Review of some ICRC 2015 results (mostly ν)

Pasquale D. Serpico
MITP Crossroads of neutrino physics

Overview

Needless to say, dominated by IceCube discovery
(as shown also by prizes)

IUPAP-TIFR Homi Bhabha Medal Medal and Prize:
Tom Gaisser

IUPAP Young Scientist Prize in Astroparticle Physics:
Claudio Kopper and Julia Tjus

Could be summarized in:

- refinements
- cross-checks
- interpretations
- future

3 Years vs 4 Years

Enriched sample ad low-E, not at high-E… steeper global fit!

Claudio Kopper
"Neutrino Astronomy" ***invited highlight talk***

WHAT DID ICECUBE FIND? (4 YEARS)

54 events!

53(+1) events observed!

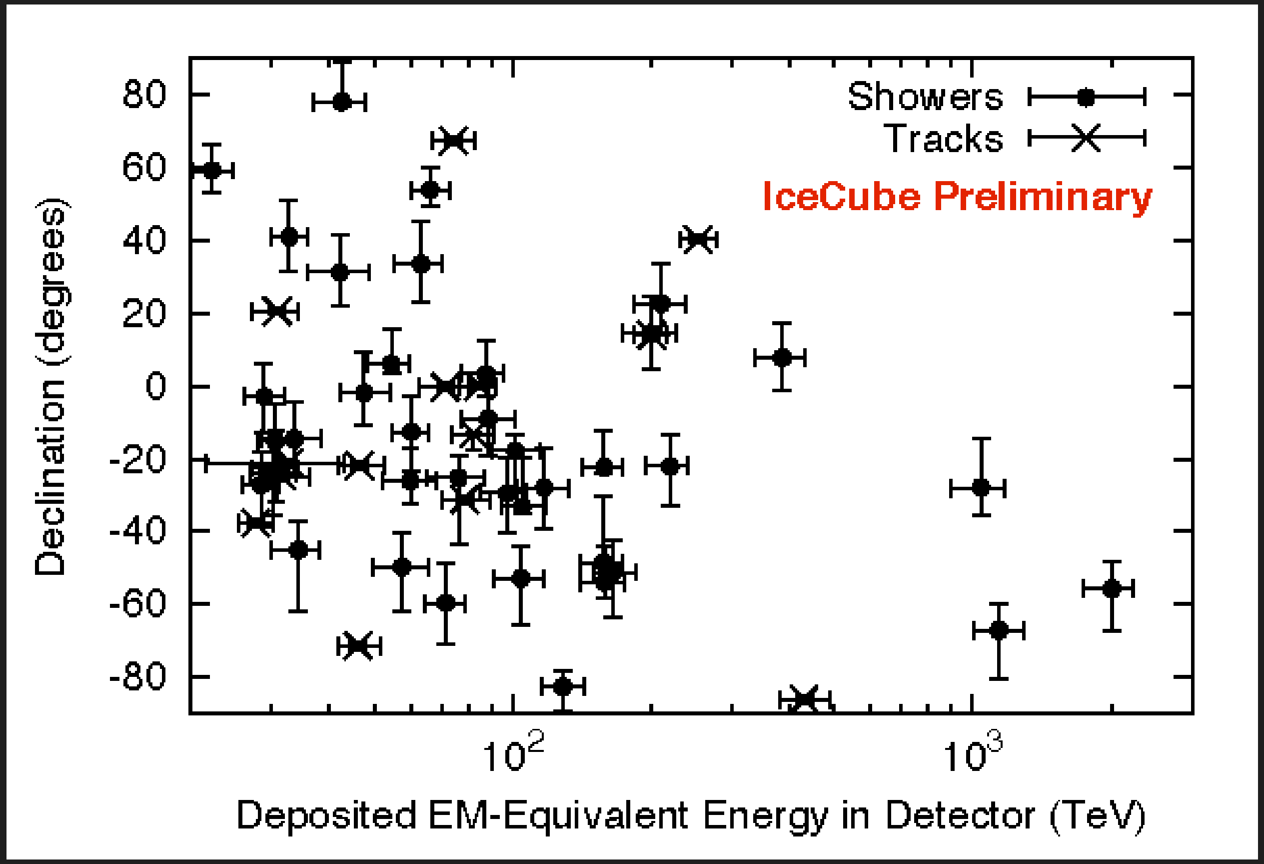
Estimated background:

$9.0^{+8.0}_{-2.2}$ atm. neutrinos

12.6±5.1 atm. muons

One of them is an obvious (but expected) background

coincident muons from two CR air showers



full likelihood fit of all components: 6.5σ for 53(+1) events

3 Years vs 4 Years

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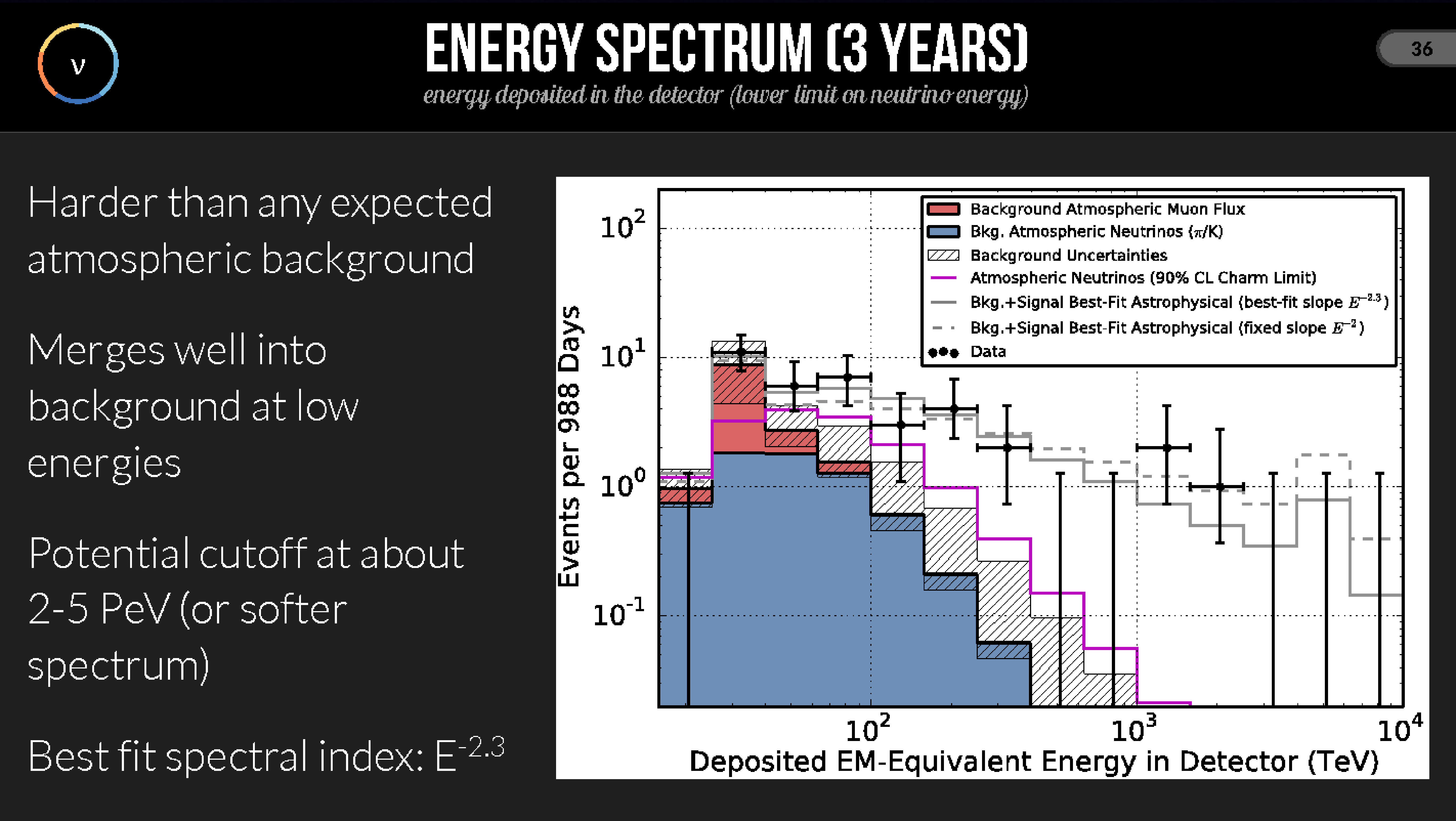

ENERGY SPECTRUM (3 YEARS)

energy deposited in the detector (lower limit on neutrino energy)

Harder than any expected atmospheric background

Merges well into background at low energies

Potential cutoff at about 2-5 PeV (or softer spectrum)

Best fit spectral index: $E^{-2.3}$

3 Years vs 4 Years

Enriched sample ad low-E, not at high-E… steeper global fit!

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"Neutrino Astronomy" ***invited highlight talk***

ENERGY SPECTRUM (4 YEARS)

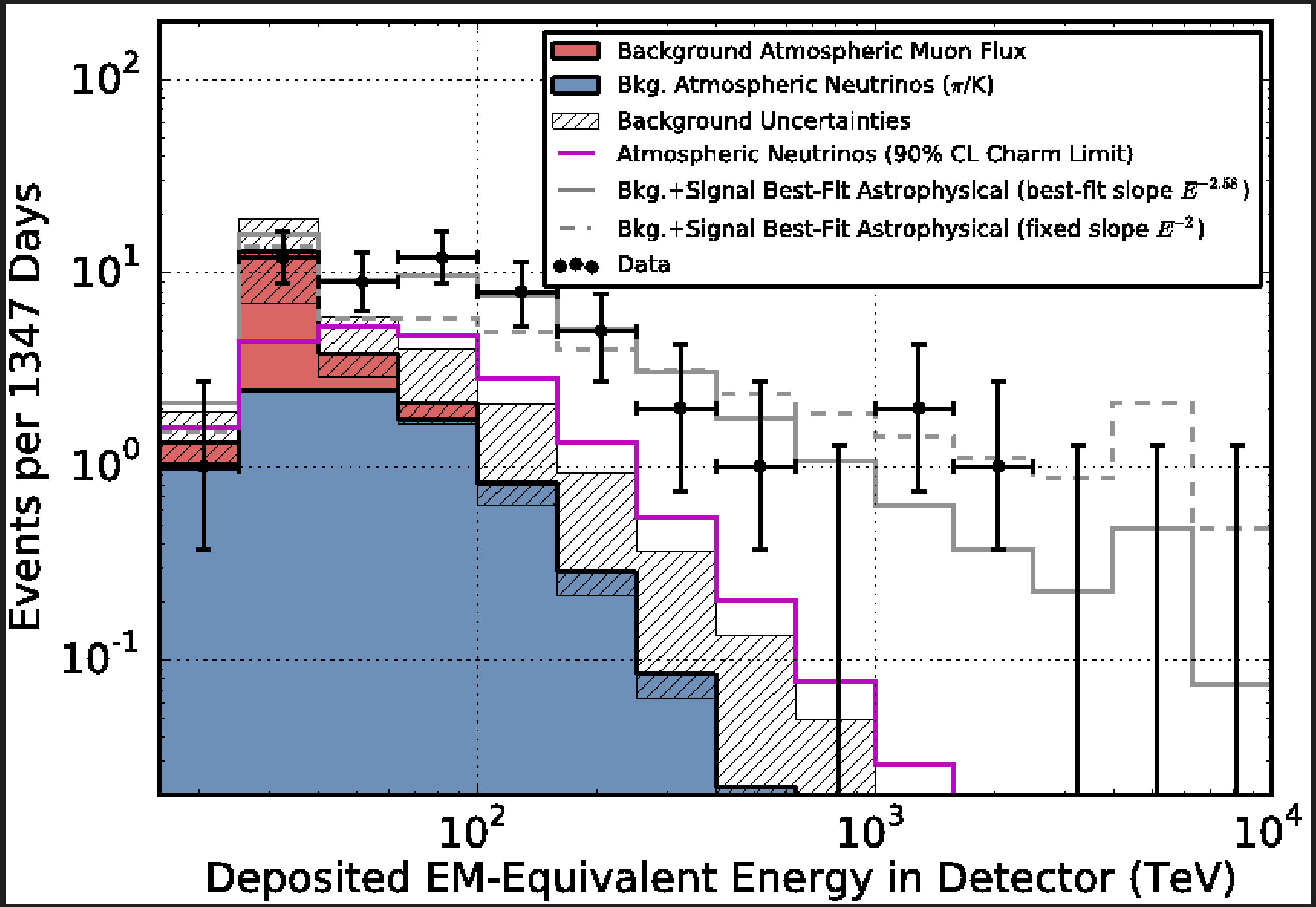
energy deposited in the detector (lower limit on neutrino energy)

Somewhat compatible with benchmark E^{-2} astrophysical model or single power-law model, but looks like things are more complicated

Best fit assuming E^{-2} (not a very good fit anymore):

$0.84 \pm 0.3\ 10^{-8}\ E^{-2}\ \mathrm{GeV\ cm^{-2}\ s^{-1}\ sr^{-1}}$

Best fit spectral index: $E^{-2.58}$



3 Years vs 4 Years

Enriched sample ad low-E, not at high-E… steeper global fit!

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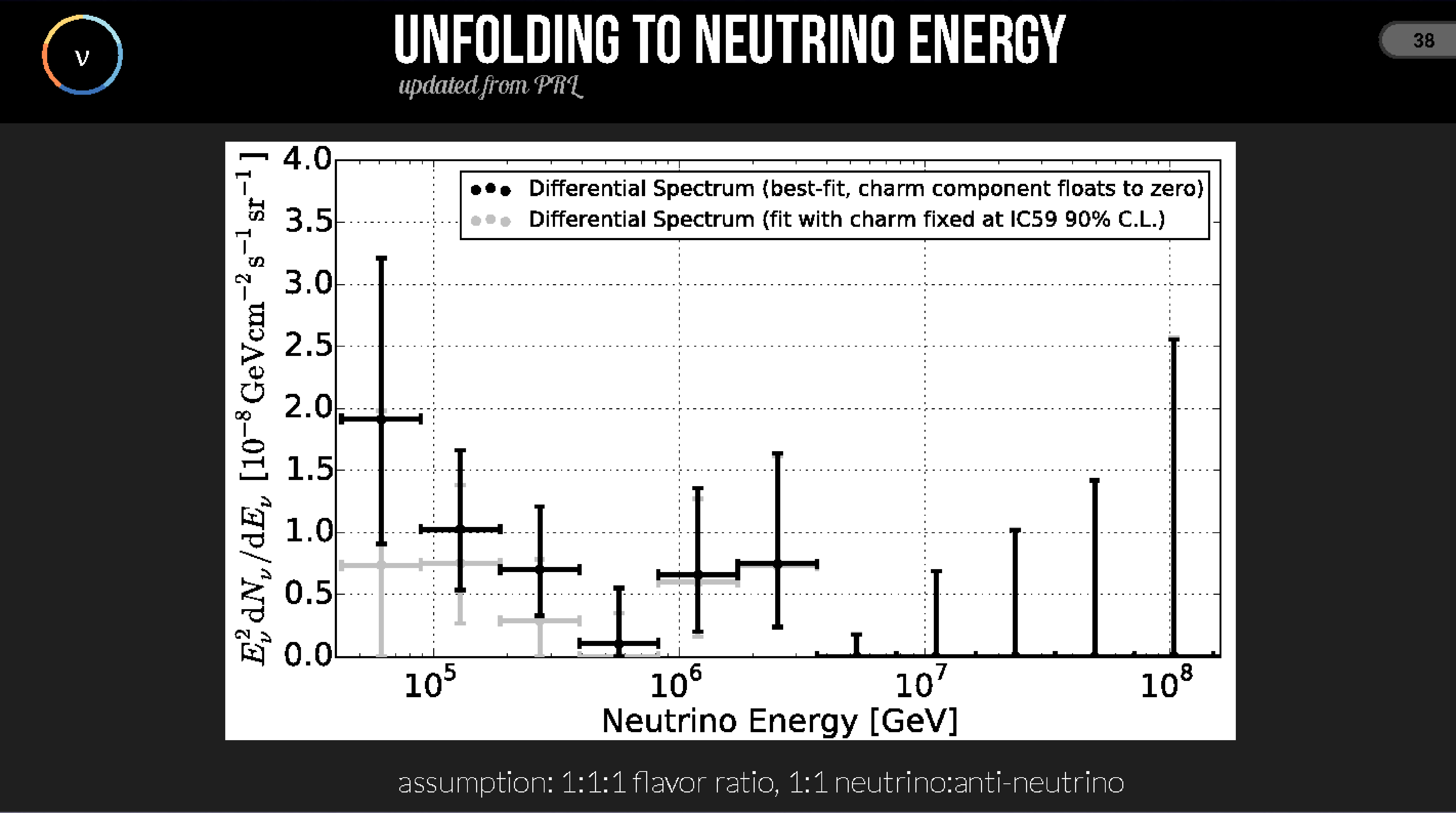


UNFOLDING TO NEUTRINO ENERGY

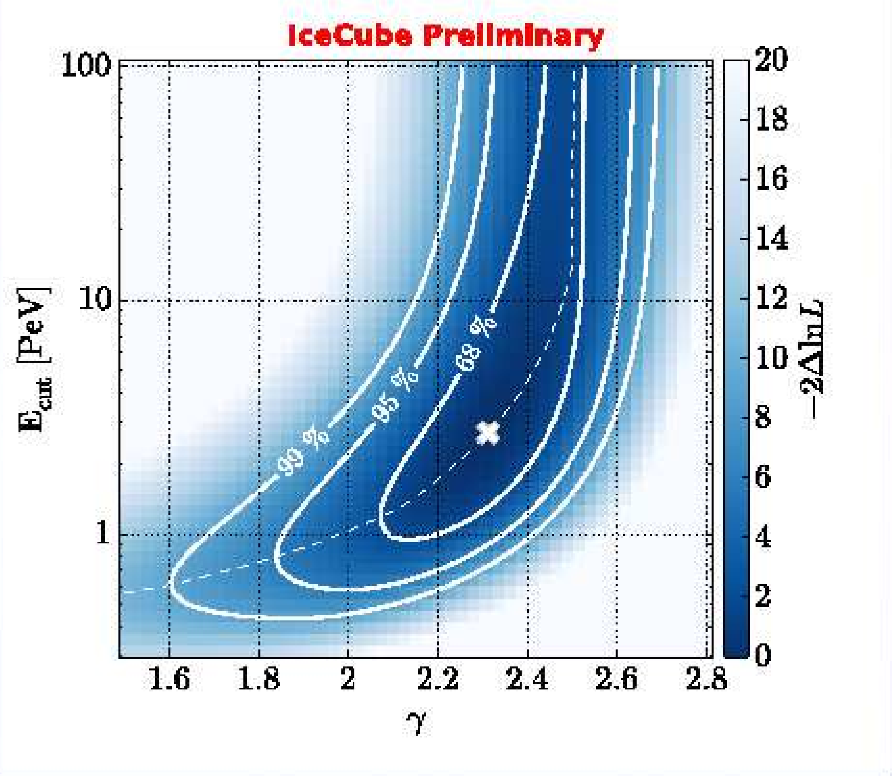
updated from PRL

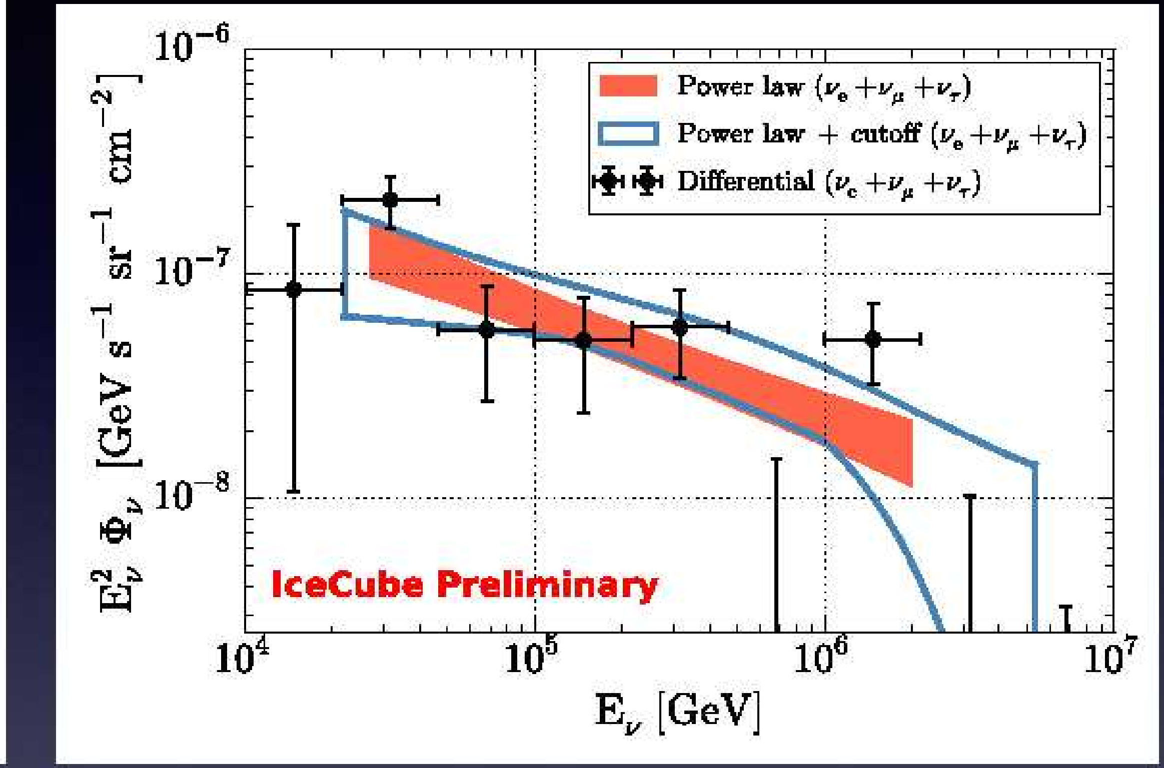
assumption: 1:1:1 flavor ratio, 1:1 neutrino:anti-neutrino

Global analysis

L. Mohrmann (#1066)

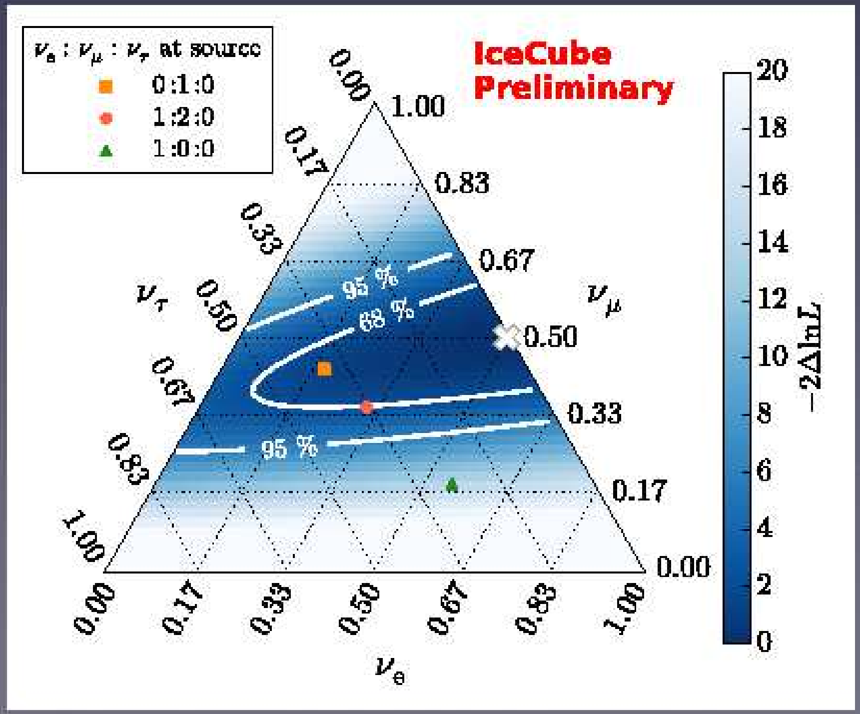
Combined Analysis of the High-Energy Cosmic Neutrino Flux at the IceCube Detector





Combining the event samples of multiple individual searches, thus covering all detection channels. We derive the energy spectrum and flavor composition of the cosmic neutrino flux in the TeV–PeV energy range

- hard spectra only consistent with a break
- Flavour composition consistent with expectations
- (includes new technique to slightly break e-tau degeneracy)

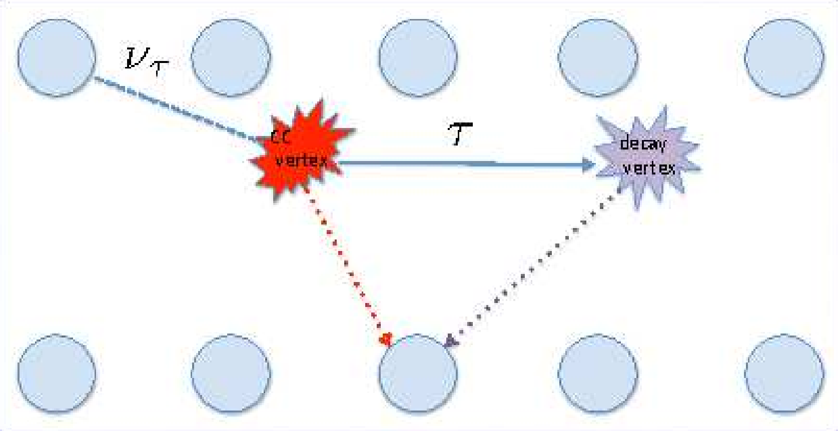


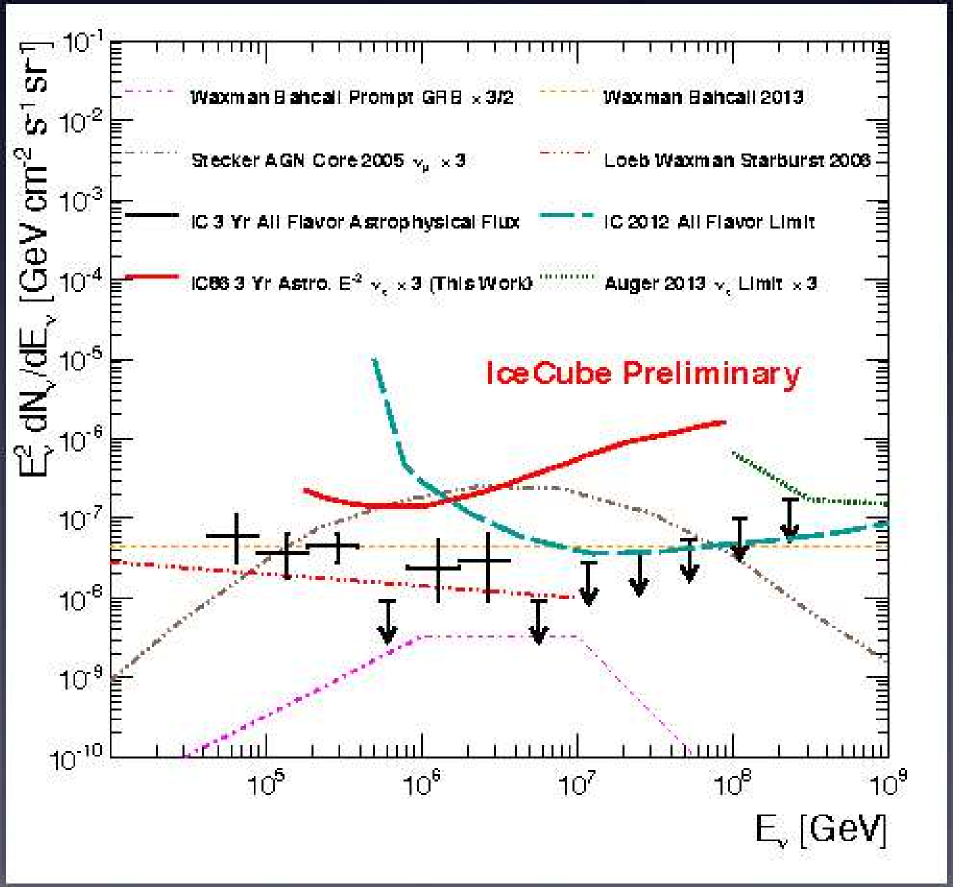
Double pulse

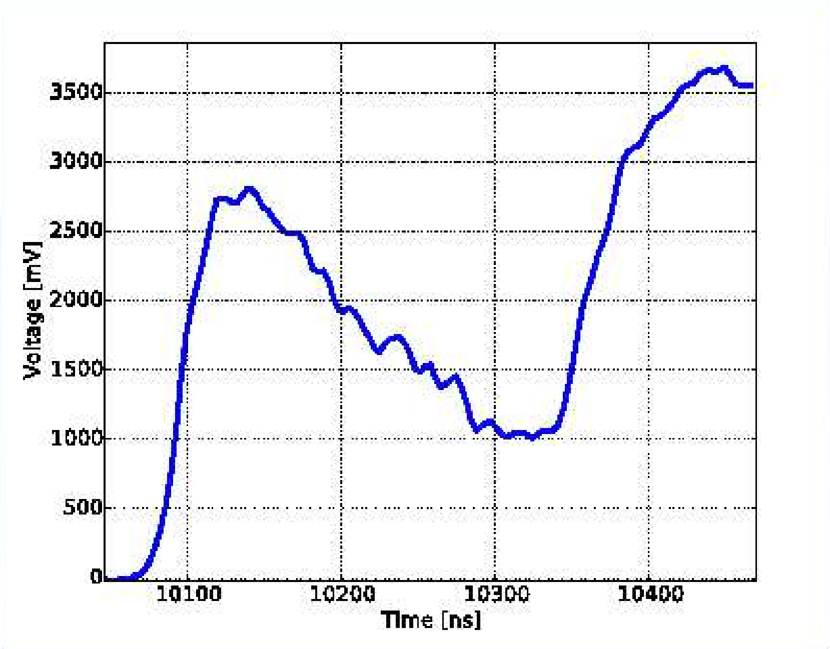
D.R Williams (#1071)

“A search for astrophysical tau neutrinos in three years of IceCube data”

“classical” search for separated bangs quite inefficient below few PeV’s. At lower energies, where data are present, new strategy being developed based on “double pulses” in the DOMs







Less than 1 event expected, zero observed… still promising for the future!

Upgoing muons

Claudio Kopper
"Neutrino Astronomy" invi... talk

UPGOING MUONS - SPECTRAL CO... S

Two years of dat...

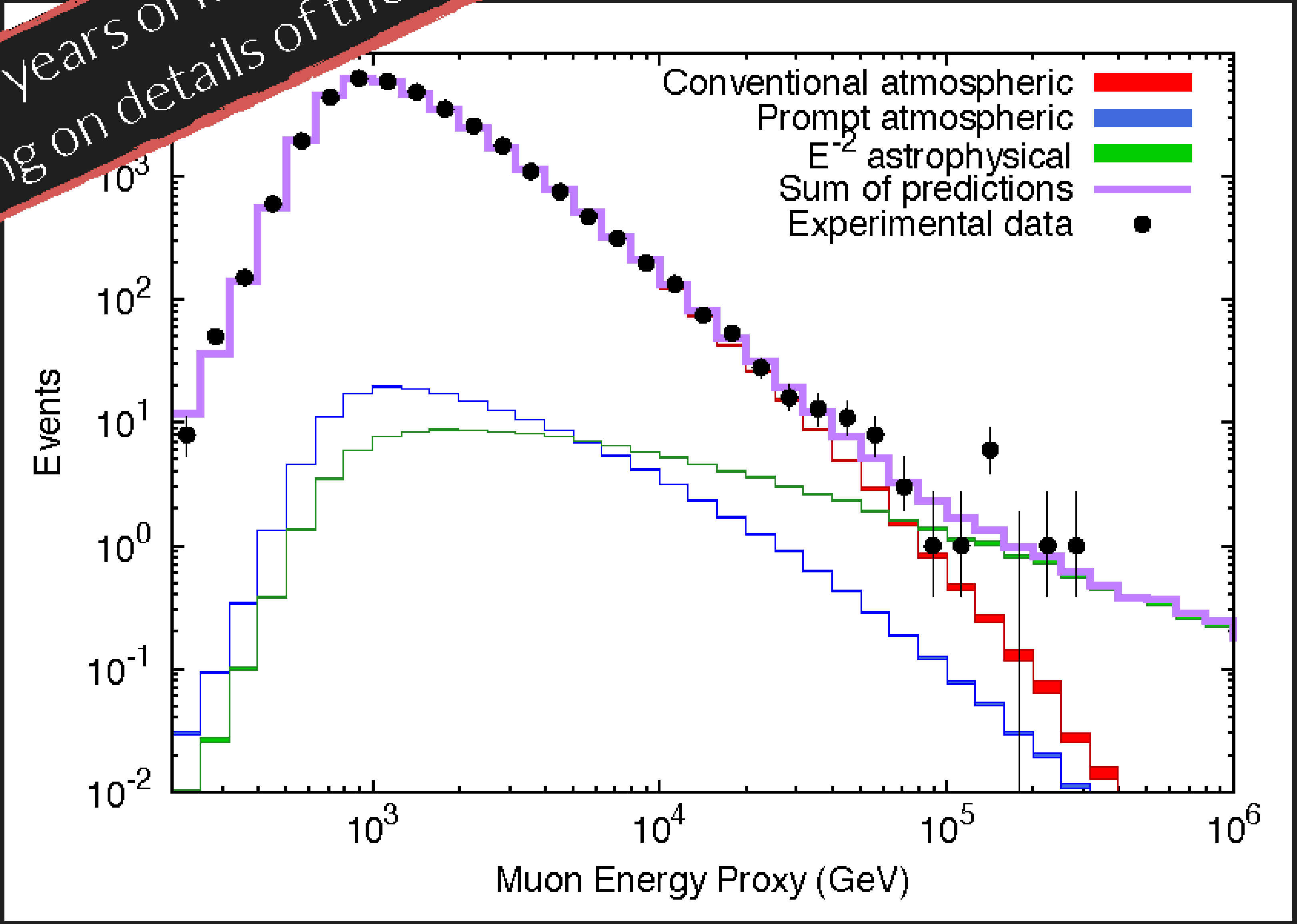
New @ ICRC - now looking at up to 6 years of muon data (work in progress) - re-analyzed 3 years (presented here) and working on details of the 6 year result

first significant ν_μ -based and northern sky-dominated measurement of the ... neutrino flux

for ... umption - (best fi...

Normalization for E^{-2}:
$0.99^{+0.4}_{-0.3}\ 10^{-8}\ E^{-2}$ GeV cm^{-2} s^{-1} sr^{-1}

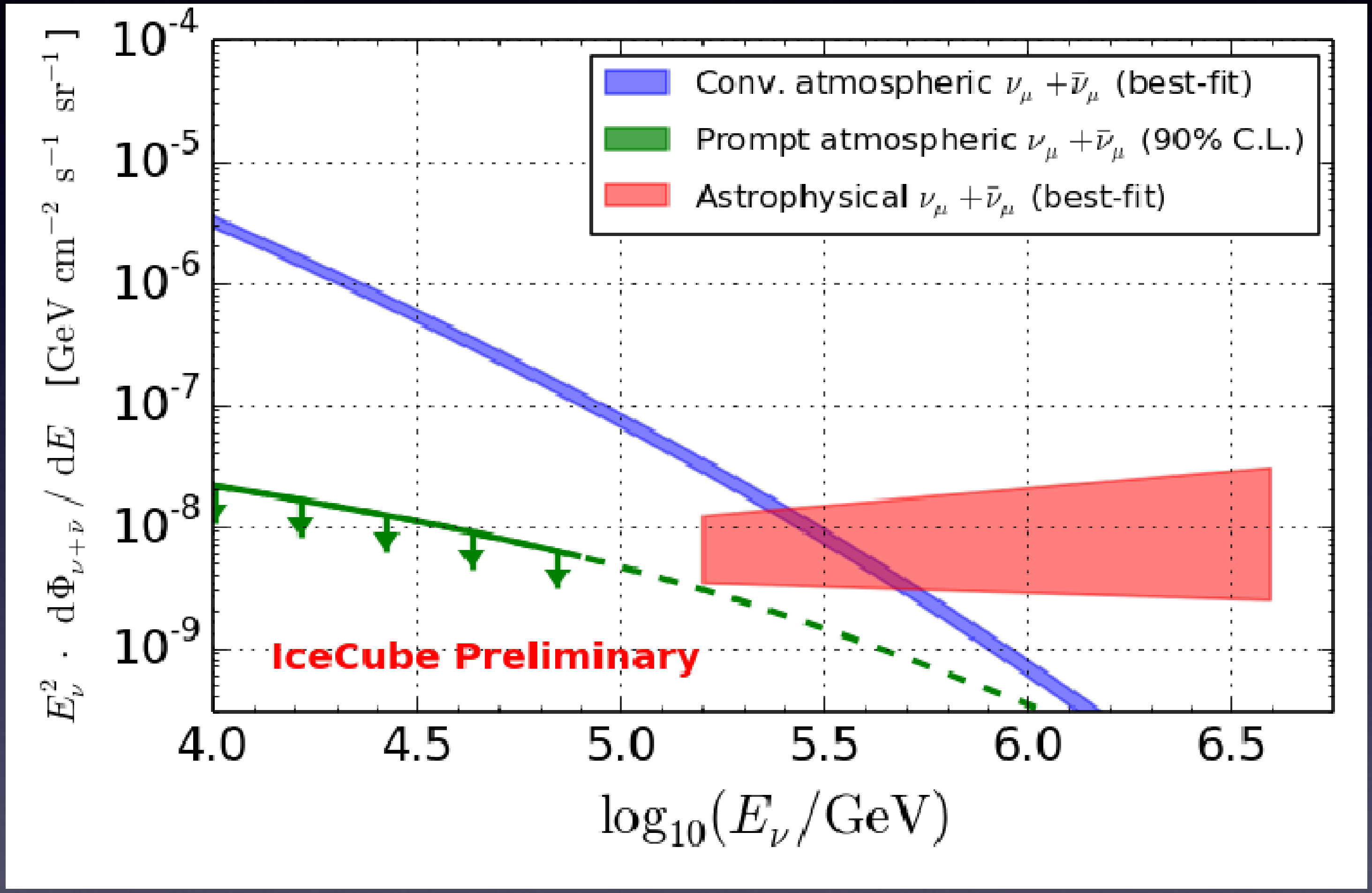
accepted by PRL,
arXiv:1507.04005



Upgoing muons

Leif Rädel

"A measurement of the diffuse astrophysical muon neutrino flux using multiple years of IceCube data"



$0.66^{+0.40} \cdot 10^{-18} \mathrm{GeV}^{-1} \mathrm{cm}^{-2} \mathrm{s}^{-1} \mathrm{sr}^{-1}$ @ 100 TeV neutrino energy and a hard spectral index 1.91 ± 0.20.

- No evidence for a cut-off at high energies is found.
- No significant evidence for a Galactic component in the measured astrophysical muon neutrino flux.
- However, due to the large uncertainties still statistically compatible with previous results

Let's stay tuned…

UPGOING MUONS

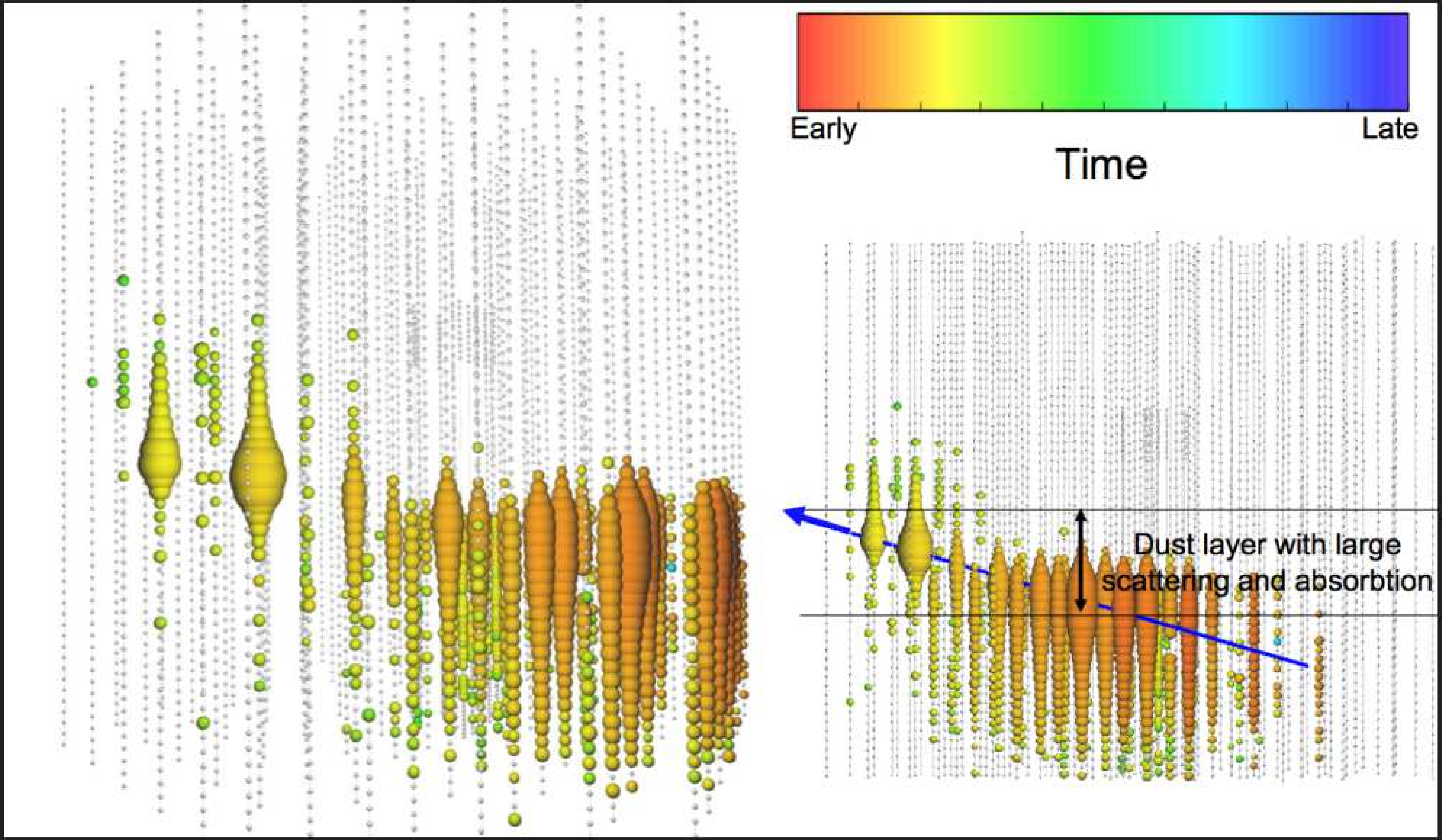
an interesting event in the six-year sample!

up-going
(i.e. not a CR muon)

deposited energy:
2.6±0.3 PeV
(lower limit on neutrino energy)

date: June 11, 2014

direction:
11.48° dec / 110.34° RA



Looking for cross-correlations

- Fermi
- HESS
- Veritas
- HAWC
- Antares

No positive result, yet, but in some cases interesting consequences…

Observatory	Contact	Letter of Collaboration	MoU in Review	MoU Signed
ANTARES	Juergen Brunner	✓	✓	✓ MOU
Auger	Miguel Mostafa	✓	✓	✓ MOU
FACT	Adrian Biland			✓ MOU
Fermi	Julie McEnery	✓		
HAWC	Ignacio Taboada	✓	✓	✓ MOU
IceCube	Doug Cowen	✓	✓	✓ MOU
LIGO	Gabriela Gonzalez	✓		
Large Millimeter Telescope	Alberto Carramiñana	✓	✓	✓
MASTER	Vladimir Lipunov			✓ MOU
Palomar Transient Factory	Tom Prince	✓		
Swift	Scott Barthelmy	✓	✓	✓
VERITAS	Abe Falcone	✓	✓	✓

AMON

Astrophysical Multimessenger Observatory Network

Several searches conducted within AMON

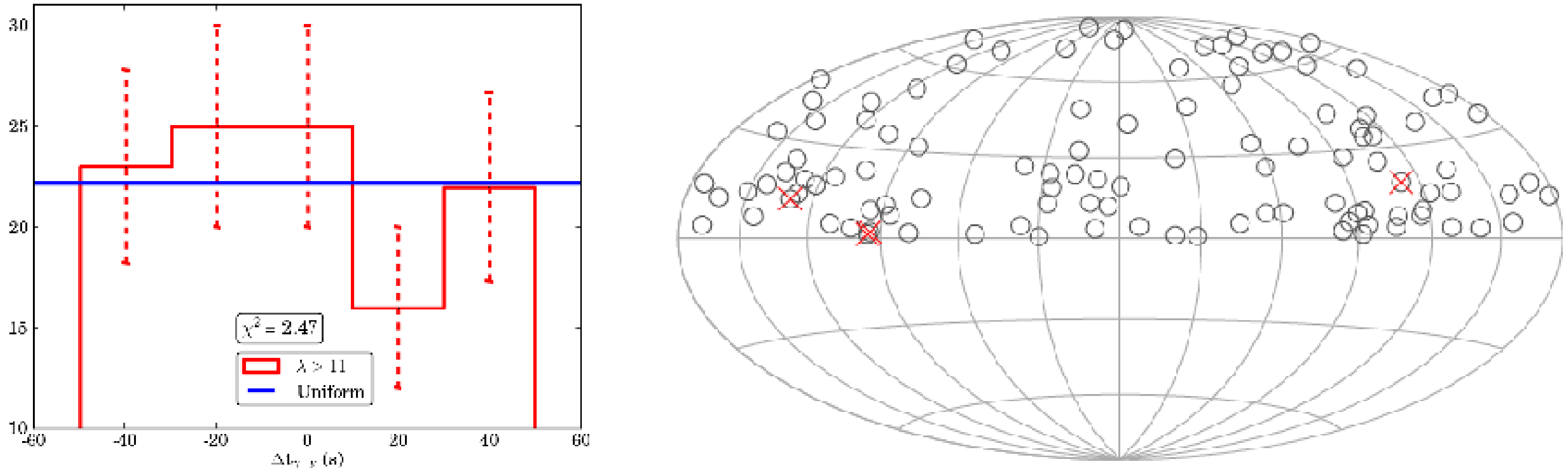
http://amon.gravity.psu.edu

With Fermi

Keivani (#786)

AMON Searches for Jointly-Emitting Neutrino + Gamma-Ray Transients

results of archival coincidence analyses using public neutrino data from the 40-string configuration of IceCube (IC40) and contemporaneous public gamma-ray data from Fermi LAT



(a) Δt

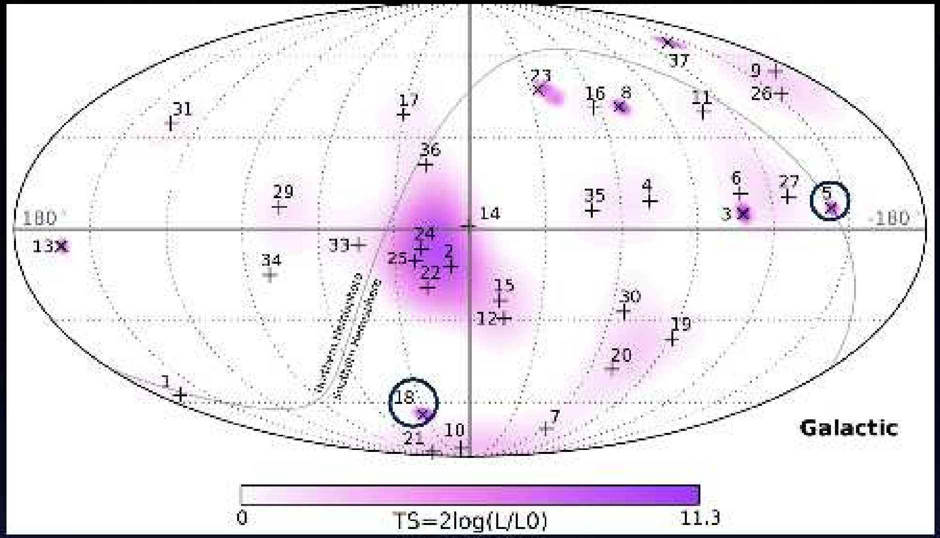
(b) Clustering

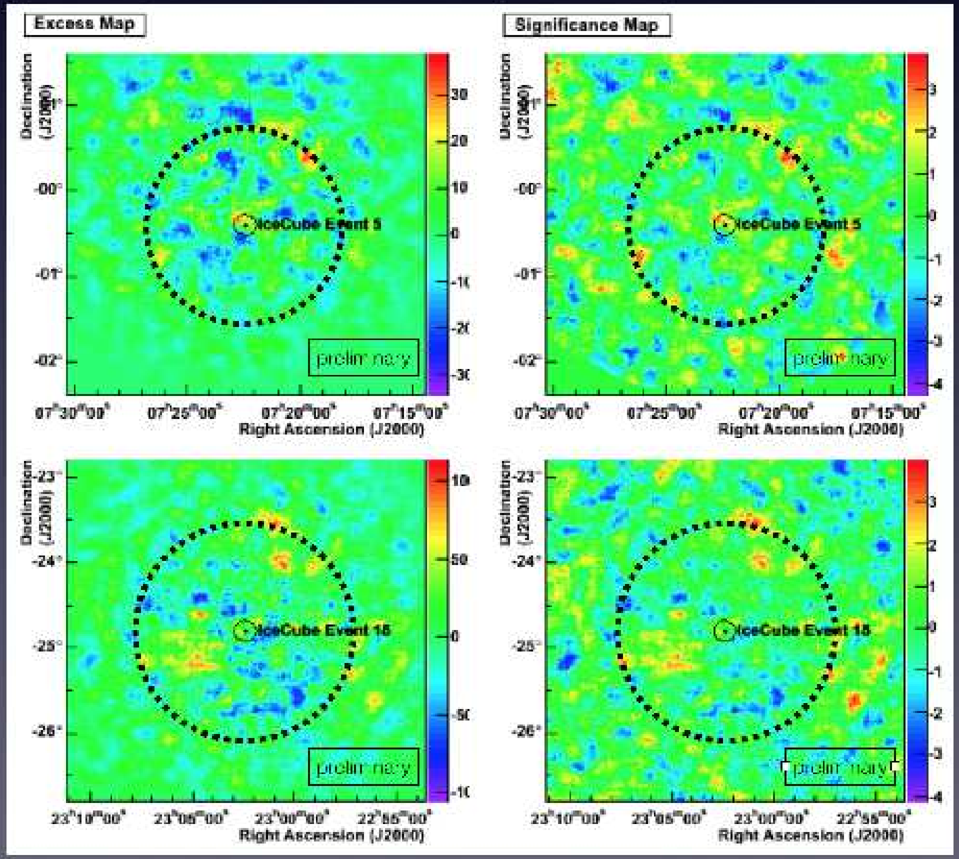
Multiplicity, time correlation and clustering tests show no significant correlation

With HESS

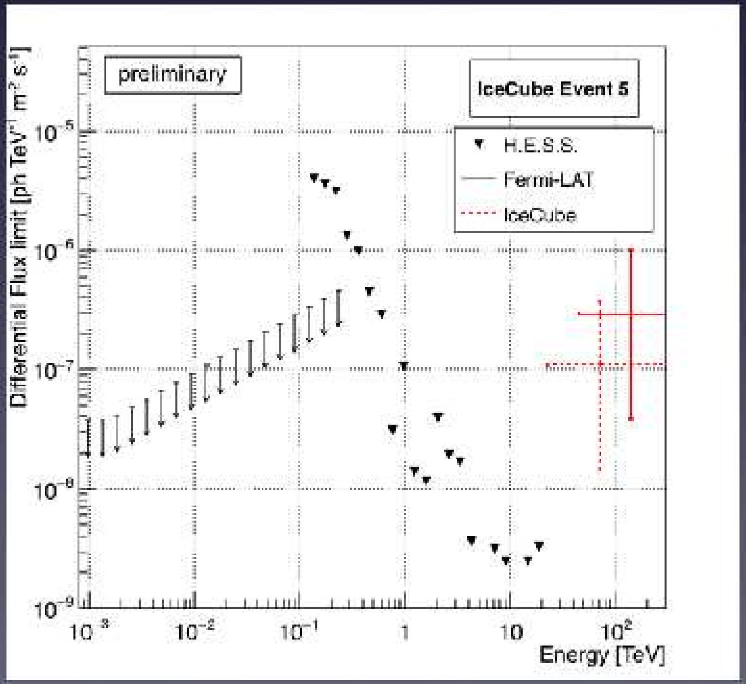
F. Schüssler (#726)

The HESS multimessenger program

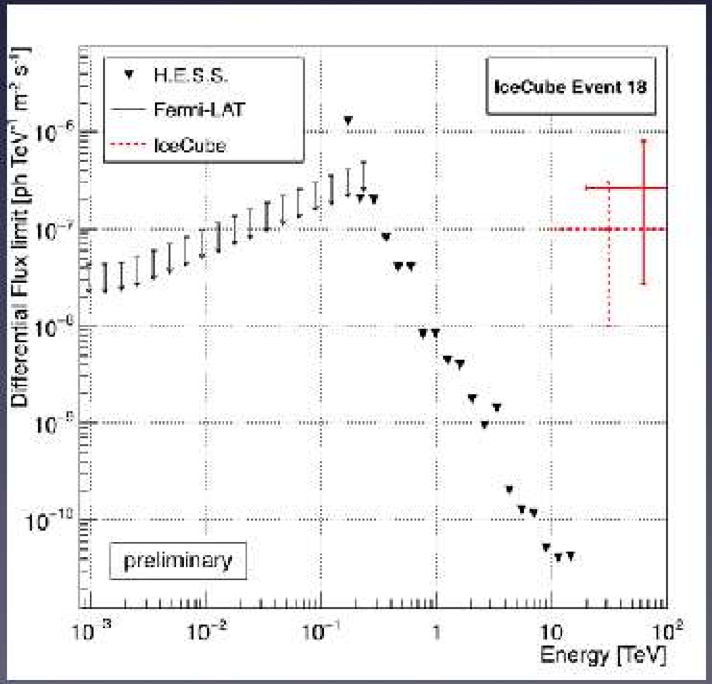




~2 hours



<12 hours



negligible probability for any of these events to be Galactic (non-trivial notably for #5)

z(#5) >0.007, z(#18)>0.012 for Franceschini et al.'s '08 EBL

With EAS UHECR detectors

Search for a correlation between the UHECRs measured by the Pierre Auger Observatory and the Telescope Array and the neutrino candidate events from IceCube

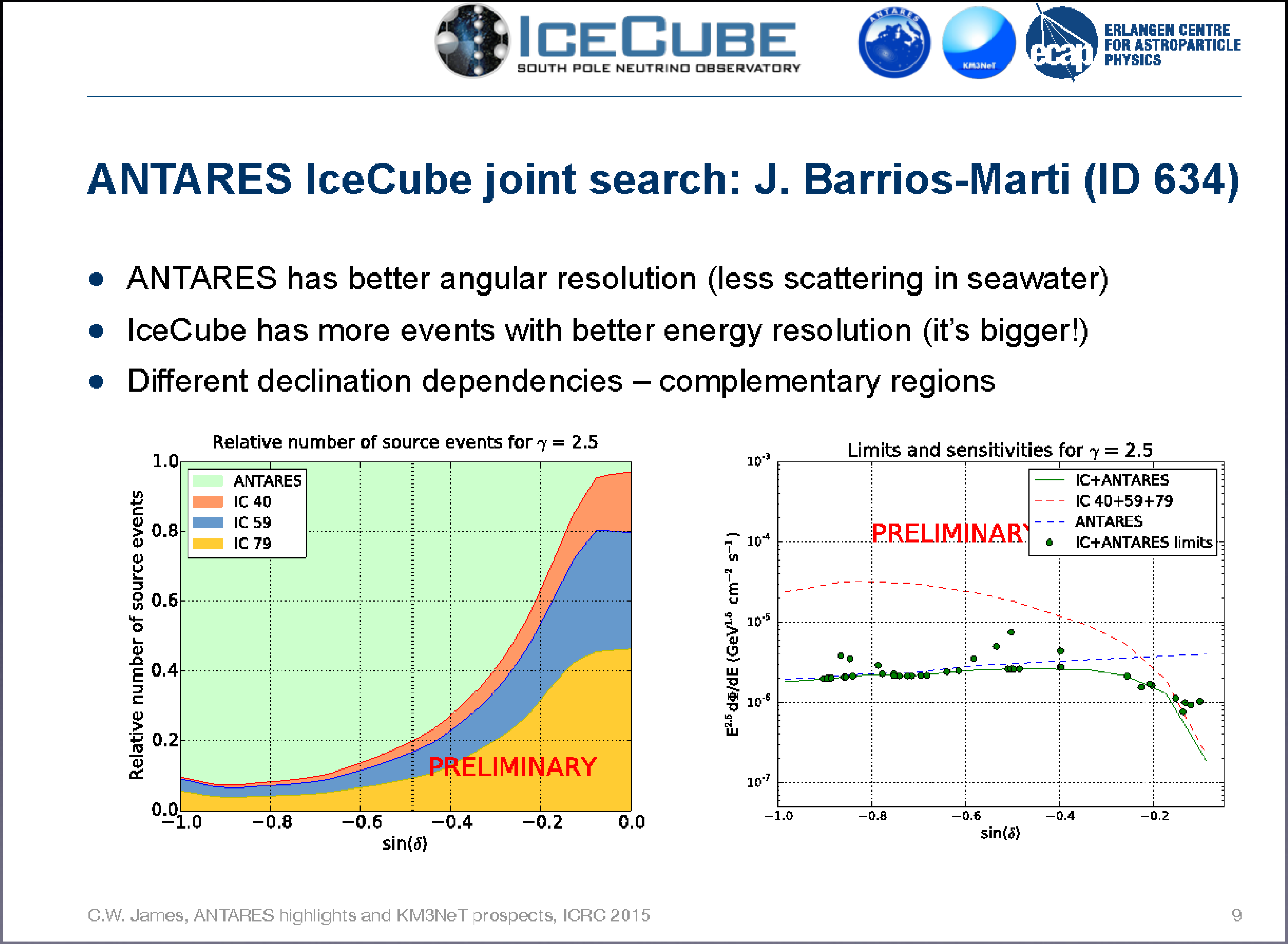
A. Christov, G. Golup, T. Montaruli, M. Rameez for the IceCube Collaboration; J. Aublin, L. Caccianiga, P.L. Ghia, E. Roulet, M. Unger for the Pierre Auger Collaboration; and H. Sagawa, P. Tinyakov for the Telescope Array Collaboration

Conclusions

- The first joint IceCube-Pierre Auger-Telescope Array correlation analysis was performed.
- All correlations found have less than 3.3 sigma significance.
- There is a potentially interesting result in the analyses with high-energy cascades - if we assume an isotropic flux of neutrinos (fixing the directions of the UHECRs) to assess the effect of the presence of anisotropies in the CR arrival directions (such as TA hot spot), the significance is ~2.4 sigma.
- These results were obtained with relatively few events and we will update these analyses in the future with more statistics.

Notable results from Antares

Clancy James invited highlight talk



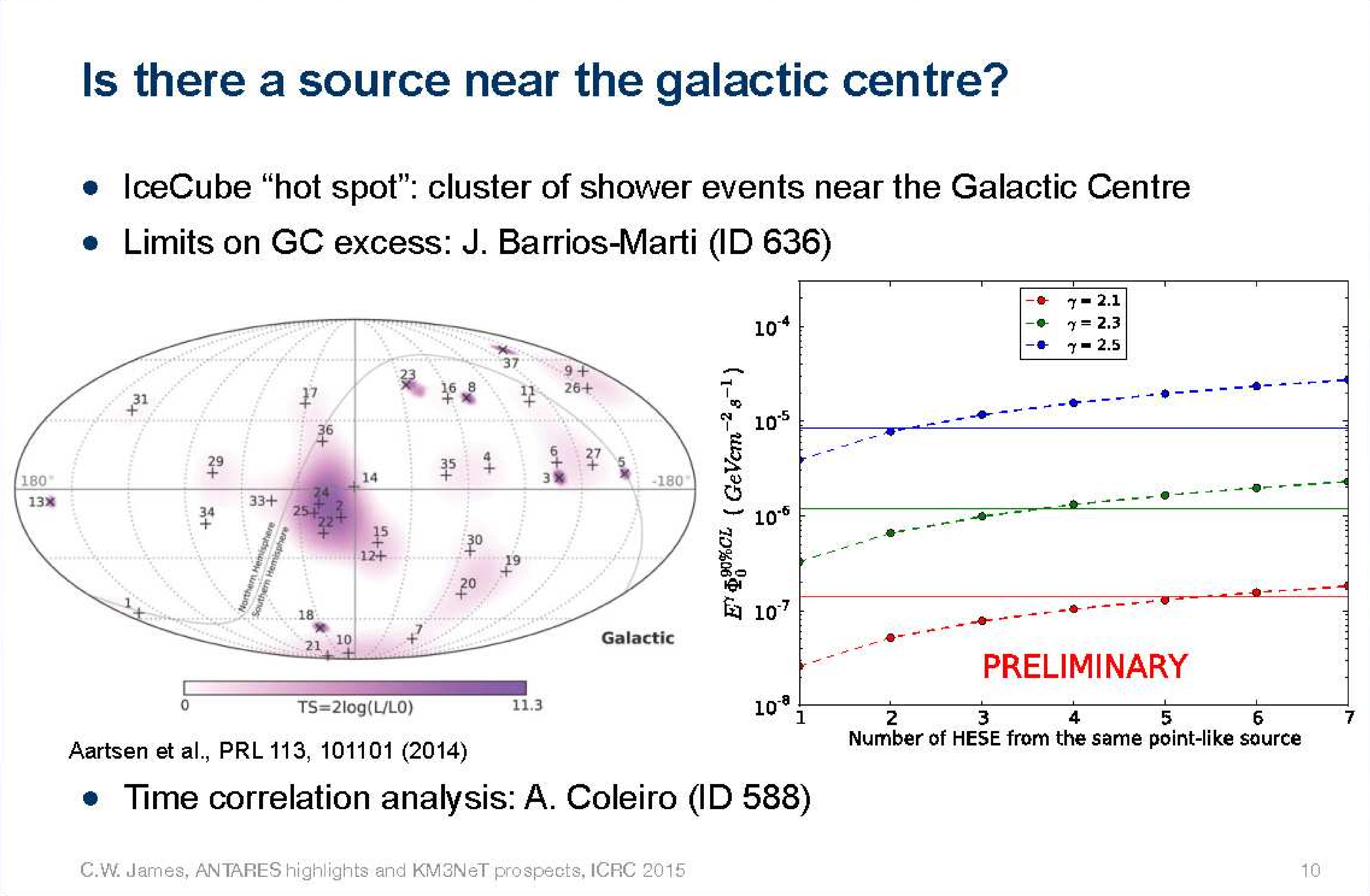
ANTARES IceCube joint search: J. Barrios-Marti (ID 634)

- ANTARES has better angular resolution (less scattering in seawater)
- IceCube has more events with better energy resolution (it's bigger!)
- Different declination dependencies – complementary regions

Bounds to # of events due to GC

Clancy James invited highlight talk

Especially for a "steep" spectrum (=more events in the ANTARES region of sensitivity) Gal. Center source should be visible… nothing seen, upper limit to the IceCube events due to that



Is there a source near the galactic centre?

- IceCube "hot spot": cluster of shower events near the Galactic Centre
- Limits on GC excess: J. Barrios-Marti (ID 636)

Aartsen et al., PRL 113, 101101 (2014)

- Time correlation analysis: A. Coleiro (ID 588)

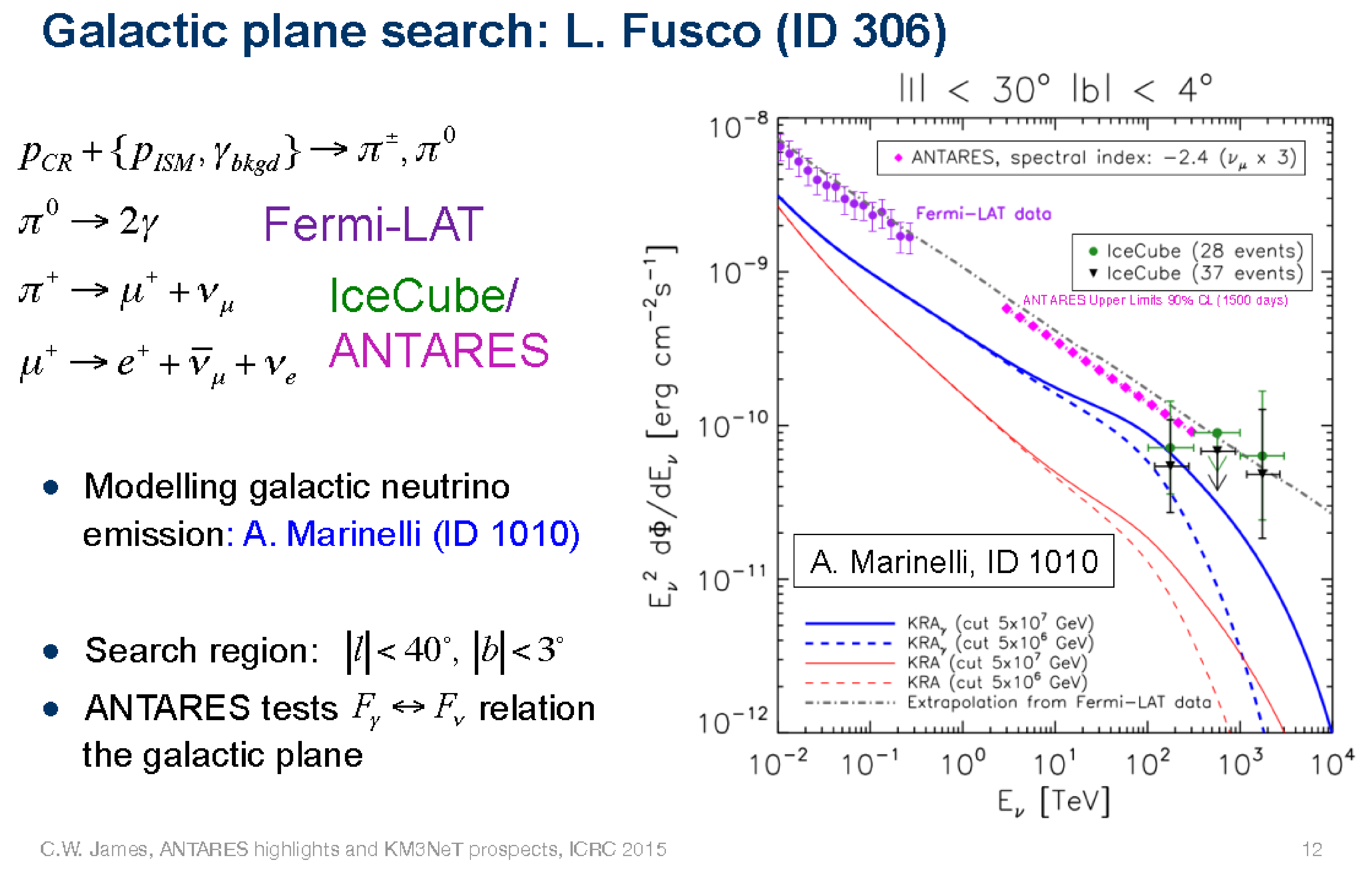
C.W. James, ANTARES highlights and KM3NeT prospects, ICRC 2015

10

Excluding inner Galaxy origin?

Clancy James invited highlight talk

Idea of a link in A. Neronov and D. Semikoz, "Neutrinos from Extra-Large Hadron Collider in the Milky Way," arXiv:1412.1690



Galactic plane search: L. Fusco (ID 306)

$p_{CR} + \{p_{ISM}, \gamma_{bkgd}\} \to \pi^{\pm}, \pi^{0}$

$\pi^{0} \to 2\gamma$ Fermi-LAT

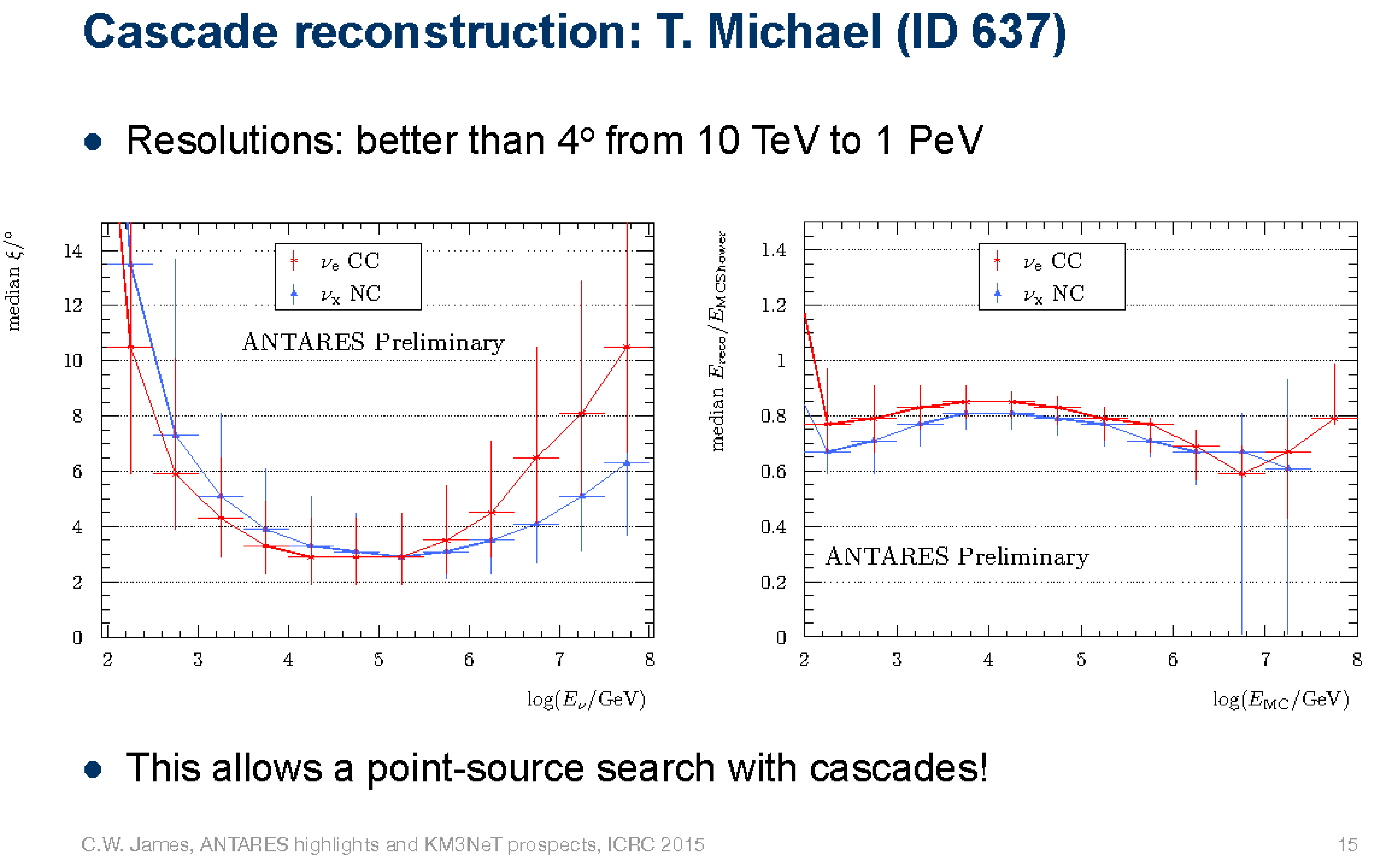
$\pi^{+} \to \mu^{+} + \nu_{\mu}$ IceCube/

$\mu^{+} \to e^{+} + \bar{\nu}_{\mu} + \nu_{e}$ ANTARES

- Modelling galactic neutrino emission: A. Marinelli (ID 1010)
- Search region: $|l| < 40^{\circ}$, $|b| < 3^{\circ}$
- ANTARES tests $F_{\gamma} \leftrightarrow F_{\nu}$ relation the galactic plane

Good news on showers

Clancy James invited highlight talk



Cascade reconstruction: T. Michael (ID 637)

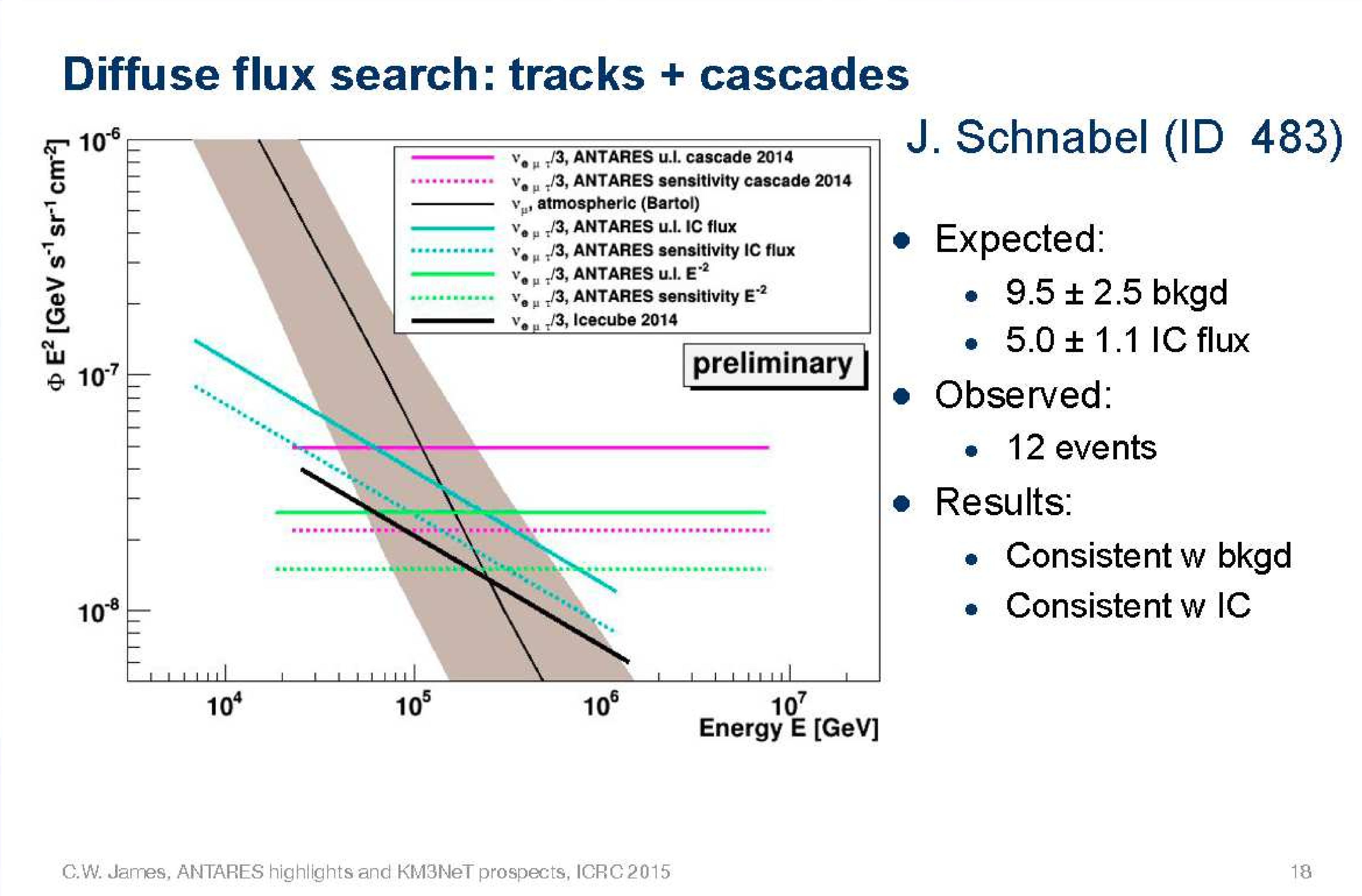
- Resolutions: better than 4° from 10 TeV to 1 PeV

- This allows a point-source search with cascades!

Cascades significantly improve sensitivity

Clancy James invited highlight talk

In the new global analysis, ANTARES is only a factor O(2) away in sensitivity for a discovery!



Diffuse flux search: tracks + cascades

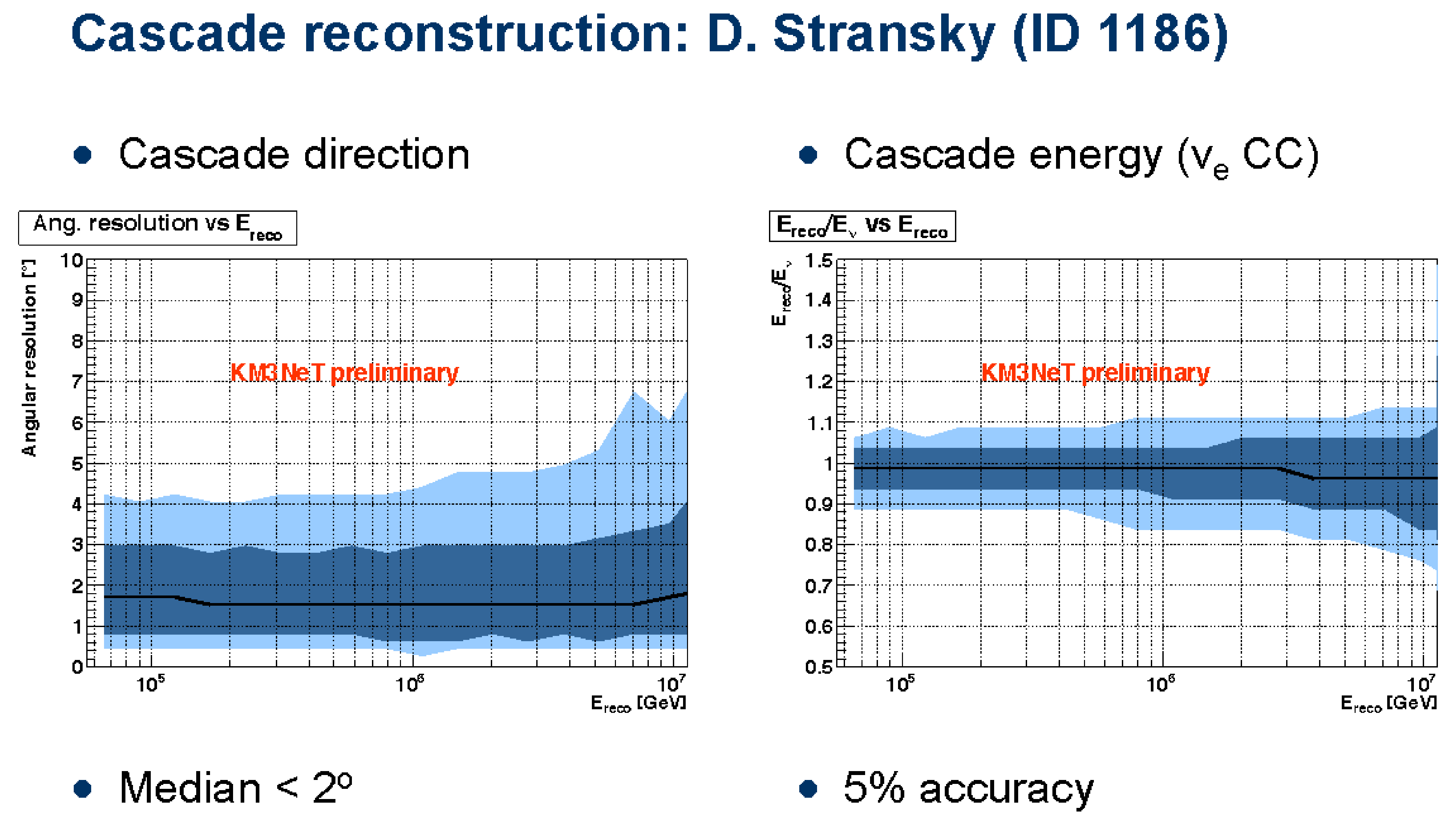
J. Schnabel (ID 483)

- Expected:
  - 9.5 ± 2.5 bkgd
  - 5.0 ± 1.1 IC flux
- Observed:
  - 12 events
- Results:
  - Consistent w bkgd
  - Consistent w IC

Promising for Km3NeT

Clancy James invited highlight talk

Even better expected: Cascade-pointing!!!



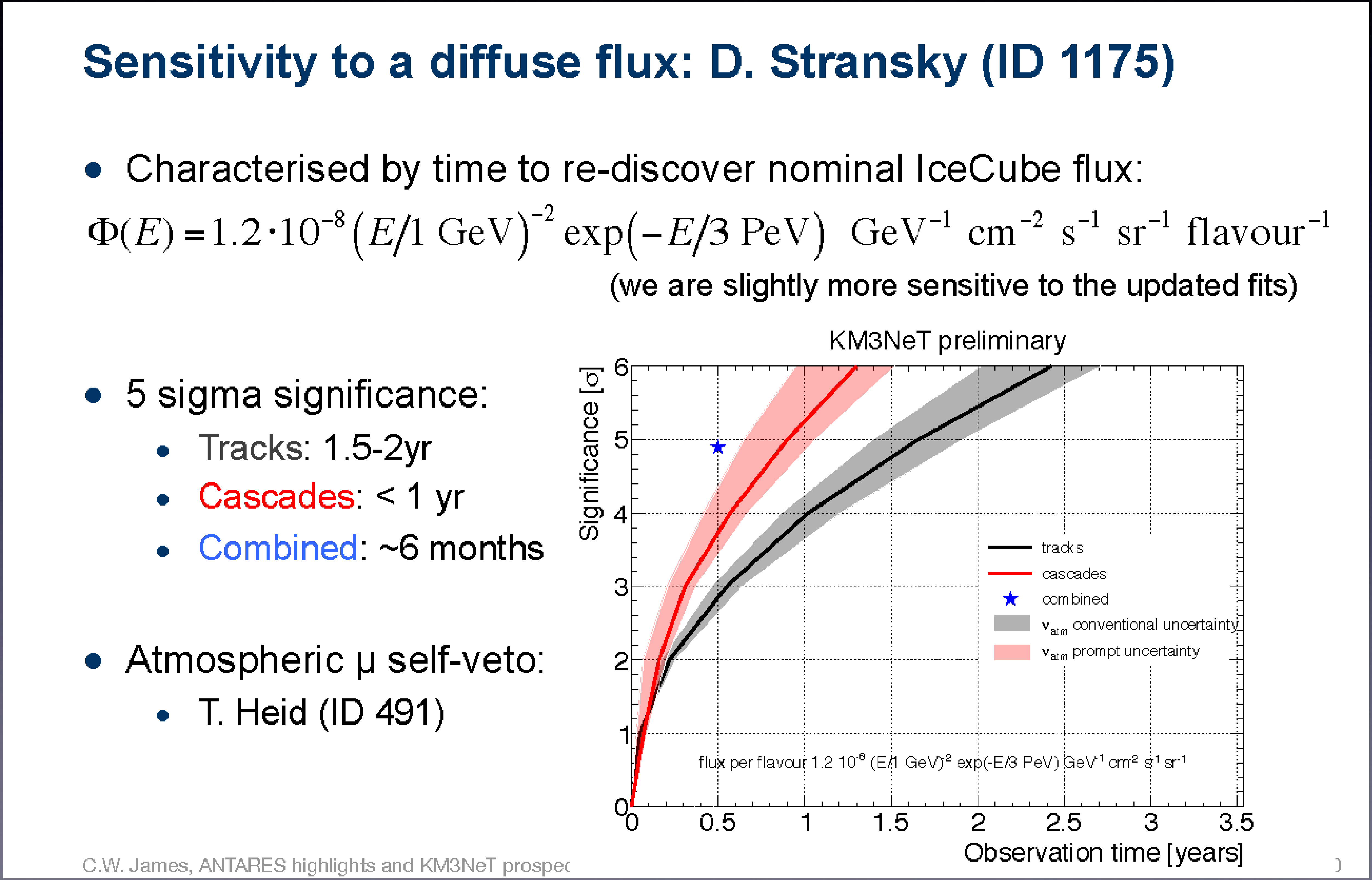
Cascade reconstruction: D. Stransky (ID 1186)

- Cascade direction
- Cascade energy (ν_e CC)

- Median < 2°
- 5% accuracy

Quick rediscovery expected

Clancy James invited highlight talk



Sensitivity to a diffuse flux: D. Stransky (ID 1175)

- Characterised by time to re-discover nominal IceCube flux:

$$\Phi(E) = 1.2\cdot10^{-8}\left(E/1\ \mathrm{GeV}\right)^{-2}\exp\left(-E/3\ \mathrm{PeV}\right)\quad \mathrm{GeV}^{-1}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{sr}^{-1}\ \mathrm{flavour}^{-1}$$

(we are slightly more sensitive to the updated fits)

- 5 sigma significance:
  - Tracks: 1.5-2yr
  - Cascades: < 1 yr
  - Combined: ~6 months
- Atmospheric μ self-veto:
  - T. Heid (ID 491)

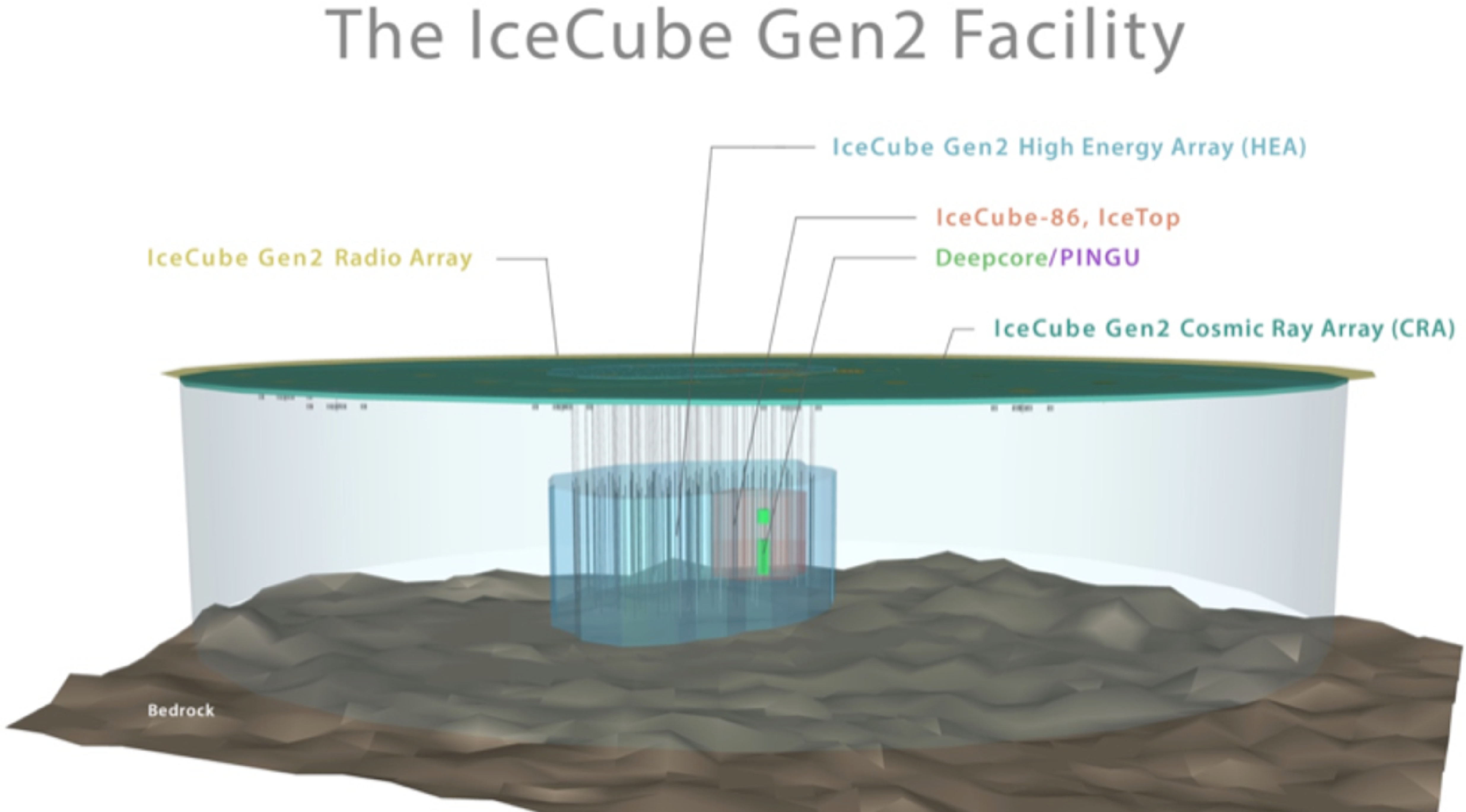
Icecube is looking at the future, too…

E. Blaufuss #741
high-E counterpart of PINGU, if you wish

IceCube-Gen2 Facility

10 years of observation with Gen2 HEA is equivalent to >200 yrs of IC86

Gains in southern hemisphere are strong.



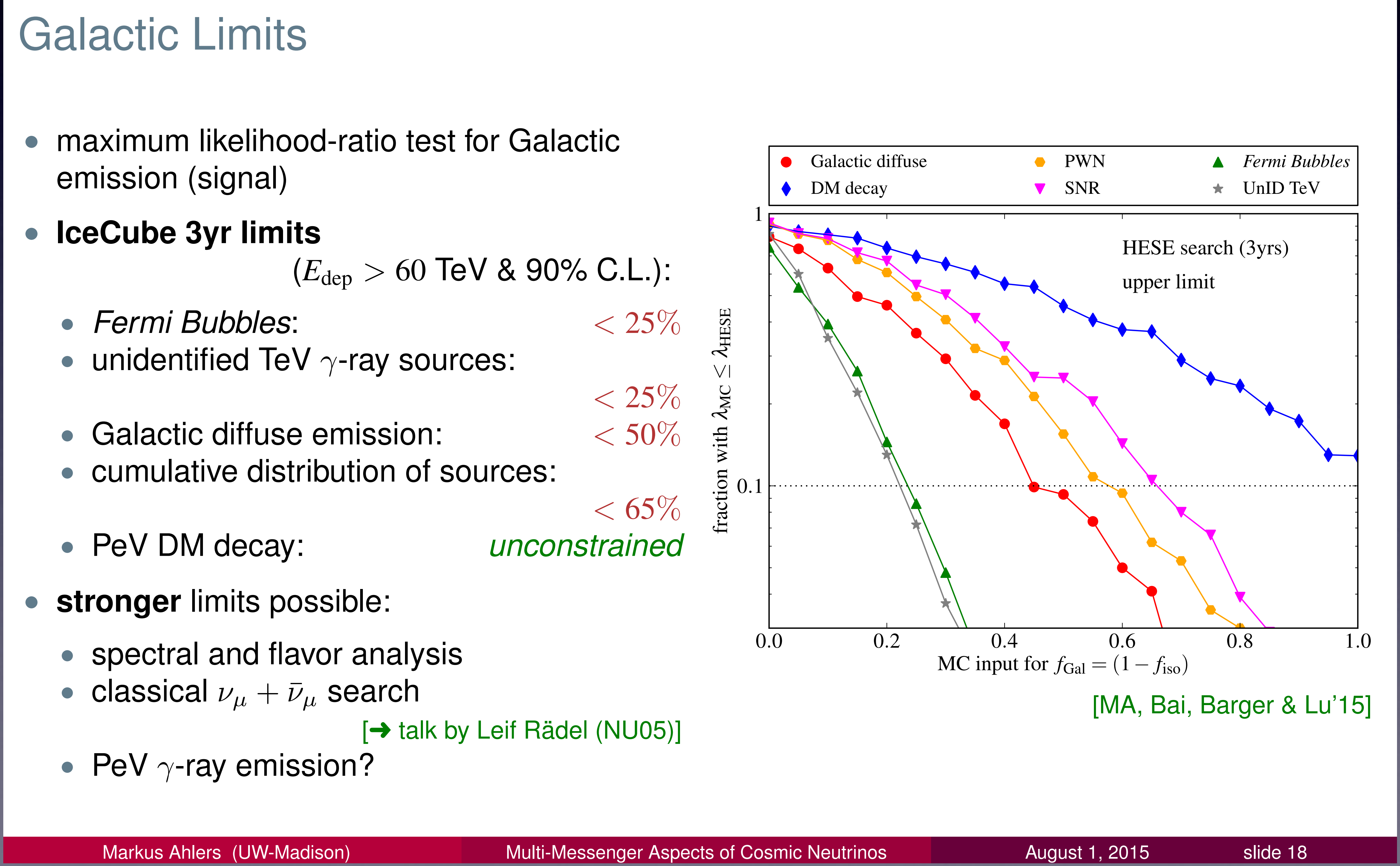
IceCube: Gen2

- While able to deliver amazing discoveries, IceCube is limited by the small numbers of astrophysical neutrinos
  - ~few 10's of astrophysical neutrinos per year
- The IceCube-Gen2 High Energy Array will instrument a significantly larger volume (~10 km^3)
  - Deliver significantly larger samples of astrophysical neutrinos
- Gains in sensitivity can grow rapidly, especially for transient events.
  - Detection of multiple events more likely
  - Sensitive to wider classes of transient phenomena

Power of current constraints on Galactic source models

M. Ahlers' invited highlight talk

Morphological studies by IceCube constrain a dominant role for a number of sources (basically all the dominant Galactic ones, but DM)



Galactic Limits

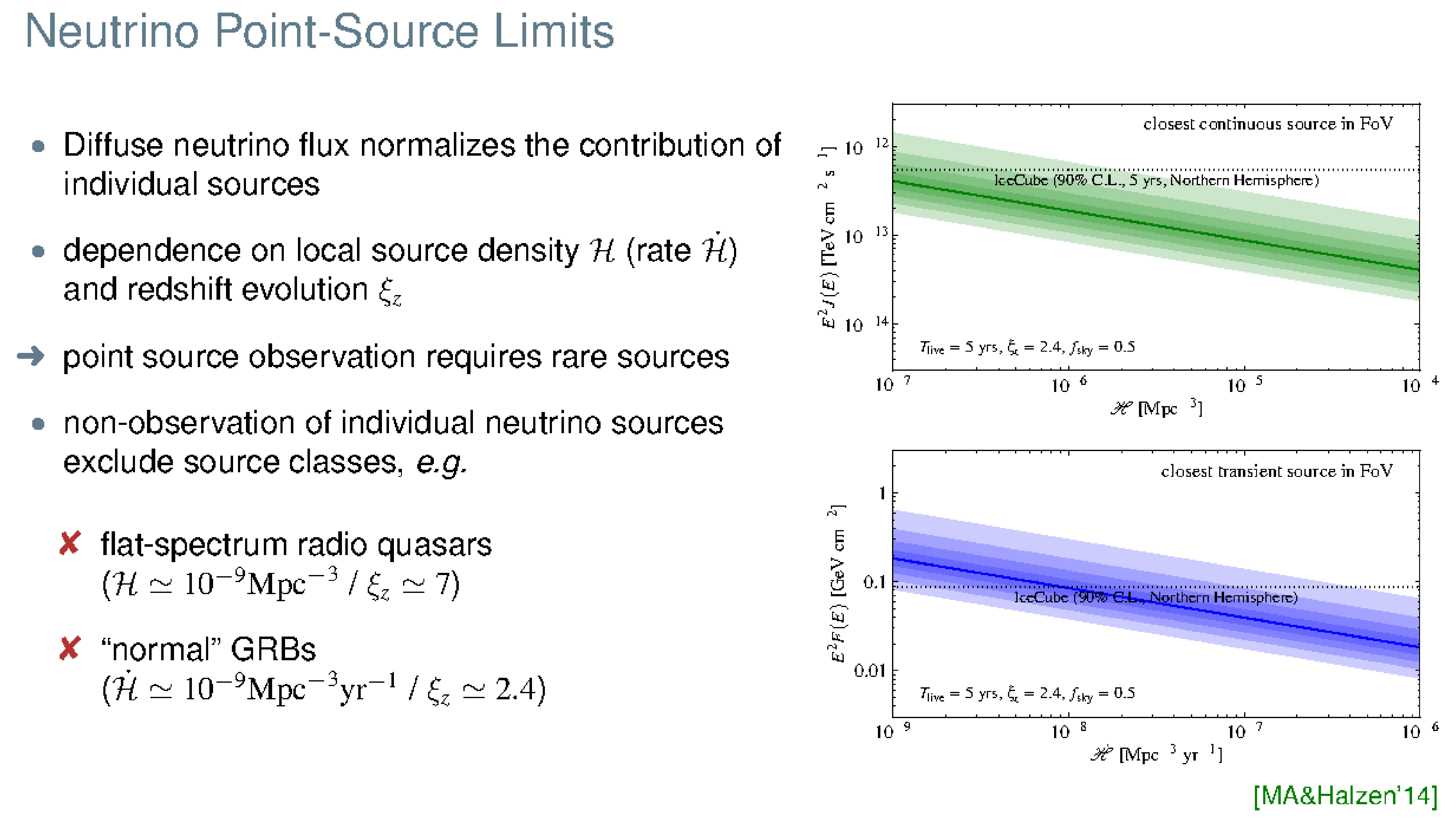
- maximum likelihood-ratio test for Galactic emission (signal)
- **IceCube 3yr limits** ($E_{\rm dep} > 60$ TeV & 90% C.L.):
  - *Fermi Bubbles*: $< 25\%$
  - unidentified TeV γ-ray sources: $< 25\%$
  - Galactic diffuse emission: $< 50\%$
  - cumulative distribution of sources: $< 65\%$
  - PeV DM decay: *unconstrained*
- **stronger** limits possible:
  - spectral and flavor analysis
  - classical $\nu_\mu + \bar{\nu}_\mu$ search
    [➔ talk by Leif Rädel (NU05)]
  - PeV γ-ray emission?

[MA, Bai, Barger & Lu'15]

What from absence of clustering?

M. Ahlers' invited highlight talk

requires sufficiently “dense” sources, excludes some classes



Neutrino Point-Source Limits

- Diffuse neutrino flux normalizes the contribution of individual sources
- dependence on local source density $\mathcal{H}$ (rate $\dot{\mathcal{H}}$) and redshift evolution ξ_z

➜ point source observation requires rare sources

- non-observation of individual neutrino sources exclude source classes, *e.g.*

✘ flat-spectrum radio quasars
($\mathcal{H} \simeq 10^{-9}\mathrm{Mpc}^{-3}$ / $\xi_z \simeq 7$)

✘ “normal” GRBs
($\dot{\mathcal{H}} \simeq 10^{-9}\mathrm{Mpc}^{-3}\mathrm{yr}^{-1}$ / $\xi_z \simeq 2.4$)

[MA&Halzen’14]

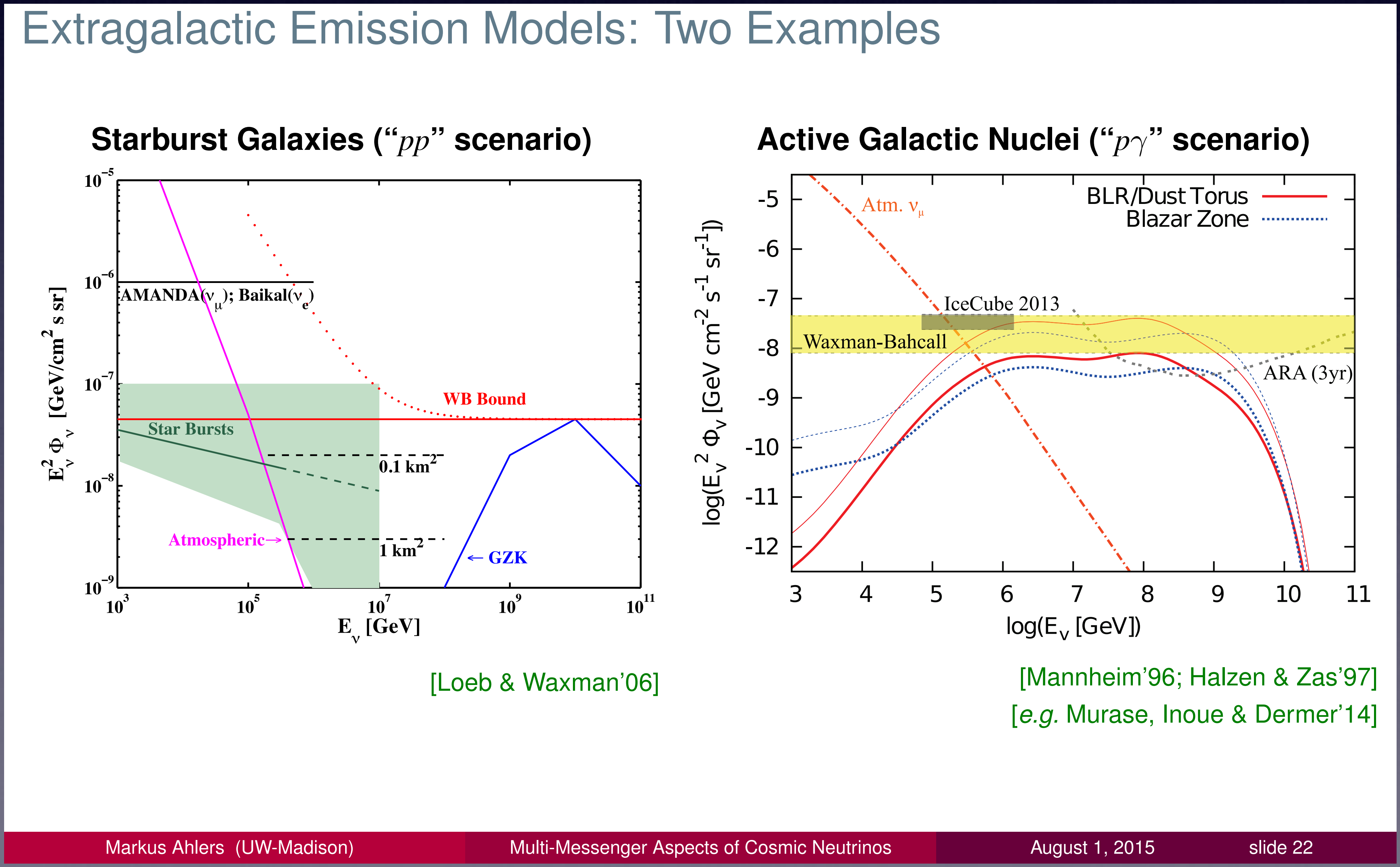
Power of current constraints on ExtraGal. source models

Spectral Constraints particularly important!

M. Ahlers' invited highlight talk

pp: at least one model (SB, scale-up of Galactic CR case) where high cutoff natural, no low-E cutoff

pγ: low-E cutoff due to threshold, high-E cutoff much higher!



Extragalactic Emission Models: Two Examples

Starburst Galaxies (“pp” scenario)

Active Galactic Nuclei (“$p\gamma$” scenario)

[Loeb & Waxman’06]

[Mannheim’96; Halzen & Zas’97]

[*e.g.* Murase, Inoue & Dermer’14]

FERMI-LAT IGRB is very useful…

M. Ahlers' invited highlight talk

Isotropic Diffuse Gamma-Ray Background (IGRB)

- neutrino and γ-ray fluxes in pp scenarios follow initial CR spectrum $\propto E^{-\Gamma}$

➜ low energy tail of GeV-TeV neutrino/γ-ray spectra

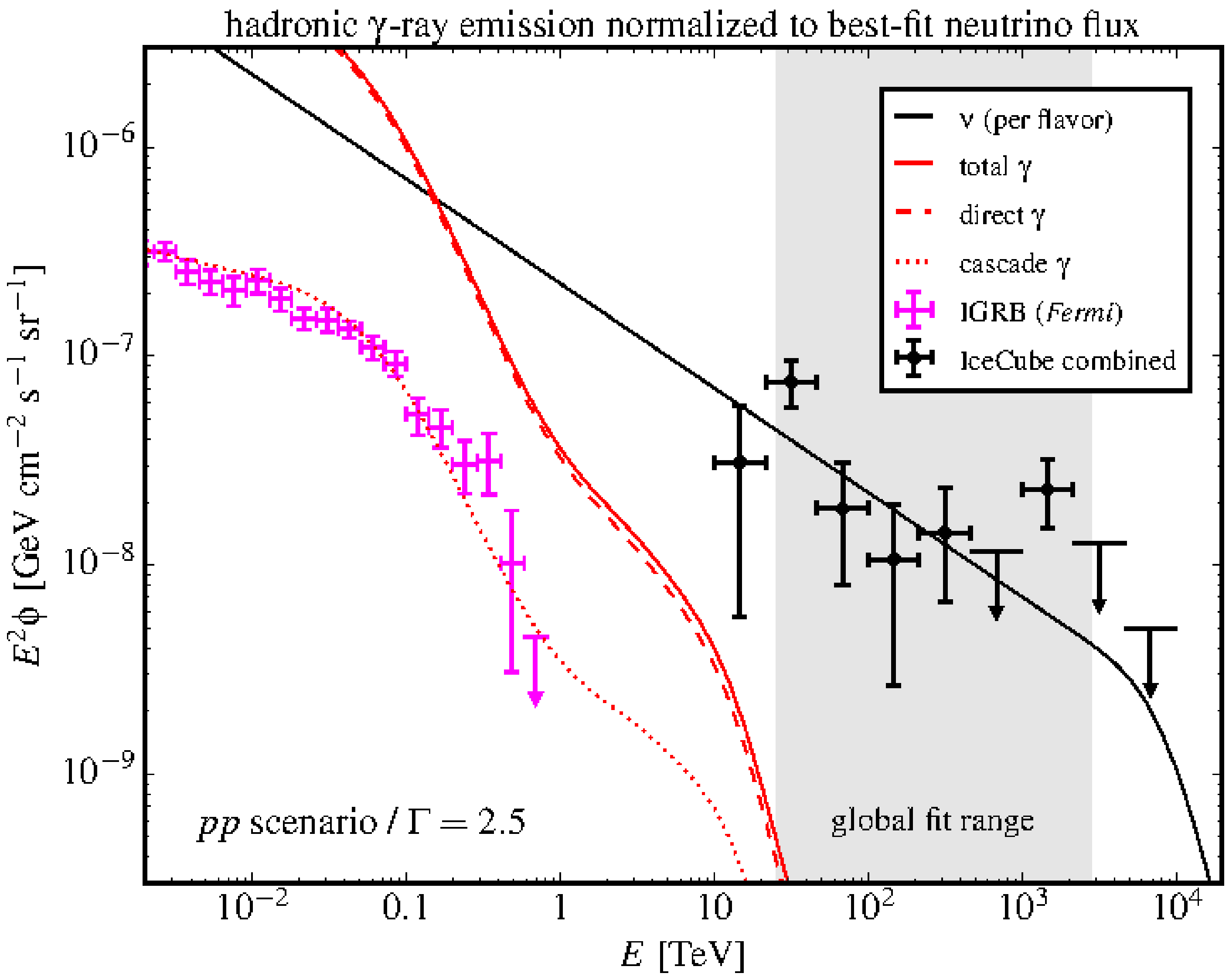
✘ constrained by IGRB

[Murase, MA & Lacki'13; Chang & Wang'14]

- extra-galactic emission (cascaded in EBL): $\Gamma \lesssim 2.15 - 2.2$

✘ Combined IceCube analysis: $\Gamma \simeq 2.4 - 2.6$

[IceCube'15; ➜ talk by Lars Mohrmann (NU05)]



[Murase, MA & Lacki'14; Tamborra, Ando & Murase'14]

…triggering several other questions

M. Ahlers' invited highlight talk

Comments & Consequences

- Strong limits apply to **CR calorimeters**, like starburst galaxies or galaxy clusters.
- Direct γ-ray emission can be reduced in $p\gamma$ scenarios, but cascade emission can still contribute at the level of 10% above 100 GeV to the IGRB.
- Is **blazar emission** above 50 GeV dominated by **hadronic interactions**?
- Is secondary γ-ray emission “hidden” by **source radiation backgrounds**?
  [Murase, Guetta & MA; in preparation]
- Are there **Galactic** “contaminations” at $E_\nu \simeq 1 - 10$ TeV that effectively lead to a softening of the observed neutrino spectrum? [IceCube’15; MA, Bai, Bargner & Lu’15]
- The diffuse flux also saturates limits from **UHE CR sources**. Is this population also responsible for UHE CRs? [Katz, Waxman, Thompson & Loeb’13]

Summary and conclusions

Similar conclusions in W. Winter's talk

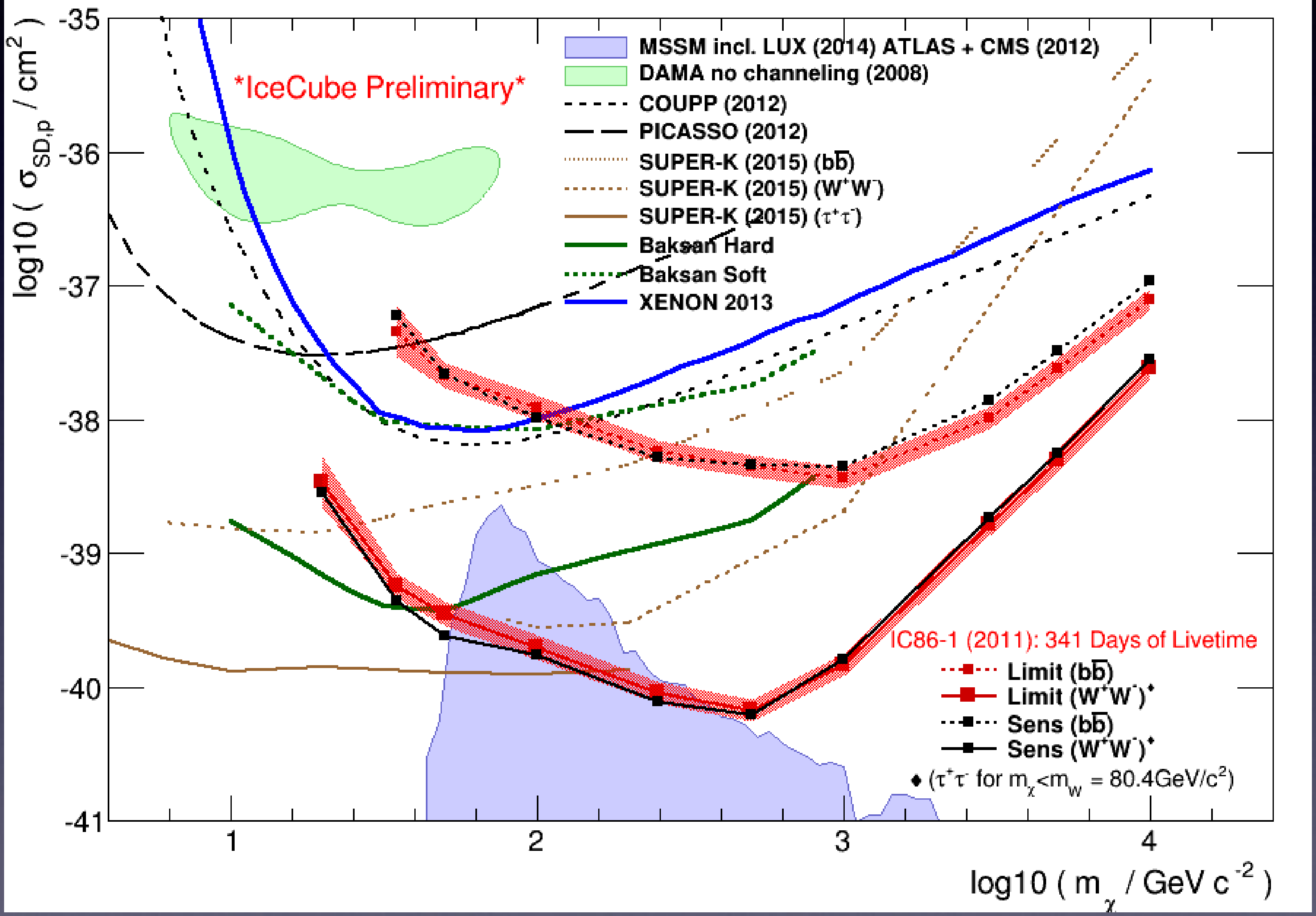
- How many of the observed cosmic neutrinos come from cosmic ray interactions in the Milky Way?
  Only a few, at most. Maybe a few addl. ones from Galactic sources
- Can the observed neutrinos come from the sources of the ultra-high energy cosmic rays, conceptually?
  This is possible, even in different spectral fit scenarios. Perhaps energy-dependent escape timescale most "natural" model
- Are gamma-ray bursts the sources of the ultra-high energy cosmic rays?
  - *They are not the main source of the observed cosmic neutrinos.*
    Yet, they could be the source of the UHECRs
  - *A key issue is the UHECR mechanism for the sources; another one that estimators from gamma-rays may not be applicable to neutrinos in (more realistic) multi-zone collision models*
  - *Neutrinos will play an important role in establishing the UHECR paradigm for GRBs, as the GRB sensitivity in IceCube is the best to any object class*

on “exotics”

WIMP signals from the Sun

analysis of 341 days of livetime of IceCube-DeepCore in the 86 string configuration

(IceCube essentially used to veto background)

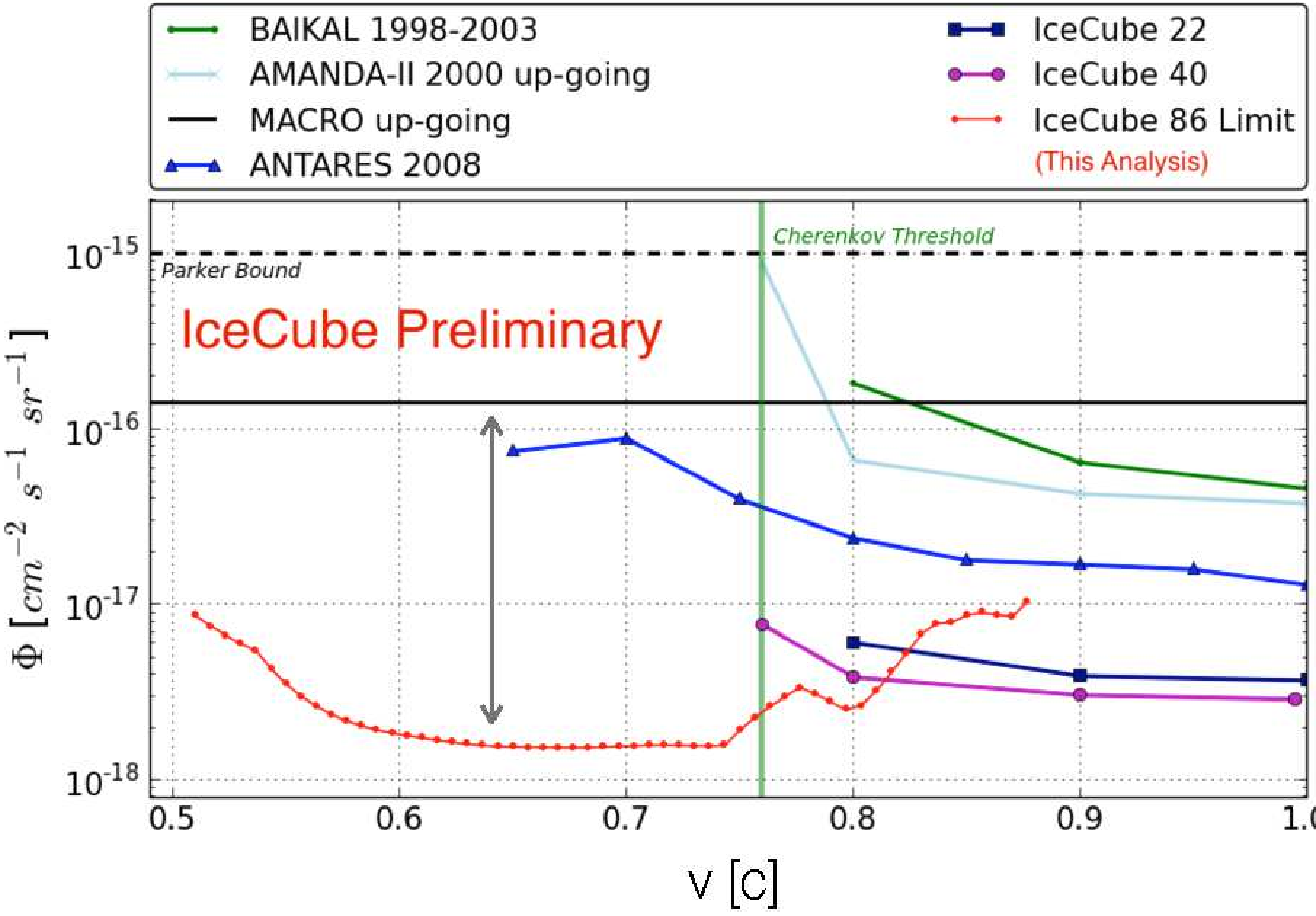


M. Rameez (#1209)

Best limits for spin-dependent DM scattering, at high masses

Limits on the flux of magnetic monopoles

- far below theoretical bound by Parker
- comparing with
  ANTARES
  MACRO
  IceCube (highly relativistic)
- best limits for
  $0.51\,c < v < 0.81\,c$
- improvement up to a factor ~90 at 0.64 *c*



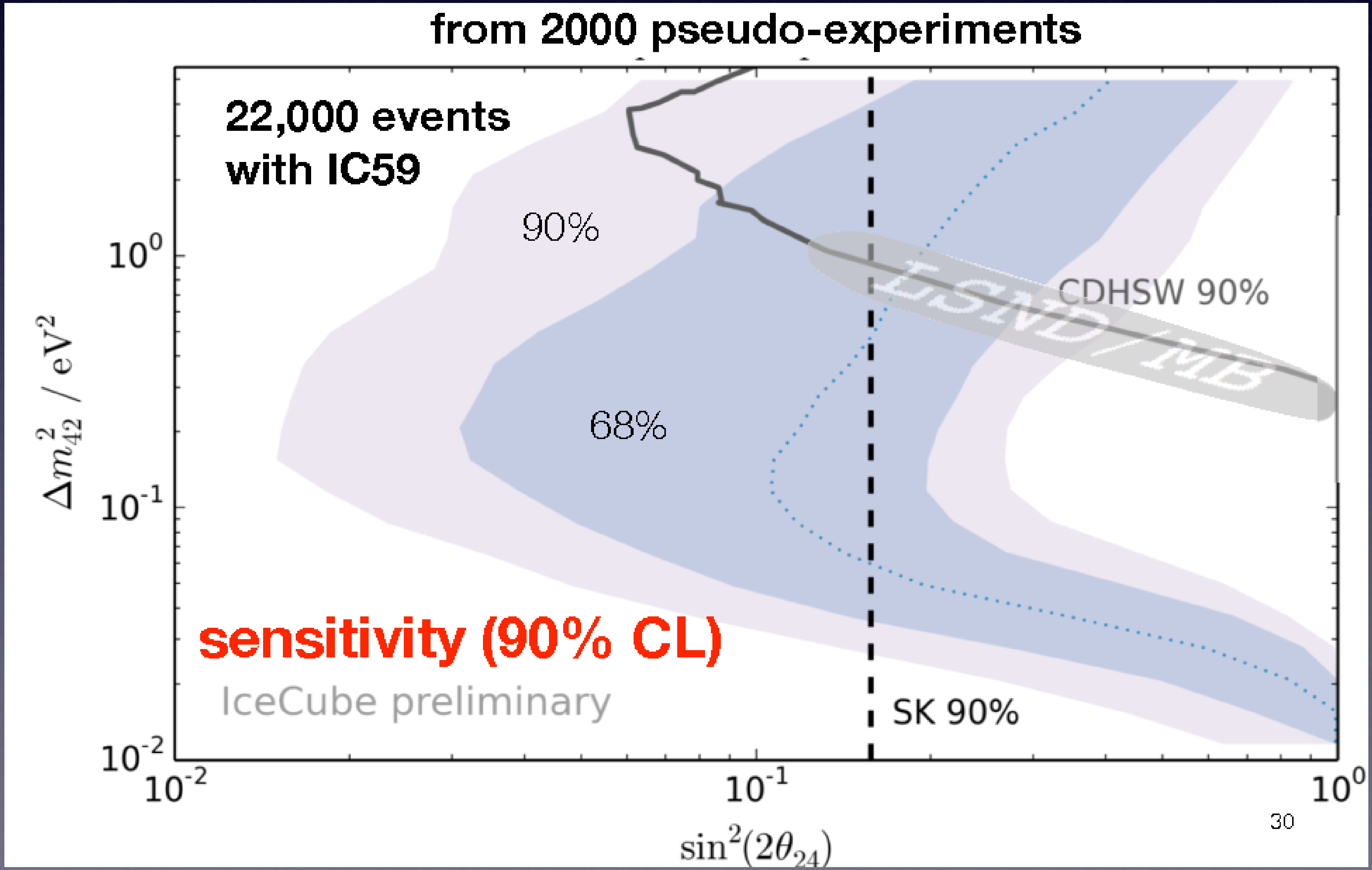
Best limits for semi-relativistic monopoles

anna.pollmann@uni-wuppertal.de

On Sterile neutrinos

M.Wallraff (#1100)
“Search for sterile neutrinos with IceCube”

No results yet, only “expected sensitivity”



Atmospheric neutrinos in IceCube

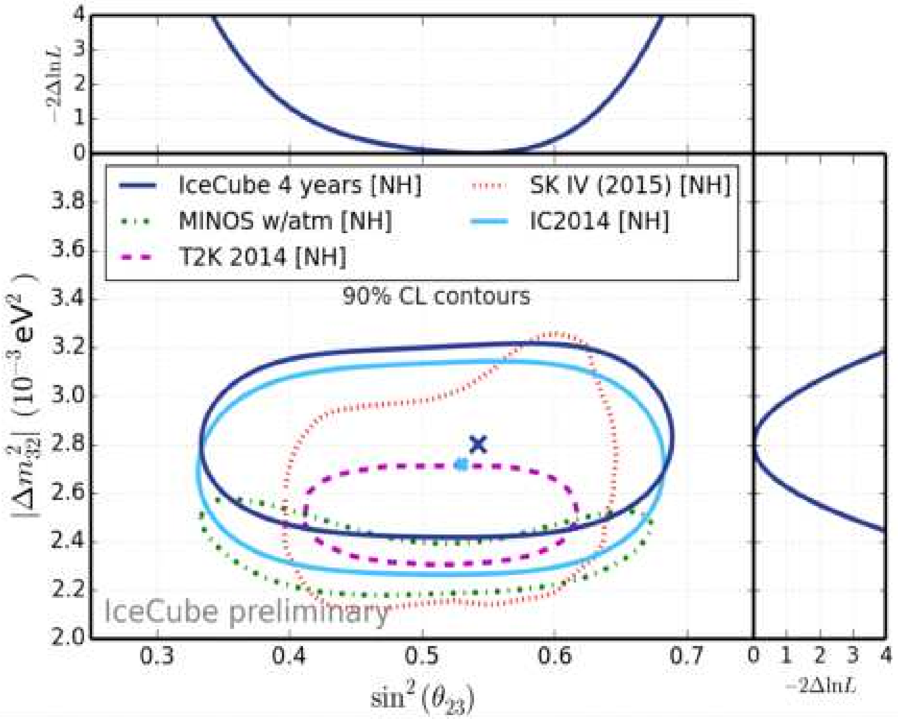
P. Desiati's invited highlight talk

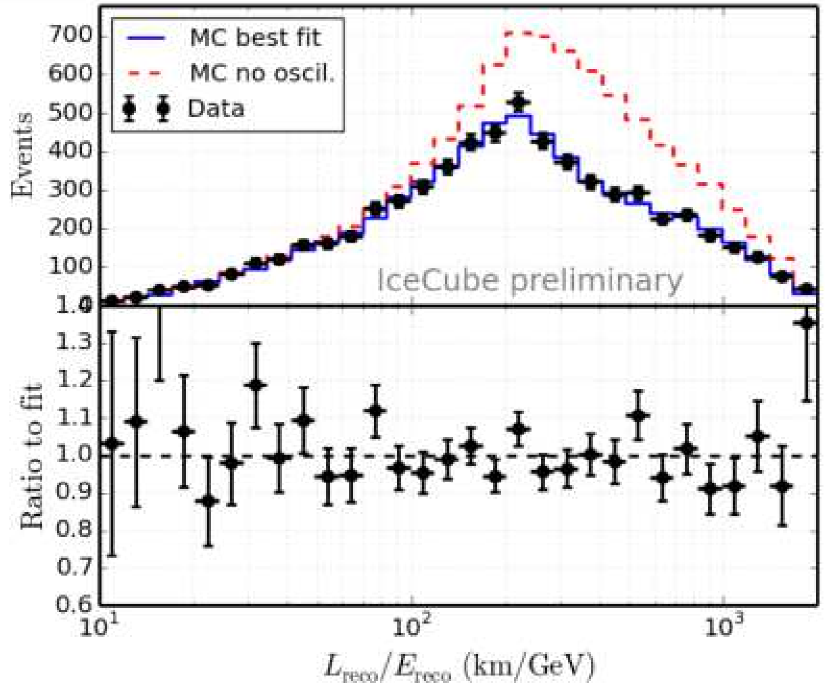
low energy neutrinos

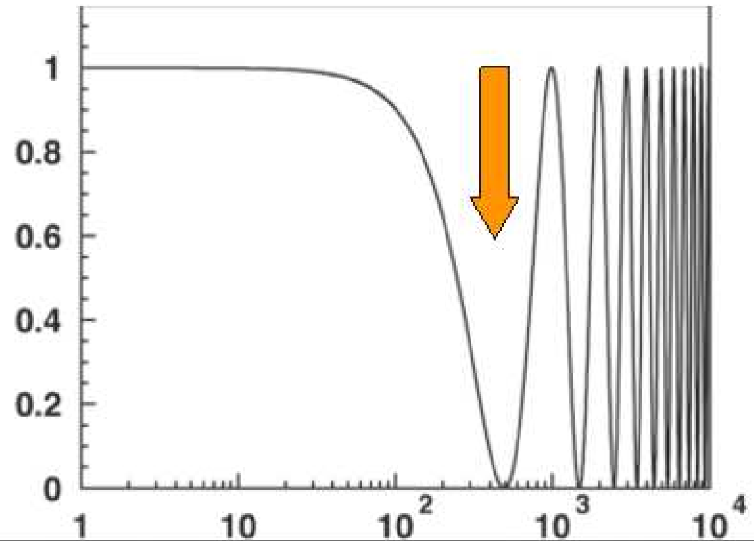
IceCube - 4 years

PRELIMINARY 2015

$$P(\nu_\mu \to \nu_\mu) = 1 - \sin^2(2\theta_{23})\,\sin^2\left(1.27\,\frac{\Delta m^2_{23}\,L}{E_\nu}\right)$$



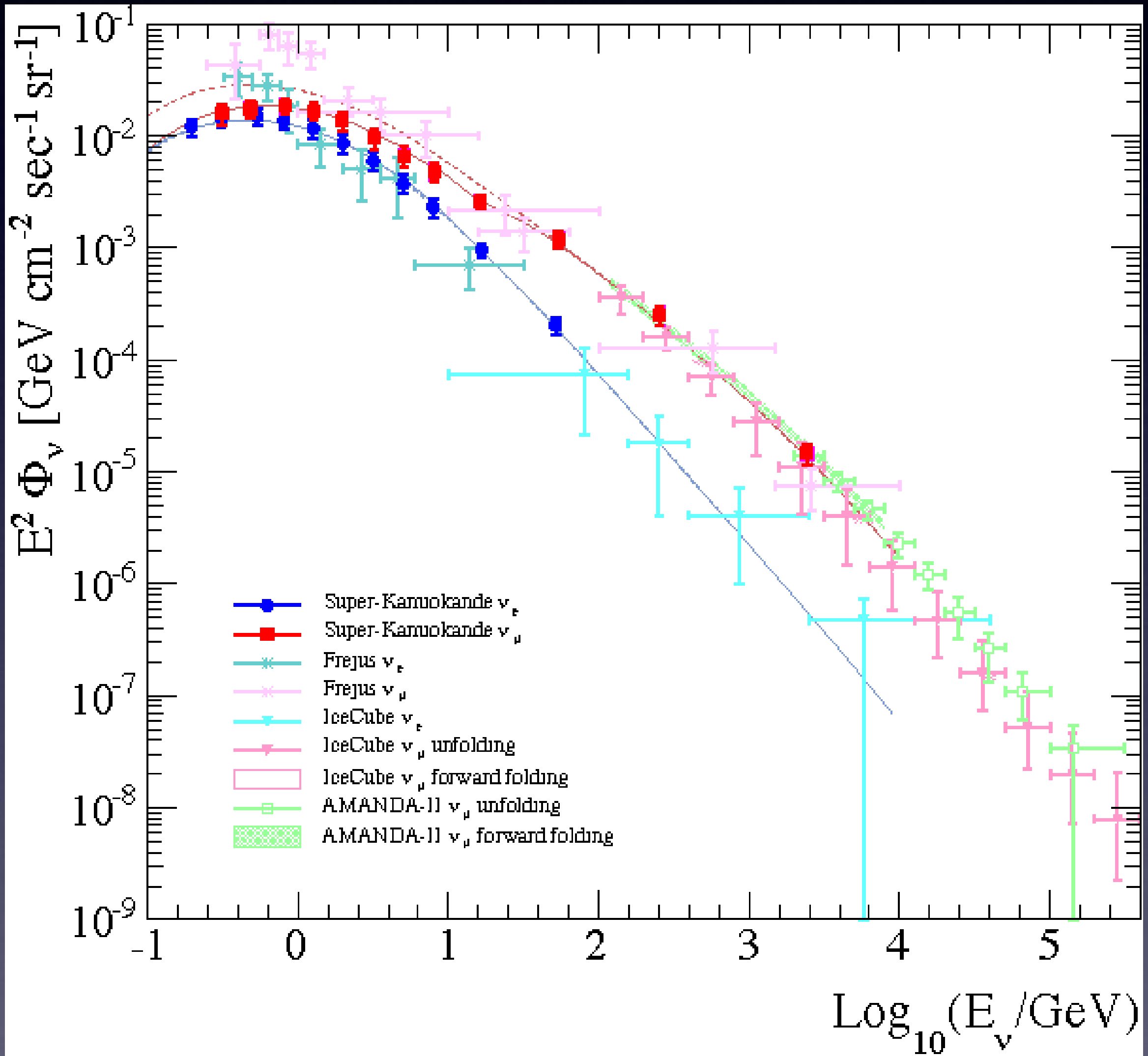




SK main results: atmospheric nu

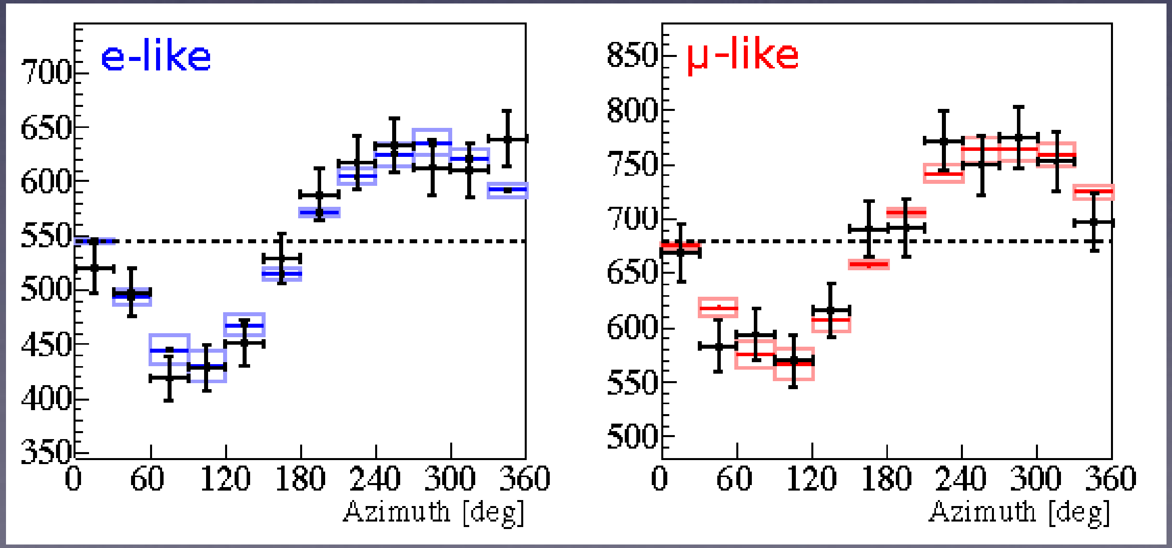
Euan Richard (#1044)

Measurements of the Atmospheric Neutrino Flux at Super-Kamiokande



Only one **new result**
(to the best of my knowledge)

> 5 σ measurement of east-to-west asymmetry in azimuth in the neutrino flux, caused by the geomagnetic field, for both flavours



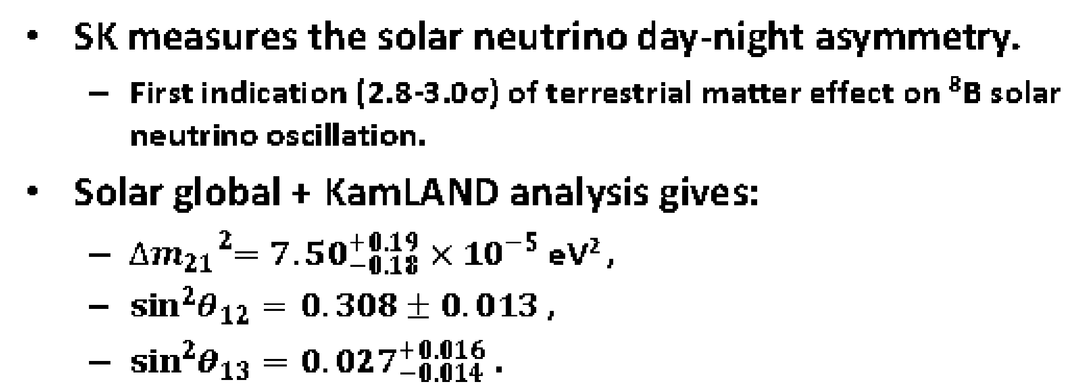
Excellent measurements of fluxes up to O(100) GeV.

Good validation of theoretical models

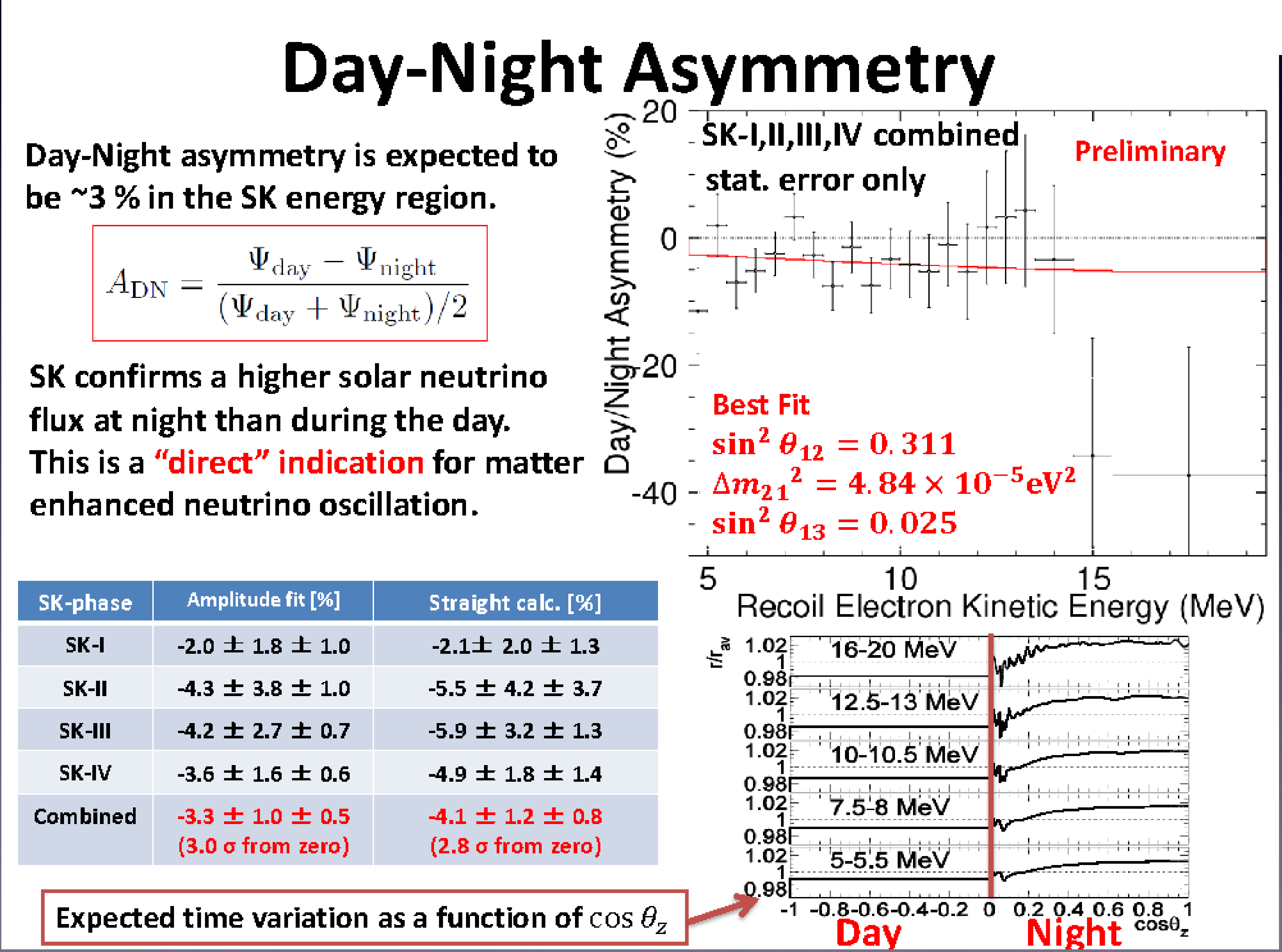
SK main results: solar nu

Y. Nakano (#1088)

Solar neutrino results from Super Kamiokande



- SK measures the solar neutrino day-night asymmetry.
  - First indication (2.8-3.0σ) of terrestrial matter effect on ^{8}B solar neutrino oscillation.
- Solar global + KamLAND analysis gives:
  - $\Delta m_{21}{}^2 = 7.50^{+0.19}_{-0.18} \times 10^{-5}$ eV^2,
  - $\sin^2\theta_{12} = 0.308 \pm 0.013$,
  - $\sin^2\theta_{13} = 0.027^{+0.016}_{-0.014}$.



Day-Night Asymmetry

Day-Night asymmetry is expected to be ~3 % in the SK energy region.

$$A_{\rm DN} = \frac{\Psi_{\rm day} - \Psi_{\rm night}}{(\Psi_{\rm day} + \Psi_{\rm night})/2}$$

SK confirms a higher solar neutrino flux at night than during the day. This is a **"direct" indication** for matter enhanced neutrino oscillation.

SK-phase	Amplitude fit [%]	Straight calc. [%]
SK-I	-2.0 ± 1.8 ± 1.0	-2.1± 2.0 ± 1.3
SK-II	-4.3 ± 3.8 ± 1.0	-5.5 ± 4.2 ± 3.7
SK-III	-4.2 ± 2.7 ± 0.7	-5.9 ± 3.2 ± 1.3
SK-IV	-3.6 ± 1.6 ± 0.6	-4.9 ± 1.8 ± 1.4
Combined	-3.3 ± 1.0 ± 0.5 (3.0 σ from zero)	-4.1 ± 1.2 ± 0.8 (2.8 σ from zero)

Expected time variation as a function of $\cos\theta_z$

Non neutrino results

- ISM CR flux measurements by Voyager 1
- debate on presence of breaks in p & He seems closed, AMS-02 now confirms.
- PAMELA preliminary measurements of Li/Be (including isotopic composition)… vs AMS?
- Super-Tiger on trans-iron elements: seems to confirm 80-20 model, volatile/refractory
- Updated Shower models post-LHC: towards muon problem solution (rho particle?)?
- Auger chemical composition + spectrum seems only consistent with no-GZK (sources!?!)
- Telescope Array qualitative difference on chemical composition confirmed.
- TA hot-spot (Cen A) still present, but significance does not grow… Auger anis. reloaded?
- Telescope Array “x 4” approved, paid by Japan
- Argo measurement of p/He knee below 10^15 eV+All particle spectrum ok
- HAWC presented its first results (not particularly competitive, yet it’s becoming true…)

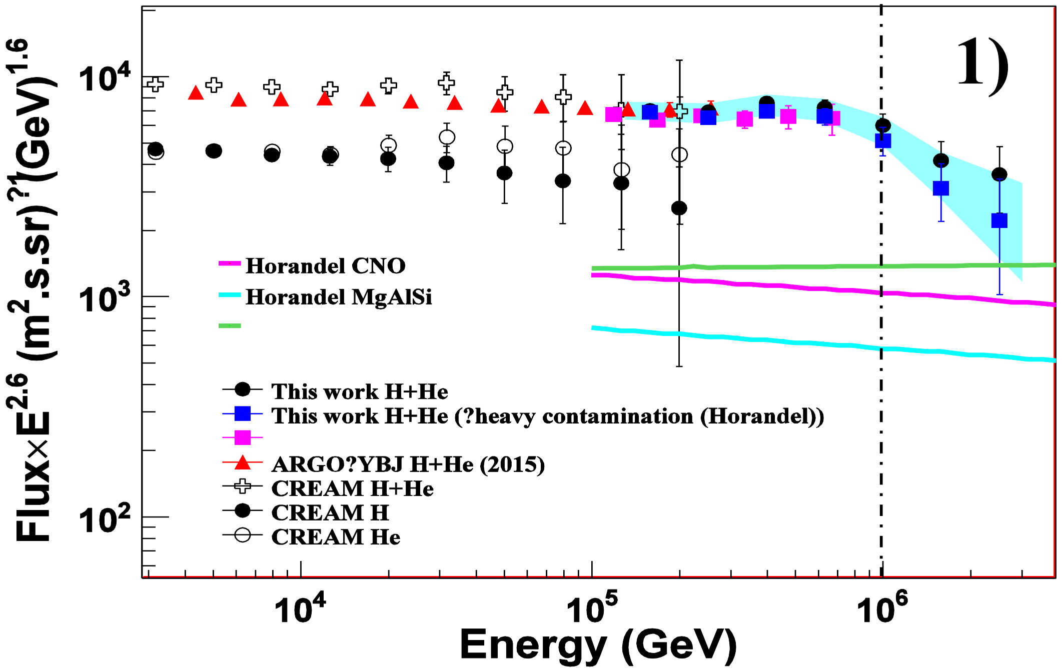
Certainly forgetting several more…

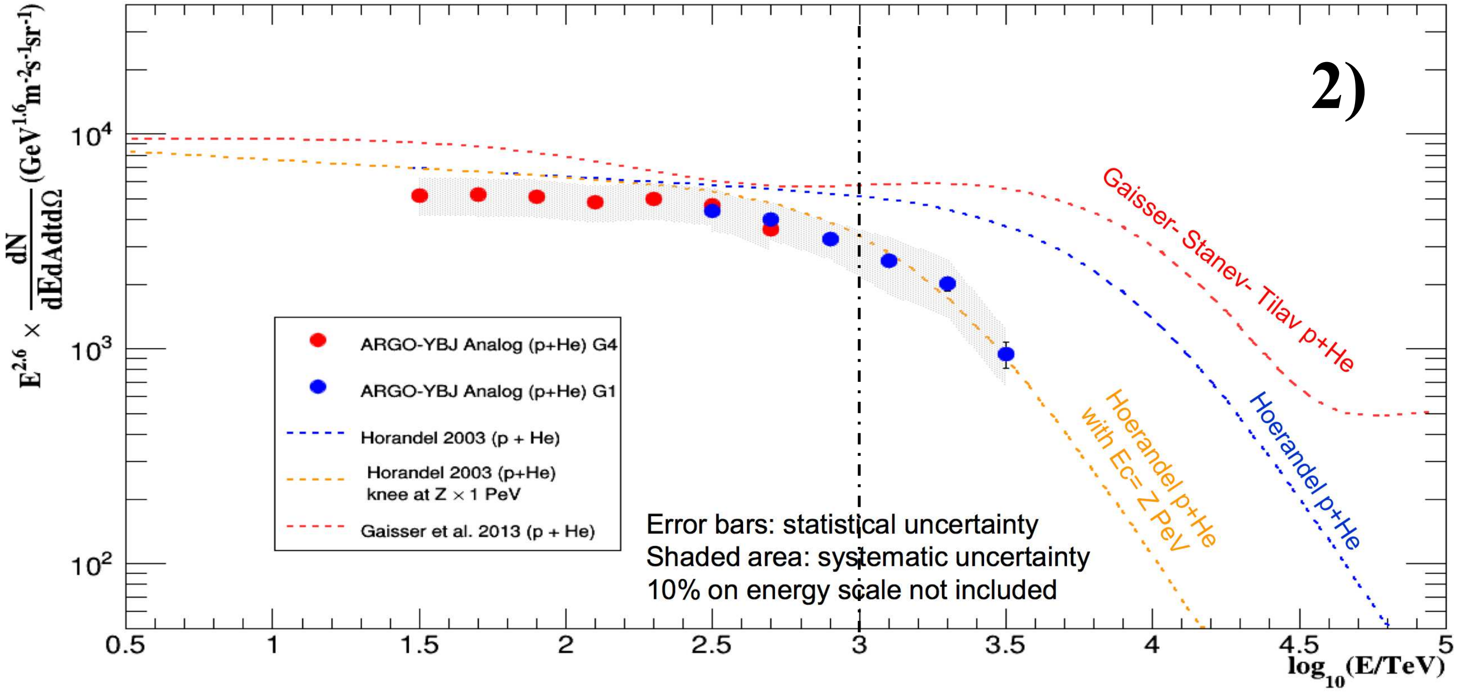
Argo p/He

ARGO-YBJ p/He spectrum bending below 1 PeV

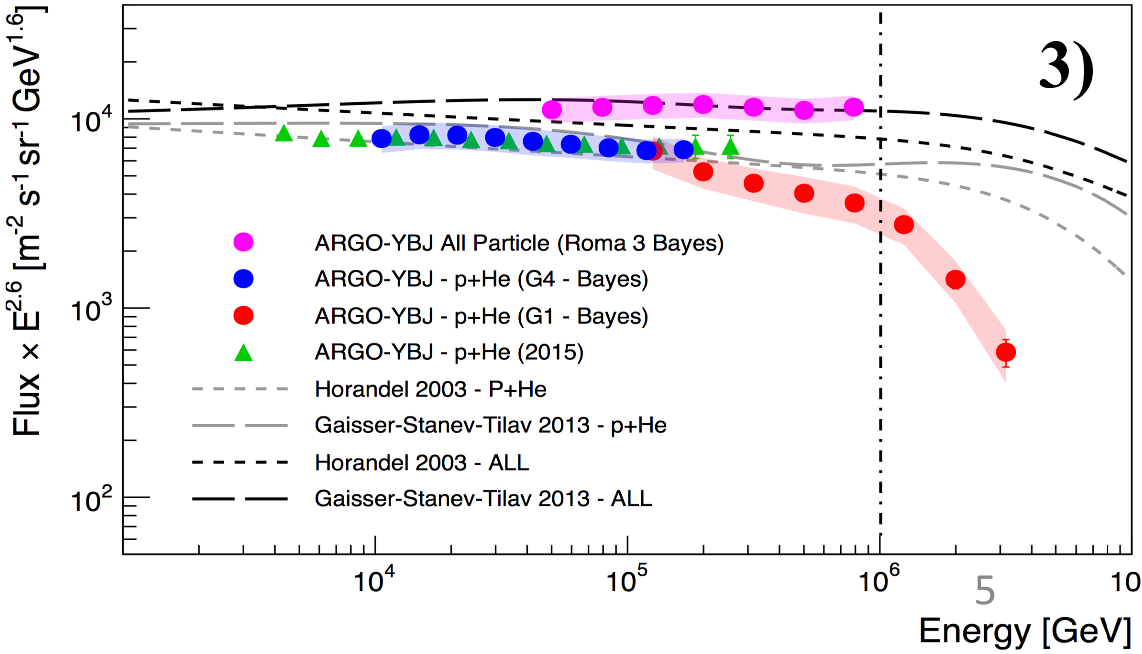
benefit of analog charge
readout very close to the core

1) **'Hybrid' (LHAASO cher. Tel.)** *Z.Cao, 261*
2) **'Analog'** *I. De Mitri, 366*
3) **'Analog-bayesan'** *P. Montini, 371*





Error bars: statistical uncertainty
Shaded area: systematic uncertainty
10% on energy scale not included

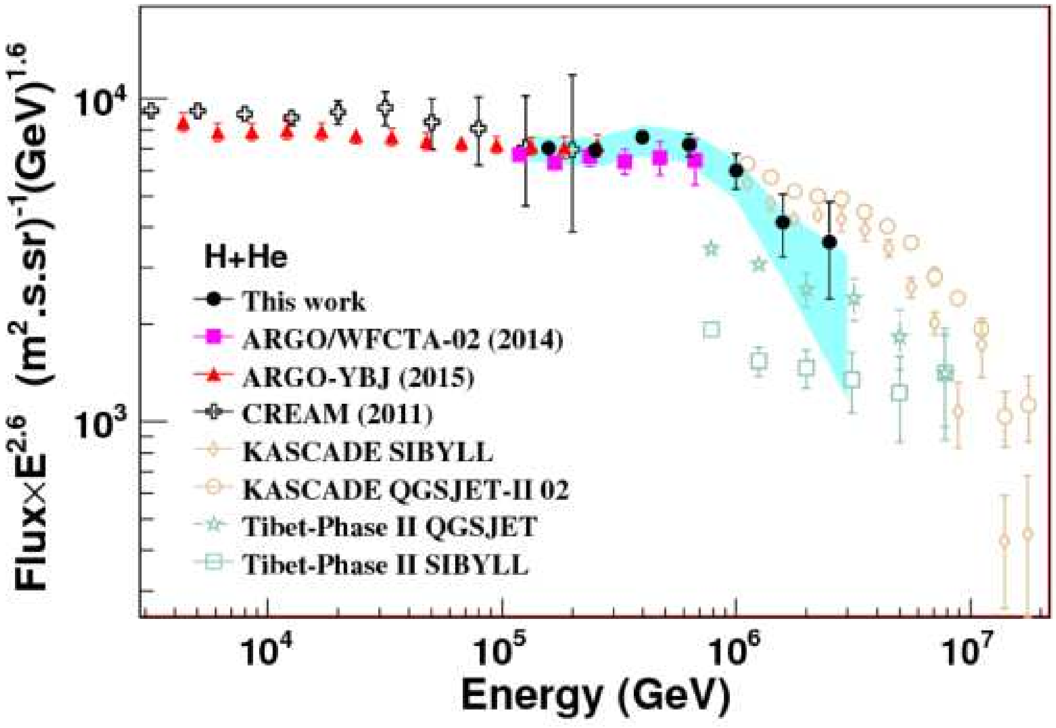


Argo consistency

ARGO-YBJ

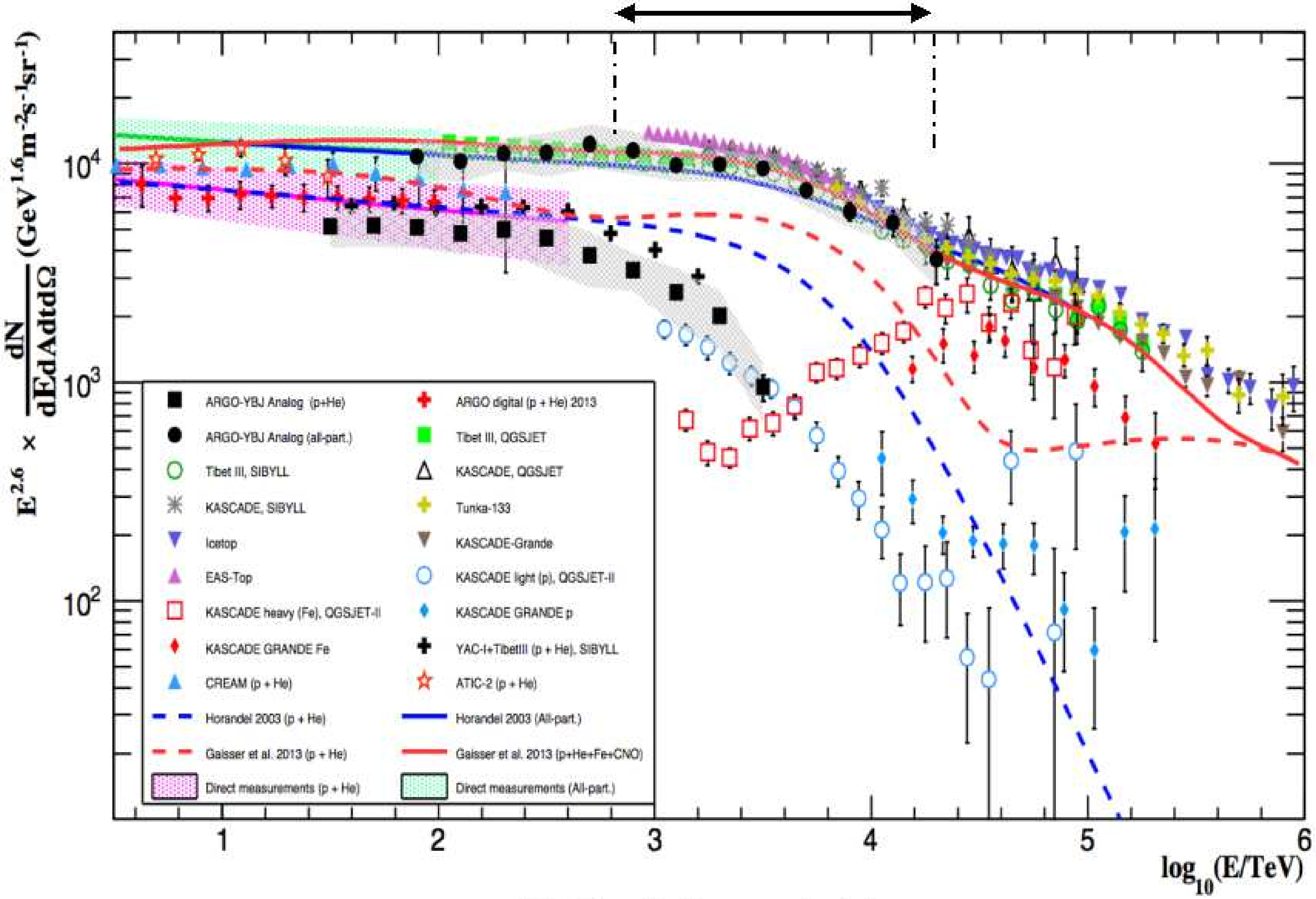
p/He spectrum bending below 1 PeV

- p/He and all particle spectrum
- consistency with direct and indirect experiments



Z.Cao, 261

700 TeV factor 26 (?)



I. De Mitri, 366

Telescope Array

Toward the highest energies

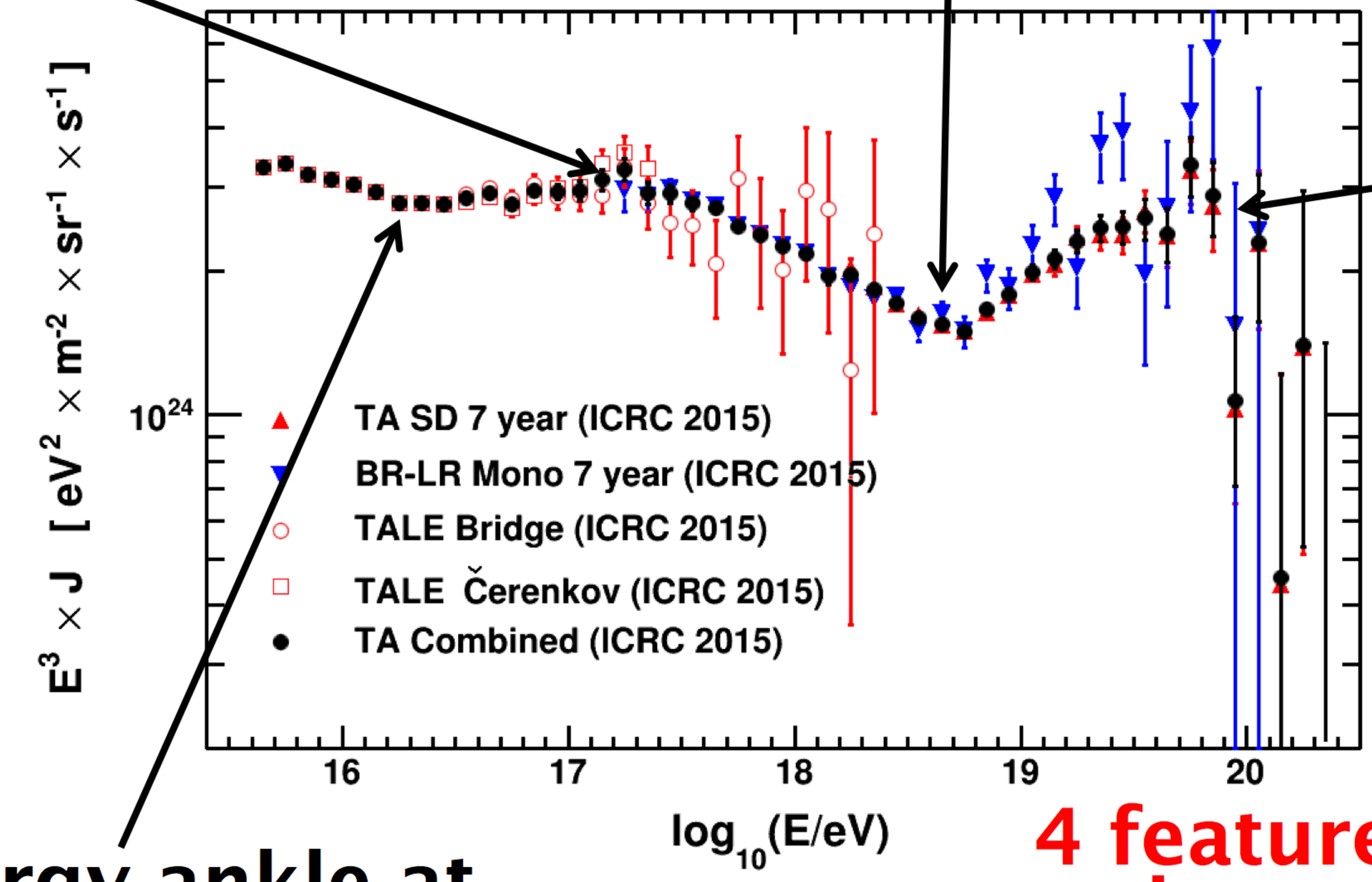
Telescope Array

D. Ivanov, 349

C. Jui, highlight

Second knee at E = $10^{17.3}$ eV

Ankle at E = $10^{18.72}$ eV



Break at $10^{19.8}$ eV

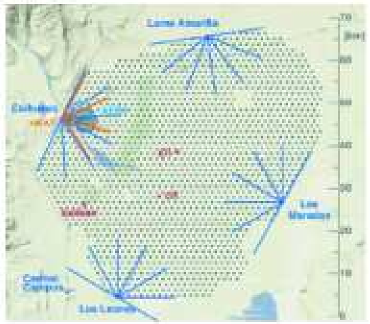
Z. Zundel, 445
T. AbuZayyad, 422
T. Fujii, 320
FD BR-LR Mono
D. Ikeda, 362 Hybrid

Low energy ankle at $10^{16.34}$ eV

4 features over 4.7 orders of magnitude in energy

Auger

Toward the highest energies

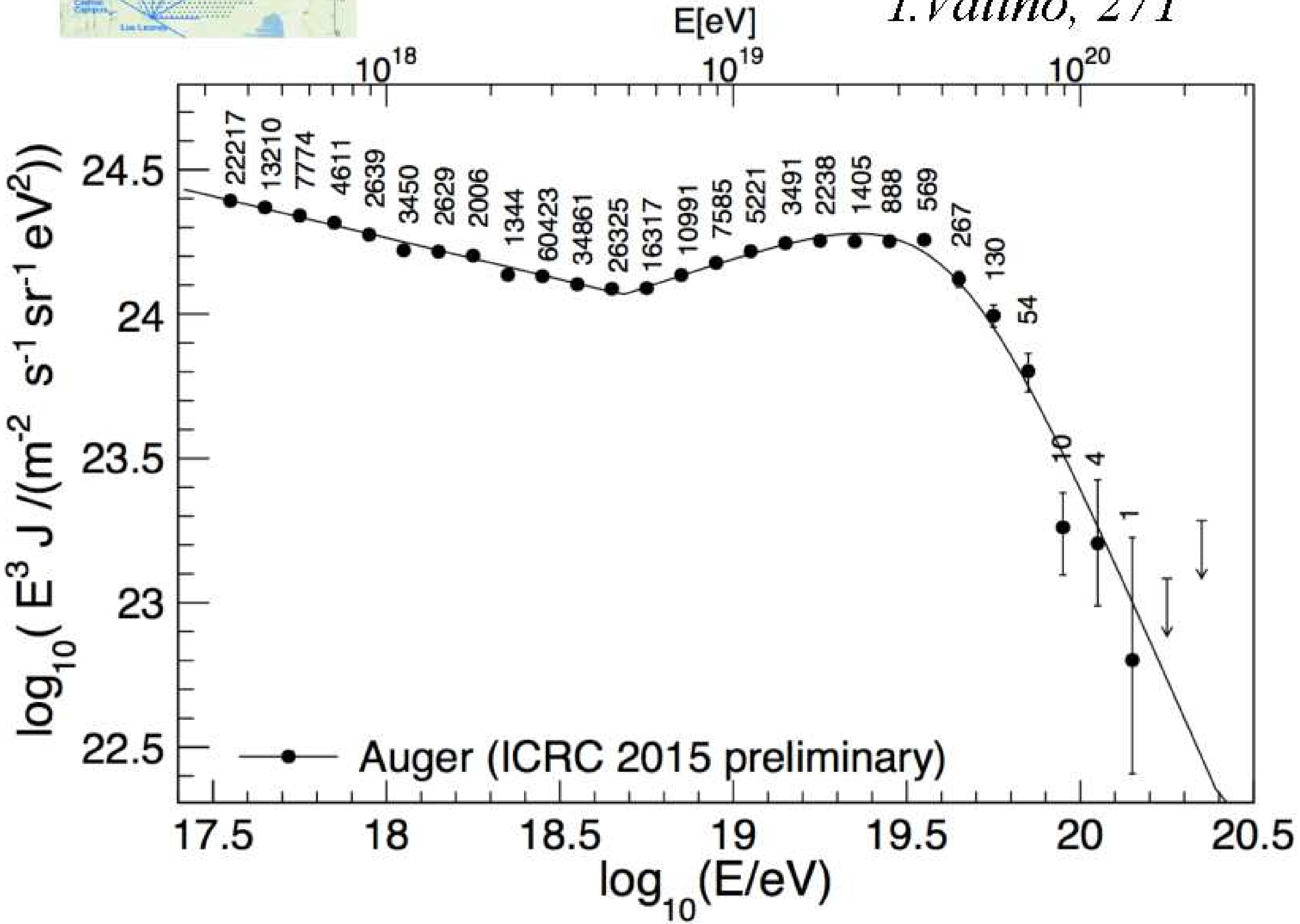


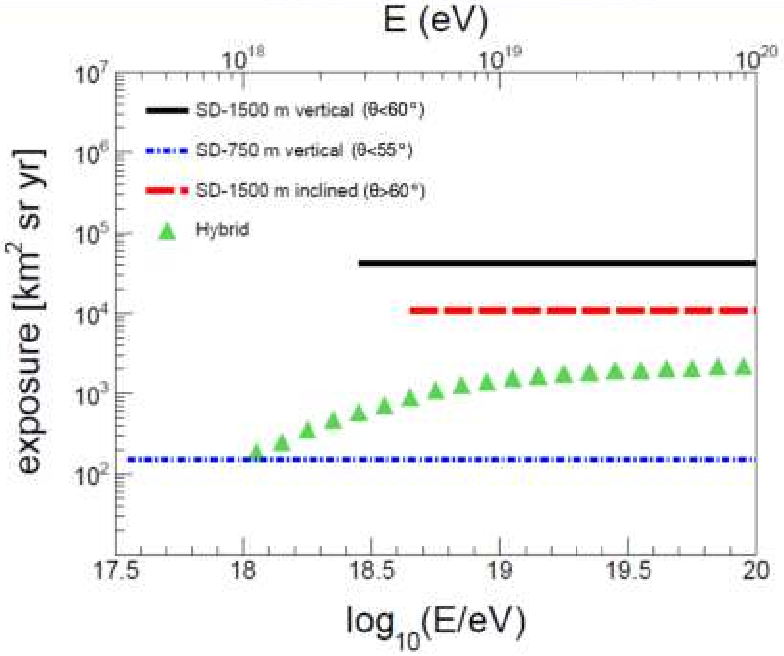
Auger

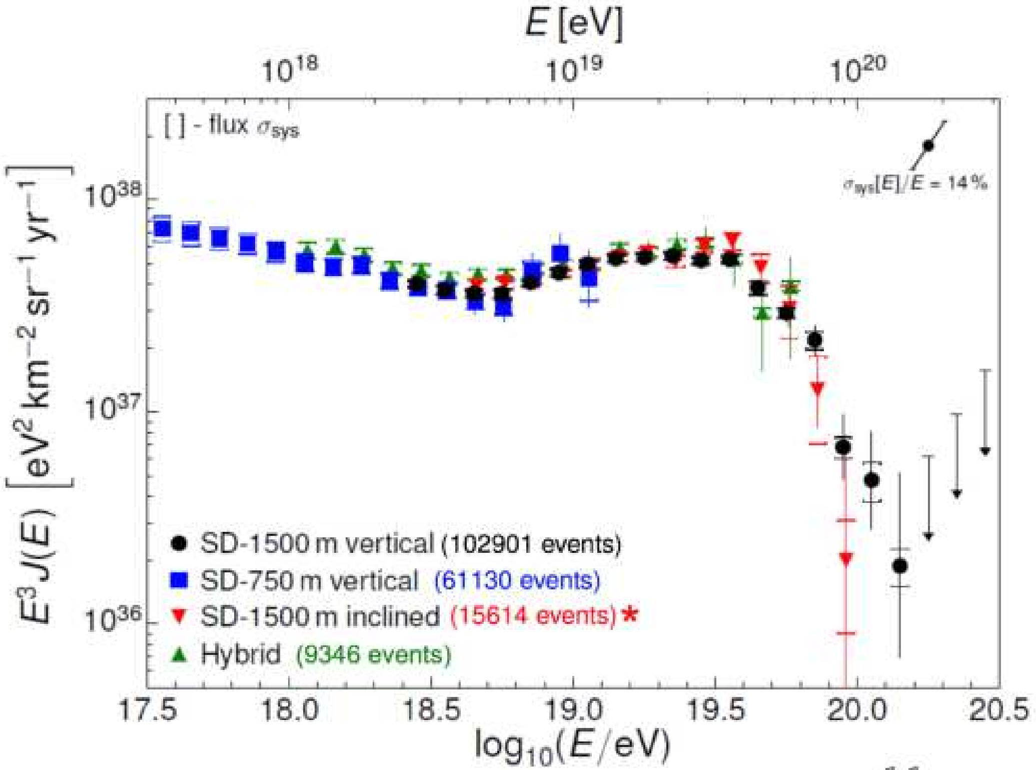
50,000 km² sr yr

P.Ghia, highlight

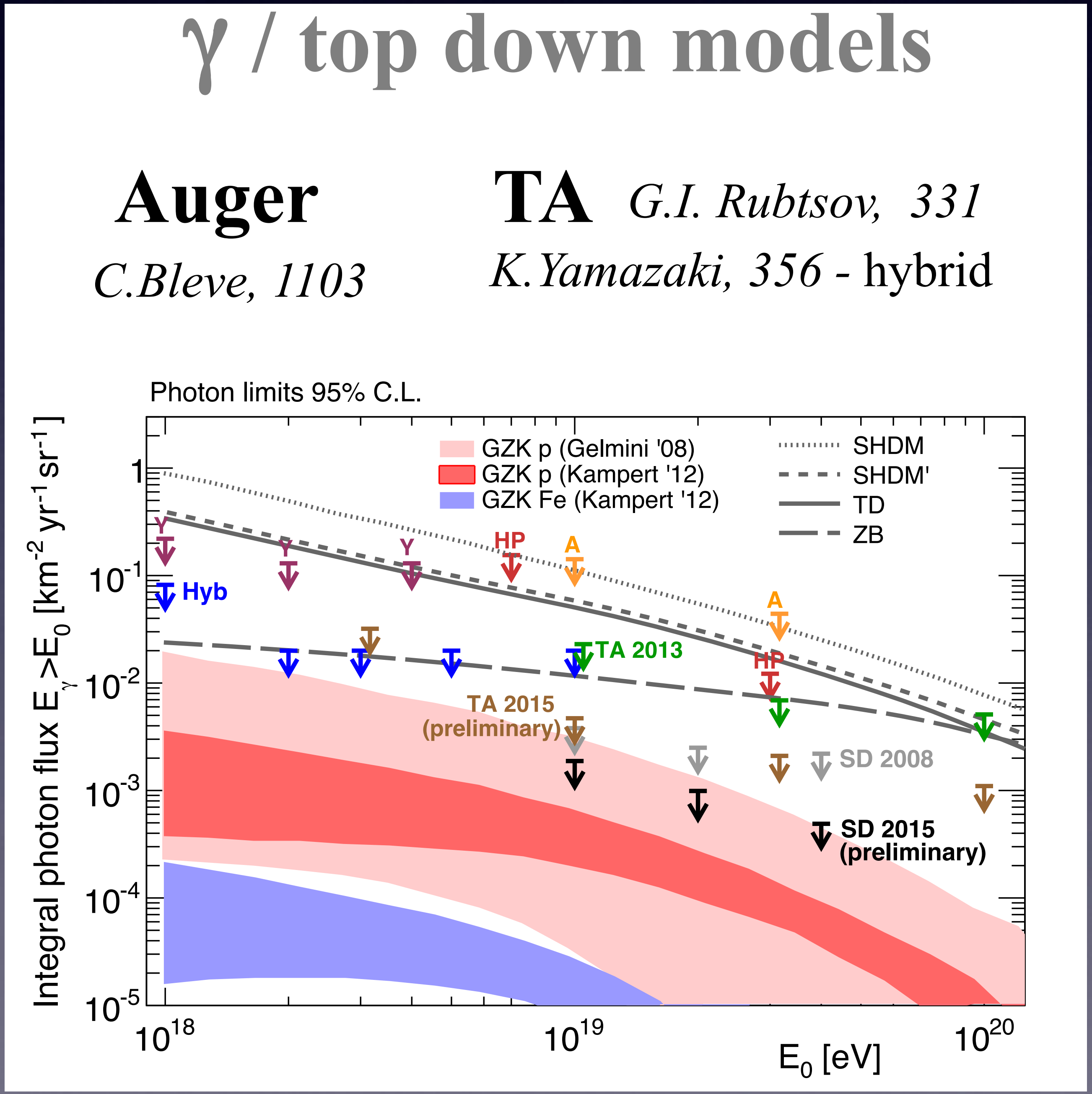
I.Valino, 271







Agreement on exotics



γ / top down models

Auger

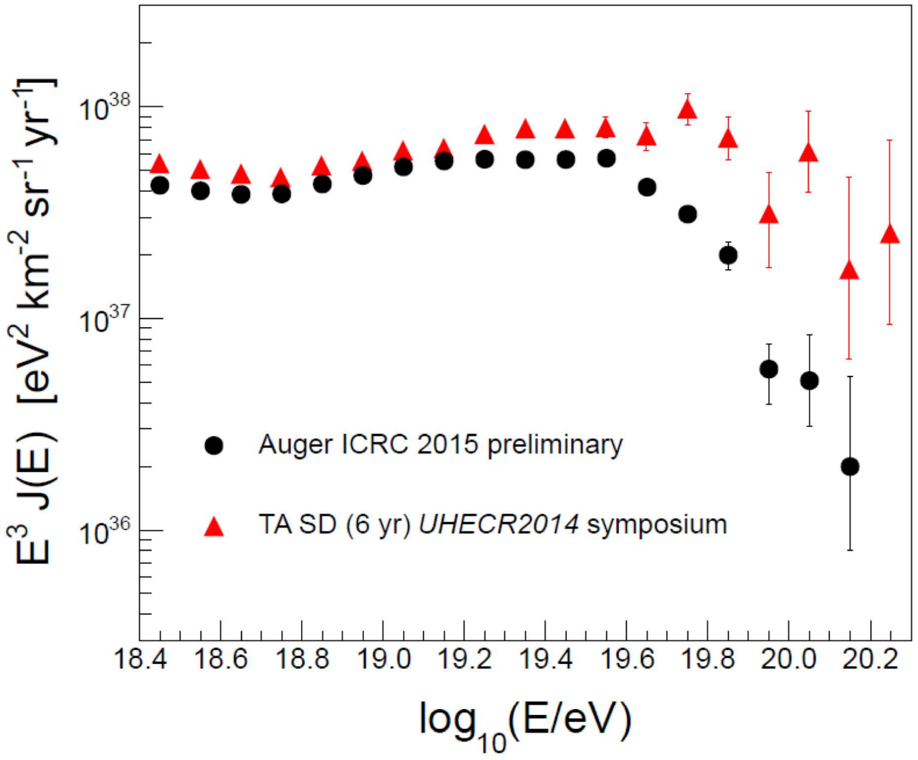
C.Bleve, 1103

TA *G.I. Rubtsov, 331*

K.Yamazaki, 356 - hybrid

Auger vs TA

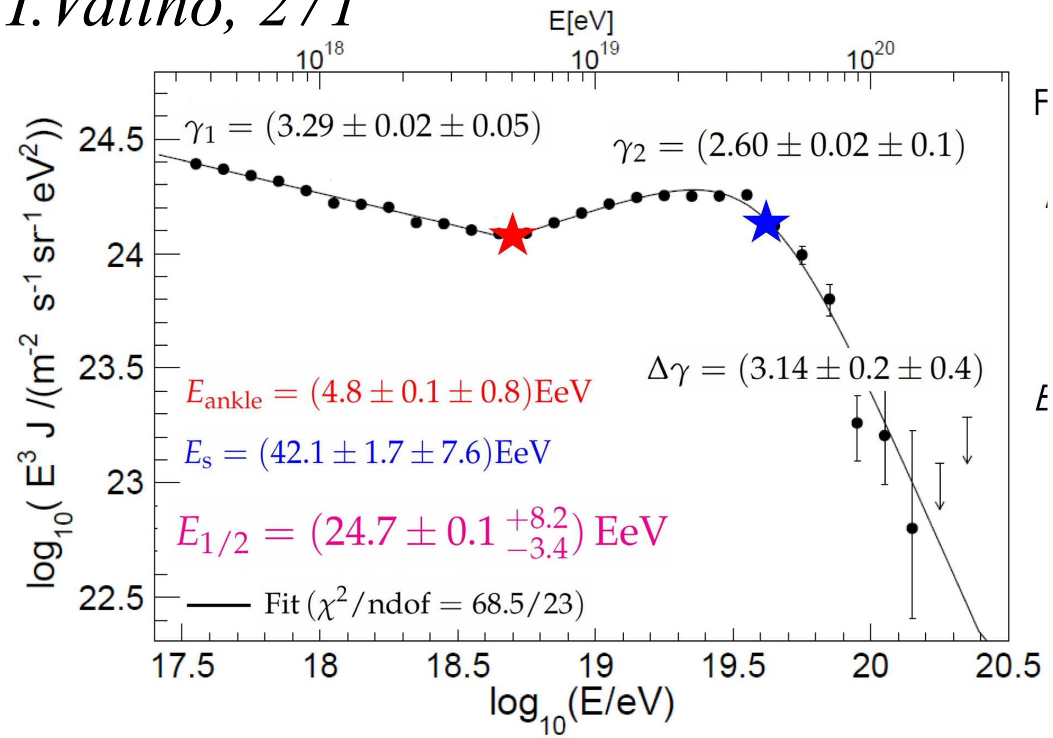
At the “GZK” energies, doubtful if there’s agreement



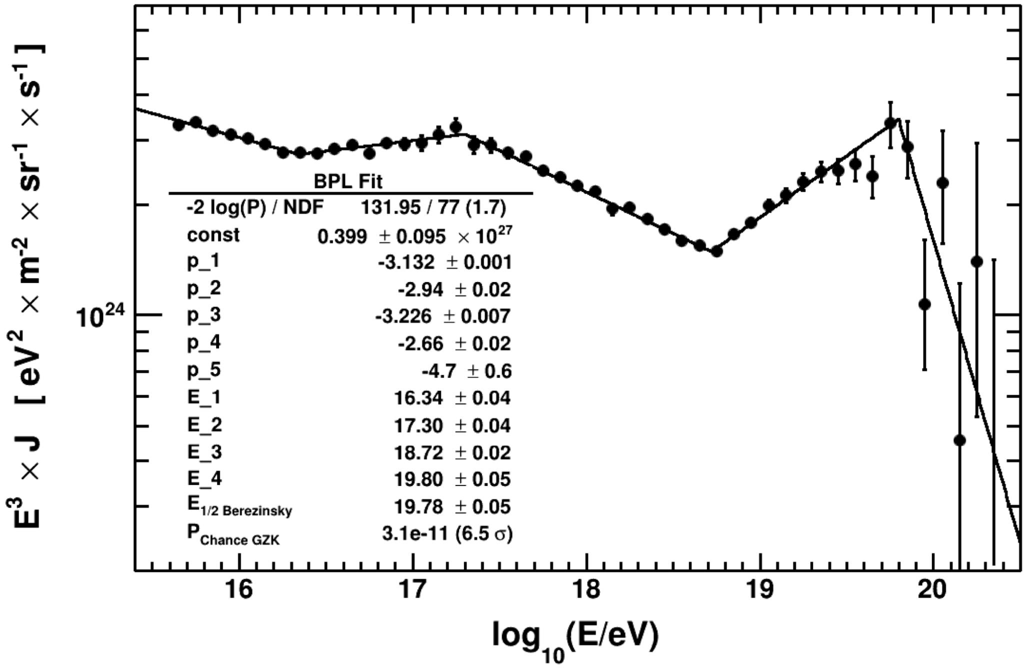
Auger vs TA

	Auger	**TA**
E_{ankle} (EeV)	≈ 4.8	≈ 5.2
$\mathbf{E_{1/2}}$ **(EeV)**	$\mathbf{\approx 25}$	$\mathbf{\approx 60}$

I.Valino, 271



D.Ivanov, 349



BPL Fit

-2 log(P) / NDF	131.95 / 77 (1.7)
const	0.399 $\pm$ 0.095 $\times 10^{27}$
p_1	-3.132 $\pm$ 0.001
p_2	-2.94 $\pm$ 0.02
p_3	-3.226 $\pm$ 0.007
p_4	-2.66 $\pm$ 0.02
p_5	-4.7 $\pm$ 0.6
E_1	16.34 $\pm$ 0.04
E_2	17.30 $\pm$ 0.04
E_3	18.72 $\pm$ 0.02
E_4	19.80 $\pm$ 0.05
$E_{1/2\ \text{Berezinsky}}$	19.78 $\pm$ 0.05
$P_{\text{Chance GZK}}$	3.1e-11 (6.5 σ)

Hot spot only seen by TA, but…

Hot Spot with 2 additional years

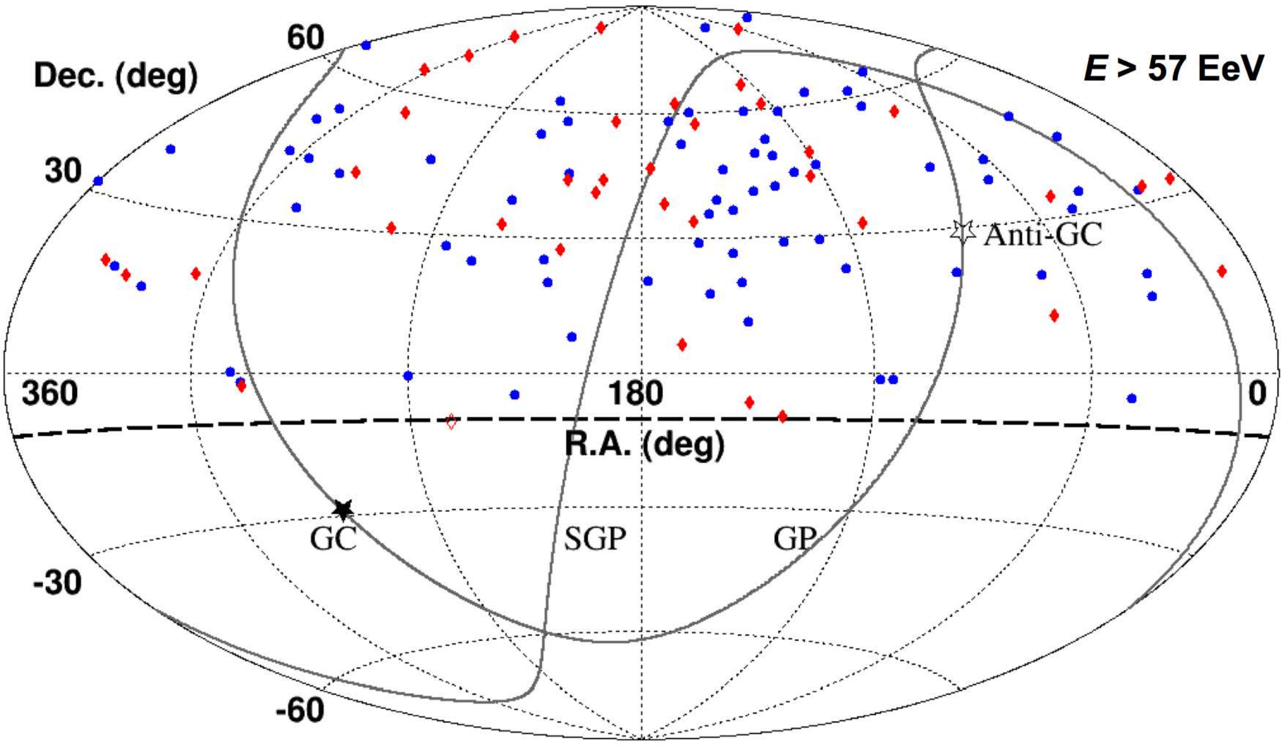
TA

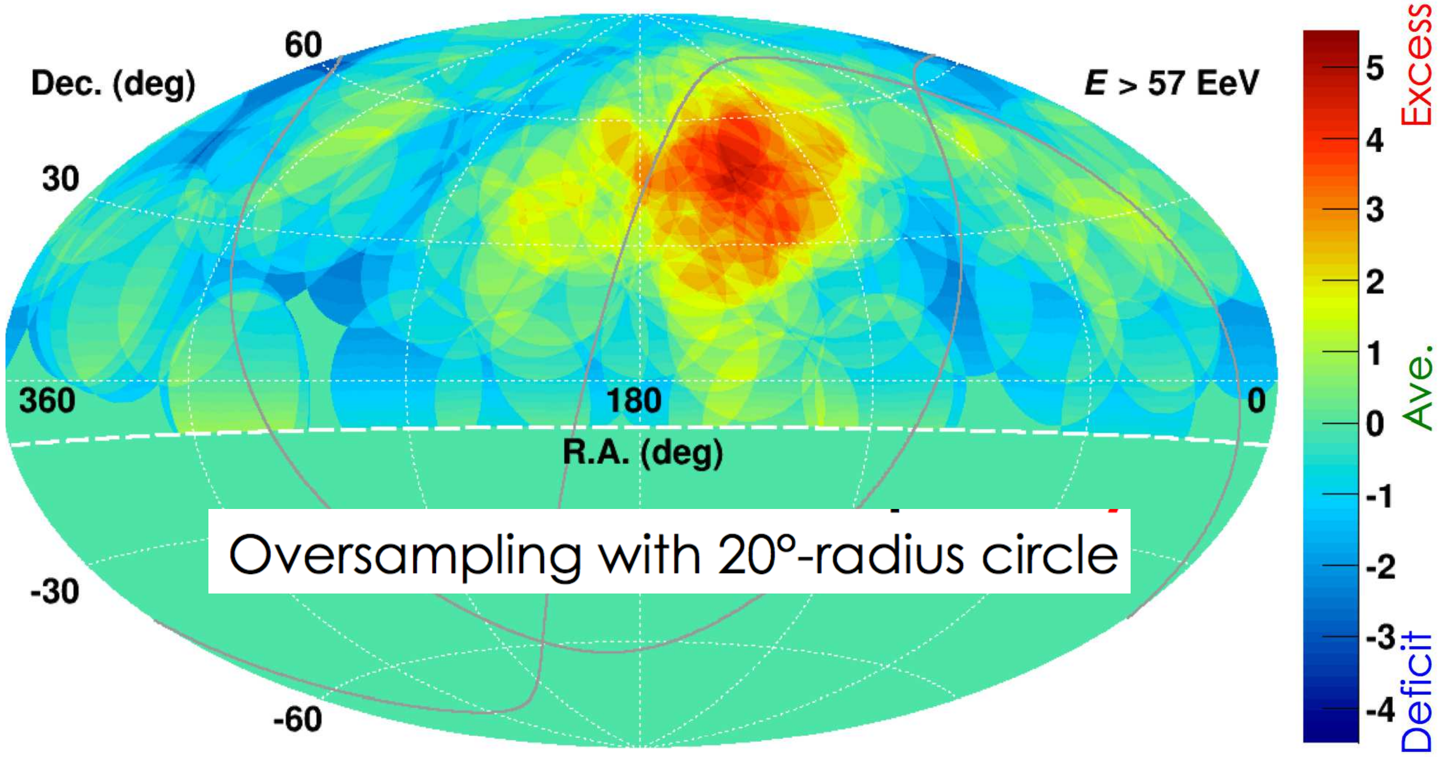
P.Tinyakov, 326

20^0 around RA=148.4^0 Dec=44.5^0

E > 57 EeV 24 events $N_{bkg} = 6.88$

7 yr: chance probability 3.7×10^{-4} 3.4σ





Oversampling with 20°-radius circle

Period	Total (>57EeV)	Hotspot Signals	B.G.	Chance Prob.	Center position (RA., Dec.)
6-th year	15	3	0.94	7%	146.7°, 43.2°
7-th year	22	1	1.37	74%	146.7°, 43.2°
6 & 7-th year	37	4	2.31	20%	146.7°, 43.2°

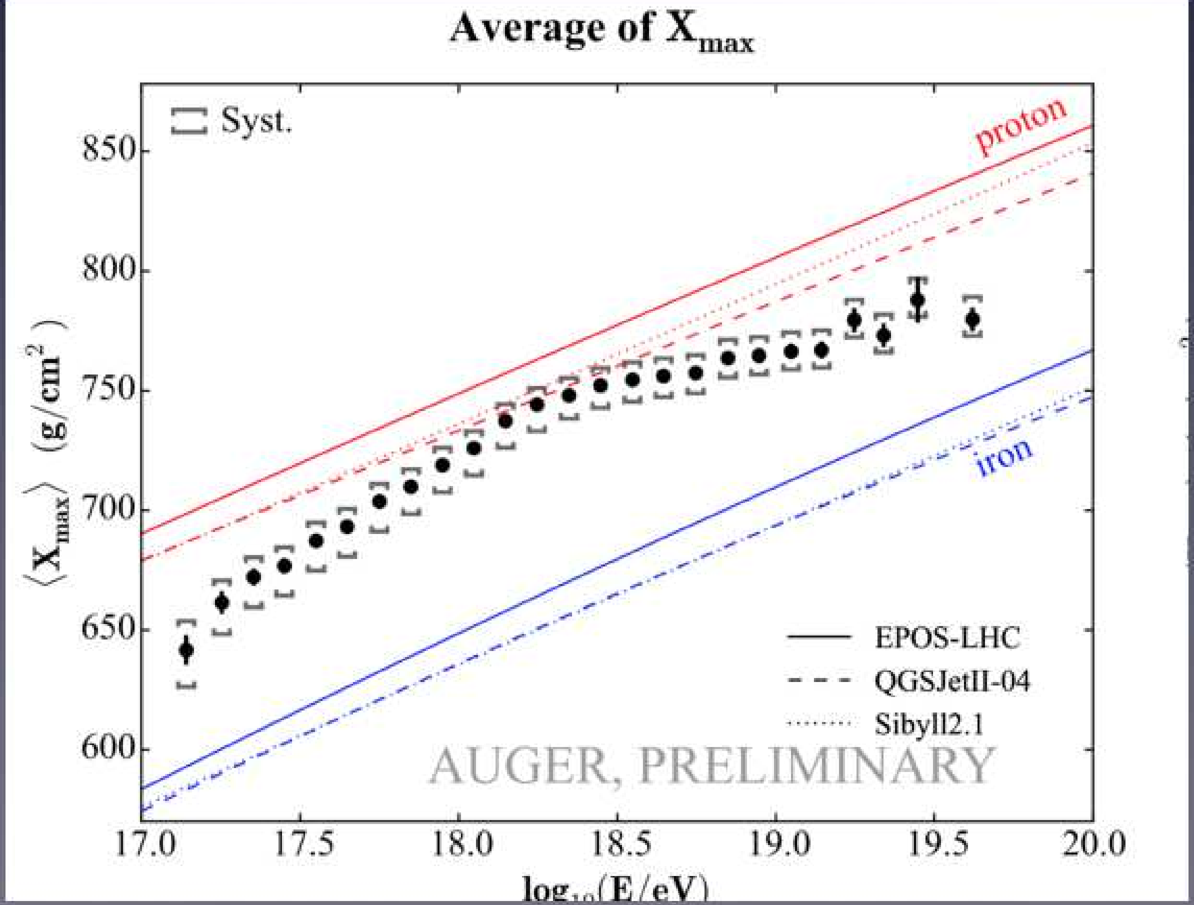
- Hot Spot near to Ursa Major Cluster (20 Mpc)
- shifted from SGP by 17^0

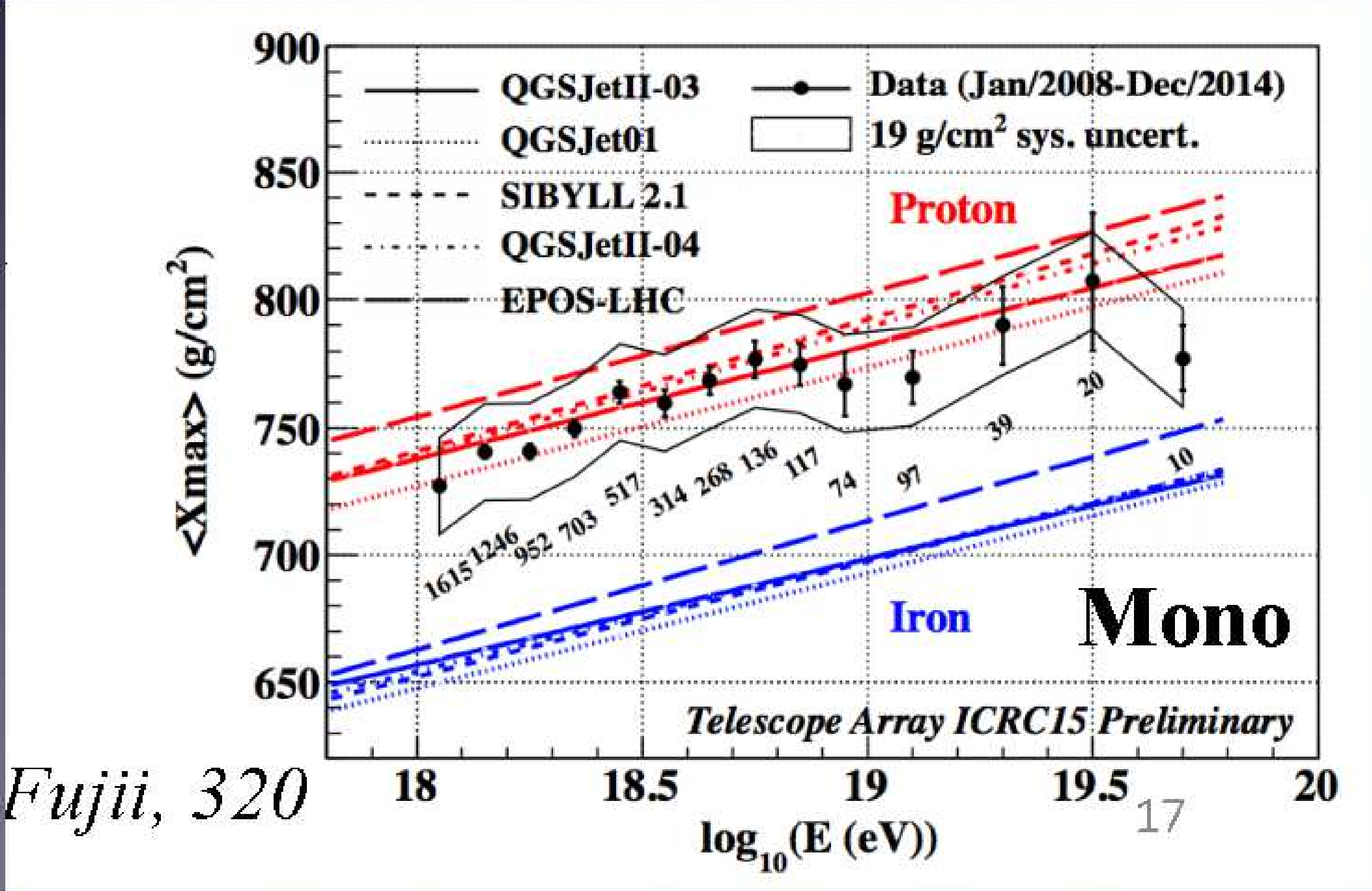
See also *Haoning He, 325* for the interpret.

Chemical composition

from shower depth:

- Mixed with heavy-light-heavy trend in Auger
- all consistent with light (p-He, not heavier than ~N, say) for TA





Fujii, 320

Some interpretation

I cannot but say that this reminds me of AGASA vs HiRes…

"Sec.1.2: Is progress in the cosmic ray field slow?"
It certainly looks like that.

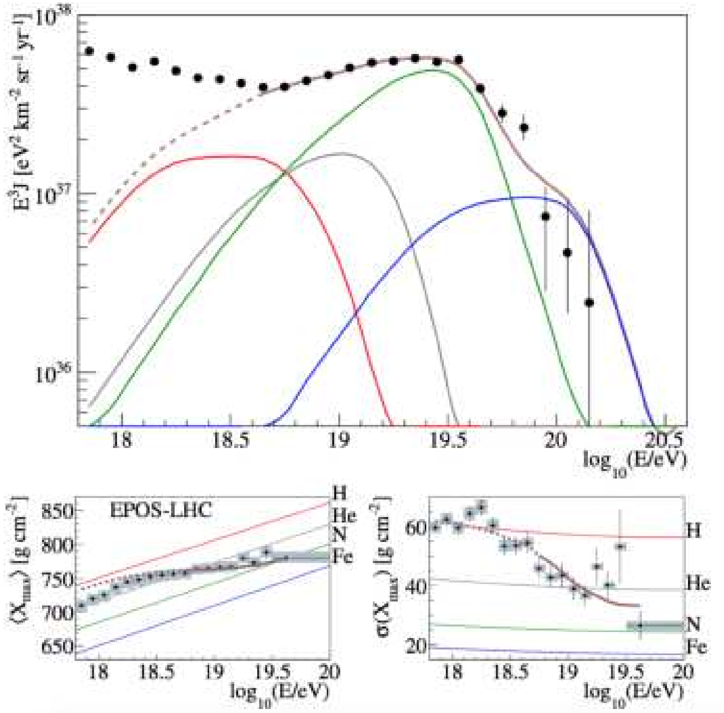
From T. Stanev's "High Energy Cosmic Rays" textbook

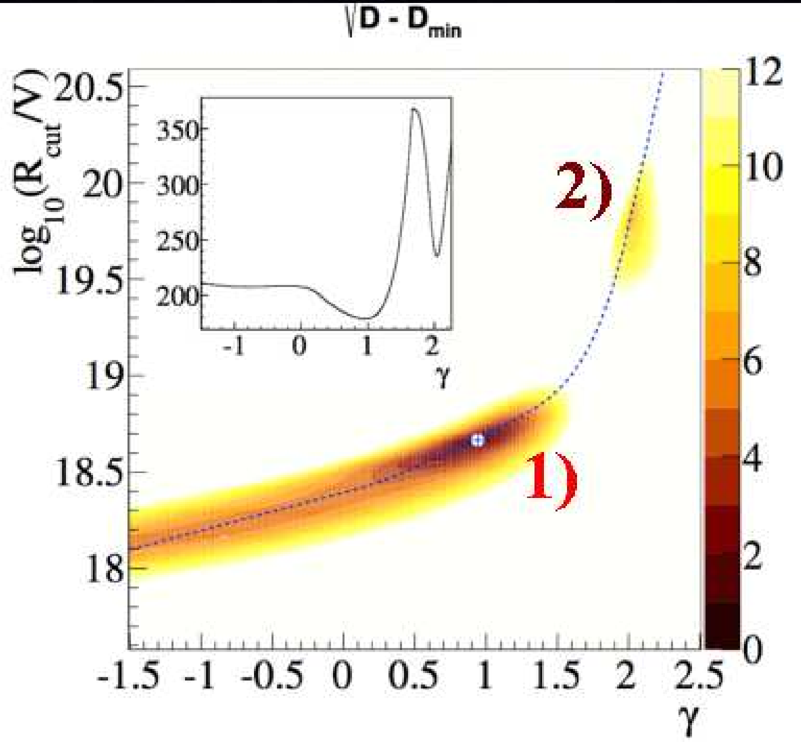
Auger

A. Di Matteo, 249

combined fit spectrum and composition

maximum rigidity (1) favored over photo-disintegration (2)





TA

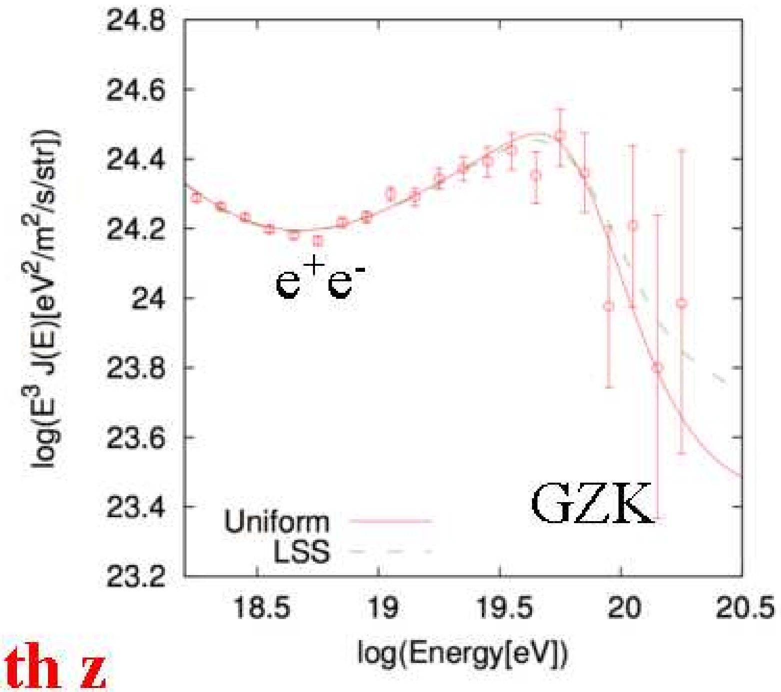
E. Kido, 258

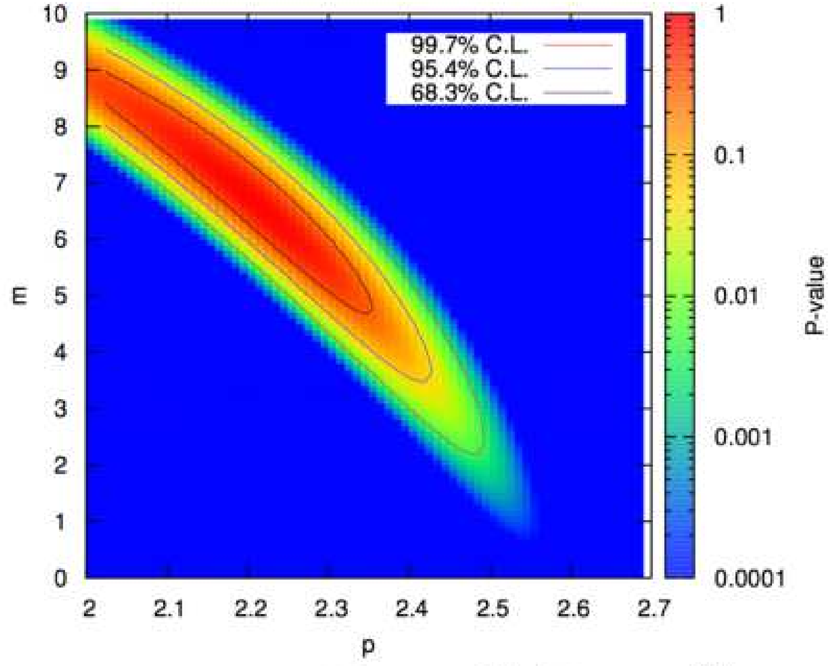
fit spectrum with a pure p composition

"no cut-off " at the source

"dip" scenario

strong evolution of sources with z



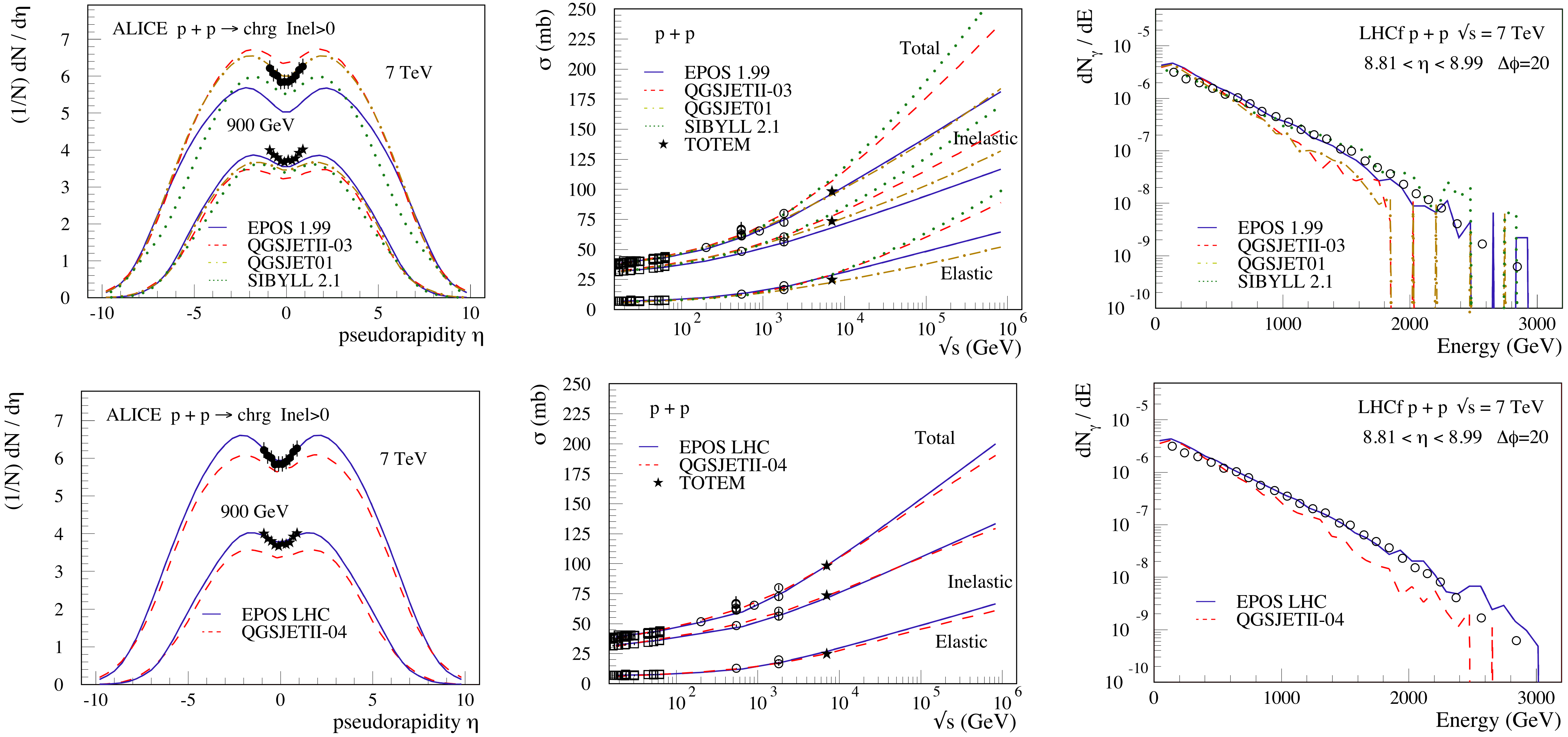


$$\alpha E^{-p}(1+z)^{3+m}$$

At least, some progress: tuning models to LHC

Engel's highlight talk

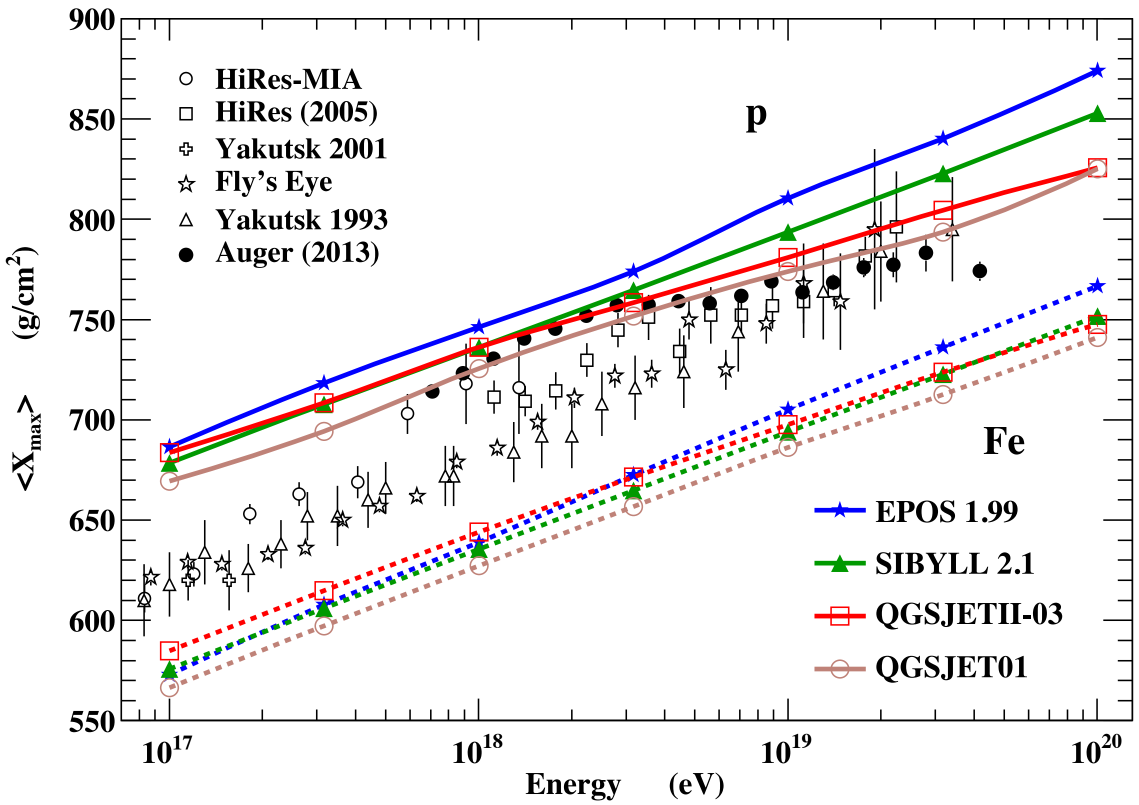
Examples of tuning interaction models to LHC data



(Pierog 2013, 2014)

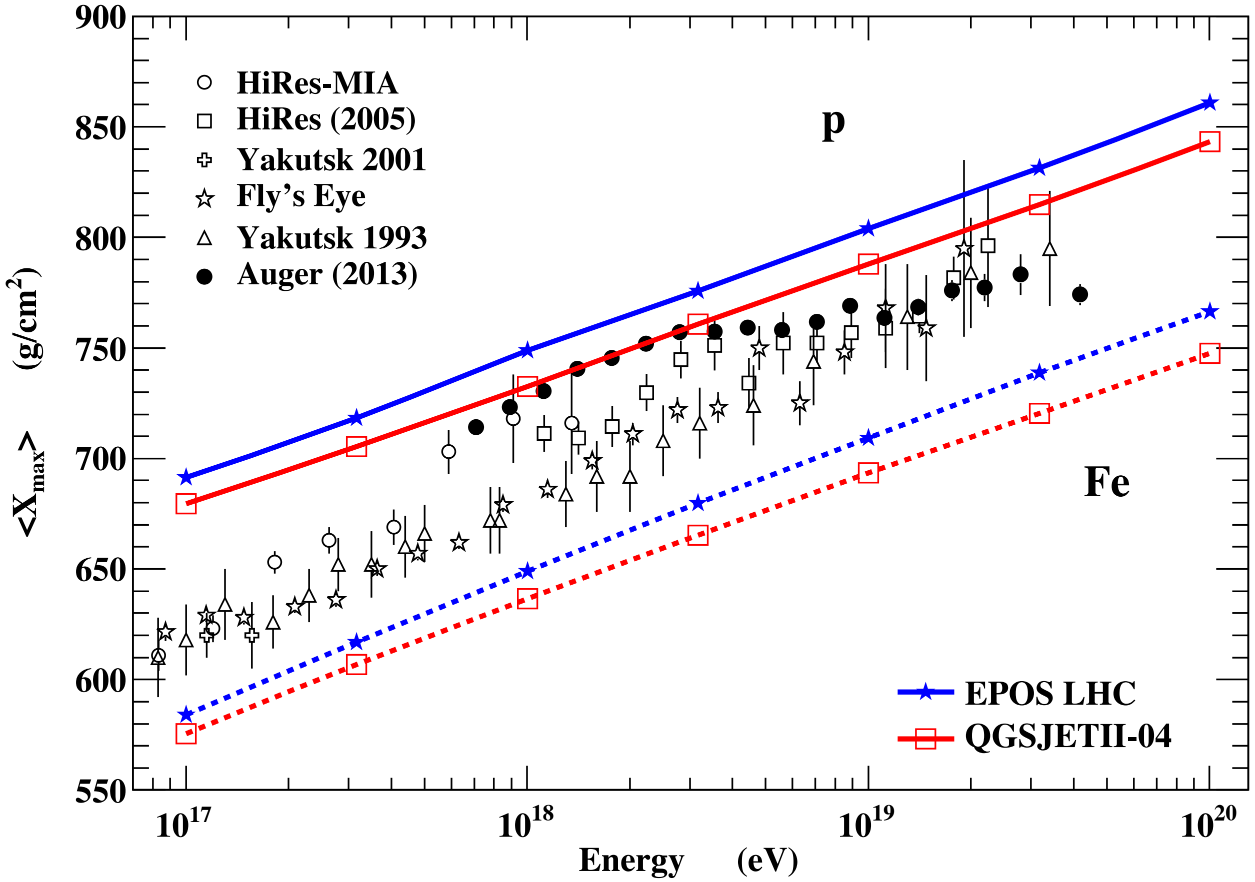
At least, some progress: tuning models to LHC

Engel's highlight talk



pre-LHC models

post-LHC models



New models favour interpretation as heavier composition than before

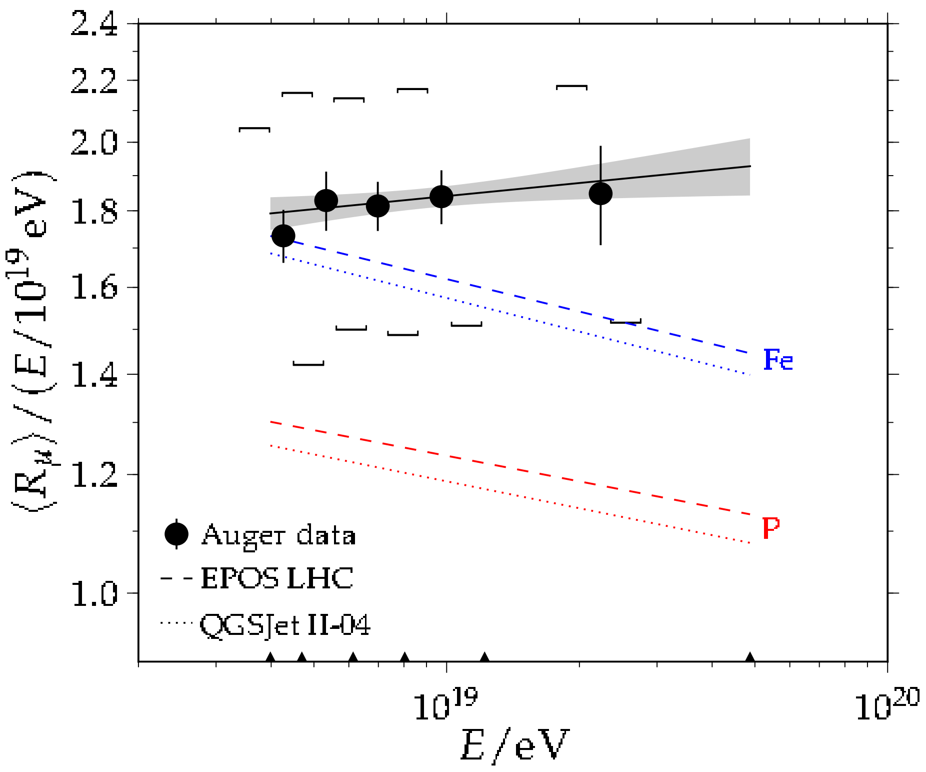
(Pierog 2013, 2014)

Towards the solution to the muon problem?

Engel's highlight talk

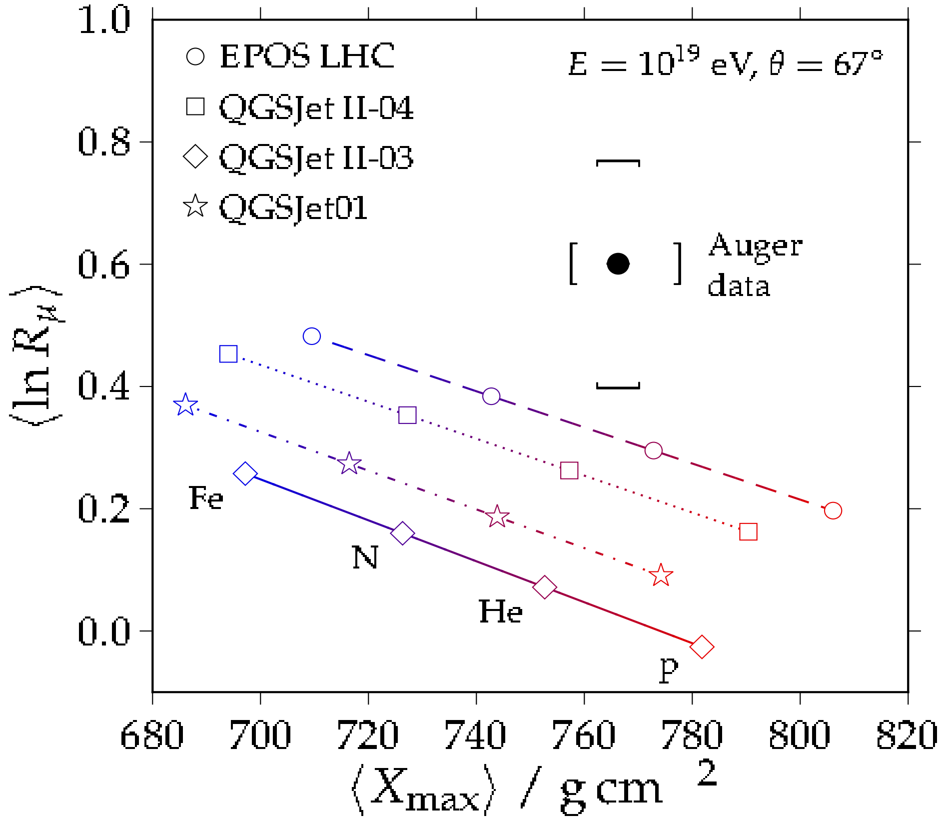
Muon number in inclined showers

Number of muons in showers with θ>60°



(Auger, PRD91, 2015)

Combination of information on mean depth of shower maximum and muon number at ground



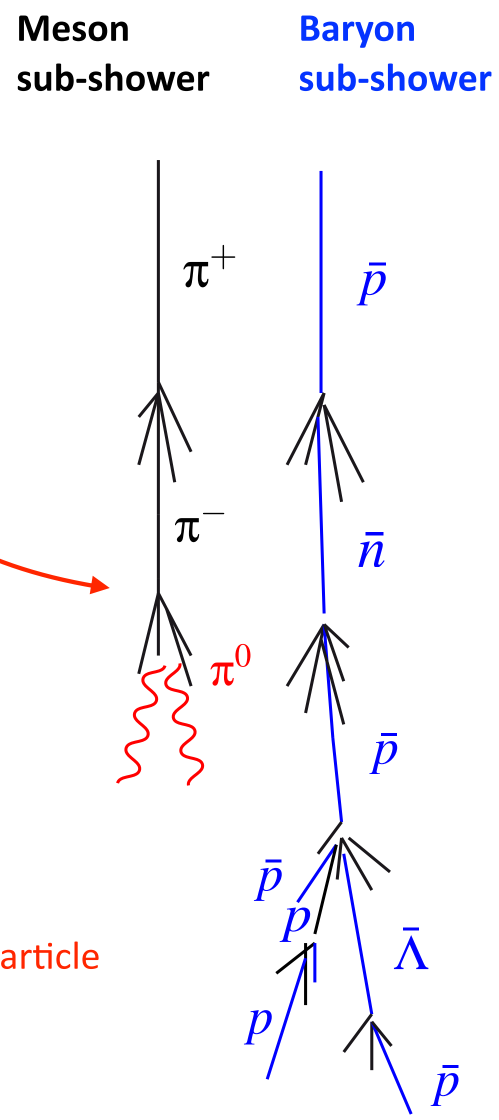
Several measurements: indications for muon discrepancy

Selecting among alternatives

What needed was known (diminish fraction of E going into e.m. showers, for fixed total E) but what causes it?

Engel's highlight talk

Change of energy transferred to electromagnetic component



30% chance to have π^0 as leading particle

Decay of leading particle

1 Baryon-Antibaryon pair production *(Pierog, Werner)*

- Baryon number conservation
- Low-energy particles: large angle to shower axis
- Transverse momentum of baryons higher
- Enhancement of mainly **low-energy** muons

(Grieder ICRC 1973; Pierog, Werner PRL 101, 2008)

2 Leading particle effect for pions *(Drescher 2007, Ostapchenko)*

- Leading particle for a π could be ρ^0 and not π^0
- Decay of ρ^0 to 100% into two charged pions

3 New hadronic physics at high energy *(Farrar, Allen 2012)*

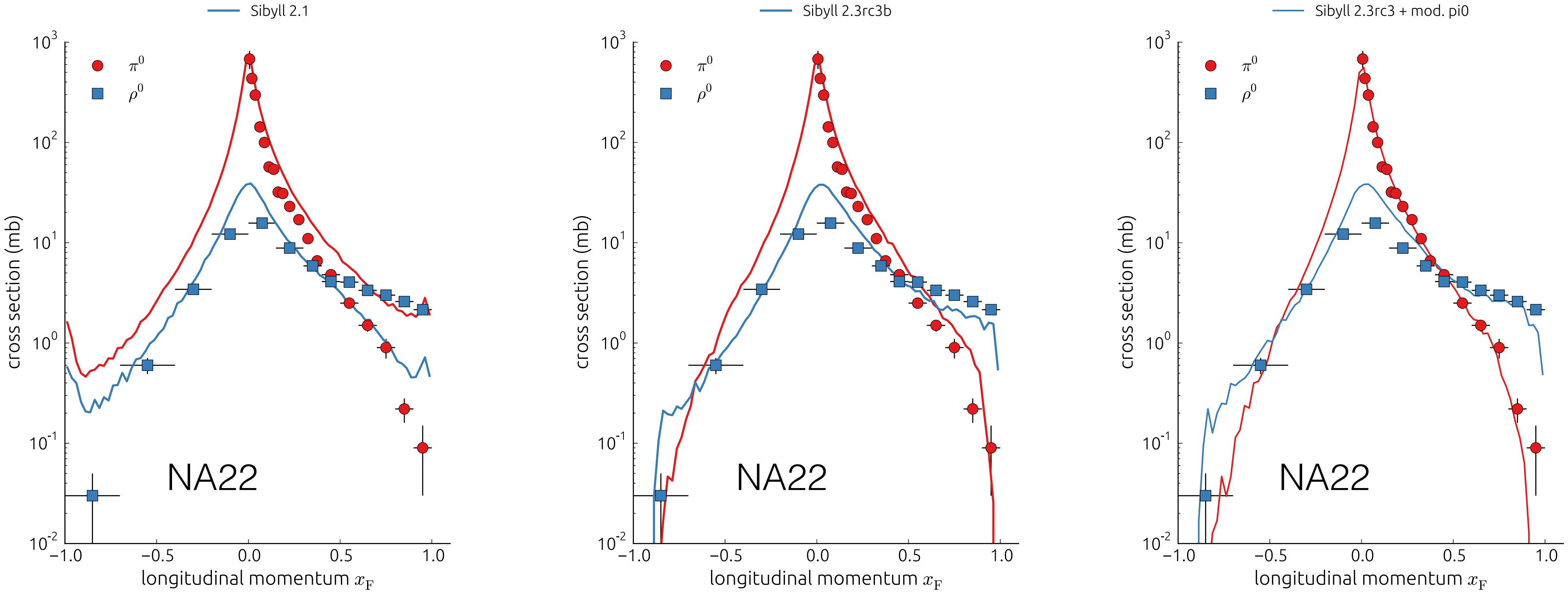
- Inhibition of π^0 decay (Lorentz invariance violation etc.)
- Chiral symmetry restauration

Selecting among alternatives

Engel's highlight talk

 # 2 seems the winner (+#1 subheading role?) !

How important is forward π⁰ and ρ⁰ production ?



$x_F = p_{\|}/p_{\max}$

$\pi^+ p \to \pi^0 \to 2\gamma$

$\pi^+ p \to \rho^0 \to \pi^+ \pi^-$

$E_{\mathrm{lab}} = 250\,\mathrm{GeV}$

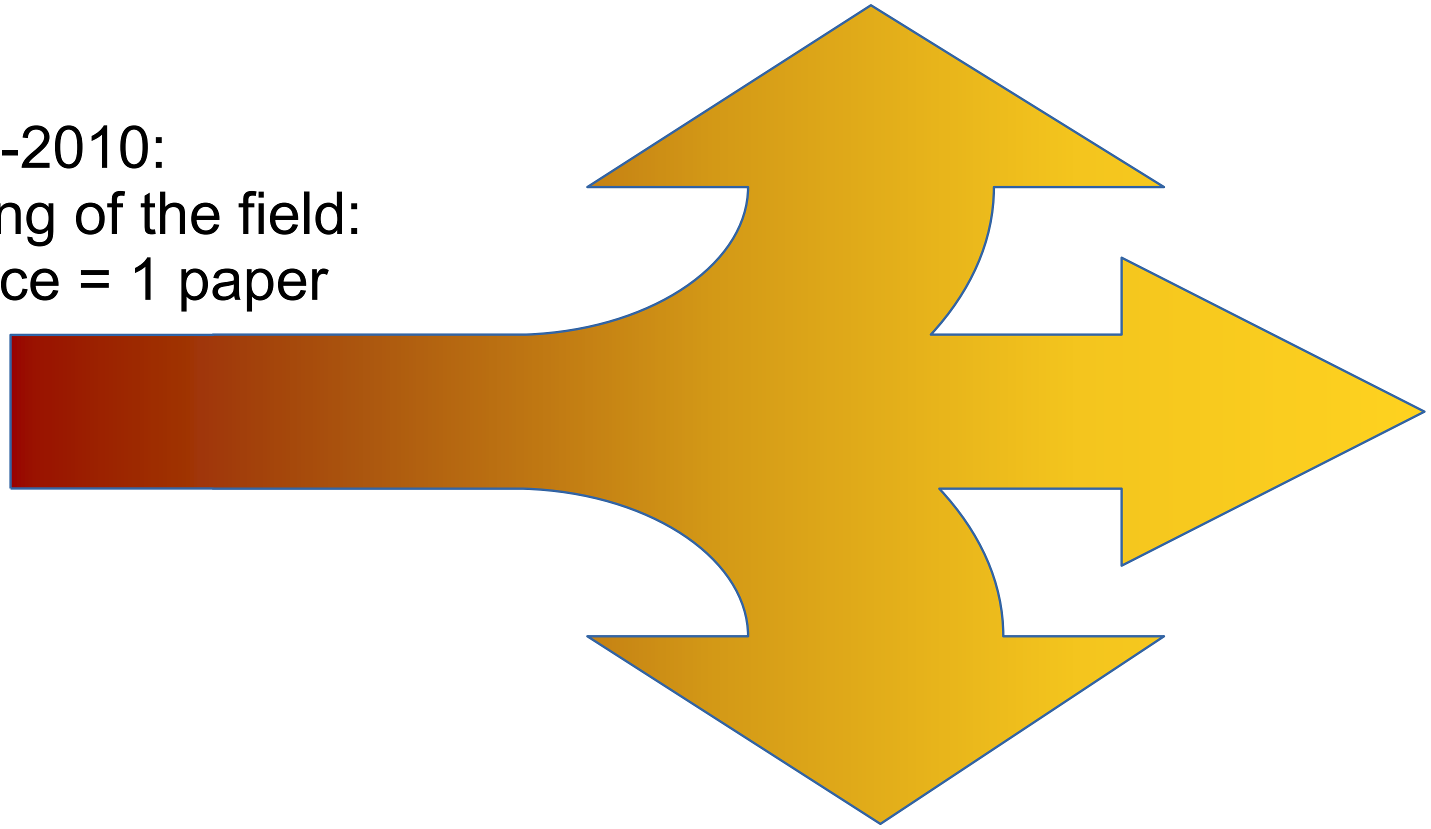
Sibyll 2.3
(release candidate)

Sibyll 2.3
(mod. π^0)

(Riehn 2015)

Evolution in VHE gamma-rays

Evolution of the Field



Surveys, populations studies

~2000-2010:
Opening of the field:
1 source = 1 paper

Key Science projects,
Deep investigation
of specific objects

The Unknown, still searching for
- Dark Matter
- Exotic Physics

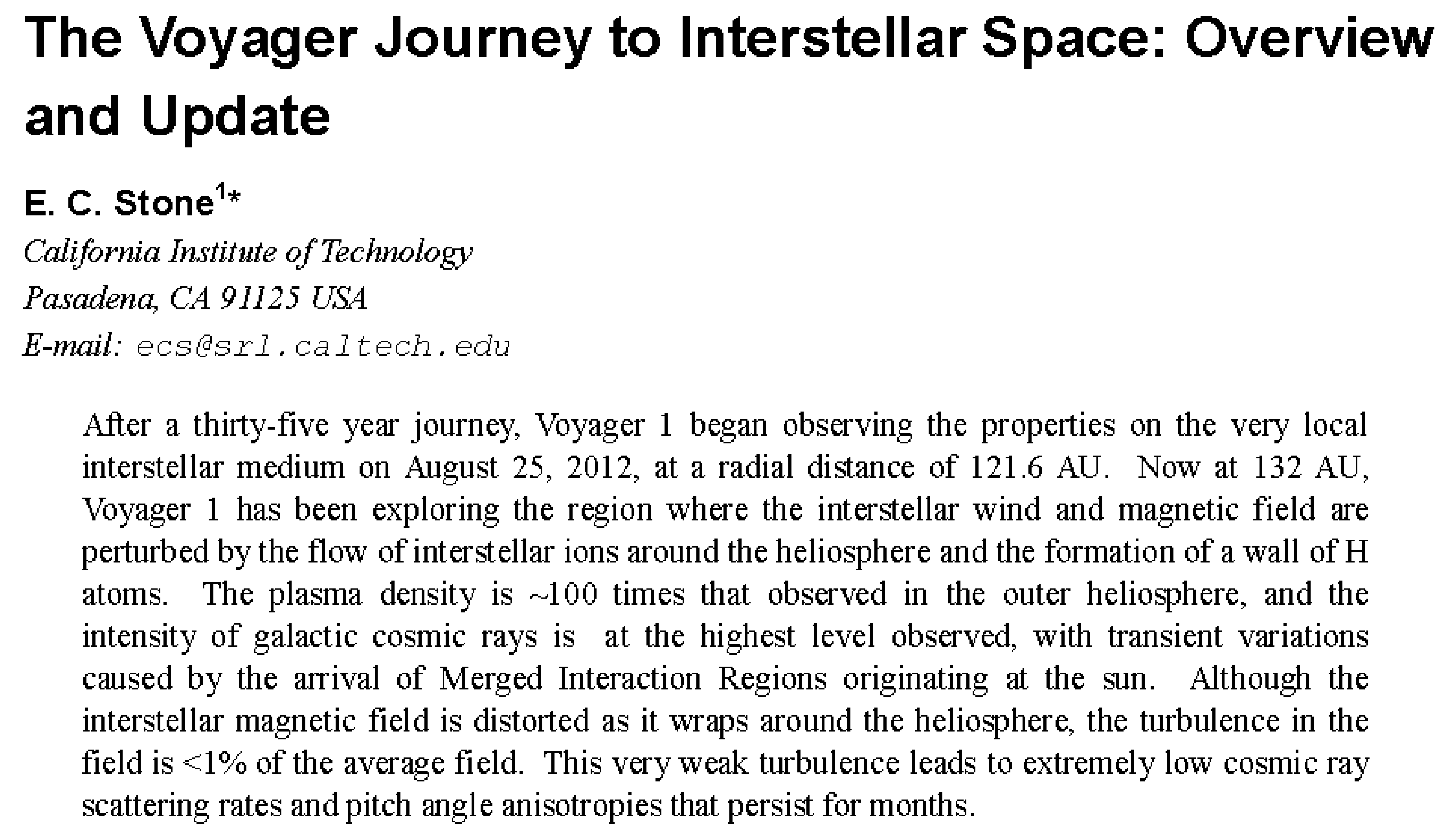
Evolution in VHE gamma-rays

- Indirect evidence for the first PeVatron at the GC “ridge”
- Pulsation in Crab detected at E>400 GeV (Magic), confirmed by Veritas: highest E!
- Second VHE detection of pulsars (Vela), HESS II goes down to ~10 GeV!
- Population studies of SNRs away morphological studies start becoming real
- New population of gamma binaries, “human scale” laboratory for acceleration studies
- “Stellar” emission (like Gal. CR) in LMC, Superbubble detected
- FSRQ detected at record z=0.939 (MAGIC), EBL constraints.
- Lensed emission of FSRQ @ z~0.94 (Fermi+MAGIC)

- VHE astronomy is experiencing a phase transition: key science projects, requiring deep (>100 h) exposure

Fishing-in-the dark time is over, precision measurement era is starting

On August 25th, 2012…



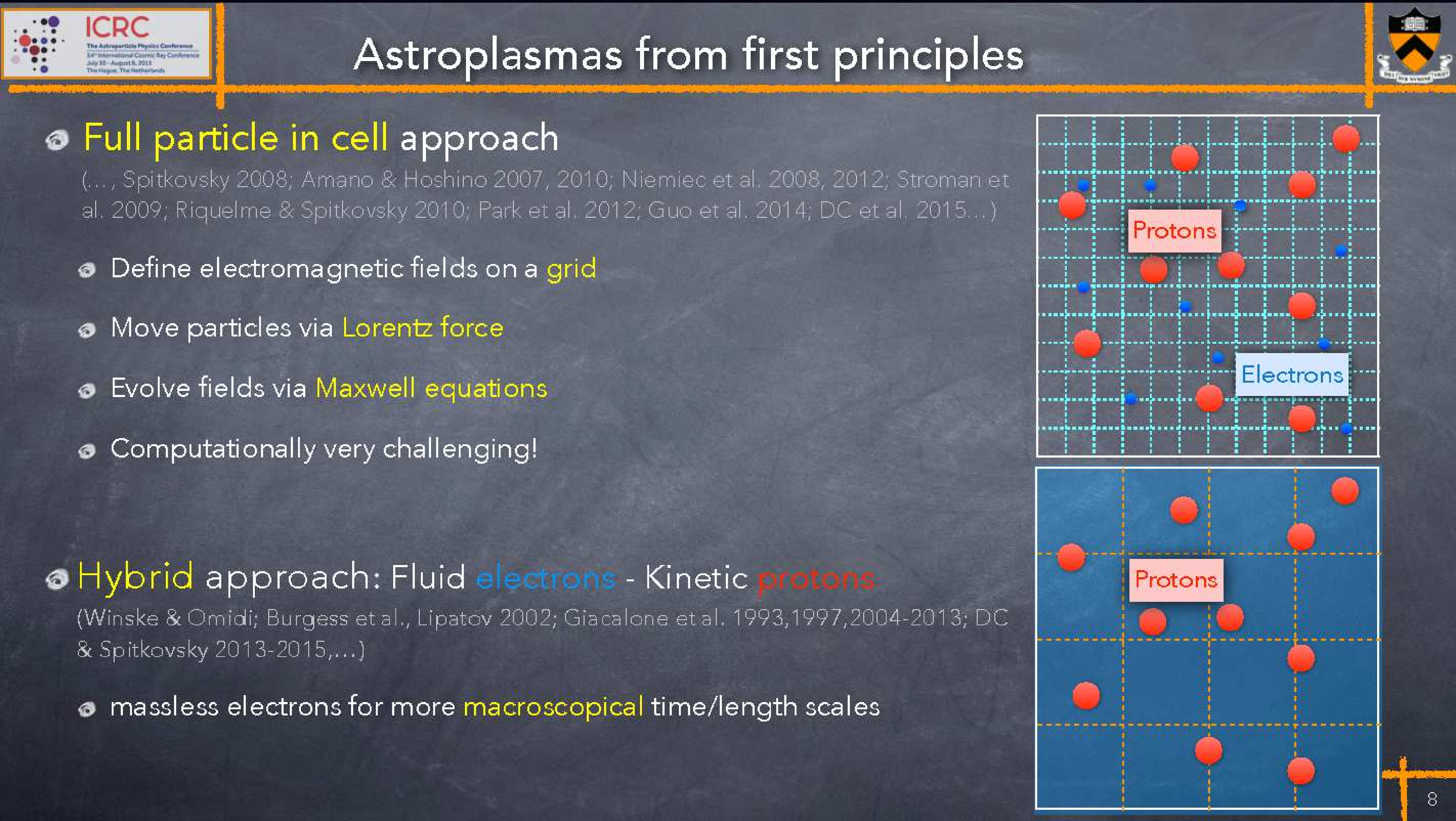
The Voyager Journey to Interstellar Space: Overview and Update

E. C. Stone[1]*
California Institute of Technology
Pasadena, CA 91125 USA
E-mail: `ecs@srl.caltech.edu`

After a thirty-five year journey, Voyager 1 began observing the properties on the very local interstellar medium on August 25, 2012, at a radial distance of 121.6 AU. Now at 132 AU, Voyager 1 has been exploring the region where the interstellar wind and magnetic field are perturbed by the flow of interstellar ions around the heliosphere and the formation of a wall of H atoms. The plasma density is ~100 times that observed in the outer heliosphere, and the intensity of galactic cosmic rays is at the highest level observed, with transient variations caused by the arrival of Merged Interaction Regions originating at the sun. Although the interstellar magnetic field is distorted as it wraps around the heliosphere, the turbulence in the field is <1% of the average field. This very weak turbulence leads to extremely low cosmic ray scattering rates and pitch angle anisotropies that persist for months.

On acceleration

D. Caprioli, highlight talk

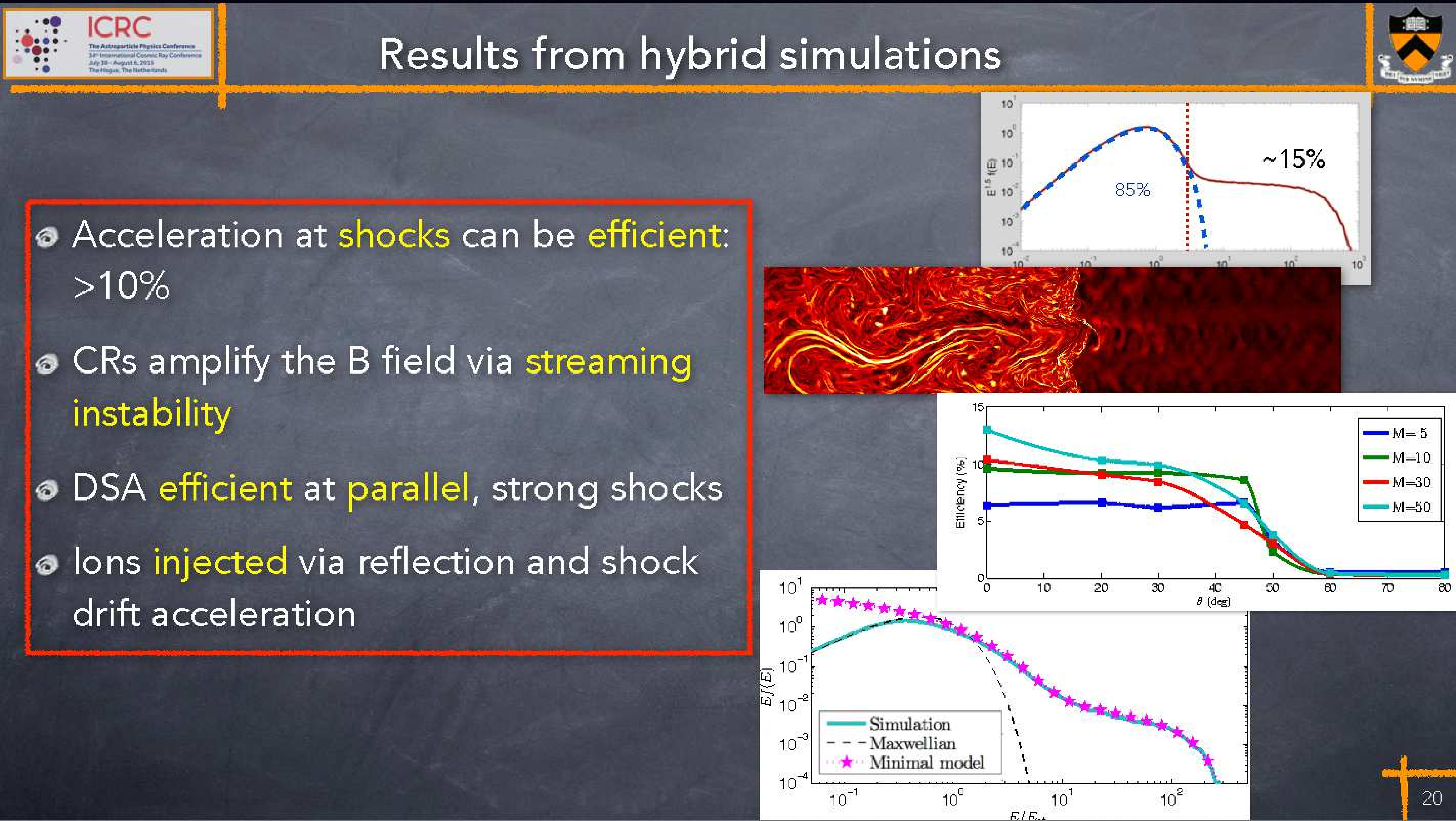


Astroplasmas from first principles

- **Full particle in cell** approach
  (..., Spitkovsky 2008; Amano & Hoshino 2007, 2010; Niemiec et al. 2008, 2012; Stroman et al. 2009; Riquelme & Spitkovsky 2010; Park et al. 2012; Guo et al. 2014; DC et al. 2015...)
  - Define electromagnetic fields on a grid
  - Move particles via Lorentz force
  - Evolve fields via Maxwell equations
  - Computationally very challenging!
- **Hybrid** approach: Fluid electrons - Kinetic protons
  (Winske & Omidi; Burgess et al., Lipatov 2002; Giacalone et al. 1993,1997,2004-2013; DC & Spitkovsky 2013-2015,...)
  - massless electrons for more macroscopical time/length scales

On acceleration

D. Caprioli, highlight talk

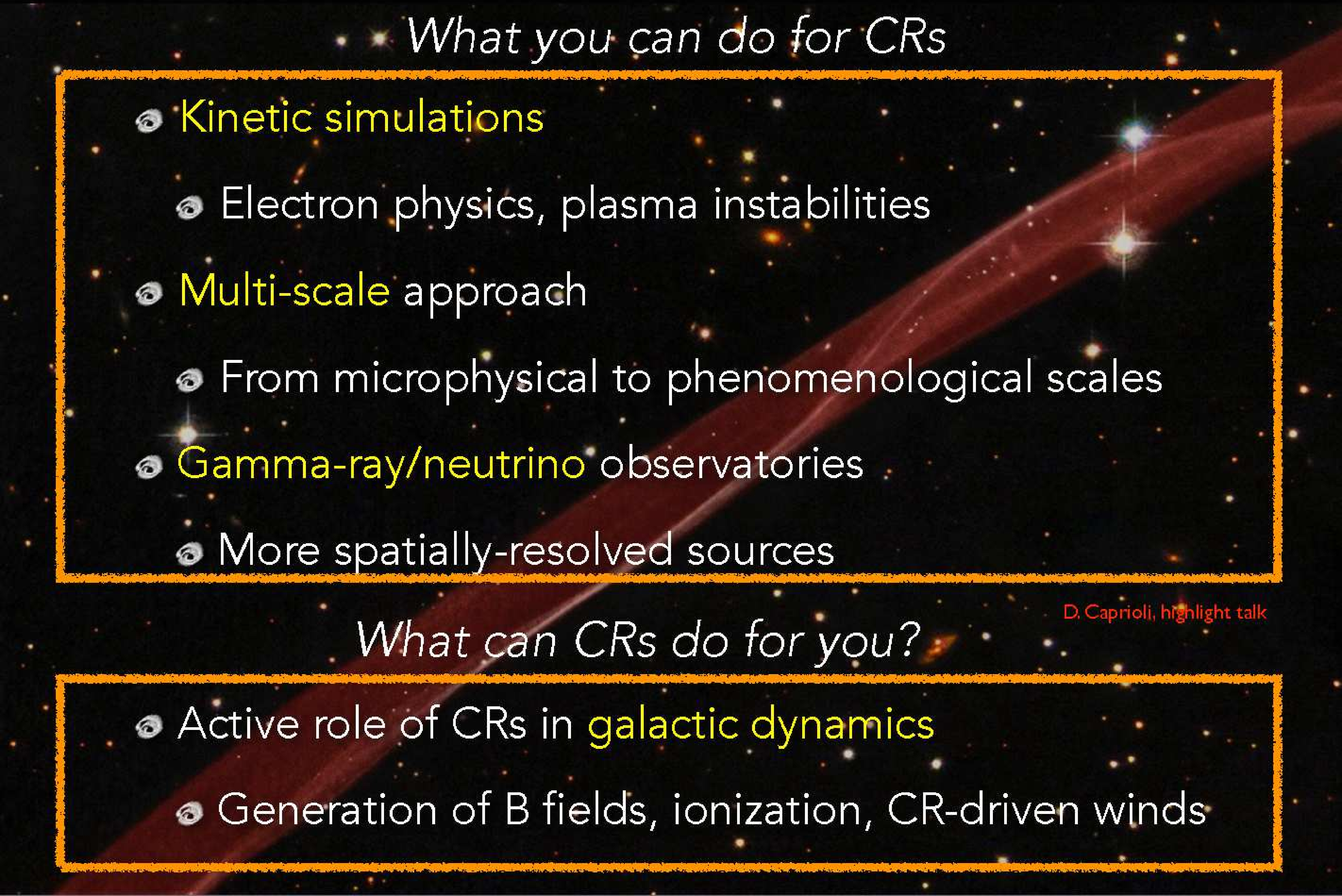


ICRC
The Astroparticle Physics Conference
34th International Cosmic Ray Conference
July 30 - August 6, 2015
The Hague, The Netherlands

Results from hybrid simulations

- Acceleration at shocks can be efficient: >10%
- CRs amplify the B field via streaming instability
- DSA efficient at parallel, strong shocks
- Ions injected via reflection and shock drift acceleration

On acceleration



What you can do for CRs

- Kinetic simulations
  - Electron physics, plasma instabilities
- Multi-scale approach
  - From microphysical to phenomenological scales
- Gamma-ray/neutrino observatories
  - More spatially-resolved sources

D. Caprioli, highlight talk

What can CRs do for you?

- Active role of CRs in galactic dynamics
  - Generation of B fields, ionization, CR-driven winds