6 August 2015
ICRC 2015 - The Hague

Dark Matter phenomena
(rapporteur talk)

Marco Cirelli

(CNRS IPhT Saclay)

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Introduction

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DM exists

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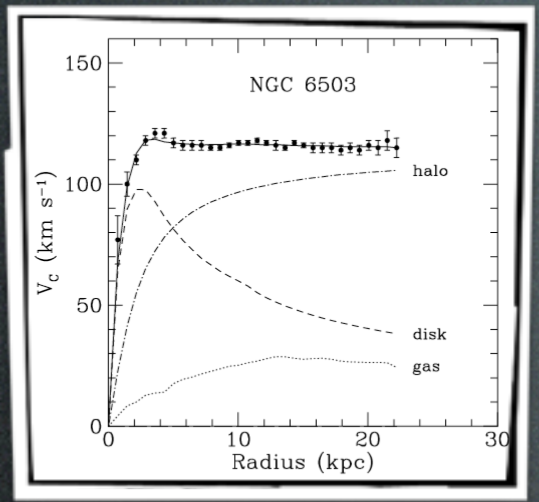
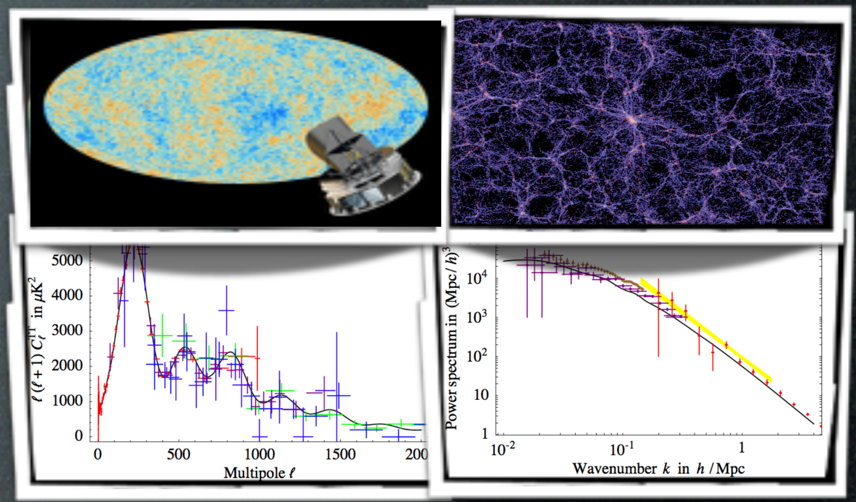


galactic rotation curves

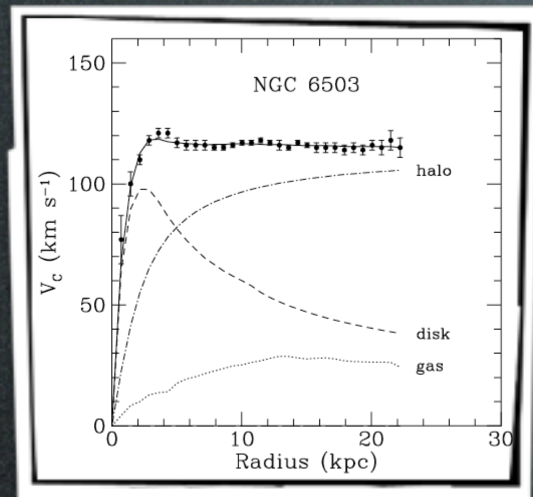
weak lensing (e.g. in clusters)



‘precision cosmology’ (CMB, LSS)

Introduction

DM exists



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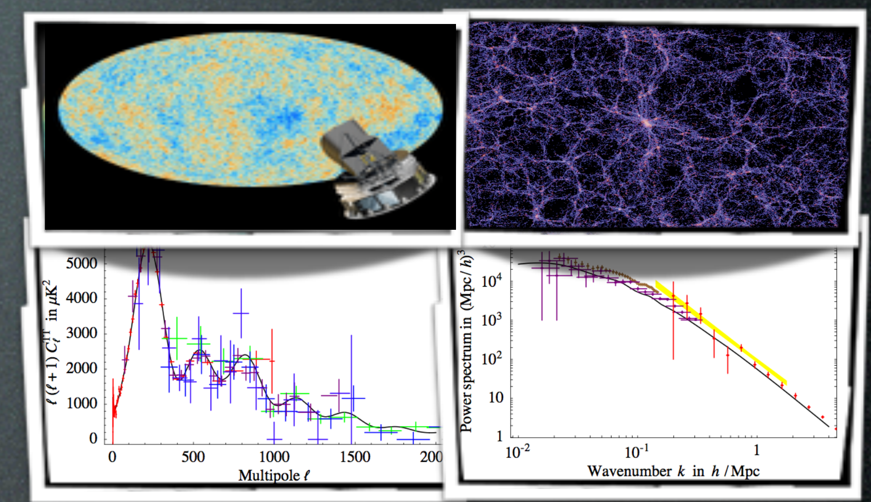
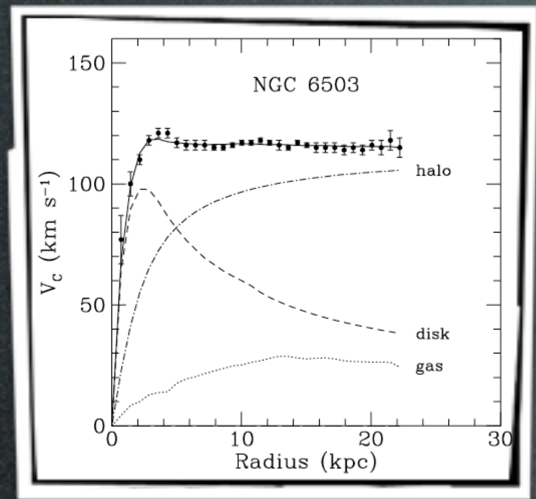


'precision cosmology' (CMB, LSS)

DM is a neutral, very long lived, feebly- interacting corpuscle.

Introduction

DM exists



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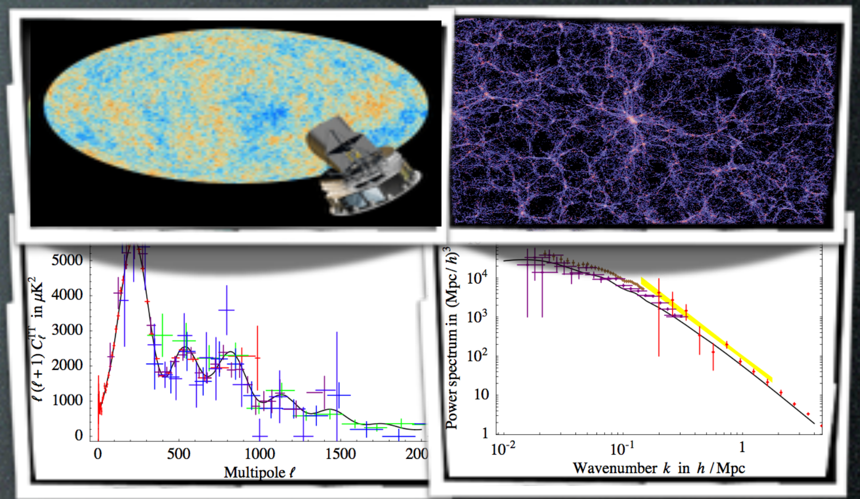
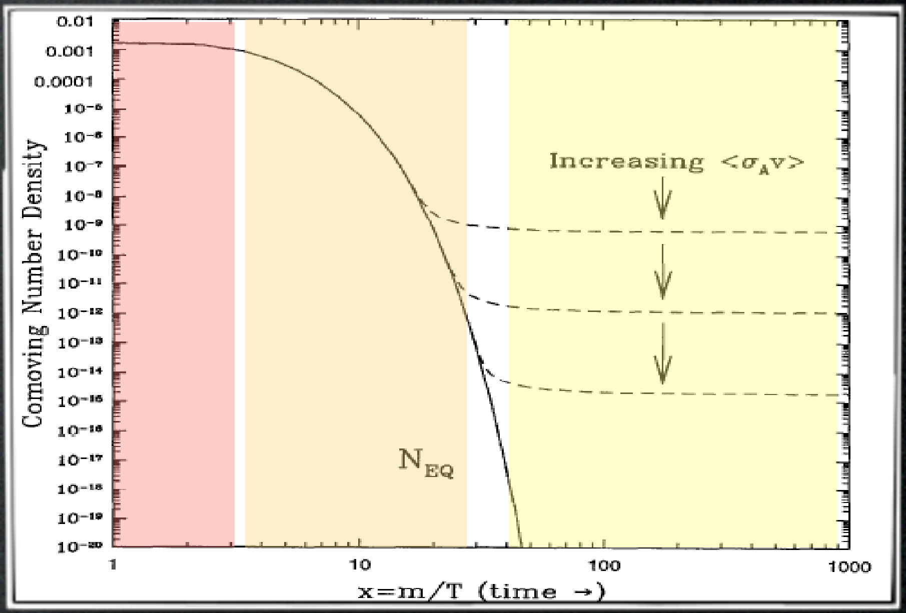


'precision cosmology' (CMB, LSS)

DM is a neutral, very long lived, weakly interacting particle.

see e.g. T. Tait's talk - ICRC2015



Some of us believe in the WIMP miracle.

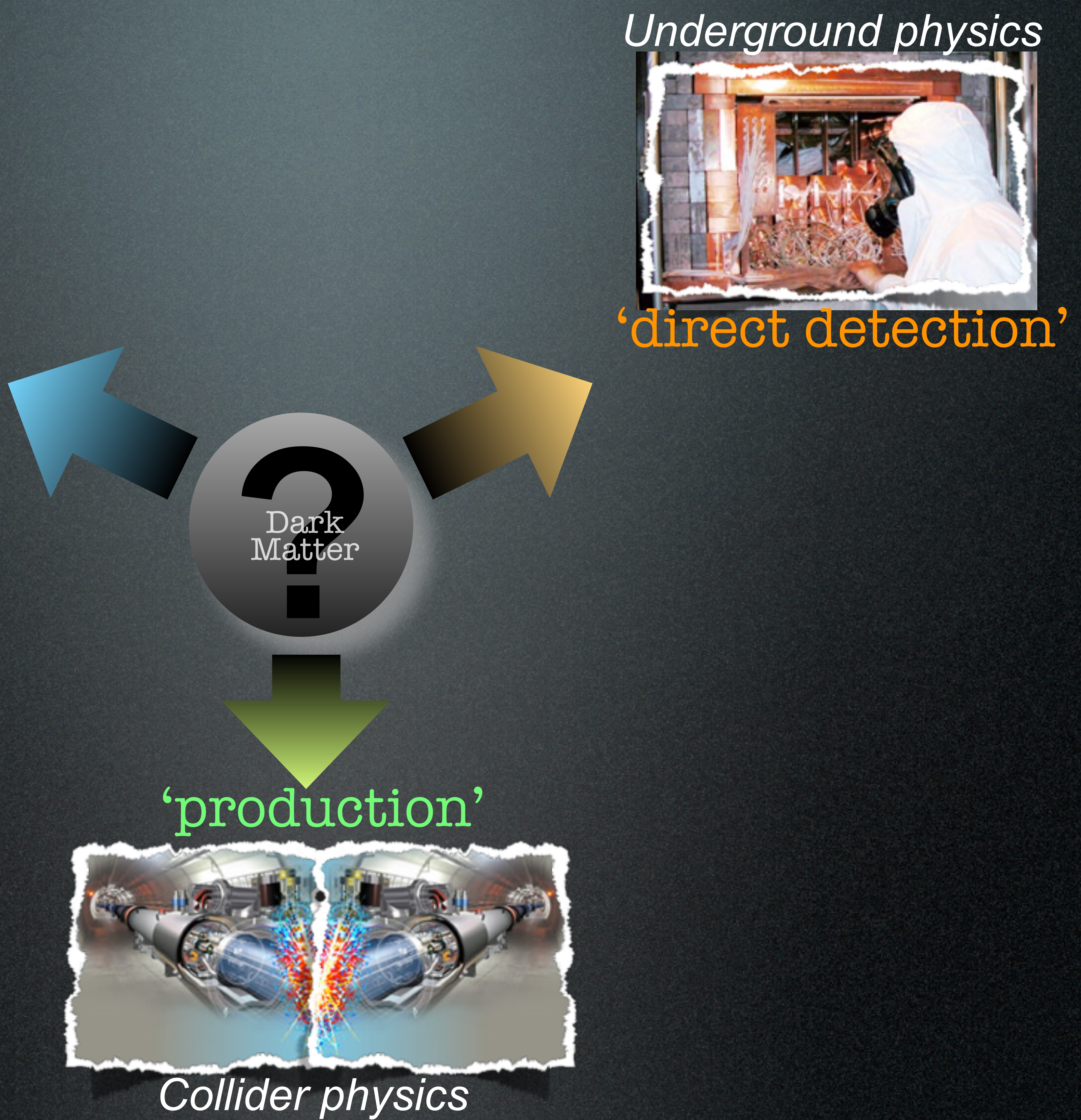
- *weak*-scale mass (10 GeV - 1 TeV)
- *weak* interactions $\sigma v = 3 \cdot 10^{-26} \text{cm}^3/\text{sec}$
- give automatically correct abundance

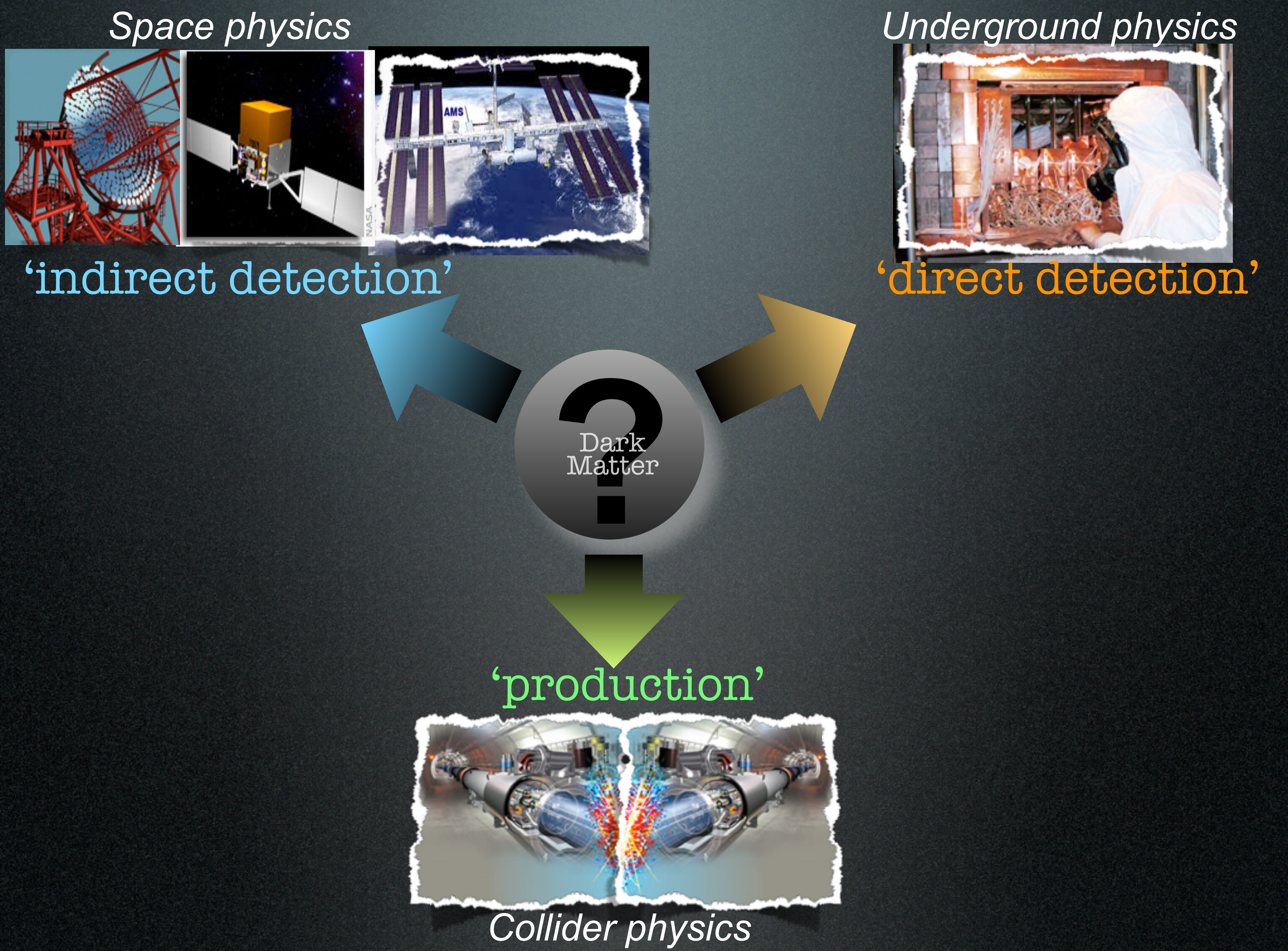

Dark
Matter


Dark
Matter

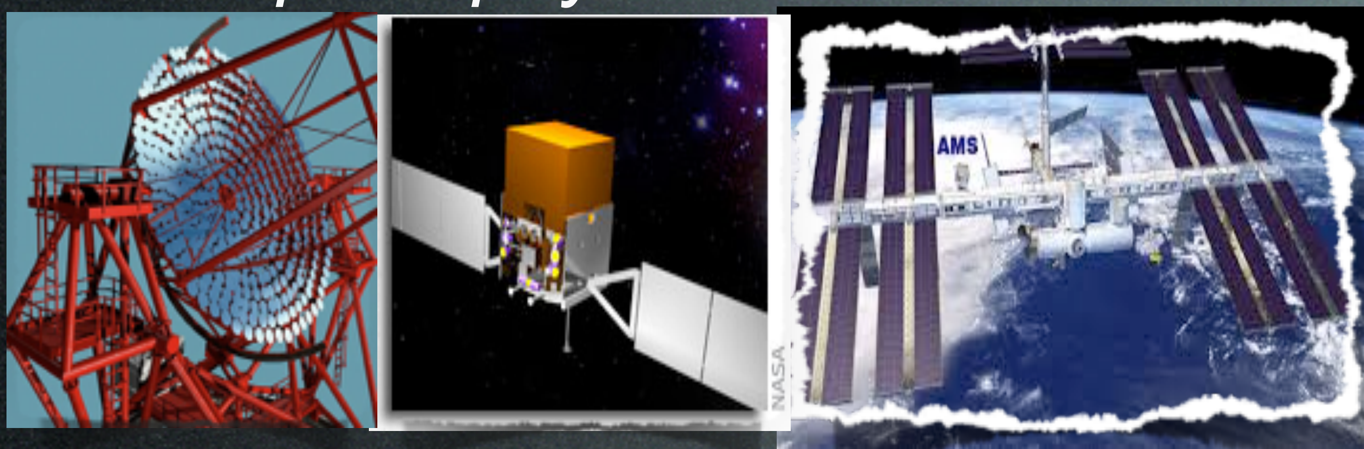
Underground physics

‘direct detection’


Underground physics
'direct detection'
Dark
Matter
'production'
Collider physics


Space physics
AMS
Underground physics
'indirect detection'
'direct detection'
Dark Matter
'production'
Collider physics

Space physics

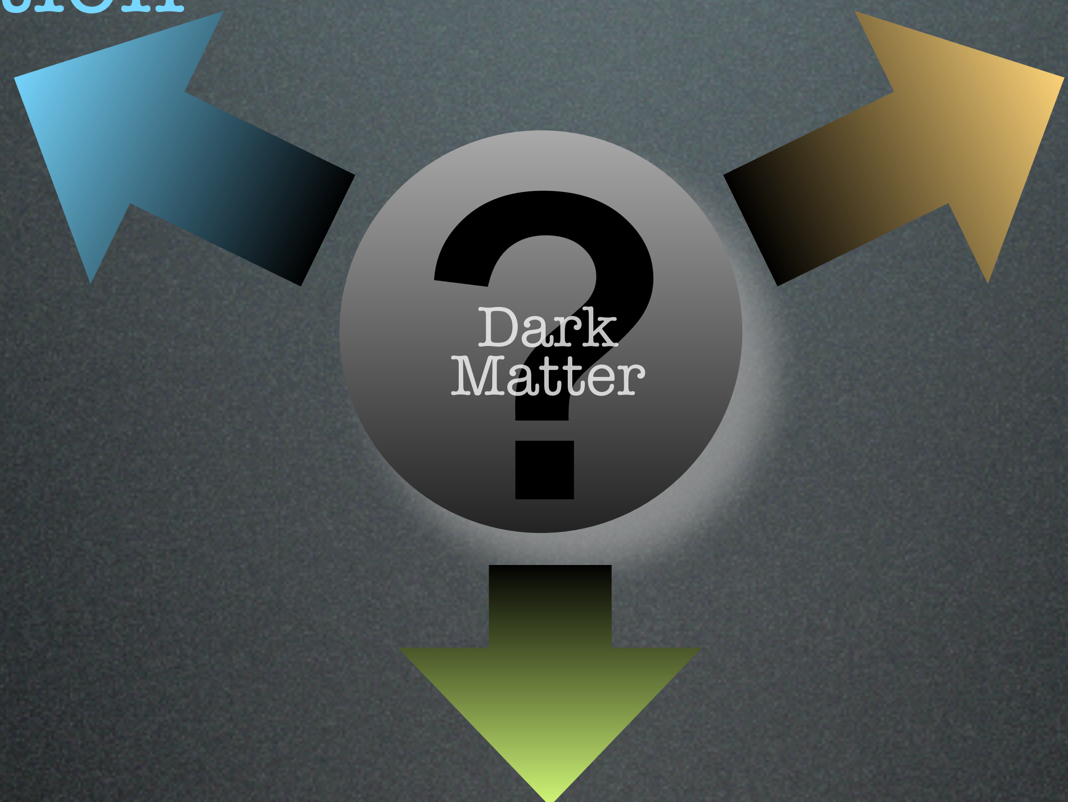


Underground physics

‘indirect detection’

$\gamma \; e^{+} \; \bar{p} \; \bar{d} \; \nu, \bar{\nu}$

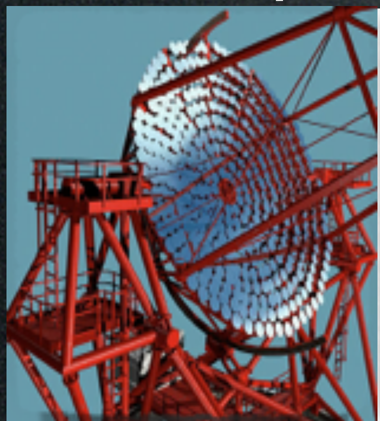
‘direct detection’

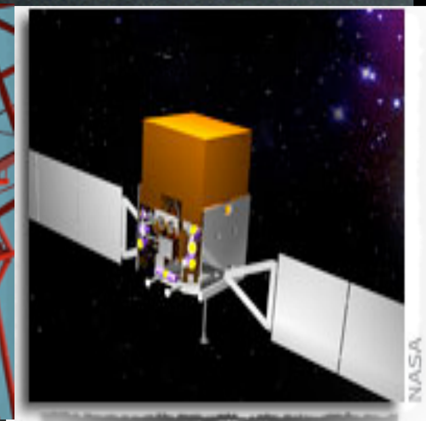


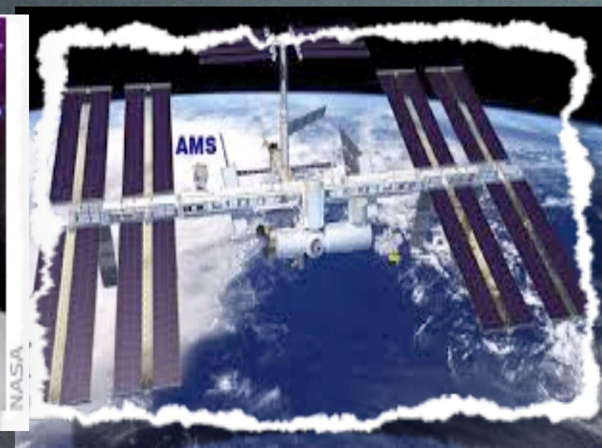
‘production’

Collider physics

Space physics







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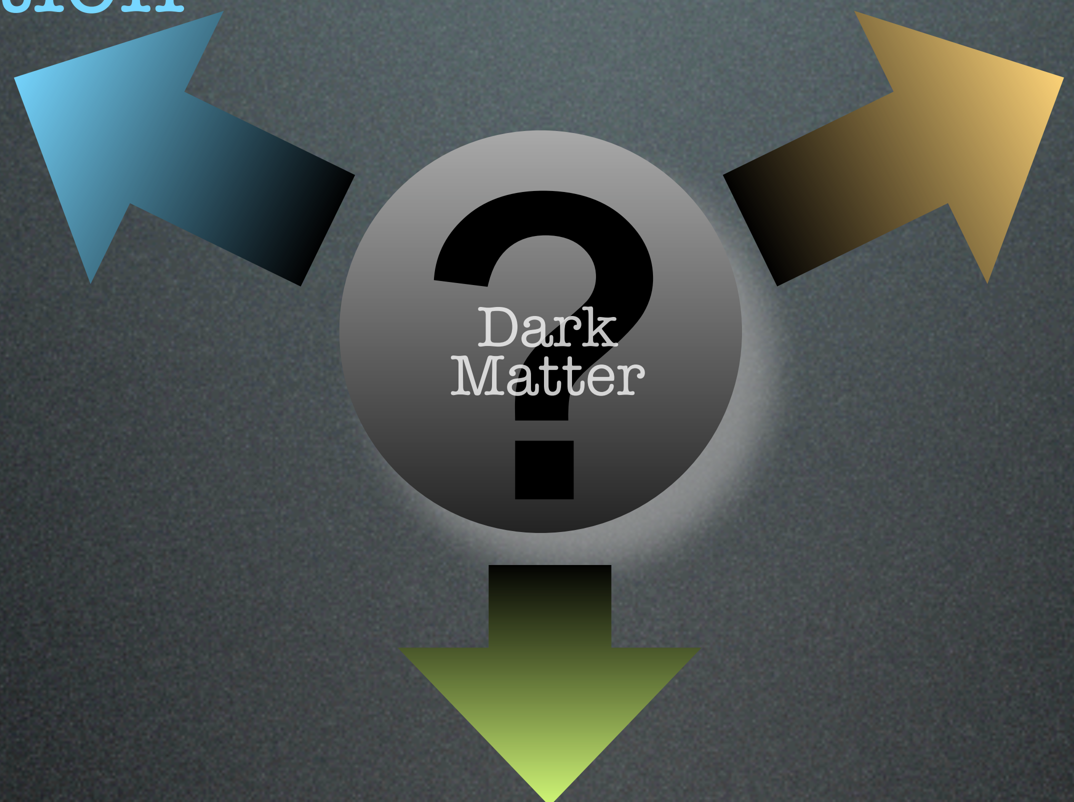
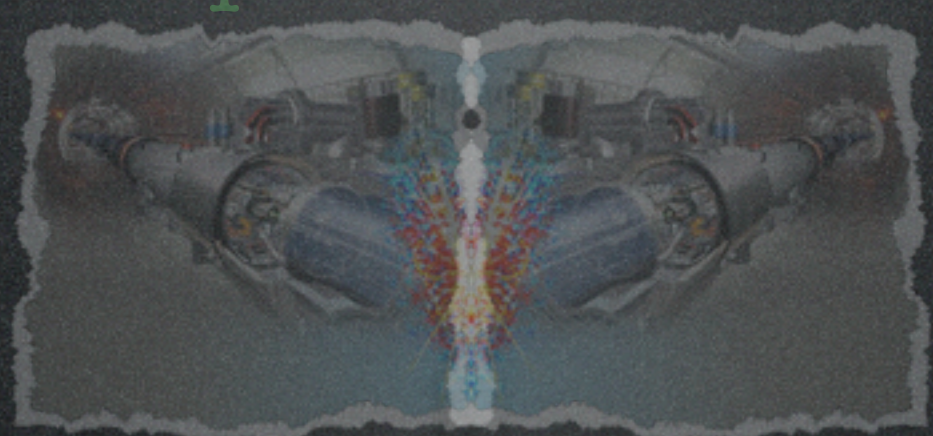


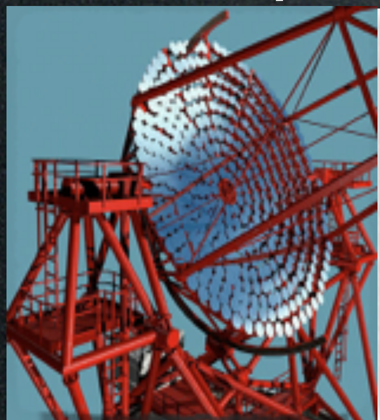
‘production’

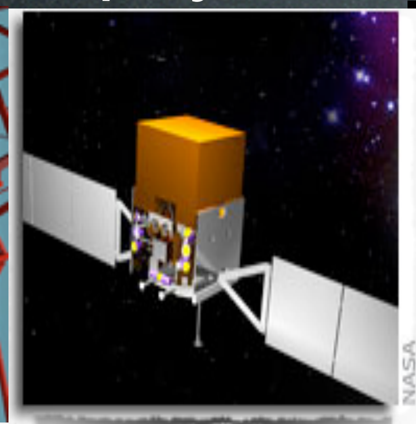


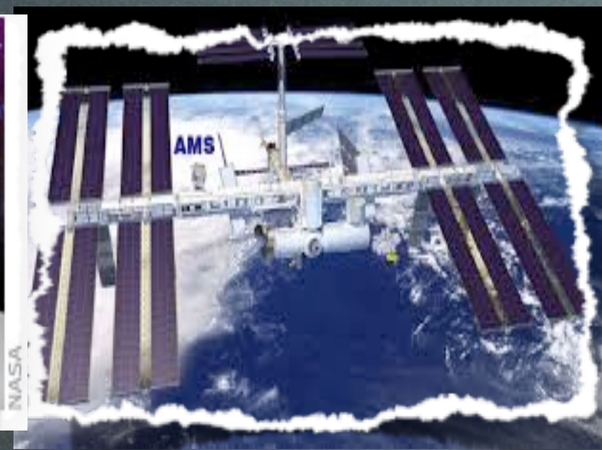
Collider physics

see T. Tait’s talk
ICRC2015

Space physics







Underground physics

‘indirect detection’

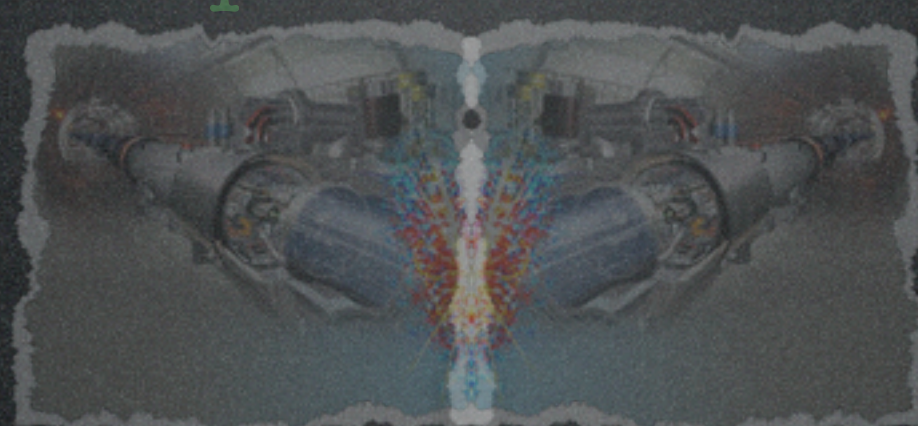
γ e^+ $\bar{p}$ $\bar{d}$ $\nu, \bar{\nu}$

ICRC
The Astroparticle Physics Conference
34th International Cosmic Ray Conference
July 30 - August 6, 2015
The Hague, The Netherlands

‘direct detection’

Dark Matter

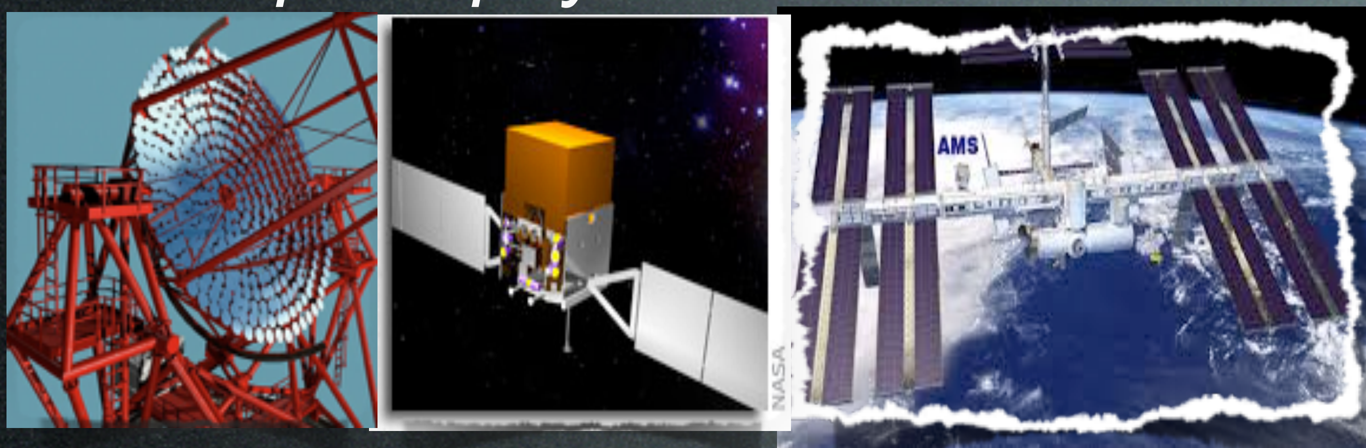
‘production’



Collider physics

see T. Tait’s talk
ICRC2015

Space physics



Underground physics

‘indirect detection’

$\gamma\ e^+\ \bar{p}\ \bar{d}\ \nu, \bar{\nu}$

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‘direct detection’

~~ICRC~~
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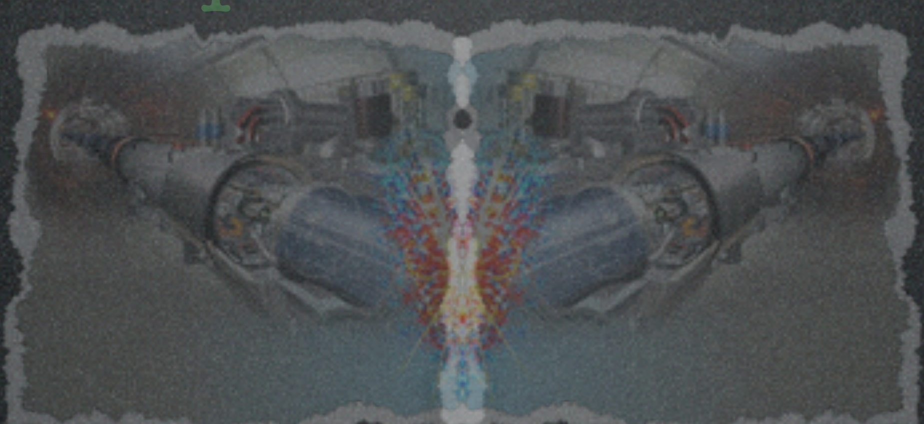
Dark Matter

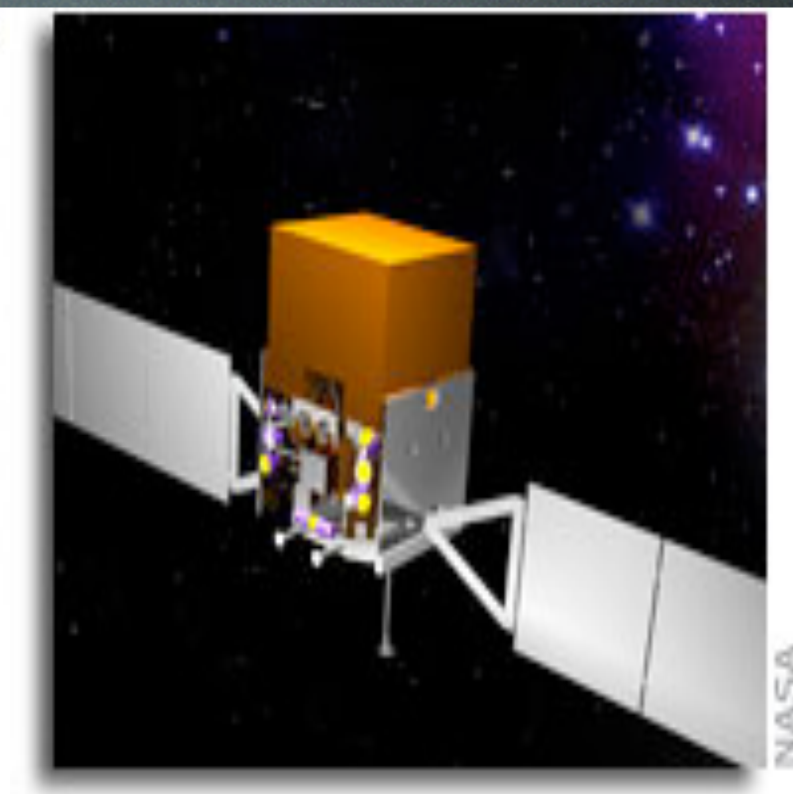
‘production’

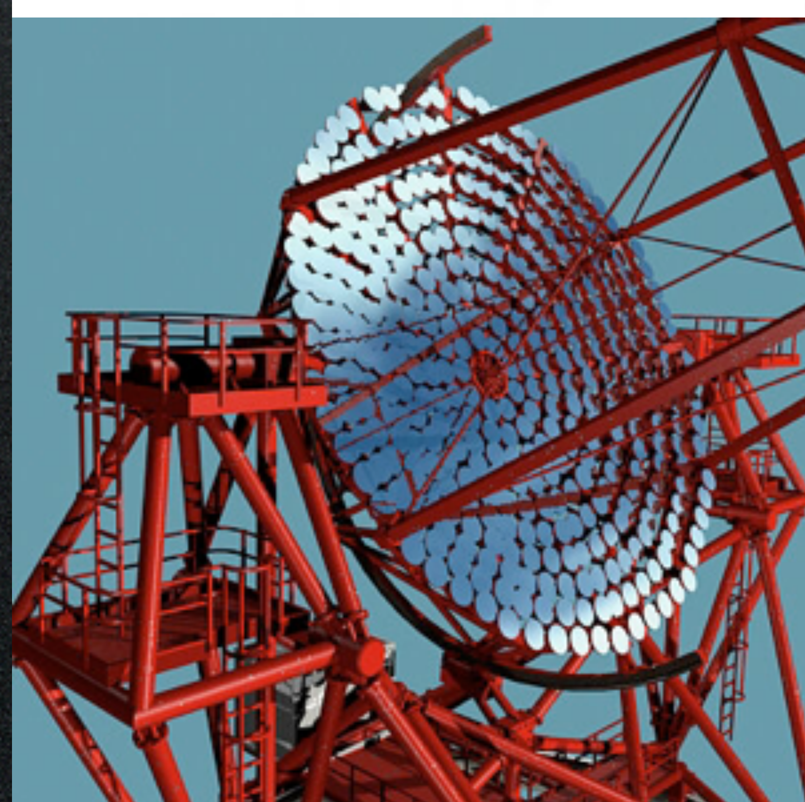


Collider physics

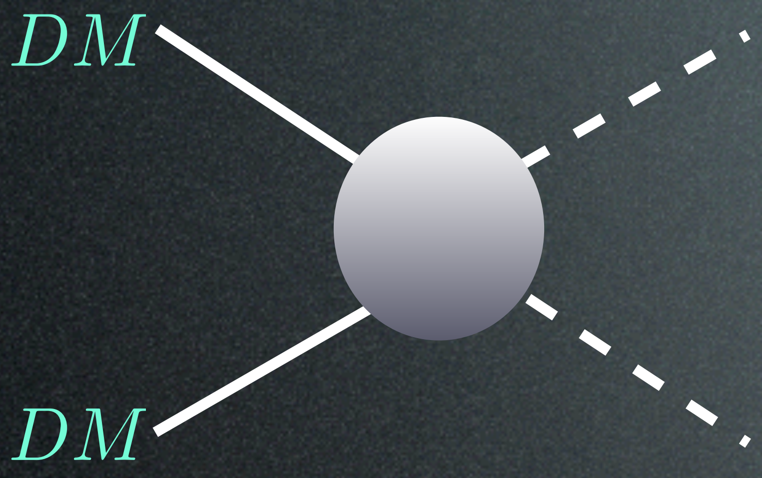
see T. Tait’s talk
ICRC2015

Charged CRs





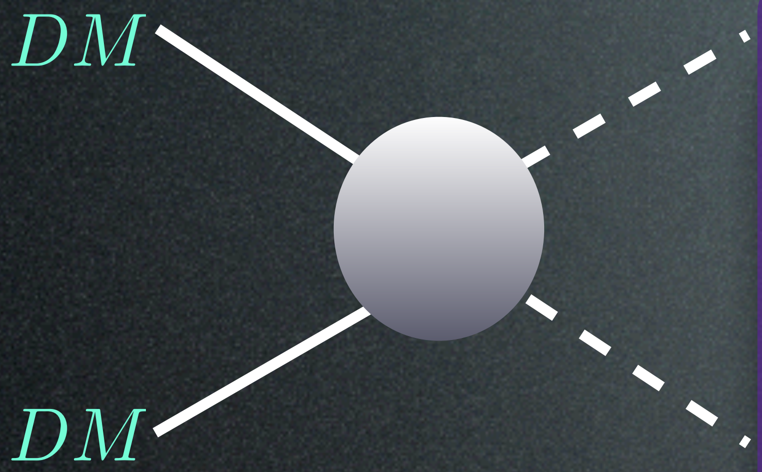
Indirect Detection: basics



$$W^-, Z, b, \tau^-, t, h \ldots \rightsquigarrow e^\mp, \overset{(-)}{p}, \overset{(-)}{D} \ldots$$

$$W^+, Z, \bar{b}, \tau^+, \bar{t}, h \ldots \rightsquigarrow e^\pm, \overset{(-)}{p}, \overset{(-)}{D} \ldots$$

Indirect Detection: basics

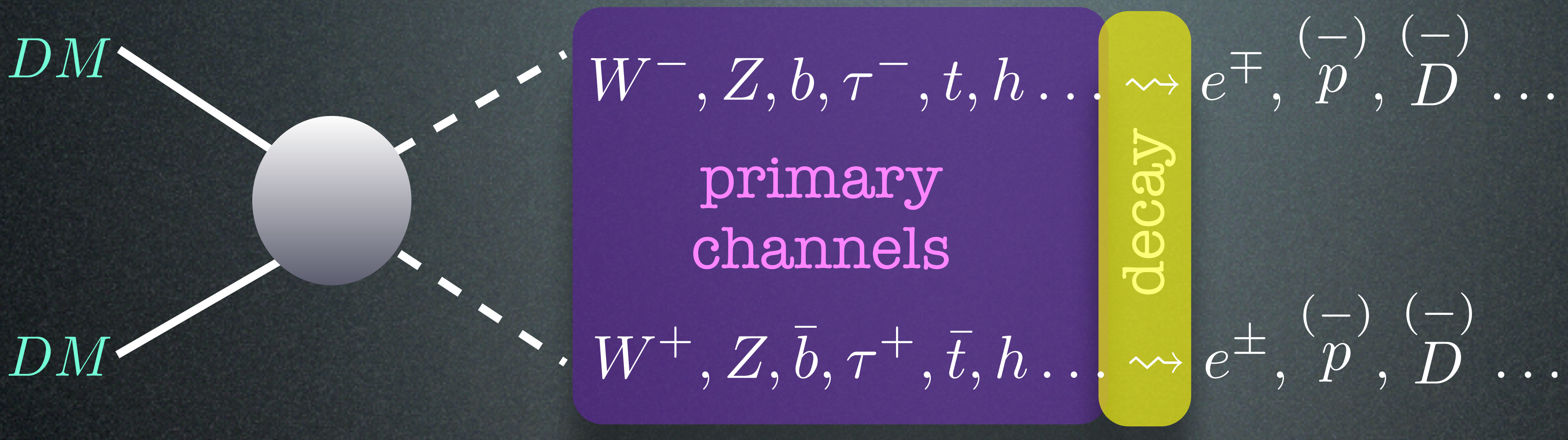


$$W^-, Z, b, \tau^-, t, h \ldots \rightsquigarrow e^{\mp}, \overset{(-)}{p}, \overset{(-)}{D} \ldots$$

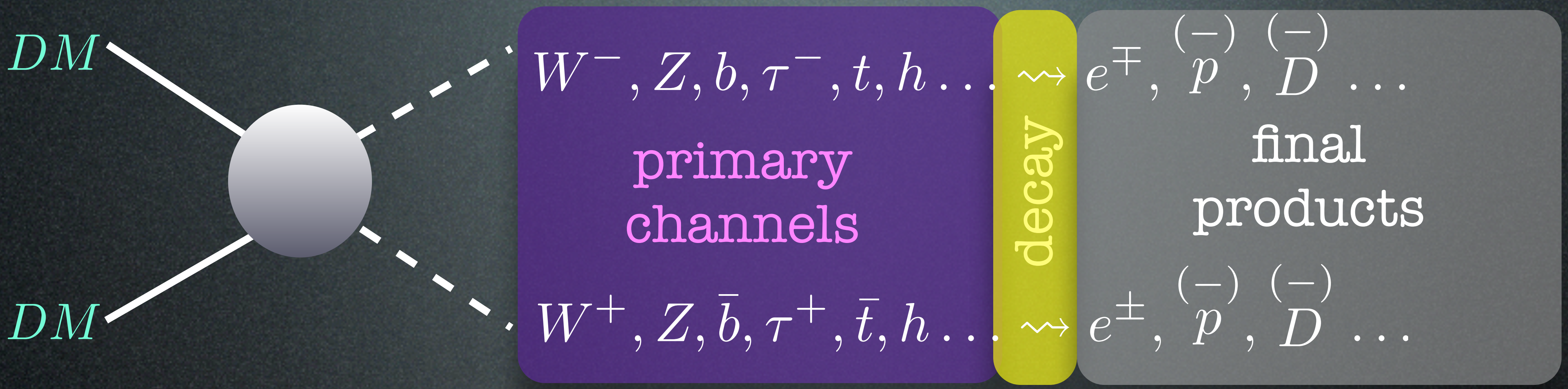
primary channels

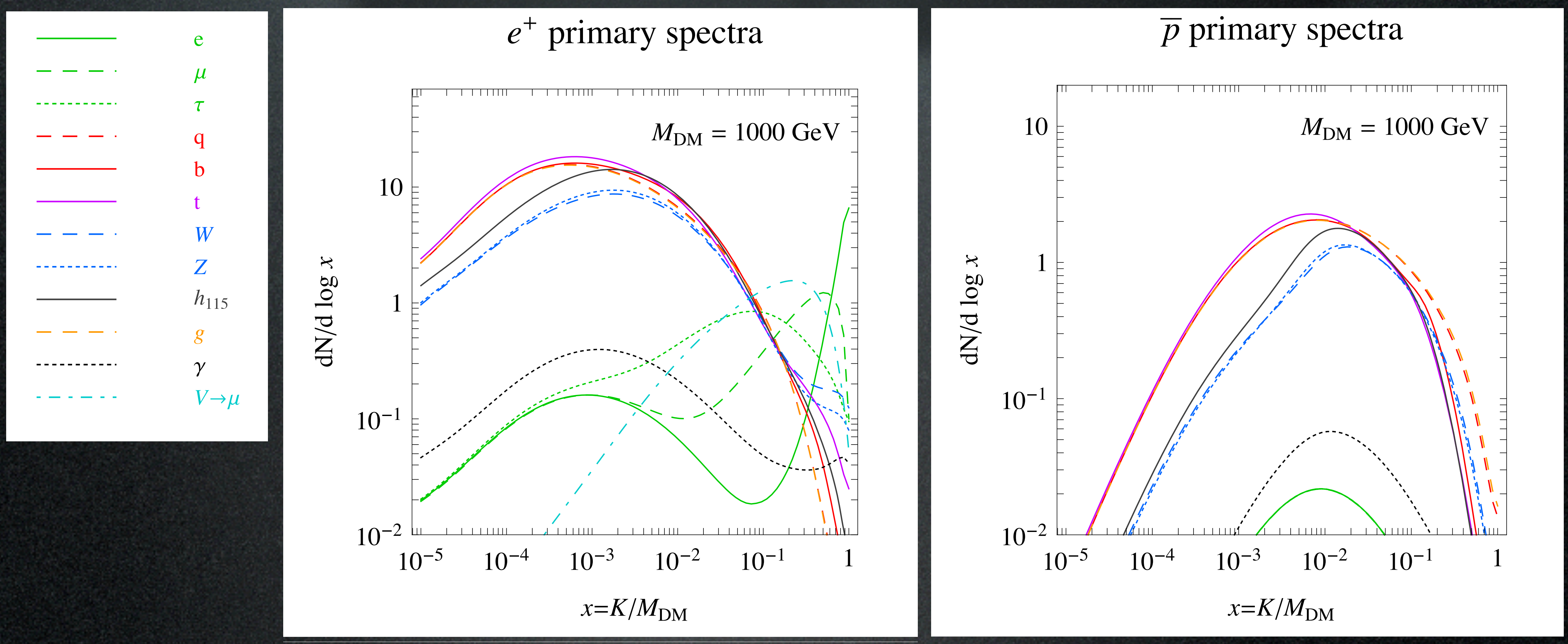
$$W^+, Z, \bar{b}, \tau^+, \bar{t}, h \ldots \rightsquigarrow e^{\pm}, \overset{(-)}{p}, \overset{(-)}{D} \ldots$$

Indirect Detection: basics

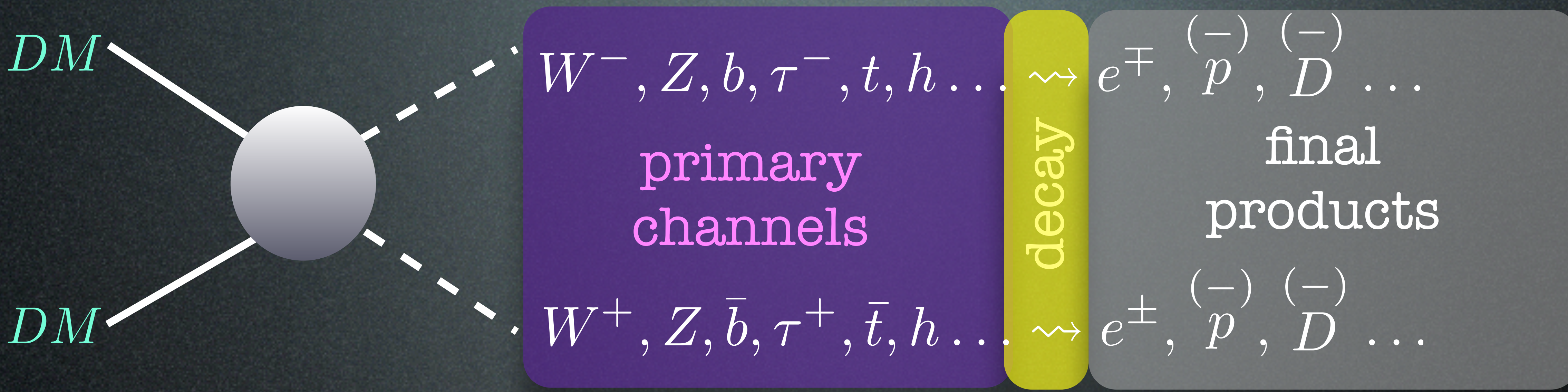


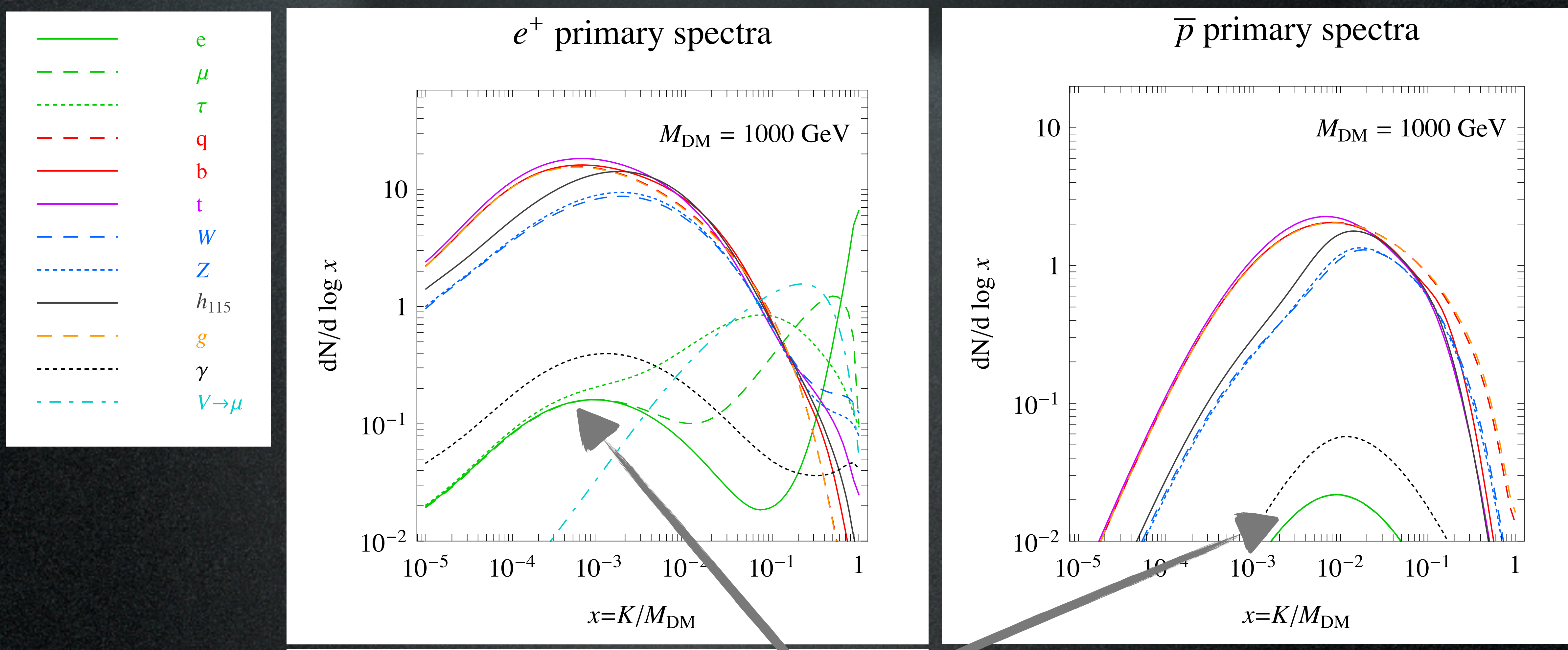
Indirect Detection: basics





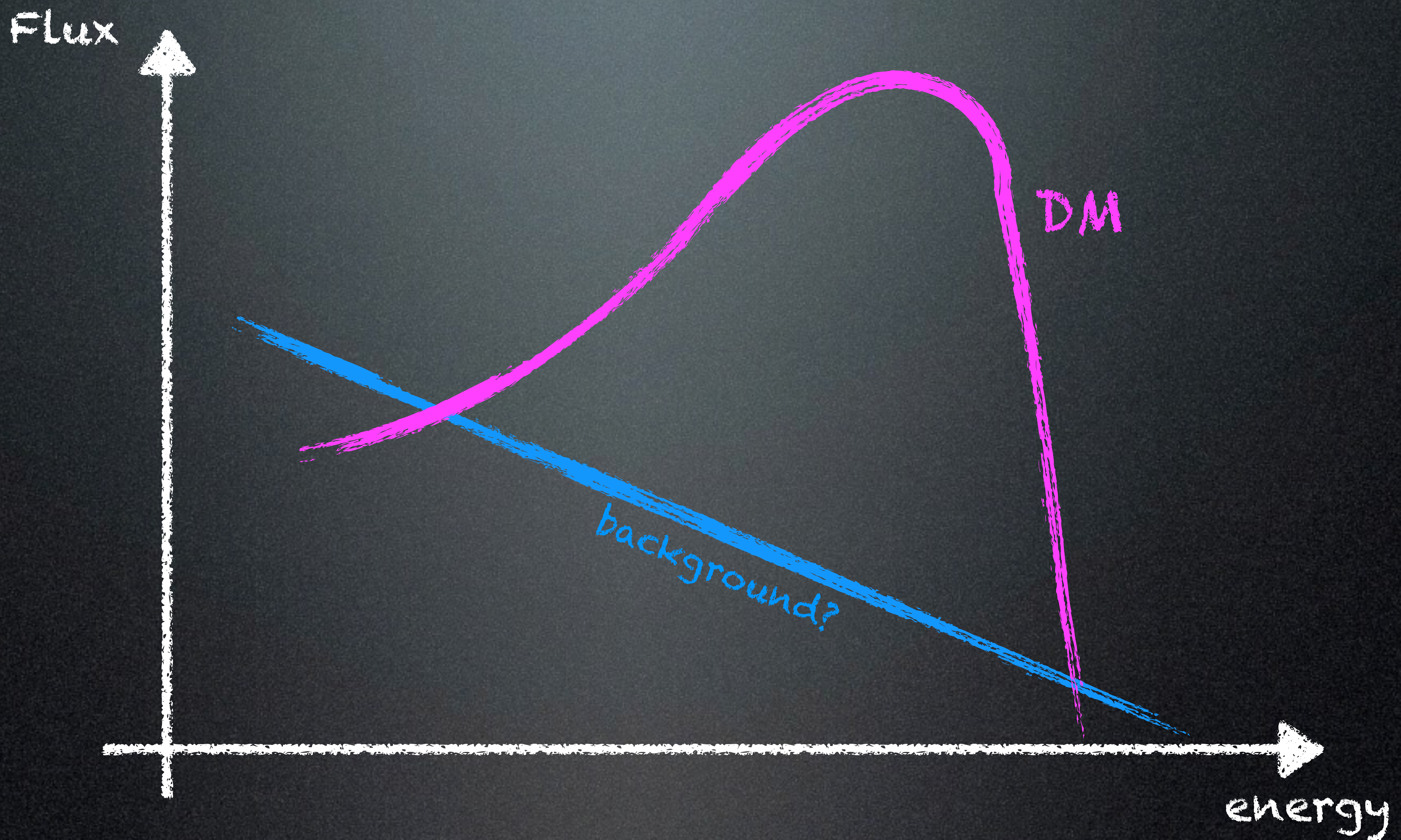
Indirect Detection: basics





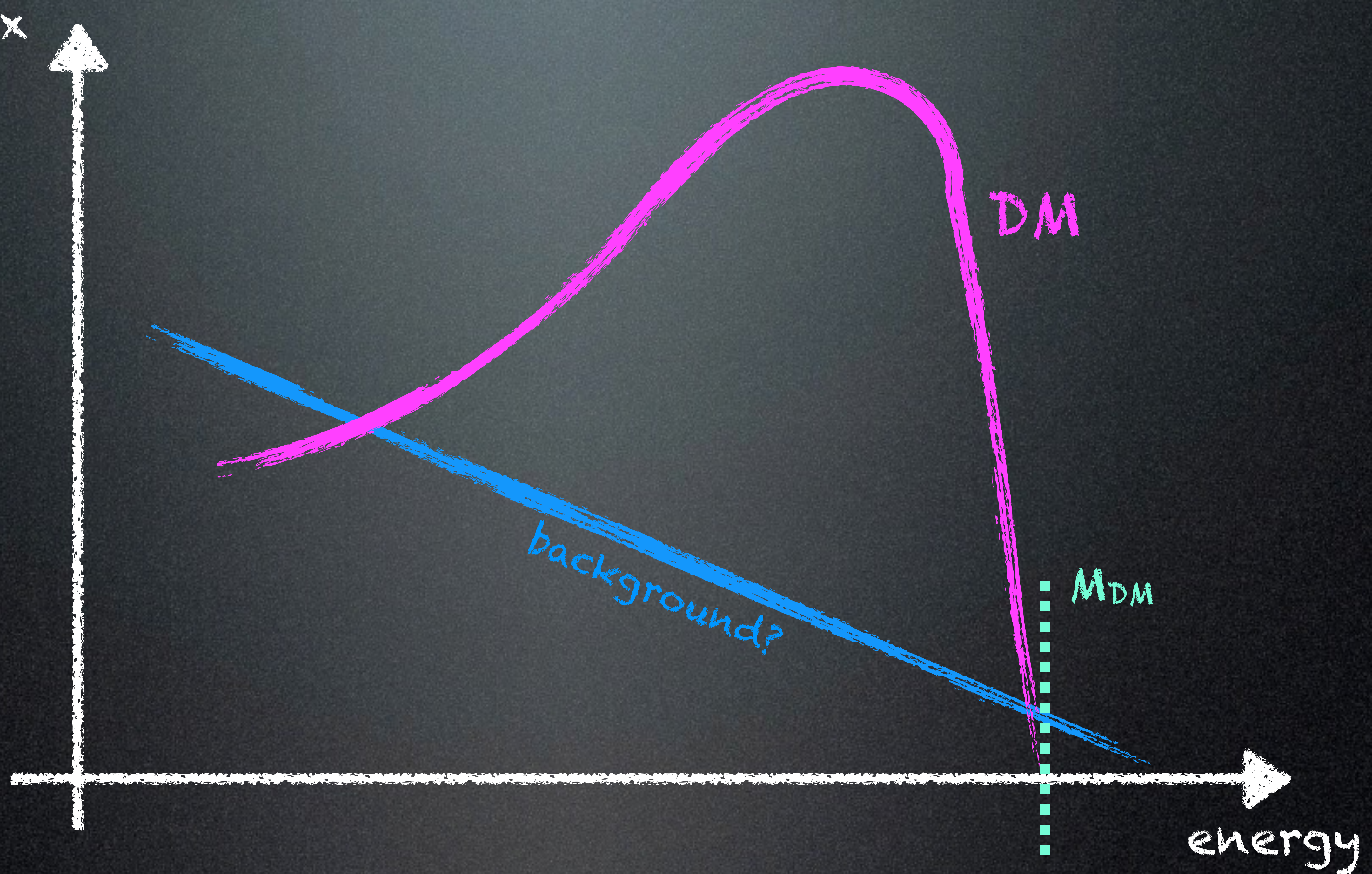
ElectroWeak corrections!

Fluxes at production



So what are the particle physics parameters?

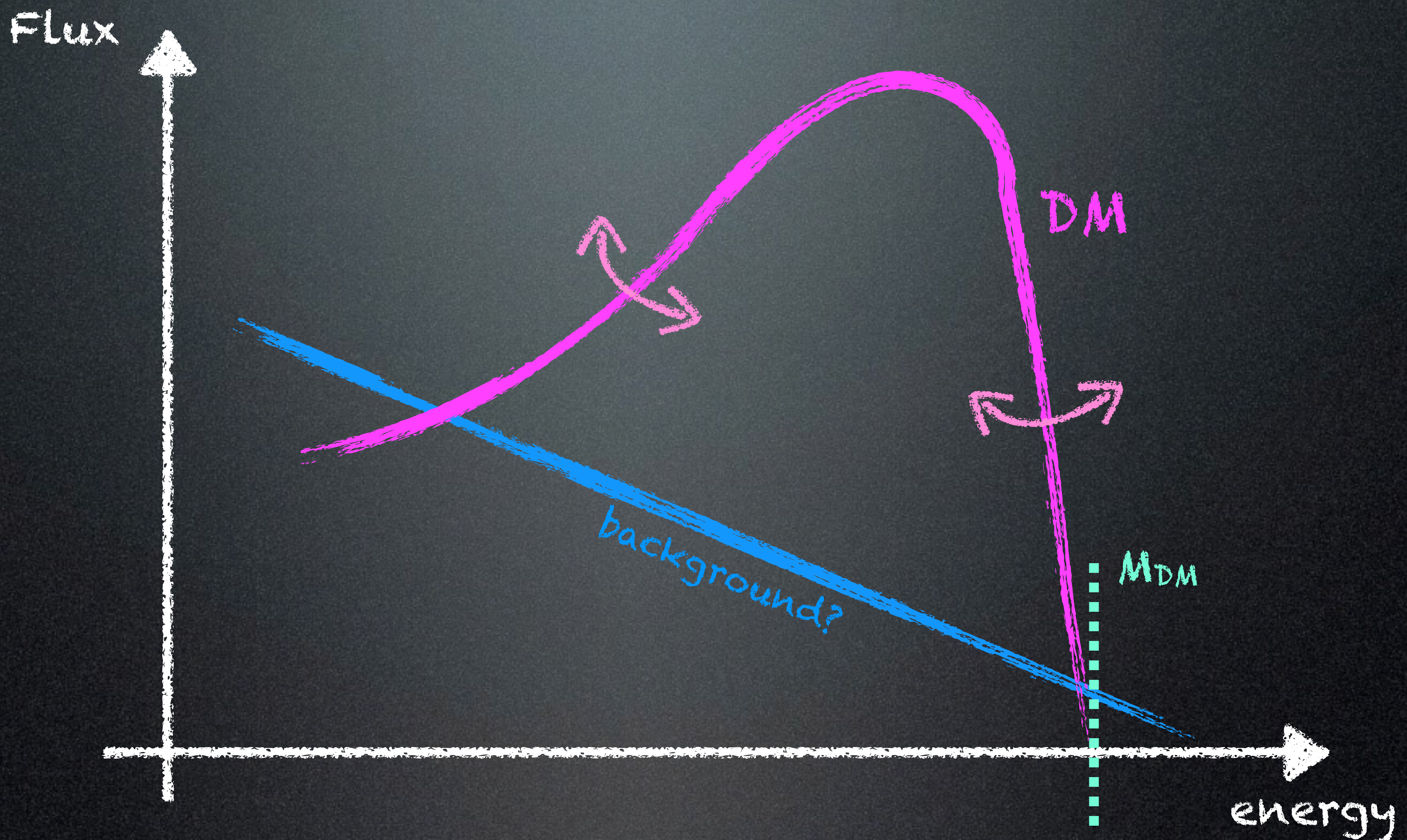
Fluxes at production



So what are the particle physics parameters?

1. Dark Matter mass

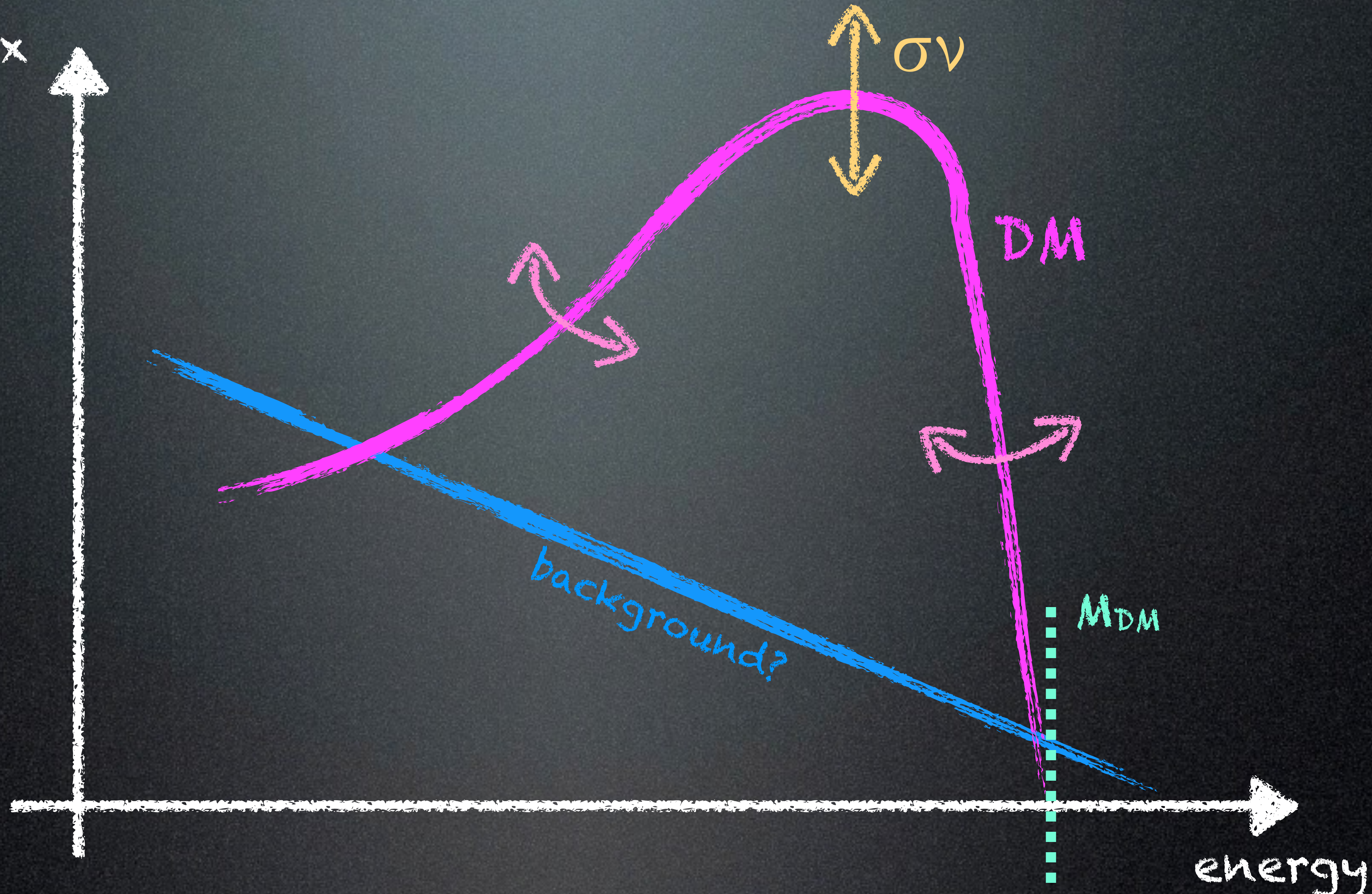
Fluxes at production



So what are the particle physics parameters?

1. Dark Matter mass
2. primary channel(s)

Fluxes at production

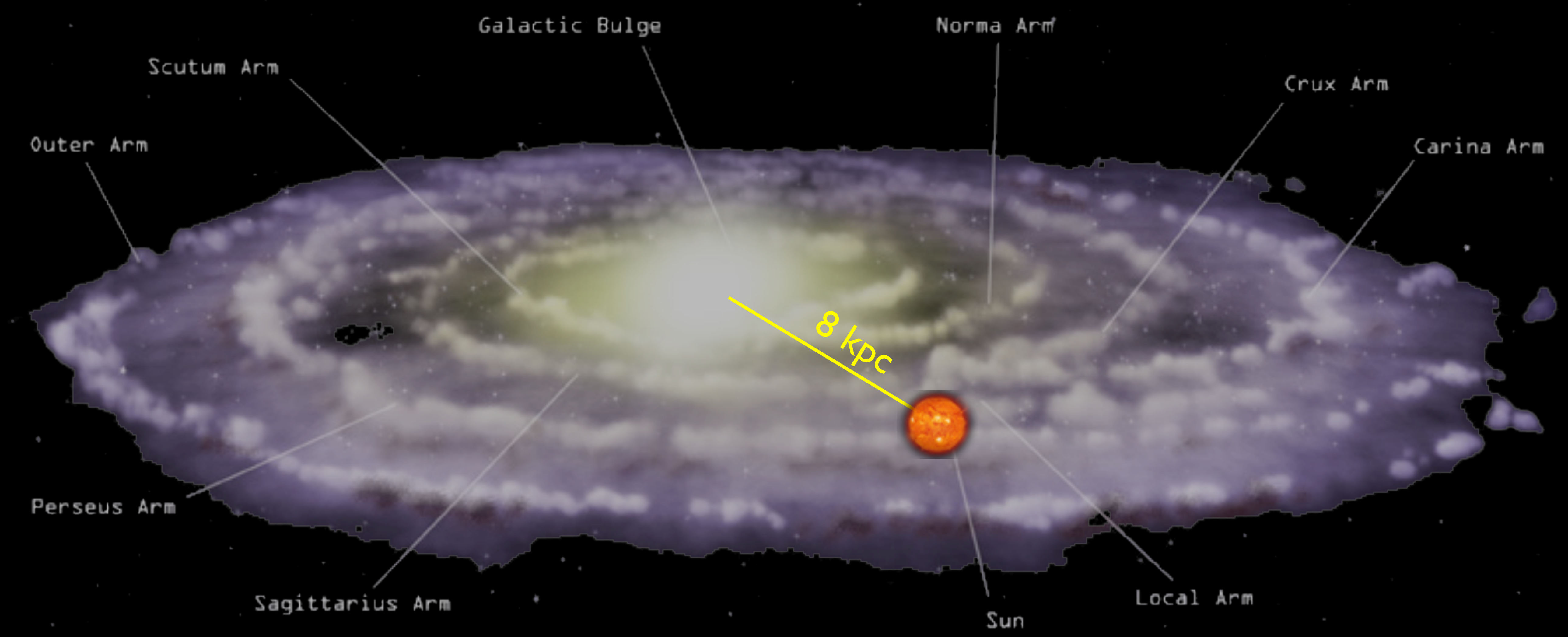


So what are the particle physics parameters?

1. Dark Matter mass
2. primary channel(s)
3. cross section

Indirect Detection: basics

$\bar{p}$ and e^+ from DM annihilations in halo



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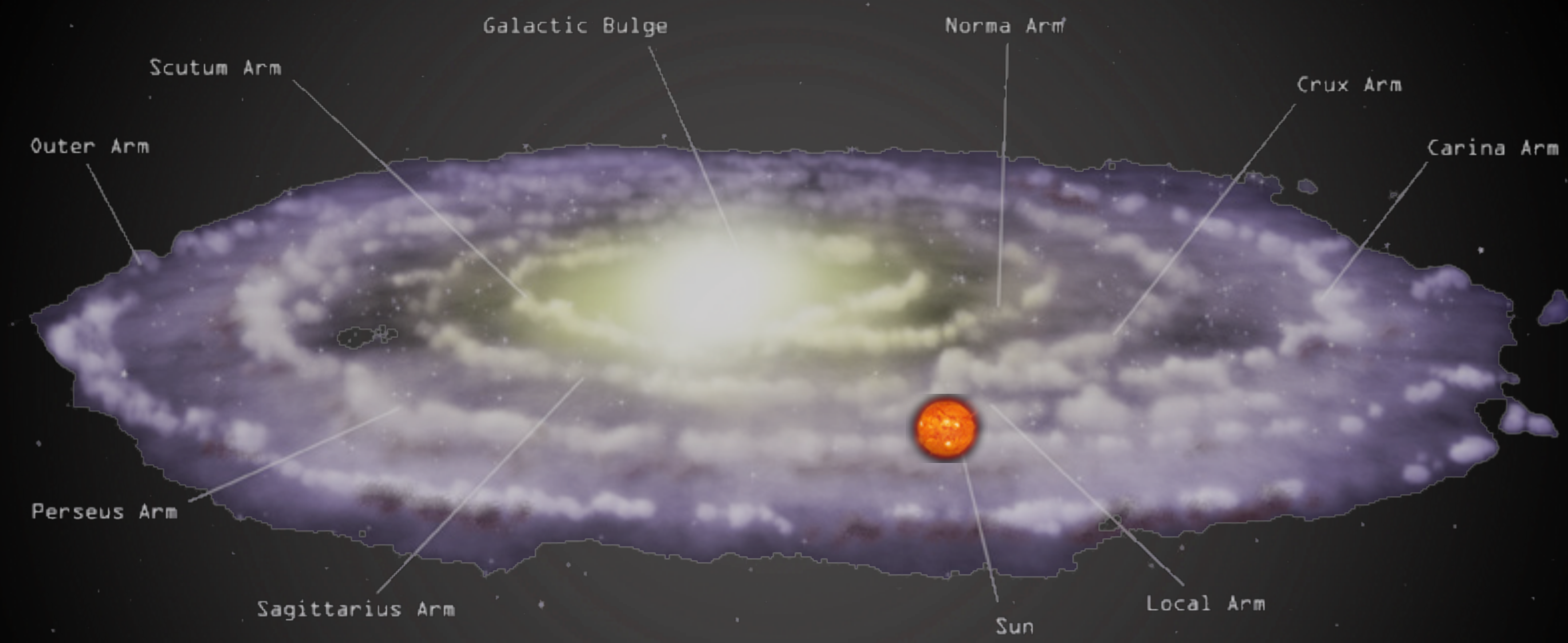
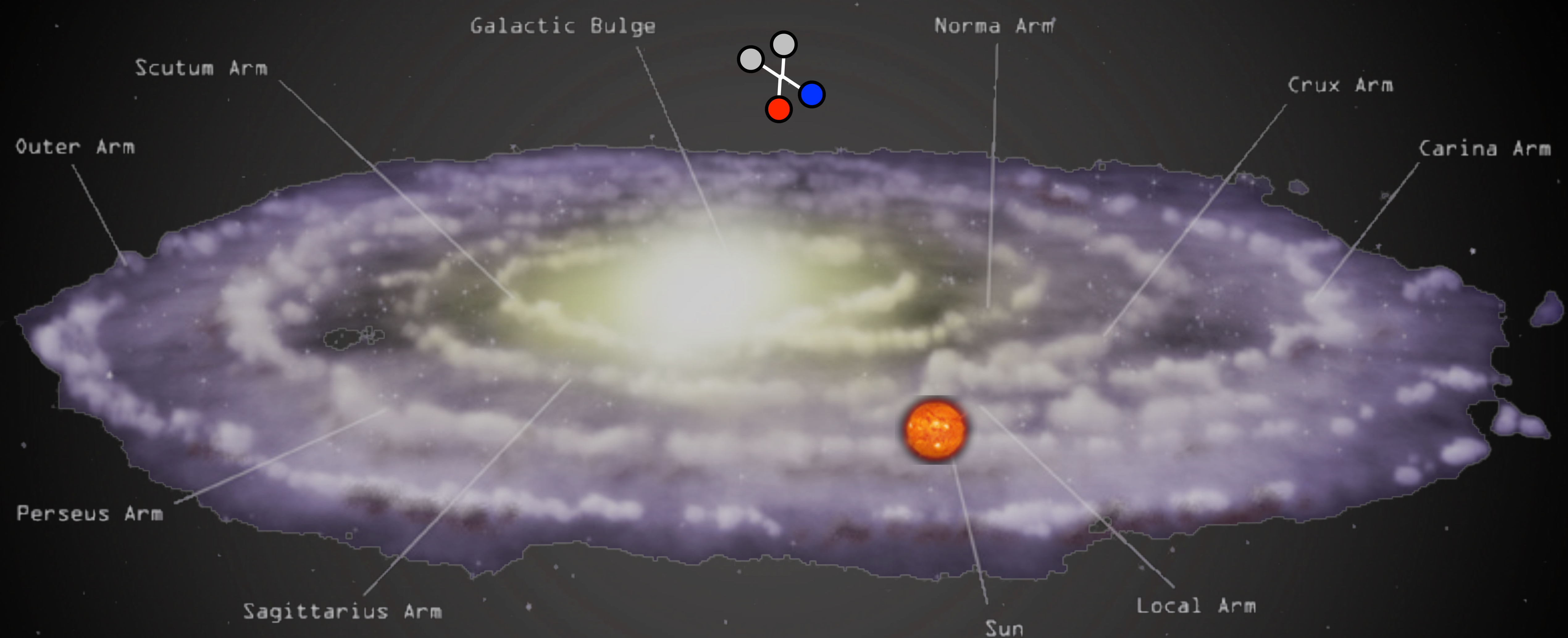
$\bar{p}$ and e^+ from DM annihilations in halo



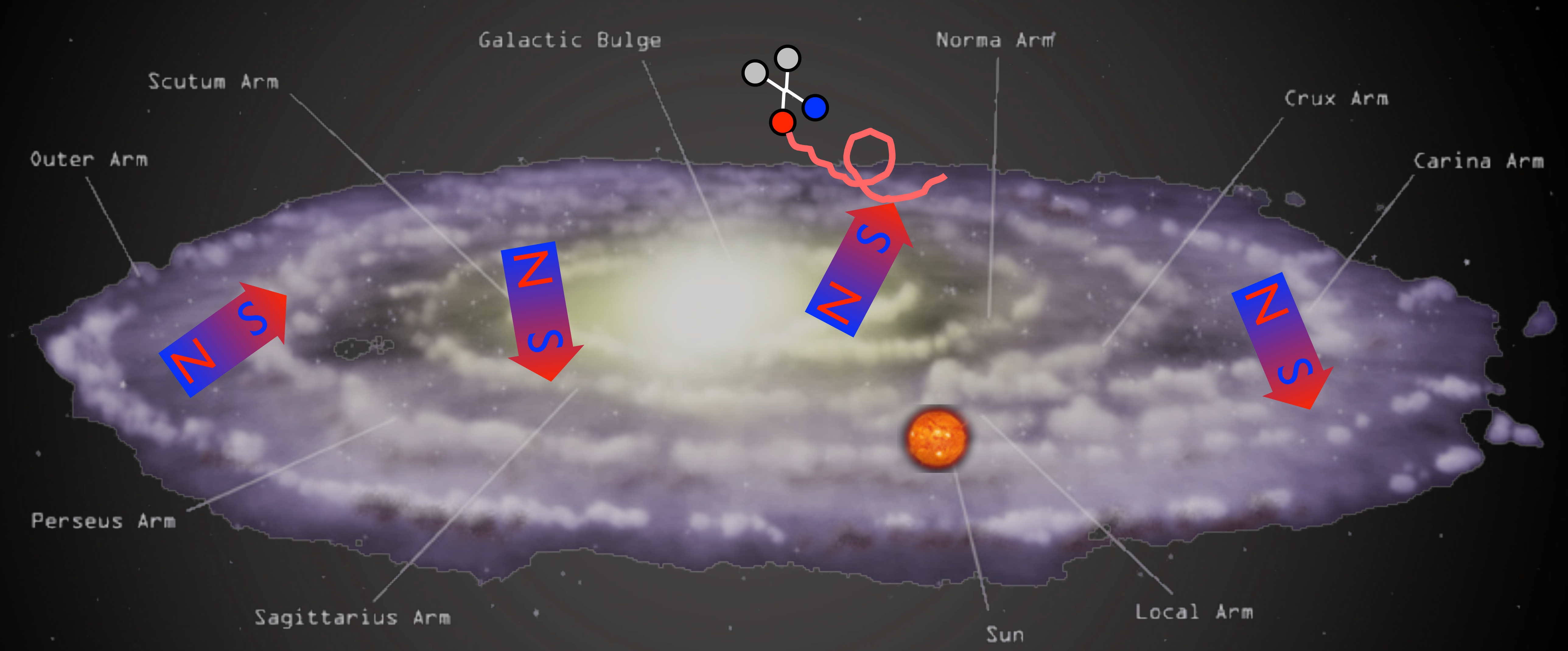
Indirect Detection: basics

$\bar{p}$ and e^+ from DM annihilations in halo



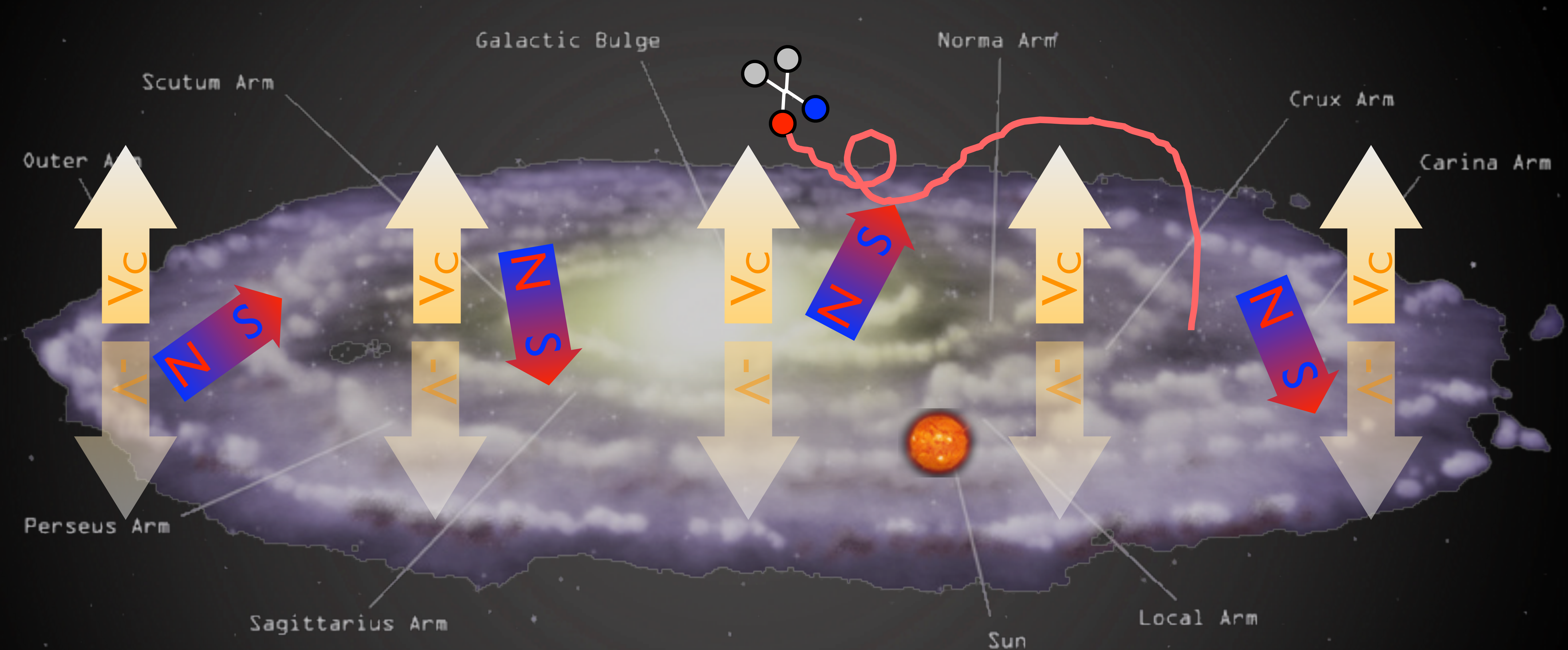
Indirect Detection: basics

$\bar{p}$ and e^+ from DM annihilations in halo



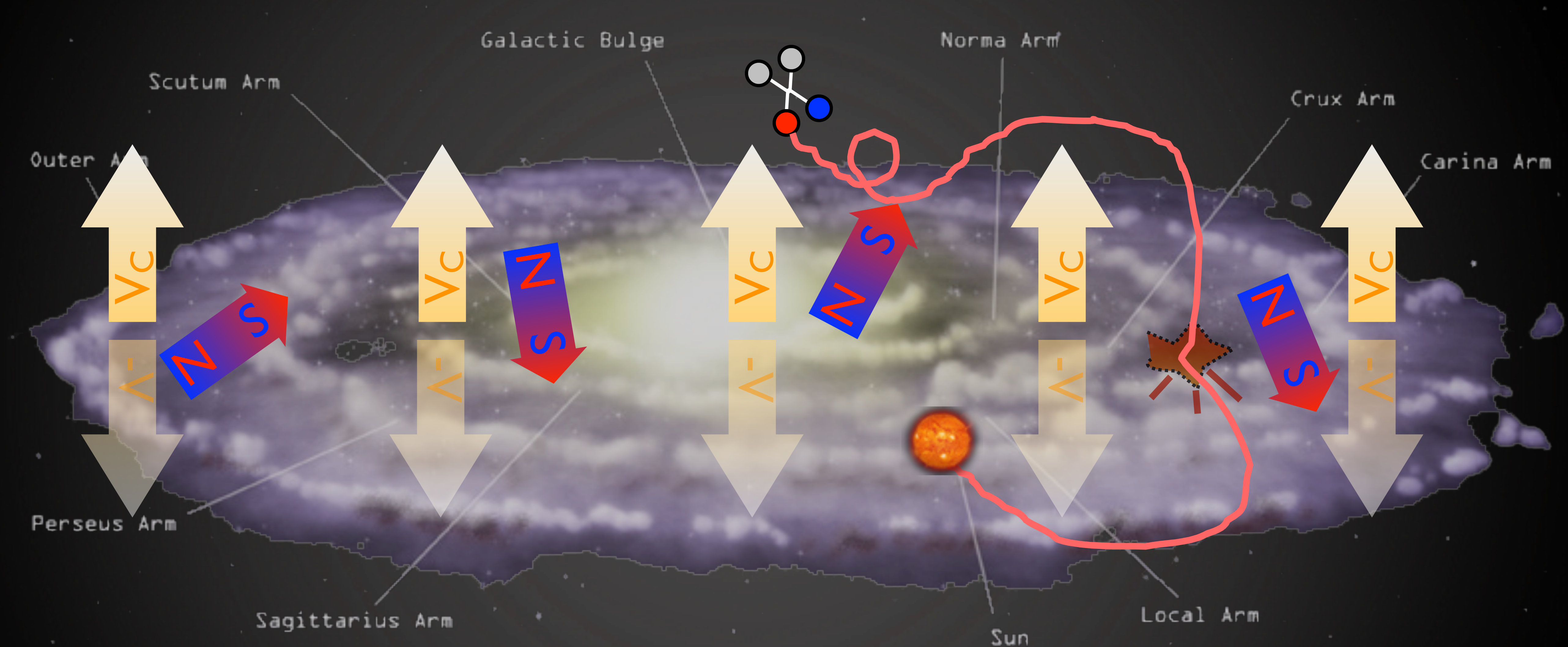
Indirect Detection: basics

$\bar{p}$ and e^{+} from DM annihilations in halo



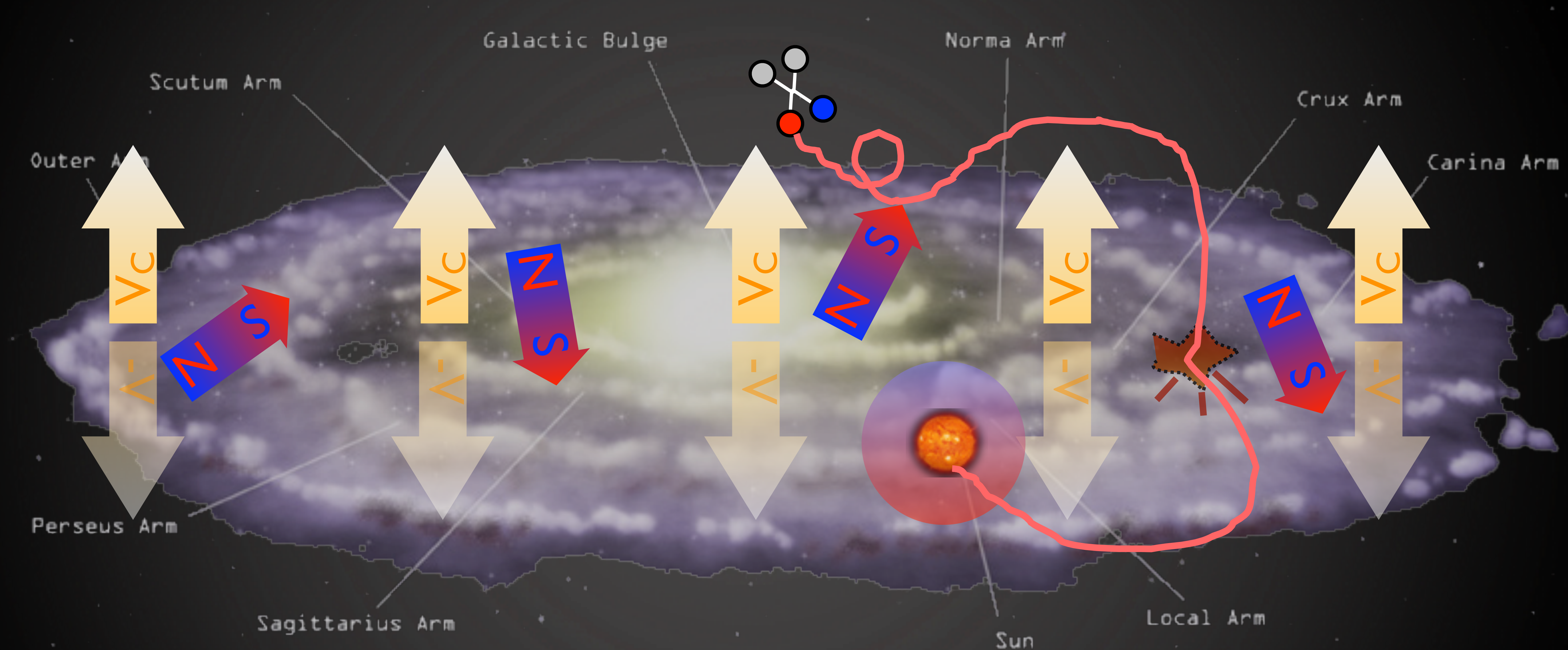
Indirect Detection: basics

$\bar{p}$ and e^+ from DM annihilations in halo



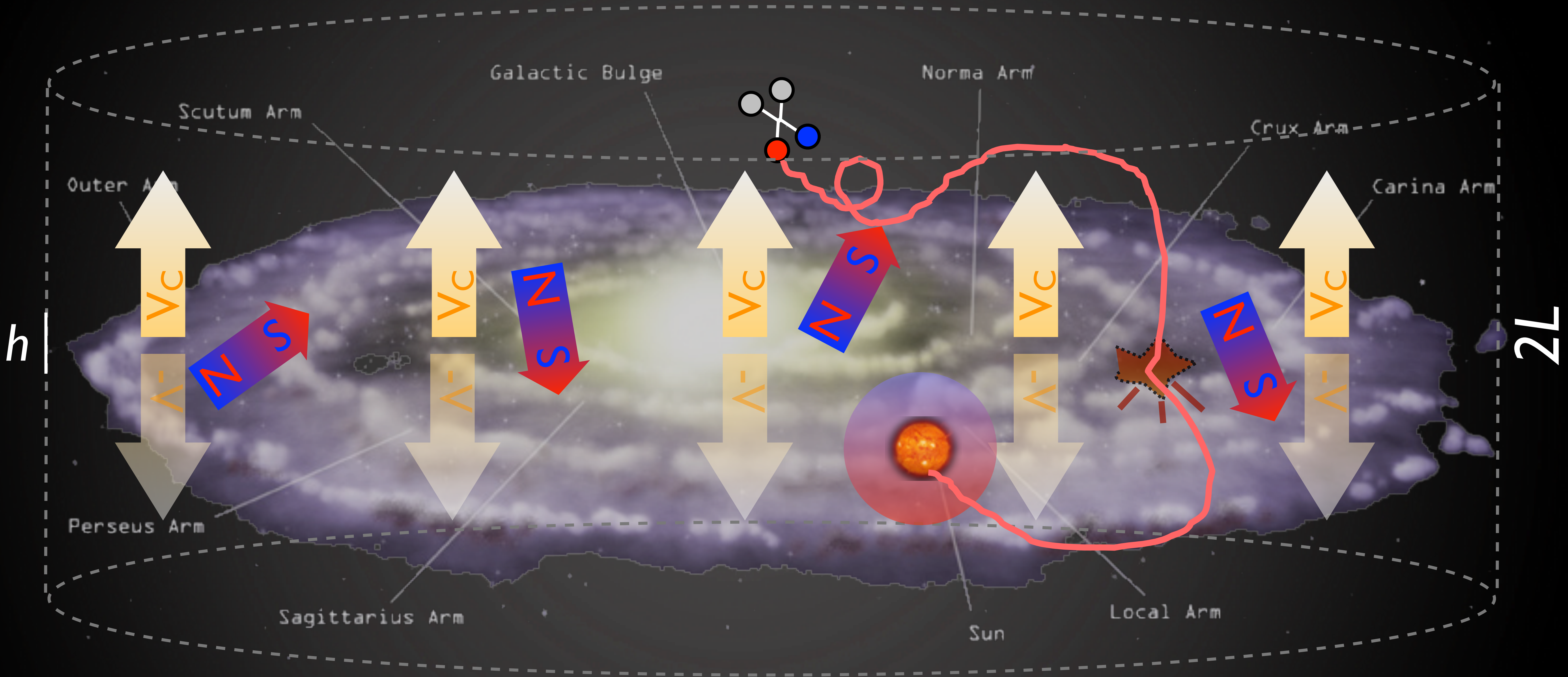
Indirect Detection: basics

$\bar{p}$ and e^+ from DM annihilations in halo



Indirect Detection: basics

$\bar{p}$ and e^+ from DM annihilations in halo



GALPROP - I.Moskalenko #492, A.Strong # 506 ICRC 2015
DRAGON - D. Gaggero ICRC 2015
USINE - D. Maurin #484 ICRC 2015

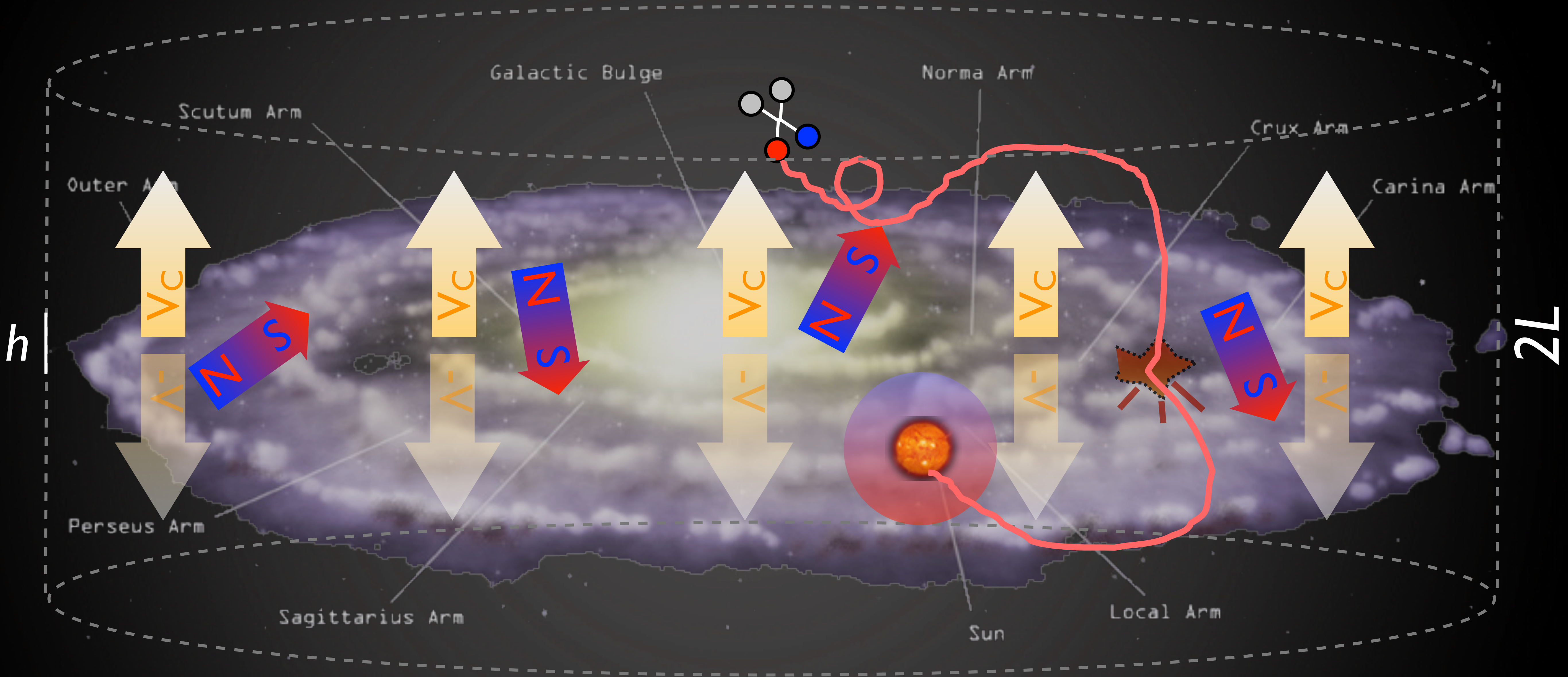
spectrum

$$\frac{\partial f}{\partial t} - K(E)\cdot\nabla^2 f - \frac{\partial}{\partial E}(b(E)f) + \frac{\partial}{\partial z}(V_c f) = Q_{\rm inj} - 2h\delta(z)\Gamma_{\rm spall} f$$

diffusion   energy loss   convective wind   source   spallations

Indirect Detection: basics

$\bar{p}$ and e^+ from DM annihilations in halo



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diffusion — energy loss — convective wind — source — spallations

DM halo profiles

From N-body simulations and/or kinematics:

$$\text{NFW}: \quad \rho_{\text{NFW}}(r) = \rho_s \frac{r_s}{r}\left(1+\frac{r}{r_s}\right)^{-2}$$

$$\text{Einasto}: \quad \rho_{\text{Ein}}(r) = \rho_s \exp\left\{-\frac{2}{\alpha}\left[\left(\frac{r}{r_s}\right)^{\alpha}-1\right]\right\}$$

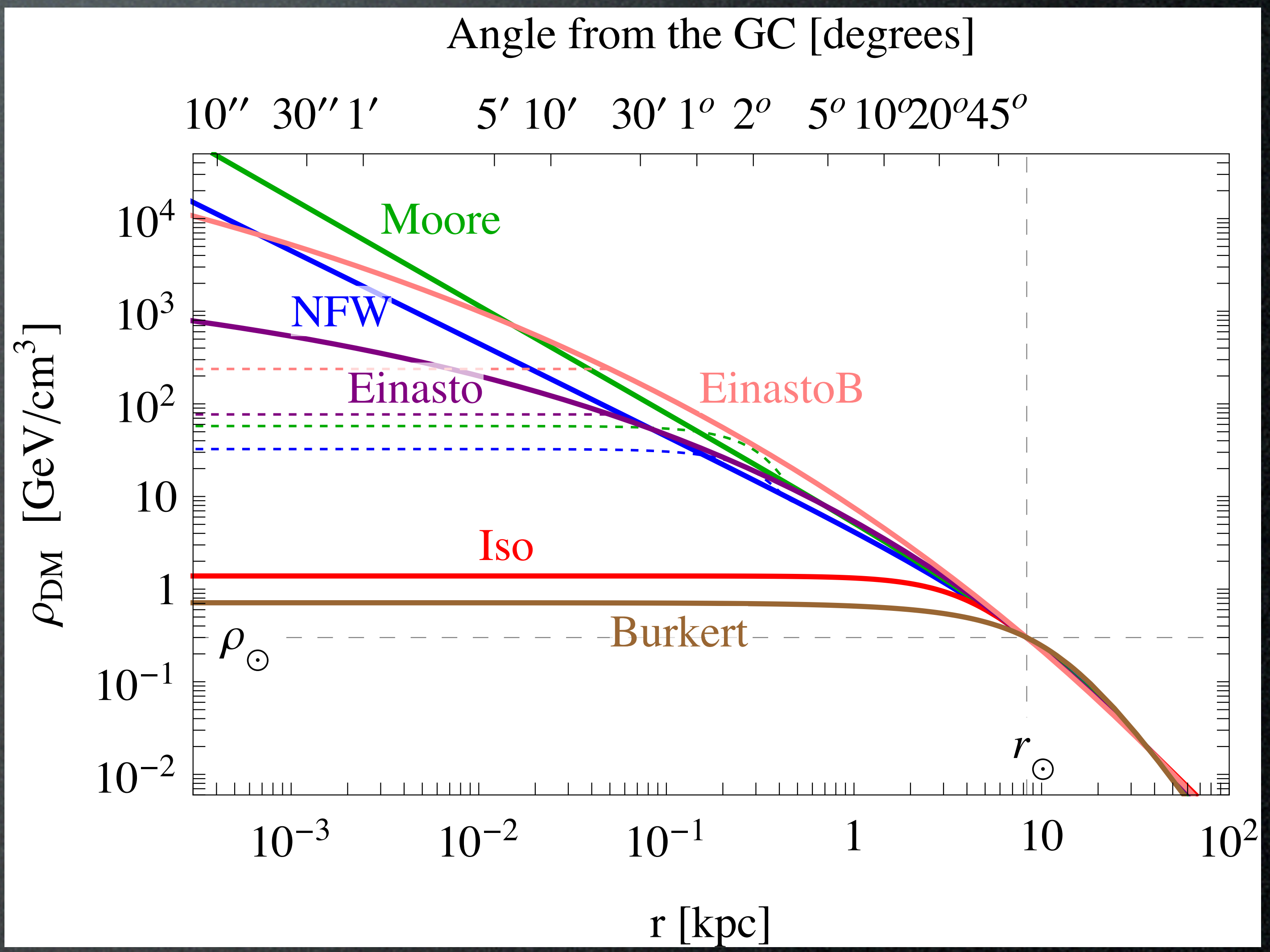
$$\text{Isothermal}: \quad \rho_{\text{Iso}}(r) = \frac{\rho_s}{1+(r/r_s)^2}$$

$$\text{Burkert}: \quad \rho_{\text{Bur}}(r) = \frac{\rho_s}{(1+r/r_s)(1+(r/r_s)^2)}$$

$$\text{Moore}: \quad \rho_{\text{Moo}}(r) = \rho_s \left(\frac{r_s}{r}\right)^{1.16}\left(1+\frac{r}{r_s}\right)^{-1.84}$$

DM halo	α	r_s [kpc]	ρ_s [GeV/cm^3]
NFW	–	24.42	0.184
Einasto	0.17	28.44	0.033
EinastoB	0.11	35.24	0.021
Isothermal	–	4.38	1.387
Burkert	–	12.67	0.712
Moore	–	30.28	0.105

At small r: $\rho(r) \propto 1/r^{\gamma}$



Many profiles:

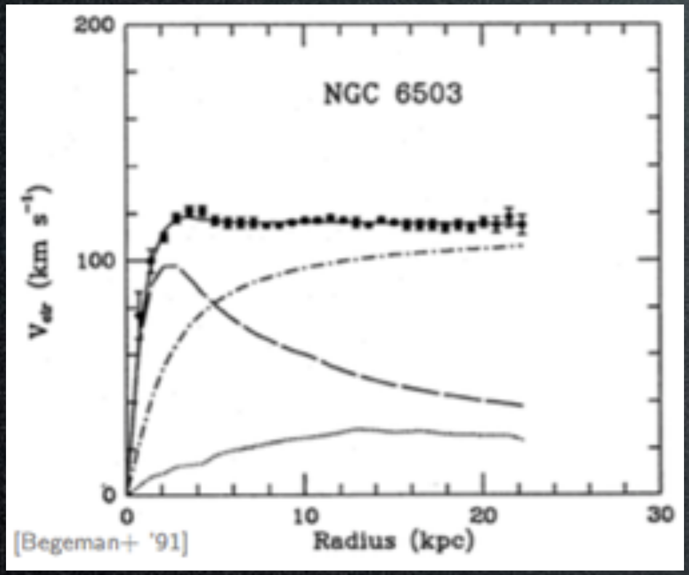
- cuspy: NFW, Moore
- mild: Einasto
- smooth: isothermal, Burkert

EinastoB = steepened Einasto

(effect of baryons?)

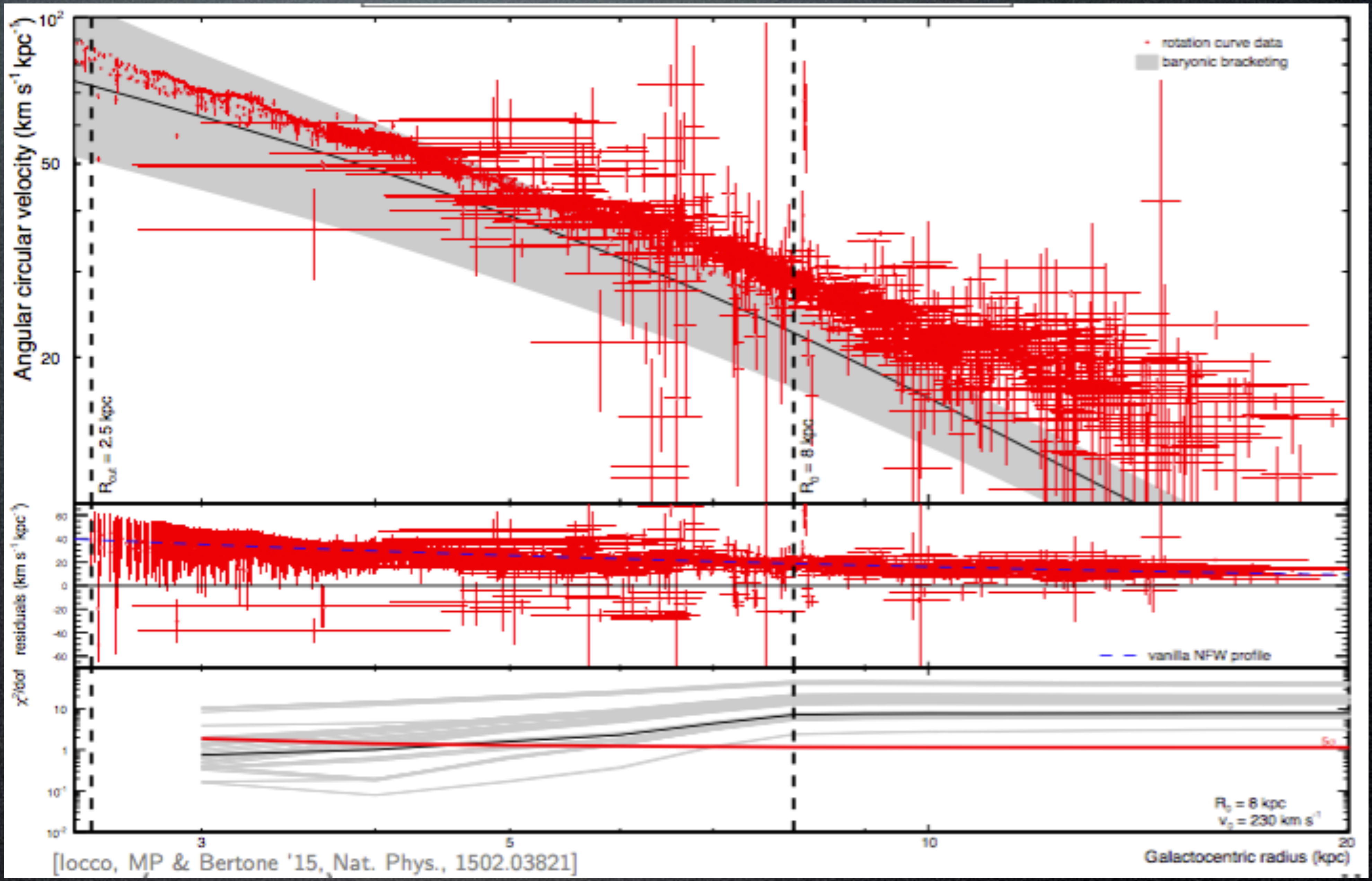
DM halo properties

Dream:



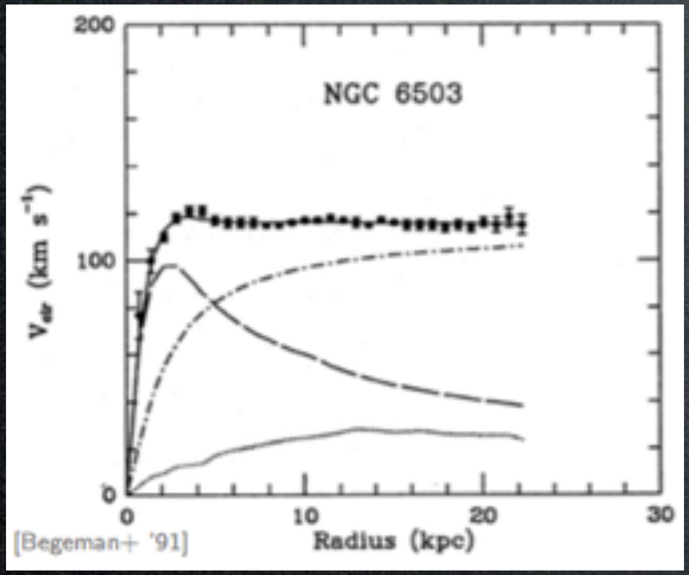
Real life:

M. Pato - ICRC 2015



DM halo properties

Dream:



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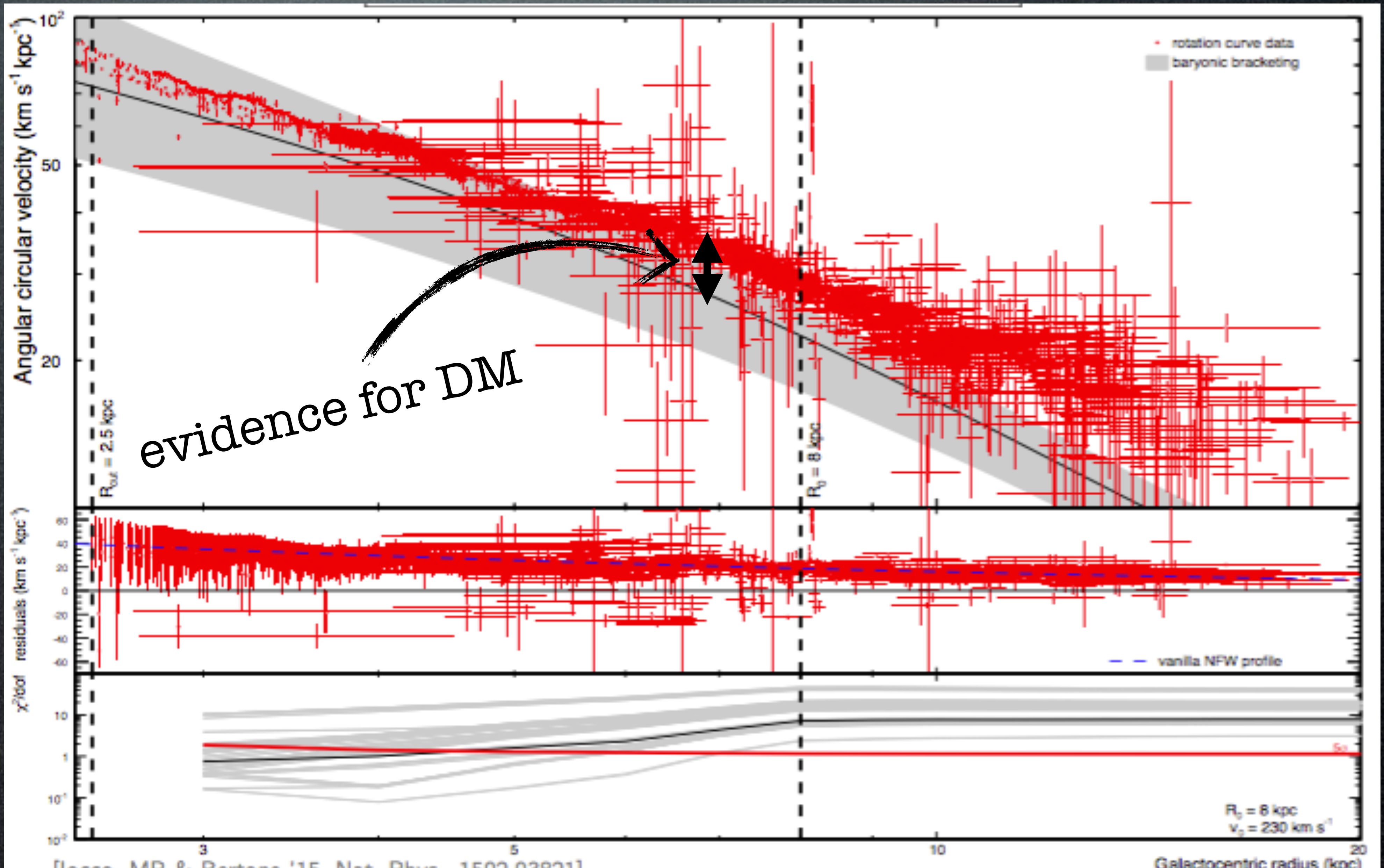

[Iocco, MP & Bertone '15, Nat. Phys., 1502.03821]

DM halo properties

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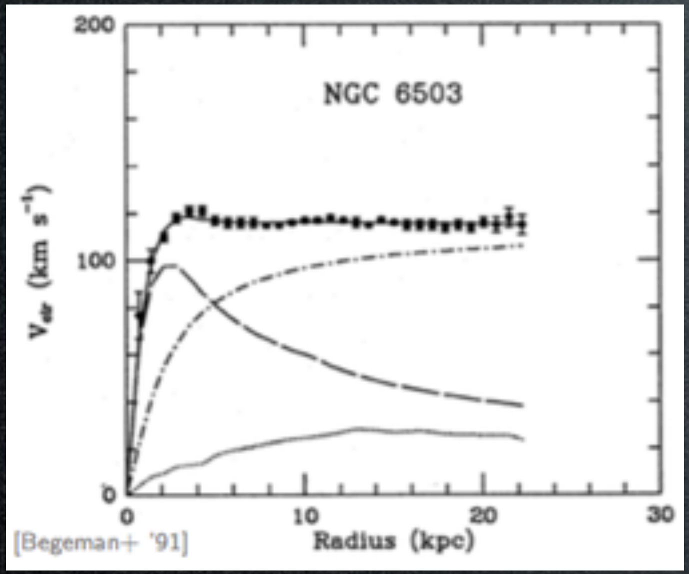
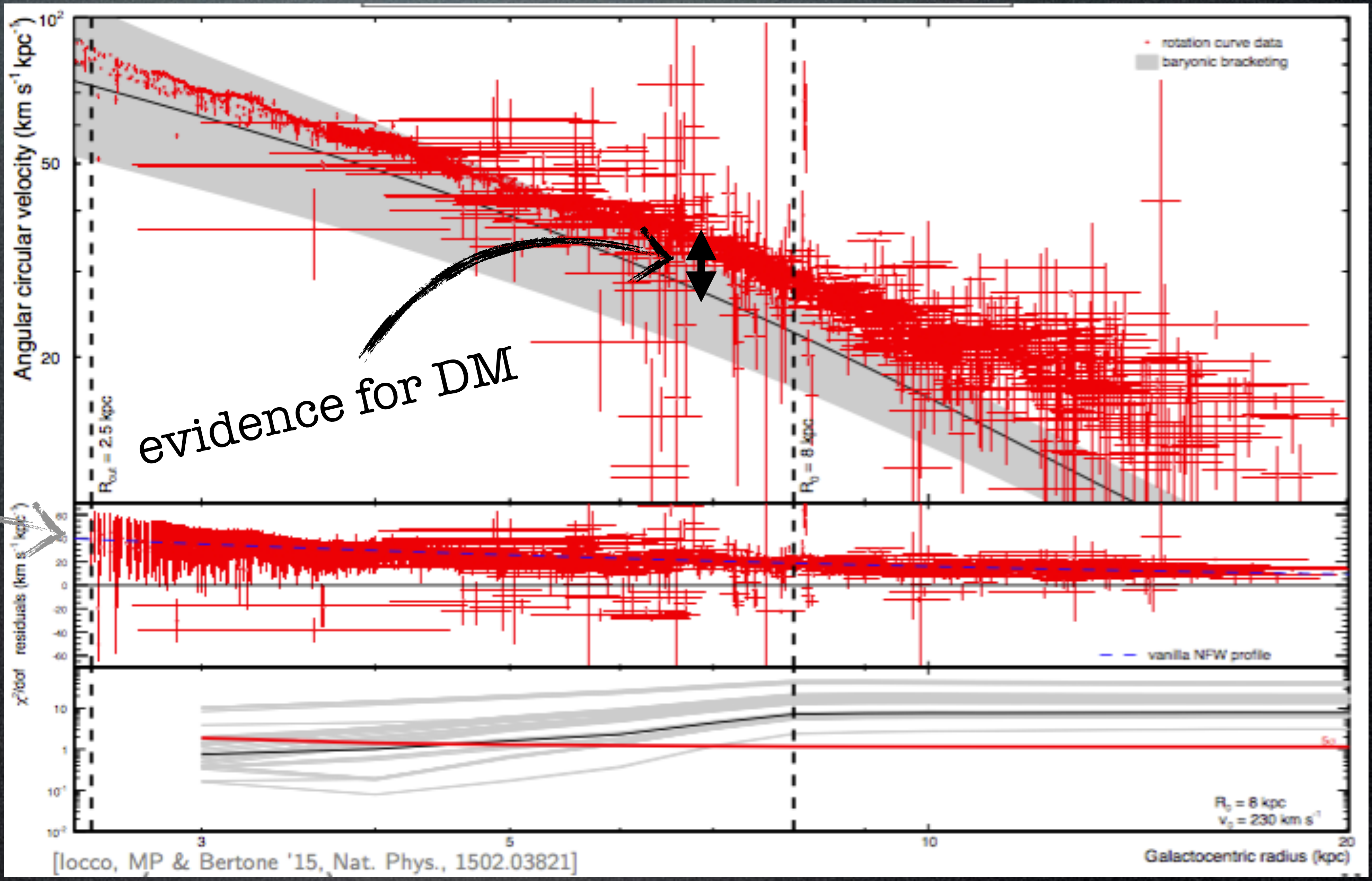


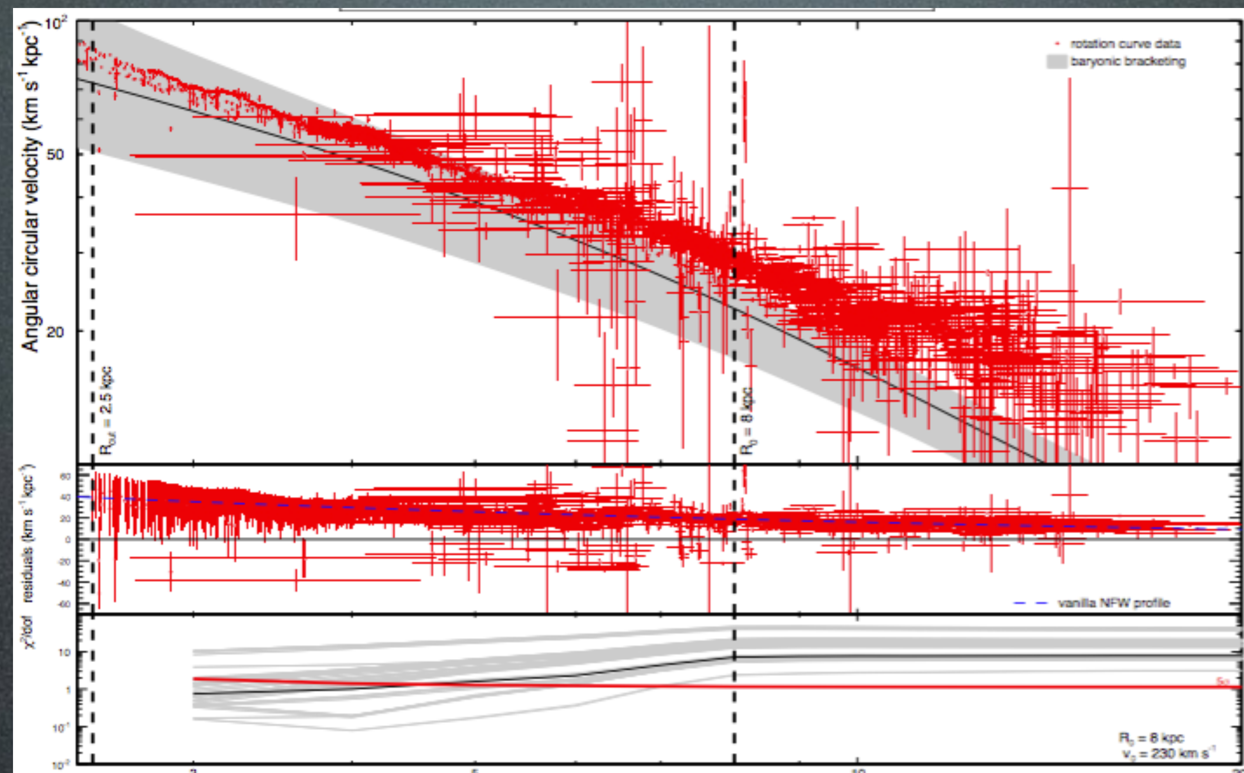
Real life:

M. Pato - ICRC 2015



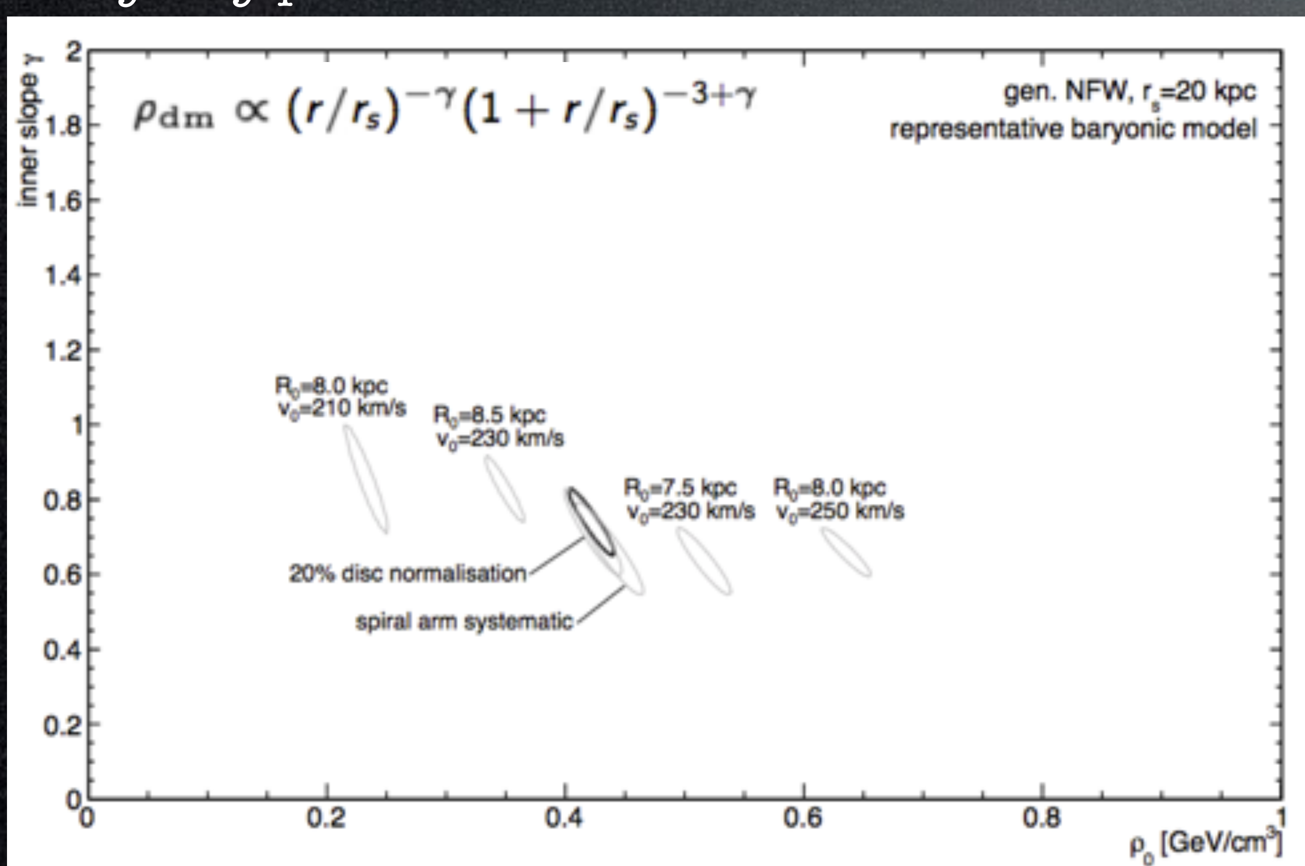
DM halo properties

M. Pato - ICRC 2015

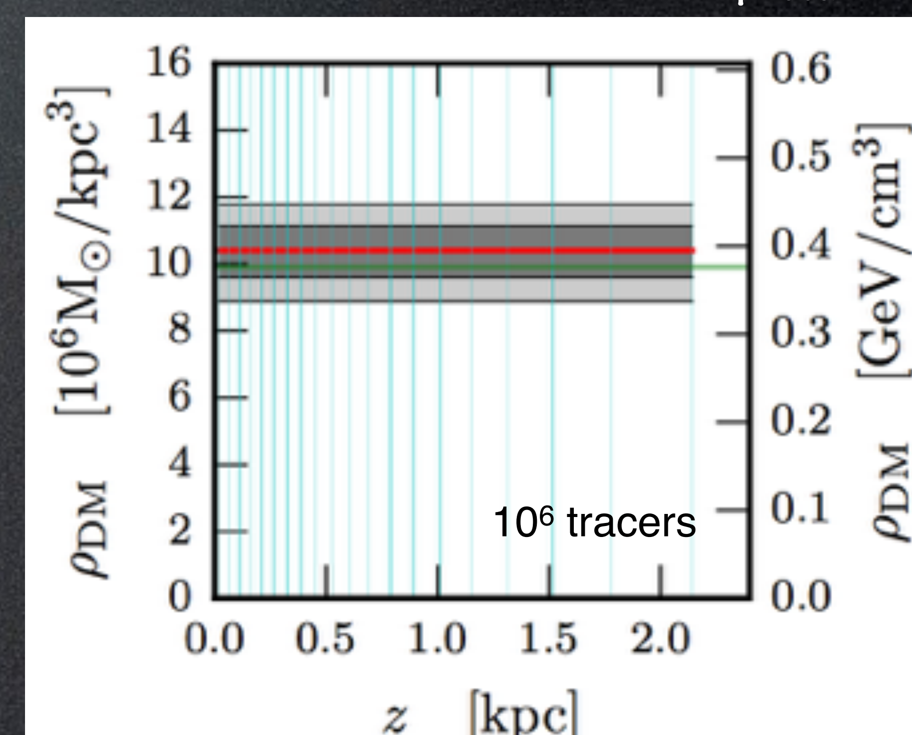


[Iocco, MP & Bertone '15, Nat. Phys., 1502.03821]

Determination of
Milky Way parameters:



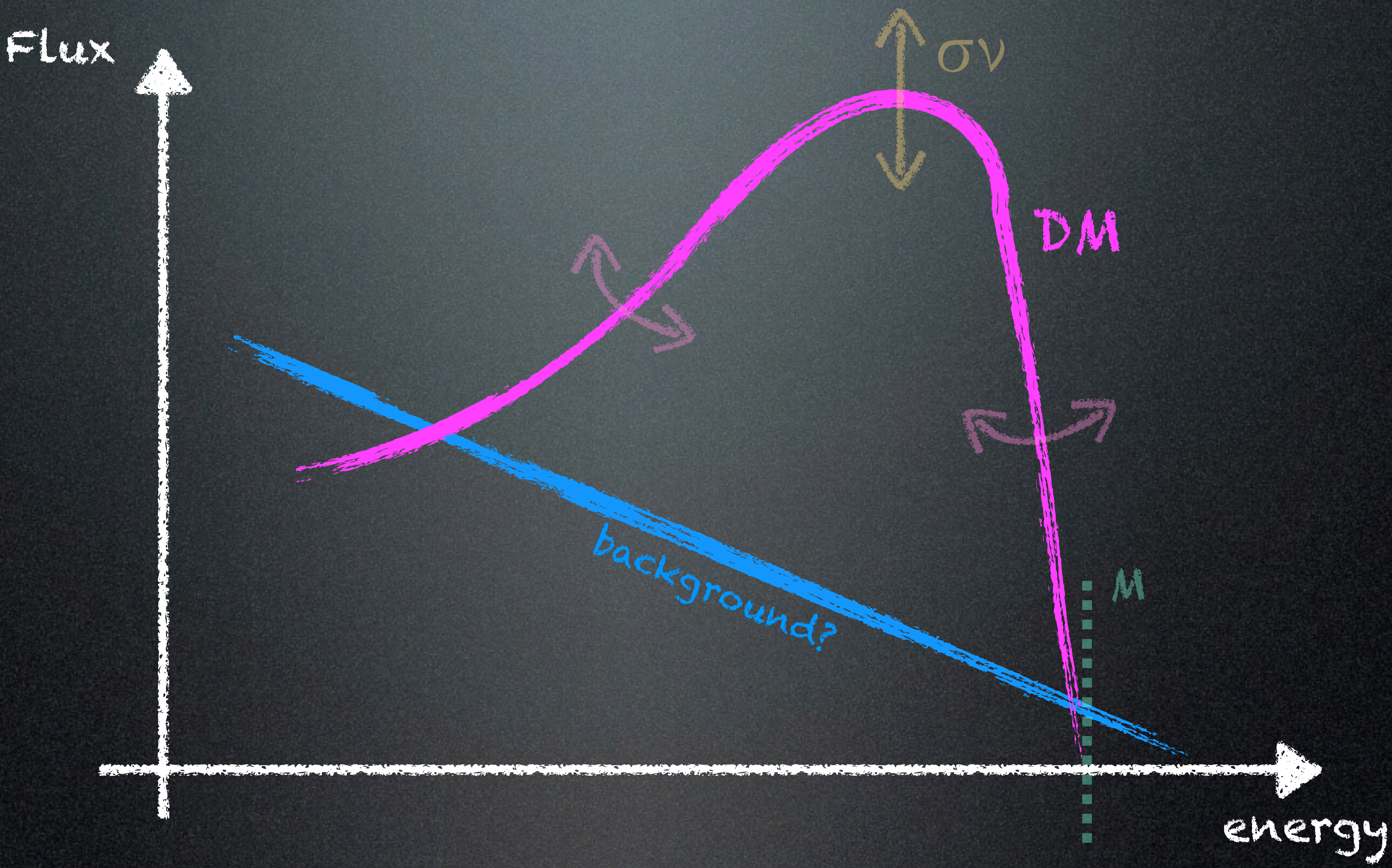
A robust method to infer ρ_{local}



(mock data!)

H. Silverwood - ICRC 2015 #1185

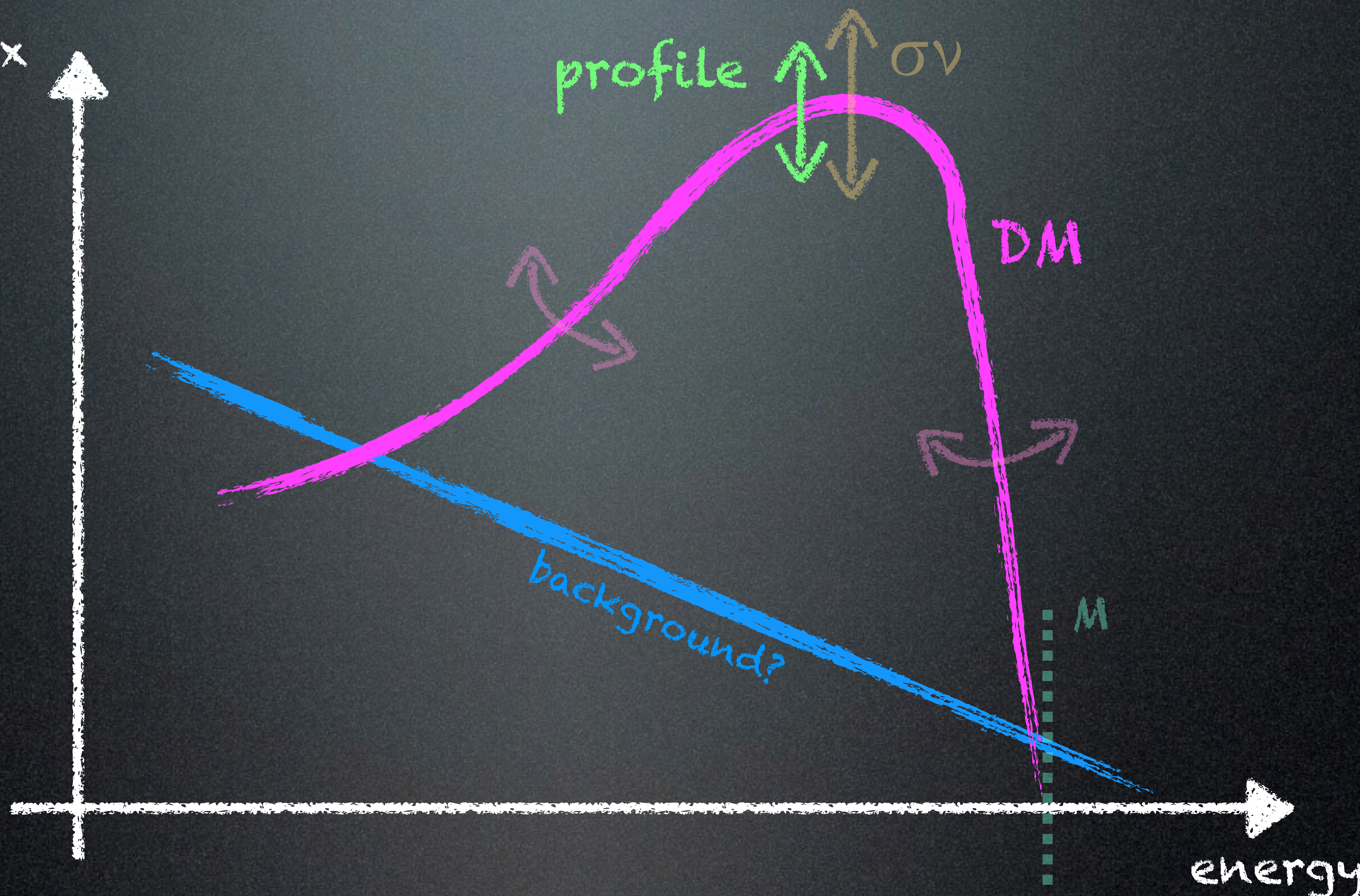
Fluxes at detection



So what are the **astrophysics** parameters?

1. Dark Matter
2.
3.

Fluxes at detection

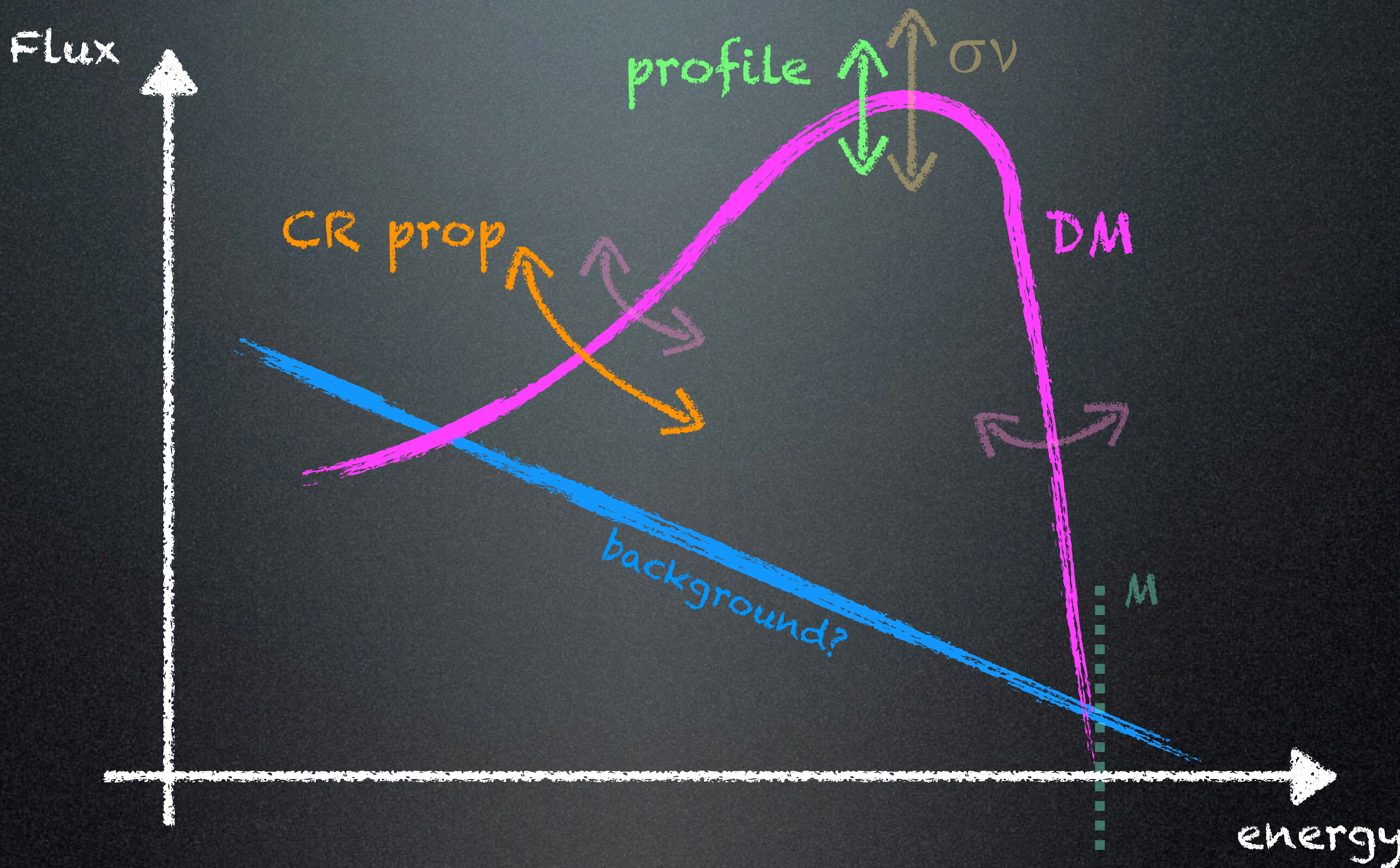


So what are the astrophysics parameters?

1. Dark Matter
2.
3.

1. DM abundance/profile

Fluxes at detection



So what are the **astrophysics** parameters?

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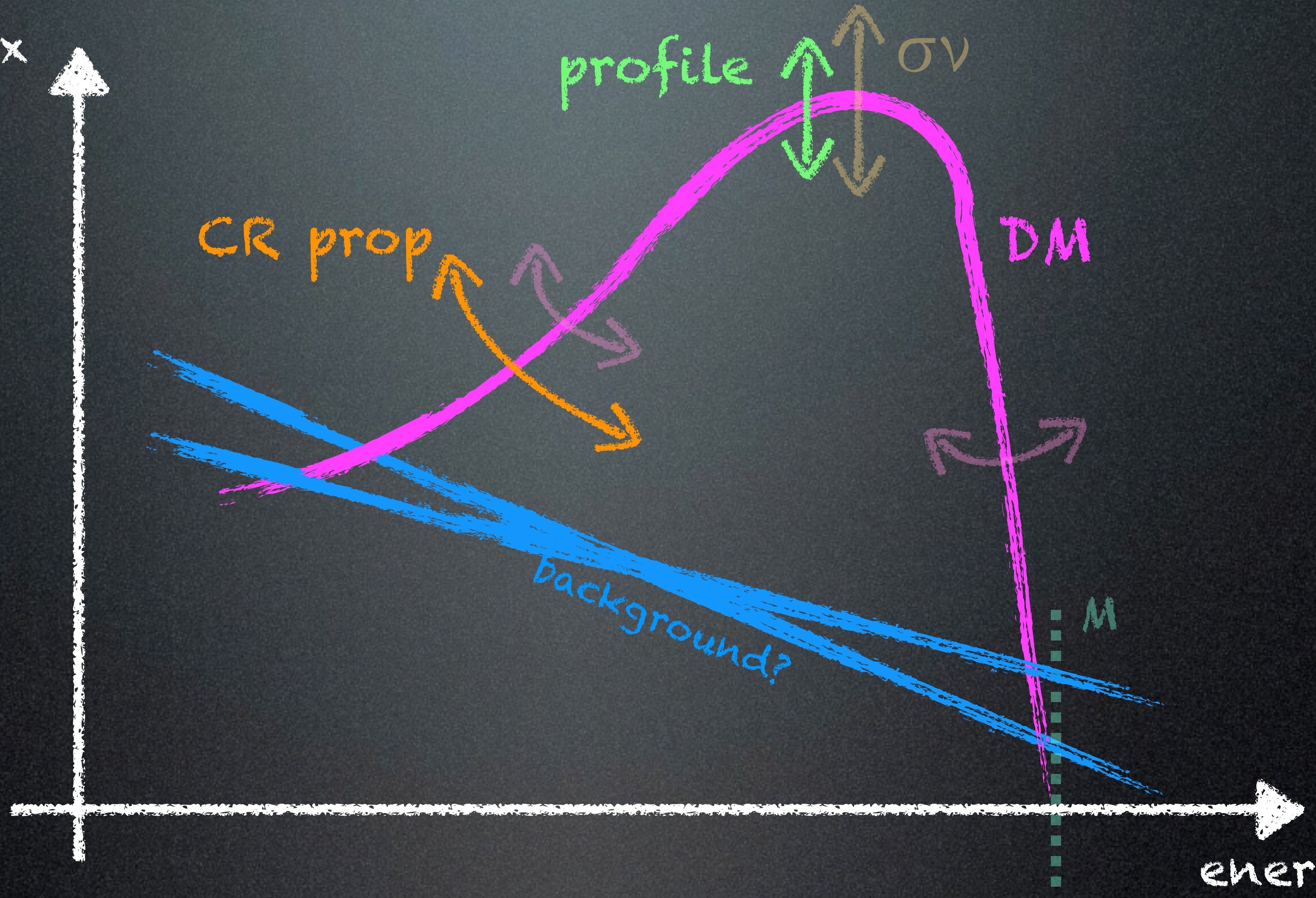
1. DM abundance/profile
2. propagation

Fluxes at detection



So what are the **astrophysics** parameters?

1. Dark Matter
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1. DM abundance/profile
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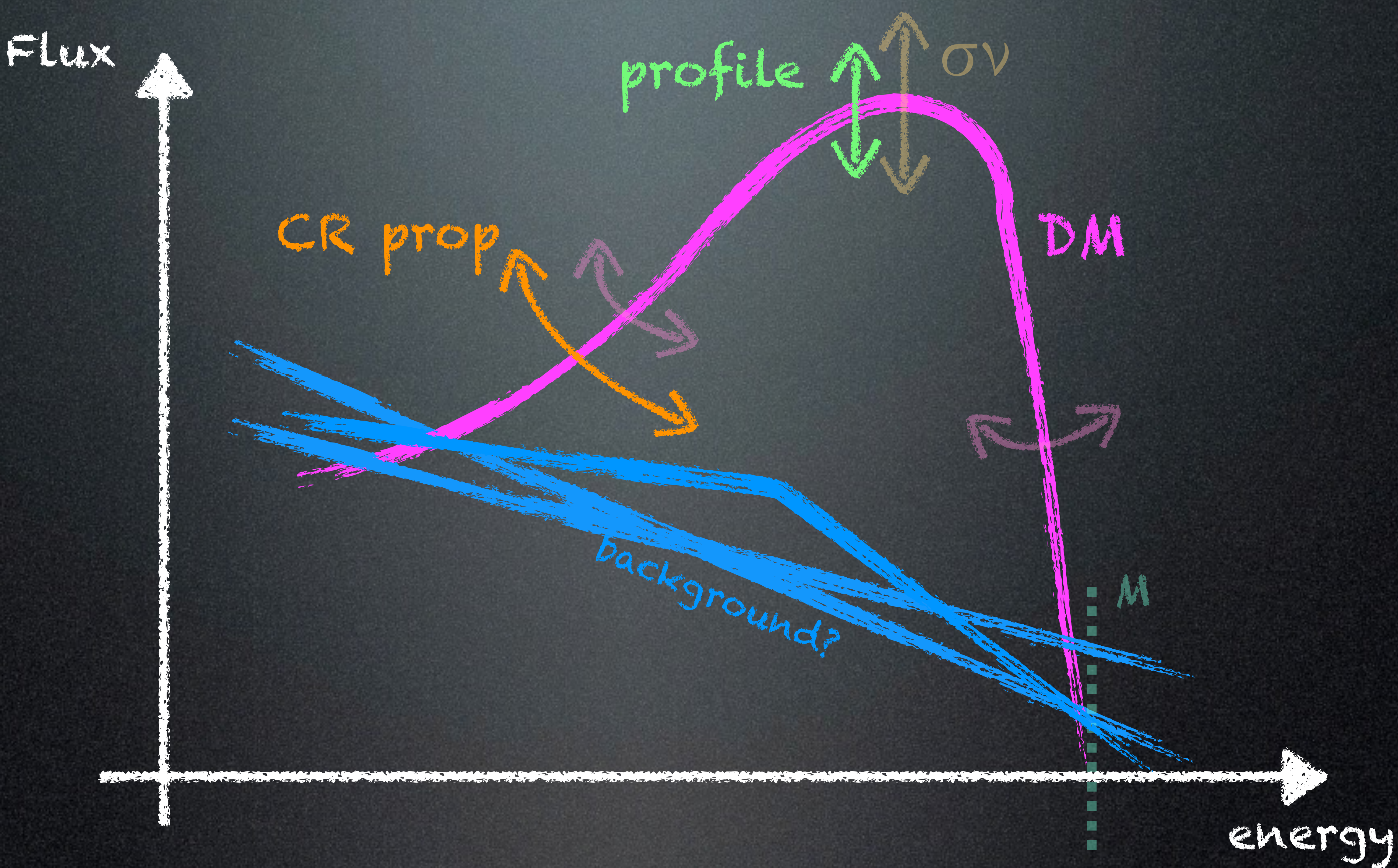
3. background

Fluxes at detection



So what are the **astrophysics** parameters?

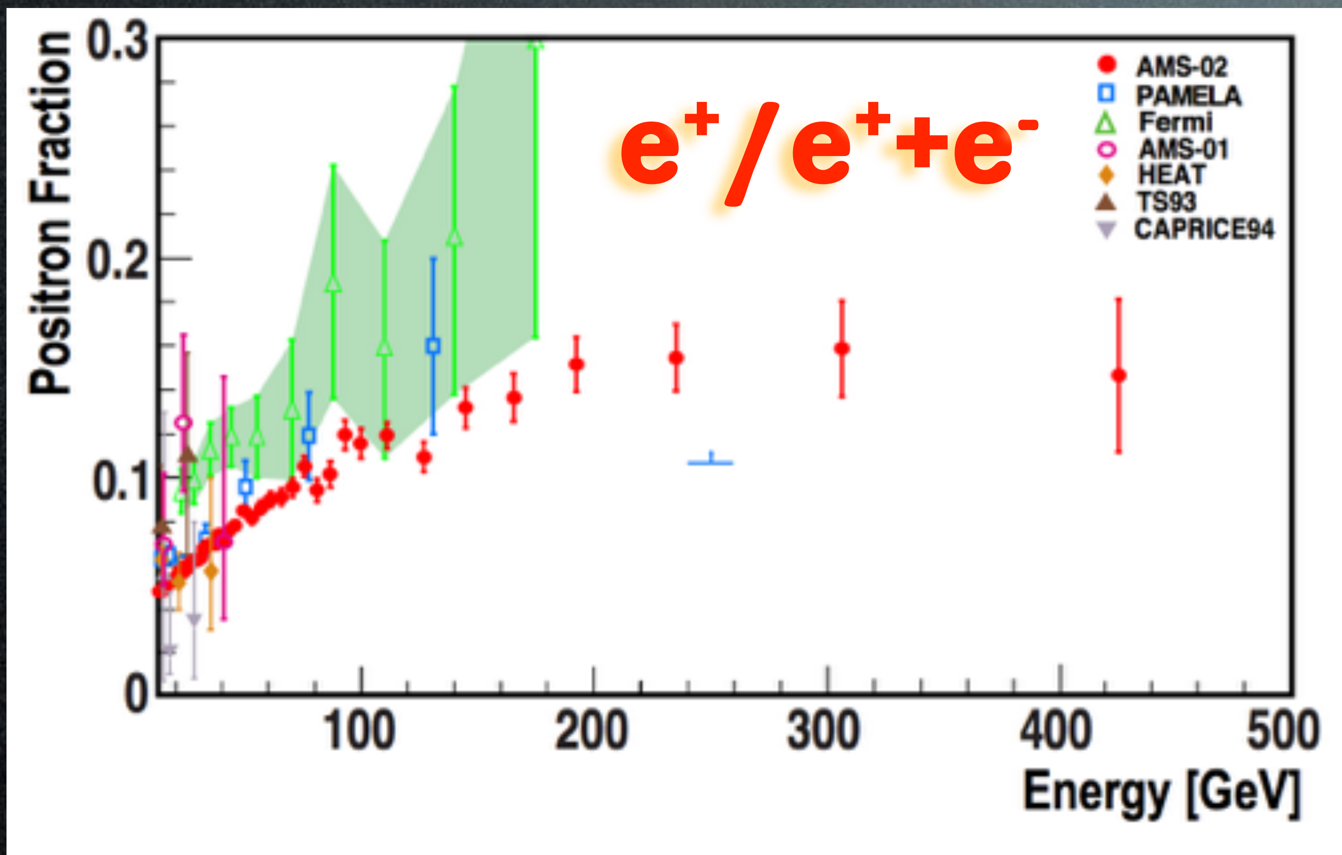
1. Dark Matter
2.
3.

1. DM abundance/profile
2. propagation
3. background

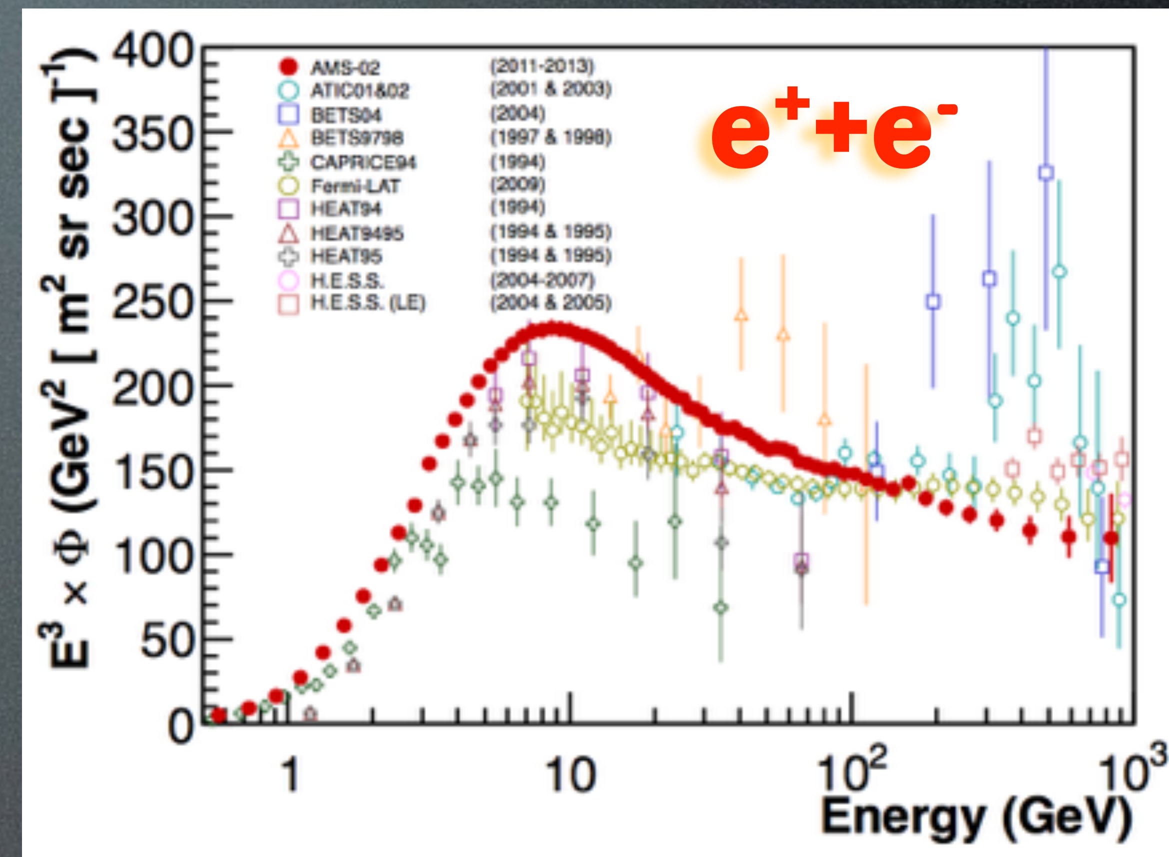
Data

Data: leptons

AMS-02

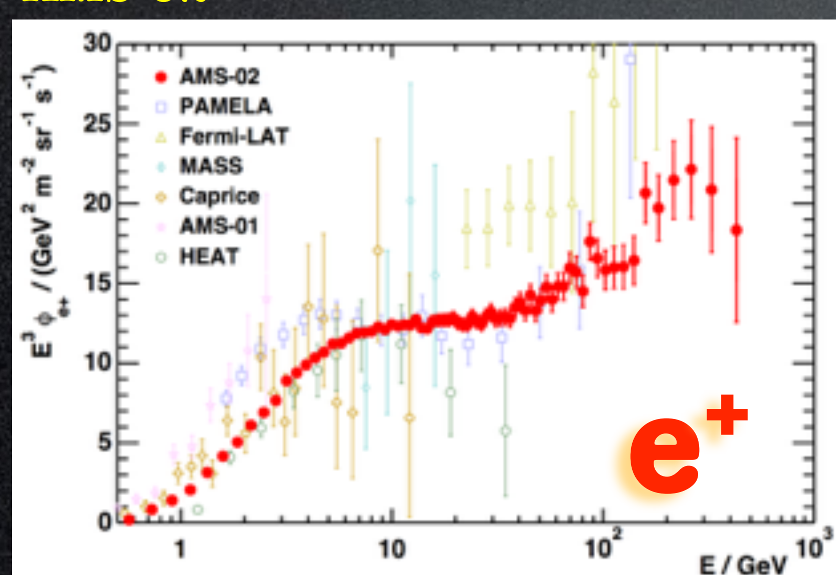


AMS-02

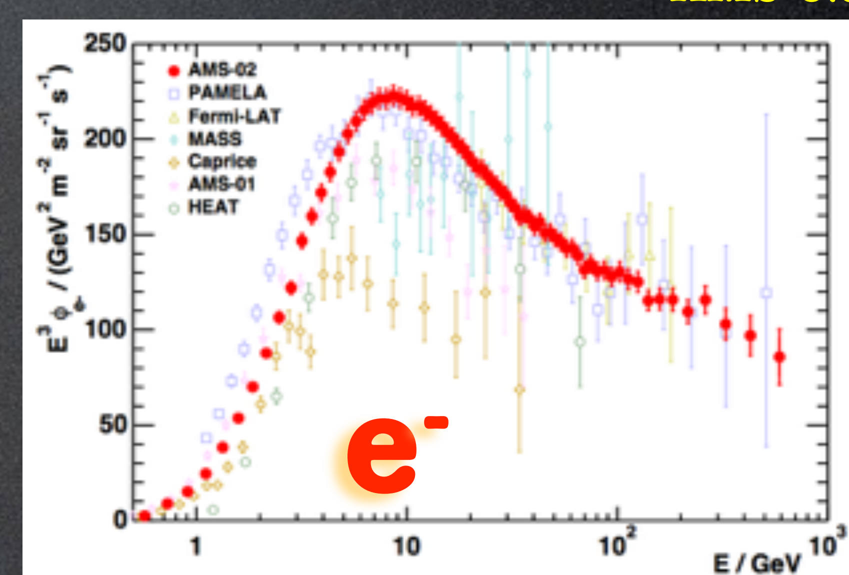


A. Kounine - ICRC2015 #300
S. Ting - ICRC2015

AMS-02

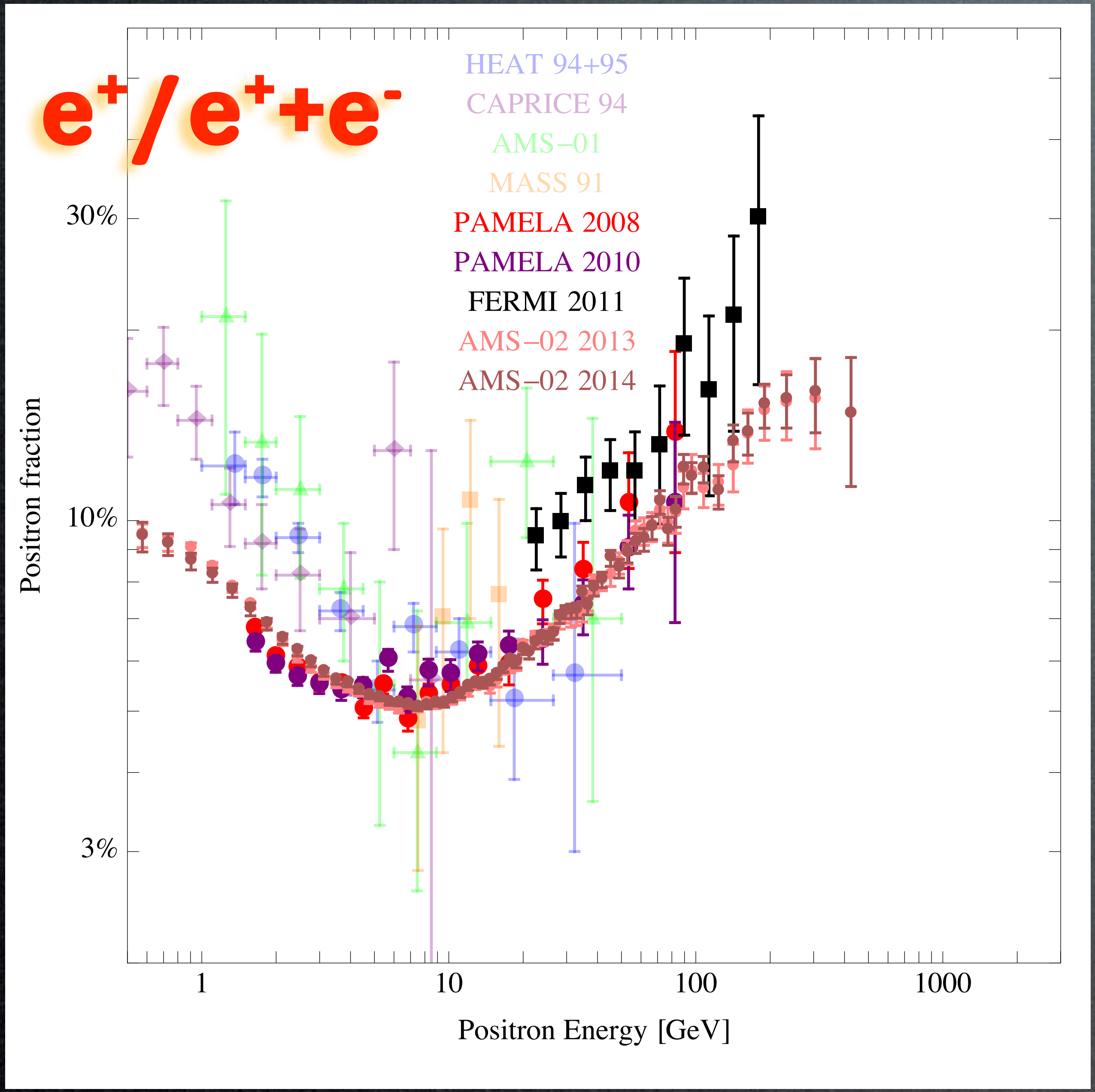


AMS-02

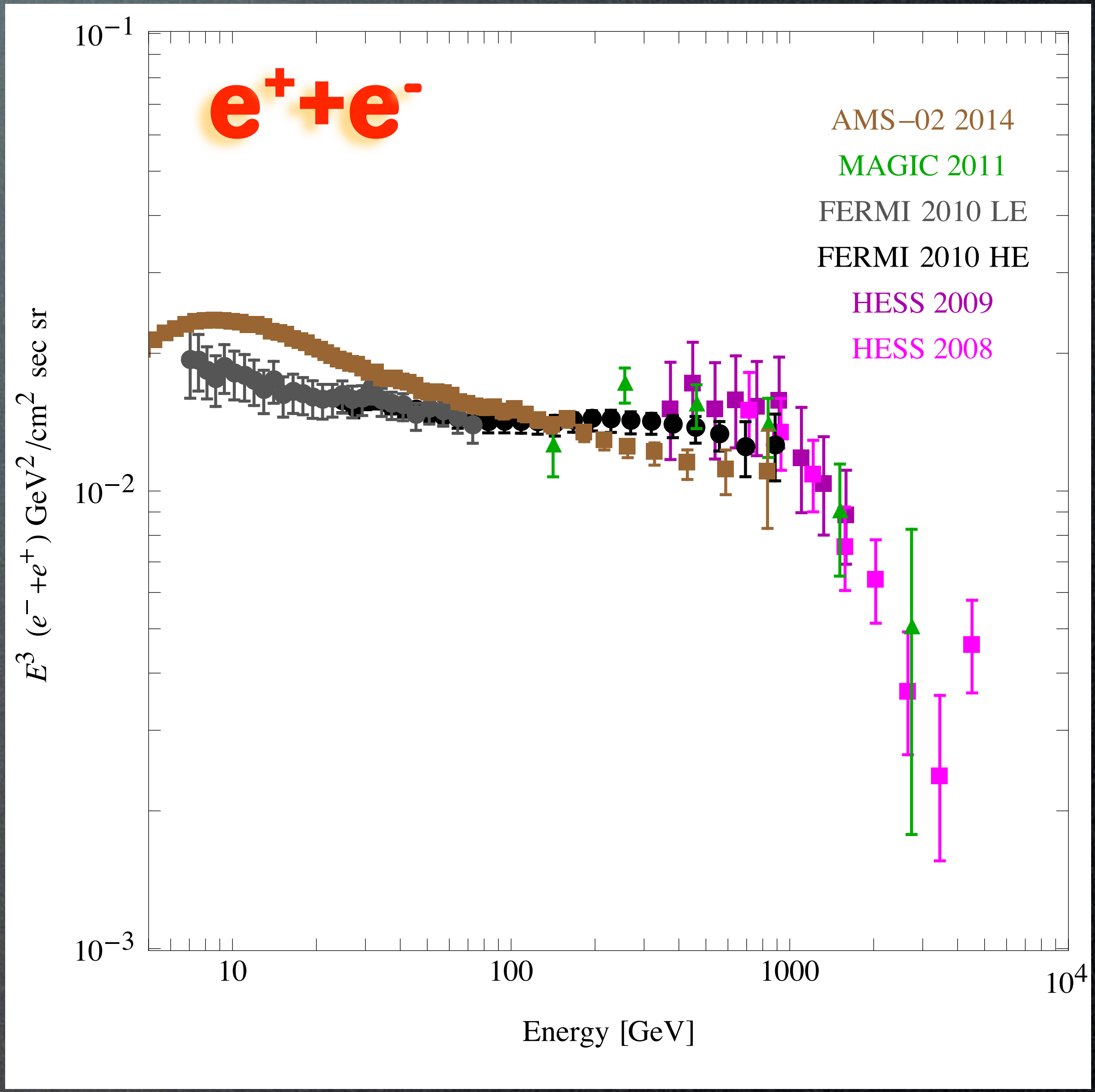


M. Duranti - ICRC2015 #237

Data: leptons

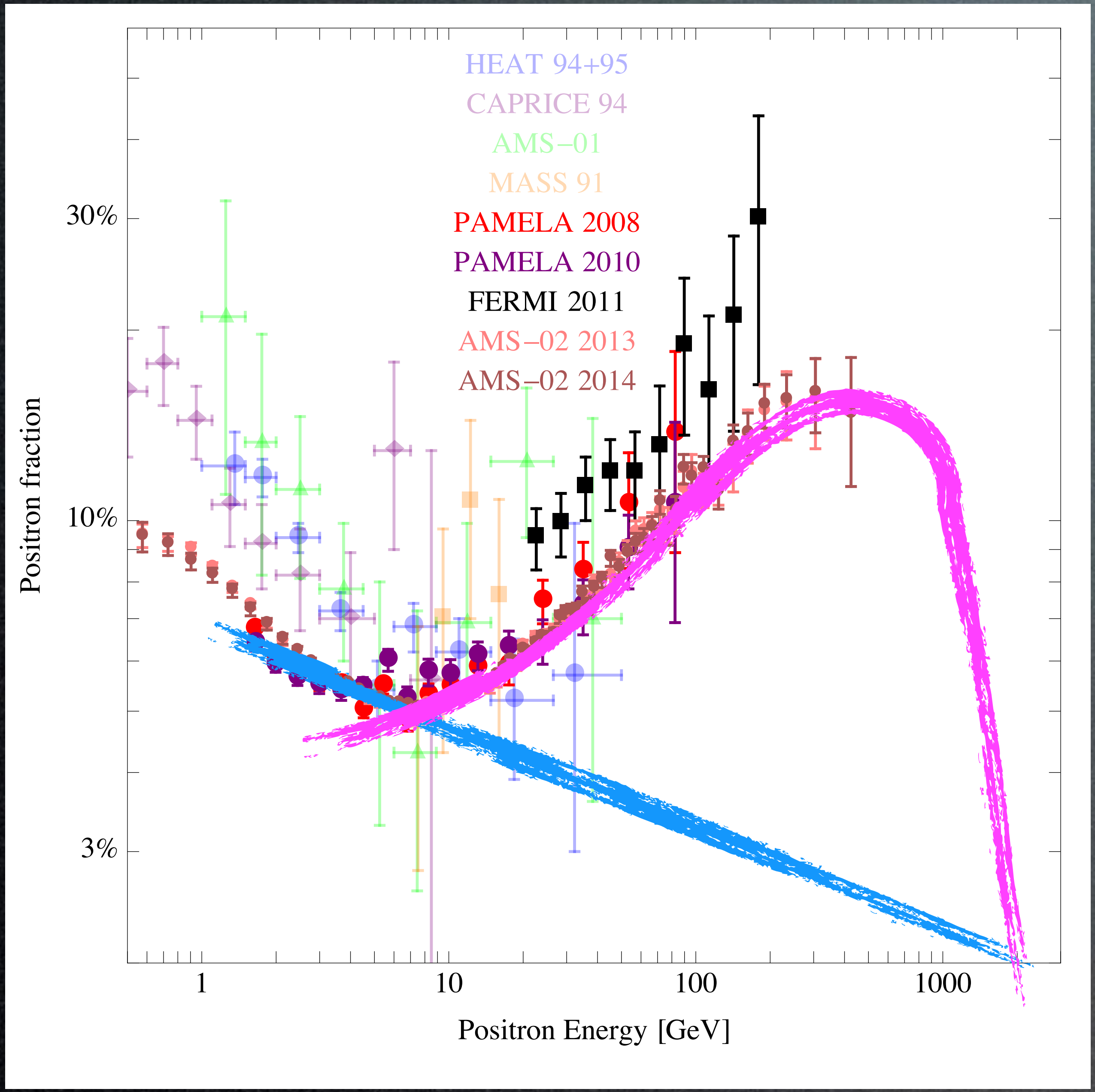


M. Cirelli - compilation ICRC 2015

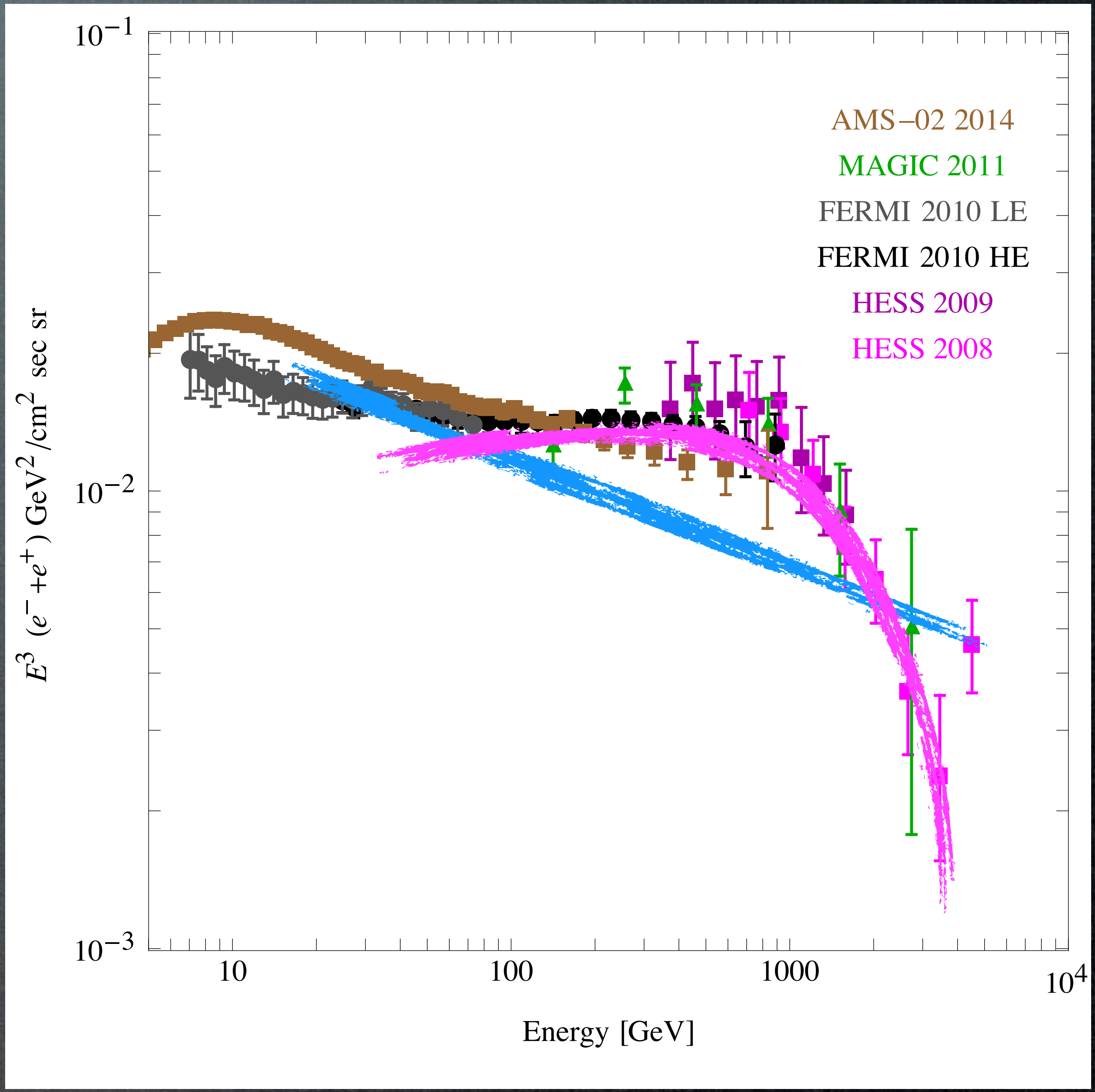


M. Cirelli - compilation ICRC 2015

Data: leptons



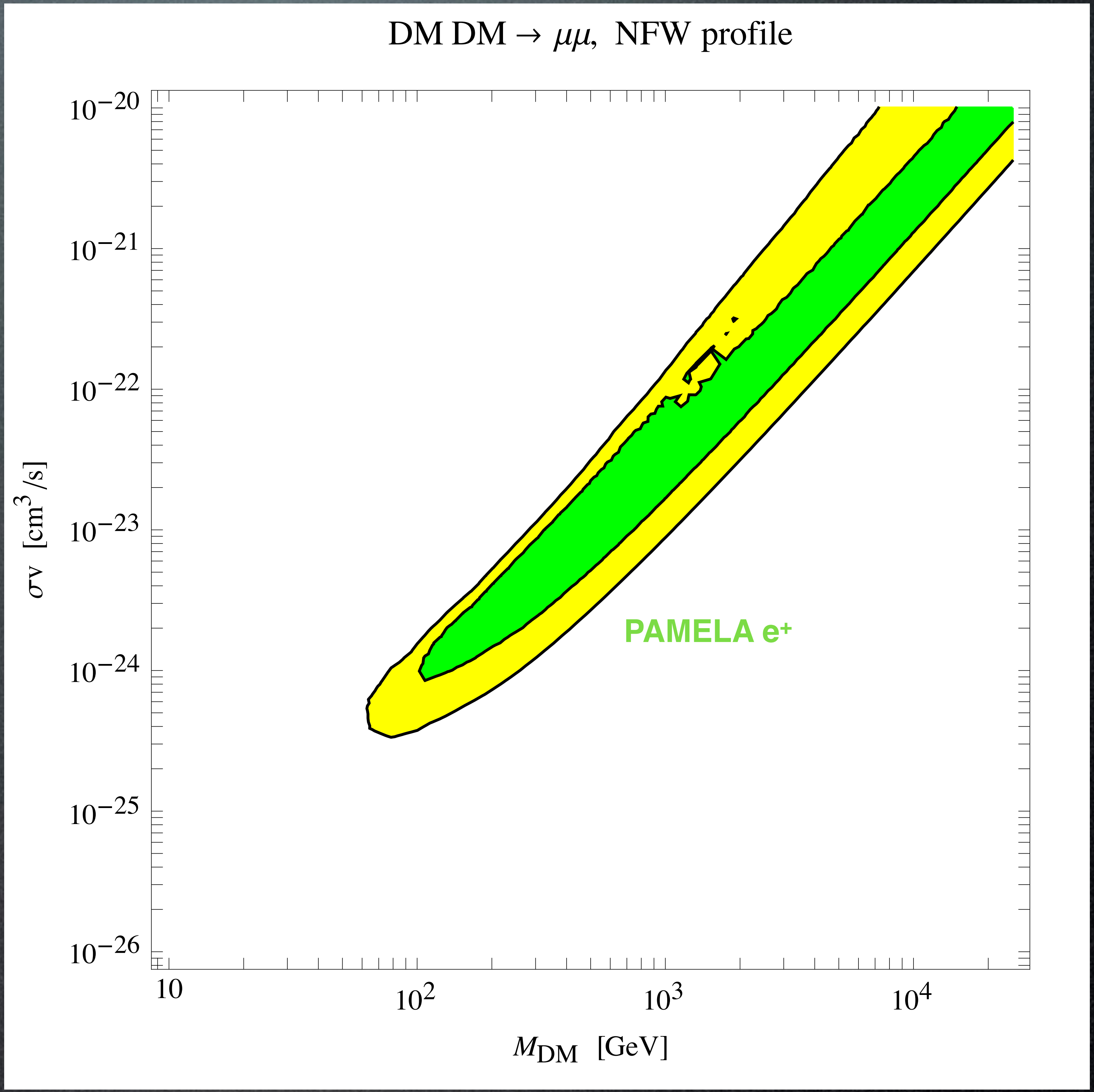
M. Cirelli - compilation ICRC 2015



M. Cirelli - compilation ICRC 2015

Dark Matter interpretation

- leptophilic
- m_{DM} > few 100 GeV
- huge annihilation cross section



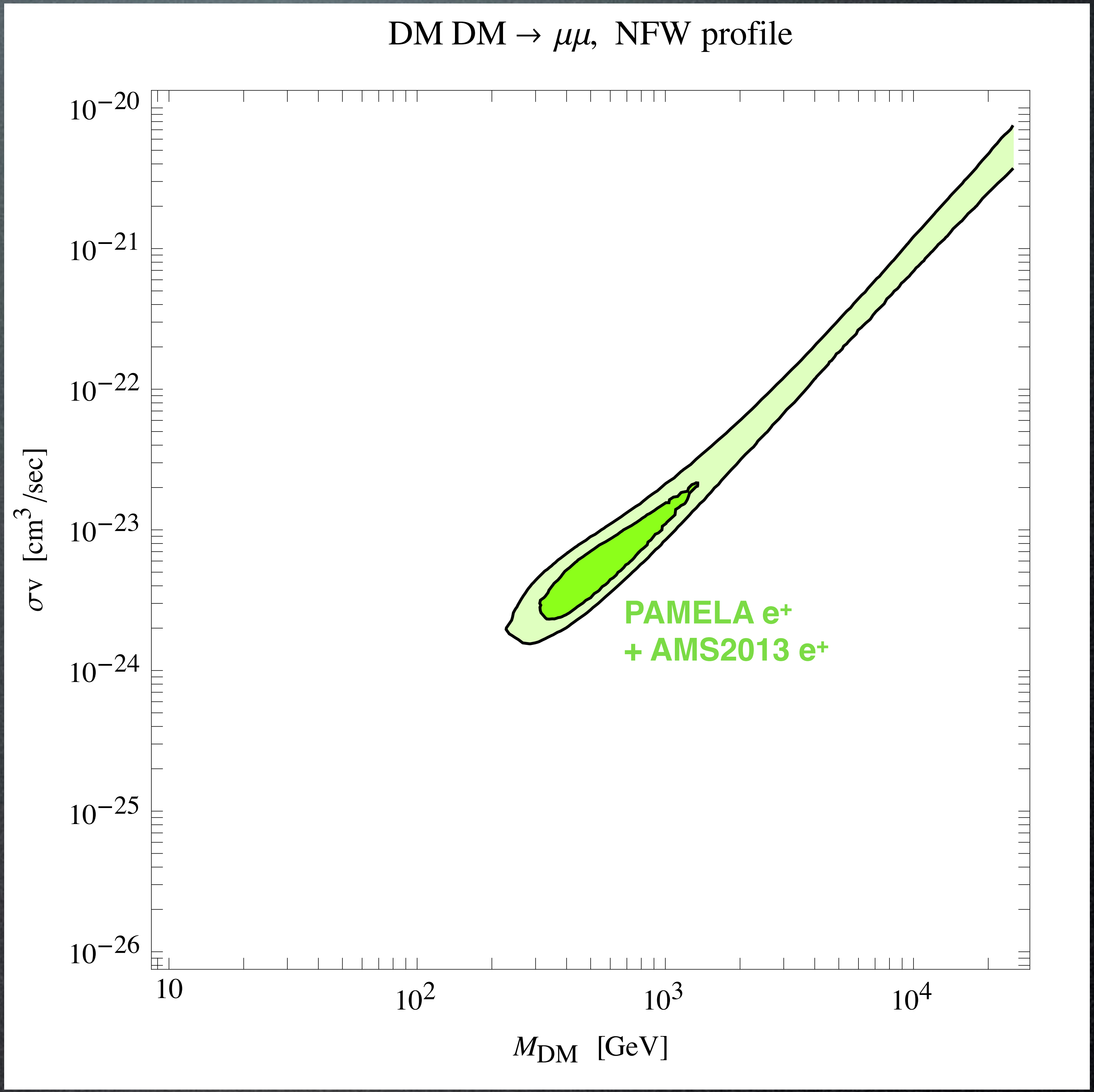
M. Cirelli - compilation ICRC 2015

Dark Matter interpretation

- leptophilic

- $m_{DM} \sim 1$ TeV

- huge annihilation cross section



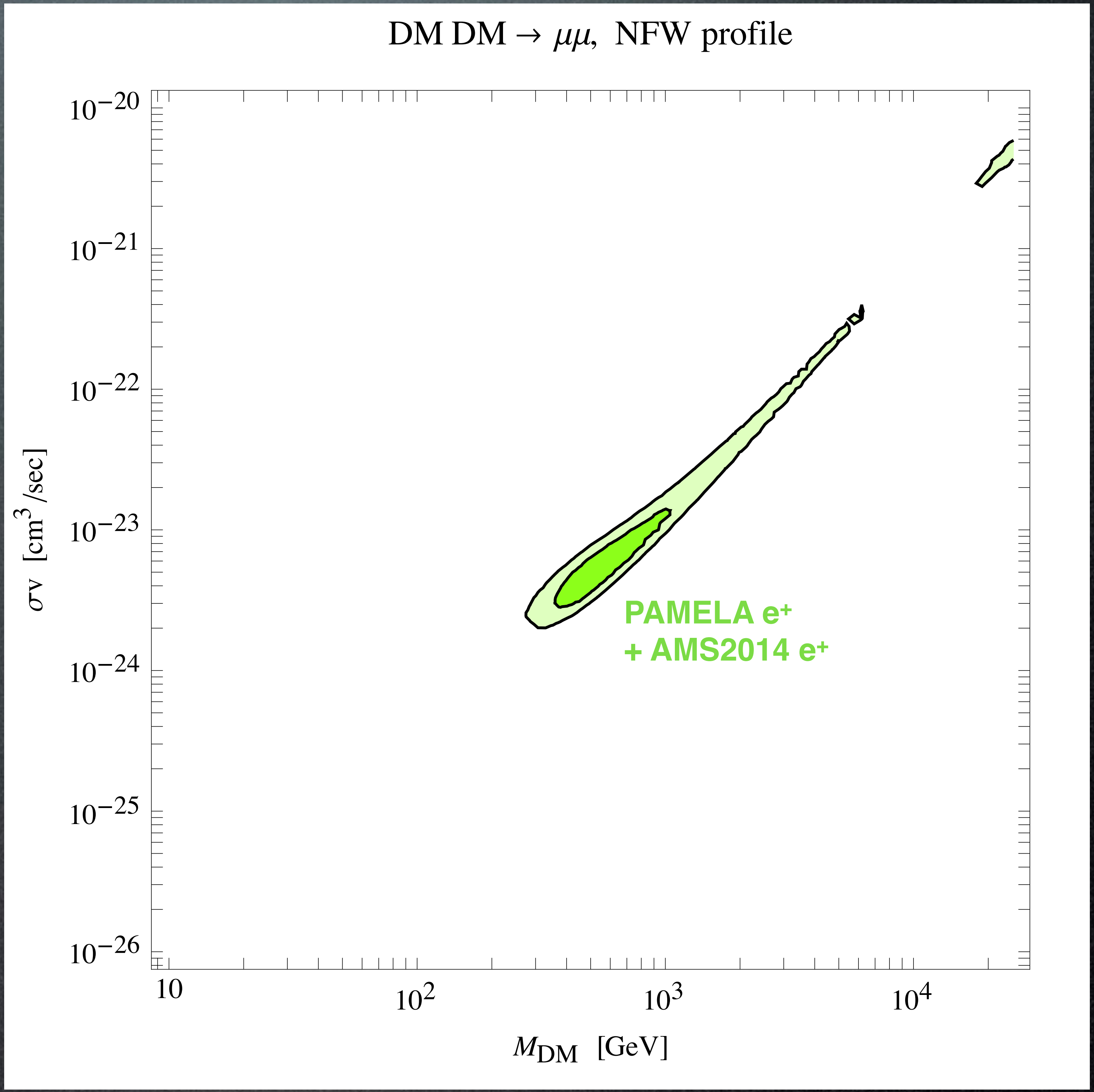
M. Cirelli - compilation ICRC 2015

Dark Matter interpretation

- leptophilic

- $m_{DM} \lesssim 1$ TeV

- huge annihilation cross section



M. Cirelli - compilation ICRC 2015

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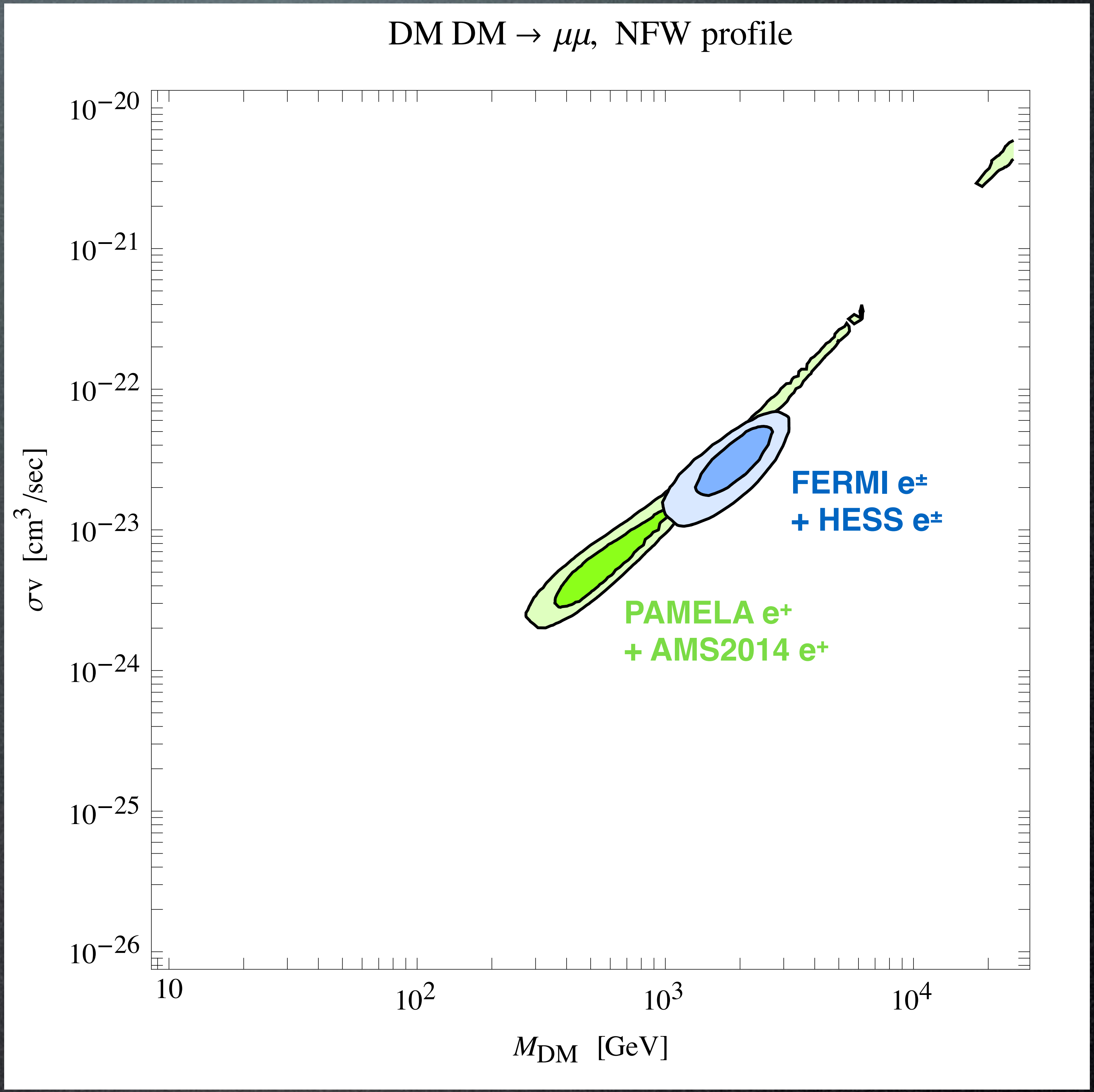
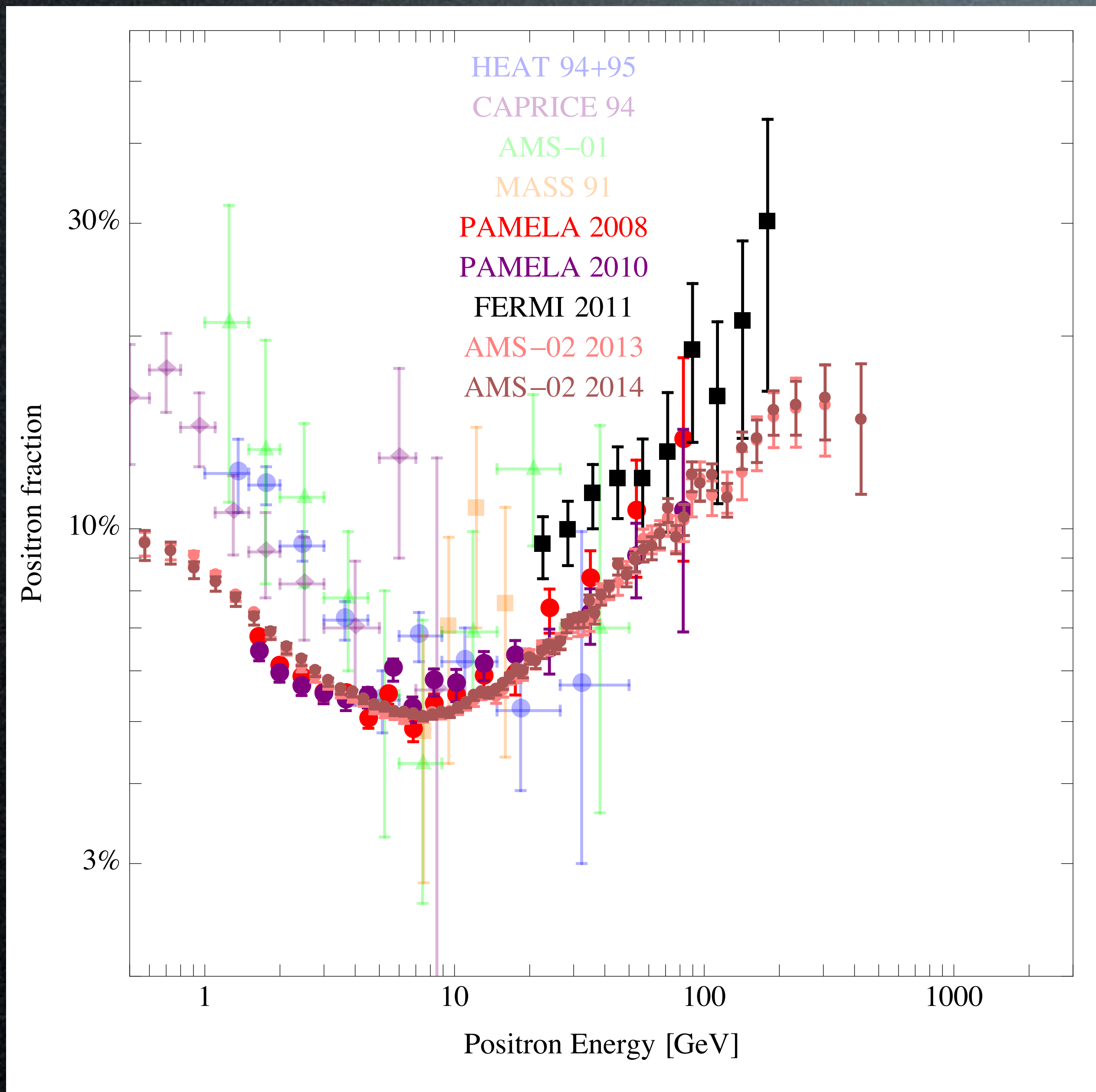
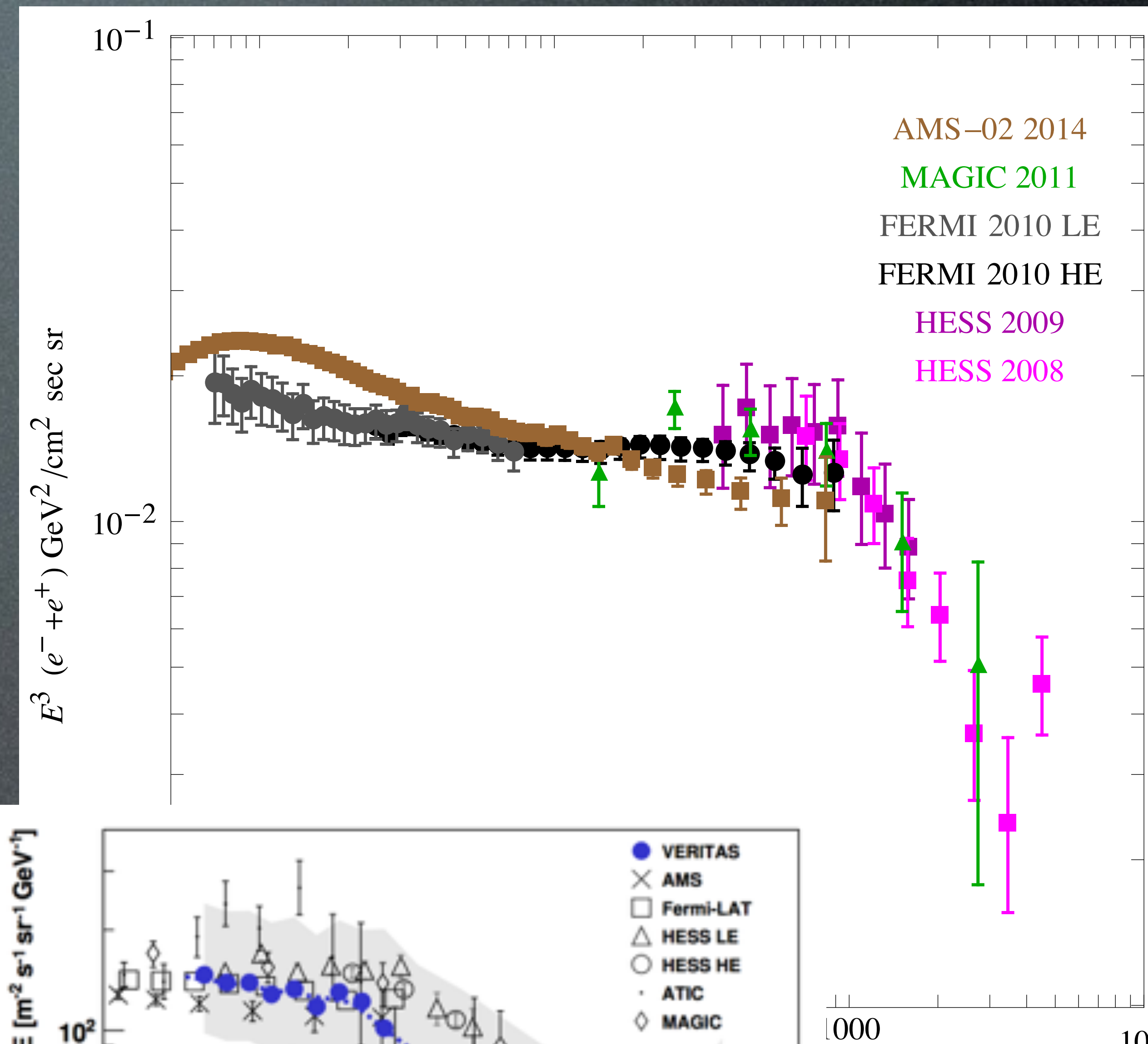
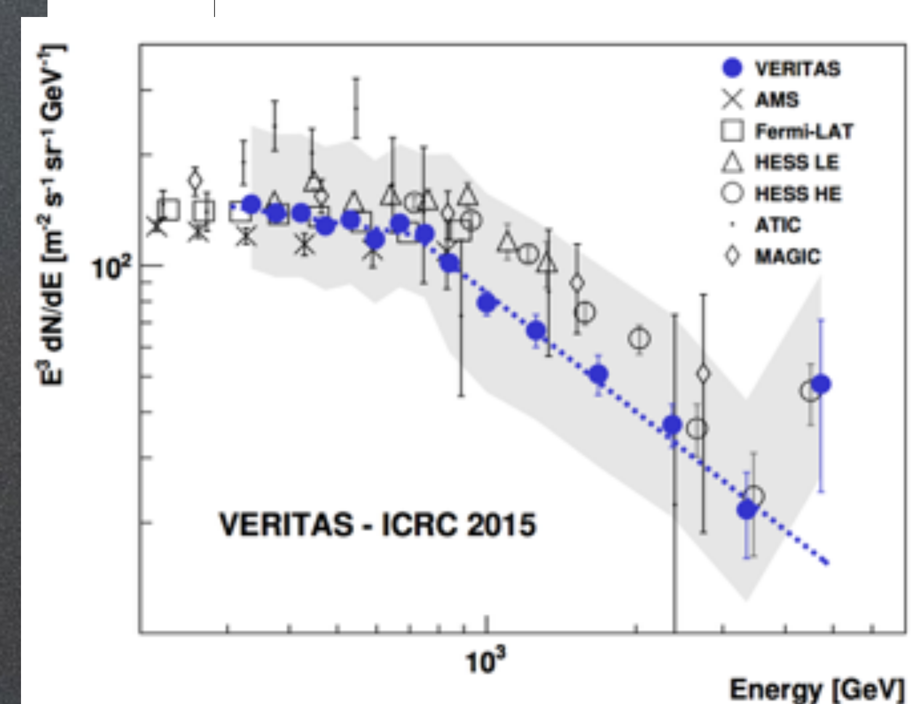


M. Cirelli - compilation ICRC 2015

Data: leptons

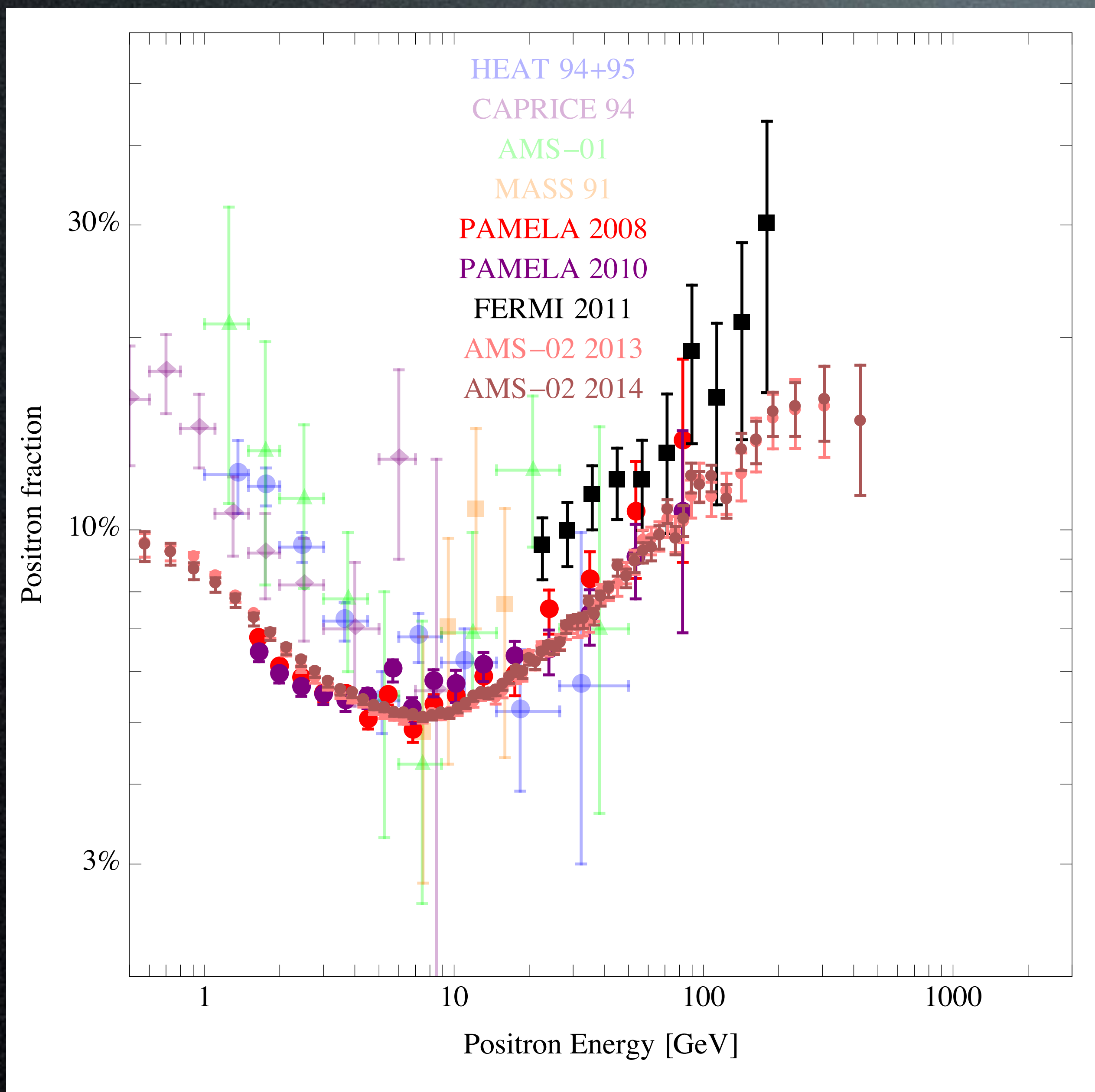


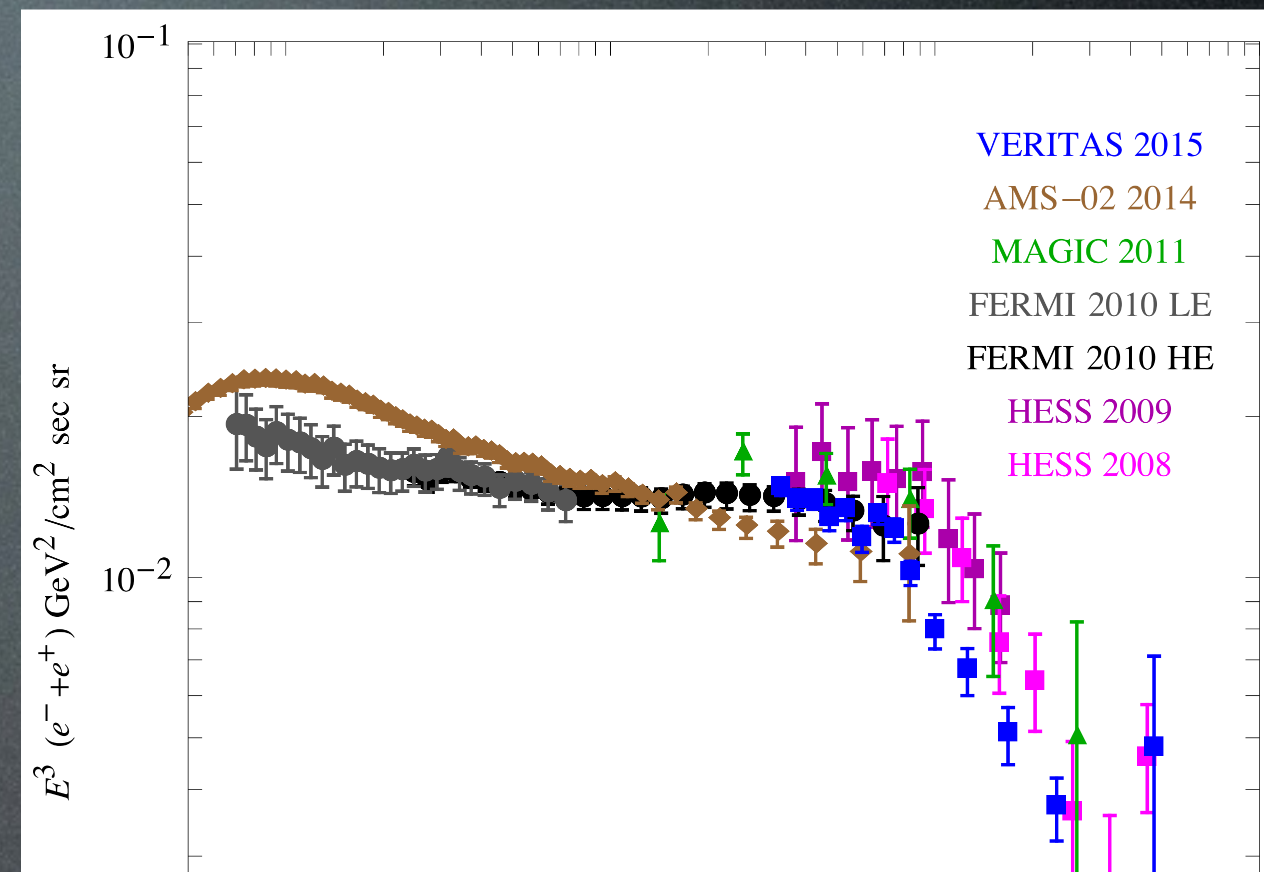


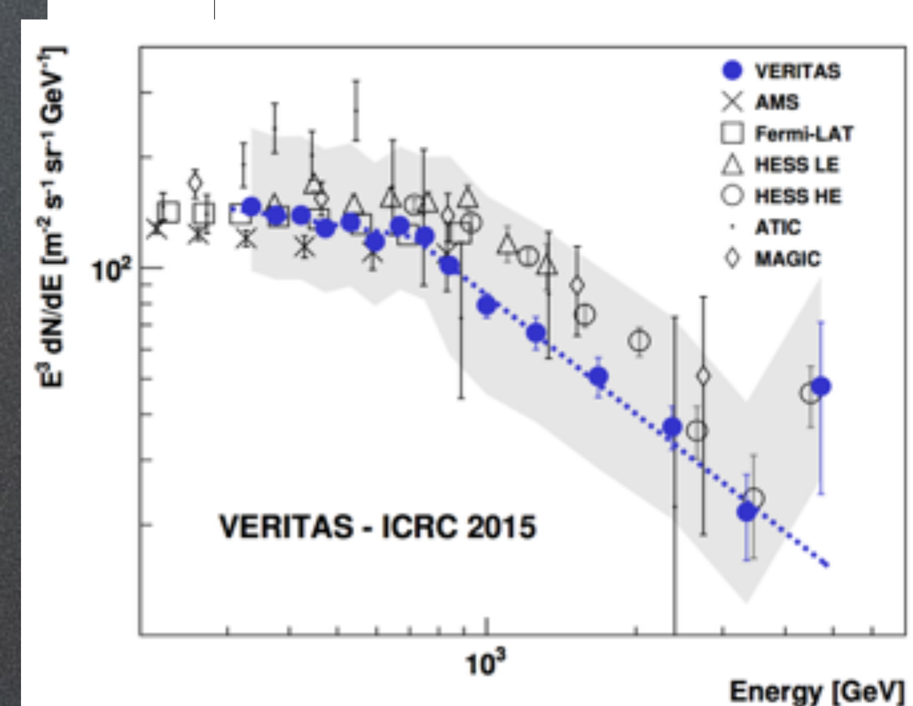


D. Staszak - ICRC2015 #411

Data: leptons







“We urge caution in over-interpretation of the uptick in the final VERITAS data point”

D. Staszak - ICRC2015 #411

D. Staszak - ICRC2015 #411

Dark Matter interpretation

- leptophilic
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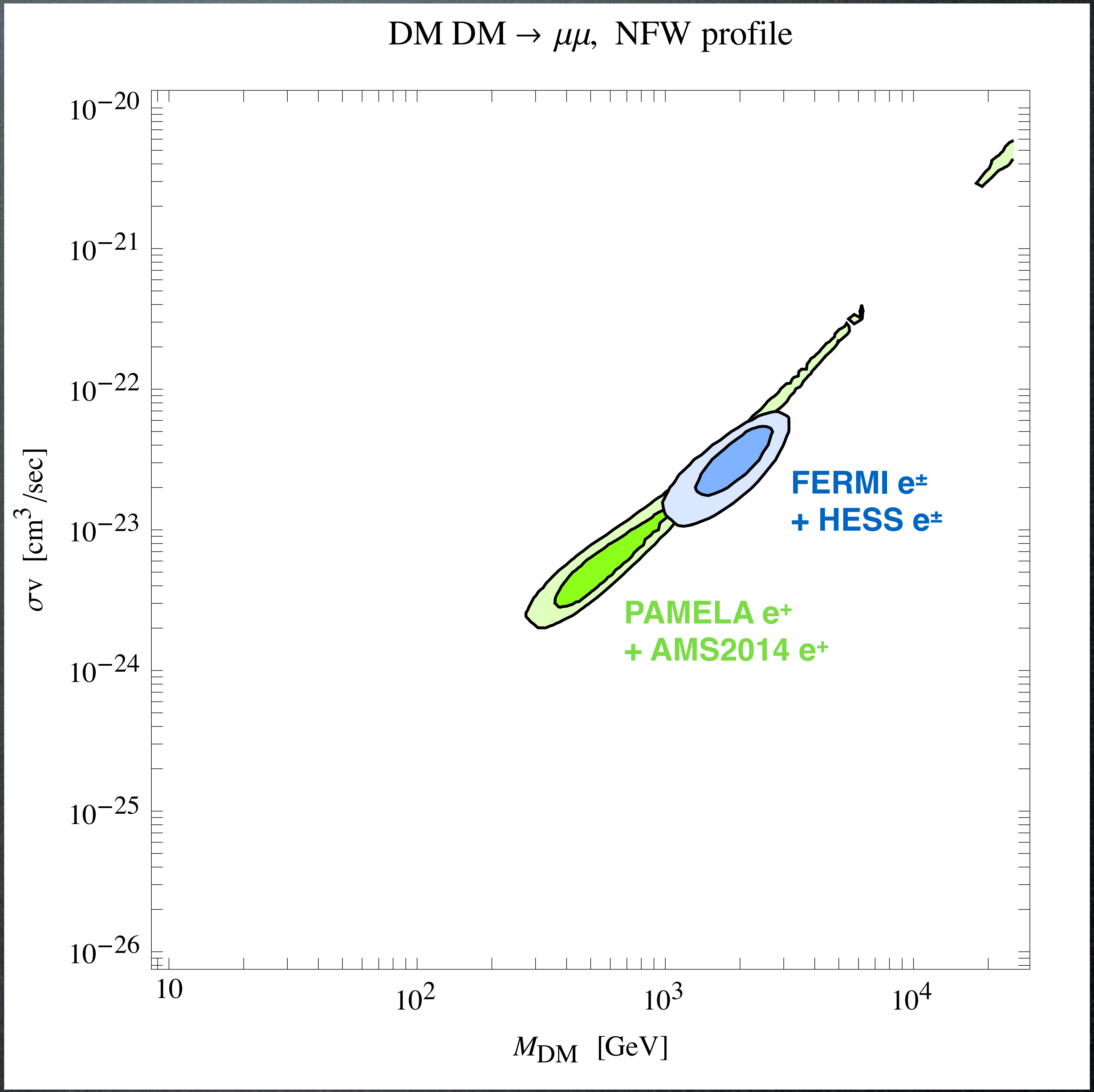

M. Cirelli - compilation ICRC 2015

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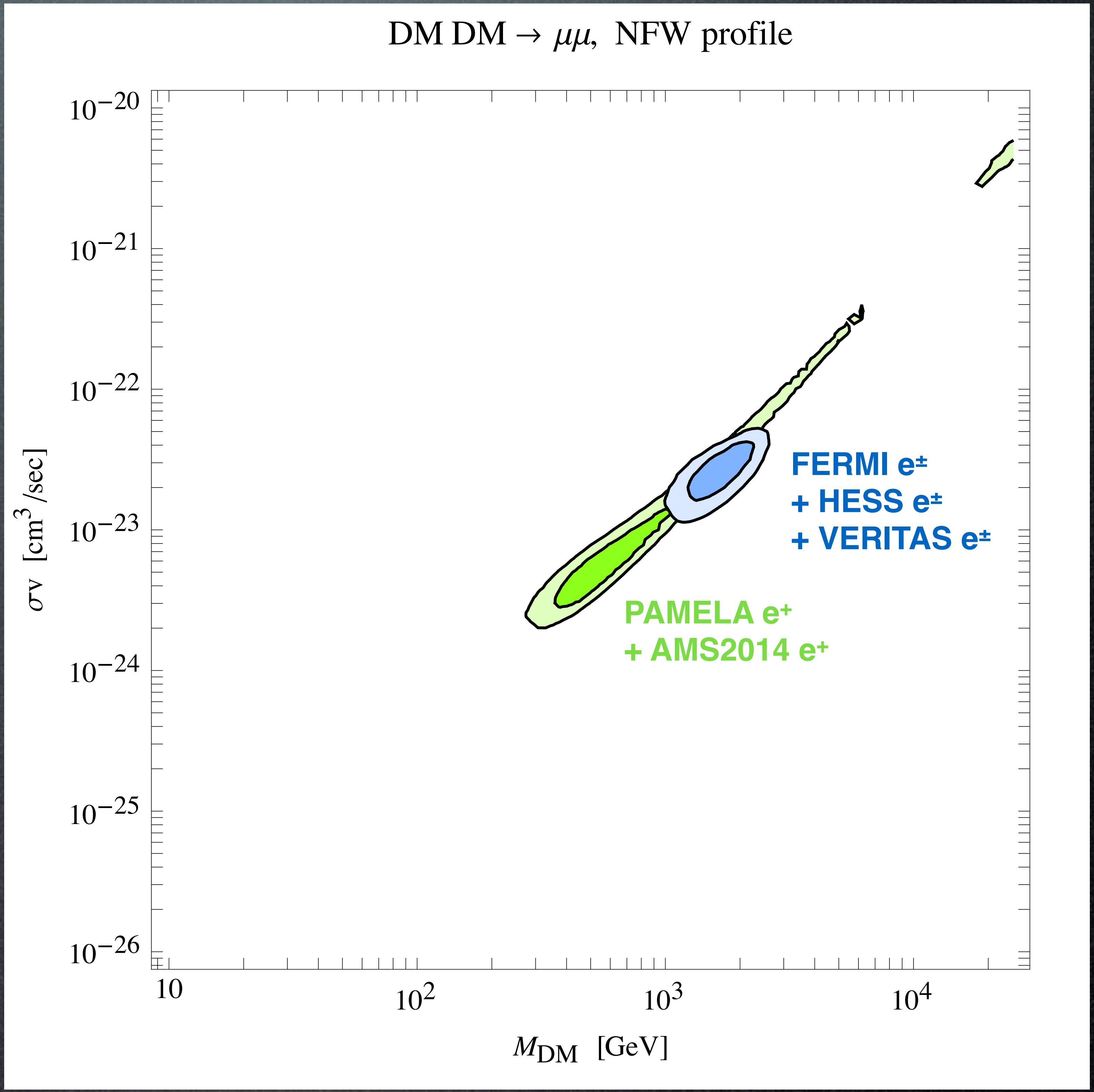

M. Cirelli - compilation ICRC 2015

Dark Matter interpretation

However:

Dark Matter interpretation

However:

- increased precision brings increased tension

  "The improved accuracy of AMS-02 on the lepton flux now excludes channels previously allowed." M. Boudaud - ICRC2015 #1183

Dark Matter interpretation

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  "The improved accuracy of AMS-02 on the lepton flux now excludes channels previously allowed." M. Boudaud - ICRC2015 #1183

- combination of annihilation channels are possible

Dark Matter interpretation

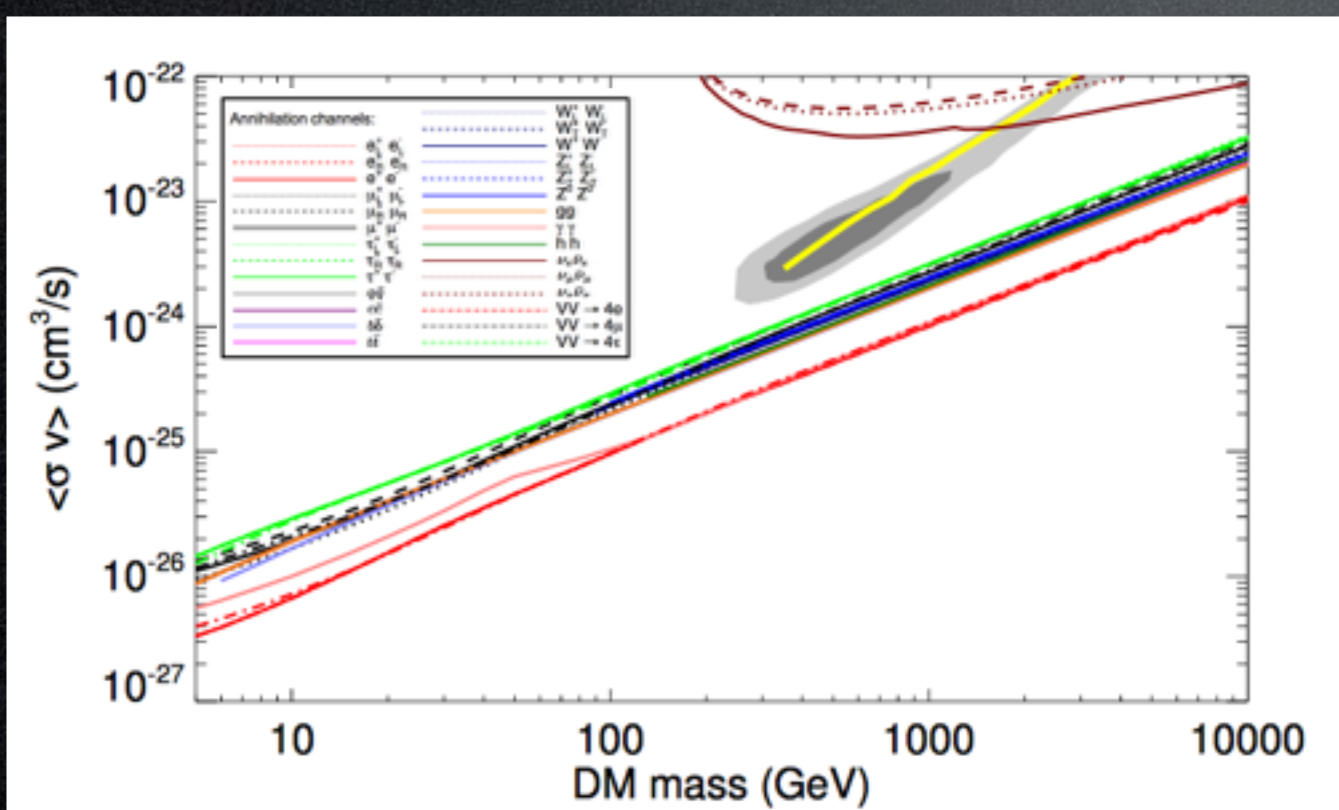
However:

- increased precision brings increased tension

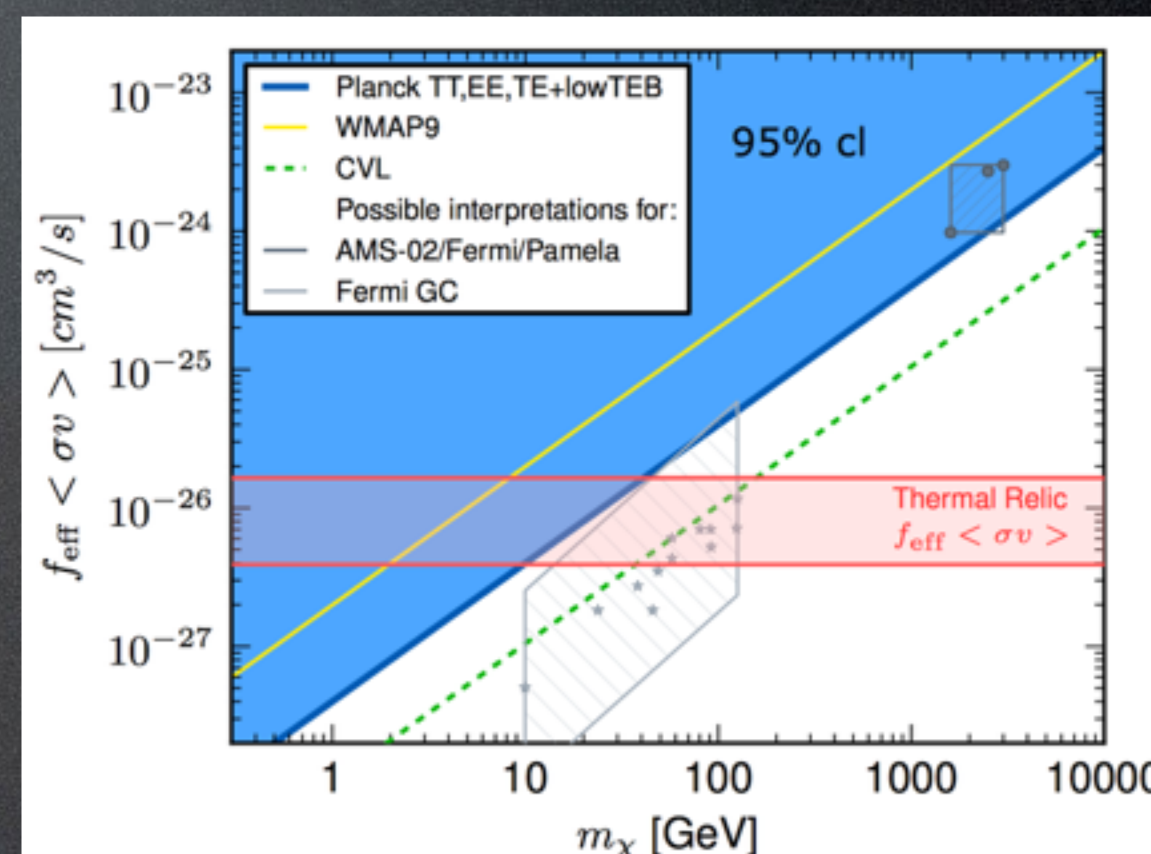
  "The improved accuracy of AMS-02 on the lepton flux now excludes channels previously allowed." M. Boudaud - ICRC2015 #1183

- combination of annihilation channels are possible

- constraints: gamma rays, neutrinos, CMB...

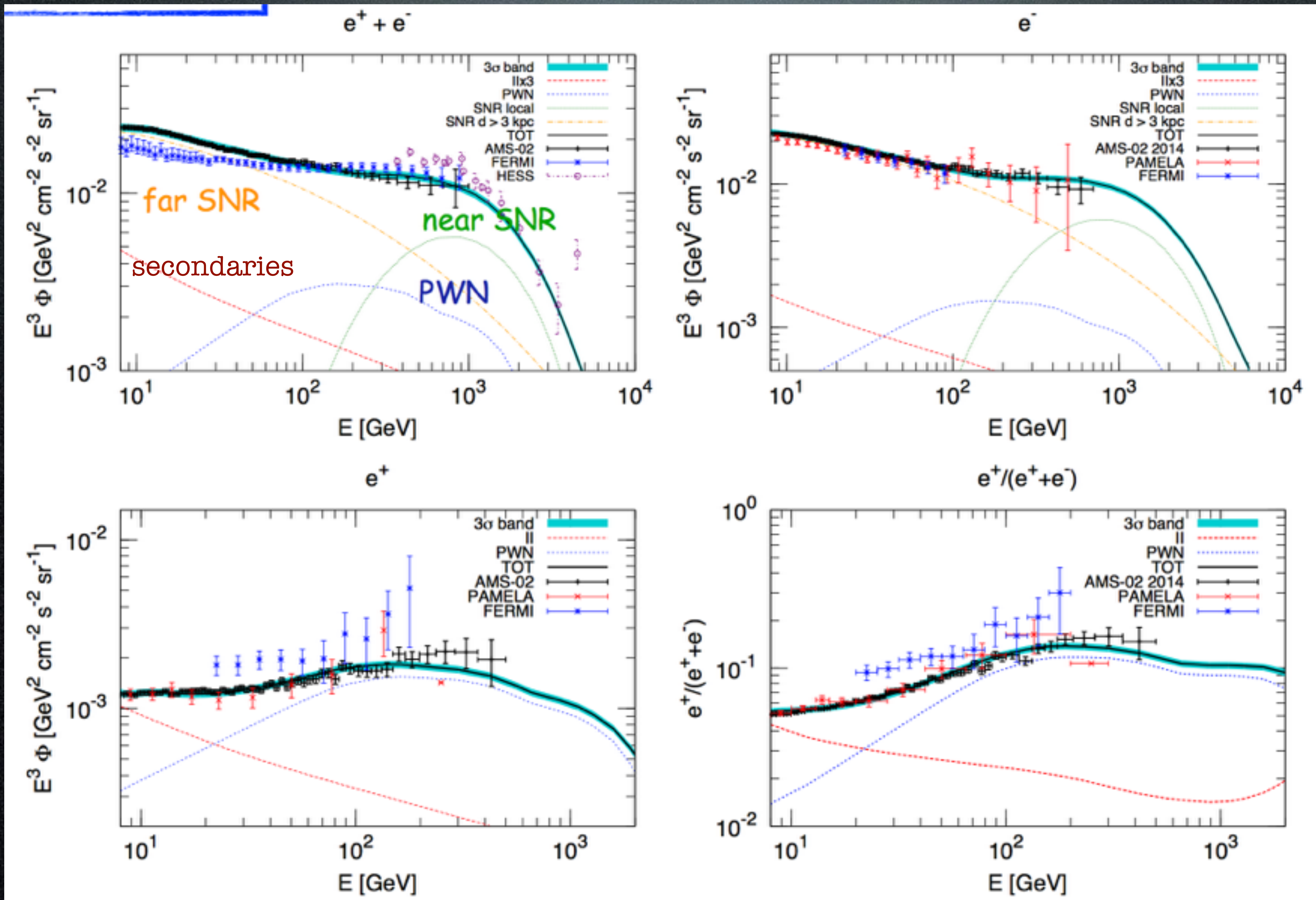


T.Slatyer 1506.03811



Planck 2015 (1502.01589)

Astro interpretation

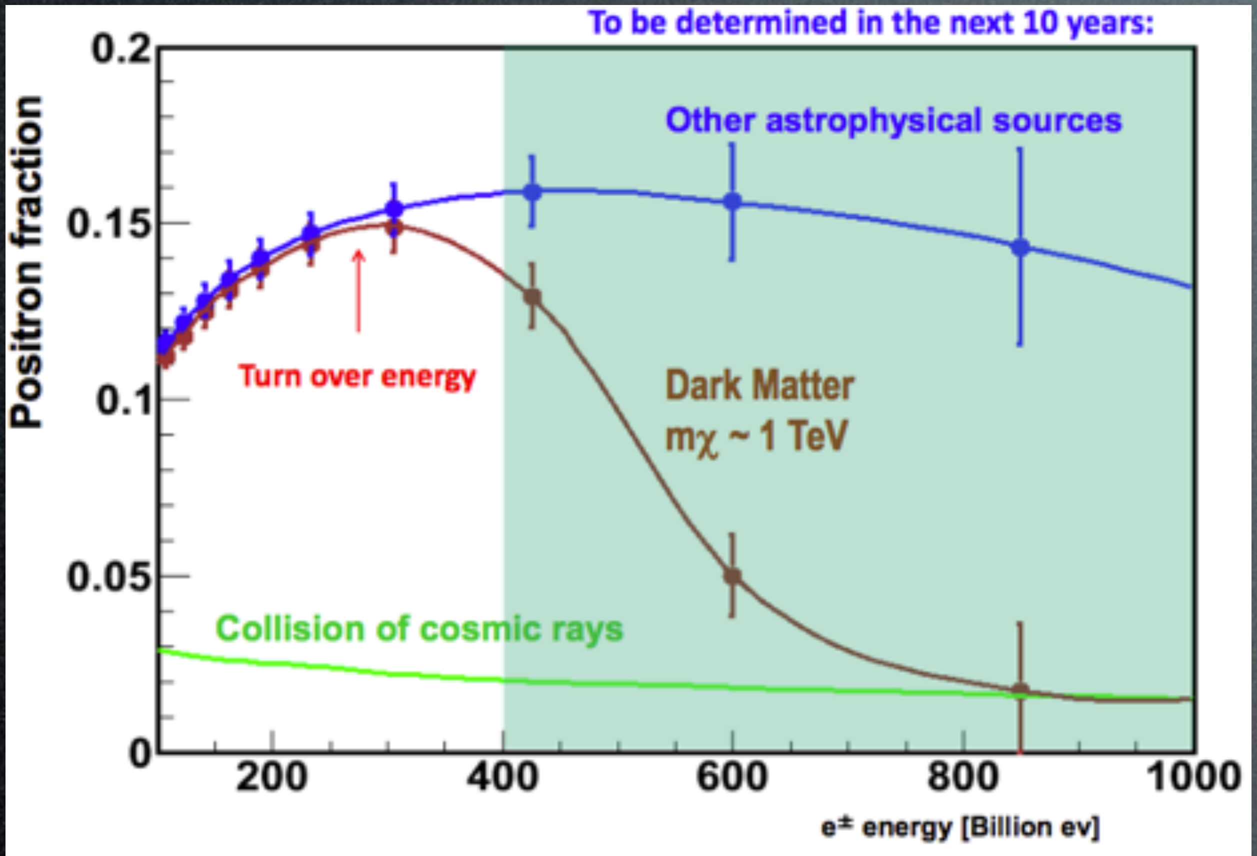


M. Di Mauro
ICRC2015
#1177

Also: magnetars consistent with known properties C. Grimani - ICRC2015 #457

Discriminating

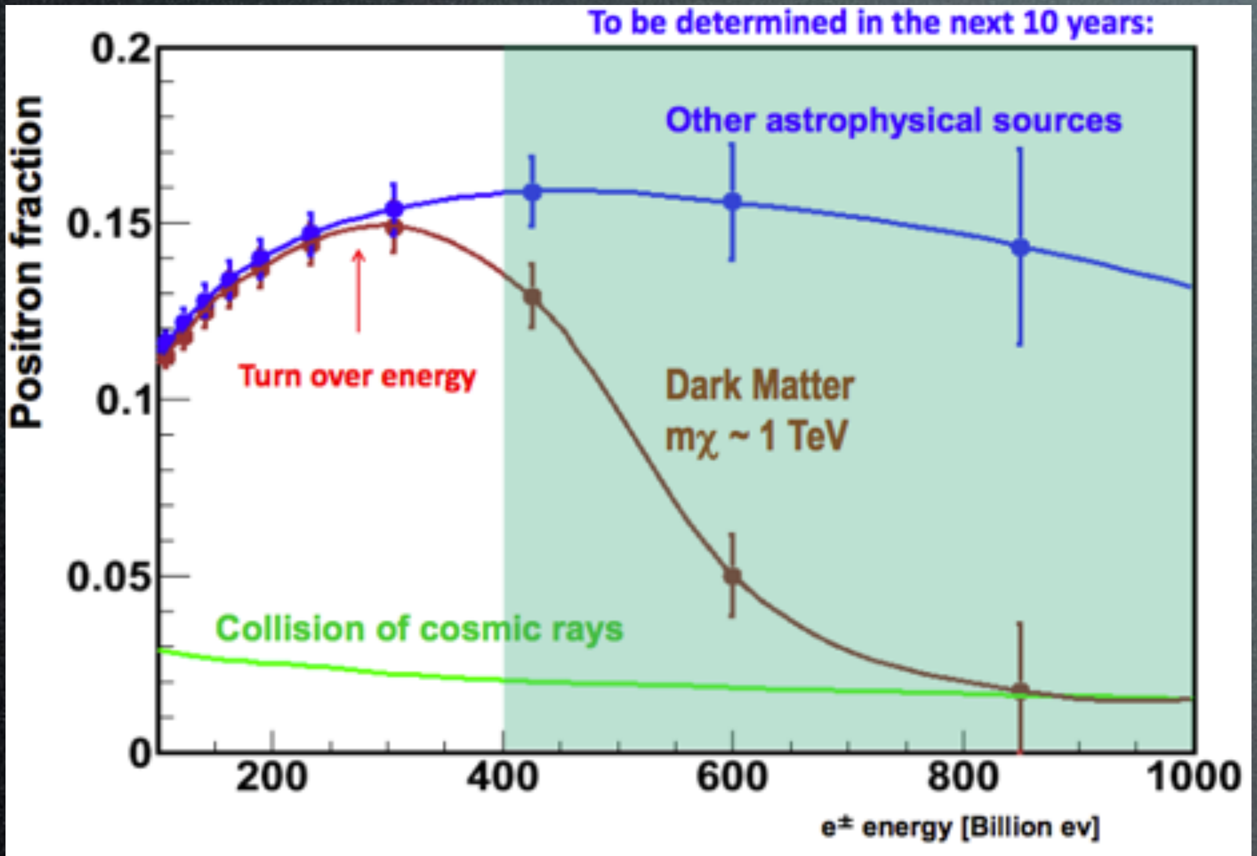
Shape of the spectrum?



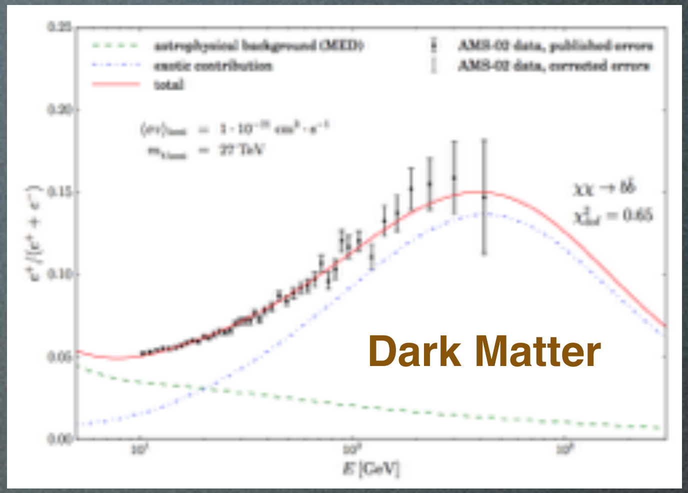
S. Ting - ICRC2015

Discriminating

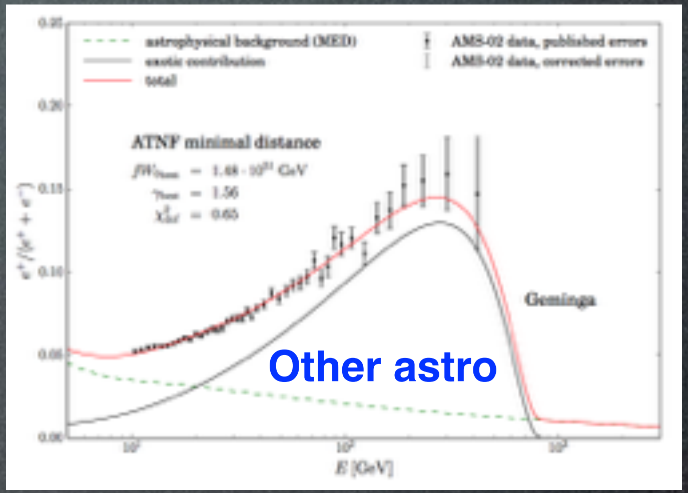
Shape of the spectrum?



S. Ting - ICRC2015

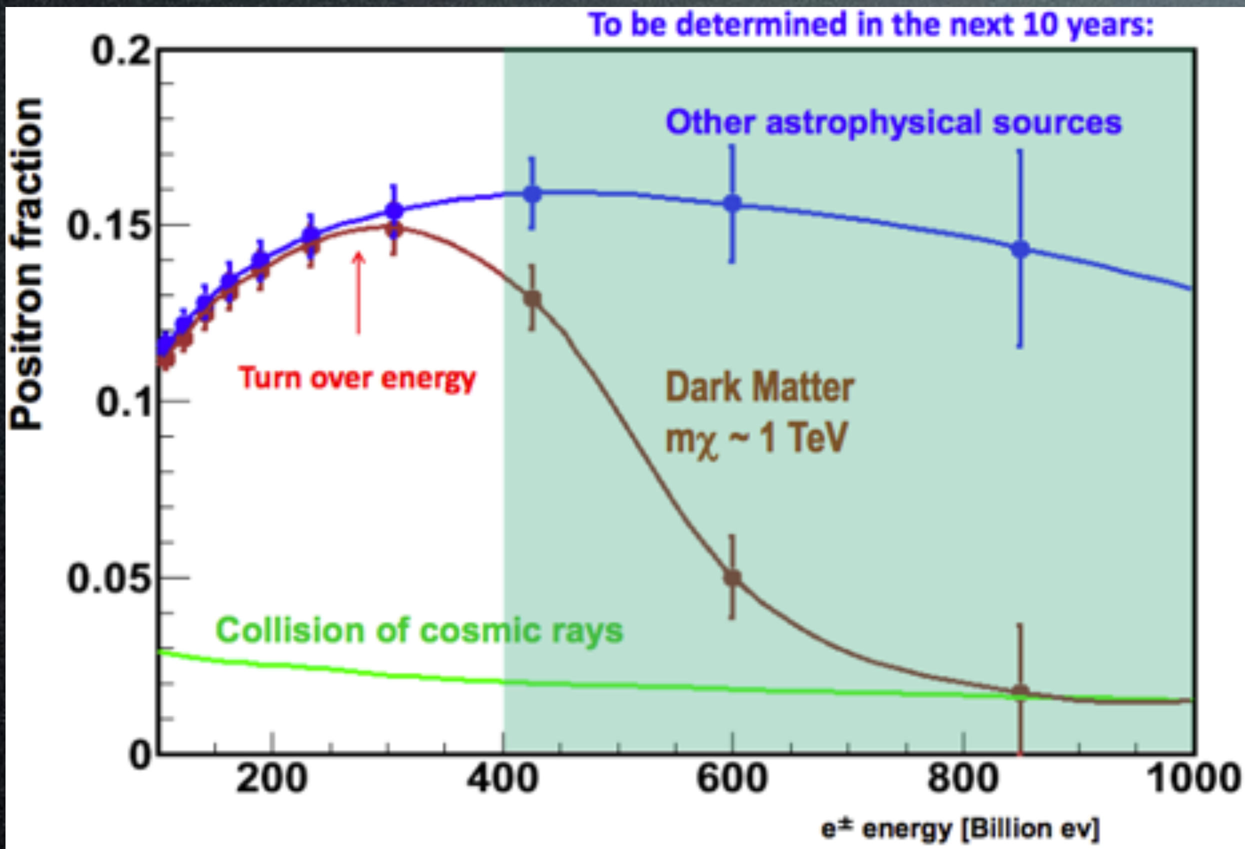


M. Boudaud - ICRC 2015 #1183

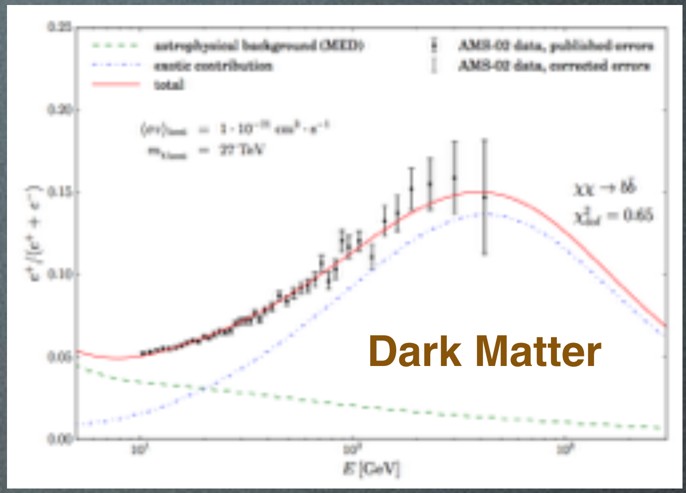


Discriminating

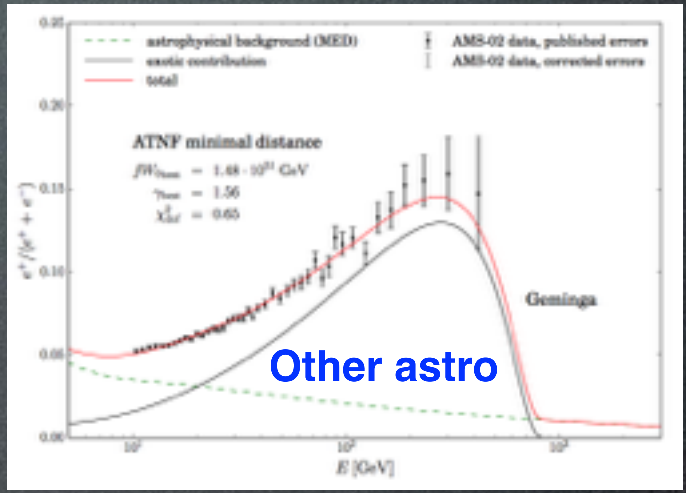
Shape of the spectrum?



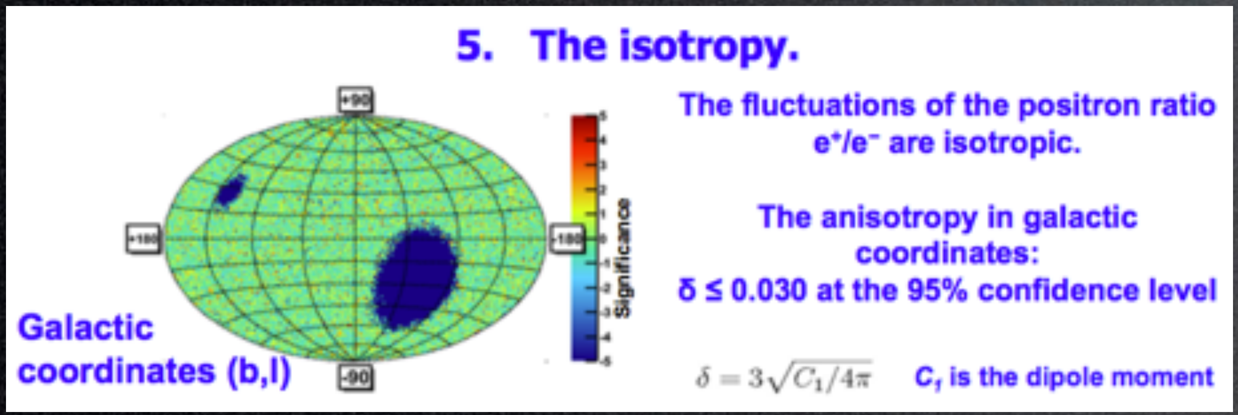
S. Ting - ICRC2015



M. Boudaud - ICRC 2015 #1183

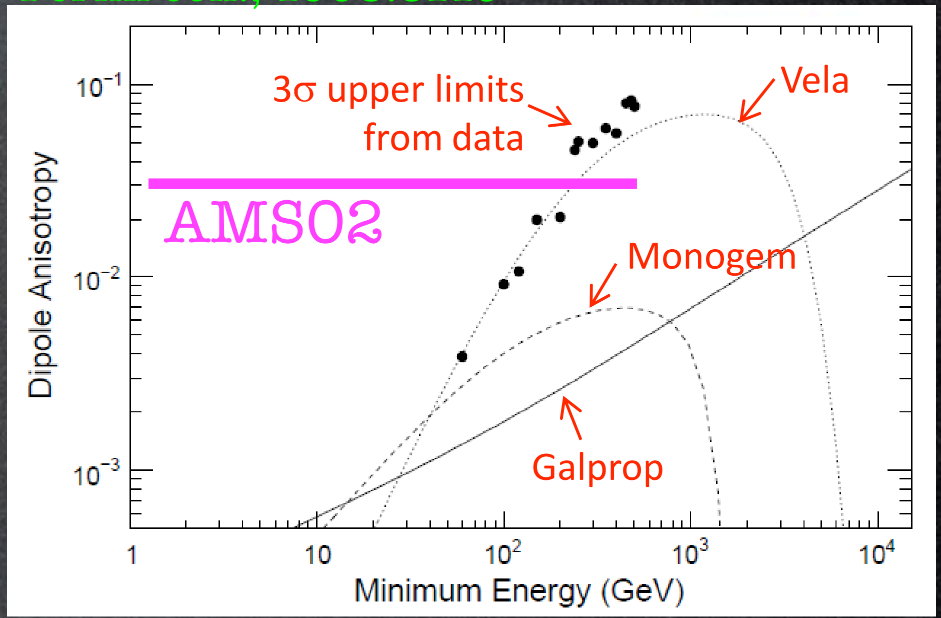


Anisotropy?



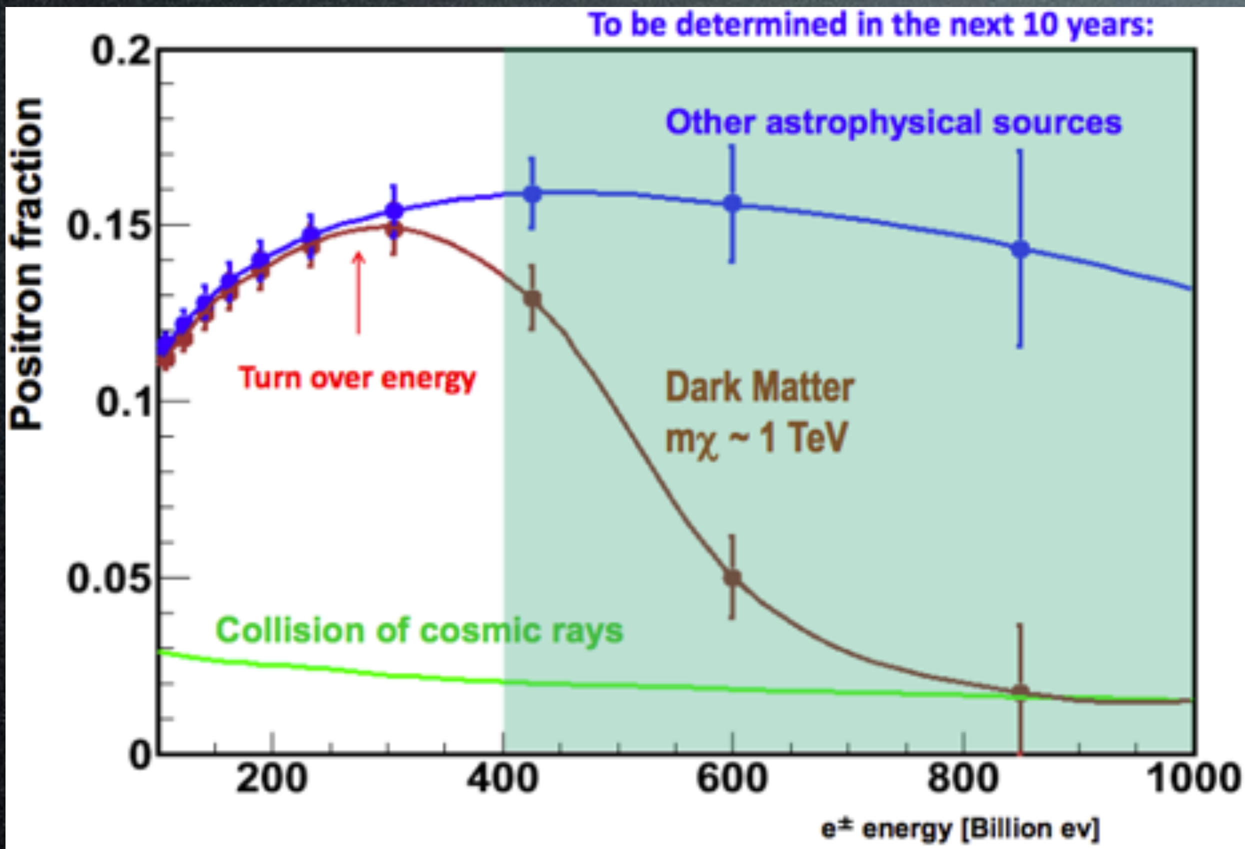
S. Ting - ICRC2015
A. Kounine - ICRC2015 #300
I. Gebauer - ICRC2015 #408

Fermi coll., 1008.5119

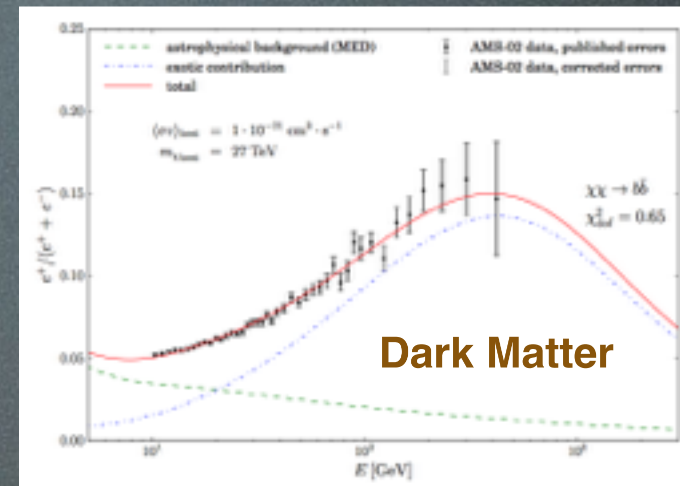


Discriminating

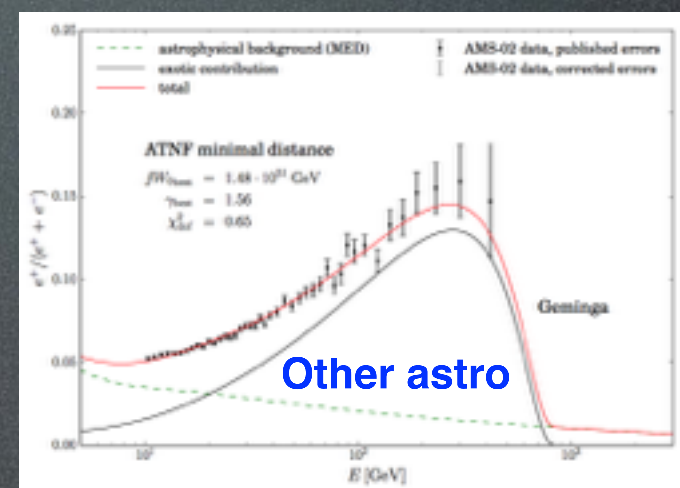
Shape of the spectrum?



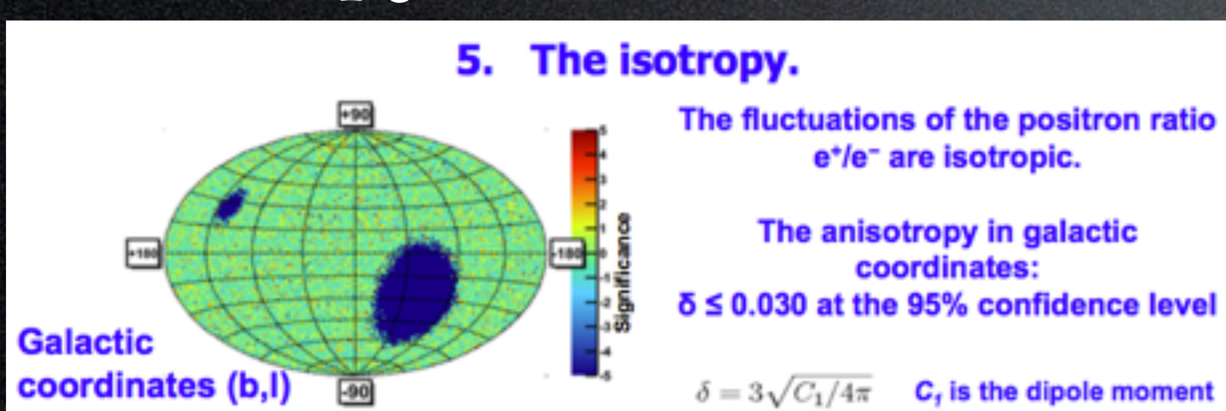
S. Ting - ICRC2015



M. Boudaud - ICRC 2015 #1183



Anisotropy?



S. Ting - ICRC2015
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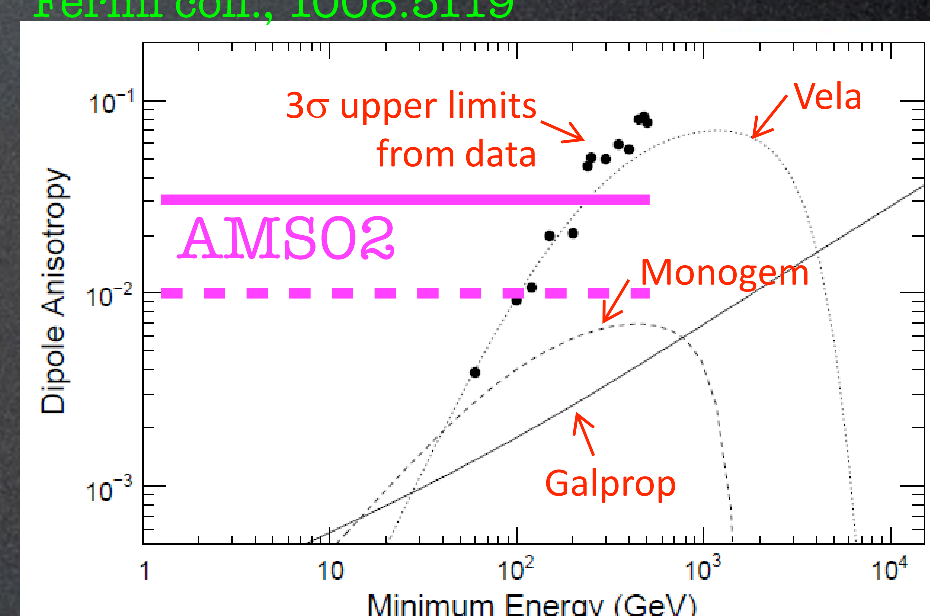
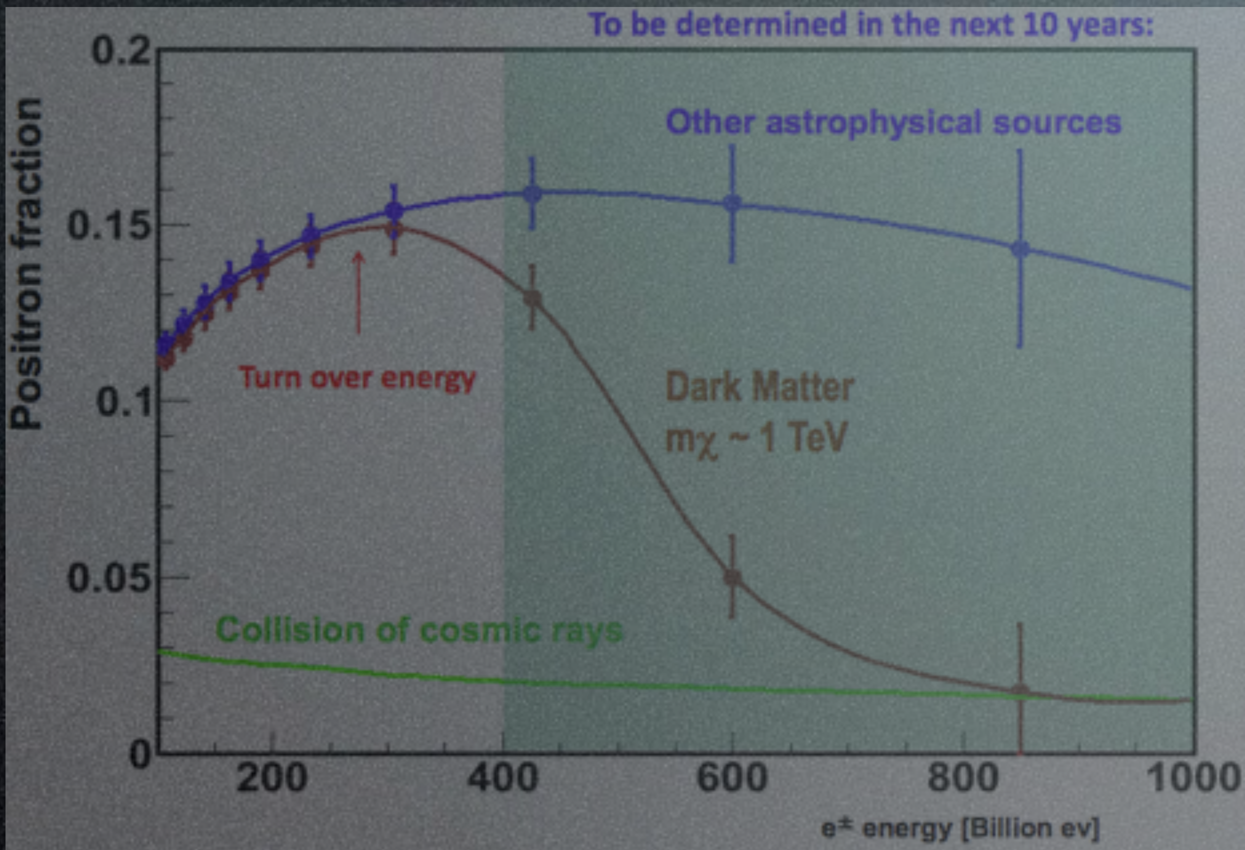
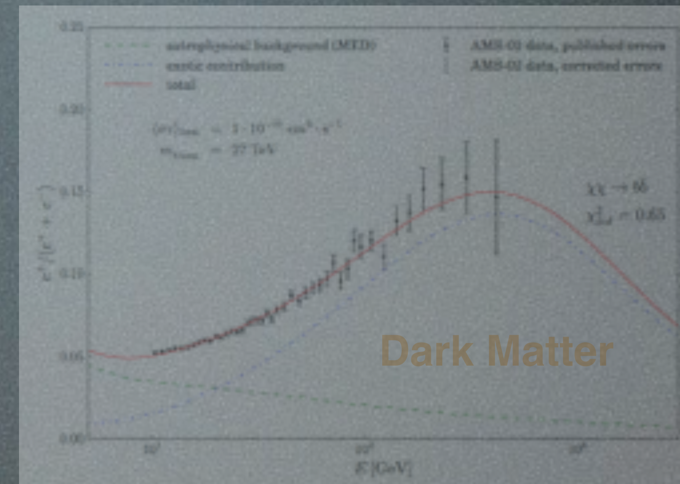


Discriminating

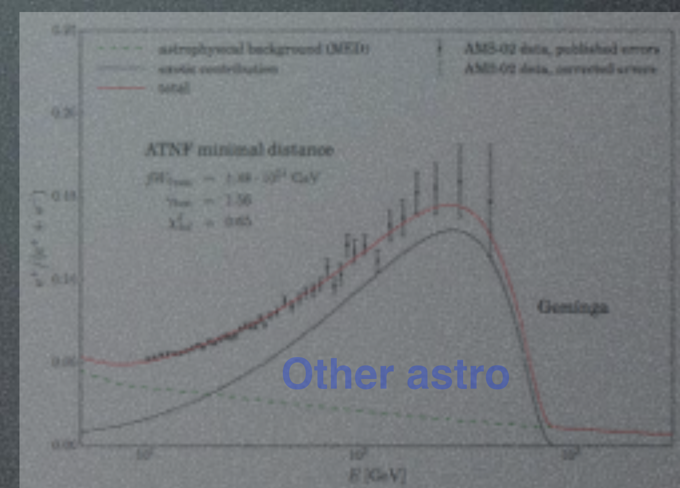
Shape of the spectrum?



S. Ting - ICRC2015



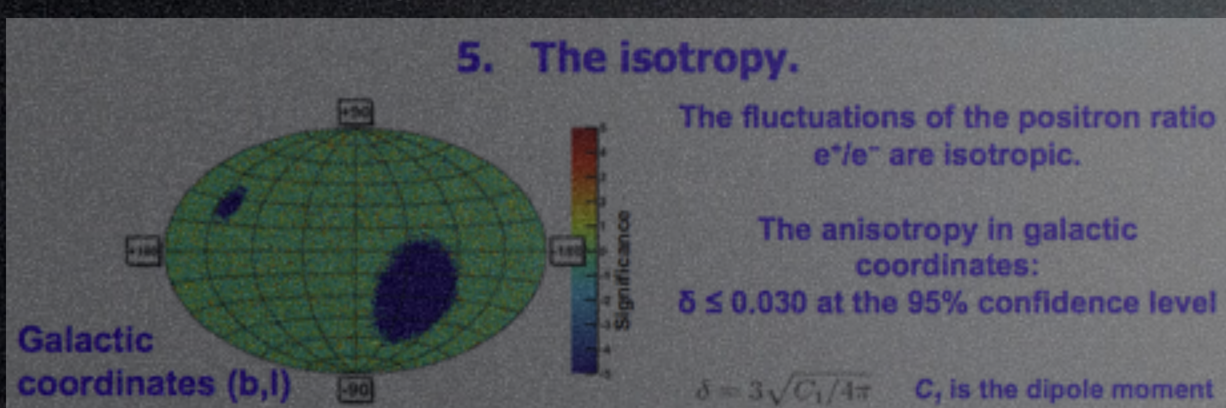
M. Boudaud - ICRC 2015



In the near future:

- CTA will measure the fraction
  J. Vandenbroucke ICRC 2015 #799
- DAMPE $e^{+}+e^{-}$
  X. Wu, V. Gallo - ICRC2015 #1199
- CALET $e^{+}+e^{-}$
  H. Motz - ICRC2015 #1194

Anisotropy?



S. Ting - ICRC2015
A. Kounine - ICRC2015
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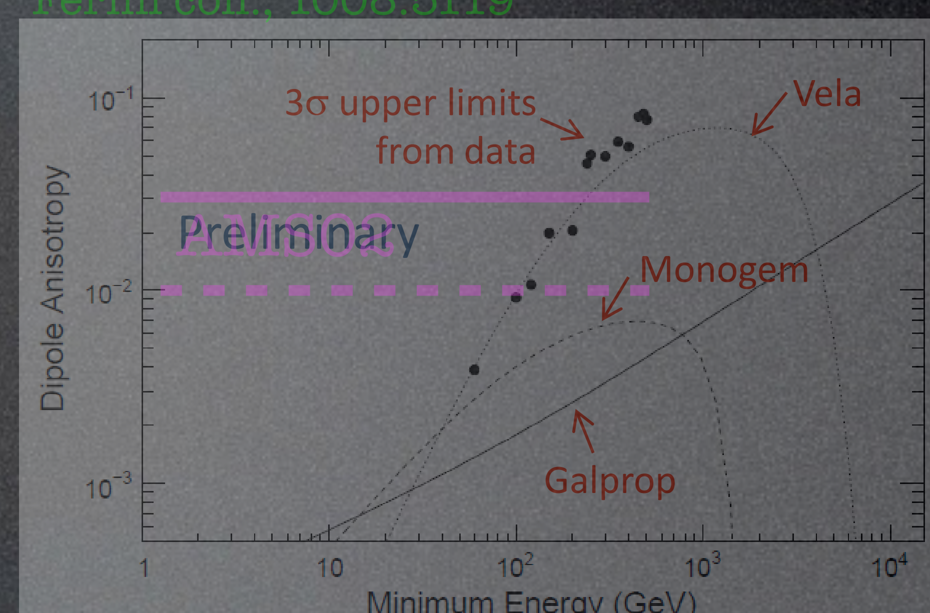
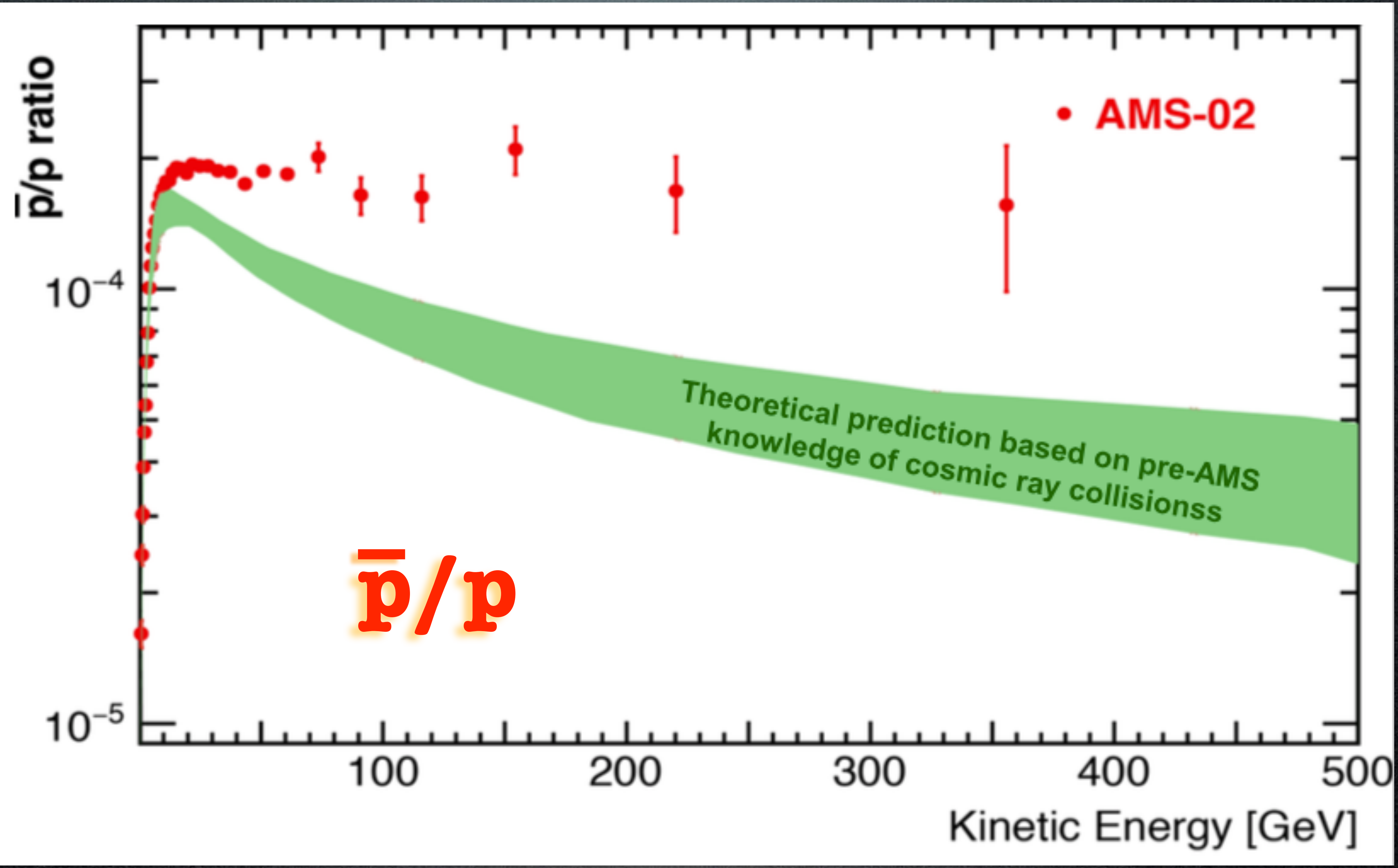


Data: antiprotons

Data: antiprotons

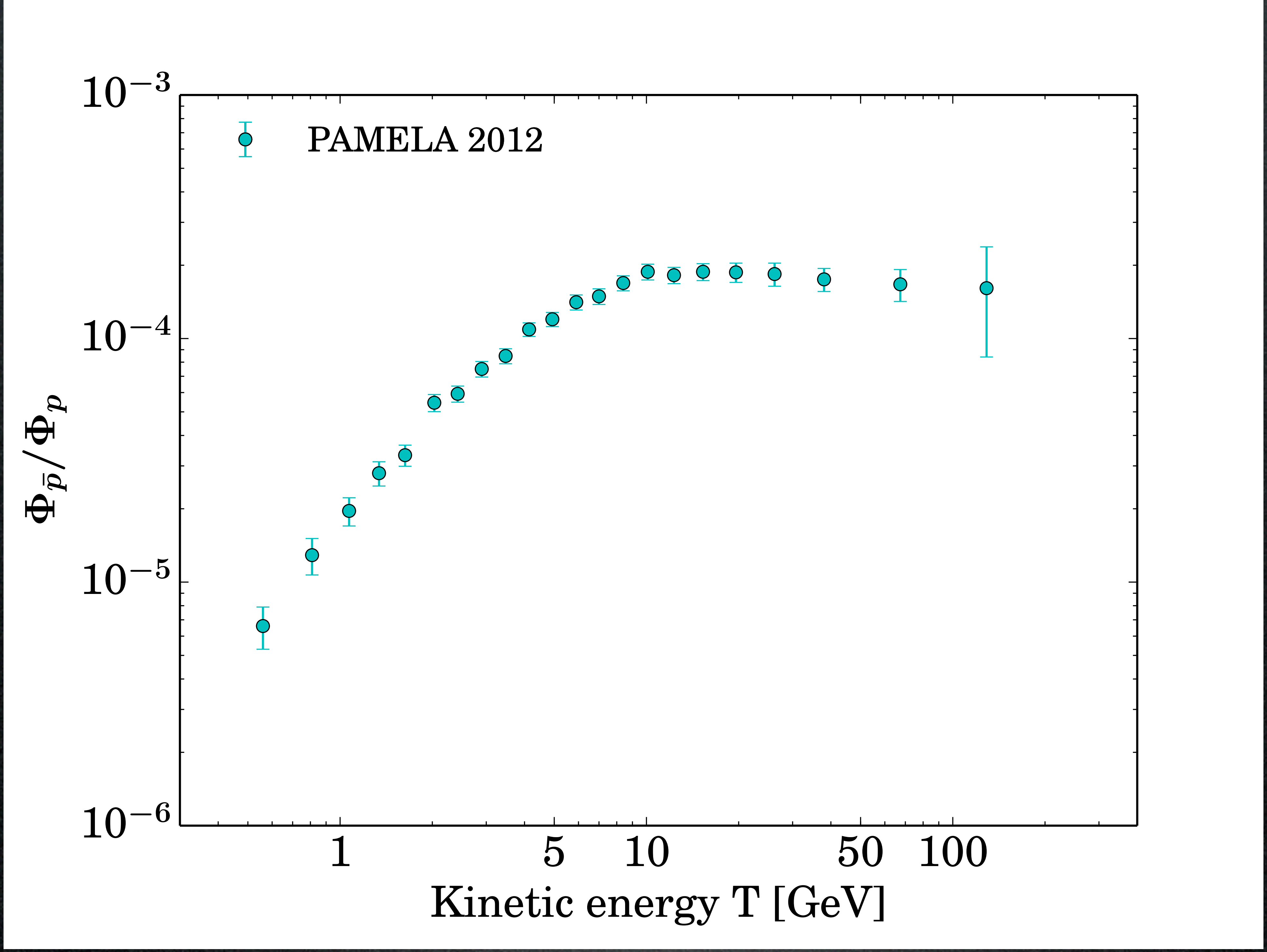
AMS-02



S. Ting - AMS days @ CERN apr 2015 - ICRC2015
A. Kounine - AMS days @ CERN apr 2015 - ICRC2015

Antiprotons

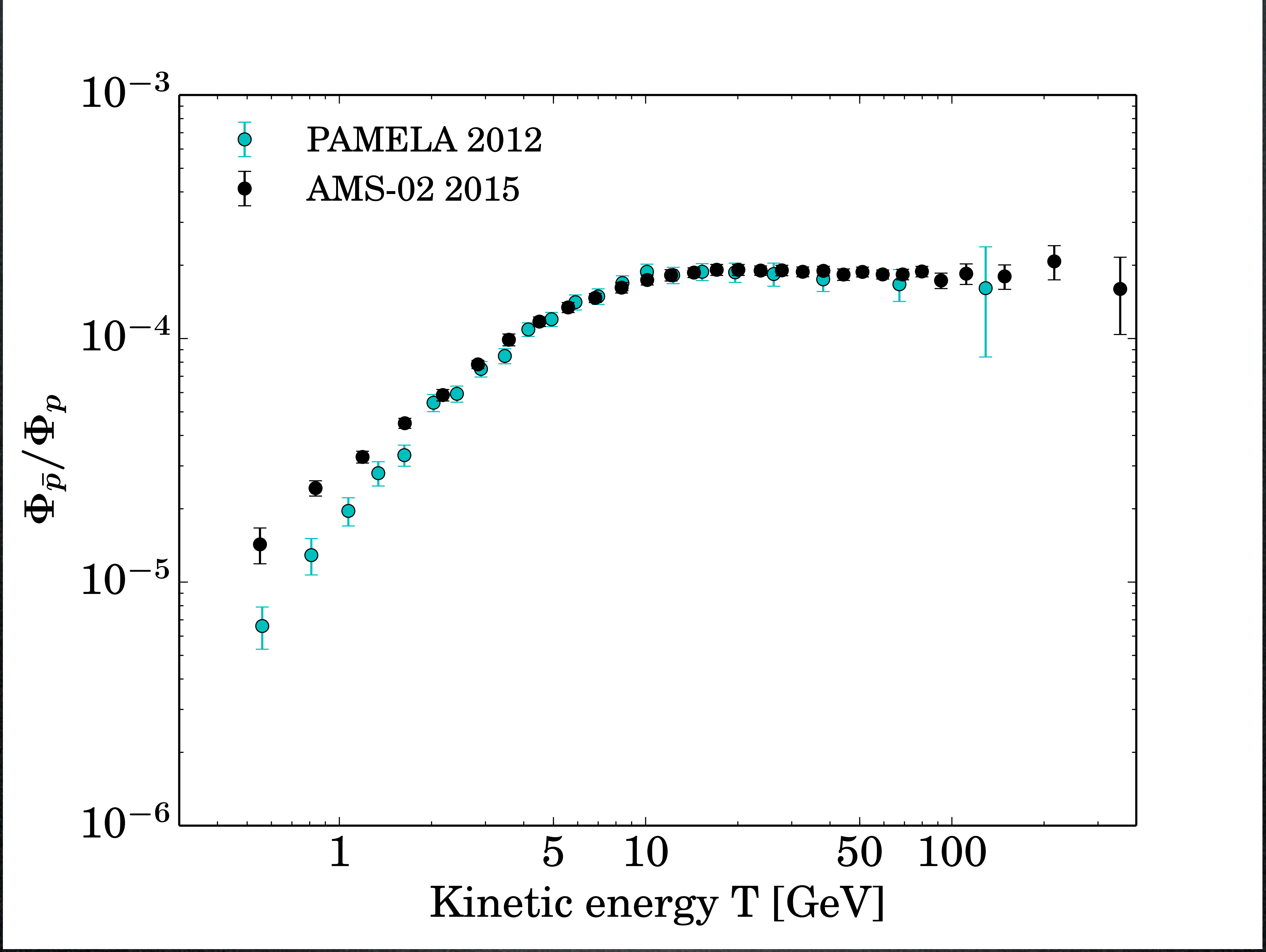
Antiproton data vis-à-vis the secondaries:



Giesen, Boudaud, Génolini, Poulin, Cirelli, Salati, Serpico
1504.04276

Antiprotons

Antiproton data vis-à-vis the secondaries:

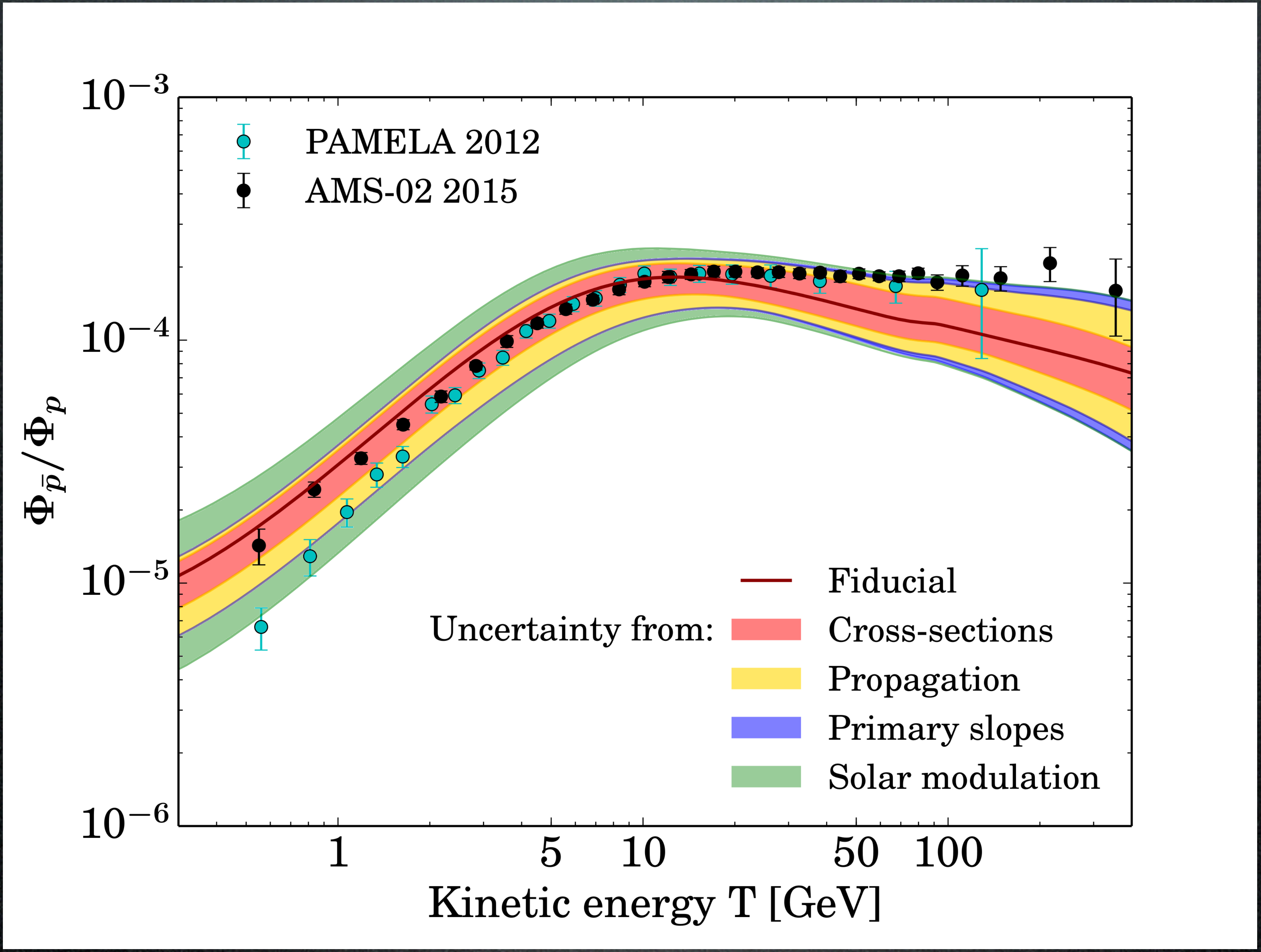


Giesen, Boudaud, Génolini, Poulin, Cirelli, Salati, Serpico
1504.04276

Antiprotons

Antiproton data vis-à-vis the secondaries:

M. Boudaud - ICRC2015 #1184

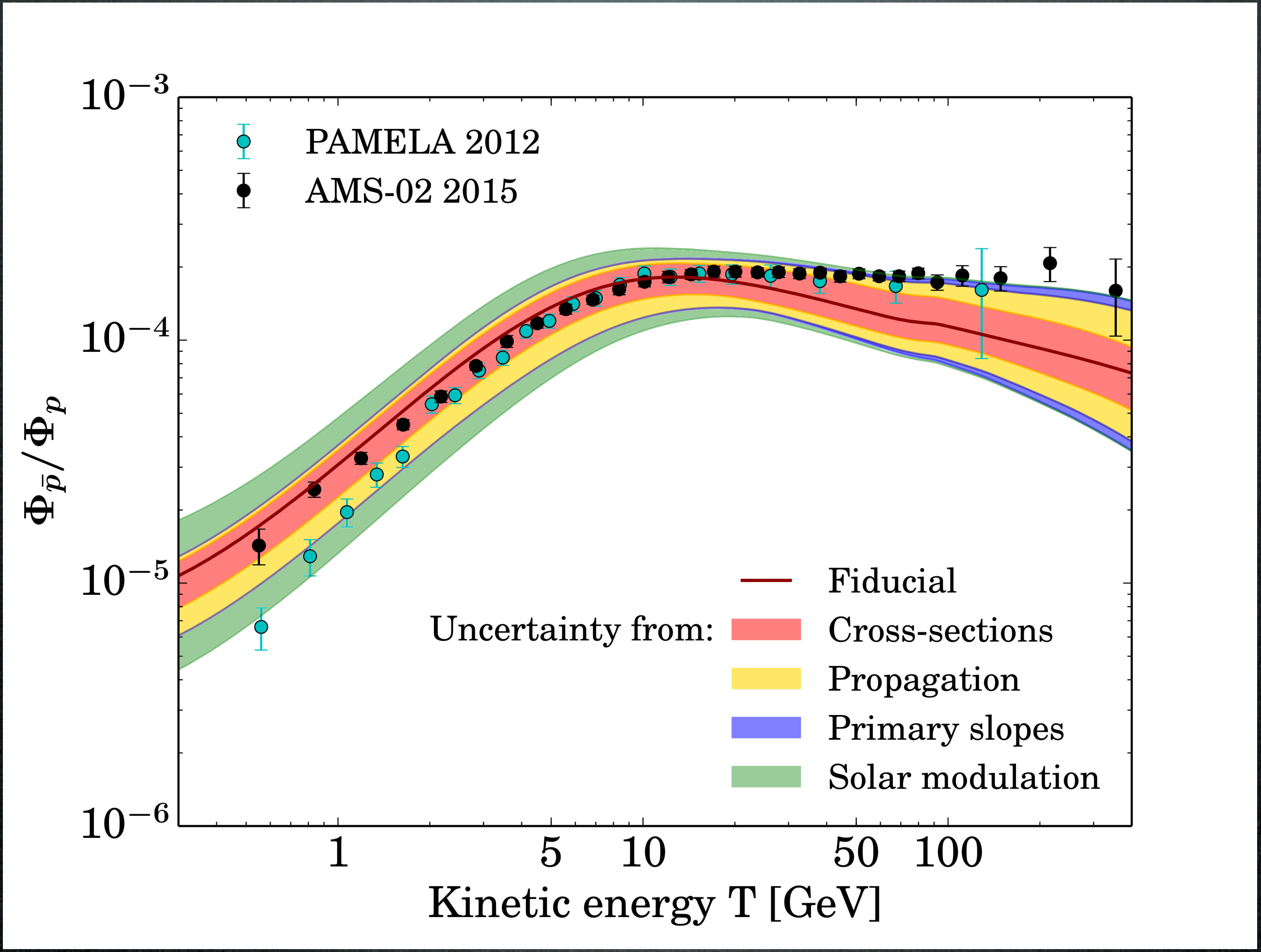


Giesen, Boudaud, Génolini, Poulin, Cirelli, Salati, Serpico
1504.04276

Antiprotons

Antiproton data vis-à-vis the secondaries:

M. Boudaud - ICRC2015 #1184



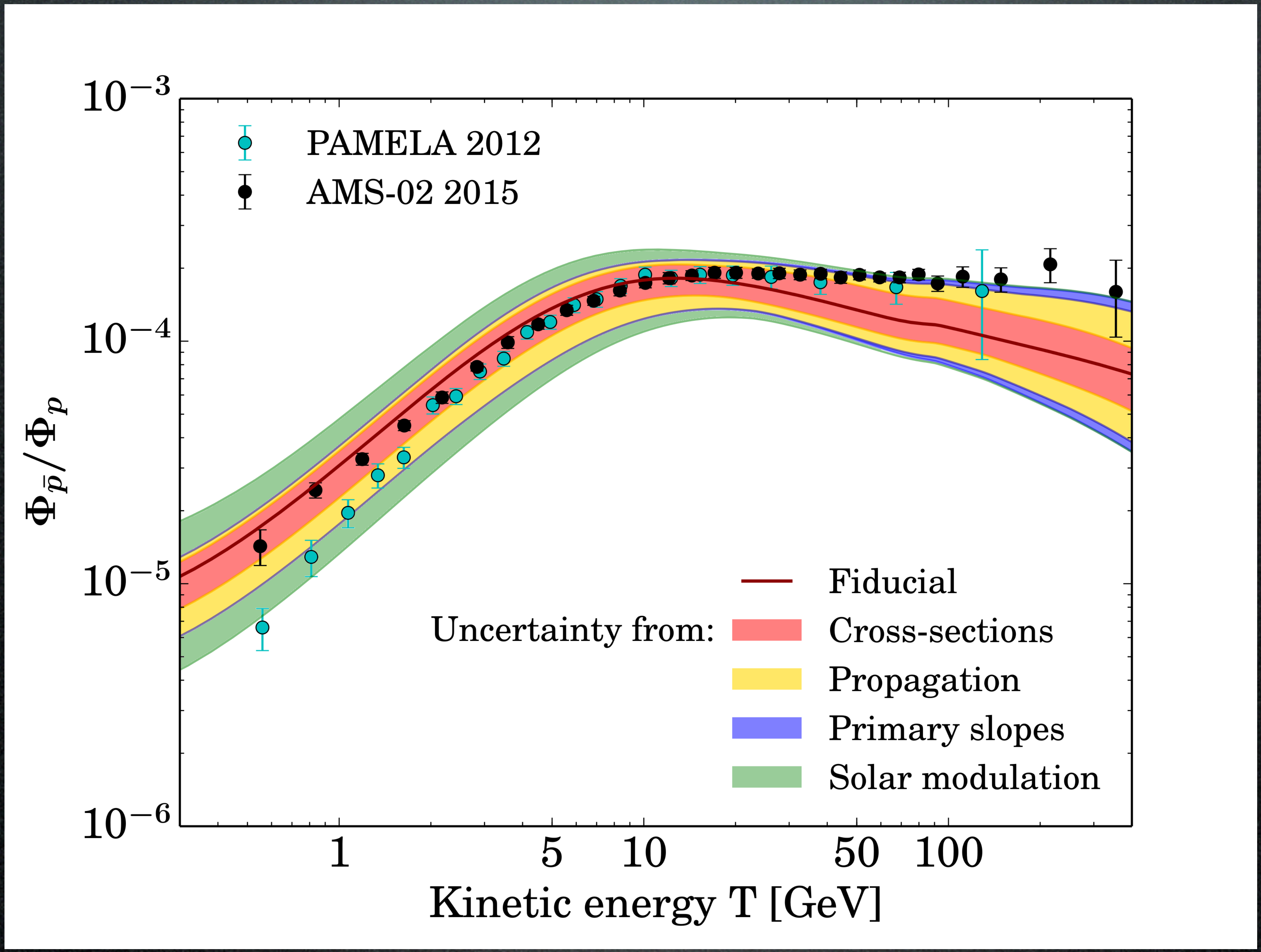
No evident **excess**

Giesen, Boudaud, Génolini, Poulin, Cirelli, Salati, Serpico 1504.04276

Antiprotons

Antiproton data vis-à-vis the secondaries:

M. Boudaud - ICRC2015 #1184



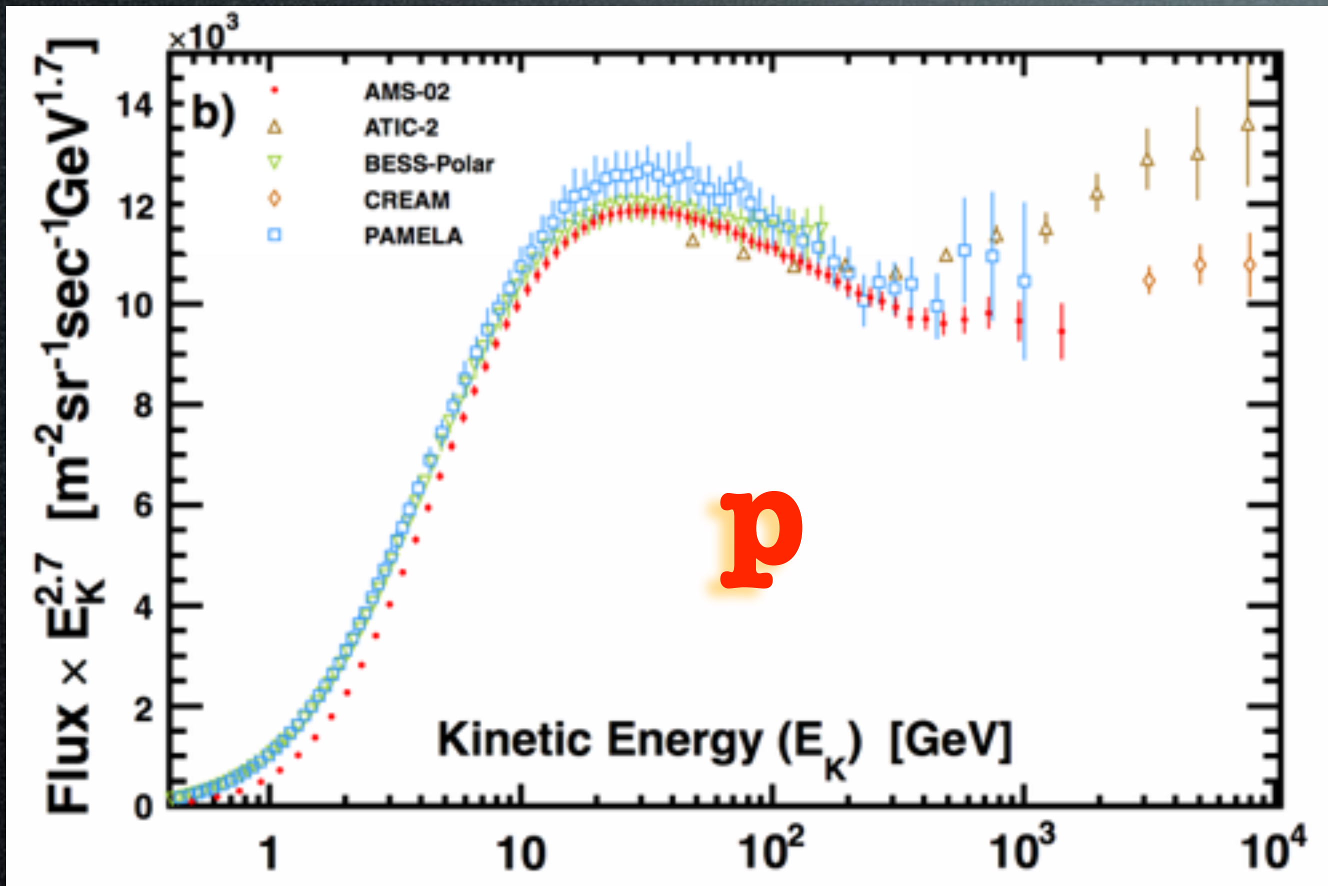
No evident **excess**

Some preference for flatness

Giesen, Boudaud, Génolini, Poulin, Cirelli, Salati, Serpico
1504.04276

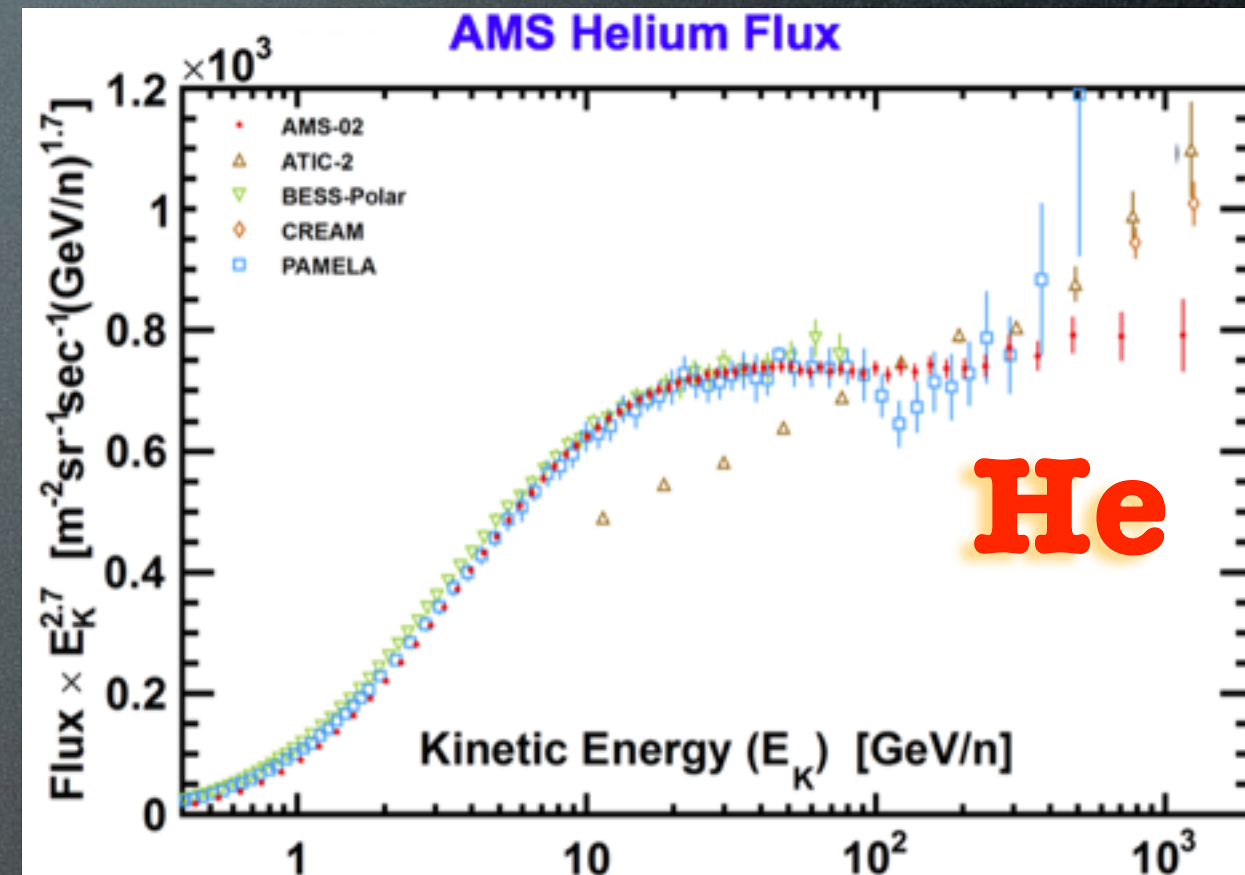
Data: protons & He

AMS-02



V. Choutko - ICRC2015 #260

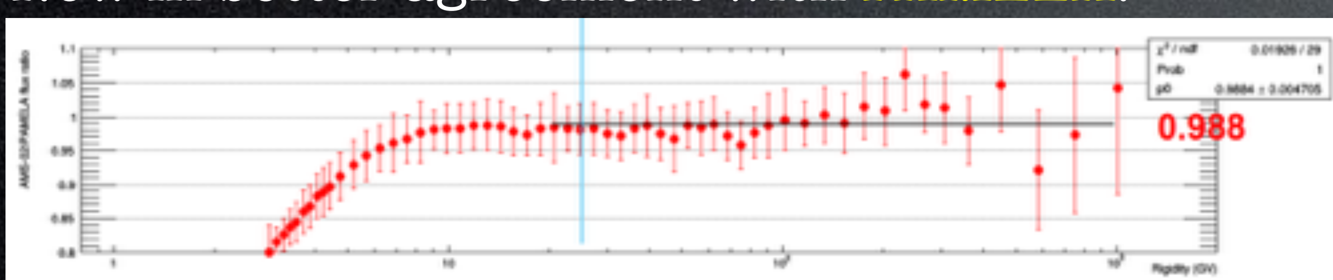
AMS-02



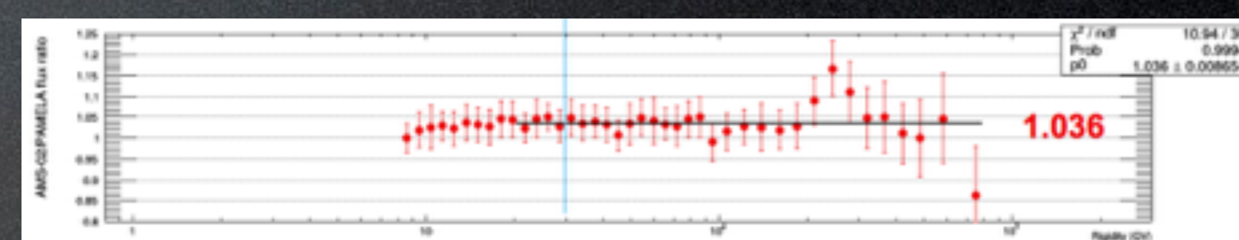
S. Haino - ICRC2015 #51

S. Ting - ICRC2015

Now in better agreement with PAMELA:



M. Boezio - ICRC2015



M. Boezio - ICRC2015

Uncertainties on production and propagation are crucial:

I. Moskalenko - ICRC2015 #495

Y. Génolini - ICRC2015 #539

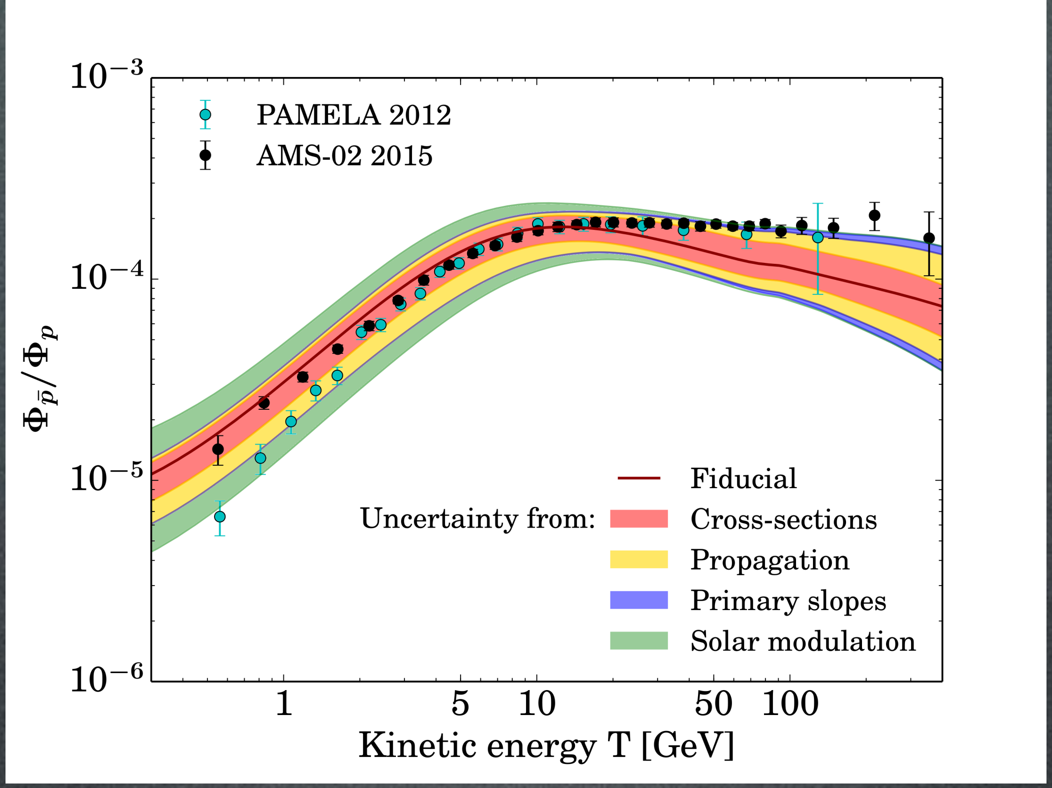
A progress report on our proton analysis was presented at the 33rd International Cosmic Ray Conference (2013). At that time our understanding of the systematic errors did not allow an accurate determination of the behavior of the proton flux.

V. Choutko footnote 23 - ICRC2015 #260

Antiprotons

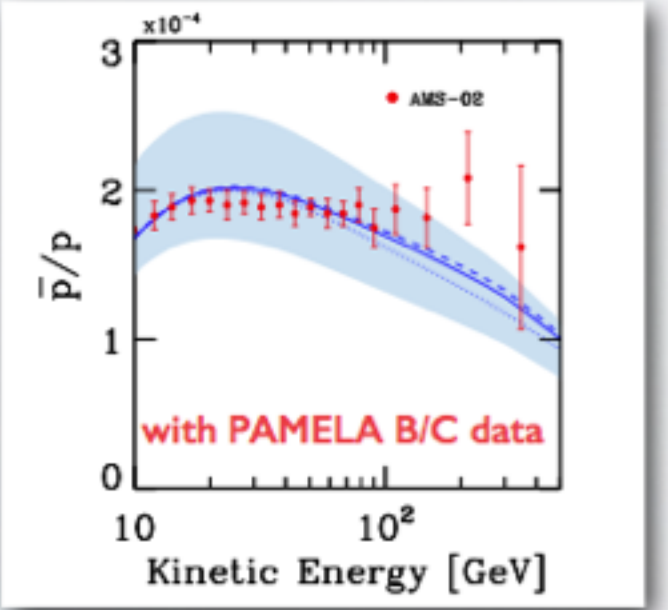
Antiproton data vis-à-vis the secondaries:

M. Boudaud- ICRC2015 #1184

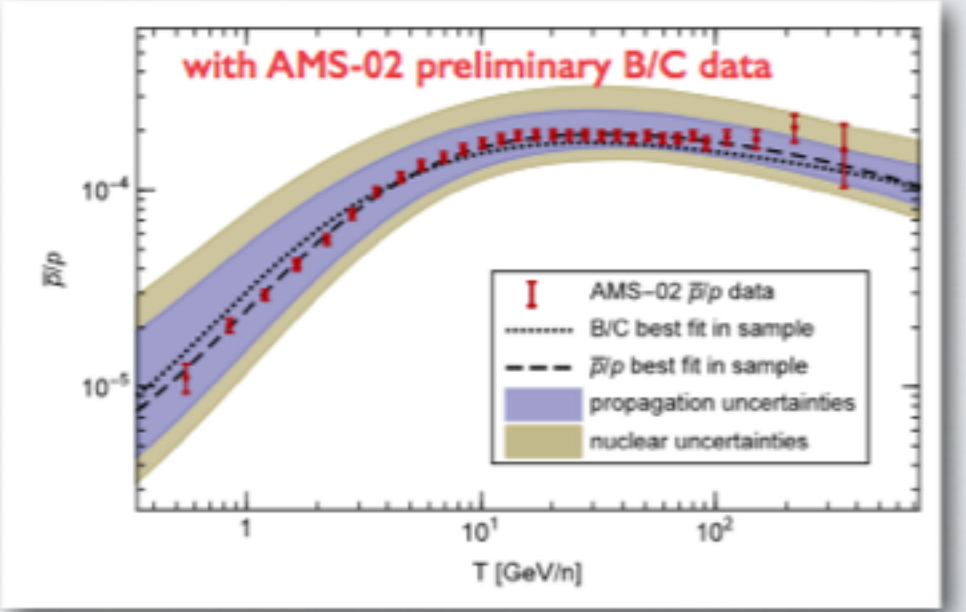


P.D. Serpico - ICRC 2015

C. Evoli, D. Gaggero and D. Grasso, arXiv:1504.05175



R. Kappl, A. Reinert and M.W. Winkler, arXiv:1506.04145

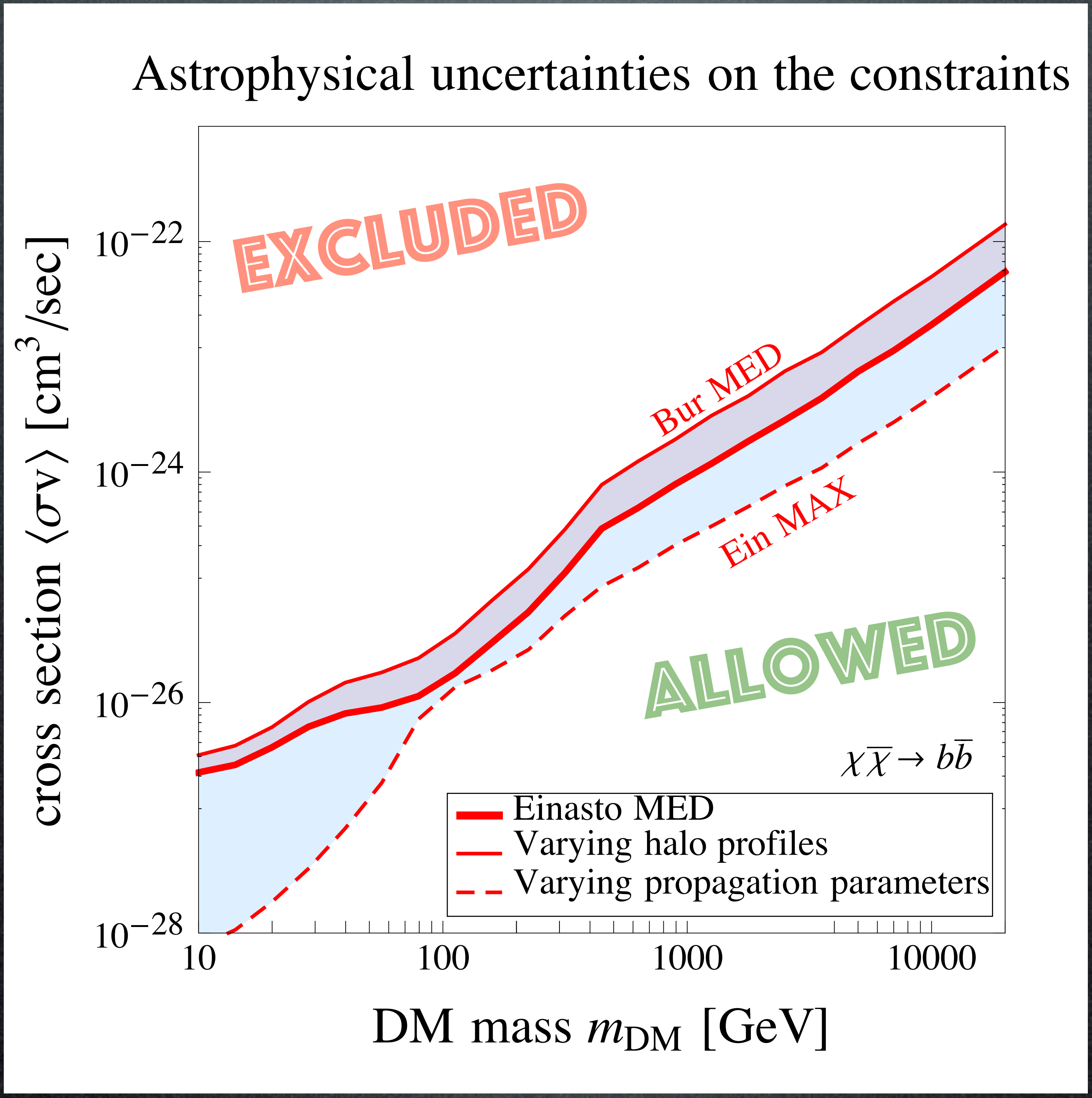


Extremely important for Dark Matter constraints! (*Cirelli's talk*) Without doubt, to be continued!

Dark Matter interpretation

Based on AMS-02 $\bar{p}/p$ data (april 2015)

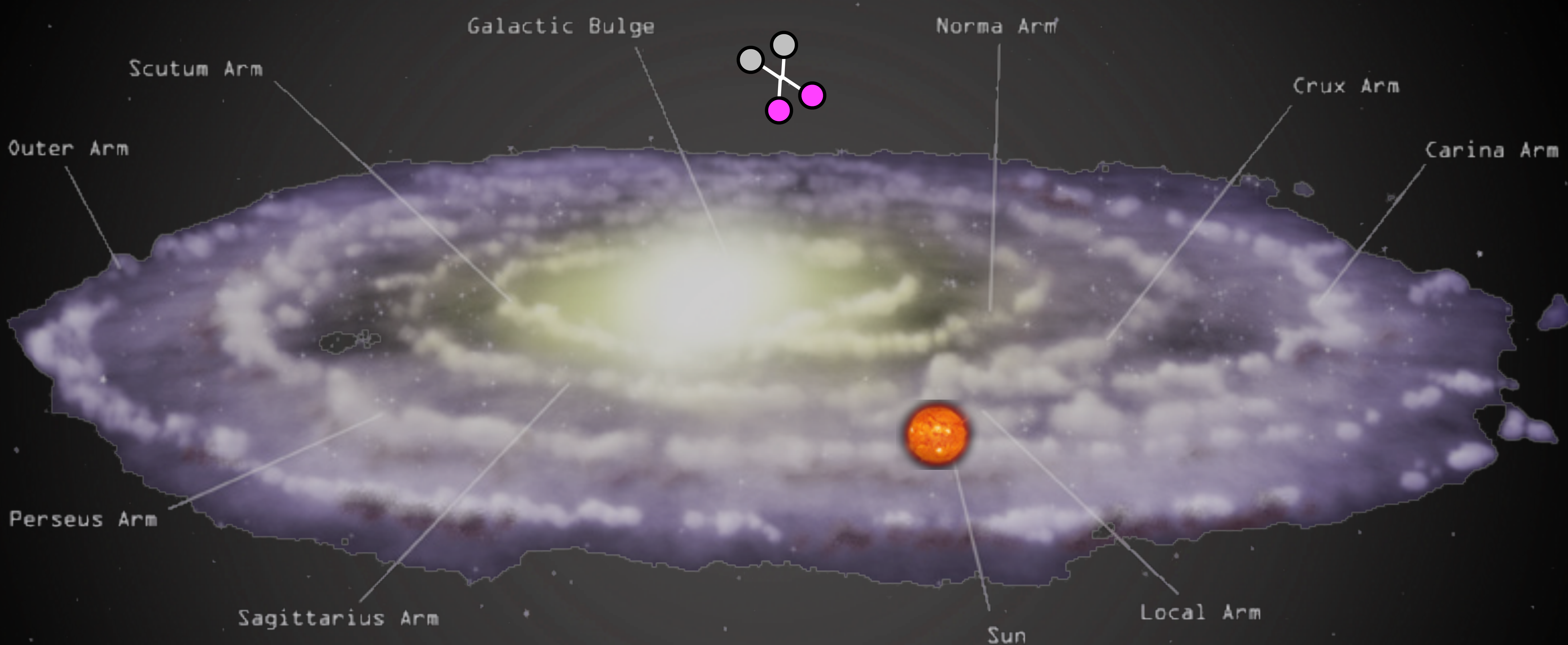
M. Boudaud - ICRC2015 #1184



Giesen, Boudaud, Génolini, Poulin, Cirelli, Salati, Serpico
1504.04276

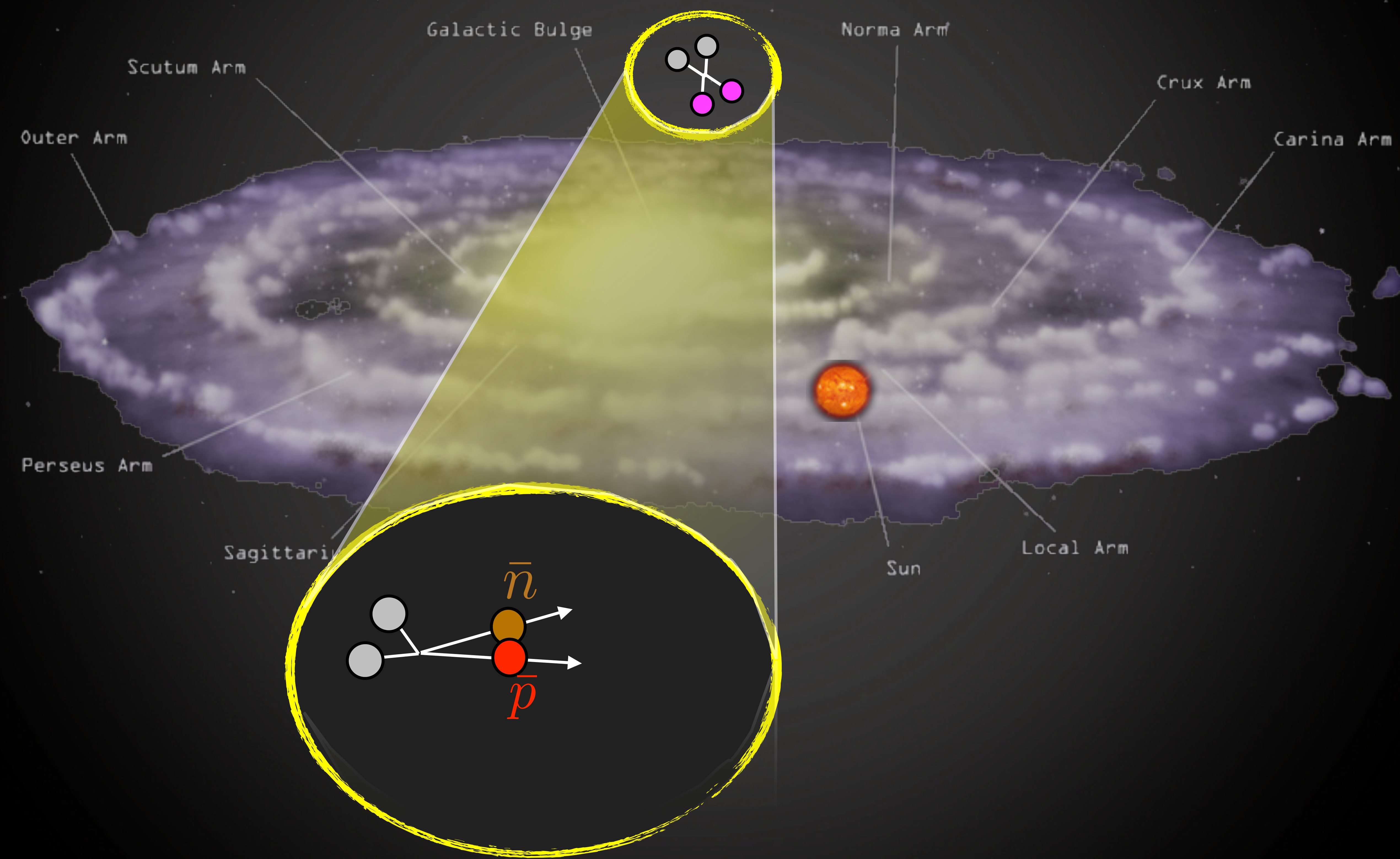
Indirect Detection

$\bar{d}$ from DM annihilations in halo



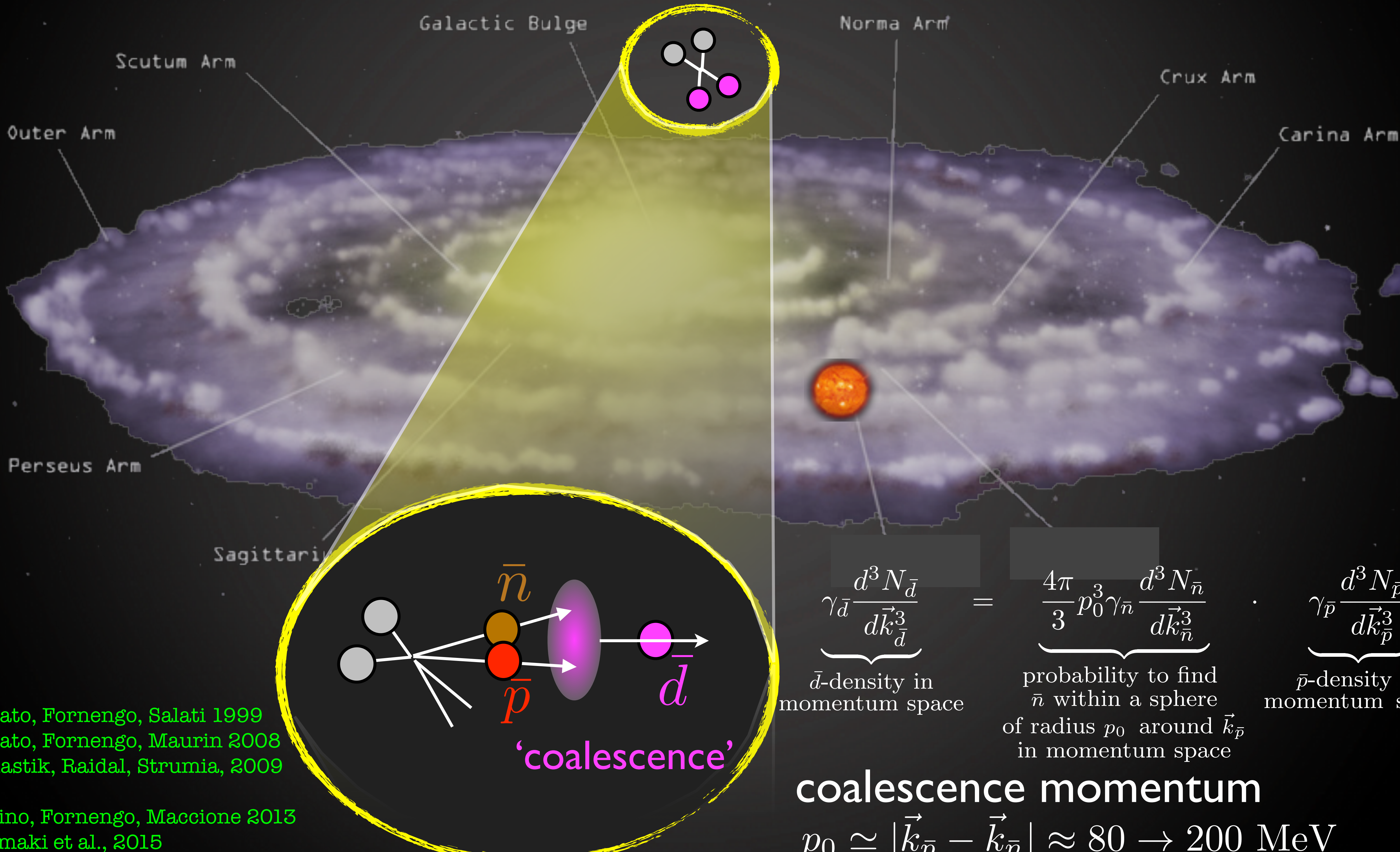
Indirect Detection

$\bar{d}$ from DM annihilations in halo



Indirect Detection

$\bar{d}$ from DM annihilations in halo



$$\gamma_{\bar{d}} \frac{d^3 N_{\bar{d}}}{d\vec{k}^3_{\bar{d}}} = \frac{4\pi}{3} p_0^3 \gamma_{\bar{n}} \frac{d^3 N_{\bar{n}}}{d\vec{k}^3_{\bar{n}}} \cdot \gamma_{\bar{p}} \frac{d^3 N_{\bar{p}}}{d\vec{k}^3_{\bar{p}}}$$

$\bar{d}$-density in momentum space

probability to find $\bar{n}$ within a sphere of radius p_0 around $\vec{k}_{\bar{p}}$ in momentum space

$\bar{p}$-density in momentum space

Donato, Fornengo, Salati 1999
Donato, Fornengo, Maurin 2008
Kadastik, Raidal, Strumia, 2009
...
Vittino, Fornengo, Maccione 2013
Aramaki et al., 2015

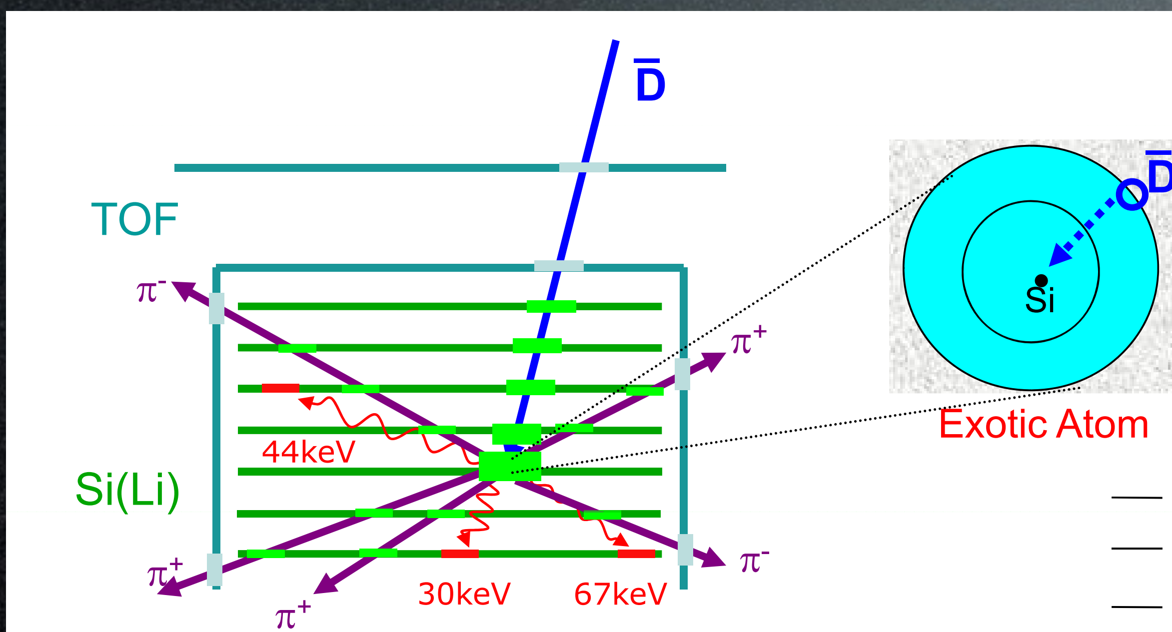
coalescence momentum

$$p_0 \simeq |\vec{k}_{\bar{p}} - \vec{k}_{\bar{n}}| \approx 80 \to 200 \text{ MeV}$$

Indirect Detection

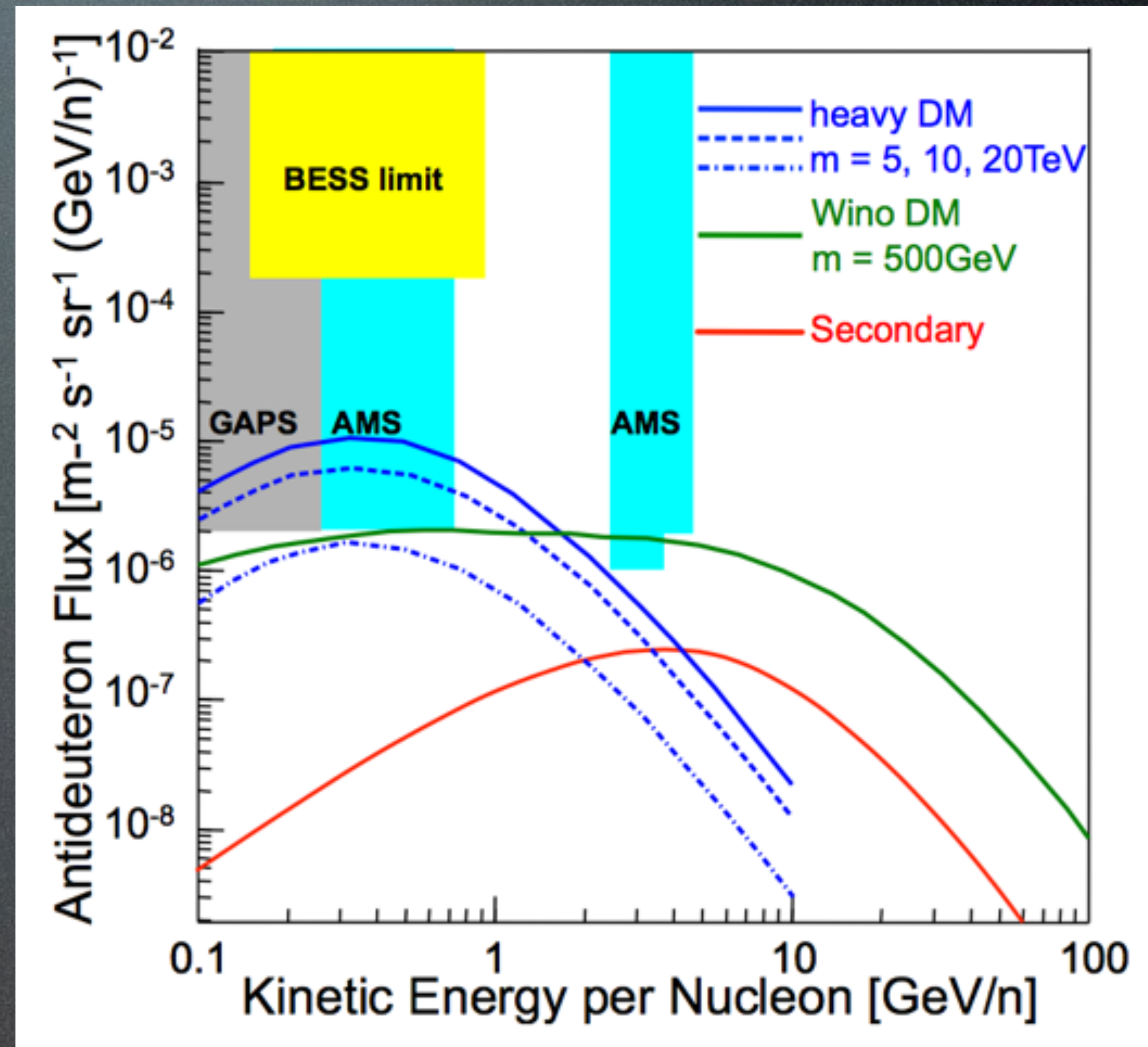
$\bar{d}$ from DM annihilations in halo

GAPS detection principle



$\bar{d}$ is slowed down,
captured (exotic atom),
annihilates w distinctive emissions

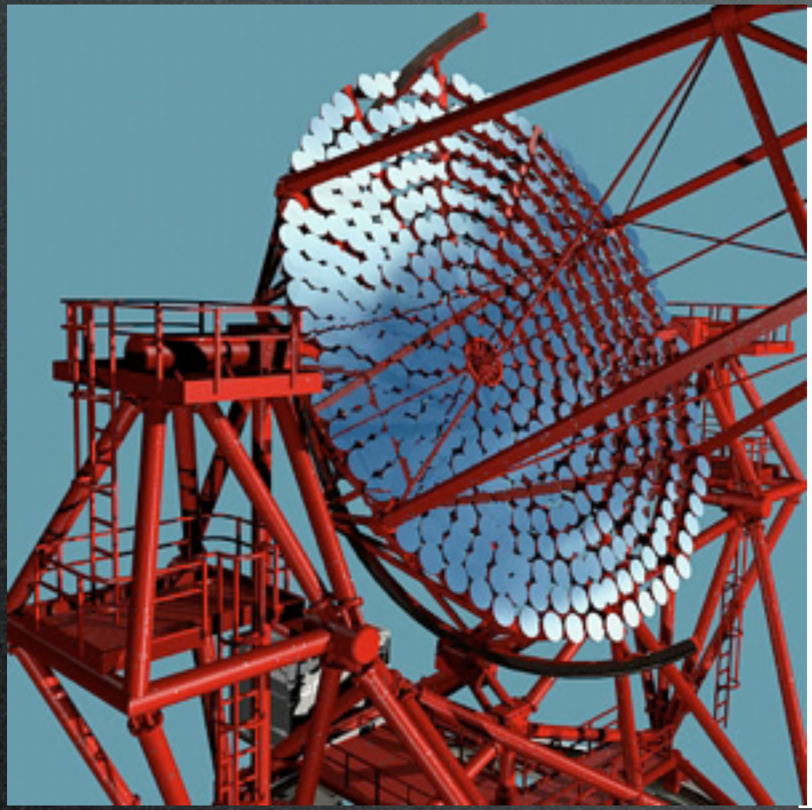
P. von Doetinchem - ICRC 2015 #1219

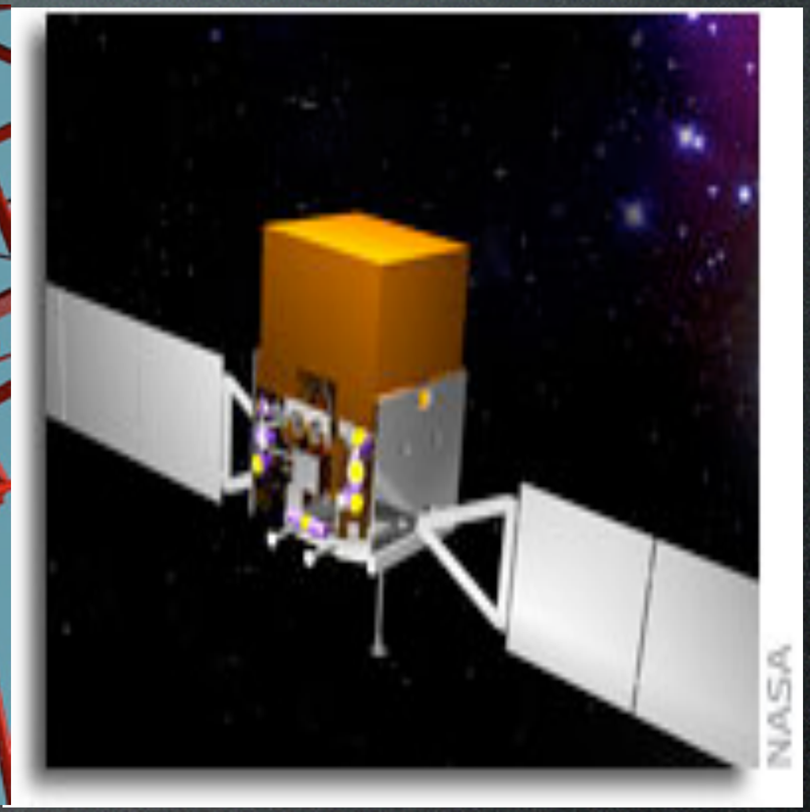


P. von Doetinchem - ICRC 2015 #1218

DM signal in the reach of GAPS and AMS-02

Gamma rays





How does DM produce γ-rays?

1. prompt emission

2. secondary emission

How does DM produce γ-rays?

1. prompt emission

1a. continuum **1b.** line(s) **1c.** sharp features

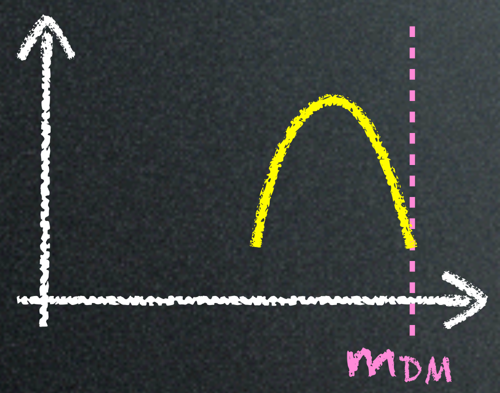
2. secondary emission

2a. ICS **2b.** bremsstrahlung **2c.** synchrotron

How does DM produce γ-rays?

1. prompt emission

1a. continuum **1b.** line(s) **1c.** sharp features



2. secondary emission

2a. ICS **2b.** bremsstrahlung **2c.** synchrotron

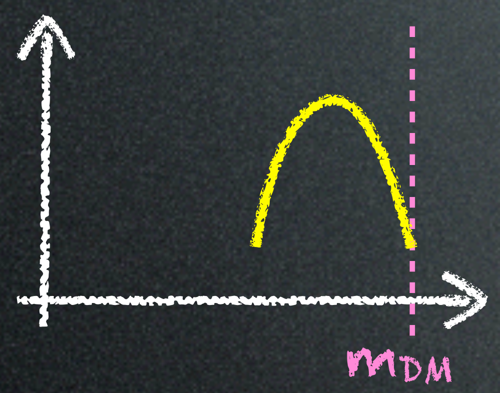
How does DM produce γ-rays?

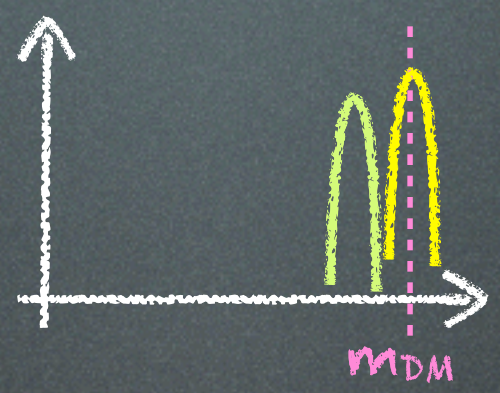
1. prompt emission

1a. continuum

1b. line(s)

1c. sharp features





2. secondary emission

2a. ICS

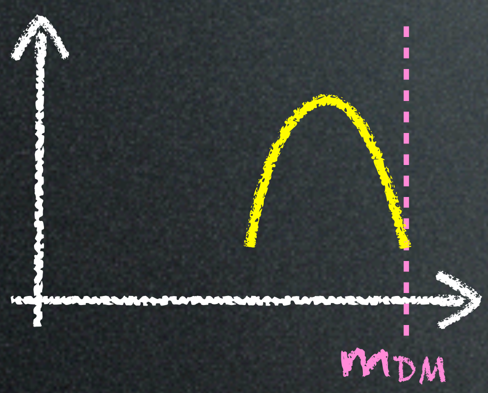
2b. bremsstrahlung

2c. synchrotron

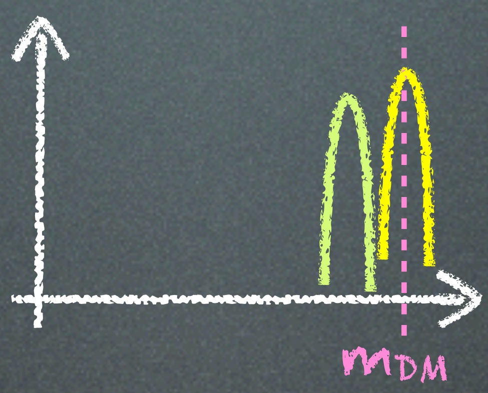
How does DM produce γ-rays?

1. prompt emission

1a. continuum



1b. line(s)



1c. sharp features

2. secondary emission

2a. ICS

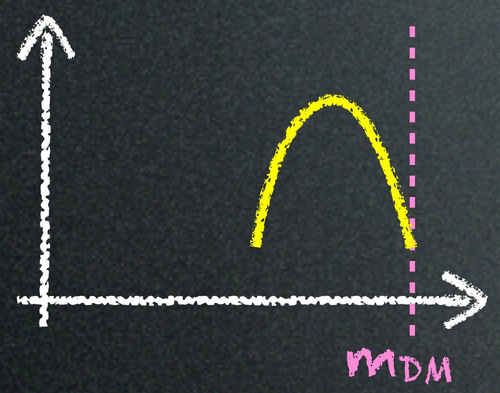
2b. bremsstrahlung

2c. synchrotron

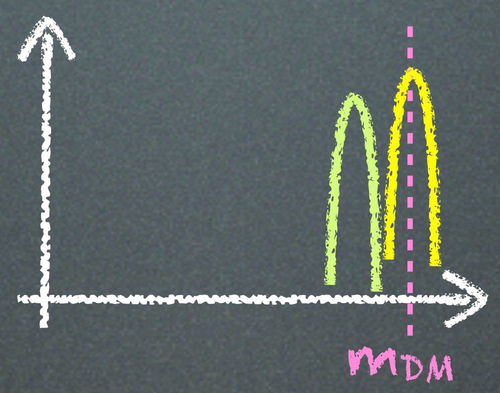
How does DM produce γ-rays?

1. prompt emission

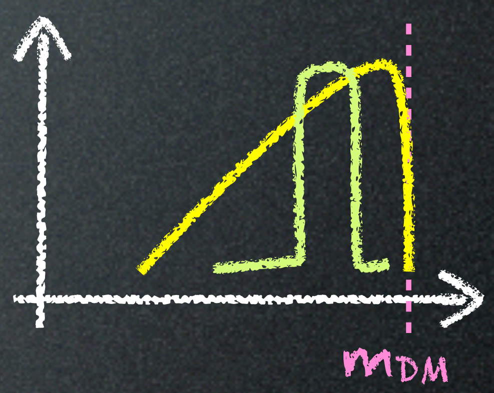
1a. continuum



1b. line(s)

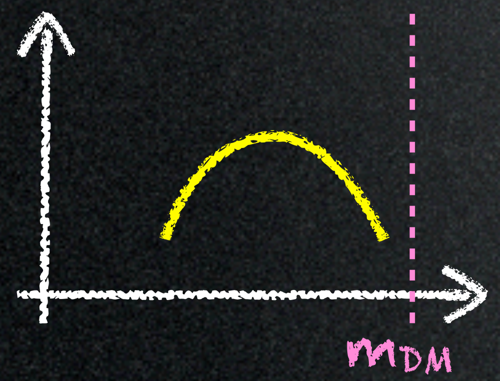


1c. sharp features



2. secondary emission

2a. ICS



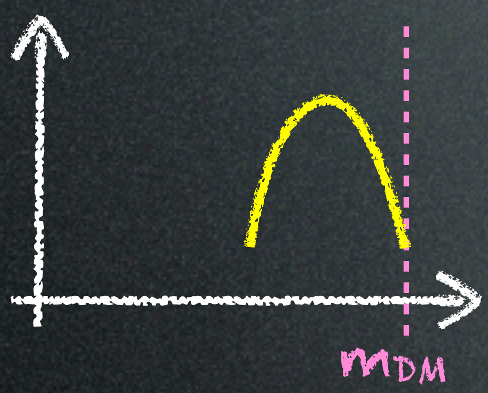
2b. bremsstrahlung

2c. synchrotron

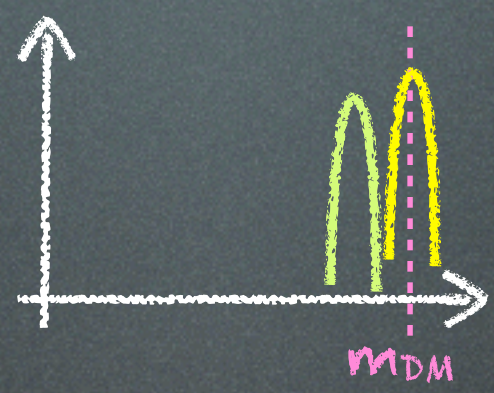
How does DM produce γ-rays?

1. prompt emission

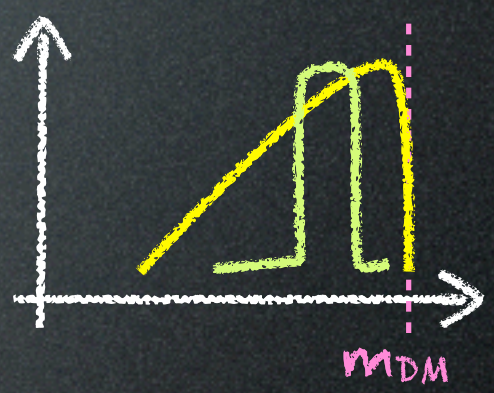
1a. continuum



1b. line(s)

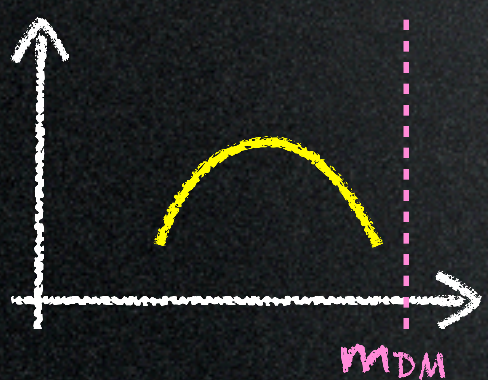


1c. sharp features

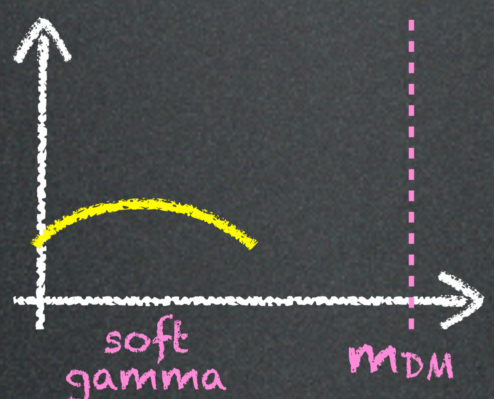


2. secondary emission

2a. ICS



2b. bremsstrahlung

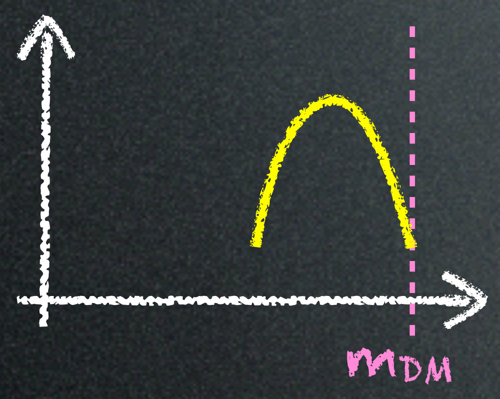


2c. synchrotron

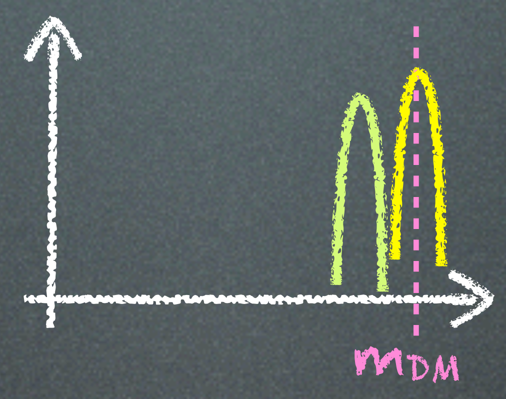
How does DM produce γ-rays?

1. prompt emission

1a. continuum



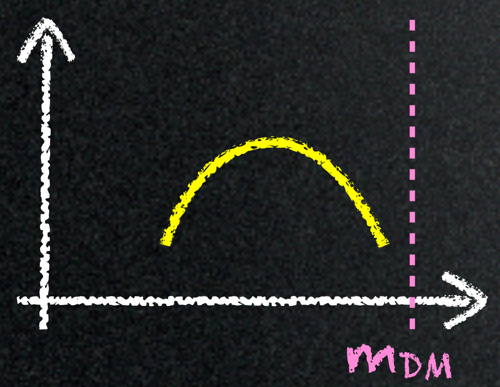
1b. line(s)



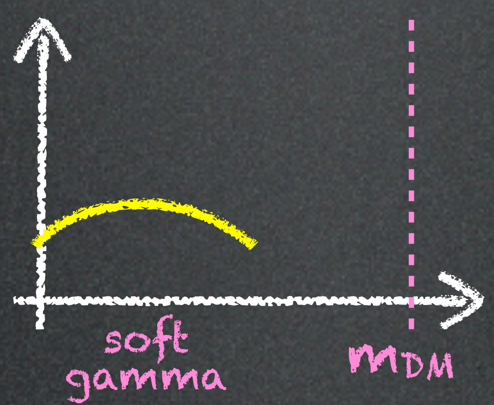
1c. sharp features

2. secondary emission

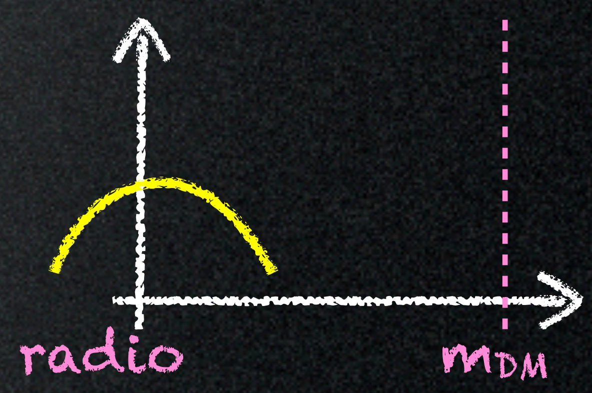
2a. ICS



2b. bremsstrahlung



2c. synchrotron

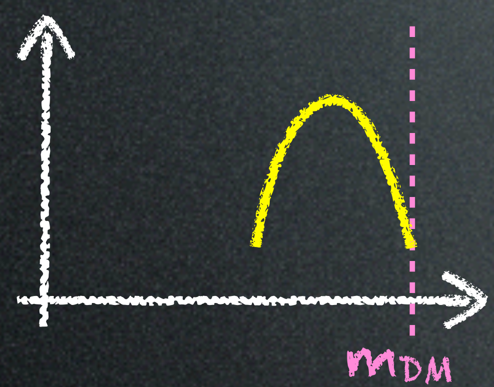


How does DM produce γ-rays?

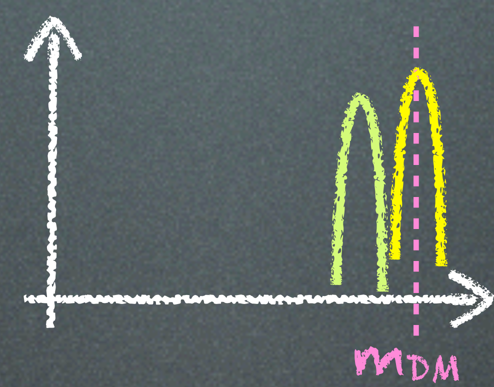
environment-independent

1. prompt emission

1a. continuum



1b. line(s)

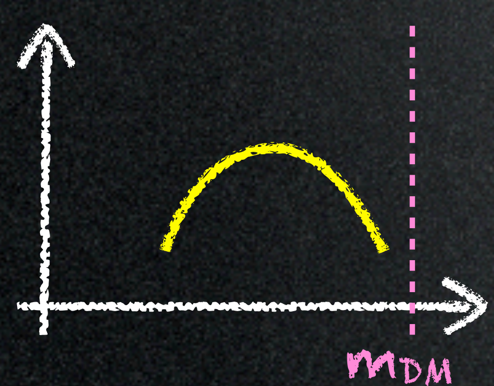


1c. sharp features

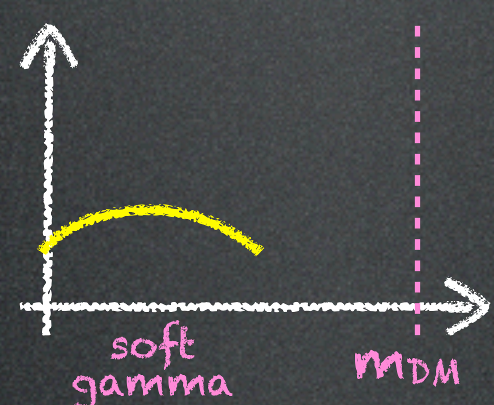
environment-dependent

2. secondary emission

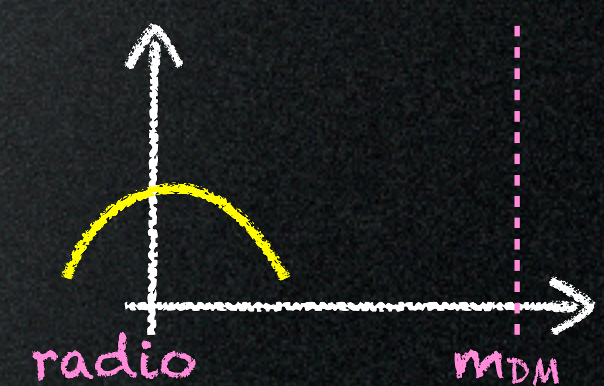
2a. ICS



2b. bremsstrahlung



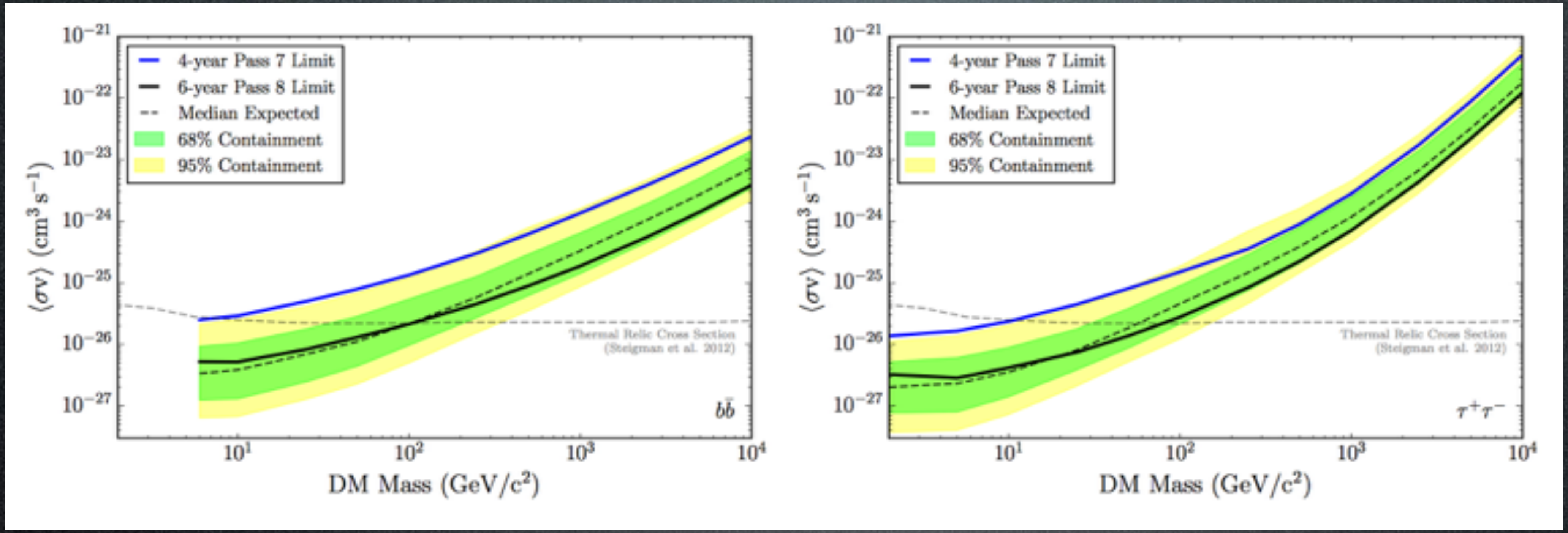
2c. synchrotron

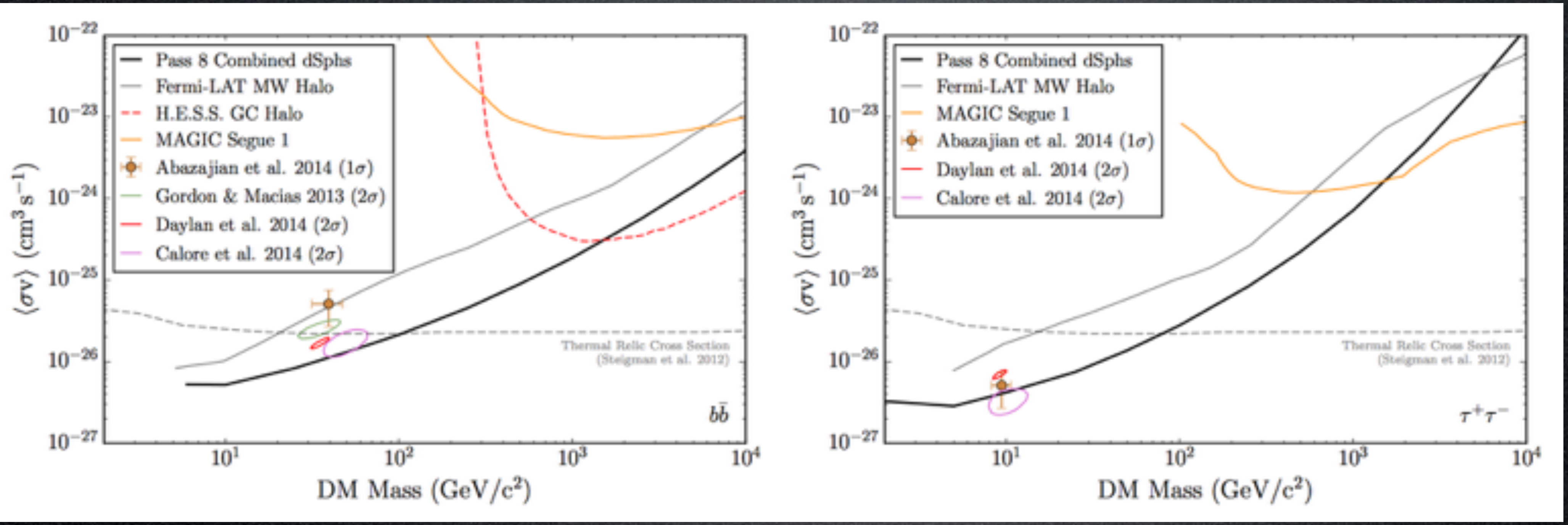


Constraints

Dwarf galaxies

FERMI





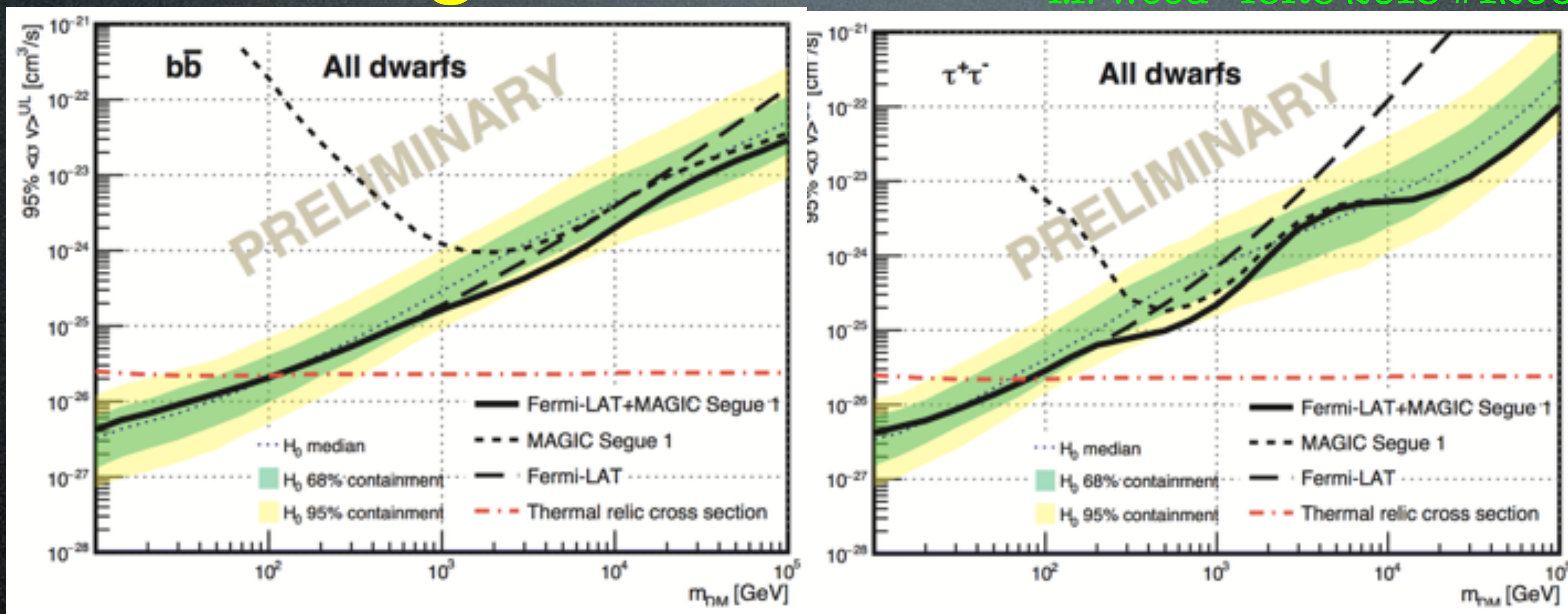
FERMI 1503.02641 M. Wood - ICRC 2015 #1226

Constraints

Dwarf galaxies

FERMI + Magic

M. Wood - ICRC 2015 #1206

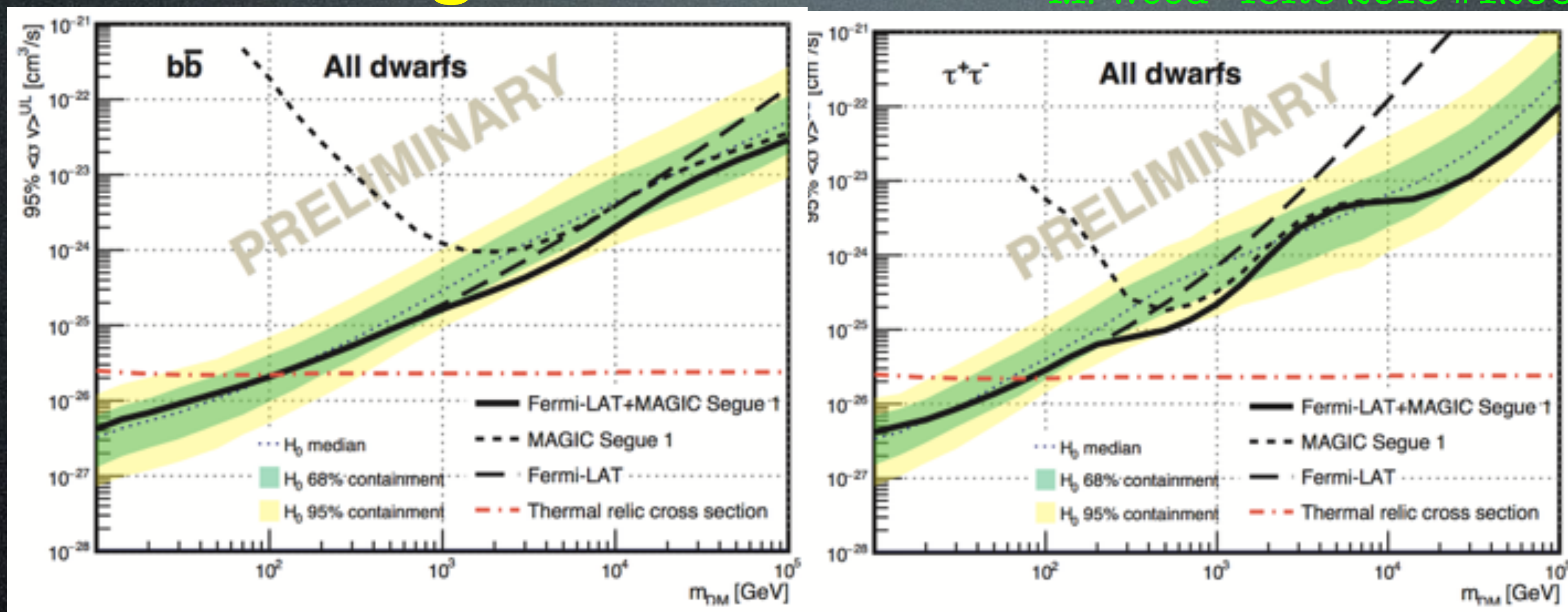


Constraints

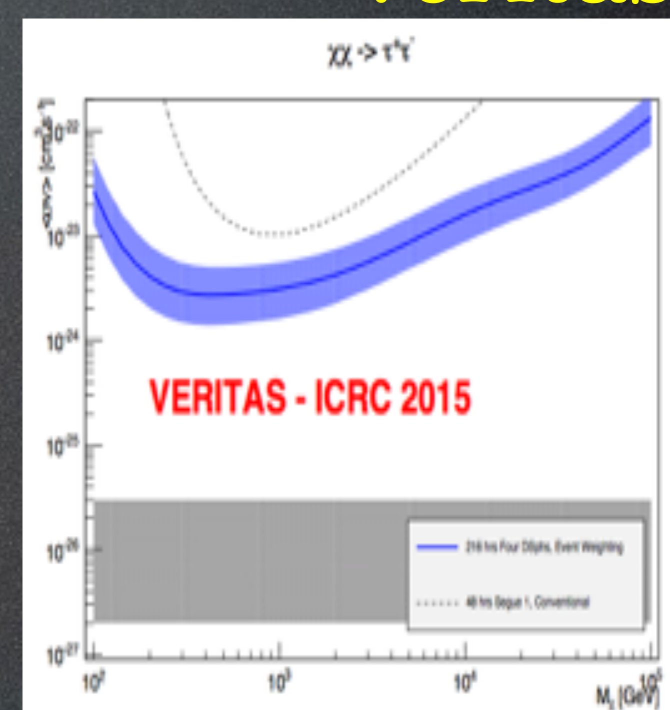
Dwarf galaxies

FERMI + Magic

M. Wood - ICRC 2015 #1206



Veritas



B. Zitzer - VERITAS - ICRC 2015 #1225

Also HAWC

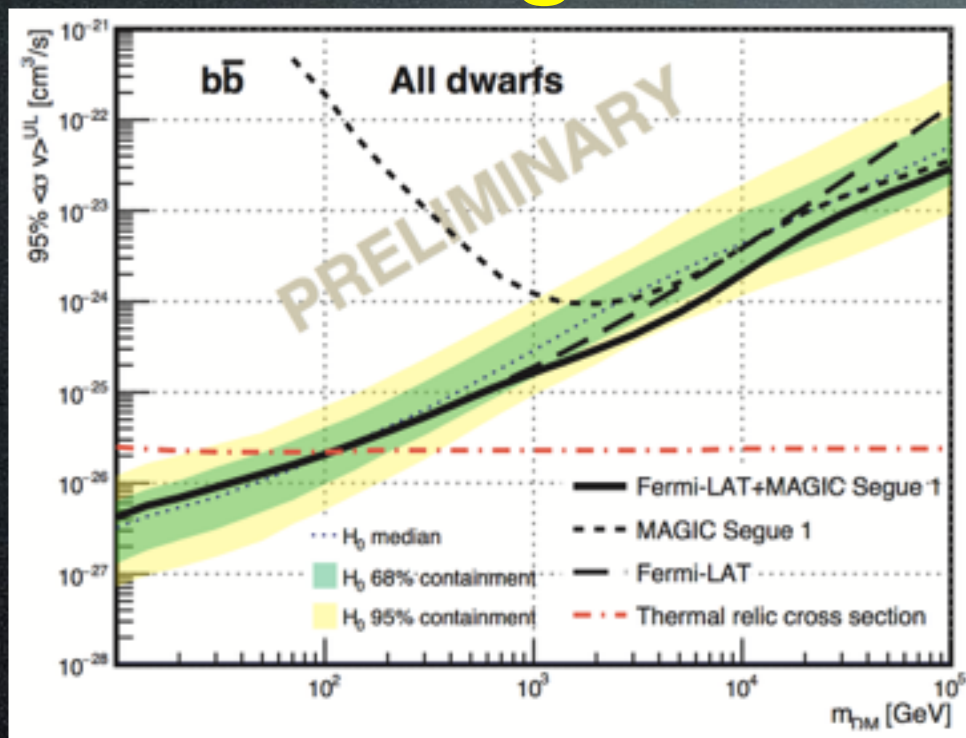
B. Dingus -
ICRC 2015 #1213

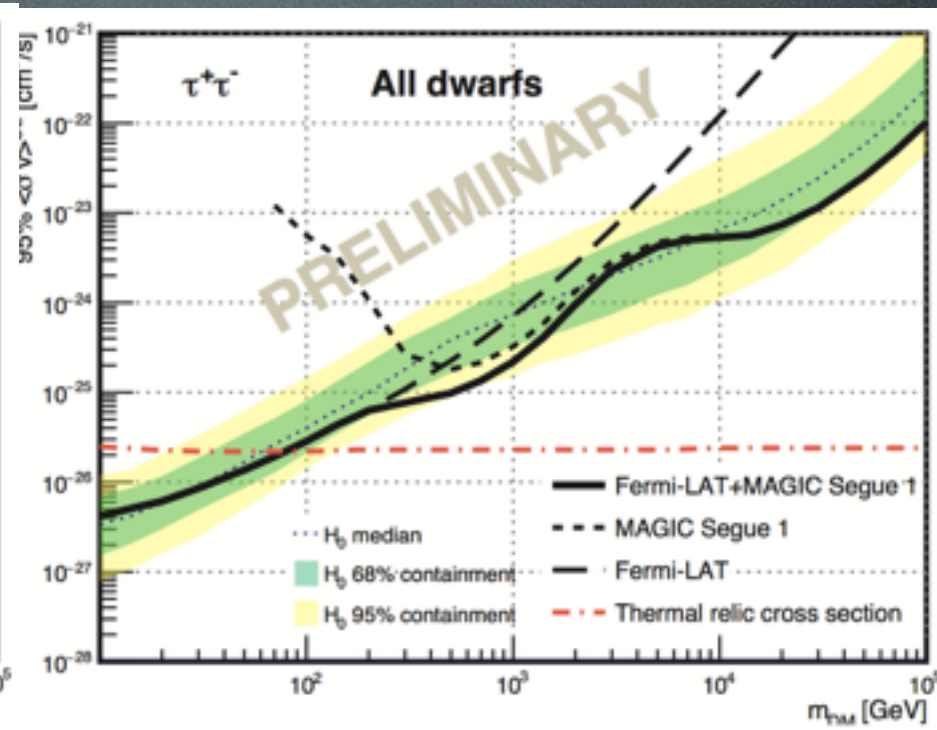
Constraints

Dwarf galaxies

FERMI + Magic

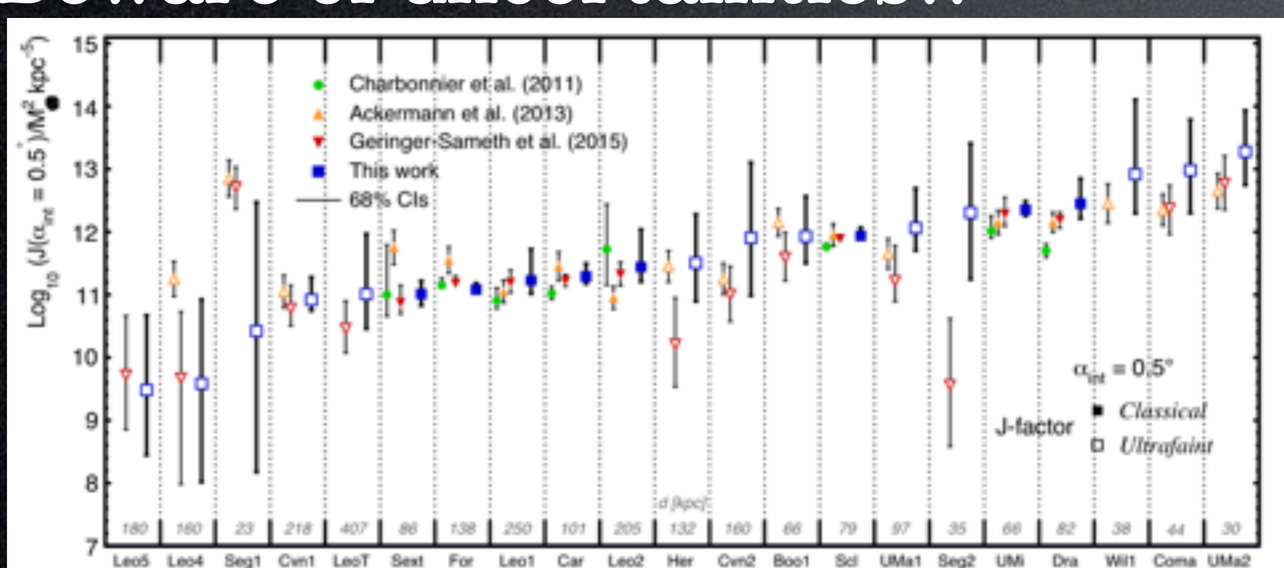
M. Wood - ICRC 2015 #1206



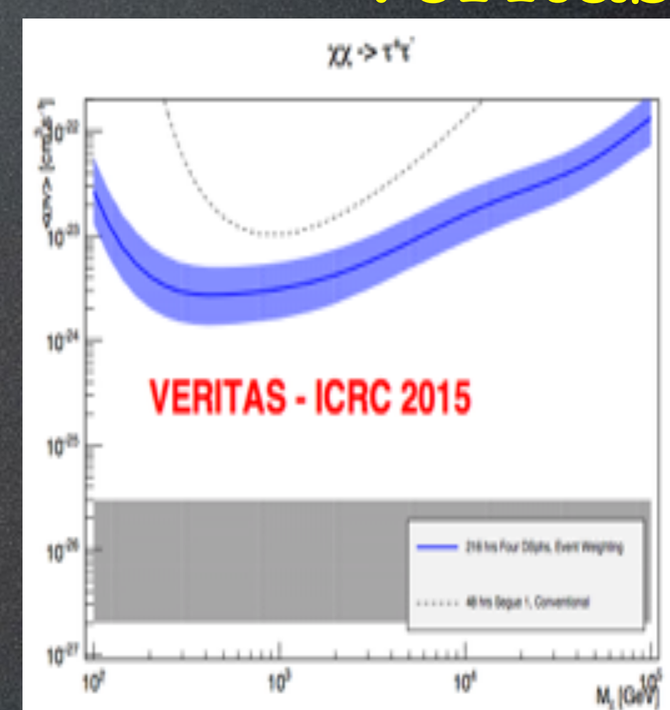


Veritas

Beware of uncertainties!:



V. Bonnivard - ICRC 2015 #1176



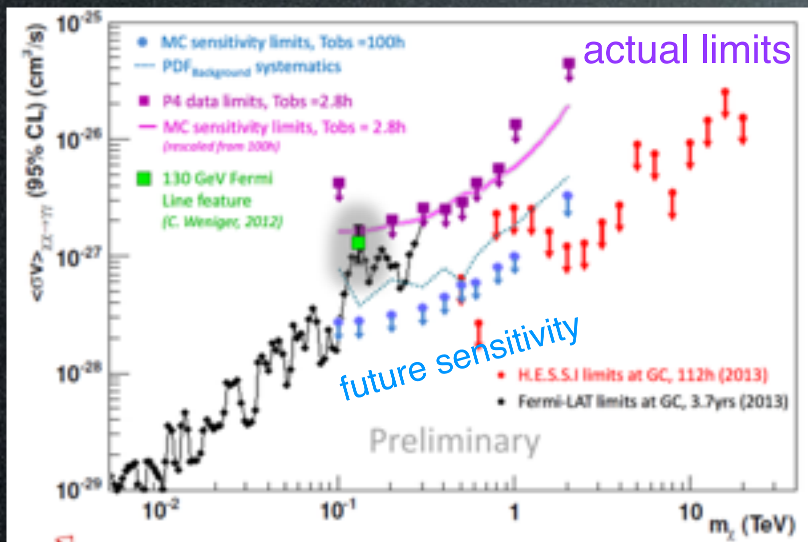
B. Zitzer - VERITAS - ICRC 2015 #1225

Also HAWC

B. Dingus - ICRC 2015 #1213

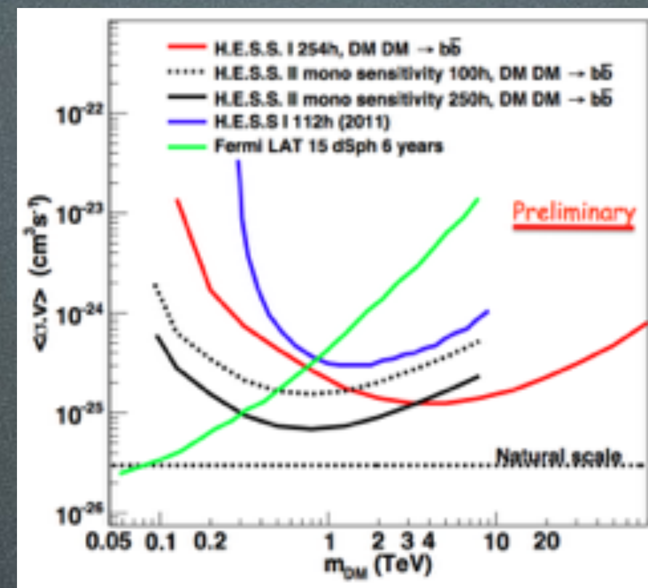
Constraints

HESS



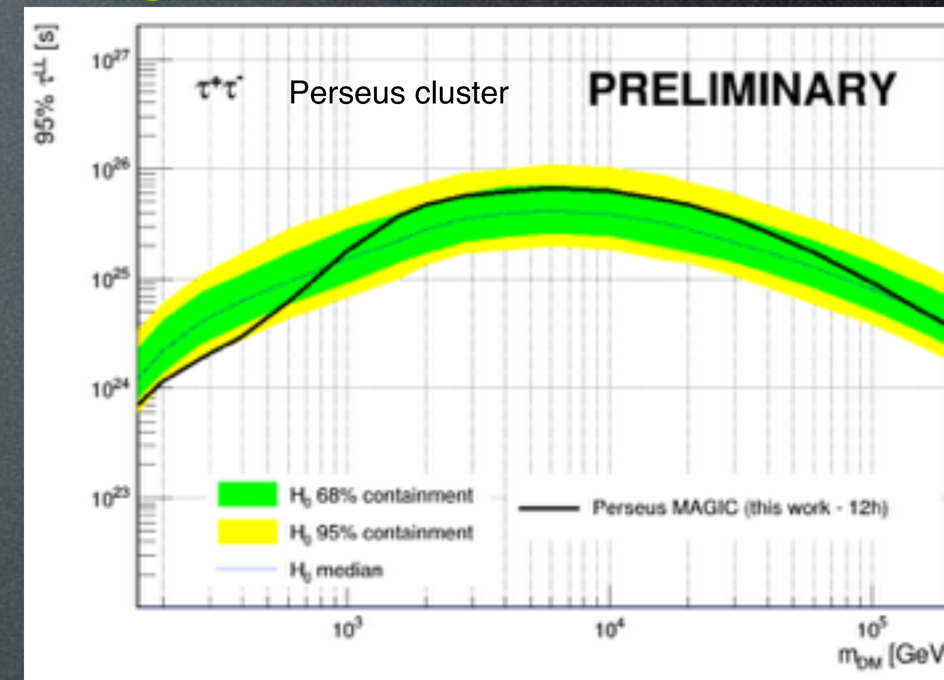
M. Kieffer - ICRC 2015 #1229

HESS



V. Lefranc - ICRC 2015 #1208

Magic



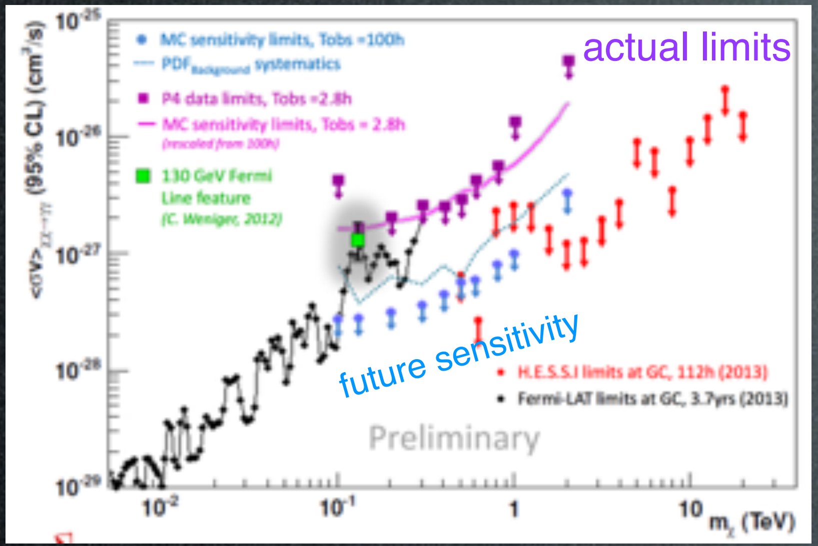
J. Palacio - ICRC 2015 #1204

WW, NFW

Perseus cluster

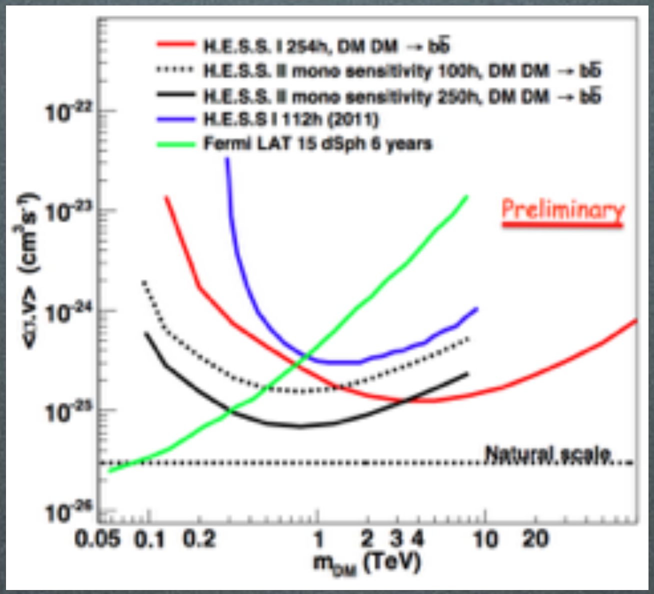
Constraints

HESS



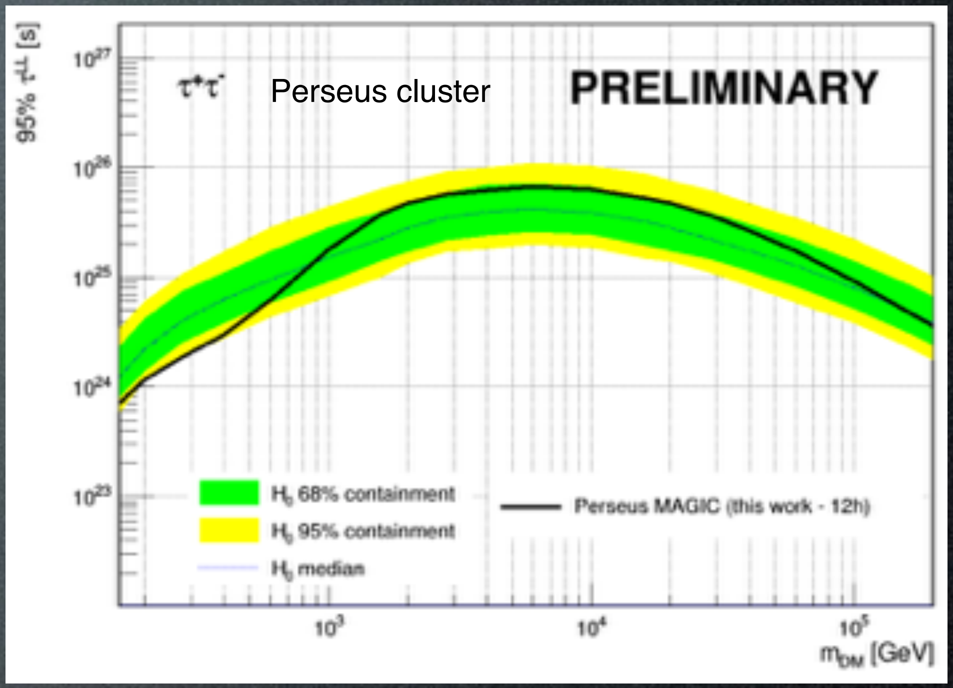
M. Kieffer - ICRC 2015 #1229

HESS



V. Lefranc - ICRC 2015 #1208

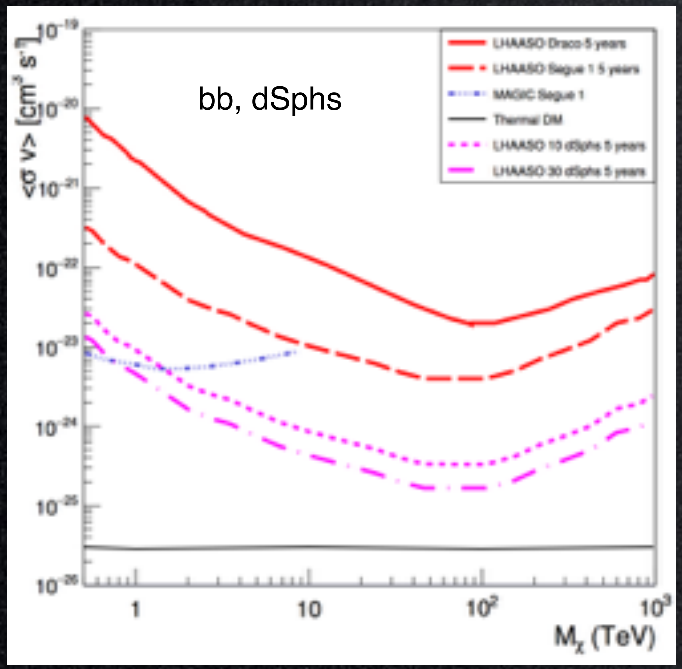
Magic



J. Palacio - ICRC 2015 #1204

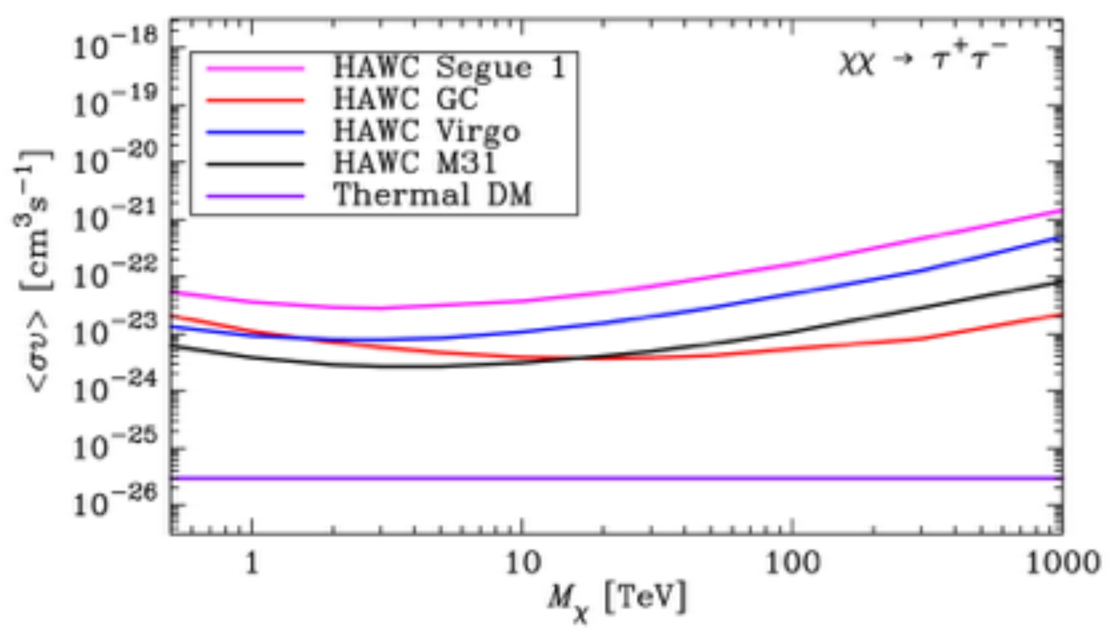
& Sensitivities

LHAASO



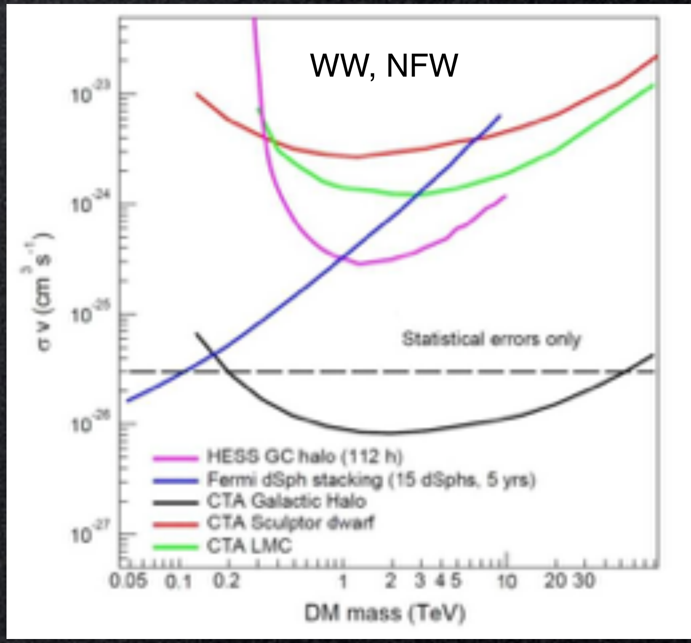
G. Di Sciascio - ICRC 2015 #296

HAWC



B. Dingus - ICRC 2015 #1227

CTA

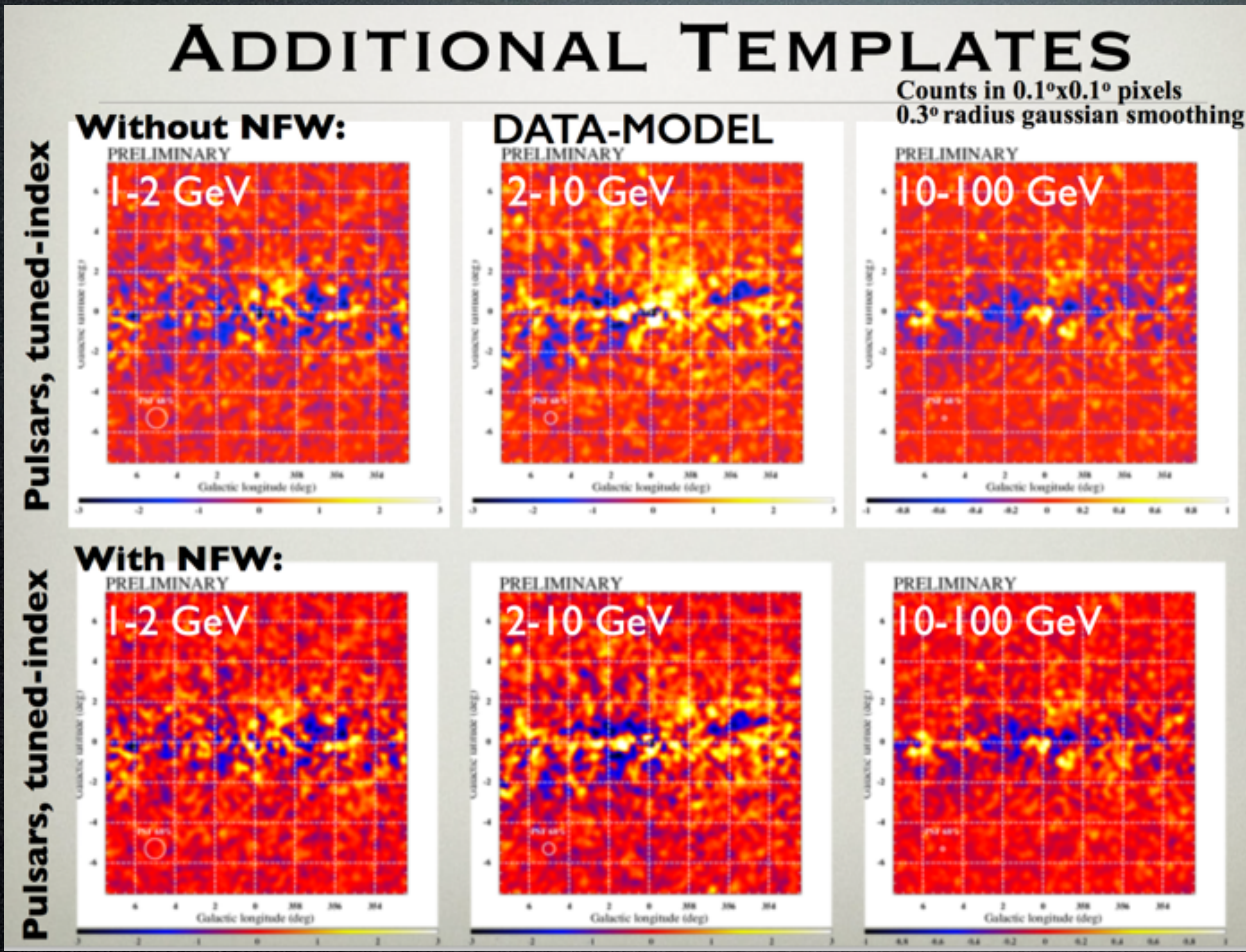


J. Carr - ICRC 2015 #1203

GC GeV excess

GC GeV excess

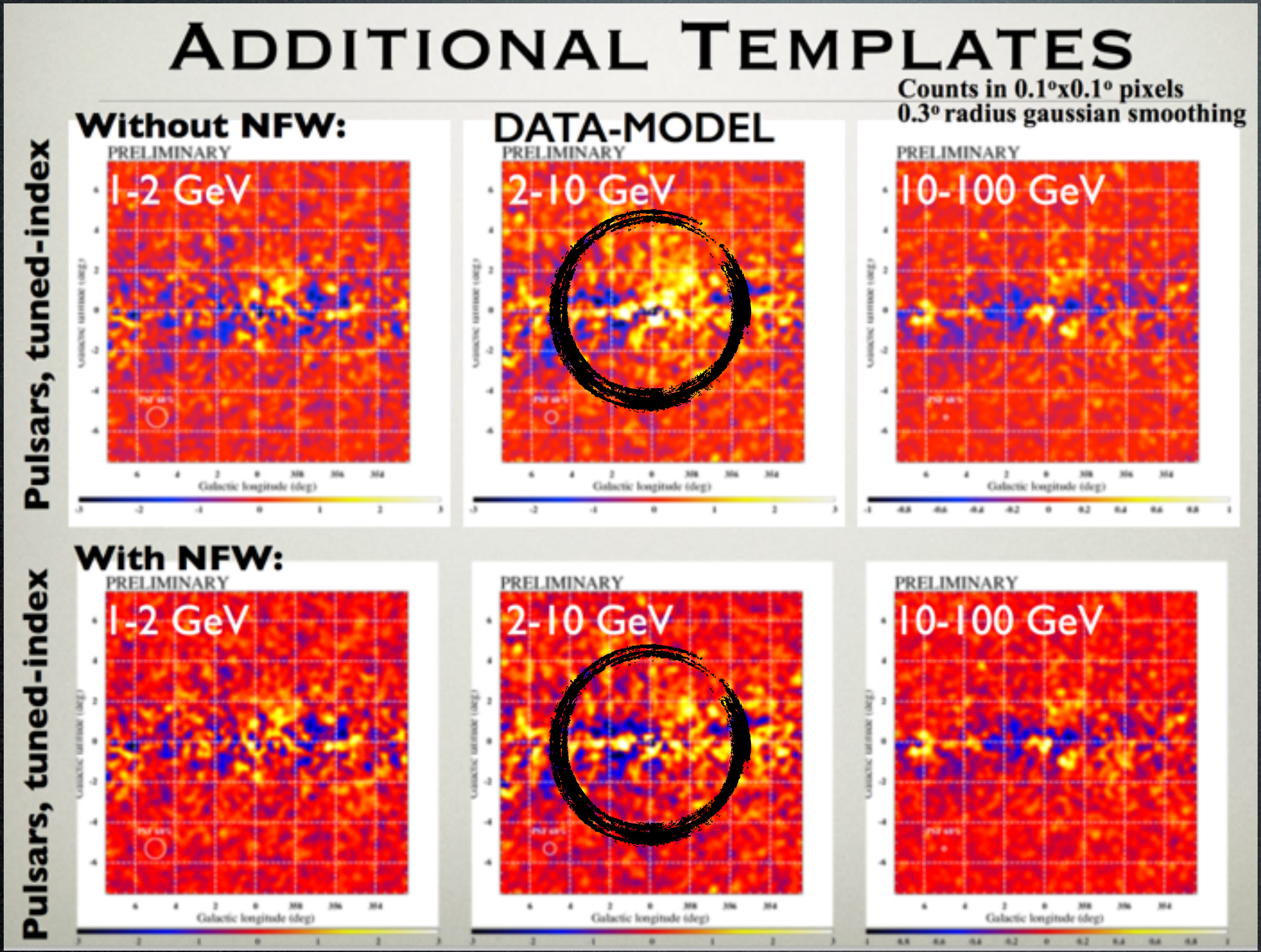
Dark Matter interpretation:



S. Murgia for FERMI-LAT - ICRC 2015
T. Porter for FERMI-LAT - ICRC 2015 #815

GC GeV excess

Dark Matter interpretation:

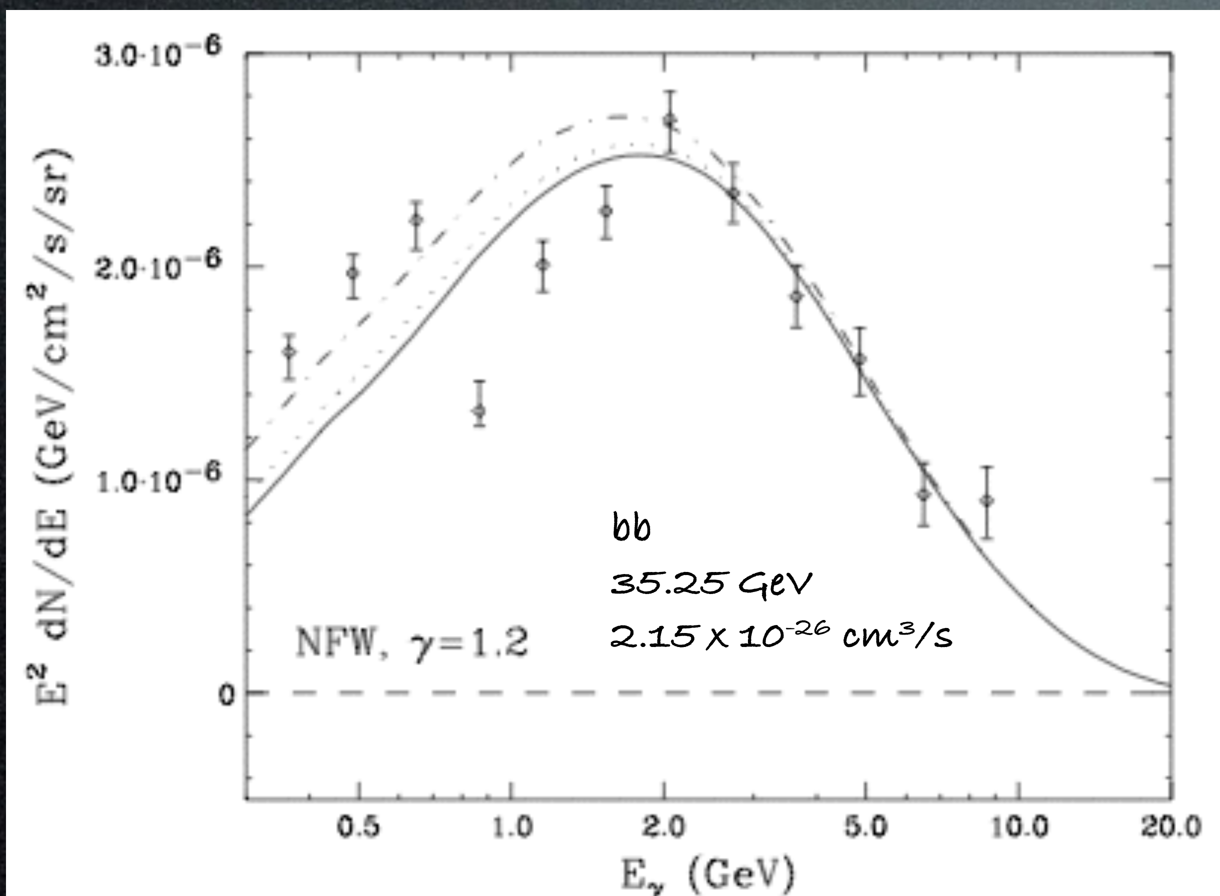


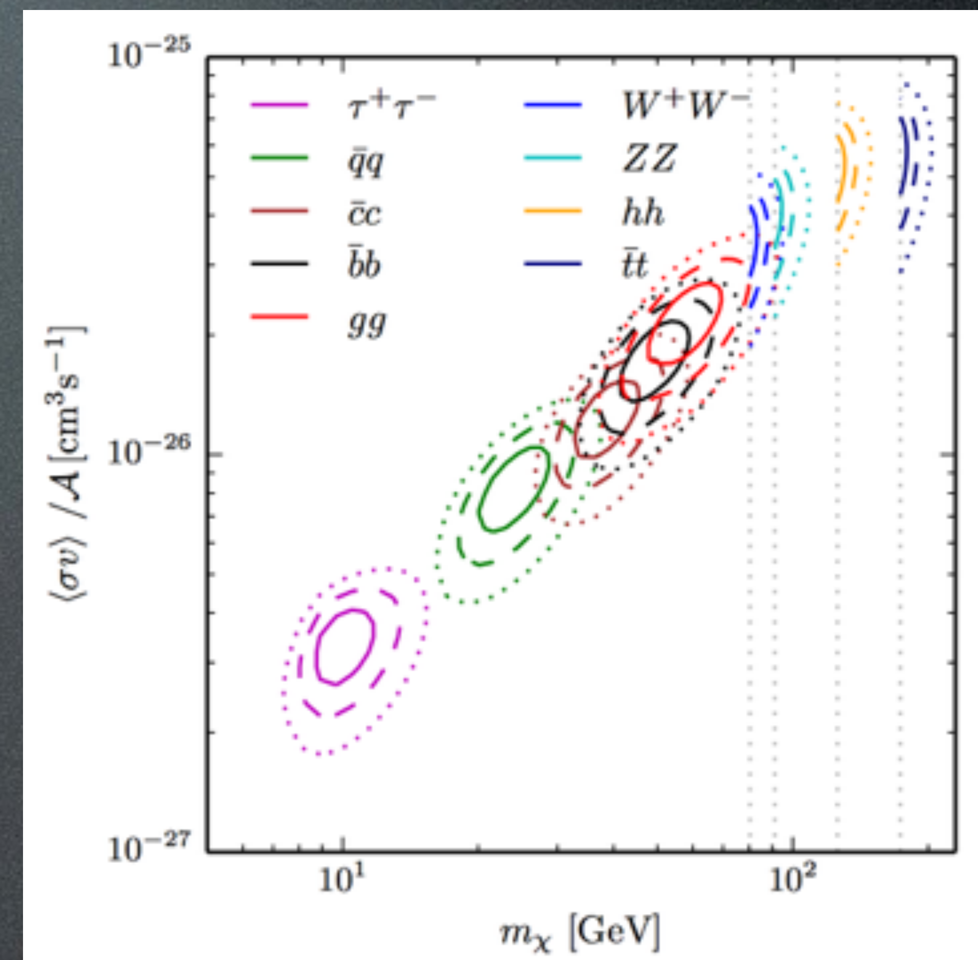
S. Murgia for FERMI-LAT - ICRC 2015
T. Porter for FERMI-LAT - ICRC 2015 #815

GC GeV excess

Dark Matter interpretation:

Best fit:
~35 GeV, quarks, ~thermal σv





F. Calore et al. 1411.4647
ICRC2015 #915

A compelling case for annihilating DM

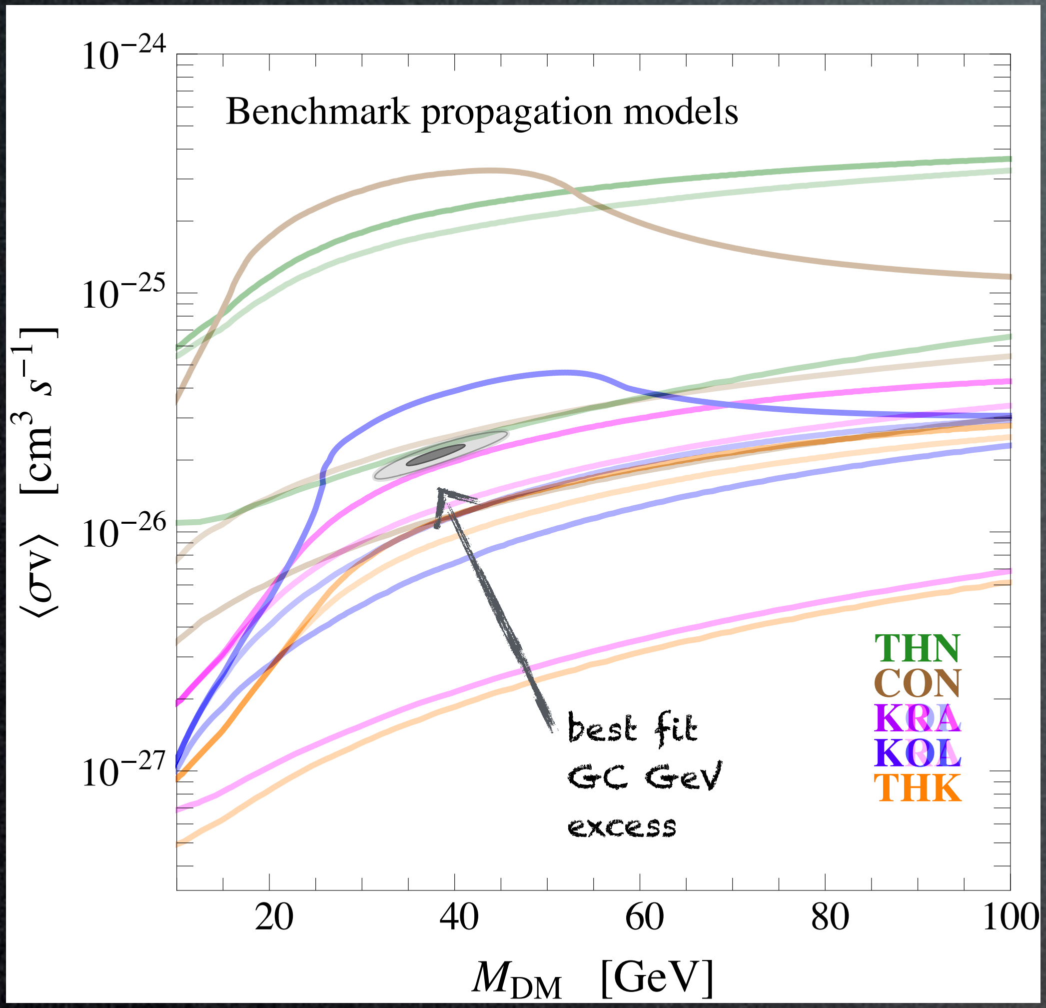
Daylan, Finkbeiner, Hooper, Linden, Portillo, Rodd, Slatyer 1402.6703

...as good as it can get.

GC GeV excess

Dark Matter interpretation:

Antiproton constraints
are not conclusive



Cirelli, Gaggero,
Giesen, Taoso,
Urbano 1407.2173

D. Gaggero - ICRC 2015

Also:

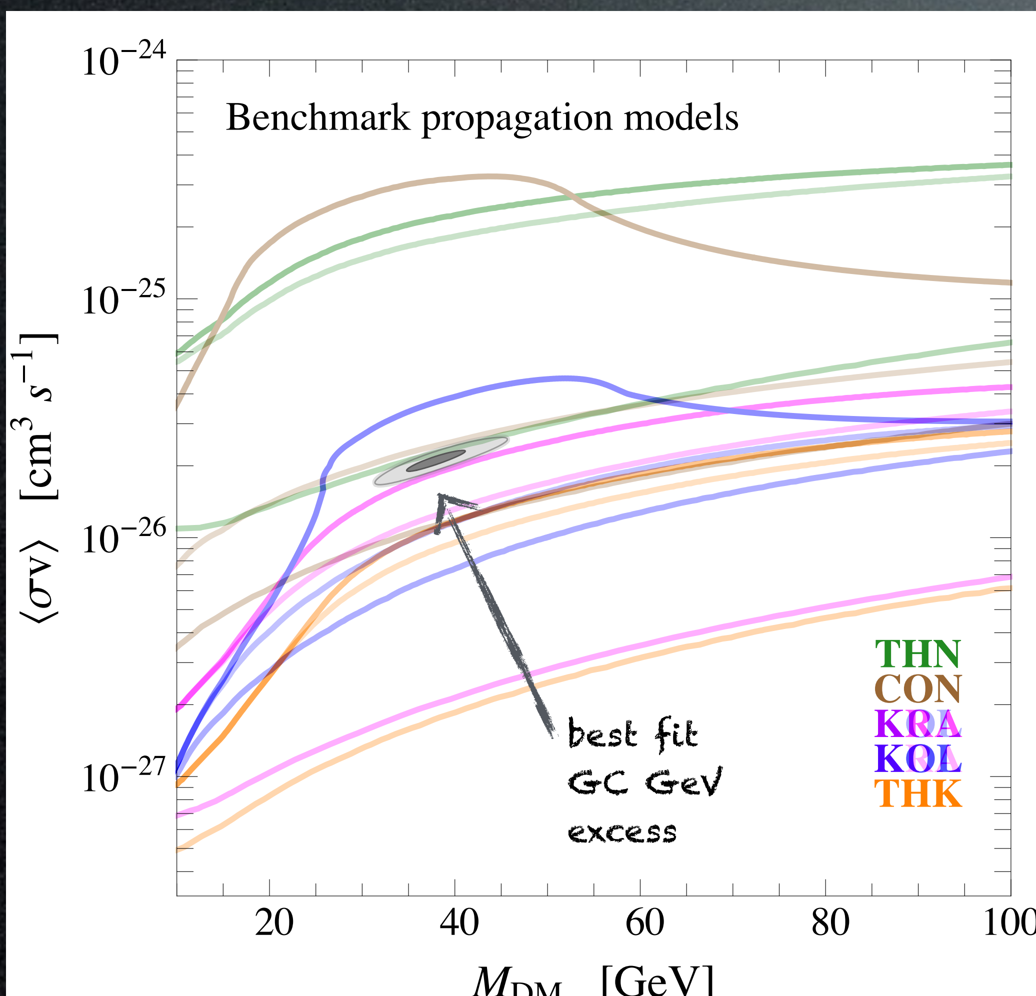
Bringmann, Vollmann,
Weniger 1406.6027

Hooper, Linden, Mertsch
1410.1527

GC GeV excess

Dark Matter interpretation:

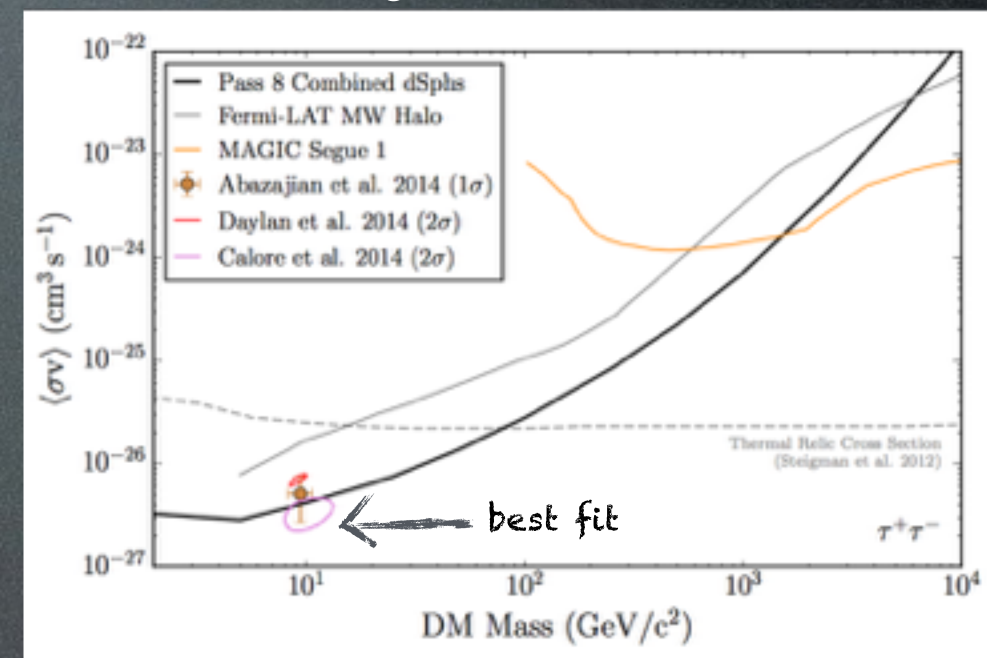
Antiproton constraints
are not conclusive



Cirelli, Gaggero,
Giesen, Taoso,
Urbano 1407.2173

D. Gaggero - ICRC 2015

Gamma ray ones neither



M. Wood - ICRC 2015 #1226

Also:

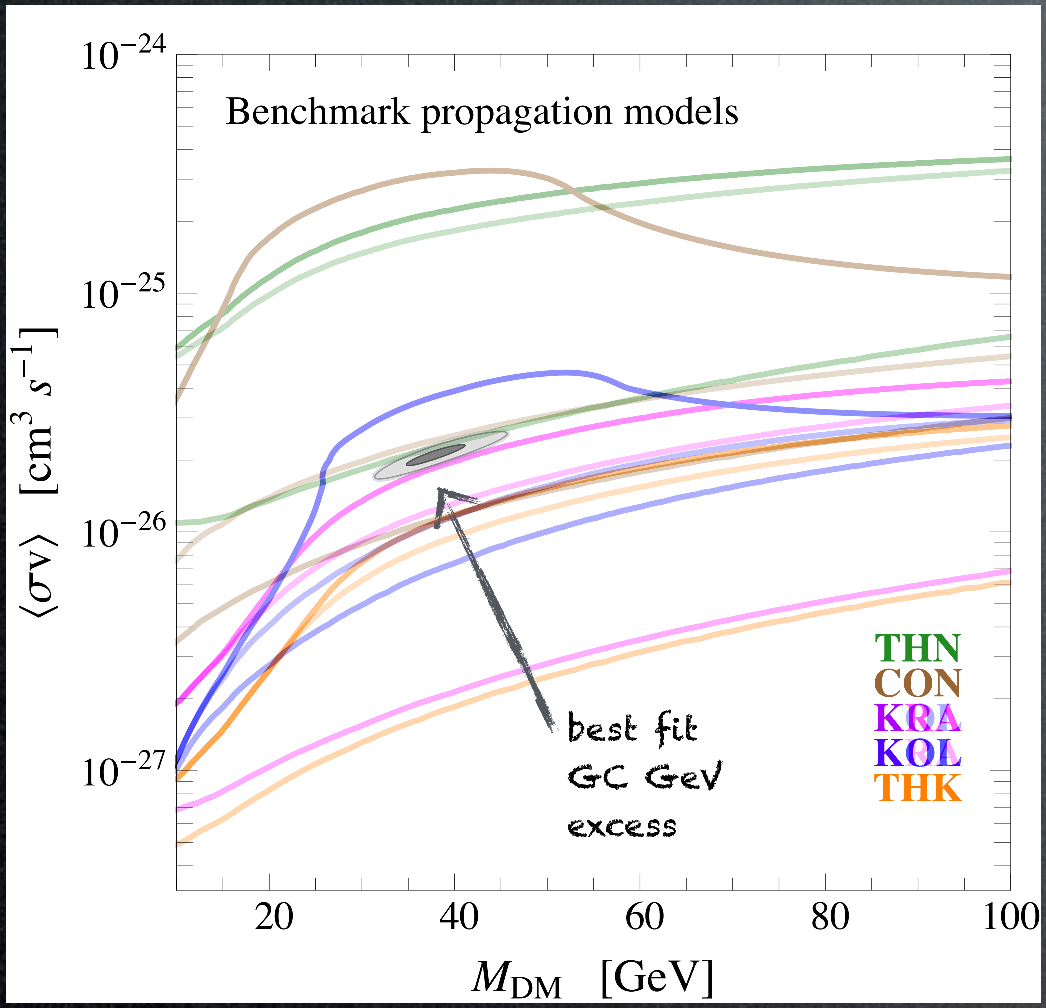
Bringmann, Vollmann,
Weniger 1406.6027

Hooper, Linden, Mertsch
1410.1527

GC GeV excess

Dark Matter interpretation:

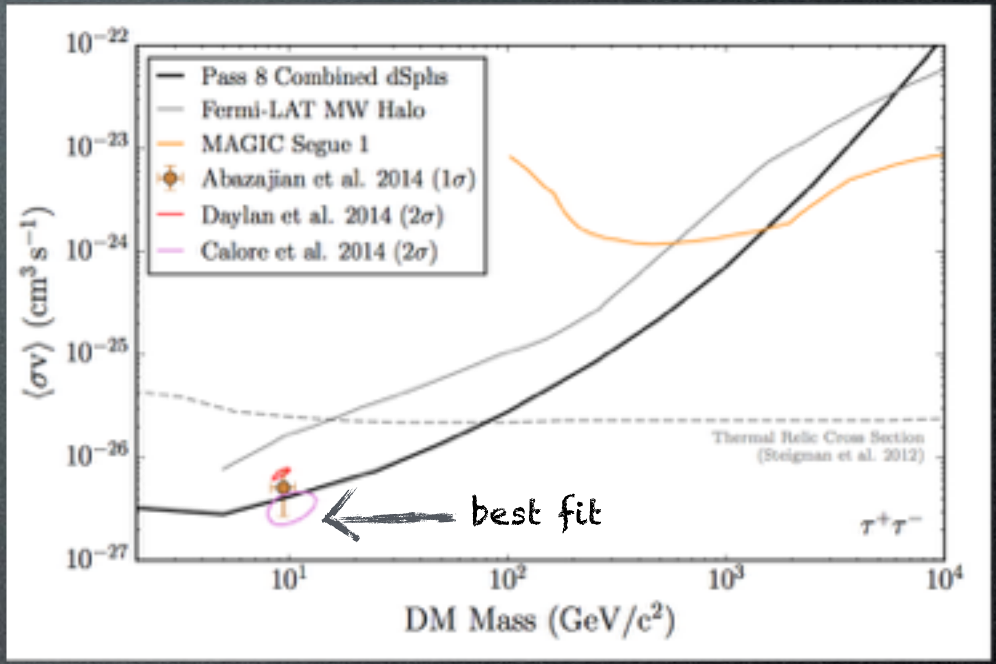
Antiproton constraints
are not conclusive



Cirelli, Gaggero, Giesen, Taoso, Urbano 1407.2173

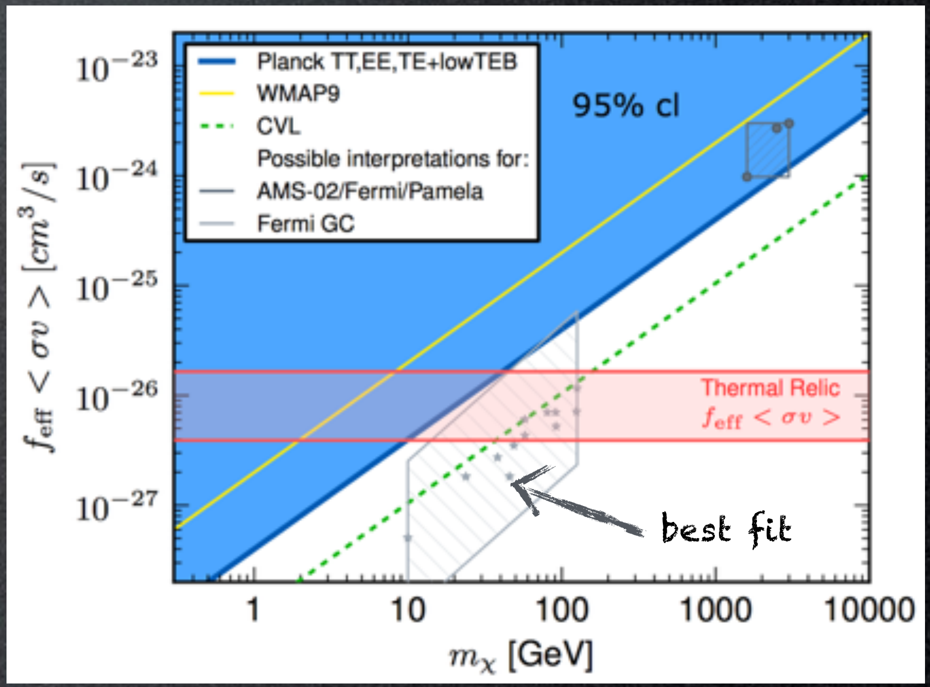
D. Gaggero - ICRC 2015

Gamma ray ones neither



M. Wood - ICRC 2015 #1226

Nor CMB



Planck 2015

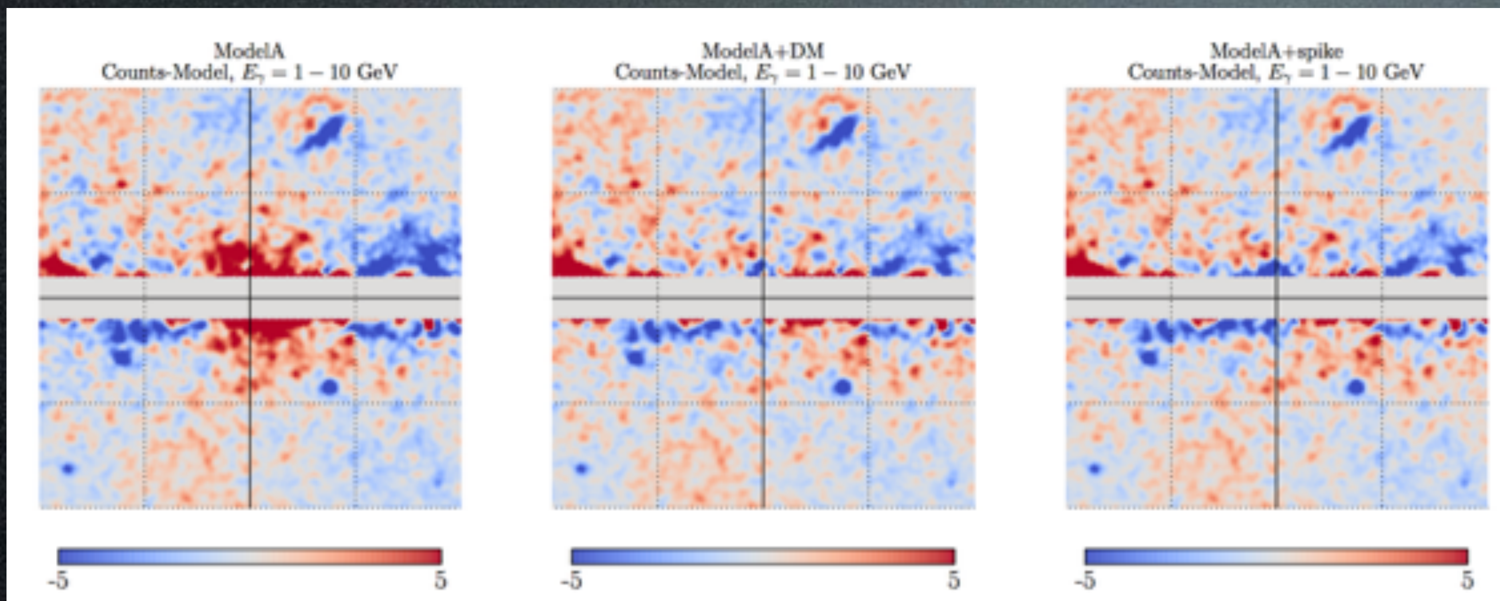
Also:

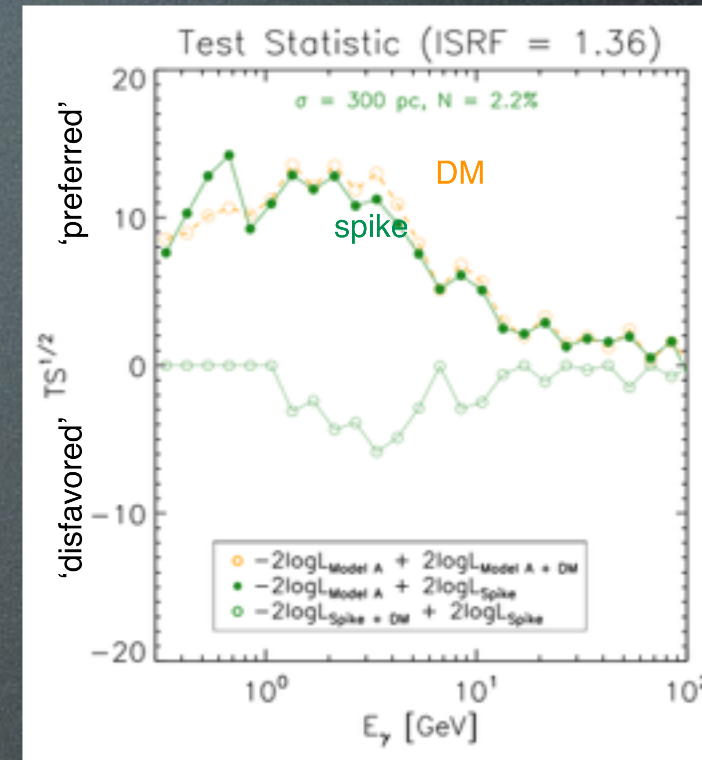
Bringmann, Vollmann, Weniger 1406.6027

Hooper, Linden, Mertsch 1410.1527

GC GeV excess

'Astro' interpretation(s):

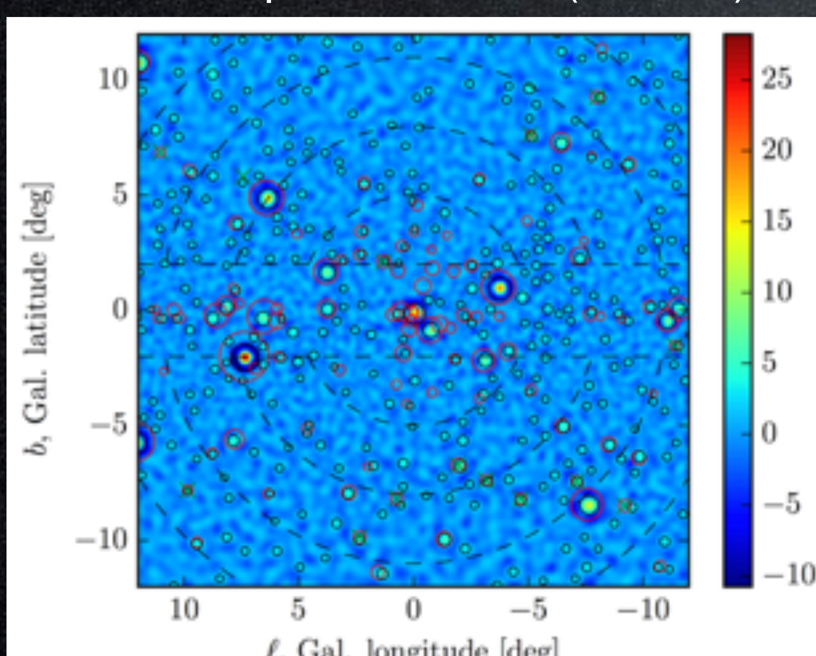




An additional steady-source spike of CRs (from SNRs?) that emit via ICS

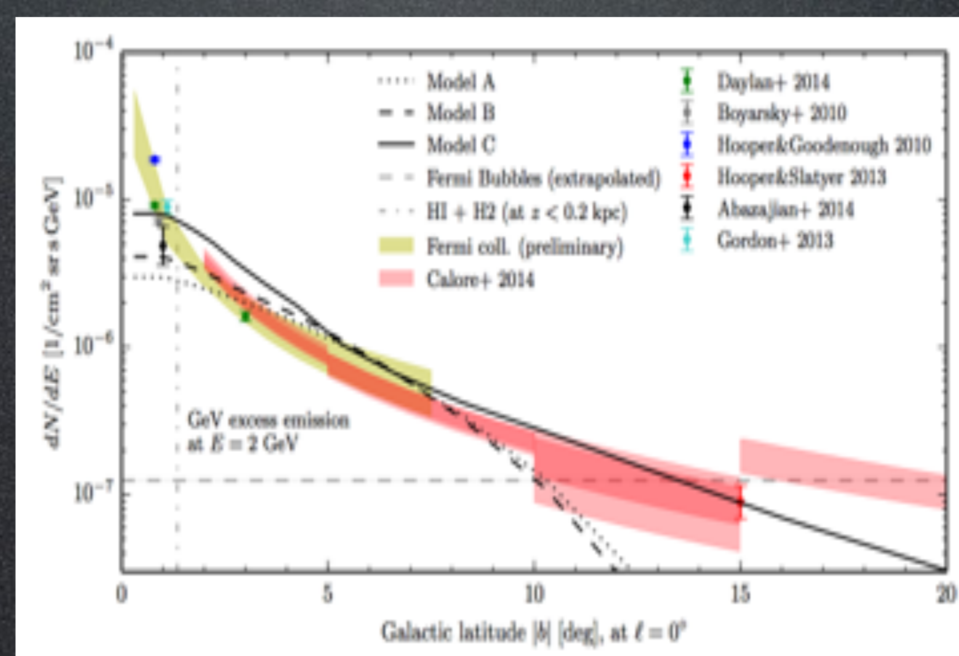
D. Gaggero - ICRC 2015
A. Urbano - ICRC 2015 #909

Unresolved point sources (MSPs?)



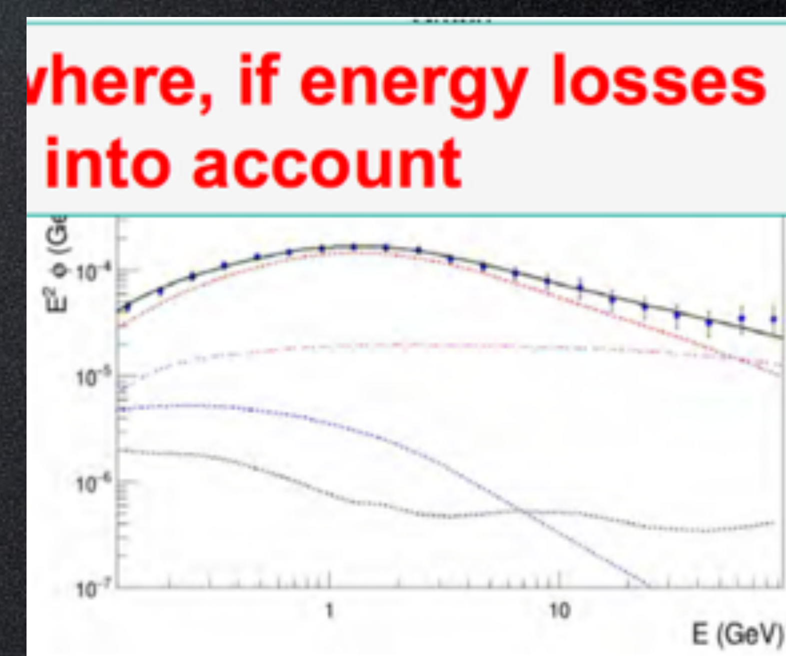
C. Weniger - ICRC 2015 #920

Leptonic outbursts: old + young (1 + 0.1 Myr)
(but even this is not ideal)



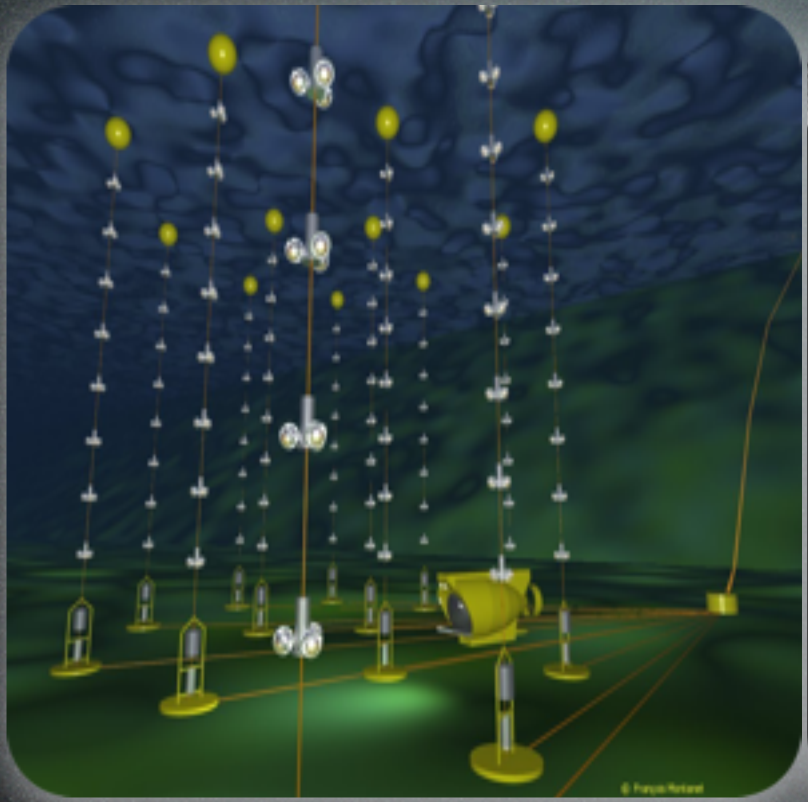
F. Calore - ICRC 2015 #915

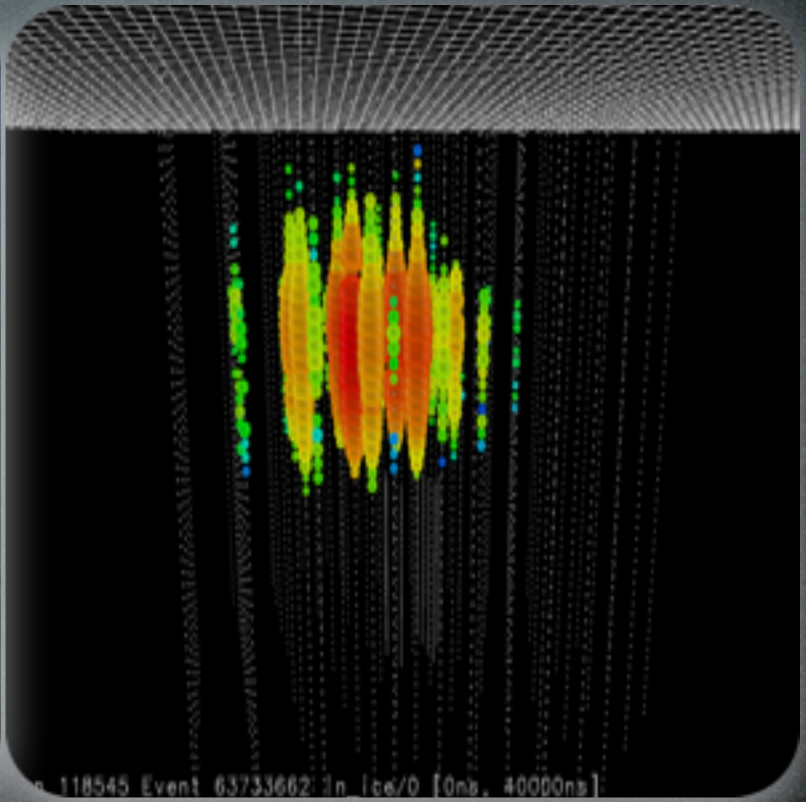
Enhanced proton energy losses
near the GC



W. De Boer - ICRC 2015

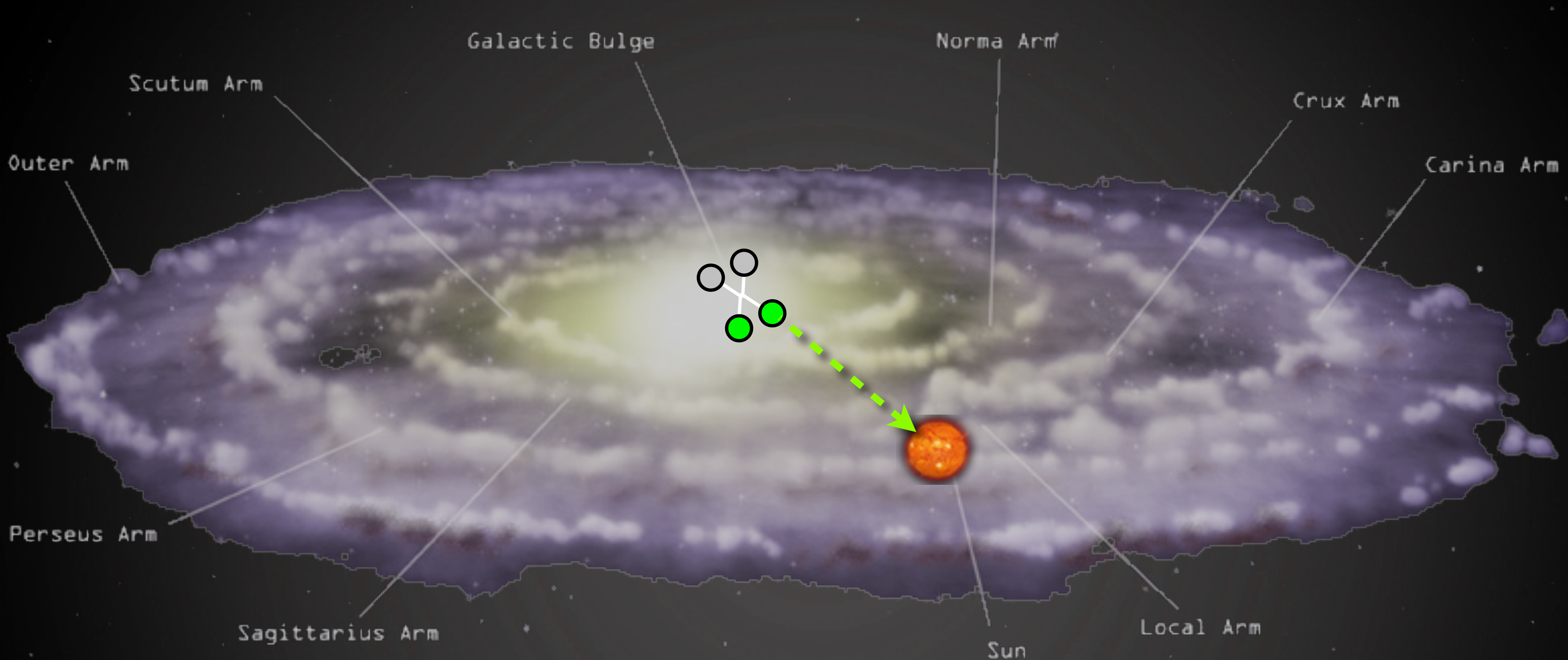
Neutrinos





ID with neutrinos

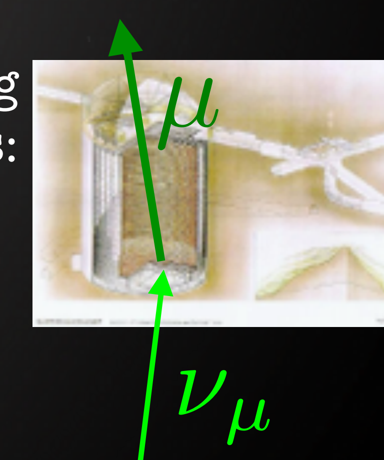
ν from DM annihilations in galactic center



$$DM\,DM \to W^-, Z, b, \tau^-, t, h \ldots \rightsquigarrow e^\mp, \overset{(-)}{p}, \overset{(-)}{D} \ldots \text{ and } \nu$$

$$W^+, Z, \bar{b}, \tau^+, \bar{t}, h \ldots \rightsquigarrow e^\pm, \overset{(-)}{p}, \overset{(-)}{D} \ldots \text{ and } \nu$$

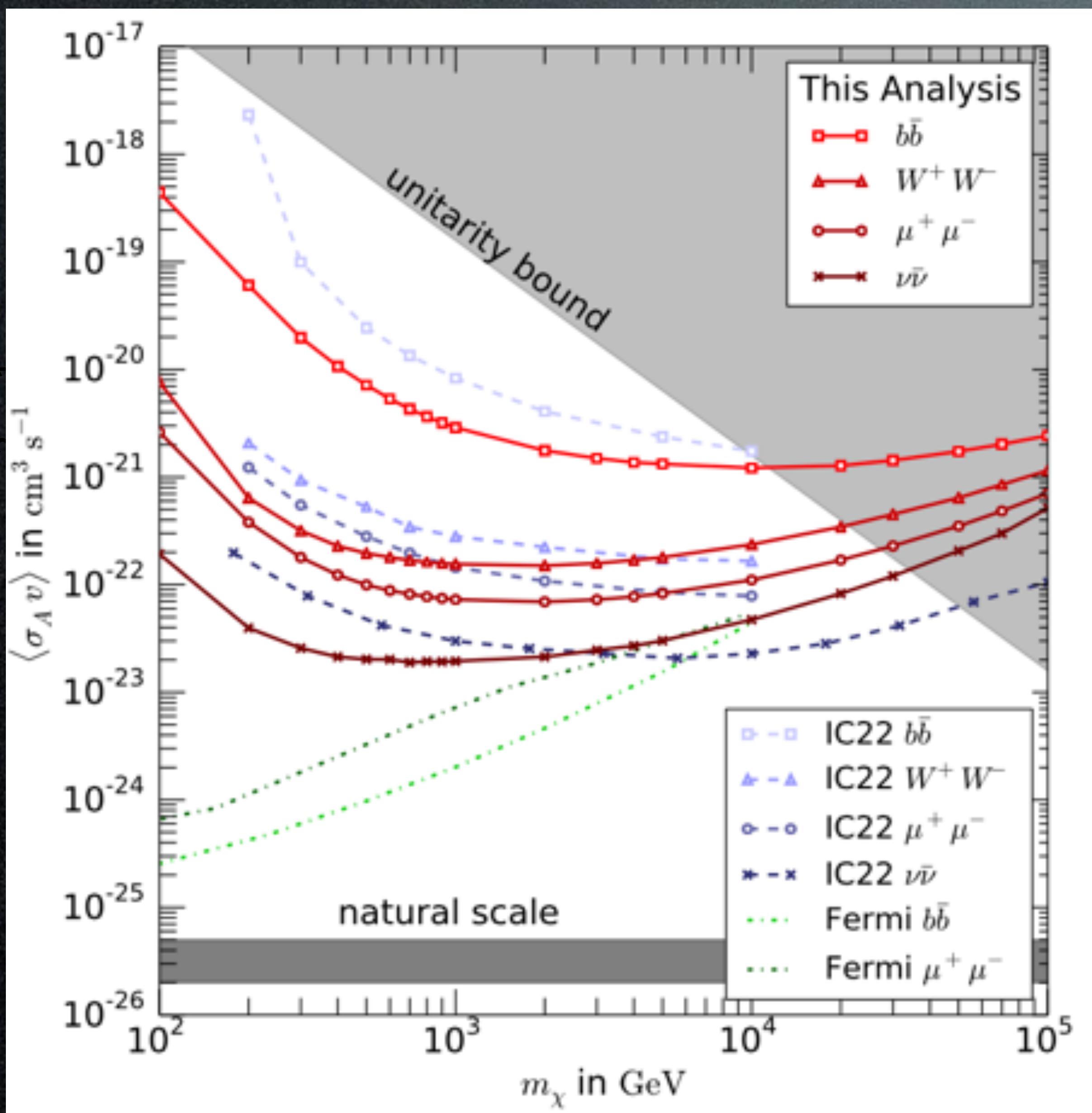
up-going muons:



ID with neutrinos

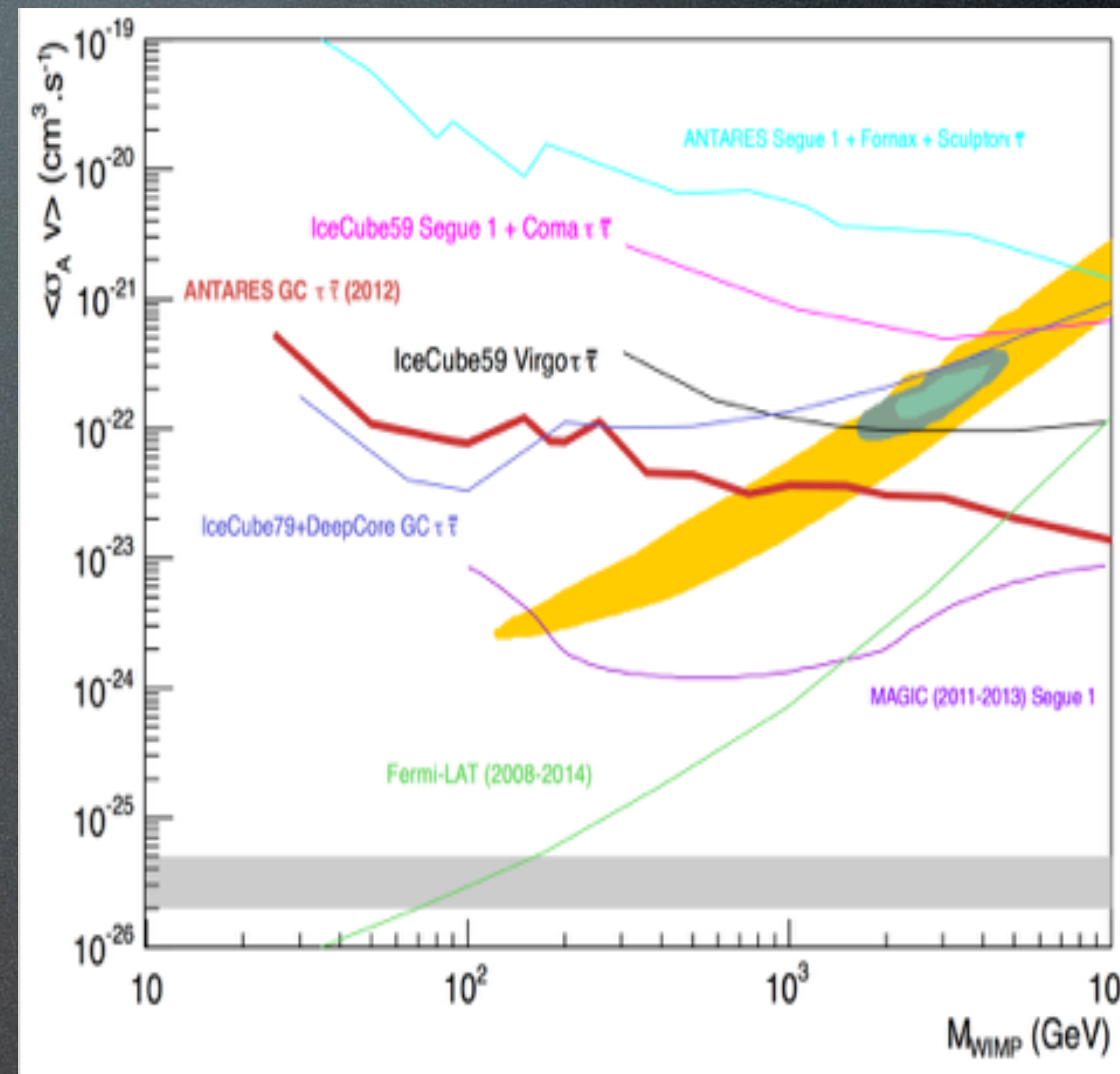
ν from DM annihilations in galactic center/halo & beyond

ICECUBE



ICECUBE coll. 1406.6868

ANTARES



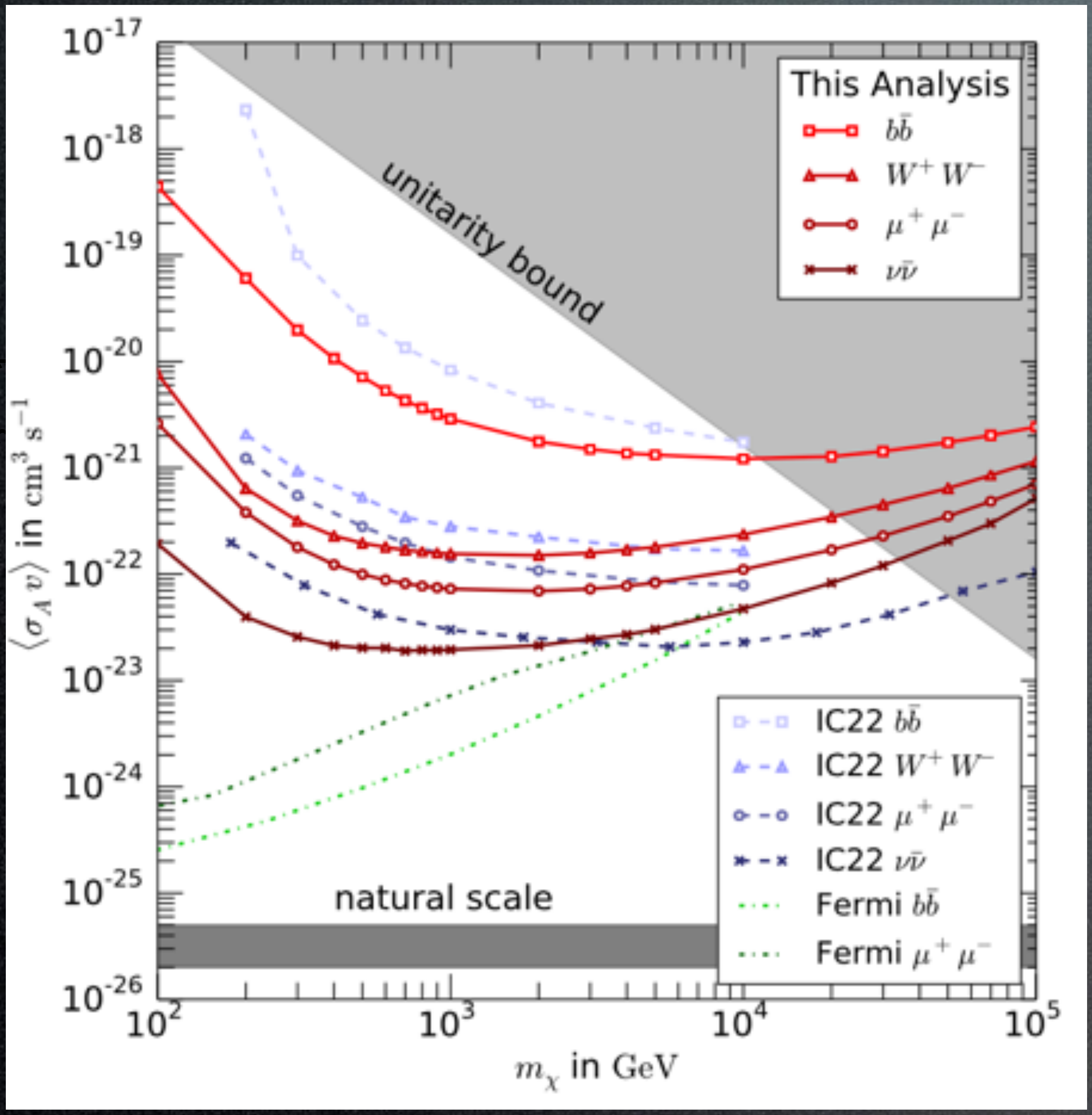
C. Tönnis - ICRC 2015 talk and #1110
ANTARES coll. 1506.04866

Warning: direct comparison is difficult
(different profiles, J-factors, channels...)

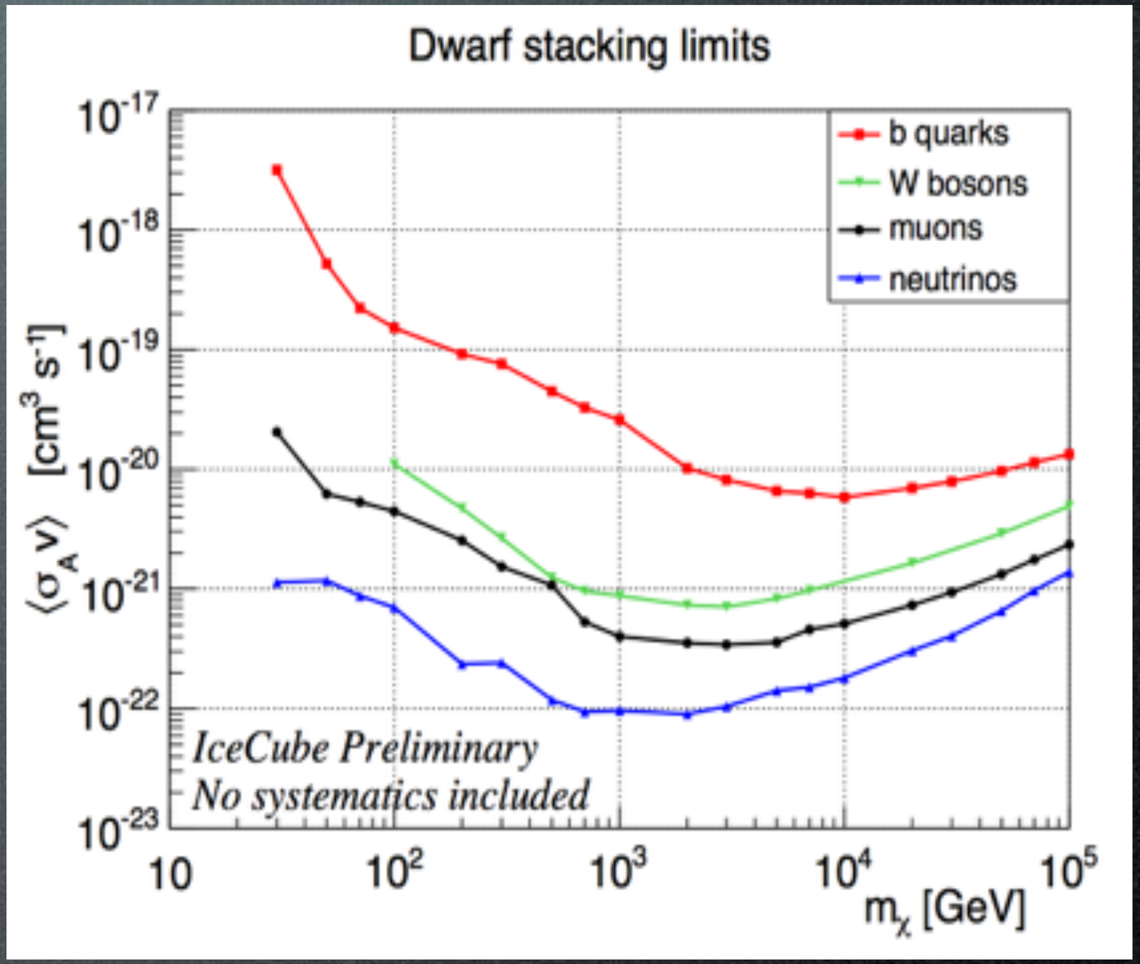
ID with neutrinos

ν from DM annihilations in galactic center/halo & beyond

ICECUBE



ICECUBE coll. 1406.6868



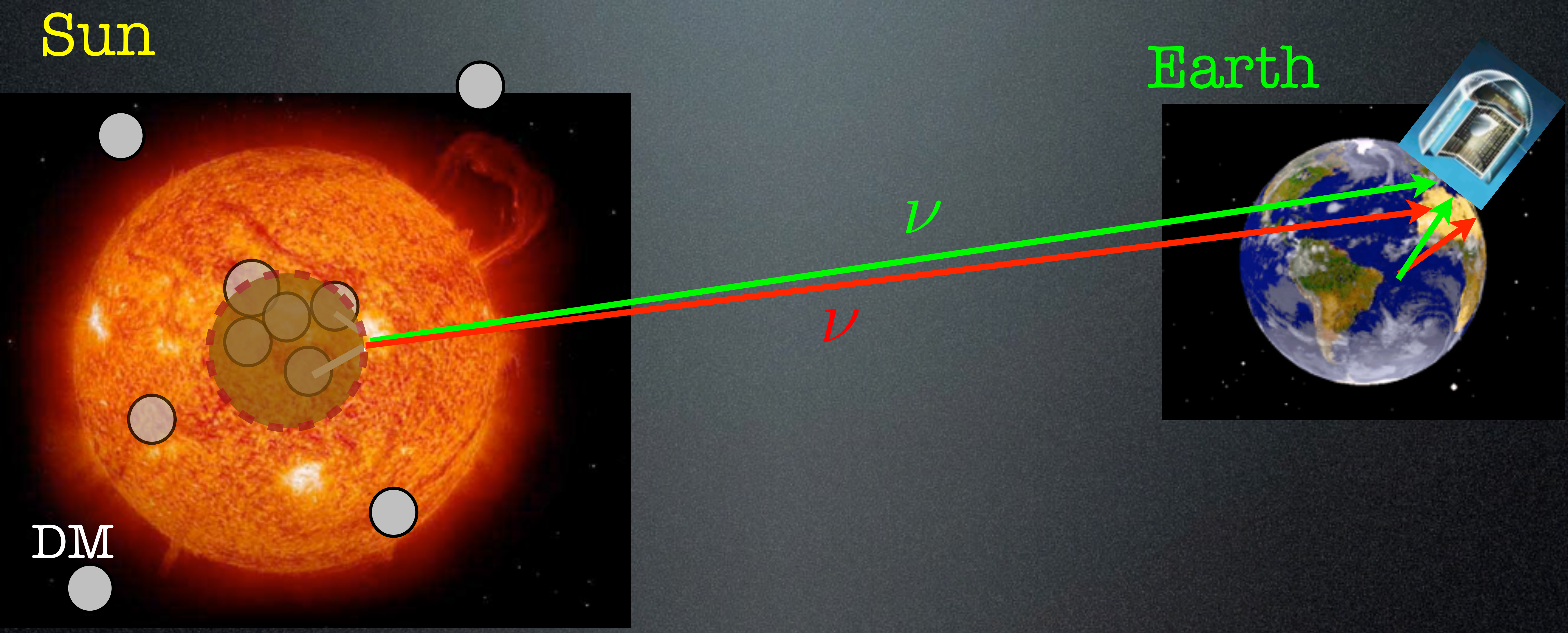
M. de With - ICRC 2015 #1215

ICECUBE Decaying PeV DM analysis upcoming

J. Pepper - ICRC 2015 #1051

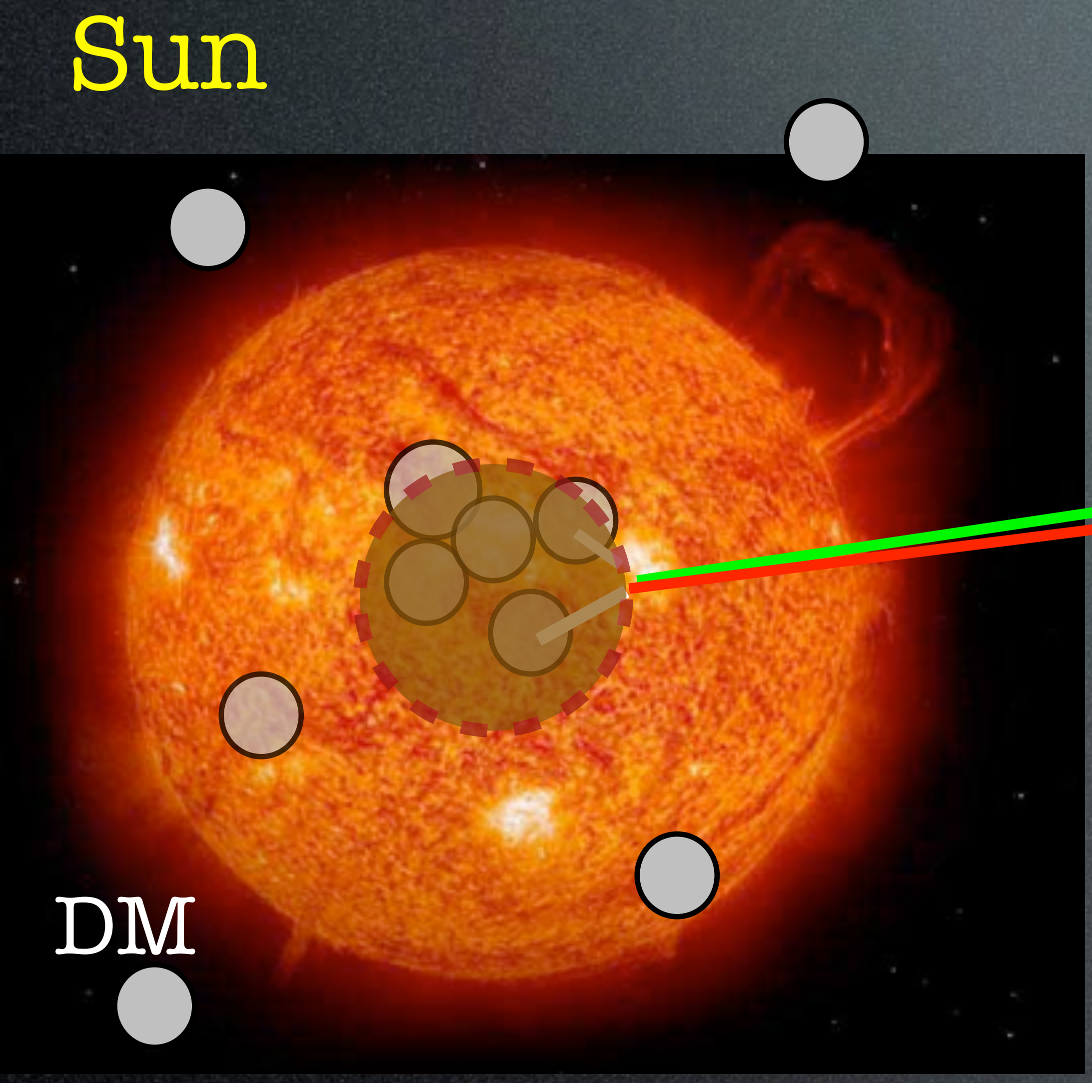
ID with neutrinos

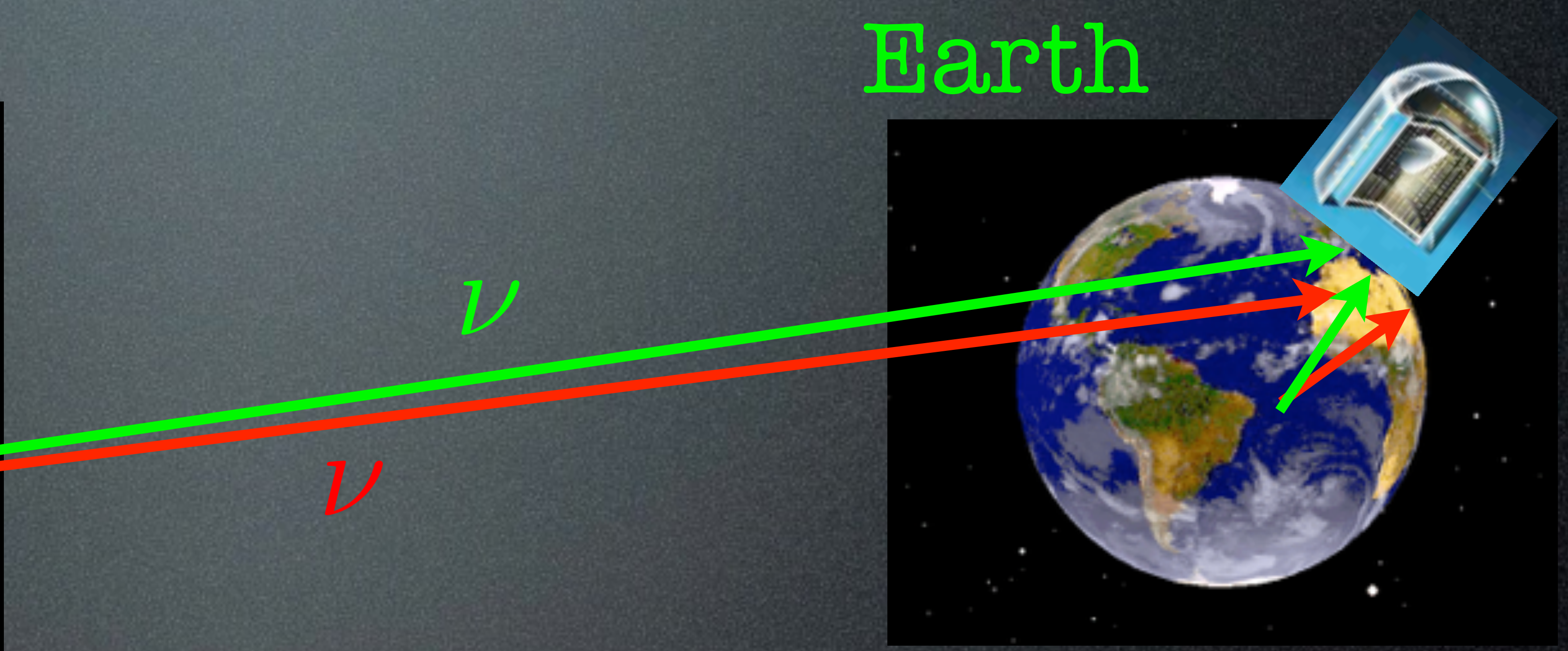
ν from DM annihilations in the Sun/Earth



ID with neutrinos

ν from DM annihilations in the Sun/Earth

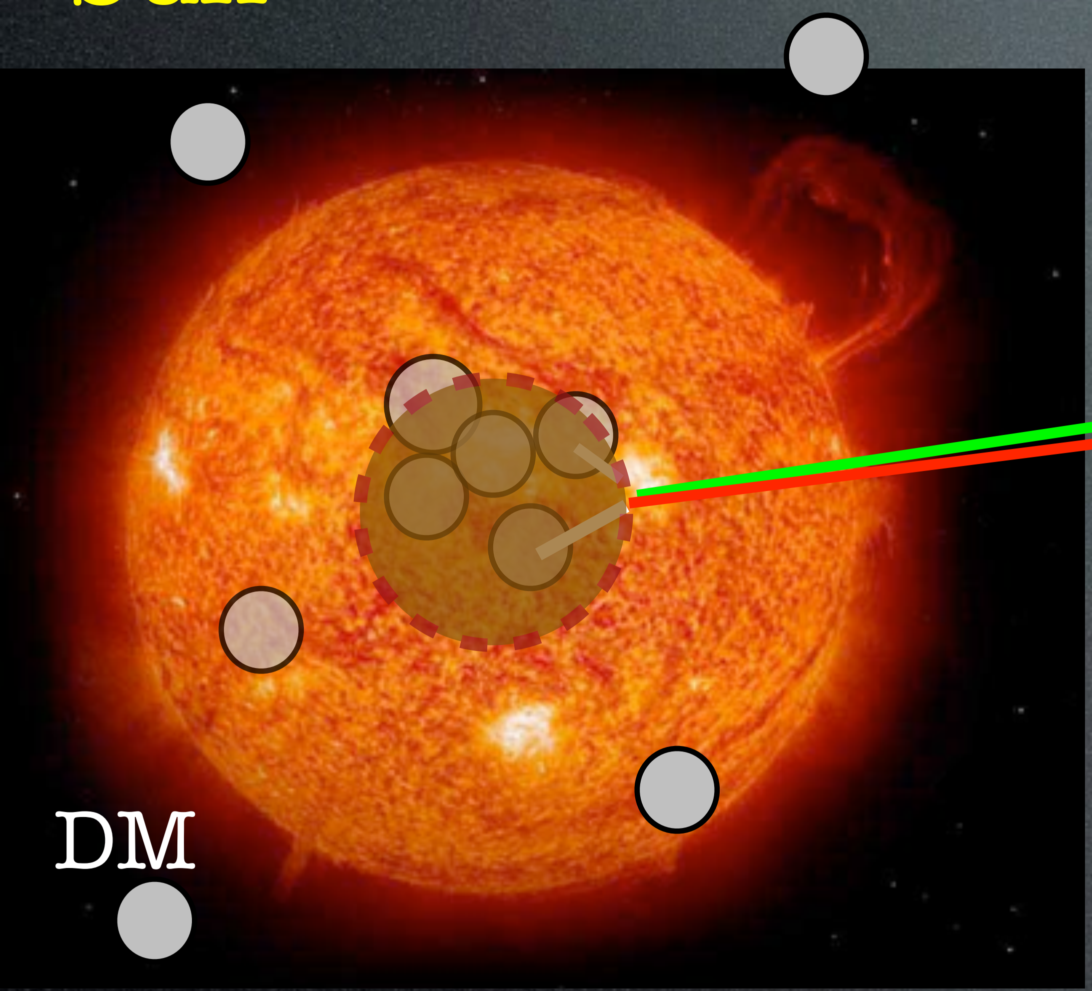


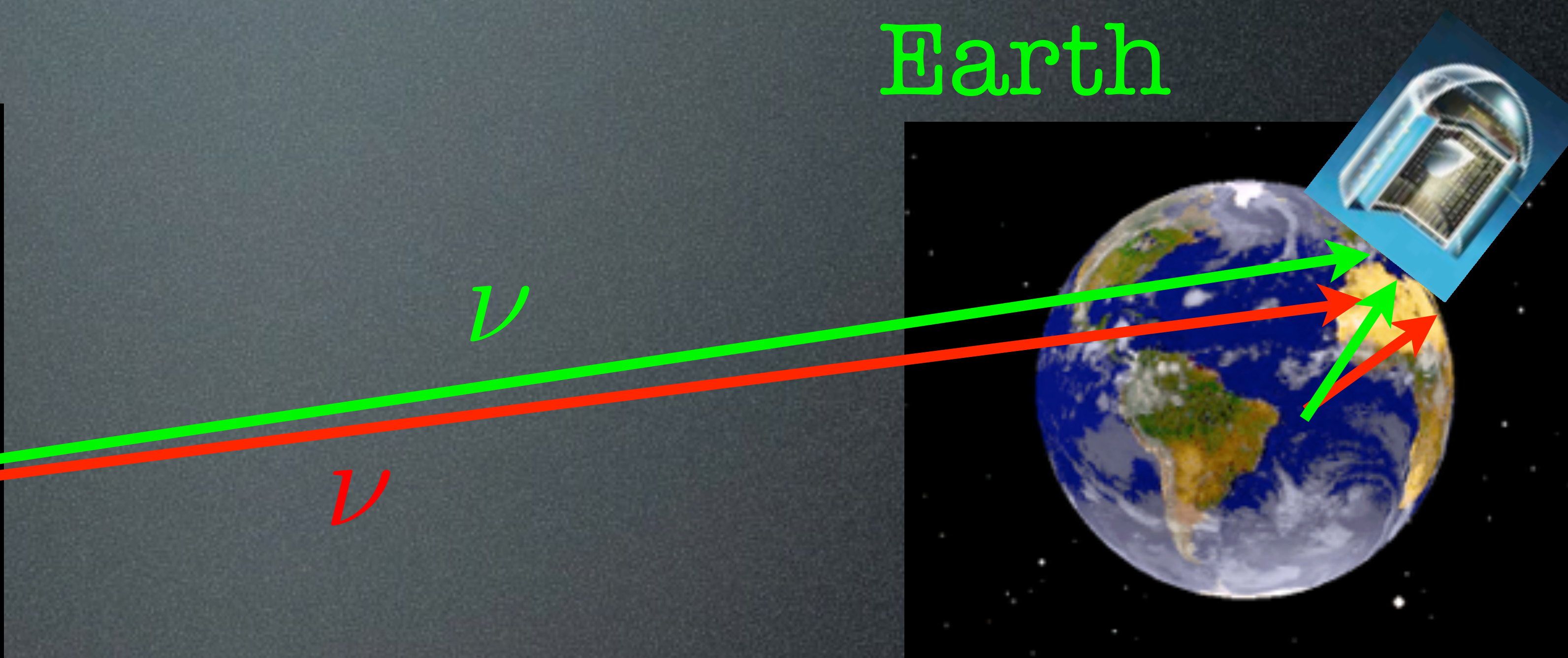


Capture is the limiting factor.
Probes scattering with nuclei (σ_{SI}, σ_{SD}).

ID with neutrinos

ν from DM annihilations in the Sun/Earth



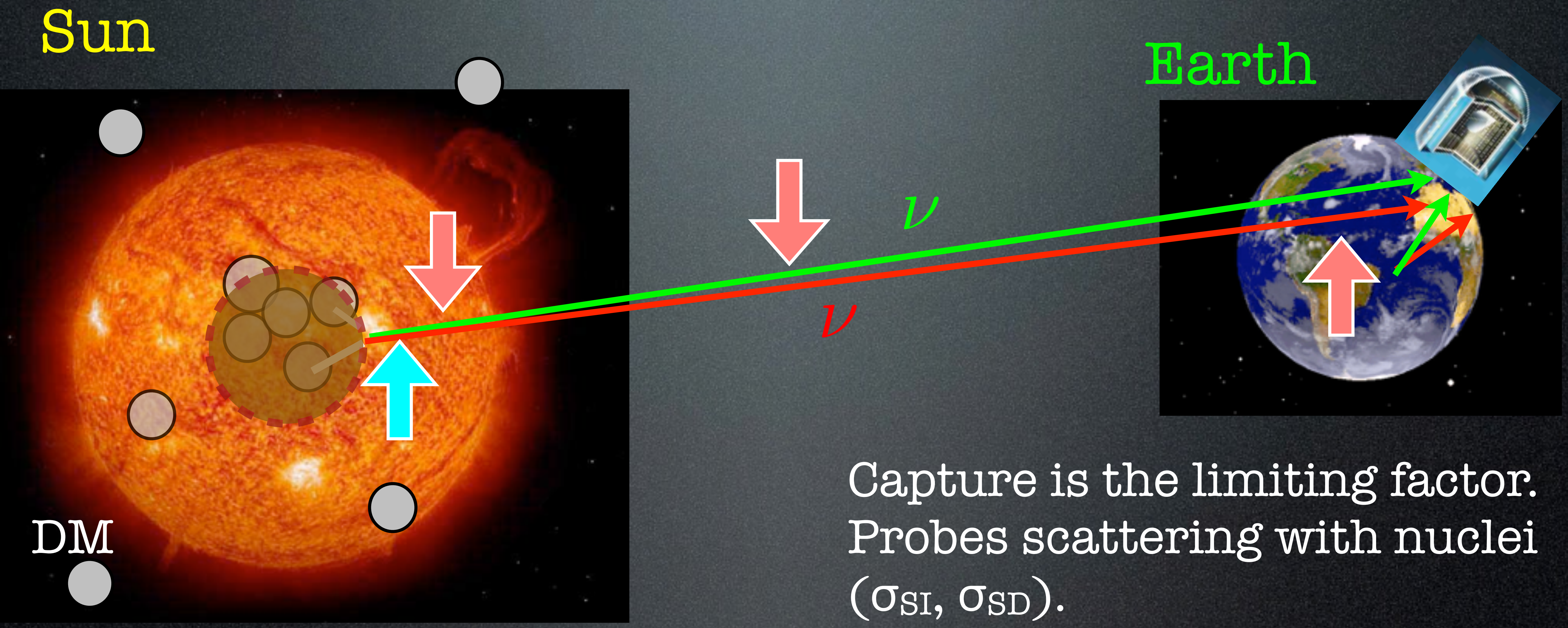


Capture is the limiting factor. Probes scattering with nuclei (σ_{SI}, σ_{SD}).

Production in a dense medium.

ID with neutrinos

ν from DM annihilations in the Sun/Earth



Capture is the limiting factor.
Probes scattering with nuclei (σ_{SI}, σ_{SD}).

Production in a dense medium.
Include oscillations + interactions:

- reshuffling of the 3 flavors
- distortions the spectra
- attenuations of the fluxes

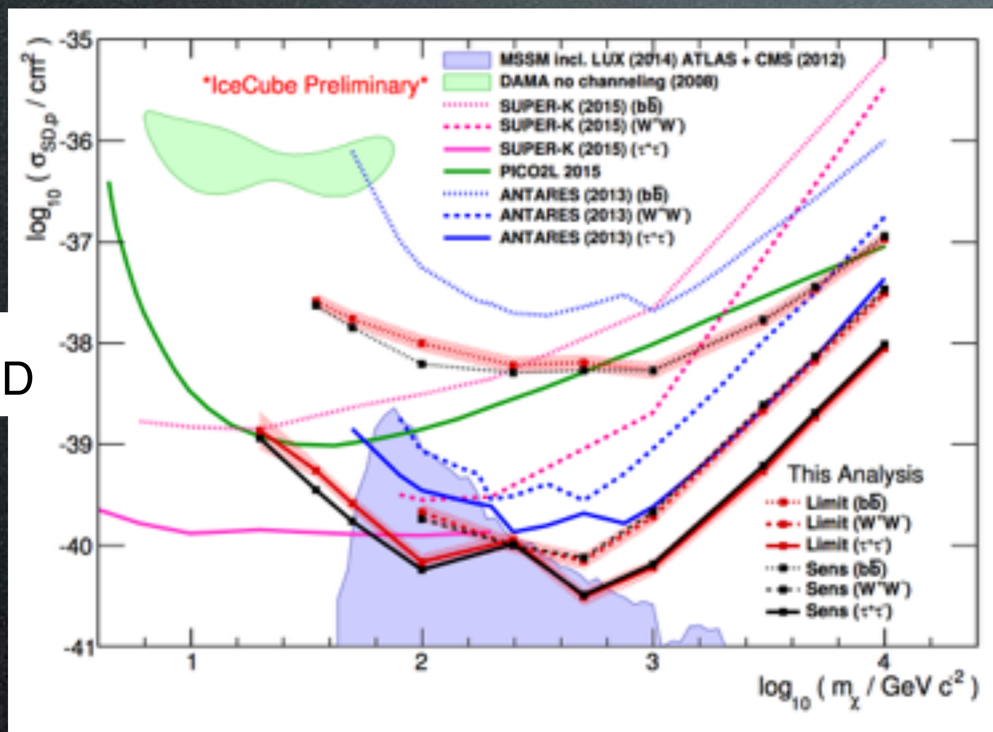
ID with neutrinos

ν from DM annihilations in the Sun

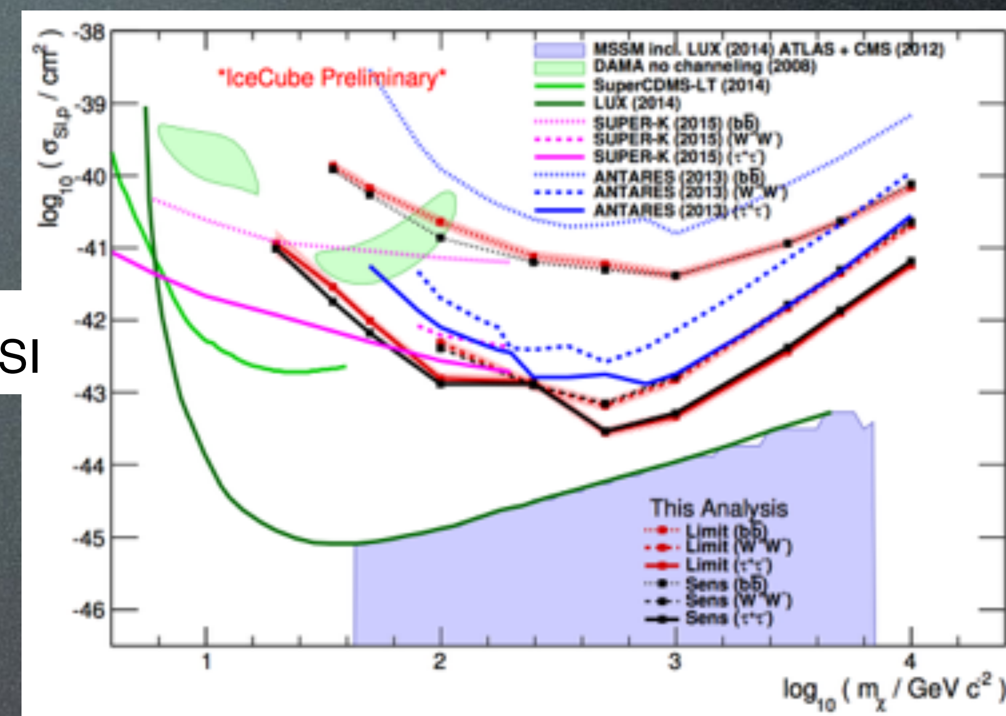
ICECUBE

ICECUBE - M.Zoll - ICRC 2015 #1099

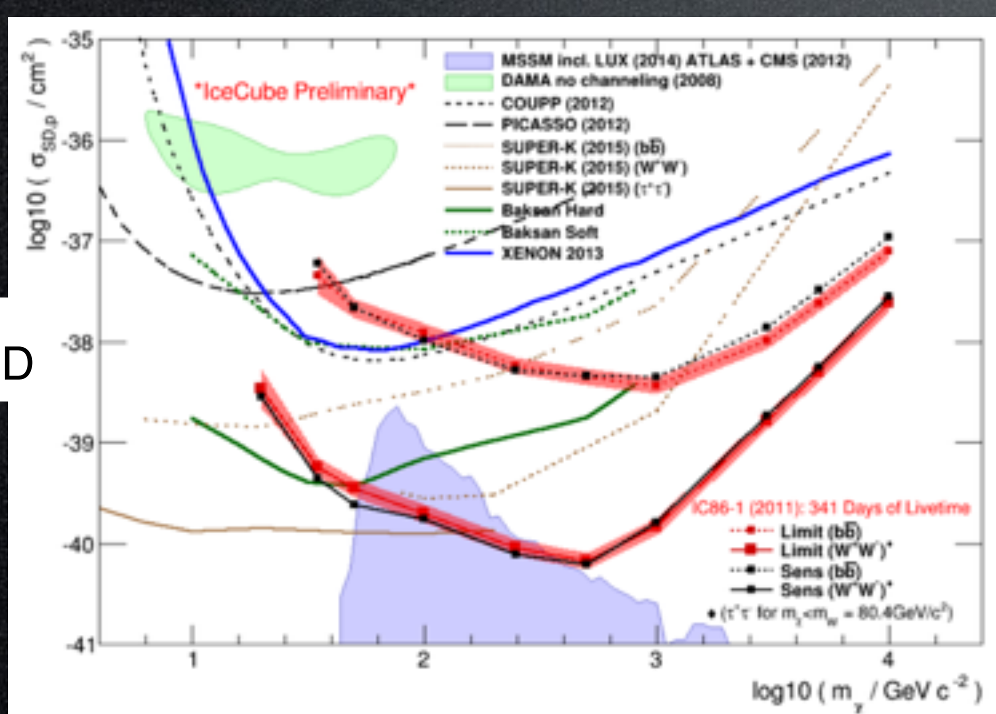
σ_{SD}



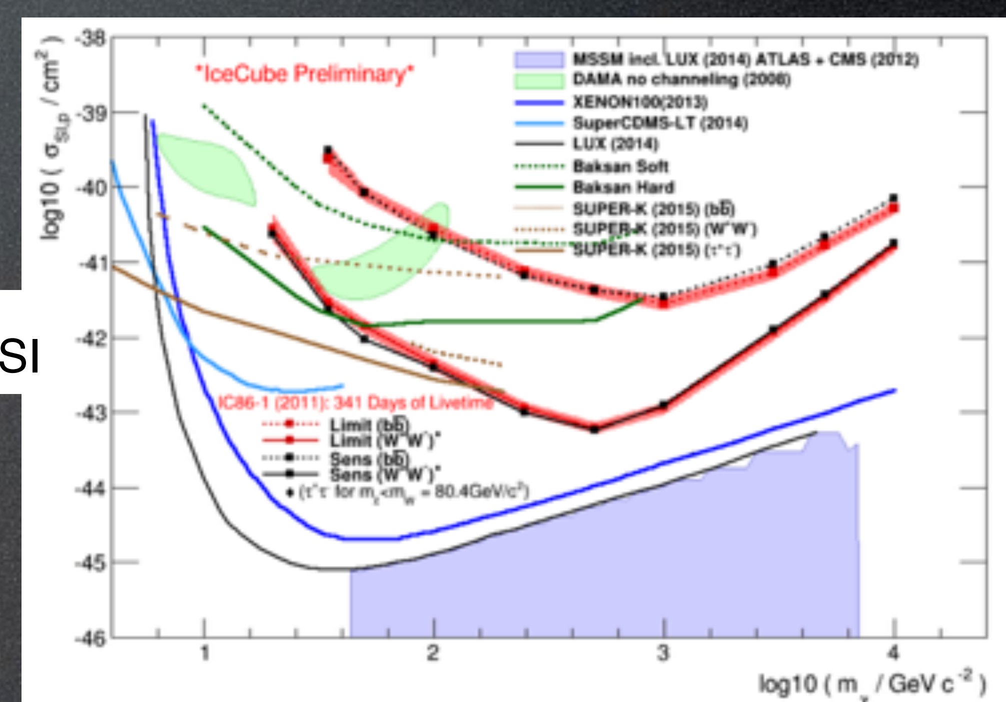
σ_{SI}



σ_{SD}



σ_{SI}



ICECUBE - M.Rameez - ICRC 2015 #1209

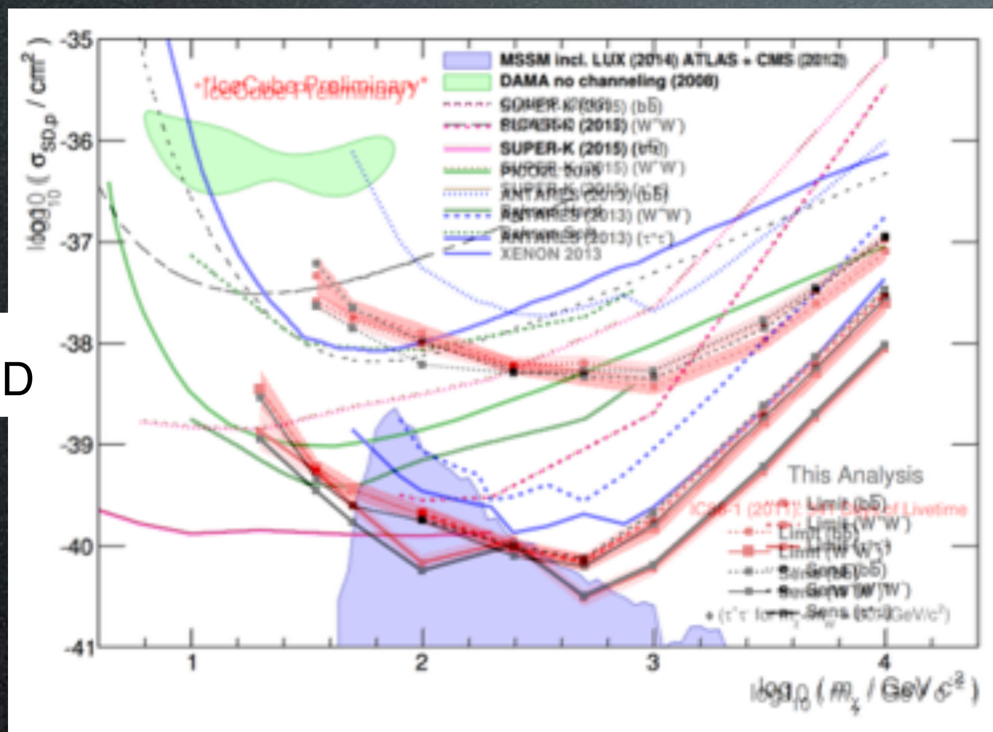
ID with neutrinos

ν from DM annihilations in the Sun

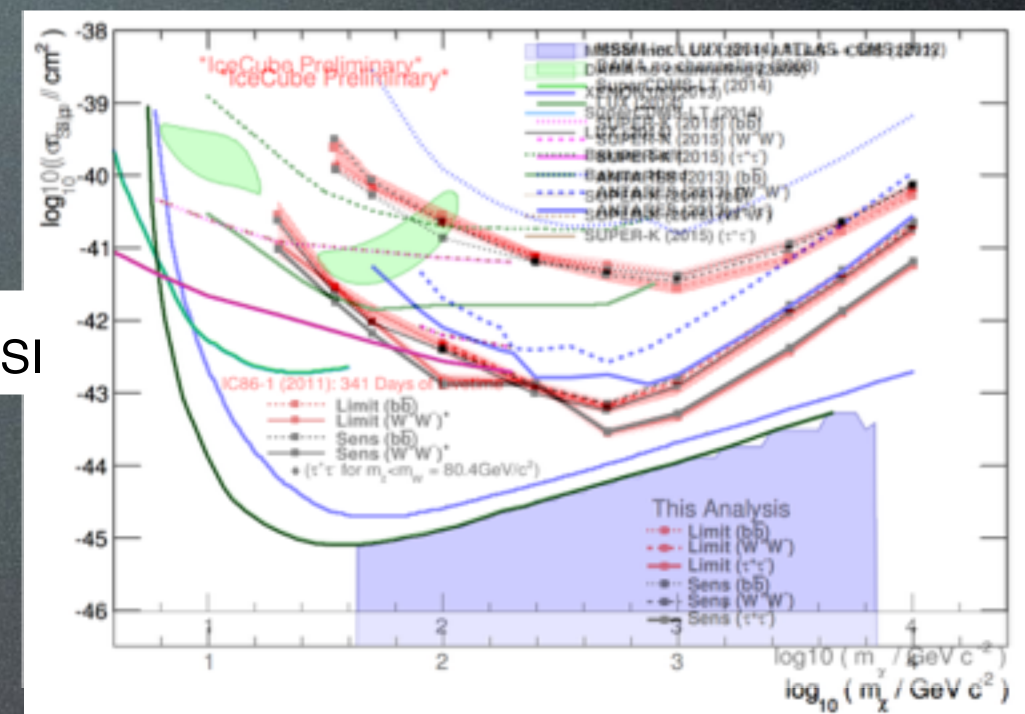
ICECUBE

ICECUBE - M.Zoll + M.Rameez - ICRC 2015 #1099+1209 (= #2308)

σ_{SD}



σ_{SI}



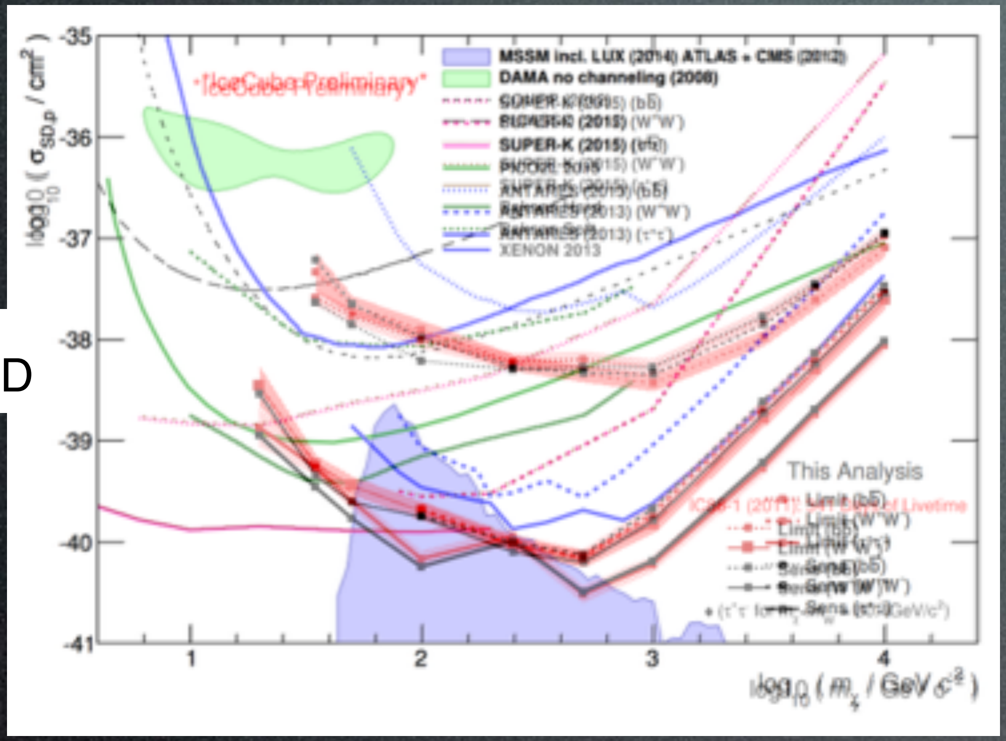
ID with neutrinos

ν from DM annihilations in the Sun

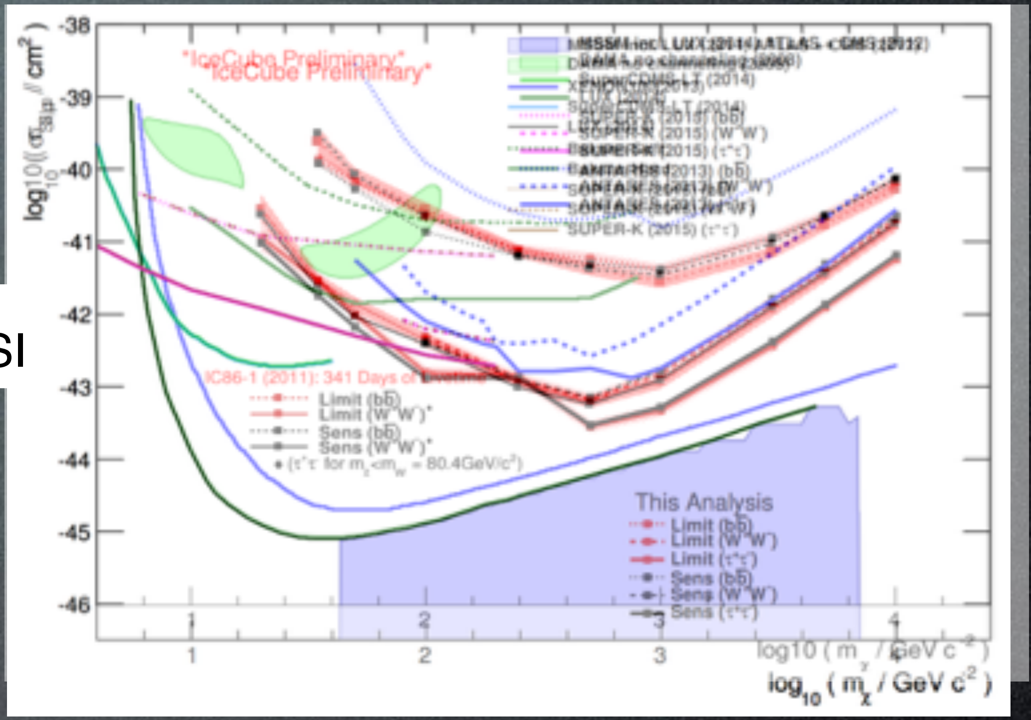
ICECUBE

ICECUBE - M.Zoll + M.Rameez - ICRC 2015 #1099+1209 (= #2308)

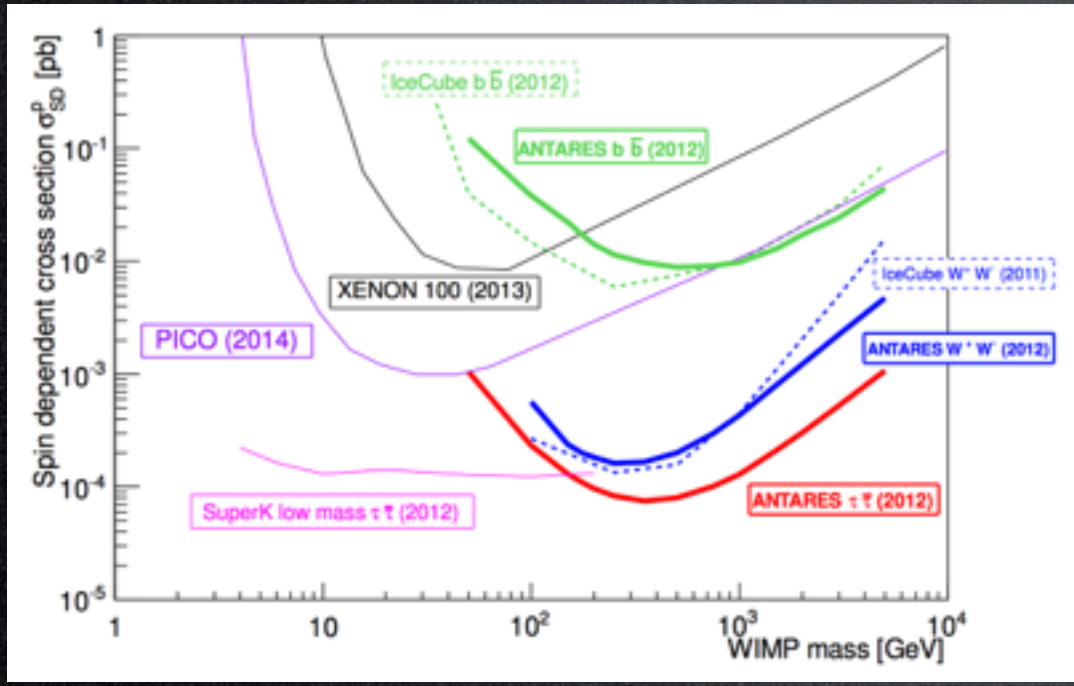
σ_{SD}



σ_{SI}



ANTARES

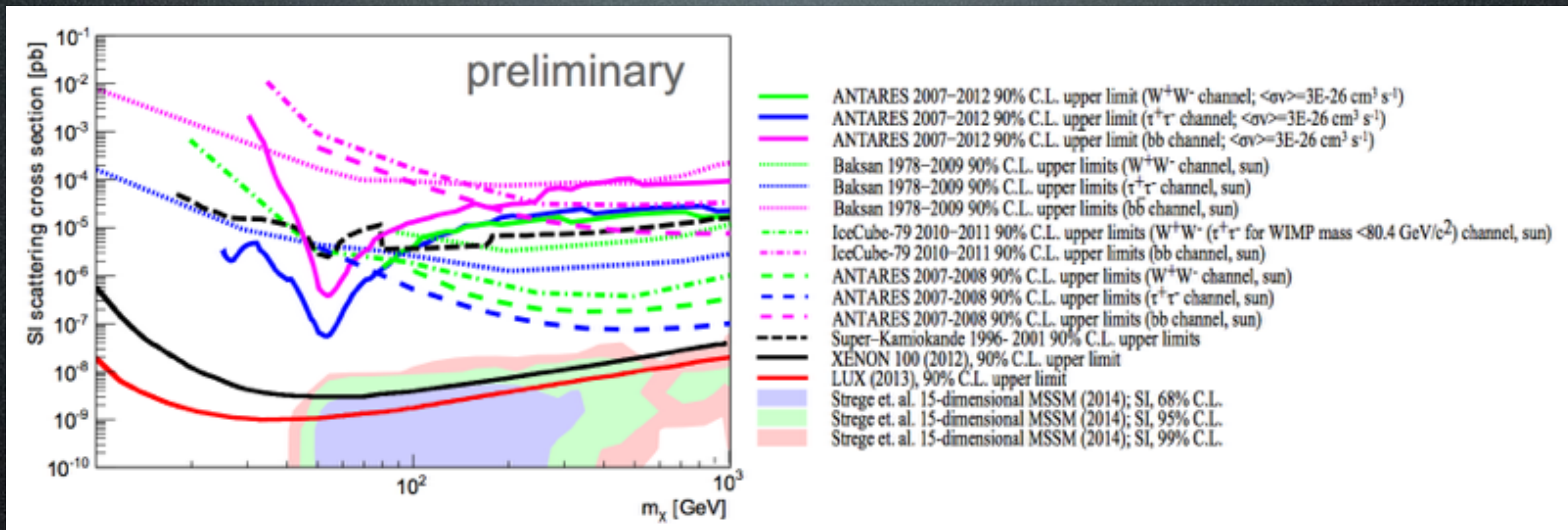


ANTARES C. Tönnis
talk and #1110
ICRC 2015

ID with neutrinos

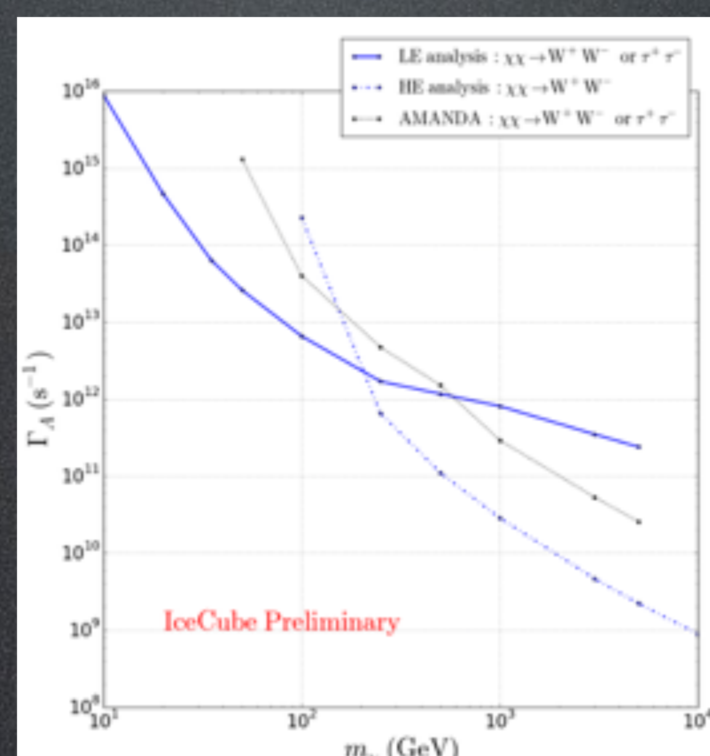
ν from DM annihilations in the Earth

ANTARES



ANTARES C. Tönnis - ICRC 2015 #1110

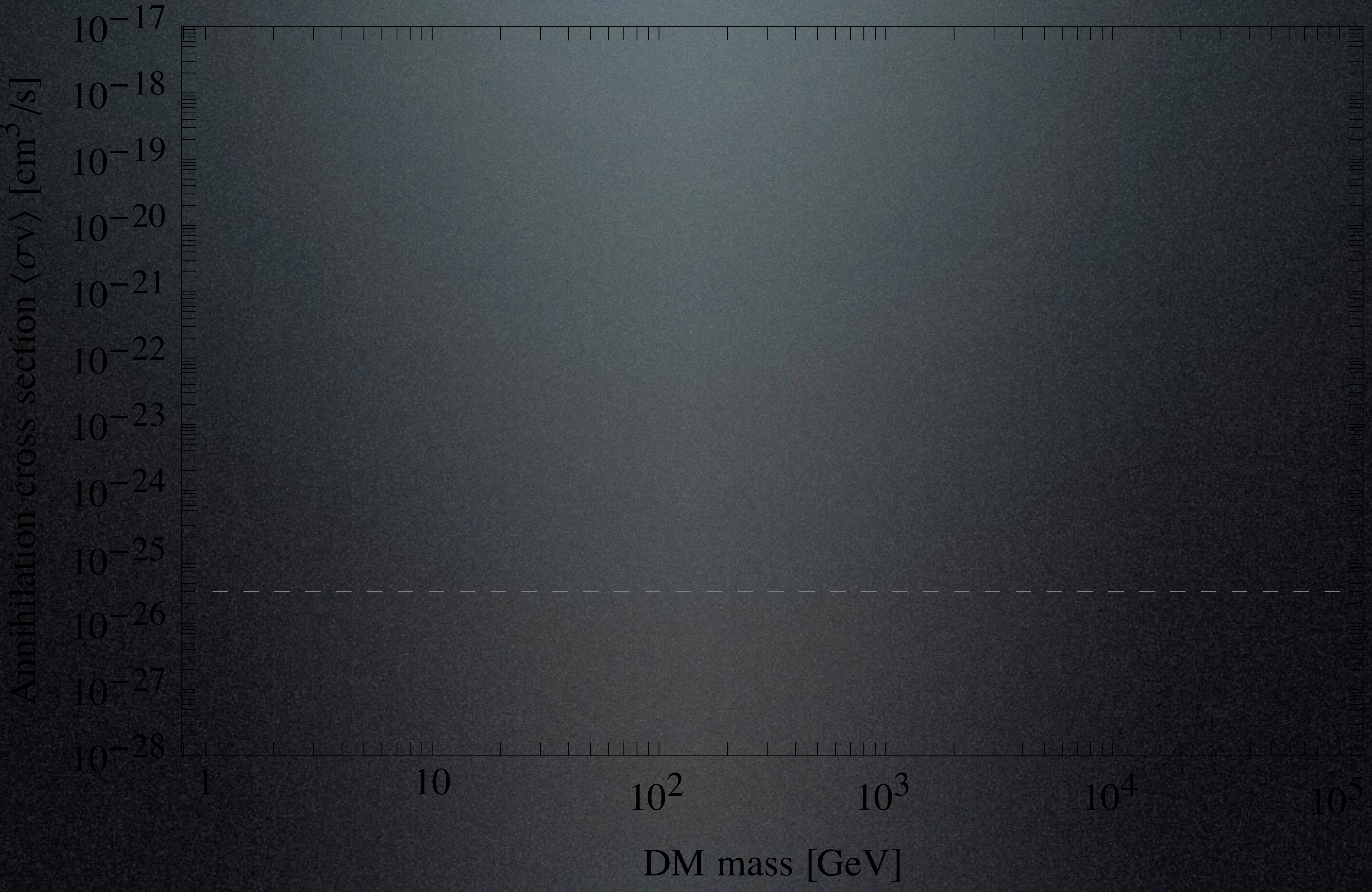
ICECUBE sensitivities:



ICECUBE
J. Kunnen
ICRC 2015
#1205

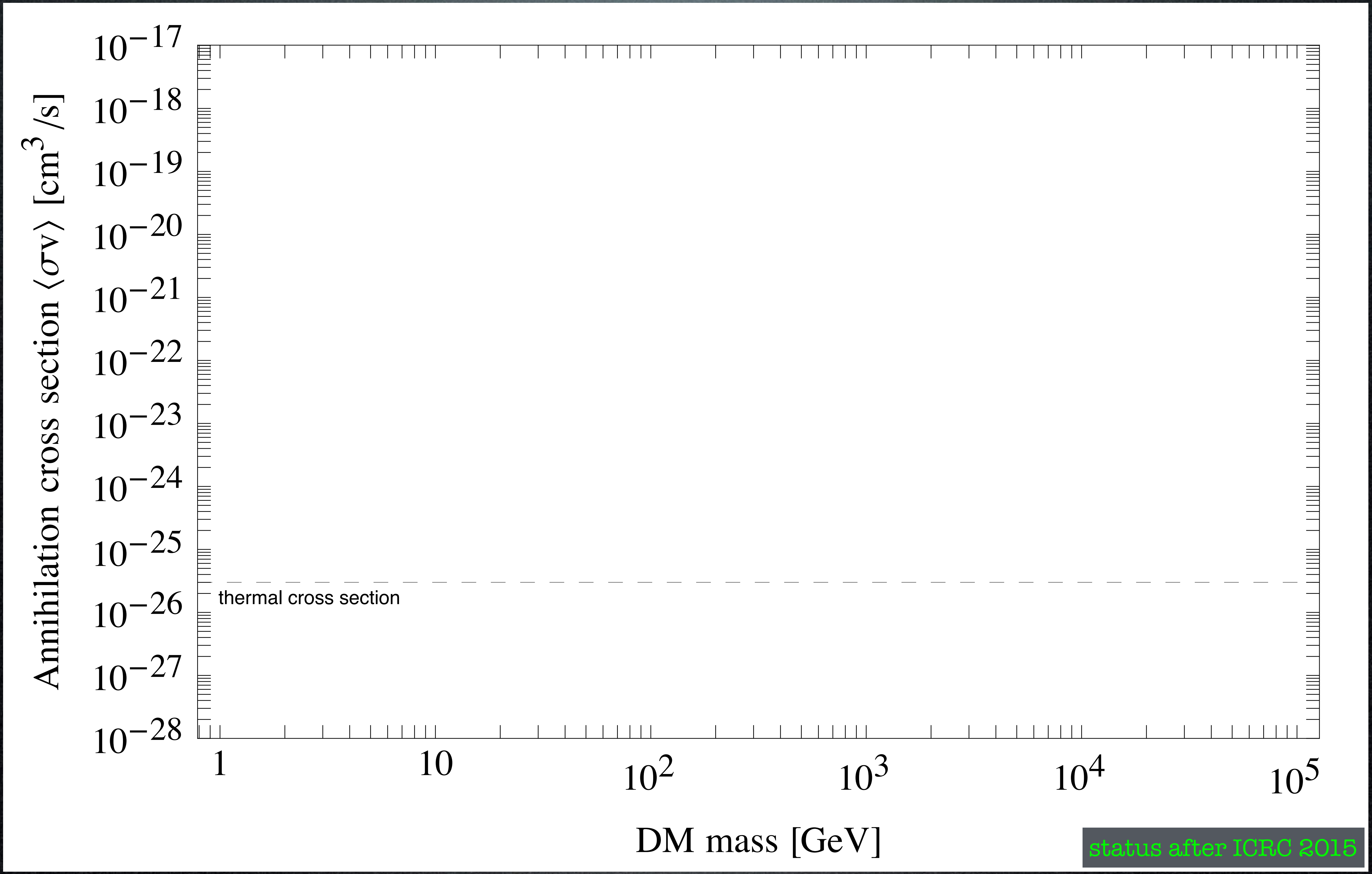
Combined DM ID constraints

antiprotons, gammas, neutrinos, CMB...



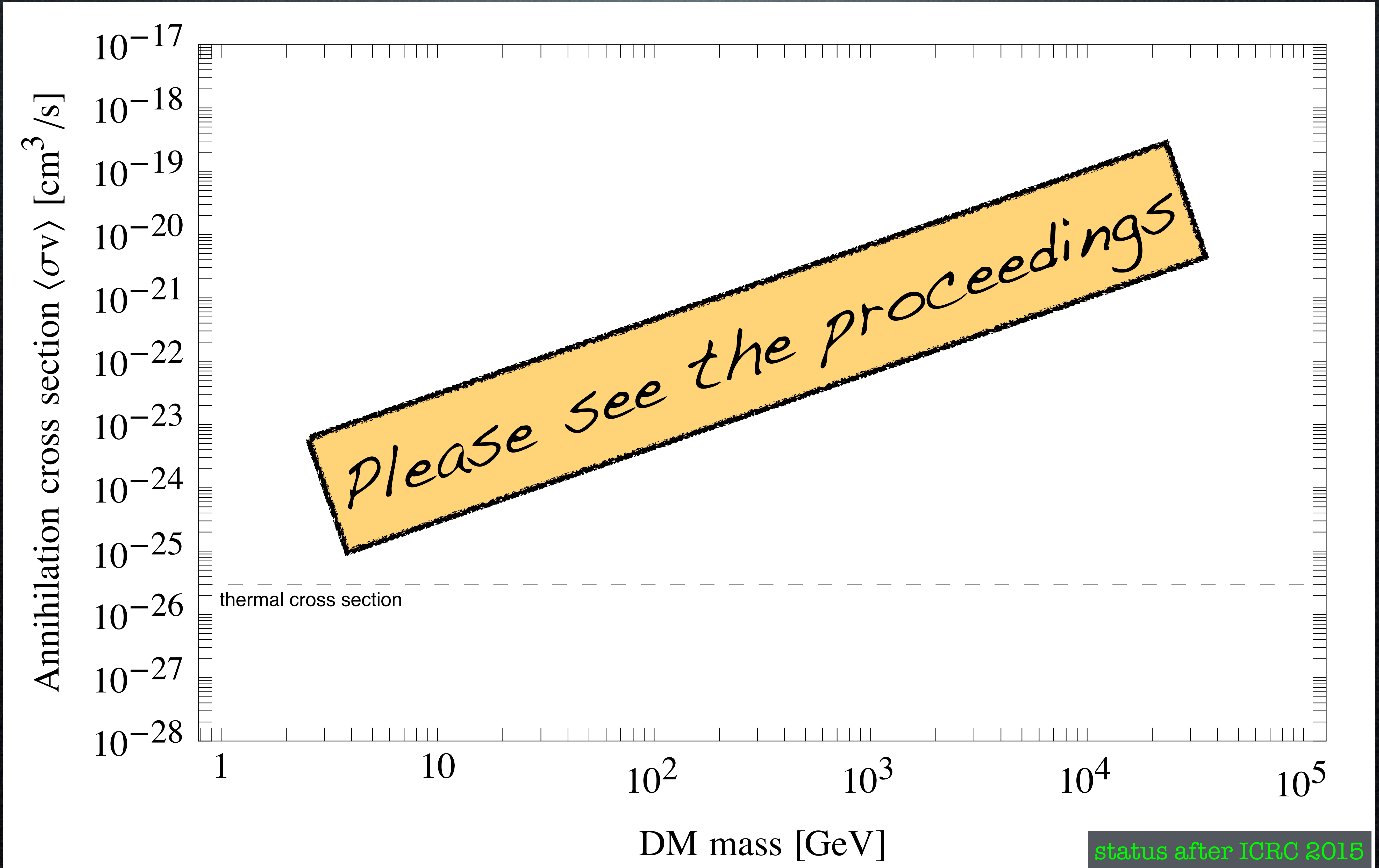
Combined DM ID constraints

antiprotons, gammas, neutrinos, CMB...



Combined DM ID constraints

antiprotons, gammas, neutrinos, CMB...



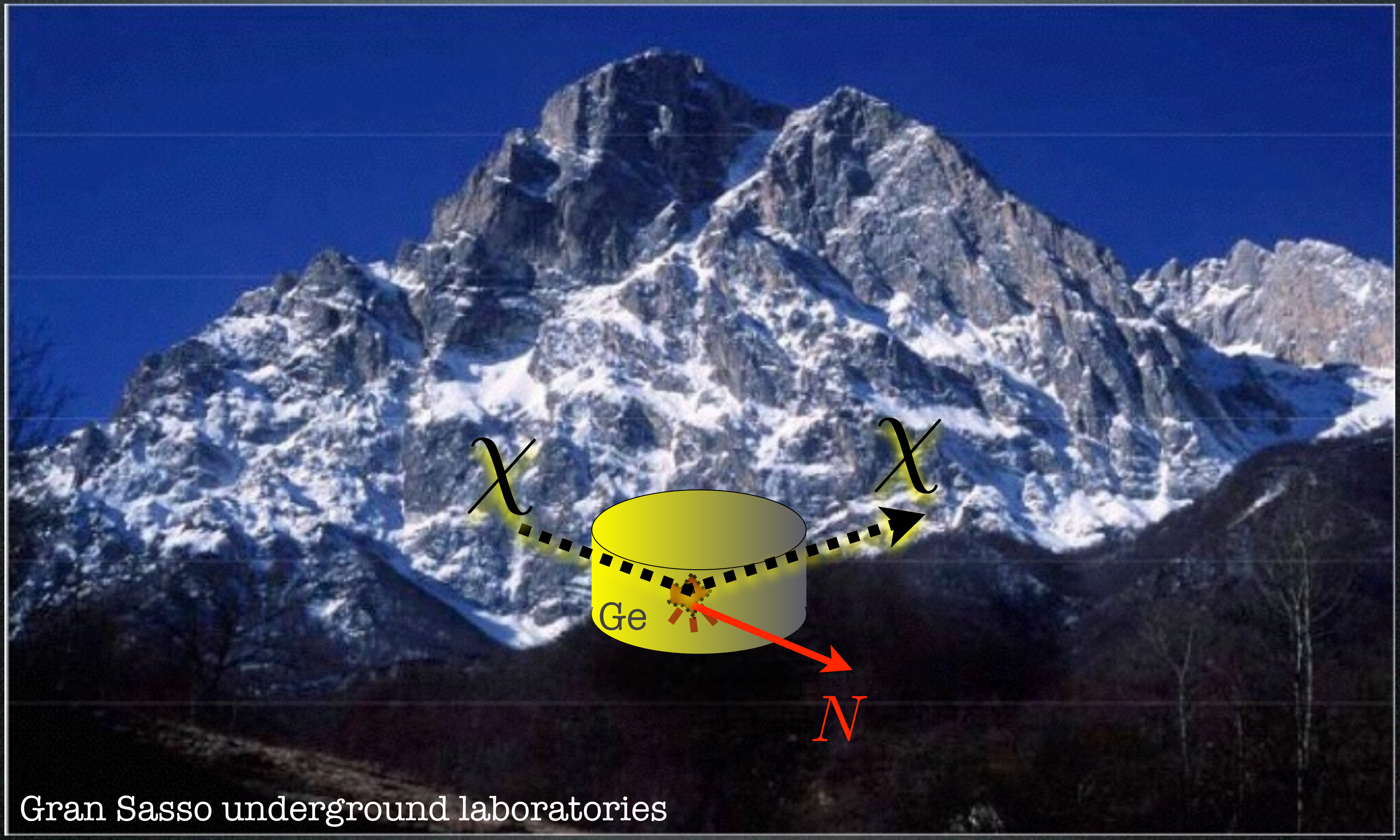
Direct Detection

Direct Detection: **basics**

Gran Sasso underground laboratories

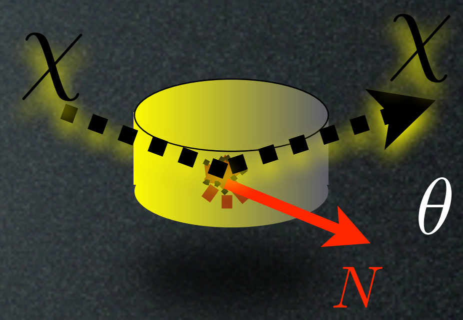
Direct Detection: basics

Direct Detection: basics



Direct Detection: basics

see E. Figueroa's talk - ICRC 2015



recoil energy $$E_R = \frac{\mu_\chi^2 v^2}{m_N}(1-\cos\theta)$$

$$\mu_\chi = \frac{m_\chi m_N}{m_\chi + m_N} \rightarrow \begin{cases} m_\chi \text{ for small } m_\chi \\ m_N \text{ for large } m_\chi \end{cases}$$

recoil energy spectrum

$$\frac{dR}{dE_R} = \frac{1}{2}\frac{\rho_\odot}{m_\chi}\frac{\sigma}{\mu^2}\int_{v_{\min}(E_R)}^{v_{\rm esc}} \frac{1}{v} f(\vec{v})\, \mathrm{d}\vec{v}$$

with $f(\vec{v}) \propto e^{-v^2/V_c^2}$ + motion of Earth in (static?)halo

$\sigma \approx \sigma_n^{\rm SI} A^4$ $\times$ nuclear form factors

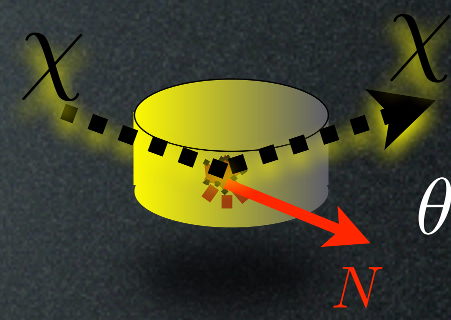
number of events

$$N = \mathcal{E}\,\mathcal{T}\int_{E_{\rm thres}}^{E_{\max}} \frac{dR}{dE_R}\, dE_R$$

Direct Detection: basics

recoil energy $E_R = \frac{\mu_\chi^2 v^2}{m_N}(1 - \cos\theta)$

$$\mu_\chi = \frac{m_\chi m_N}{m_\chi + m_N} \rightarrow \begin{cases} m_\chi \text{ for small } m_\chi \\ m_N \text{ for large } m_\chi \end{cases}$$



recoil energy spectrum

$$\frac{dR}{dE_R} = \frac{1}{2}\frac{\rho_\odot}{m_\chi}\frac{\sigma}{\mu^2}\int_{v_{\rm min}(E_R)}^{v_{\rm esc}} \frac{1}{v} f(\vec{v})\ {\rm d}\vec{v}$$

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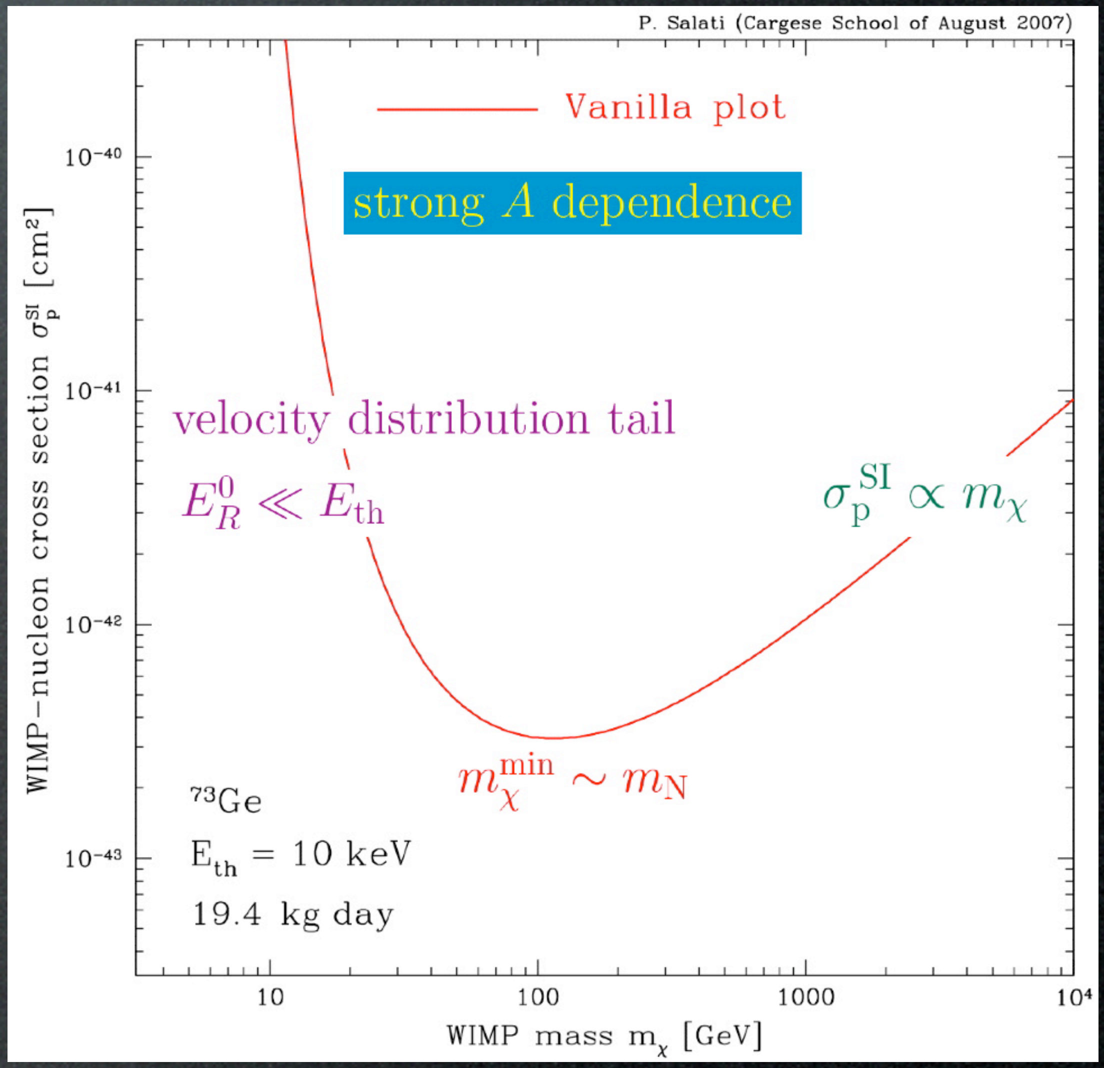
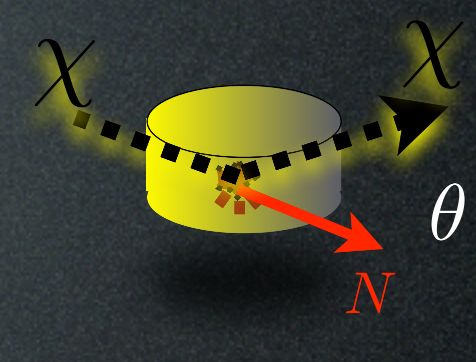


P.Salati, proceedings of Cargèse 2007

Direct Detection: basics

recoil energy

$$E_R = \frac{\mu_\chi^2 v^2}{m_N}(1-\cos\theta)$$



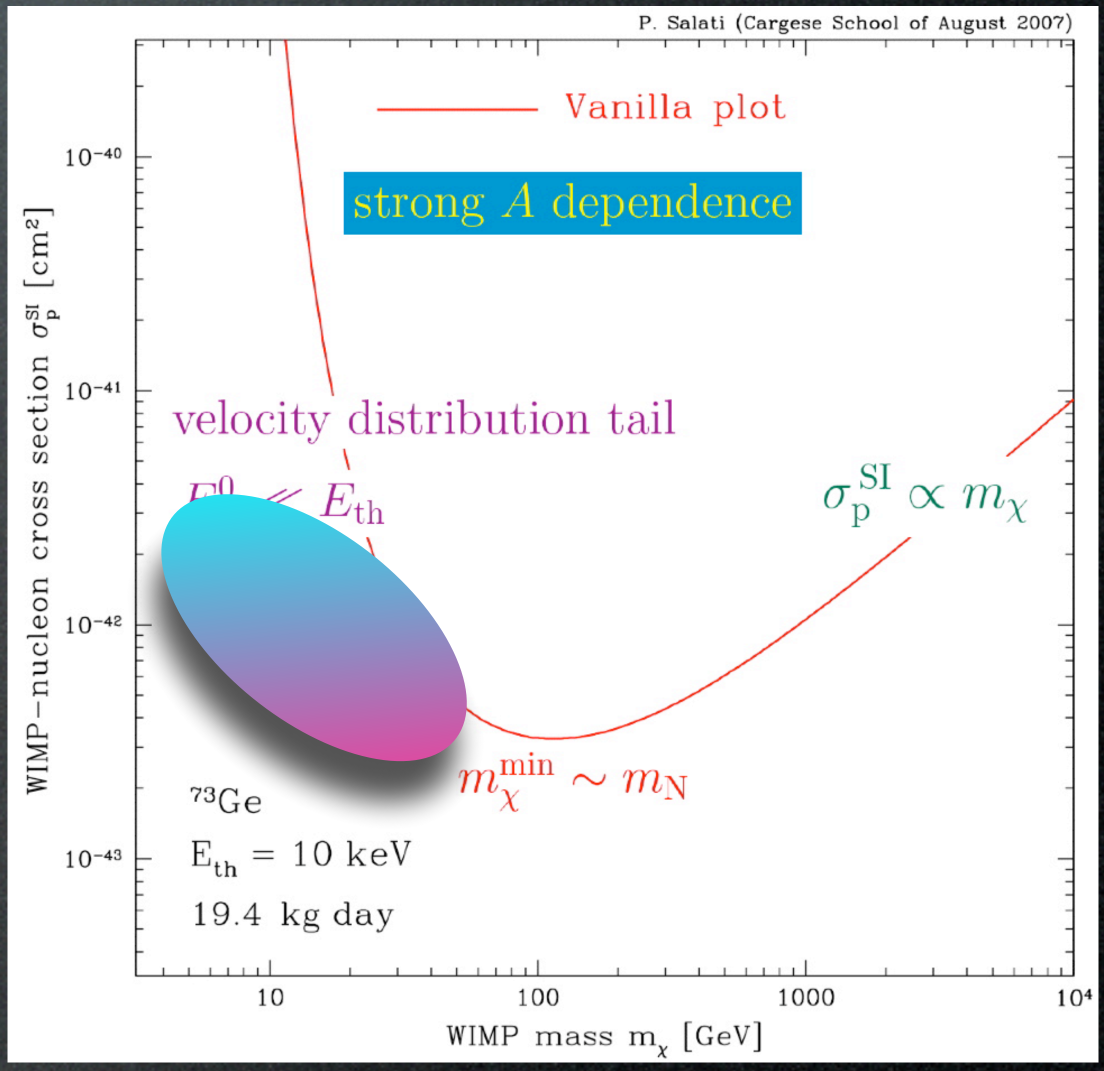
$$\mu_\chi = \frac{m_\chi m_N}{m_\chi + m_N} \to \begin{cases} m_\chi & \text{for small } m_\chi \\ m_N & \text{for large } m_\chi \end{cases}$$

recoil energy spectrum

$$\frac{dR}{dE_R} = \frac{1}{2}\frac{\rho_\odot}{m_\chi}\frac{\sigma}{\mu^2}\int_{v_{\min}(E_R)}^{v_{\rm esc}} \frac{1}{v} f(\vec{v})\, d\vec{v}$$

with $f(\vec{v}) \propto e^{-v^2/V_c^2}$ + motion of Earth in (static?)halo

$$\sigma \approx \sigma_n^{\rm SI} A^4 \quad \times \text{ nuclear form factors}$$

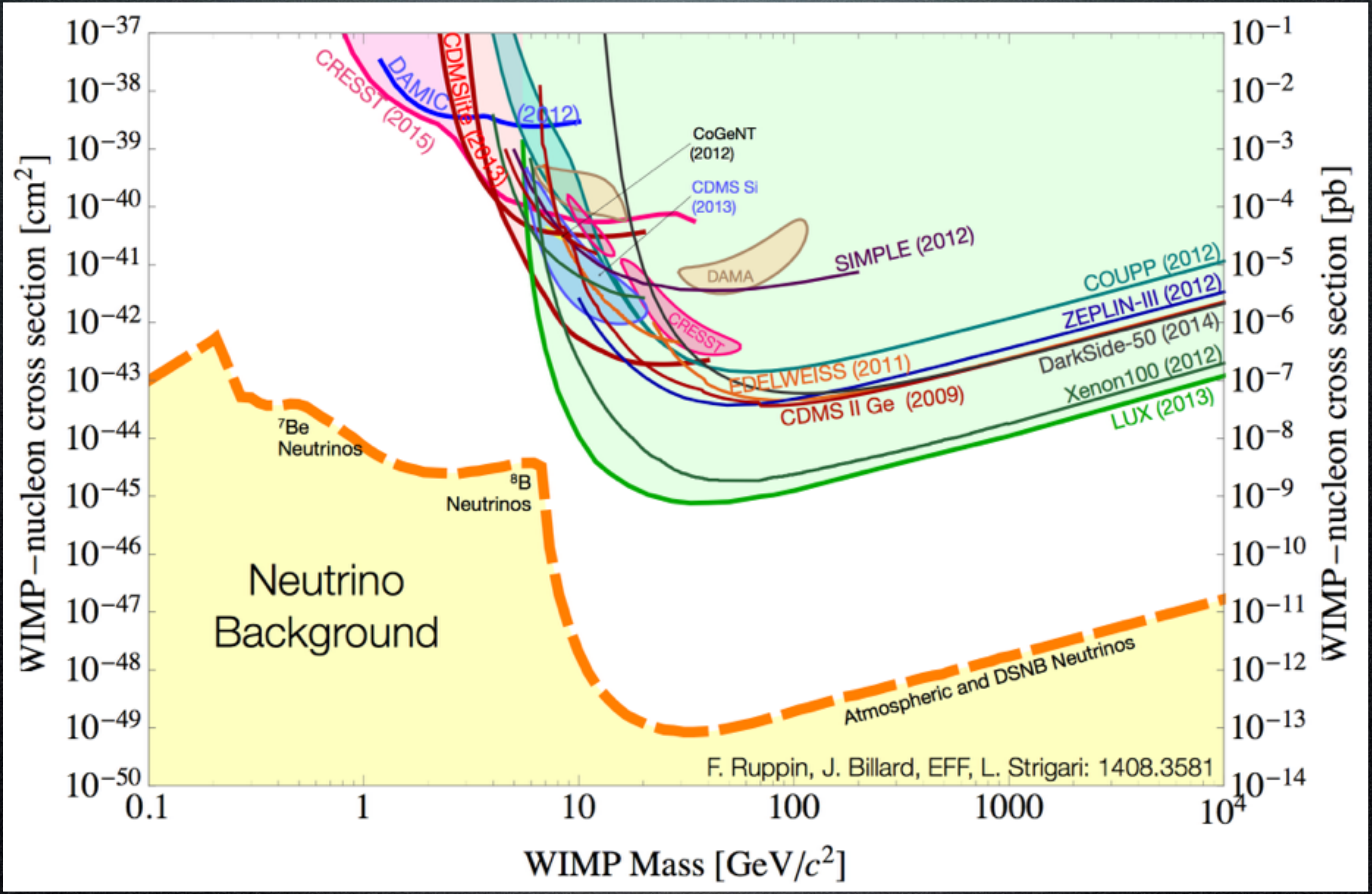


P.Salati, proceedings of Cargèse 2007

number of events

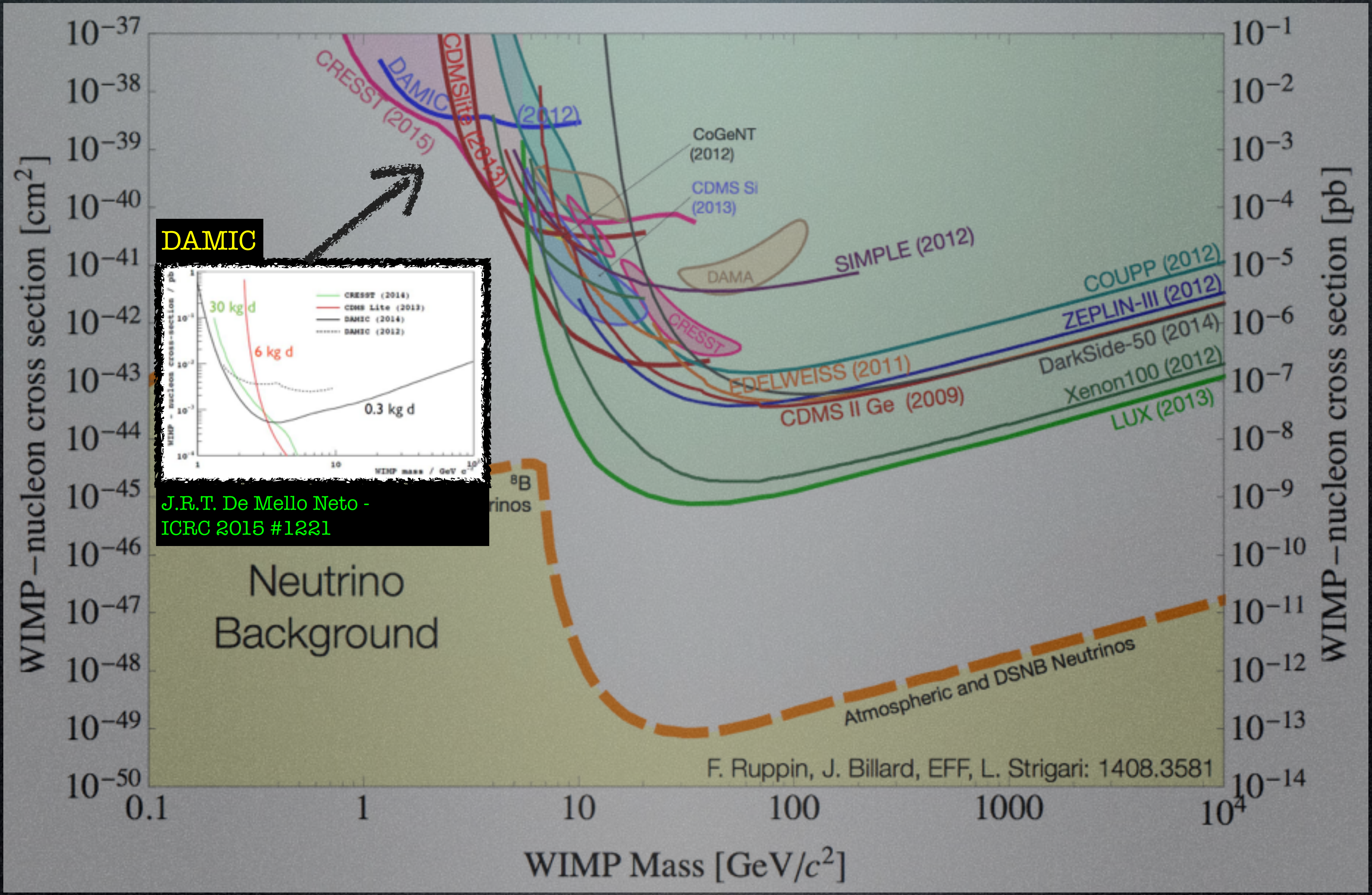
$$N = \mathcal{E}\,\mathcal{T}\int_{E_{\rm thres}}^{E_{\max}} \frac{dR}{dE_R}\, dE_R$$

Direct Detection: results



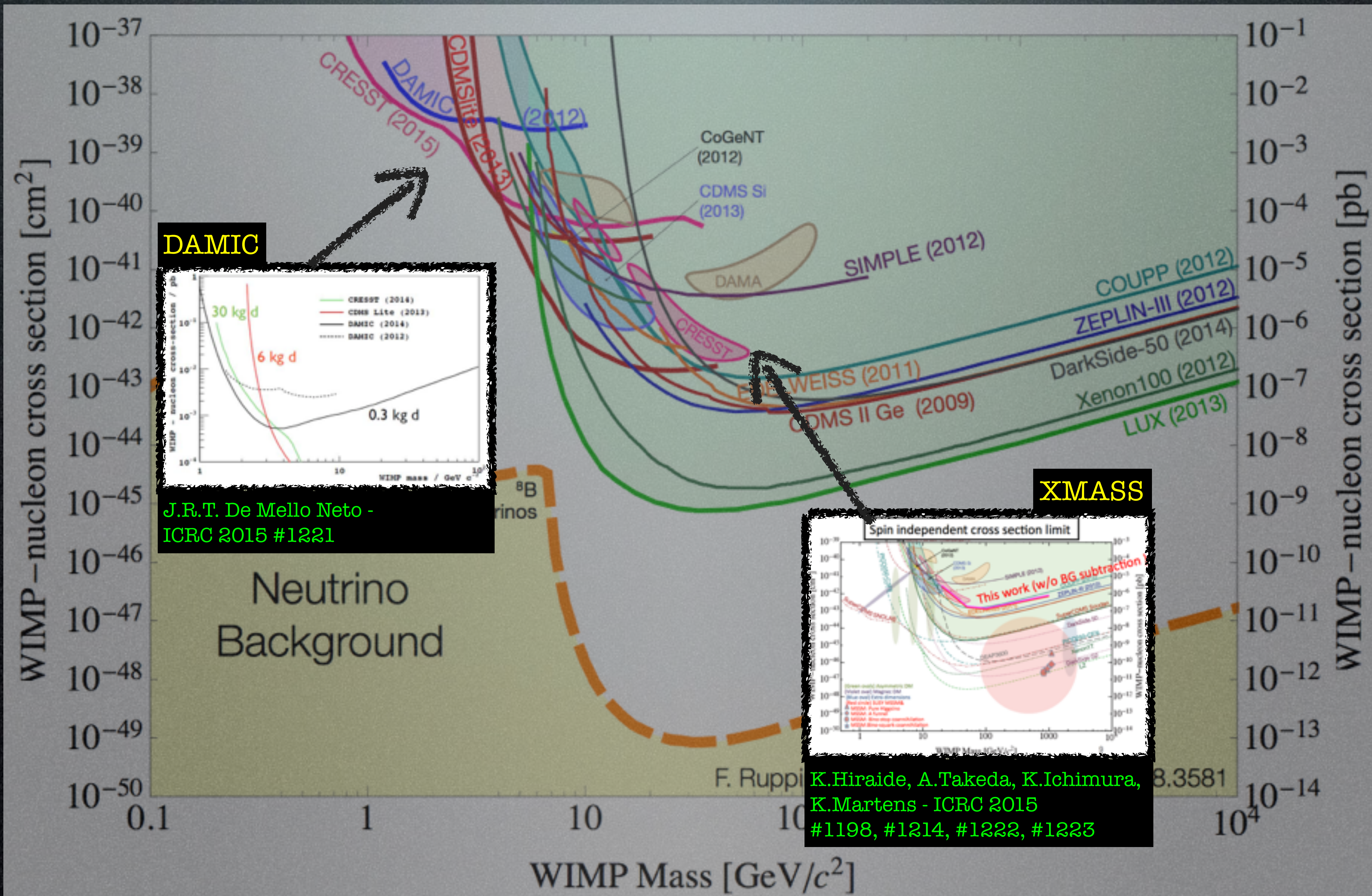
E. Figueroa-Feliciano - ICRC 2015

Direct Detection: results



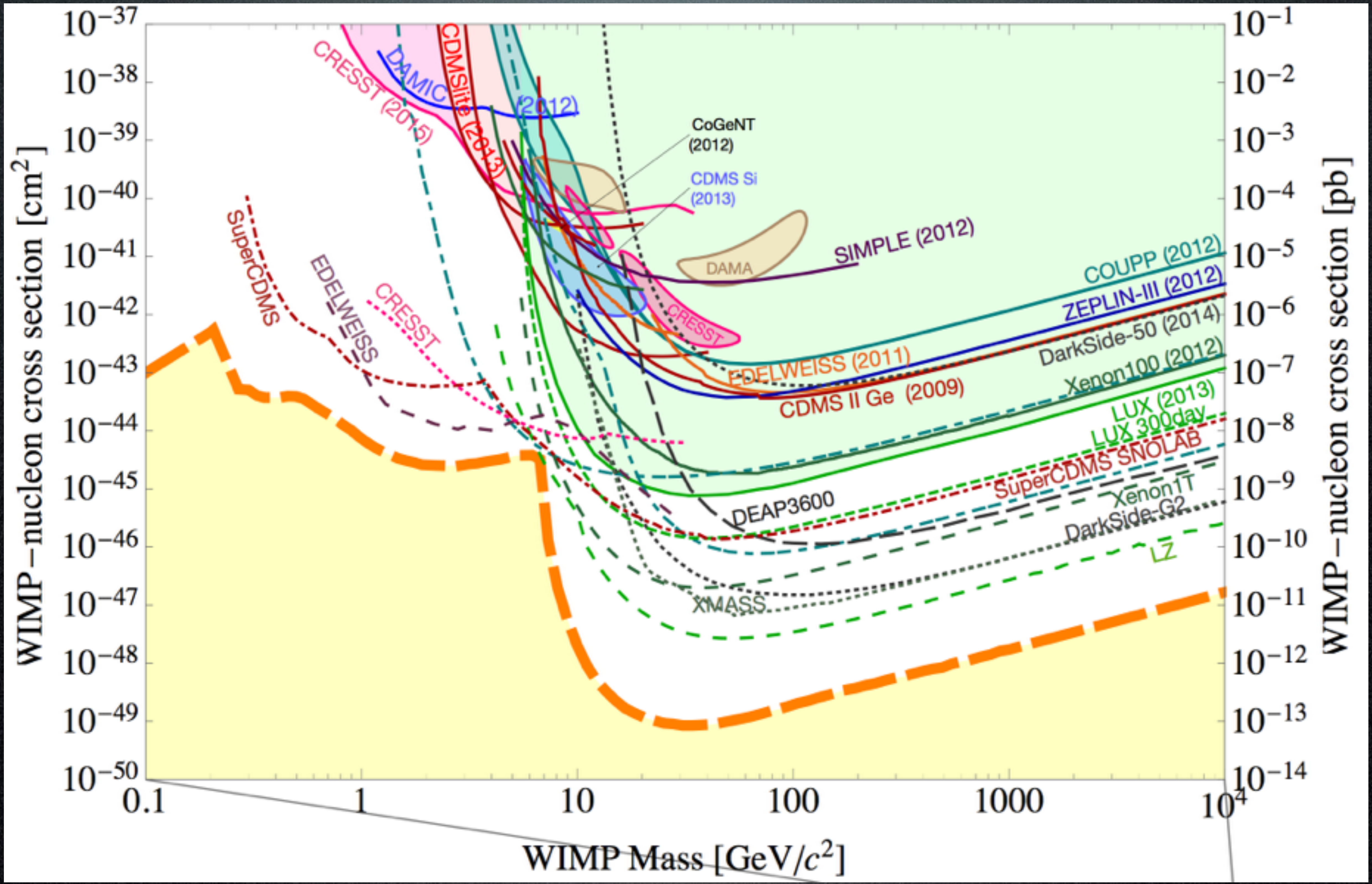
E. Figueroa-Feliciano - ICRC 2015

Direct Detection: results



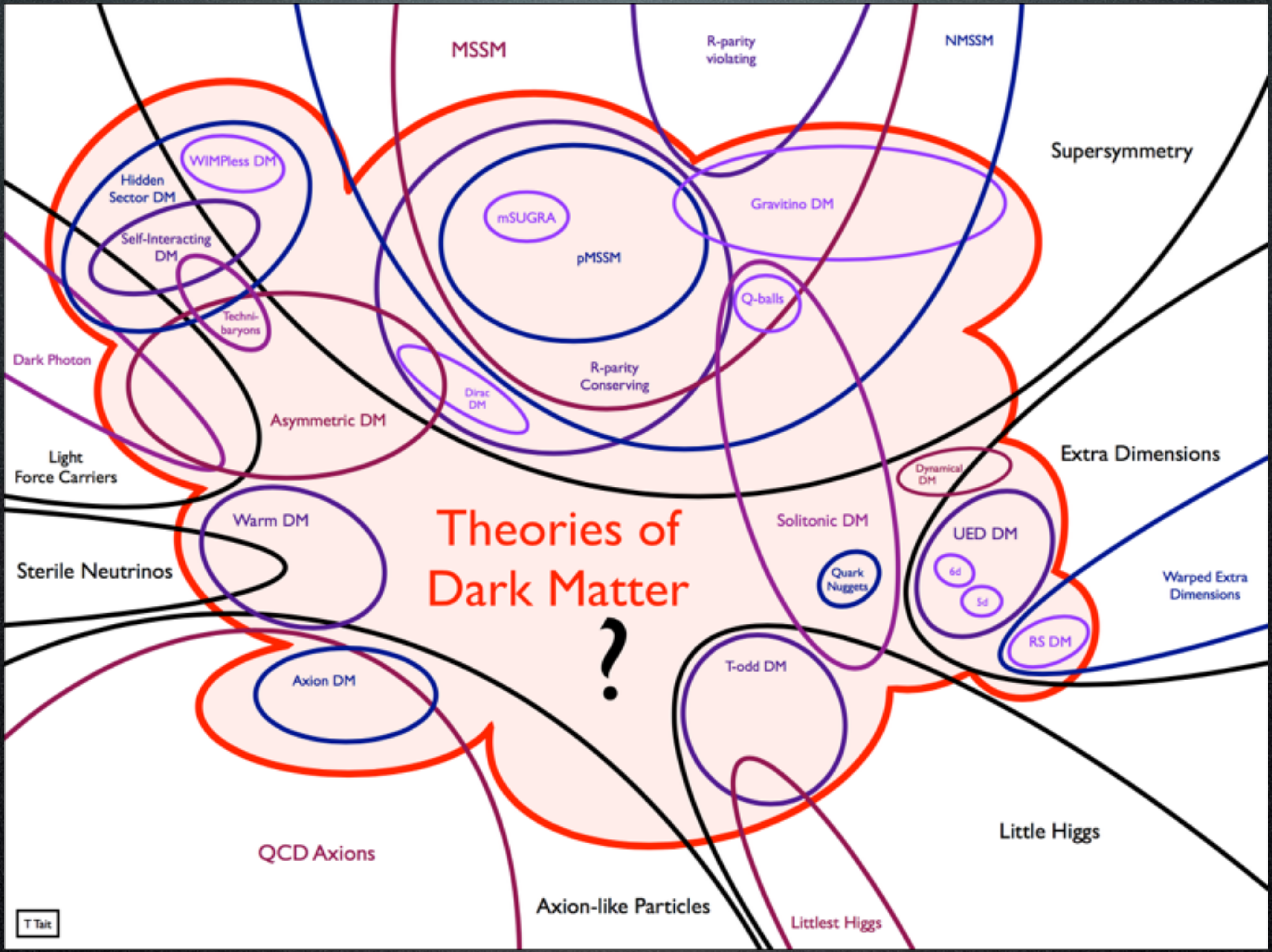
E. Figueroa-Feliciano - ICRC 2015

Direct Detection: future



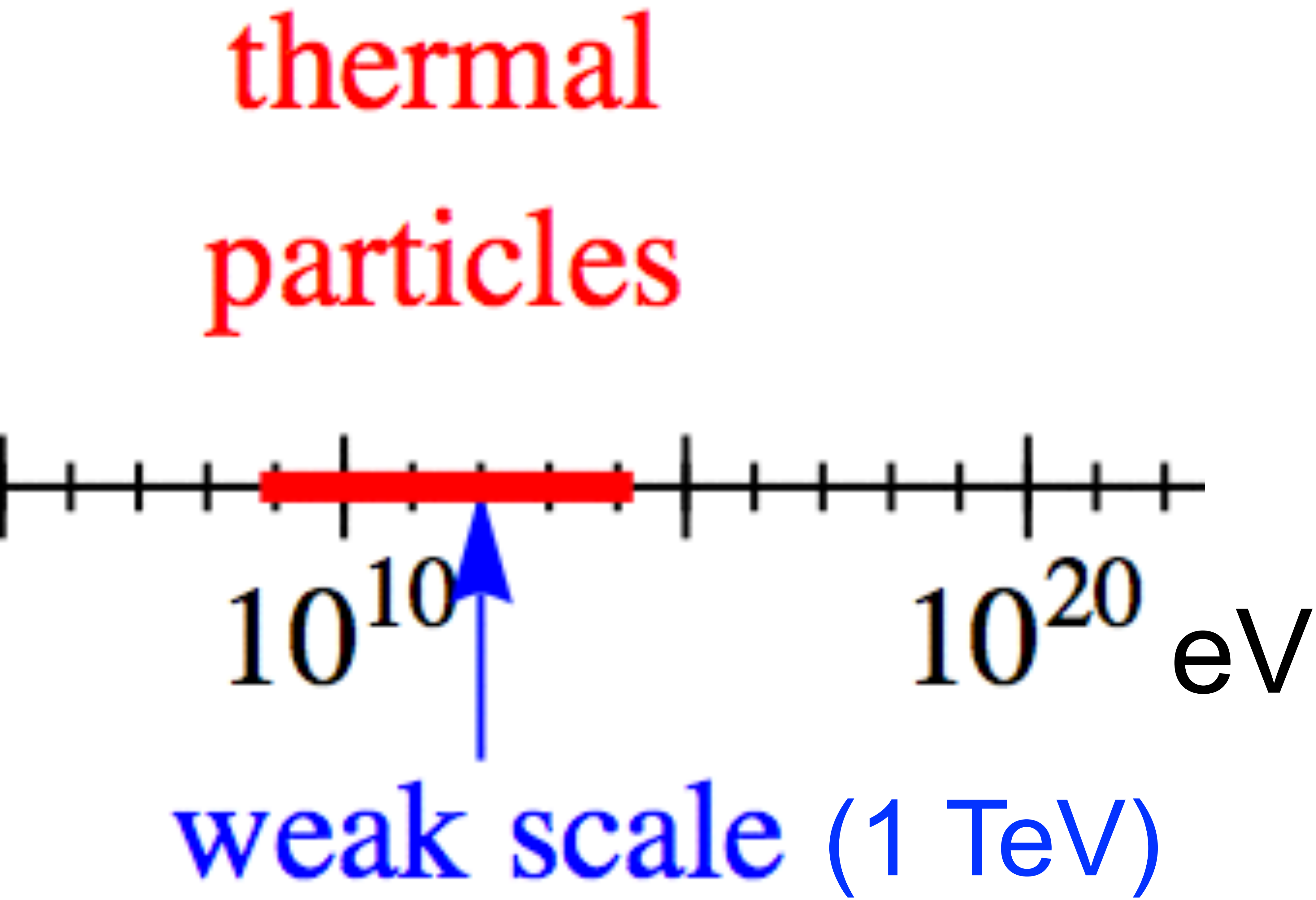
E. Figueroa-Feliciano - ICRC 2015

Outside of the WIMP box

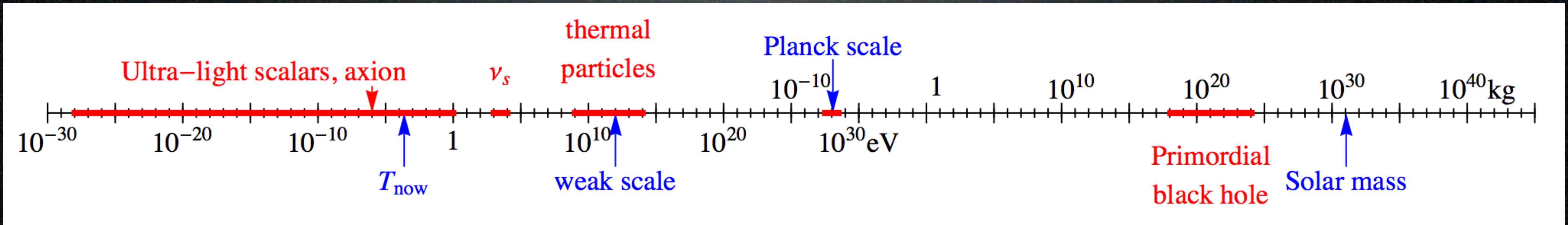


T. Tait - ICRC 2015

Outside of the WIMP box



Outside of the WIMP box

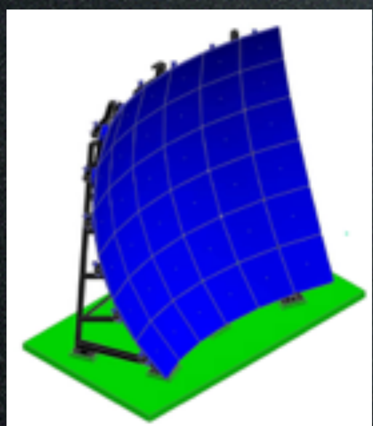


'only' 90 orders of magnitude!

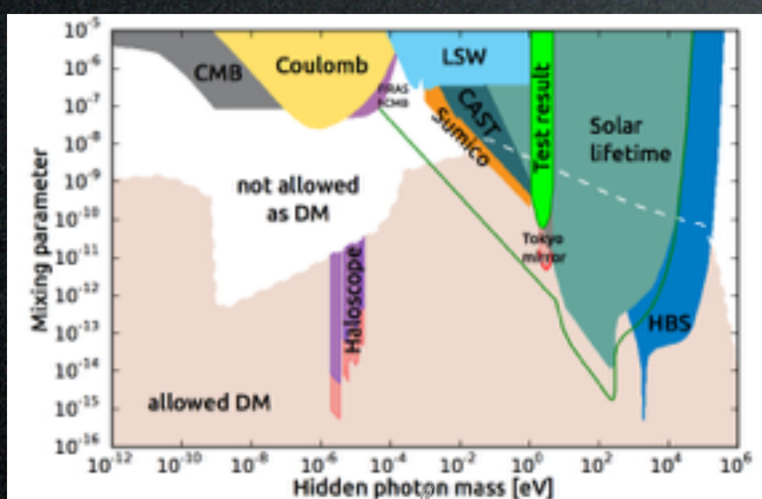
Outside of the WIMP box

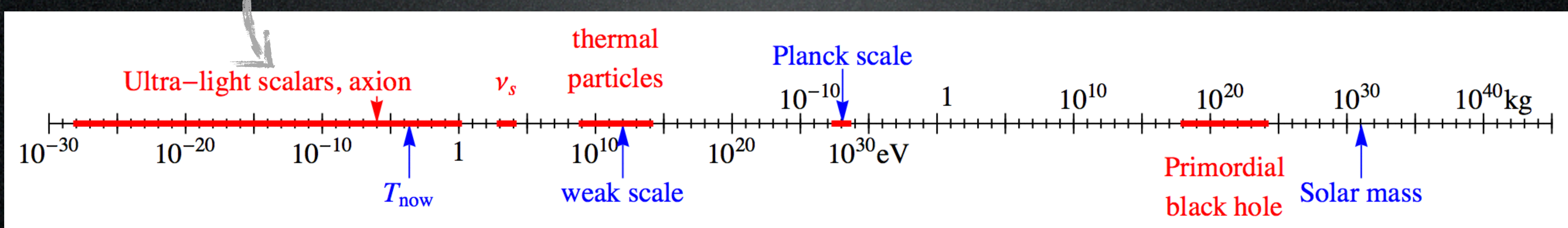
FUNK

hidden photon searches



D. Veberič
ICRC 2015
#1191



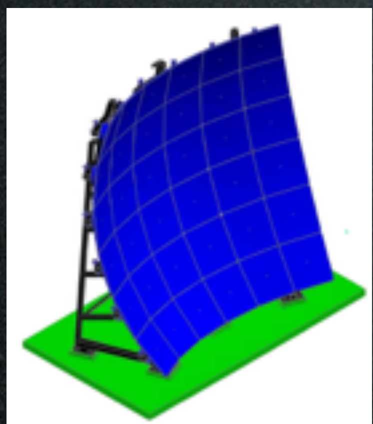


'only' 90 orders of magnitude!

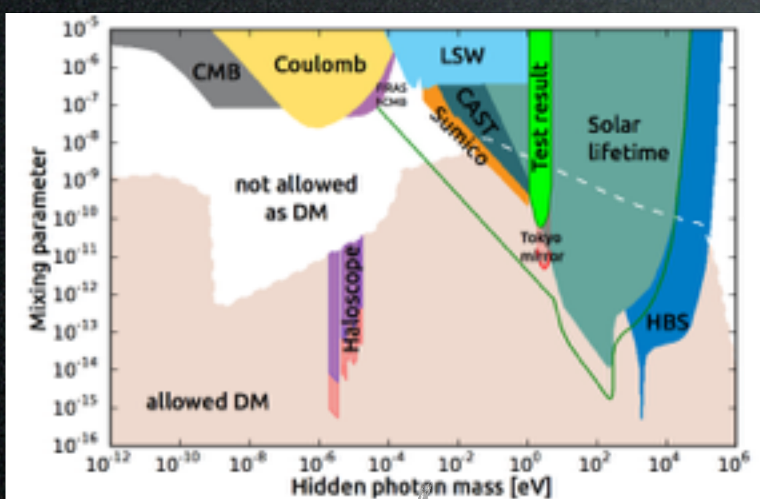
Outside of the WIMP box

FUNK

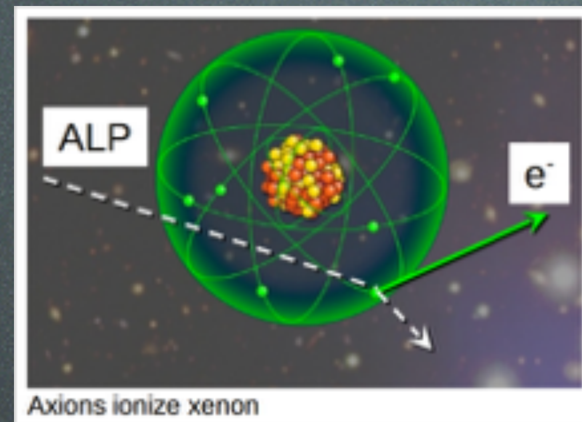
hidden photon searches



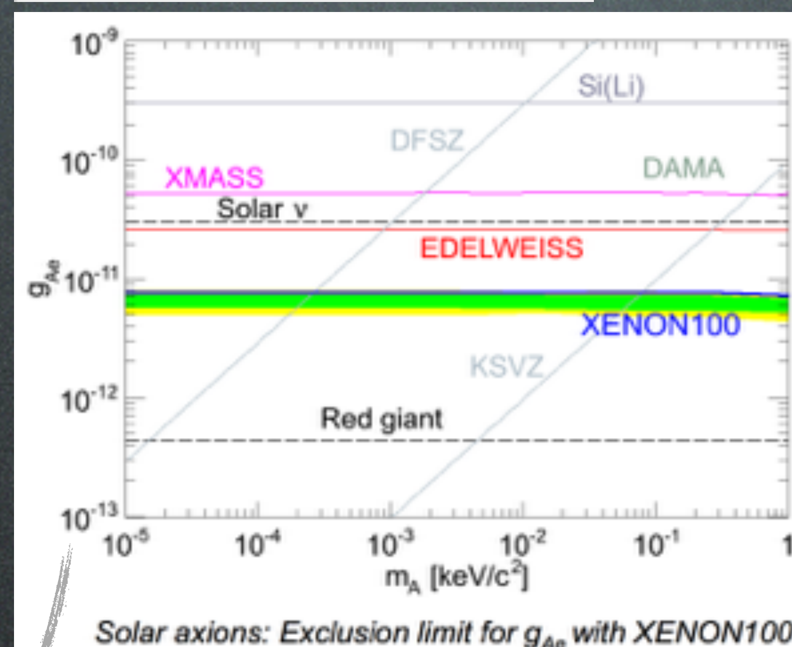
D. Veberič
ICRC 2015
#1191

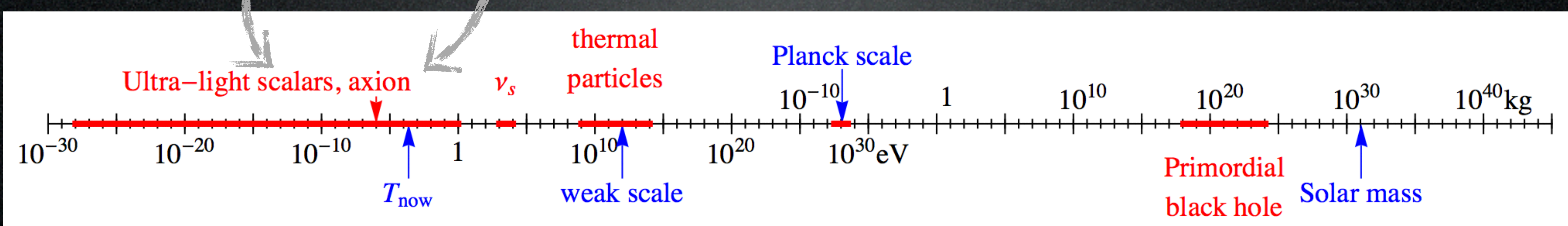


Xenon-100



J. Masbou
ICRC 2015
#1210



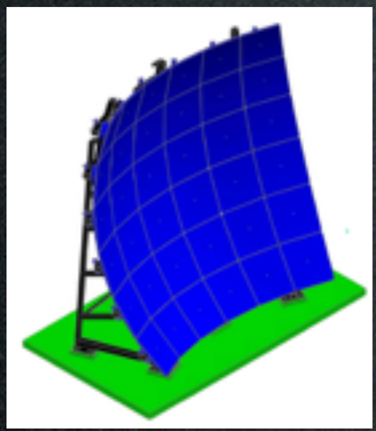


'only' 90 orders of magnitude!

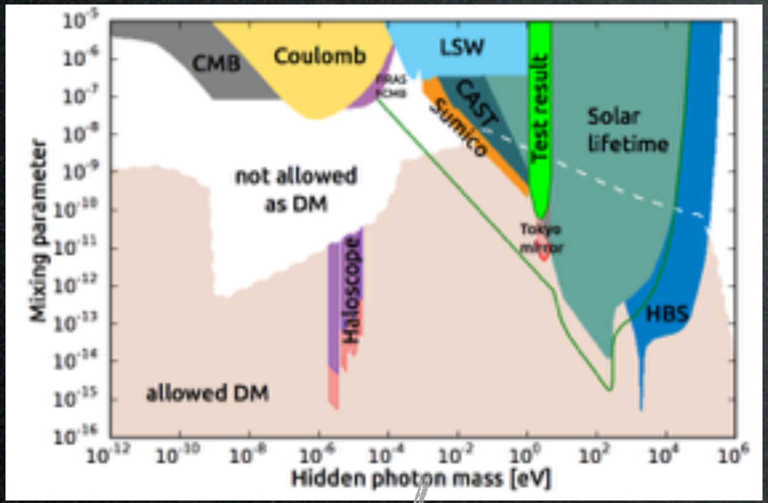
Outside of the WIMP box

FUNK

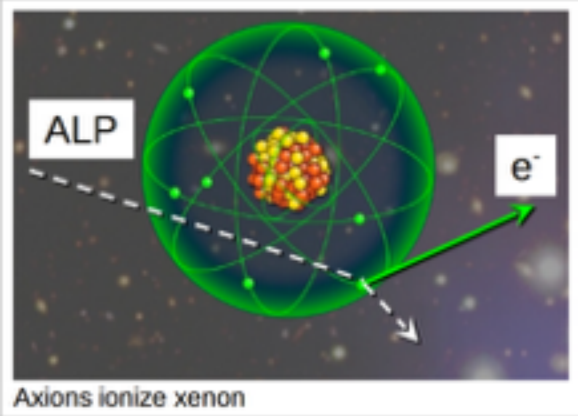
hidden photon searches



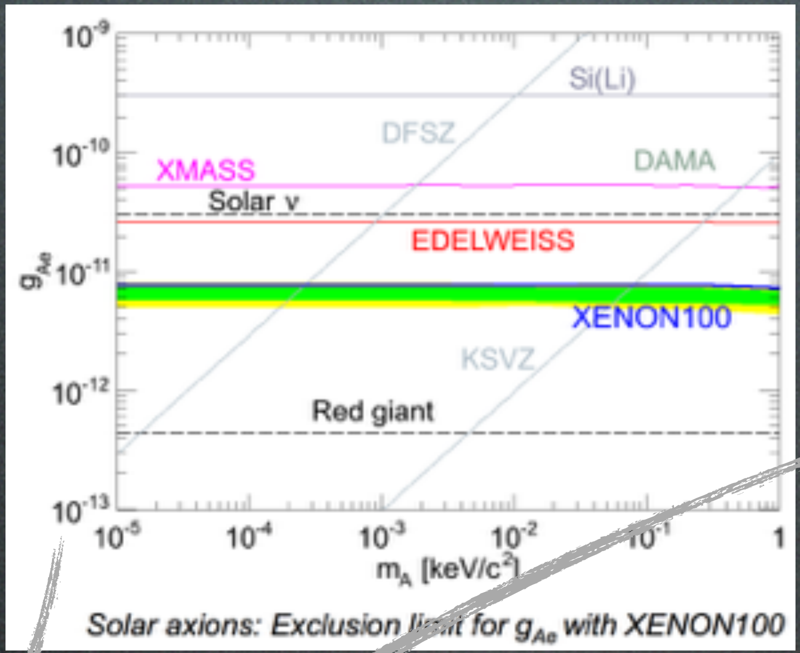
D. Veberič
ICRC 2015
#1191



Xenon-100



J. Masbou
ICRC 2015
#1210



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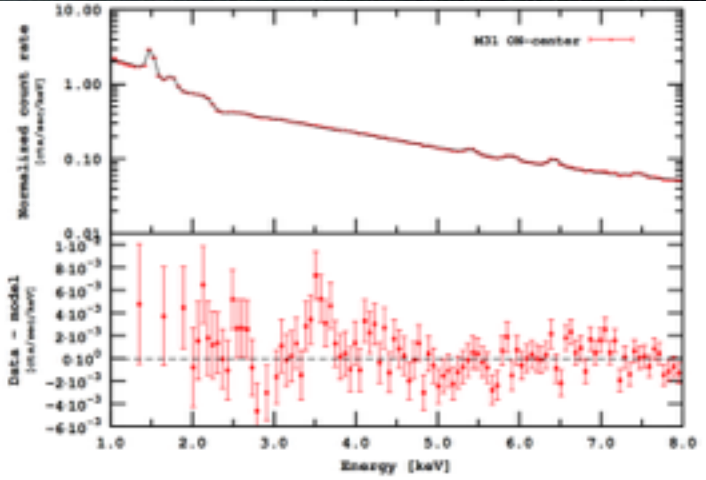
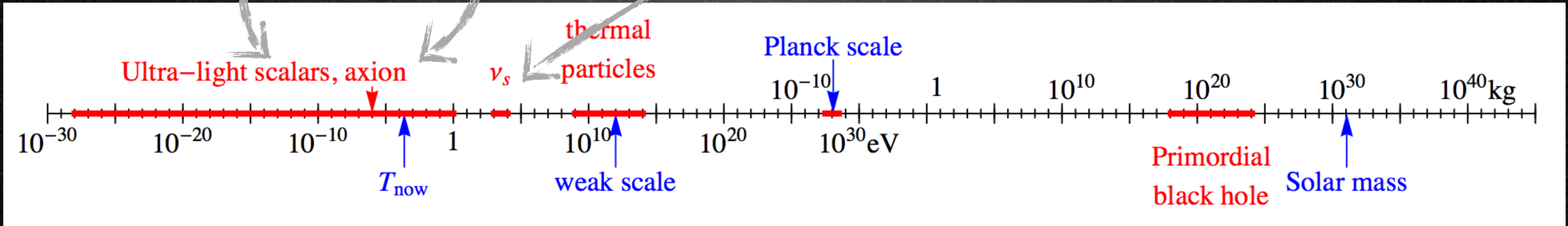


3.5 KeV signal still there, tested soon

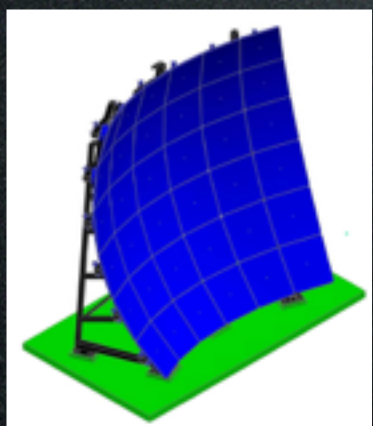


‘only’ 90 orders of magnitude!

Outside of the WIMP box

FUNK

hidden photon searches



D. Veberič
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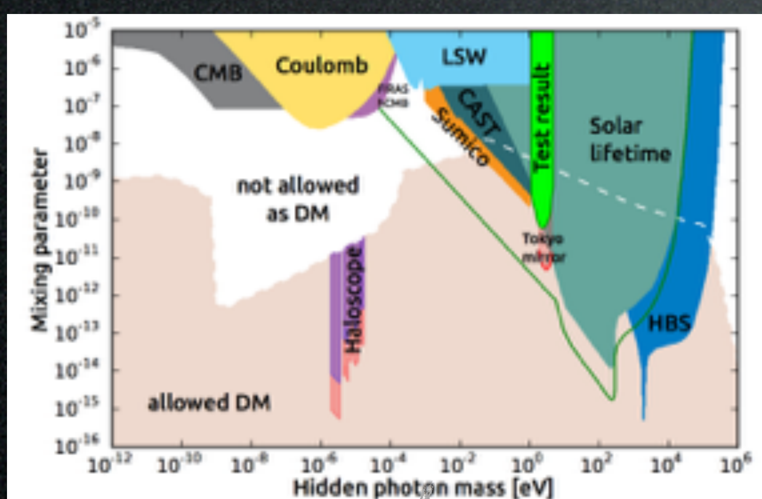
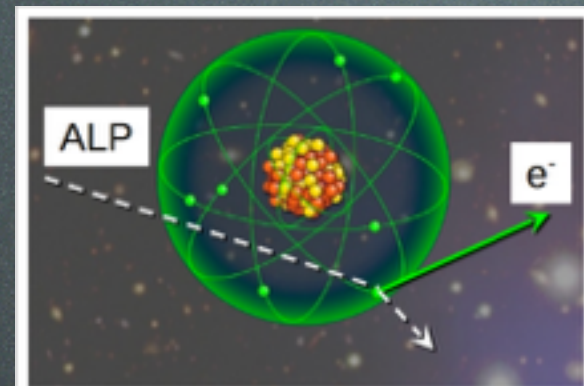


Xenon-100



Axions ionize xenon

J. Masbou
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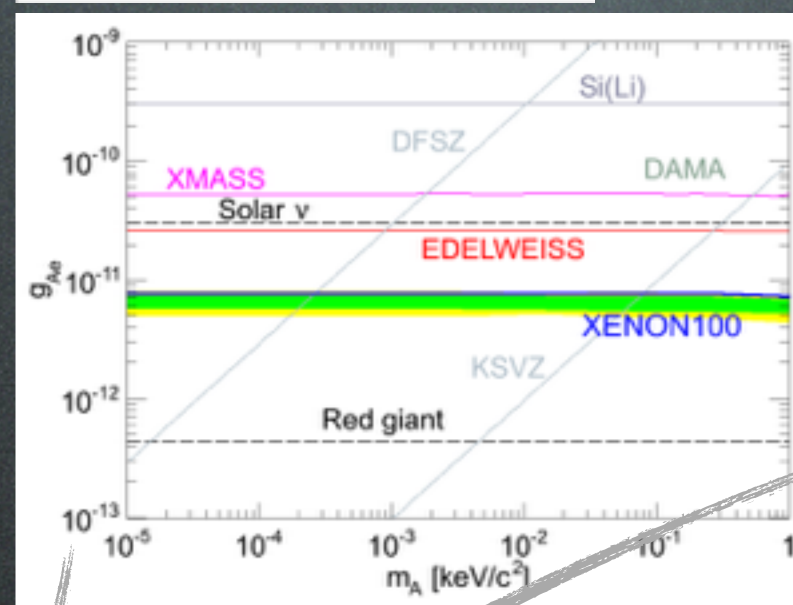
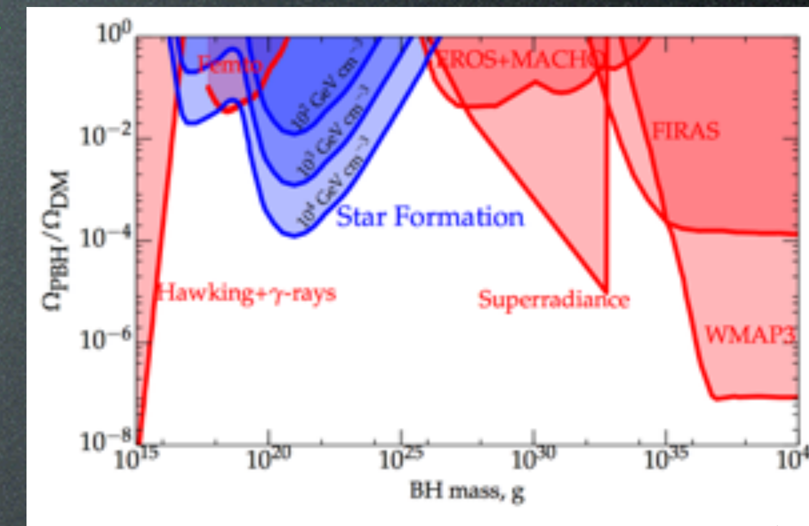


Solar axions: Exclusion limit for g_{Ae} with XENON100

M. Pshirkov
ICRC 2015
#1186



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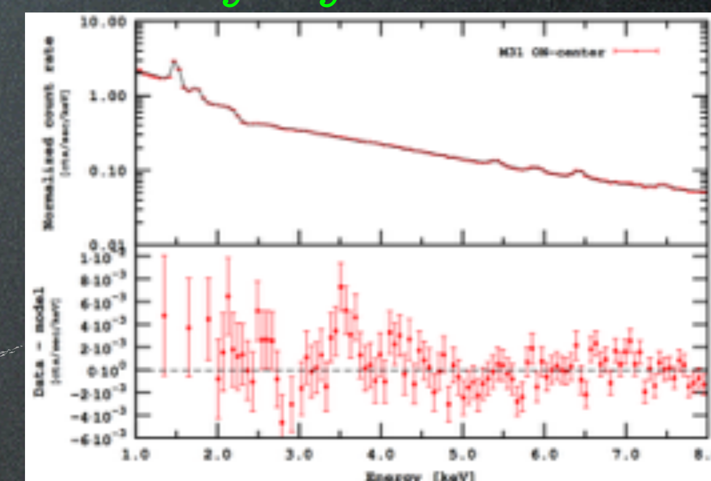
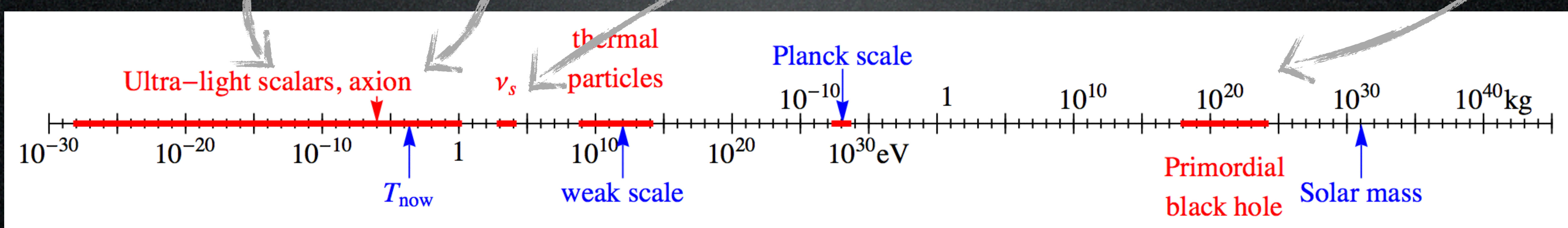


3.5 KeV signal still there, tested soon



'only' 90 orders of magnitude!

(My) Conclusions

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DM exists

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Understanding it
is a major goal of
astroparticle physics

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astroparticle physics

which requires
collaboration
and
coordination
of different disciplines