

Hadronic emission models for AGN & the gamma ray/cosmic ray/neutrino connection

A report from the γ -CR- ν working group

Andreas Zech
for the γ -CR- ν working group

Meeting of the GdR-PCHE
July 2009

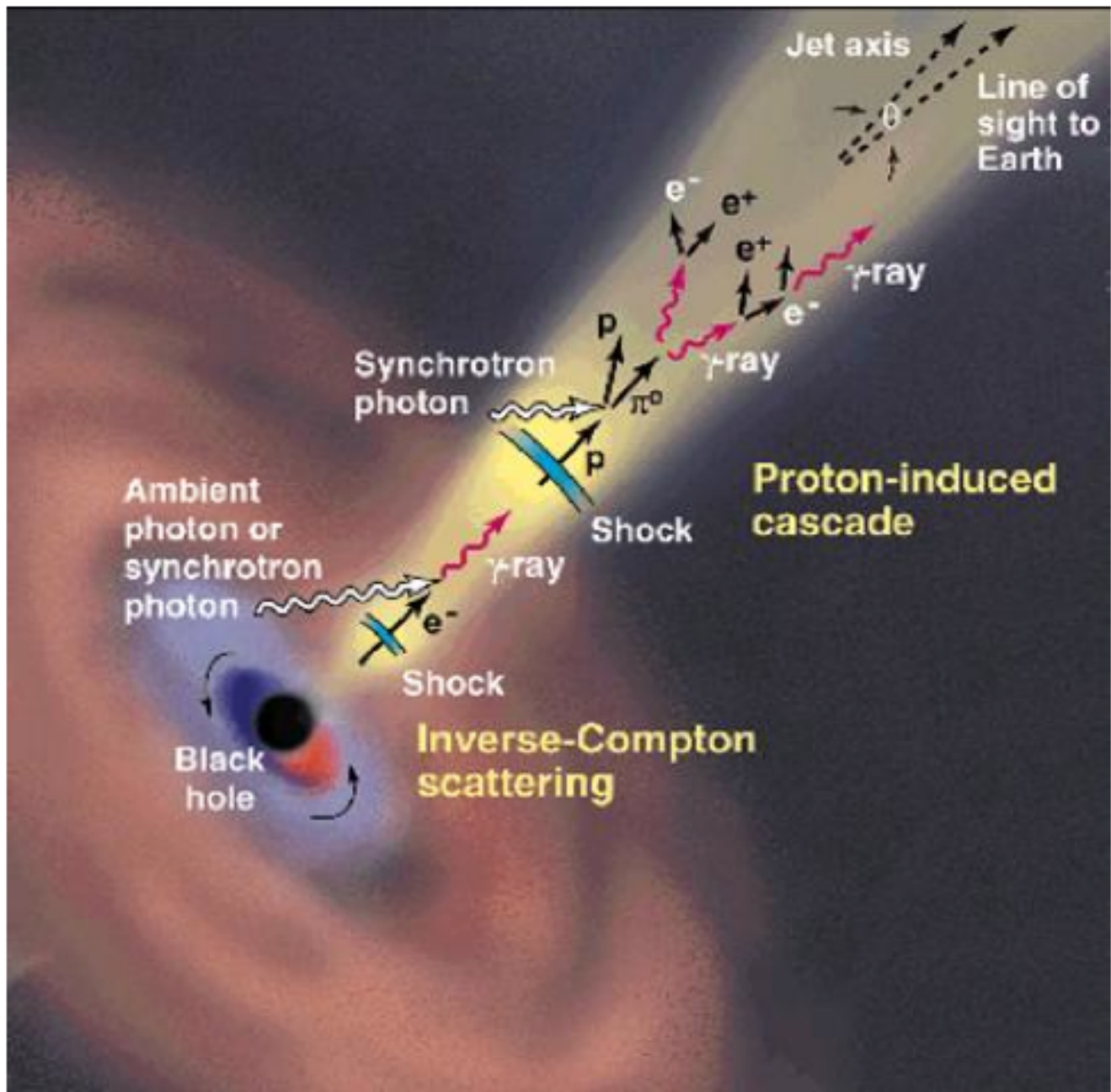


Figure: Cascade model (Mannheim 1993)

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

Scientific Objectives

- 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 model predictions.
- Making predictions for constraints to expect from future experiments (CTA, Auger North, JEM/EUSO, KM3NeT...).

Activities 08/09

First proposal to GDR-PCHE in summer 2008

=> funding to organise a first meeting in fall 2008

==> **First meeting** on December 9 at the OBSP with about 30 participants from LUTh, APC, CPPM, CESR, Universität Würzburg, Ruhr-Universität Bochum, Universidad Nacional de La Plata

==> Experts on hadronic models: G.E. Romero (U.N. de La Plata), F. Spanier (U. Würzburg)

==> Presentations on our website



<http://www.luth.obspm.fr/gammacrn>

other activities:

- visit of G.E. Romero (2008) and M. Reynoso (2009) at the LUTh
- visit of G. Halladjian at the Luth (2009)
- visit of C. Medina at U.N. de La Plata (2009)
- small meeting of group members to be held in Buenos Aires, during HEPRO II conference (October 2009)

Current members

current members (i.e. signatories of the proposals 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)
Reynoso, Matias ; Universidad Nacional de La Plata (Argentina) ; postdoc (IAR - CONICET)
Romero, Gustavo E. ; Universidad Nacional de La Plata (Argentina) ; 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 (Argentina) ; Ph.D. student (IAR - CONICET)
Zech, Andreas ; LUTh ; enseignant-chercheur (HESS/CTA)

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

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

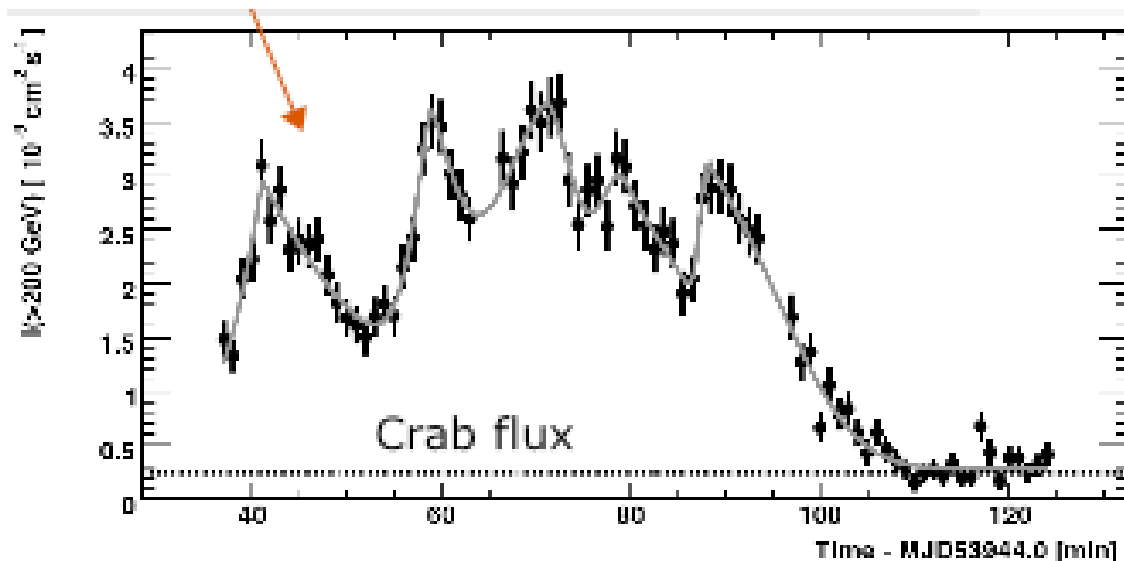
R. Belmont, A. Djannati-Ataï, C. Donzaud, G. Dubus, T. Eberl, X. Garrido, L. Gérard, N. Globus, G. Henri, I. Jung,
A. Kappes, K. Kotera, P. Lipari, A. Marcowith, D. Monnier, F. Mottez, M. Punch, A. Reimer, B. Rudak, M. Rueger,
F. Spanier, L. Stawarz

Summary of our first meeting in December '08

VHE γ -rays

AGN	z	Type
M87	0,004	FRI
Mkn 421	0,030	HBL
Mkn 501	0,034	HBL
1ES 2344+514	0,044	HBL
Mkn 180	0,046	HBL
1ES 1959+650	0,047	HBL
BL Lac	0,069	LBL
PKS 0548-322	0,069	HBL
PKS 2005-489	0,071	HBL
RGB J0152+017	0,080	HBL
W Comae	0,102	IBL
PKS 2155-304	0,116	HBL
H 1426+428	0,129	HBL
1ES 0806+524	0,138	HBL
1ES 0229+200	0,139	HBL
H 2356-309	0,165	HBL
1ES 1218+304	0,182	HBL
1ES 1101-232	0,186	HBL
1ES 0347-121	0,188	HBL
1ES 1011+496	0,212	HBL
PG 1553+113	>0.250	HBL
S5 0716+714	-0.300	HBL
3C 66A	-0.400	IBL
3C 279	0,536	FSRQ

PKS 2155-304 in 2006

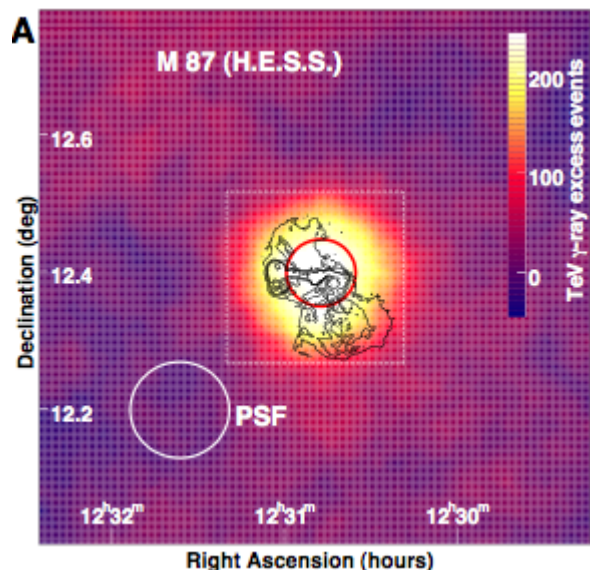


High variability and
broad band spectra
→ Require coordinated HE
and multi-lambda monitoring
to constrain SED and
evolution.

H. Sol

detected VHE-AGN
up to Dec. `08
(L. Gérard)

VHE γ -rays: M87



With M87, a new class of VHE γ -ray emitting AGN has been detected: radio galaxies

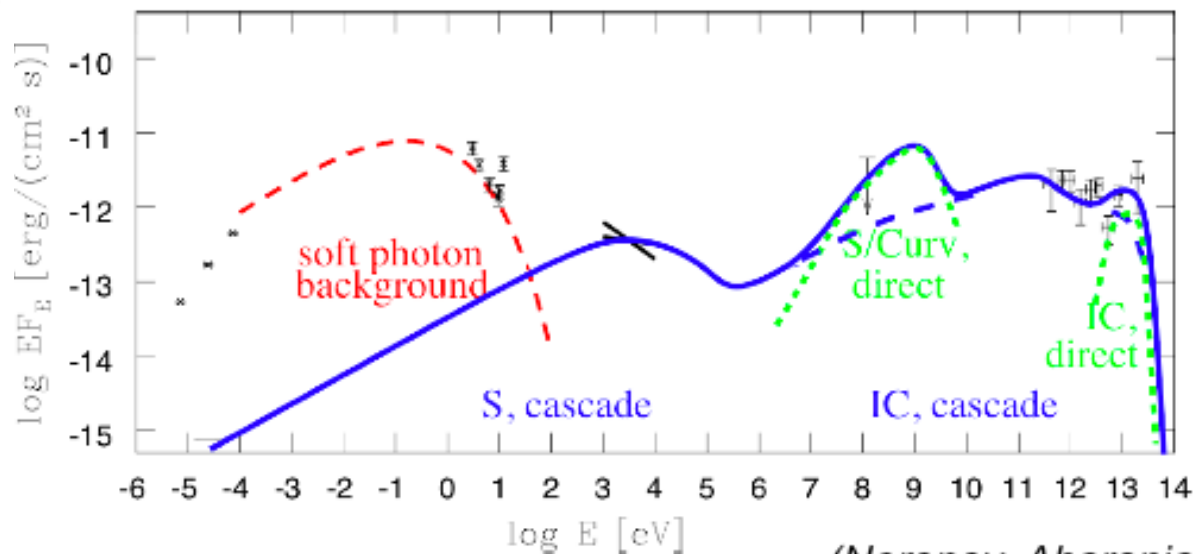
=> Recently confirmed by the discovery of TeV emission from **Centaurus A** by H.E.S.S.

=> Great discovery potential for *CTA*, with a factor 10 improvement in sensitivity (presentations C. Medina, H. Sol)

3 possible TeV emitting zones

- The peculiar knot HST-1 at ~ 65 pc from the nucleus
- The inner VLBI jet
- The central core and the black hole environment

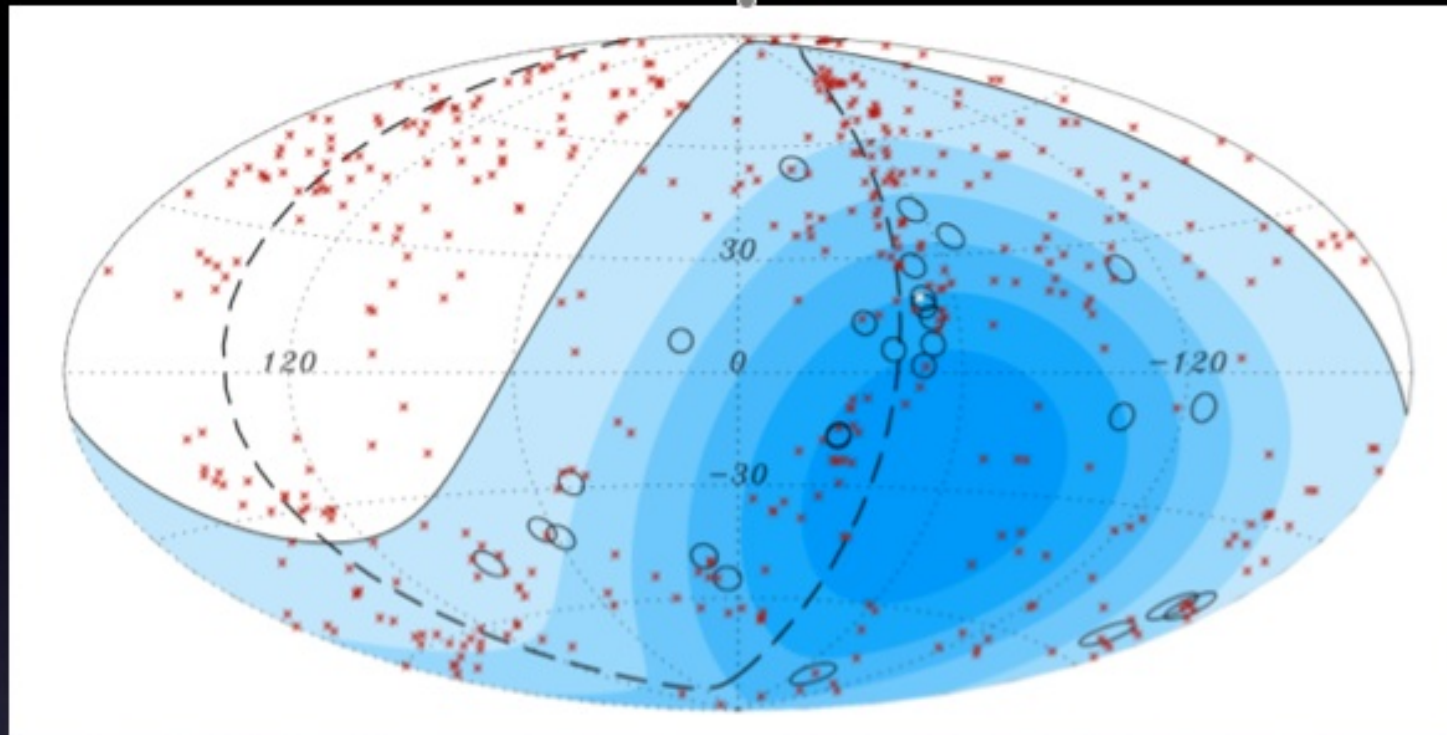
H. Sol



(Neronov, Aharonian, 2007)

Various core models developed for M87 suggest that radio-quiet or even « dormant » (but rotating) AGN could be VHE emitters.

UHECR: AGN correlation seen by Auger



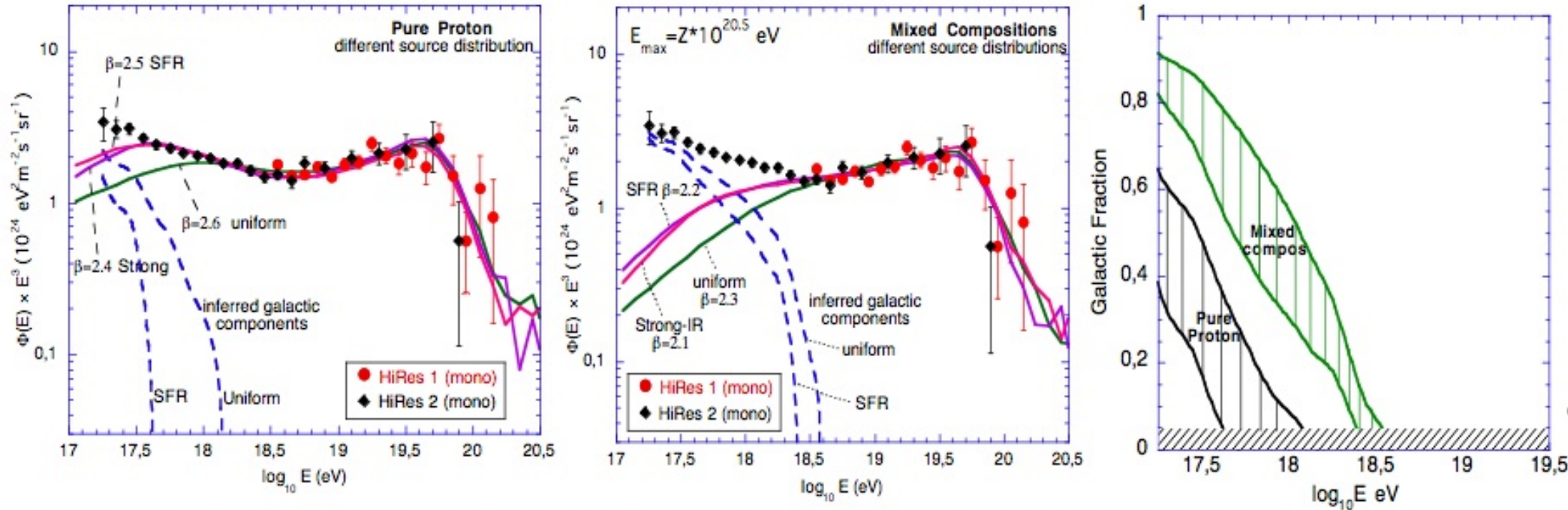
What does it tell us?

the sky is anisotropic at the highest energies : isotropy rejected at 99% C.L.
-> extragalactic origin
-> promise of cosmic-ray astrophysics

But it does not tell :

what the sources are
what the composition is
whether the correlation parameters are physical or not

UHECR: composition & spectrum



Different energy scales for the transition (finishes earlier for the pure proton model)

Different interpretations for the ankle (transition Vs proton interaction)

Impressive agreement of the pair production dip with the ankle but the scheme of the transition for the mixed composition model looks more natural

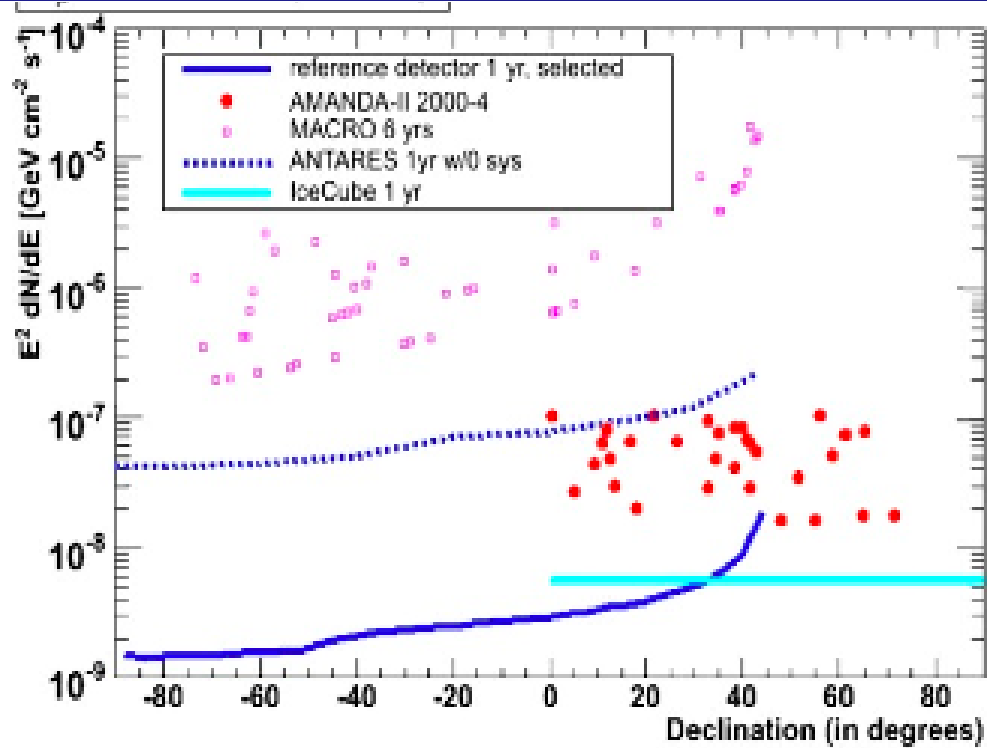
From the sole point of view of the spectrum the two models are degenerated

Other observables needed to distinguish them

D. Allard

=> Information on the observed spectrum and composition have to be evaluated together to deduce the composition at the source (and arrive at an interpretation of the ankle).

astrophysical neutrinos



D. Dornic: expected sensitivity for KM3 for point sources

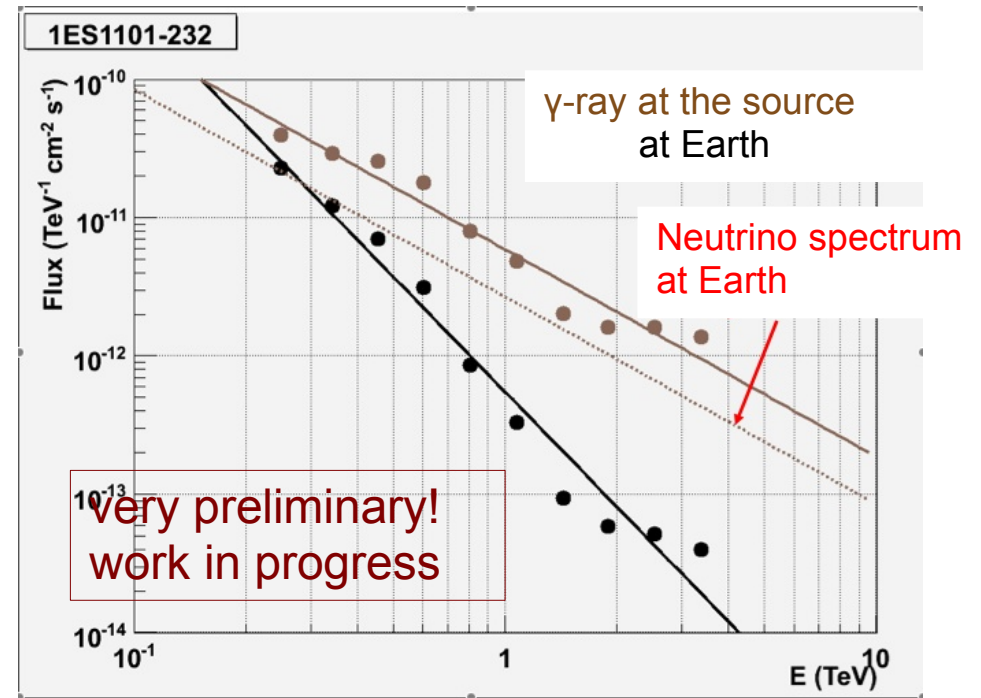
Multi-messenger approaches

Goal: enhance the discovery chance for neutrinos in case of correlations (lower detection threshold, lower the background contamination...)

“Special” neutrinos: Target of opportunity for others telescopes

Perfectly target for transient sources detection:

GRB, SN, AGN flare, μ -quasar flares...



G. Halladjian: prediction of neutrino fluxes from TeV γ -ray data; scenario of pure $p^+ + p^+ \rightarrow \pi^0$

leptonic processes

Inverse Compton

▶ SSC (Synchrotron Self Compton)

$$e^- + \gamma_{sync} \rightarrow \gamma_{VHE}$$

▶ EIC (External Inverse Compton)

$$e^- + \gamma_{ext} \rightarrow \gamma_{VHE}$$

hadronic processes

proton-synchrotron

$$p^+ (+\mu^+ + e^+) + \vec{B} \rightarrow \gamma_{VHE}$$

▶ SPB (Synchrotron Proton Blazar)

▶ PIC (Proton Induced Cascades)

proton-photon

$$p^+ + \gamma \rightarrow p^+ + \pi^0 \rightarrow \dots + \gamma_{VHE} + \nu$$

$$p^+ + \gamma \rightarrow n + \pi^+ \rightarrow \dots + e^+ + \nu$$

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

proton-proton

$$p^+ + p^+ \rightarrow \dots + \pi^+ + \pi^- + \pi^0 \rightarrow \dots + e^+ + e^- + \gamma_{VHE} + \nu$$

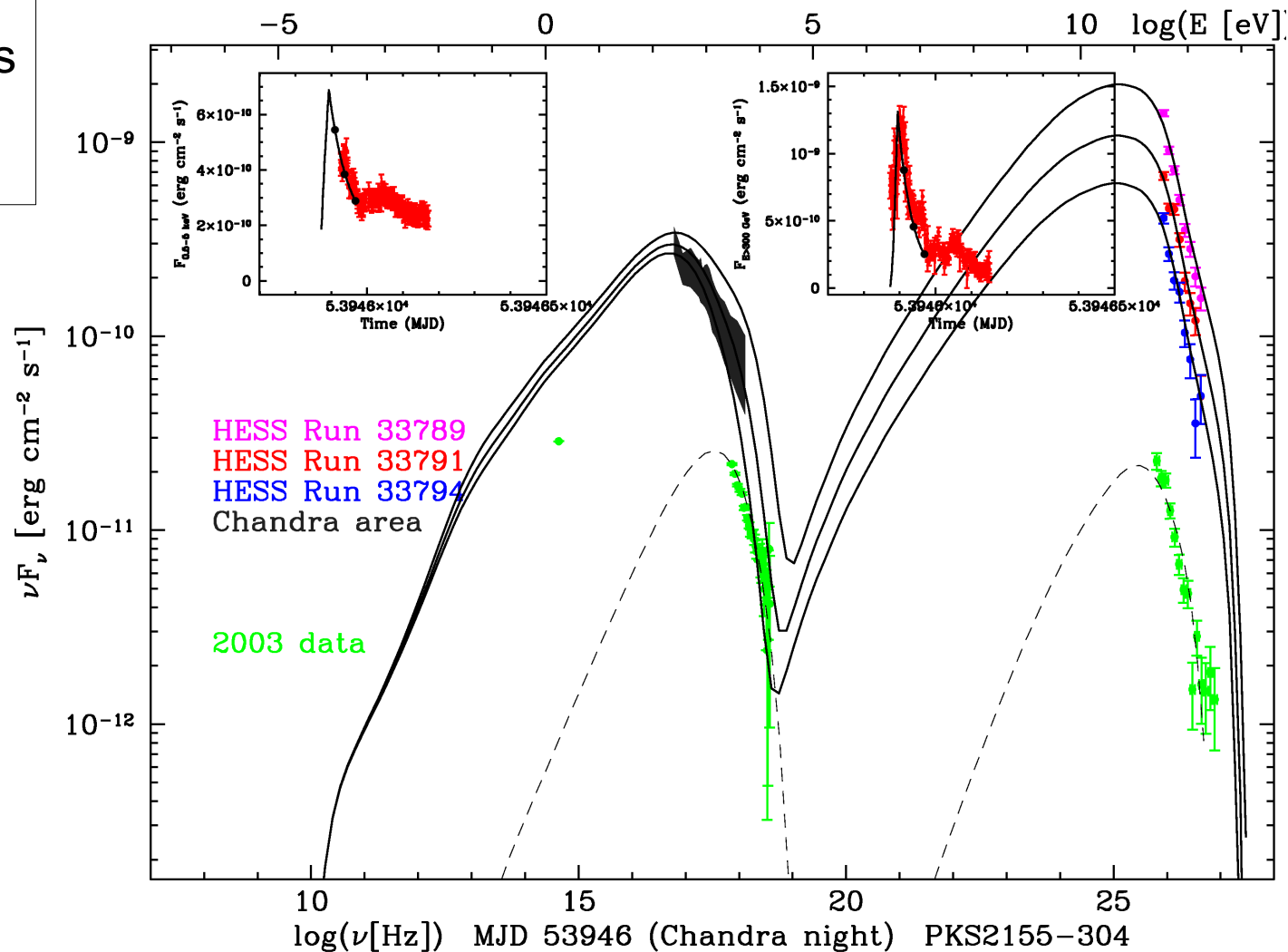
Leptonic models

SSC models can deal with

- fast variability

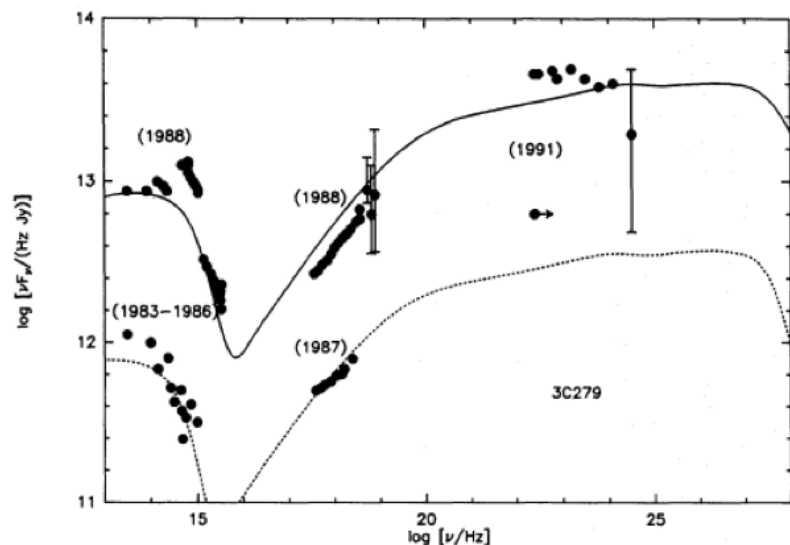
- modelling of radio galaxies like M87 or Cen A

J.-P. Lenain: time-dependent SSC model for PKS 2155-304



Hadronic models: SPB and PIC

Proton-Initiated Cascade Mannheim



Proton-Synchrotron, Mücke

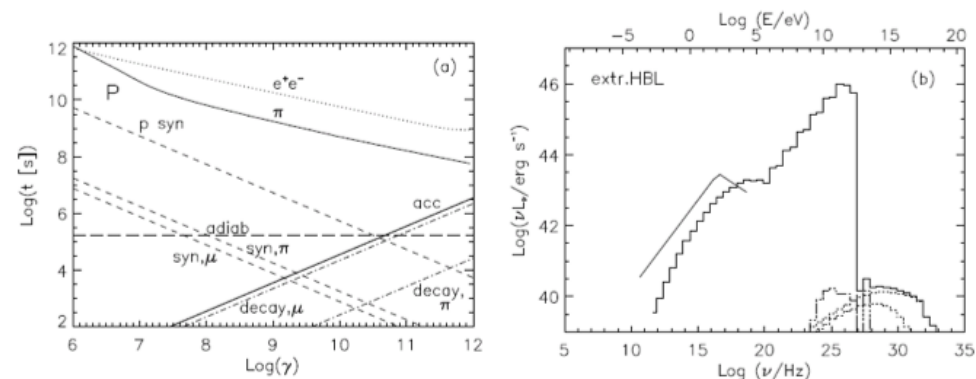


Figure: Extreme HBL parameters: $B = 30$ G, $L_{jet} = 5 \times 10^{45}$ erg/s, $\nu L_{max,syn} = 10^{43.4}$ erg/s, $u_{phot} = 10^9$ eV/cm³, p synchrotron cascade (dashed line), μ synchrotron cascade (dashed-triple dot), π^0 cascade (upper dotted line) and π^\pm -cascade (lower dotted line) (Mücke & Protheroe 2002)

Proton-Synchrotron, Aharonian

F. Spanier

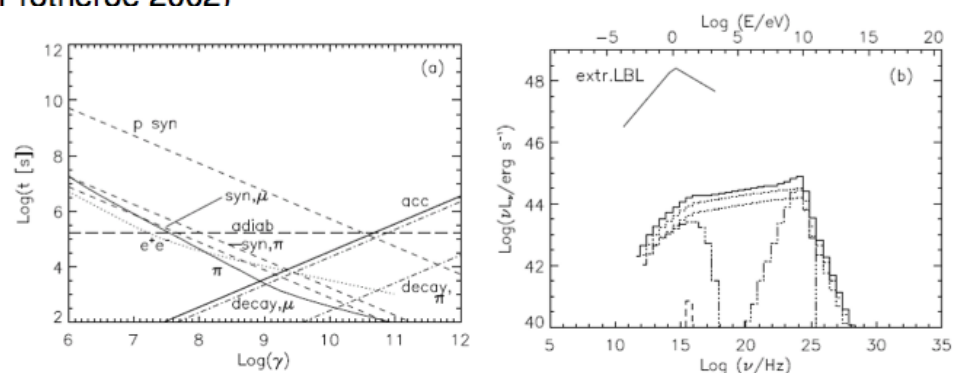
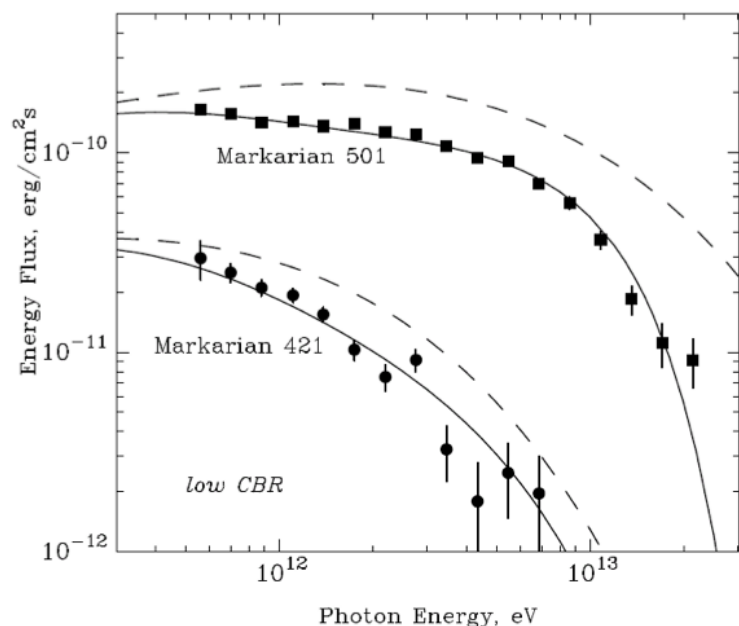


Figure: Extreme LBL parameters: $B = 30$ G, $L_{jet} = 5 \times 10^{45}$ erg/s, $\nu L_{max,syn} = 10^{48.4}$ erg/s, $u_{phot} = 10^{14}$ eV/cm³, p synchrotron cascade (dashed line), μ synchrotron cascade (dashed-triple dot), π^0 cascade (upper dotted line) and π^\pm -cascade (lower dotted line) (Mücke & Protheroe 2002)

Hadronic models: heavy jet

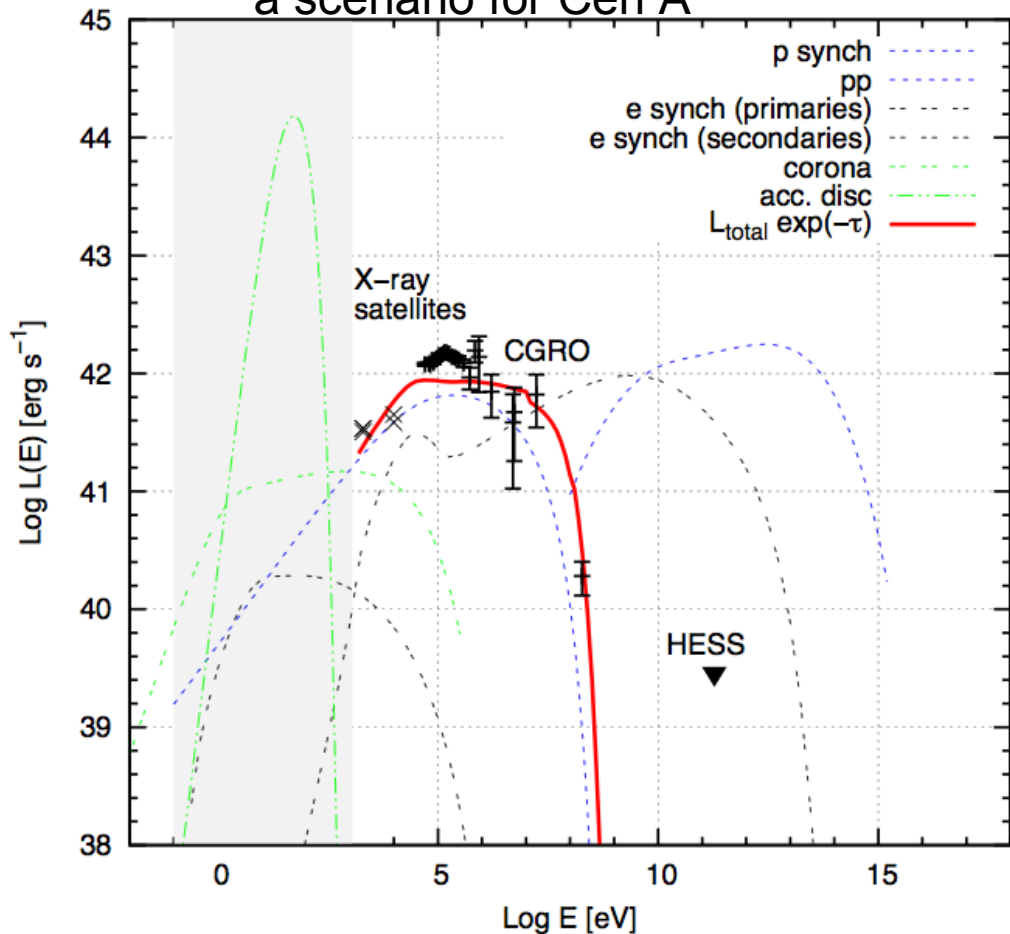
What are jets made of?

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

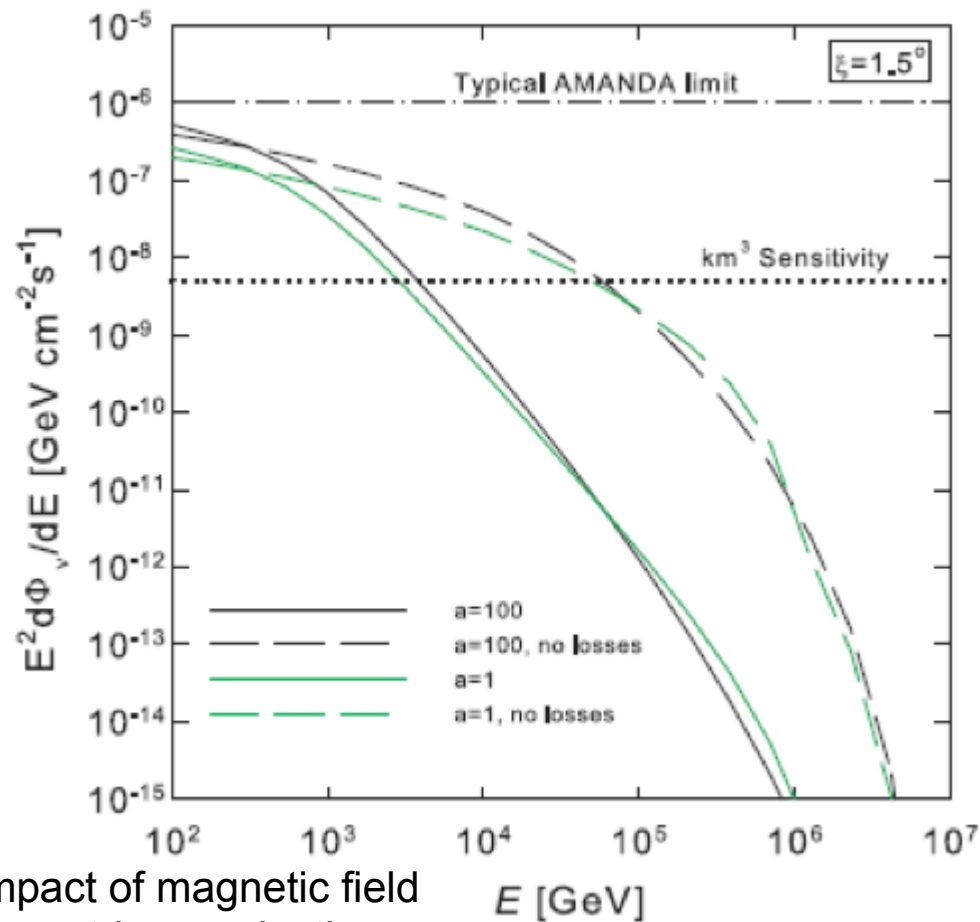
Development of a lepto-hadronic model

- based on experience with microquasar models
- assuming a heavy jet (pp interactions important)

a scenario for Cen A



G. E. Romero



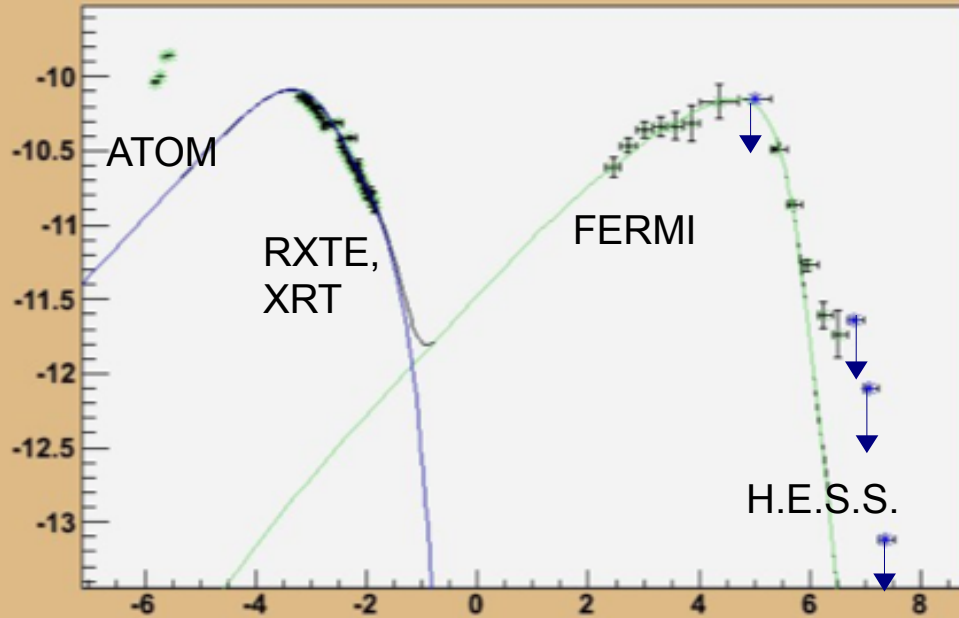
a few conclusions from the meeting

- **VHE γ -rays**: detection of new γ -ray loud AGN classes; spectral and temporal variability yields important clues
- **UHECR**: necessity of combined spectrum+composition studies
- **Neutrinos**: "Multi-messenger approaches are essential to the neutrino telescopes" (D. Dornic)
- **leptonic models**: development of time dependent models
- F. Spanier:
 - "Models so far are either leptonic or hadronic. We are missing **mixed** models."
 - "All [hadronic] models are equilibrium solutions. **Variability** is inferred only via time scales."

Work in progress on lepto-hadronic models

PKS2155-304 in 2008: leptonic interpretation (LUTh)

Simulation pour PKS 2155-304



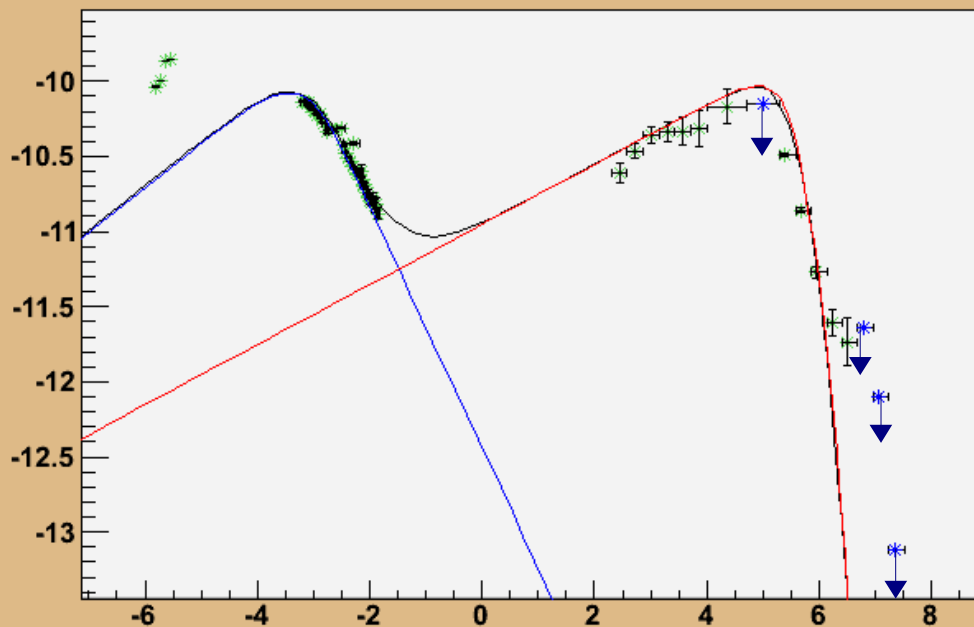
**Very Preliminary !
work in progress...**

Spectre des electrons

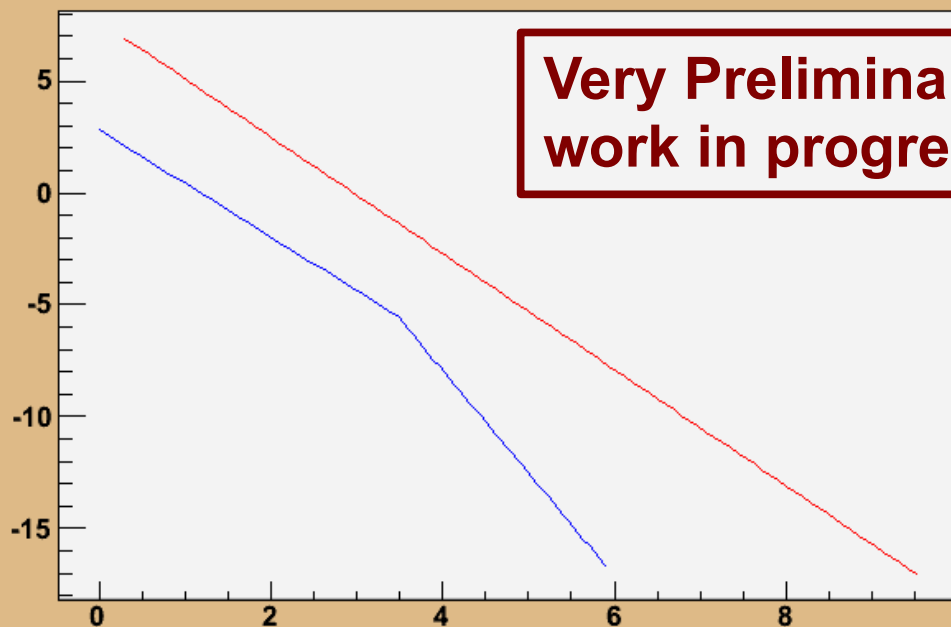


- "classical" blob-in-jet model (Katarzynski, Sol, Kus 2001)
- stationary, injection of a broken power law
- UV / X-ray peak : electron synchrotron
- gamma / VHE : SSC
- preliminary results from the internship of E. Ferrière

Simulation pour PKS 2155-304



Spectres des electrons et des protons

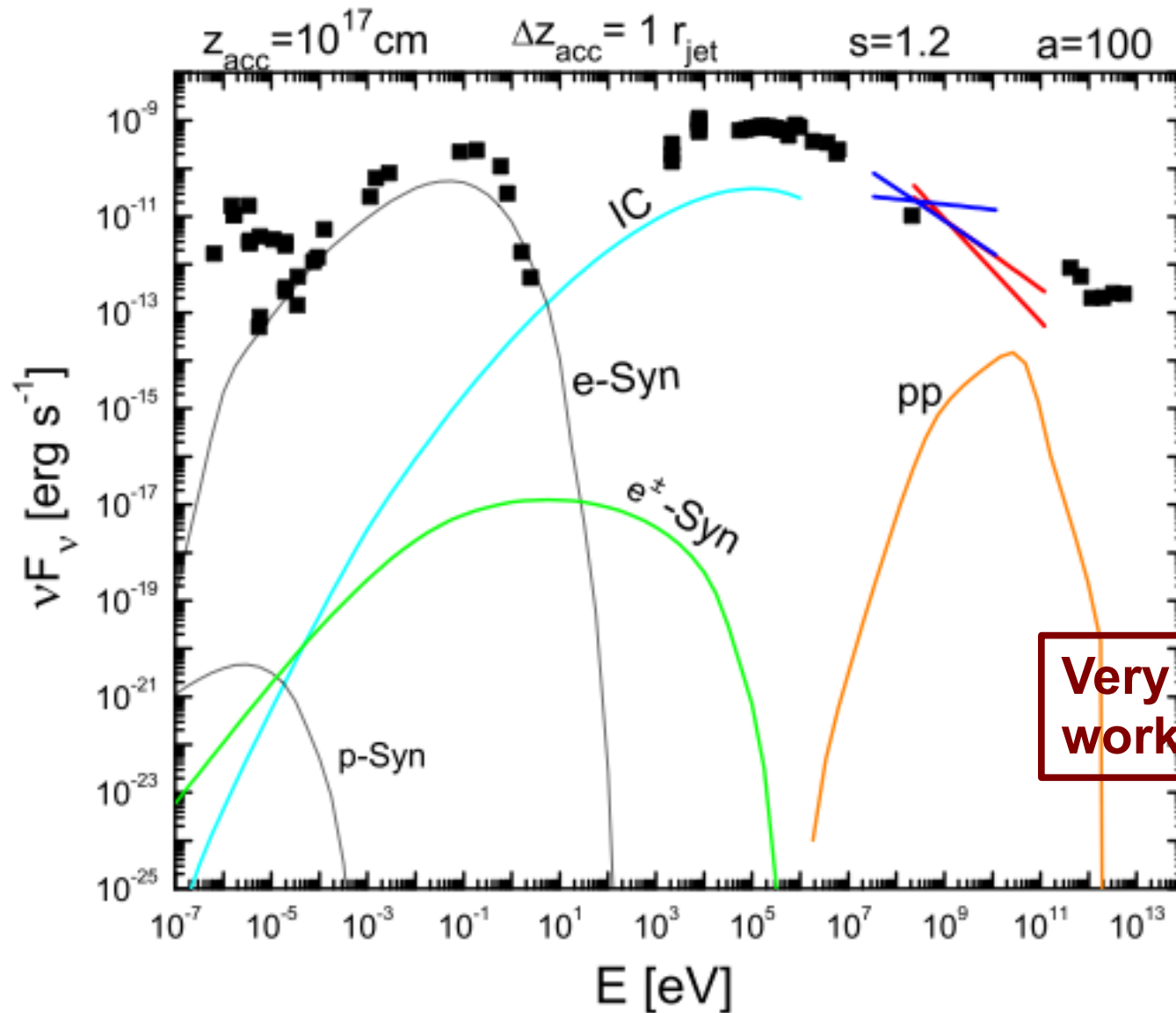


PKS2155-304 in 2008: added proton synchrotron

- following the Synchrotron Proton Blazar scenario
- so far, only proton synchrotron emission has been added (+ absorption on EBL, internal absorption, pair absorption)
- other processes (cascades, etc.) assumed to be small
- SSC is negligible
- UV / X-ray: electron sync.
- gamma / VHE: proton sync.
- preliminary results from the internship of E. Ferrière

A heavy jet model for Cen A (U.N. de La Plata / LUTh)

- approach based on successful hadronic models for micro-quasars
- assuming a high proton density \rightarrow p-p interactions



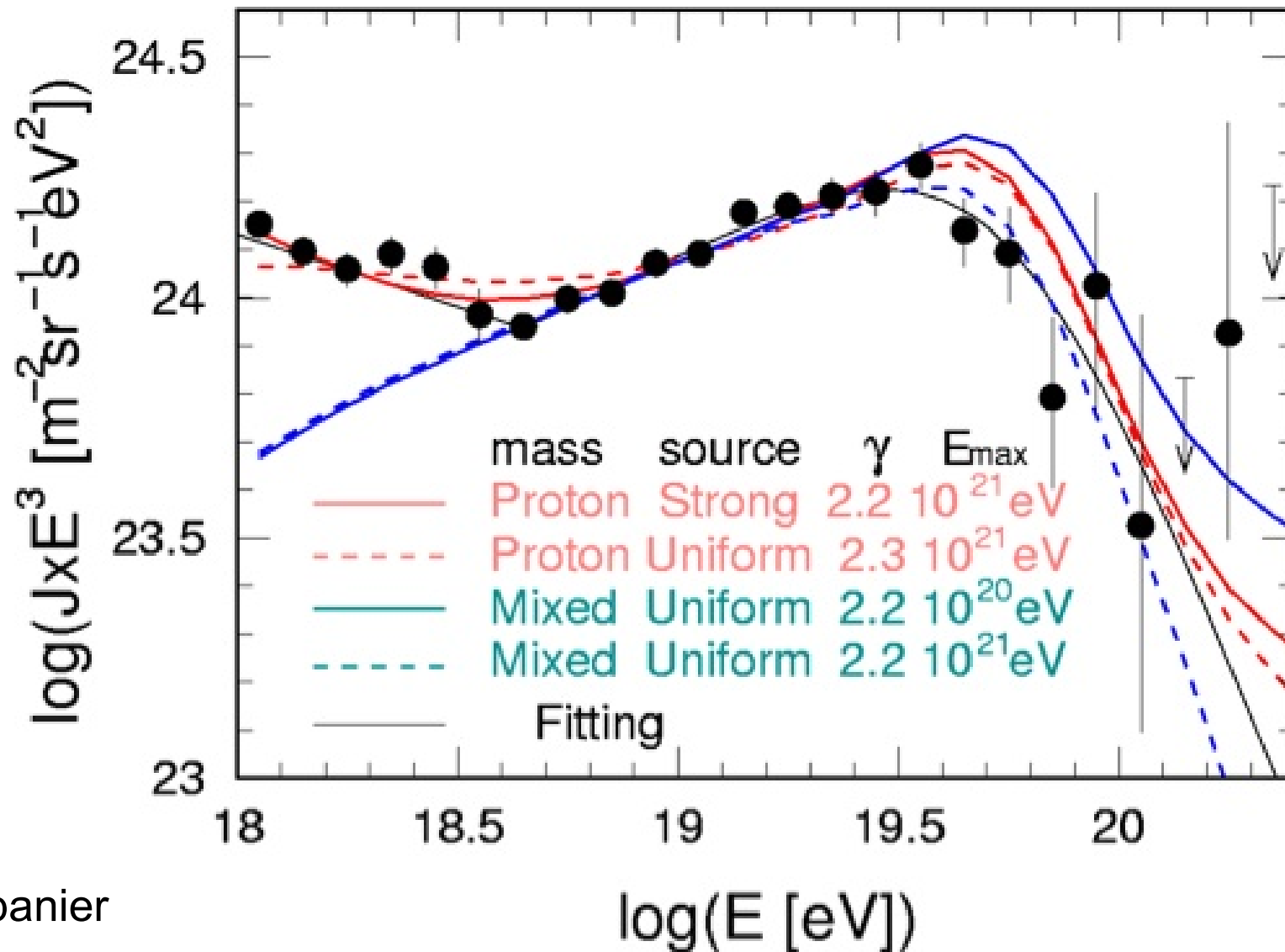
**Very Preliminary !
work in progress**

Planned activities

- Find funding for a next meeting in fall '09.
- Attract more experts on hadronic codes.
So far G. E. Romero is a member and we are in contact with P. Lipari, F. Spanier (Mannheim's group) and J. Ruppel (Schlickeiser's group)
- Work on a lepto-hadronic model at the LUTh and at the U.N. de La Plata, following different scenarios
- Try to establish more interactions between the members

<http://www.luth.obspm.fr/gammacrn>

UHECR: composition & spectrum



F. Spanier

High energy end of the CR spectrum, AUGER collaboration 07