Dark matter searches with H.E.S.S.

Björn Opitz[1], Universität Hamburg

on behalf of the H.E.S.S. collaboration

SciNeGHE, Assisi — October 8, 2009

[1] bjoern.opitz@desy.de

Overview

Indirect search for dark matter

IF dark matter particles annihilate ... or decay:

- final states (usually) decay hadronically
  $\longrightarrow$ production of very-high-energy (VHE) γ's by π_0 decay
- or production of $\gamma\gamma$ or γZ lines via loop processes

$\longrightarrow$ look for VHE γ's *coming from* regions with high DM density
$\longrightarrow$ and for antimatter: diffuse flux of charged particles

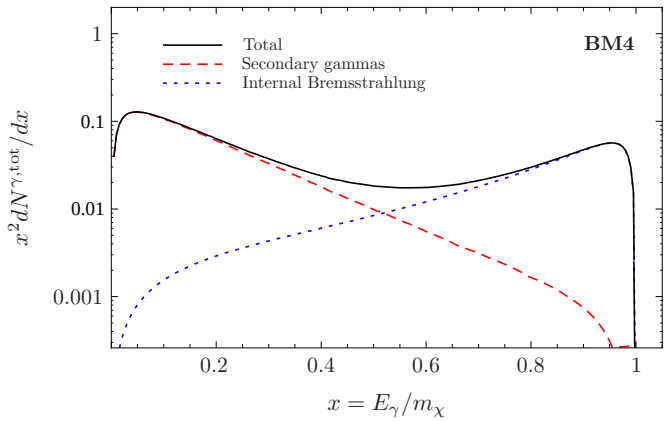
Photon flux calculation: self-annihilation

- Differential flux: $\frac{d\Phi(\Delta\Omega, E_\gamma)}{dE_\gamma} = \frac{1}{8\pi} \underbrace{\frac{\langle\sigma v\rangle}{m^2_{\mathrm{DM}}} \frac{dN_\gamma}{dE_\gamma}}_{\text{particle physics}} \times \underbrace{\bar{J}(\Delta\Omega)\Delta\Omega}_{\text{astrophysics}}$
- "halo factor": $\overline{J}(\Delta\Omega) = \frac{1}{\Delta\Omega} \int_{\Delta\Omega} d\Omega \int_{\text{l.o.s.}} dl \cdot \rho^2(l)$
- decaying DM: $\overline{J} \propto \int \rho$ $\longrightarrow$ not considered

Features of DM candidate particles

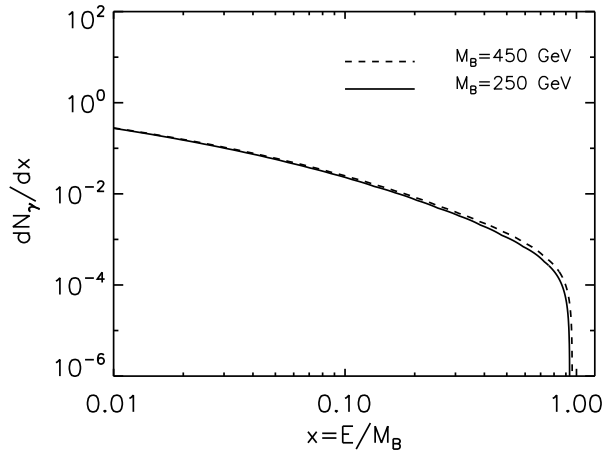
Mostly studied: Supersymmetry ...

- cf. David's talk ...
- continuous γ flux from neutralino annihilation
- here: peak from "virtual brems-strahlung" [JHEP 0801,049 (2008)] — cf. Ripken et al., ICRC '09



... or extra dimensions

- first KK excitation $\tilde{B}(1)$ as DM particle (here: 6 dim.)
- spectrum with hard cut-off [PRD 80,023512 (2009)]

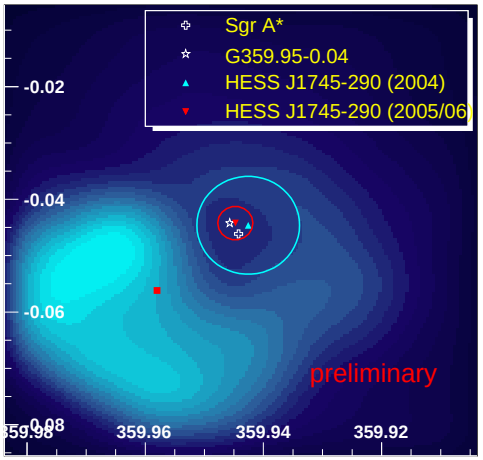


(or both: see outlook)

Possible sources of a DM signal

Centre of the Milky Way

- H.E.S.S. source J1745-290 coincident with Sgr A* [arXiv:0811.0931]



Local clumps of dark matter

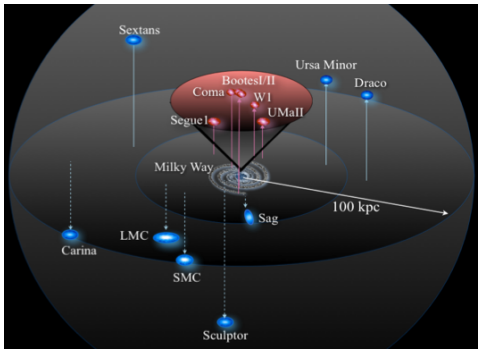
- DM “mini-spikes” [PRD 72,103517 (2005)] (and SciNeGHE 2007 proc.)

www.mpa-garching.mpg.de/aquarius

Possible sources of a DM signal (II)

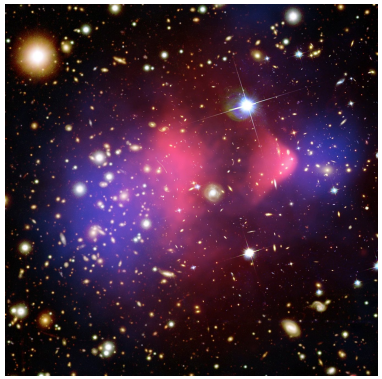
Dwarf spheroidal galaxies [0902.3492]

- most extremely DM-dominated galaxies [ApJ 678,614 (2008)]
- high M/L
- no astrophysical γ-ray background!



(Clusters of) Galaxies

- DM predictions: [PRD 61,023514 (1999)], [A&A 455,21 (2006)]



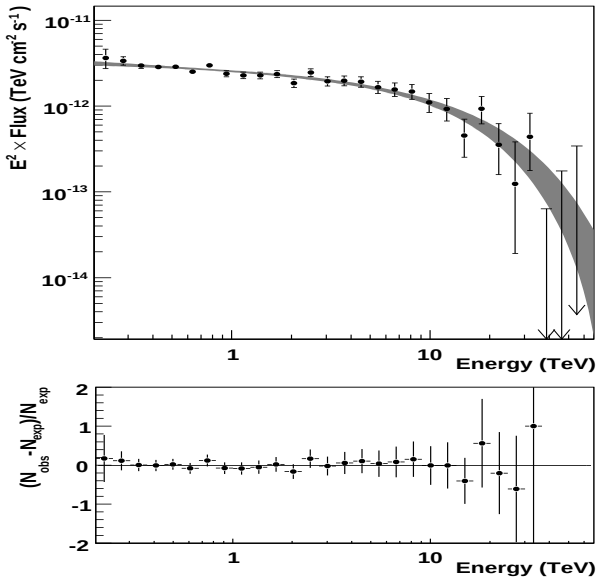
"FREE EXTRA":

- Cosmic ray electrons + positrons

Galactic centre

d = 8 kpc, M $\approx 10^6$ $M_\odot$

- **Bonus:** Nearby source of TeV photons
- **Malus:** Spectrum doesn't look like dark matter



PRL 97,221102 (2006)

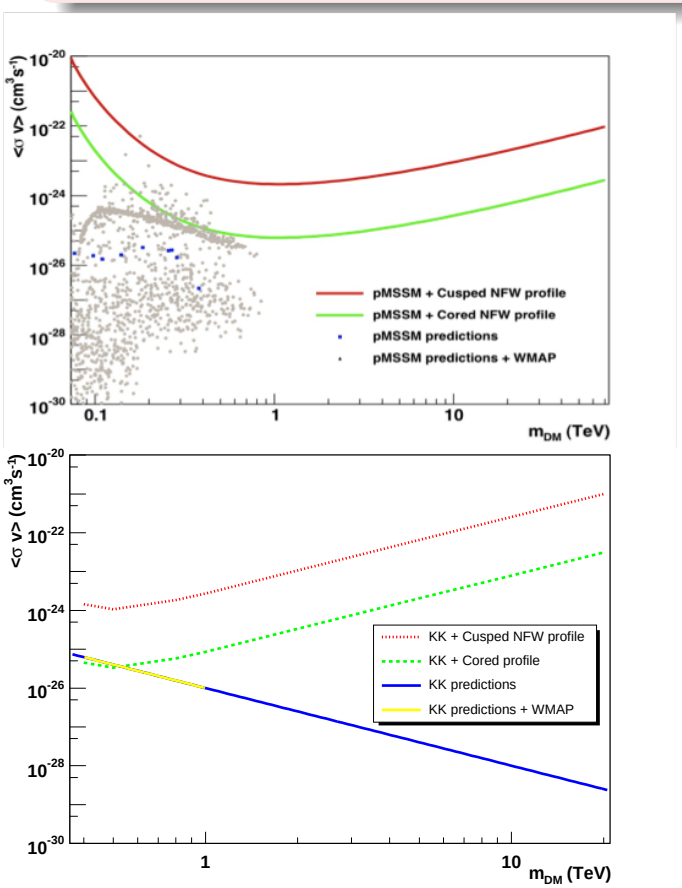
- strong source coincident with Sgr A*
- spectrum well-fit by a power law with cut-off above 10 TeV [A&A 503,817 (2009)]
- un-identified astrophysical source produces *bulk* of emission

Fit of power-law background + DM signal models to spectrum
$\longrightarrow$ robust calculation of upper limits: $\langle \sigma v \rangle \leq 1 \cdot 10^{-24}$ cm^3/s

Sagittarius Dwarf Spheroidal galaxy

d = 25 kpc, M $\approx 10^6$ $M_\odot$

- **Bonus:** Close, large dwarf spheroidal
- **Malus:** No signal. Upper limit on integrated flux (E_γ > 250 GeV)



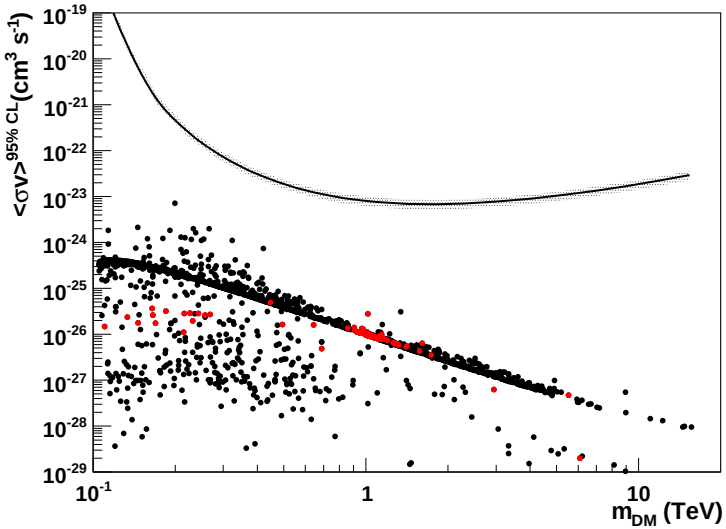
Astrop. Phys. 29,55 (2008)

- 11 h of data
- $\Phi_{\text{Int}} \leq 3.6 \cdot 10^{-12}$ /cm^{2}s
- Two diff. profile models (NFW):
  $\overline{J} = 2.2 \cdot 10^{24}$ GeV^2/cm^5 ("cusped"),
  $\overline{J} = 75 \cdot 10^{24}$ GeV^2/cm^5 ("cored")
- SUSY limit: $\langle \sigma v \rangle \leq 5 \cdot 10^{-24}$ cm^3/s
- KK limit: $\langle \sigma v \rangle \leq 1 \cdot 10^{-24}$ cm^3/s
- both for cusped NFW profile, at 95% C.L., for $m_\chi \sim 1$ TeV

Canis major overdensity

d = 8 kpc, M = ?

- **Bonus:** Very close! Good candidate for DM signal.
- **Malus:** Status as a Dwarf Spheroidal under dispute. Properties not well constrained; tidally disrupted



- black (red) points: MSSM models (WMAP OK)

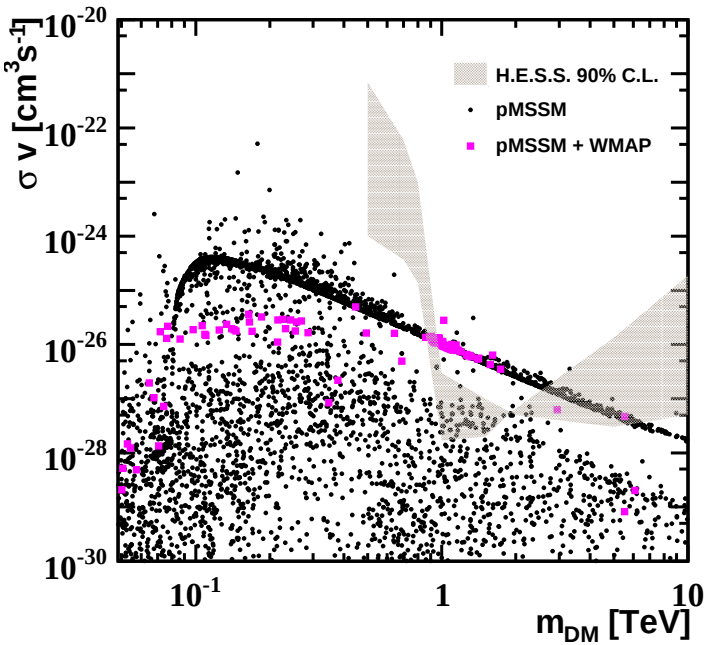
ApJ 691,175 (2009)

- 9.6 h of data
- Assumptions: $M_{halo} \approx 3 \cdot 10^8\ M_\odot$, NFW DM profile
- $\longrightarrow \overline{J} = 5.9 \cdot 10^{24}$ GeV^2/cm^5
- SUSY limit: $\langle \sigma v \rangle \leq 10^{-23}$ cm^3/s
- KK limit: $\langle \sigma v \rangle \leq 10^{-24}$ cm^3/s
- both at 95% C.L., for $m_\chi \sim 1$ TeV

Intermediate mass black holes

d = ?, 10 < M < 10^6 $M_\odot$

- **Bonus:** Should exist! 100–1000 per galaxy? DM “mini-spikes”
- **Malus:** No unambiguous observation of IMBHs to date



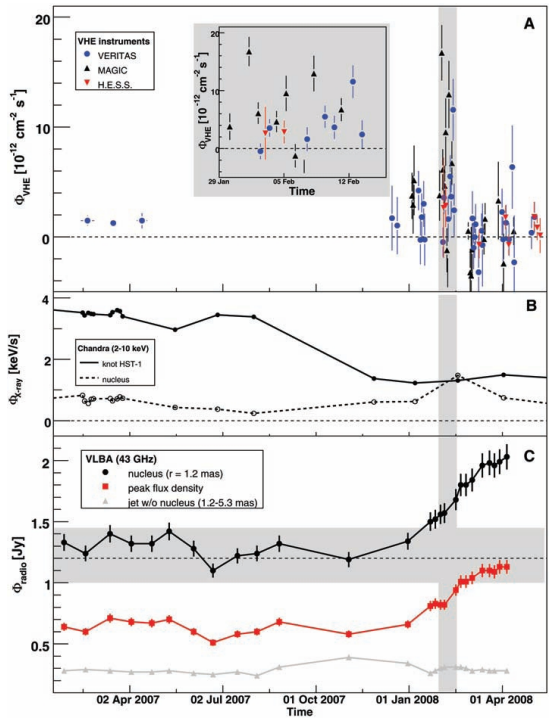
PRD 78,072008 (2008)

- IMBH: from Pop-III stars or primordial halos
- use Galactic plane scan, excluding known sources
- assume $\sim$ 100 IMBH in Milky Way halo
- SUSY limit: $\langle\sigma v\rangle \leq 10^{-27}$ cm^3/s for $m_\chi > 1$ TeV (90 % C.L.)

Radio galaxy M87

d = 16 Mpc, $M_{BH} = 10^9\ M_\odot$

- **Bonus:** Extragalactic TeV γ source!
- **Malus:** Temporal variation, signal too strong for DM



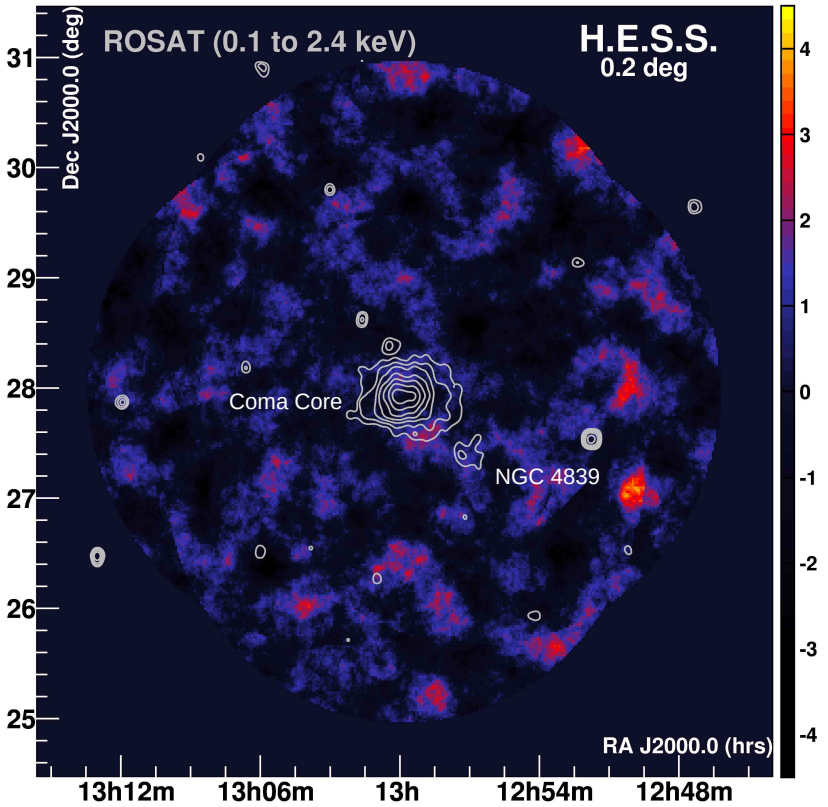
Science 314,1424 (2006) ... and 24,444 (2009)

- strong flares $\longrightarrow$ not DM
- low flux state above DM estimations
- MWL campaign: VHE γ's from core! (not resolvable with ACTs)
- cf. Marcos' talk

Coma cluster

$z = 0.023$, $M \approx 10^{15}\ M_\odot$

- **Bonus:** Giant, heavy object
- **Malus:** No signal



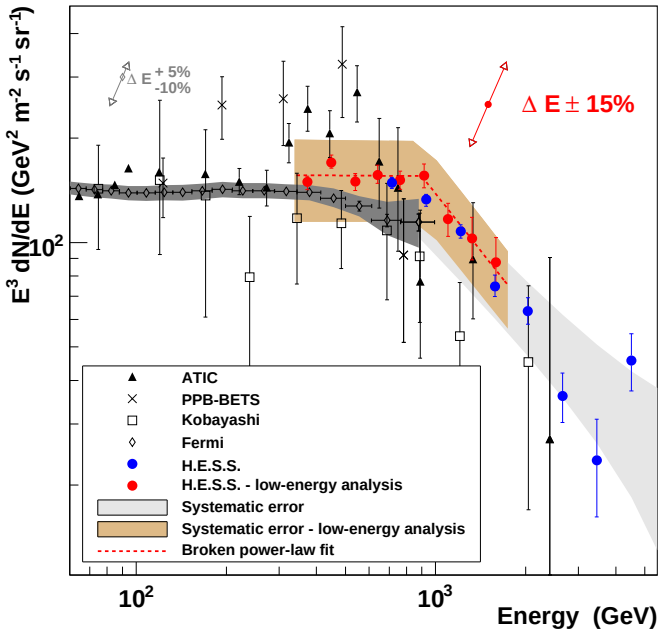
arXiv:0907.0727

- 8 h of data
- no significant flux detection
- UL (99% CL, $E_\gamma > 1$ TeV): $\Phi \leq 6 \cdot 10^{-13}/\mathrm{cm}^2\mathrm{s}$ (factor ~ 100 above expected dark matter signal)
- constraints on non-DM models derived

Cosmic ray electrons (+ positrons)

d < 1 kpc, $m_e = 4.6 \cdot 10^{-61}\ M_\odot$

- Bonus: Coming from everywhere! e^+ (cut-off) as DM signal
- Malus: Coming from everywhere. No source backtracking.



PRL 101,261104 (2008) and arXiv:0905.0105

- elm. showers from extragal. regions with small γ flux ($\sim$5 % expected)
- large coll. area $\longrightarrow$ high statistics
- hadronic background rejection: "electron likeness" parameter from simulations & Random Forest
- power law break at $\sim$1 TeV, ATIC peak not seen, good agreement with Fermi

Summary of H.E.S.S. DM searches

No, we haven't seen it yet ...

- Searches for dark matter on different mass & distance scales
- H.E.S.S. results $\longrightarrow$ (among the) most constraining DM limits from Cherenkov telescopes
- Limits on $\langle\sigma v\rangle$ vs. m_χ not reaching standard "thermal WIMP" / mSUGRA values (without substructure boosts)
- Cross-section limits dependent on DM halo uncertainties

H.E.S.S. obs.	**GC**	**Sgr dSph**	**CMa**	**IMBH**	**M87**
t_{obs} (h)	64	11	10	($\sim$ 400)	89
d (kpc)	8	25	8	(?)	16000
Core mass ($M_\odot$)	10^6	10^6	10^6 (?)	(10^5 ?)	>10^9
UL: $\langle\sigma v\rangle$ (cm^3/s)	10^{-24}	$5 \cdot 10^{-24}$	10^{-23}	10^{-27}	10^{-22}

Outlook

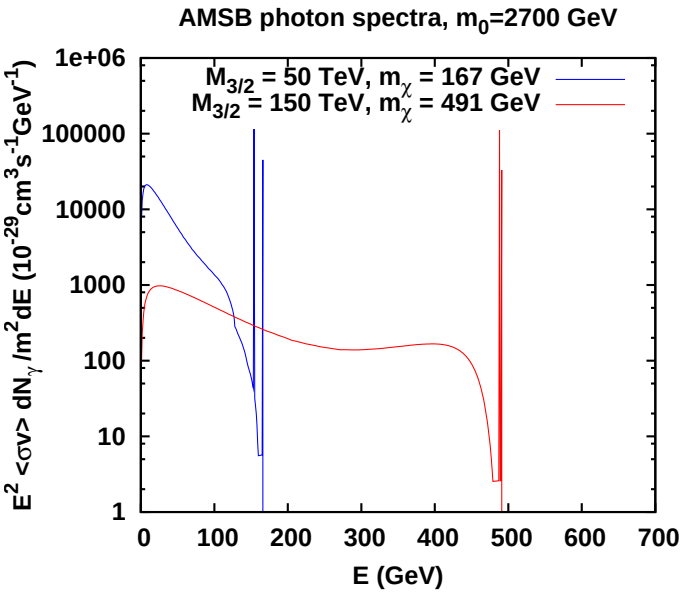
H.E.S.S. phase II

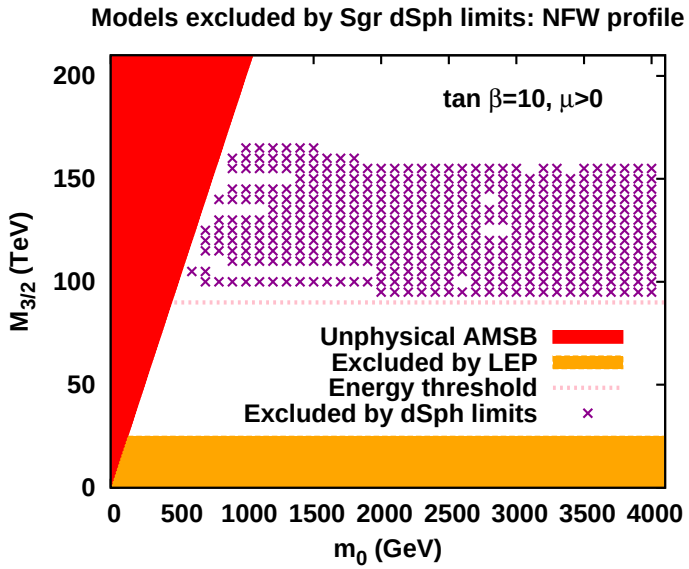
- 5th telescope: ⌀ 28m
- higher sensitivity
- E_{thr} lowered to $\sim$ 30 GeV
  $\longrightarrow$ better coverage of WIMPy mass range
  $\longrightarrow$ overlap with Fermi
- first light next year

LHC

- (Re-) Start of operation: next month!
- But: Will [*enter your favourite new physics here*] be **the** dark matter as seen in the Universe?
- **biodiversity** of collider-based, direct and indirect searches!
  $\longrightarrow$ more to come: **CTA**

Outlook (II)

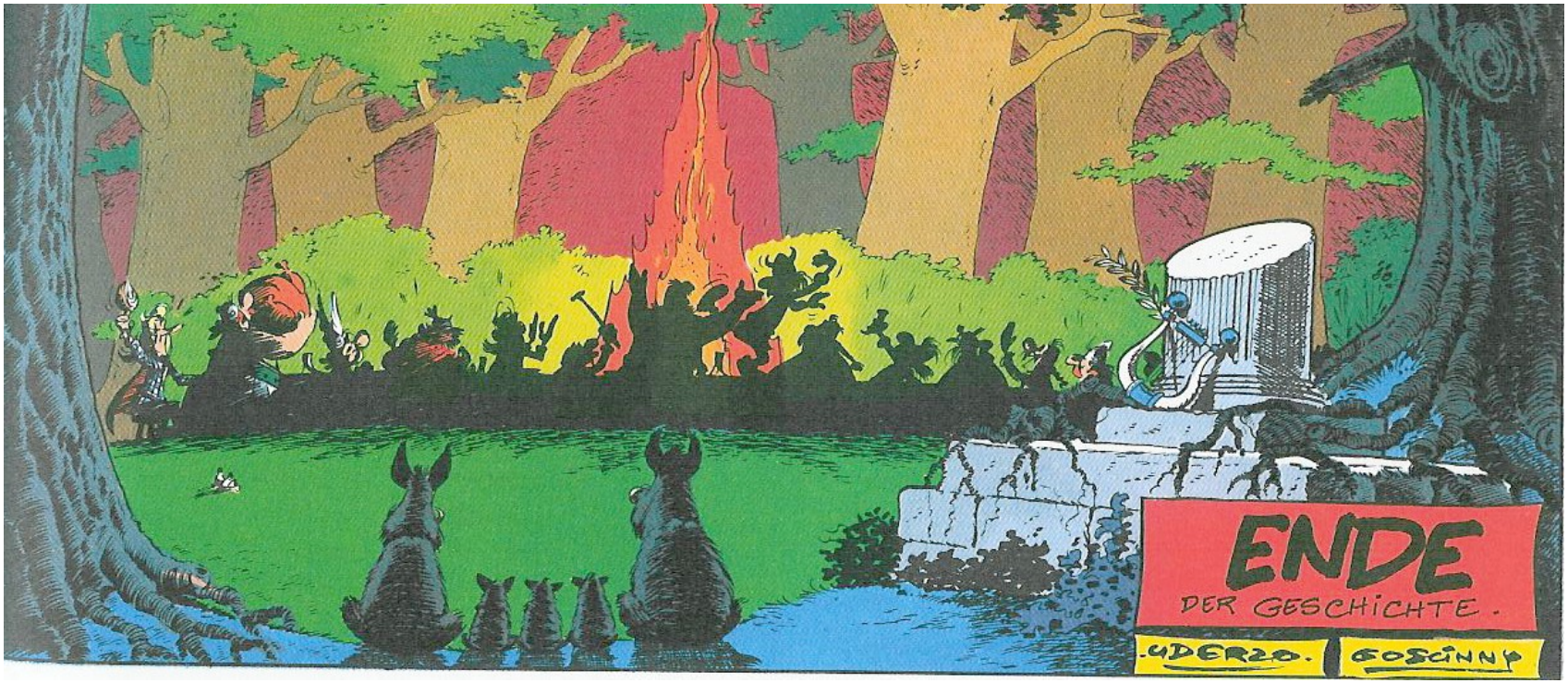




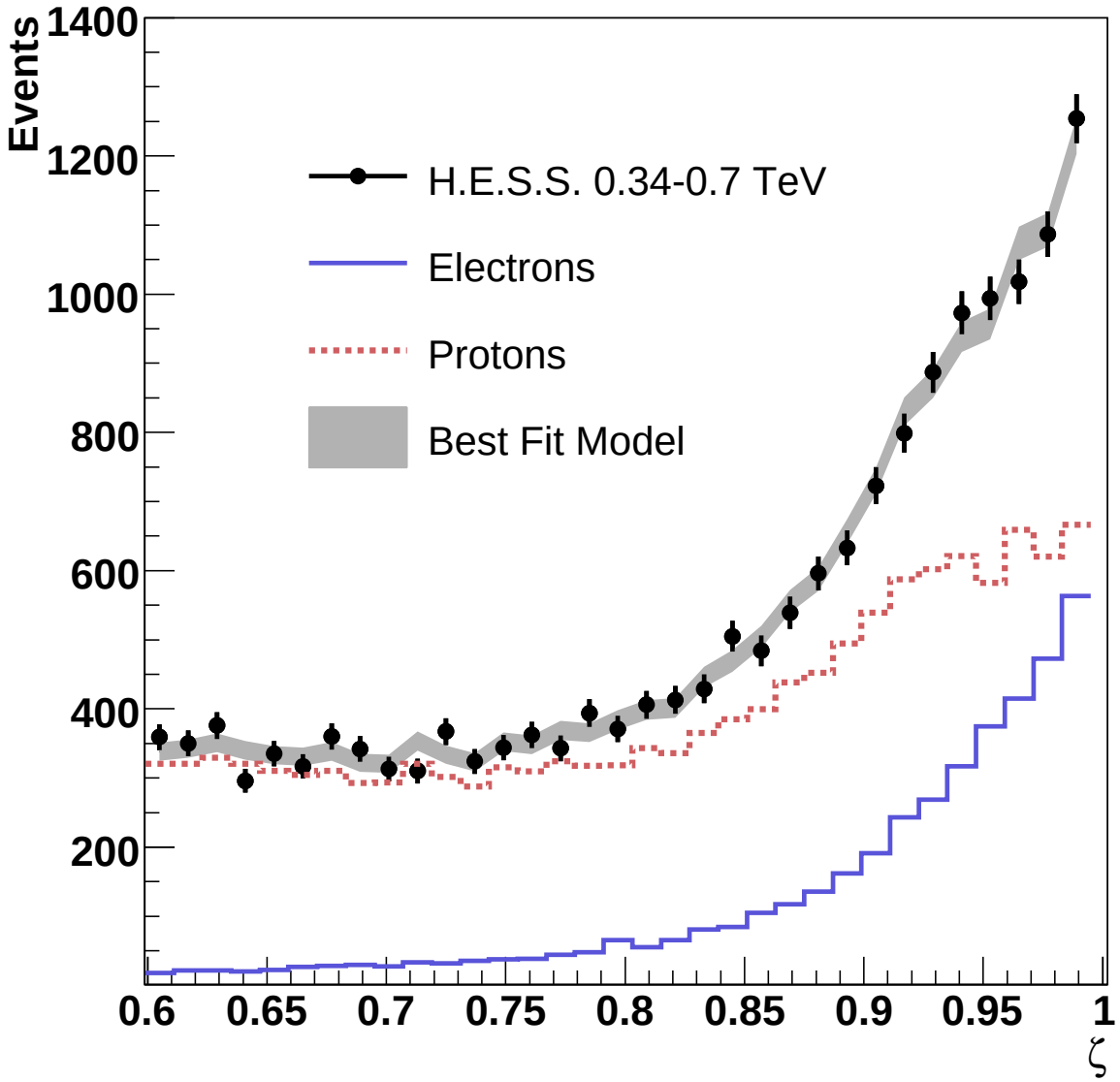
Pre-preliminary: Analysis using spectral information

- using differential ($d\Phi/dE$) flux limits from Sgr dSph ...
- assuming $\overline{J} = 2.2 \cdot 10^{24}$ GeV^2/cm^5 ...
- for AMSB Wino models [Nucl. Phys. B 570,455 (2000)] ...
- ... part of the LHC-relevant parameter space **might** actually be excluded by H.E.S.S. measurements.

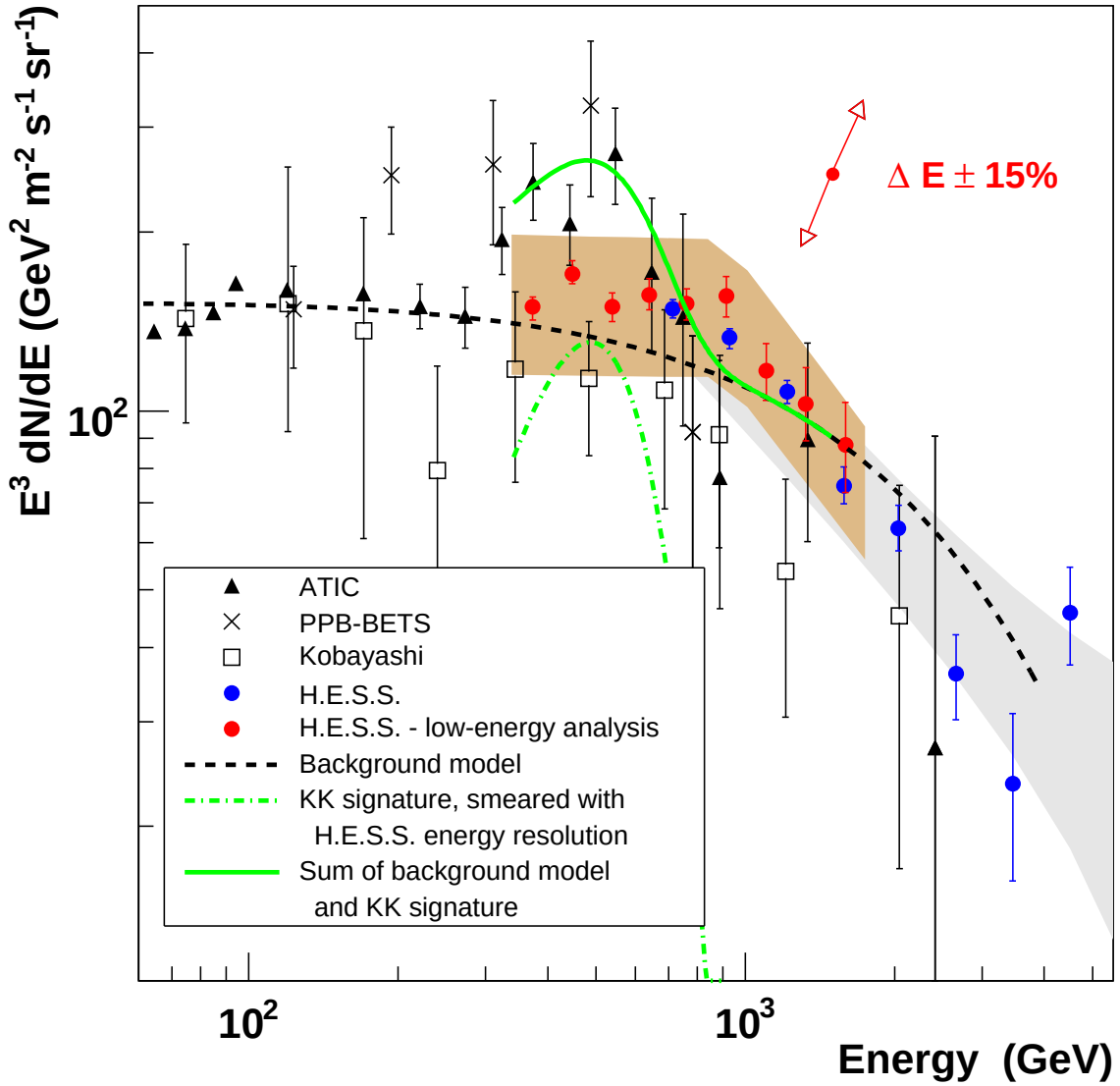
FINE



Backup: $e^{\pm}$ analysis – hadronic bkgr rejection



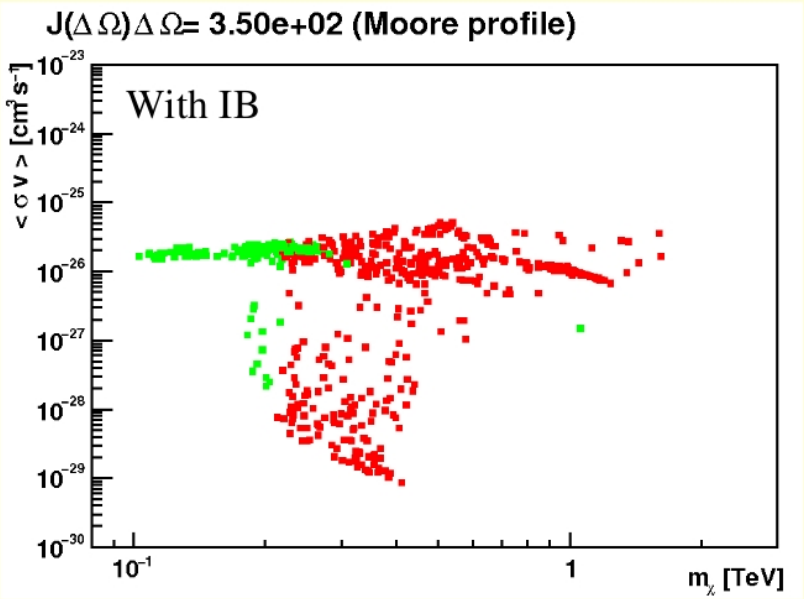
Backup: $e^{\pm}$ analysis – KK peak with H.E.S.S.

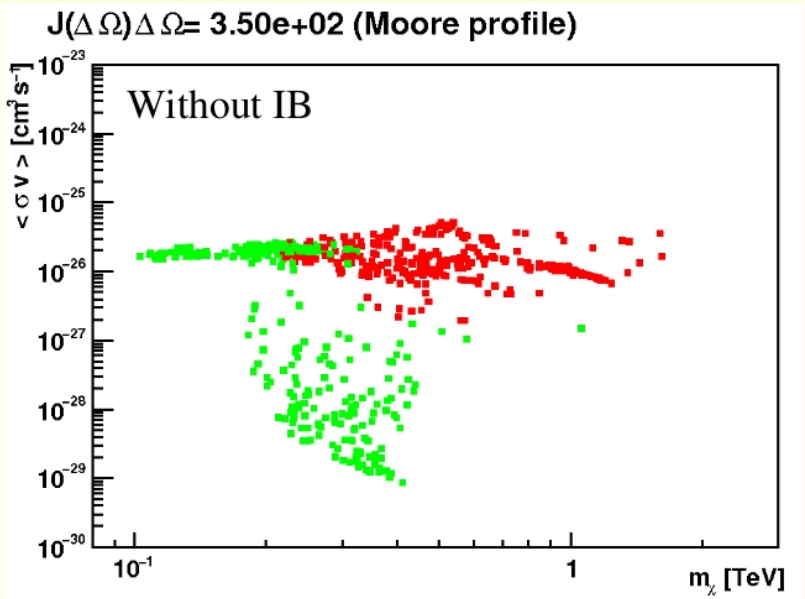


Backup: Effects of internal bremsstrahlung

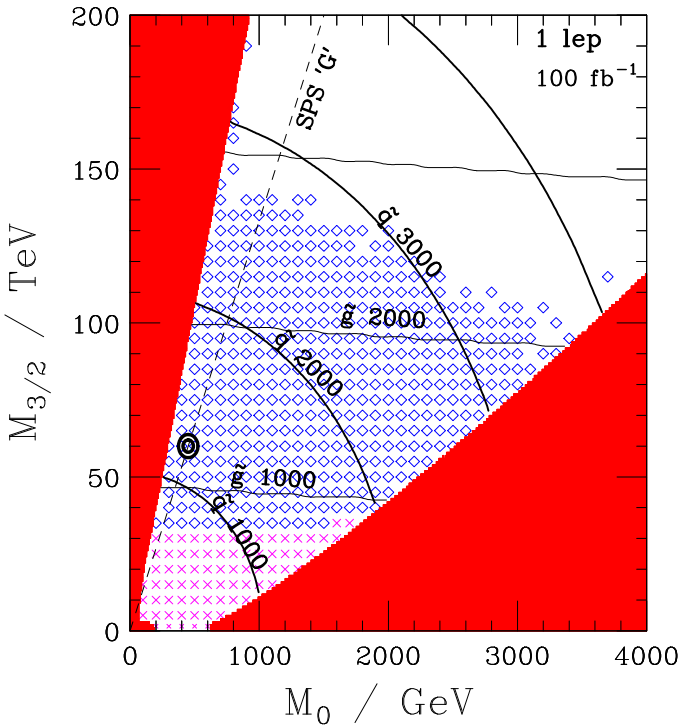
J. Ripken, ICRC 2009: Models excluded by GC observations

Limits with IB vs. without IB:

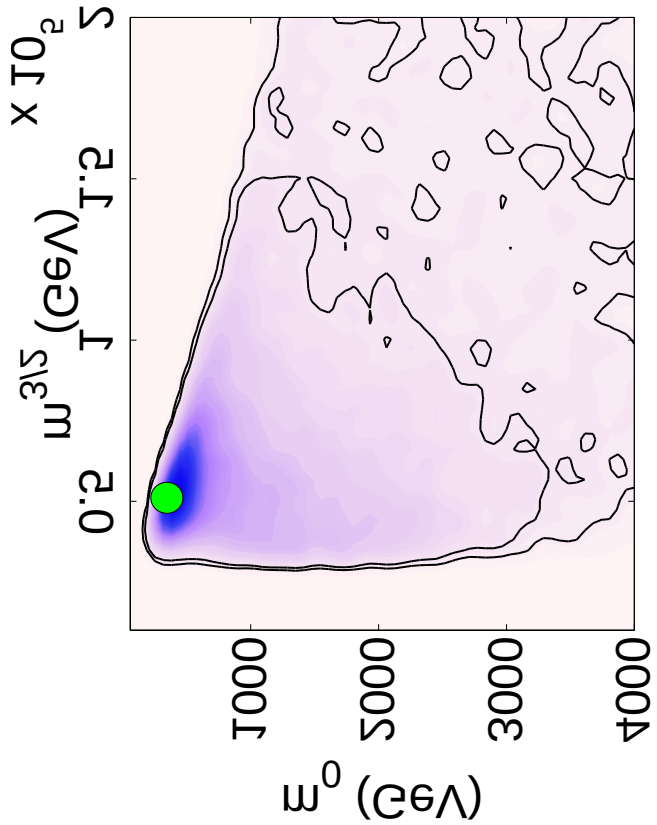




Backup: AMSB and the LHC



- Blue diamonds: LHC reach for AMSB models (A. Barr et al., [JHEP 03,045 (2003)])



- S. AbdusSalam et al.: Fit to low E observables [PRD 80,035017 (2009)]