DAMPE THEORY: Critical review

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ULB

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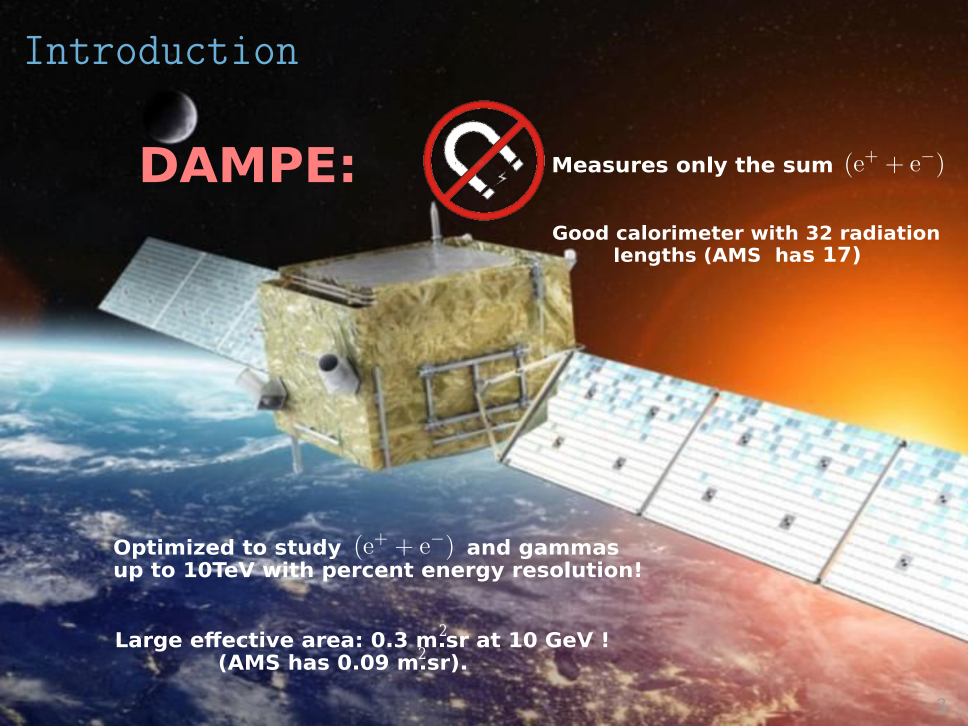
Introduction

Context : Precision era for cosmic-ray physics.

- The motto : *denser* and *higher*.
- Experiments are resolving the composition of CRs at the TeV scale.
- Interpretations of these fluxes are expected to shed light on new astrophysical mechanisms and hopefully new physics !

Introduction



DAMPE:

Measures only the sum $(e^+ + e^-)$

Good calorimeter with 32 radiation lengths (AMS has 17)

Optimized to study $(e^+ + e^-)$ **and gammas up to 10TeV with percent energy resolution!**

Large effective area: 0.3 m^2sr at 10 GeV ! (AMS has 0.09 m^2sr).

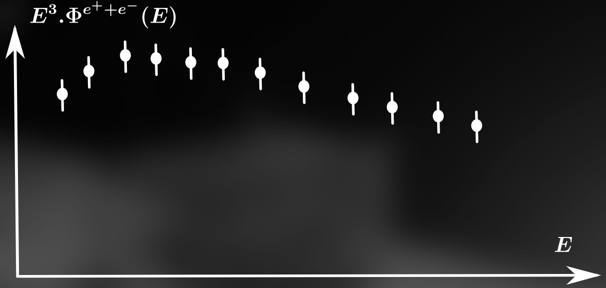
What do we expect ?

Features in DAMPE leptonic flux

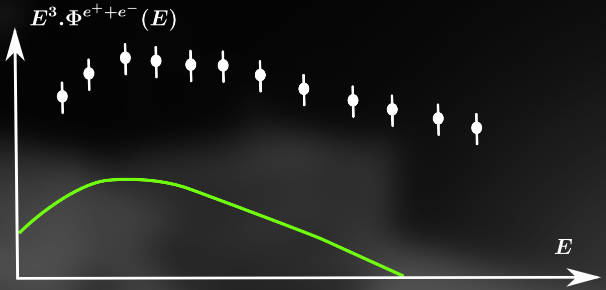
Explanation for the $(e^+ + e^-)$ knee

Hypotheses around the DAMPE peak

Expectation for the $(e^+ + e^-)$ flux

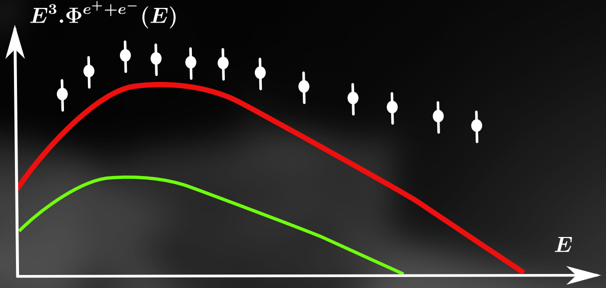


Expectation for the $(e^+ + e^-)$ flux



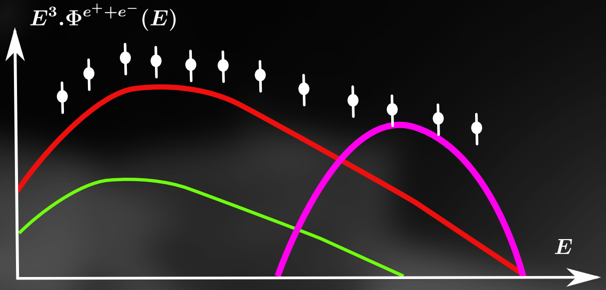
- Φ_{sec} : Secondary leptons produced in p and He CRs collisions with the ISM.

Expectation for the $(e^+ + e^-)$ flux



- Φ_{sec} : Secondary leptons produced in p and He CRs collisions with the ISM.
- Φ_{prim} : Primary leptons produced/accelerated by distant sources distributed in the all galaxy (SNR, PWN).

Expectation for the $(e^+ + e^-)$ flux



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- $\Phi^{loc}_{\mathbf{prim}}$: Primary leptons produced/accelerated in nearby sources.

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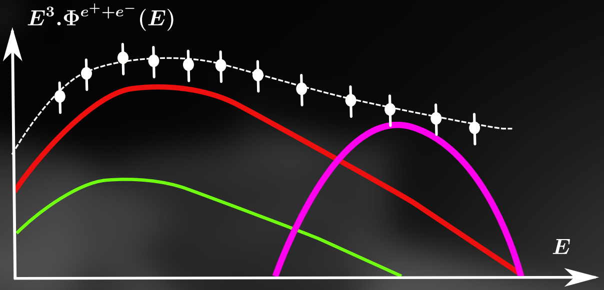

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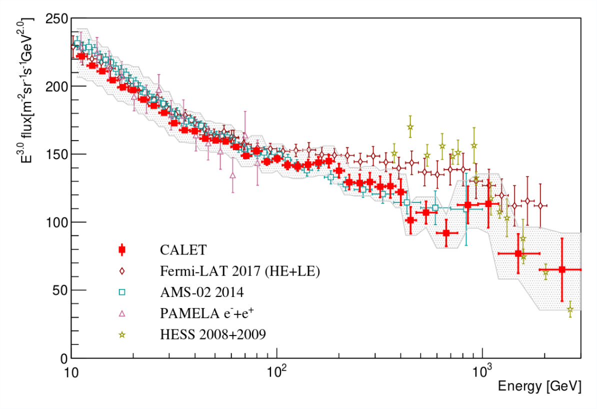
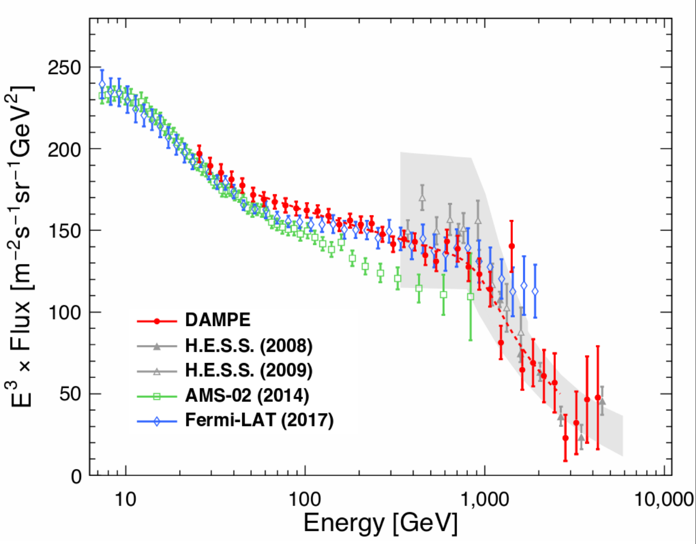
CALET flux realeased one day after!



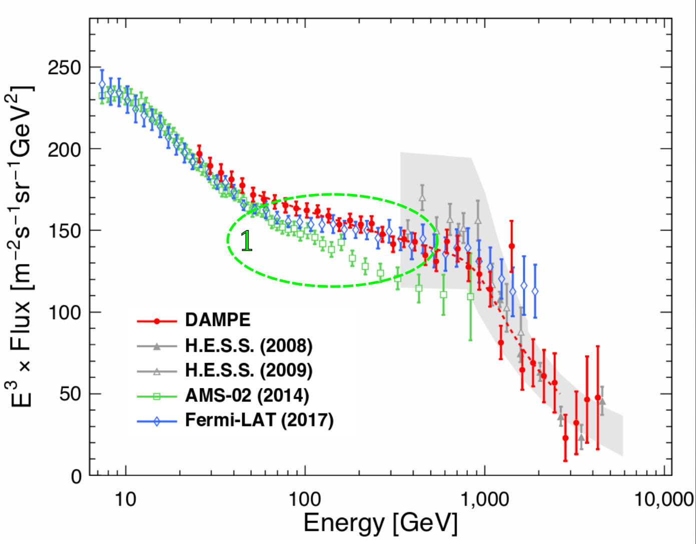
O. Adriani et al. PRL. 119 (2017)

- CALET flux is in agreement with AMS02 one.
- In 1σ tension with DAMPE in [50GeV-1TeV].
- Less statistics than DAMPE : 1/3 of the statistic.

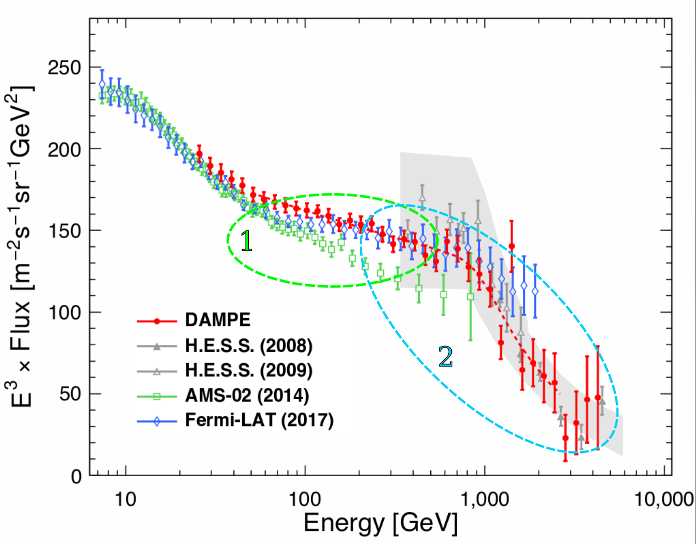
Features in DAMPE leptonic Flux



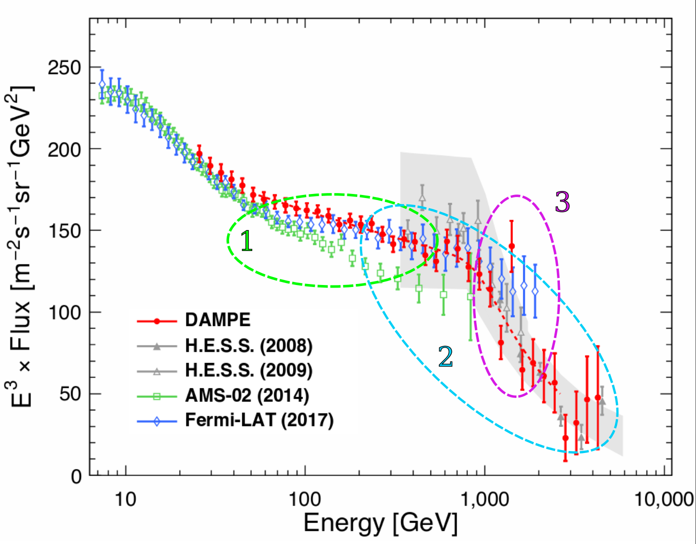
Features in DAMPE leptonic Flux



Features in DAMPE leptonic Flux



Features in DAMPE leptonic Flux



Features in DAMPE leptonic Flux

1-DAMPE data are in tension with AMS and CALET.

Only one comment in the paper :

"The difference might be partially due to the uncertainty in the absolute energy scale, which would coherently shift the CRE spectrum up or down."

2-First direct detection of the $(e^+ + e^-)$ knee.

Following *Fowlie, A., 2017. Preprint arXiv:1712.05089.*,

- **Frequentist analysis :**
  Test : Power law (PL) vs smoothly broken power law (SBPL)

  $$p_{value} = p(\Delta\chi^2 \leq \Delta_{obs}) < 0.002$$

  ↳ at least 3σ limited by the Monte Carlo

  Using the Wilks theorem the significance goes to 7σ !

- **Bayesian analysis :**
  Computation of the Bayes factor $B = \frac{p(Data|SBPL)}{p(Data|PL)} = 10^{10}$!

  $\Rightarrow$ **Strong evidence for the $(\mathbf{e^+ + e^-})$ knee !**

Features in DAMPE leptonic Flux

3-A line like signal at 1.5 TeV ?

No comment in the paper..

Following *Fowlie, A., 2017. Preprint arXiv:1712.05089.*,

- **Frequentist analysis :**
  Test : SBPL vs SBPL + generic gaussian signal

$$p_{value} = p(\Delta\chi^2 \leq \Delta\chi^2_{obs}) \sim 0.01 \rightarrow 2.3\sigma$$

- **Bayesian analysis :**
  Computation of the Bayes factor $B = \frac{p(Data|SBPL+signal)}{p(Data|SBPL)} \sim 2$!

  $\Rightarrow$ **The evidence for a "signal" is not so strong..**

- **Caveat in most of the analyses !**

  The signal can be much narrower than the bin size, so the mean flux over the bin size should be calculated in the same way as for the data.

$$\Phi_i = \langle\Phi\rangle_{bin} = \frac{1}{E_{i+1} - E_i}\int_{E_i}^{E_{i+1}} \Phi(E)\, \mathrm{d}E$$

$\Rightarrow$ **The amplitude of the "signal" is underestimated by a factor $\Delta E/\sigma > 5$.**

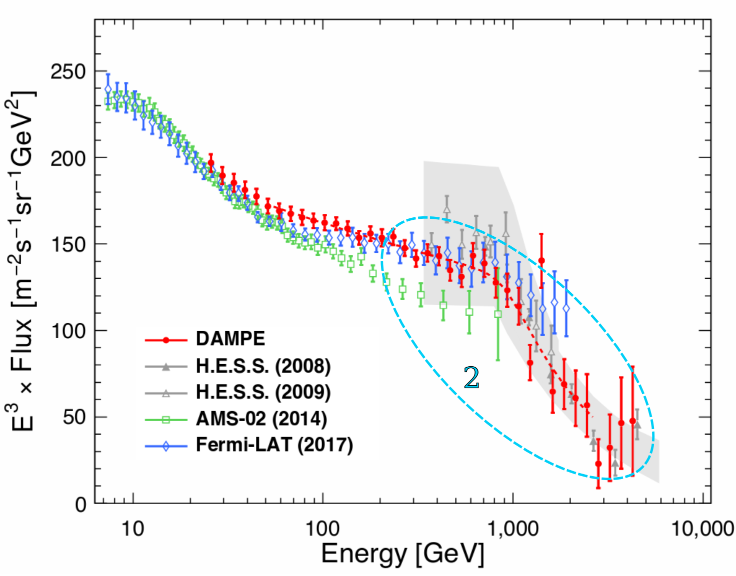
What do we expect ?

Features in DAMPE leptonic flux

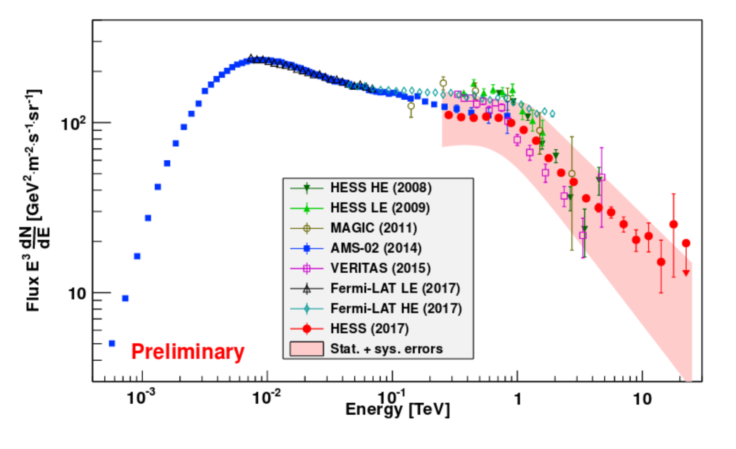
Explanation for the $(e^+ + e^-)$ knee

Hypotheses around the DAMPE peak

Explanation for the $(e^+ + e^-)$ knee



Explanation for the $(e^+ + e^-)$ knee



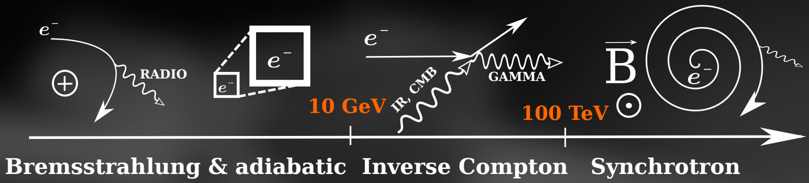
D.

Kerszberg ICRC 2017

Also confirmed by HESS preliminary results !

Explanation for the $(e^+ + e^-)$ knee

Electrons and positrons are very sensitive to the energy losses $b(E) = \frac{dE}{dt}$:



- Typical time of electrons energy losses at 1 TeV :

$$\tau_{loss} = E / \frac{dE}{dt} \sim 10^5 \text{ yr}$$

- Typical diffusion length :

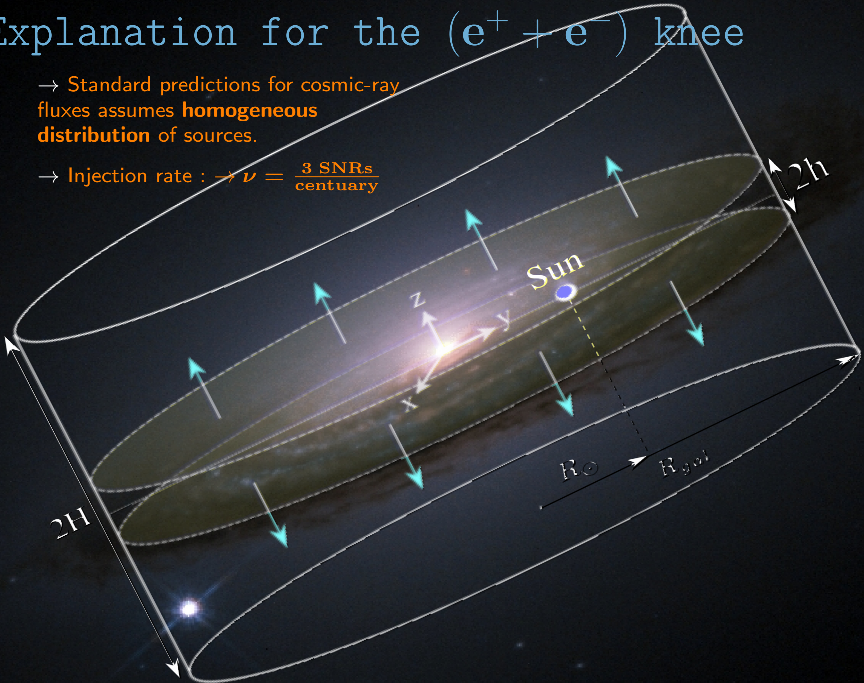
$$r_{diff} \sim \sqrt{D(E)\, \tau_{loss}} \sim 300\text{pc!}$$

Explanation for the $(\mathbf{e}^+ + \mathbf{e}^-)$ knee

Explanation for the $(e^+ + e^-)$ knee

→ Standard predictions for cosmic-ray fluxes assumes **homogeneous distribution** of sources.

→ Injection rate : → $\nu = \frac{3\ \mathrm{SNRs}}{\mathrm{centuary}}$



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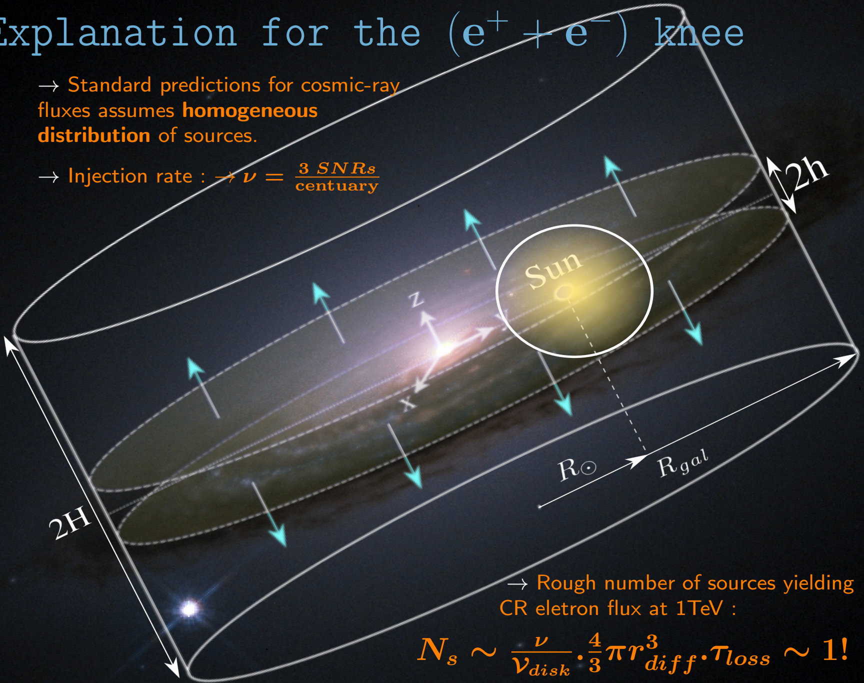
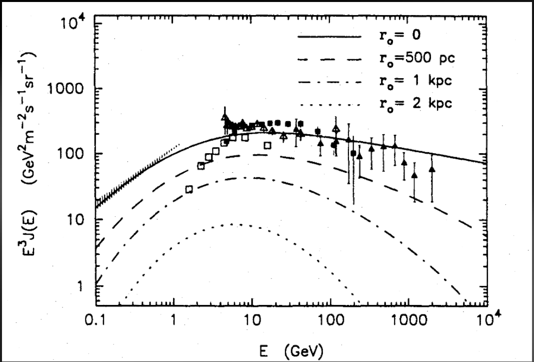


→ Rough number of sources yielding CR eletron flux at 1TeV :

$$N_s \sim \frac{\nu}{\mathcal{V}_{disk}} \cdot \frac{4}{3} \pi r^3_{diff} \cdot \tau_{loss} \sim 1!$$

Explanation for the $(e^+ + e^-)$ knee

Standard prediction of the electron flux **excavating a region of sources** of radius $\mathbf{r_0}$.



Aharonian et al. (1995) 294

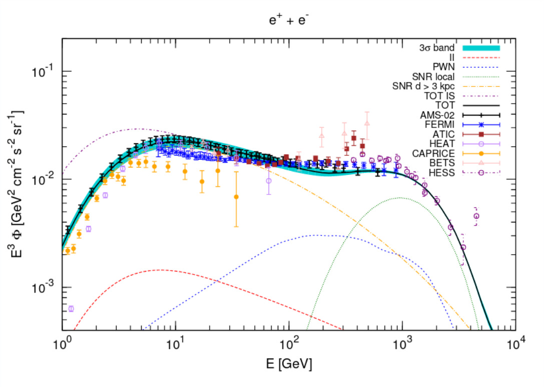
→ 90% of the TeV flux comes from region $r < r_0 = 1$kpc

→ No close sources already implies a break in the flux.

Explanation for the $(e^+ + e^-)$ knee

Two components model :

$$\Phi = \Phi_{loc} + \Phi_{far}$$



Di Mauro et al. (2014) JCAP

Φ_{far} :Continuous approximation above r_0.

Φ_{loc} :based on catalogs (i.e *Green (2009) BASI 37* or *ATNF catalog*)

Are the catalogs complete ?

→ Statistical point of view.

Mertsch, P., (2011) JCAP

Explanation for the $(e^+ + e^-)$ knee

What could we learn from a precise measurement of the $(e^+ + e^-)$ break ?

- Shape of the beak is related to the sources ages or their energy cut-off..
  .. which sources are actually contributing to the flux ?
- The information of the break has to be combined with other observables in order to constrain sources properties $\rightarrow$ multimessenger approach is needed.
- Anisotropy constraints of $(e^+ + e^-)$ by Fermi already exclude some models. (see i.e *Manconi et al. preprint 1803.01009*)

What do we expect ?

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Explanation for the $(e^+ + e^-)$ knee

Hypotheses around the DAMPE peak

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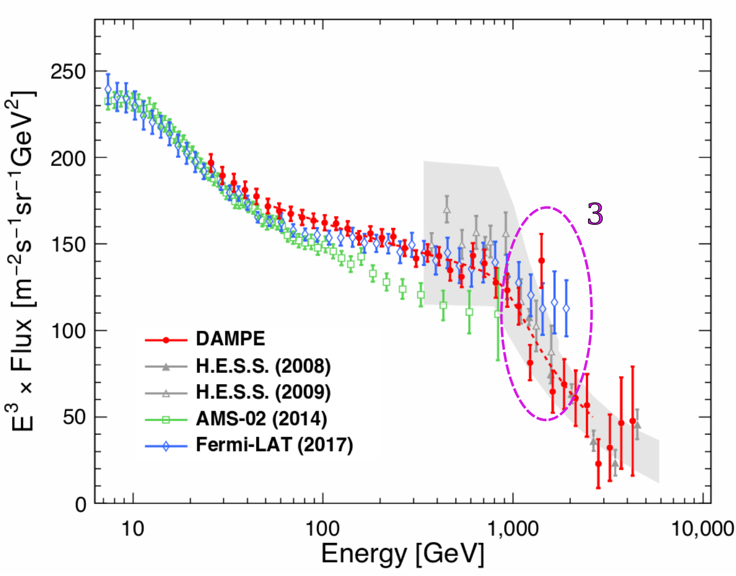
WARNING : Not that significant !

Hypotheses around the DAMPE peak



Hypotheses around the DAMPE peak

The peaked shape of the signal requires :

1-Monochromatic injection of e^- and or e^+

2-Local production unsensitive to energy losses

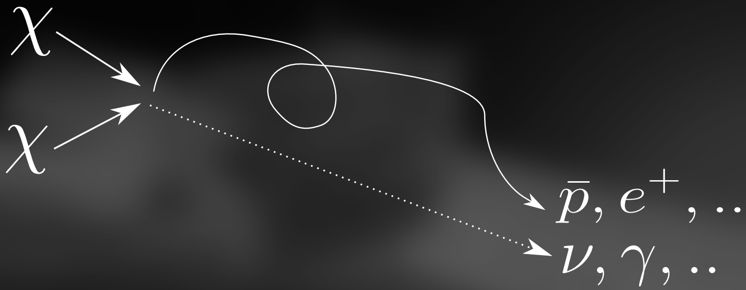
$$\tau_{\rm diff}(1.5\ {\rm TeV}) < \tau_{\rm loss} \sim 100{\rm kyr}$$

$$r < r_{diff} \sim 300\ {\rm pc}$$

$\Rightarrow$ As for the positron excess the two preferred options stem from DM annihilation/decay or pulsars...but this time with more restrictions.

Hypotheses around the DAMPE peak

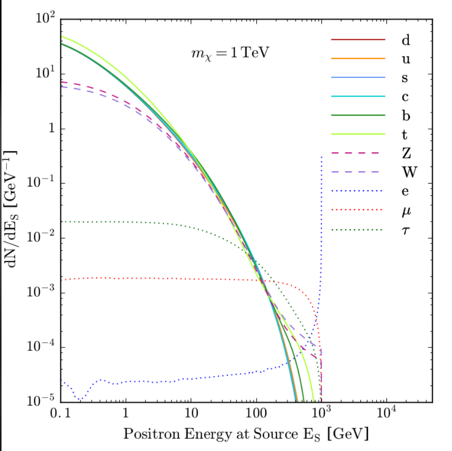
DARK MATTER explanation :



Mainly leptophilic dark matter is invoked !

Hypotheses around the DAMPE peak

DARK MATTER has to annihilate mainly in $e^+ + e^-$:



PhD, Boudaud M. (2016)

Hypotheses around the DAMPE peak

DARK MATTER model building papers :

- **SM $\times$ U(1)**, ranked by mediator :

  Scalar [1711.11058], [1711.11012]

  Z prime : [1711.11452], [1712.01244], [1711.11182], [1711.11563],
  . [1712.01239], [1711.10995], [1712.00941]

  Generic vector gauge boson : [1711.11579], [1711.11333], [1711.11012]

  Dark photon : [1711.11000]

- **SM $\times Z_2$:** [1712.02021], [1712.00869], [1712.02381], [1712.00037]
- **SM $\times$ SU(2) :** [1712.00793]
- **SM + 1D :** [1712.01143]

Papers which do not specify particle physics model :

[1711.11376], [1711.10989], [1712.00005], [1712.00362], [1712.00370], [1711.11052], [1712.00372], [1712.01724]

Common ingredient ?

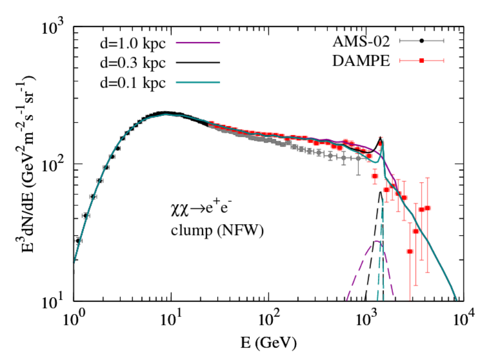
Hypotheses around the DAMPE peak

Spiky shape $+$ Amplitude of the signal

Local production   Large dark matter density

$=$

Local overdensity of dark matter



Yuan, Qiang, et al. arXiv:1711.10989, 2017.

Typical DM fit :

$$m_\chi \sim \mathbf{1.5\ TeV}$$

Fixing $\langle \sigma v \rangle = 3.10^{-26} \mathrm{cm}^3.\mathrm{s}^{-1}$ **and the DM overdensity size** λ **:**

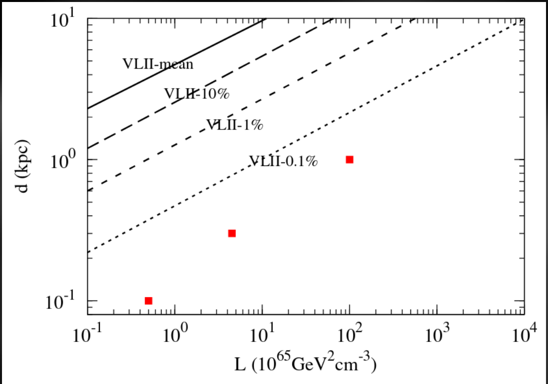
$$\lambda \sim 10 \text{ pc} \rightarrow \frac{\rho_{loc}}{\rho_0} \sim \mathbf{1000}$$

$$\lambda \sim 100 \text{ pc} \rightarrow \frac{\rho_{loc}}{\rho_0} \sim [\mathbf{17 - 35}]$$

Are these local overdensities acceptable ?

Hypotheses around the DAMPE peak

Probability to find a DM clump accounting for the required the luminosity ?



Brun, P. et al (2009). PRD, 80(3) and Yuan, Qiang, et al. arXiv:1711.10989, 2017.

For $\lambda \sim 10$ pc :

From N body simulations (Via Lactea II), probability of a clump

$$p < 10^{-3}$$

For $\lambda \sim 100$ pc :

According to *Yuan et al. arXiv:1711.10989,* **following** *Kamionkowski, (2010). PRD, 81(4)* **a DM overdensity of 100 pc would correspond to a deviation of 15 σ.**

Hypotheses around the DAMPE peak

Is dark matter explanation doomed ?

- Peculiar particle physics models like **Sommerfeld enhancement** mechanism / **Breit-Wigner type resonance** of the annihilation interaction imply lower densities and so higher probabilities of fluctuations.
- Minispike DM clump *Zhao, H. and Silk, J., (2005) PRL*
- Ultracompact micro halo *Yang, F.et al preprint arXiv:1712.01724./ T. Bringmann et al PRD (2012)*

$\Rightarrow$ Do these models evade stringent constraints from gammas and radio observation ?

Hypotheses around the DAMPE peak

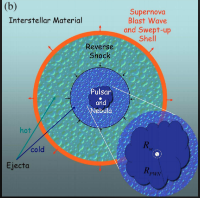
Pulsar explanation :

- **Local** and **young** pulsar is required :

J2000	Other name	Distance [kpc]	Spin-down age [kyr]	Spin-down energy [10^{49} erg]	Rank @ 5/100/1000 GeV	Known SNR counterpart
J0633+1746	Geminga	0.16	342	1.25	1/2/4	
J1932+1059	B1929+10	0.36	3100	11.9	2/–/–	
J1908+0734		0.58	4080	17.9	3/–/–	
J1741-2054		0.25	387	0.47	4/5/–	
J0953+0755	B0950+08	0.26	17 500	54.2	5/–/–	
J2043+2740		1.13	1200	25.9	–/1/–	
J1057-5226	B1055-52	0.72	535	2.8	–/3/–	
J0659+1414	B0656+14	0.29	111	0.18	–/4/2	Monogem
J0835-4510	B0833-45	0.29	11.3	0.99	–/–/1	Vela
J1740+1000		1.24	114	1.1	–/–/3	
J0742-2822	B0740-28	1.89	157	1.23	–/–/5	
J1549-4848		1.54	324	0.8	–/–/6	

ATNF catalog from Delahaye, T. et al, A&A, 524, A51.

- **Monochromatic injection :**



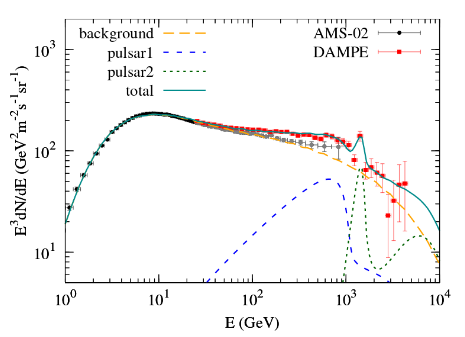
Bryan M. et al ARAA,

Astrophysics *fine tuning* :

The cold wind of unshocked relativistic electron could produced such peaked spectrum. *Kennel, C. F. and Coroniti, F. V. (1984)* or *Bogovalov, S. and Aharonian, F. (2000). MNRAS*

→ Naked pulsar : no influence from the related SNR.

Hypotheses around the DAMPE peak



	d (kpc)	L_0 (erg s^{-1})	$t_{\rm age}$ (kyr)	$\tau_{\rm dec}$ (kyr)	α	$E_{\max}$ (Θ) (TeV)
pulsar 1	0.25	5.3×10^{37}	260	3.0	1.7	3.0
pulsar 2	0.25	0.9×10^{37}	180	3.0	−2.0	2.0

Typical fit with two pulsars from *Yuan, Qiang, et al. arXiv:1711.10989, 2017.*

Source term $\mathcal{Q}(E,t) = \mathcal{Q}_E(E)\mathcal{Q}_t(t)$

1-Time dependent model :

$$\mathcal{Q}_t(t) = \frac{\mathcal{Q}_0}{(1+\tau/\tau_{\rm dec})^2}, \quad \tau_{\rm dec} \sim 3\text{kyr}$$

2-Lepton injection spectrum :

$$\mathcal{Q}_E^{p1}(E) = E^{-\alpha}\ \exp(E/\Theta)$$

$$\mathcal{Q}_E^{p2}(E) = E^{\alpha}\exp(-E/\Theta)$$

→ **Geminga** or **Monogem** good candidates for pulsar 2 ?
→ These values seems to evade the anisotropy constraints on the lepton flux from Fermi *S.Abdollahi, PRD 95 (2017)*.

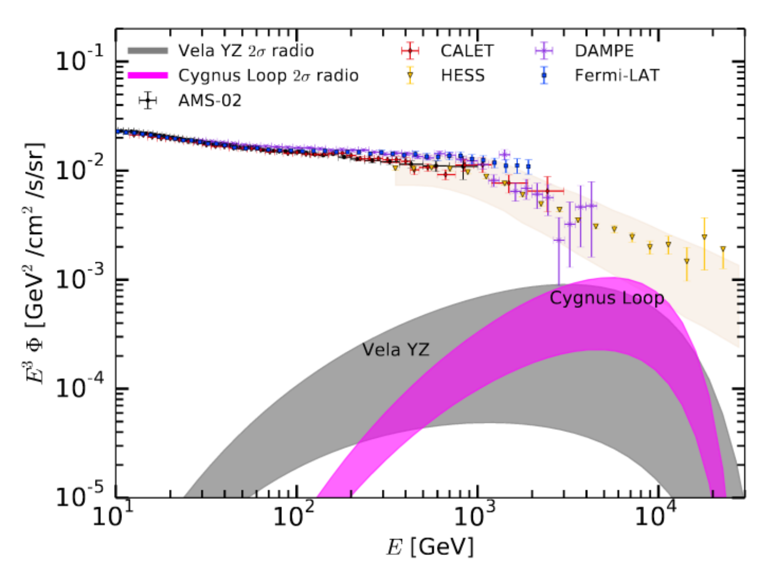
Conclusion

What do we learn from DAMPE data ?

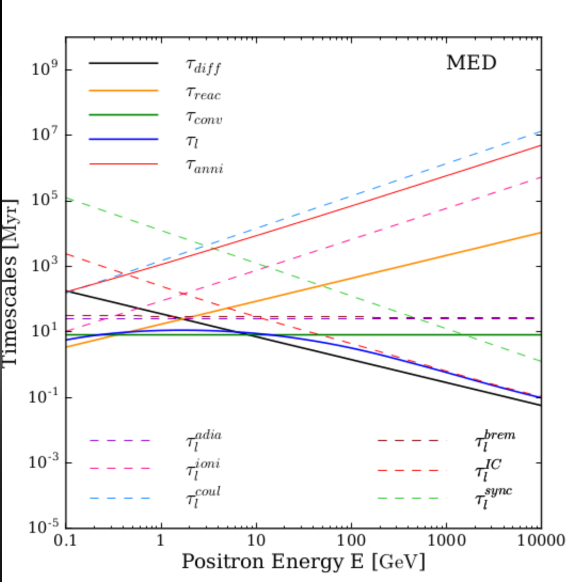
- First direct measurement of the $(e^+ + e^-)$ knee, expected from the sensitivity of $(e^+ + e^-)$ flux to the local environnement.
- Normalisation and line-like signal have to be confirmed.
- "Exotic" (DM) or "Astrophysical" (Pulsar) explanations imply fine-tuned physics which can only be probed by a multimessenger approach.

$\Rightarrow$ Looking forward next release from DAMPE and new measurements of $(e^+ + e^-)$ anisotropy.

BACKUP



Manconi et al. preprint 1803.01009



PhD, Boudaud M. (2016)