Astroparticles and fundamental physics

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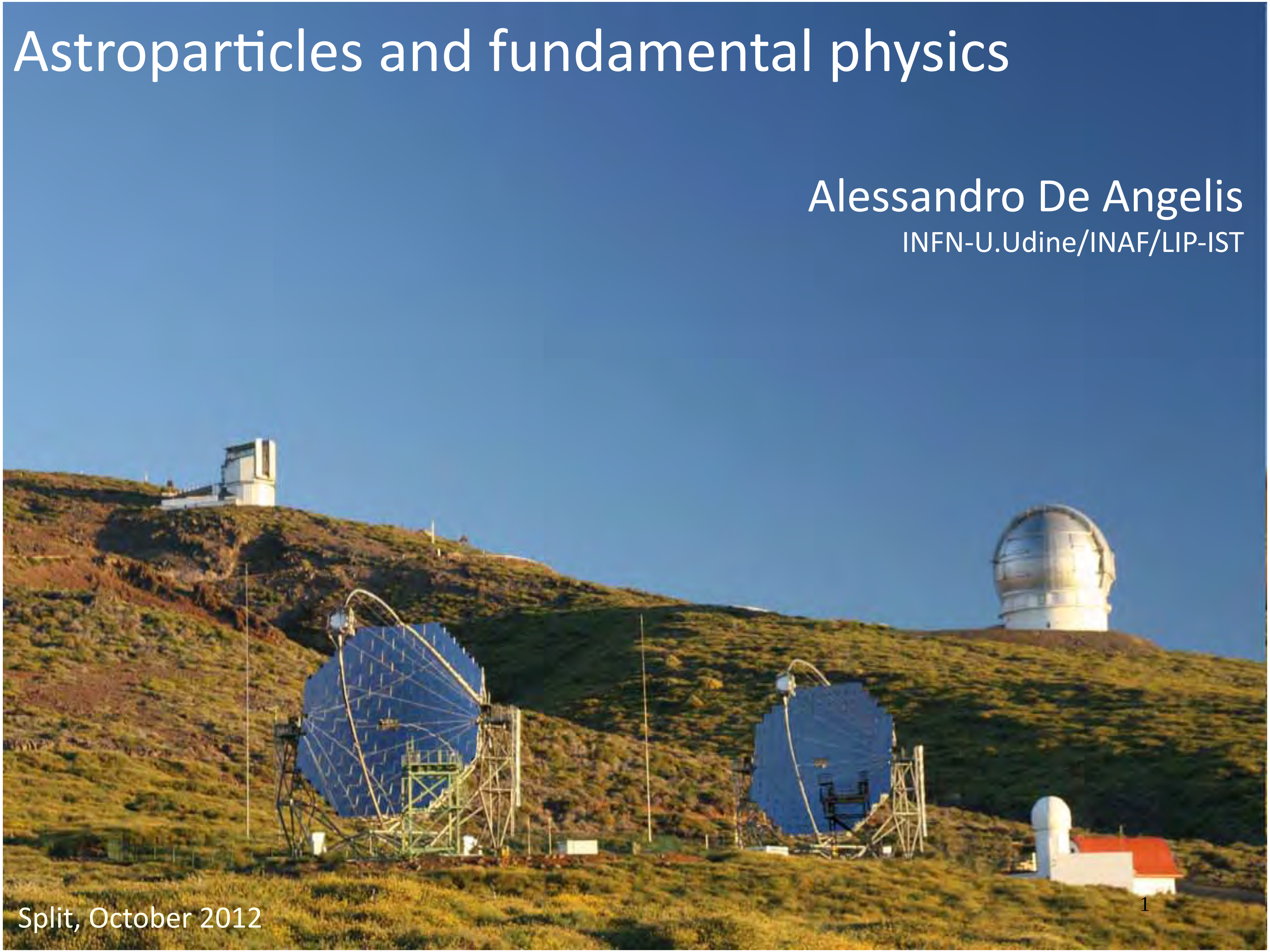


Split, October 2012

CERN/GEN/8

CONSEIL EUROPEEN POUR LA RECHERCHE NUCLEAIRE

CERN EUROPEAN COUNCIL FOR NUCLEAR RESEARCH

Organisme intergouvernemental créé par l'Accord de Genève du 15 Février 1952

CONVENTION

FOR THE ESTABLISHMENT OF A EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

PARIS, 1ST JULY, 1953

CONVENTION

POUR L'ETABLISSEMENT D'UNE ORGANISATION EUROPEENNE POUR LA RECHERCHE NUCLEAIRE

PARIS, LE 1ER JUILLET 1953

Research on cosmic rays is in CERN's constitution

3. The basic programme of the Organization shall comprise:

(...)

(c) The organization and sponsoring of international co-operation in nuclear research, including co-operation outside the Laboratory. This co-operation may include in particular:

(i) work in the field of theoretical nuclear physics;

(ii) the promotion of contacts between, and the interchange of, scientists, the dissemination of information, and the provision of advanced training for research workers;

(iii) collaboration with and advising of national research institutions;

(iv) work in the field of cosmic rays.

The origin and the nature of CR
Dark Matter
New and undiscovered particles
Photon propagation (new particles, cosmology)
Testing fundamental symmetries

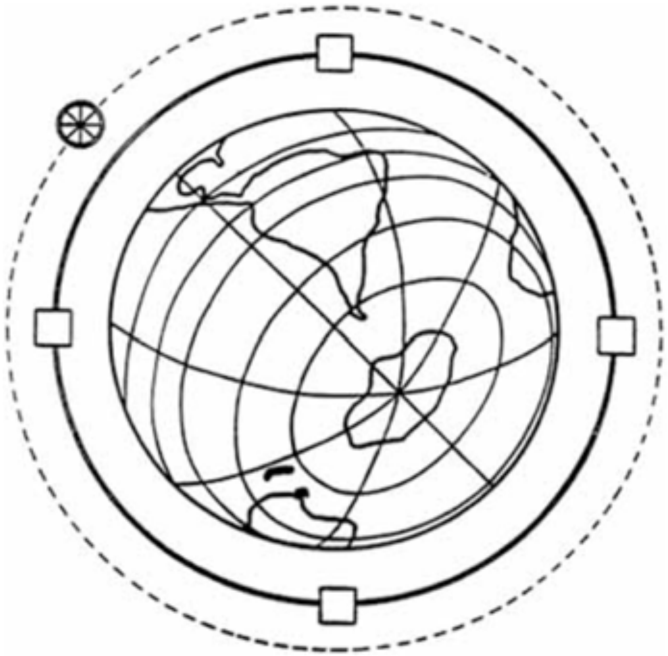
The 1953 Cosmic Ray Conference at Bagneres de Bigorre (Cronin 2011, arXiv:111.5338)

- From the concluding remarks by Leprince-Ringuet:

"If we want to draw certain lessons from this congress let's point out first that in the future we must use the particle accelerators. Let's point out for example the possibility that they will permit the measurement of certain fundamental curves (scattering, ionization, range) which will permit us to differentiate effects such as the existence of pi mesons among the secondaries of K mesons.

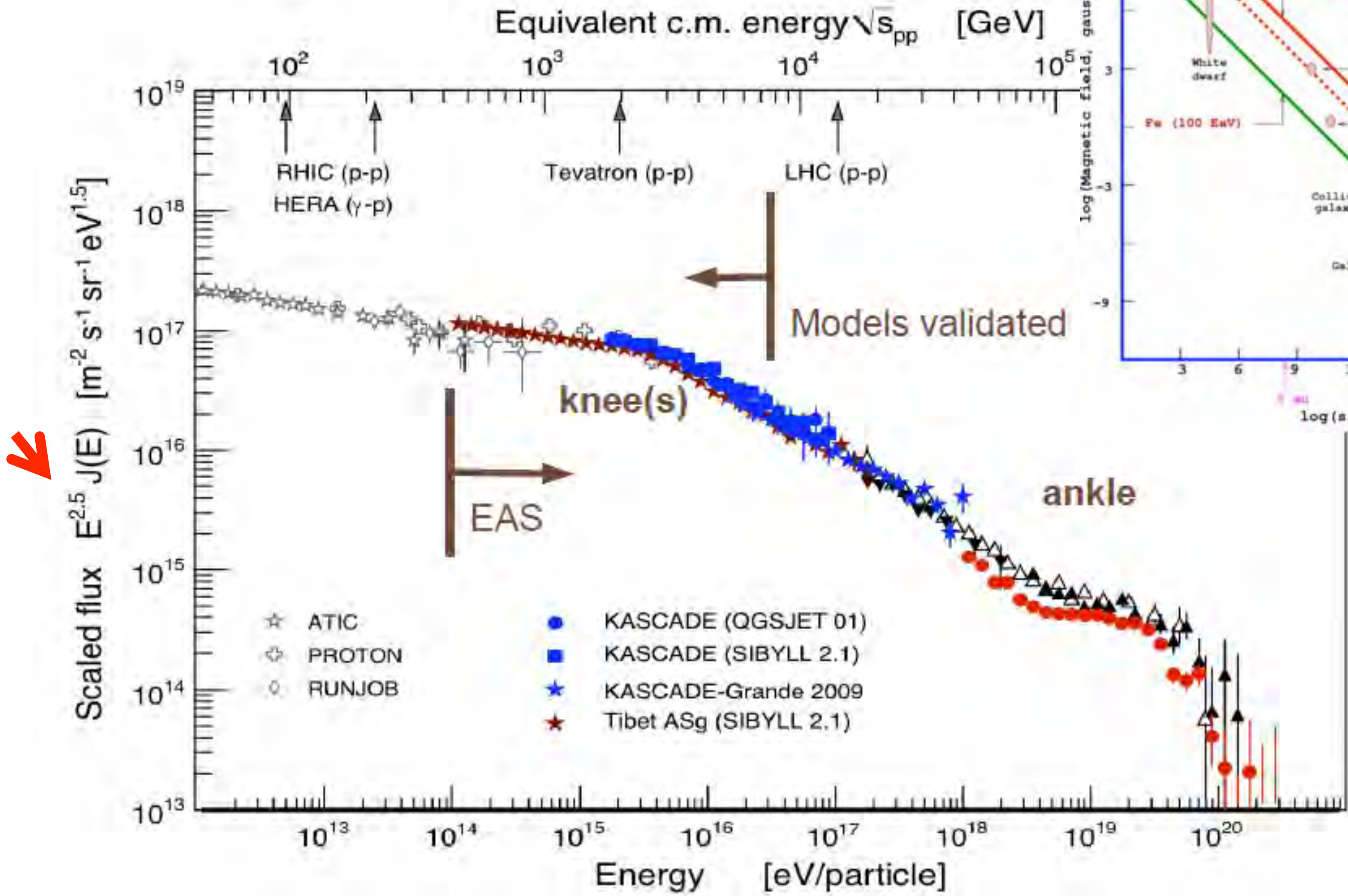
I would like to finish with some words on a subject that is dear to my heart and is equally so to all the "cosmicians", in particular the "old timers". […] We have to face the grave question: what is the future of cosmic rays? Should we continue to struggle for a few new results or would it be better to turn to the machines?

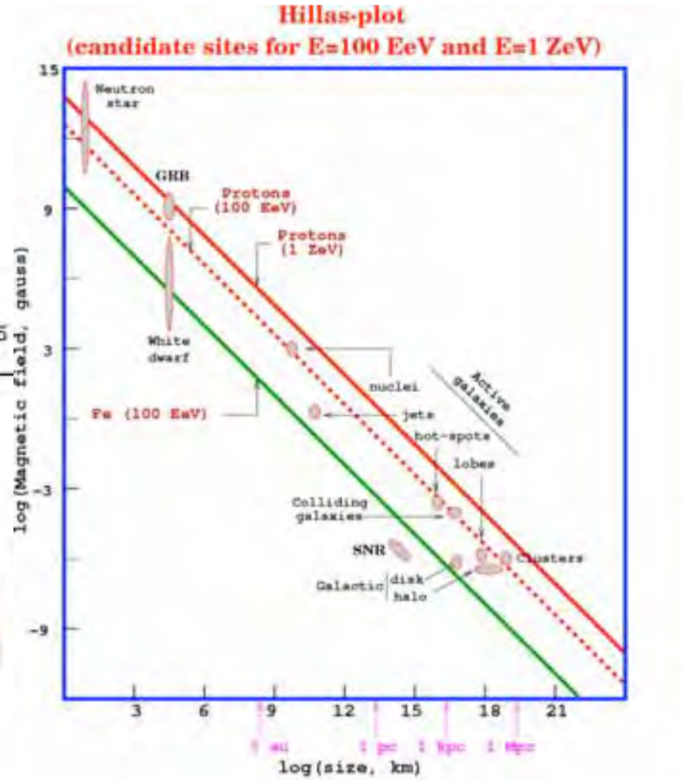
One can no doubt say that that the future of cosmic radiation in the domain of nuclear physics depends on the machines […]. But probably this point of view should be tempered by the fact that we have the uniqueness of some phenomena, quite rare it is true, for which the energies are much larger […]"



(E. Fermi 1954, a possible "maximum" accelerator reaching cm eneggy of 5000 TeV, talk to the APS)

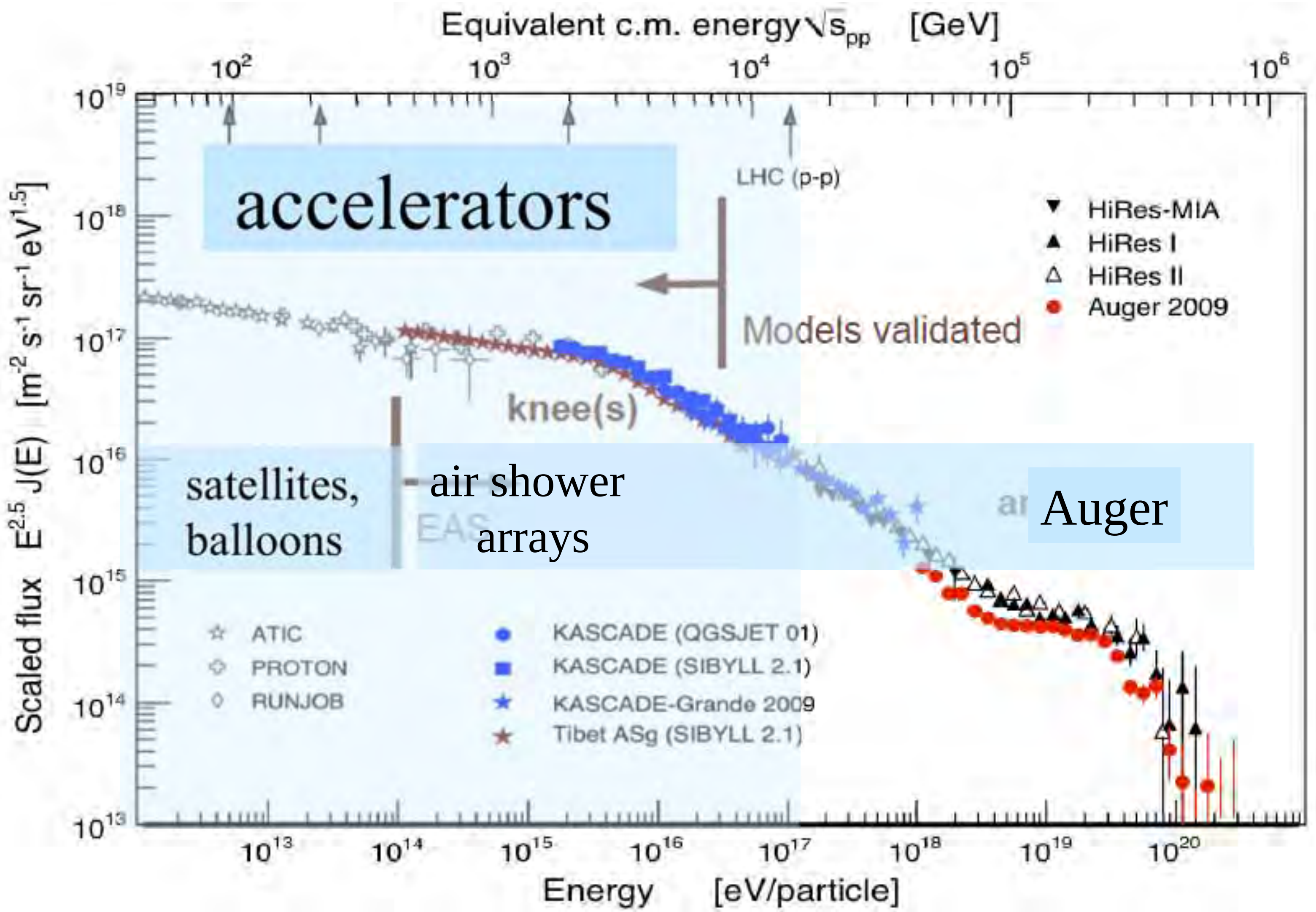
Cosmic Rays





R. Engel (KIT)

Cosmic Rays and LHC



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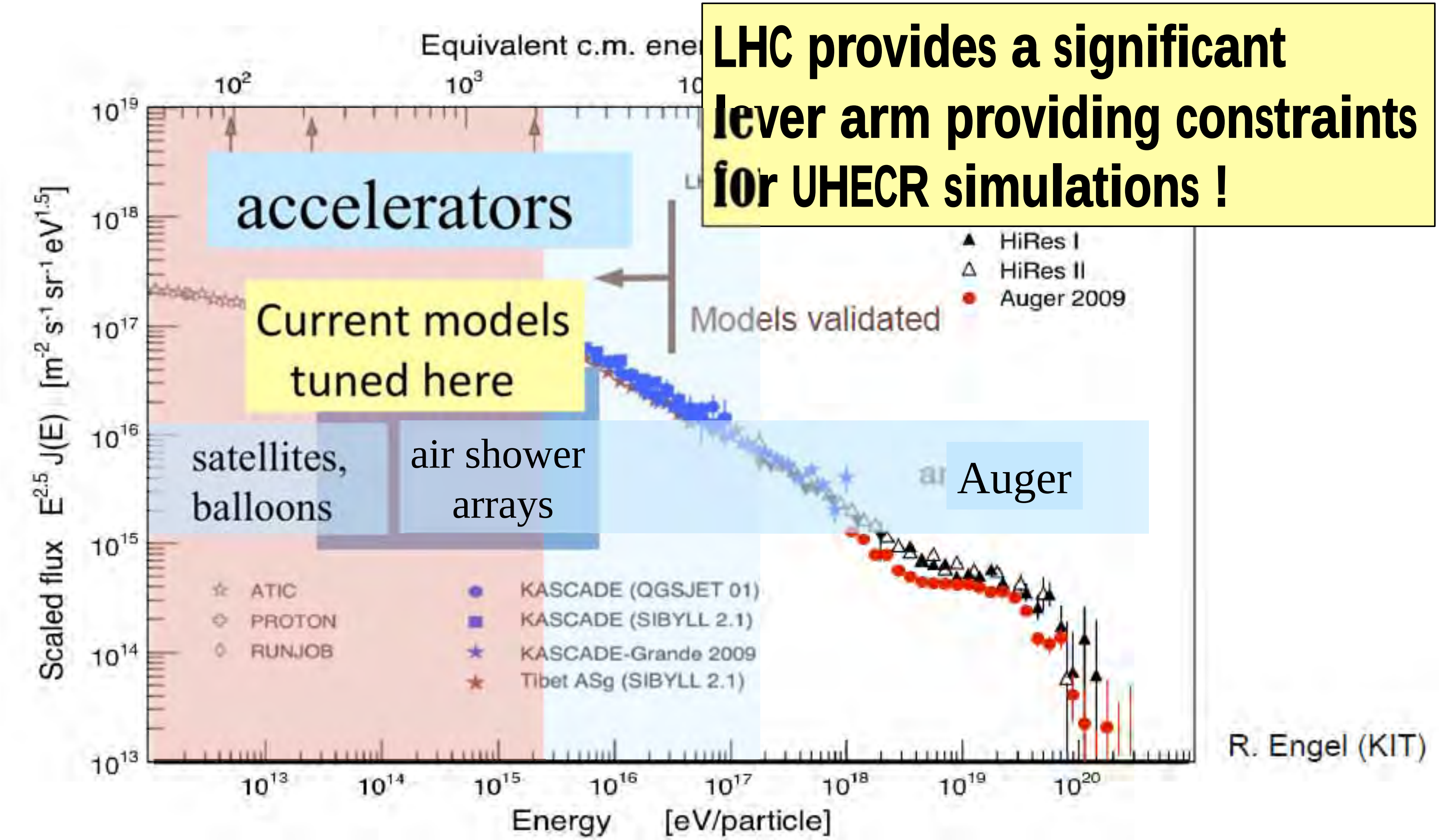
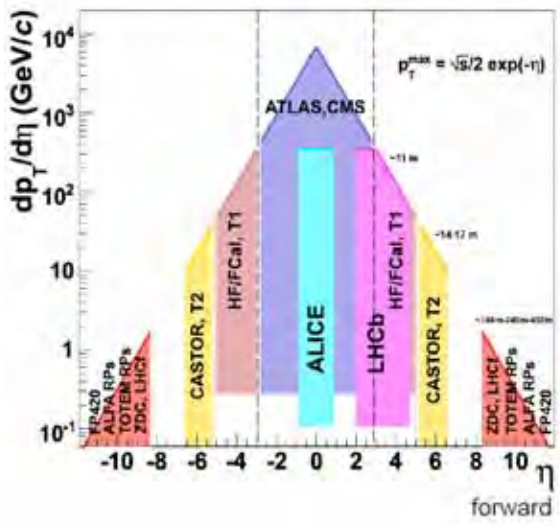
Cosmic Rays and LHC



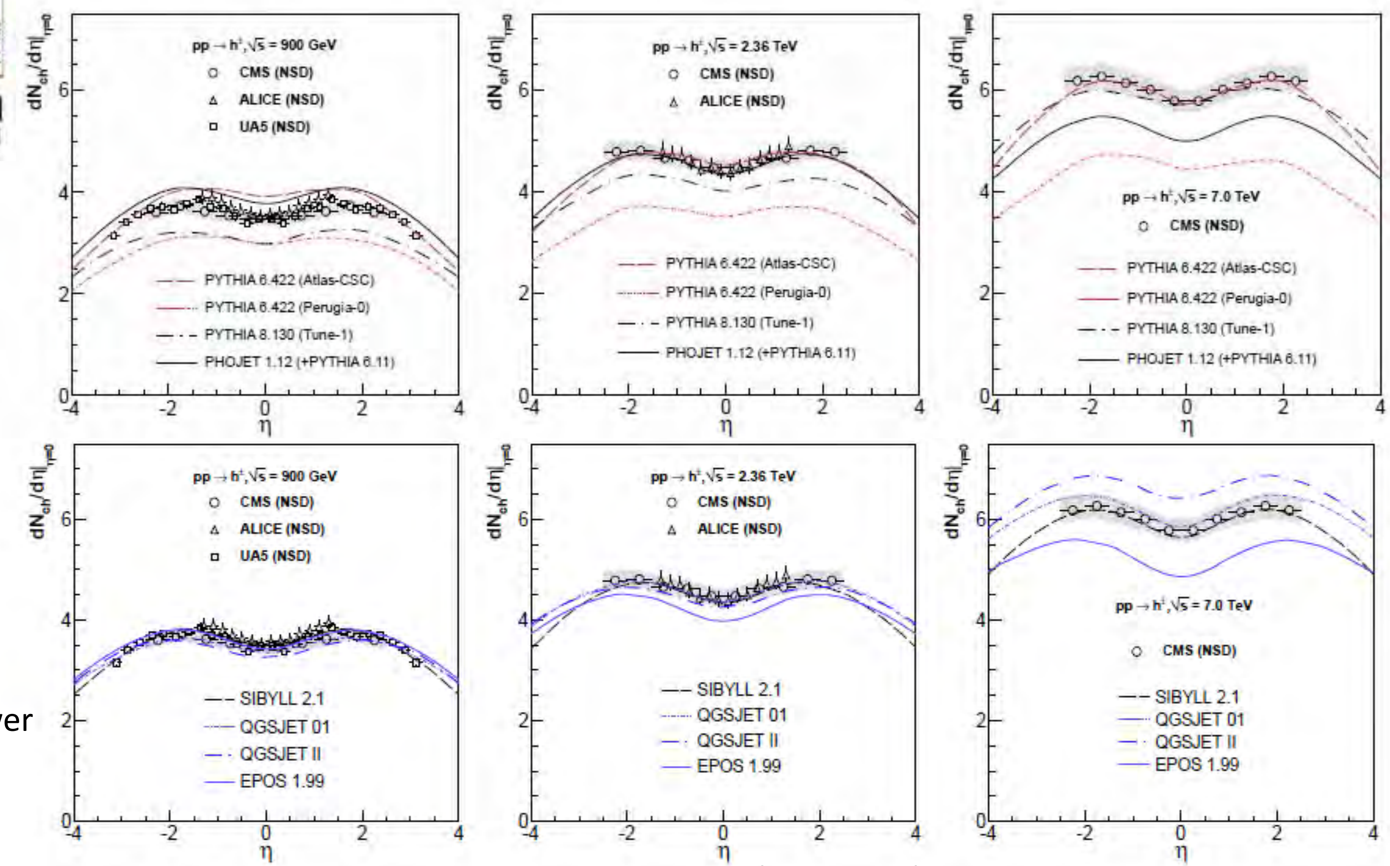
Small-x region (LHC as a pathfinder for CR, and vice-versa)



- LHC detectors cover all wide rapidity range
- EAS models bracket accelerator data
- no model perfect, but EAS models seem to do better than HEP models

- **HEP**
  High Energy Physics
  models

- **EAS**
  Extensive Air Shower
  models

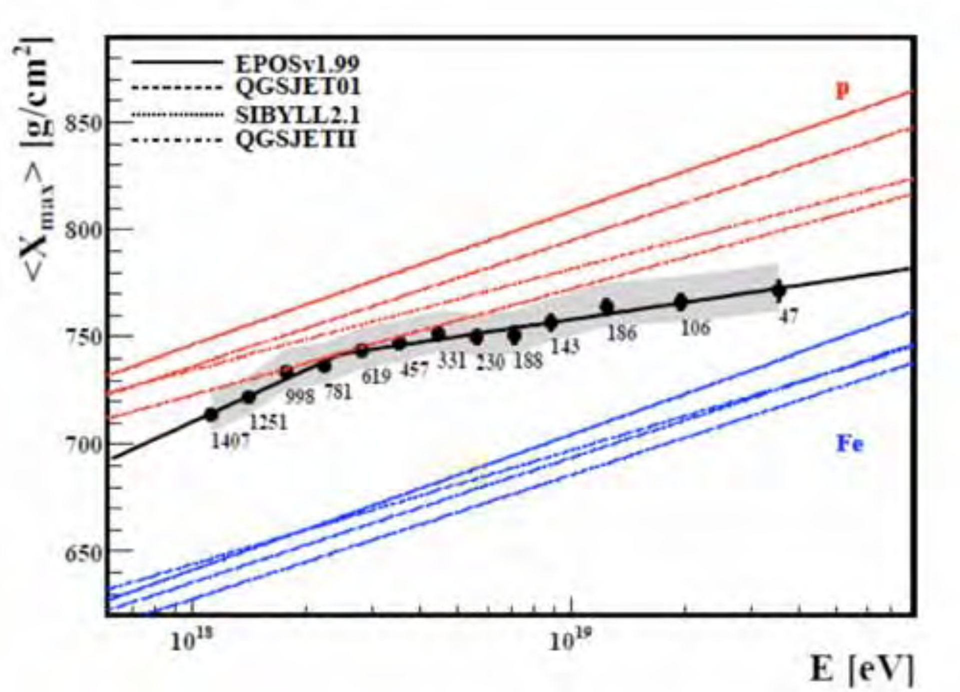


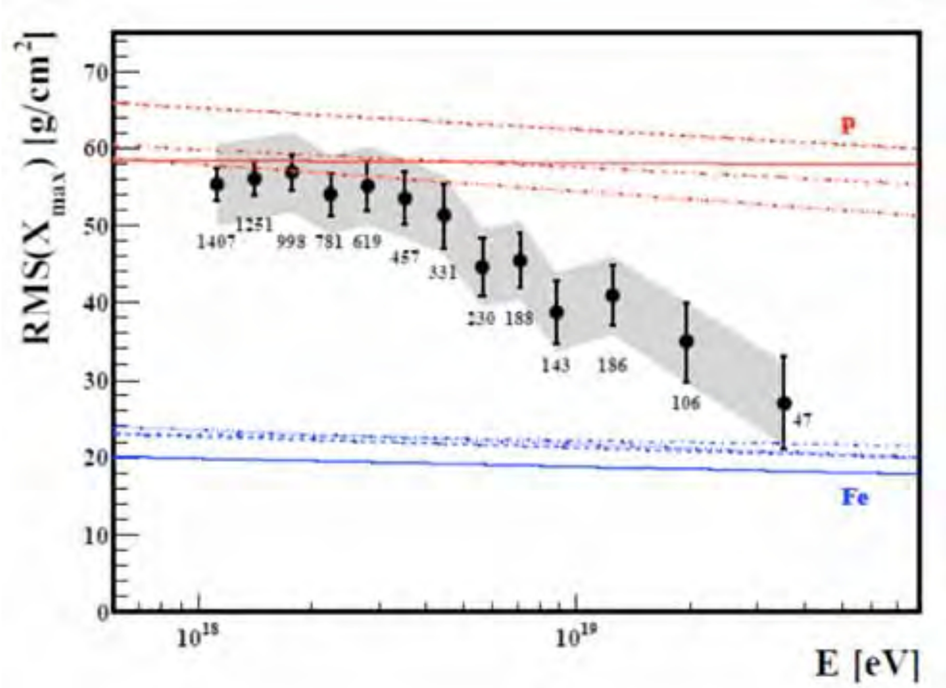
(Spiering)

Cross sections: something not understood in Auger

Shower Maximum X_{max}

(Pimenta)





These suggest high cross section and high multiplicity at high energy.

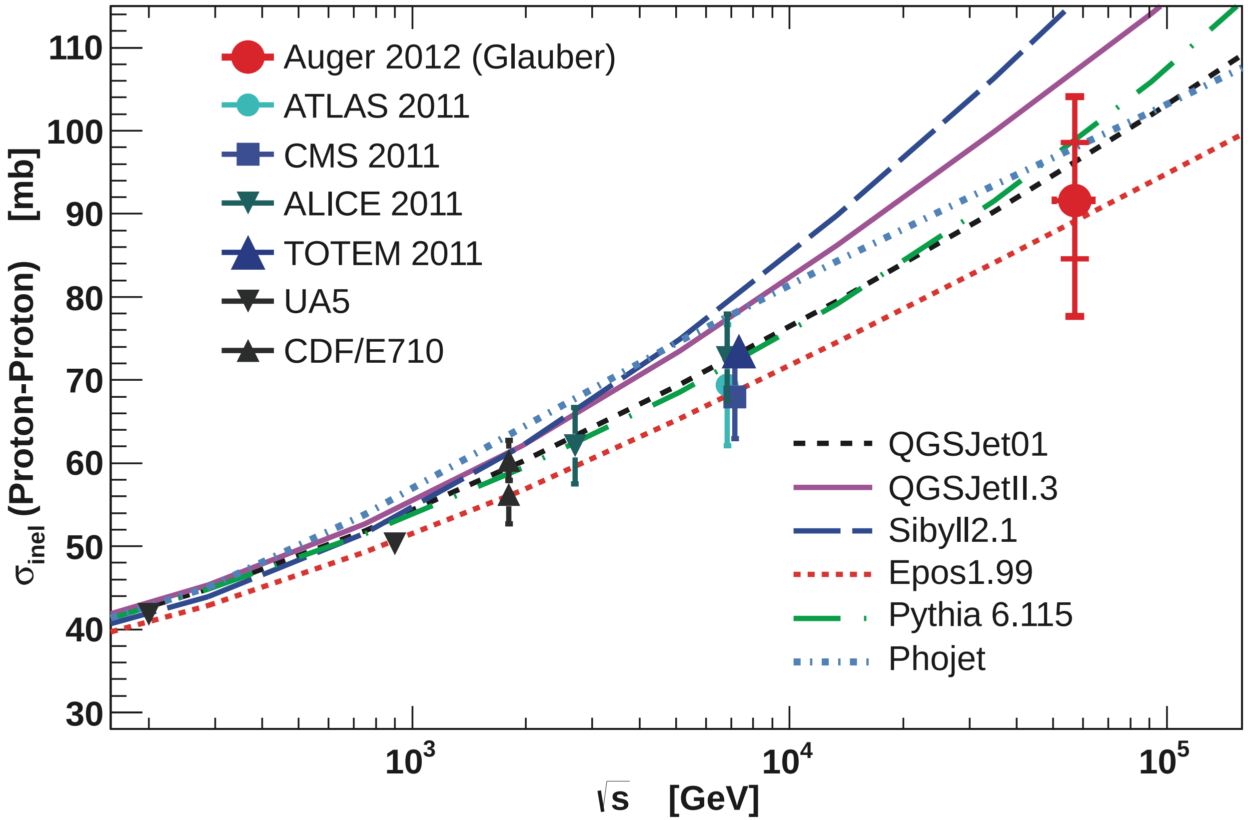
Heavy nuclei?

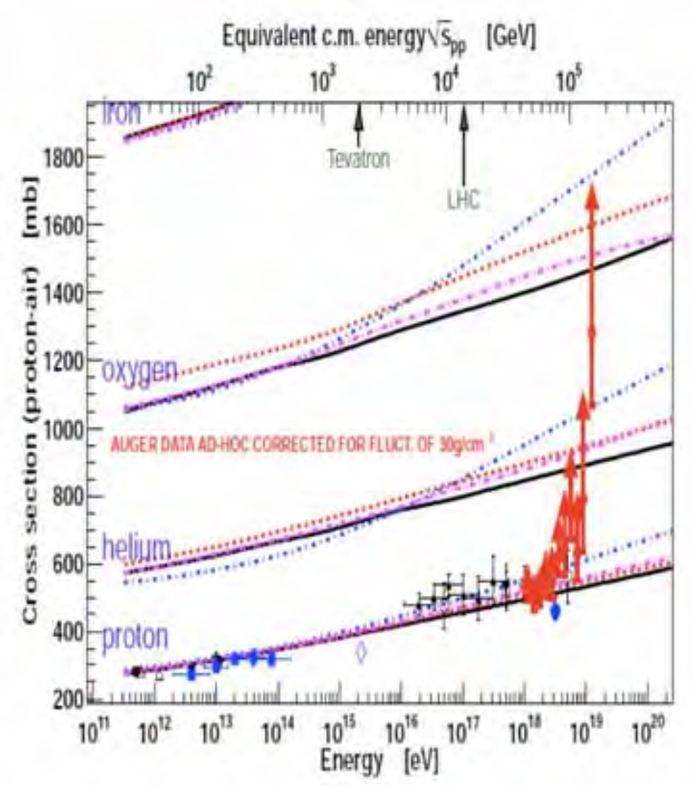
Or protons interacting differently than expected?

Information lacking for the EHE (anisotropic?) energy regime!

Cosmic Rays and LHC: total cross section

pp inel. cross section at sqrt(s)=57 TeV





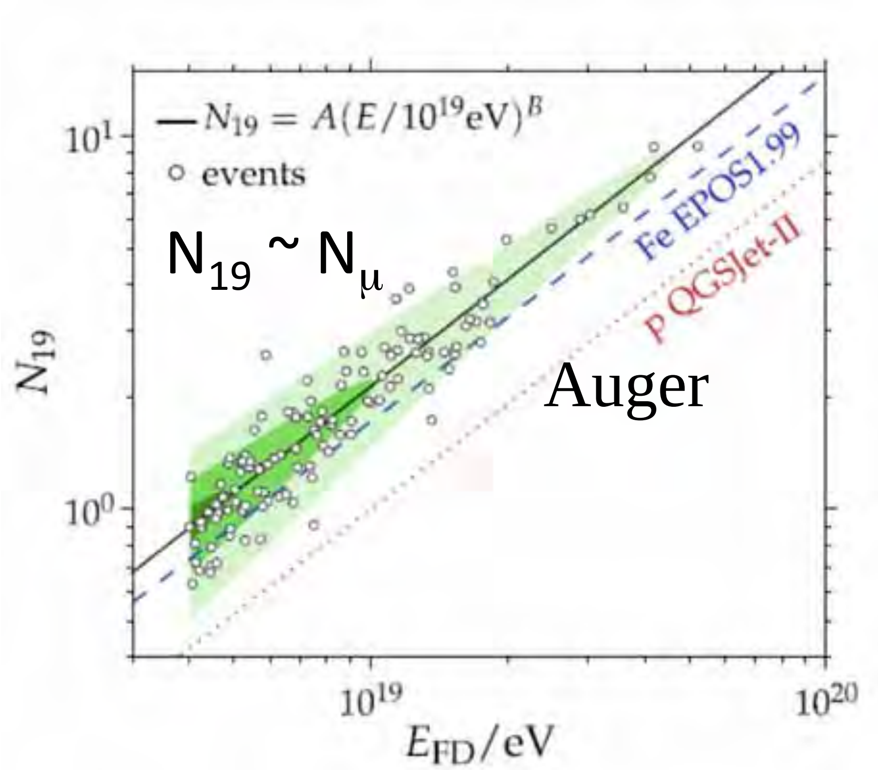
- Test Glauber model
- Tune EAS simulations

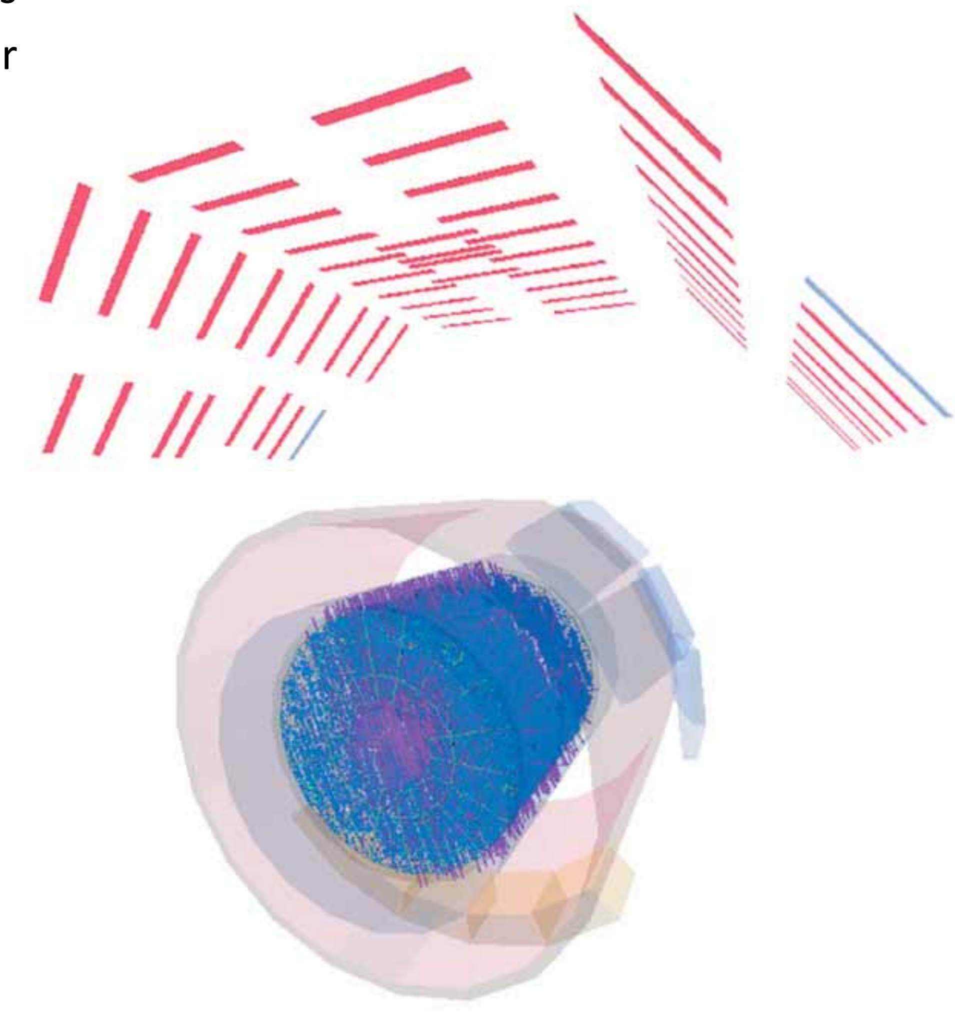
If protons, the X-section rises at ~100 TeV => A new physics scale?

Extreme muon multiplicities

- High-multiplicity cosmic event in ALICE →
  - Density of ~18 muons/m^2 (within the TPC volume)

- Similar enigmas in underground experiments
- Muon numbers in EAS about 50-100% higher predictions

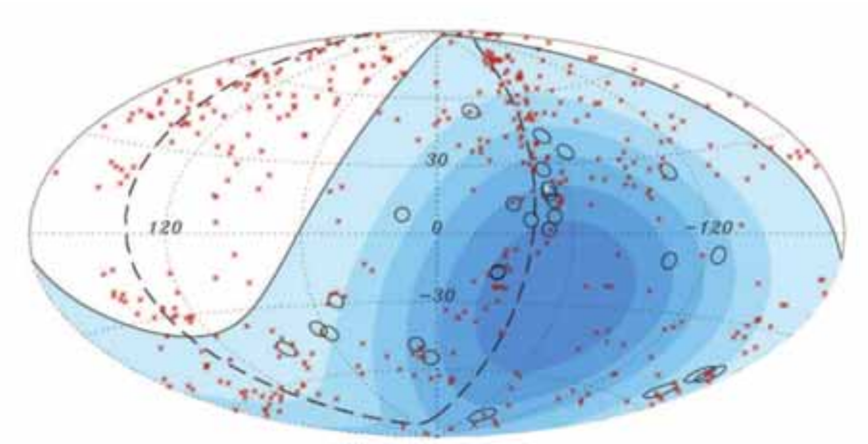




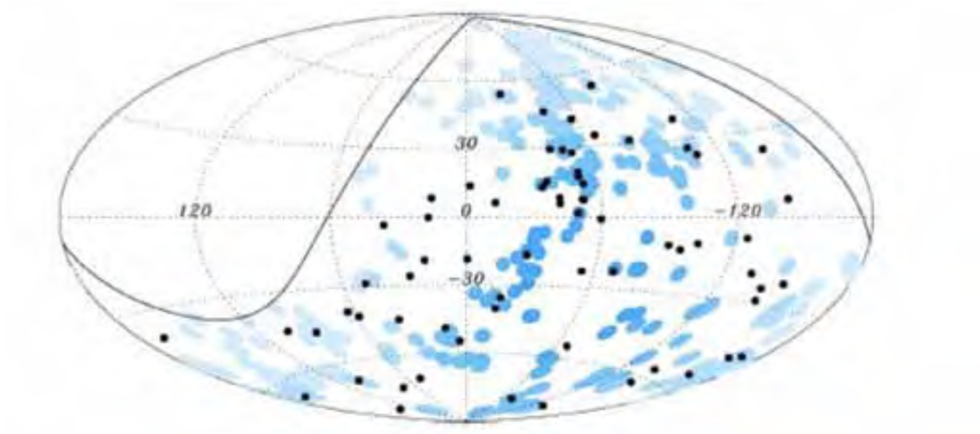
- → Upgrade EAS experiments with muon counters

Origin: the evidence for the emission of EHE hadrons by AGN almost disappeared (apart from CenA)

- The "direct" measurement by AUGER (E > 60 EeV)



27 events as of November 2007



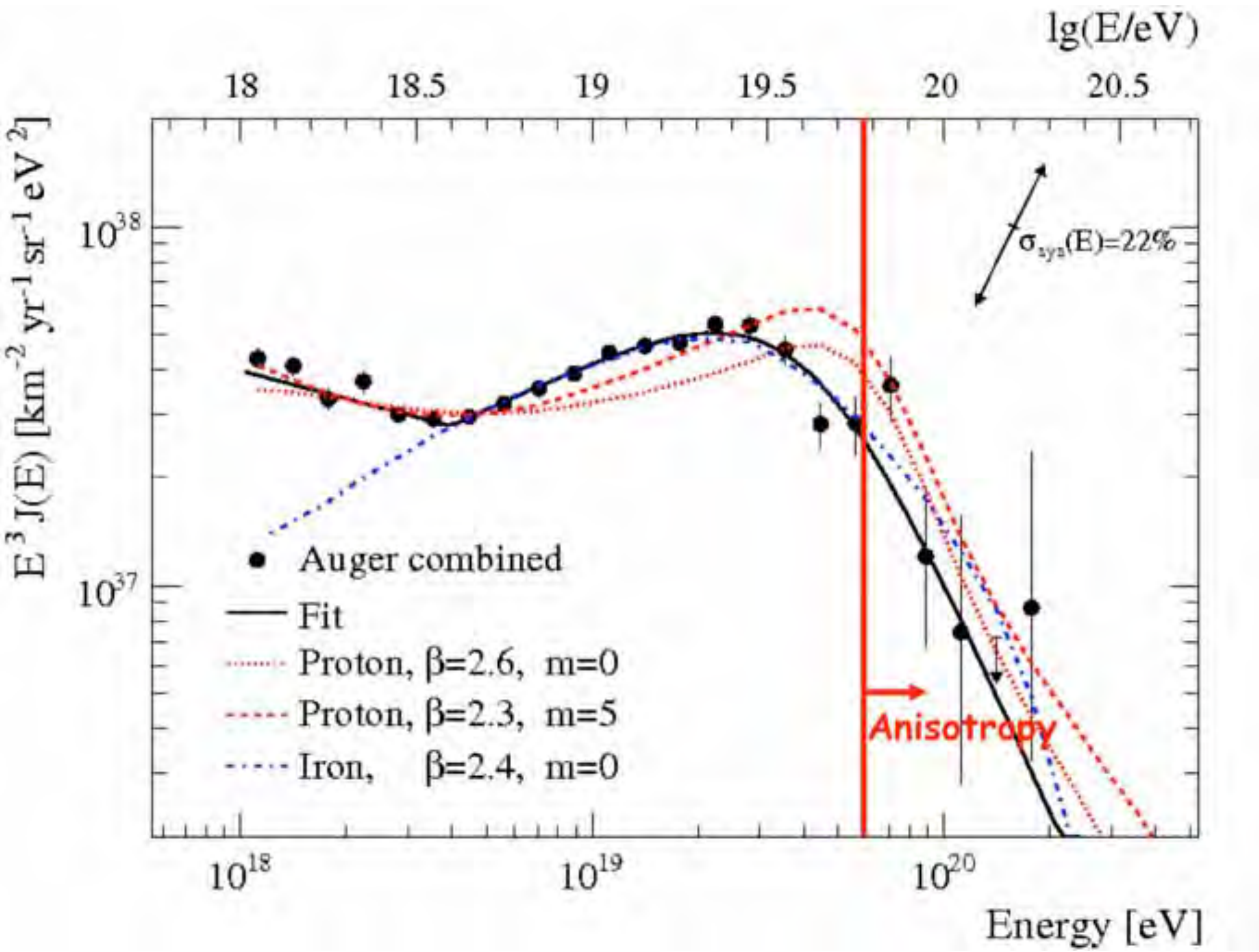
84 events now; 28 correlate with AGN

Correlation significant only around CenA

- Orphan flares in TeV band (?)
- The production region of gammas from flares in M87 is accompanied by radio activity very close to the BH, where there is abundance of protons
  - If SNRs O(10 SM) can explain CR at O(1 PeV), BH O(10^9 SM) "might" explain CR up to O(10^{23} eV)

One should be careful about astrophysics with CR …

- Auger observations confirm the GZK cutoff



$$\frac{E}{1\ \mathrm{EeV}} \cong \frac{B}{1\ \mu G} \times \frac{R}{1\ \mathrm{kpc}}$$

- Role of magnetic fields
  - Galactic astrophysics impossible (B_{MW}~1μG)
  - Extragalactic astrophysics very difficult:

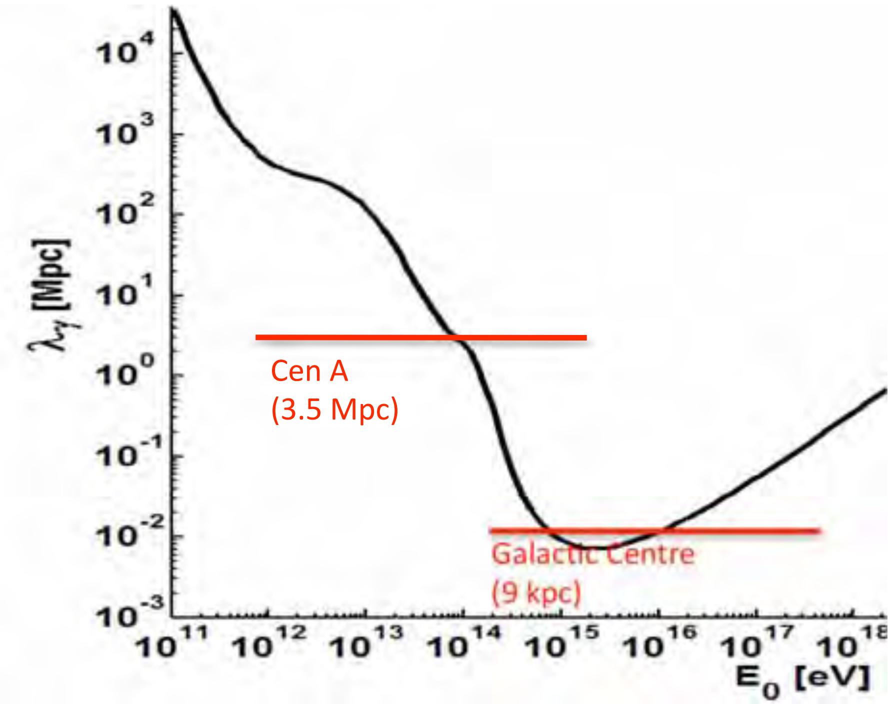
Angular spread $\theta \simeq 0.25^\circ \left(\frac{d}{\lambda}\right)^{1/2} \left(\frac{\lambda}{1\,\mathrm{Mpc}}\right) \left(\frac{B}{1\,\mathrm{nG}}\right) \left(\frac{10^{20}\,\mathrm{eV}}{E}\right)$

High energy neutrinos

- IceCube providing data with unprecedented quality and statistics
  - 2 events with E ~ 1 PeV
  - Cluster from 4C15.54 (z ~ 0.36) ?
  - Several indications that it might be close to a detection
- Possible case for a Northern detector, with substantially larger sensitivity than IceCube.
- IceCube, Km3NeT, GVD-Baikal → future Global Neutrino Observatory.

But the present is VHE gamma-rays…

However, with a limited sight for present detectors



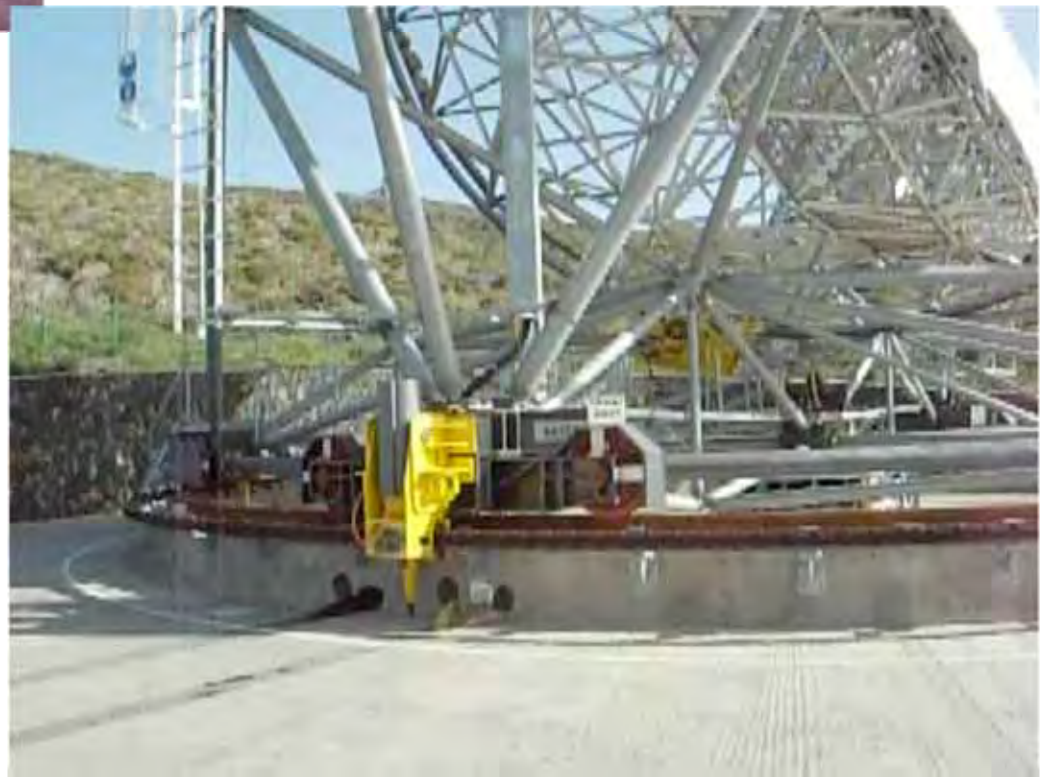
MAGIC at La Palma

(2 x 17 meters diameter telescopes)

An international collaboration of 160 scientists from institutes in Germany, Italy, Spain, Japan, Switzerland, Finland, Poland, Bulgaria, Croatia

Commissioned as a stereo system since May 2010

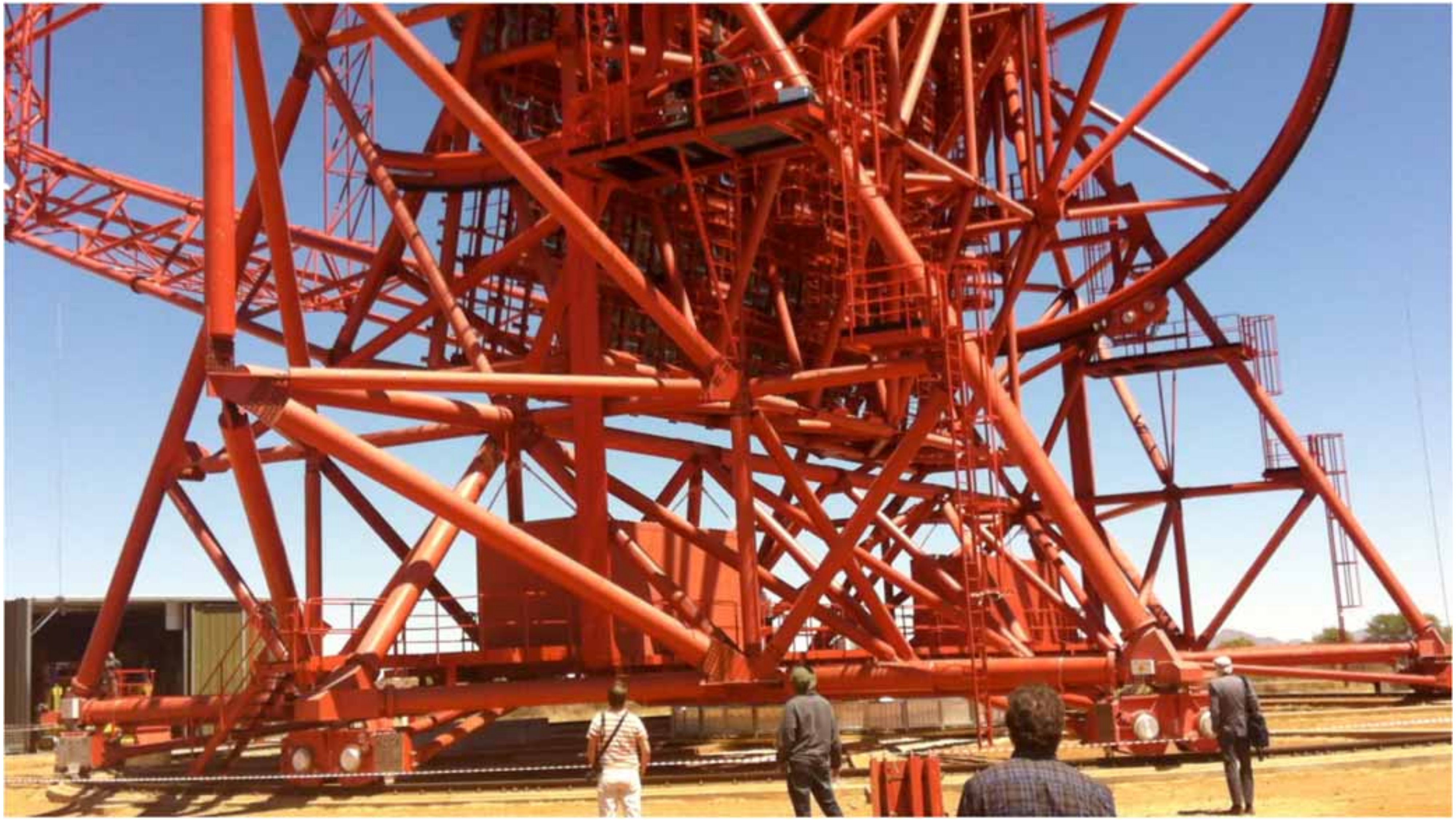
(was mono since 2004)



Instr.	Tels. #	Tel. A (m^2)	FoV (°)	Tot A (m^2)	Thresh. (TeV)	PSF (°)	Sens. (%Crab)
H.E.S.S.	4	107	5	428	0.1	0.06	0.7
MAGIC	2	236	3.5	472	0.05(0.03)	0.06	0.8
VERITAS	4	106	4	424	0.1	0.07	0.7

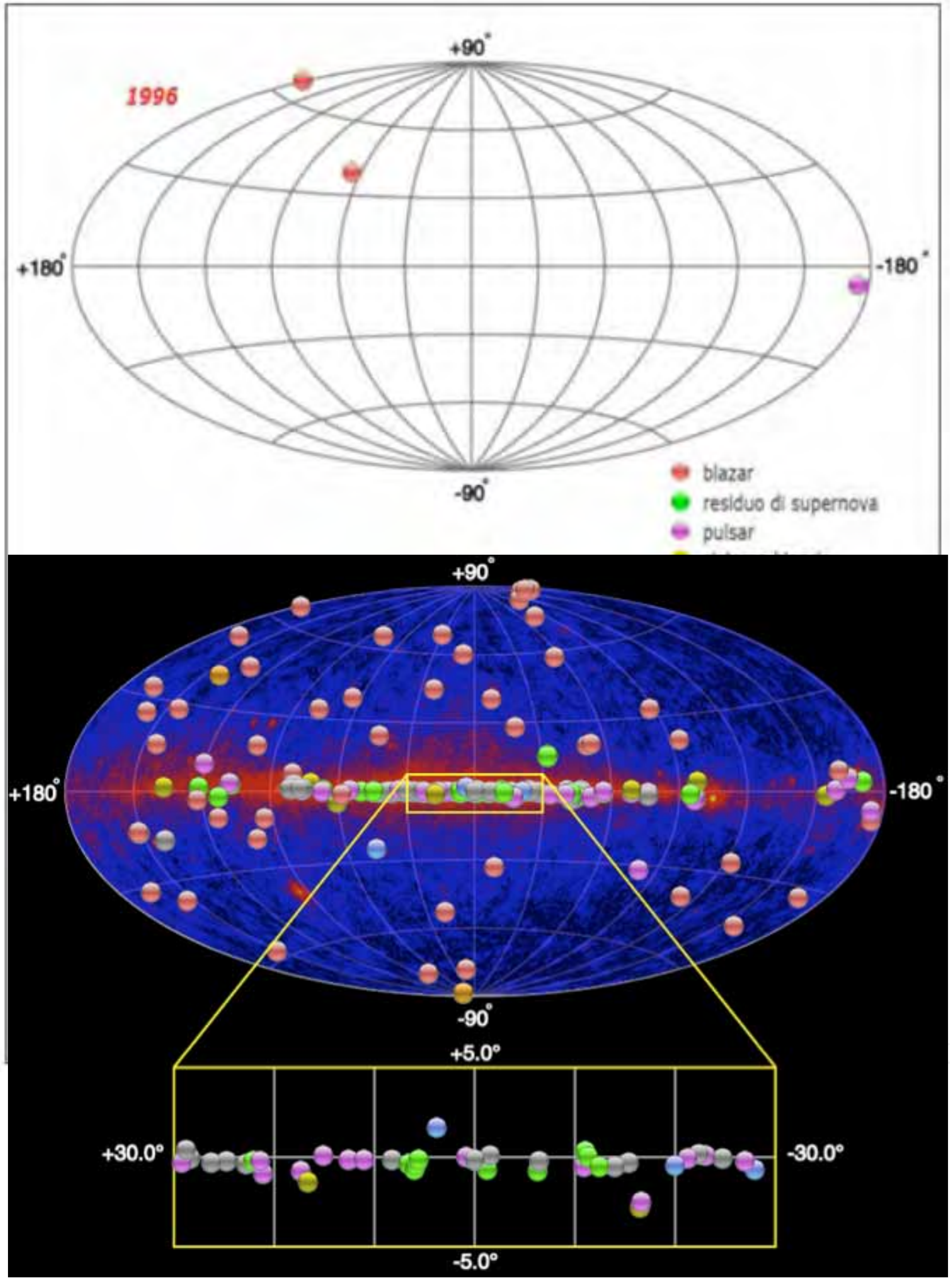
VERITAS: 4 telescopes (~12m) in Arizona operational since 2006

H.E.S.S.: 4 telescopes (~12m) in Na 003
HESS 2: 5th telescope (27-28m) will w
months

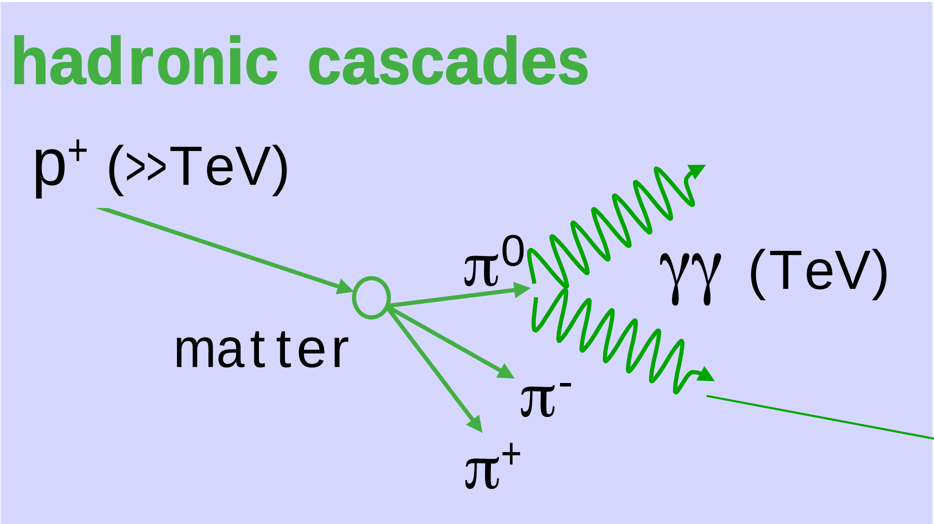


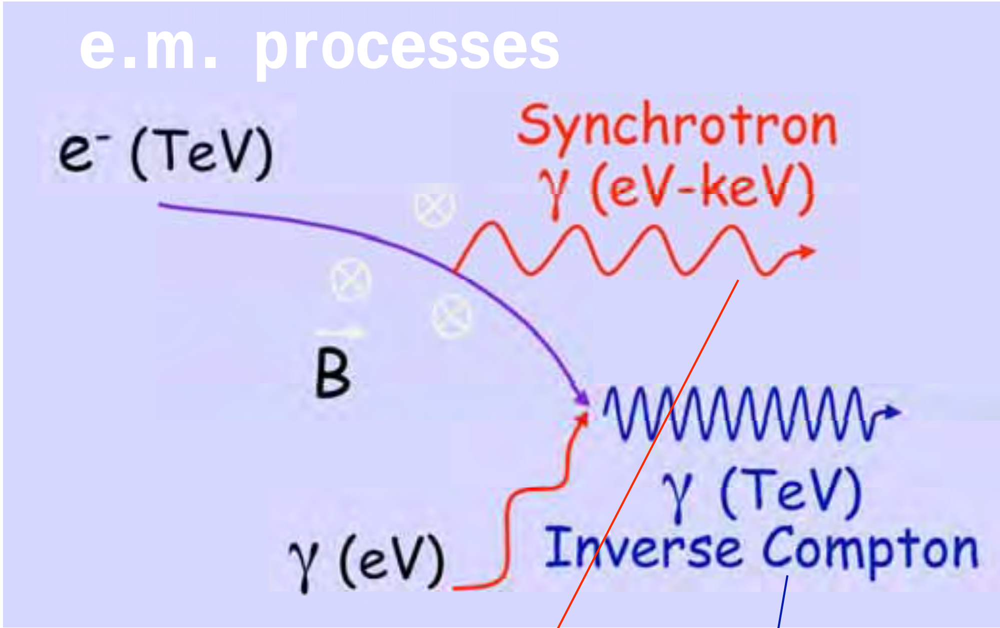
Highlight in γ-ray astrophysics (MAGIC, HESS, VERITAS)

- Thanks mostly to Cherenkov telescopes, imaging of VHE (> 30 GeV) galactic sources and discovery of many new galactic and extragalactic sources: ~ 150 (and >200 papers) in the last 7 years
  - And also a better knowledge of the diffuse gammas and electrons
- A comparable success in HE (the Fermi realm); a 10x increase in the number of sources
- A new tool for cosmic-ray physics and fundamental physics



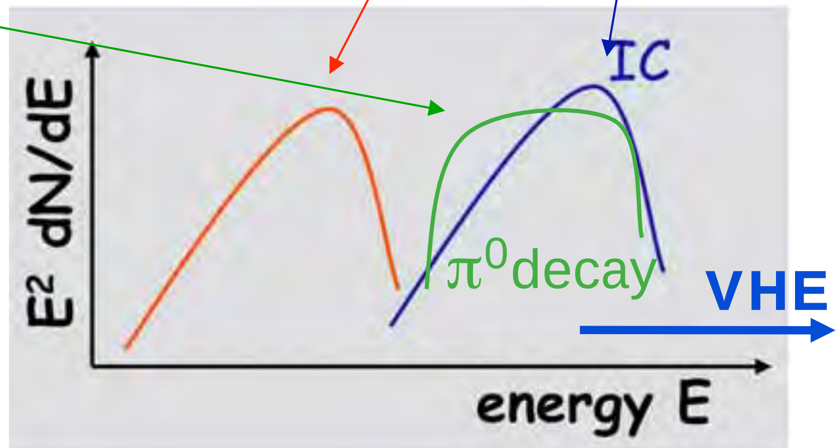
Cosmic γ rays: different production mechanisms expected to be at work





In the VHE region,
$dN/dE \sim E^{-\Gamma}$ (Γ: spectral index)

To distinguish between had/leptonic origin study Spectral Energy Distribution (SED):
(differential flux) · E^2



Leptonic vs. Hadronic models for γ emission

- SSC: currently explain most emissions
  - easy to accelerate electrons to TeV energies
  - easy to produce synchrotron and IC gamma-rays

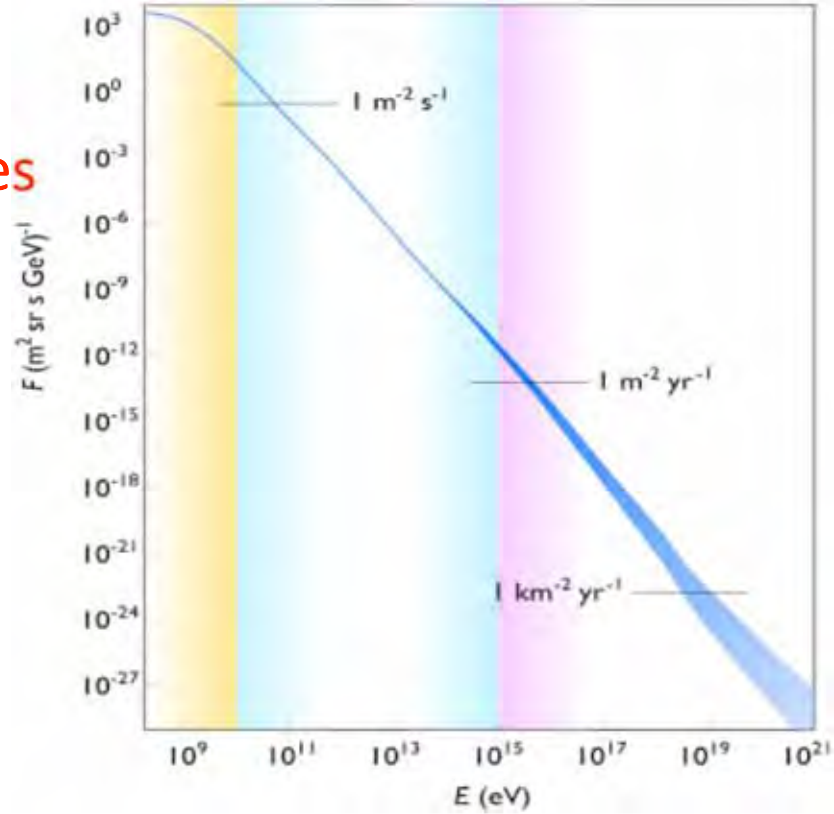
  But:
  - recent results would require more sophisticated leptonic models

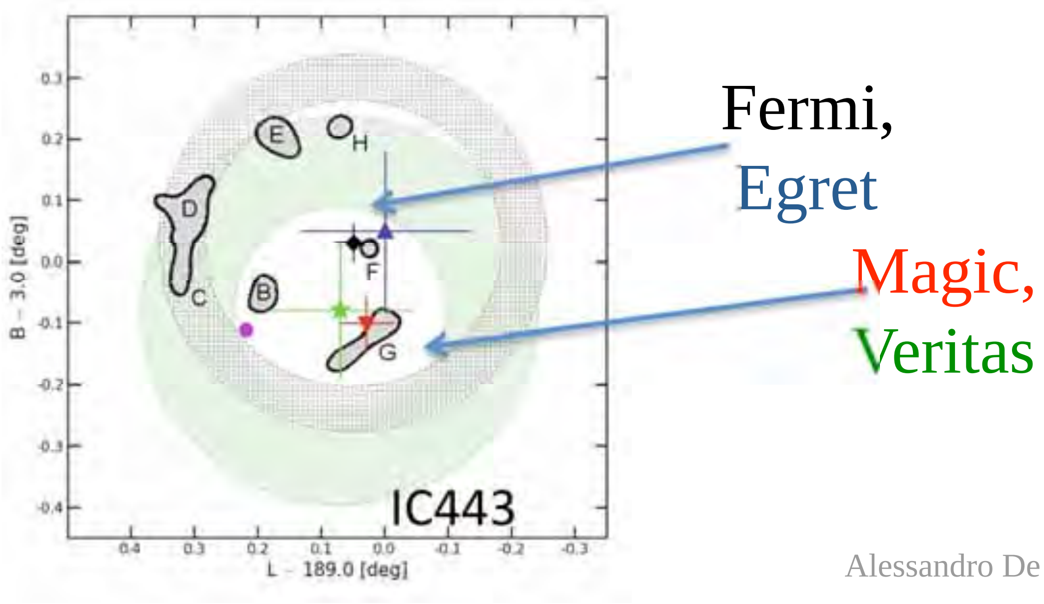
- Hadronic Models:
  - protons interacting with ambient hadronic targets -> neutrinos (1)
    - But needs adequate targets: works well for SNR, more difficult for AGN
  - protons interacting with photons (hadronic photoproduction) -> neutrinos (2)
  - proton synchrotron (no neutrinos)
    - very large magnetic fields

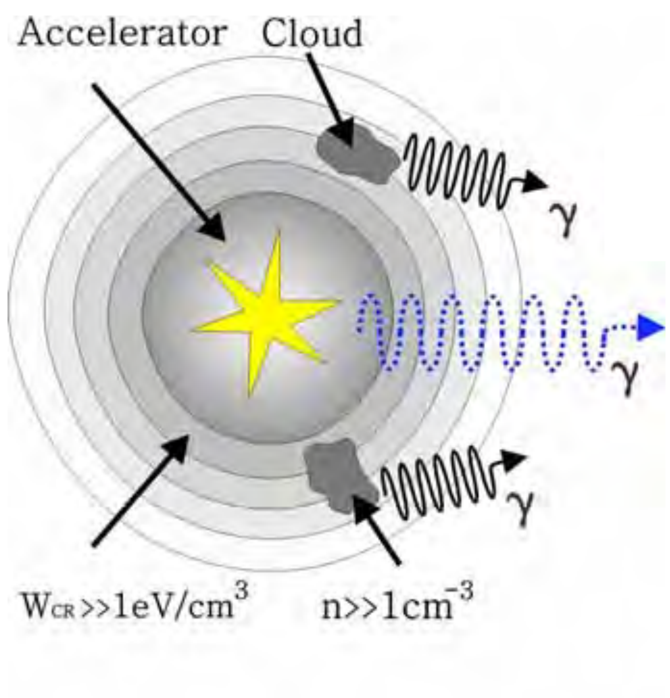
Sources of CR up to the knee

Cherenkov telescopes & gamma satellites

- Evidence that SNR are sources of CR up to ~1000 TeV (almost the knee) came from morphology studies of RX J1713-3946 (H.E.S.S. 2004)
- Striking evidence from the morphology of SNR IC443 (MAGIC + Fermi/Agile 2010)

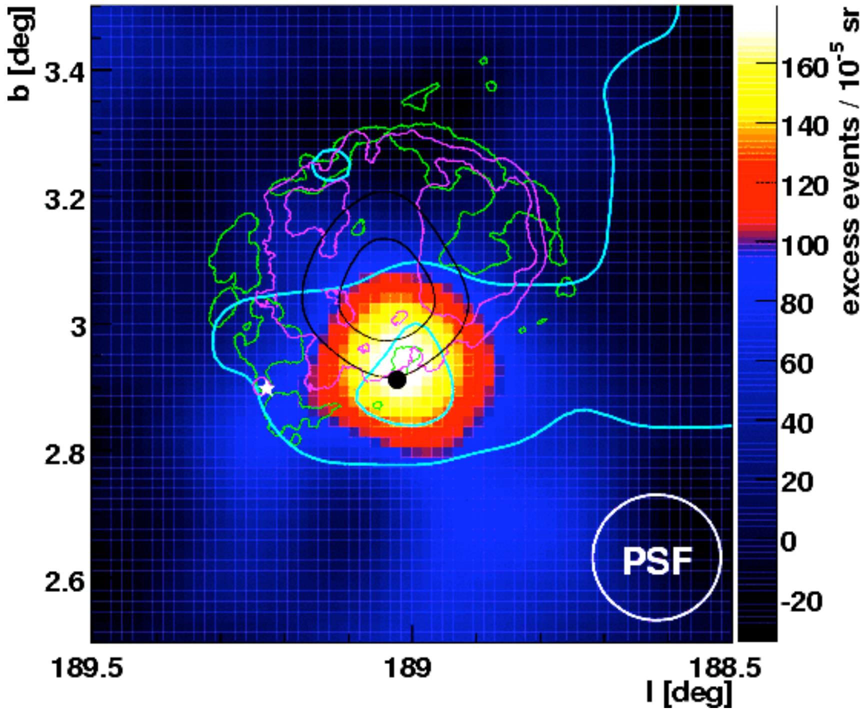


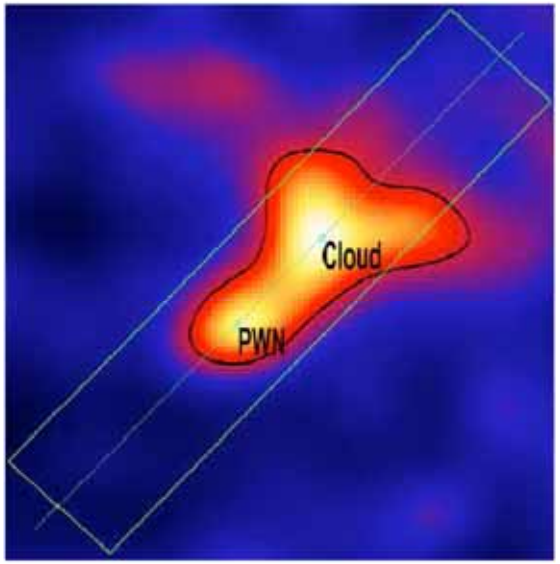


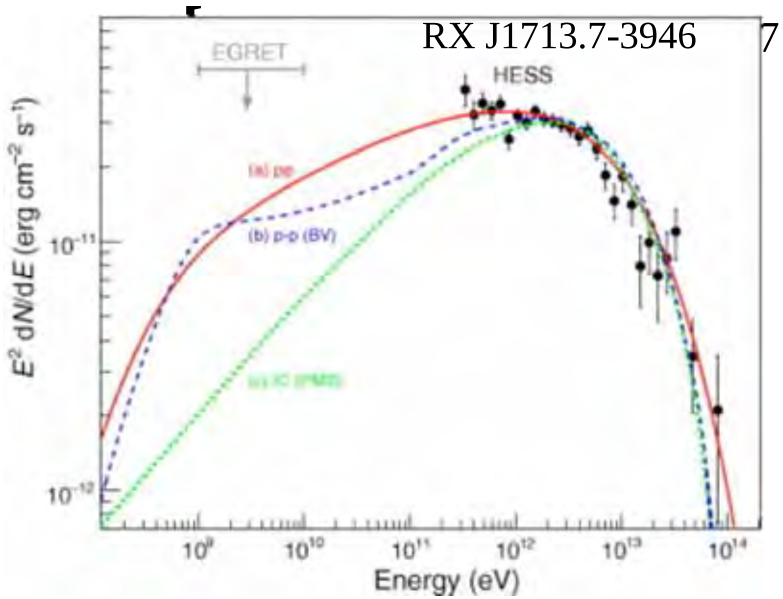


Molecular clouds close to IC 443, W51, RX J1713.7-3946

- VHE γ-ray excess compatible with cloud
- Differential energy spectrum prefers π^0 production







What we are learning on CR (great results in the recent years…)

- SNr as emitters of cosmic rays of energies (almost) the knee established
  - Gamma astrophysics can be an instrument to study the morphology of CR emitters (mostly Galactic)
  - Neutrino flux from SNR can be estimated reliably (might be detectable by IceCube)

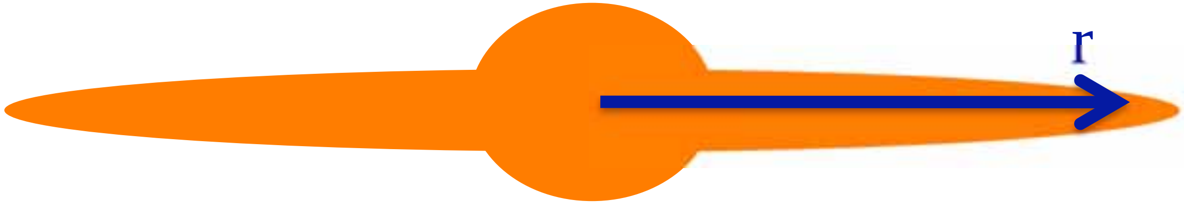
- The evidence that CRs up to the ankle come from AGN is very marginal
  - GZK cutoff, indications on the intergalactic magnetic fields
  - Astronomy with CR will be extremely difficult
  - Something interesting about composition, cross sections

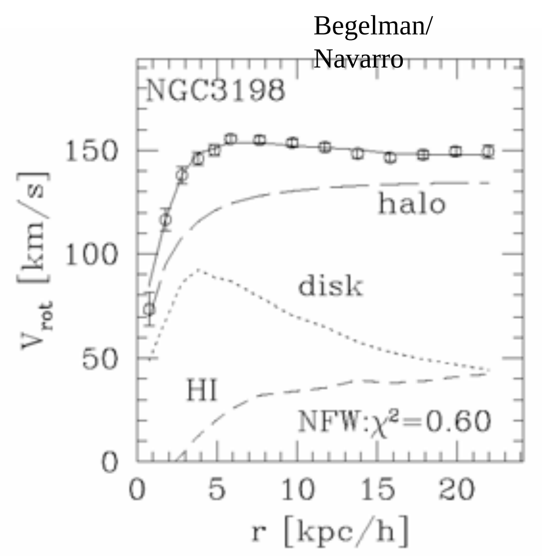
- Cooperation of particle- and CR-physicists has been intensified over the last years. This is extremely useful for understanding CR nature; accelerator data already helped improving shower models

- Tools of CR community may also help better understanding HE particle interactions: bulk LHC data are well described by EAS models, sometimes even better than by HEP models

The Dark Matter Problem

Measure rotation curves for galaxies:



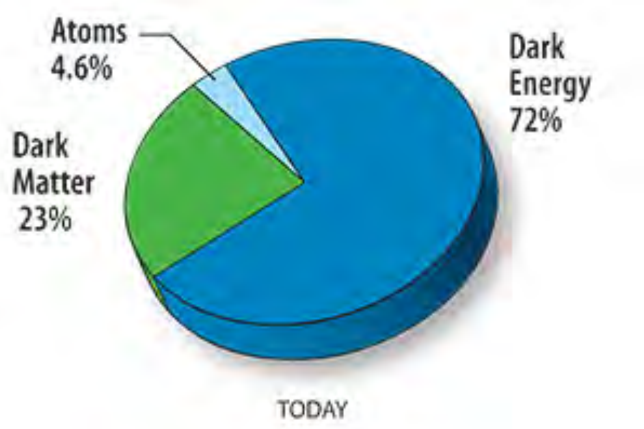


For large r, we expect:

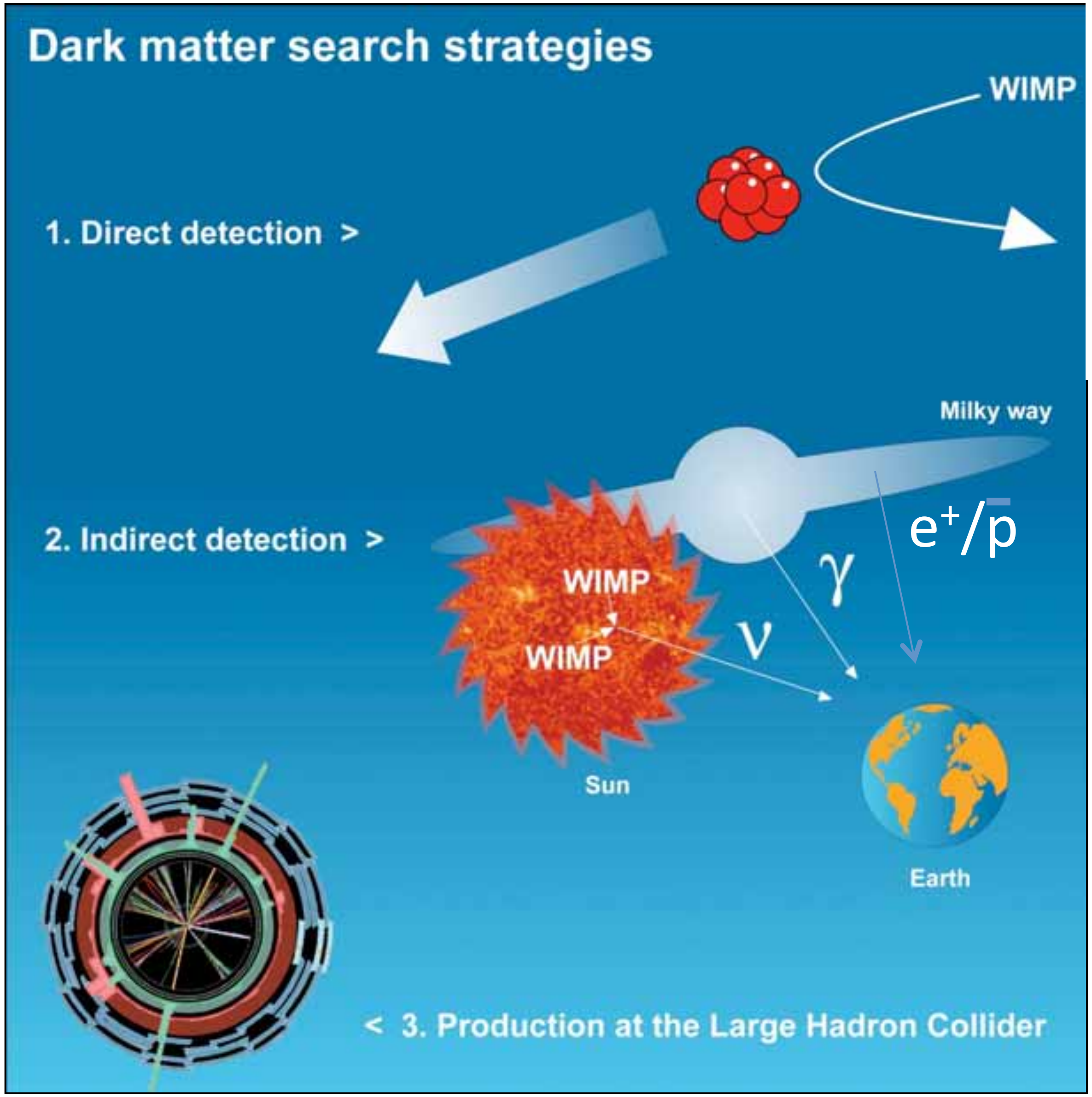
$$G\frac{M}{r^2}=\frac{v^2(r)}{r} \quad\Rightarrow\quad v(r)\sim\frac{1}{\sqrt{r}}$$

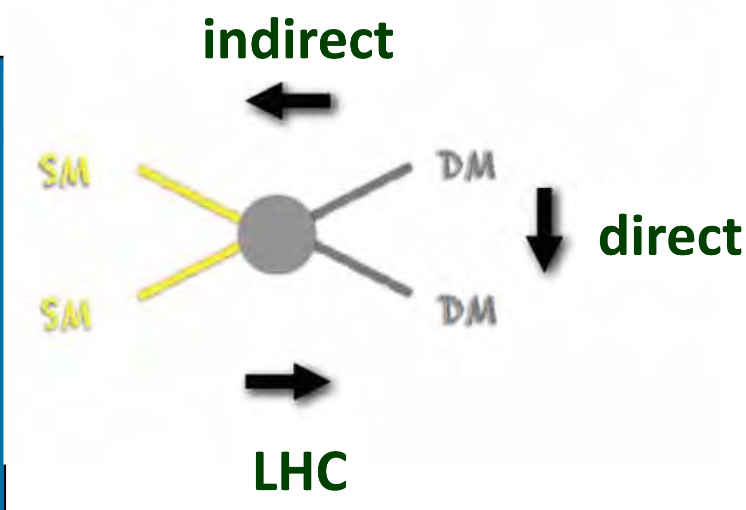
we see: flat or rising rotation curves

Hypothesized solution: the visible galaxy is embedded in a much larger halo of Dark Matter (neutral; weakly interacting; mix of particles and antiparticles - in SUSY Majorana)



Methods to search for self-annihilating WIMPs





ν	IceCube
γ	HESS/MAGIC/VERITAS
	Agile, Fermi
e/p	balloon exp.s, Pamela, Fermi, AMS

(Spiering)

Which signatures for gamma detectors?

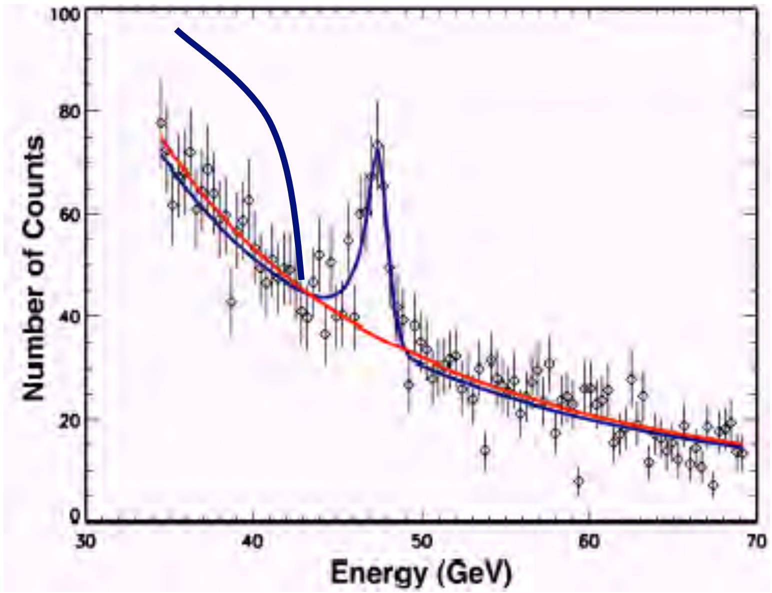
- Self-annihilating WIMPs, if Majorana (as the neutralino in SUSY), can produce:
  - Photon lines ($\gamma\gamma$, γZ)
  - Photon excess at E < m from hadronization
- Excess of antimatter (annihilation/decay)
- Excess of electrons, if unstable

$$\Phi \propto \sigma \frac{\langle v \rangle}{m^2} \int_{los} \rho^2 \, dl$$

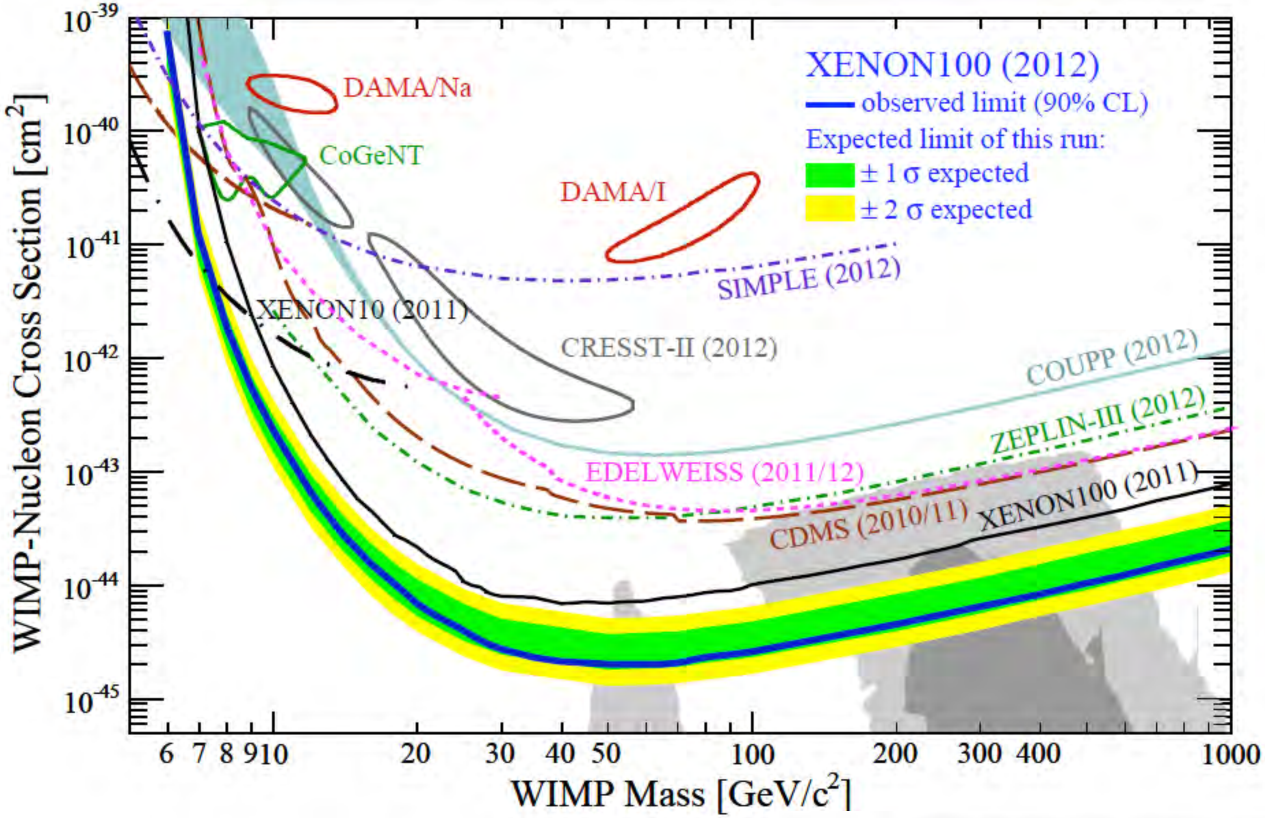
from particle physics

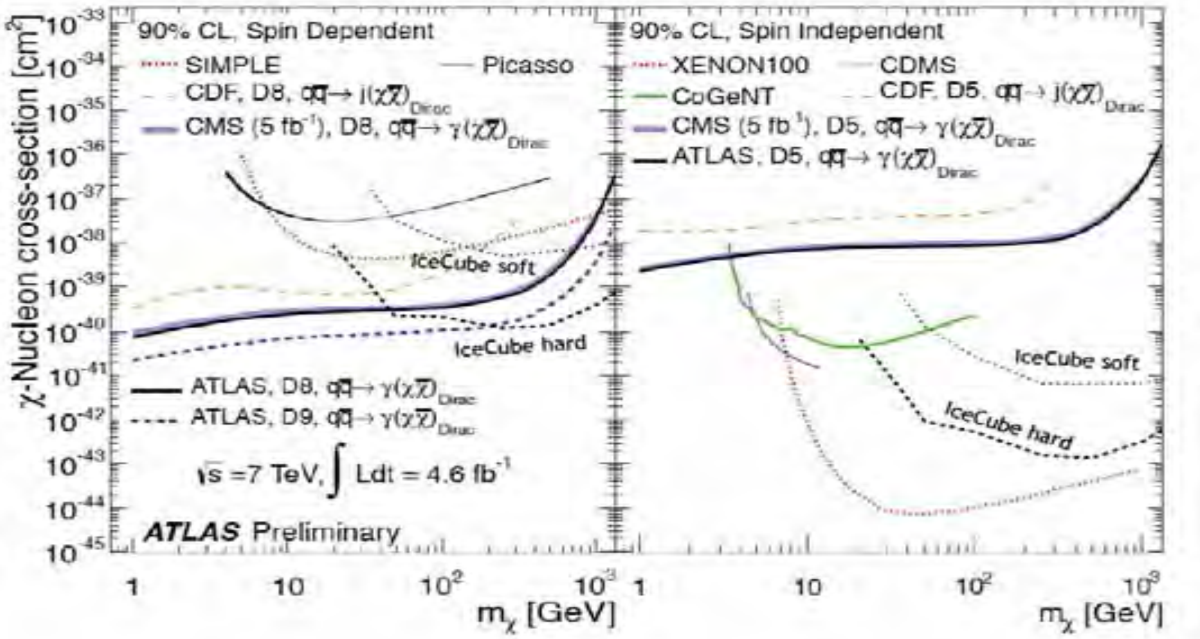
from astrophysics

Look to the closest point with M <<L

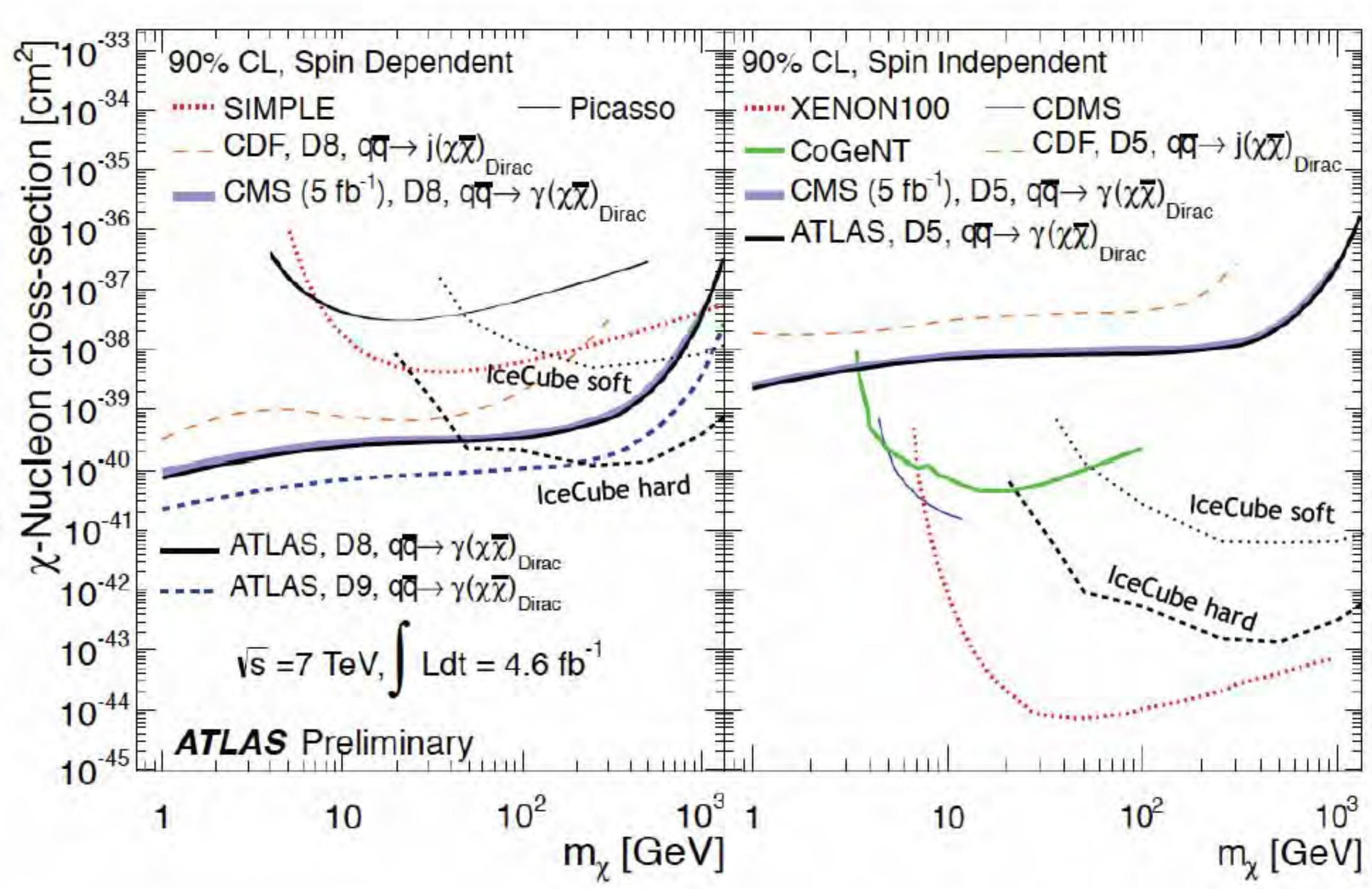


Snapshot (SUSY) summer 2012





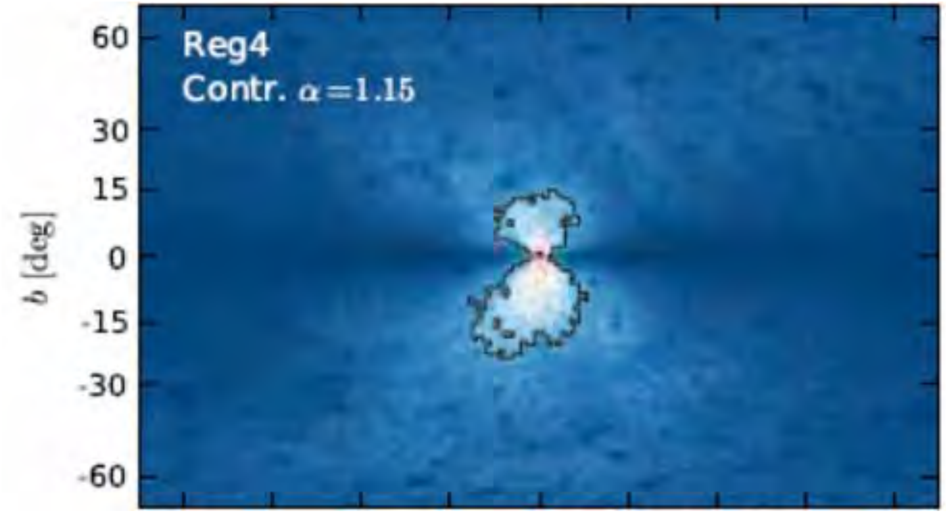
Synergy of direct, indirect and LHC searches

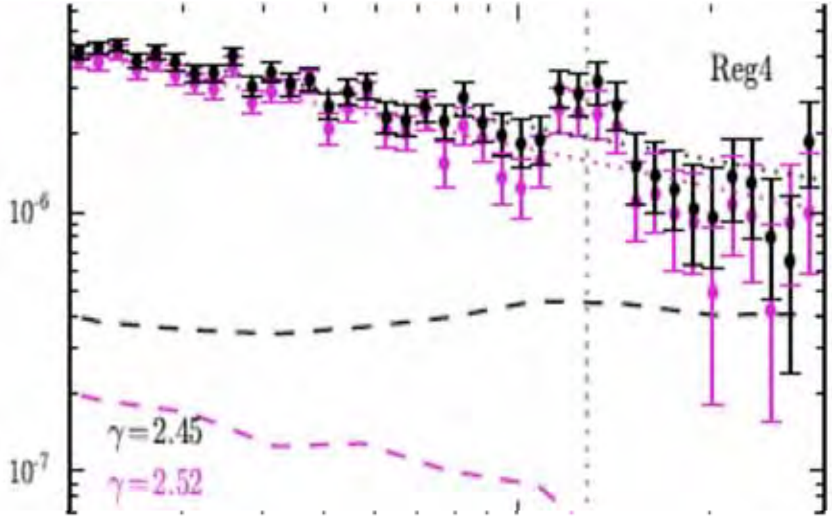


- **Direct searches will improve sensitivity by a factor of 100 over the next 5-7 years**
- **Indirect searches with IceCube will improve sensitivity by a factor 10-20**
- **AMS results: looking forward to data release end of the year!**
- **LHC 7 → LHC 14: factor 300-1000**

Data-driven indirect searches: the "Fermi" line

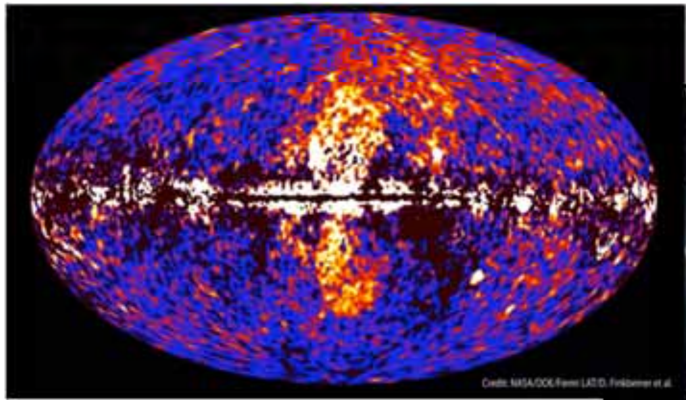
- Very recently, one paper claims a positive signal (a ~4σ photon excess at ~130 GeV from Fermi data)
  - C. Weniger, arXiv:1204.2797

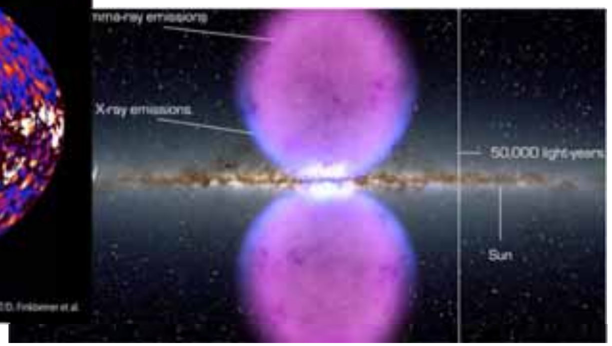




Selection of the region b(i)ased on data

Large overlapping with The Fermi "bubbles"





Data-driven line searches

- Confirmed by several independent analyses
  - Tempel+, arXiv:1205.1045

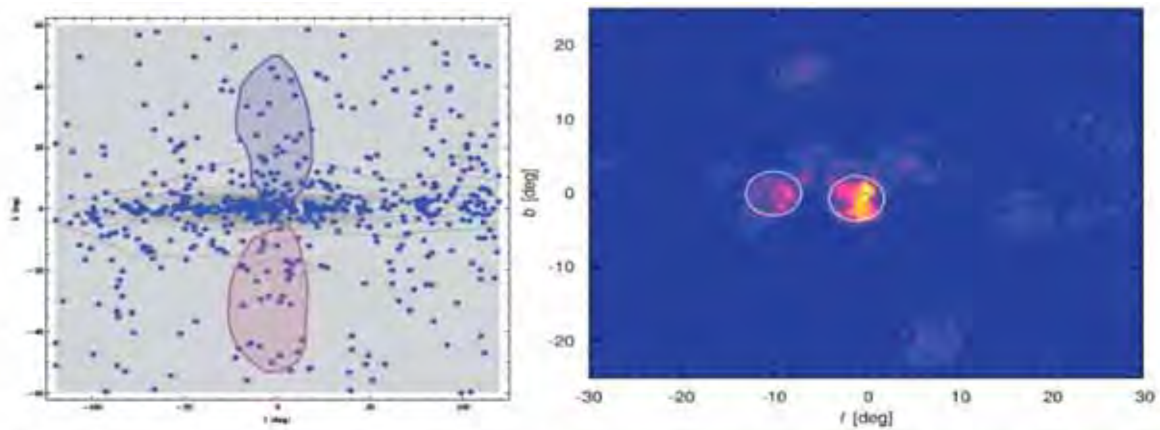


Figure 2: *Left: a Fermi "photograph" of our Galaxy in gamma-rays with the energy* 120 GeV $< E_\gamma <$ 140 *GeV. Fermi data is shown with blue dots. Fermi bubbles are also shown for illustration. Right: intensity of the* 120 GeV $< E_\gamma <$ 140 *GeV photons in the Galaxy. The white circles denote the signal regions that provide the excess with highest statistical significance; grey circles denote other regions showed in Table 1; green dot mark the assumed centre of the Galaxy.*

Not confirmed by a "blind" line search by the official Fermi team on May 14 (But warning: it's a different thing)

- Prospects for <u>present</u> Cherenkov telescopes: bad. Fermi: wait several years. LHC? <u>Future Cherenkov?</u>

dSph

Milky Way satellites Sagittarius, Draco, Segue1, Willman1, Perseus, …

- proximity (< 100 kpc)
- no central BH (which may change the DM cusp)
- large M/L ratio (low baryonic content)
- **No signal for now…**

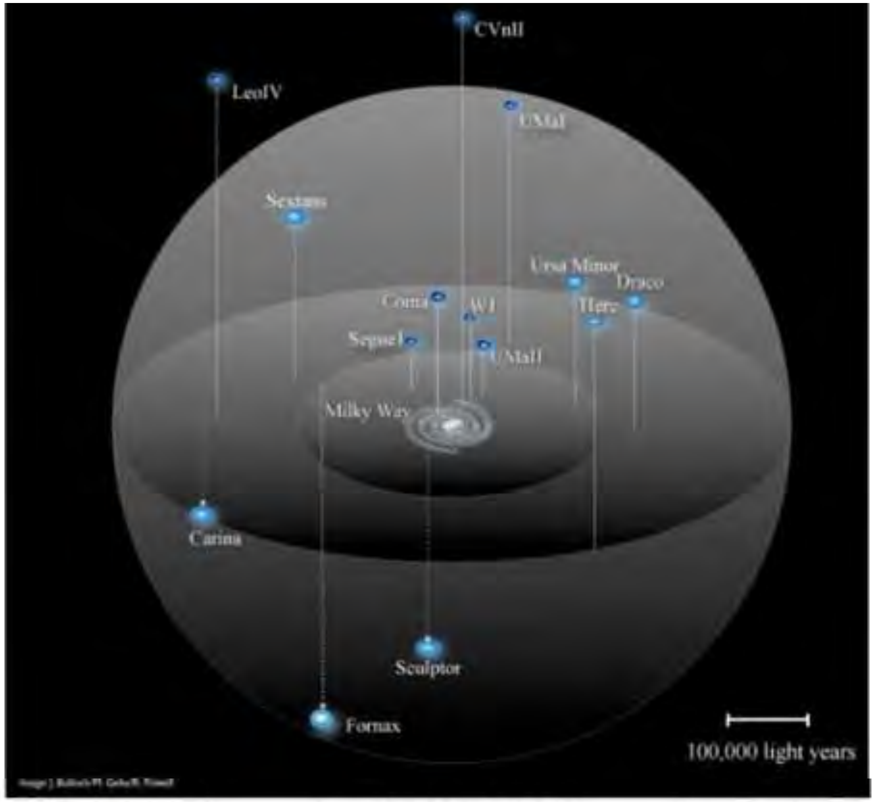
Results dominated by Fermi observations of Segue1

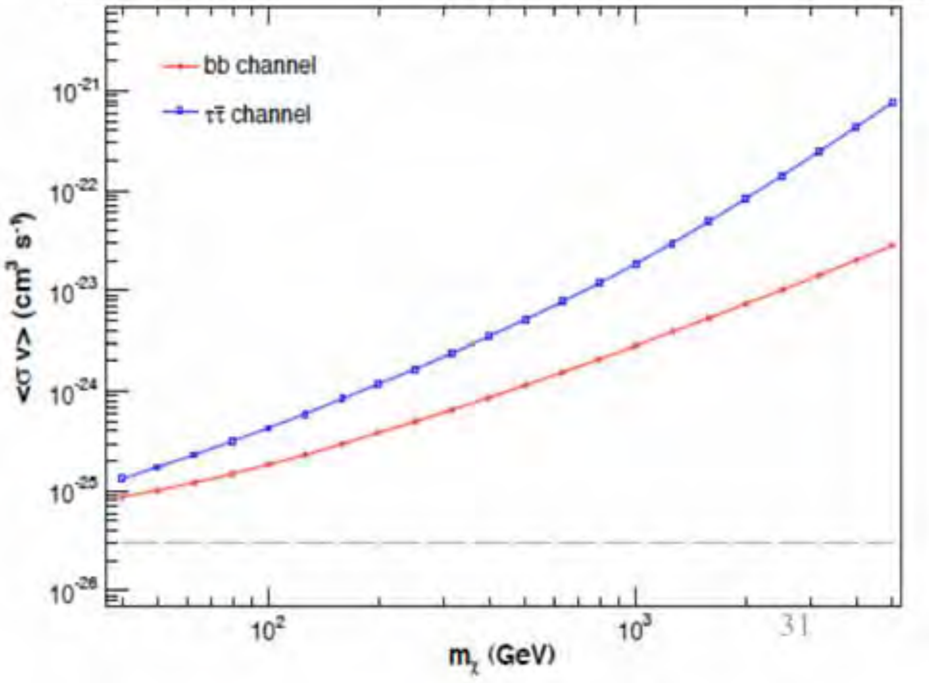
in the Leo constellation at ~23 kpc from the Sun

luminosity is ~300x the Sun, M/L ~3400

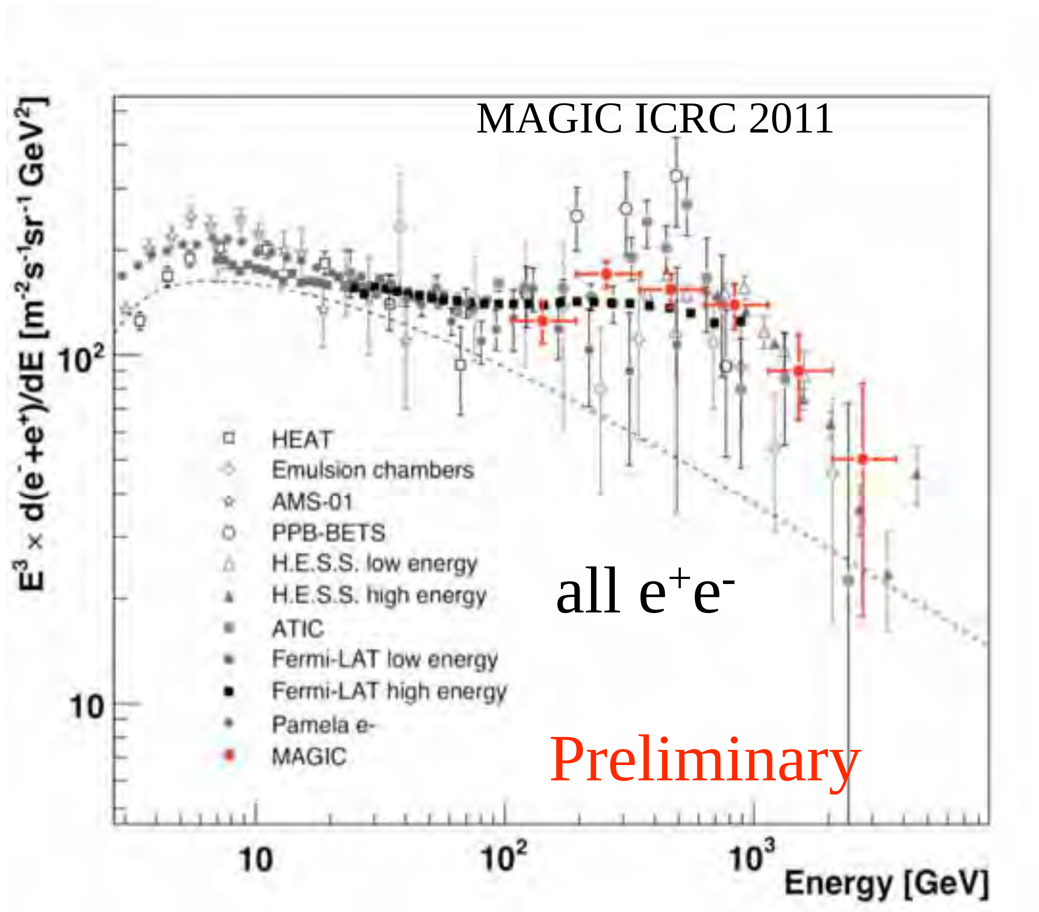
small improvement by stacking

- Still a factor of >4 larger than a possible signal, even at low mass and in the most favorable assumptions
  - Majorana WIMP, DM profiles
- What could improve it?
  - A “boost” of ρ^2 given by an anomalous DM concentration in subhalos
  - At 100 GeV, an improvement by a factor of 30 in sensitivity





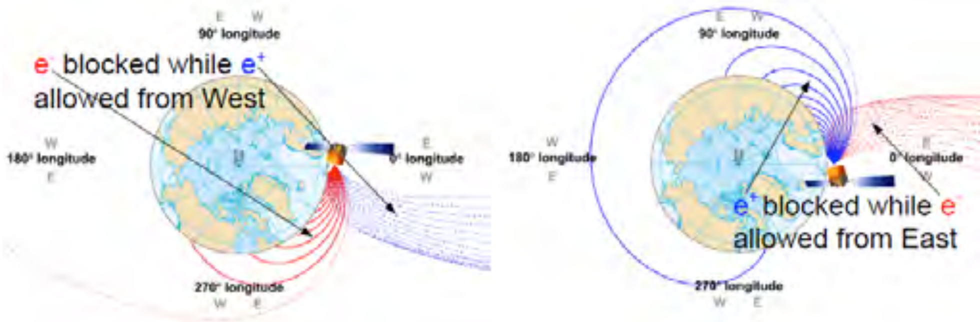
Cosmic rays: the ATIC anomaly



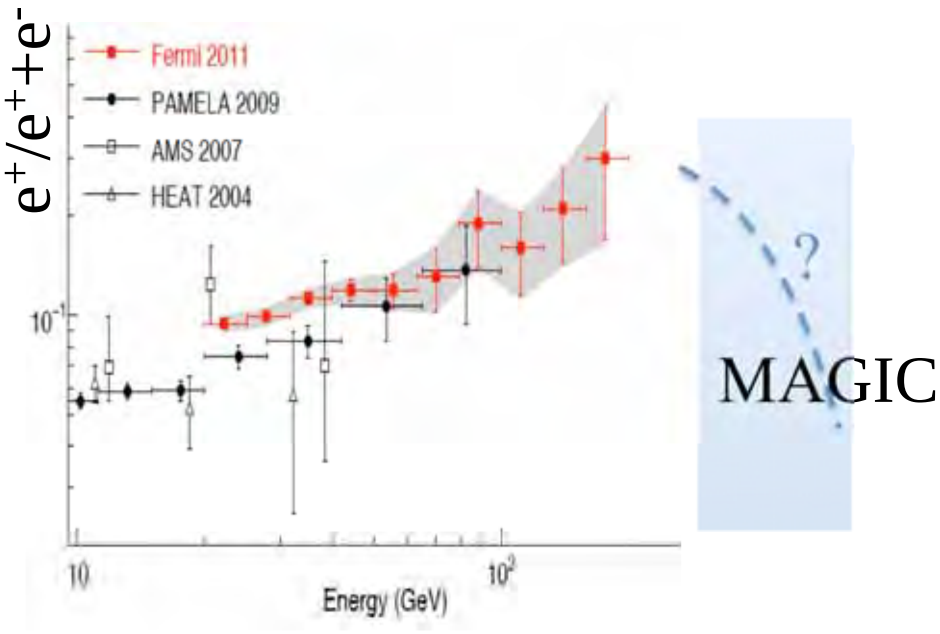
No peaks;

a possible excess might have standard/astrophysical explanations

Cosmic rays: the PAMELA anomaly



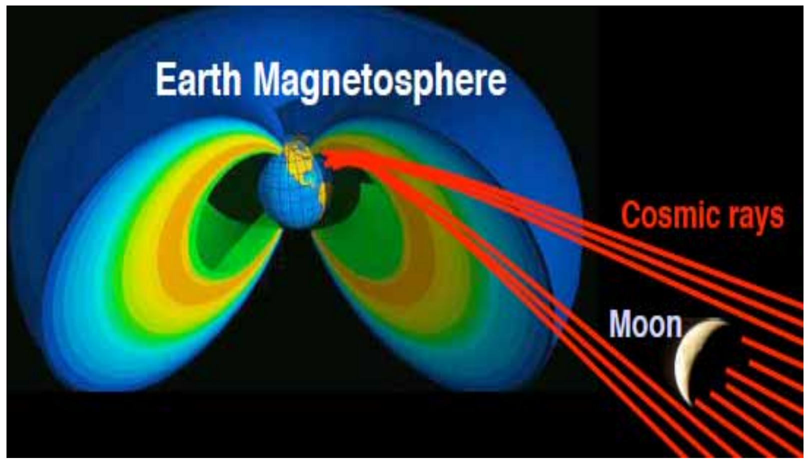
Unexpected increase in e^+/e^- ratio (PAMELA) confirmed by Fermi @ ICRC 2011:



Moon shadow observation mode developed for the MAGIC telescopes [MAGIC ICRC 2011]

probe e+/e- ratio at 300-700 GeV

sensitivity (50h): 300-700GeV: ~4.4% Crab measurement possible in few years



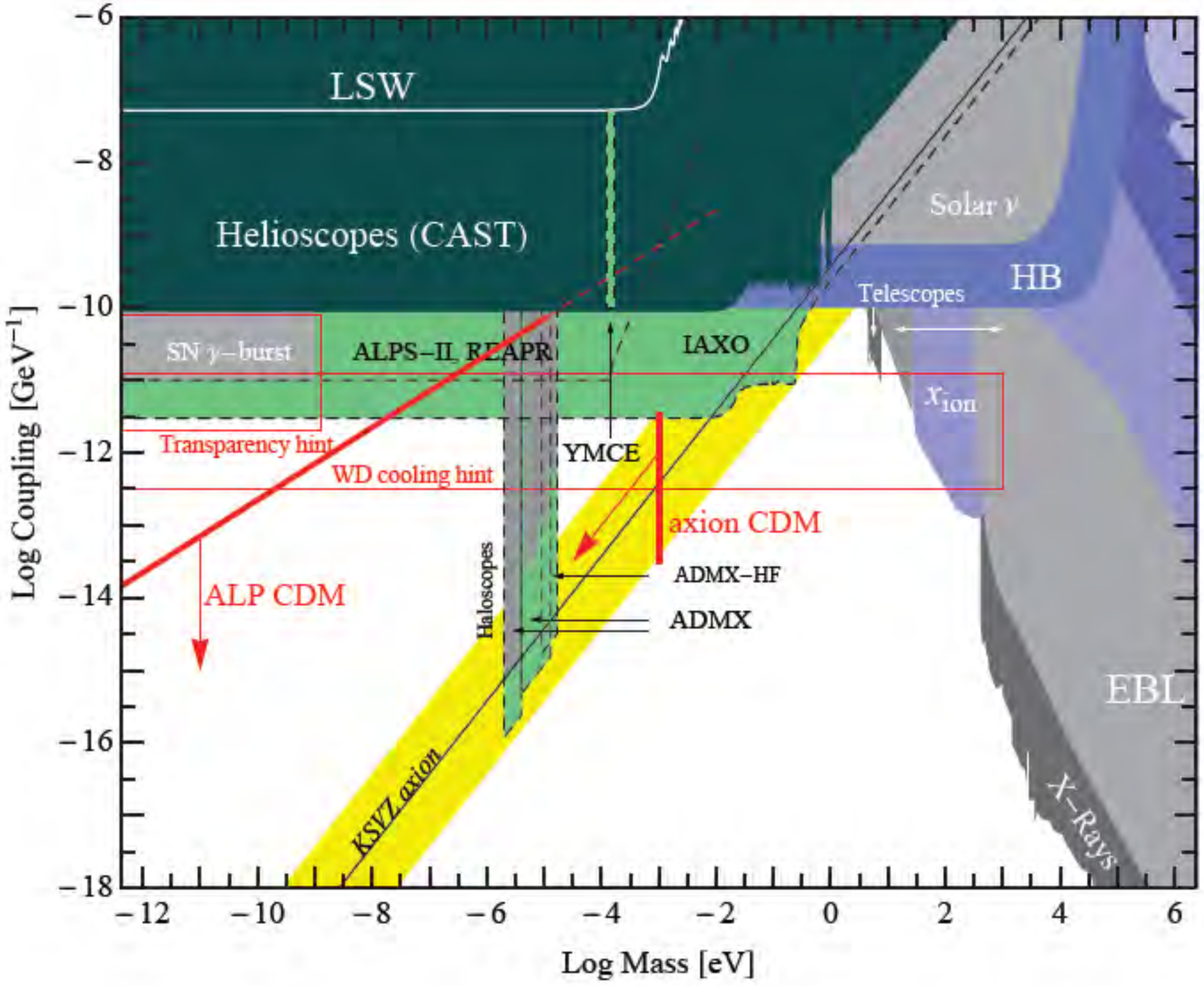
DM: interplay with accelerators

- LHC may find candidates but cannot prove that they are the observed Dark Matter, nor localize it
- *Direct searches (nuclear recoil) may recognize local halo WIMPs but cannot prove the nature and composition of Dark Matter in the sky*

- LHC reach limited to some 200-600 GeV; IACT sensitivity starts at some ~200 GeV (should improve)

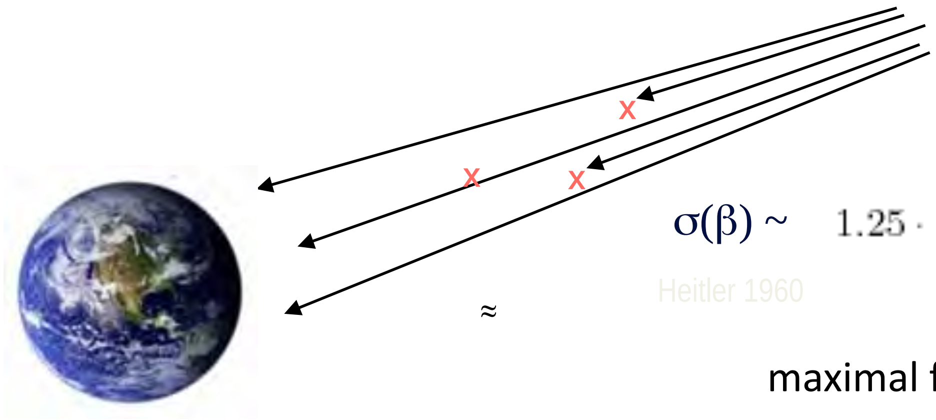
Axions

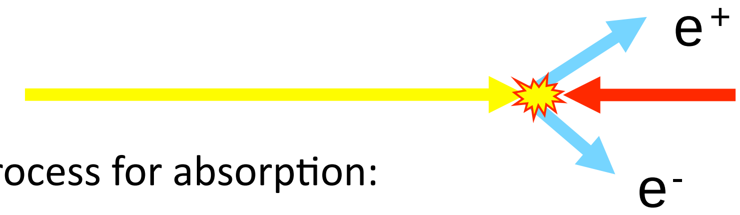
Parameter space for axions or axion-like particles



- **Experimentally excluded**
- **Astronomy constraints**
- **Cosmology constraints**
- **Sensitivity of planned experiments**

Propagation of γ-rays





dominant process for absorption:

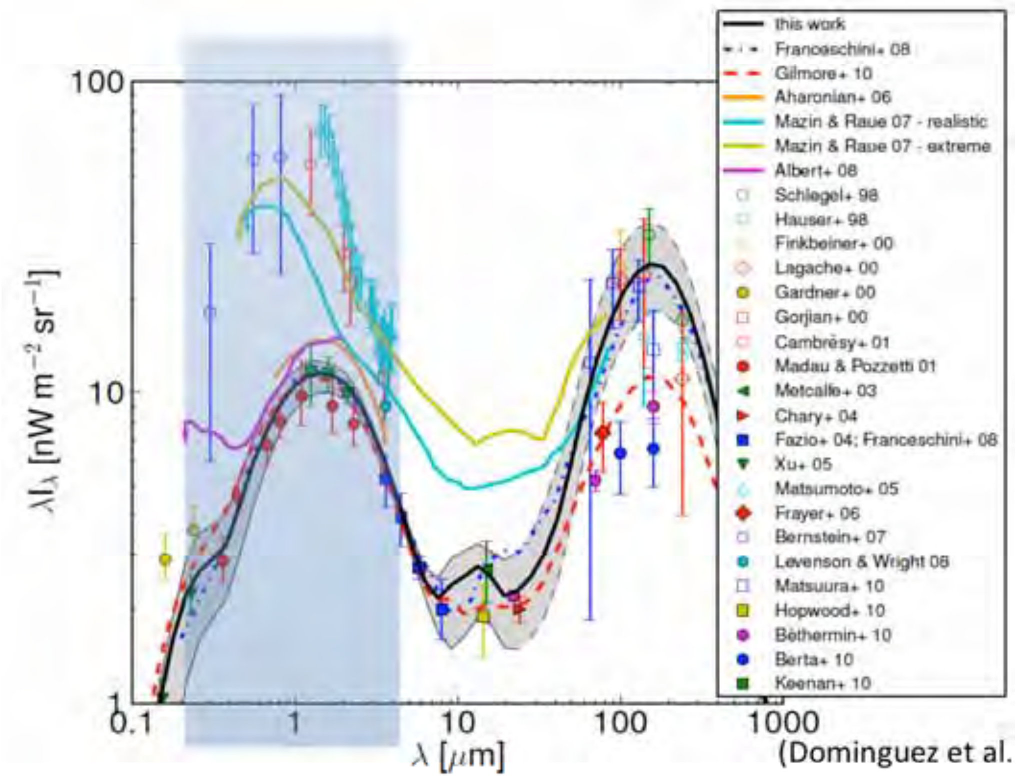
$$\gamma_{VHE}\gamma_{bck} \rightarrow e^+e^-$$

$$\sigma(\beta) \sim 1.25 \cdot 10^{-25}(1-\beta^2) \cdot \left[2\beta(\beta^2-2) + (3-\beta^4)\ln\left(\frac{1+\beta}{1-\beta}\right)\right] \mathrm{cm}^2$$

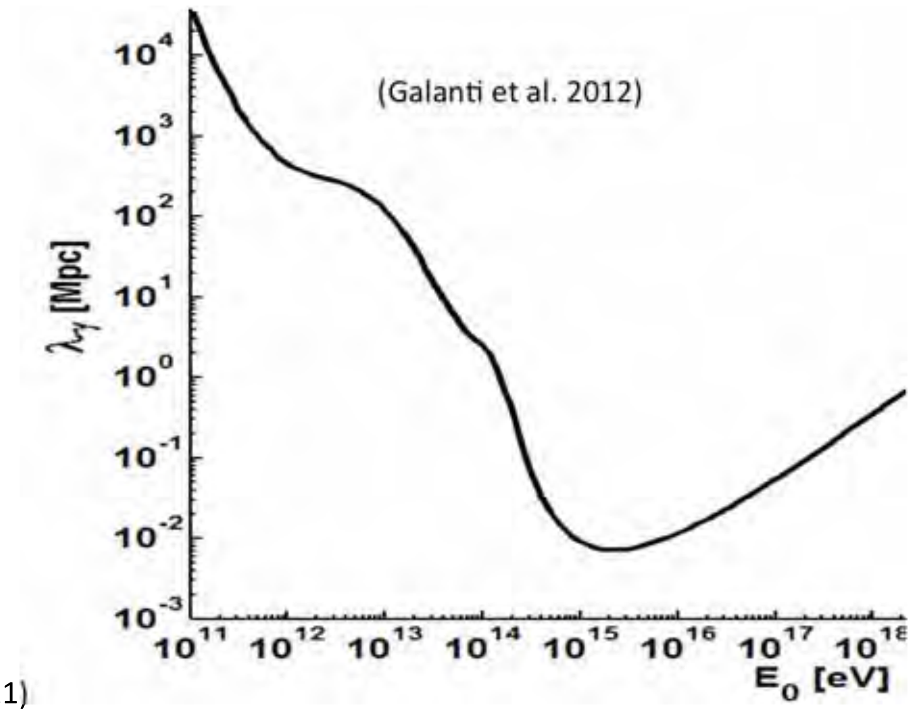
Heitler 1960

maximal for: $\epsilon \simeq \frac{2m_e^2c^4}{E} \simeq \left(\frac{500\,\mathrm{GeV}}{E}\right)\mathrm{eV}$

- For gamma rays, relevant background component is optical/infrared (EBL)
- different models for EBL: minimum density given by cosmology/star formation



(Dominguez et al. 2011)

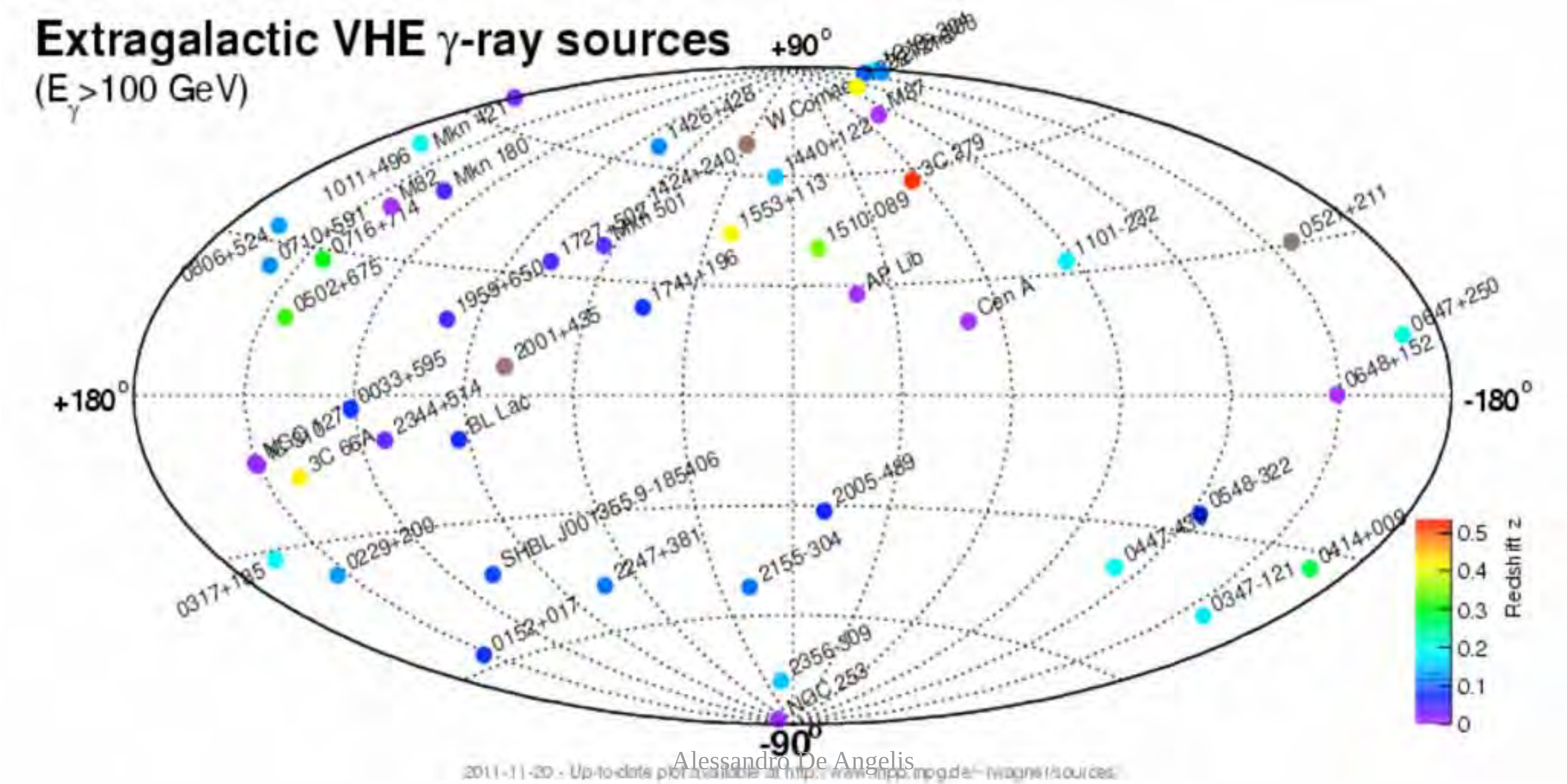


Extragalactic Sources

~50 Sources

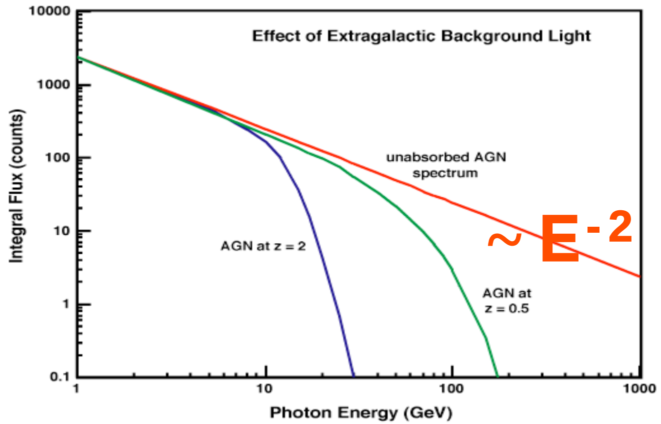
…

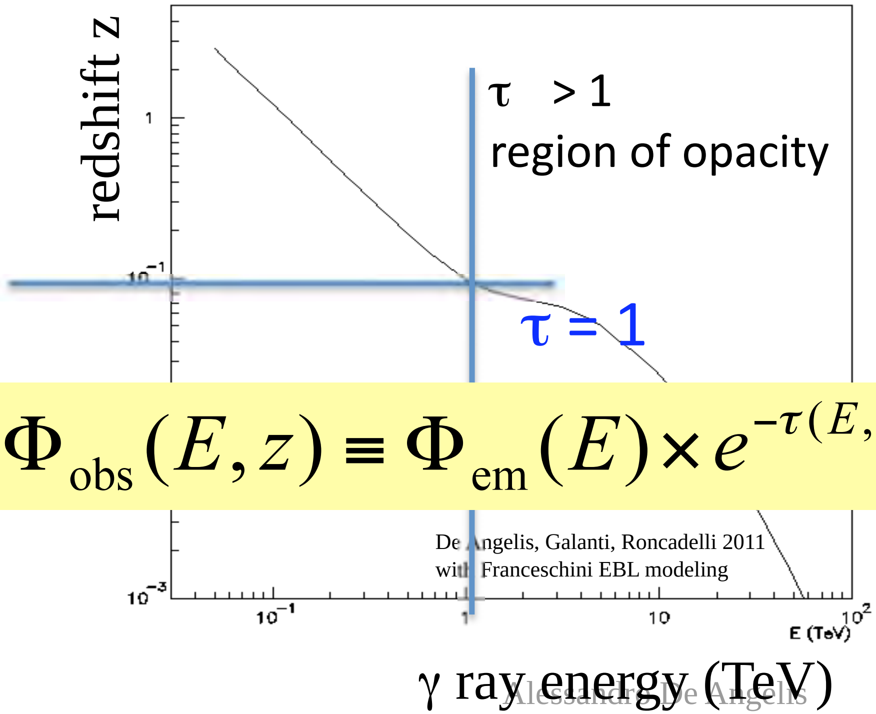
1ES 1011+496	**z=0.21**	**MAGIC 2007**
1ES 0414+009	z=0.29	HESS/Fermi 2009
S5 0716+71	**z=0.31±0.08**	**MAGIC 2009**
1ES 0502+675	z=0.34	VERITAS 2009
PKS 1510-089	z=0.36	HESS 2010
4C +21.43	**z=0.43**	**MAGIC 2010**
3C 66A	**z=0.44**	**VERITAS 2009**
3C 279	**z=0.54**	**MAGIC 2008**



Are our AGN observations consistent with theory?

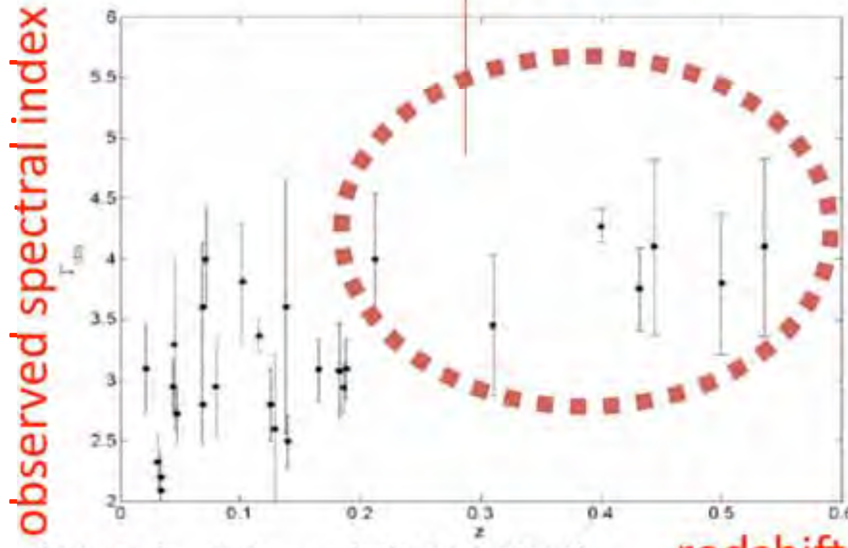
Measured spectra affected by attenuation in the EBL:



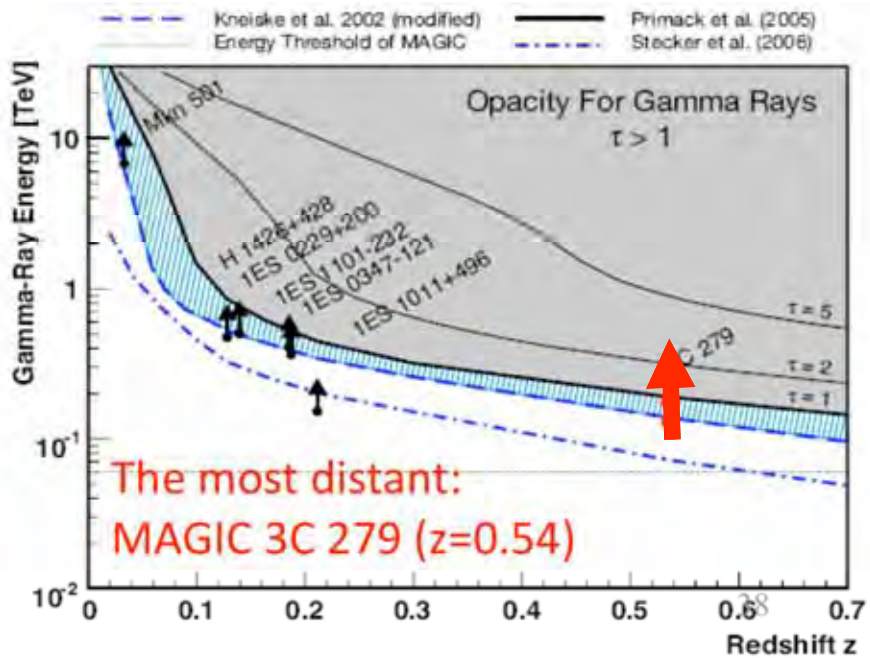


$$\Phi_{obs}(E,z) = \Phi_{em}(E) \times e^{-\tau(E,z)}$$

Selection bias?
New physics ?

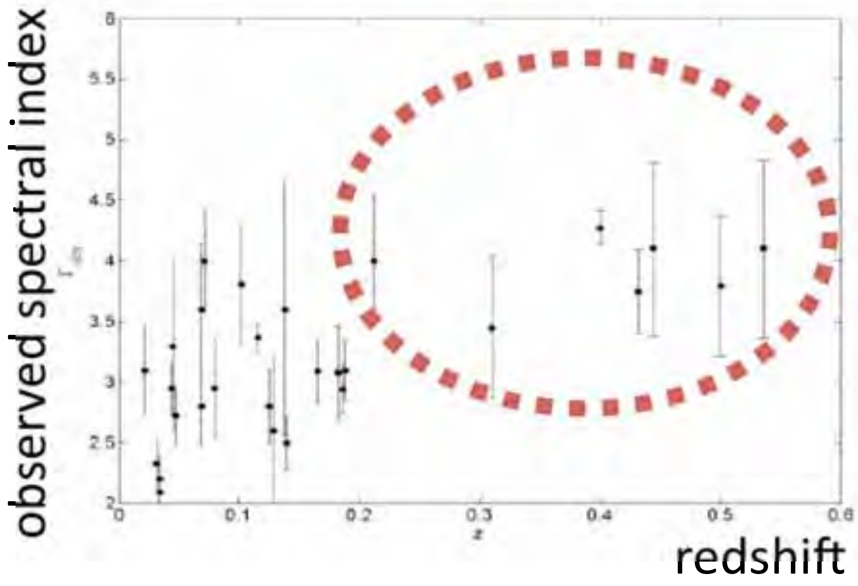


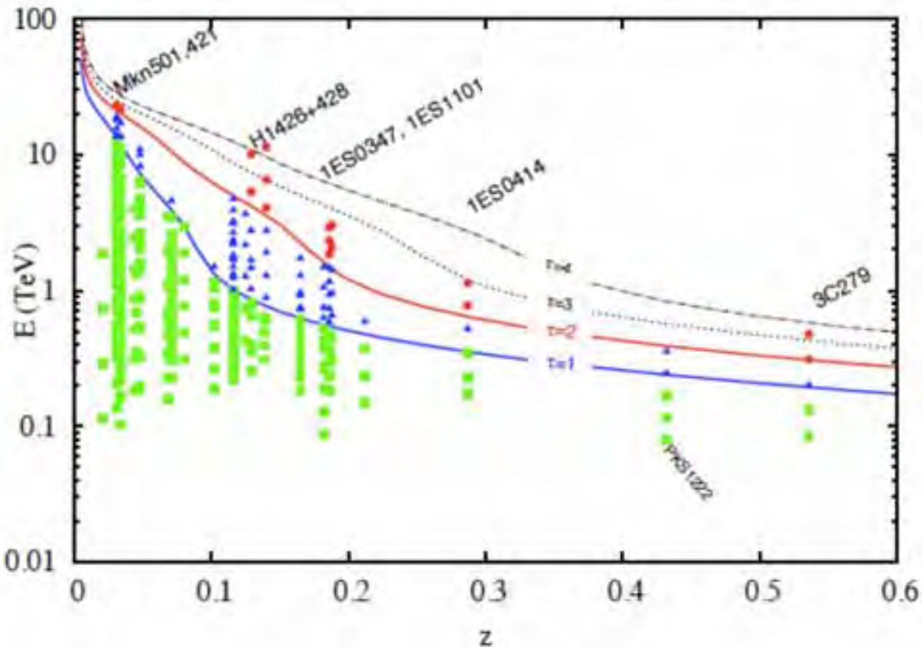
(DA, Galanti, Roncadelli; PRD 2011)



The most distant:
MAGIC 3C 279 (z=0.54)

If there is a problem





Explanations from the standard ones

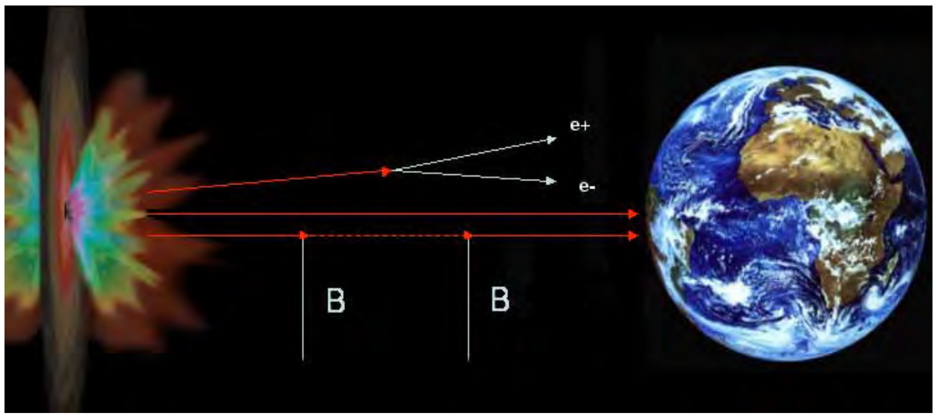
- very hard emission mechanisms with intrinsic slope < 1.5 (Stecker 2008)
- Very low EBL, plus observational bias, plus a couple of "wrong" outliers

to almost standard

- γ-ray fluxes enhanced by relatively nearby production by interactions of primary cosmic rays or ν from the same source

to possible evidence for new physics

- Oscillation to a light "axion"? (DA, Roncadelli & MAnsutti [DARMA], PRD2007, PLB2008)
- Axion emission (Simet+, PRD2008)
- A combination of the above (Sanchez Conde et al. PRD 2009)



Summarizing: if the expected photon yield at VHE is different from what we think, what might be wrong?

- Emission models are more complicated than we think (but only for sources far away: nearby sources behave well)

- Propagation: VHE photons are generated on the way (interaction of cosmic rays, neutrinos and photons with intergalactic medium: Sigl, Essey, Kusenko, …)

- Propagation: Something is wrong in the $\gamma\gamma$ -> e+e- rate calculation
  - Vacuum energy (new sterile particles coupling to the photons): DARMA, …
    - For example an ALP: consistent values for m, g=(1/M) in a range not experimentally excluded ("Se non e' vero e' ben pensato")
  - $\gamma\gamma$ -> e+e- cross section

    QED calculations appears to be in a safe region; then it must be
    - the boost (Lorentz transformations; relativity)

Is Lorentz invariance exact?

- For longtime violating Lorentz invariance/Lorentz transformations/Einstein relativity was a heresy
  - Is there an aether? (Dirac 1951)
  - Many preprints, often unpublished (=refused) in the ’90s
    - Gonzales-Mestres, ADA, Jacobson, …

- Then the discussion was open
  - Trans-GZK events? (AGASA collaboration 1997-8)
  - LIV => high energy threshold phenomena: photon decay, vacuum Cherenkov, GZK cutoff (Coleman & Glashow 1997-8)
  - GRB and photon dispersion (Amelino-Camelia et al. 1997)
  - Framework for the violation (Colladay & Kostelecky 1998)
  - LIV and gamma-ray horizon (Kifune 1999)
  - …

LIV? New form of relativity?

- Von Ignatowsky 1911: {relativity, omogeneity/isotropy, linearity, reciprocity} => Lorentz transformations with "some" invariant c (Galilei relativity is the limit $c \rightarrow \infty$)
- CMB is the aether: give away isotropy?
- QG motivation: give away linearity? (A new relativity with 2 invariants: "c" and E_P)

- In any case, let's sketch an effective theory…
  - Let's take a purely phenomenological point of view and encode the general form of Lorentz invariance violation (LIV) as a perturbation of the Hamiltonian (Amelino-Camelia+)

A heuristic approach: modified dispersion relations (perturbation of the Hamiltonian)

- We expect the Planck mass to be the scale of the effect

$$E_P = \sqrt{hc/G} \cong 1.2 \times 10^{19}\,\text{GeV}$$

$$H^2 = m^2 + p^2 \rightarrow H^2 = m^2 + p^2\left(1 + \xi \frac{E}{E_P} + \ldots\right)$$

$$H \xrightarrow[p>>]{} p\left(1 + \frac{m^2}{2p^2} + \xi \frac{p}{2E_P} + \ldots\right)$$

$$v = \frac{\partial H}{\partial p} \cong 1 - \frac{m^2}{2p^2} + \xi \frac{p}{E_P} \Rightarrow \boxed{v_\gamma \cong 1 + \xi \frac{E}{E_P}}$$

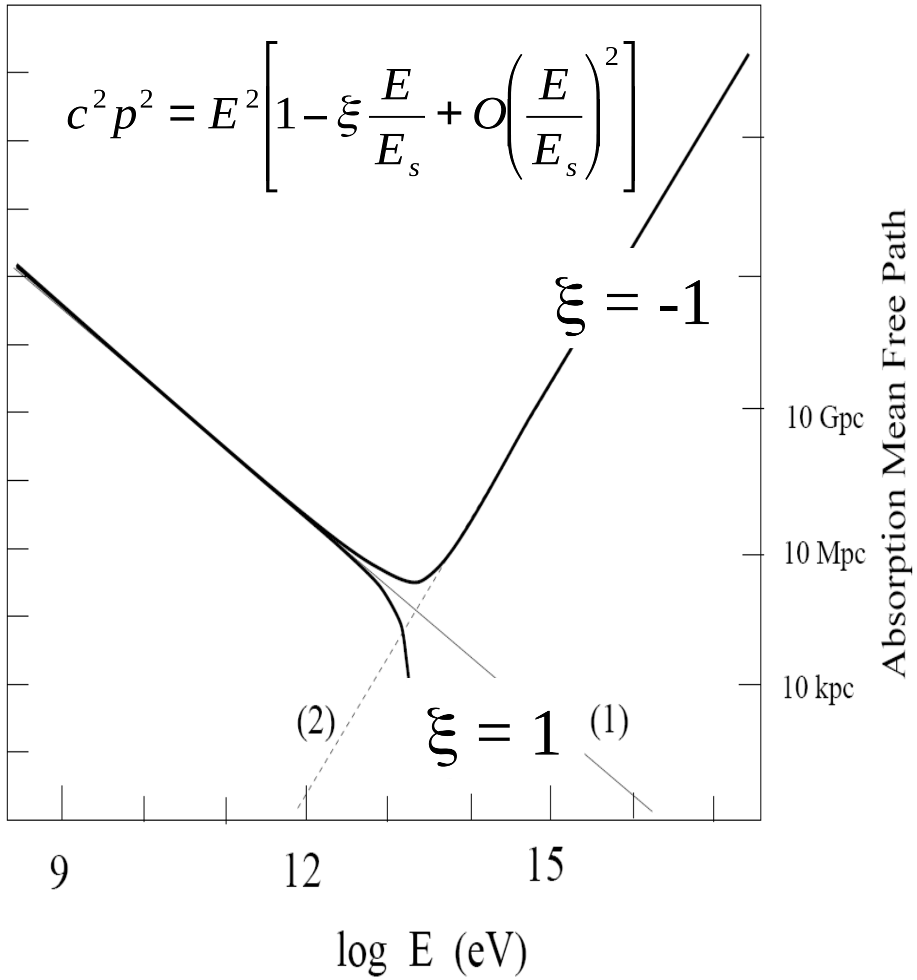
=> effect of dispersion relations at cosmological distances can be important at energies well below Planck scale:

$$\boxed{\Delta t_\gamma \cong T \Delta E \frac{\xi}{E_P}}$$

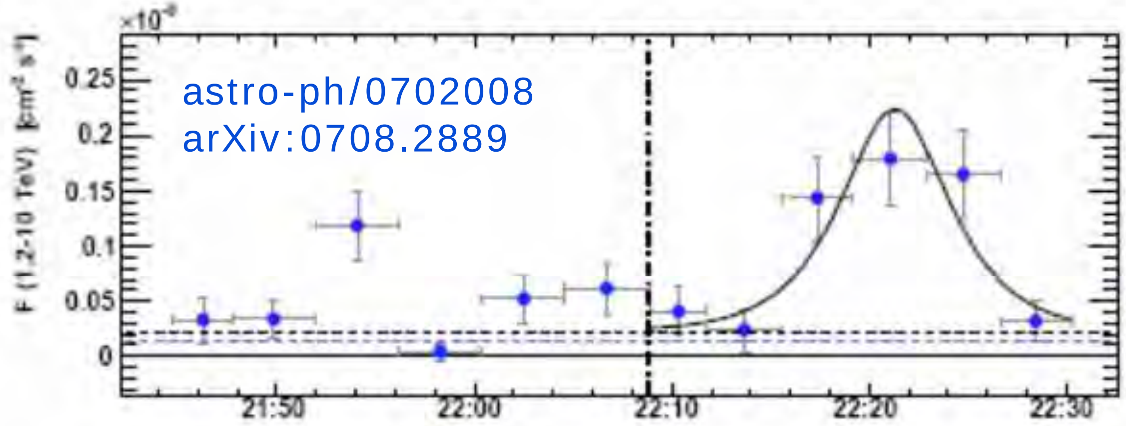
Other effects of LIV: modified thresholds (Coleman-Glashow); transparency (Kifune 99)

$$v = \frac{\partial H}{\partial p} \cong 1 - \frac{m^2}{2p^2} + \xi \frac{p}{E_P}$$

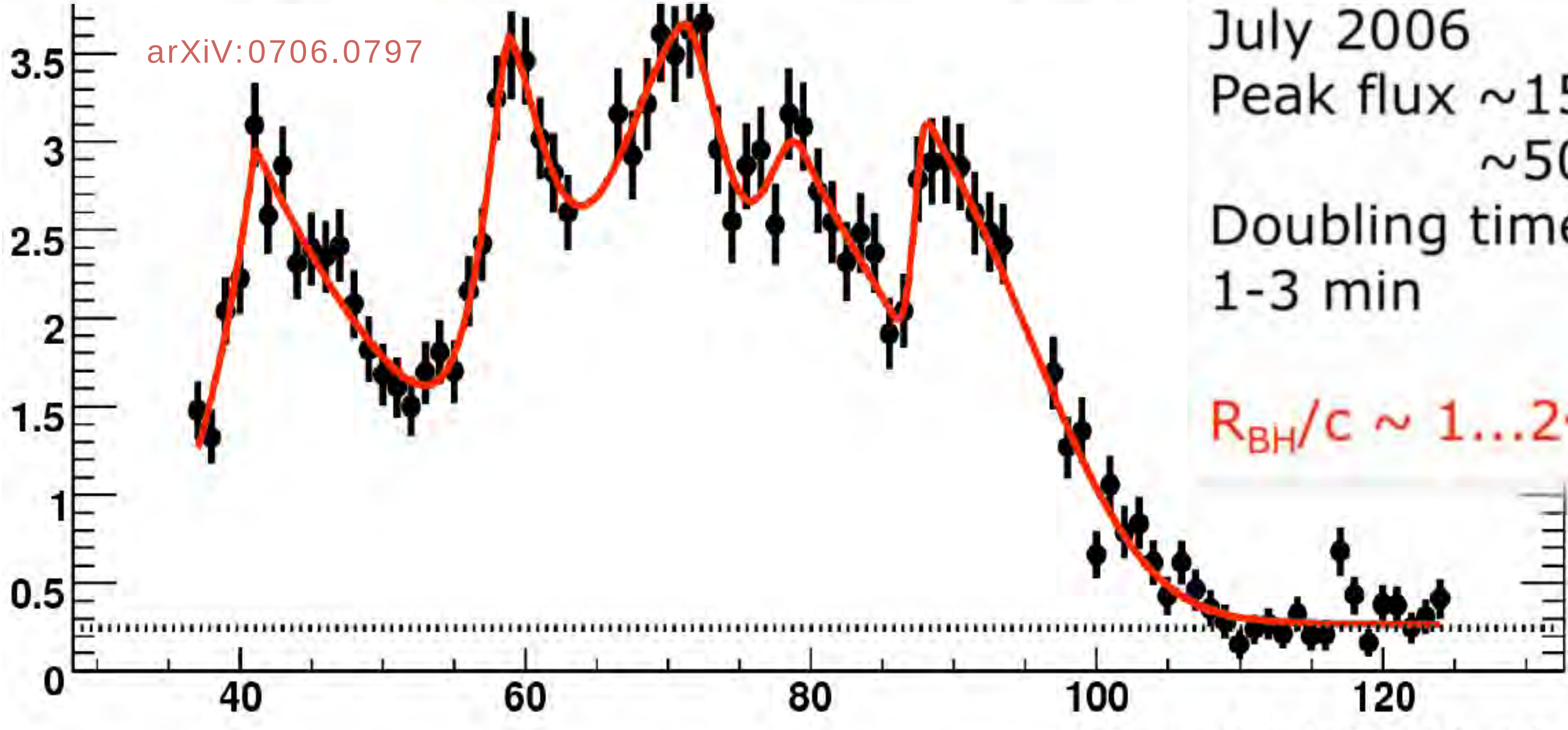
- $\xi < 0$:
  - Increased transparency (threshold γγ -> ee moves forward)



Rapid variability



MAGIC, Mkn 501
Doubling time ~ 2 min



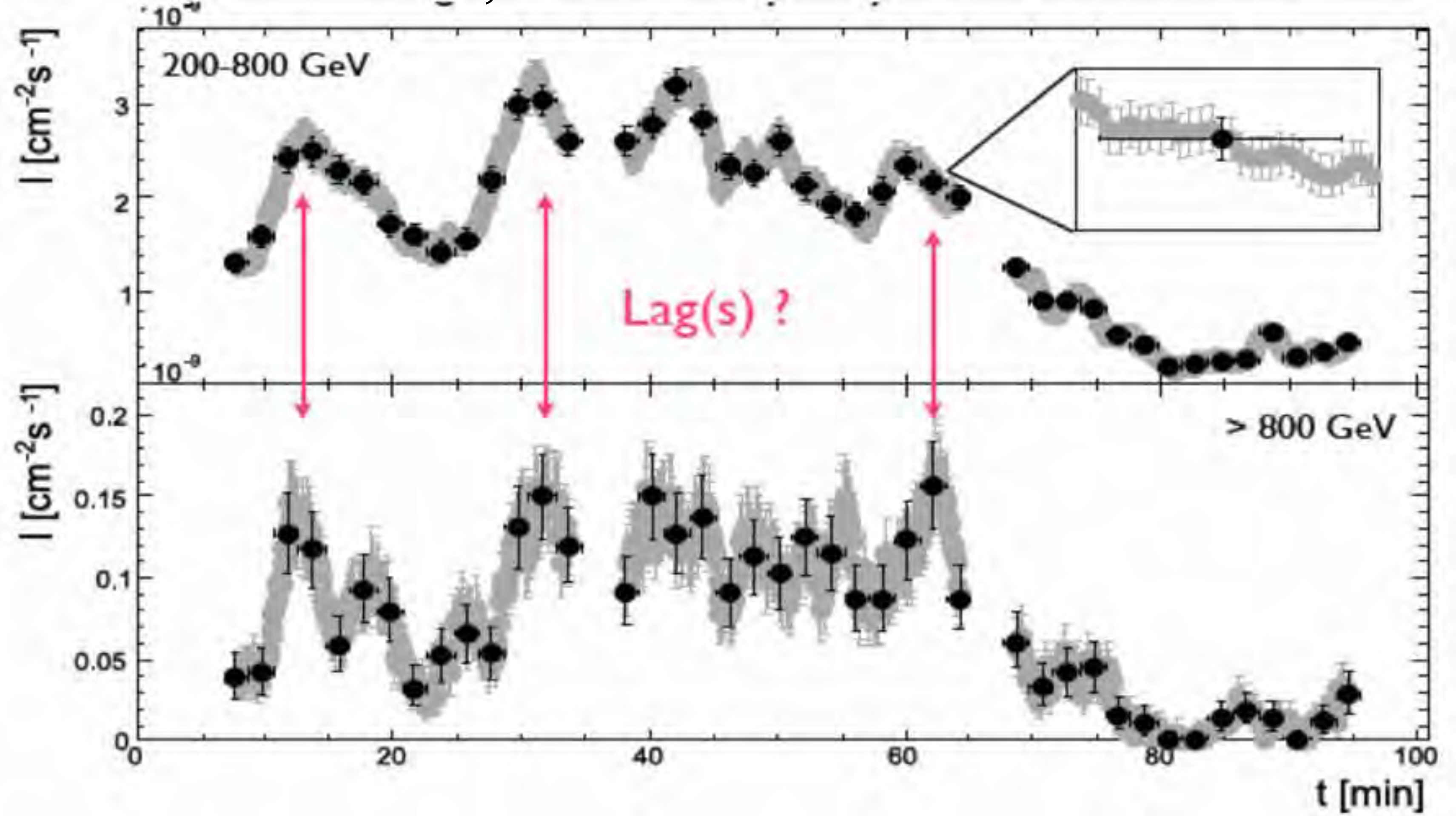
HESS PKS 2155
z = 0.116

July 2006
Peak flux ~15 x Crab
~50 x average
Doubling times
1-3 min

$R_{BH}/c \sim 1...2 \cdot 10^4$ s

Tests of Lorentz violation: the name of the game

HESS, PKS 2155



Sensitivity O(Mp) already reached (Fermi, HESS, MAGIC)

No signatures of new physics

If standard physics only, cosmological parameters can be measured

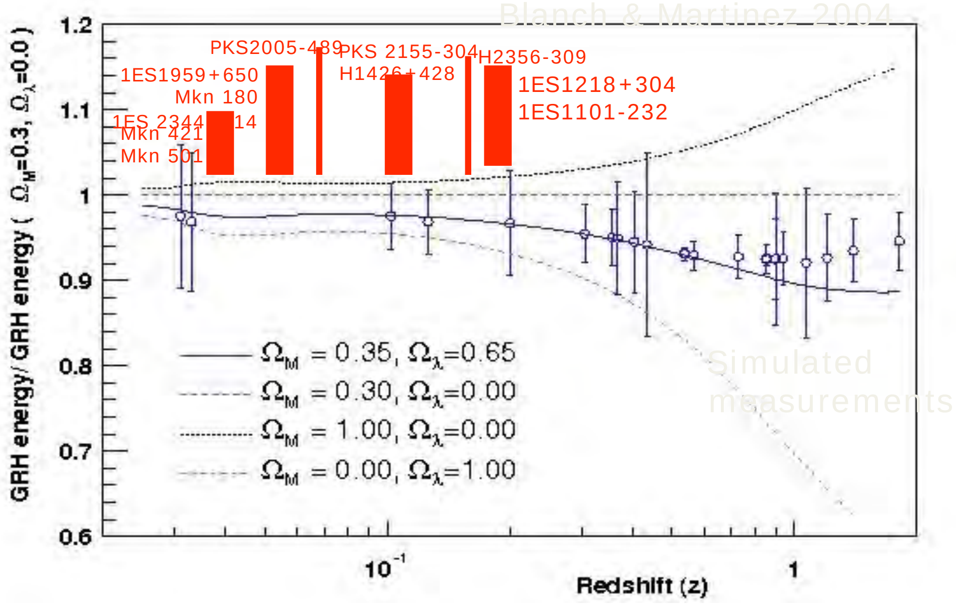
If propagation is standard, cosmology with AGN

GRH depends on the γ–ray path and there the **Hubble constant and the cosmological densities** enter => if EBL density and intrinsic spectra are known, the GRH might be used as a **distance estimator**

$$\frac{dl}{dz} = \frac{c}{H_0} \frac{1}{(1+z)\left[(1+z)^2(\Omega_M\, z+1) - \Omega_\Lambda\, z(z+2)\right]^{\frac{1}{2}}}$$

GRH behaves differently than other observables already used for cosmology measurements.

EBL constraints are paving the way for the use of AGN to fit Ω_M and Ω_Λ …

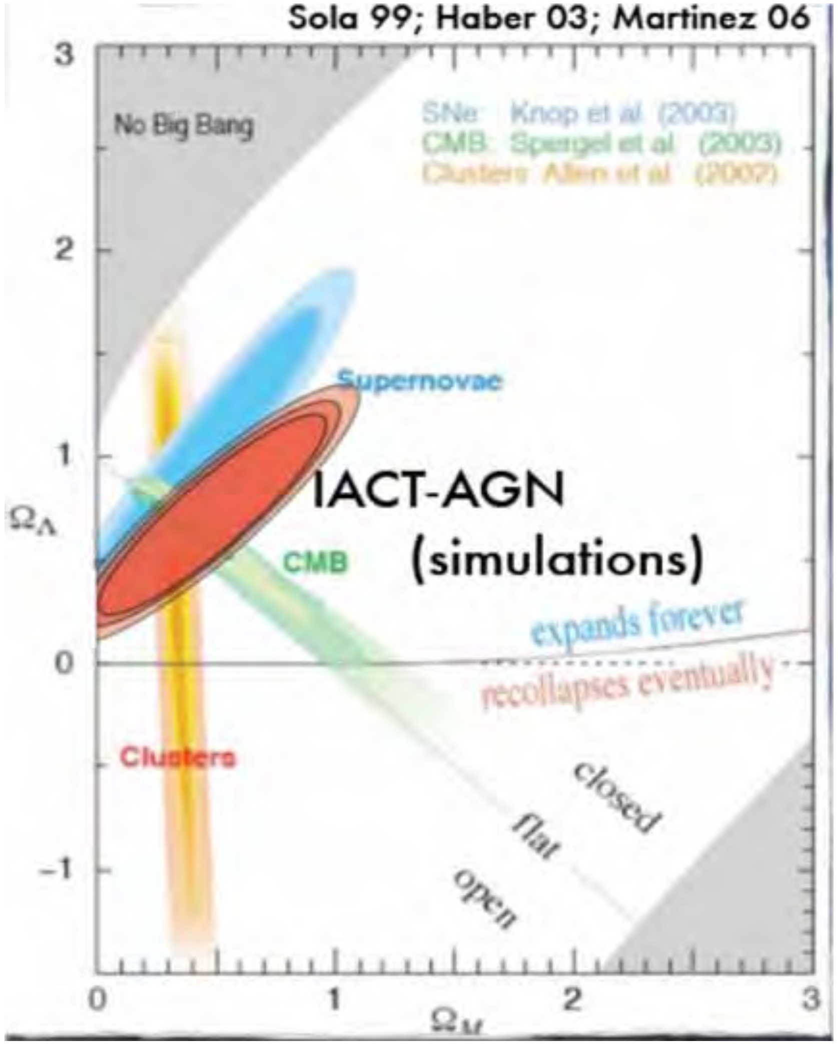


Determination of H_0, Ω_M , Ω_L

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

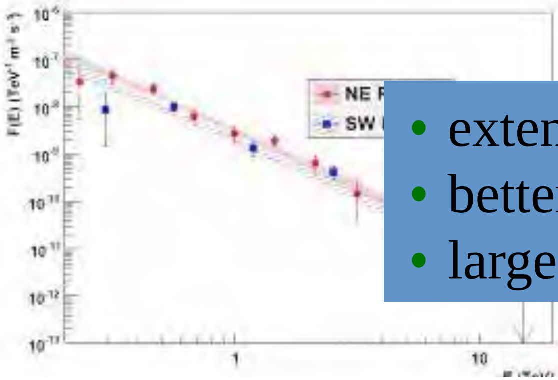
Using the foreseen precision on the GRH (distance at which τ(E,z)=1) measurements of 20 extrapolated AGN at z>0.2, cosmological parameters can be fitted.

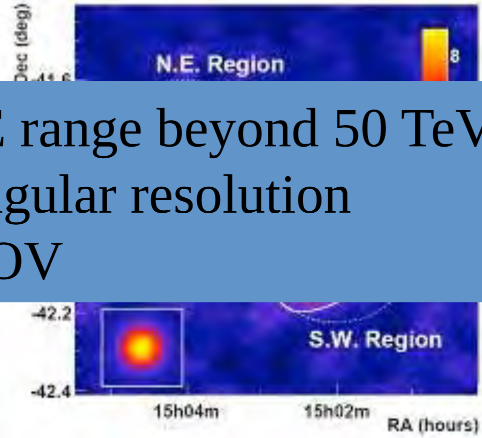
=> The $\Delta\chi^2$=2.3 2-parameter contour might improve by a factor 2 the 2004' Supernovae combined result !



Gamma rays: a wish list for the future

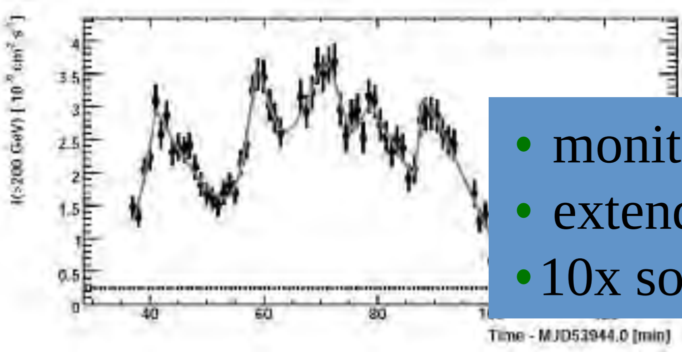
- Galactic sources & CR





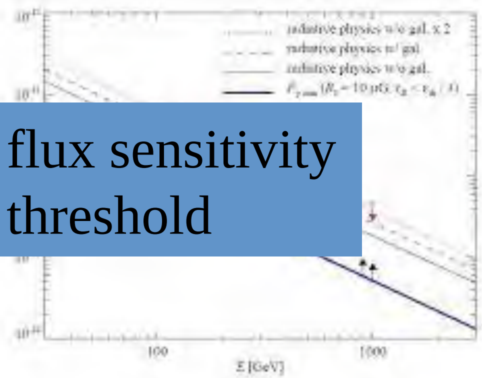
- extend E range beyond 50 TeV
- better angular resolution
- larger FOV

- AGN & gamma prop.
  Axions



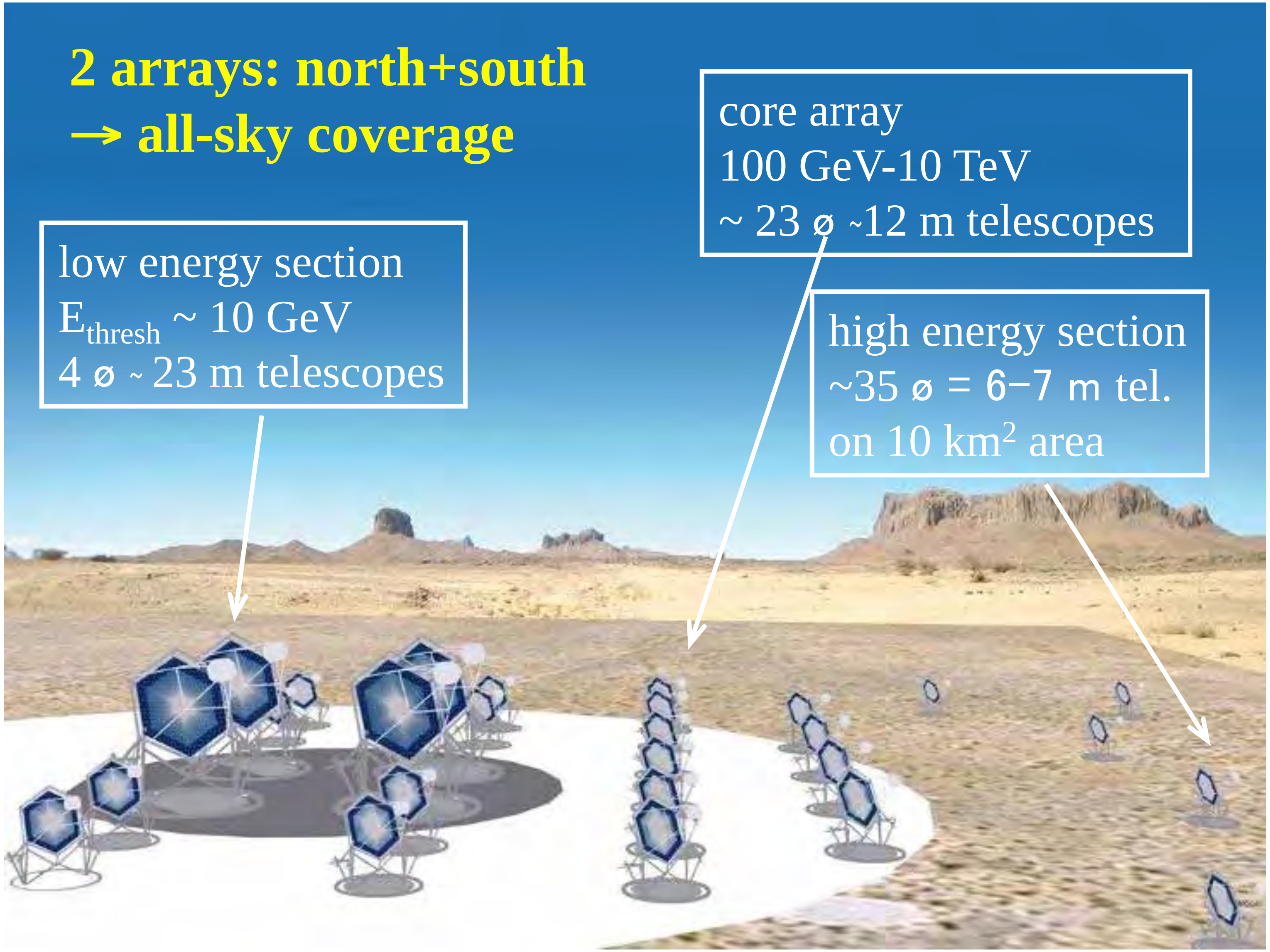
- monitor many objects simult.
- extend E range under 50 GeV
- 10x sources

- New particles, new phenomena
  - dark matter and astroparticle physics

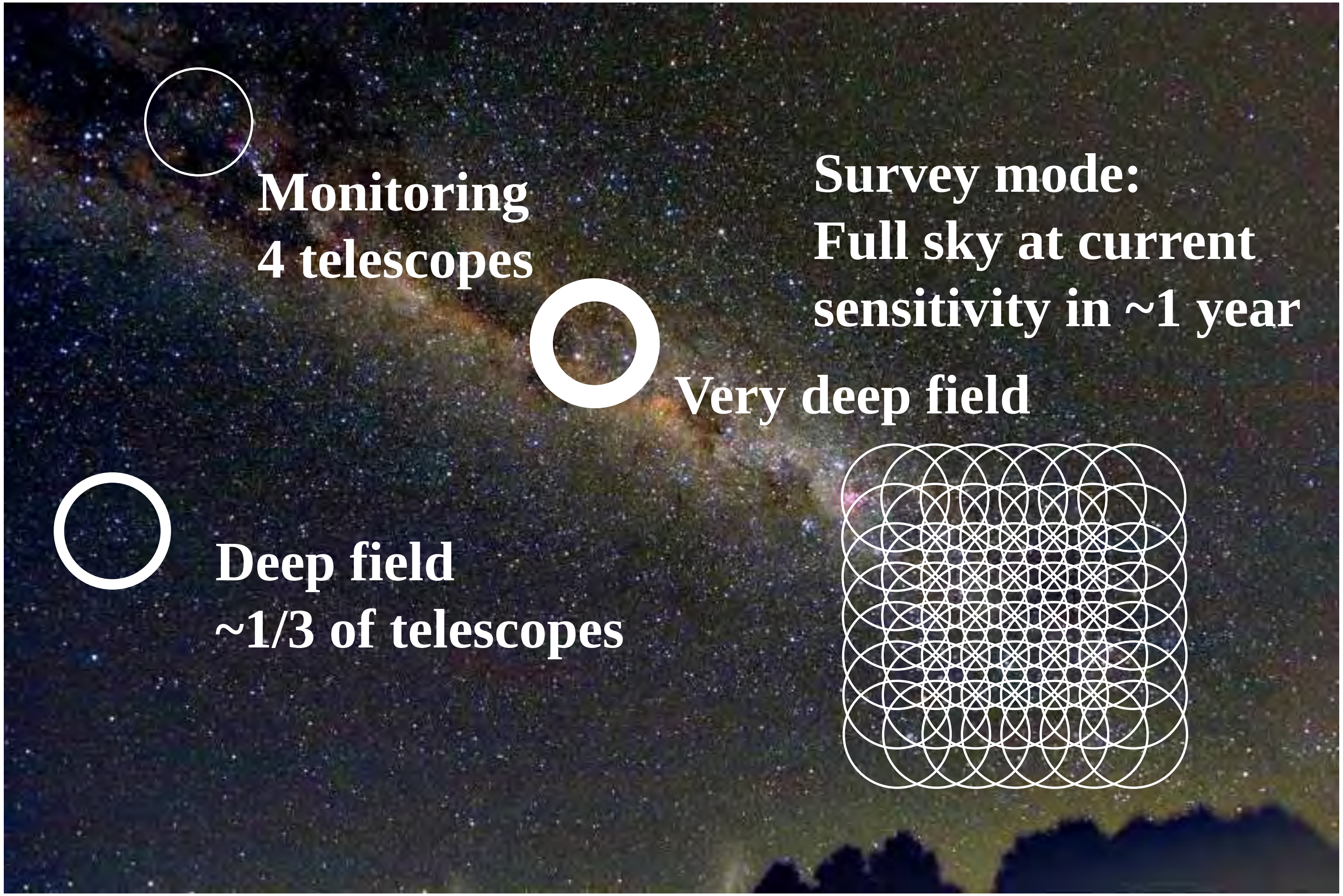


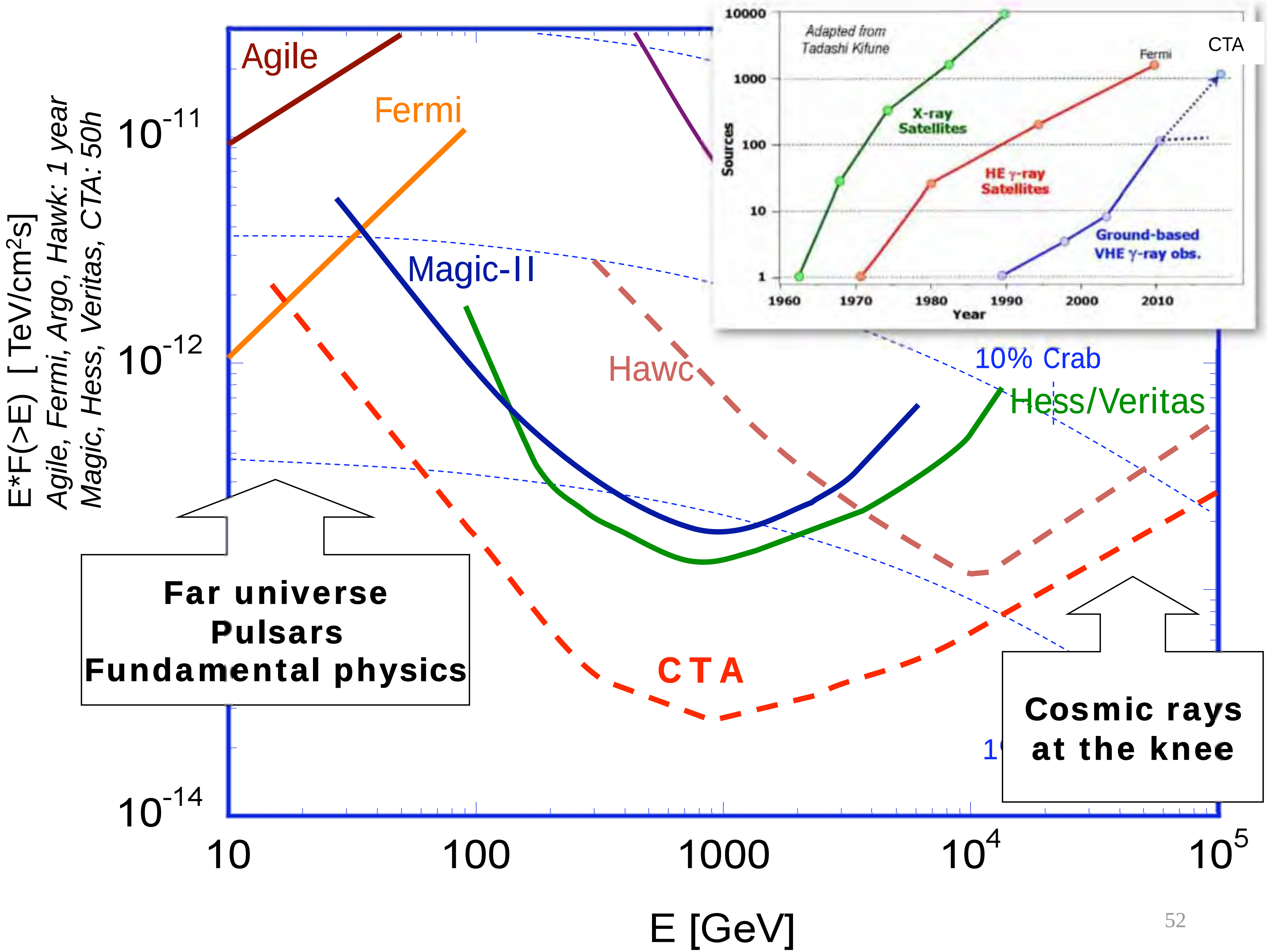
- better flux sensitivity
- lower threshold

The CTA concept (a possible design)



CTA operation modes





Agile
Fermi
Magic-II
Hawc
CTA
10% Crab
Hess/Veritas
Far universe
Pulsars
Fundamental physics
Cosmic rays
at the knee
E*F(>E) [TeV/cm2s]
Agile, Fermi, Argo, Hawk: 1 year
Magic, Hess, Veritas, CTA: 50h
10-11
10-12
10-14
10
100
1000
10^4
10^5
E [GeV]
Adapted from
Tadashi Kifune
X-ray
Satellites
HE γ-ray
Satellites
Ground-based
VHE γ-ray obs.
Fermi
CTA
Sources
Year

Relevance to HEP, needs and opportunities

- Physics
  - Energy: TeV energy scale (particle acceleration, elementary processes in the Universe)
  - Evolution of the Universe
  - Fundamental physics
    - Search for cosmological Dark Matter
    - Axion-like particles and new particles
    - Probe Quantum gravity (space time structure of vacuum) – close to the Planck Scale
  - Hadronic interactions (Gamma / Hadron separation)
  - Synergy with neutrino detectors

- Cutting edge technologies developed in HE physics
  - High QE advanced photodetectors, HPDs, SiPMs
  - Analogue signal transmission via optical fibers
  - Readout system 2GHz ultra fast analogue ring sampler
  - Ultra fast trigger system
  - Large data flow, massive computing (GRID computing)

Summary

- Clear interplay between astroparticle and fundamental physics; this model of cooperation is working well, and can work well in the future
- Cosmic Rays:
  - SNR as galactic sources established
    - Astronomy with charged CR is difficult
    - Astronomy with neutrinos will be difficult
    - VHE photons can be the pathfinder
  - Beyond the knee: only hints
    - Something not understood at EHE – can be big
- Still no detection of DM
  - The information from no detection is not as good as for accelerators
- A few clouds might hide new physics
  - Cross sections at EHE
  - Photon propagation
- Rich fundamental science (and astronomy/astrophysics)
  - HEA is exploring regions beyond the reach of accelerators
  - A “simple” extension of present gamma detectors is in fast progress: CTA