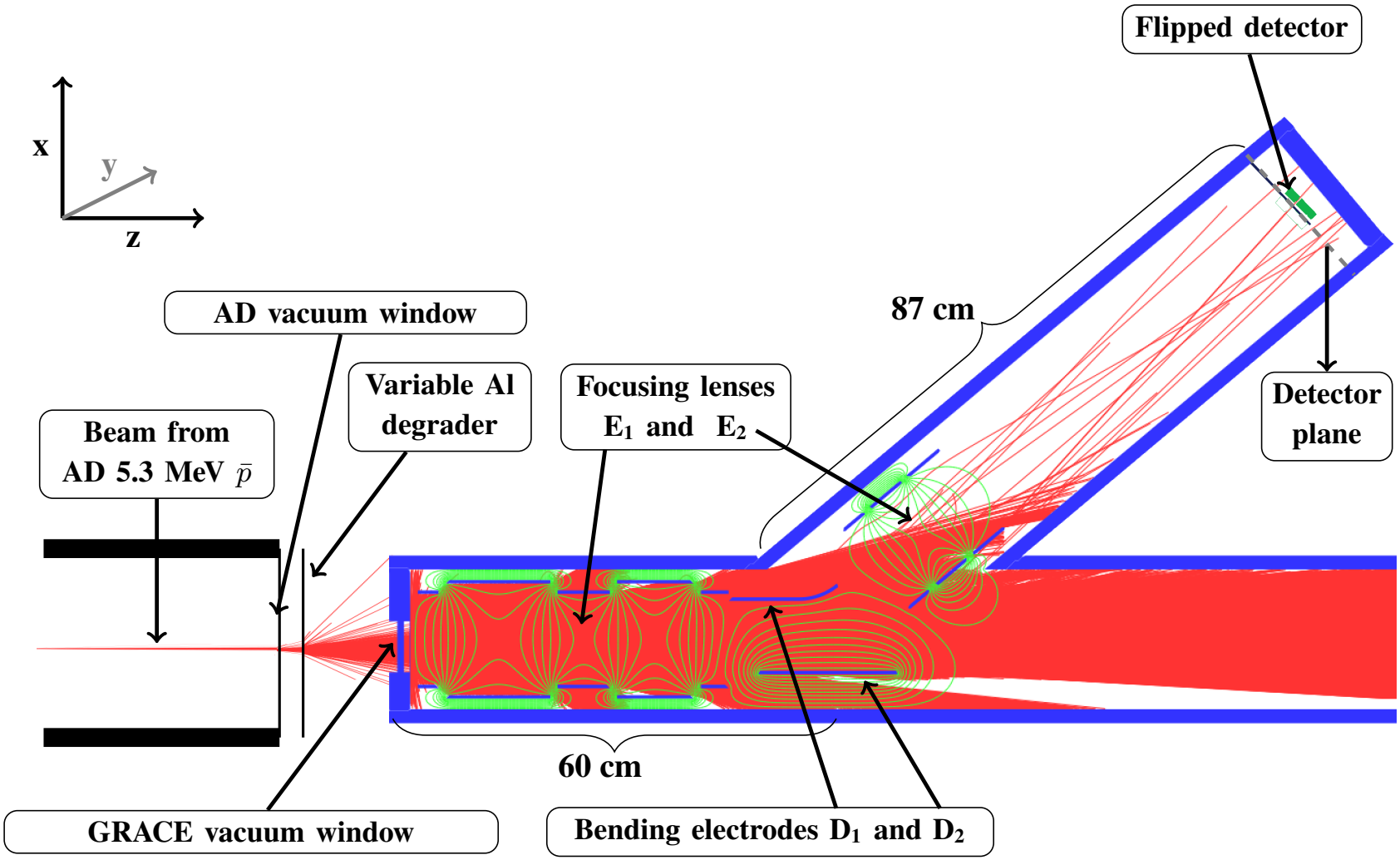
GRACE beamline



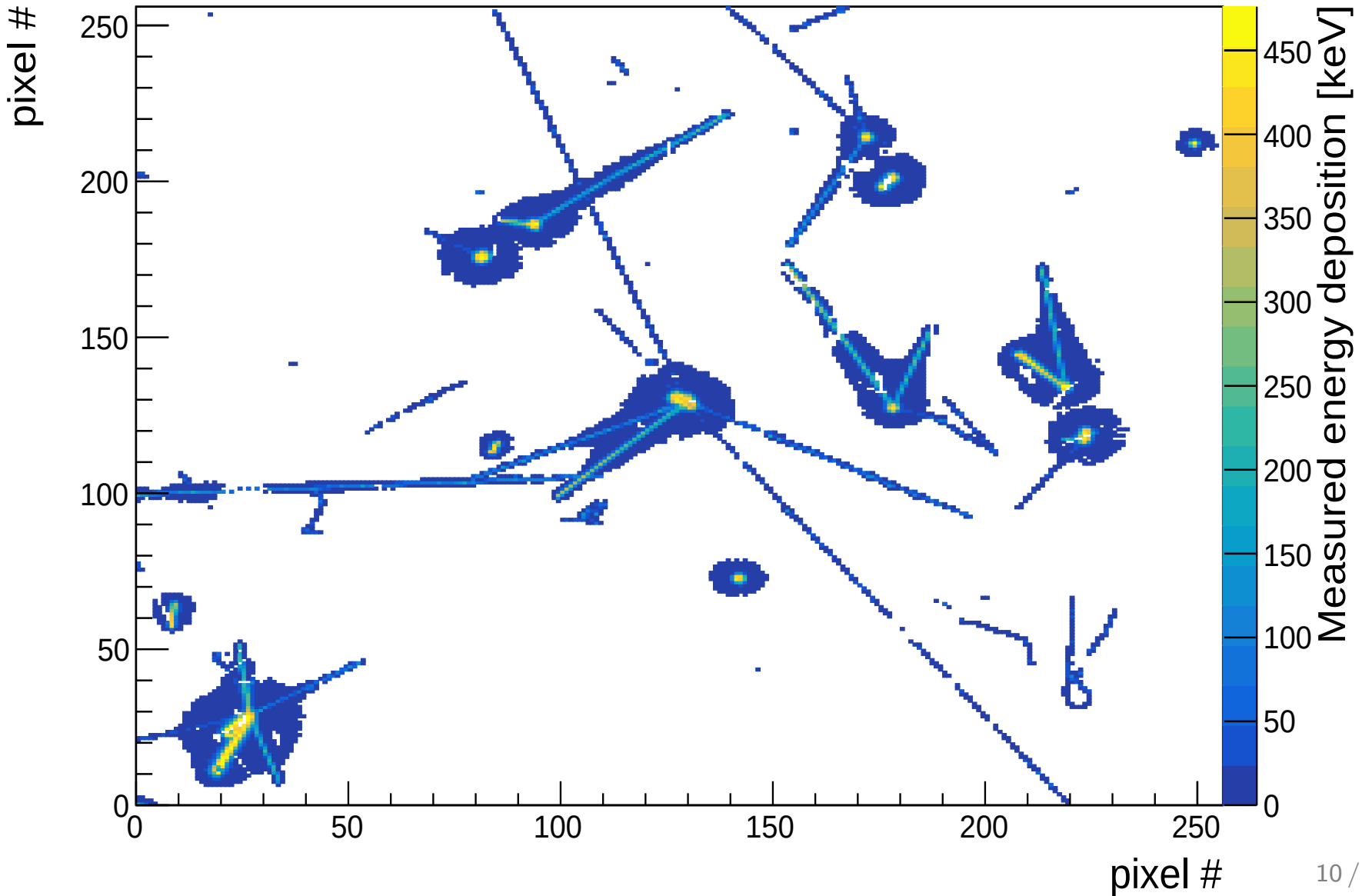
GRACE in standard setting



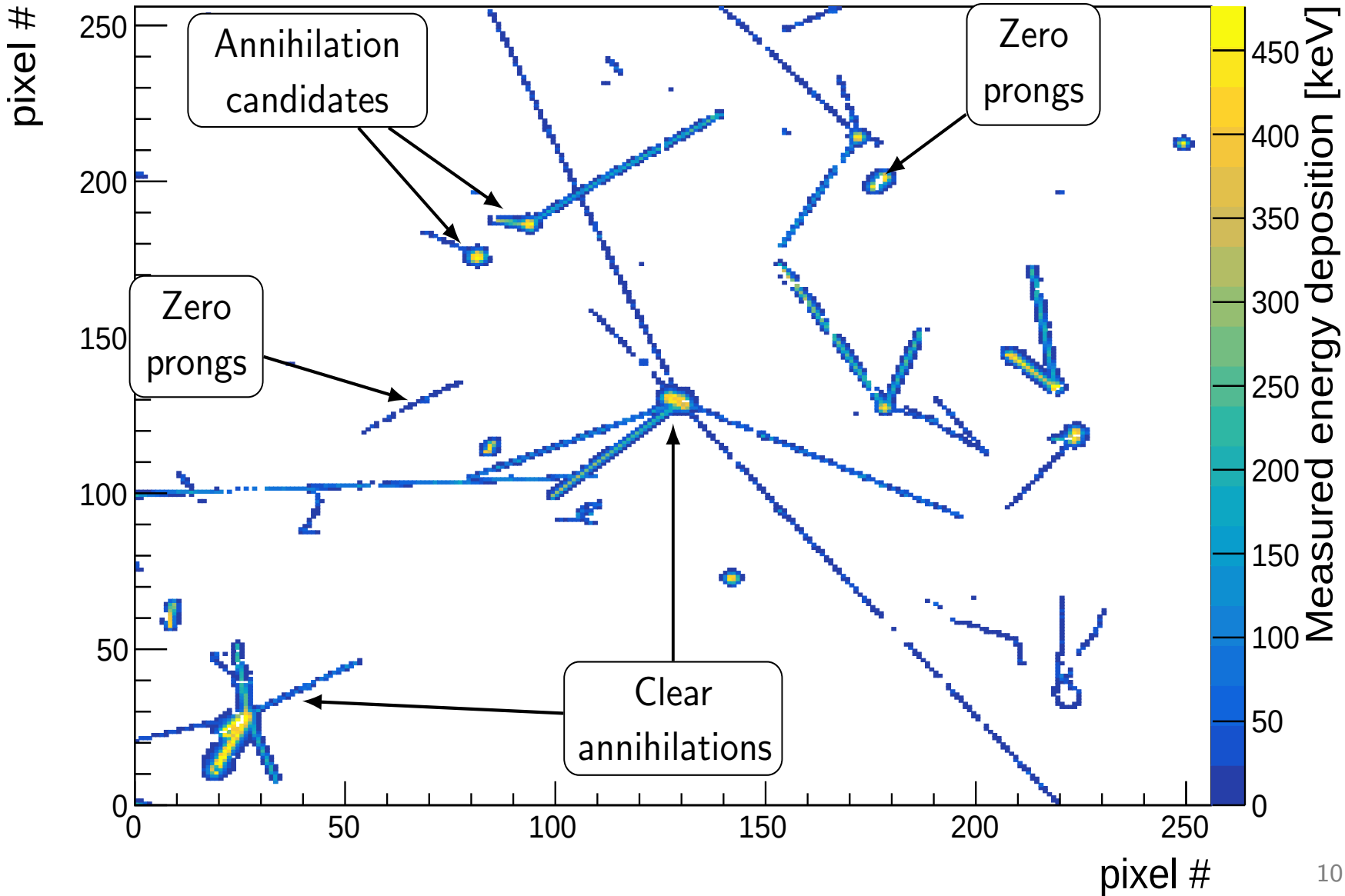
GRACE for reference sample

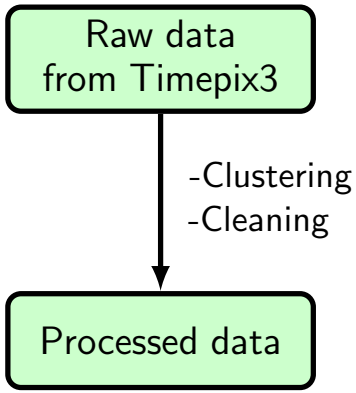


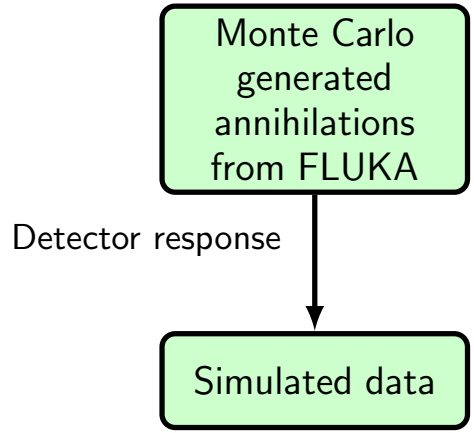
Antiproton data

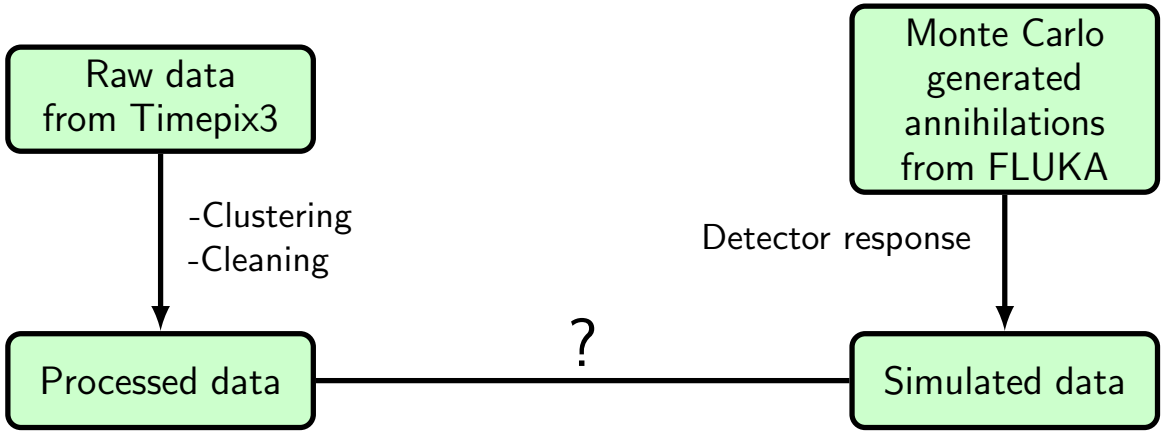


Antiproton data




Raw data
from Timepix3
-Clustering
-Cleaning
Processed data


Monte Carlo
generated
annihilations
from FLUKA
Detector response
Simulated data


Raw data
from Timepix3
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?
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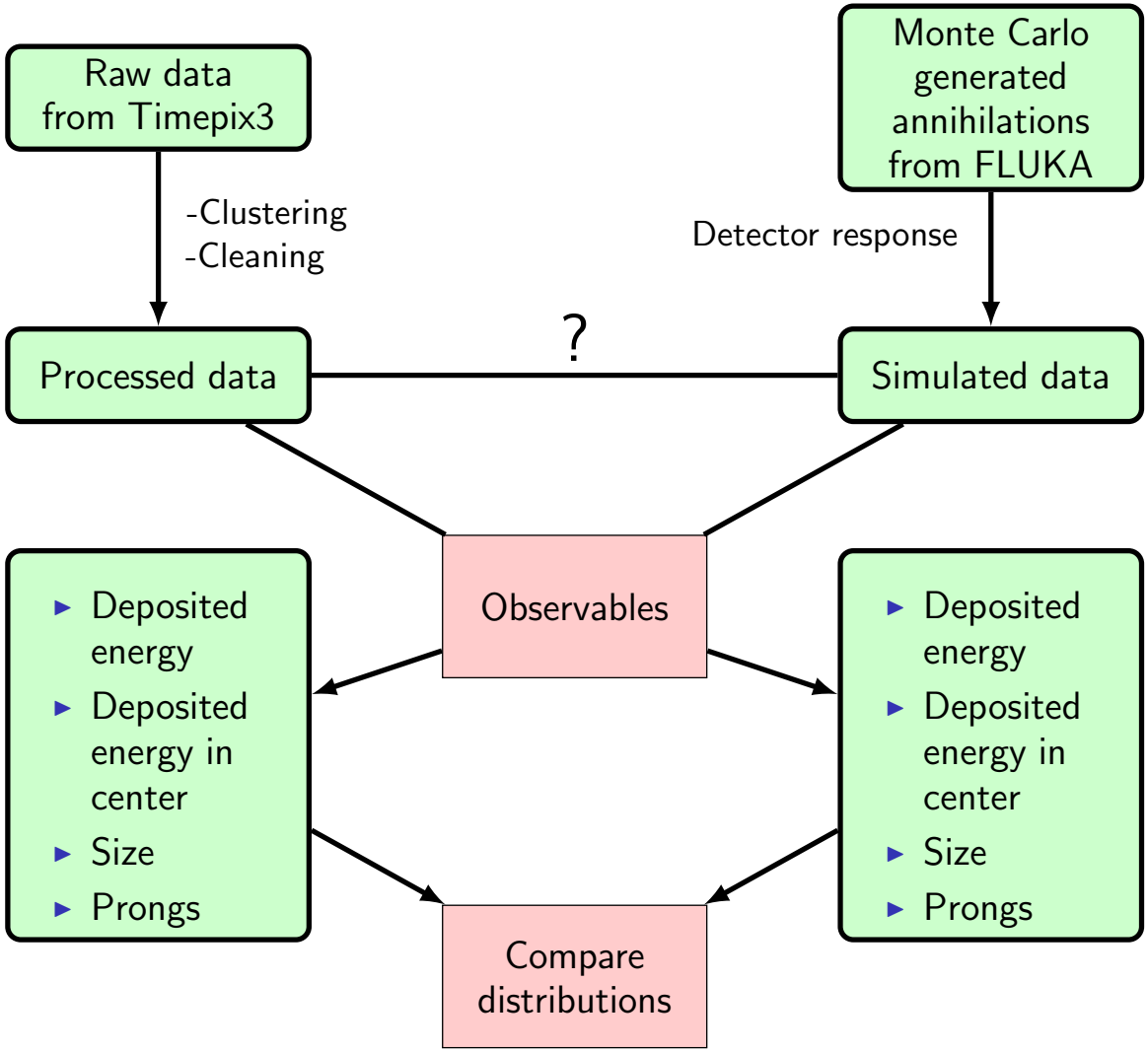
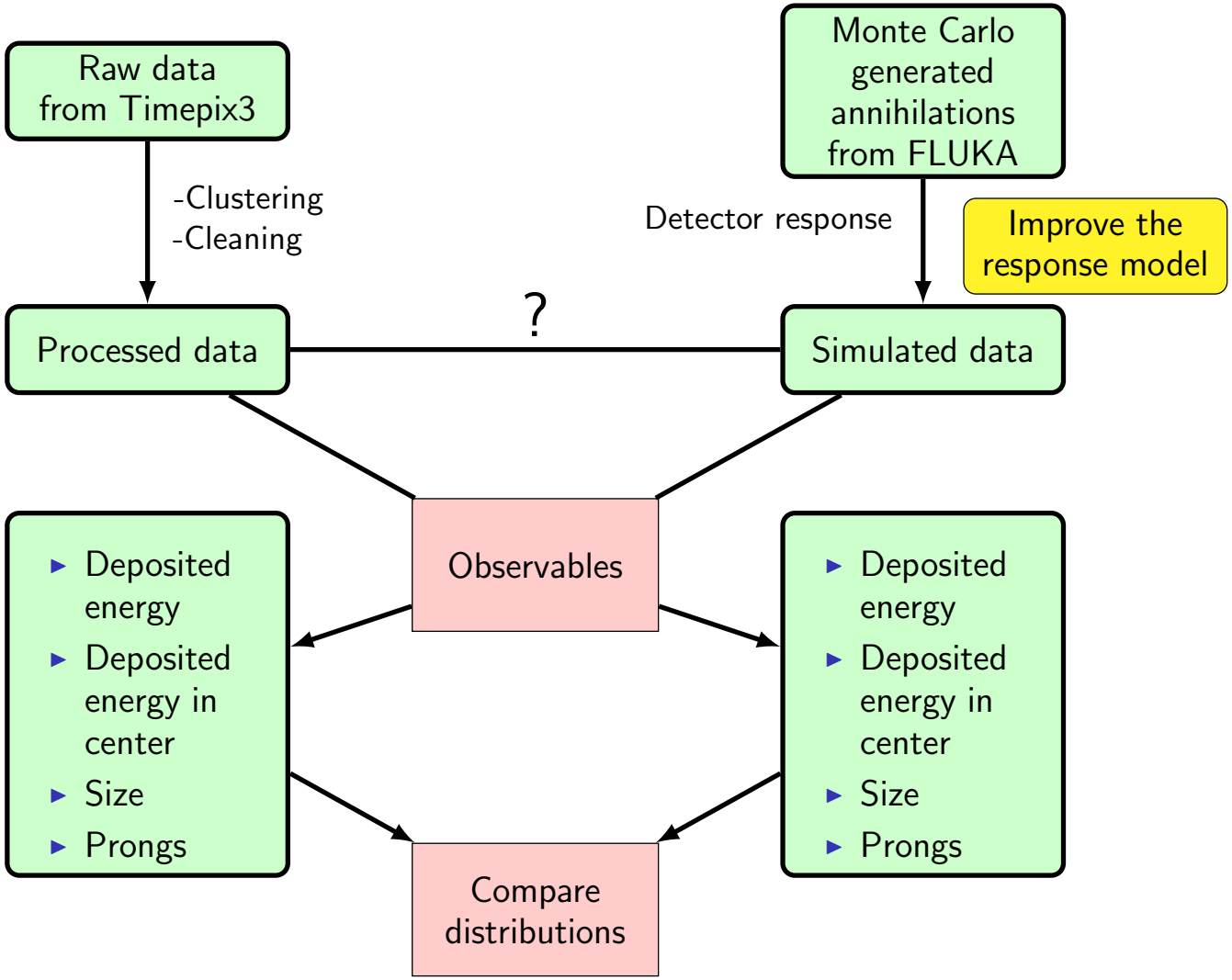
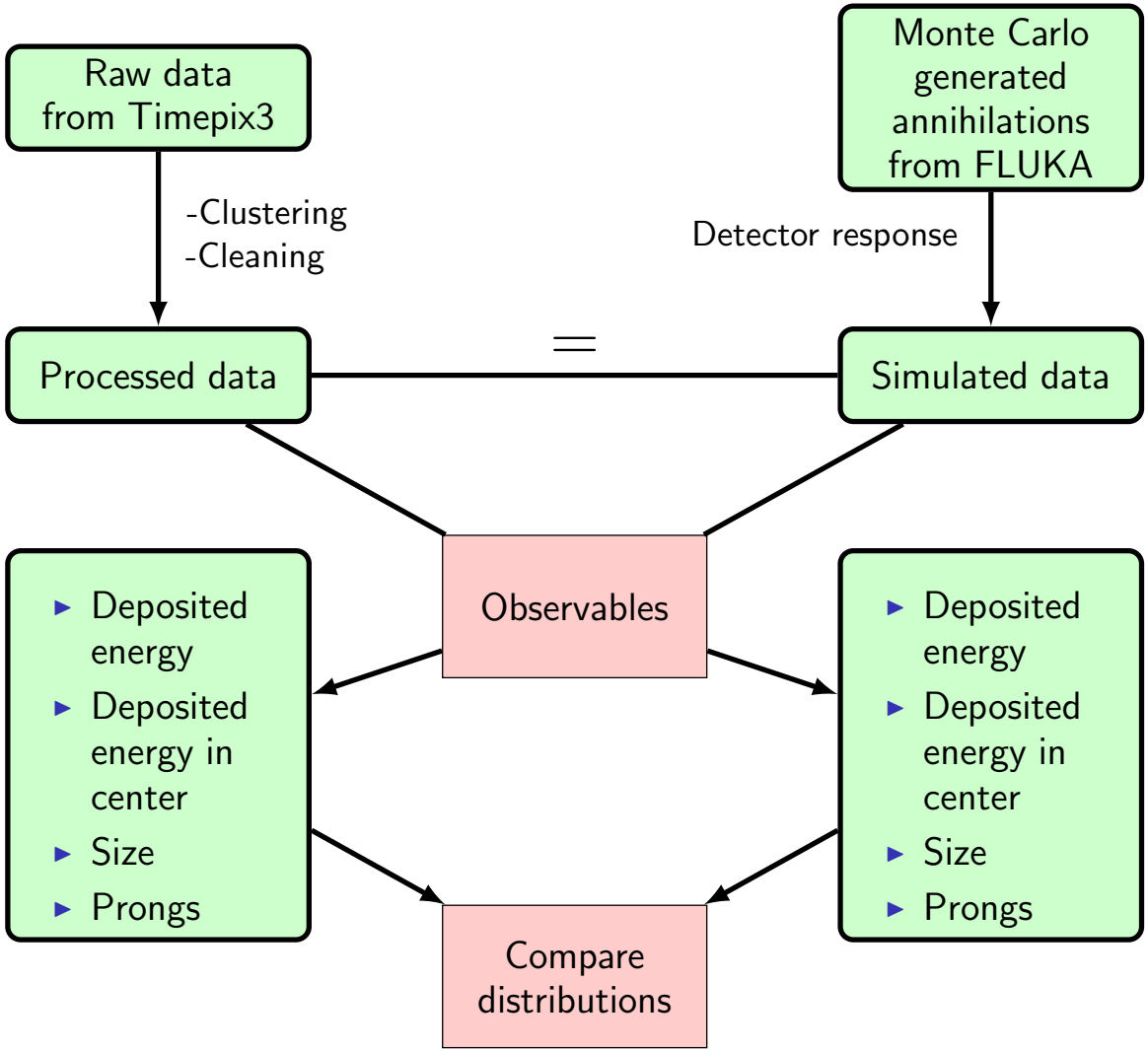

Raw data from Timepix3
Monte Carlo generated annihilations from FLUKA
-Clustering
-Cleaning
Detector response
?
Processed data
Simulated data
Observables
Deposited energy
Deposited energy in center
Size
Prongs
Deposited energy
Deposited energy in center
Size
Prongs
Compare distributions


Raw data from Timepix3
-Clustering
-Cleaning
Monte Carlo generated annihilations from FLUKA
Detector response
Improve the response model
Processed data
?
Simulated data
Observables
Deposited energy
Deposited energy in center
Size
Prongs
Deposited energy
Deposited energy in center
Size
Prongs
Compare distributions


Raw data from Timepix3
Monte Carlo generated annihilations from FLUKA
-Clustering
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Detector response
Processed data
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Simulated data
Observables
Deposited energy
Deposited energy in center
Size
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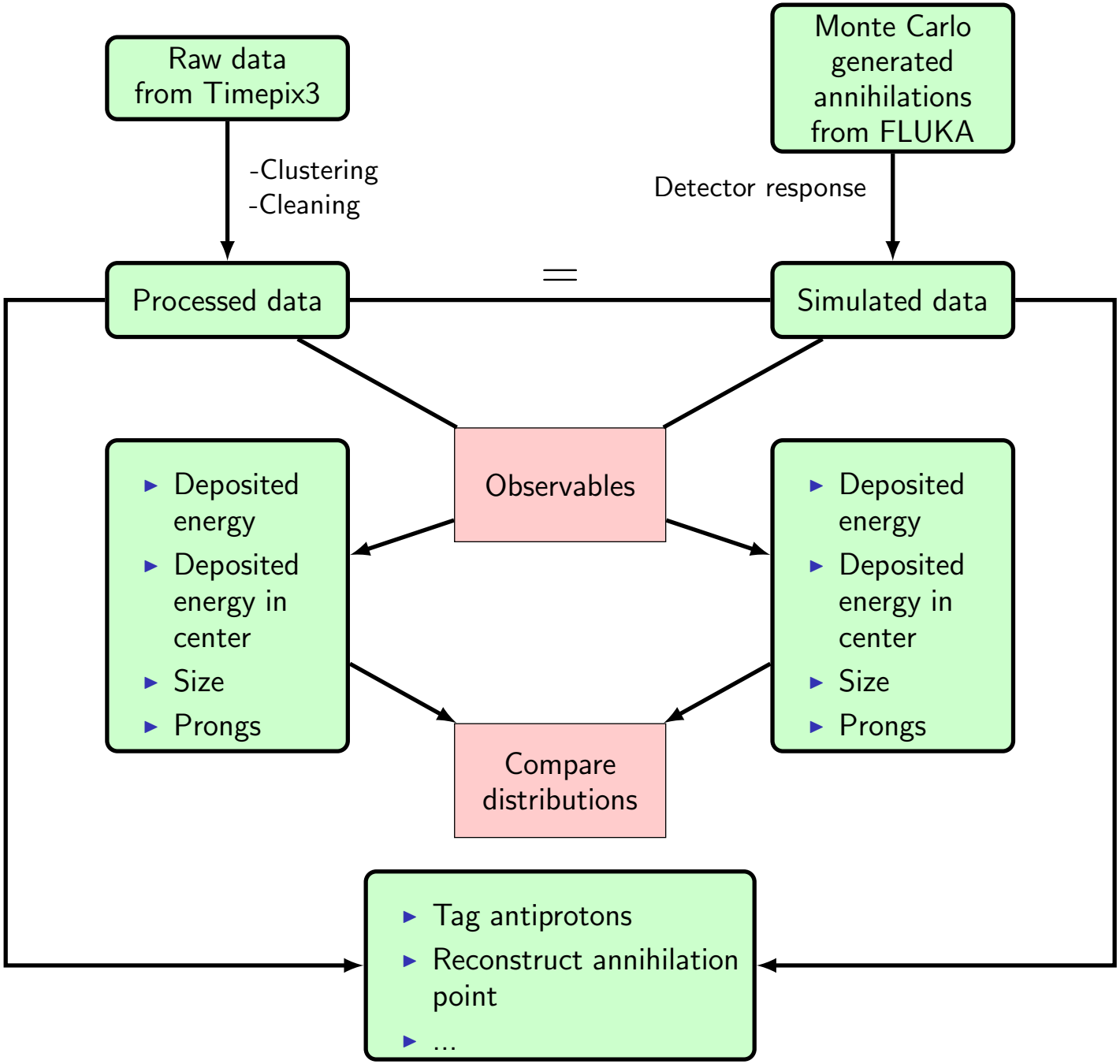
Raw data from Timepix3
Monte Carlo generated annihilations from FLUKA
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Detector response
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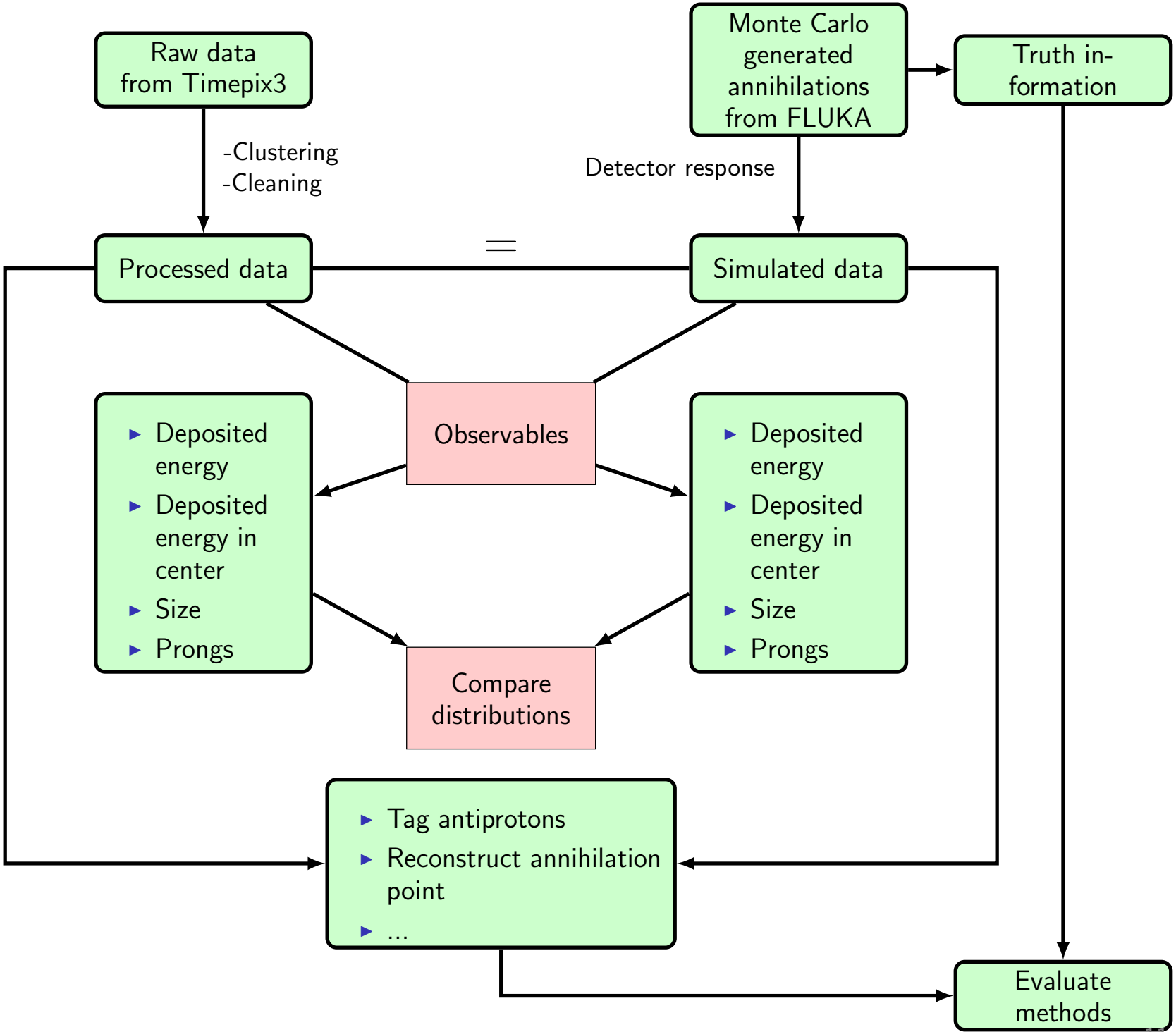
Simulated data
Observables
Deposited energy
Deposited energy in center
Size
Prongs
Deposited energy
Deposited energy in center
Size
Prongs
Compare distributions
Tag antiprotons
Reconstruct annihilation point
...


Raw data from Timepix3
Monte Carlo generated annihilations from FLUKA
Truth information
-Clustering
-Cleaning
Detector response
Processed data
=
Simulated data
Observables
Deposited energy
Deposited energy in center
Size
Prongs
Deposited energy
Deposited energy in center
Size
Prongs
Compare distributions
Tag antiprotons
Reconstruct annihilation point
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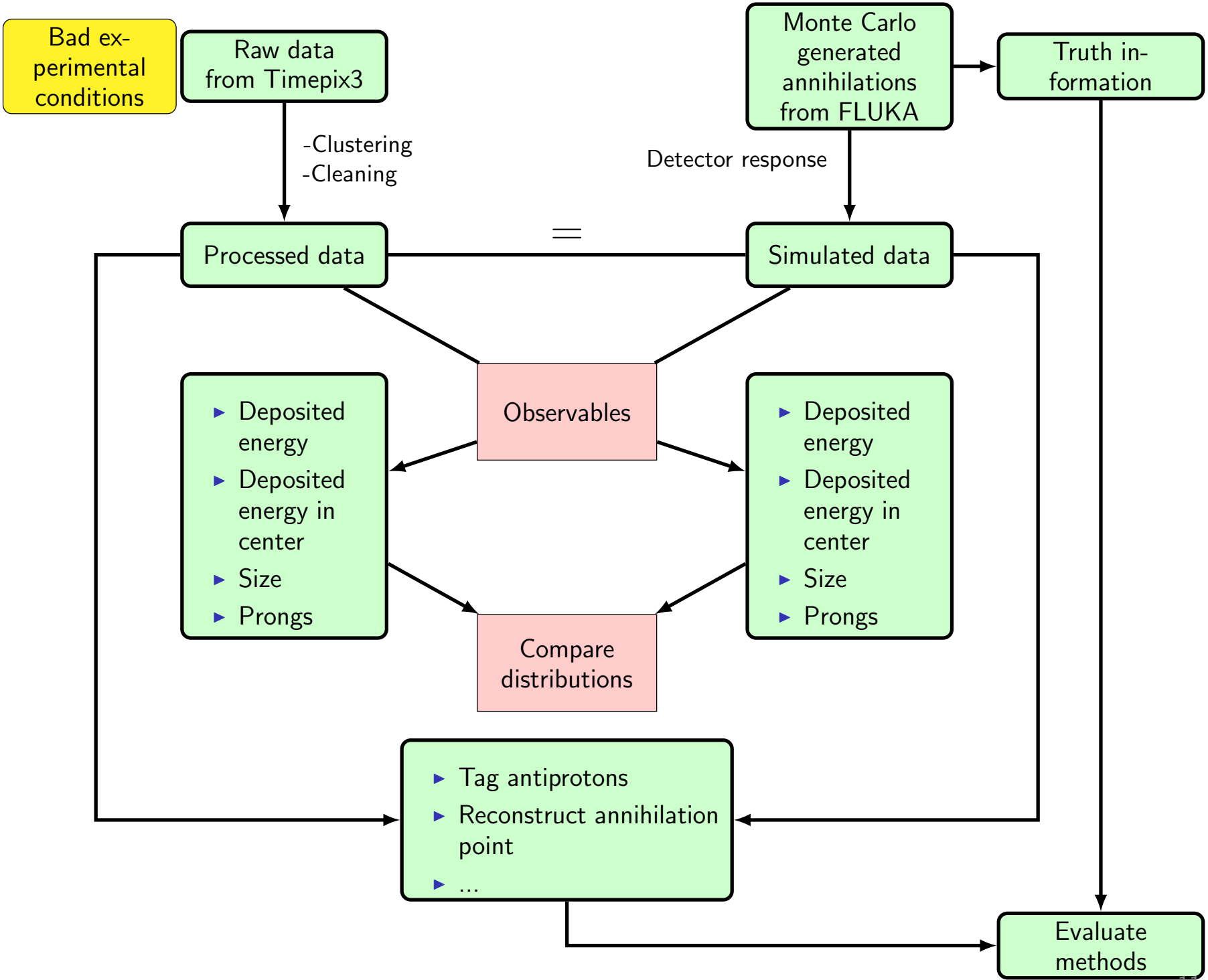
Evaluate methods


Bad experimental conditions
Raw data from Timepix3
-Clustering
-Cleaning
Monte Carlo generated annihilations from FLUKA
Truth information
Detector response
Processed data
=
Simulated data
Observables
Deposited energy
Deposited energy in center
Size
Prongs
Deposited energy
Deposited energy in center
Size
Prongs
Compare distributions
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Reconstruct annihilation point
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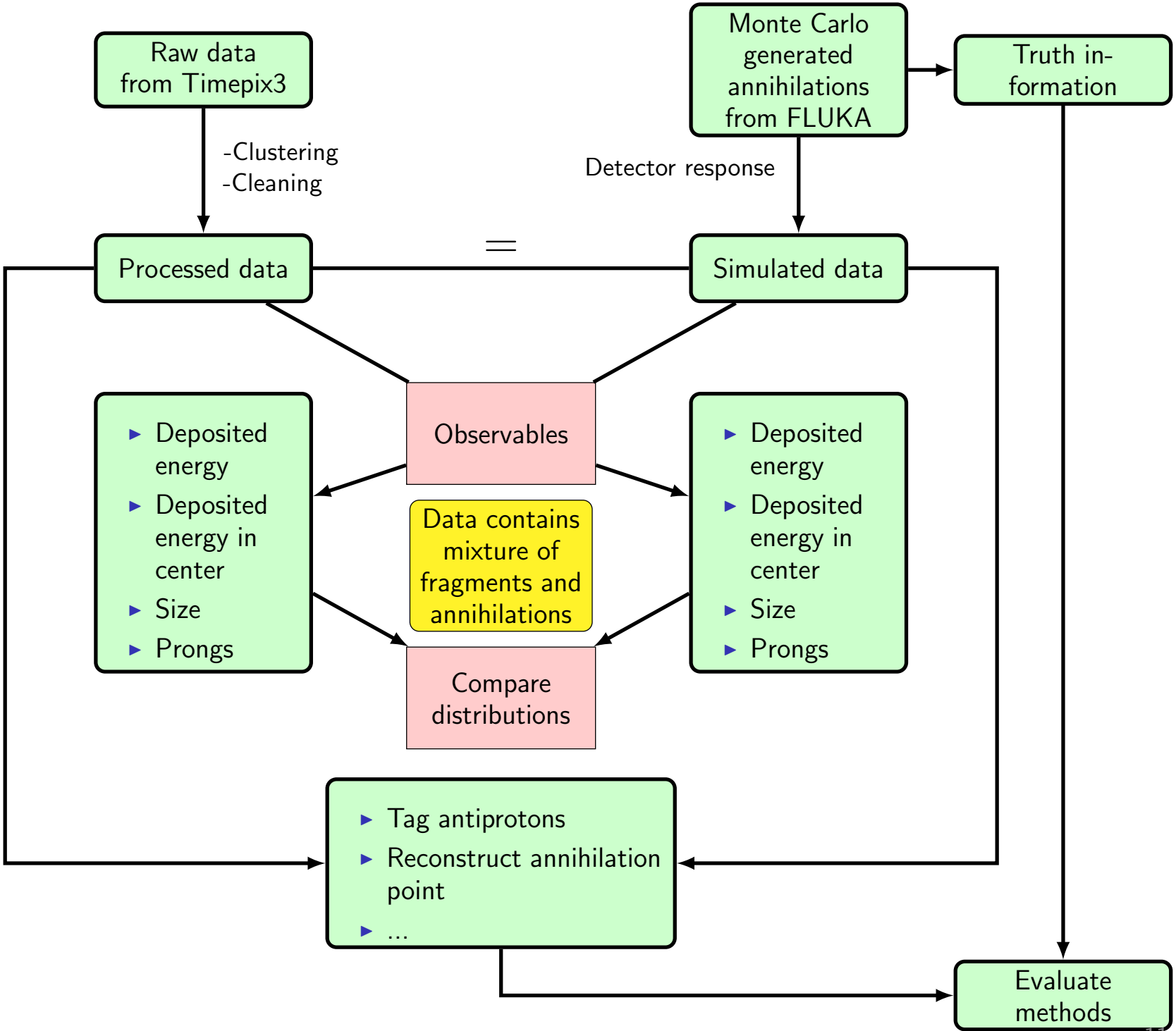
Evaluate methods


Raw data from Timepix3
-Clustering
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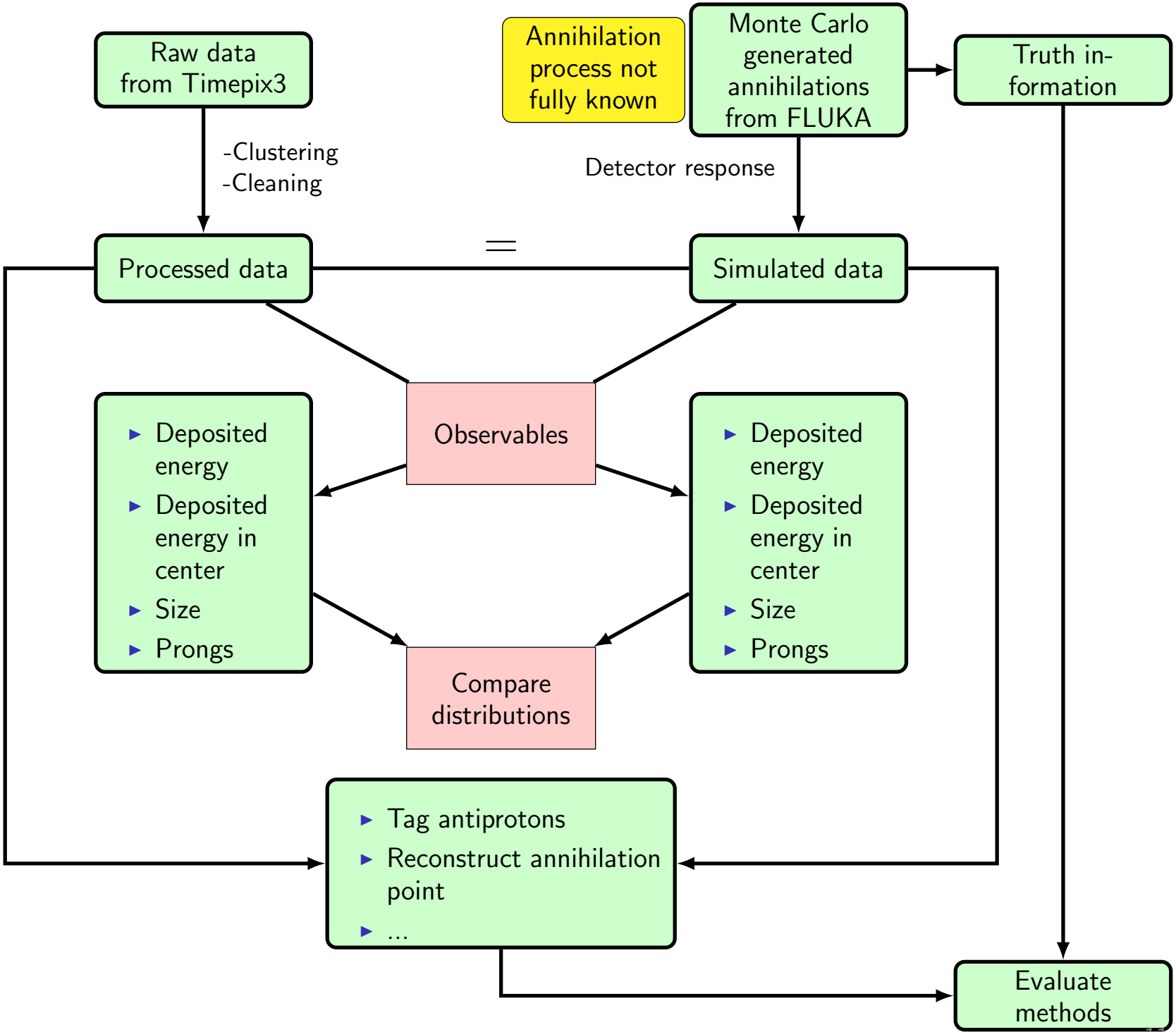
Monte Carlo generated annihilations from FLUKA
Detector response
Truth information
Processed data
=
Simulated data
Observables
Deposited energy
Deposited energy in center
Size
Prongs
Data contains mixture of fragments and annihilations
Deposited energy
Deposited energy in center
Size
Prongs
Compare distributions
Tag antiprotons
Reconstruct annihilation point
...
Evaluate methods


Raw data from Timepix3
-Clustering
-Cleaning
Annihilation process not fully known
Monte Carlo generated annihilations from FLUKA
Truth information
Detector response
Processed data
=
Simulated data
Observables
Deposited energy
Deposited energy in center
Size
Prongs
Deposited energy
Deposited energy in center
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Prongs
Compare distributions
Tag antiprotons
Reconstruct annihilation point
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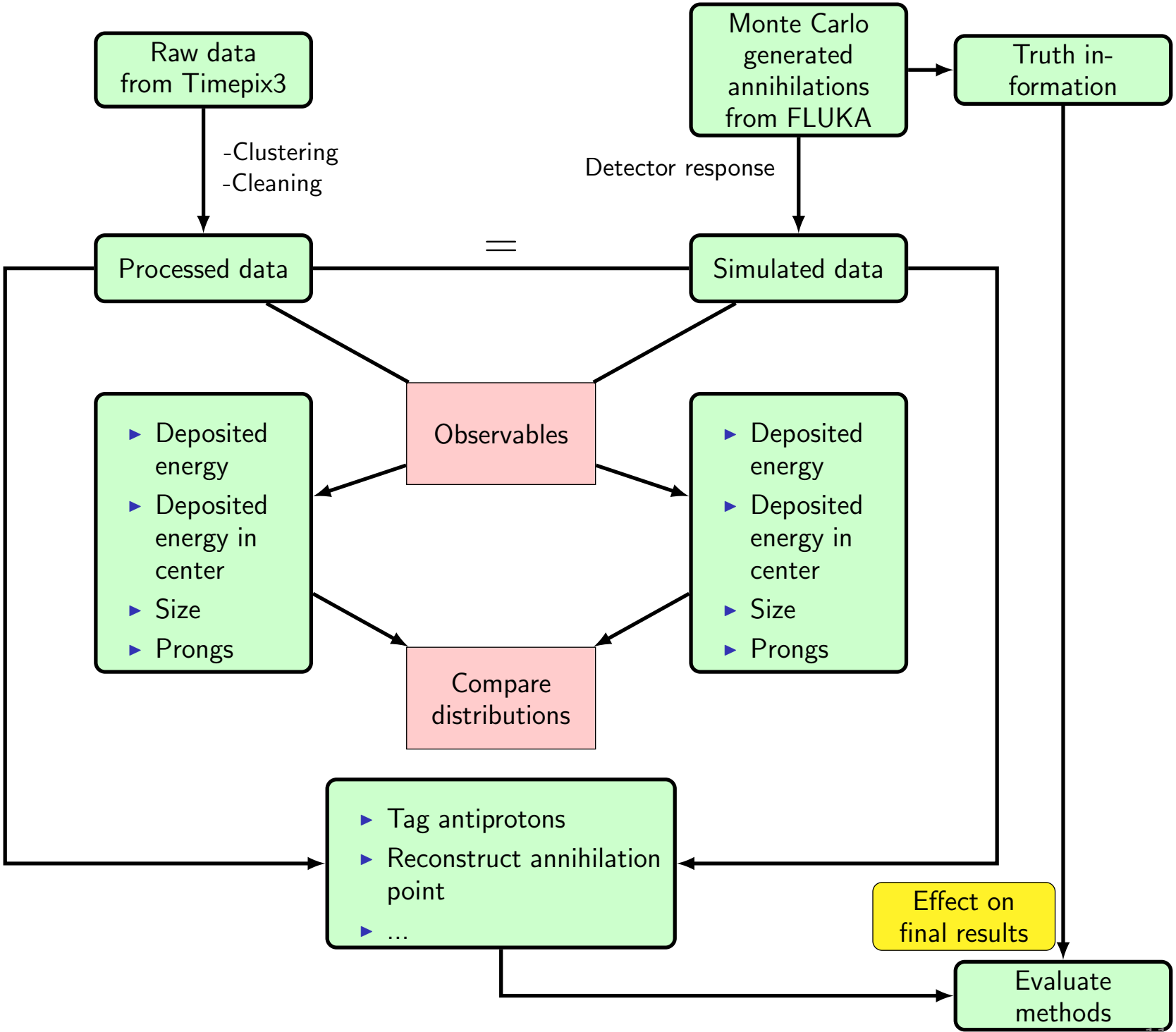
Raw data from Timepix3
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Compare distributions
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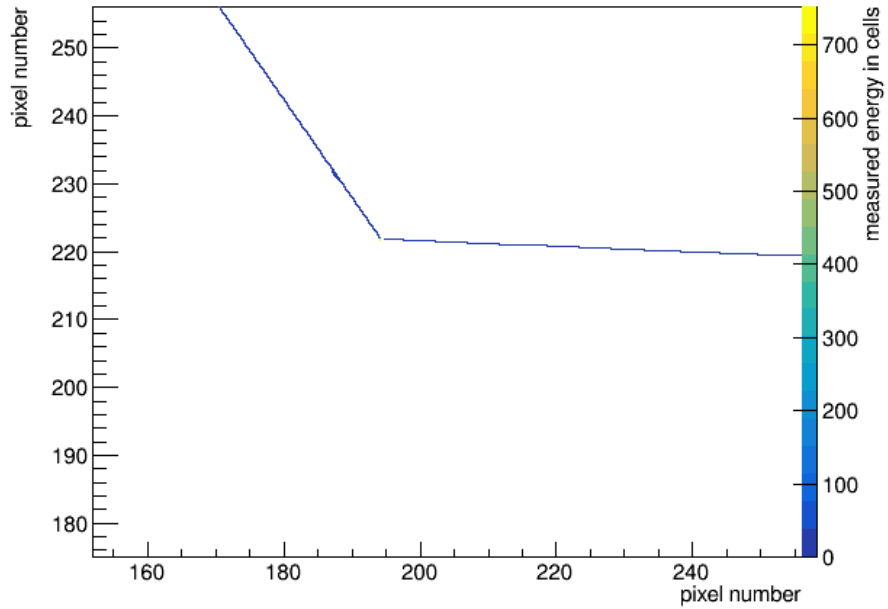
...
Effect on final results
Evaluate methods

Detector response model

- Raw energy depositions in small voxels (FLUKA)
- Parametrized model for charge sharing including the plasma effect
- Volcano effect
- Suppressed pixels in the experimental set-up
- Re-clustering



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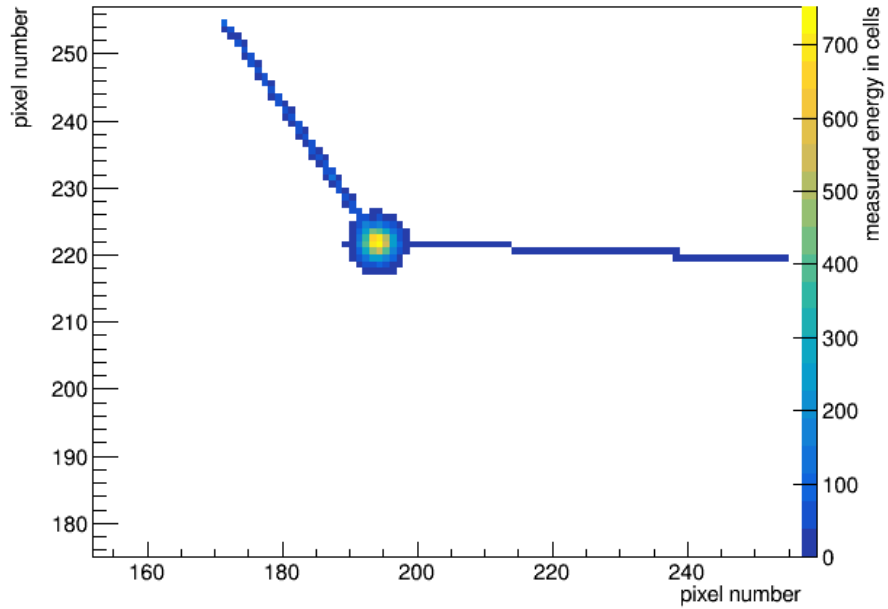

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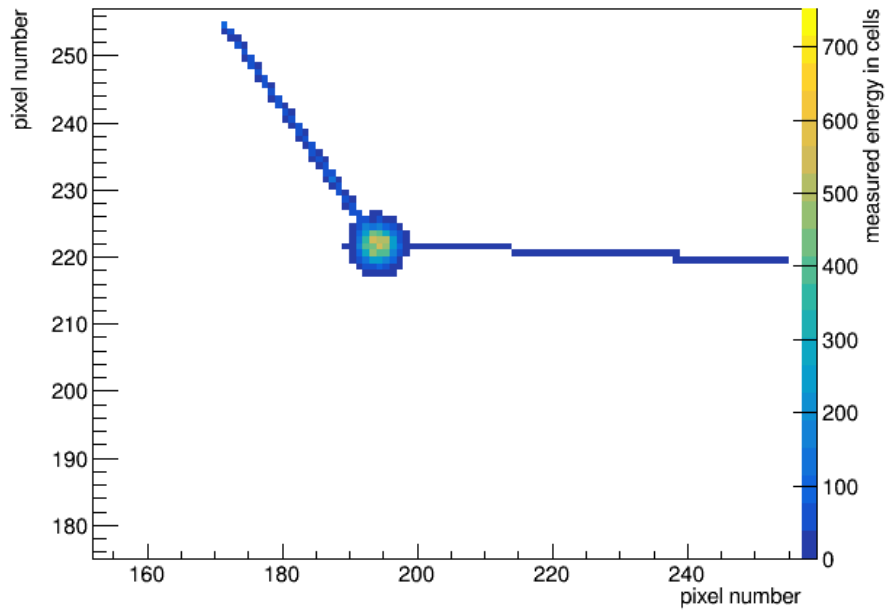
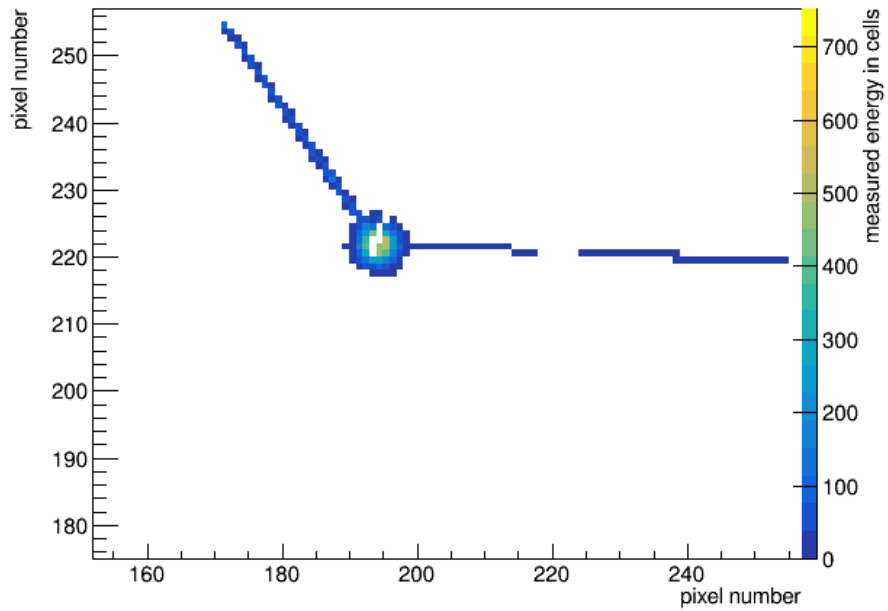


Detector response model

- Raw energy depositions in small voxels (FLUKA)
- Parametrized model for charge sharing including the plasma effect
- Volcano effect
- Suppressed pixels in the experimental set-up
- Re-clustering



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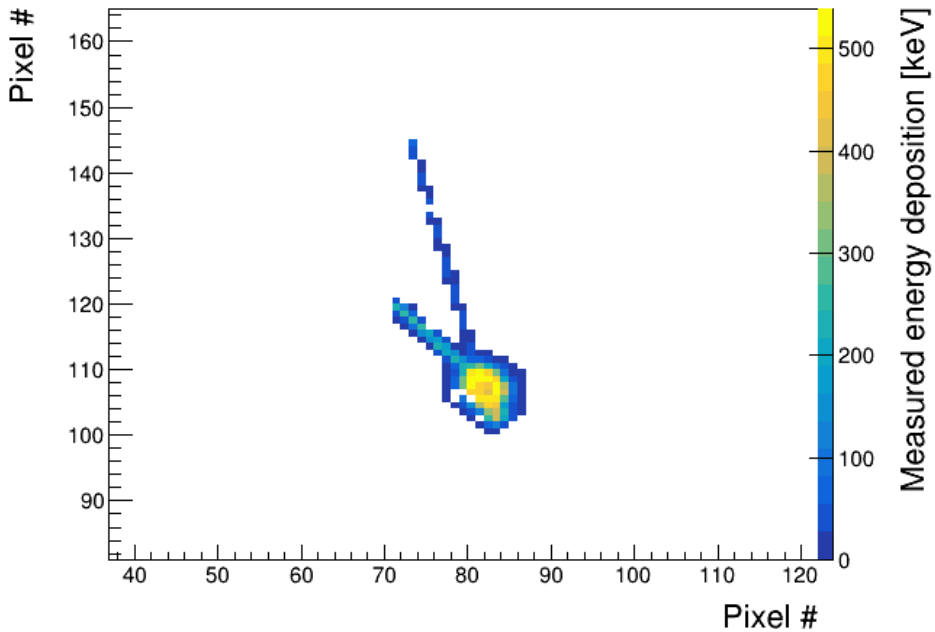

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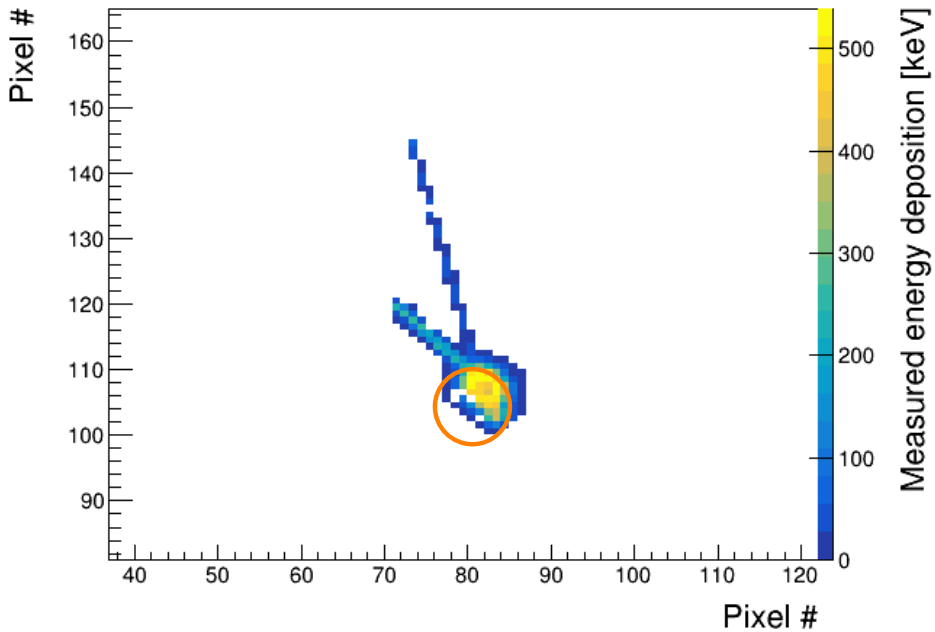

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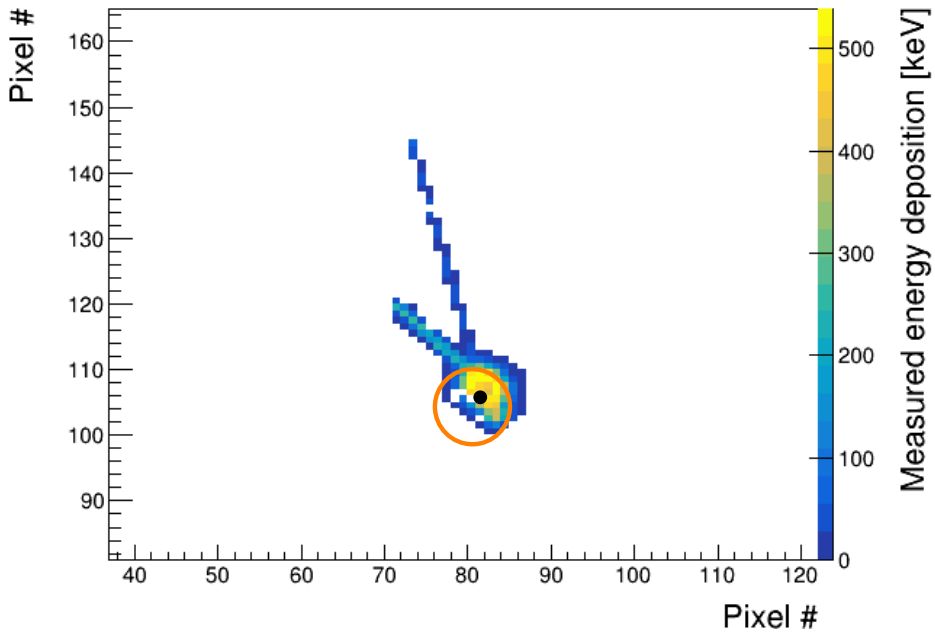

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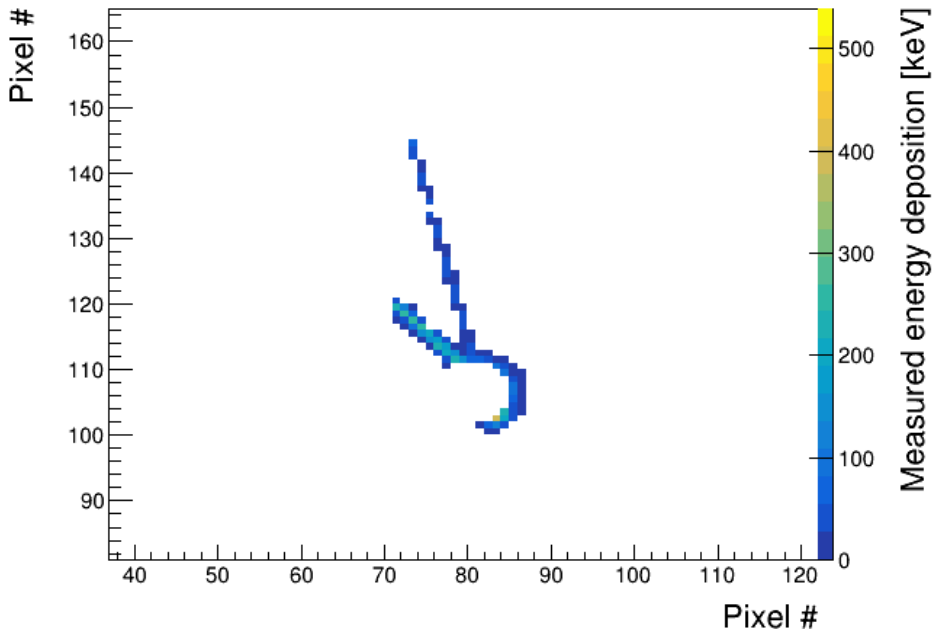

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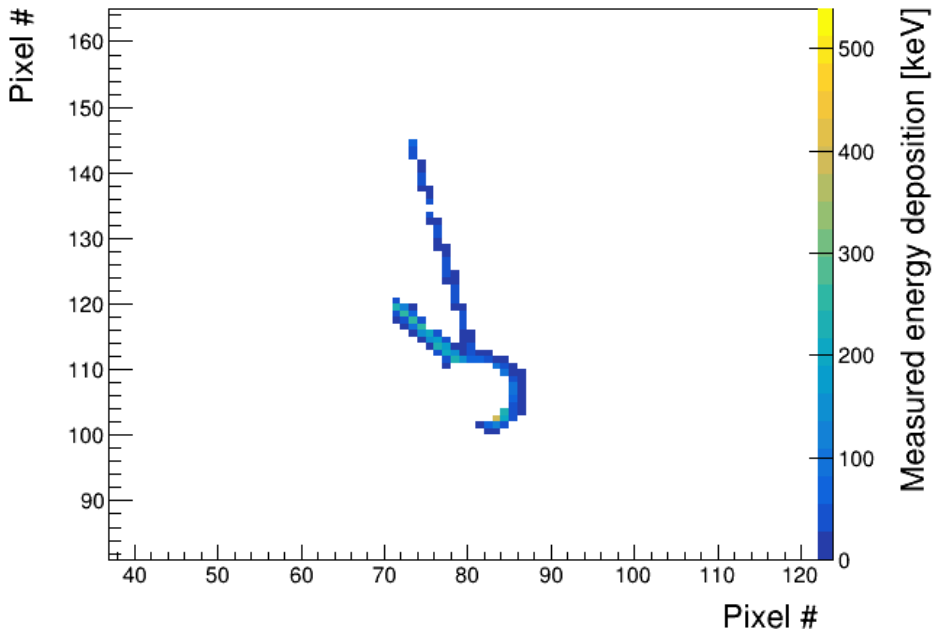

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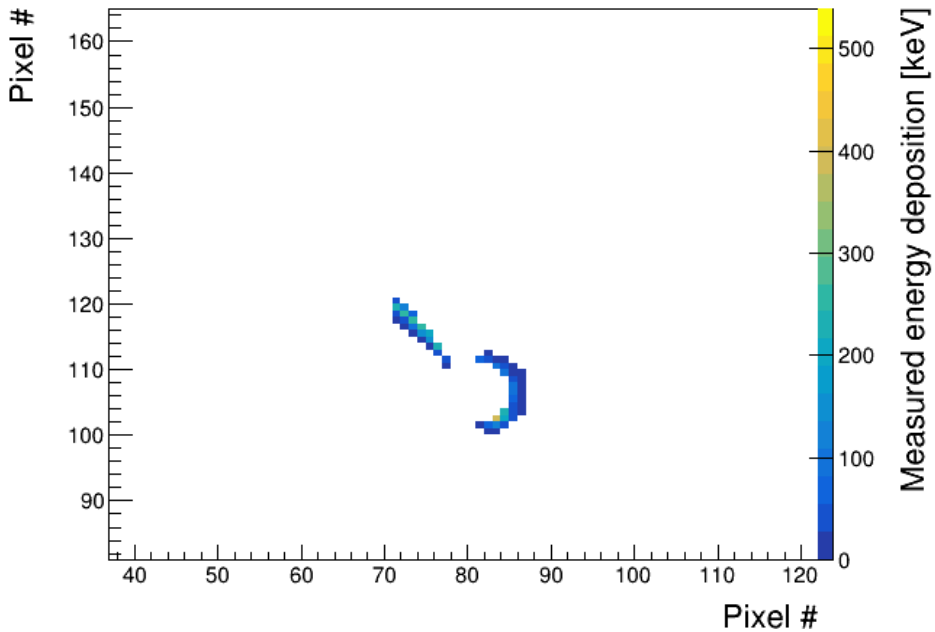

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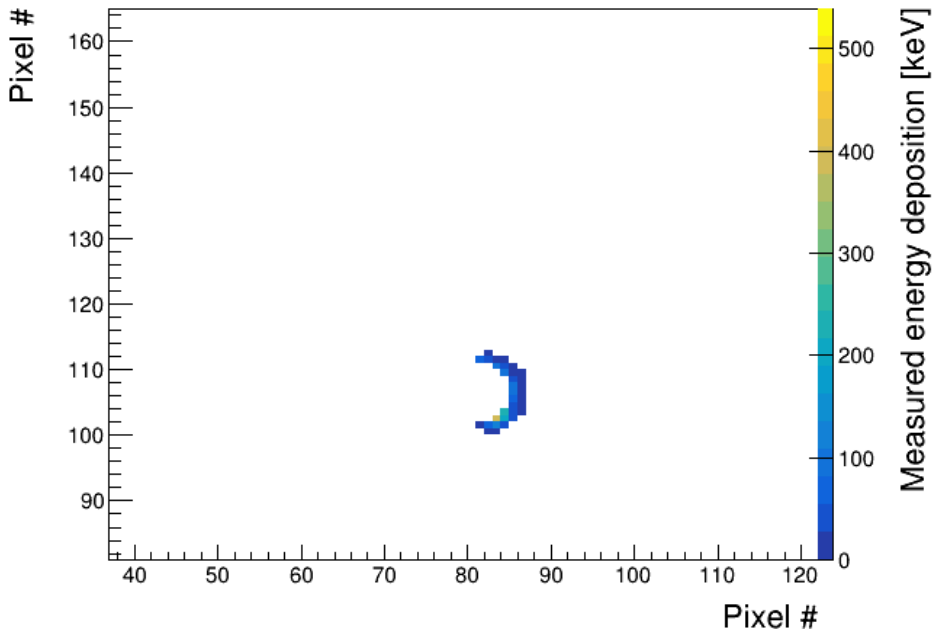

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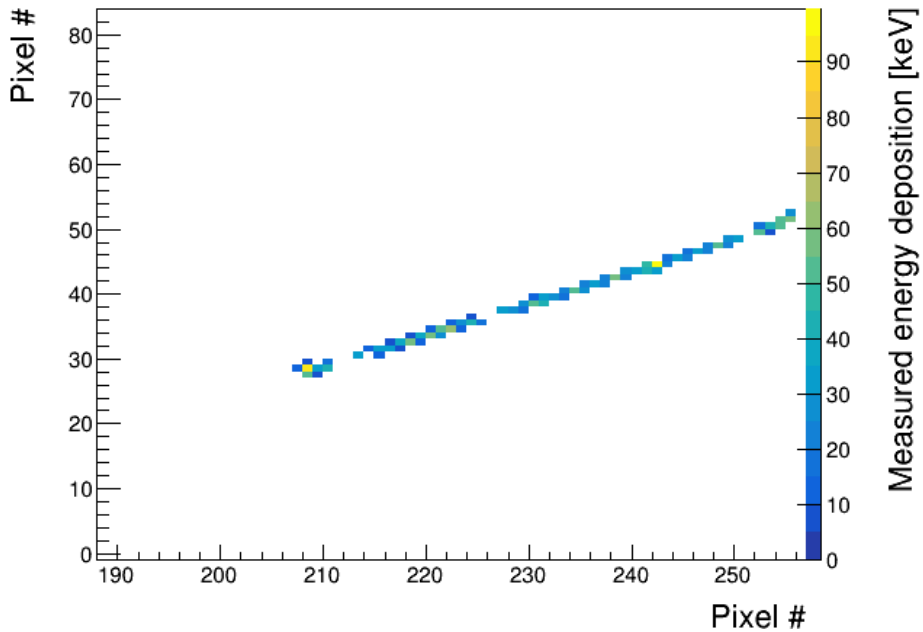

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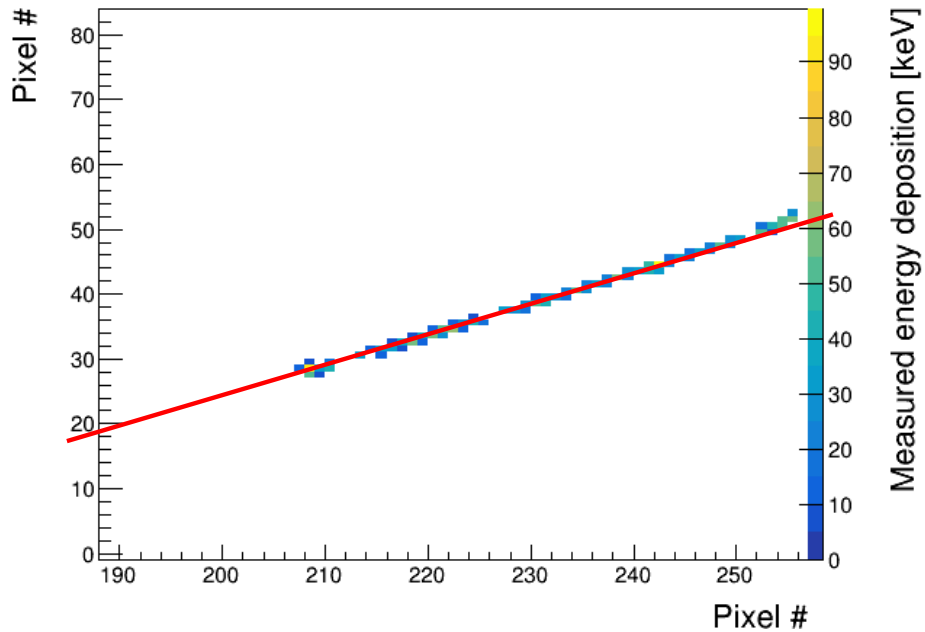

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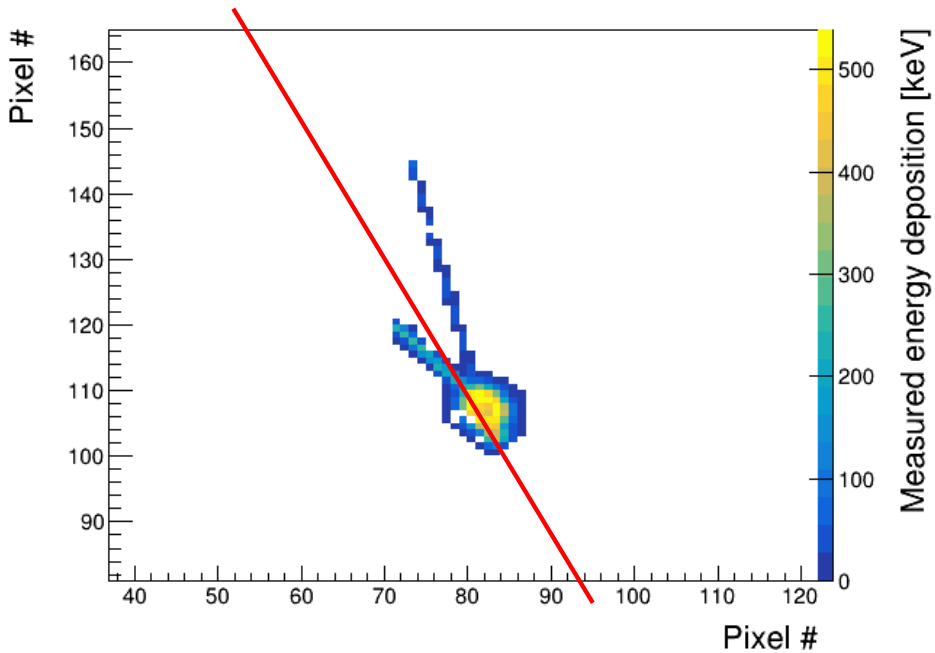

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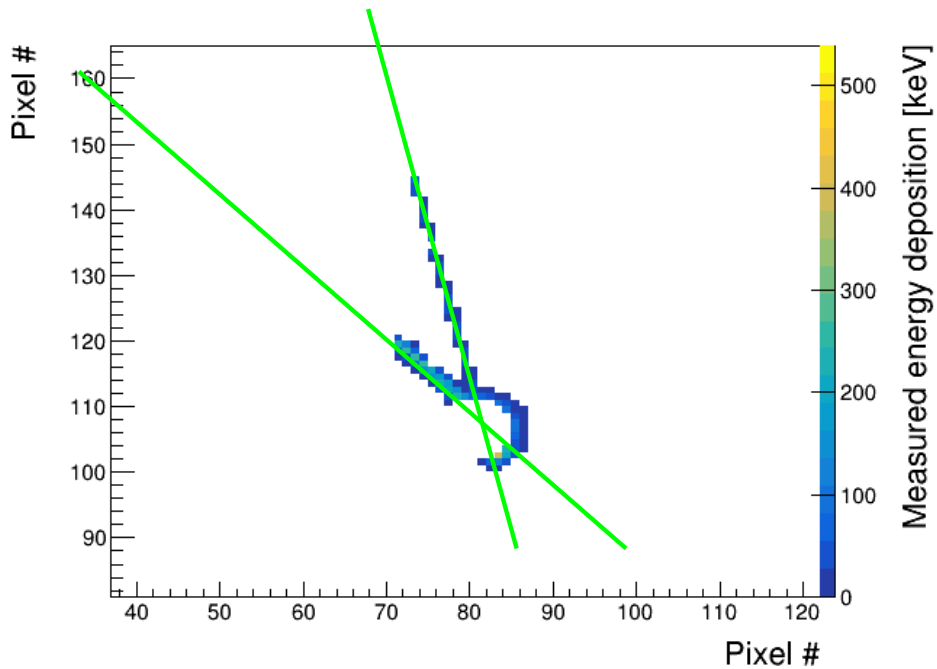
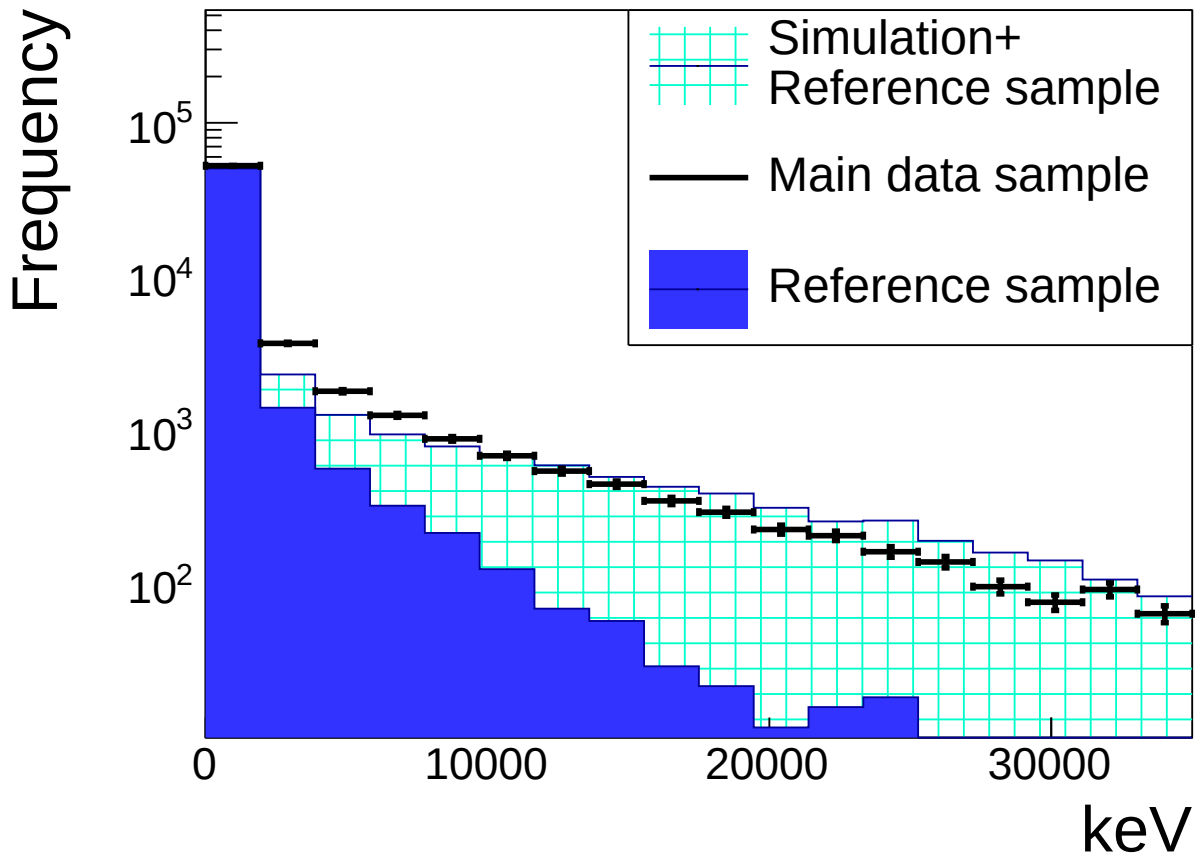


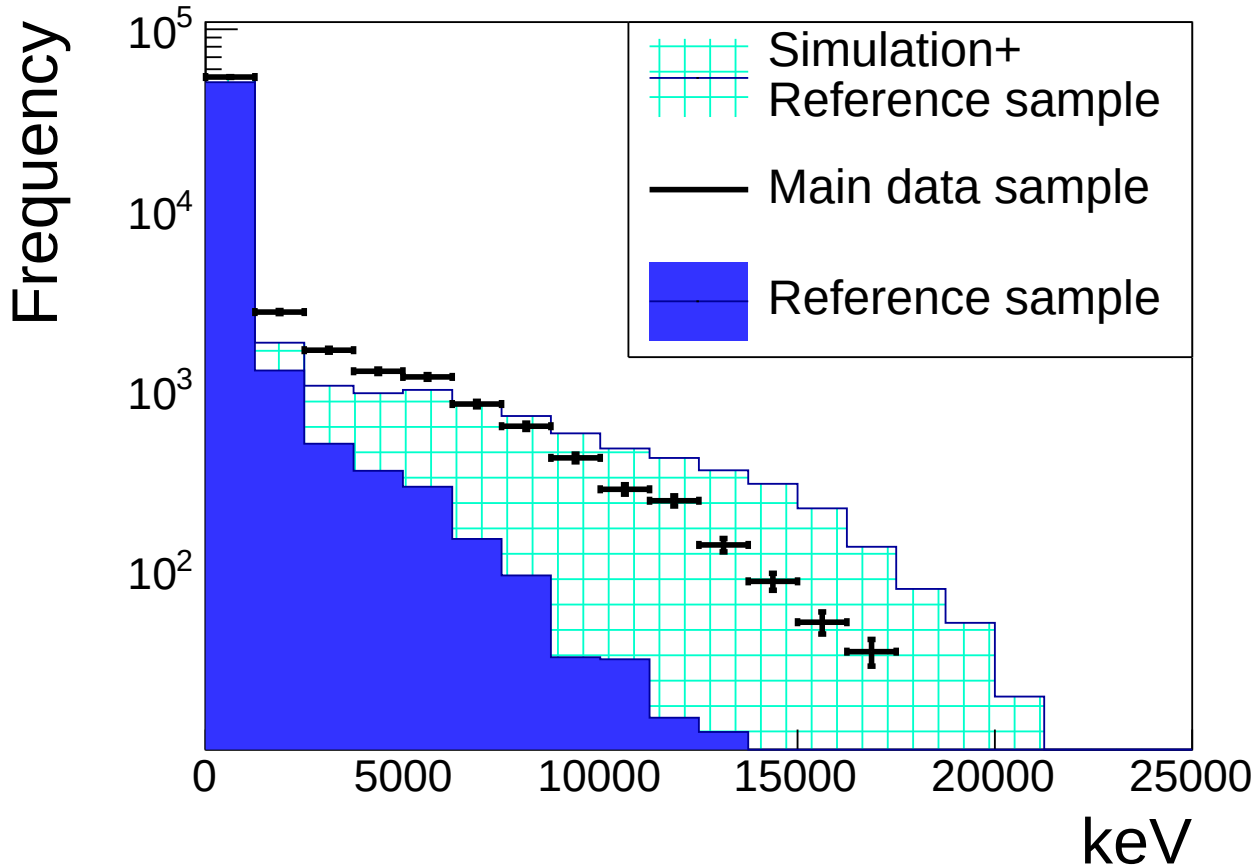
Verification of the simulation

Cluster energy



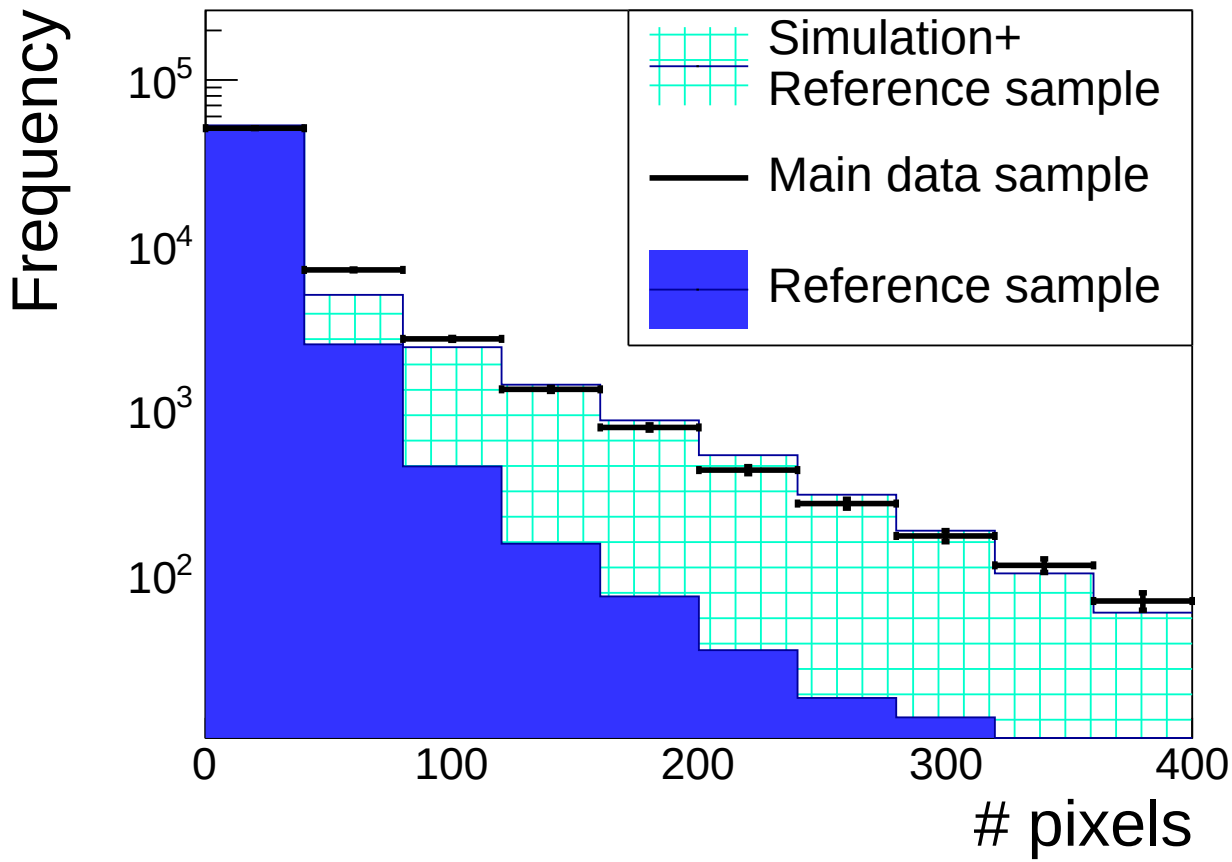
Verification of the simulation

Cluster energy in center



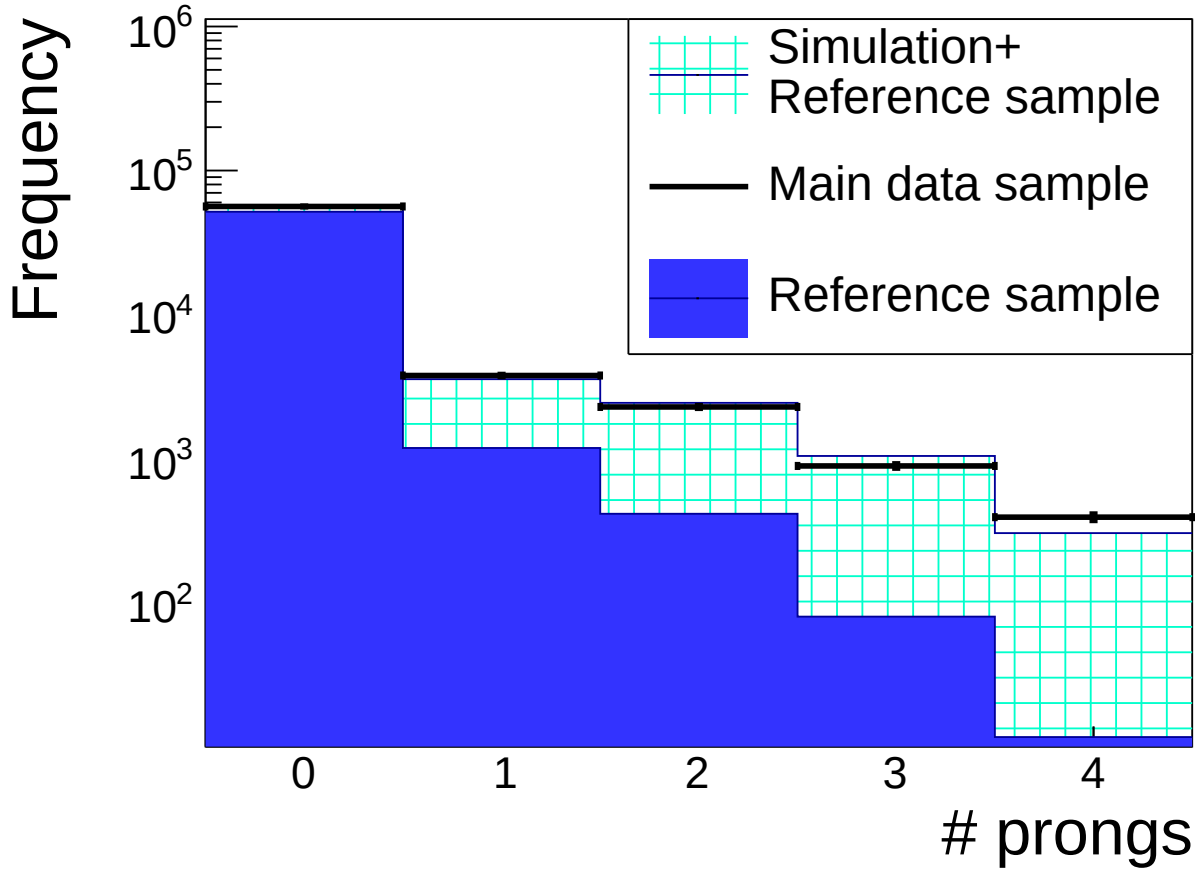
Verification of the simulation

Cluster size



Verification of the simulation

Number of prongs



Tagging efficiency

- Annihilation clusters are larger and have prongs
- Trade off between tagging efficiency and false positive rate
- A good compromise: At least 70 pixels and at least 1 prong
  - Tagging efficiency $50 \pm 10\%$
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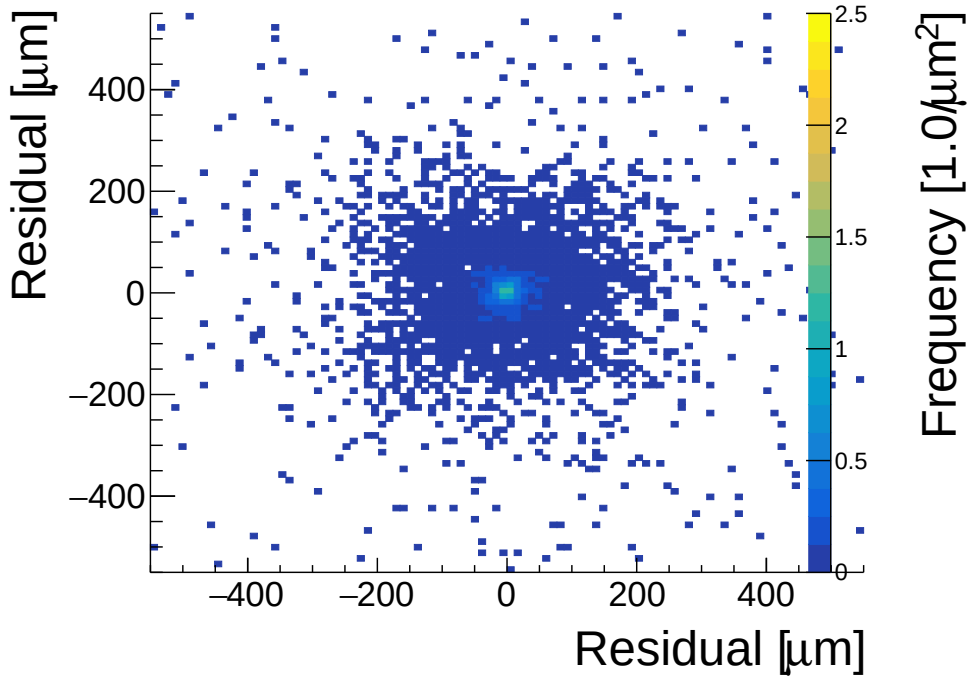
Position resolution

- Mass center method
  - All clusters
  - 93 μm resolution
- Vertex fitting method
  - 45% of all clusters
  - 48 μm resolution
- Vertex fitting method excluding bad fits
  - 22% of all clusters
  - 22 μm resolution
- Systematic uncertainty $\approx \pm 1 \mu m$



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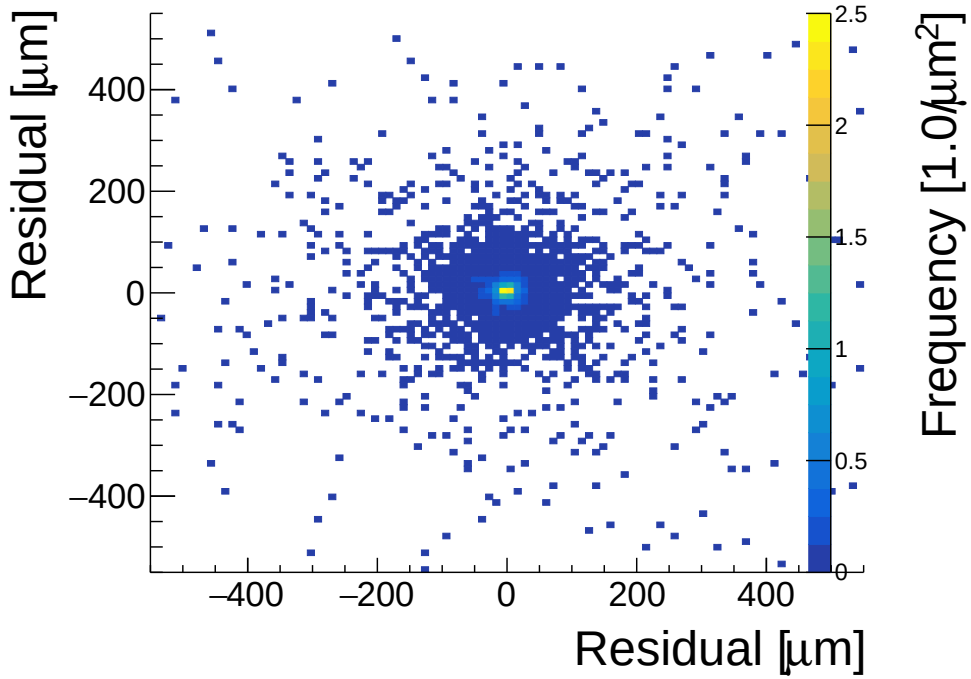

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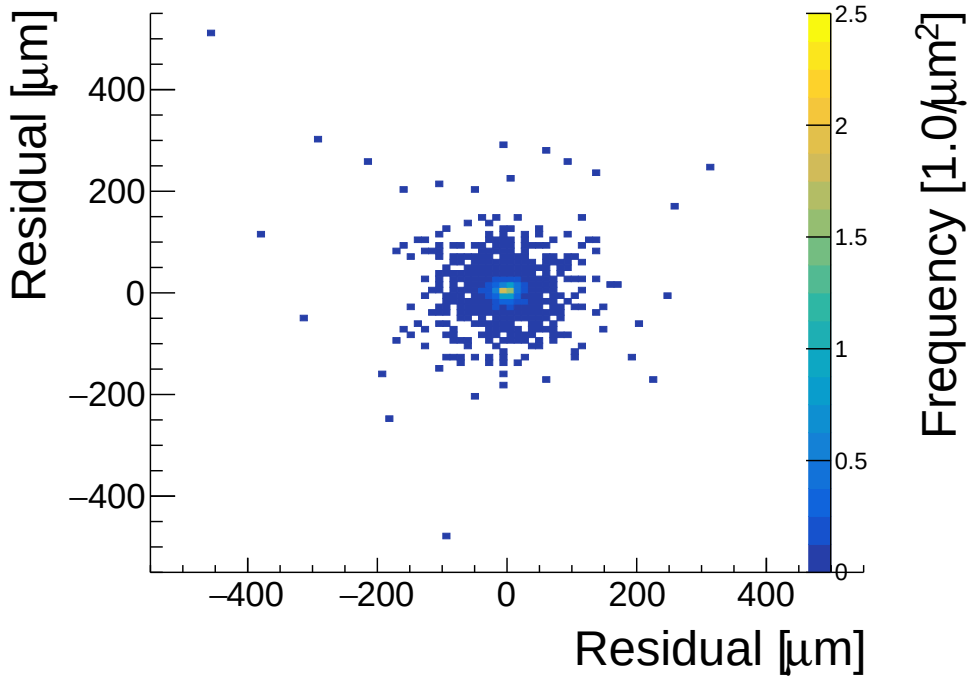

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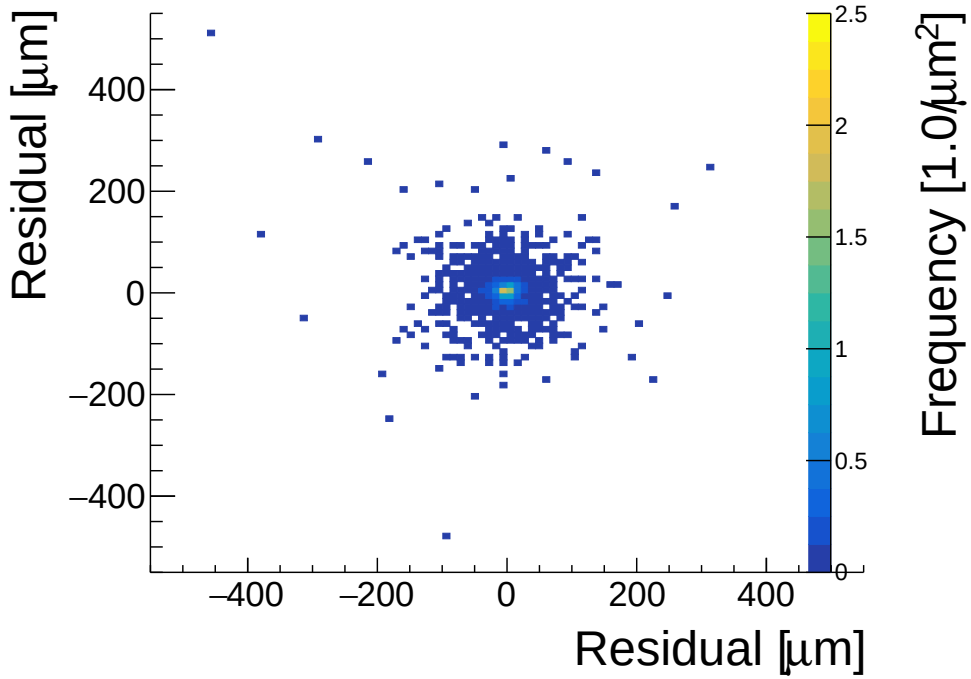

Conclusion

- Clearly see the annihilation clusters
- Better understanding of annihilations in material
- Better understanding of large energy depositions
- Developed a detector response model, and a full simulation of the GRACE beamline
- Tagging efficiency of $50 \pm 10\%$
- False positive rate $< 1.0\%$
- Position resolution of 22 μm