Cosmic Signals from the Hidden Sector

arxiv:0905.3749

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Dark Matter explanation of PAMELA, FERMI and HESS

- **Source of $e^+ e^-$**
  Broad spectum extending to ~few TeV
  No new source of $p\bar{p}$

- **DM: Annihilation vs. Decay**

– Boost Factor / non-thermal production
vs. 10^{26}s lifetime

– Constraints favour decay

e.g. Cirelli et.al. 0907.0719
Profumo & Jeltman 0906.0001
Meade et.al. 0905.0480
J.M., Y. Nomura, D. Stolarski & J. Thaler 0901.2926

A Framework for Dark Matter

- **Dark matter** is **composite** of new **strongly coupled sector** at ***O*(10 – 100 TeV)**
- **Protected by accidental symmetry** broken at high scale
- **Decay to pseudo– NGB** of spontaneously broken global symmetry

Very low scale dynamical SUSY breaking is a natural setting

PAMELA, FERMI, HESS and leptonic final states

- No new source of antiprotons + broad spectrum

⇒ **decay through new light state**

-extra step broadens spectrum

-kinematics prevents baryonic final states

e.g. Cholis et.al. 0802.2922
Arkani-Hamed et.al. 0810.0713
Nomura & Thaler 0810.5397

PAMELA, FERMI, HESS and the WIMP Paradigm

- $e^+ e^-$ excess up to ~few TeV

  $\Rightarrow$ $\boldsymbol{m_{DM} \sim 10\ \text{TeV}}$

- WIMP paradigm: fix $\frac{g_{DM}^4}{m_{DM}^2}$

  $g_{DM} \sim 1 \Rightarrow m_{DM} \sim$ EW scale

- thermal abundance $\Rightarrow$ $g_{DM} \sim \pi$

  $\Rightarrow$ **strongly coupled physics**

  composite dark matter

SUSY Cosmology and Dark Matter

- SUSY breaking $\longrightarrow$ massive gravitino

$$\left(m_{\frac{3}{2}} = \frac{F}{M_{\rm Pl}}\right)$$

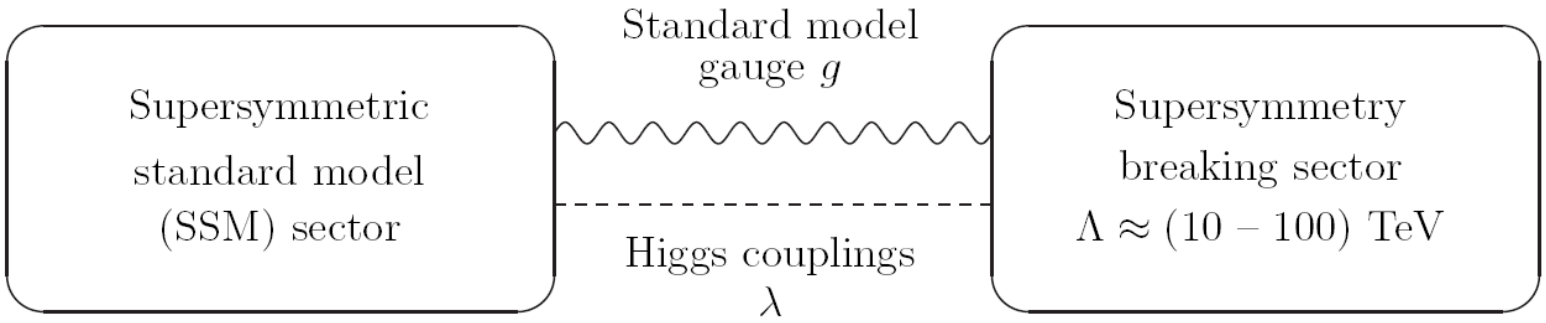
$\rightarrow$ **Cosmological problems**

-gravitino over-abundance

-late decays spoil BBN

- Problems disappear if $\boldsymbol{m_{\frac{3}{2}} \lesssim 10\ \text{eV} \Longleftrightarrow \sqrt{F} \lesssim 100\ \text{TeV}}$

SUSY Cosmology and Dark Matter



$$\Lambda \sim 10 - 100\,\mathrm{TeV}$$

$$m_{\tilde{q},\tilde{l}} \sim \frac{\alpha}{4\pi}\,\Lambda \sim 100\,\mathrm{GeV} - \mathrm{TeV}$$

$$m_{\frac{3}{2}} \sim \frac{\Lambda^2}{M_{\mathrm{Pl}}} \lesssim 10\,\mathrm{eV}$$

~**single scale theory**:
all scales generated by strong dynamics

SUSY Cosmology and Dark Matter

- Gravitino is LSP ... no neutralino DM!

- Dynamical SUSY breaking $\longrightarrow$ strong dynamics
  $\longrightarrow$ **stable states?**

Think of proton stability:

-elementary: $\mathcal{L} \subset$ ep $\longrightarrow$ immediate proton decay

-composite: $\mathcal{L} \subset$ LQQQ : non-ren.

$\longrightarrow$ accidental $U(1)_B \longrightarrow$ proton stable

- **Composite states can be naturally stable**

  lightest stable state is **DM candidate**

SUSY Cosmology and Dark Matter

- Dimension 6 proton decay: $\mathcal{L} \subset \frac{\mathrm{LQQQ}}{M_{\mathrm{GUT}}^2}$

$$\rightarrow \text{proton lifetime} \sim 8\pi \, \frac{(4\pi)^2 \, M_{\mathrm{GUT}}^4}{m_P^5} \sim 10^{40}\,\mathrm{s}$$

- **Symmetry protecting DM broken at high scale by dim 6 operator**

$$\Longrightarrow \text{DM lifetime} \sim 8\pi \, \frac{(4\pi)^2 \left(10^{17}\,\mathrm{GeV}\right)^4}{(10\,\mathrm{TeV})^5} \sim \mathbf{10^{26}\,s}$$

e.g. Nardi et.al. 0811.4153
Dimopoulos et.al. 0812.2075

- **10 TeV composite DM** with **lifetime ~ 10^{26} s**

can appear *naturally* from

***O*(10 – 100 TeV) dynamical SUSY breaking sector**

Light Axion-like States

DM decay through light states?

- **Spontaneously break global $U(1)$** in strong sector
  → massless NGB ("axion")

- **Small explicit breaking**
  → small mass

- E.g. $U(1)_R$ + supergravity $\longrightarrow m_{\text{axion}} \sim O(1 - 100)\,\text{MeV}$

  or $U(1)_{\text{PQ}}$ broken by dim 5 operator at $\sim 10^9\,\text{GeV} - M_{\text{Pl}}$
  $\longrightarrow m_{\text{axion}} \sim \text{Mev} - 10\,\text{GeV}$

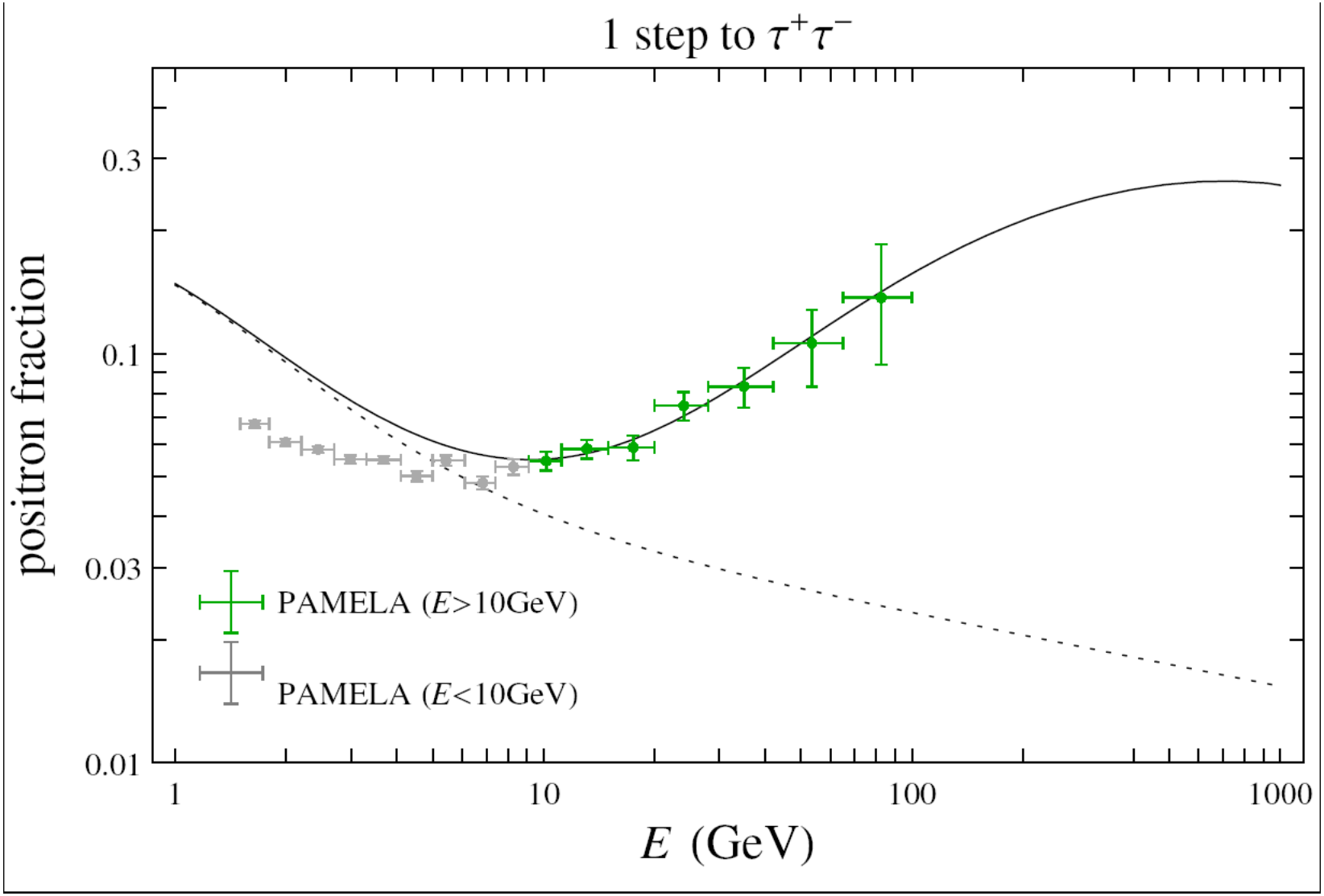
Light Axion-like States

- Higgs charged under $U(1)$
  $\Longrightarrow$ axion mixes with Higgs

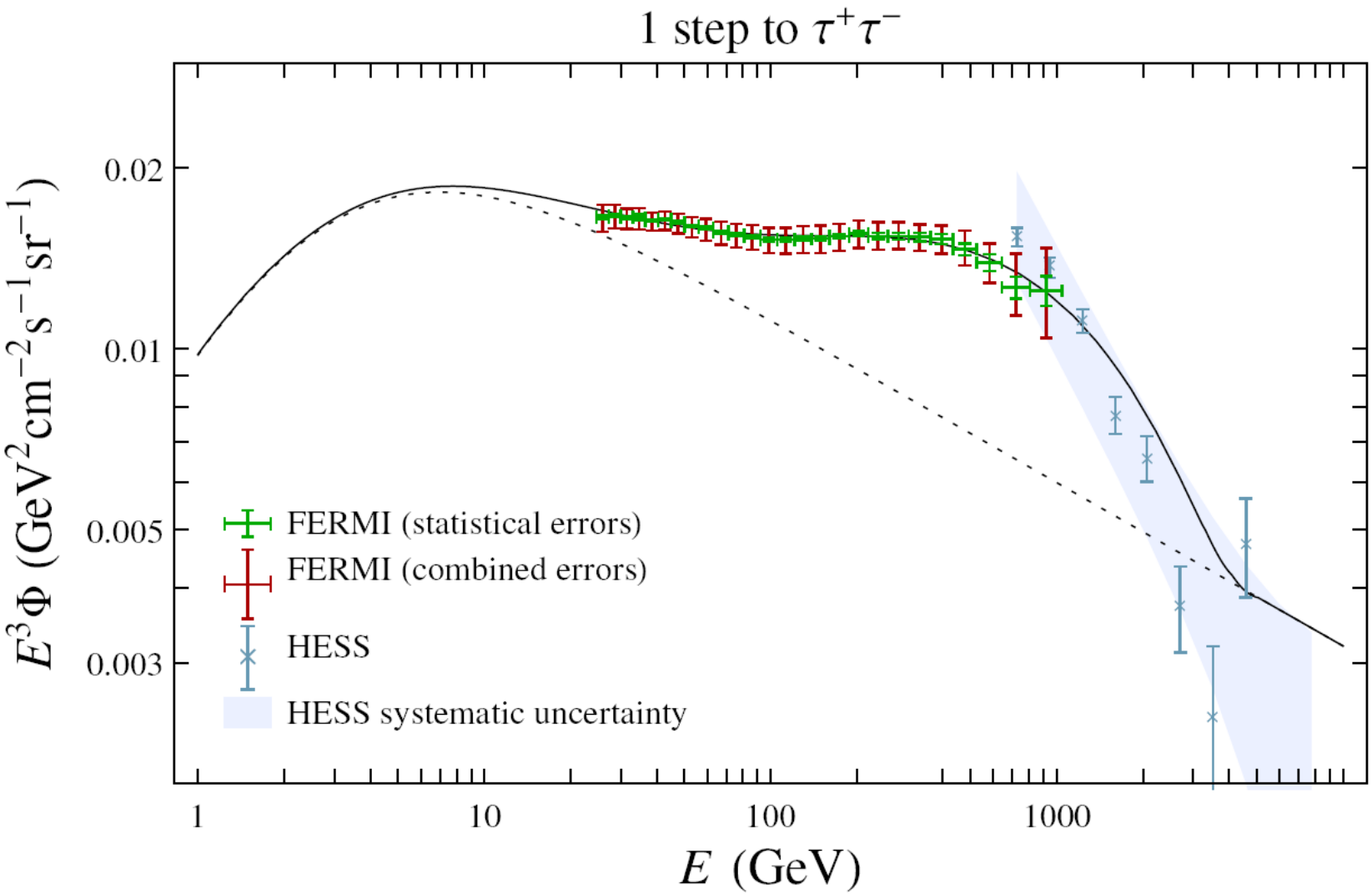
- Axion decays to ~heaviest allowed state

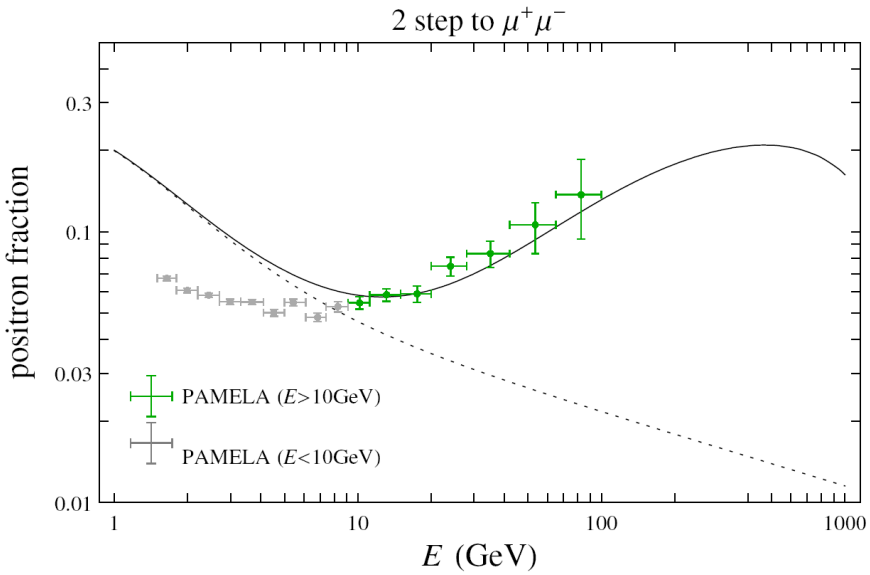
axion mass :	$2\,m_e - 2\,m_\mu$	$2\,m_\mu - 800\ \mathrm{MeV}$	$800\ \mathrm{MeV} - 2\,m_P$	$2\,m_\tau - 2\,m_b$
decay channel :	$\boldsymbol{e^+\,e^-}$	$\boldsymbol{\mu^+\,\mu^-}$	$\rho^*\,\pi^0 \to \boldsymbol{\pi^+\,\pi^-\,\pi^0}$	$\boldsymbol{\tau^+\,\tau^-}$

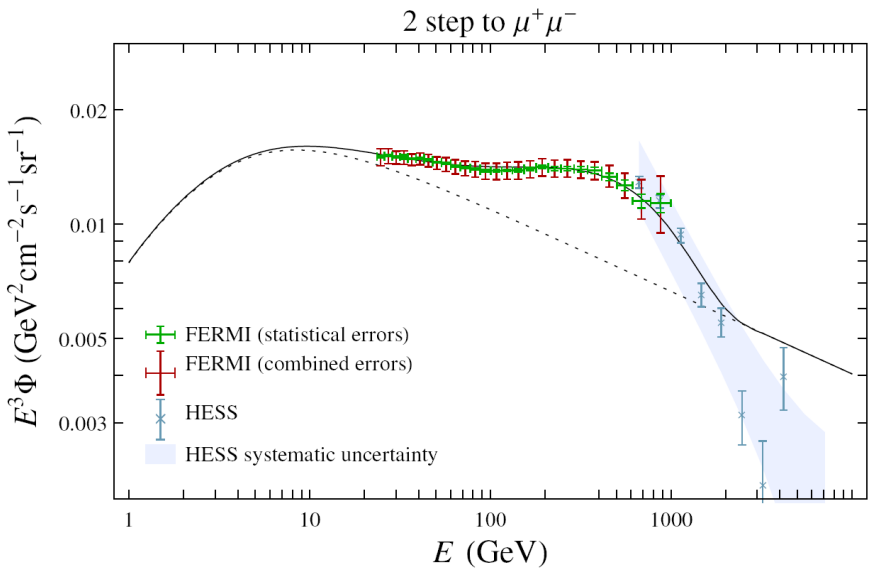
Comparison with PAMELA

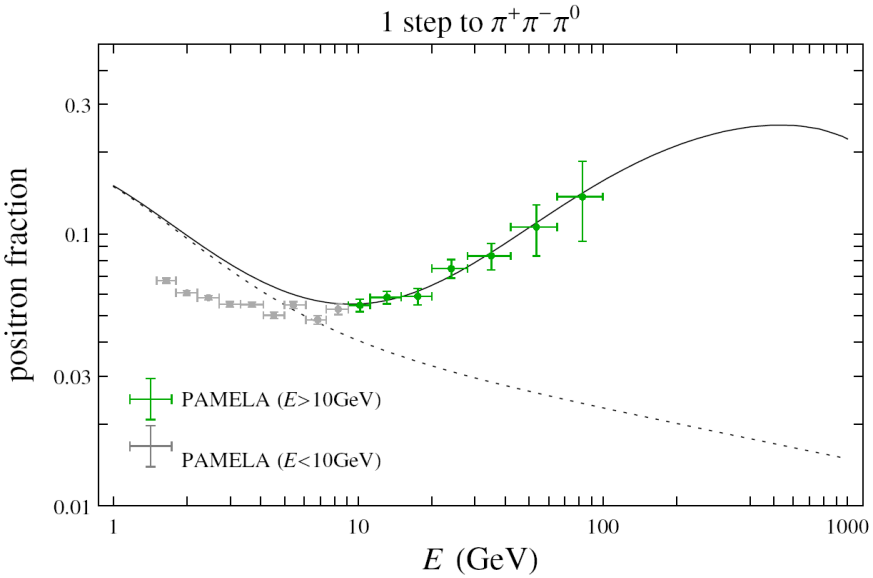


Comparison with FERMI and HESS




2 step to $\mu^+\mu^-$
positron fraction
0.3
0.1
0.03
0.01
1
10
100
1000
E (GeV)
PAMELA (E>10GeV)
PAMELA (E<10GeV)


2 step to $\mu^+\mu^-$
$E^3\Phi$ (GeV^{2}cm^{-2}s^{-1}sr^{-1})
0.02
0.01
0.005
0.003
1
10
100
1000
E (GeV)
FERMI (statistical errors)
FERMI (combined errors)
HESS
HESS systematic uncertainty


1 step to $\pi^+\pi^-\pi^0$
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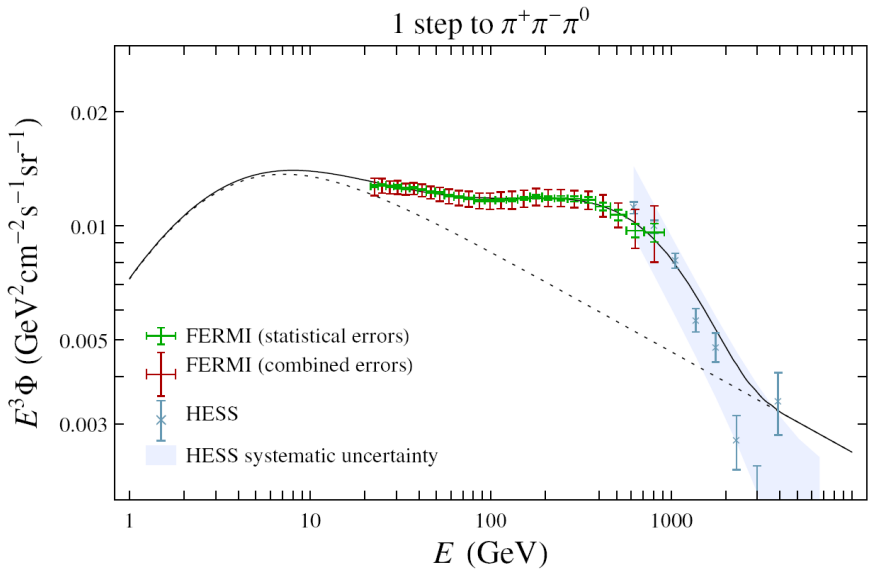
E (GeV)
PAMELA (E>10GeV)
PAMELA (E<10GeV)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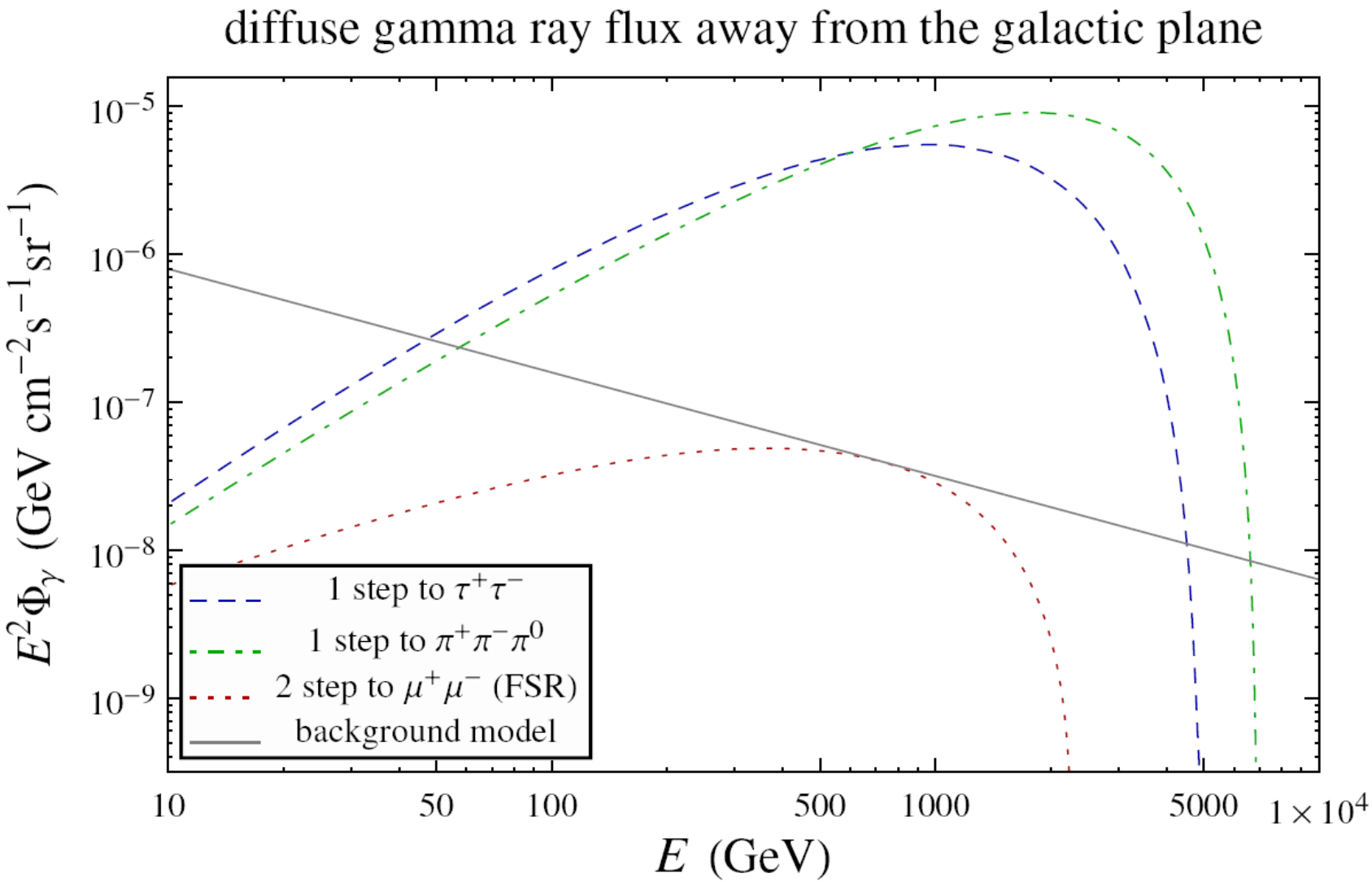
HESS systematic uncertainty

Implications: γ -ray signals?



Implications: collider signals?

- Direct axion production from gluons?
  $\longrightarrow \mu^+ \mu^-$ + displaced vertex

- Higgs decay to axions?
  axion $\longrightarrow \mu^+ \mu^-$

Goh & Ibe 0810.5773
Nomura & Thaler 0810.5397
Lisanti & Wacker 0903.0363

Summary

- **Cosmic ray data ⟶ decaying DM**

↓

- **$m_{\mathrm{DM}} \sim 10$ TeV ⟶ composite DM**

↓

- **natural stability due to accidental symmetry**

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- **symmetry violation at high scale ⟶ decay**

+

- **decay to pseudo NGB ⟶ leptonic final states**

Conclusion

natural in context of dynamical SUSY breaking

excellent fit to data

future astrophysical/collider signatures?