Precision measurements via MuC neutrinos: PDFs, CKM, and more

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The most important slide

1. The high energy, collimated neutrino flux from muon decays at a MuC will enable highly precise forward target deep-inelastic scattering (DIS) measurements.

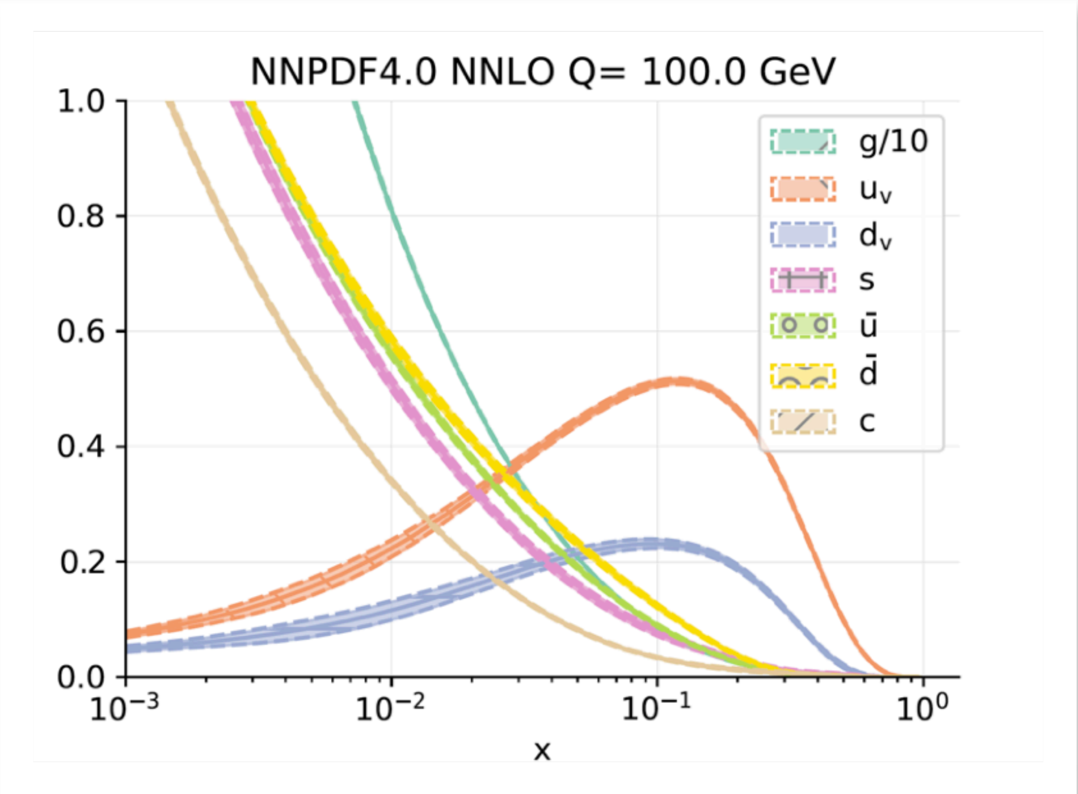
2. The setup will allow for exceptionally sensitive measurements of quantities like CKM matrix elements, parton distribution functions (PDFs), fragmentation functions (FFs), and others, greatly surpassing current standards.

3. The exploitation of correlations and shape information of different dynamical quantities is crucial for precision measurements.

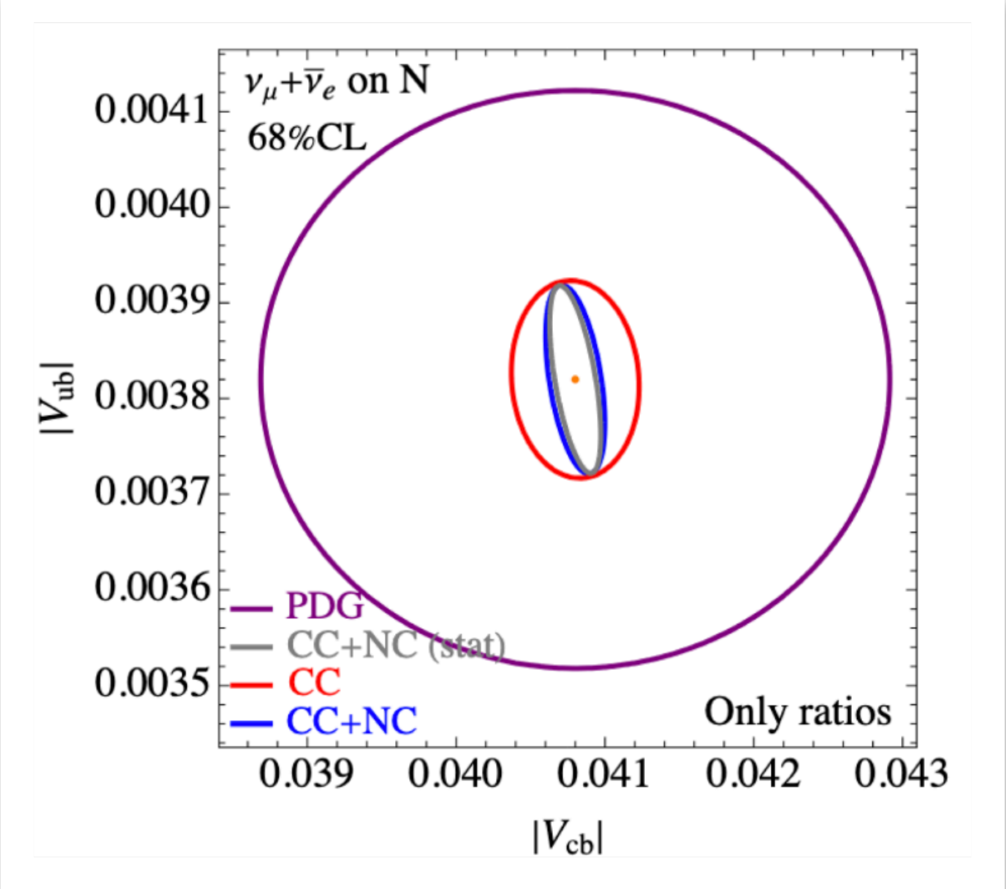
4. The precision reached will constitute a demanding test of SM physics and potential BSM signatures.

5. This analysis will benefit from parallel MuC studies: additional observables and constraints, experiment design, estimation of systematics, …

Outline



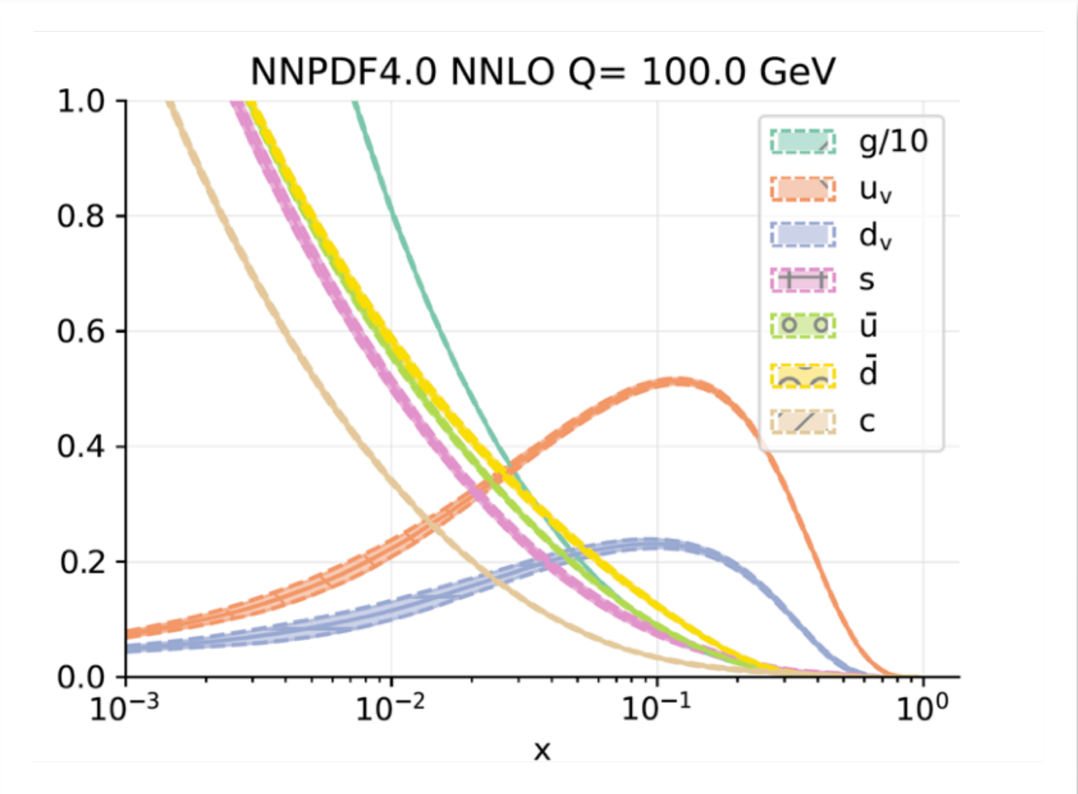
Background



CKM & PDFs from MuC neutrinos

Summary

Outline

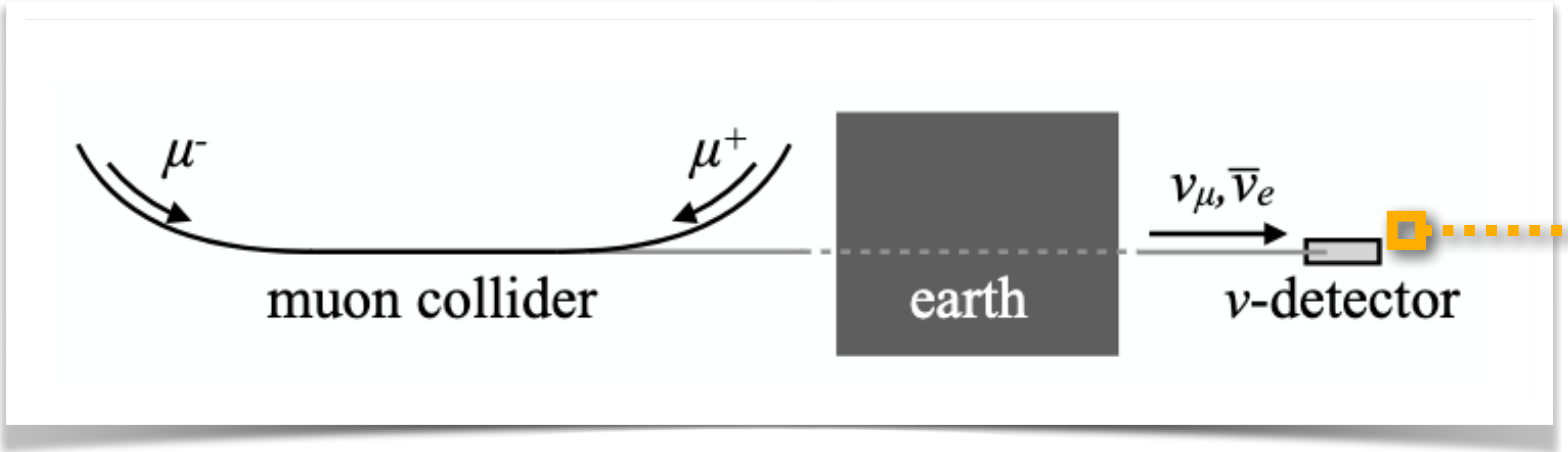


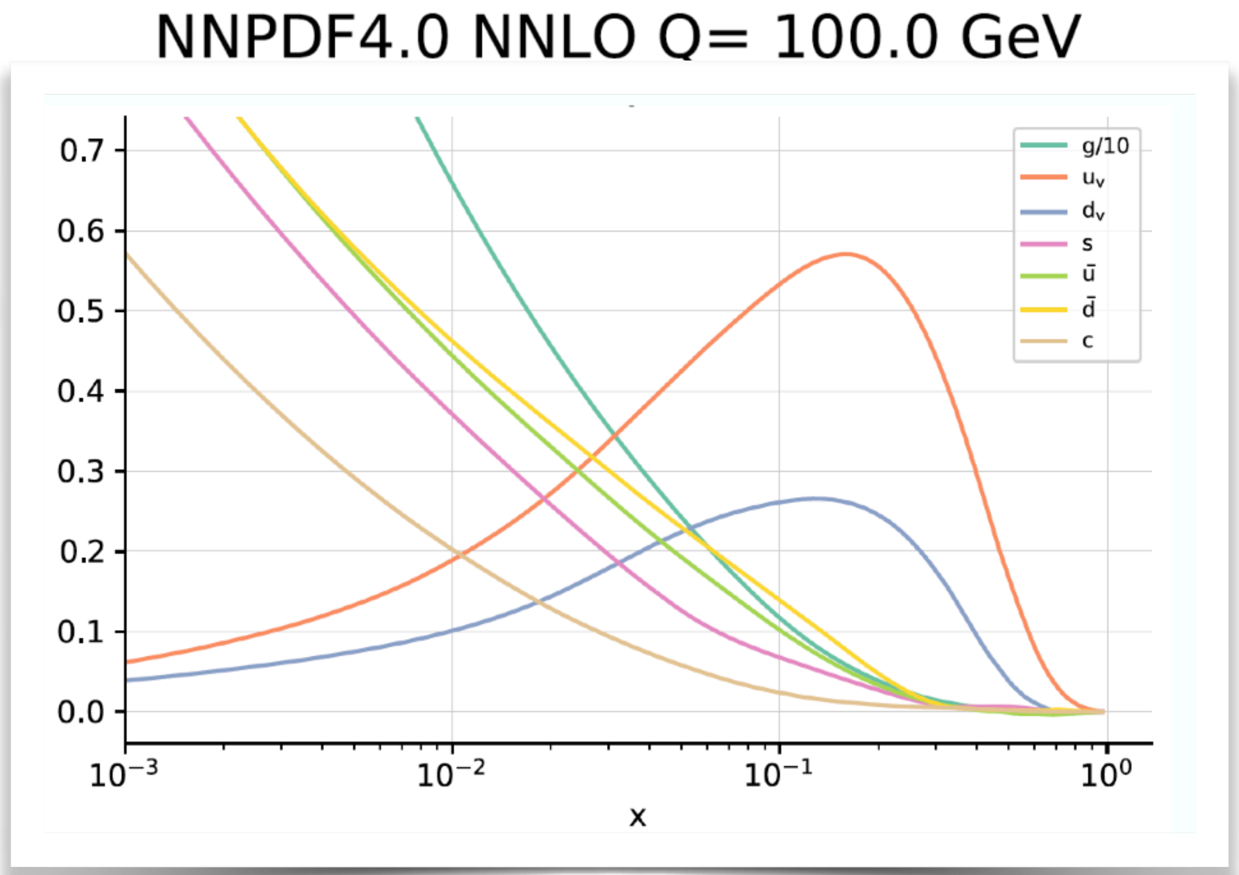
Background

Why proton (or nuclei) PDFs?

In the context of muon collider (MuC) physics prospects, why do we need them?

Spoiler: they are crucial to parametrise the interactions between the neutrino beam coming from decaying muons and a forward detector.



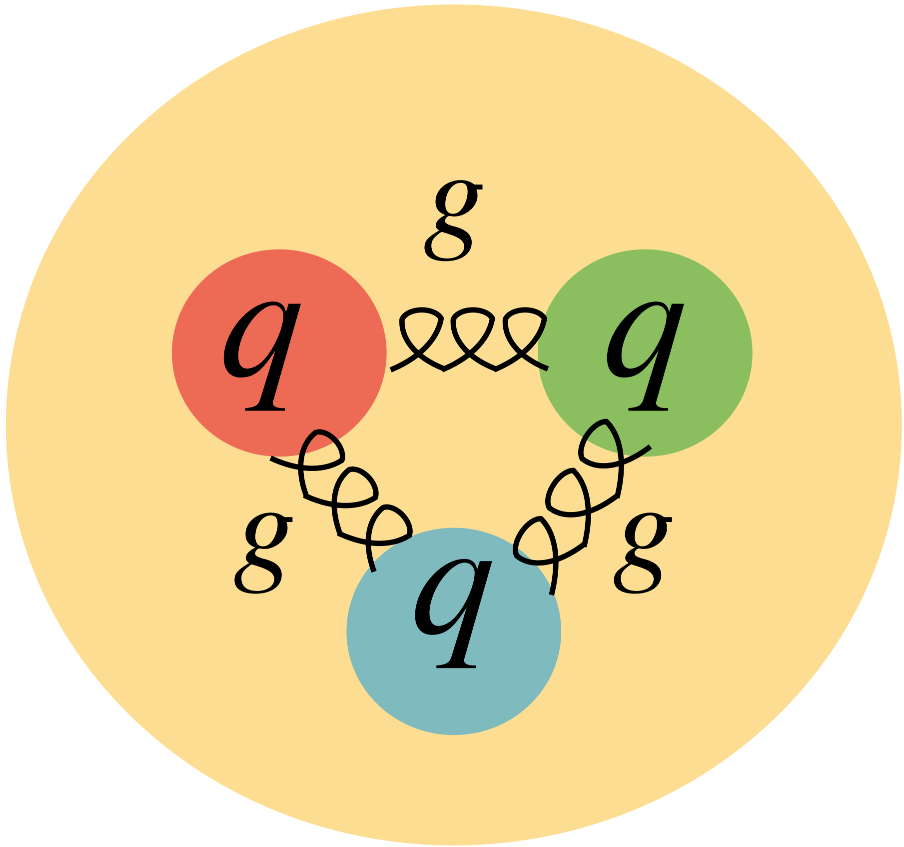


NNPDF, 2109.02653

Protons and partons

- The most powerful collider we have at the moment is the LHC, at which we collide *protons*.
- Proton are not elementary particles. They are QCD bound states of elementary particles called *partons* (quarks, gluons, …).
- The parton model postulates that interactions between hadrons (protons, in particular) are interactions of point-like parton convolved with functions that parametrise the structure of the hadron: *parton distribution functions* (PDFs).

Proton



Parton distribution functions

- PDFs describe the structure of protons in terms of elementary constituents.

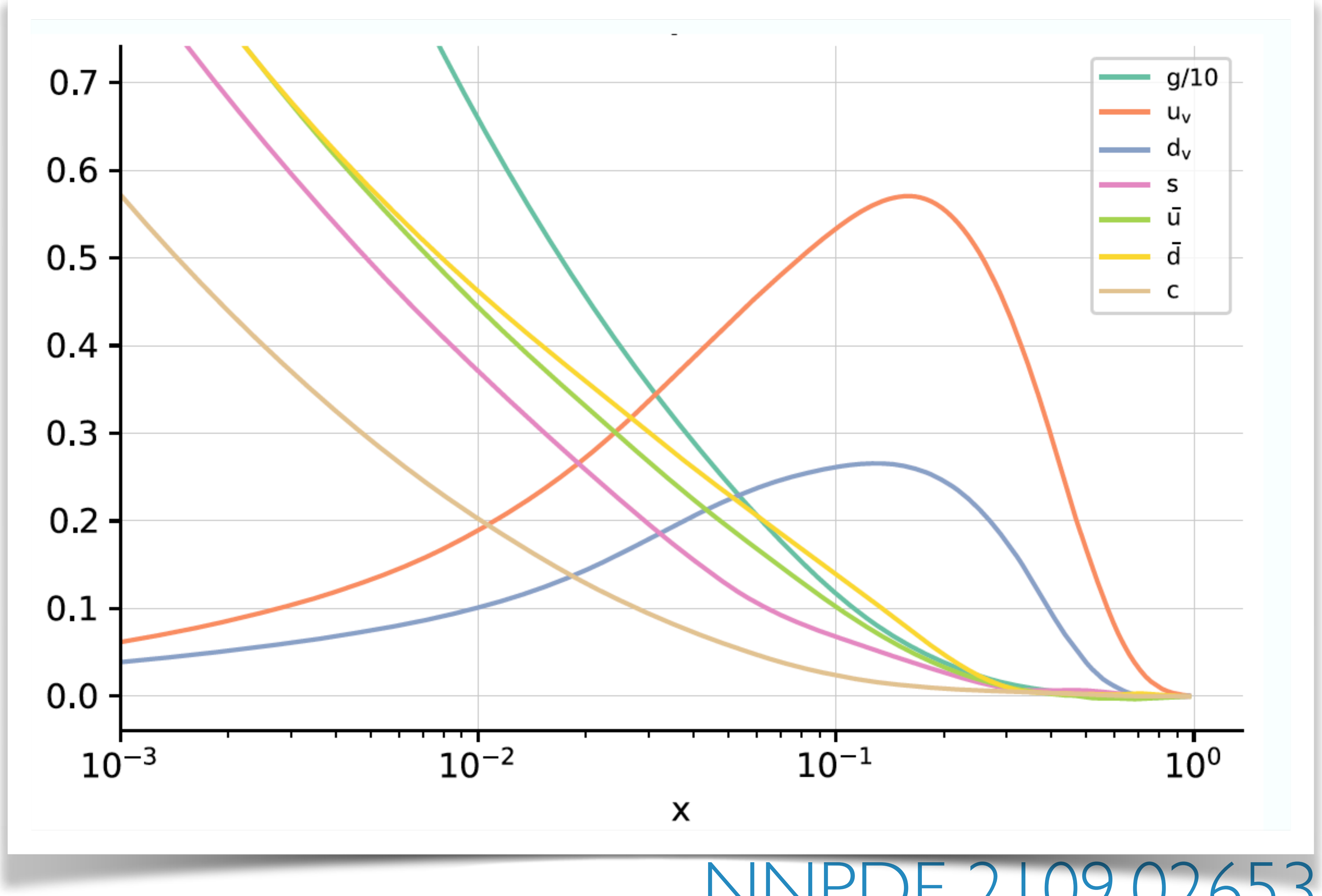
- Some intuition. Consider the proton PDF of the up quarks:

$$f_u(x) = u(x)$$

$u(x)$ → PDF: the 'probability' of finding an up-quark in the proton carrying a fraction x of the momentum of the proton.

$u(x)dx$ → # of up quarks carrying a momentum fraction between x and x +dx

NNPDF4.0 NNLO Q= 100.0 GeV

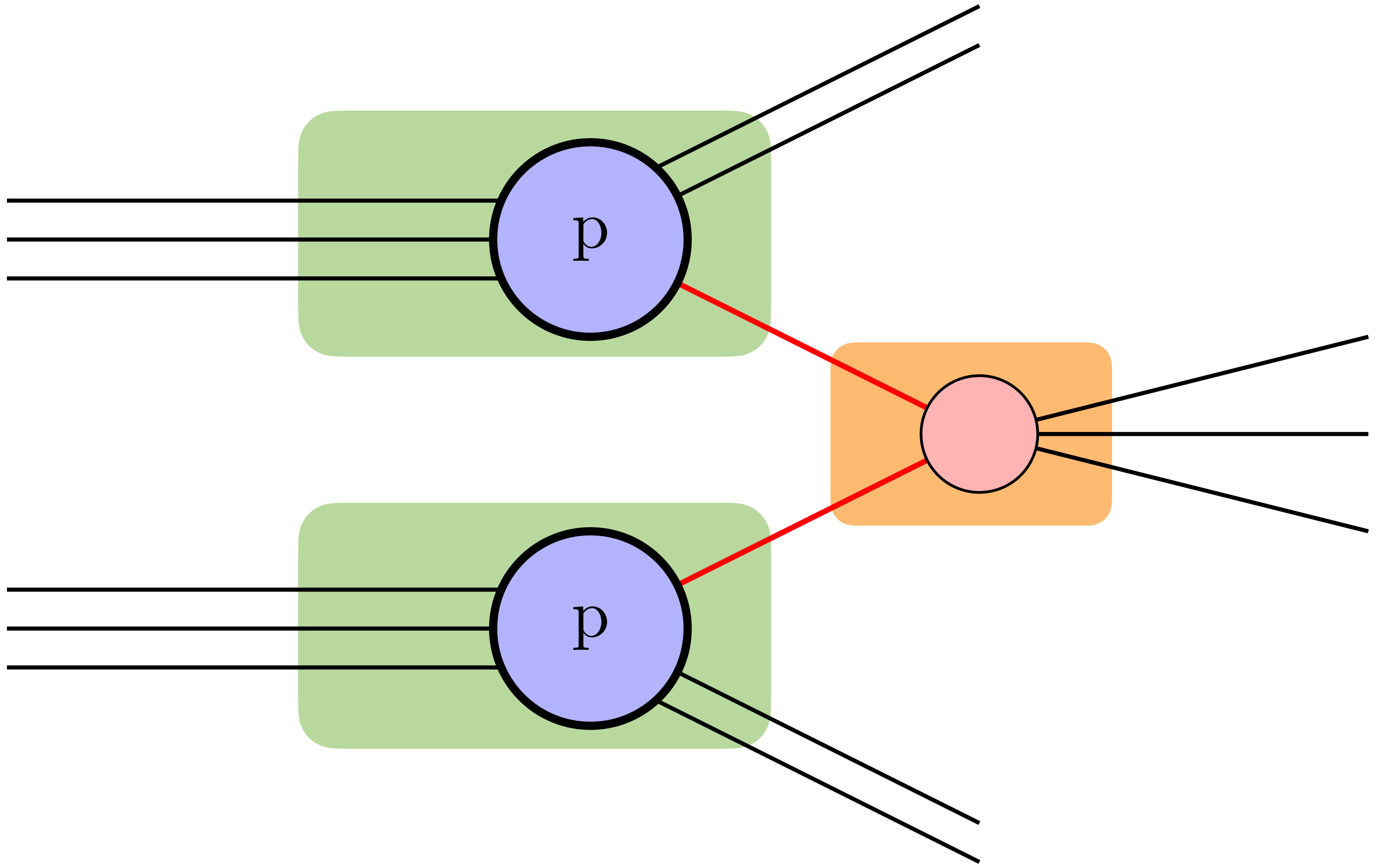


NNPDF, 2109.02653

- PDFs are *dynamical* quantities $f_i(x) \to f_i(x, Q^2)$ … and are very important in our setup.

Factorisation and hadronic observables

Consider a proton-proton collision:



$$\sigma = \sum_{i,j} \int_0^1 dx_1 \int_0^1 dx_2 f_i(x_1) f_j(x_2) \hat{\sigma}_{ij}(x_1, x_2)$$

$x_{1,2}$: fraction of the hadron's momentum that is carried by the hadron

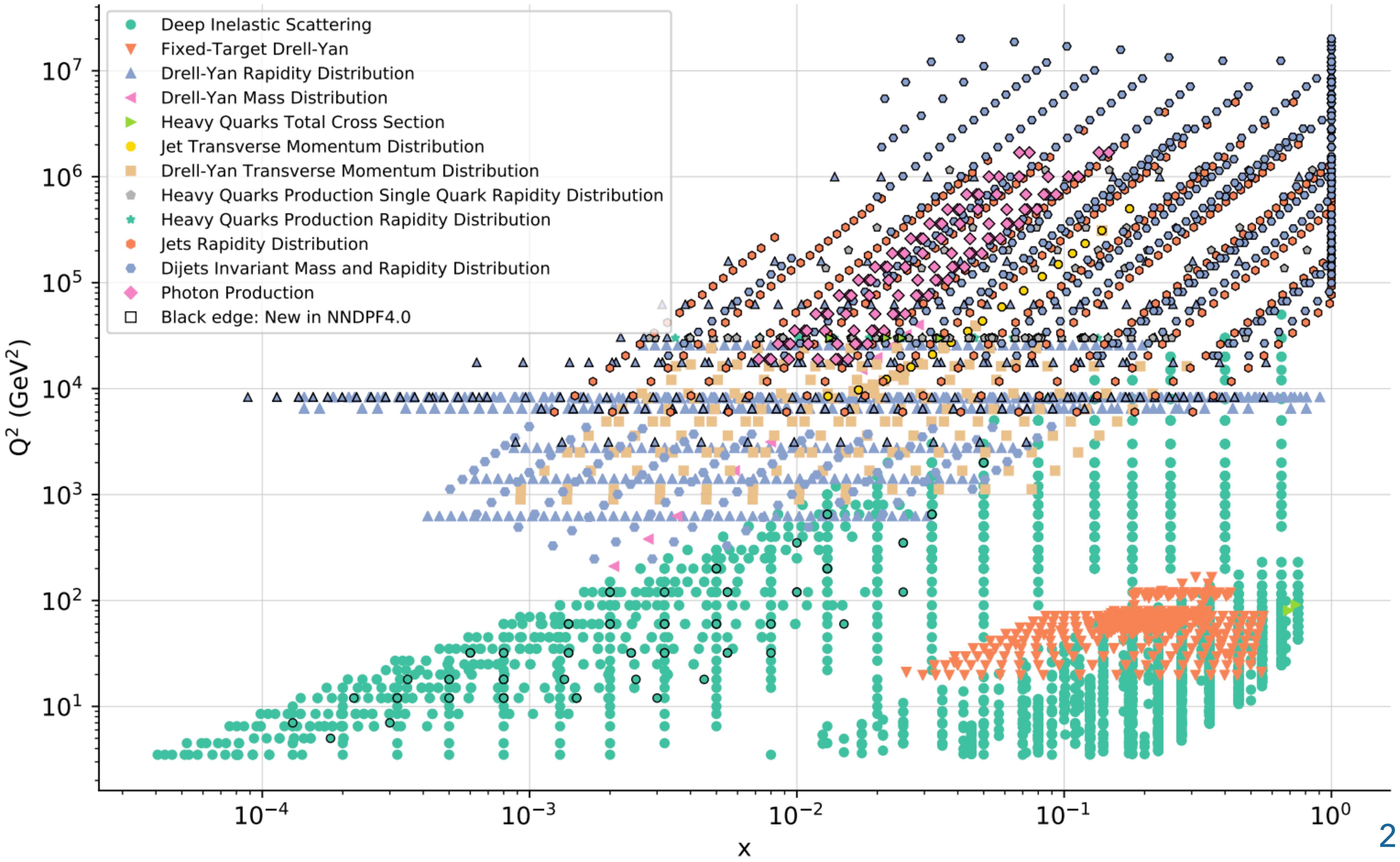
$\hat{\sigma}_{ij}$: partonic cross section

$f_i(x)$: PDF of parton of type i

- Radiative corrections introduce IR singularities that have to be factorised: $f(x) \rightarrow f(x, Q^2)$

PDF determination

PDFs **cannot** be calculated from first principles in perturbation theory, they have to be extracted from *data*.

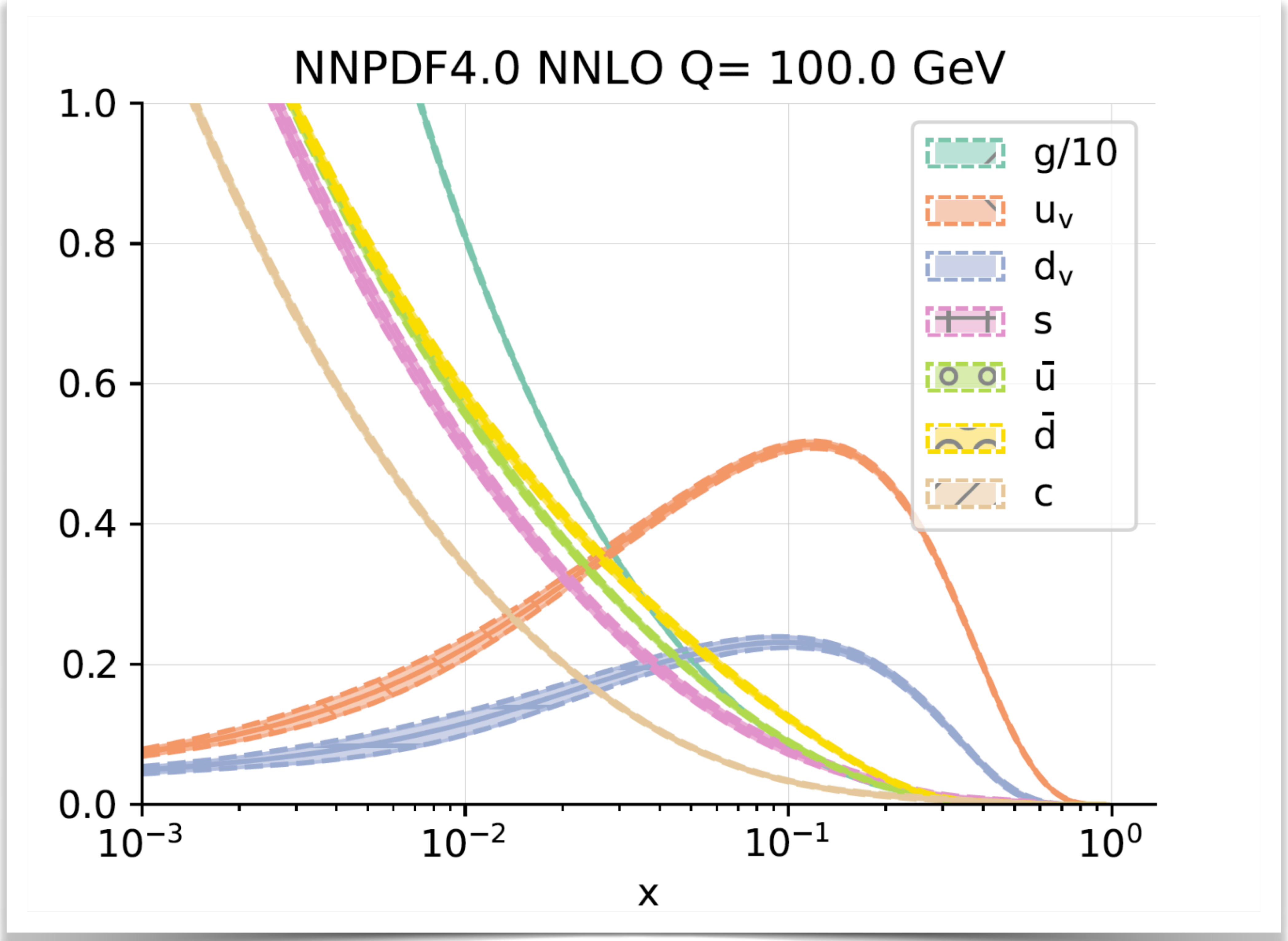


2109.02653

PDF determination

PDFs **cannot** be calculated from first principles in perturbation theory, they have to be extracted from *data*.

$$f(x, Q^2)$$



Some recent PDF fits include:

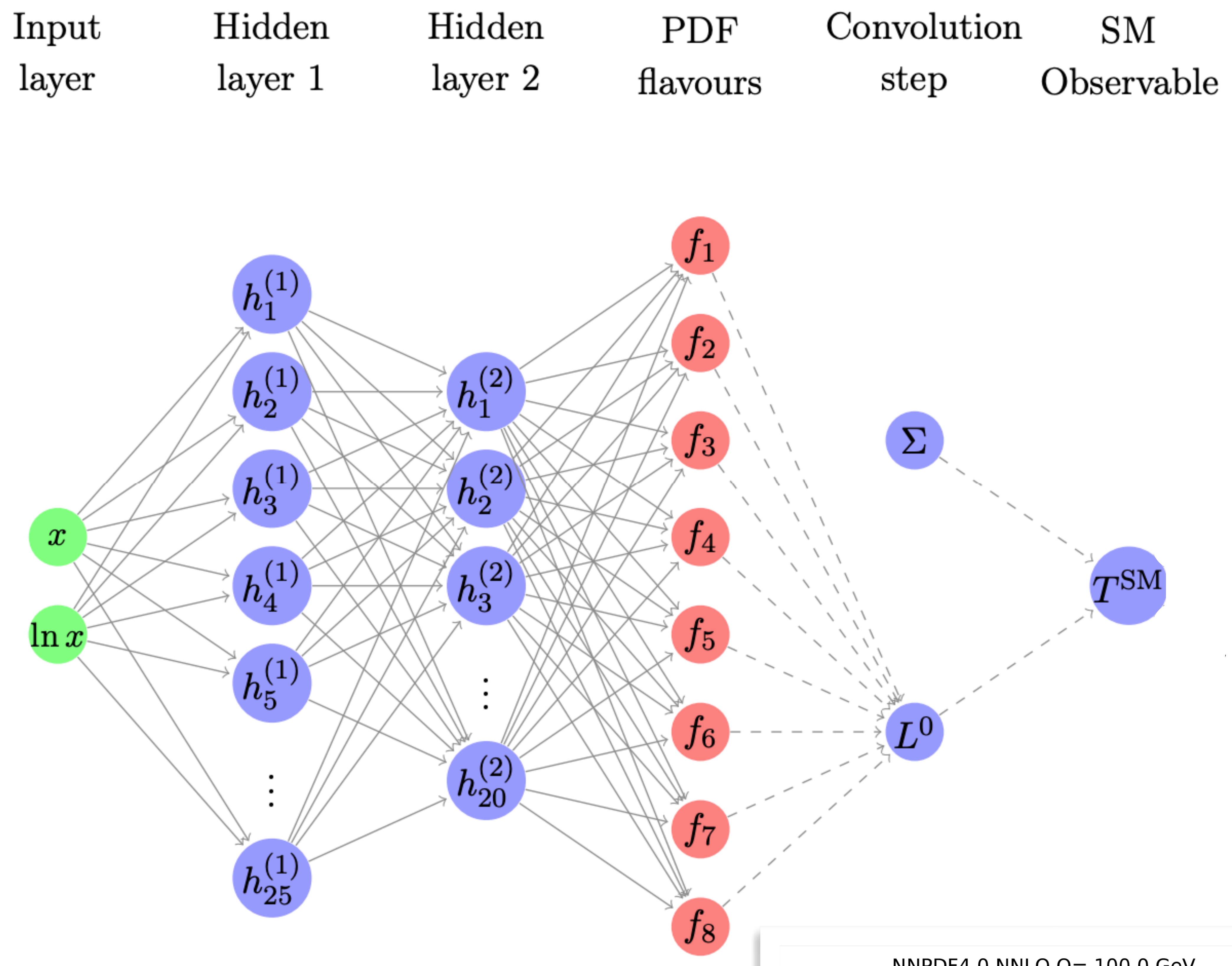
- NNPDF4.0, Ball et al., 2109.02653
- MSHT20, McGowan et al., 2012.04684
- CT18, Hou et al., 1912.10053

Let's delve deeper into a specific methodology…

NNPDF4.0

- PDFs are parametrised by neural networks (NNs):

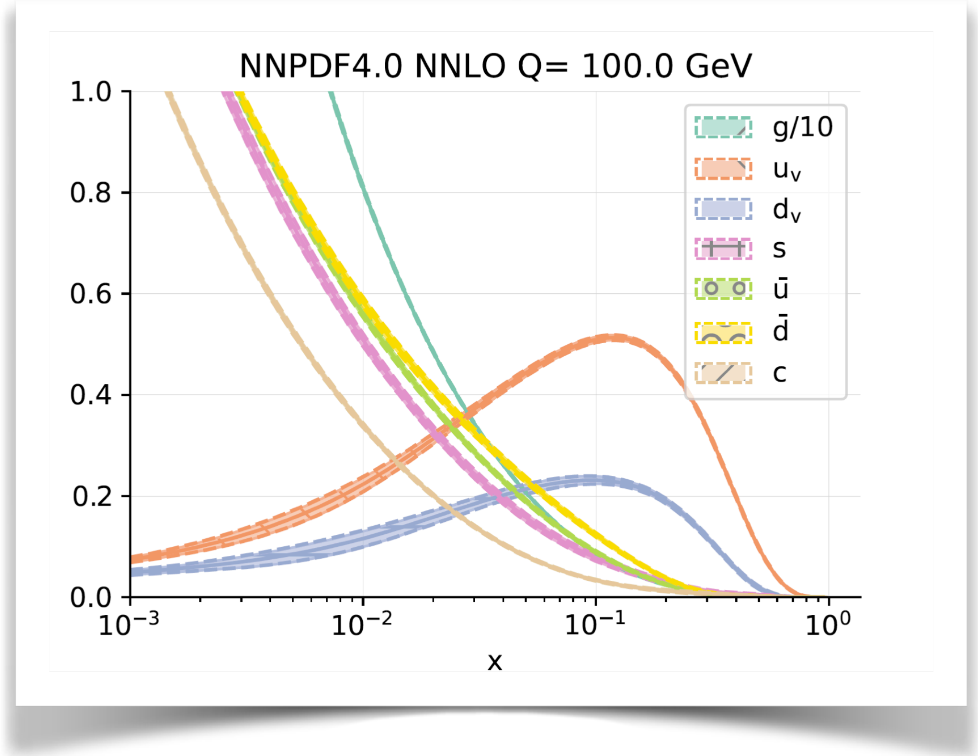
$$f(x, Q_0^2) = \mathrm{NN}(x)$$



- The optimal weights of the NN are found by minimising a loss function:

$$\chi^2(\theta) = \frac{1}{N_{\mathrm{dat}}}(\mathbf{D} - \mathbf{T}(\theta))^T(\mathbf{cov})^{-1}(\mathbf{D} - \mathbf{T}(\theta))$$

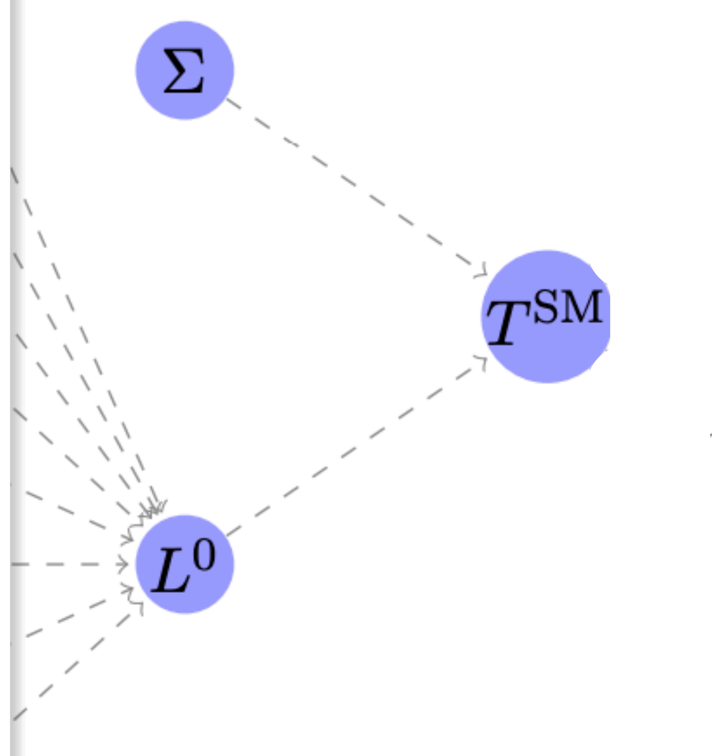
$$\theta = \theta_{opt}$$



- Uncertainty is propagated via de *Monte Carlo replica* method, sampling from the exp. cov. matrix.

2109.02653, 2404.10056

NNPDF4.0



- PDFs are par
networks (N

$f(x,$

- The optimal
minimising a

$\chi^2(\theta) = \frac{1}{N_{\rm da}}$

where

- Uncertainty is propagated via de *Monte Carlo replica* method, sampling from the exp. cov. Matrix.

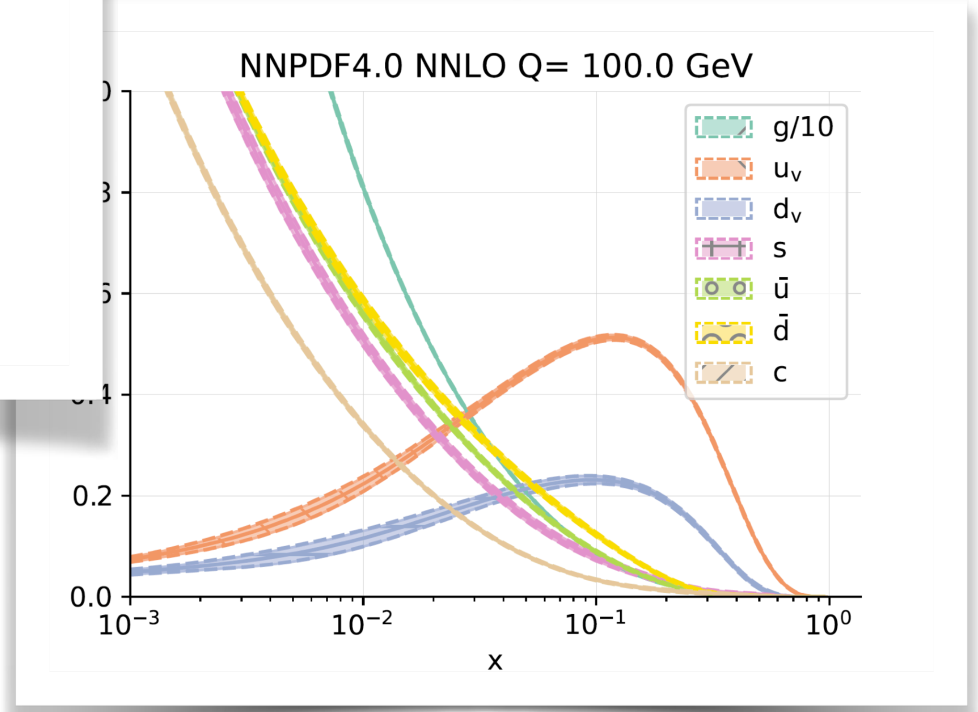
2109.02653, 2404.10056

Other parametrisations are possible. For example, in the case of MSHT20, PDFs are parametrised with *fixed functional forms* of the type:

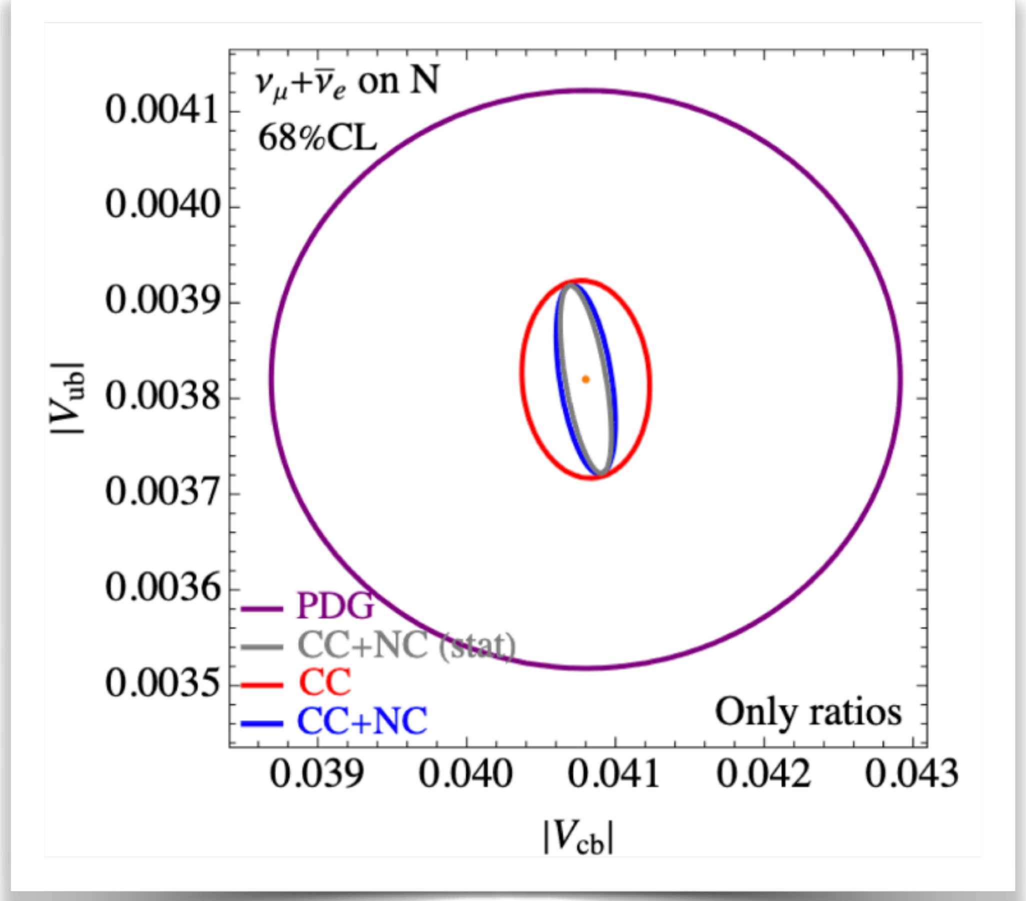
$$xf(x,Q_0^2) \;=\; A(1-x)^{\eta}x^{\delta}\left(1+\sum_{i=1}^{n}a_iT_i^{\rm Ch}(y(x))\right)$$

$T_i^{\rm Ch}$: Chebyshev polynomials

Unc. is propagated via the *Hessian* prescription (fluctuating the parameters around the minimum of the loss)



Outline

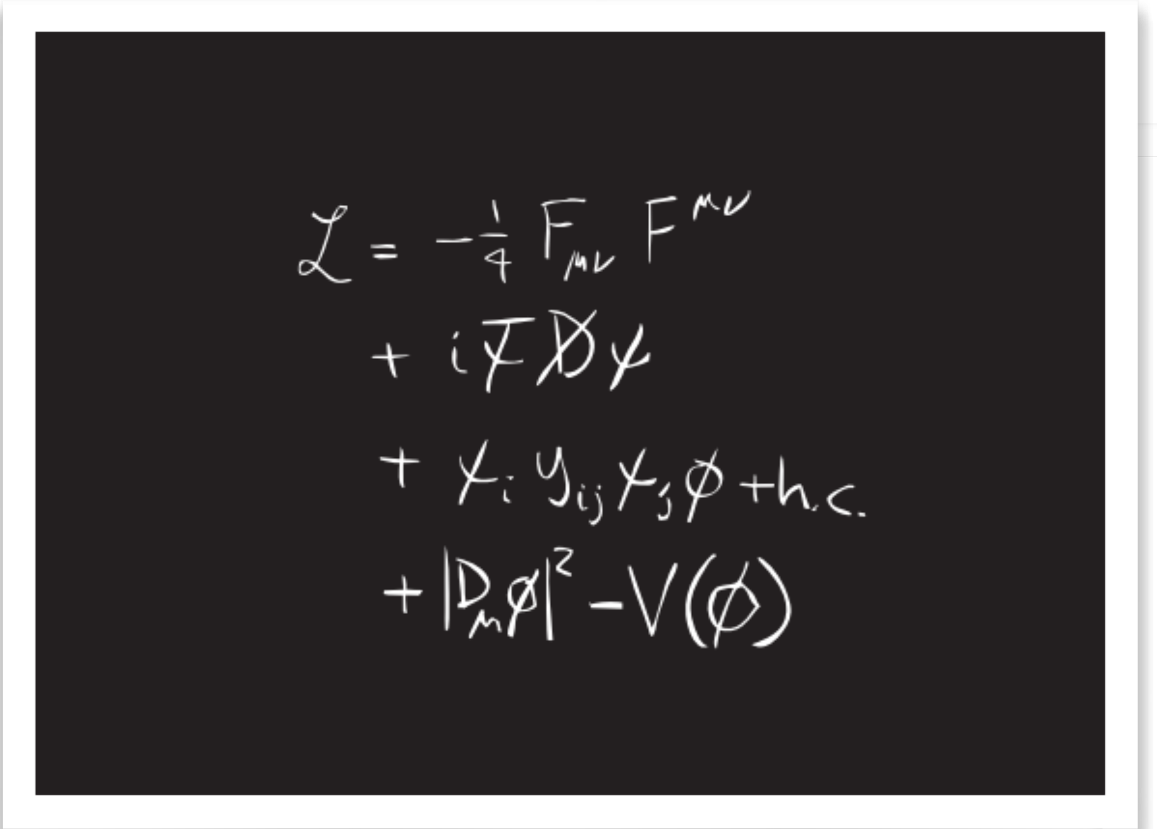


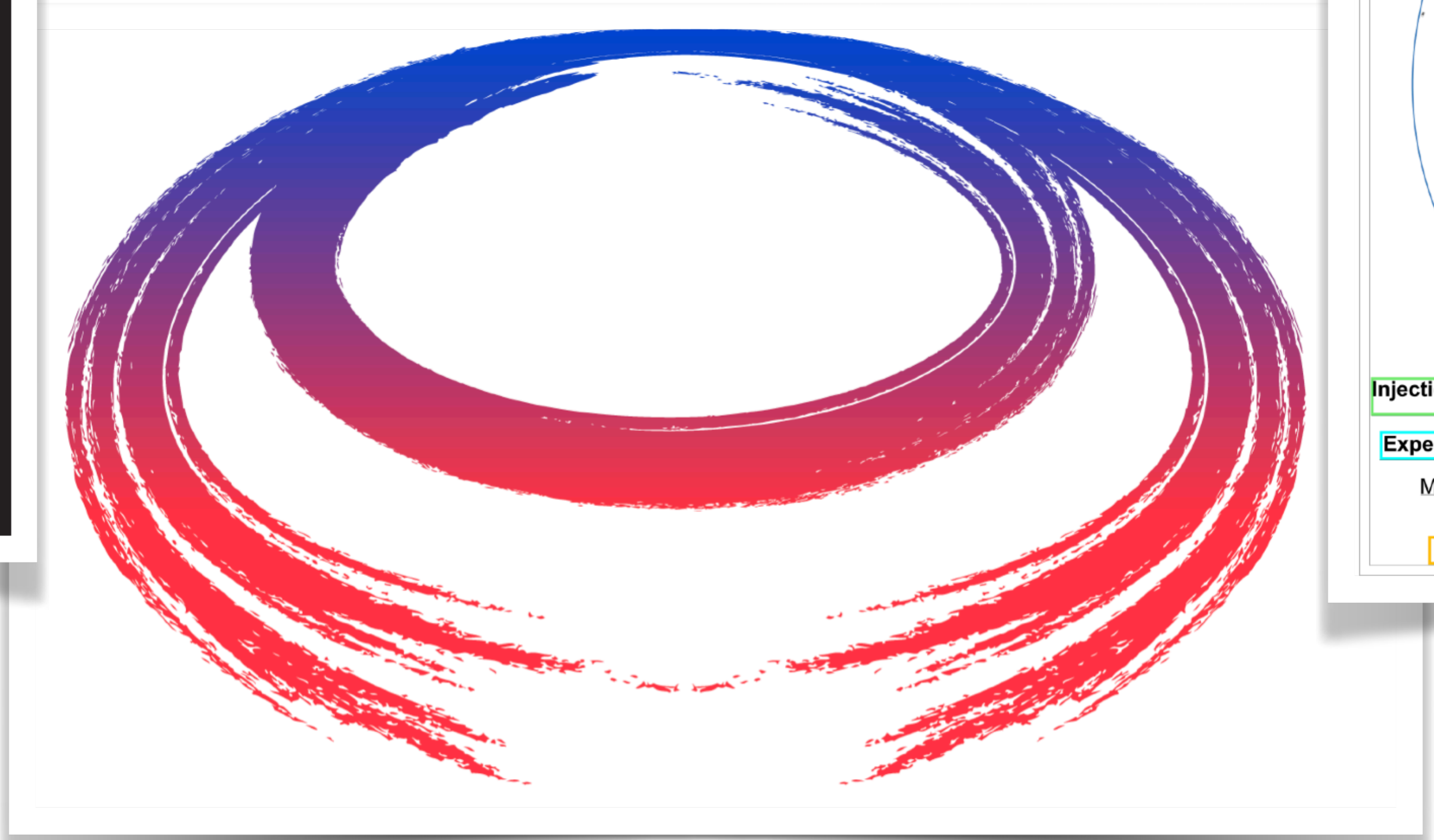
CKM & PDFs from MuC neutrinos

MuC for the Standard Model and beyond

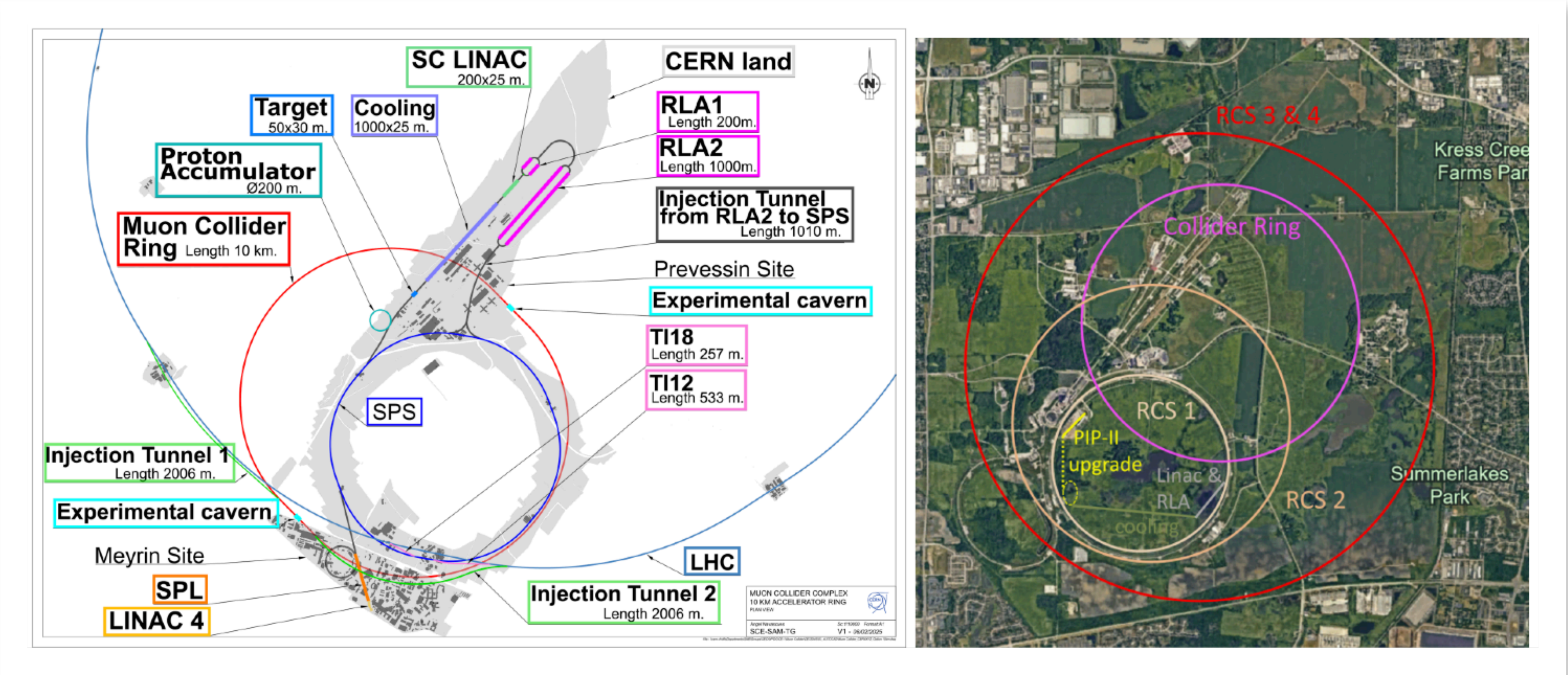
The MuC is a revolutionary proposal to explore the Universe at the most fundamental level.

Theory





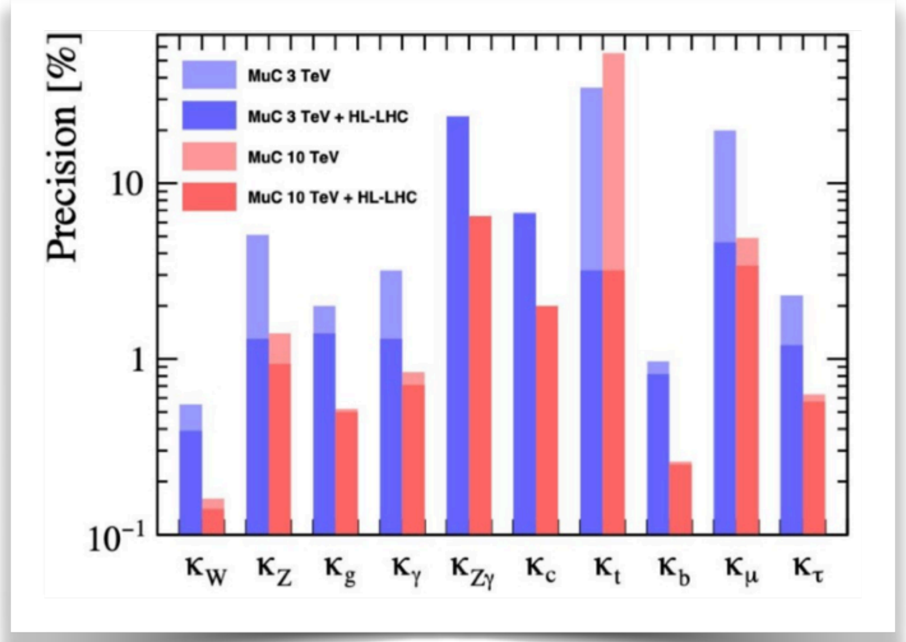
Experiment

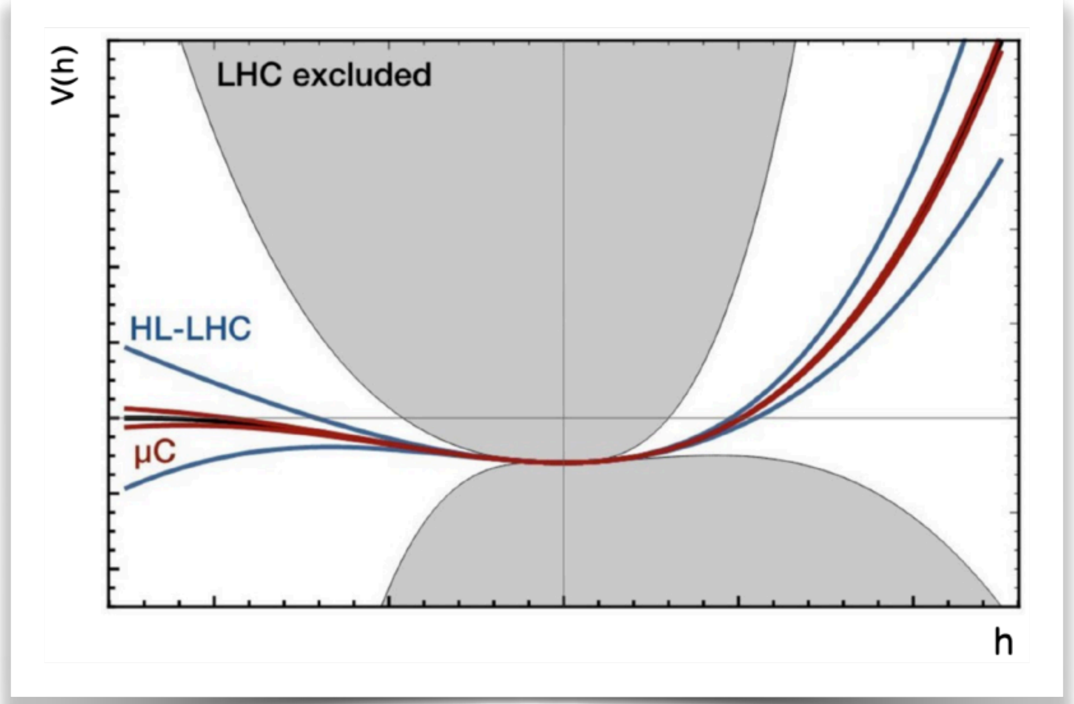


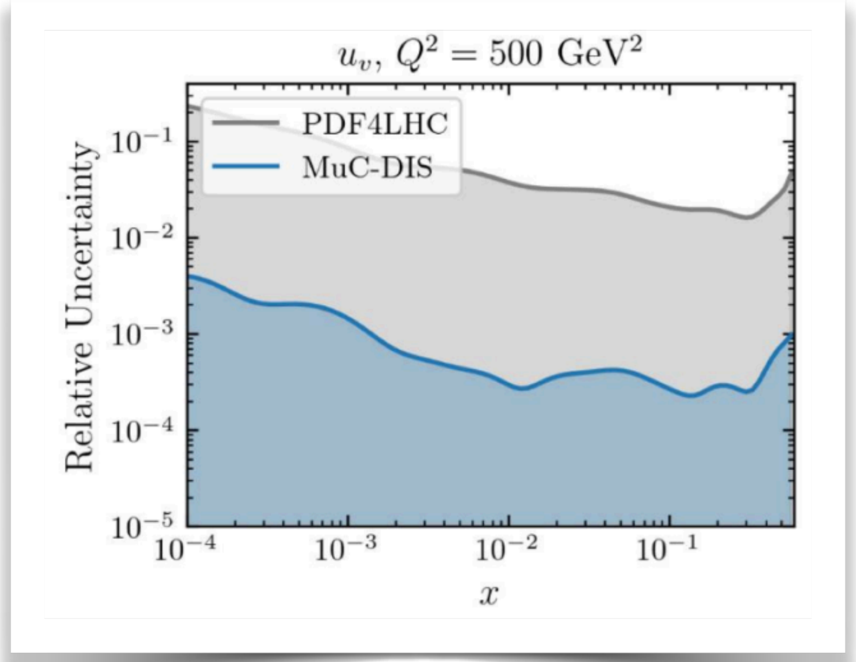
MuC for the Standard Model and beyond

The physics program at a MuC is very broad:

Precision SM measurements at high energies (Higgs physics, EW, …).

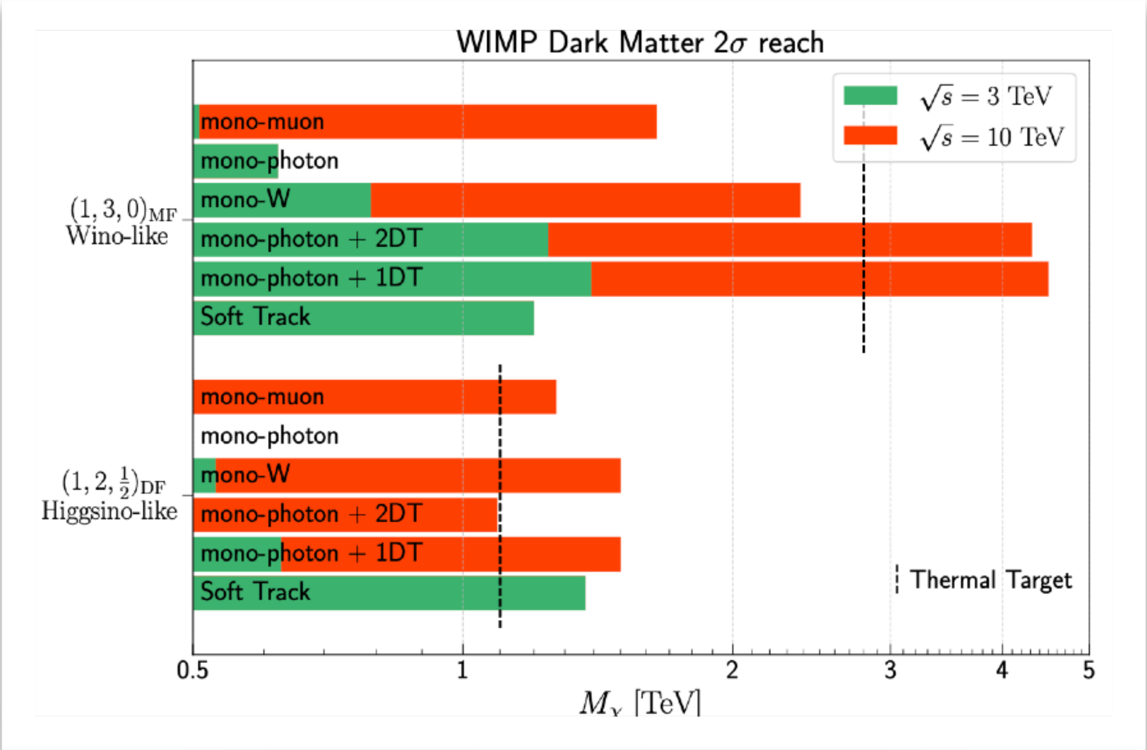


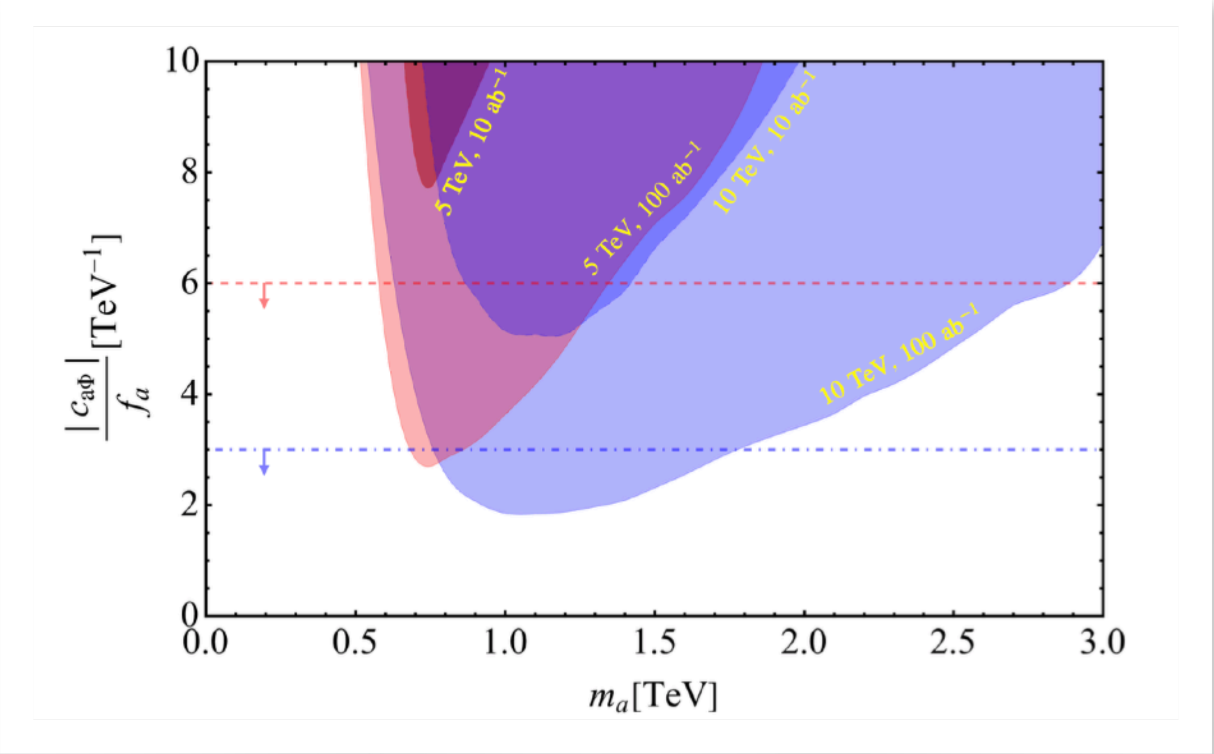




Direct and indirect searches of new physics (EFT, DM, ALPS, …).

Coefficient	MuC-10 [TeV^{-2}]	$\delta(\lvert g_\mu/g_e\rvert^2)$	$\delta(\lvert g_\tau/g_\mu\rvert^2)$	$\delta(\lvert g_\tau/g_e\rvert^2)$
$[C_{ll}]_{1221}$	$[-(136)^{-2},\ (139)^{-2}]$	0	3.3×10^{-6}	3.3×10^{-6}
$[C_{ll}]_{2332}$	$[-(96)^{-2},\ (100)^{-2}]$	6.6×10^{-6}	0	6.6×10^{-6}
$[C_{le}]_{1221}$	$[-(74)^{-2},\ (74)^{-2}]$	0	3.1×10^{-11}	3.1×10^{-11}
$[C_{le}]_{2332}$	$[-(62)^{-2},\ (62)^{-2}]$	6.2×10^{-11}	0	7.0×10^{-11}
$[C_{Hl}^{(3)}]_{22}$	$[-(183)^{-2},\ (183)^{-2}]$	3.6×10^{-6}	6.2×10^{-6}	1.1×10^{-6}





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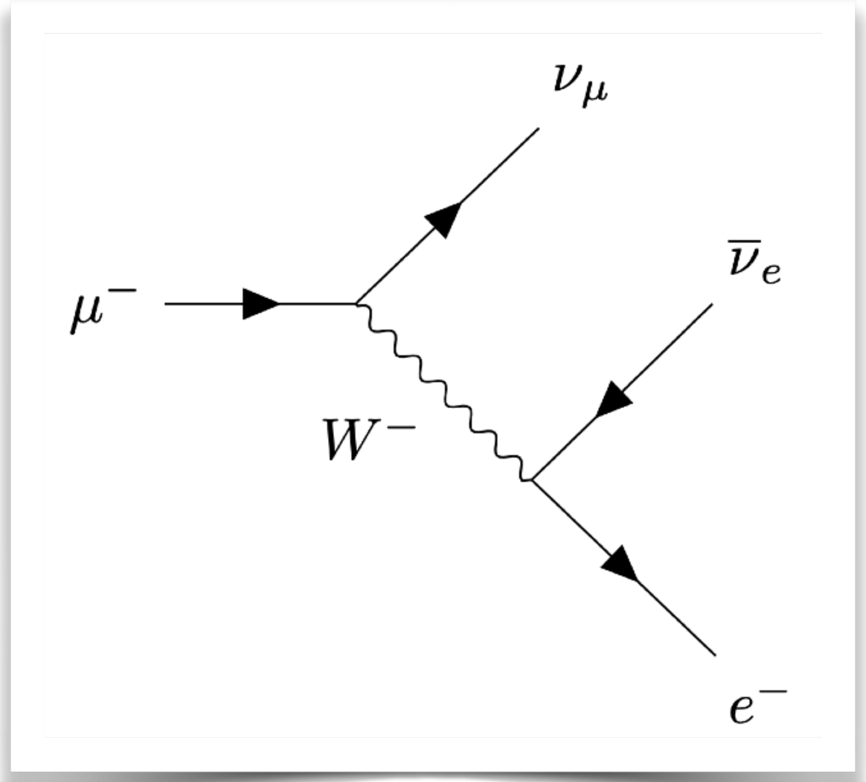
MuC neutrinos

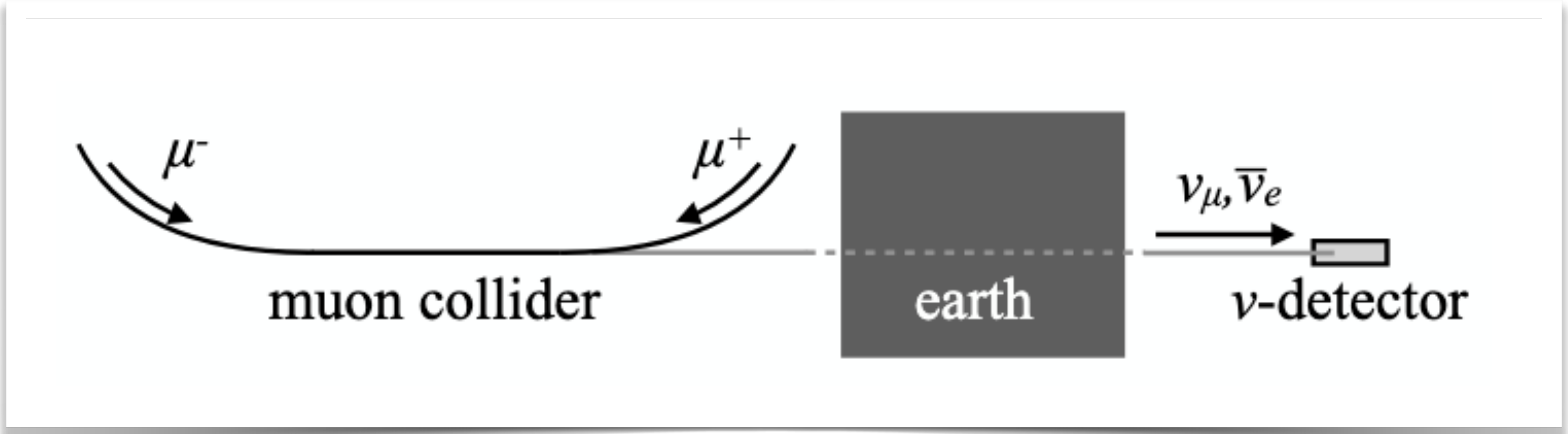
The muon beam offers excellent precision and discovery potential, but there is more …

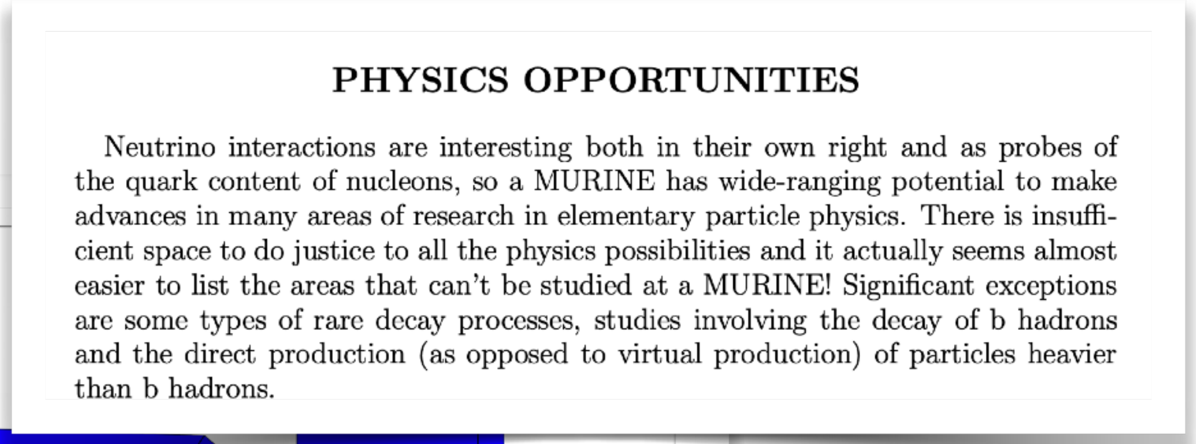


$$\mu^- \rightarrow \nu_\mu + e^- + \overline{\nu}_e$$

Via muon decay, we have access to *collimated, high energy, neutrino beams*.

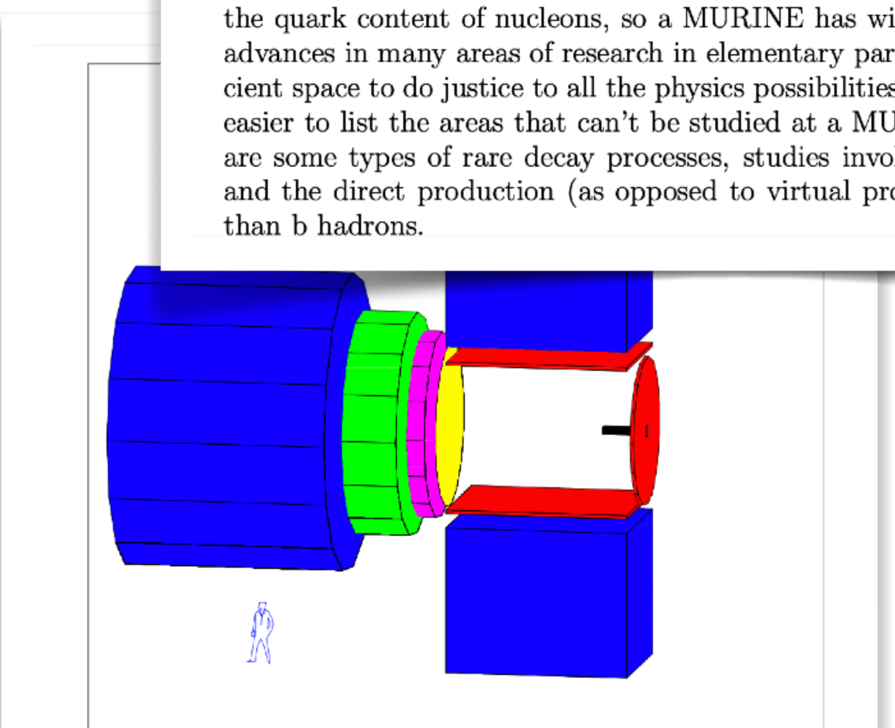
The neutrino beam can interact with a forward target via DIS and enable high precision measurements.





PHYSICS OPPORTUNITIES

Neutrino interactions are interesting both in their own right and as probes of the quark content of nucleons, so a MURINE has wide-ranging potential to make advances in many areas of research in elementary particle physics. There is insufficient space to do justice to all the physics possibilities and it actually seems almost easier to list the areas that can't be studied at a MURINE! Significant exceptions are some types of rare decay processes, studies involving the decay of b hadrons and the direct production (as opposed to virtual production) of particles heavier than b hadrons.



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The CKM matrix

It can be regarded as a rotation between quark mass and weak eigenstates

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

The elements of the matrix are *fundamental* SM parameters.

(We will devote our attention to the first 2 rows of the CKM matrix).

The CKM matrix

Why measure it?

- It mediates flavour changing transitions in quarks.
- Direct source of CP violation in the SM.
- Further constrain the Cabibbo angle anomaly: $|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 \neq 1$
- Constrain new physics from rare meson decays: $|V_{cb}|$
- Shed light on the inclusive/exclusive tension in b to c transitions.
- …

The CKM matrix

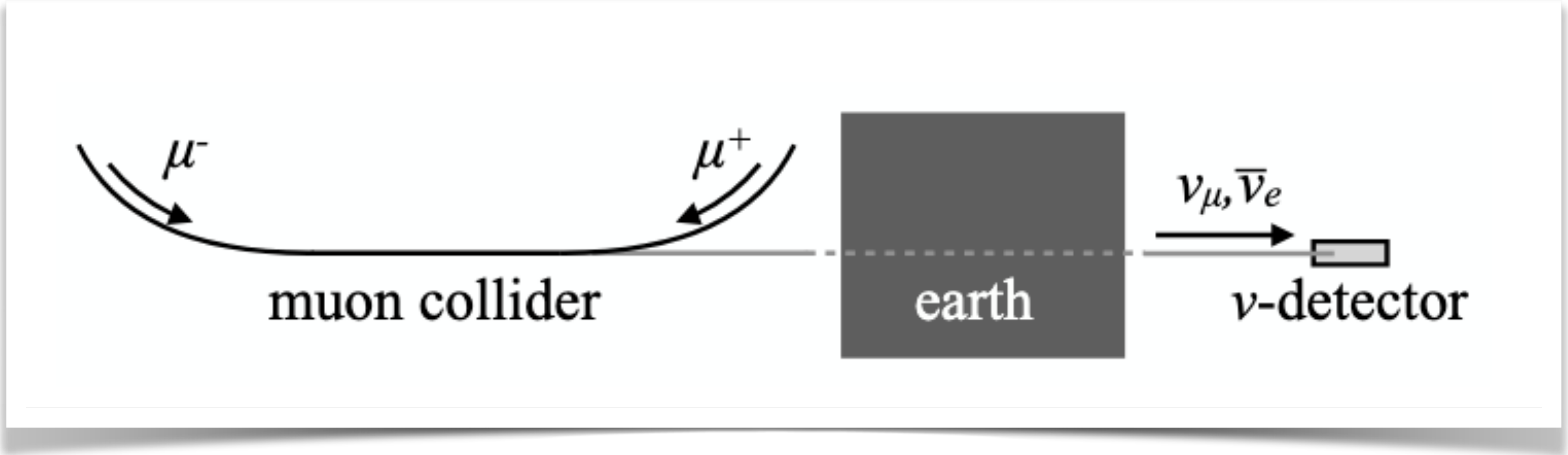
The current precision boundary:

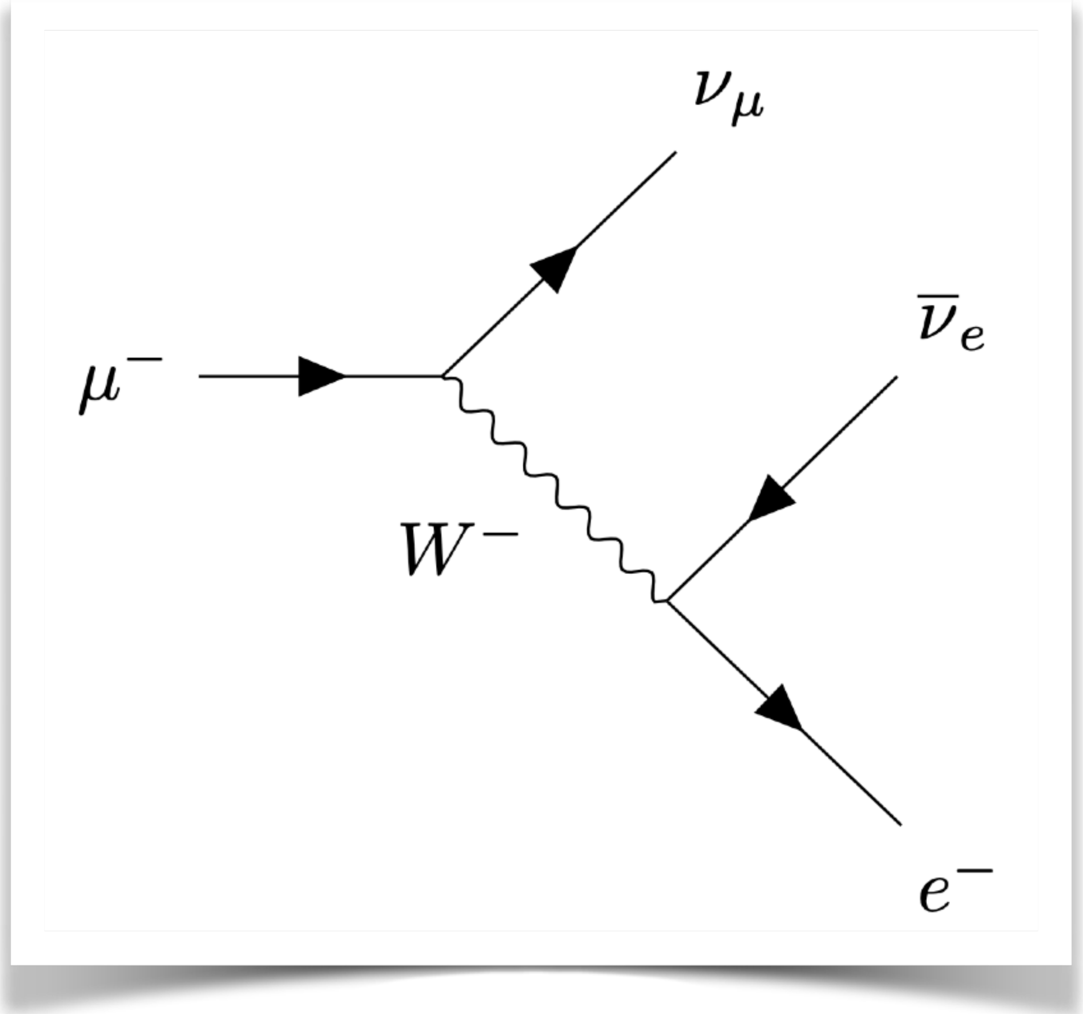
δ_{CKM}	PDG
$\lvert V_{cs}\rvert$	0.62%
$\lvert V_{cd}\rvert$	1.8%
$\lvert V_{cb}\rvert$	3.4%
$\lvert V_{ub}\rvert$	5.2%
$\lvert V_{ud}\rvert$	3.2×10^{-4}
$\lvert V_{us}\rvert$	0.36%

MuC neutrino flux

Muons decaying in the straight section near the MuC interaction point produce an extremely collimated high energy neutrino beam

$$\mu^- \rightarrow \nu_\mu + e^- + \overline{\nu}_e$$

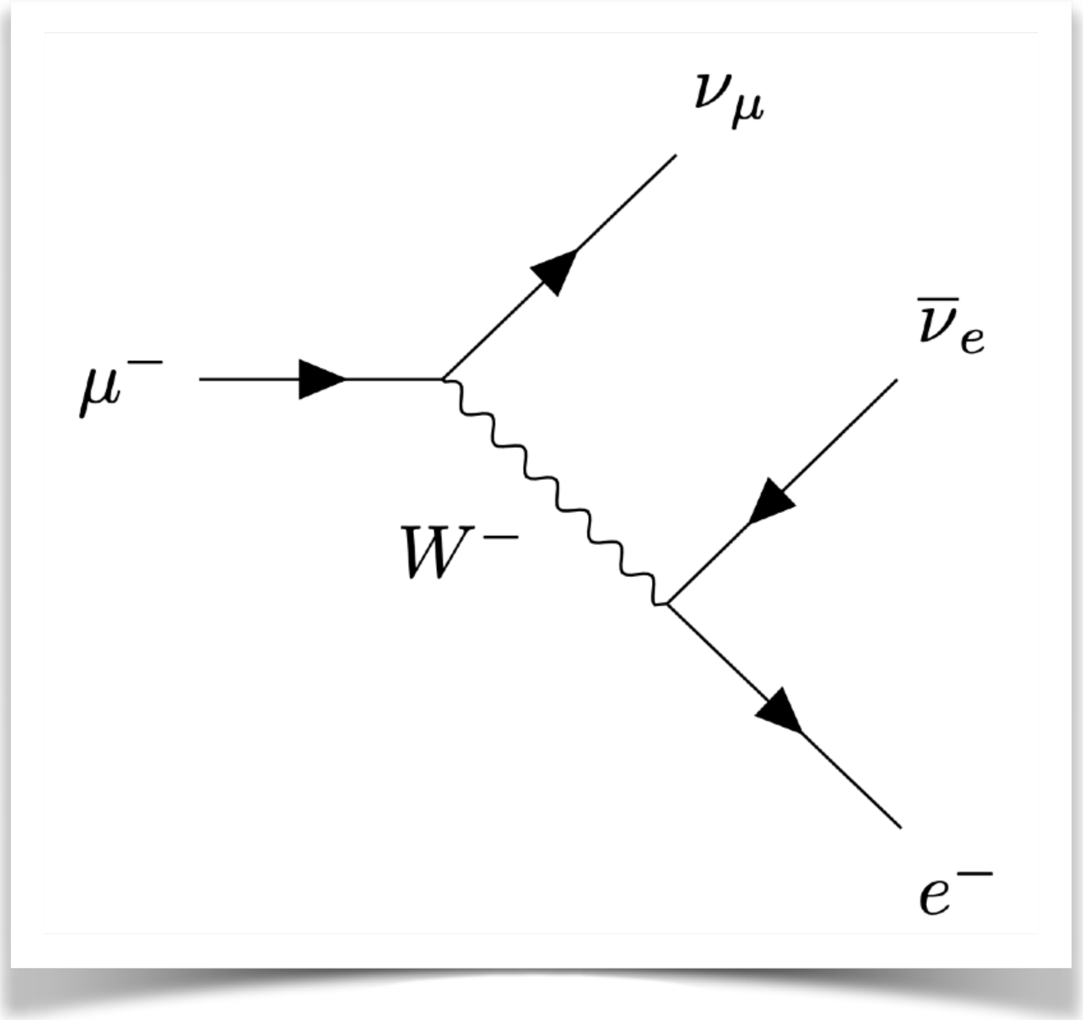


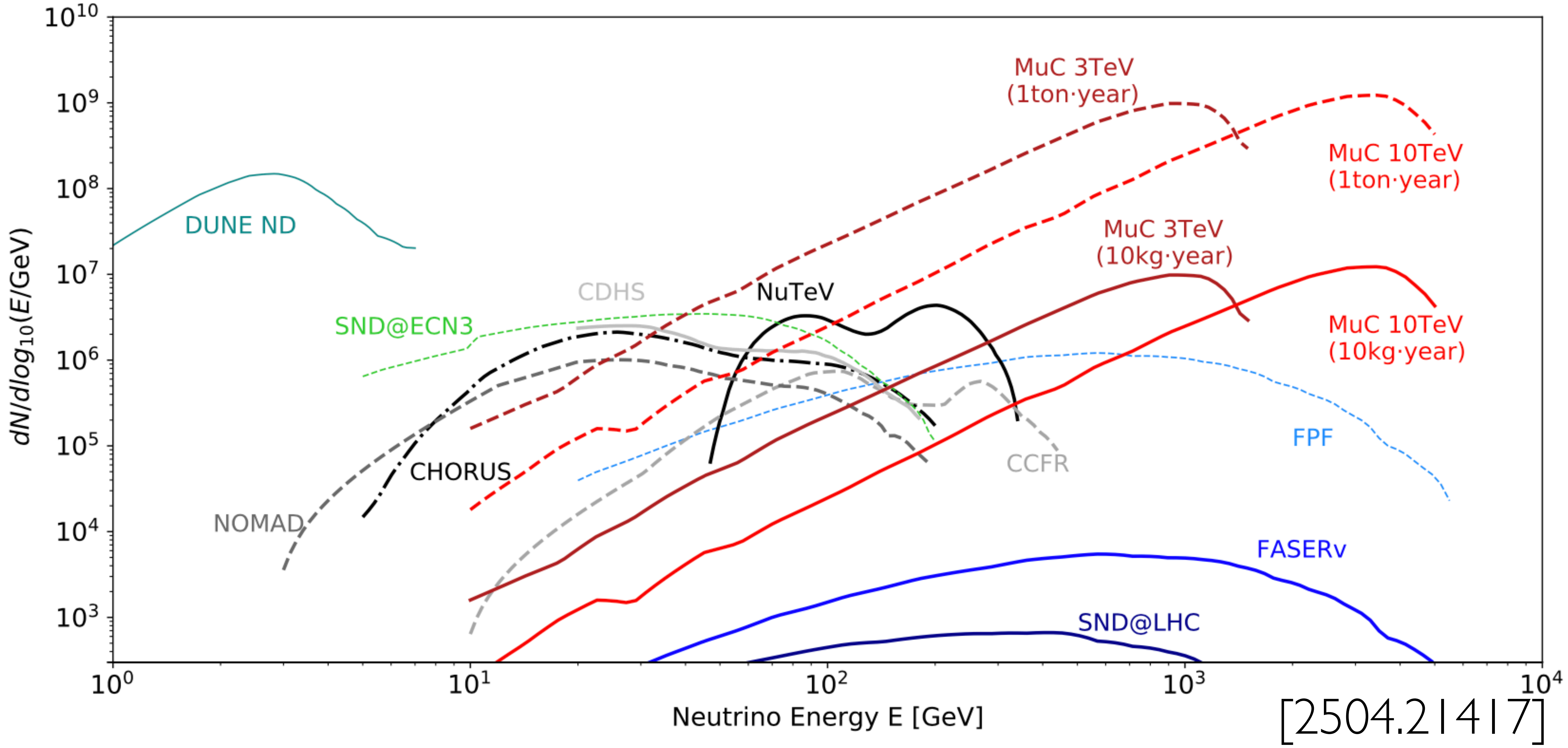


MuC neutrino flux

Muons decaying in the straight section near the MuC interaction point produce a highly collimated high energy neutrino beam

$$\mu^- \to \nu_\mu + e^- + \bar{\nu}_e$$





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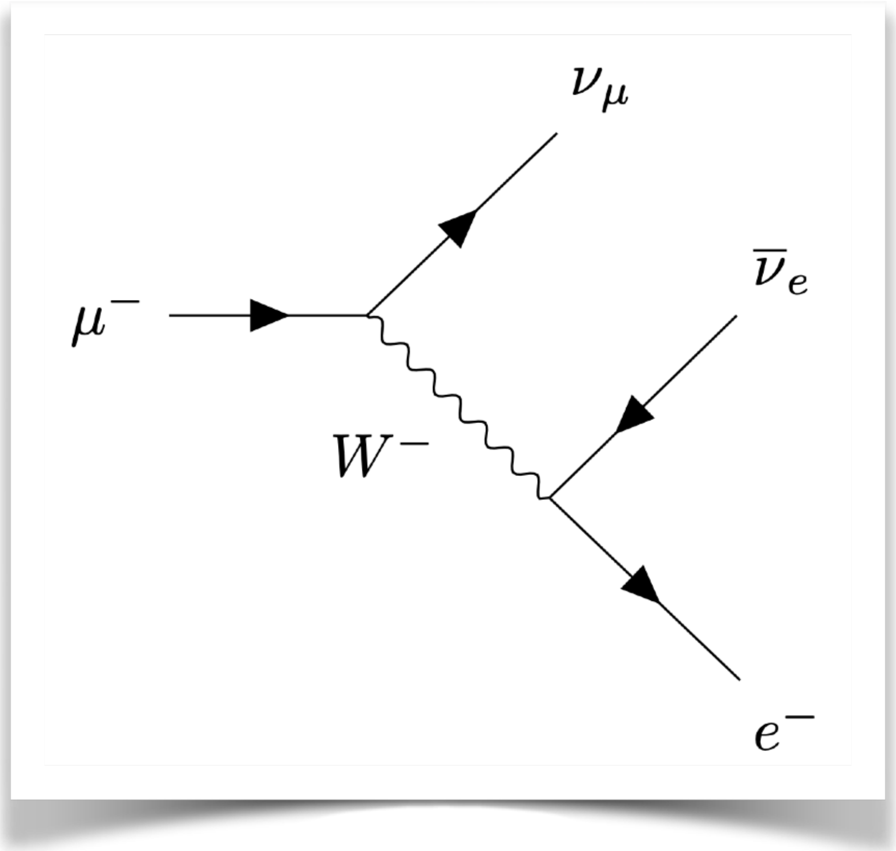
MuC neutrino flux

The number of neutrinos can estimated from the MuC target parameters [2504.21417].
We consider a 10 TeV MuC.



Muons per bunch: $N \approx 10^{12}$

Injected every: $1/f_r \approx 0.2$ sec

The # of neutrinos that decay in the straight section (assumed eff. ~10 m.):

per second: $9 \cdot 10^9$

per year: $9 \cdot 10^{16}$

MuC neutrino flux

Each neutrino crossing the target has a probability of interaction of

$$p_{\mathrm{int}} \simeq 6 \times 10^{-12} \frac{\rho \cdot L}{\mathrm{g\ cm^{-2}}} \frac{E_\nu}{\mathrm{TeV}}$$

It increases with the mass of the fixed target and the energy of the neutrino.

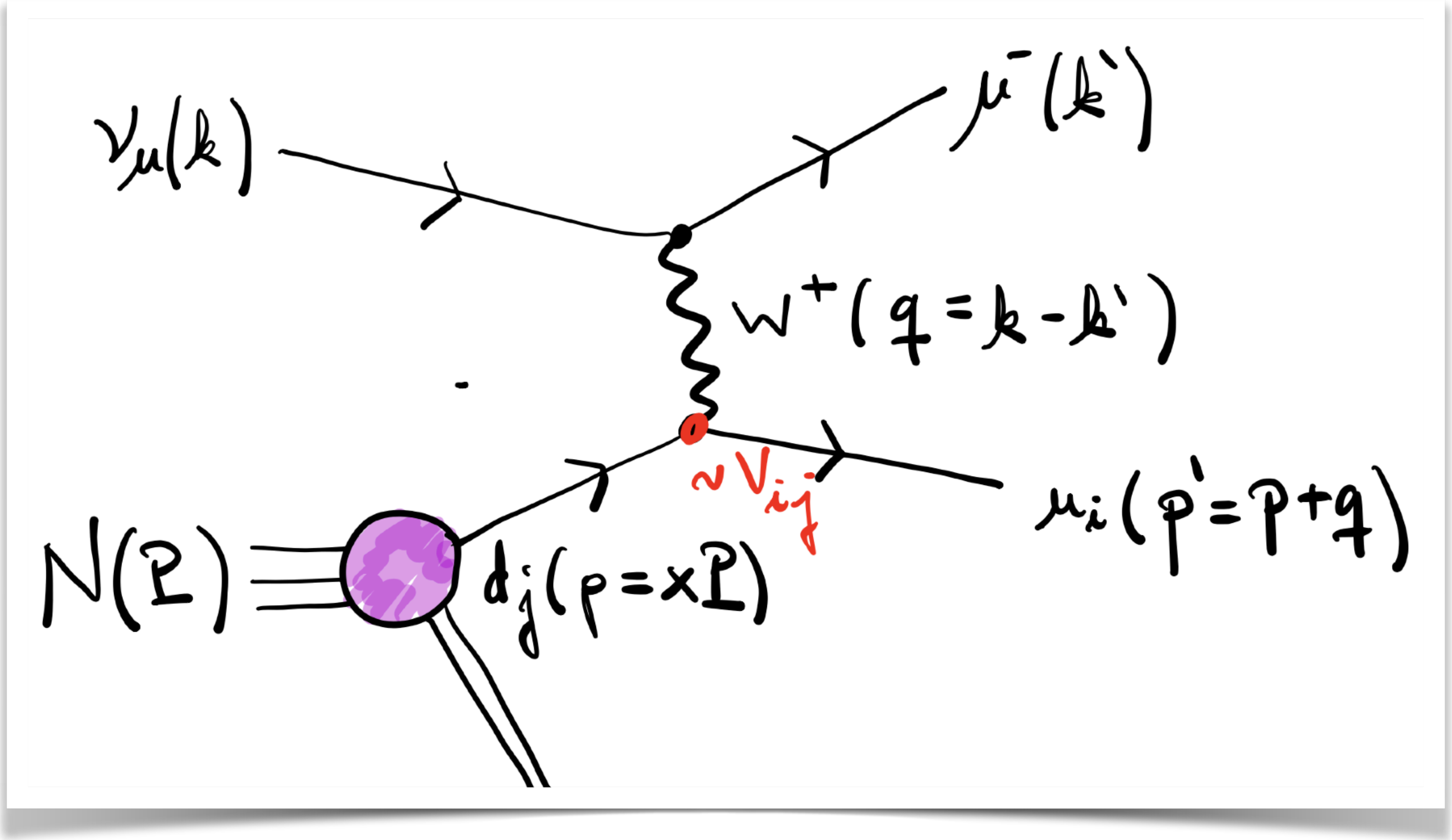
At present, no neutrino detector design exists for this forward target experiment

In what follows, we consider a target of 1 ton (similar to current experiments, e.g. FASERnu at the LHC).

Now, some kinematics…

Neutrino DIS

Consider the charged current (CC) diagram:



With the kinematics:

$$q = k - k'$$

$$Q^2 = -q^2 \qquad \text{(Momentum transfer)}$$

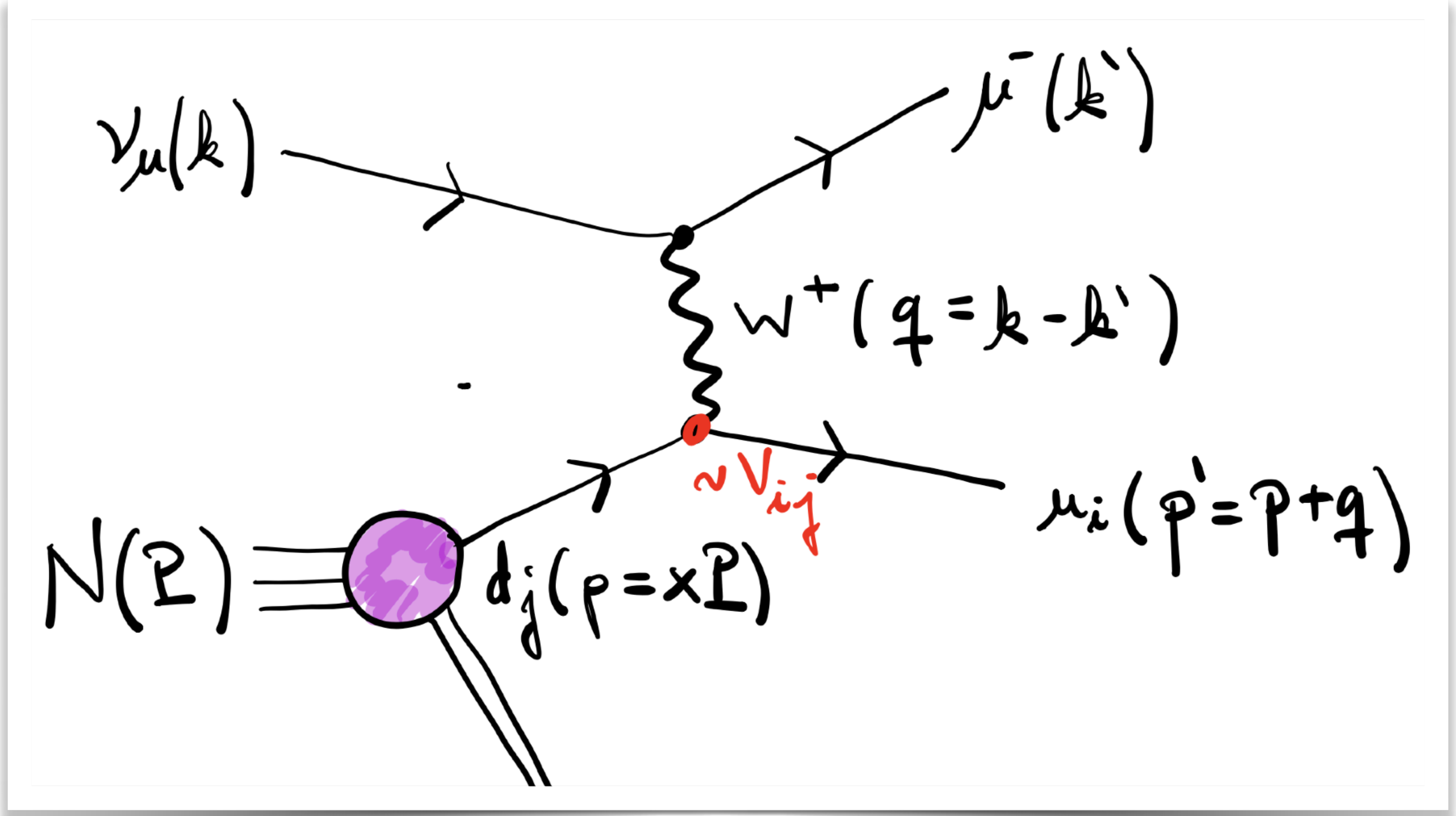
$$x = \frac{Q^2}{2P \cdot q} \qquad \text{(Parton momentum fractions)}$$

DIS double differential cross section:

$$\frac{d\sigma}{dxdQ^2} \Leftrightarrow \frac{d\sigma}{dxdy} \qquad (Q^2 = 2ME_\nu xy)$$

Neutrino DIS

We have both (muon and antielectron) neutrino contributions…



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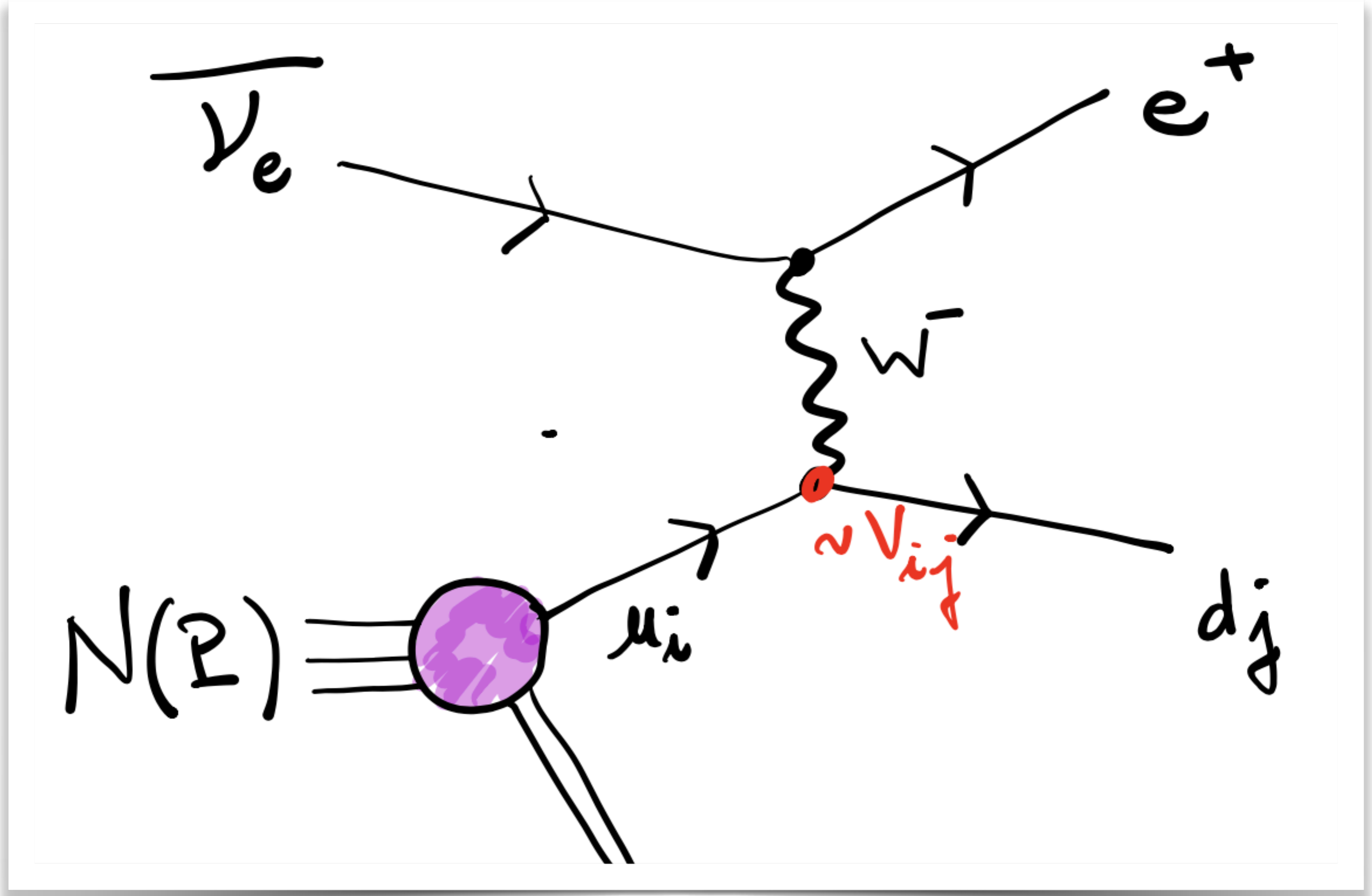
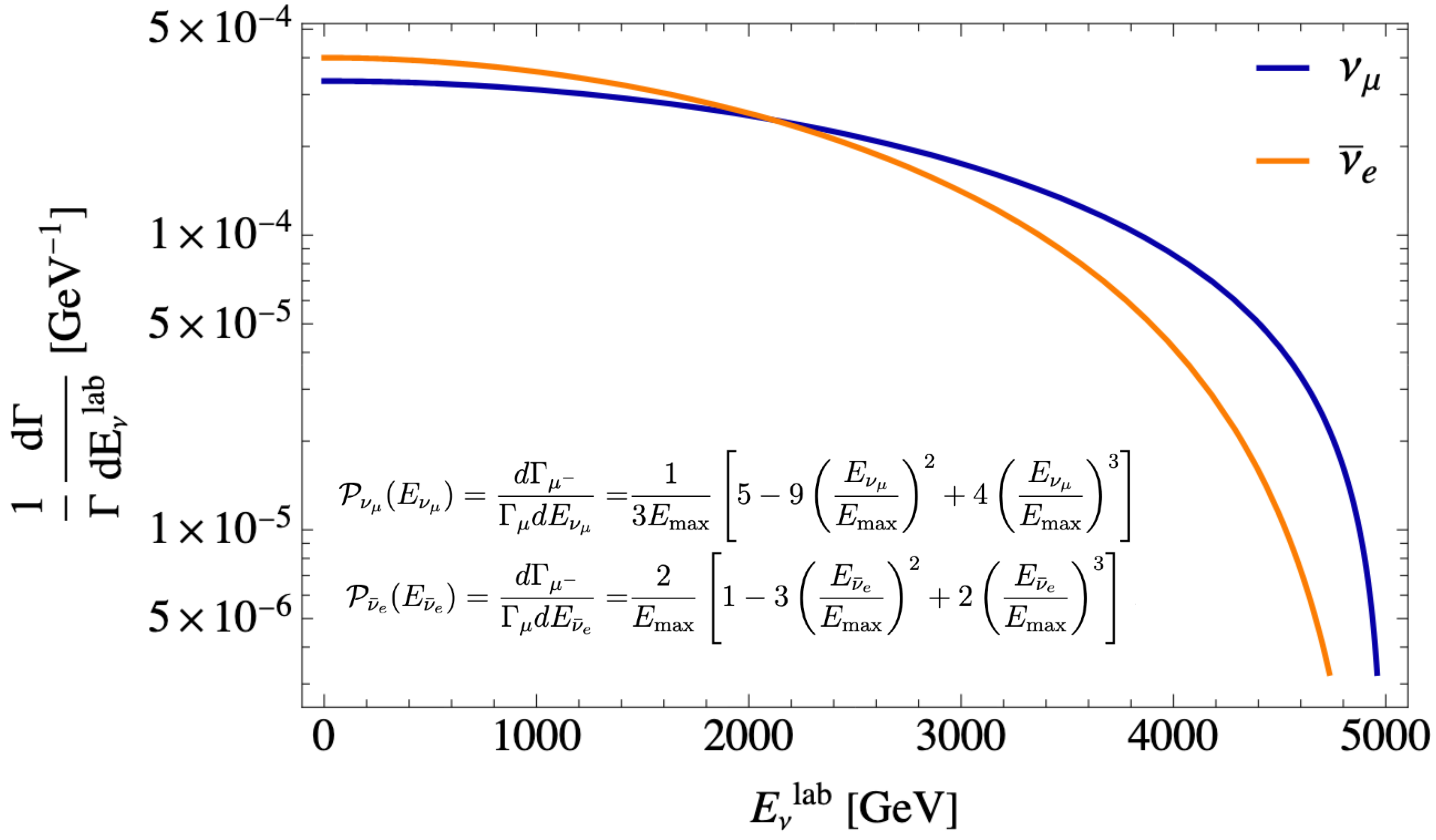


… and *also* the *neutral current* contributions.

Neutrino DIS

An additional consideration: the neutrino beam is *not* monochromatic, we need to account for the energy distribution of the neutrinos.



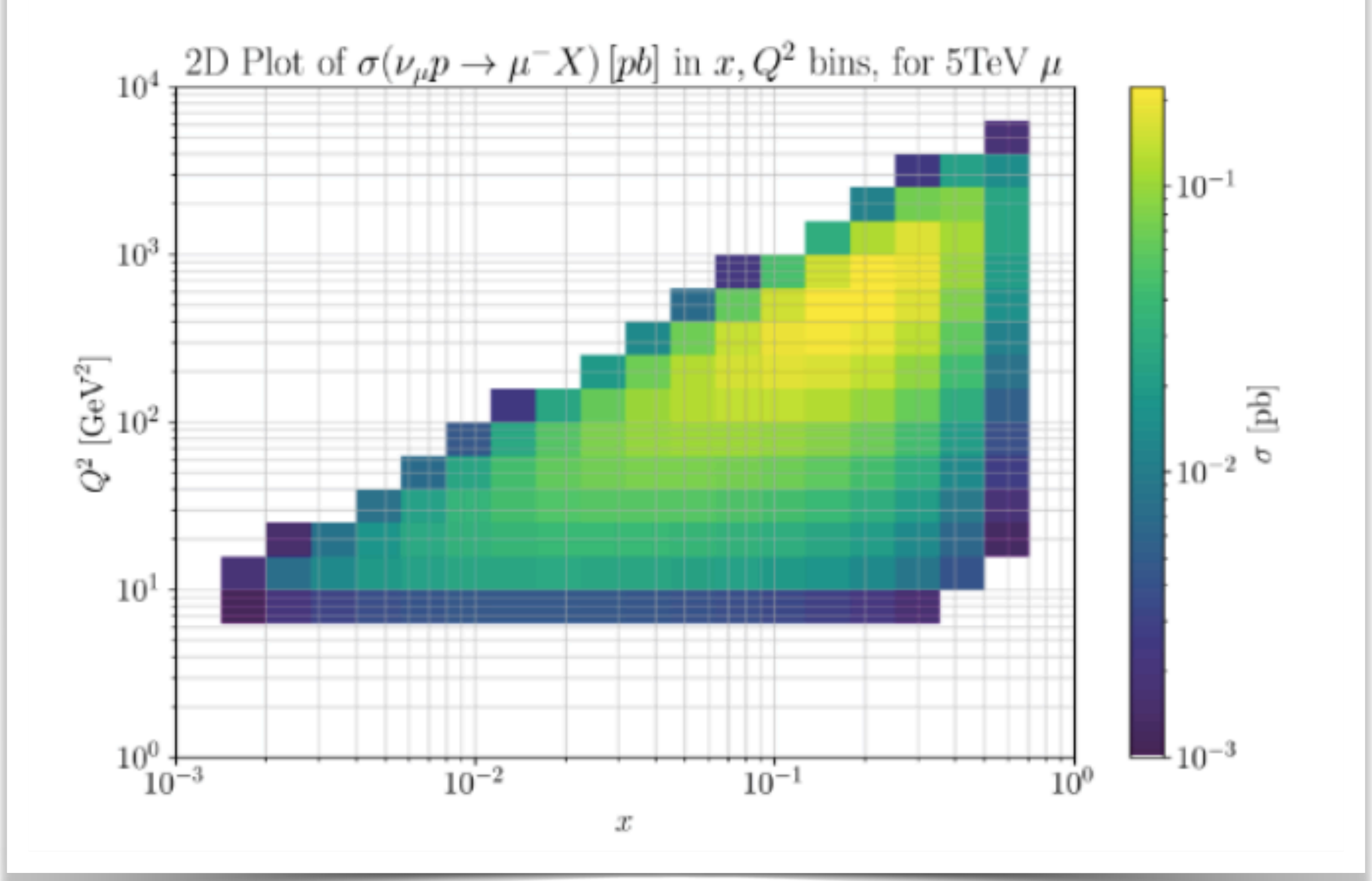
The cross section acquires an extra kinematic dependence due to the variable neutrino energy:

$$\frac{d\sigma}{dx\,dy} \rightarrow \frac{d\Sigma}{dE\,dx\,dy}$$

Neutrino DIS

A representative distribution would look like:

$$\frac{d\sigma}{dxdy} \to \frac{d\Sigma}{dEdxdy}$$



(We have integrated over the neutrino spectrum!)

In these last slides we have been modelling the neutrino beam…

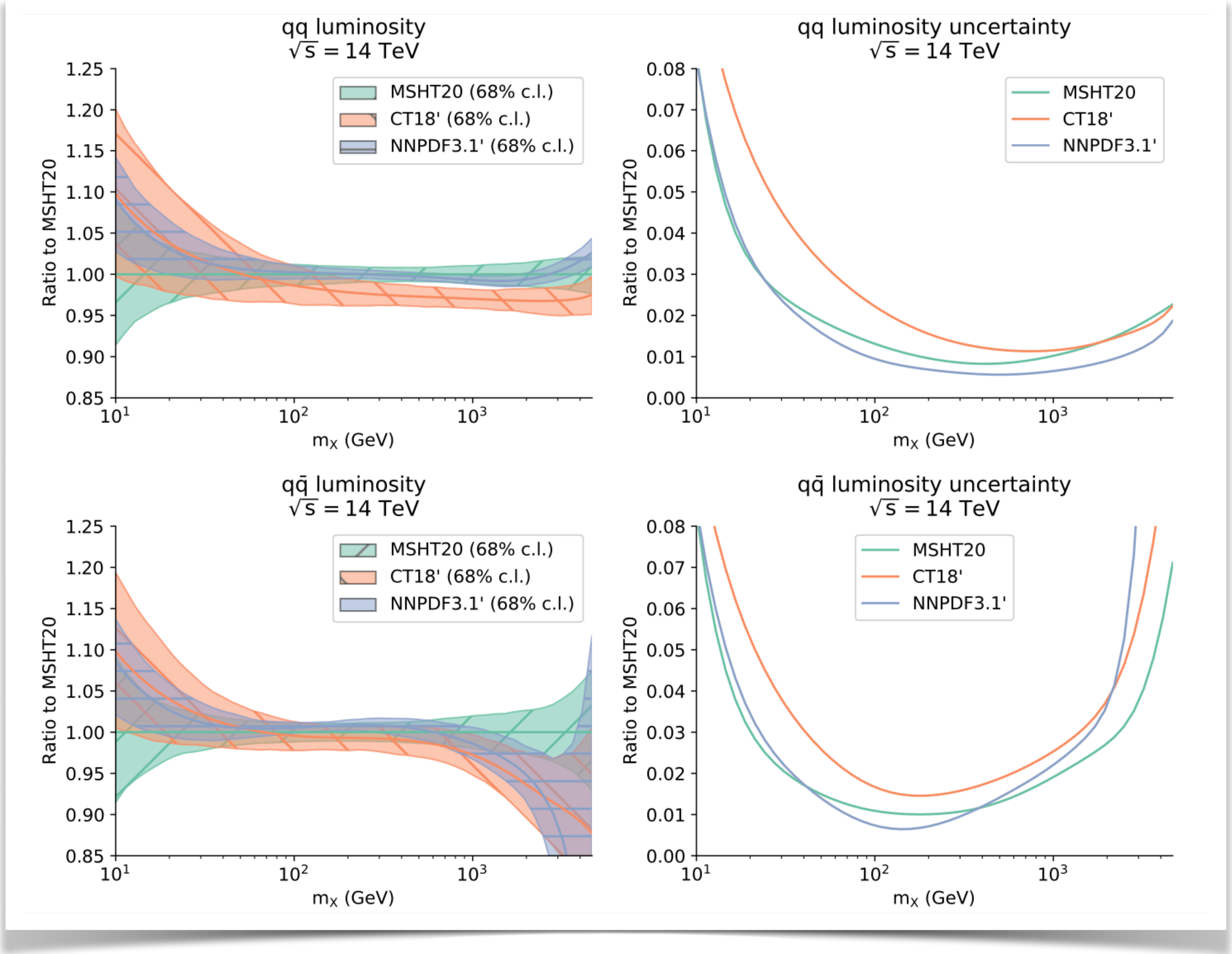
What did we say about the target?

We can describe it in terms of PDFs … but *which* PDFs?

Neutrino DIS PDFs

We saw that PDFs are extracted from fits to data, and different methodologies are available (e.g. NNPDF, MSHT, CT, etc).

PDF determination is a challenging task, and different state-of-the-art methodologies can lead to different results….



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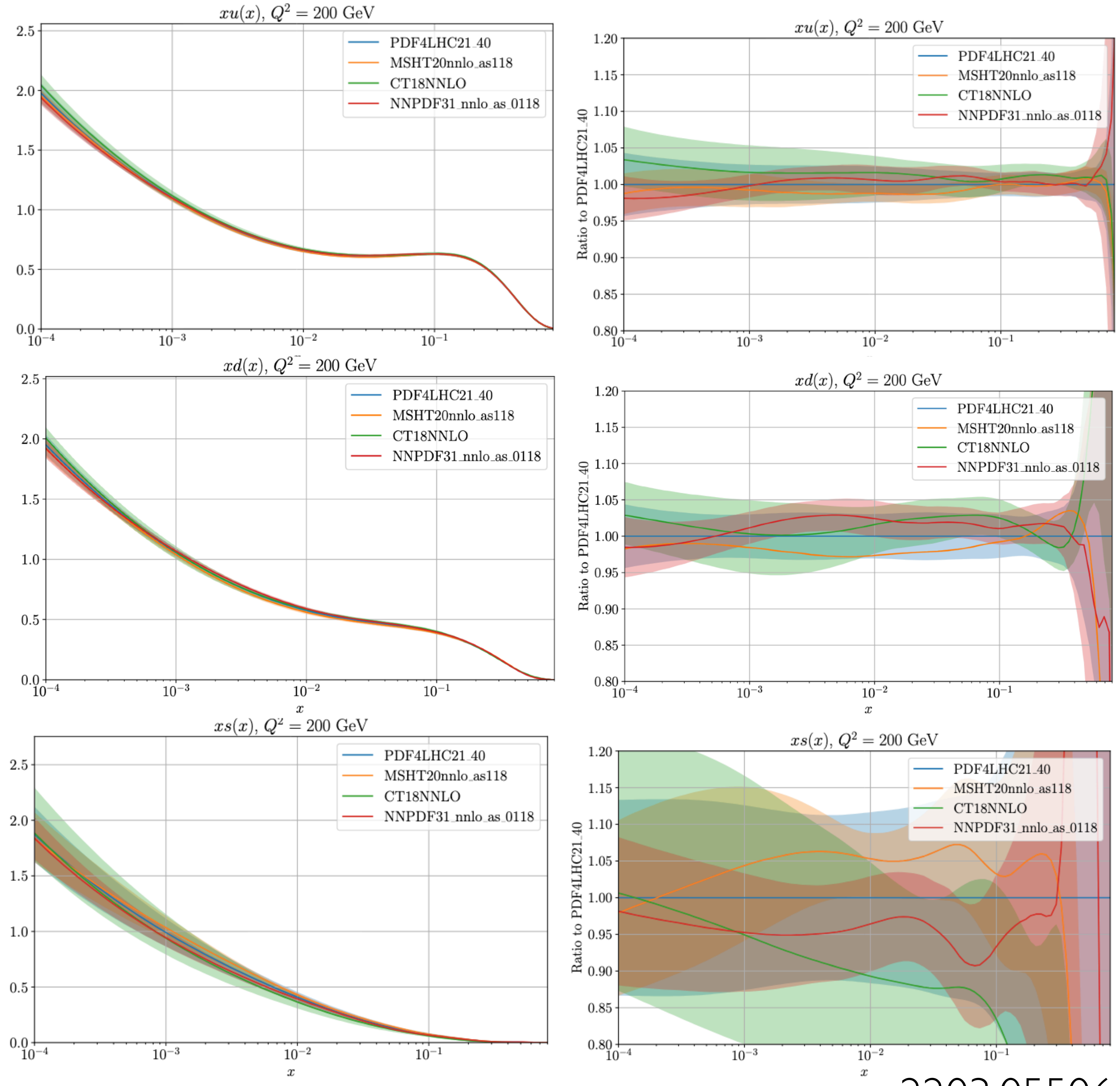
Neutrino DIS PDFs

- For our analysis we adopt PDF4LHC21, a combined PDF fit of individual methodologies.

- It is designed to be a *conservative* joint representation.

- The *baseline* PDF4LHC21 consists of 900 members/replicas which are compressed for public use to a set of *40 replicas.*

But enough about *proton* PDFs…



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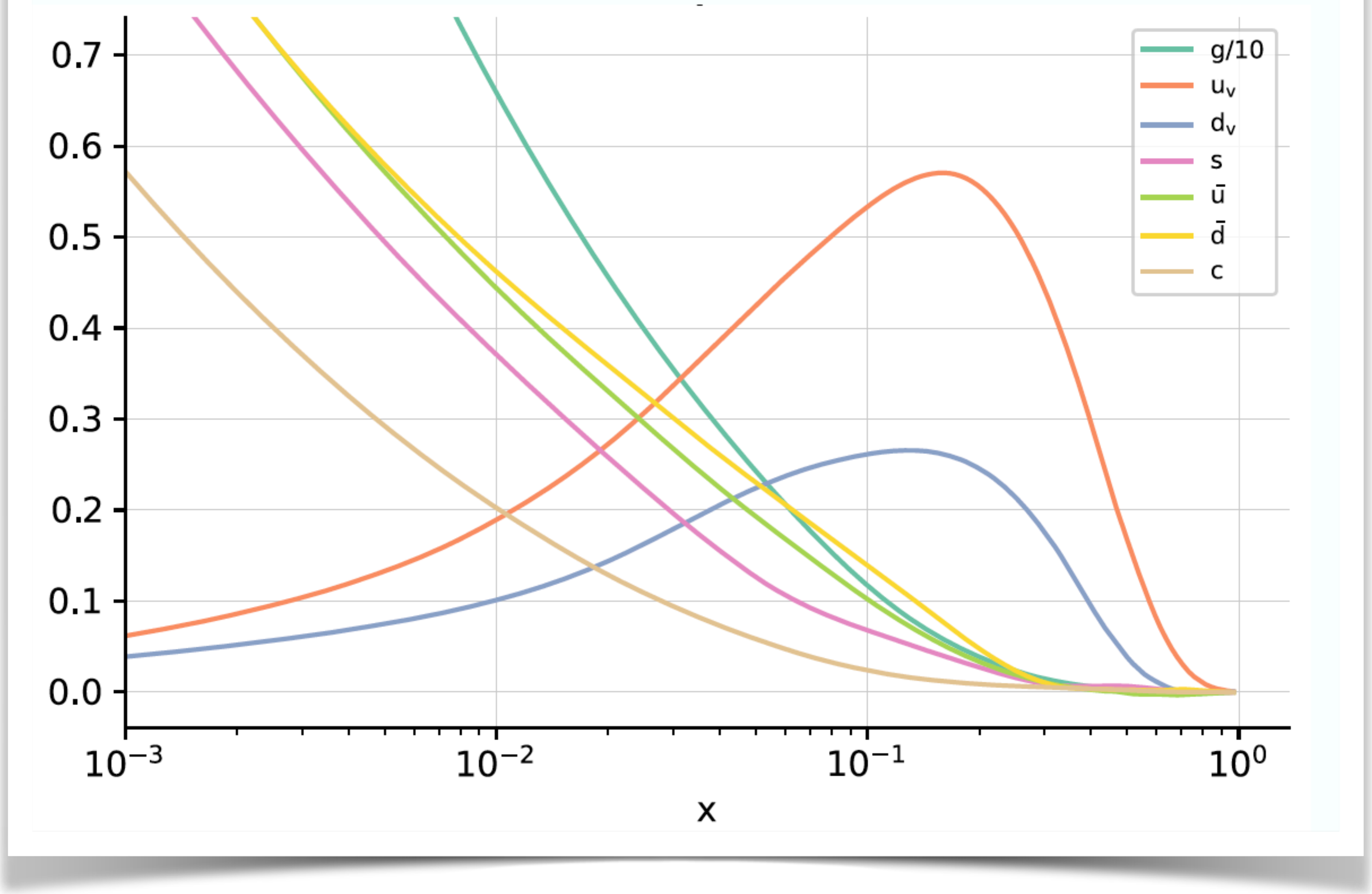
Neutrino DIS PDFs

Finally, we consider the target to be *isoscalar*.

This means that its PDFs can be built from linear combinations of the proton PDF.

Proton PDFs, Q = 100 GeV

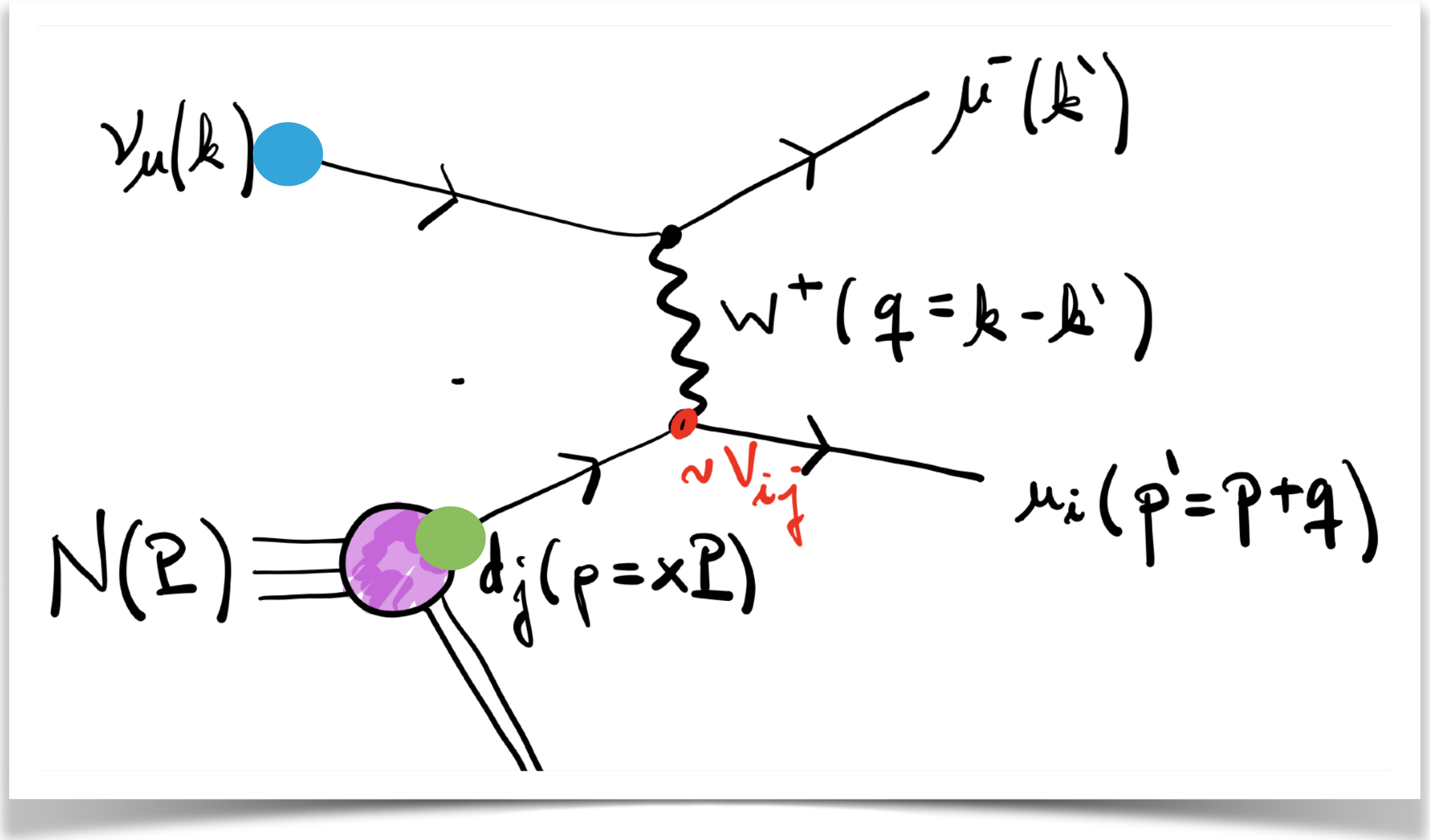


Isoscalar target

$$
\begin{aligned}
u(x,Q^2) &= (u_p(x,Q^2) + d_p(x,Q^2))/2\,,\\
d(x,Q^2) &= (d_p(x,Q^2) + u_p(x,Q^2))/2\,,\\
\bar{u}(x,Q^2) &= (\bar{u}_p(x,Q^2) + \bar{d}_p(x,Q^2))/2\,,\\
\bar{d}(x,Q^2) &= (\bar{d}_p(x,Q^2) + \bar{u}_p(x,Q^2))/2\,,\\
s(x,Q^2) &= s_p(x,Q^2)\,,\\
\bar{s}(x,Q^2) &= \bar{s}_p(x,Q^2)\,,\\
c(x,Q^2) &= c_p(x,Q^2)\,,\\
\bar{c}(x,Q^2) &= \bar{c}_p(x,Q^2)\,.
\end{aligned}
$$

Going back to the observable…

Neutrino DIS



The (CC) muon neutrino distribution is given by

$$\frac{d\Sigma^{\rm DIS}_{\nu_\mu}}{dE\,dx\,dy} = \underbrace{\mathcal{P}_{\nu_\mu}(E)}_{\text{spectrum}} \underbrace{\frac{2G_F^2 M E x}{\pi(1+Q^2/m_W^2)^2}}_{\text{parton kin.}} \times \left(\sum_{f=u,c} \sum_{i=d,s} \underbrace{|V_{fi}|^2}_{\text{CKM}} \underbrace{f_i(x,Q^2)}_{\text{PDF}} + \sum_{f=\bar{d},\bar{s},\bar{b}} \sum_{i=\bar{u},\bar{c}} \underbrace{|V_{fi}|^2}_{\text{CKM}} \underbrace{f_i(x,Q^2)}_{\text{PDF}}(1-y)^2 \right)$$

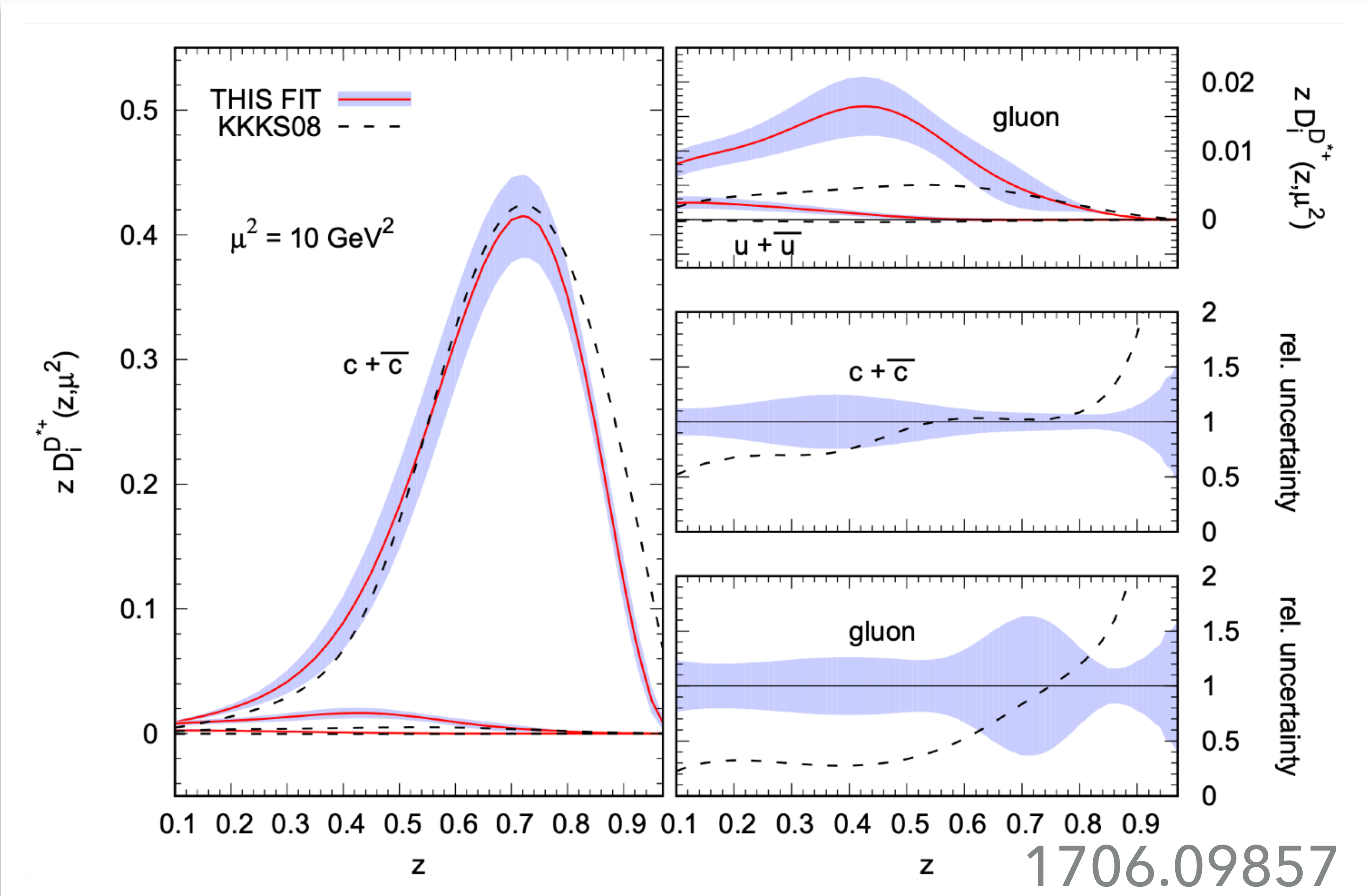
And analogous for electron antineutrino (change spectrum and parton channels).

However, to reconstruct the outgoing parton we need to be able to account for *fragmentation functions*. The aim is to estimate uncertainties coming from the tagging of the final state…

Fragmentation functions

Some intuition: fragmentation functions are the final state analog of PDFs.

$D_q^H(z, Q^2)$: the 'probability' that a parton of type q hadronises into a hadron of type H carrying a fraction z of its momentum at an energy scale Q2.

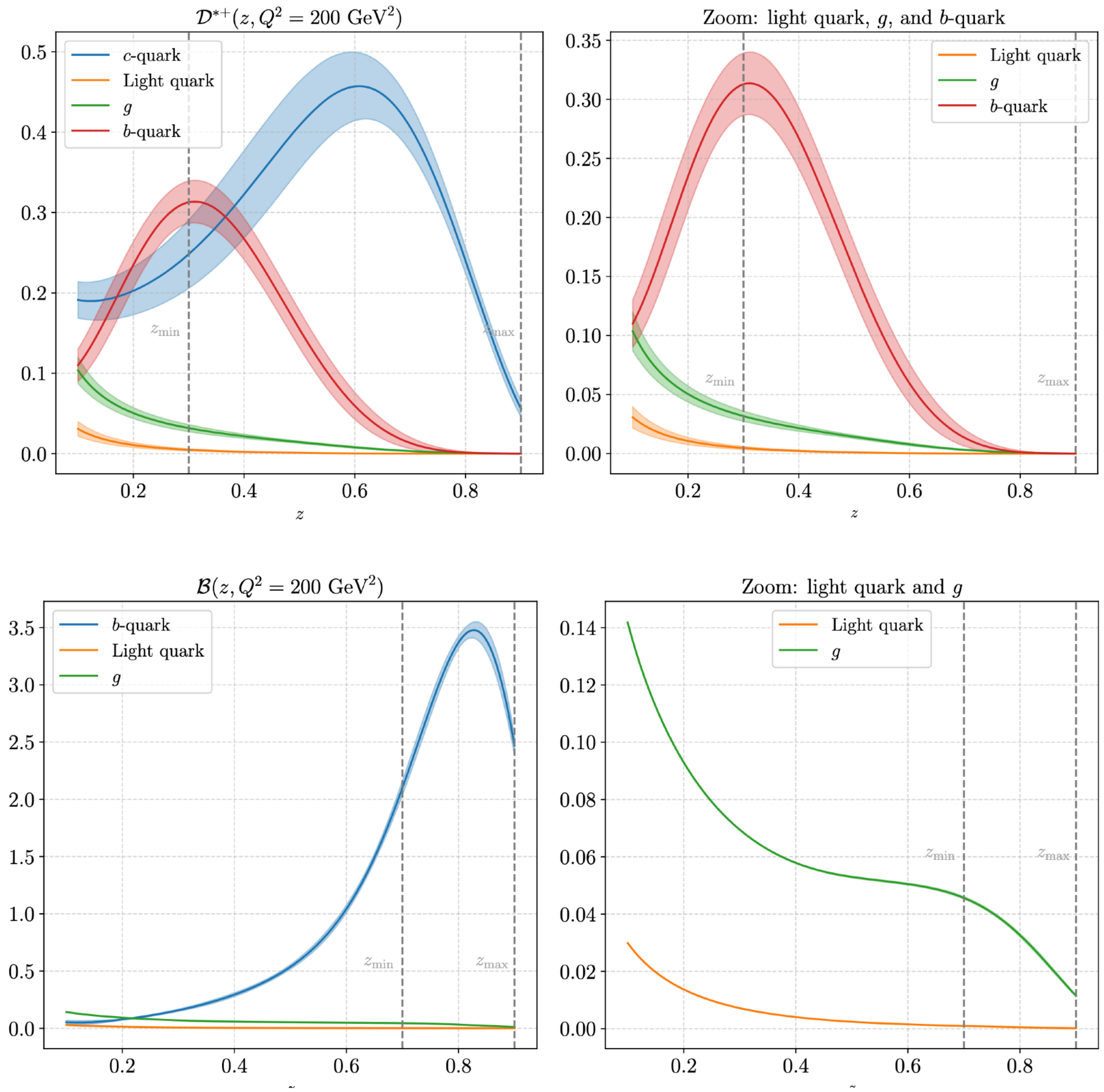


1706.09857

Fragmentation functions

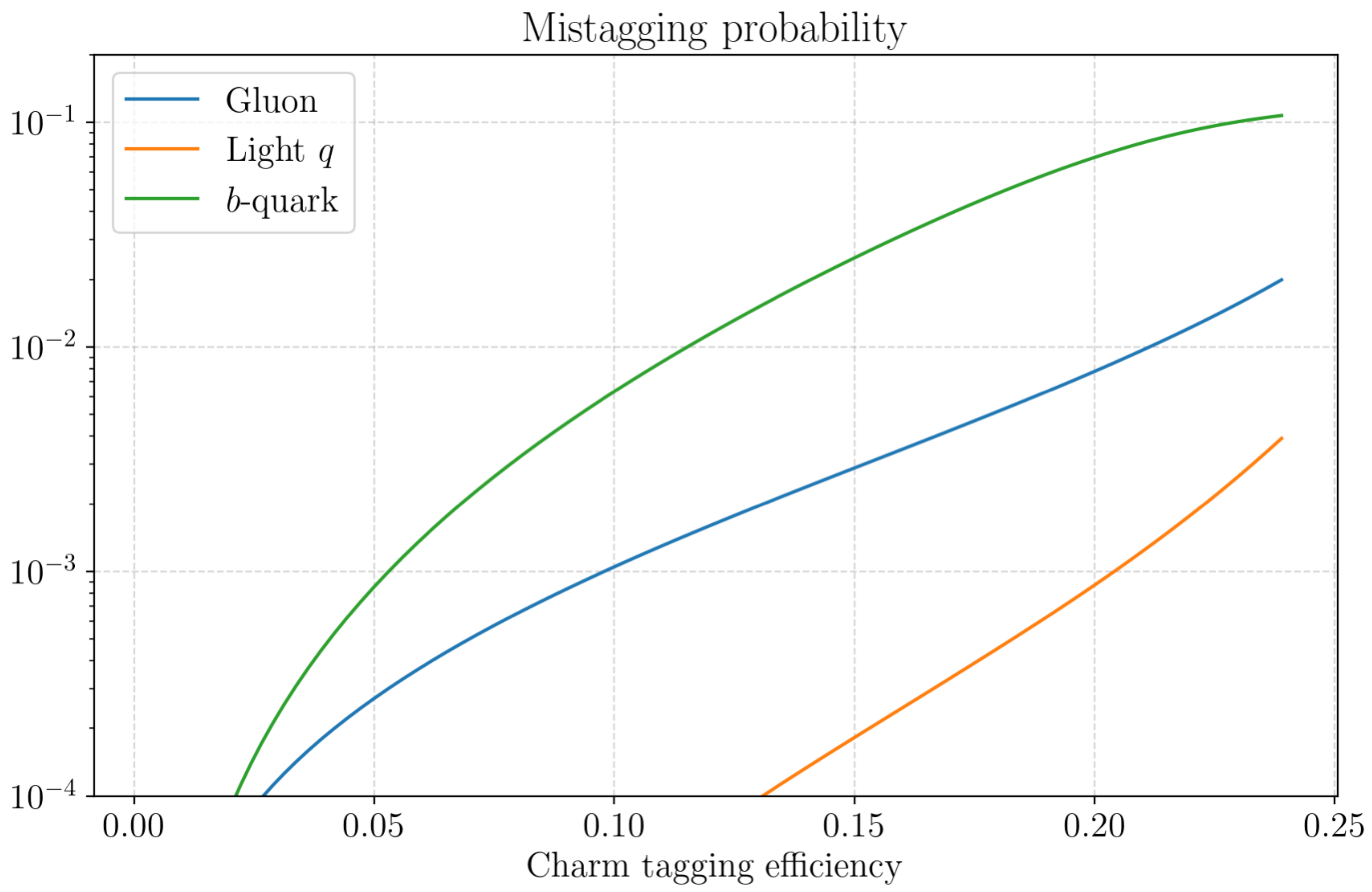
- FFs are used to model the reconstruction of the outgoing parton.
- With them we can estimate uncertainties coming from the tagging of the final state
- We have access to FFs for
  - D* mesons (c-tagging) 1706.09857
  - B-hadrons (b-tagging) 2210.06078

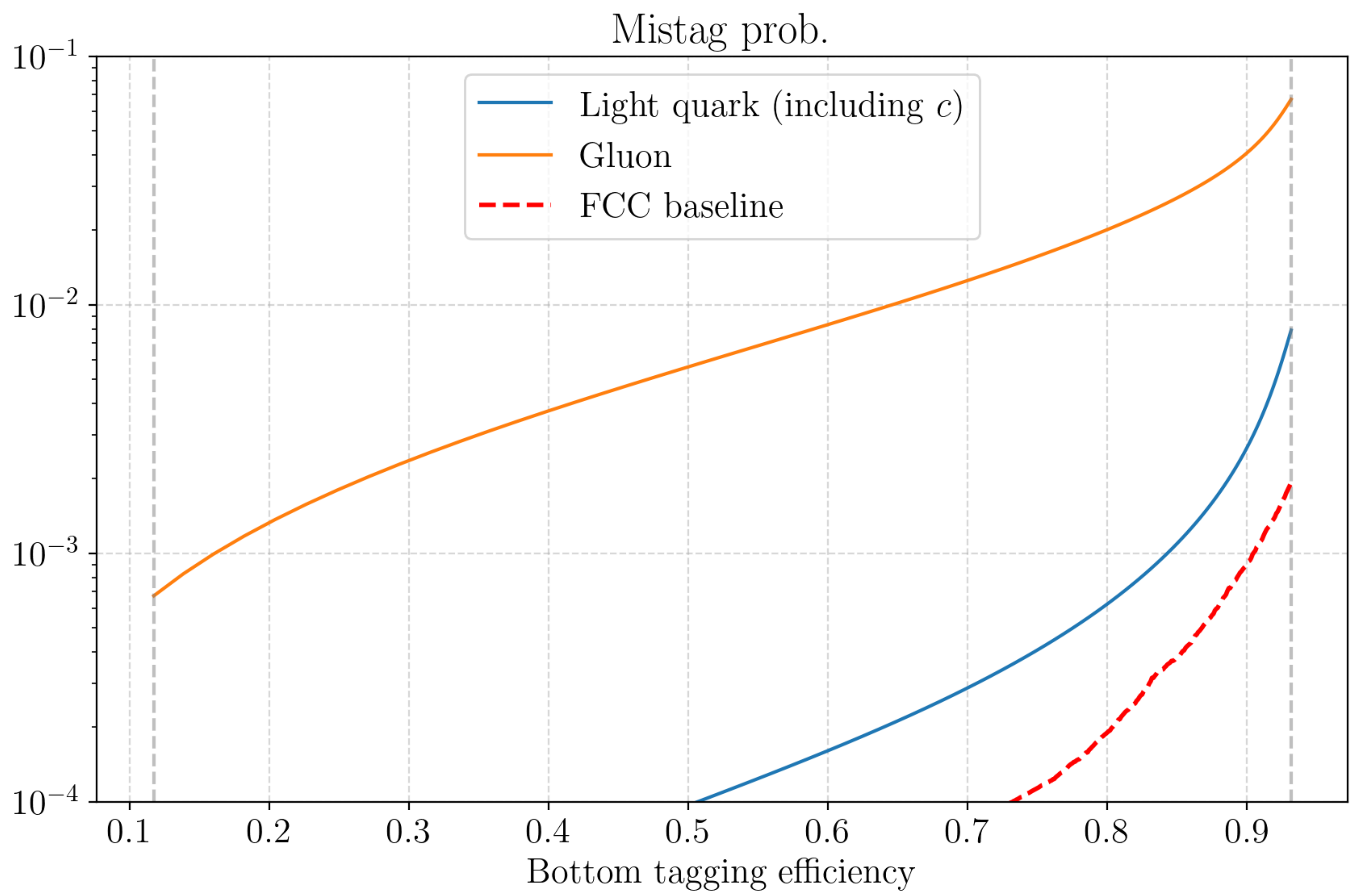
- Defining z-windows for integration allows us to model tagging efficiencies



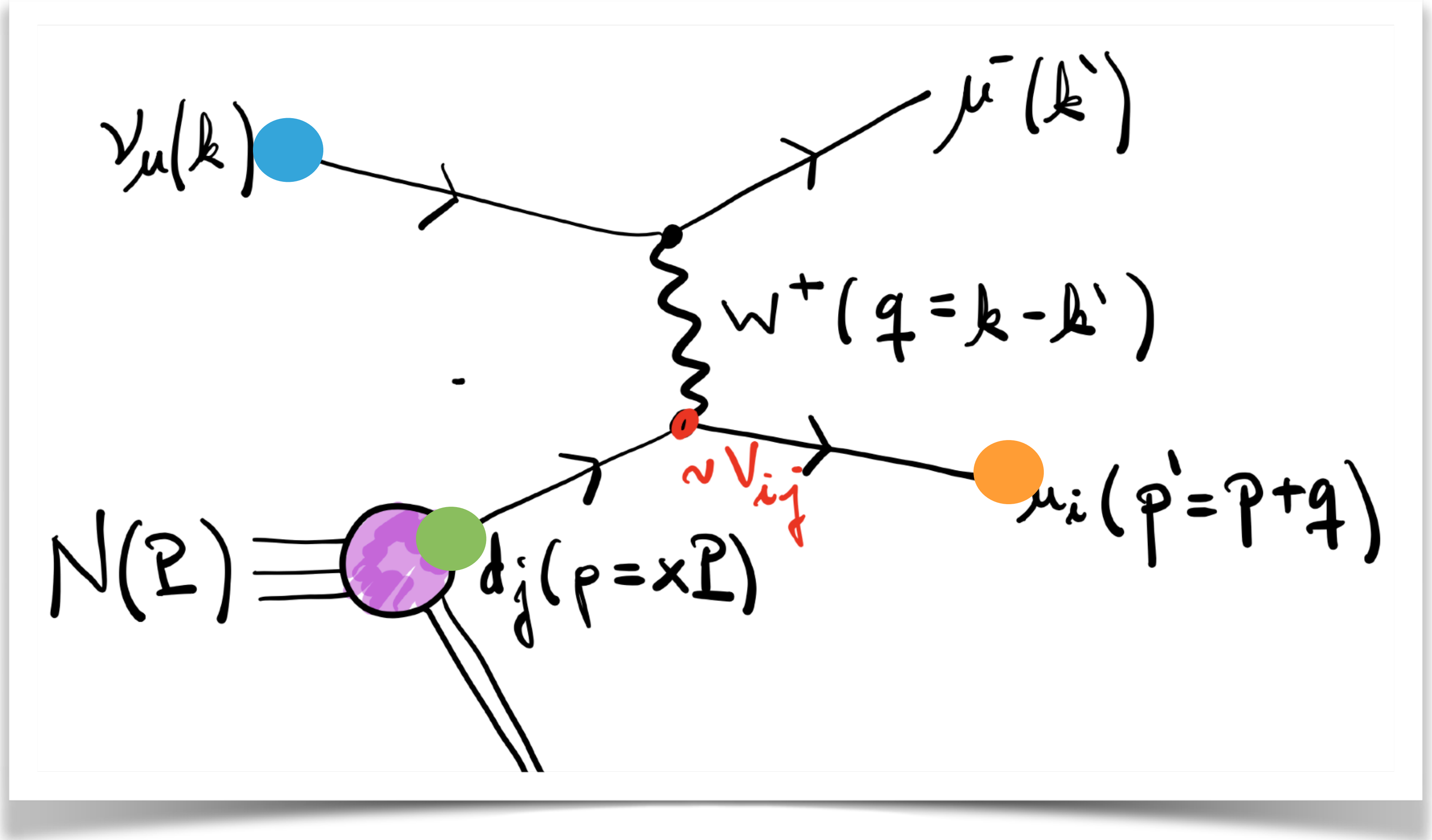
Fragmentation functions

- Defining z-windows for integration allows us to model tagging efficiencies





Neutrino DIS complete



Going back to our CC example:

$$\frac{d\Sigma^{\mathrm{SIDIS}}_{\nu_\mu\to H}}{dEdxdydz} = \overbrace{\mathcal{P}_{\nu_\mu}(E)}^{\text{spectrum}} \overbrace{\frac{2G_F^2 MEx}{\pi(1+Q^2/m_W^2)^2}}^{\text{parton kin.}} \times$$

$$\left(\sum_{f=u,c} \sum_{i=d,s} \underbrace{|V_{fi}|^2}_{\text{CKM}} \underbrace{f_i(x,Q^2)}_{\text{PDF}} \underbrace{D_f^H(z,Q^2)}_{\text{Fr.}} + \sum_{f=\bar{d},\bar{s},\bar{b}} \sum_{i=\bar{u},\bar{c}} \underbrace{|V_{fi}|^2}_{\text{CKM}} \underbrace{f_i(x,Q^2)}_{\text{PDF}} \underbrace{D_f^H(z,Q^2)}_{\text{Fr.}}(1-y)^2 \right)$$

And we are ready to carry out the statistical analysis.

Observables

In bins of (x, Q^2, E_ν) :

In CC:

- Ratio of c- and b-tagged events over the inclusive count $R_{c,b}^{\nu_\mu,\overline{\nu}_e}$

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

In NC:

- Ratio of c- and b-tagged events over the inclusive count $R_{c,b}^{\nu}$

Nuisance parameters account for PDF, fragmentation, luminosity uncertainties, etc.

CKM determination

More specifically,

$\delta_{\rm CKM}$ [%]	PDG
$\lvert V_{cs}\rvert$	0.62
$\lvert V_{cd}\rvert$	1.8
$\lvert V_{cb}\rvert$	3.4
$\lvert V_{ub}\rvert$	5.2
$\lvert V_{ud}\rvert$	0.032
$\lvert V_{us}\rvert$	0.38

CKM determination

More specifically,

δ_{CKM} [%]	PDG	CC+NC (stat.)
$\|V_{cs}\|$	0.62	0.0030
$\|V_{cd}\|$	1.8	0.0091
$\|V_{cb}\|$	3.4	0.28
$\|V_{ub}\|$	5.2	1.7
$\|V_{ud}\|$	0.032	0.00091
$\|V_{us}\|$	0.38	0.026

CKM determination

More specifically,

δ_{CKM} [%]	PDG	CC+NC (stat.)	CC
$\|V_{cs}\|$	0.62	0.0030	0.16
$\|V_{cd}\|$	1.8	0.0091	0.29
$\|V_{cb}\|$	3.4	0.28	0.70
$\|V_{ub}\|$	5.2	1.7	1.8
$\|V_{ud}\|$	0.032	0.00091	0.032
$\|V_{us}\|$	0.38	0.026	0.12

CKM determination

More specifically,

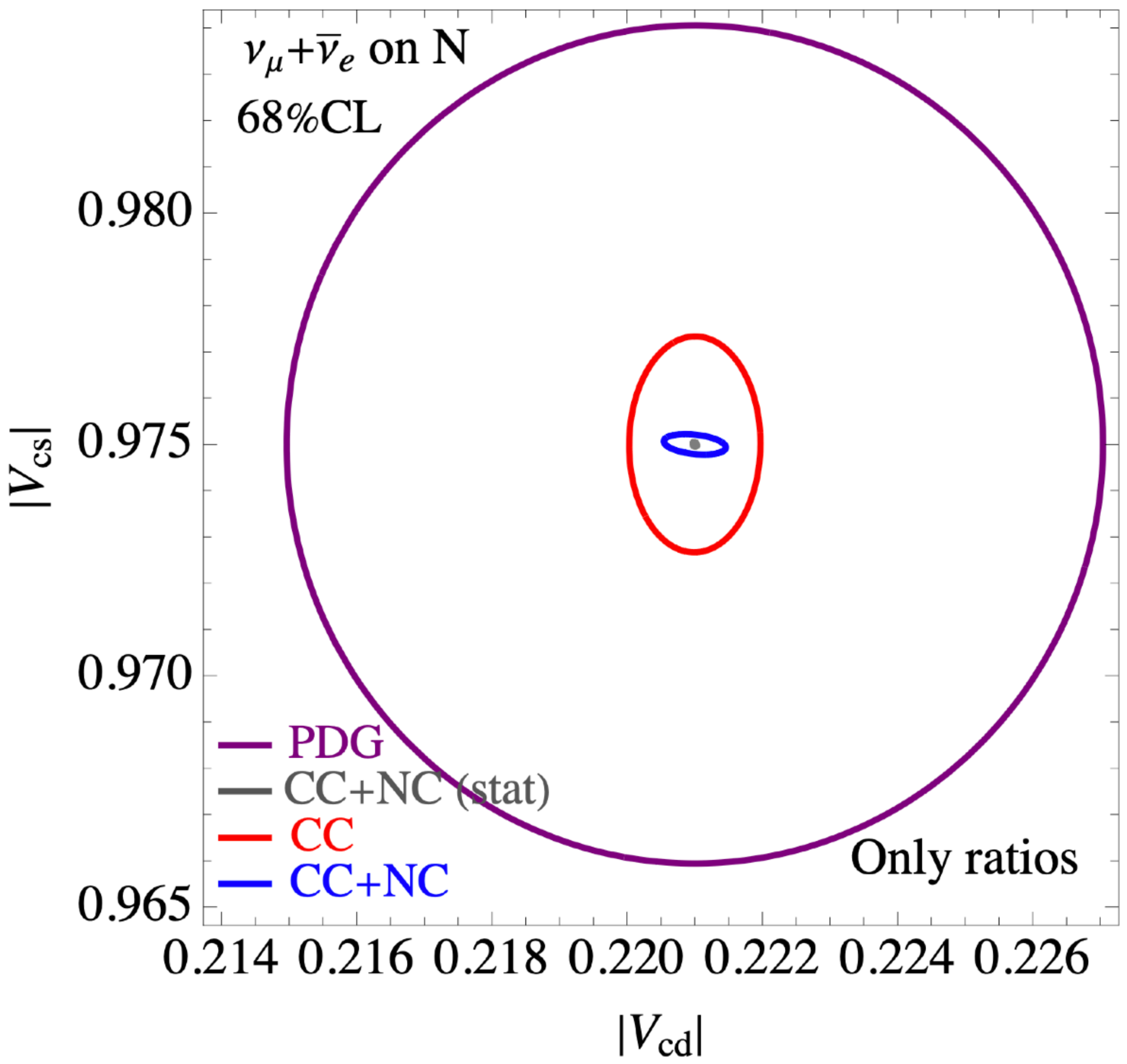
δ_{CKM} [%]	PDG	CC+NC (stat.)	CC	CC+NC
$\lvert V_{cs}\rvert$	0.62	0.0030	0.16	0.015
$\lvert V_{cd}\rvert$	1.8	0.0091	0.29	0.14
$\lvert V_{cb}\rvert$	3.4	0.28	0.70	0.32
$\lvert V_{ub}\rvert$	5.2	1.7	1.8	1.7
$\lvert V_{ud}\rvert$	0.032	0.00091	0.032	0.0051
$\lvert V_{us}\rvert$	0.38	0.026	0.12	0.048

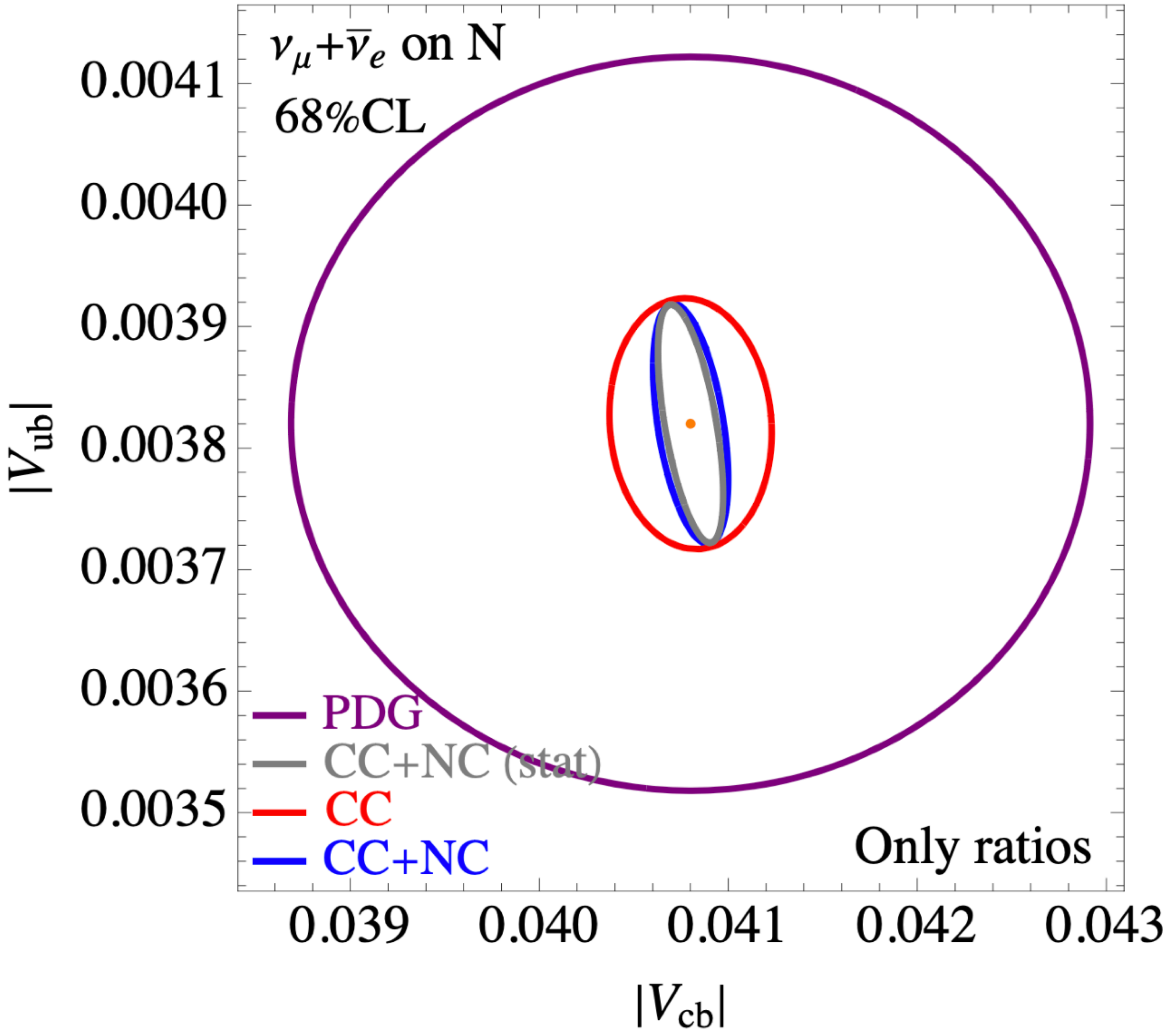
We see a strong improvement in precision.

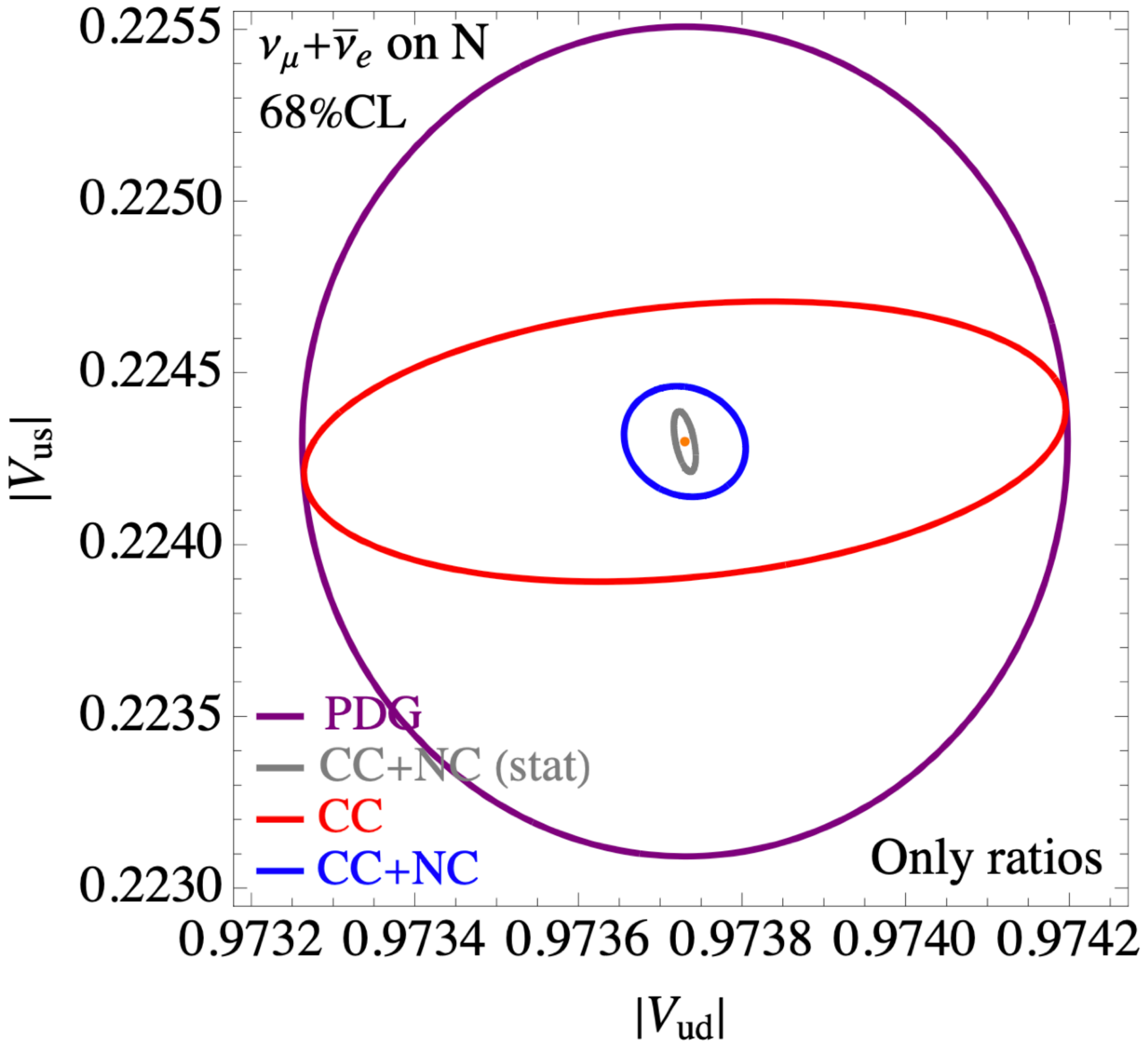
This improvement is driven by the high statistics of the neutrino flux and the exploitation of correlations and shape information (from the PDFs, FFs, spectrum, parton level kinematics, etc).

CKM determination

Constraints on CKM elements (profiled over the nuisance and other elements):







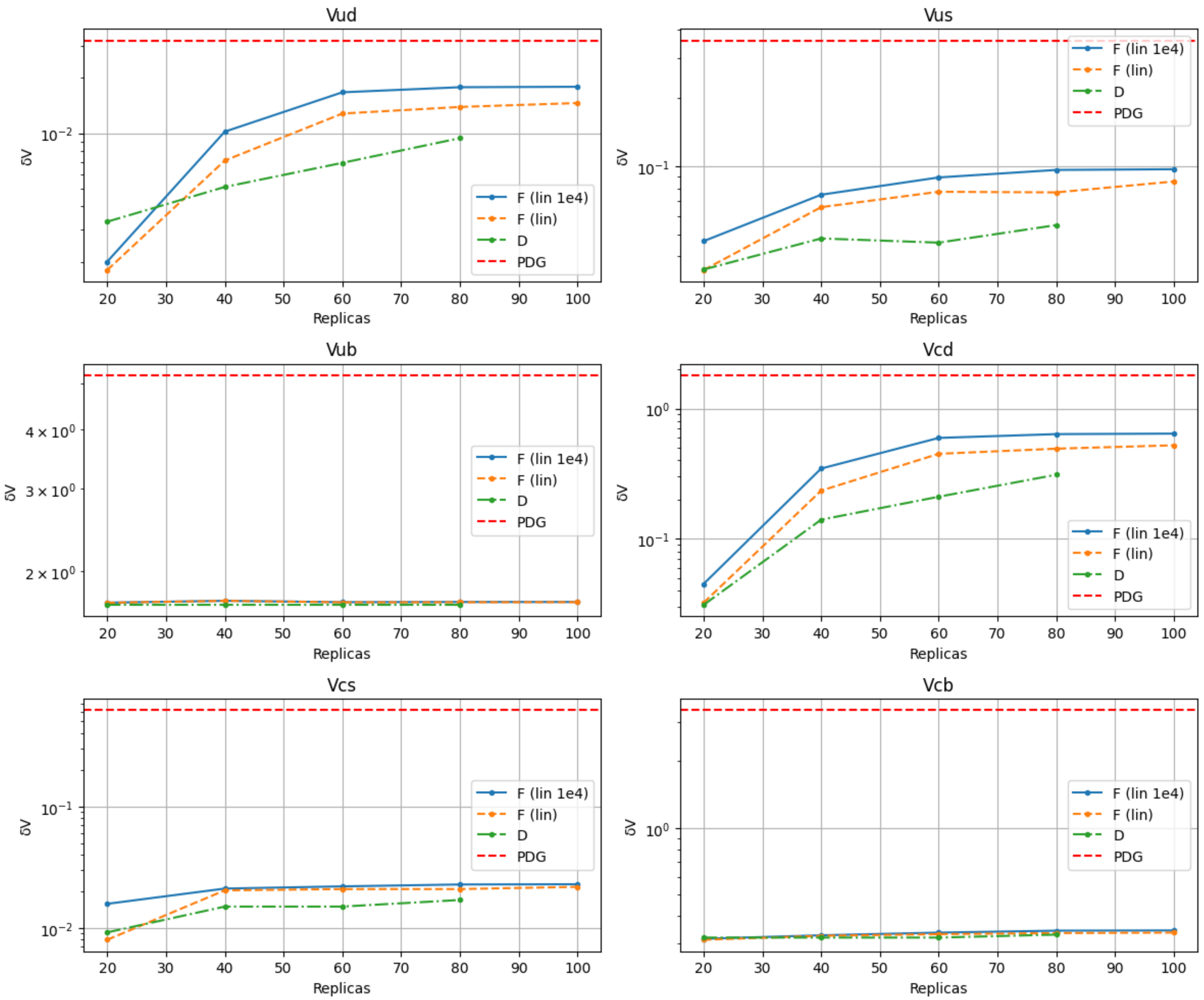
We see a good improvement in precision (even in the presence of systematics).

Stability in the PDFs

- We assess the stability of the results by carrying out the analysis with Hessian sets of different dimensions: 20, 40, 60, 80, 100, and ask:

- Do more flexible PDF parametrisations yield the same result?

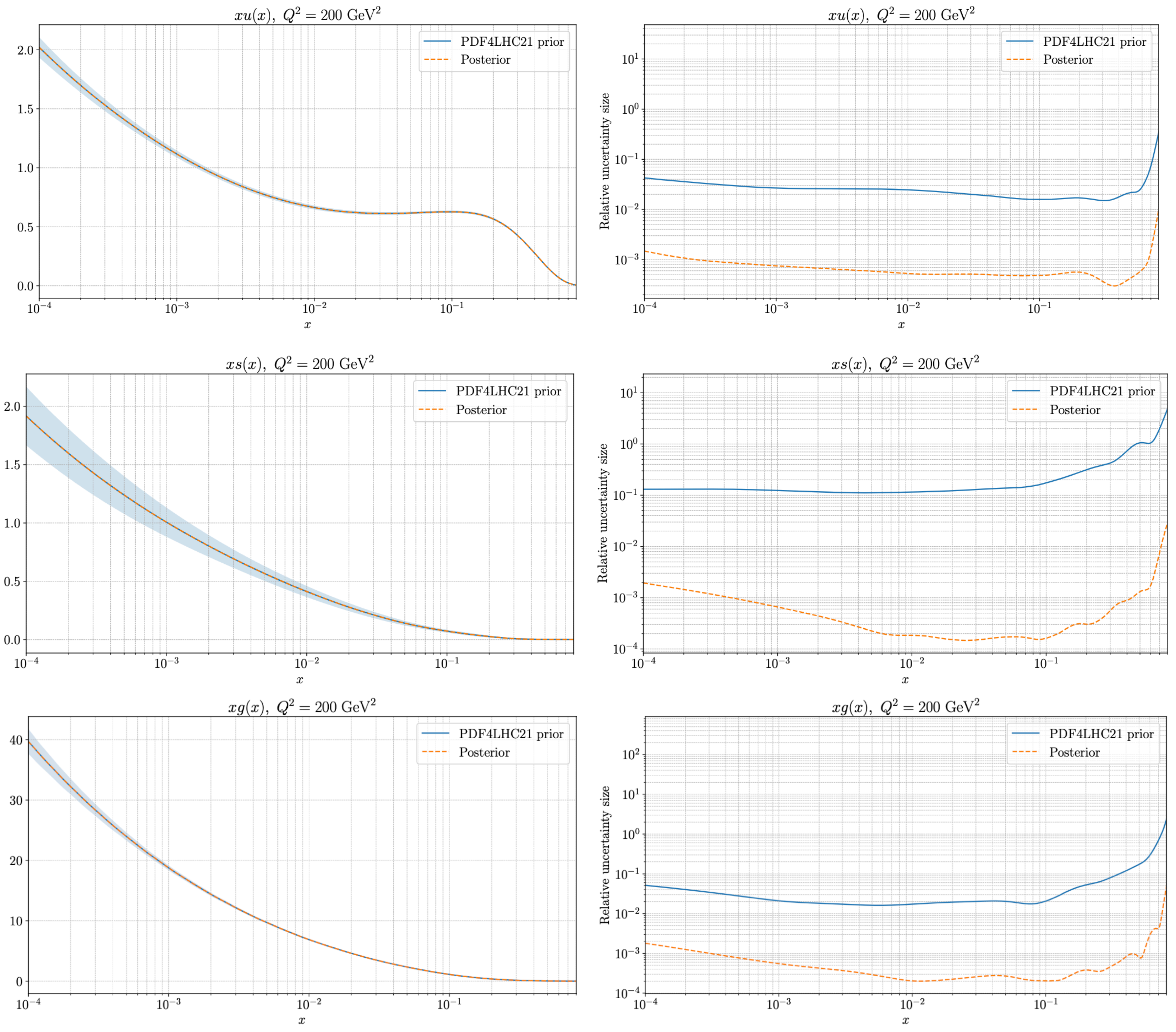
- The Hessian sets are produced via mc2hessian conversion from the PDF4LHC21 baseline fit (900 MC replicas)



PDF posteriors

Our DIS setup allows us to constrain also the PDFs.

A substantial improvement in precision is achieved across the board.



CKM determination

To be further explored:

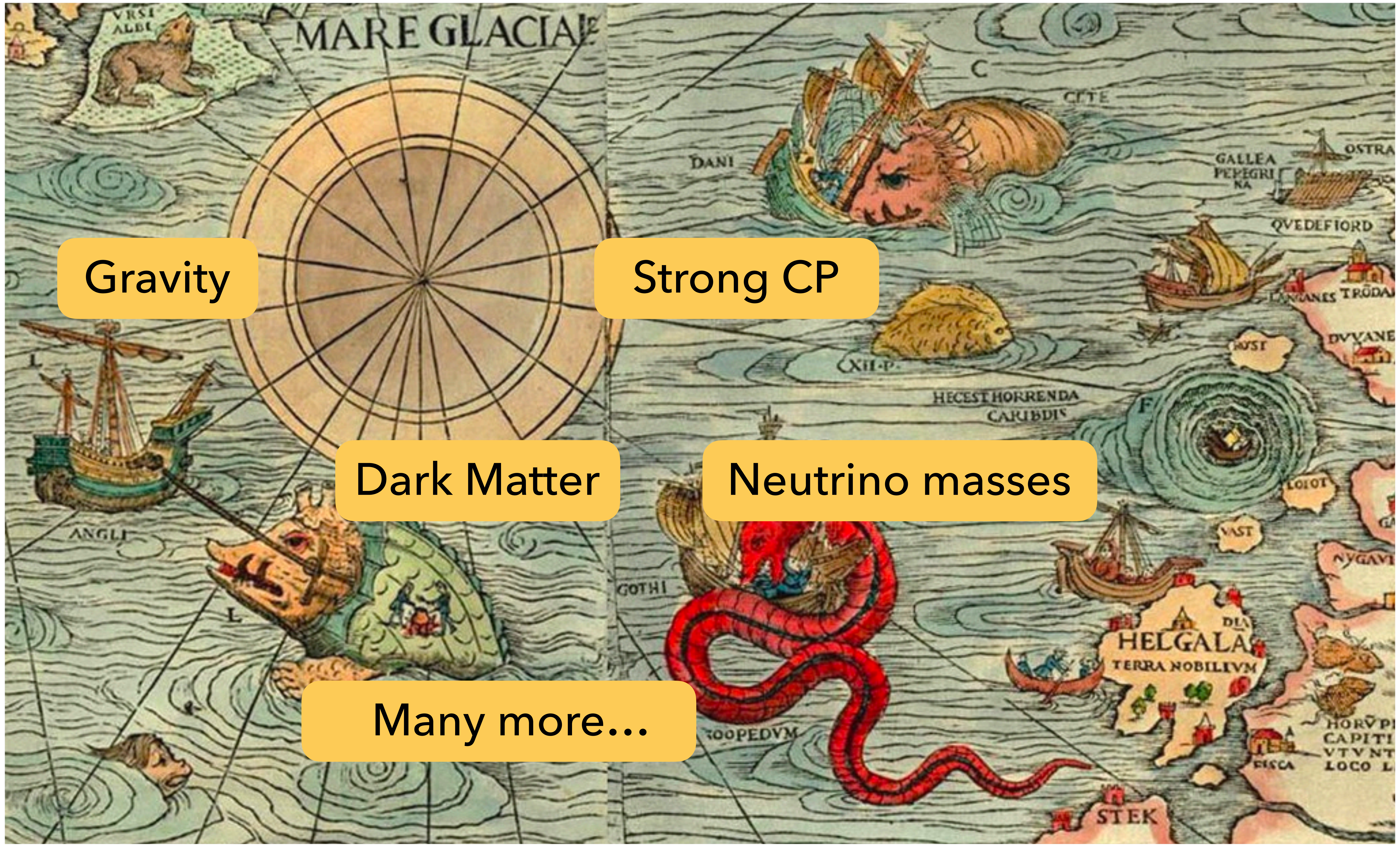
- Additional sources of theory uncertainties (higher order contributions, mass effects, …)
- Reconstruction of event kinematics and tagging/fragmentation….
- Nuclear corrections in parton densities, isospin symmetry breaking effects…
- …

The analysis we have presented goes forward in parallel with other aspects of the MuC physics programme.

Precision for PDF-BSM interplay

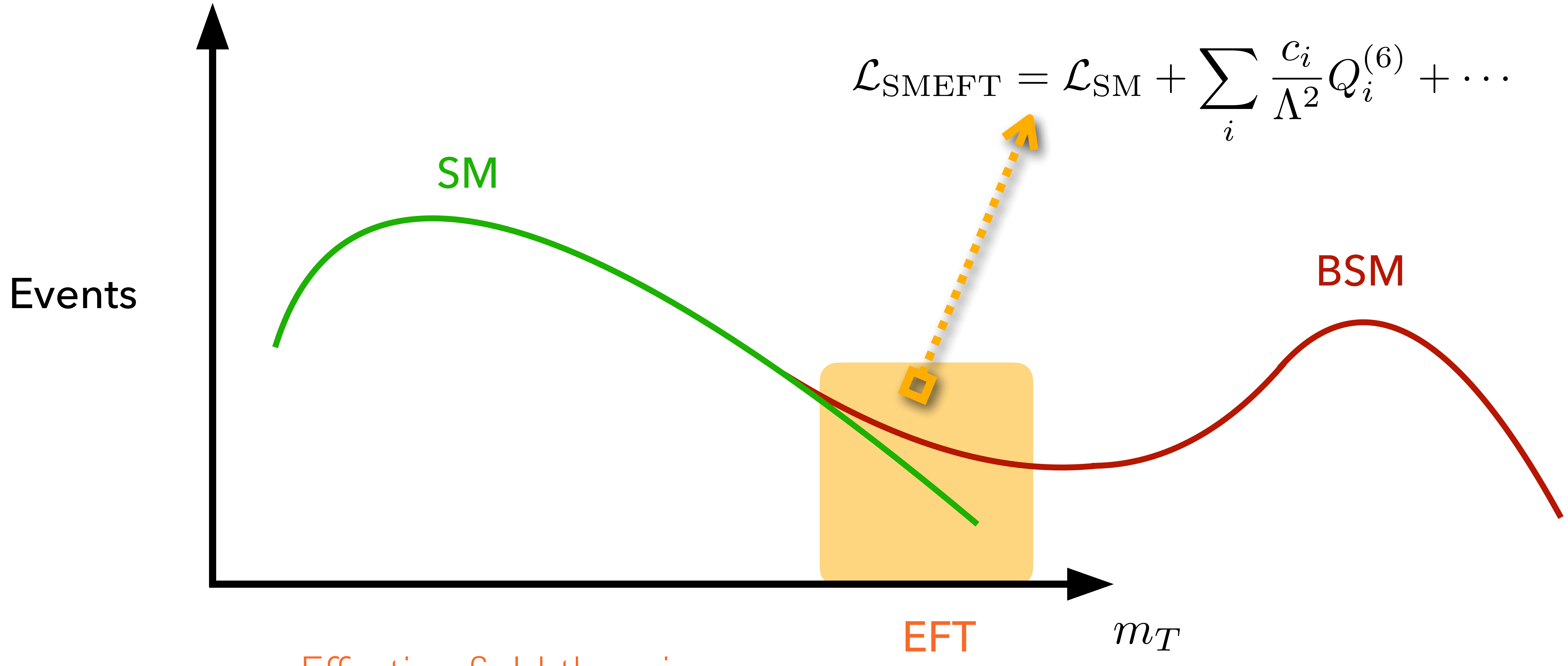
Is that it?

All that we have discussed so far is in the context of the SM, but we know that it cannot be the whole story …



Beyond the SM

In the language of EFTs



Effective field theories

PDF-BSM interplay

A problem in global searches: PDF and BSM worlds do not usually talk to each other.

θ : PDF parameters

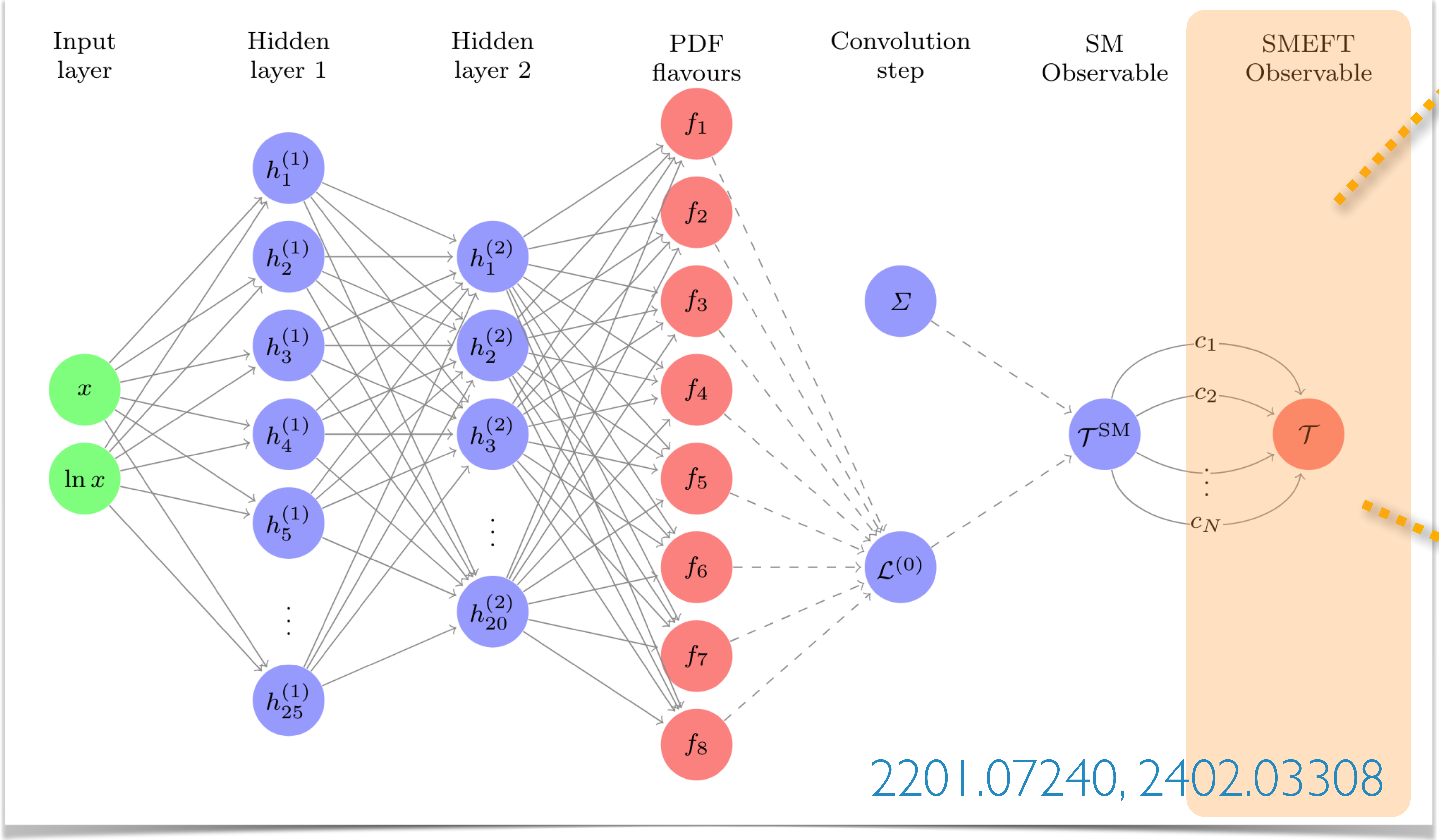
c : BSM parameters

PDF fits	EFT fits
BSM coefficient are kept fixed	PDF coefficients are kept fixed
$c = \bar{c}$	$\theta = \bar{\theta}$
$\sigma(\theta, \bar{c}) = \mathrm{PDF}(\theta) \otimes \hat{\sigma}(\bar{c})$	$\sigma(\bar{\theta}, c) = \mathrm{PDF}(\bar{\theta}) \otimes \hat{\sigma}(c)$

The most general description needs a *simultaneous* determination.

SIMUnet

We can explore the structure of the proton and potential signals of BSM physics *simultaneously* with NNs



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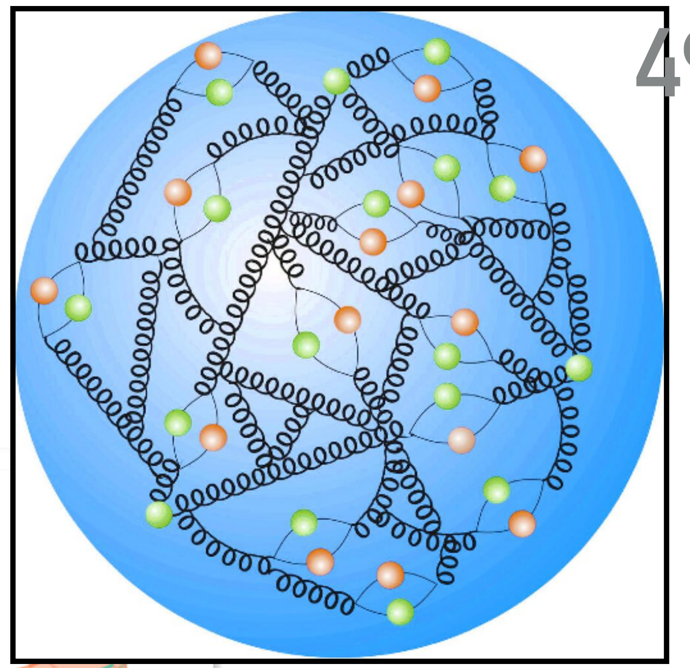
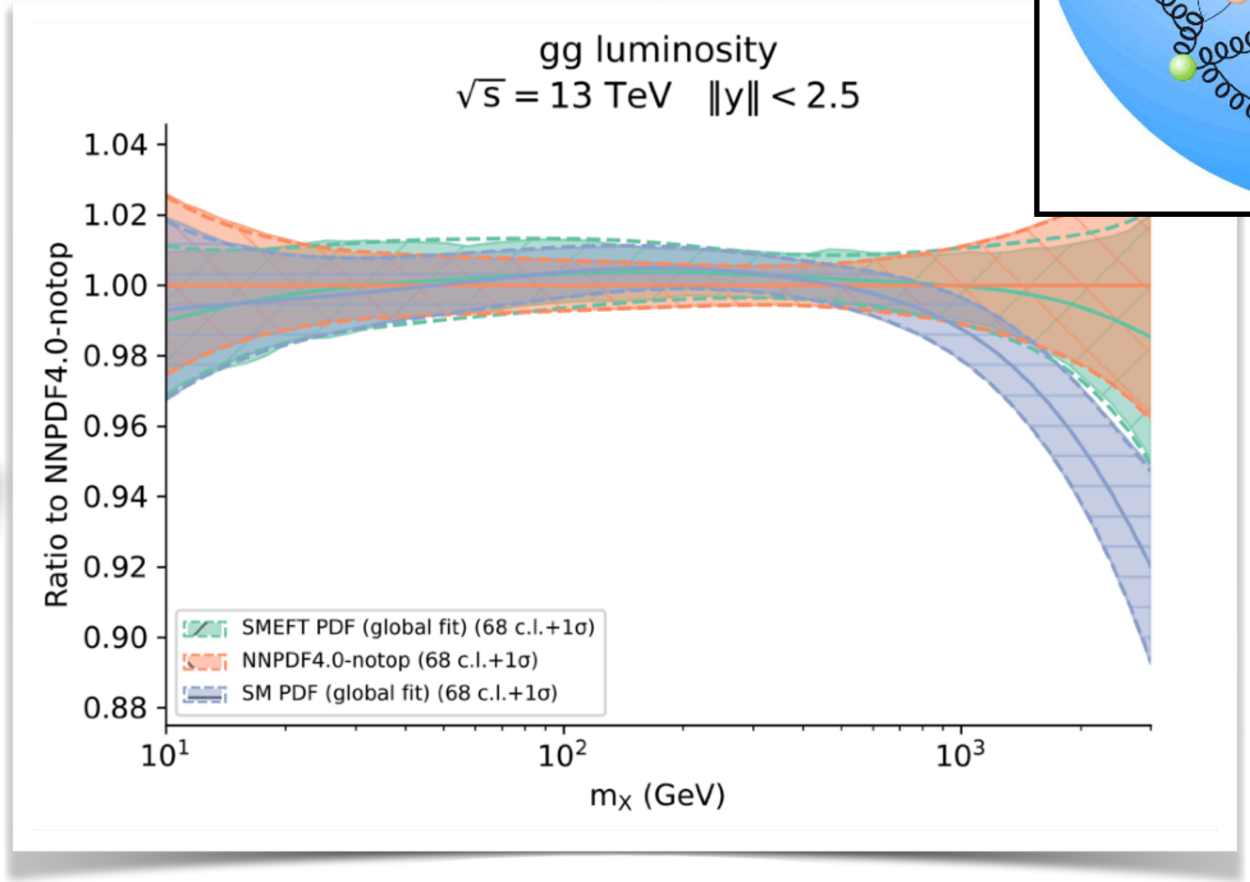
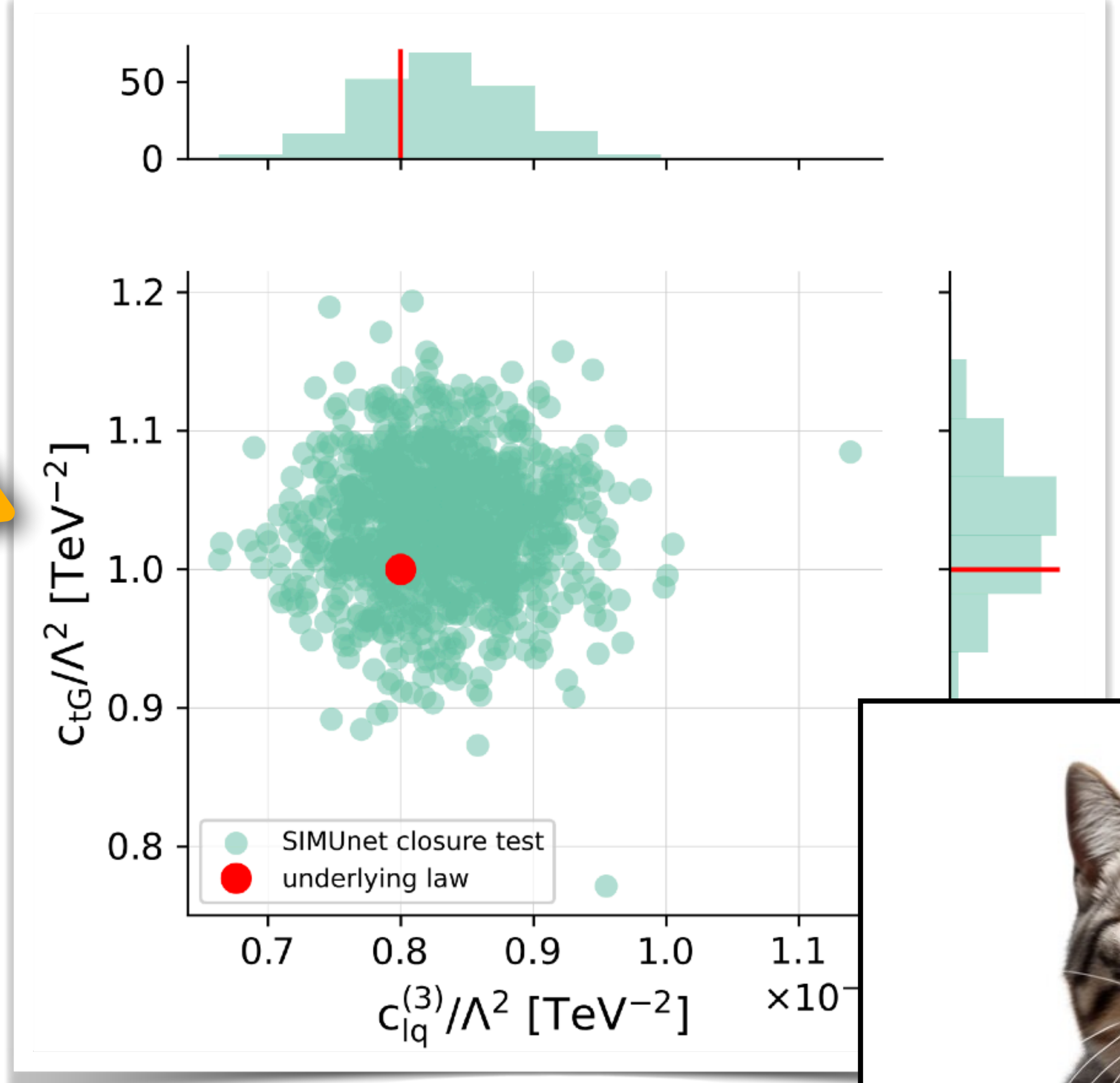




proton structure



new physics

SIMUnet

The SIMUnet architecture allows to perform two types of analyses:

1. Simultaneous fits of PDF and new physics (EFT) coefficients (not discussed here).
2. Assess the potential **absorption** of new physics effects by the PDFs.

We will work in a setting where we *know* the law of Nature: we generate 'pseudodata' according to our model, perform a fit, and assess fit quality metrics.

$$T \equiv T(\theta_{\mathrm{SM}}, \theta_{\mathrm{NP}})$$

Fit name	**Nature**	**Fitted parameters**
Baseline	Standard Model: $\theta^*_{\mathrm{NP}} \equiv 0$	Standard Model only: θ_{SM}
Contaminated	SM + new physics: $\theta^*_{\mathrm{NP}} \neq 0$	Standard Model only: θ_{SM}

NP absorption

- How can we assess if PDFs have been contaminated by NP?
- If there is a considerable number of data that enter the fit that are not affected NP, and *some* that data that are affected by NP, they could appear inconsistent and poorly described in the global fit.
- PDFs have **absorbed** NP if the fit quality of the global dataset is good i.e., for each dataset,

$$n_\sigma = \frac{\chi^2 - 1}{\sigma_{\chi^2}} < 2$$

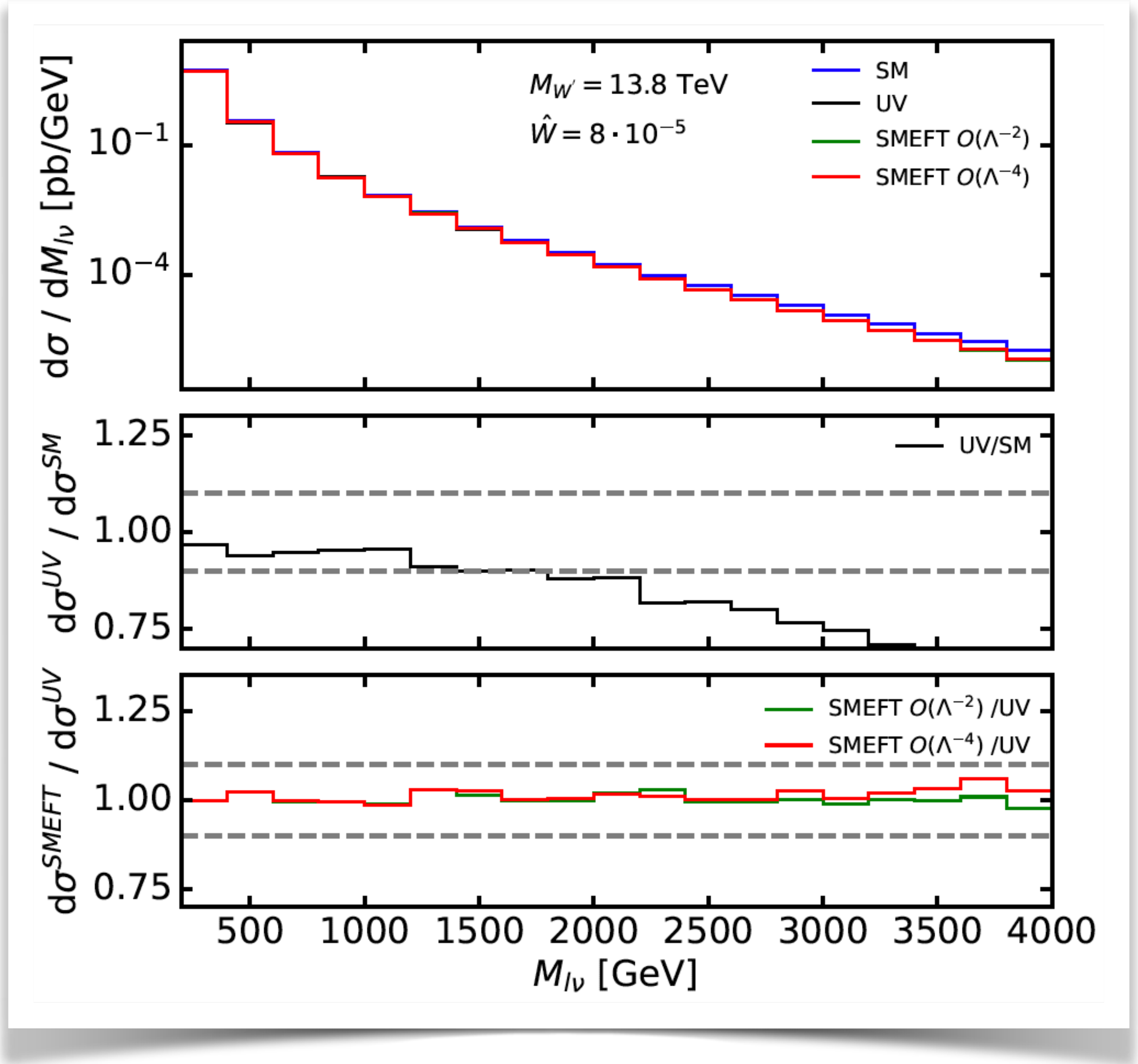
[2109.02653]

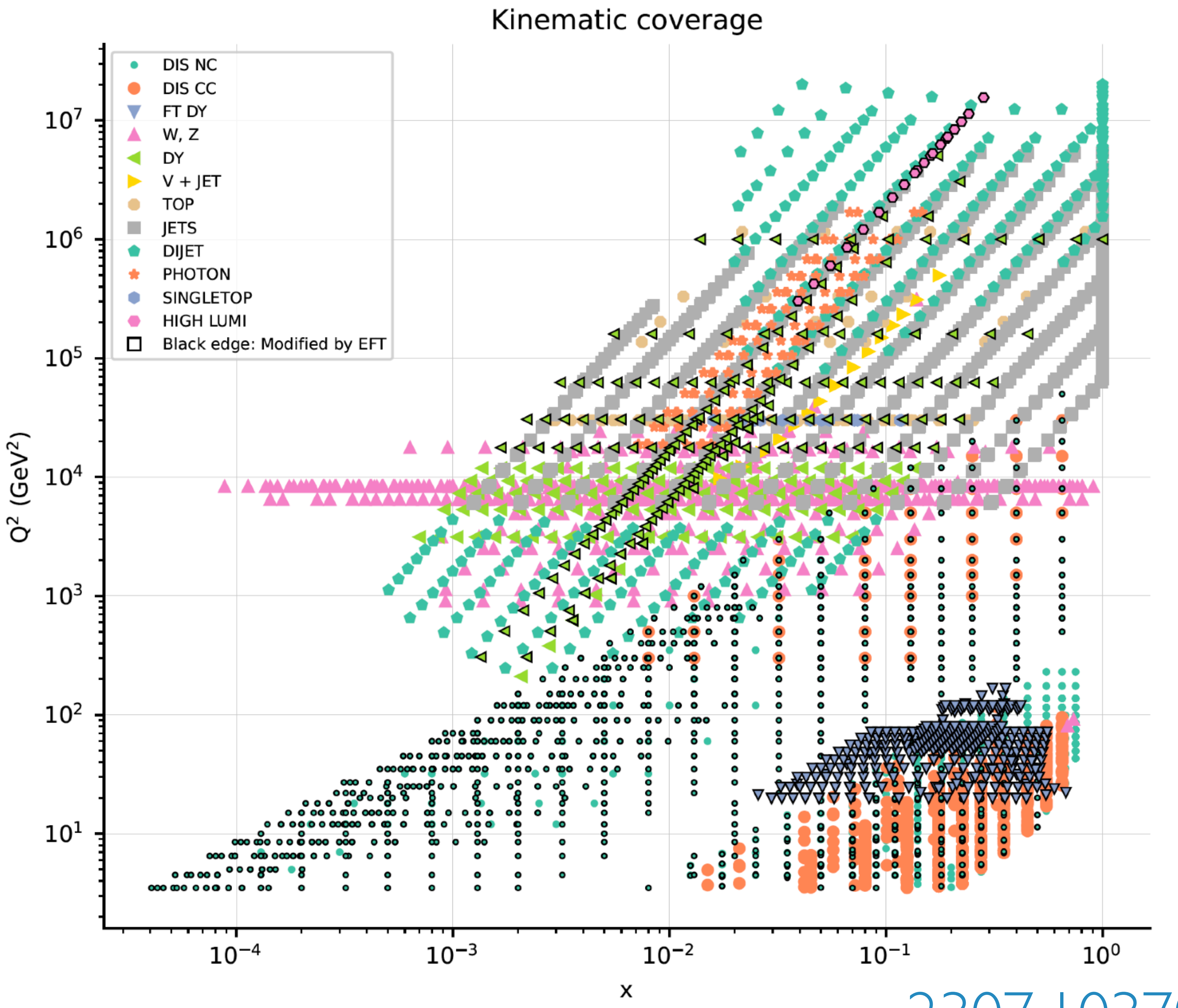
- Alternatively, we say that the PDFs would be "**contaminated**".

New physics model

- We work with a W' NP model and see its effects with respect to the SM.
- This NP model affects Drell-Yan and DIS datasets.

$$\mathcal{L}_{\mathrm{SMEFT}}^{W'} = \mathcal{L}_{\mathrm{SM}} - \frac{g^2 \hat{W}}{2m_W^2} J_L^{a,\mu} J_{L,\mu}^a$$





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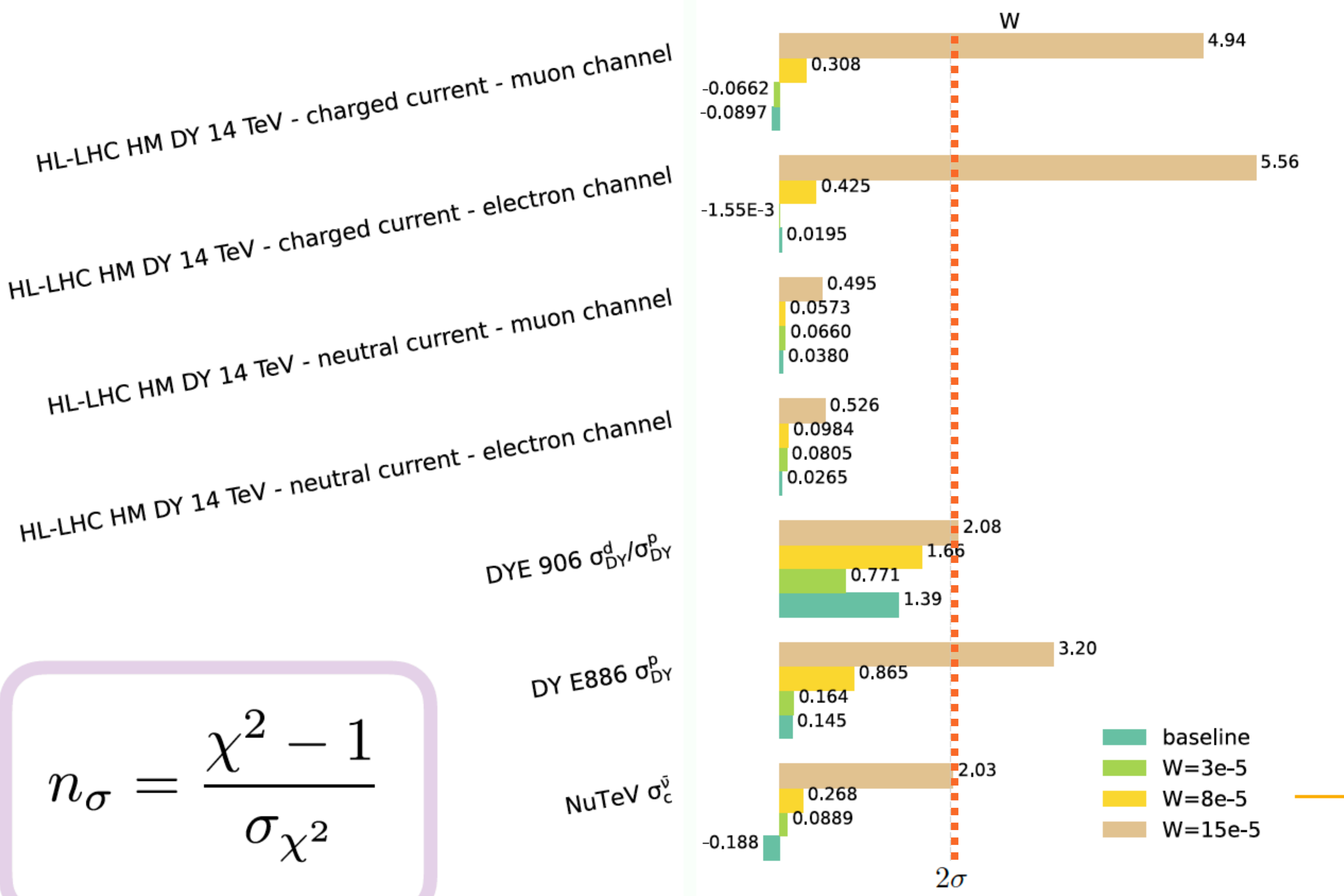
PDF fit quality summary

* Slide by M. Madigan!



$$n_\sigma = \frac{\chi^2 - 1}{\sigma_{\chi^2}}$$

✓ ***Yes: PDFs absorb new physics***

$$\hat{W} = 8 \cdot 10^{-5}, \quad M_{W'} \approx 14 \text{ TeV}$$

Effects of using a contaminated PDF set

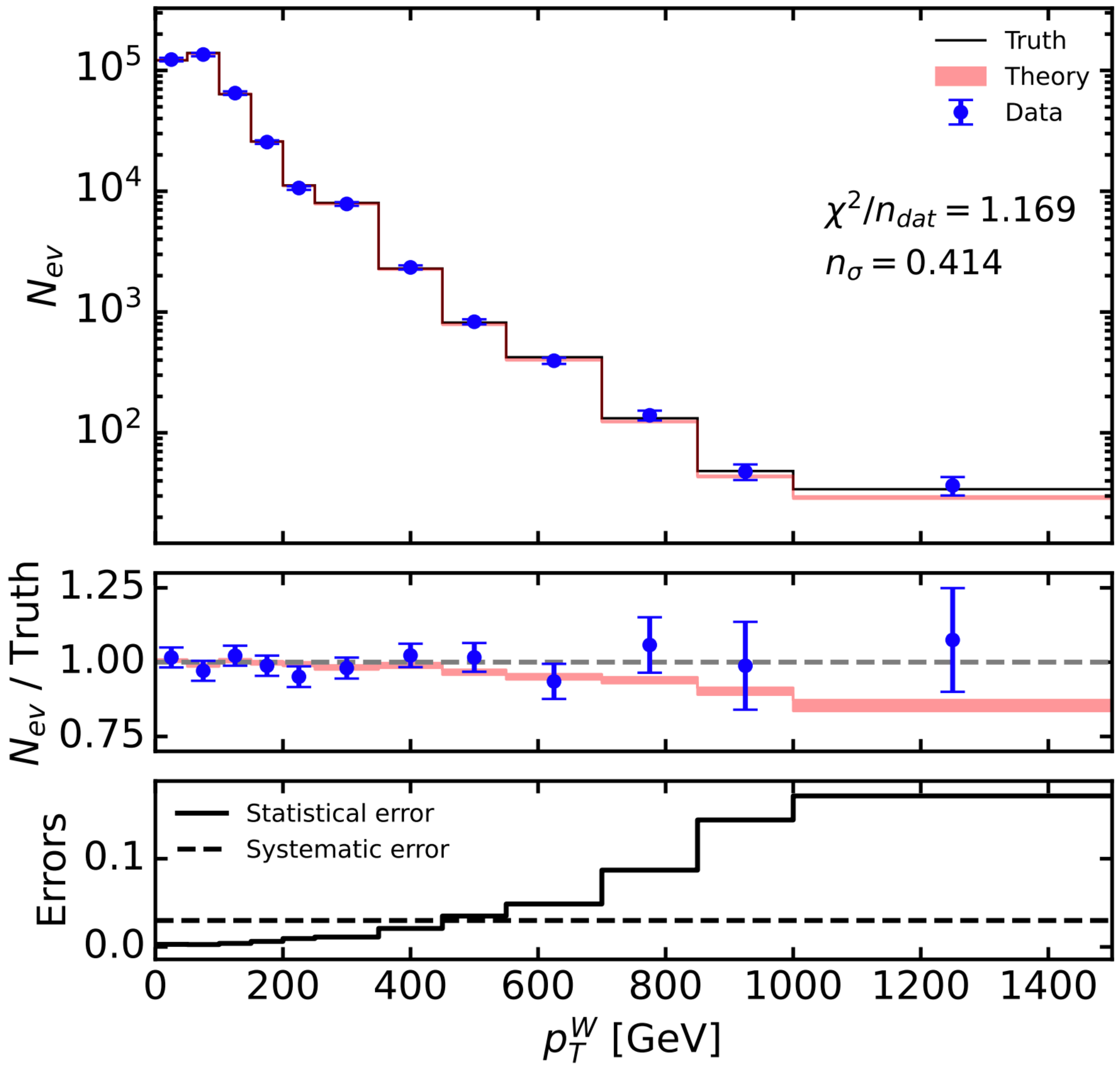
@ HL-LHC

What happens is we unknowingly use contaminated PDFs?

- Consider the results of W+ H production (not affected by NP).
- There is an apparent but *spurious* tension with the SM.

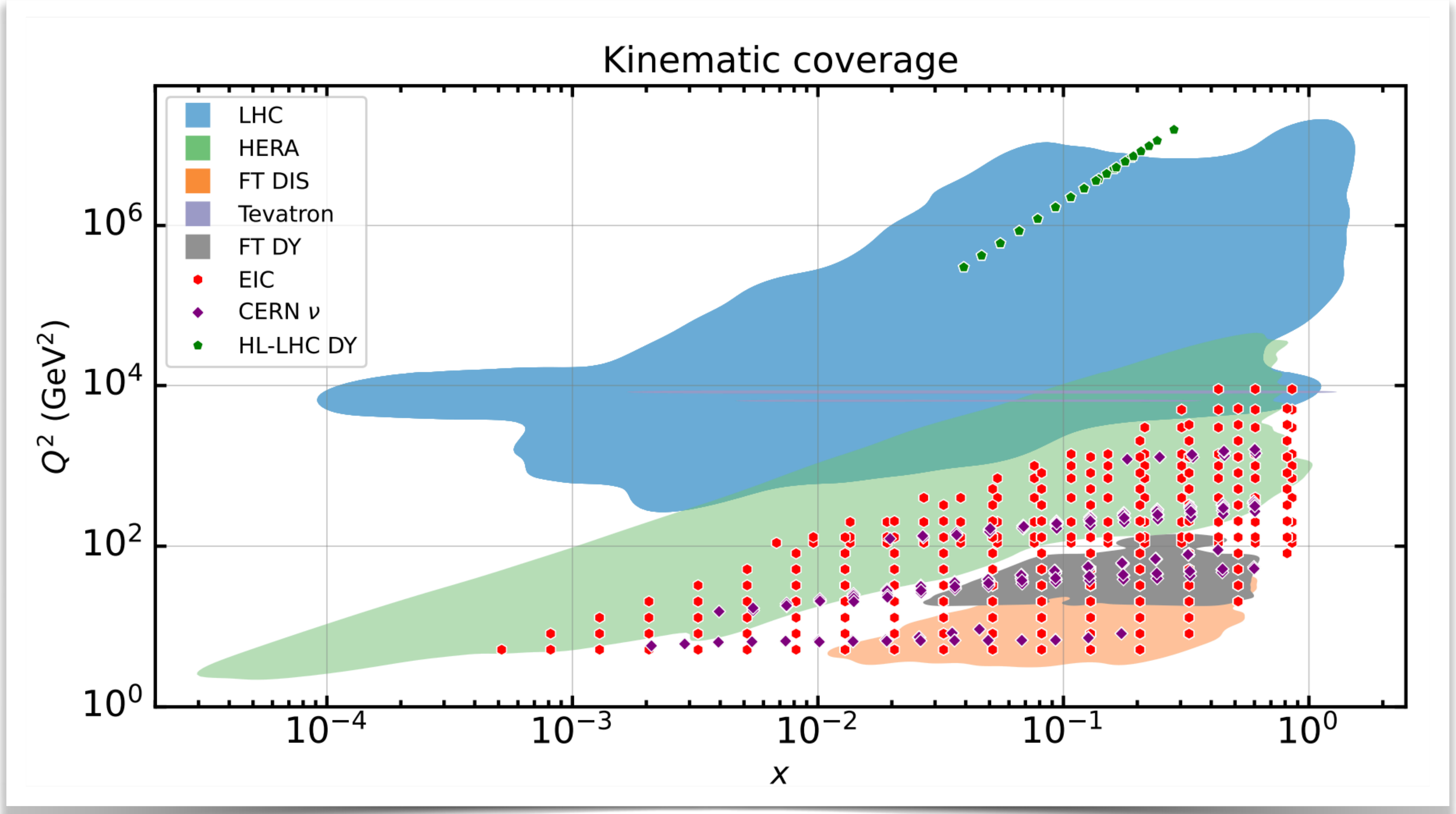
Data: "True" PDF x SM

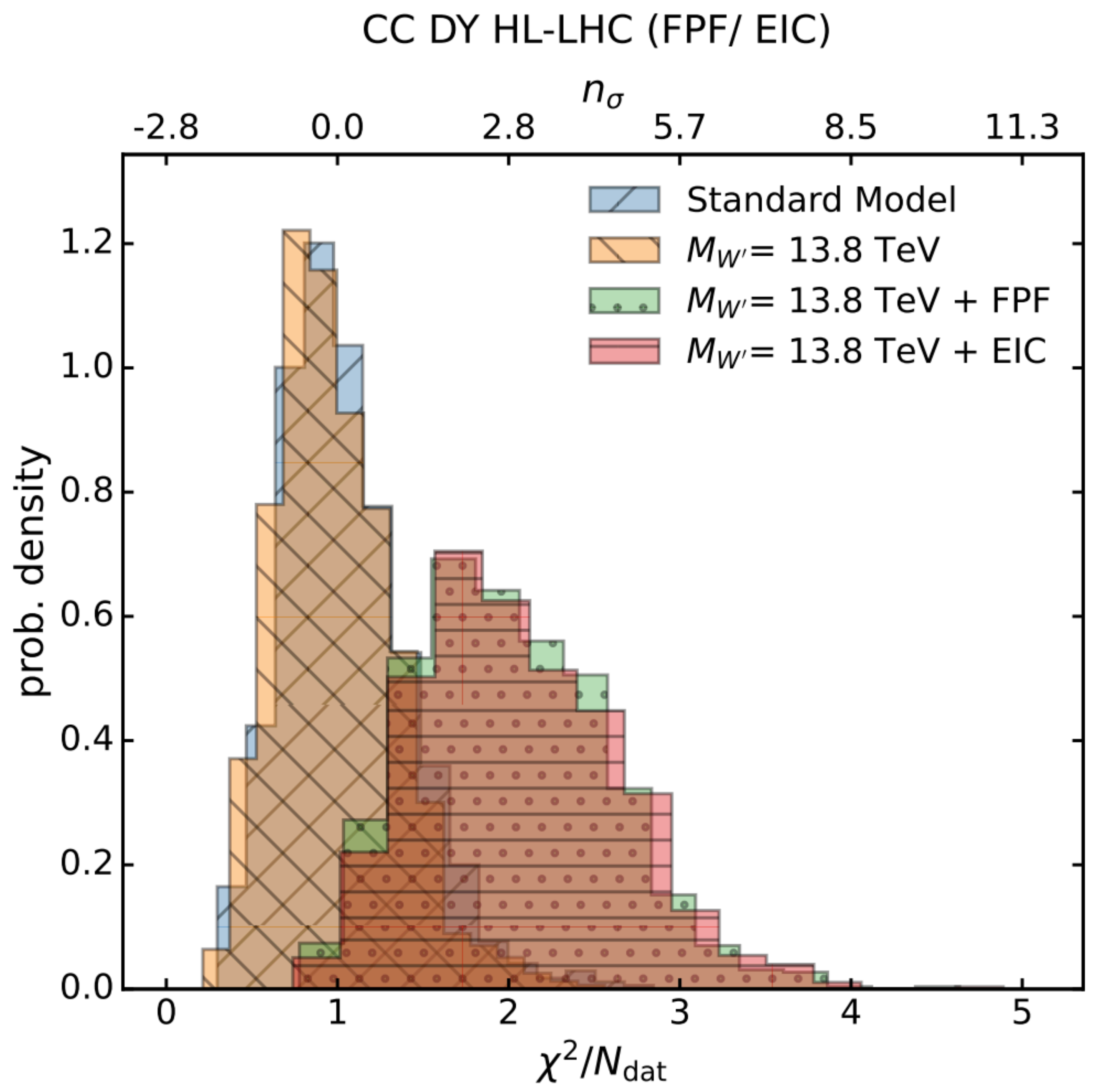
Theory: "Cont" PDF x SM



The importance of DIS measurements

There is great potential to disentangle new physics absorption by the PDFs.





2410.00963

DIS with MuC neutrinos would constitute the *ultimate test* to prevent the absorption of NP by the PDFs.

The most important slide

1. The high energy, collimated neutrino flux from muon decays at a MuC will enable highly precise forward target deep-inelastic scattering (DIS) measurements.

2. The setup will allow for exceptionally sensitive measurements of quantities like CKM matrix elements, parton distribution functions, and fragmentation functions, among others, surpassing current standards.

3. The exploitation of correlations and shape information of different quantities is crucial for precision measurements.

4. The precision reached will constitute a demanding test of SM physics and potential BSM signatures.

5. This analysis will benefit from parallel MuC studies: additional observables and constraints, experiment design, estimation of systematics, …

Thank you for your attention!

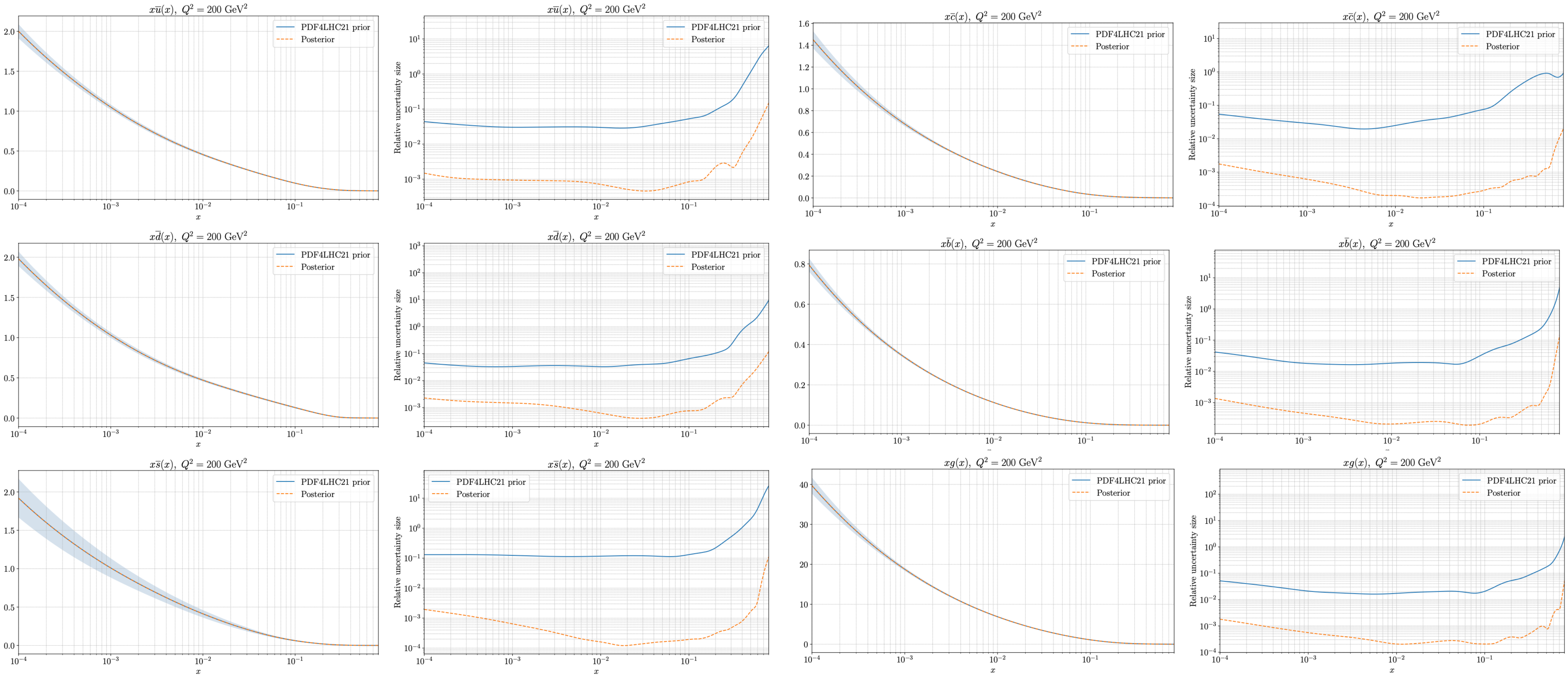
Extra

PDF posteriors

Substantial reduction of uncertainties is obtained.

PDF posteriors

Substantial reduction of uncertainties is obtained.



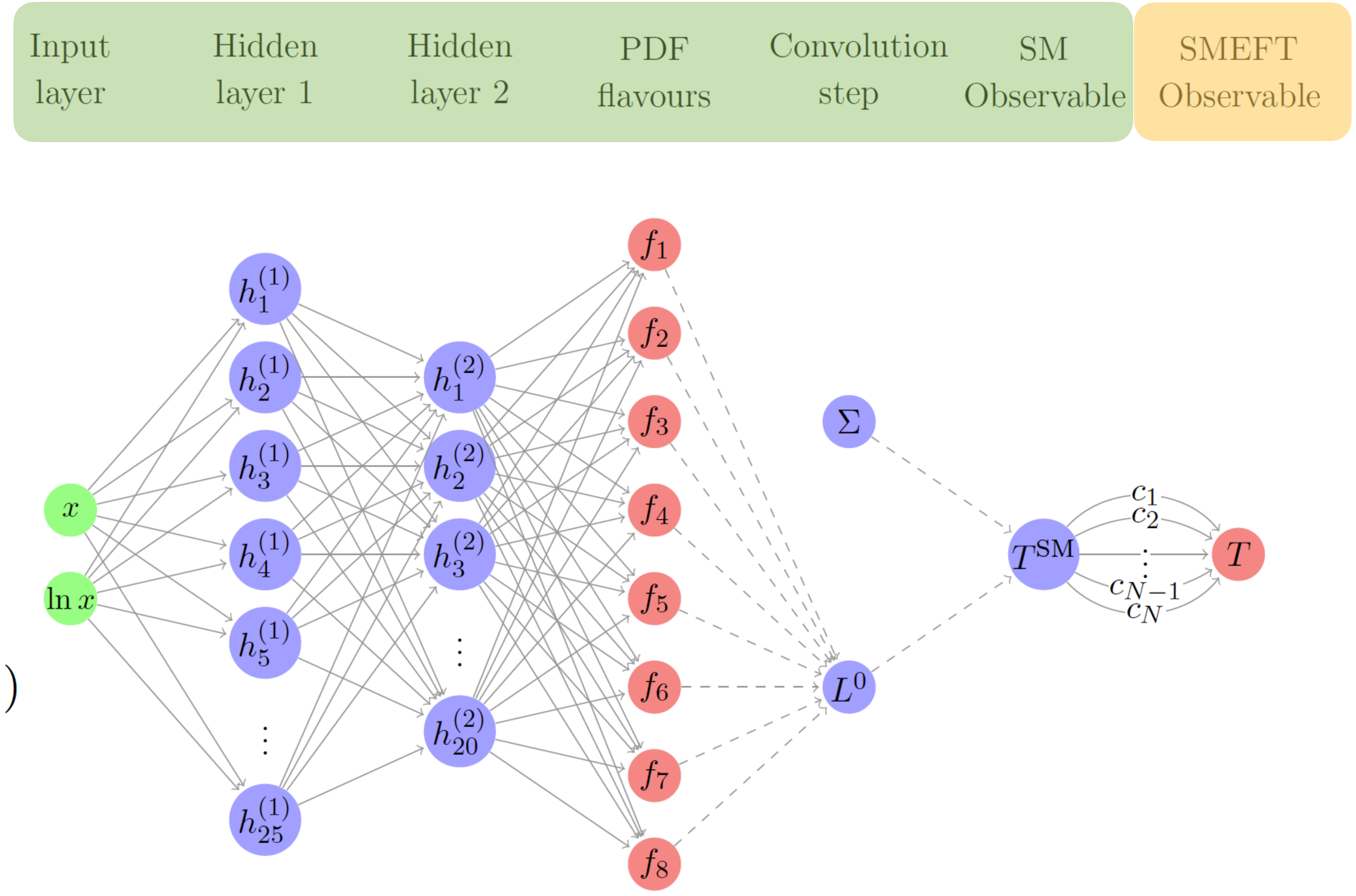
SIMUnet

- SIMUnet: NNPDF architecture supplemented with a SMEFT layer.

- PDF and BSM parameters are optimised simultaneously.

$$\chi^2(\hat{\theta}) = \frac{1}{N_{\rm dat}}(\mathbf{D} - \mathbf{T}(\hat{\theta}))^T(\mathbf{cov})^{-1}(\mathbf{D} - \mathbf{T}(\hat{\theta}))$$

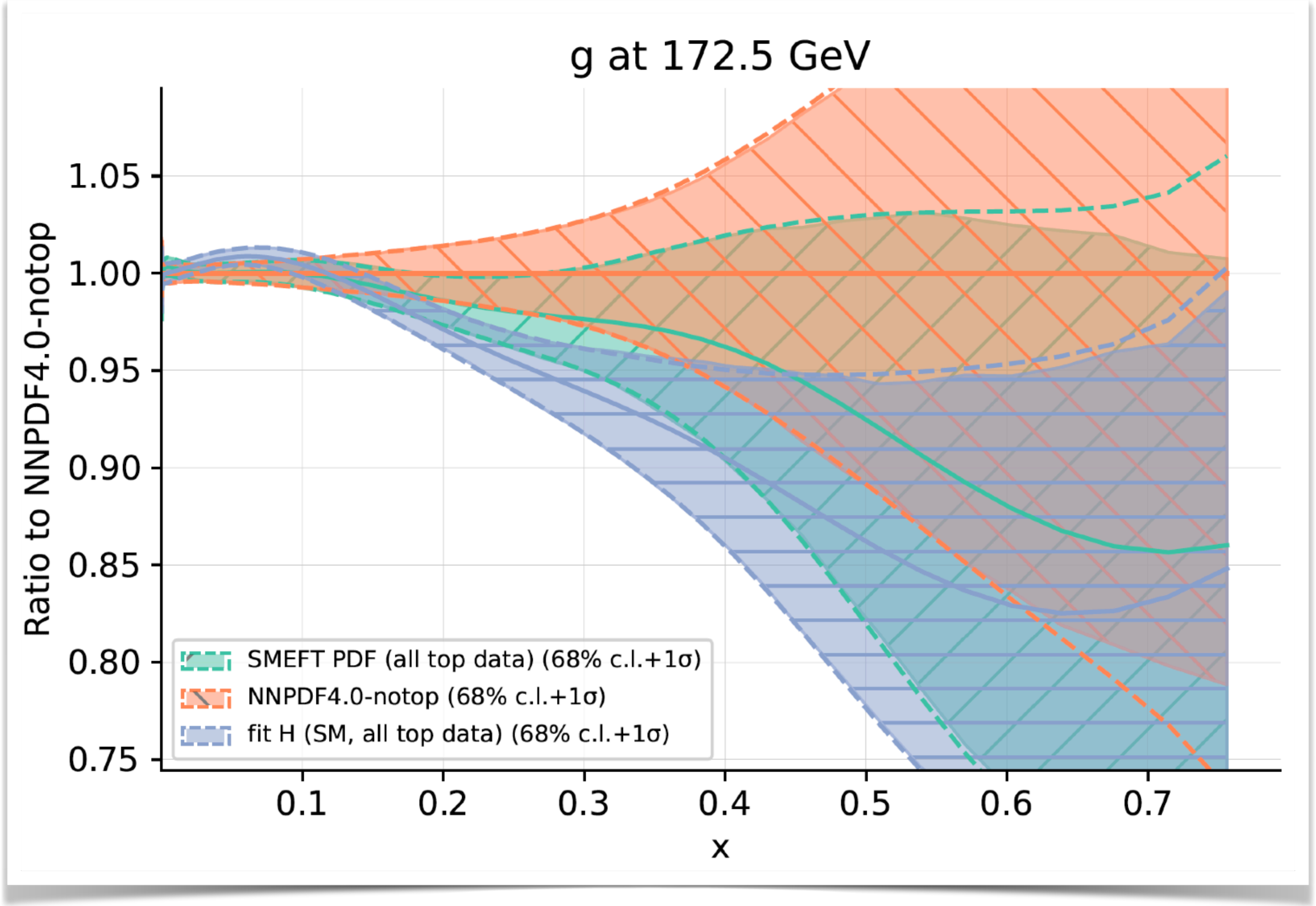
$$\hat{\theta} = \theta \cup \{c_i\}$$



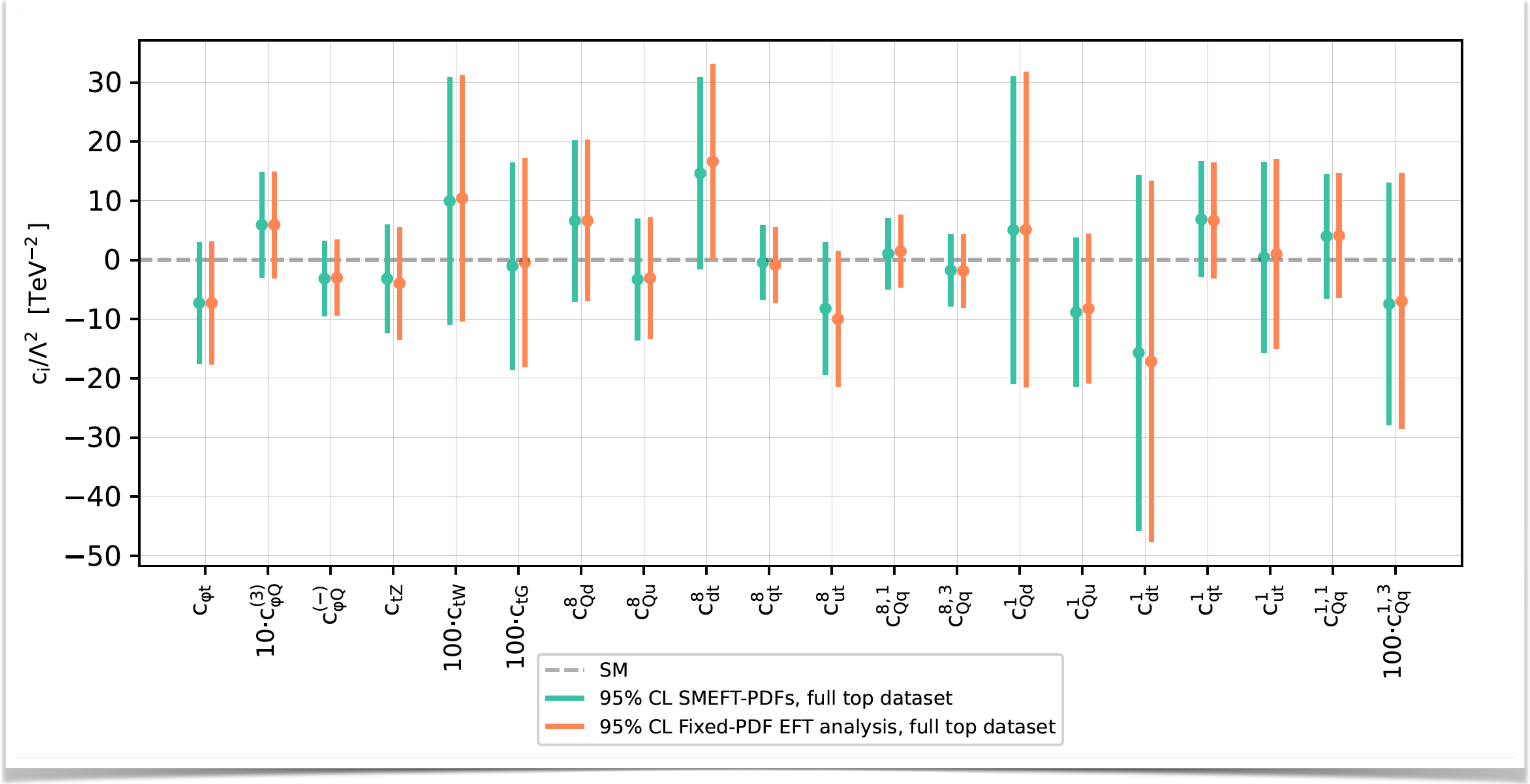
SIMUnet: simultaneous PDF + BSM coefficients

Here we perform a fit in the top-quark sector.

PDFs



BSM



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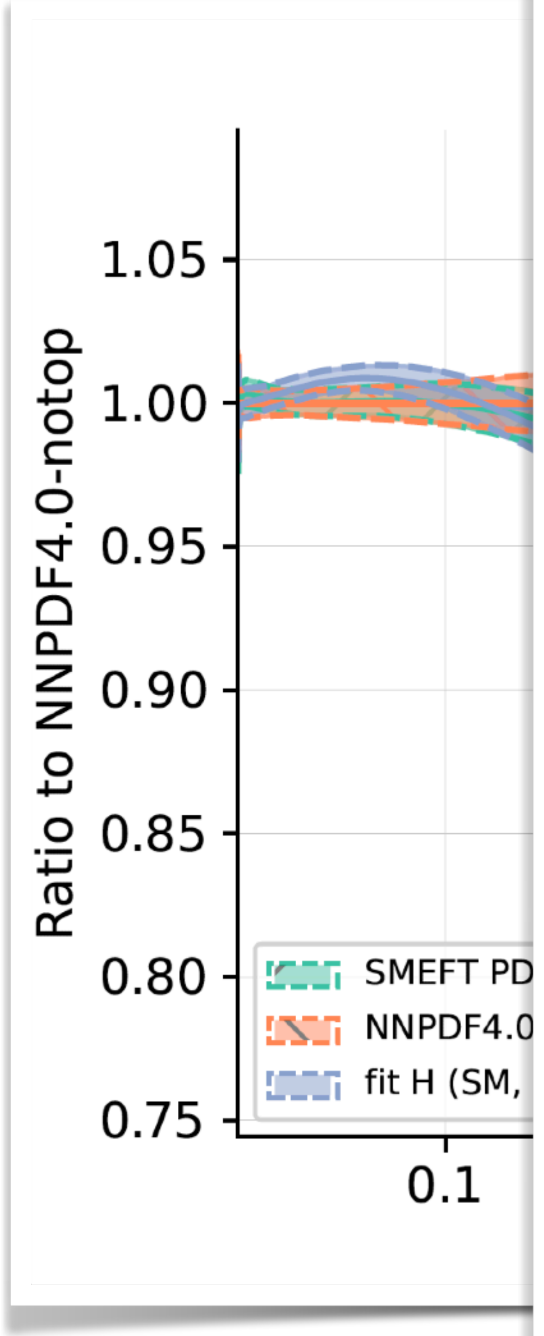
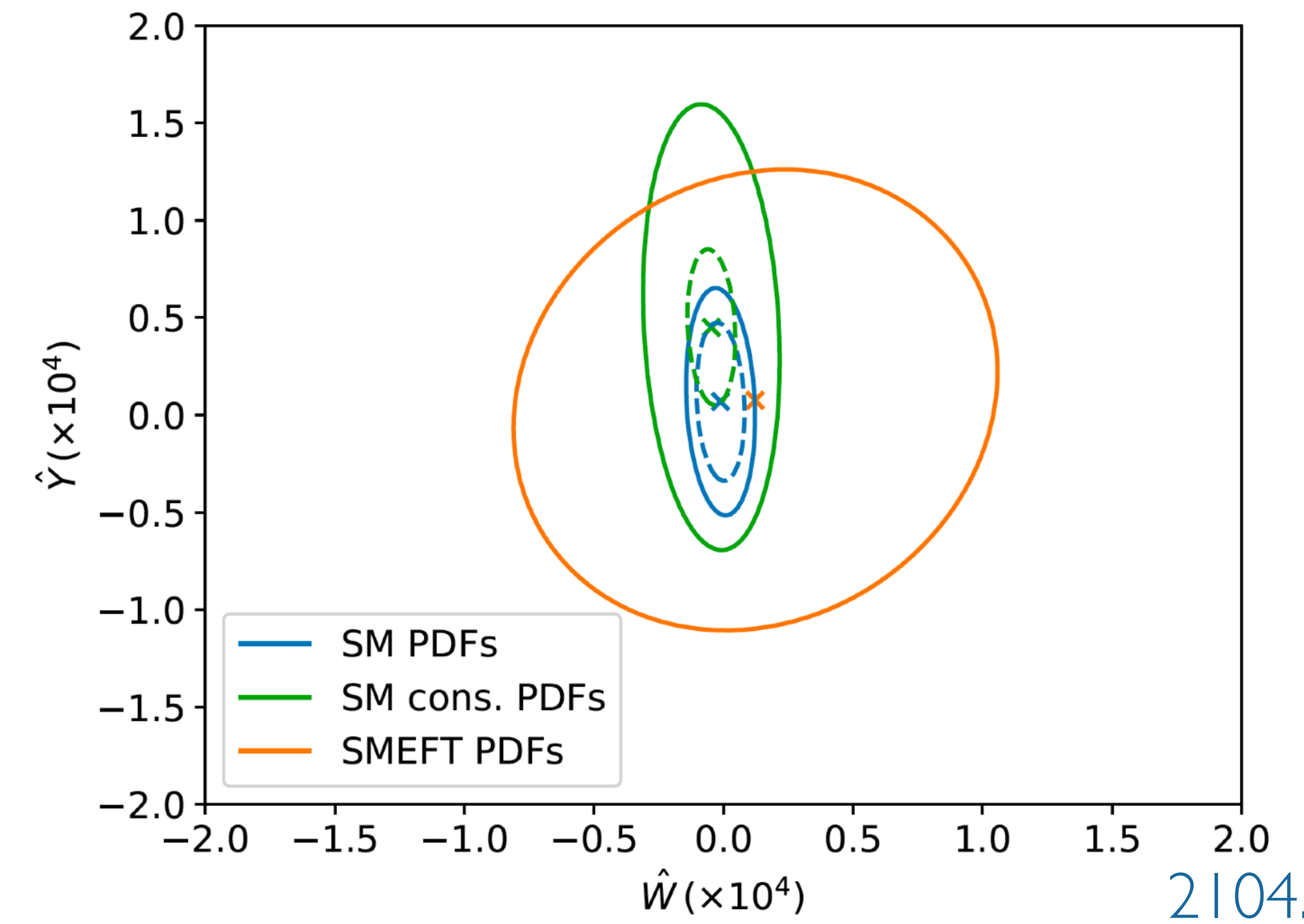
SIMUnet: simultaneous PDF + BSM coefficients

Here we

Neglecting the PDF-BSM interplay can lead to an overestimate of the constraints on BSM physics in other sectors.





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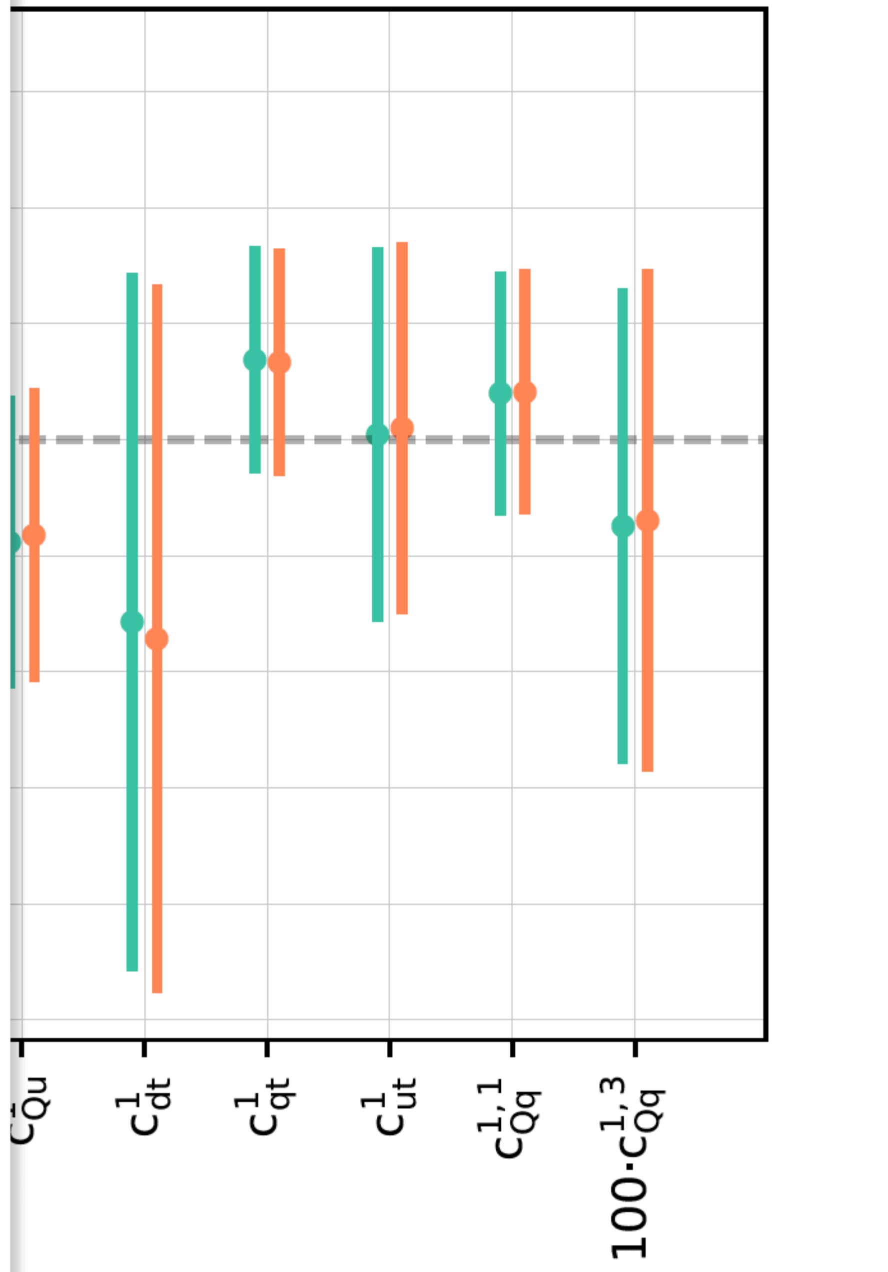

2303.06159

Pseudodata generation

- We perform two kinds of fits:

Fit name	**Nature**	**Fitted parameters**
Baseline	Standard Model: $\theta^*_{\mathrm{NP}} \equiv 0$	Standard Model only: θ_{SM}
Contaminated	SM + new physics: $\theta^*_{\mathrm{NP}} \neq 0$	Standard Model only: θ_{SM}

- NP is injected into the pseudodata via K-factors

$$T \equiv \left(1 + cK_{\mathrm{lin}} + c^2 K_{\mathrm{quad}}\right) \hat{\sigma}^{\mathrm{SM}} \otimes \mathcal{L}$$

SIMUnet

The SIMUnet architecture allows to perform two types of analyses:

1. Simultaneous fits of PDF and new physics (EFT) coefficients (not discussed here).
2. Assess the potential **absorption** of new physics effects by the PDFs.

Let us suppose that the law of Nature is given by the SM plus some new physics (NP) contributions

- We will work in a setting where we know the law of Nature: we will generate pseudodata according to our model, perform a fit, and see what comes out. $T \equiv T(\theta_{\mathrm{SM}}, \theta_{\mathrm{NP}})$

We have

True value of the observable

$$T^* \equiv T(\theta^*_{\mathrm{SM}}, \theta^*_{\mathrm{NP}})$$

The observed data

$$D_0 = T^* + \eta \qquad \eta \sim \mathcal{N}(0, \Sigma)$$