Indirect Dark-Matter Search with Imaging Atmospheric Cherenkov Telescopes

Adrian Biland, ETH Zurich

DMUH11, CERN, 26.July 2011

DM Search Strategies

[mainly SuSY / mSUGRA/MSSM]

a) creation at colliders [if found -> DM ???]

b) direct detection [only measure local DM]

c) indirect (DM annihilation if Majorana part.)

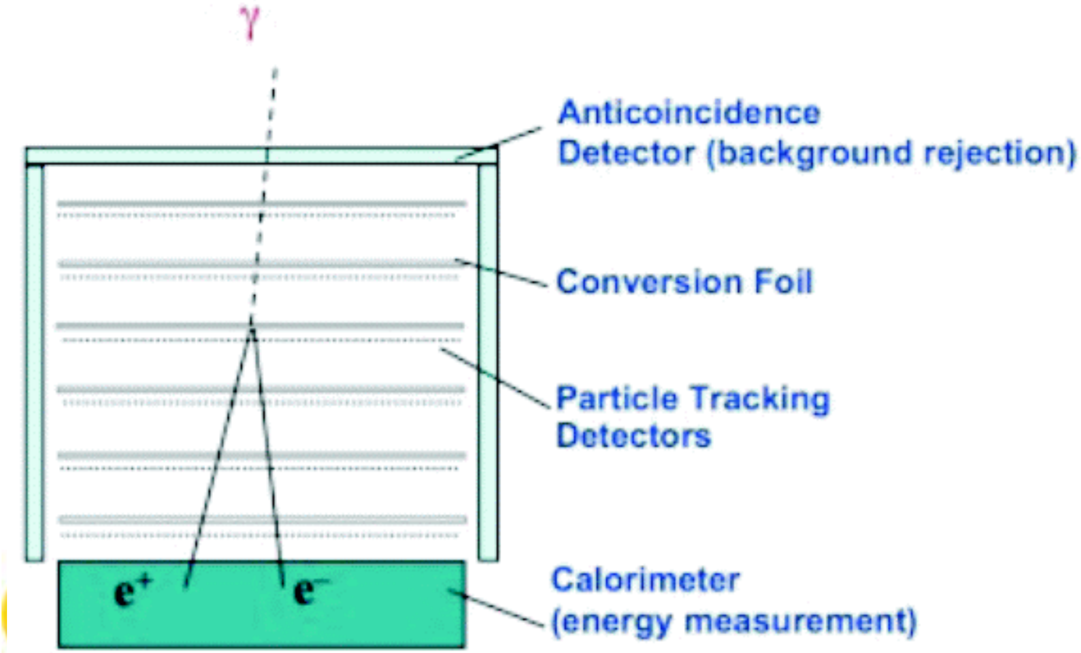
- charged particles: only measure galact. DM
- uncharged: map DM distribution in universe

==> need to measure neutrinos or

high-energy (>GeV) photons

HE: <50GeV ; VHE: 50-5000GeV

HE gamma (Satellite: Fermi LAT)



can measure HE gamma >0.1GeV

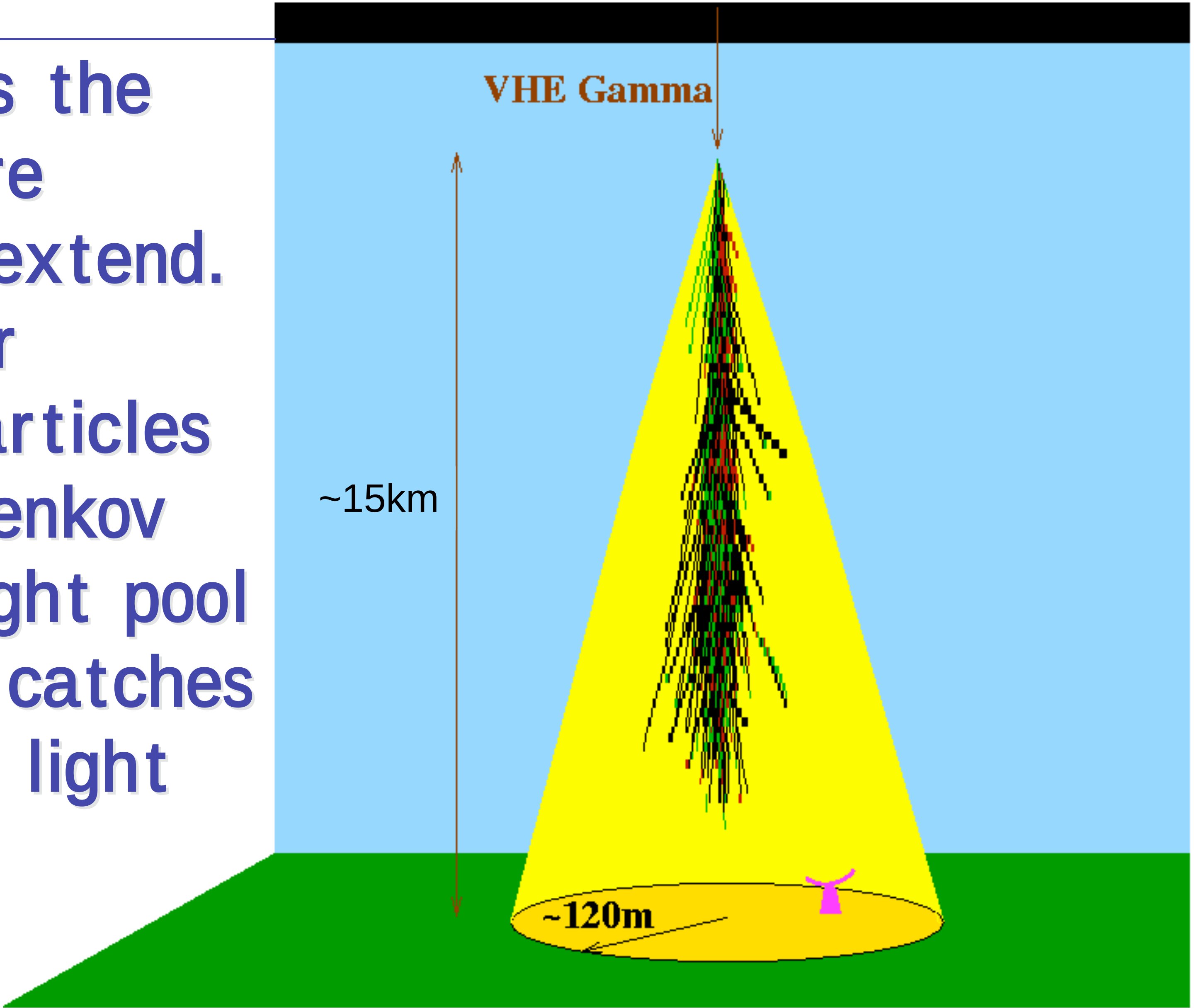
active area ~1m^2
⇒ VHE limited by statistics

background free !!
(but diffuse gamma)

full-sky coverage
ang. resol. ~0.1deg

VHE gamma: Cherenkov Telescopes

- VHE γ hits the atmosphere
- produces extend. air-shower
- shower particles emit cherenkov light => light pool
- telescope catches cherenkov light



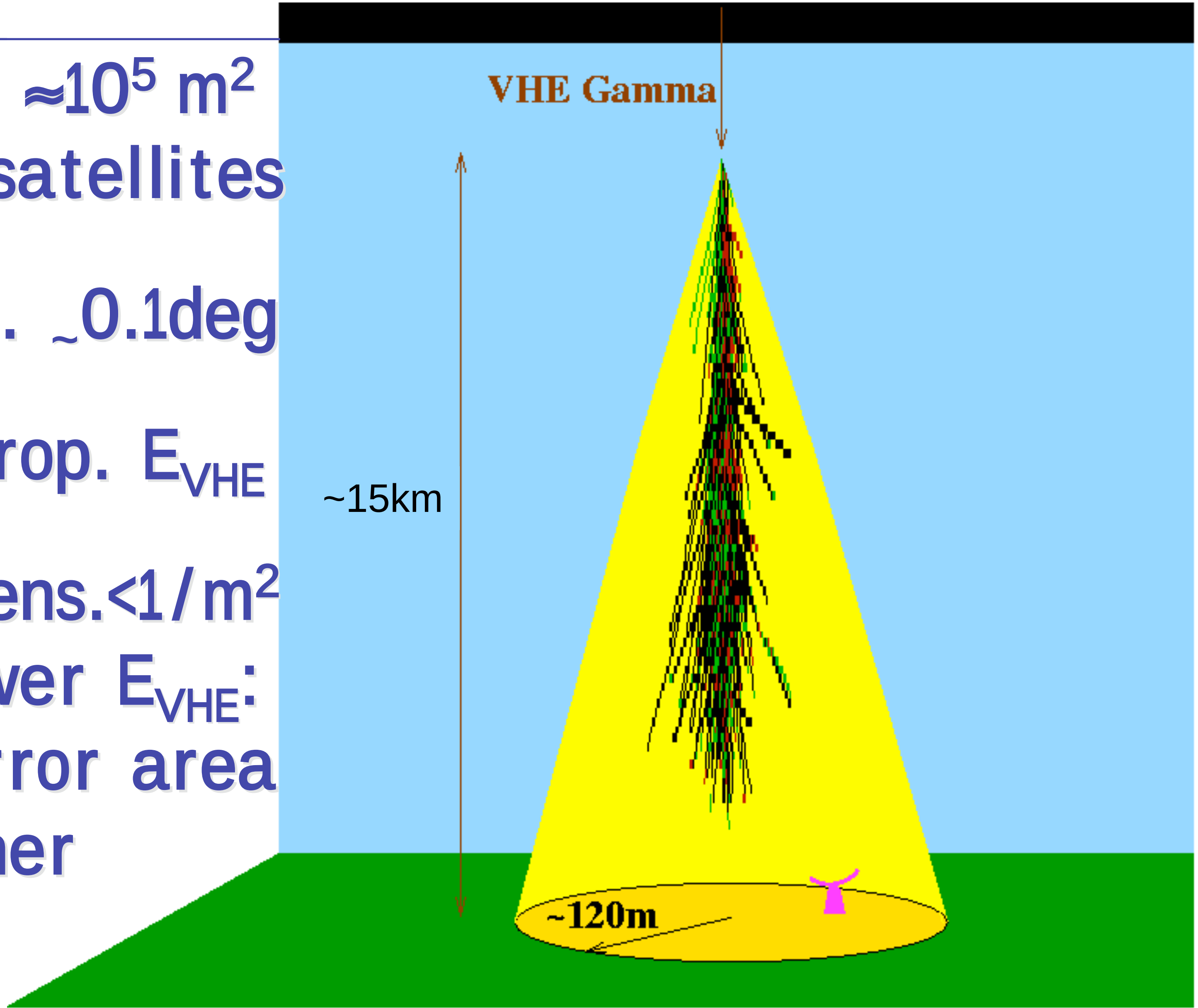
Cherenkov Telescope Principle

- eff. area: $\approx 10^5$ m^2 vs. 1 m^2 satellites

- ang. resol. ~0.1deg

- γ_{ch}dens. prop. E_{VHE}

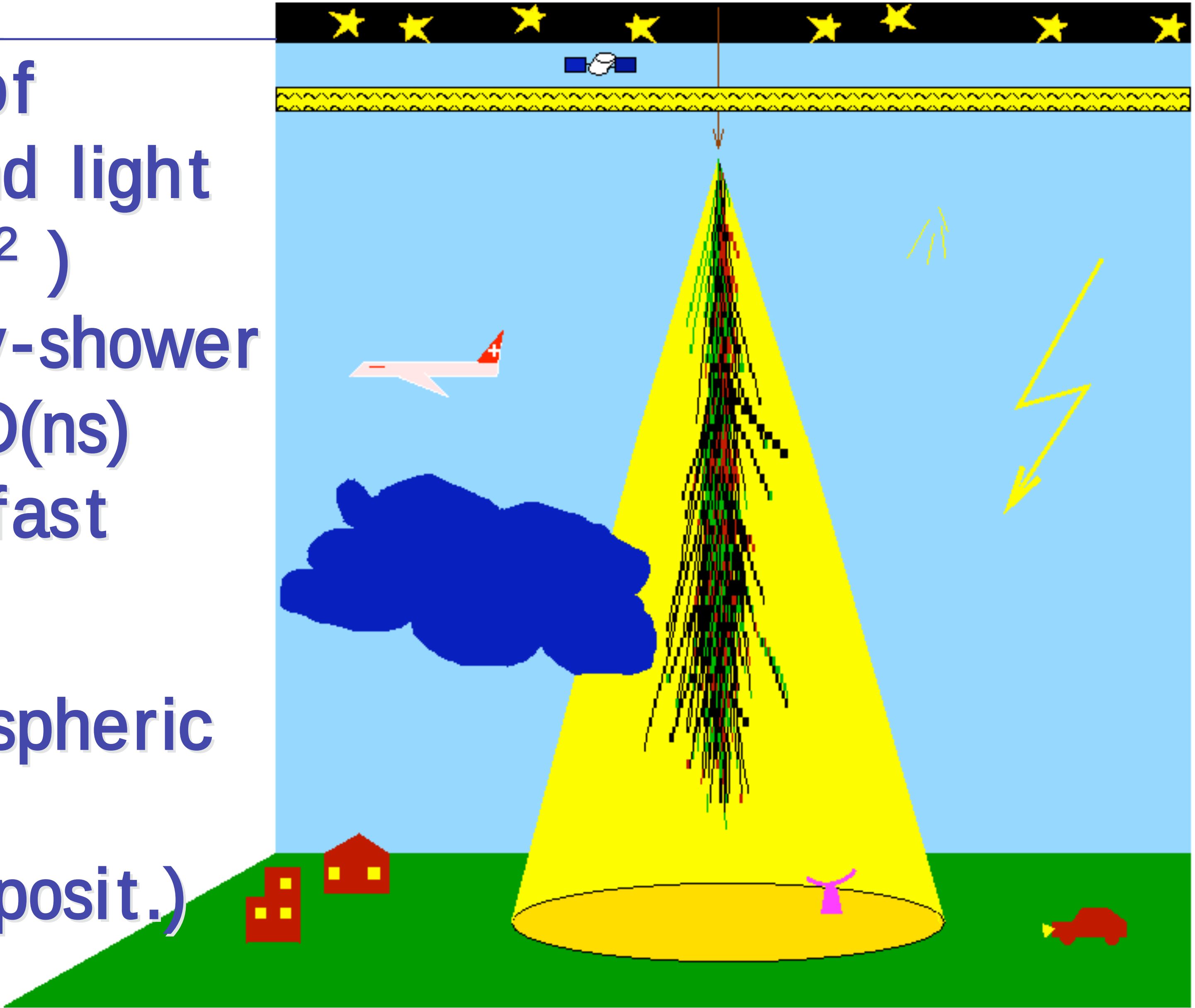
typical γ_{ch}dens.<1/m^2
measure lower E_{VHE}:
- larger mirror area
- go to higher altitude



Cherenkov Telescope Problems

- all kinds of background light ($\sim$GHz/m^2)
- Cherenkov-shower duration O(ns) ==> need fast camera

- var. atmospheric conditions (T, p, composit.)



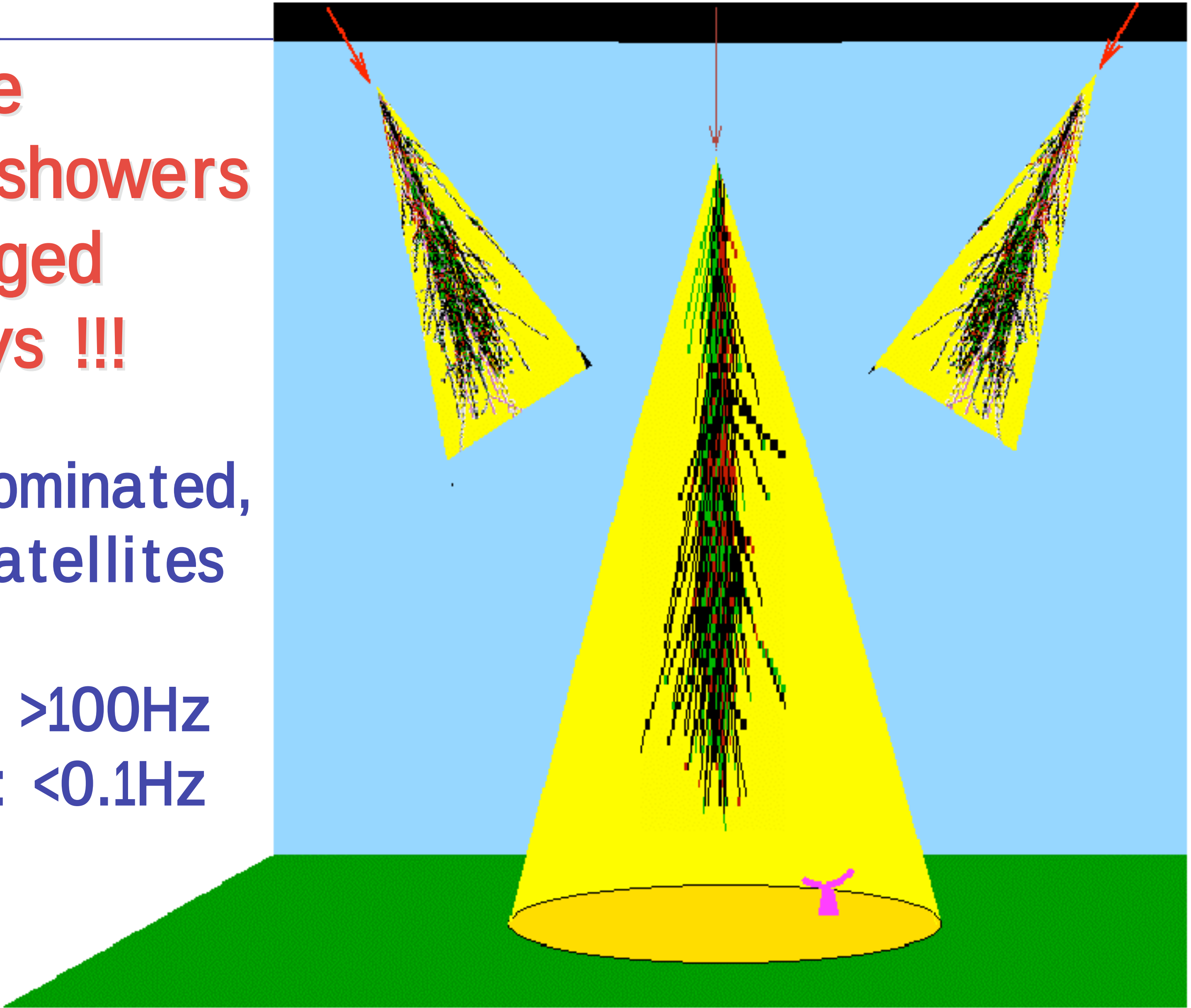
ETH Institute for Particle Physics
biland@phys.ethz.ch

Cherenkov Telescope Problems

- much more abundant showers from charged cosmic rays !!!

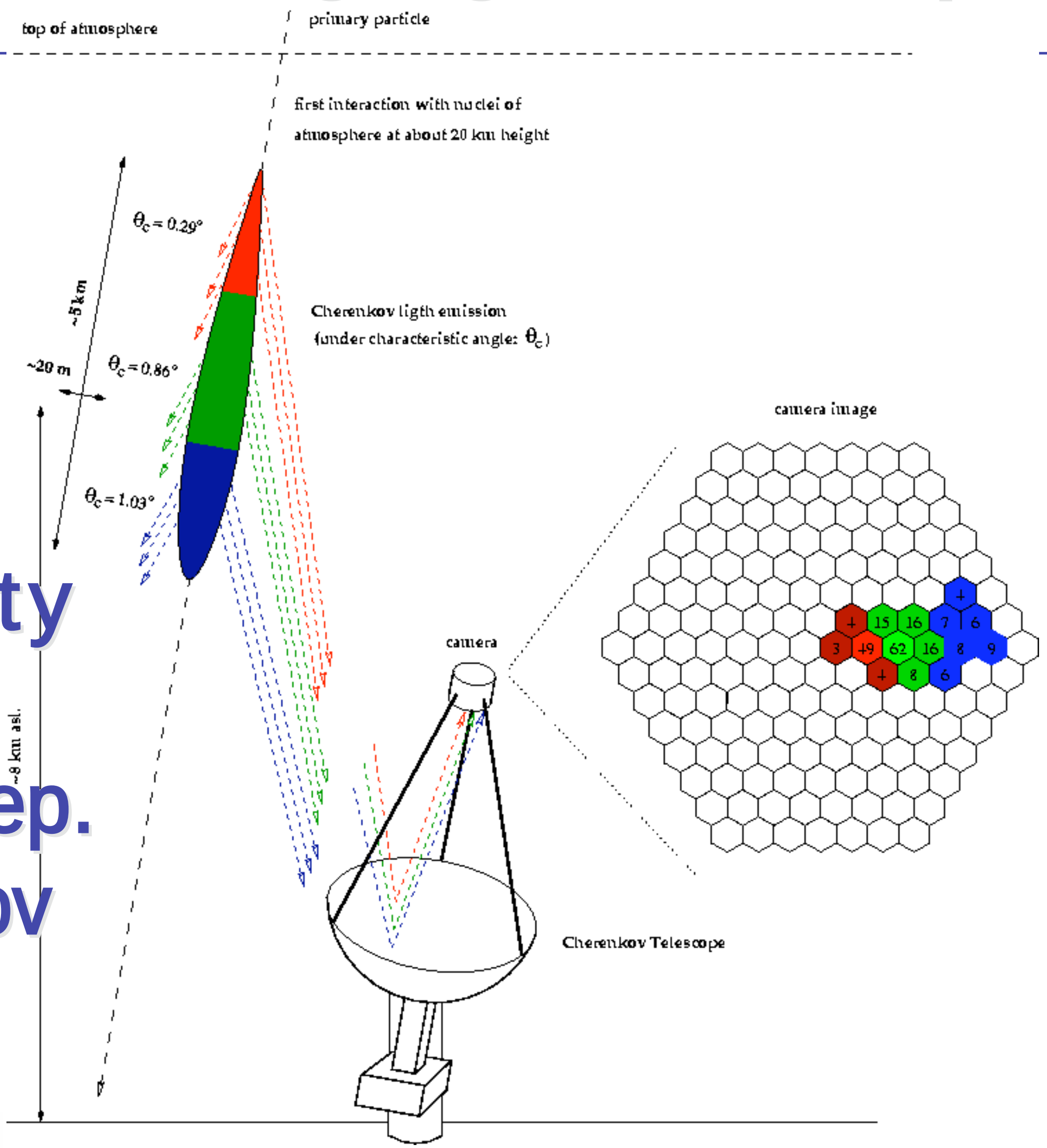
Background dominated,
vs. BG-free satellites

hadron-rate: >100Hz
bright source: <0.1Hz



Imaging Technique

height
depend.
air density
 ==>
height dep.
Cherenkov
angle



do not look
at lateral
distribution
on ground,

but see the
projection
of (part of)
shower

Imaging Technique

electromagnetic and hadronic showers have different shapes

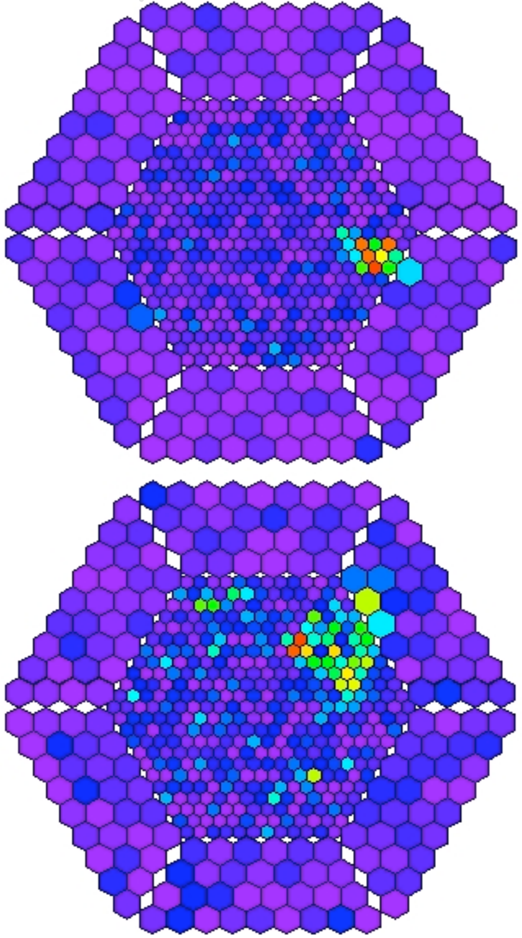
===>

using a high resolution Camera allows to distinguish (statistically) between γ- and hadron-showers

Works excellent > 100 GeV

but very difficult < 100 GeV

γ candidate



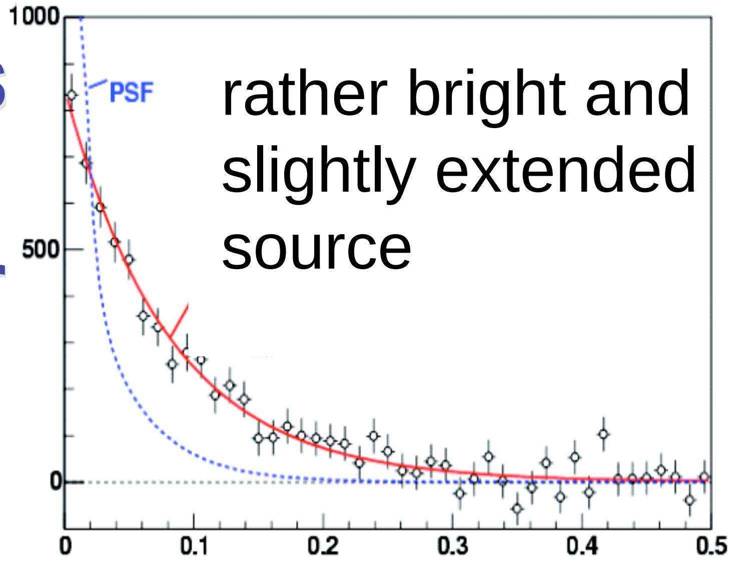
hadron shower

Imaging Technique

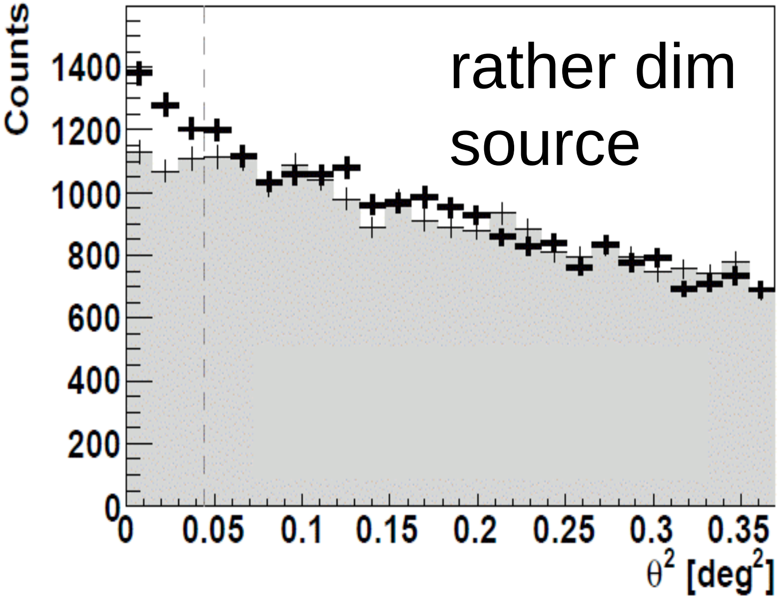
shower-images from particles parallel to telescope axis (source) point towards center of camera

other showers (background) have random direction ==> angle-cut (and measure/estim remaining hadronic (and e-) BG)

BG is NOT constant !



rather bright and slightly extended source



rather dim source

Stereo Technique

several telescopes separated <100m

==> measure identical showers

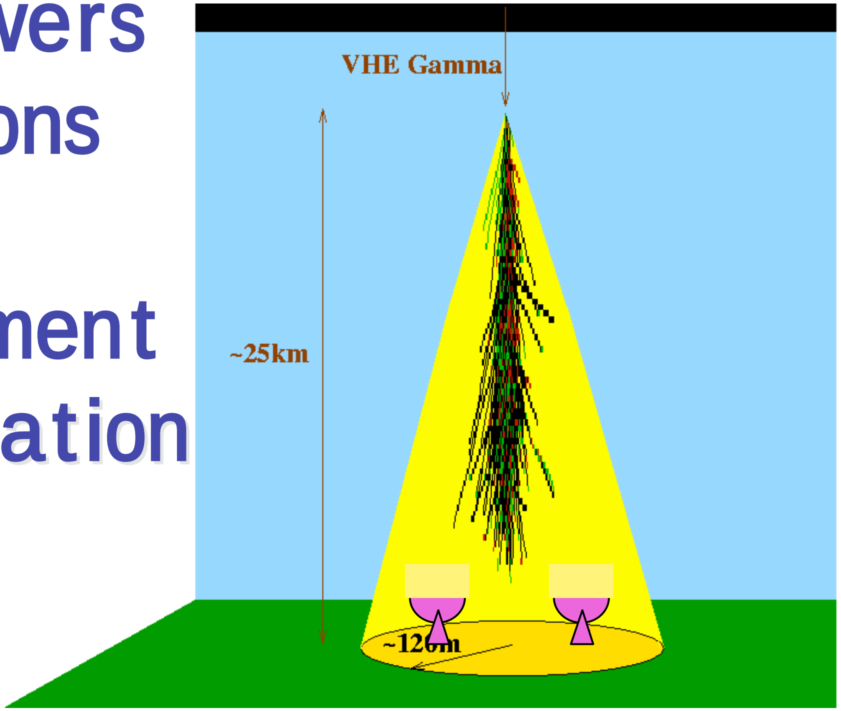
==> get different projections
for each shower

==> more precise measurement

==> better γ/hadron separation

==> less background

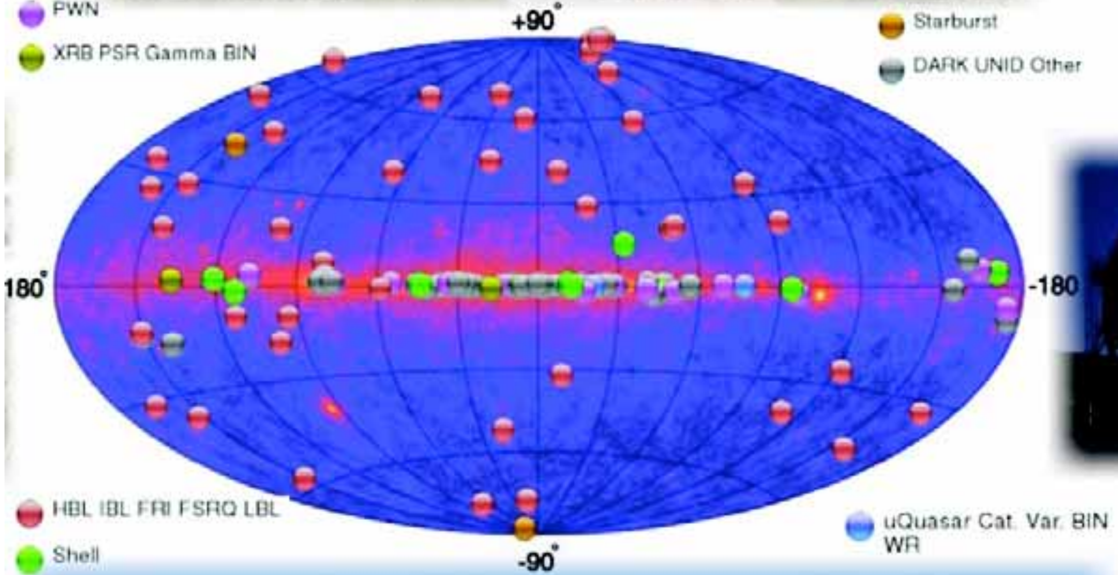
==> higher sensitivity



(two indep. telescopes: gain sqrt(2) from statistics;
two stereo telescopes: gain ~factor 2 ...)

Actual Instruments

VERITAS:
4x12m, Arizona



MAGIC:
2x17m
La Palma

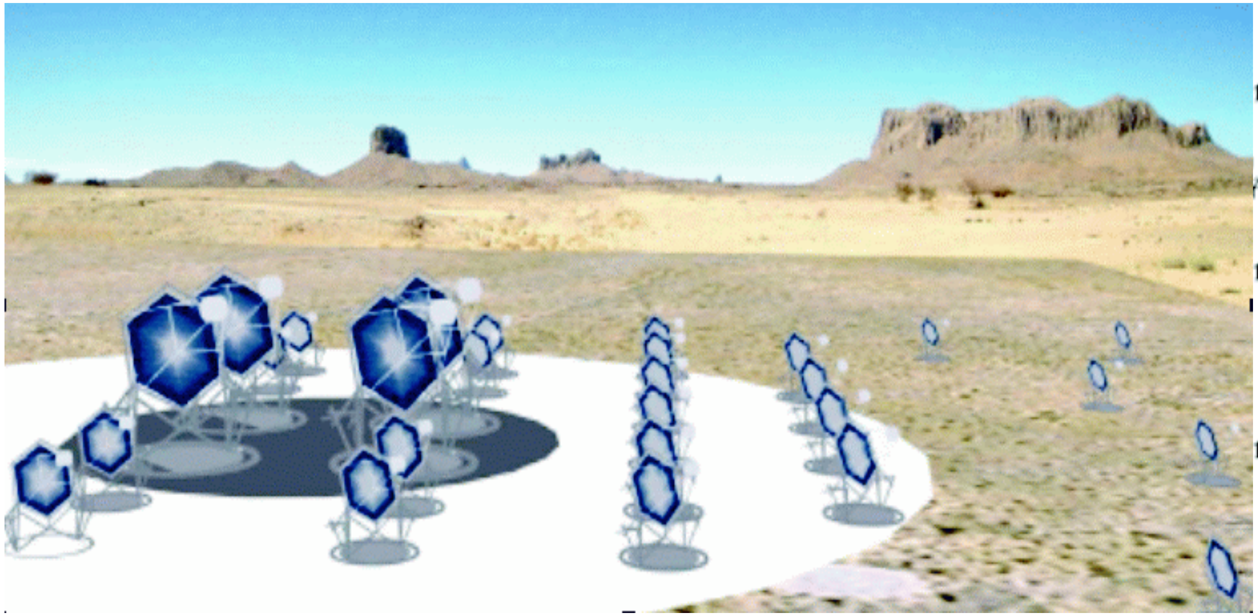
H.E.S.S.:
4x12m, Namibia

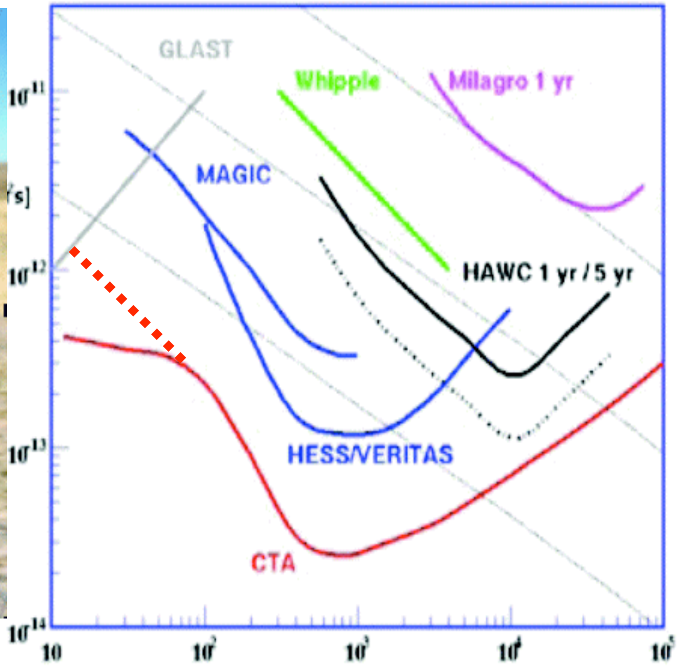
Next Generation

Cherenkov Telescope Array:

~4x23m , >>24x12m , ~50x6m southern array

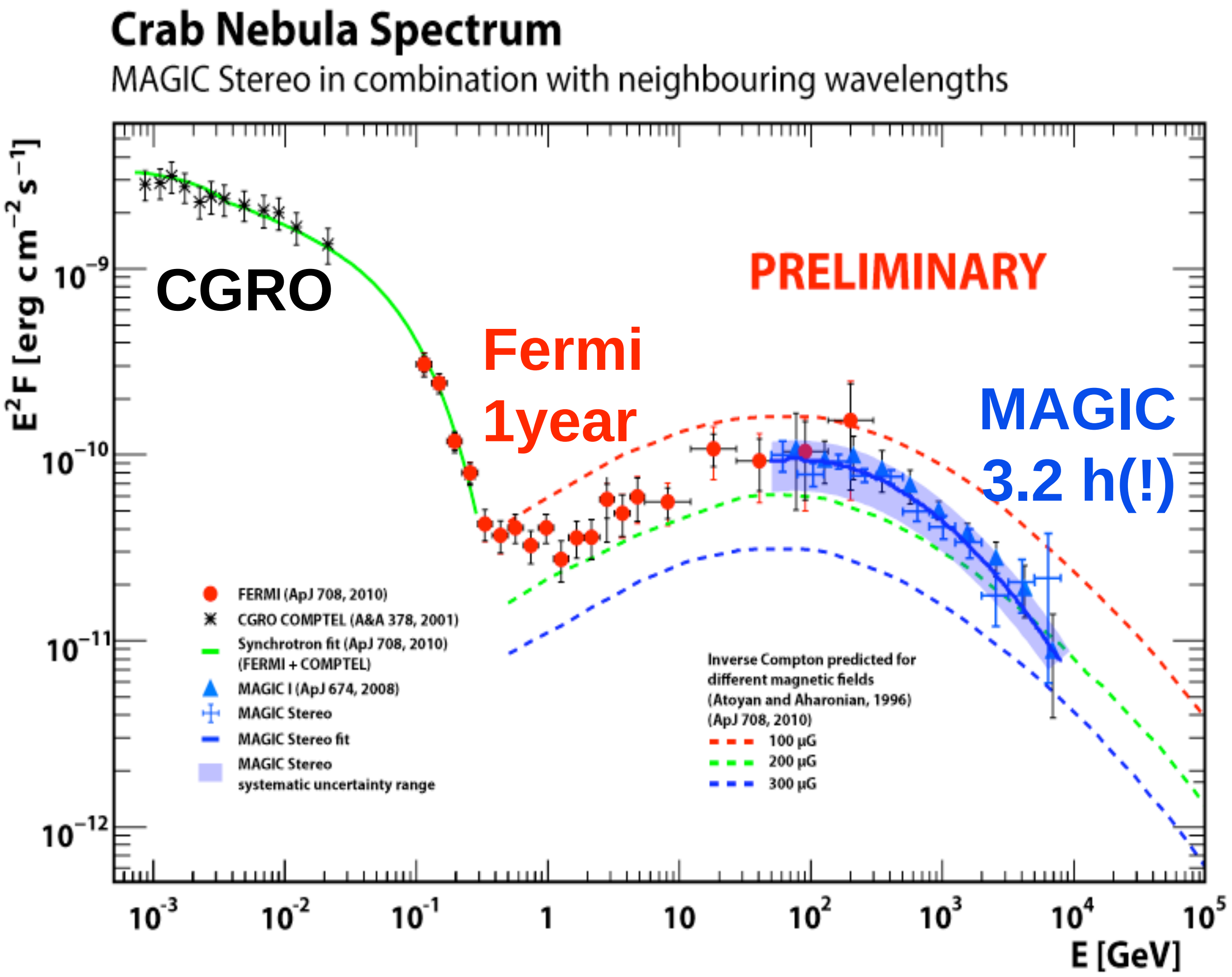
~4x23m , ~24x12m northern array





Goal: 10xhigher sensitivity and energy coverage

Fermi vs. IACTs

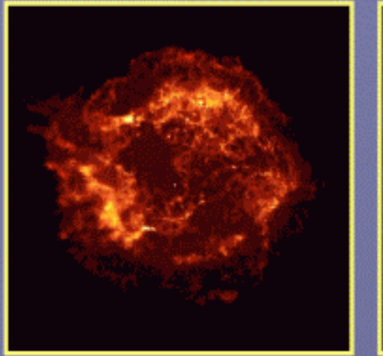


taking into account no 'testbeam' to calibrate IACTs, only Monte Carlo

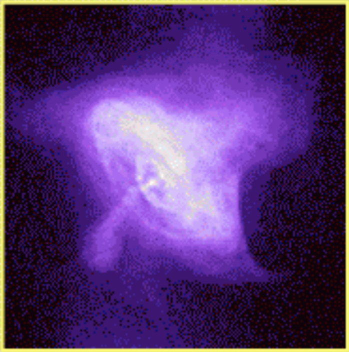
==>

surprisingly good agreement...

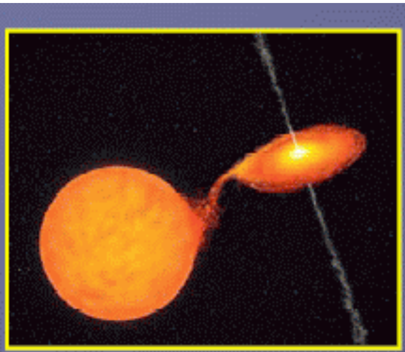
IACTs: Pointed Observations
==> DM must Fight for Obs.Time ...



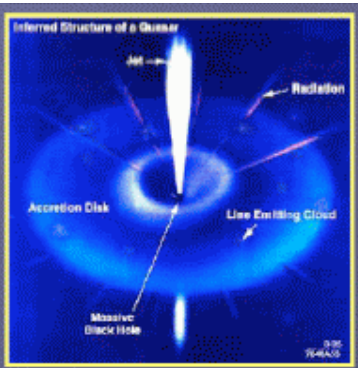
SNRs



Pulsars
and PWNe



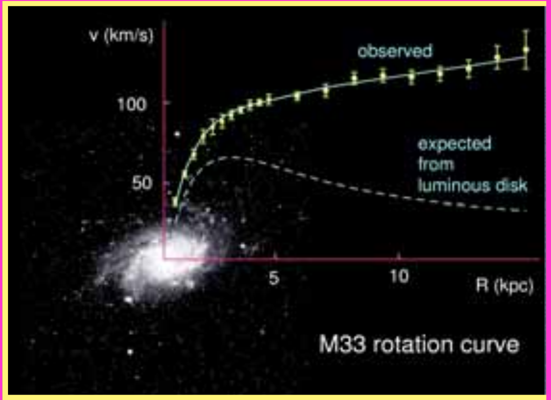
Micro quasars
X-ray binaries



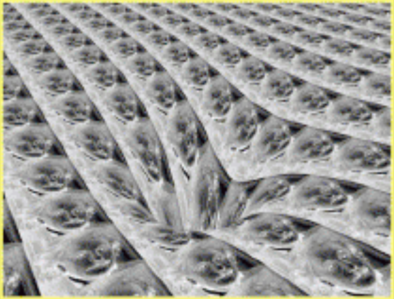
AGNs

GRBs

Origin of
cosmic rays

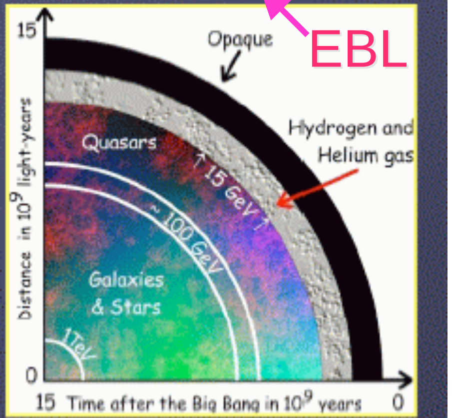


Dark matter



Space-time
& relativity

Axions; DM Stars

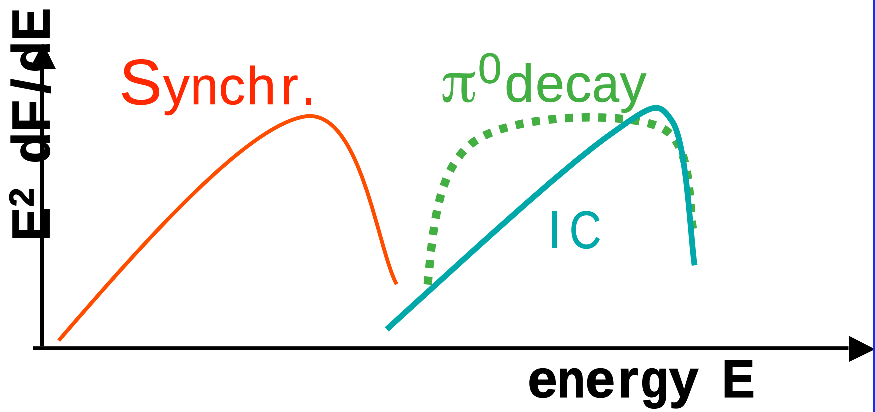


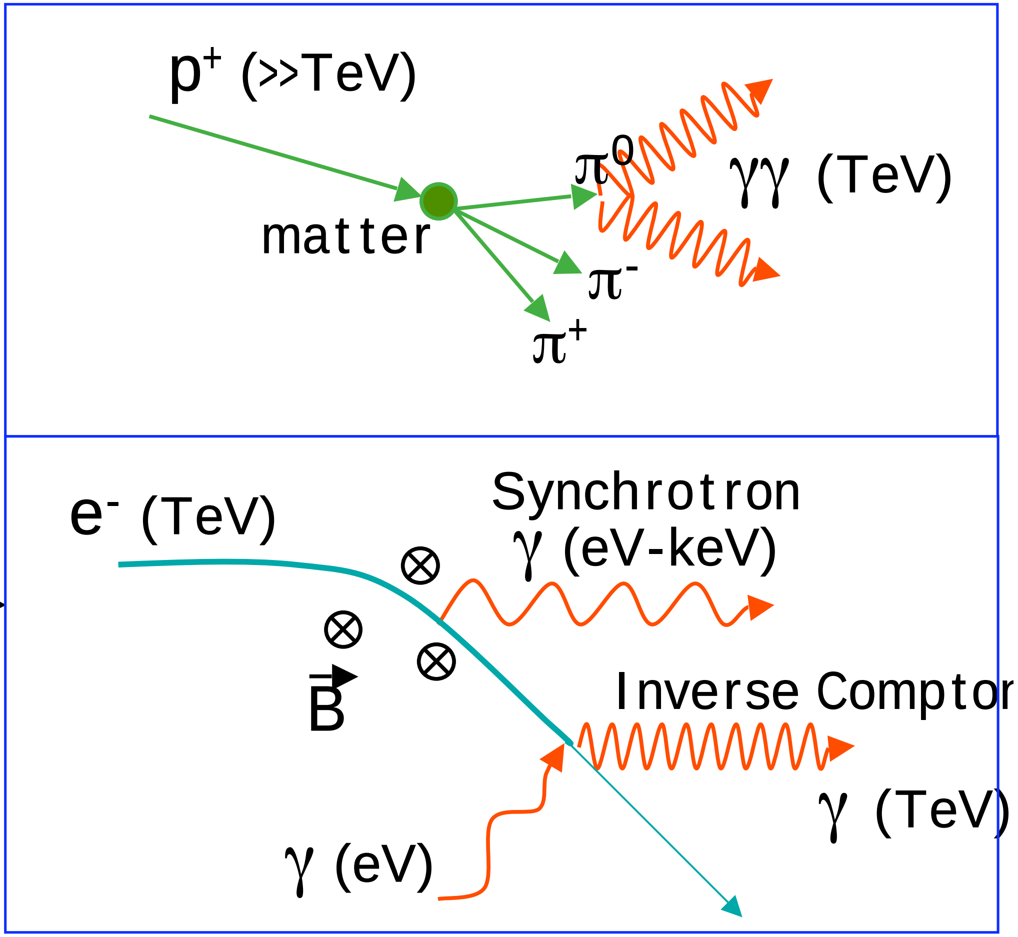
Cosmology

‘Standard’ Origins of VHE-γ

VHE photons do have non-thermal origin(s)

Do p or e^- act as seed particles?





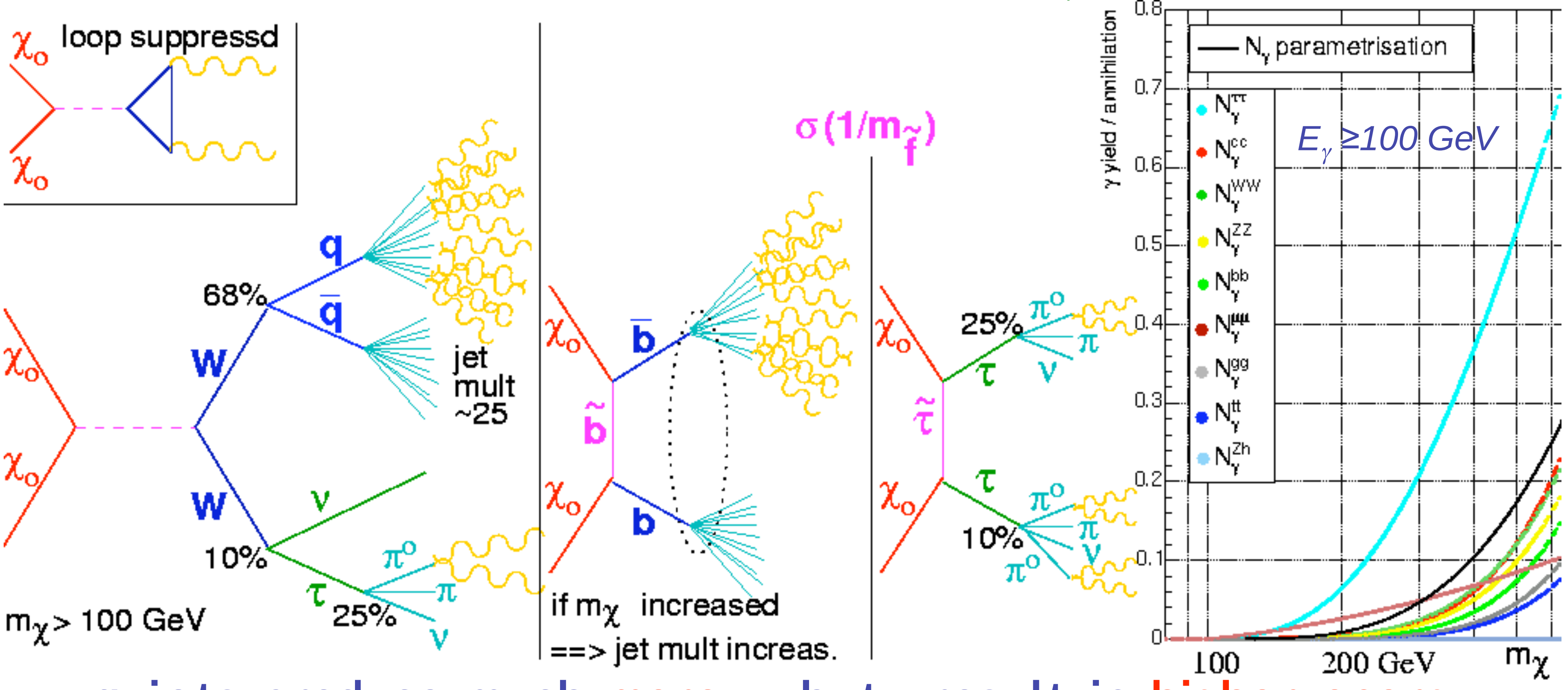
distinguish hadronic vs.
leptonic ‘acceleration’:
=> shape of spectrum;
Multi-wavelength

biland@phys.ethz.ch

VHE-γ from e.g. χ_0-annihilation

X_0 does **not directly** couple to γ (else not 'dark') ==>

Some important processes to produce VHE γ:



q-jets produce much **more** γ, but τ result in **higher energy** γ

==> VHE γ rare or (rather) low energy

Where to look for DM ?

Flux calculation:

$$\Phi = \underbrace{\frac{N(\sigma v)}{2\,\pi\, m_{\chi}^{2}}}_{\text{Particle physics}} \times \frac{1}{\Delta\Omega} \underbrace{\int d\Omega \int \rho^{2} ds}_{\text{CDM density distribution}}$$

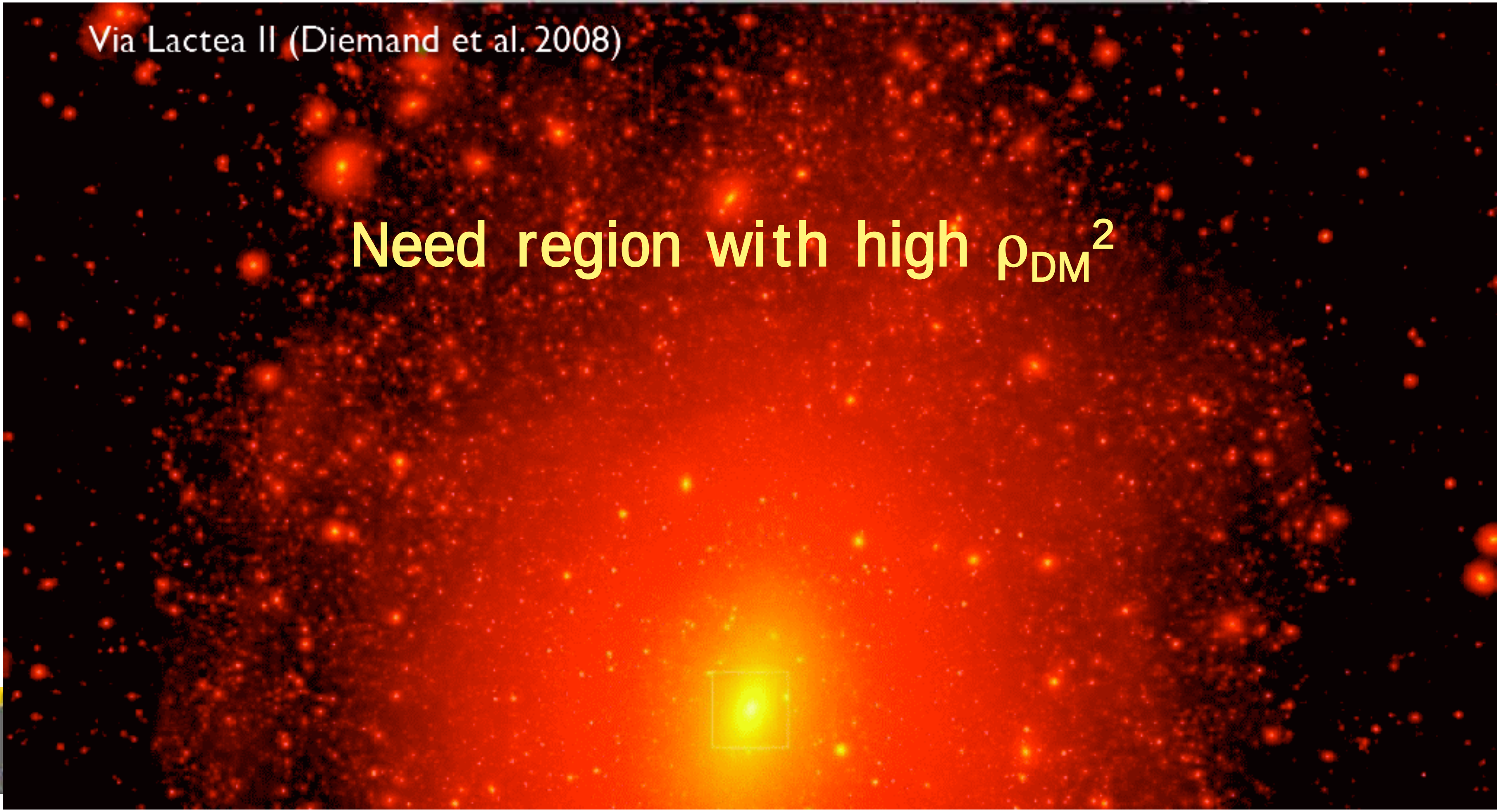
uncertainties O(10^{x})

Particle Physics part:
concentrate on mSUGRA and MSSM ...

Where to look for DM ?

Flux calculation:

$$\Phi = \frac{N(\sigma \upsilon)}{2\,\pi\, m_\chi^2} \times \frac{1}{\Delta\Omega} \int d\Omega \int \rho^2 ds$$



Via Lactea II (Diemand et al. 2008)

Need region with high $\rho_{DM}{}^2$

The Usual Suspects

- Galactic Center

- Spheroidal Dwarf Galaxies

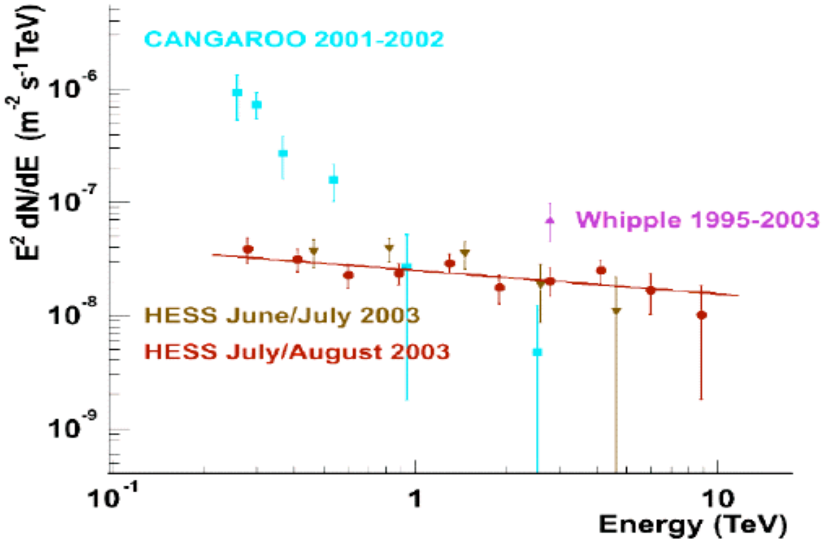
- MiniHalos, Intermediate Mass Black Holes...

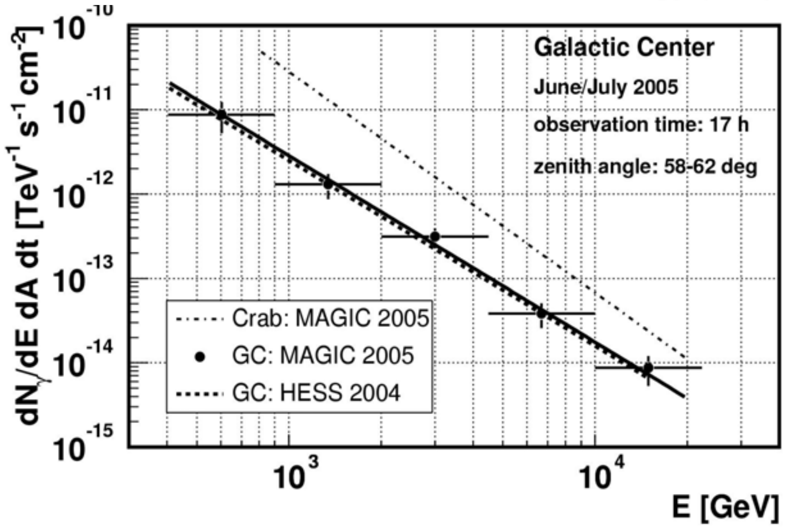
- Galaxy Clusters

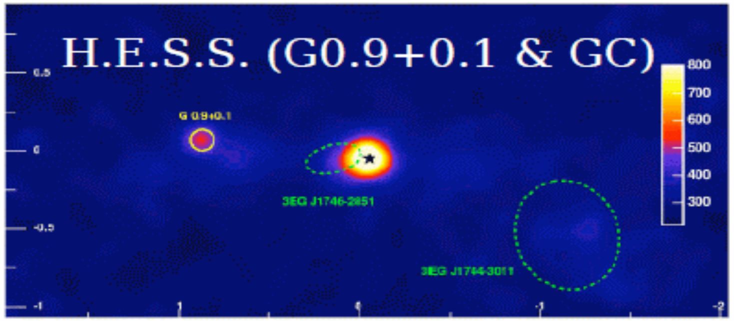
Galactic Center

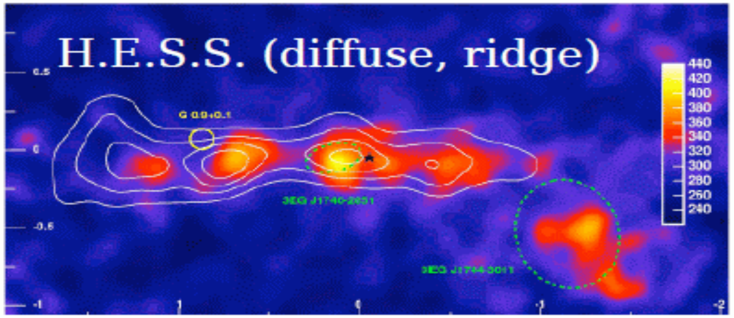
existed contradicting measurements
CANGAROO vs. H.E.S.S.

CANGAROO looked more DM-like, but (unfortunately) MAGIC showed H.E.S.S. to be correct ...





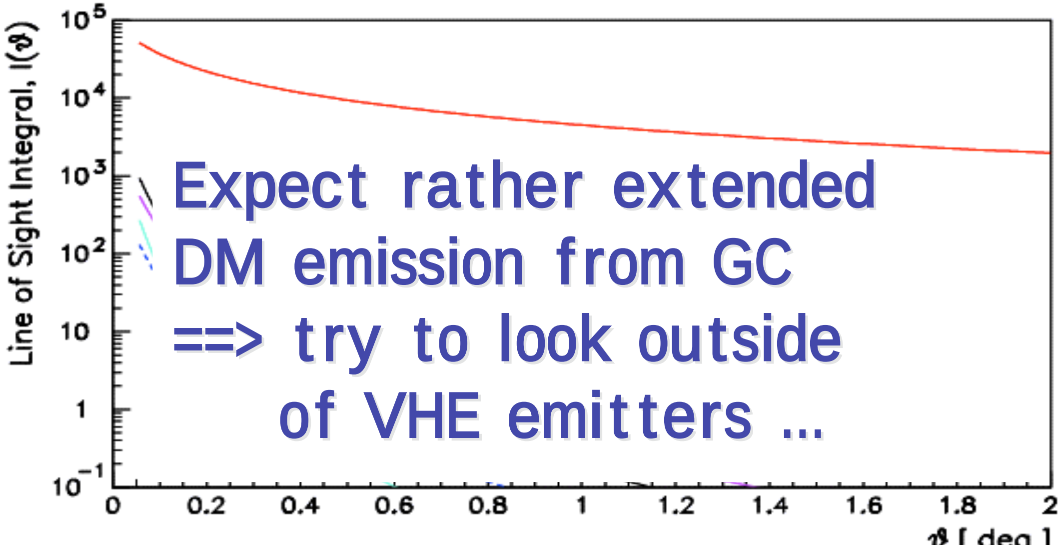




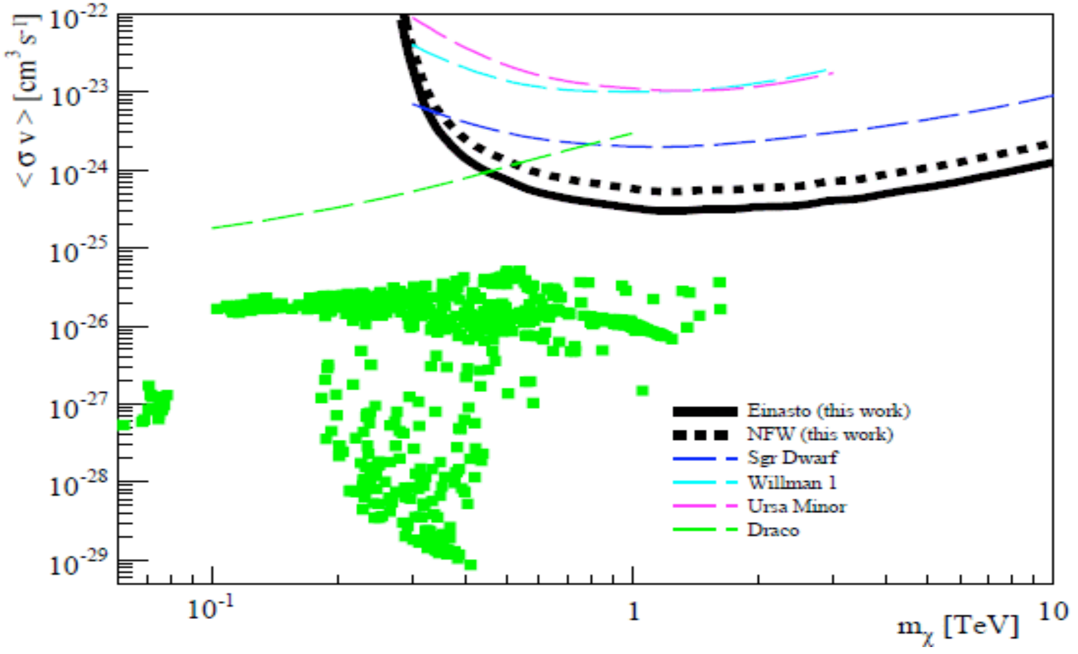
Aharonian, et al. (2006)

additional diffuse emission from GC region ...

Galactic Center

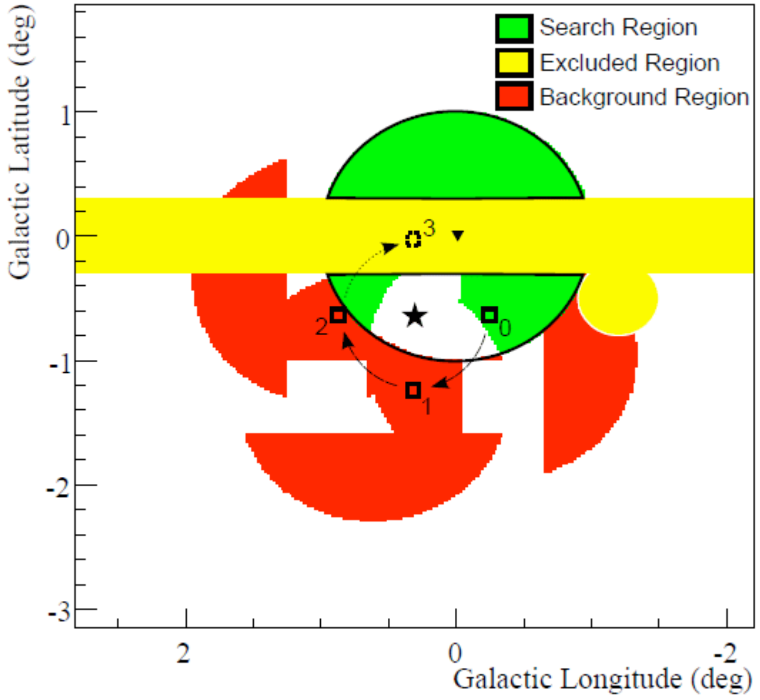


Expect rather extended
DM emission from GC
==> try to look outside
of VHE emitters ...



where exactly to look?

HESS arXiv
1103.3266



The Usual Suspects

- Galactic Center
  - expect by far brightest DM signal
  - strong VHE source obscuring hypot. DM signal

- Spheroidal Dwarf Galaxies

- MiniHalos, Intermediate Mass Black Holes...

- Galaxy Clusters

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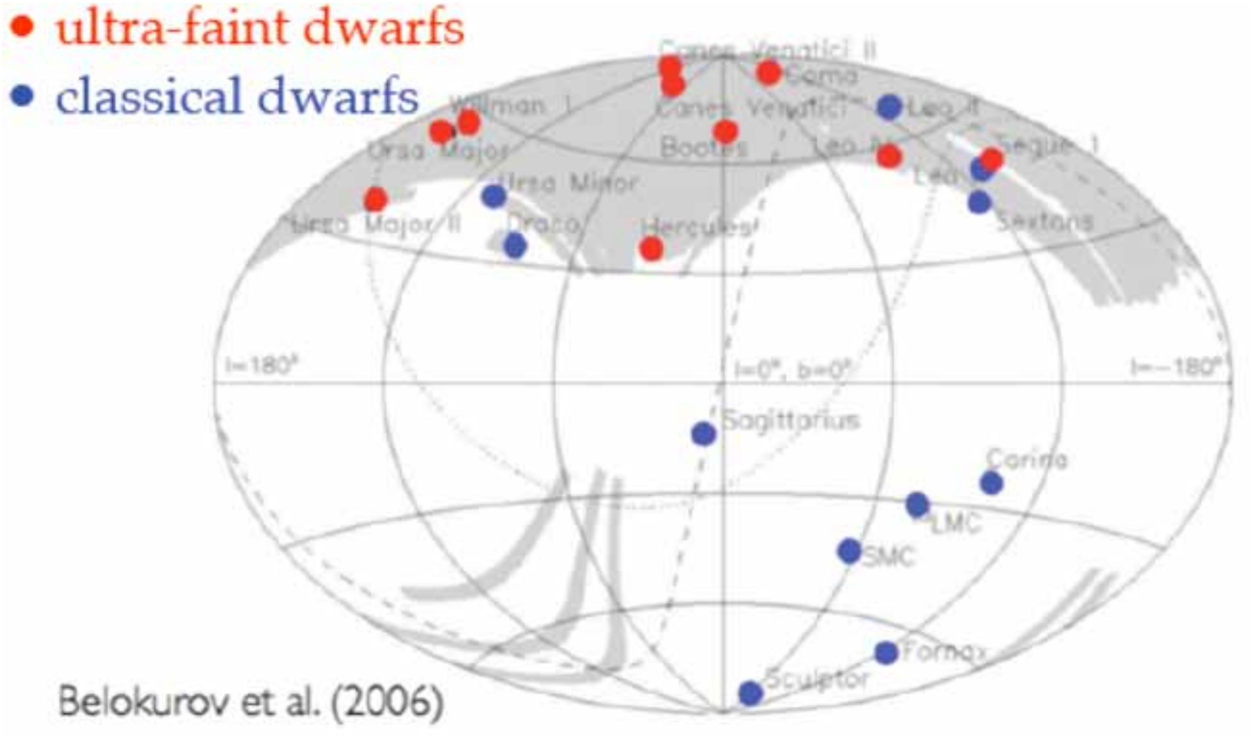
Spheroidal Dwarf Galaxies

- small companion galaxies of Milky Way
  - ==> rather nearby
- usually have very large M/L ratio
  - ==> high ρ_{DM}^2



Belokurov et al. (2006)

e.g. DRACO ('classical Dwarf')

8h MAGIC:

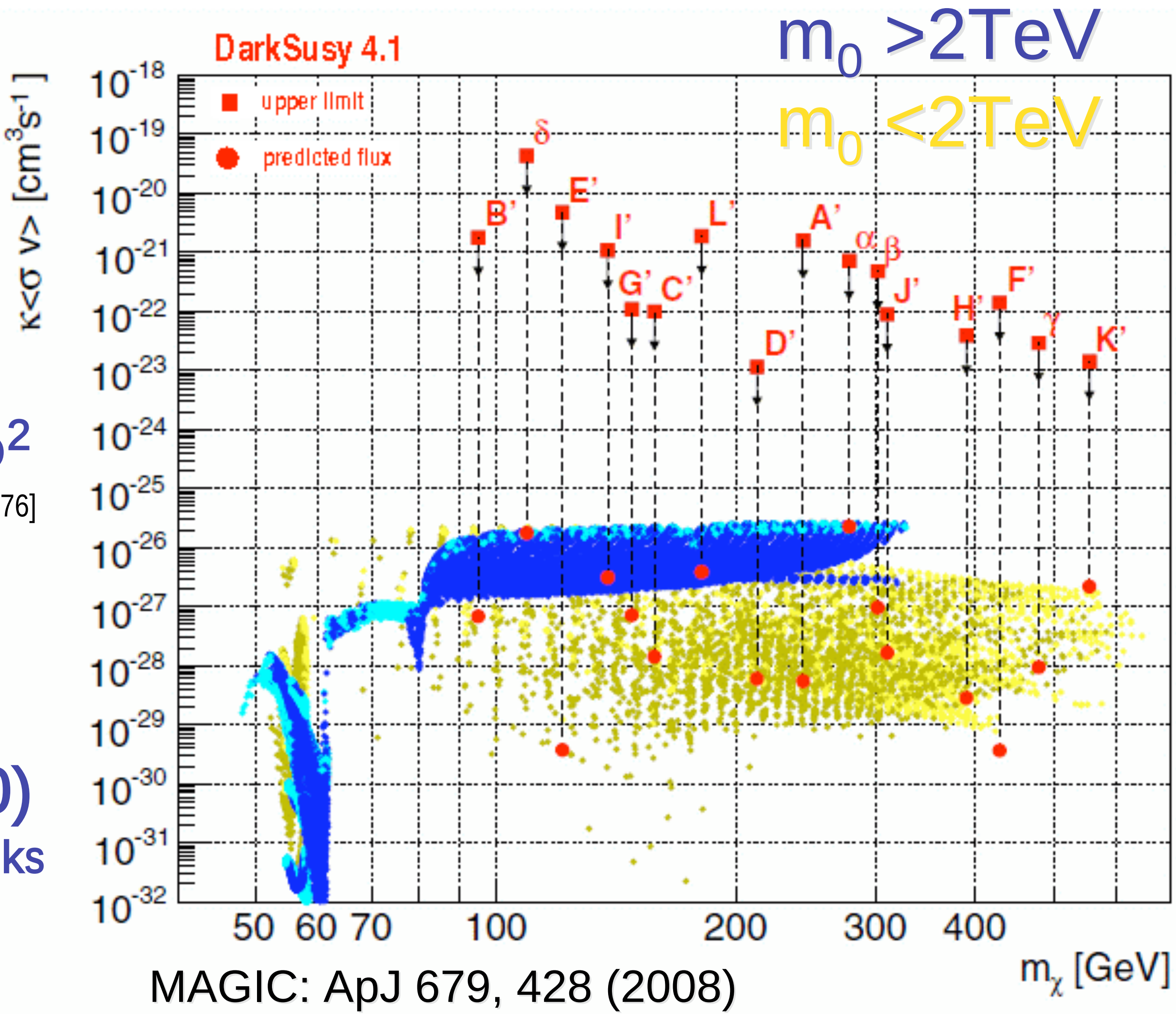
u.l. far from expected flux if assume conservative ρ^2

[Sanchez-Conde at al., Phys Rev D76]

and no boost

(can exclude boosts >>1000)

snowmass benchmarks

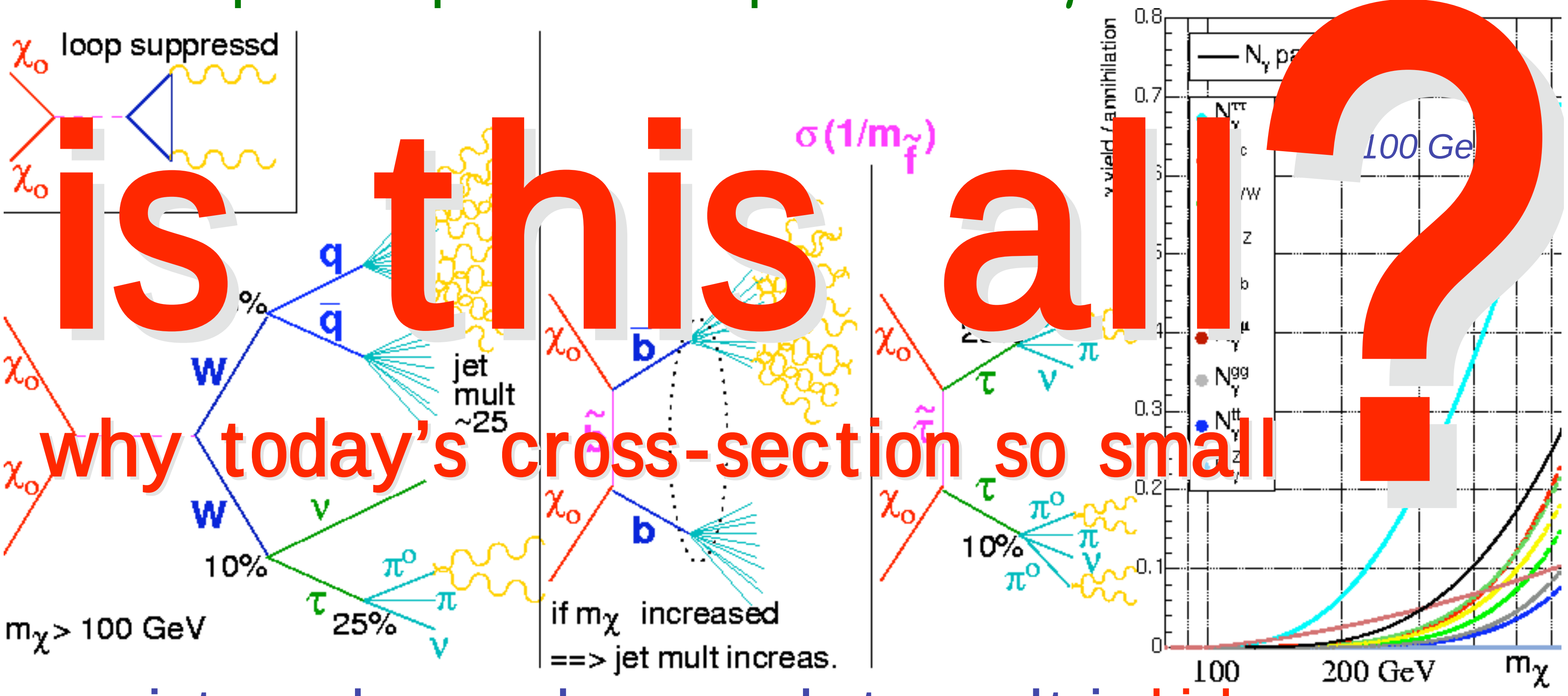


MAGIC: ApJ 679, 428 (2008)

ETH Institute for
Particle Physics
biland@phys.ethz.ch

VHE-γ from e.g. χ_0-annihilation

X_0 does not directly couple to γ (else not 'dark') ==>
Some important processes to produce VHE γ:



is this all ?

why today's cross-section so small

q-jets produce much more γ, but τ result in higher energy γ
==> VHE γ rare or (rather) low energy

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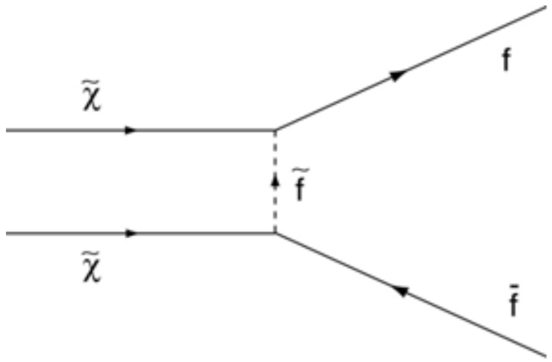
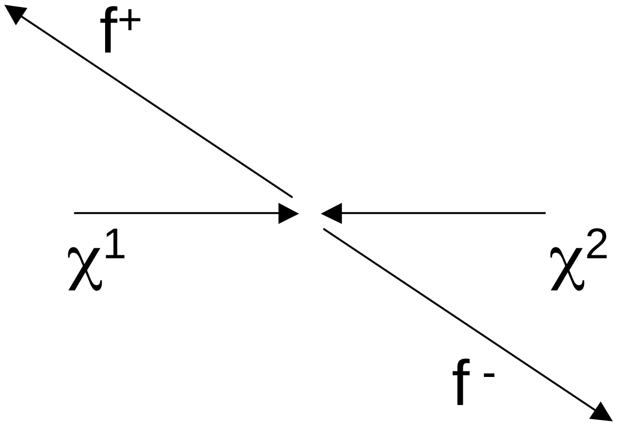
VHE-γ from e.g. χ_0-annihilation





In center of mass system:

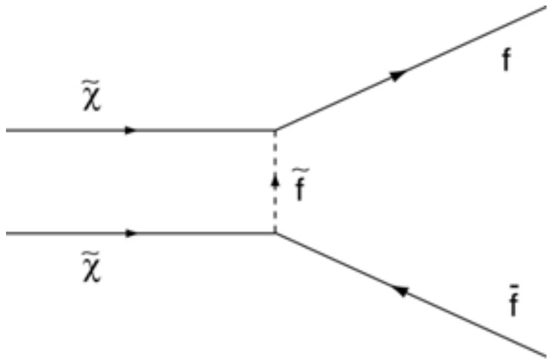
$p_{tot}=0 \implies p_{f+}= -p_{f-}$; $p_{\chi1}= -p_{\chi2}$

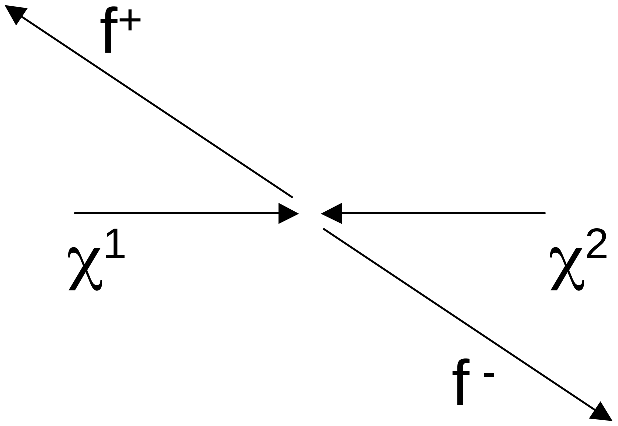
$\implies$ **helicity:** $s_{f+}= +s_{f-} \implies s_{\chi1}= s_{\chi2}$

Annihilation: $x_{\chi1}= x_{\chi2}$

Early Universe (=>relic density): no problem

VHE-γ from e.g. χ_0-annihilation





In center of mass system: **today**

$p_{tot}=0 \implies p_{f+}= -p_{f-}$; $p_{\chi 1}= -p_{\chi 2}$ $=0$

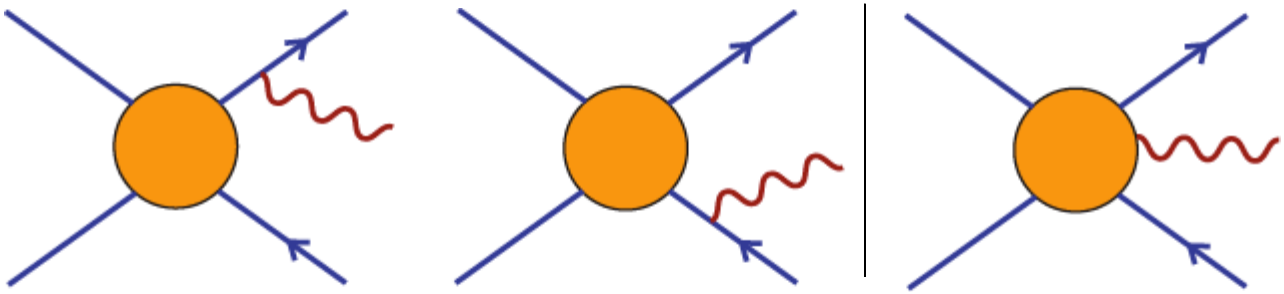
$\implies$ **helicity:** $s_{f+}= +s_{f-} \implies s_{\chi 1}= s_{\chi 2}$

Annihilation: $x_{\chi 1}= x_{\chi 2}$

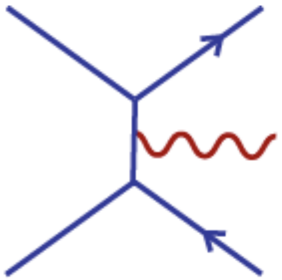
identical quantum state ==> annihilation suppressed by Pauli-Principle

VHE-γ from e.g. χ_0-annihilation

Bringmann, Bergstrom, Edsjo; JHEP 0801,049 (2008)



Bremsstrahlung: does not help YES !!!



photon has $s_\gamma=1$ => $s_{\chi1}=-s_{\chi2}$ => allowed

==> much higher cross-section

QED correction $O(10^6)$ instead $O(10^{-2})$

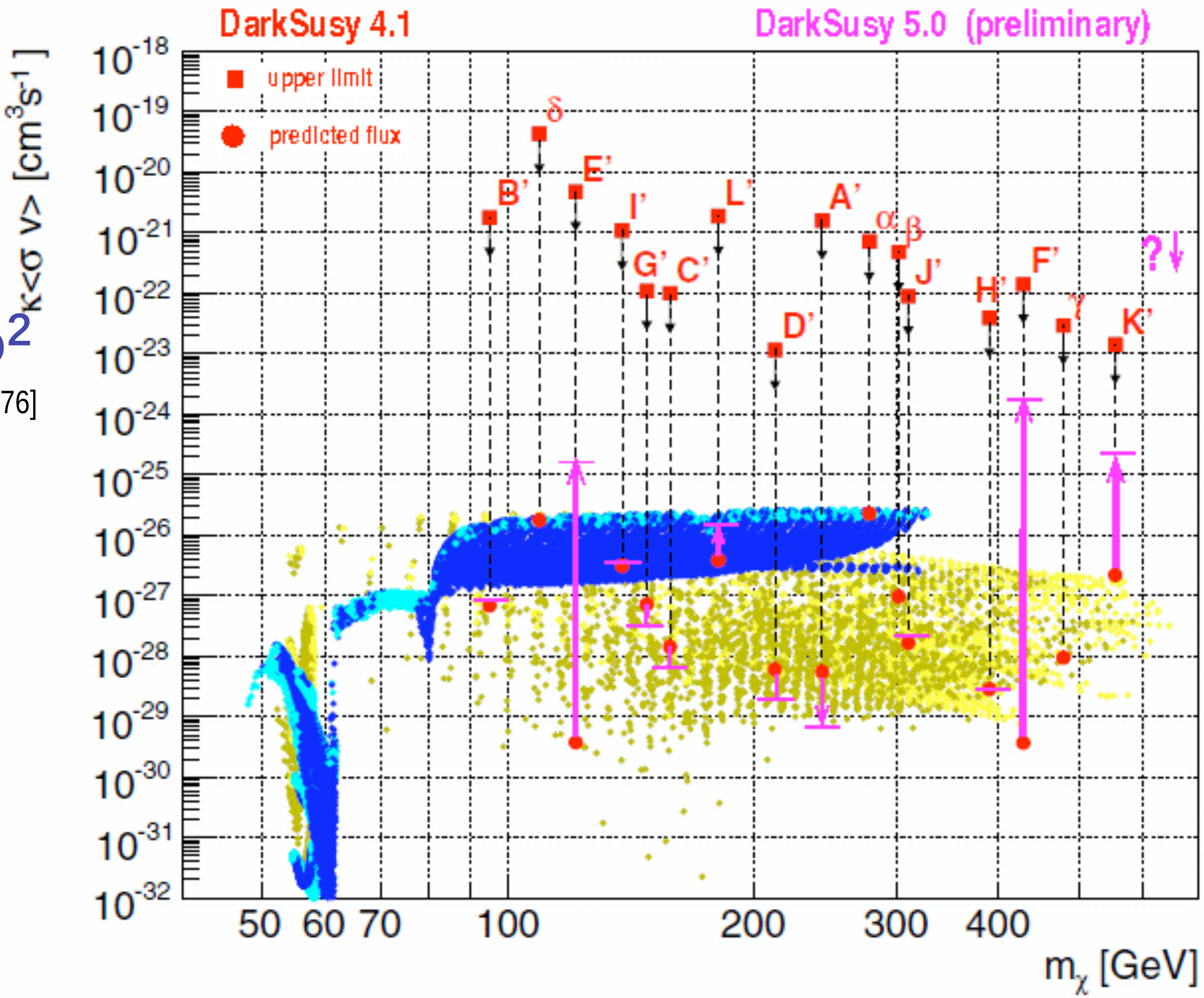
Additionally: typical $E_\gamma > 0.5\ m_\chi$

(perfect for Cherenkov Telescopes)

e.g. DRACO ('classical Dwarf')

u.l. far from expected flux if assume conservative ρ^2 [Sanchez-Conde at al., Phys Rev D76] and no boost

expected flux can change drastically with Int.BS



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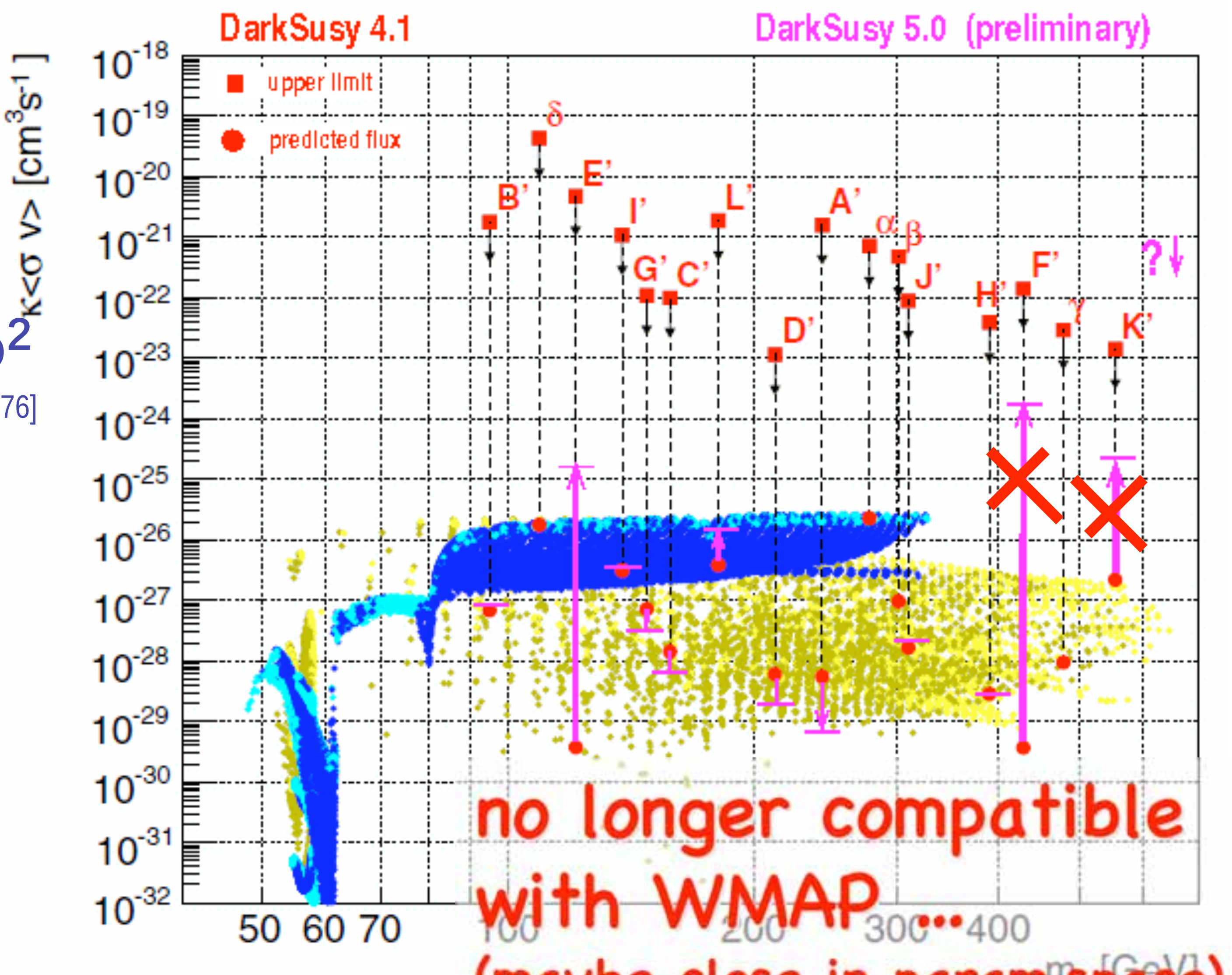

no longer compatible with WMAP...

(maybe close in param.space)

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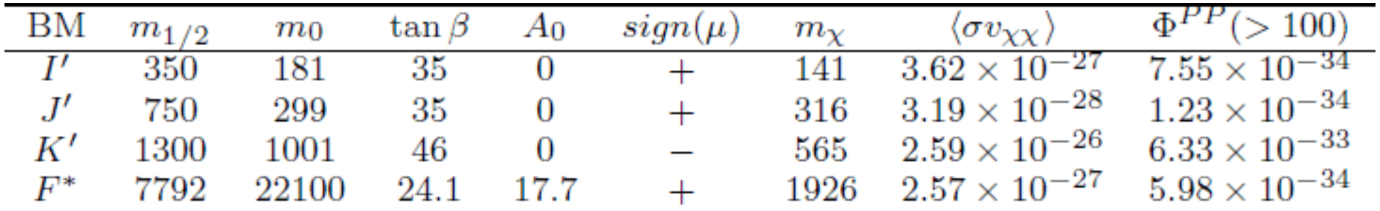
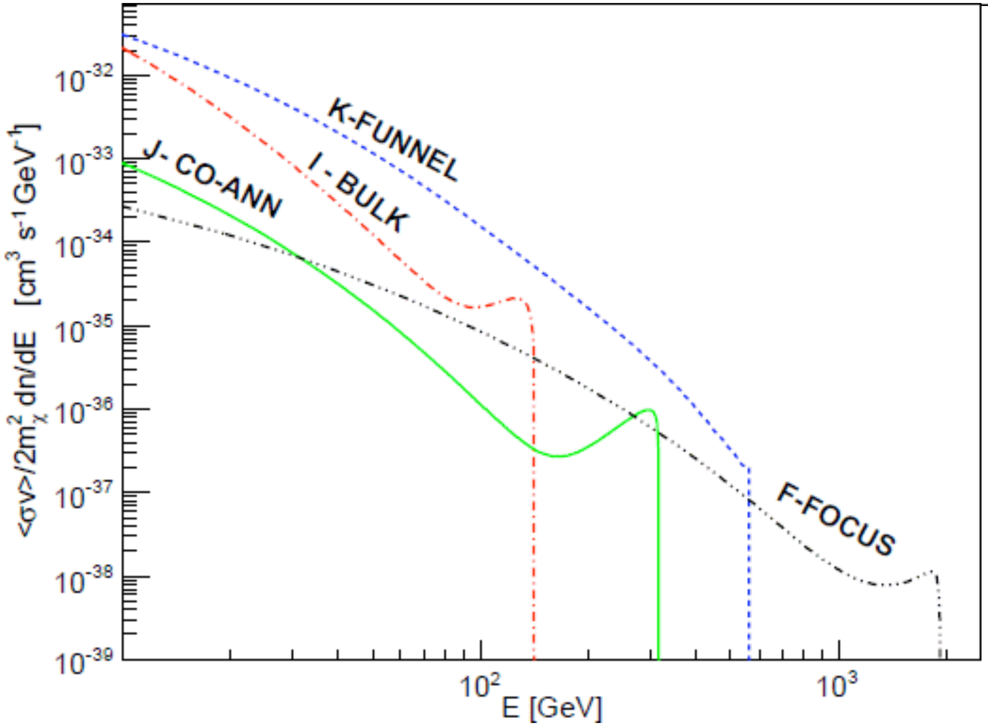
biland@phys.ethz.ch

Other Benchmark Points ...

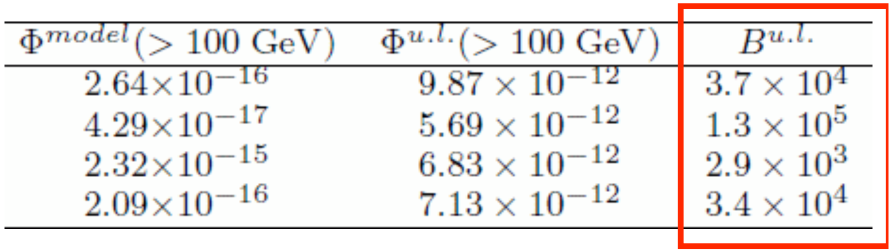
Bringmann, Doro, Fornasa; JCAP01, 016 (2009)



BM	$m_{1/2}$	m_0	$\tan\beta$	A_0	$sign(\mu)$	m_χ	$\langle\sigma v_{\chi\chi}\rangle$	$\Phi^{PP}(>100)$
I'	350	181	35	0	+	141	3.62×10^{-27}	7.55×10^{-34}
J'	750	299	35	0	+	316	3.19×10^{-28}	1.23×10^{-34}
K'	1300	1001	46	0	−	565	2.59×10^{-26}	6.33×10^{-33}
F^*	7792	22100	24.1	17.7	+	1926	2.57×10^{-27}	5.98×10^{-34}



MAGIC 15h Obs.: of ultra-faint Dwarf Willman-1



$\Phi^{model}(>100$ GeV)	$\Phi^{u.l.}(>100$ GeV)	$B^{u.l.}$
2.64×10^{-16}	9.87×10^{-12}	3.7×10^4
4.29×10^{-17}	5.69×10^{-12}	1.3×10^5
2.32×10^{-15}	6.83×10^{-12}	2.9×10^3
2.09×10^{-16}	7.13×10^{-12}	3.4×10^4

again 'only' exclude boosts >1000

MAGIC: ApJ 697,1299 (2009)

Other Results

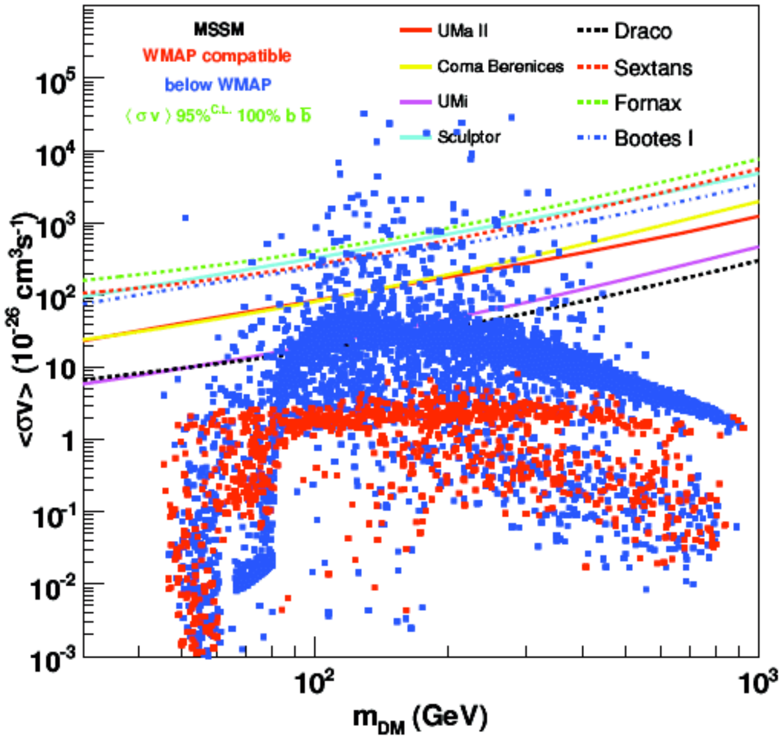
Several measurements also from H.E.S.S. and VERITAS; all 10-20h obs. time; all similar ...

VERITAS

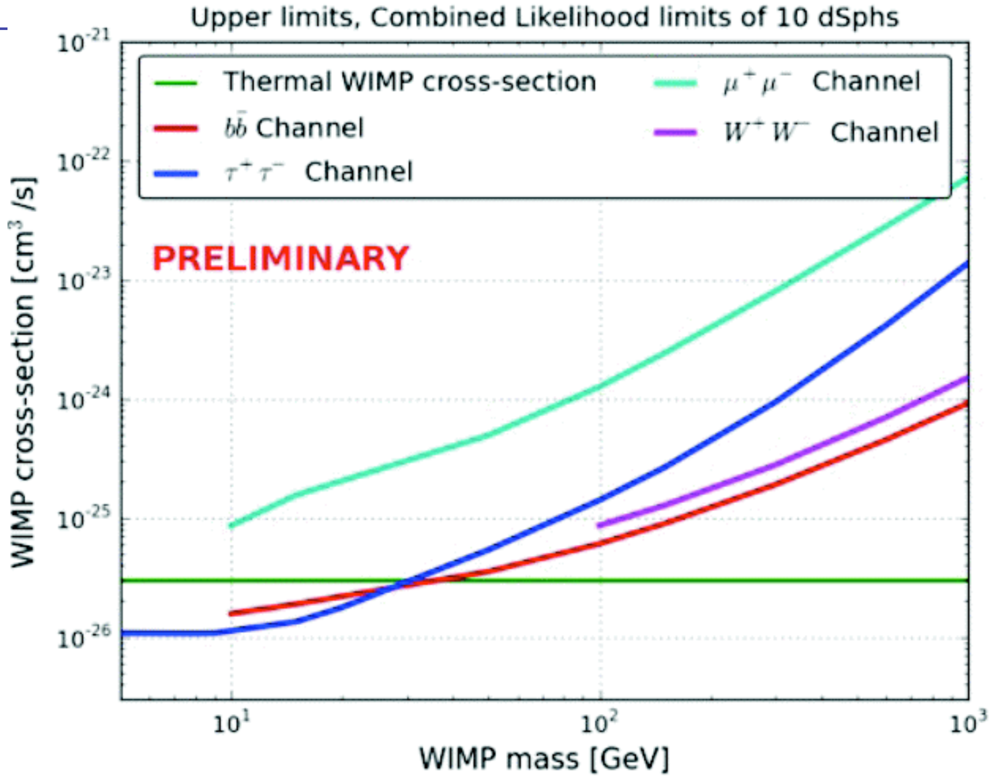
HESS

dSph	Draco	Ursa Minor	Bootes I	Willman	Segue I	Sgr	Carina	Sculptor	Canis Major
Distance (kpc)	82	66	62	38	23	24	101	79	8
DM profile	NFW	NFW	NFW	NFW	Einasto	NFW/ Core	NFW	NFW	NFW
$\mathrm{Log}_{10}\langle J\rangle$ ($\mathrm{GeV}^2\ \mathrm{cm}^{-5}$)	18.2	18.4	18.1	18.9	19	19.3/ 20.8	17.6	18.5	18.0
T_{obs} (h)	18.4	18.9	14.3	13.7	25.0	11.0	14.8	11.8	9.6
Ann. channel	$\tau^+\tau^-$, bbar	$\tau^+\tau^-$, bbar	$\tau^+\tau^-$, bbar	$\tau^+\tau^-$, bbar	$\tau^+\tau^-$, bbar	W^+W^-	W^+W^-	W^+W^-	W^+W^-
$\langle\sigma v\rangle^{95\%}$ ($\mathrm{cm}^3\ \mathrm{s}^{-1}$)	5×10^{-23}	2×10^{-23}	5×10^{-22}	10^{-23}	8×10^{-24}	10^{-23}/ 2×10^{-24}	2×10^{-22}	6×10^{-23}	10^{-23}

Dwarfs in Fermi



Abdo A A, Ackermann M, Ajello M, Atwood W B, Baldini L, *et al.* [*Fermi*-Collab.]. 2010b. *Ap. J.* 712:147



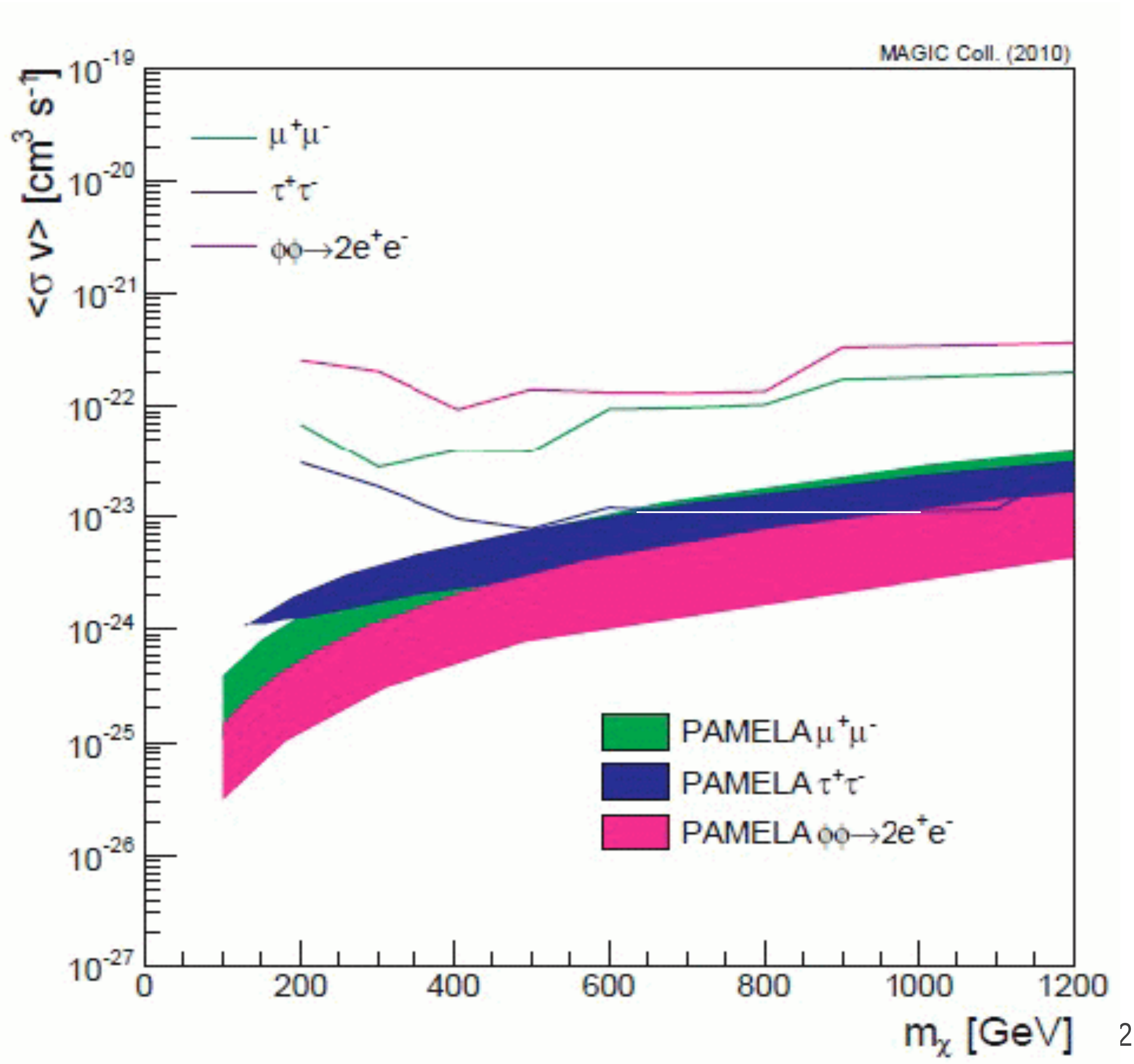
Liena Garde, M., Conrad, J., Cohen-Tanugi, J. for Fermi-LAT Collaboration, Fermi Symposium, May 2011

'increase obs.time' by stacking 10 objects

(DM spectrum must be universal)

-> starts to become intersting ...

Non MSSM/mSUGRA



Start to challenge models ($\tau^+\tau^-$) invented for PAMELA...

MAGIC
arXiv:1103.0477

The Usual Suspects

- Galactic Center
  - expect by far brightest DM signal
  - strong VHE source obscuring hypot. DM signal

- Spheroidal Dwarf Galaxies
  - too faint to be detectable within reasonable observation time (IACTs for mSUGRA models)

- MiniHalos, Intermediate Mass Black Holes...

- Galaxy Clusters

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UFOs

Unassociated
Fermi
Objects

- Predicted existance of DM-clumps within our galaxy (smaller version of Dwarf Gal.)
- Hypothetical Intermediate Mass Black Holes within our galaxy could have accreated large amount of DM

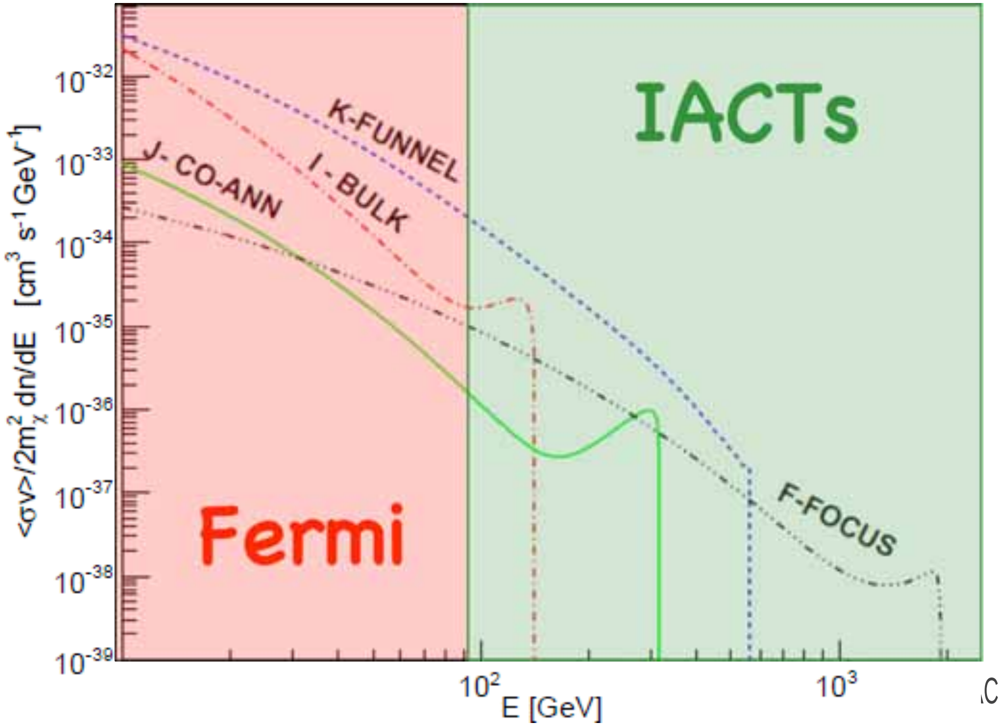
==> could be very nearby ==> very bright

But only significant emission from DM
==> invisible to 'ordinary Astronomers'
but bright(?) for Fermi or AGILE (???)

UFOs

Unassociated
Fermi
Objects

smoking gun: Fermi finds several objects
- without counterpart in other wavelengths
- all having same spectrum
(spectrum compatible with a DM model ?)



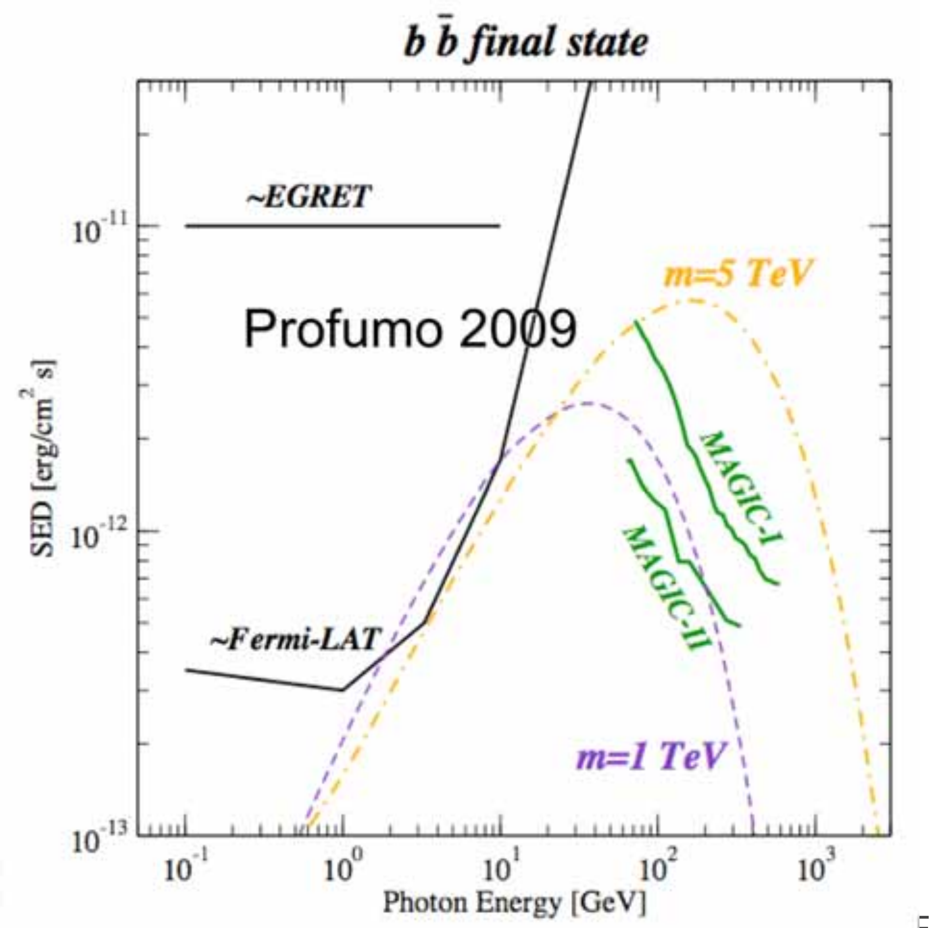
Most probably,
Fermi energy range
not sufficient to
measure spectrum
(especially cutoff)

UFOs

Unassociated
Fermi
Objects

No good candidates from 2 years Fermi ?!?

but:



We need VHE sky scan ...

Not possible with current IACTs

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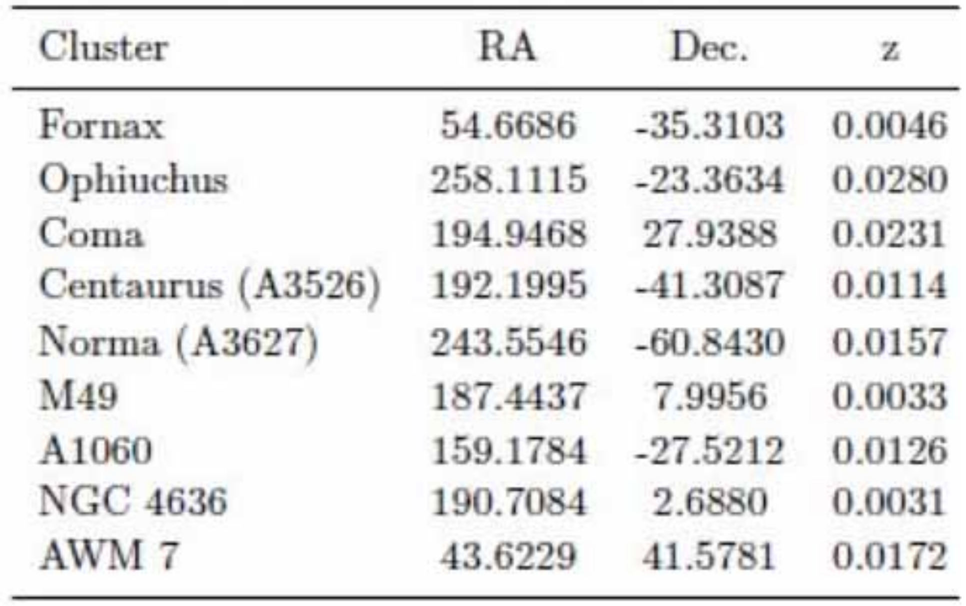
Galaxy Clusters

(Zwicky 'invented' DM in 1933 because Coma Cluster has *not enough mass to be bound* ...)

Some clusters do not have a bright AGN in the center ==> expect less BG

but difficult to get obs. time ?



Cluster	RA	Dec.	z
Fornax	54.6686	-35.3103	0.0046
Ophiuchus	258.1115	-23.3634	0.0280
Coma	194.9468	27.9388	0.0231
Centaurus (A3526)	192.1995	-41.3087	0.0114
Norma (A3627)	243.5546	-60.8430	0.0157
M49	187.4437	7.9956	0.0033
A1060	159.1784	-27.5212	0.0126
NGC 4636	190.7084	2.6880	0.0031
AWM 7	43.6229	41.5781	0.0172

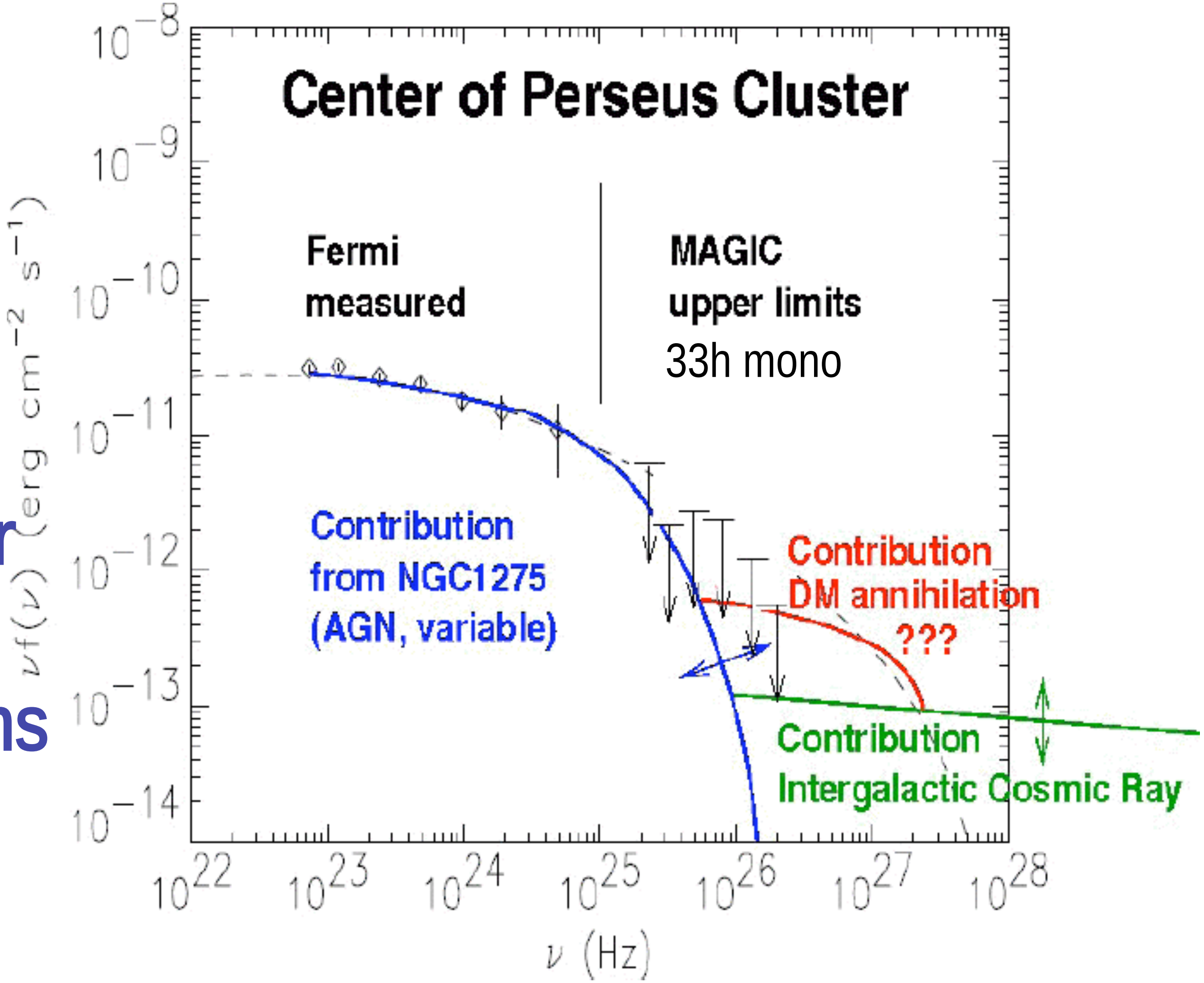
Perseus Cluster / NGC1275

MAGIC: ApJ 710,634 (2010)

Or try to disentangle signal from

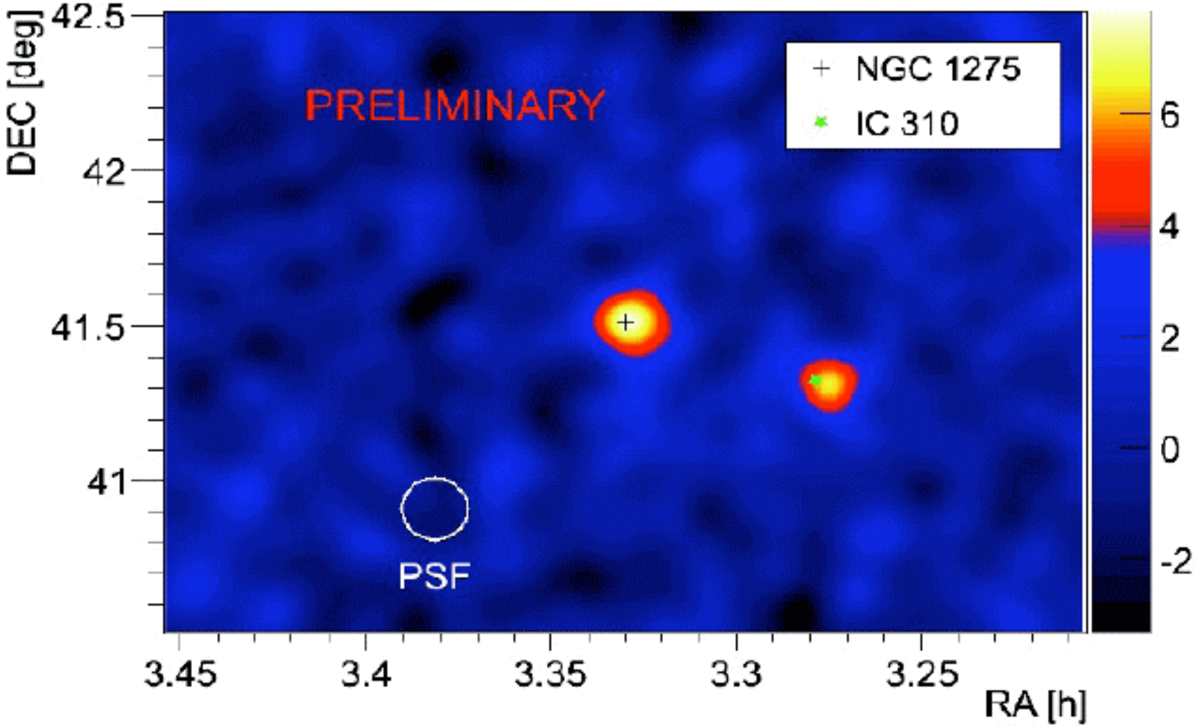
- AGN
- Cosmic Rays
- Dark Matter

NGC1275 seems to have soft spectrum ...



Perseus Cluster / IC310

MAGIC: ApJ 723, L207 (2010)



Another bright source showed up in the same field of view...

==> making search for CR and DM even more difficult; other galaxies in the cluster could also be VHE emitters ?!

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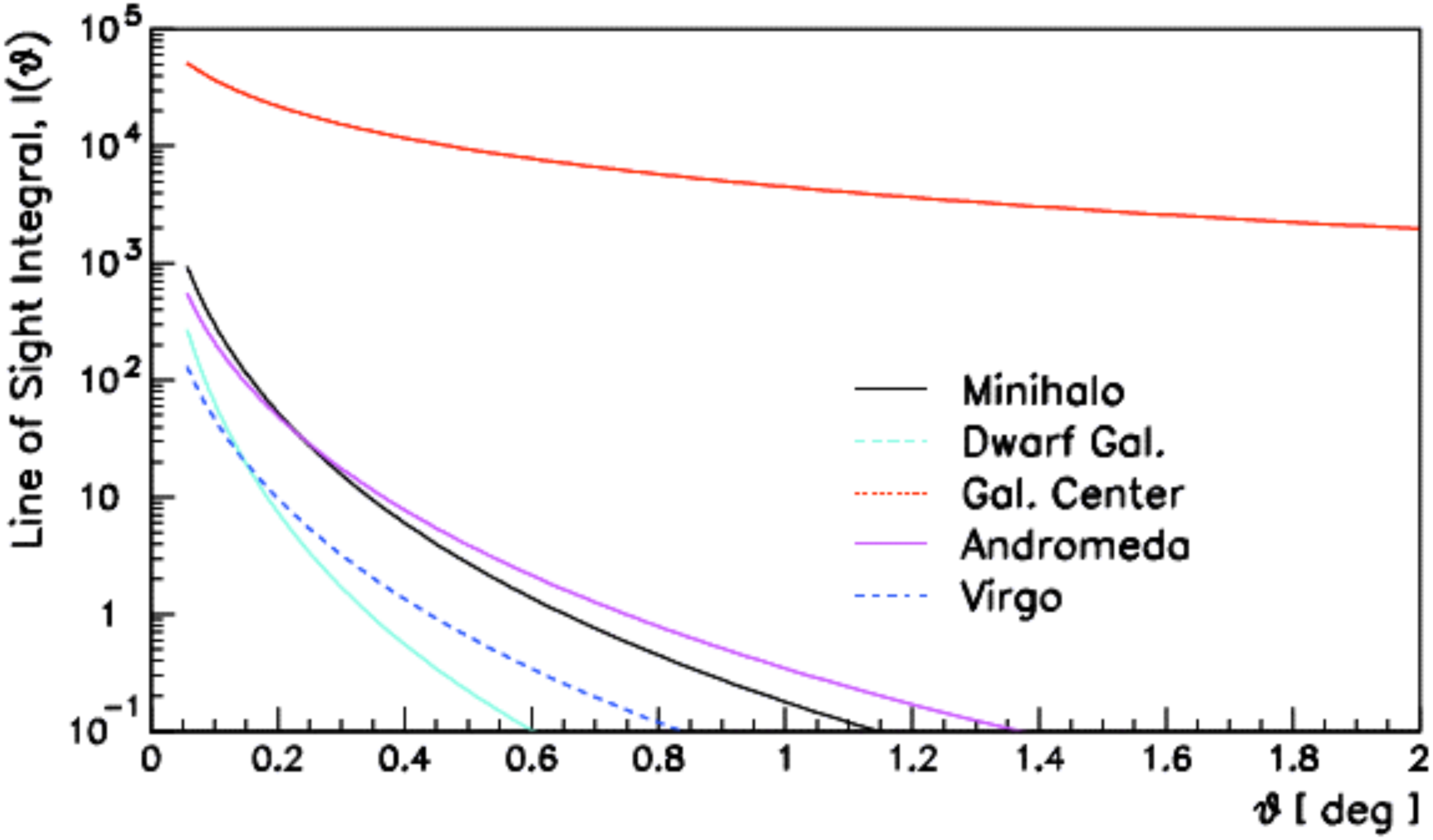
- MiniHalos, Intermediate Mass Black Holes...
  - might be rather bright, but don't know where to look; Fermi found no definite candidates yet?

- Galaxy Clusters
  - faint and difficult because of other sources

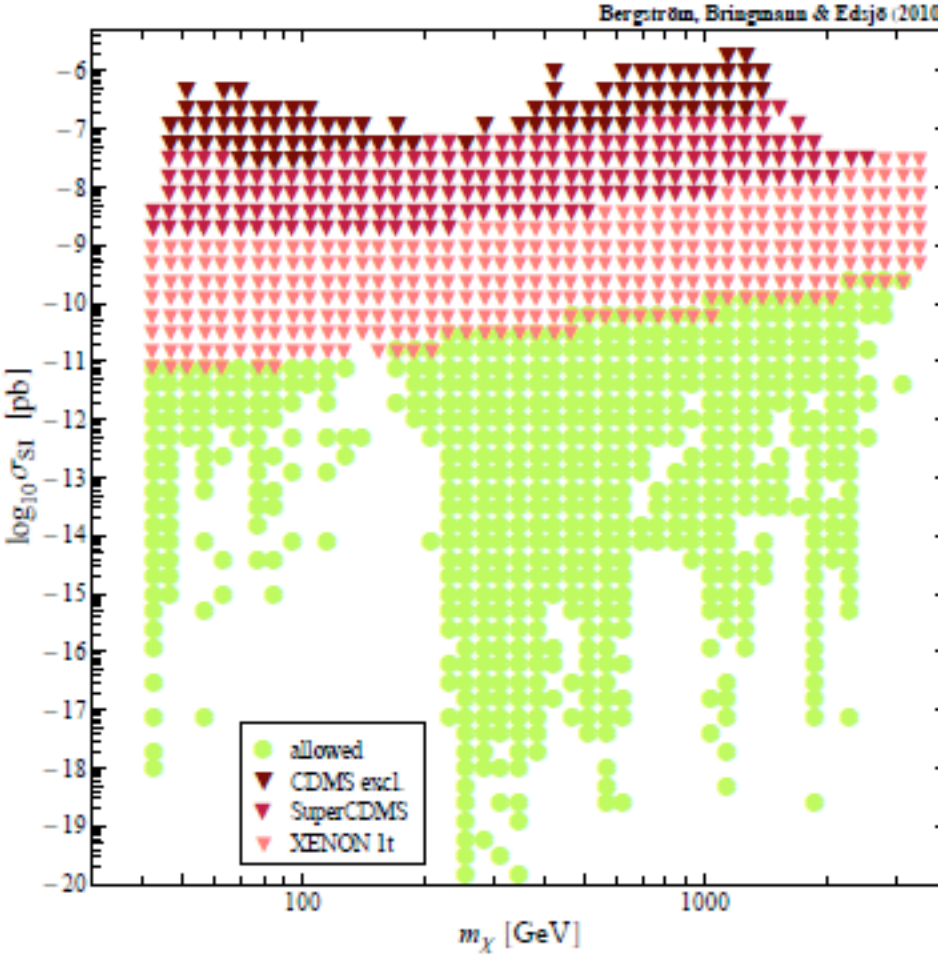
The Usual Suspects

Also Andromeda, Globular Clusters, ...
but nothing beats Galactic Center



Is it Worth the Effort ?

Bergstroem, Bringman & Edsjoe: arXiv 1011.4514

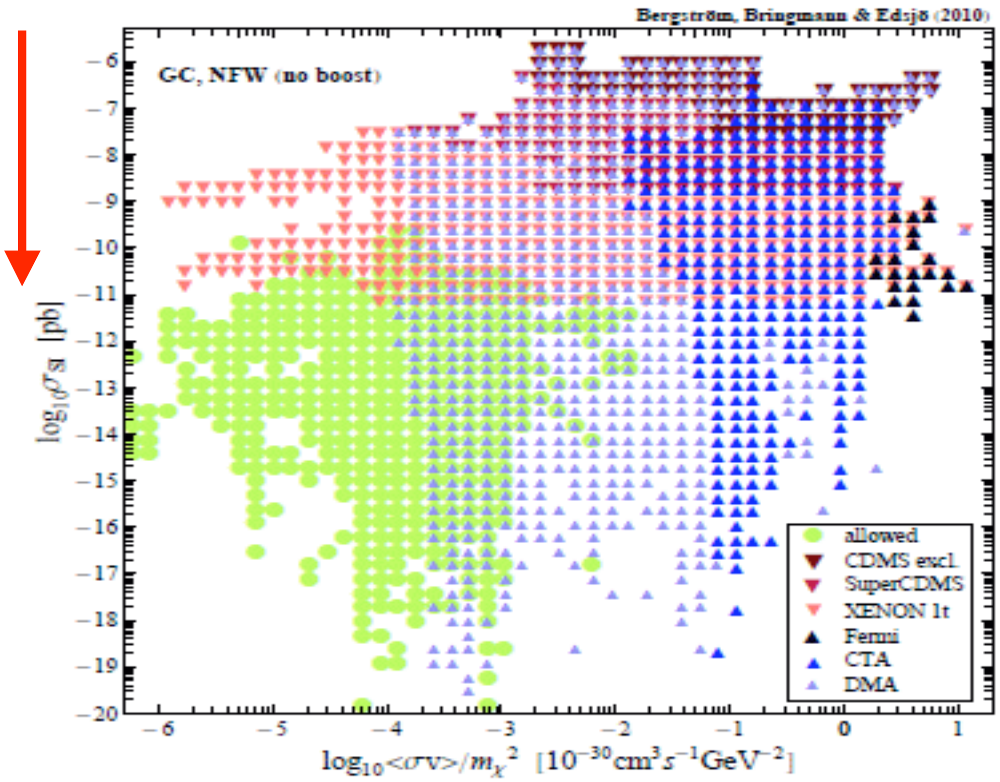


Direct searches can only cover fraction of phase space ...

Is it Worth the Effort ?

Bergstroem, Bringman & Edsjoe: arXiv 1011.4514

direct

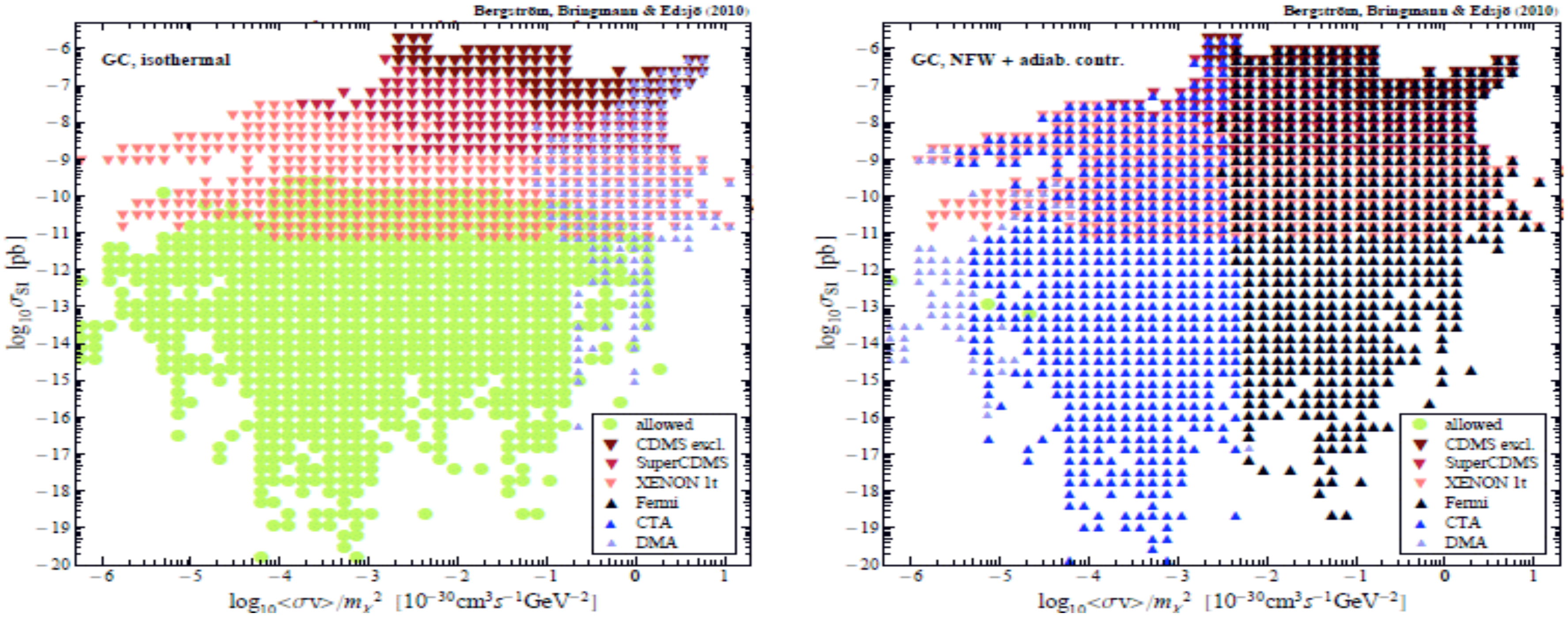


indirect

Direct and indirect searches probe different phase space

Is it Worth the Effort ?

Bergstroem, Bringman & Edsjoe: arXiv 1011.4514



Large uncertainties in DM-distribution, but a CTA-like installation optimized and dedicated to DM search might cover 'full' phase-space

Is it Worth the Effort ?

YES

But we should investigate dedicated instruments for indirect DM search

ETH Institute for Particle Physics
biland@phys.ethz.ch