Partikeldagarna 2026

Towards global interpretation of the LHC data

Simultaneous extraction of SM parameters, proton PDFs, and effective couplings of New Physics

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"Standard Model at Ultimate Precision"

MOTIVATION

No *direct signal* of BSM at LHC: BSM scale much larger than LHC can probe

Solution: Indirect Search - look for deviations from the Standard Model

Validity of the SM relies on knowledge of its parameters:
- **particle masses**
- **interaction strengths**

Challenges:

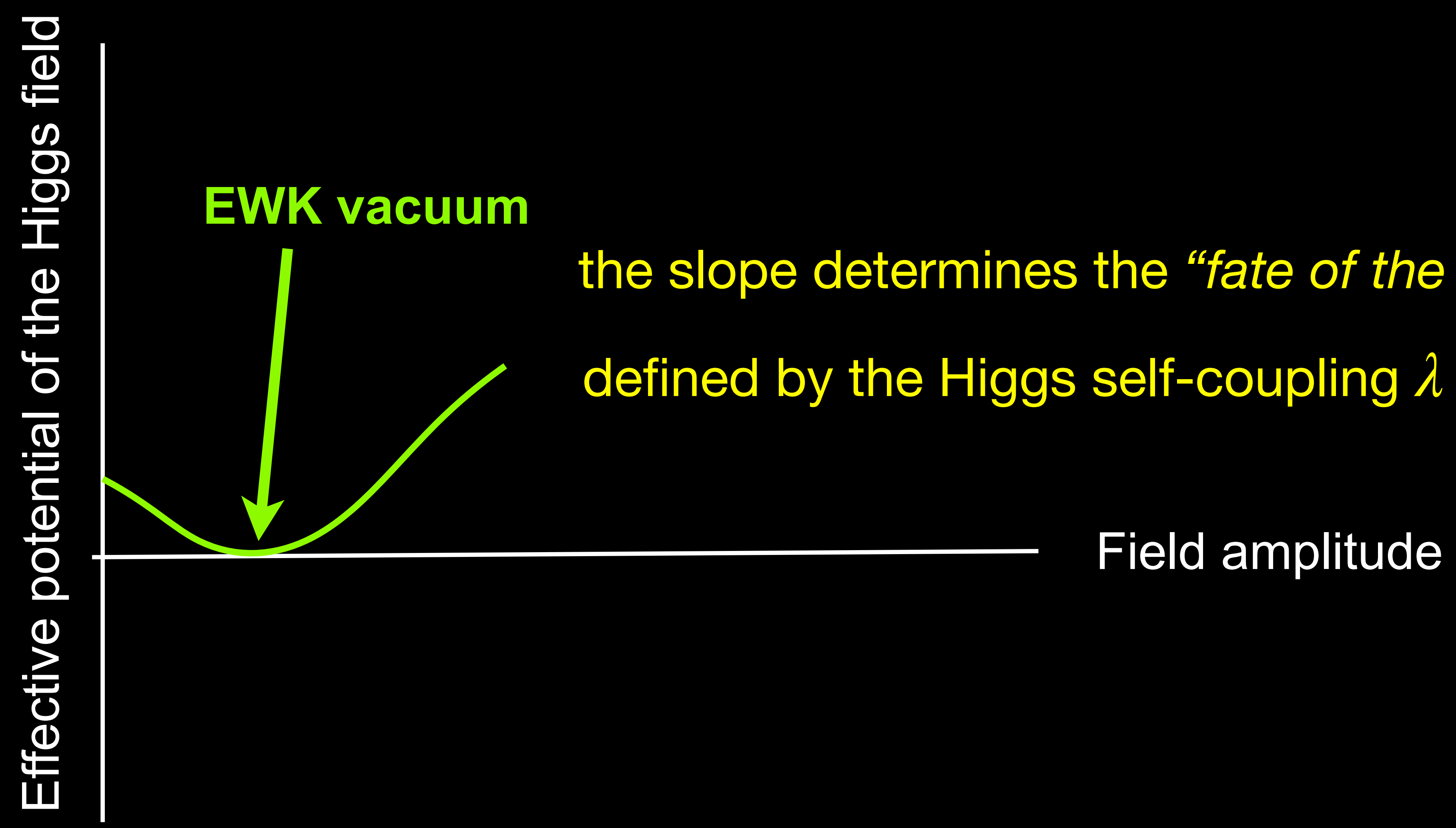
- **SM predicts only "running" of its parameters, values at a certain scale must be measured $\rightarrow$ Uncertainties**

- **SM parameters correlated among each other, variation of one mimics change of another $\rightarrow$ Ambiguities/Bias**

EXAMPLE: STABILITY OF THE UNIVERSE

Our Universe occupies a *vacuum state* of the Higgs field

Whether this is the *true* minimum (and thus *stable*) is decided by the Higgs potential



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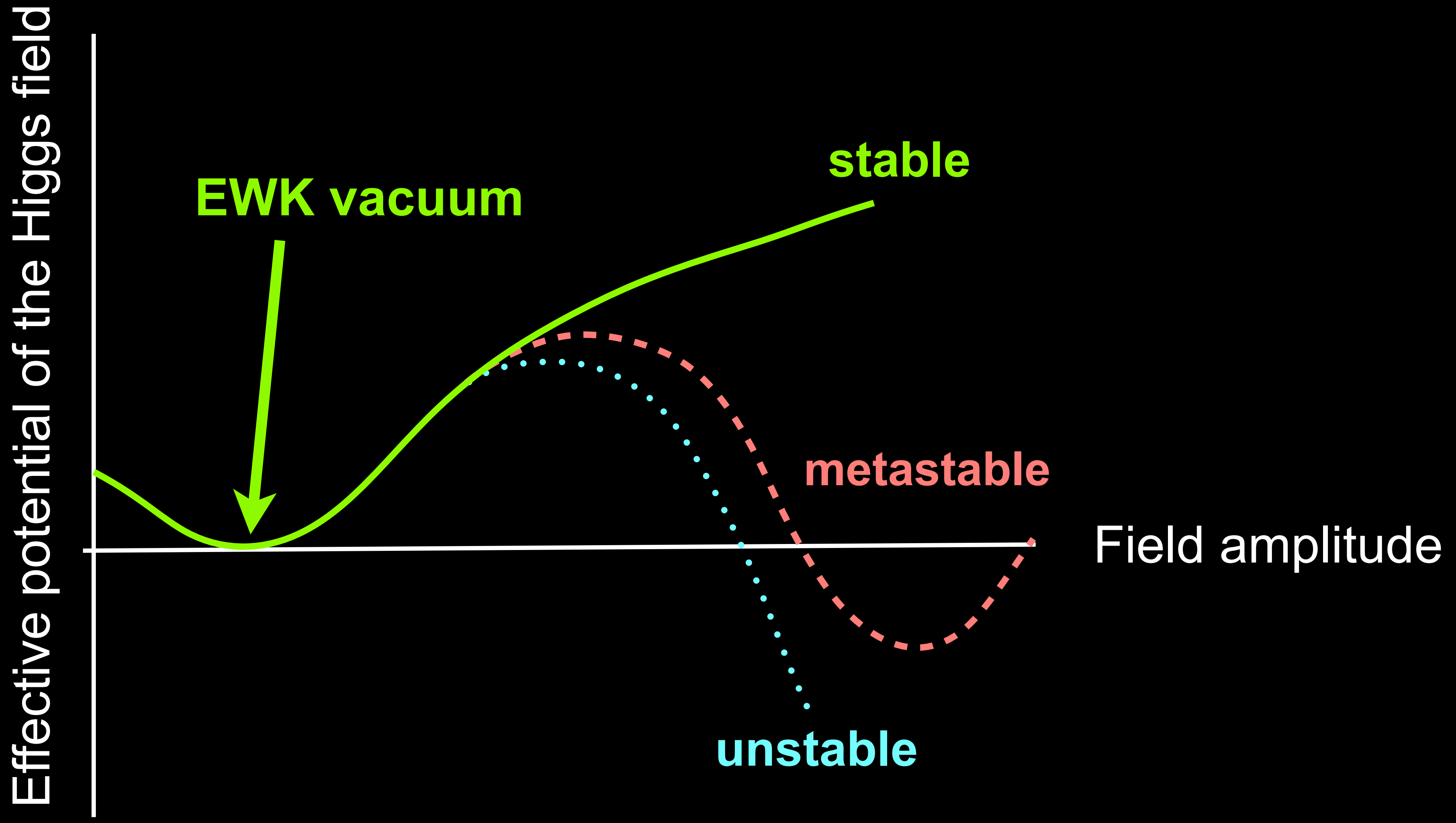

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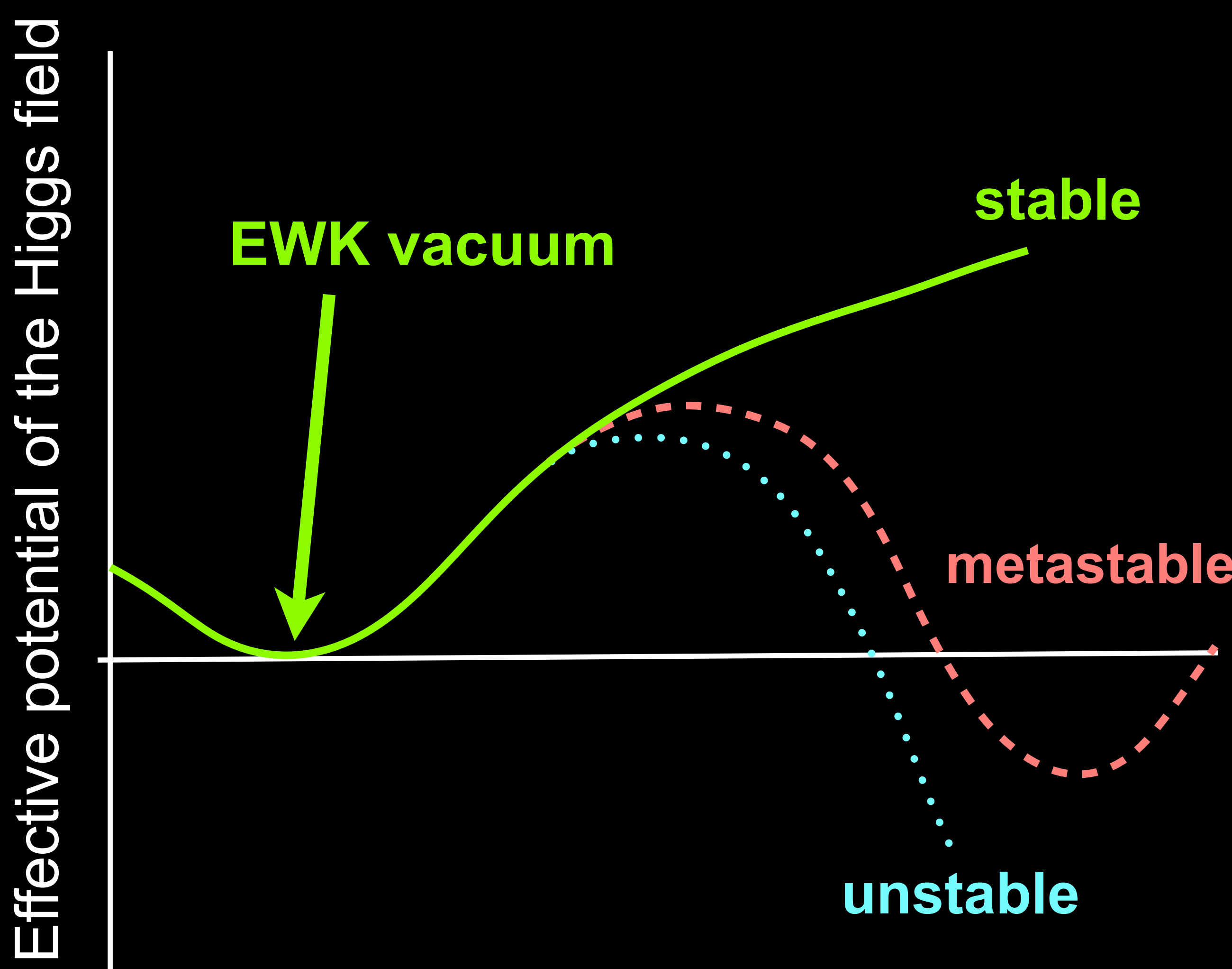
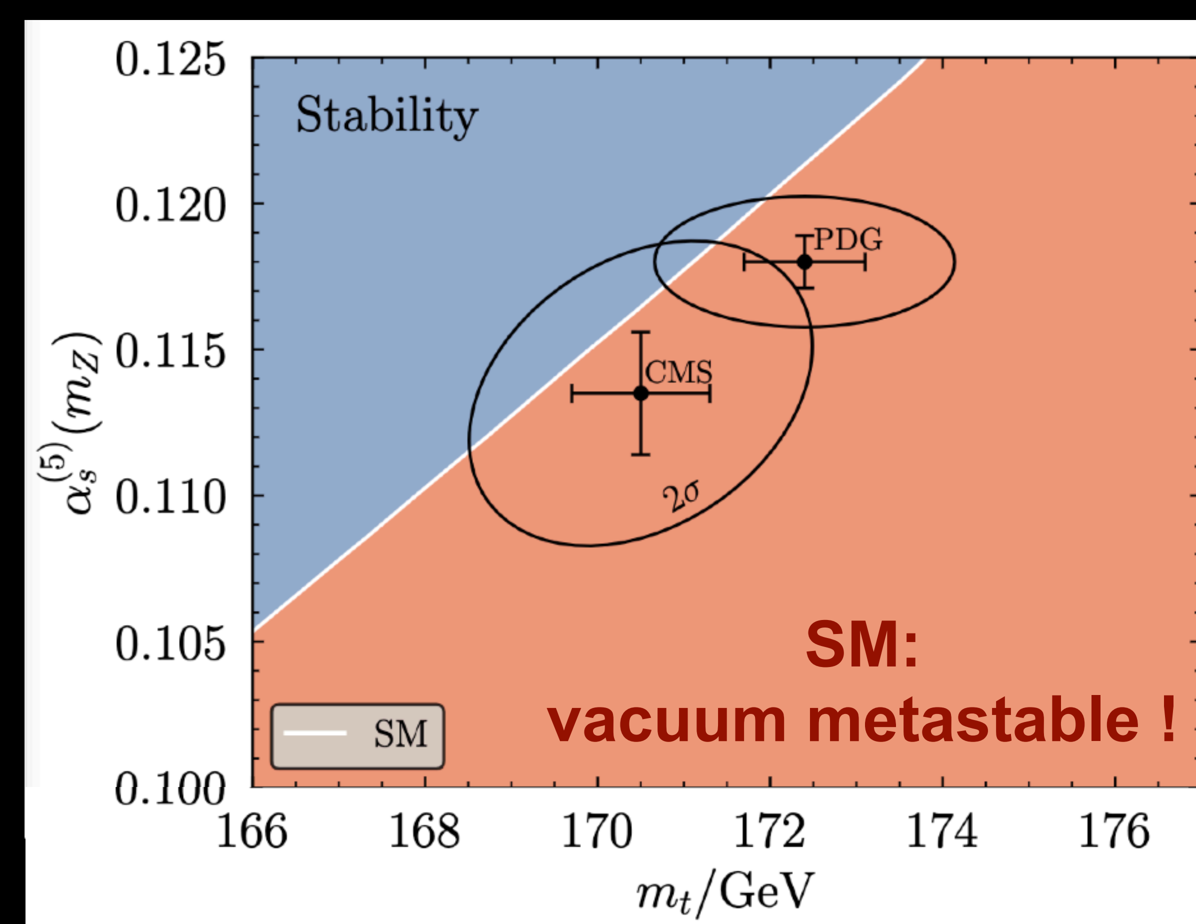


SM quantum effective potential at $[\alpha_S^5]$

Hiller et al arXiv:2607.12039



Driven by the values of the top quark mass m_t and strong coupling constant α_S

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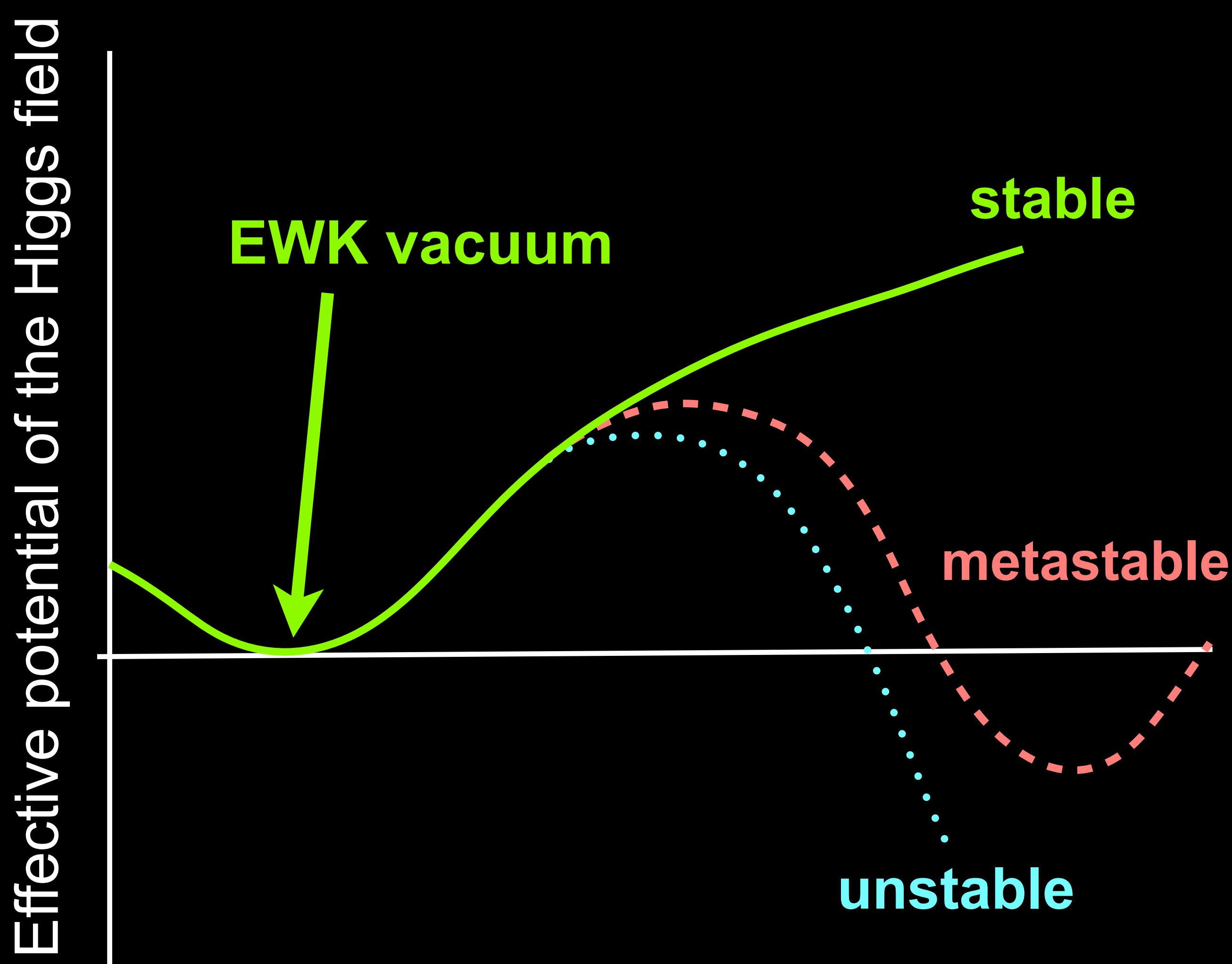
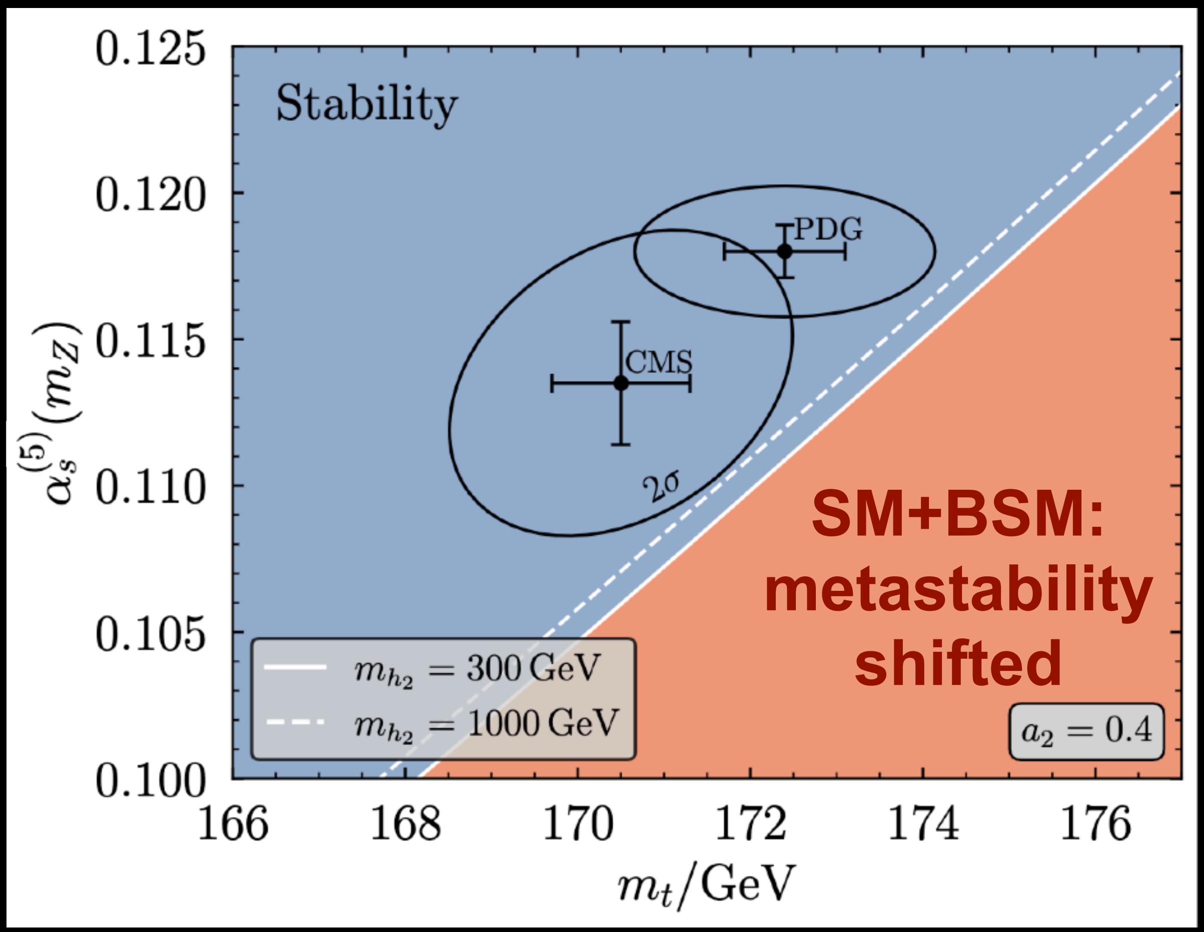


SM + BSM (scalar singlet)

Hiller et al arXiv:2607.12039



e.g. scalar singlet coupled to Higgs via portal interaction shifts the vacuum toward stability

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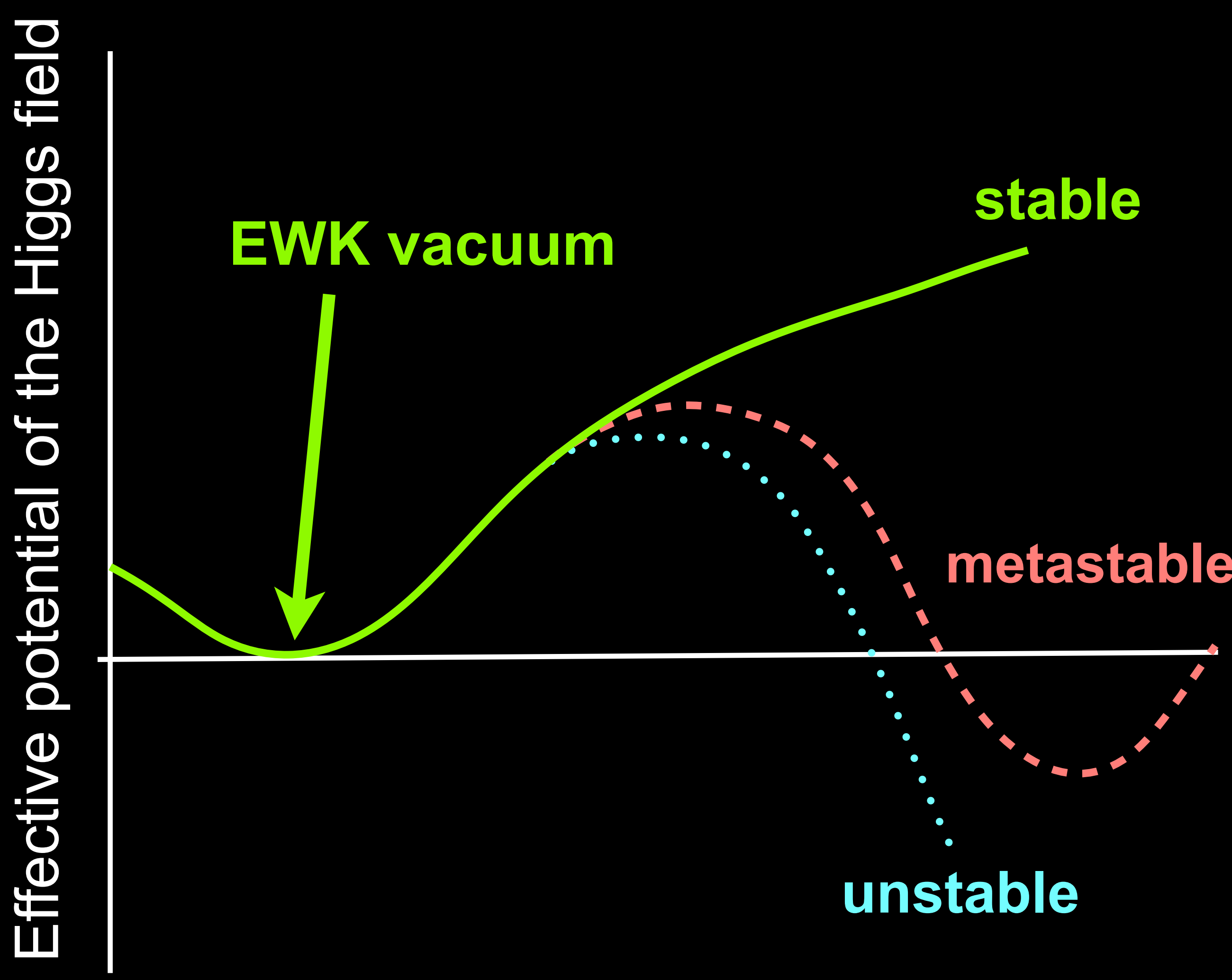

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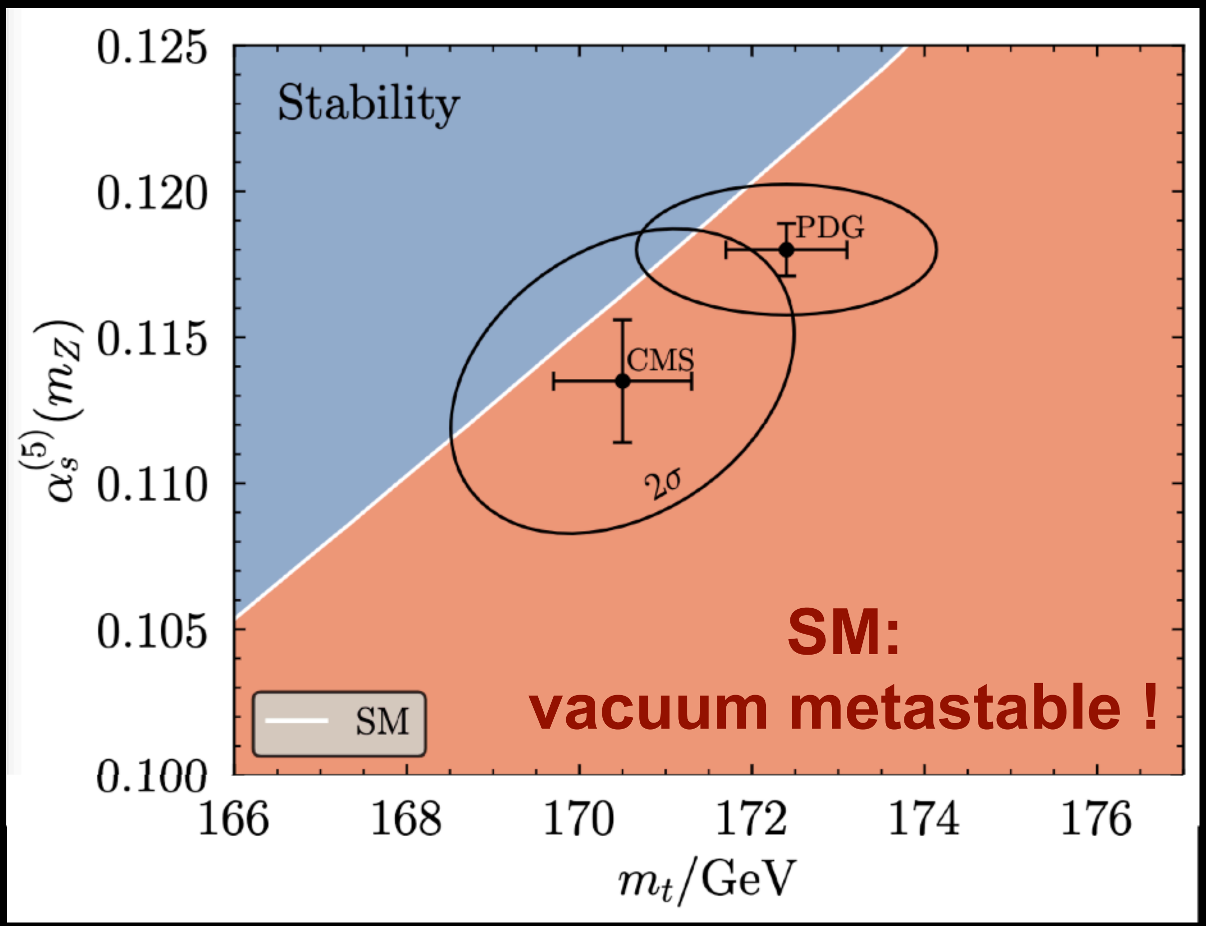
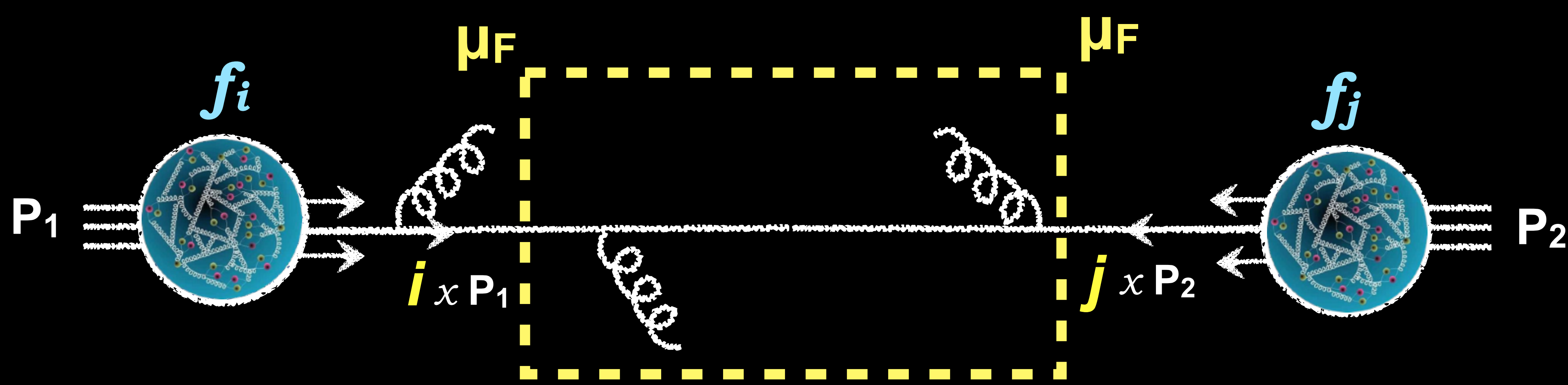


Input: experimentally extracted top quark mass m_t and strong coupling constant α_S obtained from comparison of experimental and SM-predicted cross sections

FACTORISATION OF pp @ LHC



Parton Distribution Functions **Matrix Element (perturbative)**

$$\sigma_{pp\to X} = \sum_{ij} f_i(x_1,\mu_F^2) \times f_j(x_2,\mu_F^2) \otimes \hat{\sigma}_{ij\to X}(x_1,x_2,\alpha_S(\mu_R),\frac{Q^2}{\mu_R},\frac{Q^2}{\mu_F})$$

fitted to
experimental data

↓

Uncertainties

DGLAP

Precision of SM predictions for any LHC cross section is limited by proton PDFs

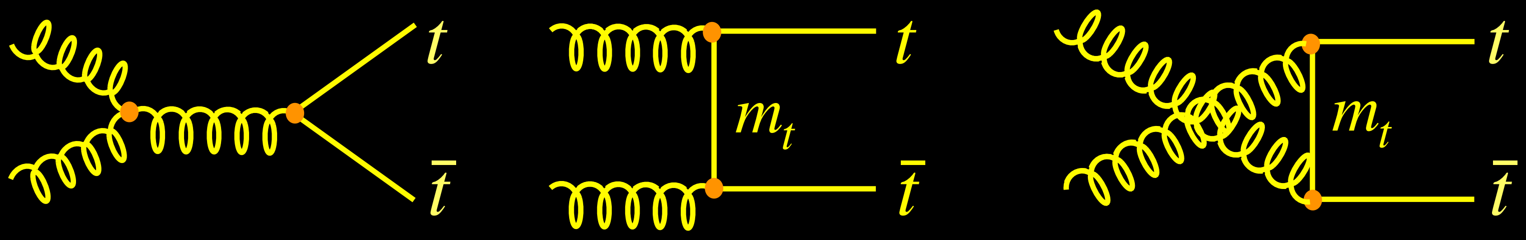
→ **Precision of SM parameters is limited by PDFs**

→ **Accuracy of BSM interpretation of LHC data is biased by PDFs**

TOP QUARK AT THE LHC

Produced mostly in quark-antiquark pairs ($t\bar{t}$), dominant partonic processes:

probe PDF, α_S , m_t



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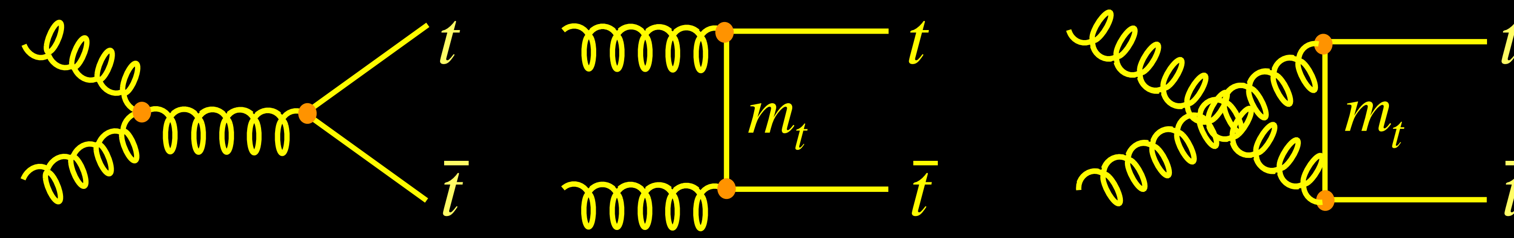
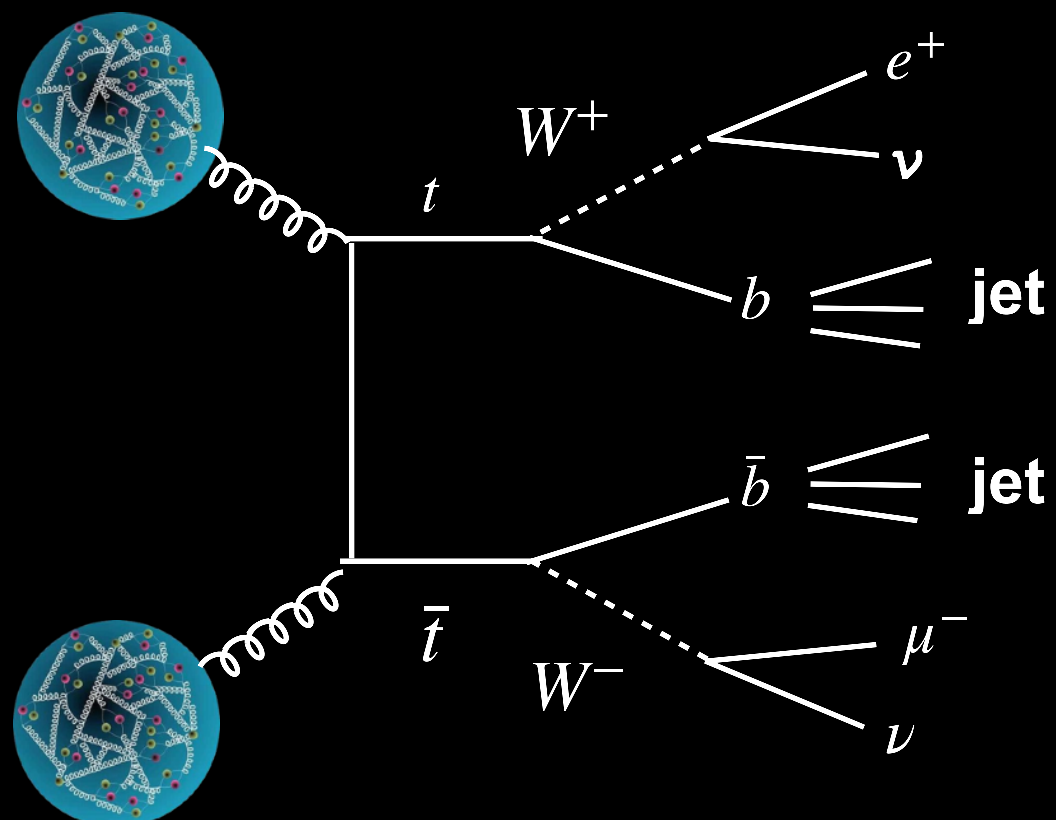


Decay and final state (to be reconstructed in the experiment):



W boson:

- isolated lepton of high energy
- missing energy (neutrino)

b-quark jets:

use large mass and long lifetime of B-hadrons

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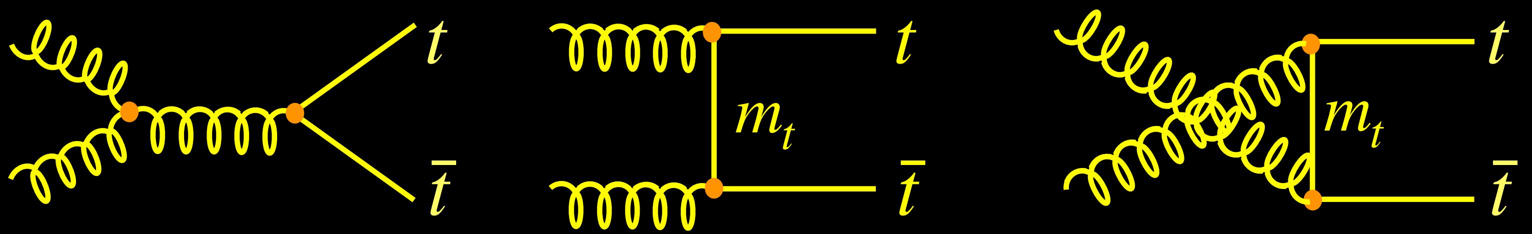

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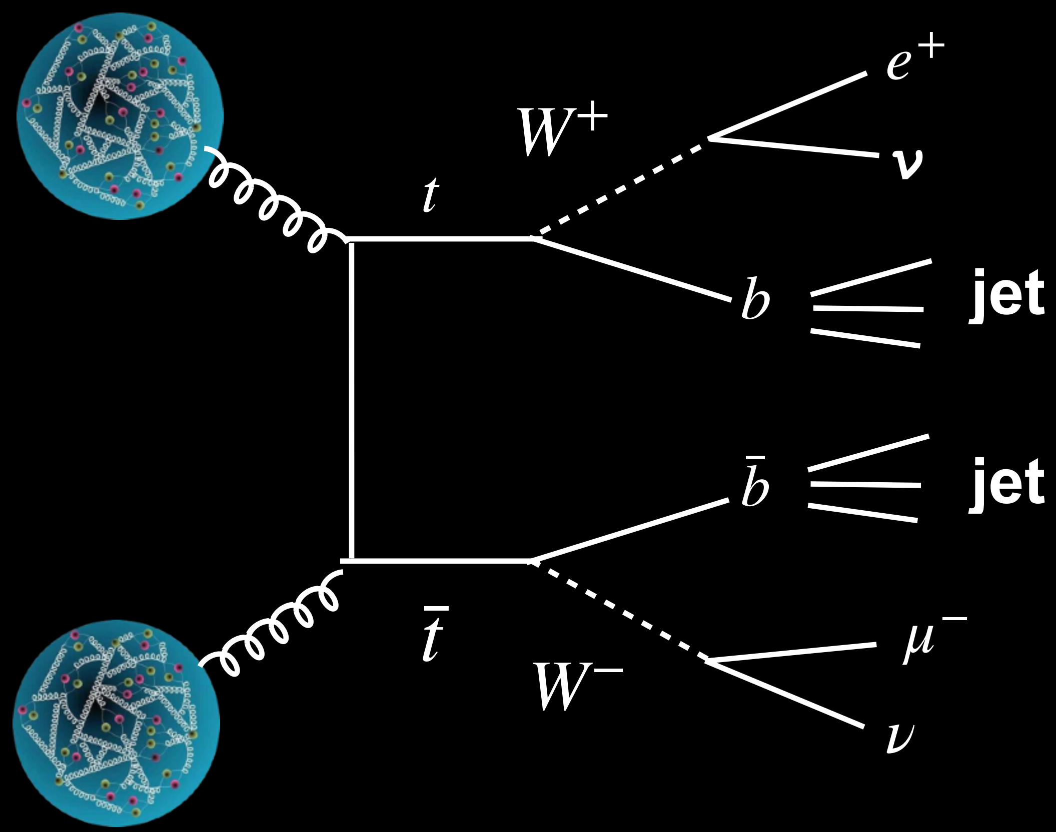
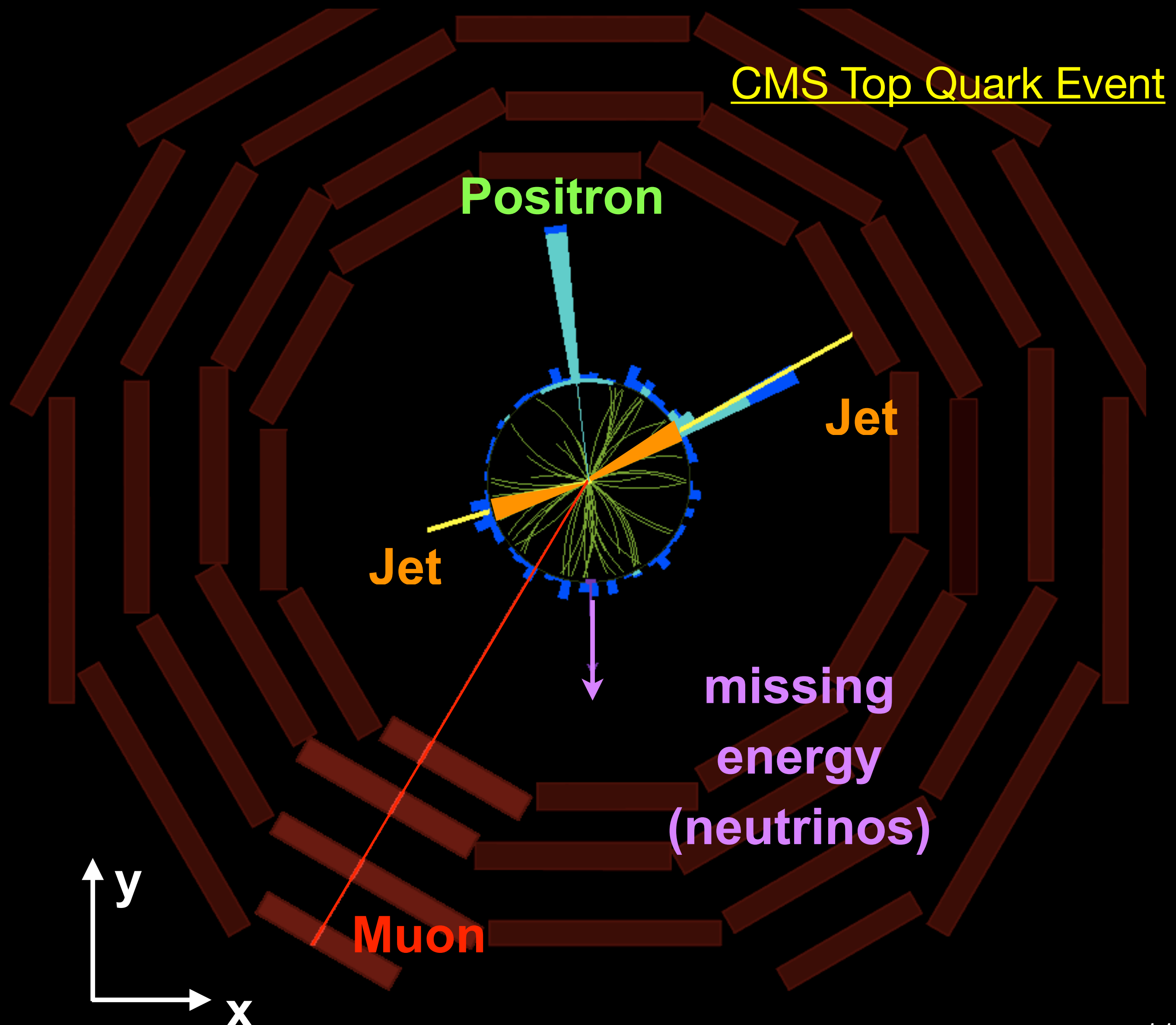


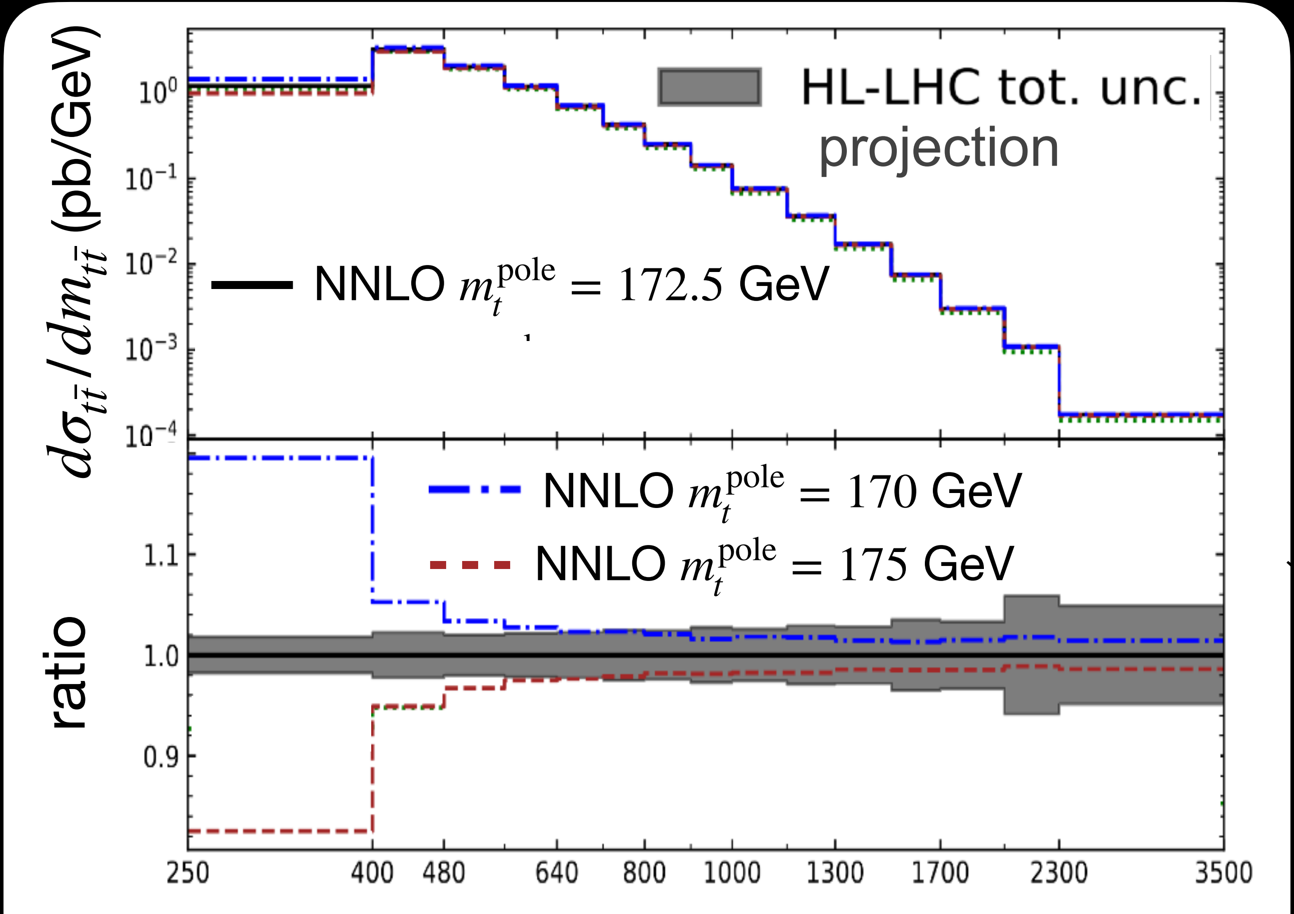


PRINCIPLE OF m_t EXTRACTION

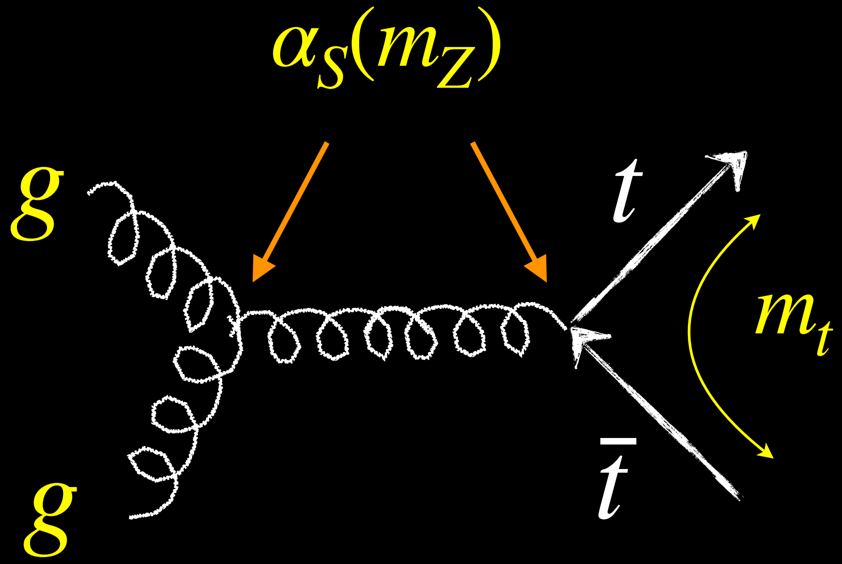
Fit SM prediction with varied m_t to the experimentally measured cross section

↓

driven by m_t



[EPJC 84 (2024) 1235]



(but also by PDFs and α_S)

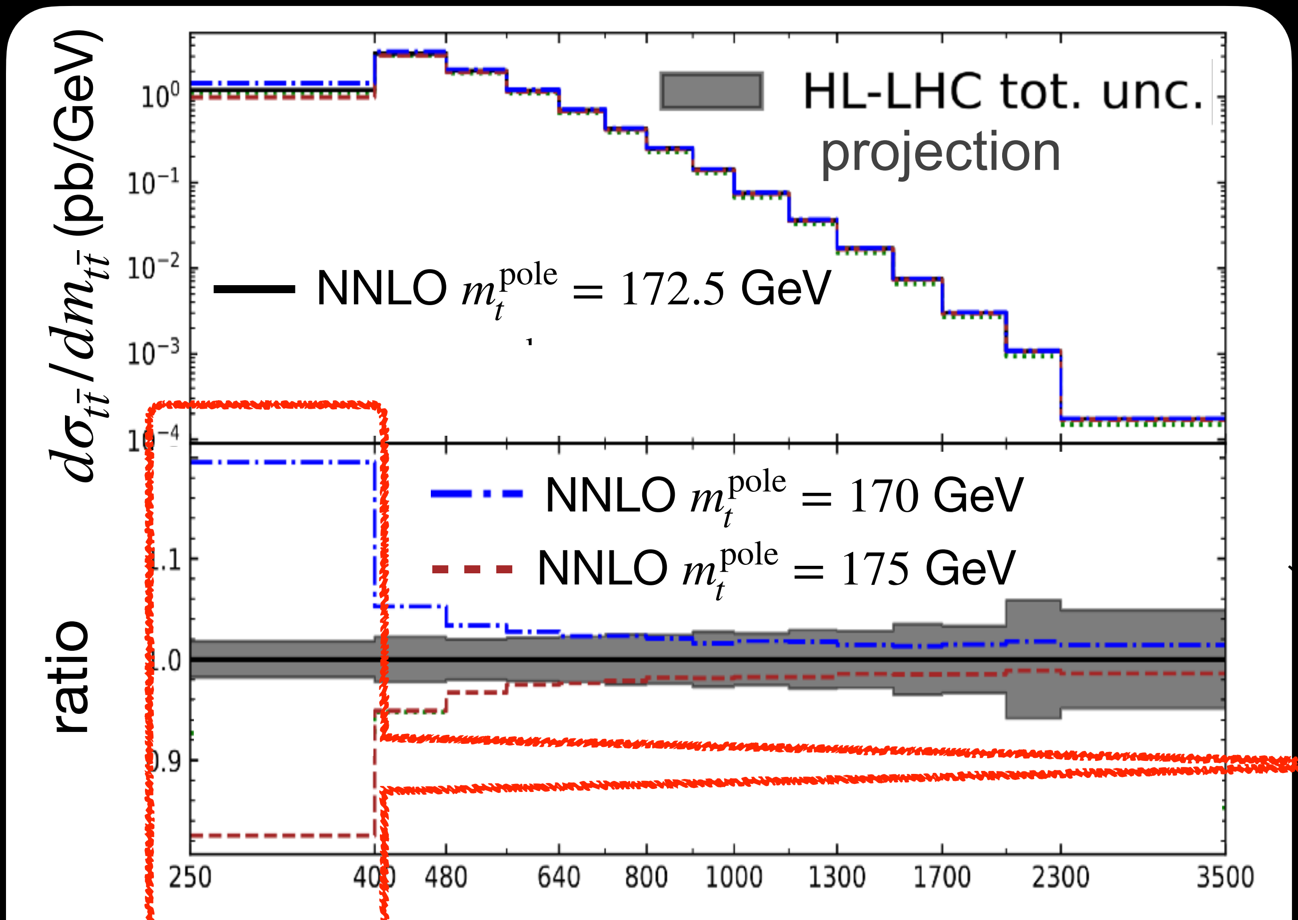
Precision of m_t limited by uncertainties in cross-section measurement, PDFs and α_S

PECULIARITY OF $m_{t\bar{t}}$ AT THE THRESHOLD

Fit SM prediction with varied m_t to the experimentally measured cross section

↓

driven by m_t



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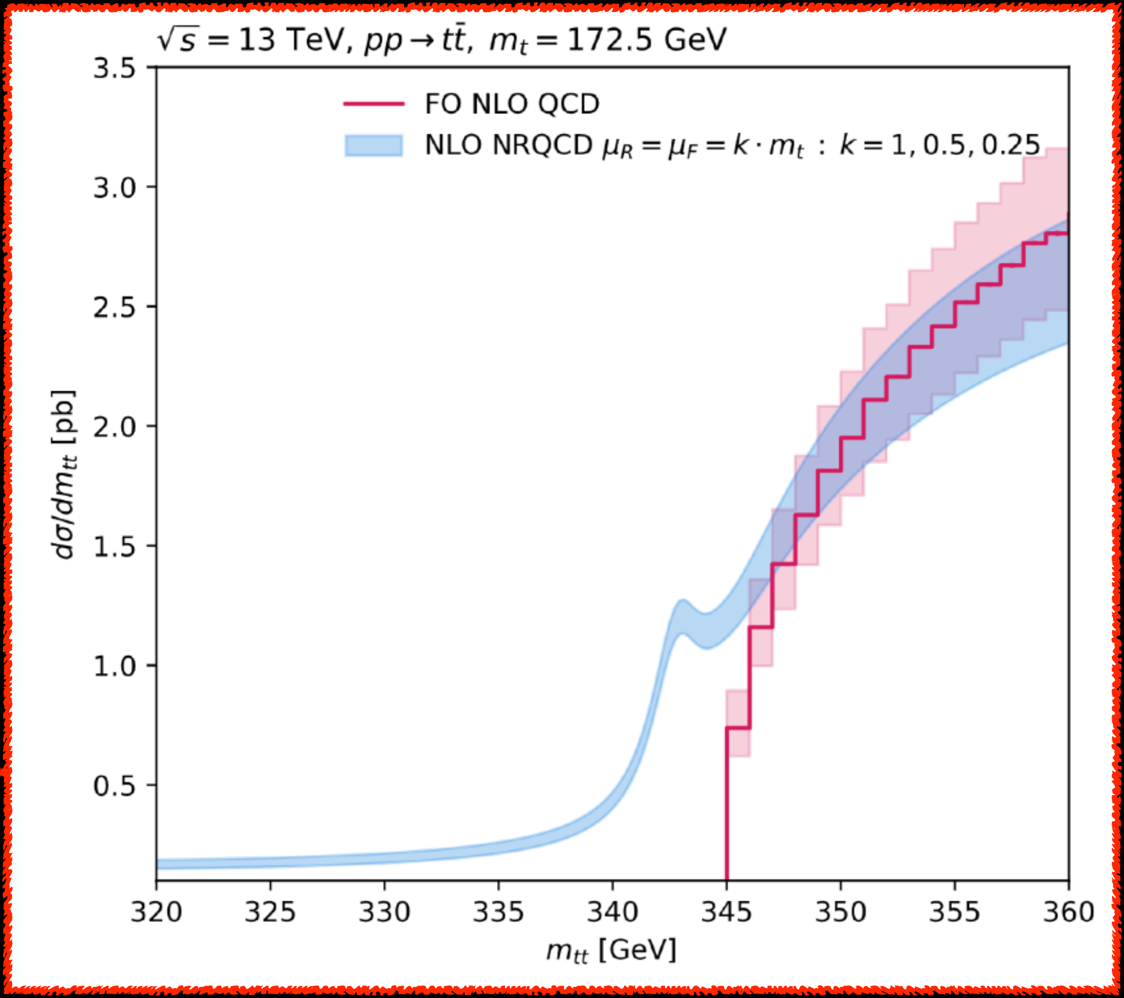


Most sensitive $m_{t\bar{t}}$ region receives contribution from non-relativistic behaviour of the (slow) $t\bar{t}$ pair → shift in the central value of m_t expected !

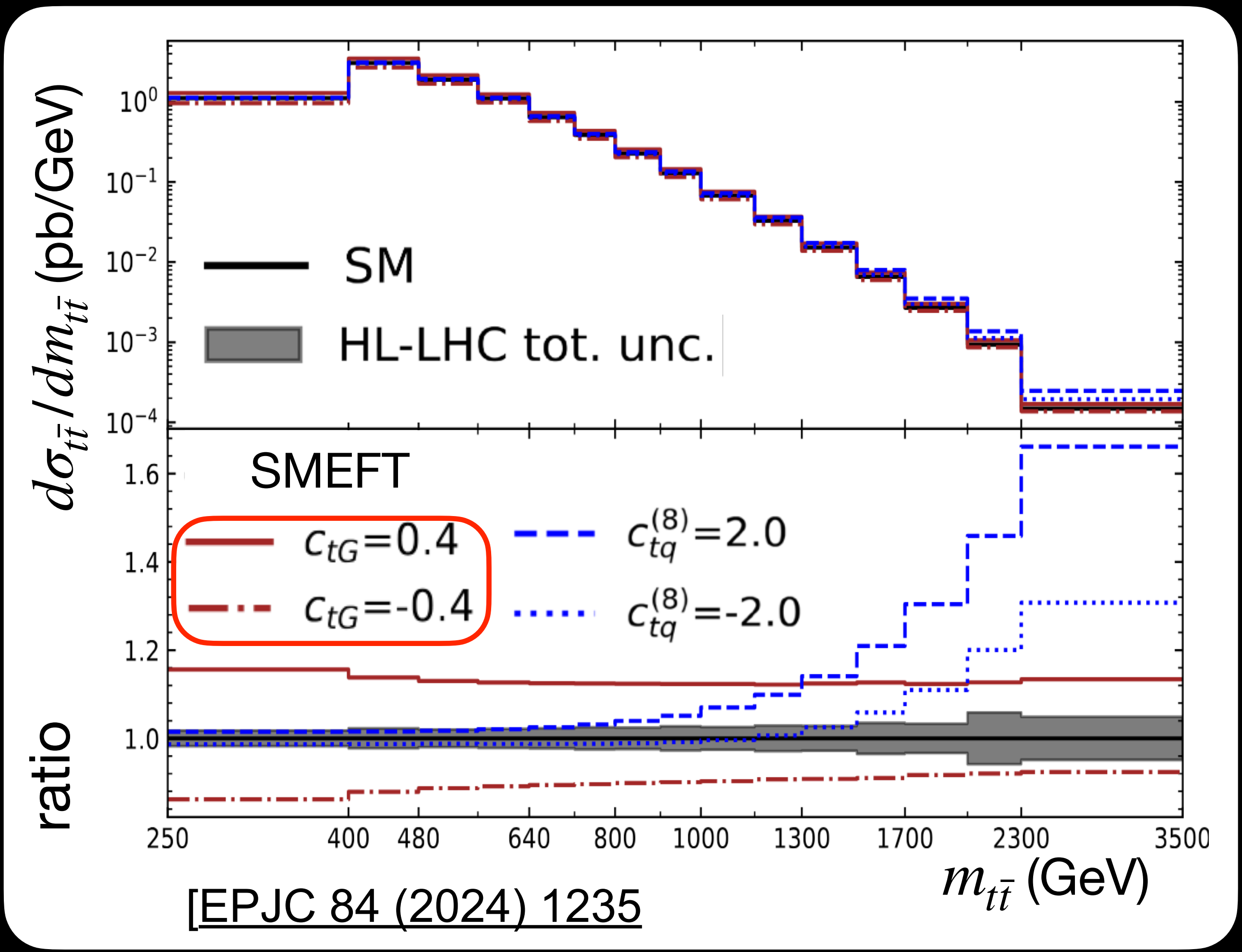
Accuracy of m_t limited by accuracy of QCD + NRQCD description of $t\bar{t}$ threshold

BSM IN TOP QUARK PRODUCTION

now assume SM + BSM at a scale Λ with effective coupling c

$\downarrow$

still driven by m_t !



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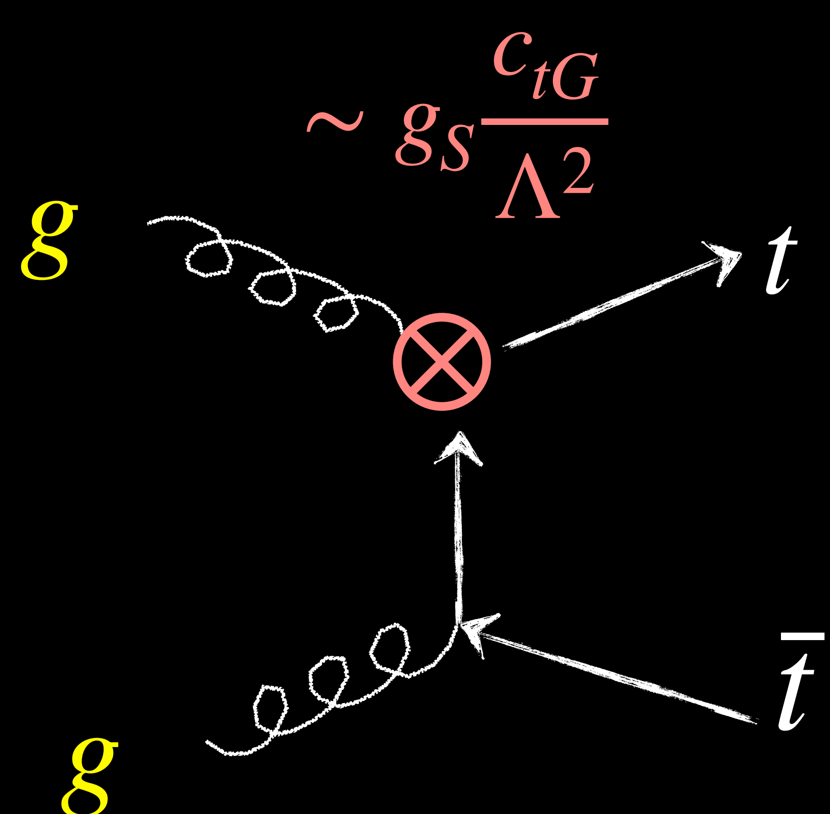

BSM operators depend on PDFs and on m_t

→ Bias in the interpretation of the $t\bar{t}$ cross sections in terms of SMEFT

PRESENT ANALYSIS [arXiv:2607.22390]

Simultaneous extraction of PDFs, SM and (some) EFT parameters

NNLO in QCD, NLO NR-QCD (+ soft gluon resummation**), NLO SMEFT operators**

Data: ep DIS (light quarks)

LHC Run 2 $t\bar{t} \rightarrow$ gluon PDF, m_t, $\alpha_S(m_Z)$, BSM : c_{tG}, c_{tq}^8

LHC Run 1+2 inclusive jets $\rightarrow$ light-quark and gluon PDFs, $\alpha_S(m_Z)$

LHC Run 2 DY $\rightarrow$ light-quark PDFs, effective mixing angle $\sin^{\text{eff}}(\theta)$

FIt: open-source QCD+SMEFT analysis tool xFitter [arxiv:1709.01151]

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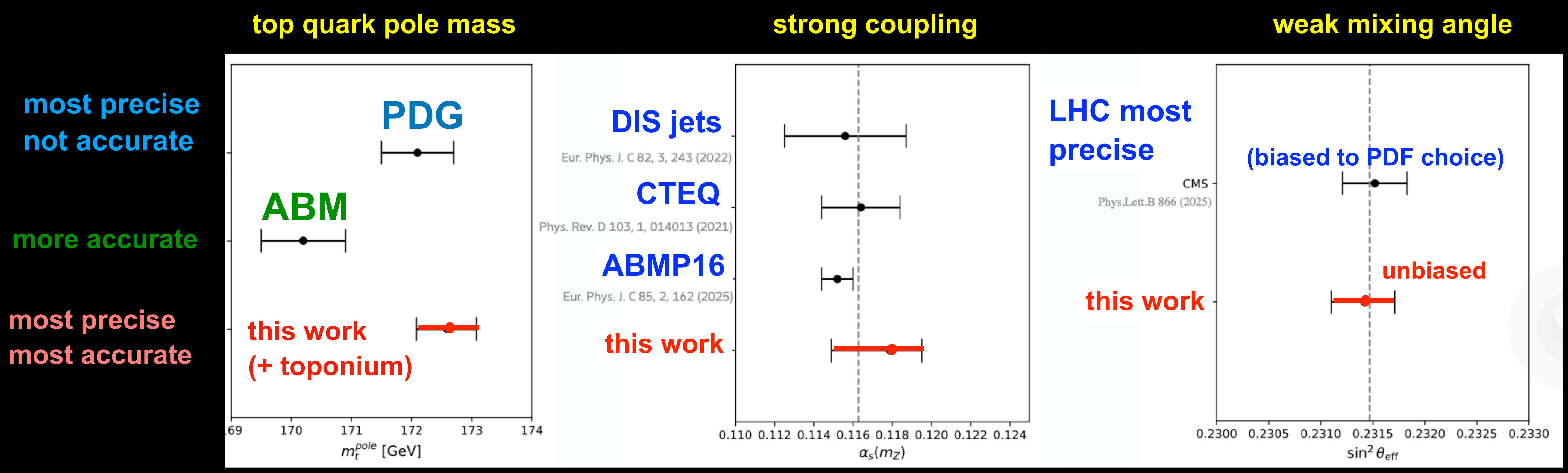

Precision competitive to most precise results, unbiased to PDFs and EFT

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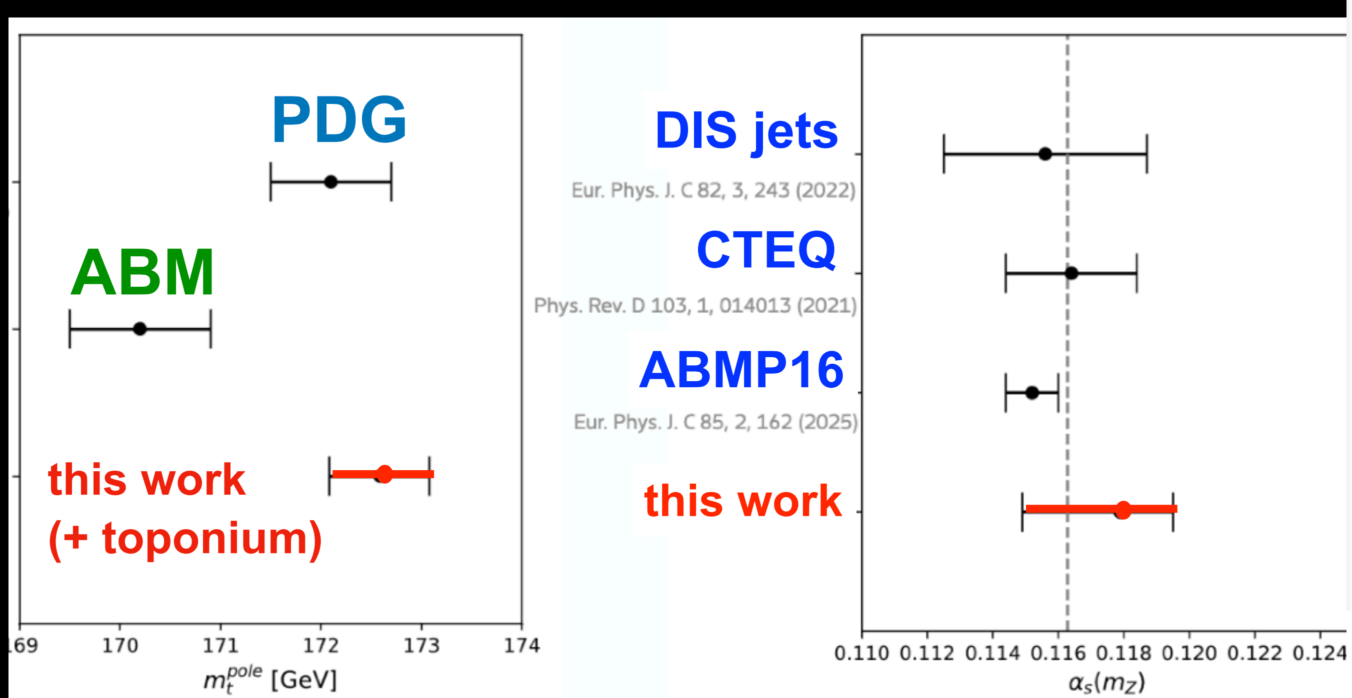
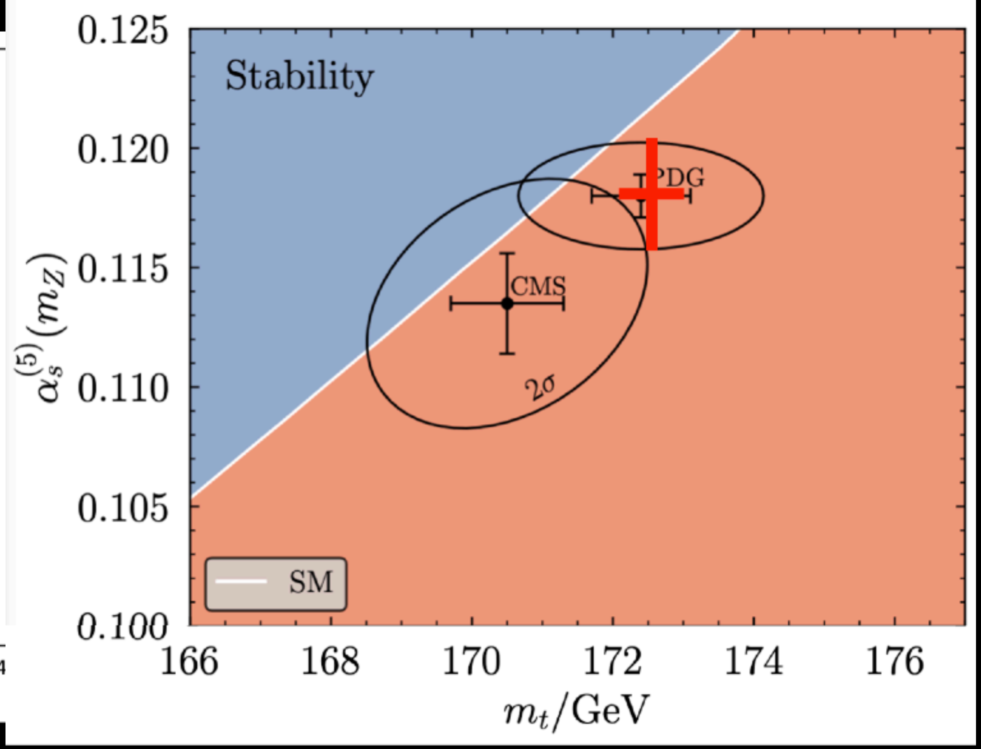
top quark pole mass **strong coupling**

most precise not accurate

more accurate

most precise most accurate





FUTURE

Simultaneous extraction of PDFs, SM and (some) EFT parameters

NNLO in QCD, NLO NR-QCD (+ soft gluon resummation**), NLO SMEFT operators**

- **Include more LHC data (ATLAS) with respective, new, NNLO theory predictions**
- **Include more EFT operators (incl. jets, dijets, EWK boson)**
- **So far, NR QCD is included effectively, matching to NNLO ongoing work**
- **Improve theory uncertainty treatment (so far, scale variations, TNP wanted…)**

BACKUP

PROTON PDFs: A PROBLEM FOR LHC

Dilute precision of SM parameters

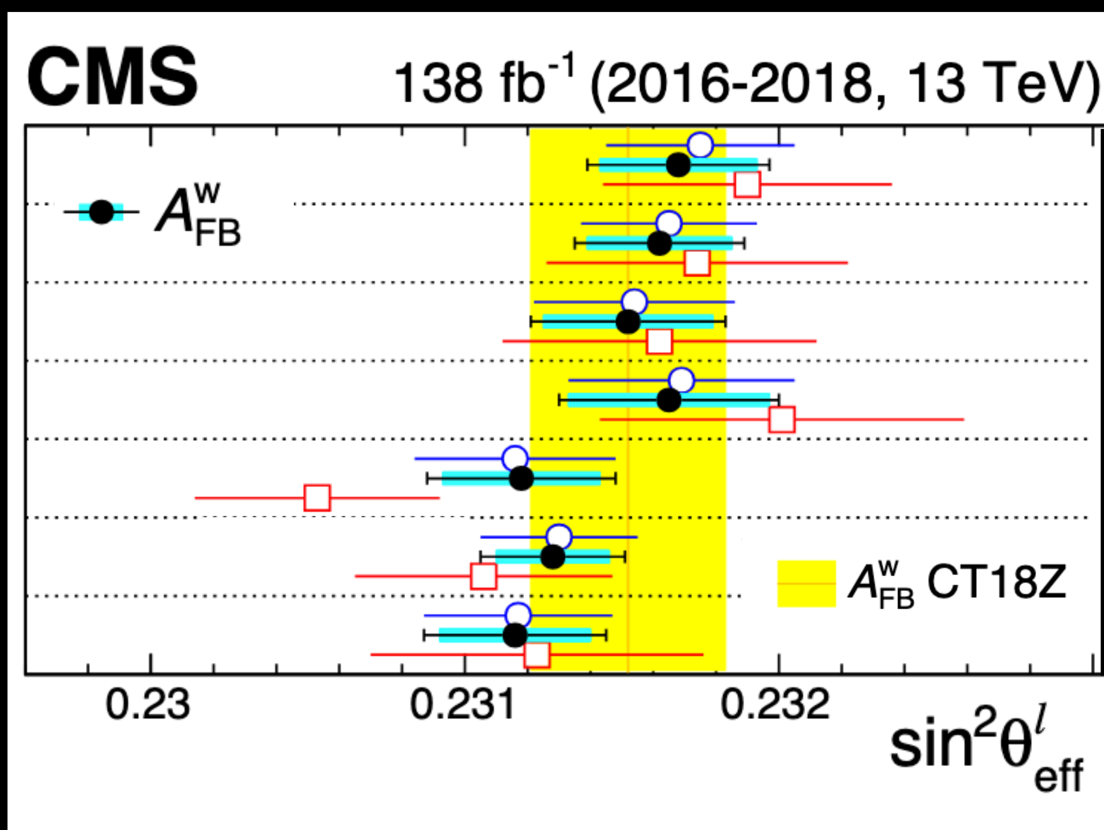
Electroweak mixing angle

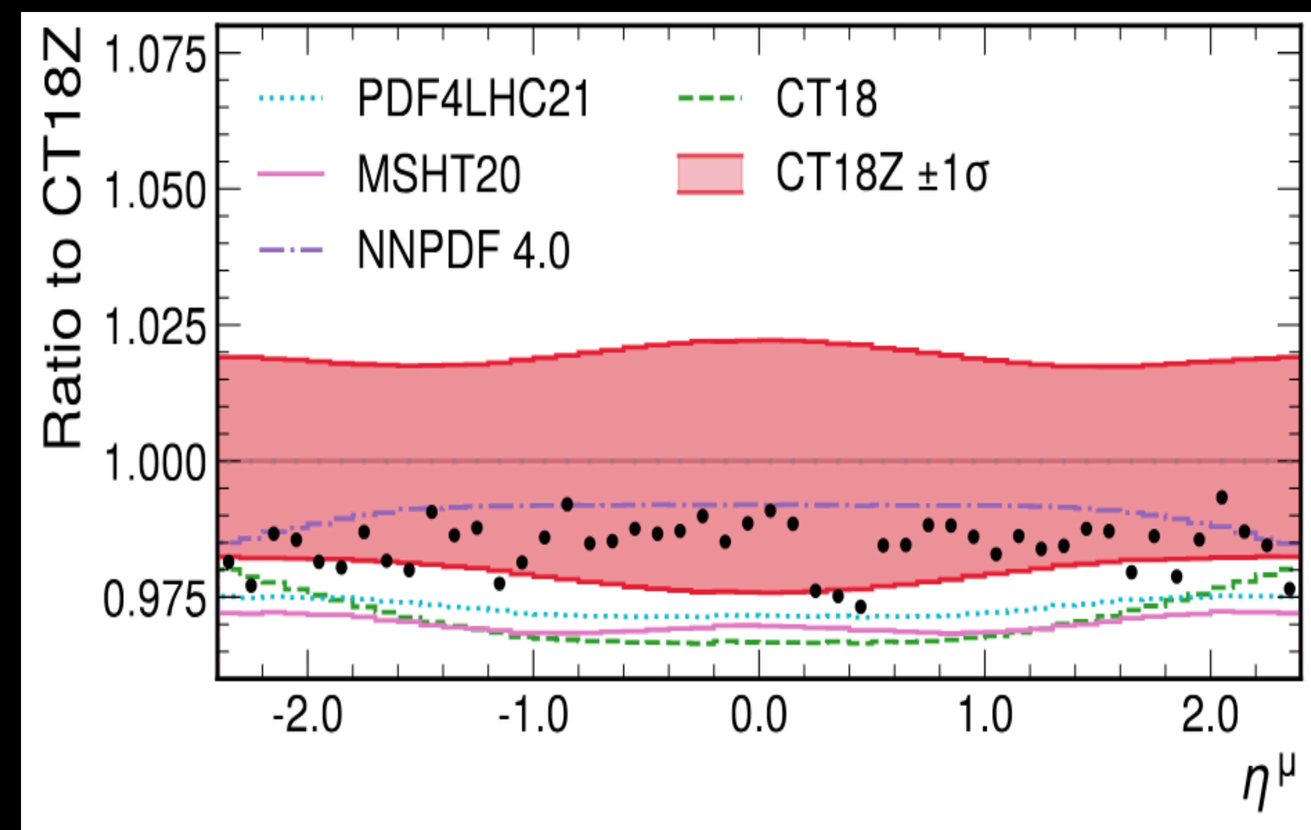
(strength of neutral part of EW force)

W mass

(strength of charged part of EW force)

different PDFs



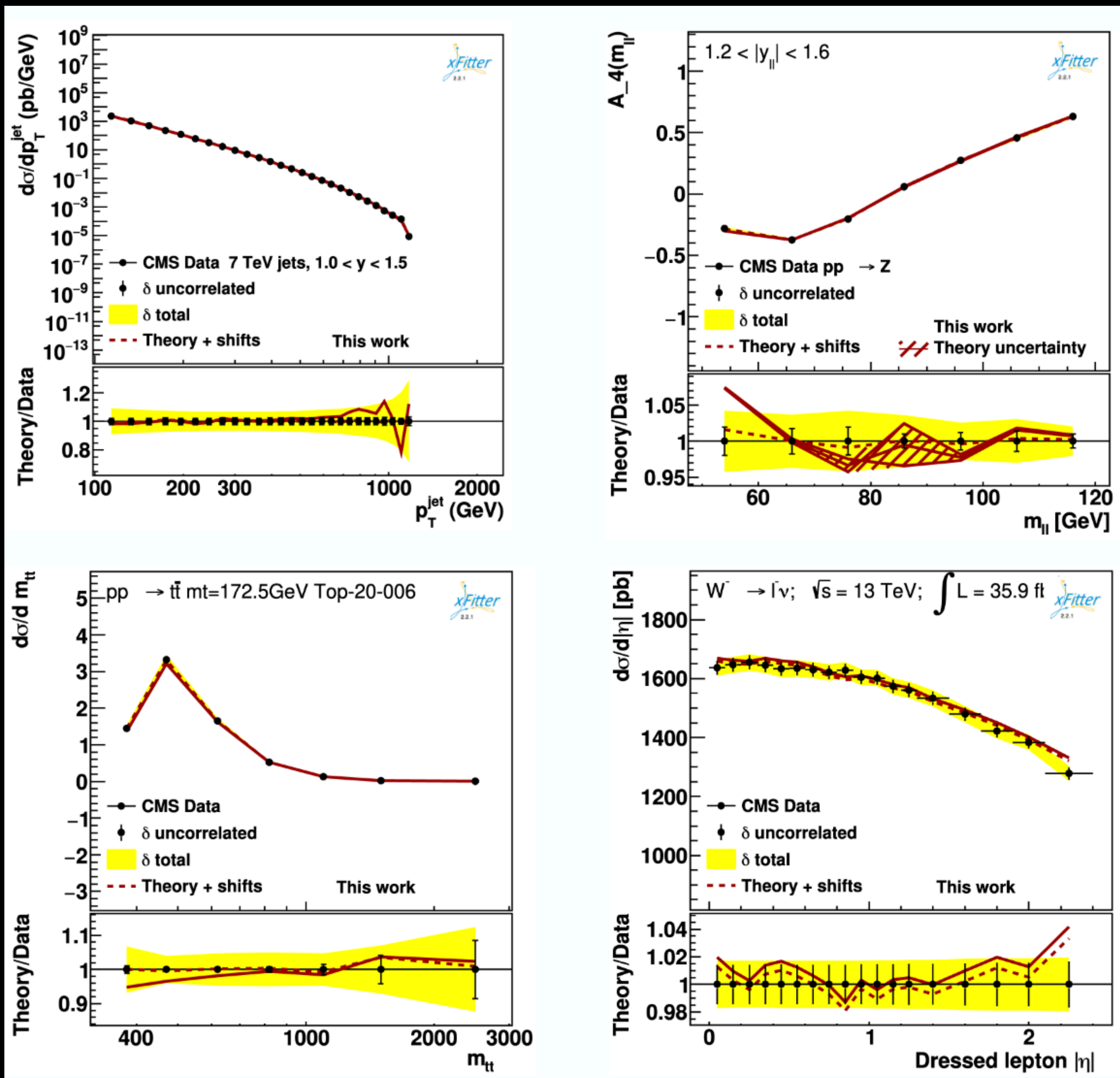


$\sigma_{PDF} \sim \sigma_{tot}$

$\sigma_{PDF} \sim 1/2\ \sigma_{tot}$

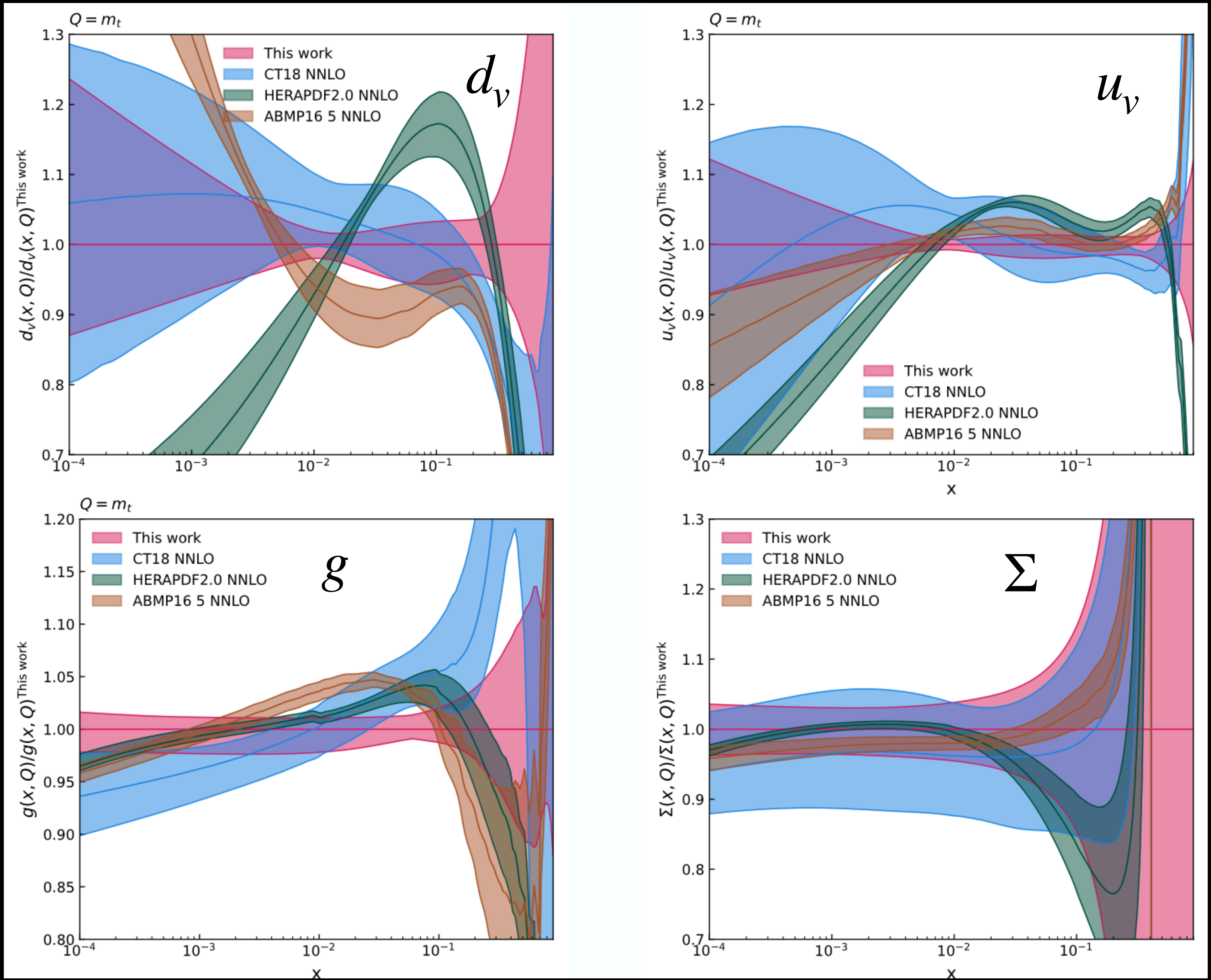
AND LIMIT INDIRECT SEARCHES FOR BSM PHYSICS

DATA CONSISTENCY



Measurement	χ^2/N_{dp}
HERA I+II	1244/1016
CMS inclusive jets 13 TeV	79/78
CMS inclusive jets 8 TeV	140/165
CMS inclusive jets 7 TeV	74/130
CMS inclusive jets 2.76 TeV	62/80
CMS DY A_4 13 TeV	62/63
CMS W asymmetry 13 TeV	21/36
CMS $t\bar{t}$ l+ jets	14/15
CMS $t\bar{t}$ 2l	4/7
Total χ^2/N_{dof}	1658/1572

RESULTING PDFs



RESULTING PARAMETERS

	m_t^{pole} [GeV]	$\alpha_s(m_Z)$	$\sin^2\theta_{\text{eff}}^{ll}$
FO NNLO	172.03	0.1178	0.23144
FO NNLO + NLO NRQCD	172.48	0.1179	0.23143
FO NNLO + NLO NRQCD + NLL + EFT	172.80	0.1175	0.23153
FO NNLO + NLO NRQCD + NLL	$172.59^{+0.51}_{-0.49}$	$0.1179^{+0.0030}_{-0.0016}$	$0.23142^{+0.00032}_{-0.00029}$

values competitive with state-of-the-art individual extractions

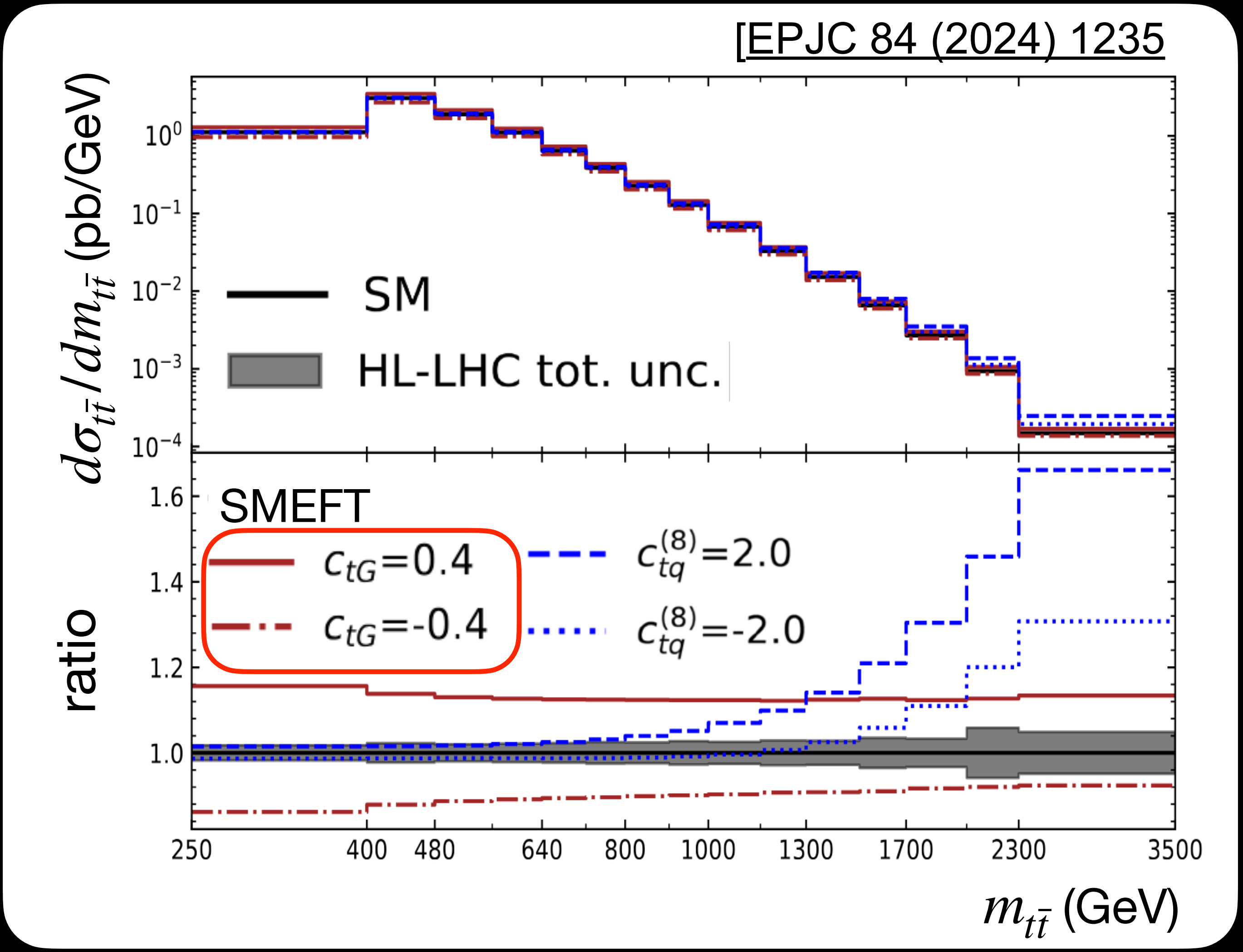
• including NRQCD and soft gluon resummation corrections shifts m_t by $+0.55$ GeV

• small correlation between m_t and $\sin^2_{\text{eff}}\theta$, significant correlations with α_S remains

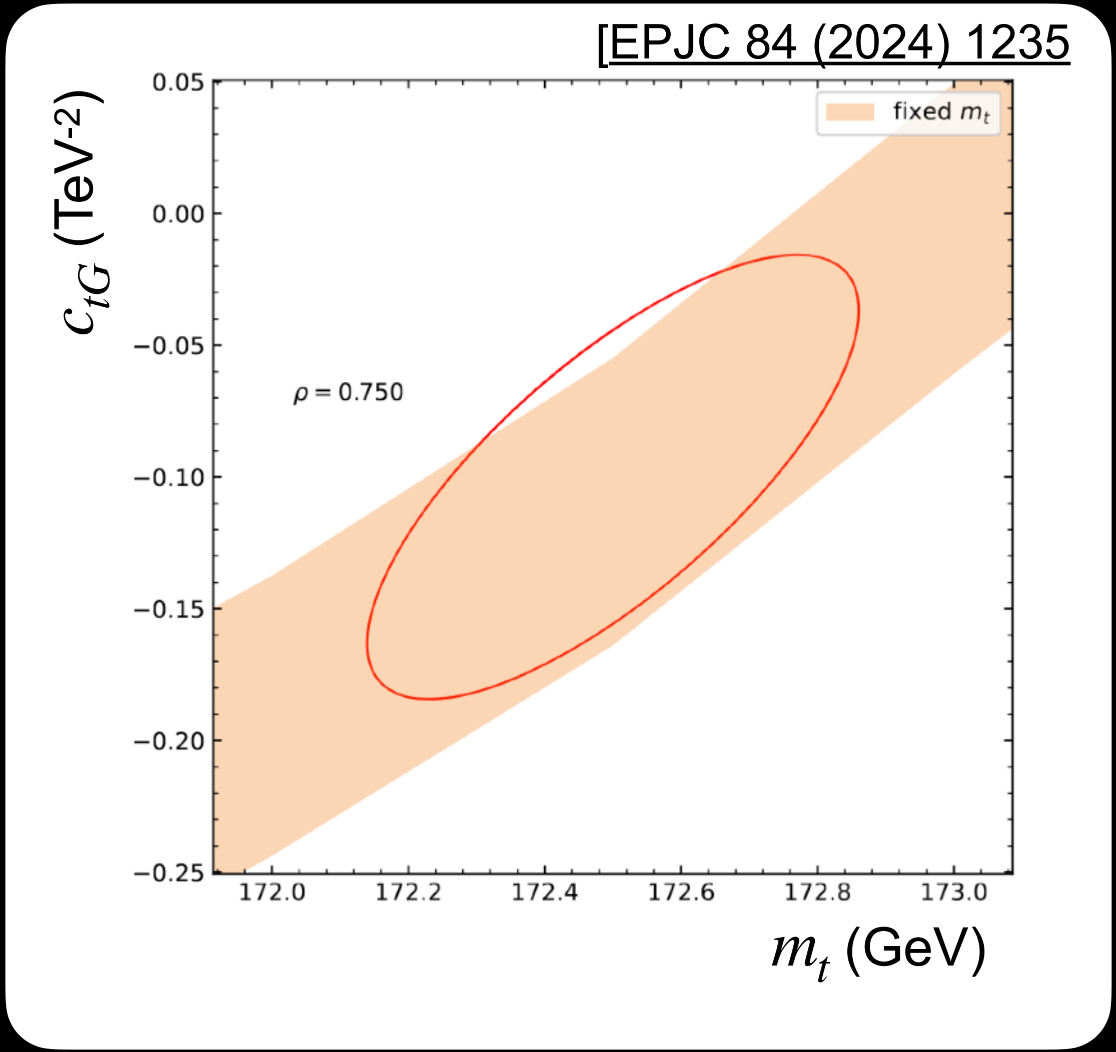
→ Simultaneous approach necessary to exploit future LHC precision data

BSM IN TOP QUARK PRODUCTION

now assume SM + BSM



Example: m_t dependence (BSM)



BSM operators depend on PDFs and m_t