Major updates in neutron paper draft v1.2

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Data shape and scale corrections

- Scale: (v1.1) Use Am/Be calibrated efficiency scales for all SK phases
  → (v1.2) Trust SK6 Am/Be calibration, and adjust SK4/5 scales
  to match the overall neutron multiplicity in SK6

- Shape: (v1.1) No artificial shape adjustment
  → (v1.2) Adjust data shape based on
  True vs. Reco differences in MC,
  and take the same difference as uncertainty

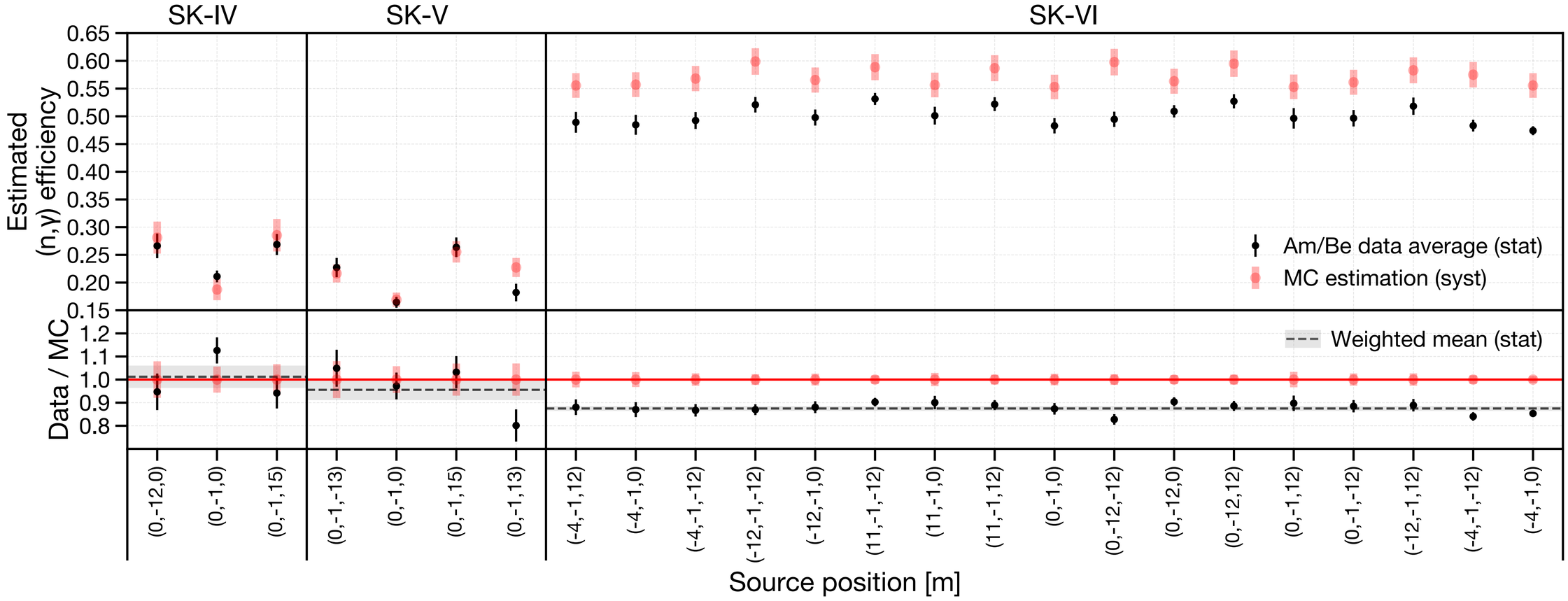
Are we overestimating SK4 neutron efficiency?

<N> = signals/efficiency

TABLE III. Summary of atmospheric neutrino events and detected neutron signals in the final sample. $\langle N \rangle_{\text{overall}}$ is the unbinned application of the signal efficiency correction given by Equation 5, estimated using signal efficiency scales from Am/Be calibration (Section IV B). The "SK-VI (Reference)" column shows SK-VI results using a neutron-energy-independent algorithm. Errors for the observed $\langle N \rangle_{\text{total}}$ are listed as statistical first, followed by systematic uncertainty, which mainly arises from signal efficiency calibration. Other errors are statistical only. The bottom two rows show the expected $\langle N \rangle_{\text{overall}}$ and the true overall (n, γ) multiplicity extracted from the baseline full MC simulations.

	SK-IV	SK-V	SK-VI	SK-VI (Reference)
ν events	29,942	4,231	5,203	Same as SK-VI
Events/day	9.23 ± 0.05	9.18 ± 0.14	9.22 ± 0.13	Same as SK-VI
n signals	15,705	2,035	5,752	4,412
n signals/event	0.525 ± 0.004	0.481 ± 0.011	1.106 ± 0.015	0.848 ± 0.017
Observed $\langle N \rangle_{\text{overall}}$	$2.21 \pm 0.03 \pm 0.11$	$2.46 \pm 0.10 \pm 0.11$	$2.50 \pm 0.06 \pm 0.05$	$2.49 \pm 0.06 \pm 0.05$
Expected $\langle N \rangle_{\text{overall}}$	2.83	2.84	2.85	2.87
True (n, γ) multiplicity	2.85	2.85	2.86	Same as SK-VI

For SK4 that spans 10 years, we only have 2 Am/Be datasets in 2008/2016, at 3 different positions
For SK6 that spans 2 years, we have ~15 Am/Be datasets periodically, at ~16 different positions

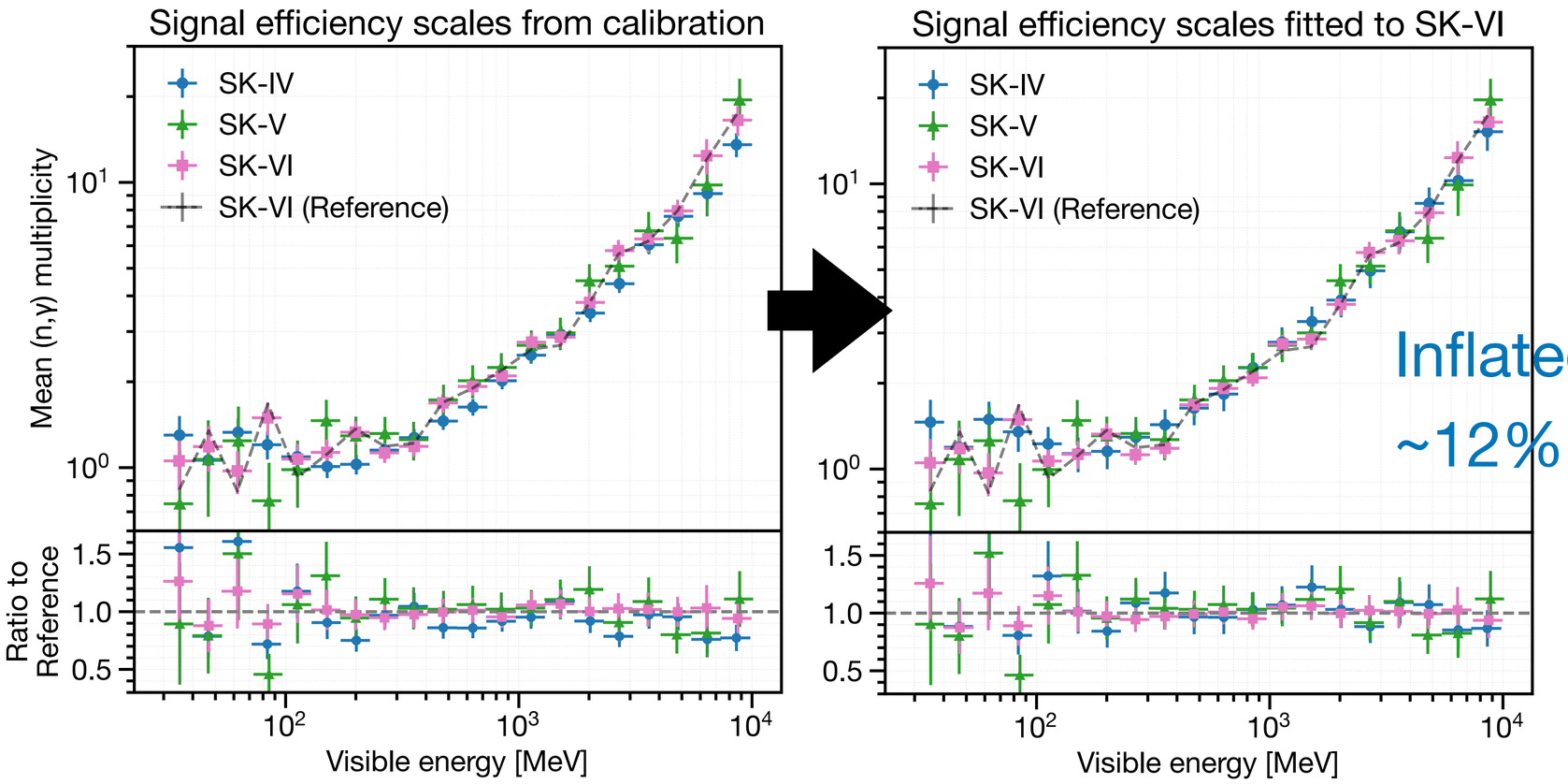


SK4 has the most neutrino statistics, but SK6 has better signal efficiency estimate

→Scale SK4 to fit SK6 <N>, and take the diff btw Am/Be-based and fitted scales as uncertainty

Data scale correction

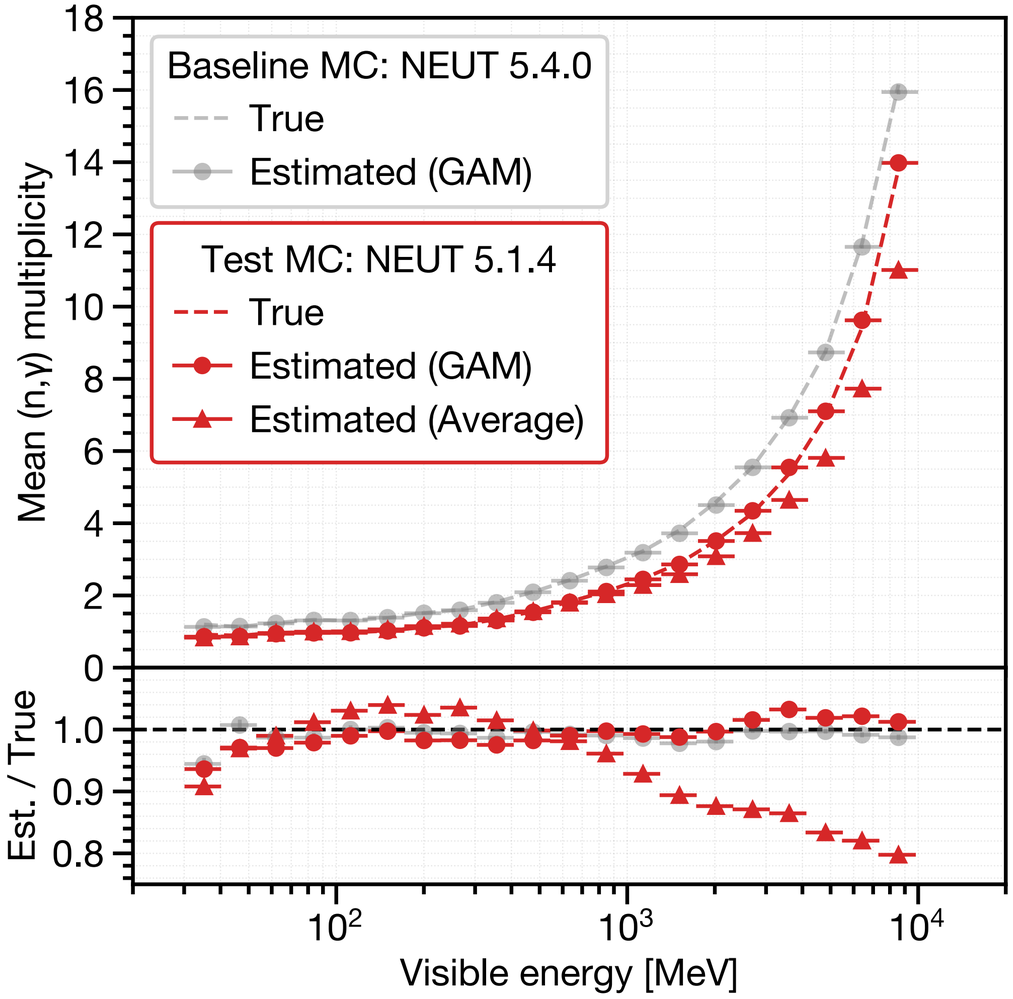
Fig 18.



Inflated error for SK4 ~12%

Am/Be estimated scale error for SK4 ~5%

Data shape correction



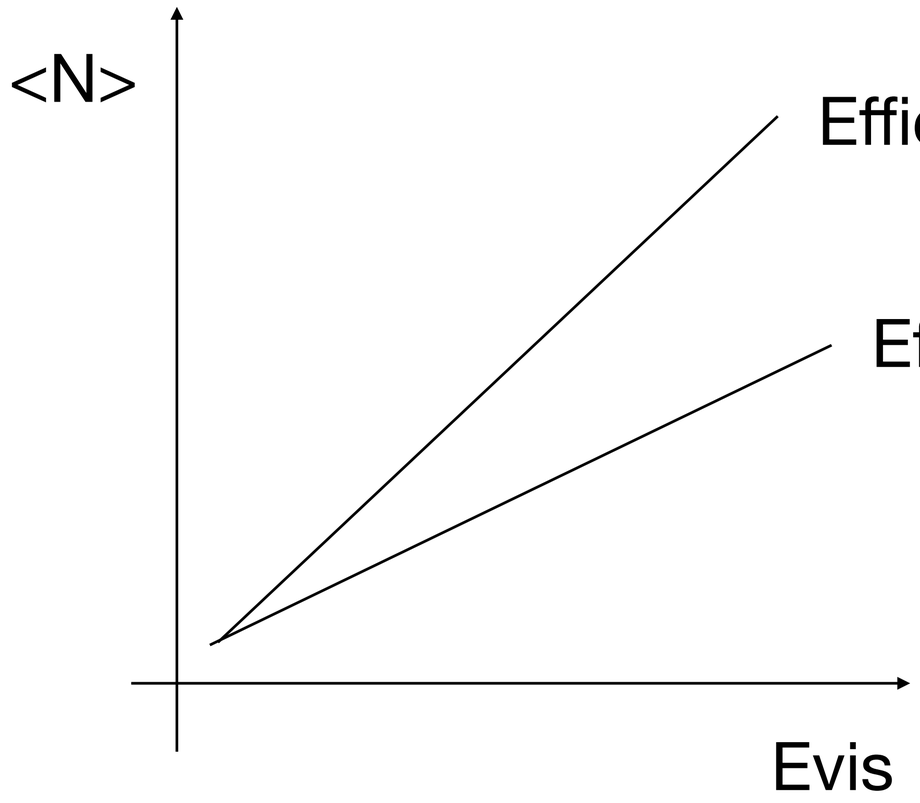
GAM-estimated signal efficiencies
are not perfectly accurate.

There still is 5-10% unresolved bias
especially with very-low/high energy events

This biases the fitted slopes for data,
but not for model predictions

→ Take true/GAM diff ratio to correct data shape
(so far, this has been added as errors only)

Add signal efficiency error to slope fit



Efficiency affects slopes!

After data scale/shape correction + adding efficiency syst error,
the slope fit results are consistent across SK phases, and also with MC!

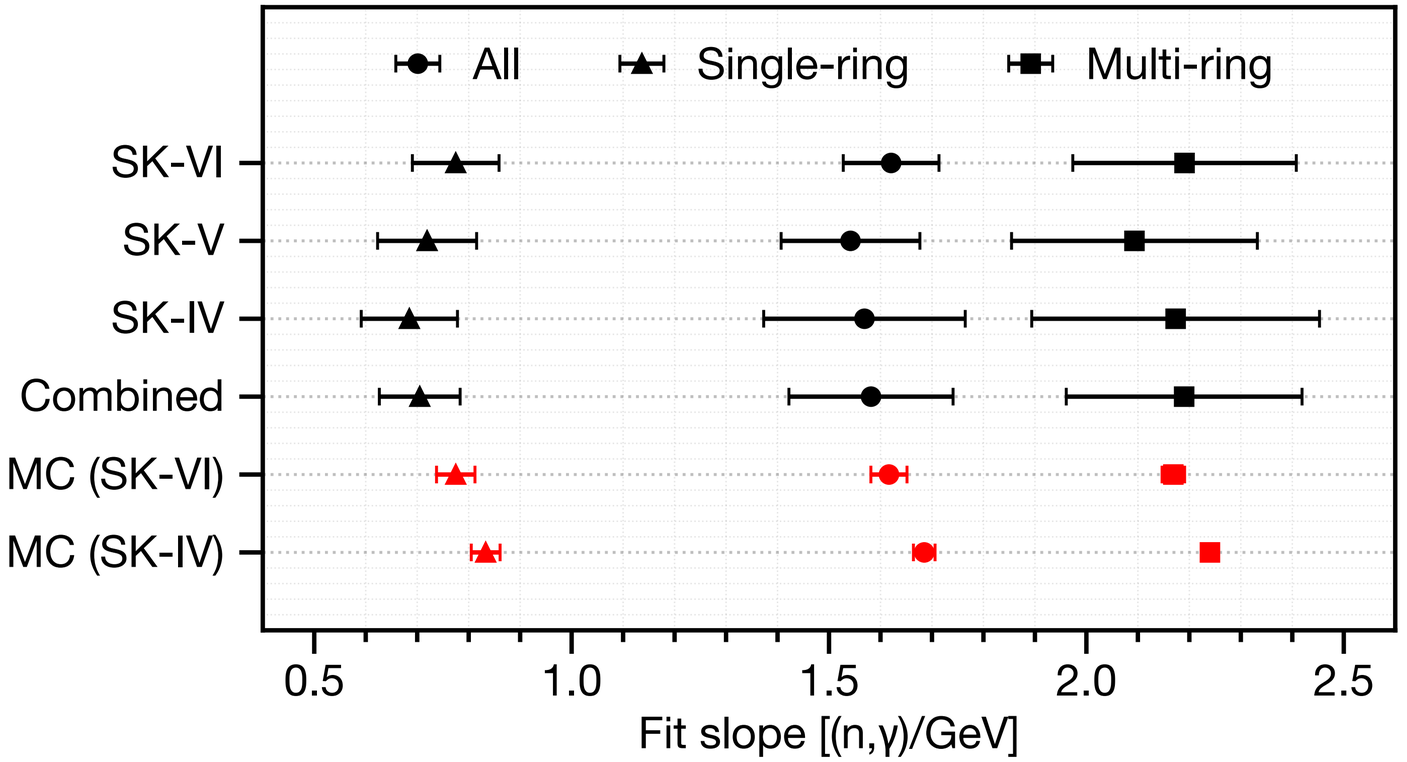


Fig. 21

Data was scaled 10% upwards,
so that difference with INCL in multi-ring multi-GeV got larger,
while agreement with BERT_PC improved

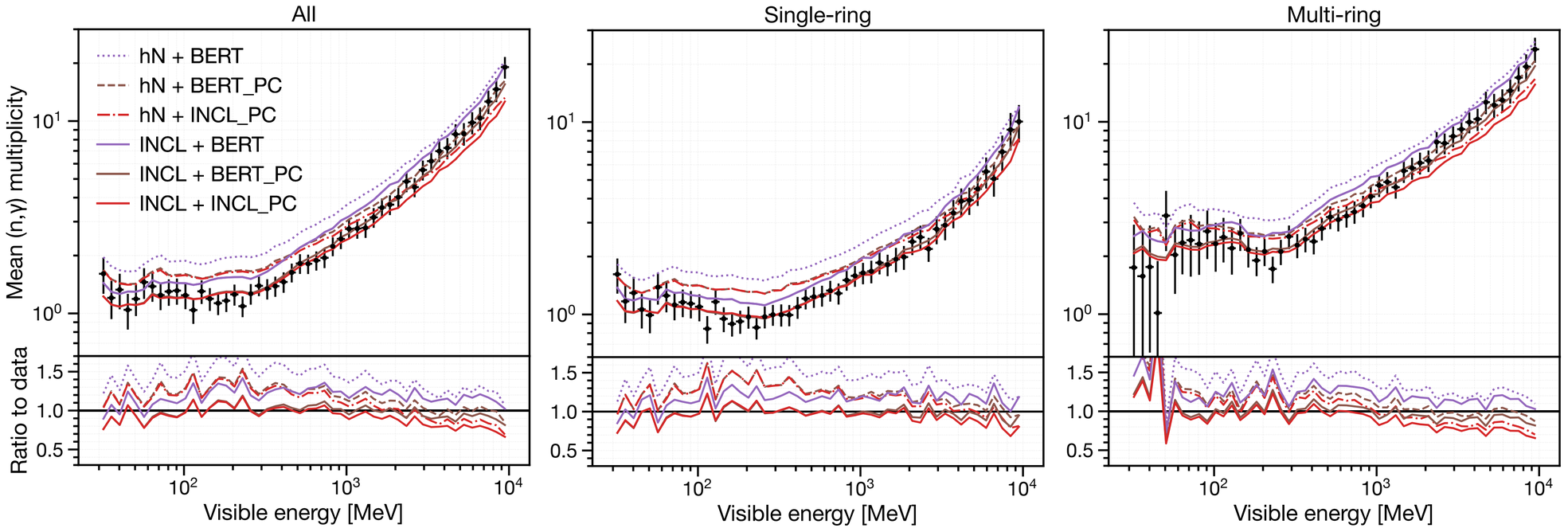
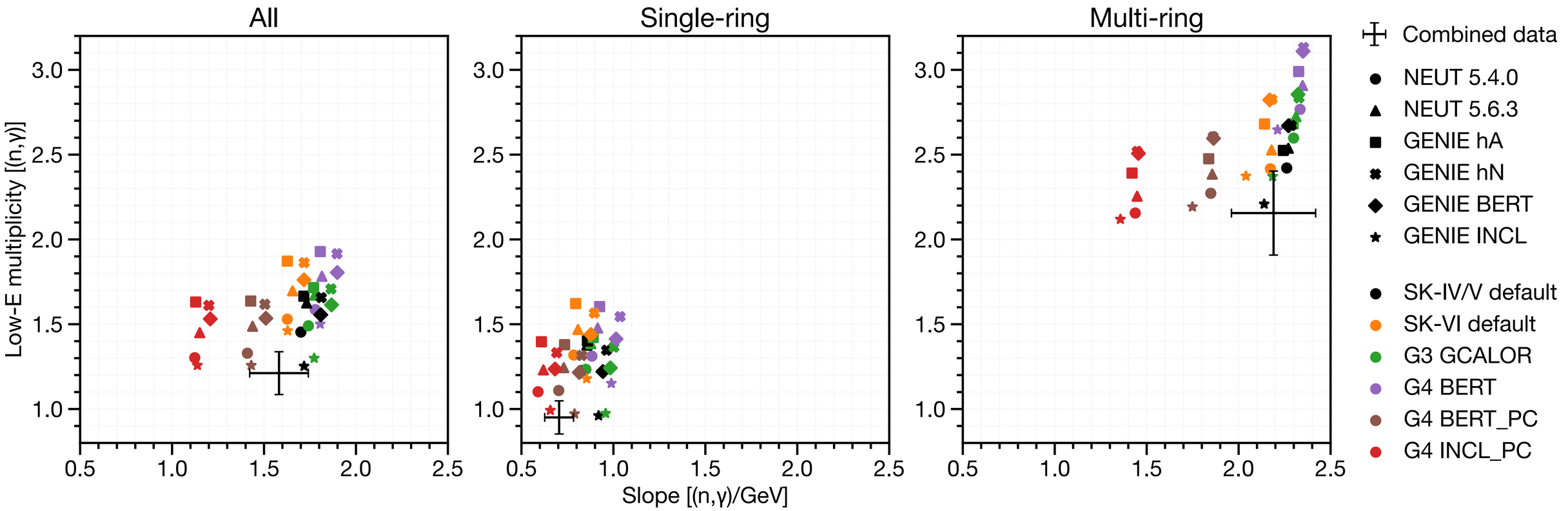


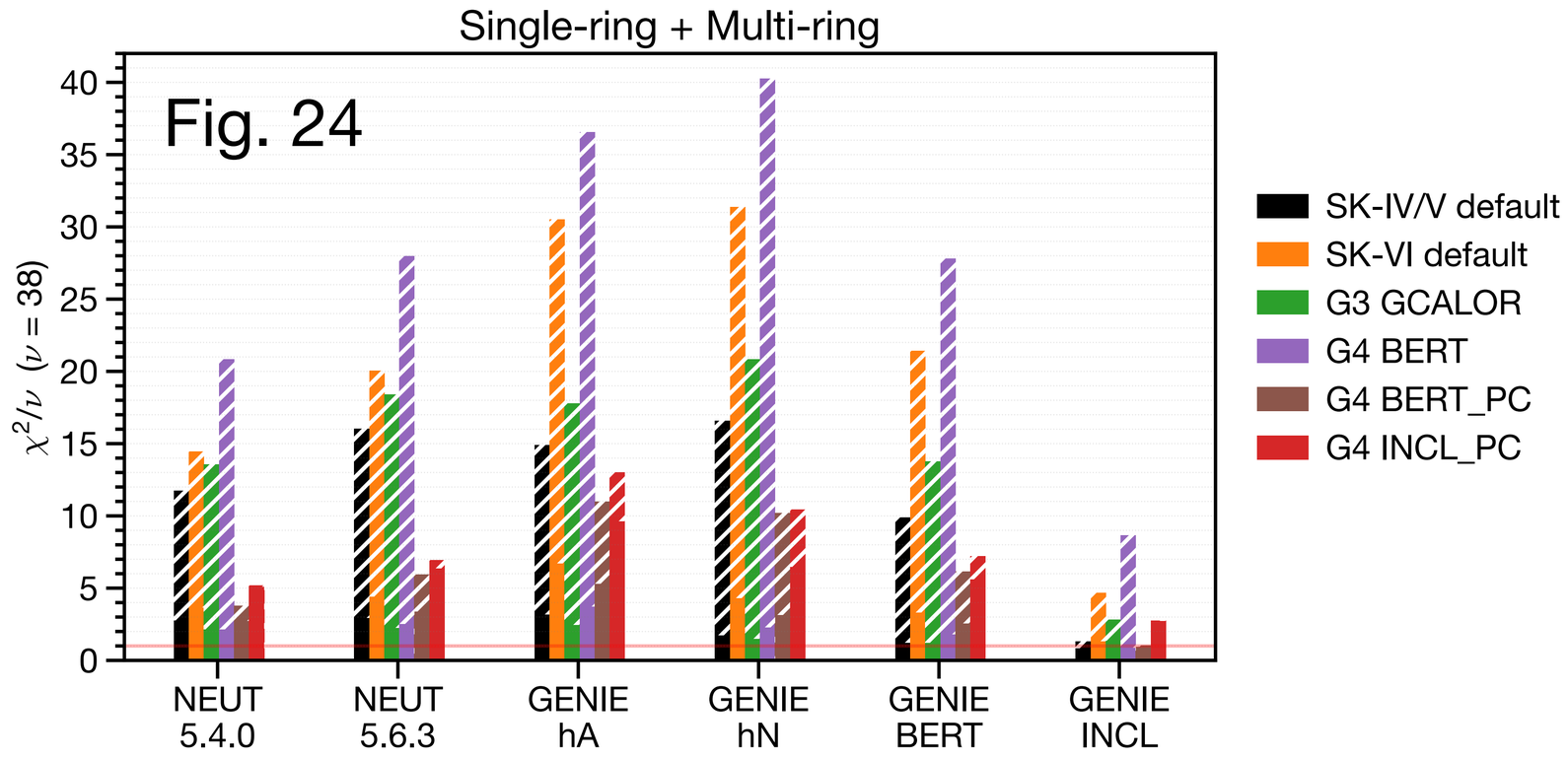
Fig. 22



Observed multi-ring slope is consistent with GCALOR/SK4/5/6 MC predictions

INCL predicts much smaller slope than observed

Goodness-of-fit: very simple $\chi^2 = \sum_i^{N_{\text{bins}}} \frac{(sO_i - E_i)^2}{\sigma^2_{\text{stat},i}}$ (s=normalization scale to be minimized)



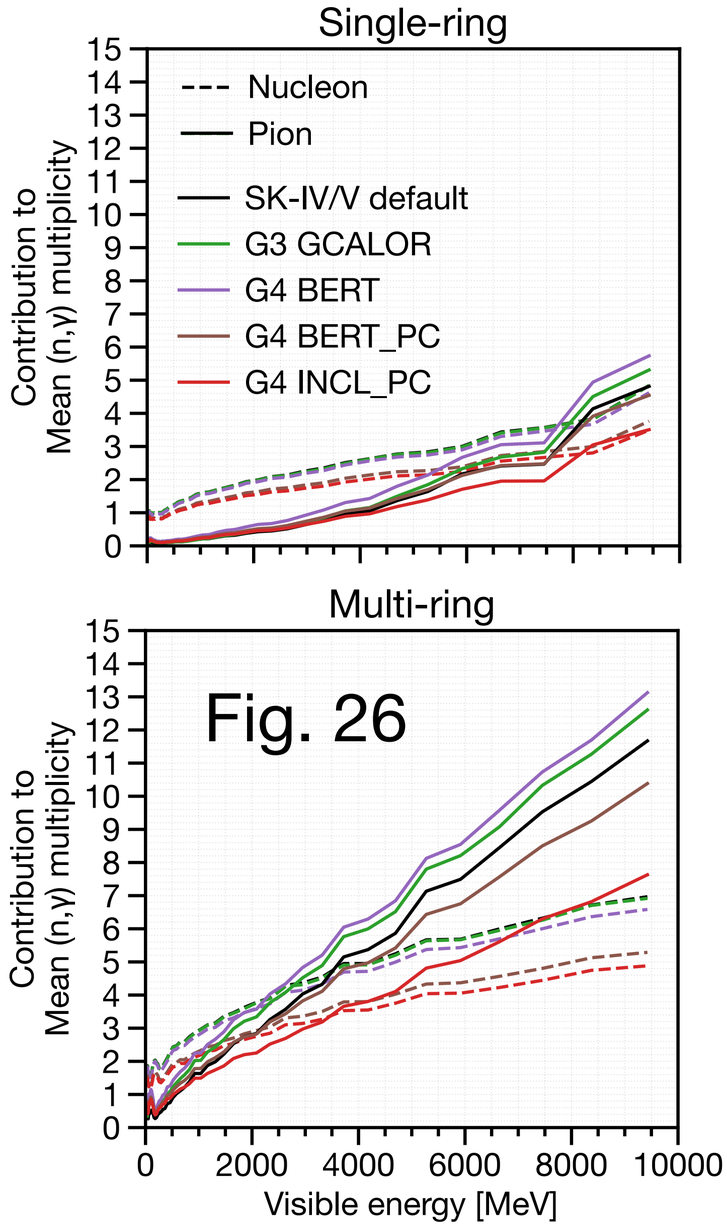
With s constraint,

1. FSI best: GENIE INCL
2. SI best: G4 BERT_PC

When coupled with GENIE INCL,
SK4/5-default and GCALOR
also shows good shape agreement

Unhatched: χ^2 with unconstrained, free s (~shape agreement)

Hatched: contribution from constraint $|s - 1| < 0.1$ + penalty (~scale discrepancy)



The reason why INCL predicts lower slopes especially for multi-ring events, is probably due to the internal πN→Nxπ xsec

arXiv:1603.05453

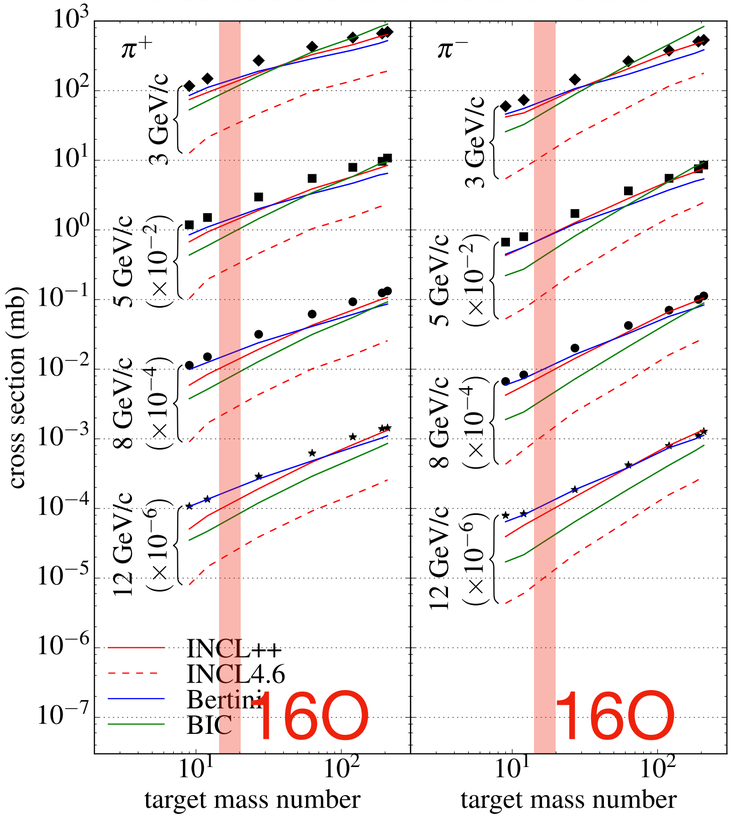


Figure 4. Same as Fig. 3, but for π^+-nucleus reactions.

Predicted inclusive π prod xsec in π-16O reaction:
INCL < Bertini < HARP data

This makes sense,
as we also observe multi-ring slope:
INCL < BERT_PC < Data
Less π = less n

Contacted INCL group for comments