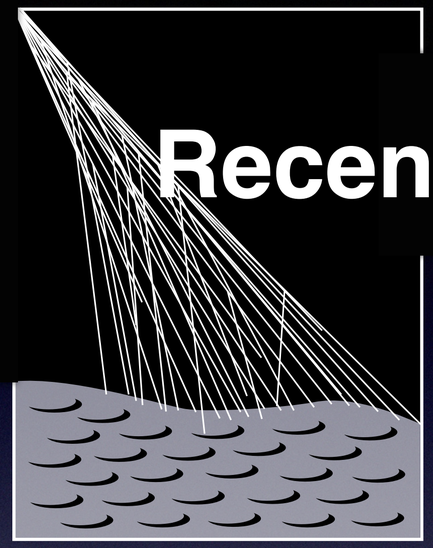
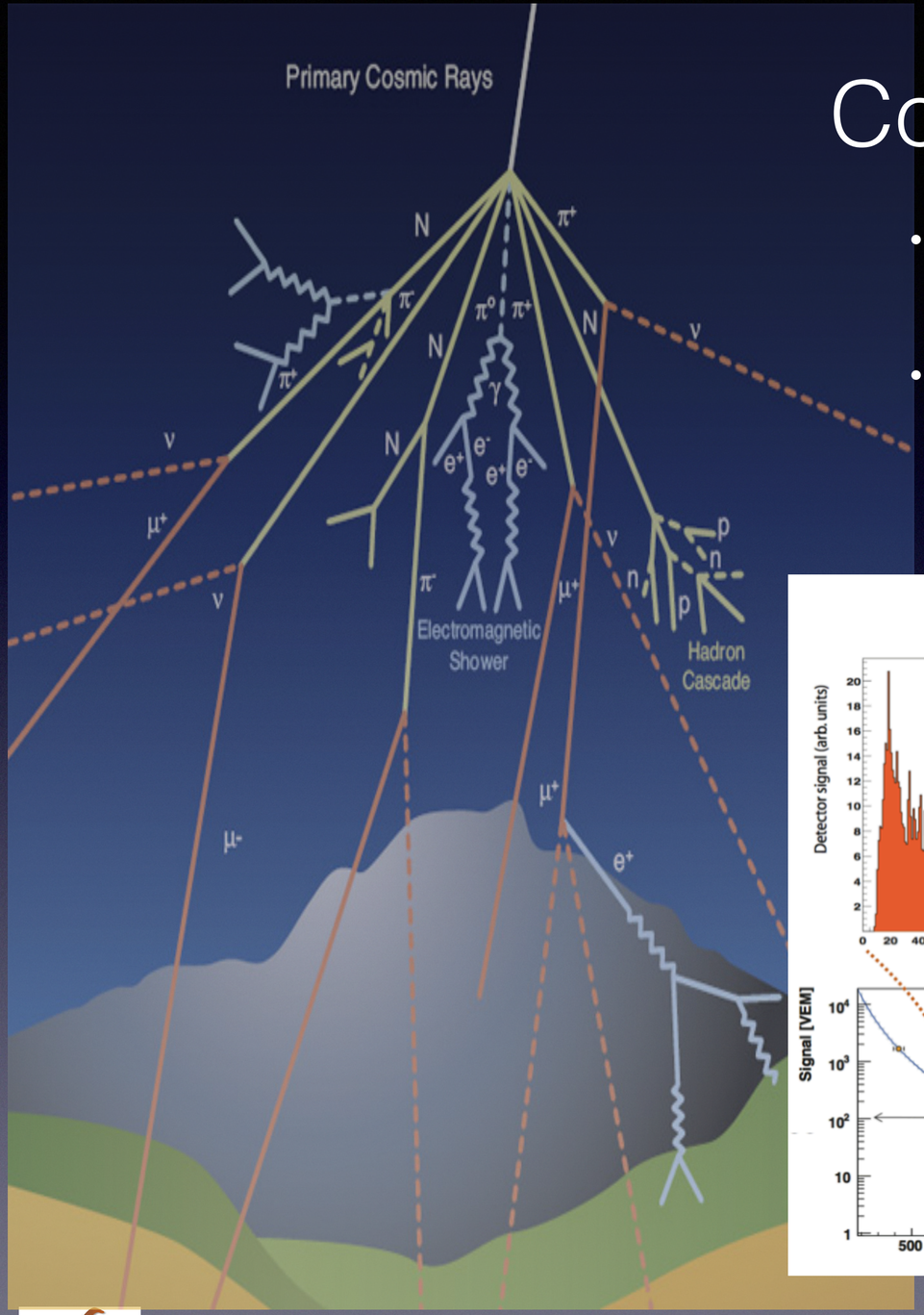


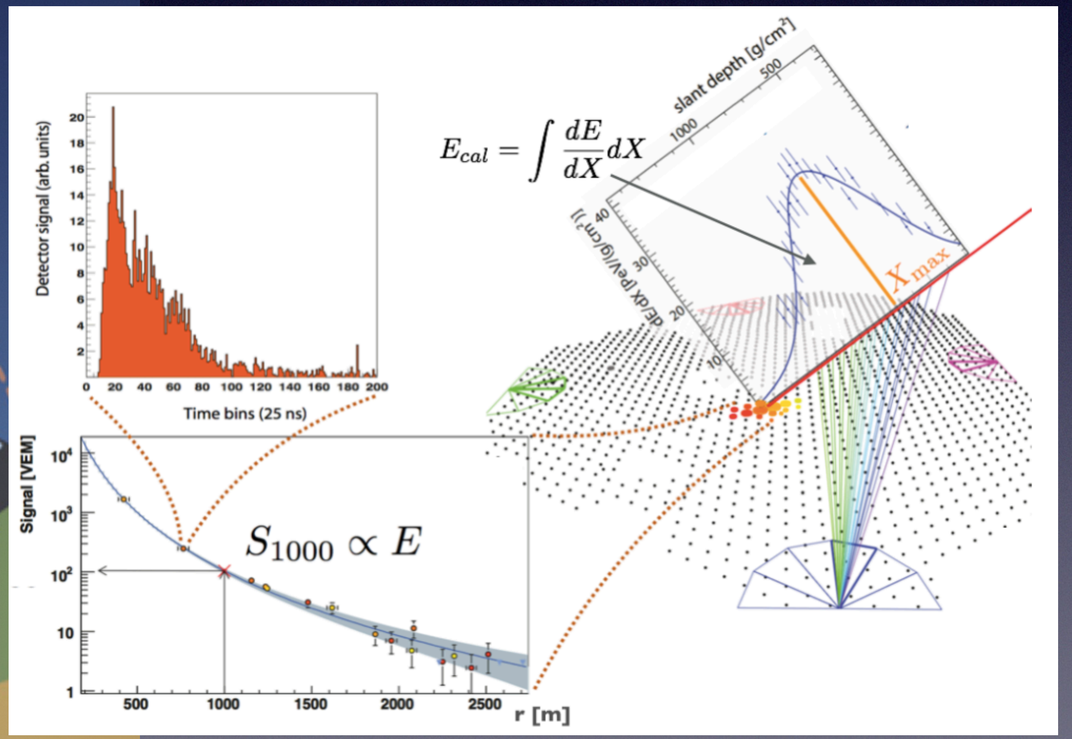
Recent activities at the Pierre Auger Observatory and the Brussels group

22/11/2019 IIHE annual meeting
Koun Choi for the IIHE-Brussels group
of the Pierre Auger Collaboration

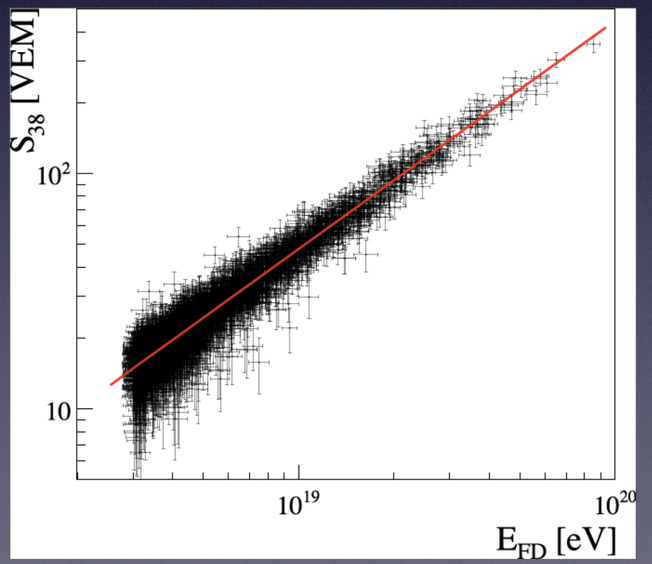
Cosmic ray showers

- UHECRs can only be studied through air showers
- hybrid detection technique:
  - measuring longitudinal profile in air (a few kms) & footprint on ground (~O(10-100) km^2)



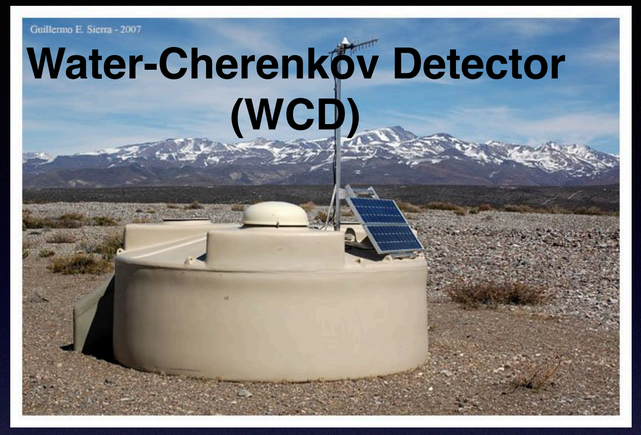


$$E_{FD} = E_{cal} + E_{inv}$$



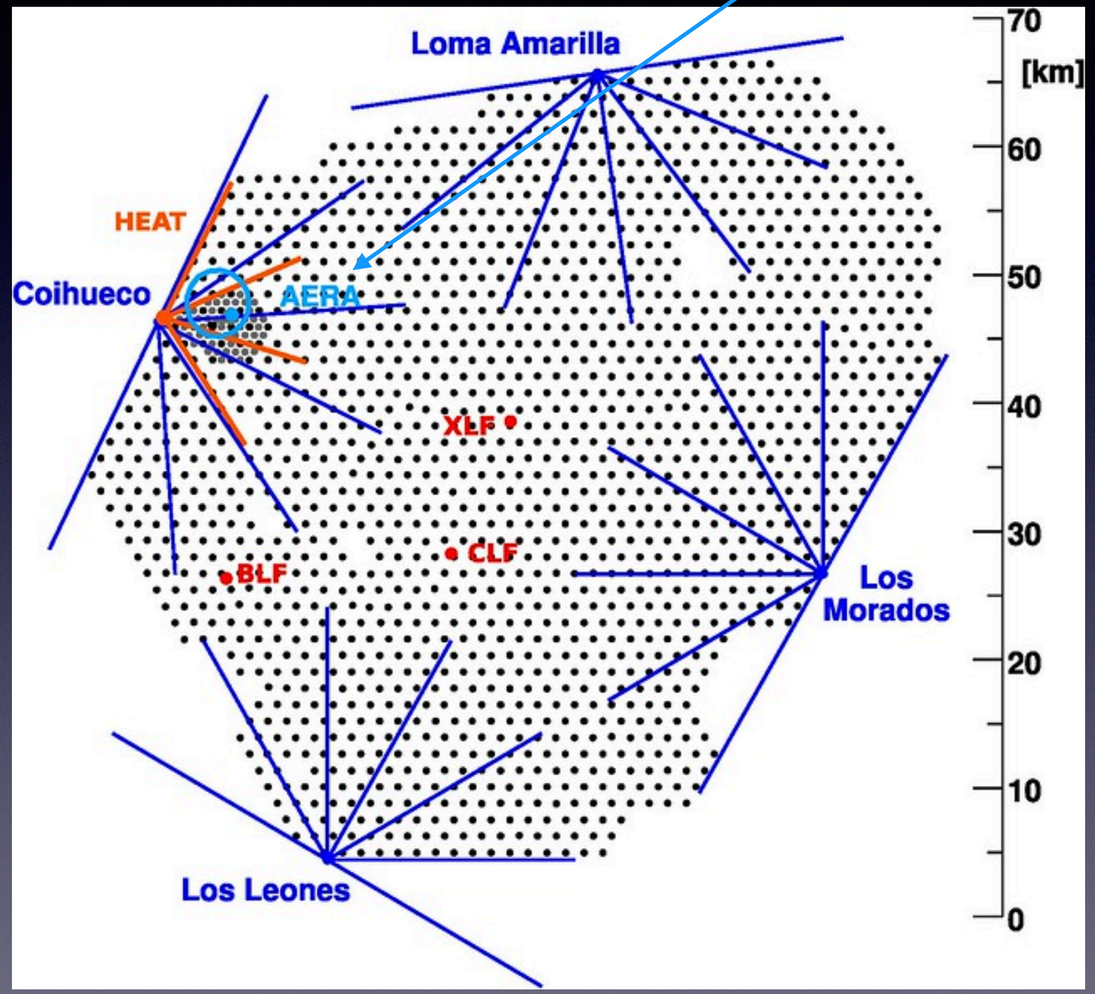
The Pierre Auger Observatory

Auger Engineering Radio Array
150 autonomous antenna stations



Surface detector (SD)
100% duty cycle

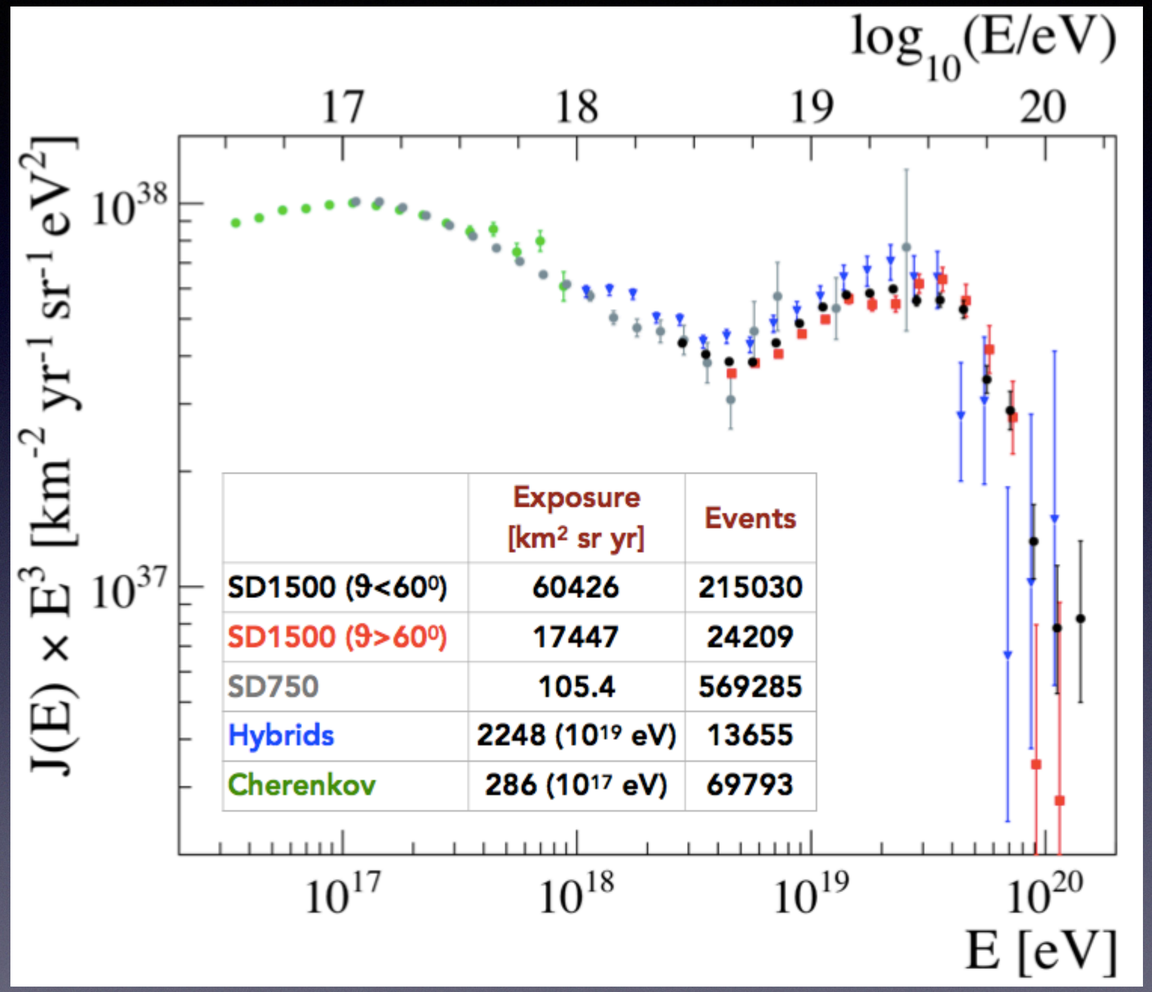
$>\sim 10^{18} eV$	$>\sim 10^{17} eV$
SD-1500m	SD-750m
3000 km^2	23.5 km^2
1600 WCDs	61 WCDs



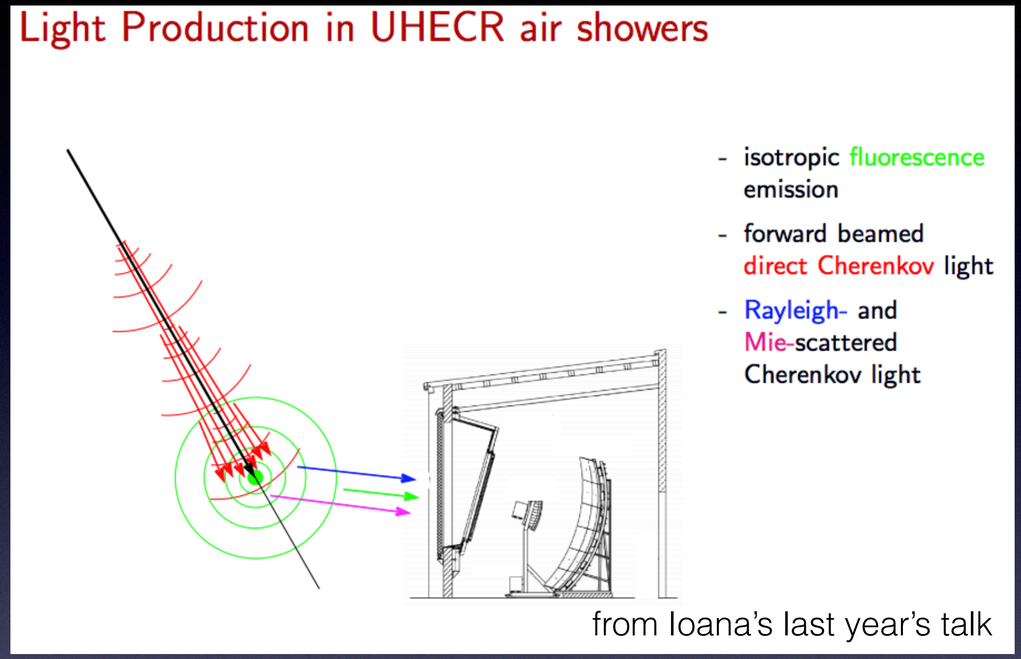
Fluorescence detector (FD)
15% duty cycle

$>\sim 10^{18} eV$	$>\sim 10^{16.5} eV$
4 x 6 telescopes	1 x 3 telescopes (HEAT)
overlooking SD-1500m	overlooking SD-750m
FOV 30° x 30°	FOV 30° x 30°
Minimum elevation 1.5°	Minimum elevation 30°

Recent results in a nutshell - energy spectrum



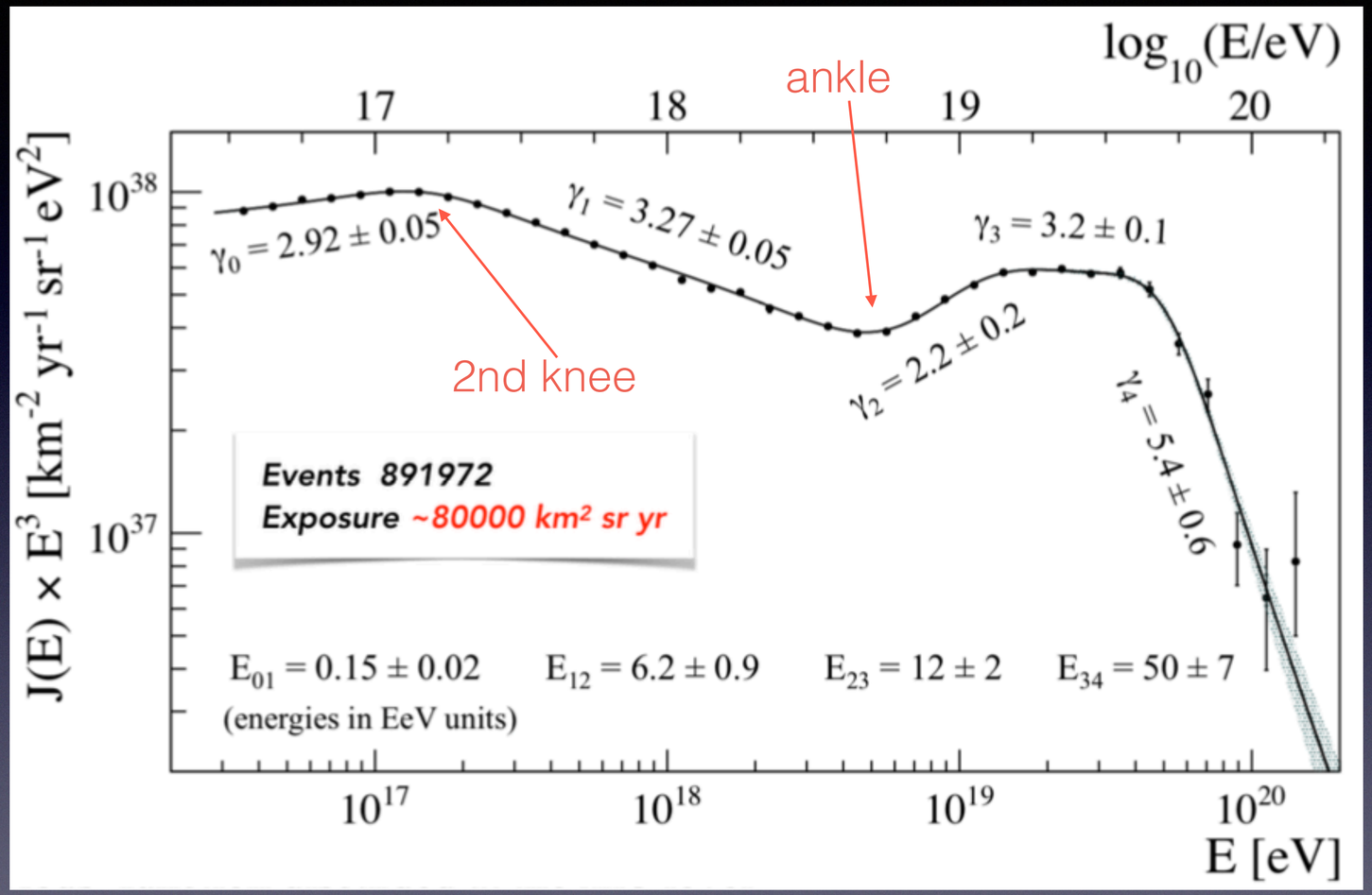
	Exposure [km² sr yr]	Events
SD1500 (9<60⁰)	60426	215030
SD1500 (9>60⁰)	17447	24209
SD750	105.4	569285
Hybrids	2248 (10^{19} eV)	13655
Cherenkov	286 (10^{17} eV)	69793

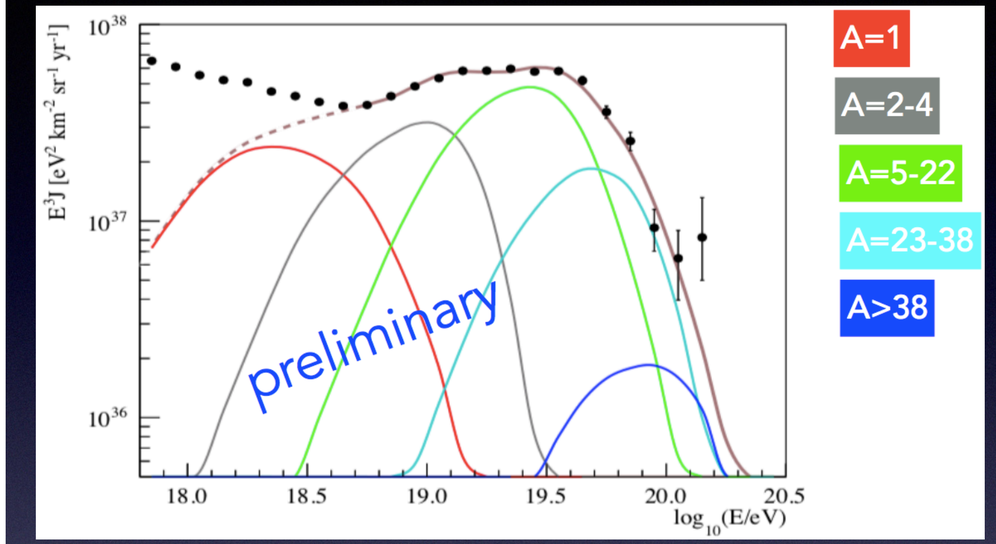


new analyses in low E:

SD-750 analysis - enabled by SD-750 deployment in 2011 & new trigger installed in 2013
Cherenkov analysis - uses HEAT data (2012-), new reconstruction technique called "Profile Constrained Geometry Fit (PCGF)" PoS(ICRC2019)374

Combined spectrum

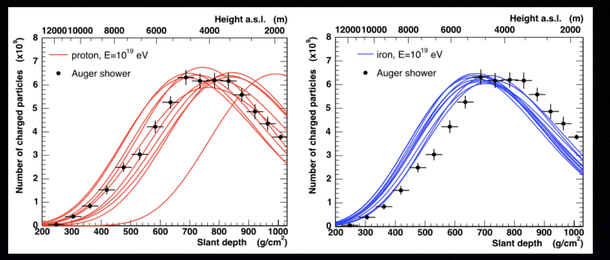


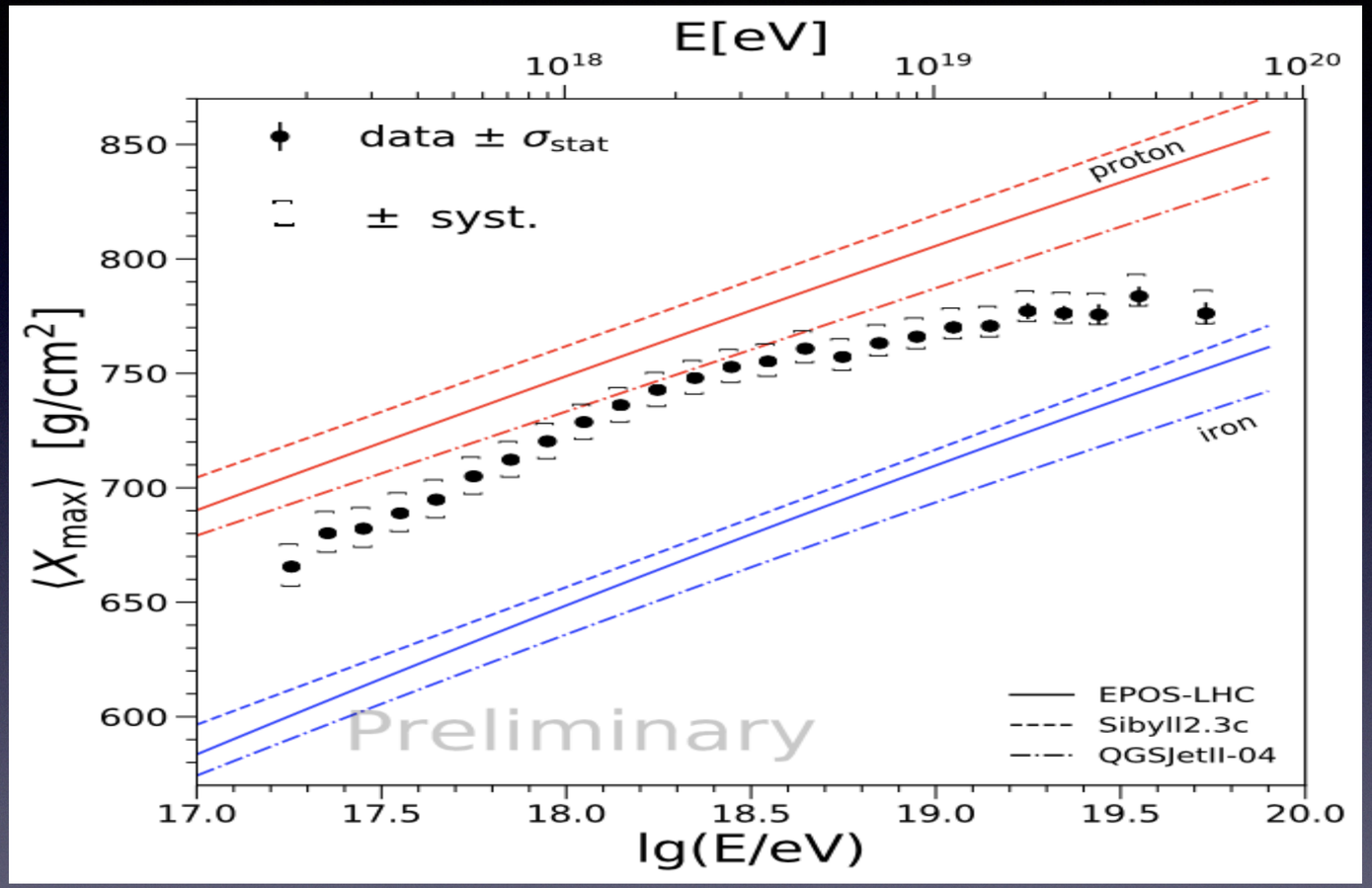


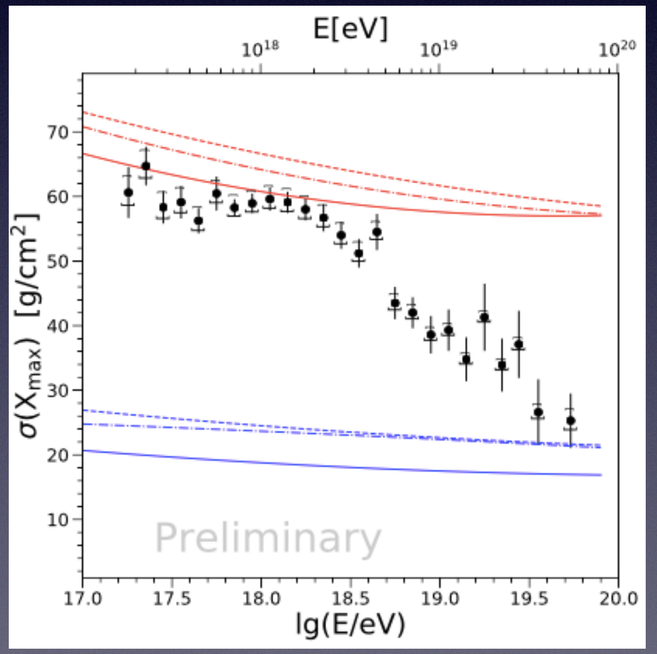
Combined fit (E + Xmax)
using the EPOS-LHC model
fitted value of E_{max} cut ~ 5Z EeV

to be published soon

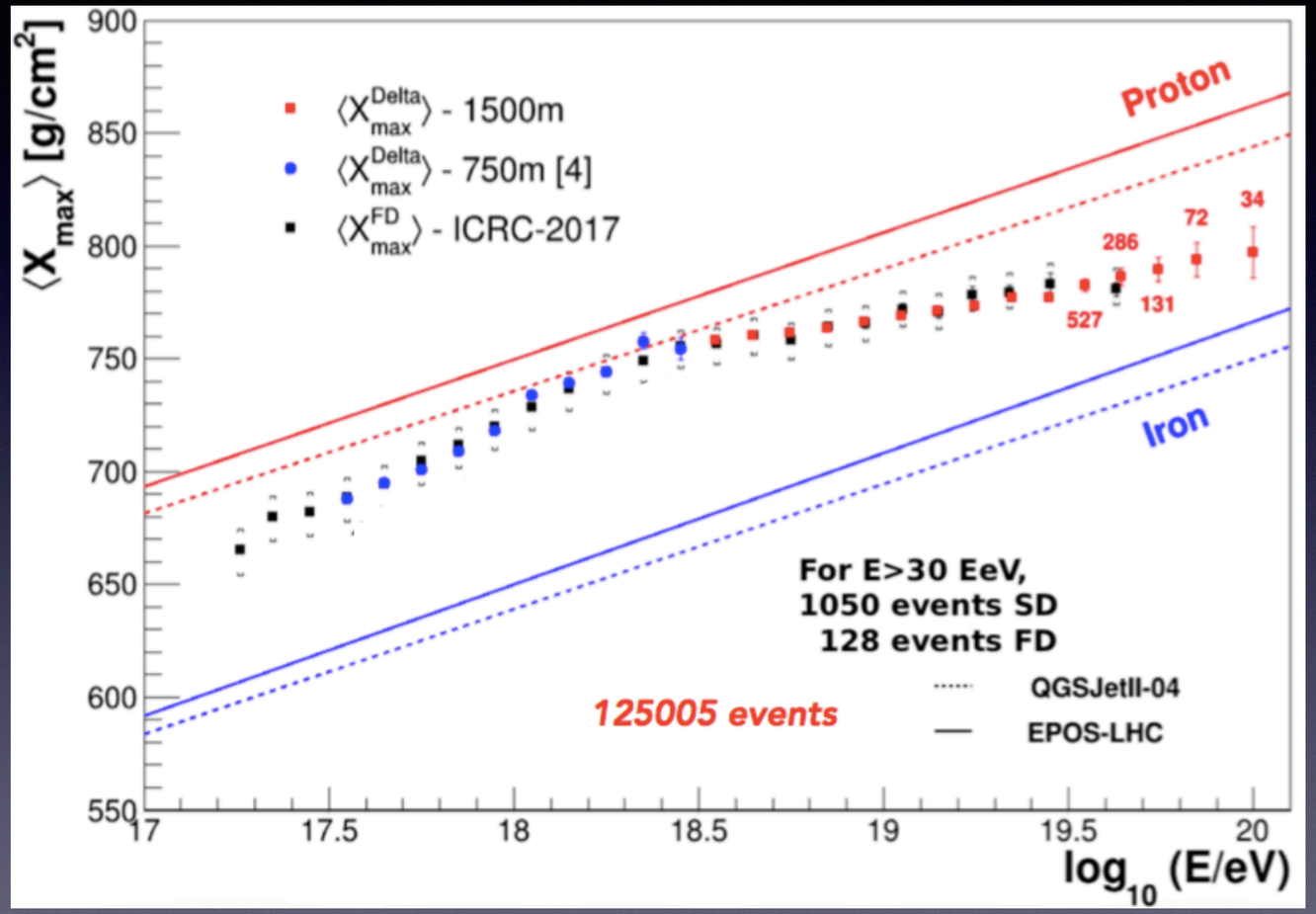
Mass composition

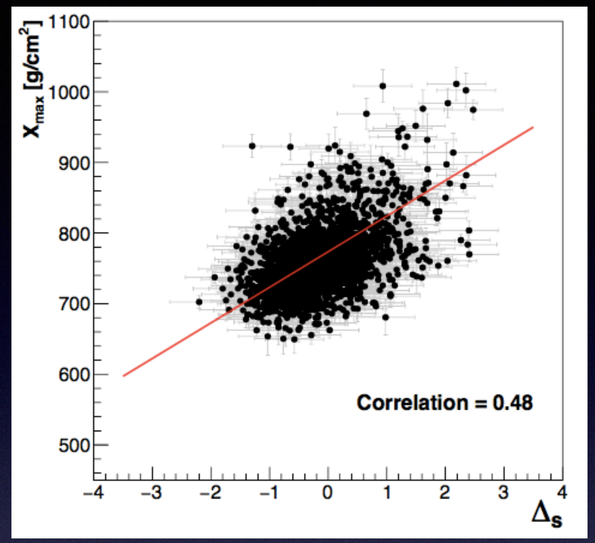






Mass composition from SD



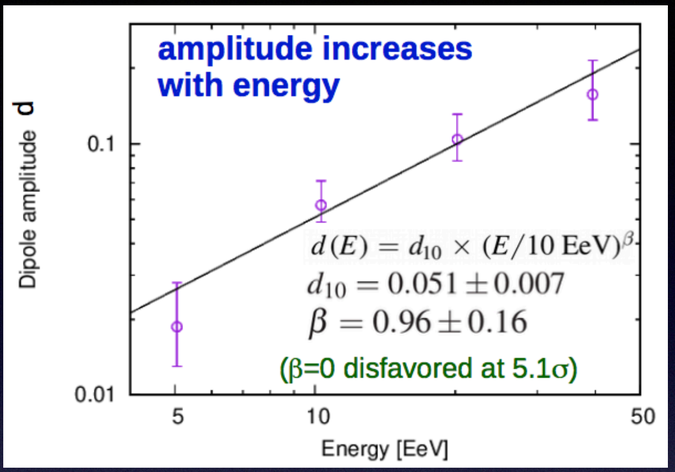


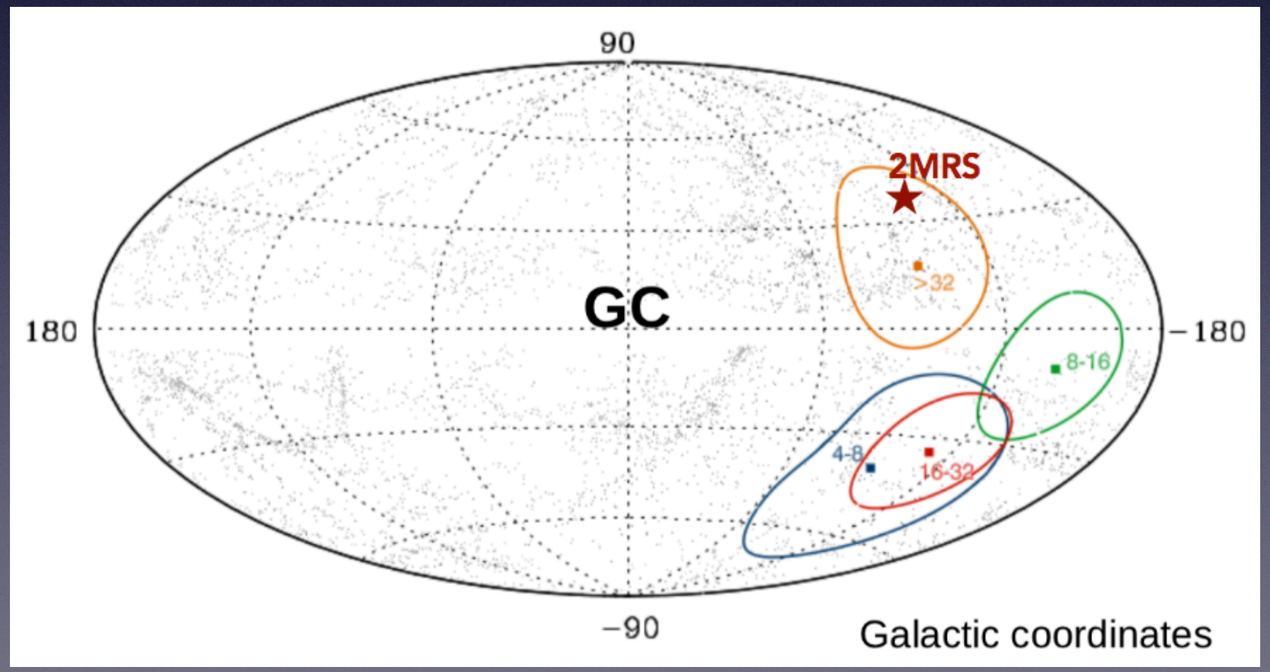
PoS(ICRC2019)440

Arrival direction - large scale anisotropy

Energy [EeV] interval	median	N	$d_\perp$	d_z	d	α_d [°]	δ_d [°]
4 - 8	5.0	88,325	$0.010^{+0.007}_{-0.004}$	-0.016 ± 0.009	$0.019^{+0.009}_{-0.006}$	69 ± 46	-57^{+24}_{-20}
≥ 8	11.5	36,928	$0.060^{+0.010}_{-0.009}$	-0.028 ± 0.014	$0.066^{+0.012}_{-0.008}$	98 ± 9	-25 ± 11
8 - 16	10.3	27,271	$0.056^{+0.012}_{-0.010}$	-0.011 ± 0.016	$0.057^{+0.014}_{-0.008}$	97 ± 12	-11 ± 16
16 - 32	20.2	7,664	$0.075^{+0.023}_{-0.018}$	-0.07 ± 0.03	$0.10^{+0.03}_{-0.02}$	80 ± 17	-44 ± 14
≥ 32	39.5	1,993	$0.13^{+0.05}_{-0.03}$	-0.09 ± 0.06	$0.16^{+0.06}_{-0.03}$	152 ± 19	-34^{+19}_{-20}

p = 1.4×10^{-9} (6σ)



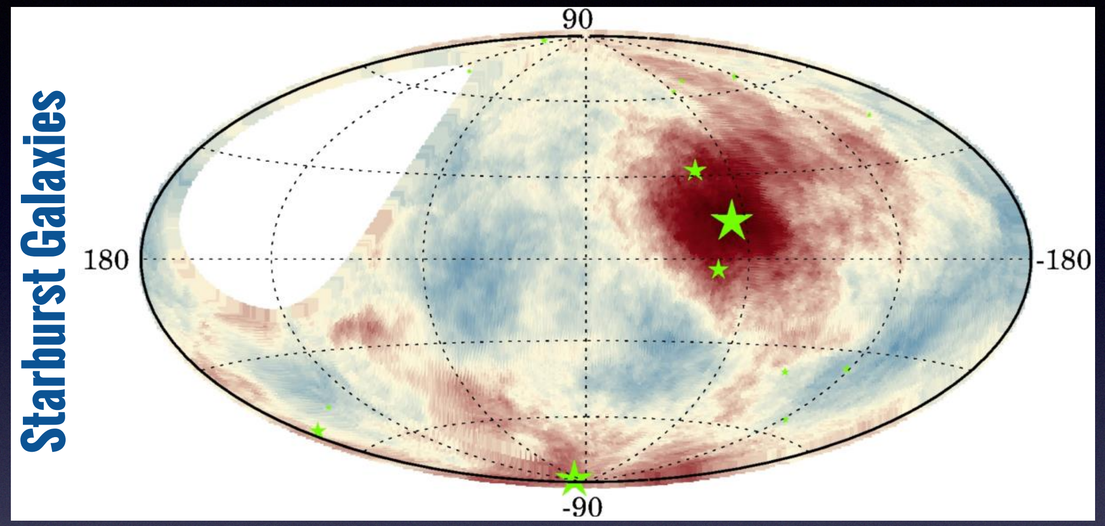


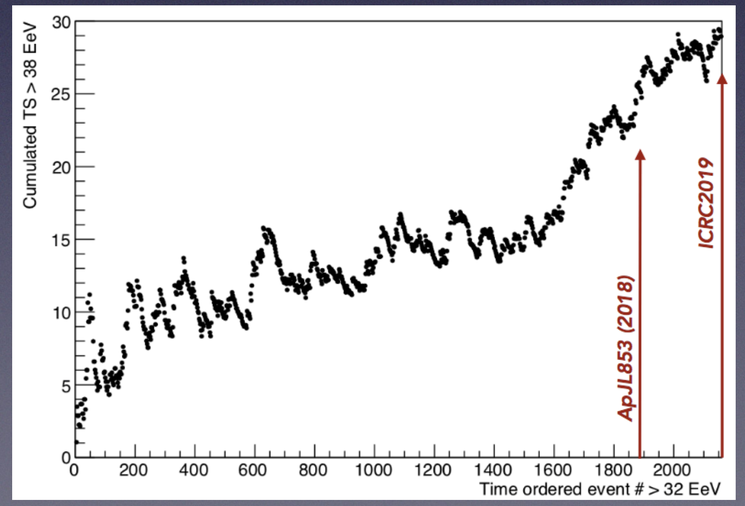
Science 357 (2017)

PoS(ICRC2019)408

Arrival direction - intermediate scale anisotropy

Likelihood test with astrophysical source catalogs - for Energy ≥32 EeV



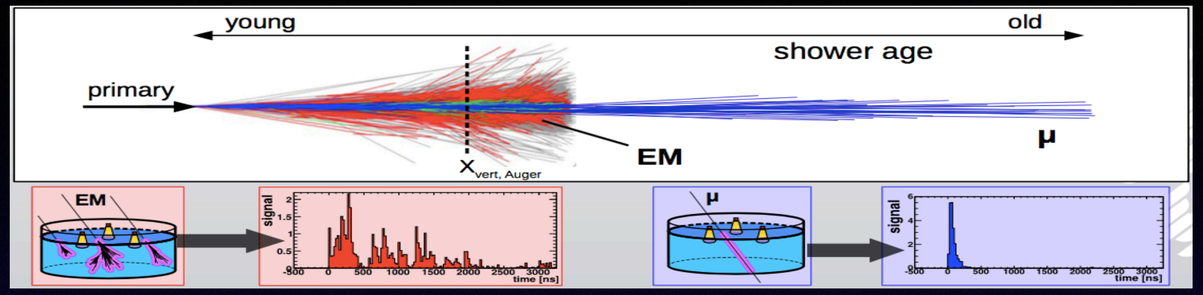


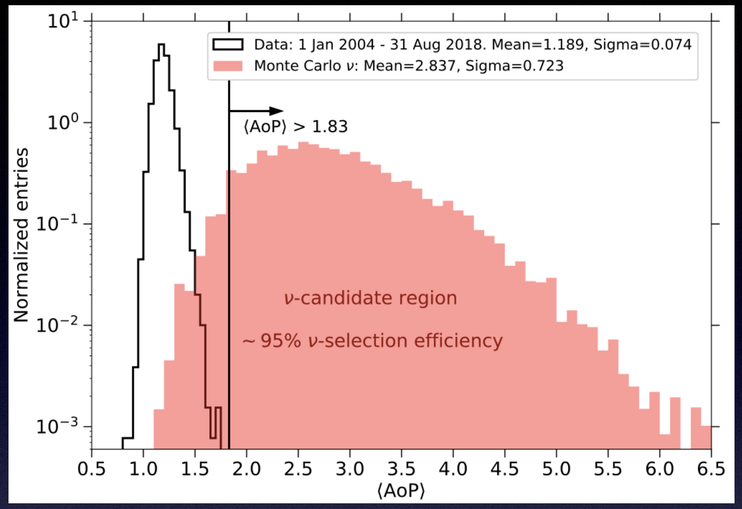
$$TS = 2\,\mathrm{Log}\,[L(\boldsymbol{\theta}, f_{aniso})/L(f_{aniso} = 0)]$$

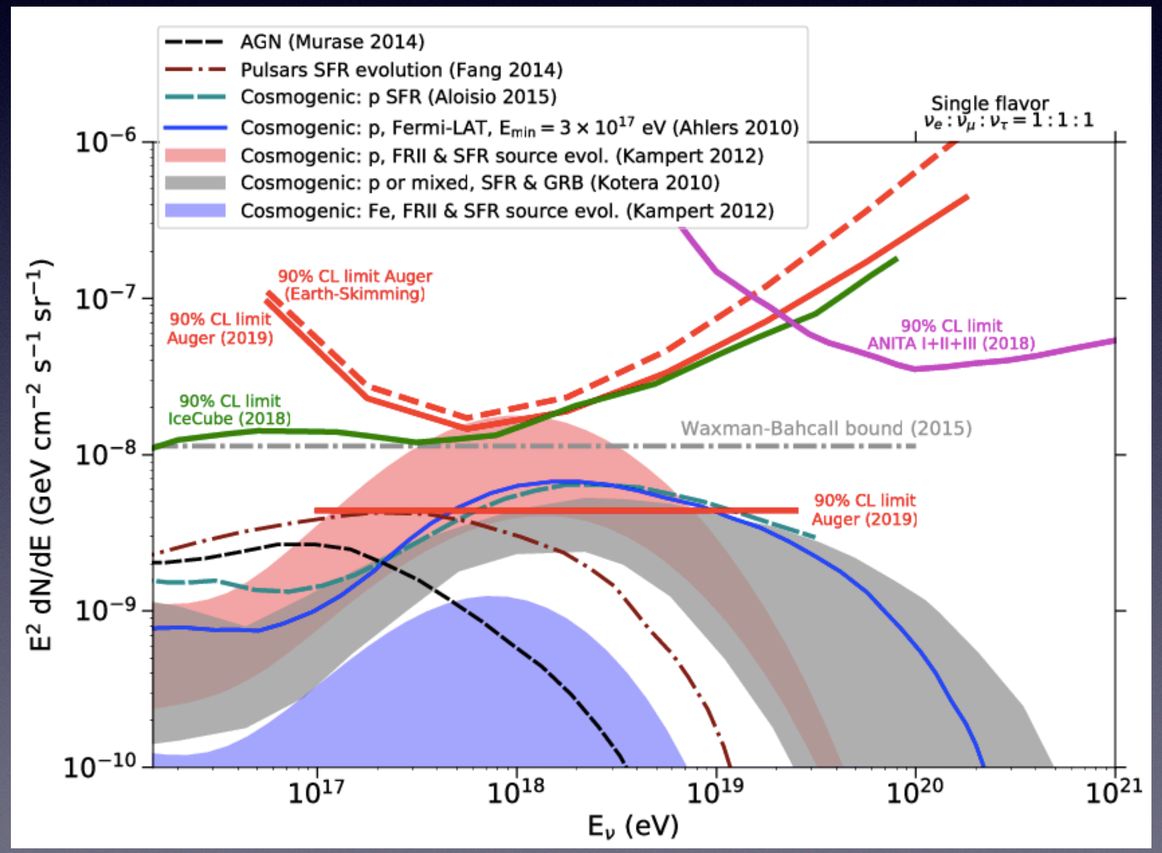
Catalog	E_{th}	θ	f_{aniso}	TS	Post-trial
Starburst	38 EeV	$15^{+5}_{-4}{}^{\circ}$	$11^{+5}_{-4}\%$	29.5	$4.5\,\sigma$
γ-AGNs	39 EeV	$14^{+6}_{-4}{}^{\circ}$	$6^{+4}_{-3}\%$	17.8	$3.1\,\sigma$
Swift-Bat	38 EeV	$15^{+6}_{-4}{}^{\circ}$	$8^{+4}_{-3}\%$	22.2	$3.7\,\sigma$
2MRS	40 EeV	$15^{+7}_{-4}{}^{\circ}$	$19^{+10}_{-7}\%$	22.0	$3.7\,\sigma$

PoS(ICRC2019)206

Cosmogenic Neutrinos







diffuse neutrino limit

integrated limit:
kE^{-2}
$k \sim 4.4E^{-9}$ GeV/cm2/s/sr

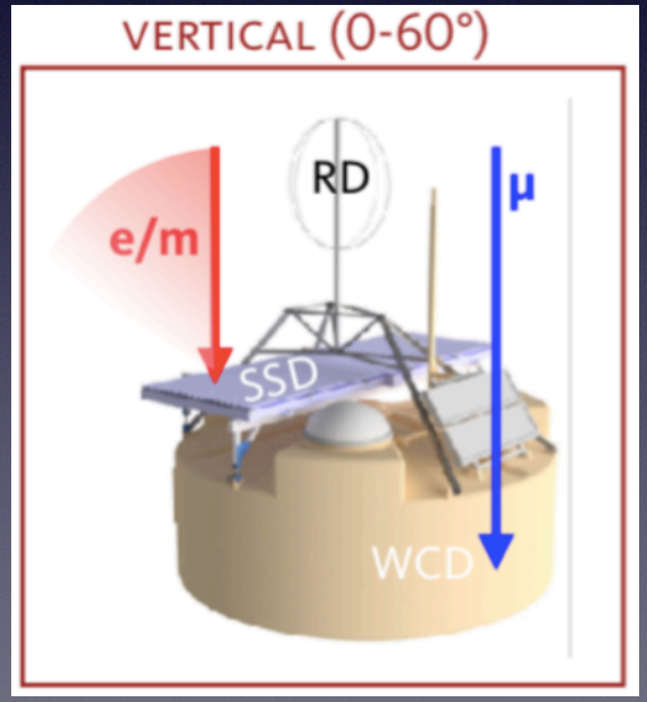
JCAP 1910 (2019) no.10, 022

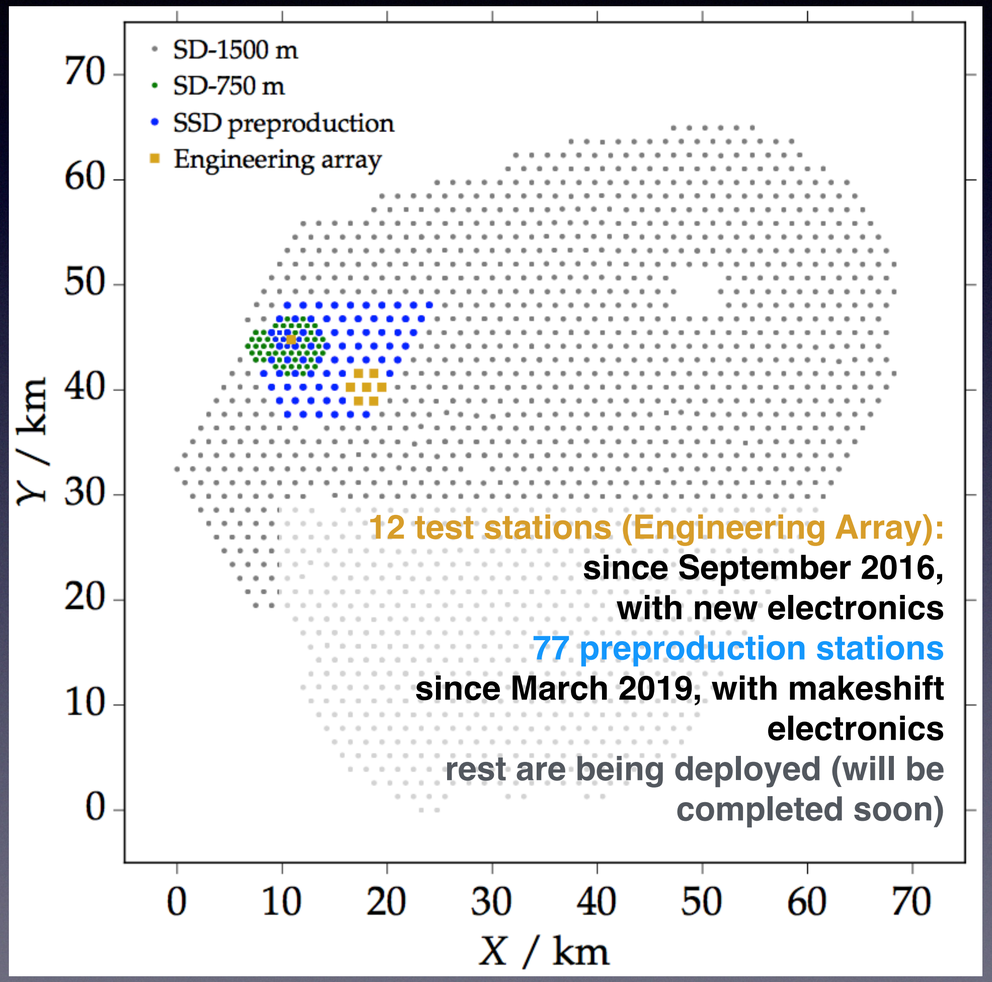
Upgrade to “AugerPrime”

for: improving mass composition determination
by: more statistics + better sensitivity to muonic & EM parts separation

SSD upgrade

Surface Scintillator Detector (SSD):
3.8 m^2 plastic scintillator detector on top of each WCD



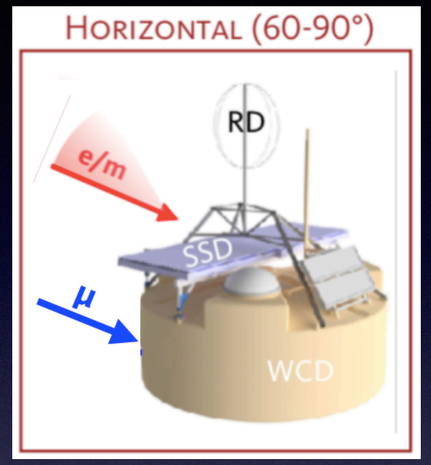


Upgrade to “AugerPrime”

RD upgrade

Proved detection technique by AERA
Installation of SALLA radio antennas on top of each WCD

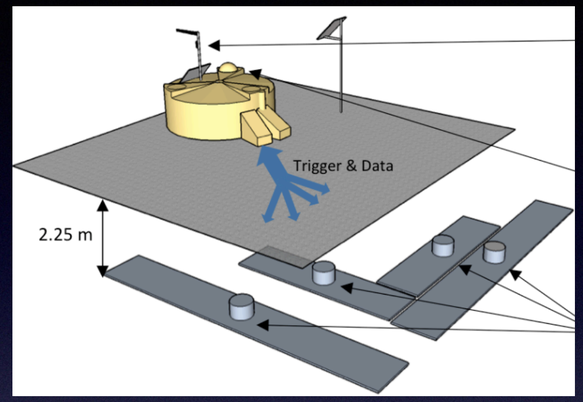
The largest radio detector so far (3000 km^2)



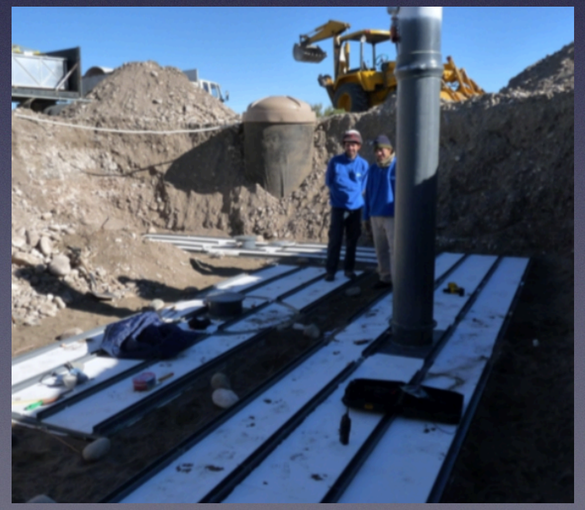
First antenna deployed in March 2019

UMD upgrade

Underground muon detector
100% duty cycle
3x10m^2 Plastic Scintillators buried at 2.3m depth
23.5 km^2 (61 stations, in the whole SD-750 area)



installation will be completed before mid 2020



+ extended dynamic range & new electronics for SD

The collaboration and the IIHE-Brussels group

The Pierre Auger Collaboration:
~500 members from 89 institutions
including Belgium: ULB+VUB (iihe)

ULB:

Ioana Mariş

Orazio Zapparrata

Koun Choi

Daniela Mockler

VUB:

Stijn Buitink

Katie Mulrey

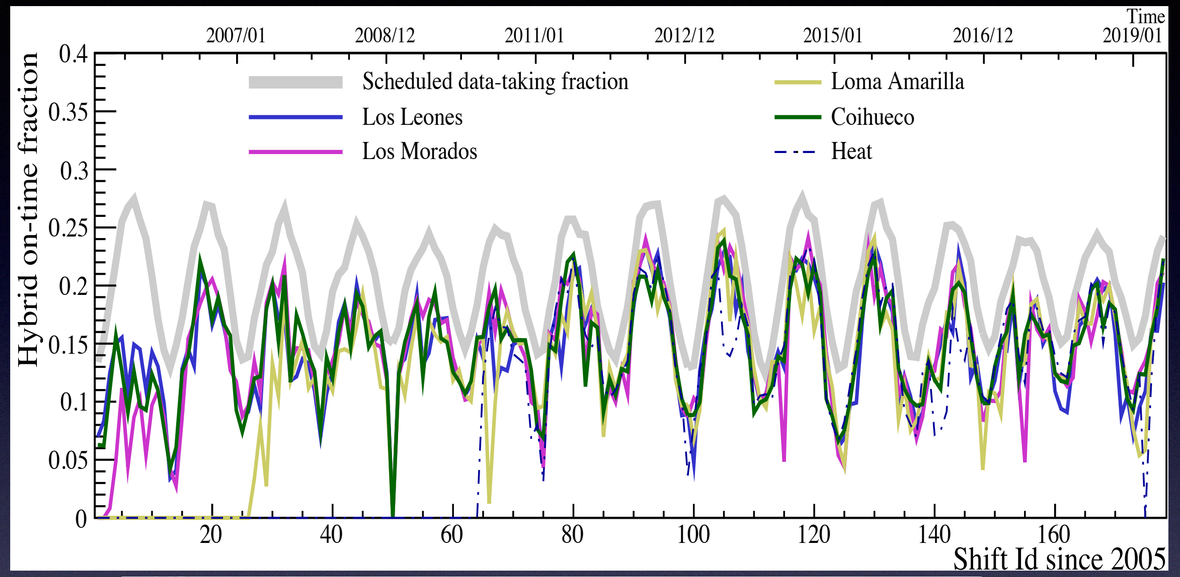
The Brussels group - Duties & recent activities for the collaboration

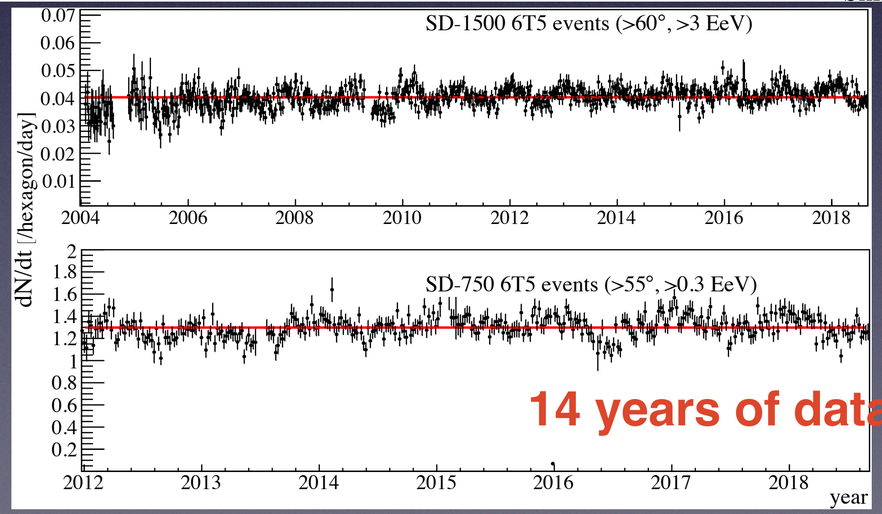
- Since this year, Belgium is an official full-member country
- Task leader of long term performance (Ioana)
- Member of review committee for the new electronics (Ioana) & in charge of related works (Yannick, Yifan)
- Member of Auger+TA energy spectrum joint working group (Daniela, Ioana)
- (will-be) Member of Auger+TA arrival direction joint working group (Ioana, Koun)

- **SSD production in Grenoble by Michael & Patrick (Jan 2019)**

- On-site FD shift (Koun, Sep 2018) & remote SD shifts (Mar & Oct 2019)
- Collaboration meetings and analysis meetings

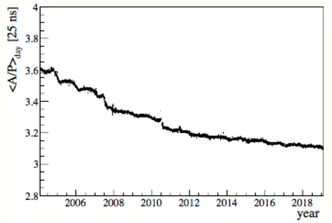
The Brussels group - Long term performance of the detector



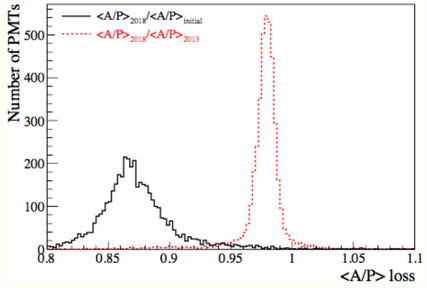


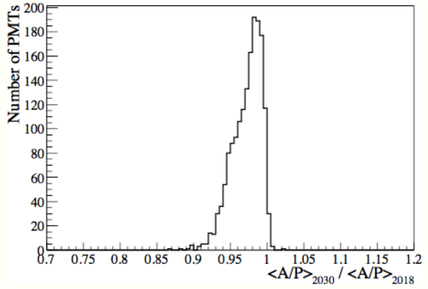
14 years of data!!!

AREA OVER PEAK OF ATMOSPHERIC MUONS



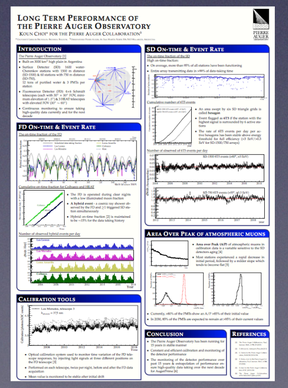
- **Area over Peak (A/P)** of atmospheric muons in calibration data is a variable sensitive to the SD detectors aging [4]
- Most stations experienced a rapid decrease in initial period, followed by a milder slope which tends to become flat [5]



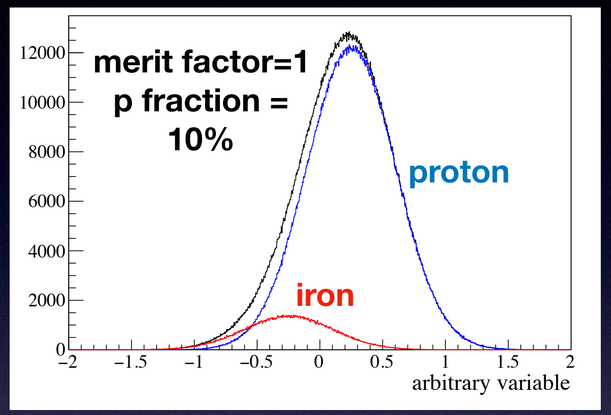


- Currently, >80% of the PMTs show an A/P >85% of their initial value
- In 2030, 85% of the PMTs are expected to remain at >95% of their current values

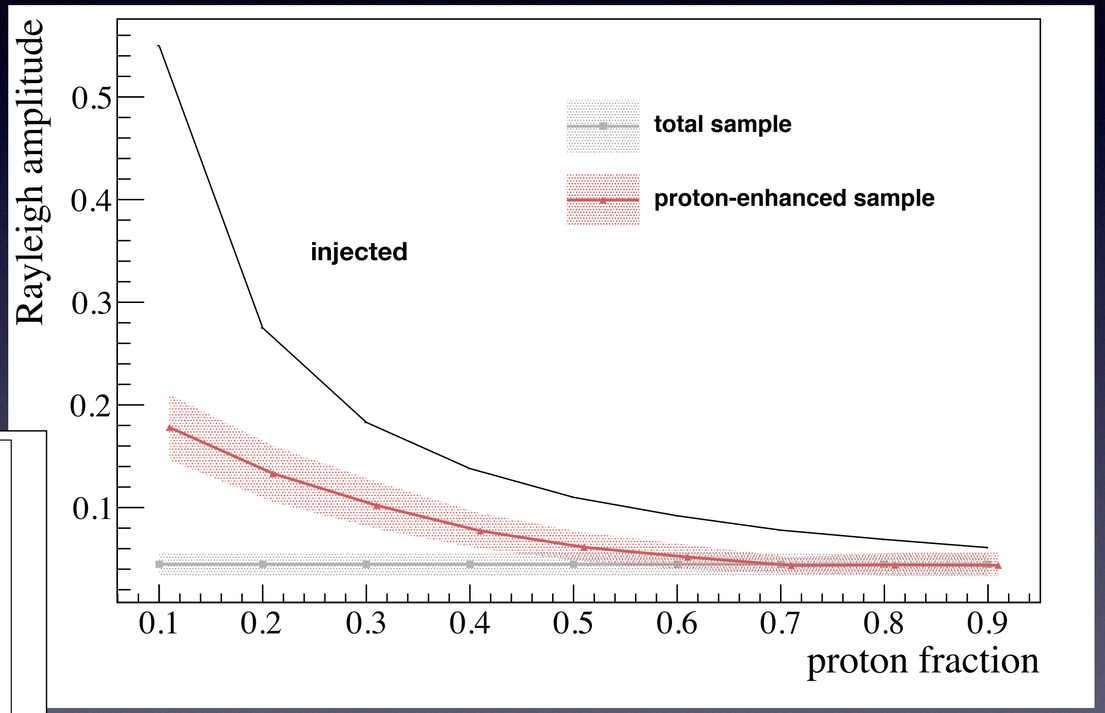
published in 2 internal notes (“GAP notes”) and presented in ICRC2019 as a poster



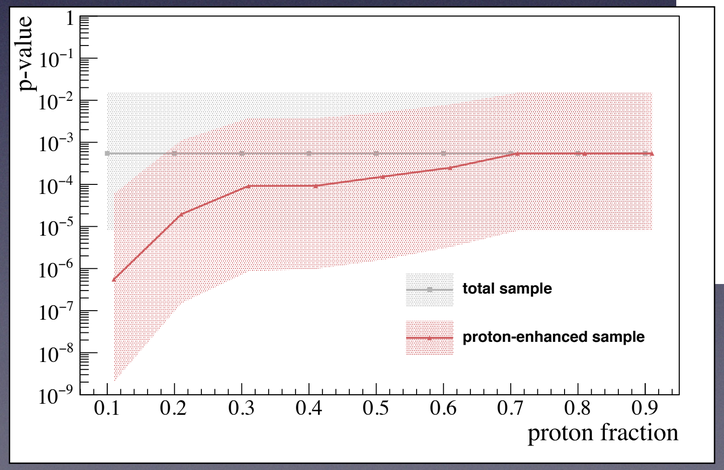
The Brussels group - Dipole study in composite mass scenarios



in a simple case of dipolar proton & isotropic iron…

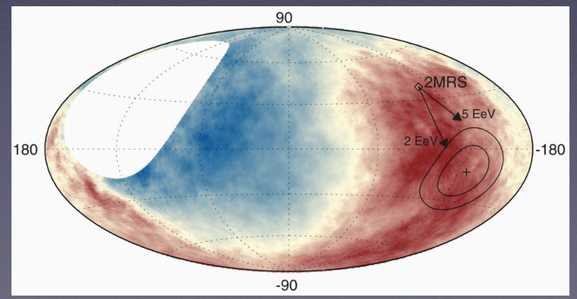


Mean & 1σ of dipole amplitudes



future plan:
- Partial-sky study for more realistic AugerPrime conditions & modelings of mass composition

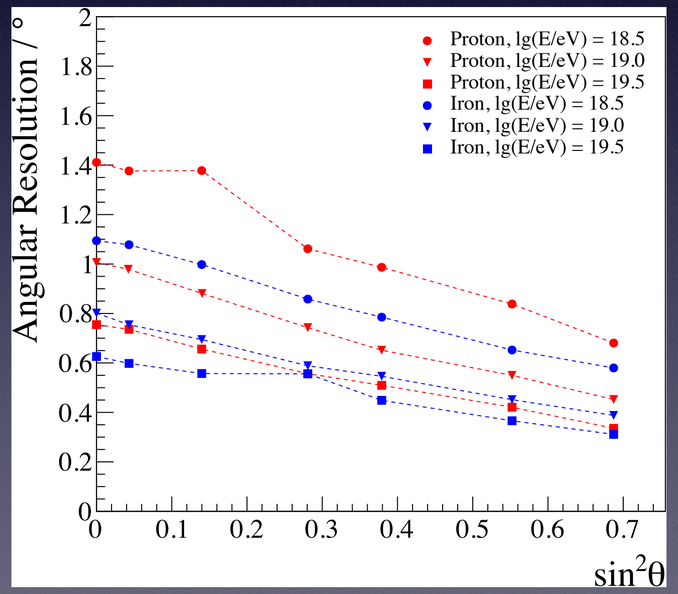
- Full-sky analysis (w/ TA collaboration) for several composition scenarios with P.Tinyakov & M.Kuznetsov (ULB)

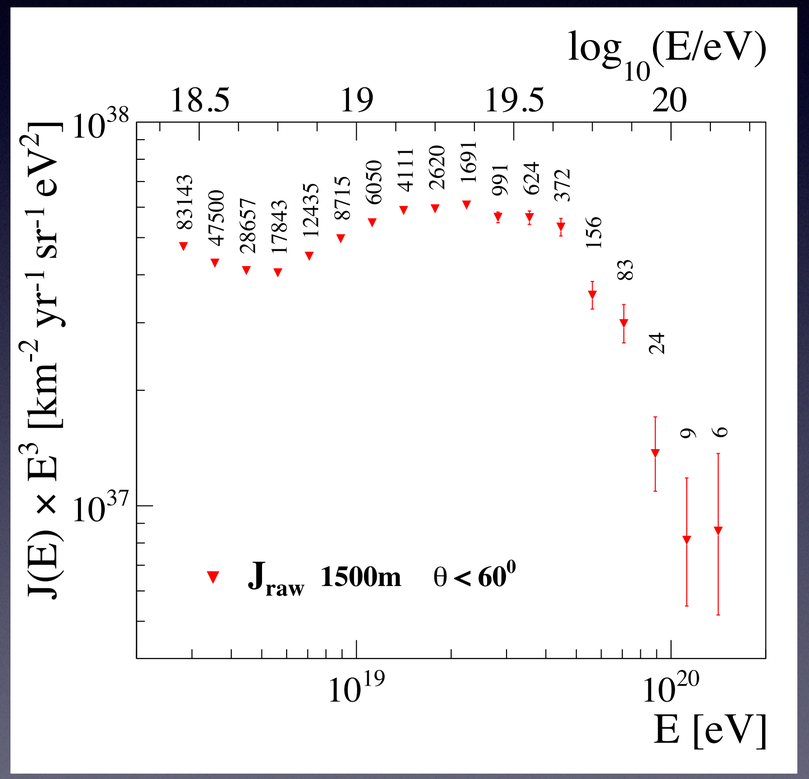


The Brussels group - SD Energy reconstruction

SD energy spectrum (θ<60°) reconstruction:
using FD-SD energy calibration, considering atmospheric correction, systematic uncertainties, …

Simulation studies on the angular and energy resolutions of the SD





Converged into 3 manuscripts (Ioana & Daniela in the EB), presented at ICRC2019 as a poster

"Reconstruction of events recorded by the surface detector of the Pierre Auger Observatory"
(to be published)

"A measurement of the cosmic ray energy spectrum above 2.5 x 10^18 eV using the Pierre Auger Observatory"
(to be published in PRD)

"Features of the energy spectrum of cosmic rays above 2.5 x 10^18 eV using the Pierre Auger Observatory"
(to be published in PRL)

The Brussels group - Activities in international conferences

- EPS 2019 (Ioana - talk *"Review of the results from the Pierre Auger Observatory"*)

- ICNFP 2019 (Daniela - talk *"The Pierre Auger Observatory: review of latest results and future perspectives"*)

- Daniela won Belgian Physics Society prize for the talk *"Measurement of the cosmic ray spectrum with the Pierre Auger Observatory"*

- ICRC 2019 (Daniela - poster *"Reconstruction of Vertical Events Recorded by the Surface Detector of the Pierre Auger Observatory"*, Koun - poster *"Long term performance of the Pierre Auger Observatory"*)

- COSPA 2019 (Daniela - talk *"The Pierre Auger Observatory – Latest results and future perspectives"*)

Outlook

- *The Pierre Auger Observatory is getting through an exciting era with AugerPrime upgrade*
  - better separation between mass components will be achieved by SSD, RD & UMD upgrades
  ☞ *towards charged particle astronomy & particle physics*

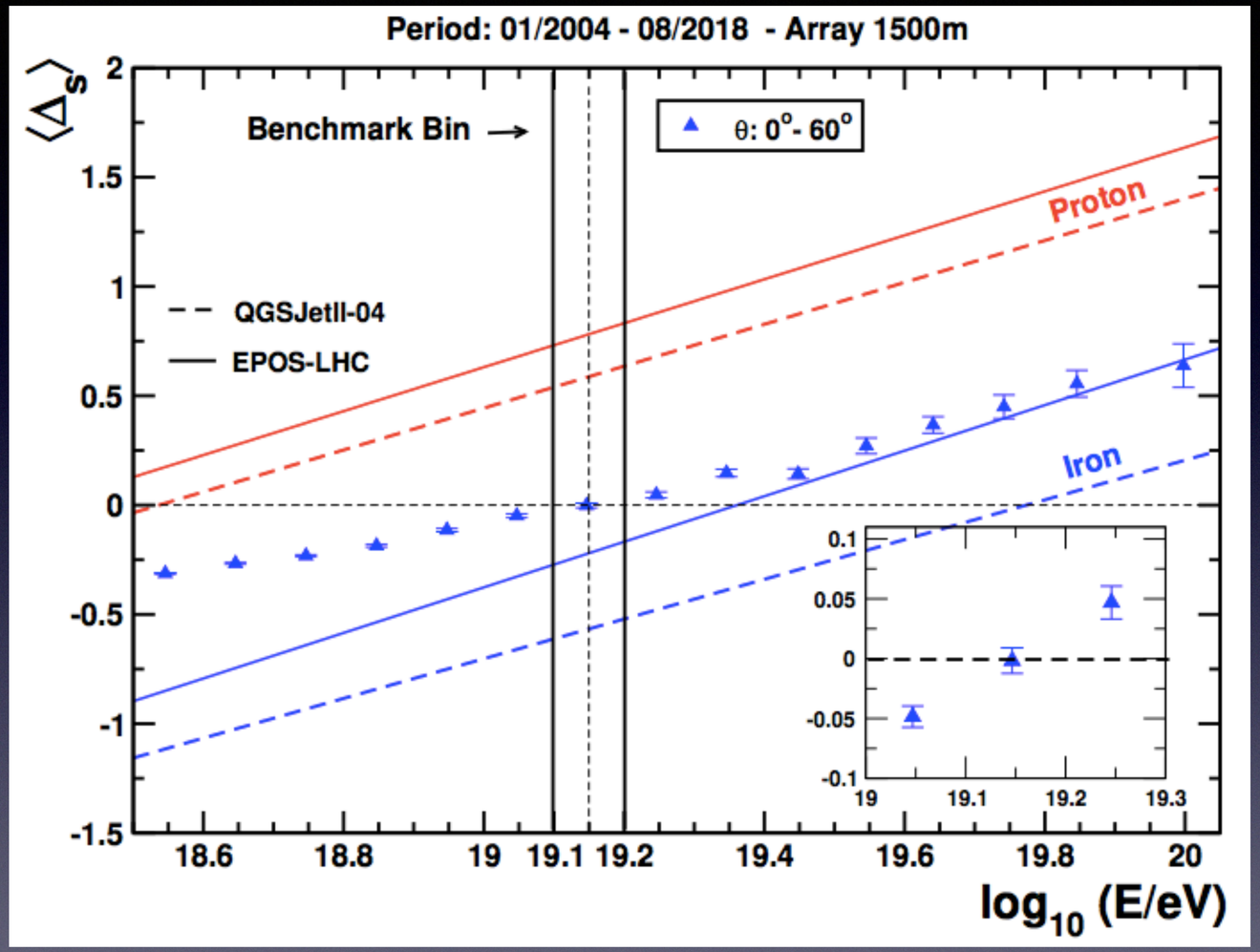
  - increased statistics & reduced background & new electronics & radio technique
  ☞ *cosmogenic neutrino & photon discoveries*

- *iihe-Brussels is a dynamic group involved in several analyses:*
  - use SSD data, Auger+TA data, Radio data for anisotropy analyses
  - Observatory lifetime extended to 2030
  ☞ *keep high visibility in long-term performances of the detector*

  - and more

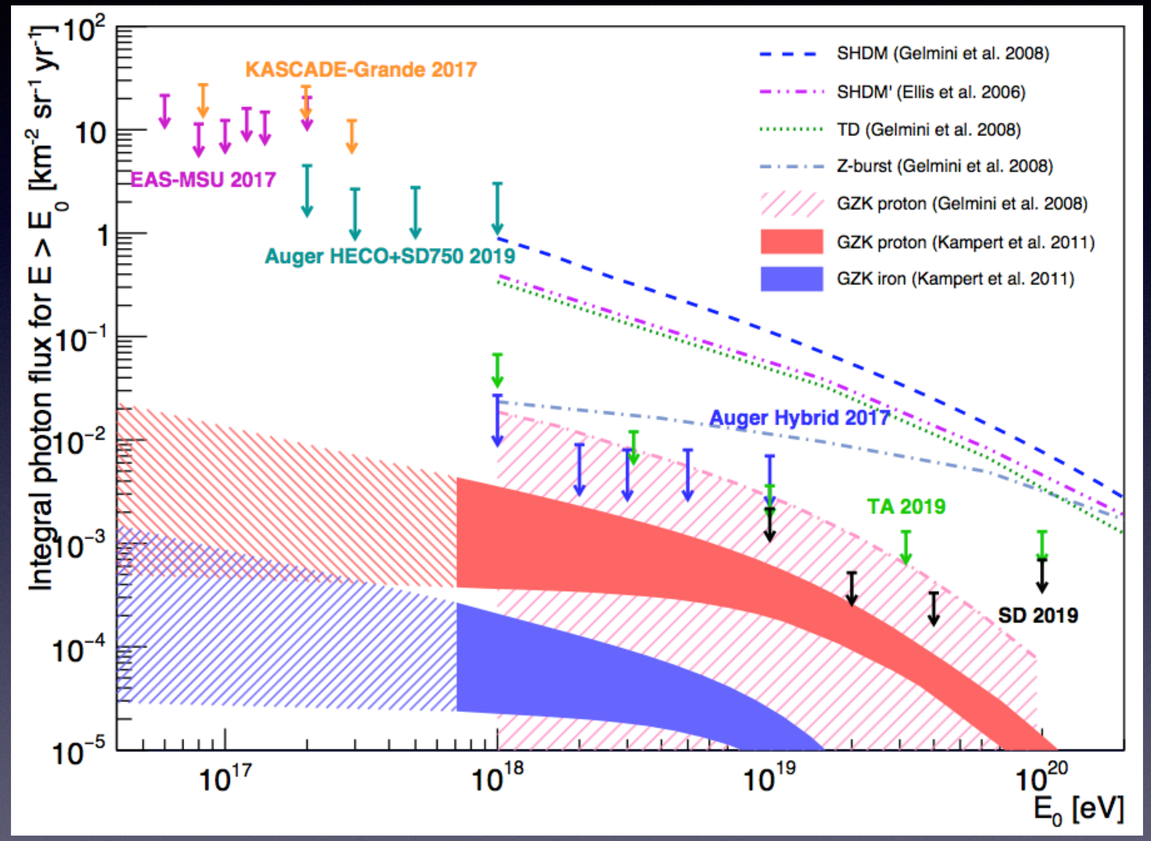
Back up

SD analysis
“delta method” using risetime
shows similar result to FD result
with smaller error

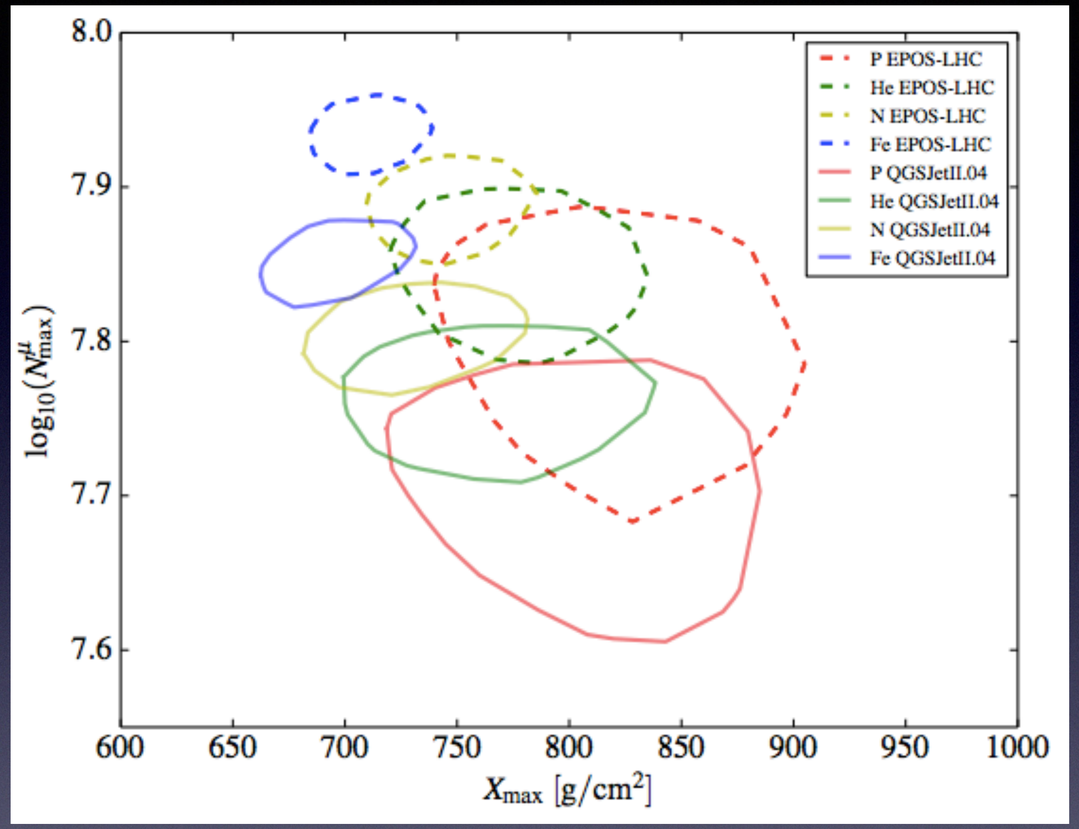


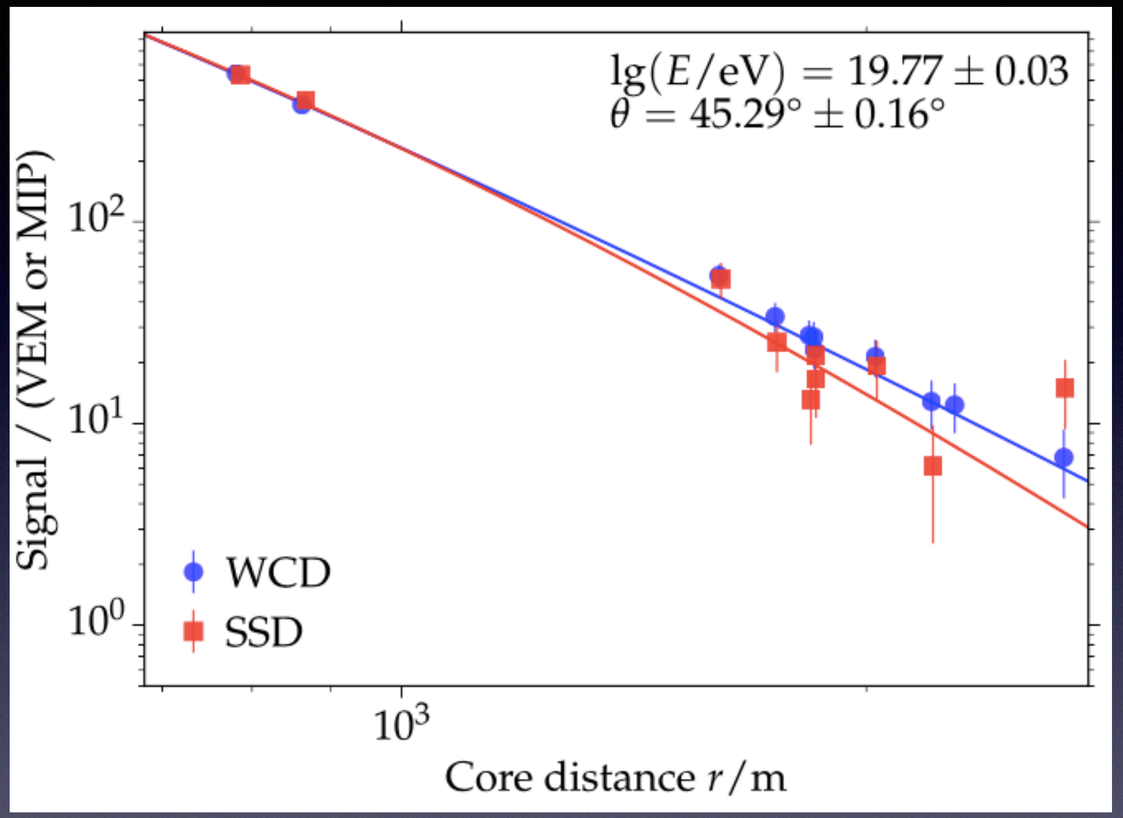
photons

diffuse photon limit



Above 10 EeV: 11 events, consistent with background
below 1 EeV:1 event, consistent with background


P EPOS-LHC
He EPOS-LHC
N EPOS-LHC
Fe EPOS-LHC
P QGSJetII.04
He QGSJetII.04
N QGSJetII.04
Fe QGSJetII.04
8.0
7.9
7.8
7.7
7.6
$\log_{10}(N^{\mu}_{\max})$
600
650
700
750
800
850
900
950
1000
$X_{\max}$ [g/cm^2]


$\lg(E/\mathrm{eV}) = 19.77 \pm 0.03$
$\theta = 45.29° \pm 0.16°$
Signal / (VEM or MIP)
10^2
10^1
10^0
WCD
SSD
10^3
Core distance r/m

Arrival direction - intermediate scale anisotropy

full-sky source search without target source

scan over 32<***Eth***<80 EeV, 1<***θ***<30°
most significant (post-trial p-value=2.5%) at:
Eth=38 EeV, ***θ***=27°, ~2° away from CenA