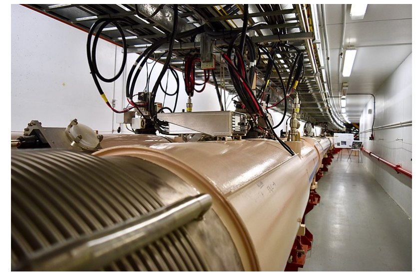
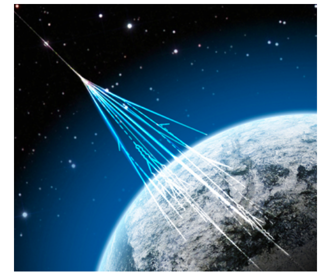
Center for Frontiers in Nuclear Science





CFNS workshop on Forward Physics And Instrumentation From Colliders To Cosmic Rays

17-19 October 2018
Charles B. Wang Center
US/Eastern timezone

J. Kiryluk (Stony Brook University)

Inaugural Symposium and the first review of the CFSN
30 November 2018

Workshop Organizers:
A. Deshpande, N.Feege, Y. Goto, J. Kiryluk, J.H. Lee, Ch. Royon, T. Sako

This meeting follows the successful previous "Workshop On Forward Physics And High-energy Scattering At Zero Degrees" held at the Nagoya University in Fall 2015 and 2017. This year, it aims at covering all aspects of forward physics and detector aspects at the LHC, at RHIC, and at the future EIC, benefiting from the experience gained at HERA and the Tevatron, as well as cosmic rays and neutrinos. The spirit of this meeting is to favor fruitful and informal discussions between experimentalists and theorists. Lots of time is devoted to discussion of new results, hot topics, and exciting open problems in forward physics from colliders to cosmic rays.

The topics discussed during the workshop are:

- Low x, Saturation, and Heavy Nuclei
- Photon Exchange, Pomeron, and Hard Diffraction
- Total Cross Section and Soft Diffraction
- Spin, GPDs, and TMDs
- Physics with Heavy Flavors
- Cosmic Rays and Neutrinos
- Future Experiments and Instrumentation

~60 participants
~30 talks

https://indico.bnl.gov/event/4737/overview

QCD strong interactions & nuclear effects
Systems: e(γ)p, e(γ)A, pp, AA, pA

<u>EIC physics & instrumentation (including LHC/RHIC)</u>

R. Milner
Ch. Weiss
M. Bruschi
M. Strikman
M. Baker
L. Elouadrhiri
P. Nadel-Turonski
M. Rijssenbeek
P. Steinberg
A.Mignerey
M. Murray
C. daSilva
T. Peitzmann
O. Eyser
A. Bazilevsky
B. Schenke

<u>Spin:</u>

M. Krelina
I. Nakagawa

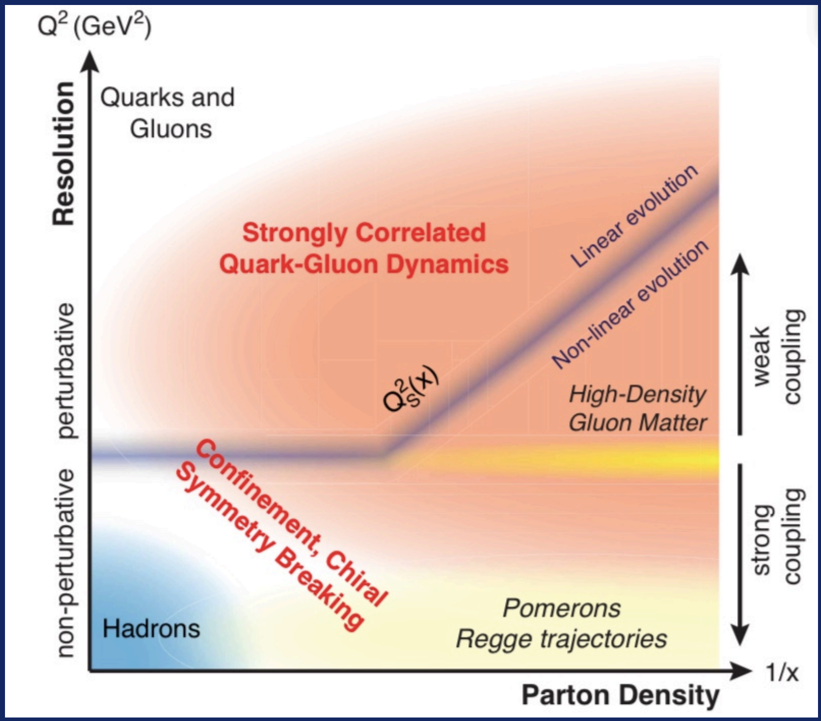


Fig. from: E.C. Aschenauer et al: arXiv:1708.01527

Physics with cosmic rays and neutrinos ("fixed target" <u>observatories</u>) covers different parts of the diagram.

<u>Cosmic Rays & Neutrinos</u>

R. Englel
S. Tilav
F. Riehn
H. Dembinski
T. Gaisser
A.Stasto
A.Fedynich
D. Kharzeev

<u>Total c. section, soft and hard diffraction</u>

Ch. Royon
W. Guryn
B. Kopeliovitch
R. Ciesielski
S. Brodsky

Center for Frontiers in Nuclear Science

Goal: Evaluate connections, find overlap and common interests between DIS, Heavy Ion and Astro-particle communities

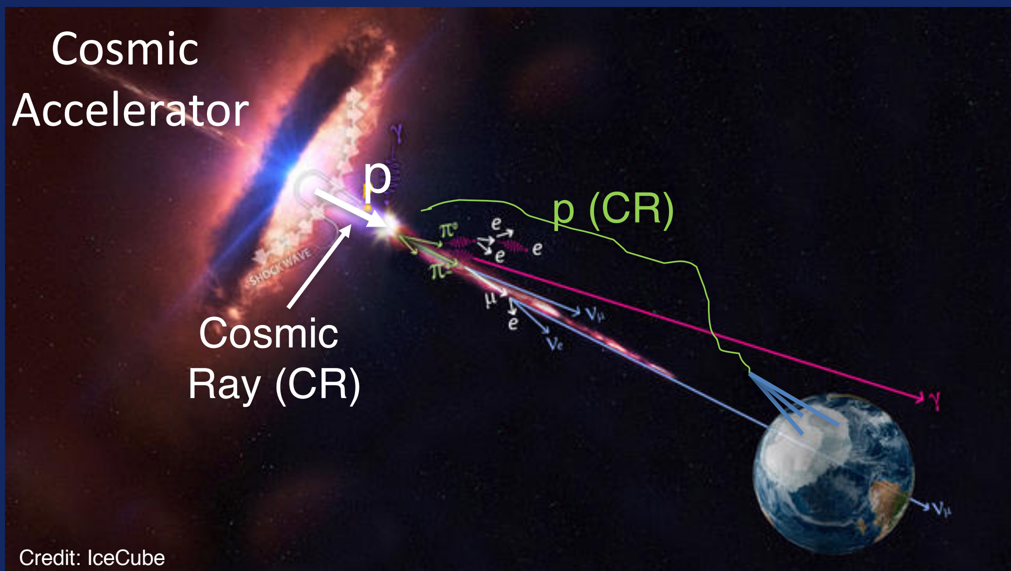
From Astro-particle (cosmic rays and neutrino) community:

- What measurements are of interest? CR-XMax, pi/K/heavy flavor production in Cosmic Ray + Air hadronic interactions, neutrino-nucleon X-section at high energies
- What are the kinematics are interesting? Energies, pseudo-rapidity, Bjorken-x, Feynman-x, …
- Forward production of hadrons, low-x phenomena (saturation, …)

From DIS and Heavy Ion (RHIC and LHC) community:

- Specify clearly the processes you are measuring or encountering (as background), especially if they may be of interest to CR/Neutrino community
- What kinematics are explorable? And see if those physics scenarios might occur in upper atmosphere: Energies, pseudo-rapidity, Bjorken-x, Feynman-x, …
- Forward production of hadrons, low-x phenomena (saturation, …)

Multi-messenger Astronomy to observe the High Energy Universe



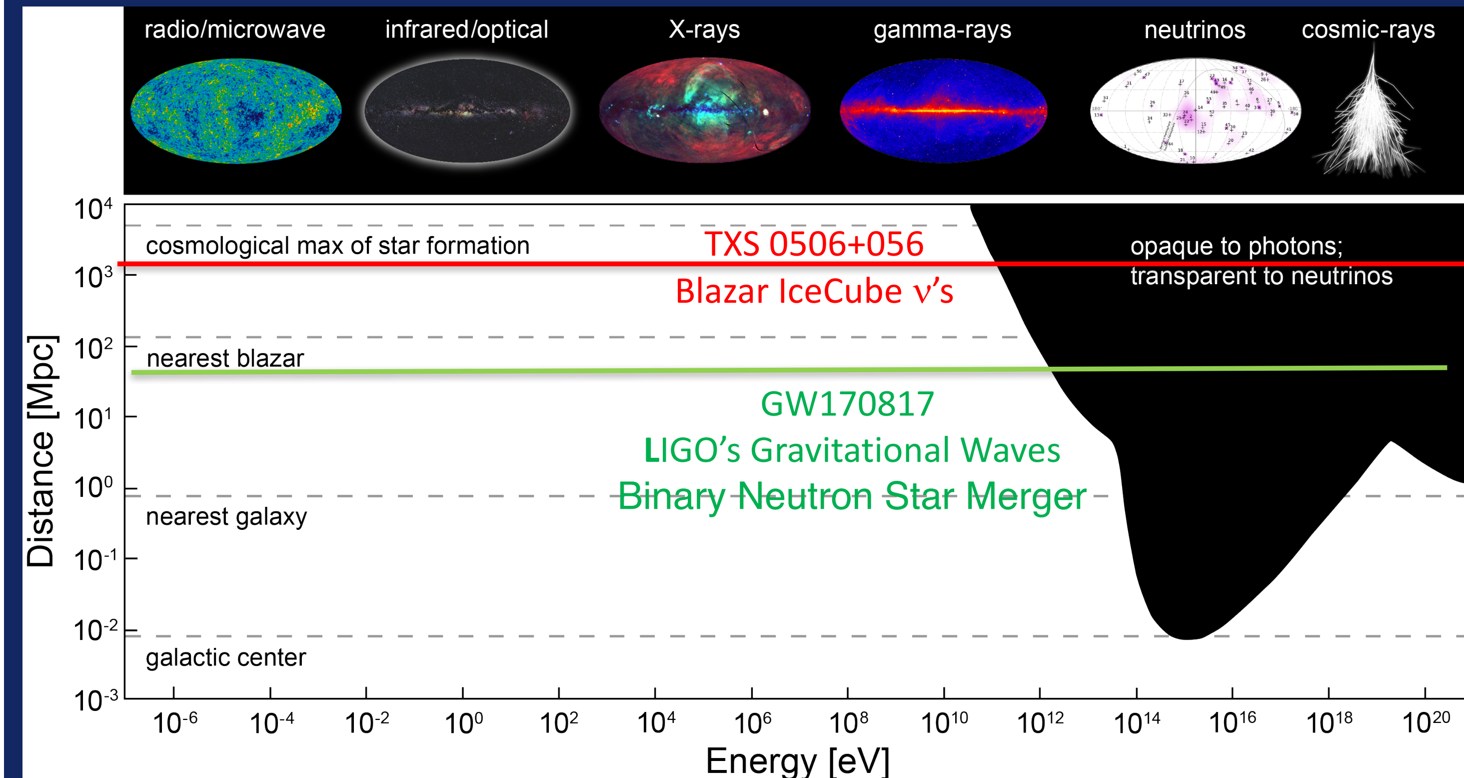
Source / Cosmic Accelerator site:
$p\gamma$ (photo-nuclear) or pp (hadronic)

Detection 'probes':

- Cosmic Rays
- Gamma Rays
- Neutrinos
- Gravitational waves

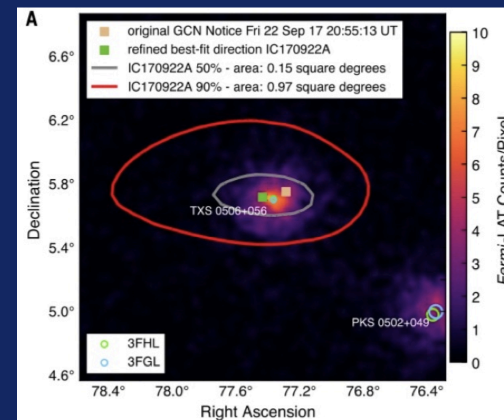
They help us understand the most violent phenomena in the Universe

Multi-messenger Astronomy to observe the High Energy Universe



1pc ~ 3 lyr

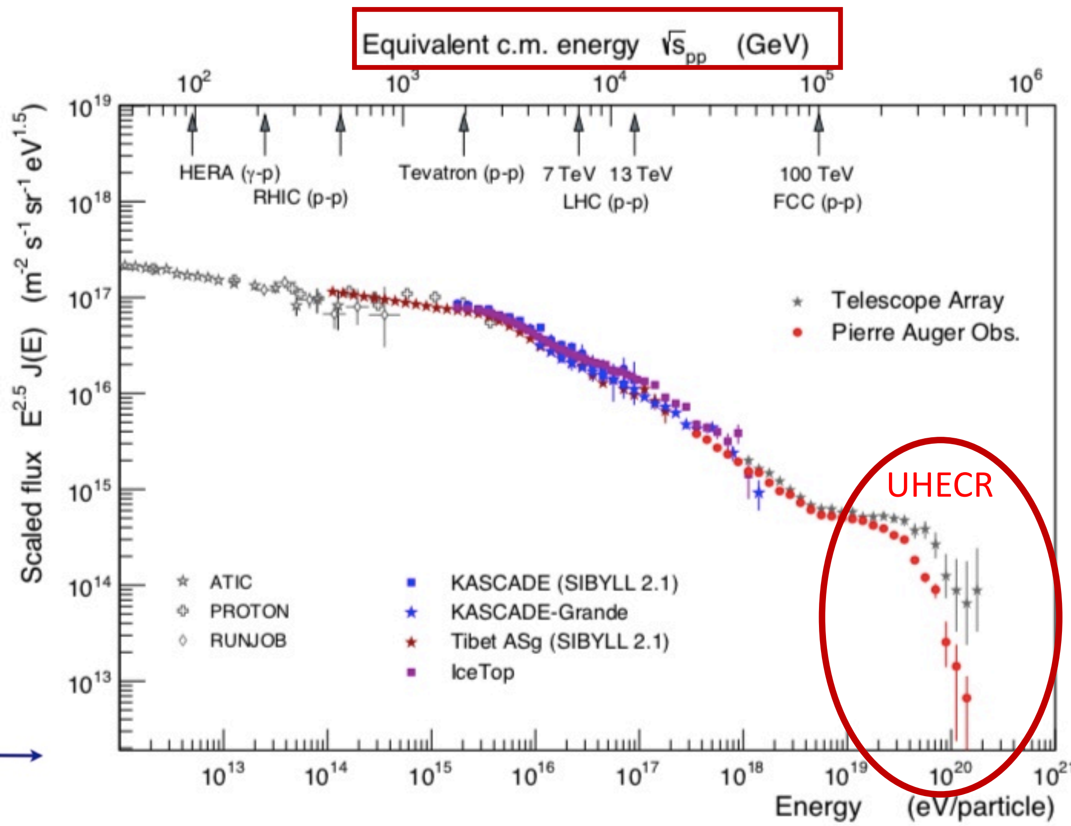
Science 361, eaat1378 (2018)
Science 361, 146 (2018)

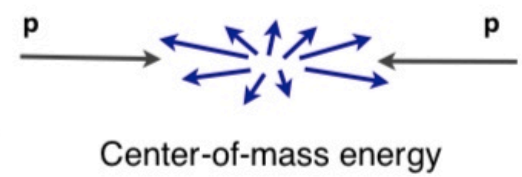


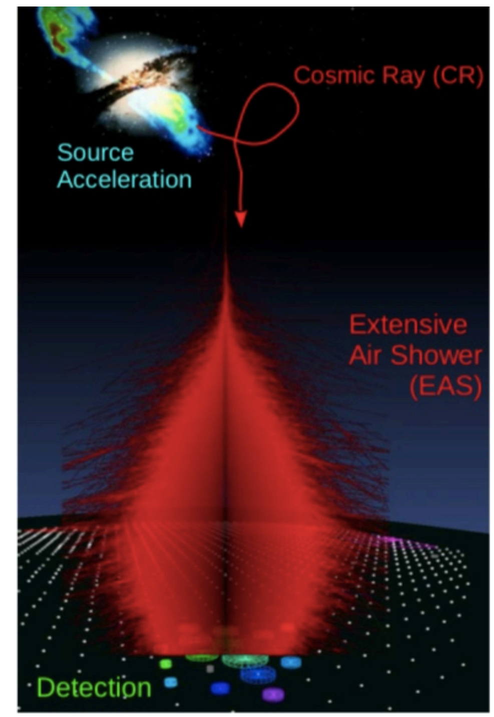
July 12, 2018 NSF press release
On 22 September 2017 IceCube detected a ~290-TeV neutrino from a direction, as reported by Fermi-LAT on September 28 2017, consistent with the flaring γ-ray blazar TXS 0506+056.

R. Englel
S. Tilav
F. Riehn
H. Dembinski
M. Murray

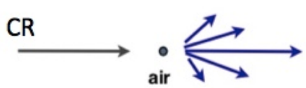
Cosmic rays: flux and origin







From R. Ulrich (KIT)



- Known fact: cosmic accelerators exist, because the UHECR flux has been measured.
- Sources of Ultra High Energy Cosmic Rays (UHECR) not yet been directly identified.
- Composition of UHECR important but currently uncertain.

R. Englel
S. Tilav
F. Riehn
H. Dembinski
M. Murray

Cosmic rays: hadronic interactions

Reference systems used for model tuning

LHC:
pp @ **0.9** ... **14** TeV
pPb @ **5** ... **8.14** TeV
PbPb @ **2.76** ... **5** TeV
SPS:
pC, πC @ **O(10)** GeV

Other experiments:
RHIC, Tevatron, ...

Hadronic interaction models
EPOS, QGSJet, SIBYLL

Theory & Phenomenology

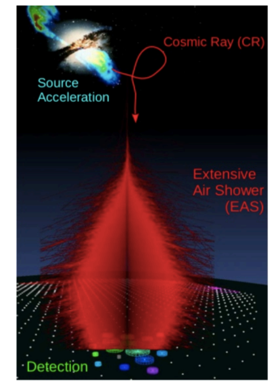
Glauber
Gribov-Regge
pQCD
...

Pomerons
Mini-jets
Multi-parton interactions

Systems in air showers
sorted by frequency of occurring

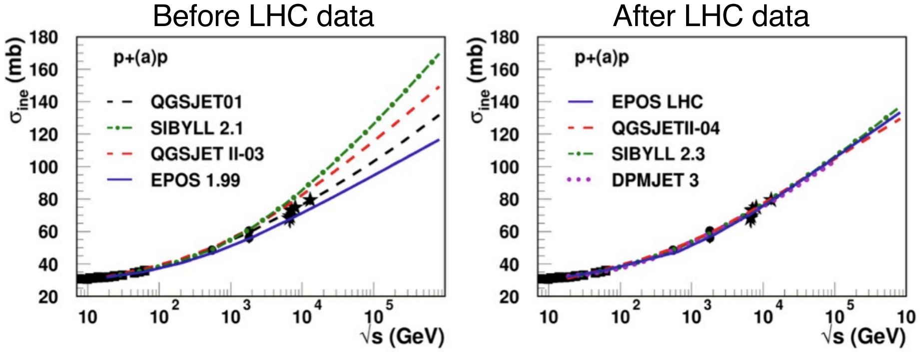
π(N, O)
K(N, O)
(p, n)(N, O)
...
Fe(N, O)

@ **1** GeV ... **1000** TeV

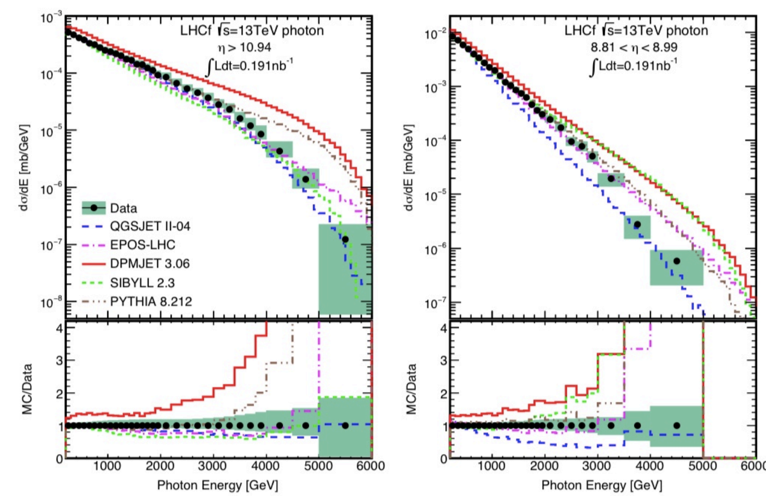


From R. Ulrich (KIT)

Impact of the LHC data on Hadronic Interaction Models tuning, example:



LHCf Forward Photon:
room for further improvement of models:



(Future) data with light ions important:
p-Oxygen (LHCf Run3 2021-2023)
Modelling of nuclear effects, c. sec, particle spectra, etc
(discussion topic at the workshop)

R. Englel
S. Tilav
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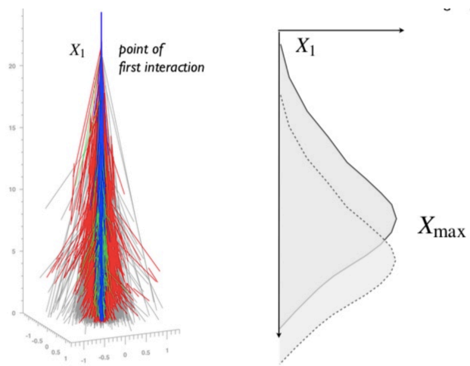
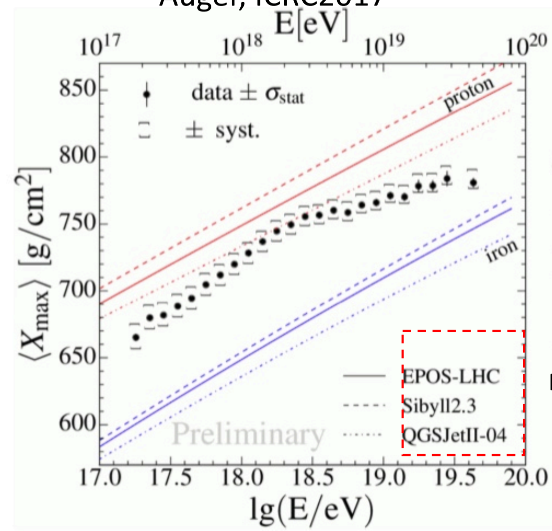
Cosmic rays: composition

1) Composition from the longitudinal shower profile



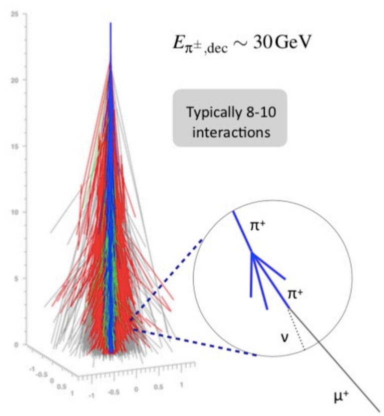
Auger, ICRC2017

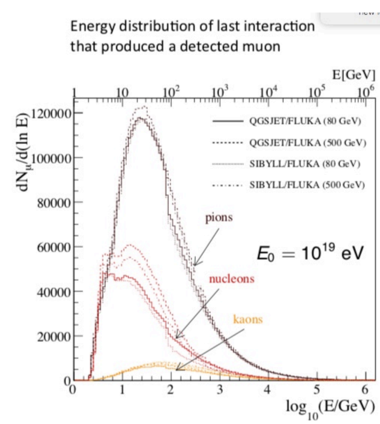


Post-LHC data models

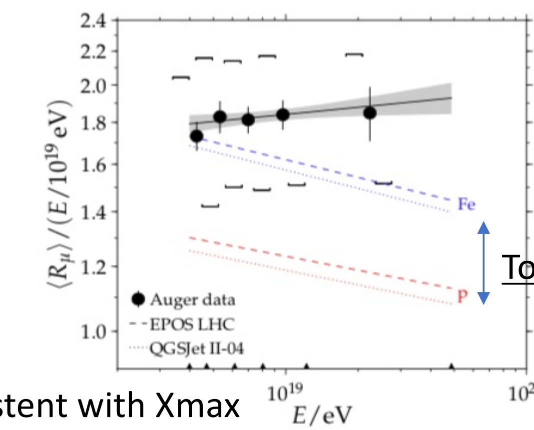
2) Composition from the number of muons in the shower:

Low Energy interactions





Number of muons in showers with θ>60°

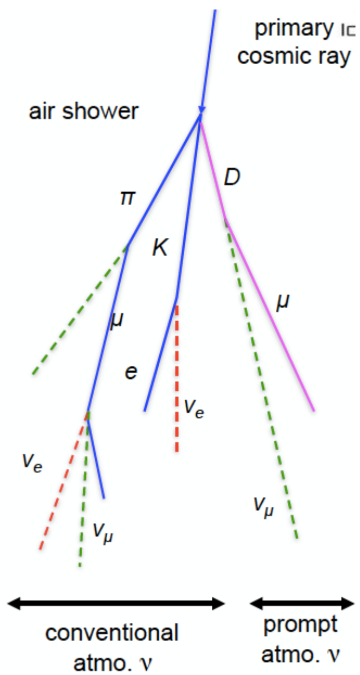


Too low!

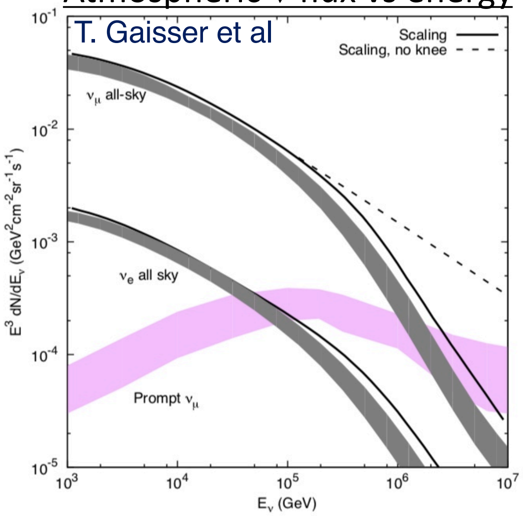
CR Muon puzzle: Muon predictions in air showers (in all models) inconsistent with Xmax
Long standing issue in the field of Cosmic Rays (not just Auger), not yet solved, critical for CR composition.

T. Gaisser
A.Stasto
A.Fedynich
D. Kharzeev

Atmospheric neutrinos: conventional (π,K’s) and promp (D’s) from CR’s



Atmospheric ν flux vs energy

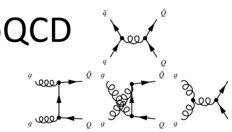


- Largest contribution to the uncertainty is from models of hadro-production, especially K’s
- Shaded bands for conventional n’s span Sib2.3, Epos LHC, QGSjet II-04 and for prompt ν’s : PROSA, Sib2.3, GRRST, BERSS
- High energy atmospheric ν’s are bg to astrophysical neutrinos. Their flux modelling important!

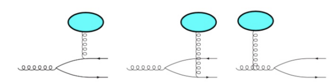
Prompt ν’s, expected to be produced in CR-Air interaction from heavy flavor decays:

$$\sigma^{pp\to Q\bar{Q}} = \sum_{i,j}\int\int_0^1 dx_1 dx_2 f_i(x_1,\mu_f^2) f_j(x_2,\mu_f^2) \times \hat{\sigma}_{ij\to Q\bar{Q}}(x_1,x_2,\mu_f^2,\mu_r^2,\ldots)$$

pQCD

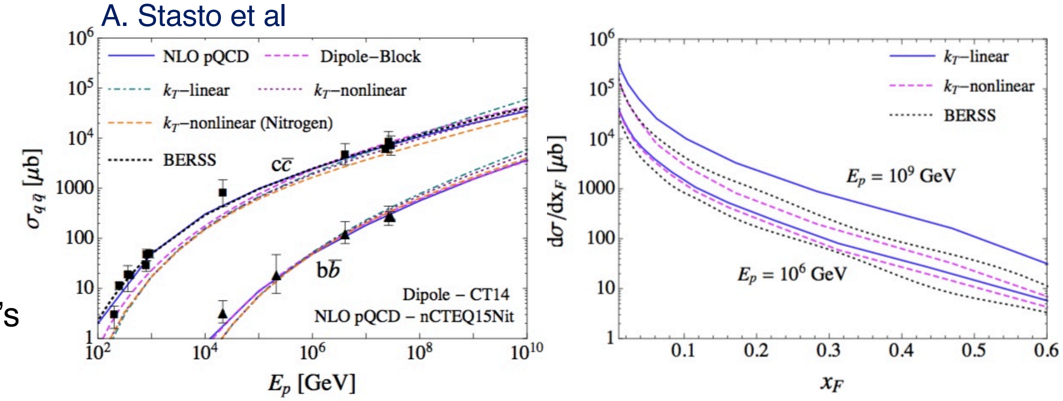


Color dipole model:



Cosmic Ray-Air (composition), pdfs, nuclear effects
small-x / saturation, gluons

A. Stasto et al



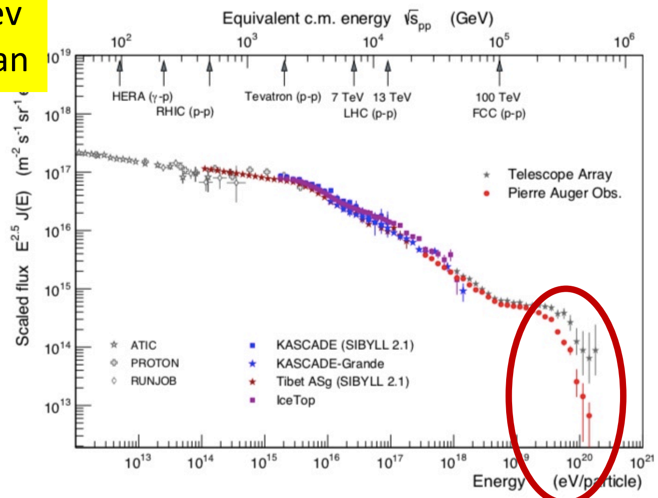
Nuclear corrections to the total cross section $(\sigma_{pA}/A)/\sigma_{pp}$ are small (5-15%), but large for the differential $d\sigma_{pp}/dx_F$ cross section.

Atmospheric prompt ν’s have not yet been observed.

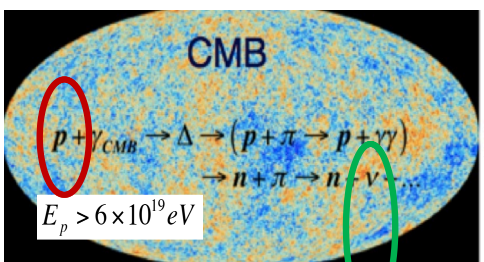
T. Gaisser
A.Stasto
A.Fedynich
D. Kharzeev
M. Strikman

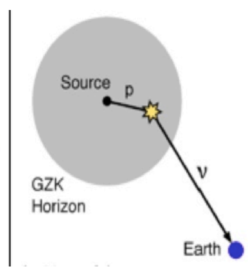
Impact of UHE CR composition on Future UHE Neutrino detection

UHE=Ultra High Energy



GZK-cutoff



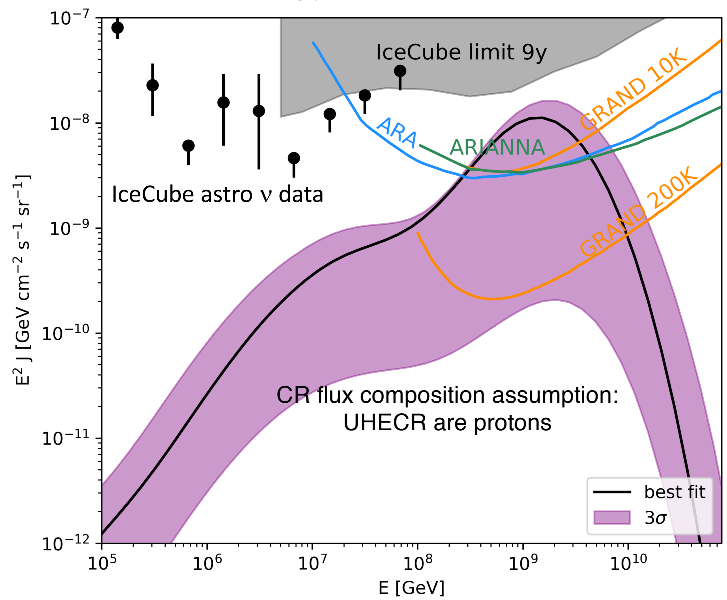


GZK-neutrinos (not yet observed)

Future/planned UHE n experiments, such as ARA/ARIANNA in the US, will:

- be sensitive to GZK neutrinos <u>if</u> UHECR are protons
- not be sensitive to GZK neutrinos if UHECR are nuclei (much lower flux, not shown)

Flux vs energy



Cosmic Rays composition is crucial to further advance the field

T. Gaisser
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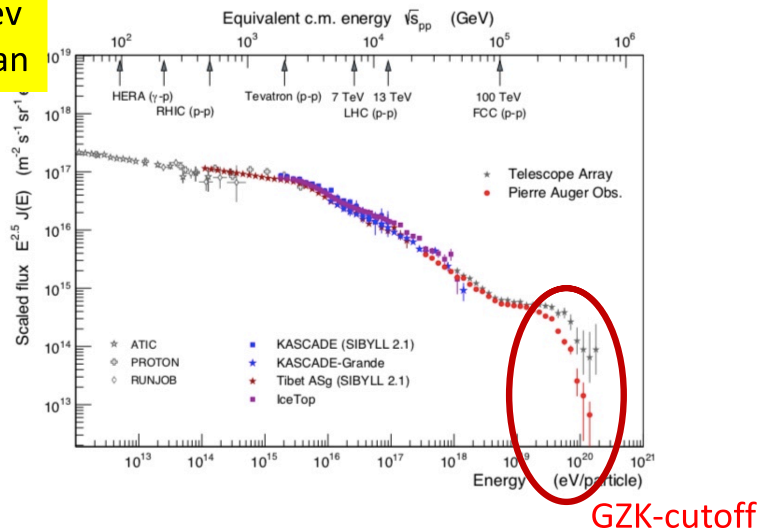
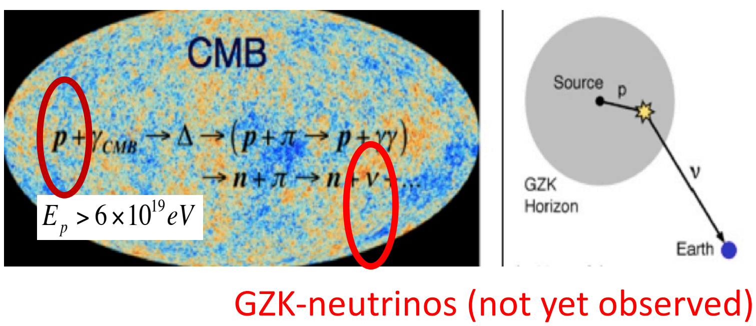
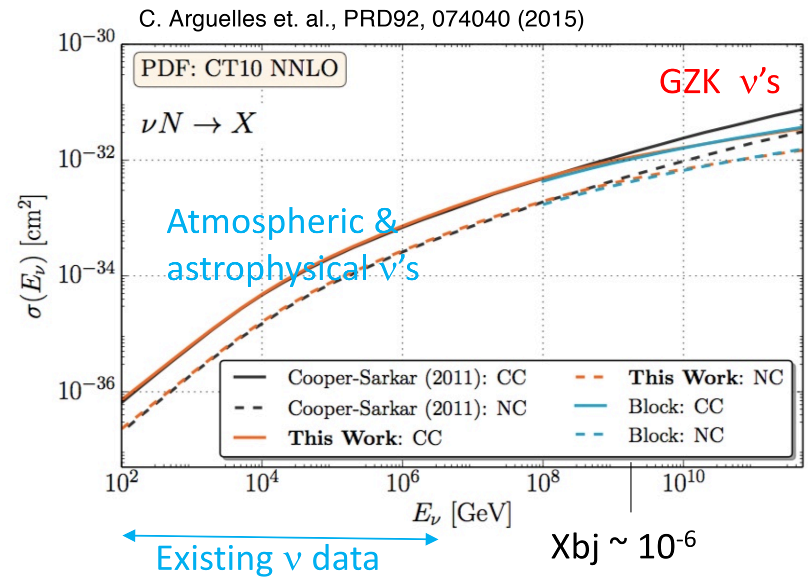
Nucleon Structure at low-x & high Q^2 with (future) UHE neutrinos







UHE neutrino-nucleon cross section will bring new Information about **Nucleon Structure@ low x** and high Q^2

"For GZK neutrinos, gluon densities in a nucleon ~ 5x higher than @LHC, similar to pPb central collisions at the LHC"
M. Strikman

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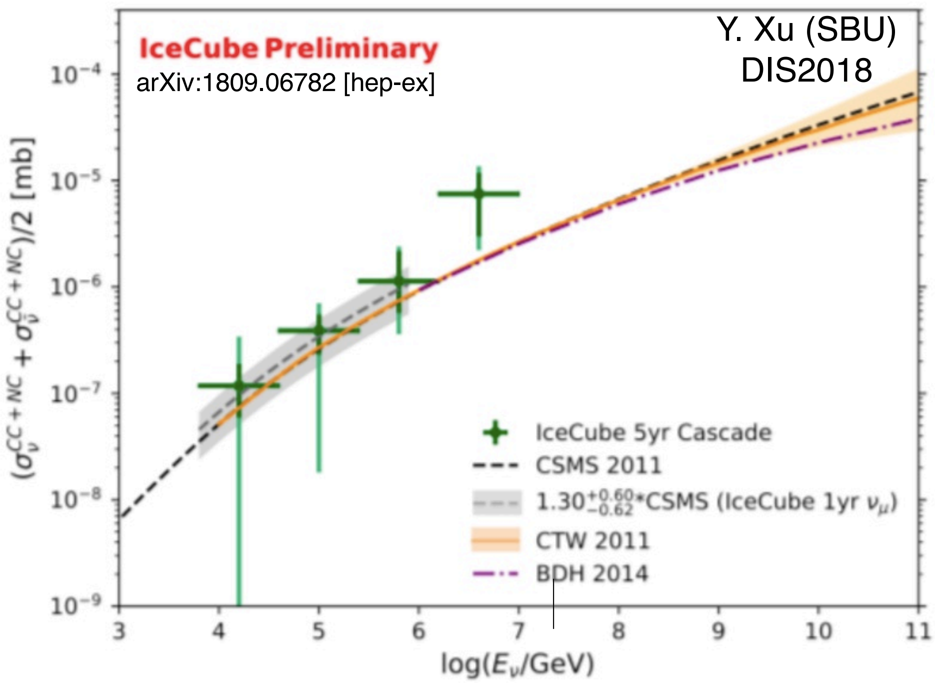
M. Strikman

Nucleon Structure at low-x & high Q^2 with (future) UHE neutrinos

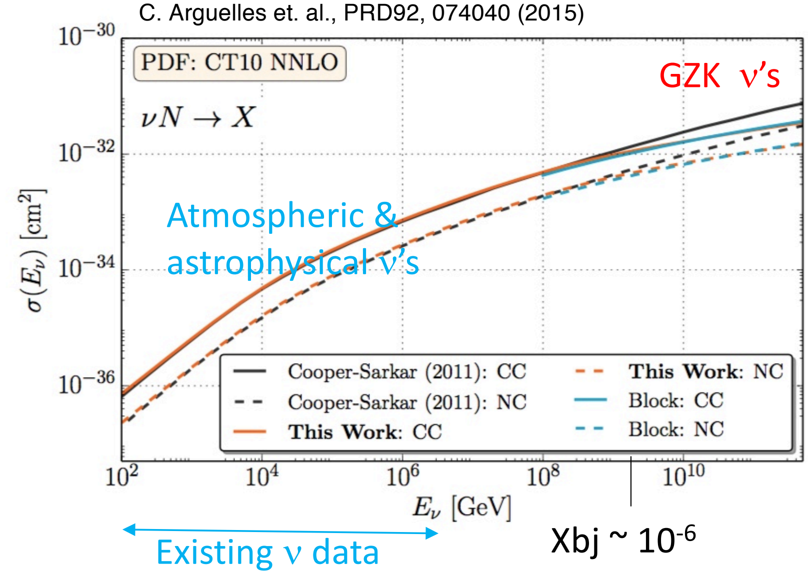
Current status:
Neutrino-Nucleon Cross Section with Atmospheric and Astrophysical HighEnergy (10TeV-10PeV) neutrinos



Xbj ~ 10^{-4}

Data taking with IceCube continues …

C. Arguelles et. al., PRD92, 074040 (2015)



UHE neutrino-nucleon cross section will bring new Information about **Nucleon Structure@ low x and high Q^2**

"For GZK neutrinos, gluon densities in a nucleon ~ 5x higher than @LHC, similar to pPb central collisions at the LHC"
M. Strikman

Concluding remarks:

- Interesting and successful workshop!

- Achieved the initial goal of the workshop to evaluate existing connections, find overlap and common interests between DIS, Nuclear and High Energy Astro-particle communities.

- Important to keep the momentum to identify relevant cross-field measurements that would help individual fields and further develop and broaden the science potential for existing and future programs, such as an EIC.

- New ideas and input, especially from theorists, crucial.

- Next workshop in Mexico (October/November 2019)

- Looking forward to future workshop(s) and community discussions!

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