Precision determination of the small-x gluon from forward charm production at LHCb

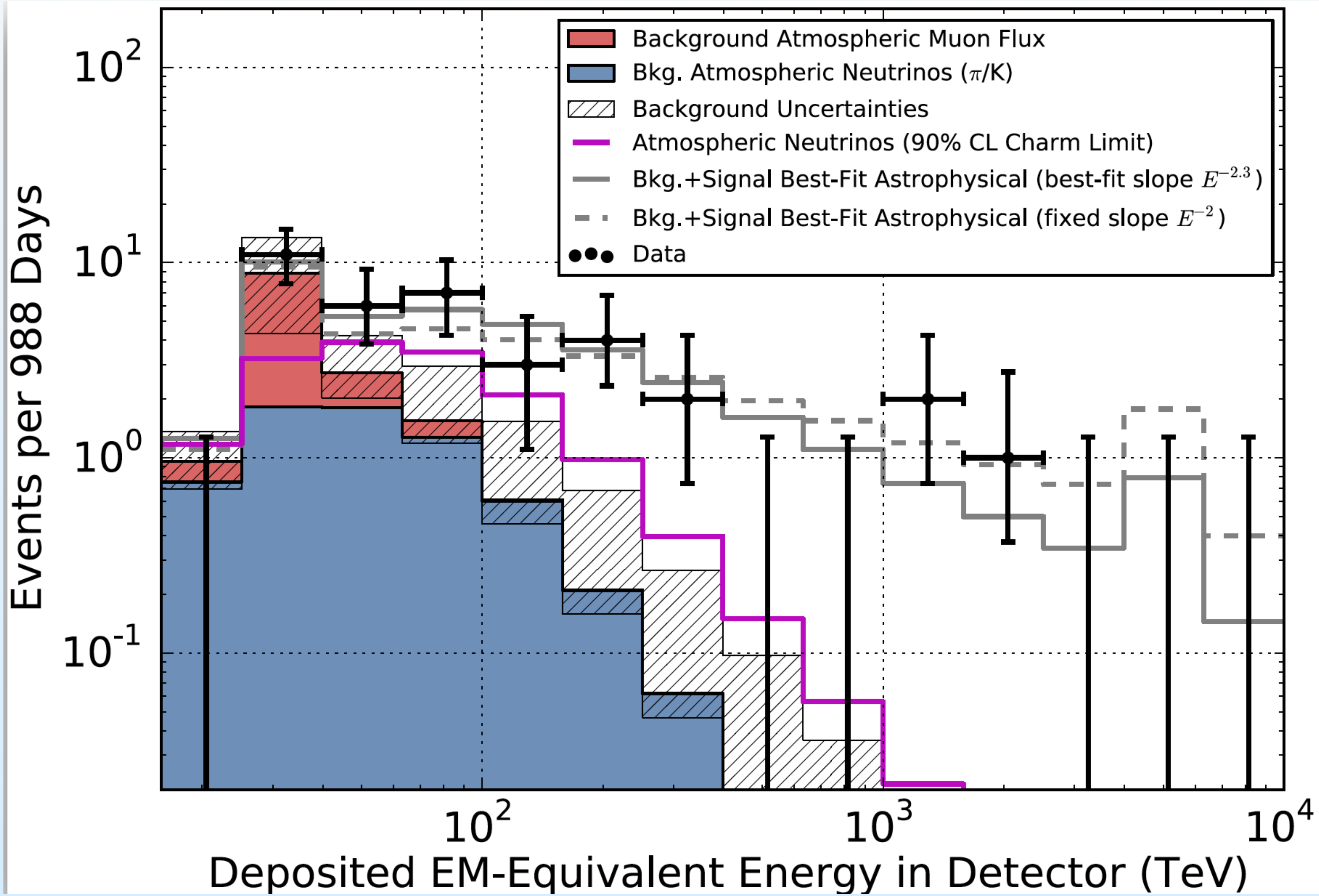
Juan Rojo
VU Amsterdam & Theory group, Nikhef

Gauld, Rojo, Rottoli, Talbert JHEP 15
Gauld, Rojo, Rottoli, Sarkar, Talbert JHEP 15
Gauld, Rojo PRL17
Rojo, Slade, preliminary

From the LHC to Neutrino Telescopes

Observation of Ultra-High Energy (UHE) neutrino events at IceCube heralds start of **Neutrino Astronomy**

New window to the Universe, but interpretation of IceCube data requires **control over backgrounds**

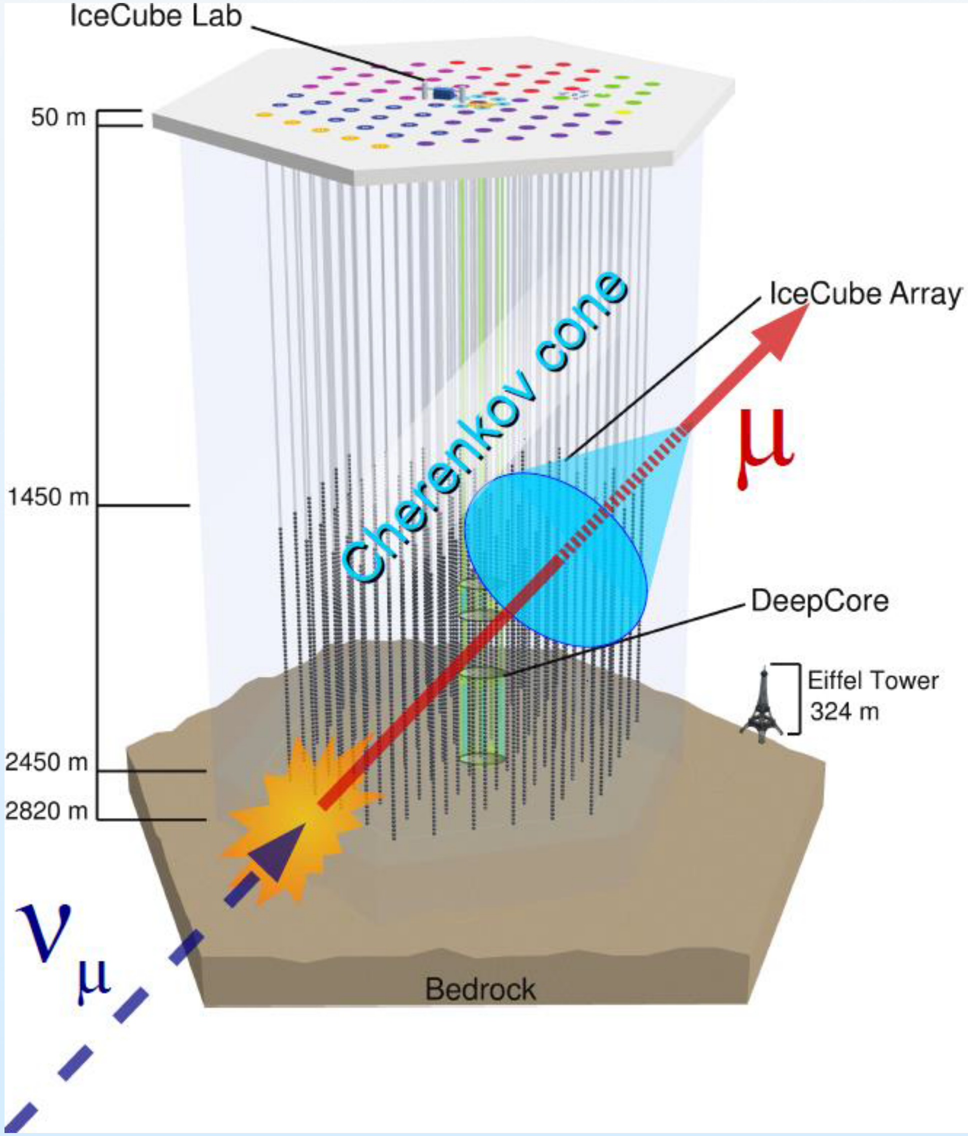


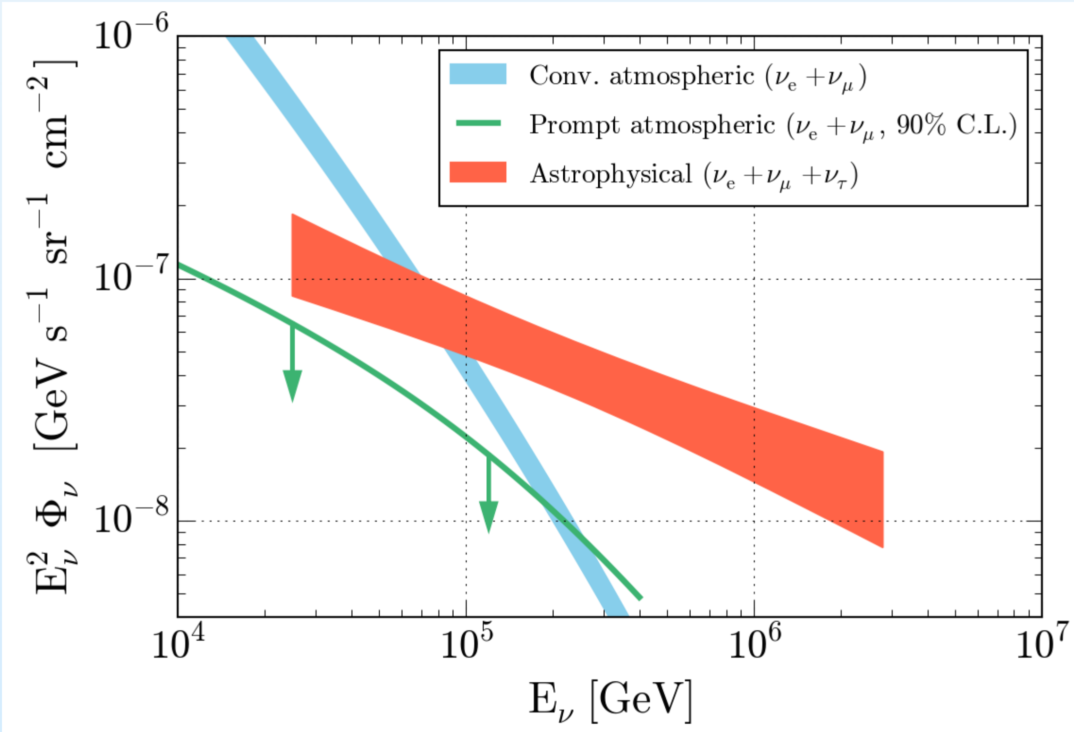
From the LHC to Neutrino Telescopes

- The main **background for astrophysical neutrinos at IceCube** is the flux of neutrinos from the **decays of charm mesons** in cosmic ray collisions in atmosphere

- Theoretically, this **prompt neutrino flux** is affected by large uncertainties: very small-x PDFs, very low scales - can pQCD be applied?

- Use **LHC data itself** to pin down this prompt flux!

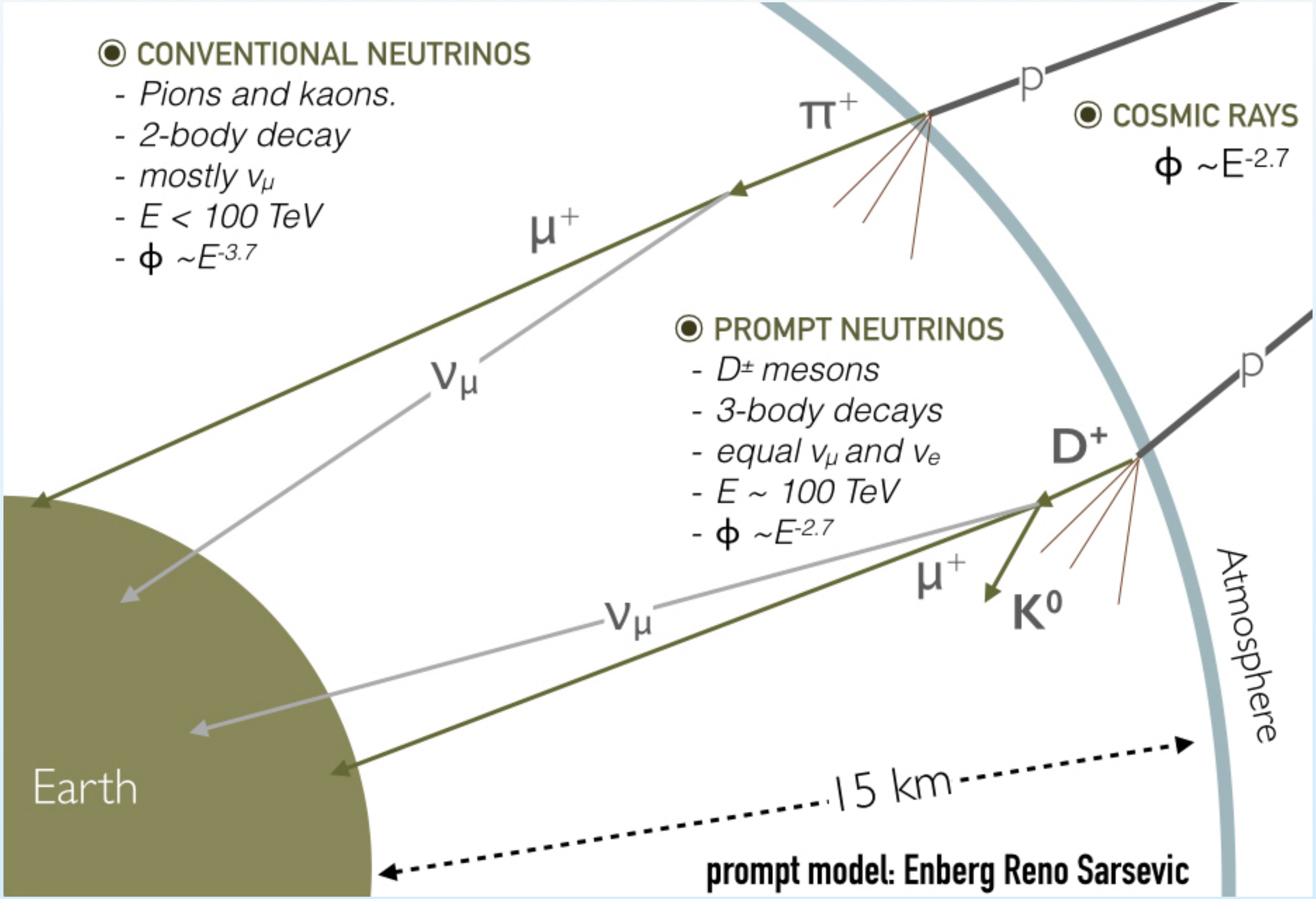




From the LHC to Neutrino Telescopes

Observation of Ultra-High Energy (UHE) neutrino events at IceCube heralds start of **Neutrino Astronomy**

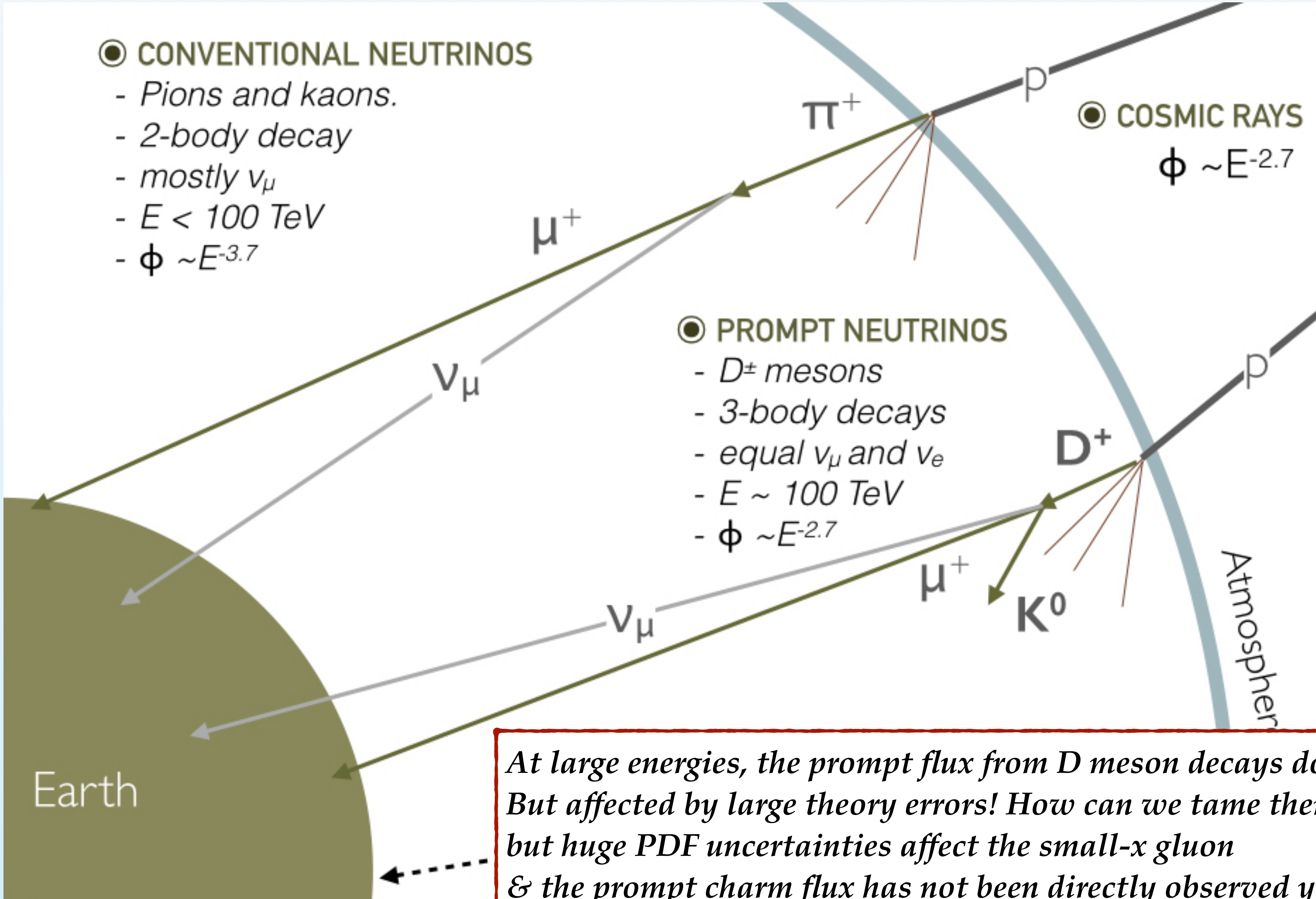
New window to the Universe, but interpretation of IceCube data requires **control over backgrounds**



From the LHC to Neutrino Telescopes

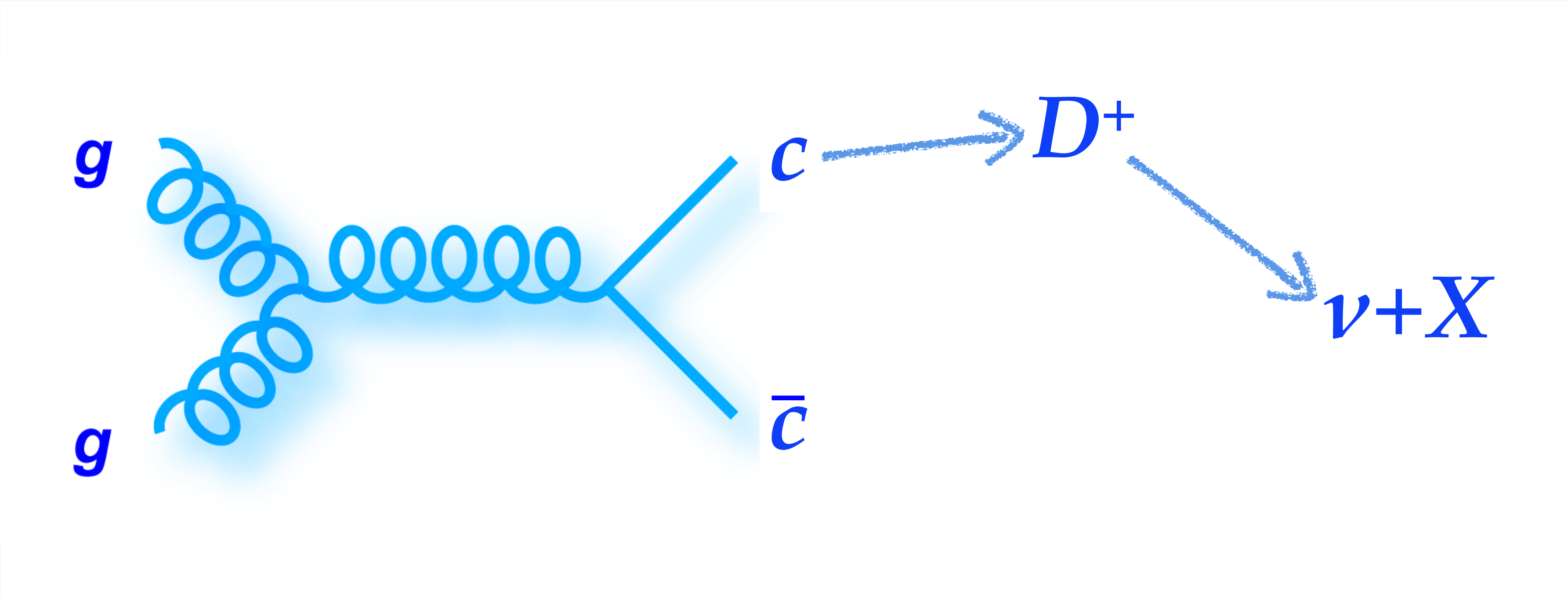
Observation of Ultra-High Energy (UHE) neutrino events at IceCube heralds start of **Neutrino Astronomy**

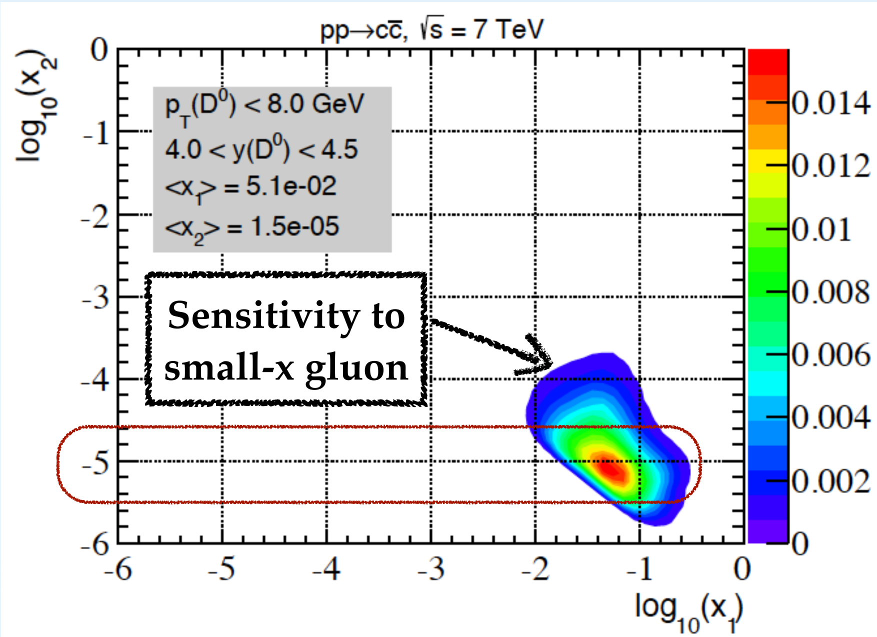
New window to the Universe, but interpretation of IceCube data requires **control over backgrounds**



At large energies, the prompt flux from D meson decays dominates
But affected by large theory errors! How can we tame them?
but huge PDF uncertainties affect the small-x gluon
& the prompt charm flux has not been directly observed yet …

The low-x gluon from charm production





Lab frame $E_{lab} = (2m_pE_{CR})^{1/2}$

$E_{CR} = 100$ *PeV* $\longrightarrow E_{lab} \approx 14$ *TeV*

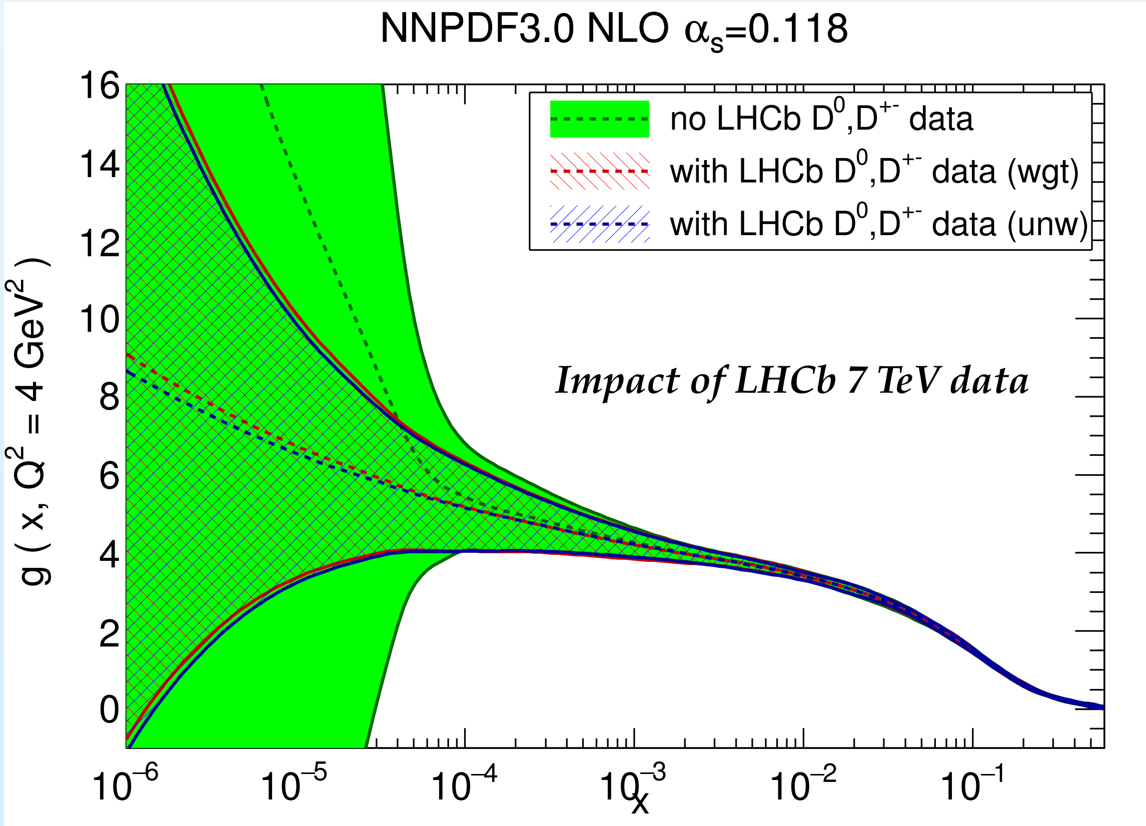
Overlap kinematics between charm production in UHE cosmic rays and at the LHC

From the LHC to Neutrino Telescopes

Use **collider data** to provide state-of-the-art **predictions for backgrounds at Neutrino Telescopes**

The **LHCb forward charm production data** at 7 TeV cover the **same kinematical region** as prompt neutrino production in high-energy cosmic rays

- ☑ Include **7 TeV LHCb forward charm production data** in the global fit
- ☑ Validate **perturbative QCD calculations** on collider data, and **constrain the small-x gluon**
- ☑ Compute optimised predictions for **prompt neutrino fluxes at high energies**



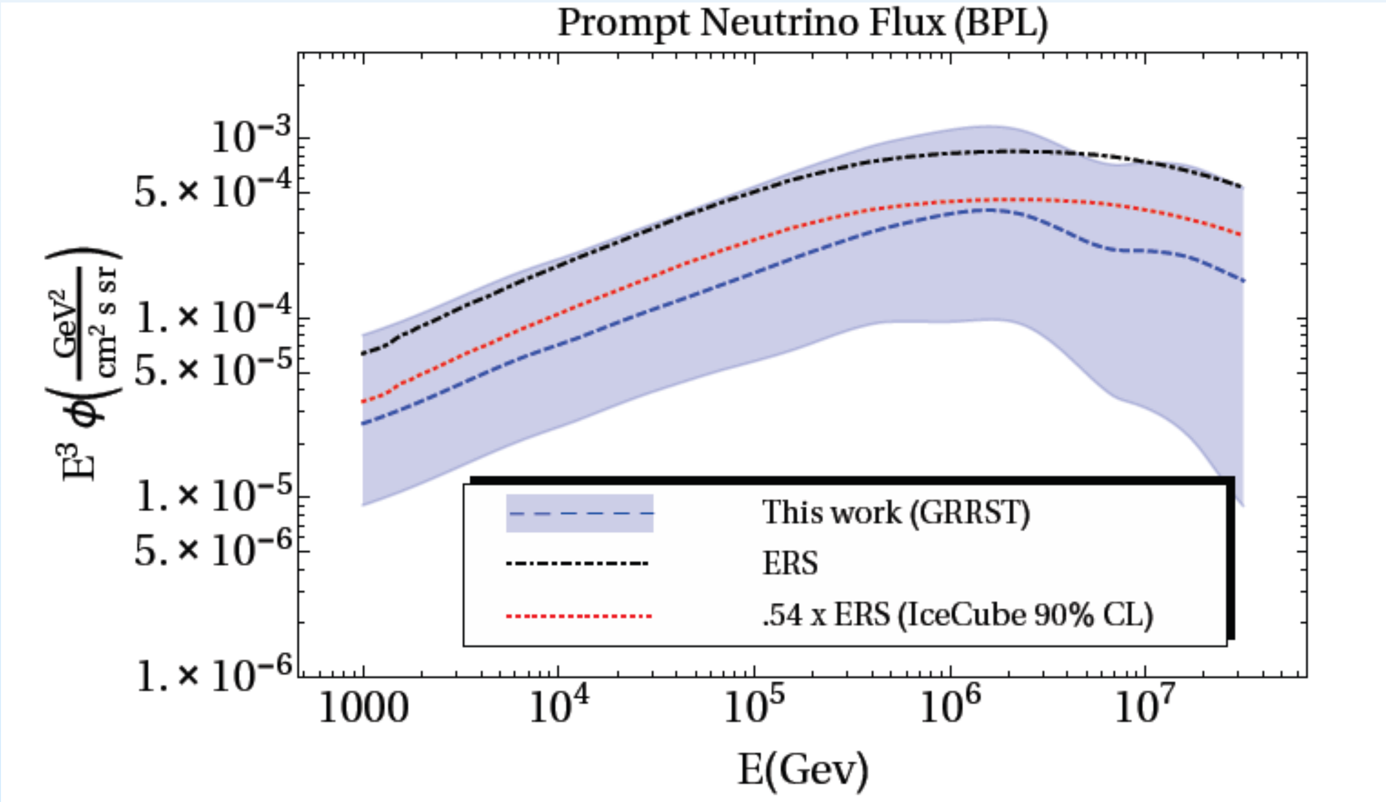
See also PROSA analysis, EPJC15

From the LHC to Neutrino Telescopes

Use **collider data** to provide state-of-the-art **predictions for backgrounds at Neutrino Telescopes**

The **LHCb forward charm production data** at 7 TeV cover the **same kinematical region** as prompt neutrino production in high-energy cosmic rays

- ☑ Include **7 TeV LHCb forward charm production data** in the global fit
- ☑ Validate **perturbative QCD calculations** on collider data, and **constrain the small-x gluon**
- ☑ Compute optimised predictions for **prompt neutrino fluxes at high energies**



We predict that detection of the prompt neutrino flux should be within IceCube reach

Precision determination of the small-x gluon

- Recently LHCb presented charm data at **5 and 13 TeV**

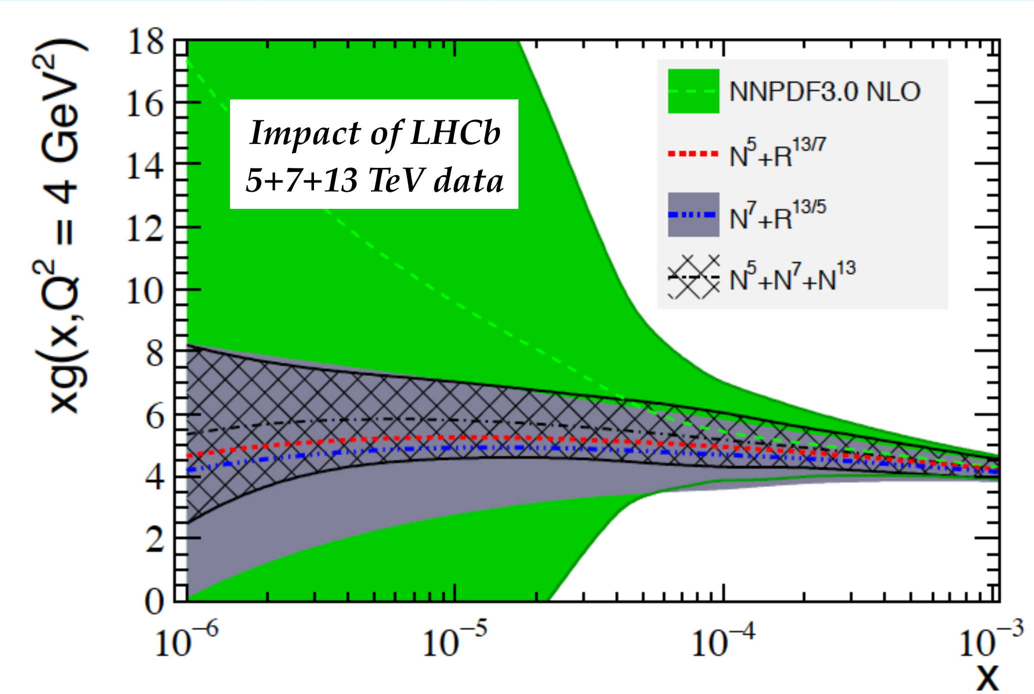
- Different options to fit data, either normalised distributions or cross-section ratios (13 TeV/7 TeV and 13 TeV/5 TeV)

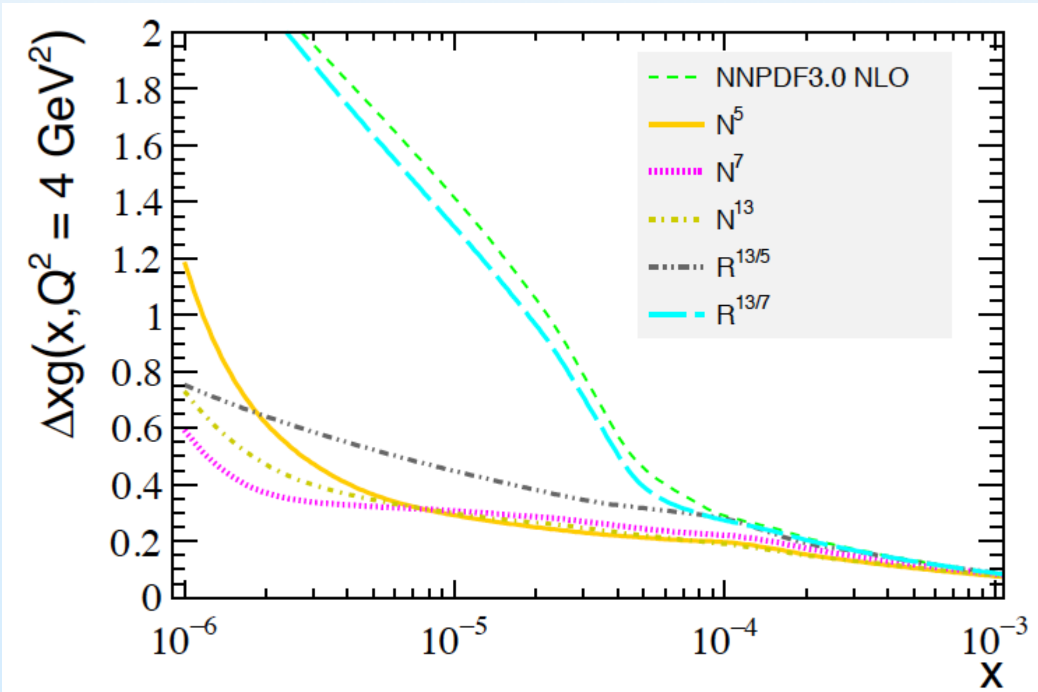
- As compared to NNPDF3.0, we achieve up to a **factor 10 reduction on the small-x gluon** uncertainties down to **x ≲ 10^{-6}**

- High-precision predictions of UHE neutrino-nucleus cross section for energies up to **$E_\nu \simeq 10^6$ PeV**

$$N_X^{ij} = \frac{d^2\sigma(\text{X TeV})}{dy_i^D d(p_T^D)_j} \Bigg/ \frac{d^2\sigma(\text{X TeV})}{dy_{\text{ref}}^D d(p_T^D)_j}$$

$$R_{13/X}^{ij} = \frac{d^2\sigma(13\ \text{TeV})}{dy_i^D d(p_T^D)_j} \Bigg/ \frac{d^2\sigma(\text{X TeV})}{dy_{\text{i}}^D d(p_T^D)_j}$$





Precision determination of the small-x gluon

- Recently LHCb presented charm data at **5 and 13 TeV**

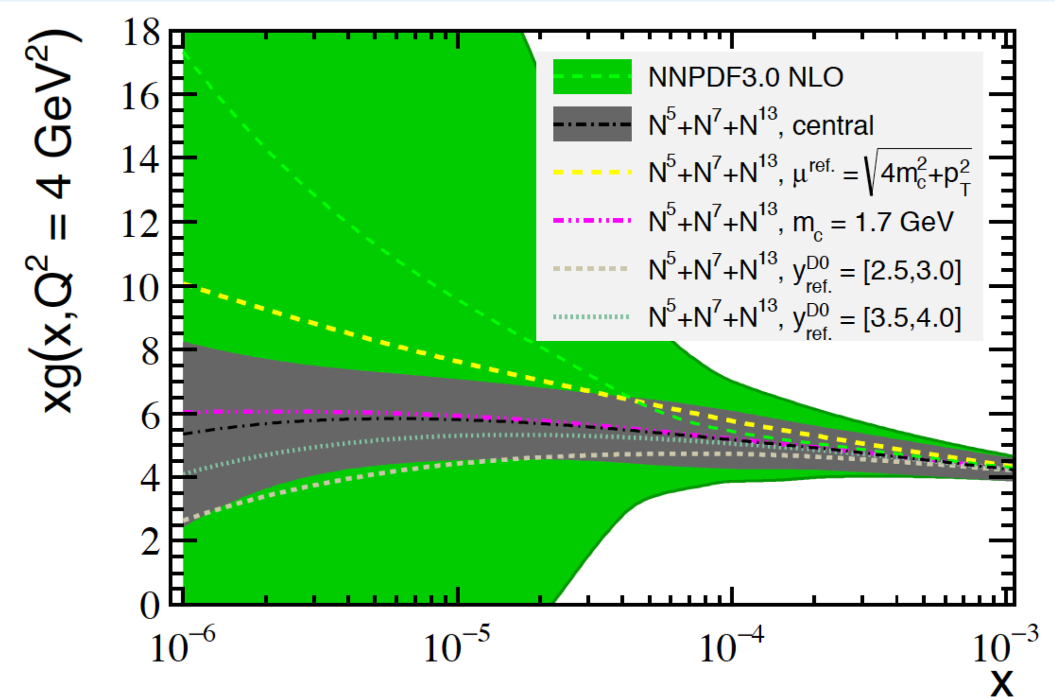
- Different options to fit data, either normalised distributions or cross-section ratios (13 TeV / 7 TeV and 13 TeV / 5 TeV)

- As compared to NNPDF3.0, we achieve up to a **factor 10 reduction on the small-x gluon** uncertainties down to **x ≲ 10^{-6}**

- High-precision predictions of UHE neutrino-nucleus cross section for energies up to **$E_\nu \simeq 10^6$ PeV**

$$N_X^{ij} = \frac{d^2\sigma(\mathrm{X\ TeV})}{dy_i^D d(p_T^D)_j} \Bigg/ \frac{d^2\sigma(\mathrm{X\ TeV})}{dy_{\mathrm{ref}}^D d(p_T^D)_j}$$

$$R_{13/X}^{ij} = \frac{d^2\sigma(\mathrm{13\ TeV})}{dy_i^D d(p_T^D)_j} \Bigg/ \frac{d^2\sigma(\mathrm{X\ TeV})}{dy_i^D d(p_T^D)_j}$$



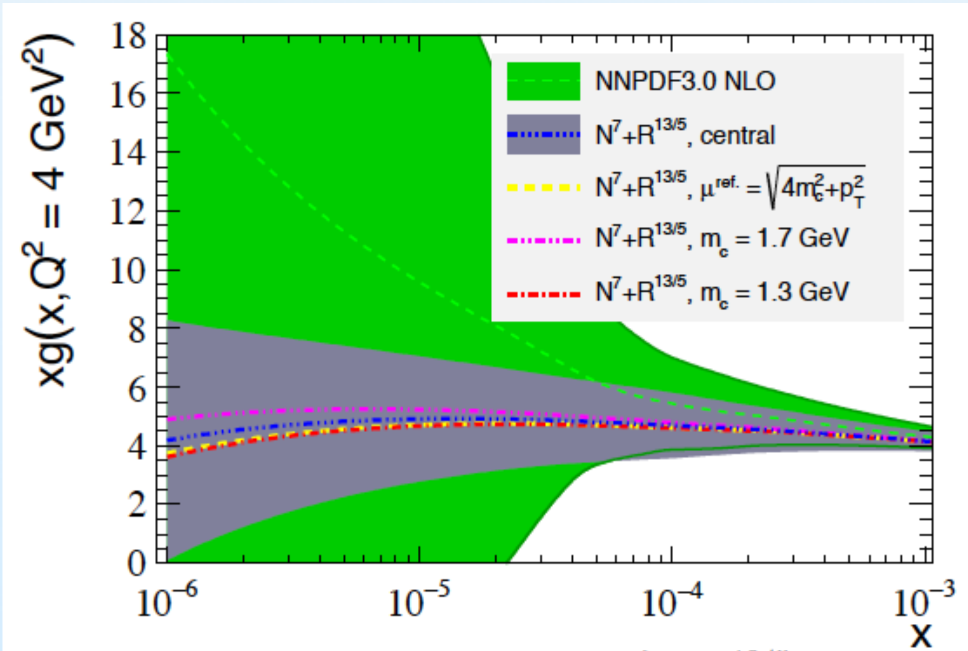


FIG. 4: Same as Fig. 3 for the $N^7 + R^{13/5}$ fits.

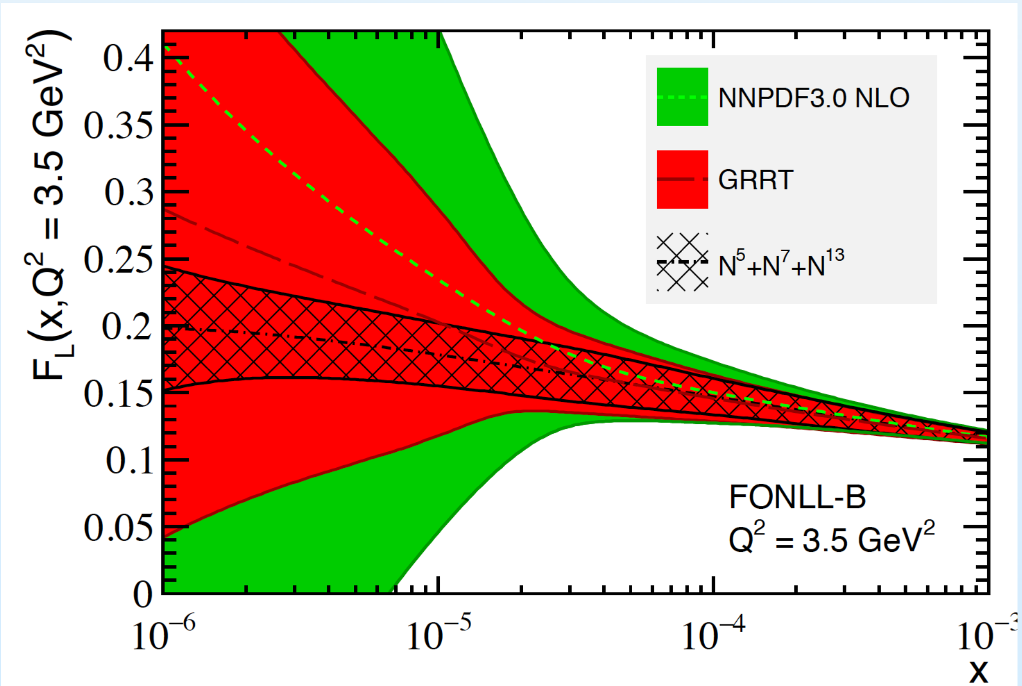
Phenomenological implications

- Improved theoretical predictions for any cross-section **sensitive to the small-x gluon and quarks** (related via DGLAP evolution)

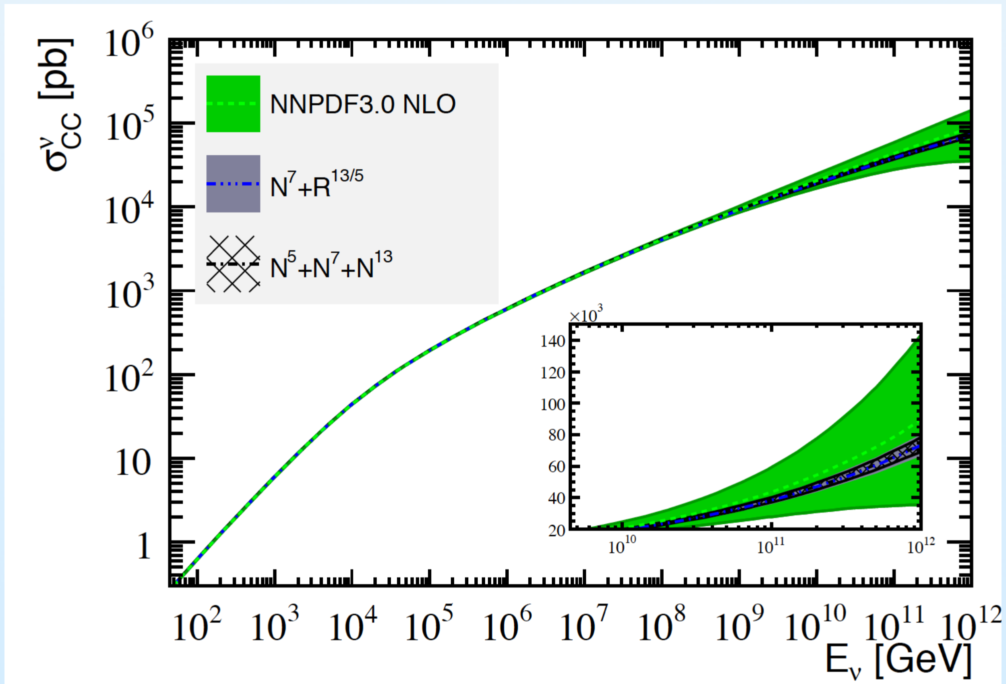
- The **longitudinal structure function $F_L(x,Q)$** can be predicted with high precision down to **$x=10^{-6}$**. Allows stringent tests of departures from linear DGLAP evolution at **future lepton-proton colliders**

- **Few-percent PDF uncertainties for the UHE neutrino-nucleus cross-section**: exploit neutrino telescopes as the ultimate DIS experiments!

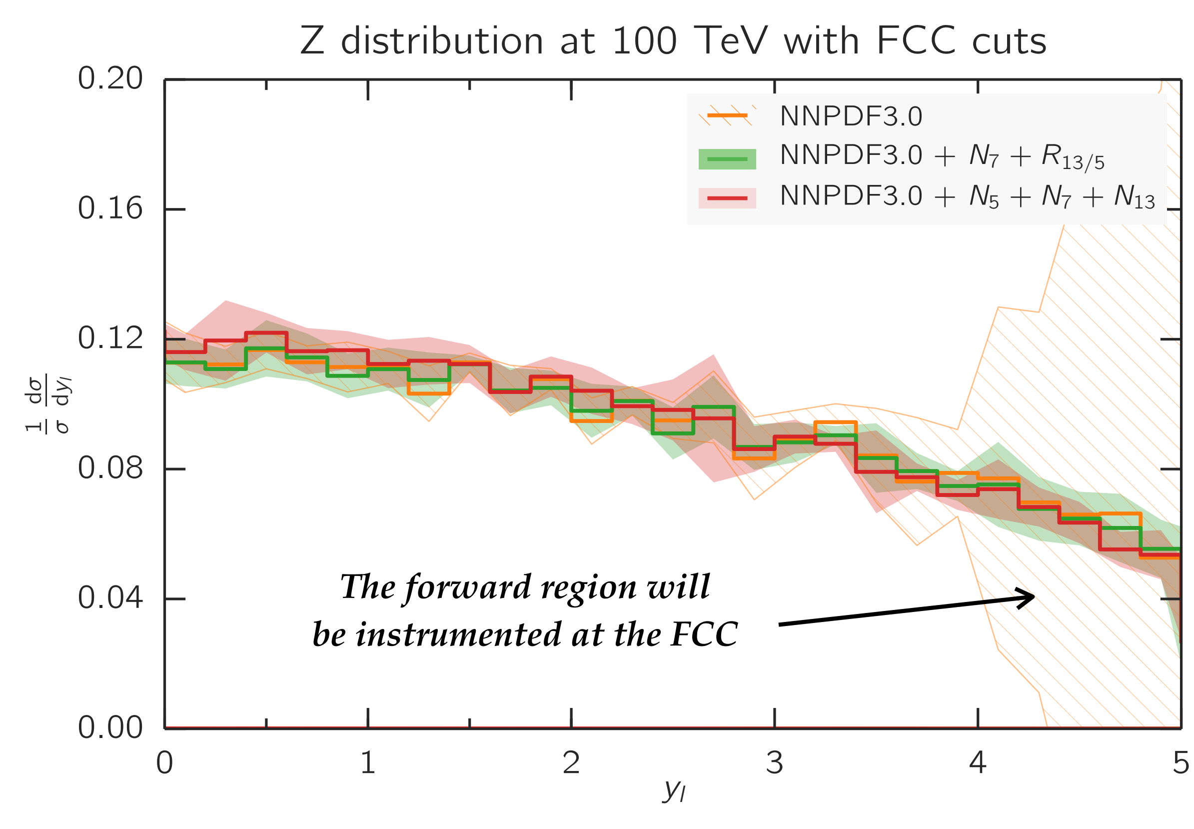
F_L at future high-energy lepton-proton colliders



Ultra-high energy neutrino-nucleus cross-section



Implications for 100 TeV proton-proton collisions



- At the FCC 100 TeV, even **inclusive EW cross-section depend on small-x PDFs** unless restricted to central rapidity region
- **Stabilise FCC cross-section predictions** by using the NNPDF3.0+LHCb improved small-x gluon PDFs

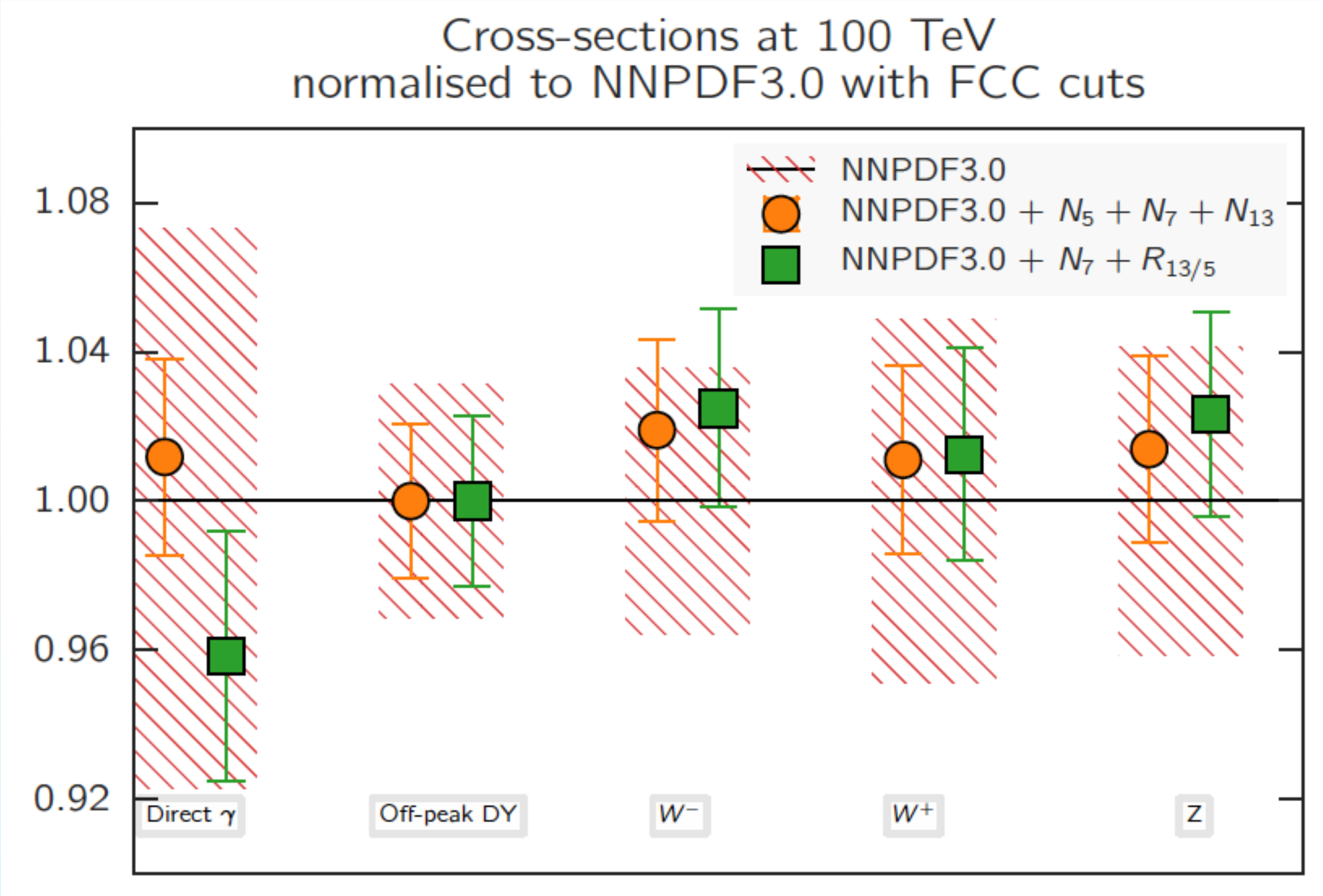
LHC cuts: $p_T^l \geq 20$ GeV, $|y_l| \leq 2.5$
FCC cuts: $p_T^l \geq 20$ GeV, $|y_l| \leq 5$.

(percentage uncertainties in FCC inclusive xsecs)

$\sigma(pp \to V \to l_1 l_2)$ [nb] $(\pm\delta_{\rm pdf}\sigma)$	14 TeV		100 TeV		
	No cuts	LHC cuts	No cuts	LHC cuts	FCC cuts
W^+	11.8 (1.9)	6.4 (2.0)	73.5 (7.0)	27.8 (2.9)	52.8 (4.9)
W^-	8.8 (1.8)	4.7 (1.4)	61.9 (5.5)	26.0 (3.0)	44.1 (3.6)
Z	2.0 (1.7)	1.5 (1.8)	14.1 (5.1)	7.9 (3.2)	12.5 (4.1)

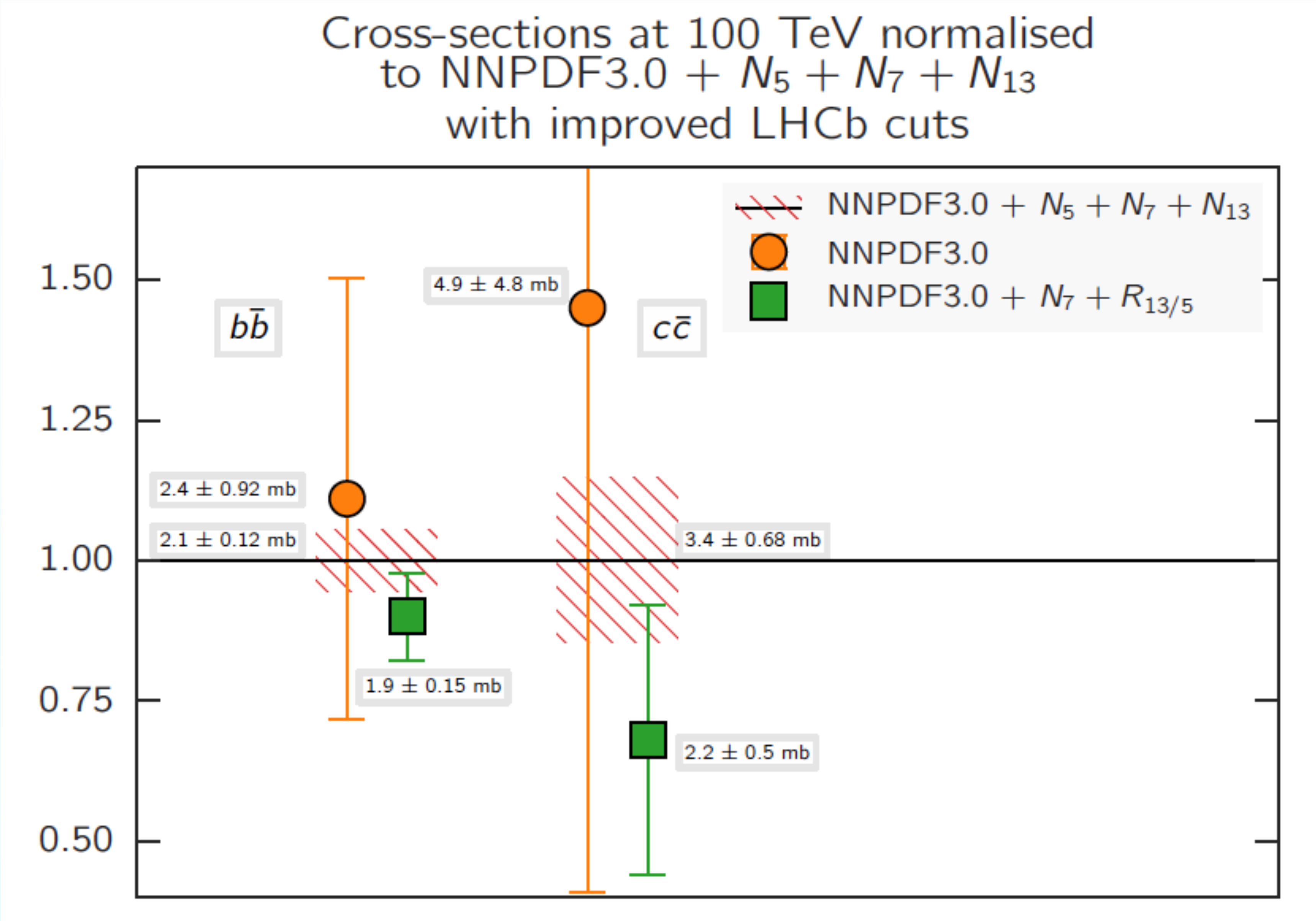
Gauld, Rojo 16

Implications for 100 TeV proton-proton collisions



The LHCb charm data allows to stabilize FCC 100 TeV inclusive cross-sections

Implications for 100 TeV proton-proton collisions



Same for inclusive charm and bottom production at 100 TeV

Summary and outlook

- Charm production in the forward region by LHCb provides stringent constraints on the **small-x gluon** (and on the small-x quarks via DGLAP evolution)

- The combination of **5 TeV, 7 TeV and 13 TeV *D* meson production from LHCb** allows a **precision determination of the small-x gluon PDF** way beyond the HERA coverage

- This improved small-x gluon allows accurate predictions for **signal and background events at neutrino telescopes**, making possible the start of a precision physics program with UHE neutrino events

- At a future 100 TeV proton-proton collider, even **inclusive electroweak cross-sections depend directly on the small-x PDFs**. Using the NNPDF3.0+LHCb, updated cross-sections exhibit stabilised PDF uncertainties

Summary and outlook

- Charm production in the forward region by LHCb provides stringent constraints on the **small-x gluon** (and on the small-x quarks via DGLAP evolution)

- The combination of **5 TeV, 7 TeV and 13 TeV *D* meson production from LHCb** allows a **precision determination of the small-x gluon PDF** way beyond the HE[illegible]verage

- This improved small-x gluon allows accurat[illegible] **background events at neutrino telescopes**, maki[illegible]cision physics program with UHE neutrino events

- At a fu[illegible]roton collider, even **inclusive electroweak cross-sections depend** [illegible] **the small-x PDFs**. Using the NNPDF3.0+LHCb, updated cross-sections [illegible]ibit stabilised PDF uncertainties

Thanks for your attention!