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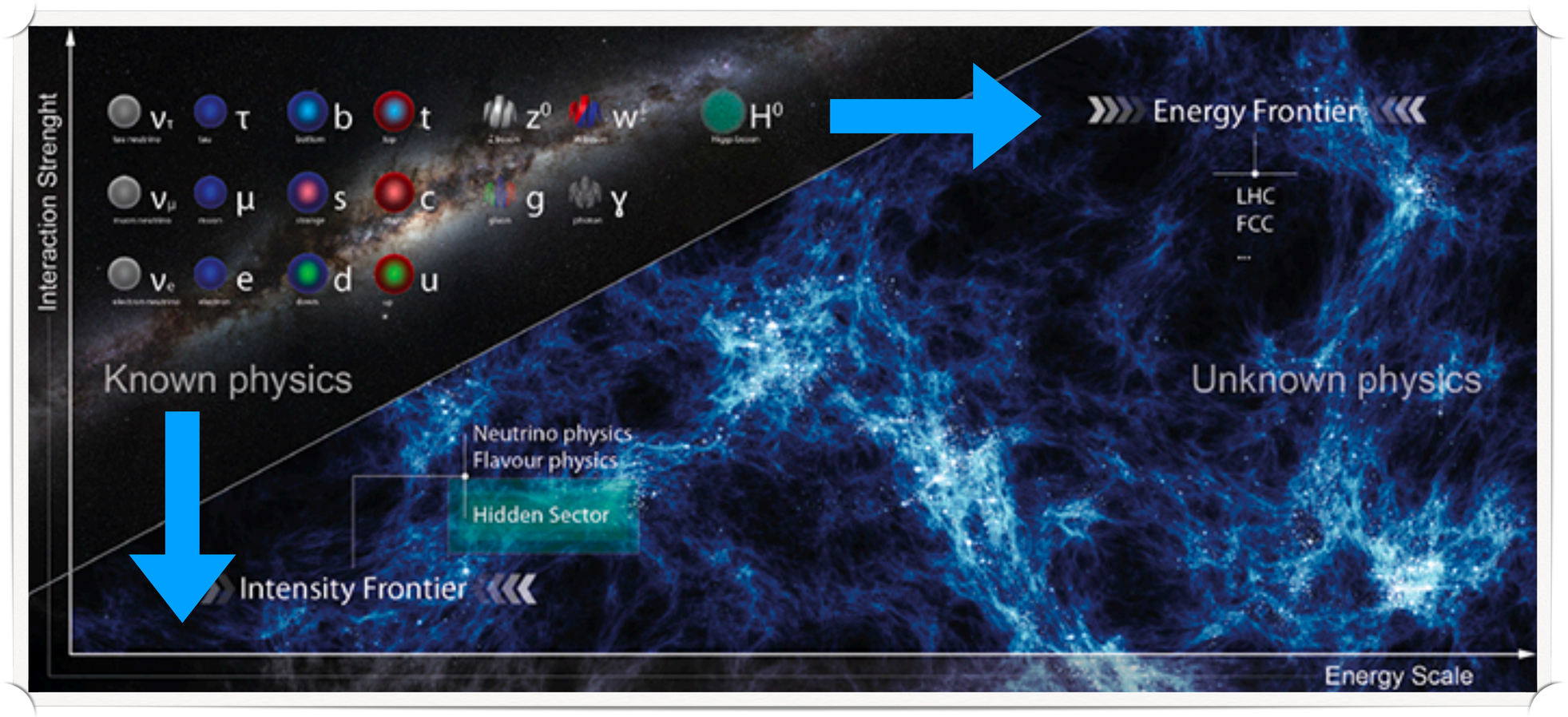
PRECISION PHYSICS AT THE LHC AND BEYOND

NATIONAL SEMINAR THEORETICAL HIGH ENERGY PHYSICS, NIKHEF

13TH MARCH 2026

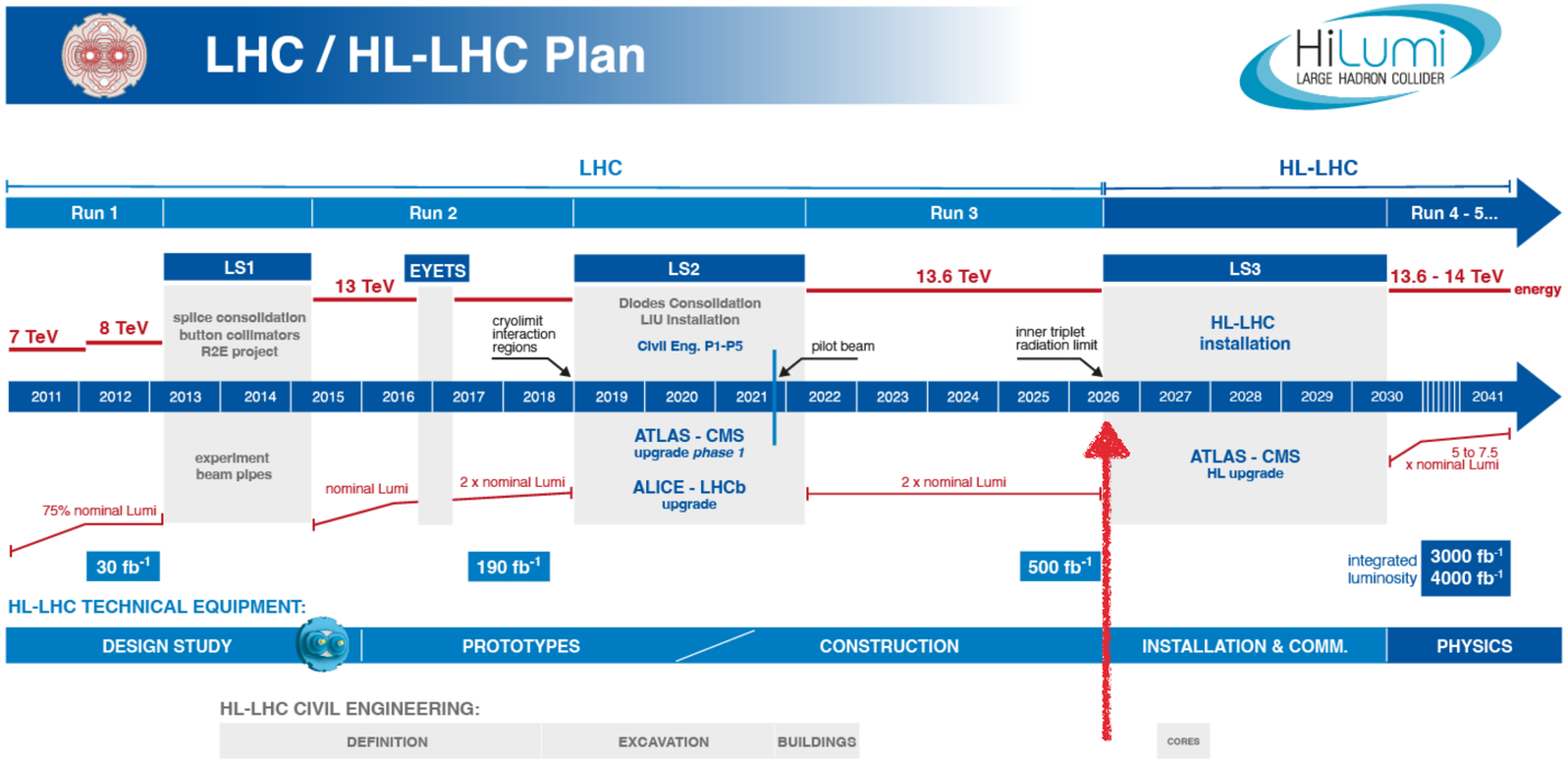
THE INTENSITY AND THE HIGH ENERGY FRONTIERS

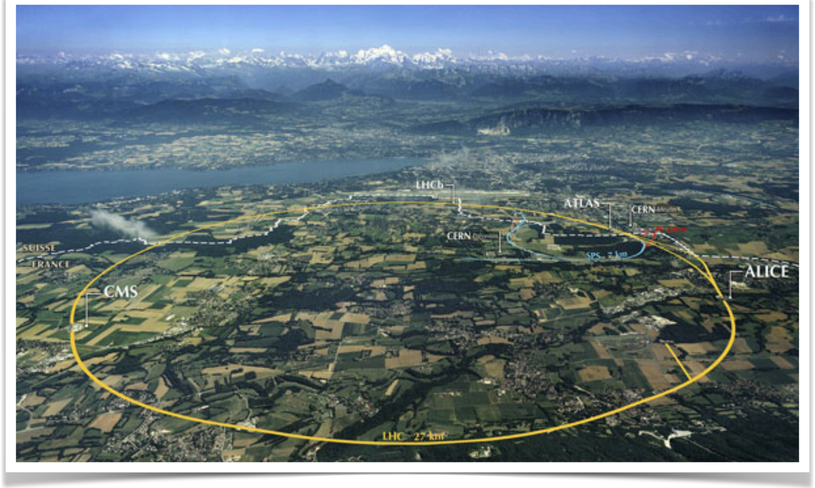
- Standard Model (SM) of Particle Physics extremely successful model of elementary particles
- Modern understanding of QFT tells us that the SM is necessarily incomplete
- Several experimental evidences for New Physics: neutrino masses, dark matter, baryon asymmetry…
- Theory hints: naturalness (Higgs mass, cosmological constant, strong CP problem), unification of forces…

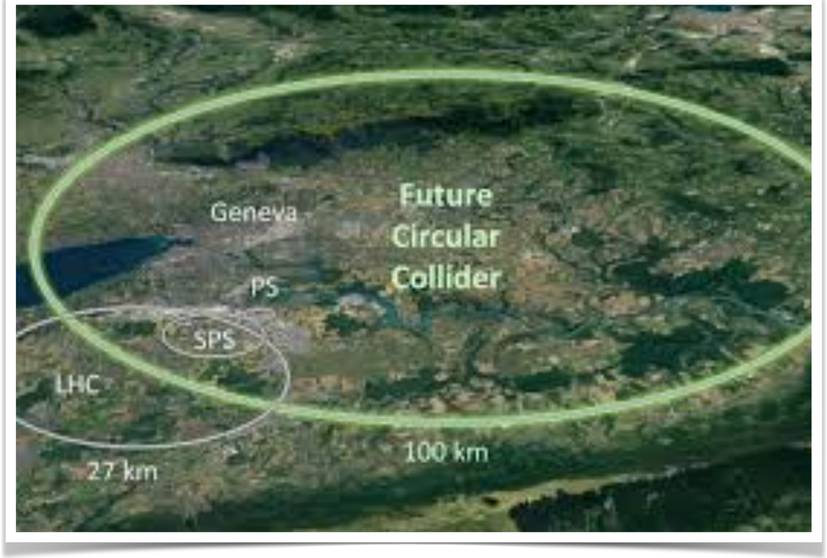


@ CERN courier, image credit: Richard Jacobsson, Dominic Dominguez

EXPLORING THE HIGH ENERGY FRONTIER AT THE LHC



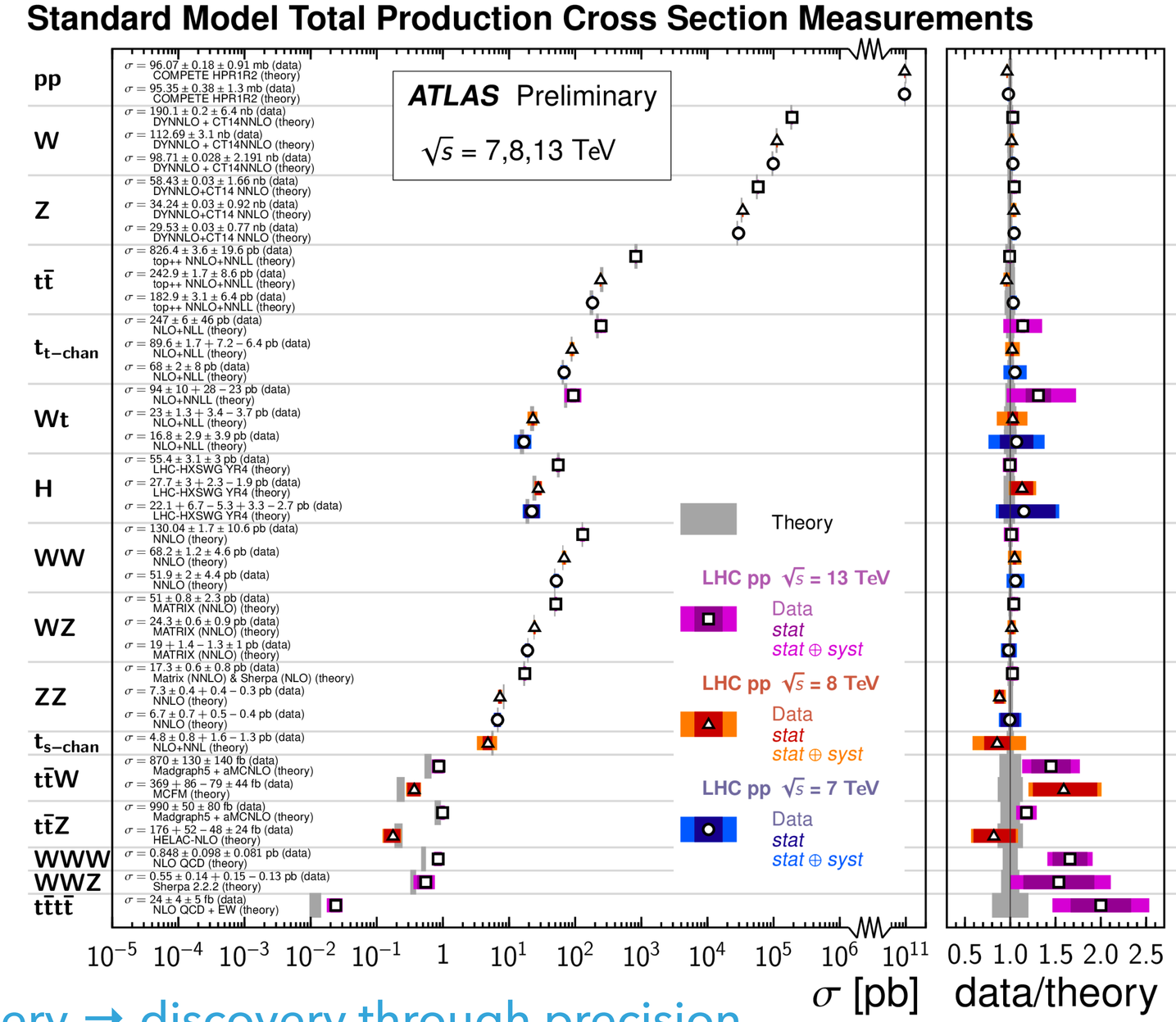




- Large Hadron Collider (LHC) most powerful particle collider built to date
- HL-LHC will be collecting a huge statistics in the next 20+ years
- Future Circular Collider may reach up to 100 TeV

A NEW PRECISION ERA AT THE LHC

- Impressive range of precise cross section measurements and huge progress in theoretical calculations
- Overall stunning agreement between data and SM predictions
- New Physics where are thou?



LHC paradigm: discovery → discovery through precision

A NEW PRECISION ERA AT THE LHC

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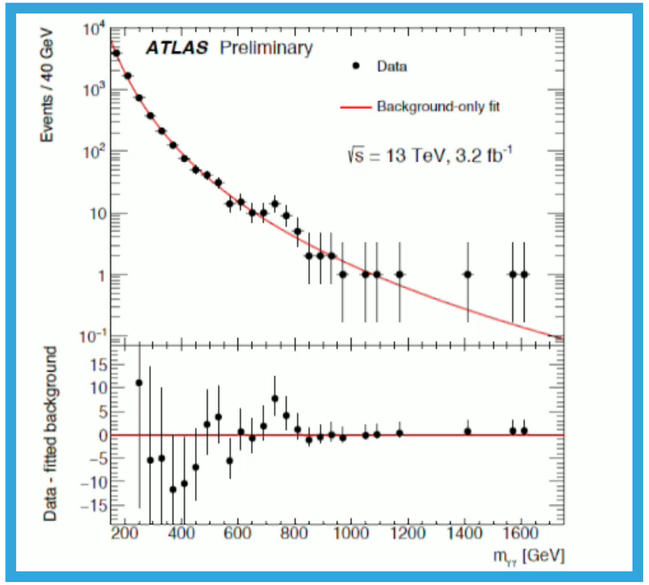
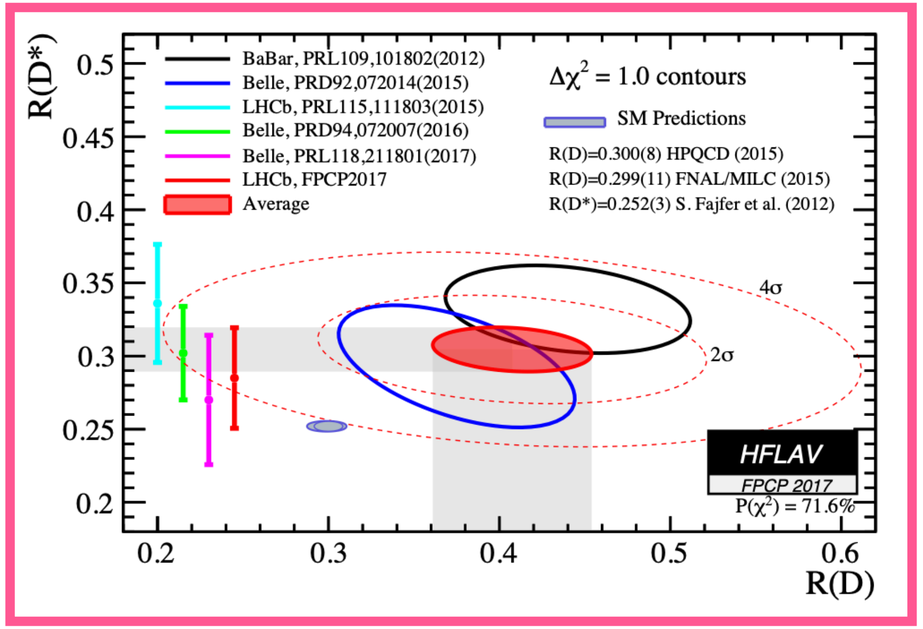
2015 - diphoton excess at 750 GeV ✗

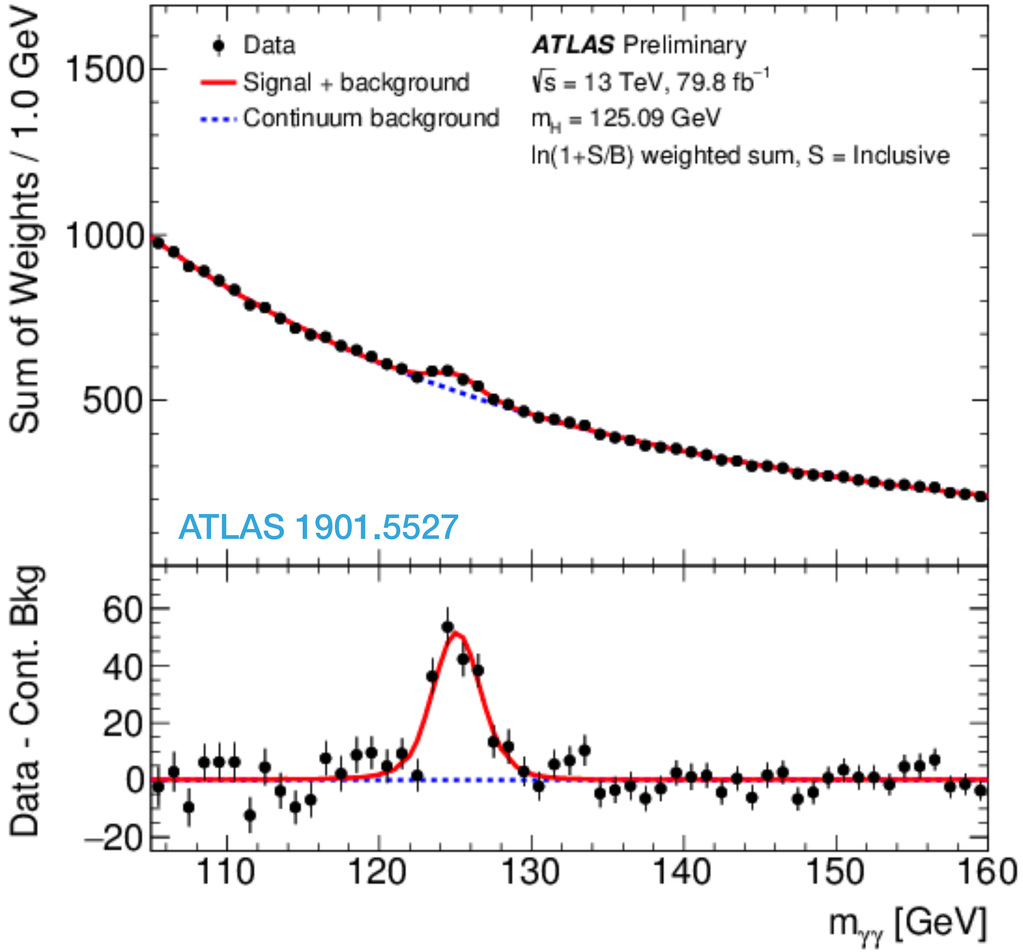


2018 - flavour anomalies ~

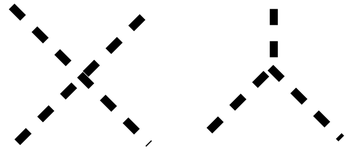


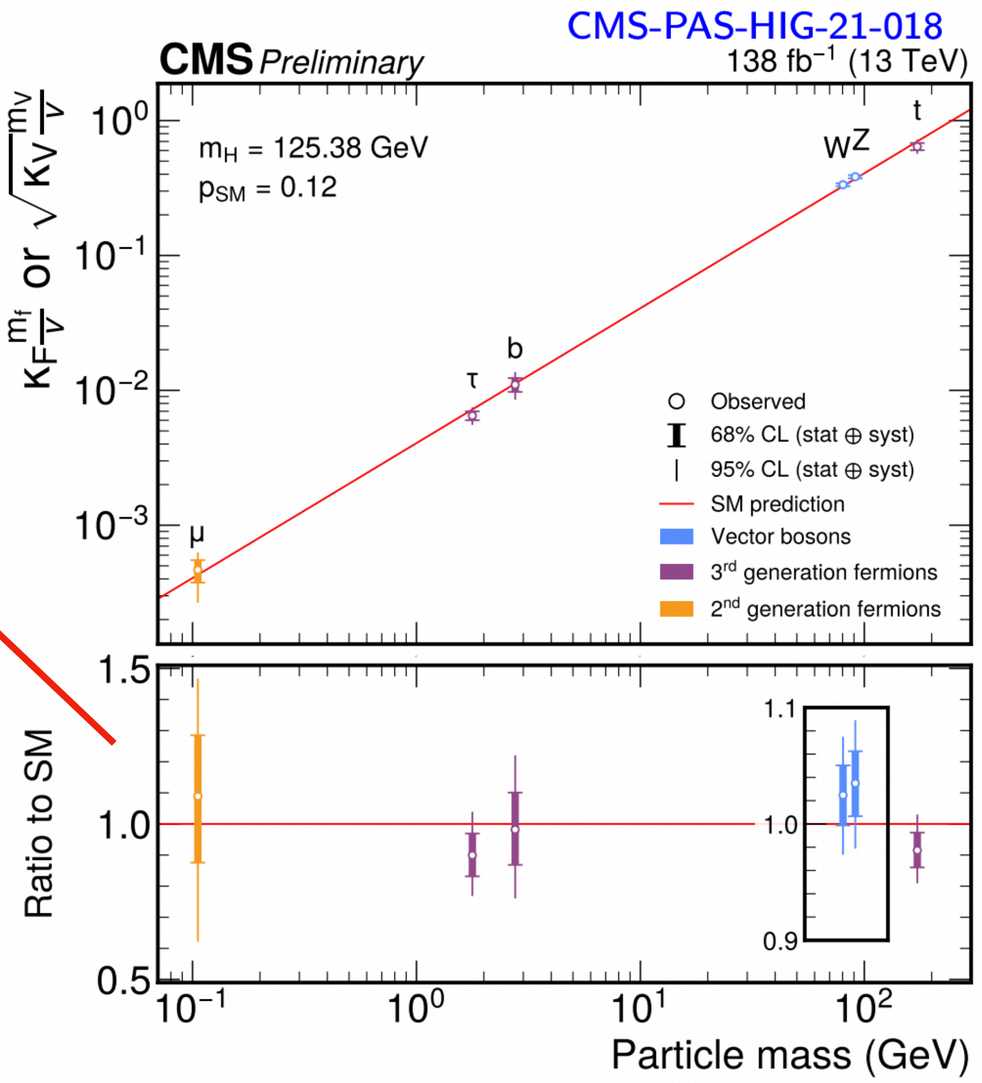
LHC paradigm: discovery → discovery through precision

THE HIGGS AS A PORTAL TO NEW PHYSICS



10-50% error & H self-coupling unknown



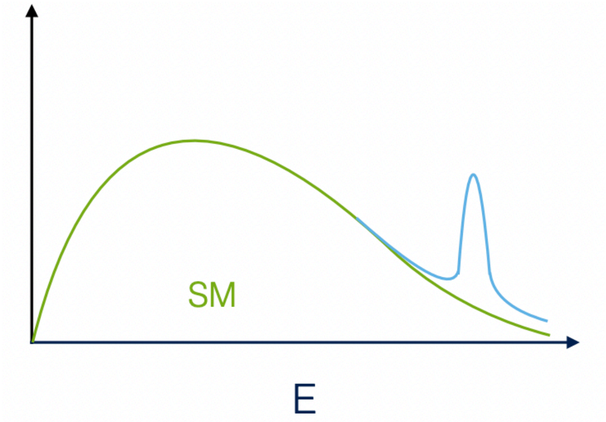


- The discovery of the Higgs boson at the LHC in 2012 it is not just the last missing piece of the SM jigsaw puzzle, on the contrary it opened a new era of exploration of the high energy frontier at particle colliders with new Yukawa force still largely unknown.

DISCOVERY THROUGH PRECISION

GeV

10^{19} : PLANK SCALE



Direct searches:
precision not needed for discovery unless NP is weakly coupled but required to characterise NP

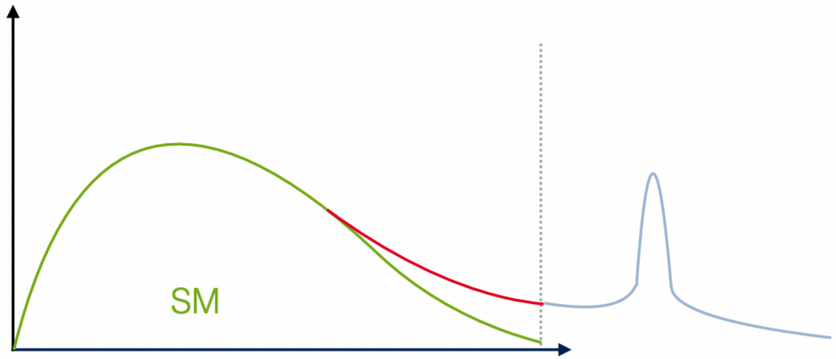
Λ

LHC

10^{2} : EW SCALE

GeV

10^{19} : PLANK SCALE



Λ

Indirect searches:
precision essential to spot subtle deviations from SM

LHC

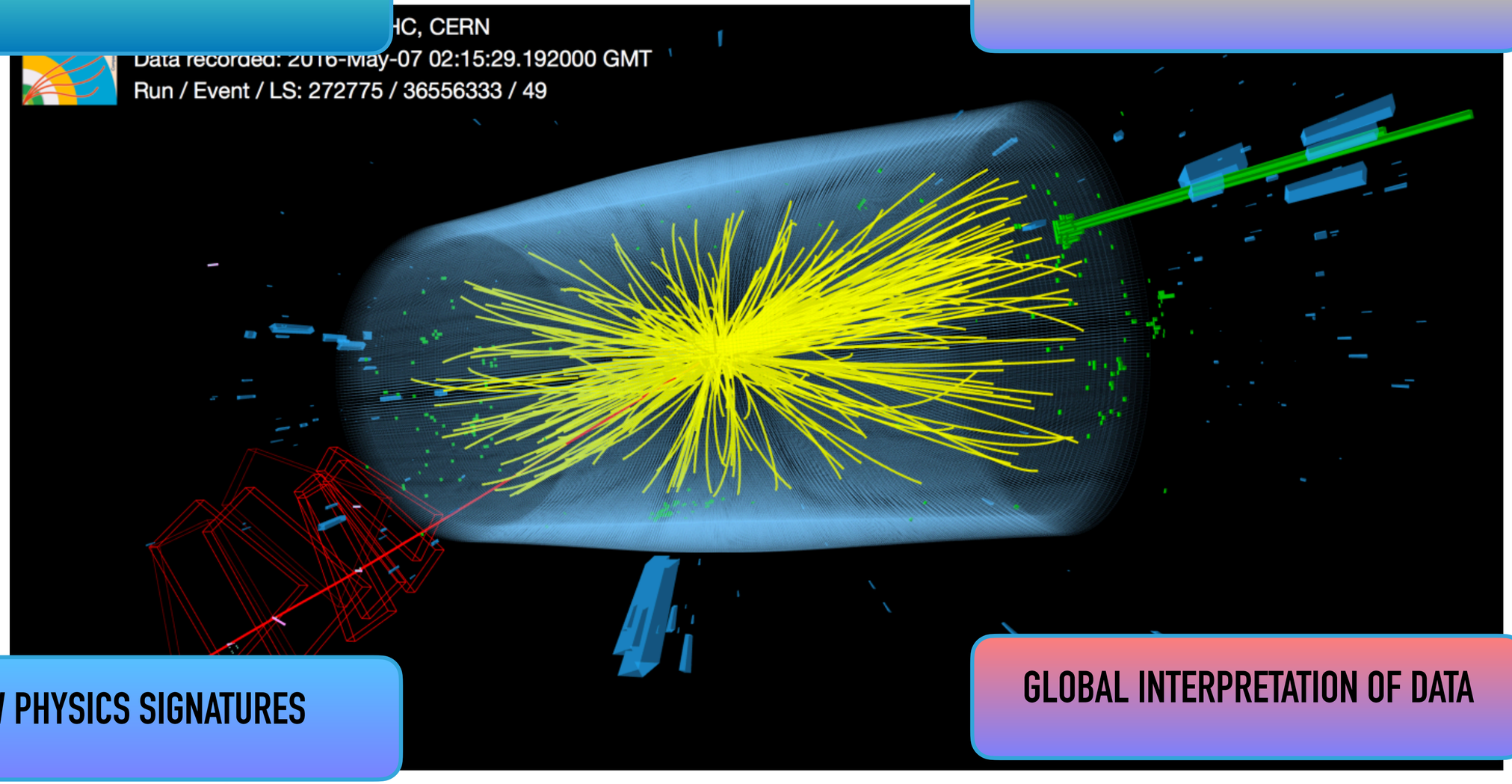
10^{2} : EW SCALE

OUTLINE

Part I

PROTON STRUCTURE

PRECISION PHYSICS



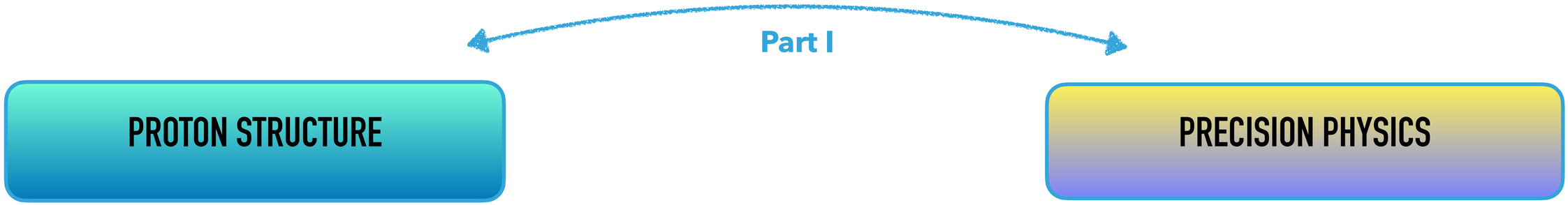
Part II

Part III

NEW PHYSICS SIGNATURES

GLOBAL INTERPRETATION OF DATA

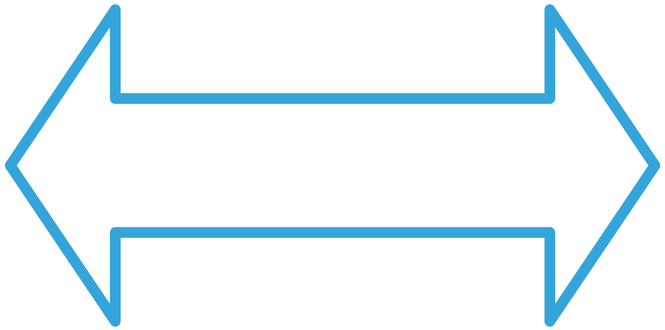
Part III



PROTON STRUCTURE AND PRECISION PHYSICS

MY JOB AS A PHENOMENOLOGIST

Experimental observations



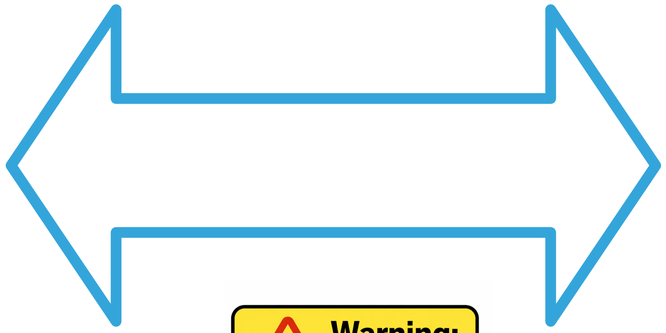
Theoretical model



@ G. Renee Guzlas

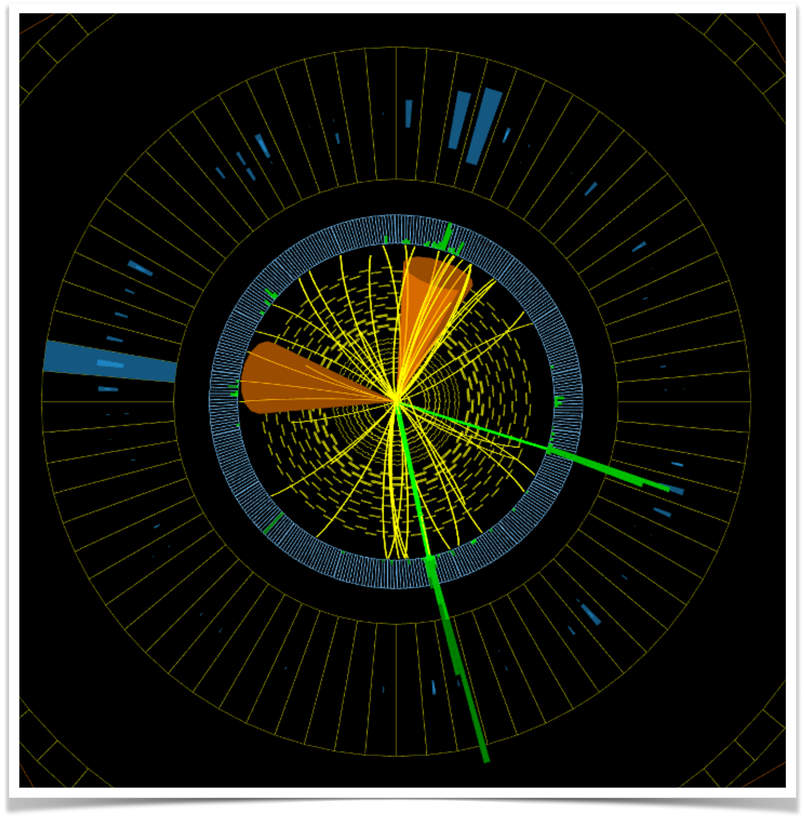
BRIDGING DATA AND THEORY

Experimental observations

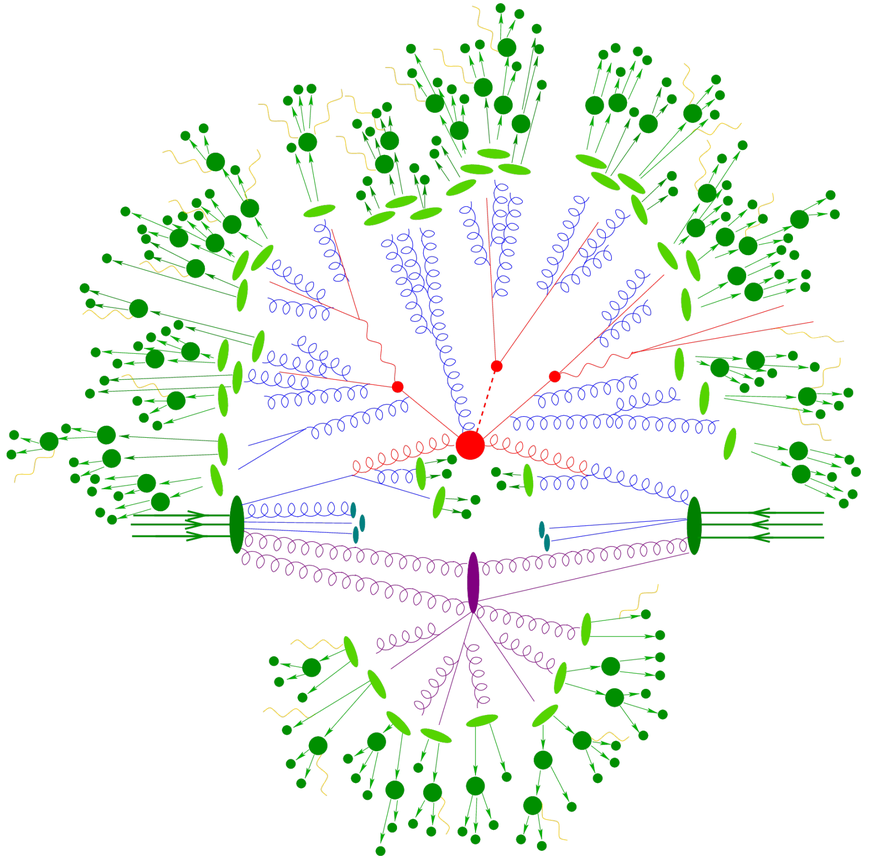


Theoretical model





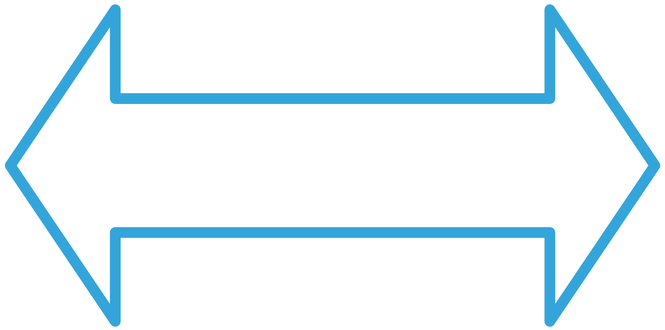
CMS event, CERN website



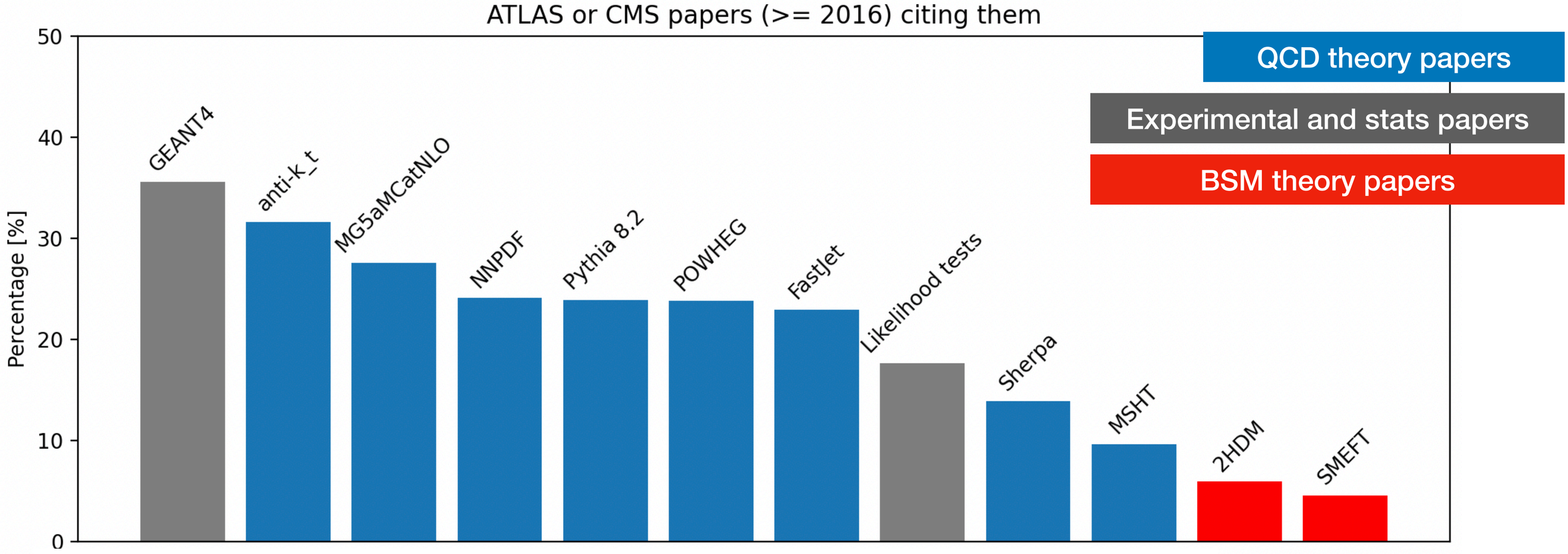
@SHERPA artist

BRIDGING DATA AND THEORY

O(10^4) ATLAS and CMS papers since 2016



Papers they cite



Selection of papers cited ≥ 500 times *[inspired from G. Salam's talk colloquium at CERN (June 2025)]*

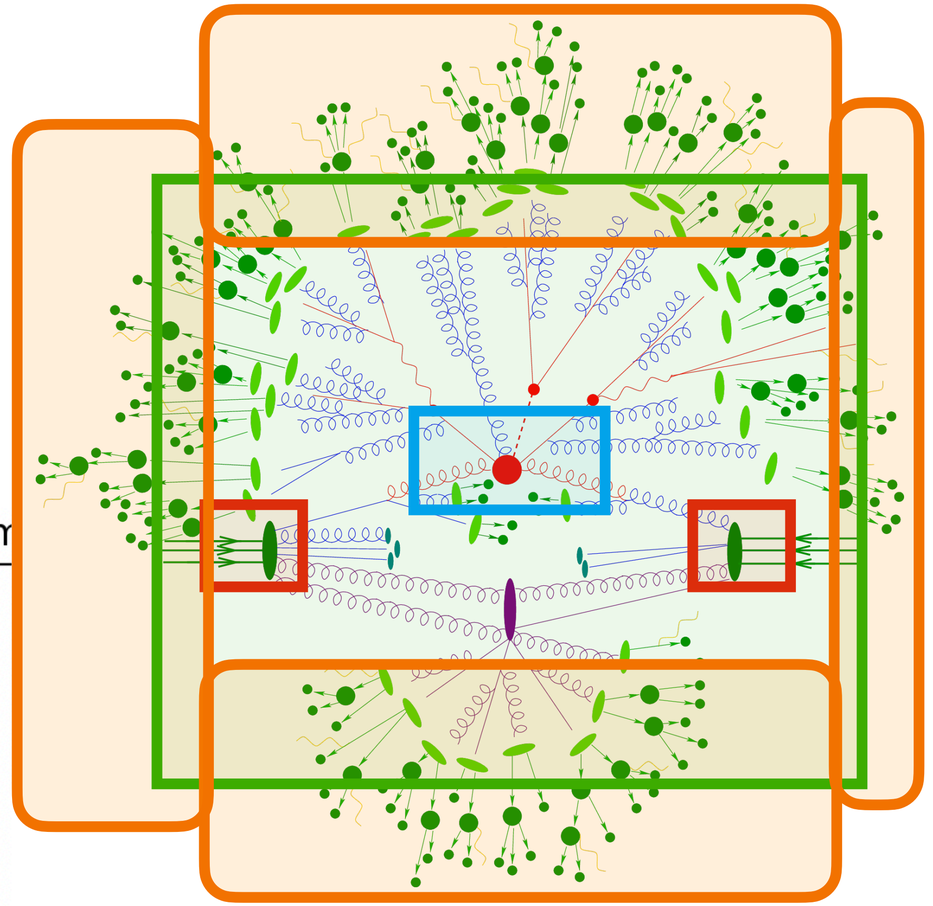
BRIDGING DATA AND THEORY

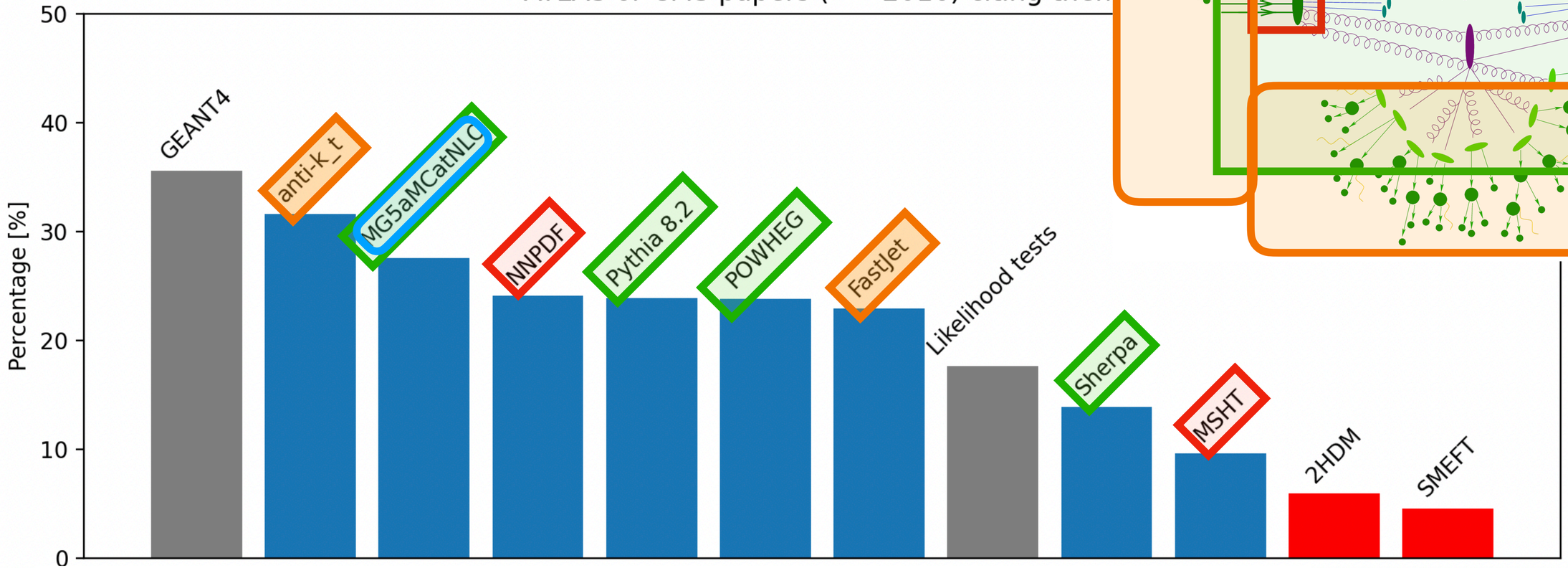
PDFs (proton structure)

Monte Carlo event generator

Hard scattering

Jet algorithm





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BRIDGING DATA AND THEORY

PDFs
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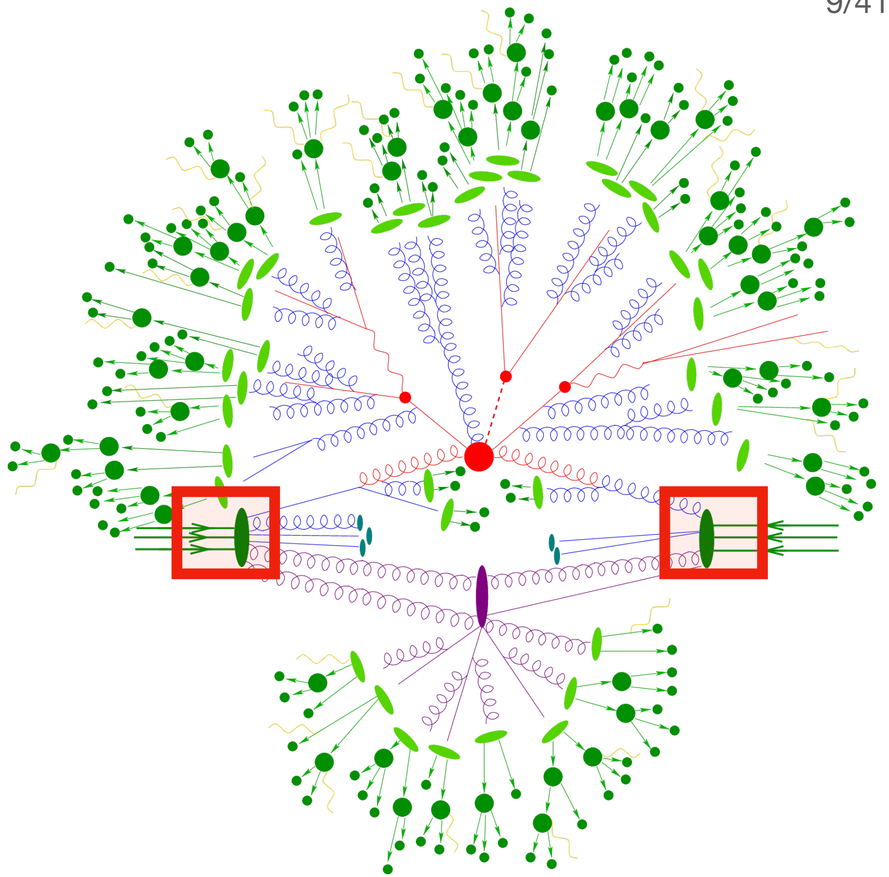

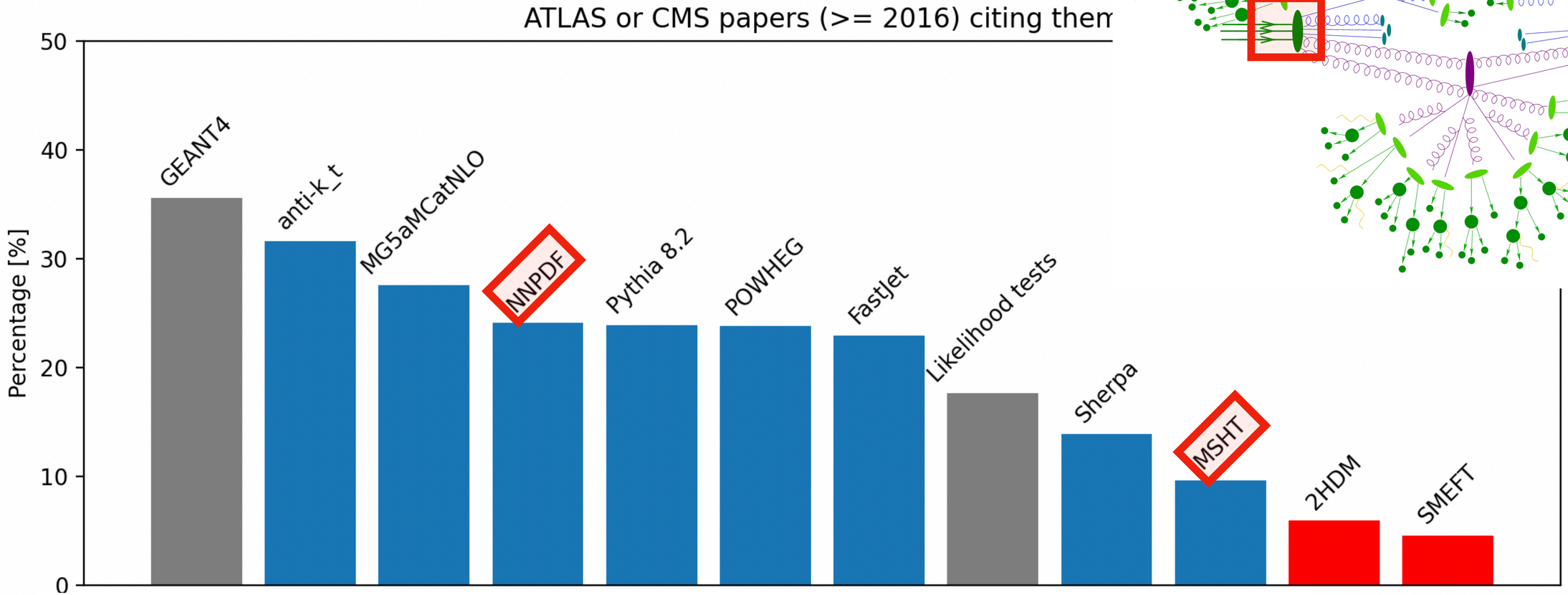

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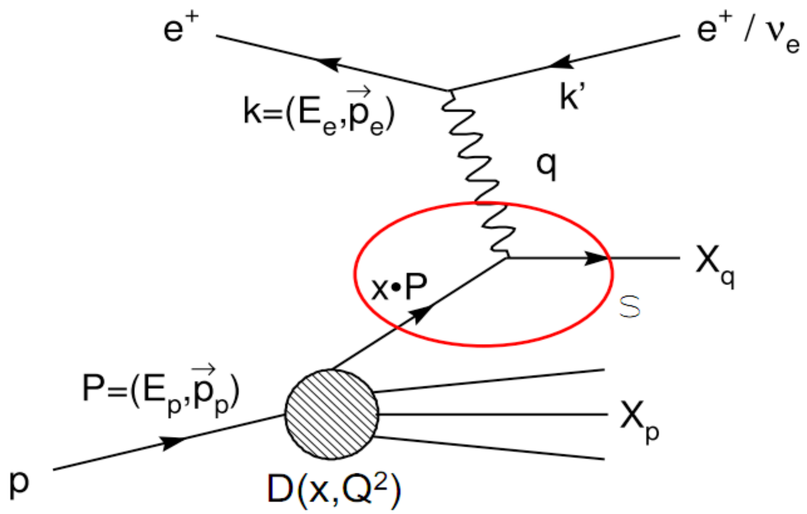
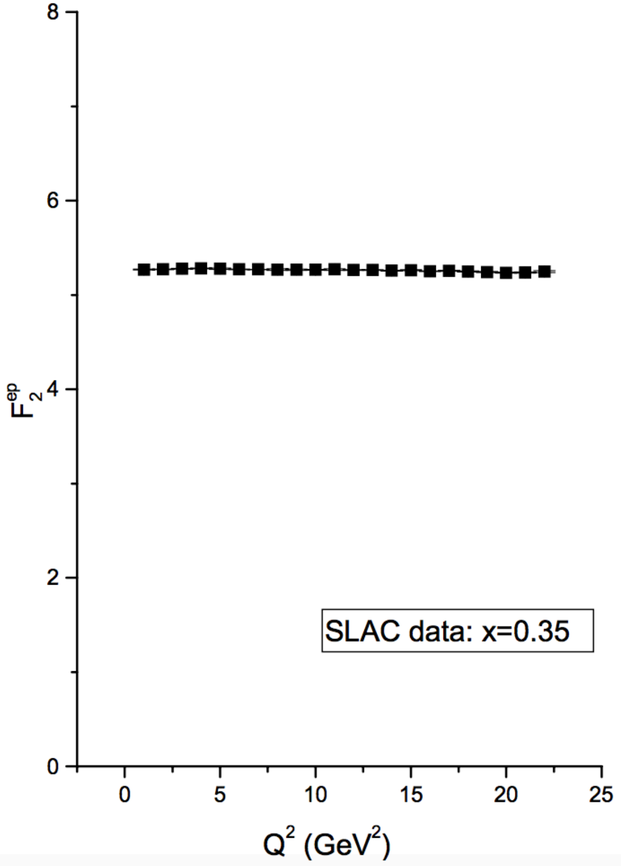
FEYNMAN'S PARTON MODEL

$$\sigma^{ep\to ab} = \sum_i \int dz f_i(z)\, \hat{\sigma}^{ei\to ab}(zP)$$

- **1967**: First deep-inelastic scattering experiments at SLAC 20 GeV linear collider gave surprising first evidence of Bjorken scaling, i.e. structure functions of the proton did not vanish as Q^2 increased, rather they remained finite and constant.





- Such scaling pointed to the fact that the exchanged photon scatters elastically off point-like objects that have no mass or scale associated. The lepton scatters off charged spin 1/2 constituents (partons) that carry a fraction x of proton momentum **(Feynman's Parton model)**

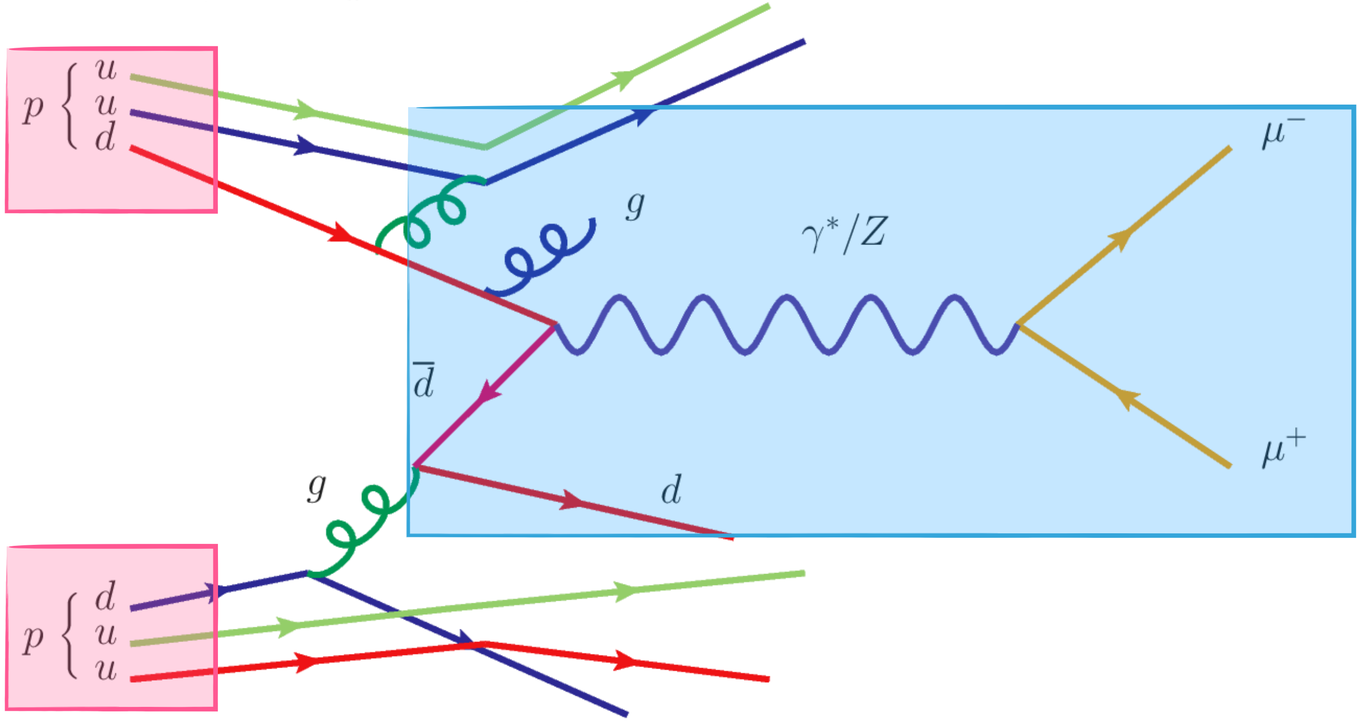
QCD **1973**

COLLINEAR FACTORIZATION THEOREM

$$\sigma^{pp\to ab} = \sum_{i,j=-n_f}^{n_f} \int dz_1\, dz_2\, f_i(z_1,\mu_F)\, f_j(z_2,\mu_F)\, \hat{\sigma}^{ij\to ab}(z_1 z_2 S, \alpha_s(\mu_R), \mu_F) + \mathcal{O}\left(\frac{\Lambda^n}{S^n}\right)$$

Collinear factorisation theorem: separate long-distance universal information on proton structure in terms of partons (quarks, antiquark, gluons, photons…) from short-distance parton interaction (hard scattering)

Parton Distribution Functions

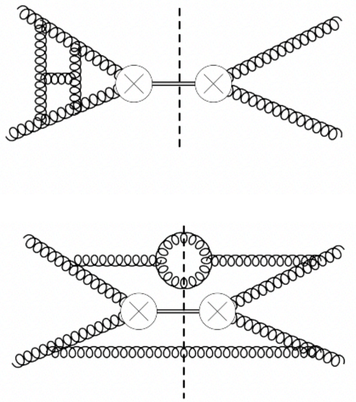


Hard Scattering: Perturbative QCD + EW

$$d\sigma^{pp\to ab} = \sum_{i,j} f_i \otimes f_j \otimes d\hat{\sigma}^{ij\to ab} + \ldots$$

6 processes know up to 4th order in the QCD perturbative expansion,

e.g. gluon fusion to Higgs



B. Mistlberger

PARTON DISTRIBUTION FUNCTIONS

$$f_i(x,\mu)$$

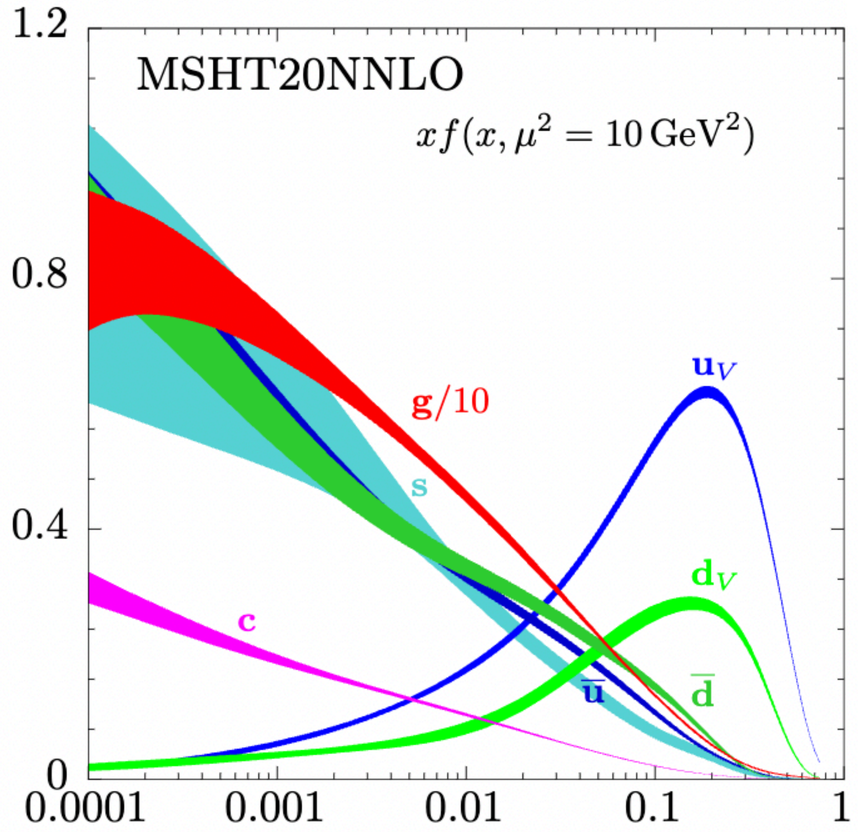
Perturbative QCD

$$\frac{d}{dt}\begin{pmatrix} q_i(x,t) \\ g(x,t) \end{pmatrix} = \frac{\alpha_s(t)}{2\pi}\int_x^1 \sum_{j=q,\bar{q}} \frac{d\xi}{\xi} \begin{pmatrix} P_{ij}\left(\frac{x}{\xi},\alpha_s(t)\right) & P_{ig}\left(\frac{x}{\xi},\alpha_s(t)\right) \\ P_{gj}\left(\frac{x}{\xi},\alpha_s(t)\right) & P_{gg}\left(\frac{x}{\xi},\alpha_s(t)\right) \end{pmatrix} \otimes \begin{pmatrix} q_j(\xi,t) \\ g(\xi,t) \end{pmatrix}$$

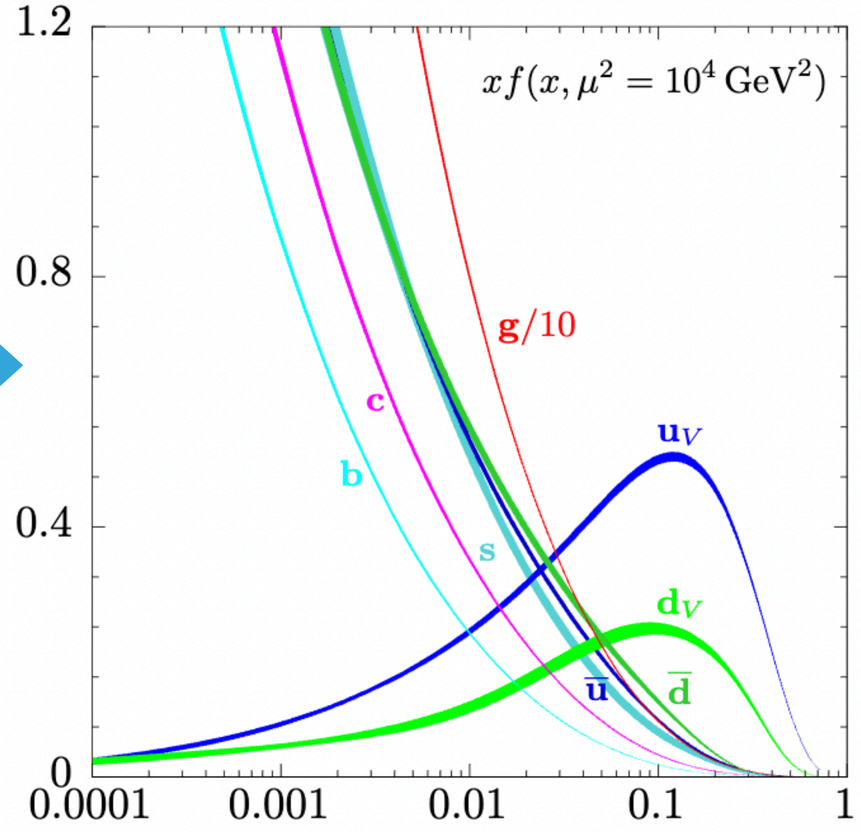
Dokshitzer - Gribov - Lipatov - Altarelli - Parisi

DGLAP evolution equation

Hadronic scale: global fit of PDFs



DGLAP



High scale: input to the LHC

PDG 2023

PARTON DISTRIBUTION FUNCTIONS

$$f_i(x,\mu)$$

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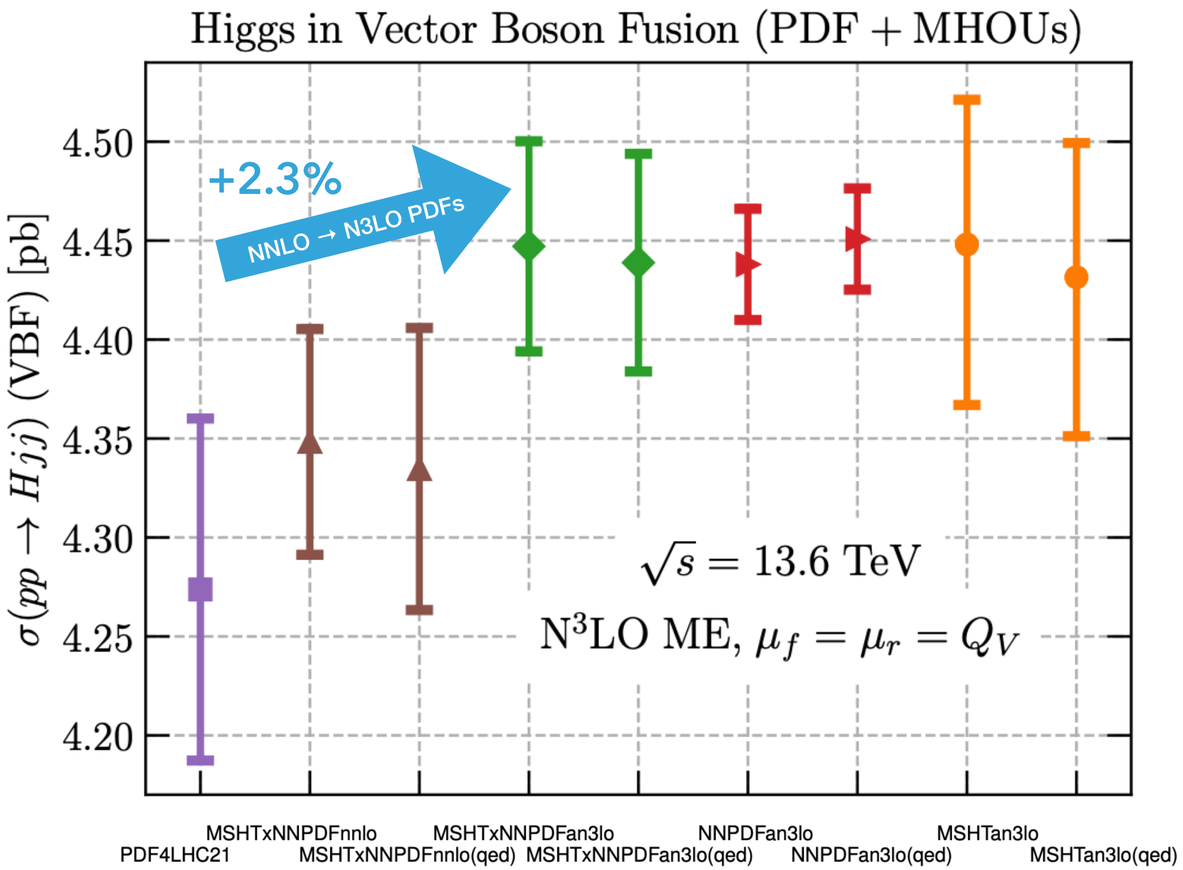


MSHT+NNPDF 2411.05373

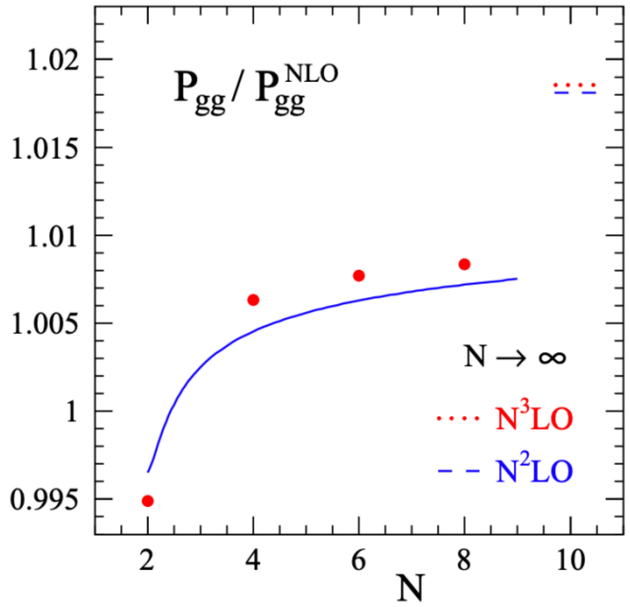
DGLAP splitting functions

$$P_{ij}(x,\alpha_s) = \alpha_s P_{ij}^{(0)}(x) + \alpha_s^2 P_{ij}^{(1)}(x) + \alpha_s^3 P_{ij}^{(2)}(x) + \alpha_s^4 P_{ij}^{(3)}(x) + \alpha_s^5 P_{ij}^{(4)}(x)$$

☑ LO (1973) ☑ NLO (1982) ☑ NNLO (2004) N³LO partial results N⁴LO partial results

The effect of NNLO/N3LO mismatch between order of PDFs is large → **N3LO PDFs** needed for precision physics

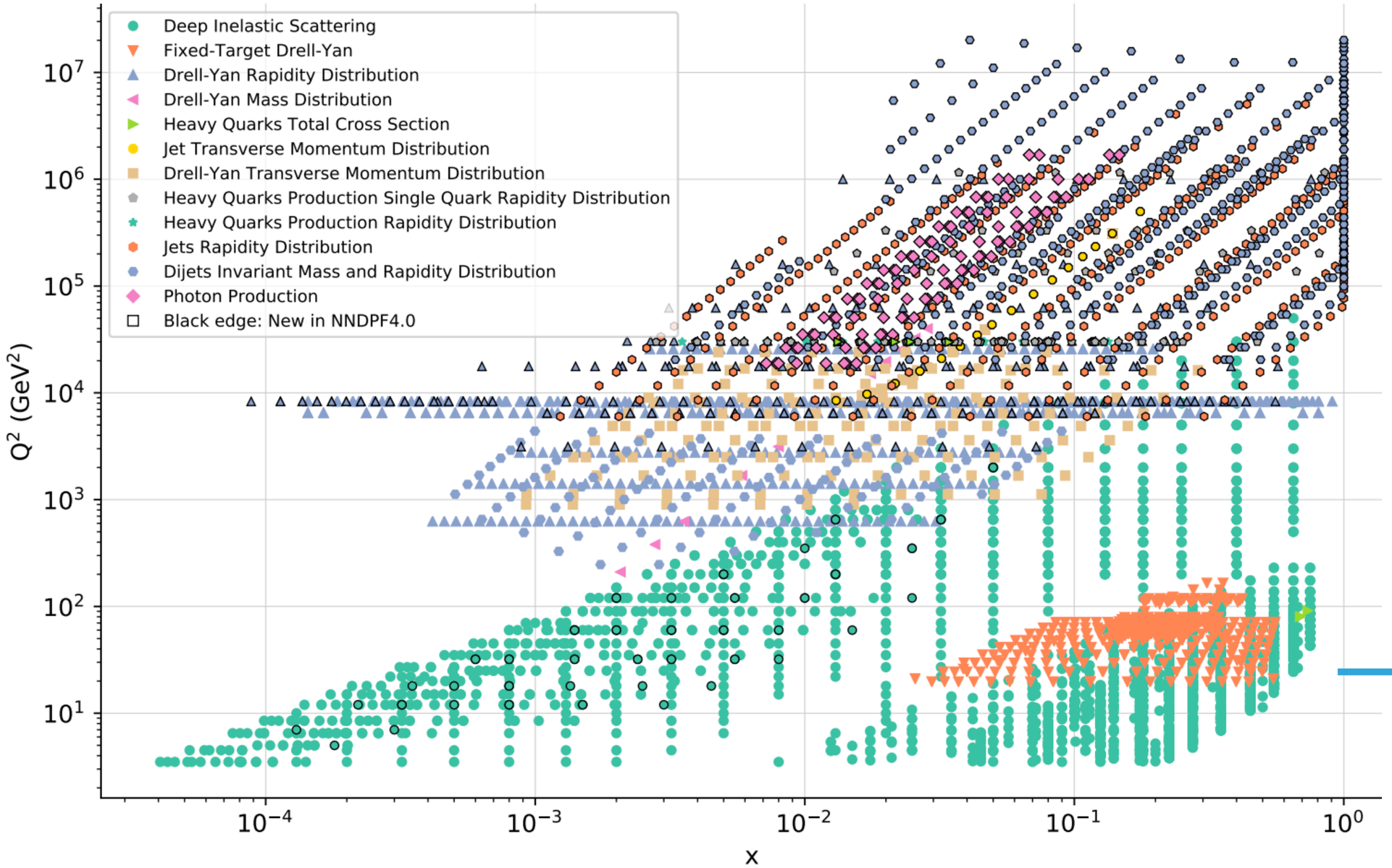
Moch et al, 2111.15561



A WEALTH OF INPUT DATA

$$f_i(x, \mu)$$

Data

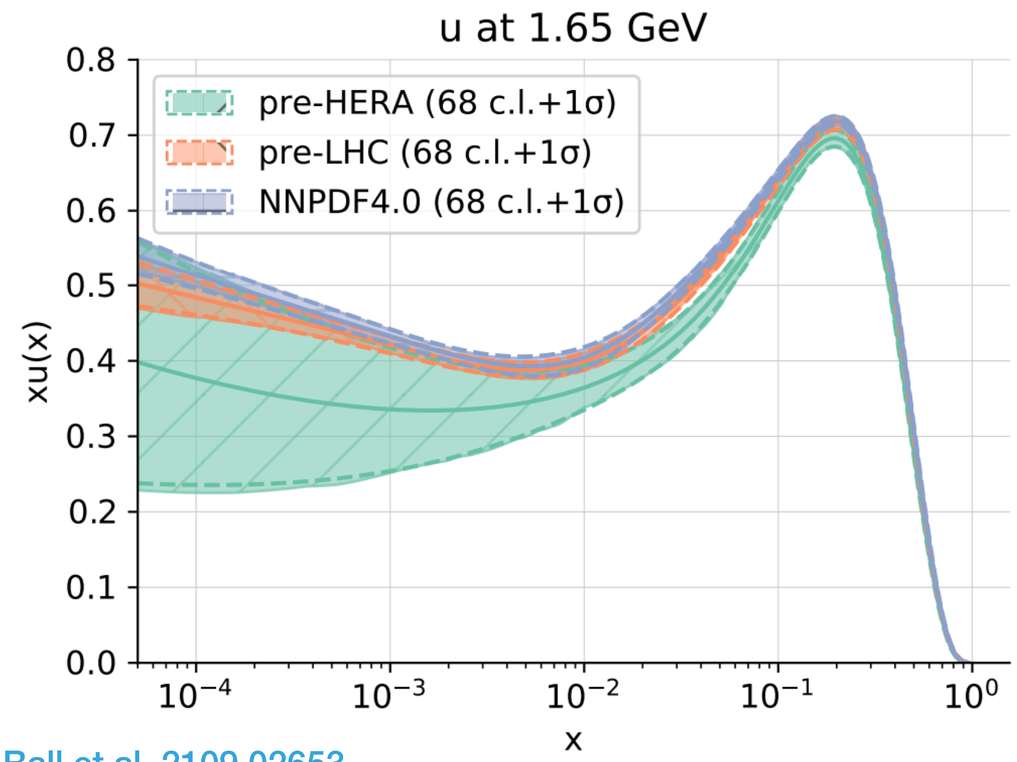


- 8 functions, each for a different quark flavor and the gluon binding them all: up, anti-up, down, anti-down, strange, anti-strange, charm, gluon
- Different data constrain different flavour combinations in different x regions depending on the kinematics of the experiment

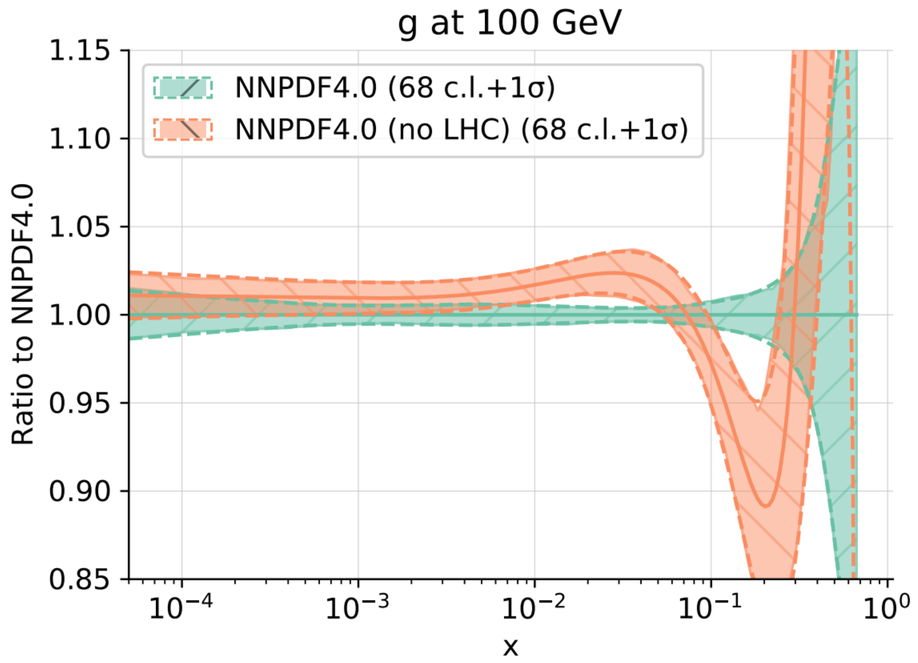
NNPDF4.0:
O(5000) datapoints,
about 30% from LHC

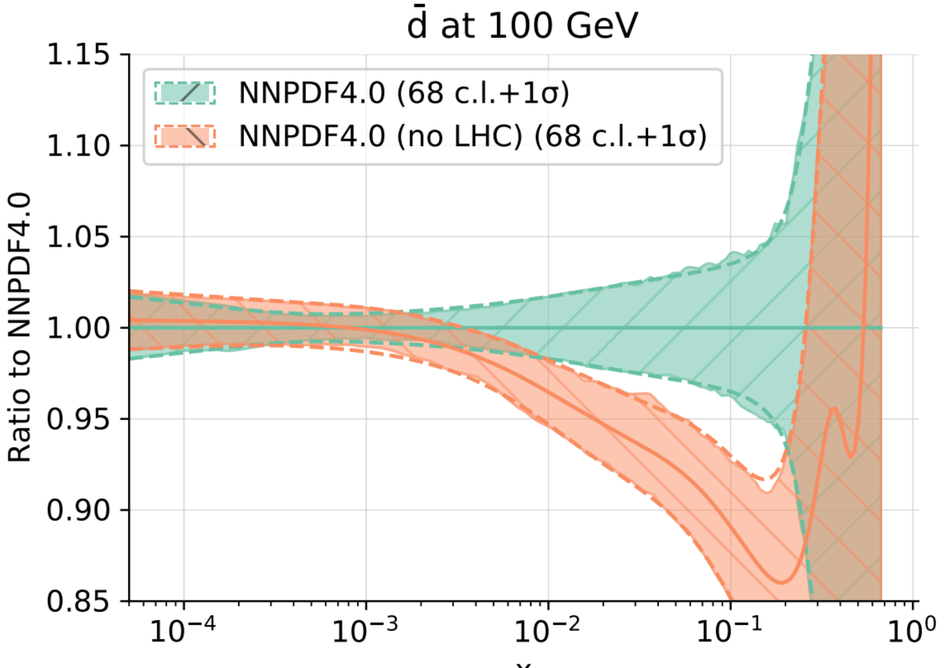
Ball et al, 2109.02653

A WEALTH OF INPUT DATA



Ball et al, 2109.02653





- Deep Inelastic Scattering data from HERA data crucial to constrain quark valence (up and to less extent down valence) across intermediate to small x and gluon at small x
- LHC high energy data crucial to provide additional constraints to PDFs, in particular in medium- to large-x gluon and quarks.
- Mild tension with older fixed-target Drell-Yan and DIS data visible in the large-x region (especially gluon and anti-quarks)

EXTRACTING FUNCTIONS FROM DATA

- Given some model constraints and given O(5000) experimental data points **D** want to determine the set of functions **{f}** (with i = 1, …, $n_{partons}$) and **estimate their uncertainty**
- Want to find a infinite-dimensional object from a finite number of information.
- Hence, PDF inference is an example of a **non-linear infinite-dimensional** inverse problem.
- Mapping **D** into **f** is mathematically ill defined, nobody knows the true **f = f***
- Best we can do it to find best **f** given the data **D**.

$$P(f|D) \propto P(D|f)\,P(f)$$

✓ Likelihood

? Prior

$$P(\mathbf{D}|f) \sim \exp(-\chi^2/2)$$

$$\chi^2 = \sum_{a,b=1}^{N_{\rm dat}} \left(T_a(\{f\},\vec{c}) - D_a\right) \Sigma_{ab}^{-1} \left(T_b(\{f\},\vec{c}) - D_b\right)$$

Two ways of assuming a **prior**:

- Explicit parametrization (parametrical modelling)
  Function is projected on a vector space of parameters θ
- Non-parametrical inference (NNs): use data to also infer probable ‘smoothness’ of f(x) and thus infer probability function P(f) throughout the space of functions
- No explicitly Bayesian PDF fits so far!

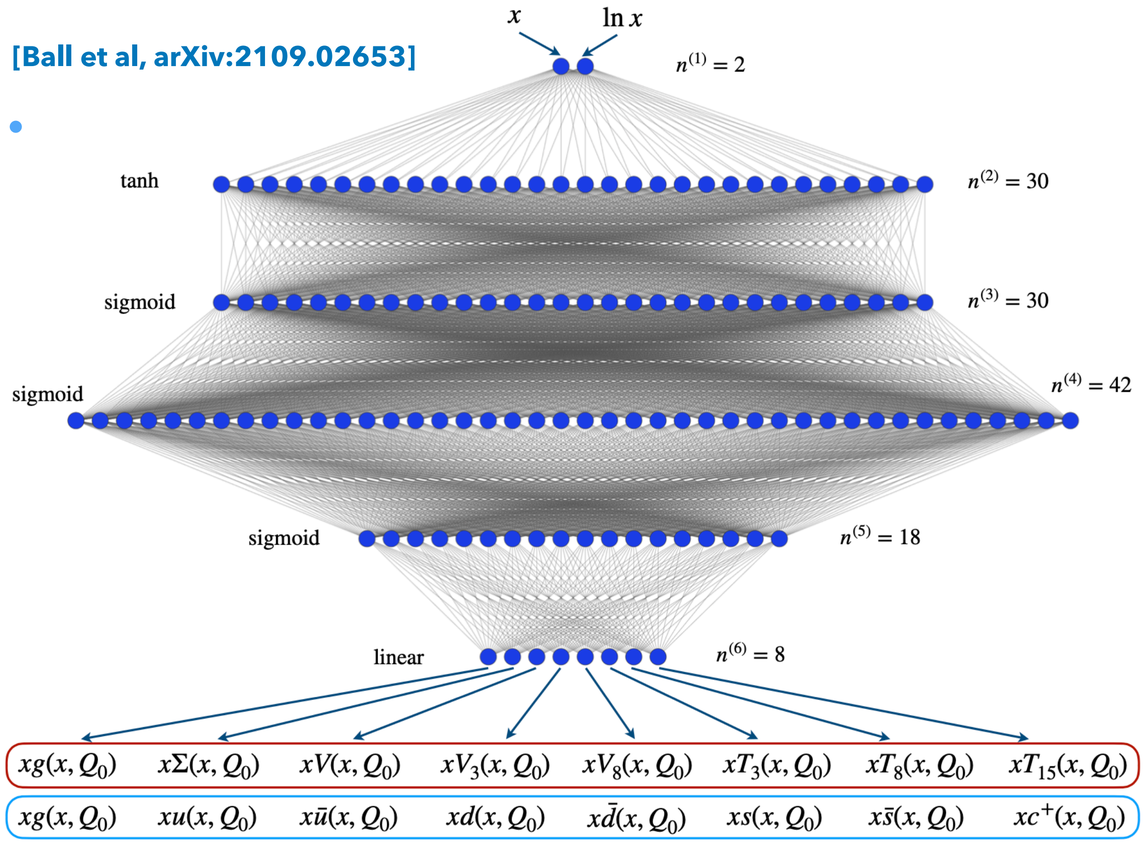
EXTRACTING FUNCTIONS FROM DATA

- Idea: choose parametrisation so large that in principle can fit any conceivable function f.
- One option is to use NNs [Del Debbio, Forte, Latorre, Piccione, Rojo, MU 2008]
- NNDF4.0 parametrisation involves 763 free parameters
- Hessian approach not applicable. Use Monte Carlo - or bootstrap - error propagation by importance sampling

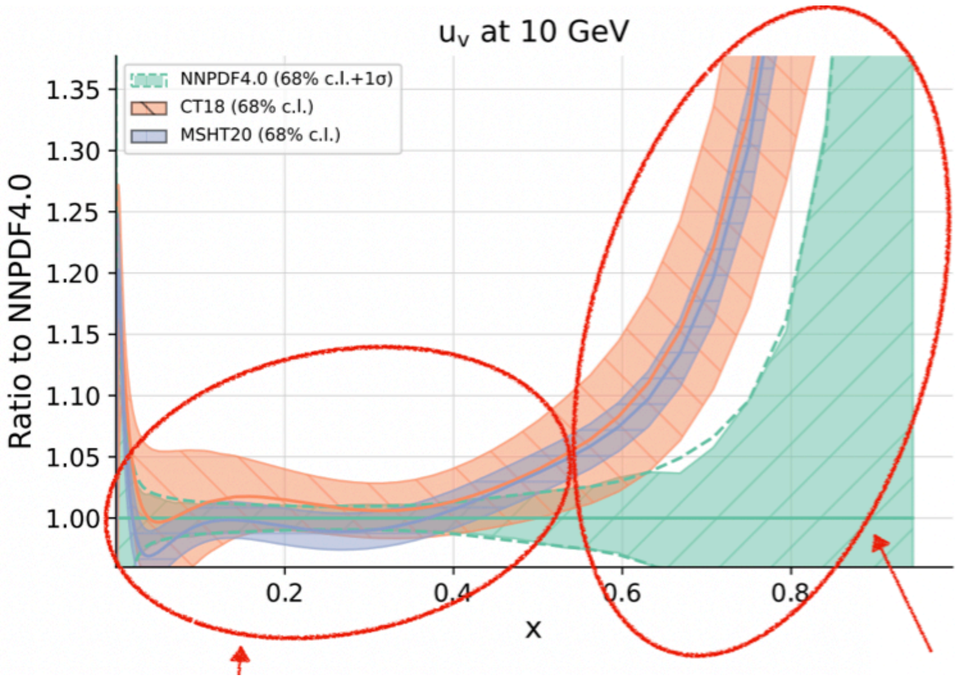
[Giele, Kosover 1993] [Forte et al, 2006]

$$f(x,\mu_0) = x^{\alpha}(1-x)^{\beta}\mathrm{NN}(x)$$

[Ball et al, arXiv:2109.02653]



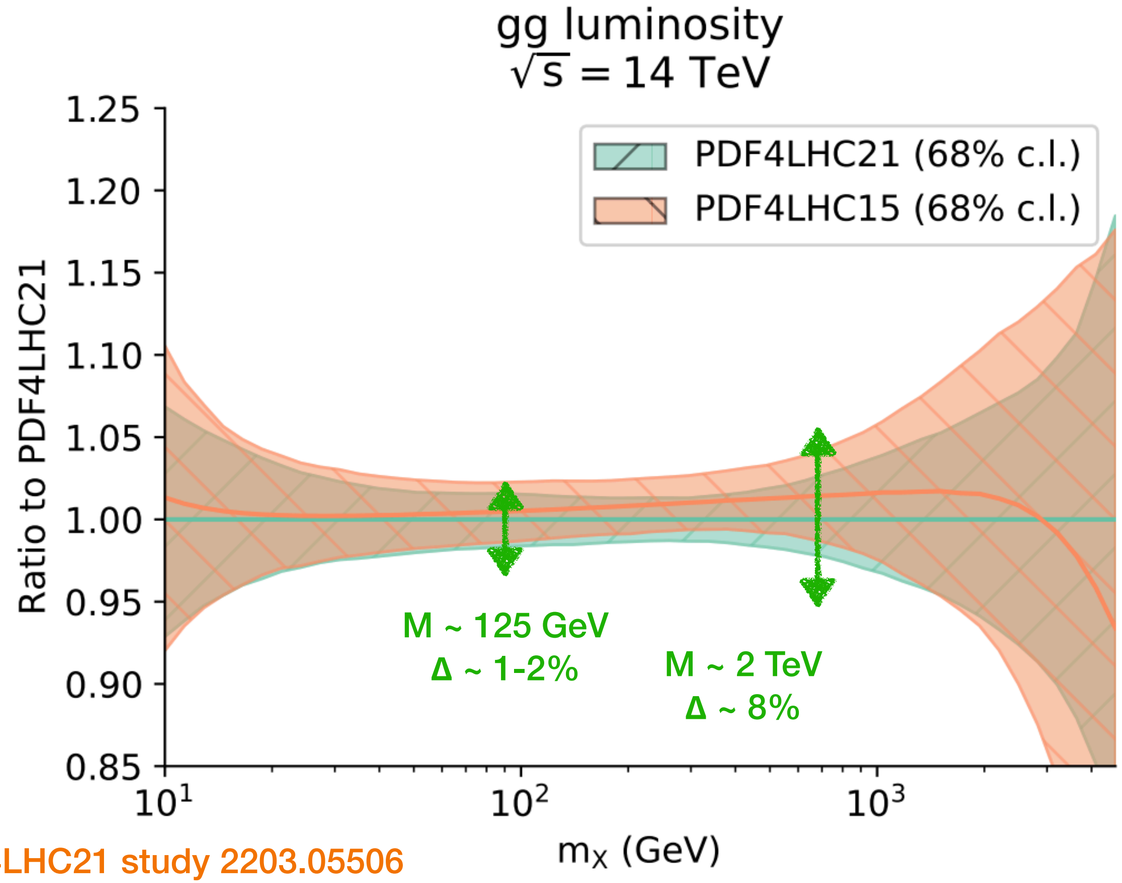
NN model exhibits smaller uncertainty in data region compared to other sets but larger uncertainties in extrapolation region.



Data region

Extrapolation region

TOWARDS 1% ERROR

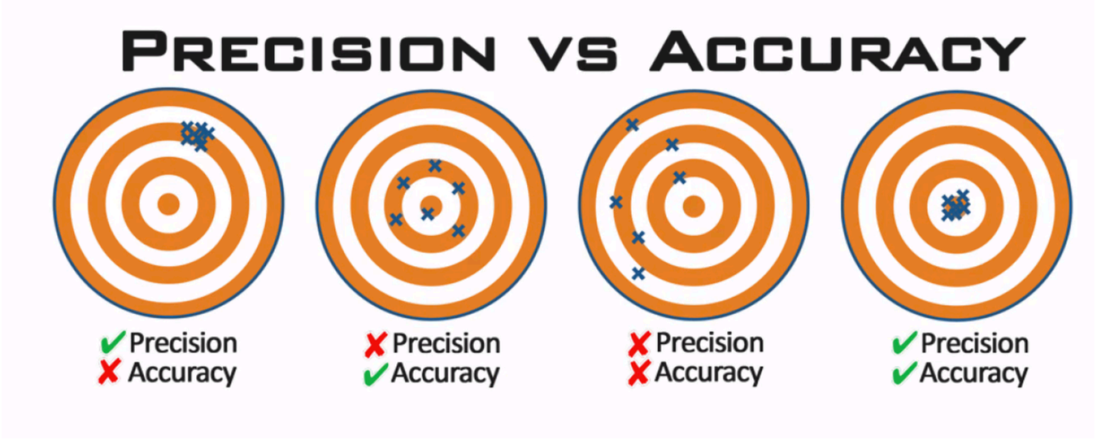


PDF4LHC21 study 2203.05506

Now that thanks to progress in input data, methodology and theory PDFs are getting more and more precise, it is crucial for them to be accurate.

Challenges:

- Genuine inconsistencies in experimental inputs
- Imperfect fitting methodology
- Inaccurate theoretical framework
  - ➡ Missing higher order uncertainties & N3LO
  - ➡ Other corrections (nuclear, non-perturbative effects…)
  - ➡ New physics effects - second part of the talk



WHY IS THIS GOAL SO RELEVANT?

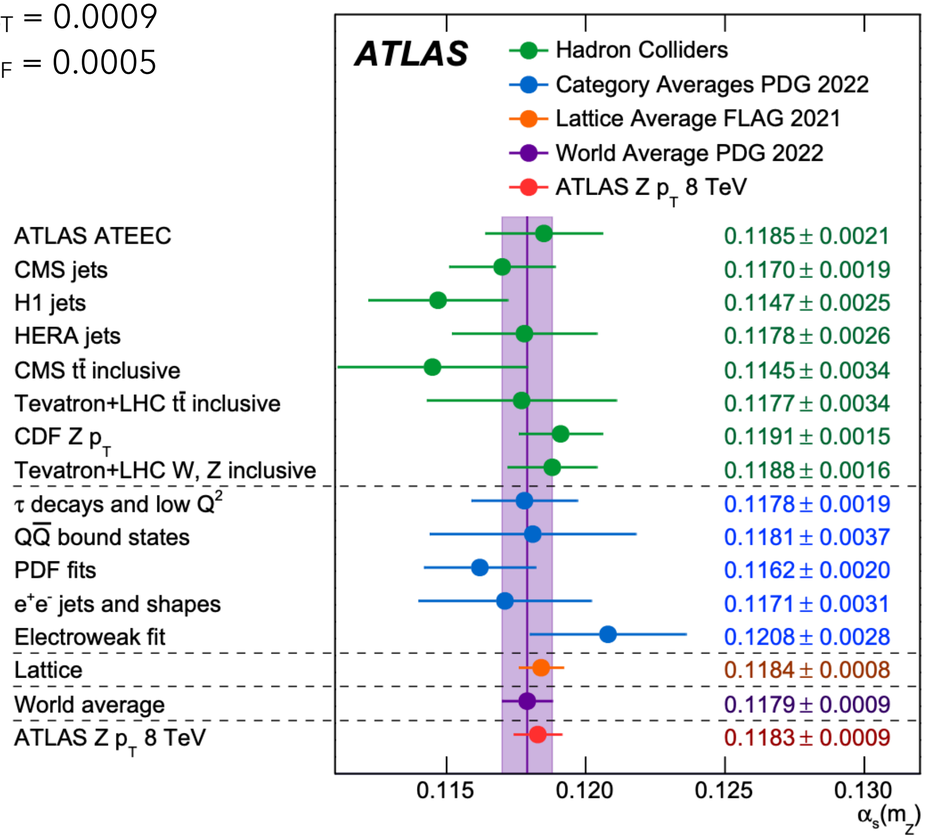
$$d\sigma^{pp\to ab} = \sum_{i,j} f_i \otimes f_j \otimes d\hat{\sigma}^{ij\to ab} + \ldots$$

$$x \approx \frac{M}{\sqrt{S}}$$

High-mass final states
⇔
Large-x PDFs

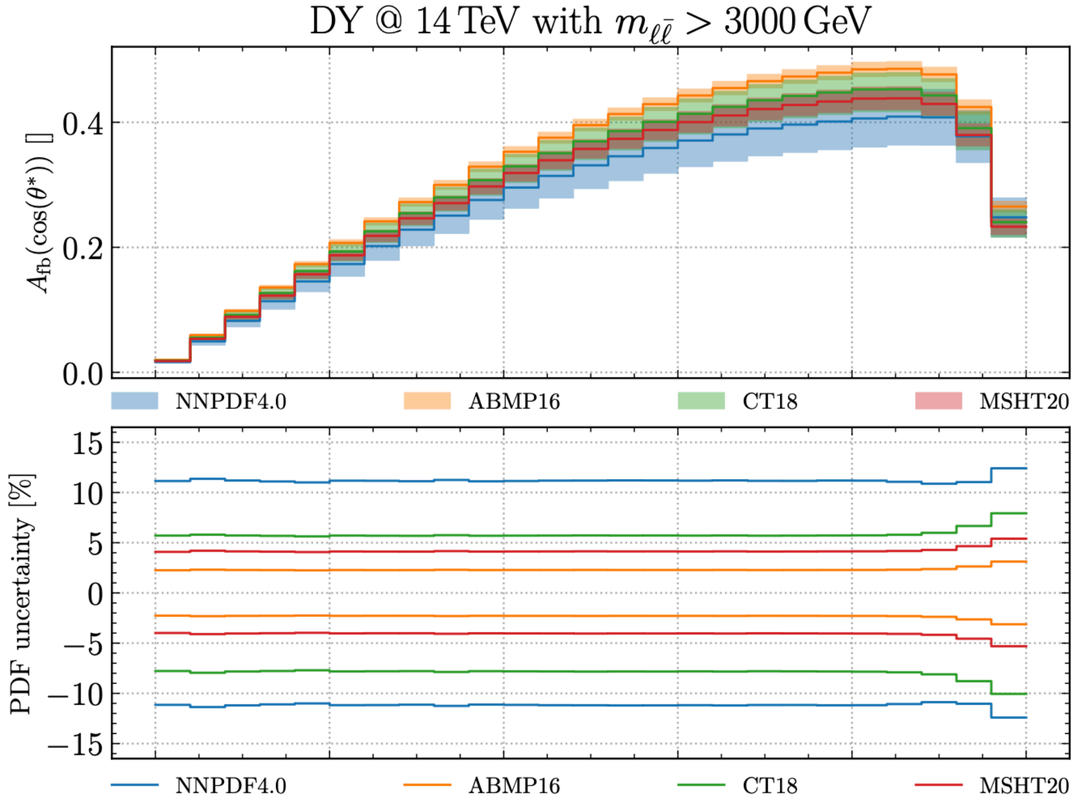
ATLAS α_S determination

Δ_{TOT} = 0.0009
Δ_{PDF} = 0.0005



ATLAS collaboration, arXiv: 2309.12986

Heavy Z′ search in DY Forward-Backward asymmetry



Ball et al arXiv: 2209.08115

PROTON STRUCTURE

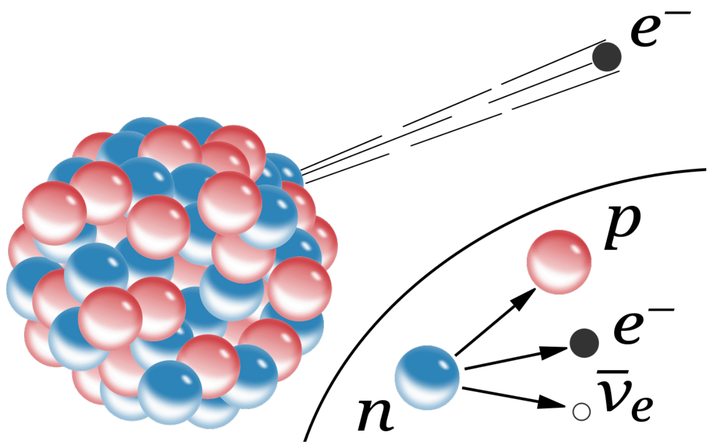
Part II

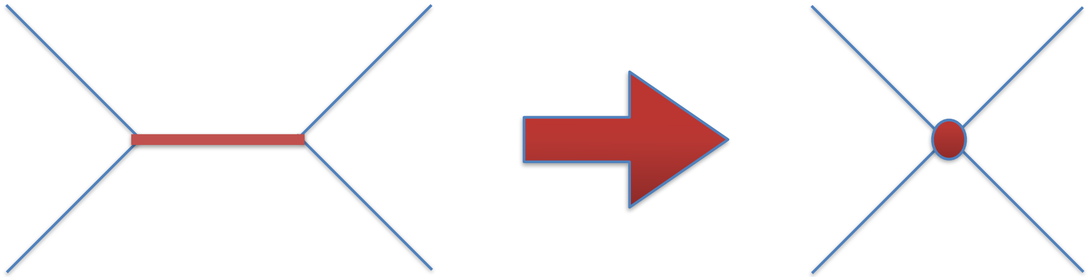
NEW PHYSICS SIGNATURES

AN UNEXPECTED INTERPLAY

EFFECTIVE FIELD THEORIES

- Beta decay of a neutron into proton and electron plus missing energy (neutrino) was perfectly described by Fermi theory (Fermi, 1934) as the interaction of the four particles involved. Only in 1983 the W boson mediating the interaction was discovered.





If intermediate particle much heavier than energy of the system…

… it is integrated out and its effect is only an "effective interaction"

Strengths of new interactions

$$\mathcal{L}_{\mathrm{SMEFT}} = \mathcal{L}_{\mathrm{SM}} + \sum_i^{N_{d6}} \frac{c_i}{\Lambda^2} \mathcal{O}_i^{(6)}$$

Suppression by the mass of the new heavy particles

SM fields

SMEFT: A FRAMEWORK FOR INDIRECT DISCOVERIES

- EFT is a well-defined theoretical approach for indirect searches
- Assumption: new physics states are heavy
- Write the Lagrangian with only light SM particles
- BSM effects can be incorporated as a momentum expansion
- SMEFT: assume SM field content and gauge symmetries (apart from accidental)

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_{i}^{N_{d6}} \frac{c_i}{\Lambda^2} \mathcal{O}_i^{(6)} + \sum_{j}^{N_{d8}} \frac{b_j}{\Lambda^4} \mathcal{O}_j^{(8)} + \dots$$

- Full dim-6 basis of operators under SMEFT assumptions includes **2499** operators
  [Grzadkowski et al, arXiv:1008.4884]

LOOKING FOR PATTERNS

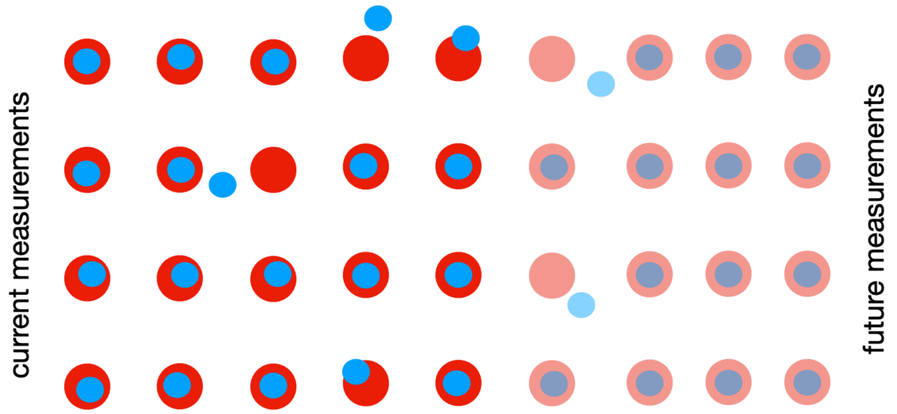
$$\Delta \mathrm{Obs}_n = \mathrm{Obs}_n^{\mathrm{EXP}} - \mathrm{Obs}_n^{\mathrm{SM}} = \frac{1}{\Lambda^2} \sum_i a_{n,i}^{(6)}(\mu)\, c_i^{(6)}(\mu) + \mathcal{O}\left(\frac{1}{\Lambda^4}\right)$$

Experimental measurements

SM predictions

Coefficients parametrising the deviations due to BSM physics

Image credit: F. Maltoni



LOOKING FOR PATTERNS

Image credit: F. Maltoni

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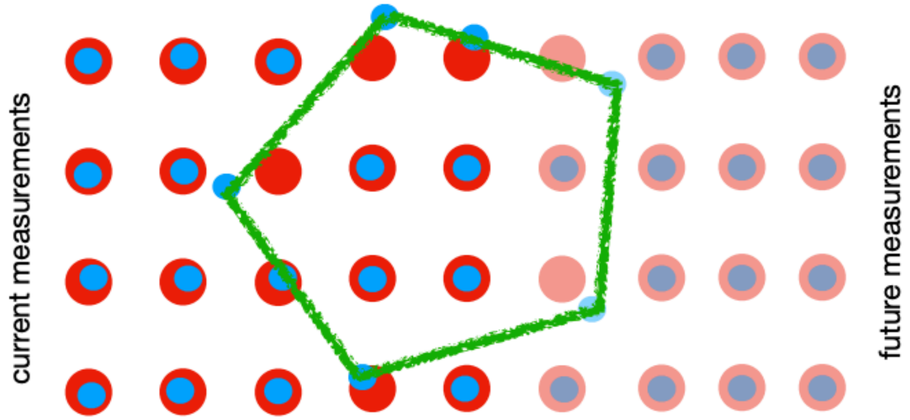
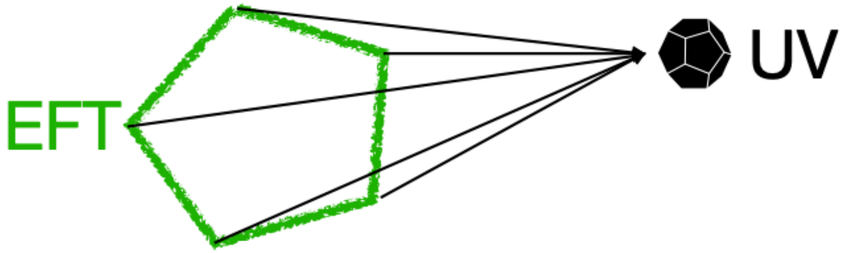


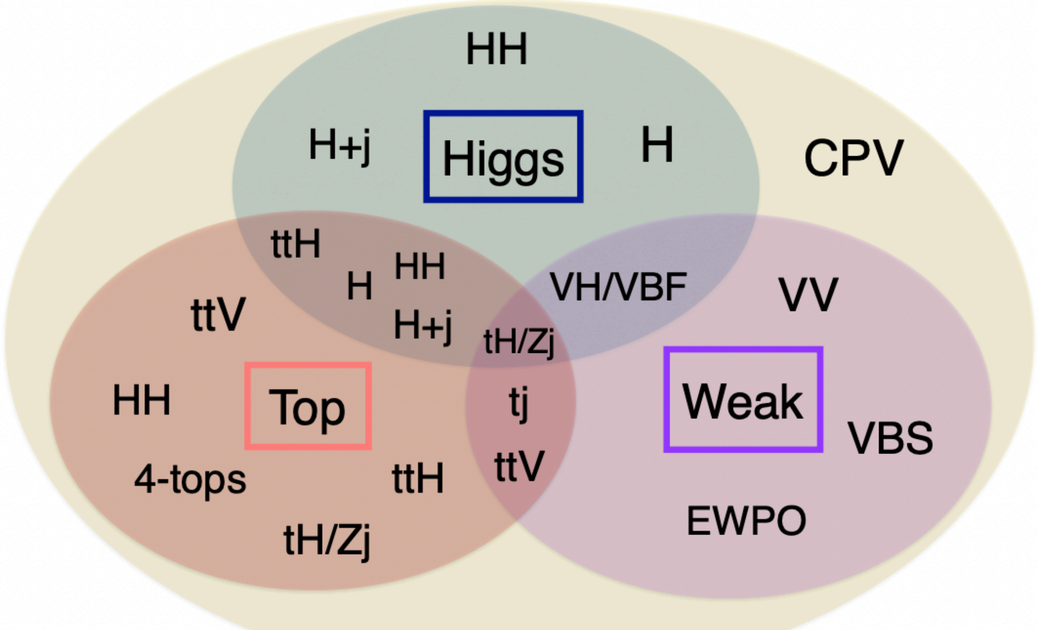
As more precise data and SM theoretical predictions become available, we can identify patterns of small differences induced by new physics and from there deduce what is the new model that causes a given pattern!

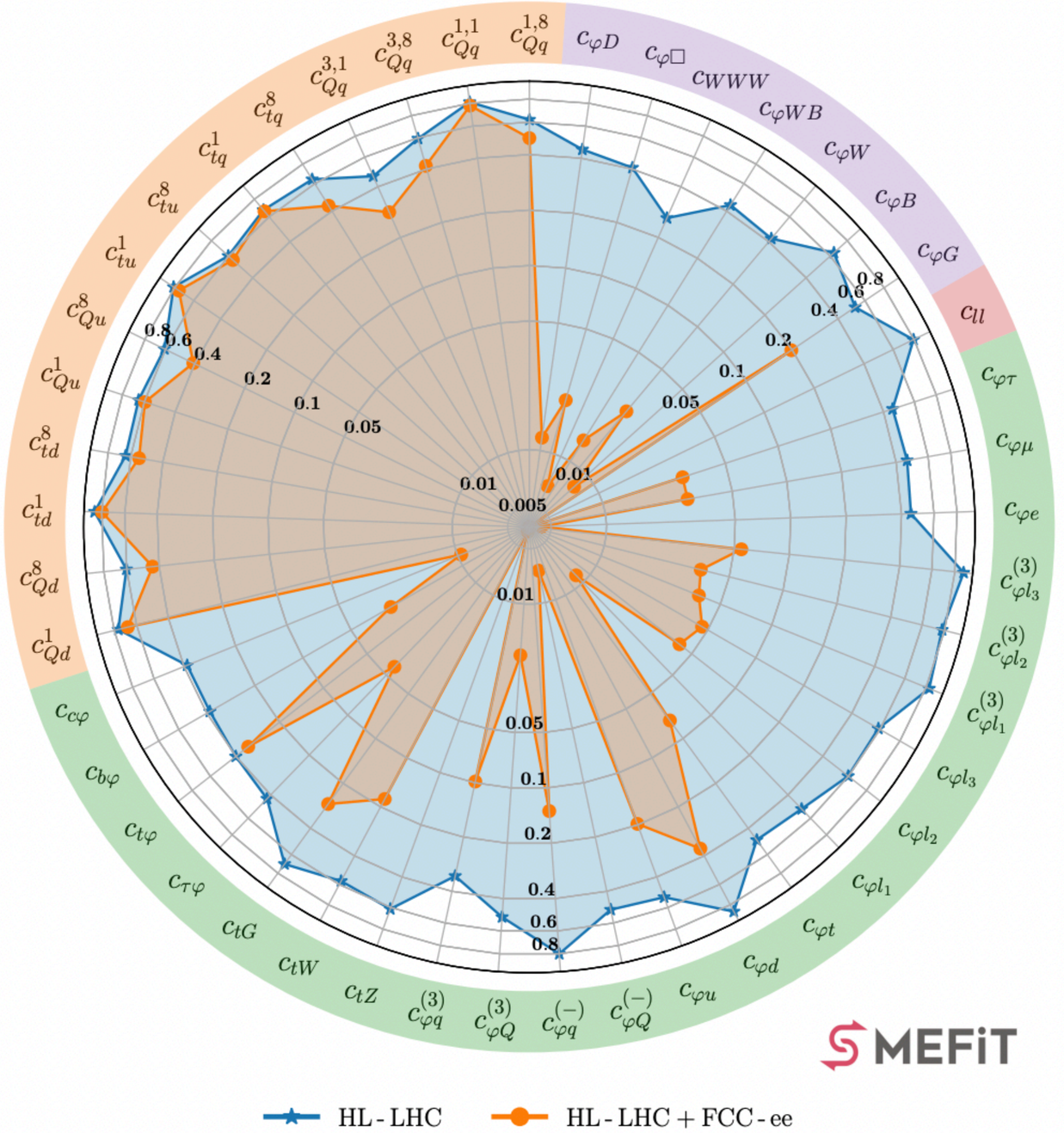


GLOBAL SMEFT FITS

- Current SMEFT fits make flavour assumptions and restricted to a few observables/sectors & reduce the number of operators.
- Several global dim-6 SMEFT fit including combination of Higgs, electroweak and top quark sector observables constraining O(40-50) Wilson coefficients

[SMEFiT, 2105.0006, 2302.06660, 2404.12809] [HEPfit, 1708.01133, 1905.03764, 2206.08326][FitMaker, 2012.02779] [Falkowski et al, 1911.07866][Allwicher et al, 2311.00020][Bartocci et al, 2412.09674]...





@ E. Vryonidou

SMEFiT collab, 2404.12809

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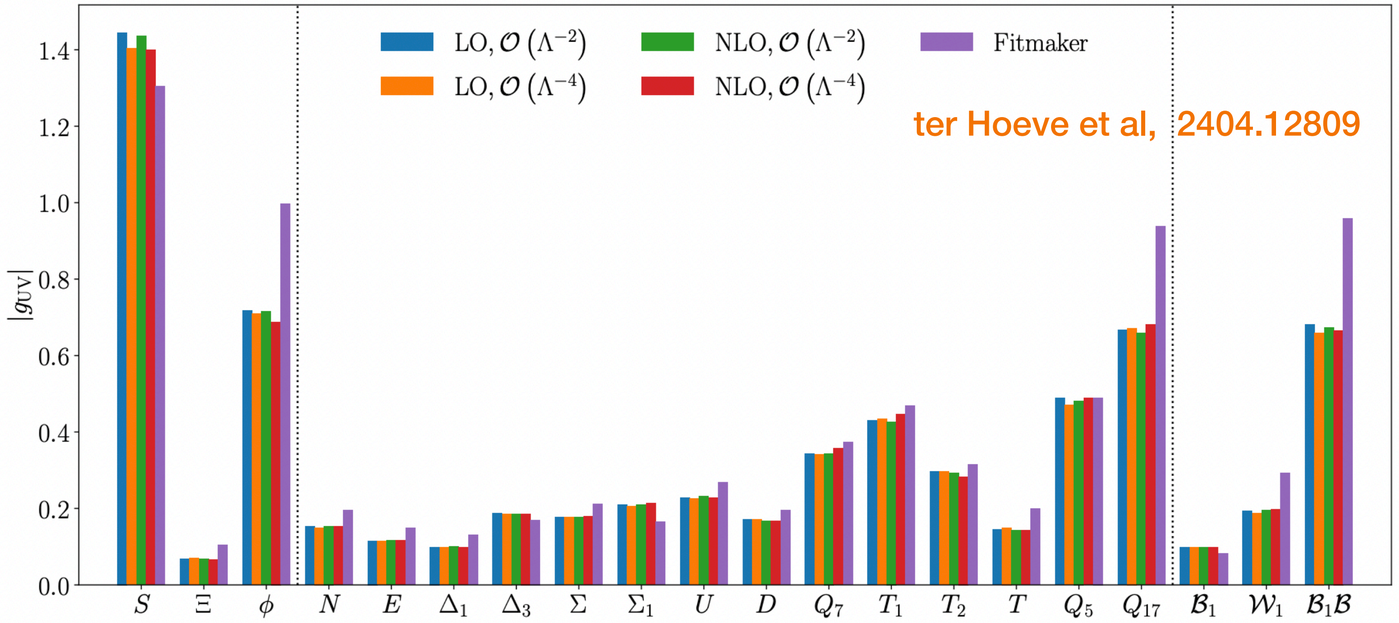
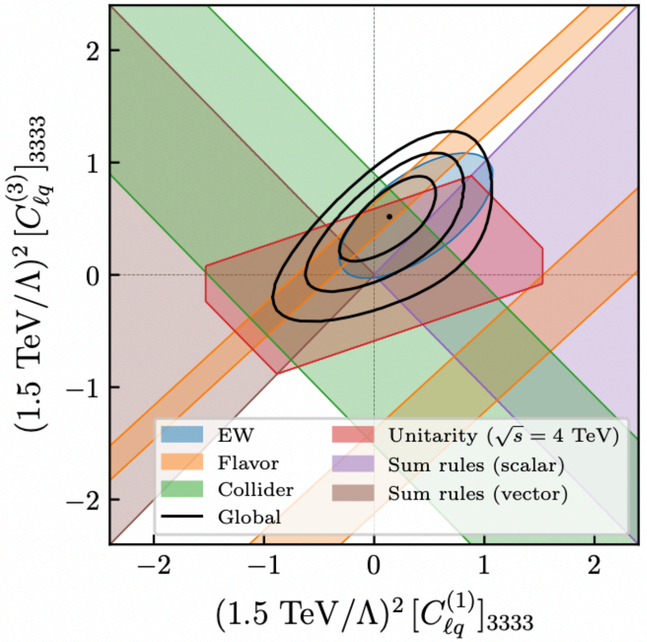


ter Hoeve et al, 2404.12809

➡ Lots of progress in matching SMEFT bounds with UV scenarios

➡ Lots of work on perturbative unitarity and positivity bounds



Bresciani et al, 2603.03423

SMEFT AND PDF INTERPLAY

$$\chi^2 = \frac{1}{N_{\rm dat}} \sum_{i=1}^{N_{\rm dat}} \left(T_i(\{\theta\},\{c\}) - D_i\right) {\rm cov}_{ij}^{-1} \left(T_j(\{\theta\},\{c\}) - D_j\right)$$

$$T_i(\{\theta\},\{c\}) = {\rm PDFs}(\{\theta\},\{c\}) \otimes \hat{\sigma}_i(\{c\})$$

SMEFT WCs

Parameters determining PDFs at initial scale

$$\mathcal{L}_{\rm SMEFT} = \mathcal{L}_{\rm SM} + \sum_i^{N_{d6}} \frac{c_i}{\Lambda^2} \mathcal{O}_i^{(6)} + \sum_j^{N_{d8}} \frac{b_j}{\Lambda^4} \mathcal{O}_j^{(8)} + \ldots$$

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✓ In a PDF fit typically

$$T_i(\{\theta\}) = {\rm PDFs}(\{\theta\},\{c=0\}) \otimes \hat{\sigma}_i(\{c=0\})$$

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✓ In a PDF fit typically

$$T_i(\{\theta\}) = {\rm PDFs}(\{\theta\},\{c=0\}) \otimes \hat{\sigma}_i(\{c=0\})$$

✓ In a fit of SMEFT Wilson Coefficients

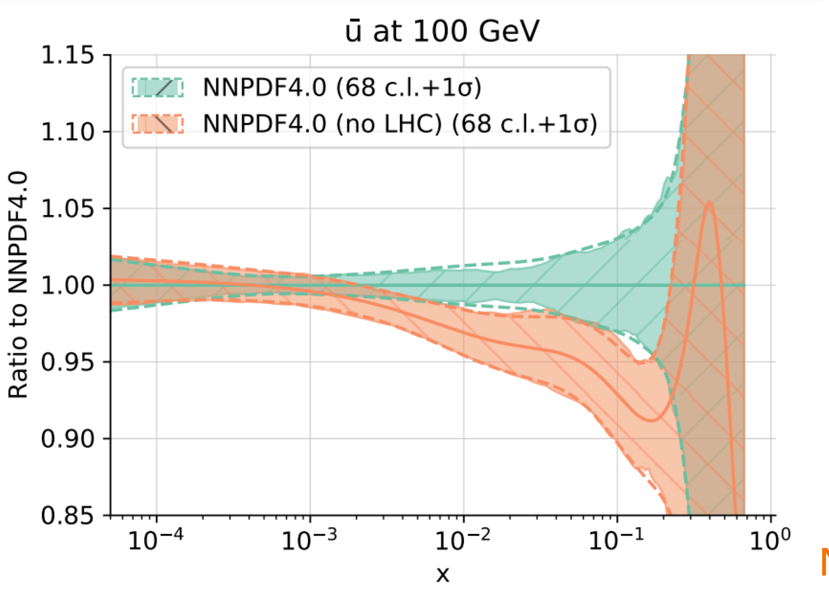
$$T_i(\{c\}) = {\rm PDFs}(\{\theta=\bar{\theta}\},\{c=0\}) \otimes \hat{\sigma}_i(\{c\})$$

SMEFT AND PDF INTERPLAY

- PDFs are low-scale quantities extracted from experimental data at all scales, without considering any potential high-scale contamination due to new physics.

- (SM)EFT fits are performed by assuming a priori that PDFs are SM-like.

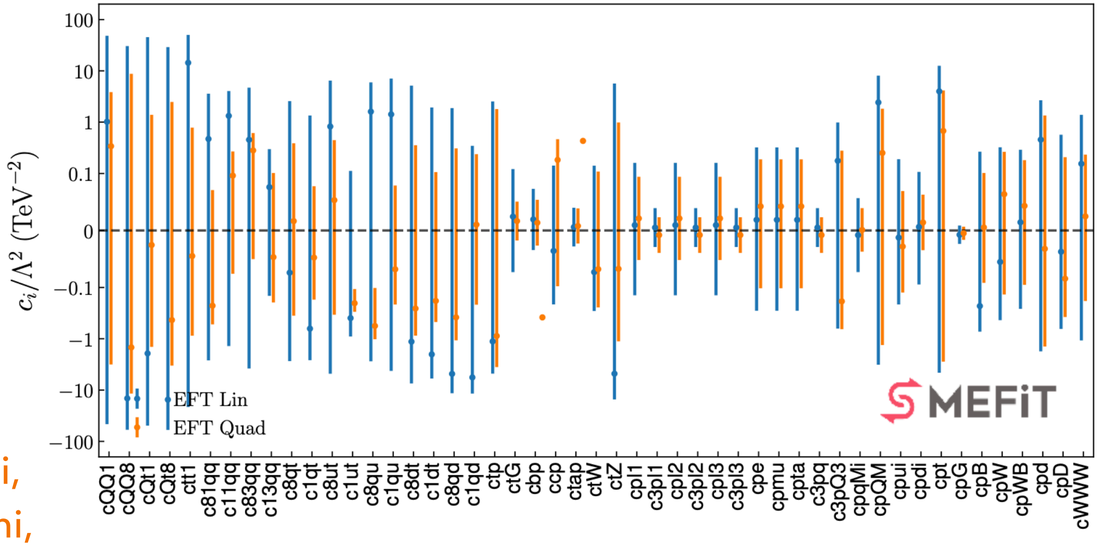
- In principle low-scale physics is separable from high-scale physics, BUT the complexity of LHC environment might well intertwine them.



Ball et al, arXiv:2109.02653

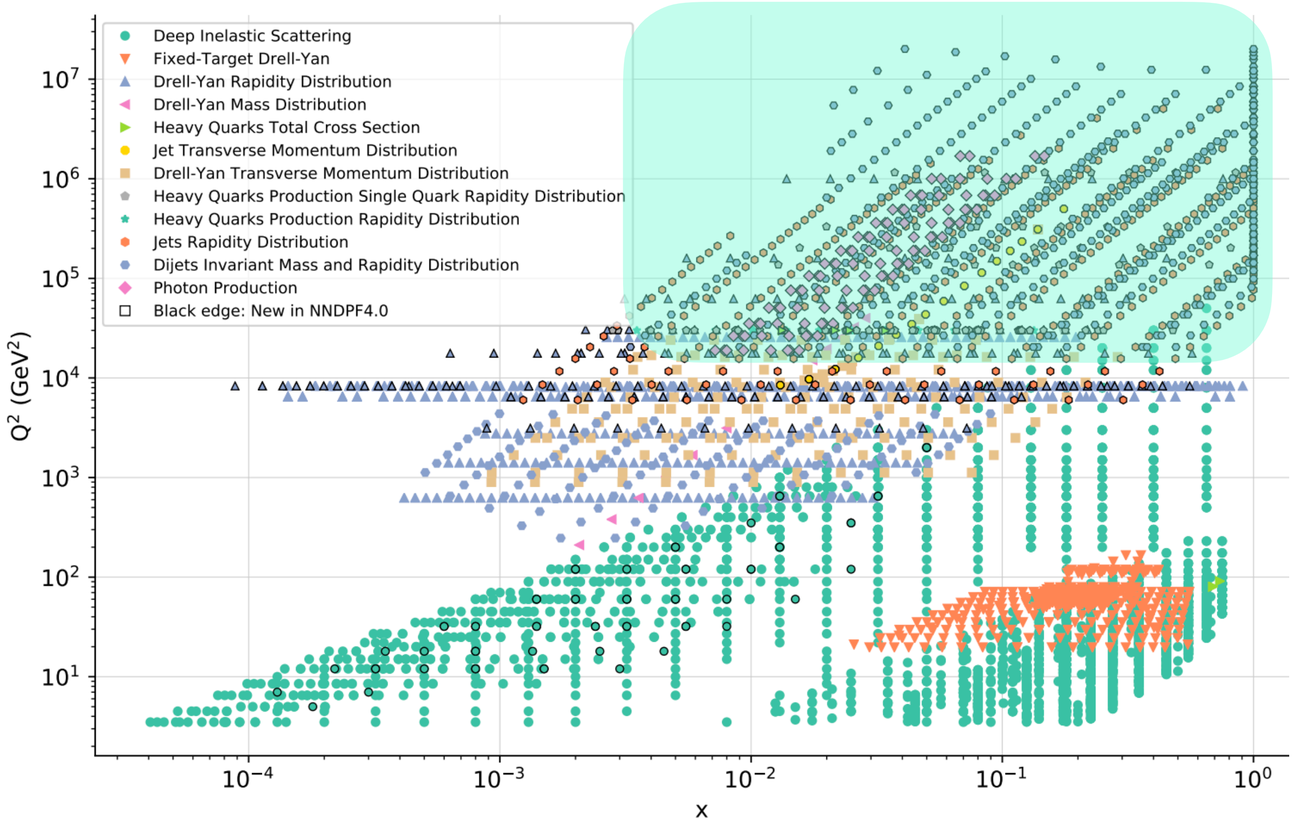
PBSP

MU (PI) + E. Cole, M. Costantini, N. Elmer, E. Hammou, L. Mantani, F. Merlotti, J. Moore, M. Morales Alvarado, V. Schütze-Sanchez



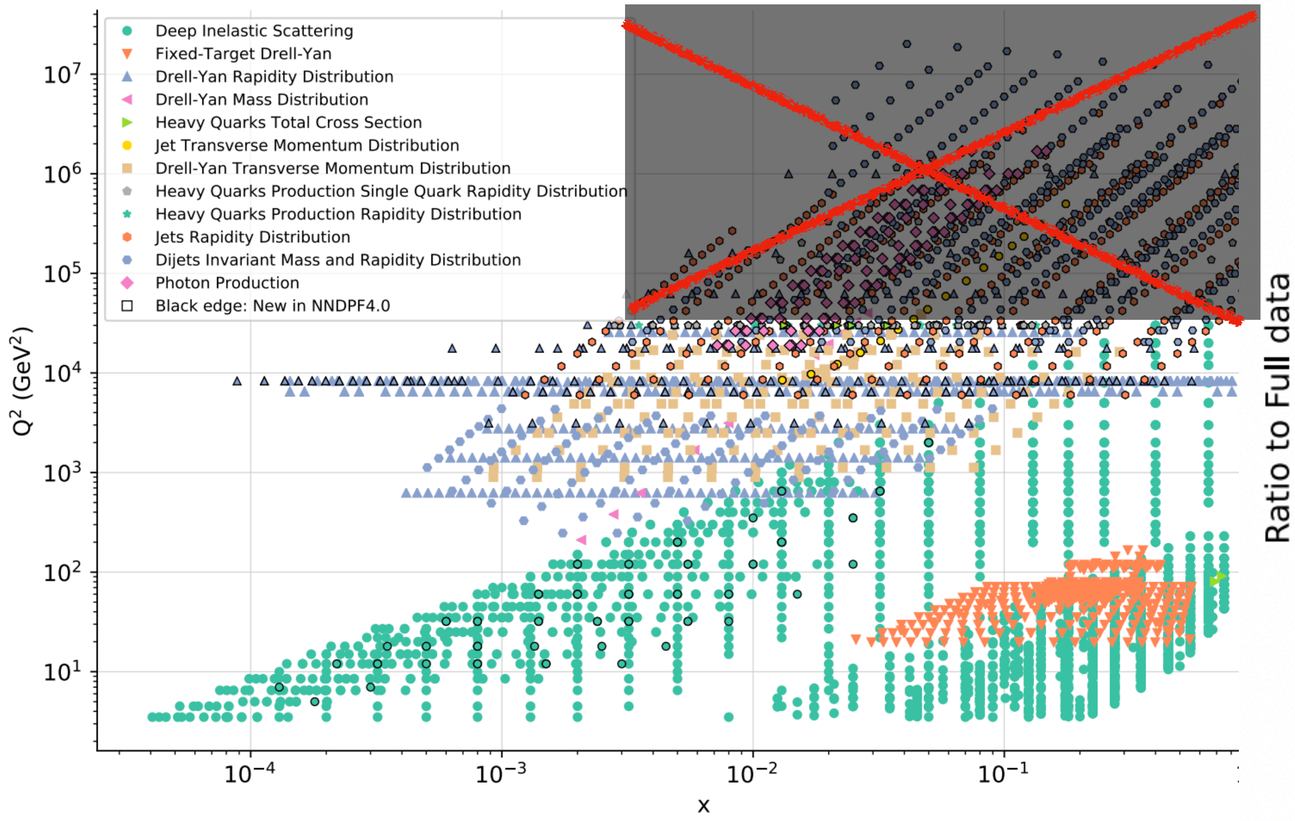
Ethier et al, arXiv: 2105.00006

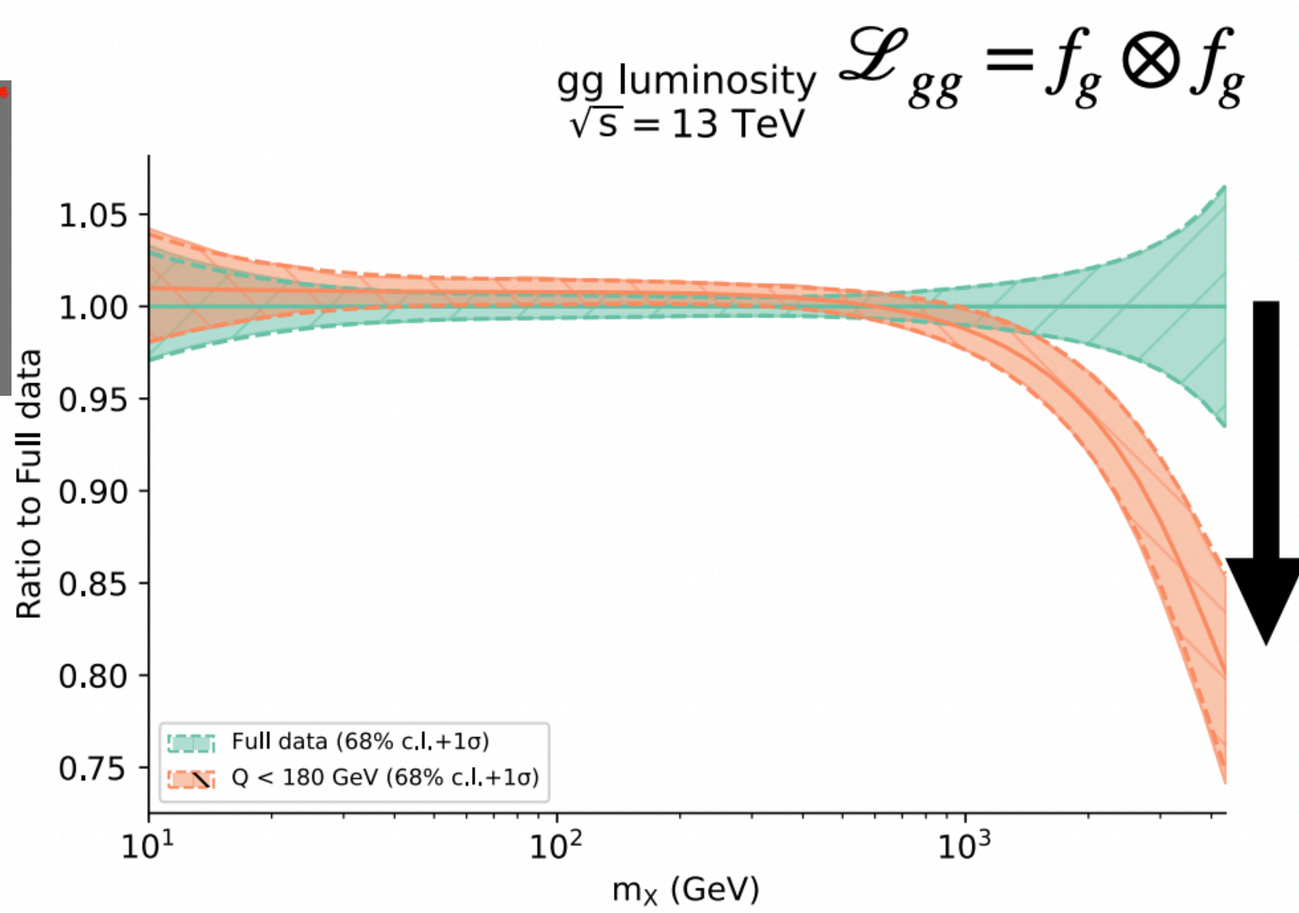
DATA OVERLAP



- Top pair production and single top data included in SMEFT analysis [Hartland et al 1901.05965] [Ellis et al 2012.02779]
- Drell-Yan high mass data [Farina et al 1609.08157, Torre et al 2008.12978]
- Inclusive Jets data [Alte et al 1711.07484]
- Dijets data [Krauss et al 1611.00767] [Alioli et al 1706.03068] [Bordone et al 2103.10332]
- Overlap enhanced in HL-LHC projections [Abdul Khalek et al1810.03639]

DATA OVERLAP



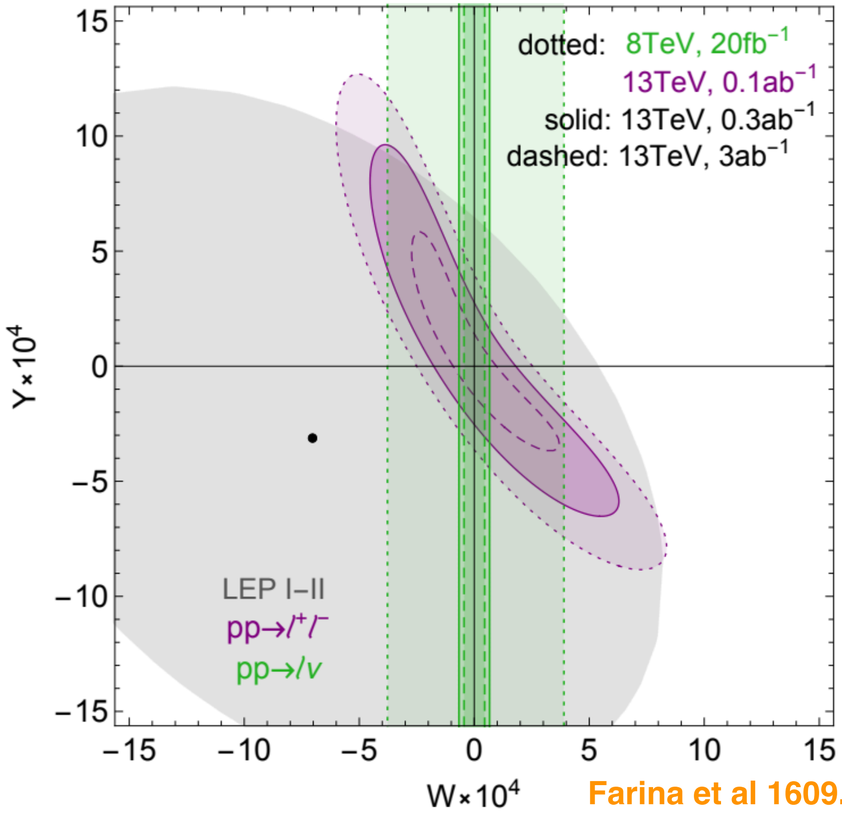


- Conservative solution: remove all data above $Q > Q_{high}$ for example $Q_{high} \gtrsim m_{top}$
- However away all high energy data would result in dramatic uncertainty increase and loss of precision. Knowledge of PDFs at large x would rely on rather old DIS data and on ability to define uncertainties in the extrapolation region.
- Thorough study in Cole et al arXiv: 2602.20235

CAN PDFS ABSORB NEW PHYSICS?

- Generate synthetic data in PDF fits assuming a given BSM model but fit PDFs assuming SM theory prediction.
- Can PDFs absorb signs of new physics? In some model **YES!**

$$\sigma_{obs} = \hat{\sigma}_{BSM} \otimes \mathscr{L}_{SM} \approx \hat{\sigma}_{SM} \otimes \mathscr{L}_{BSM-biased}$$



Farina et al 1609.08157

Consider simple SM extension with new heavy vectors that mix with SM - universal models (Z′, W′, G′).
Effect parametrise by 4-fermion operators and grows with energy in the tails of the Drell-Yan and Top distributions

	universal form factor ($\mathcal{L}$)	contact operator ($\mathcal{L}'$)
W	$-\frac{\mathrm{W}}{4m_W^2}(D_\rho W^a_{\mu\nu})^2$	$-\frac{g_2^2 \mathrm{W}}{2m_W^2} J_L{}^a_\mu J_L{}^\mu_a$
Y	$-\frac{\mathrm{Y}}{4m_W^2}(\partial_\rho B_{\mu\nu})^2$	$-\frac{g_1^2 \mathrm{Y}}{2m_W^2} J_{Y\,\mu} J_Y{}^\mu$
Z	$-\frac{Z}{4m_W^2}(\partial_\mu G^A_{\mu\nu})^2$	$-\frac{g_s^2 Z}{2m_W^2} J_{\mathcal{G}\,\mu} J_{\mathcal{G}}{}^\mu$

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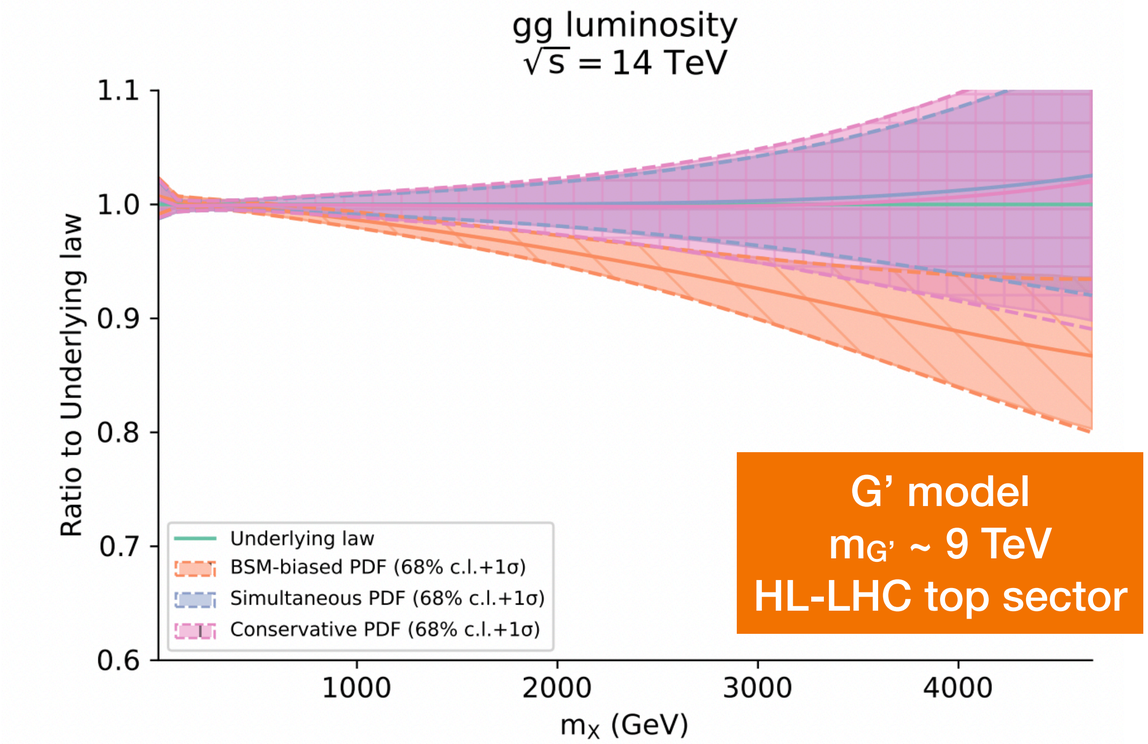
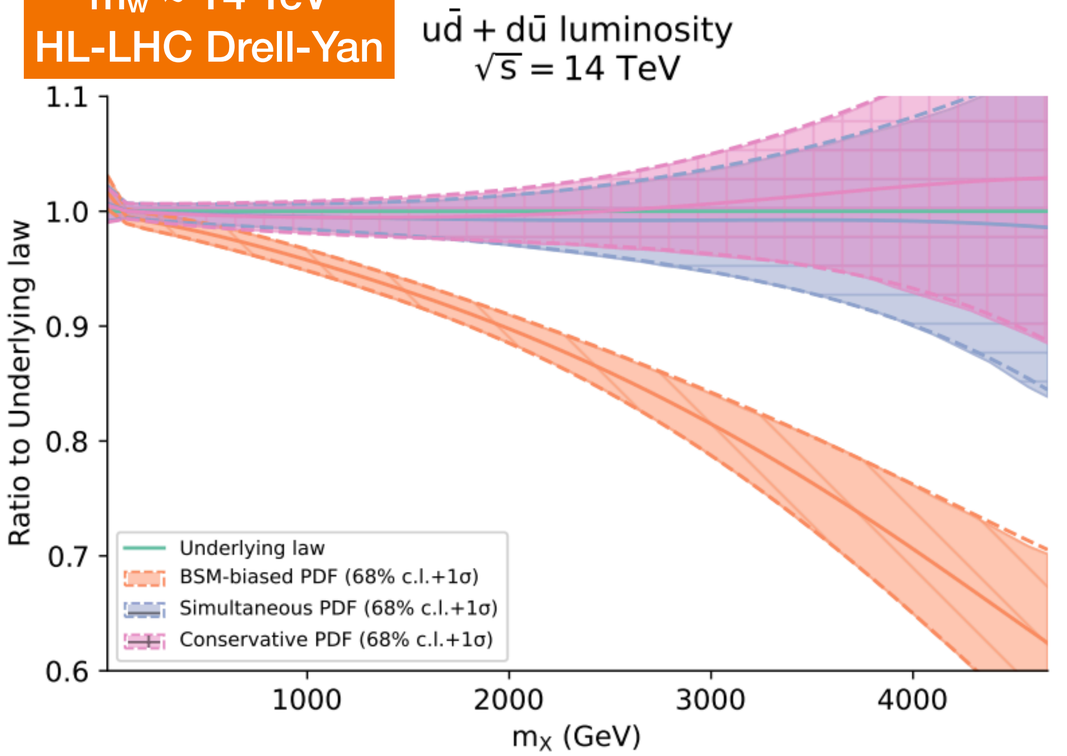
- Serious consequences if BSM-induced bias on PDFs undetected: missing indirect signs of BSM or see spurious deviations

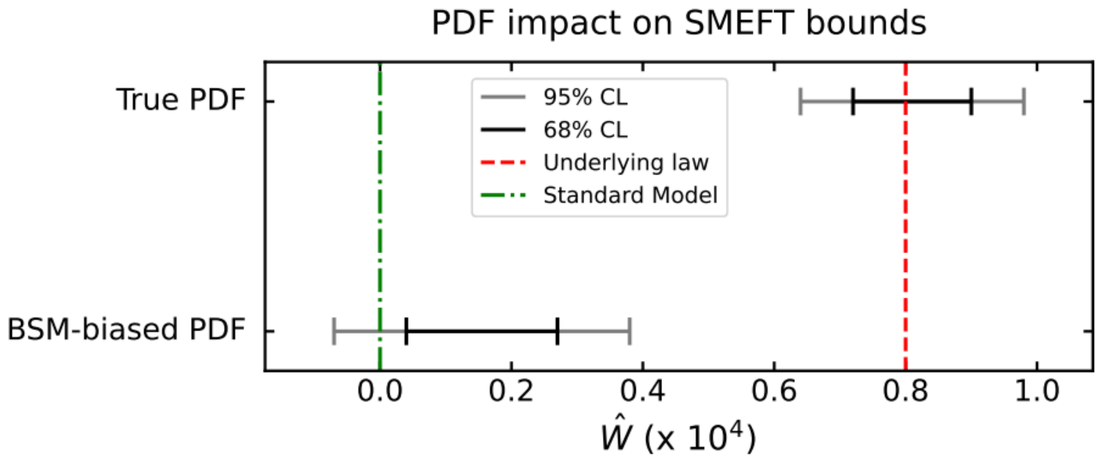


G' model
$m_{G'}$ ~ 9 TeV
HL-LHC top sector

W' model
m_W ~ 14 TeV
HL-LHC Drell-Yan



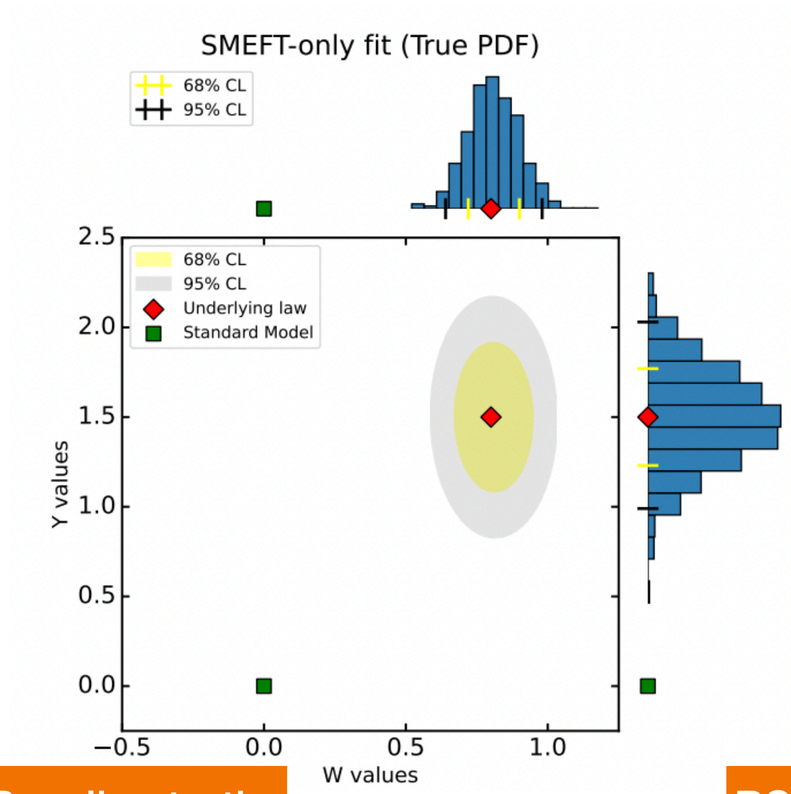
Cole et al 2602.20235



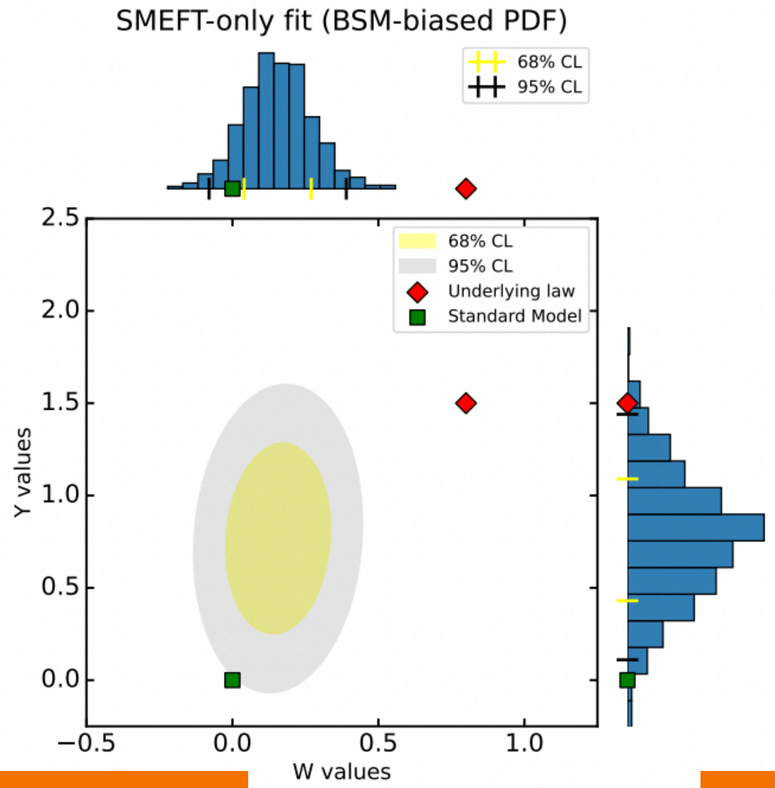
HOW TO ACCOUNT FOR BSM/PDF INTERPLAY

- Important to tackle the issue:
  - ➡ Explore conservative fits that exclude high energy data
  - ➡ Complementary large-x constraints (EIC, FPF, lattice)
  - ➡ Simultaneous SMEFT&PDF fits [next part!]
  - ➡ Broaden understanding of interplay to more realistic BSM models
  - ➡ Explore more sectors besides Drell-Yan and top (jets, di-jets, flavor..)

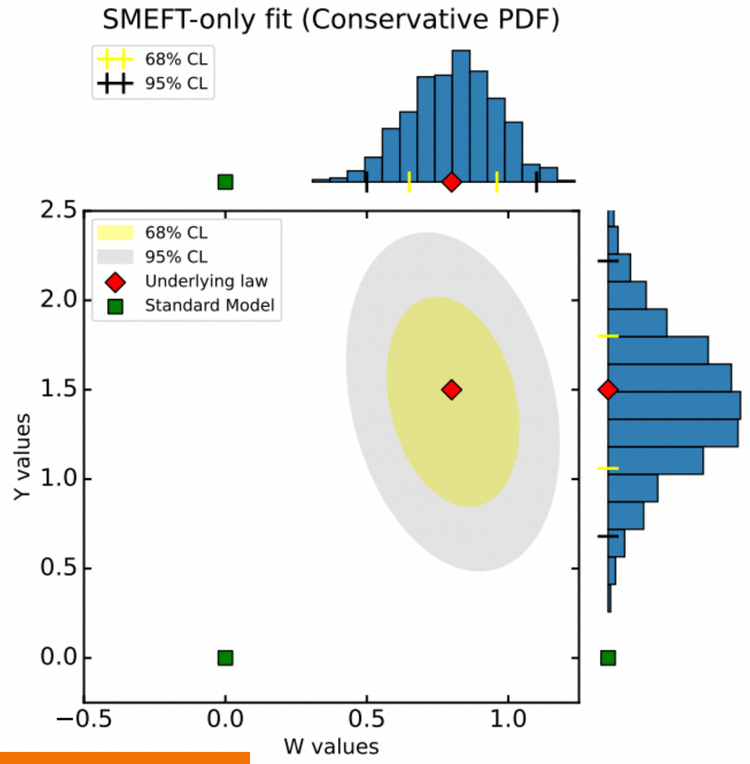
Cole et al 2602.20235
Hammou et al 2307.10370, 2410.00963
Costantini et al 2402.03308
Kassabov et al 2303.06159
Iranipour et al 2201.07240
Greljo et al 2104.02723
Carrazza et al 1905.05215...



Baseline truth



BSM-biased PDFs



Conservative PDFs

Cole et al 2602.20235

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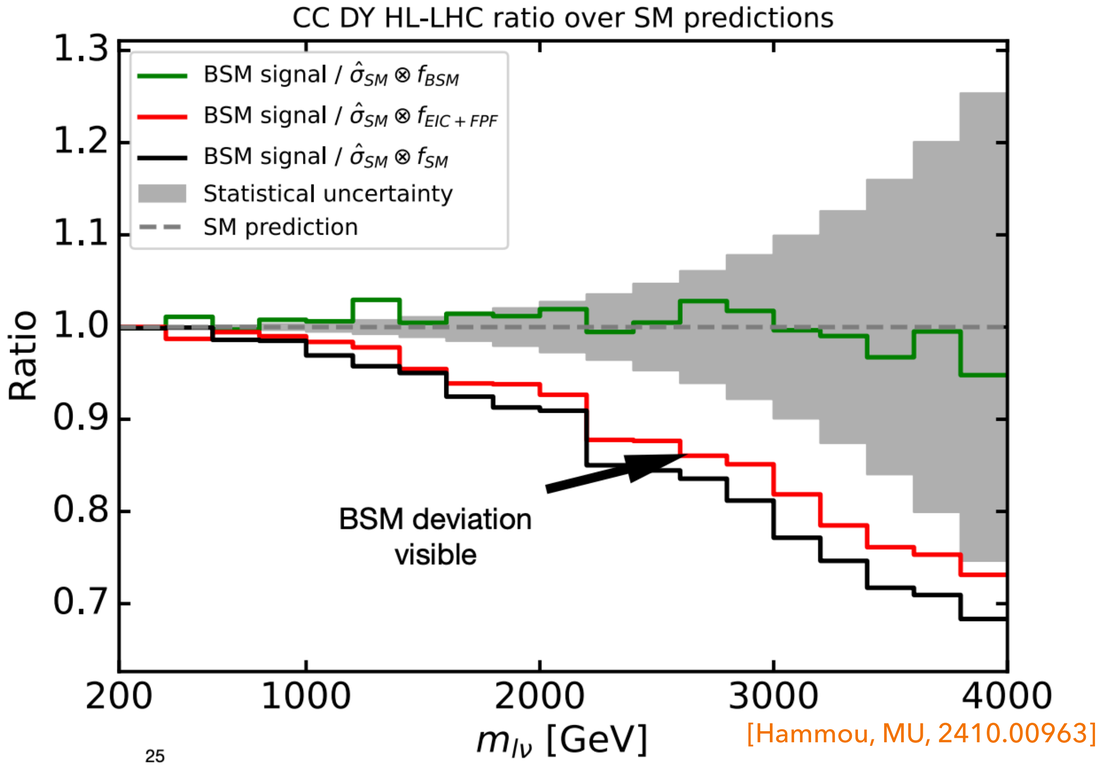
Cole et al 2602.20235
Hammou et al 2307.10370, 2410.00963
Costantini et al 2402.03308
Kassabov et al 2303.06159
Iranipour et al 2201.07240
Greljo et al 2104.02723
Carrazza et al 1905.05215...

Inclusion of Forward Physics Facilities and EIC data (FASERv, FASERv2, advSNDv) along with HL-LHC (DY NC and DY CC) data would disentangle the BSM/PDFs interplay.

$$\hat{\sigma}_{BSM} \otimes \mathscr{L}_{SM} \approx \hat{\sigma}_{SM} \otimes \mathscr{L}_{BSM}$$

$$\hat{\sigma}_{BSM} \otimes \mathscr{L}_{SM} \neq \hat{\sigma}_{SM} \otimes \mathscr{L}_{EIC+FPF}$$

$M_{W'}$: 13.8 TeV



[Hammou, MU, 2410.00963]

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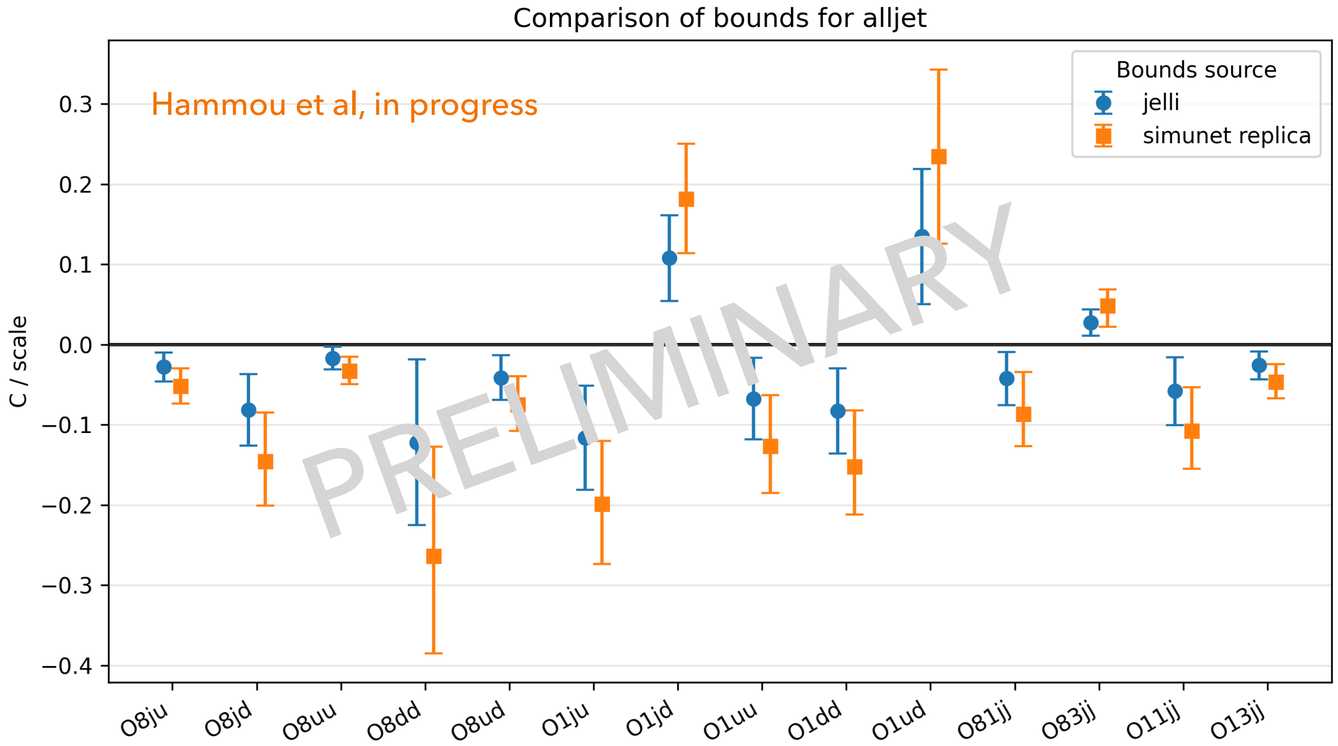
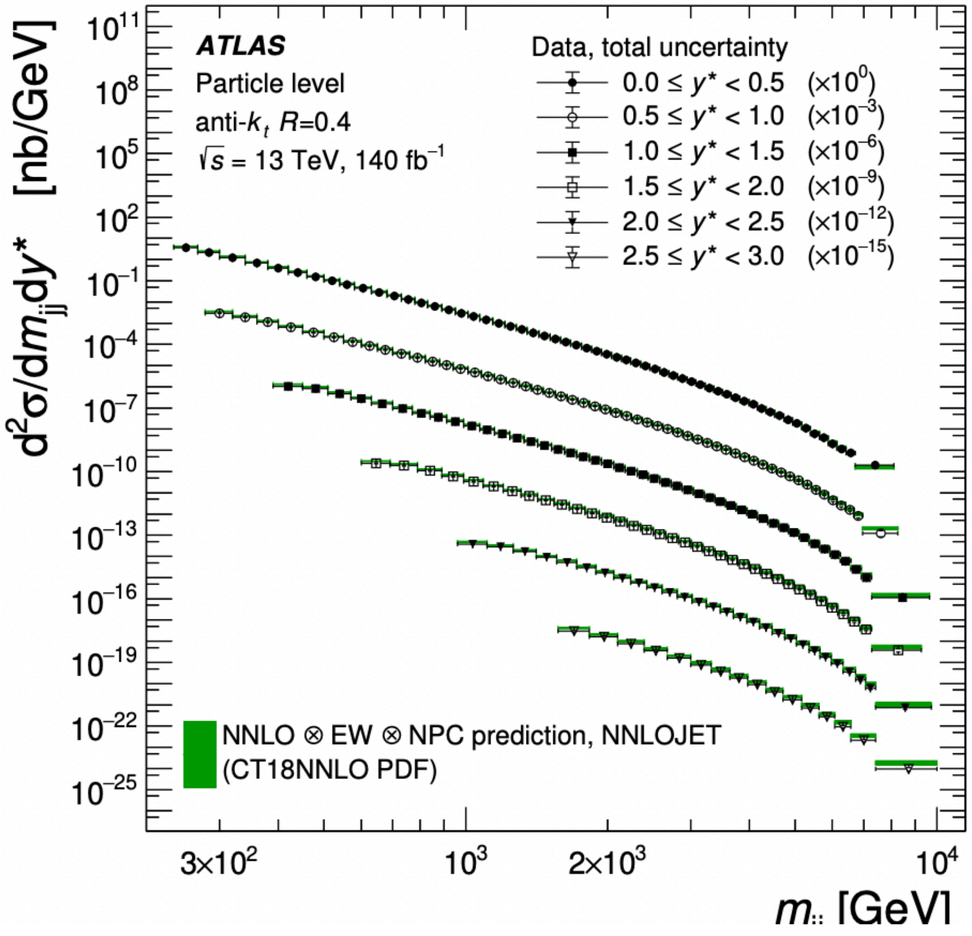




ATLAS, arXiv:2512.19073

A GLOBAL INTERPRETATION OF THE LHC DATA

PRECISION PHYSICS

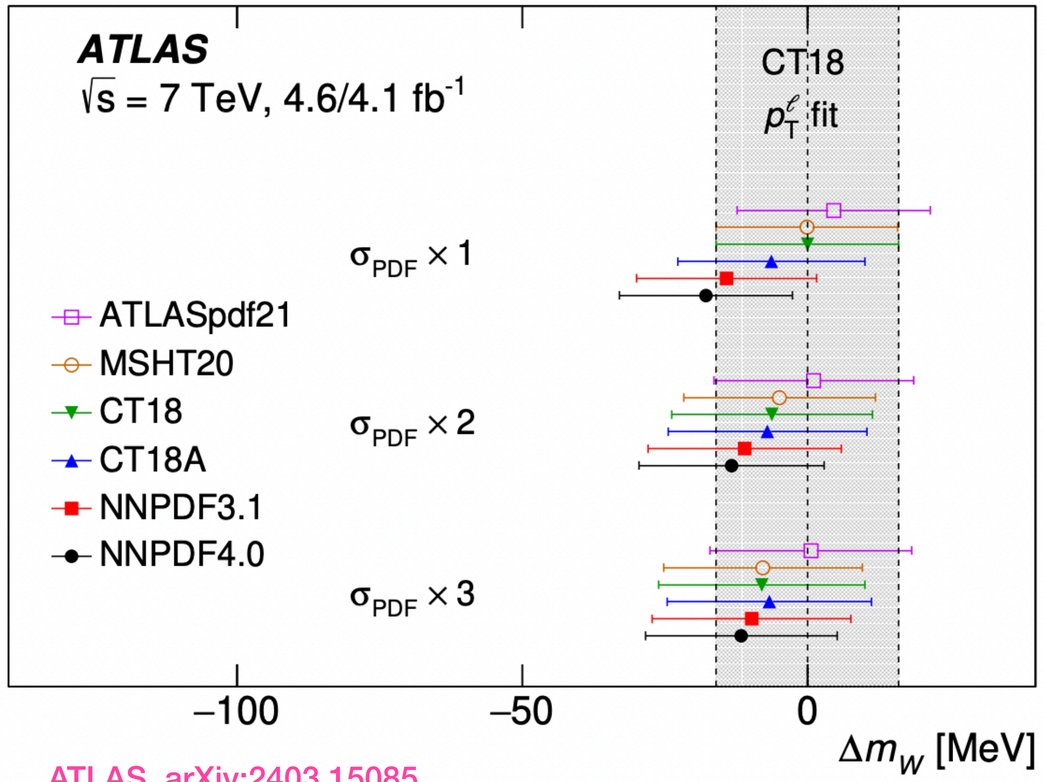
Part III

GLOBAL INTERPRETATION OF DATA

Part III

NEW PHYSICS SIGNATURES

GLOBAL INTERPRETATION OF LHC DATA



ATLAS, arXiv:2403.15085

Extremely precise LHC data & advances in theoretical predictions and statistical techniques allow to extract SM (and BSM) parameters to a great level of precision but strong dependence on PDF choice is observed, in some cases larger than nominal uncertainty!

- $\alpha_s(M_z)$
- M_w
- SMEFT Wilson coefficients
- …

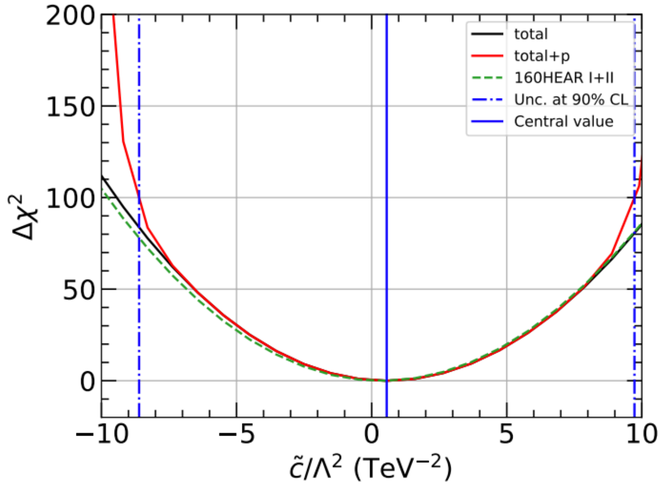
While huge progress made in determining each of these key ingredients of theoretical predictions from the data, not yet evident how to combine all these partial fits into a global interpretation of the LHC data. Simultaneous fits are pivotal step in this direction.

SIMULTANEOUS FITS OF PDFS AND SM/BSM PARAMETERS

- Simultaneous fits of PDFs and SM/BSM parameters pursued by several groups and experimental collaborations.
- Capture the correlation between PDFs of the proton and parameters that are otherwise neglected.
- Effort towards a new generation of global simultaneous fits

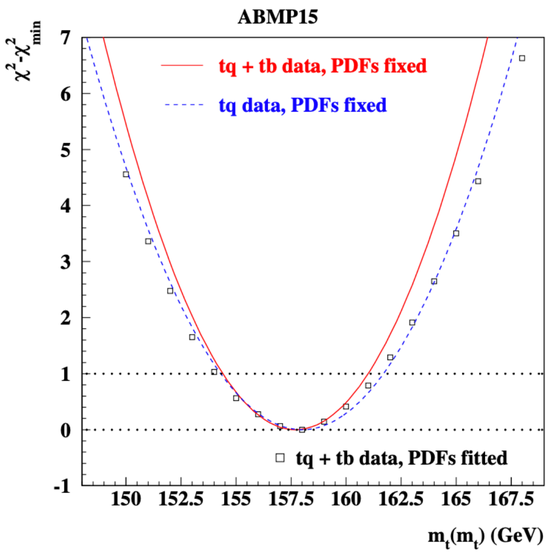
$$T_i(\{\theta\},\{c\}) = \mathrm{PDFs}(\{\theta\},\{c\}) \otimes \hat{\sigma}_i(\{c\})$$

c = c_{oq3l}



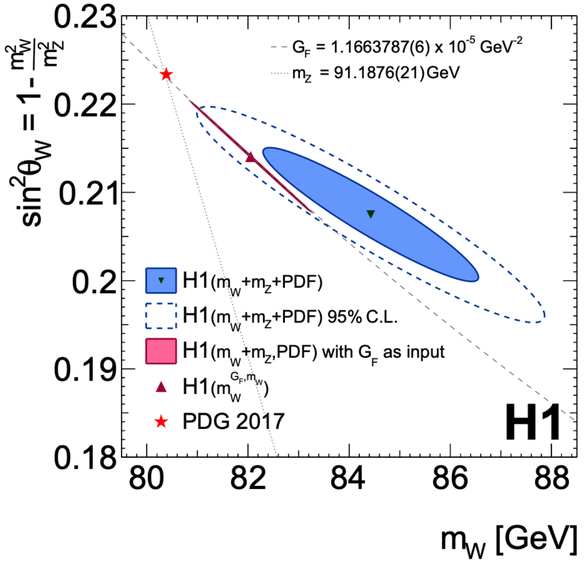
Liu, Sun, Gao, 2201.06586

c = m_{top}



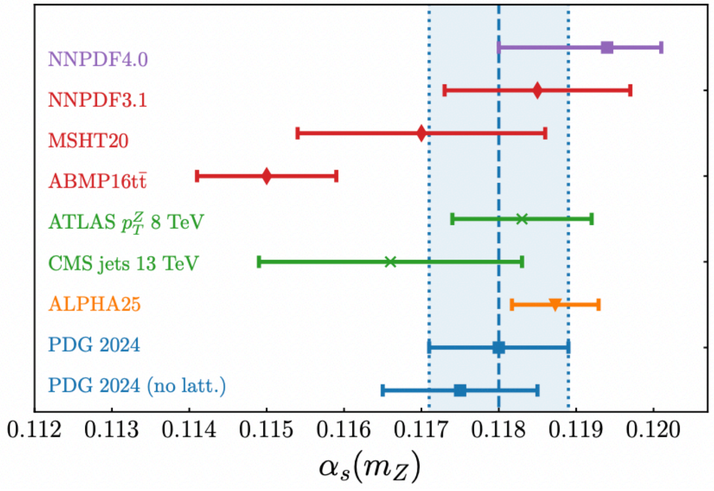
Alekhin, Moch, Their 1608.05212

c = {m_W, m_Z}



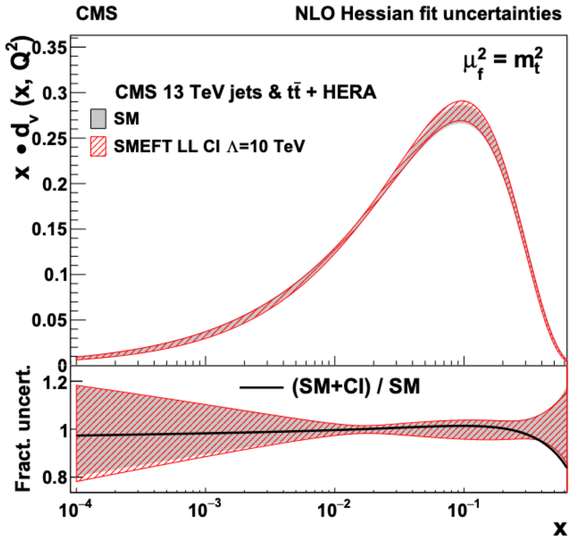
H1 collaboration 1806.01176

c = α_s



Ball et al, 2506.13871

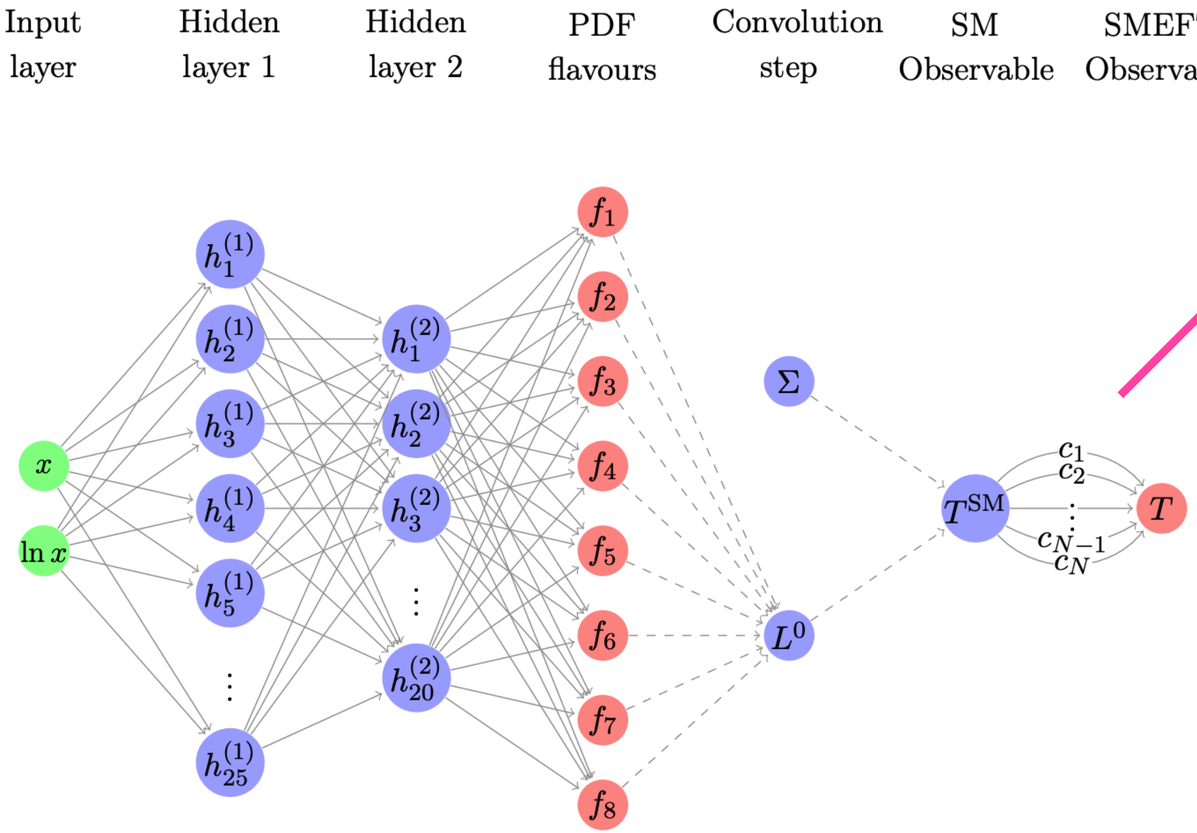
c = c_{tg}



CMS collaboration, 2111.10431

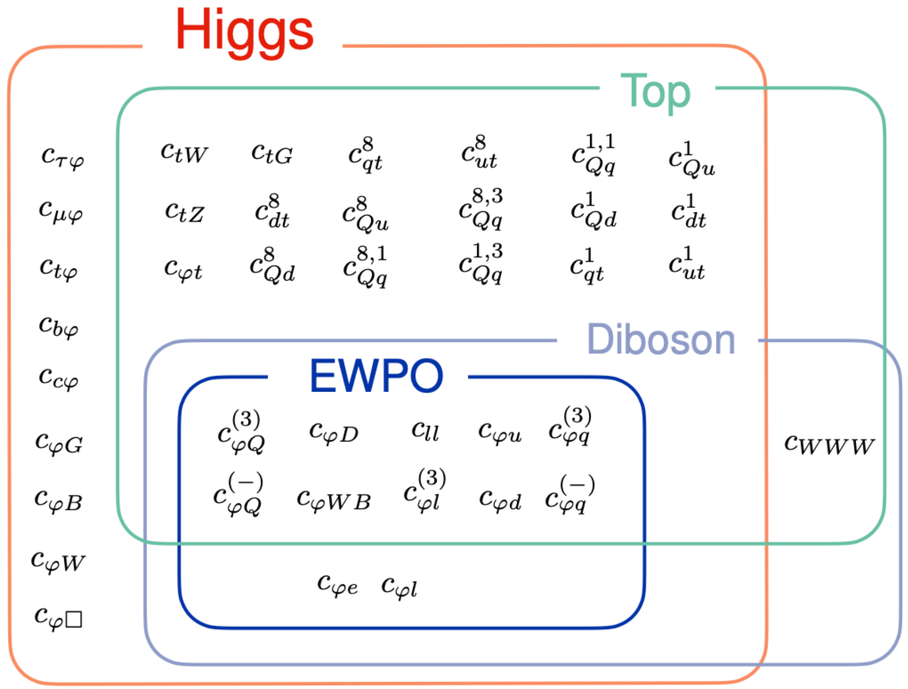
SIMUNET: A NN-BASED TOOL FOR SIMULTANEOUS FITS OF SMEFT AND PDFS

- How to efficiently perform simultaneous fits of PDFs and SM/BSM parameters?
- SIMUnet yields simultaneous fit of PDFs and SMEFT coefficients, and can check effect of BSM injection it does not have limit in number of parameters that can be fitted alongside PDFs
- Extendable to SM parameters!



$$T(\hat{\theta}) = \Sigma(\{c_n\}) \cdot L^0(\theta) = T^{\rm SM}(\theta) \cdot \left(1 + \sum_{n=1}^{N} c_n R^{(n)}_{\rm SMEFT}\right)$$

Linear dim-6 operator



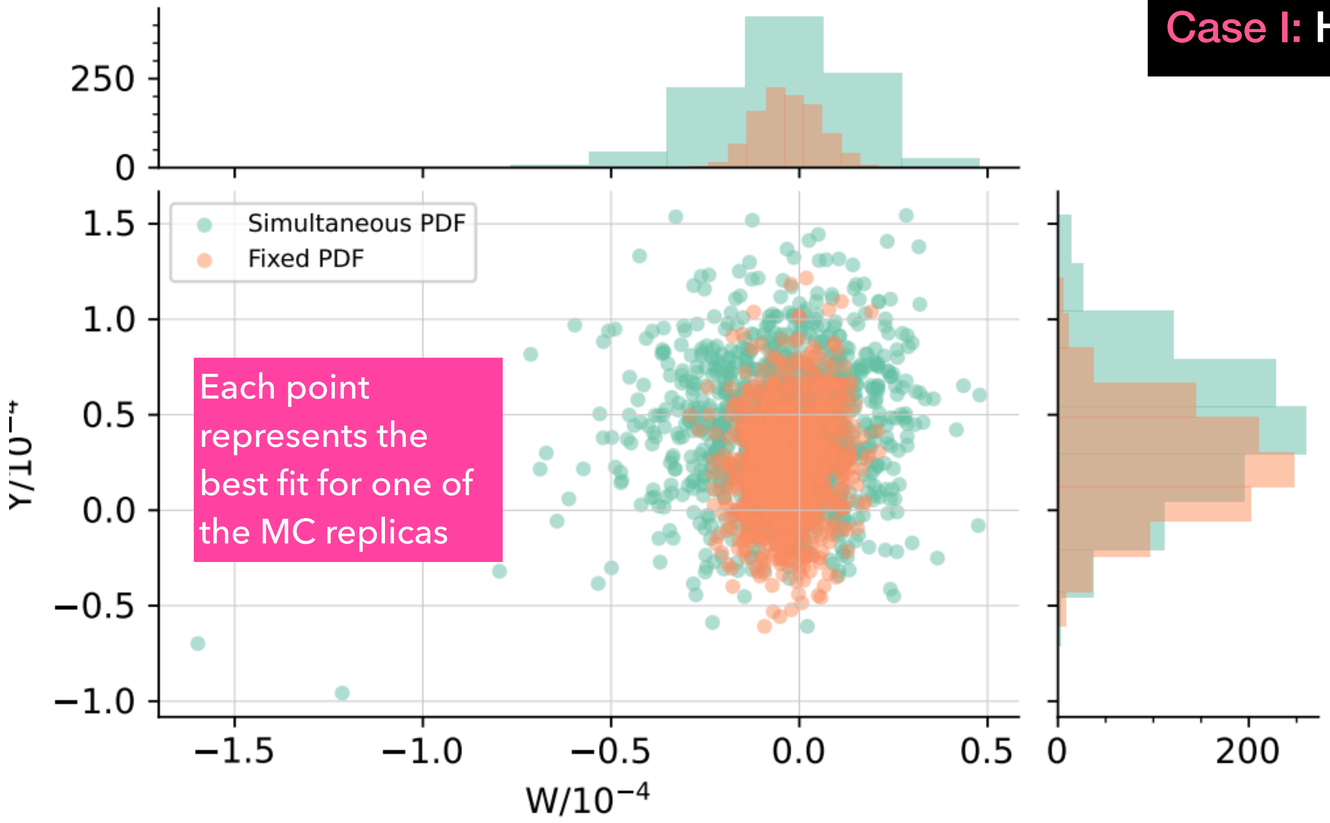
S. Iranipour, MU (arXiv: 2201.07240)
M. Costantini, E Hammou, M. Madigan, L. Mantani, J. Moore, M. Morales, MU (arXiv: 2402.03308)

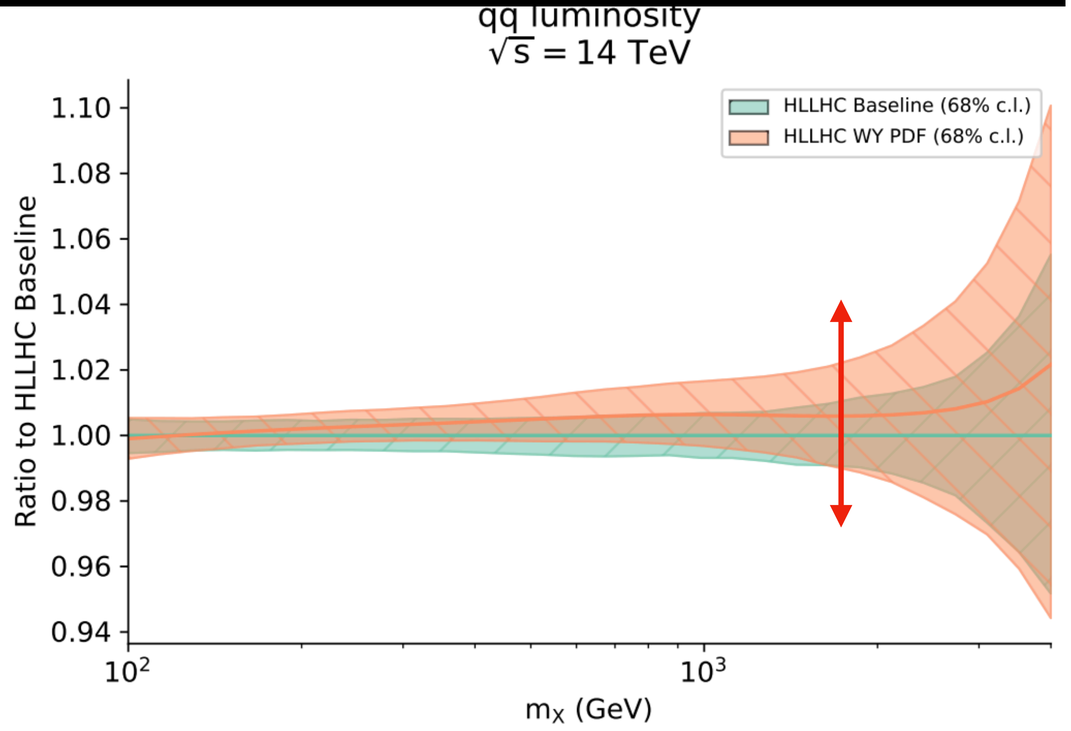
https://github.com/HEP-PBSP/SIMUnet

SIMUNET: APPLICATION TO DRELL-YAN SECTOR

S. Iranipour, MU - arXiv: 2201.07240

Case I: HL-LHC MC data generated assuming law of Nature = SM





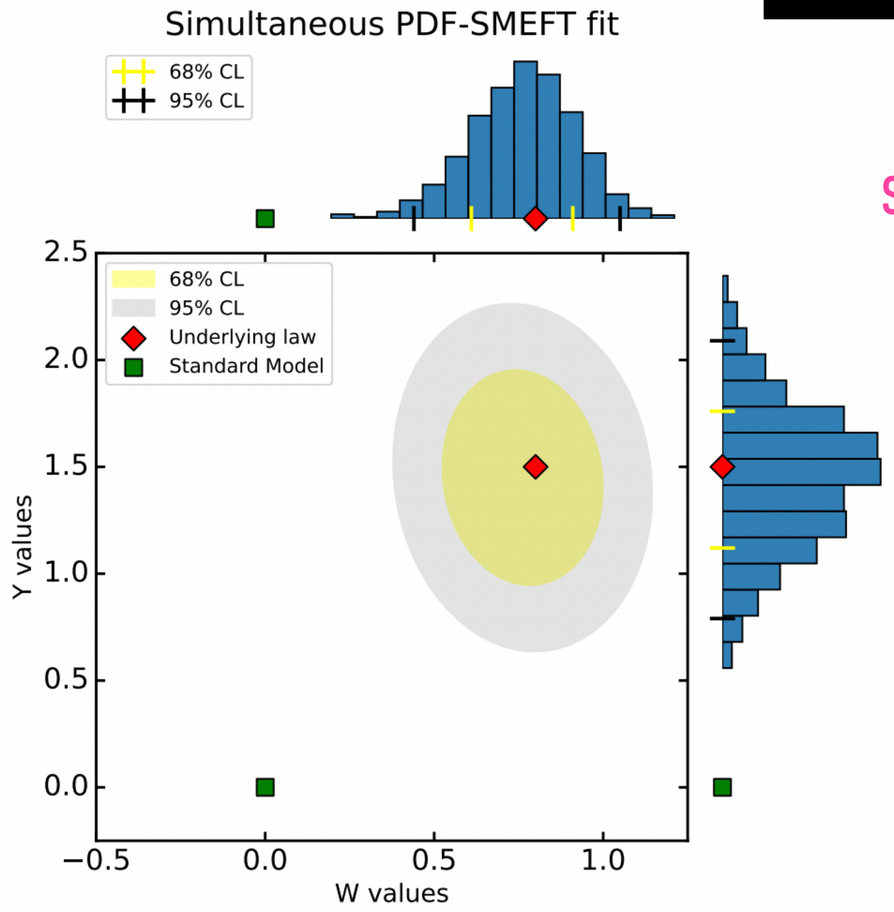
✓ Simultaneous analysis of PDFs and **Drell-Yan sector** Wilson coefficient in the context of universal parameters of DIS + DY (including HL-LHC projections) using simuNET method shows if HL-LHC projections were generated by using a SM model, then WCs bounds broaden and PDF uncertainties change significantly once SMEFT effects allowed in theory predictions entering PDF fit

[Greljo et al 2104.02723] [Iranipour, MU 2201.07240]

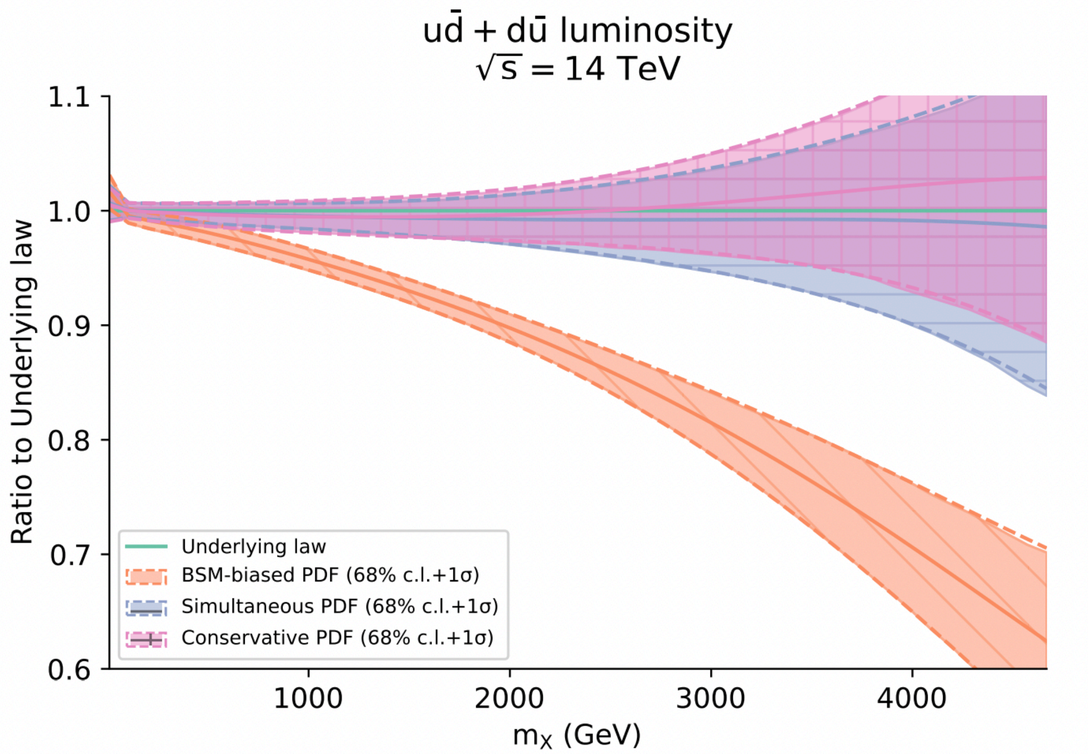
SIMUNET: APPLICATION TO DRELL-YAN SECTOR

Case II: HL-LHC MC data generated assuming law of Nature = BSM model

SMEFT



PDFS

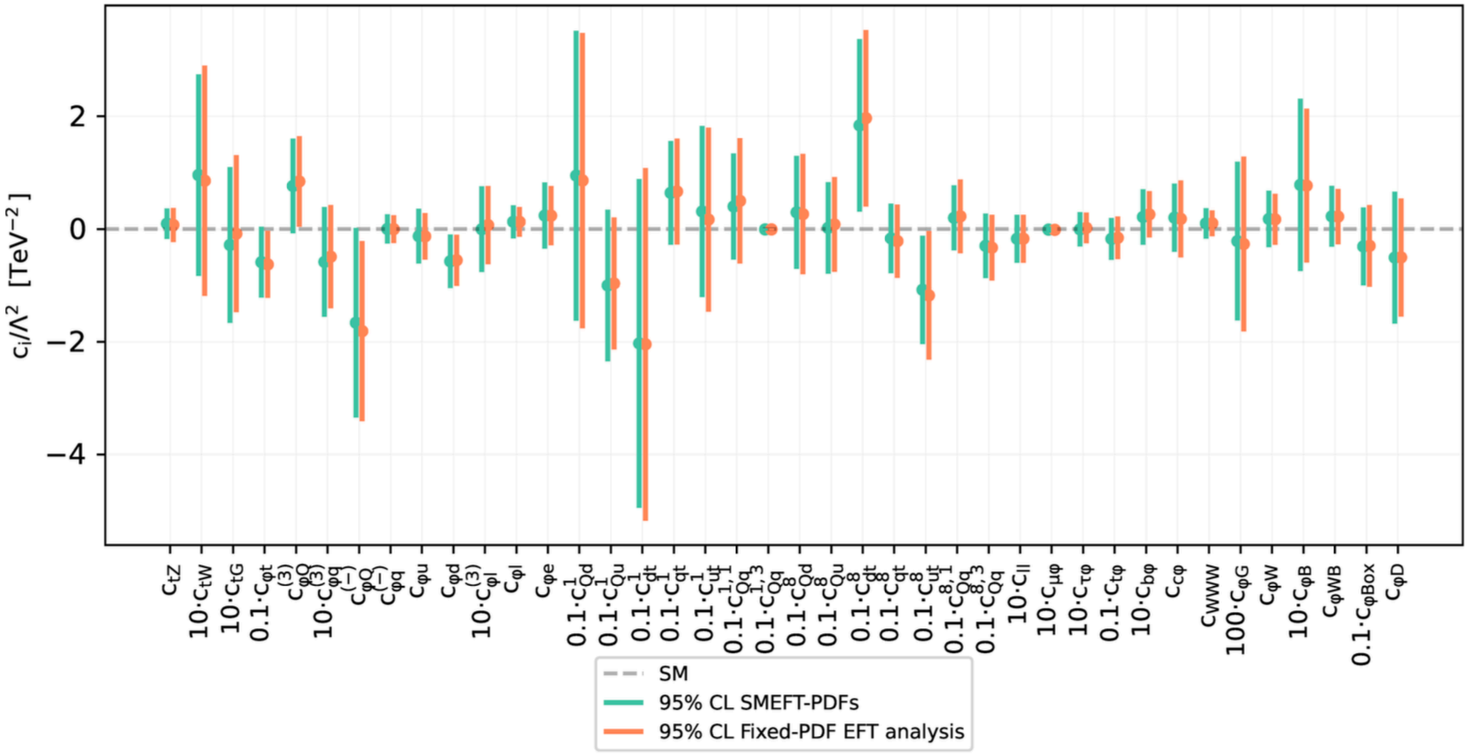


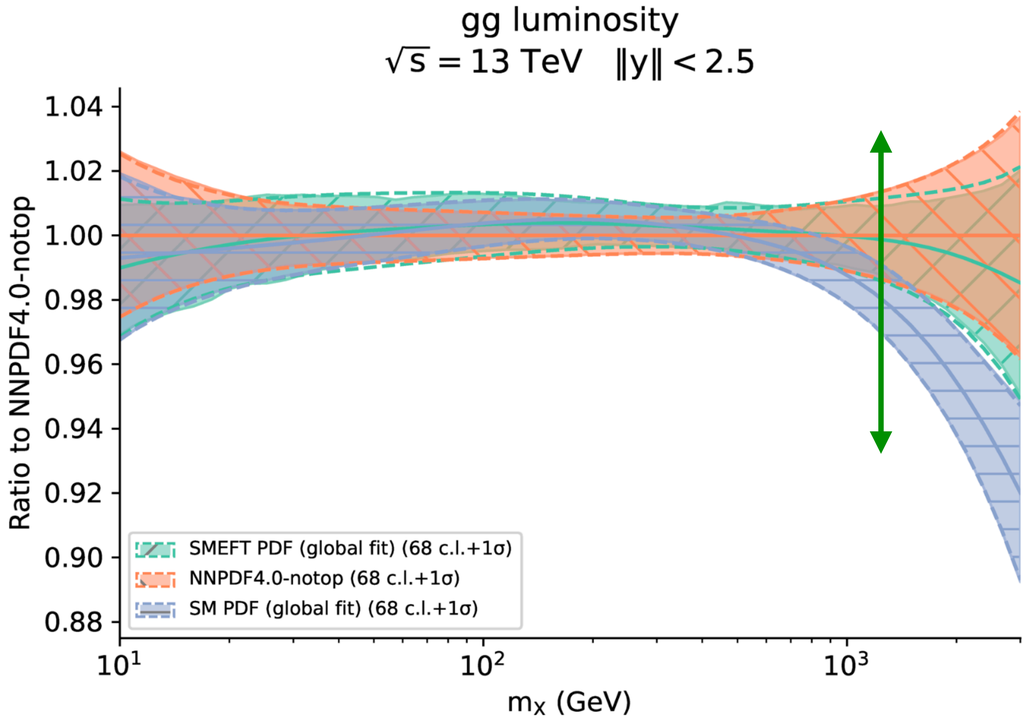
✓ Simultaneous analysis of PDFs and **Drell-Yan sector** Wilson coefficient in the context of universal parameters of DIS + DY (including HL-LHC projections) using simuNET method shows that if HL-LHC projections were generated by using a W' BSM model, the simultaneous fit would be able to find the "true" SM PDFs and the "true" SMEFT value!

[Cole et al 2602.20235]

SIMUNET: APPLICATION TO GLOBAL FIT

Kassabov et al, 2303.06159 + Costantini et al - arXiv: 2402.03308

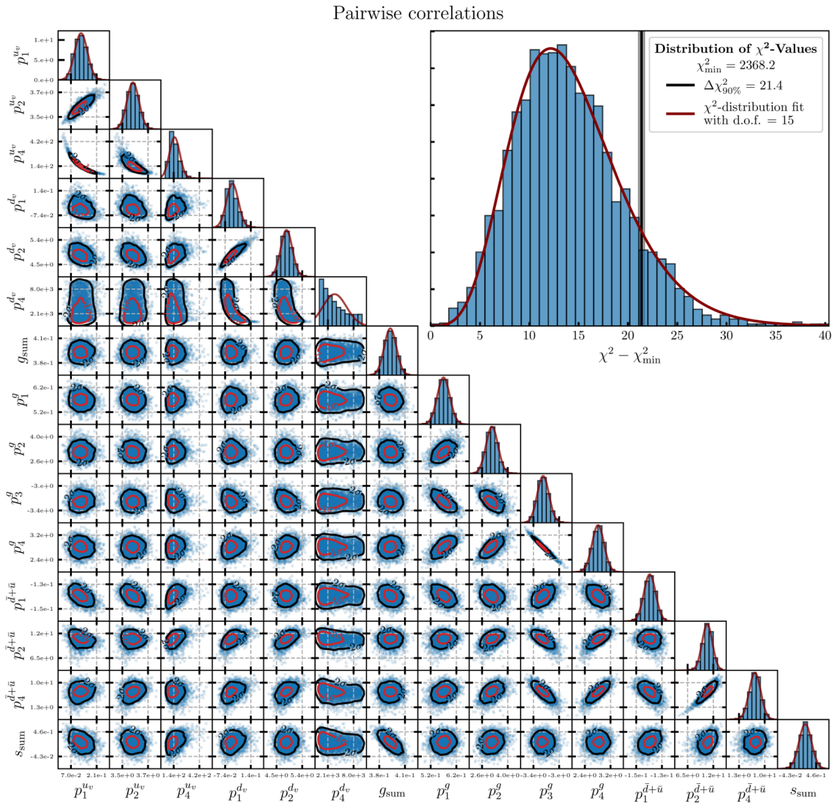




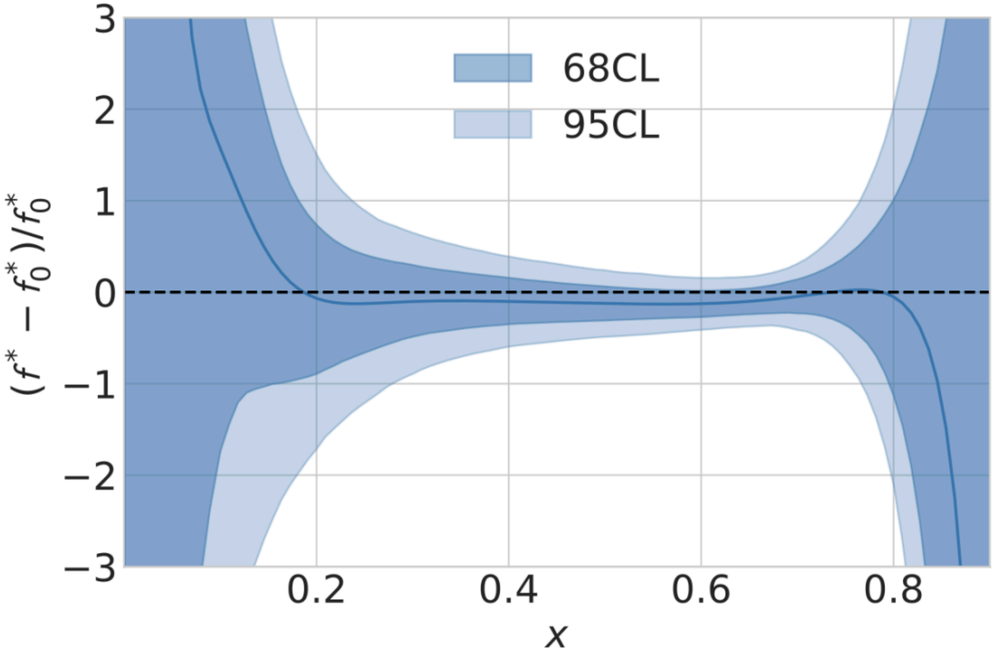
✓ Simultaneous analysis of PDFs and 40 operators in the **top+Higgs+EWPO+di-boson sector** using simuNET methodology shows that WCs are stable, while PDF uncertainties broaden and PDF fitted simultaneously alongside WCs sits nicely between PDF-only fit without top data and PDF fit including all data - sign of partial NP absorption

TOWARDS BAYESIAN PDF FITS

- Several proof-of-concepts and public tools for explicitly Bayesian PDF fits in the literature
  [Candido et al: 2404.07573, Risse et al: 2510.16158, Costantini et al 2507.16913, Costantini et al 2510.03391, Costantini et al 2404.10056, Capel et al 2401.17729…]
- Full development would allow to
  - ➡ Determine model(s) with largest evidence (balance between $\chi 2$ and complexity)
  - ➡ Have explicit control on prior choices.
  - ➡ Bayesian average models based on evidence



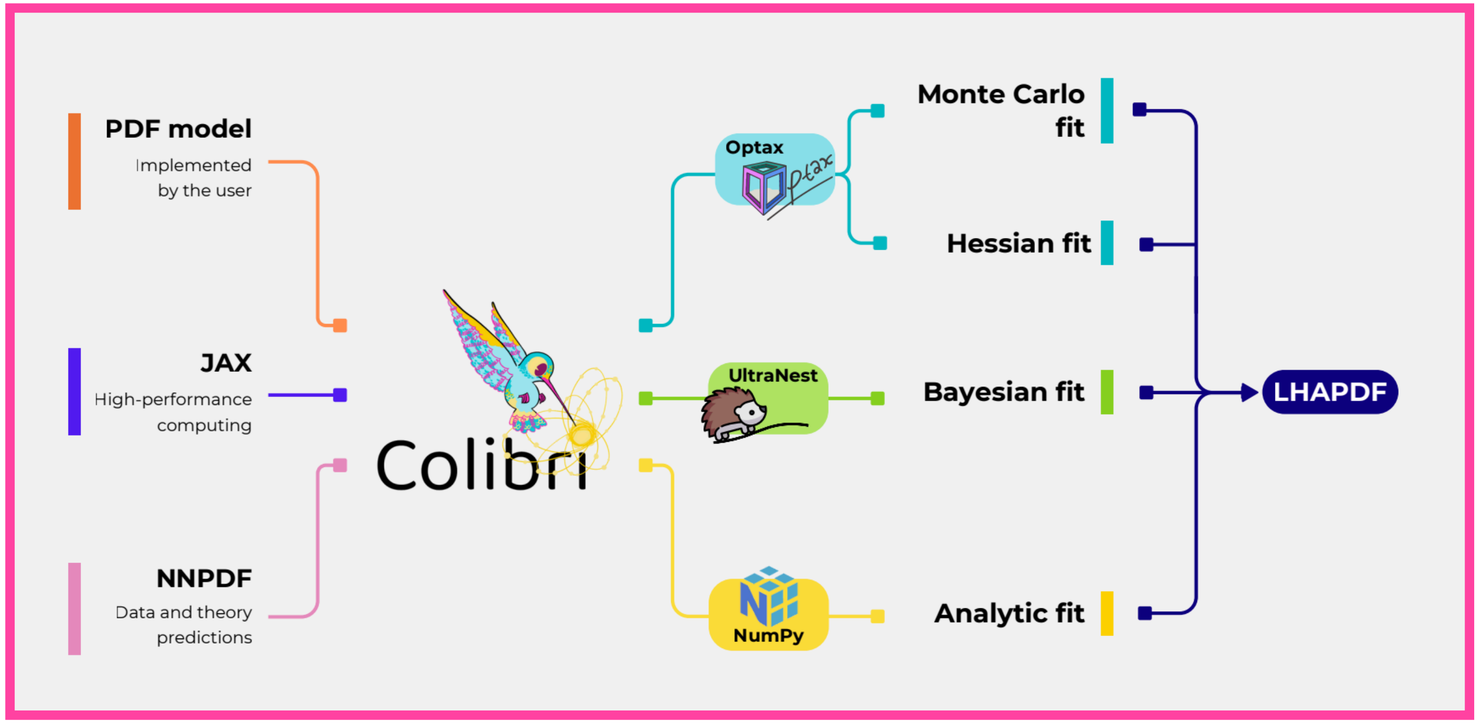
Risse et al: 2510.16158



Candido et al: 2404.07573

TOWARDS BAYESIAN PDF FITS

- Colibri: open-source Python code for users to implement PDF model, using the built-in functionalities for fast forward map computation and easy access to data [Costantini et al arXiv:2510.03391 [https://github.com/HEP-PBSP/colibri]
- Several error propagation methodologies built in (Hessian, Monte Carlo bootstrapping and Bayesian)
- Prior can be extended to SM / BSM parameters along with PDF parameters (simultaneous Bayesian fits)



M. Costantini, L. Mantani, J. Moore, V. Schütze Sanchez, MU, arXiv:2510.03391
M. Costantini et al, 2507.16913

CONCLUSIONS AND OUTLOOK

- In an era of unprecedented precision, need precise and accurate determination of proton subnuclear structure
- New exciting avenues being explored, such as interplay between new Physics and PDFs, hinting to complementarity of low-energy experiments/lattice to determine large-x PDFs (EIC, FFP)
- Simultaneous fits of SM/BSM parameters and control on priors crucial for interpretation of LHC data

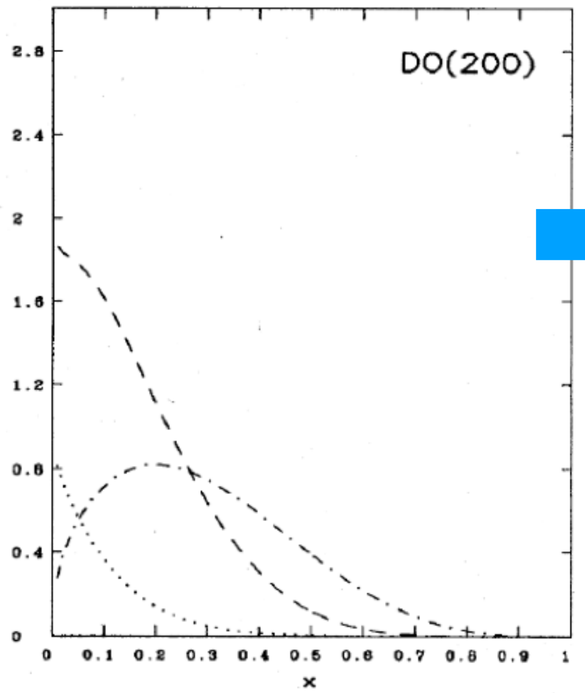


FIG. 27. "Soft-gluon" ($\Lambda = 200$ MeV) parton distributions of Duke and Owens (1984) at $Q^2 = 5$ GeV^2: valence quark distribution $x[u_v(x) + d_v(x)]$ (dotted-dashed line), $xG(x)$ (dashed line), and $q_v(x)$ (dotted line).

