Proton and Helium Daily Flux

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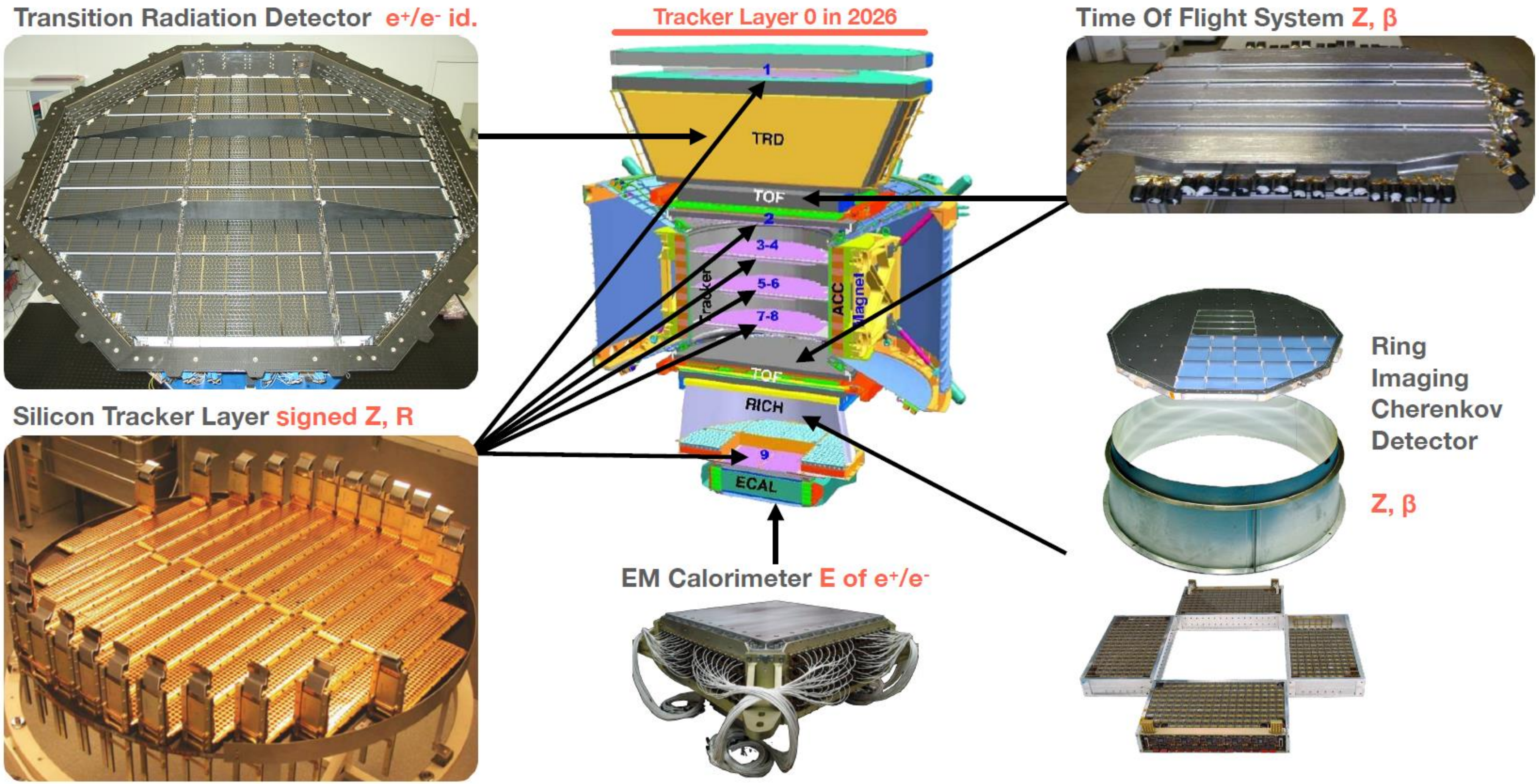
The AMS-02 Detector



Subdetectors

TRD – Transition Radiation Detector

Purpose:
To distinguish light particles (like electrons and positrons) from heavier particles (like protons).

Principle:
When a relativistic charged particle crosses the boundary between two materials with different refractive indices, it emits transition radiation, mostly in the X-ray range.

Electrons and positrons, due to their low mass and high Lorentz factor (γ), emit more X-ray photons than protons at the same energy.

The amount of transition radiation (X-rays) detected helps distinguish.

TOF – Time Of Flight System

Purpose:
To measure the velocity (β) of particles.
To give an estimate of the electric charge (Z).

Principle:
Measures the time difference as a particle travels between upper and lower planes, with a known distance.

Silicon Tracker + Permanent Magnet

Purpose:
To measure the rigidity (R) of a particle based on the trajectory of the charged particle.

Principle:
Charged particles are deflected in a magnetic field and the trajectory depends on momentum and charge. Based on this, the rigidity (momentum/charge) can be calculated.

In addition, the sign of the particle's charge is also determined because particles with opposite charge are deflected in the opposite direction.

Subdetectors

RICH – Ring Imaging Cerenkov Detector

Purpose:
Velocity (β) measurement. Determine electric charge (Z).

Principle:
If a particle moves faster than light in a medium, it emits Cerenkov radiation (visible blue light). The Cherenkov radiation angle depends on β.
The charge of a particle can be determined based on the intensity of the light.

Combining β (from RICH) and momentum (from the Silicon tracker) can determine the mass of particle.

ECAL – Electromagnetic Calorimeter

Purpose:
Measure the energy of electrons, positrons and photons. Discriminate electron/positron and proton based on shower shape.

Principle:
Electrons, positrons and photons create electromagnetic showers in dense material (like lead).

Photons produce ($e+e-$)pairs.
Electrons/positrons emit Bremsstrahlung photons. Total energy deposition can be measured.

Shower shape helps distinguish:
Electrons/positrons: compact, symmetric EM showers
Protons: broader, hadronic showers

ACC – Anti-Coincidence Counters

Purpose:
It can suppress side-entering particles that would interfere with proper event reconstruction.
Improve signal-to-noise ratio.

Principle:
These side signals coincide with tracker/TOF hits and can be flagged as invalid.

Three main types of triggers

Fast Trigger

This trigger is primarily based on the Time-of-Flight (TOF) detector signals. When a particle passes through the TOF layers, if the signals appear in the correct time sequence and satisfy predefined conditions, a fast trigger is generated. This process happens extremely quickly, within nanoseconds, to decide whether to keep the event for further processing.

Level-1 Trigger

After the fast trigger, the Level-1 trigger combines information from multiple subdetectors, such as the Transition Radiation Detector (TRD) and the Electromagnetic Calorimeter (ECAL). It checks if the particle's trajectory, energy deposition, and other characteristics meet certain criteria. If these conditions are met, the event is accepted for further detailed analysis.

Physics Trigger (Level-2 Trigger)

This is a more refined trigger stage where detailed physics parameters are analyzed. It verifies the particle's path in the magnetic field, timing consistency, energy measurements, and other sophisticated features. Only events that pass this high-level filter are fully recorded and stored for offline analysis.

These trigger levels work together as a filtering system to efficiently select interesting particle events from the huge flux passing through AMS-02, ensuring that only high-quality data is saved while reducing unnecessary data load.

Why are Monte Carlo simulation data needed to find the real flux of cosmic particles?

Because the flux detected in AMS is different from the real flux of cosmic particles due to the following reasons:

Geometrical Acceptance

Only particles entering the detector from certain directions and positions are able to pass through all required subdetectors and be reconstructed. This angular and positional filtering limits the measurable sample compared to the total cosmic ray flux.

Trigger and Selection Efficiency

The trigger system and subsequent event selection criteria accept only a subset of events—those that fulfill quality conditions such as consistency between timing, track, and energy measurements. Events outside these criteria are not recorded or later rejected in the analysis.

Detector Resolution Limits

Due to finite spatial and energy resolution, the measured rigidity (momentum/charge) or energy may differ from the true value. This causes bin-to-bin migration, where events shift from their true interval into neighboring measurement bins.

Charge Confusion

Particularly in high-energy regimes, a positively charged particle like a positron may be misidentified as its negative counterpart (electron) or vice versa. This can occur due to misreconstructed curvature in the magnetic field or due to scattering processes.

Secondary Interactions

Primary particles may undergo nuclear or electromagnetic interactions inside the detector material, creating secondary particles (e.g., delta rays—electrons) that contaminate the event or mimic other particle species, leading to misclassification.

Energy Loss in Detector Material

As particles traverse the detector, they lose energy through processes like ionization (dE/dx) or bremsstrahlung (especially electrons and positrons). This results in a measured energy that is lower than the initial particle energy.

All of the above detector effects must be modeled using Monte Carlo simulations, and corrected using methods like efficiency weighting, response matrix inversion (unfolding), and systematic uncertainty estimation. Without accounting for these effects, the measured spectrum would significantly deviate from the real cosmic ray flux.

Cosmic Ray Flux Definition

Rigidity = $\frac{\text{Momentum}}{\text{Charge}}$

$$\Phi_i(t) = \frac{N_{selected,i}(t)}{\Delta R_i \cdot T_{exp,i}(t) \cdot A_{eff,i}(t)} \qquad i = i^{th} rigidity\ interval$$

$N_{selected}$ ⟶ **Selected counts identifying proton events**

T_{exp} ⟶ **Effective Exposure Time in seconds**

$A_{eff} = A_{MC} \cdot C_{tot}$ ⟶ **Effective acceptance: Monte Carlo acceptance multiplied by the total correction**

C_{tot} ⟶ **Total correction: product of all the DATA/MC corrections**

DATA/MC corrections are defined as the **ratio** between **efficiencies** over **on-flight data** and **Monte Carlo**.

Daily proton flux

For two time periods:
January 1 to March 1, 2022
and May 2024

3 months in total

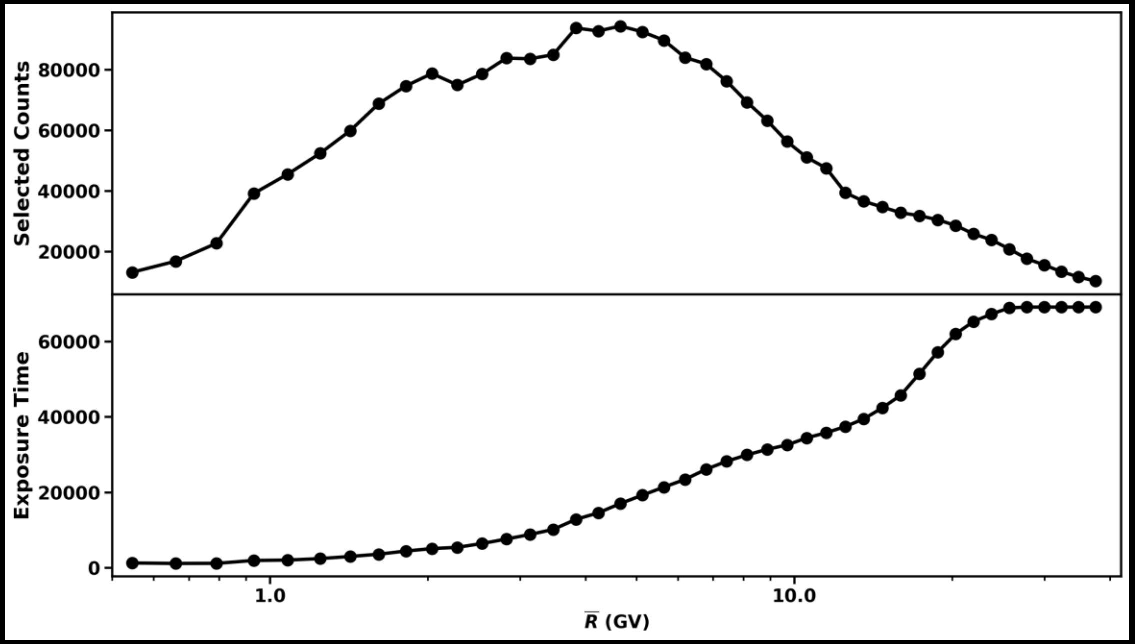
Daily helium flux

For two time periods:
January 1 to March 1, 2016
and January 1 to March 1, 2018

4 months in total

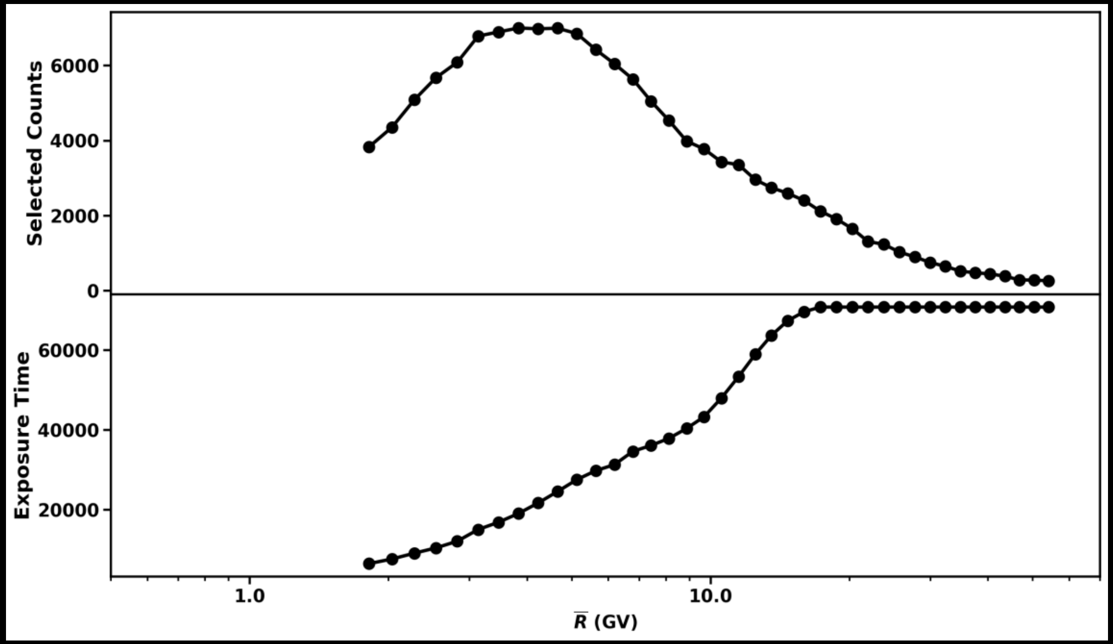
Exposure Time for proton

For 1 January 2022



Exposure Time for helium

For 1 January 2016



Event selection for proton

Run Time Information (RTI) Cuts
- Livetime Fraction > 0.05
- Zenith Angle < 25
- Not in South Atlantic Abnormally (SAA)
- Good Event Data Acquisition

Physical Cuts
- Any Physical Trigger
- 0.7 < Inner Charge < 1.5
- Good Hit Pattern
- Inner Charge / Inner Charge RMS < 0.4
- 0.6 < L1 Charge < 2
- Chi2Y < 10 (Inner track)
- At least 5 Hits in inner Tracker
- Chi2Y < 10 (InnerL1 track)
- Inside Inner Fiducial (InnerL1 track)
- Inside L1 Fiducial (InnerL1 track)
- L1 Normalized Residual < 10
- Beta > 0.4
- 0.5 < Upper Tof Charge < 2.5
- InnerL1 Rigidity > MAX IGRF Cutoff

Event selections for helium are the same as for protons, but with the following changes

Run Time Information (RTI) Cuts
- Livetime Fraction > 0.5
- Zenith Angle < 40

Physical Cuts
- Hitting to L1 (HitCut)
- 1.5 < Inner Charge < 2.5
- 1.5 < L1 Charge < 2.5
- 1.5 < L2 Charge < 2.5
- 1.5 < Upper Tof Charge < 2.5
- 1.5 < Lower Tof Charge < 2.5
- No anticoincidence signal
- Number of Tof cluster < 5
- Good path length in Tof (1st and 3rd layers)

Properties of Daily Helium Fluxes
Phys. Rev. Lett. 128, 231102 (2022)

Efficiency for the 1st layer silicon tracker (proton)

Denominator
- RTI cuts (see event selection)
- Any Physical Trigger
- Chi2Y < 10 (Inner track)
- At least 5 Hits in inner Tracker
- 0.7 < Inner Charge < 1.5
- Good Hit Pattern
- Inner Charge / Inner Charge RMS < 0.4
- Beta > 0.4
- Mass cut
- 0.5 < Upper Tof Charge < 1.7
- 0.5 < Lower Tof Charge < 1.7
- Tof Chi2 Coo < 2
- Number of Tof cluster < 5
- No ACC signal
- Inner Rigidity > MAX IGRF Cutoff

Numerator
- Denominator
- 0.6 < L1 Charge < 2
- Chi2Y < 10 (InnerL1 track)
- Inside Inner Fiducial (InnerL1 track)
- Inside L1 Fiducial (InnerL1 track)
- L1 Normalized Residual < 10

Efficiency for the 1st layer silicon tracker (helium) same as protons but with the following changes

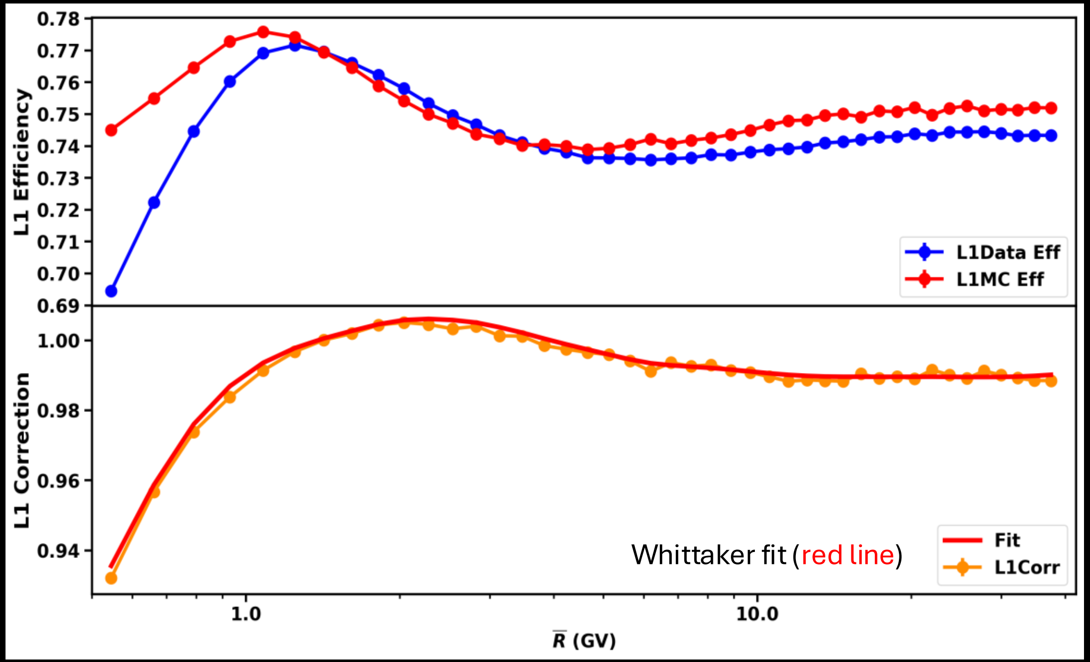
Denominator
- 1.5 < Inner Charge < 2.5
- 1.5 < L2 Charge < 2.5
- 1.5 < Upper Tof Charge < 2.5
- 1.5 < Lower Tof Charge < 2.5
- Inside Inner Fiducial (Inner Only)
- Good path length in Tof (1st and 3rd layers)

Numerator
- Hitting to L1 (HitCut)
- 1.5 < L1 Charge < 2.5

$$\text{Efficiency} = \frac{\text{Numerator}}{\text{Denominator}}$$

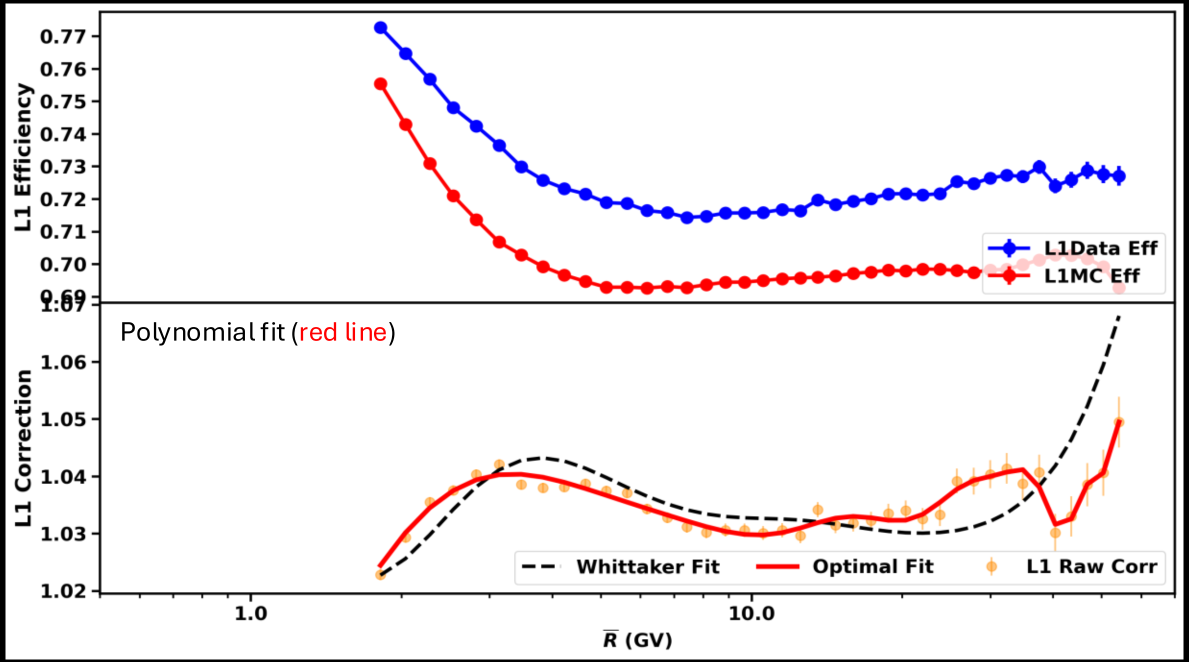
Efficiency for the 1st layer silicon tracker (Proton)

For 1 January 2022



Efficiency for the 1st layer silicon tracker (Helium)

For 1 January 2016



Efficiency for the Tof (proton)

Denominator

- RTI cuts (see event selection)
- Any Physical Trigger
- Chi2Y < 10 (Inner track)
- Chi2Y < 10 (InnerL1 track)
- At least 5 Hits in inner Tracker
- 0.7 < Inner Charge < 1.5
- 0.6 < L1 Charge < 2
- Good Hit Pattern
- Inside Inner Fiducial (InnerL1 track)
- Inside L1 Fiducial (InnerL1 track)
- Inner Charge / Inner Charge RMS < 0.4
- L1 Normalized Residual < 10
- Inner L1 Rigidity > MAX IGRF Cutoff

Numerator

- Denominator
- Beta > 0.4
- 0.5 < Upper Tof Charge < 1.7

Efficiency for the Tof (helium)
same as protons but with the following changes

Denominator

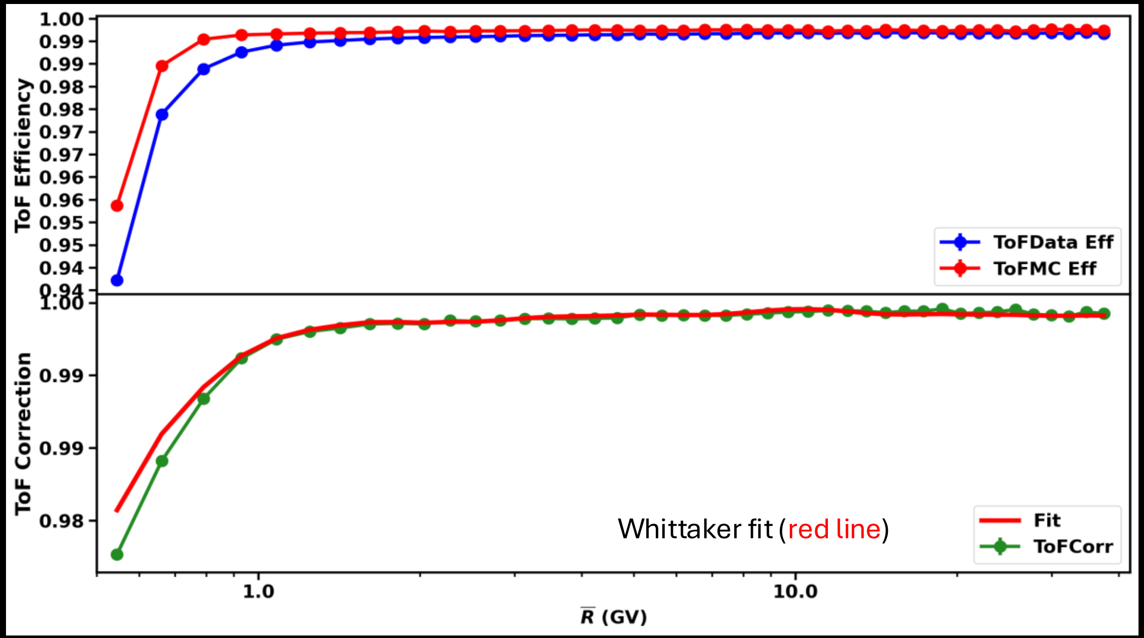
- Hitting to L1 (HitCut)
- 1.5 < Inner Charge < 2.5
- 1.5 < L1 Charge < 2.5
- 1.5 < L2 Charge < 2.5
- Inside Inner Fiducial (Inner Only)
- No ACC signal

Numerator

- Good path length in Tof (1st and 3rd layers)
- 1.5 < Upper Tof Charge < 2.5
- 1.5 < Lower Tof Charge < 2.5
- Number of Tof cluster < 5
- Tof Chi2 Coo < 2

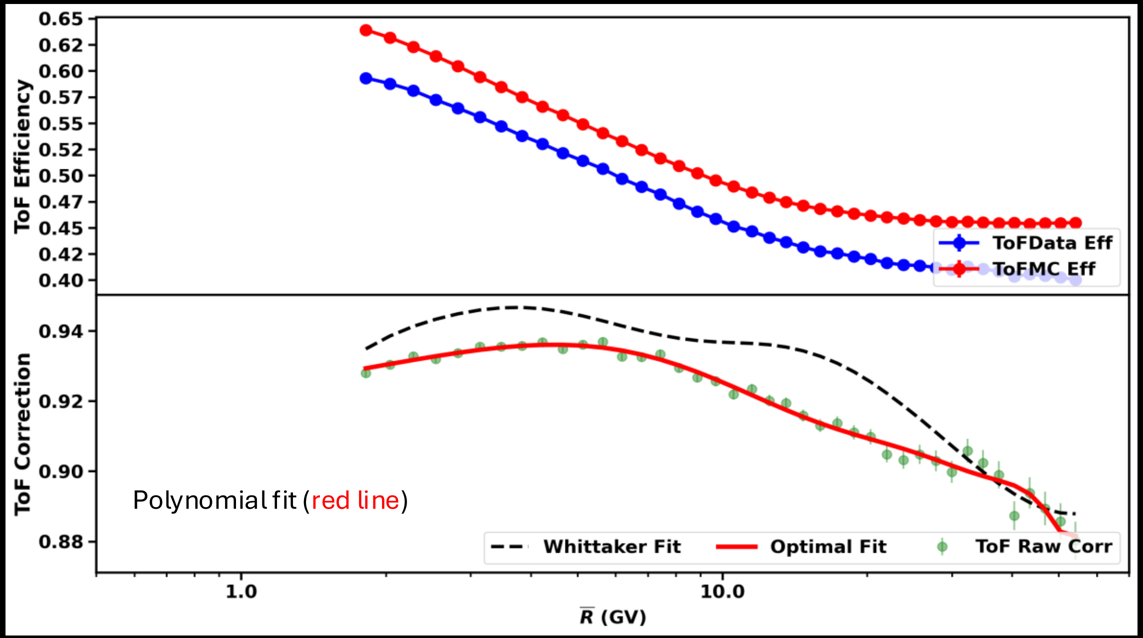
Efficiency for the Tof (Proton)

For 1 January 2022



Efficiency for the Tof (Helium)

For 1 January 2016



Efficiency for the Inner Tracker(proton)

Denominator

- RTI cuts (see event selection)
- Any Physical Trigger
- 0.6 < L1 Charge < 2 (UnbExtLayer)
- Beta > 0.4
- 0.5 < Upper Tof Charge < 1.5
- Lower Tof Charge > 0.5
- Tof Track Inside Inner Fiducial
- Tof Track Inside L1 Fiducial
- TRD Track Inside L1 Fiducial
- Number of Tof cluster < 5
- Tof Chi2 Coo < 2
- Tof Chi2 Time < 2
- Rigidity from Beta > MAX IGRF Cutoff

Numerator

- Denominator
- Chi2Y < 10 (Inner track)
- Good Hit Pattern
- At least 5 Hits in inner Tracker
- 0.7 < Inner Charge < 1.5
- Inner Charge / Inner Charge RMS < 0.4

Efficiency for the Inner Tracker (helium)

same as protons but with the following changes

Denominator

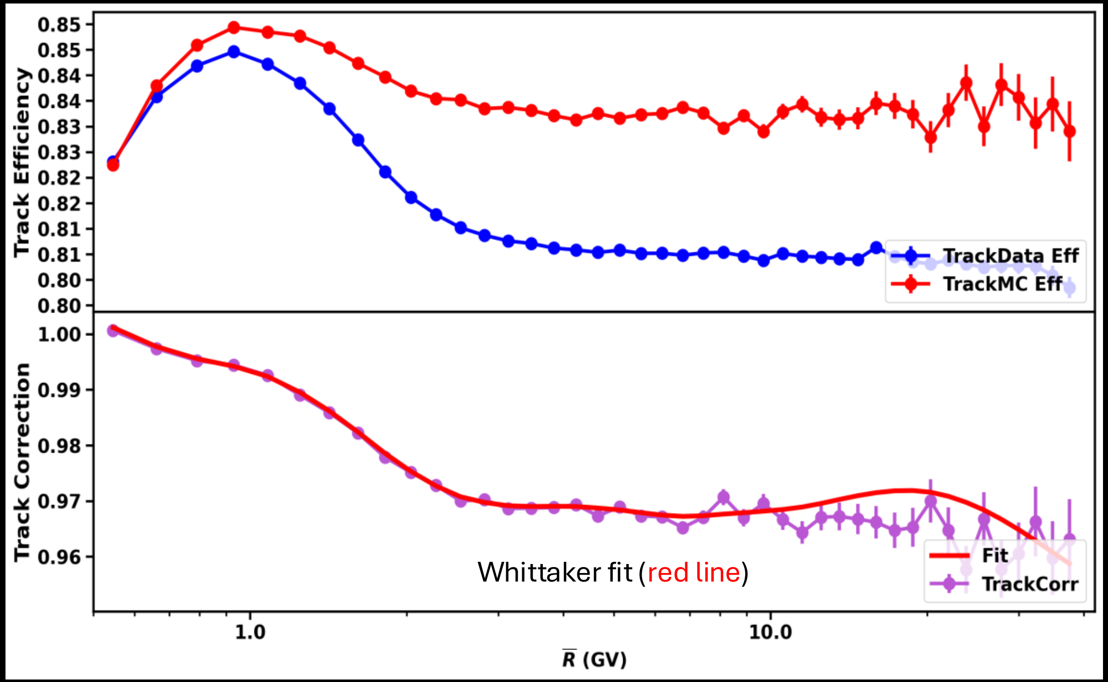
- 1.5 < L1 Charge < 2.5 (UnbExtLayer)
- 1.5 < Upper Tof Charge < 2.5
- 1.5 < Lower Tof Charge < 2.5

Numerator

- 1.5 < Inner Charge < 2.5

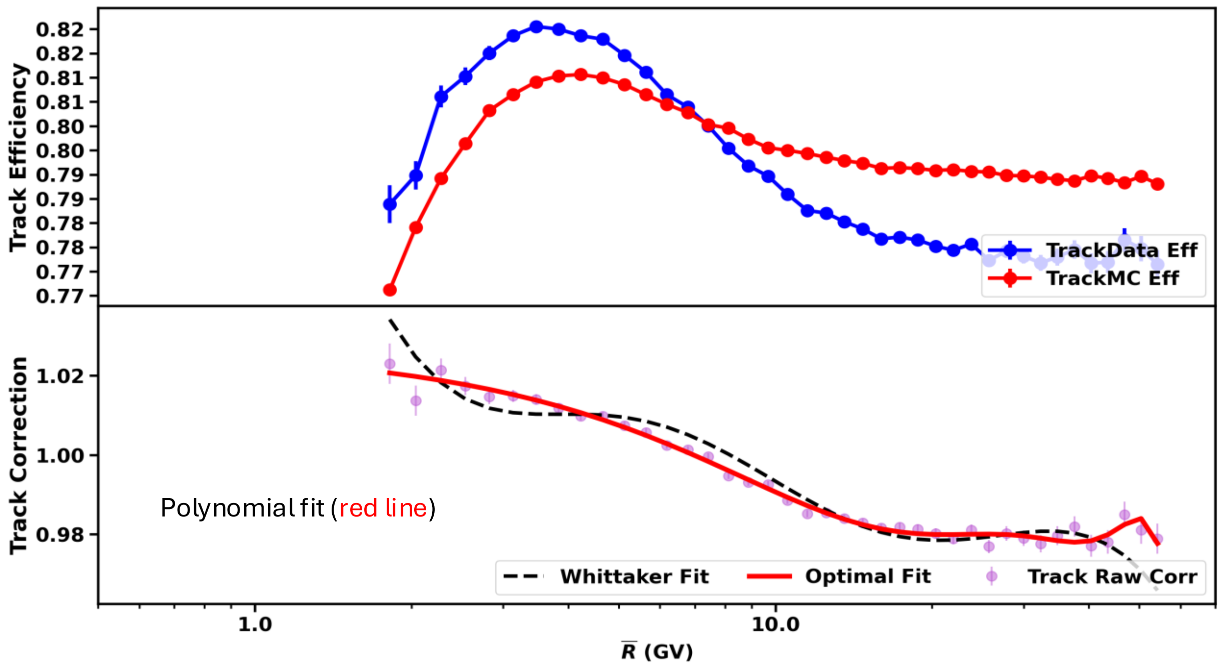
Efficiency for the Inner Tracker (Proton)

For 1 January 2022



Efficiency for the Inner Tracker (Helium)

For 1 January 2016



Efficiency for the Trigger (proton)

Denominator

- RTI cuts (see event selection)
- Chi2Y < 10 (Inner track)
- Chi2Y < 10 (InnerL1 track)
- Good Hit Pattern
- At least 5 Hits in inner Tracker
- 0.7 < Inner Charge < 1.5
- 0.6 < L1 Charge < 2
- Inside Inner Fiducial (InnerL1)
- Inside L1 Fiducial (InnerL1)
- Beta > 0.4
- 0.5 < Upper Tof Charge < 2.5
- Lower Tof Charge > 0.5
- Inner Charge / Inner Charge RMS < 0.4
- Number of Tof cluster < 5
- InnerL1 Rigidity > IGRF Cutoff
- Unbiased Trigger (PhysBPatt)

Numerator

- Denominator
- Any Physical Trigger

Efficiency for the Trigger (helium)
same as protons but with the following changes

Denominator

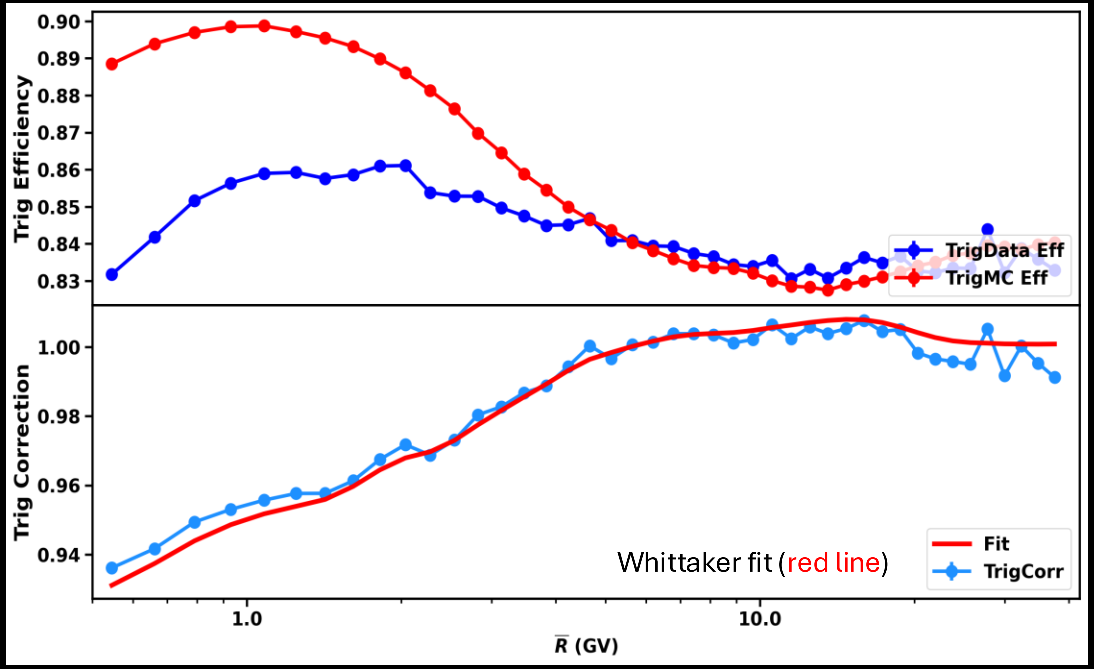
- Hitting to L1 (HitCut)
- 1.5 < L1 Charge < 2.5
- 1.5 < L2 Charge < 2.5
- 1.5 < Inner Charge < 2.5
- L1 Normalized Residual < 10
- 1.5 < Upper Tof Charge < 2.5
- 1.5 < Lower Tof Charge < 2.5
- Tof Chi2 Coo < 2
- Good path length in Tof (1st and 3rd layers)
- No ACC signal

Numerator

(Nothing change)

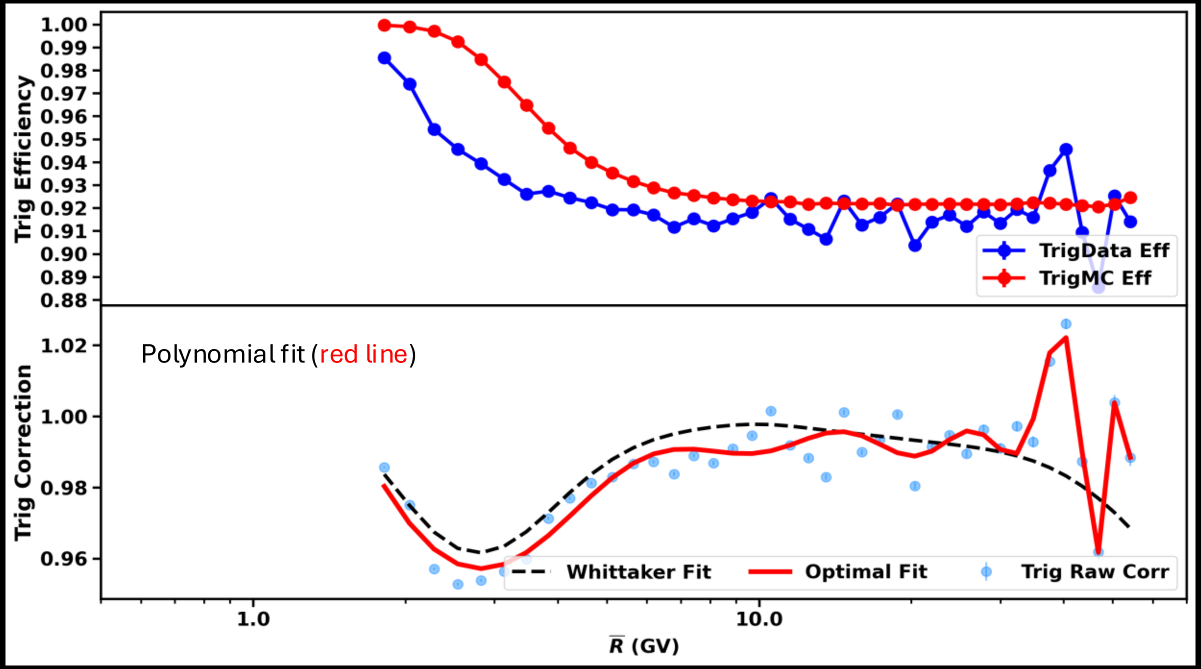
Efficiency for the Trigger (Proton)

For 1 January 2022



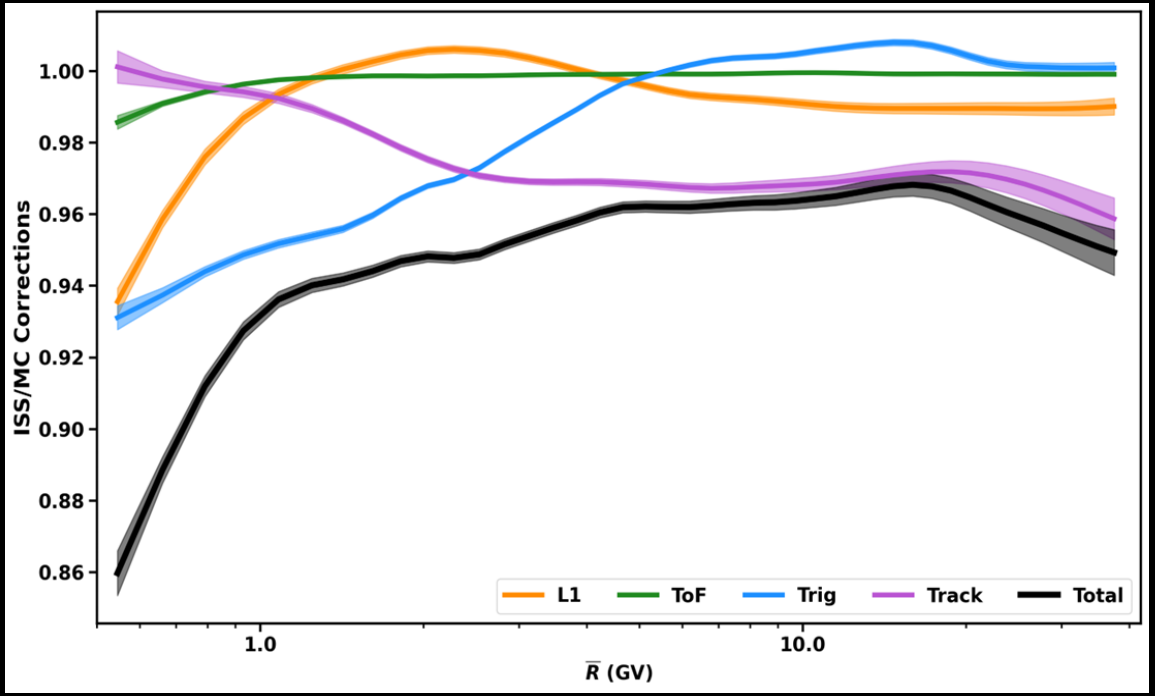
Efficiency for the Trigger (Helium)

For 1 January 2016



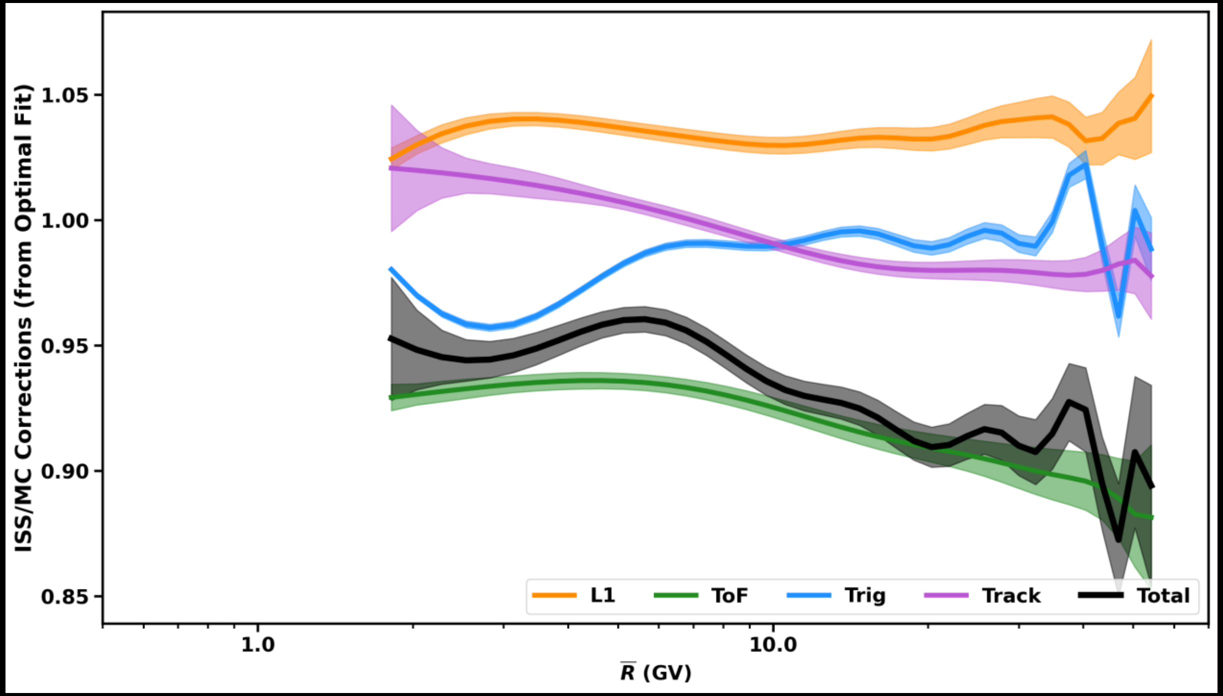
Total correction (Proton)

For 1 January 2022



Total correction (Helium)

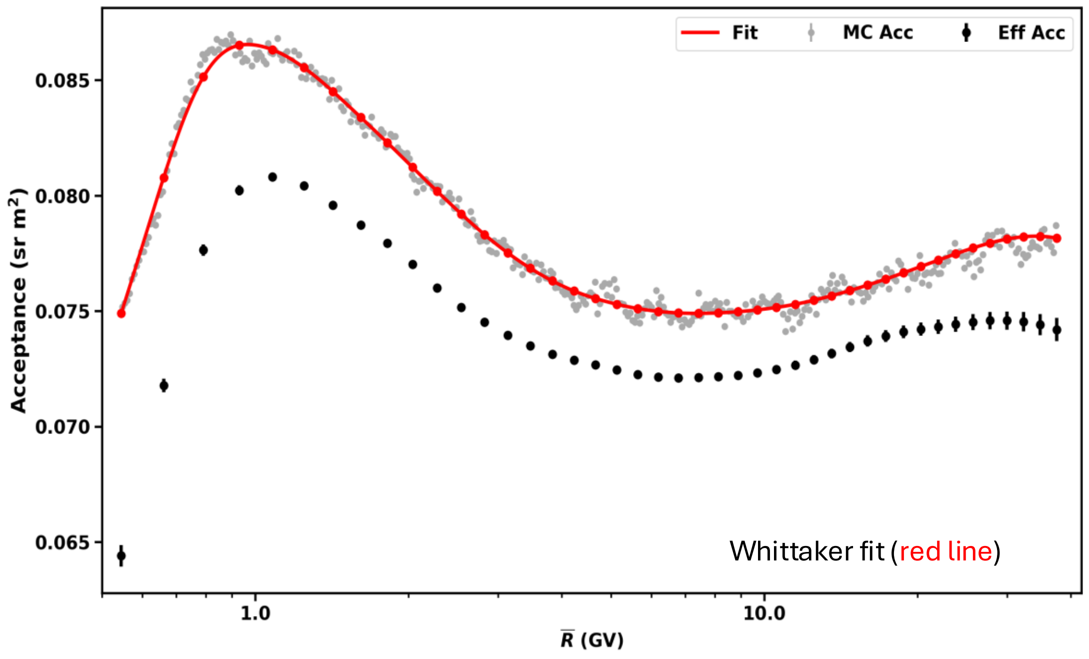
For 1 January 2016



$$C_{tot} = C_{l1} \times C_{tof} \times C_{trig} \times C_{track}$$

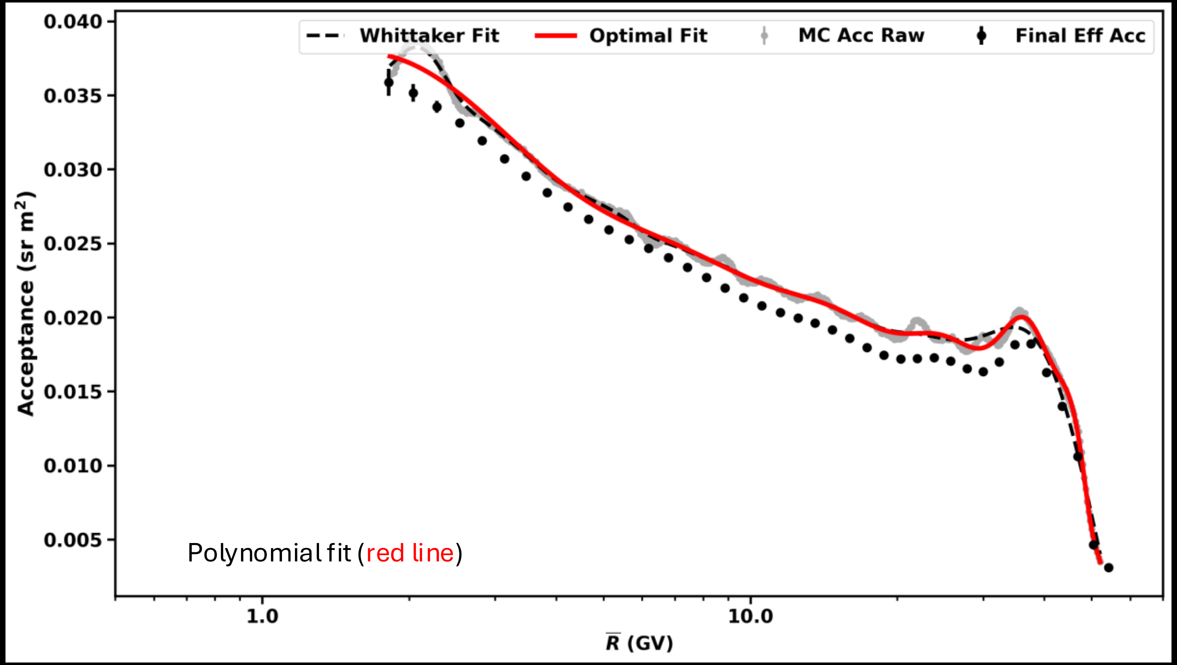
Monte Carlo and Effective Acceptance (Proton)

For 1 January 2022



Monte Carlo and Effective Acceptance (Helium)

For 1 January 2016

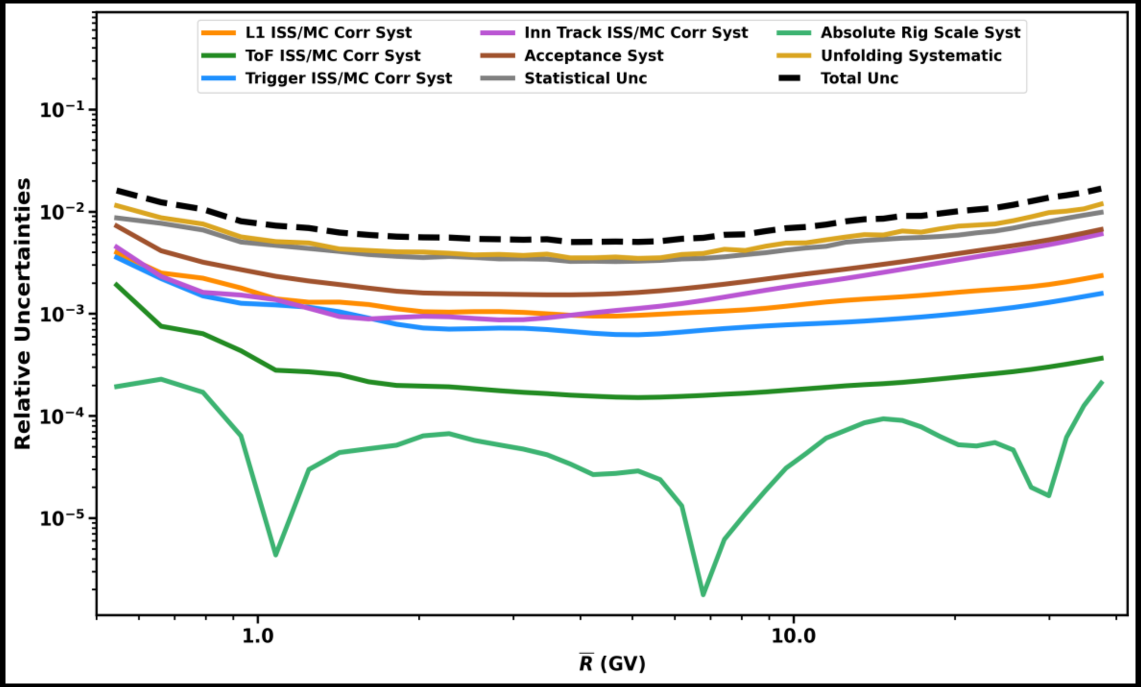


$$Acc_{MC}(R) = \frac{N_{sel}(R)}{N_{gen}(R)} (3.9\ m)^2\ (\pi\ sr)$$

$$Acc_{eff}(R) = Acc_{MC}(R) \times C_{tot}$$

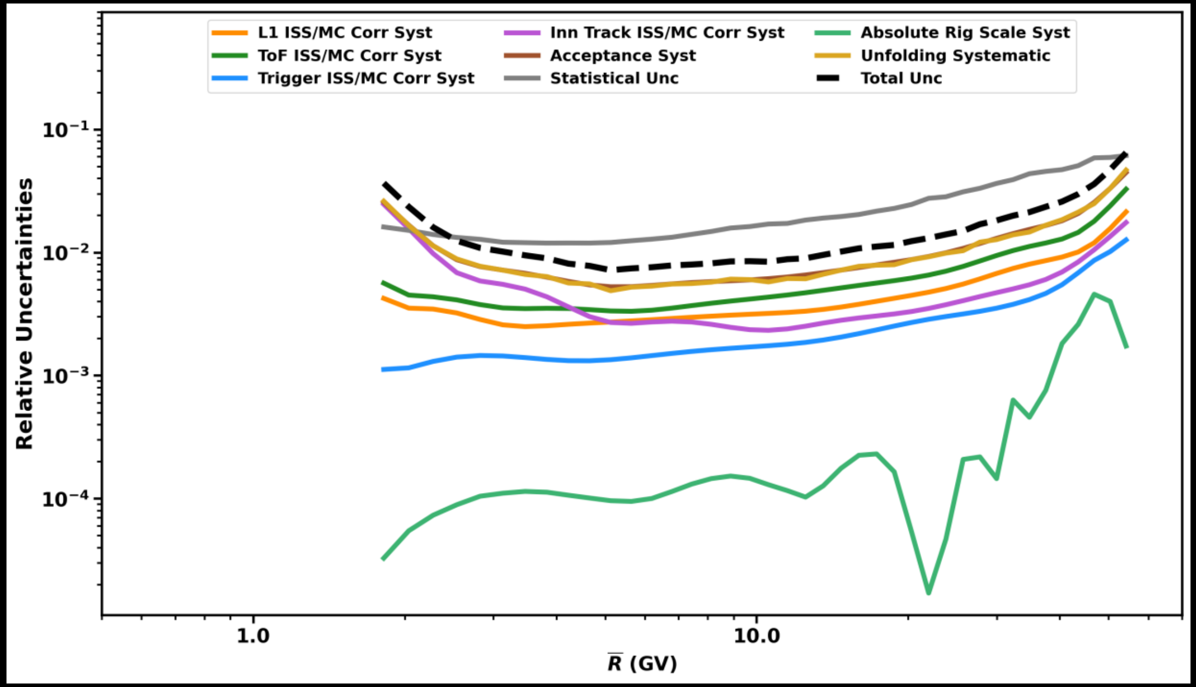
Daily flux uncertainties (Proton)

For 1 January 2022



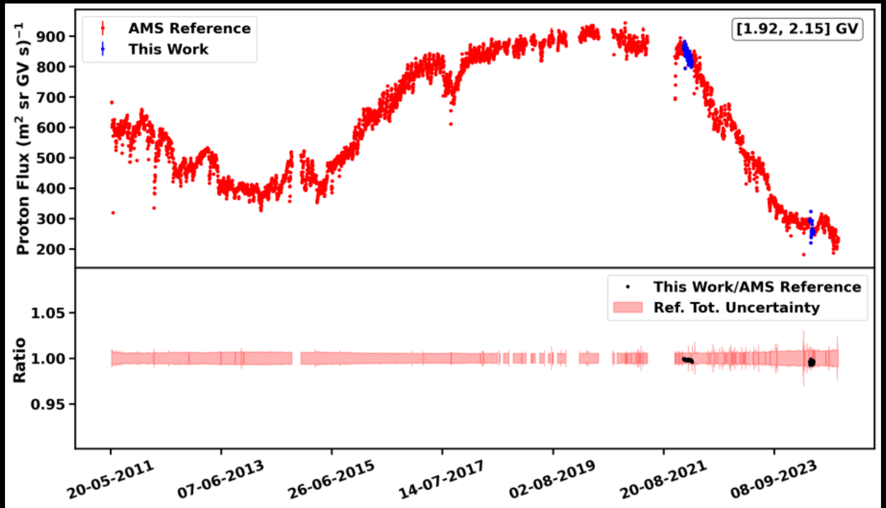
Daily flux uncertainties (Helium)

For 1 January 2016

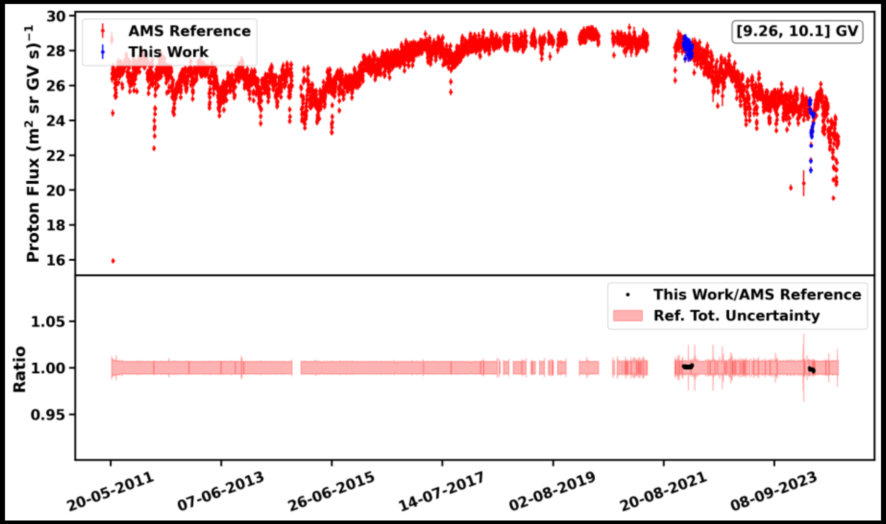


Daily proton flux

For two time periods:
January 1 to March 1, 2022 and May 2024
3 months in total



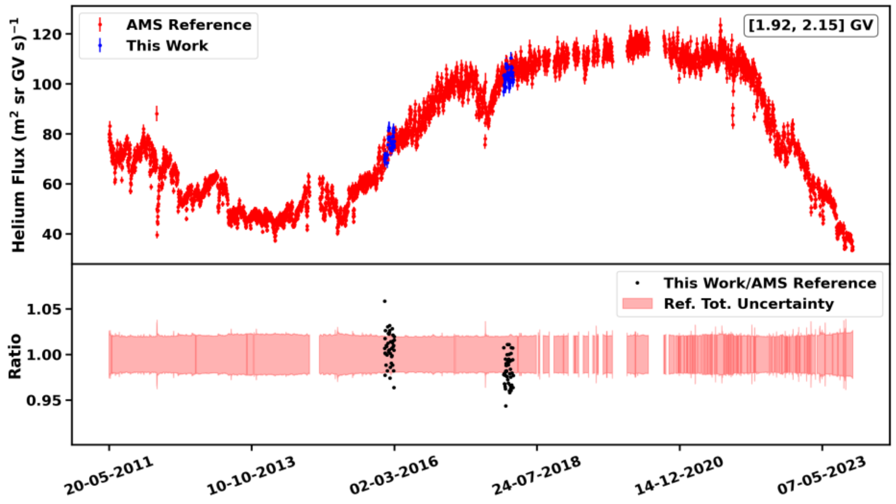
[1.92 – 2.15] GV

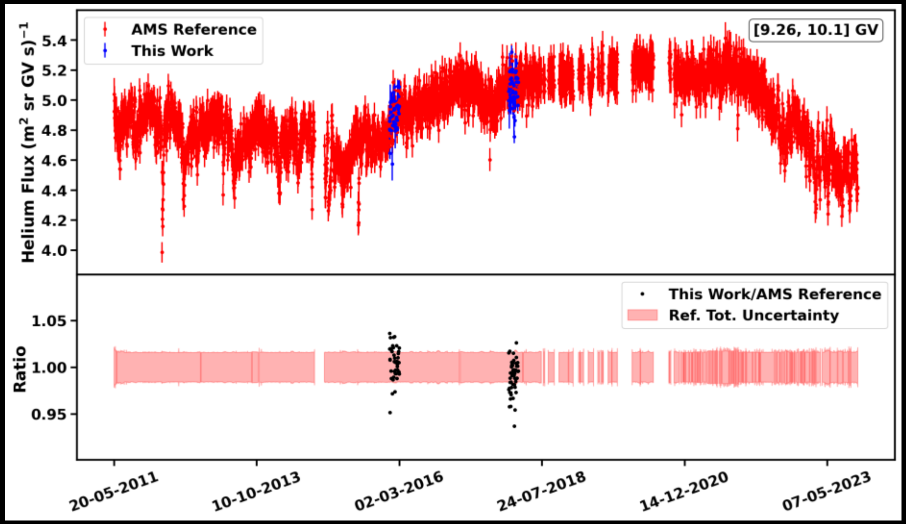


[9.26 – 10.1] GV

Daily helium flux

For two time periods:
January 1 to March 1, 2016 and January 1 to March 1, 2018
4 months in total





Thank you
for
attention