PAMELA and Dark Matter

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LCWS 2008 - Cosmological Connections

Determining the Spin of DM

- CDM today is non-relativistic (annihilation in static limit)
- Helicity suppression for annihilation to light fermions (spin 0, 1/2-Majorana)
  - Only Spin 1/2-Dirac and Spin 1 DM candidates annihilate to positron "line"
- Annihilation to gauge bosons dependent on polarization

spin	s-channel Higgs	t,u-channel fermion	t,u-channel boson
0	LL, TT	X	LL
$\frac{1}{2}$	0	TT	X
1	LL, TT	X	LL, TT

TABLE II: Polarizations of W pairs produced by static annihilations $DM\,DM \to W^+W^-$ depend on the spin of the DM particle. "LL" and "TT" indicate that the W bosons are longitudinally and transversely polarized, respectively. "X" indicates that there is no contribution at the tree-level, and "0" indicates that the amplitude vanishes in the static limit. Note that a Dirac fermion also has contributions from s-channel Z-exchange.

Is it possible to determine spin of DM with new results from indirect detection experiments?

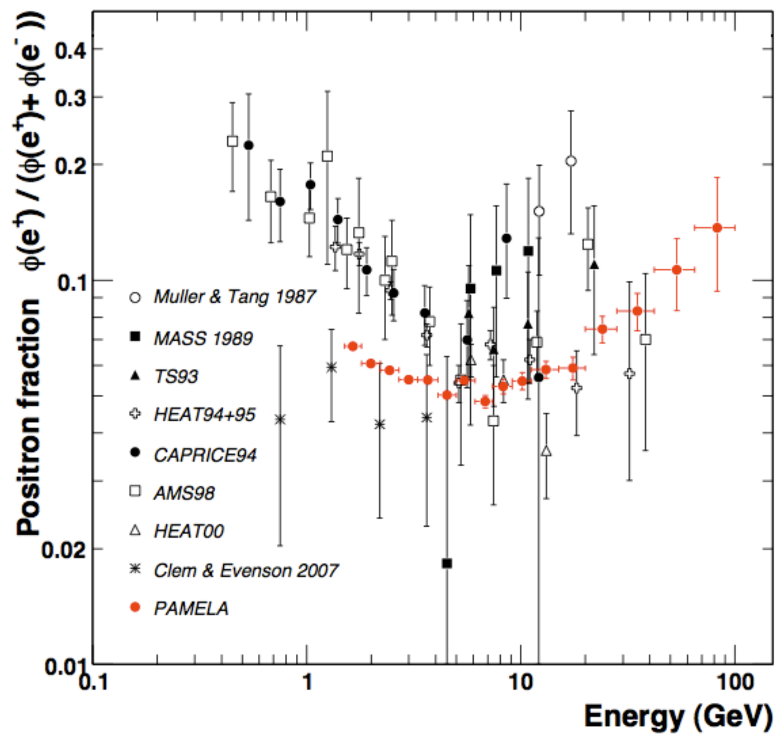
PAMELA satellite (positrons)

Observation of an anomalous positron abundance in the cosmic radiation

O. Adriani,[1,2] G. C. Barbarino,[3,4] G. A. Bazilevskaya,[5] R. Bellotti,[6,7] M. Boezio,[8] E. A. Bogomolov,[9] L. Bonechi,[1,2] M. Bongi,[2] V. Bonvicini,[8] S. Bottai,[2] A. Bruno,[6,7] F. Cafagna,[7] D. Campana,[4] P. Carlson,[10] M. Casolino,[11] G. Castellini,[12] M. P. De Pascale,[11,13] G. De Rosa,[4] N. De Simone,[11,13] V. Di Felice,[11,13] A. M. Galper,[14] L. Grishantseva,[14] P.

arxiv:0810.4995

Data features an abrupt rise in positron fraction



Propagation through the Halo

- Positron spectra at source propagates to Earth via diffusion-loss equation

$$\frac{\partial f}{\partial t} - K_0 E^{\delta} \nabla^2 - \frac{\partial}{\partial E}\left(\frac{f E^2}{\tau_E}\right) = \frac{1}{2}\frac{\rho^2}{M_{DM}^2} f_{inj} \qquad f = \frac{dN_{e^+}}{dE}$$

  – Positron flux at Earth

Cirelli, Franceshini, Stumia

$$\Phi_{e^+}(E, \vec{r}_\odot) = B \frac{v_{e^+}}{4\pi b(E)} \frac{1}{2}\left(\frac{\rho_\odot}{M_{\rm DM}}\right)^2 \int_E^{M_{\rm DM}} dE' \; f_{\rm inj}(E') \cdot I\left(\lambda_D(E, E')\right)$$

- Halo function $I(\lambda_D)$ describes propagation through galaxy and depends on Halo model and propagation parameters:

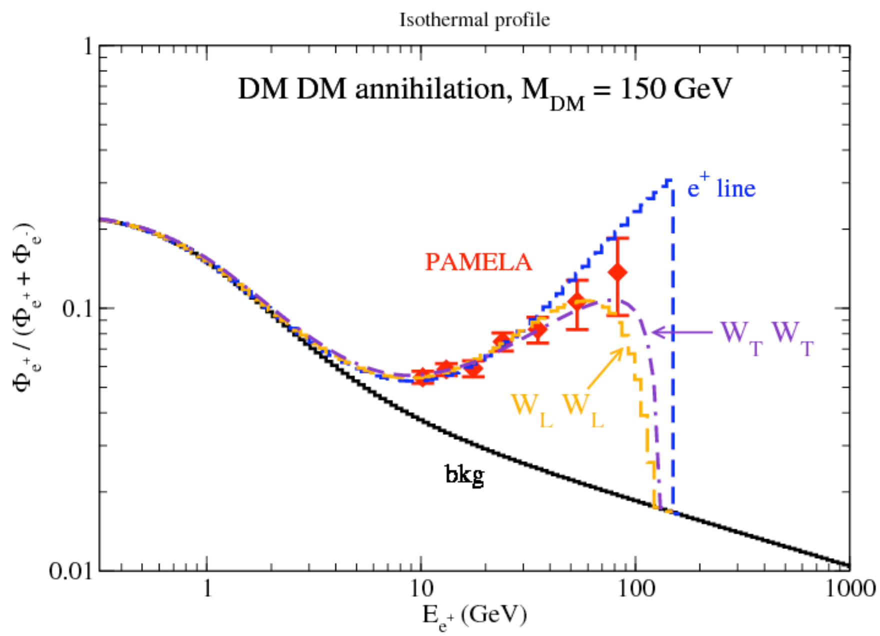
Model	δ	K_0 in kpc^2/Myr	L in kpc
min (M2)	0.55	0.00595	1
med	0.70	0.0112	4
max (M1)	0.46	0.0765	15

Here, we assume med propagation model in isothermal halo

PAMELA and Dark Matter

Barger, Keung, Marfatia, GS. arxiv:0809.0162

- Recent PAMELA results that show a sharp excess in high energy positrons may be fit to various annihilation modes
- Spin of DM determines possible annihilation modes
- Perhaps possible to determine spin of DM candidate via positron spectrum!
- Higher energy data needed to help infer spin of DM particle

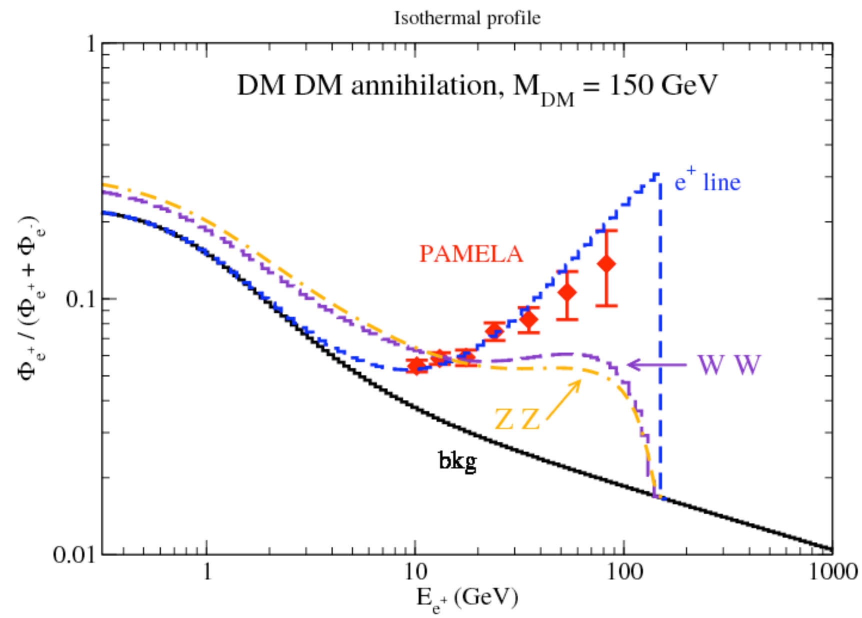


$$\langle \sigma v \rangle = 3 \times 10^{-26} \frac{\mathrm{cm}^3}{\mathrm{s}}$$

	$W_L W_L$	$W_T W_T$	e^+e^-
M_{DM}	150	150	150
B_{e+}	1537	1773	30.7
χ^2_{PAMELA} (total)	2.41	2.08	5.63

PAMELA and Dark Matter

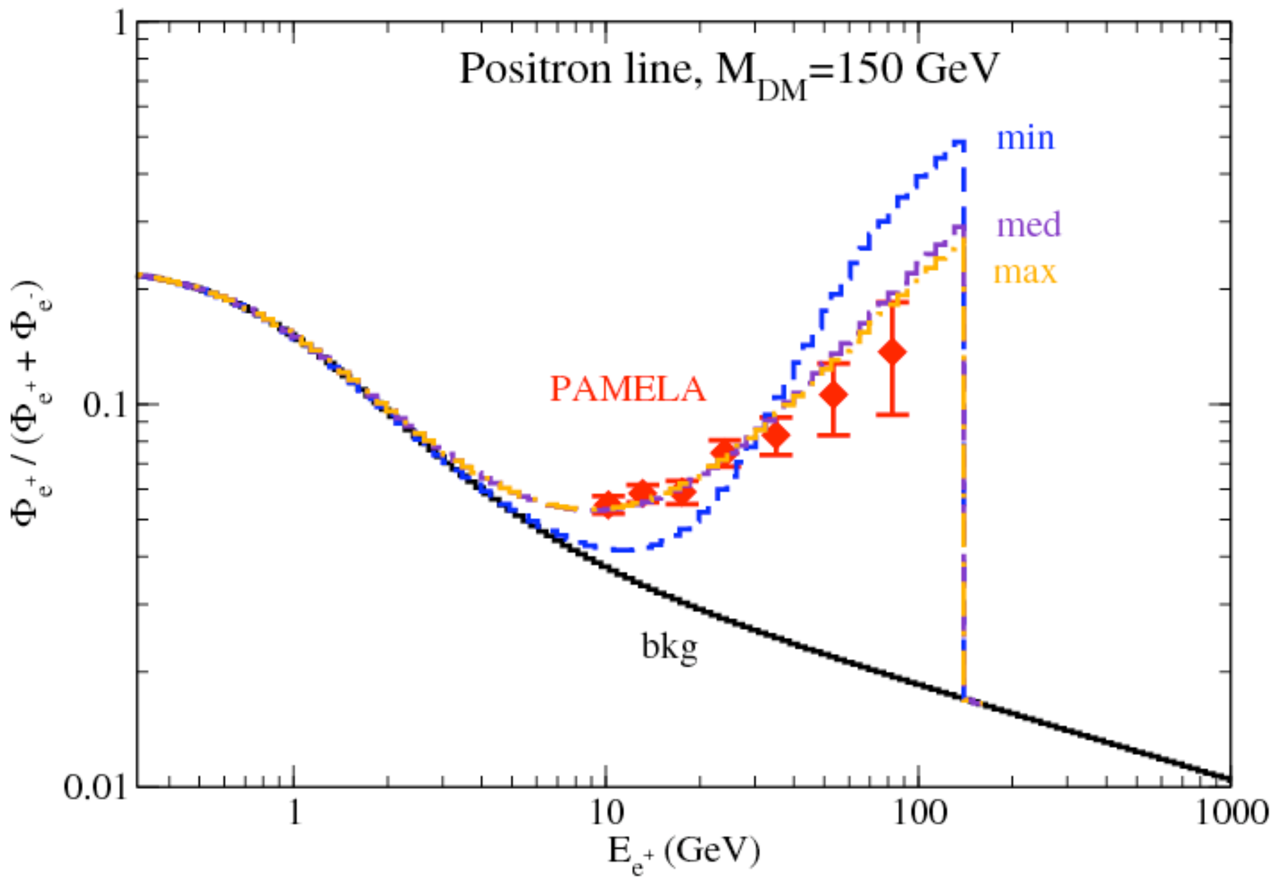
- Need to include soft positrons from showering of gauge bosons and light quarks
- Enhances softer end of spectrum, worsens fit for gauge bosons compared to just hard, spin-correlated spectrum
- ZZ spectra generally softer than WW



$$\langle \sigma v \rangle = 3 \times 10^{-26} \frac{\mathrm{cm}^3}{\mathrm{s}}$$

	WW	ZZ	e^+e^-
M_{DM}	150	150	150
B_{e+}	359.7	467.1	30.7
χ^2_{PAMELA} (total)	31.7	42.6	5.63

Halo model variation



- Quality of fit of PAMELA data to positron line dependent on propagation parameters

Model	δ	K_0 in kpc^2/Myr	L in kpc
min (M2)	0.55	0.00595	1
med	0.70	0.0112	4
max (M1)	0.46	0.0765	15

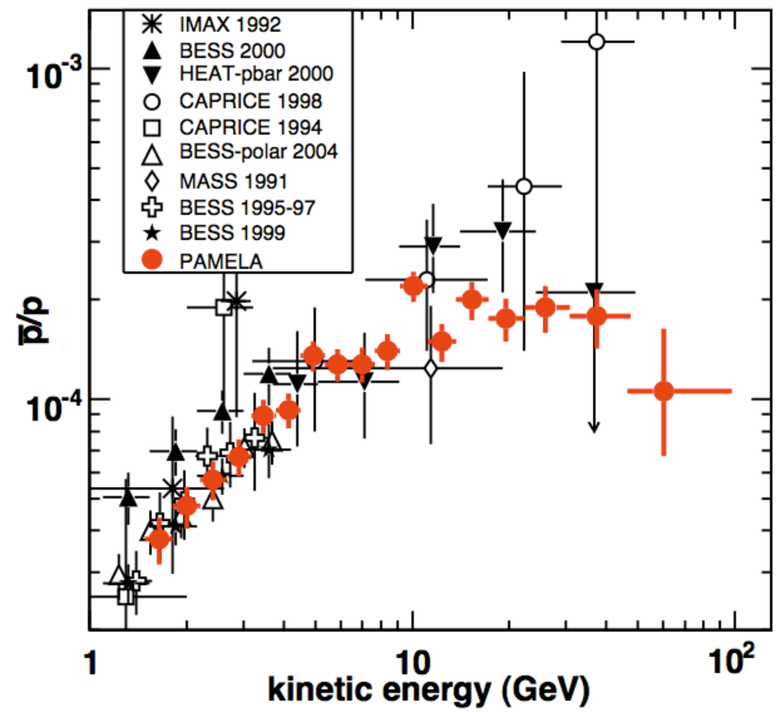
PAMELA Data (antiprotons)

A new measurement of the antiproton-to-proton flux ratio up to 100 GeV in the cosmic radiation

O. Adriani,[1,2] G. C. Barbarino,[3,4] G. A. Bazilevskaya,[5] R. Bellotti,[6,7] M. Boezio,[8] E. A. Bogomolov,[9] L. Bonechi,[1,2] M. Bongi,[2] V. Bonvicini,[8] S. Bottai,[2] A. Bruno,[6,7] F. Cafagna,[7] D. Campana,[4] P. Carlson,[10] M. Casolino,[11] G. Castellini,[12] M. P. De Pascale,[11,13] G. De

arxiv:0810.4994

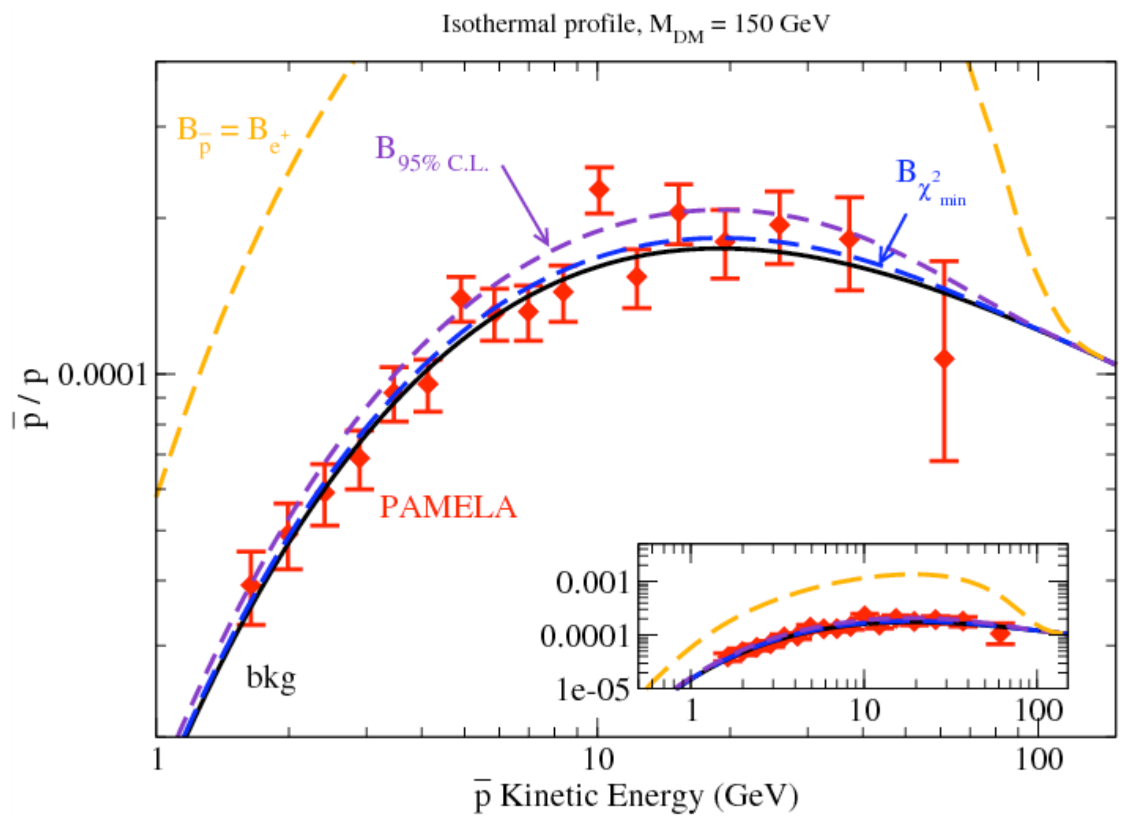
No significant excess seen above expectation



Antiproton spectra

- Requires much smaller boost factors than needed for positron data

- Suppression of annihilation to hadronic states, or an astrophysical effect?



$$\langle \sigma v \rangle = 3 \times 10^{-26} \frac{\mathrm{cm}^3}{\mathrm{s}}$$

	WW
M_{DM}	150
$B_{\bar{p}}$	0.84
χ^2_{PAMELA} (total)	14.7
$B_{\bar{p}-95\%C.L.}$	3.3
χ^2_{PAMELA} (total)	26.3

Model independent global scan (update)

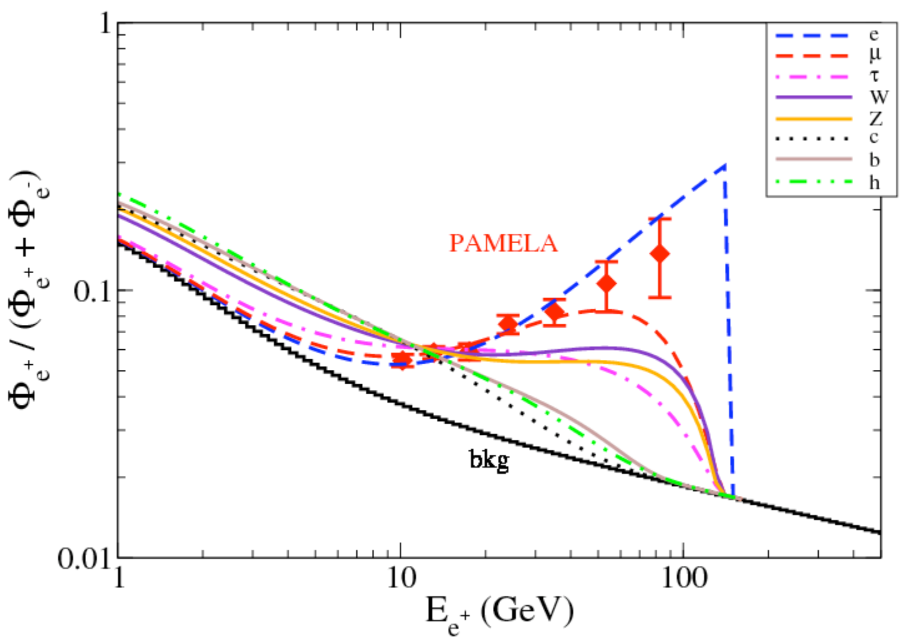
Barger, Keung, Marfatia, GS. arxiv:0809.0162

- Perform Markov Chain Monte Carlo to scan parameters:
  - M_{DM}
  - Fraction of annihilation to modes:
    $$e^+e^-, \mu^+\mu^-, \tau^+\tau^-, c\bar{c}, b\bar{b}, t\bar{t}, W^+W^-, ZZ, hh$$
  - Vary positron boost factor to minimize χ^2
- MCMC scan optimally scans over parameter space
  - Bayesian approach that optimally scans parameter space
  - More efficient with large number of parameters
  - Chain based on collection of points chosen by relative likelihood

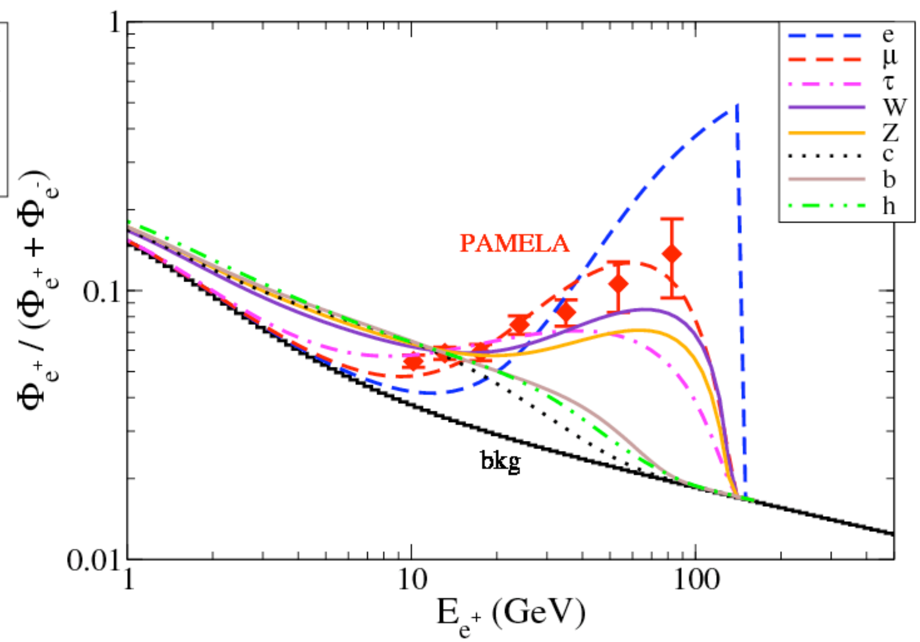
Fit by mode

- For 150 GeV DM mass,
  - Good fit: annihilation to lepton
  - In the middle: W/Z boson depending on propagation model
  - Bad fit: annihilation to quarks / Higgs boson

Med

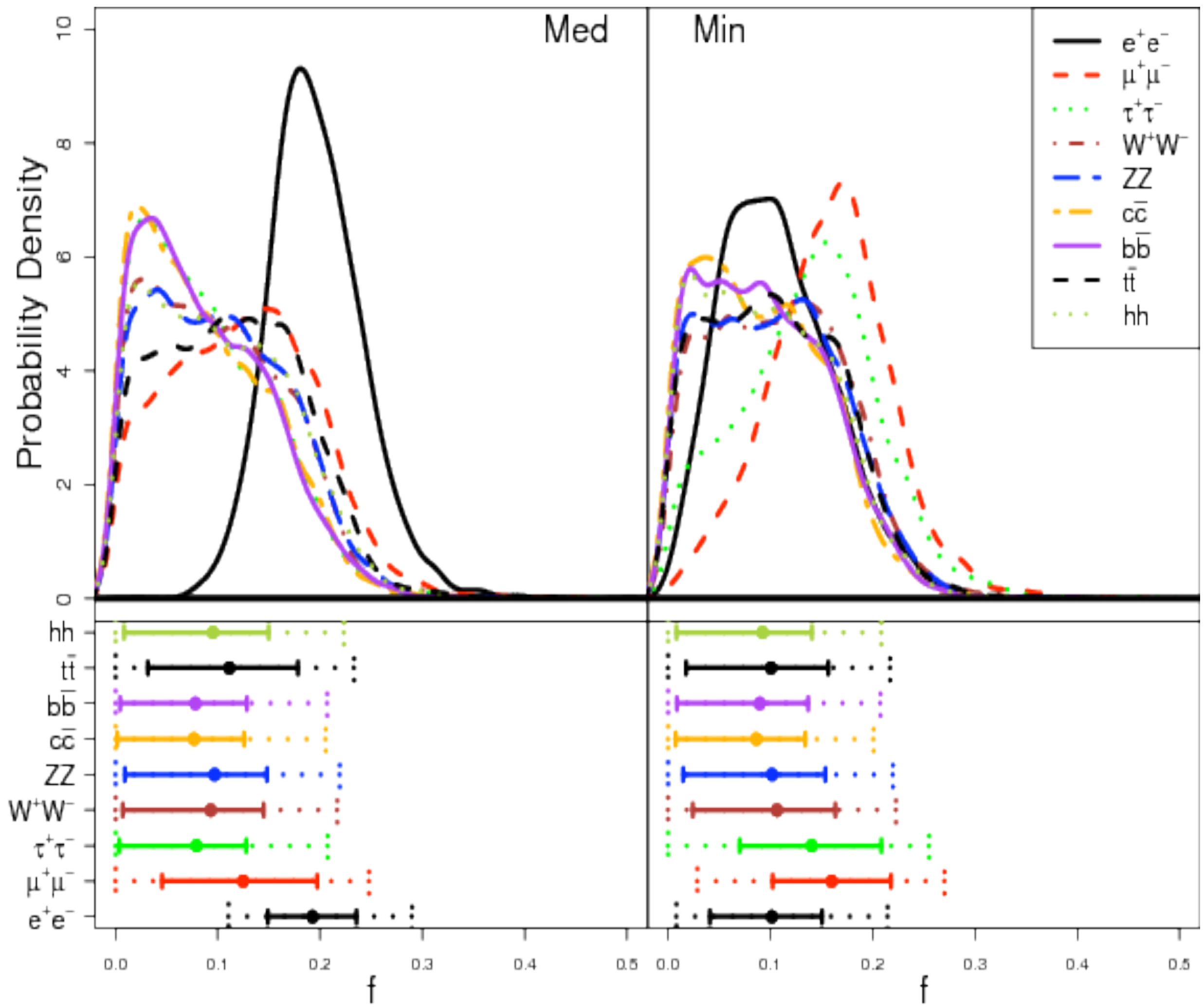


Min



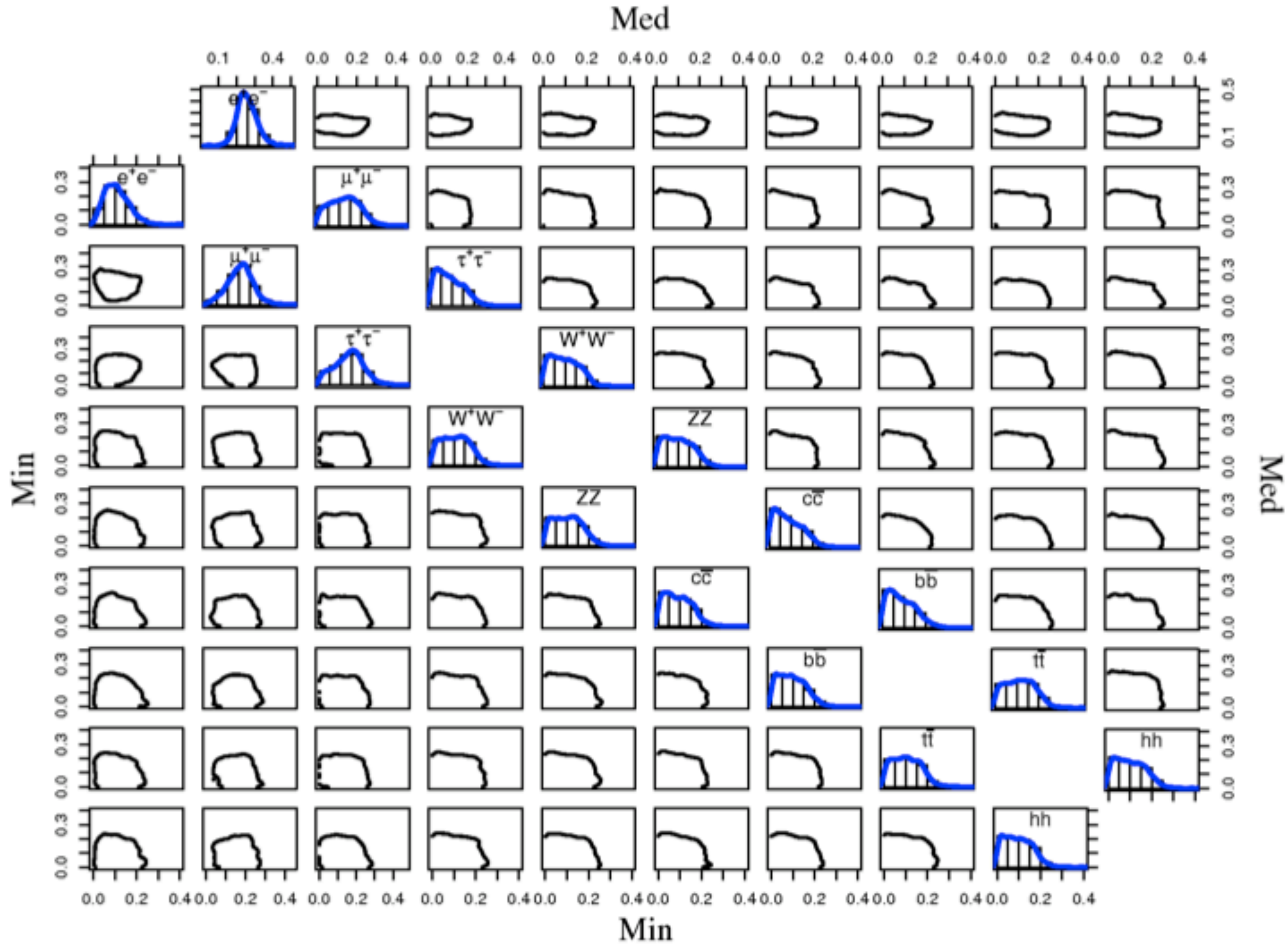
Annihilation mode distribution

- Annihilations to positrons preferred in Med propagation model
- Annihilations to μ, τ preferred in Min model
- Small soft component in positron spectra suggestive



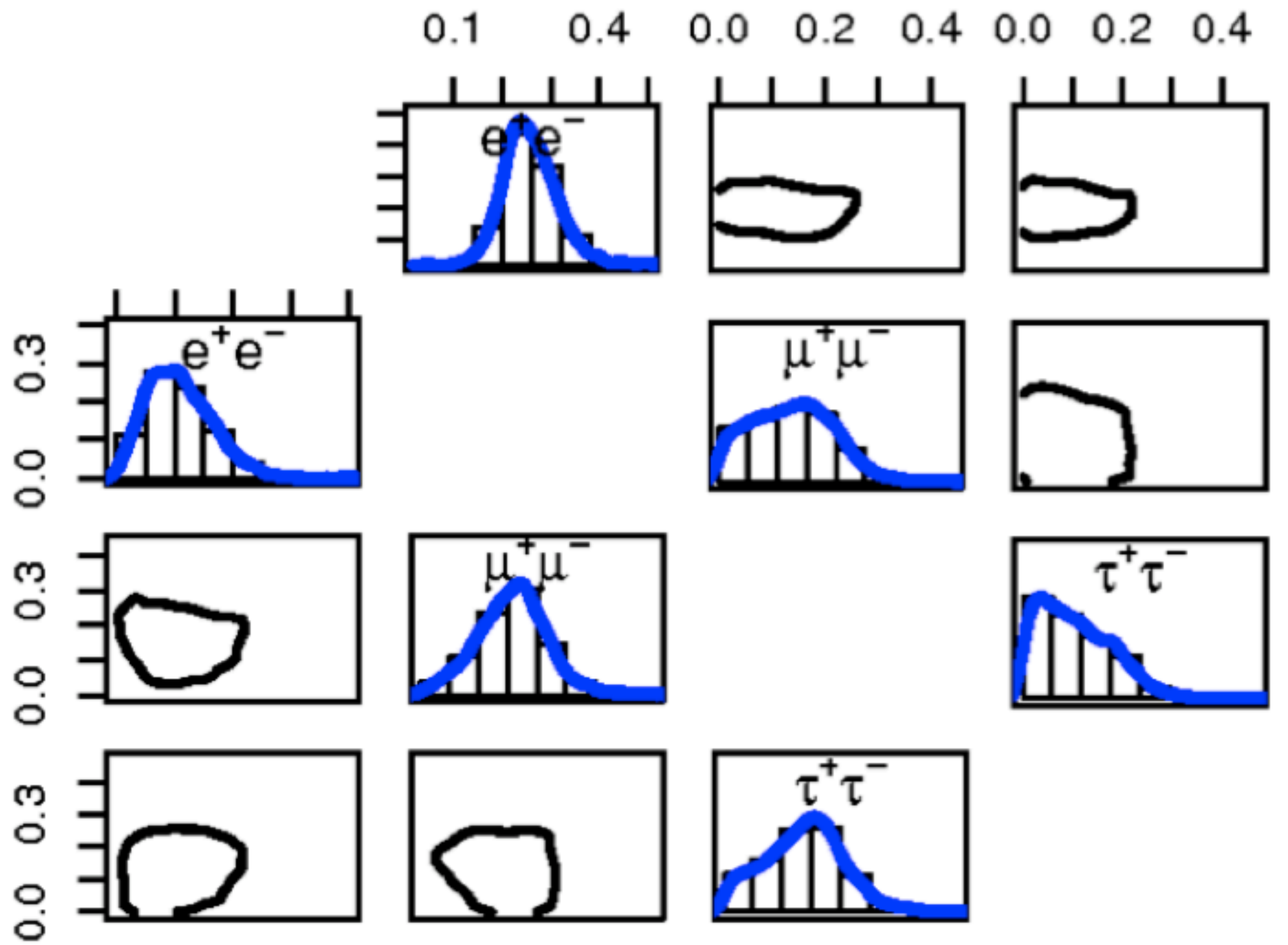
whiskers cover $1, 2\sigma$ range

Correlations among modes



2σ bands given

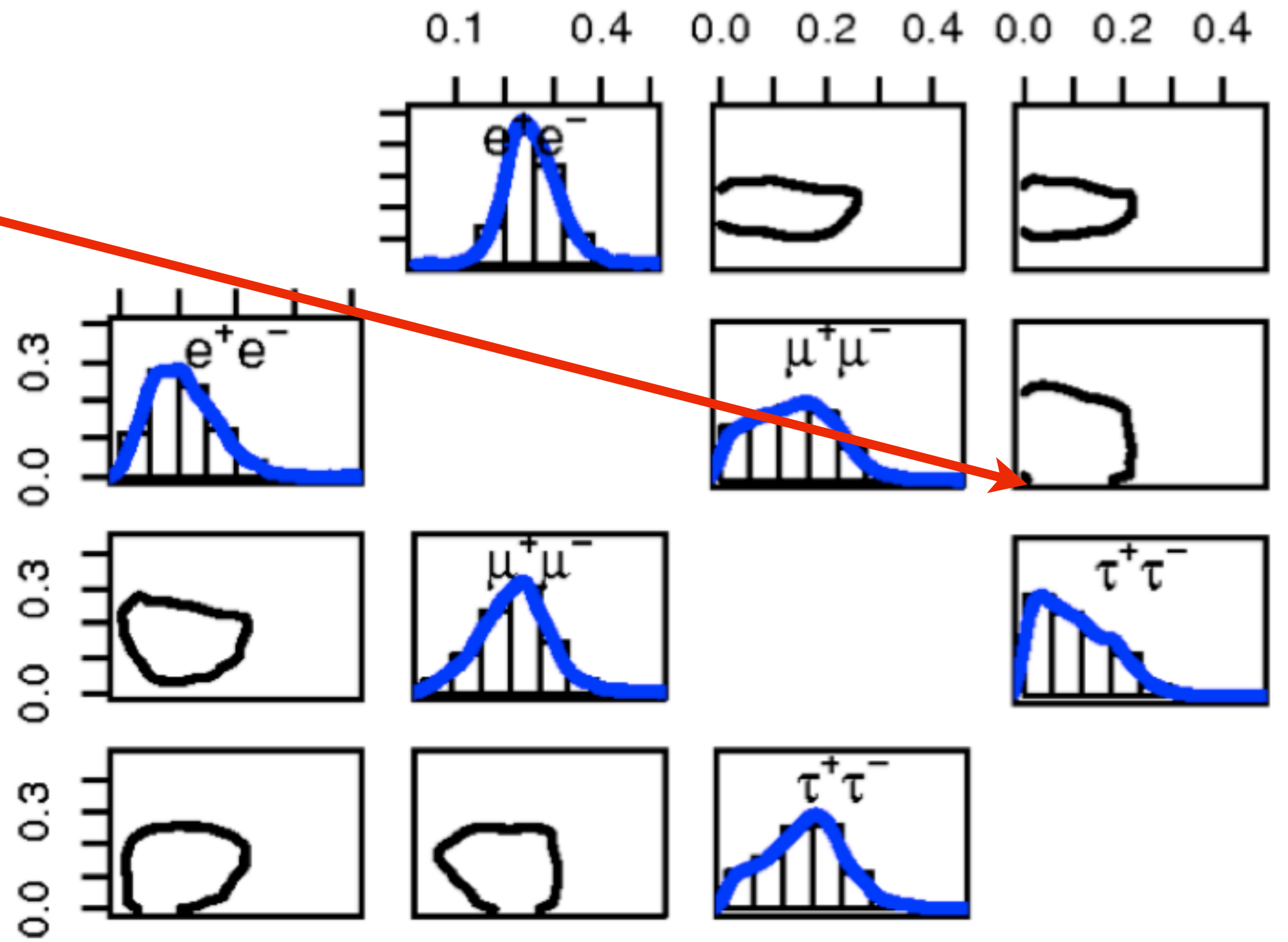
Correlations among modes



2σ bands given

Correlations among modes

μ, τ consistent with (0,0) in Med propagation model

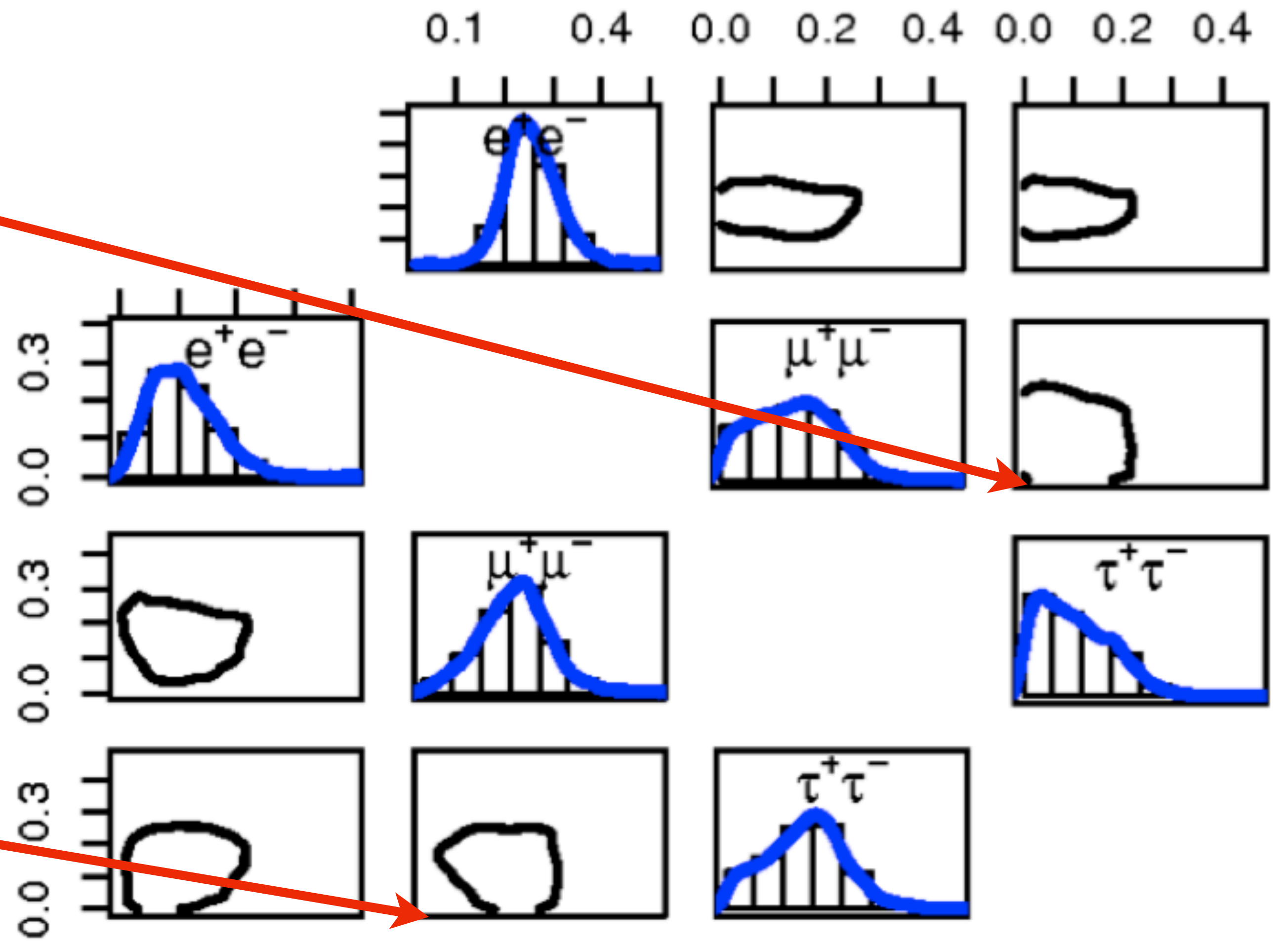


2σ bands given

Correlations among modes

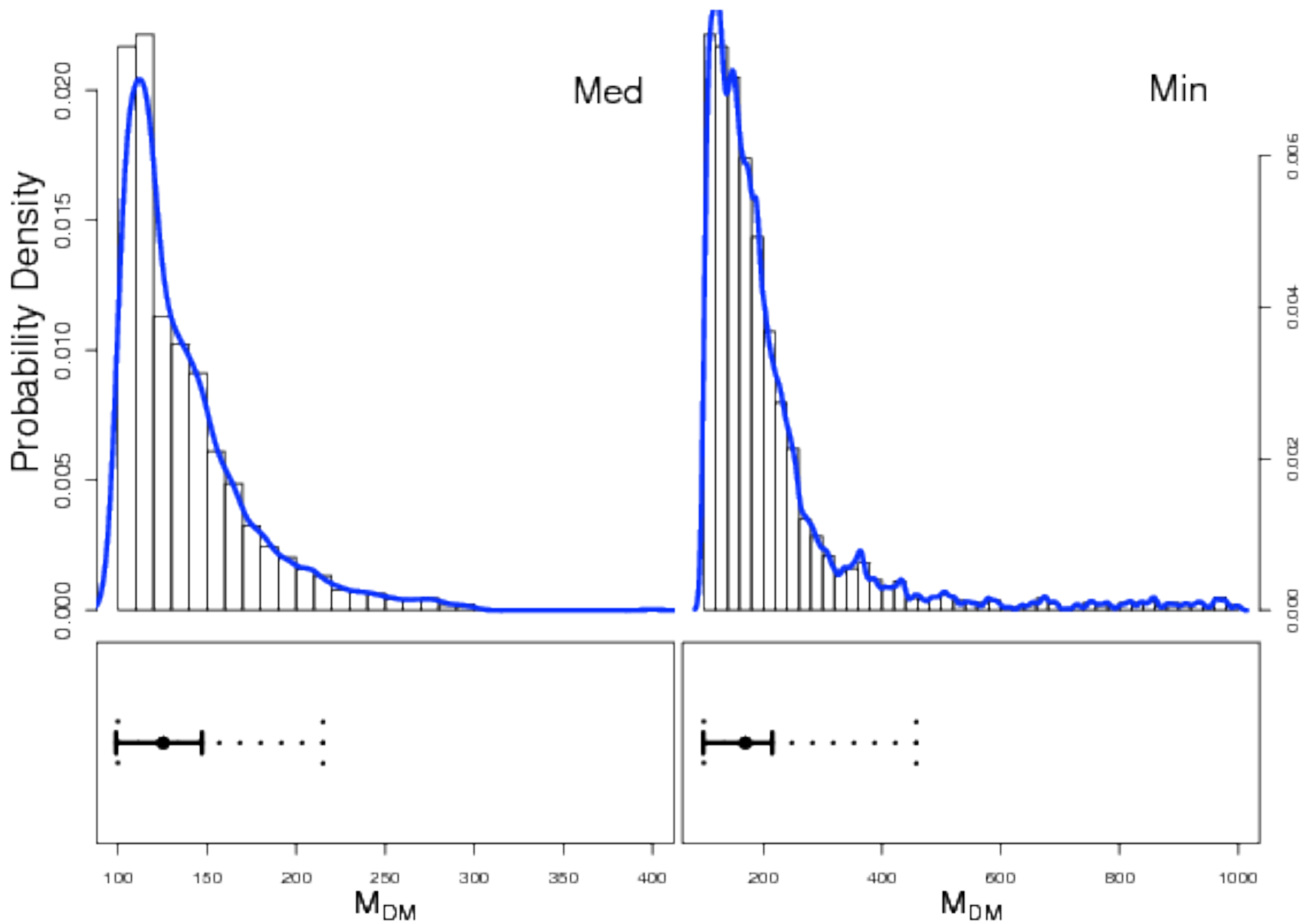
μ, τ consistent with (0,0) in Med propagation model

μ, τ not consistent with (0,0) in Min propagation model



2σ bands given

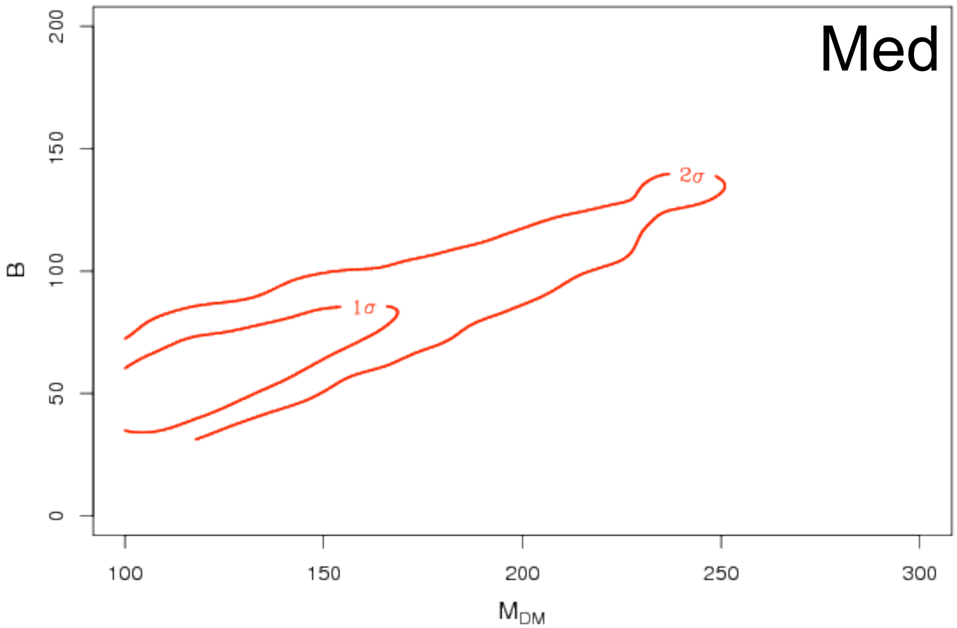
Mass distribution



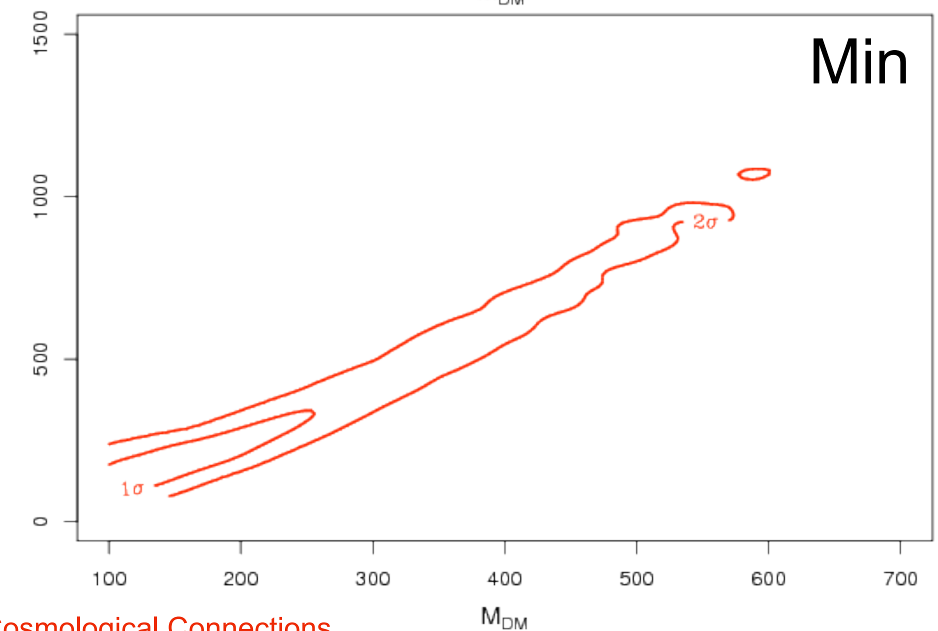
whiskers cover $1, 2\sigma$ range

Mass and Boost factor distribution

- Med propagation model consistent with relatively small boost factors and DM mass



- Min propagation model gives larger range of values



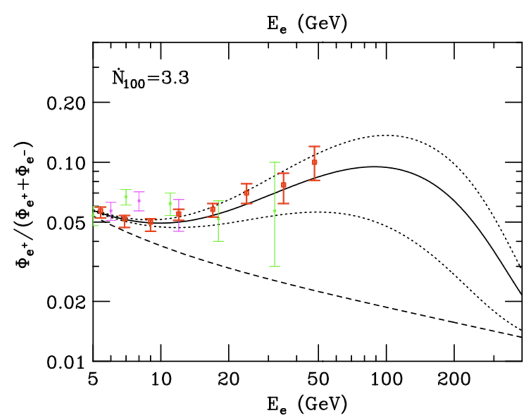
Other explanations of PAMELA

- Bremstrahlung off light fermion can dominate positron spectra in stau-coannihilation region of mSUGRA (Bergstrom, Bringmann, Edsjo)
  - Helicity suppression removed
  - Positron spectra fits PAMELA well, but with very large boost factors (~10^4)

- Model independent: annihilation to positrons/muons give good fit to PAMELA with large cross section/boost factors (Cholis, Goodenough, Hooper, Simet, Weiner)

- eXciting Dark Matter (XDM) (Arkani-Hamed, Finkbinder, Slatyer, Weiner)
  - Sommerfeld enhancement at low velocities

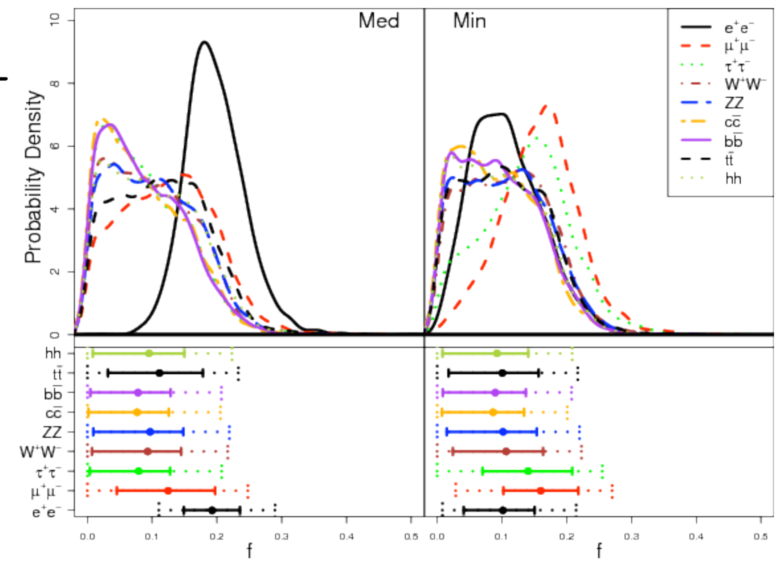
- Local pulsars (Hooper, Blasi, Serpico & Yuksel, Kistler, Stanev)



Summary

- Abrupt rise in PAMELA positron fraction at high energies could be evidence of DM annihilations
- Model independent analysis with MCMC

- Dominant annihilation to e^+e^- fits spectra quite well if Med propagation model is assumed
- Fit with Min propagation model suggests a soft component in positron spectra
  - Can be achieved with annihilations to μ, τ



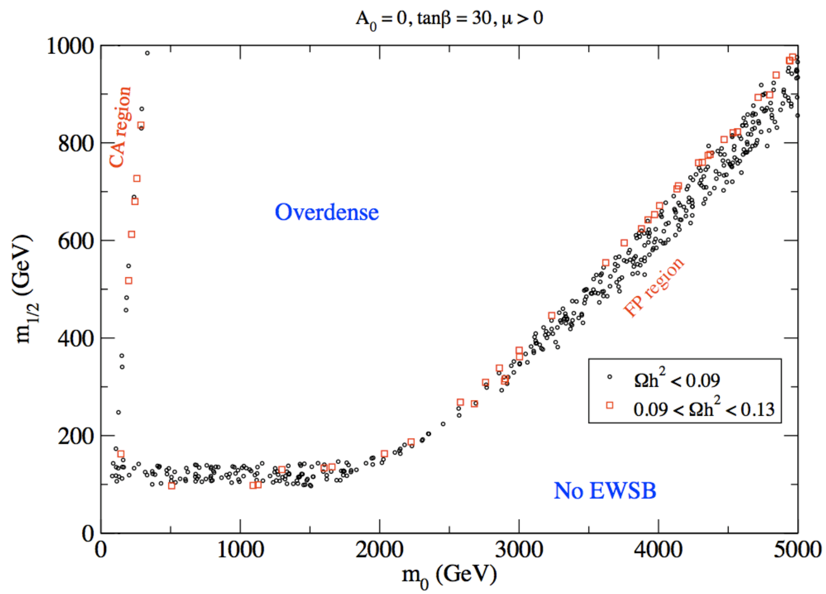
- More details can be extracted with more data, better statistics

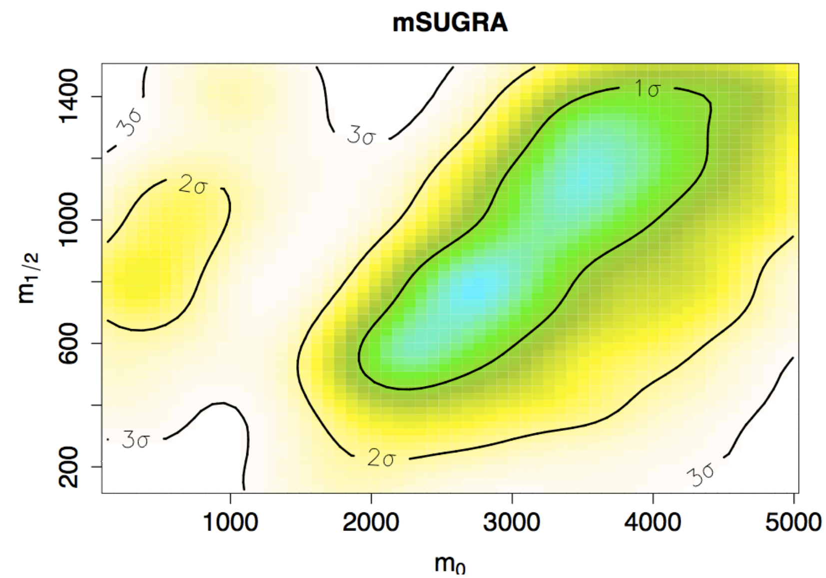
Backup Slides

Parameter scan

- Traditional scans typically inefficient and decision to keep point based on hard cut. Example: $\Omega_{DM}h^2$

- Markov Chain Monte Carlo (MCMC) scan allows all possible directions in parameter space to be explored simultaneously with uncertainties included

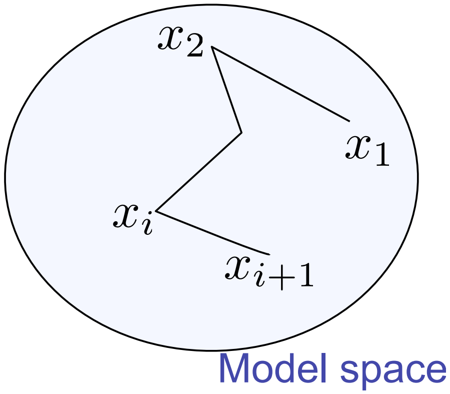




MCMC scan

- Bayesian approach that optimally scans parameter space
- More efficient with large number of parameters
- Chain based on collection of points chosen by relative likelihood
- Algorithm:
  - Probability of jump from current to next point in chain related to relative likelihood

$$P(x_i \rightarrow x_{i+1}) = \mathrm{Min}\left(1, \frac{\mathcal{L}_{i+1}}{\mathcal{L}_i}\right)$$



  - Likelihood constructed from chi-square

$$\mathcal{L}_i = e^{-\sum_j \chi_j^2/2}$$

  - Collection of points in chain x_i approach posterior distribution of parameters given constraining data