Development of LOST and Energy Reconstruction with LHAASO-WCDA

Ruiyi Tang ,Liu Shijie, Hao Zhou

Unfolding the name

Line-of-Sight Trigger

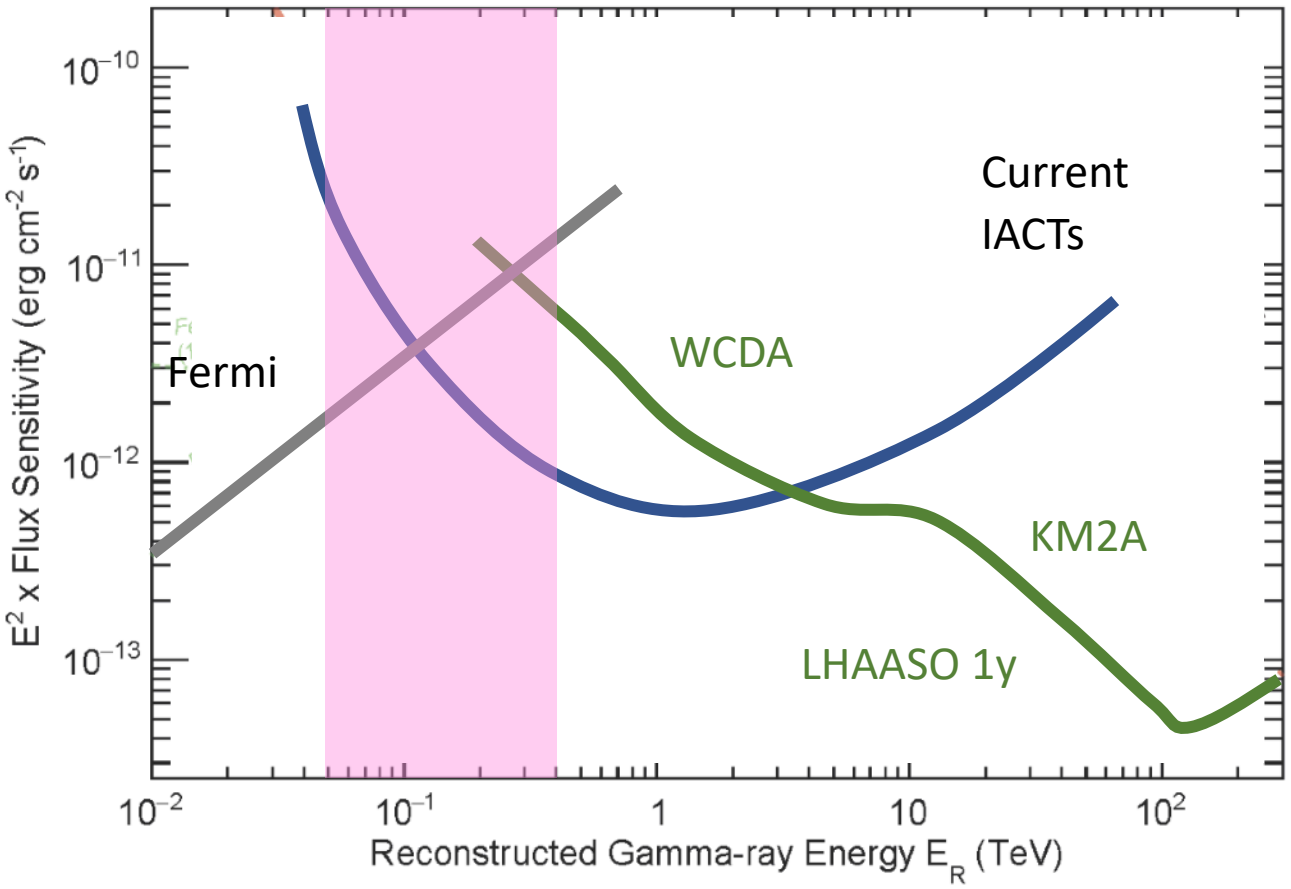
LOST Updates

Ruiyi Tang , Hao Zhou, Minhao Gu

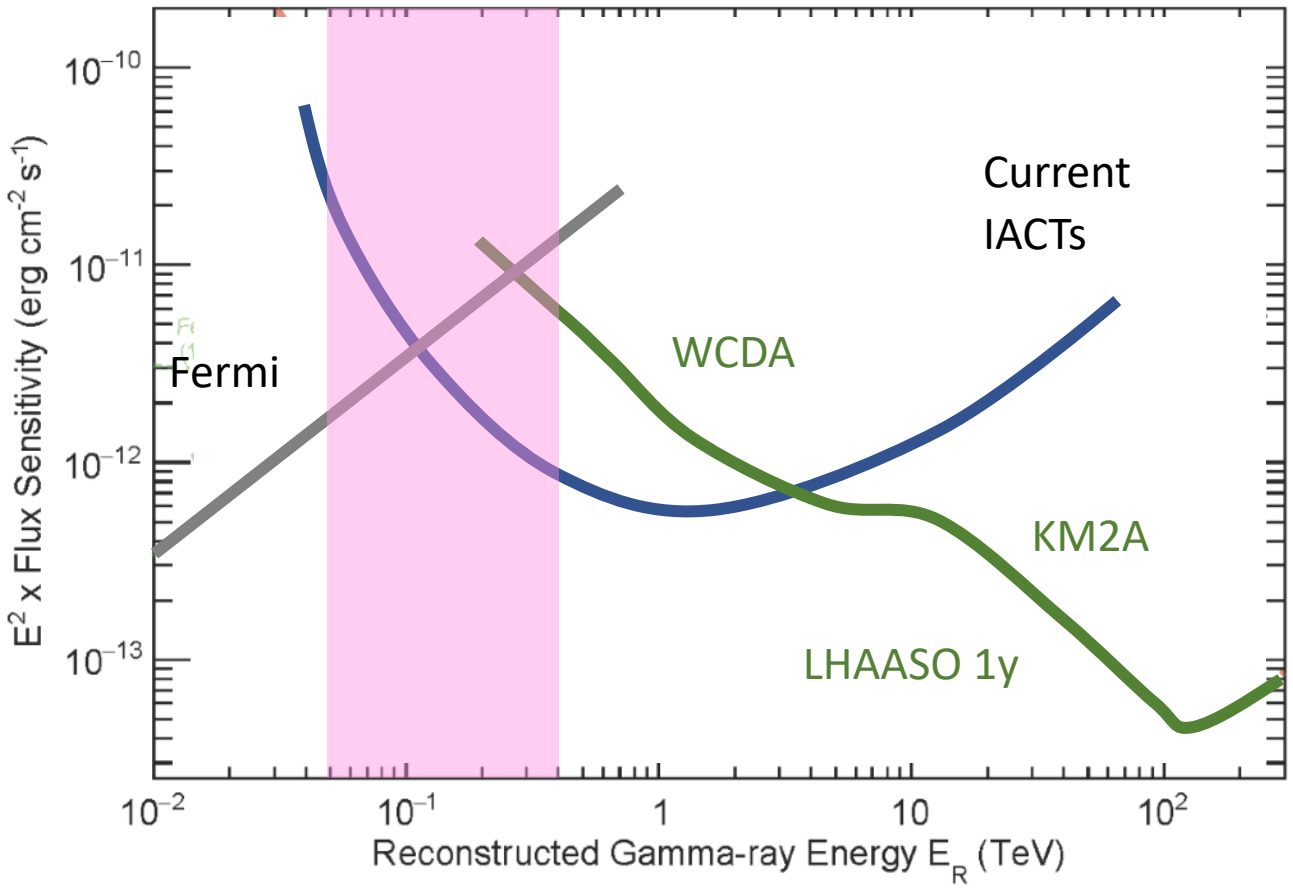
LOST trades all-sky coverage for enhanced low-energy sensitivity toward target directions

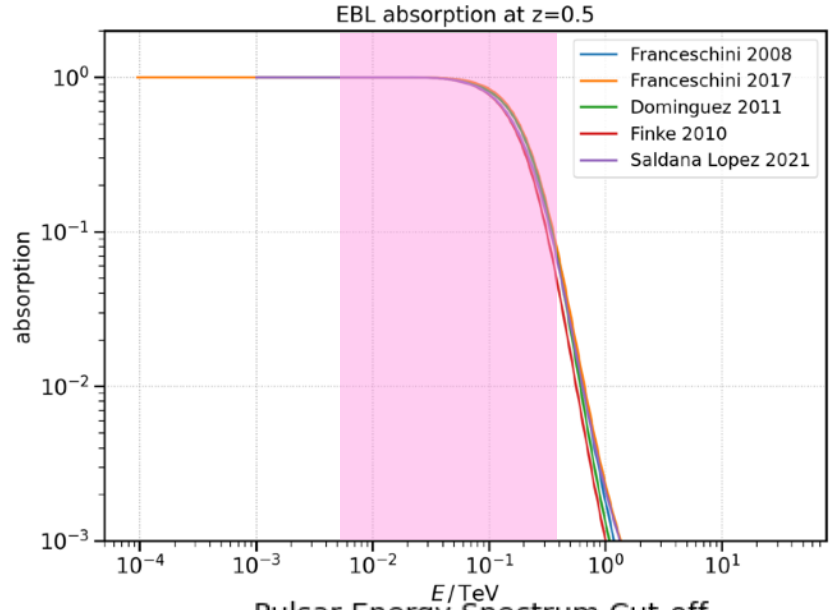


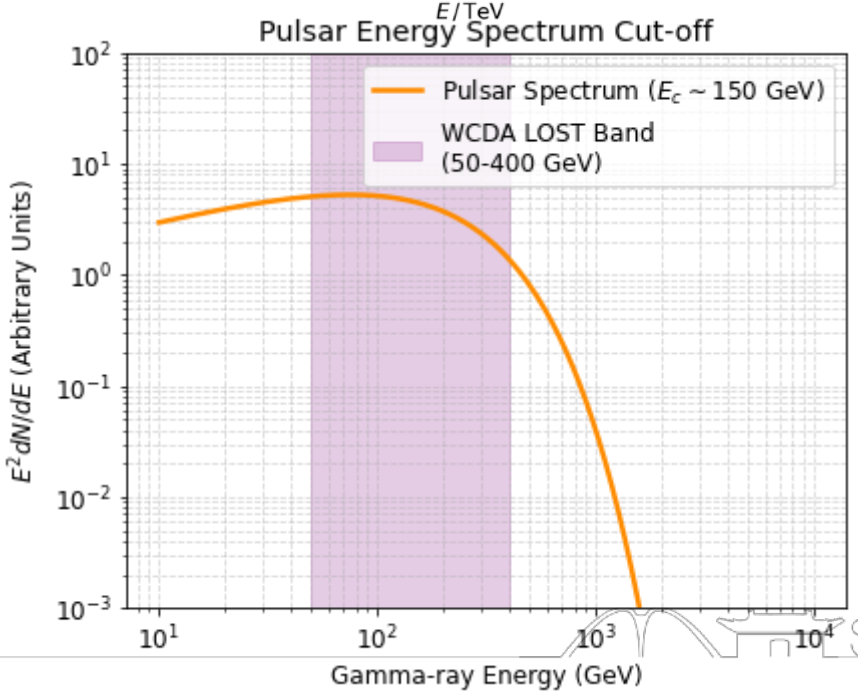
Motivation: Sensitivity Gap



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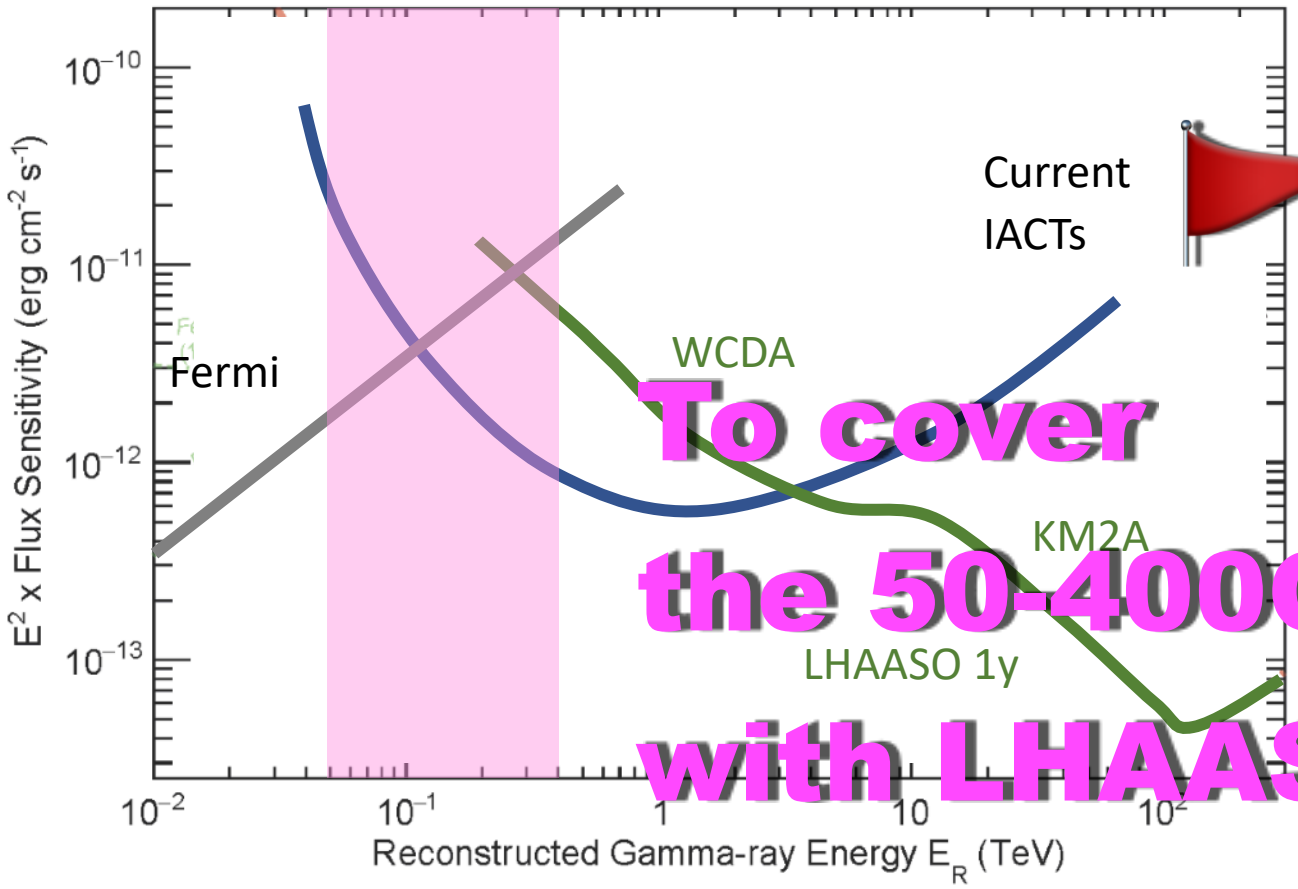




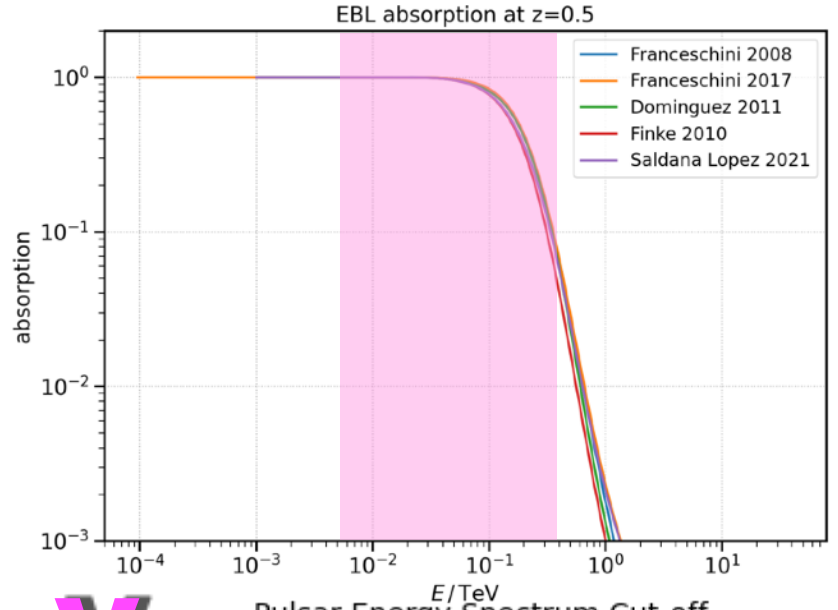


The highest-energy photons from distant or highly absorbed astrophysical sources fall within this sensitivity gap

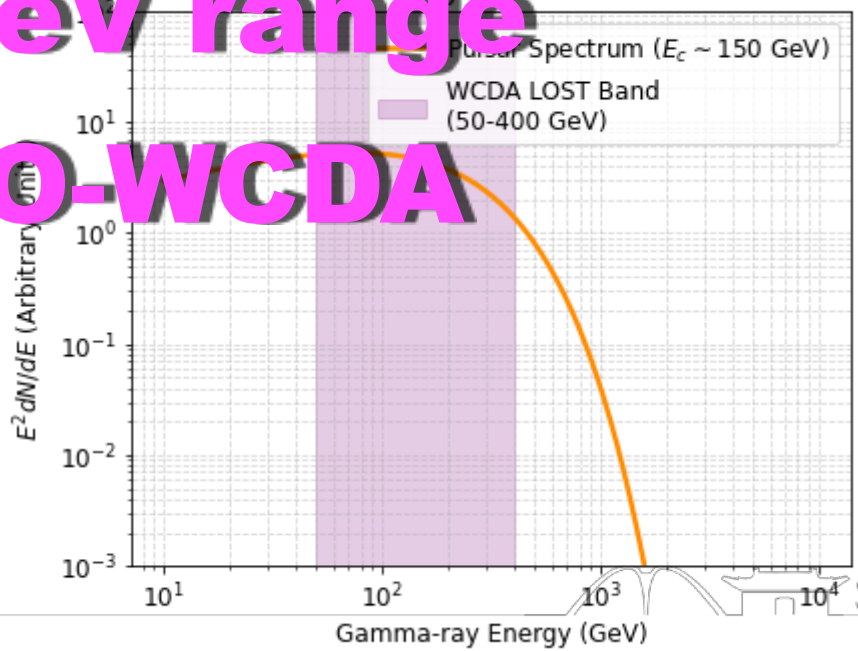
Motivation: Sensitivity Gap



To cover the 50-400GeV range with LHAASO-WCDA



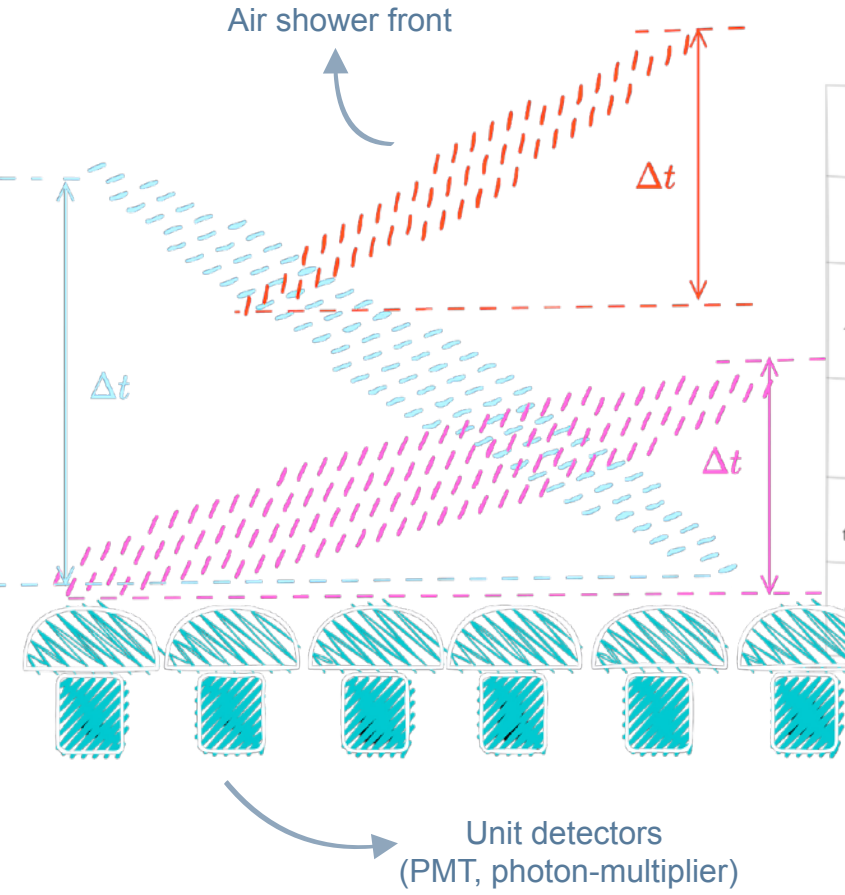
Pulsar Energy Spectrum Cut-off



The highest-energy photons from distant or highly absorbed astrophysical sources fall within this sensitivity gap

Method: From Standard Trigger to LOST

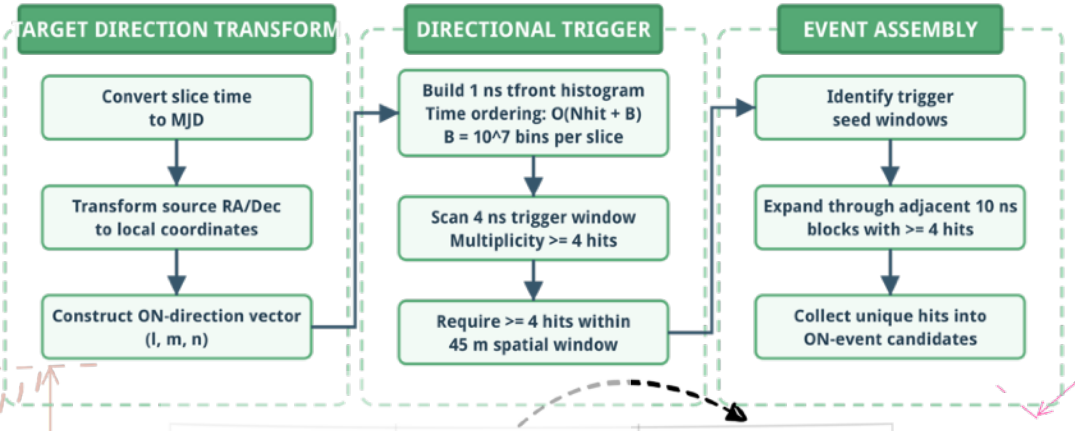
Energy threshold set by standard trigger: ~400GeV



	Standard Trigger
Target showers from	all directions
θ Angle between detector plane and EAS plane	Uncertain: varies from 0 up to $\frac{\pi}{2}$
Time spread of one shower from θ	$\Delta t \sim \sin\theta \cdot R \sim 10^2 ns$ Dominated by geometric effect
Time window to collect such a shower	**300ns** refer to detector plane
Nhit threshold to reject noise in such a time window	**30 hits**

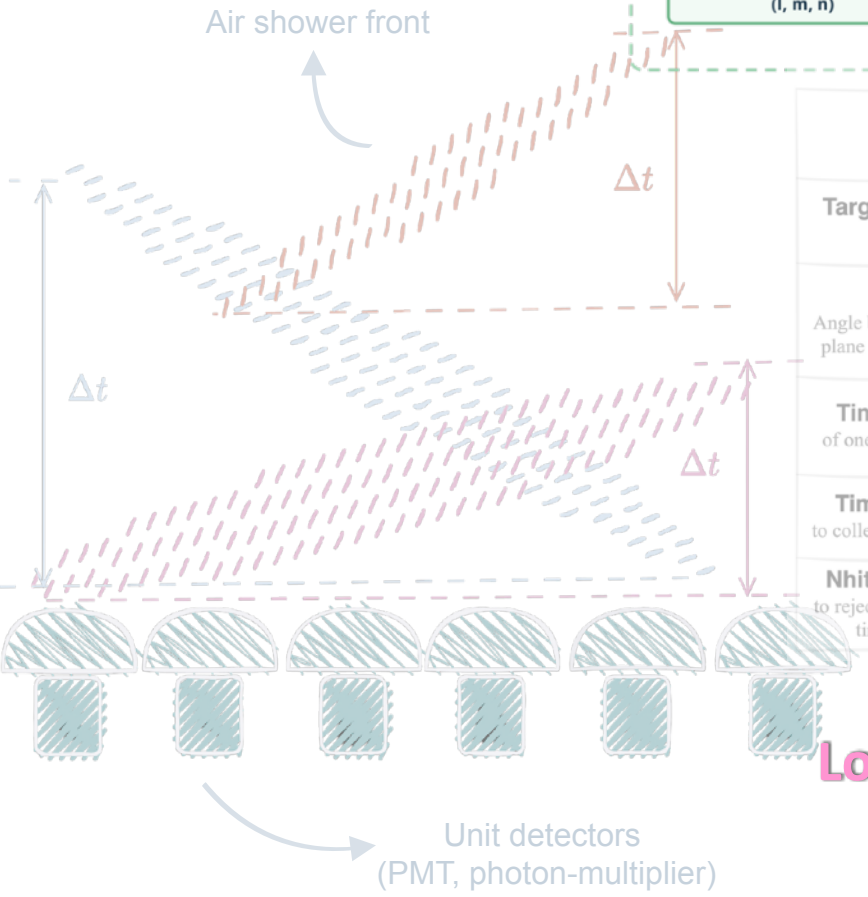
Limits low energy threshold

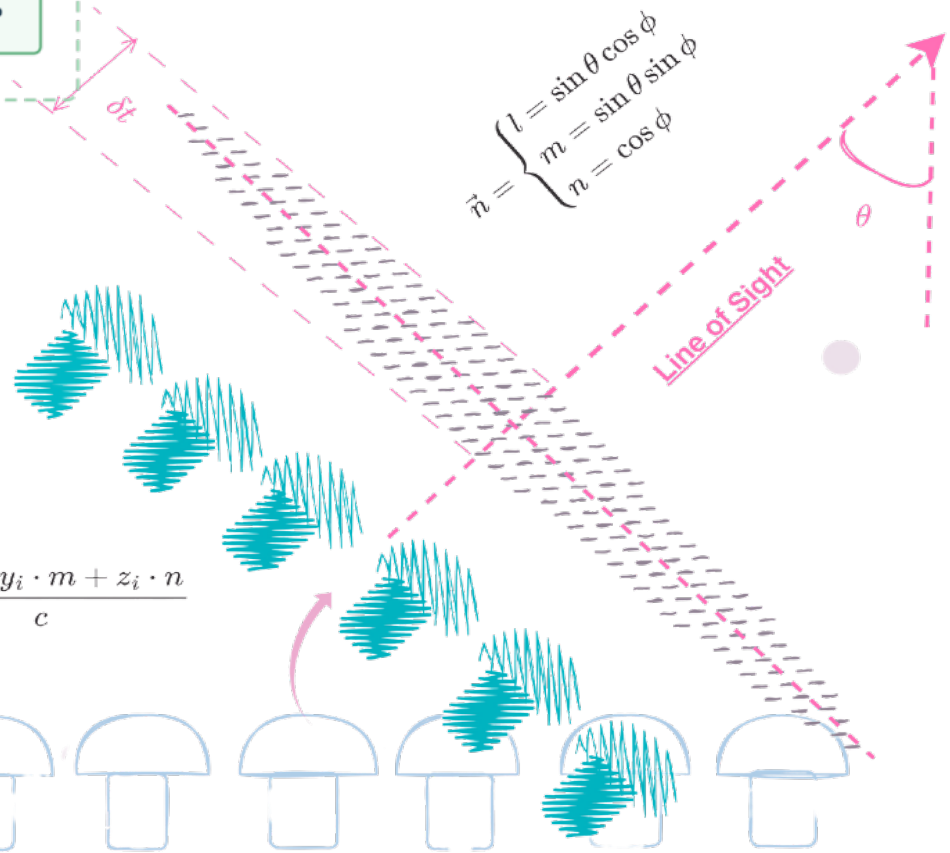
Method: From Standard Trigger to LOST



Imitating a telescope: virtually pointing to the source direction

	Standard Trigger	LOST
Target showers from	all directions	certain known direction
θ Angle between detector plane and EAS plane	Uncertain: varies from 0 up to $\frac{\pi}{2}$	Certain angle Plane transformation to parallel array with ESA
Time spread of one shower from θ	$\Delta t \sim \sin\theta \cdot R \sim 10^2 ns$ Dominated by geometric effect	$\delta t \sim ns$ Intrinsic thickness of shower front
Time window to collect such a shower	300ns refer to detector plane	10ns refer to ESA front
Nhit threshold to reject noise in such a time window	30 hits	4 hits



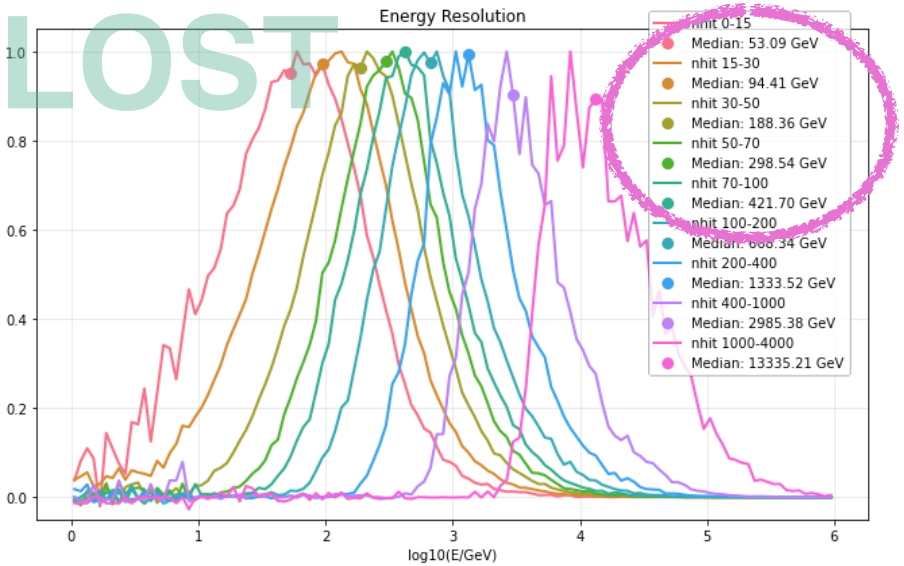


$$t_{\exp} = \frac{x_i \cdot l + y_i \cdot m + z_i \cdot n}{c}$$

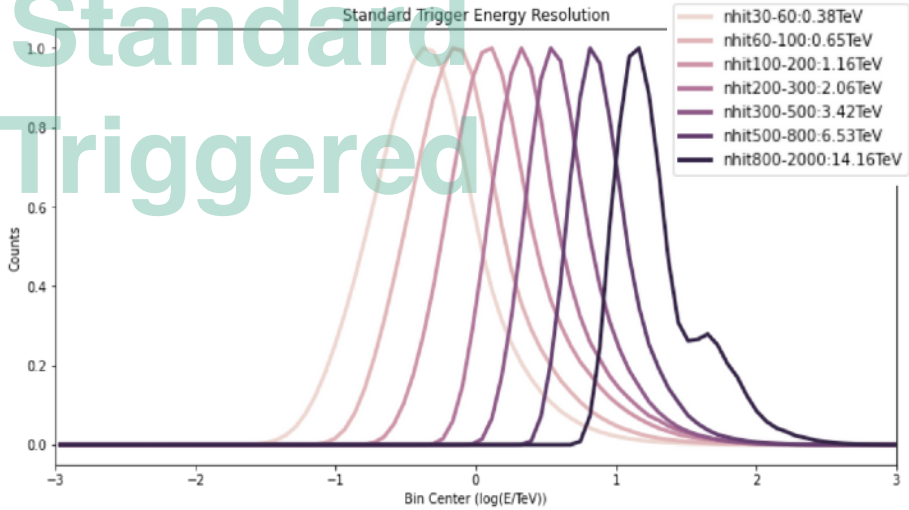
Lowered the energy threshold !!!

Offline Performance

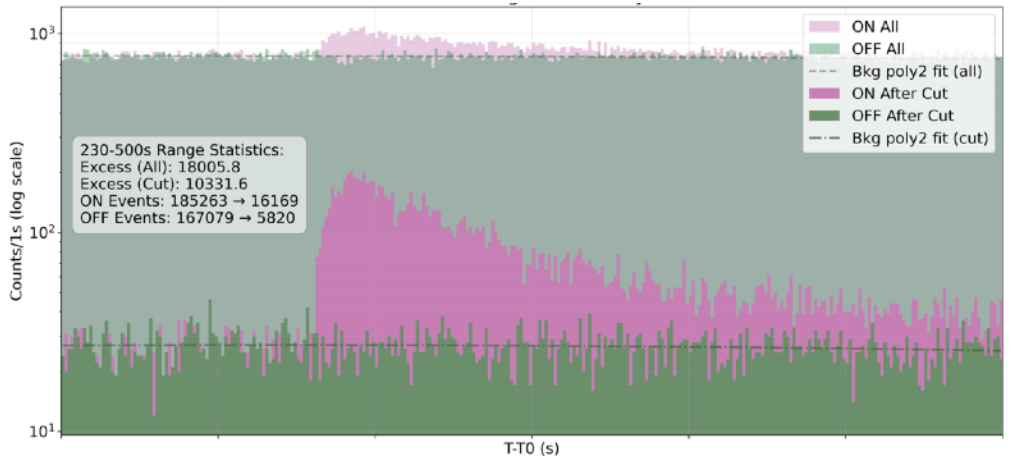
LOST

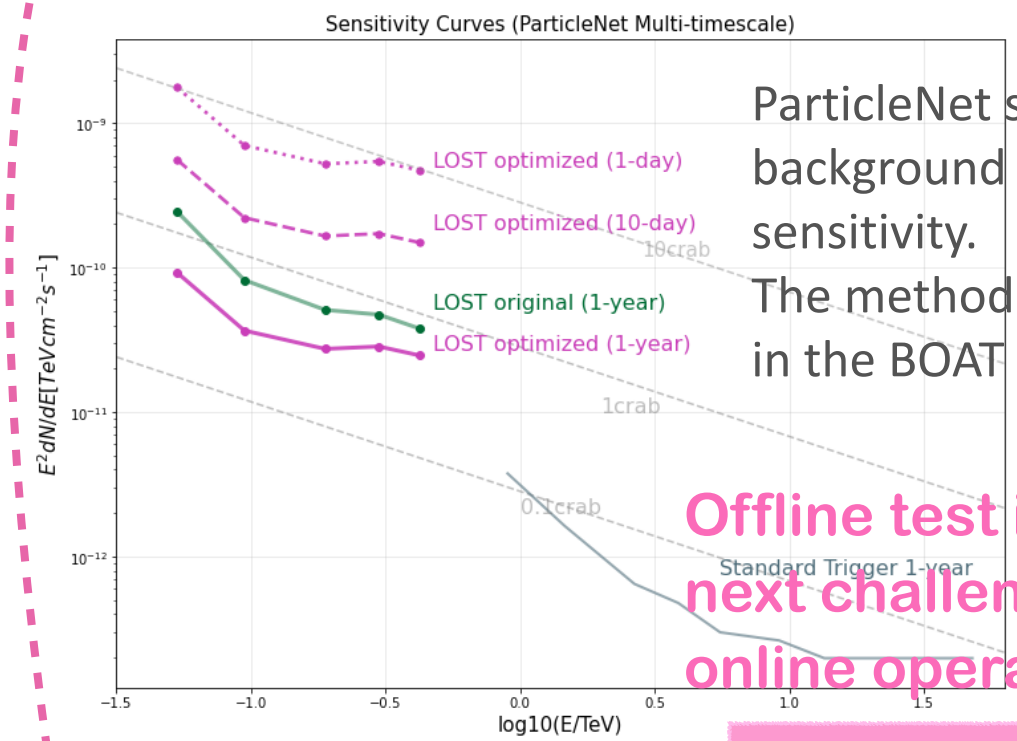


Standard Triggered



Energy threshold is effectively extended below 100GeV



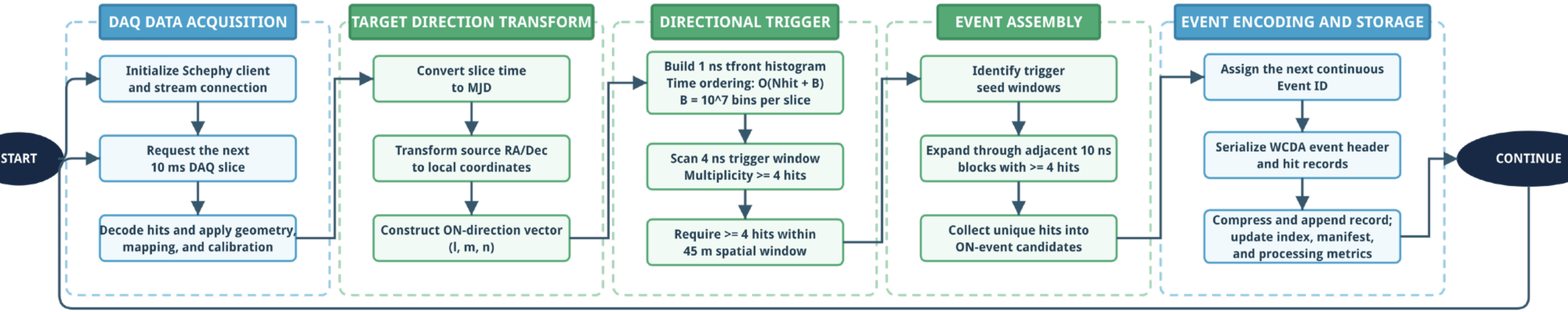


ParticleNet suppresses the background and improves sensitivity.

The method has been demonstrated in the BOAT GRB light curve.

Offline test is practical, the next challenge is sustainable online operation

Online Implementation



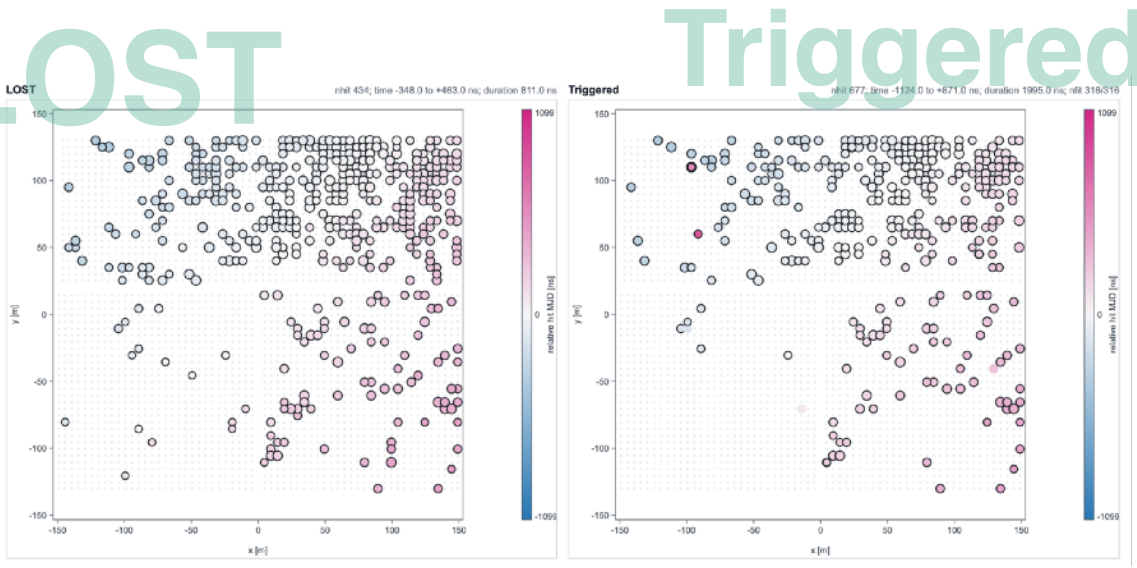
Expectations:

1. Recover all events accepted by the standard-trigger
2. Recover additional low-energy candidates missed by the standard-trigger
3. Sustain long-term real-time operation below 10 MB/s per directional window

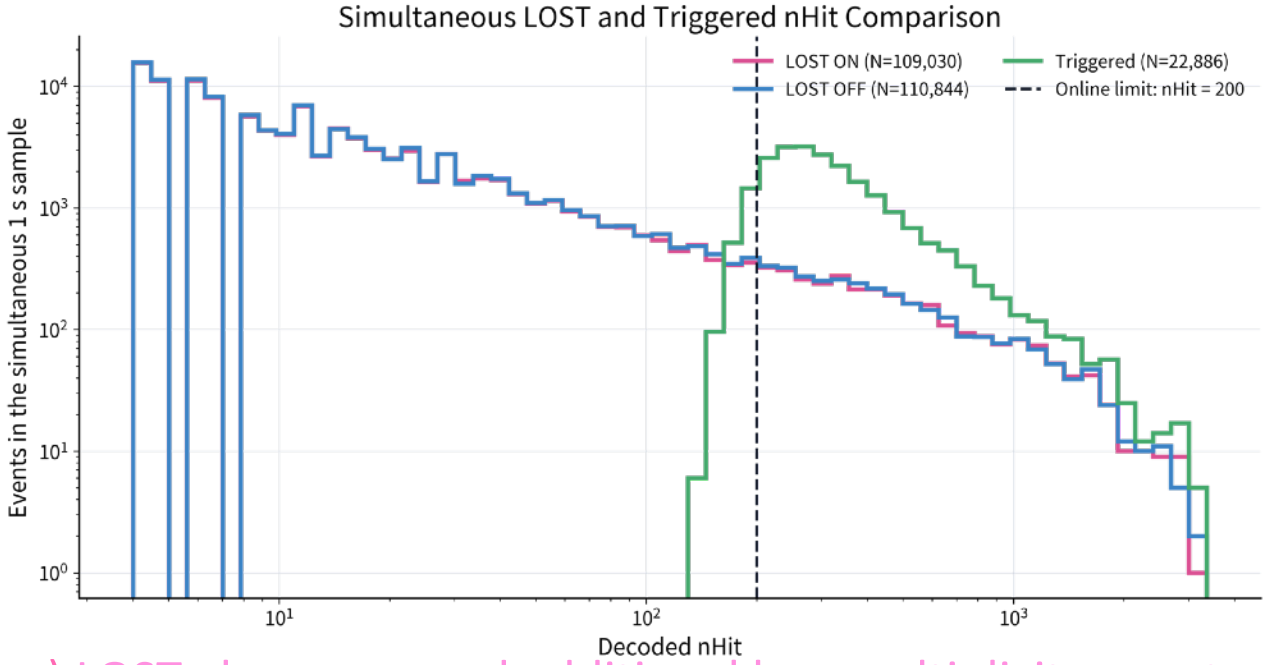
Test Run:

Simultaneous LOST & standard-trigger data for a direct performance and throughput comparison

Online Test: High Efficiency, Unsustainable Throughput



:) LOST recovered 100%(98%) of standard-trigger events within 3° (10°) of the target direction



:) LOST also recovered additional low-multiplicity events

Expectations:

1. Recover all events accepted by the standard-trigger :)
2. Recover additional low-energy candidates missed by the standard-trigger :)
3. Sustain long-term real-time operation below 10 MB/s per directional window :(

Stream	Event rate [Hz]	Binary-equivalent throughput [MB/s]
ON	109,030	39.71
OFF	110,844	40.29
Combined	219,874	80.00

:(DATA FLOOD!
comparable to whole sky standard-trigger

Online cut strategies

Events Decomposition:

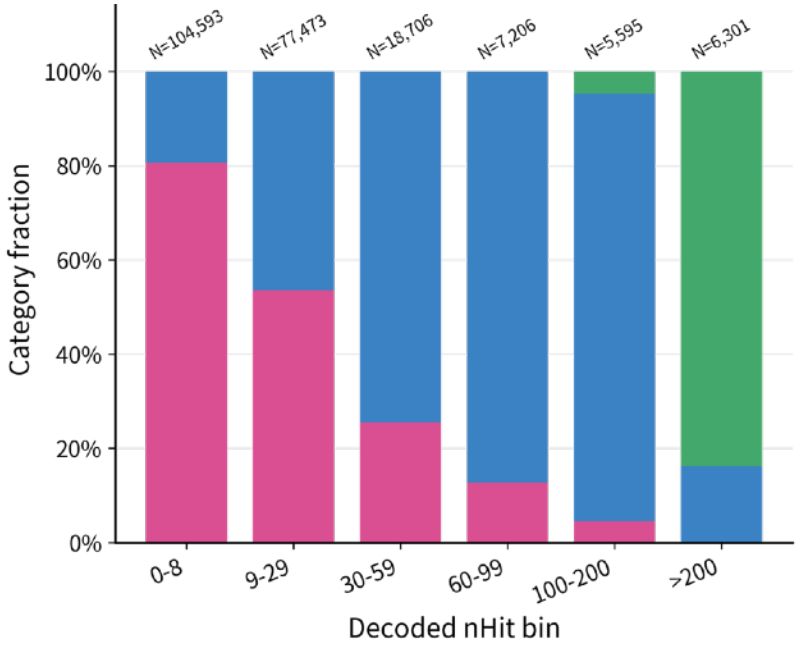
Shared: Large event shared by LOST and Triggered from around LoS

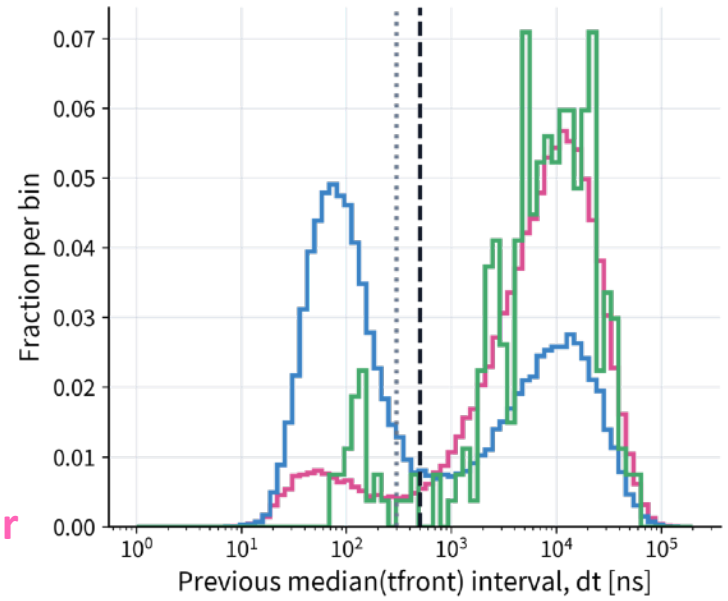
Fragment: Small fragments of large Triggered events away from LoS

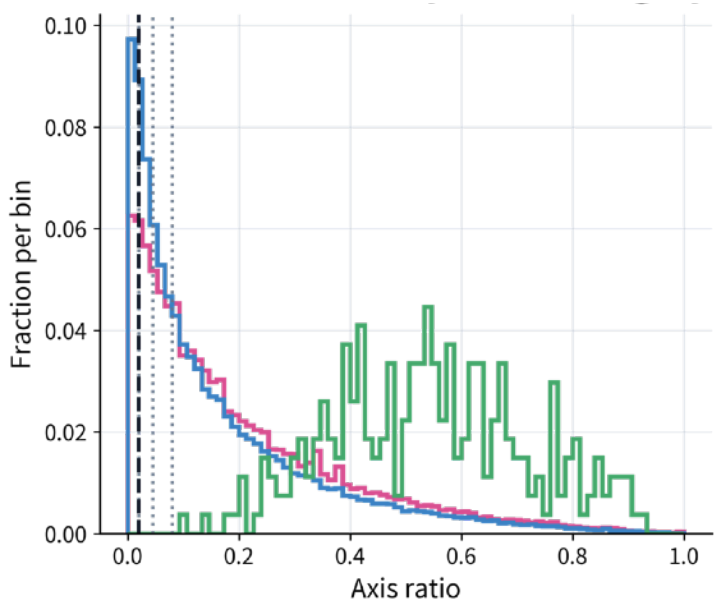
Other: LOST only small events

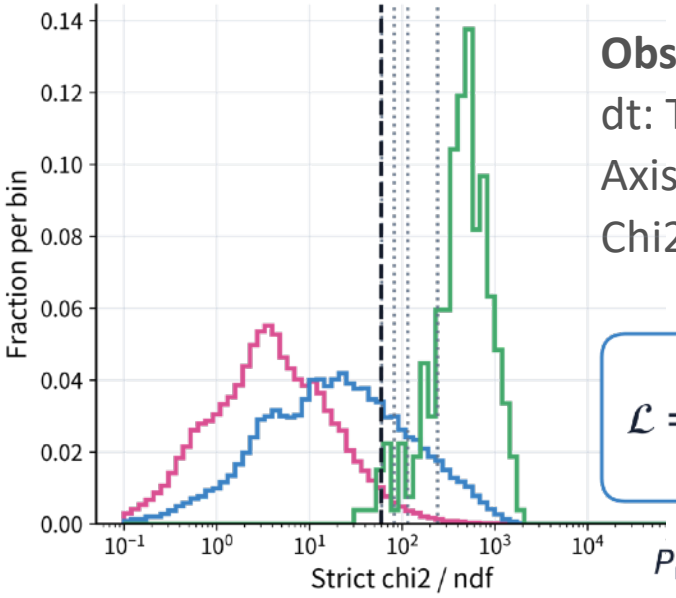
Optimization objective:

Reject Shared and Fragment, while retain **Other**









Observable construction:

dt: Time interval along LoS for adjacent events

Axis ratio: Lateral elongation of shower footprint

Chi2/ndf: Directional timing fit quality

$$\mathcal{L} = -\sum_{k=1}^{4}(\varepsilon_{S,k} - w\,\varepsilon_{F,k}) + \lambda\,\mathrm{Var}_k(\varepsilon_{S,k}) + P_{\mathrm{rate}}$$

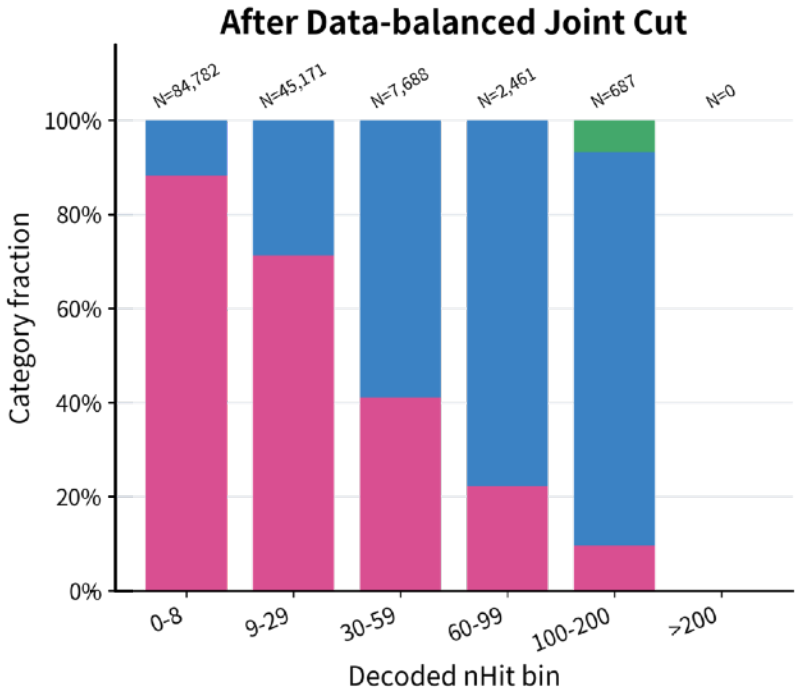
$$P_{\mathrm{rate}} = 0 \quad (R \le 10), \qquad P_{\mathrm{rate}} = 10^6(R-10)^2 \quad (R > 10)$$

$$R = \max(R_{\mathrm{ON}}, R_{\mathrm{OFF}})\ [\mathrm{MB/s}]$$

Online + Offline data reduction

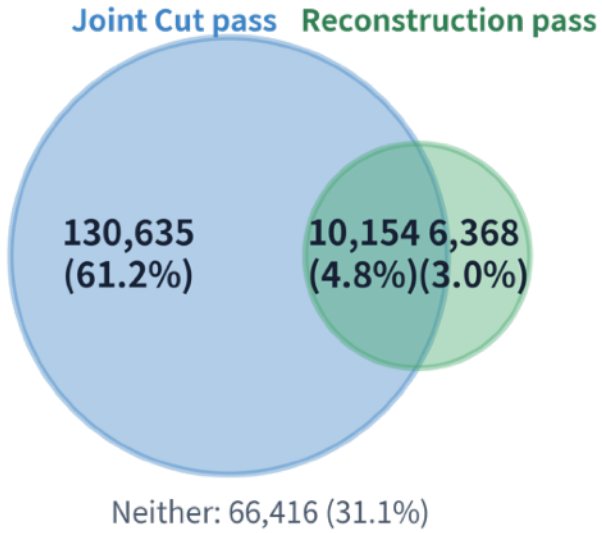
The Joint Cut reduces the data stream from 40.00 to 9.78 MB/s, a 75.6% reduction.

Stage	Rate [Hz]	Binary [MB/s]
Original	109,937	40.00
Joint Cut	70,394	9.78

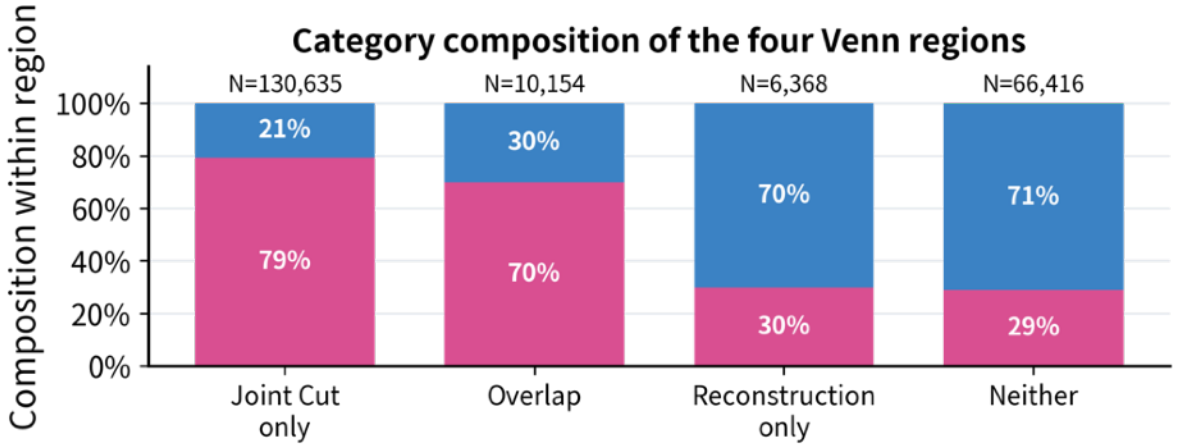


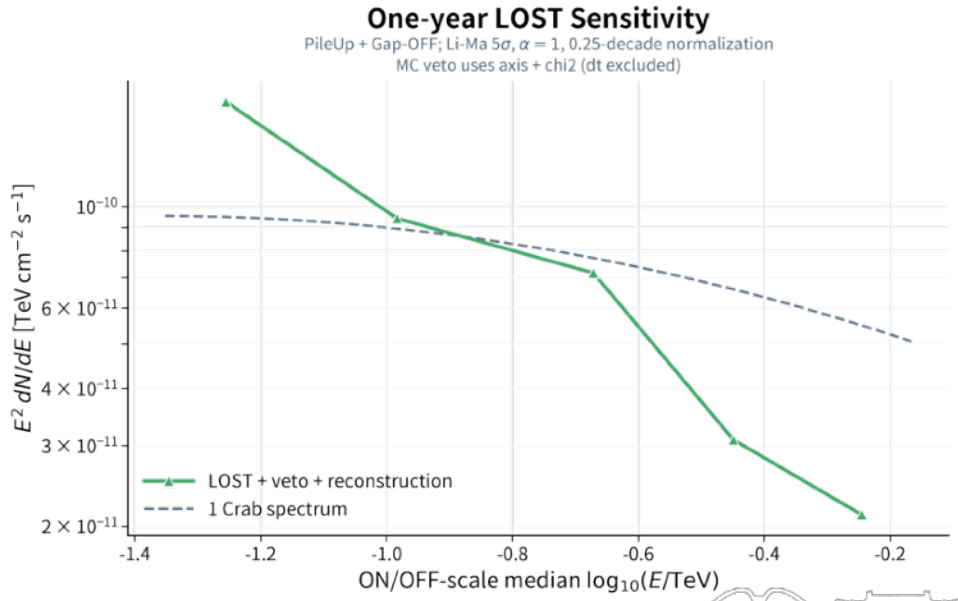
Online + Offline data reduction

Reconstruction further reduces the stream to 1.06 MB/s and extends the selection beyond the Joint Cut.



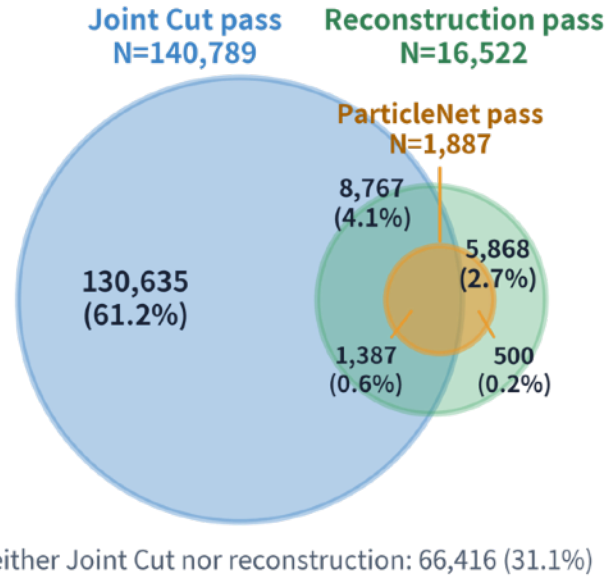
Stage	Rate [Hz]	Binary [MB/s]
Original	109,937	40.00
Joint Cut	70,394	9.78
+ Reconstruction	5,077	1.06



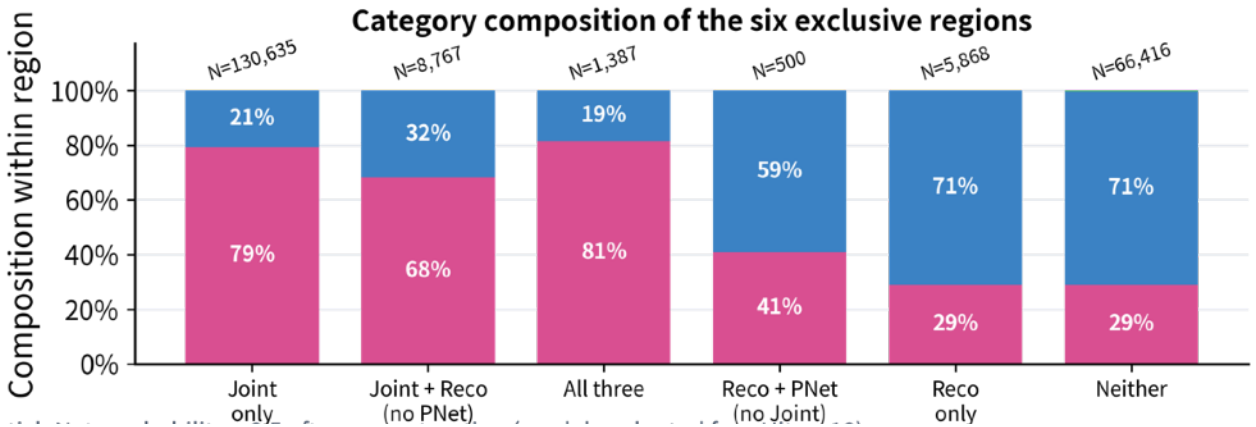


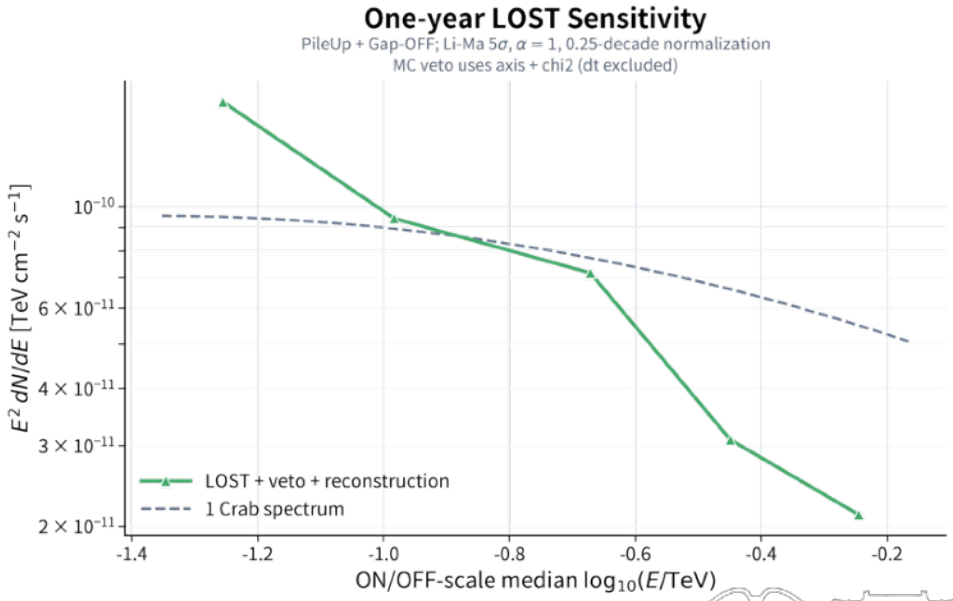
Online + Offline data reduction

Adding ParticleNet lowers the stream to 0.14 MB/s, a 99.65% reduction from the original data load.

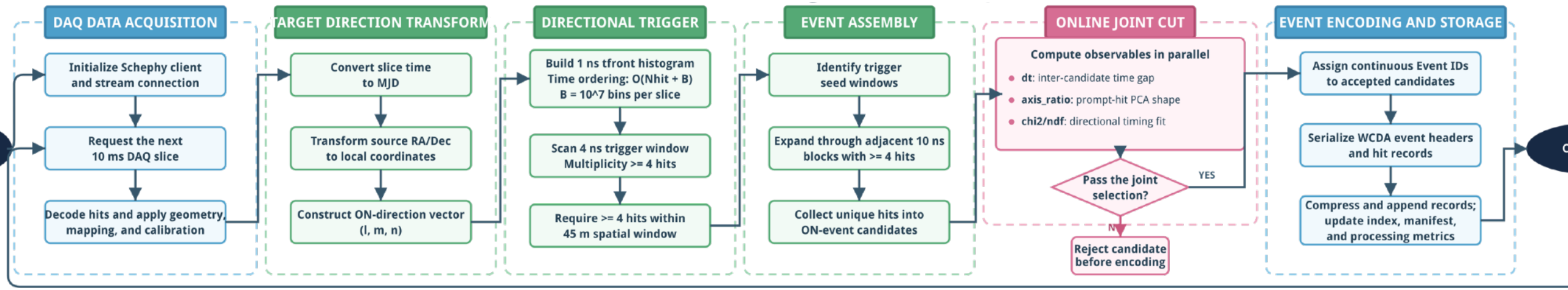


Stage	Rate [Hz]	Binary [MB/s]
Original	109,937	40.00
Joint Cut	70,394	9.78
+ Reconstruction	5,077	1.06
+ ParticleNet	694	0.14





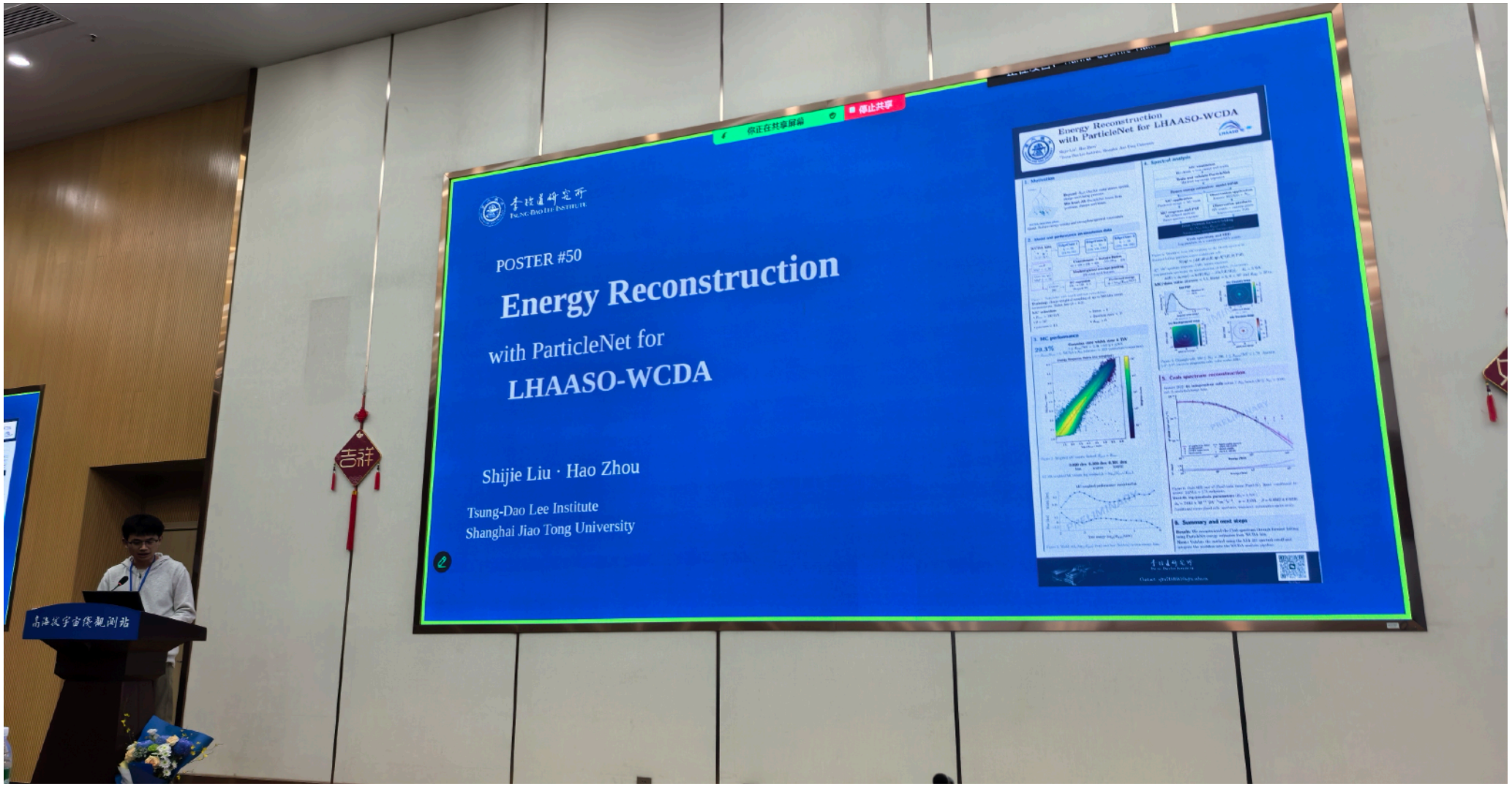
Current Status and Next Steps



Current status
Pipeline running online with an after-selection stream: <10 MB/s per window.
Preliminary sensitivity extends below the standard WCDA threshold.

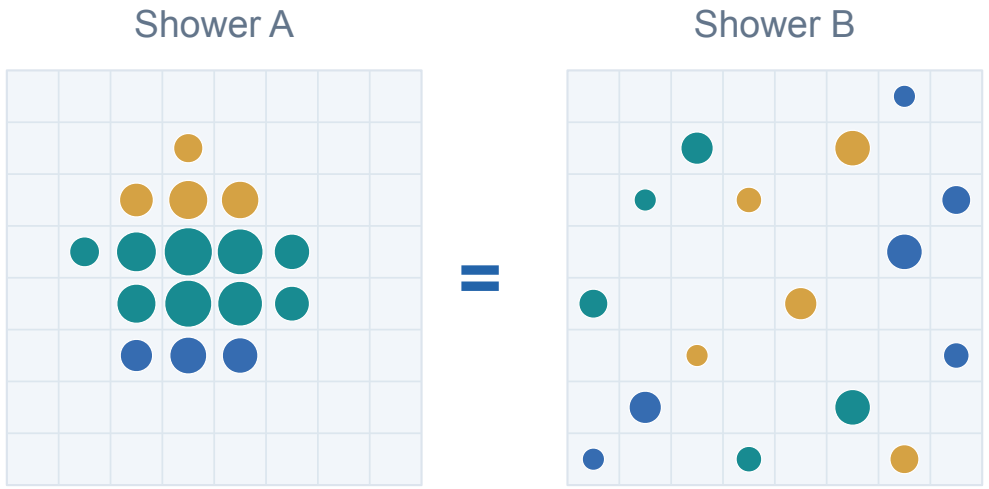
Next steps
Validate efficiency with longer test data samples.
Develop a background template
Complete long-term tests and deploy physics alerts.

Takeaways
LOST has WCDA mimic a pointing telescope,
targeting for continuous observations in the 50–400 GeV sensitivity gap.


POSTER #50
Energy Reconstruction
with ParticleNet for
LHAASO-WCDA
Shijie Liu · Hao Zhou
Tsung-Dao Lee Institute
Shanghai Jiao Tong University
Energy Reconstruction with ParticleNet for LHAASO-WCDA

Motivation: beyond Nhit as an energy proxy

Nhit

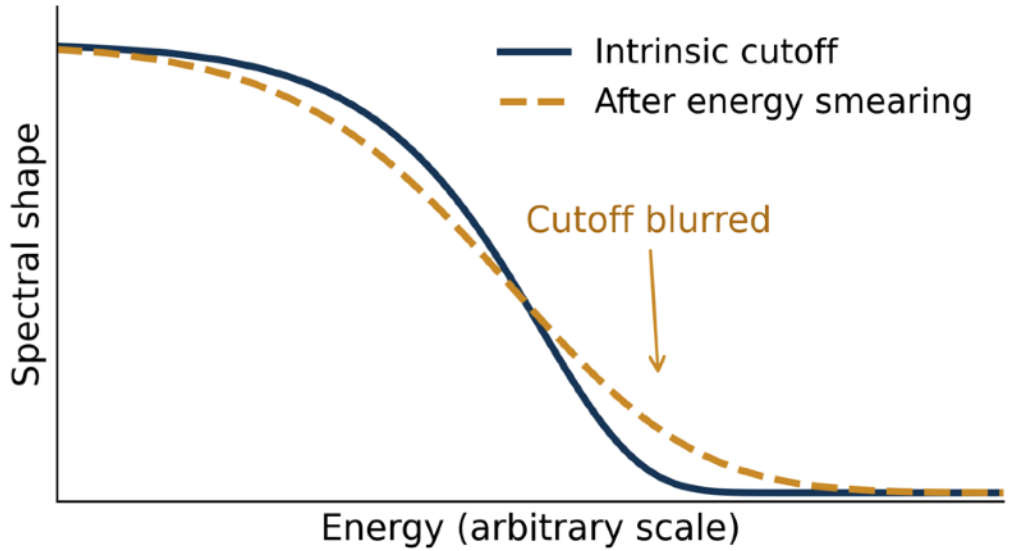


Same Nhit, different hit patterns

Size: charge q; color: time t

Events with the same Nhit can have different true energies.
Hit-level information helps distinguish these events.

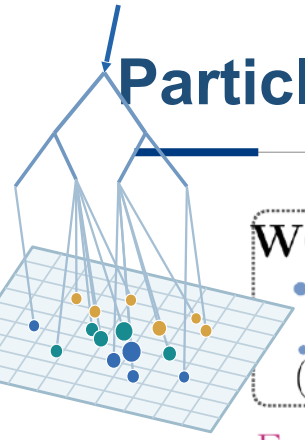
Spectral smearing

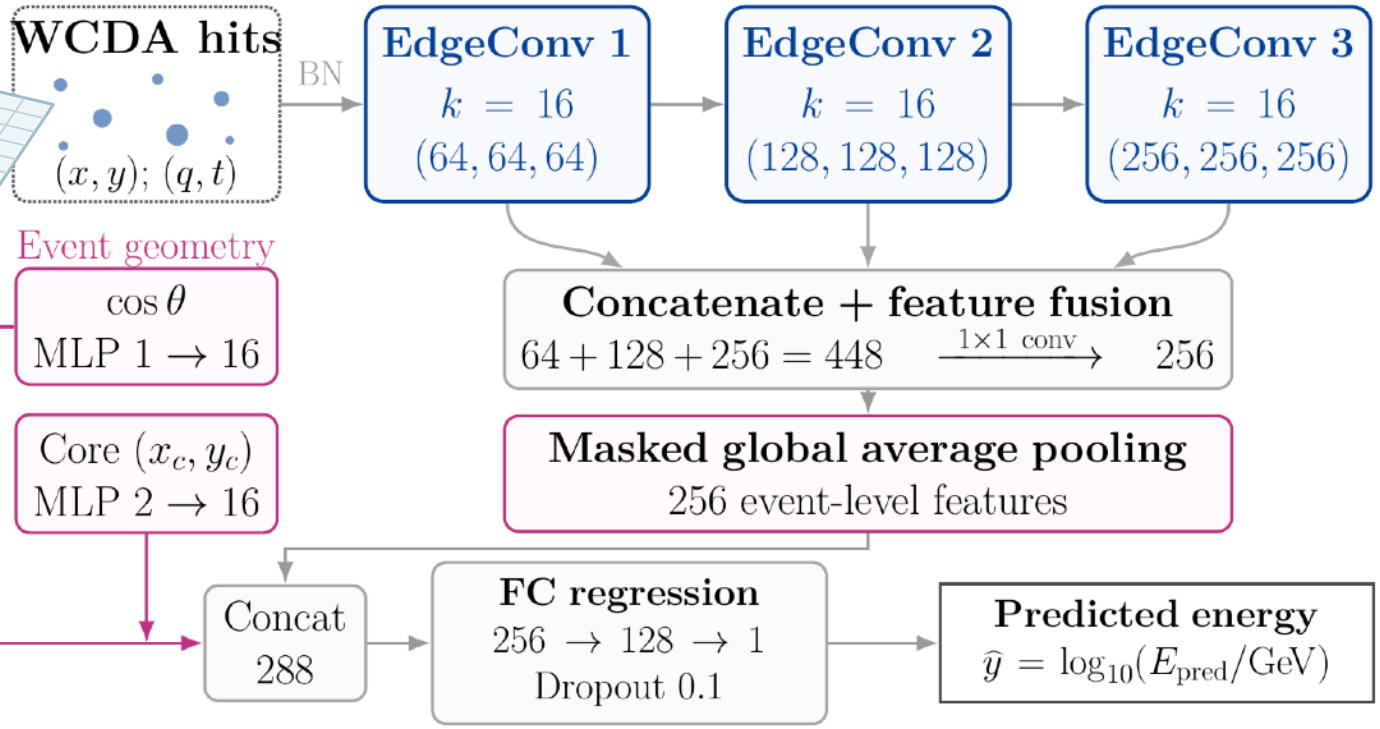


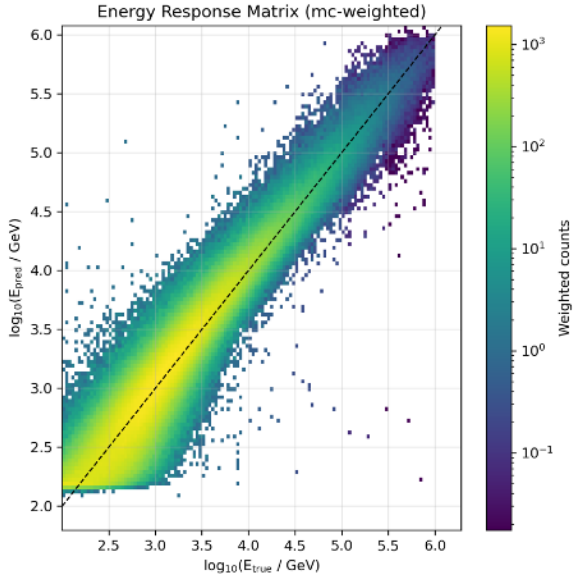
Curvature and cutoffs are blurred

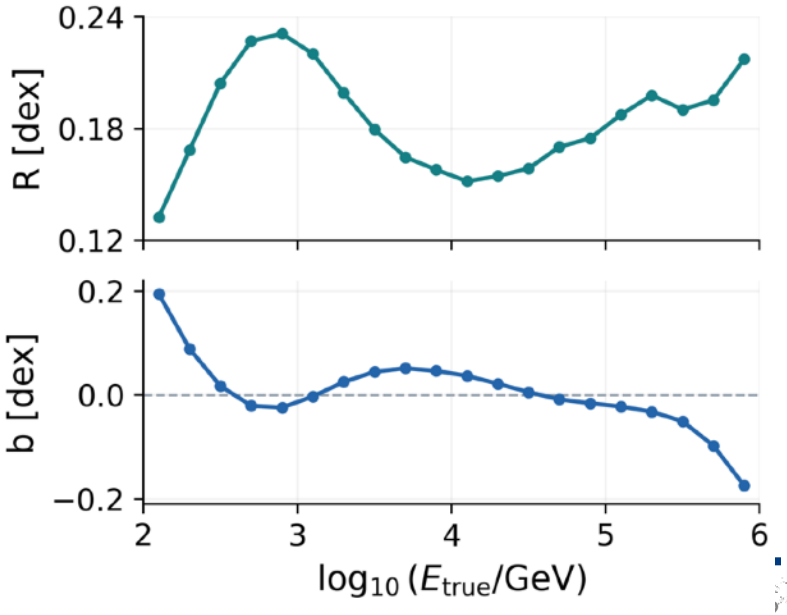
Use hit information to reduce energy migration and constrain spectral curvature and cutoffs.

ParticleNet: from WCDA hits to event energy







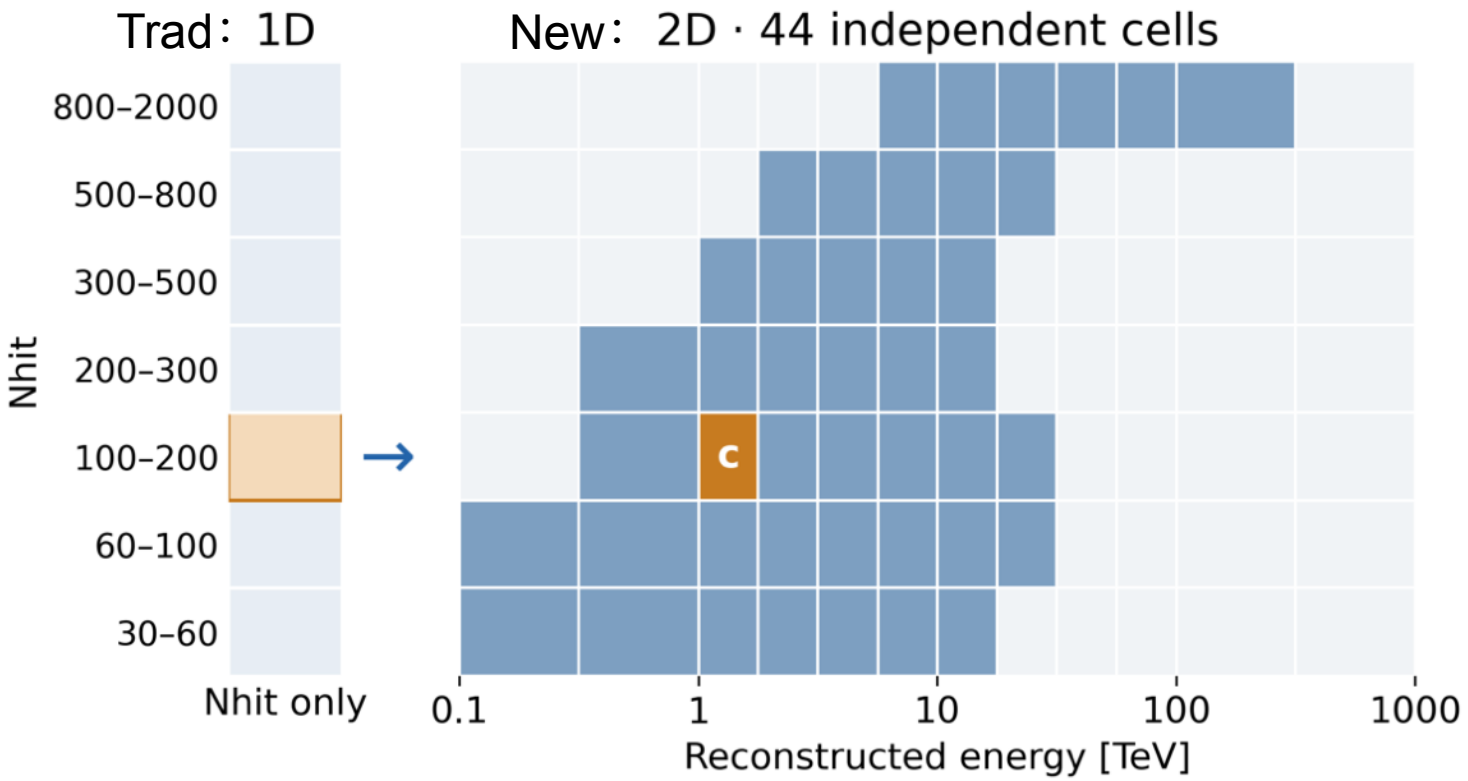


Resolution: $r = \sqrt{\left\langle \left(\log_{10}\hat{E} - \left\langle \log_{10}\hat{E} \right\rangle\right)^2 \right\rangle}$

Bias: $b = \left\langle \log_{10}\hat{E} - \log_{10}E \right\rangle$

Nhit × Erec binning

Cell selection: MC 1%-99% quantile band



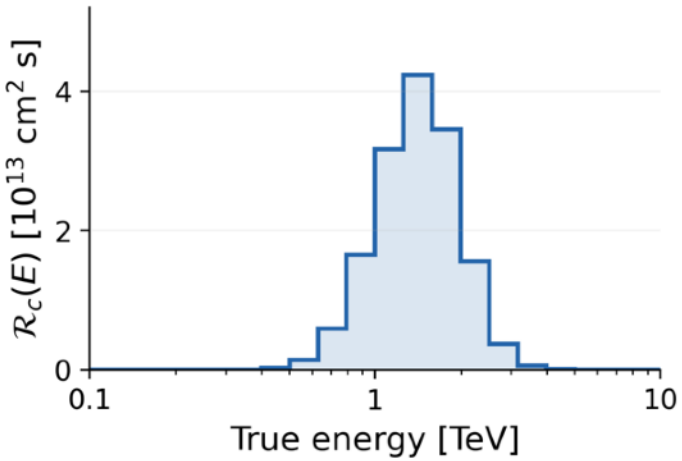
Example：

Cell c: n3:e3

100 ≤ Nhit < 200

1.00 ≤ Erec < 1.78 TeV (0.25dex)

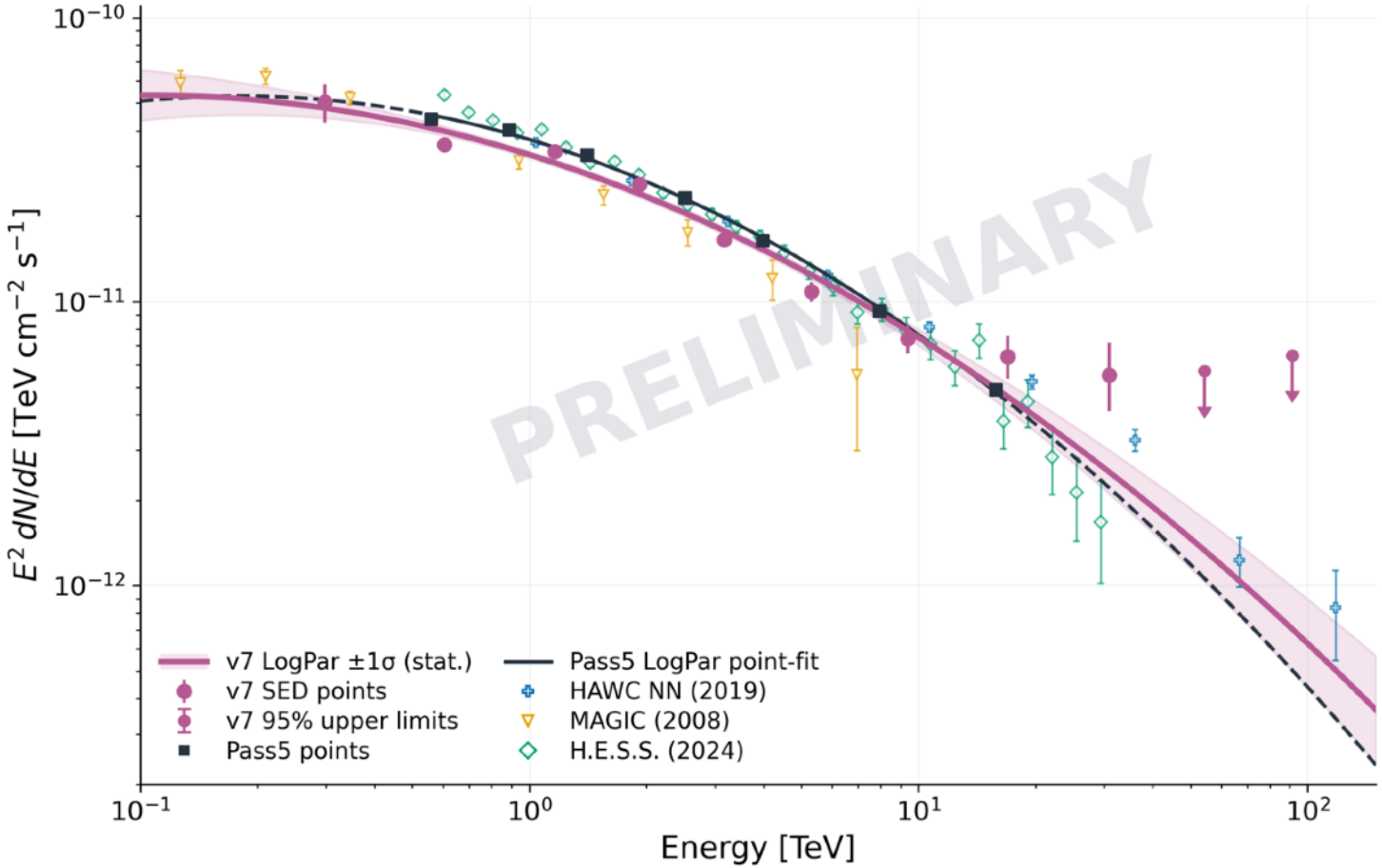
MC weighted distribution



DATA: **MC:** T043g: 10,000 files; **Obs:** January 2022: 681 files

Crab spectrum (preliminary)

Obs DATA: January 2022; 44 independent cells



χSQ Pass5 for reference.

Log-parabola

E_0 = 3 TeV

α = 2.633 ± 0.033

β = 0.094 ± 0.024

Next steps

- Validate with the Mrk 421 spectral cutoff.
- Integrate into the current WCDA analysis code.