

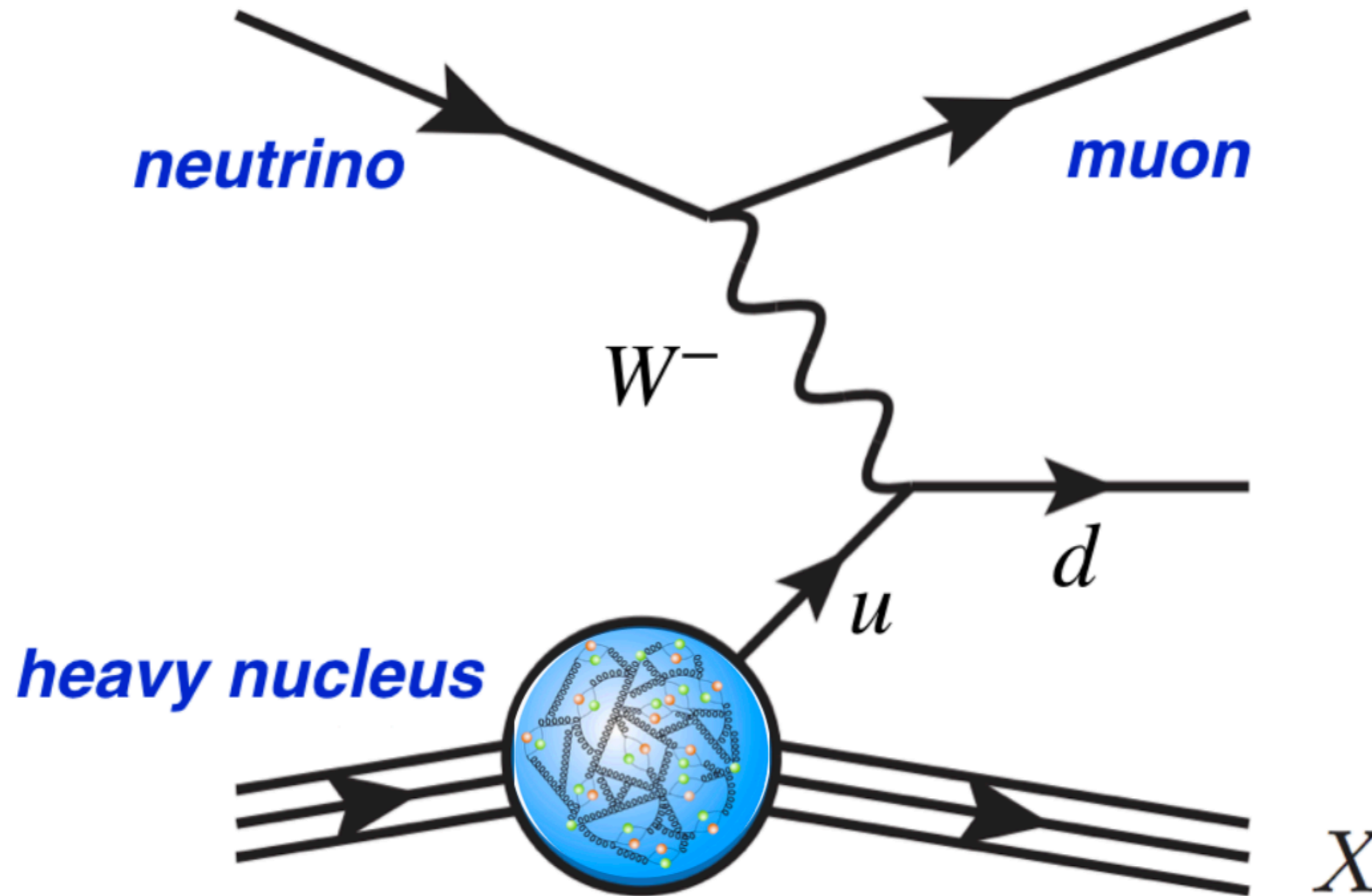
What can we learn from high-energy neutrino-nucleon collisions?

Juan Rojo

VU Amsterdam & Theory group, Nikhef

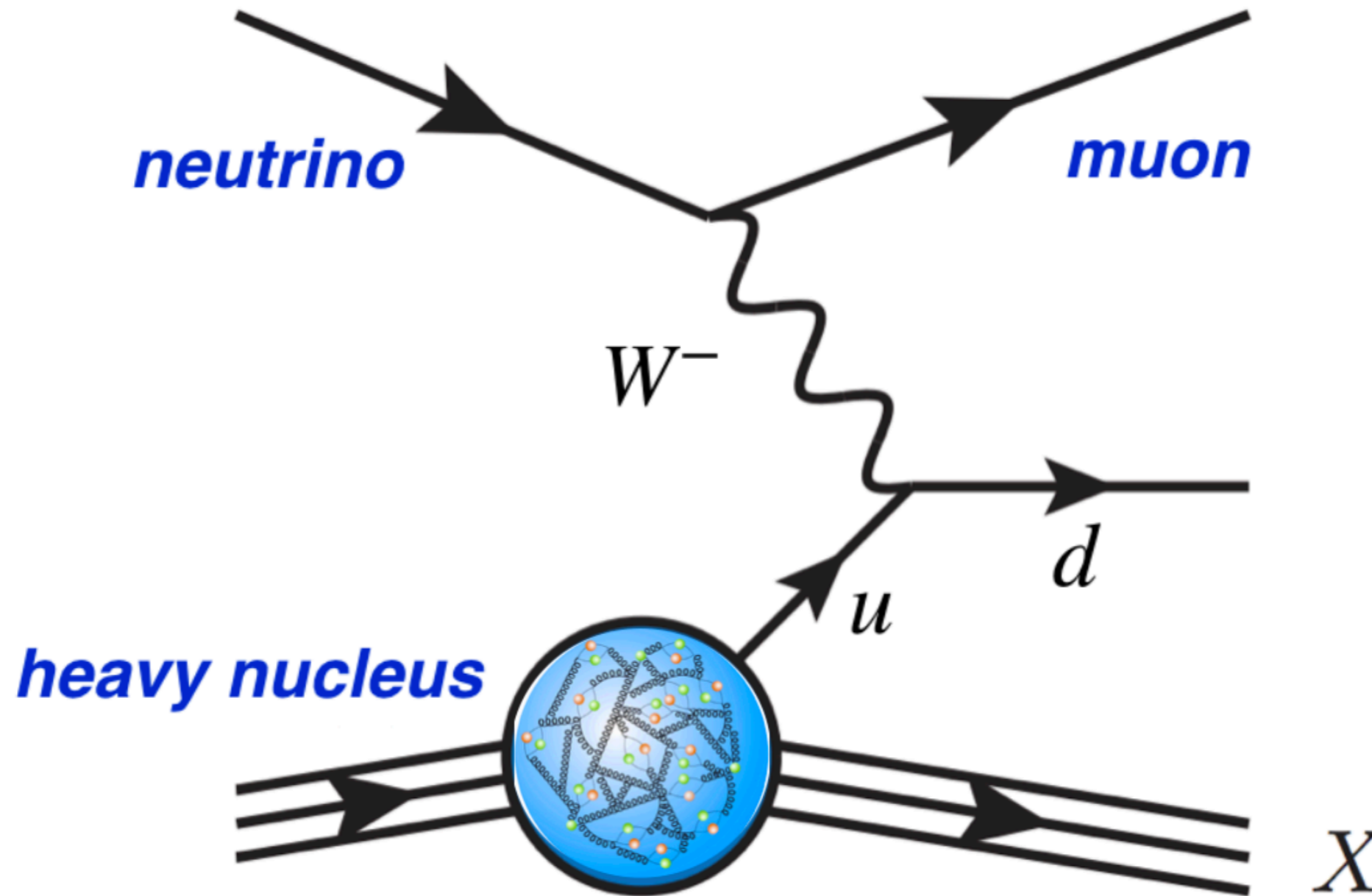
***Nikhef Workshop Theory Meets Experiment
High-energetic neutrino scattering processes and
interactions of cosmic rays***

Neutrino-nucleus scattering



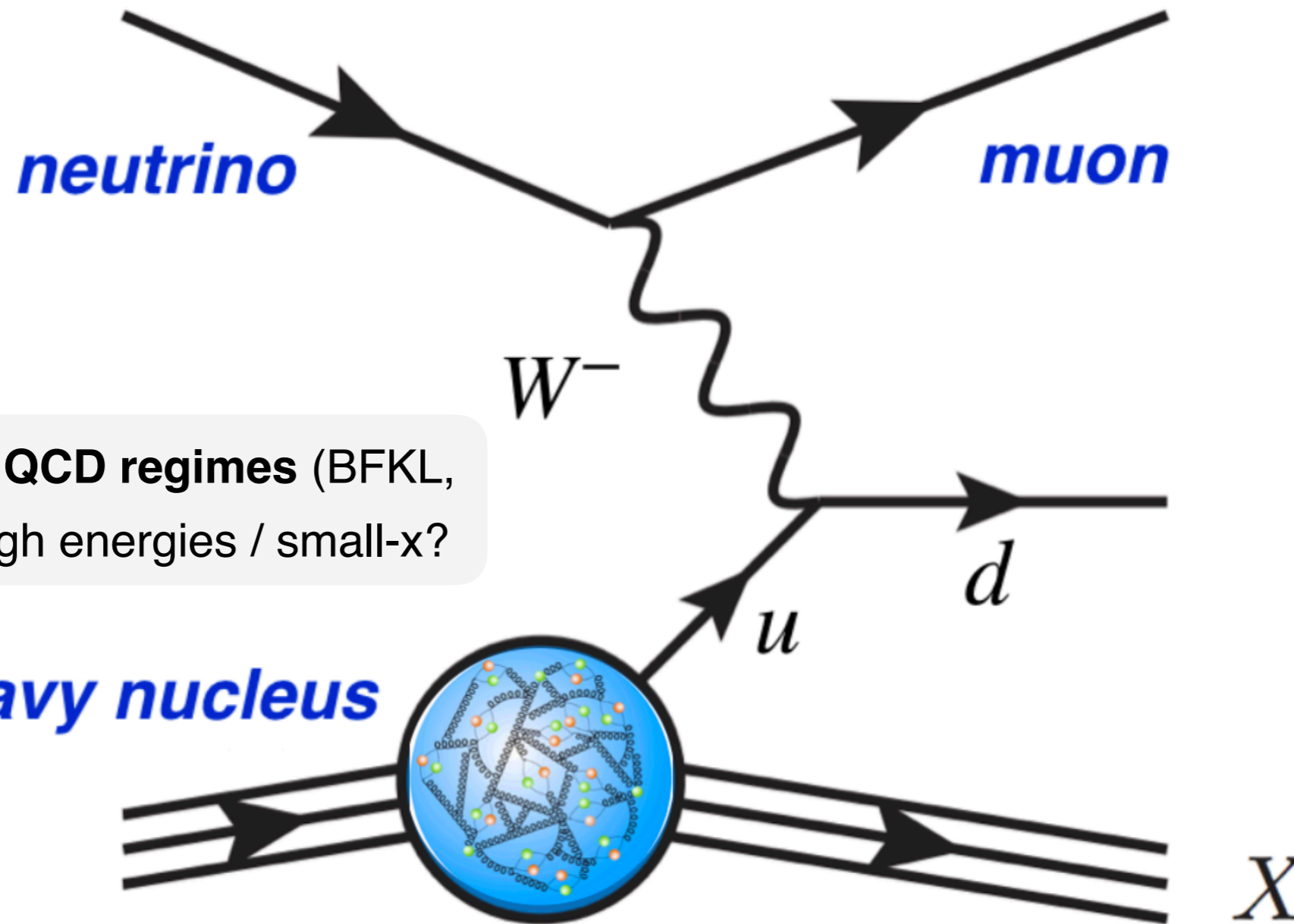
Rhorry's talk: review of the theory of neutrino-nucleus scattering

Neutrino-nucleus scattering



what is quark and gluon content of nucleons and nuclei at high energies / small-x?

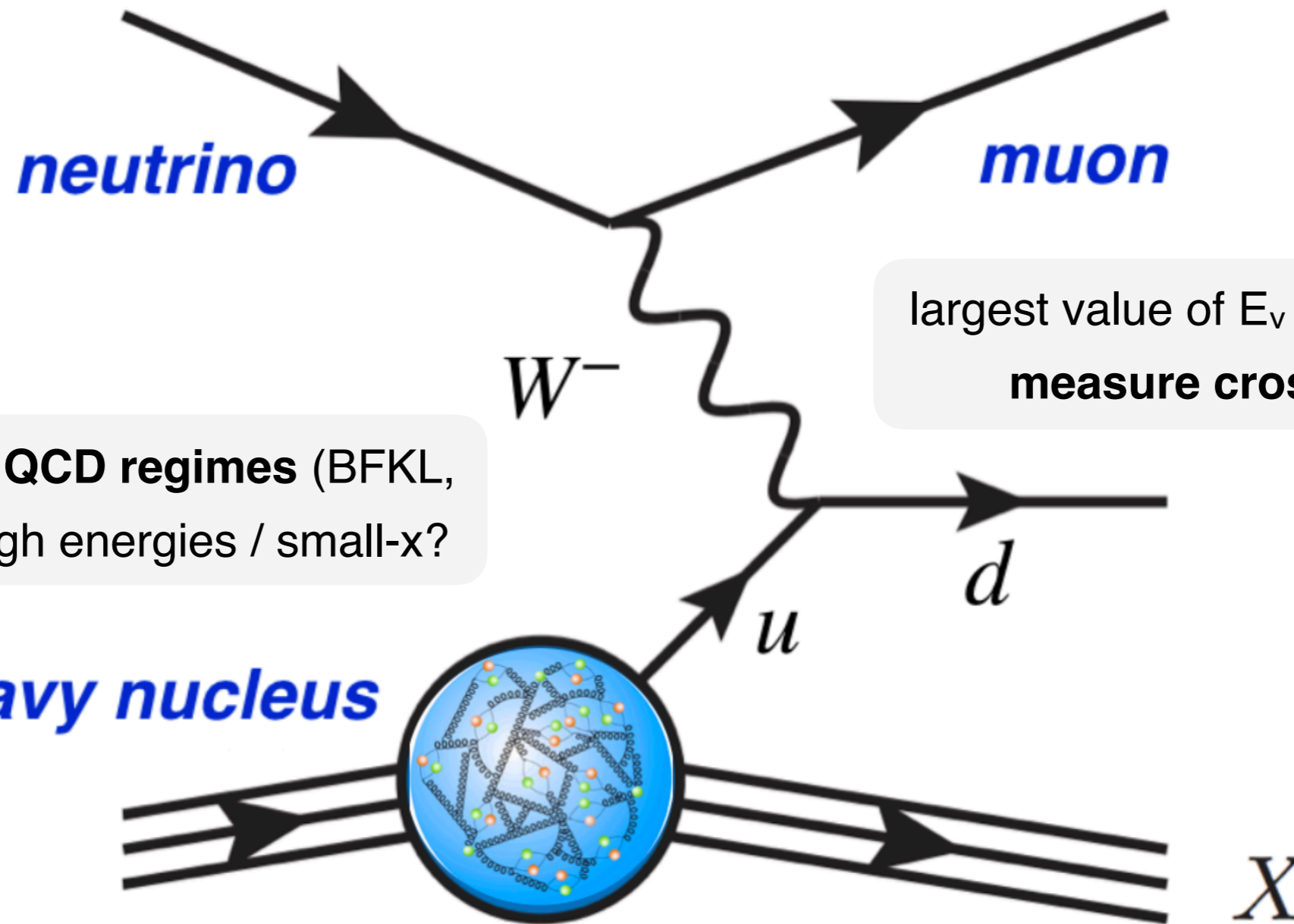
Neutrino-nucleus scattering



new **dynamical QCD regimes** (BFKL, non-linear) at high energies / small-x?

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Neutrino-nucleus scattering



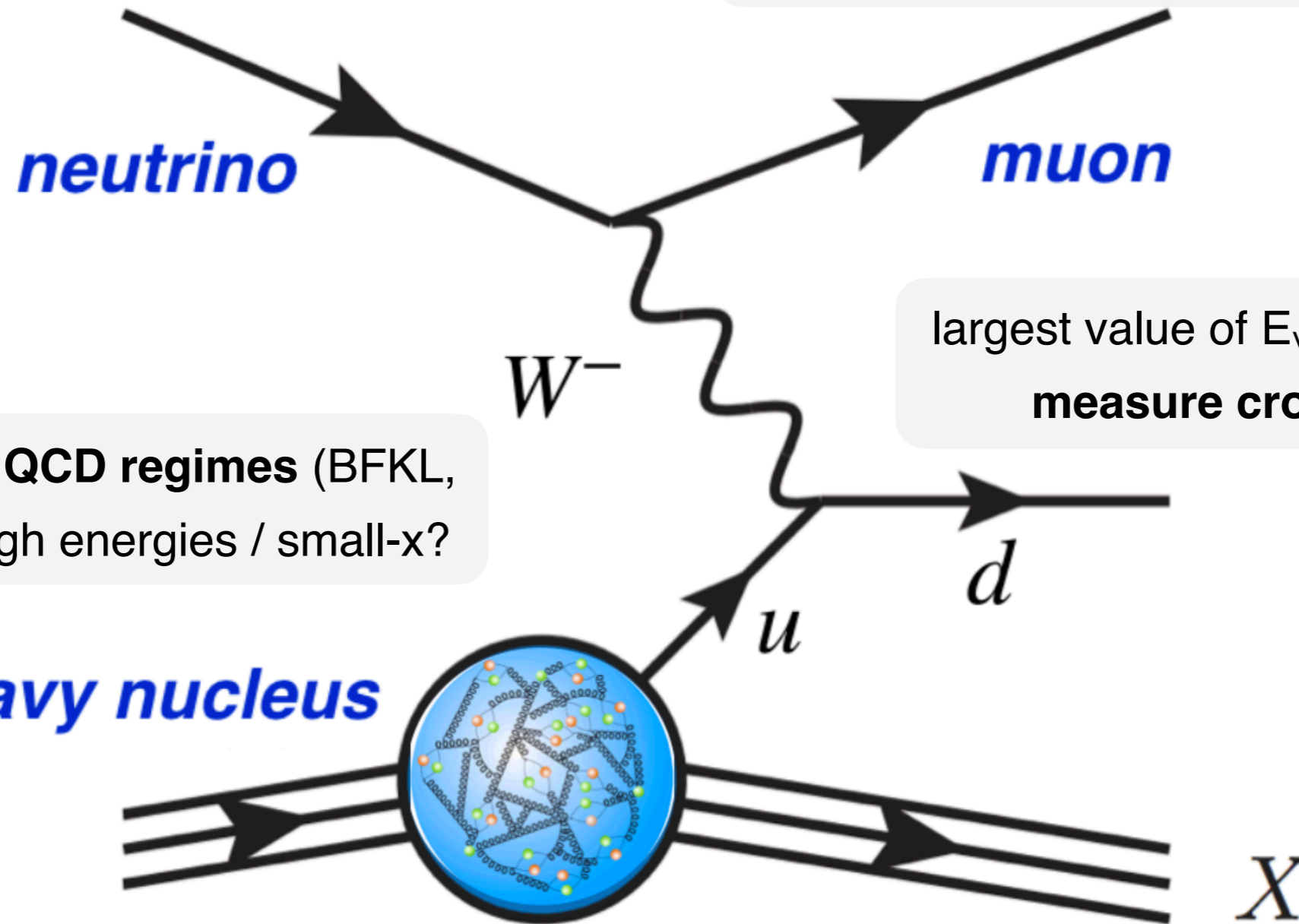
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largest value of E_ν for which we can **measure cross-section**?

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Neutrino-nucleus scattering

theory uncertainties affect interpretation of KM3NET/IceCube data?



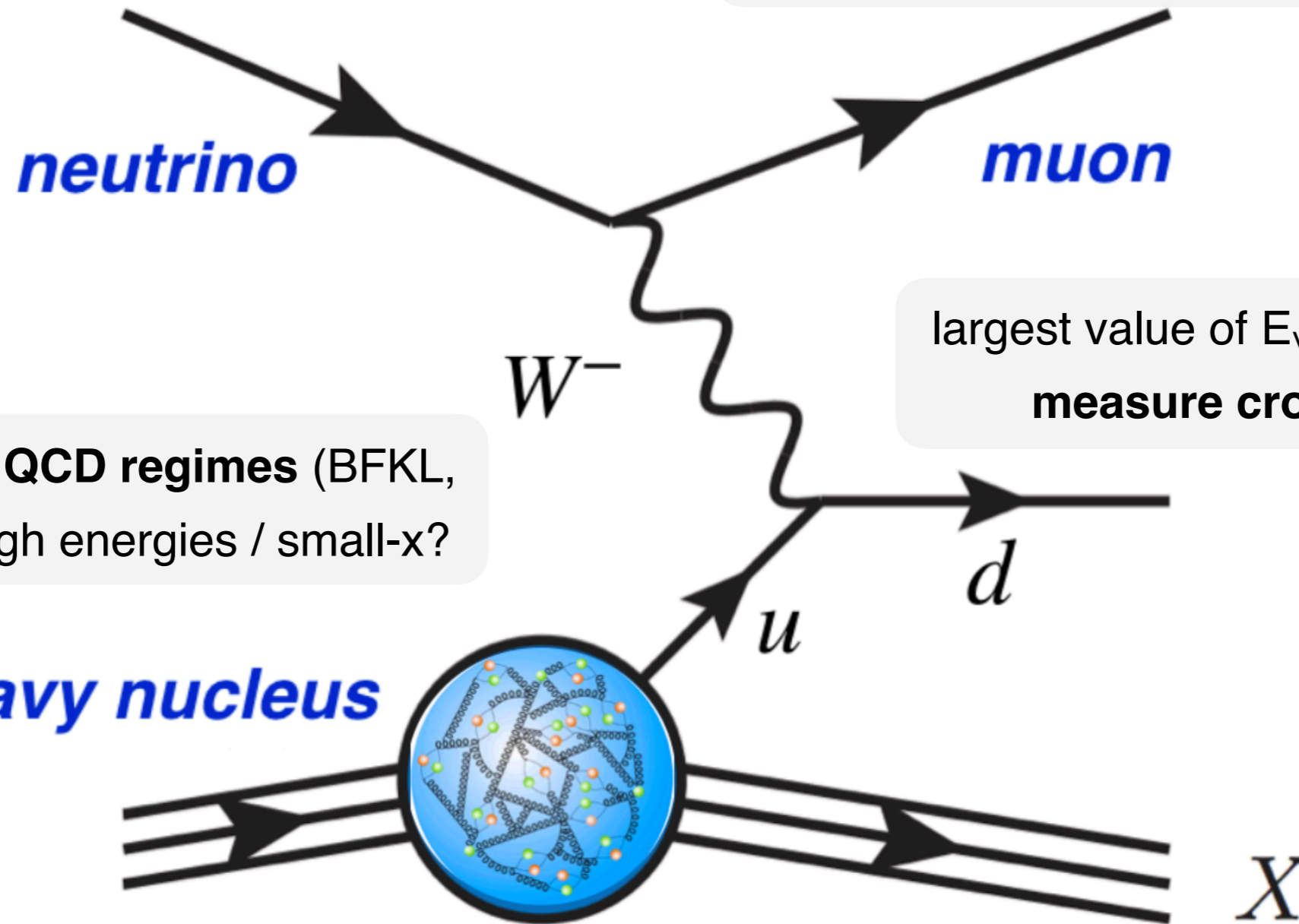
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UHE neutrinos and **geophysics**

Neutrino-nucleus scattering

connection with **Muon Puzzle**
in Cosmic Ray physics?

theory uncertainties affect interpretation
of KM3NET/IceCube data?

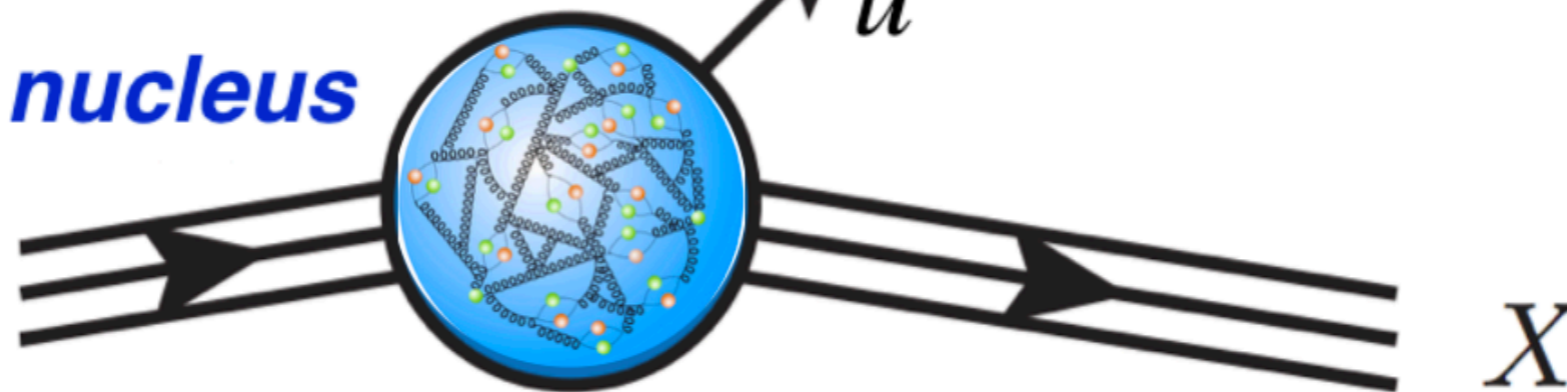
neutrino

muon

new **dynamical QCD regimes** (BFKL,
non-linear) at high energies / small-x?

largest value of E_ν for which we can
measure cross-section?

heavy nucleus

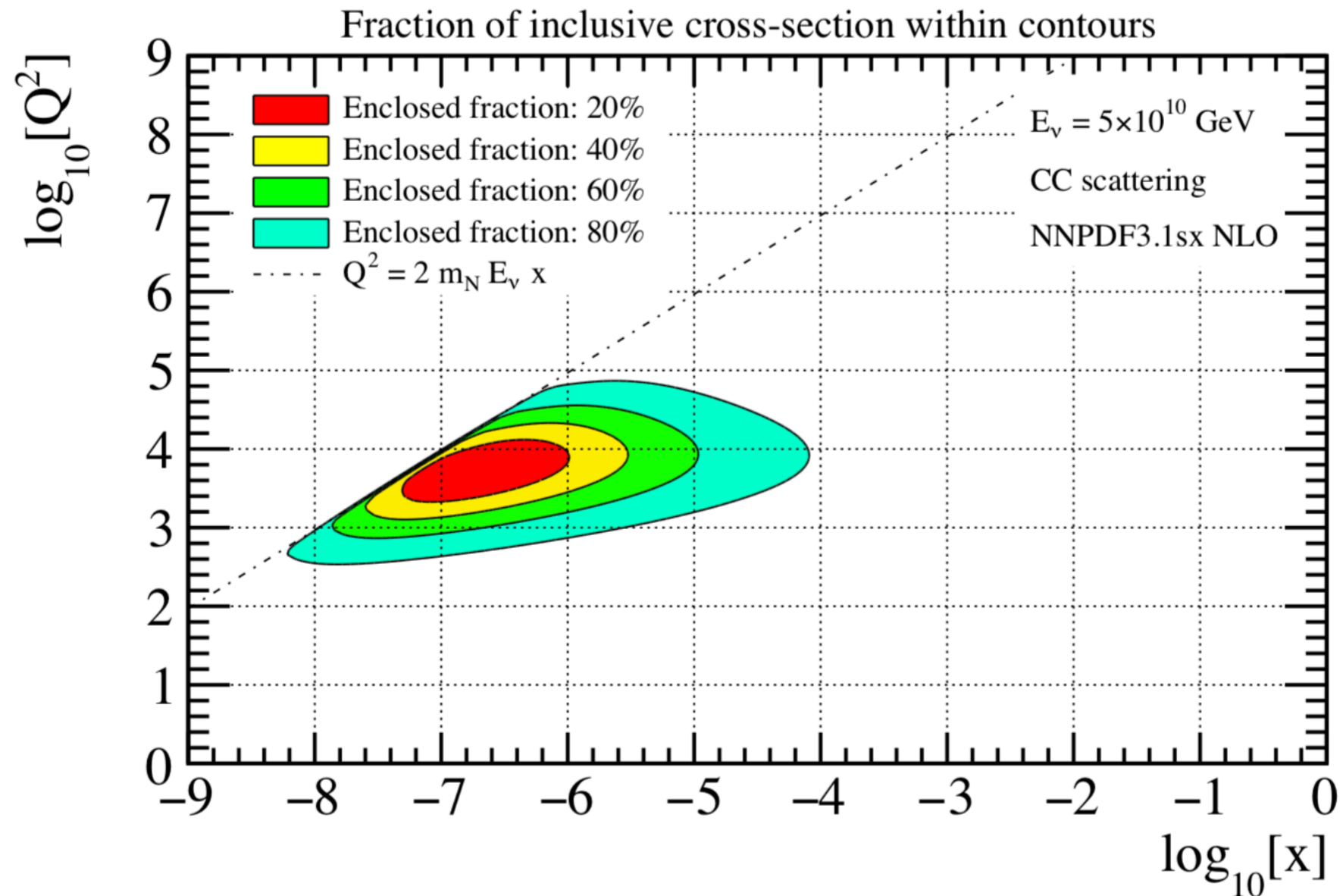


what is **quark and gluon content of nucleons**
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UHE neutrinos and geophysics?

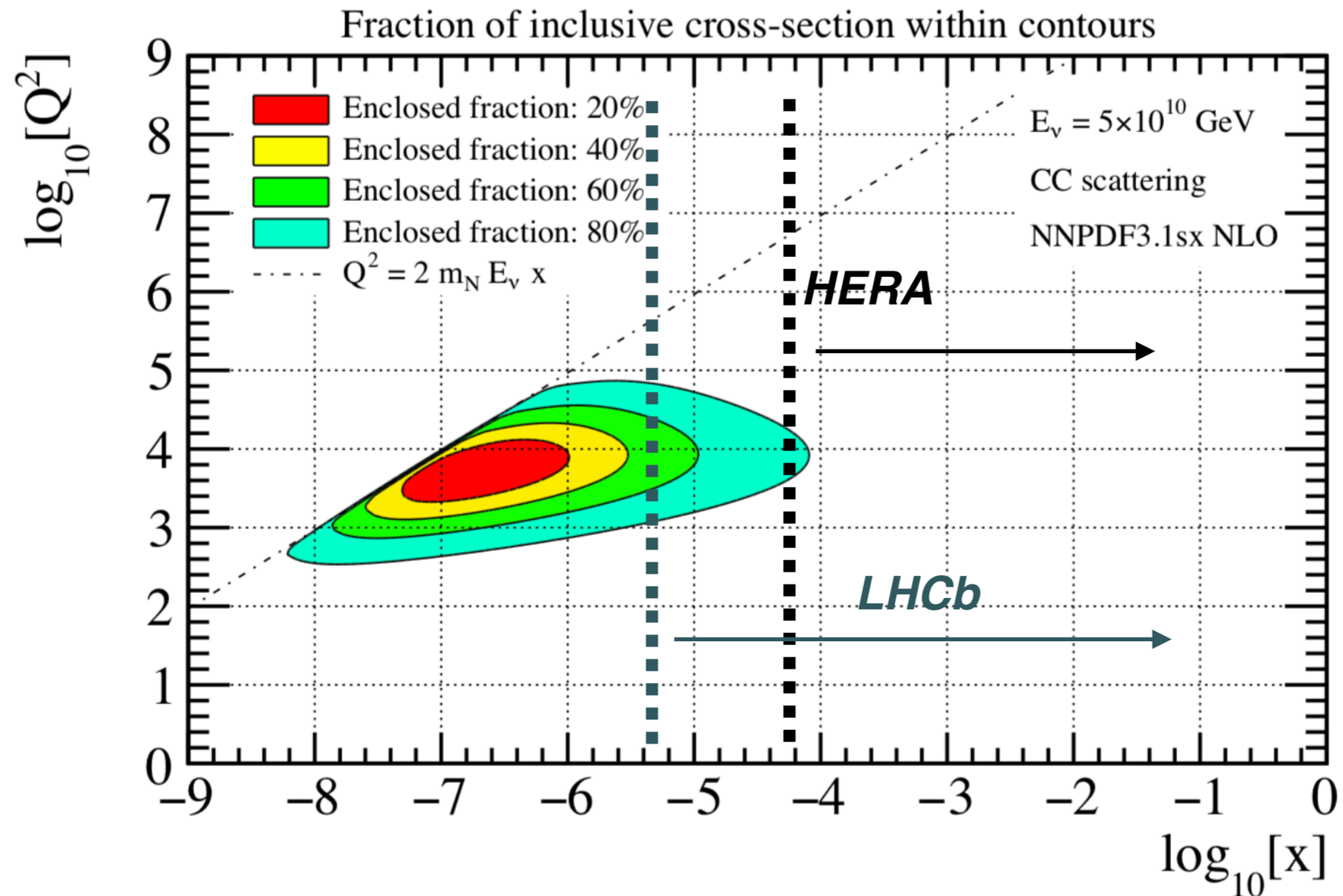
Neutrino telescopes as probes of small-x QCD

Bertone, Gauld, JR 18



sensitive to **small-x quarks** (and thus gluons via evolution) down to $x \approx 10^{-8}$ and $Q \approx M_W$

Neutrino telescopes as probes of small-x QCD

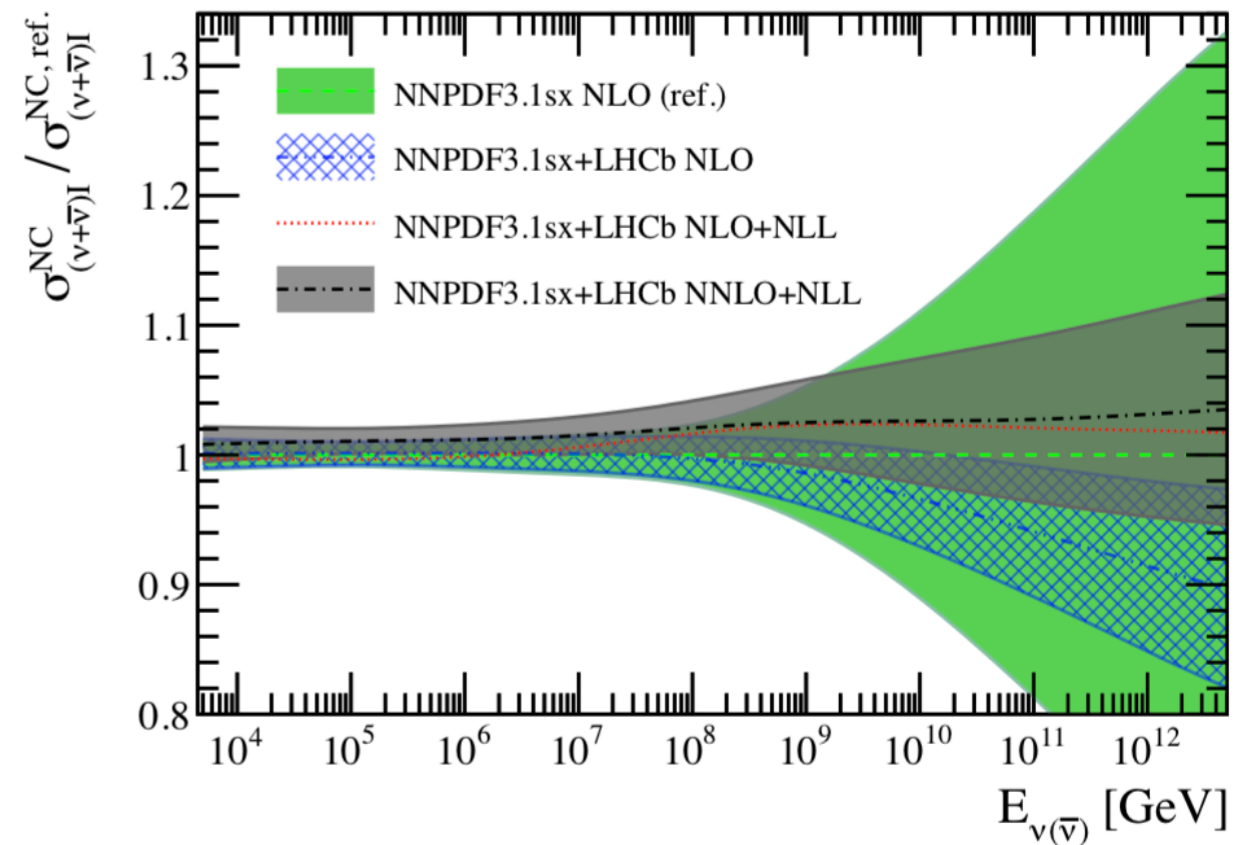
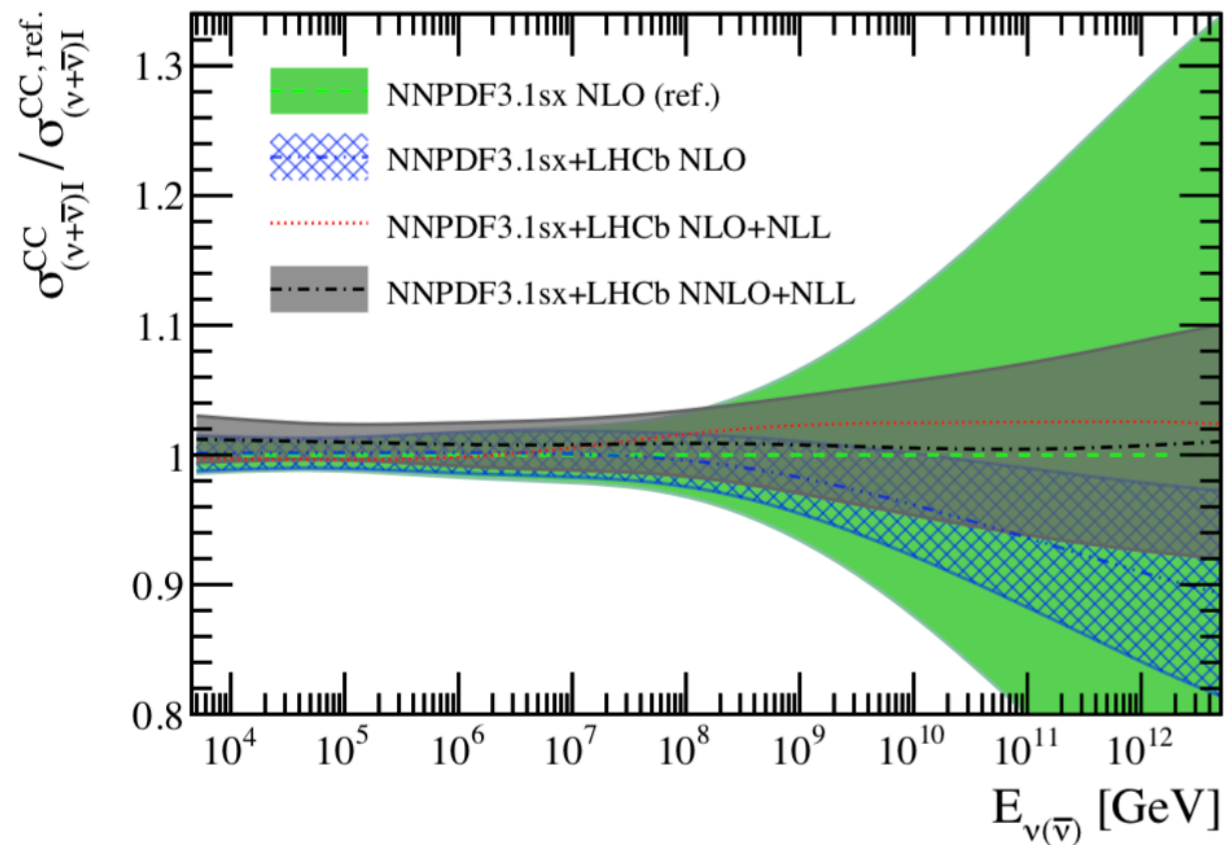


sensitive to **small-x quarks** (and thus gluons via evolution) down to $x \approx 10^{-8}$ and $Q \approx M_W$

unique access to small-x in the foreseeable future!

Neutrino telescopes as probes of small-x QCD

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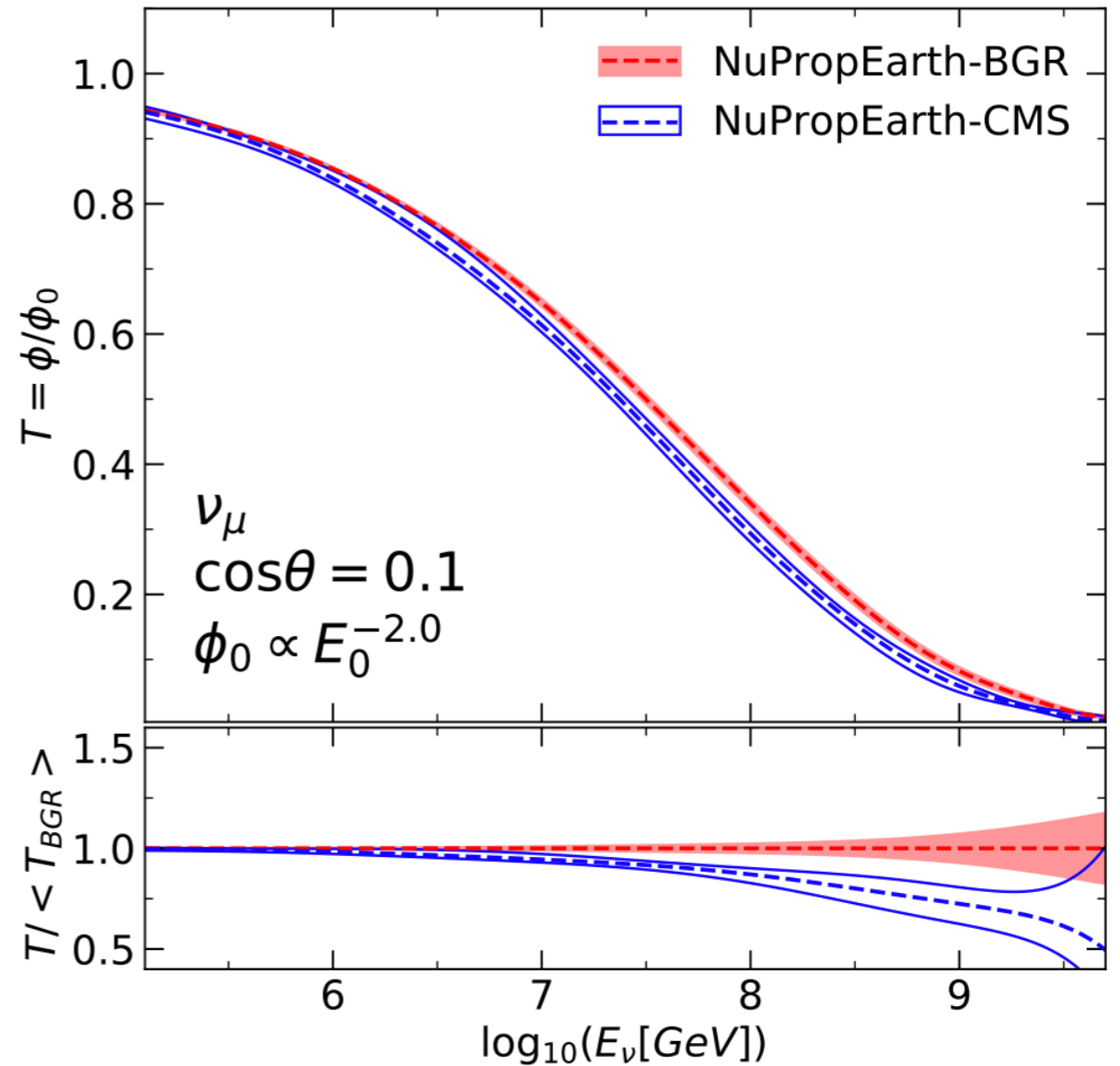
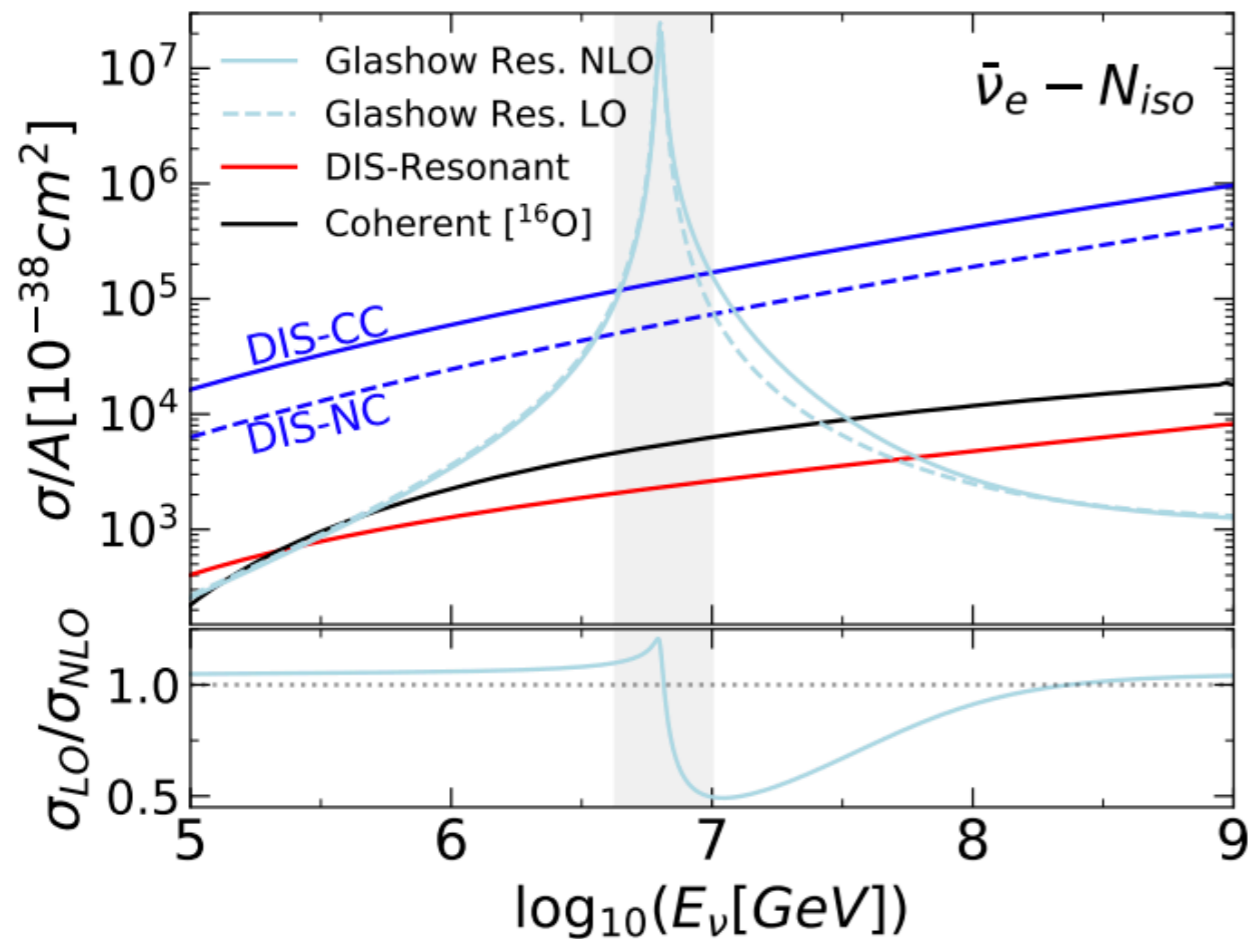
State-of-the-art predictions for **ultra-high energy** neutrino interactions

- 🔍 **BFKL small-x effects** in PDFs and deep-inelastic structure functions
- 🔍 Constraints on small-x PDFs from **LHCb charm production**
- 🔍 Accounting for **nuclear corrections** and heavy-quark-initiated contributions

Complete predictions for attenuation rates

Garcia, Gauld, Heijboer, JR 20

See Alfonso's talk!



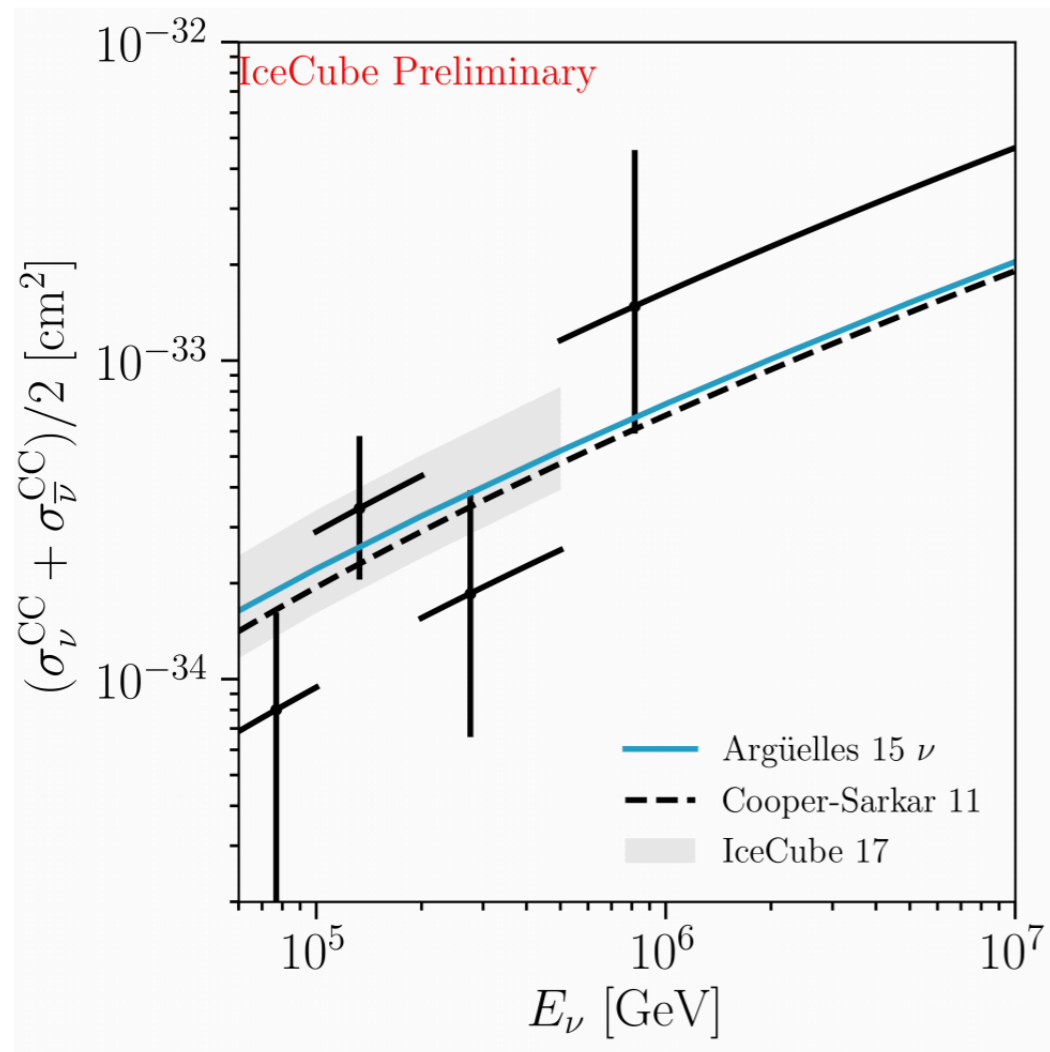
State-of-the-art predictions for ultra-high energy neutrino **attenuation rates**

- All subleading channels included, implemented in **GENIE Monte Carlo**
- Used to constrain nuclear structure, Earth model: **geophysics with neutrinos**

Cross-section measurement: how far in energy?

charged-current scattering at very high-energies:

fundamental measurement of neutrino telescopes, impossible in other facilities



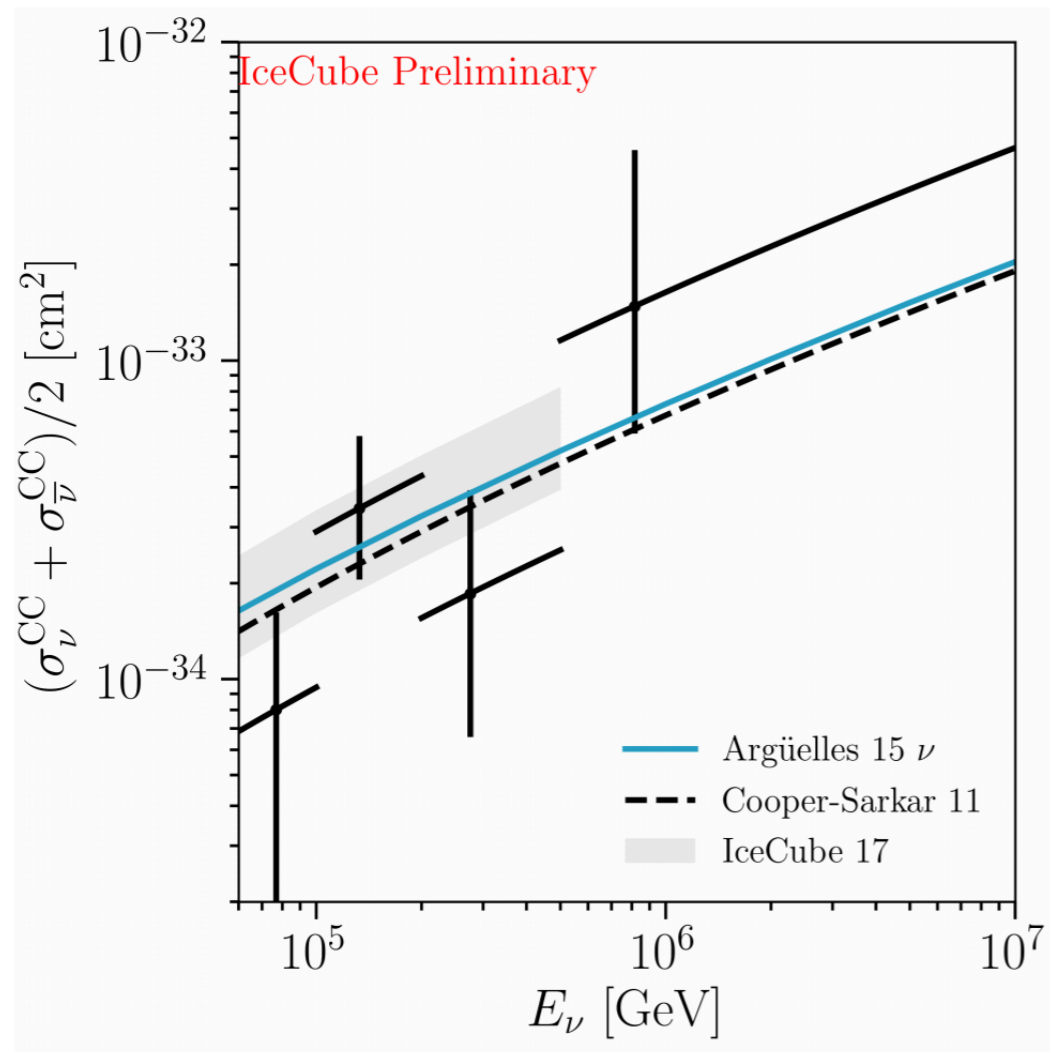
current IceCube measurements sensitive to

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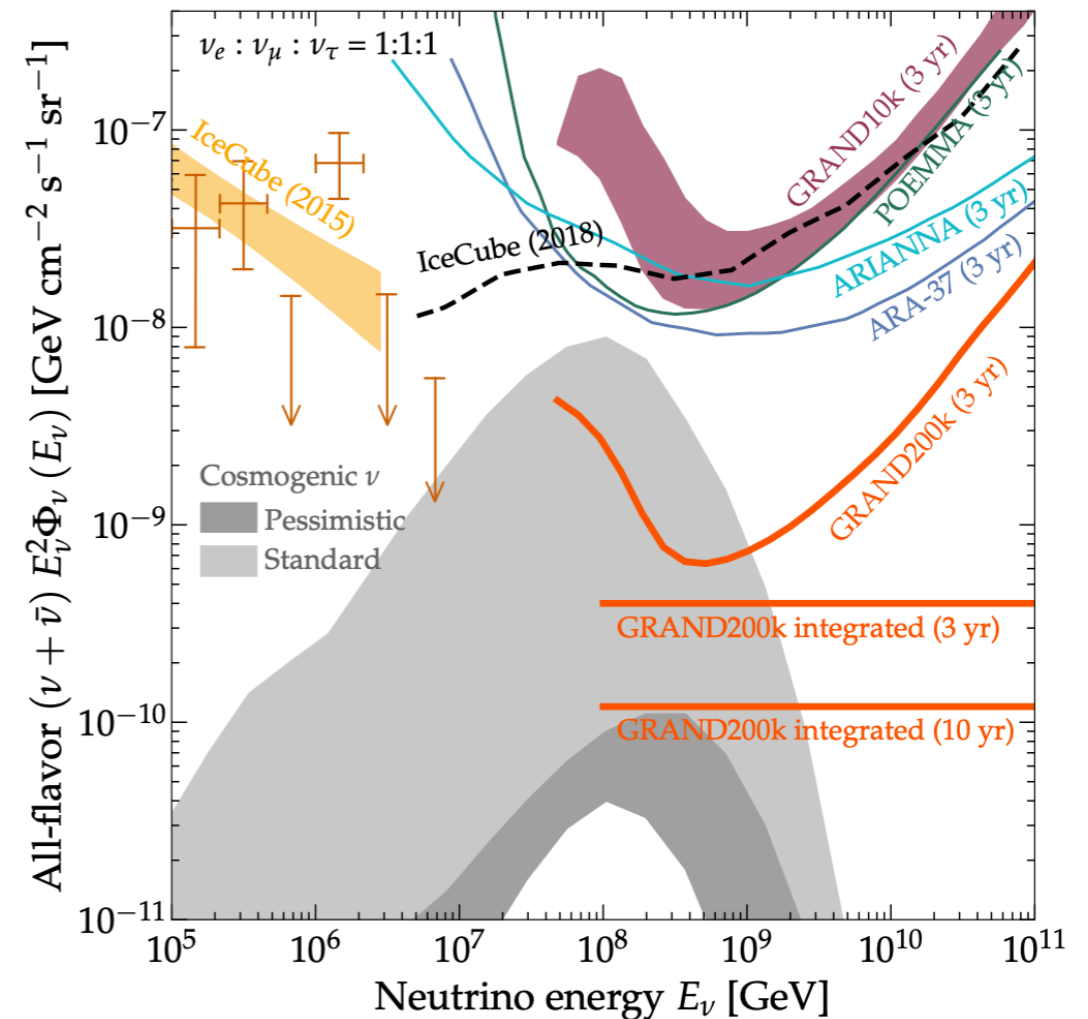
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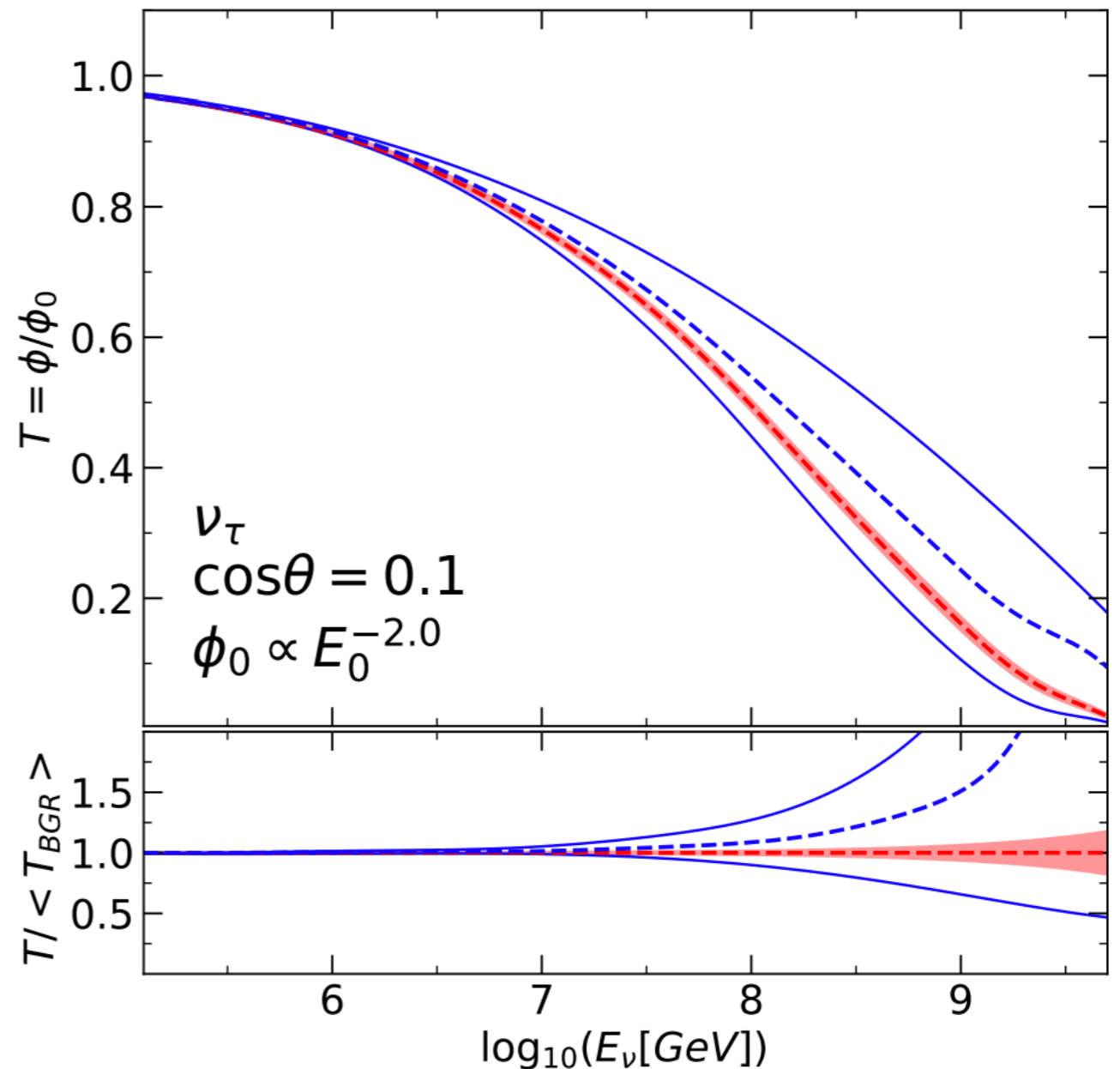
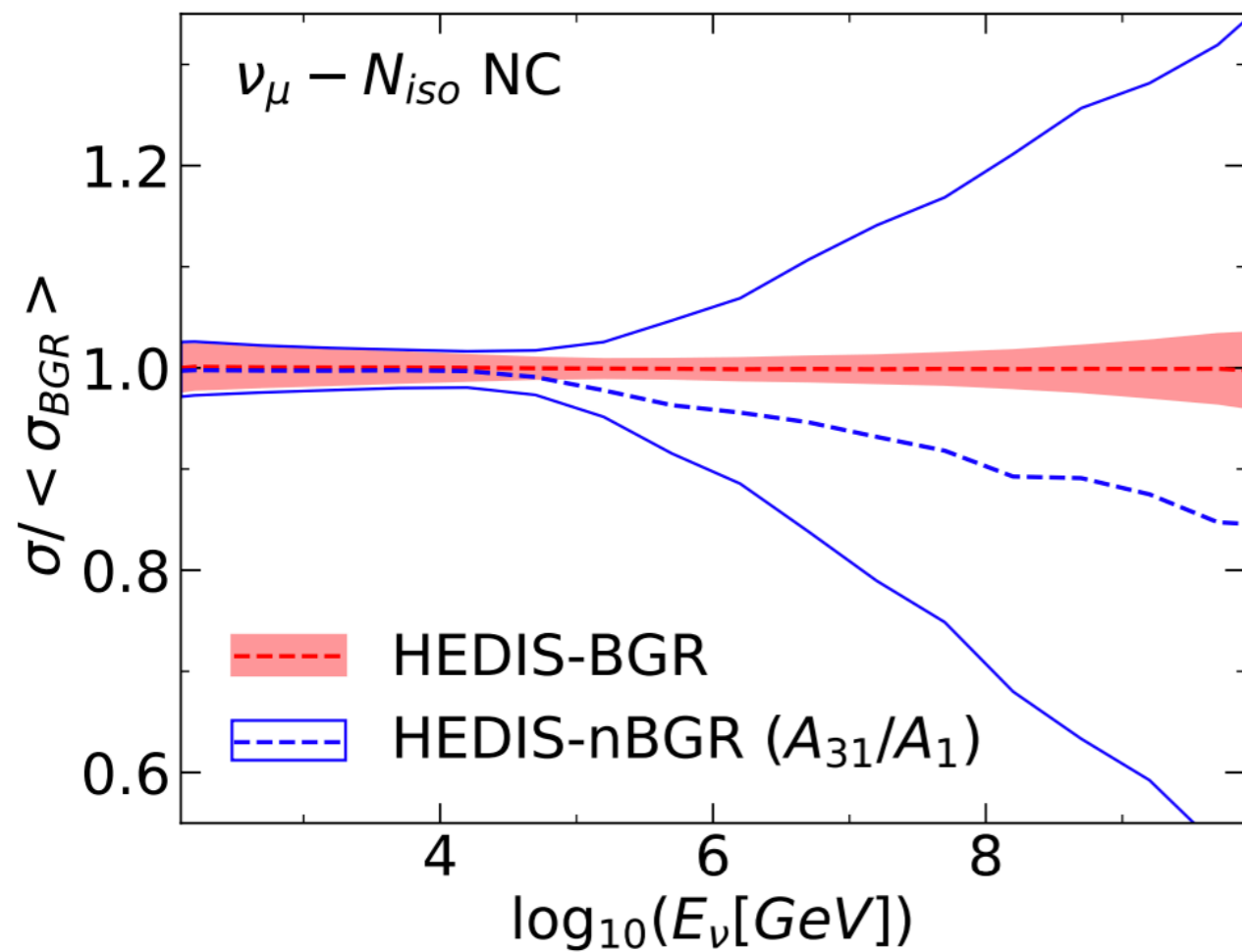
GRAND could reach

$$\sqrt{s} = \sqrt{2m_N E_\nu} \simeq 100 \text{ TeV}$$

what would be precision of such measurement?

Nuclear effects in neutrino DIS

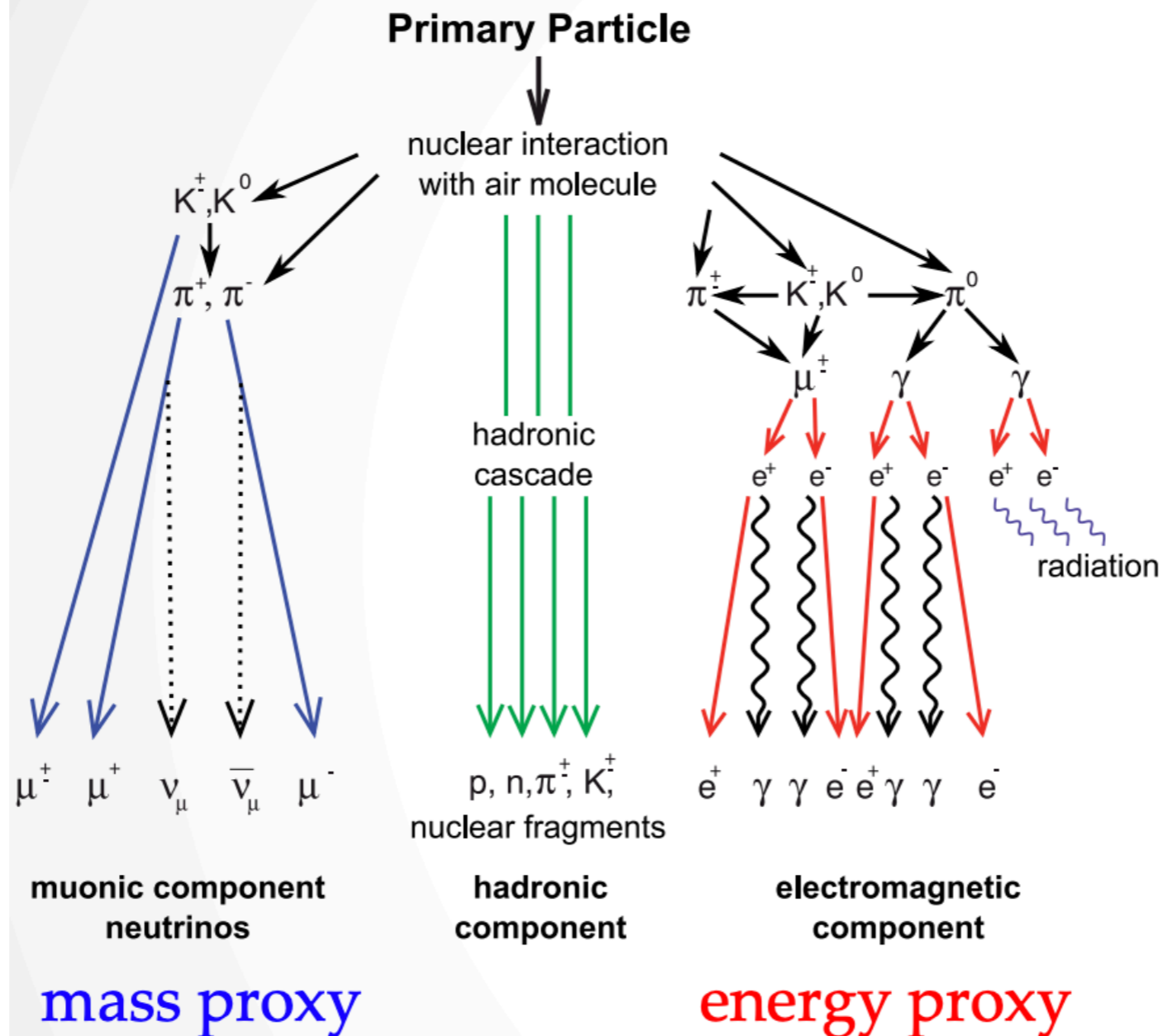
nuclear modifications (shadowing) main source of TH error at high-energies
exploit information from **LHC pPb collisions** (WIP) + future colliders (eg **EIC**)



The muon puzzle in cosmic rays

cosmic ray collisions: highest energy natural collider available!
 properties of cosmic ray primary extracted from resulting shower

Haungs et al., JoP Conf. Ser. 632 (2015) 012011

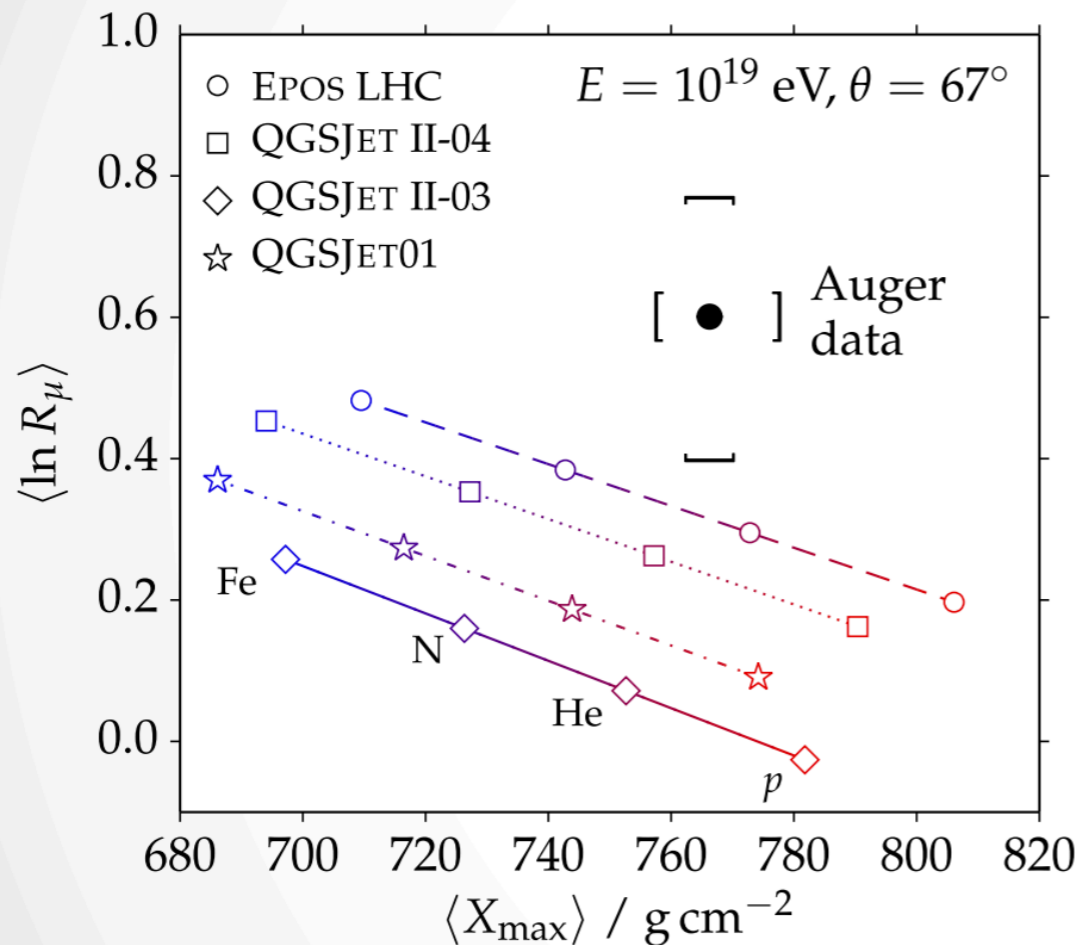


The muon puzzle in cosmic rays

the number of muons in energetic air showers **systematically higher** than theory simulations: where is the problem?

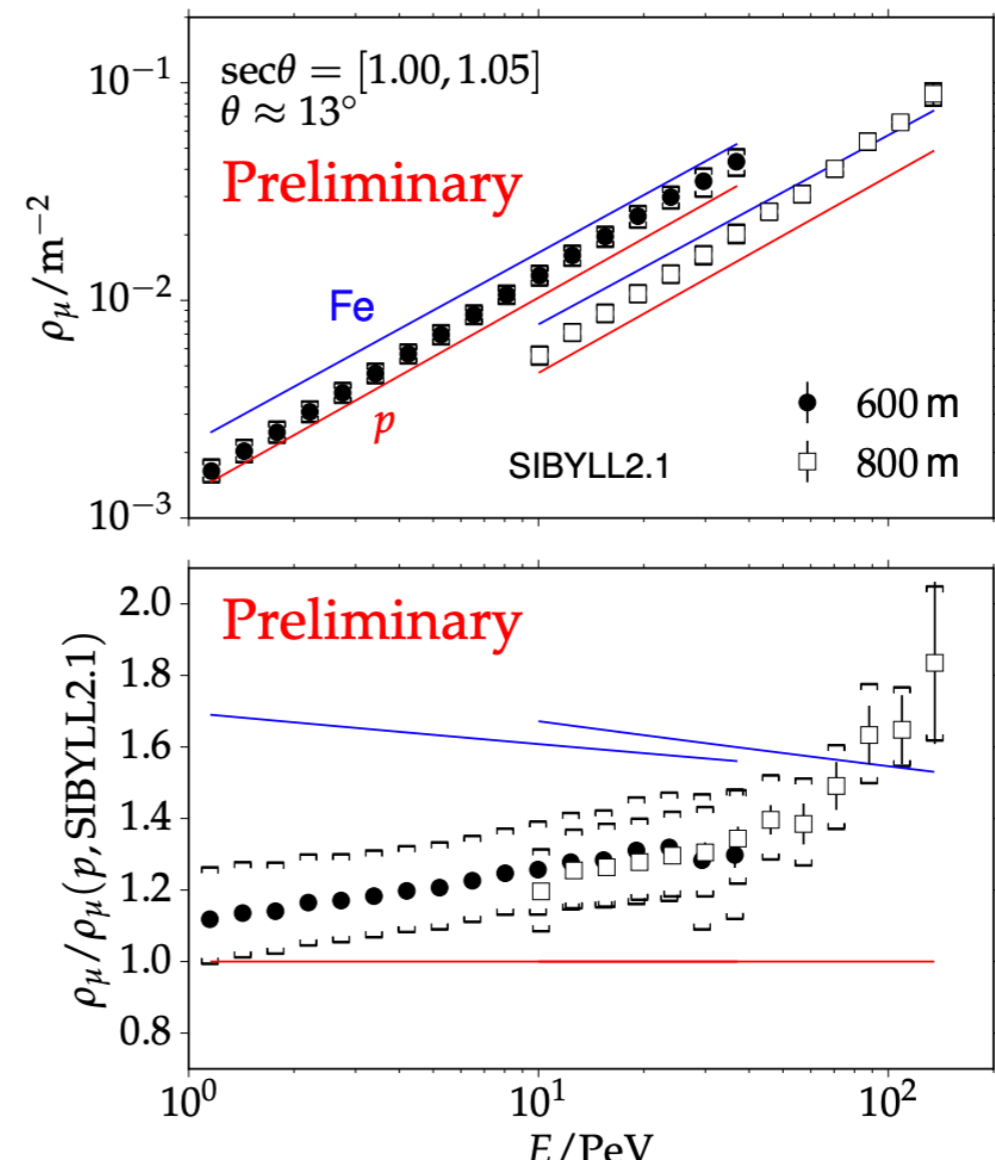
Muon deficit in simulated air showers for cosmic rays above 10^8 GeV

HD et al. (Auger collab.), PRD 91 (2015) 032003



Muon number in data **20 % higher** than closest model (EPOS-LHC)

HD et al. (IceCube collab.), EPJ WoC 145 (2017) 01003



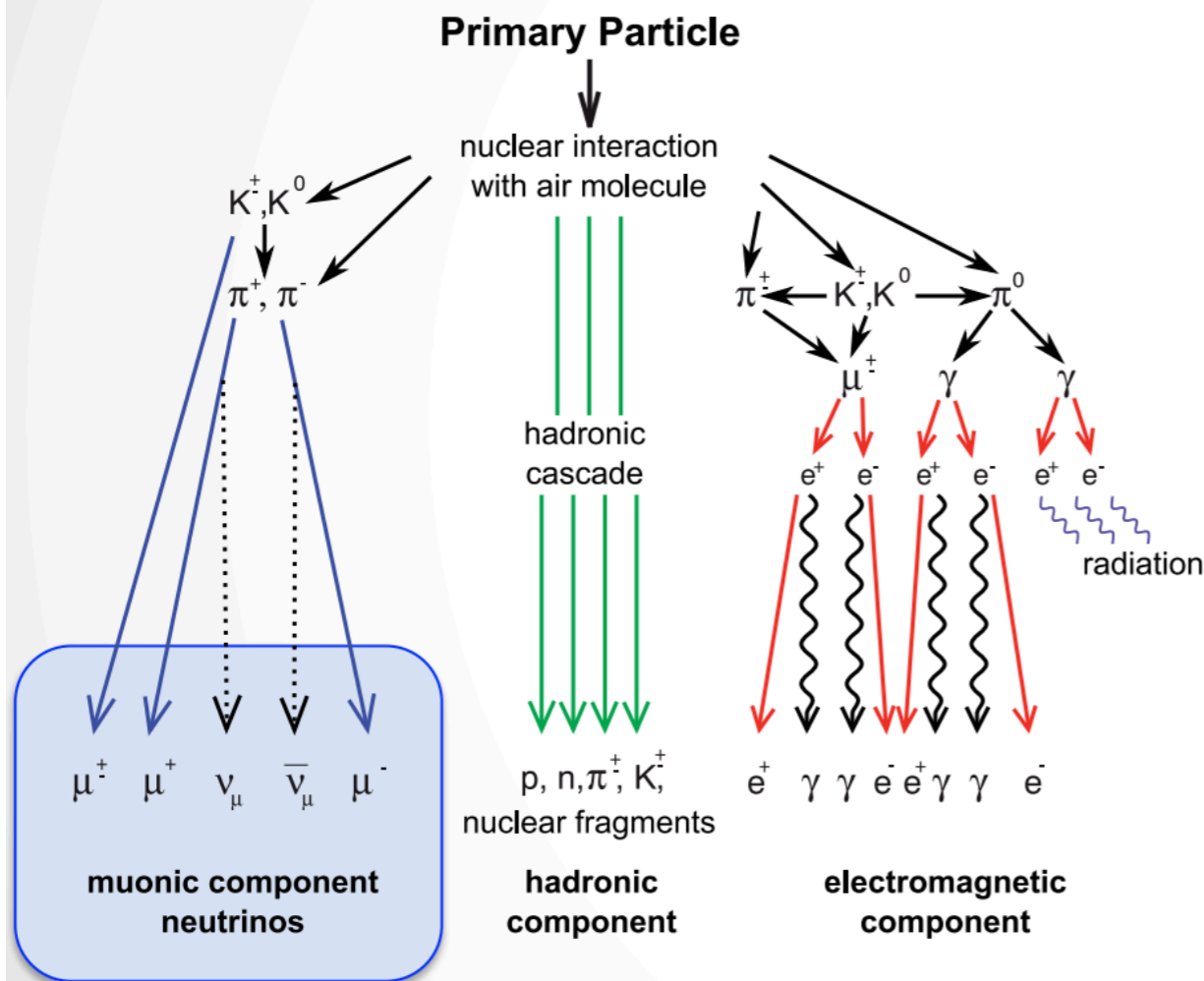
from Hans Dembinsky

The muon puzzle in cosmic rays

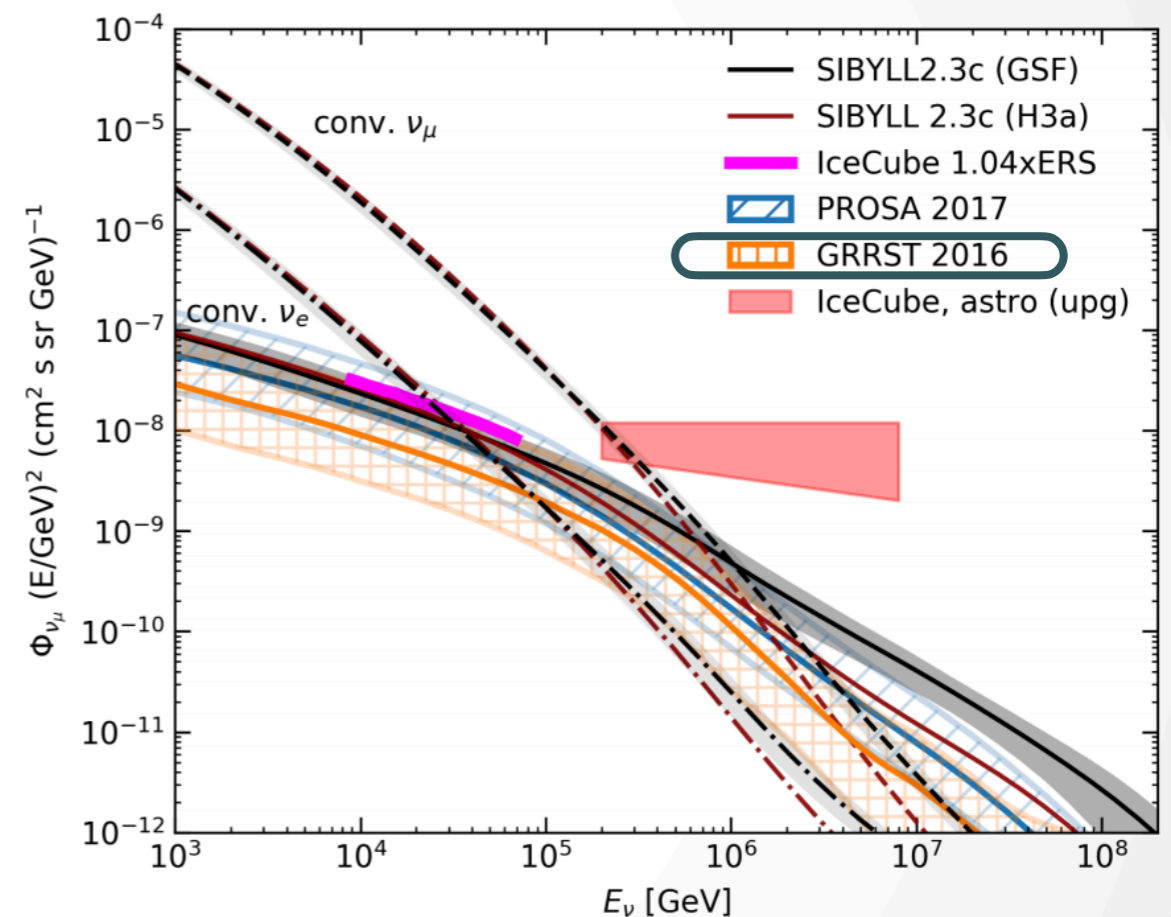
The same energetic cosmic rays responsible for the main backgrounds to astrophysical neutrinos: **prompt neutrinos from charm decay**

To get better predictions of atm. neutrino background for neutrino observatories

Haungs et al., JoP Conf. Ser. 632 (2015) 012011



Fedynitch et al., PoS(ICRC2017)1019



Muon production and neutrino production in air showers coupled
 Wrong number of muons = wrong prediction of atm. neutrino background

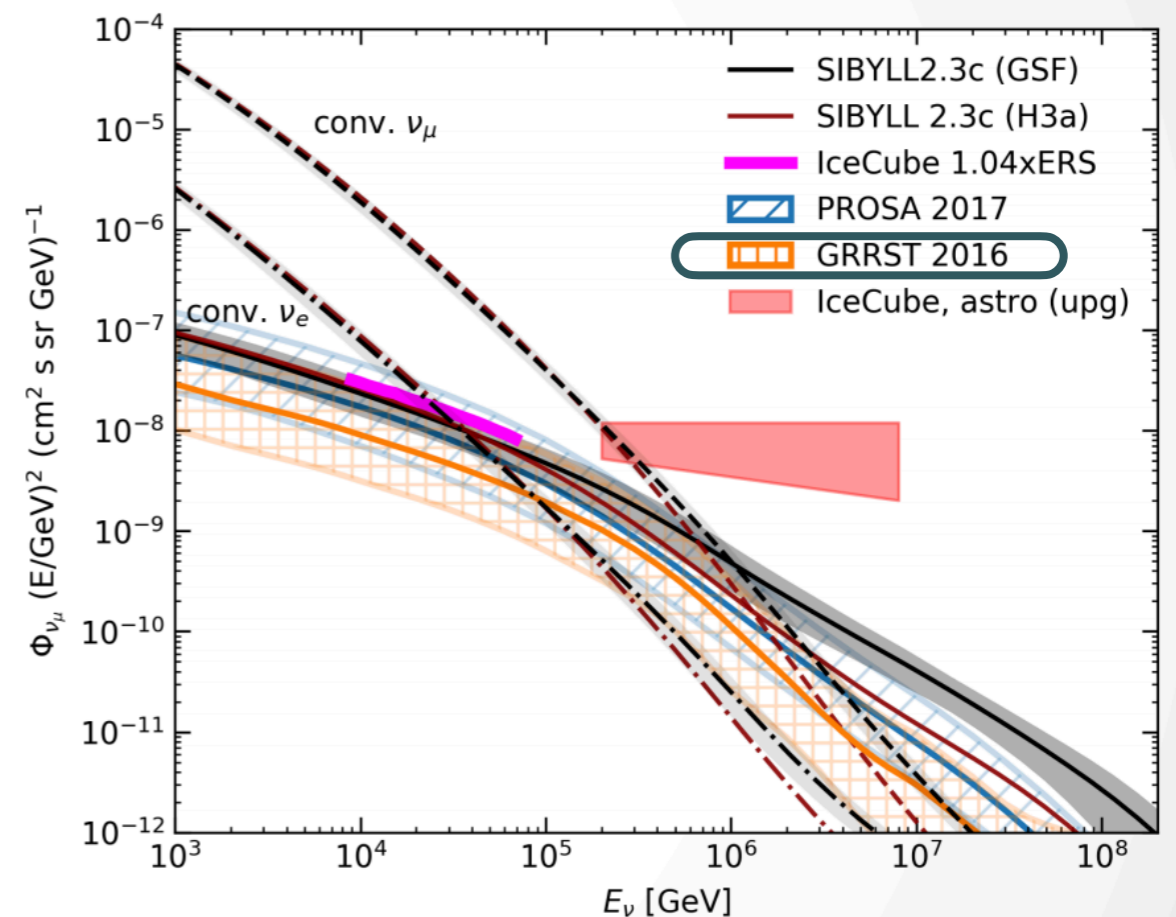
The muon puzzle in cosmic rays

maybe muons from **heavy quark decays** are being mismodeled?

how we can use best the **constraints from the LHC** to solve the muon puzzle

can we, QCD theorists, apply our neutrino know-how to **cosmic ray physics**?

Is there interest to kick-start collaborations **between Nikhef CR experimentalists and theorists**?



For discussion

UHE neutrino and cosmic ray physics are exciting fields with lots of potential for cross-field collaborations and synergies: **from LHC to astroparticles!**

Some possible topics to further explore in the discussion:

precise pQCD predictions for **charm production in cosmic rays?**

Connection with models of nuclear structure and **pPb collisions at LHCb?**

ultimate precision for the **measurement** of the UHE neutrino cross-sections?

Where else is the input from theorists required by **KM3NET/Auger?**