Presentation of the *γ-CR-ν* working group & Summary of our first meeting

Andreas Zech

réunion PPF-NAG
12/12/2008
at the OBSPM

Presentation of the *γ-CR-ν* working group

Proposal to GDR-PCHE in summer 2008:
establish a working group between scientists from VHE gamma-ray, UHECR, neutrino astrophysics and experts on hadronic emission scenarios for AGN.

=> 2 000 euros to organise a first meeting in fall 2008

==> First meeting on December 9 at the OBSP with about 30 participants

Goals:

- Opening a dialogue between the VHE gamma-ray, UHECR and Neutrino astrophysics communities.
- Learning about scenarios of hadronic emission for AGN in a dialogue with experts on this topic.
- Deriving possible constraints from the most recent data in our fields against the model predictions.
- Making predictions for constraints to expect from future experiments (CTA, Auger North, JEM/EUSO, KM3NeT...).

→ http://www.luth.obspm.fr/gammacrnu

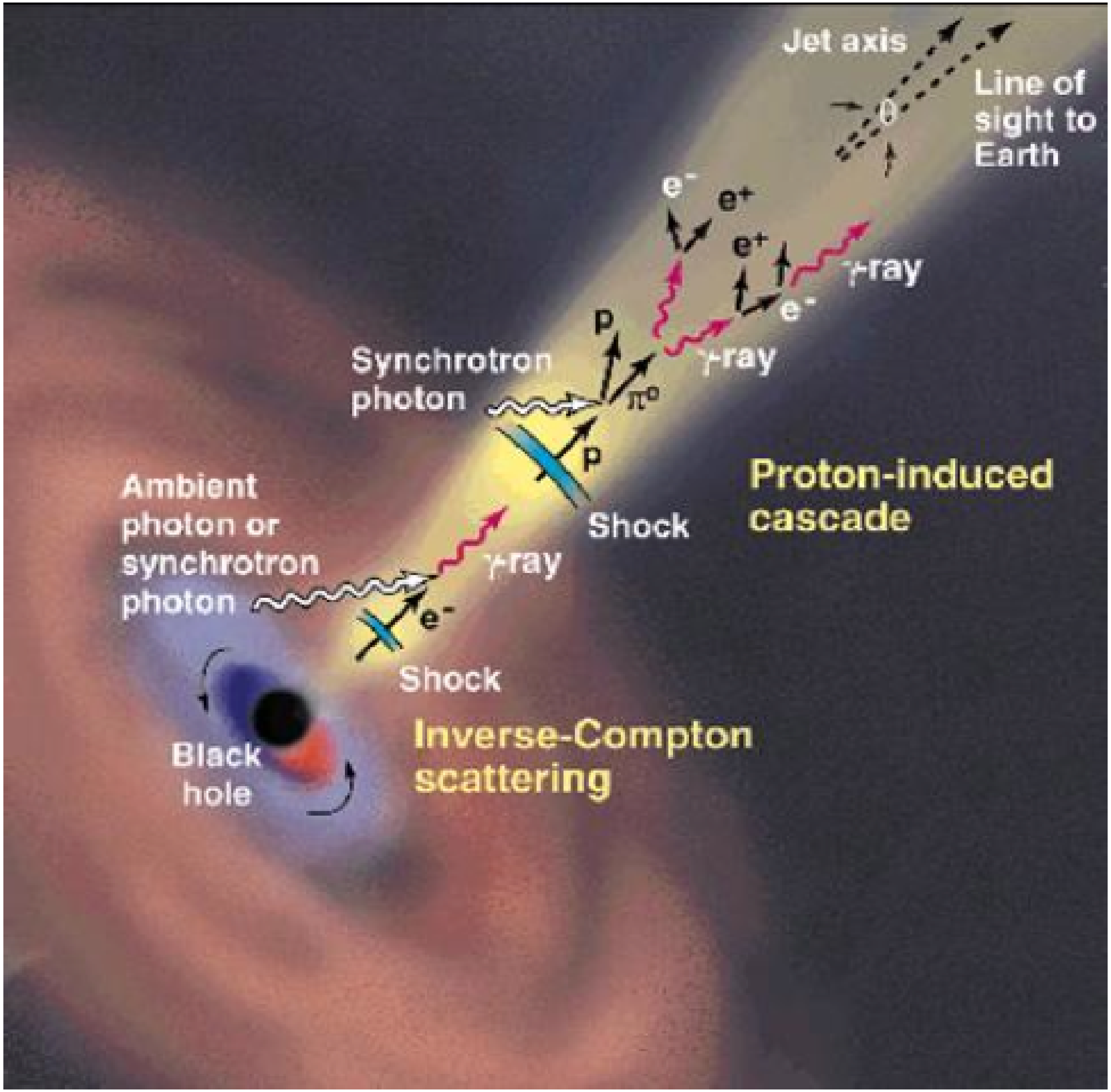


Figure: Cascade model (Mannheim 1993)

Current members

current members (i.e. signatories of the demand to the GDR-PCHE)

Allard, Denis ; APC ; researcher (Auger)
Baret, Bruny ; APC ; postdoc (Antares/KM3NeT)
Becherini, Yvonne ; APC ; postdoc (HESS/CTA, Antares)
Boisson, Catherine ; LUTh ; researcher (HESS/CTA)
Brown, Anthony ; CPPM ; postdoc (Antares/KM3NeT)
Coyle, Paschal ; CPPM ; researcher (Antares/KM3NeT)
Decerprit, Guillaume ; APC ; Ph.D. student (Auger)
Dornic, Damien ; CPPM ; postdoc (Antares/KM3NeT)
Halladjian, Garabed ; CPPM ; Ph.D. student (Antares/KM3NeT)
Kouchner, Antoine ; APC ; lecturer/researcher (Antares/KM3NeT)
Lenain, Jean-Philippe ; LUTh ; Ph.D. student (HESS/CTA)
Medina, Clementina ; LUTh ; postdoc (HESS/CTA , Auger)
Parizot, Etienne ; APC ; lecturer/researcher (Auger)
Pita, Santiago ; APC ; researcher (HESS/CTA)
Romero, Gustavo E. ; Universidad Nacional de La Plata (Argentinia) ; researcher (IAR - CONICET)
Ruppel, Jens ; Ruhr-Universität Bochum (Allemagne) ; Ph.D. student (HESS)
Sol, Hélène ; LUTh ; researcher (HESS/CTA)
VanElewyck, Véronique ; APC ; lecturer/researcher (Antares/KM3NeT)
Venter, Louis ; LUTh ; postdoc (HESS/CTA)
Vila, Gabriela S. ; Universidad Nacional de La Plata (Argentinia) ; Ph.D. student (IAR - CONICET)
Zech, Andreas ; LUTh ; enseignant-chercheur (HESS/CTA)

the working group is obviously open to any interested scientist !!!

current "associates" (i.e. on our mailing list, but not signatories of the first demand)

Renaud Belmont, Arache Djannati-Ataï, Corinne Donzaud, Guillaume Dubus, Thomas Eberl, Xavier Garrido, Lucie Gérard, Noémie Globus, Gilles Henri, Ira Jung, Alexander Kappes, Kumiko Kotera, Paolo Lipari, Alexandre Marcowith, Delphine Monnier, Fabrice Mottez, Michael Punch, Anita Reimer, Bronislaw Rudak, Michael Rueger, Felix Spanier, Lukasz Stawarz

(very incomplete) Summary of the first meeting

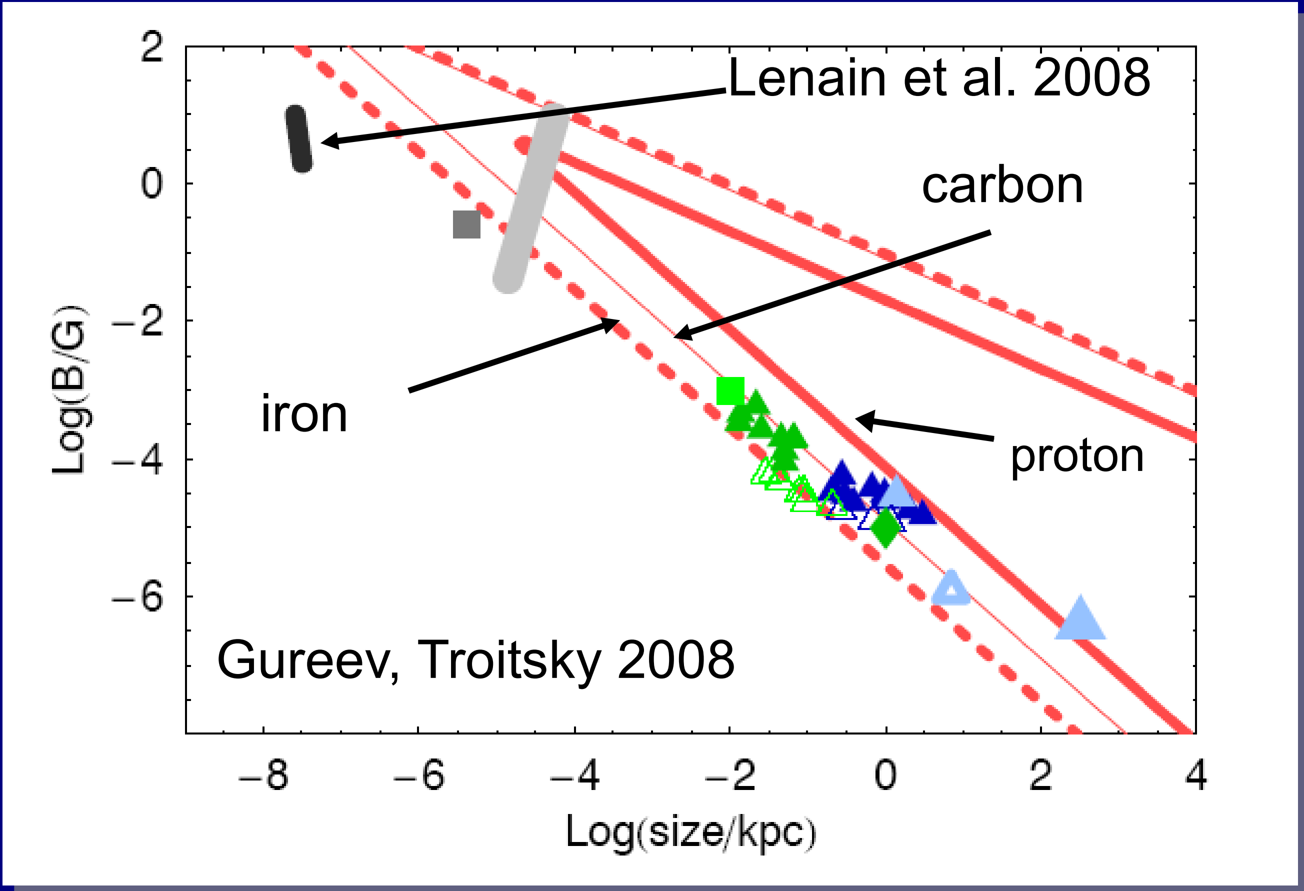
Introduction

AGN, Massive Black Holes, Accretion and Ejection (S. Collin)

In FRI radio-galaxies, pc-jets can be as powerful as kpc jets ! Example: Centaurus A

Evans et al. 2004

Component	1 keV X-Ray Flux Density (μJy)	Radio Flux Density (Jy) (frequency)
Kiloparsec-scale jet..............................	0.22 ± 0.01	0.74 ± 0.12 (8.4 GHz)
Second power law/parsec-scale jet.......	3.31	5 (4.8 GHz)



"Hillas diagram" for Cen A for acceleration to 7x10^19 eV

S. Collin

Experimental Status, Results & Interpretation

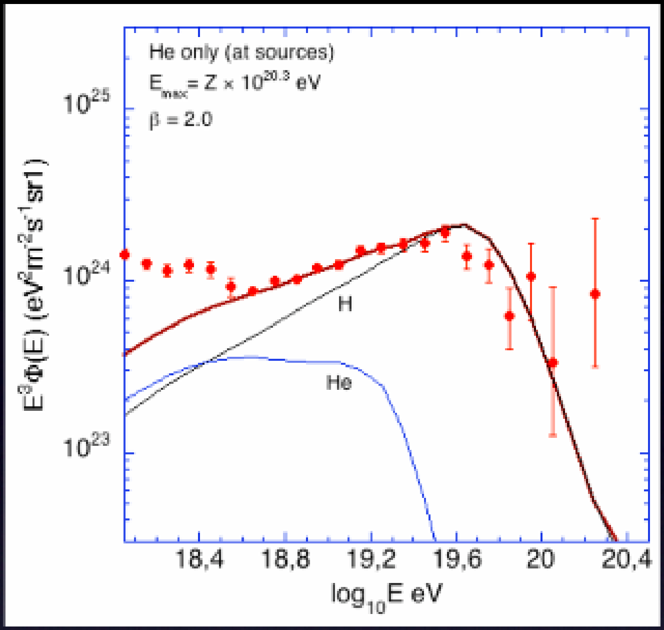
- *Summary on AGN observations at very high energies* (L. Gérard)
- *Status of the CTA design study* (C. Medina)
- *The AGN science case for CTA* (H. Sol)

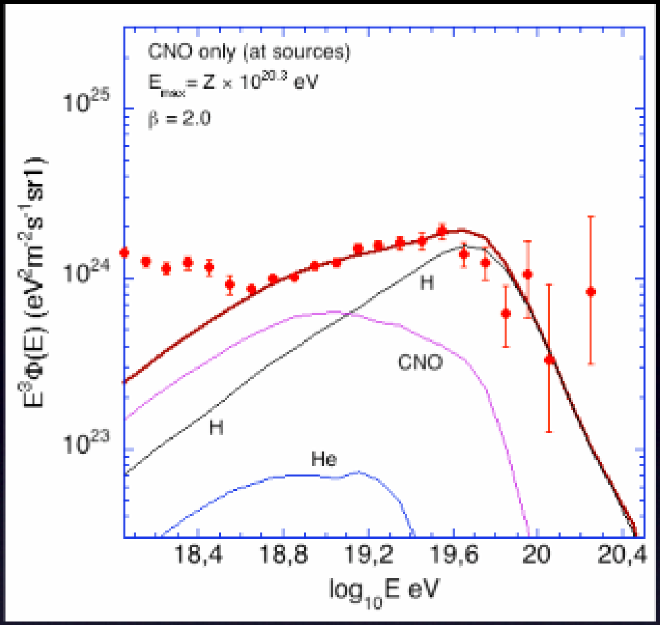
- Auger Results & *Interpretation of the existing data on UHECR composition* (D. Allard)

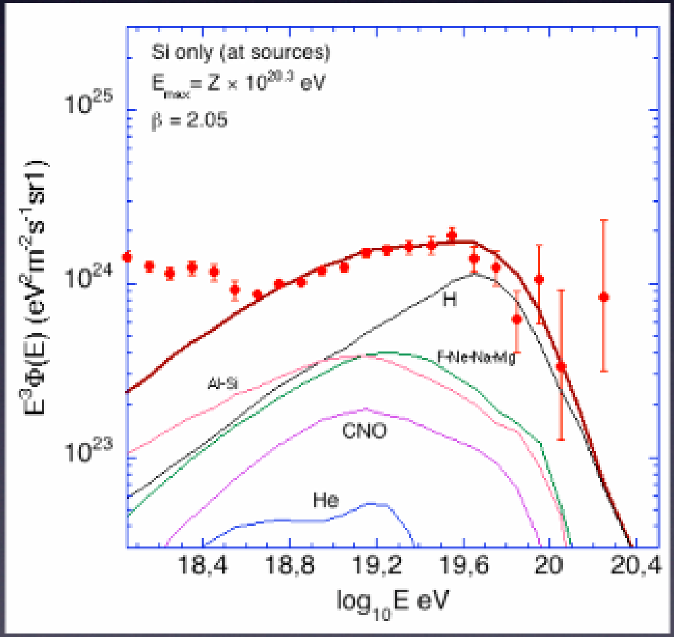
- *The status of astro-neutrino experiments* (D. Dornic)
- *Estimation of the neutrino spectrum from AGNs using the measured VHE gamma-ray spectrum* (G. Halladjian)

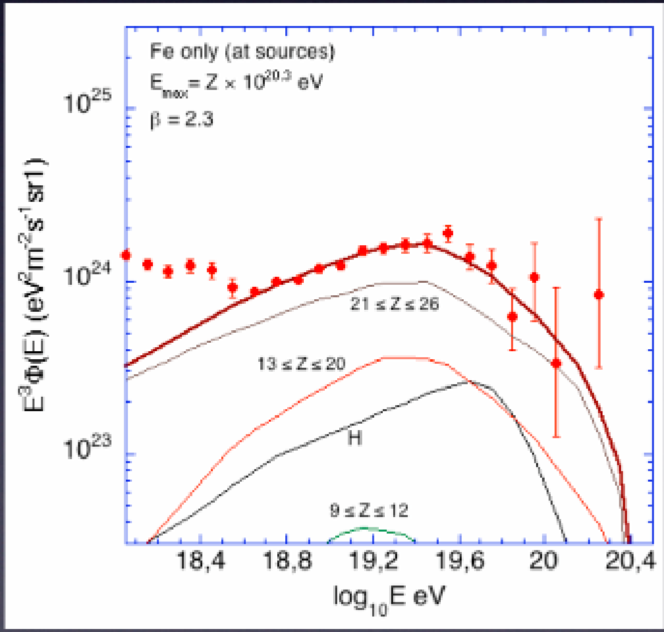
Ultra High Energy cosmic rays

Pure nuclei spectra







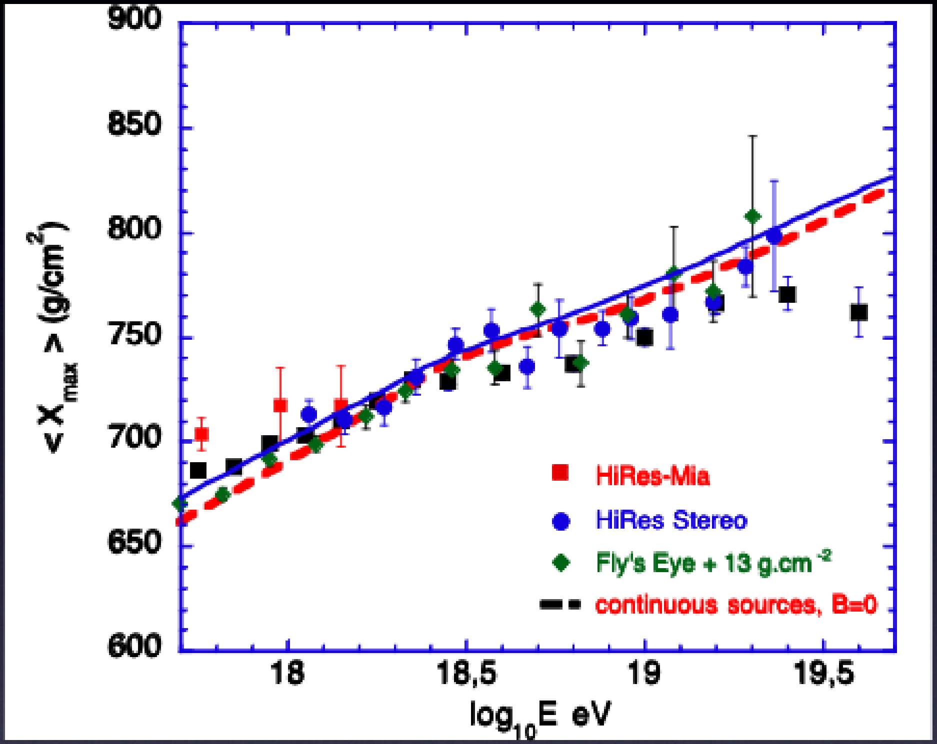


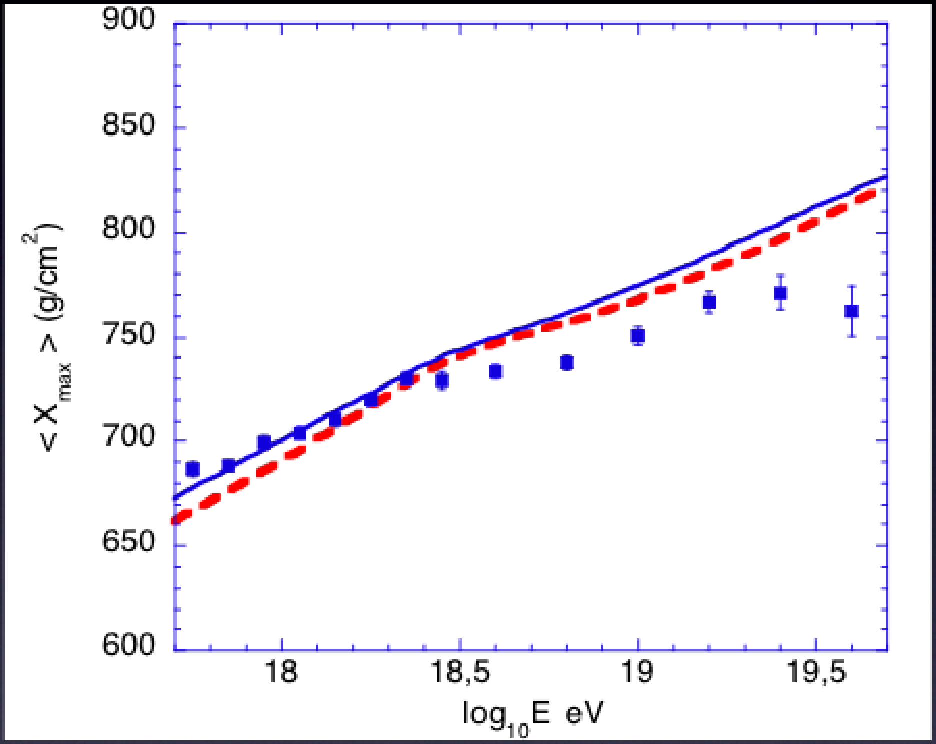
one can fit Auger spectrum with any source composition

at the highest energies the composition should either proton or heavy nuclei

D. Allard

Adding Auger data... It does not work anymore



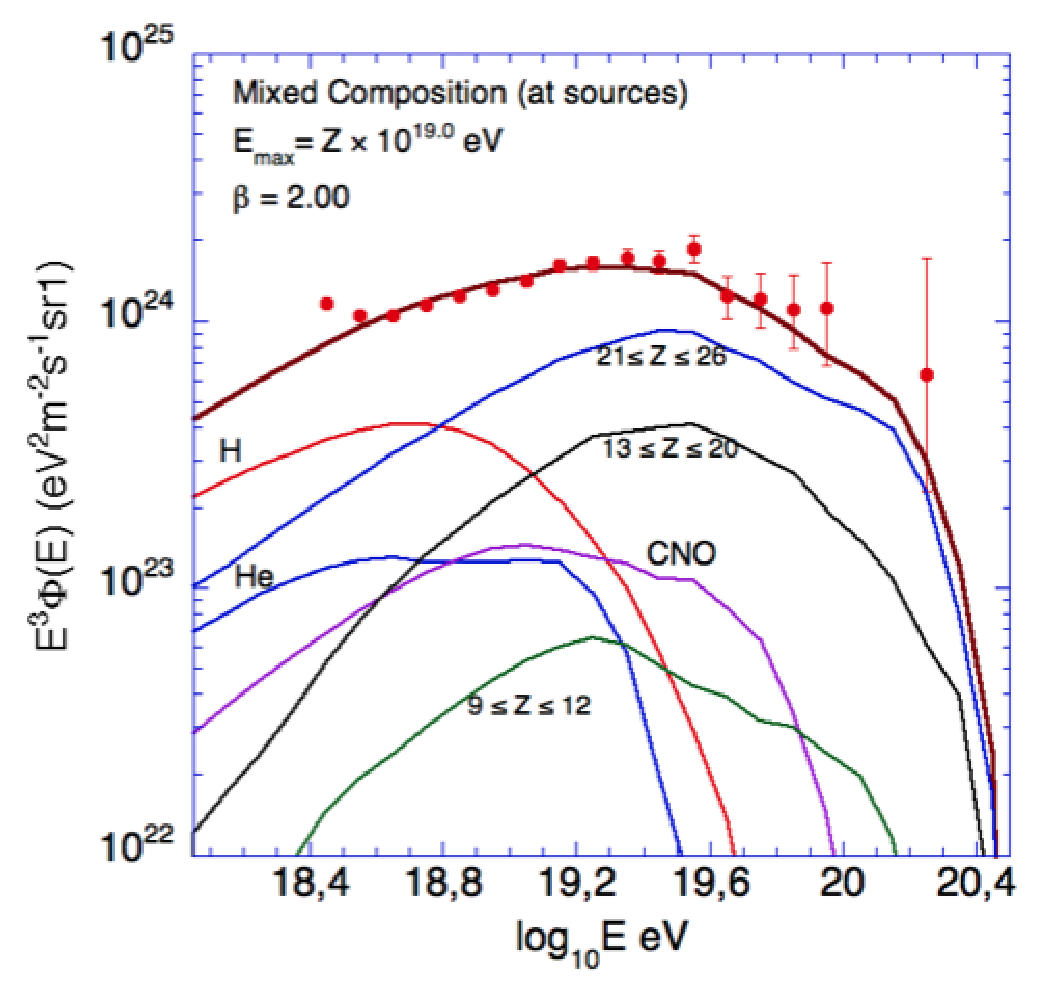


Break in the evolution compatible with the energy of the ankle
(very difficult to handle for pure proton models)
But the composition seems to get heavier at the highest energies
Latest Auger data seem to confirm this trend

D. Allard

What could it be?

Mixed composition but with a low Emax for protons?

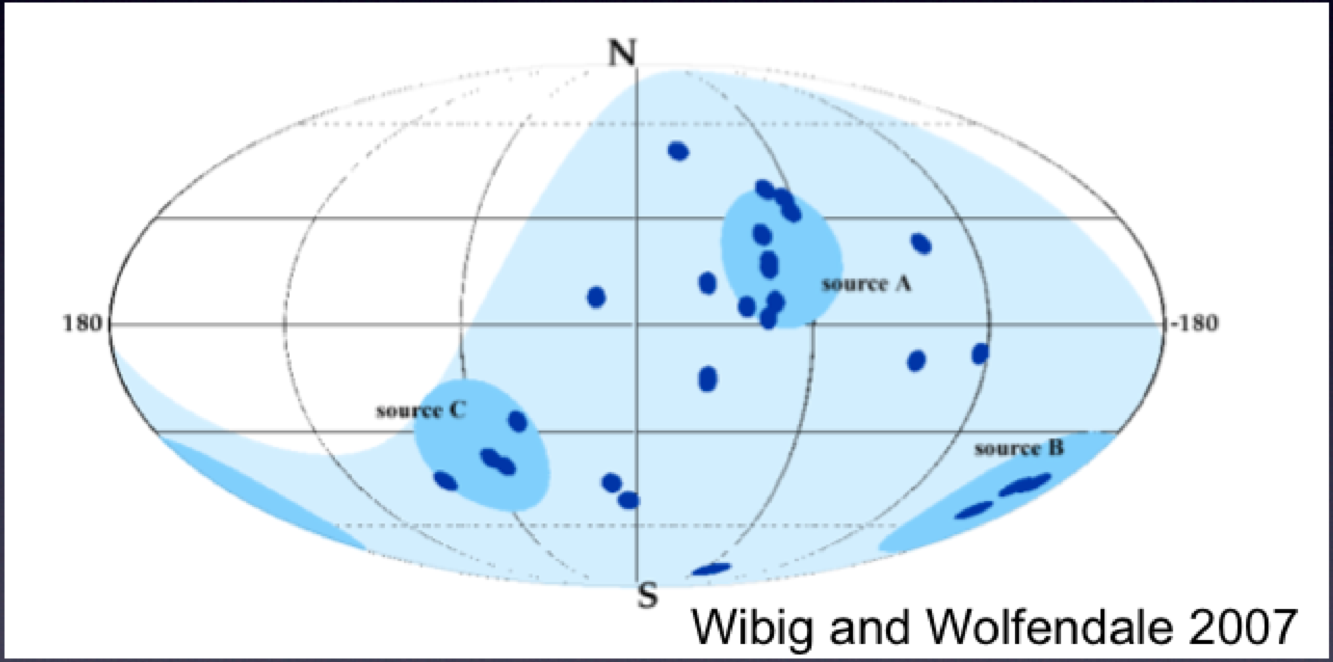


Fits well but requires more iron than the typical Galactic composition
quite light at the ankle, heavy at the highest energies

D. Allard

Does a composition getting heavy contradict Auger anisotropy result?

Not at the current level of statistics : Anisotropy depends on the source density, the magnetic fields and the composition. An anisotropic sky does not imply protons (neither do protons imply anisotropy).
Significant small scale clustering would be difficult to handle but is not seen so far

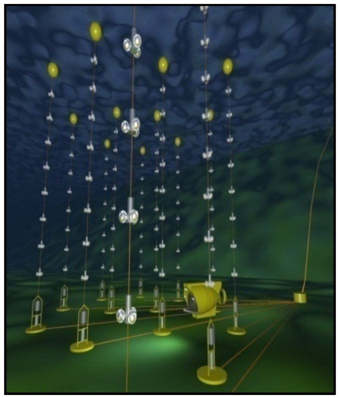


Wibig and Wolfendale 2007 : a few dominant sources of heavy nuclei reproduce most of the correlation

D. Allard

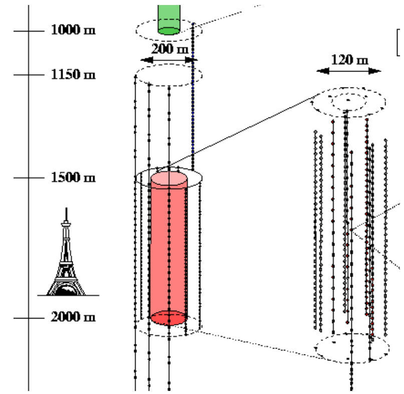
High Energy neutrinos

ANTARES



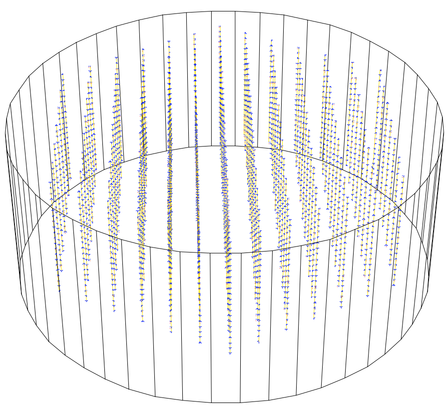
Complete June 2008

AMANDA

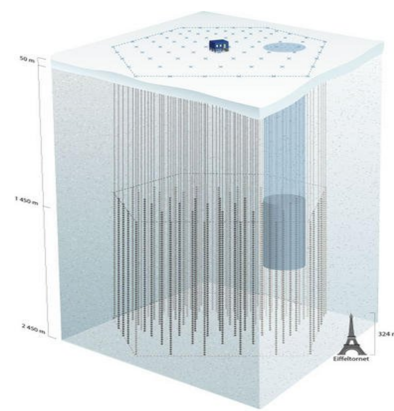


2000- 2007

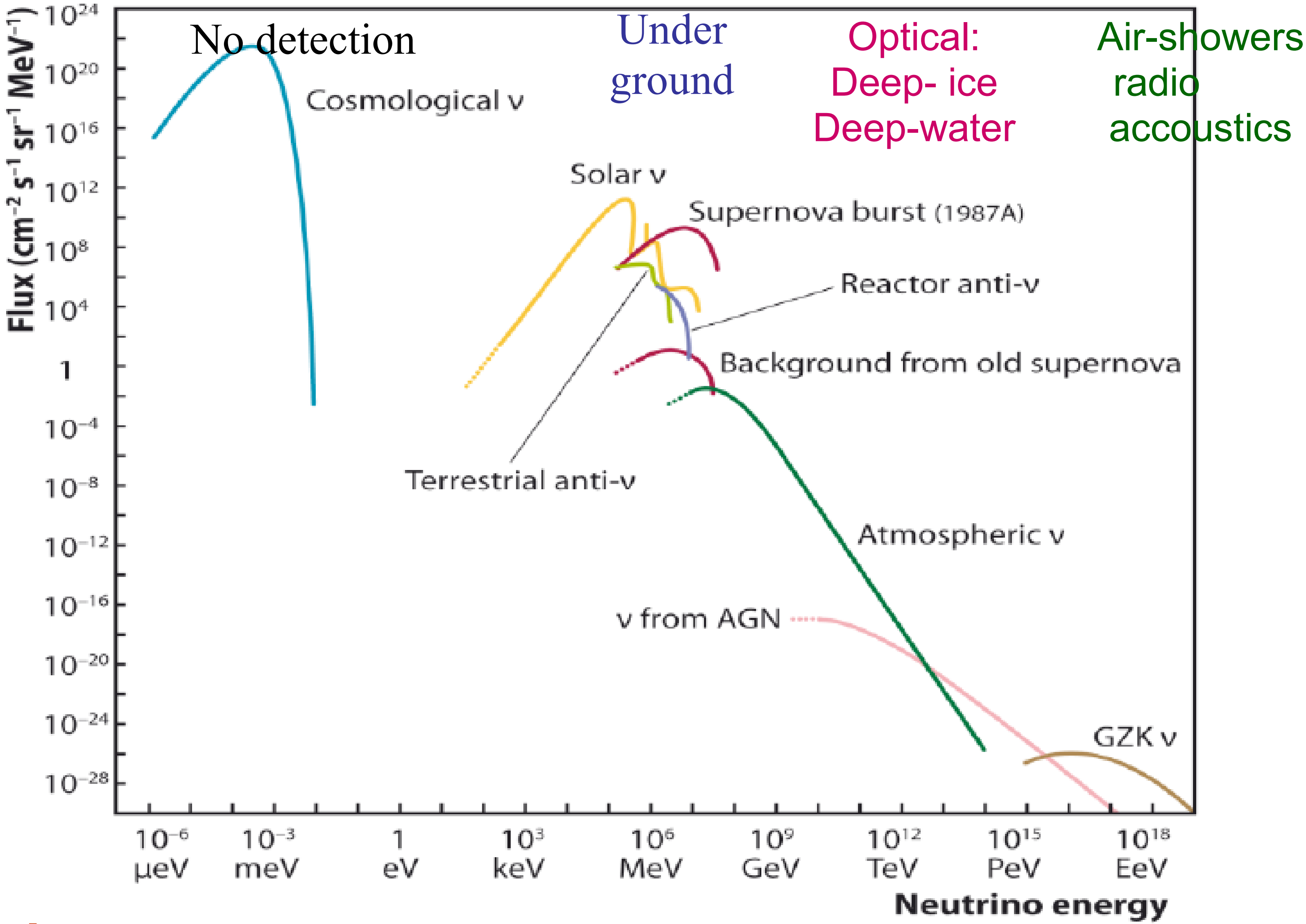
KM3NeT



IceCube



Neutrino - astronomy



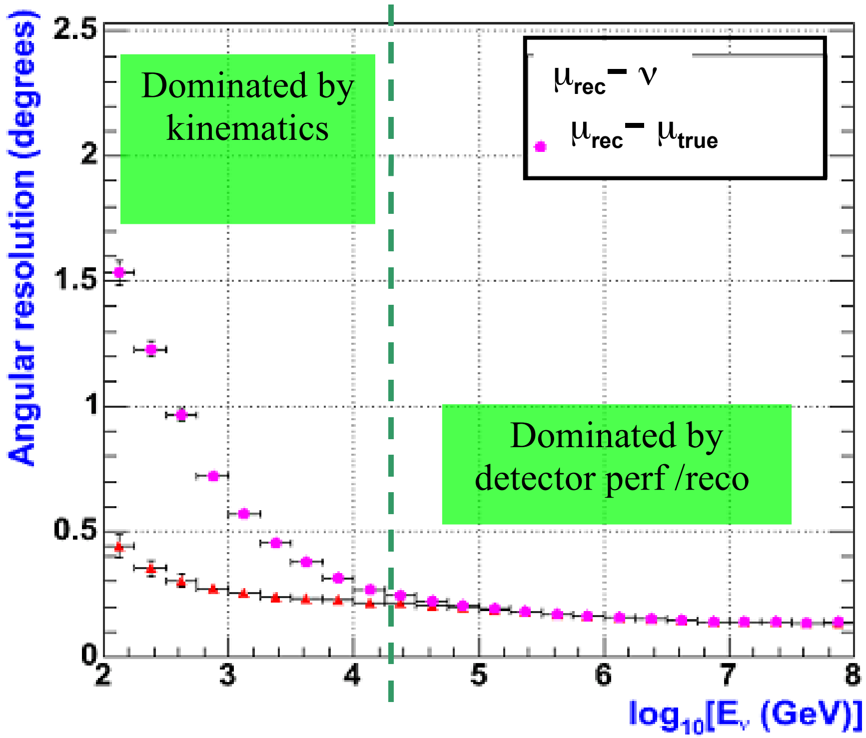
Detection volume (m^3)

10^3 - 10^4 10^7 - 10^9 10^{11} →

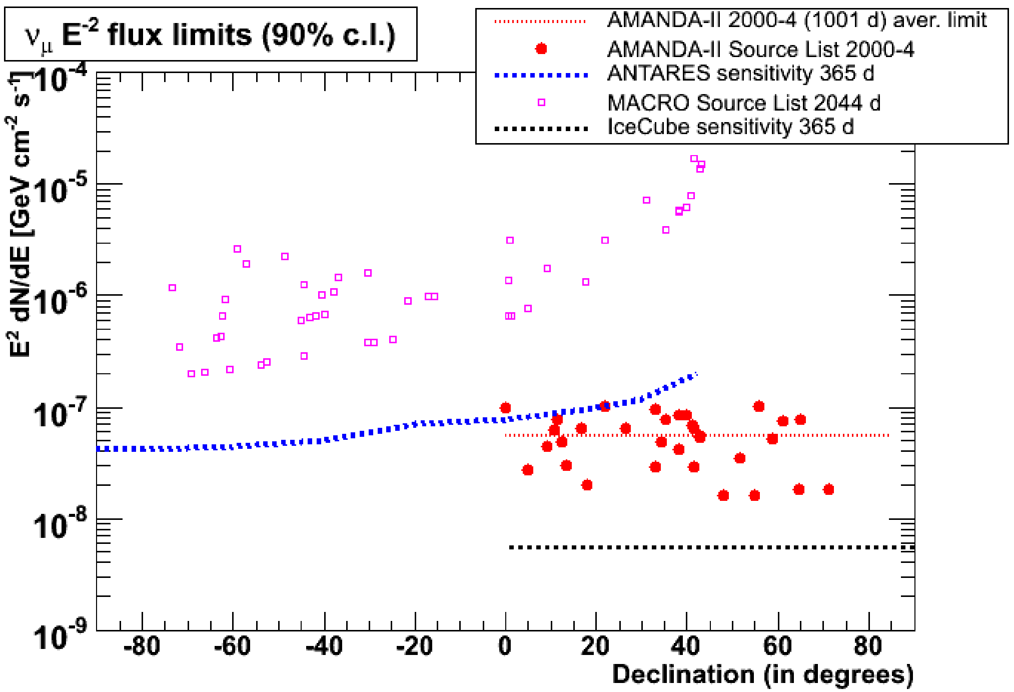
ANTARES Results

Expected performances for the 12 line detector

Angular resolution



Expected sensitivity



Expected angular resolution better than 0.3° above a few TeV

~ 8 better resolution (~ 60 better sensitivity)

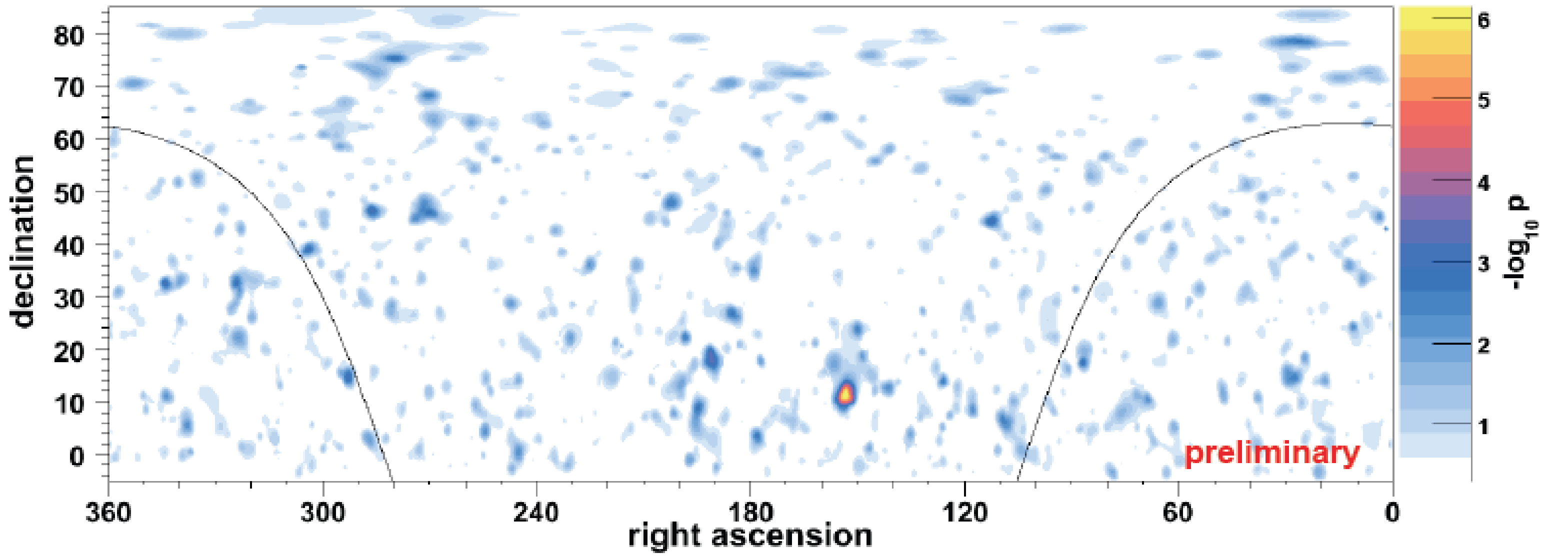
IceCube results (IC22)

Point-source study

Upper limit: $1.3 \times 10^{-11} E_\nu^{-2} TeV^{-1}.cm^{-2}.s^{-1}.sr^{-1}$

> Factor 2 improvement compared to AMANDA

Sky map:



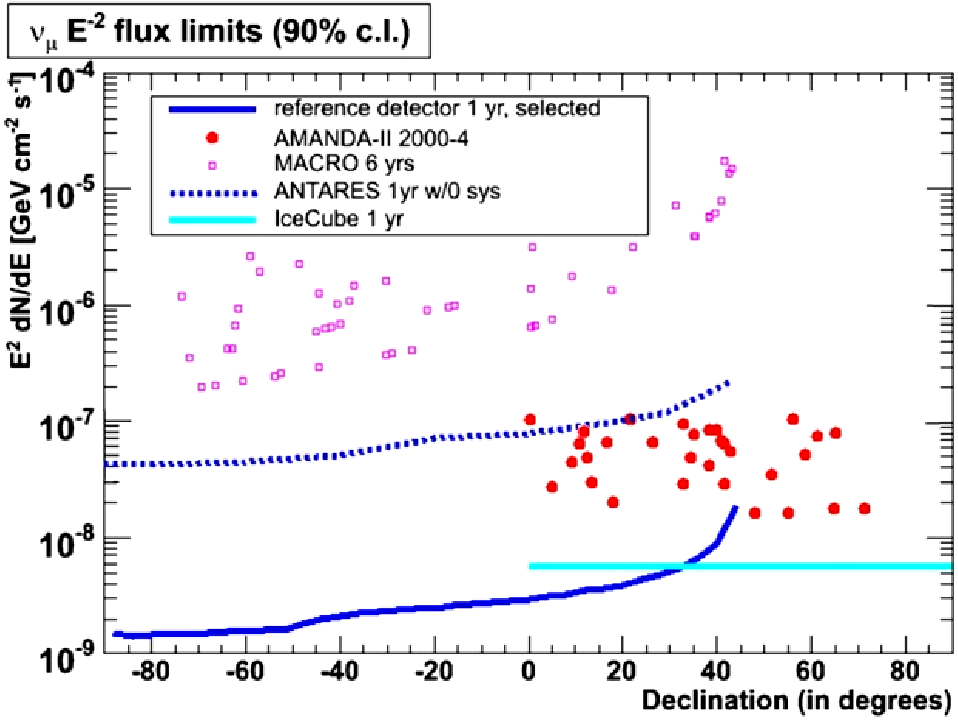
- Unbinned likelihood method using energy information
- Hottest spot found at r.a. 153º , dec. 11º
- pre-trial p-value: 7×10^{-7} (4.8 sigma)
- Accounting for all trials, p-value for analysis is 1.34% (2.2 sigma).
- At this significance level, consistent with fluctuation of background.

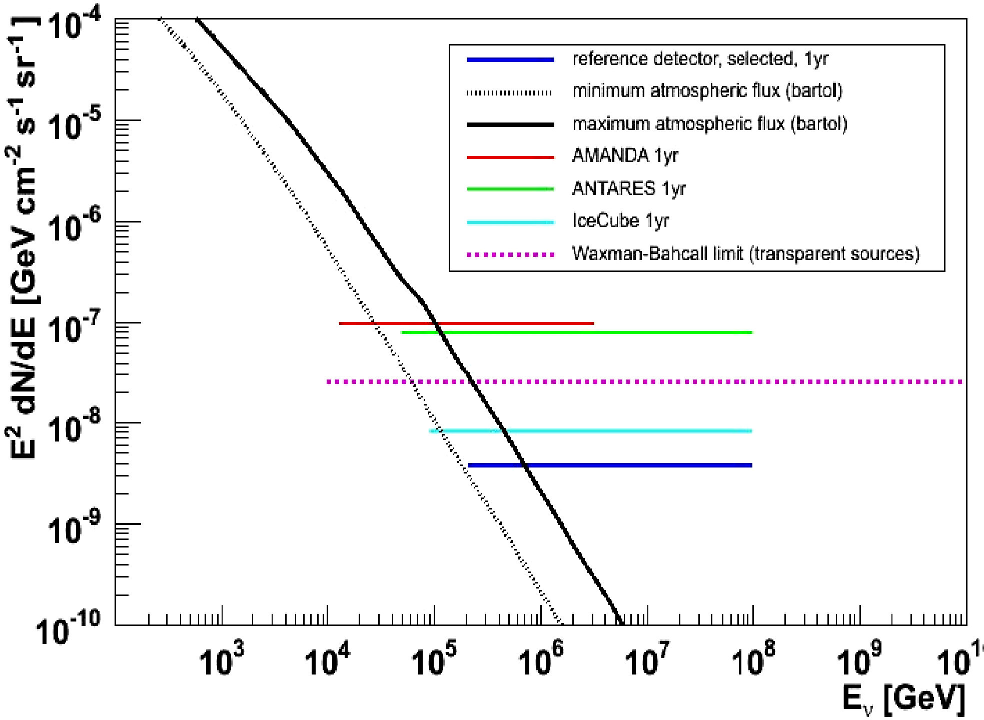
KM3NeT: expected performances

Based only on muon neutrino ν_μ detection generated with a E^{-2} spectrum

Point source

Diffuse





8.1×10^{-9} E^2 GeV cm^{-2} s^{-1} sr^{-1}

3.8×10^{-9} E^2 GeV cm^{-2} s^{-1} sr^{-1}

~ 50 more sensitive than ANTARES

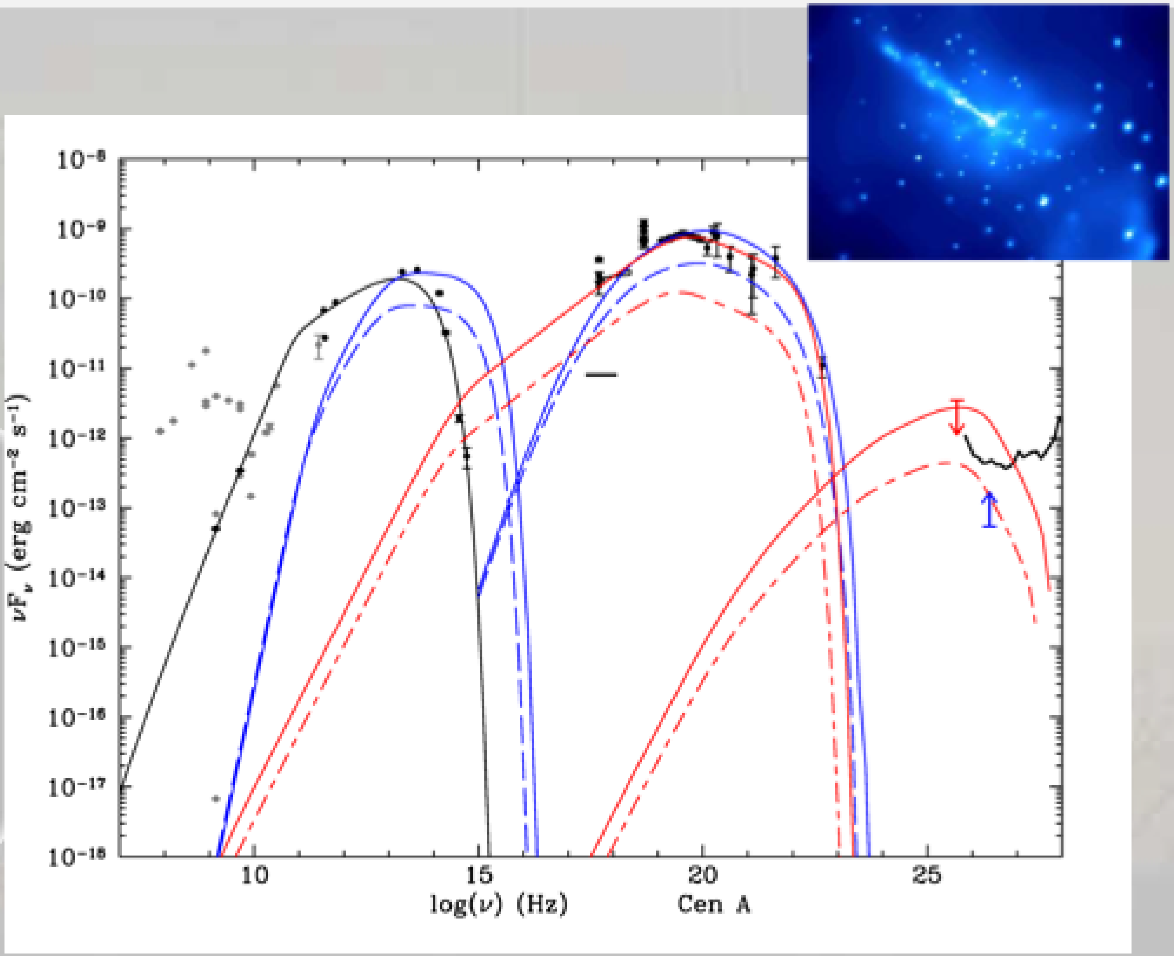
~ 3 more sensitive than IceCube (better photocathode area and better angular resolution)

Emission models & related subjects

- *Leptonic jet models for VHE AGN (J.-P. Lenain)*
- *Hadronic emission models* (F. Spanier)
- *High-energy processes at the base of magnetized, baryon loaded jets* (G. E. Romero)
- *Secondary content of the high energy cosmic ray electron spectrum* (J. Ruppel)
- *Thermal and non-thermal coronae of accreting black-holes* (R. Belmont)

Prediction on the nuclear flux expected from Cen A with the multi-blob SSC model

- Nature of the X/soft γ emission not yet clear:
  synchrotron or inverse Compton ?
- If X=synchrotron (cf. Bai & Lee, 2001) then Cen A should be detectable by the current Čerenkov facilities at 5σ within 50 h.

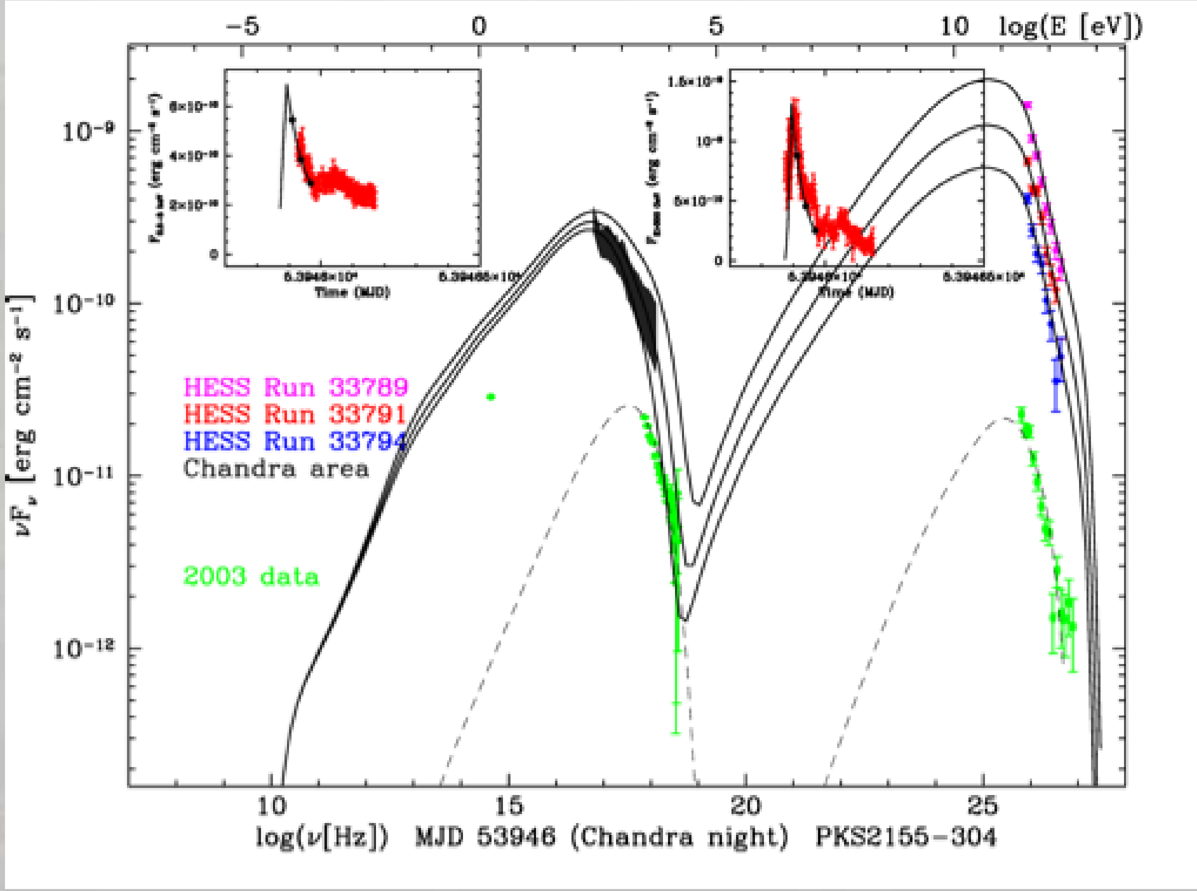


Lenain, Boisson, Sol, Katarzyński, 2008, A&A, 478, 111

PKS 2155–304 in July 2006: dynamic SSC modelling

$\delta = 50$
$B_{\text{blob}} \sim 30\,\text{mG}$
$B_{\text{blob}}/B_{\text{jet}} \sim 3$
$K_{\text{blob}} \sim 10^7\,\text{cm}^{-3}$
$K_{\text{blob}}/K_{\text{jet}} \sim 4 \times 10^3$
$n_{\text{blob}} = 2.45$, $\gamma_{\text{blob}}^{\text{min}} = 10^3$,
$\gamma_{\text{blob}}^{\text{max}} = 7.4 \times 10^5$

Launch dynamic spectrum
(click)



Snapshots of the dynamic MWL SED.

Classes of models

Three basic models

Proton-Synchrotron

Photo-Hadron

Proton-Proton

Photo-Hadron interaction

Principal interactions

π^0 cascade

$p + \gamma \rightarrow p + \pi^0$

$\pi^\pm$ cascade

$p + \gamma \rightarrow n + \pi^+$

Bethe-Heitler process

$p + \gamma \rightarrow p + e^+ + e^-$

p-p-Interactions

Principal interactions

$$
\begin{aligned}
p + p &\rightarrow p + p + a(\pi^+ + \pi^-) + b\pi^0 \\
p + p &\rightarrow p + n + \pi^+ + a(\pi^+ + \pi^-) + b\pi^0 \\
p + p &\rightarrow n + n + 2\pi^+ + a(\pi^+ + \pi^-) + b\pi^0
\end{aligned}
$$

Felix Spanier

Proton-Initiated Cascade

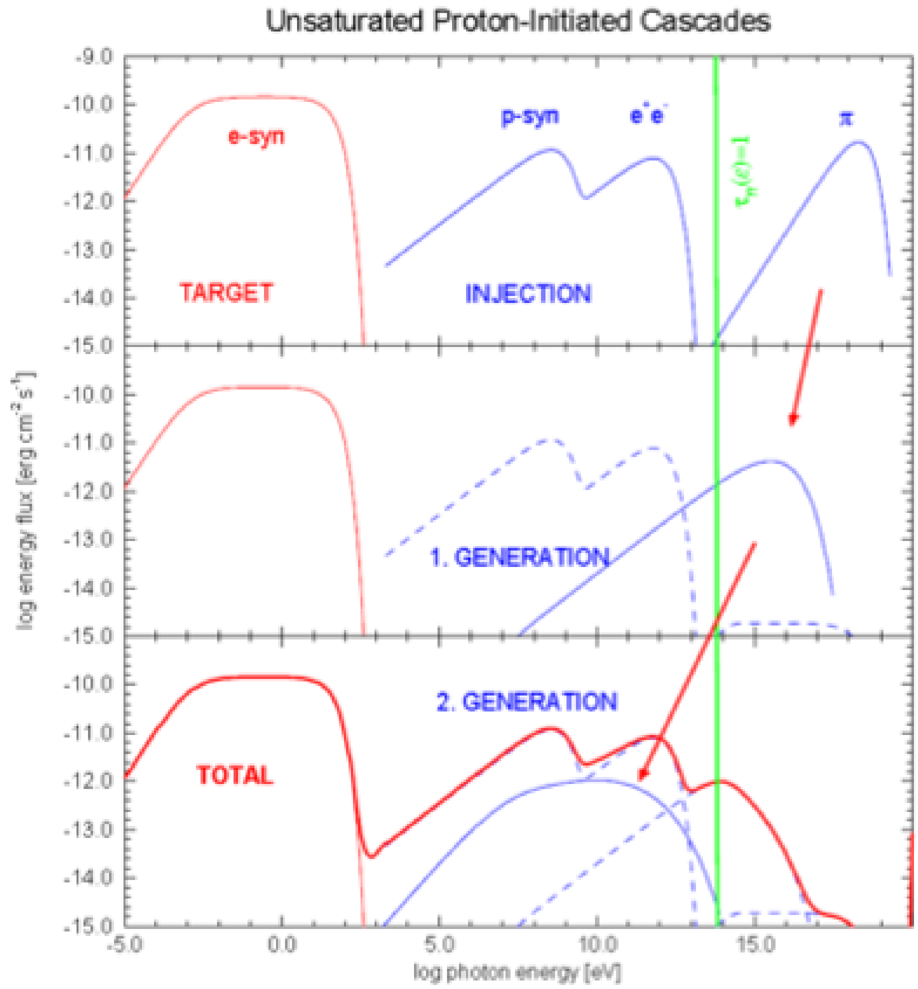


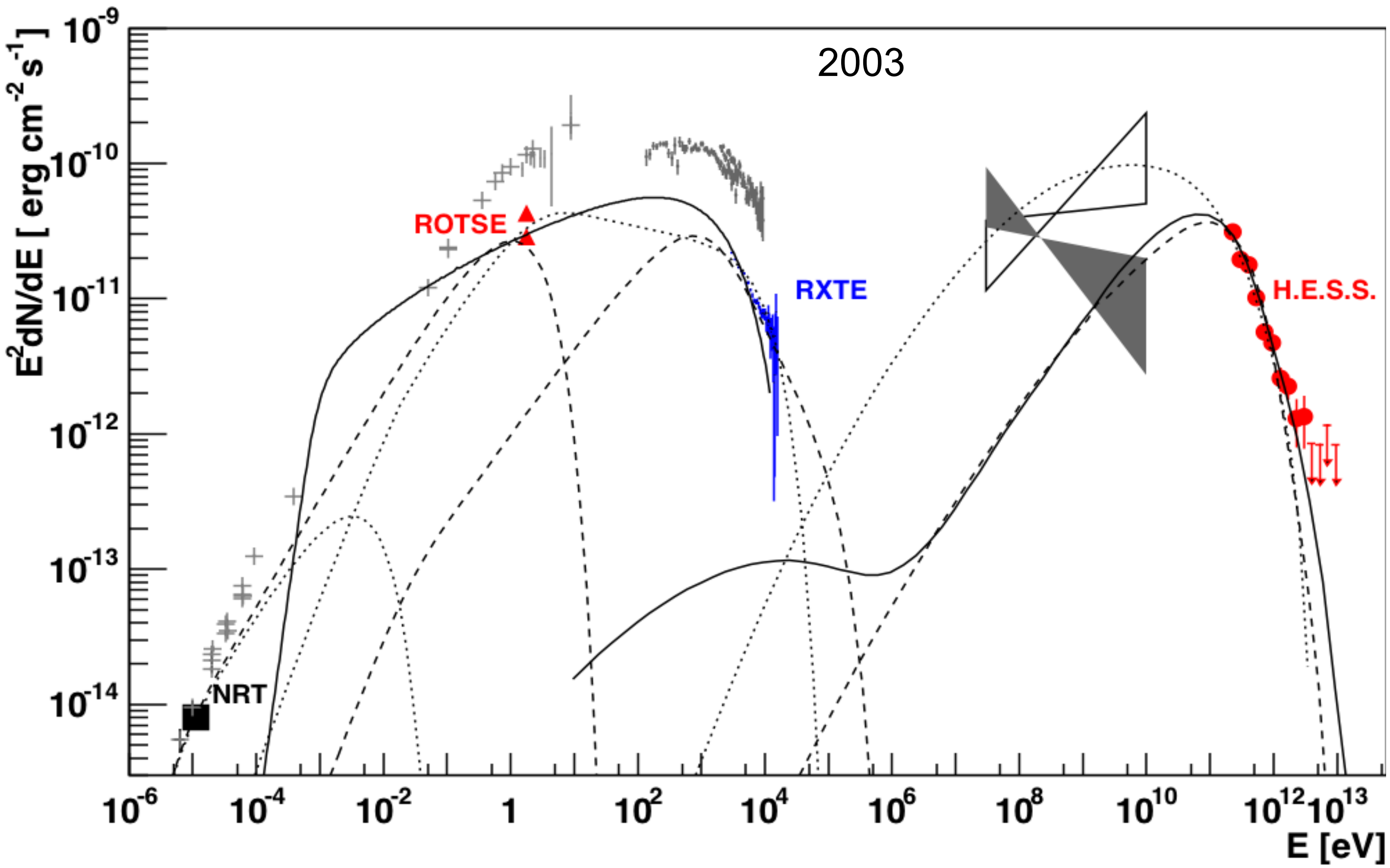
Figure: Sketch of the cascade (Mannheim 1995)

Proton-Synchrotron, Mücke

Alternative model

Different approach from Mücke& Protheroe (1999)

- Fully modeled cascade
- Co-acceleration of *e* and *p*
- includes *p*-, μ- and *e*-synchrotron
- includes neutrino-emission



Proton Synchrotron Blazar model (Mücke, Protheroe 2000, 2001) applied to the blazar PKS2155 observed in 2003 (Aharonian et al. 2005). (solid lines)

this scenario: Doppler factor ~ 20 , B ~ 40 G, e/p ratio 0.15

low-E peak: dominated by primary e-synchrotron (+ secondary e-synch. from p- and muon-synch. cascades)

high-E peak: dominated by p-synchrotron (+ muon-, pion-cascades)

What are jets made of?

- Relativistic electron-positron plasma?
- Relativistic electrons plus cold protons?
- Relativistic electron-proton plasma plus cold barionic flow?

In the case of MQs and YSOs there is evidence for the presence of hadrons in the outflow. There is also evidence for the couplng of the accretion power and the jet power.

G. E. Romero

Proton-dominated jet models (e.g. Romero & Vila, A&A 485, 623, 2008, also Romero & Vila, A&A, submitted)

Interaction of relativistic *p* and e^- with

- magnetic field
- matter fields
- radiation fields

in the jet

- Synchrotron radiation $$p,\ e^- + B \rightarrow p,\ e^- + \gamma$$
- Inverse Compton (IC) $$e^- + \gamma \rightarrow e^- + \gamma$$
- Proton-proton inelastic collisions $$p + p \rightarrow p + p + a\,\pi^0 + b(\pi^+ + \pi^-)$$
- Photohadronic interactions ($p\gamma$) $$p + \gamma \rightarrow p + e^+ + e^-$$

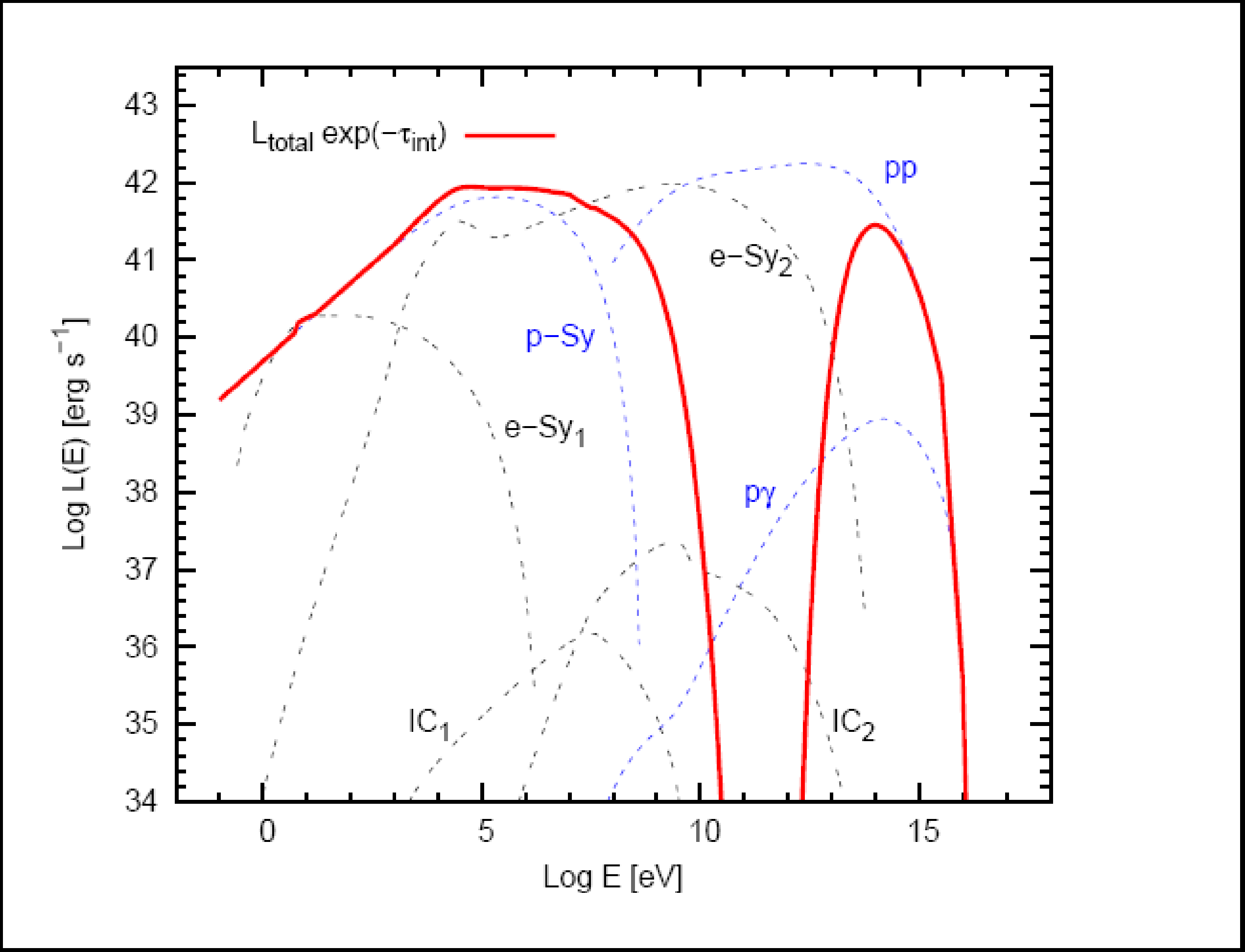
$$e^\pm + B \rightarrow e^\pm + \gamma$$

$$p + \gamma \rightarrow p + a\pi^o + b(\pi^+ + \pi^-) \qquad \pi^o \rightarrow 2\gamma$$

$$p + \gamma \rightarrow n + \pi^+ + a\pi^o + b(\pi^+ + \pi^-) \qquad \pi^\pm \rightarrow \mu^\pm + \nu_\mu\left(\bar{\nu}_\mu\right) \qquad \mu^\pm \rightarrow e^\pm + \nu_e(\bar{\nu}_e) + \bar{\nu}_\mu\left(\nu_\mu\right)$$

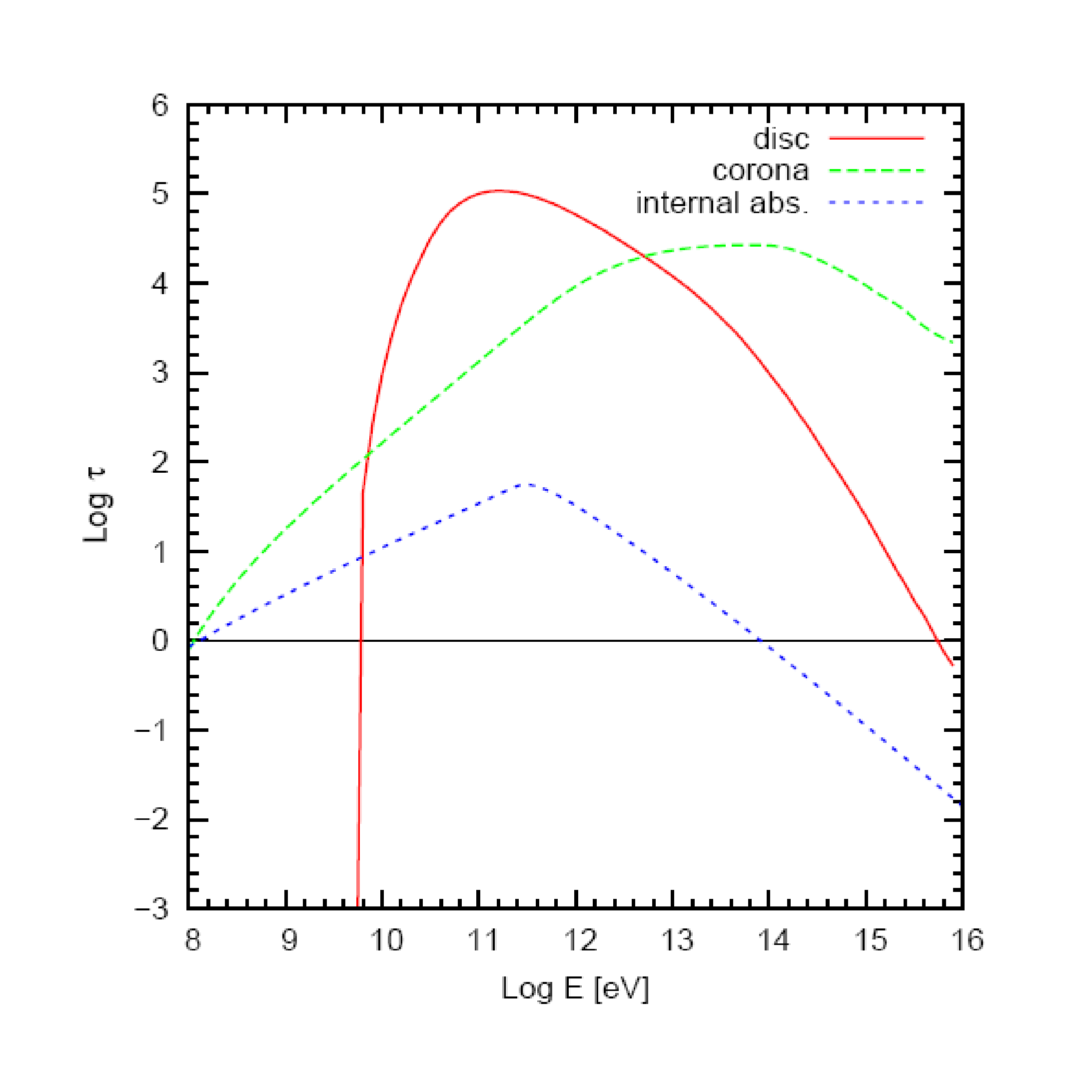
G. E. Romero

Application to extragalactic sources: Cen A



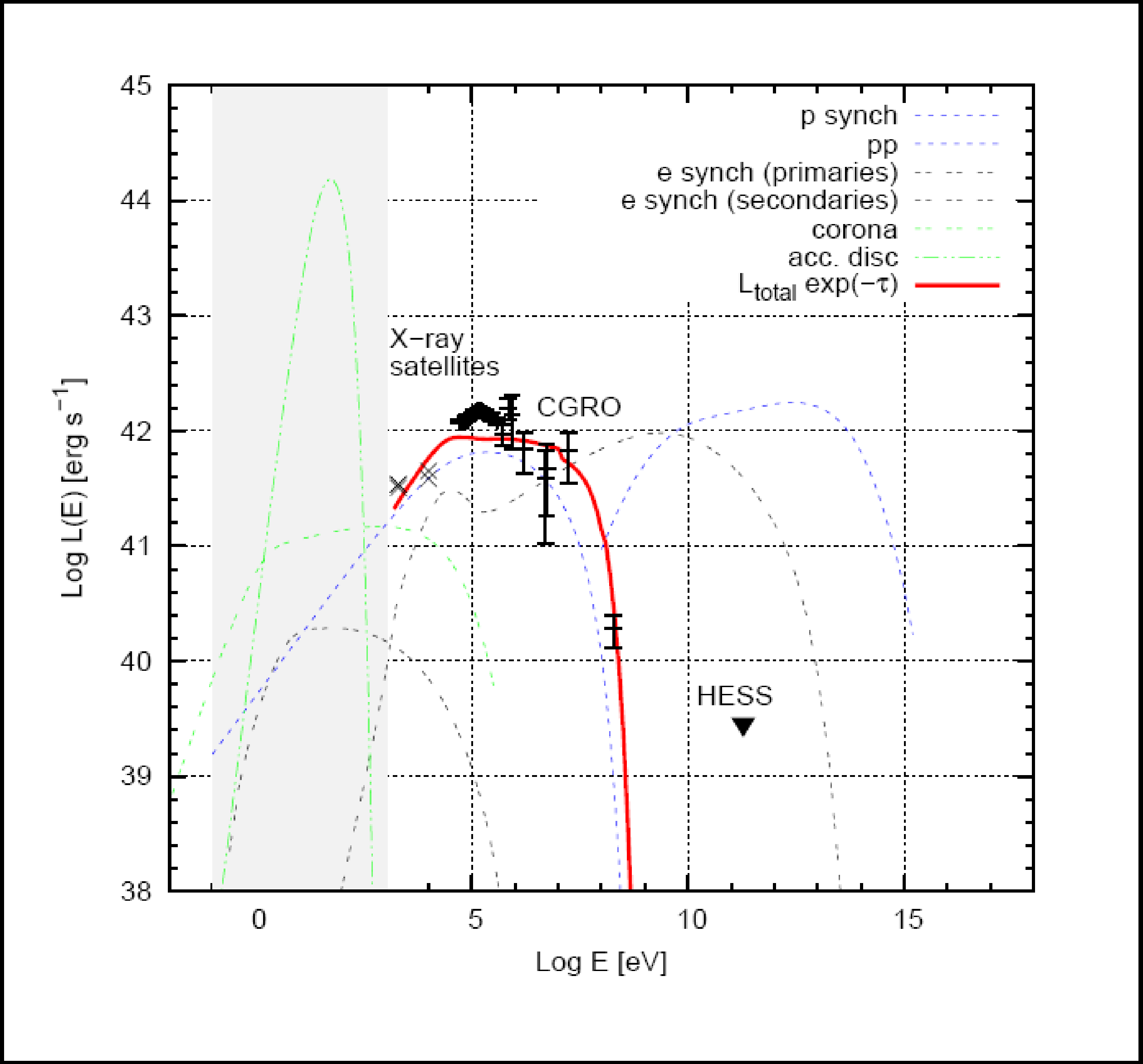
G. E. Romero

Application to extragalactic sources: Cen A



Orellana & Romero 2009

Application to extragalactic sources: Cen A



L_{jet}~10^{44} erg/s, B_0=10^4 G

Orellana & Romero 2009

Summary of the Summary

- hadronic models remain an option to explain AGN emission at high E
- Cen A "signal" in Auger data awaits confirmation
- better predictions for ν flux from AGN needed
- Development towards "lepto-hadronic" models
- some challenges for hadronic models:
  - how to explain rapid variability ?
  - how to create time dependent hadronic models ?
  - magnetic field strength in the emission region ?
    (Romero: ~10^4 G , others: 10^1 - 10^2 G)
- analogy with micro-quasars very useful - how far does it hold ?