THE UNIVERSITY of EDINBURGH

Towards a combined α_s and m_t determination from a global PDF analysis

CENTRE FOR THEORETICAL PHYSICS
Higgs

In collaboration with R. Ball, T. Sharma and R. Stegeman

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07/07/2025

NNPDF

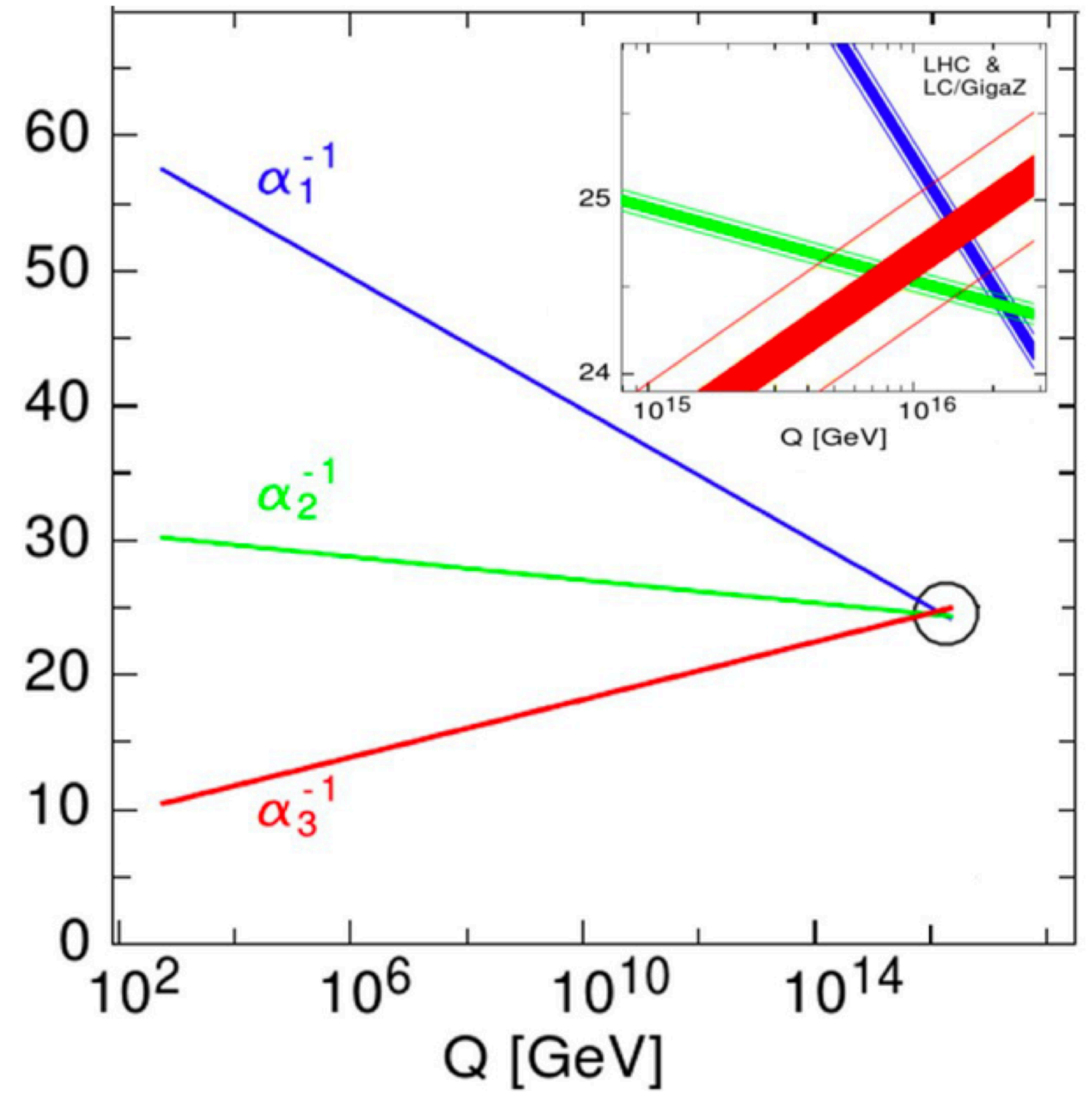
The top mass and α_s

The top mass m_t and the strong coupling α_s

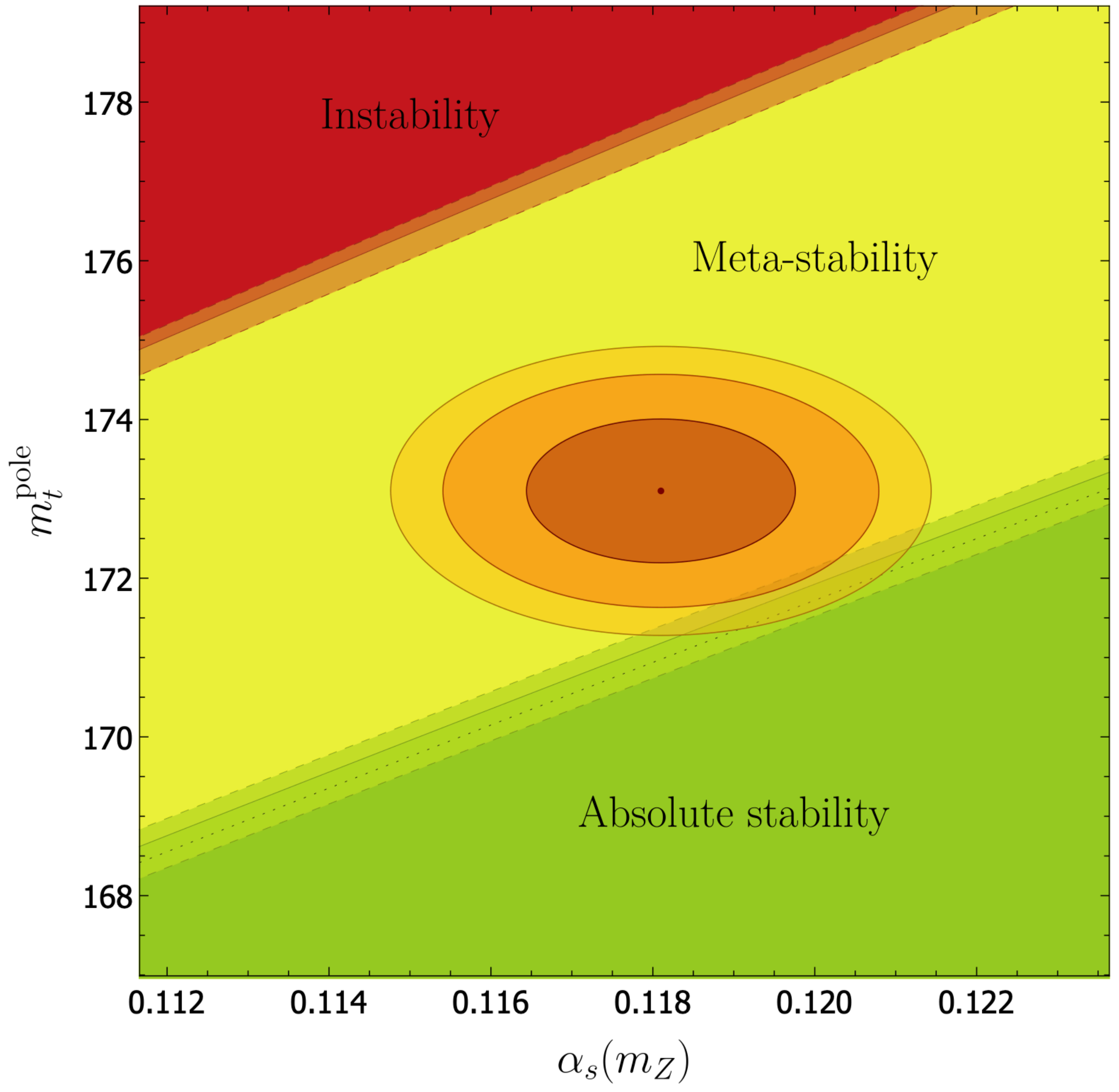
- are **key input** to many (HL)-LHC processes
- are essential to **stress test** the SM
- show strong interplay with many **BSM models**
- hamper the unification of forces at the GUT scale
- determine the **stability** of the universe, 3σ requires $\delta m_t \sim 250$ MeV, $\delta\alpha_s(M_Z) < 0.00025$

PDG: $m_t = 172.4 \pm 0.7$ GeV

$\alpha_s = 0.1180 \pm 0.0009$

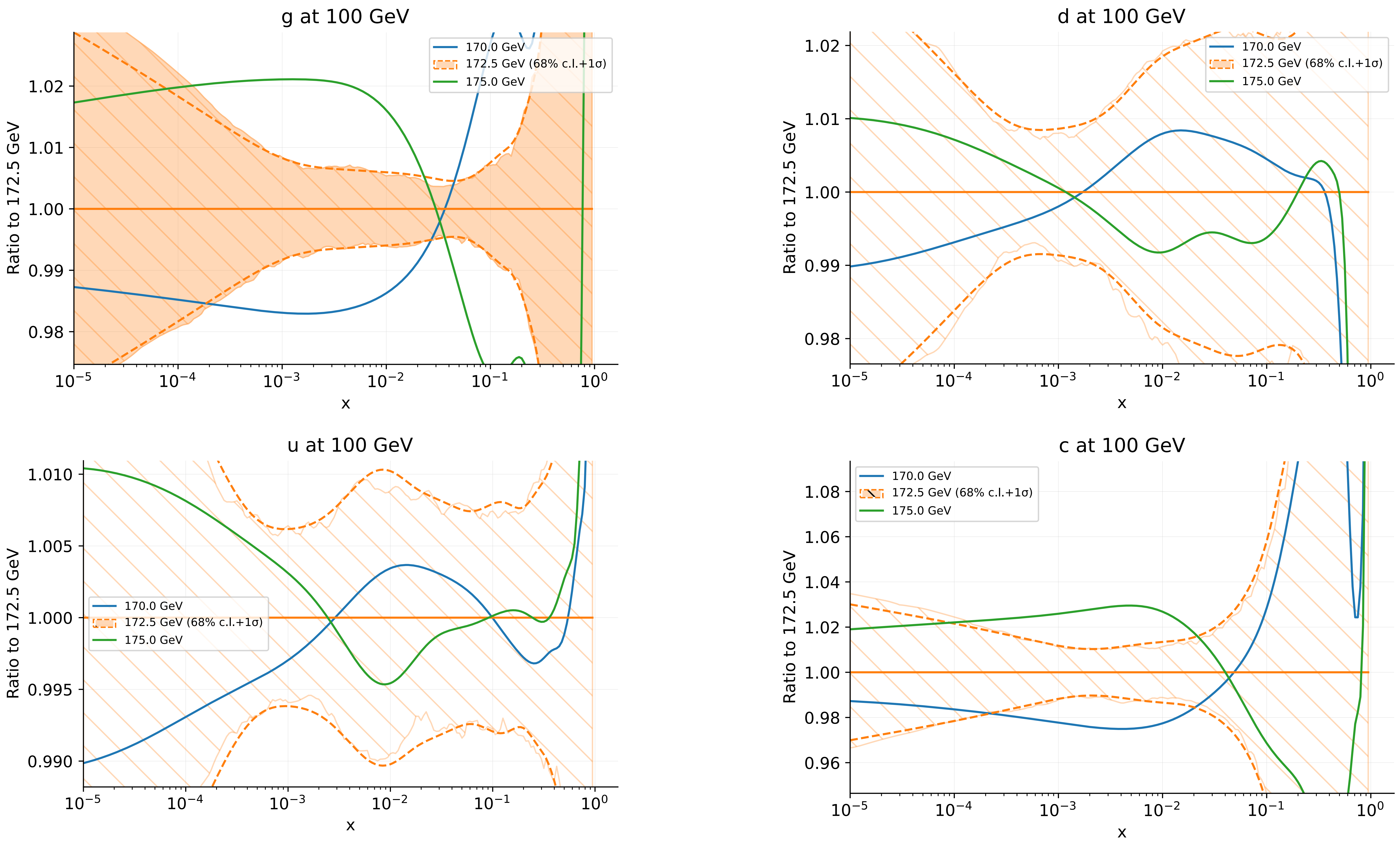


[hep-ph/0410364]

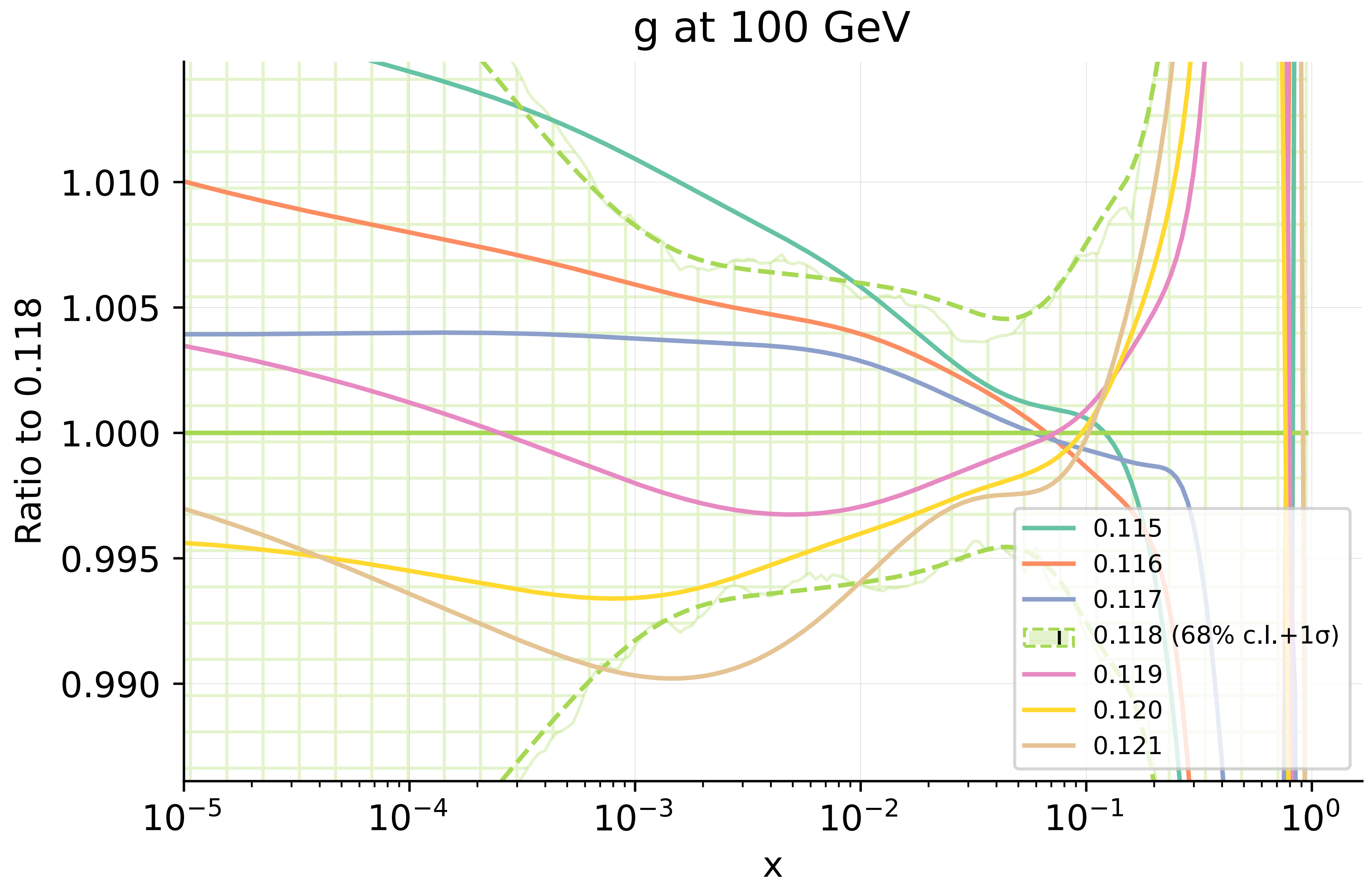


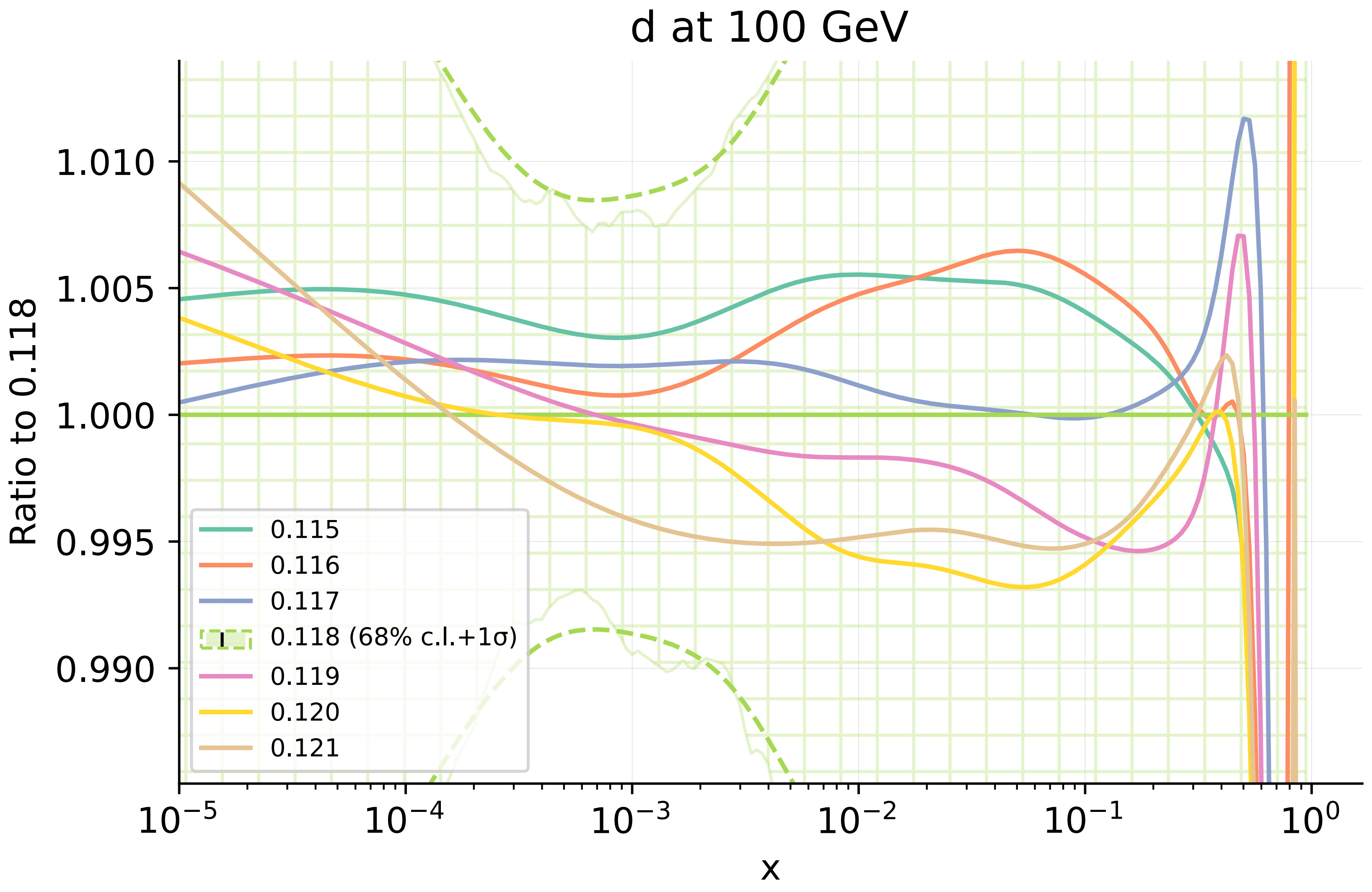
[1701.08124]

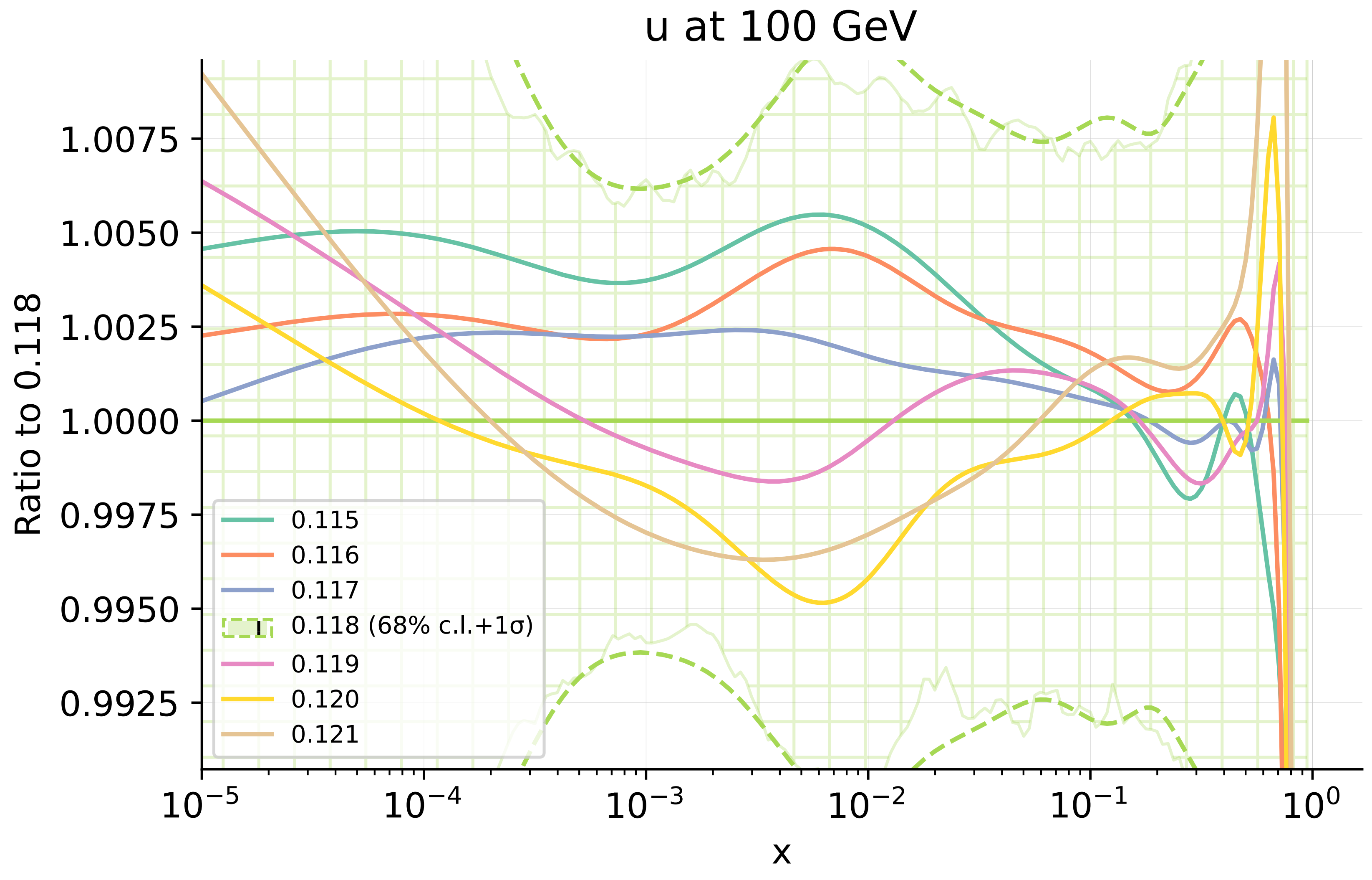
The top mass is correlated to the PDFs …

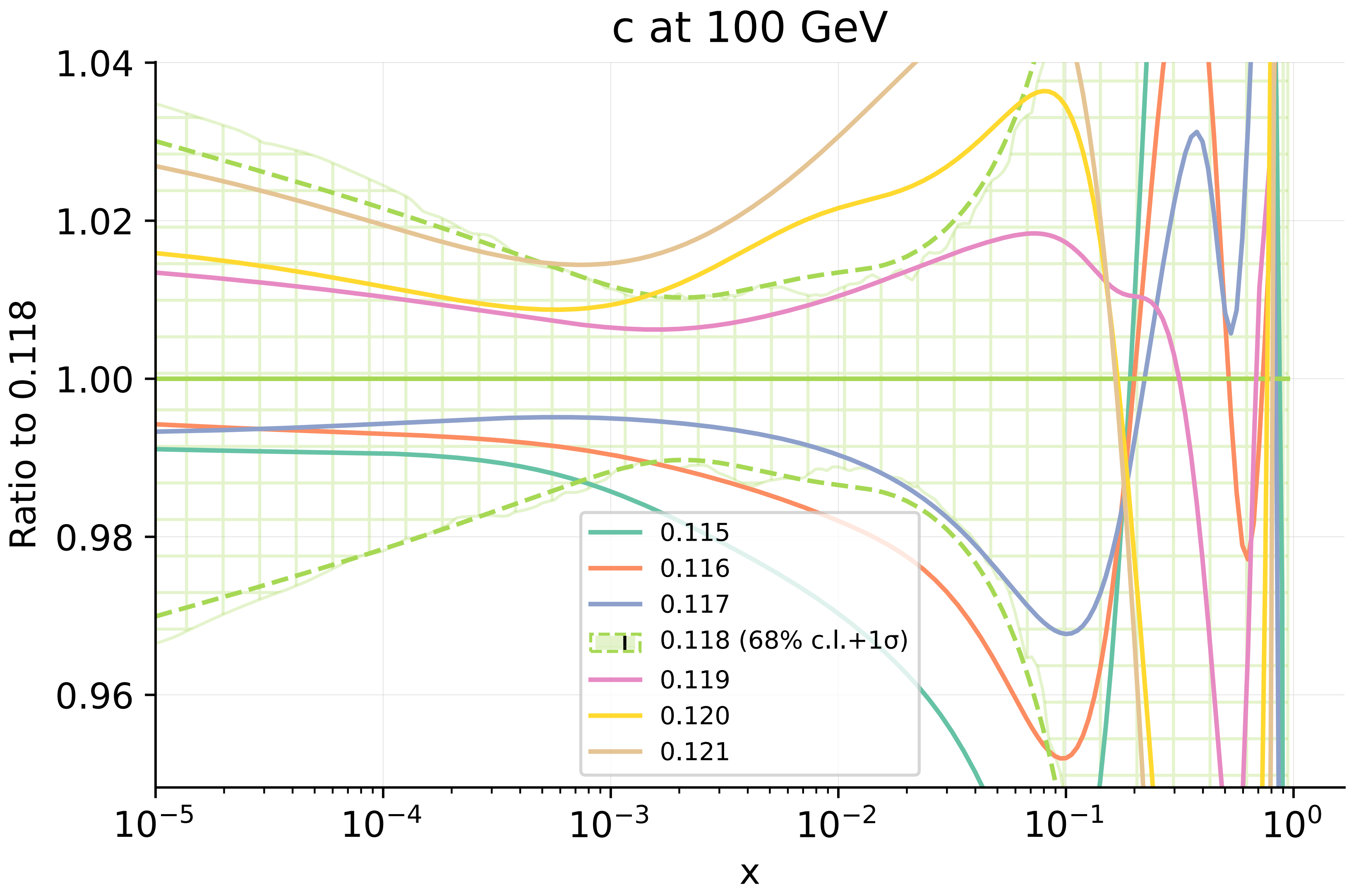


… and so is α_s



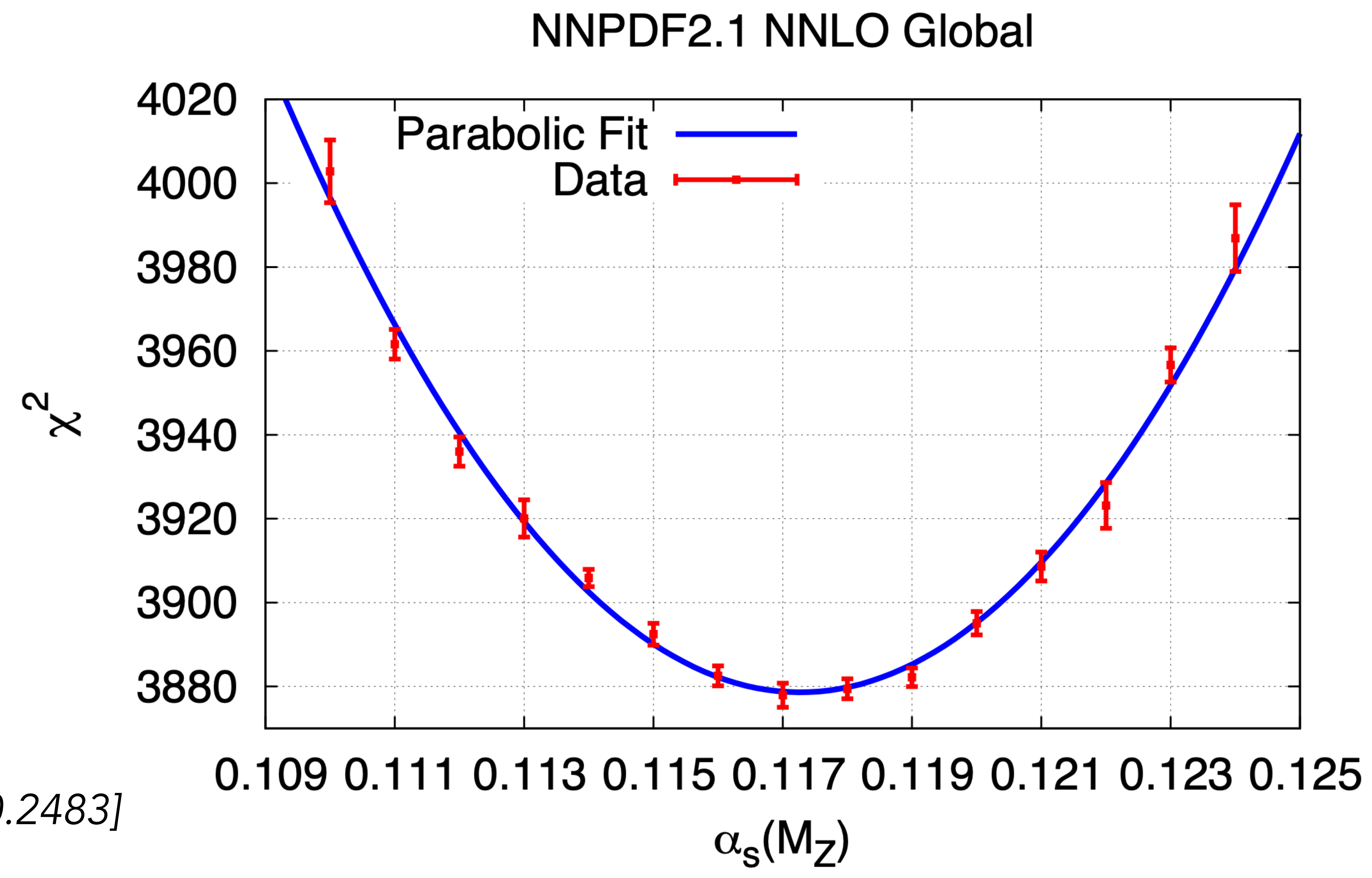




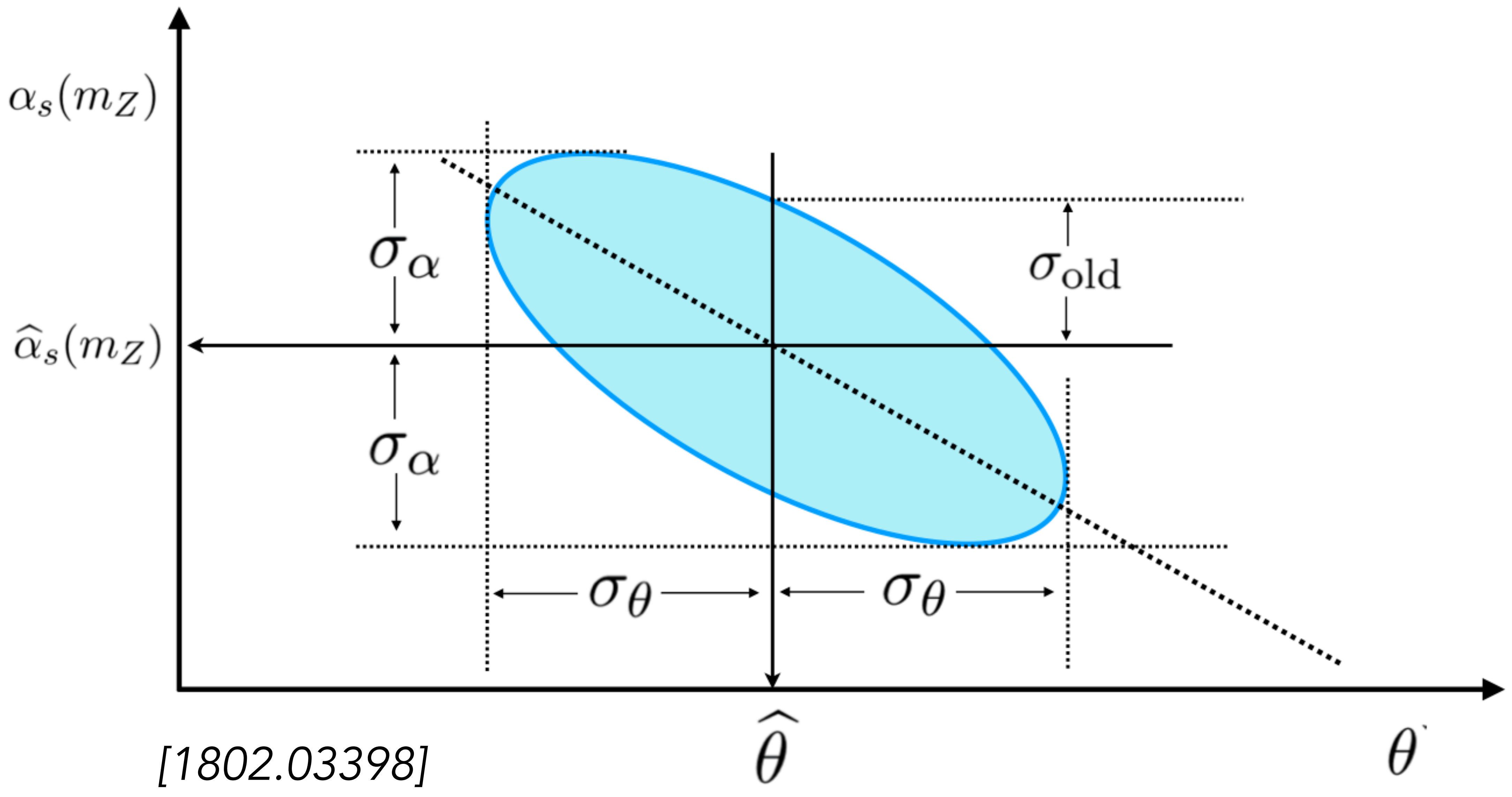


Accounting for correlations

Uncertainties on α_s and m_t are **underestimated** when not fitted simultaneously with the PDFs



[1110.2483]



[1802.03398]

✗ Fit a PDF at a **given** value of α_s to find χ^2

✔ **Jointly** optimise the PDFs and α_s

Accounting for correlations

Q: So why not include α_s directly as fit parameter?

A: requires running DGLAP repeatedly during optimisation…

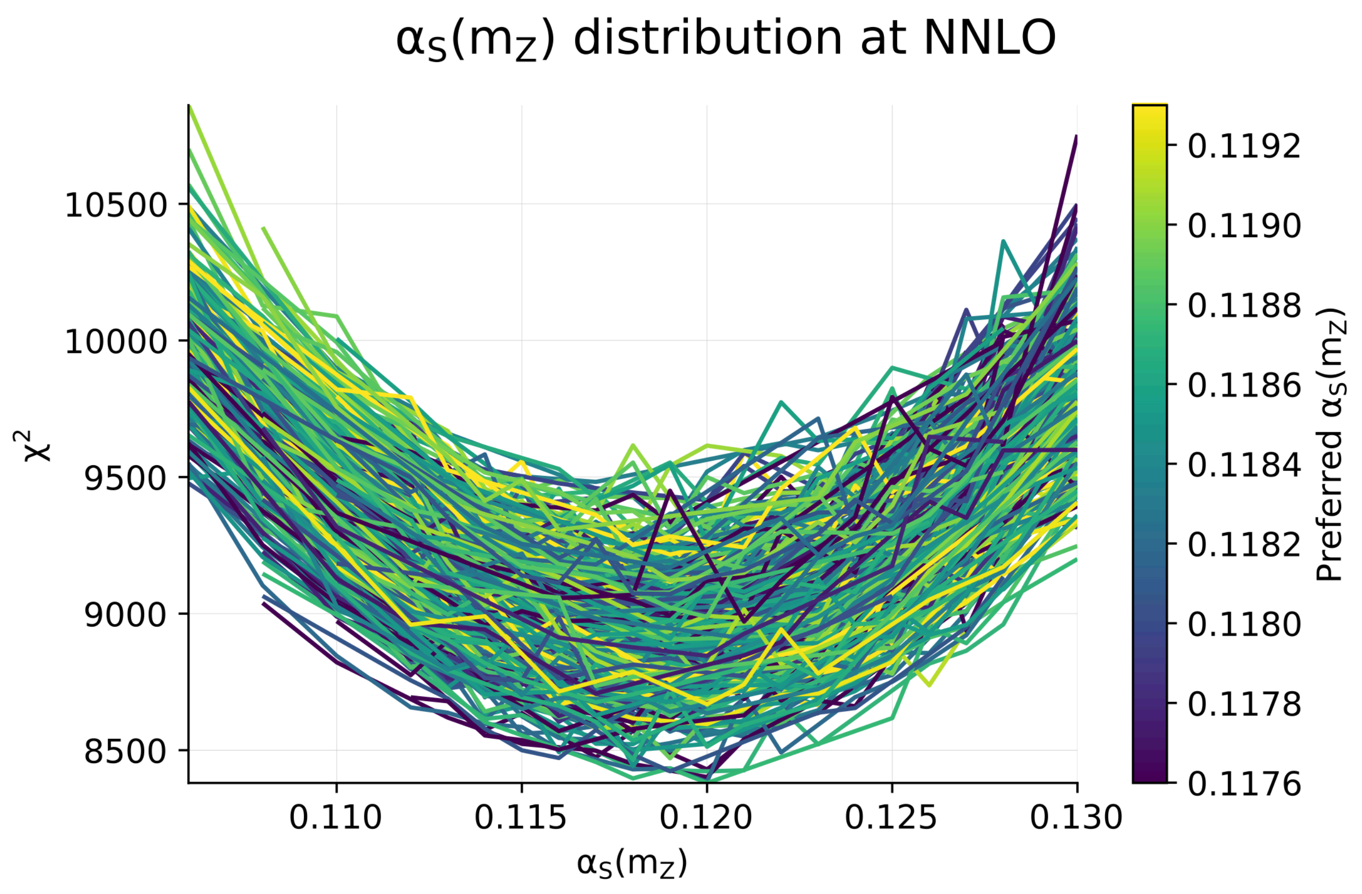
Challenge: NNPDF works with precomputed grids at a given value of α_s

Solutions:

1. Correlated Replica Method - compute χ^2 at each value of α_s for each replica…

2. Theory Covariance Method - **single fit only** using an α_s, m_t theory covariance matrix in a Bayesian framework!

CRM: many fits needed!



[1802.03398]

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This talk

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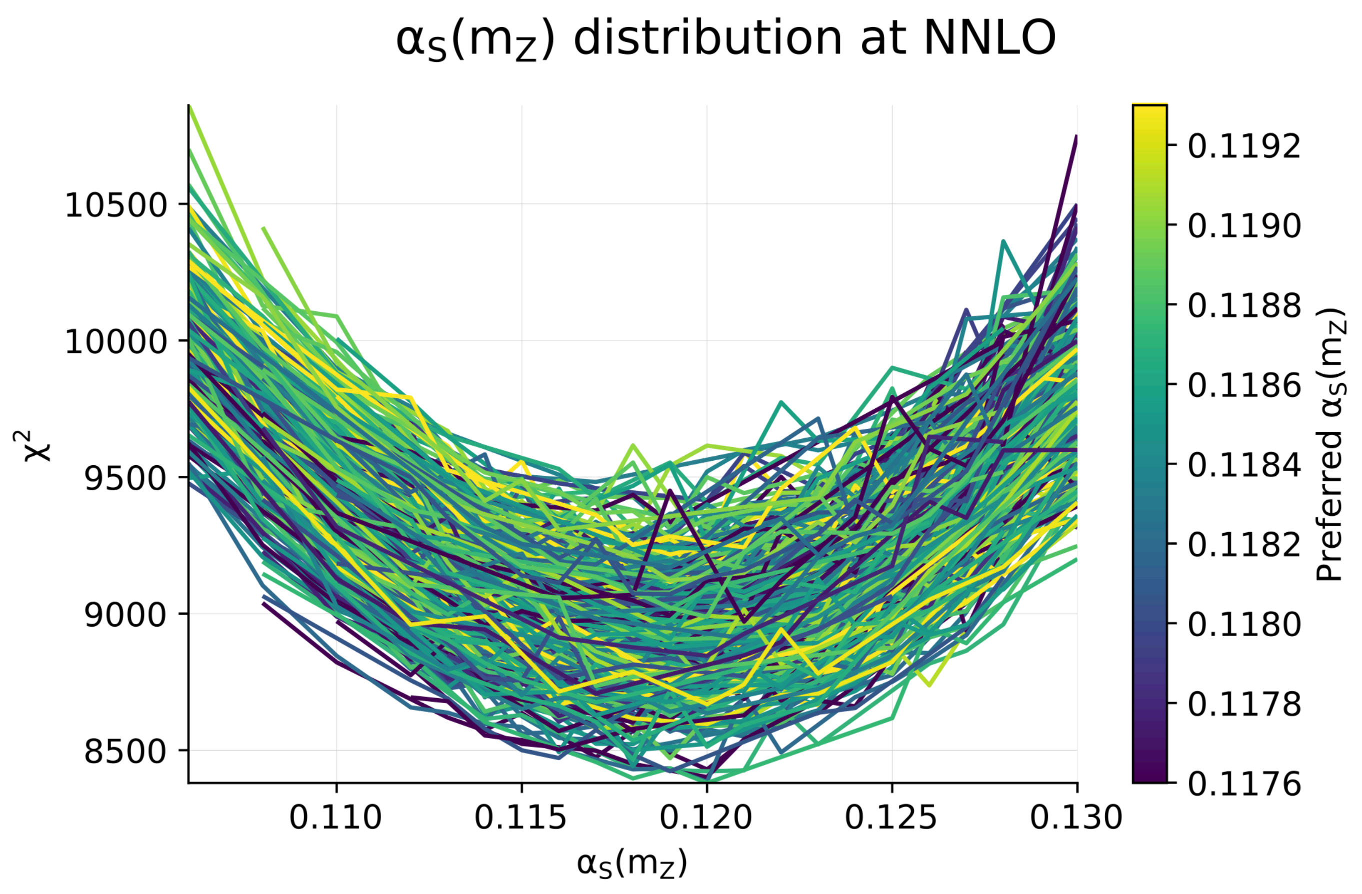


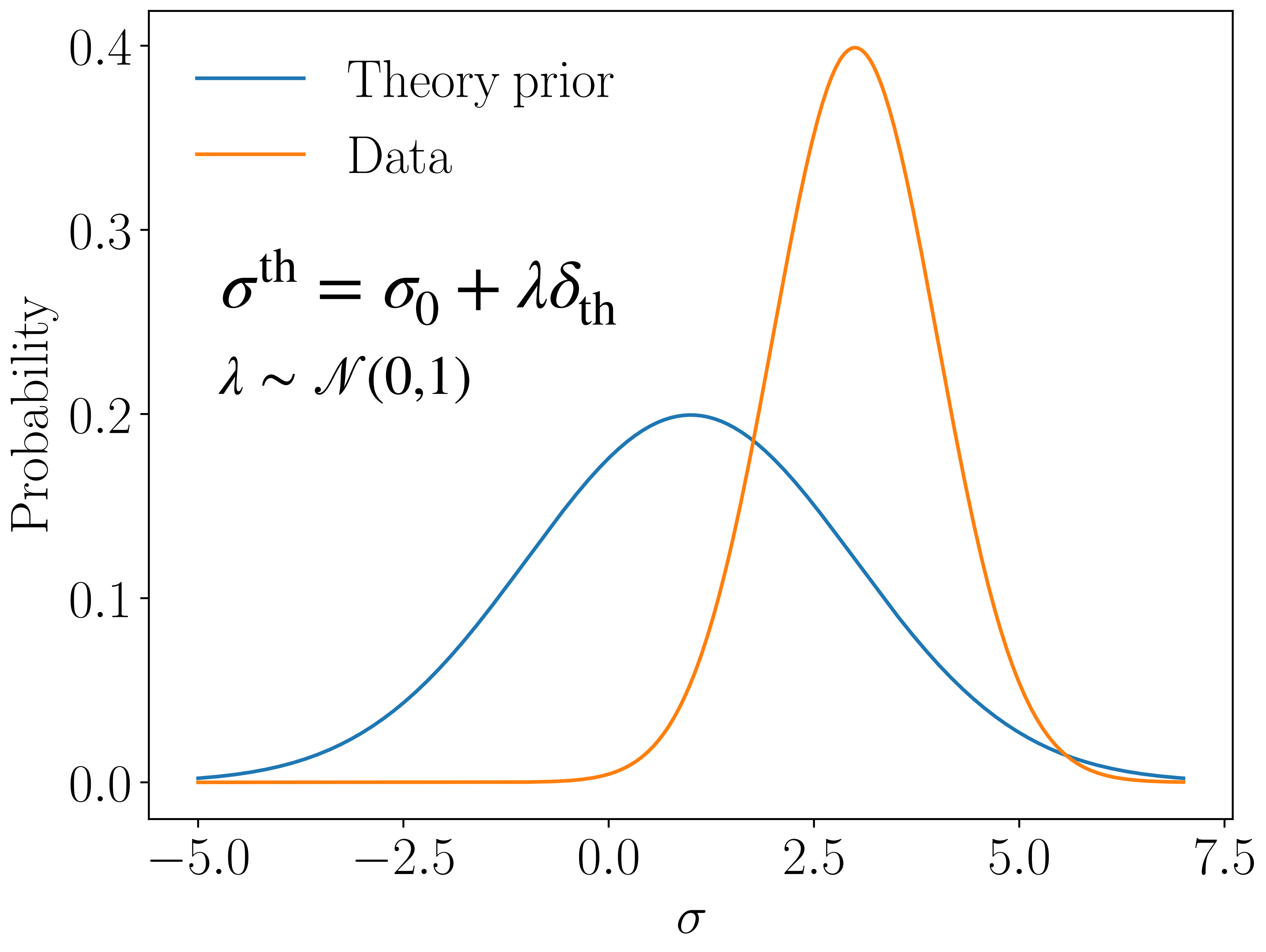
[1802.03398]

Theory covariance method

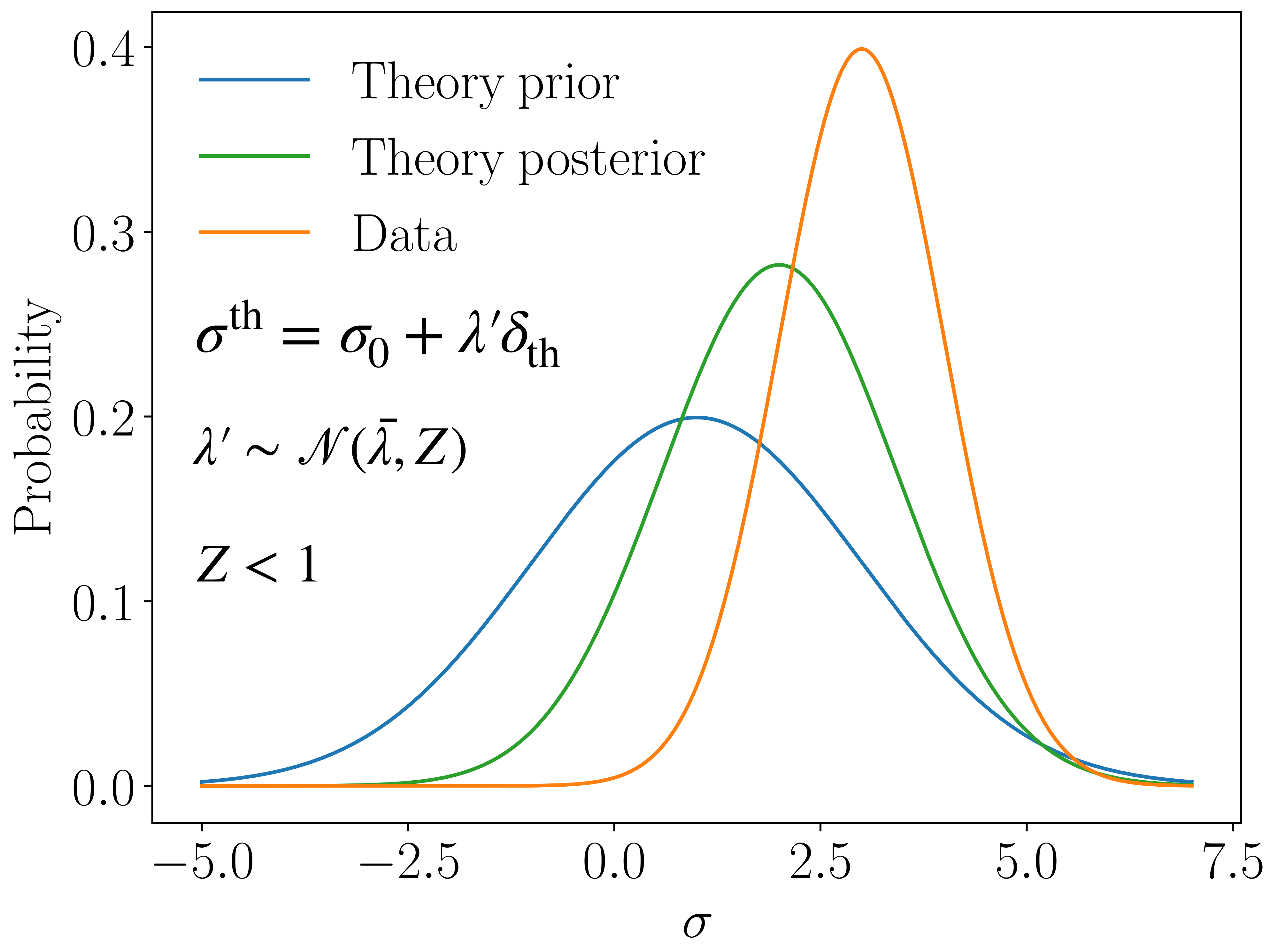
Ball, Pearson [2105.05114]

Bayesian framework: let the data inform our prior knowledge through nuisance parameters

Prior knowledge

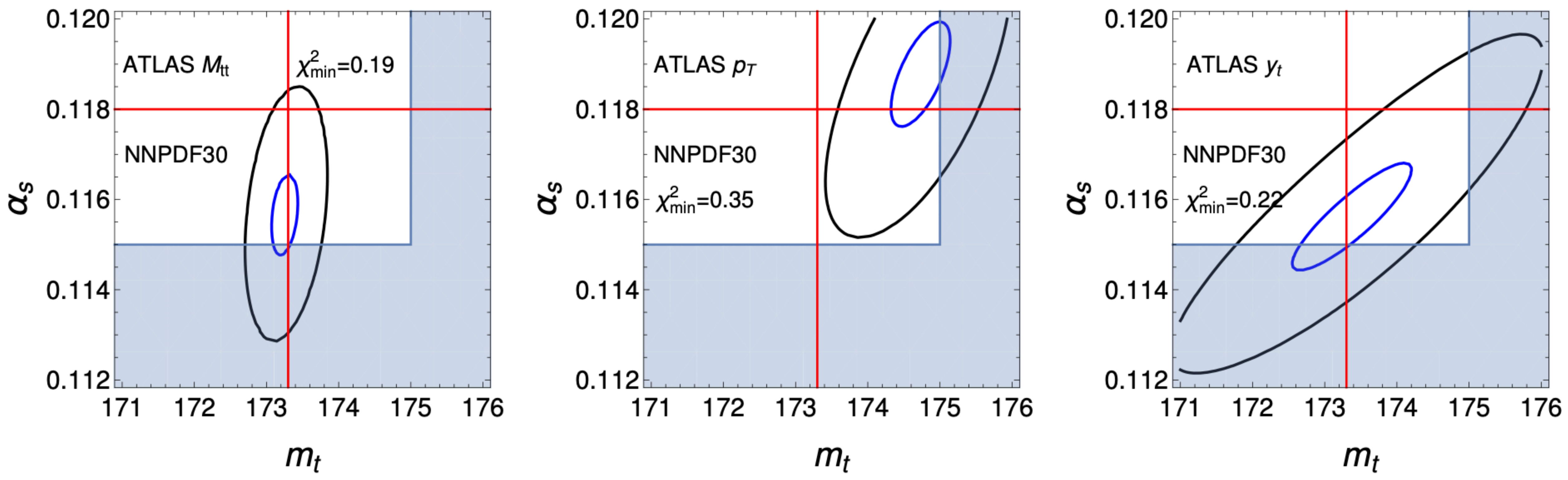


Posterior



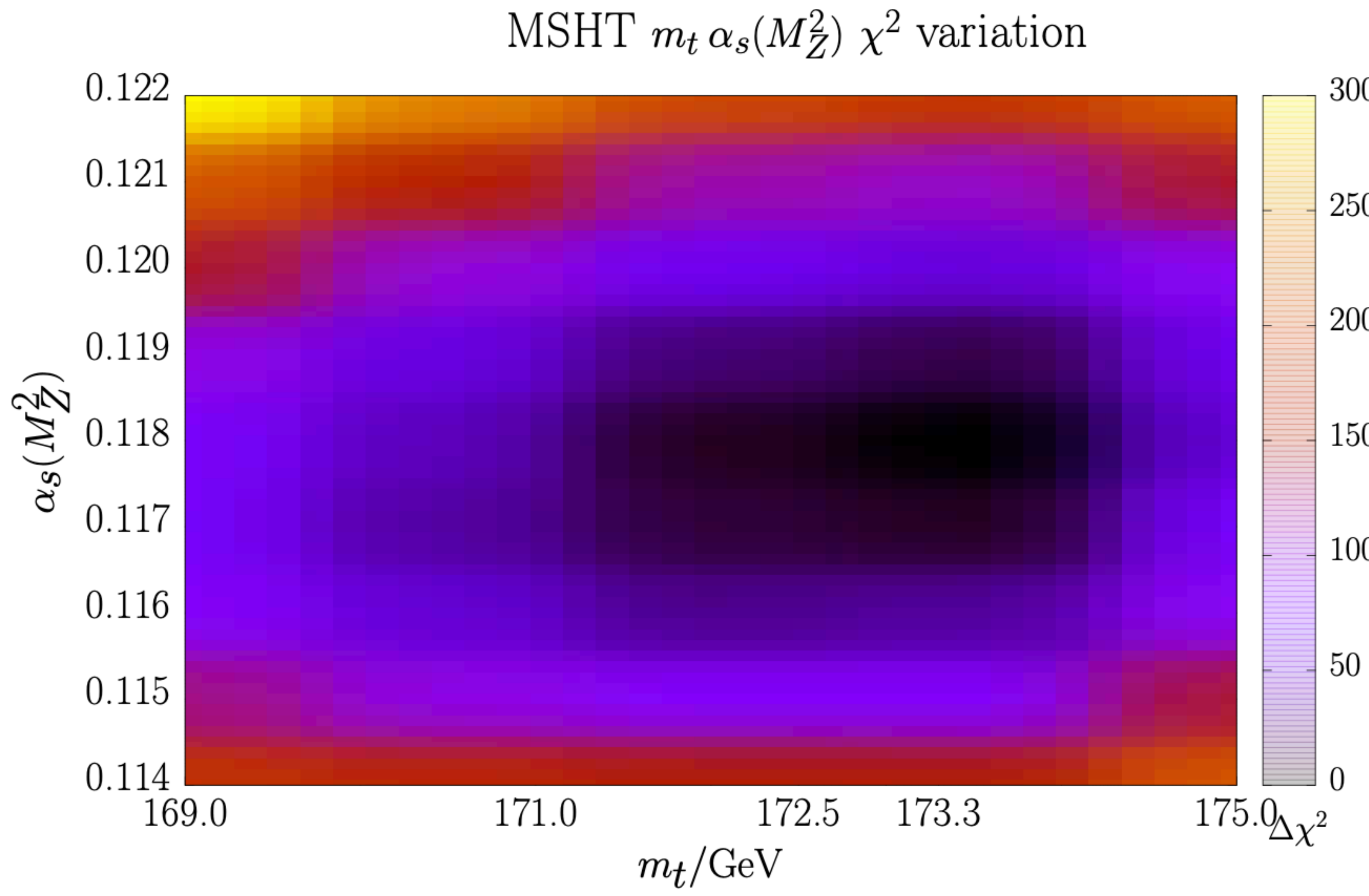
Can be **similarly** applied to α_s and m_t (or any other parameter!)

Existing work



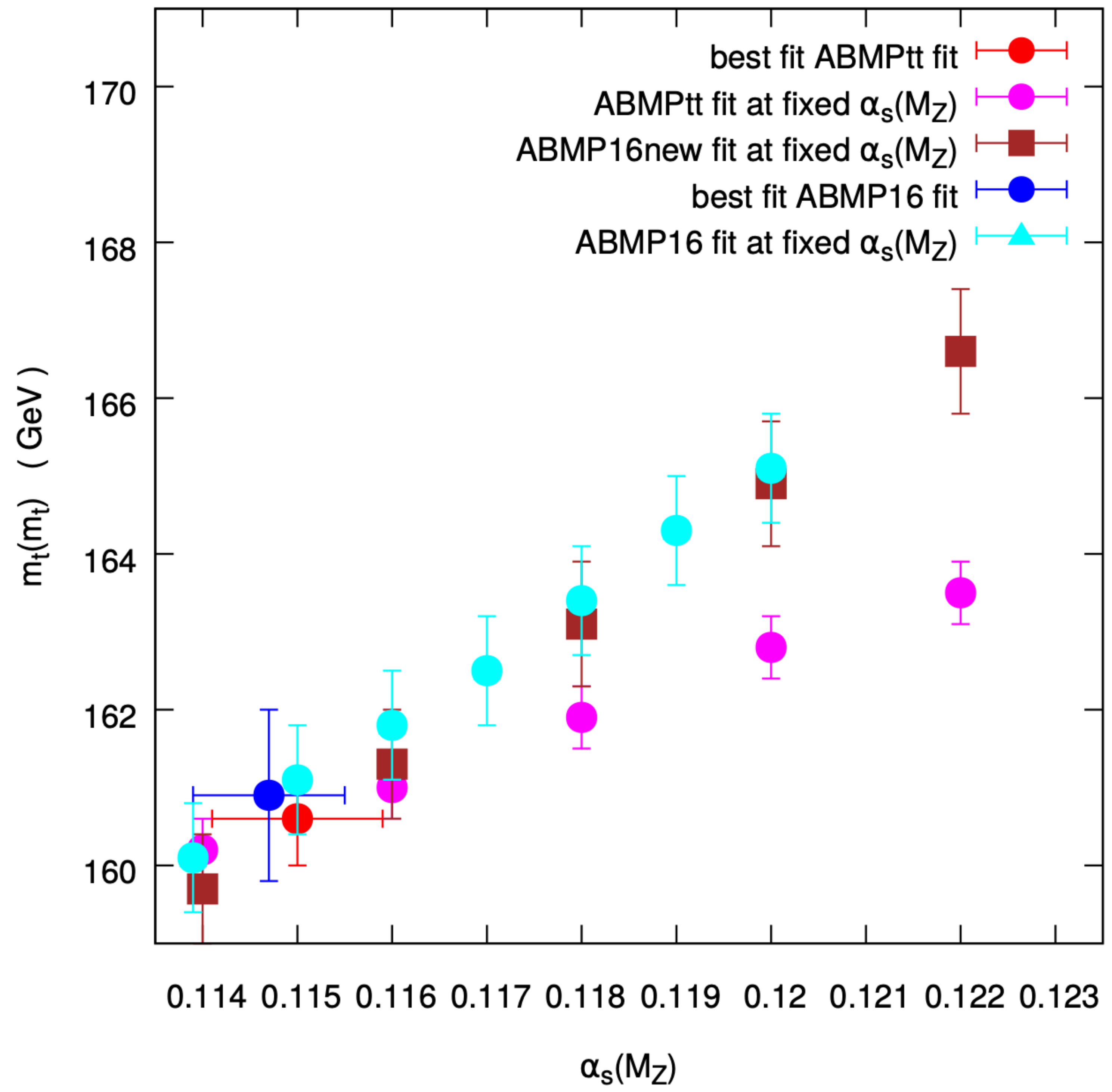
A. Cooper-Sarkar et al.
[2010.04171]

$$m_t = 173.8 \pm 0.8\,\mathrm{GeV}$$
$$\alpha_s = 0.1159 \pm 0.0014$$



T. Cridge et al. (MSHT)
[2306.14885]

$$m_t = 173.0 \pm 0.6\,\mathrm{GeV}$$



S. Alekhin et al. (ABMP)
[2407.00545]

$$m_t = 170.2 \pm 0.7\,\mathrm{GeV}$$
$$\alpha_s = 0.1150 \pm 0.0009$$

Input to the fit

Experimental input

We benefit from the NNPDF4.0 global dataset, with in the top sector specifically

Experiment	$\sqrt{s}$	Variables	Channel	$\mathscr{L}$ [fb-1]	Refs.
ATLAS	7, 8, 13	Total	-	4.6, 20.3, 139	[1406.5375], [2006.13076]
ATLAS	8	$m_{t\bar{t}}, y_{t\bar{t}}$	dilepton	4.6, 20.2	[1607.07281]
ATLAS	8	$y_t, y_{t\bar{t}}, p_T^t, m_{t\bar{t}}$	ℓ+ jets	20.3	[1511.04716]
ATLAS	13	$m_{t\bar{t}}, y_{t\bar{t}}, (m_{t\bar{t}}, y_{t\bar{t}})$	hadronic	36.1	[2006.09274]
ATLAS	13	$y_t, y_{t\bar{t}}, p_T^t, m_{t\bar{t}}, (m_{t\bar{t}}, p_T^t), (y_t, p_T^t)$	ℓ + jets	36	[1908.07305]
CMS	5, 7, 8, 13	Total	-	0.0274, 5, 19.7, 0.043	[1711.03143], [1603.02303], [1510.05302]
CMS	8	$(m_{t\bar{t}}, y_t), (m_{t\bar{t}}, y_{t\bar{t}}), (p_T^t, y_t)$	dilepton	19.7	[1703.01630]
CMS	8	$y_t, y_{t\bar{t}}, p_T^t, m_{t\bar{t}}$	ℓ+ jets	19.7	[1505.04480]
CMS	13	$y_t, y_{t\bar{t}}, p_T^t, m_{t\bar{t}}$	dilepton	35.9	[1811.06625]
CMS	13	$m_{t\bar{t}}, p_T^t, y_t, y_{t\bar{t}}, (m_{t\bar{t}}, y_{t\bar{t}}),$	ℓ + jets	137	[2108.02803]

Theory predictions

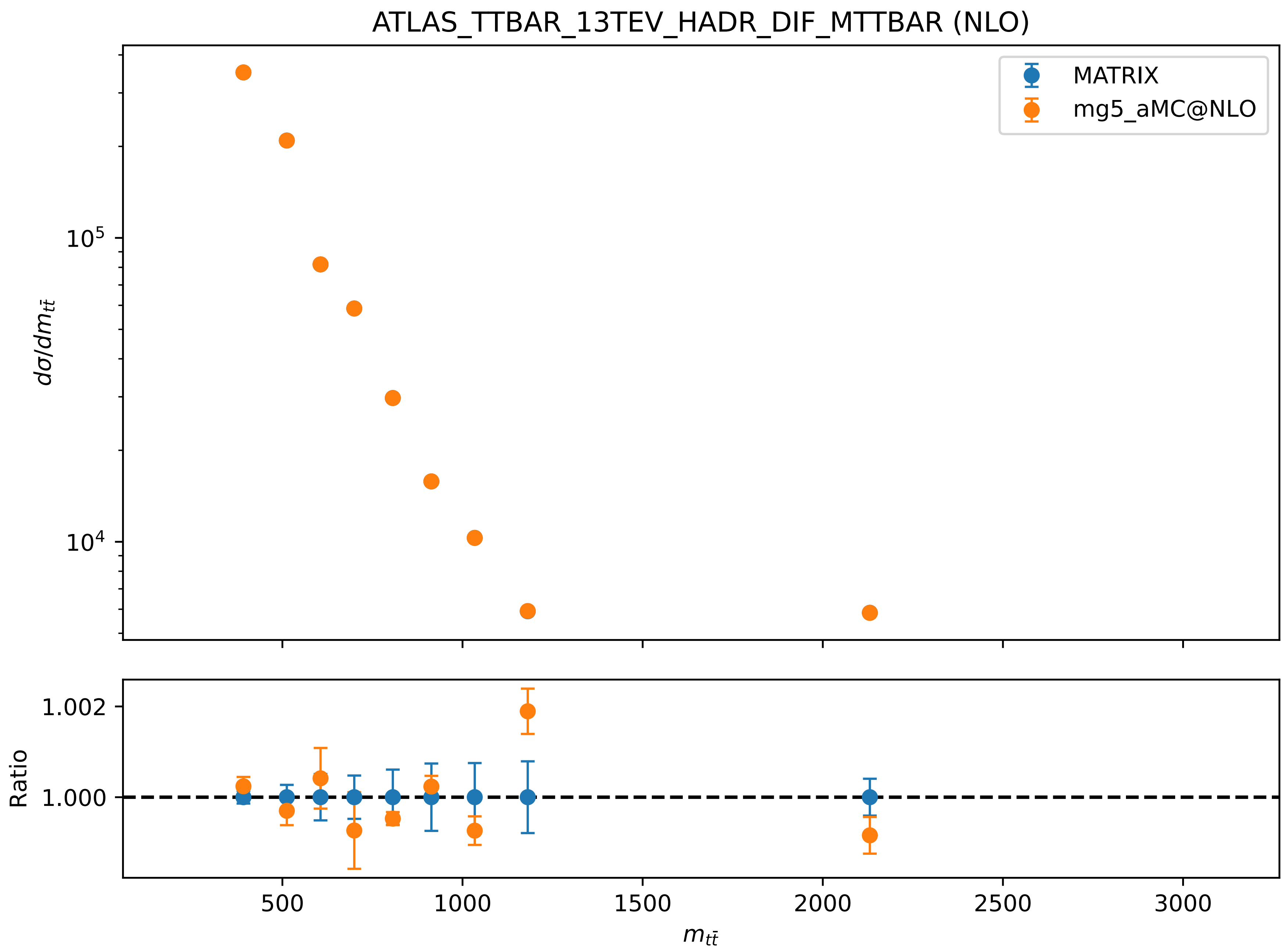
- All differential top processes are computed at NNLO QCD (parton level) with **`MATRIX`** interfaced to **`PineAPPL`**

S. Devoto et al. [2506.14486]

- All inclusive cross sections are computed at NNLO QCD with `top++`

M. Czakon et al. [1112.5675], [1303.6254]

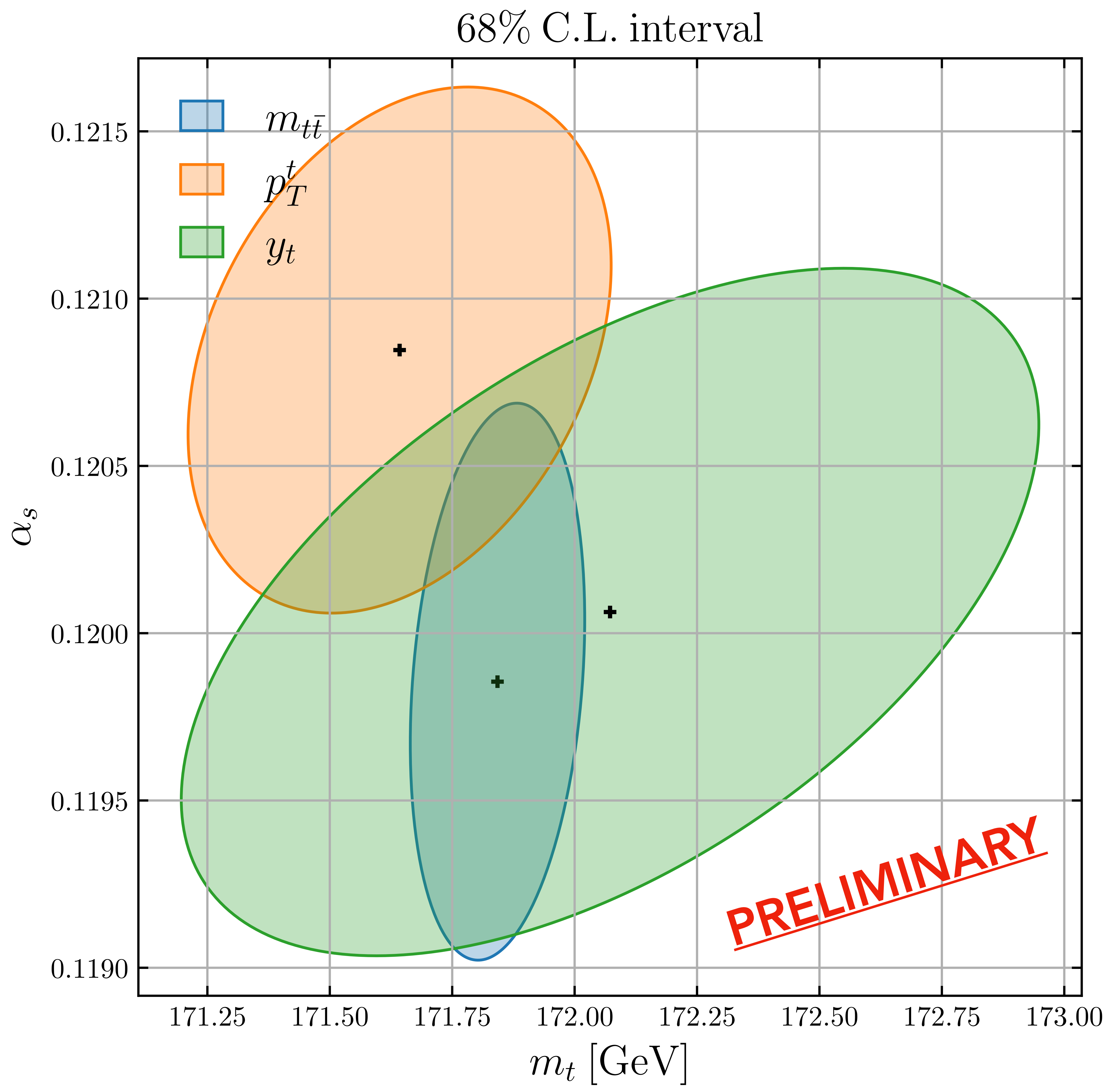
- Prior values $m_t^{\text{pole}} = 170, 172.5, 175\,\text{GeV}$, $\alpha_s = 0.116, 0.118, 0.120$
- Relative MC precision $\Delta\sigma/\sigma \approx 10^{-3}$
- Careful benchmark against `mg5_aMC@NLO`, `top++`, `hightea` finding excellent agreement within uncertainties



Results

Impact of kinematic distributions

- Theory setting: NNLO QCD + Missing Higher Order Uncertainties (MHOUs)
- Consistent results within one sigma
- Top mass is mostly sensitive to the $m_{t\bar{t}}$ distribution due to $t\bar{t}$ threshold
- The PDFs and m_t each benefit from different observables: $m_{t\bar{t}}$ for m_t and y_t for the gluon PDF



Closure tests

NNPDF collab. [1410.8849]

To test the methodology, we run the methodology on pseudodata generated from a **known underlying law**

$$T(\alpha_s, m_t) = \hat{\sigma}_{\mathrm{NNLO}} \otimes (f \otimes f)_{\mathrm{true}}$$

$$D = T + \eta$$

Experimental noise

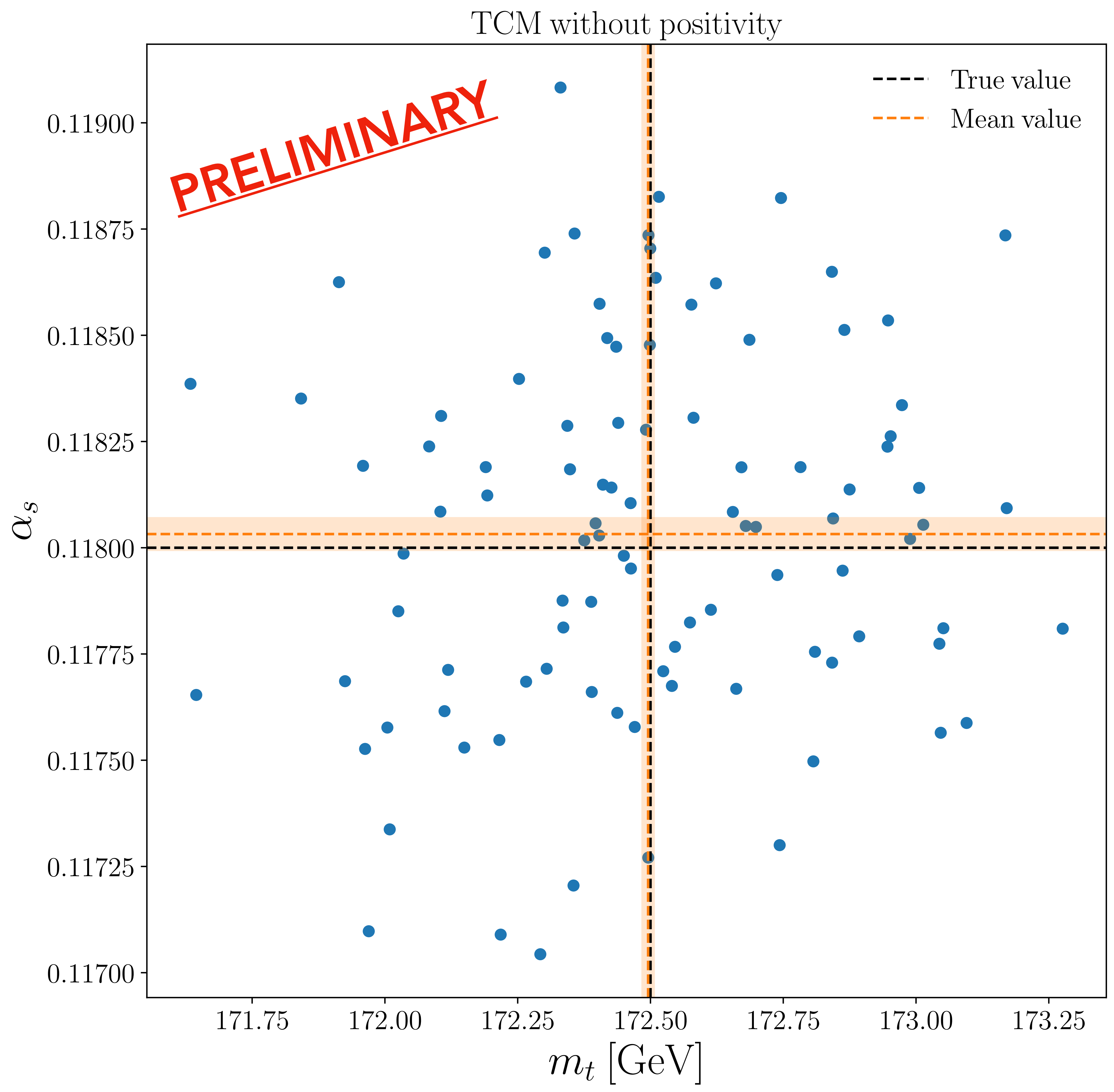
Methodology

Extract α_s, m_t

Are α_s, m_t the same (within uncertainties)?

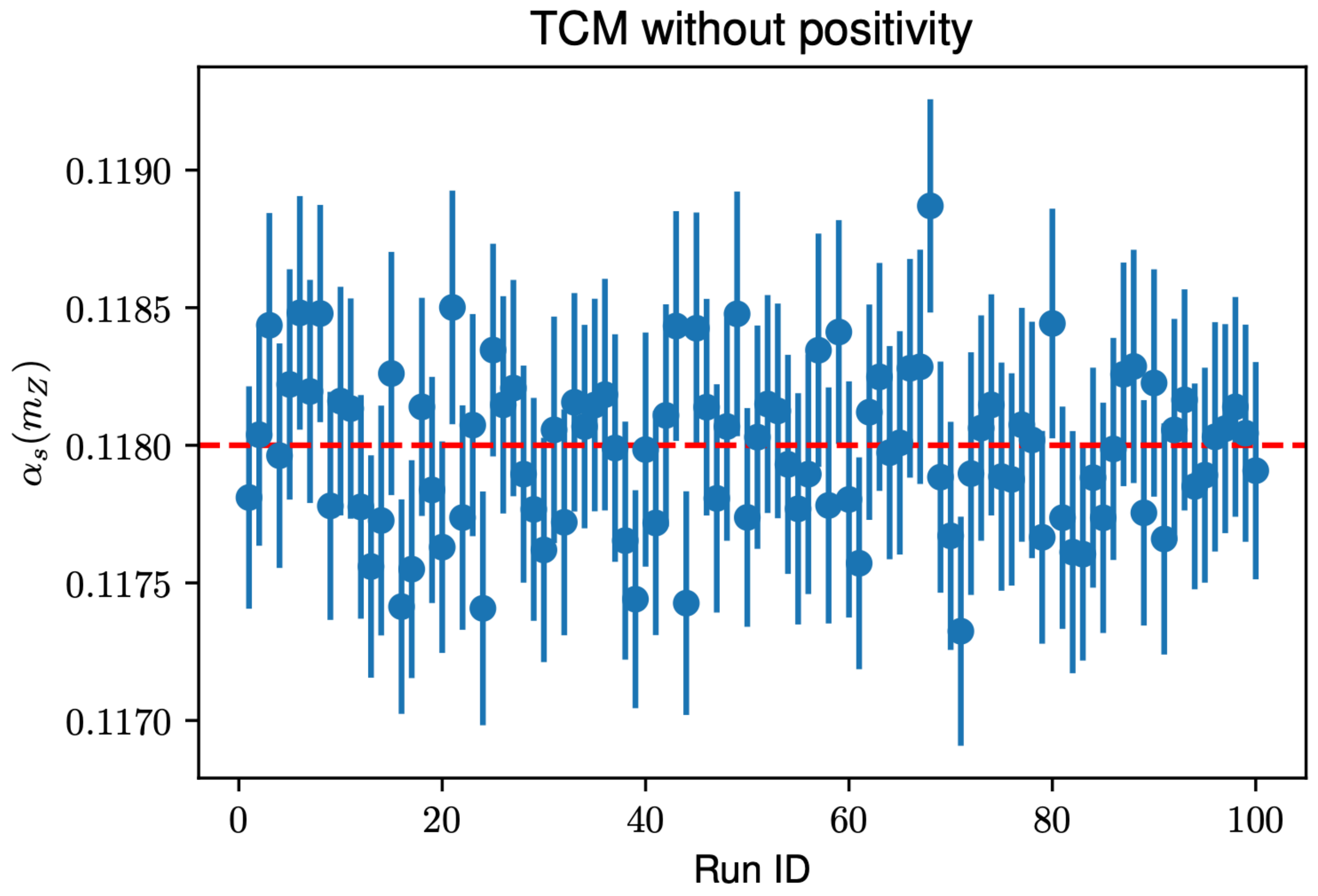
Result

- Draw pseudo data a 100 times at $\alpha_s = 0.118, m_t = 172.5$ GeV
- We nicely **validate** our methodology within uncertainties
- Positivity constraints introduce non Gaussian effects, while the TCM assumes Gaussianity



See Roy Stegeman's Talk in the next session!

NNPDF collab. [2506.13871]



Conclusion and next steps

- The top mass and strong coupling are essential input to stress test the SM, and are correlated to the PDFs

- Presented a simultaneous extraction of the top mass, $\alpha_s(M_Z)$ and the PDFs in the NNPDF framework

Next:

- Move to aN3LO + QED + MHOU

- Incorporate more SM and BSM parameters, such as m_W, m_H and Wilson coefficients in the SMEFT framework

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Contact: jaco.ter.hoeve@ed.ac.uk **Thanks for your attention!**