An exotic tour with CTA

Michele Doro michele.doro@pd.infn.it (UAB-IFAE)

1st CTA LINK meeting, Oxford, 2010

About the talk…

- ☹ Several caveats
  - I tried to put all interesting studies that I found or heard of…
  - Some of the studies present are not up-to-date
  - Several results will be quantitative, I wanted only give the general idea
  - Overview on physics → focus on IACT signatures

- Most materials is taken from external authors
  - I try to give credits to them
  - Not all involved people were mentioned

- I will add a basic bibliography

Motivations and expectations

- **Pursuing exotic with IACTs (and CTA)**
  - It is not impossible
  - It can contribute to real fundamental discoveries
  - It is much fun!
- Expectations largely depends on scenarios and novel scenarios may pop-up anytime
- It is where theoreticians must meet experimentalists
  - Thoreticians are more updated on recent theories
  - Deeper knowledge of theoretical aspects
  - Experimentalist needed to adapt experiment/analysis/data interpretation
  - Theoreticians may not be able to understand CTA easily as us

…it is the drunk
who looks for the lost keys
below the street light…

The exotic tour

- Tau-neutrino searches
- Axions searches
- Cosmological parameters
- Magnetic monopoles
- Gravitational waves
- Various CR searches

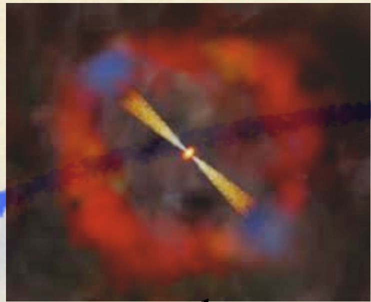
CTA as a neutrino telescope Tau-Neutrino searches

Thanks to: Markus Gaug, Oscar Blanch

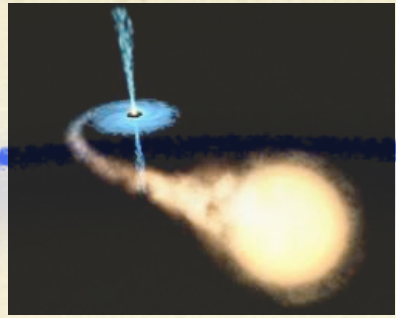
Proposal for the observation of tau-neutrinos with MAGIC-phase1 (2006)

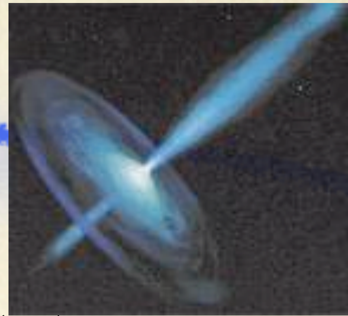
High-Energy neutrinos

Point-like

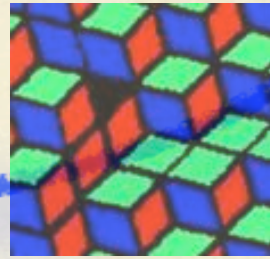


Gamma-ray bursts





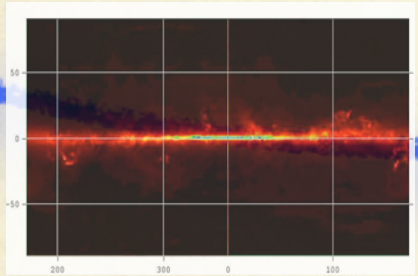
Microquasar and Blazars



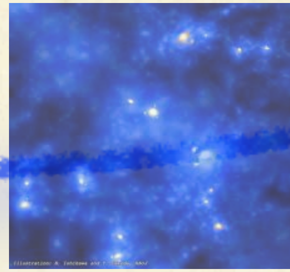
Topological defects

Exotic

Diffuse



Diffuse neutrinos



WIMPs

Fargion, 1997

Pions production (at source or propagation)

$$p\,\gamma \rightarrow \Delta^+ \rightarrow \begin{cases} n\,\pi^+ \\ p\,\pi^0 \end{cases}$$

$$pp \longrightarrow pp\pi^+\pi^-\pi^0$$

Neutrinos production (at source or propagation)

$$\pi^+ \longrightarrow \mu^+\nu_\mu$$

$$\mu^+ \longrightarrow \bar{\nu_\mu} e^+ \nu_e$$

$$(\nu_e : \nu_\mu : \nu_\tau) = (1:2:0)\,.$$

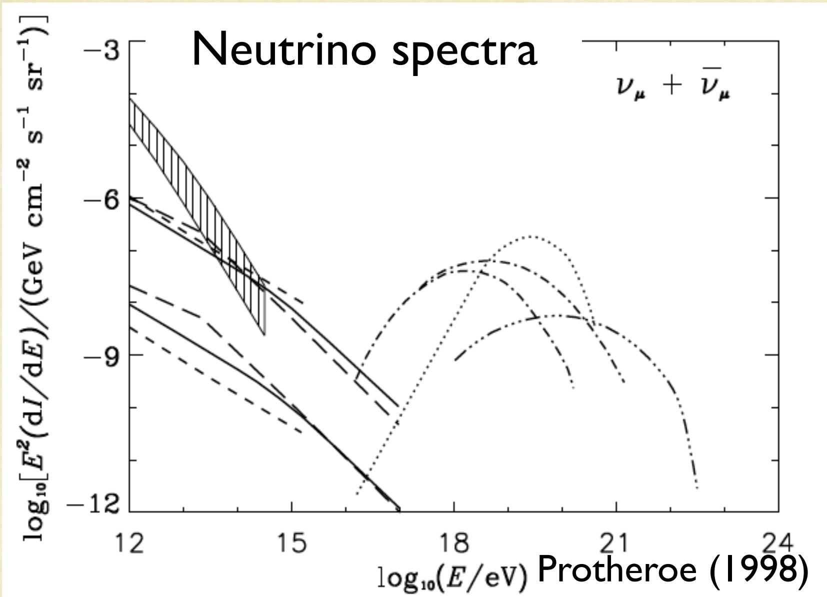
...and ν_τ...

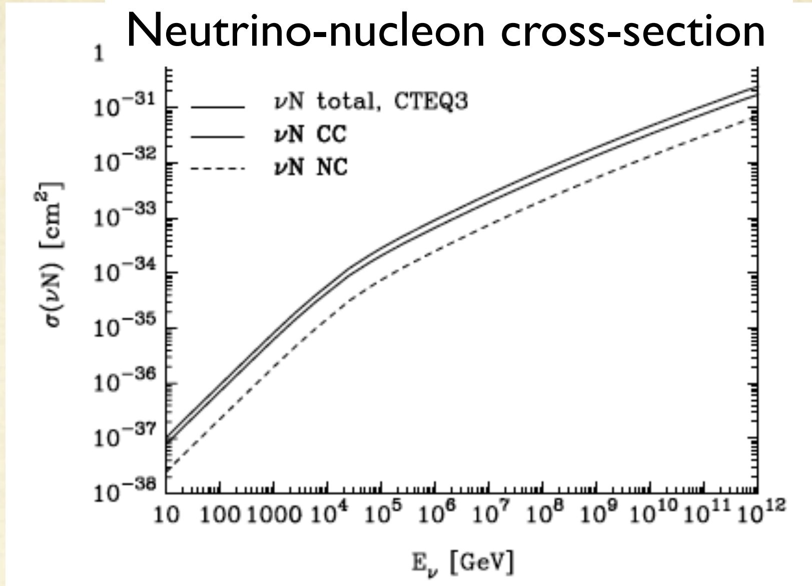
* At the source if charmed mesos are produced

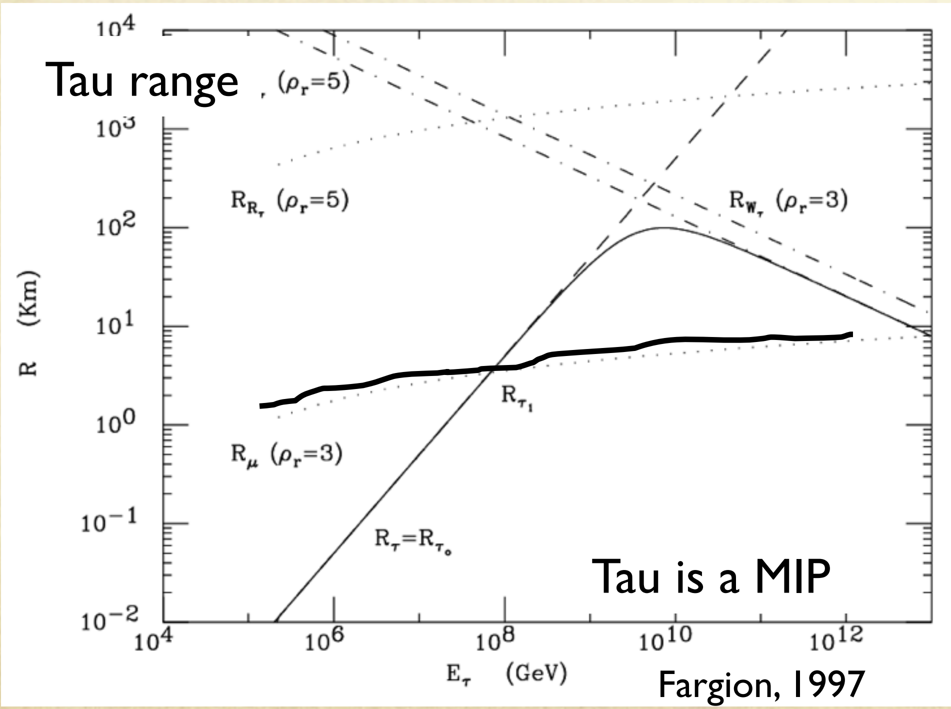
* At the Earth, after flavor mixing

$$(\nu_e : \nu_\mu : \nu_\tau)_{Earth} = (1:1:1)$$

The importance of being **tau**







Tau decays

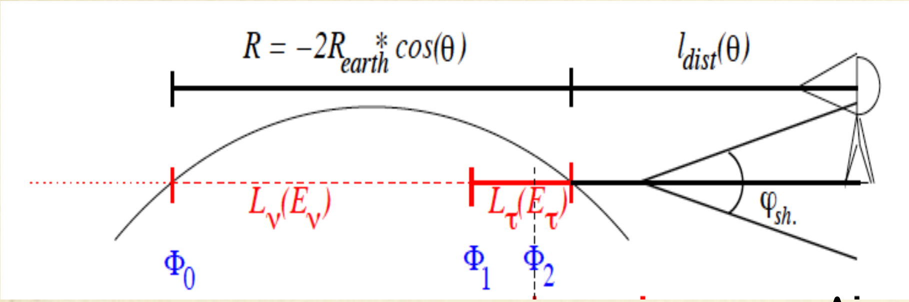
Tau decays	Secondaries	Probability
$\tau \to \mu^- \nu_\mu \nu_\tau$	μ^-	$\sim 17.4\%$
$\tau \to e^- \nu_e \nu_\tau$	e^-	$\sim 17.8\%$
$\tau \to \pi^- \nu_\tau$	π^-	$\sim 11.8\%$
$\tau \to \pi^- \pi^0 \nu_\tau$	$\pi^-,\ \pi^0 \to 2\gamma$	$\sim 25.8\%$
$\tau \to \pi^- 2\pi^0 \nu_\tau$	$\pi^-,\ 2\pi^0 \to 4\gamma$	$\sim 10.79\%$
$\tau \to \pi^- 3\pi^0 \nu_\tau$	$\pi^-,\ 3\pi^0 \to 6\gamma$	$\sim 1.23\%$
$\tau \to \pi^- \pi^- \pi^+ \nu_\tau$	$2\pi^-,\ \pi^+$	$\sim 10\%$
$\tau \to \pi^- \pi^+ \pi^- \pi^0$	$2\pi^-,\ \pi^+,\ \pi^0 \to 2\gamma$	$\sim 5.18\%$

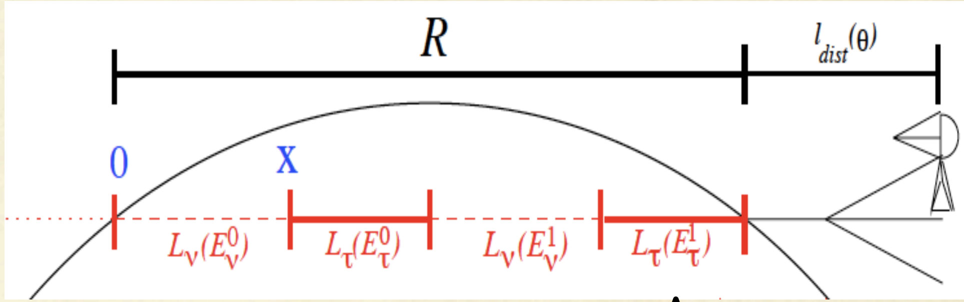
Fargion, 2000

* Taus leads to many observable showers
* Tau is a m.i.p.
* Tau has a large range

Principles of observation for IACT

Neutrinos → [Matter → Leptons] → [Air → E.M. shower]





Downward observation

Horizontal observation

Main advantage: background should have clear signatures or even background free

An exercise for MAGIC 1 (Diffuse and GRBs)

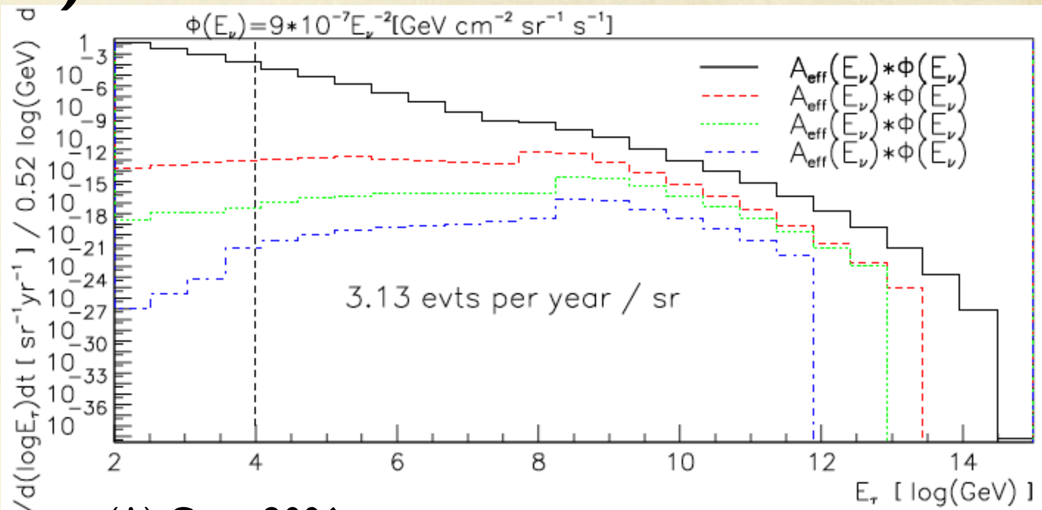
SEVERAL CAVEATS:

1) analytic calculation of the effective area (no MC simulation)
2) no background simulation
3) took AMANDA upper limits (2005, best case scenario)
4) Observation at the sea (exactly at 92 deg zenith)

RESULTS:

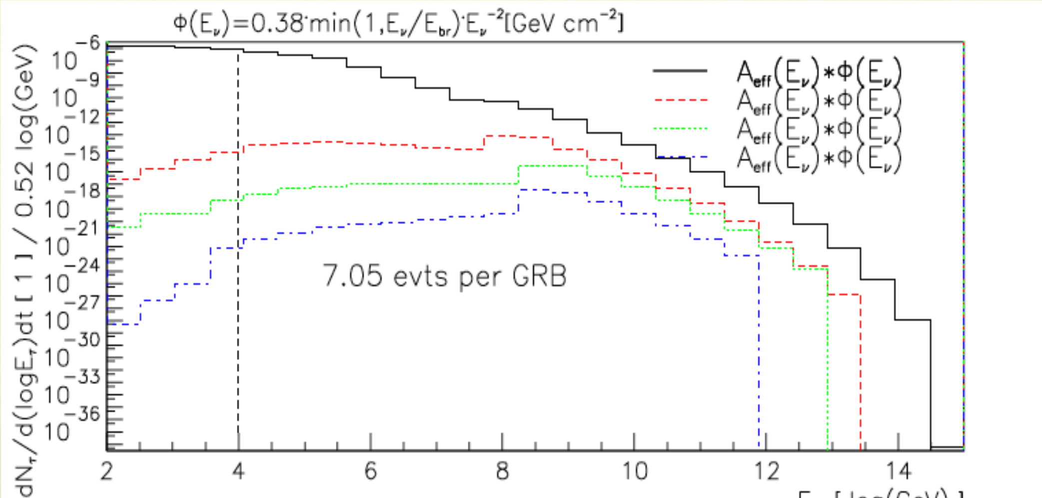
1) Sensitivity [100 TeV , 1 EeV]
2) Mountain would be better!
3) Diffuse #1: is very low because of the limited FOV (3evts/year/sr)
   Diffuse #2: No competition with (icecube, biakal, auger, antares)
4) GRB #1: 7 events for entire GRB
   GRB #2: Possible delayed observation (<1day from burst)

A) Diffuse neutrinos fluxes



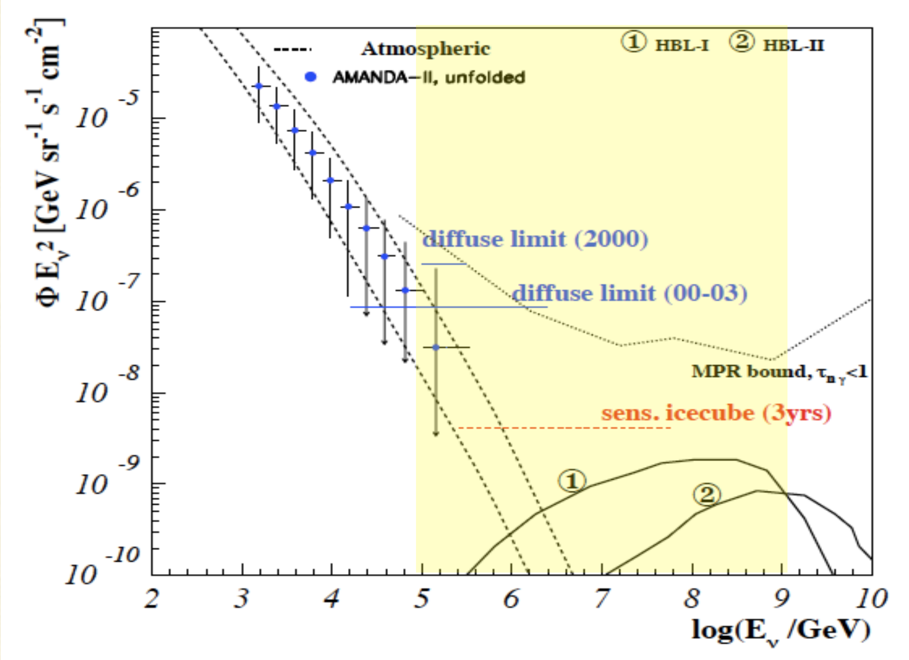
(A) Gaug, 2006

B) Average GRB



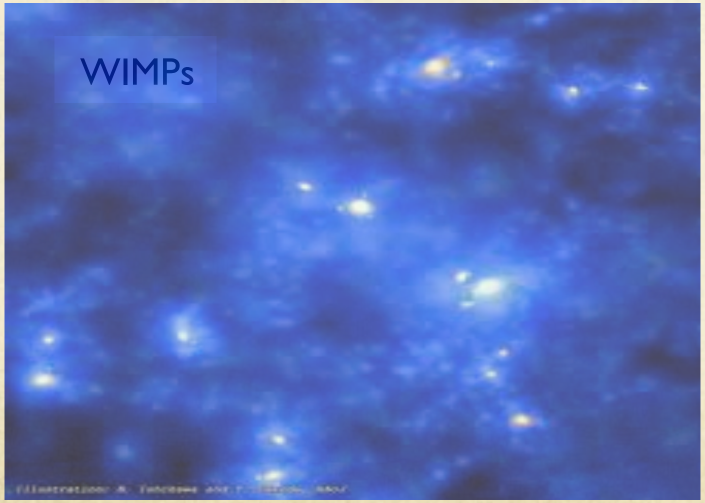
(B) Gaug, 2006

Other point-like neutrino sources



Need VHE neutrinos

- Microquasars and LBL are possible targets but hardly En > 100 TeV
- High-peaked blazars (HBLs)
  - Good candidates En>10^{17} eV
  - (e.g. 1ES 1959+650, 1ES 2344+514)
- Milagro sources!
- Galaxy clusters
- …or a supernova events!

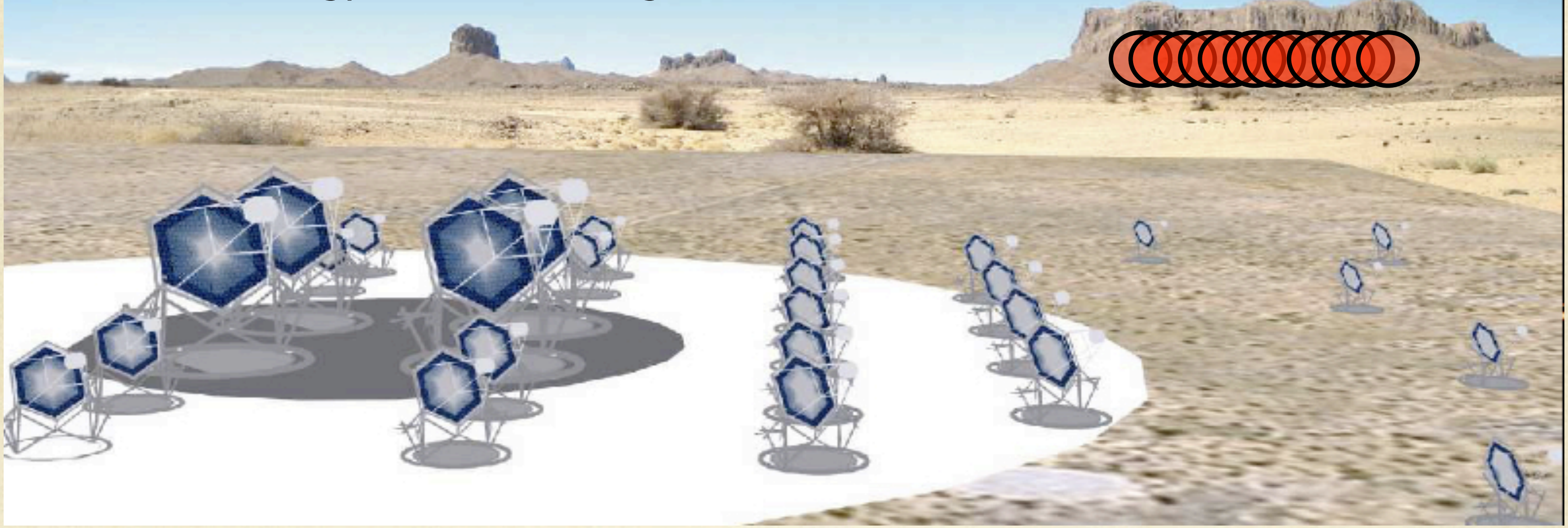


In principle, the galactic center (and the sun) could have neutrino signatures

But typical WIMP mass is below few TeV (excluded high-mass DM models)
→ too low

CTA {if the artist was a fortune-teller}

- Extended observation mode (30xMAGIC)
- Higher-eff.area
- Lower energy threshold -> higher fluxes



* Diffuse emission: simple scaling from MAGIC1: ~10 evts/year

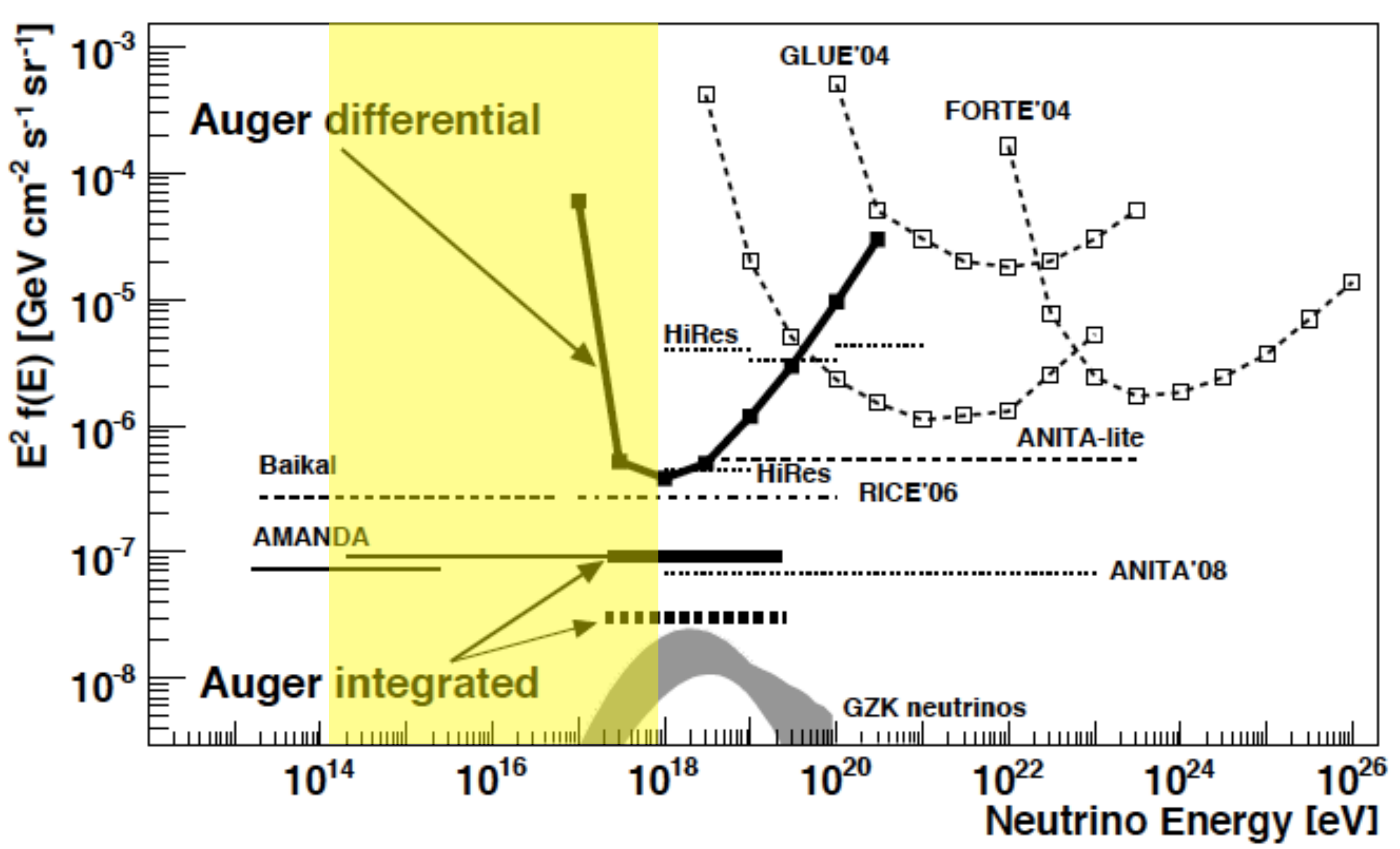
* Point-like source: depends on models.

{naïve? : observe when high clouds are present!}

→MC SIMULATIONS ARE NEEDED (AND COMPLICATE)

→POSSIBLY DIFFERENT TRIGGER CONFIGURATION

Other experiments



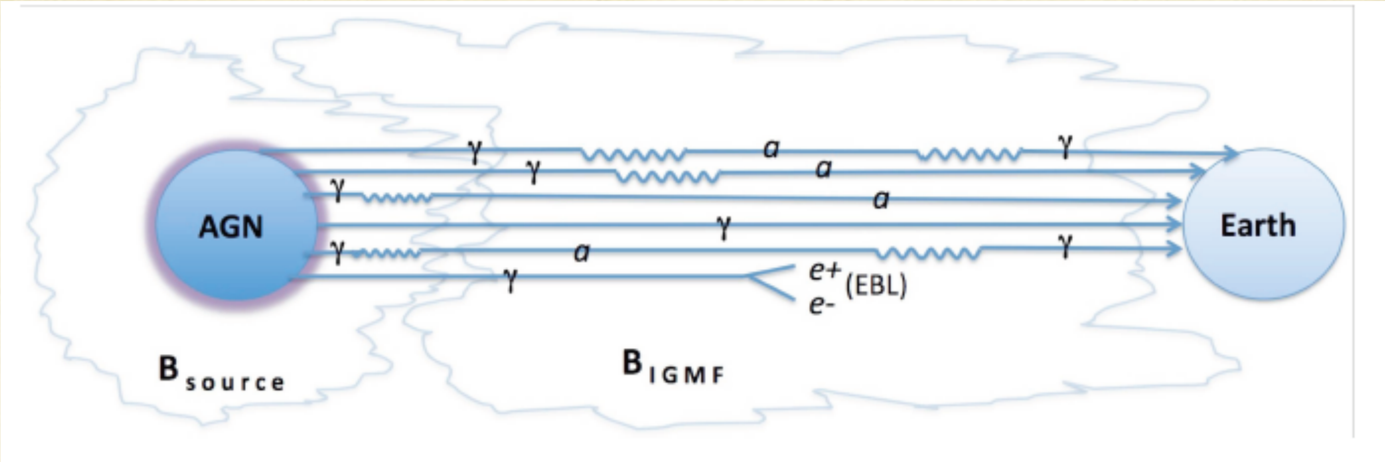
Still preliminary to make estimation on CTA sensitivity

Axion(-like) searches

Thanks to: M.A. Sanchez-Conde (masc@iac.es)

Sánchez-Conde et al., 2009, Physical Review D, vol. 79, Issue 12, id. 123511

Axions-photons conversion



$$P_0 = \frac{1}{1+(E_{crit}/E_\gamma)^2}\sin^2\left[\frac{B\ s}{2\ M}\sqrt{1+\left(\frac{E_{crit}}{E_\gamma}\right)^2}\right] \quad \text{with} \quad E_{crit} \equiv \frac{m^2\ M}{2\ B}$$

≥ 1

- For an efficient conversion: $\frac{15 \cdot B_G \cdot s_{pc}}{M_{11}} \geq 1$

M_{11}: coupling constant inverse ($g_{a\gamma}/10^{11}$ GeV)
B_G: magnetic field (G)
s_{pc}: size region (pc)

$$\frac{15 \cdot B_G \cdot s_{pc}}{M_{11}} \geq 1$$

$M_{11} \geq 0.114$ GeV (CAST limit)

Astrophysical sources with $B_G \bullet s_{pc} \geq 0.01$ will be valid.

In IGMFs, $B_G \approx 10^{-9}$
Mixing possible for cosmological sources ($s_{pc} \geq 10^8$)

Axion good "cold" DM candidate for axion masses 1e-3 – 1e-6 eV

Photon-axion conversions in magnetic field (no direct detection)

Axions and VHE gamma-rays

$$E_{crit}(GeV) \equiv \frac{m_{\mu eV}^2 \, M_{11}}{0.4 \, B_G}$$

We want E_crit at the GeV scale

{m_a<10^{-2}eV}

- Mixing at the source (AGN, B~G)

Gamma-rays converts into axions for **axion mass < 10^{-6} eV**

- Mixing in the IGMF (B~nG)

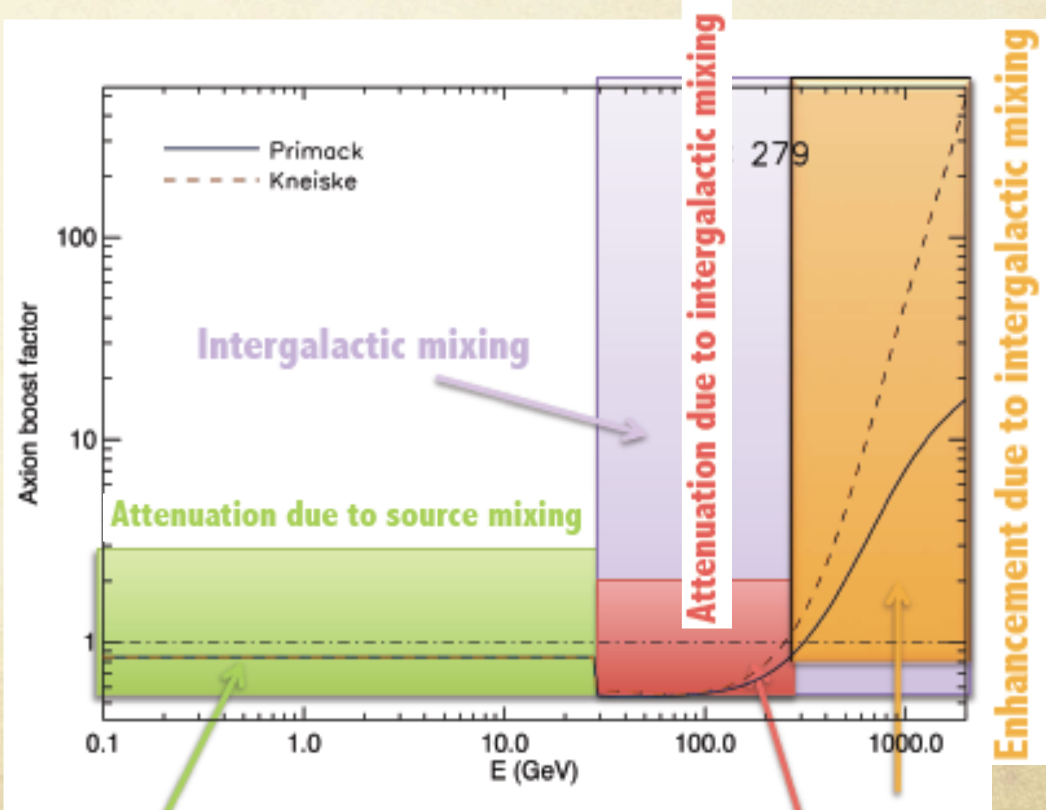
Gamma-rays converts into axions for **axion mass ≈ 10^{-10} eV**

- EBL influence

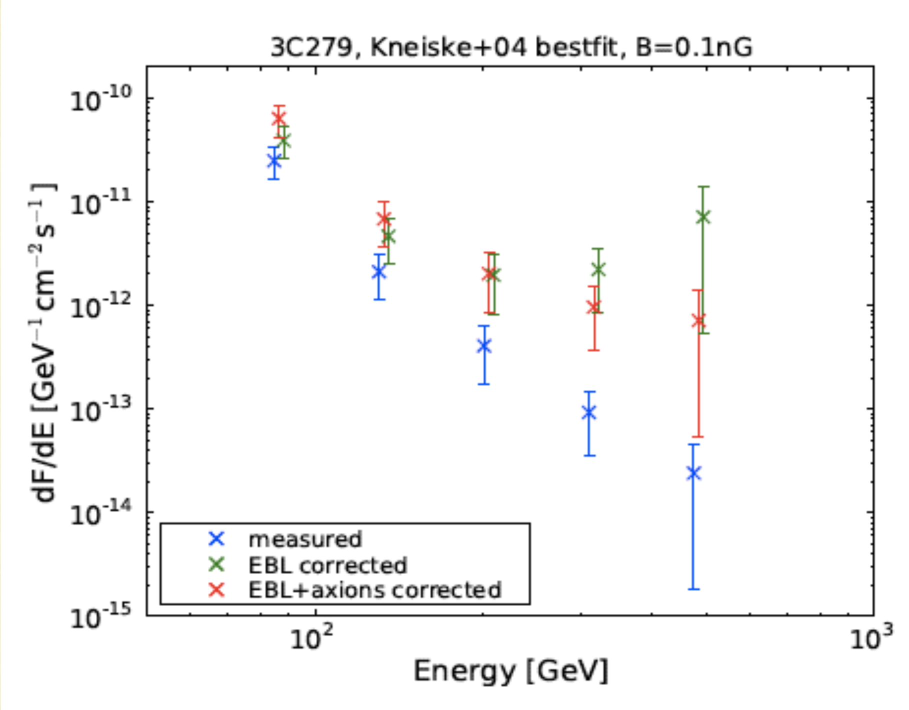
When photons convert to axions are not EBL-absorbed → gamma-ray boost

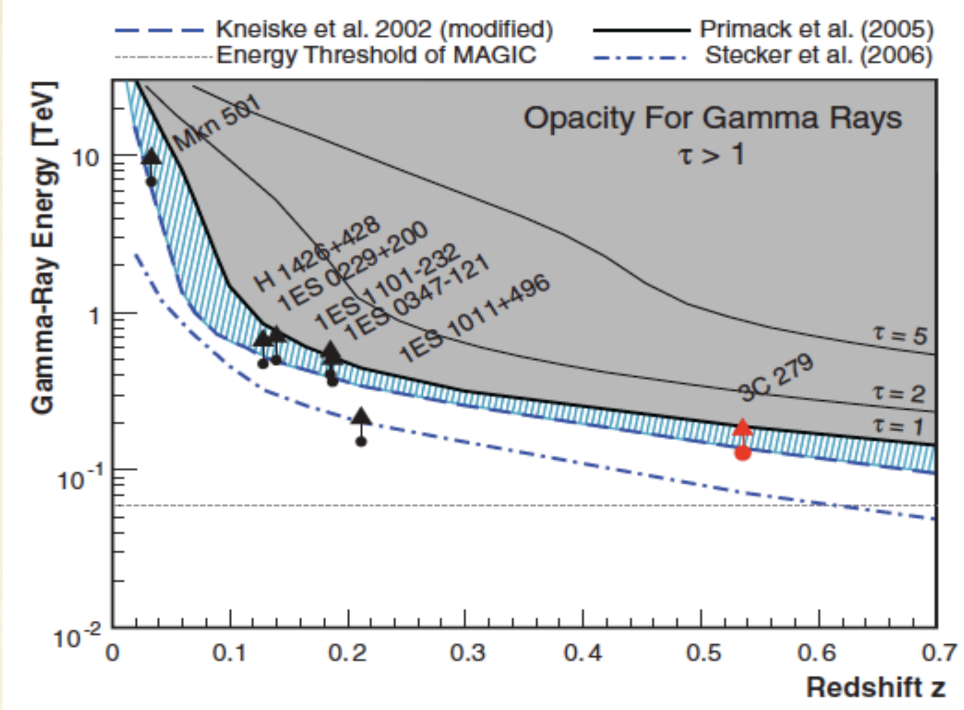
Three regions at GeV-TeV (modulo the definition of E_crit):

* E<30 GeV: gamma-ray attenuation due axion conversion at source
* 30 GeV < E < 200 GeV: gamma-ray attenuation due axion conversion in IGMF
* E> 200 GeV: gamma-ray boost due to fact that axions are not EBL-absorbed



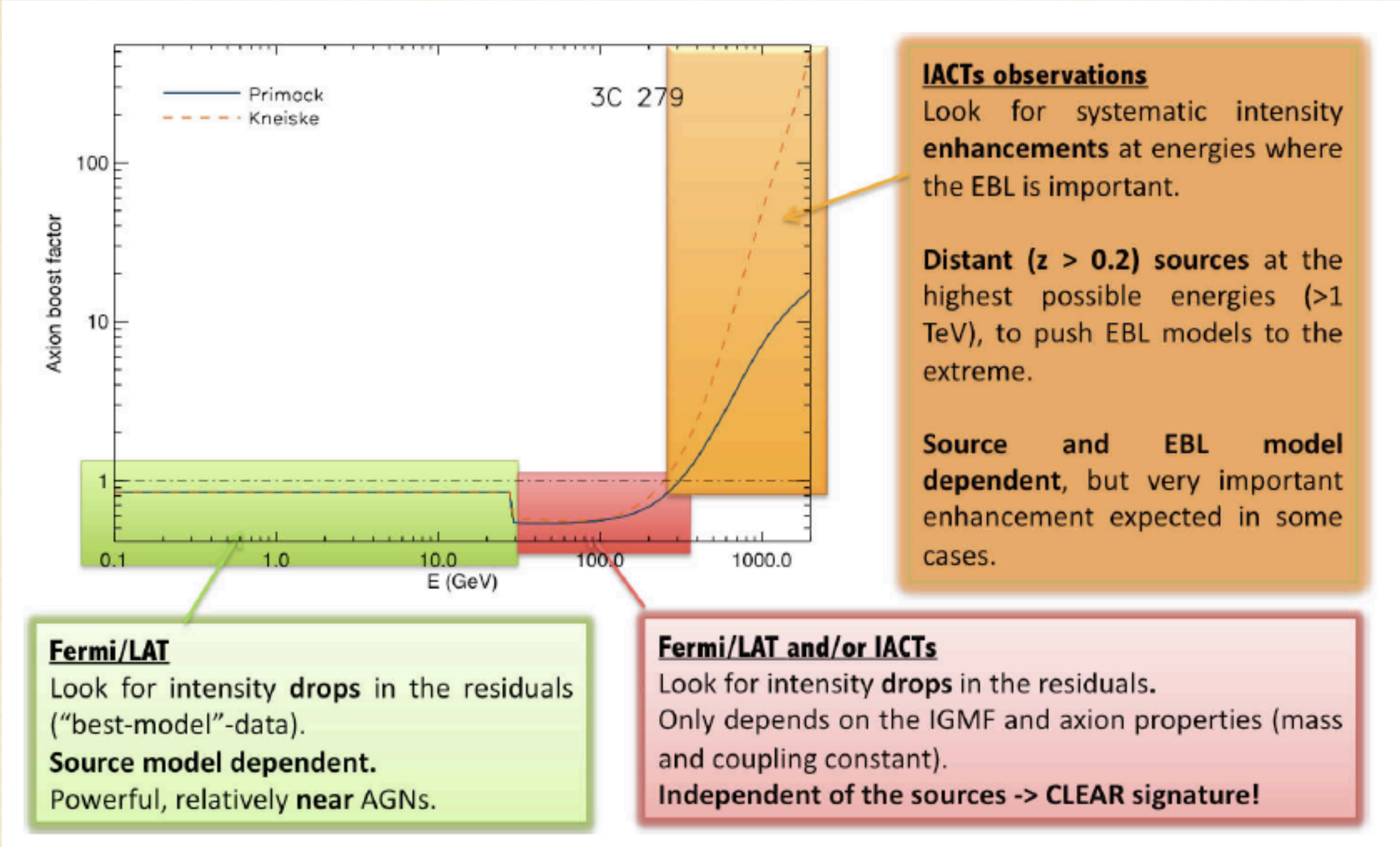
Spectral-features





- Axion-conversion milds the effect of the EBL absorption
- To disentangle axion / photons mixing
  - Need many blazars at different large redshifts (>0.1 in most cases)
  - Need better blazar intrinsic models and EBL models (and/or blazar flares)

Strategy and prospects for CTA



- * Higher sensitivity ➔ more (& fainter) blazars
- * Lower energy threshold ➔ more (& farther) blazars
- * CTA also probes galaxy clusters

Together they will produce better EBL constraining and Blazar models

➔ stronger Axion-like constraints

Cosmological parameters

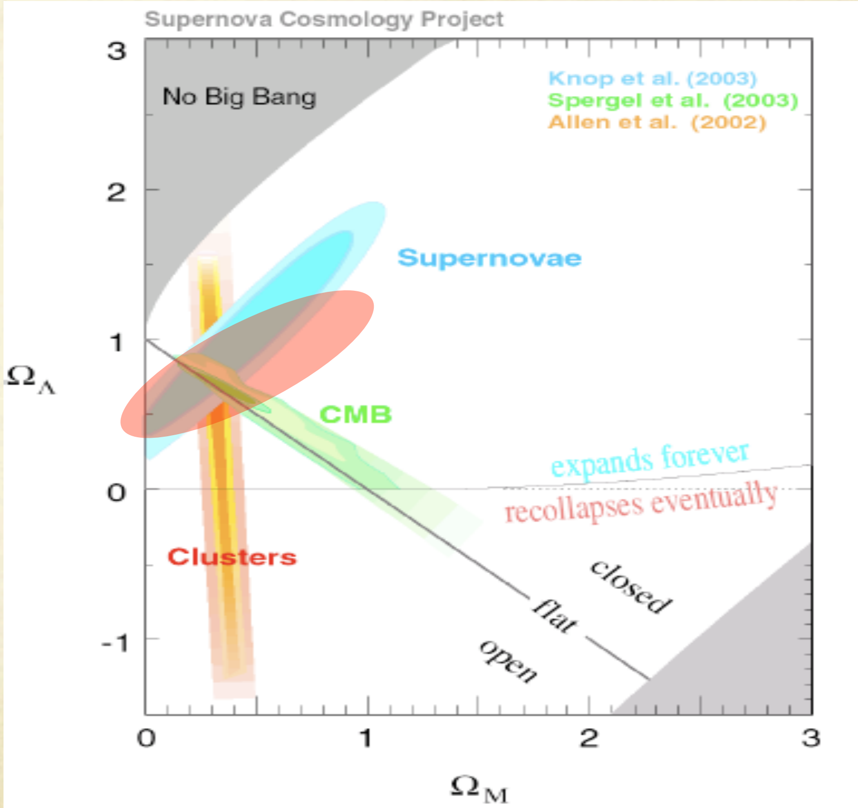
Thanks to: Oscar Blanch (blanch@ifae.es), Phd Thesis 2004

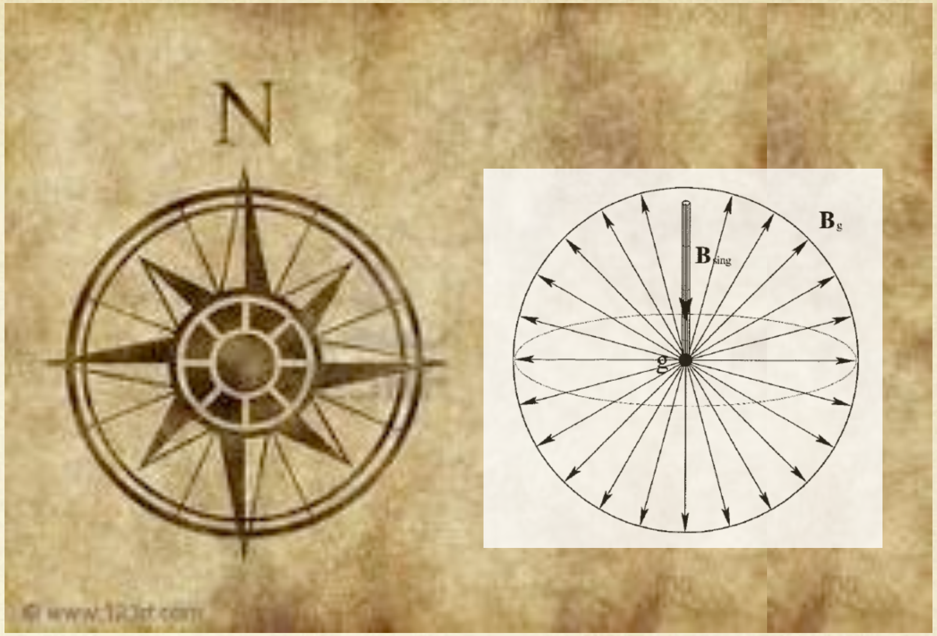
IACT contribution

$$\tau(E,z) = \int_0^z dz' \frac{dl}{dz'} \int_0^2 dx \frac{x}{2} \int_{\frac{2m^2c^4}{Ex(1+z')^2}}^{\infty} d\epsilon \cdot n(\epsilon, z') \cdot \sigma[2xE\epsilon(1+z')^2]$$

$$\frac{dl}{dz} = c \cdot \frac{1/(1+z)}{H_0[\Omega_m(1+z)^3 + \Omega_k(1+z)^2 + \Omega_\lambda]^{1/2}}$$

- Optical depth depends on cosmological parameters
- Blazar cutoffs can put constraints
  - ☺ Independent from other estimations.
  - ☺ AGNs can provide high-redshifts exploration
  - ☹ rely on EBL models
- O.Blanch, M.Martinez (2004)calculated before MAGIC I was operating. Need several updates…
- CTA: ☺ lower threshold, higher sensitivity

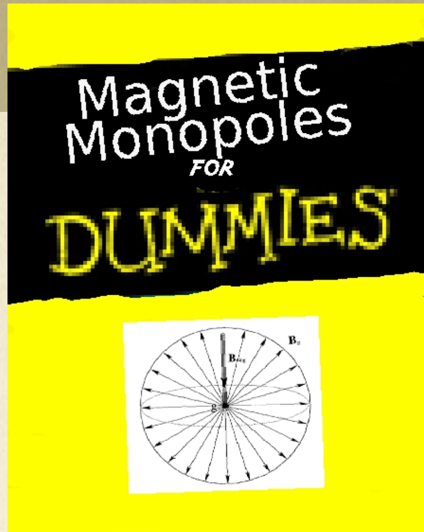




Magnetic Monopoles

From: G.C.Spengler's Diploma thesis, 2009

Introduction



- Original idea from Dirac ('30s):
  - If one adds magnetic monopoles r_M and magnetic current j_M Maxwell's equation become fully symmetrical not only in vacuum
- MM arisen in GUT theories ('74 t'Hooft & Polyakov)
  - The MM mass in general O(GUT)~10^{16}-10^{17} GeV (thus measure MM ➔ measure GUT)
- Searches: MM produce huge Cherenkov light in matter
  - MACRO: wide-range experiment
  - AMANDA: Cherenkov emission from MM is ~8000 stronger than from electromagnetic shower.

$$\frac{d^2N}{dxd\lambda}^{\text{Ice}}_{\text{Monopole}} \approx 8000 \frac{d^2N}{dxd\lambda}_{\text{Electric}} .$$

What about IACTs

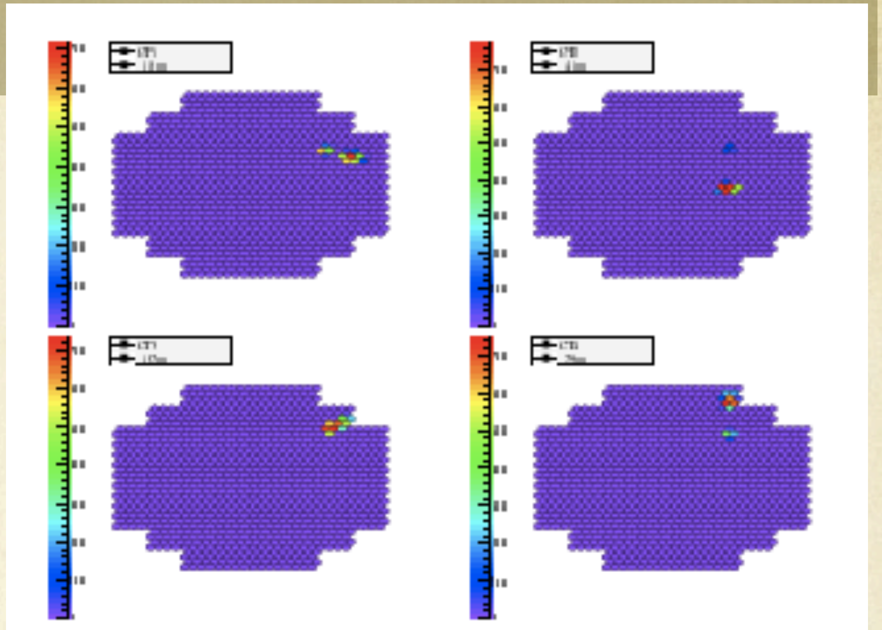
- MM are charged → initiates E.M. Cherenkov shower

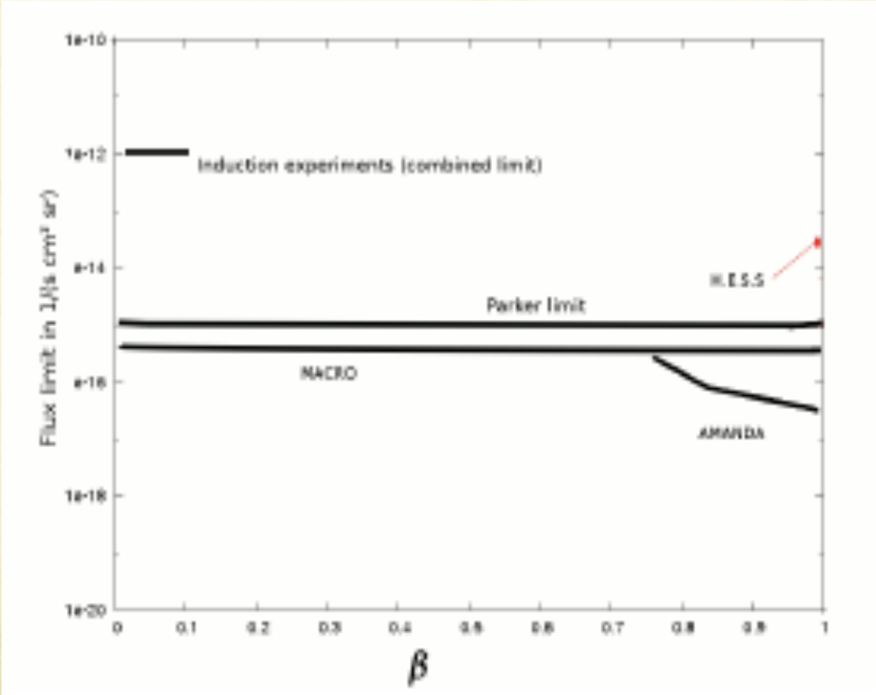
$$\frac{d^2N}{dxd\lambda}^{\text{Air}}_{\text{Monopole}} \approx 4700 \frac{d^2N}{dxd\lambda}_{\text{Electric}} .$$

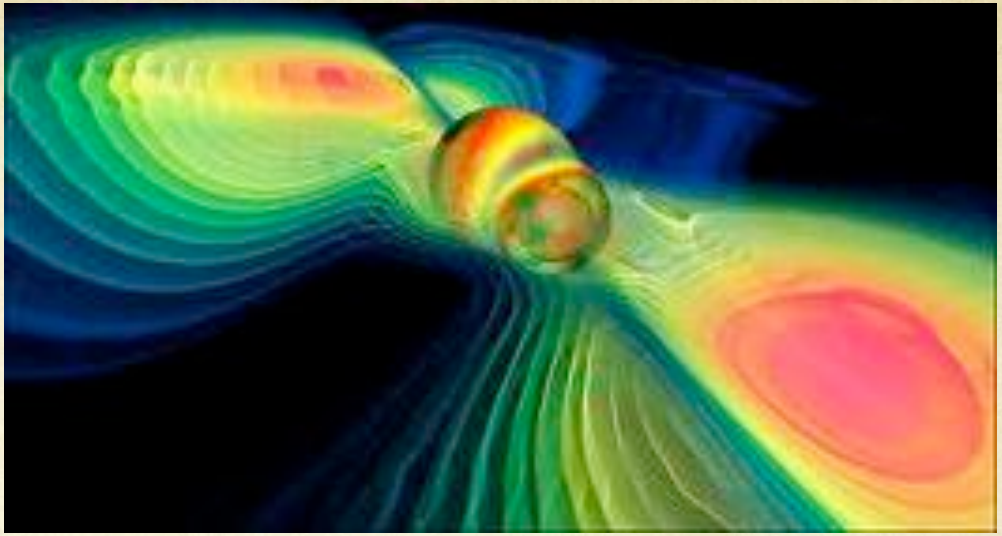
- Very complicated MC simulation
- IACT can probe $m_{MM}>10^{15}$ eV and large β
- But…
  - very clear signatures in the camera: few extremely bright pixels
  - Analysis on all data taken, no need to allocate time

CTA

- Maybe a factor 10 better achieved due to larger effective area
- Larger region of the sky surveyed







Gravitational Waves

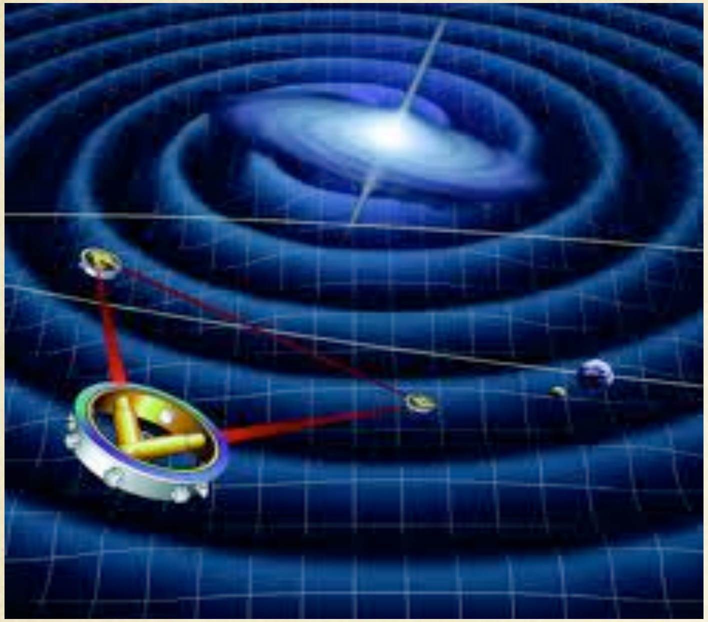
Thanks to: Antonio Stamerra (Proposal of follow-up of GW for MAGIC), internal note

Current status

- Gravitational waves in Einstein's theory
- Merging of compact binary systems, Supernova or neutron-star core-collapse, Star-quakes, Pulsar glitches, …
- Duration <1sec
- Rate???

- GW-network of experiments (5 in total):
  - Virgo, Ligo (3x), Geo 600
- Kilometer-scale Michelson interferometry to measure DL/L
- Measure from 10^{-22} -10^{-16} Hz
- When operated together 2deg angular resolution
- Trigger can come after 10 minutes
- Significant improvement in few years (good expectations for future)

When CTA will operate



- LISA pathfinder (2013) and LISA space interferometry (2020)
- Upgrades on Ligo and Virgo foresee 1000x monitored Universe volume → great expectations
- Maybe we will have some events

- CTA scope:
  - Find the gamma-ray counterparts
  - Even ULs would be important

- CTA to do list:
  - Plan for triggers accepted
  - Fast repositioning needed (a-la GRBs)

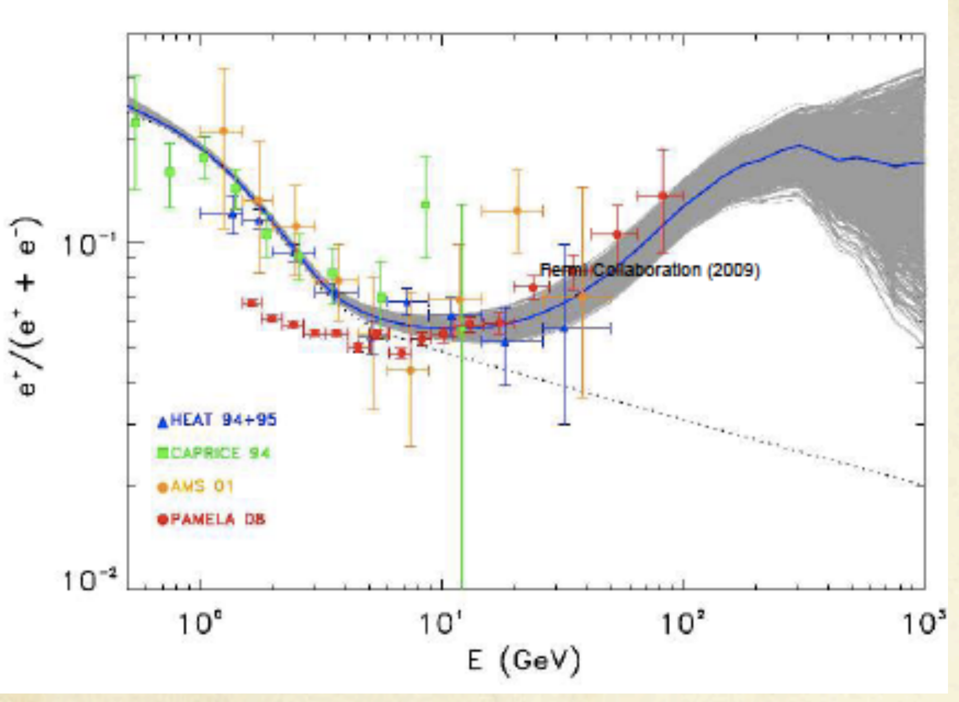
No need of particular activity (nor th. nor exp.)
Unknown predictions but possible fundamental discoveries

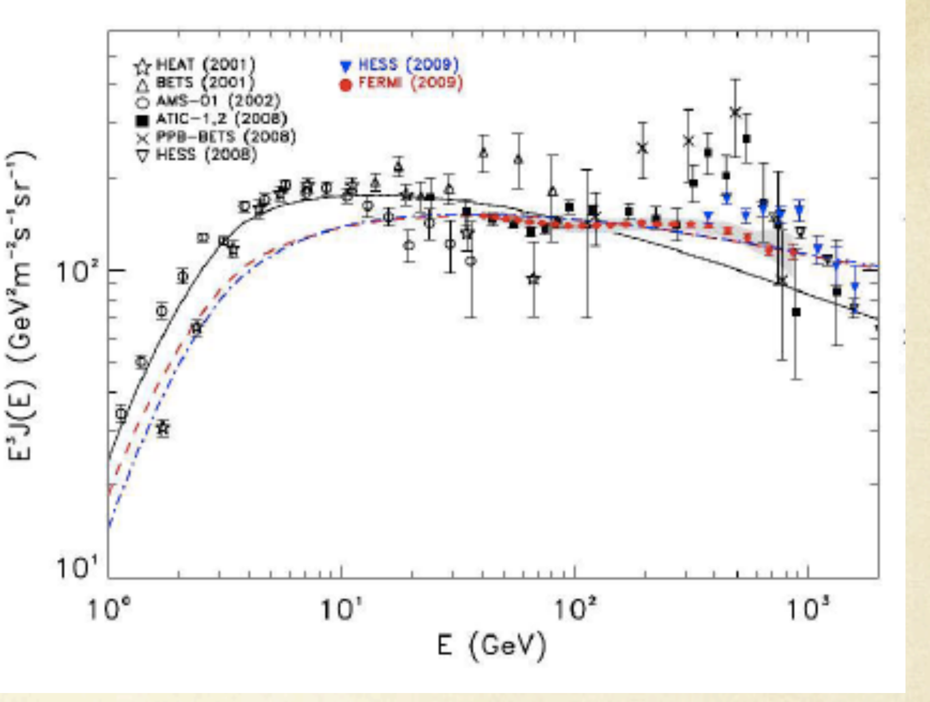
Cosmic rays
Electrons, Positrons, protons, antiprotons, etc

Less exotic but quite fundamental too...

(here many contributions and already published results)

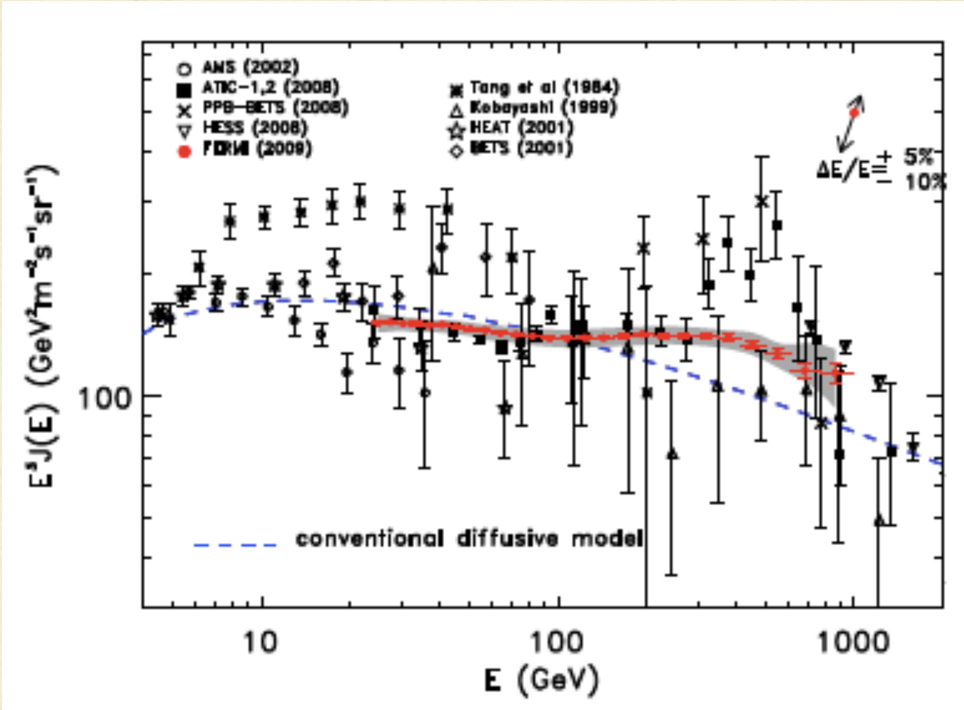
CR signature are bizzarre





- Recent multiple anomalies in CRs fluxes
  - PAMELA: rising e+/e± ratio above 10 GeV
  - PAMELA confirms antiproton-spectrum
  - Fermi, HESS: rising e± spectrum above 100 GeV
- Explanations
  - nearby pulsars/SNRs (<1-2 kpc)
  - Dark Matter annihilation/decay
  - Wrong Local CR model

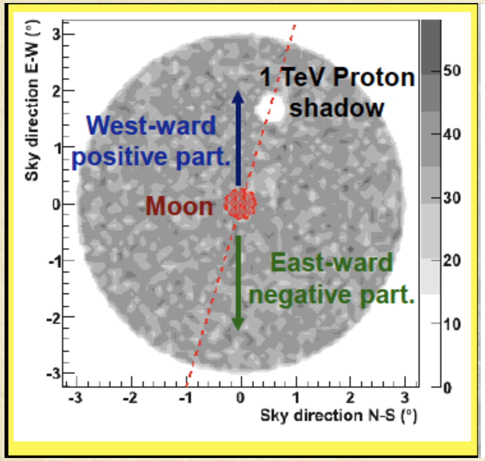
With IACTs: Electrons + Positrons

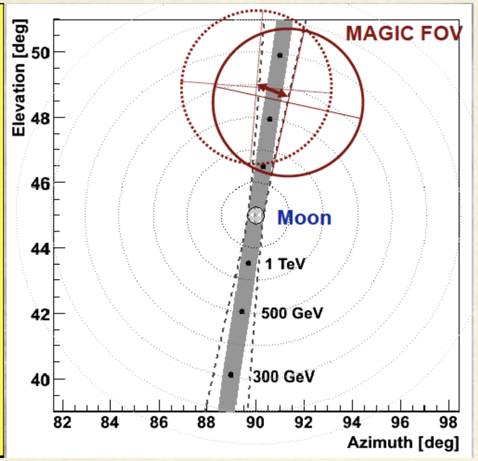


- HESS did it:
  - http://lanl.arxiv.org/abs/0811.3894
  - http://lanl.arxiv.org/abs/0905.0105
- From 300 GeV to 5 TeV analyzing 2004-5 data (77h good quality) and introducing "electroness"
- Again, no-need to point sources but rather analyze OFF data → big success!

Electrons, positrons, protons, antiprotons

* Pierre Colin et al, Proceeding ICRC 2009

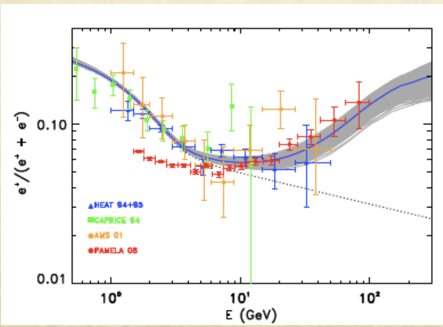




- The moon absorbs charged particle selectively based on charge (e±, p ±, etc)
- A shadow is cast depending on:
  - Charge
  - Energy
- Separation of charges!

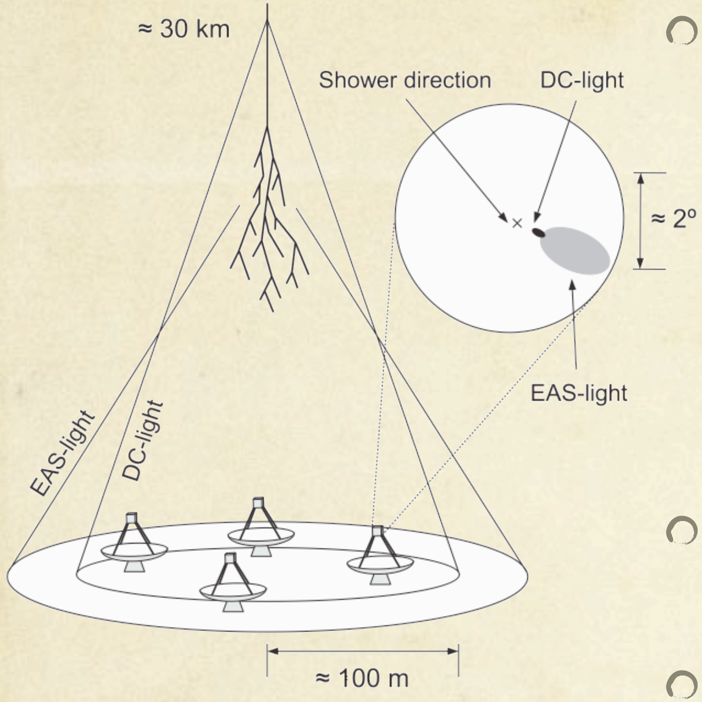
- Complications:
  - Adapted tracking system
  - High DC currrent
  - Reduced HV voltages (flatfield)

- Electron/Positron
  - Results can arrive in 50h (30/year) for MAGIC-stereo
- Proton/Antiproton
  - Higher energy threshold (2-3x)



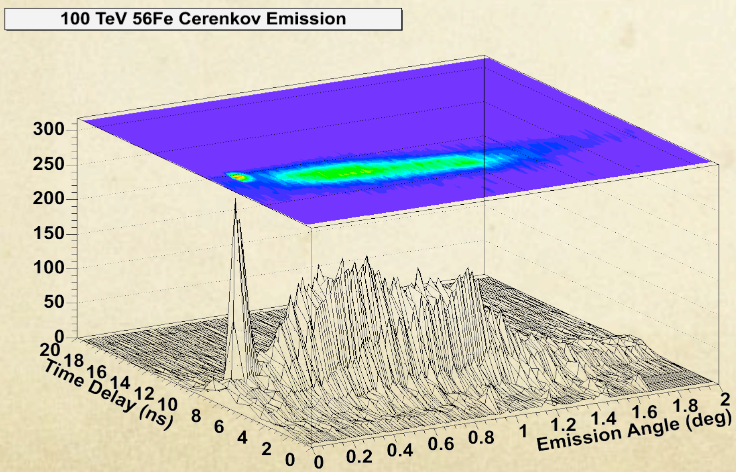
We can extend PAMELA results to higher energies (300Gev-1TeV)

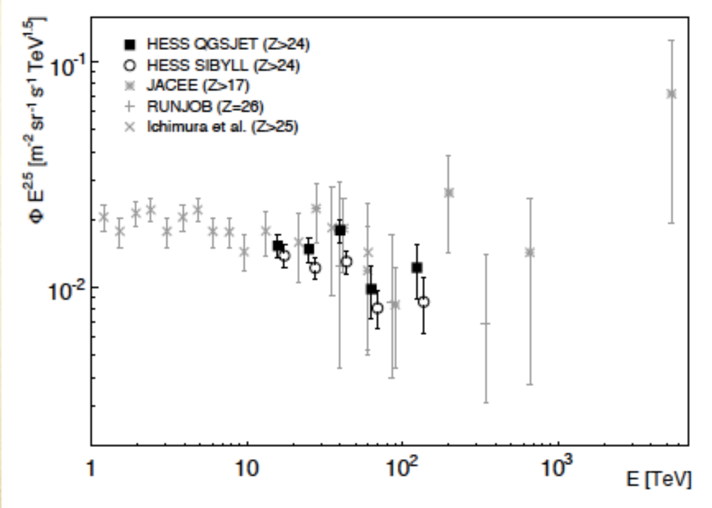
Direct Cherenkov Observation (HESS)



- High Z particles can directly emit Cherenkov light in high atmosphere
  - ☺ Light arrives later 3-5ns
  - ☺ Short duration ~300ps
  - ☺ Toward the center of the camera
  - ☹ Overwhelming Showers (1DC ph / 100 EAS ph.)
  - ☹ >1000 phe in 1 pixel
  - ☹ Difficult Z-estimation

- HESS, "First ground based measurement of atmospheric Cherenkov light from cosmic rays, PRD 75 (2007) 042004")
- Again, Just need to analyze data!





Conclusions

Conclusions #1

- We have seen that IACTs can be:
  - Neutrino detectors
  - Cosmic-ray detectors
- From the theory point of view
  - Need MC studies to really exploit possibilities for CTA
  - Estimations are hardly robust
- From the experimental point of view
  - Important to understand experimental features that better suite the scenarios (CTA-north or south, high energy or low energy, etc)
  - Think about sub-arrays and observation modes
  - Exploit new hardware solutions (different trigger, different tracking, different pointing modes)
  - Exploit new analysis methods

Conclusions #2

- I do not draw conclusions on each argument, it is clear that several scenarios (sometimes bizzarre) had appeared. Nevertheless, maybe searching for India we find America!

Thanks!

References consulted #1

- Tau-neutrino searches
  - Protheroe, “High energy neutrino astrophysics”, arXiv:astro-ph/9809144v2
  - Gaug+, “Proposal for the observation of tau-neutrinos with the MAGIC telescope pointing at the horizon”, internal note
  - Fargion, D. “DISCOVERING ULTRA–HIGH-ENERGY NEUTRINOS THROUGH HORIZONTAL AND UPWARD AIR SHOWERS: EVIDENCE IN TERRESTRIAL GAMMA FLASHES?”, The Astrophysical Journal, 570:909–925, 2002
  - Fargion, D. “The role of ultrahigh energy astrophysics in km^3 detectors”, arXiv:astro-ph/9704205v1
  - Bertou+, “Tau Neutrinos in the Auger Observatory : A New Window to UHECR Sources.”, arXiv:astro-ph/0104452v4
  - Abraham+ [Auger], “Limit on the diffuse flux of ultra-high energy tau neutrinos with the surface detector of the Pierre Auger Observatory”, arXiv:0903.3385v1
  - Abraham+ [Auger], “Upper limit on the diffuse flux of UHE tau neutrinos from the Pierre Auger Observatory”, arXiv:0712.1909v2
  - De Young [Amanda], “Recent Results from IceCube and AMANDA”, Proceedings of the DPF-2009 Conference, Detroit, MI, July 27-31, 2009
- Axion searches
  - Sanchez-conde+, “The search of axion-like-particles with Fermi and Cherenkov telescopes”, arXiv: 1001.1892v1
  - Sanchez-conde+, “Hints of the existence of Axion-Like-Particles from the gamma-ray spectra of cosmological sources”
  - Sanchez-conde+, “Axion searches with Fermi and IACTs”, RICAP ’09

References consulted #2

- Magnetic monopoles
  - Gerrit-Christian Spengler, “Signatures of Ultrarelativistic Magnetic Monopoles in Imaging Cherenkov Telescopes”, PhD Thesis Humboldt-Universit¨at zu Berlin 2009
- Gravitational Waves
  - Stamerra A. “Proposal for observation with MAGIC”, Internal note, 2008
  - Hughes, Thorne “Seismic gravity-gradient noise in interferometric gravitational-wave detectors”, PHYSICAL REVIEW D, VOLUME 58, 122002
  - Abadie+ [Vigo, Lirgo, Eso], “All-sky search for gravitational-wave bursts in the first joint LIGO-GEO-Virgo run”, PHYSICAL REVIEW D 81, 102001 (2010)
- Cosmic-rays
  - Pomarede+, “Search for shadowing of primary cosmic radiation by the moon at TeV energies”, Astroparticle Physics 14 (2001) 287±317
  - Colin P.+ “Observation of the cosmic-ray moon shadow”, MAGIC internal note 2010
  - Colin P+, “Observation of shadowing of the cosmic electrons and positrons by the Moon with IACT”, PROCEEDINGS OF THE 31st ICRC, Ł´OD´Z 2009 1
  - Aharonian et al [HESS Coll], “The energy spectrum of cosmic-ray electrons at TeV energies”, Phys.Rev.Lett.101:261104, 2008
  - Aharonian et al [HESS Coll], “Probing the ATIC peak in the cosmic-ray electron spectrum with H.E.S.S”, Astron.Astrophys.508:561, 2009
  - Aharonian et al [HESS Coll], “First ground based measurement of atmospheric Cherenkov light from cosmic rays.”, Phys.Rev.D75:042004,2007

Backup Slides

Diffuse muon-nuetrino fluxes (Protheroe)

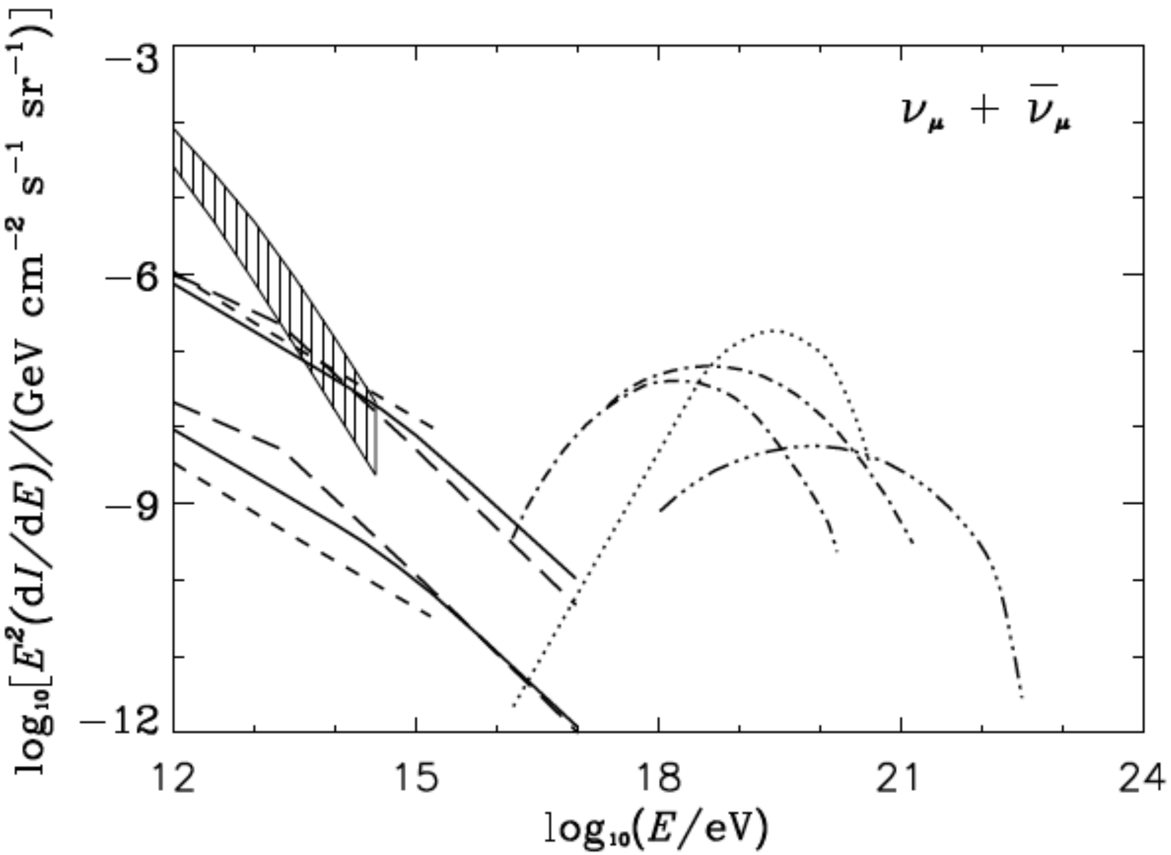


Figure 1. Neutrinos from cosmic ray interactions with the interstellar medium (upper curves for $\ell = 0°$, $b = 0°$, lower curves for $b = 90°$): — — — Domokos et al. [9]; - - - - Berezinsky et al. [10]; —— Ingelman and Thunman [11]. The band with vertical hatching shows the range of atmosheric neutrino background [12] as the zenith angle changes from 90° (highest) to 0° (lowest). Neutrinos from cosmic ray interactions with the microwave background: – · – · – · – Protheroe and Johnson [23] for $E_{max} = 3 \times 10^{20}$ eV and 3×10^{21} eV; · · · · · · Hill and Schramm [24]; – · · · – · · · – · · · – assuming the highest energy cosmic rays are due to GRB according to Lee [25].

Diffuse nu_mu fluxes from GRBs and AGNs