Karl-Heinz Kampert
University Wuppertal

Summary of ISVHECRI 2024

Thanks to the organisers for choosing such a beautiful venue!

…. but no much time to enjoy the surroundings

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Well, some had…

ISVHECRI Statistics

- 24 invited talks
- 34 contributed talks
- Discussion session
- Public Lecture
- Tribute

15	CR measurements
8	Accelerator experiments
18	Interaction models, related theory
10	EAS features, interactions
5	Tools and Methods
2	Others

Discussion session:
- consistency of CR energy spectrum and composition
- consistency of muon measurements in EAS
- challenges and issues of hadronic interaction models

ISVHECRI Statistics

Excellent talks, many interesting new results! Thanks to all the speakers!

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10 EAS features, interactions

5 Tools and Methods

2 Others

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ISVHECRI Statistics

• 24 invited talks

Excellent talks, many interesting new results! Thanks to all the speakers!

Also the discussion session was very fruitful, thanks to the topical convenors!

Discussi… …pectrum and composition

…cy of muon measurements in EAS

• challenges and issues of hadronic interaction models

ISVHECRI Statistics

- 24 invited talks
- 34 contributed talks
- Dis

15 CR measur

Apologies:
I will not be able to discuss all this wonderful and important presentations, will rather focus on a few subjects.

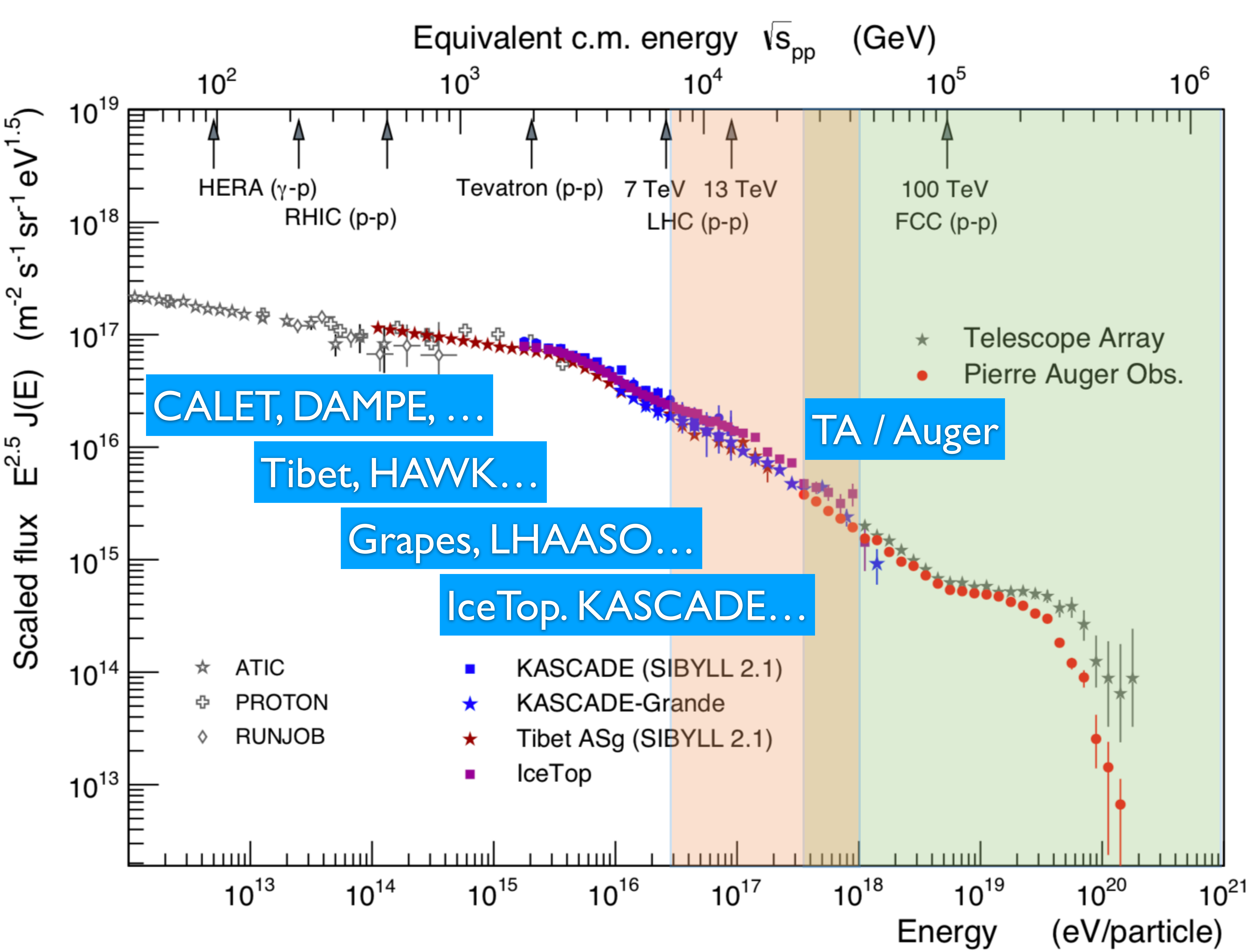
D ... CR energy spectrum and composition

- consistency of muon measurements in EAS
- challenges and issues of hadronic interaction models

Cosmic Ray Measurement from 10^{12} - 10^{20} eV

CALET (Akaike), LHAASO (Zhang), HAWK (Avila Rojas), Tibet ASγ (Kawata), Grapes (Rameez), IceTop (Plum, Verpoest), ALPACA (Anzorena), KASCADE-Grande (Arteaga-Velazquez), TA (Matthews), Auger (Castellina)

The Cosmic Ray Energy Spectrum

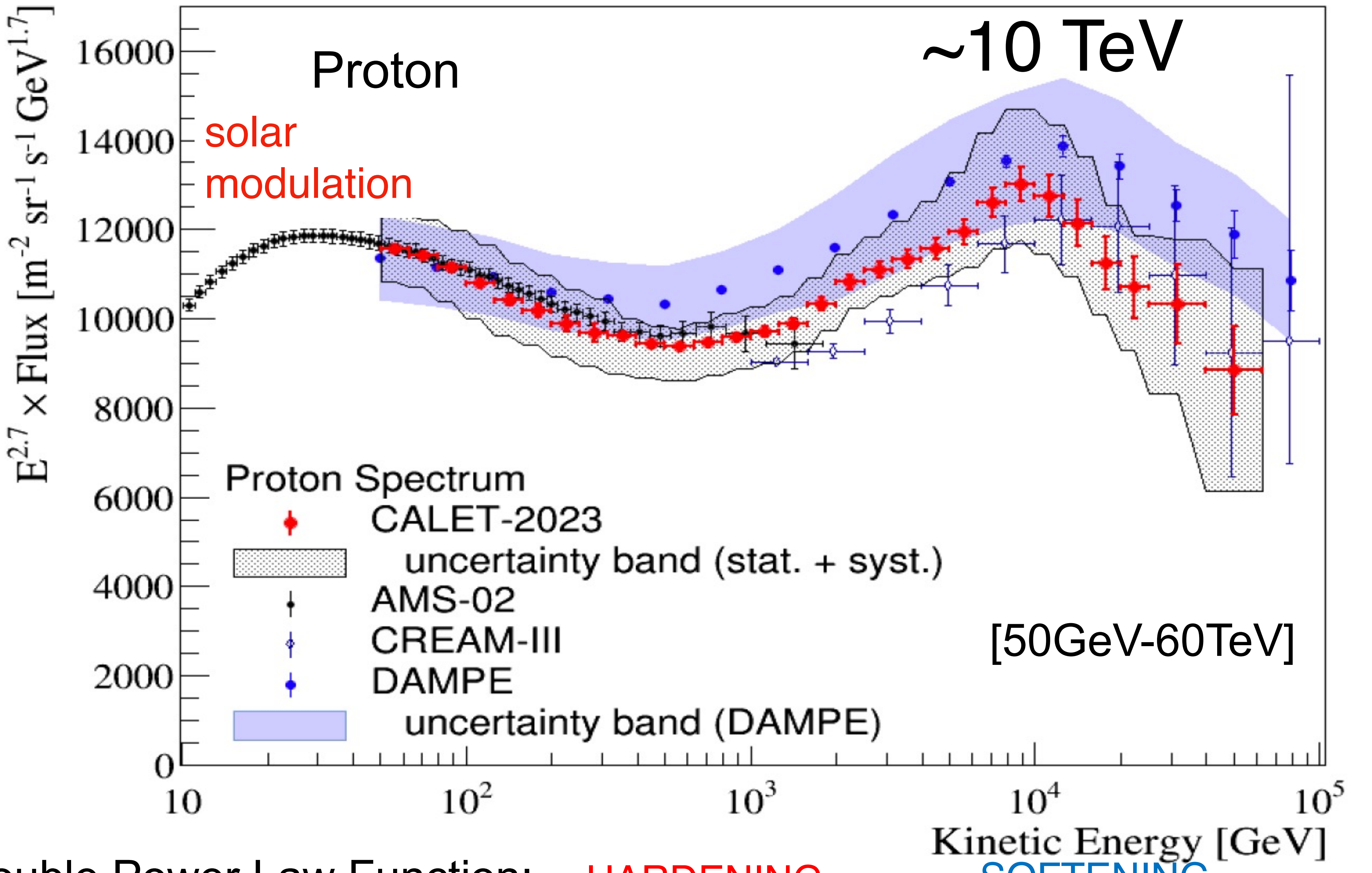


CR Spectrum and Features

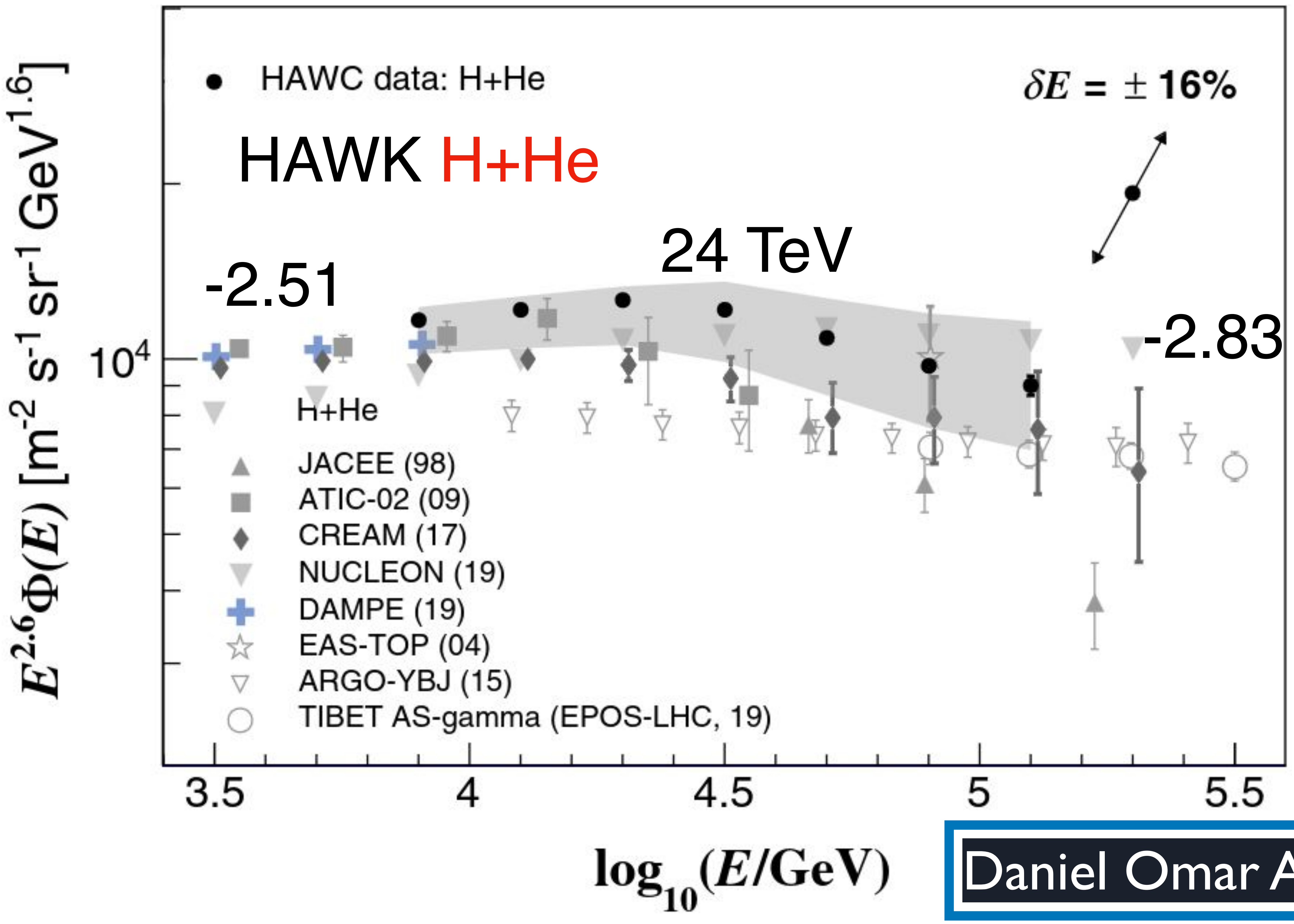
No simple power-laws anymore…

… first knee in p- around 10 TeV, He ~25 TeV, (all particle ~50 TeV)

Flux x $E^{2.7}$ vs. Kinetic energy [Oct.2015- Apr.2023]



Double Power Law Function: HARDENING SOFTENING



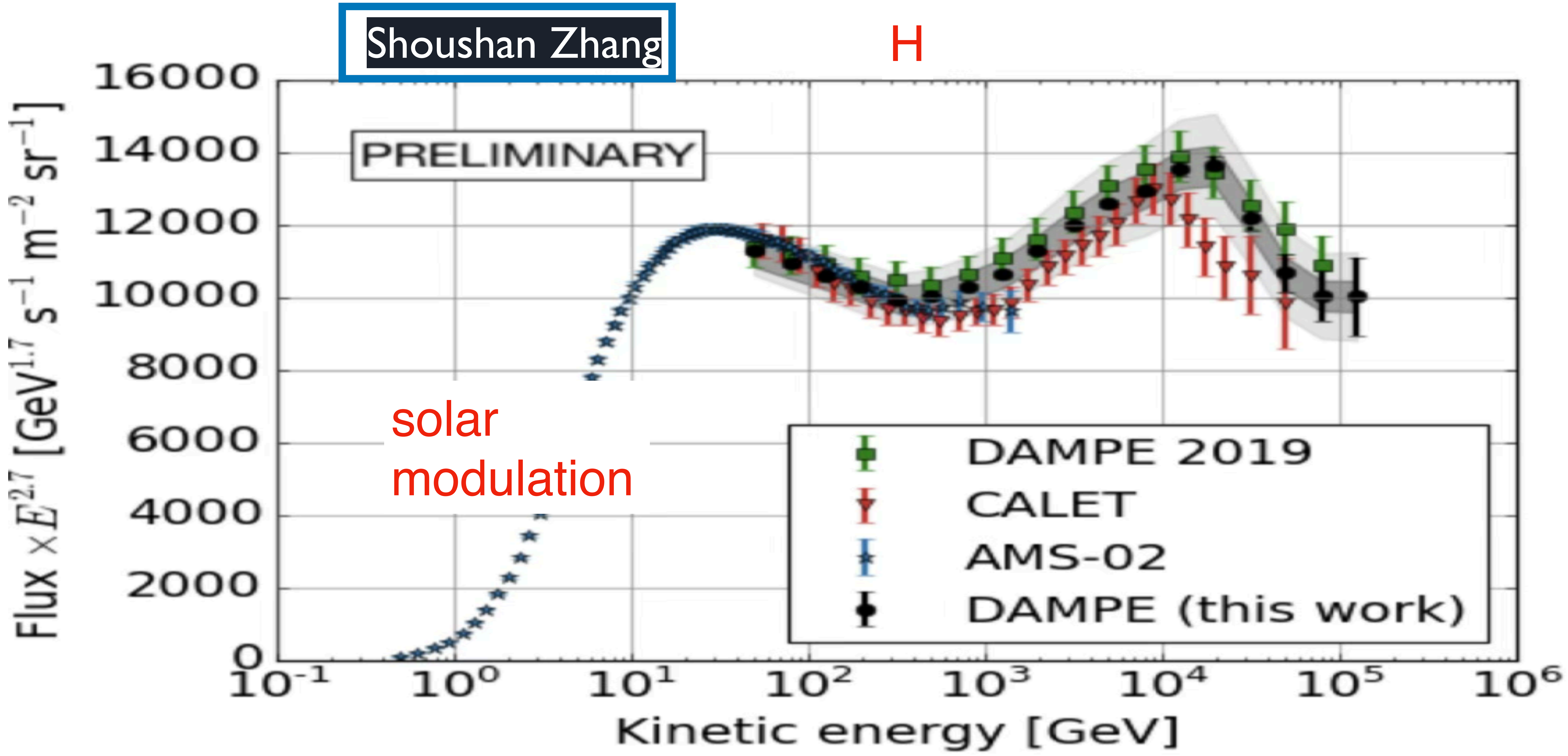
Yoshi Akaike, CALET

Daniel Omar Avila Rojas

Observed consistently by CALET, DAMPE, AMS-02, ATIC-2, CREAM I-III, NUCLEON, ….

… and also in EAS, here HAWK

CR Spectrum and Features



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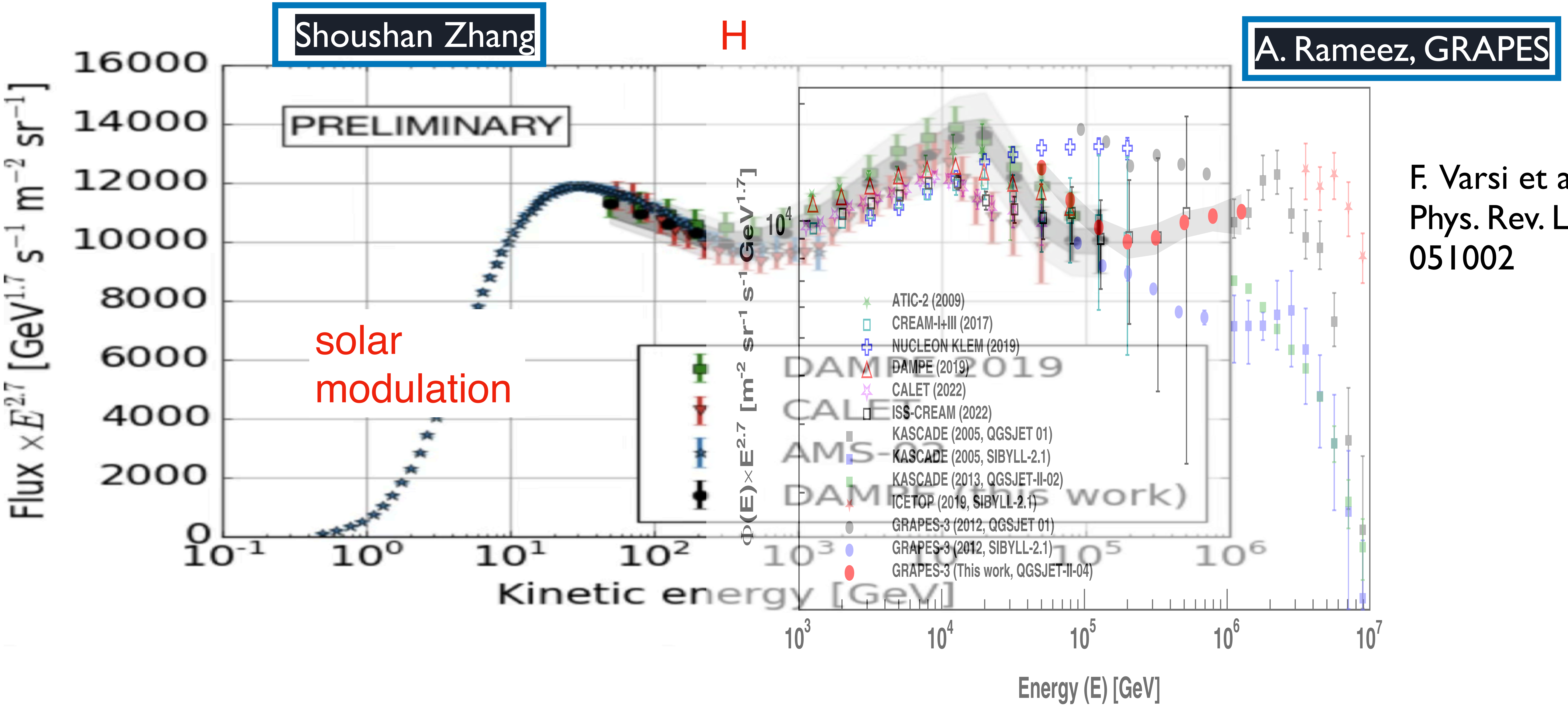
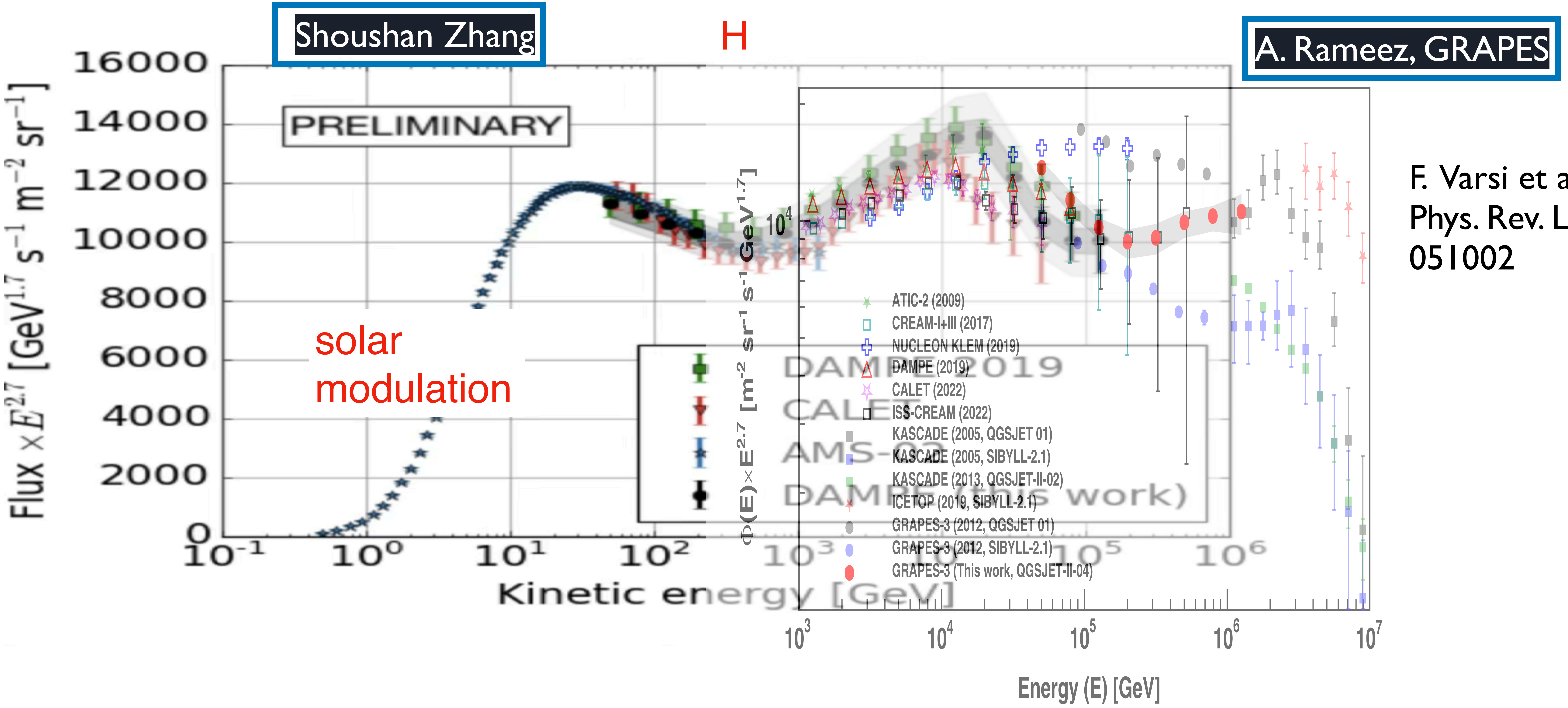


F. Varsi et al. (GRAPES), Phys. Rev. Lett. 132 (2024) 5, 051002

CR Spectrum and Features



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Grapes: new „ankle“ feature observed at ~200 GeV in proton spectrum

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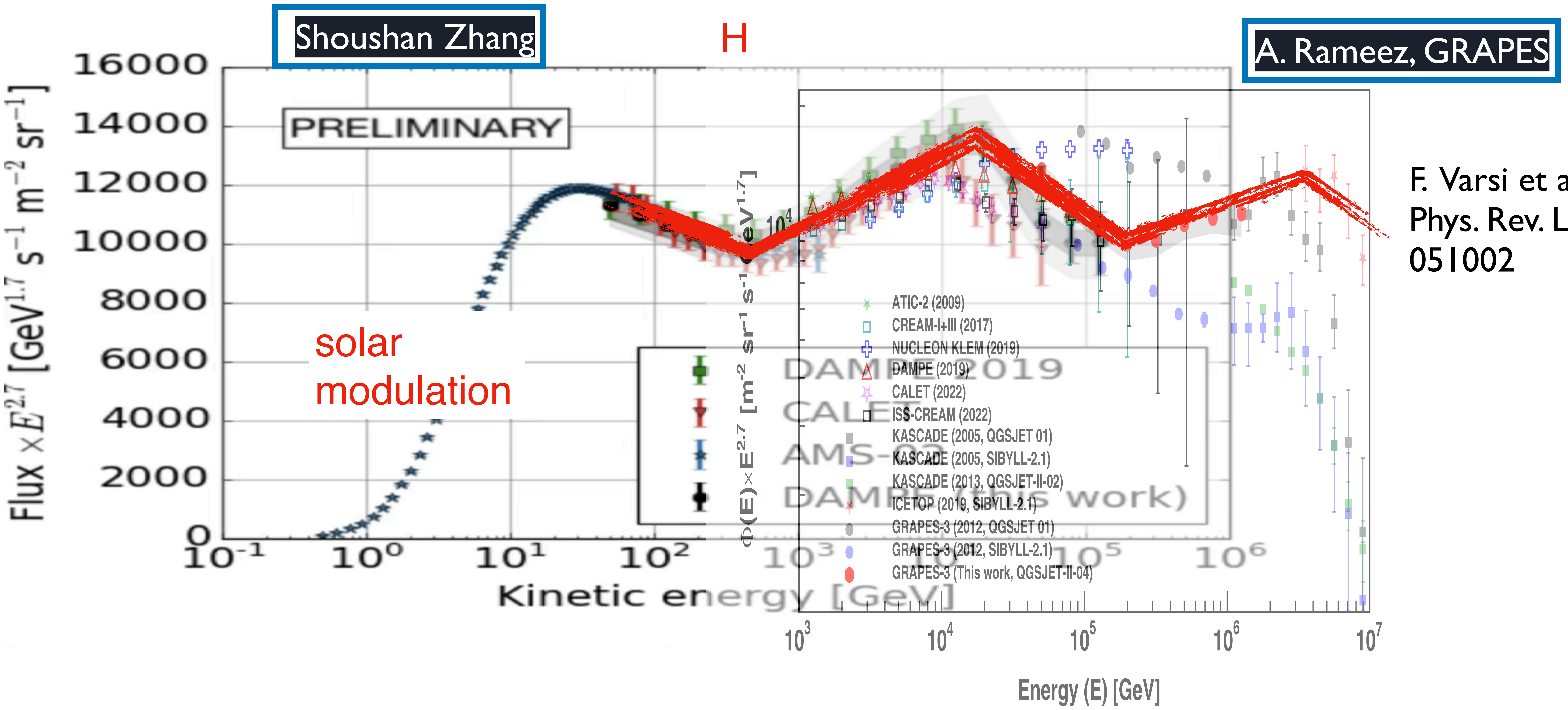

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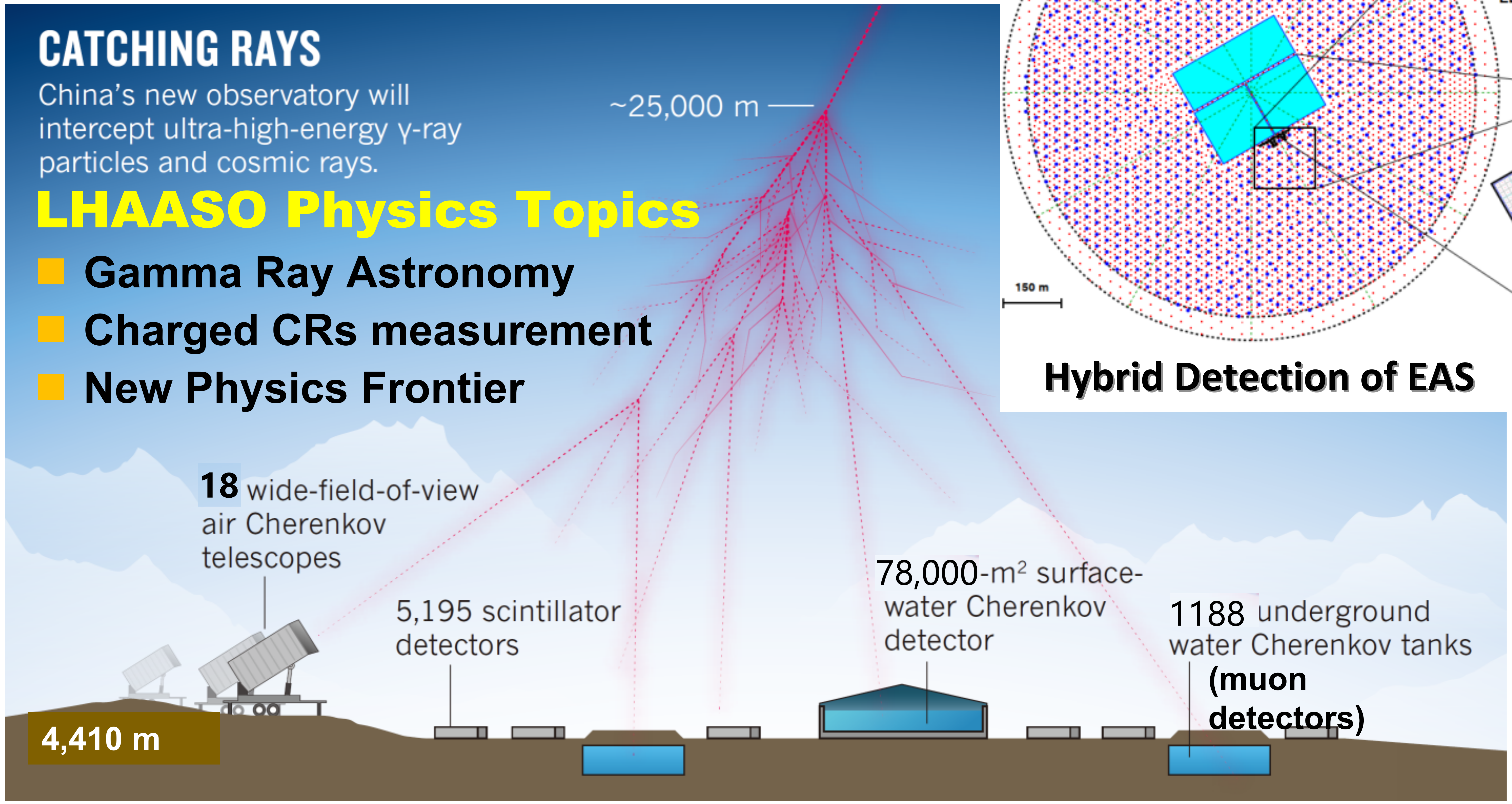
Grapes: new „ankle“ feature observed at ~200 GeV in proton spectrum

LHAASO: A new player in town….

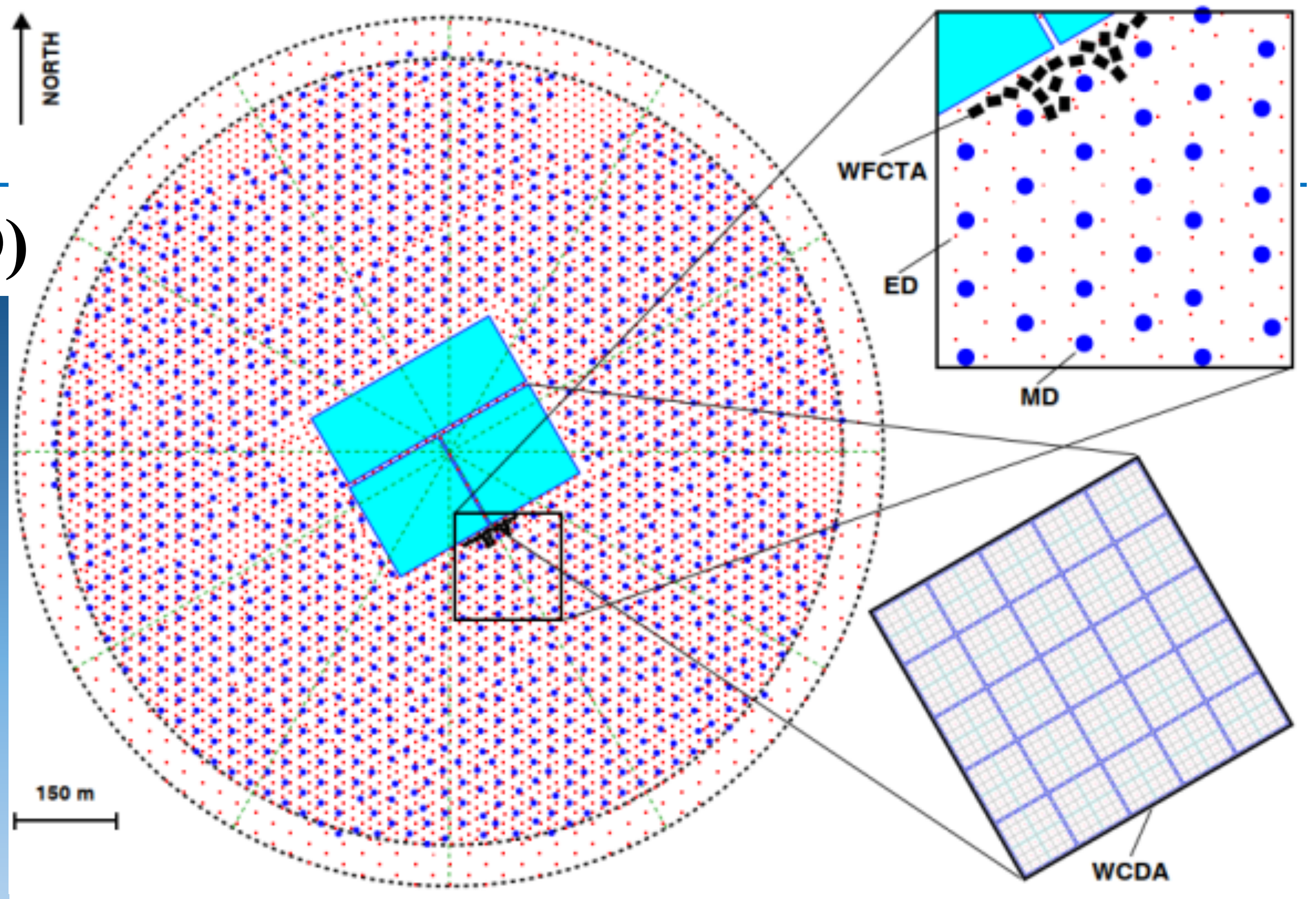
High Energy Cosmic Rays

Large High Altitude Air Shower Observatory (LHAASO)

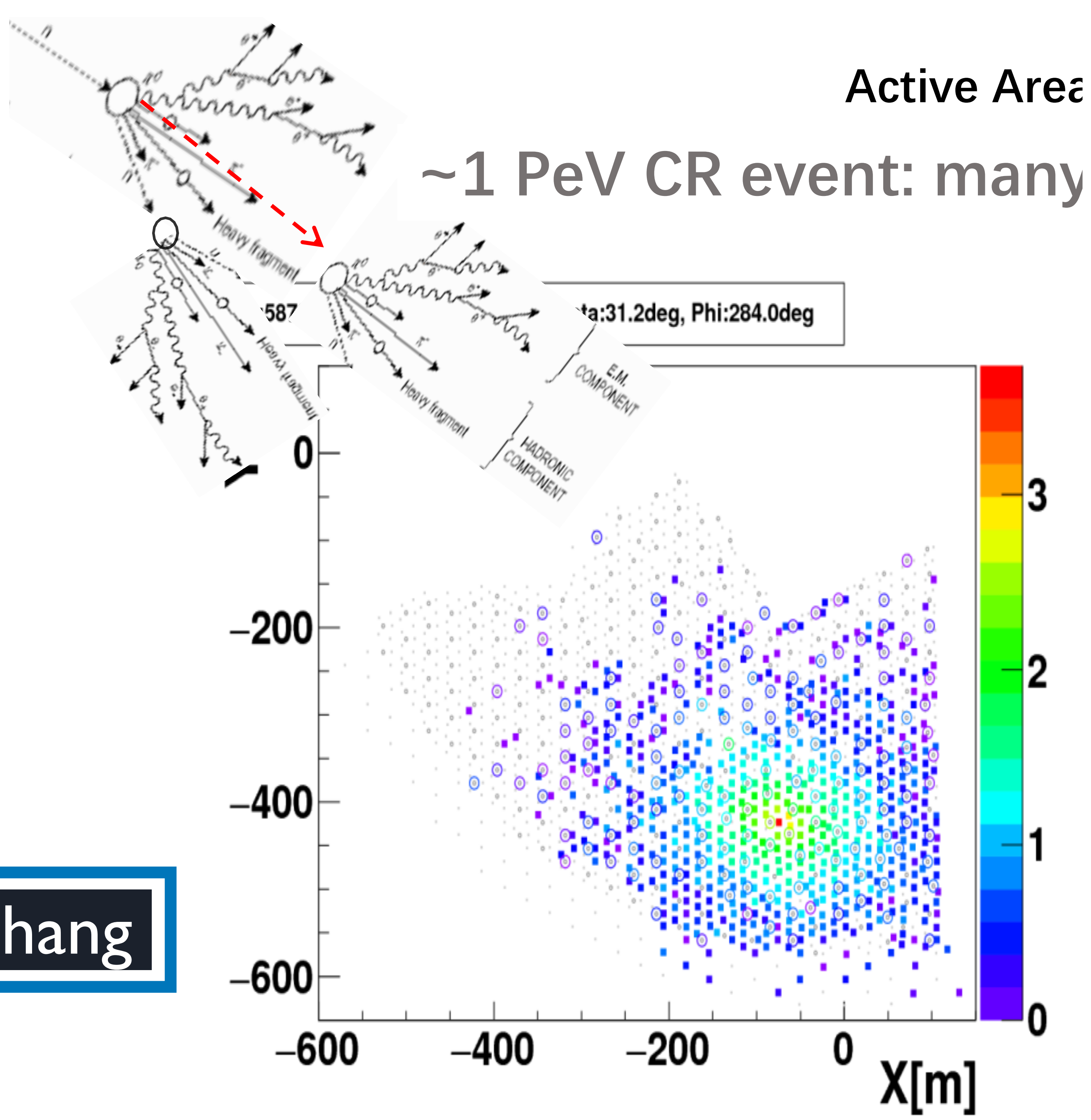


LHAASO Physics Topics

- Gamma Ray Astronomy
- Charged CRs measurement
- New Physics Frontier



Hybrid Detection of EAS

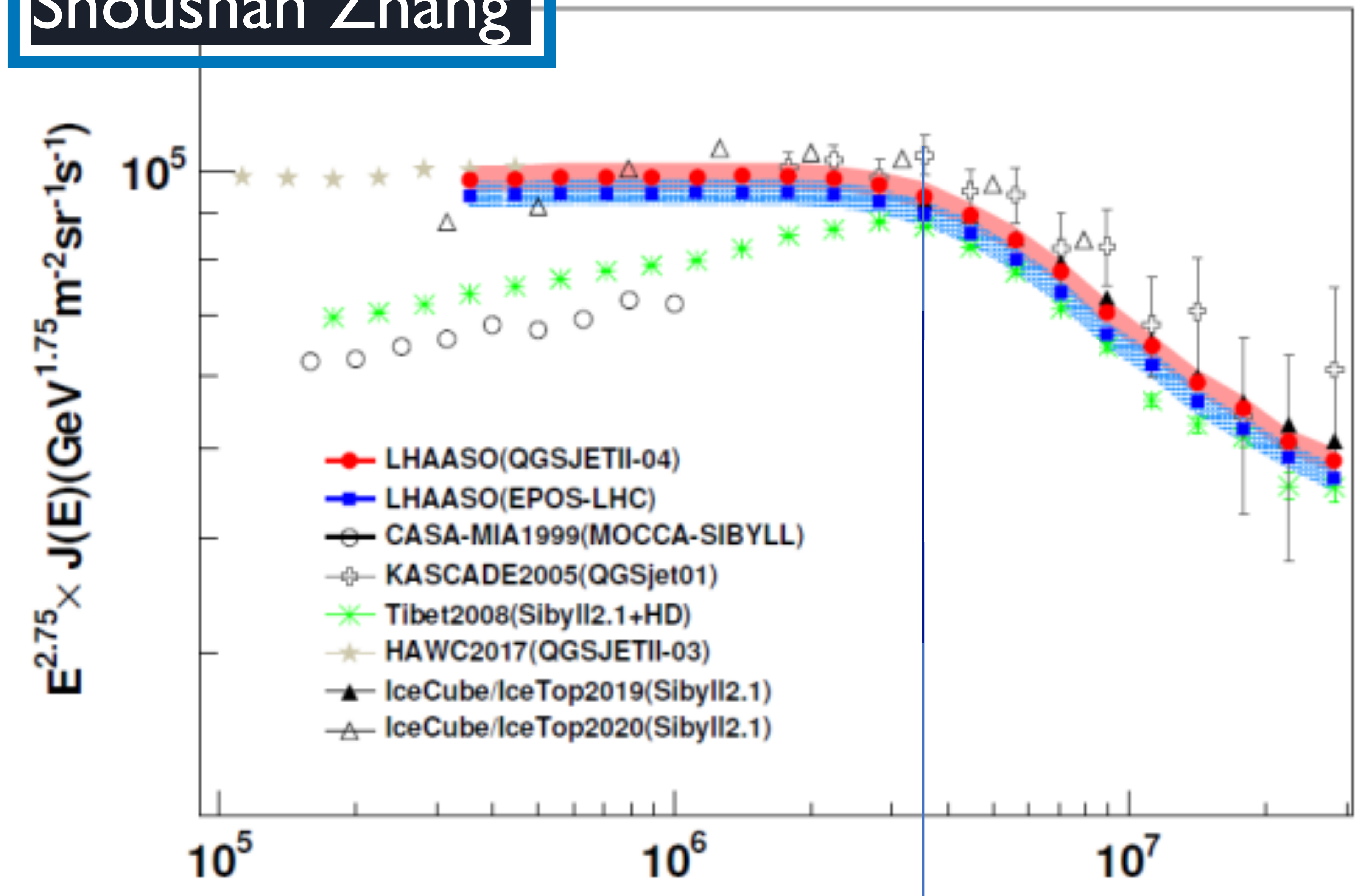


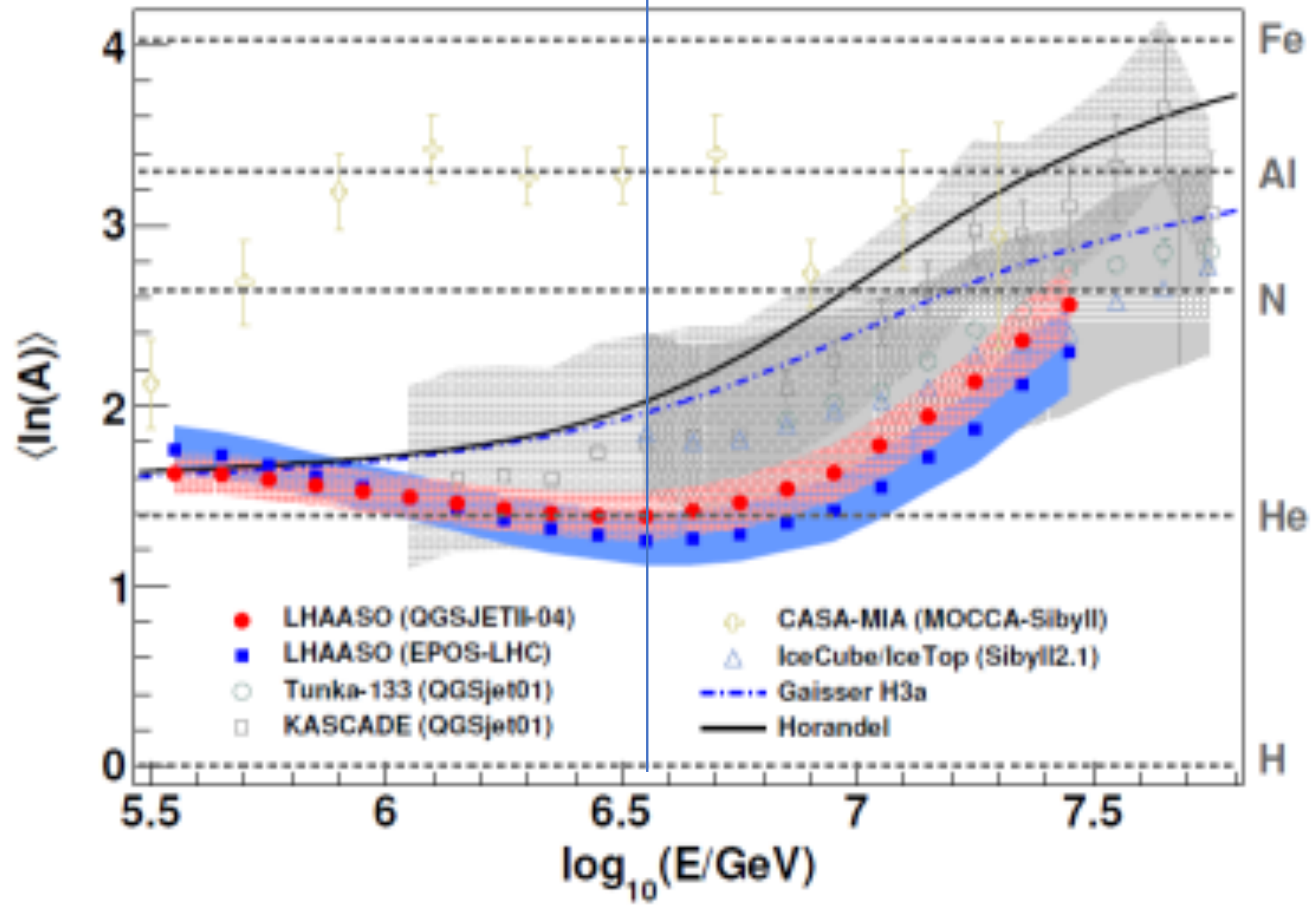
Shoushan Zhang

Rich information about CR induced EAS

LHASSO at knee energies

Shoushan Zhang





All-particle spectrum:

„second" Knee at 3.7 PeV, γ_1=-2.7, γ_2=-3.1

Very good agreement between EAS experiments…

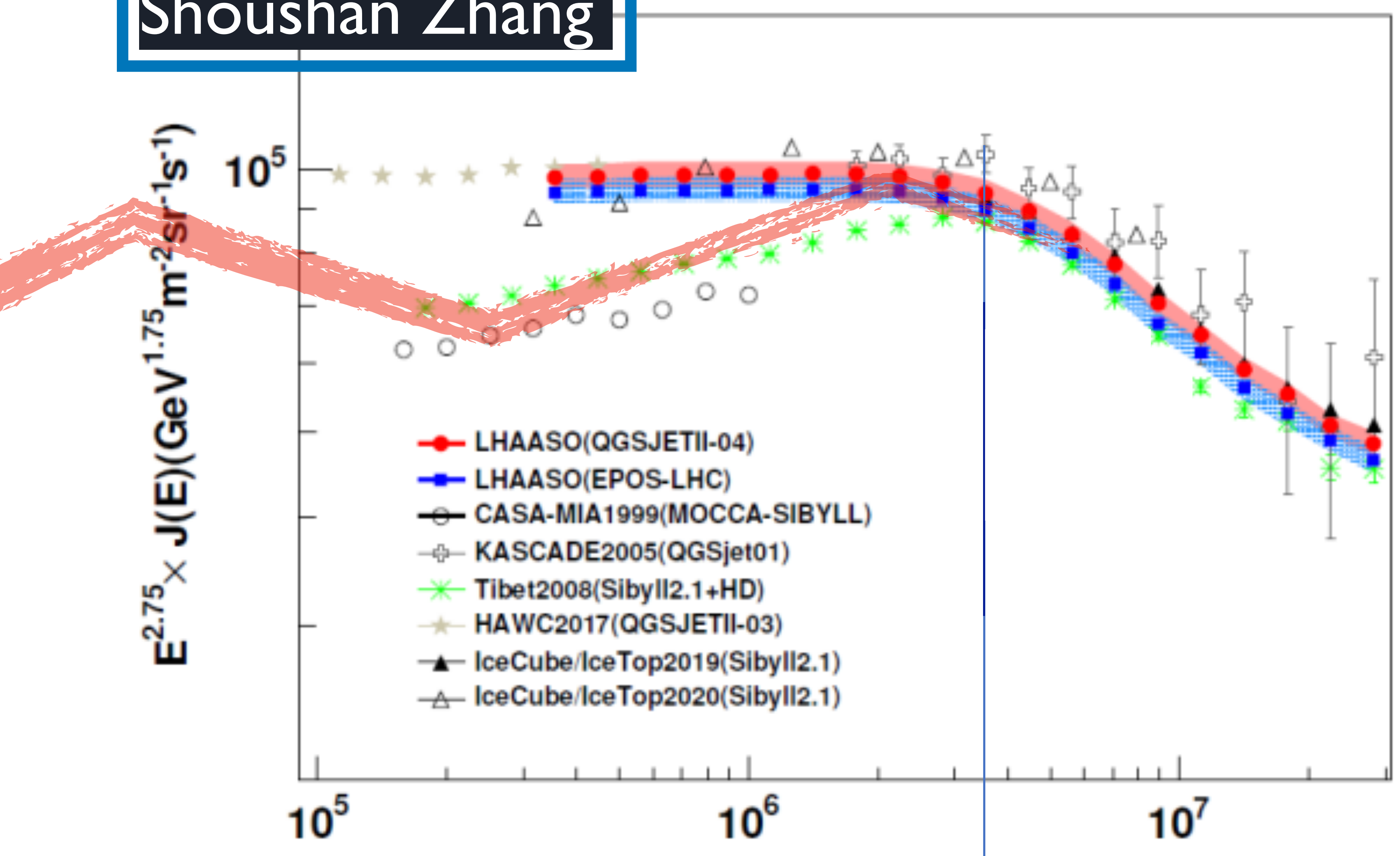
… and it also connects well to direct measurements

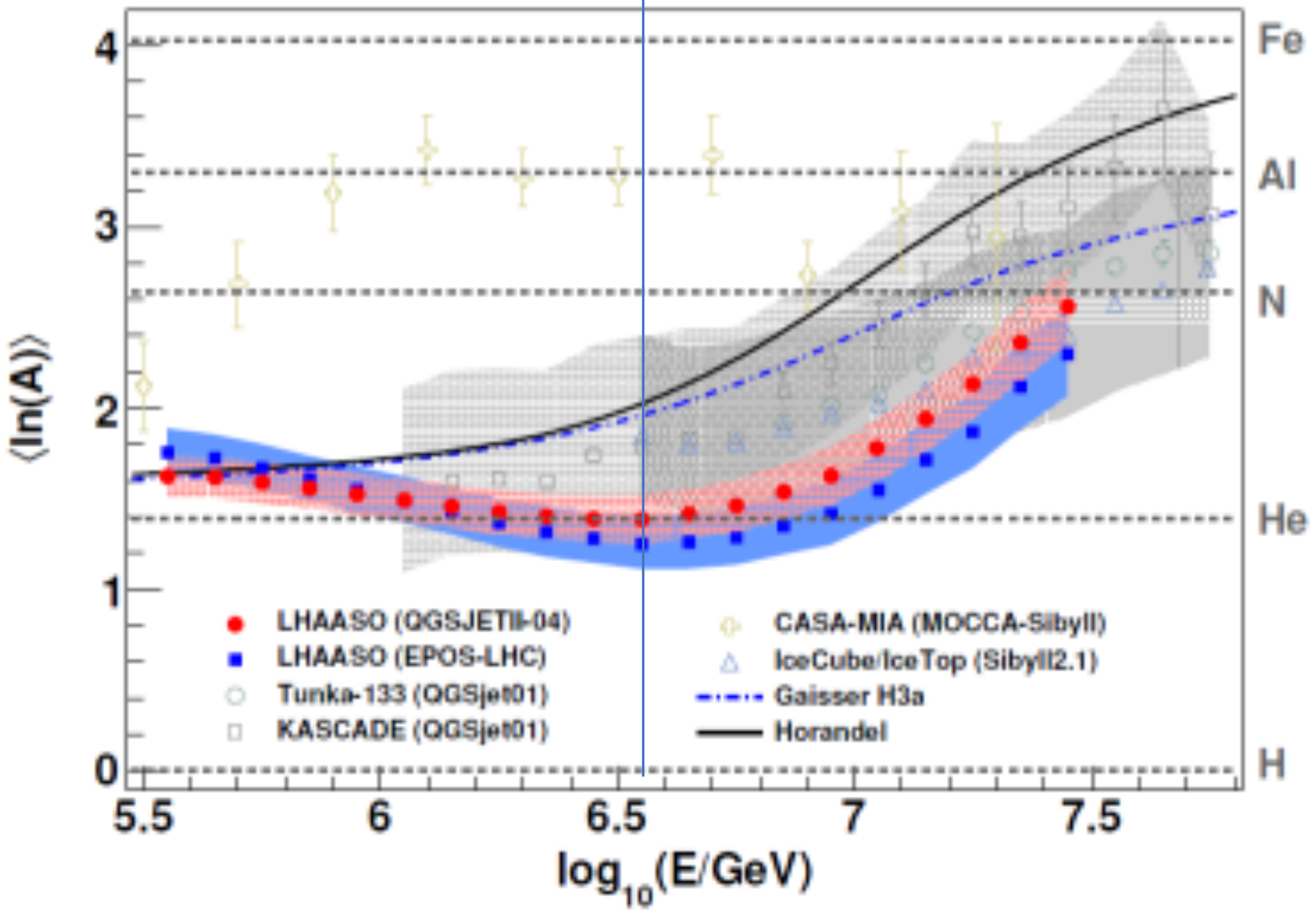
Energy spectra for individual mass groups expected within the next 3 years!

also, composition increasingly heavier above knee

LHASSO at knee energies

Shoushan Zhang





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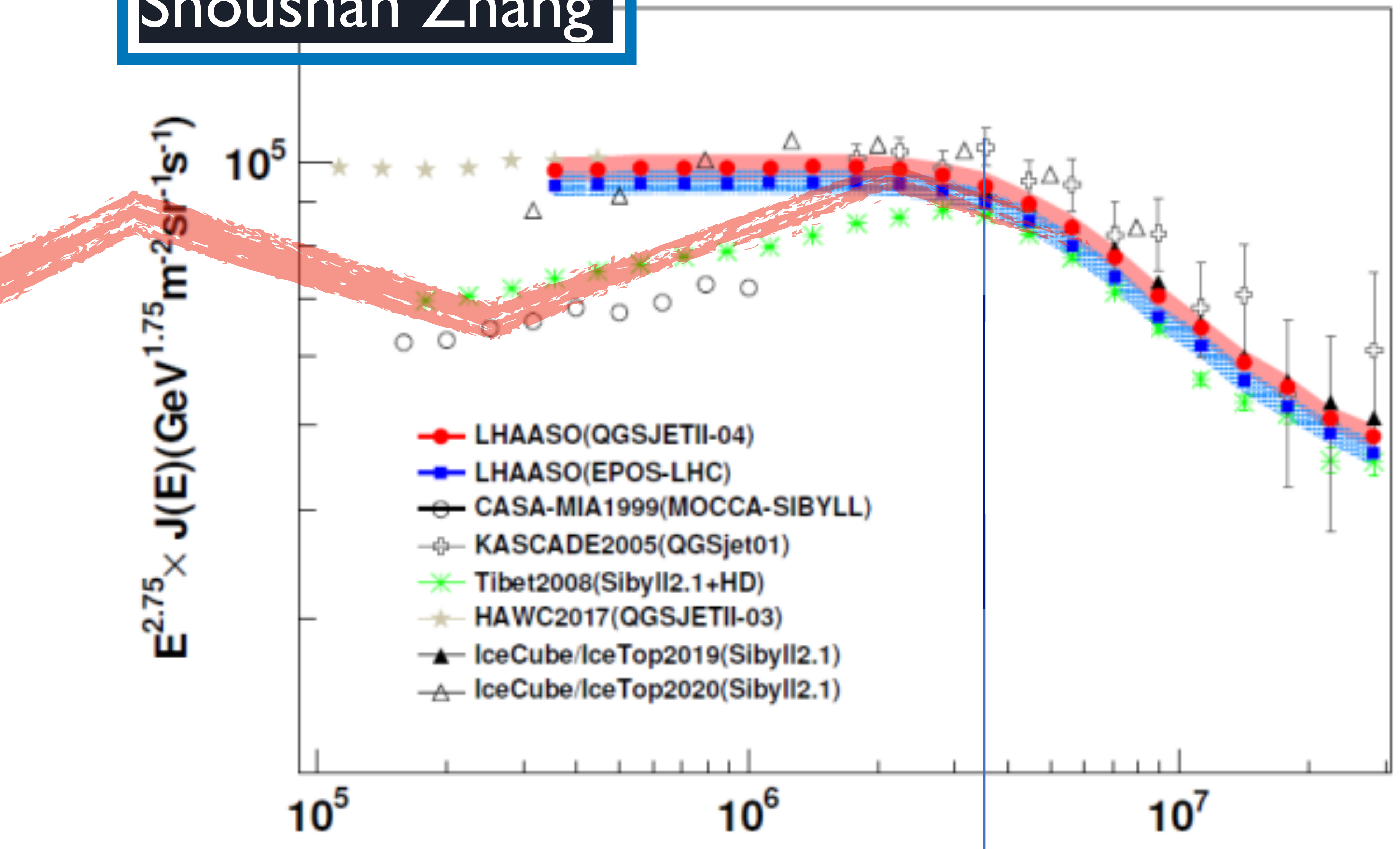

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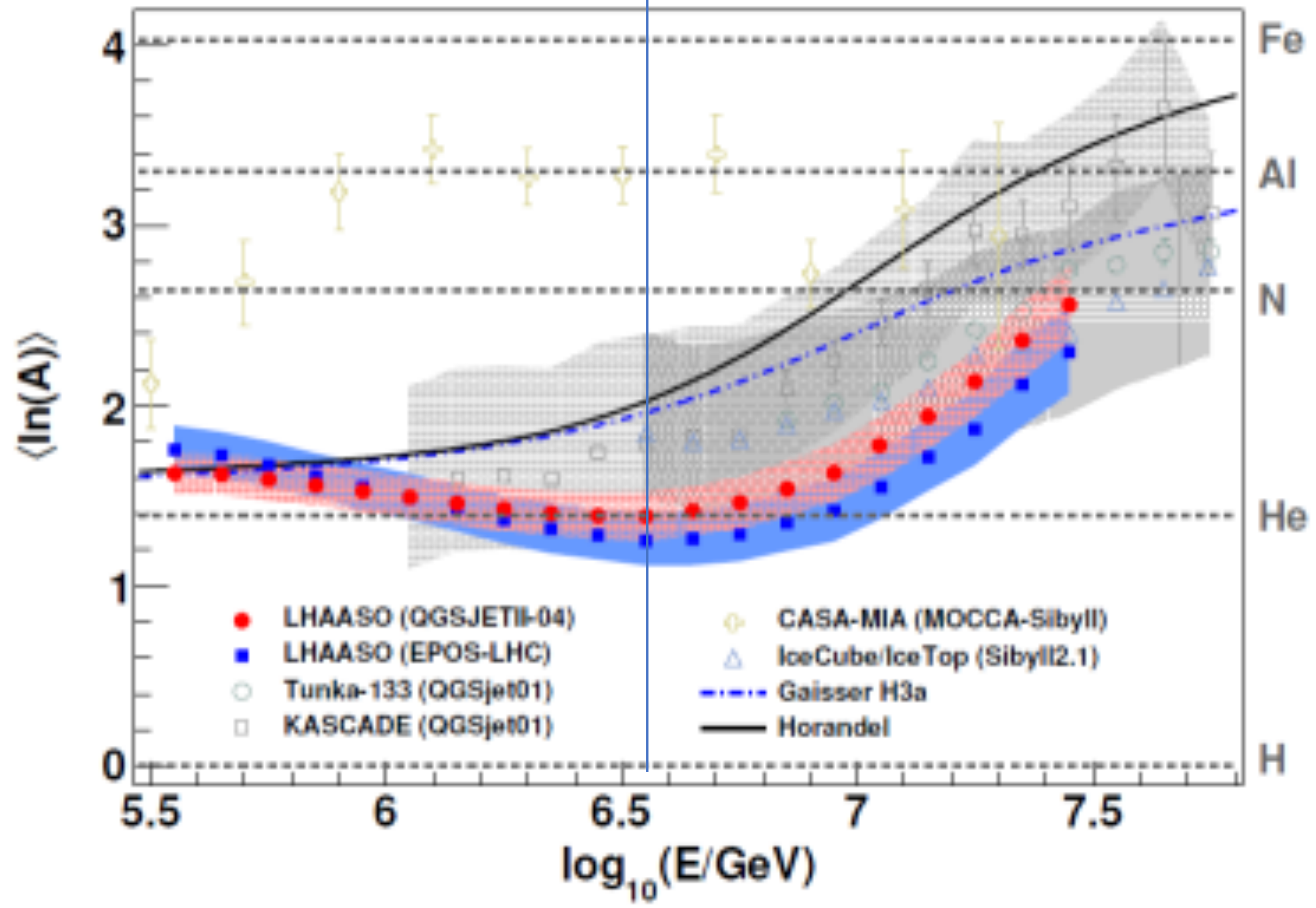

Energy spectra for individual mass groups expected within the next 3 years!

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LHAASO should become member of WHISP - WG

ALPACA: under construction in Bolivia

ALPAQUITA full operation April 2023 …. Mega-ALPACA

Marcos Anzorena

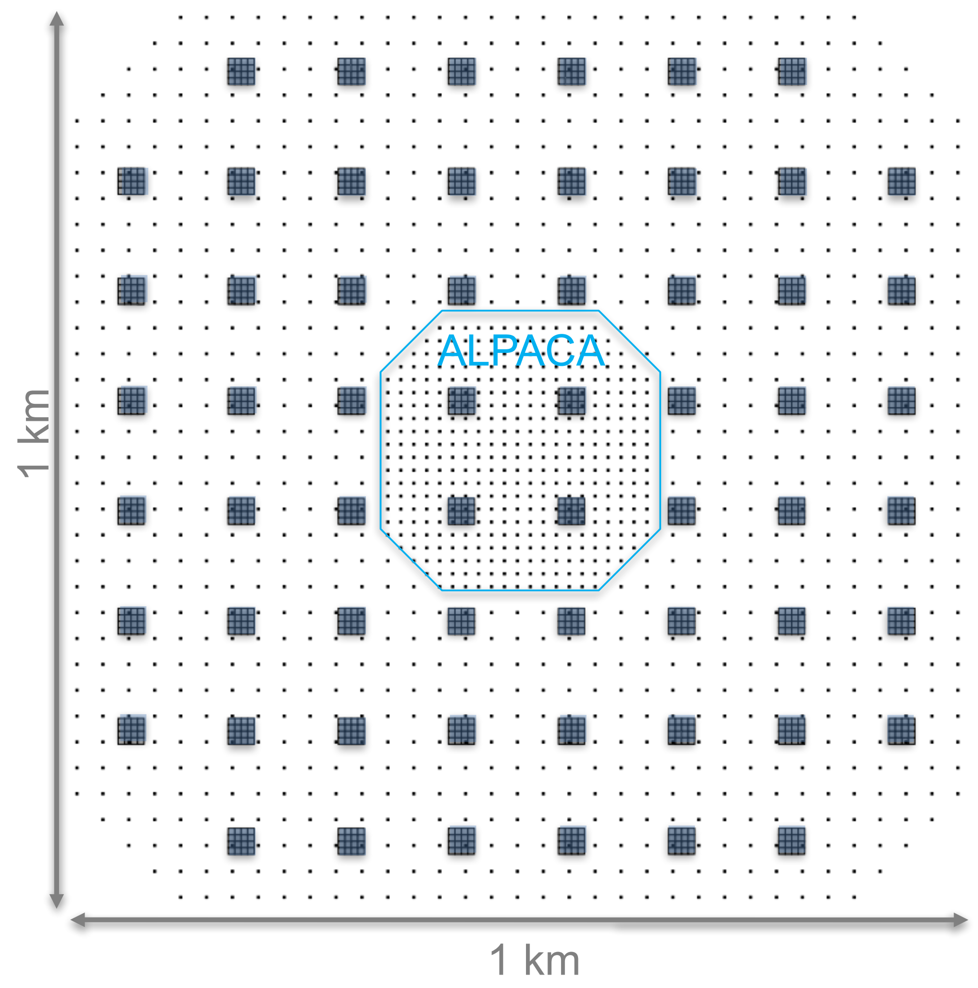
1 km² Array + MD

30 m spacing AS array
Area 1,011,600 m²
# of det. 1185

15 m spacing AS array
Area 82,800 m²
# of det. 313
(Additional to 15 m spacing)

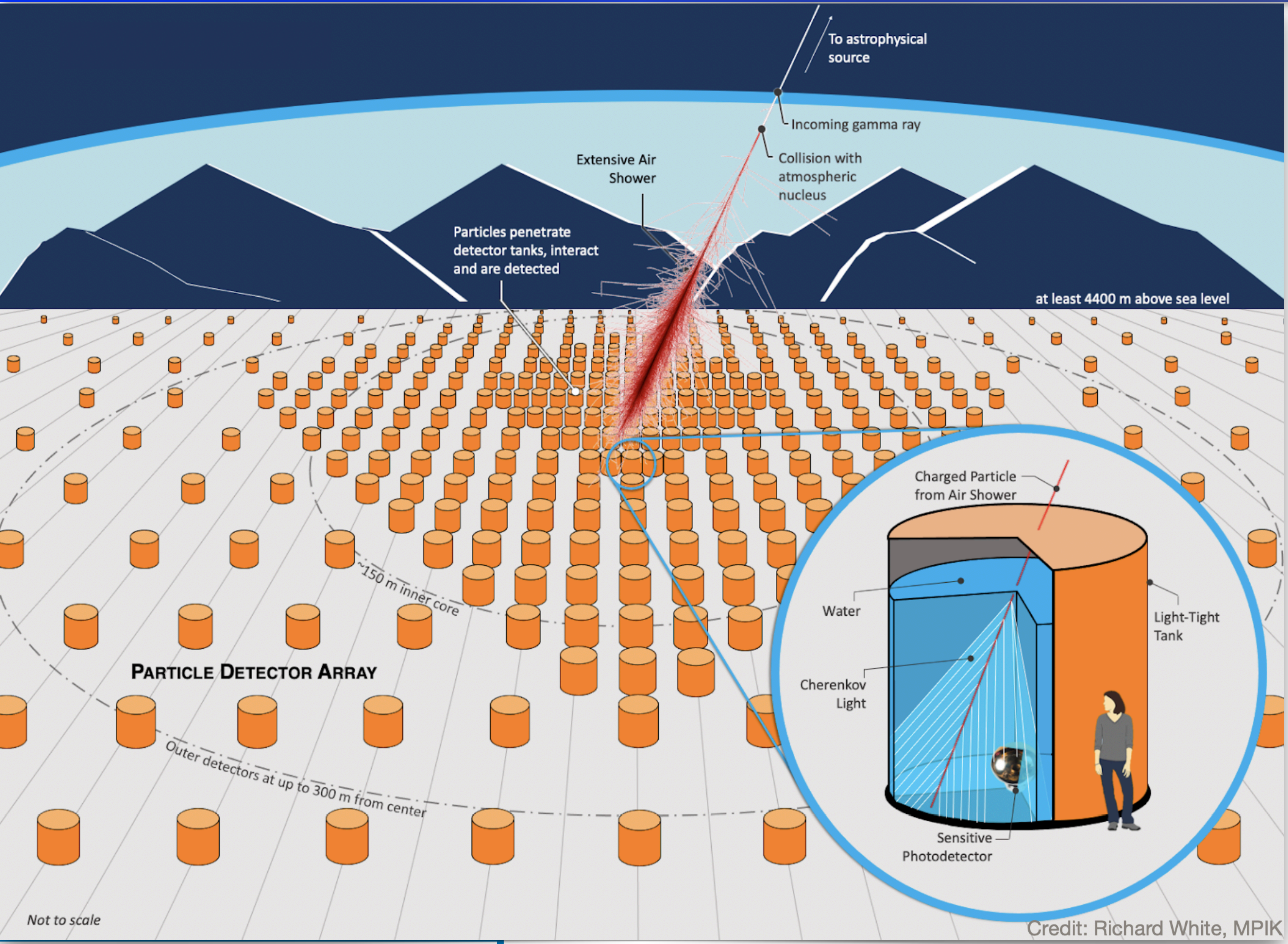
# of total det. 1185 + 313 = 1498

Muon Detector (MD) Array
900 m² (16 Cells) x 60
= 54,000 m²
# of cells 960



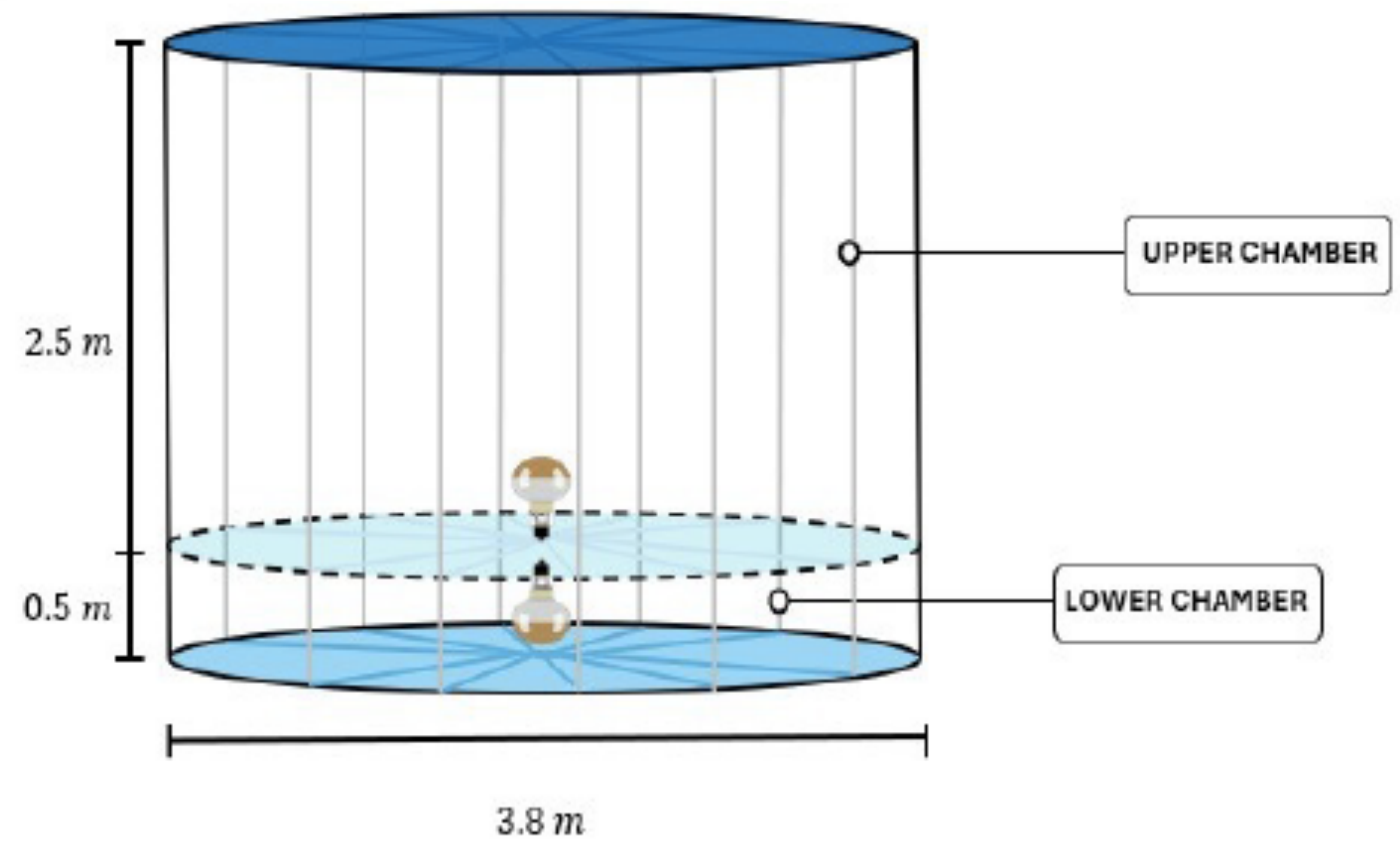
Optimized for gamma-detection but potentially also capabilities as CR-EAS detector

SWGO: to be constructed in South America



Karen Salomé Caballero Mora

Double layer WCD

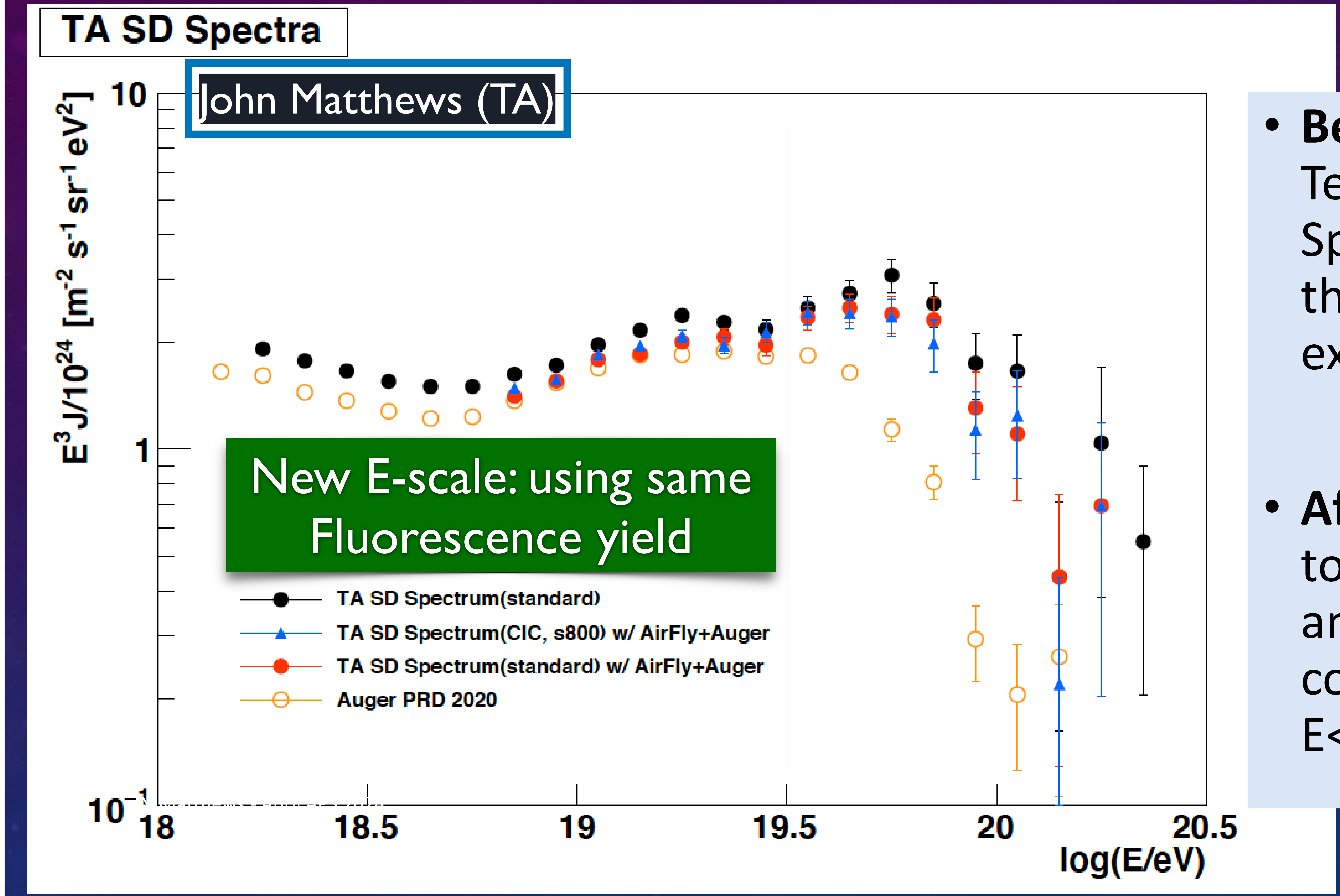


Like LHAASO and ALPACA, optimised for gammas, but CRs will be detected as well.

Site in SA to be chosen next month

Towards the highest energies

TELESCOPE ARRAY WITH AIRFLY YIELD & AUGER MISSING ENERGY



- **Before**: difference between Telescope Array and Auger Spectra was ~9%, well within the uncertainty of either experiment
- **After** modifying Telescope Array to use AirFly fluorescence yield and Auger missing energy correction, agree ~1%, for E<10^19.5 eV

8

Towards the highest energies

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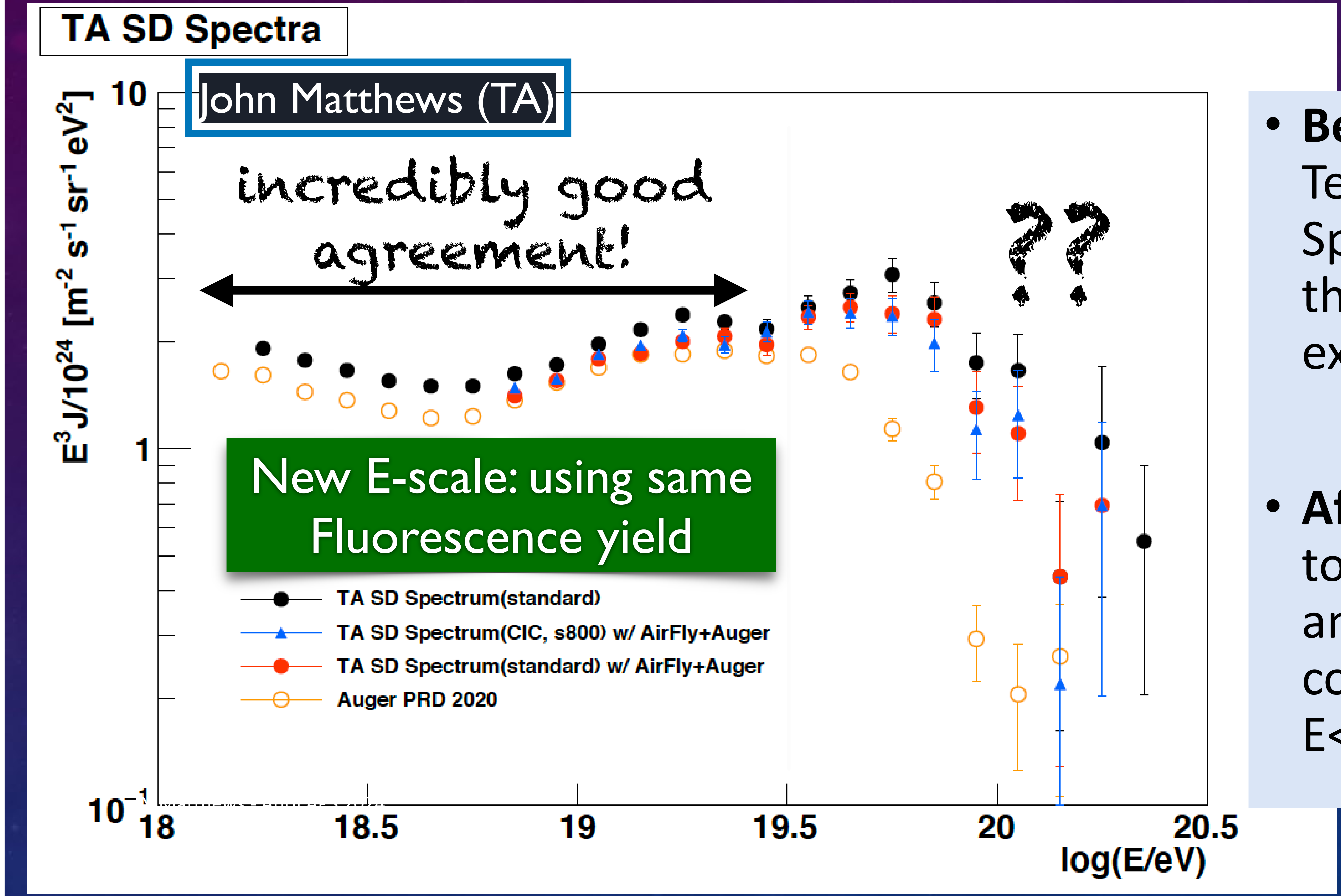

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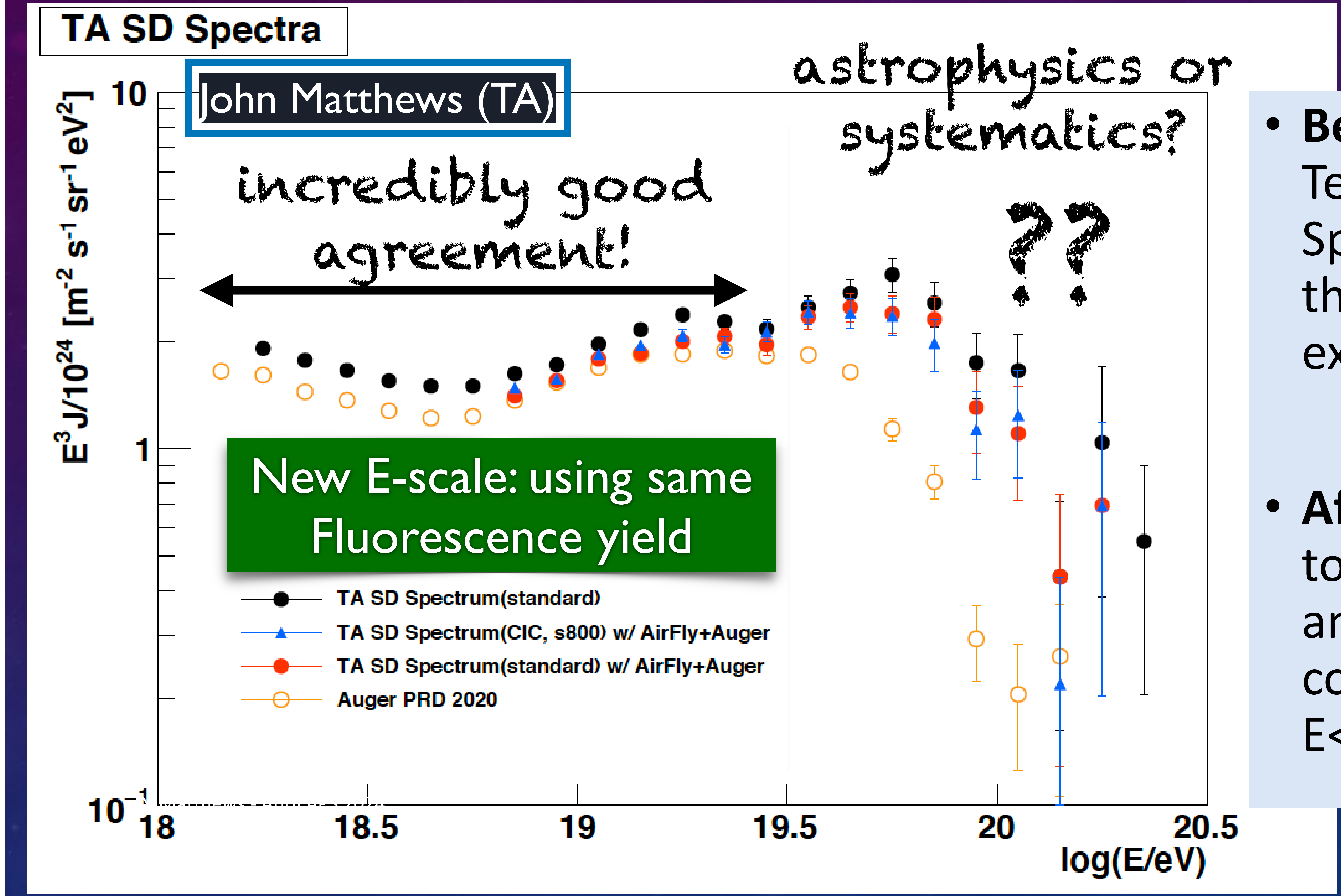

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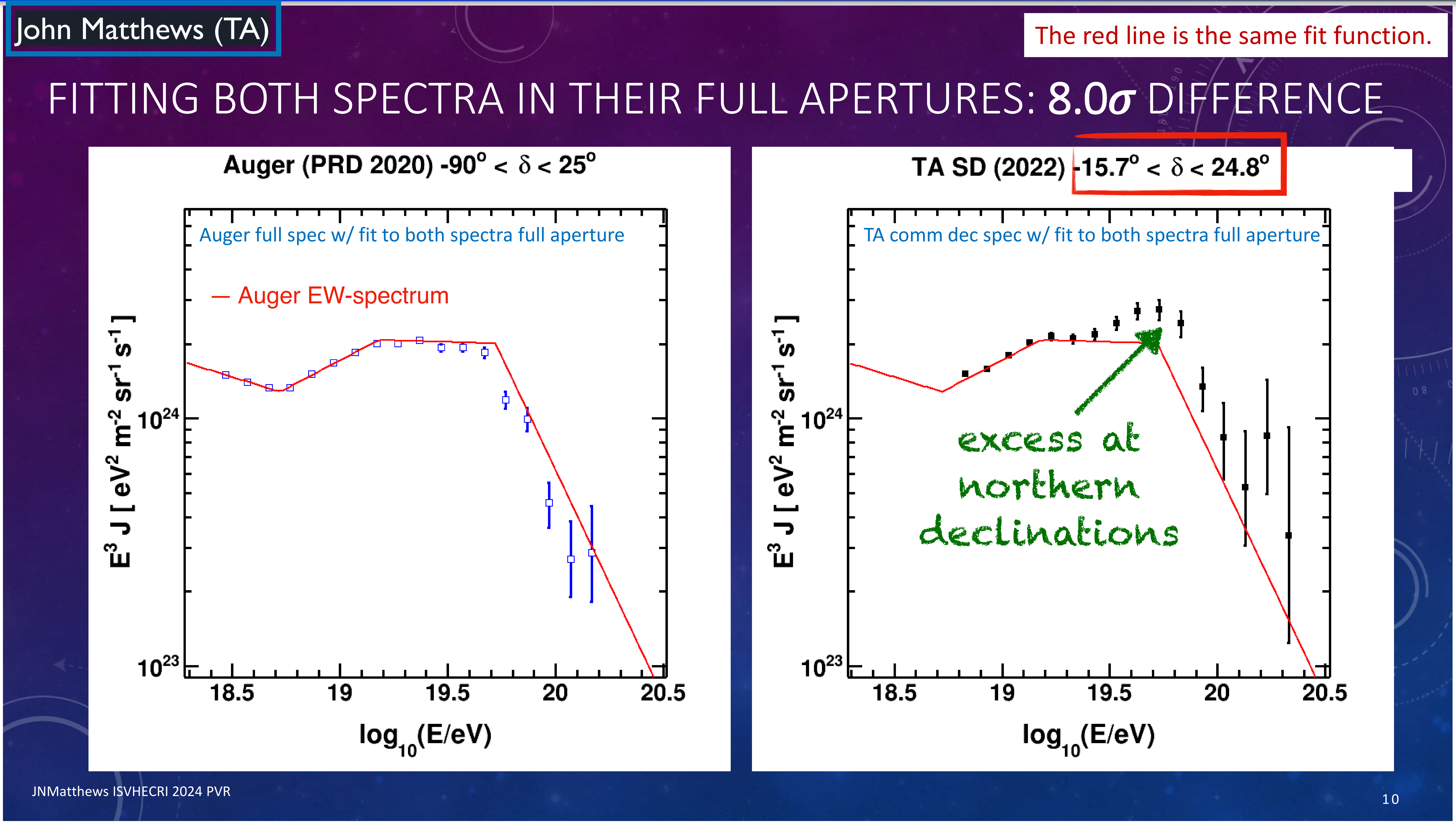
8

TA Flux Excess…

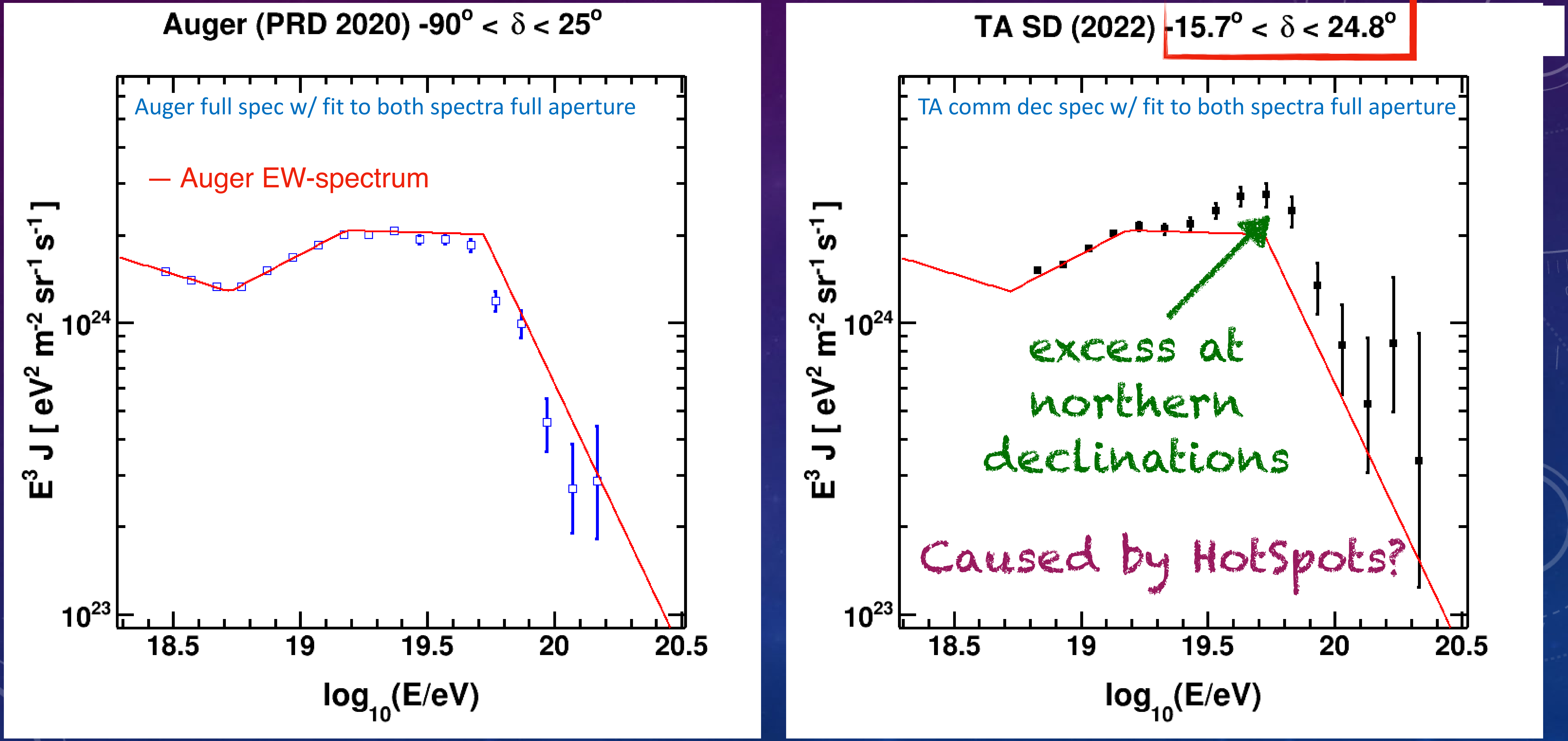


TA Flux Excess…

John Matthews (TA)

The red line is the same fit function.

FITTING BOTH SPECTRA IN THEIR FULL APERTURES: 8.0σ DIFFERENCE



JNMatthews ISVHECRI 2024 PVR

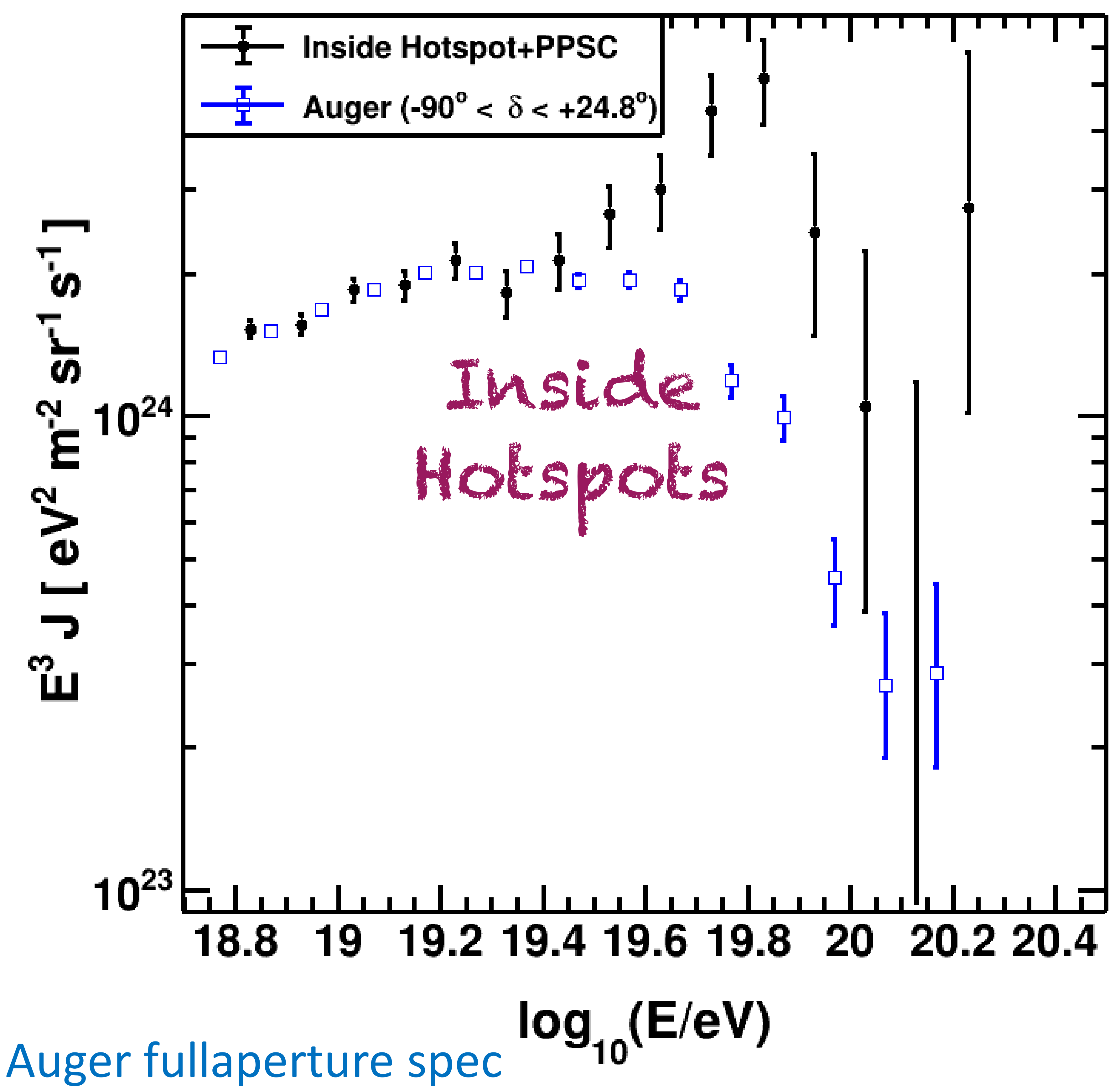
10

TA Flux Excess...: stronger in hot spot regions

John Matthews (TA)

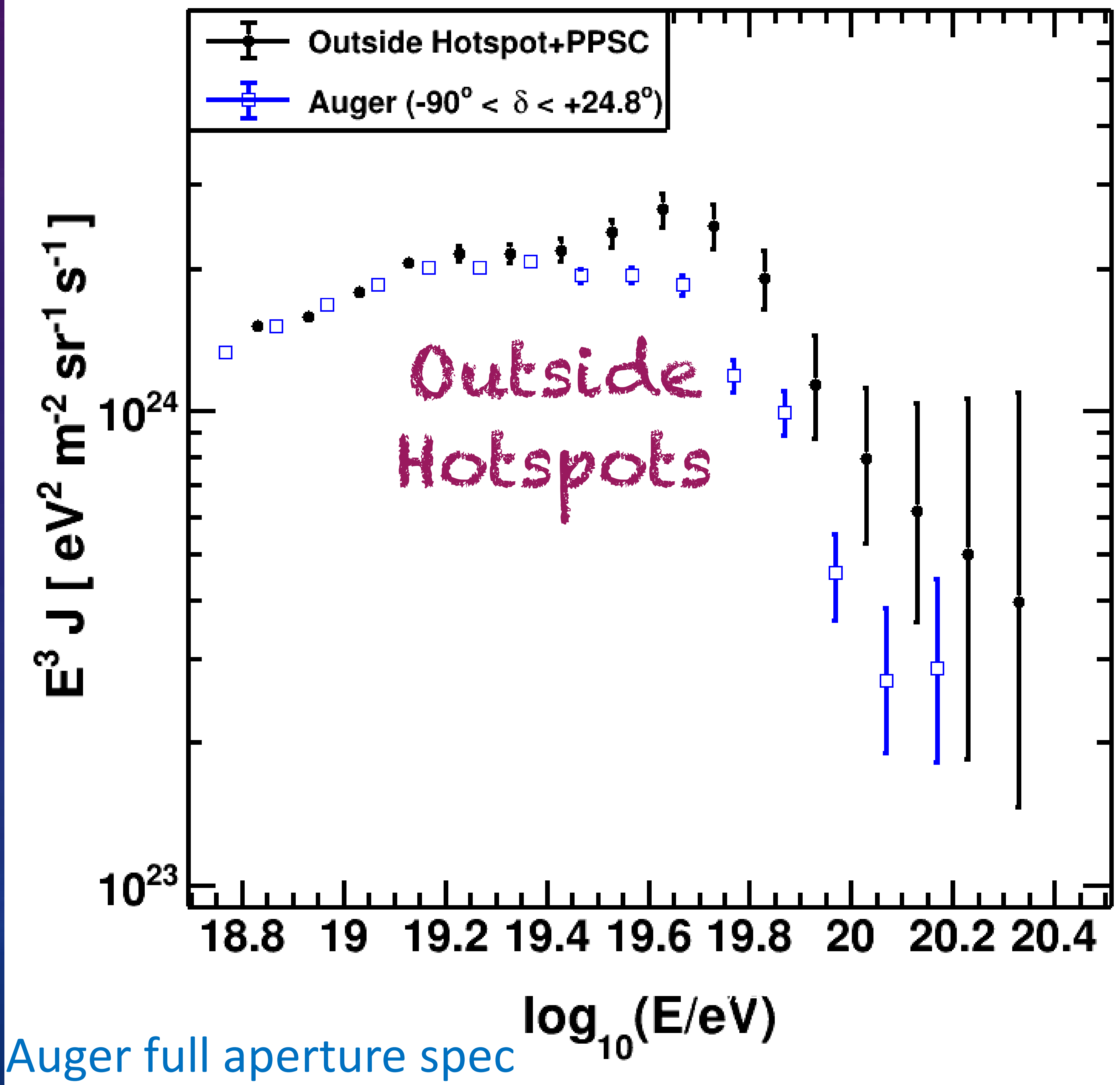
TA INSIDE/OUTSIDE HOTSPOT+PPSC

Telescope Array INSIDE the Excesses



Auger fullaperture spec

Telescope Array OUTSIDE the Excesses



Auger full aperture spec

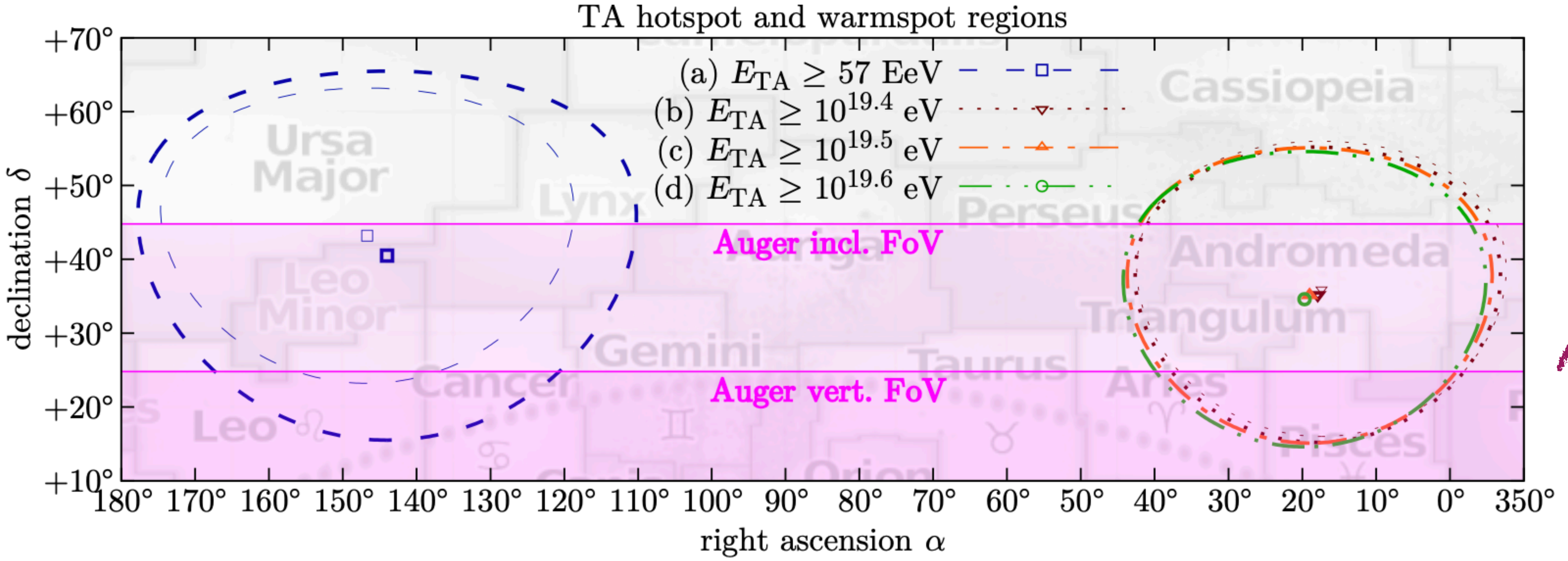
JNMatthews ISVHECRI 2024 PVR

2024-04-08 14

Auger does not confirm this observation

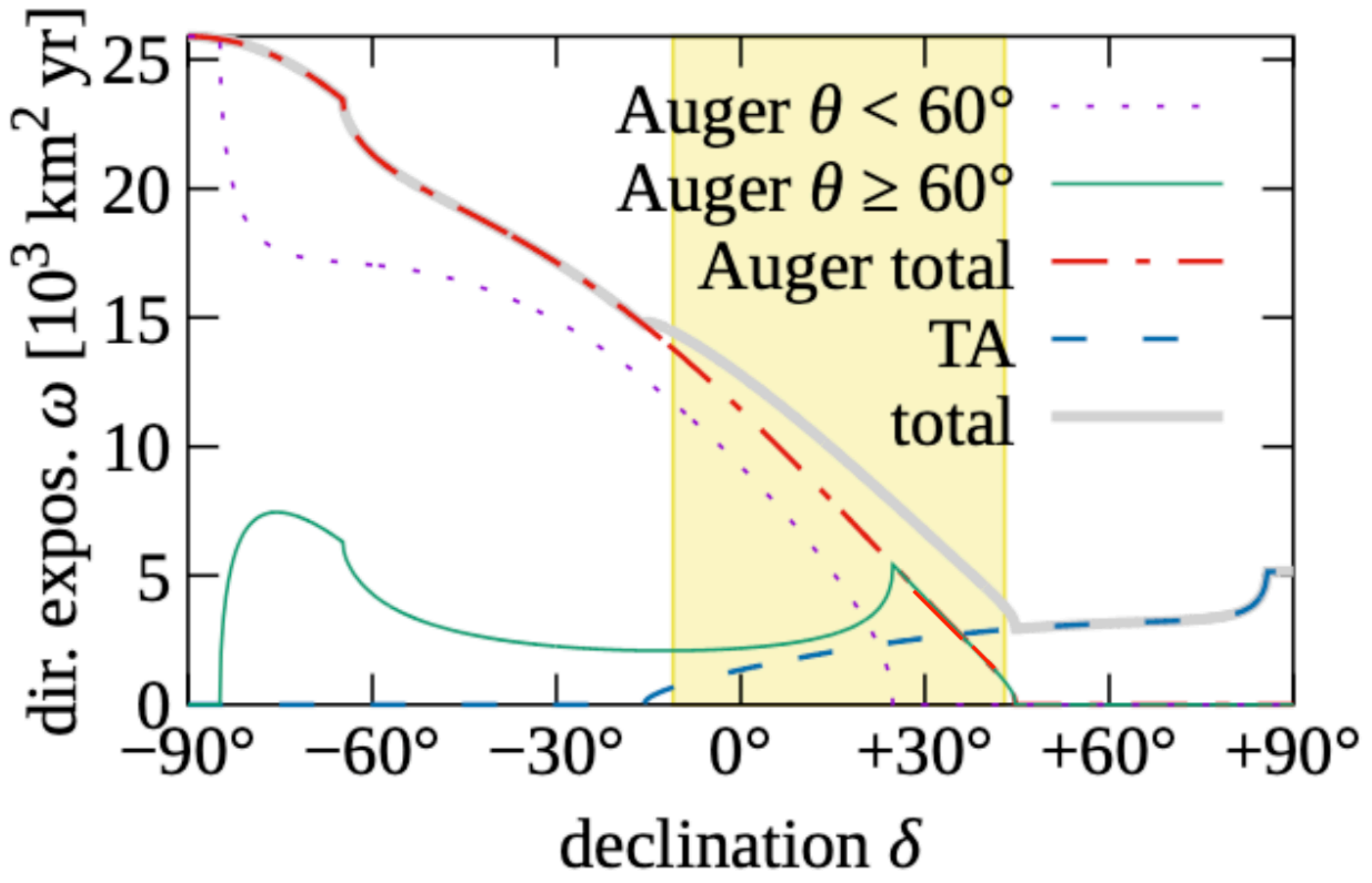
Antonella Castellina (Auger)

Using vertical+inclined events we have partial coverage of the Northern sky



TA

Auger



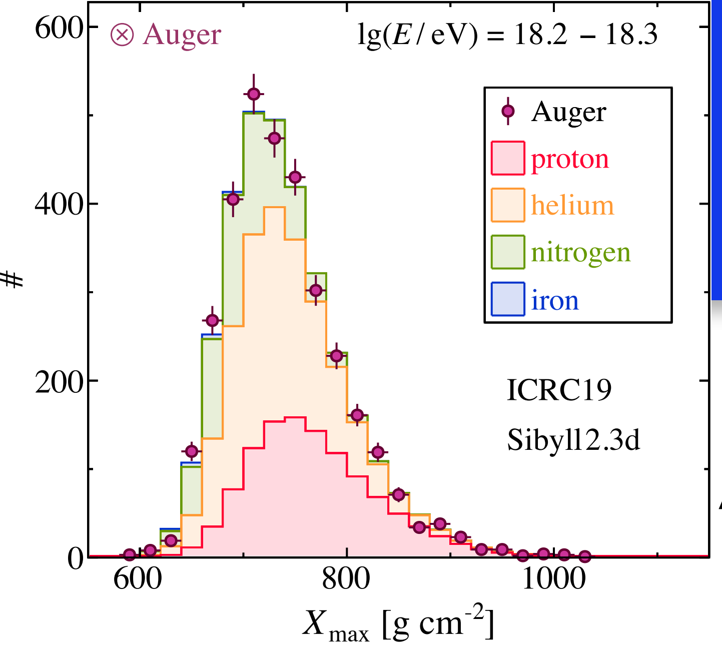
G.Golup, PoS(ICRC2023) 252
Auger Coll., subm.ApJ

	(α_0, δ_0) [°]	E^{TA}	N^{TA}_{obs}	N^{TA}_{exp}	σ^{TA}_{post}	E^{Auger}	N^{Auger}_{obs}	N^{Auger}_{exp}	σ^{Auger}_{Li-Ma}
PPSC	(17.4, 36.0)	25.1	95	61.4	3.1σ	20.1	68	69.3	-0.2σ
	(19.0, 35.1)	31.6	66	39.1	3.2σ	25.3	40	45.2	-0.8σ
	(19.7, 34.6)	39.8	43	23.2	3.0σ	31.8	27	26.5	0.1σ
TA hot spot	(144.0, 40.5)	57	44	16.9	3.2σ	45.6	7	10.1	-1.0σ

3σ-excesses in TA HotSpots not confirmed by Auger; may dissolve with more data

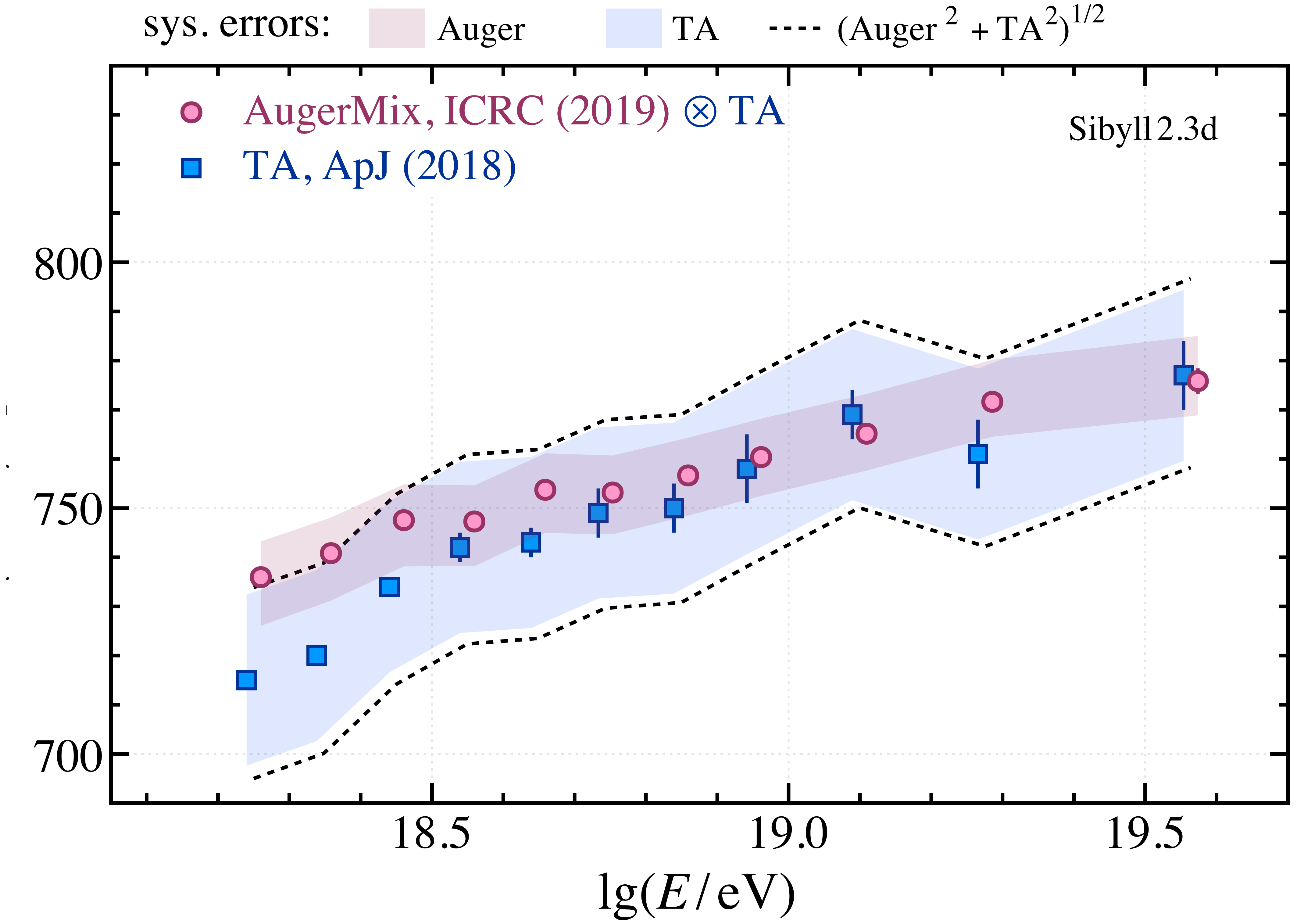
➡️confirmation of the Centaurus region as most significant excess (4.0σ post-trial), extended to lower energies (20 EeV)

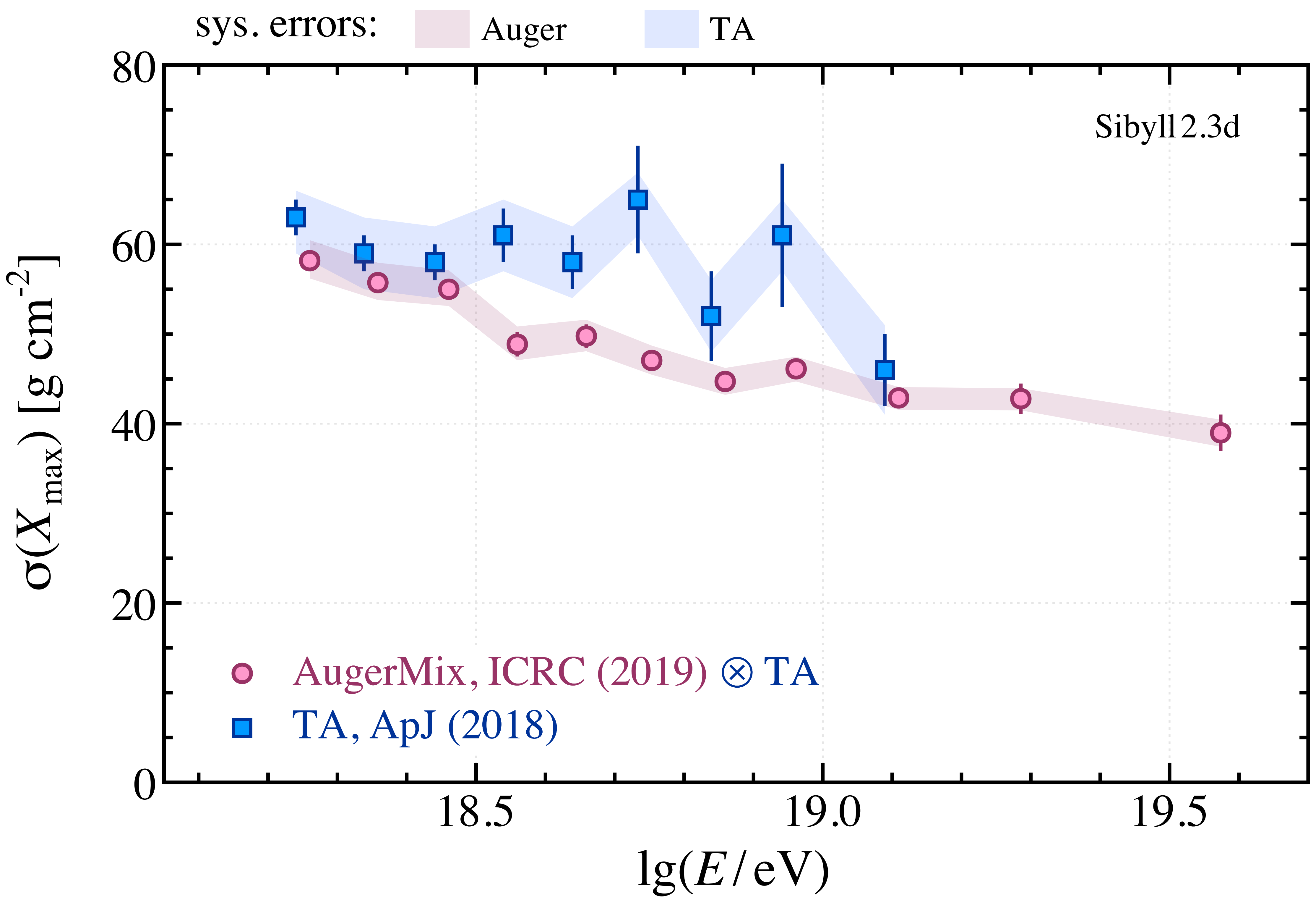
➡️no hints for excesses in the TA “spots” with data of comparable size —> at variance with the claim of TA that the declination dependence of the UHECR energy spectrum is due to the presence of excesses in particular regions of the Northern sky



UHECR Composition: TA-Auger WG

Auger mass templates simulated through TA acceptance and compared to TA





Composition of TA compatible with Auger-Mix up to $10^{19.5}$ eV

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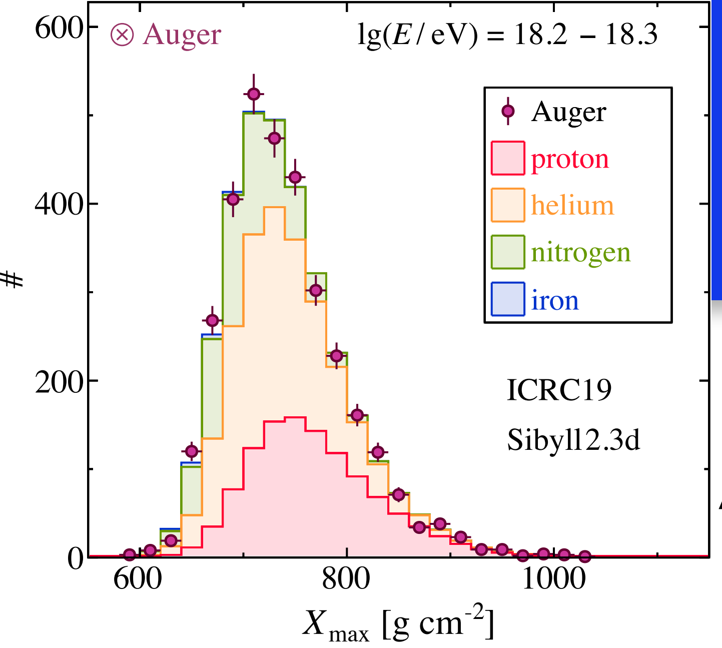

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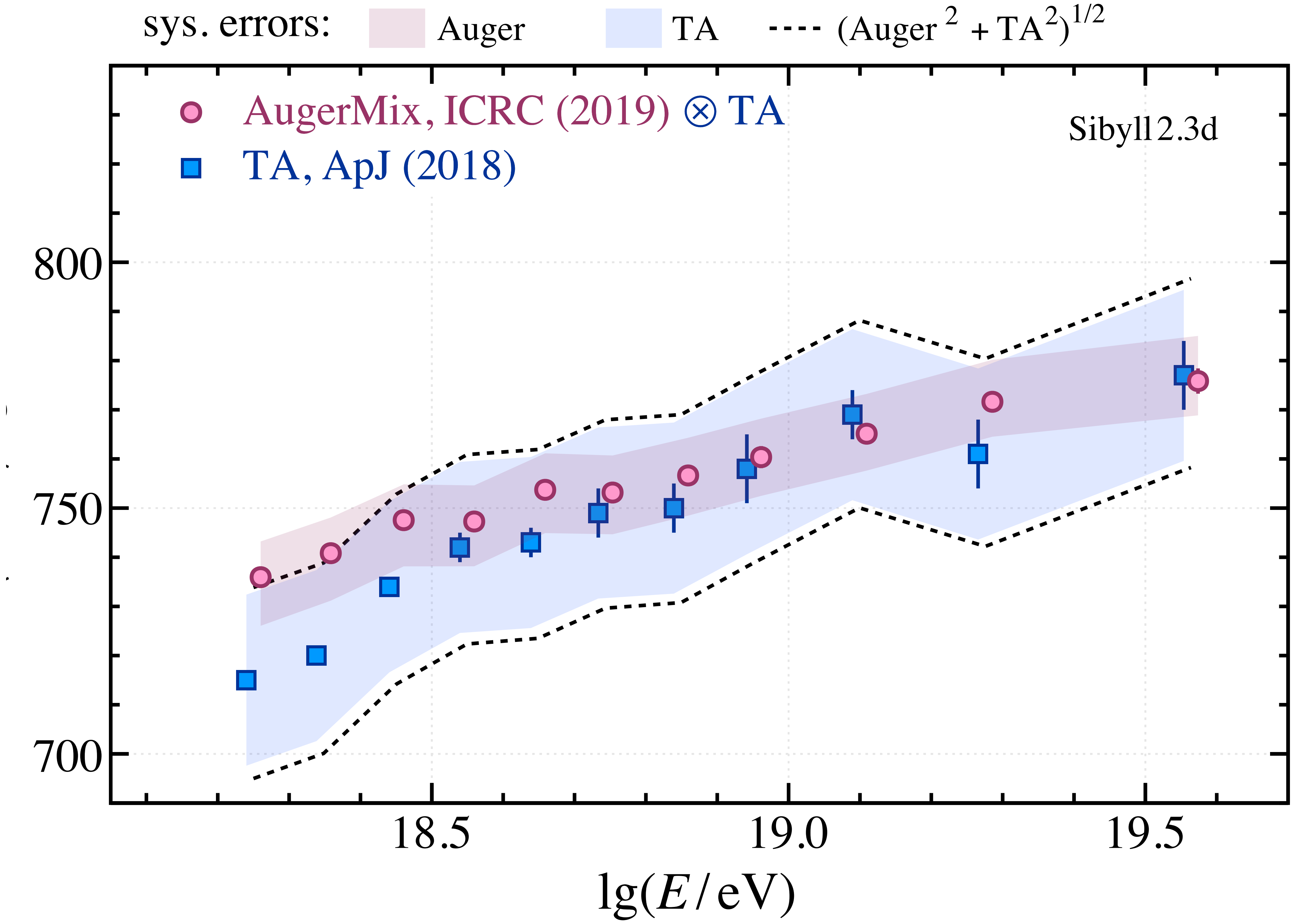

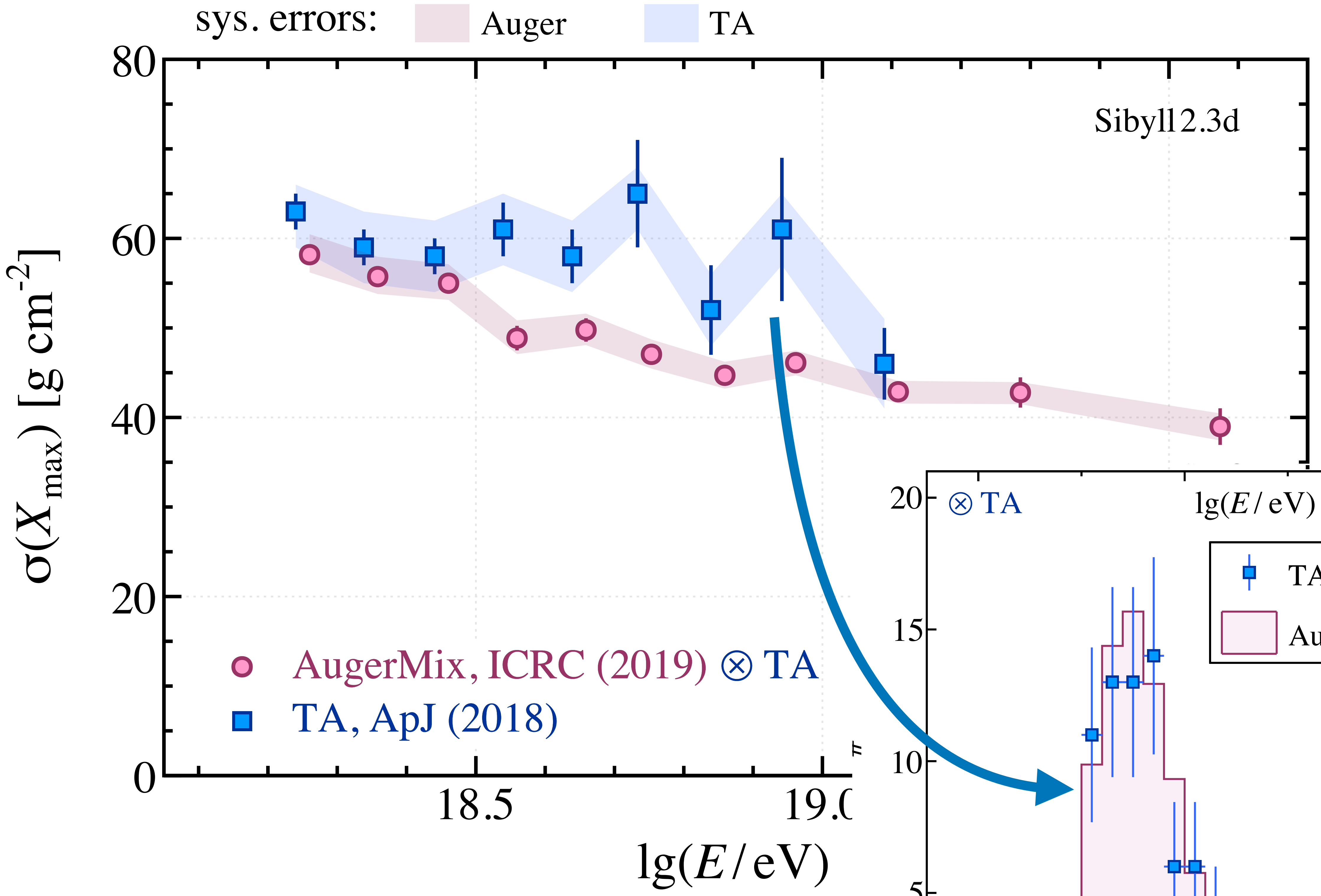

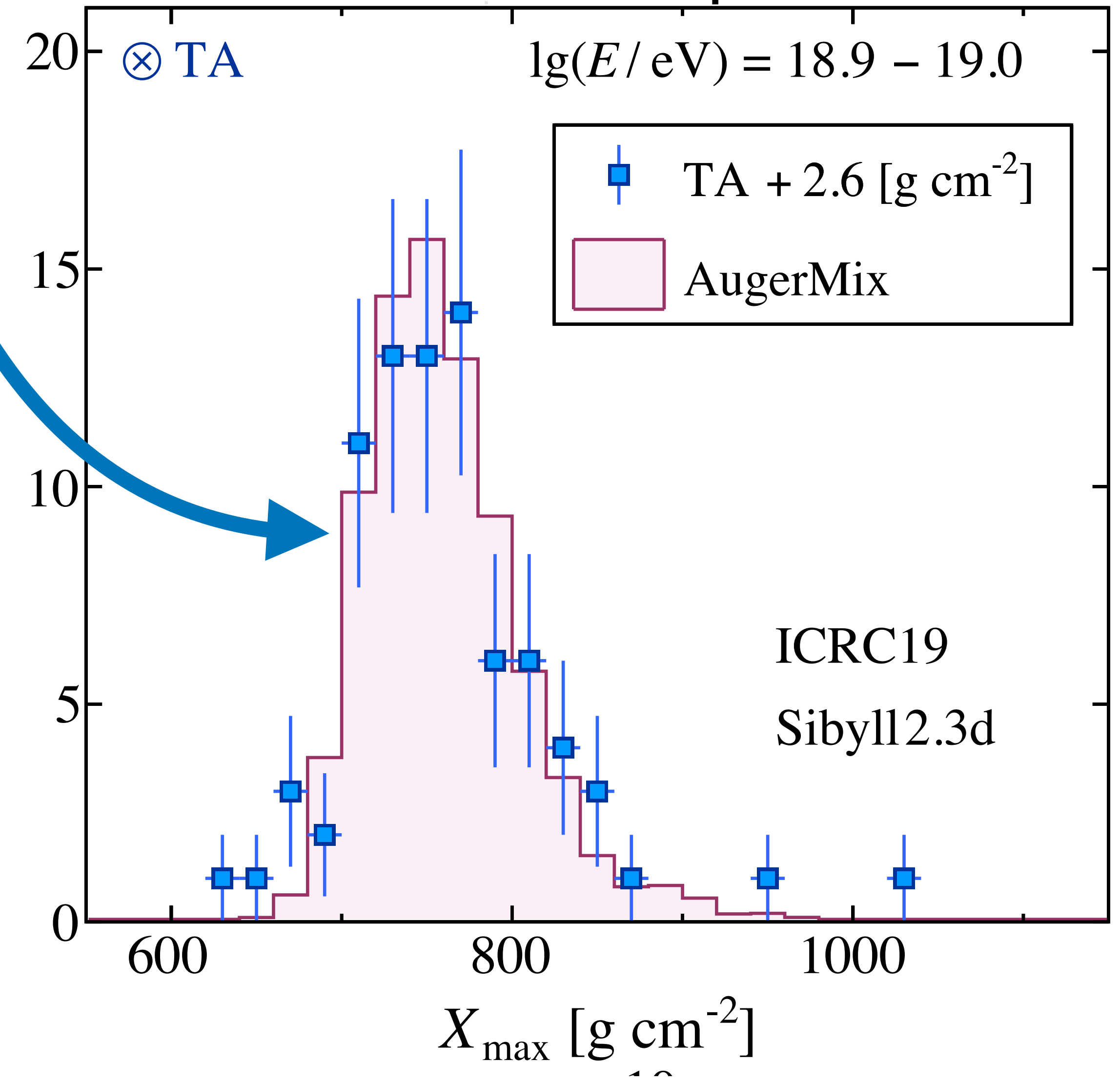

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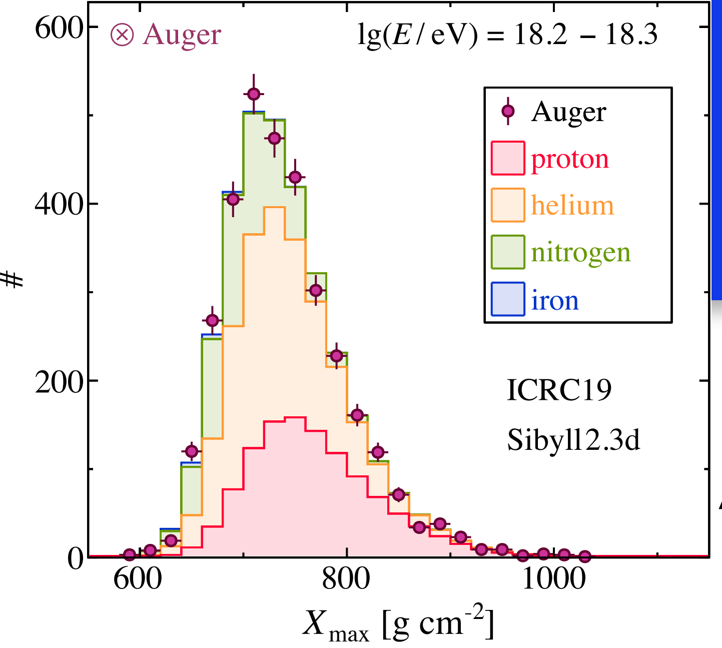

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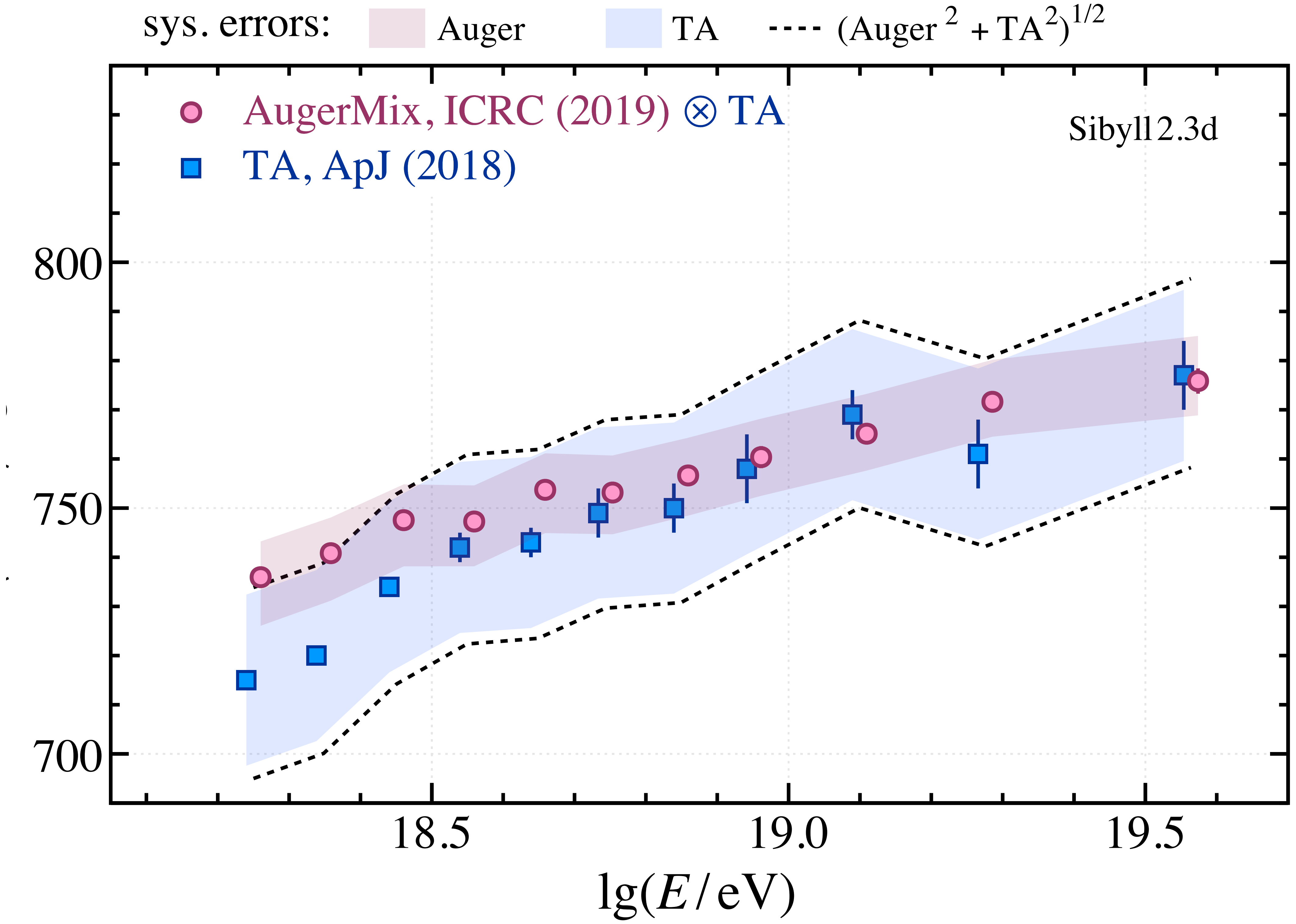
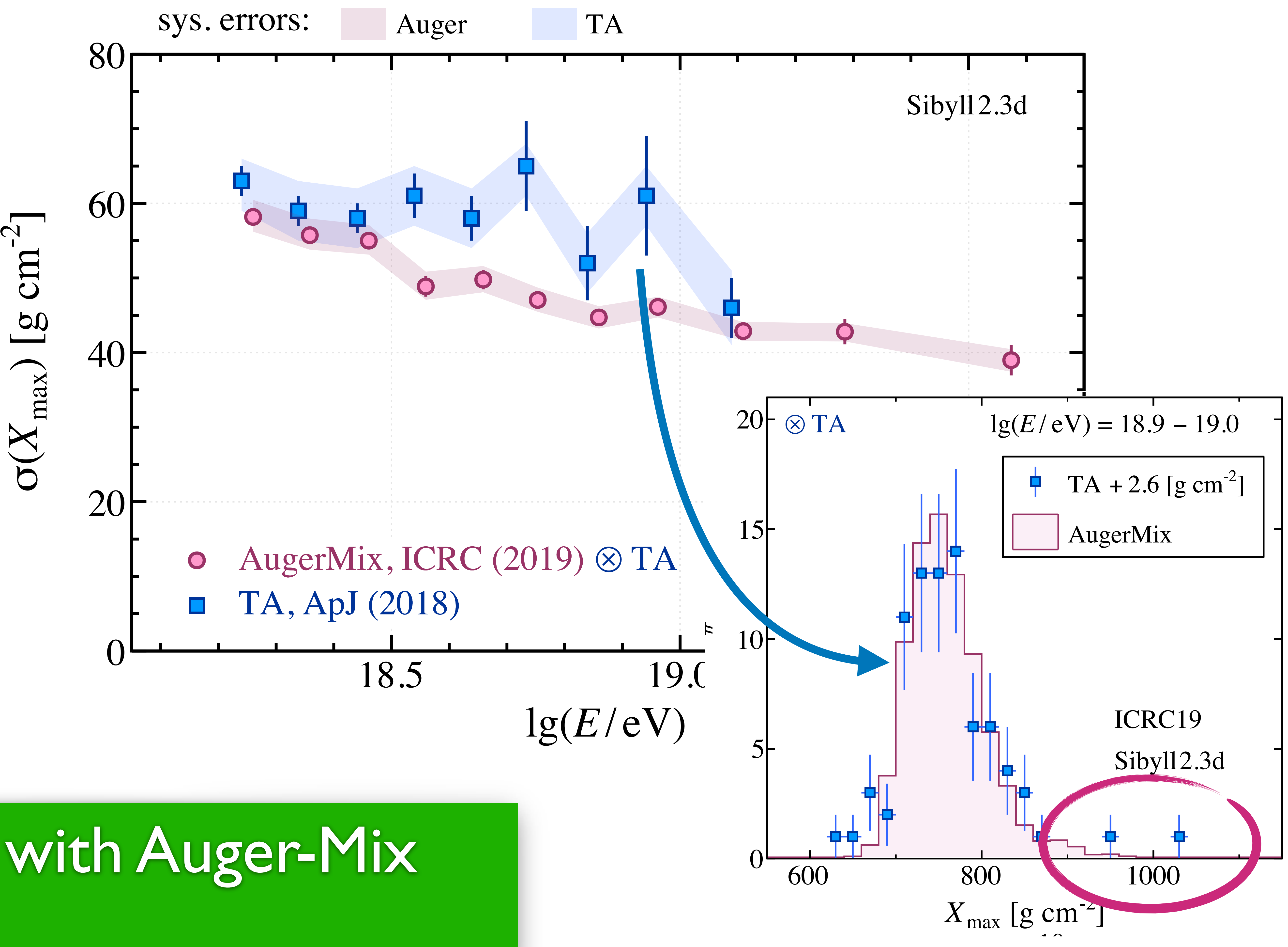




Composition of TA compatible with Auger-Mix up to $10^{19.5}$ eV

Muon Measurements and tests of interaction models in EAS

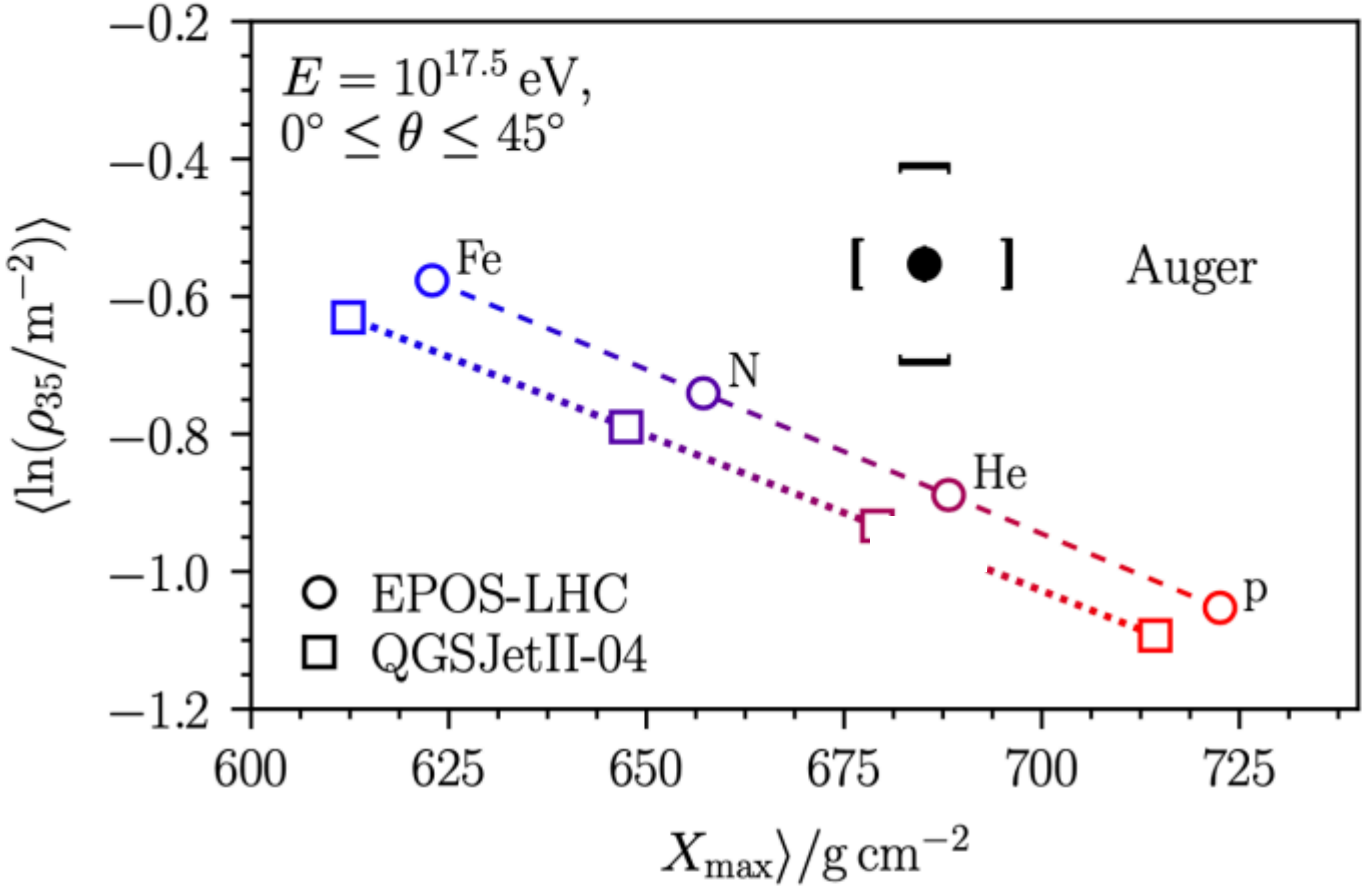
IceCube/IceTop (Plum, Verpoest), Auger (Cheminan, Tkachenko, Conceicao, Kampert), KASCADE-Grande (Arteaga-Velazquez), CALET (Akaike), Borisov, WHISP (Arteaga-Velazquez, Soldin), Guiseppe di Sciascio

Pierre Auger Observatory

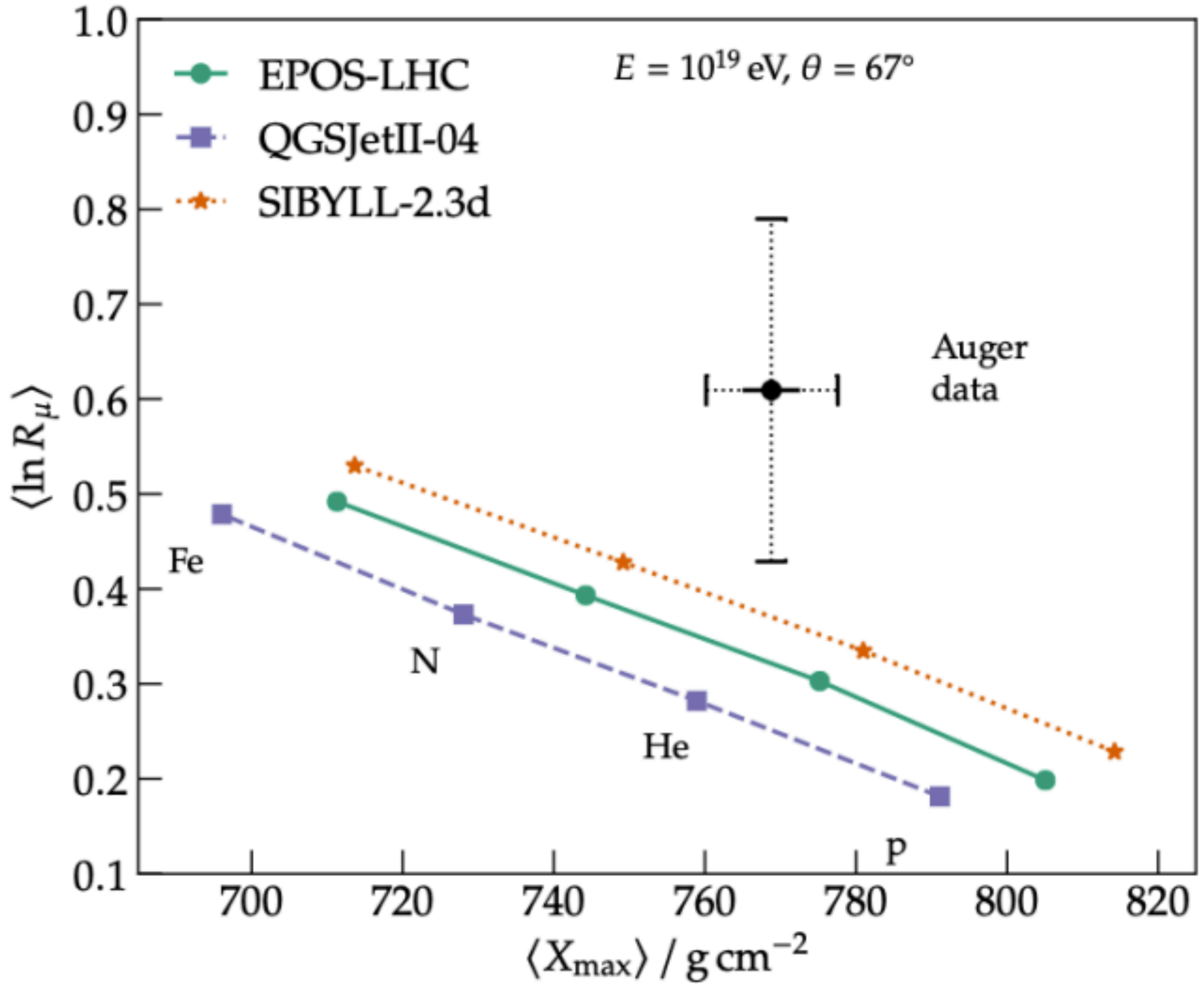
Talks by R. Conceição and A. Castellina

Multi Hybrid observations

Buried Scintillators + FD



SD inclined + FD



Slide from D. Soldin (Discussion Session)

μ-Puzzle

see also: Kevin Almeida Cheminant

→ top down reco to quantify μ-deficit

Pierre Auger Observatory

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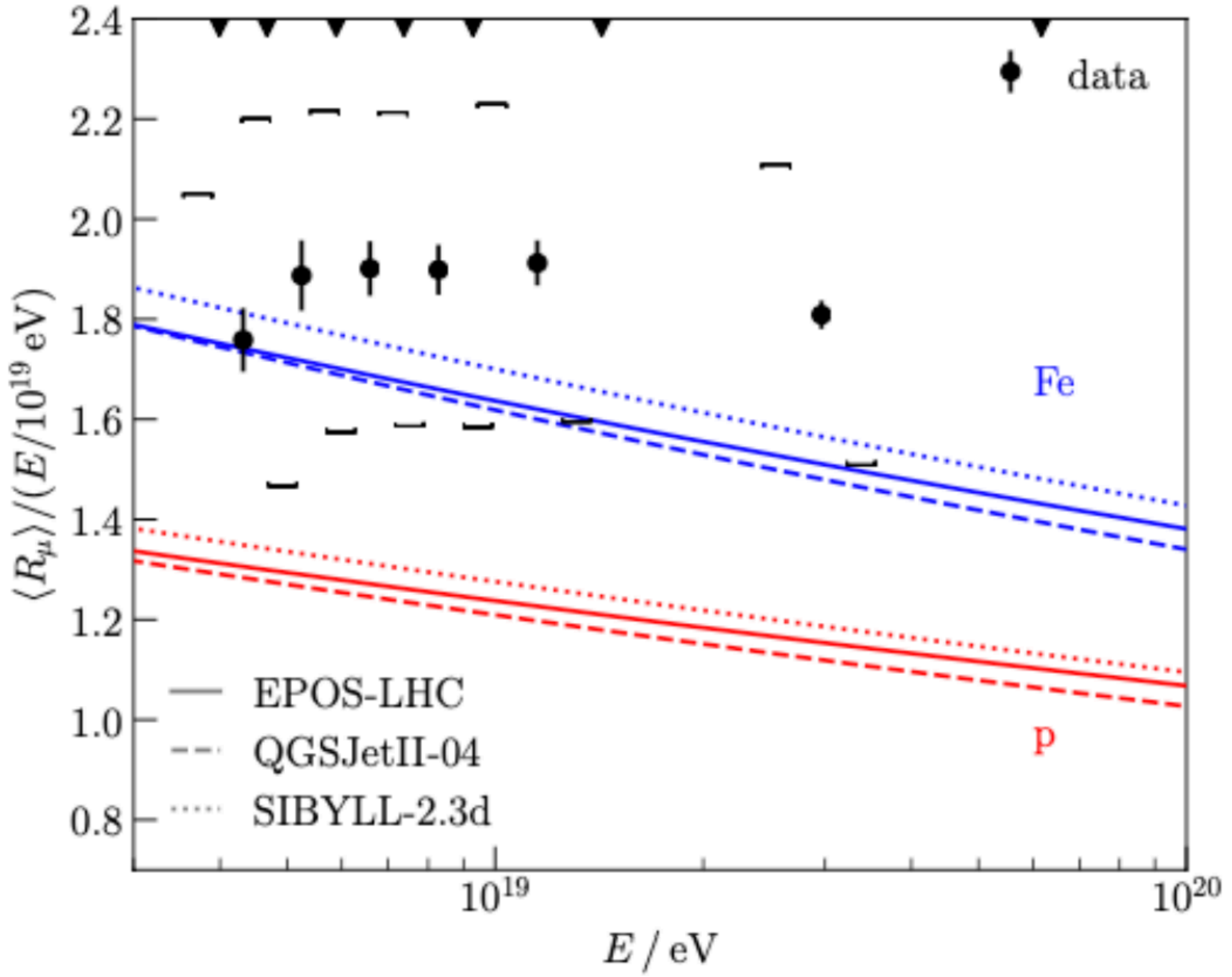
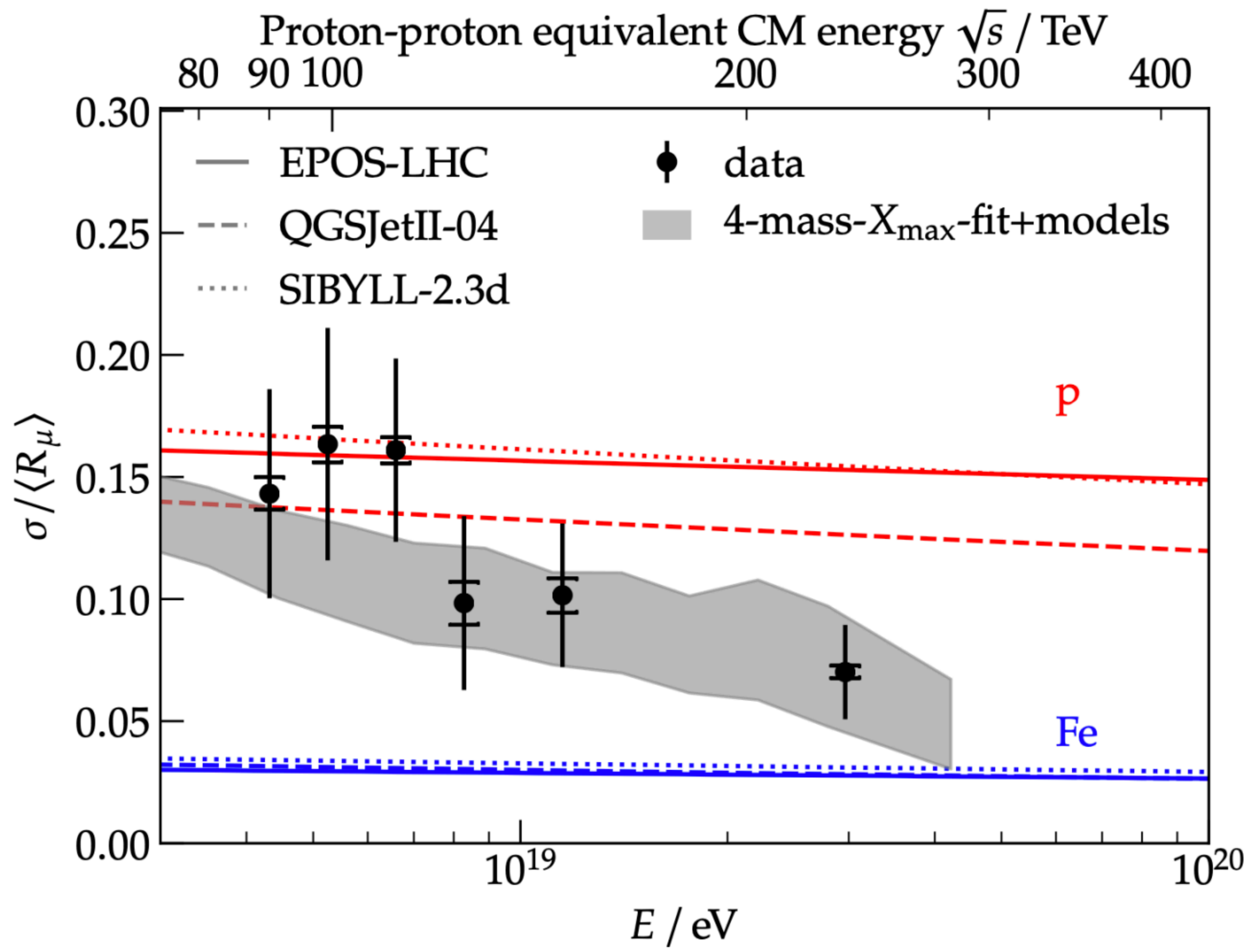
Multi Hybrid observations

Underground Muon Detector



Muon Fluctuations



μ-number too low, μ-fluctuations ok

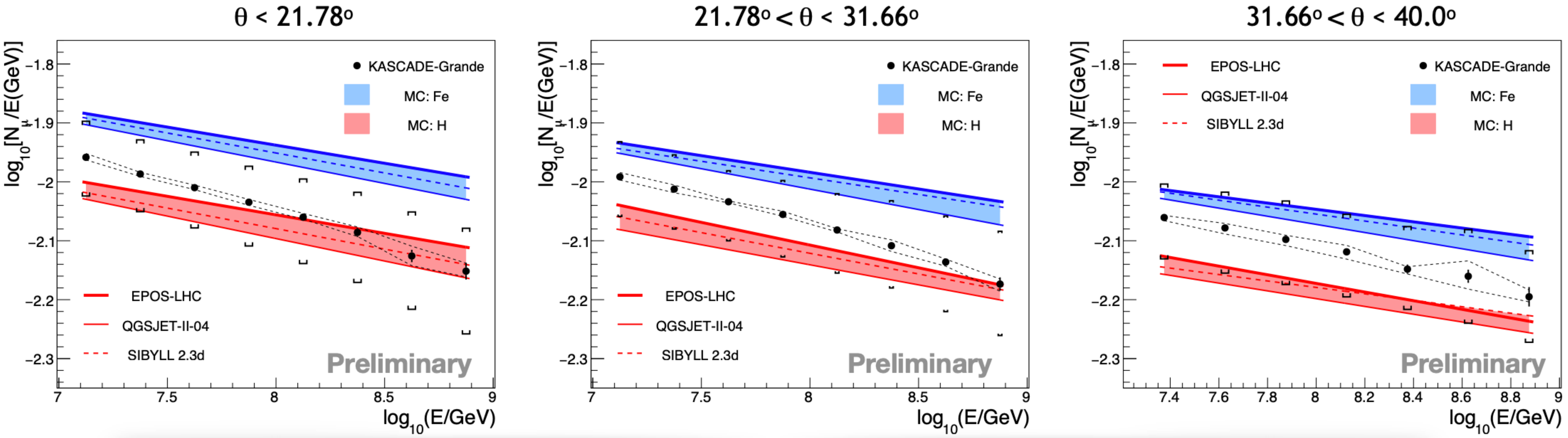
Indicates that muon puzzle is related with description of low-energy interactions

Slide from D. Soldin (Discussion Session)

KASCADE-Grande

Talk by J. C. Arteaga-Velázquez

Zenith angle dependent μ-number



zenith angle dependence of μ-number only poorly described

- Attenuation of μ's smaller in data than in MC;
- Likewise: μ-energy spectra data/MC differ
- Caveat: E-scale itself depends on N_μ!

IceCube Neutrino Observatory

Talk by S. Verpoest

Comparing μ-Number at ground and at E>500 GeV

$$z = \frac{\ln(N_\mu) - \ln(N_{\mu,\mathrm{p}})}{\ln(N_{\mu,\mathrm{Fe}}) - \ln(N_{\mu,\mathrm{p}})}$$

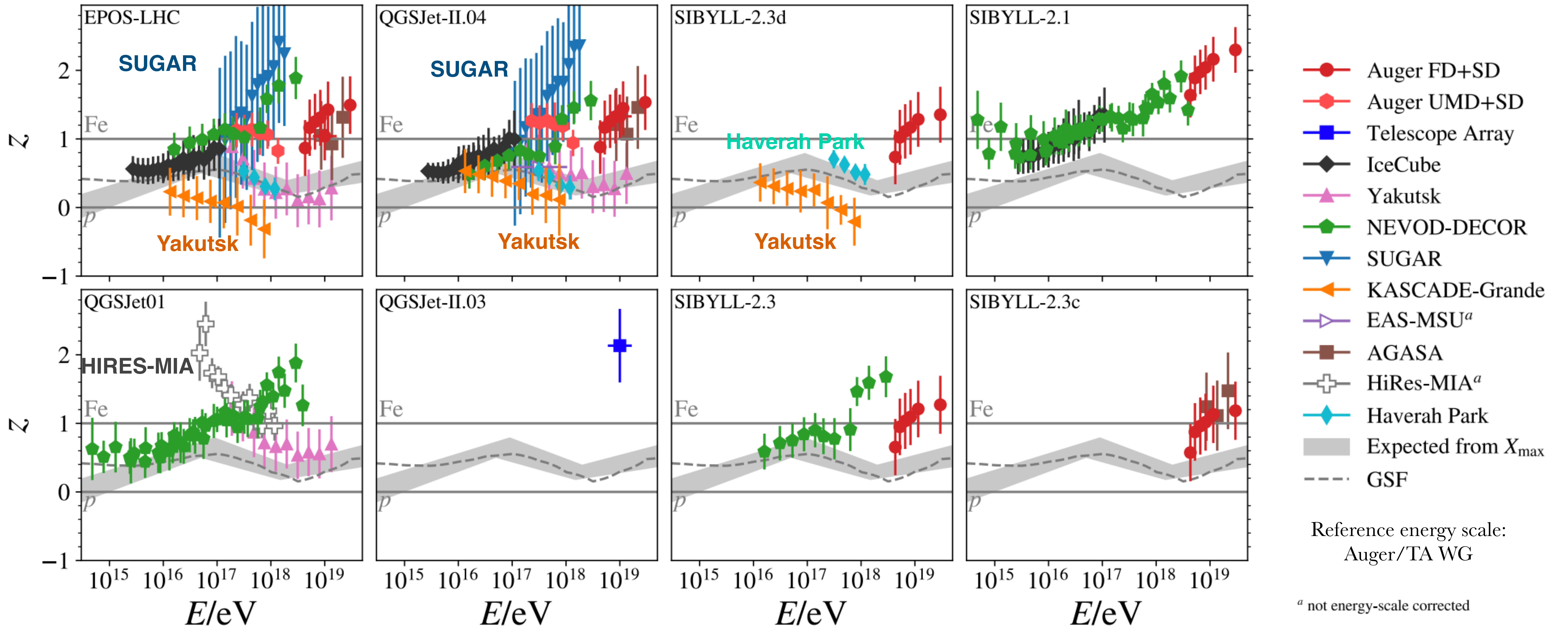
Overall: HE μ's better described than μ's at ground
Sibyll 2.1 does fine, tough

WHISP

Talk by J. C. Arteaga-Velázquez

Global muon data comparison after energy cross calibration

$$z = \frac{\ln(N_\mu) - \ln(N_{\mu,\mathrm{p}})}{\ln(N_{\mu,\mathrm{Fe}}) - \ln(N_{\mu,\mathrm{p}})}$$



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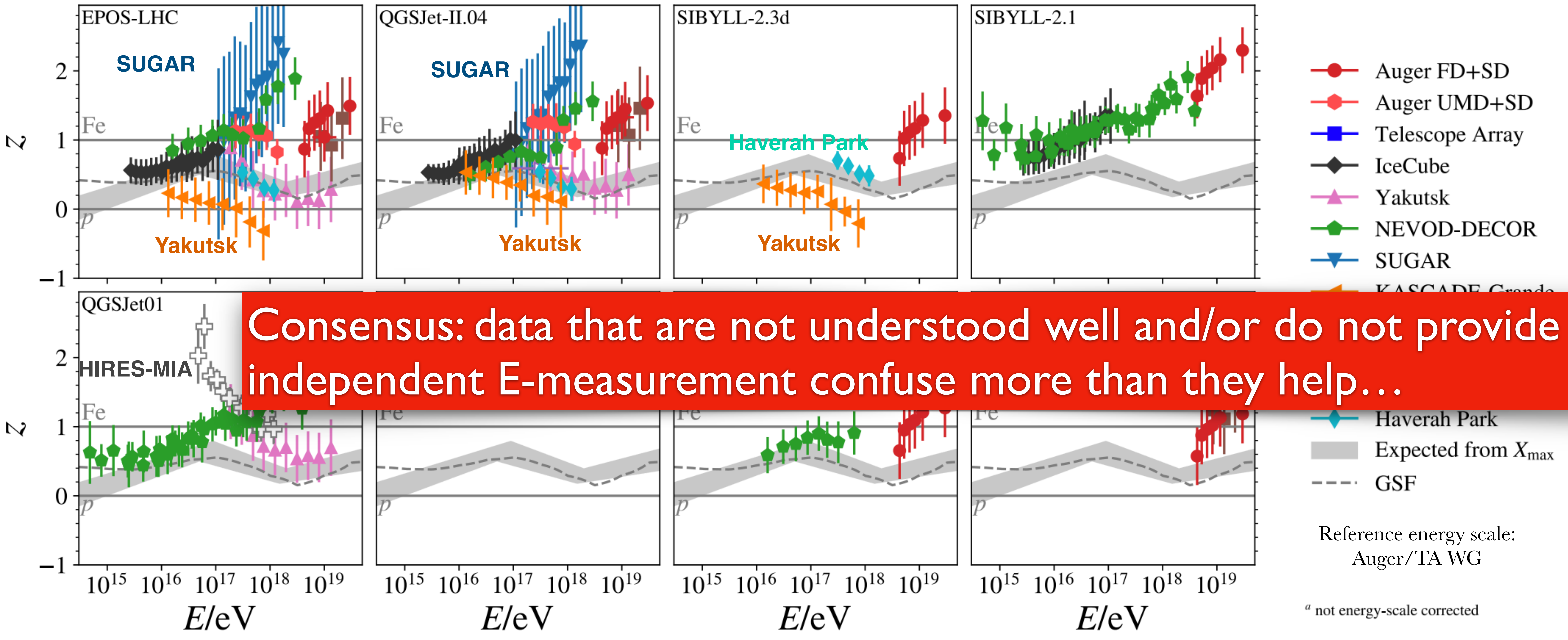

Consensus: data that are not understood well and/or do not provide independent E-measurement confuse more than they help…

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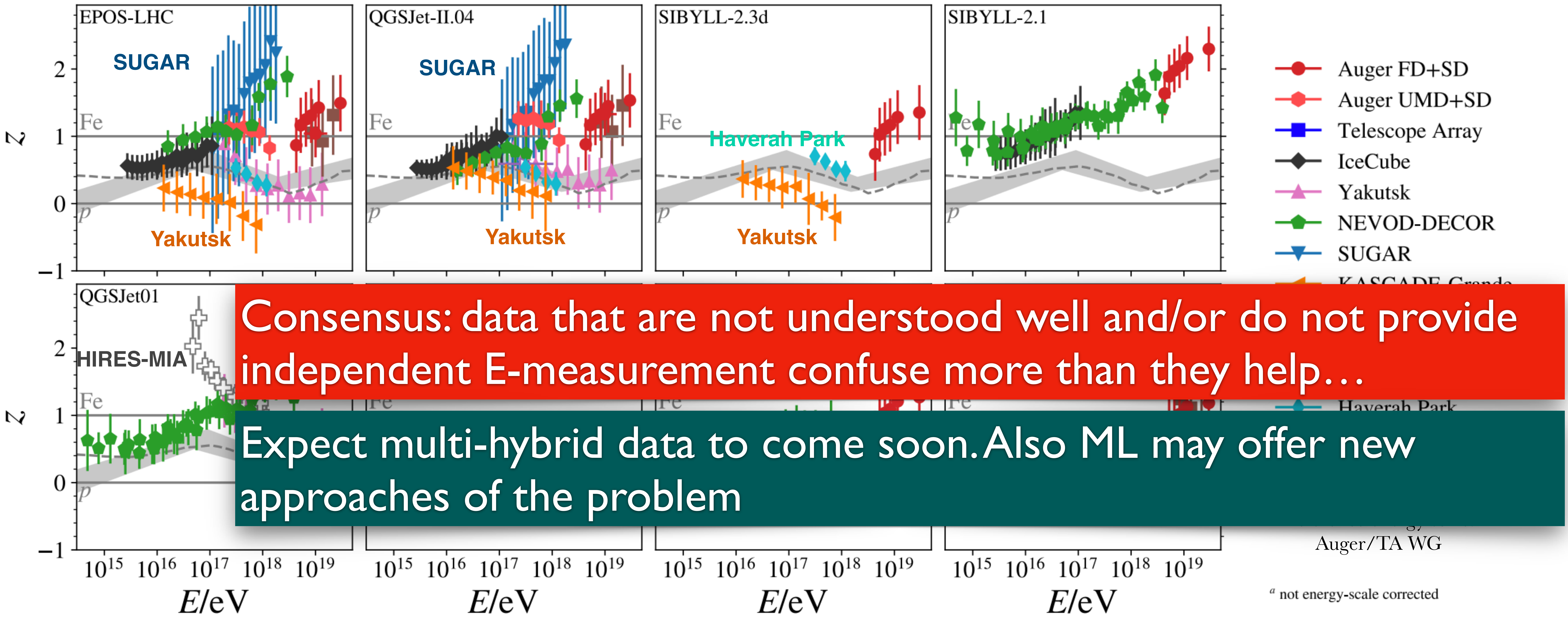


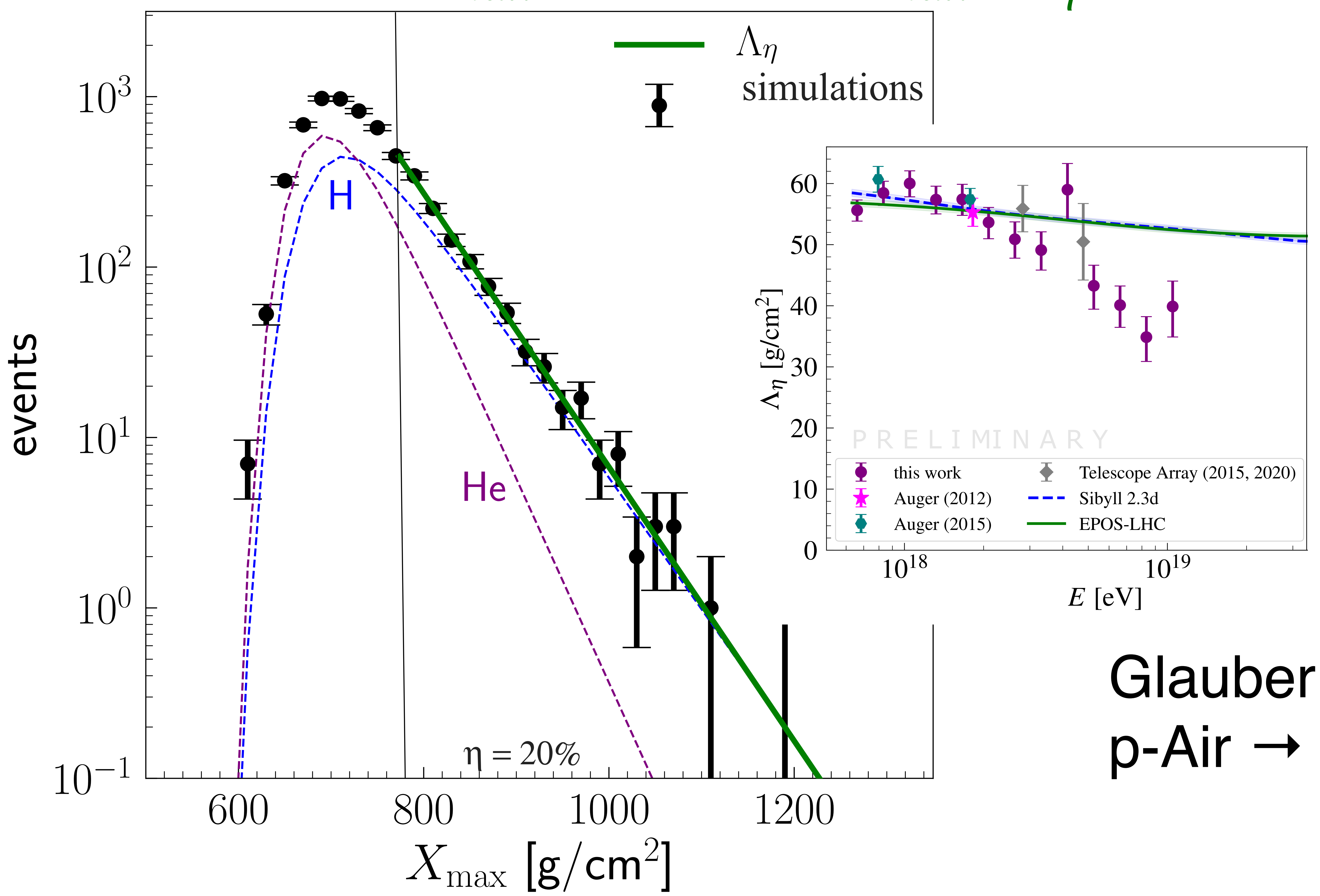
Consensus: data that are not understood well and/or do not provide independent E-measurement confuse more than they help…

Expect multi-hybrid data to come soon. Also ML may offer new approaches of the problem

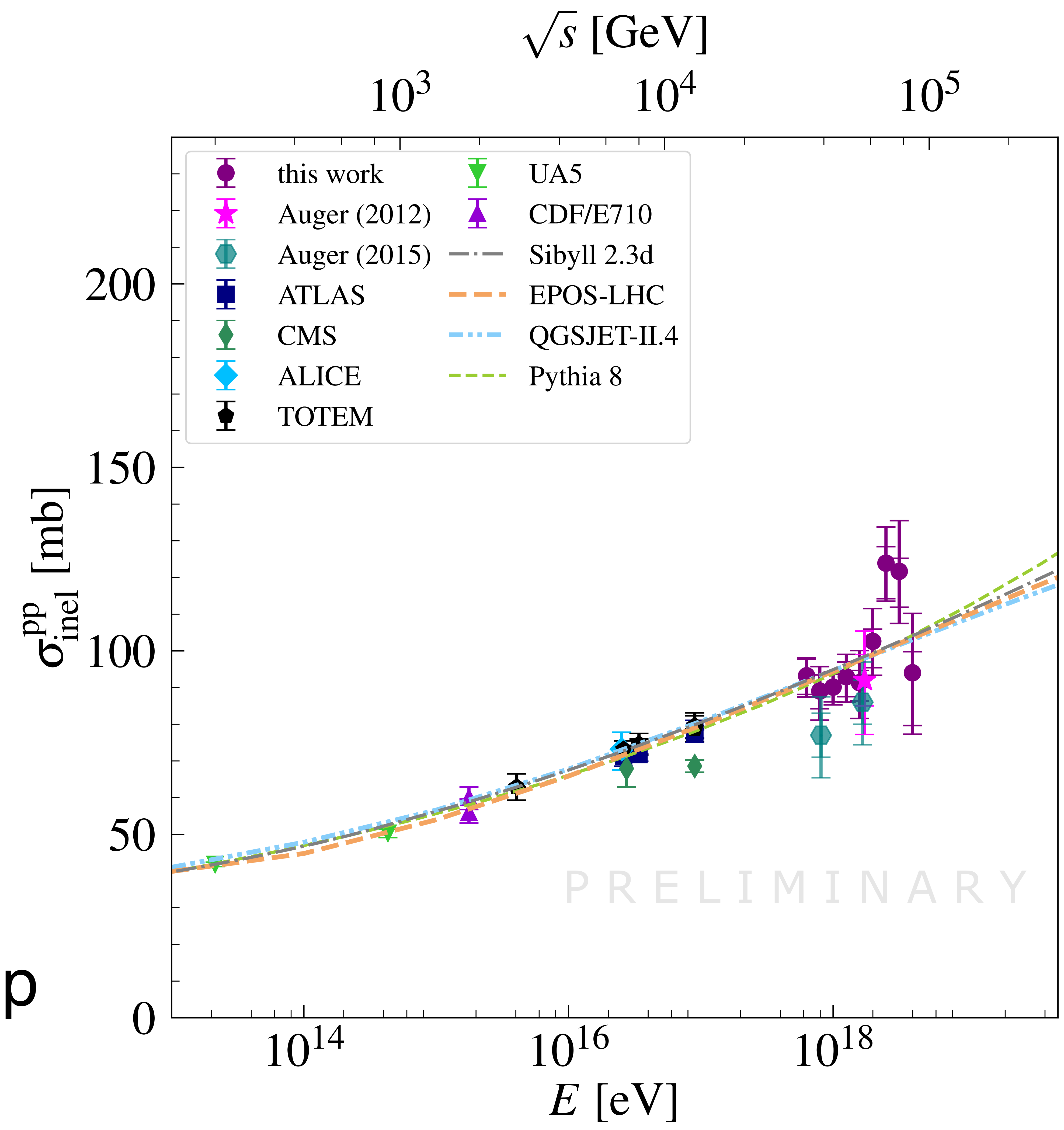
Extracting pp X-section from EAS-data

Olena Tkachenko

$$f(X_{max}) \propto \exp(-X_{max}/\Lambda_\eta)$$



Glauber:
p-Air → pp

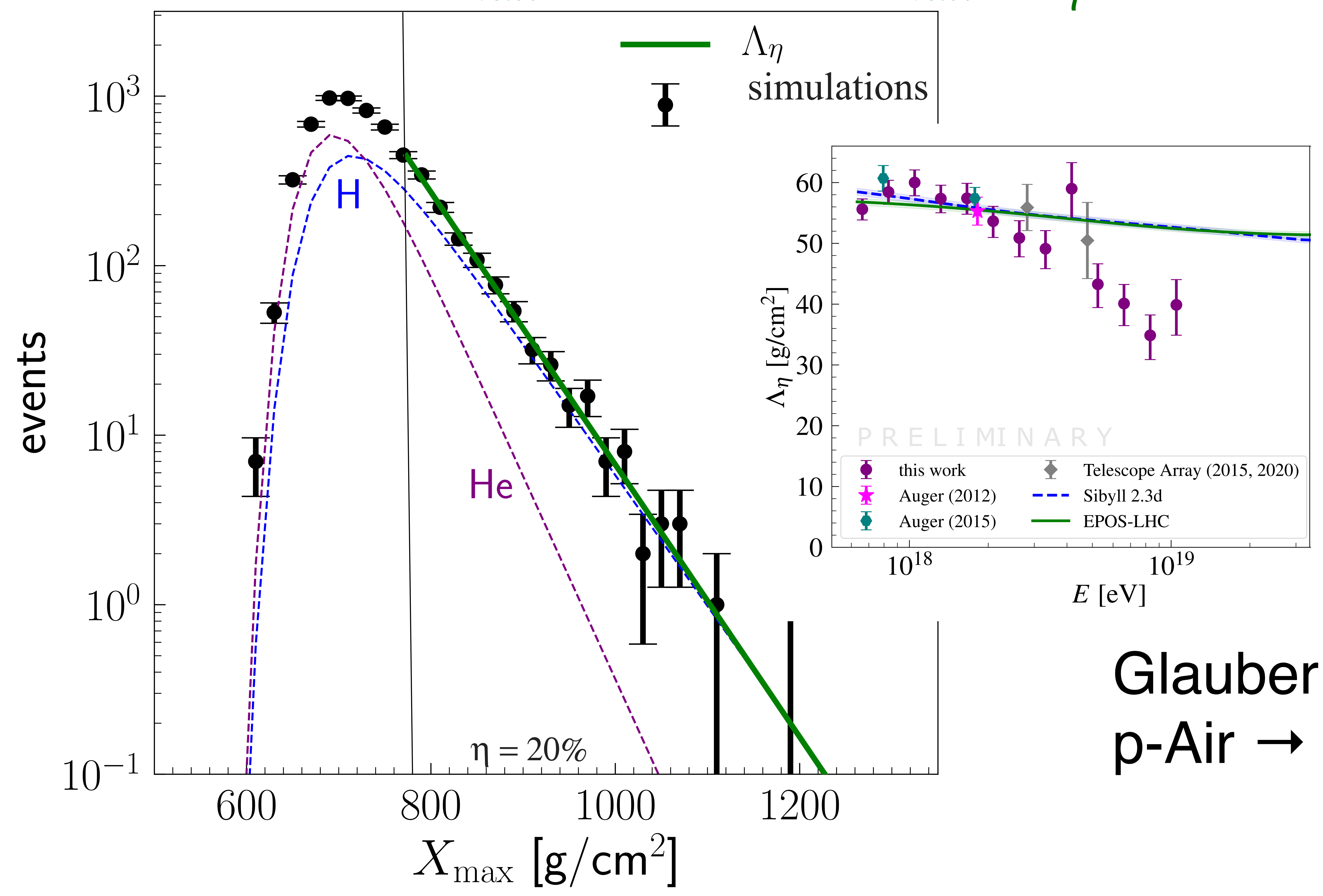


New: Simultaneous estimation of X-section and composition

Extracting pp X-section from EAS-data

Olena Tkachenko

$$f(X_{max}) \propto \exp(-X_{max}/\Lambda_\eta)$$



Glauber:
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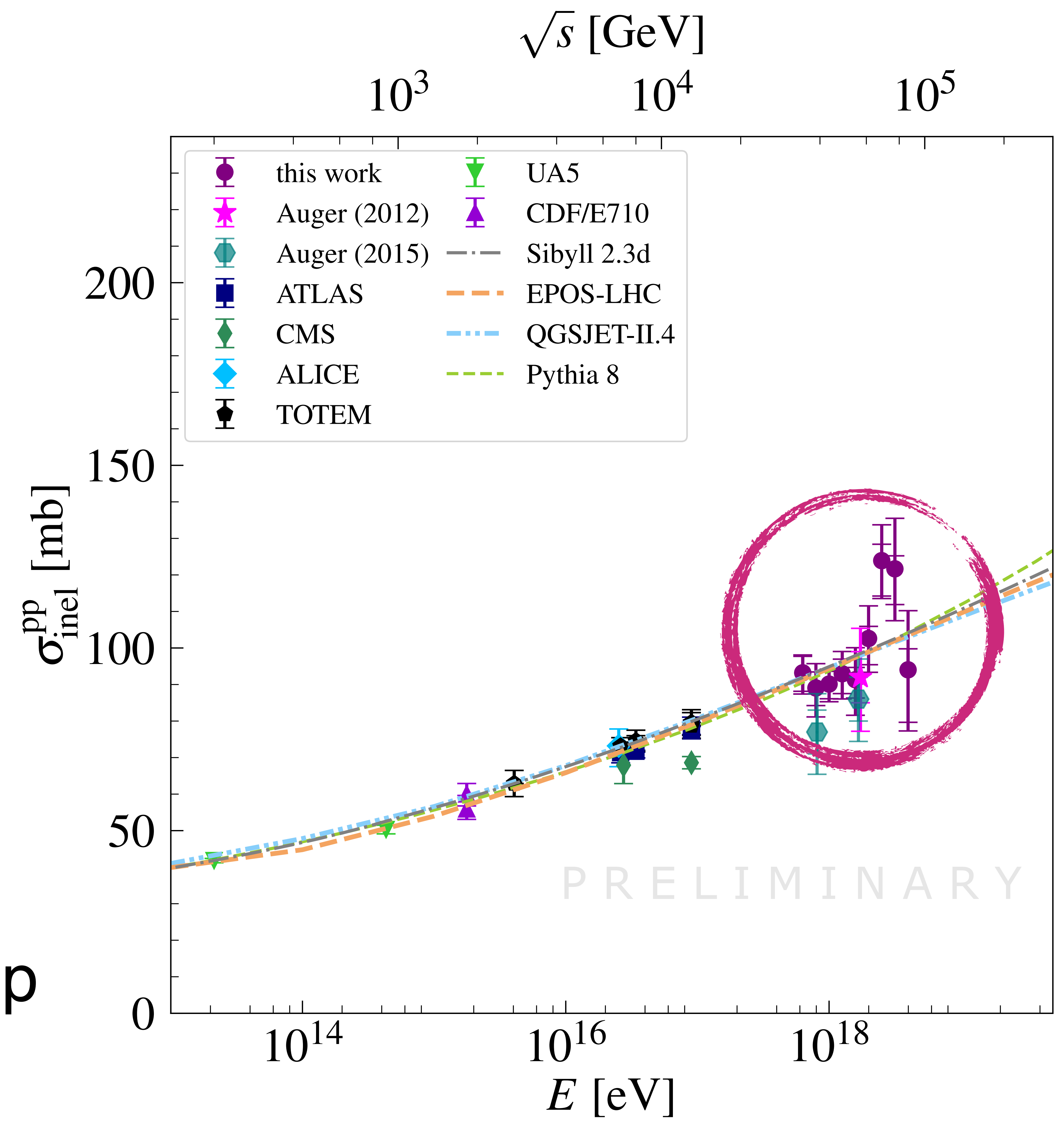
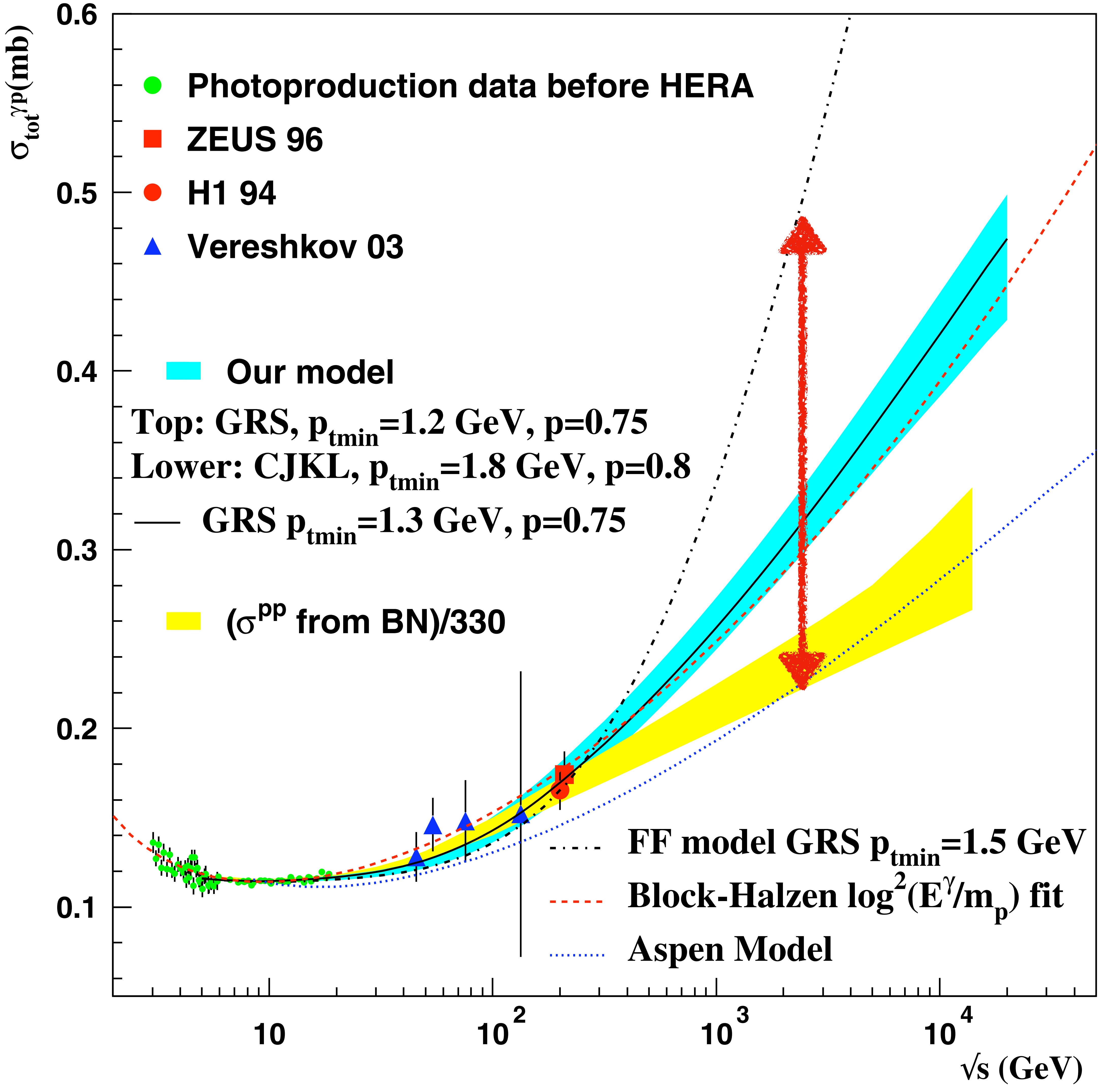


New: Simultaneous estimation of X-section and composition

Other Tests with EAS Experiments

Guiseppe di Sciascio

Photo-Production Cross Section from EAS Data



Idea:

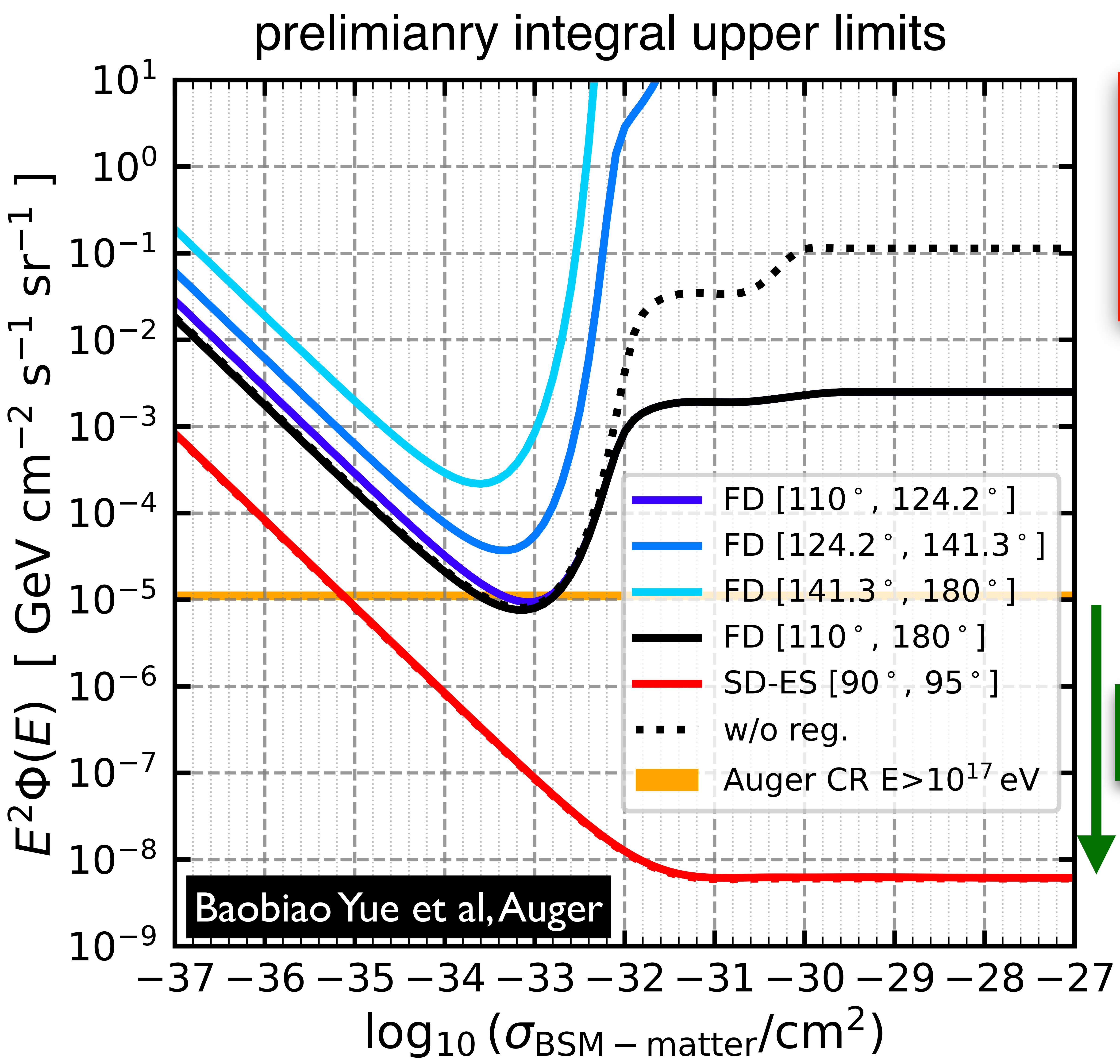
LHAASO and other experiments will observe a large number of > 100 TeV photons

→ study characteristics of photon induced showers and compare with models

So far cross section relies on HERA data, large uncertainties in extrapolation

BSM Tests with EAS-Experiments

Karl-Heinz Kampert



No Upwards-Showers observed → Upper Bounds of BSM-Particles passing through the Earth

ϕ_{BSM} bounds from FD incl. τ regeneration

UHECR flux (E>10^{17} eV)

$\phi_{BSM} < 10^{-3} \times \phi_{UHECR}$

ϕ_{BSM} bounds from ES-SD incl. τ regeneration

Accelerator Experiments and Input to Interaction Models

Farès Djama (ATLAS), Isabel Pedraza (CMS), Hiroaki Menjo (LHCf), Mario Rodriguez (ALICE), Ralph Engel (NA61), Osamu Sato (FASER), Dennis Soldin (FPF), Eduard De La Cruz Burelo (Belle II)

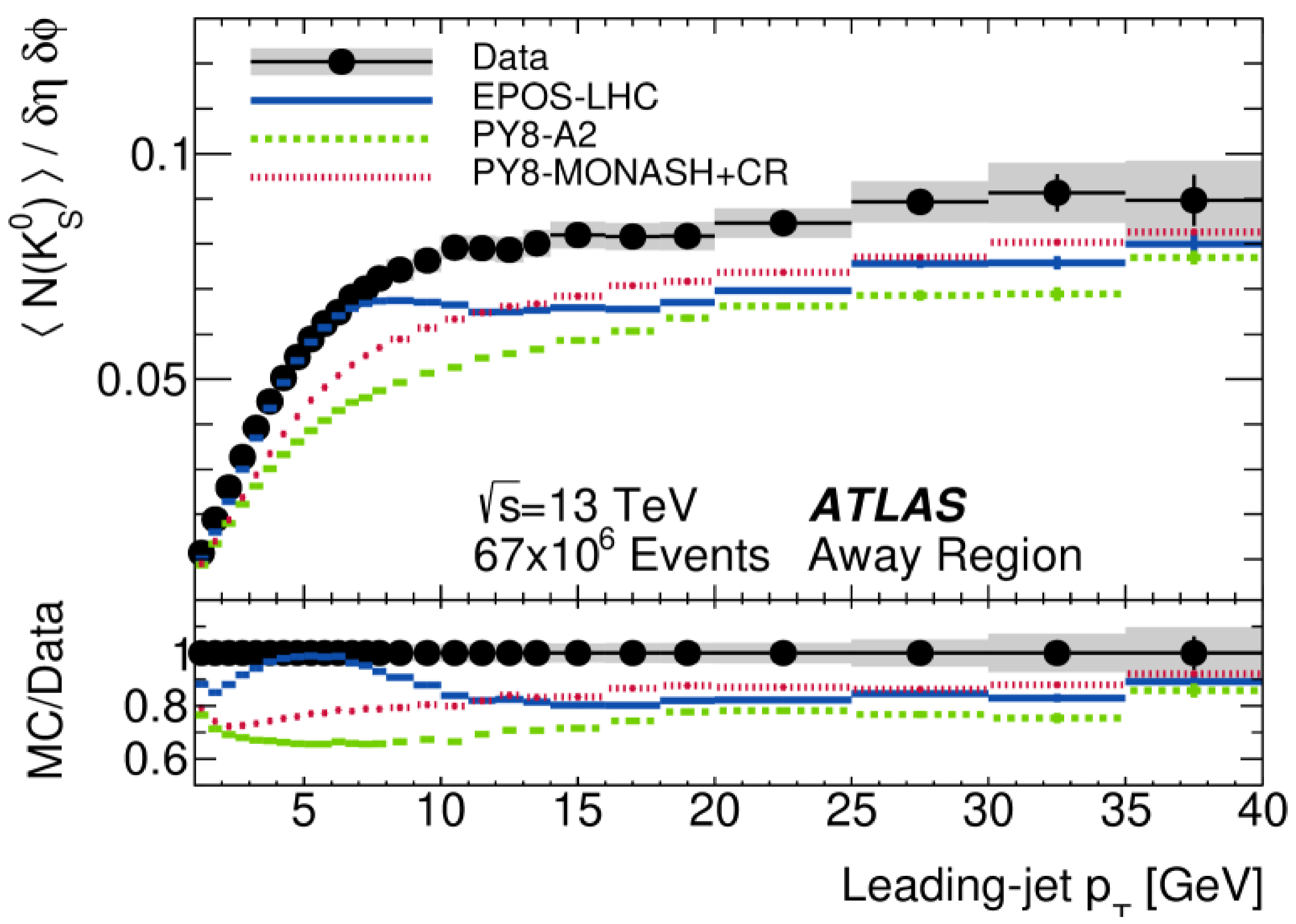
Strangeness Production compared to EAS models

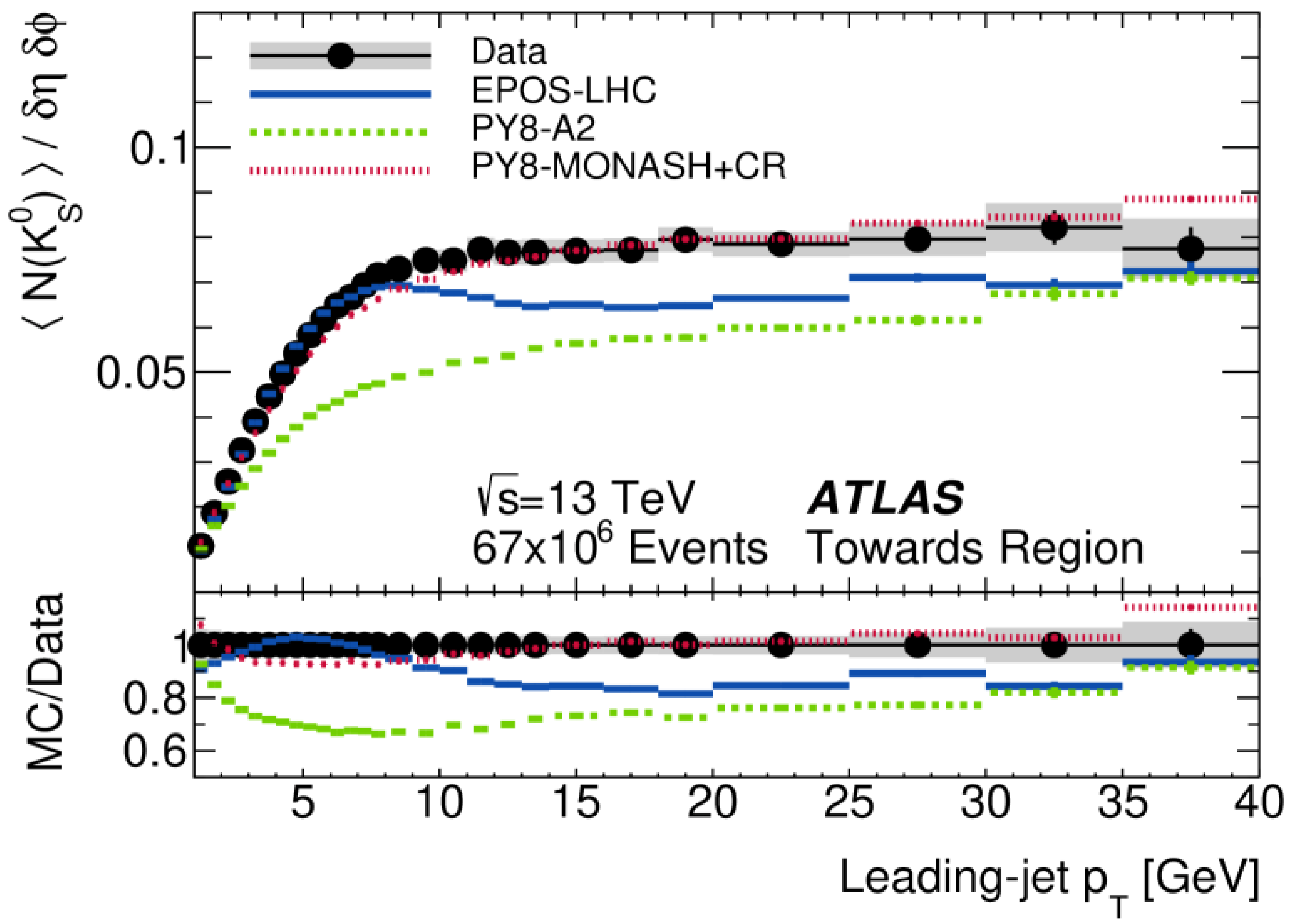
K_S^0 Production in pp

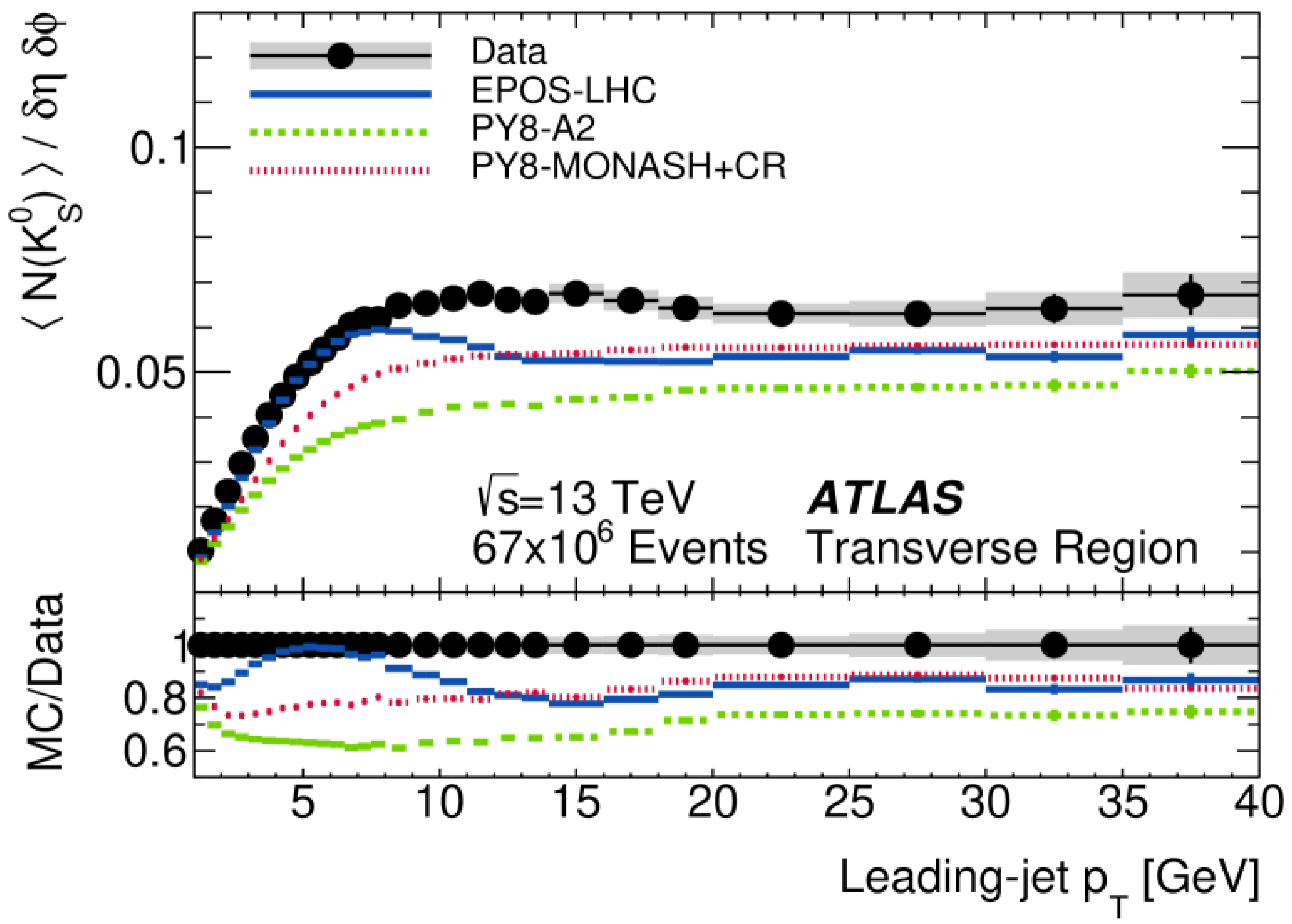
Farès Djama (ATLAS)

- Data: Soft and hard regime. Transition around leading jet P_T of 10 GeV.
- Soft regime:
  - EPOS LHC closest to data.
  - PYTHIA Monash + CR is better in the Towards region.
- Hard regime:
  - EPOS LHC shows a dip absent from data and other models.
  - PYTHIA A2 models well the data shape.
  - PYTHIA Monash + CR models well the Towards region.

Strangeness too low in models
→ μ-problem







Strangeness Production compared to EAS models

Λ Production in pp

- Data: Soft and hard regime. Transition around leading jet P_T of 10 GeV.
- Soft regime:
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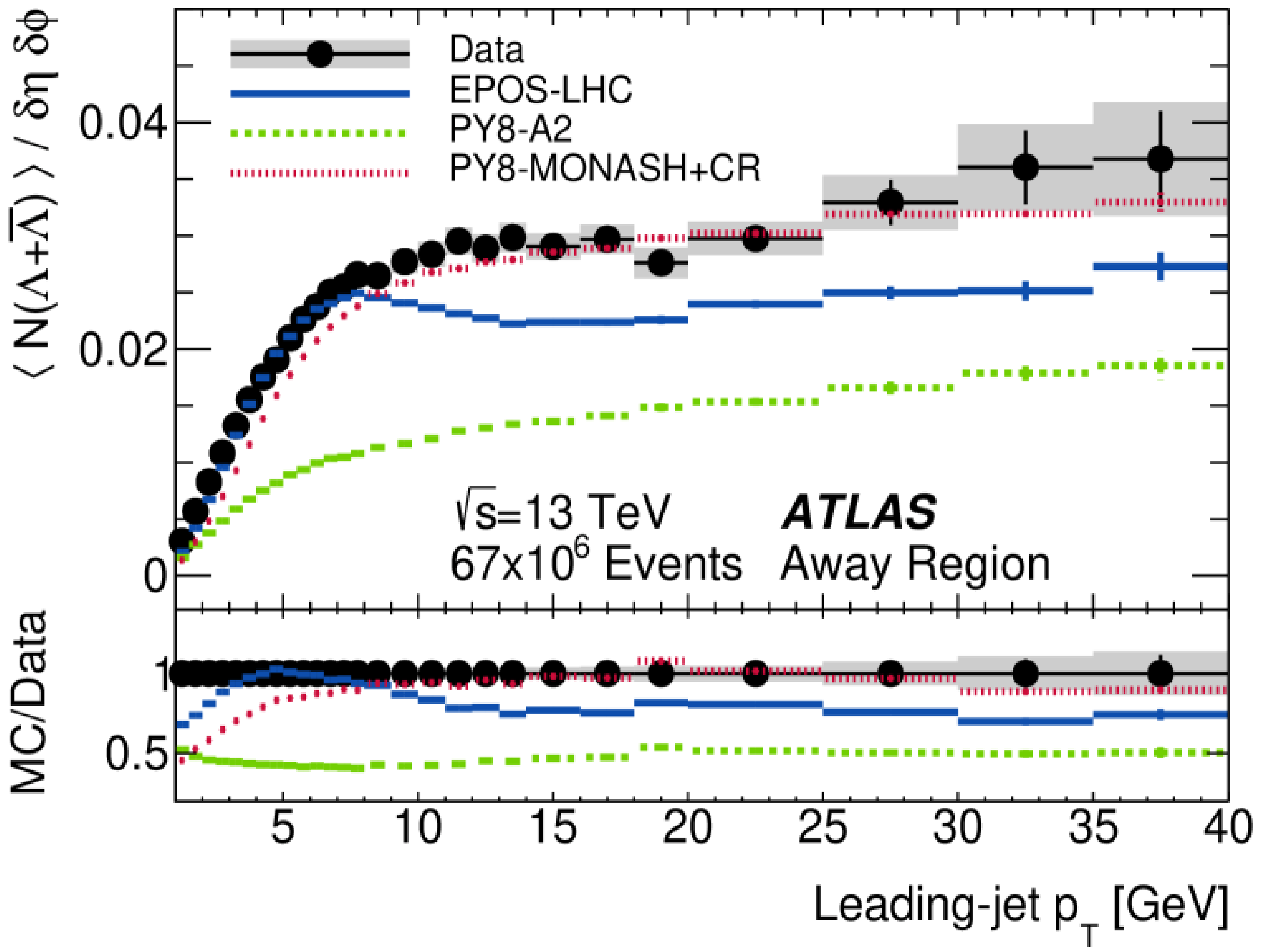
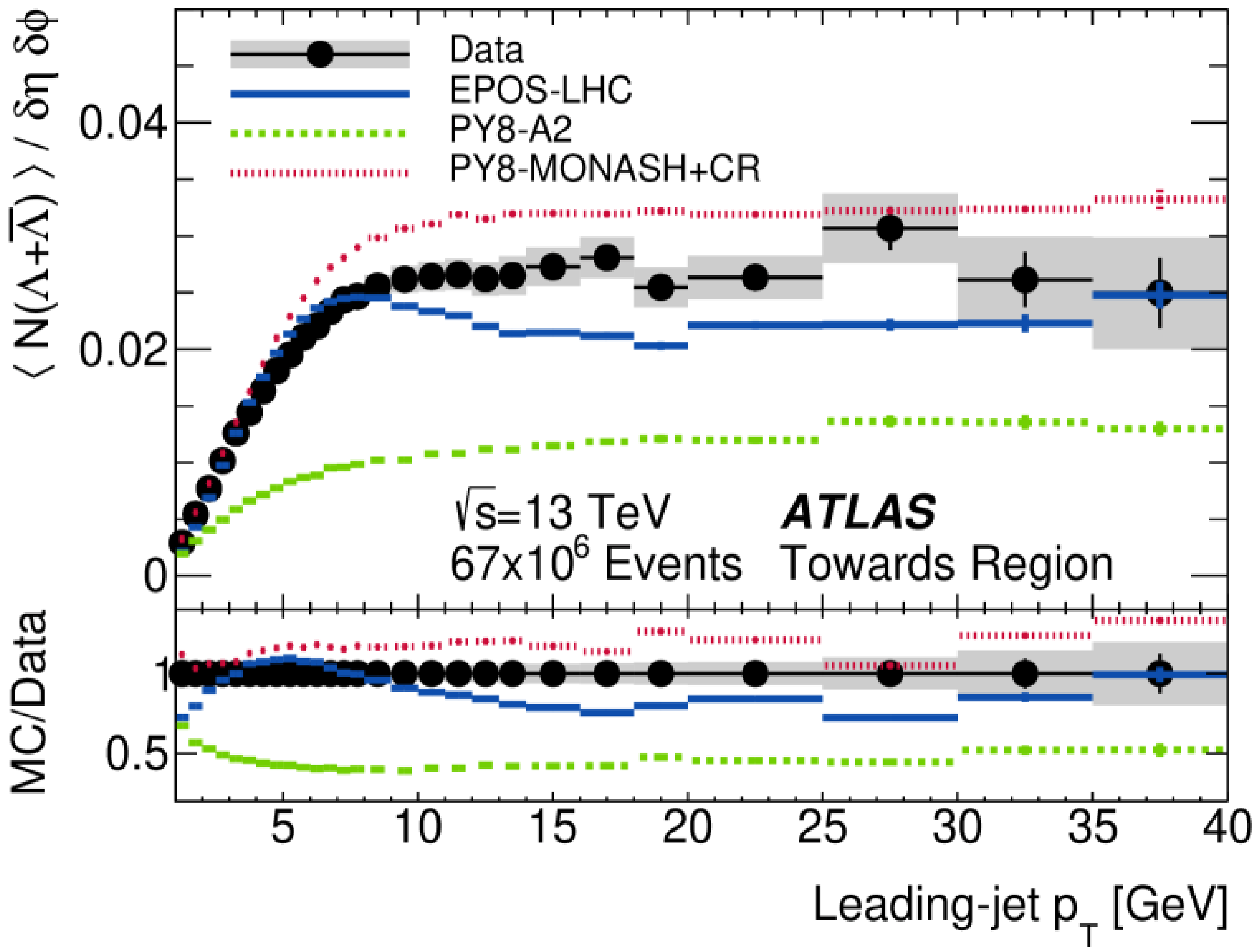
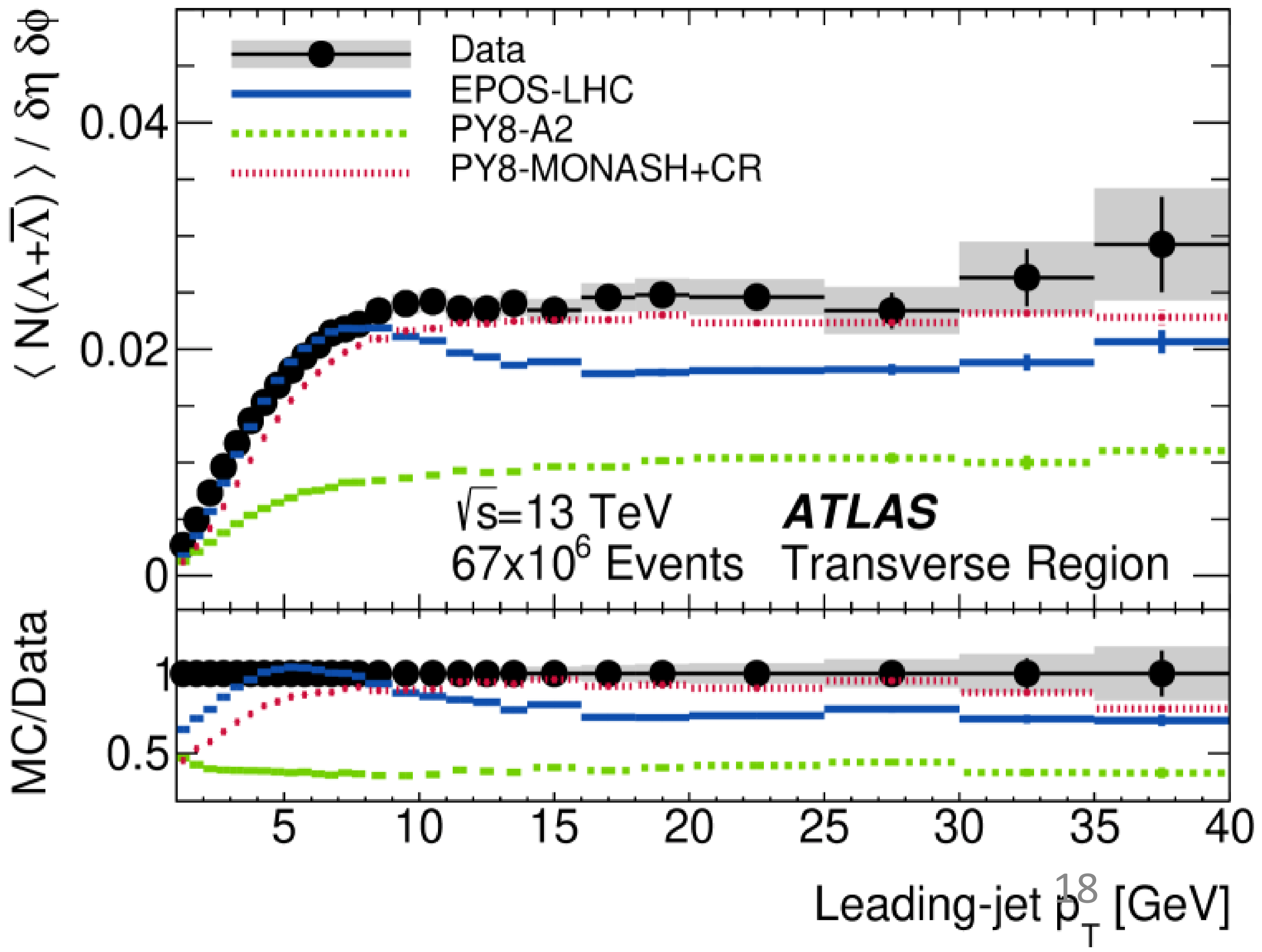
- Hard regime:
  - EPOS LHC shows a dip absent from data and other models.
  - PYTHIA A2 models well the data shape.
  - PYTHIA Monash + CR models well the Away and Transverse regions.







Farès Djama (ATLAS)

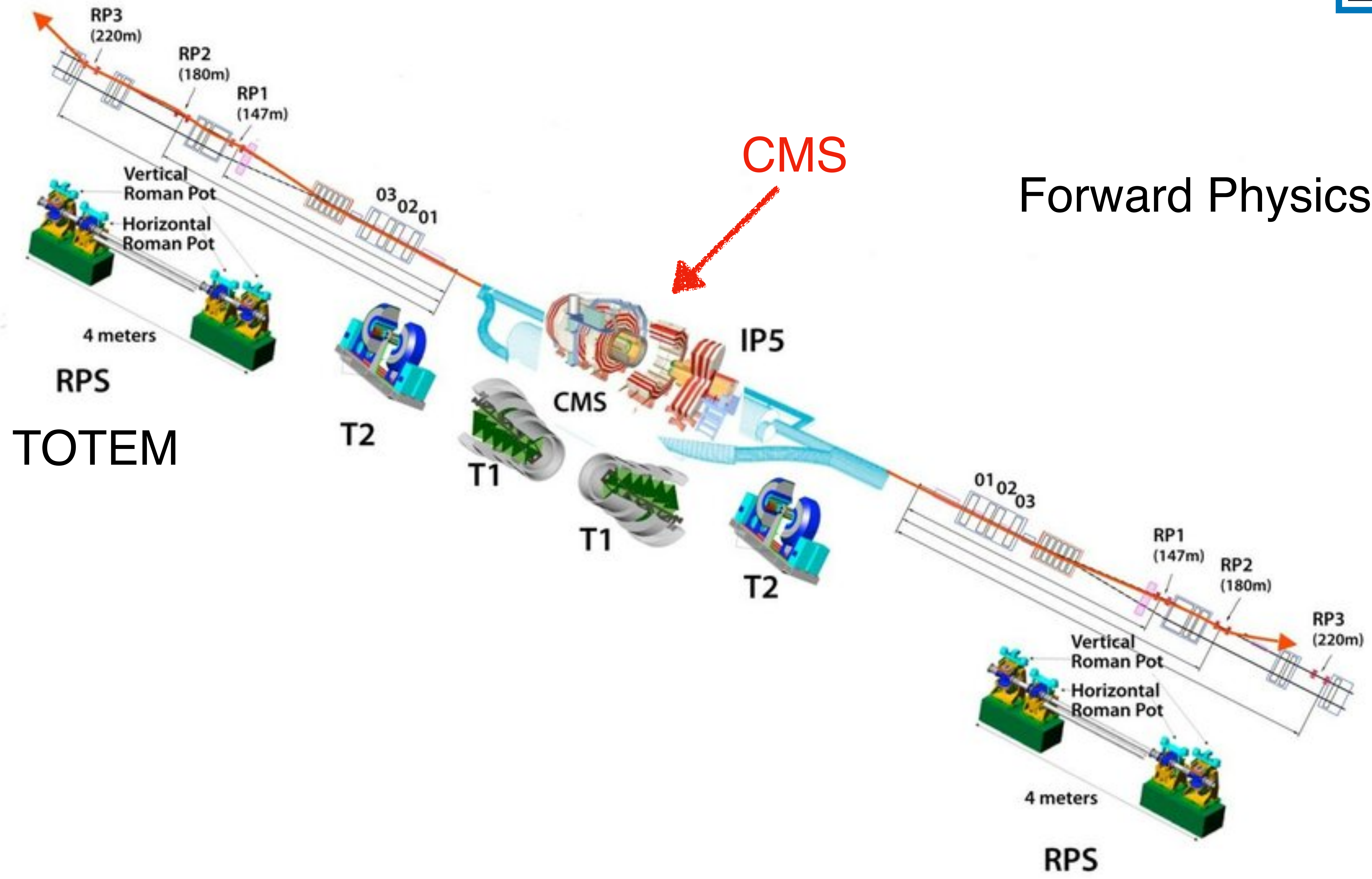
Strangeness too low in models
→ μ-problem

Pythia 8 - Monash tune does fine

CMS / TOTEM

Isabel Pedraza (CMS)

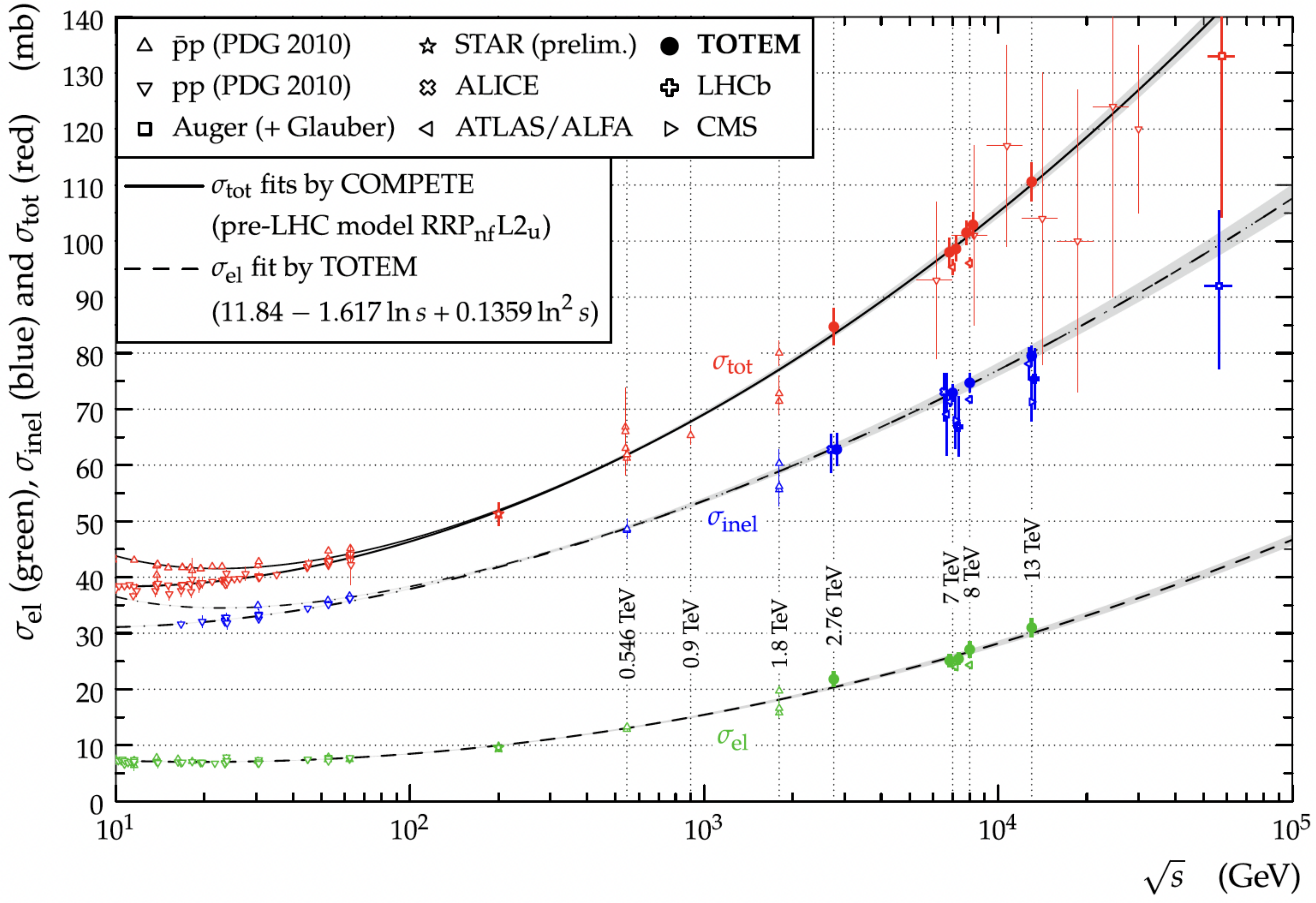
Forward Physics Program



CMS / TOTEM

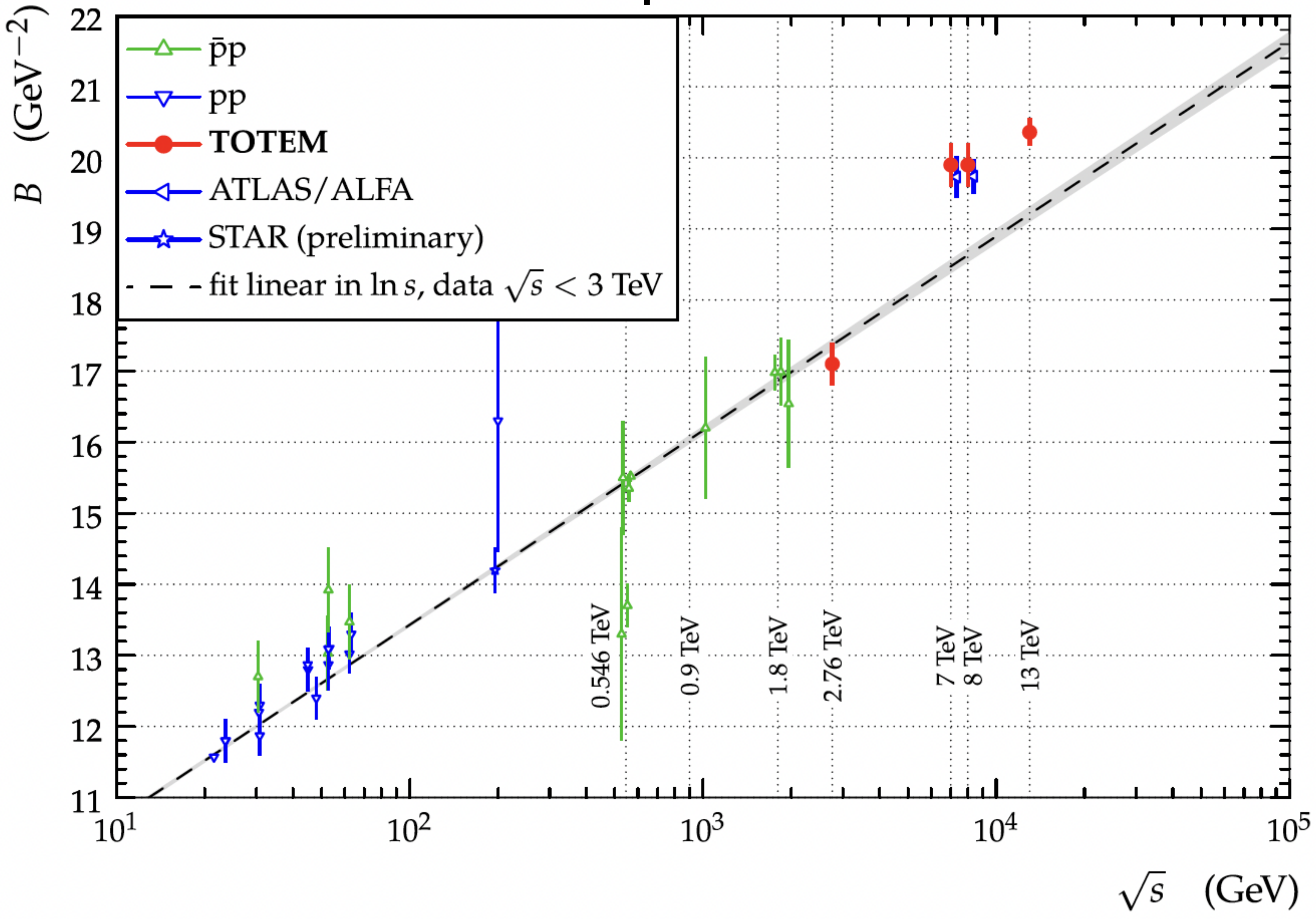
Isabel Pedraza (CMS)

Cross Sections: pp, pp-bar



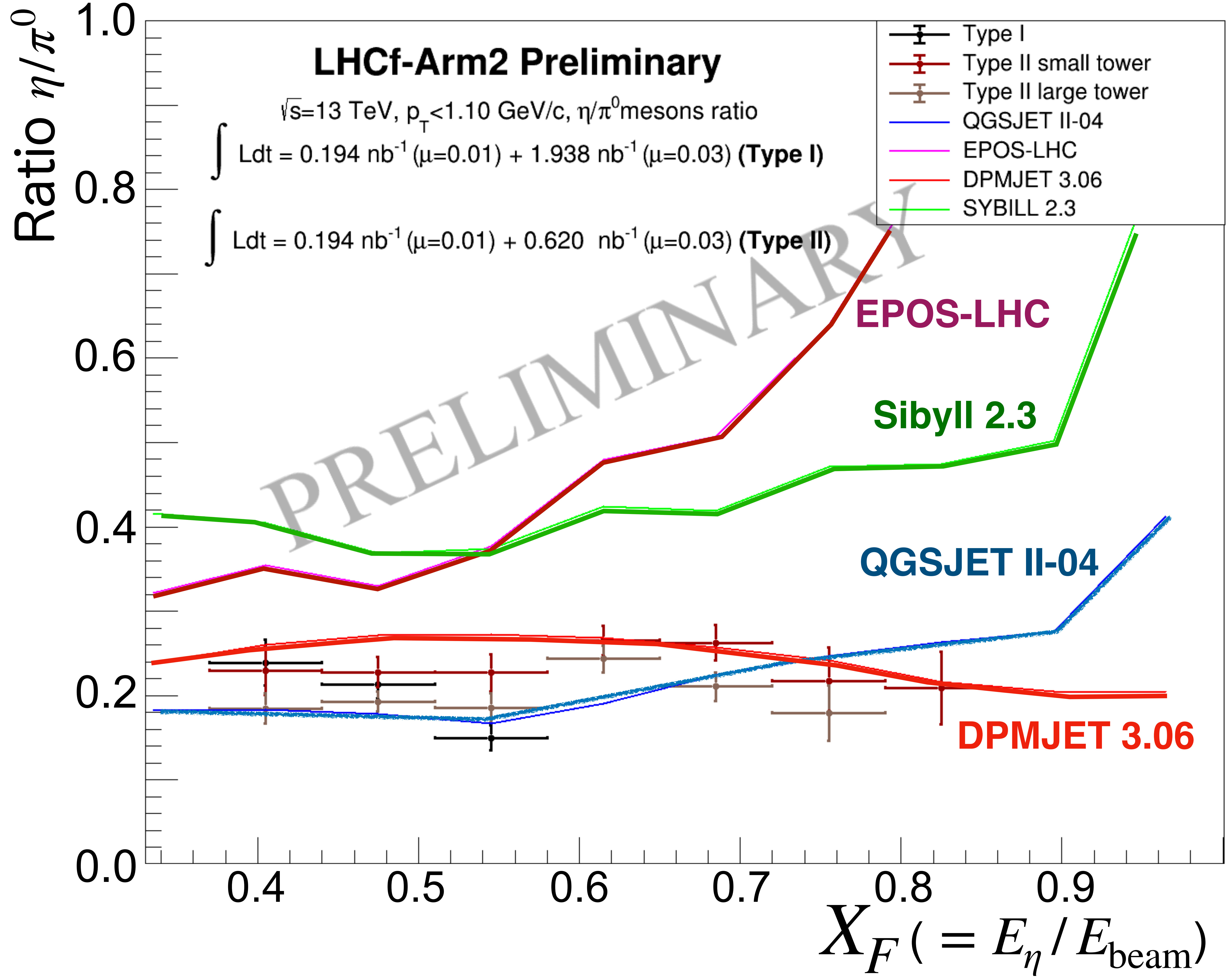
Eur. Phys. J. C (2019) 79: 103

Nuclear Slope Parameter



LHCf: η/π^0 Ratio

Hiroaki Menjo (LHCf)



- Data : constant in the whole energy range

EPOS-LHC, SIBYLL2.3

- Much larger than data

QGSJETII-04, DPMJET III

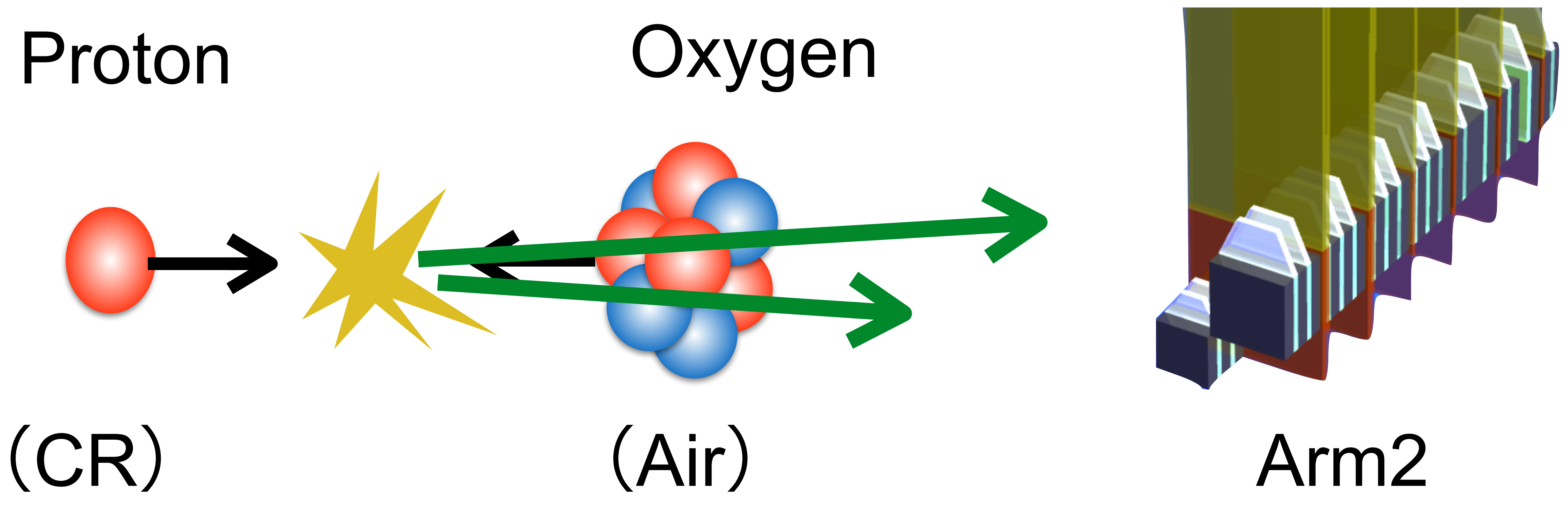
- Good agreement with data

However, may not be too relevant for the μ-puzzle

Preparing with ATLAS for p+O and O+O in 2025

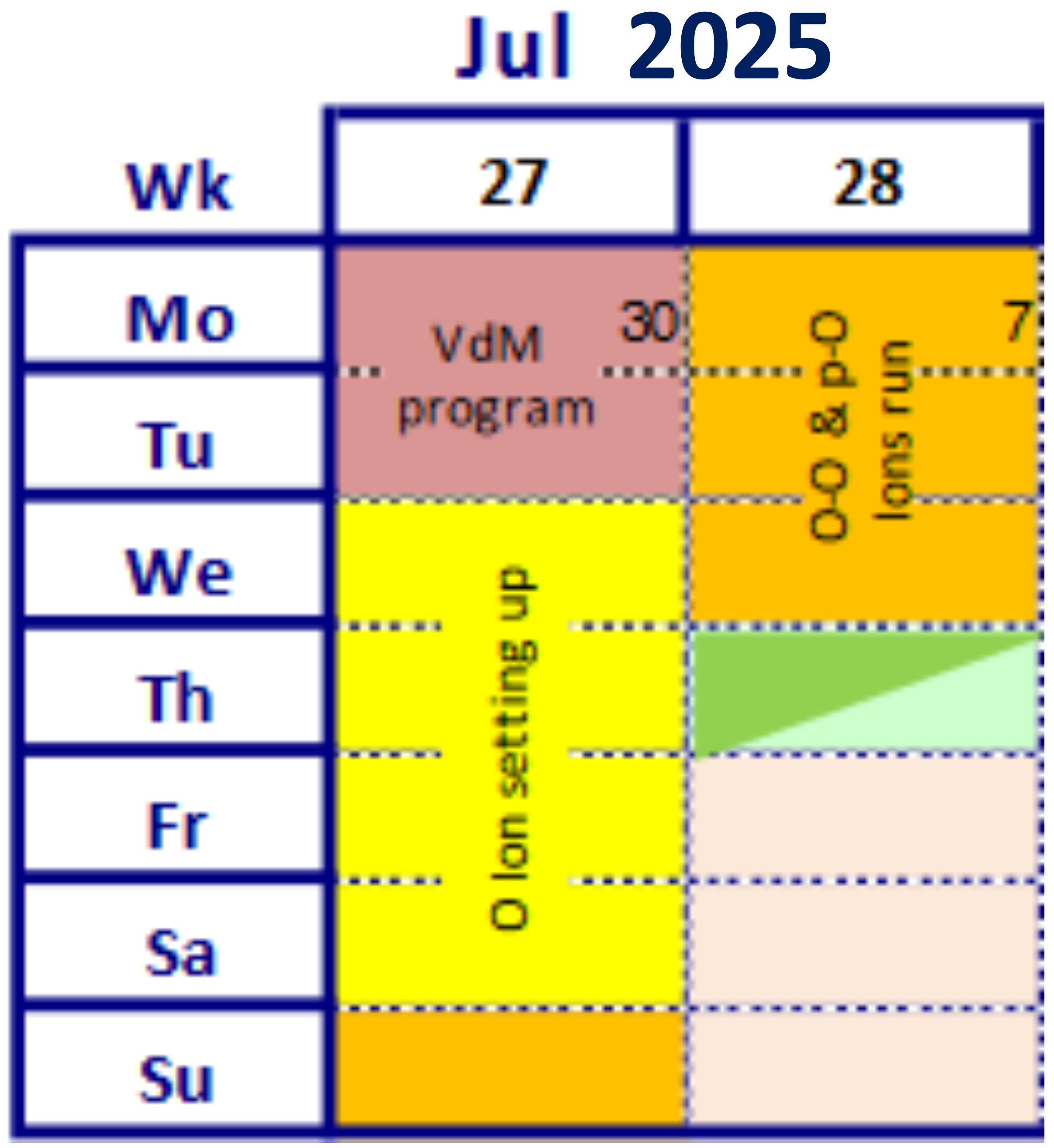
Hiroaki Menjo (LHCf)

- Setup
  - Only Arm2 detector is installed in p-remnant side.
    too-high multiplicity (<#Hits> > 5) in O-remnant side
  - Joint operation with ATLAS



- Oxygen run in July 2025
  - 1 week special run (p-O and O-O)
  - Install the detector during TS1
  - Beam commissioning (4 day)
  - **p-O collisions (2 days) ← LHCf Operation**

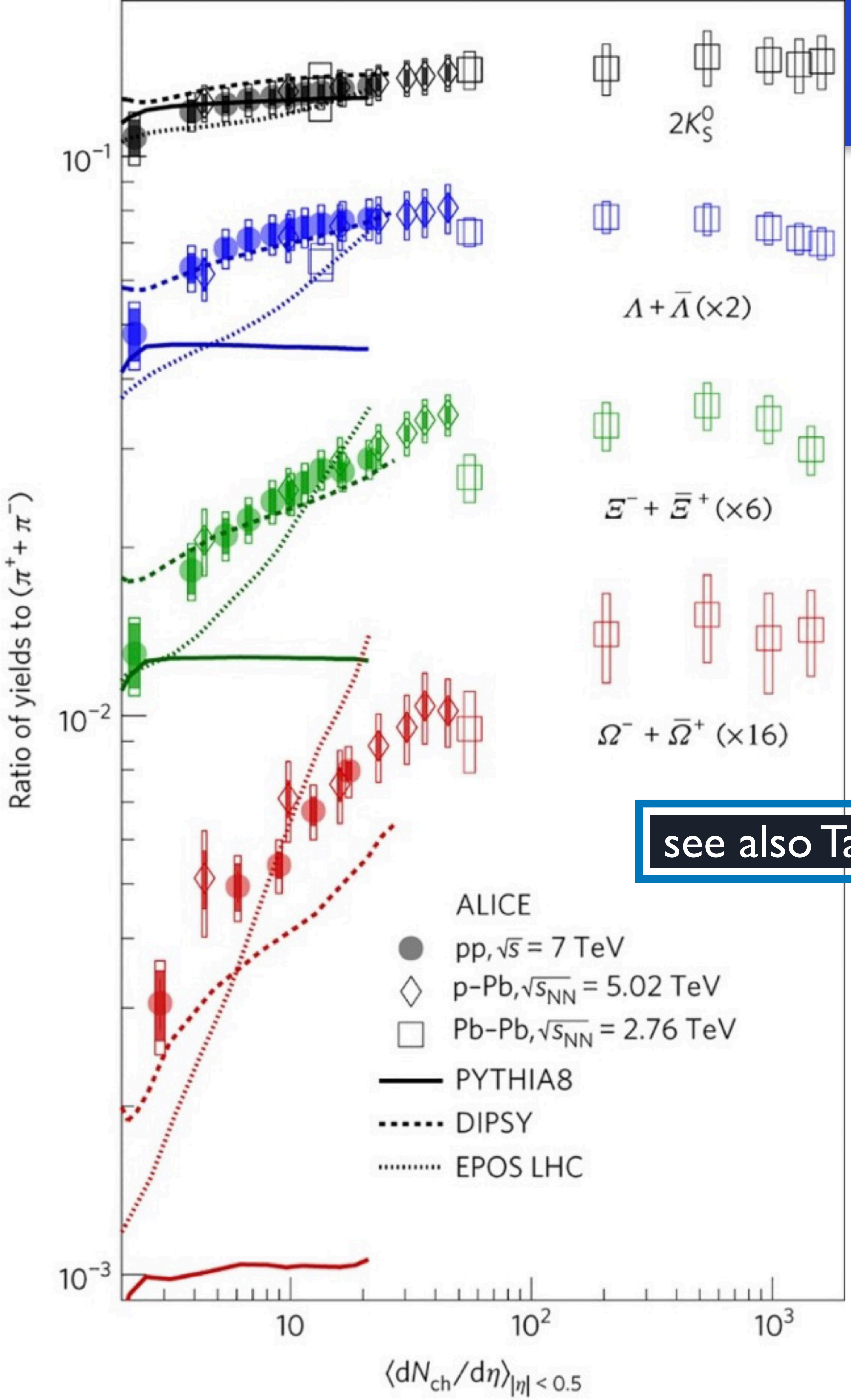
    \- - - - - Remove the detector from LHC - - - - -
  - O-O collisions (2 days) ← too high multiplicity



*) This schedule might be changed

ALICE: Enhanced Strangeness

Mario Rodriguez

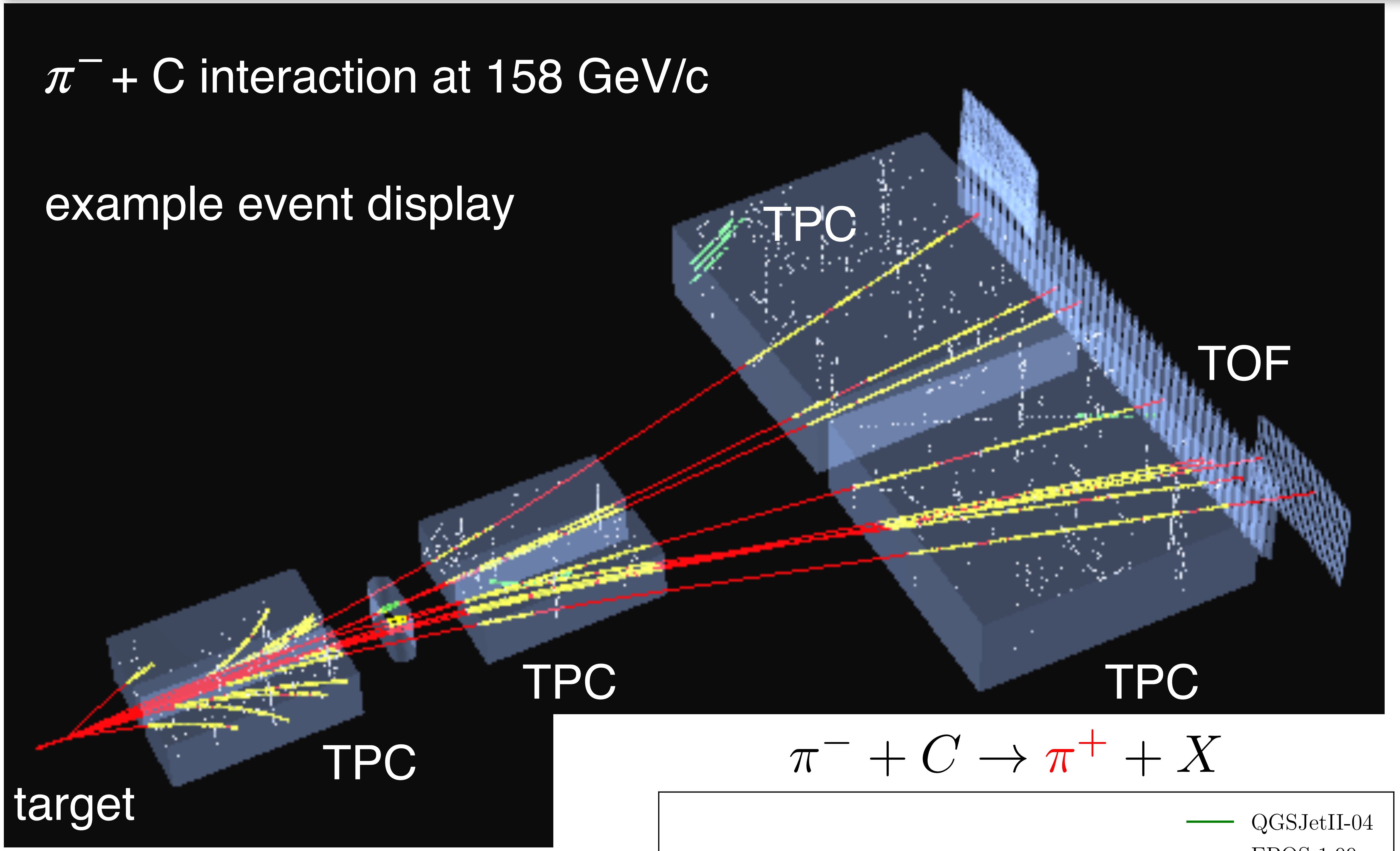


see also Tanguy Pierog

Strange particle yields relative to $\pi^+\pi^-$ underestimated by interaction models

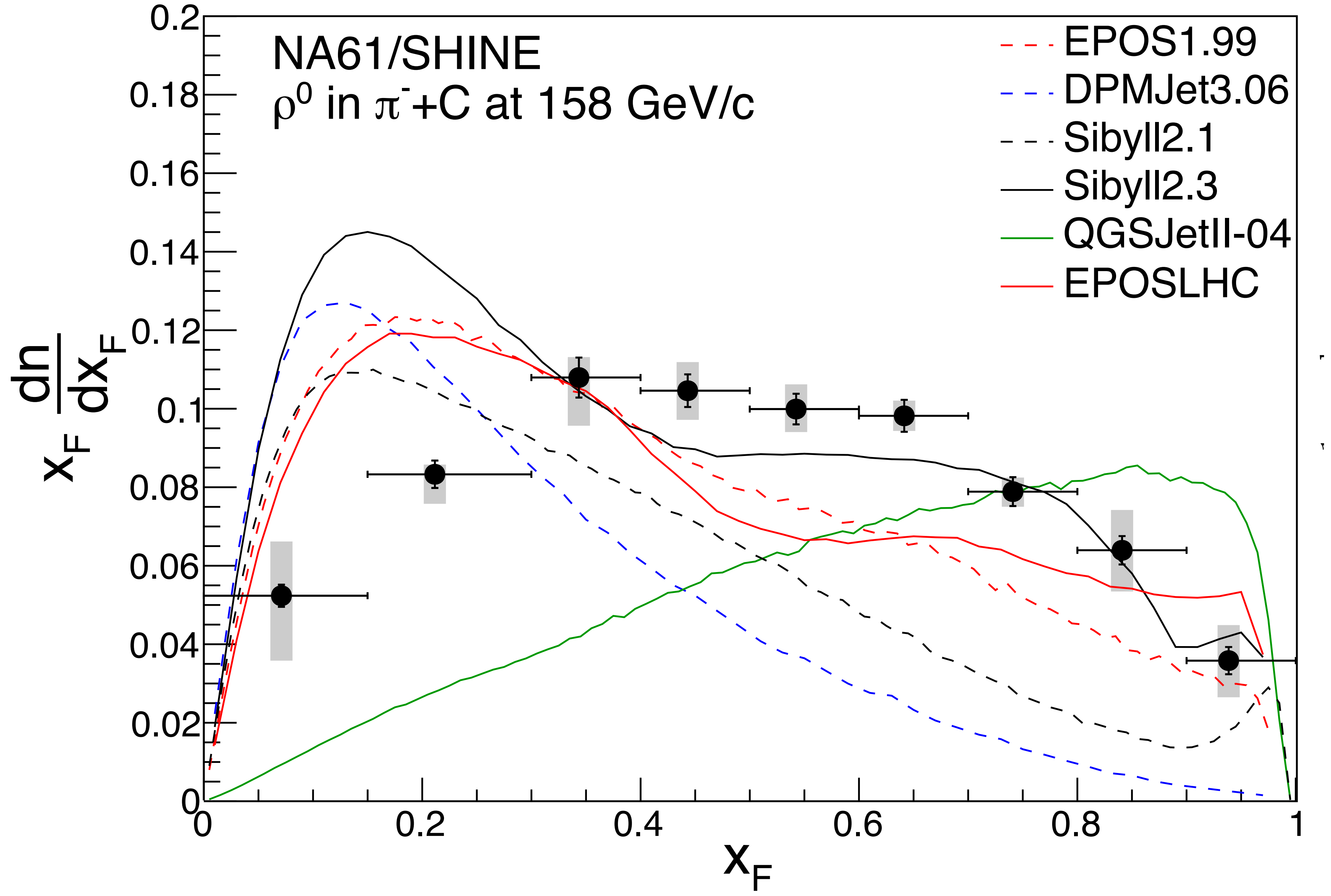
Enhanced strangeness production not only in AA, but also in pp, increases with charged particle multiplicity (centrally)

NA61/SHINE

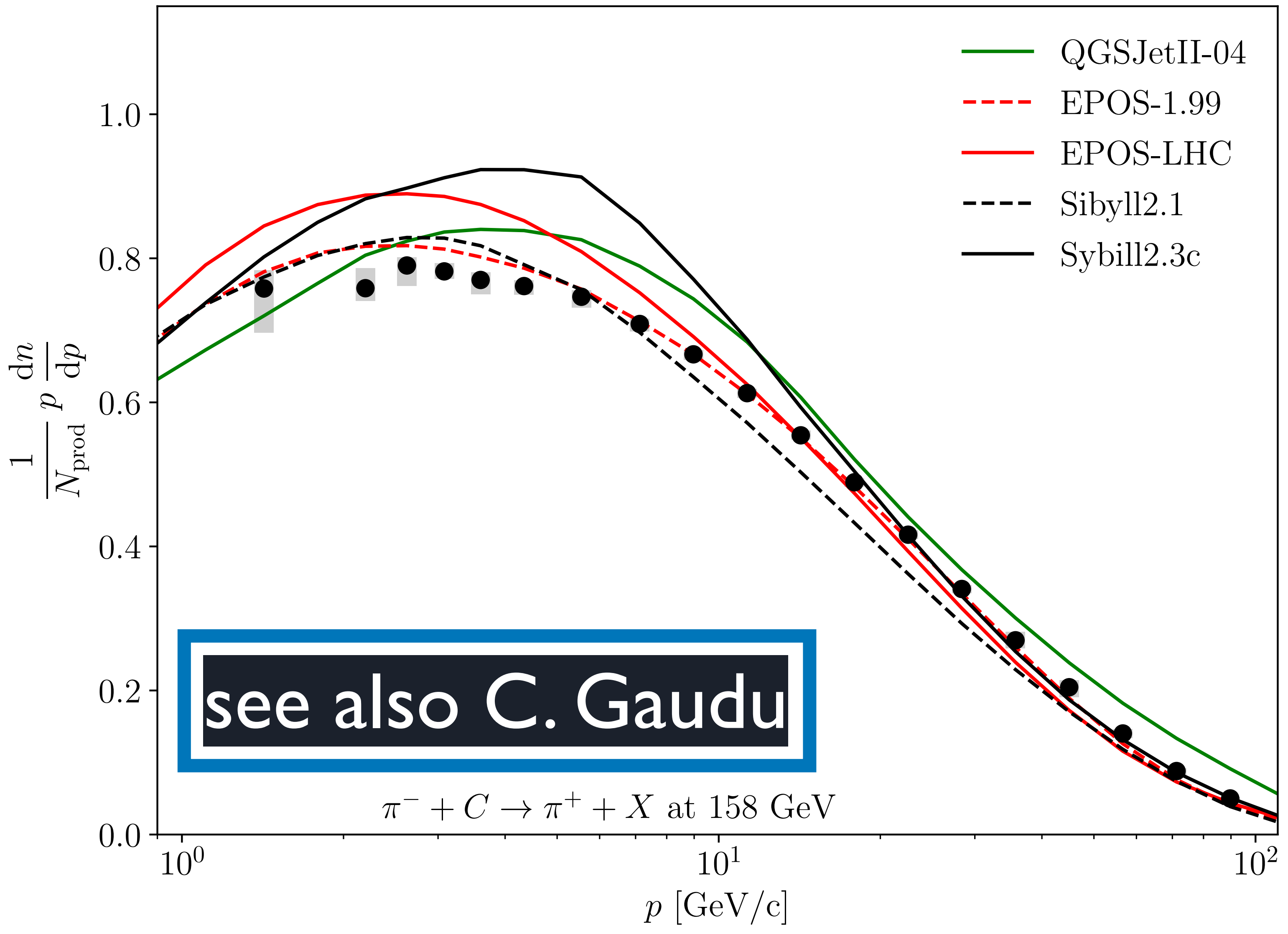


early result on ρ^0 - production

Ralph Engel



$\pi^- + C \rightarrow \pi^+ + X$

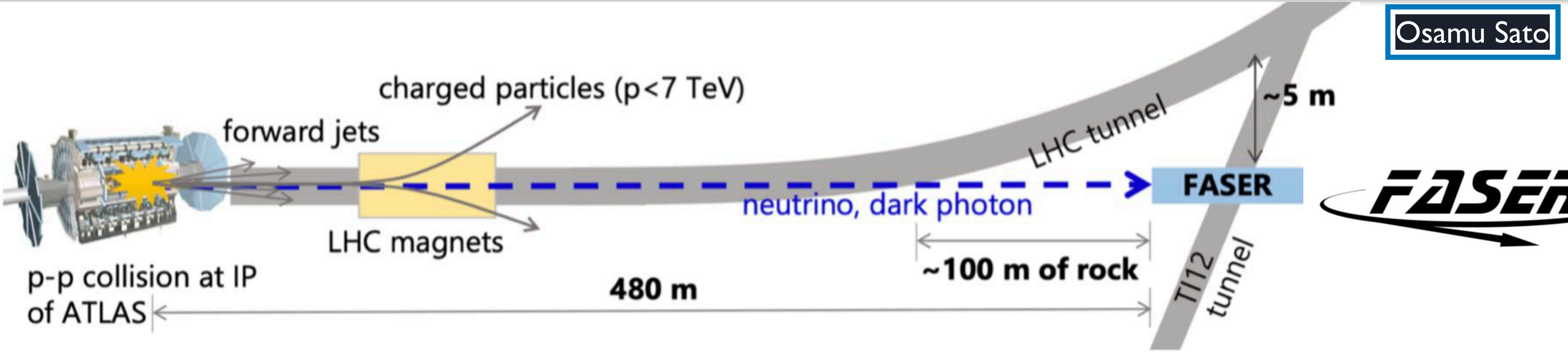


see also C. Gaudu

Highly relevant for model tuning

expect end 2024 one week of data for CR spallation reactions
→ Galactic CR propagation, Li, Be, B / C

FASER



Primary goal: measure neutrino cross sections for all flavours → lepton universality check

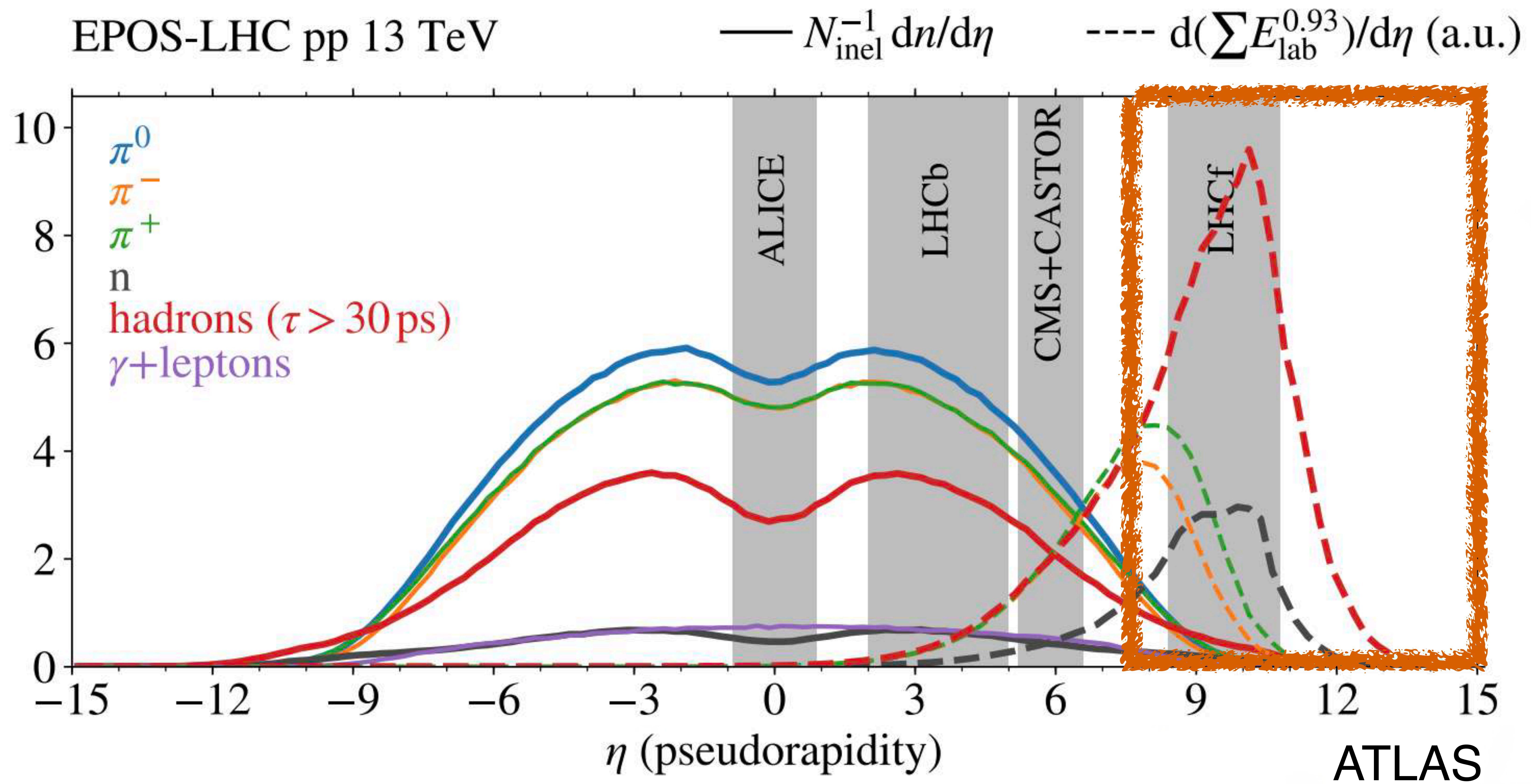
Forward particle production with flavour sensitivity → Input also to atmospheric leptons

Thereby also info about forward mother π, K, charm production

Taking data at end of Run3 → Forward Physics Faculty

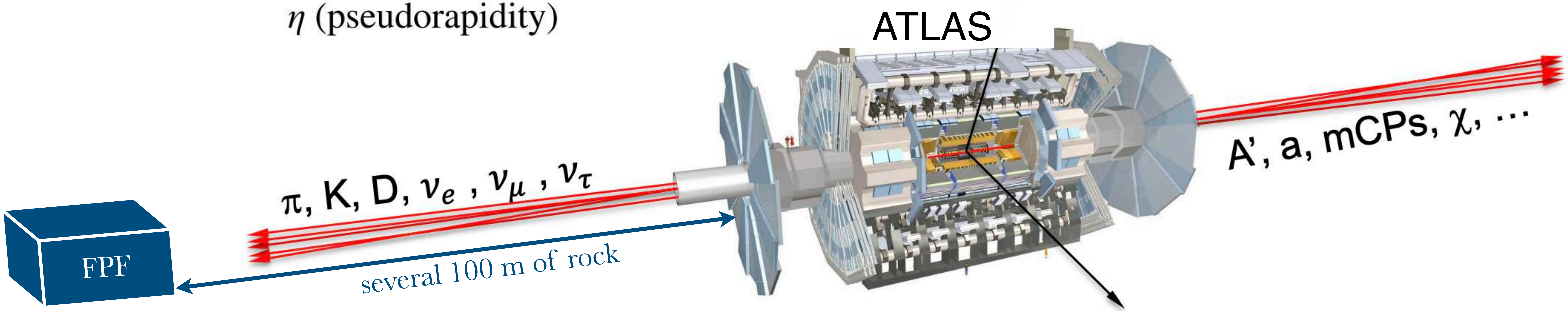
CERNs Forward Physics Facility (FPF)

Dennis Soldin



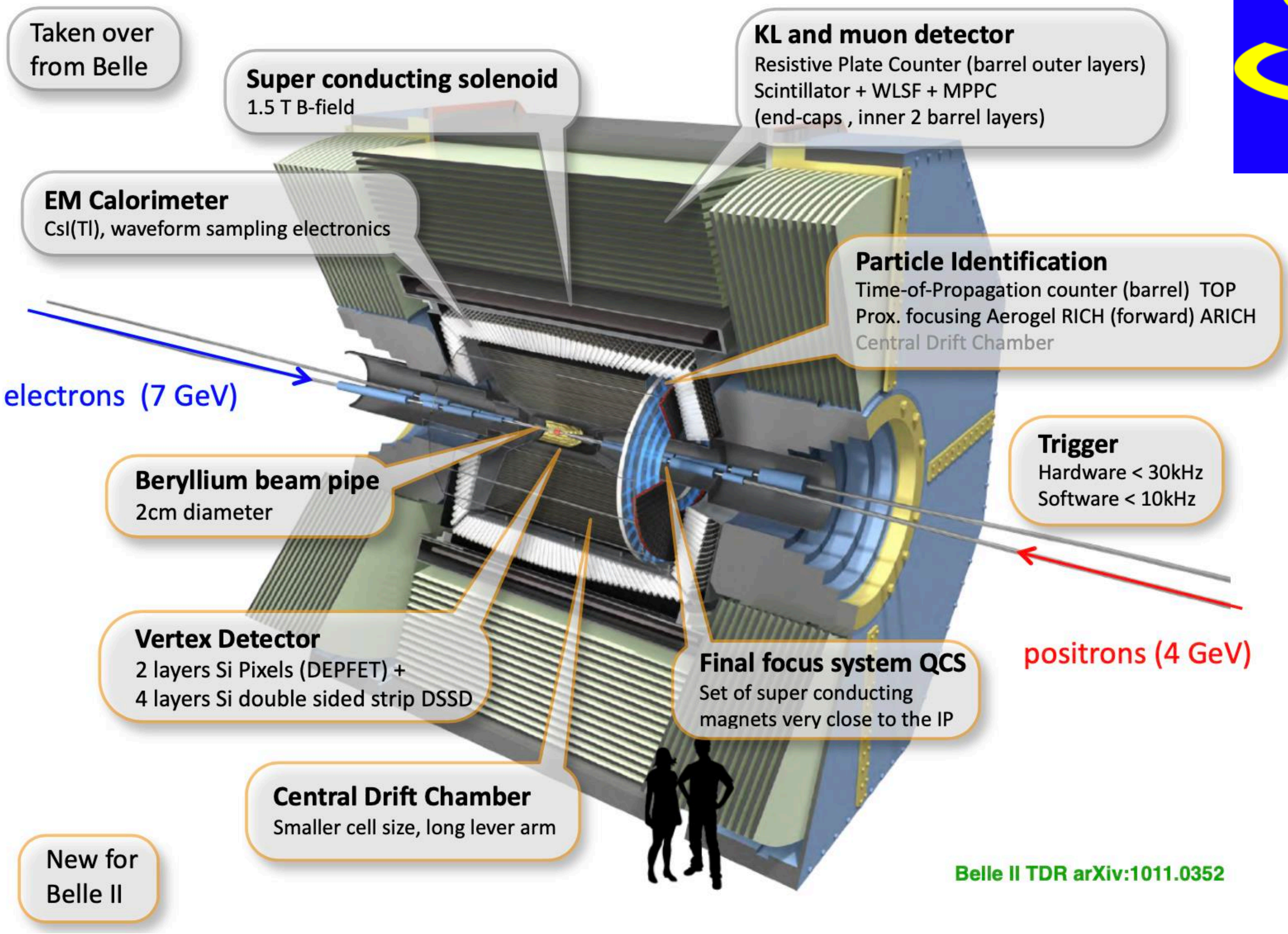
Forward Physics Facility

Proposed to CERN for operation in a separate cavern with rich science program



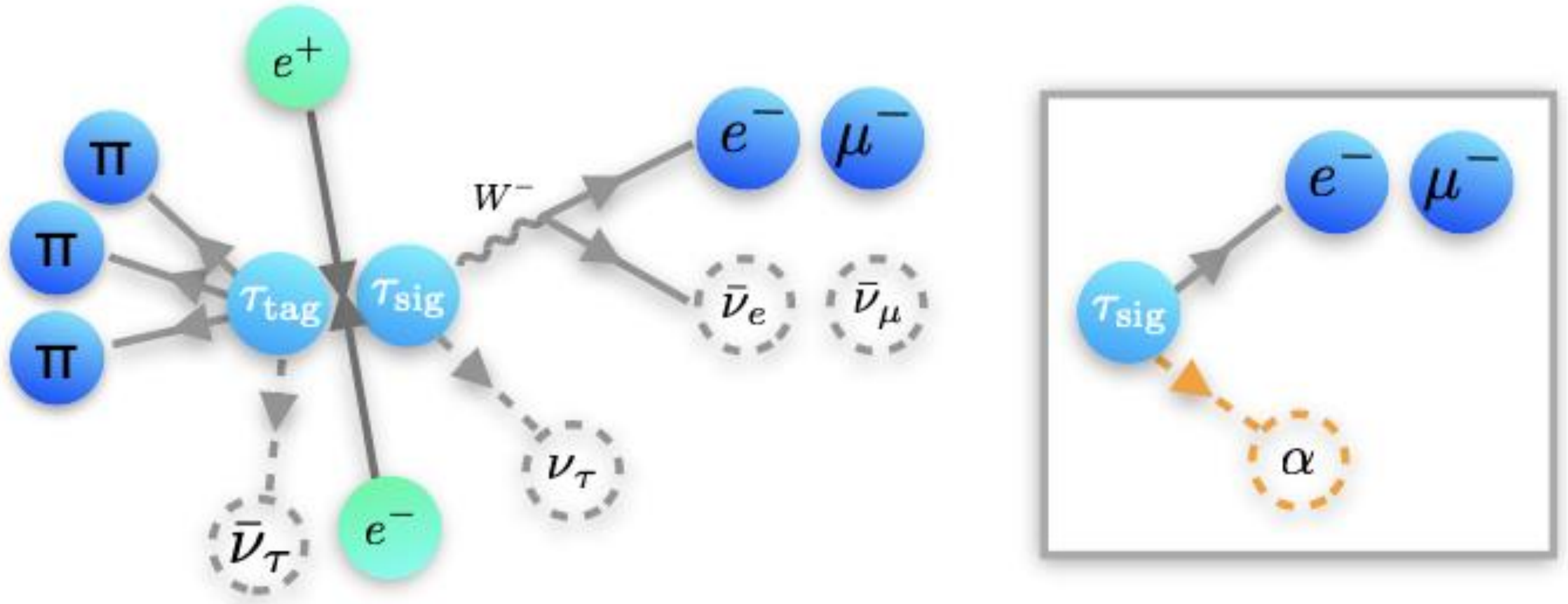
Belle II @ SuperKEKB

Eduard De La Cruz Burelo



Belle II TDR arXiv:1011.0352

Search for invisible τ decays

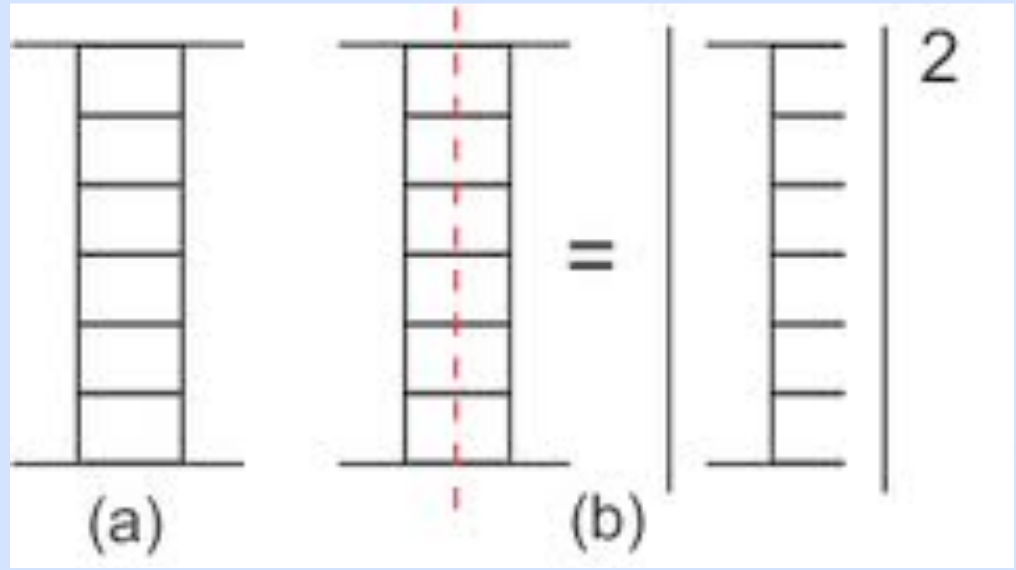


Interaction Models and EAS Modelling

Peter Skands (Pythia), Chloé Gaudu (tuning), Sergey Ostapchenko (QGSJet), Tanguy Pierog (EPOS), Klaus Werner (EPOS4), Felix Riehn (Sibyll), Ralph Engel (neutrons), Lukas Nellen (CORSIKA8)

Soft QCD Review (Peter Skands)

A — **Regge Theory**



Optical Theorem
+ Eikonal multi-Pomeron exchanges

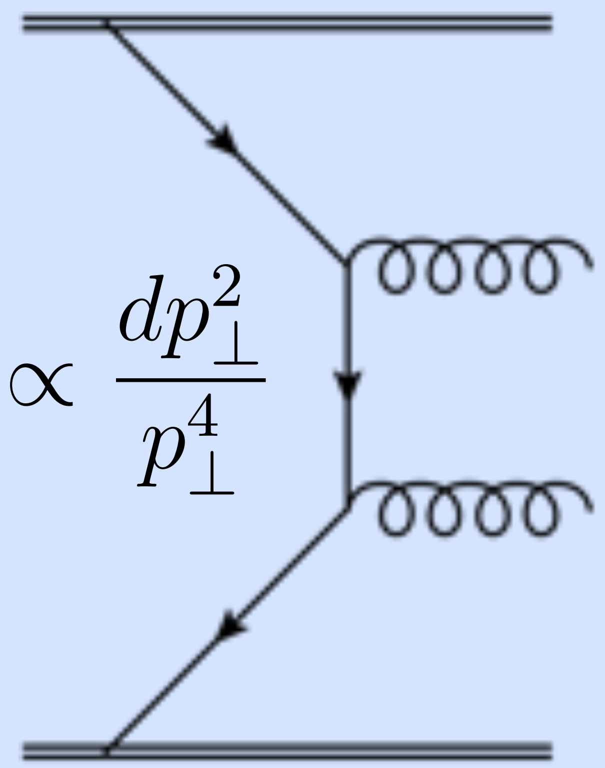
$\sigma_{tot,inel} \propto s^{\varepsilon}$ or $\log^2(s)$

Cut Pomerons → Flux Tubes (strings)
Uncut Pomerons → Elastic (& eikonalization)
Cuts unify treatment of all soft processes
EL, SD, DD, … , ND

Perturbative contributions added above Q_0

QGSJET

B — **pQCD-Based**



$$d\sigma_{2\to 2} \propto \frac{dp_\perp^2}{p_\perp^4} \otimes \text{PDFs}$$

+ Unitarity & IR Regularisation

→ **Multi-parton interactions (MPI)**
+ Parton Showers & Hadronization
Regulate $d\sigma$ at low p_{T0} ~ few GeV
Screening/Saturation → $\sqrt{s}$-dependent p_{T0}

Total cross sections from Regge Theory
(Donnachie-Landshoff + Parametrizations)

HERWIG, PYTHIA, SHERPA, SIBYLL

+ "Mixed"
EPOS, PHOJET

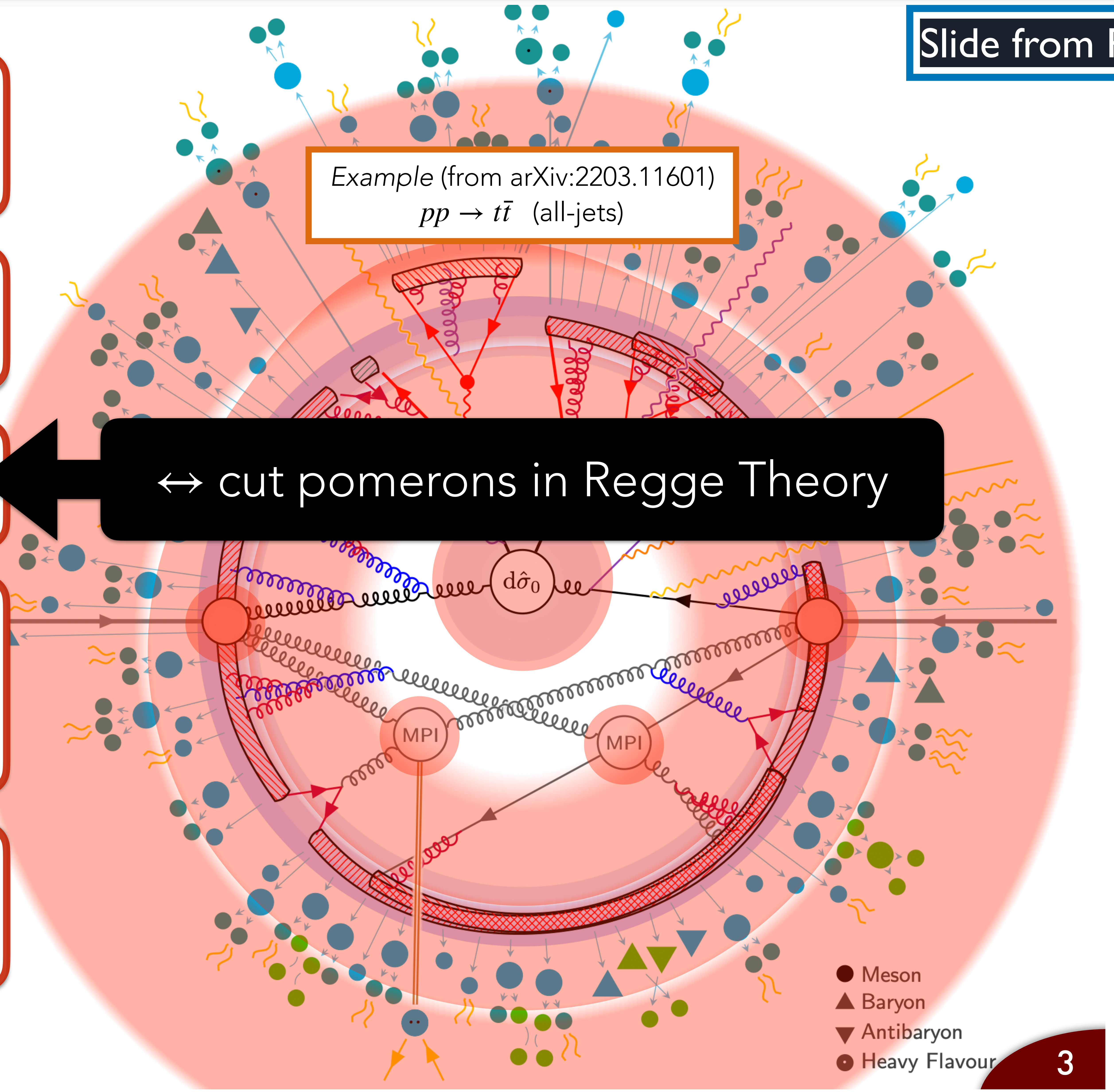
Structure of a HE pp-collision

Slide from P. Skands

Hard Process	○ Hard Interaction ● Resonance Decays ■ MECs, Matching & Merging
Parton Showers	■ QCD Final-State Radiation ■ QCD Initial-State Radiation* ■ Electroweak Radiation
2 **Underlying Event**	○ Multiparton Interactions □ Beam Remnants*
1 **Hadronization**	▨ Strings ■ Colour Reconnections ■ String Interactions ■ Bose-Einstein & Fermi-Dirac
Hadron (& τ) Decays	■ Primary Hadrons ■ Secondary Hadrons ■ Hadronic Reinteractions

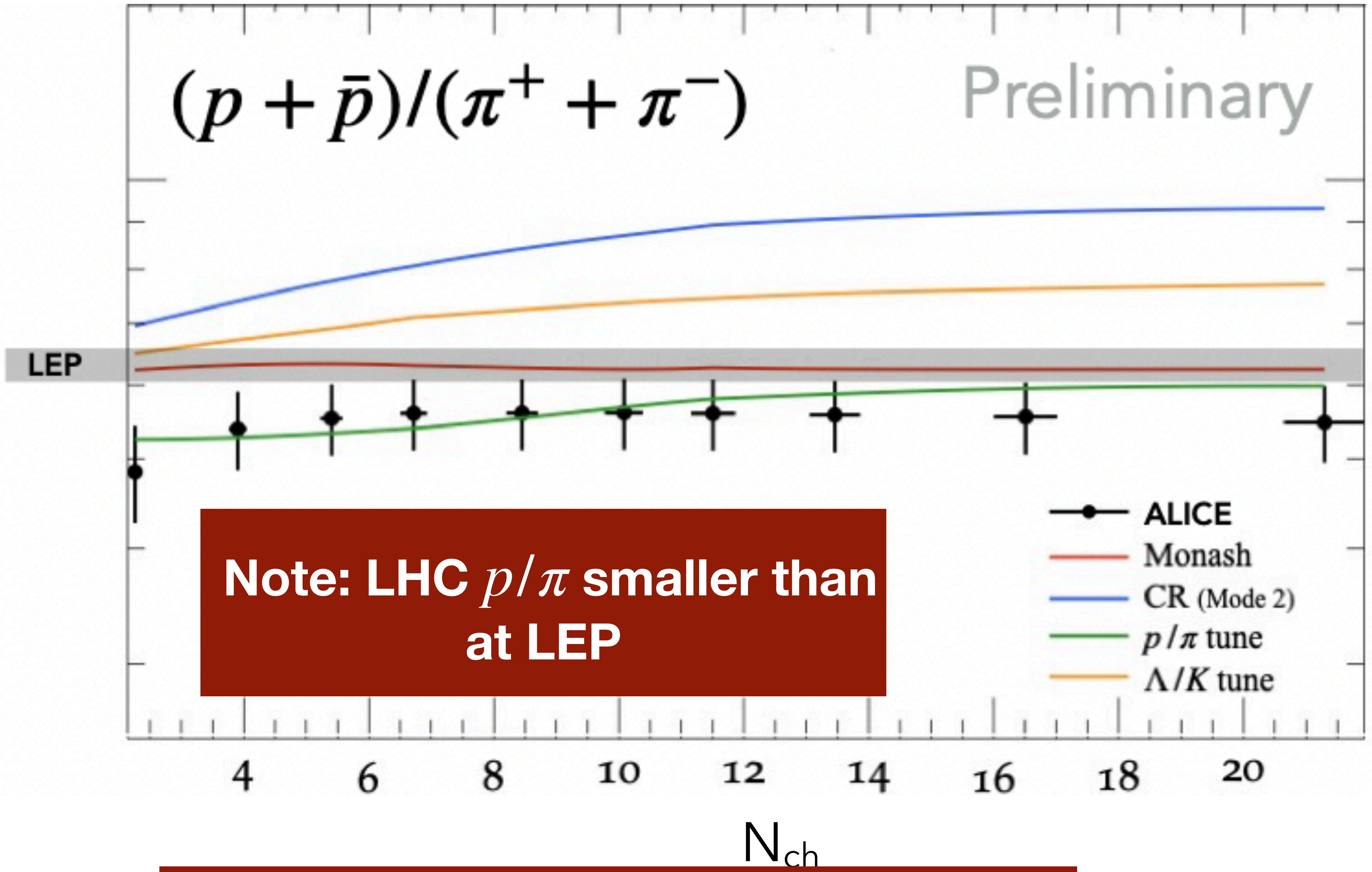
(: incoming lines are crossed)*

P. Skands



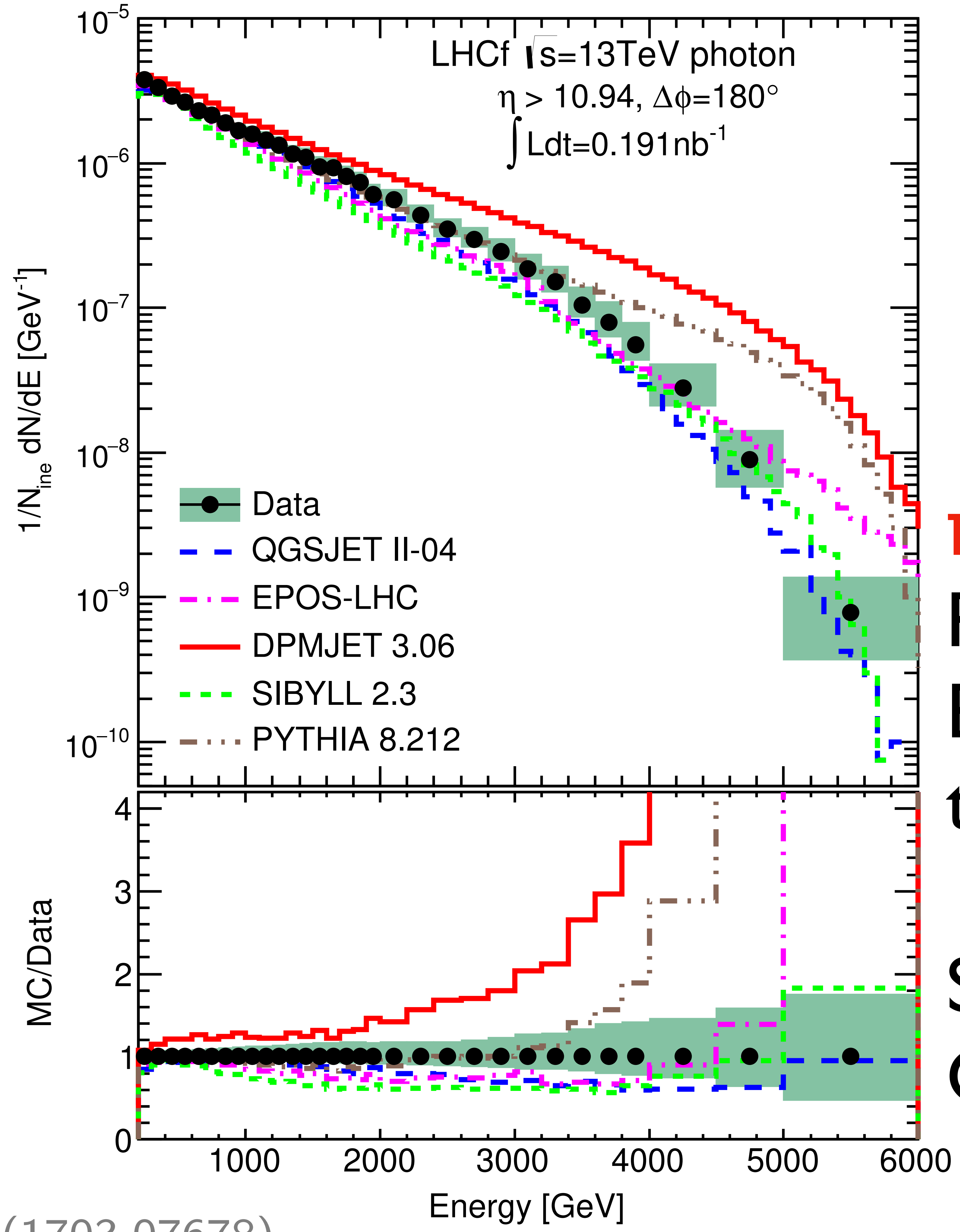
Some Issues: p/pi-ratio, pi0 production

P. Skands



Note: LHC p/π smaller than at LEP

Physics behind is not understood!



(1703.07678)

LHCf
(see also talk by H. Menjo)

π^0 spectra:
PYTHIA and EPOS-LHC too hard,

SIBYLL 2.3 and QGSJET II-04 ok

New Pythia Tune to LHCf Results

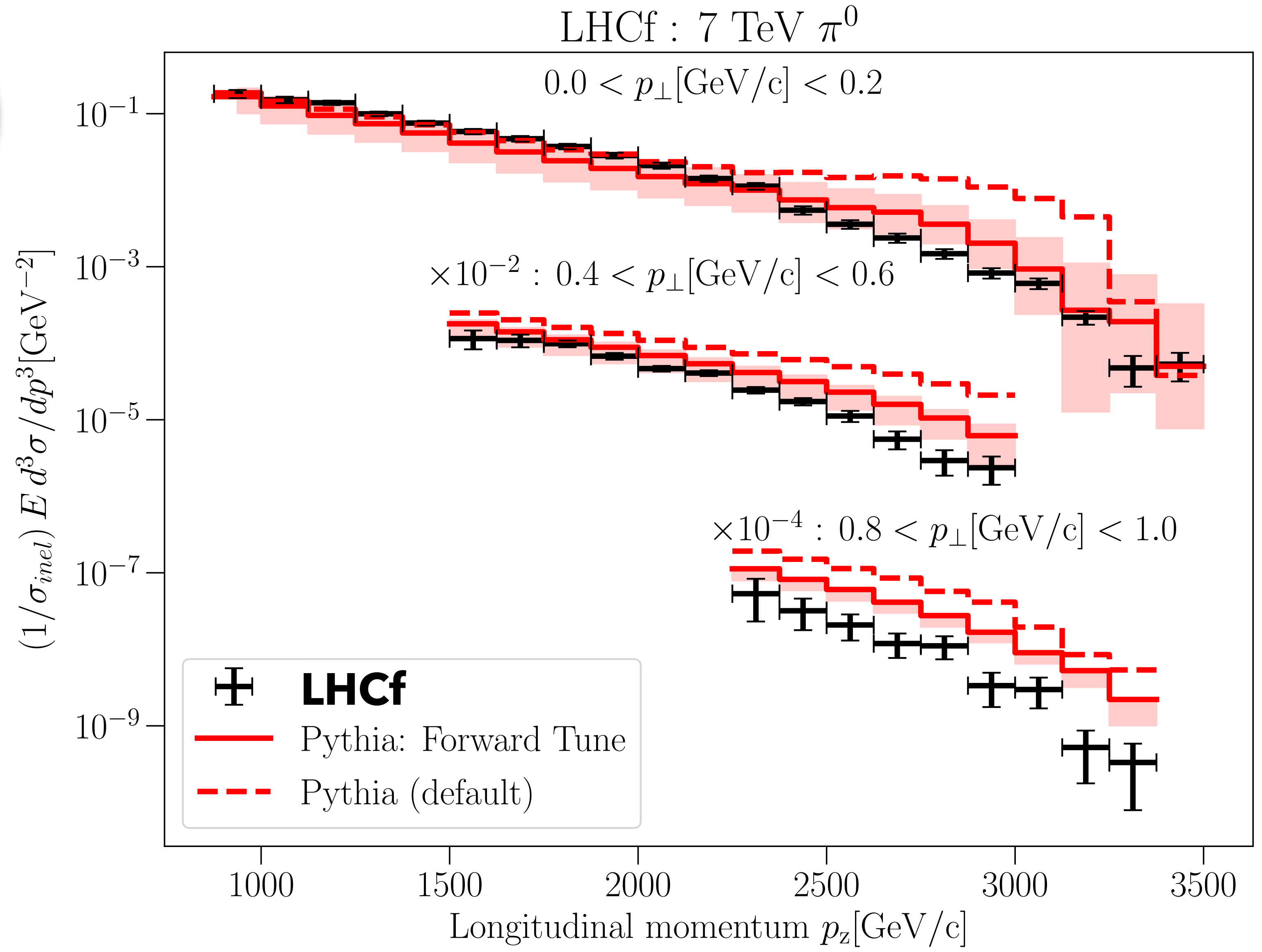
P. Skands

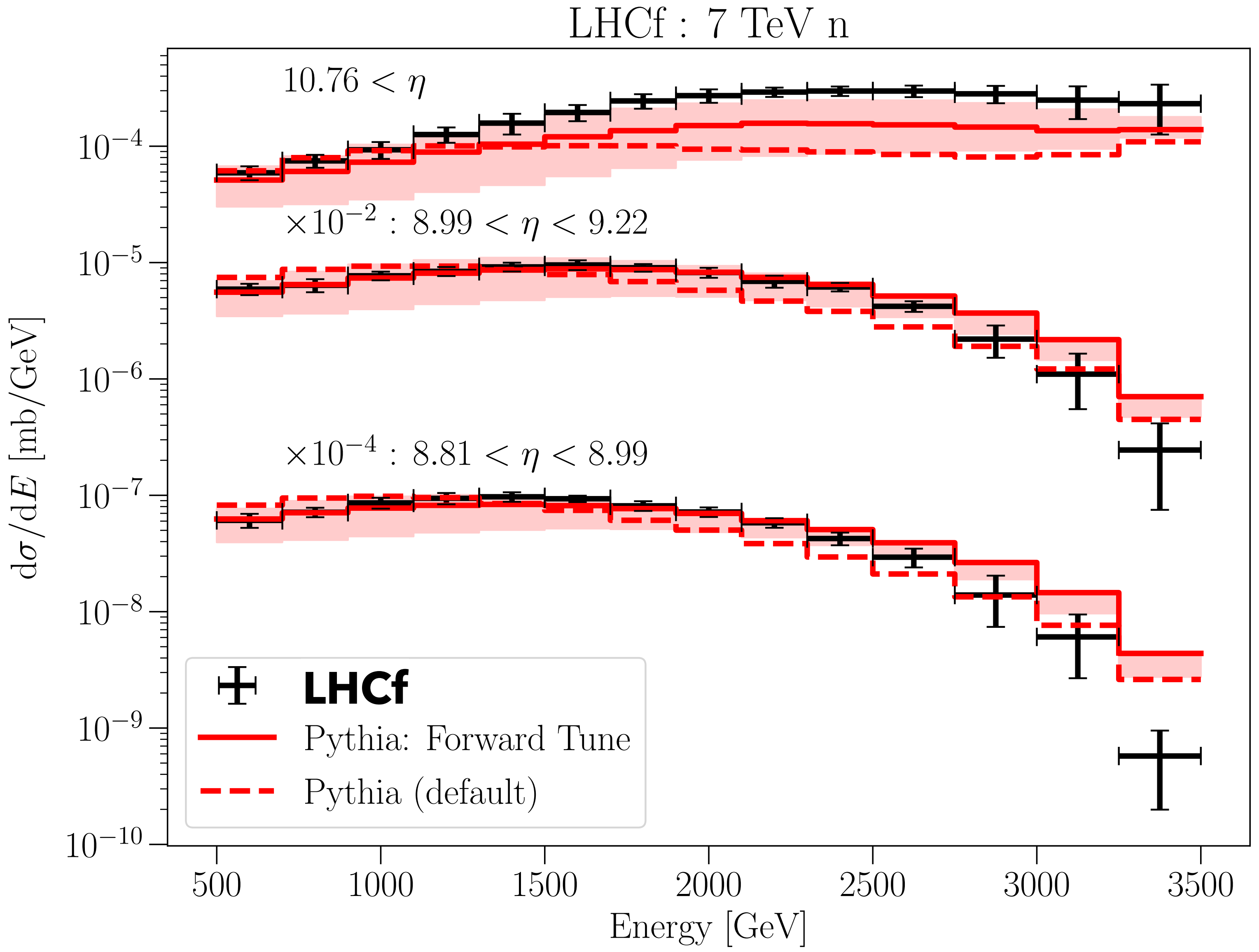
π^0

7 TeV

Recall:

Default was overshooting the pions and undershooting the neutrons





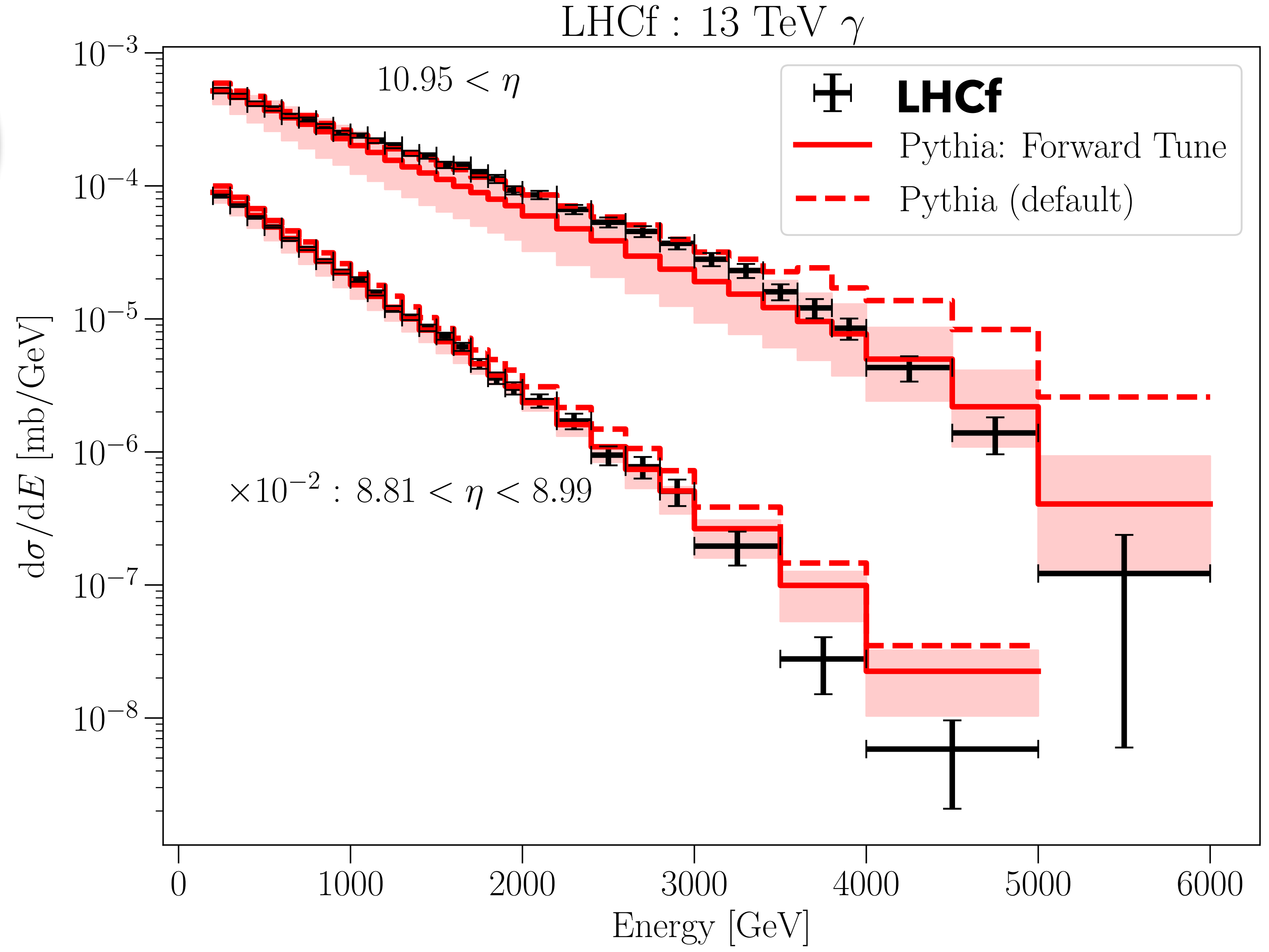
n

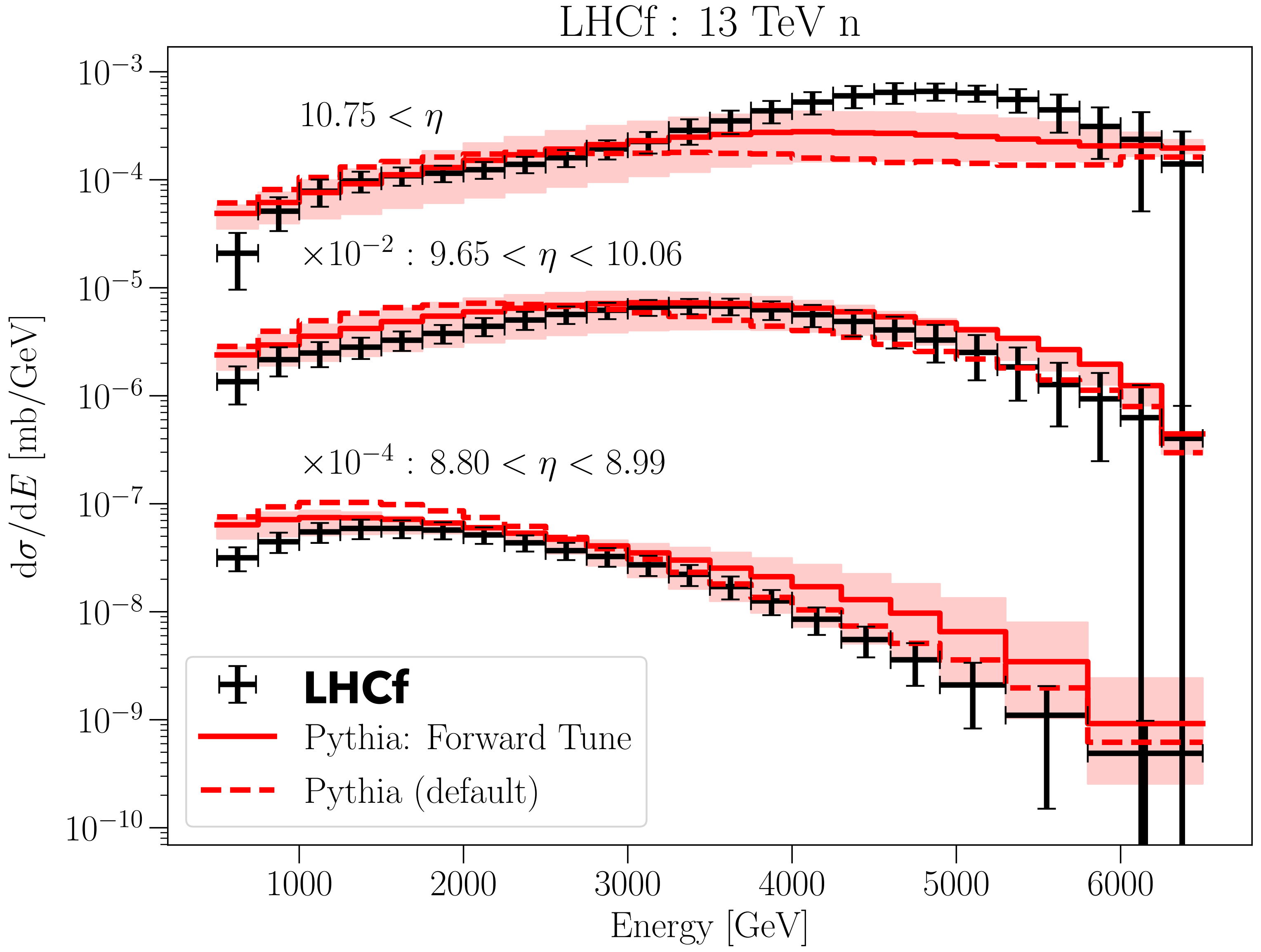
7 TeV

Sieg, Kling, Schulz, Sjöstrand; 2309.08604

γ

7 TeV





n

13 TeV

Conclusion:

Not perfect but significantly improved

New Pythia Tune to LHCf Results

P. Skands

π^0

7 TeV

Recall:

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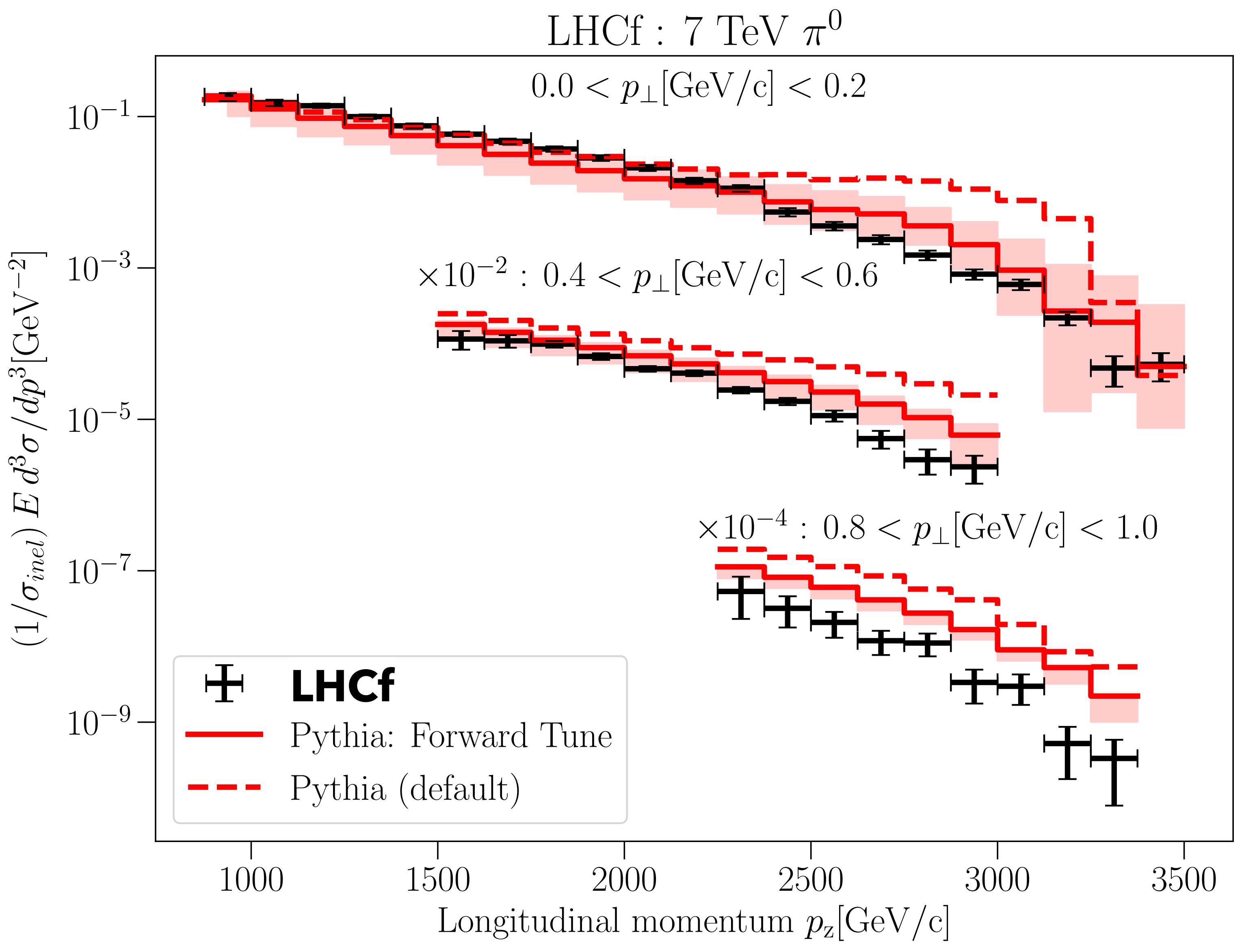
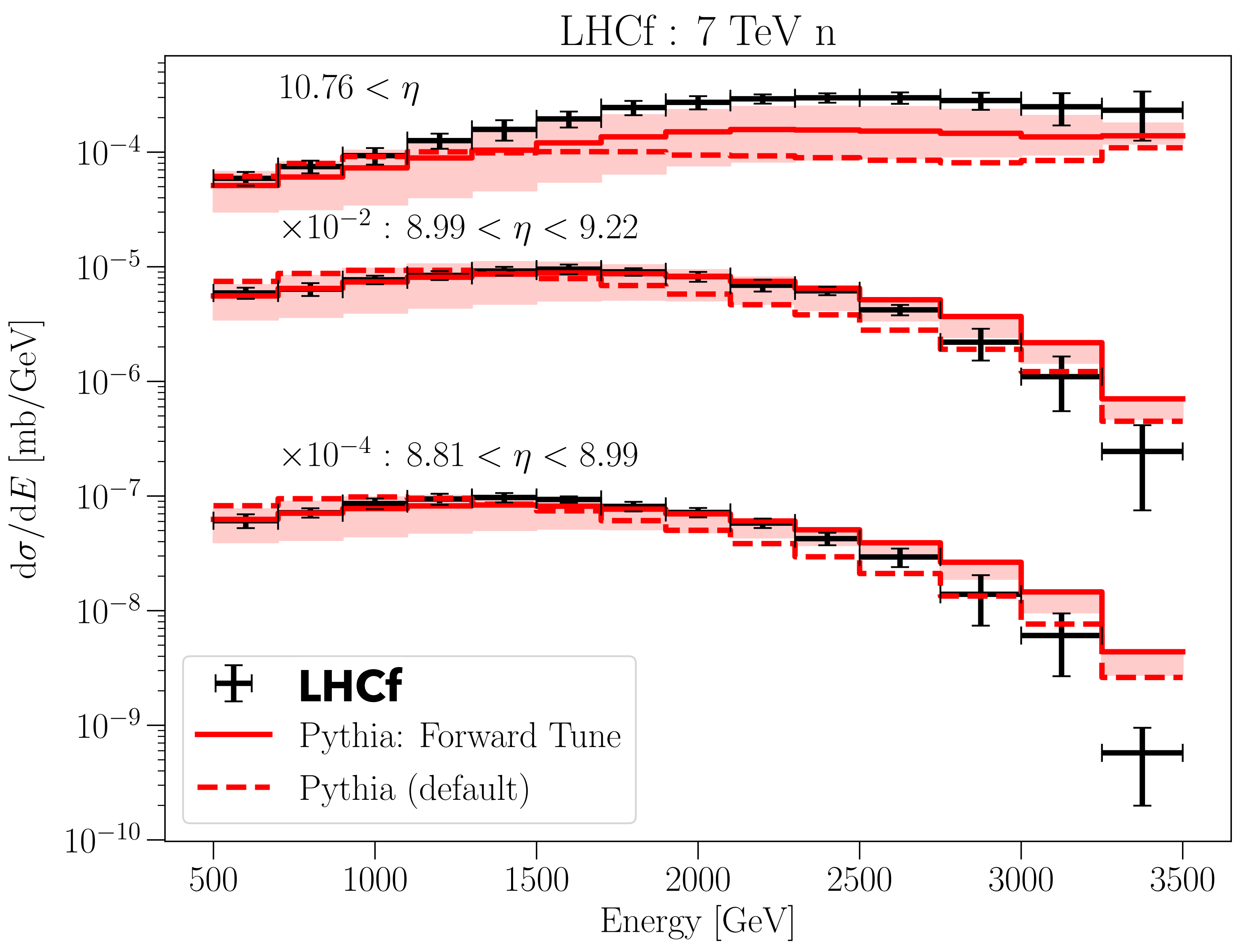




n

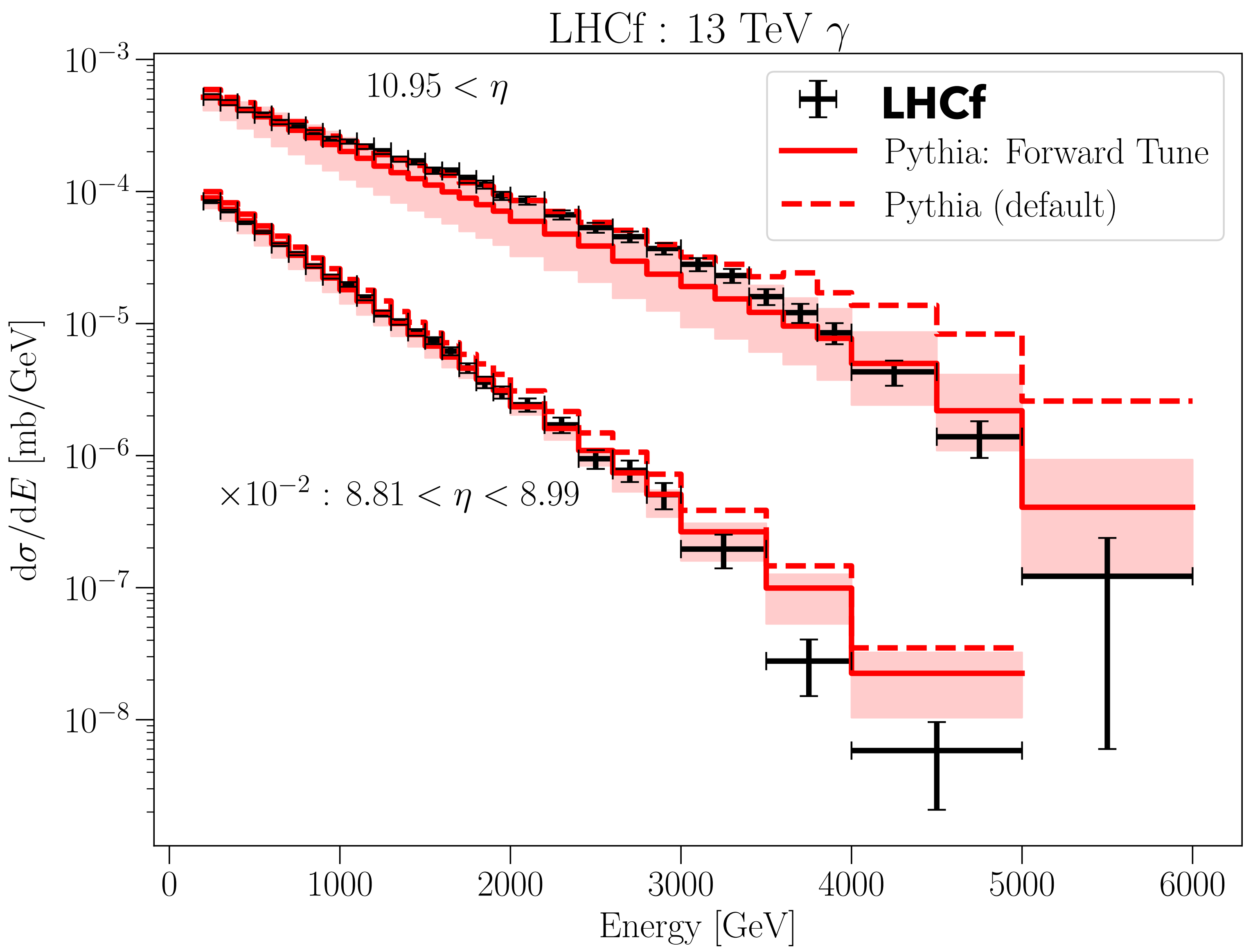
7 TeV

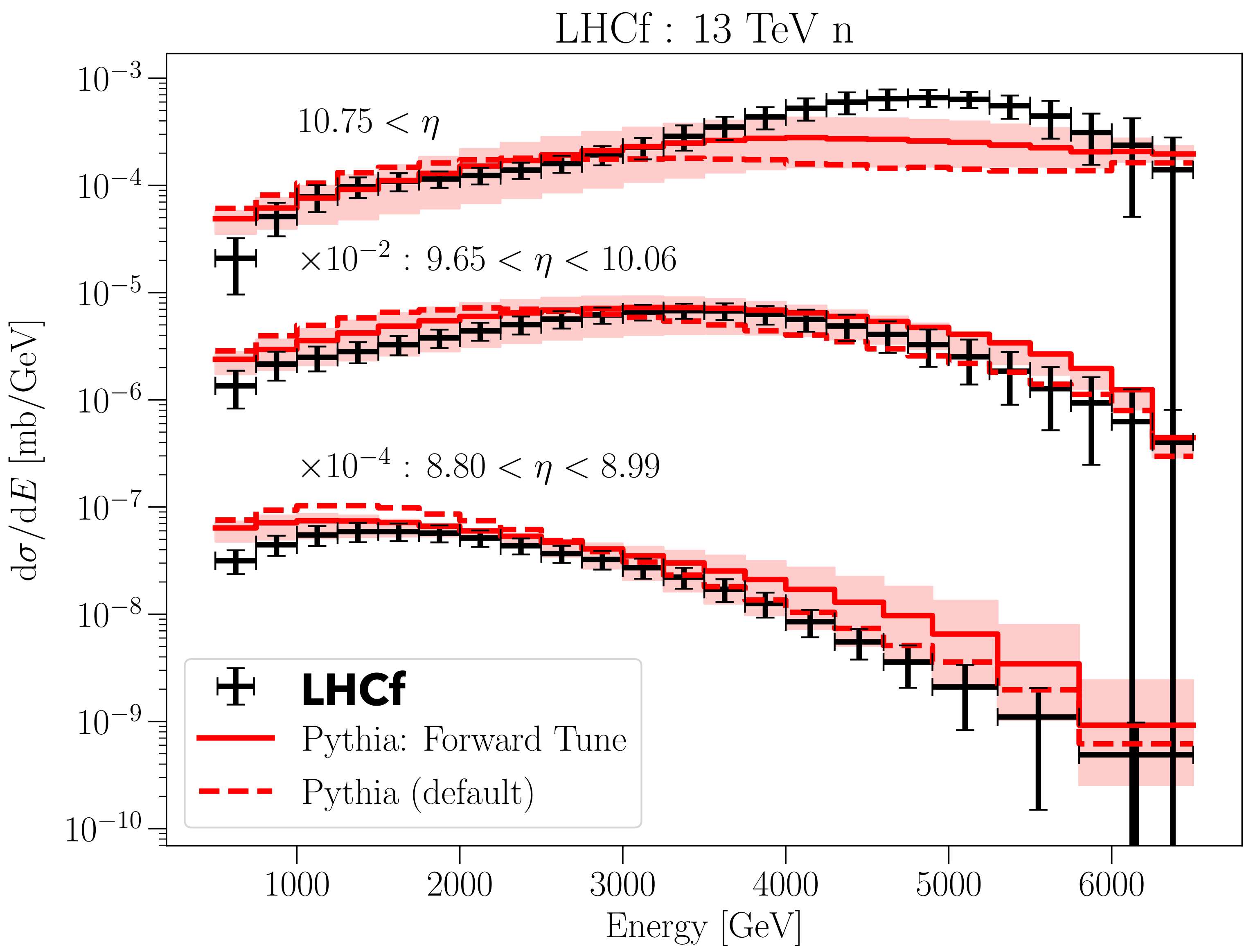
Sieg, Kling, Schulz, Sjöstrand; 2309.08604

Pythia now also applied to EAS data

γ

7 TeV





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New Pythia Tune to LHCf Results

P. Skands

π^0

7 TeV

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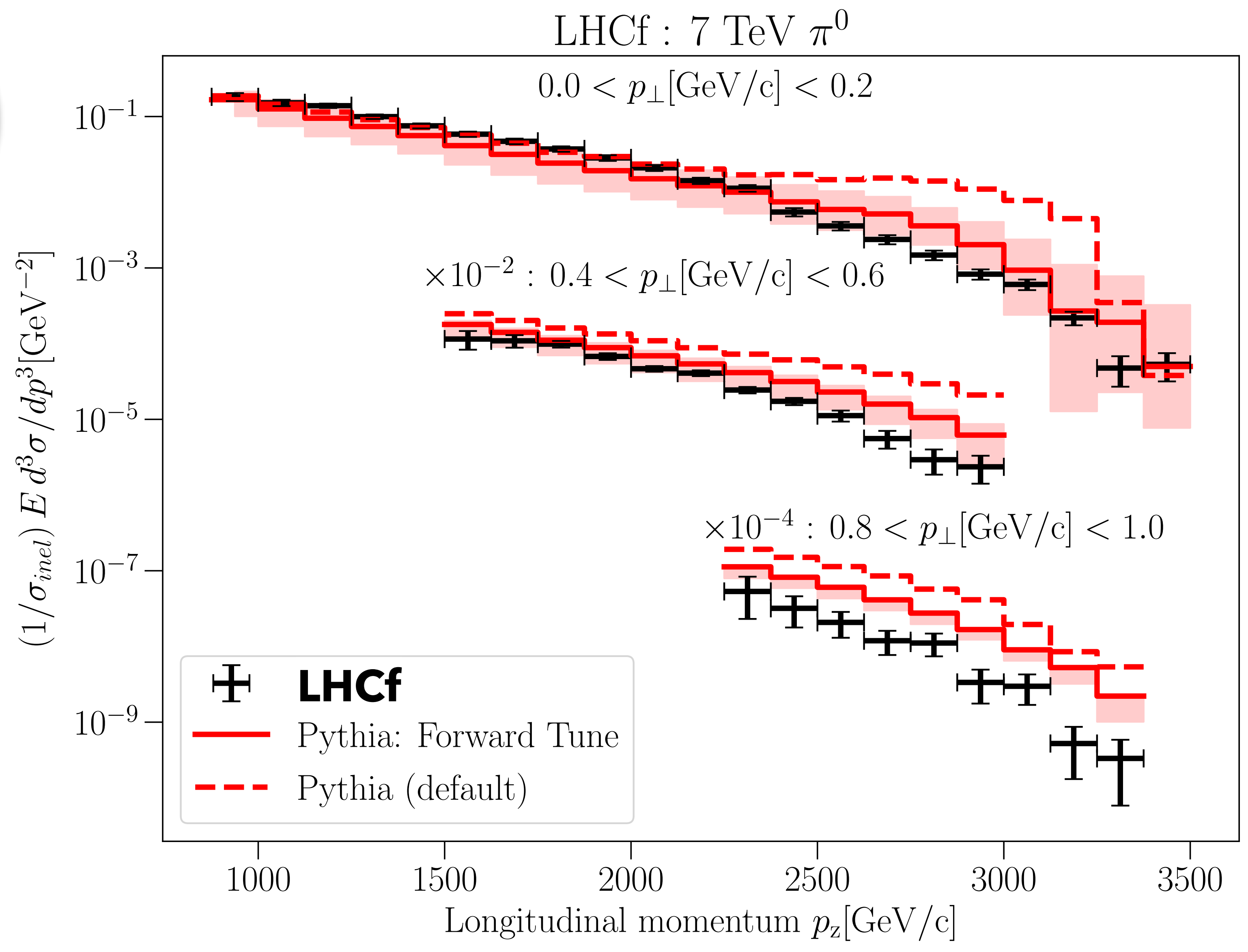
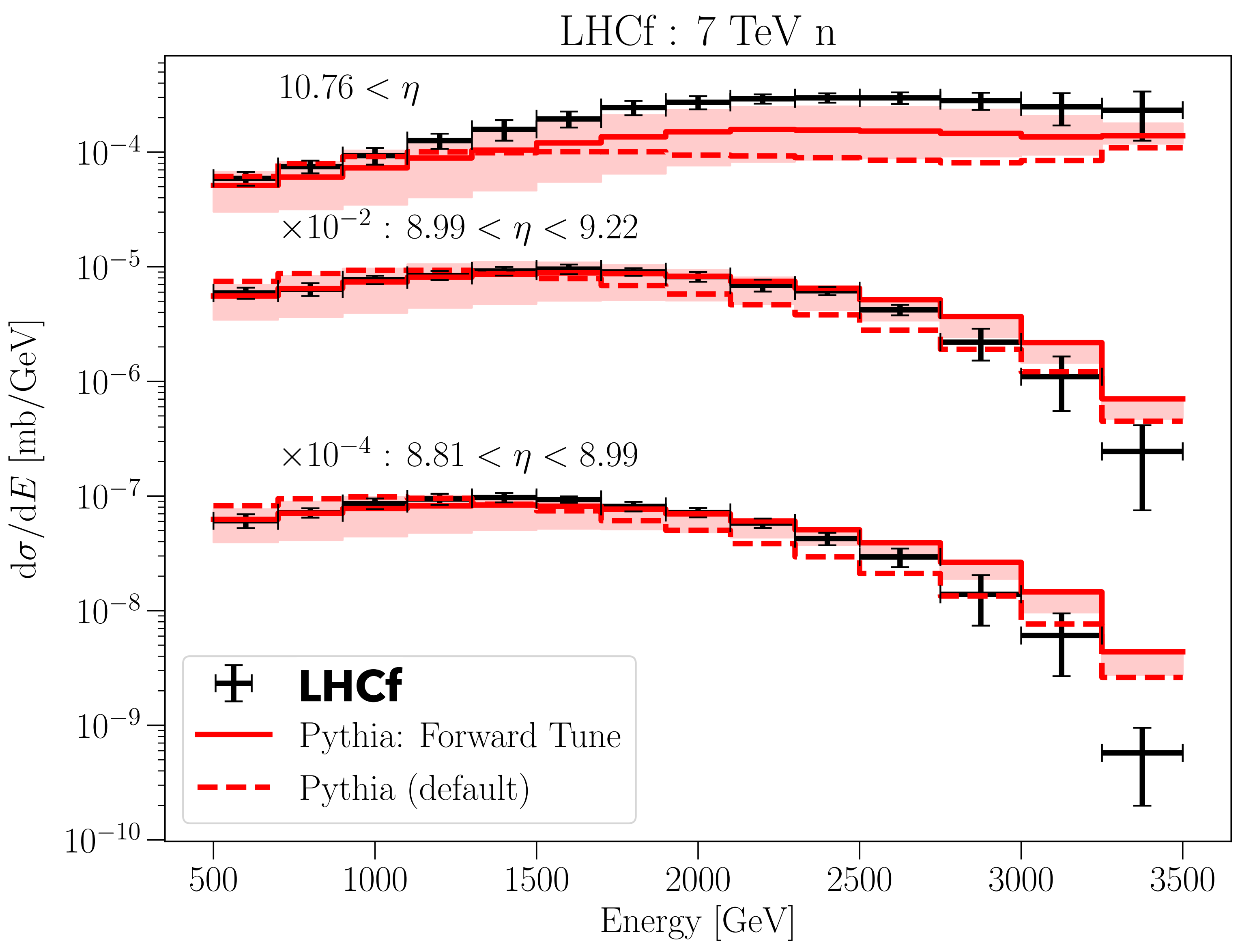




n

7 TeV

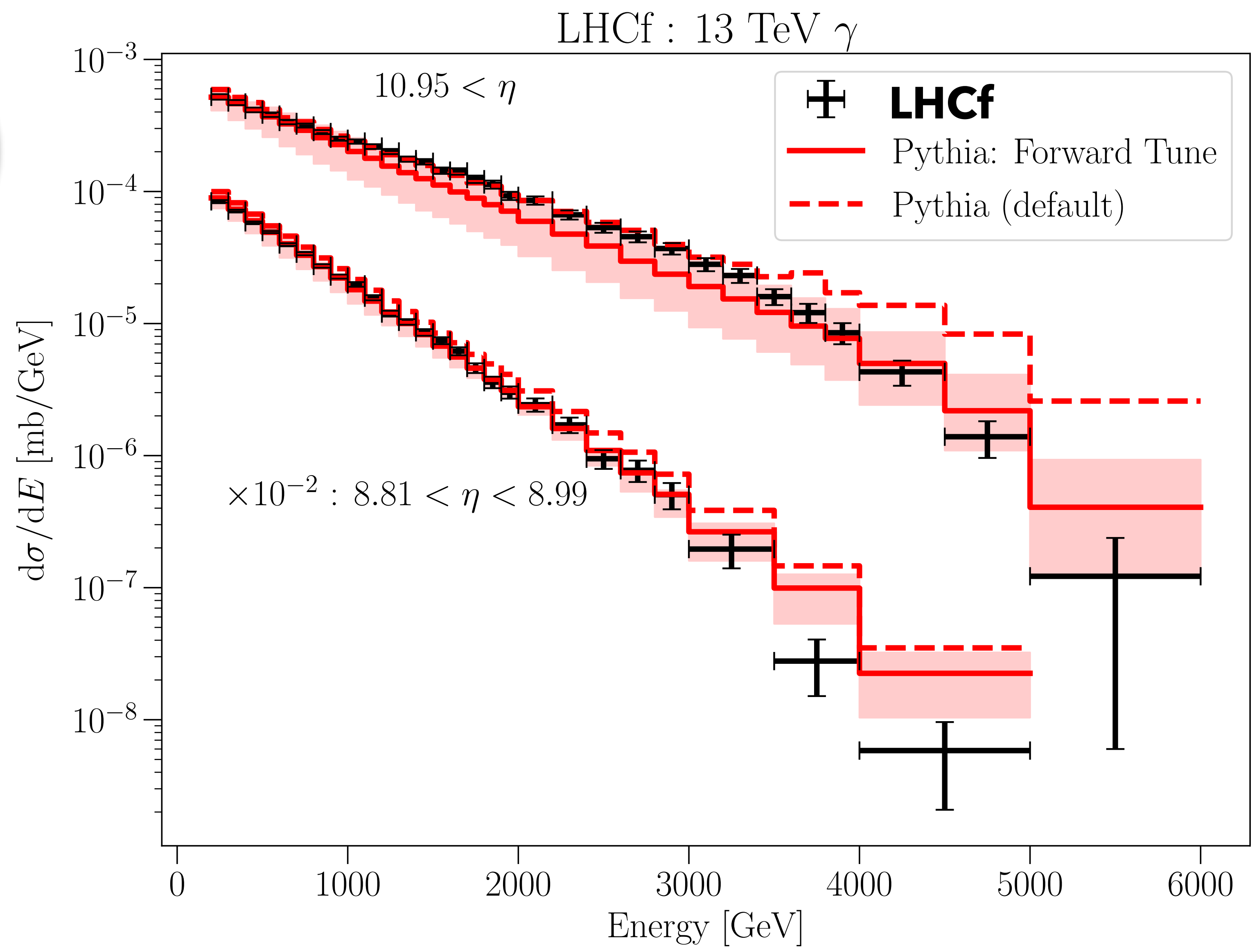
Sieg, Kling, Schulz, Sjöstrand; 2309.08604

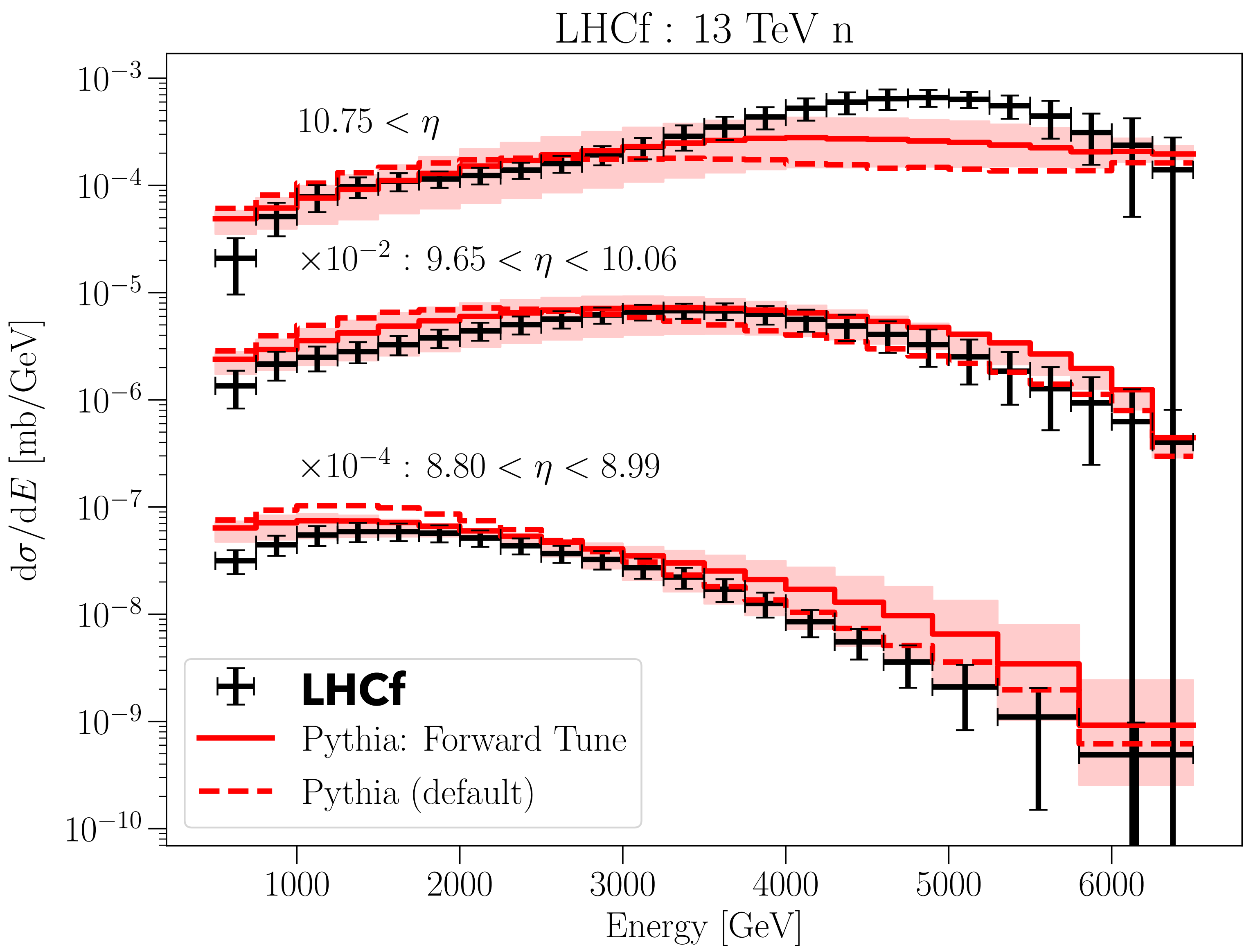
Pythia now also applied to EAS data

Angantyr → allow hadron-nucleus

γ

7 TeV





n

13 TeV

Conclusion:

Not perfect but significantly improved

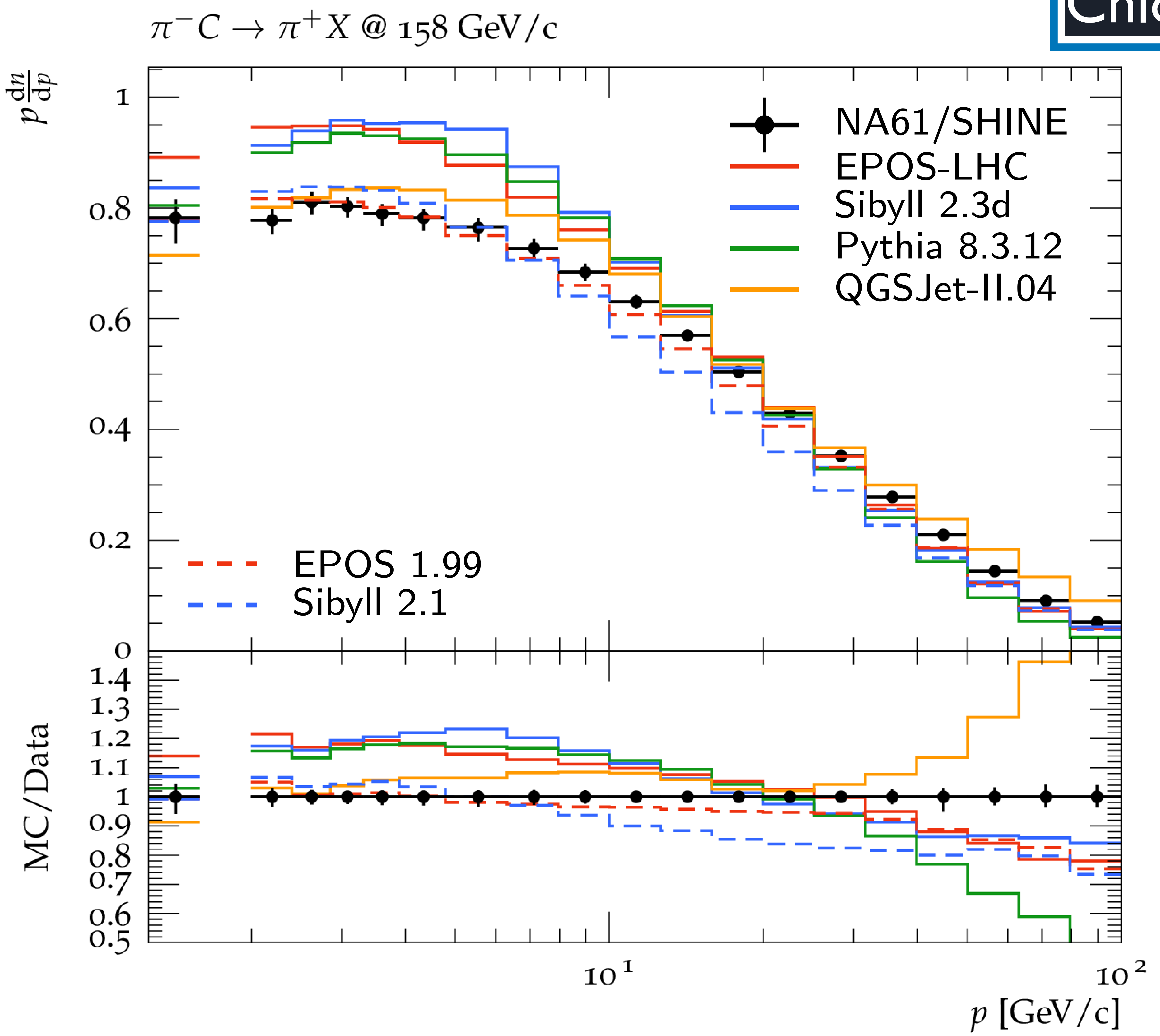
Global EAS/Accelerator tuning of PYTHIA (Angantyr)

Chloé Gaudu

Rivet plug-in

↳ NA61/SHINE publication[3]

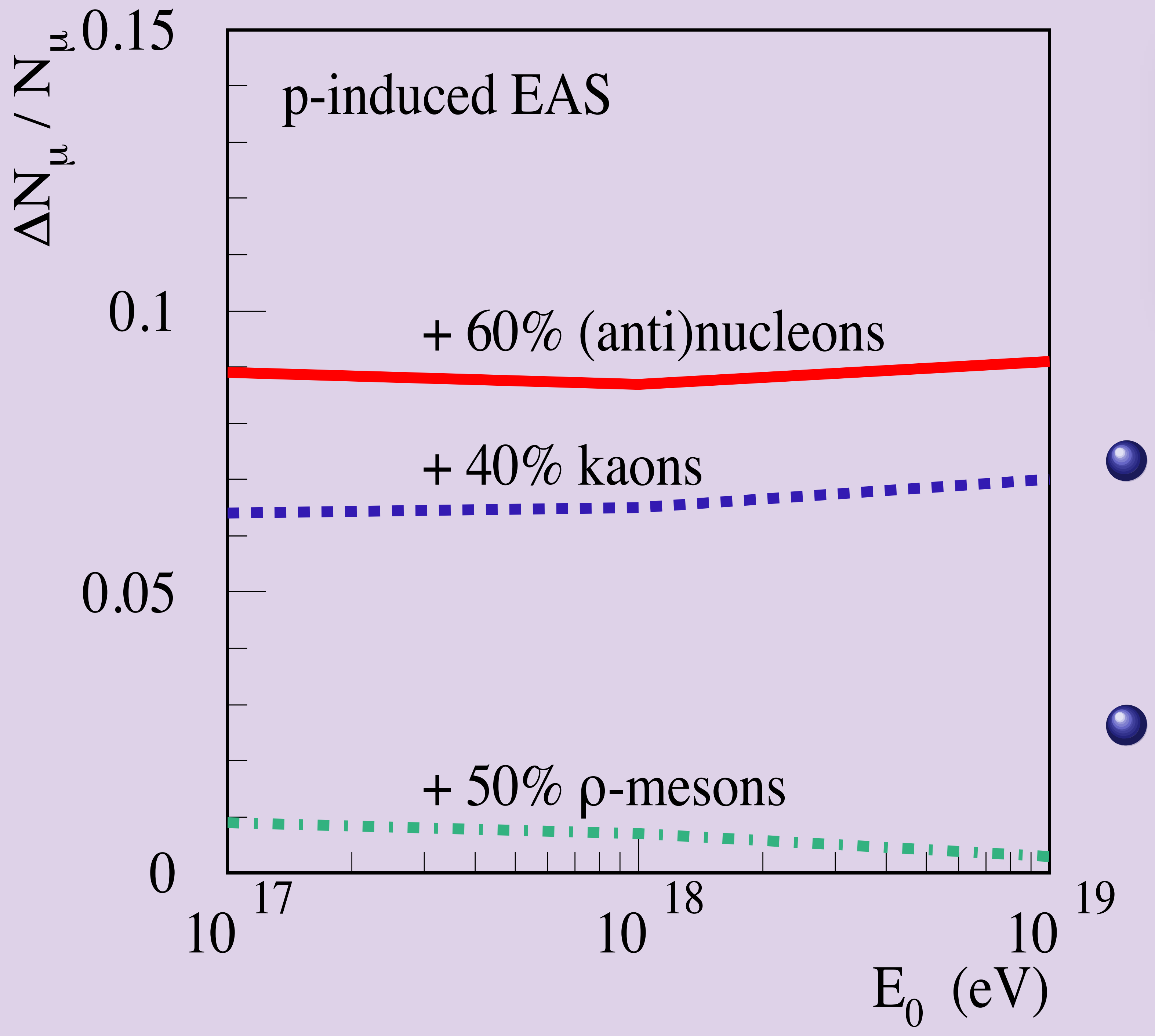
- fixed-target collisions
  - ↳ $\pi^- C$ interactions
  - ↳ $p_z(\pi^-) = 158,\ 350$ GeV/c
- hadron production spectra
  - ↳ $p\frac{dn}{dp}$ distributions
  - ↳ π^+, π^-, K^+, K^-, p and $\bar{p}$
  - ↳ (+ K^0_s, Λ, $\bar{\Lambda}$)



[3] Phys. Rev. D 107, 062004 (2023)

QGSJET-III (Sergey Ostapchenko)

Relative changes of the calculated N_μ: $\lesssim 10\%$



Number of improvements, but increasing μ-number by more than 10% difficult w/o violating accelerator data

- small impact of the the considered enhancements on $\sum_{h=\text{stable}} \langle x_E^h \rangle$
- $\Rightarrow$ one can't enhance N_μ by more than $\sim 10\%$, without contradicting accelerator data!

3 main 'switches' for changing $X_{\max}$ predictions

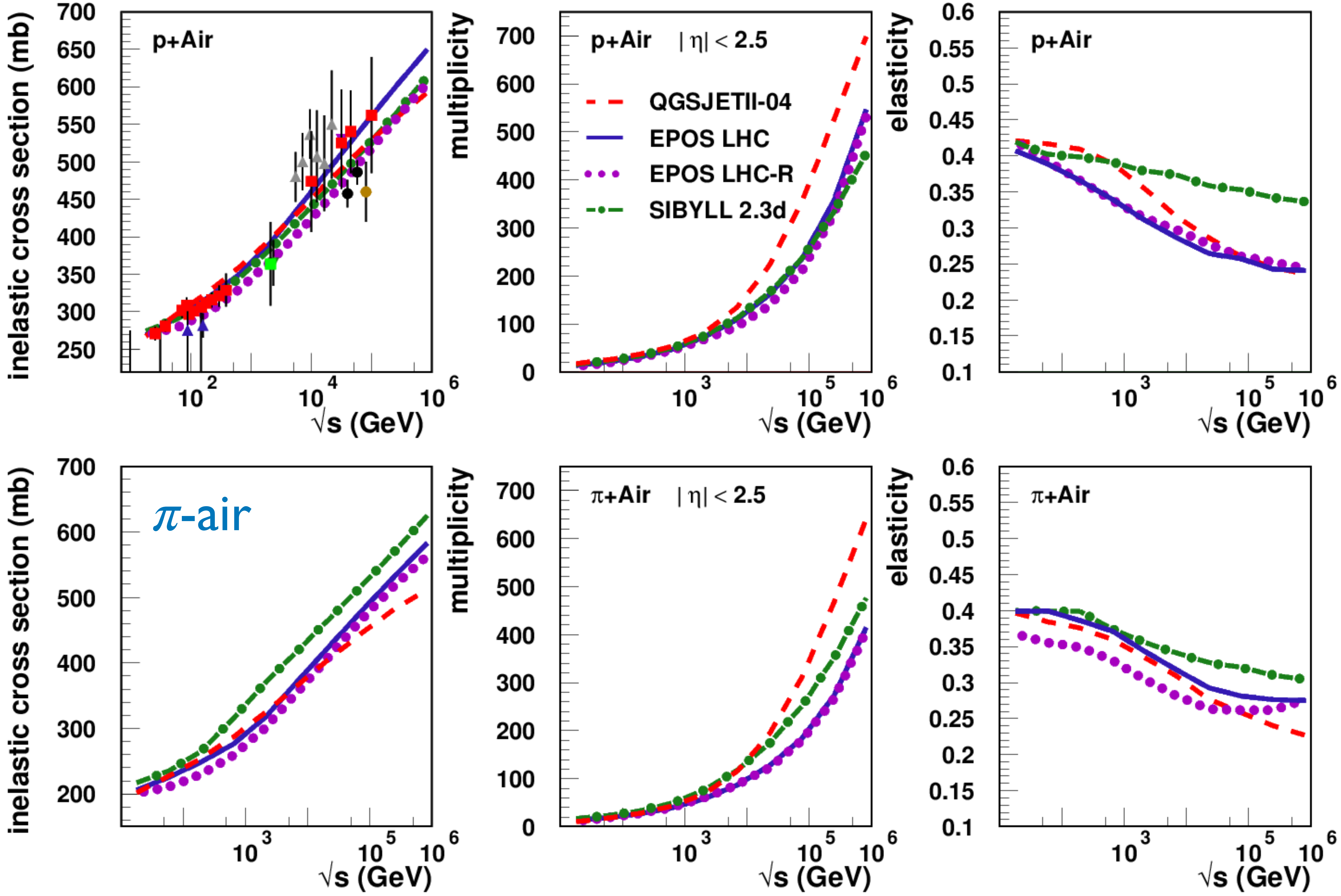
- inelastic proton-air cross section ($\sigma^{\text{inel}}_{p-\text{air}}$)
- inelastic diffraction rate ($\sigma^{\text{diffr}}_{p-\text{air}} / \sigma^{\text{inel}}_{p-\text{air}}$)
- inelasticity of non-diffractive interactions ($K^{\text{inel}}_{p-\text{air}}$)

EPOS LHC-R

Tanguy Pierog

EPOS LHC-R:
Updates in cross section, multiplicity, fragmentation, and diffraction

Impact on X_{max}, core-corona, and μ-number



differences to EPOS LHC mostly in π-Air (not in p-Air)

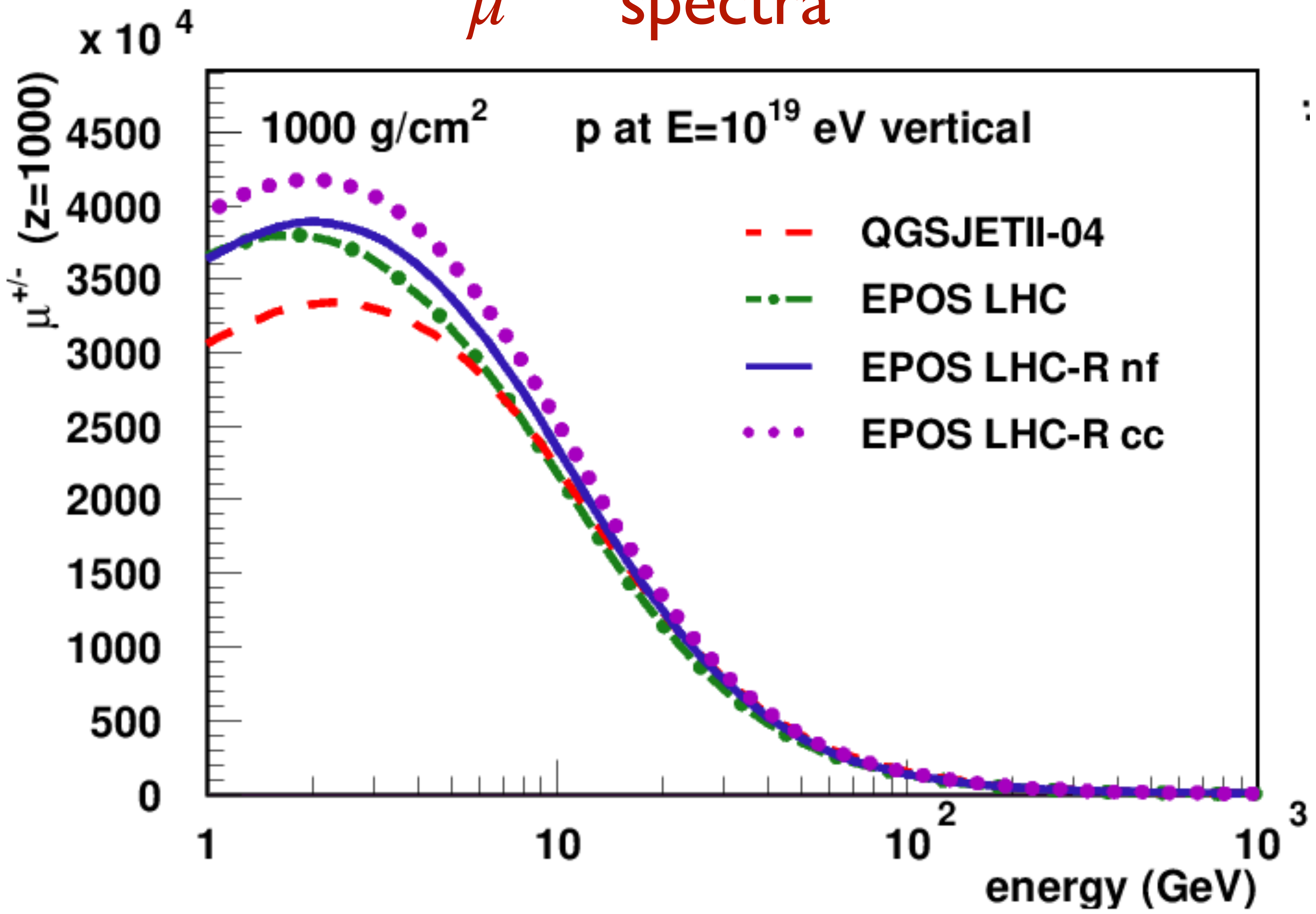
X_{max} shifted by +10 g/cm²

EPOS LHC-R

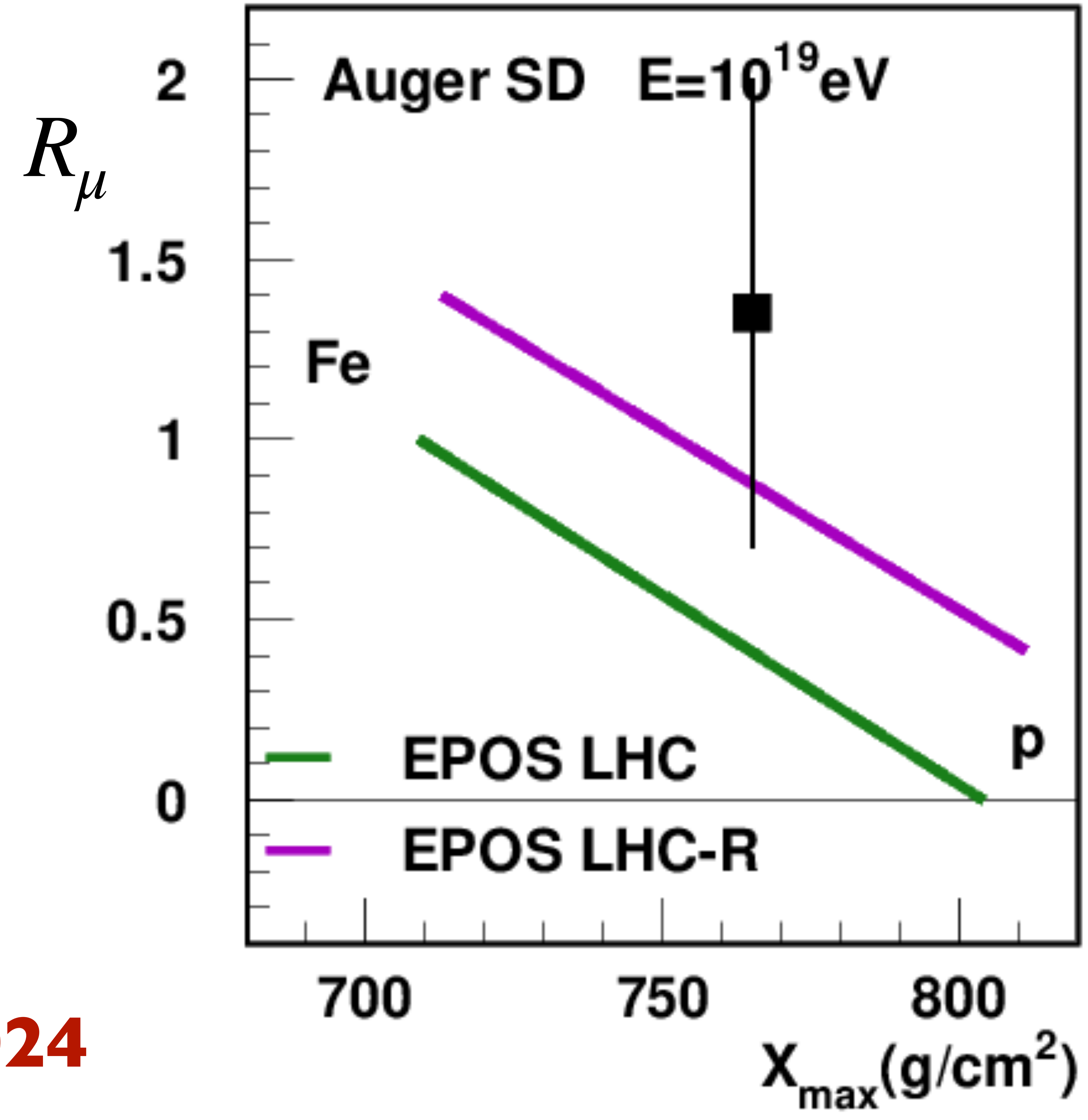
Tanguy Pierog

Now also up-to-date Core-Corona implementation…

$\mu^{+/-}$ spectra



μ-puzzle solved ⁇



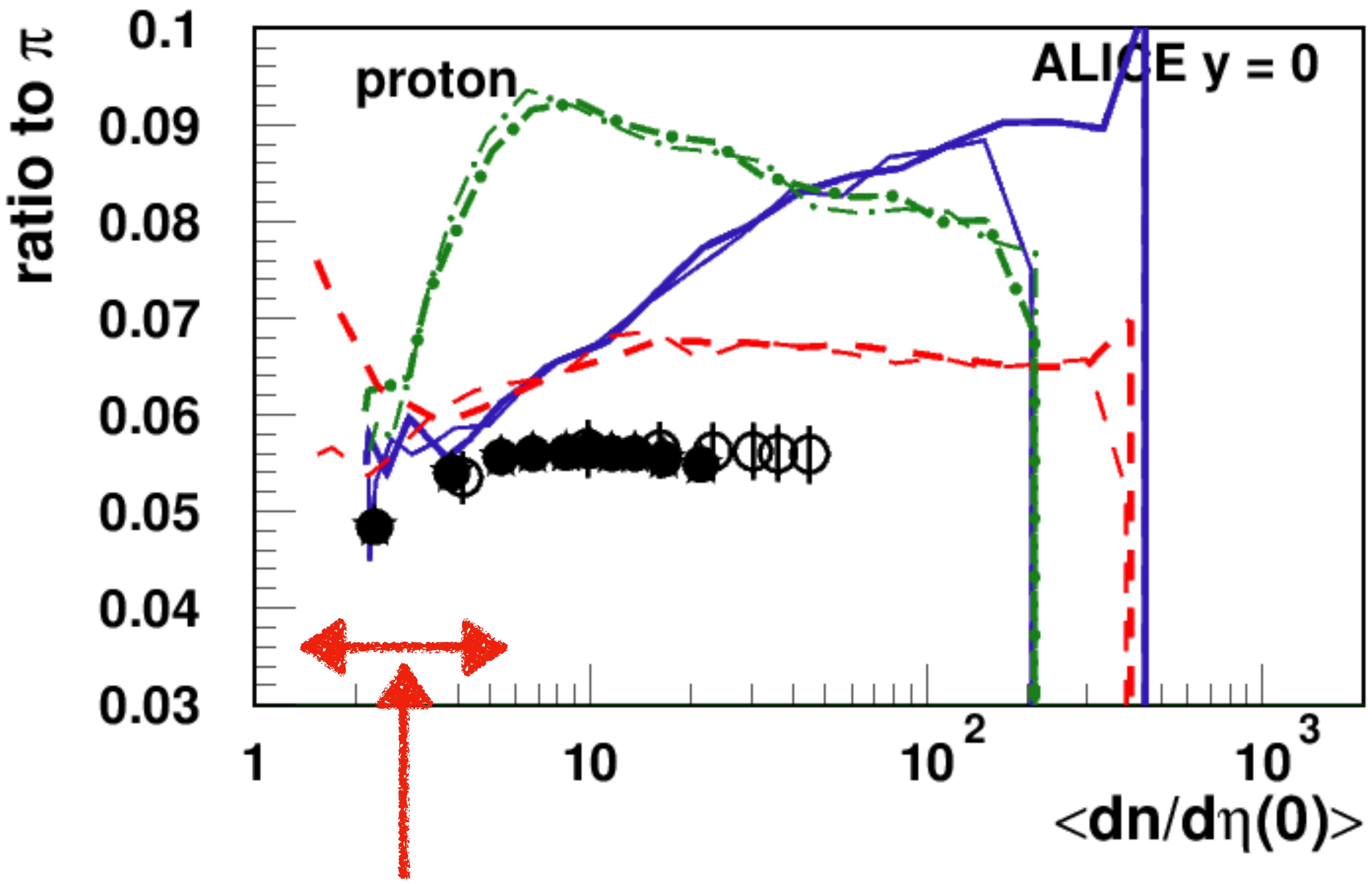
promised to be released 2024

EPOS LHC-R

Tanguy Pierog

However, some puzzles need to be addressed, still

e.g. p/π ratio compared to ALICE

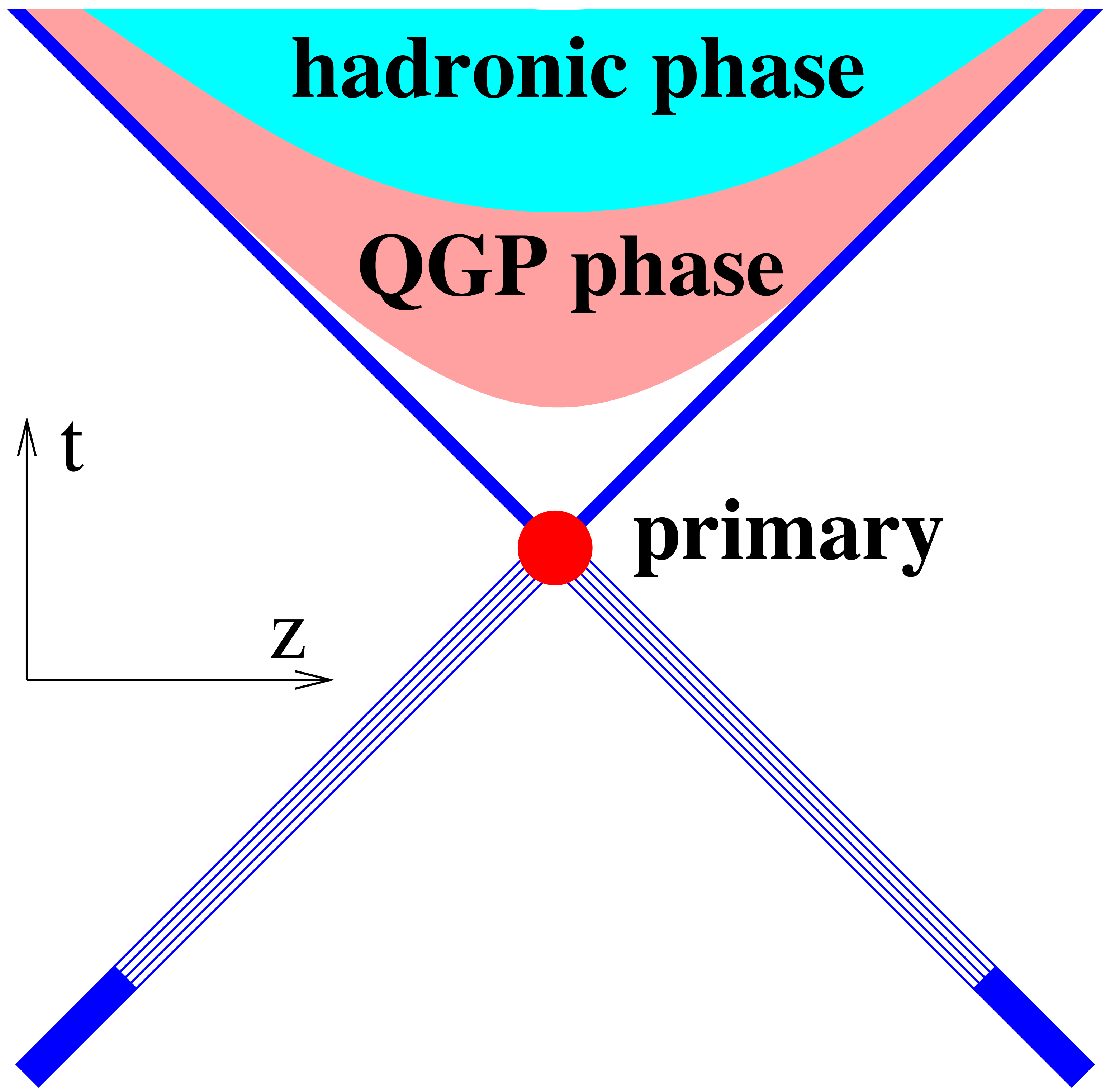


However, most important part is this…

EPOS4: A New Approach

Klaus Werner

More realistic space-time picture



EPOS4 philosophy

concerning primary interactions

- **Avoid sequential scatterings,**
  - **concerning both parton-parton**
  - **and nucleon-nucleon interactions**
- **Do multiple scatterings rigorously in parallel**
- **Respect the rule "MC = theory"**

→ one gets factorisation (in pp and A+B) for inclusive X-sections at high pt in a fully self consistent multiple (parallel) scattering scheme

FLUKA: „Low-Energy Interaction Model"

Alfredo Ferrari

Major Updates and Improvements

Hadronization recently completely revised
→ much better description of ω, ρ^0 Feynman-x in $\pi + p$ @ 250 GeV

Glauber with cross section fluctuations → $\sigma(p - Air)$ described well

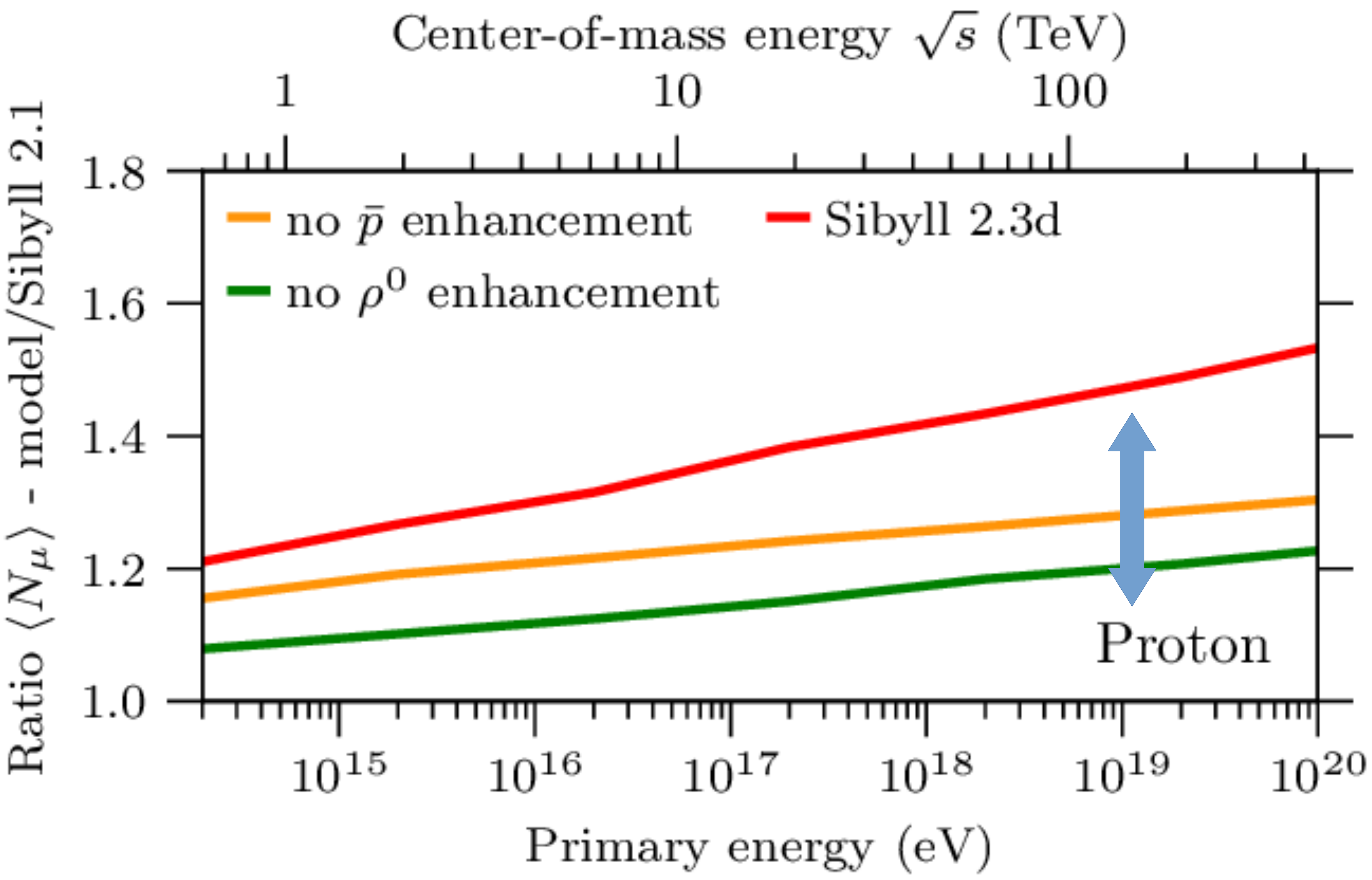
Improved neutron production

Improved photo-nuclear interactions

Interface with UHECR generators (and with CORSIKA 7/8)

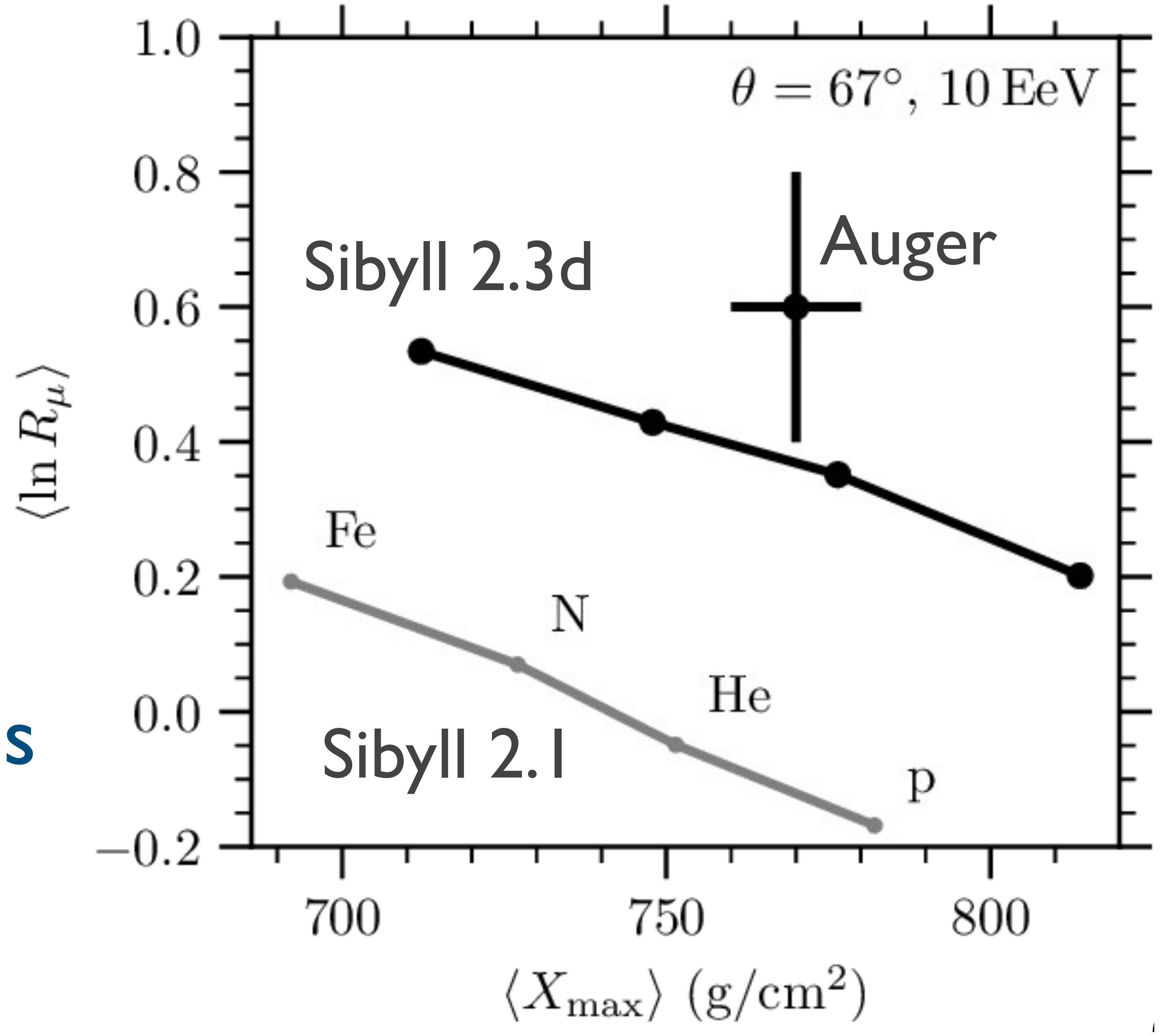
Sibyll 2.3d

Felix Riehn



Modified baryon and
forward rho production

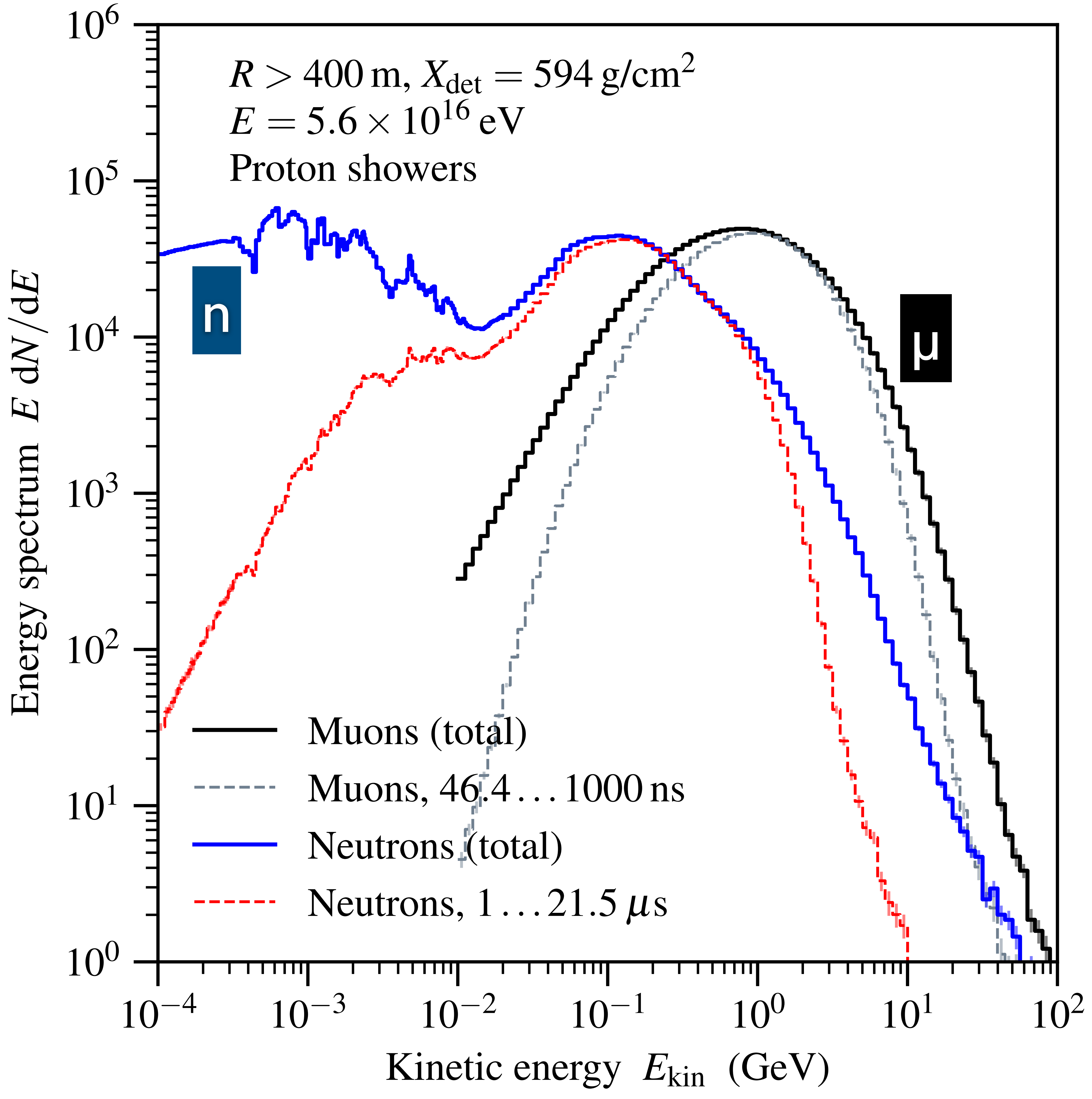
→ μ-number increases by ~40%

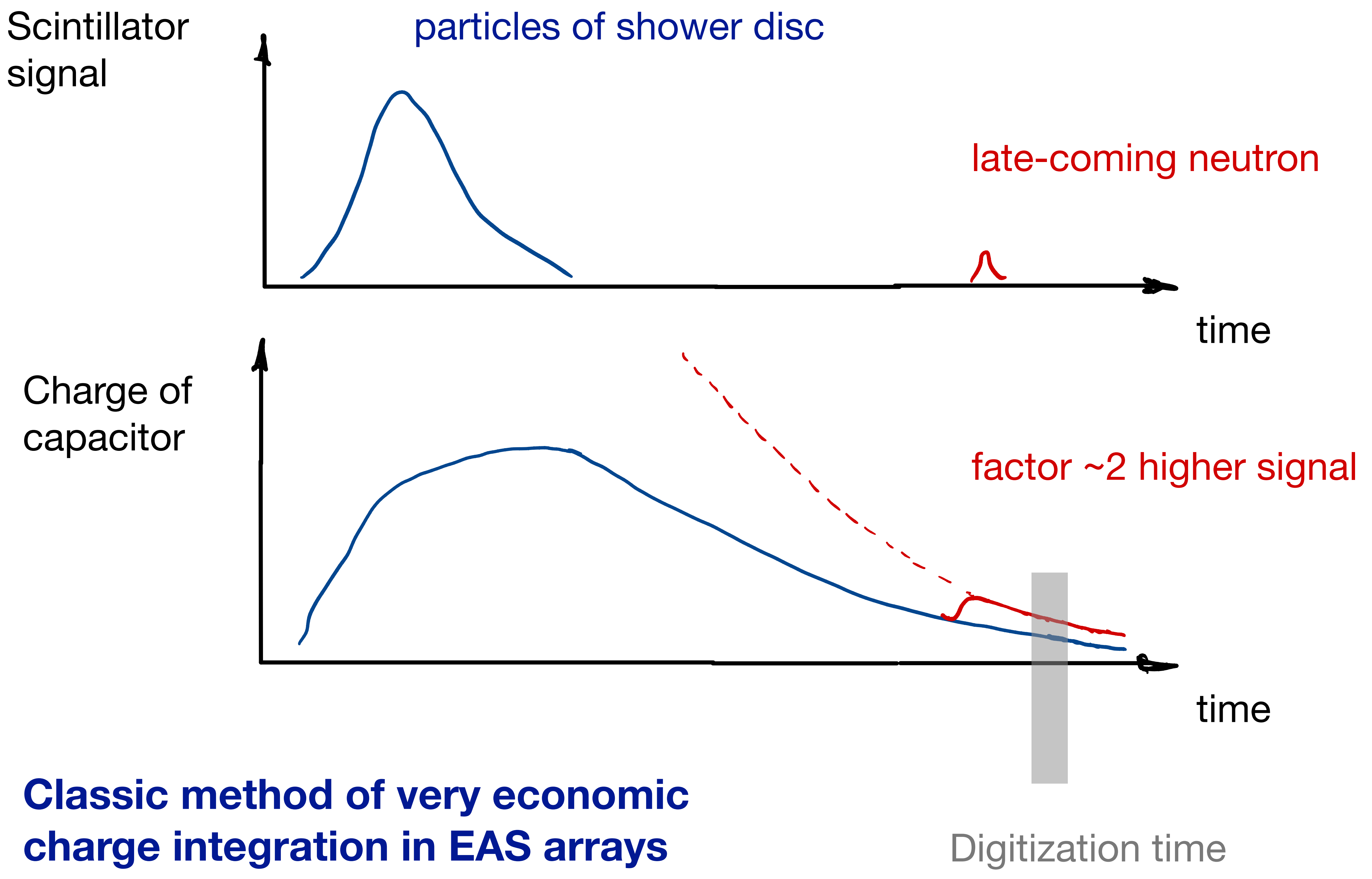


For testing purposes (with ML) → Sybill*
post-processing to replace pions with desired hadrons
→ muon number can be made to agree with data

Neutrons in EAS… a disregarded component

Ralph Engel





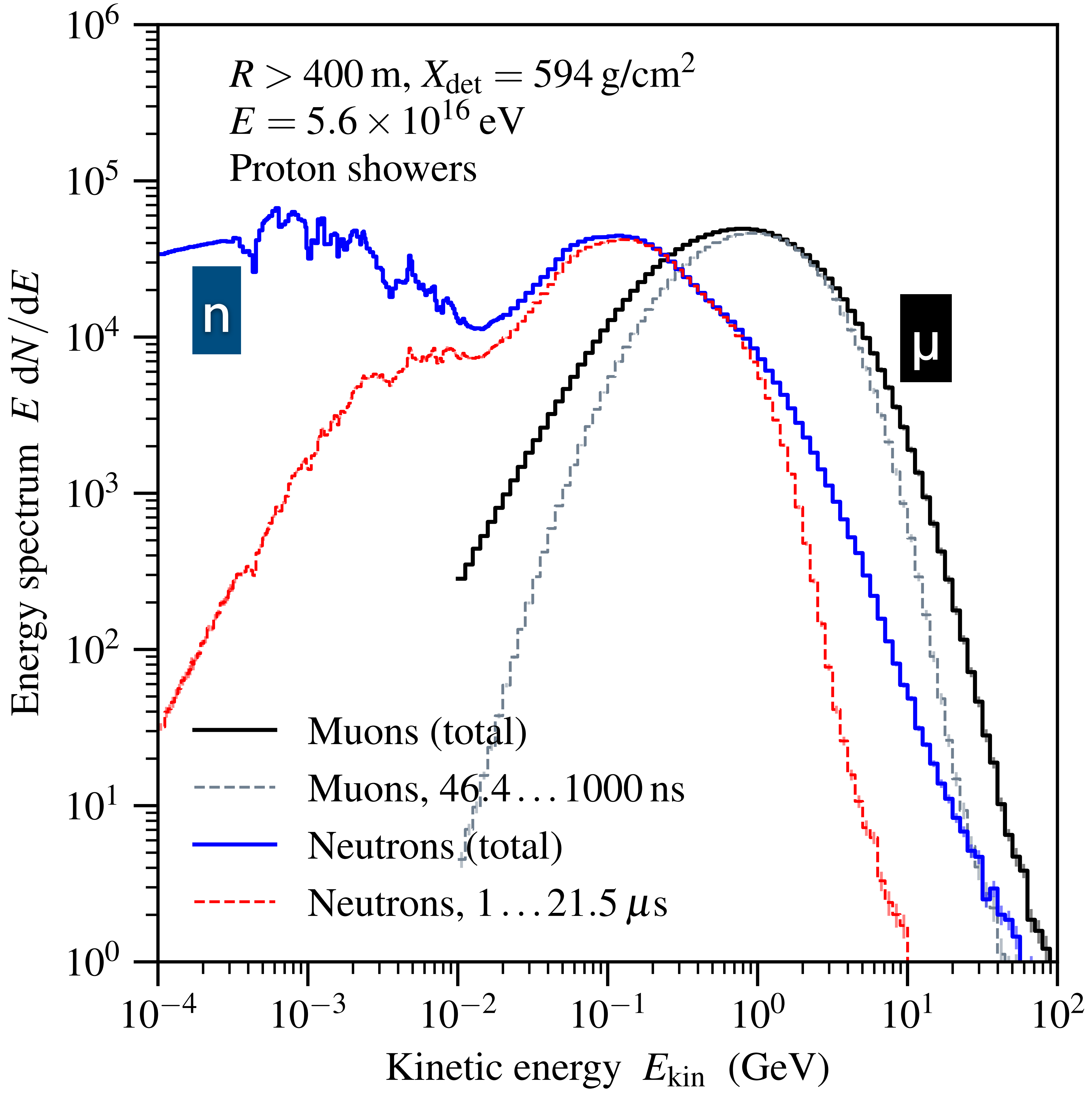
Classic method of very economic charge integration in EAS arrays

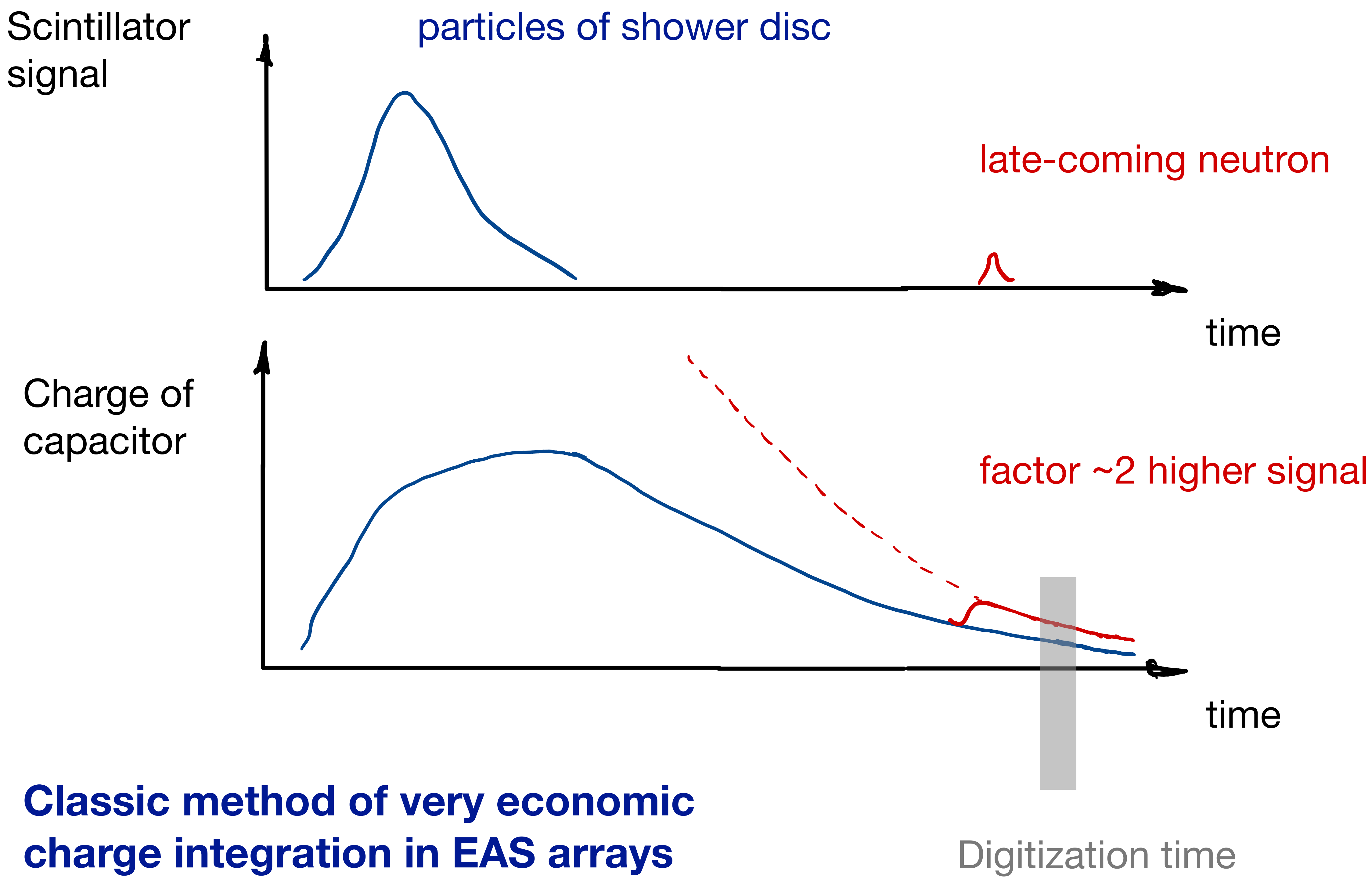
Plastic Scintillators particular sensitive
→ give rise to delayed signals
→ thereby increase shower size

Close to shower maximum, neutrons as abundant as muons!

Neutrons in EAS… a disregarded component

Ralph Engel





Classic method of very economic charge integration in EAS arrays

Close to shower maximum, neutrons as abundant as muons!

Plastic Scintillators particular sensitive
→ give rise to delayed signals
→ thereby increase shower size

something to be carefully accounted for

CORSIKA 8

Lukas Nellen

- Complete rewrite of FORTAN code to C++ (Python)
  Physics maintained (except e.g. EGS → Proposal)
- High energy interaction models „contained“
- Many new features (radio, GPU usage, cross media showers, …)
- Community effort lead by KIT
- Agreement between C7 / C8 at 10% level

Still some todo list before beta-release

Issue: dependent on type of simulation up to factor 10 slower!

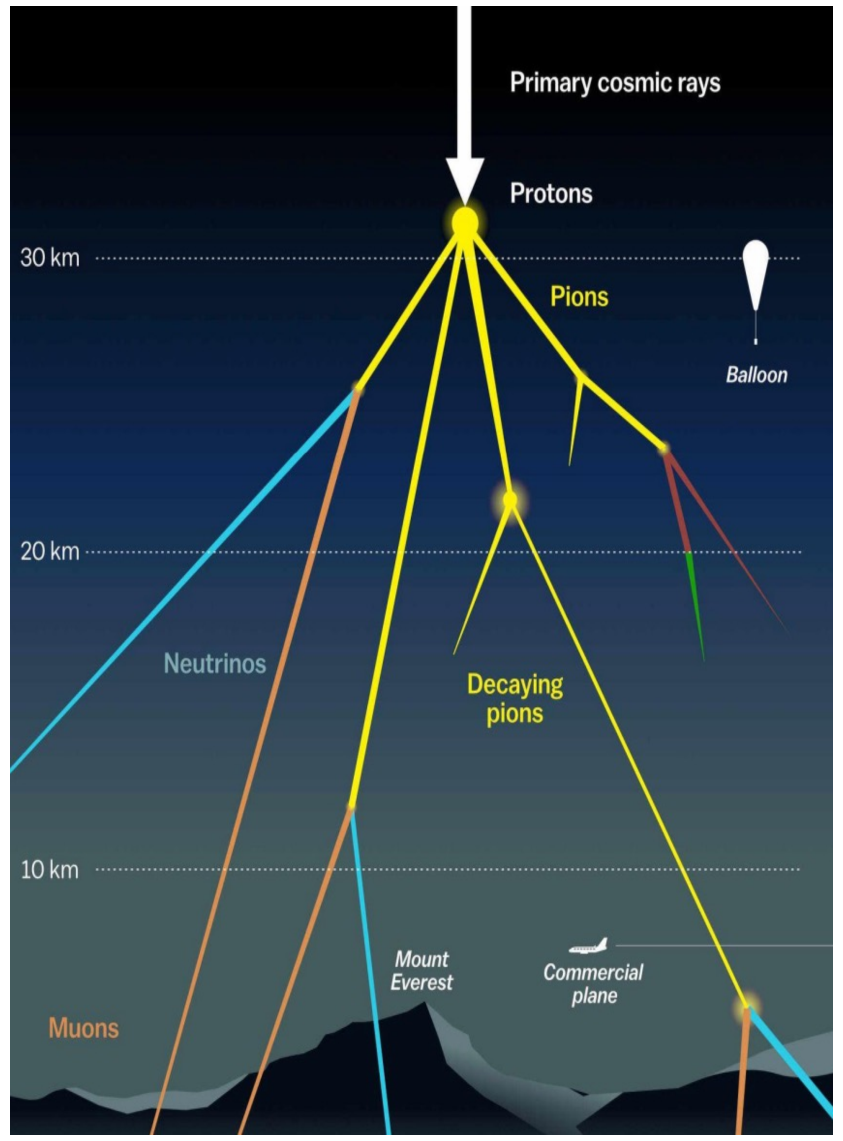
MCEq and chromo

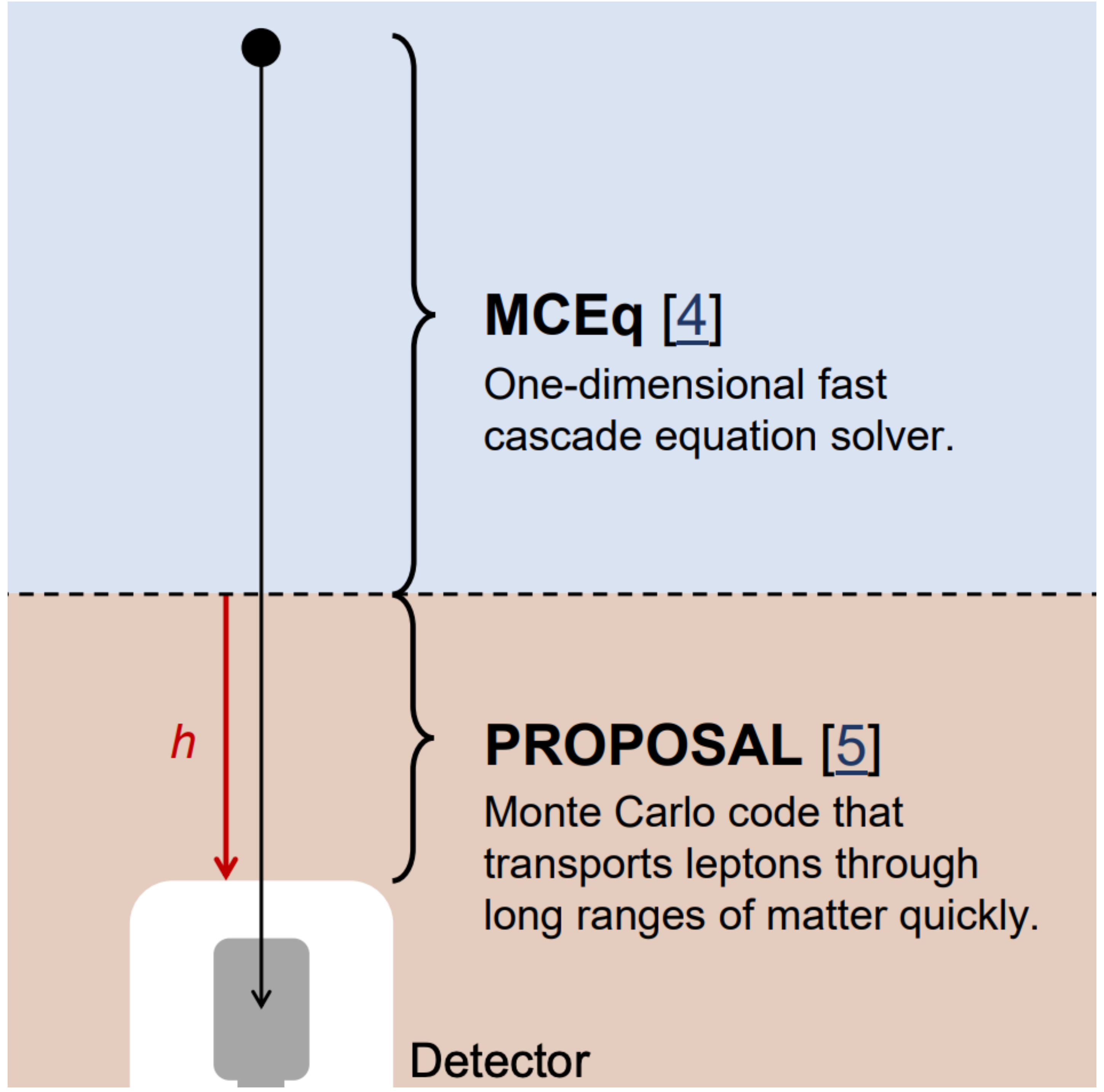
Anatoly Fedynitch

MCEq: Matrix-Cascade Equations Code (open source)

→ Complement to the CORSIKA transport code

→ has hadronic interaction models build in





MUTE (Muon inTensity codE)

predict μ-flux underground

chromo

Cosmic ray HadROnic interaction MOnte carlo frontend

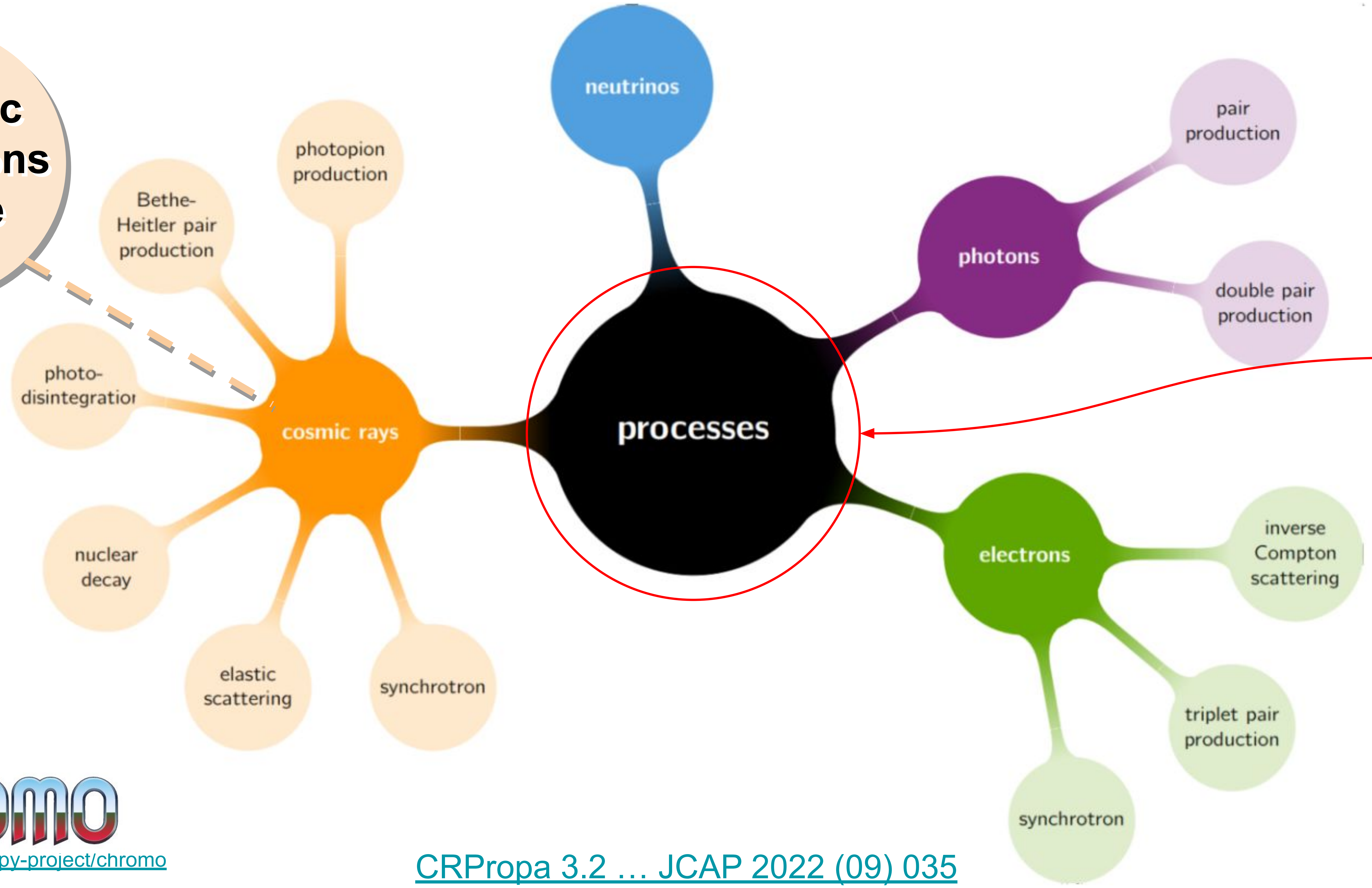
- Python frontend to generators written in Fortran & C++
  - DPMJet-III*, PhoJet*, EPOS-LHC, Pythia-6.4, Pythia-8.3, QGSJet*, QGSJet- II*, SIBYLL*, SOPHIA, UrQMD 3.4 (* = several versions)
  - Use as Python library or command-line interface
- Open source development on Github
  - https://github.com/impy-project/chromo
  - BSD 3-clause license, contributions welcome
- Main authors
  - Anatoli Fedynitch (project lead), Hans Dembinski, Anton Prosekin
- Available on PyPI
  - Authors already use it for science projects
  - pip install chromo to install
  - For installation from source, see README.md

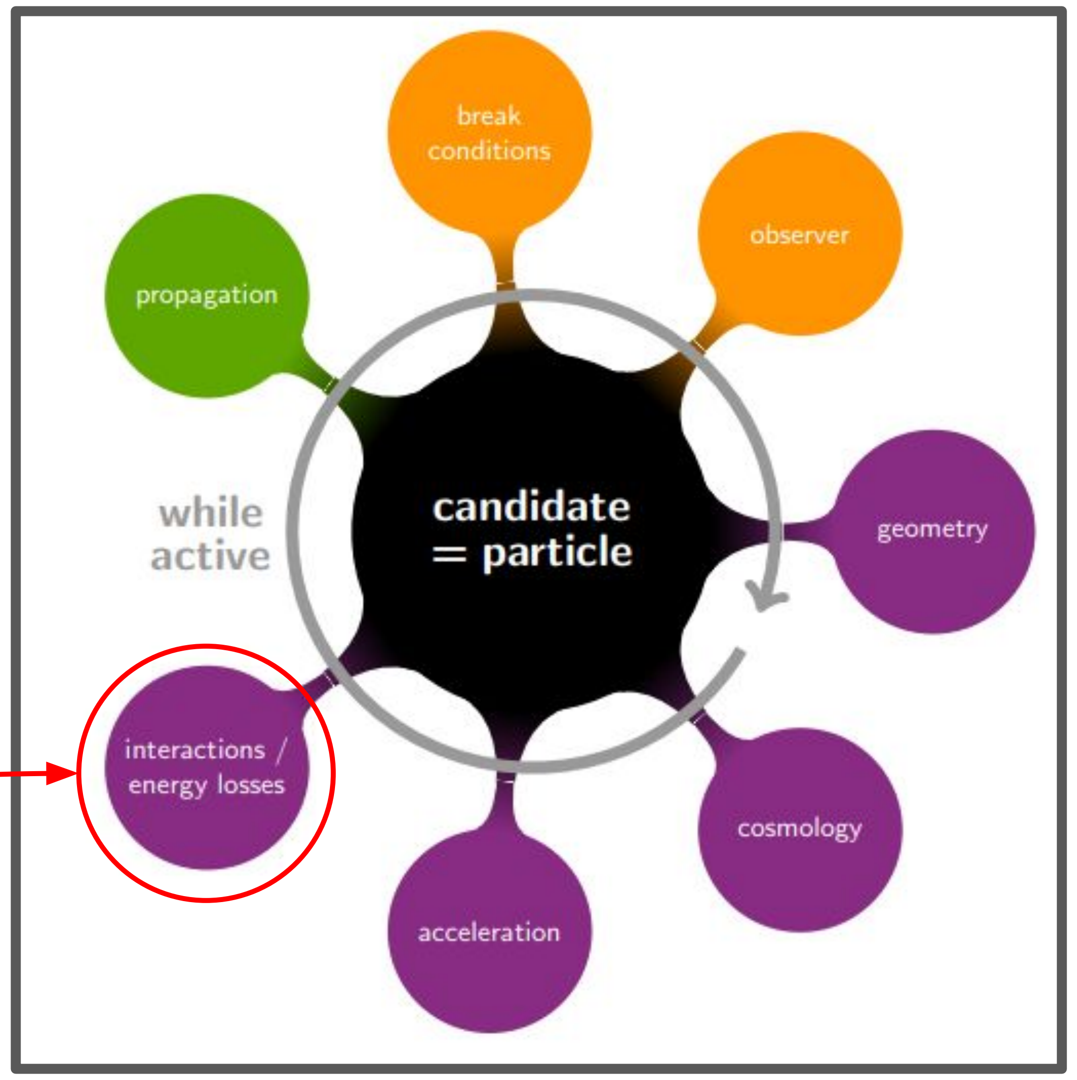
See for more details A. Prosekin's talk at PoS(ICRC2023)189

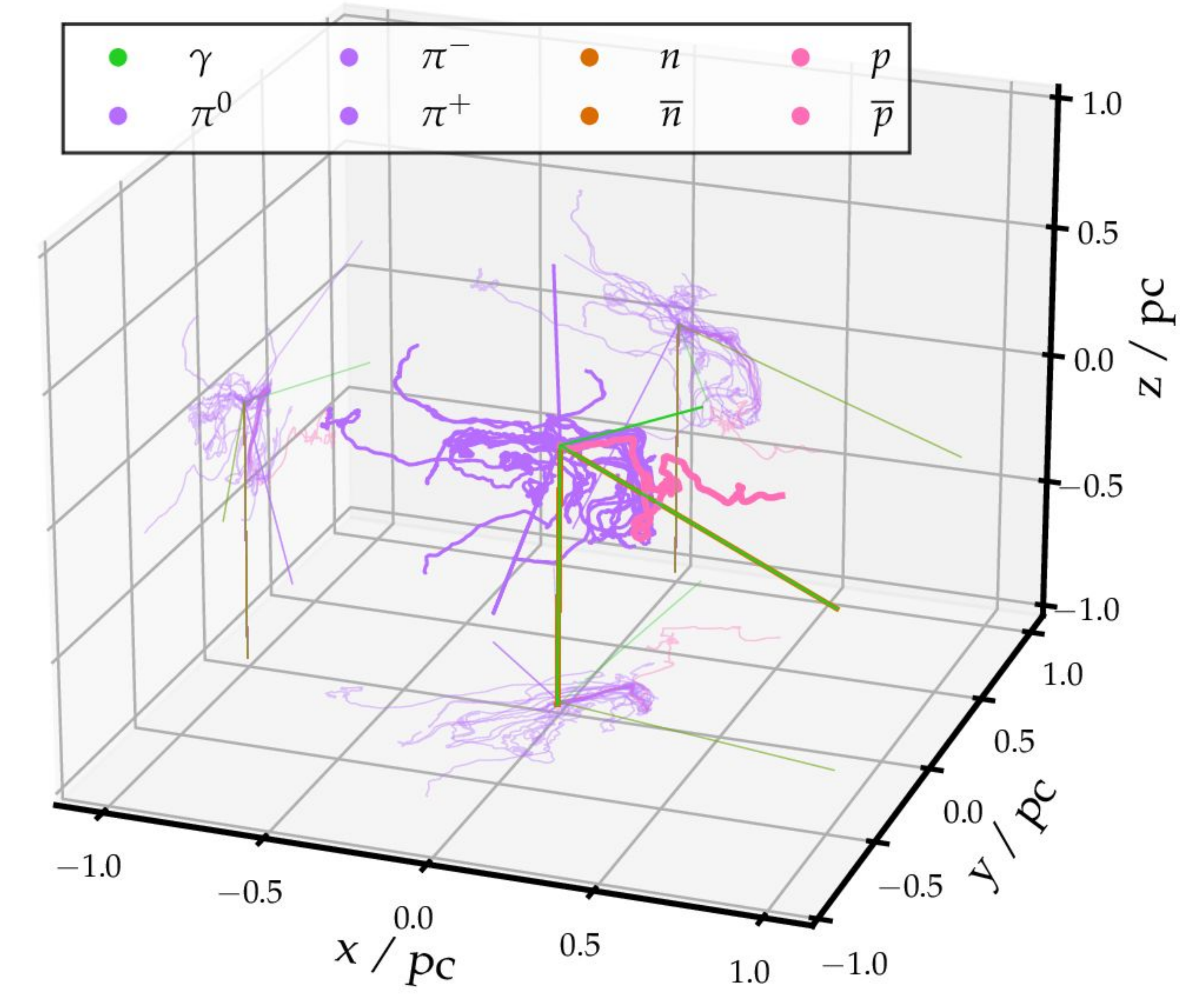
used e.g. by CRPropa…

CRPropa 3.2

Hadronic Interactions Module







chromo

https://github.com/impy-project/chromo

CRPropa 3.2 … JCAP 2022 (09) 035

Leonel Morejon

Propagation code like CORSIKA, but for (inter)galactic propagation

Other Topics

Astro- and CR-Physics related

Amir Farzan Esmaeili: MUNHECA framework for HE electromagnetic cascades

Leonel Morejon: CRPropa framework now with hadronic interactions

Luis Fernando Galicia Cruztitla: Production and propagation of secondaries in the Galaxy

Juan Manuel Gonzalez: Magnetic Horizon effects in CRs

Gabriela Xol: LGRB redshift relation I

Jose Rodrigo Sacahui Reyes: X-ray-Gamma-ray correlation in HBL Blazars

Paula Yuc: LGRB redshift relation II

Alexander Borisov: Abnormal weak aborption of CR hadrons

Other Topics

ML Applications

Erik Mallea: ML for muon tracks in WCD

Maria Romo Fuentes: Neutrino Classification through DL

Hyper-K

Saul Cuen Rochin: Hyper-Kaminokande

Outreach

Sonali Bhatnagar: Outreach with CRs

Judith Torres Jiménez : Outreach related to HyperK

Experimental

Rajesh Gana: RPCs

Brenda Elisa Medina Estrad: PMT tests