Perturbative Uncertainties in the Back-to-Back EEC and Sensitivity to α_s

European Research Council
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Nicole Oberth

Work in progress with

Giulia Marinelli & Frank Tackmann

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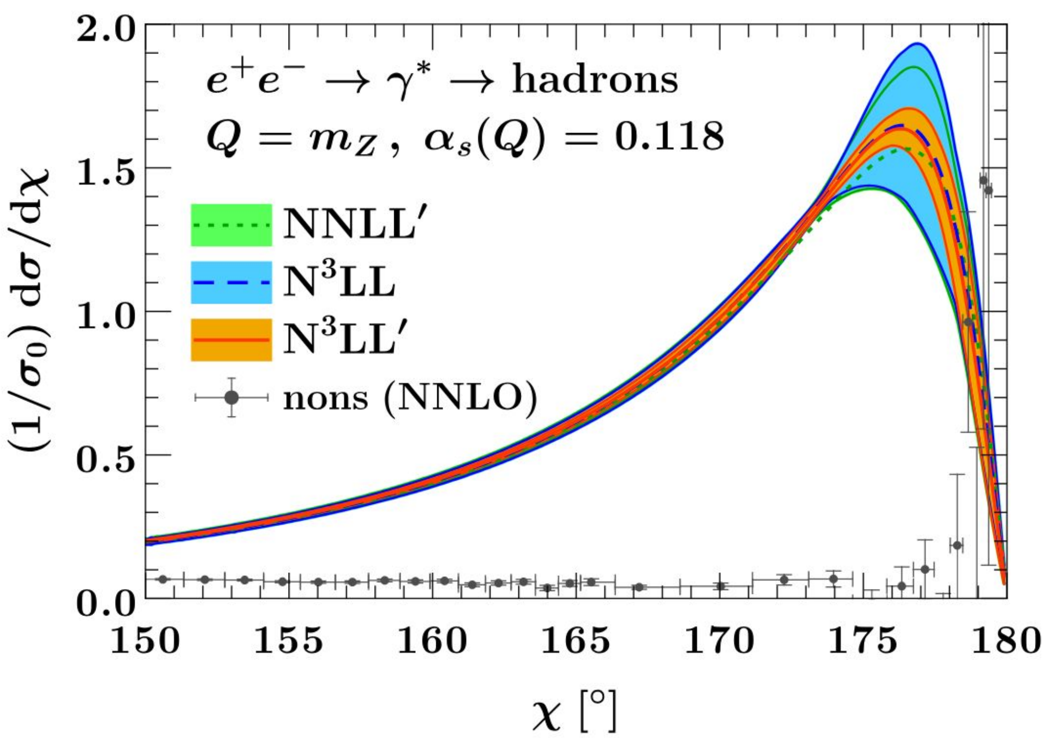
BACKGROUND

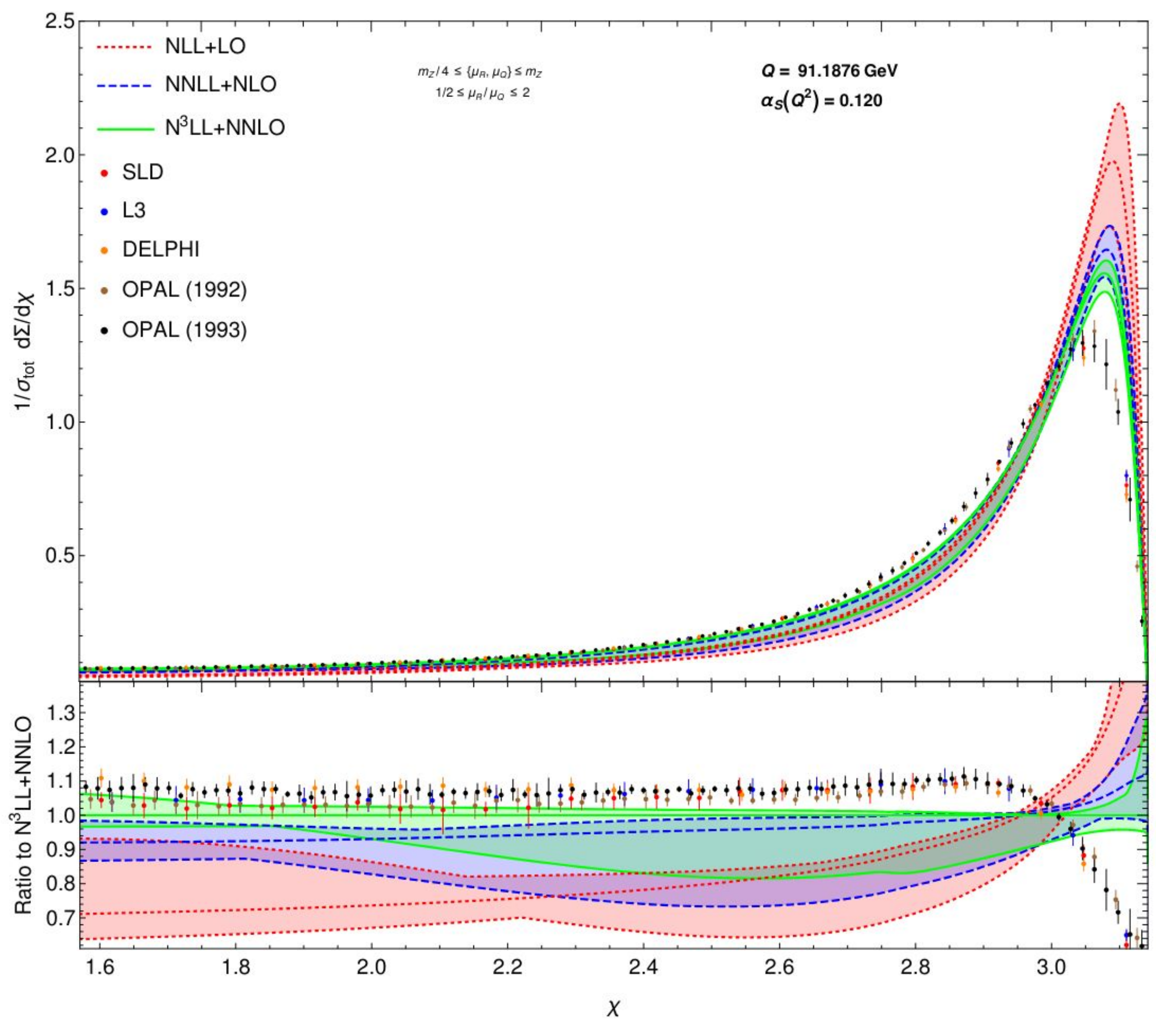
- Goal: use EEC spectrum to fit α_s
- Examining EEC cross-section in the back-to-back limit ($z \to 1$; $\chi \to \pi$)
- Improve theory uncertainty analysis via TNPs
- Work-in-progress => Simplifications:
  - only LP resummation uncertainties
  - not examining nonsingular or nonperturbative contributions

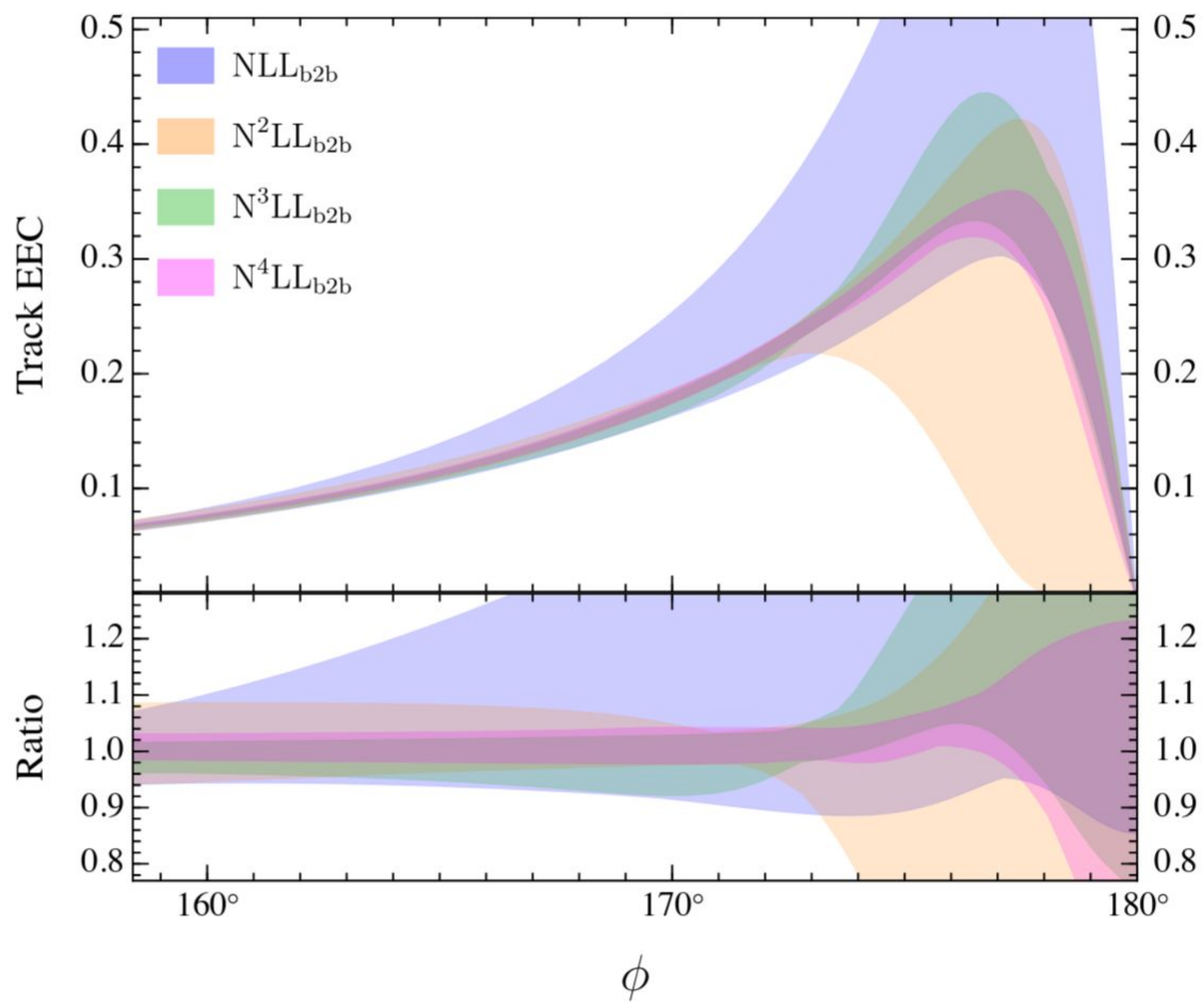
LIMITATIONS OF SCALE VARIATIONS: EXAMPLE

Arbitrary choices in scales ⇒ differing uncertainties

Ebert, Mistlberger, Vita; 2012.07859 Aglietti, Ferrera; 2403.04077 Jaarsma et al., 2512.11950 (using track functions, but same principle)







THEORY NUISANCE PARAMETERS

[Tackmann; 2411.18606]

- For a series $f(\alpha) = \hat{f}_0 + \hat{f}_1 \alpha + \hat{f}_2 \alpha^2 + \hat{f}_3 \alpha^3 + \mathcal{O}(\alpha^4)$ with known $\hat{f}_n$
  - approximate unknown part as leading uncertainty f_4

THEORY NUISANCE PARAMETERS

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  - approximate unknown part as leading uncertainty f_4
  - f_4 has internal structure $\rightarrow$ $f_n = f_n(\theta_n)$
- θ_n theory nuisance parameter with true (but unknown) value $\hat{\theta}_n$ such that $\hat{f}_n = f_n(\hat{\theta}_n)$
- The θ_i are proper parameters:
  - have their own uncertainties $\theta_n = u_n \pm \Delta u_n$
  - can be propagated $\Rightarrow$ correct correlations
  - parametrize: factorization, RGE equations

TNPS FOR THE BACK-TO-BACK EEC

[Moult, Zhu ; 2506.09114]

- Resummation : $\frac{1}{\sigma_0}\frac{d\sigma}{dz} \sim \frac{1}{2}\int_0^\infty \frac{b_T\, db_T}{2} J_0(b_T Q\sqrt{1-z})$

$$\times H(Q,\mu)\, J_a(b_T,\mu,\nu)\, J_b(b_T,\mu,\nu)\, S(b_T,\mu,\nu) + \mathcal{O}(1-z)$$

- For general RGE solution $F = \{H, J_i, S\}$ rewrite to logs : $[H \times J_a \times J_b \times S](\alpha_s, L \equiv \ln(\sqrt{1-z}))$

$$F(\alpha_s, L) = F(\alpha_s)\exp\left\{\int_0^L dL'\left(\Gamma[\alpha_s(L')]L' + \gamma_F[\alpha_s(L')]\right)\right\}$$

- TNPs:

boundary terms:	$\theta_{Hq\bar{q}V}$, θ_J, θ_S

anom. dims.:	$\theta_{\Gamma_{cusp}}$, θ_{γ_μ}, θ_{γ_ν}

NONPERTURBATIVE MODELS

- Collins-Soper kernel:

$$\boxed{\tilde{\gamma}_\nu^{np}(b_T) = -\lambda_\infty \tanh\left(\frac{\lambda_2}{\lambda_\infty} b_T^2 + \frac{\lambda_4}{\lambda_\infty} b_T^4\right)}$$ with

$\lambda_\infty = 1.68529$

$\lambda_2 = 0.087011$

$\lambda_4 = 0.00739108$

- TMD boundary condition:

$$\boxed{\tilde{f}^{np}(b_T) = \exp\left\{-2 b_T^2 \left(\lambda_2 + \lambda_4 b_T^2\right)\right\}}$$ with

$\lambda_2 = 0.106$

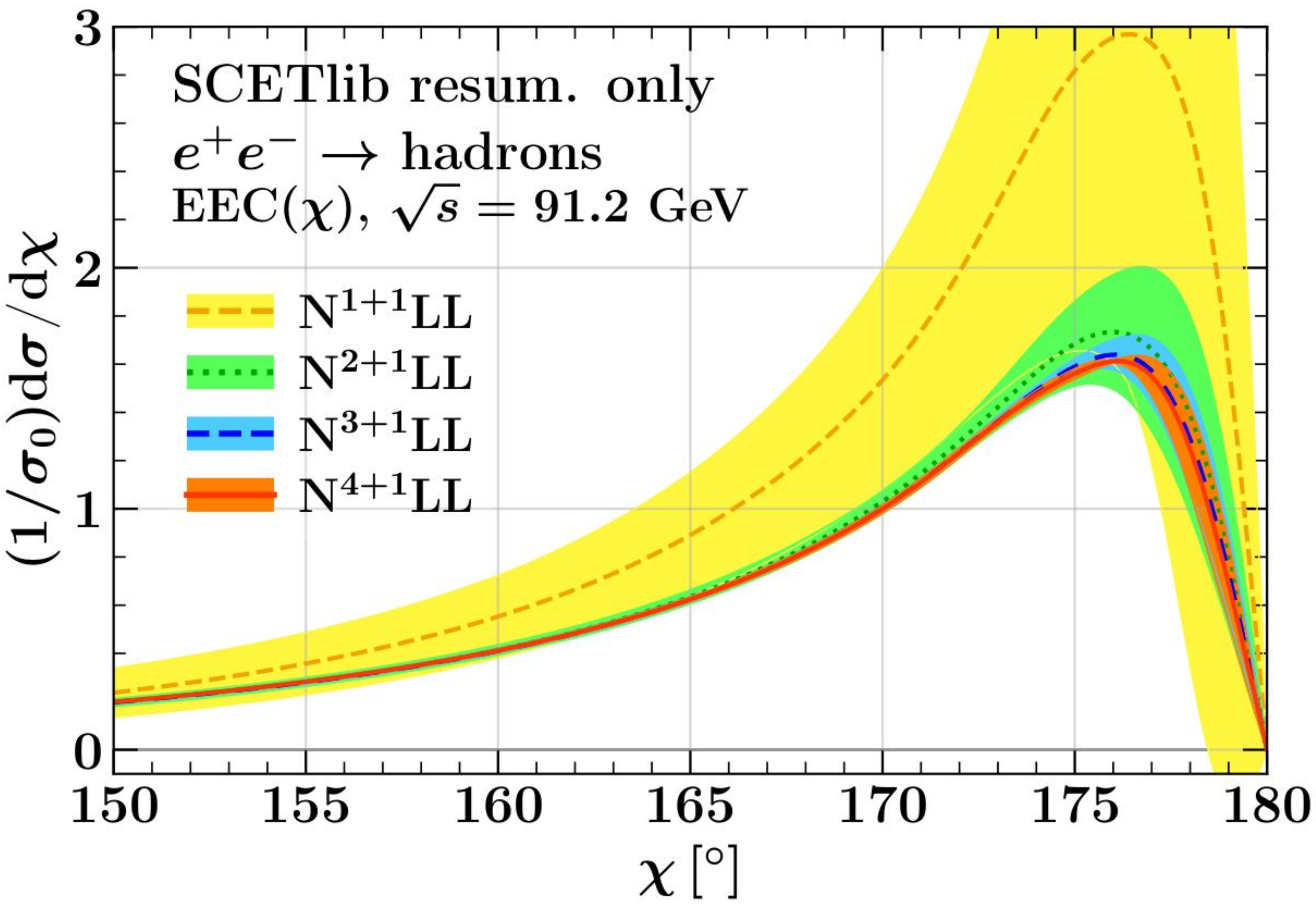
$\lambda_4 = 0$

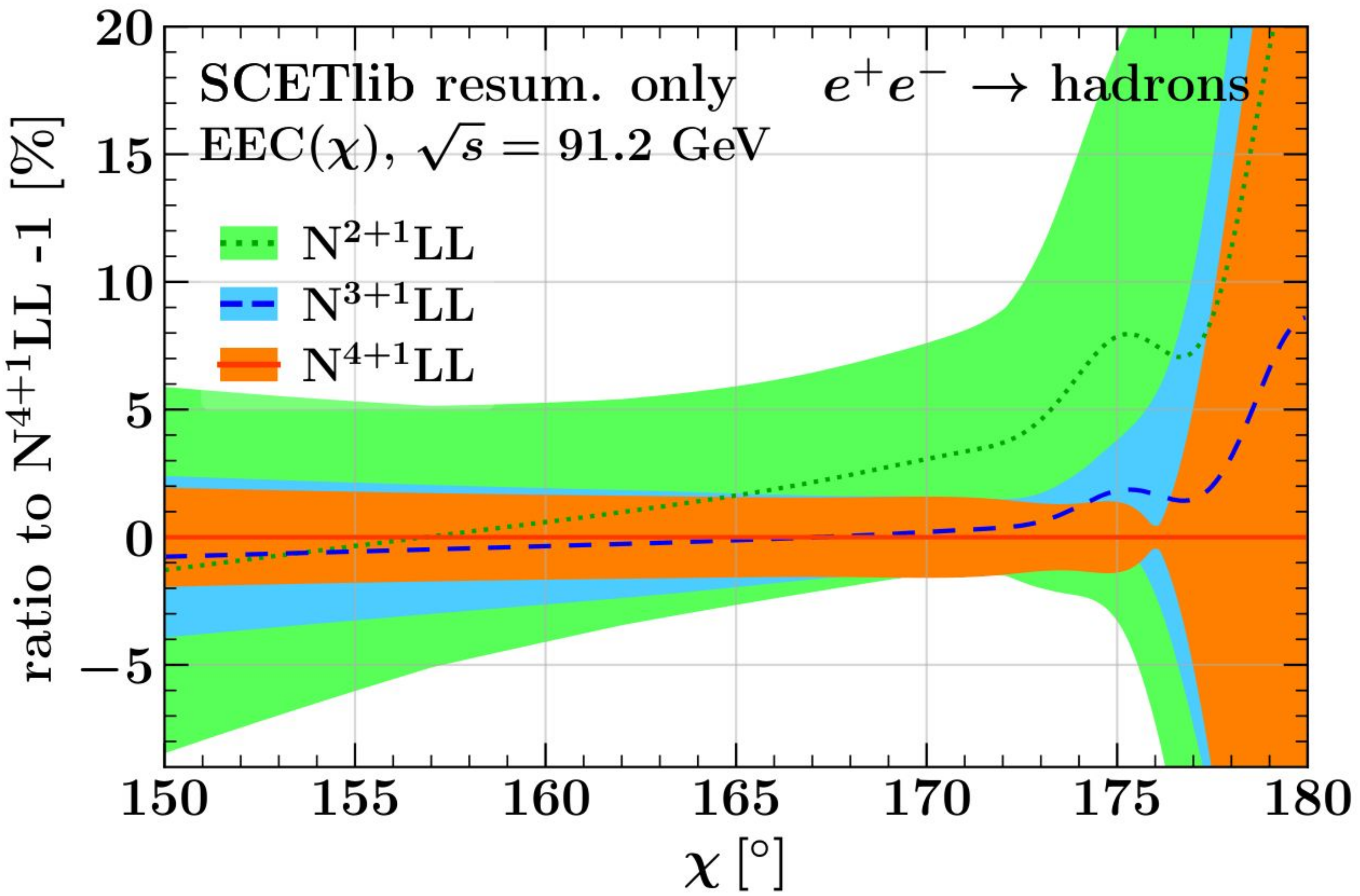
- leaving out linear nonpert. Ω_1 term

DISCLAIMER ⚠

- Examining leading power cross section
- Using simplified and fixed TMD nonperturbative model
- Leaving out nonsingular components

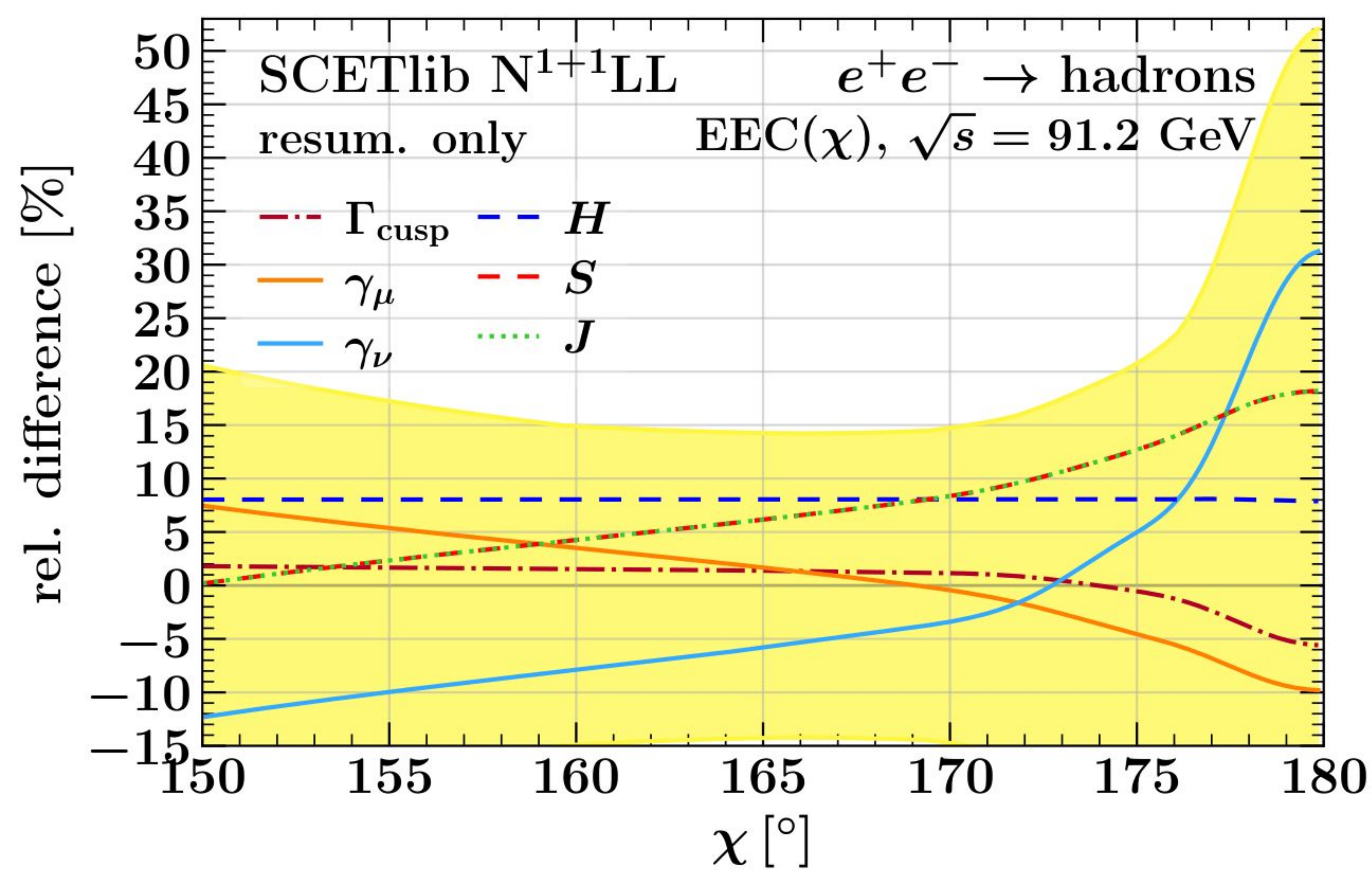
RESULTS: CONVERGENCE PLOTS

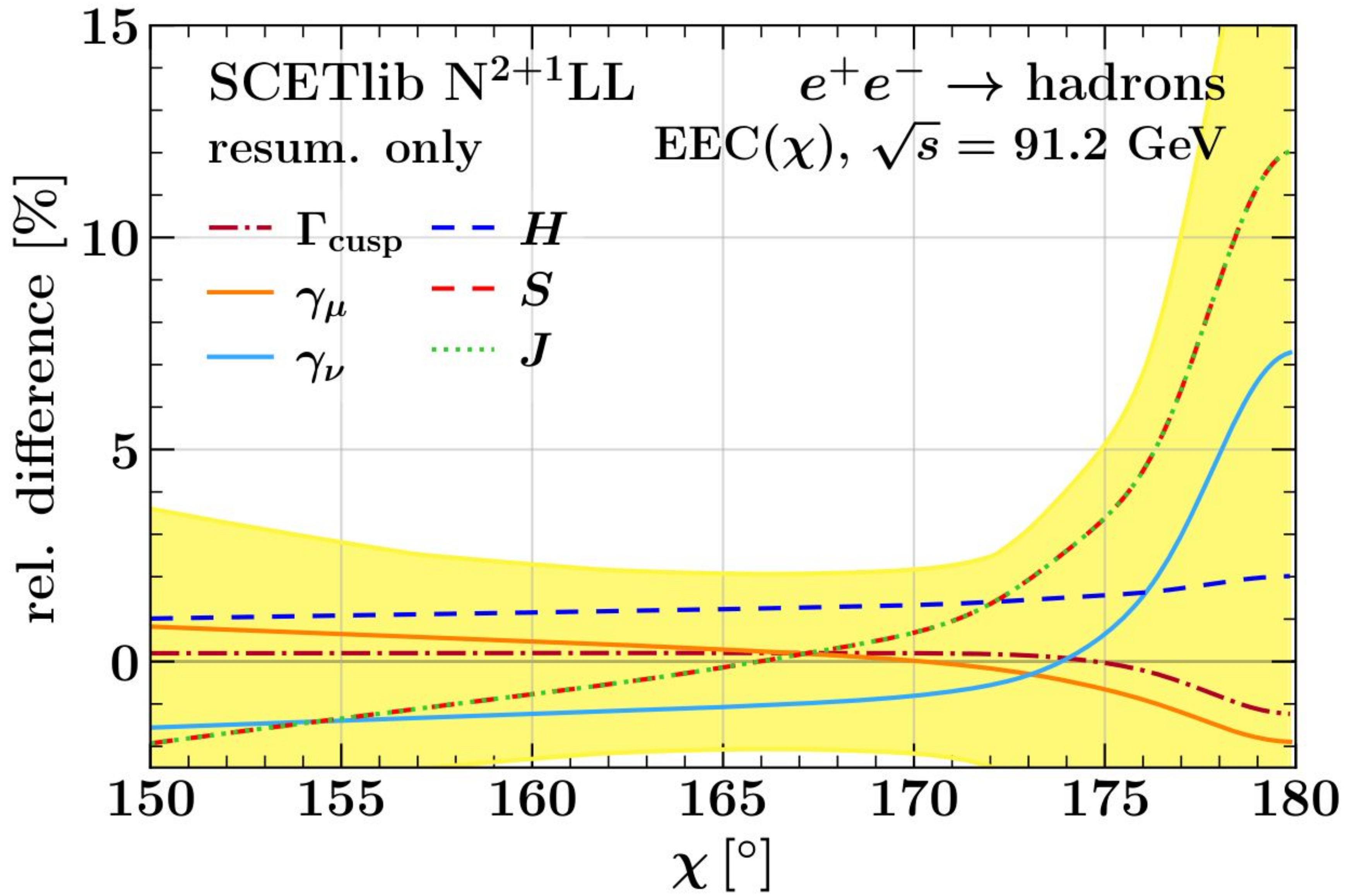




- $N^{k+l}LL$: boundary conditions: $N^{k-1}LO$, ADMs: N^kLL,
  TNPs parametrize $N^{k+l}LL$ ingredients
- Here: 95% CL → $\theta_i = 0 \pm 2$
- TNPs are independent sources of uncertainty
  ↳ summed in quadrature for total uncertainty (≙ colored bands)

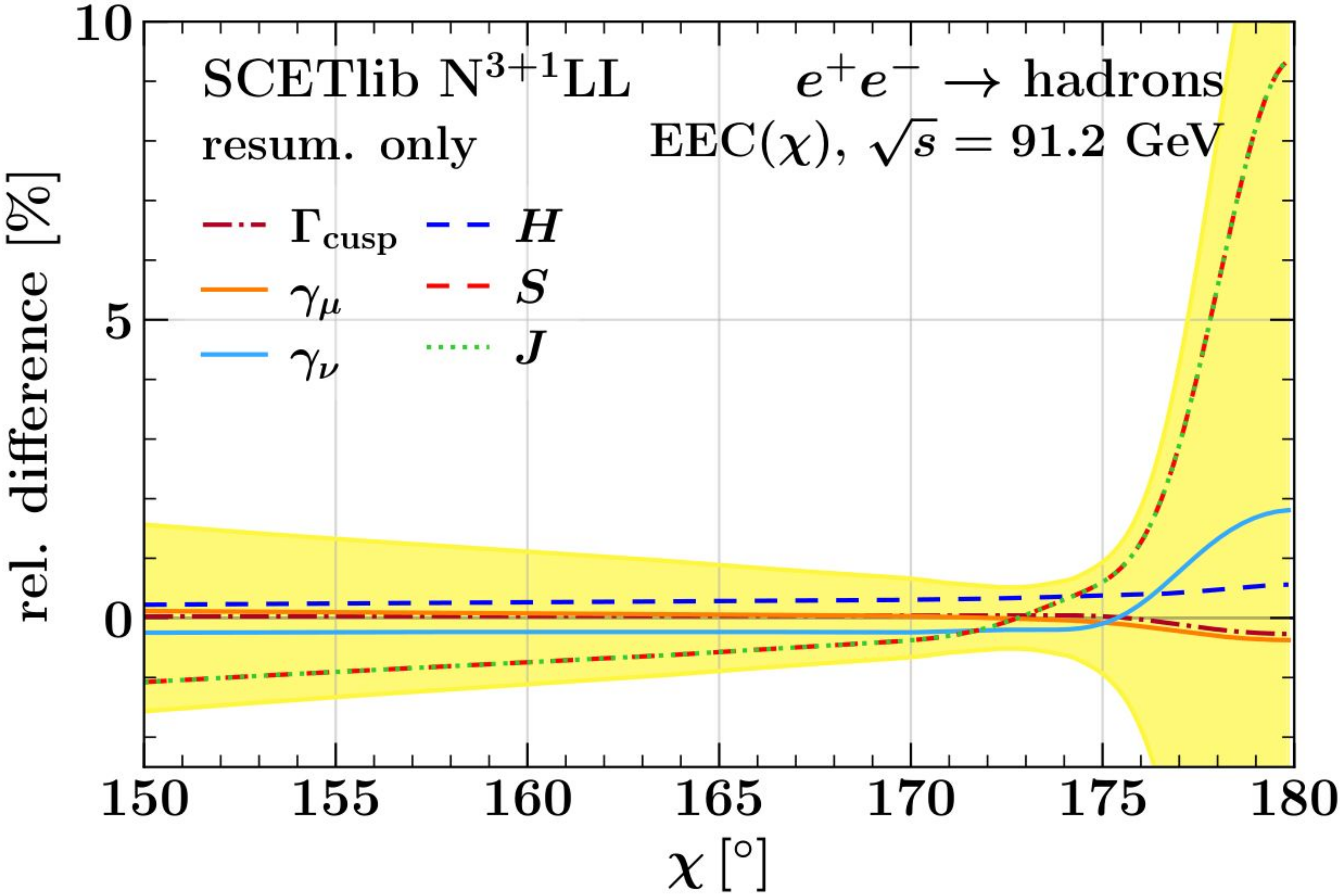
RESULTS: INDIVIDUAL TNPS

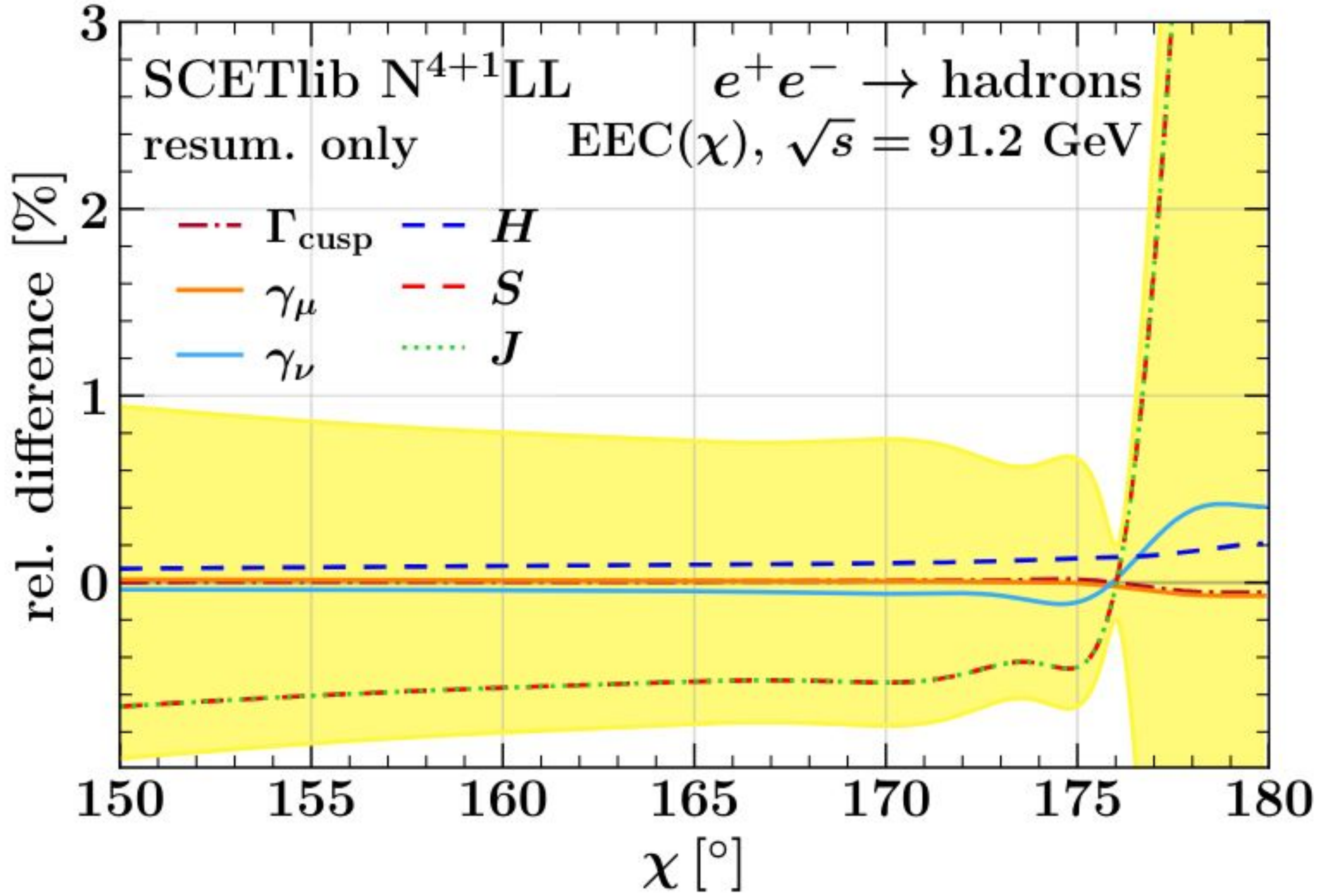




- Uncertainty shrinks for higher resummation order
- 68% CL $\rightarrow$ $\theta_i = 0 \pm 1$
- TNPs are independent sources of uncertainty
  - ↳ summed in quadrature for total uncertainty ($\triangleq$ yellow band)

RESULTS: INDIVIDUAL TNPS





- Uncertainty shrinks for higher resummation order
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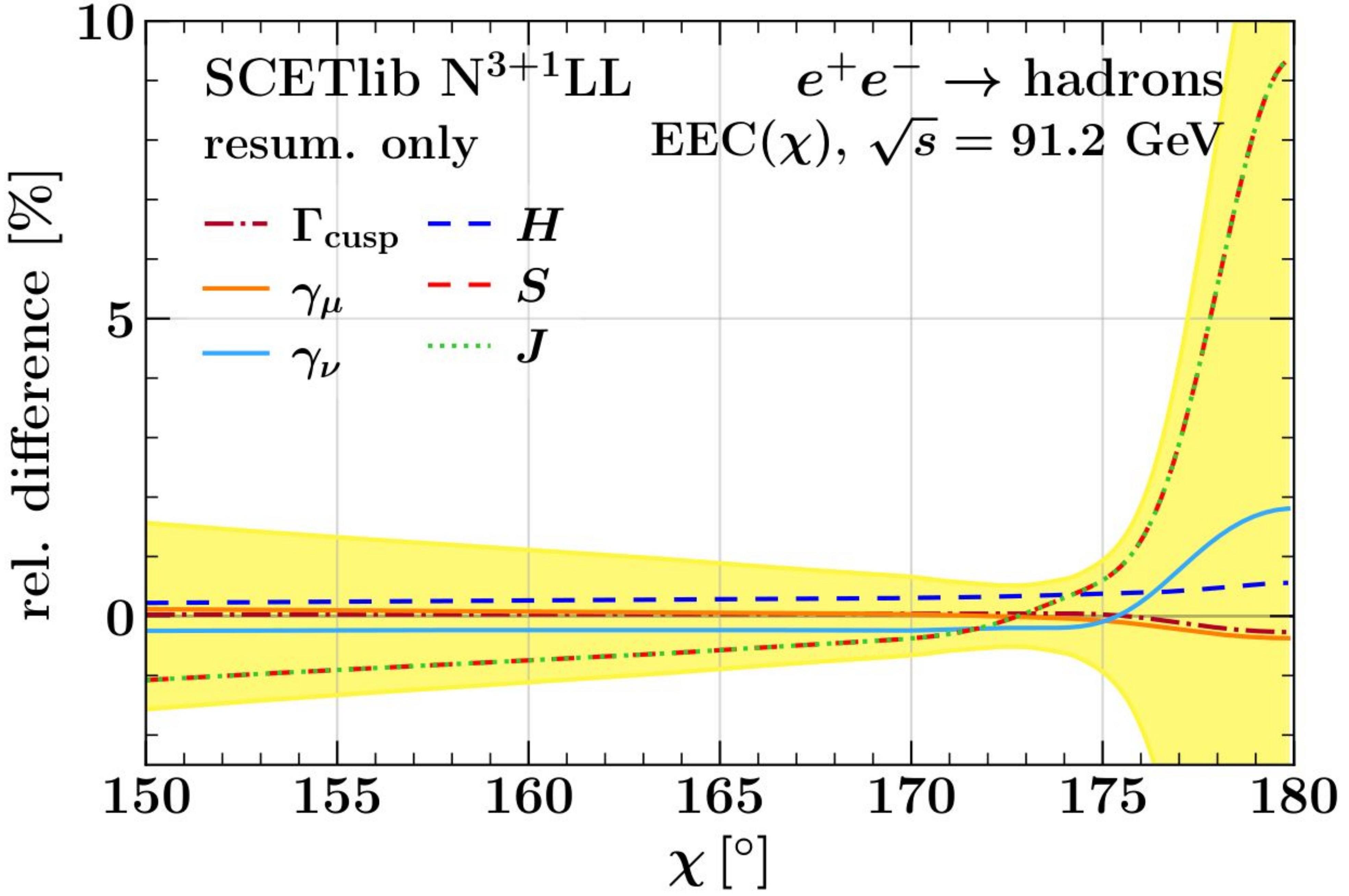
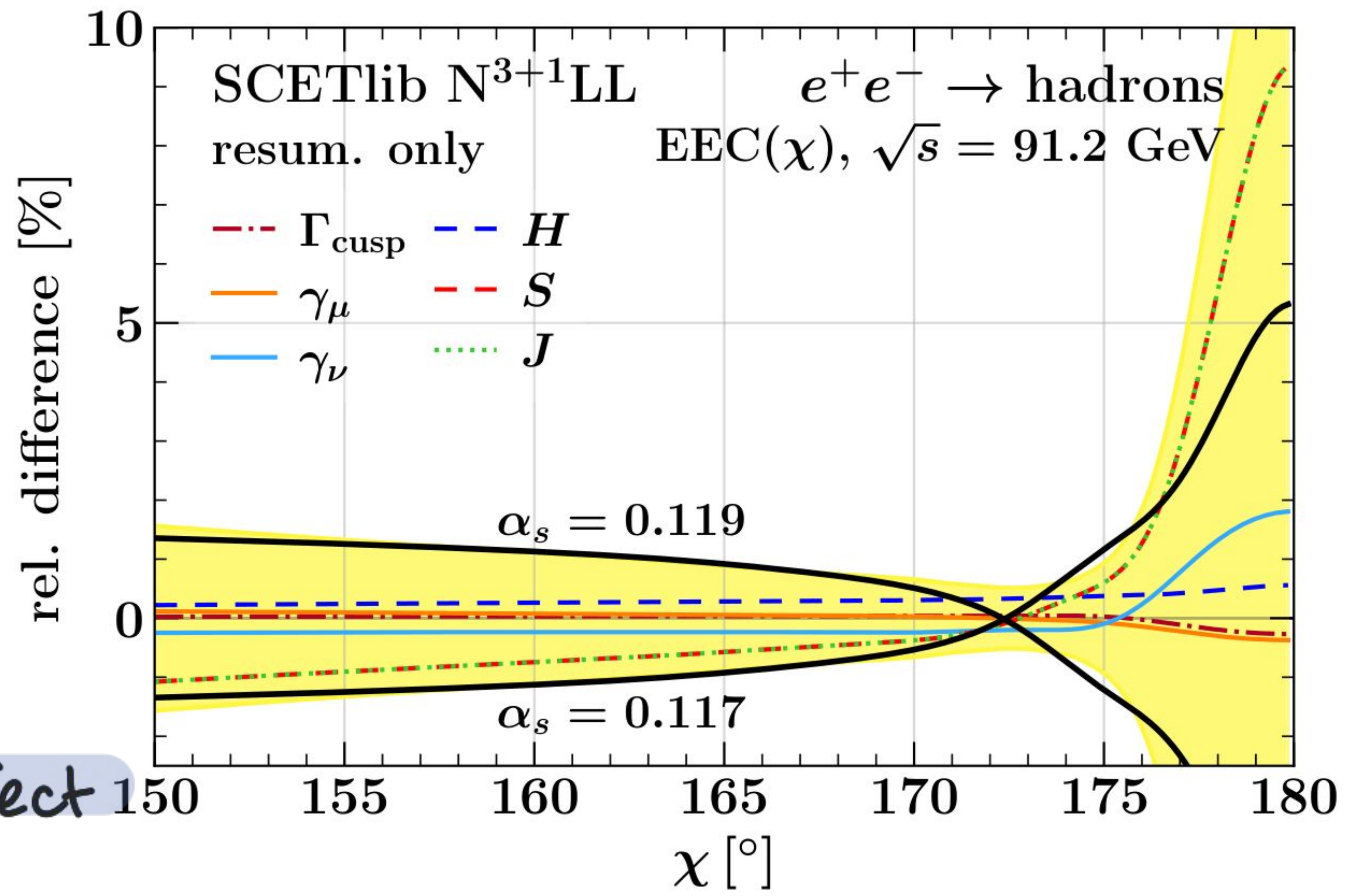
RESULTS: INDIVIDUAL TNPS

- 68% CL → $\theta_i = 0 \pm 1$
- Point-by-point correlations are important
- Jet functions don't contain pdfs
  ↳ identical impact to soft



RESULTS: α_s SENSITIVITY

- 68% CL → $\theta_i = 0 \pm 1$
- Changes in shape
  ↳ Point-by-point correlations are important!
- α_s is a %-level shape effect
  ↳ highly precise!



FITTING α_s: ASIMOV FIT SETUP

[Cridge, Marinelli, Tackmann; 2506.13874]

- Current theory model: $N^{3+1}LL$ → use N^4LL for pseudodata (Asimov data)

[OPAL collaboration; doi: 10.1007/BF01555834]

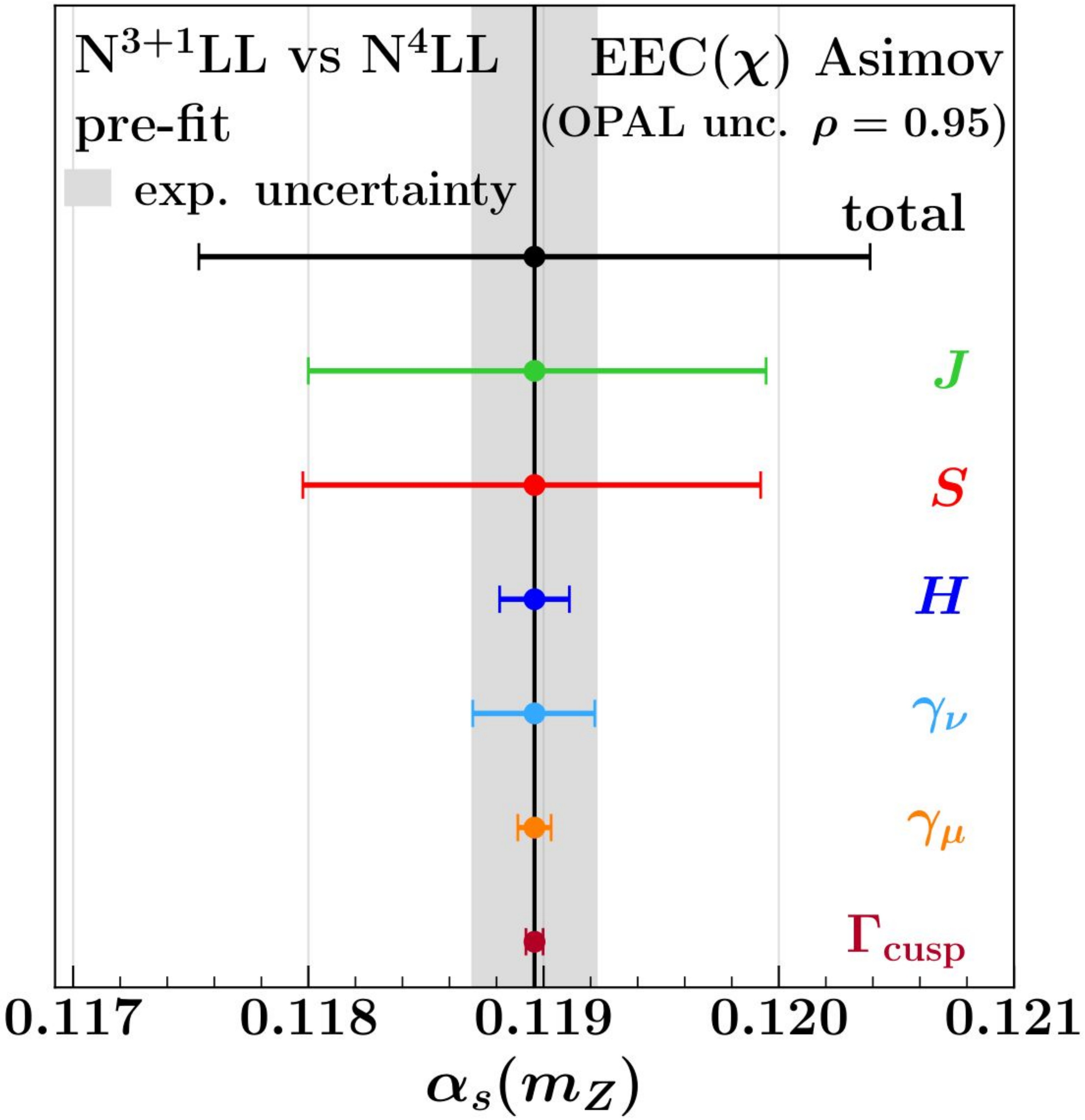
- Experimental uncertainties from OPAL data
  - Correlation model not given by the data
    ⇒ have to assume a realistic one
  - Using 95% correlation: $\rho_{ij} = 1 - 0.05(|j-i|)$
    $(\mathrm{CoV}_{ij} = \rho_{ij}\,\sigma_i\,\sigma_j)$

- Perform fit with χ^2 mimization and Minuit

- Nonperturbative models fixed

RESULTS: SCANNING TNPS

- fit only α_s
- for total uncertainty: take the individual ones in quadrature

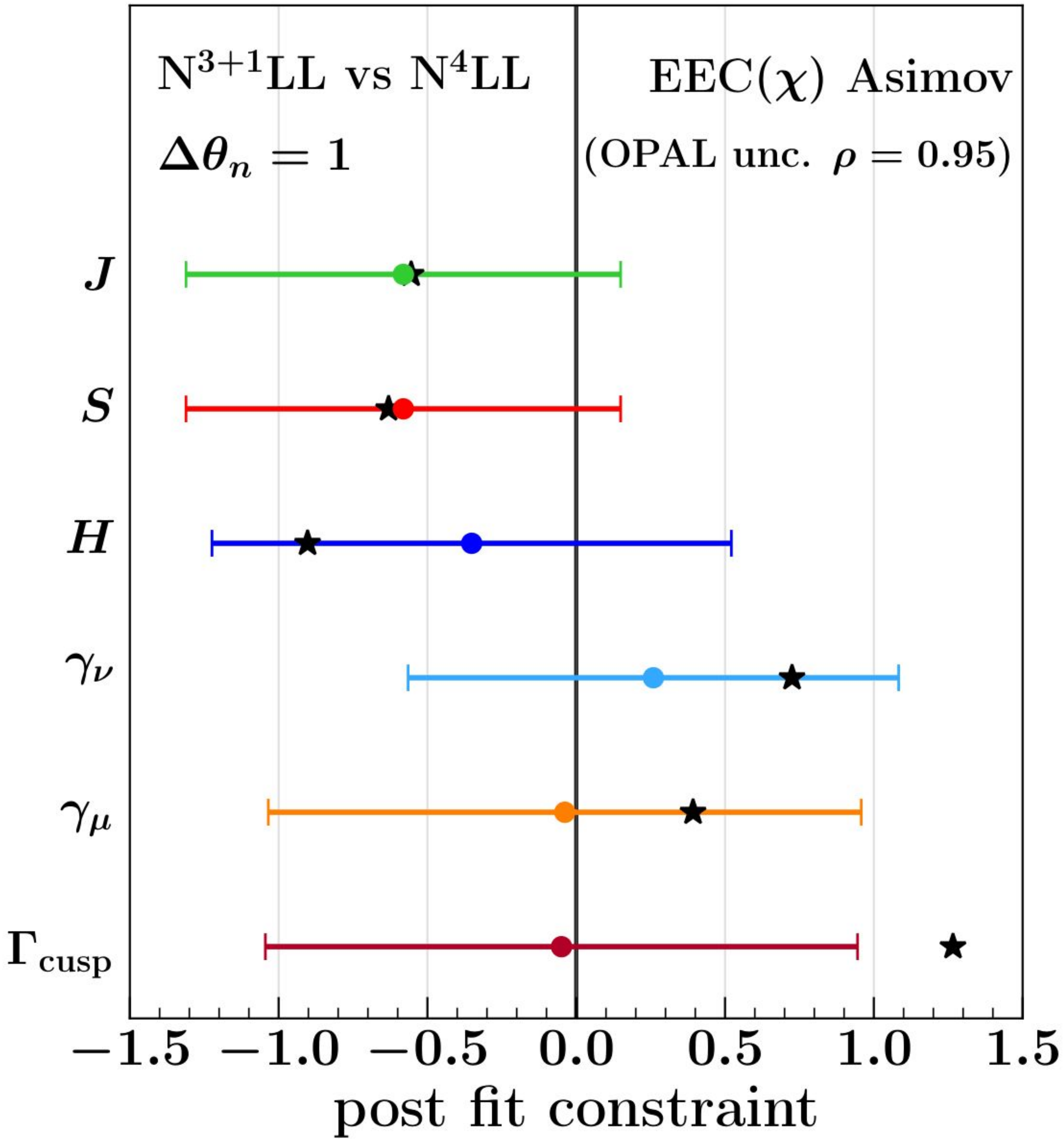


- TNPs for γ_ν anom. dim and boundary terms of jet and soft function have the largest impact

- $\Delta\alpha_s = 1.2663 \times 10^{-3}$

RESULTS: PROFILING TNPS

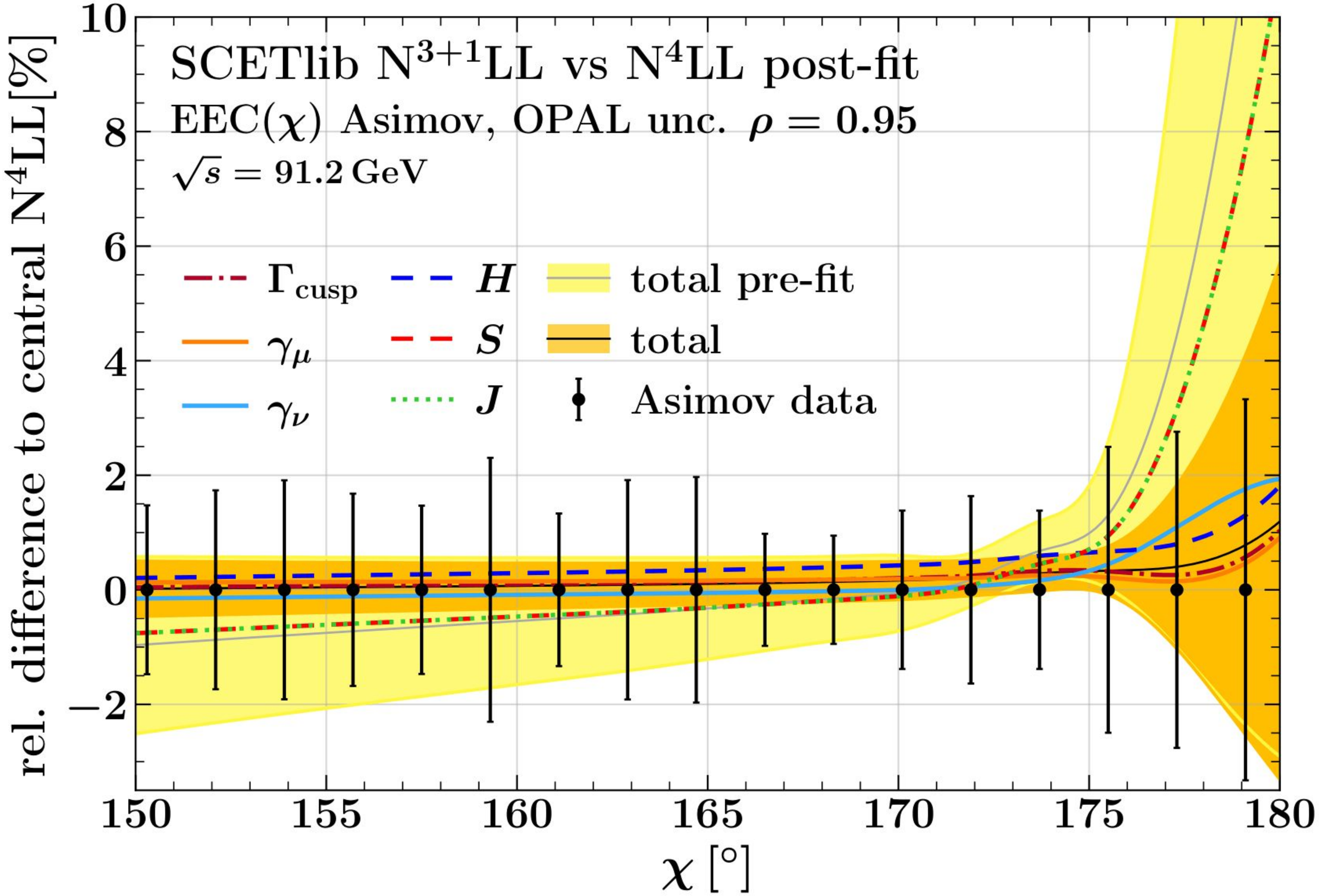
- Better: fit the TNPs alongside α_s
- Allow fit to adjust model as needed
- $\alpha_s = 0.1179 \pm 0.4779 \times 10^{-3}$



- Fitted TNPs pulled towards their true values $\hat{\theta}_i$
  (marked by stars ★ in the plot)
- Consistent with scanning for θ_{γ_ν}, θ_{J_q}, θ_S
  → the hard function TNPs are also pulled more

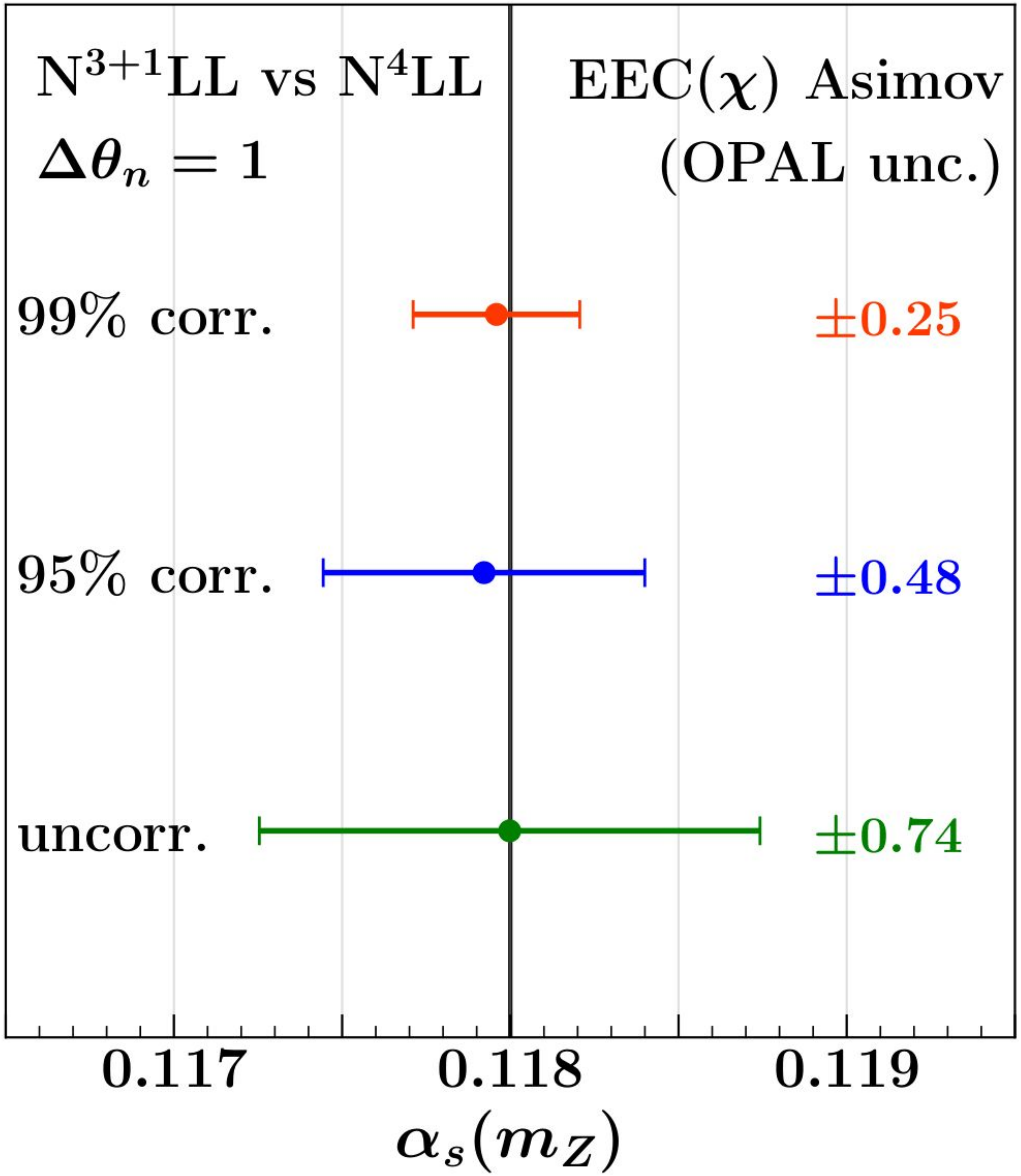
RESULTS: PROFILING TNPS

- Better: fit the TNPs alongside α_s
- Showing pre- and postfit uncertainties
  → profiling leads to reduction in overall uncertainty



RESULTS: CHANGE IN EXPERIMENTAL CORRELATIONS

(for profiling)



- Note:
  uncertainties are given as $\pm\Delta\alpha_s(m_Z) \cdot 10^{-3}$
- It is apparent that the correlation has a significant impact on the uncertainty of α_s
  → knowing the correct experimental correlation model is crucial
- Profiling: bias becomes negligible

SUMMARY & OUTLOOK

- TNPs are introduced to the back-to-back EEC for the anom. dims. and each factorization component
  - individual and overall effects on the cross section are examined
  - need for proper uncertainty breakdown and importance of correct experimental and theory correlations for precise α_s fit are shown

- Outlook / possible improvements:
  - expand on and fully examine nonperturbative model
  - include nonsingular terms

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Established by the European Commission

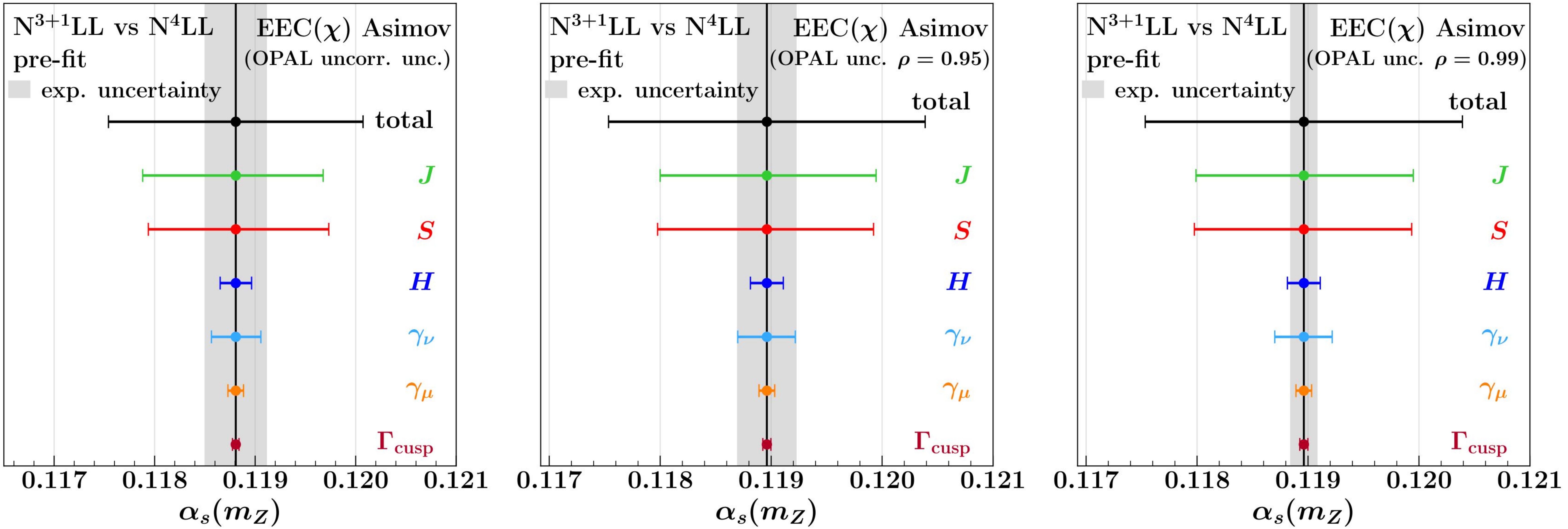
REFERENCES

- Ebert, Mistlberger, Vita; 2012.07859 [arXiv]
- Aglietti, Ferrera; 2403.04077 [arXiv]
- Jaarsma et al.; 2512.11950 [arXiv]
- Moult, Zhu; 2506.09119 [arXiv]
- Tackmann; 2411.18606 [arXiv]
- Cridge, Marinelli, Tackmann; 2506.13874 [arXiv]
- OPAL collaboration; doi: 10.1007/BF01555834 [CDS]

RESULTS: SCANNING TNPS

[Backup]

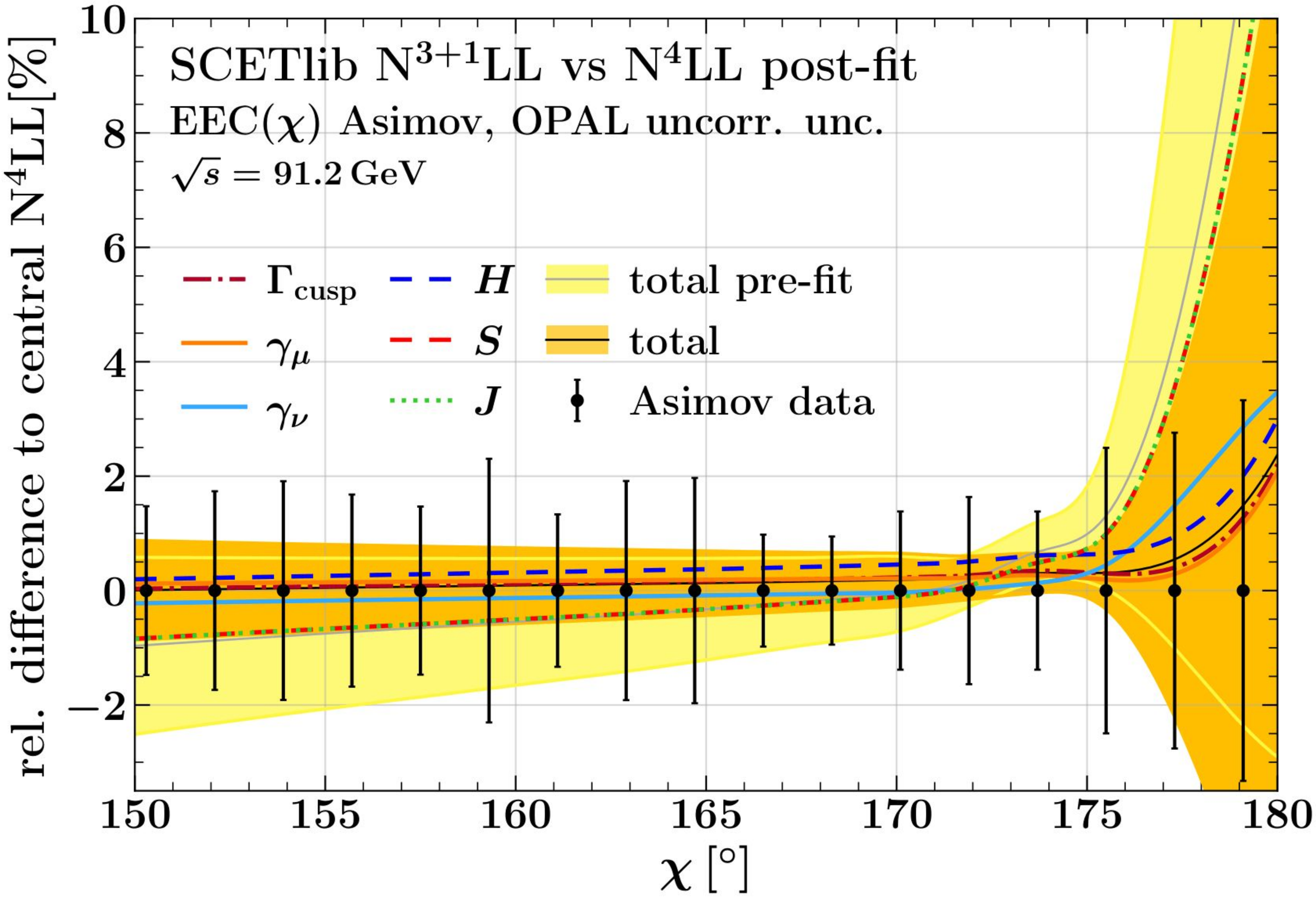
Different correlations {uncorrelated, 95%, 99%}



RESULTS: PROFILING TNPS

[Backup]

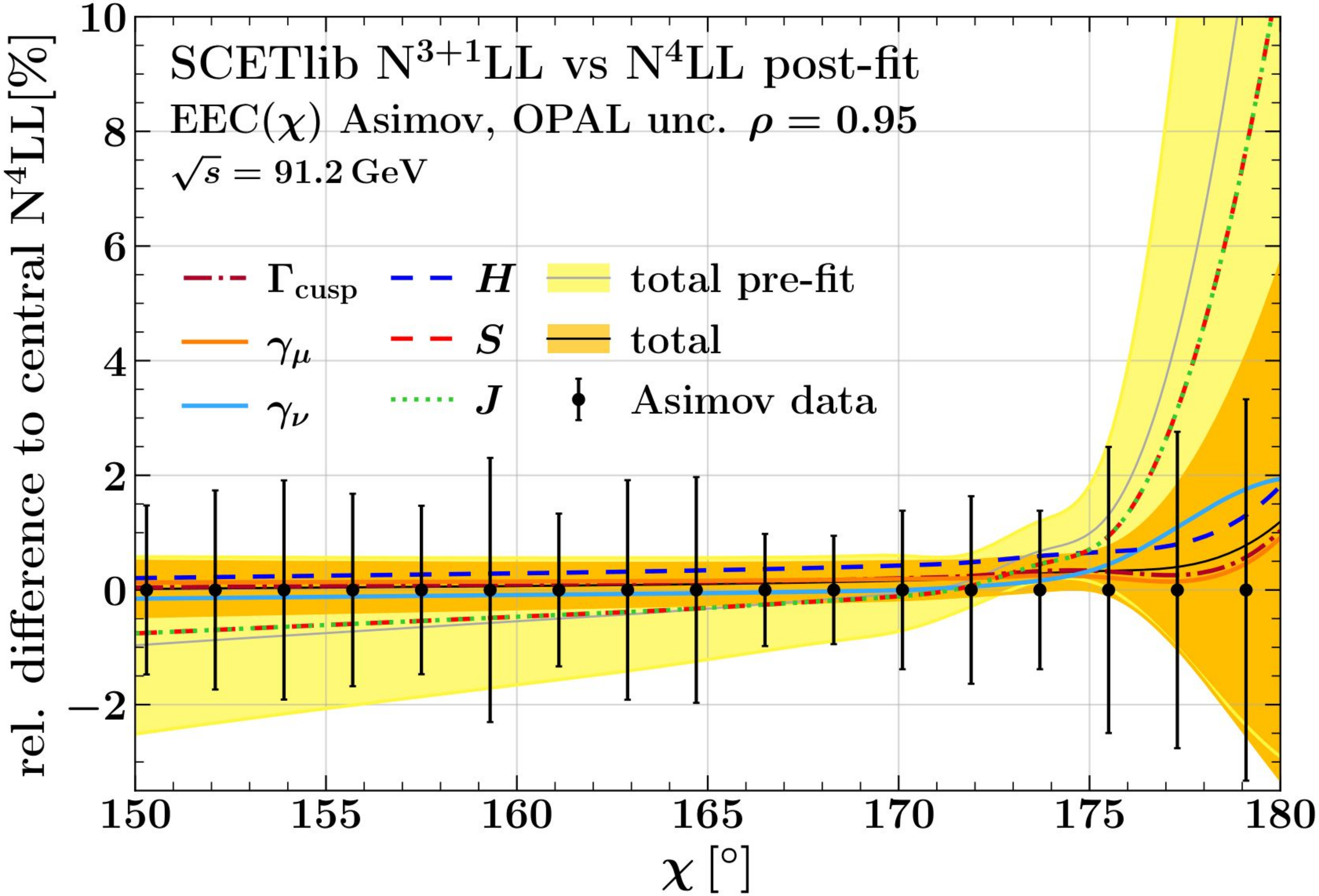
Uncorrelated case: pre- and postfit uncertainty



RESULTS: PROFILING TNPS

[Backup]

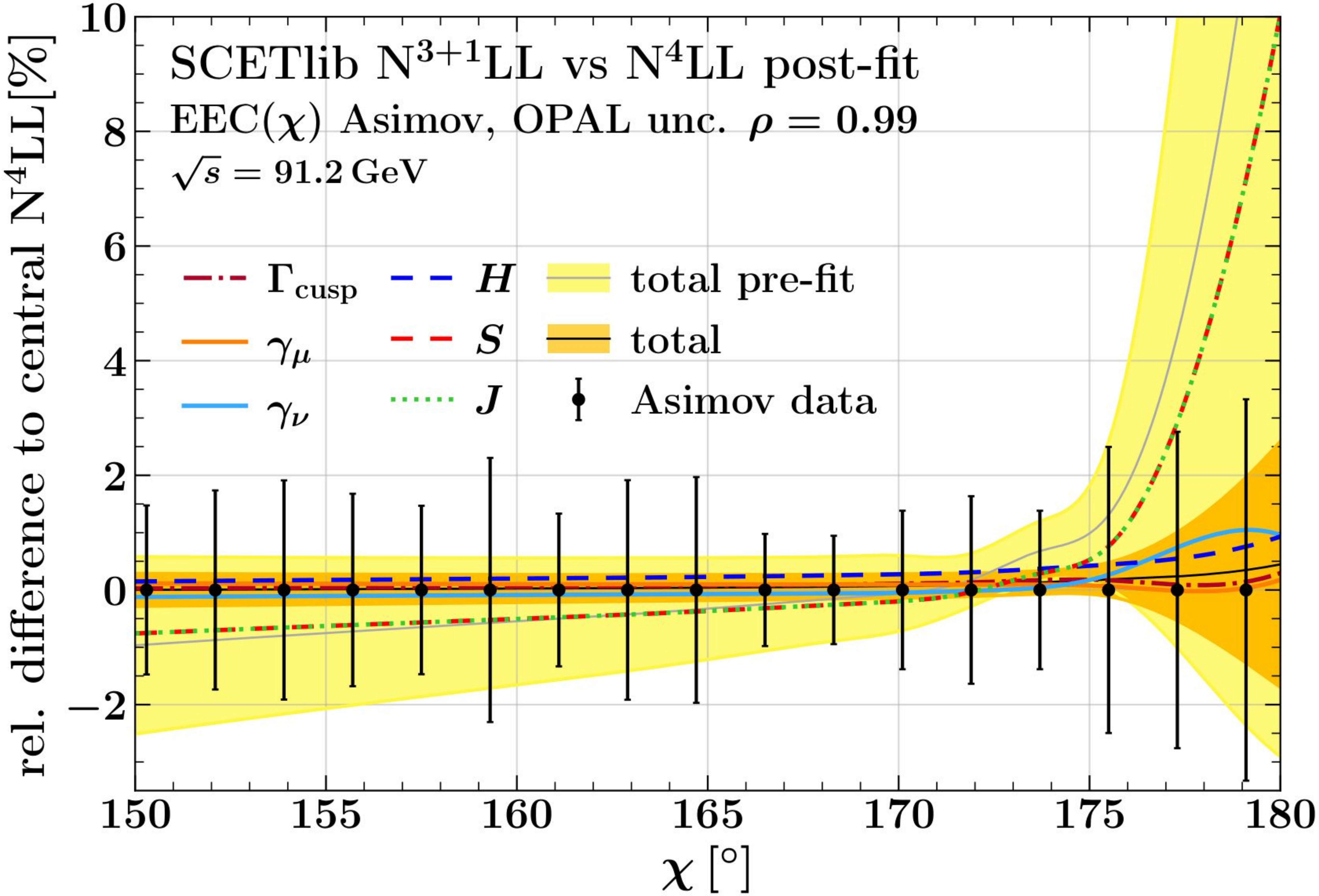
95% correlation: pre- and postfit uncertainty



RESULTS: PROFILING TNPS

[Backup]

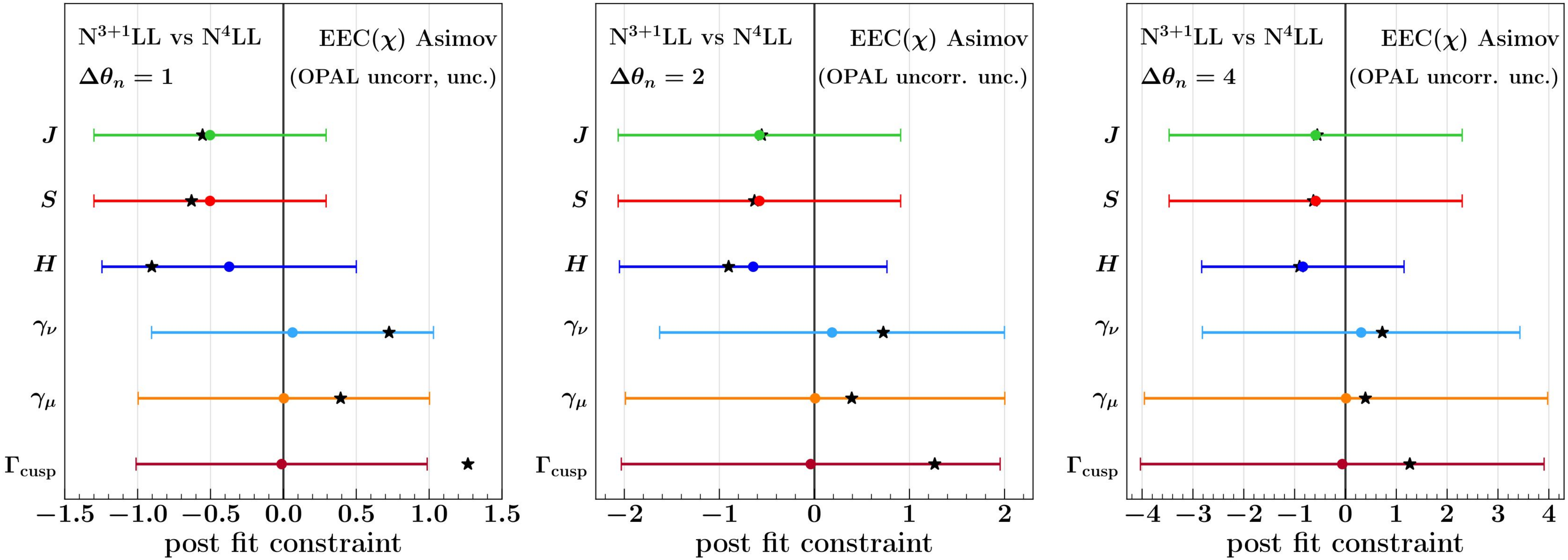
99% correlation: pre- and postfit uncertainty



RESULTS: PROFILING TNPS

[Backup]

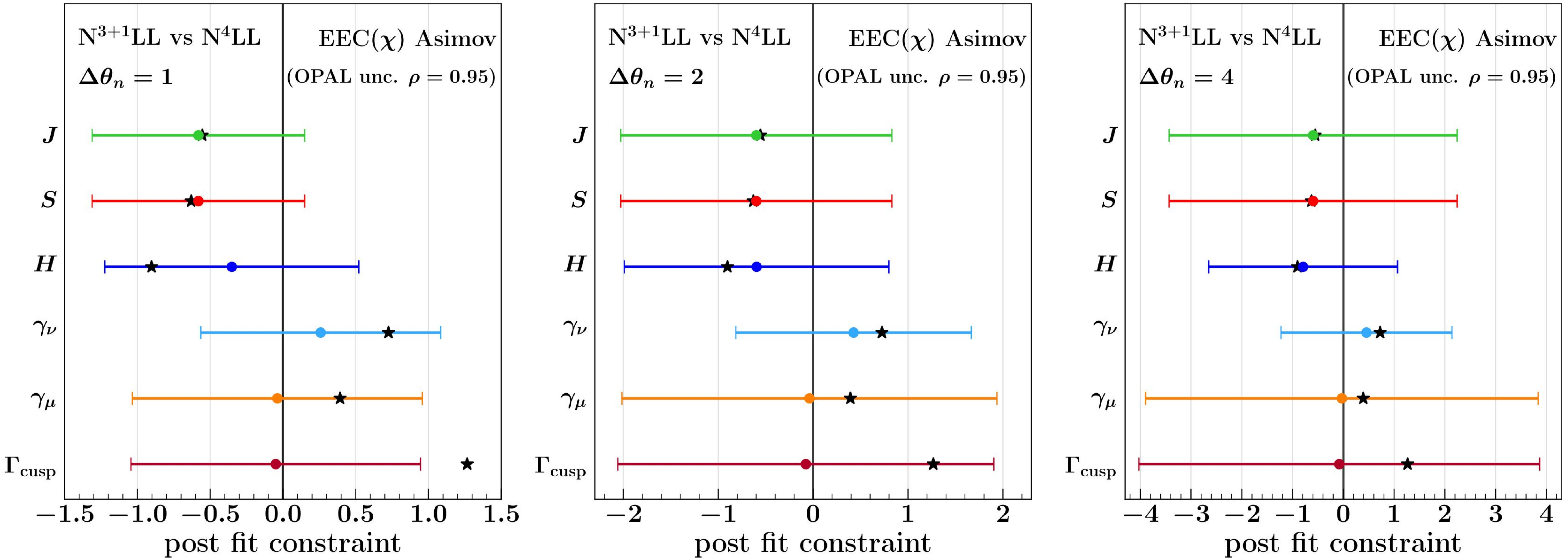
Uncorrelated case: different $\Delta\theta_n = \{1., 2., 4.\}$



RESULTS: PROFILING TNPS

[Backup]

95% correlation: different $\Delta\theta_n = \{1., 2., 4.\}$



RESULTS: PROFILING TNPS

[Backup]

99% correlation: different $\Delta\theta_n = \{1., 2., 4.\}$