hadron and charm production in the atmosphere

introductory remarks from ISVHECRI 2014

Paolo Desiati

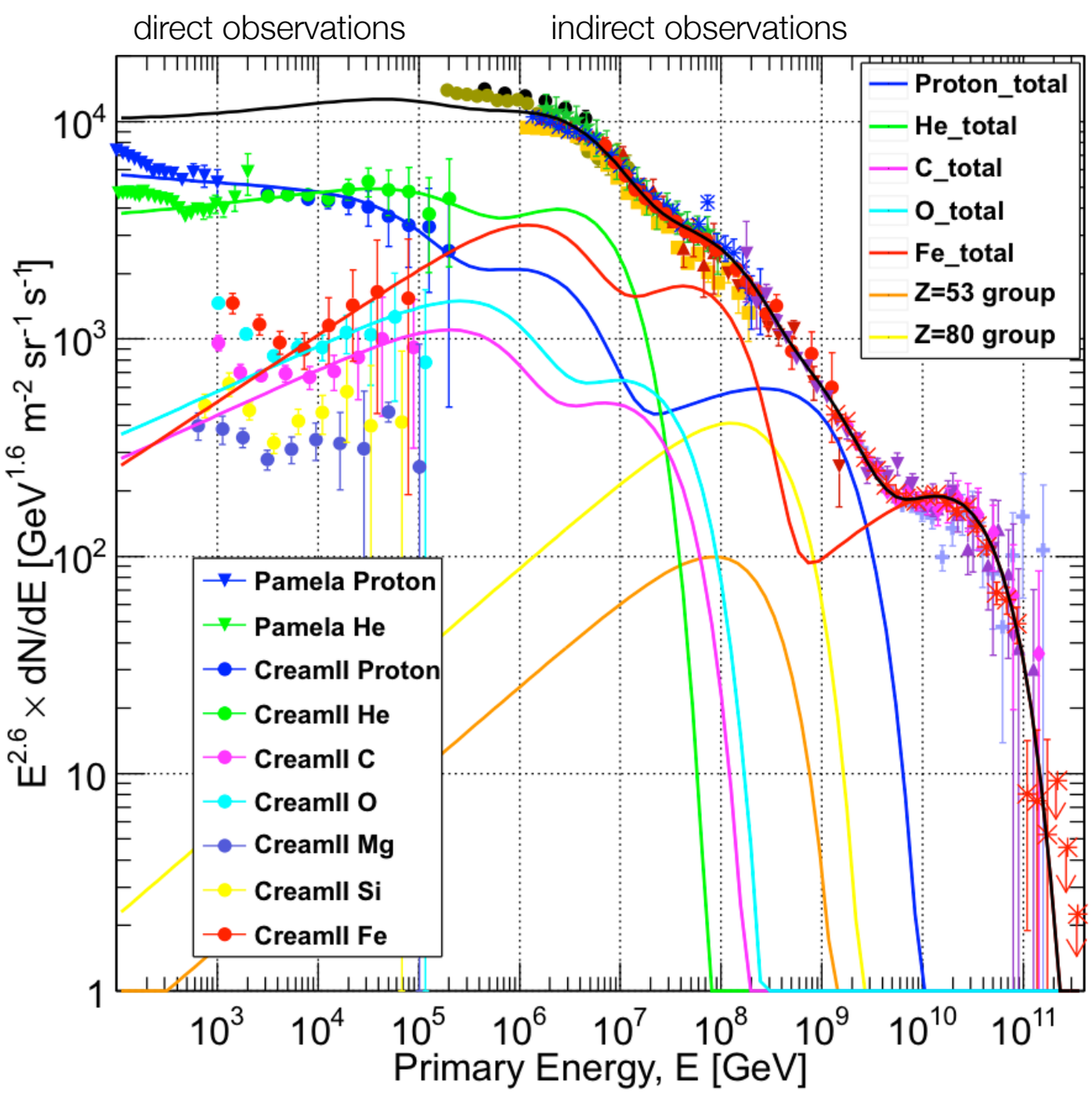
Wisconsin IceCube Particle Astrophysics Center
& Department of Astronomy

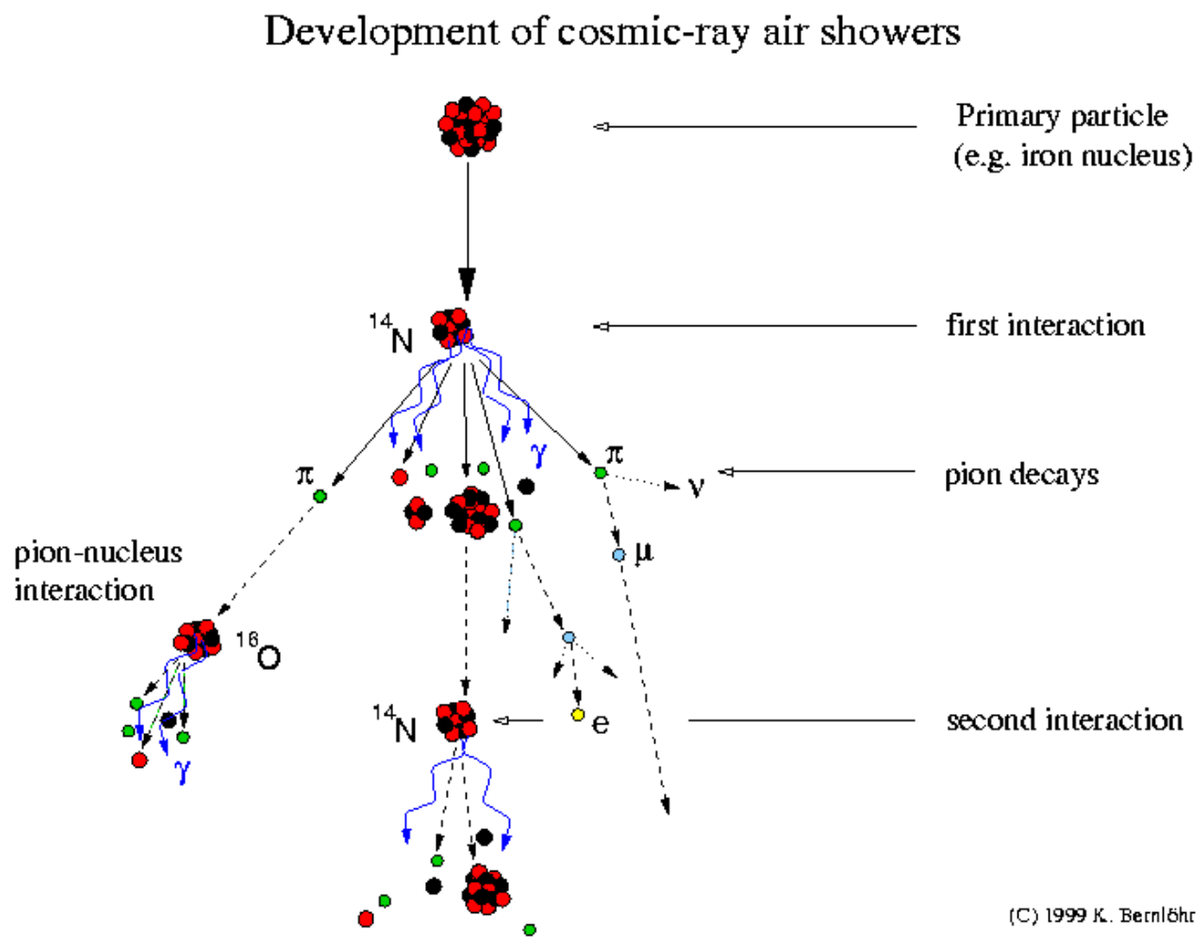
University of Wisconsin - Madison

MANTS Meeting 2014
CERN - September 20, 2014

particle production in the atmosphere

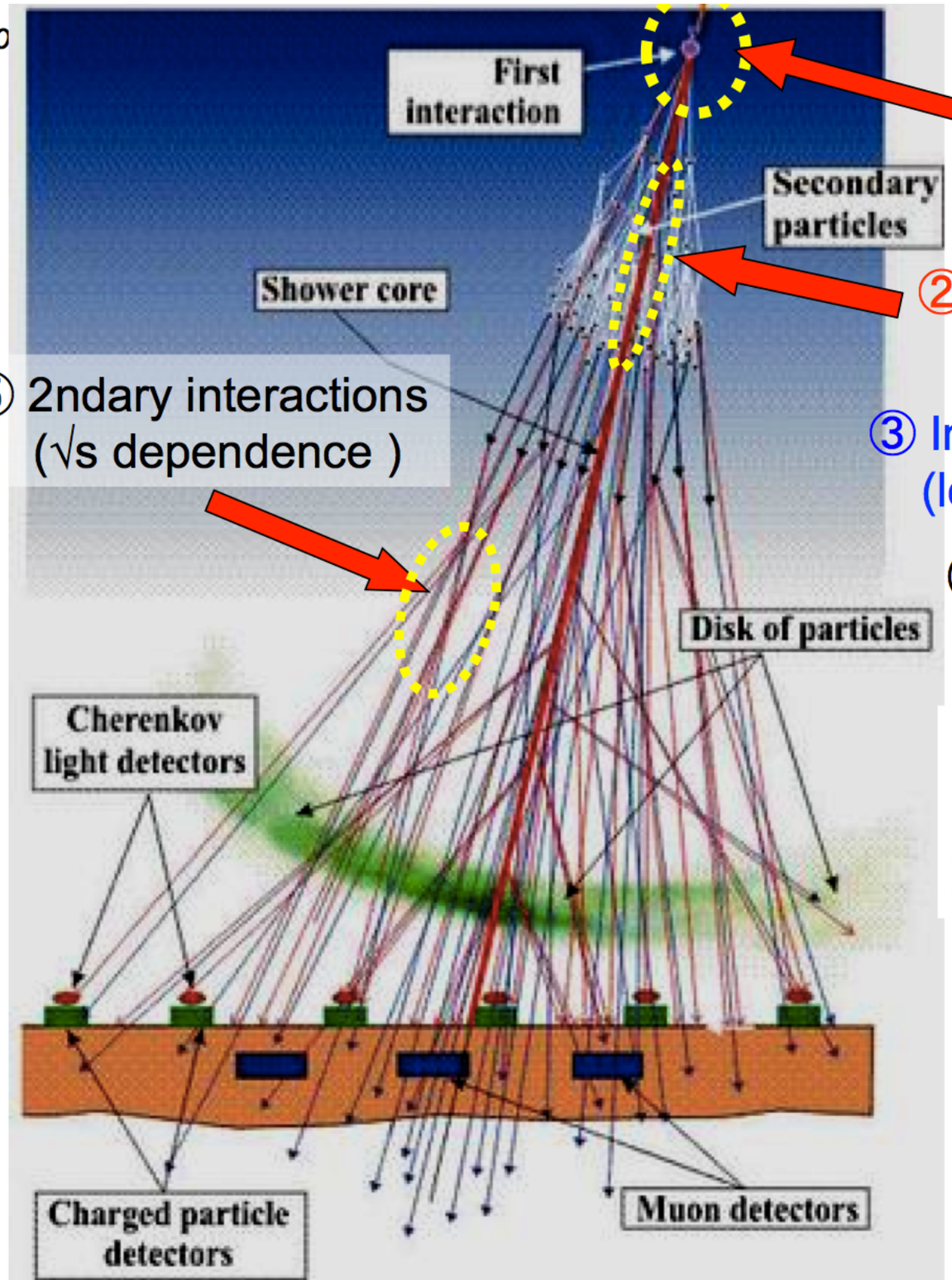
Gaisser, Stanev, Tilav, 2013 - arXiv:1303.3565





$$N_{CR} + N_{air} \longrightarrow X \quad + \pi + K + D + \Lambda + \ldots$$

particle production in the atmosphere

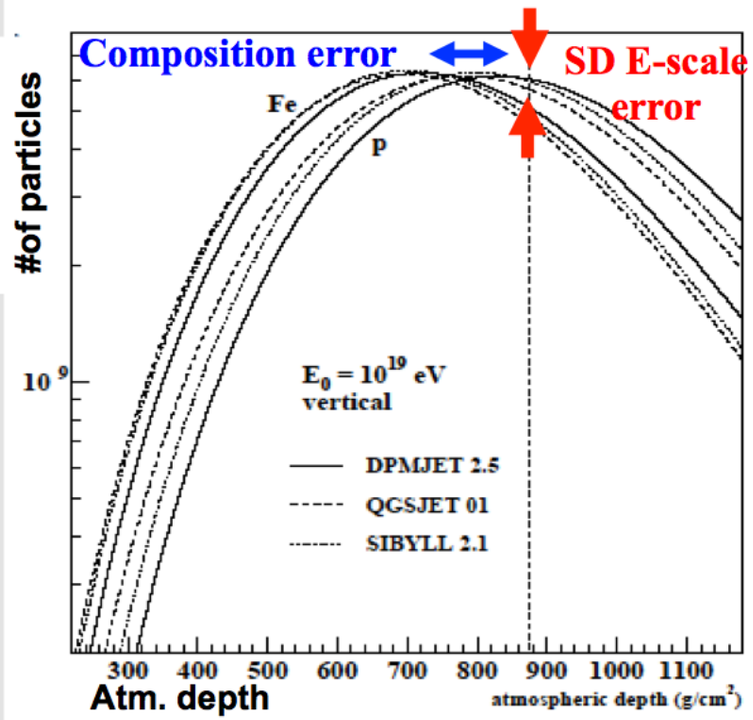


① Inelastic cross section
(TOTEM and others)

② Forward energy spectrum
(γ /π^0 , hadron spectrum)

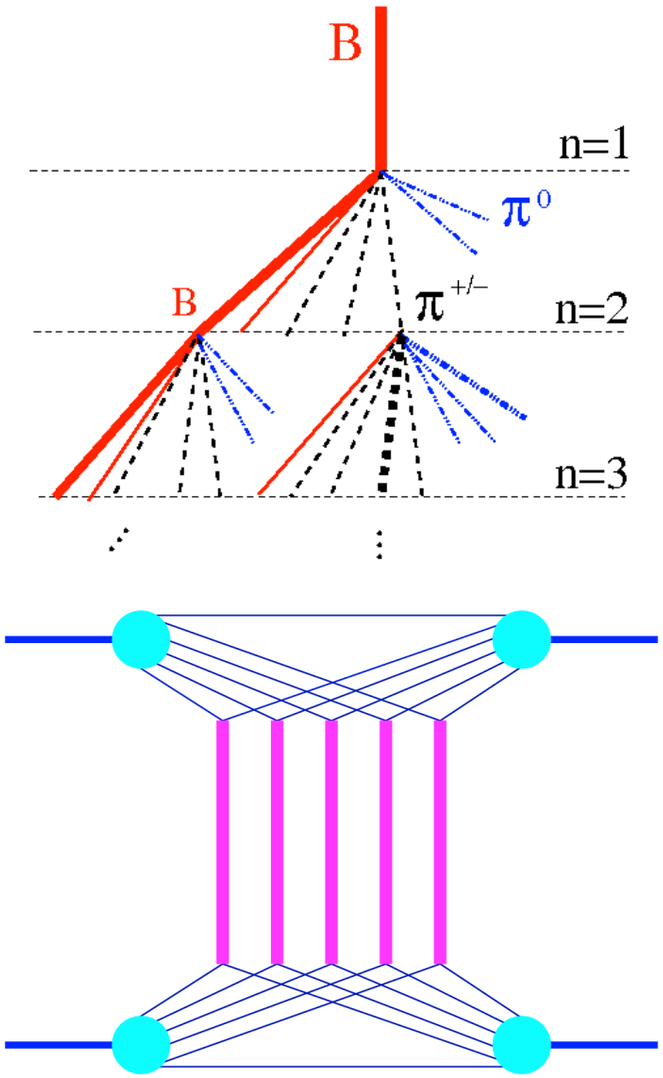
③ Inelasticity k= 1-p_{lead}/p_{beam}
(leading baryon / γ ratio)

④ Nuclear effect
(shadowing, Cronin effect)



⑤ 2ndary interactions
(√s dependence)

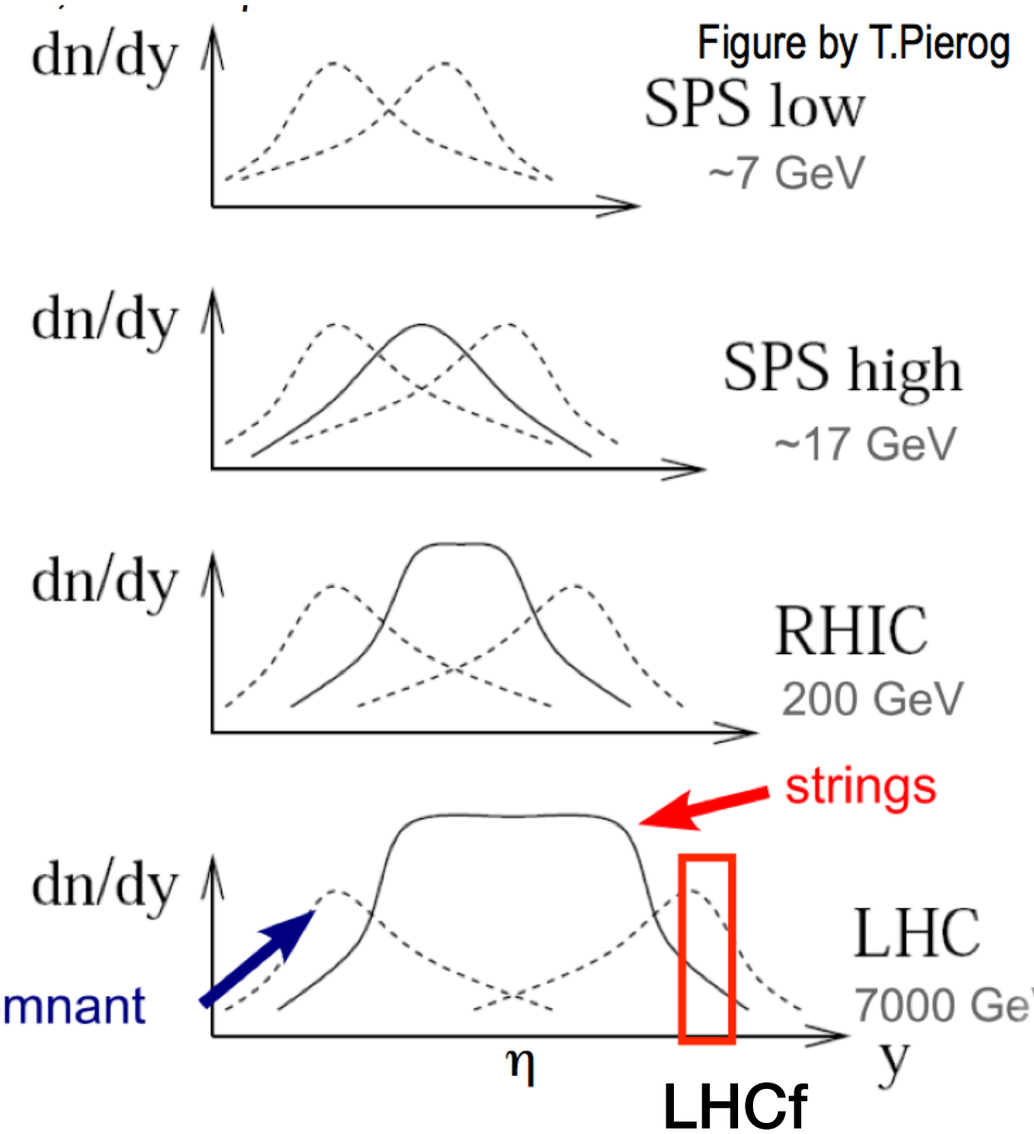
particle production in the atmosphere
hadronic interactions

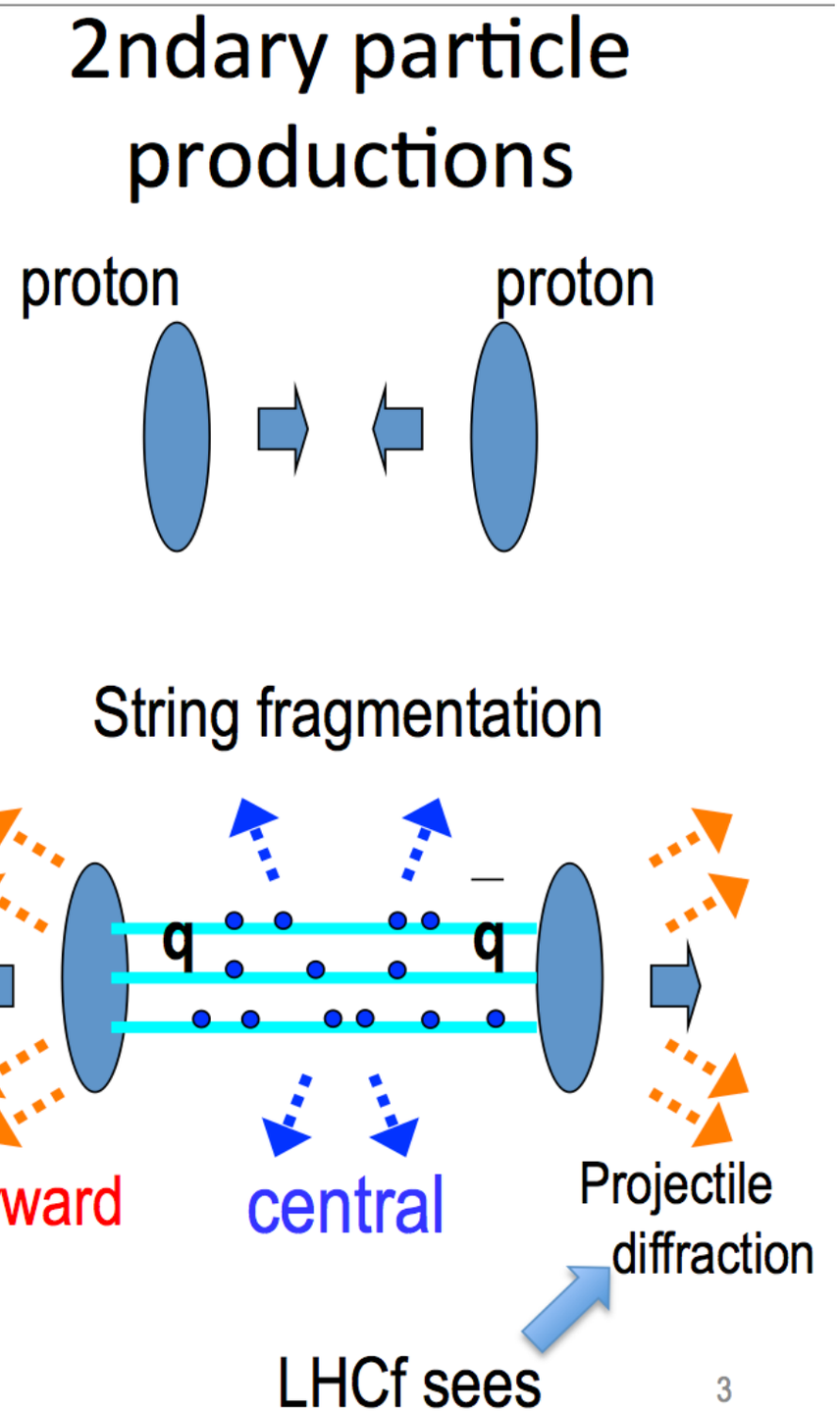


- CR showers dominated by **soft component with small p_T** (*non-perturbative QCD*)
- **hard component with high p_T** with heavy quarks (pQCD)
- **phenomenological** descriptions of hadronic interactions with minijet production for hard component
- **models** to describe soft/hard **interactions** in **forward region** & **extrapolated to high energy**

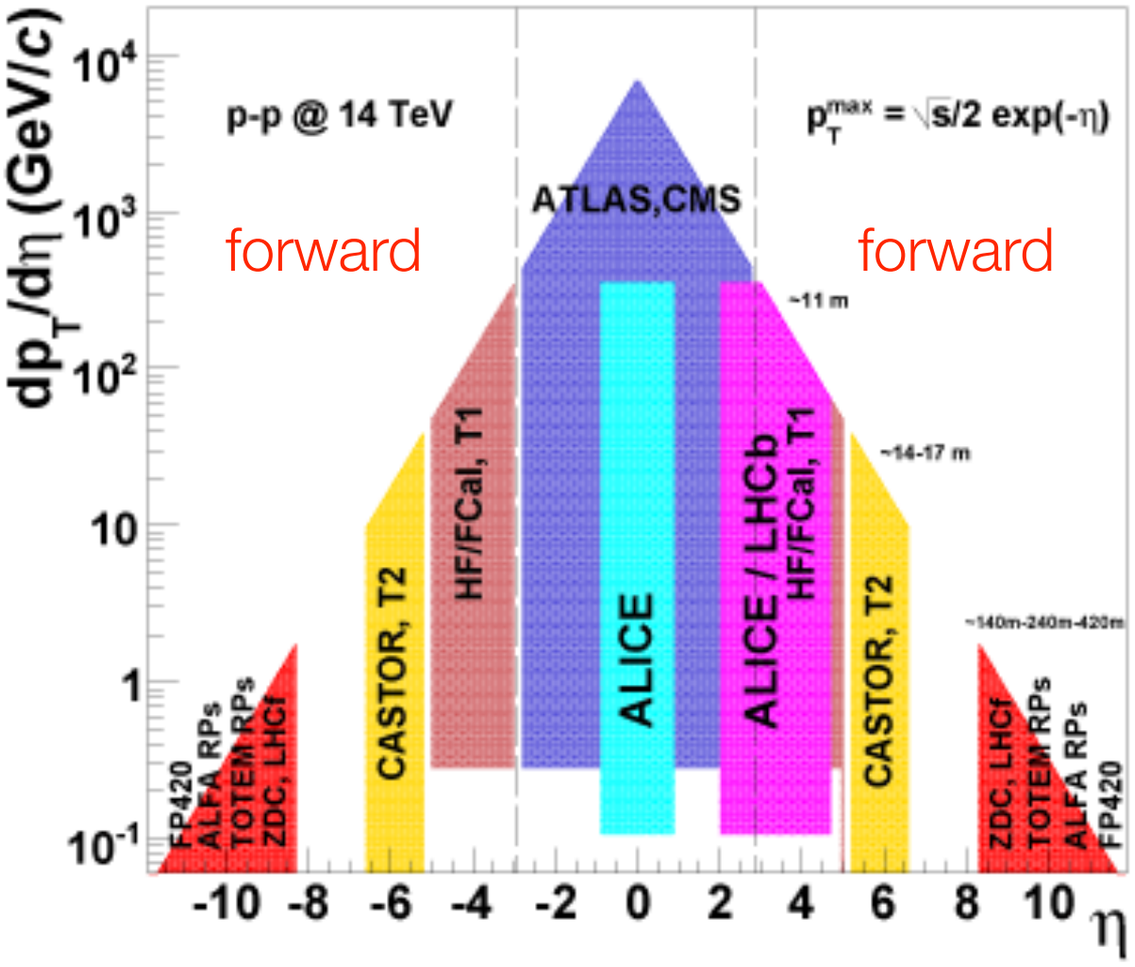
- **interaction models** from accelerators, **extrapolated** to forward region at high energy

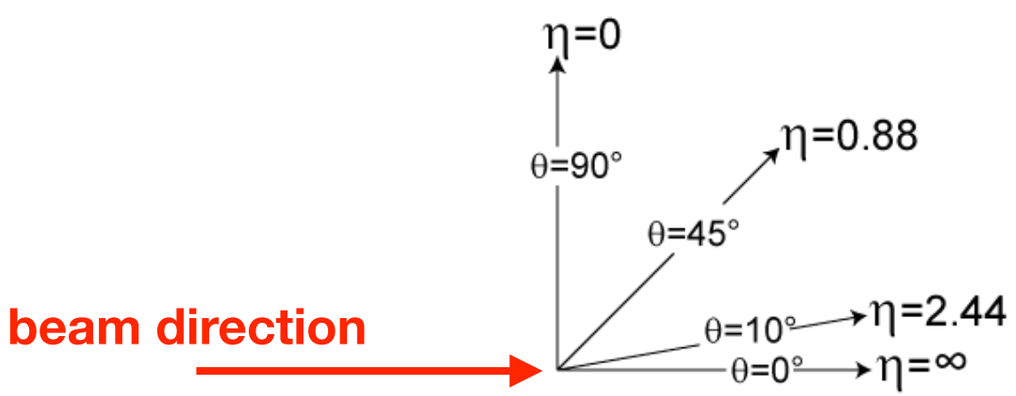
particle production in the atmosphere
forward physics

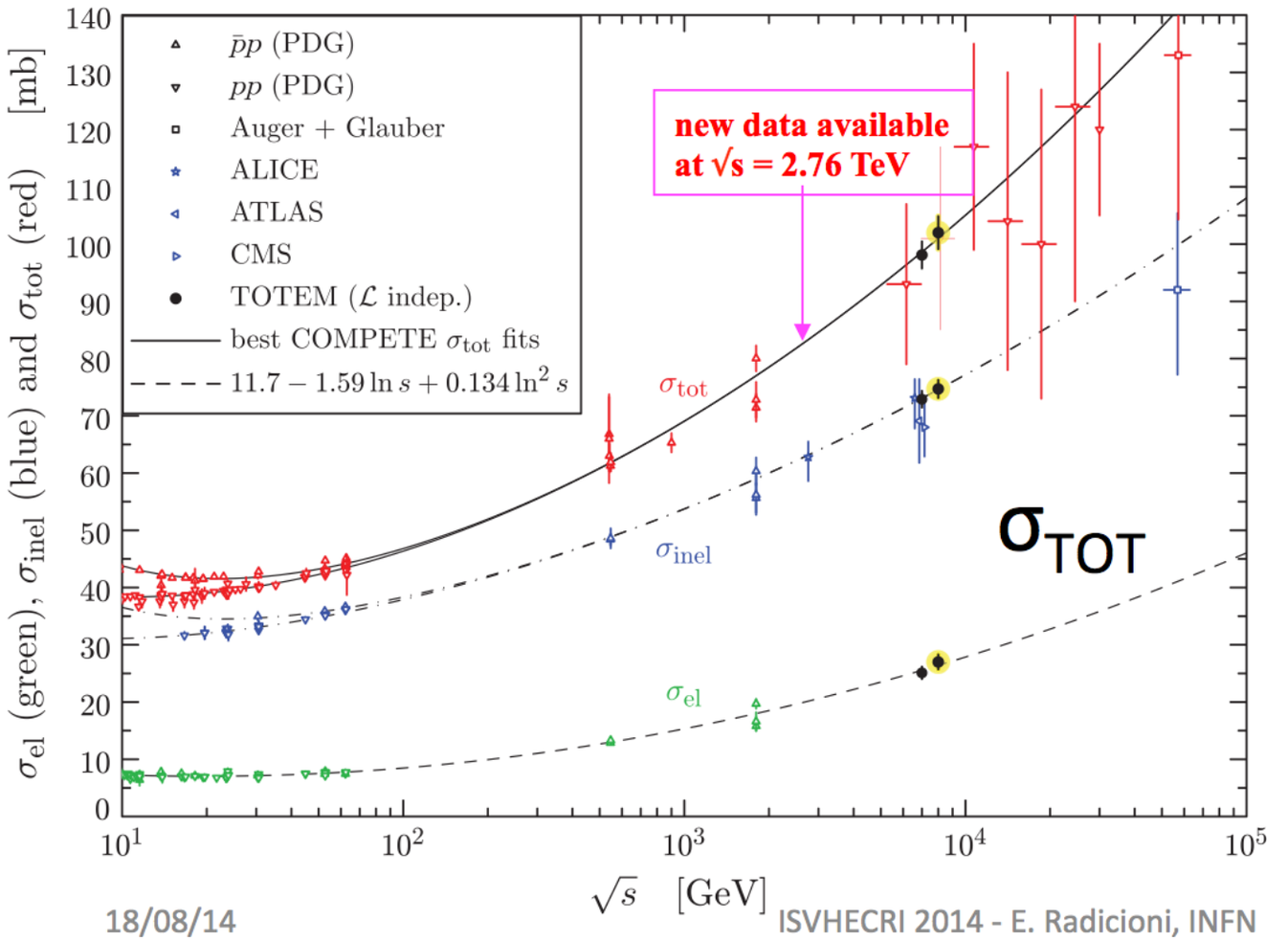




particle production in the atmosphere
forward physics



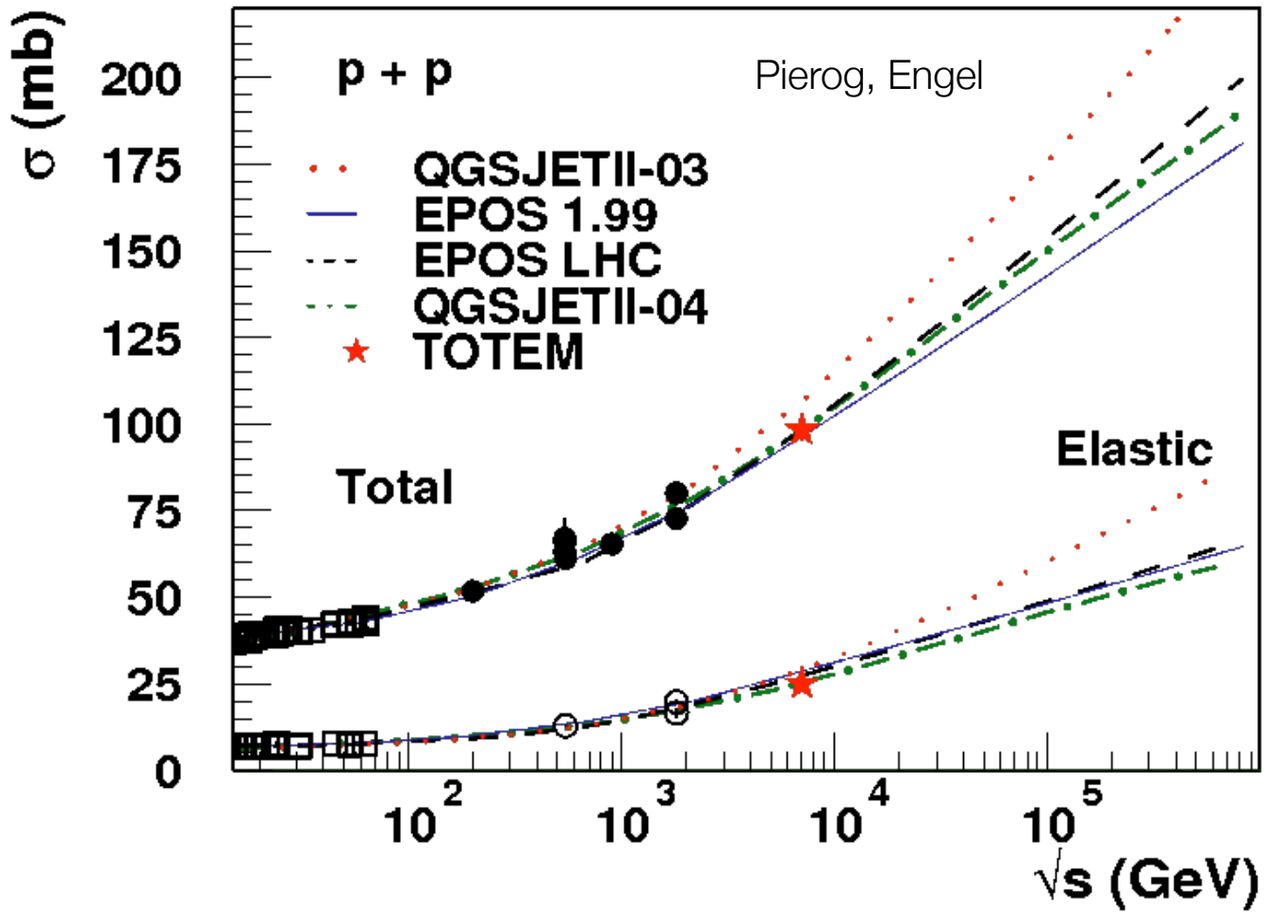


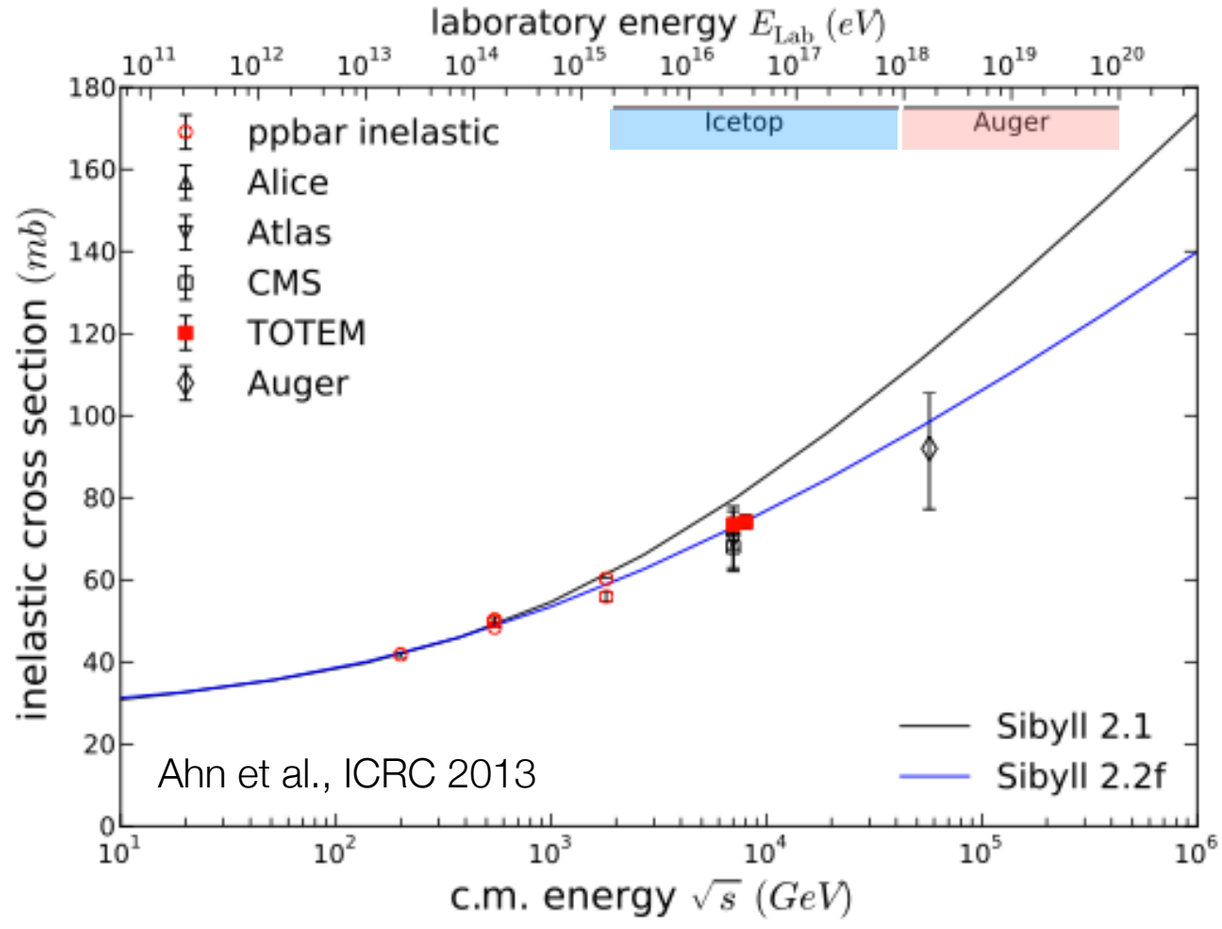


Higher diffraction: slower EAS development (deeper shower maximum)

particle production in the atmosphere
forward physics

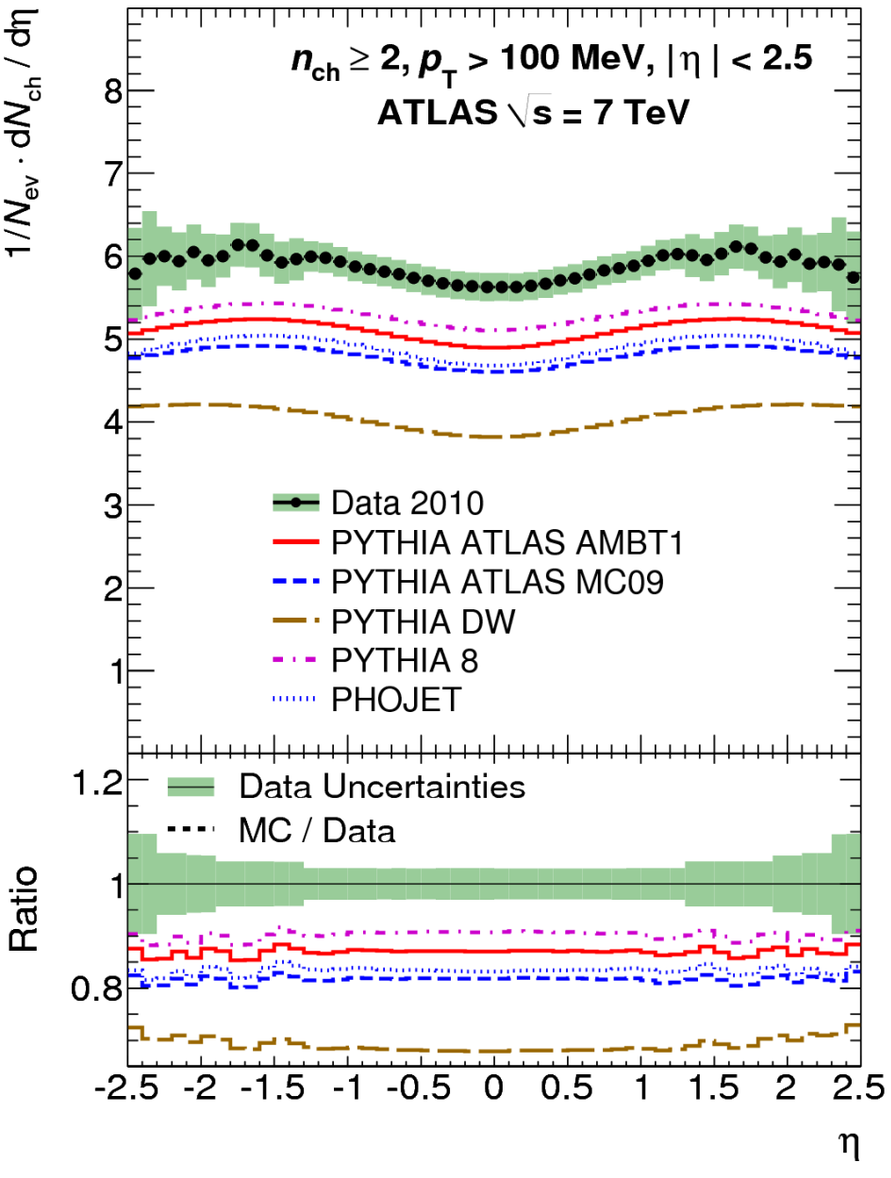
tuning hadronic interaction models

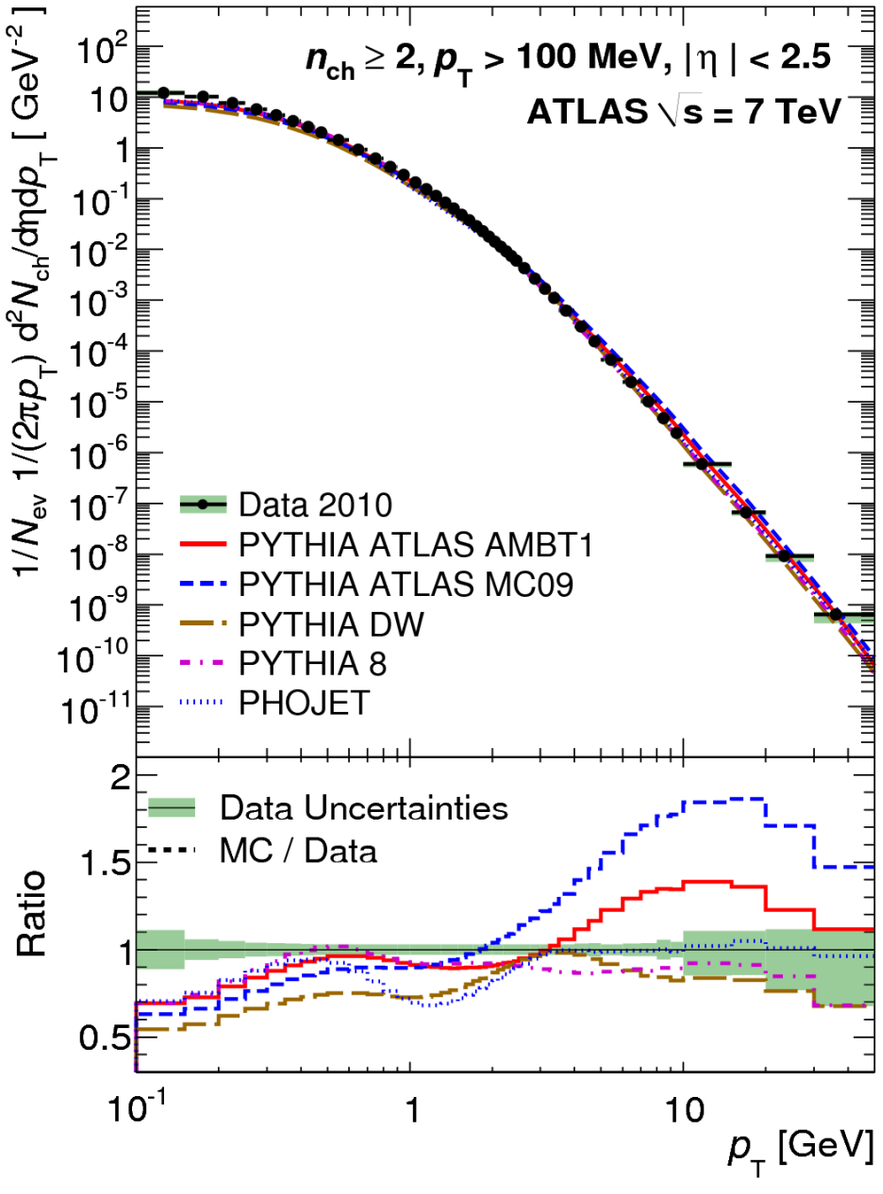


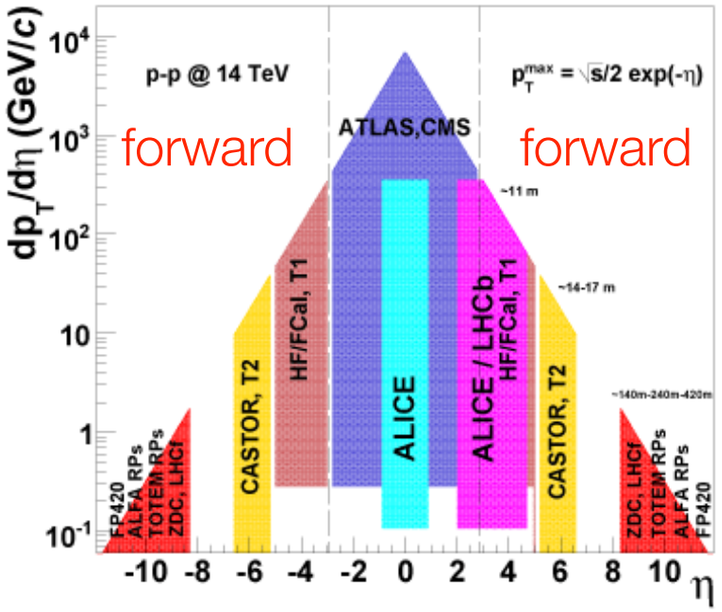


use energy spectra and multiplicities in forward region?

particle production in the atmosphere
central region

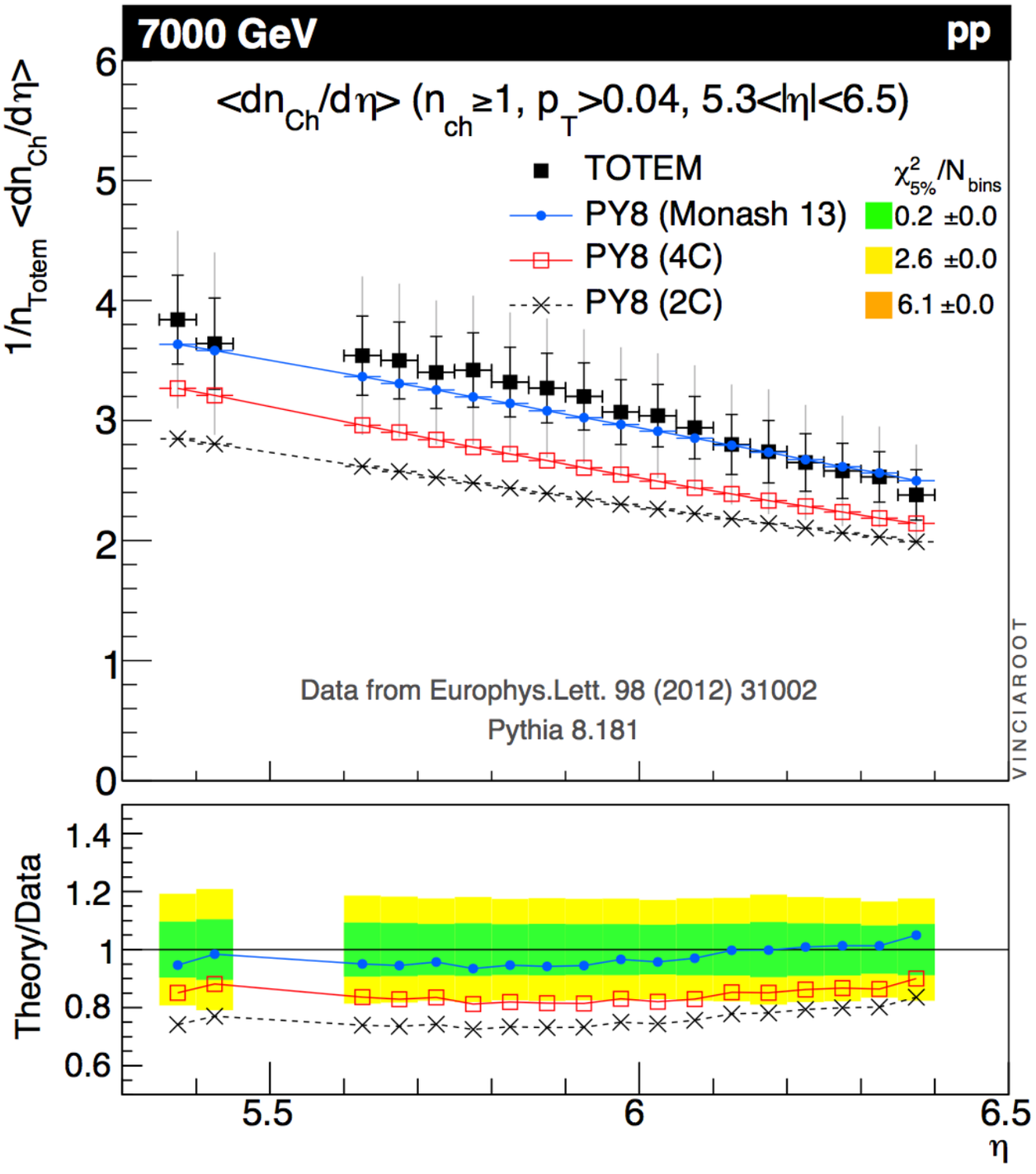


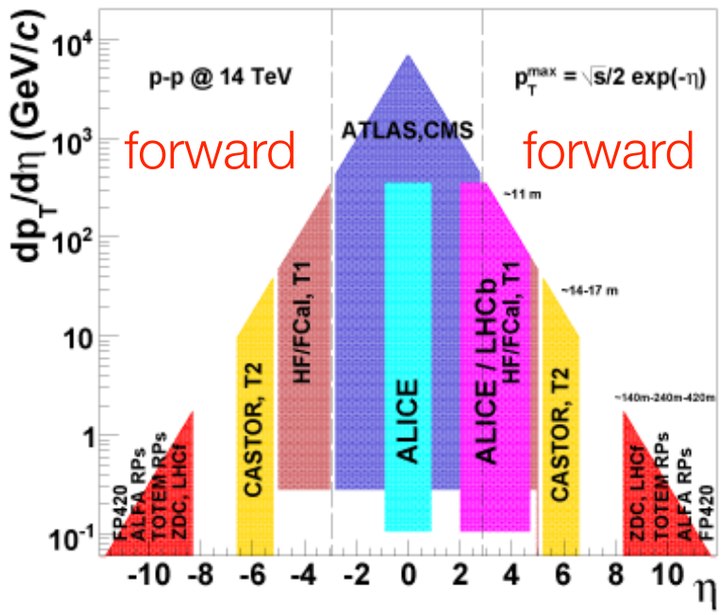




no *tuned* Pythia model consistently describes experimental data consistently

particle production in the atmosphere
central region



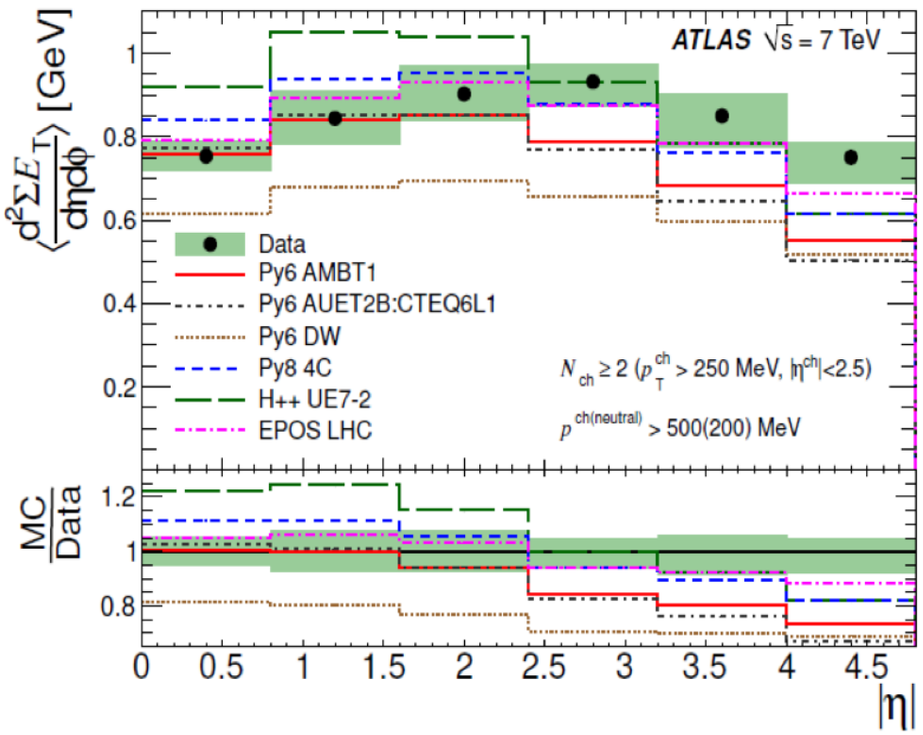


new *tuned* Pythia model to better describe multiplicity observations

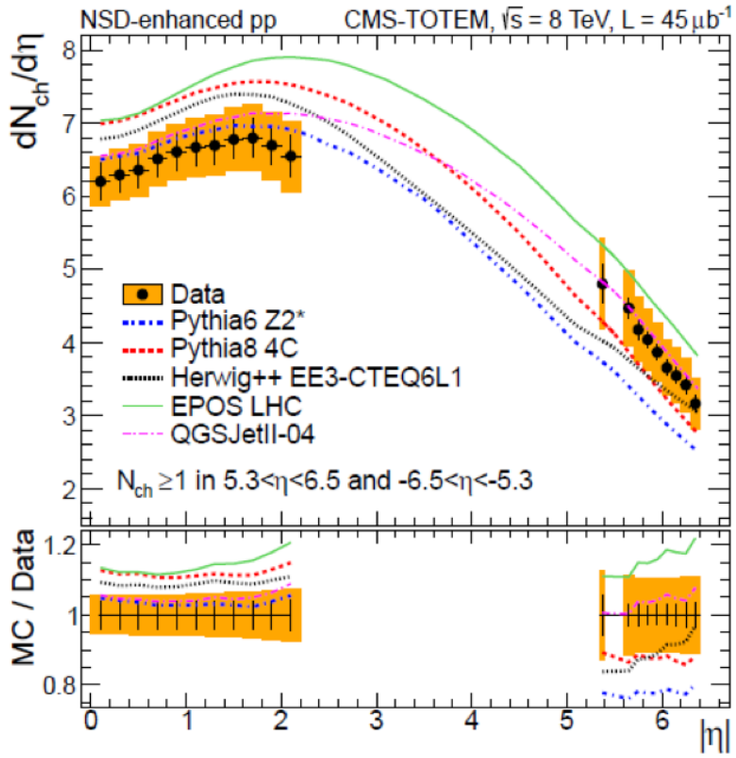
(diffraction & saturation still needs work)

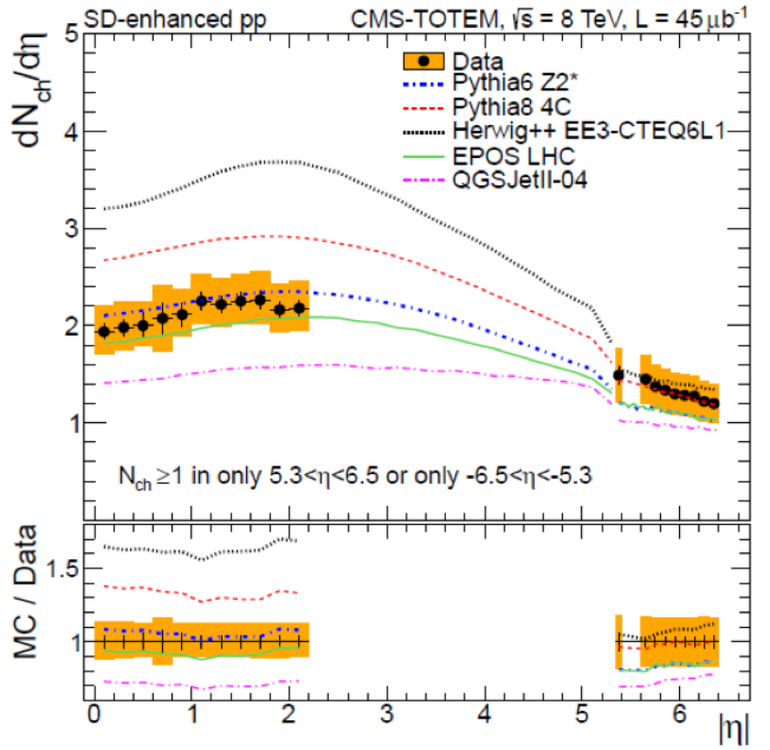
particle production in the atmosphere
central-forward region correlation

[JHEP 11 (2012) 033]



[arXiv:1405.0722]



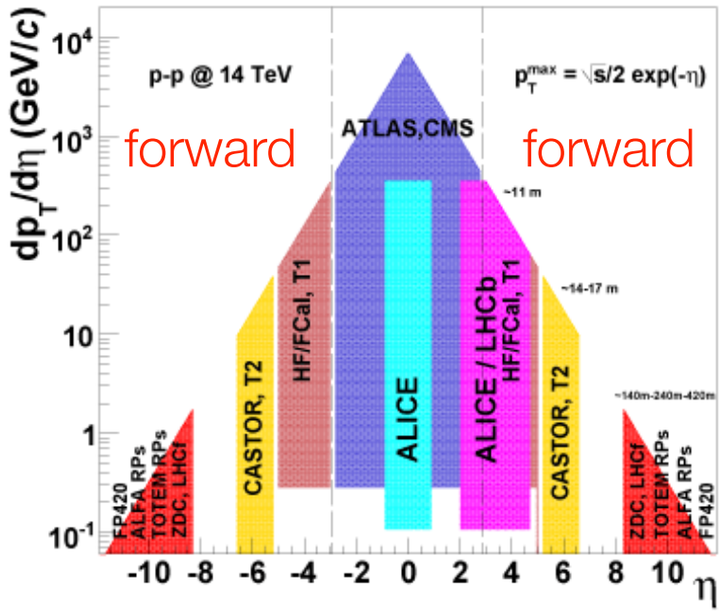


diffractive dissociation (forward)
central-forward correlation is challenging
large spread in model predictions

particle production in the atmosphere
forward region

hadronic interaction models for CRs don't describe **energy flow & multiplicity** in forward region

does this matter for cosmic rays & atmospheric neutrinos ?

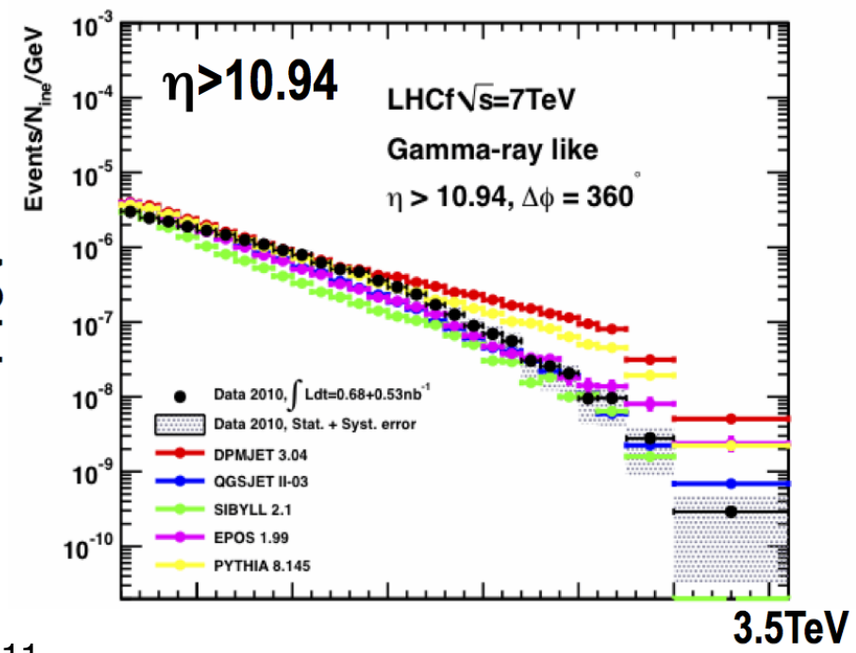


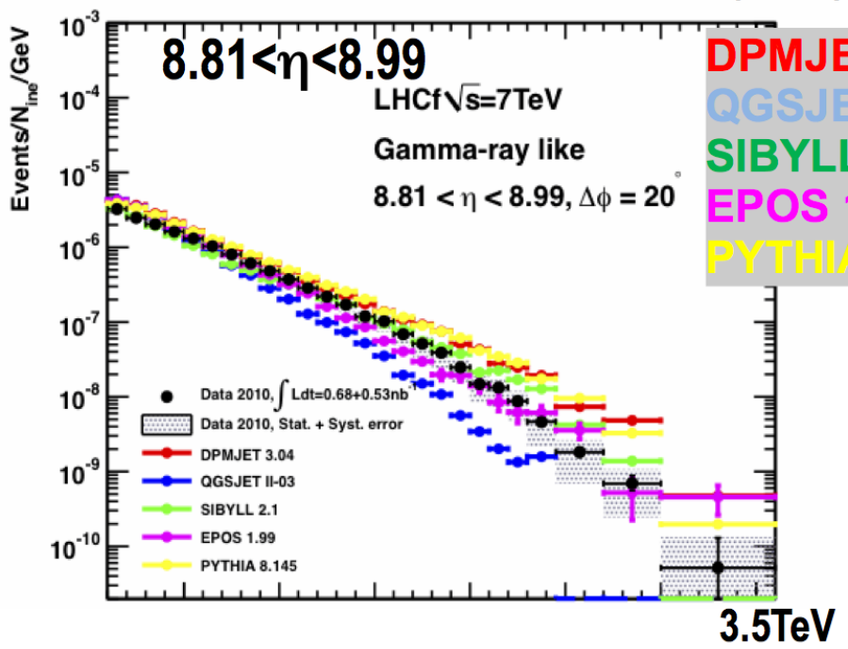
Y.Itow, Forward production at LHC *ISVHECRI2014@ 18Aug2014*

PLB 703 (2011) 128-134
PLB 715 (2012) 298-303

LHCf single Eγ at 7TeV and 0.9 TeV pp

7TeV



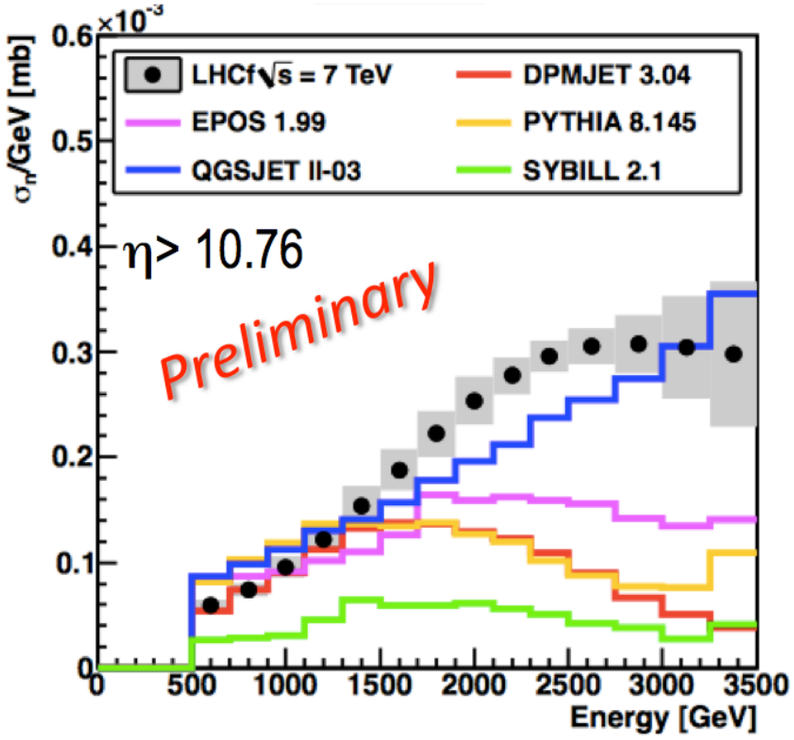


DPMJET 3.04
QGSJETII-03
SIBYLL 2.1
EPOS 1.99
PYTHIA 8.145

particle production in the atmosphere
forward region

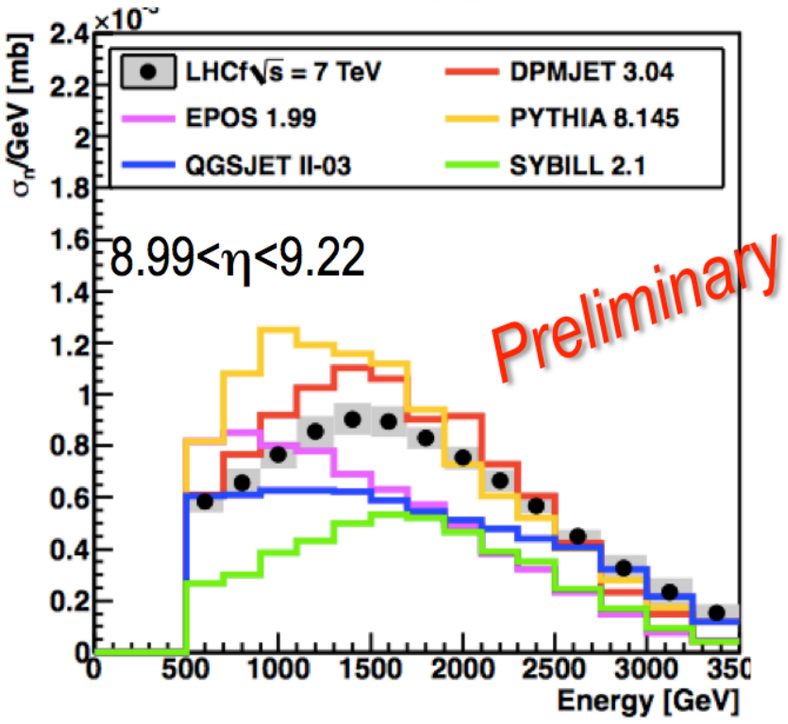
Very forward neutron at 7TeV p-p

- η>10.76 : QGSJET03 good, >h>9.22 DPMJET3 good
- Larger neutron / gamma ratio than expected



n / γ ratio	Data	3.05±0.19
	DPMJET3.04	1.05
	EPOS 1.99	1.80
	PYTHIA 8.145	1.27
	QGSJET II-03	2.34
	SYBILL 2.1	0.88

40% E res. unfolded



n / γ ratio	Data	1.26±0.08
	DPMJET3.04	0.76
	EPOS 1.99	0.69
	PYTHIA 8.145	0.82
	QGSJET II-03	0.65
	SYBILL 2.1	0.57

23

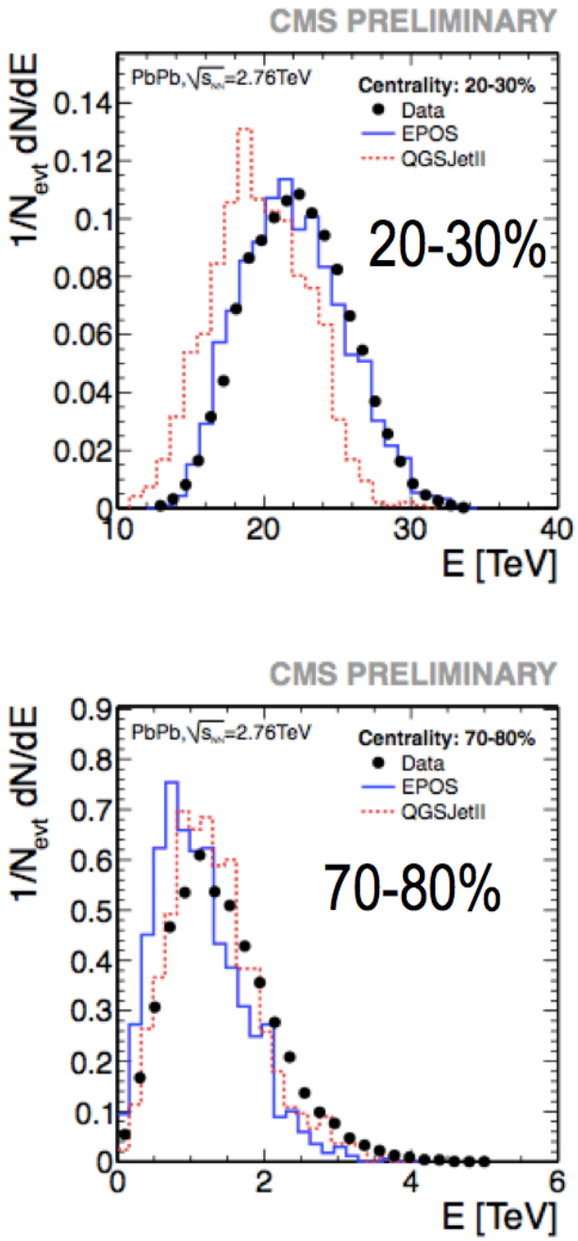
no hadronic interaction model describes observations

particle production in the atmosphere
p/ion-ion collisions

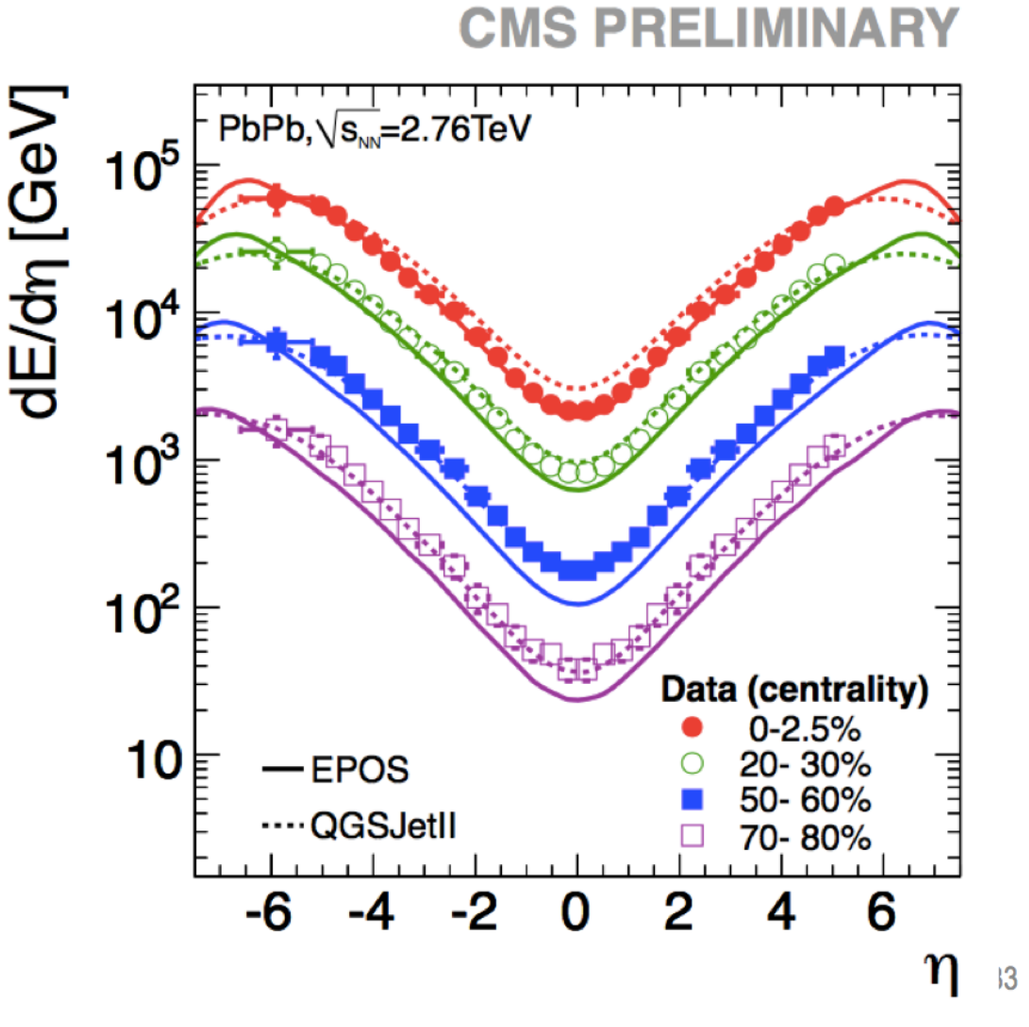
Y.Itow, Forward production at LHC *ISVHECRI2014@ 18Aug2014*

CMS forward energy flow in Pb-Pb

CMS PAS HIN-12-006



- Central : EPOS better
- Peripheral : QGSJET better

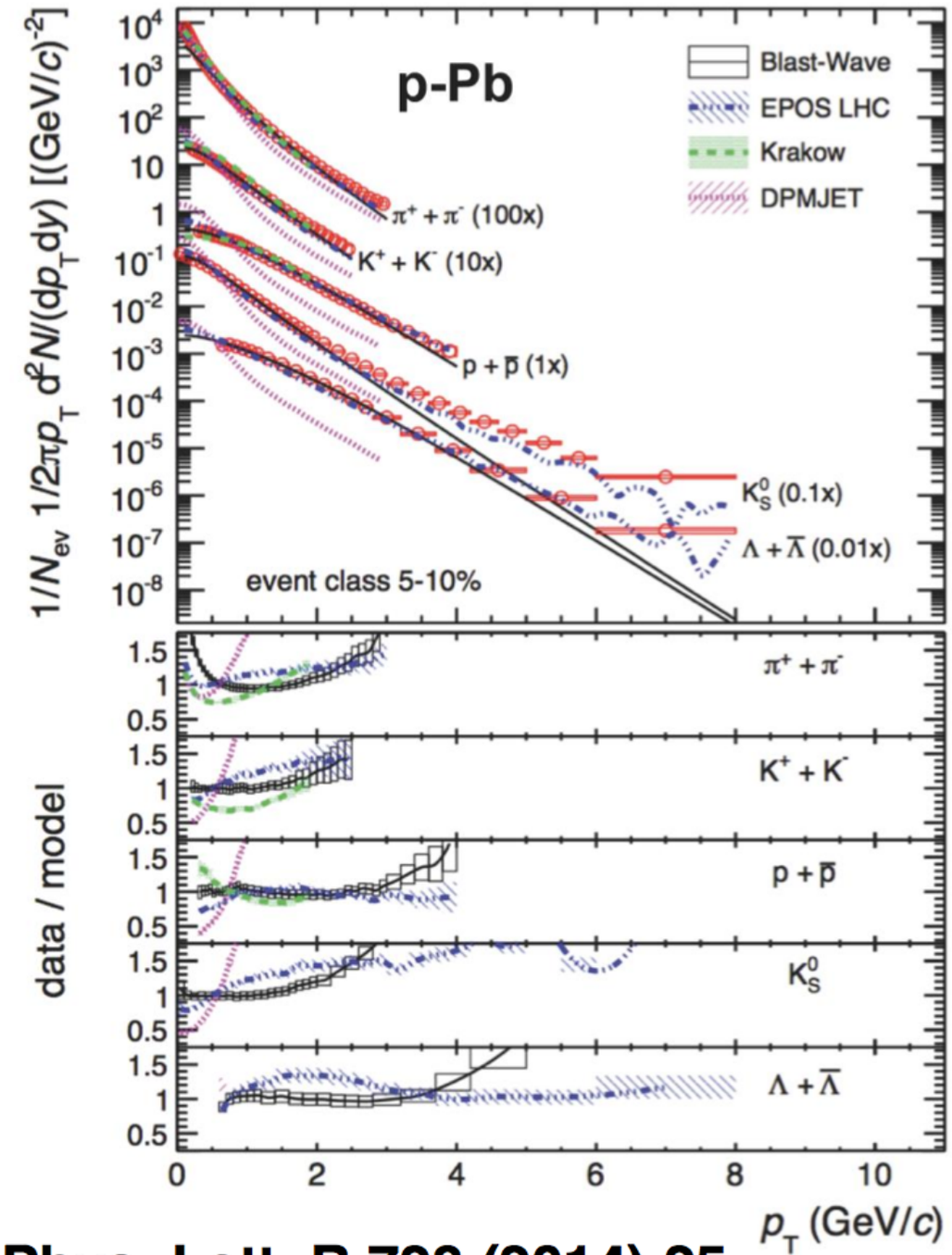


dependency on **collision centrality**

nuclear shadowing
gluon saturation

affecting forward region and low p_T

particle production in the atmosphere
p/ion-ion collisions



Phys. Lett. B 728 (2014) 25

collective flow effects in ion/ion collisions

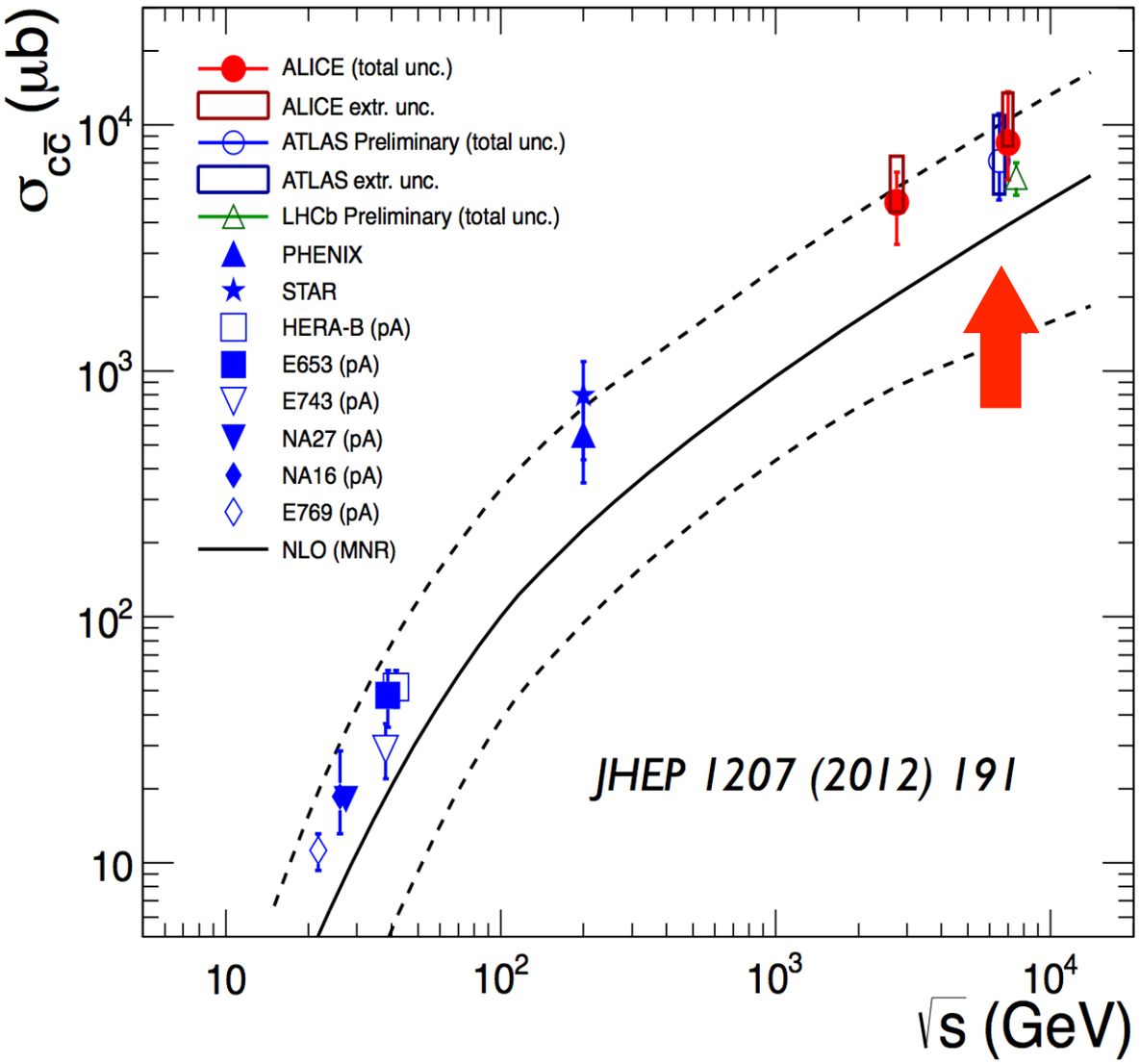
currently only in EPOS

Hydrodynamic models (EPOS, Krakow) show a better agreement than QCD inspired models (DPMJET).

summary #1

- **soft component** of hadronic processes (non perturbative)
  - tuned collider & CR hadronic models not able to explain all observations
  - extrapolation to forward region is challenging
- **forward region** is important for cosmic rays & atmospheric neutrino predictions
- pp collisions important but p-ion (pPb, pO, pN, pC) necessary for CR
  - nuclear collective effects, saturation and shadowing

heavy quark production
laboratory for perturbative QCD



- LHC data show agreement of observations within FONLL (wide range of η) - **pQCD**

- **intrinsic charm** production: asymmetry in $c\bar{c}$ baryon production (SELEX 2002)

- $p \rightarrow \Lambda_c^+ + \bar{D}^0$ of order 1% $(m_s/m_c)^2$ compared to associated production $p \rightarrow \Lambda K^+$

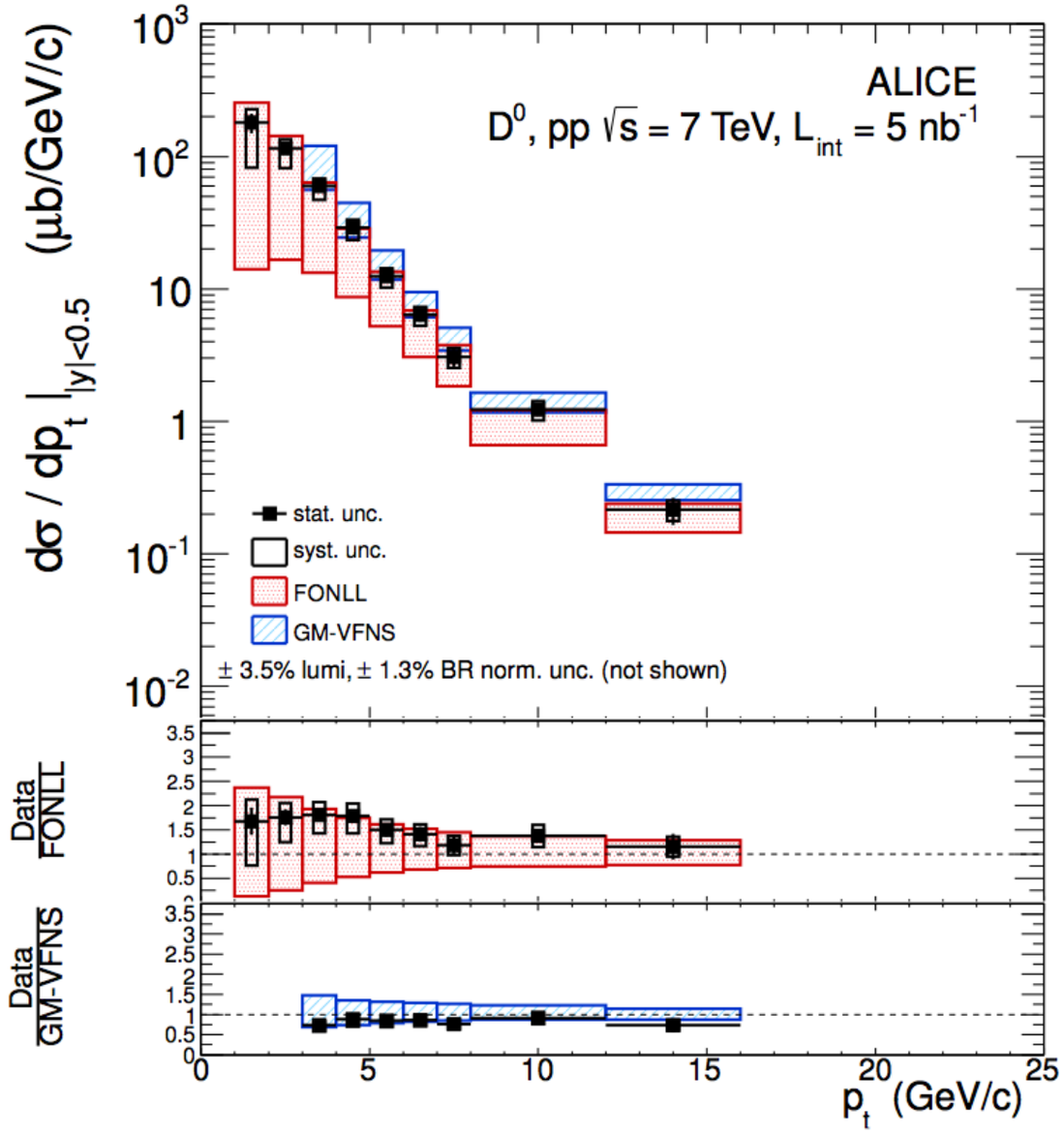
- inclusive D-meson spectrum dominated by intrinsic charm at **high pseudo-rapidity** & **p_T**

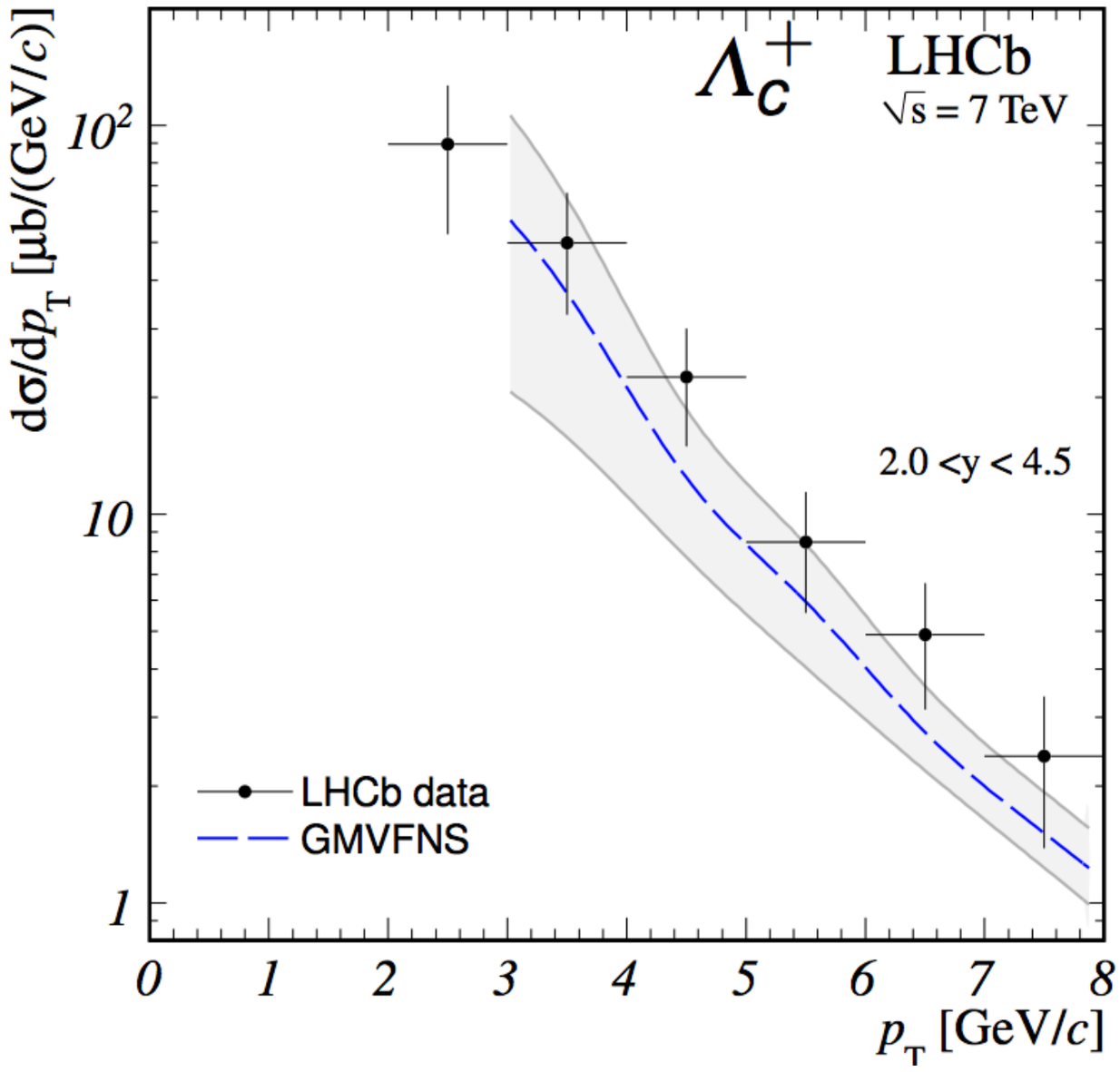
  (Lykasov+ 2012; @LHC: Bednyakov+ 2013)

- **non-perturbative QCD**

heavy quark production
benchmark for perturbative QCD

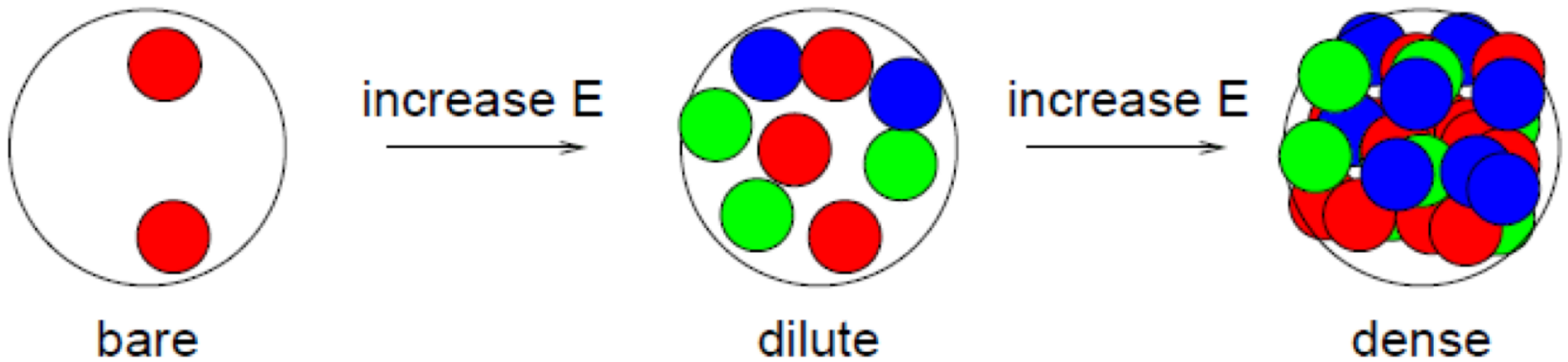
data slightly marginal but in agreement with pQCD





heavy quark production
benchmark for perturbative QCD

at high energy increase of gluon distribution for x~0
non-linear QCD effects
slows down cross section growth

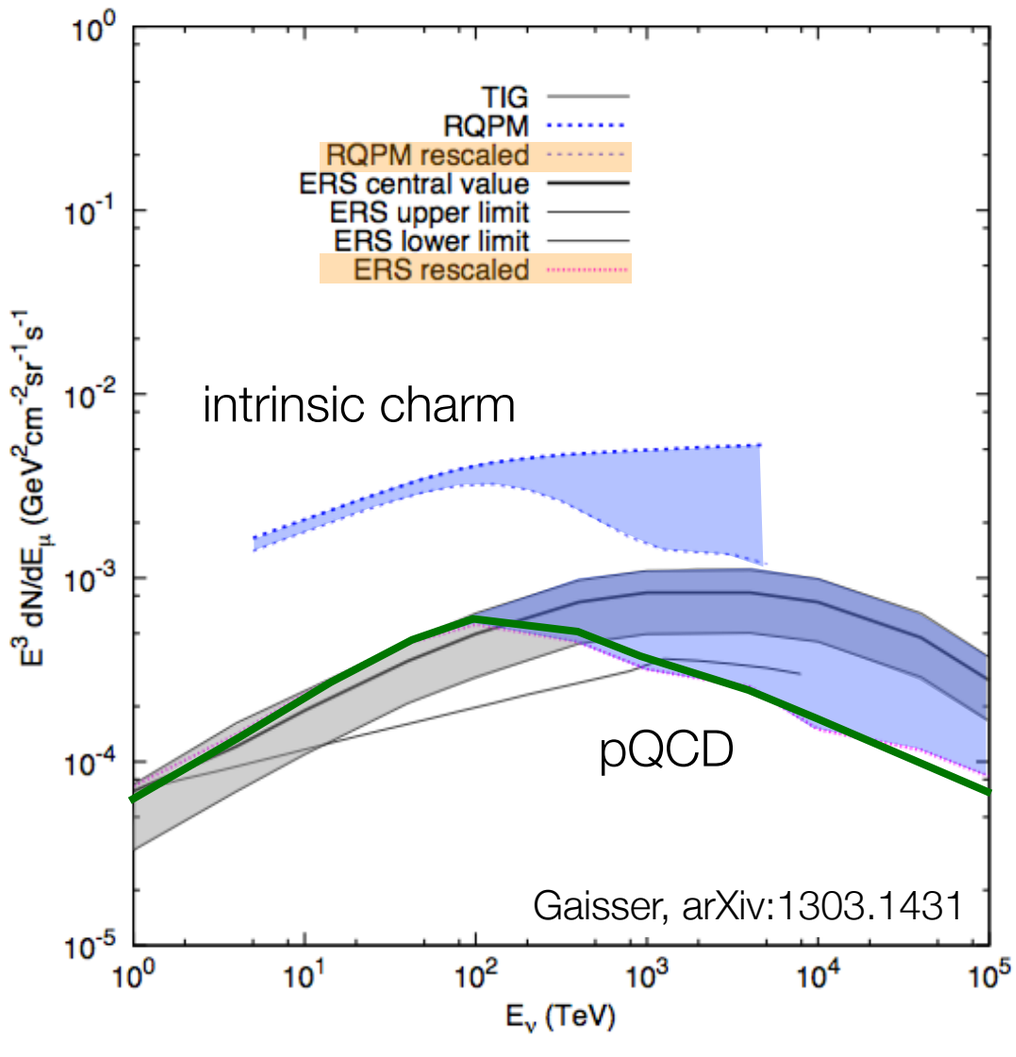


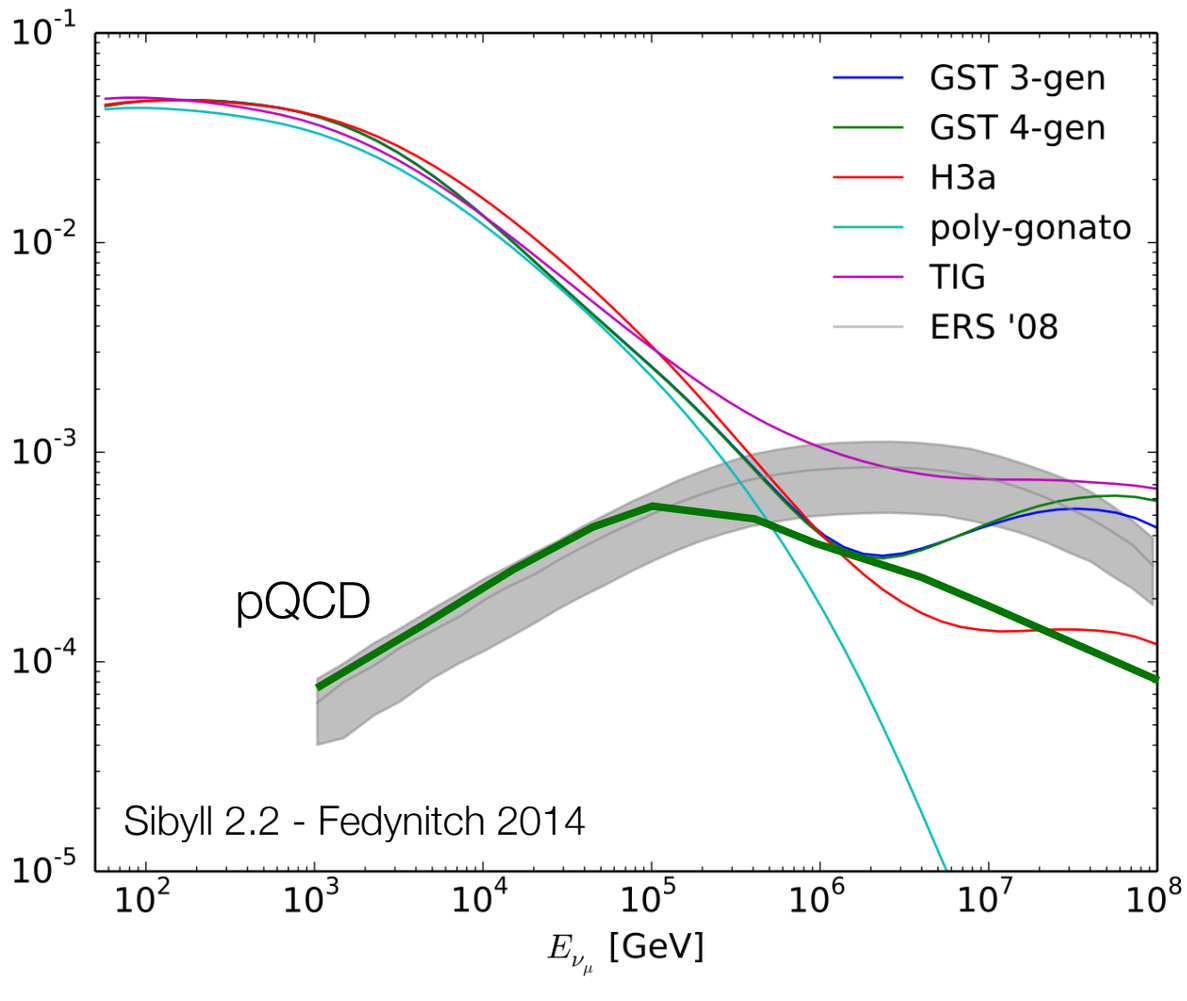
are non-perturbative effects important ?
intrinsic charm production
experimental evidence ?

heavy quark production and astrophysics

- effect of charm production **models**

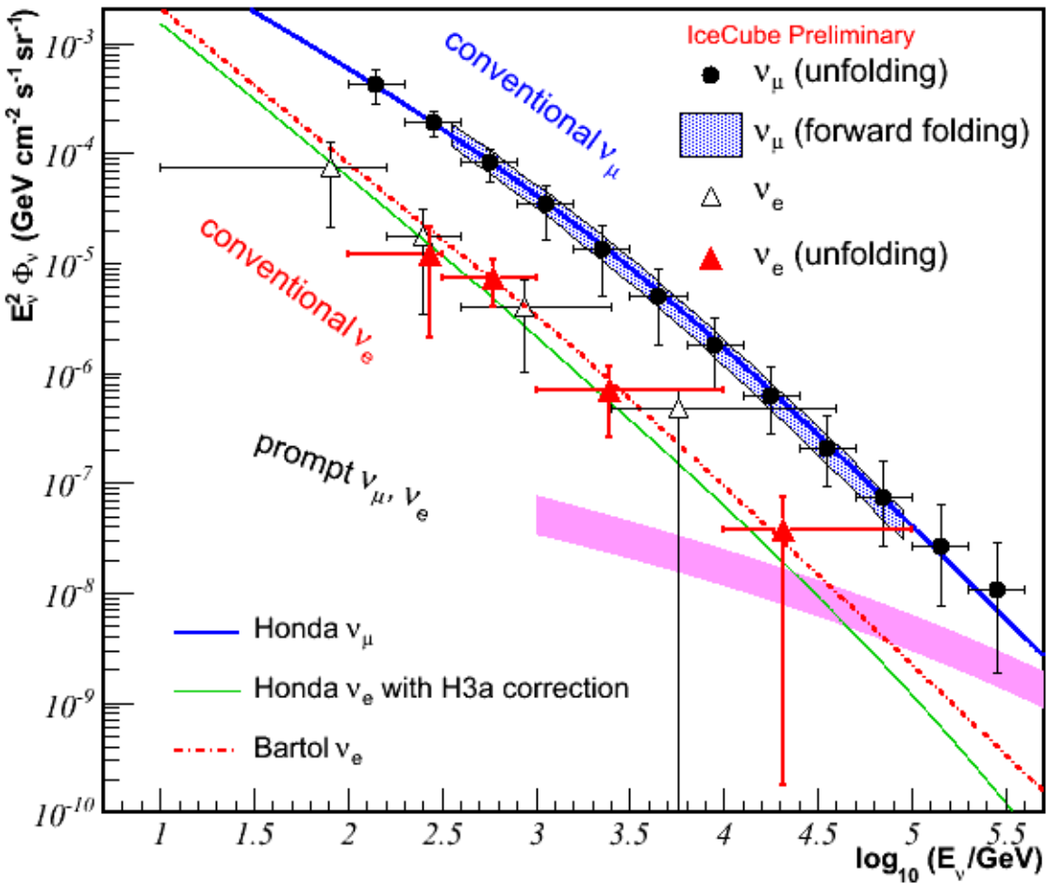
- effect of primary **cosmic ray spectrum**

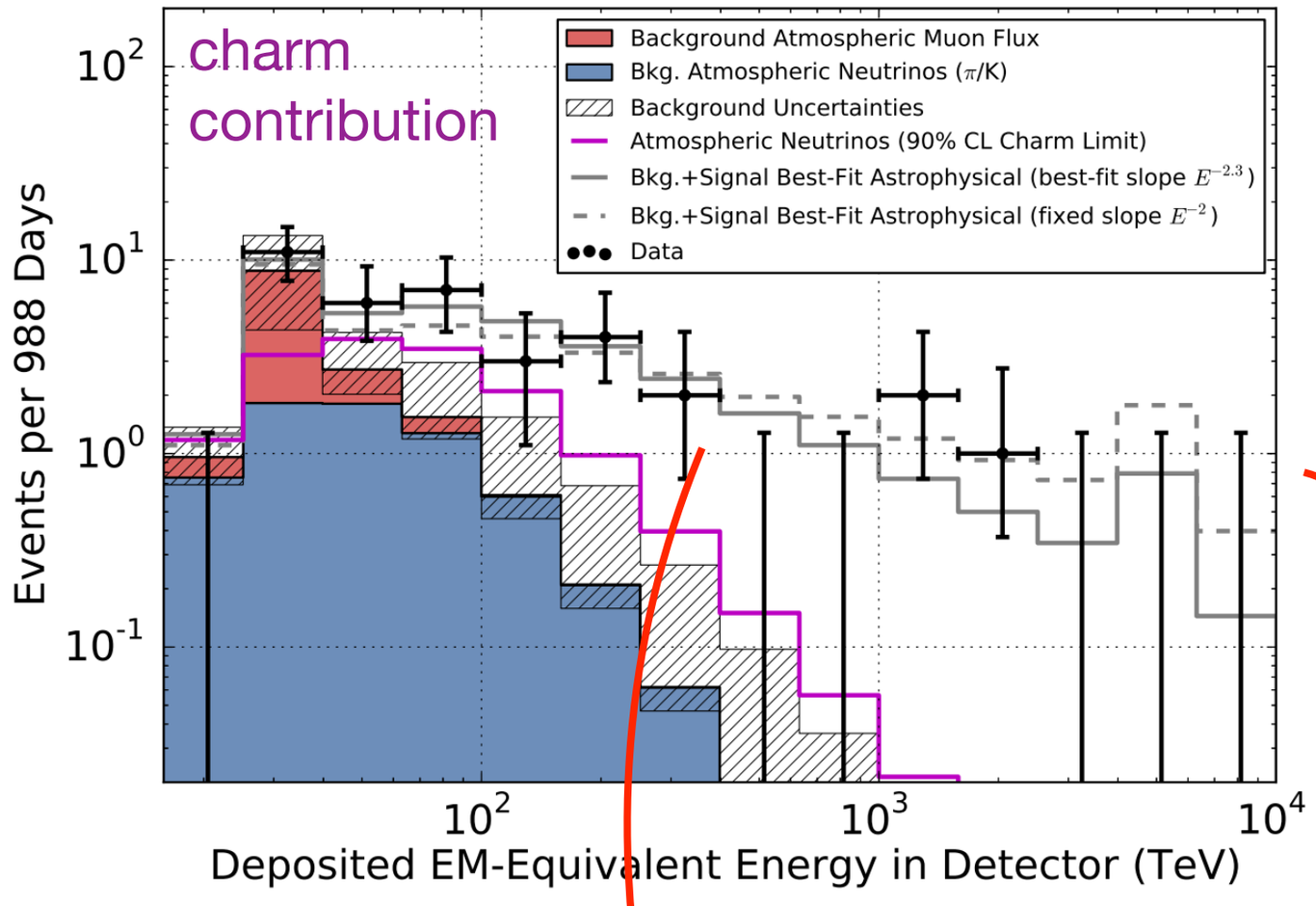




heavy quark production and astrophysics
degeneracy prompt-astrophysical

observed starting all-direction **all-flavor**





Aartsen et al. Science 342 (2013) 1242856
Aartsen et al. arXiv:1405.5303

→ can neutrino telescopes probe charm production ?

prompt neutrinos?

astrophysical neutrinos

summary #2

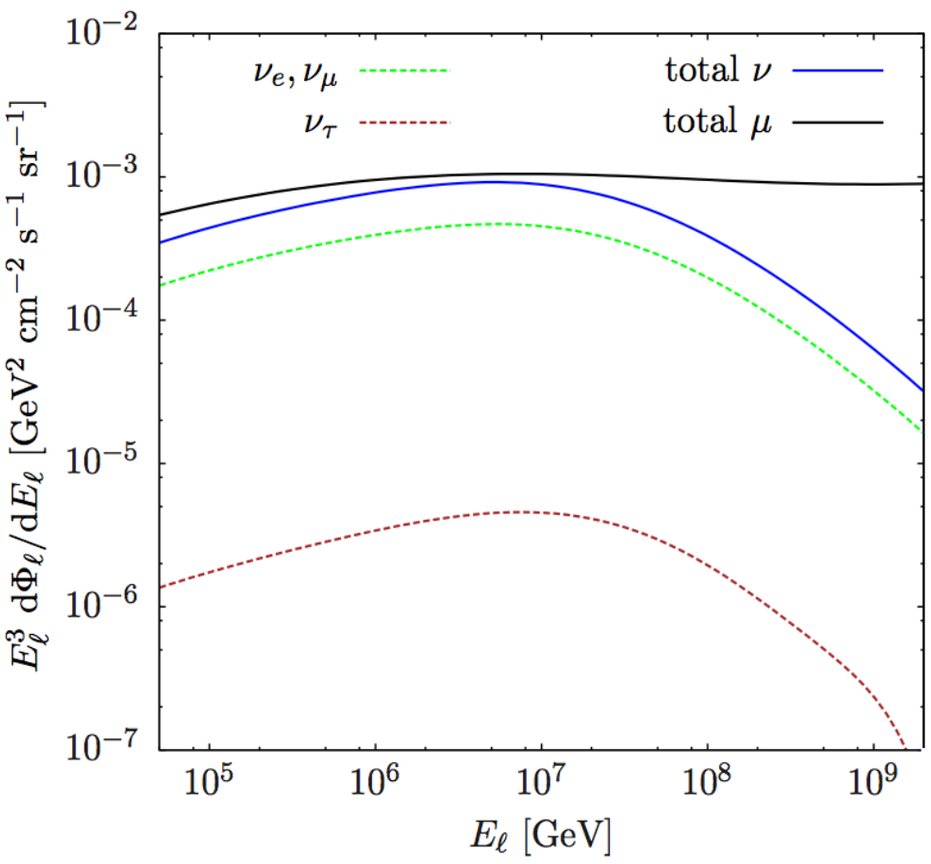
- prompt neutrino contribution **unknown** but currently affecting astrophysical spectrum estimate (and viceversa)

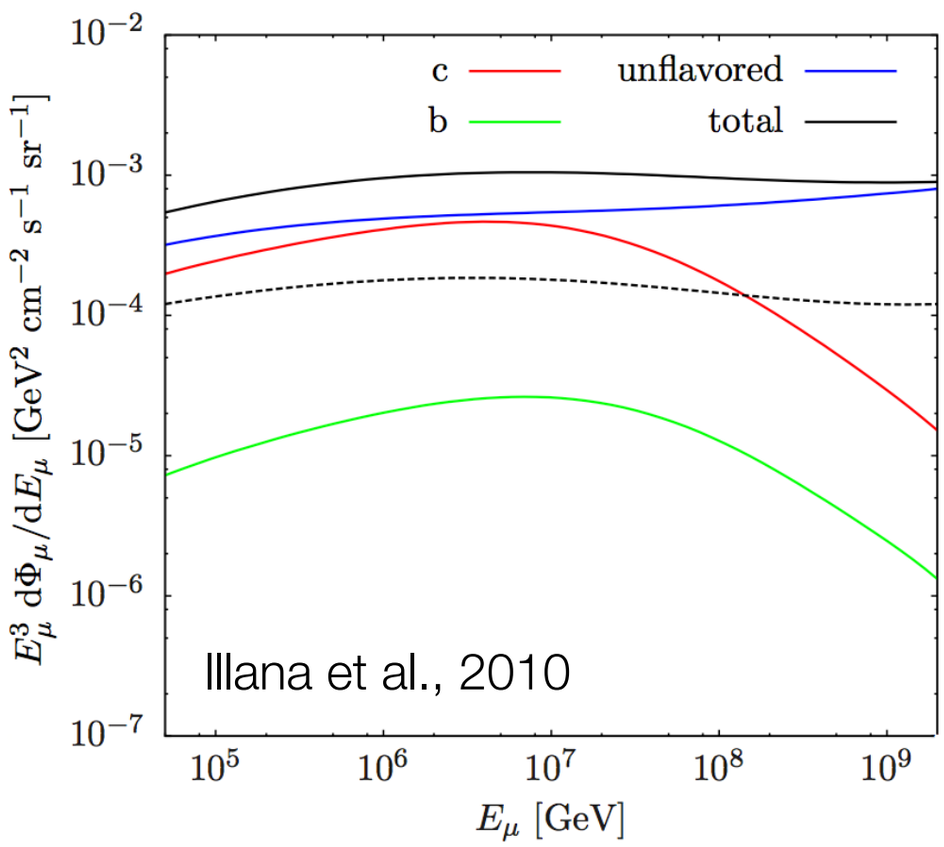
- **probe** charm production with neutrino telescopes?
  - consistent multi-flavor & north-south (self-veto) neutrino detection
  - leading muons in muon bundles (complications from multiplicity)
  - muon bundle lateral distribution (composition sensitive)

- **model** (pQCD+intrinsic charm) and **composition** dependency

one final remark

- **asymmetry** between muon and neutrino @ high energy
- muons dominated by unflavored η mesons > PeV





atmospheric & charm session

Introductory remarks
Paolo Desiati **20+5**

Self-veto and charm production with HE neutrinos in IceCube
Gary Binder **20+5**

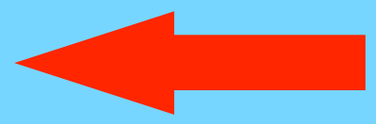
Atmospheric neutrinos and charm production
Chang Hyon **20+5**

Charm with high energy muons in IceCube Summary of P. Berghaus´ results
H.P. Bretz **20+5**

Coffee 15:40-16:10

ANTARES atmospheric/diffuse searches (with emphasis on atmospheric background)
A Margiotta **25+5**

IceCube MESE analyses (point source and diffuse)
Albrecht Karle (Madison) **25+5**



Remarks on Kshort production in the atmosphere
Tom Gaisser **10+5**

Review of charm production in colliders (RHIC, ALICE, LHCb, ...)
Alessandro Grelli (Utrecht) **25+5**

High energy hadronic interaction models bridging accelerator with cosmic ray physics
Anatoli Fedynitch (Karlsruhe) **25+5**