arxiv: 1206.2929 Dan Hooper, Neal Weiner, XW
arXiv: 1411.???? Jia Liu, Neal Weiner, XW

DARK PHOTON SEARCH AND DARK MATTER INDIRECT DETECTION

Wei XUE

Nov. 10, 2014

PLAN

1. Dark Photon Search

2. GeV Gamma Ray Excess in the Galatic Center
   statistical and systematical uncertainties

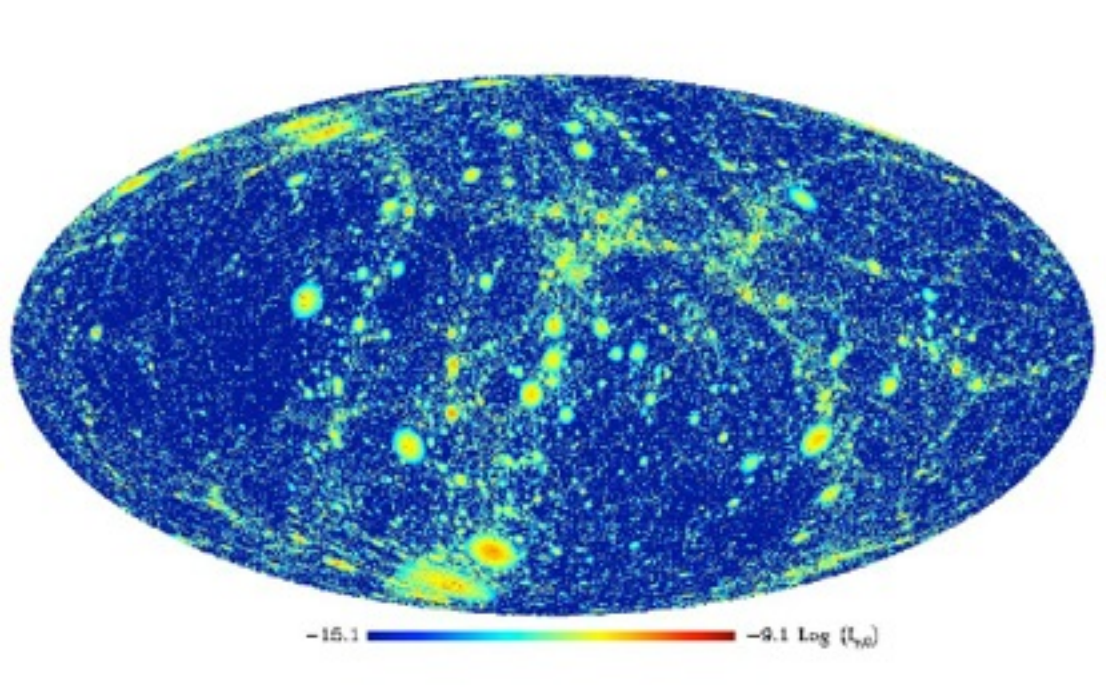
3. Dark Photon Portal
   Gamam Ray and Electrons

4. Constraints
   AMS02 constraints on 2e , 4e final states

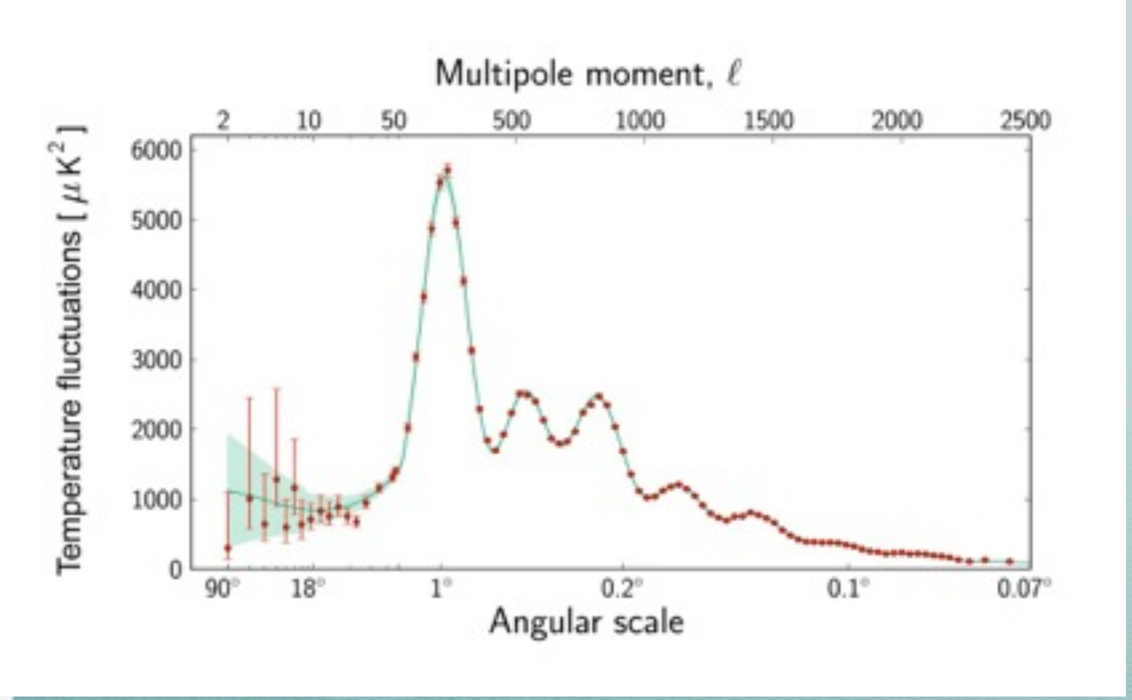
5. Dark Scalar

6. Conclusion

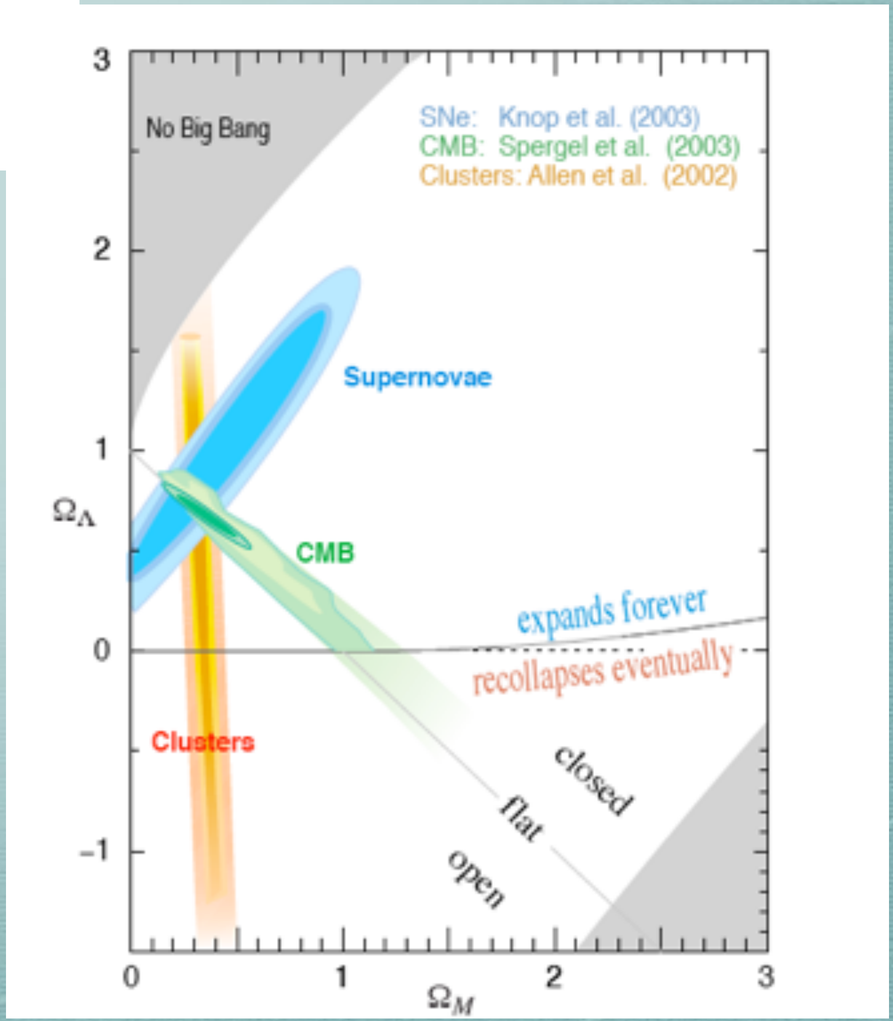
We know



−15.1
−9.1 Log (I)



Multipole moment, ℓ
2
10
50
500
1000
1500
2000
2500
Temperature fluctuations [μK²]
6000
5000
4000
3000
2000
1000
0
90°
18°
1°
0.2°
0.1°
0.07°
Angular scale



No Big Bang
SNe: Knop et al. (2003)
CMB: Spergel et al. (2003)
Clusters: Allen et al. (2002)
Supernovae
CMB
Clusters
expands forever
recollapses eventually
closed
flat
open
ΩΛ
ΩM
3
2
1
0
−1
0
1
2
3

We don't know

1. Dark matter mass

   axion meV , WIMP 100 GeV

2. Dark matter talks to Standard Model

3. Hidden Universe.

   One component or two components dark matter?

   composite field.

   excited dark matter.

   self-interact or not

4. ...

However, we have constraints and some hints of dark matter from many observations

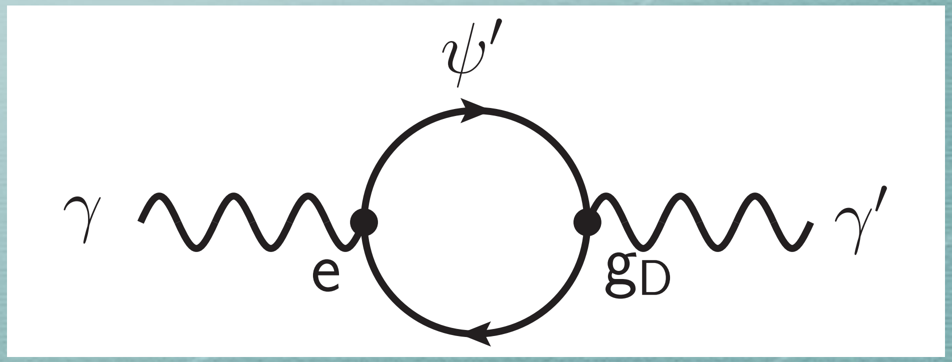
Vector Portal

1. Neutrino Portal, Higgs Portal, Vector Portal
   - $H^{+}H\ (\lambda S^2 + \mu S)$ Higgs portal, Singlet scalar
   - $L\ H\ N$ neutrino portal
   - $B_{\mu\nu} V^{\mu\nu}$ vector portal

2. Lagrangian and field redefinition
   $L = -1/4\ (B_{\mu\nu} B^{\mu\nu} + F'_{\mu\nu}F'^{\mu\nu} - 2\varepsilon\ B_{\mu\nu}F'^{\mu\nu}) + 1/2\ m^2\ A'_{\mu}\ A'^{\mu} - g_Y J_{\mu} B^{\mu}$
   Field redefinition: $B^{\mu\nu} \simeq B^{\mu\nu} + \varepsilon\ F'^{\mu\nu}$, (mass basis)
   modify EM $\varepsilon\ g_Y J_{\mu} A'_{\mu}$

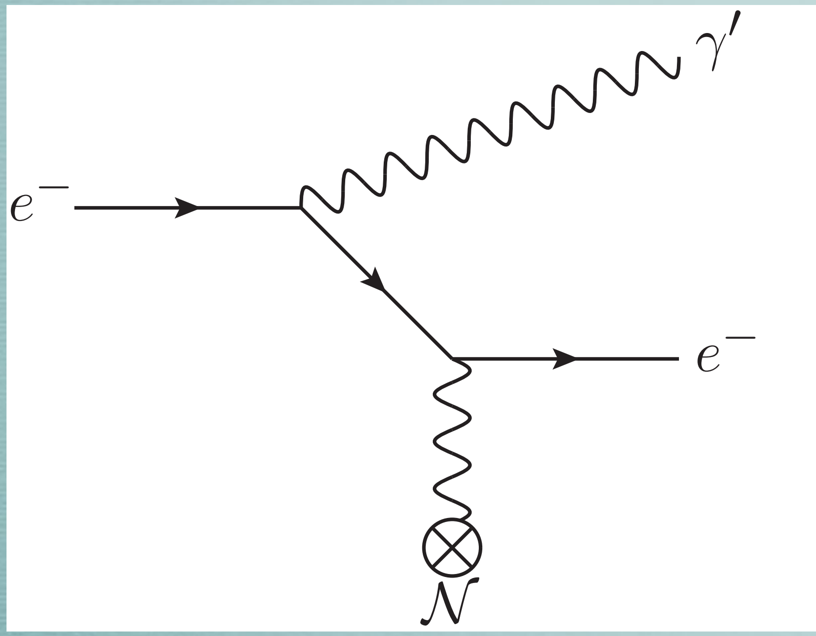
3. ε range

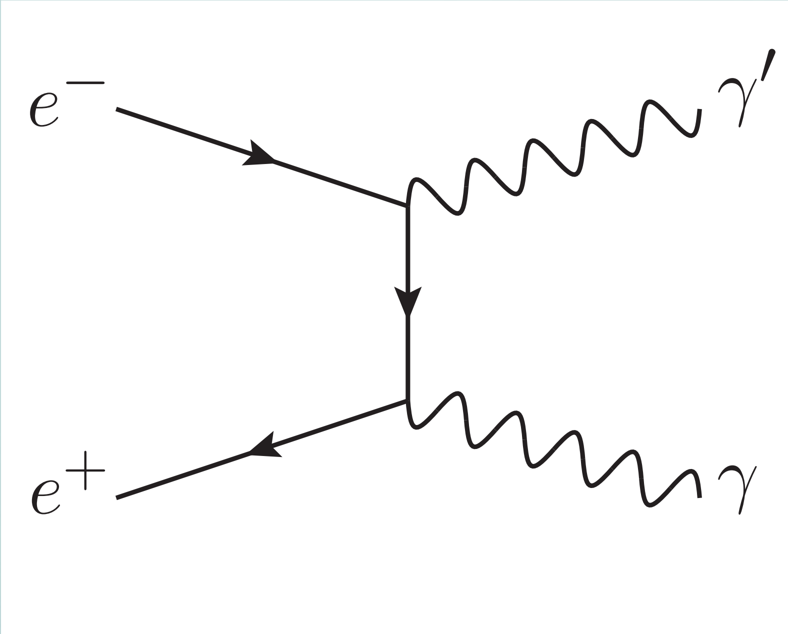
   1-loop, $\varepsilon \sim 10^{-4}$
   2-loop, $\varepsilon \sim 10^{-8}$



making dark photon

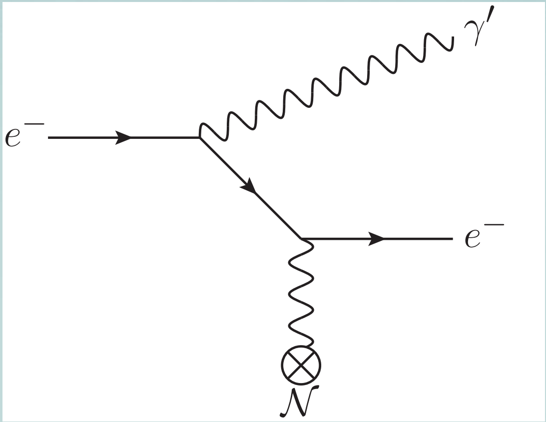
1. Bremsstrahlung
2 Direct
3. Meson decay $(\pi^0 \rightarrow \gamma\, e^+ e^-)$

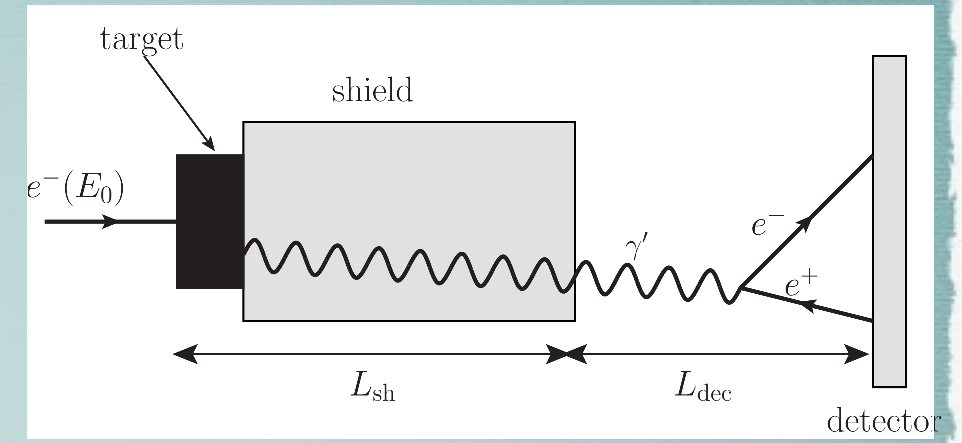




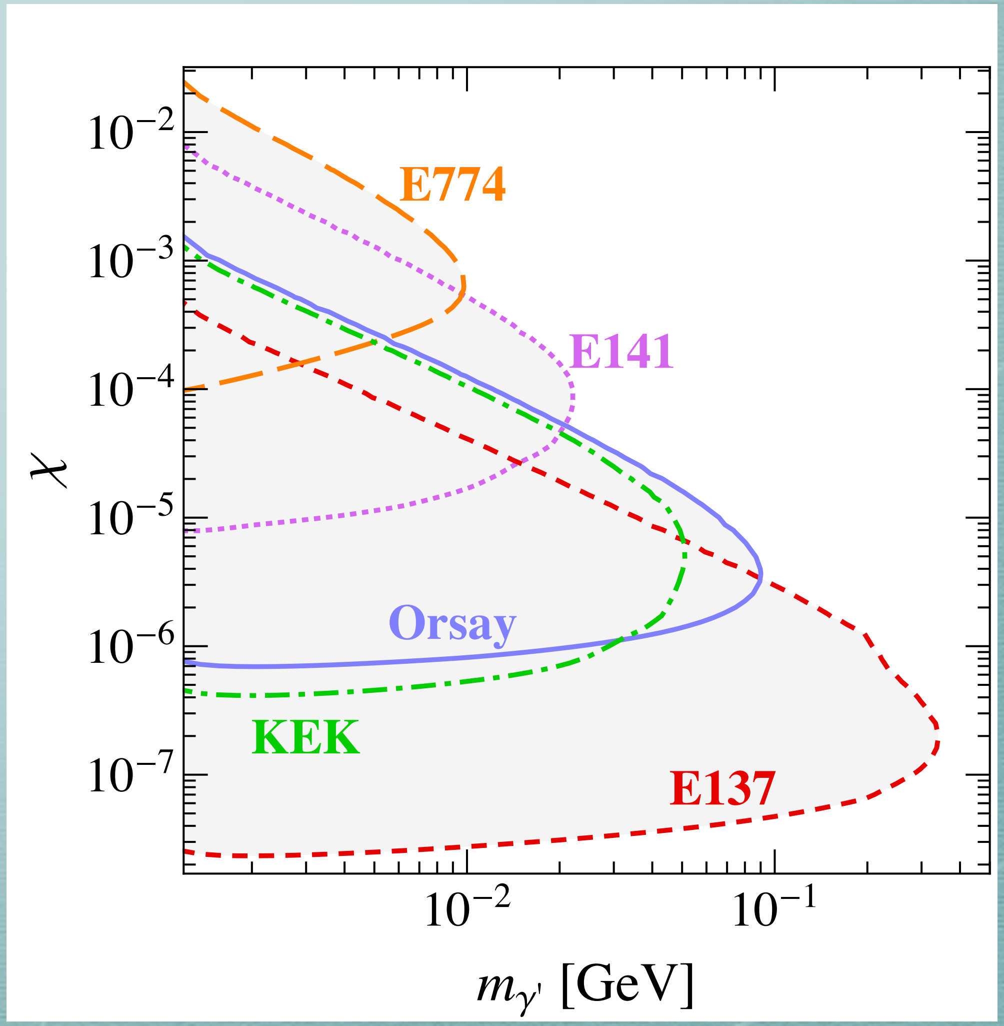
Beam Dump Experiments

1. beam dump experiments





2. Decay length of dark photon, (displaced vertex vs. prompt decay)
decay length ≃ 0.8 cm × (E_0/ 10 GeV) × $(10^{-4}/\varepsilon)^2$ (100 MeV/ $m_{A'})^2$
decay length ~ $1/(\varepsilon \times m_{A'})^2$



$$N_{\gamma'} \simeq N_e \frac{N_0 X_0}{A} \int_{m_{\gamma'}}^{E_0 - m_e} dE_{\gamma'} \int_{E_{\gamma'}+m_e}^{E_0} dE_e \int_0^{T_{sh}} dt_{sh}$$
$$\left[I_e(E_0, E_e, t_{sh}) \frac{1}{E_e} \frac{d\sigma}{dx_e}\bigg|_{x_e = \frac{E_{\gamma'}}{E_e}} e^{-L_{sh}/l_{\gamma'}} \left(1 - e^{-L_{dec}/l_{\gamma'}}\right) \right] \mathrm{BR}_{\mathrm{detect}}$$

Meson Decays

Low energy collider can produce large numbers of mesons.

1. reach estimation

$$\frac{\mathrm{S}}{\sqrt{\mathrm{B}}} \approx \sqrt{n_X}\frac{\epsilon^2 \times \mathrm{BR}(X \to Y + \gamma) \times \mathrm{BR}(U \to \ell^+\ell^-)}{\sqrt{\mathrm{BR}(X \to Y + \gamma^* \to Y + \ell^+\ell^-)}}\sqrt{\frac{m_U}{\delta m}\log\left(\frac{m_X - m_Y}{2m_\ell}\right)}.$$

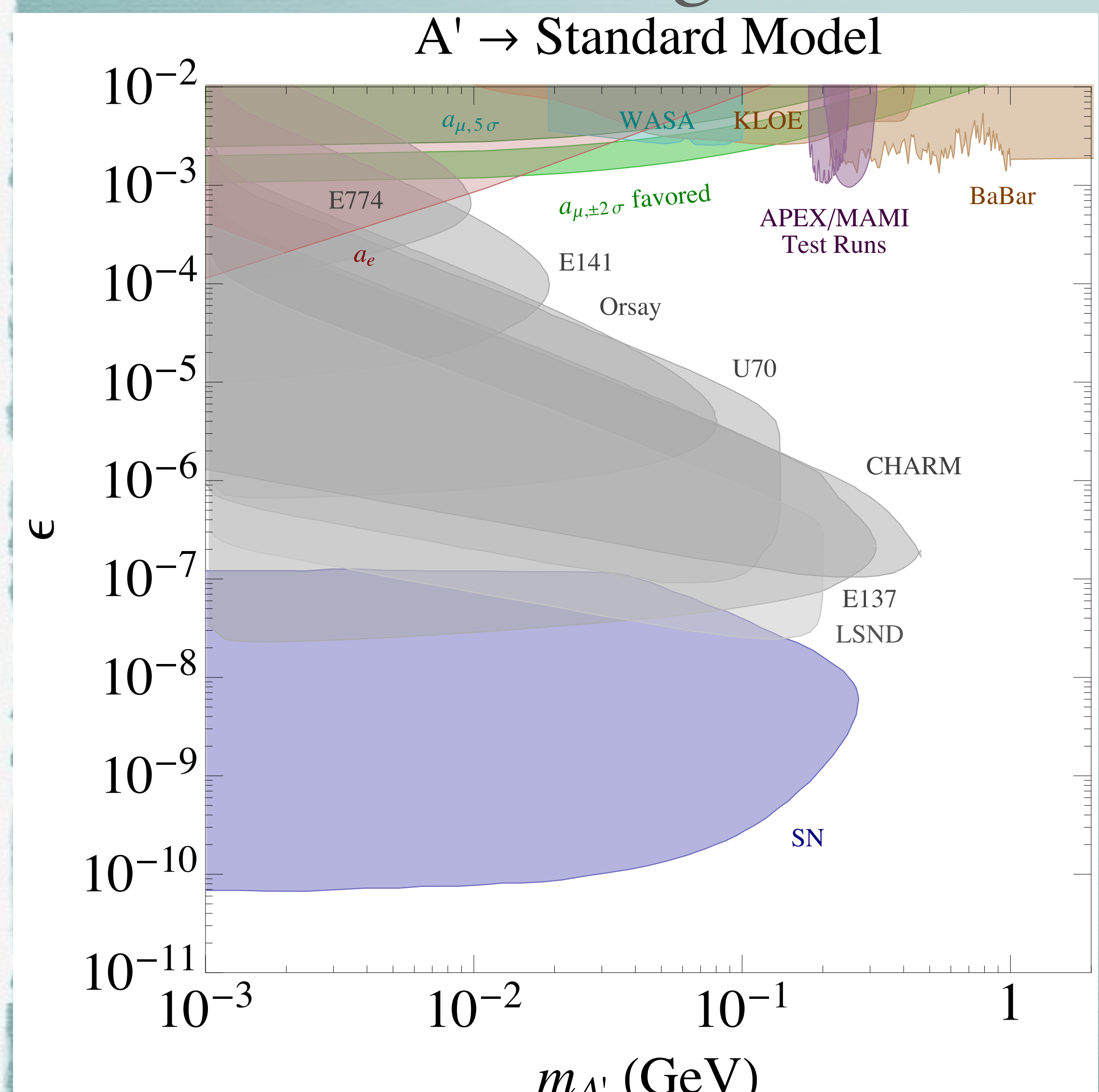
$X \to YU$	n_X	$m_X - m_Y$ (MeV)	$\mathrm{BR}(X \to Y + \gamma)$	$\mathrm{BR}(X \to Y + \ell^+\ell^-)$	$\epsilon \leq$
$\eta \to \gamma U$	$n_\eta \sim 10^7$	547	$2 \times 39.8\%$	6×10^{-4}	2×10^{-3}
$\omega \to \pi^0 U$	$n_\omega \sim 10^7$	648	8.9%	7.7×10^{-4}	5×10^{-3}
$\phi \to \eta U$	$n_\phi \sim 10^{10}$	472	1.3%	1.15×10^{-4}	1×10^{-3}
$K_L^0 \to \gamma U$	$n_{K_L^0} \sim 10^{11}$	497	$2 \times (5.5 \times 10^{-4})$	9.5×10^{-6}	2×10^{-3}
$K^+ \to \pi^+ U$	$n_{K^+} \sim 10^{10}$	354	-	2.88×10^{-7}	7×10^{-3}
$K^+ \to \mu^+ \nu U$	$n_{K^+} \sim 10^{10}$	392	6.2×10^{-3}	$7 \times 10^{-8\,a}$	2×10^{-3}
$K^+ \to e^+ \nu U$	$n_{K^+} \sim 10^{10}$	496	1.5×10^{-5}	2.5×10^{-8}	7×10^{-3}

M. Reece and L. T. Wang, JHEP **0907** (2009) 051

dark photon search

1. Beam dump   Fixed target   Collider

2. Bremsstrahlung   Direct   Meson decay



e⁻ Beam dump: E774, E141, E137,KEK,Orsay

reaction: e (A,Z) → e (A,Z) $l^+ l^-$

e⁻ fixed-target: MAMI, APEX,

reaction: e (A,Z) → e (A,Z) $l^+ l^-$

Collider : BaBar

reaction: ee→ e (A,Z) l+ l-

Meson decay : WASA (collider pp→ppπ^0)

reaction: $\pi^0 \rightarrow \gamma\, e^+ e^-$

Meson decay : KLOE (ee collider)

reaction: $\phi \rightarrow \eta\, e^+ e^-$

INDIRECT DETECTION

1. Galatic Center Excess
   statistical and systematical uncertainties

2. Dark Photon and Dark Scalar Model

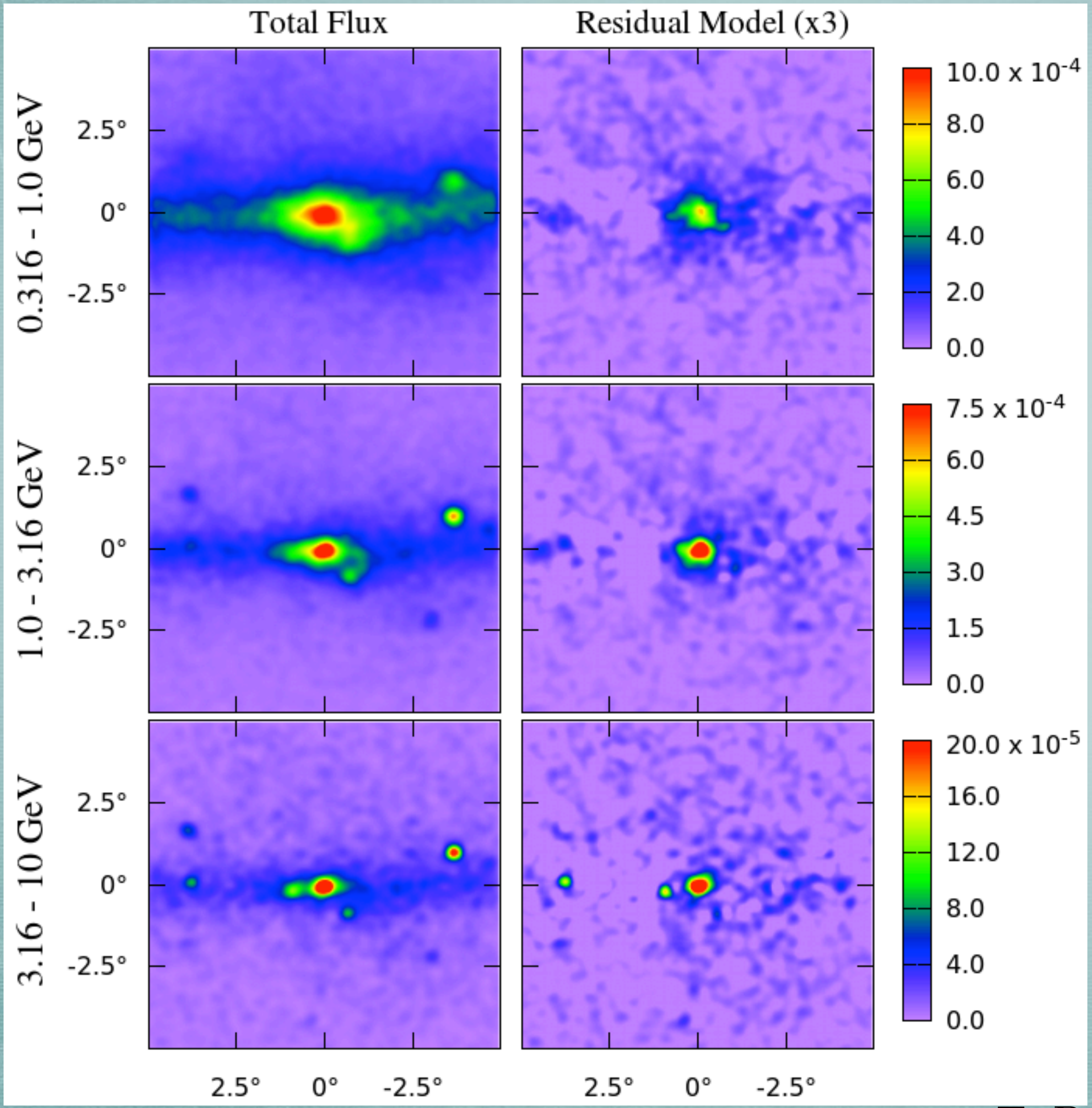
3. Constraints

GeV Excess

1. L. Goodenough, D. Hooper, arXiv: 0910.2998
   D. Hooper, L. Goodenough, arXiv: 1010.2752
   D. Hooper, T. Linden, arXiv: 1110.0006
   K. Abazajian, M. Kaplinghat, arXiv: 1207.6047
   D. Hooper, T. Slatyer, arXiv: 1302.6589
   C. Gordon, O. Macias, arXiv: 1306.5725
   W. Huang, A. Urbano, XW arXiv: 1307.6862
   ....
   T. Daylan, D. Finkbeiner, D. Hooper,
   &T. Linden, S. Portillo, N. Rodd, T. Slatyer
   arXiv: 1402.6703
   ...

Galactic Center

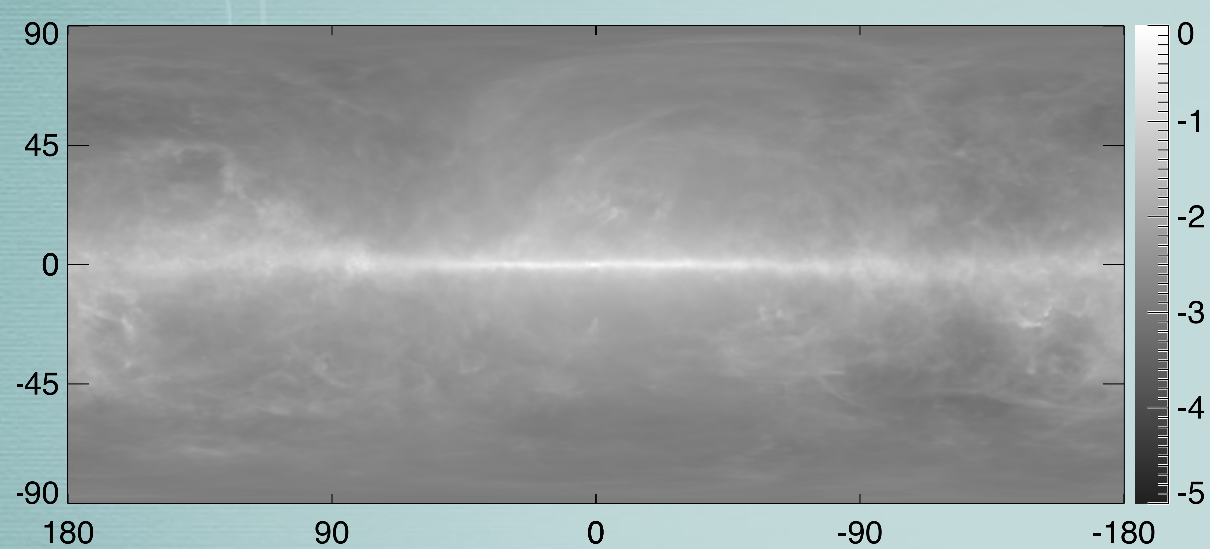
1. Galatic Center GeV excess

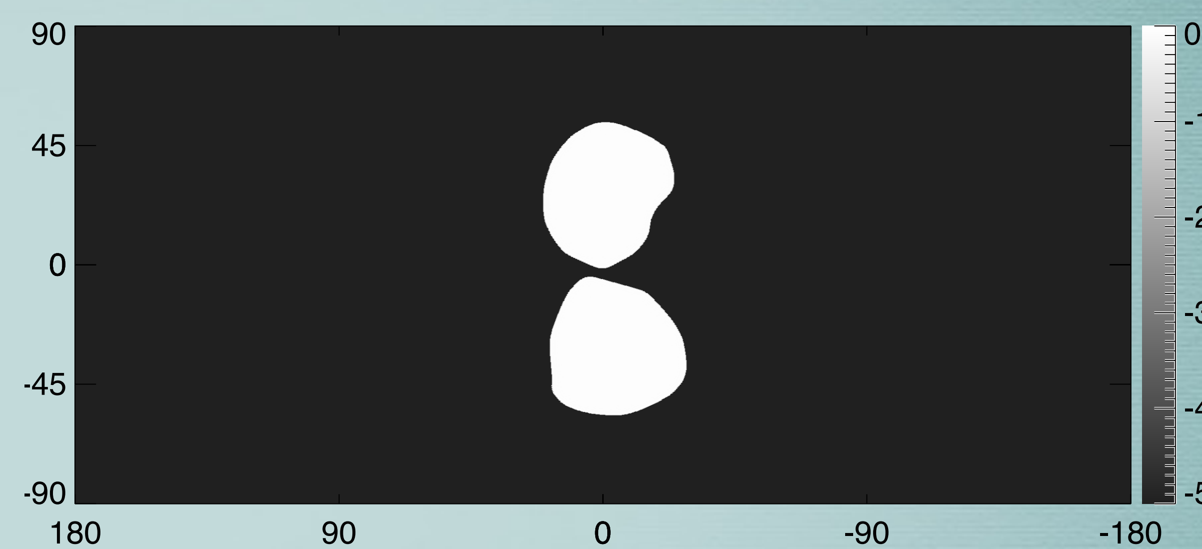


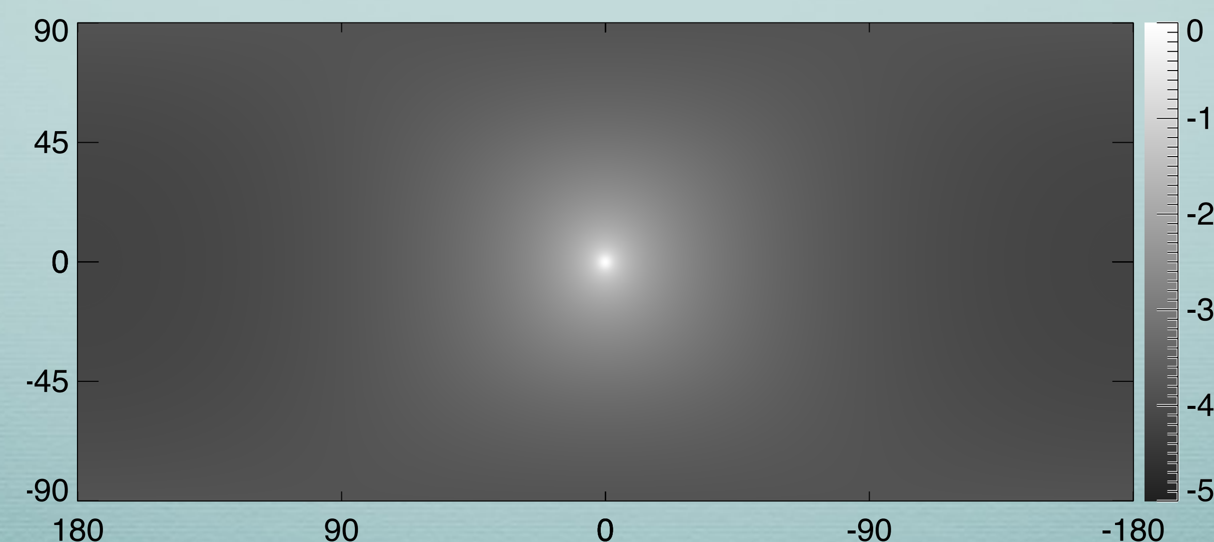
T. Daylan *et al.*, (2014), 1402.6703

Template method

1. Diffuse Map, Fermi Bubbles, and dark matter templates







T. Daylan *et al.*, (2014), 1402.6703

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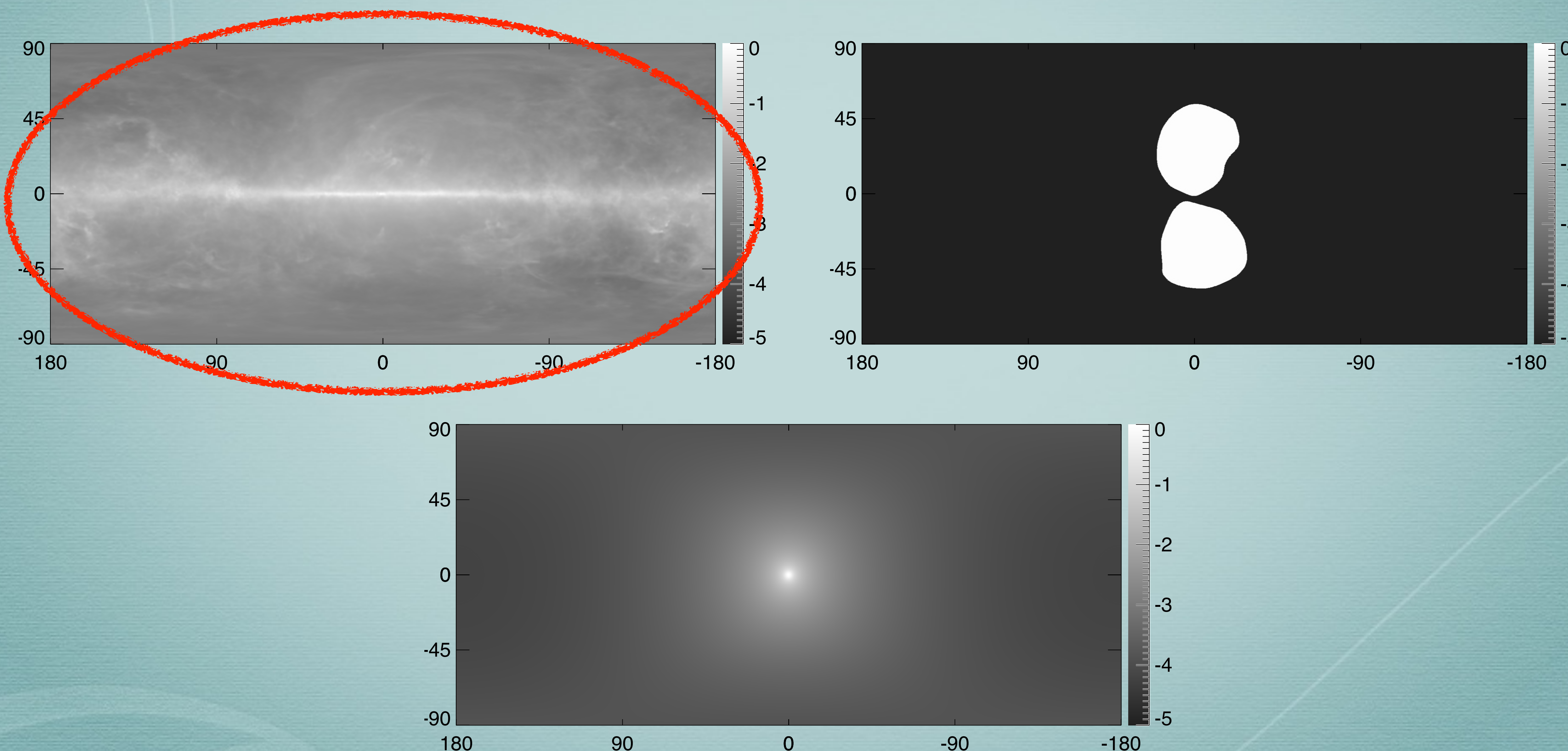


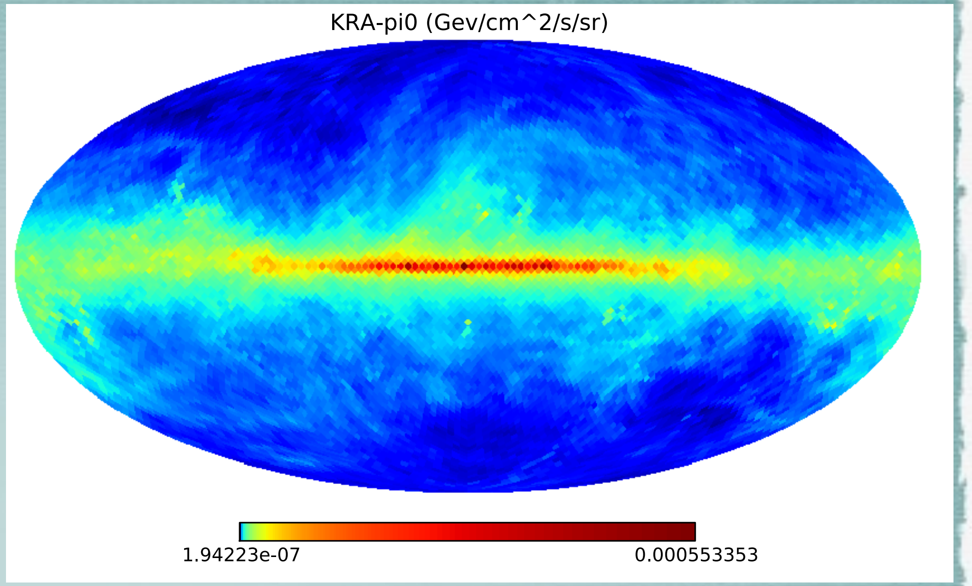
T. Daylan *et al.*, (2014), 1402.6703

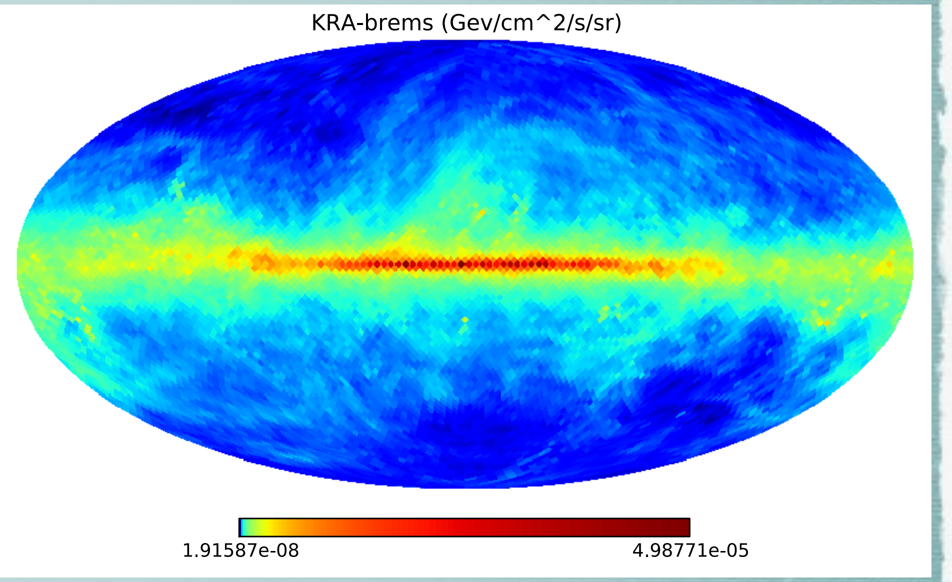
Galprop

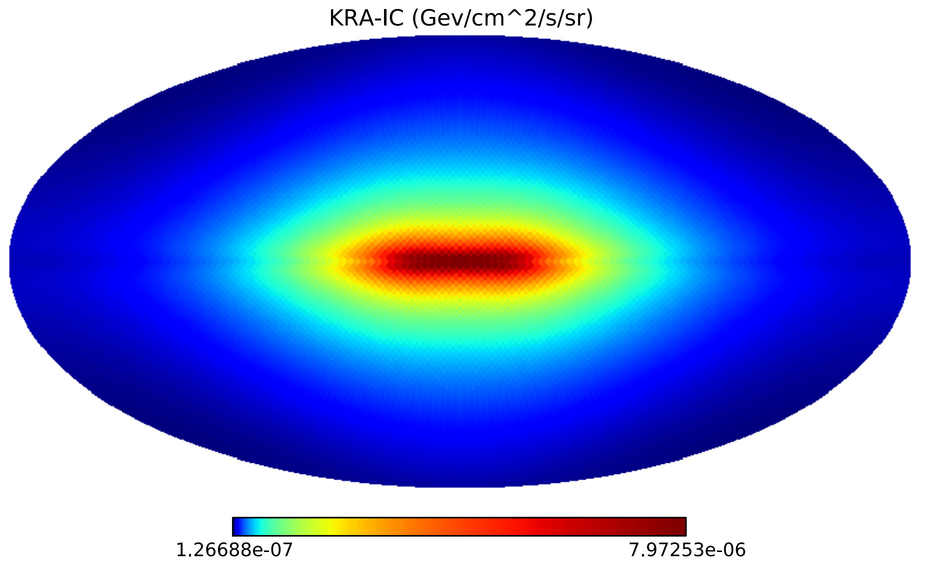
1. Decay of π^0 (cosmic-ray protons striking on Interstellar medium)

2. Bremsstrahlung (fast moving electron scattering on the gas)

3. ICS from CR electrons scattering with ISRF

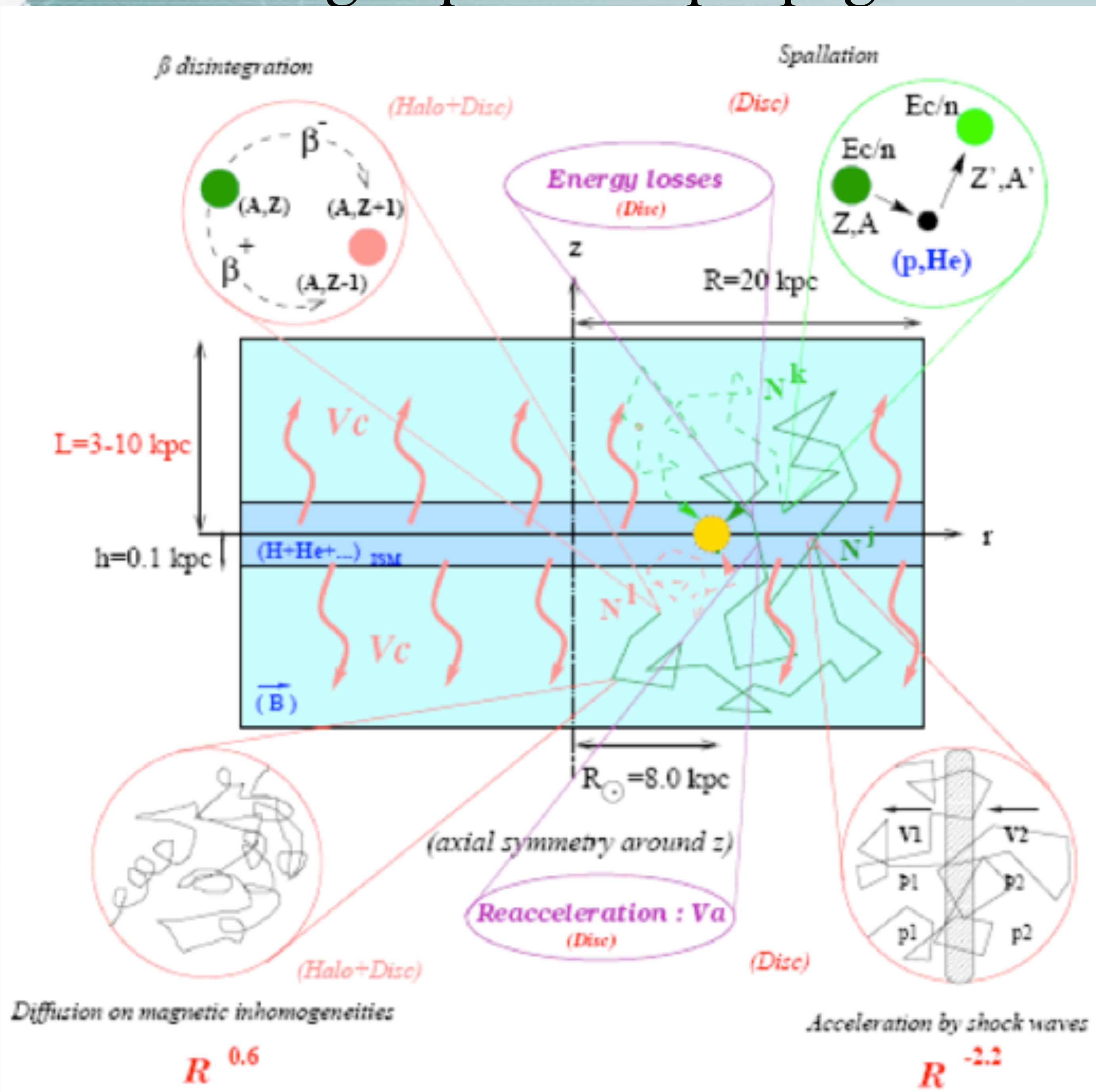






Galprop Test

1. Charged particles propagate in the galaxy



$$
\begin{aligned}
\frac{\partial N_i}{\partial t} &= -\nabla\cdot(D\nabla - v_c)\,N_i - \frac{\partial}{\partial p}\left(\dot{p} - \frac{p}{3}\nabla\cdot v_c\right)N_i \\
&+ \frac{\partial}{\partial p}p^2 D_{pp}\frac{\partial}{\partial p}\frac{N_i}{p^2} + Q_i(p,r,z) \\
&+ \sum_{j>i}\beta n_{gas}(r,z)\sigma_{ji}N_j - \beta n_{gas}\sigma_i^{in}(E_k)N_i
\end{aligned}
$$

1. acceleration
2. Diffusion
3. Energy loss
4. Convection
5. Re-acceleration
6. Spallation

... ...

Galprop test

1. What we can learn from Galprop test

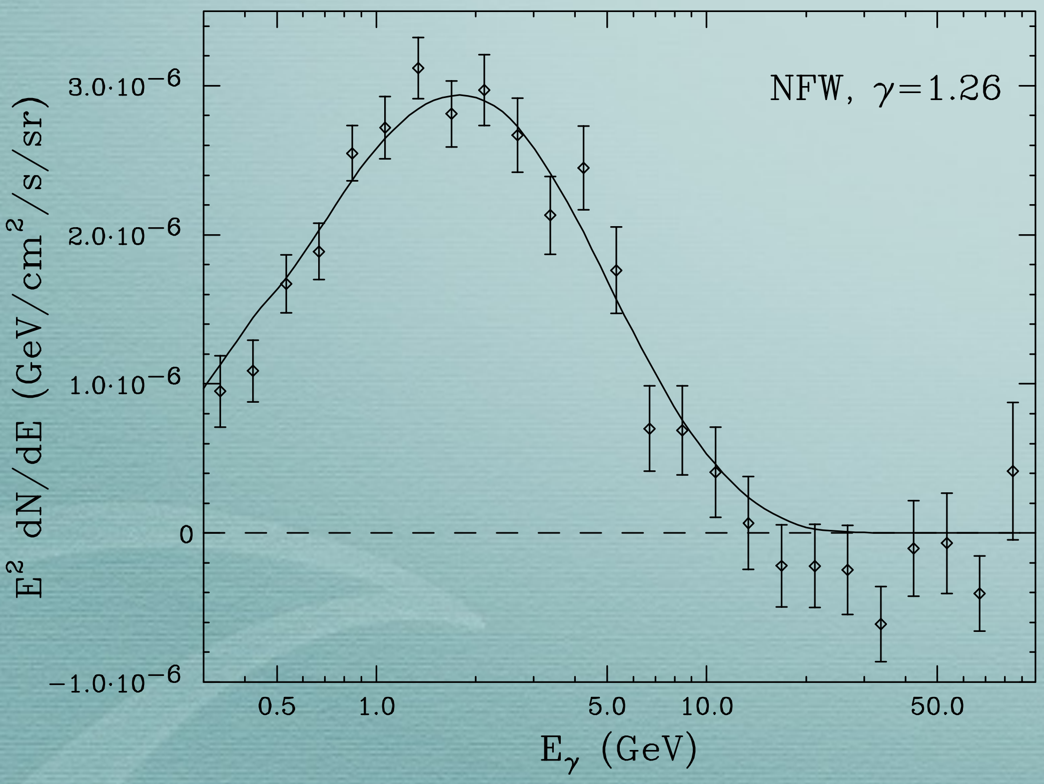
F. Calore, I. Cholis, and C. Weniger, (2014), 1409.0042

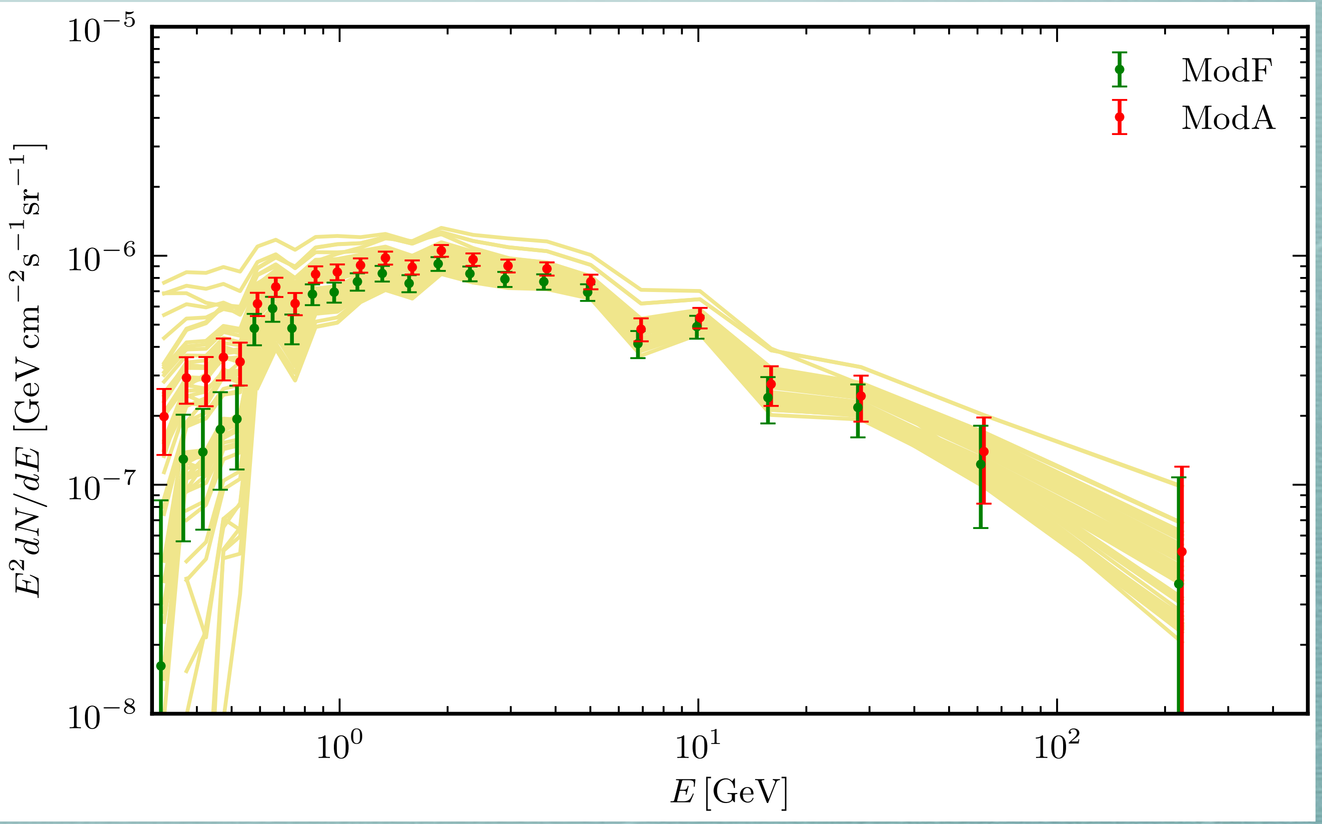
2. Limitation

    Constant Diffusion coefficient (no R dependent)

    Local cosmic ray fit

    Gas Map

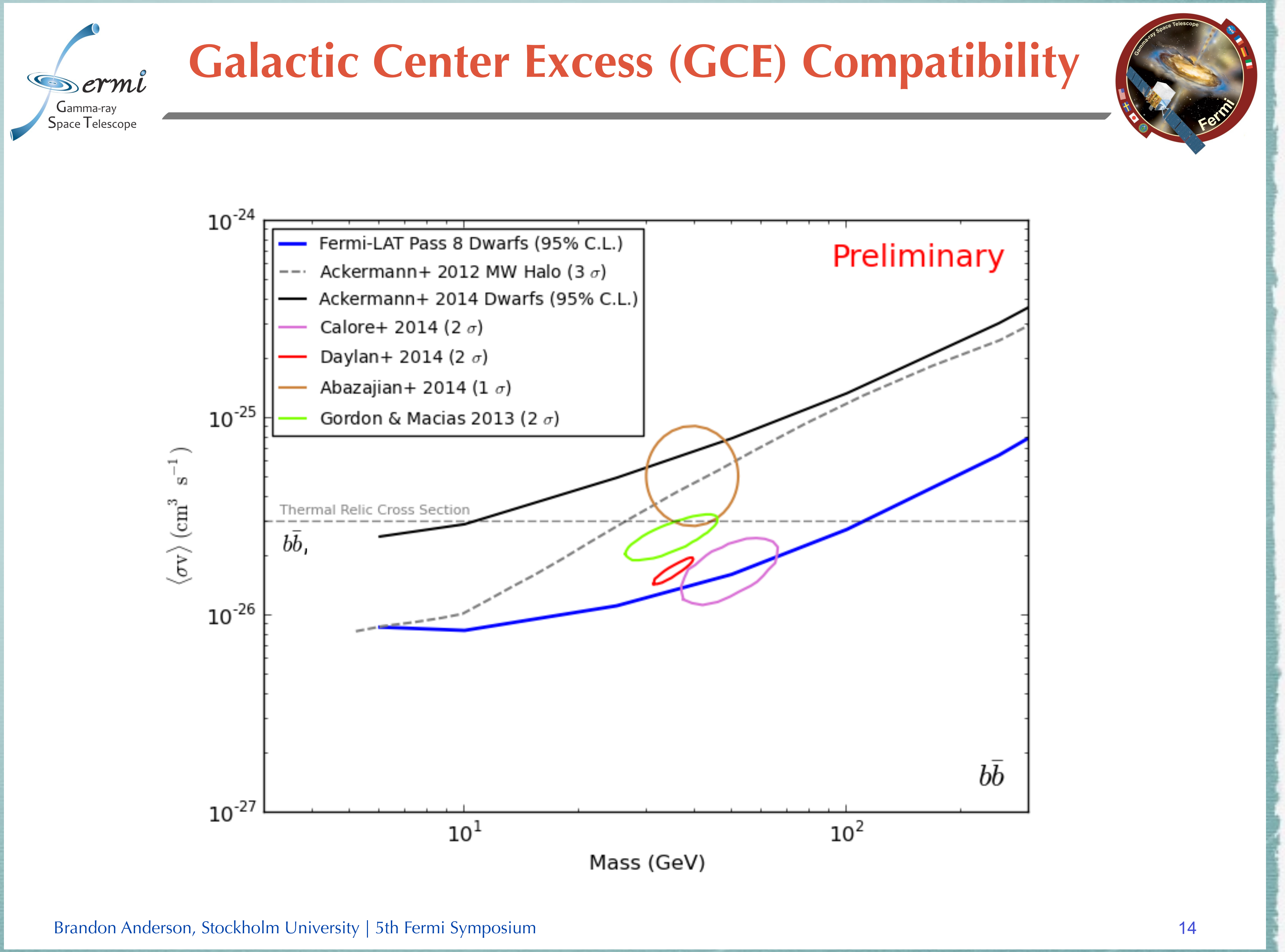




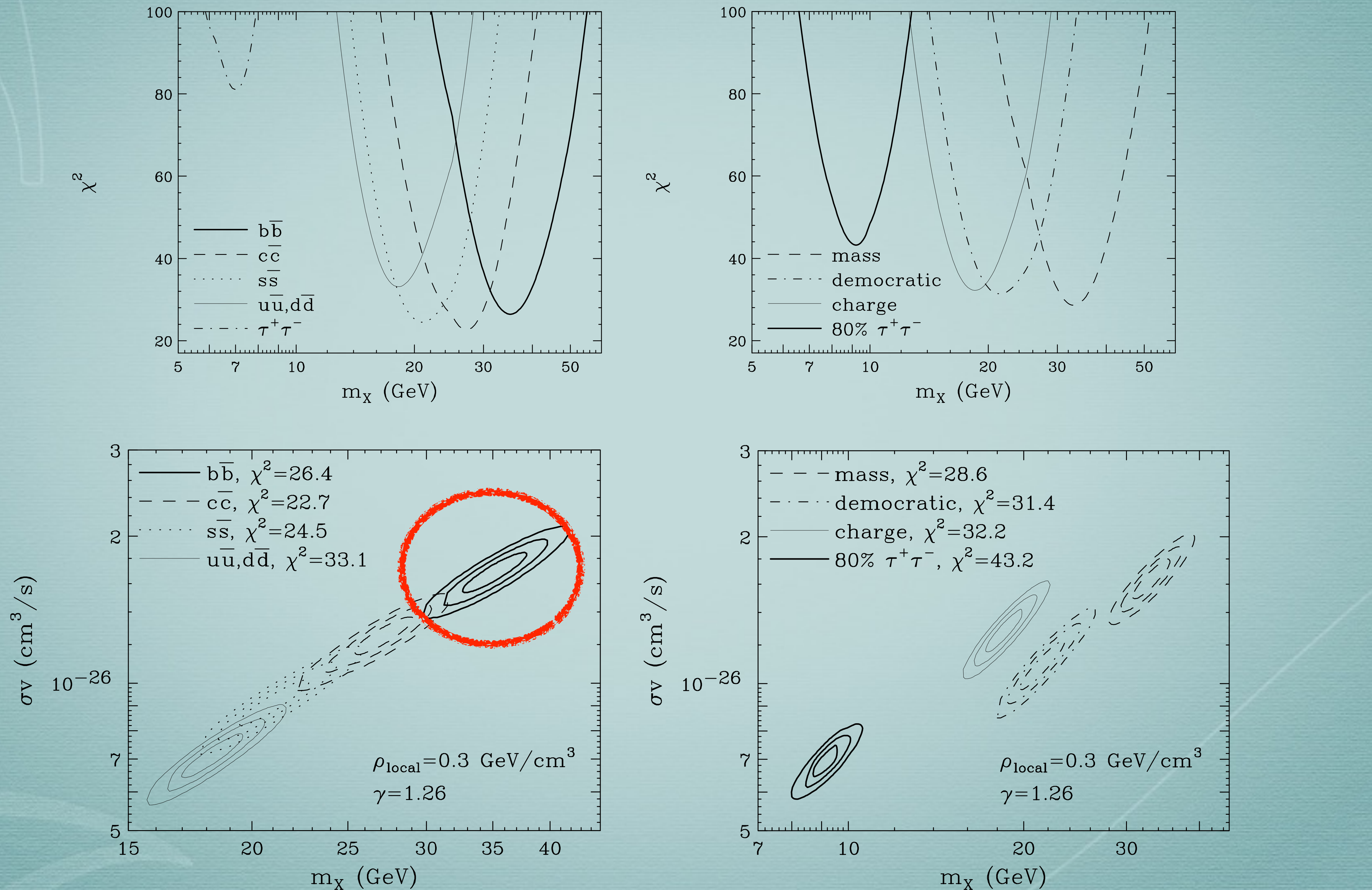
Alternatives and Constraints

1. Pulsars

2. Dwarfs



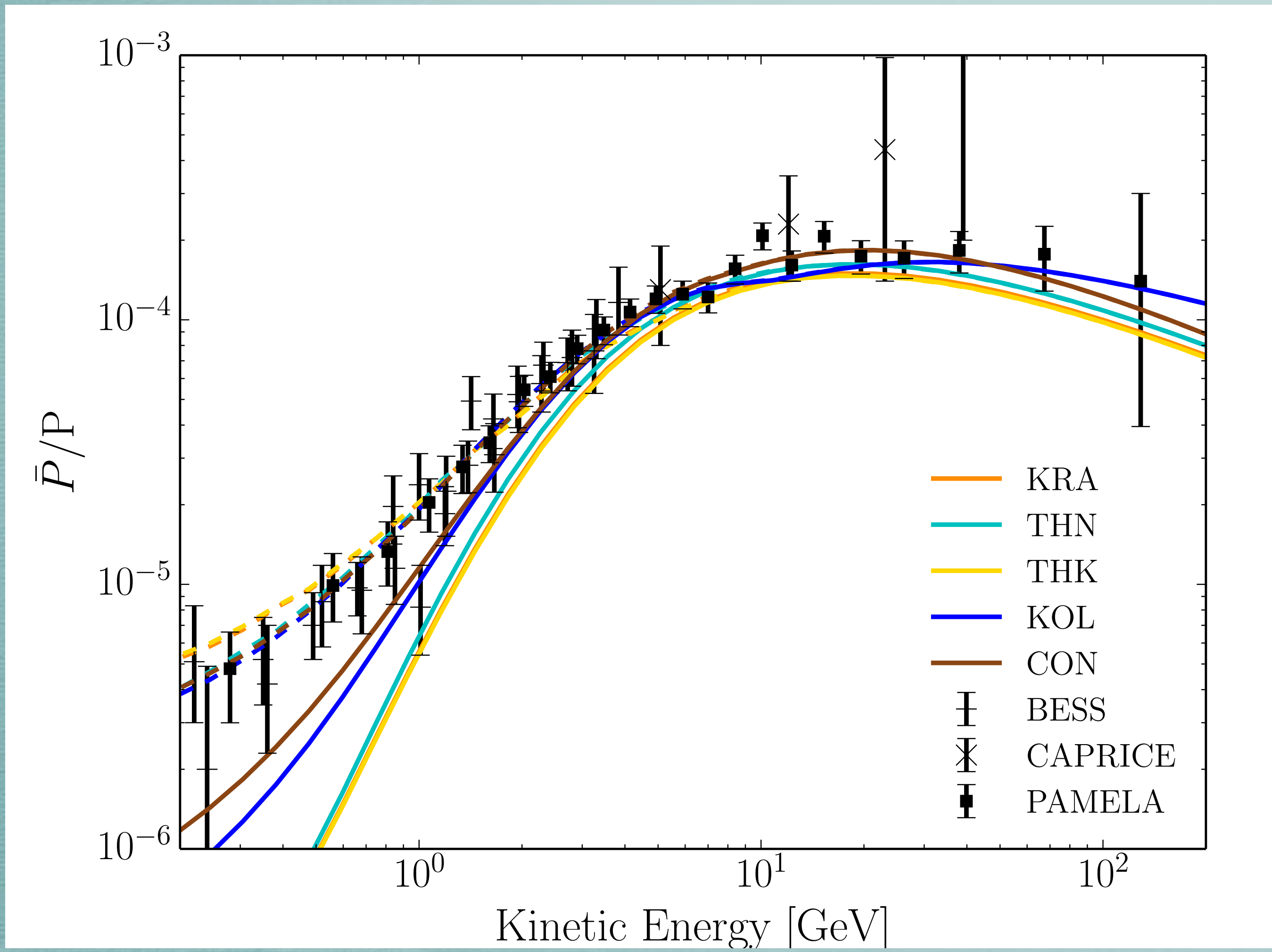
$\chi + \chi \rightarrow b + b$

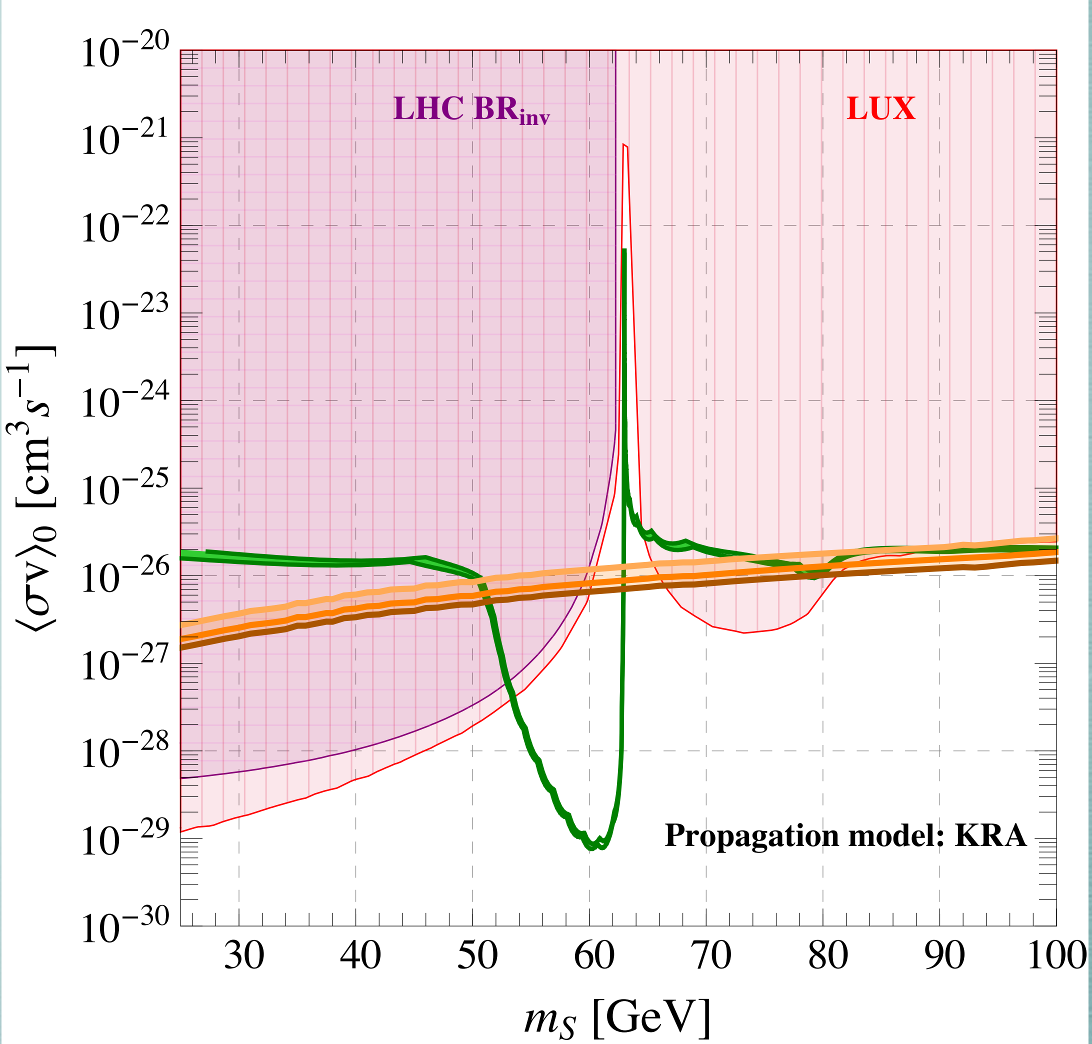


T. Daylan *et al.*, (2014), 1402.6703

χ + χ→ b + b (hydronic Channel)

1. The first model you think is Higgs portal dark matter, but it is ruled out by dark matter direct detection



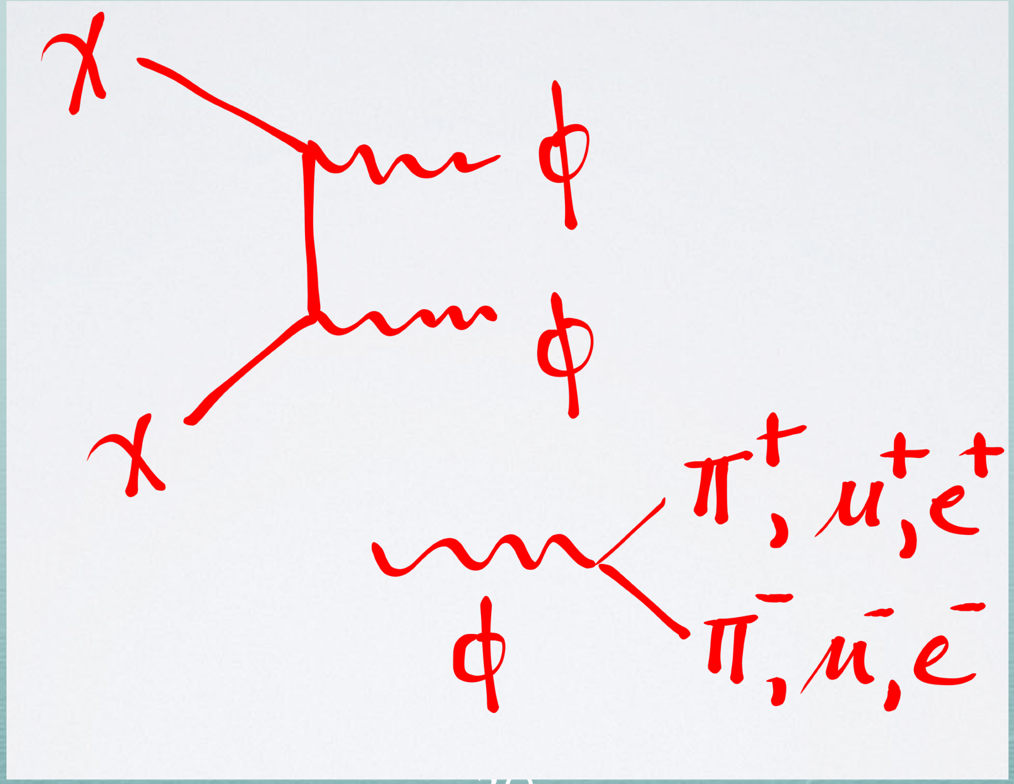


our model

1. dark matter is fermion.
   dark matter mass > dark photon mass
   its cross section and thermal relic does not depend on ε

$$\sigma v_{XX\to\phi\phi} \simeq \frac{\pi\alpha_X^2}{m_X^2} \approx 3\times10^{-26}\,\mathrm{cm^3/s}\left(\frac{g_X}{0.06}\right)^4\left(\frac{10\,\mathrm{GeV}}{m_X}\right)^2$$

2. GeV dark photon, Cascade decay to leptons and mesons

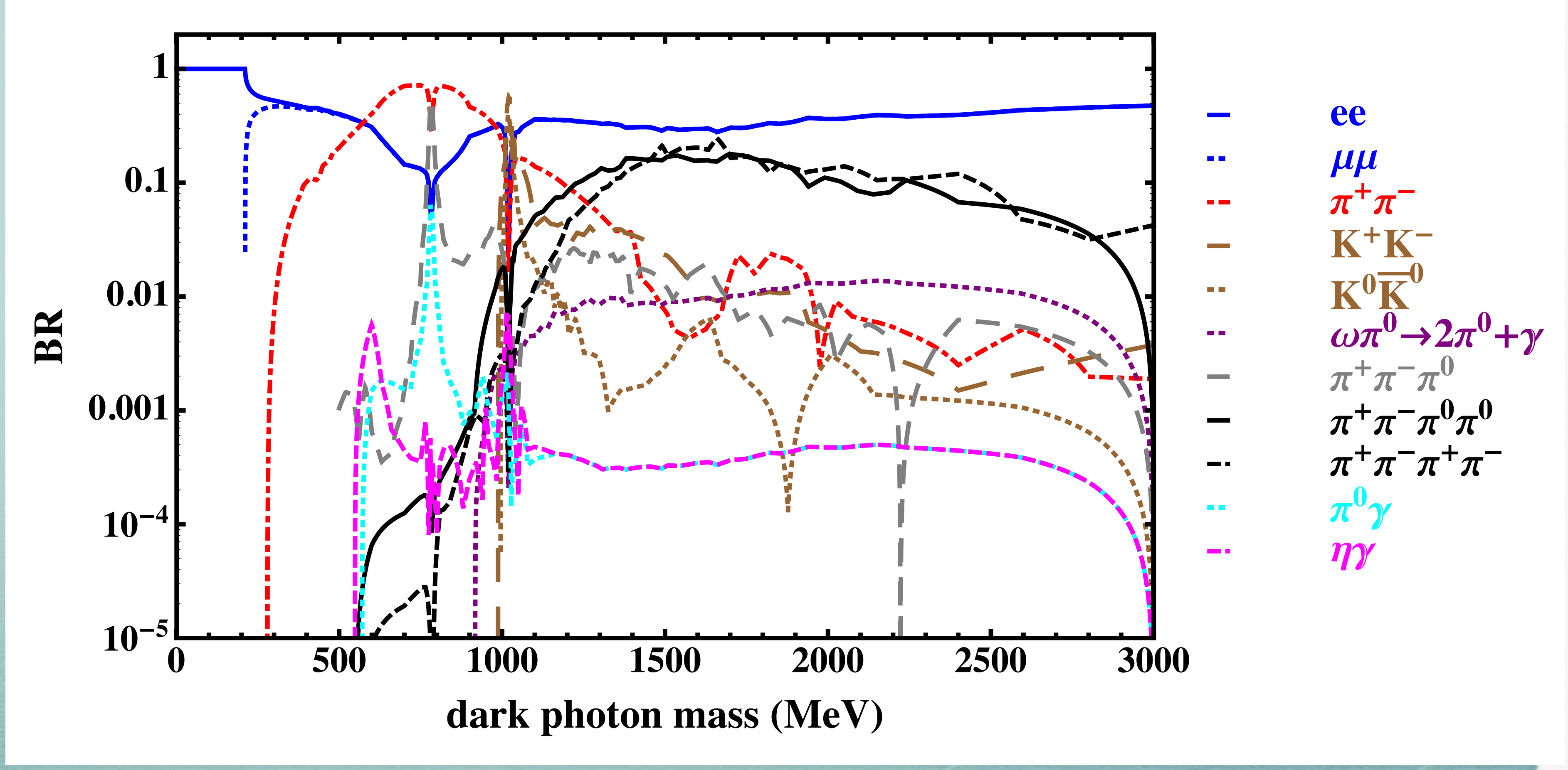


Photon Spectrum Computation

1. Branching ratio (data driven method is employed)

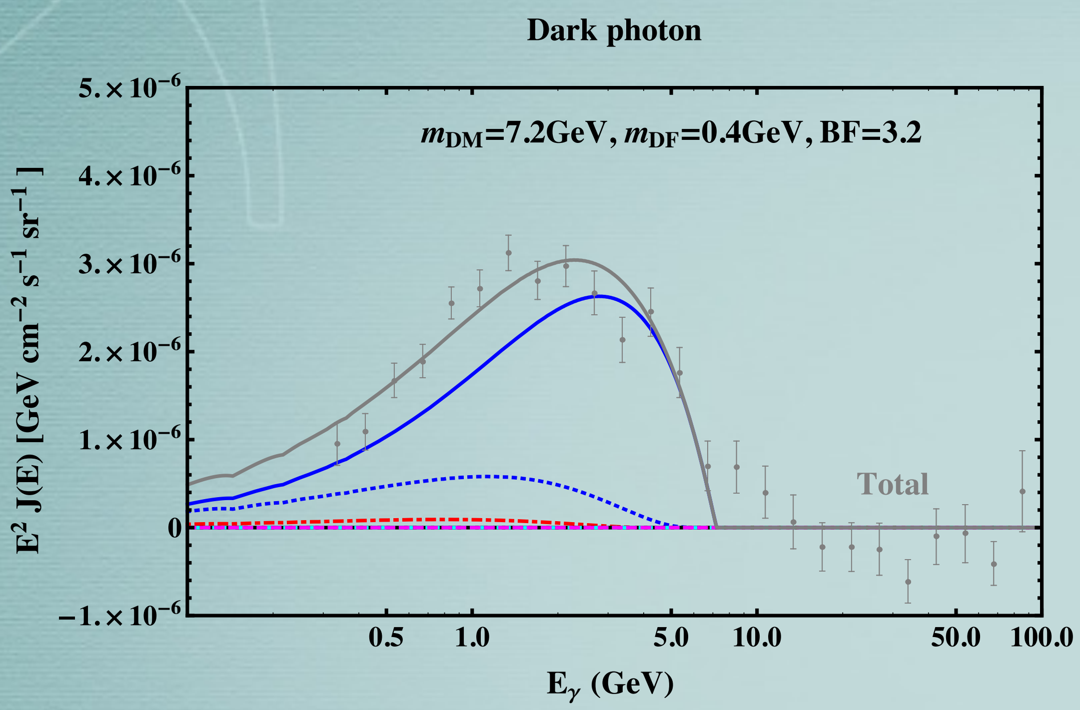
m_ϕ	Mode	BF
200 MeV	$\phi \to e^+e^-$	1
500 MeV	$\phi \to e^+e^-$	$4 \cdot 10^{-1}$
	$\phi \to \mu^+\mu^-$	$4 \cdot 10^{-1}$
	$\phi \to \pi^+\pi^-$	$2 \cdot 10^{-1}$
1.2 GeV	$\phi \to e^+e^-$	$3.4 \cdot 10^{-1}$
	$\phi \to \mu^+\mu^-$	$3.3 \cdot 10^{-1}$
	$\phi \to \omega\pi^0$	$7.9 \cdot 10^{-2}$
	$\phi \to \pi^+\pi^-\pi^0\pi^0$	$7.5 \cdot 10^{-2}$
	$\phi \to \pi^+\pi^-$	$6.4 \cdot 10^{-2}$
	$\phi \to K^+K^-$	$4.5 \cdot 10^{-2}$
	$\phi \to \pi^+\pi^+\pi^-\pi^-$	$4.1 \cdot 10^{-2}$
	$\phi \to \pi^+\pi^-\pi^0$	$2.4 \cdot 10^{-2}$
	$\phi \to K^0\bar{K}^0$	$5 \cdot 10^{-3}$

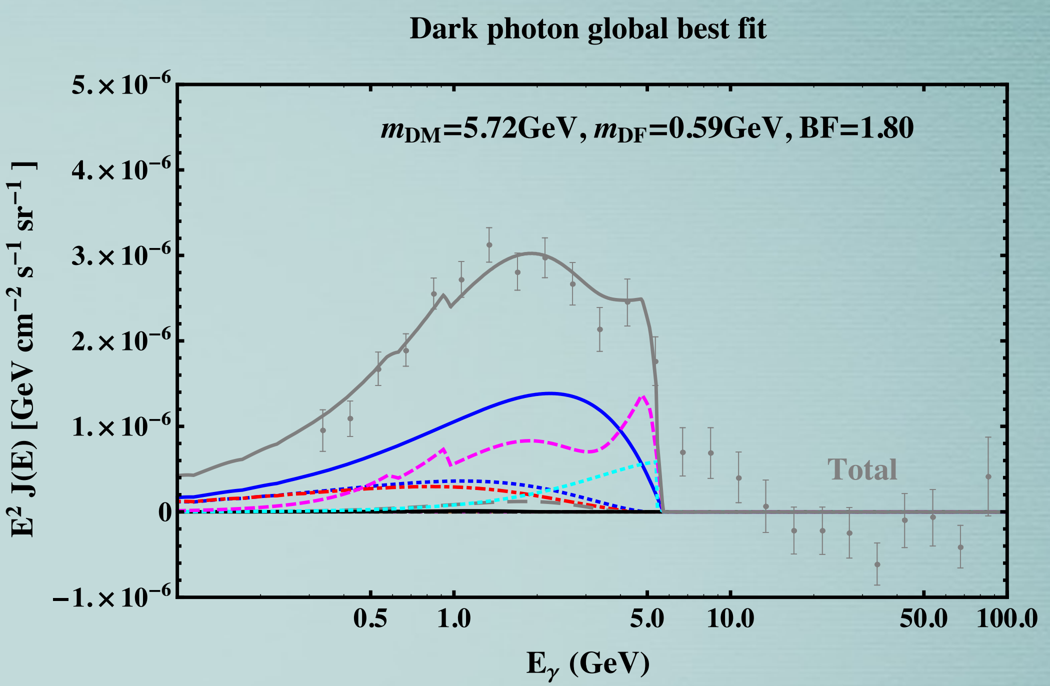
m_ϕ	Mode	BF
8 GeV	$\phi^+ \to e^+e^-$	$1.6 \cdot 10^{-1}$
	$\phi \to \mu^+\mu^-$	$1.6 \cdot 10^{-1}$
	$\phi \to \tau^+\tau^-$	$1.6 \cdot 10^{-1}$
	$\phi \to u\bar{u}$	$2.1 \cdot 10^{-1}$
	$\phi \to d\bar{d}$	$5.2 \cdot 10^{-2}$
	$\phi \to c\bar{c}$	$2.1 \cdot 10^{-1}$
	$\phi \to s\bar{s}$	$5.2 \cdot 10^{-2}$



2. Boost Spectrum to DM frame

Results





1. Dark force mass 0.4 GeV.

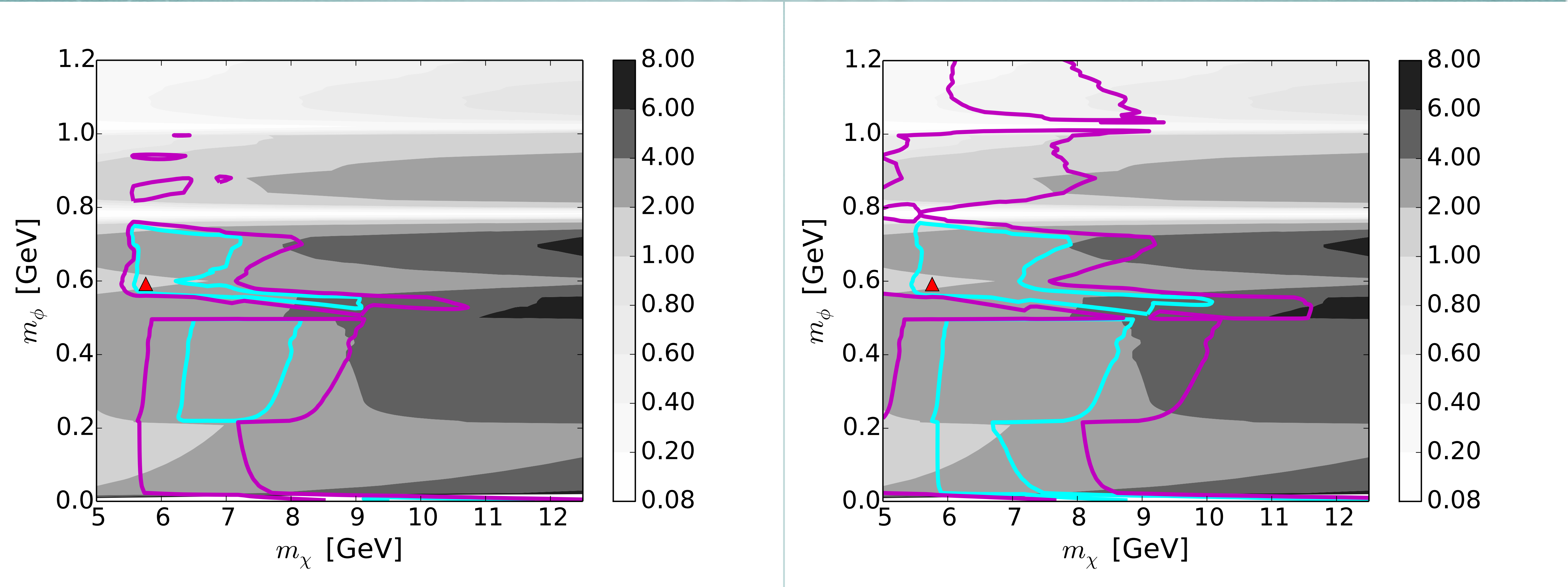
   $\phi \rightarrow 2e$, 2μ, 2π

2. Dark force mass 0.59 GeV.

   $\phi \rightarrow 2e$, 2μ, 2π, 3π, $\pi^\circ\gamma$, $\eta\gamma$

   $\eta \rightarrow$ 39.31 % $\gamma\gamma$, 32.56% $\eta \rightarrow 3\pi^\circ$, 22.73% $\eta \rightarrow \pi^+\pi^-\pi^\circ$

Result

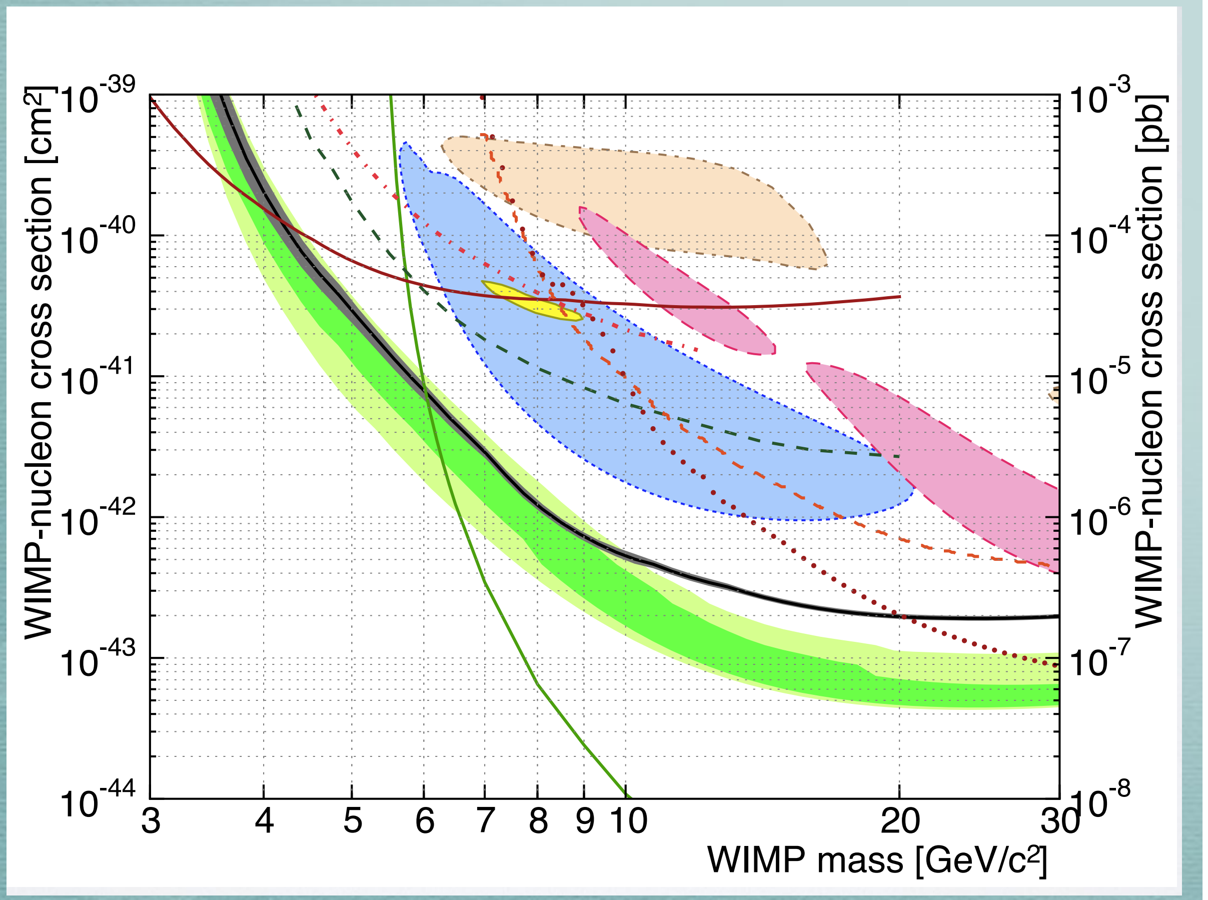


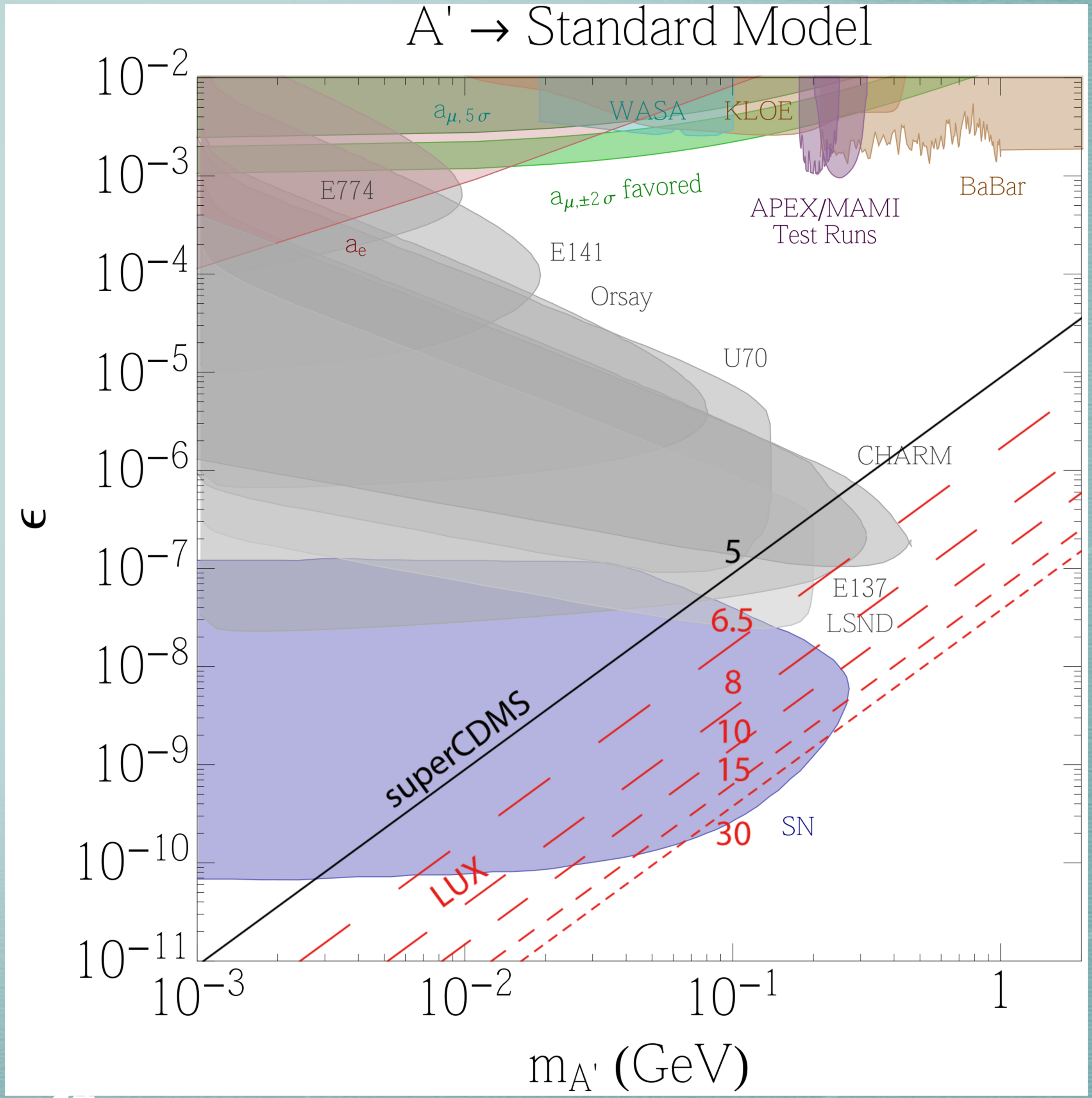
Best fit region is m_χ (5.5 -8 GeV) m_ϕ (0.2 - 0.8 GeV). In this region, the BR is dominated by 2e 2μ 2π, but the photon spectrum is dominated by 2e, $\pi\gamma$, $\eta\gamma$.

Constraints

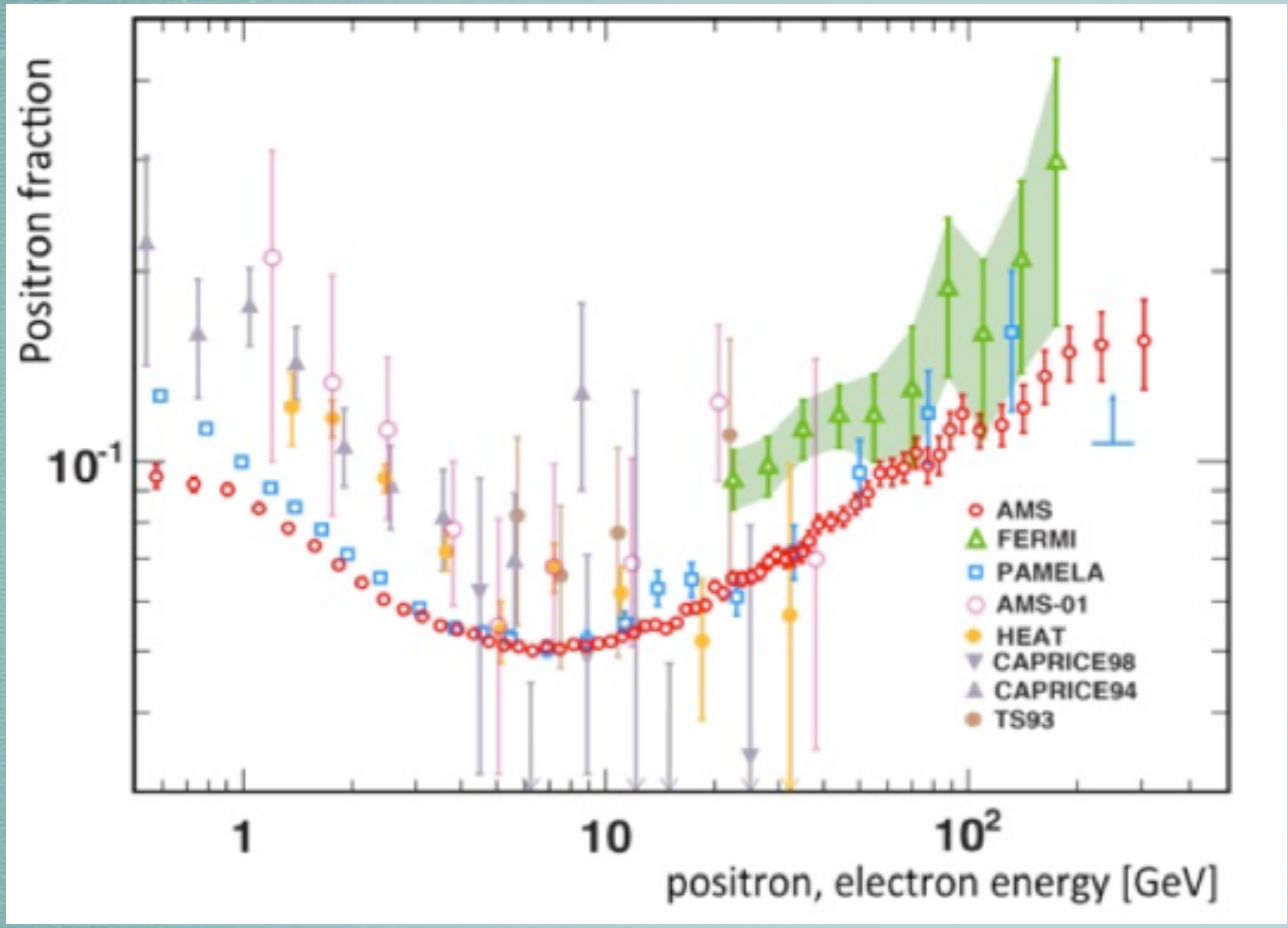
The constrains on light dark mediator models are mainly related to its mixing parameter

1) collider
2) direct detection
3) Anti-proton

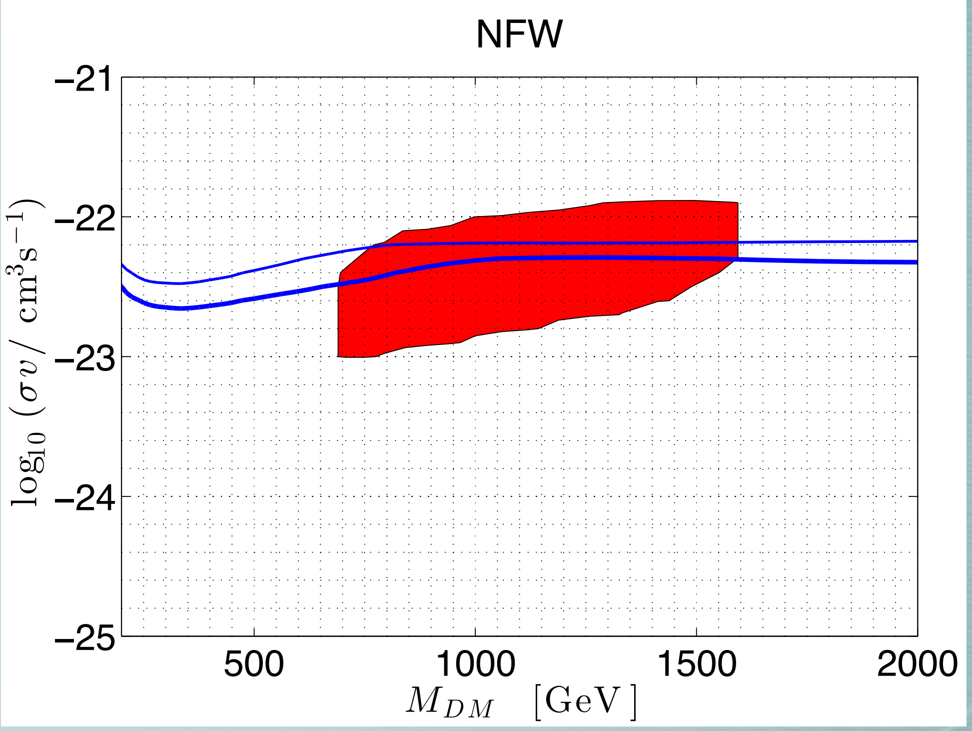




AMS-02



$\chi + \chi \rightarrow \mu + \mu$

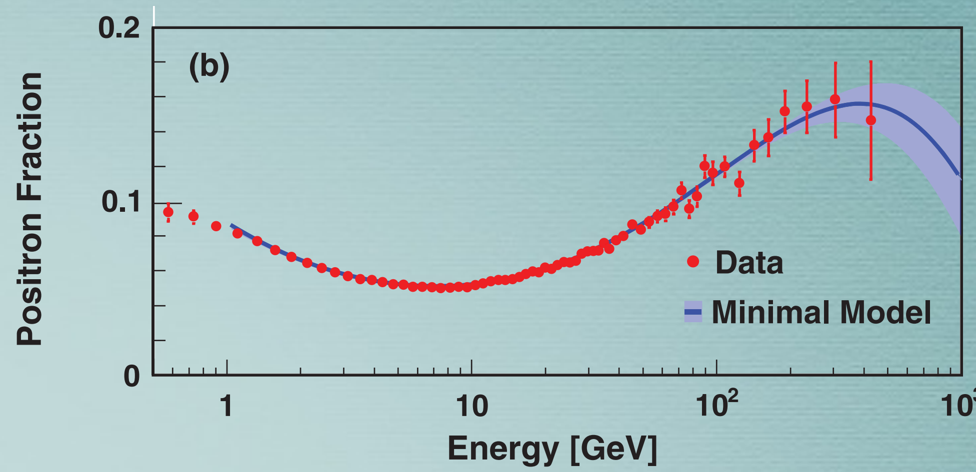


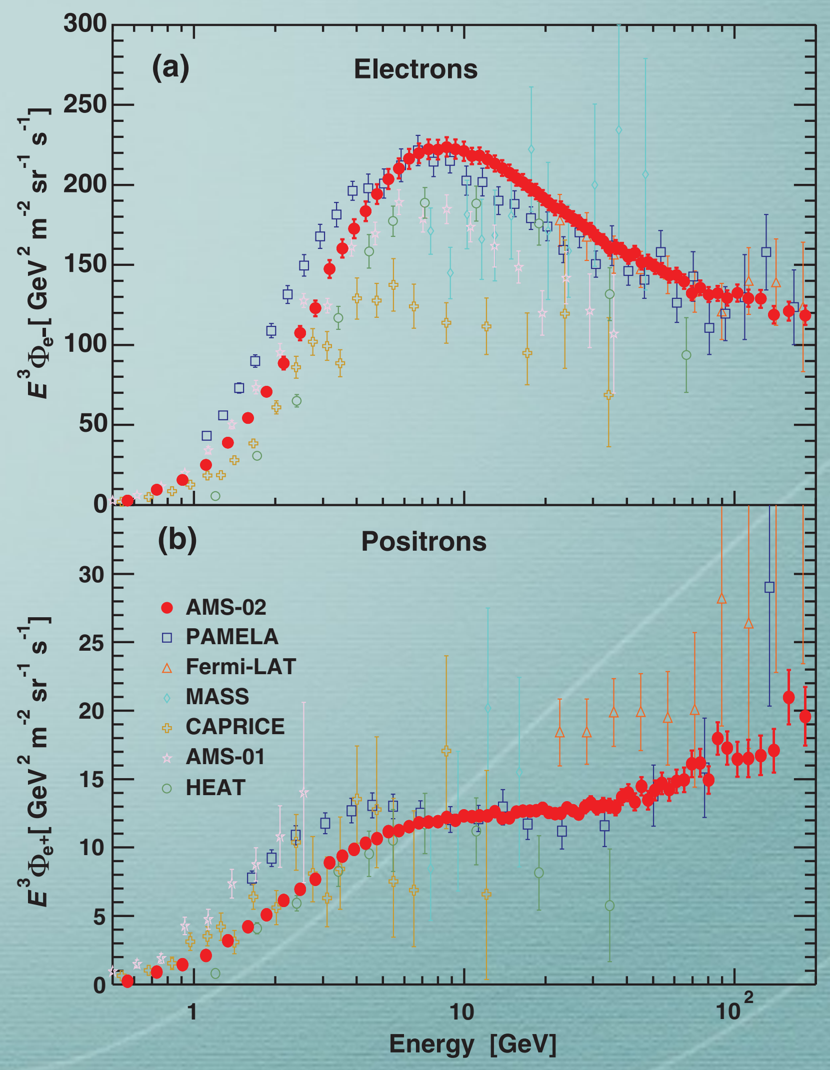
Dark Matter or Pulsar??

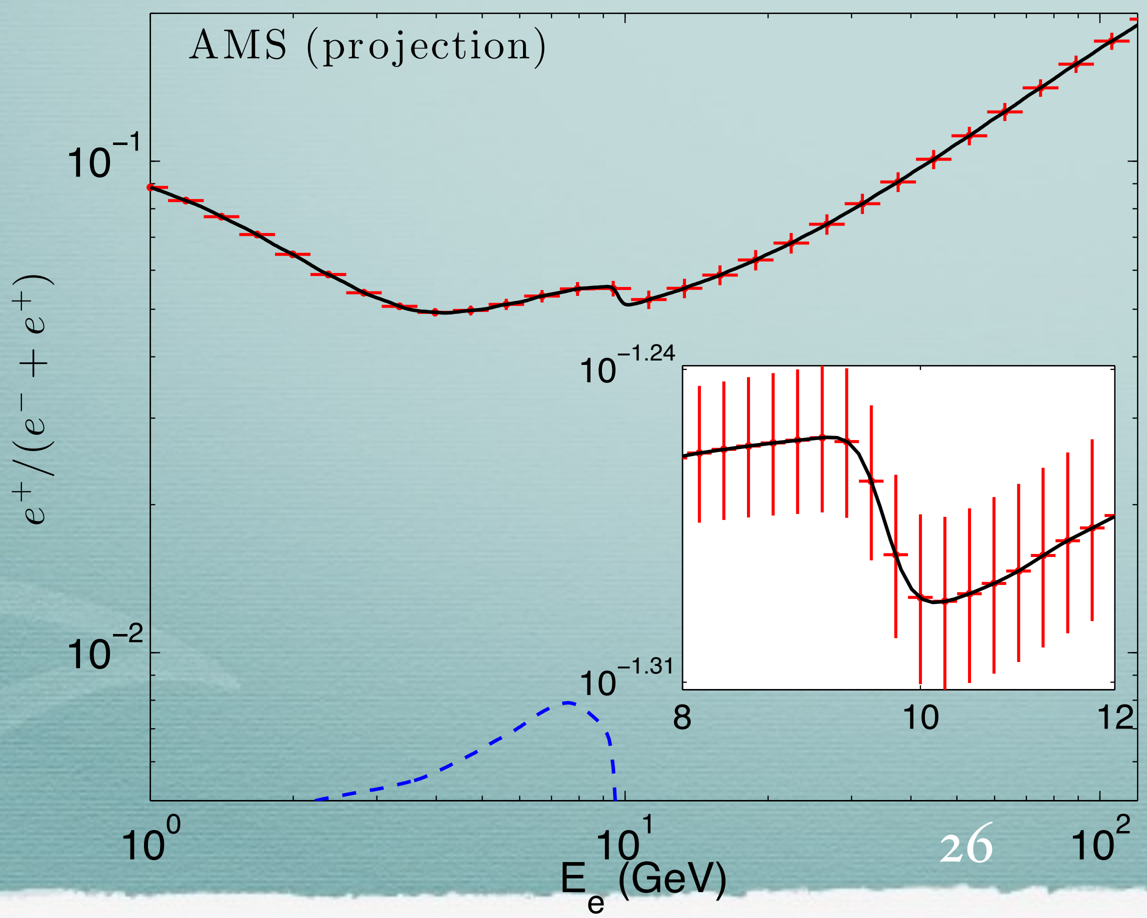
ASM-02

1. Precise Measurement of positron flux, electron flux, positron ratio

2. For the Smooth spectrum,
   Could we put bounds on dark matter?
   before AMS-02
   D. Hooper, XW arXiv:1210.1220

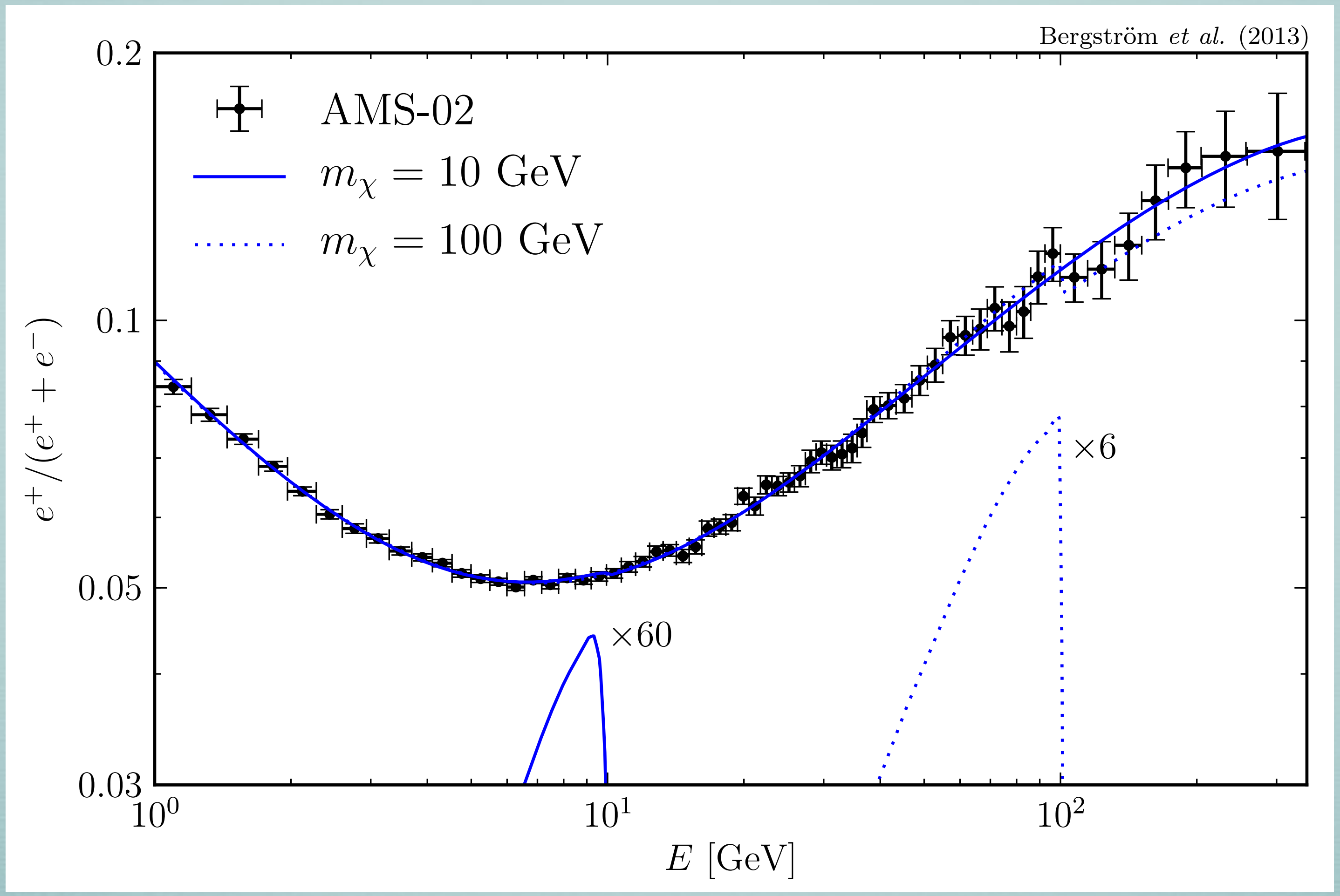






AMS-02 Constraint

1. L. Bergstrom, T. Bringmann, I. Cholis, D. Hooper, C. Weniger
   arXiv: 1306.3983



AMS-02

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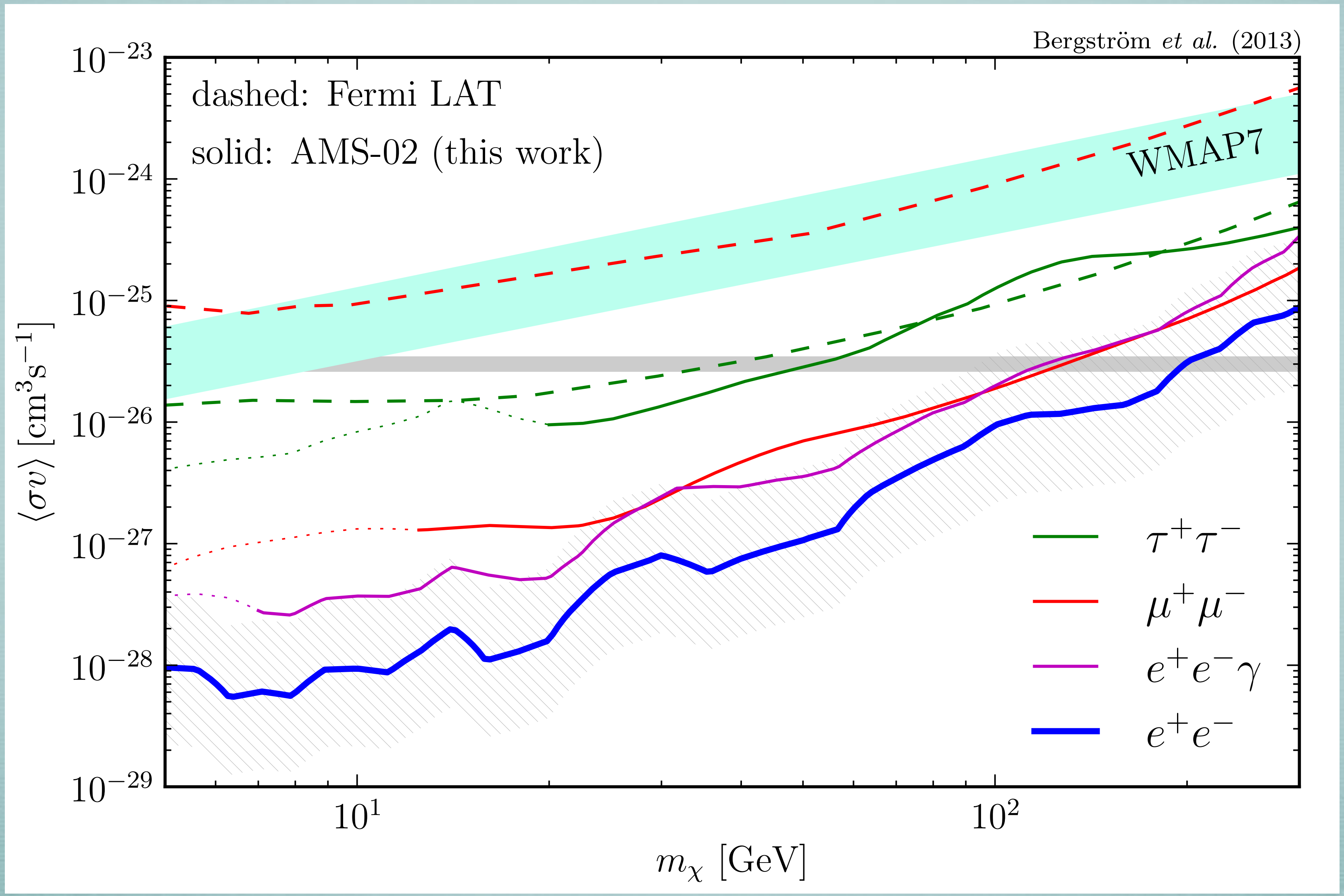
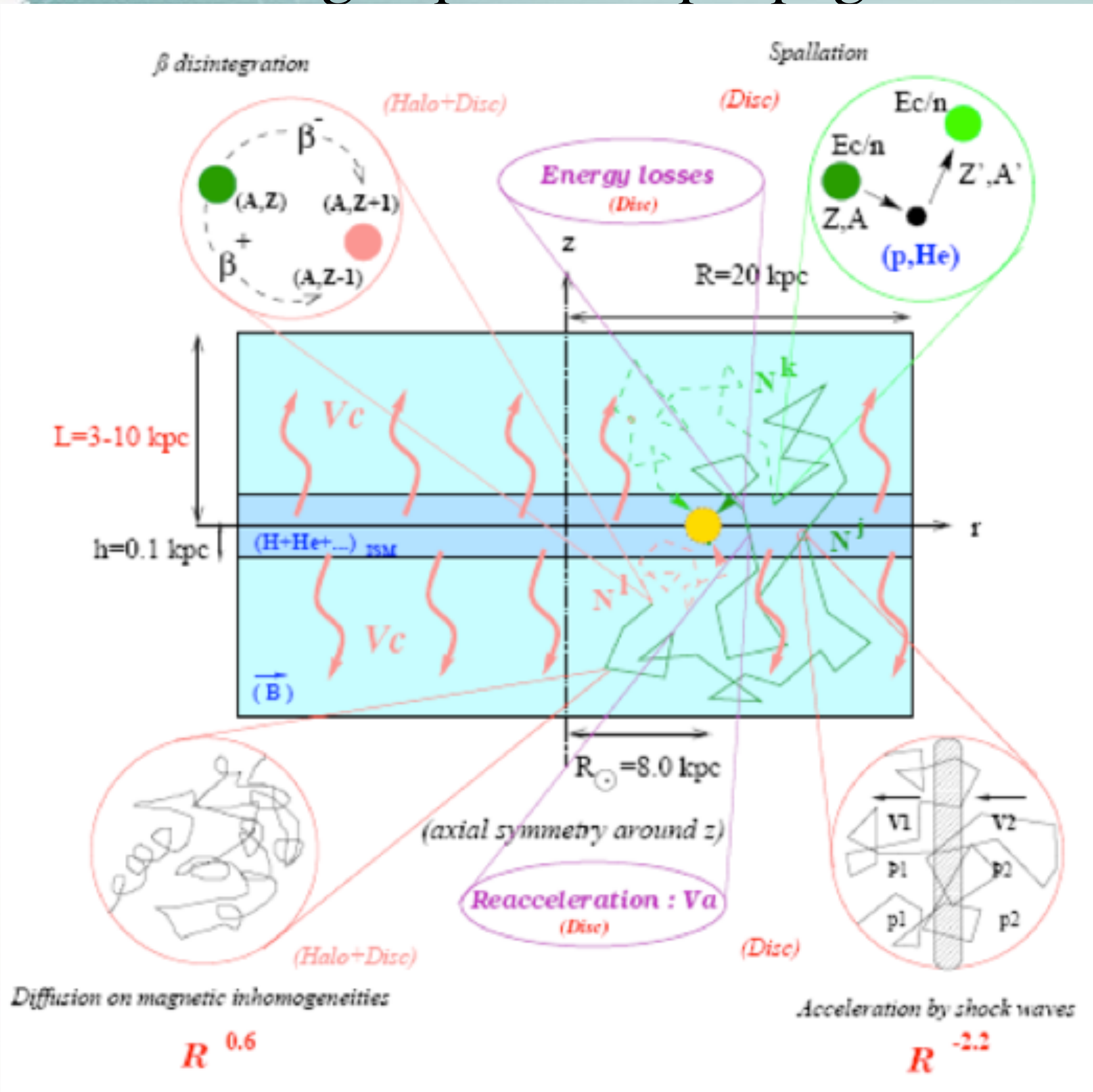
   arXiv: 1306.3983



Uncertainties from Propagation

1. Charged particles propagate in the galaxy



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&+ \frac{\partial}{\partial p} p^2 D_{pp} \frac{\partial}{\partial p} \frac{N_i}{p^2} + Q_i(p, r, z) \\
&+ \sum_{j>i} \beta n_{gas}(r,z)\sigma_{ji} N_j - \beta n_{gas} \sigma_i^{in}(E_k) N_i
\end{aligned}
$$

1. acceleration
2. Diffusion
3. Energy loss
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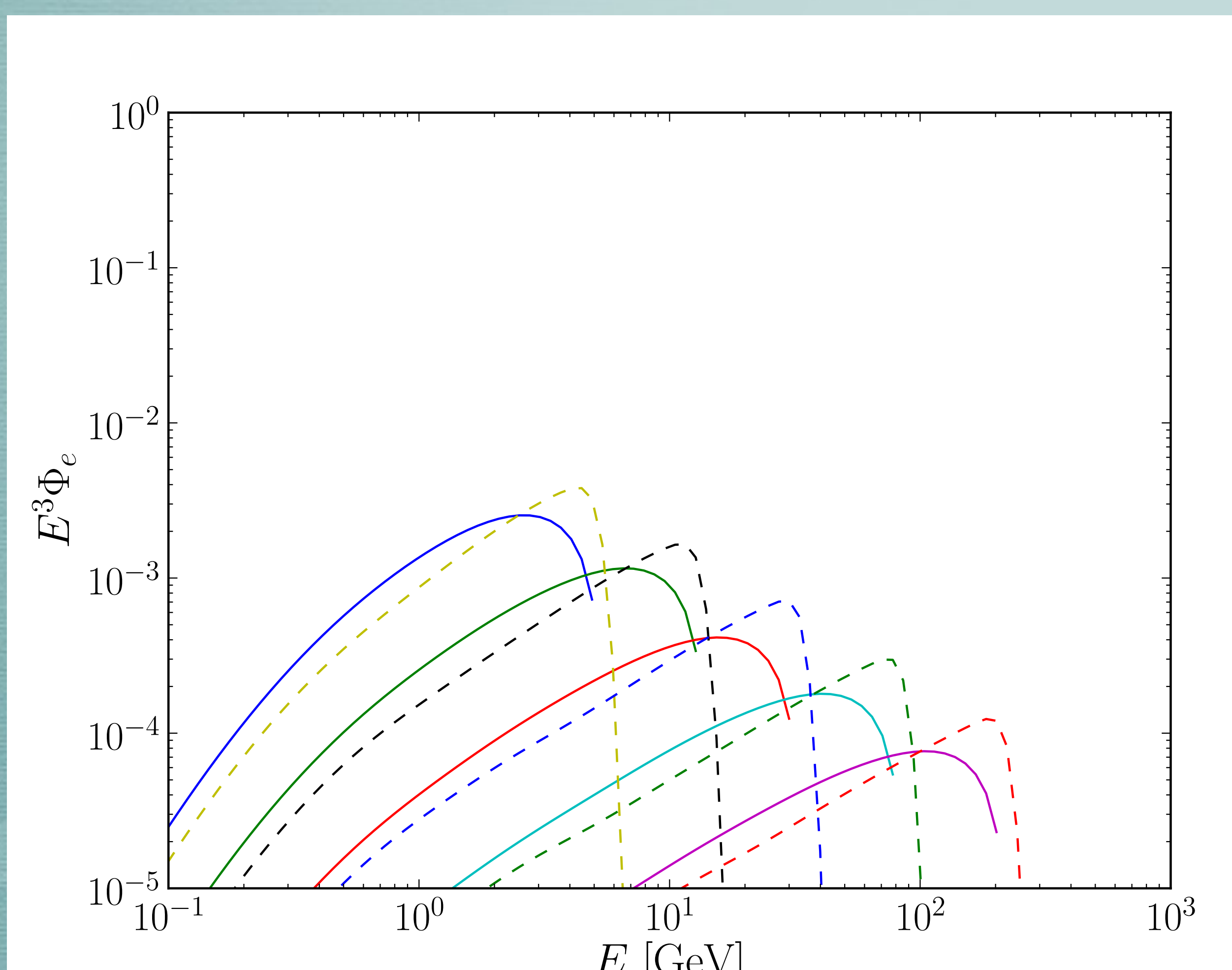
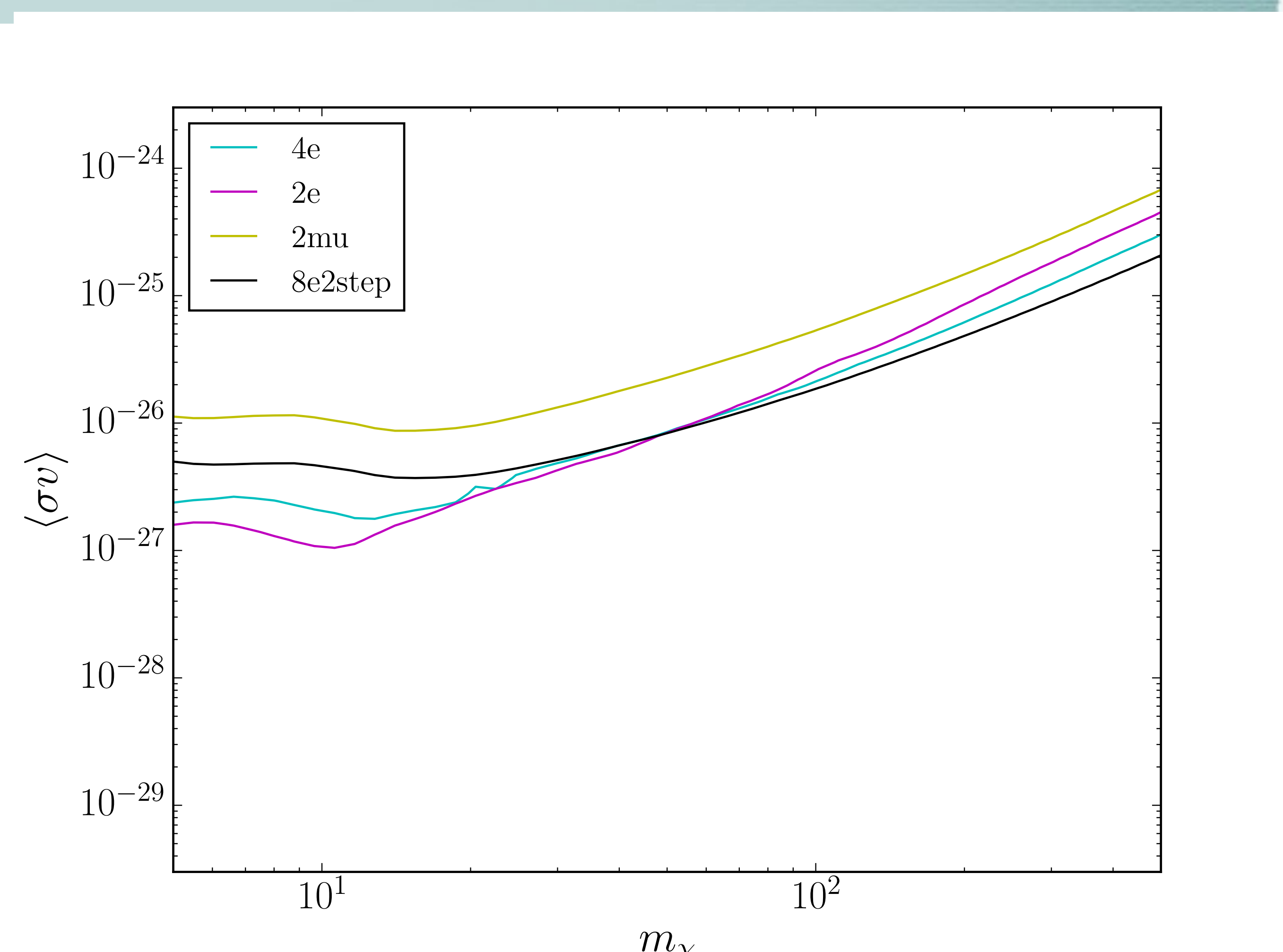
5. Re-acceleration
6. Spallation

... ...

AMS-02

1. surprisingly, dm + dm -> 4e is as strong as 2e
2. We consider the uncertainties from solar modulation.
3. Implication : 10 GeV DM, 10 % BR of dm dm -> 2e or 4e is ruled out AMS-02???



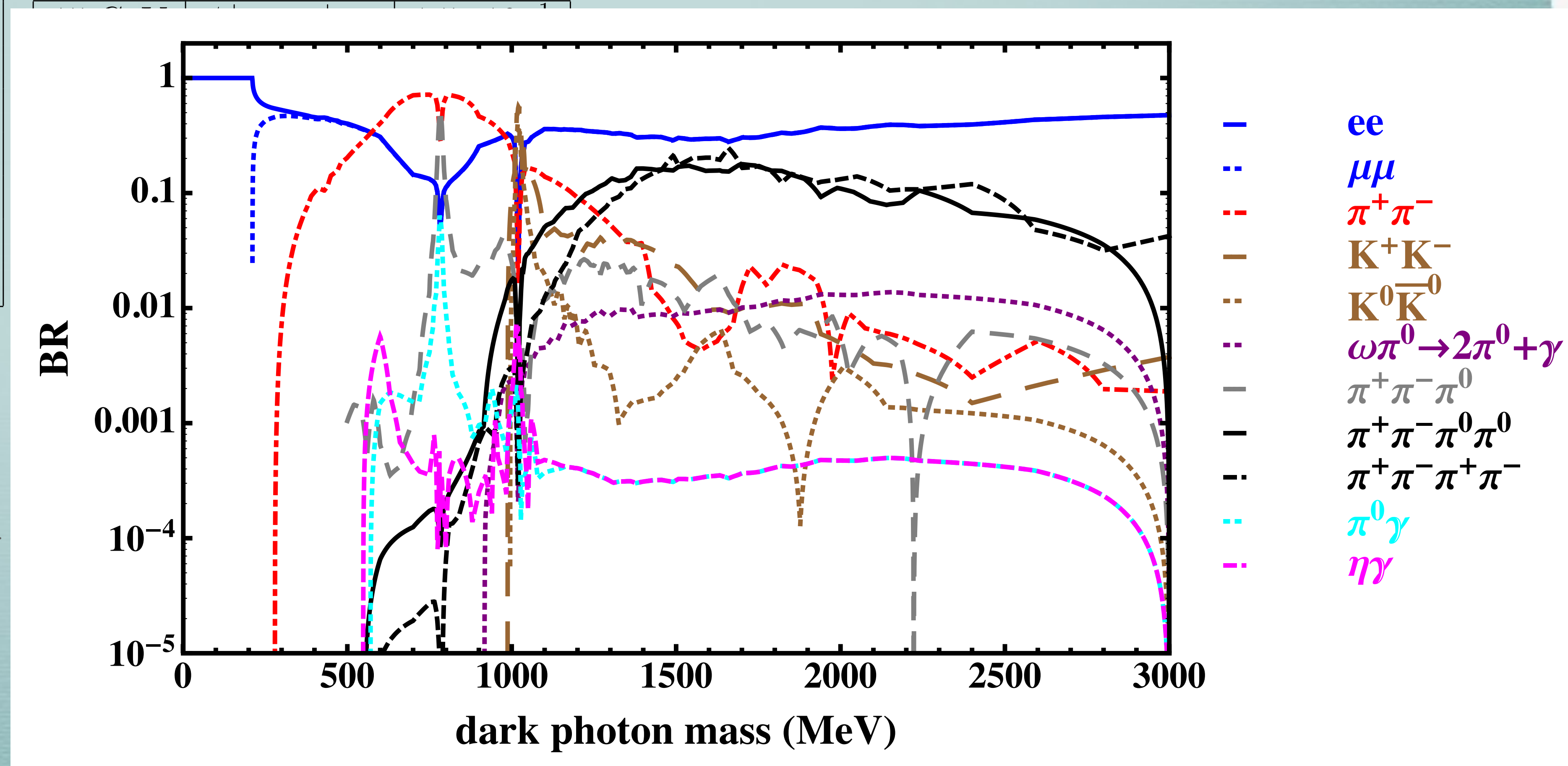


Photon Spectrum Computation

1. Branching ratio (data driven method is employed)

m_ϕ	Mode	BF
200 MeV	$\phi \to e^+e^-$	1
500 MeV	$\phi \to e^+e^-$	$4 \cdot 10^{-1}$
	$\phi \to \mu^+\mu^-$	$4 \cdot 10^{-1}$
	$\phi \to \pi^+\pi^-$	$2 \cdot 10^{-1}$
1.2 GeV	$\phi \to e^+e^-$	$3.4 \cdot 10^{-1}$
	$\phi \to \mu^+\mu^-$	$3.3 \cdot 10^{-1}$
	$\phi \to \omega\pi^0$	$7.9 \cdot 10^{-2}$
	$\phi \to \pi^+\pi^-\pi^0\pi^0$	$7.5 \cdot 10^{-2}$
	$\phi \to \pi^+\pi^-$	$6.4 \cdot 10^{-2}$
	$\phi \to K^+K^-$	$4.5 \cdot 10^{-2}$
	$\phi \to \pi^+\pi^+\pi^-\pi^-$	$4.1 \cdot 10^{-2}$
	$\phi \to \pi^+\pi^-\pi^0$	$2.4 \cdot 10^{-2}$
	$\phi \to K^0\bar{K}^0$	$5 \cdot 10^{-3}$

m_ϕ	Mode	BF
8 GeV	$\phi^+ \to e^+e^-$	$1.6 \cdot 10^{-1}$
	$\phi \to \mu^+\mu^-$	$1.6 \cdot 10^{-1}$
	$\phi \to \tau^+\tau^-$	$1.6 \cdot 10^{-1}$
	$\phi \to u\bar{u}$	$2.1 \cdot 10^{-1}$
	$\phi \to d\bar{d}$	$5.2 \cdot 10^{-2}$
	$\phi \to c\bar{c}$	$2.1 \cdot 10^{-1}$
	$\phi \to s\bar{s}$	$5.2 \cdot 10^{-2}$



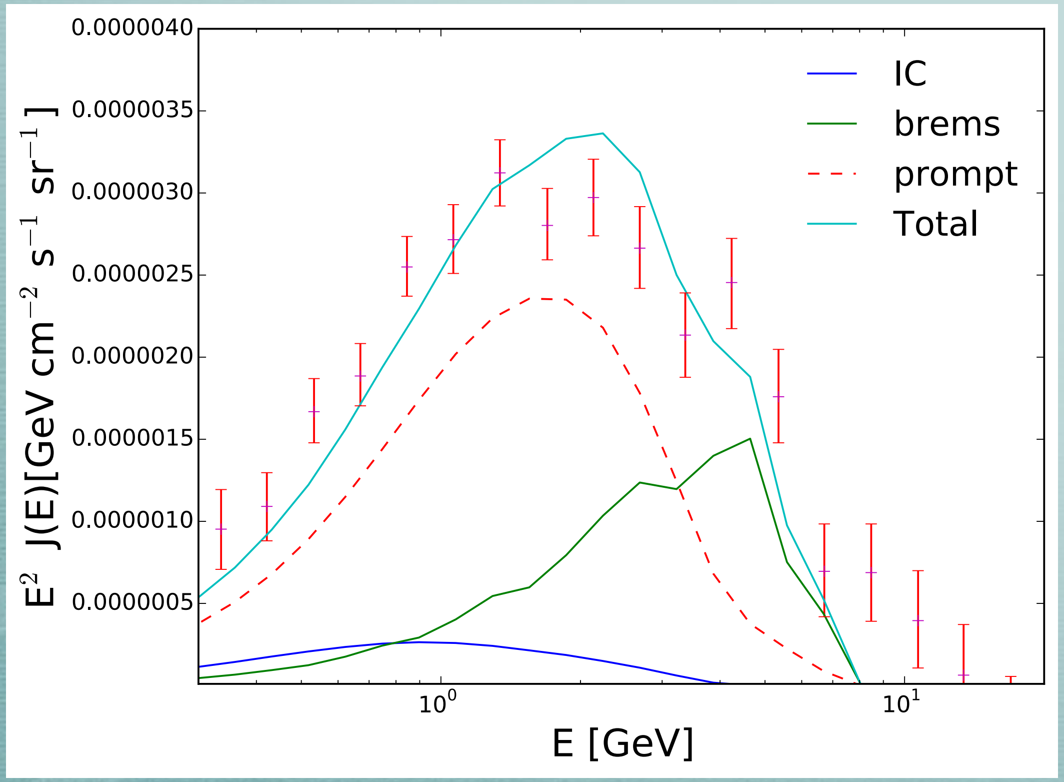
2. Boost Spectrum to DM frame

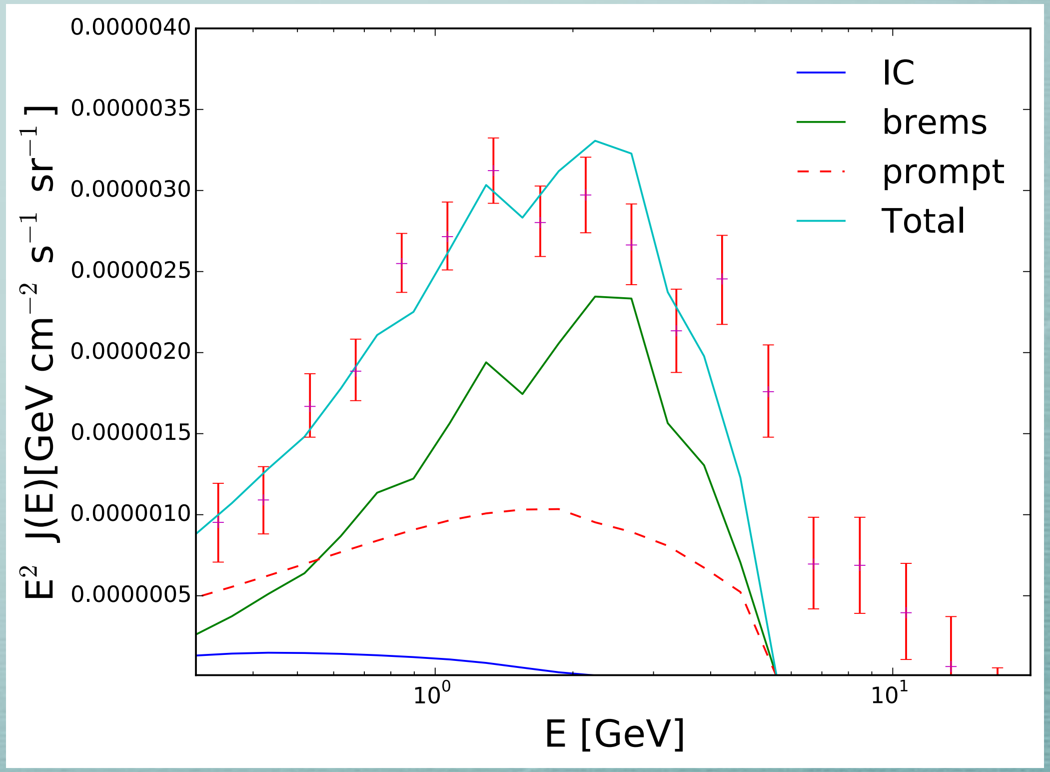
Dark Photon in trouble?

1. DM in the Galactic Center not only generate gamma ray, but also populate electrons and positrons.

2. The propagated electron scattering with gas and ISR will also has Bremsstrahlung and Inverse Compton Scatter.

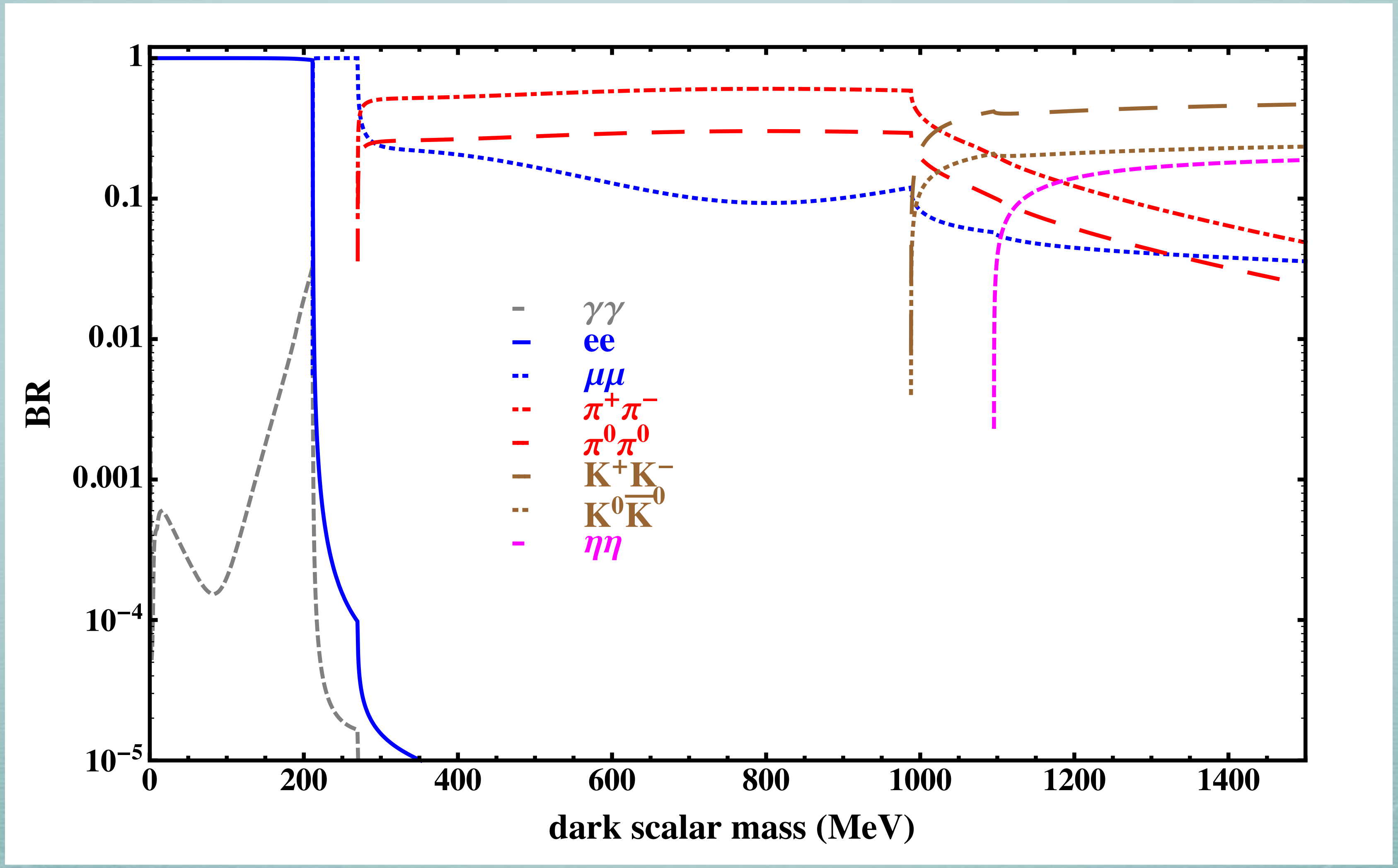
3. Release the tension with Dwarf galaxy



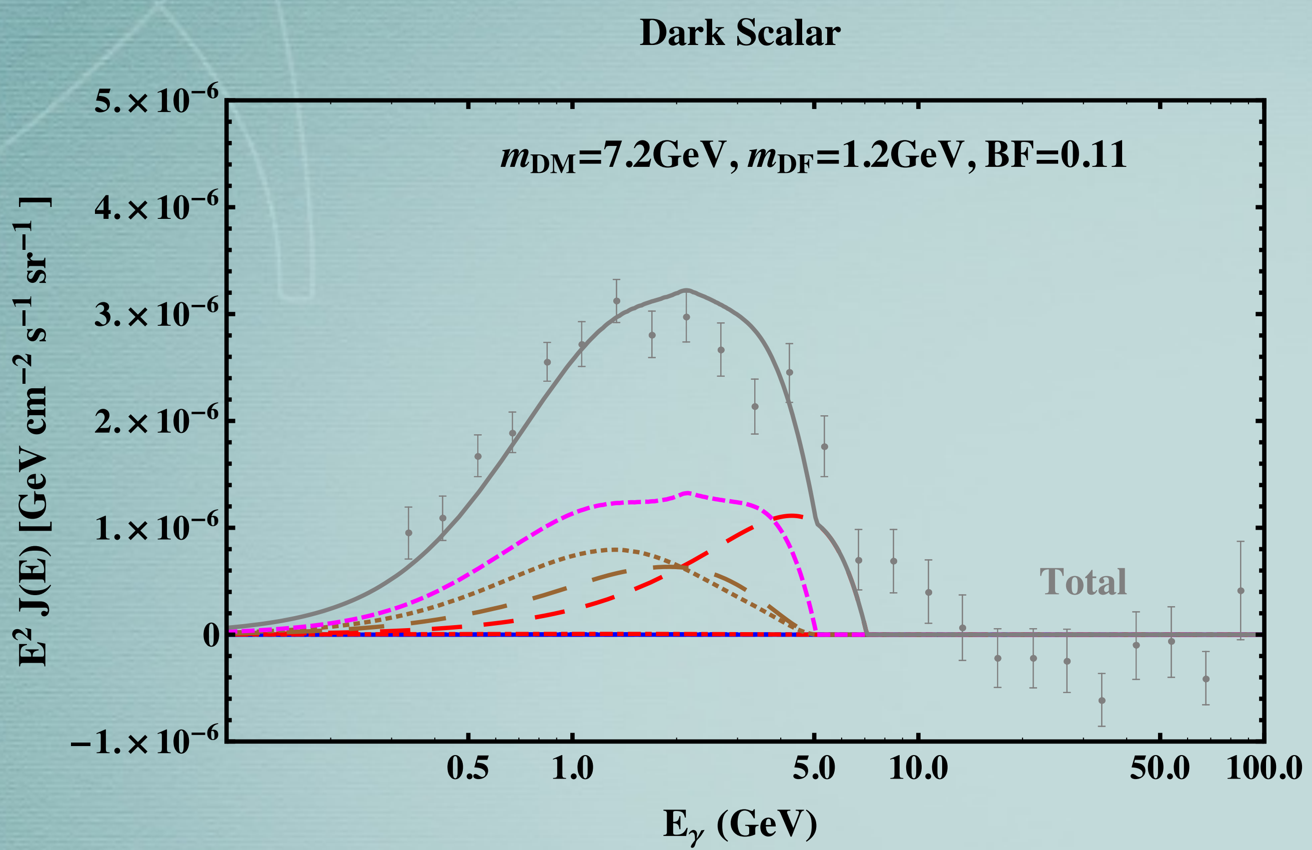


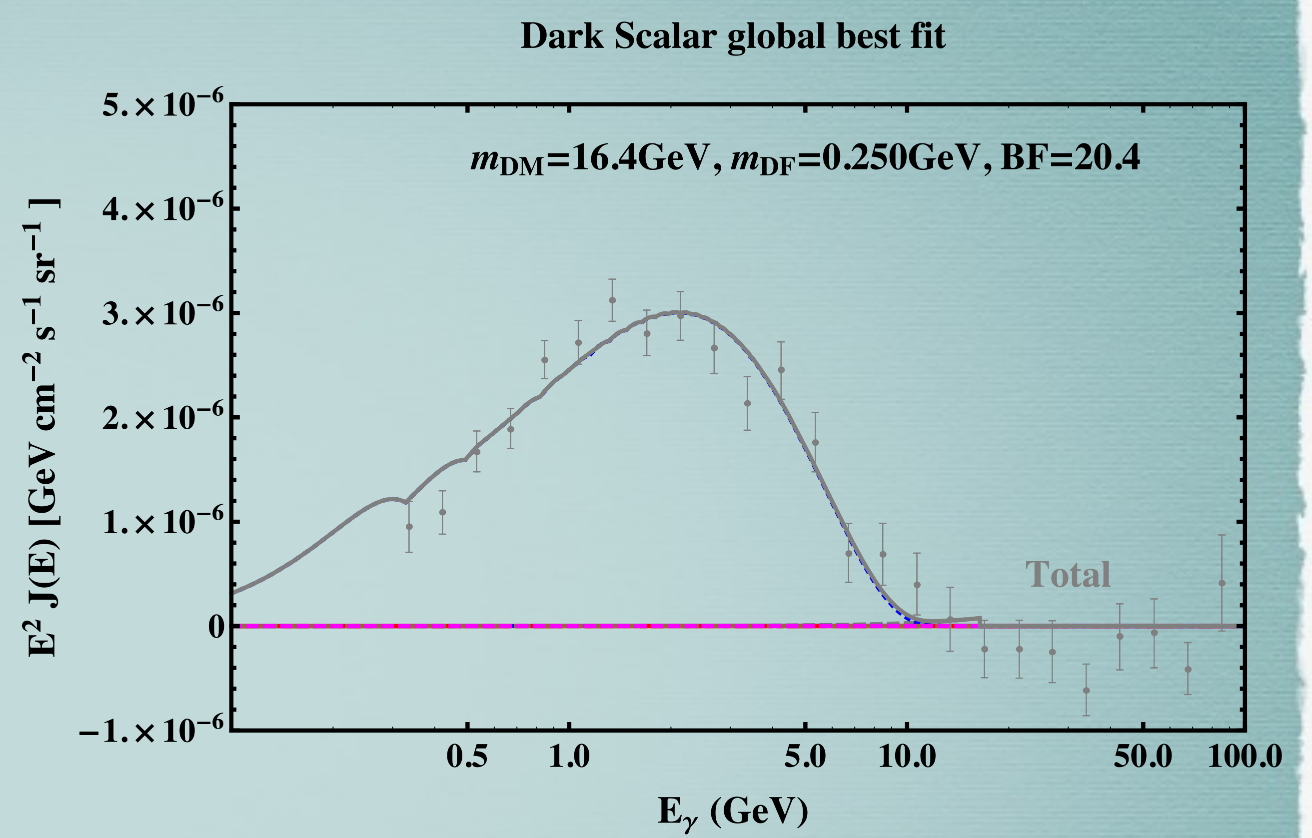
other possibilities (dark scalar)

Derive the branching ratio from chiral perturbation theory



dark scalar (best fit)





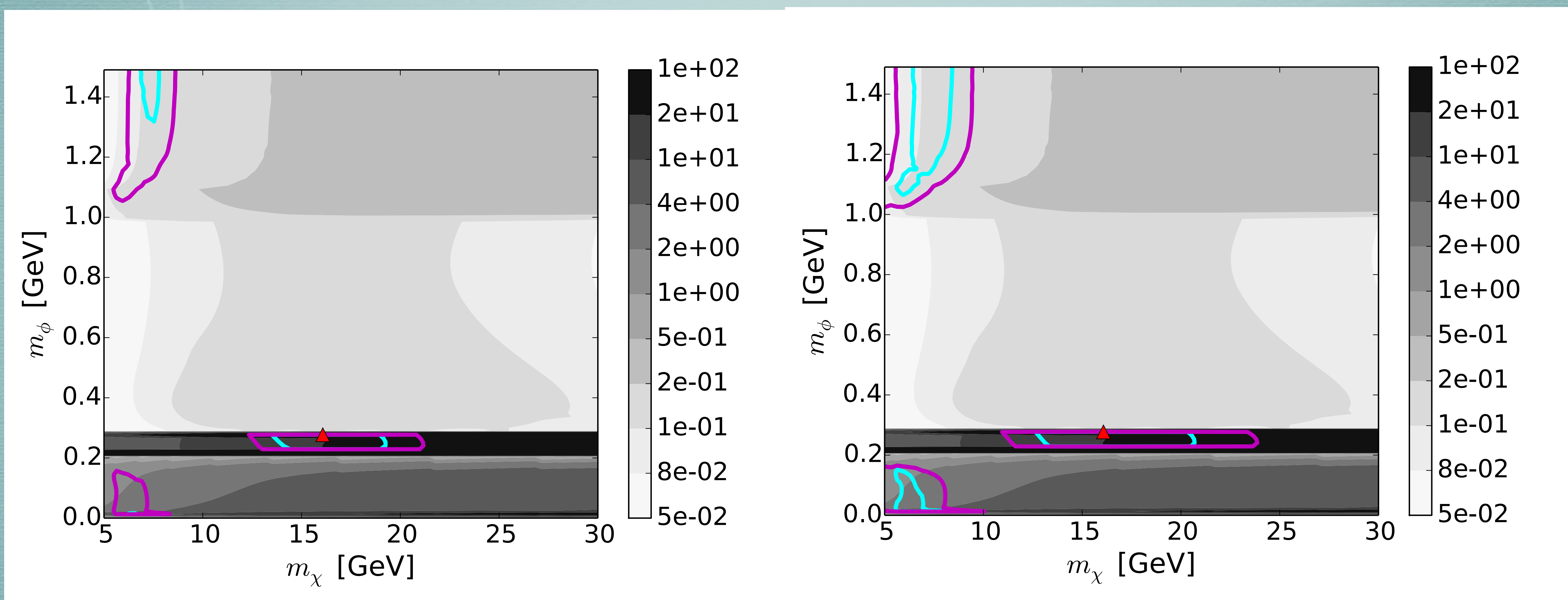
1. Dark force mass 1.2 GeV.

   $\phi \rightarrow K^+K^-, 2K^0, 2\pi^0, 2\eta$

2. Dark force mass 0.25 GeV.

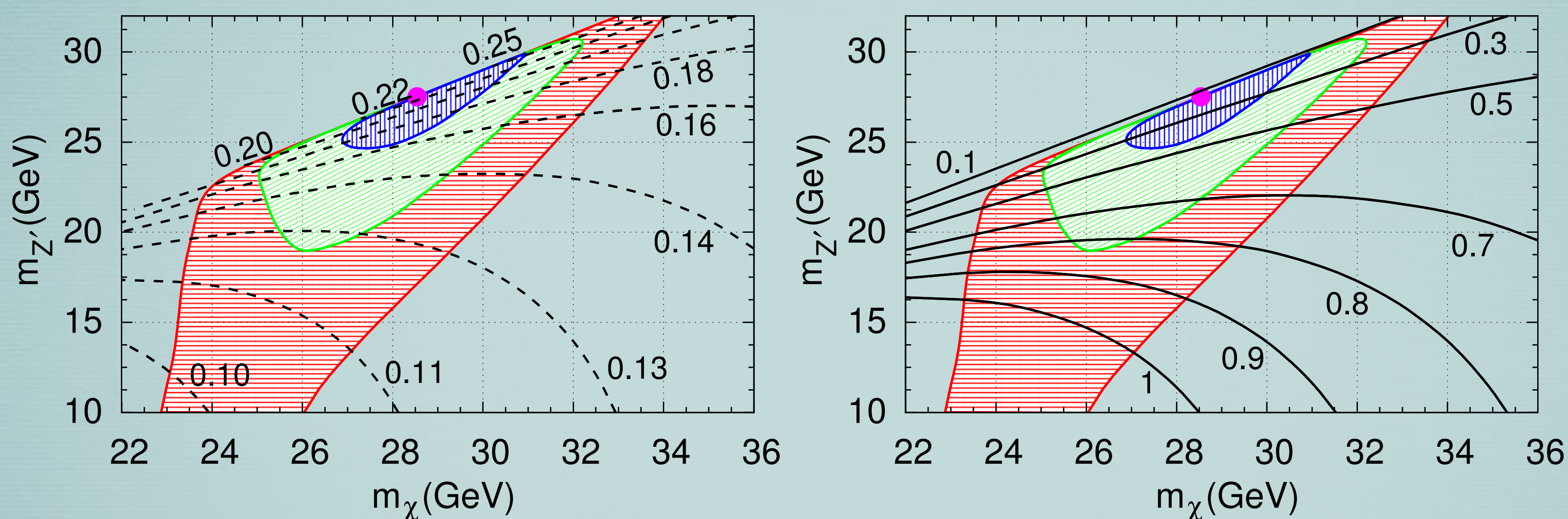
   $\phi \rightarrow 2e\ , 2\mu, 2\pi^0$

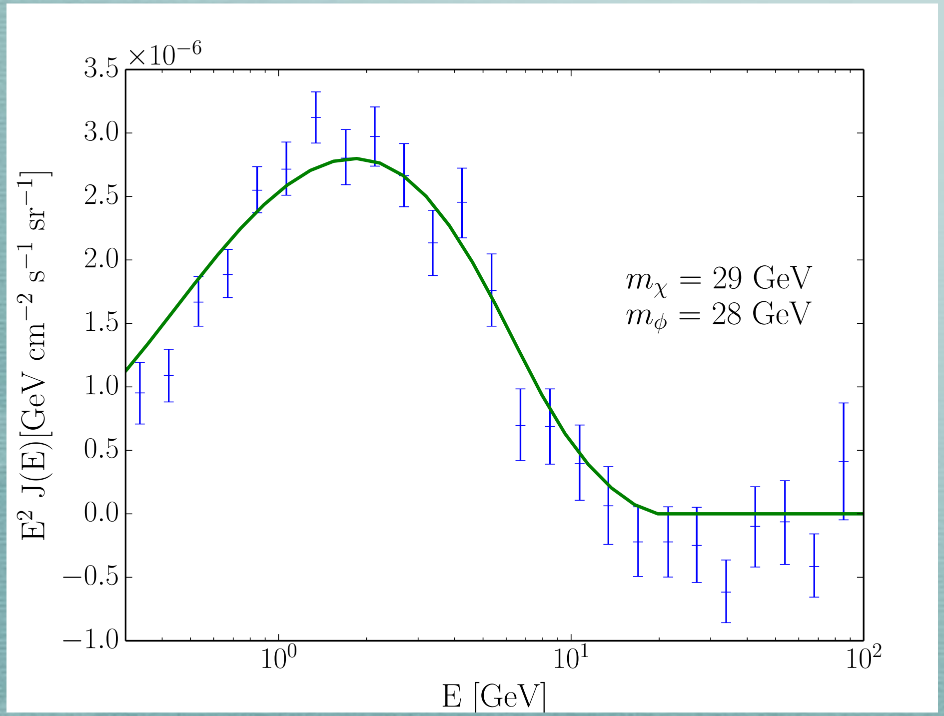
dark scalar fit to data



1. m_χ (5.5 - 7.5 GeV) m_ϕ (0 - 0.2 GeV) $\phi \rightarrow 2e$
2. m_χ (12.5- 22 GeV) m_ϕ (0.2 - 0.3 GeV) $\phi \rightarrow 2\mu$ BF~20
3. m_χ (5.3 - 8.5 GeV) m_ϕ (1.1 - 1.5 GeV) $\phi \rightarrow K^+K^-, 2K^0, 2\pi^0, 2\eta$

other possibility
(heavy dark photon)





1405.7691
Cline, Dupuis, Liu, XW

Conclusion

1. Dark photon search
   Beam dump, fixed target, Collider

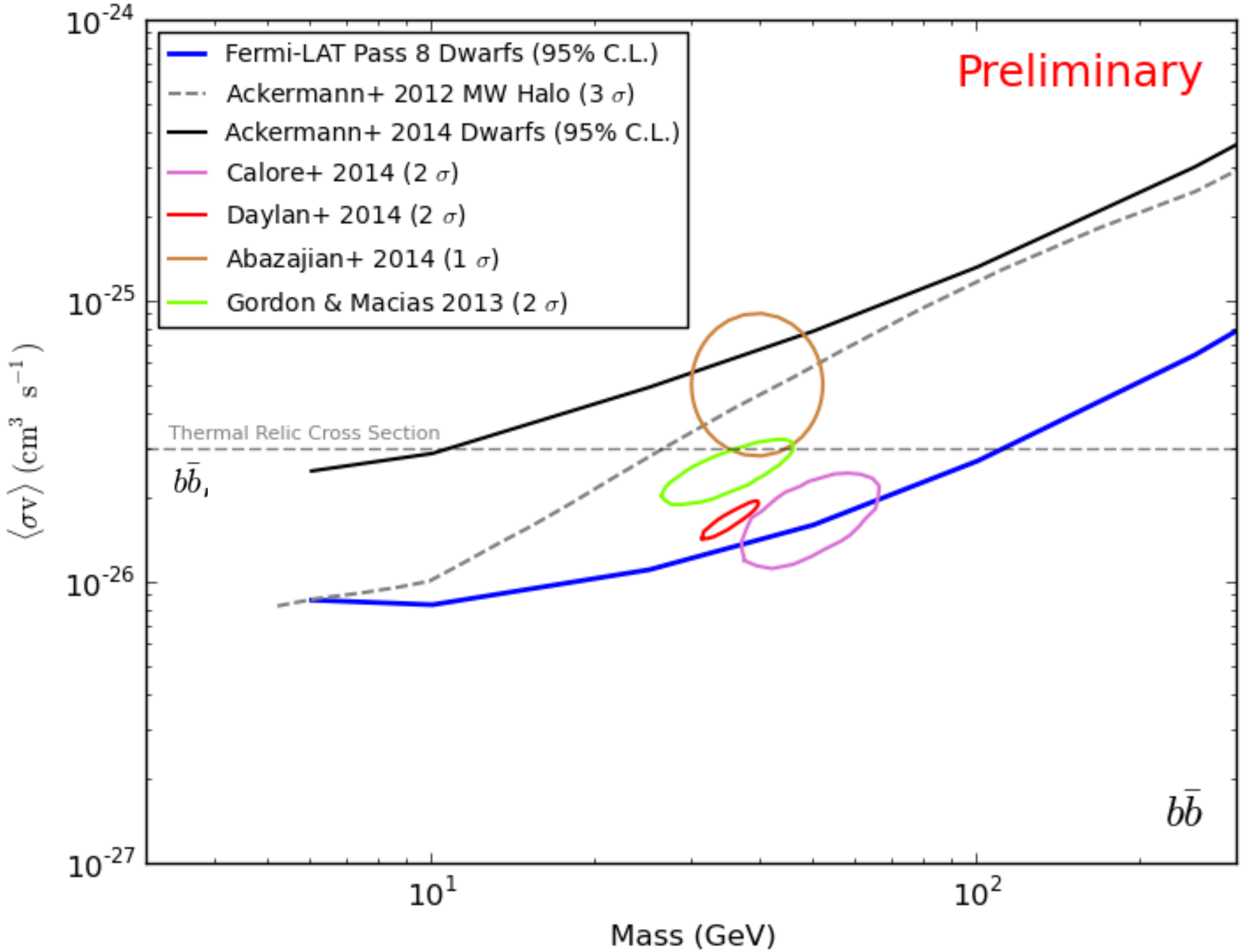
2. GeV excess

3. Dark photon GeV and dark matter 10 GeV

4. AMS02 Constraints

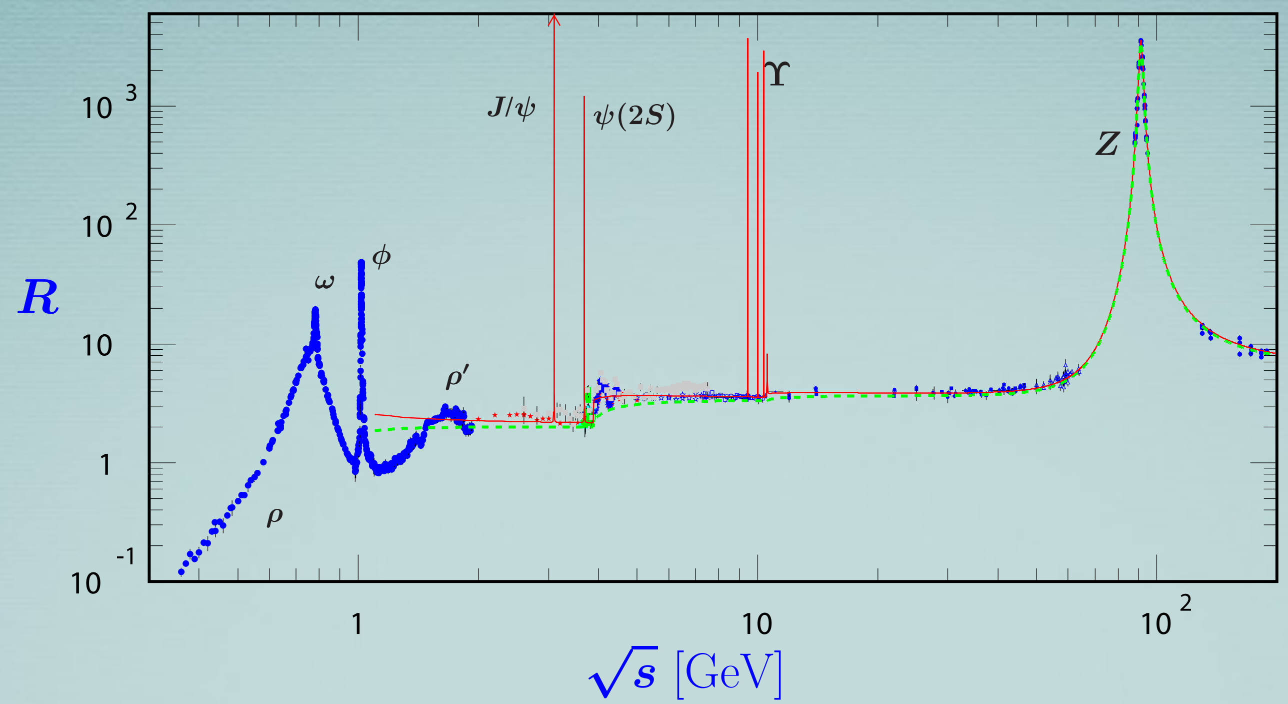
5. Dark Scalar and heavy dark photon

Galactic Center Excess (GCE) Compatibility

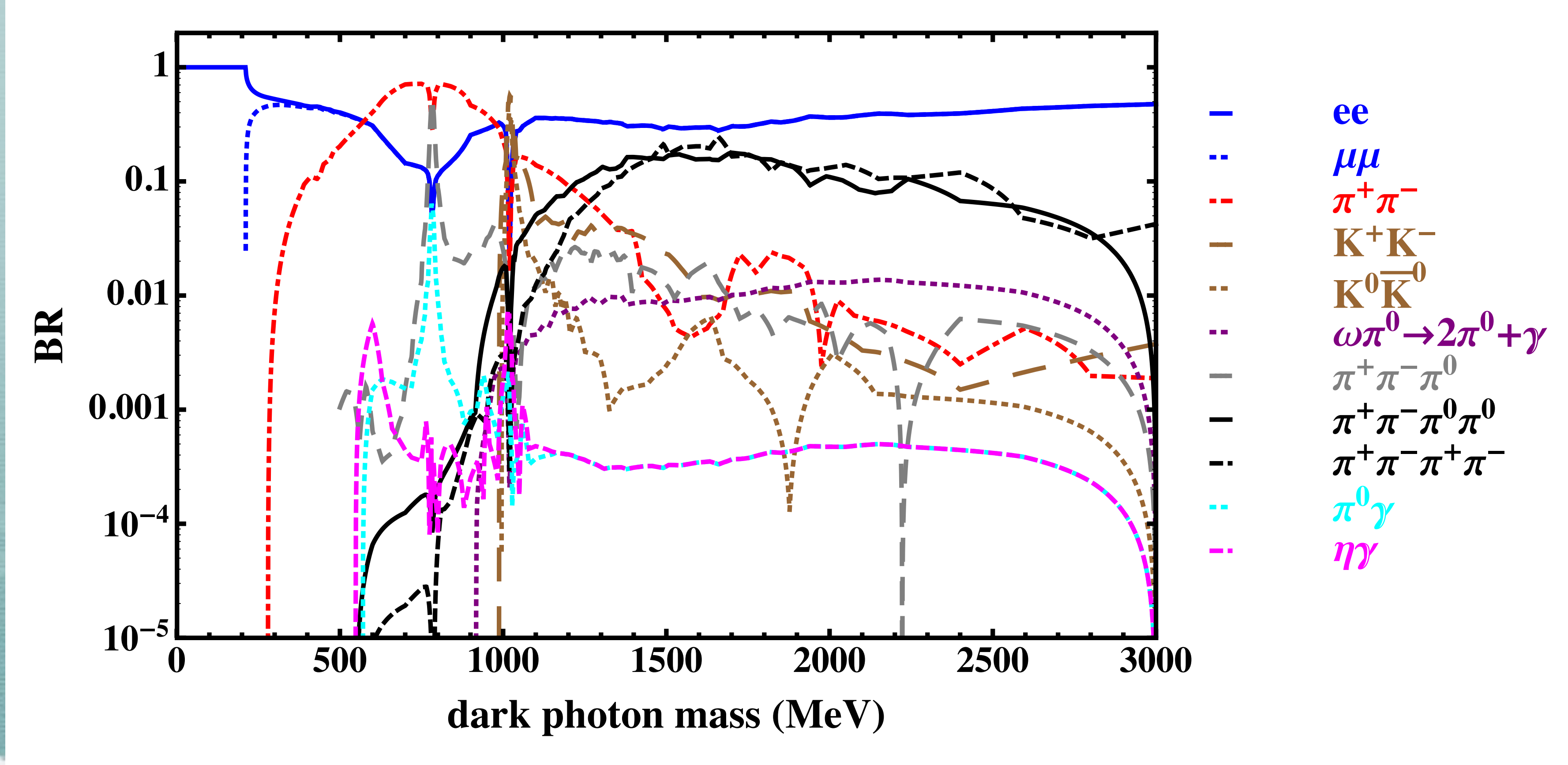


Limit name	**Type**	**Reaction**
$(g-2)_\mu$	(g-2)	
$(g-2)_e$ vs α	(g-2)	
E141	e^- beam dump	$e(A,Z) \to e(A,Z)l^+l^-$
E137	e^- beam dump	$e(A,Z) \to e(A,Z)l^+l^-$
E774	e^- beam dump	$e(A,Z) \to e(A,Z)l^+l^-$
KEK	e^- beam dump	$e(A,Z) \to e(A,Z)l^+l^-$
SN	Supernova reminiscents	
BABAR	Collider	$e^+e^- \to \gamma l^+l^-$
ν-Cal I	p beam dump	$pp \to \gamma' X$
MAMI 2011	e^- fixed-target	$e(A,Z) \to e(A,Z)l^+l^-$
APEX Test	e^- fixed-target	$e(A,Z) \to e(A,Z)l^+l^-$
KLOE 2011	Meson decay	$\phi \to \eta e^+e^-$
Orsay	e^- beam dump	$e(A,Z) \to e(A,Z)l^+l^-$
BABAR	Meson decay	$e^+e^- \to \gamma l^+l^-$
NOMAD	Meson decay	$\pi^0 \to \gamma l^+l^-$
PS191	Meson decay	$\pi^0 \to \gamma l^+l^-$
CHARM	Meson decay	$\eta/\eta' \to \gamma l^+l^-$
KLOE 2012	Meson decay	$\phi \to \eta e^+e^-$
SINDRUM	Meson decay	$\pi^0 \to e^+e^-$
WASA	Meson decay	$\pi^0 \to \gamma e^+e^-$
HADES	Meson decay	$\pi^0/\eta \to \gamma e^+e^-$
HADES	Resonance decay	$\Delta \to N e^+e^-$
ν-Cal I	p beam dump	$pp \to \gamma' X$

dark photon decay



$$R(s) = \sigma(e^+e^- \to hadrons, s)/\sigma(e^+e^- \to \mu^+\mu^-, s)$$



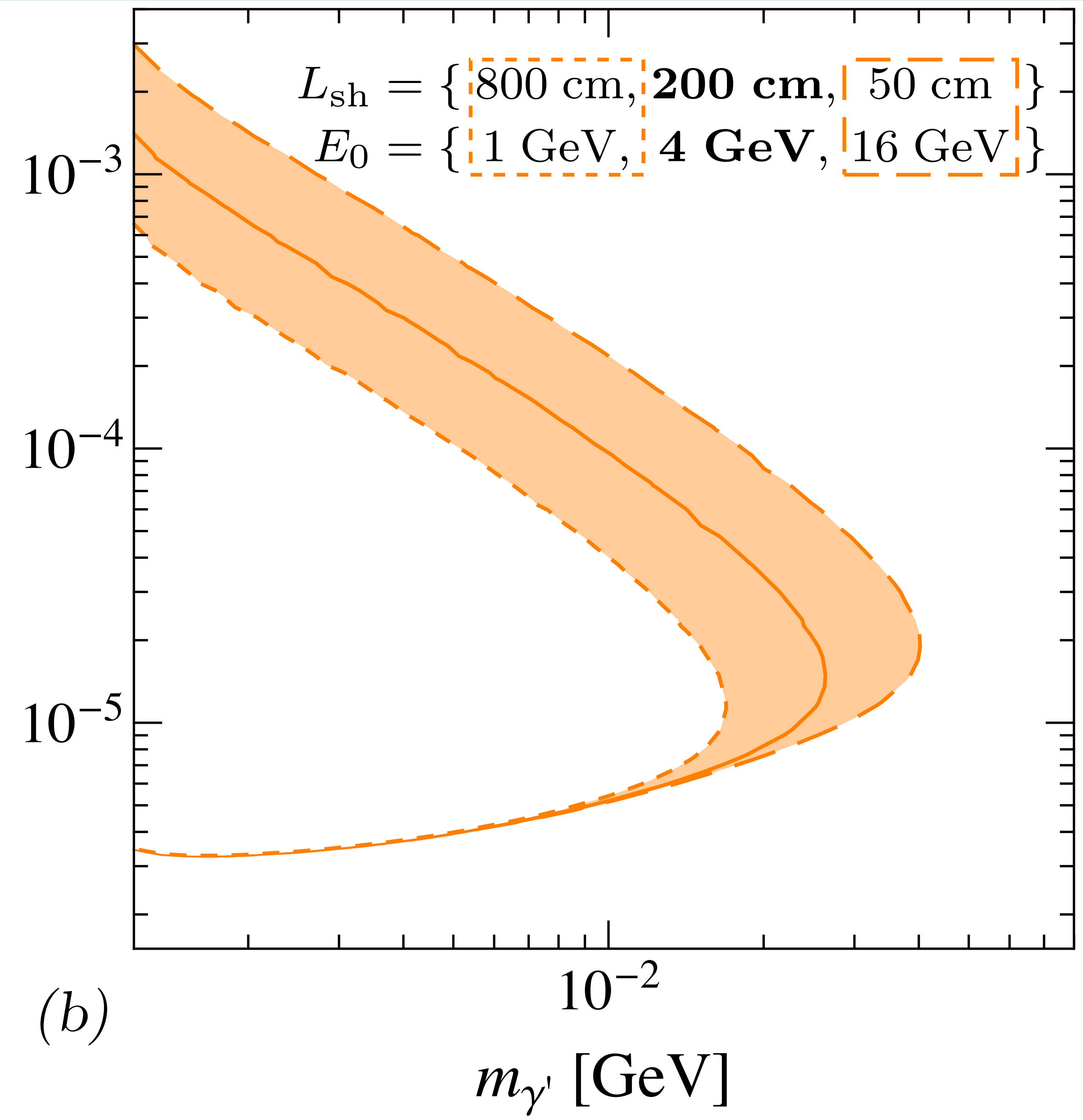
toy model

$$N_{\gamma'} \simeq N_e \frac{N_0 X_0}{A} \int_{m_{\gamma'}}^{E_0 - m_e} dE_{\gamma'} \int_{E_{\gamma'}+m_e}^{E_0} dE_e \int_0^{T_{sh}} dt_{sh}$$

$$\left[I_e(E_0, E_e, t_{sh}) \frac{1}{E_e} \frac{d\sigma}{dx_e}\bigg|_{x_e = \frac{E_{\gamma'}}{E_e}} e^{-L_{sh}/l_{\gamma'}} \left(1 - e^{-L_{dec}/l_{\gamma'}}\right) \right] \mathrm{BR}_{detect}$$

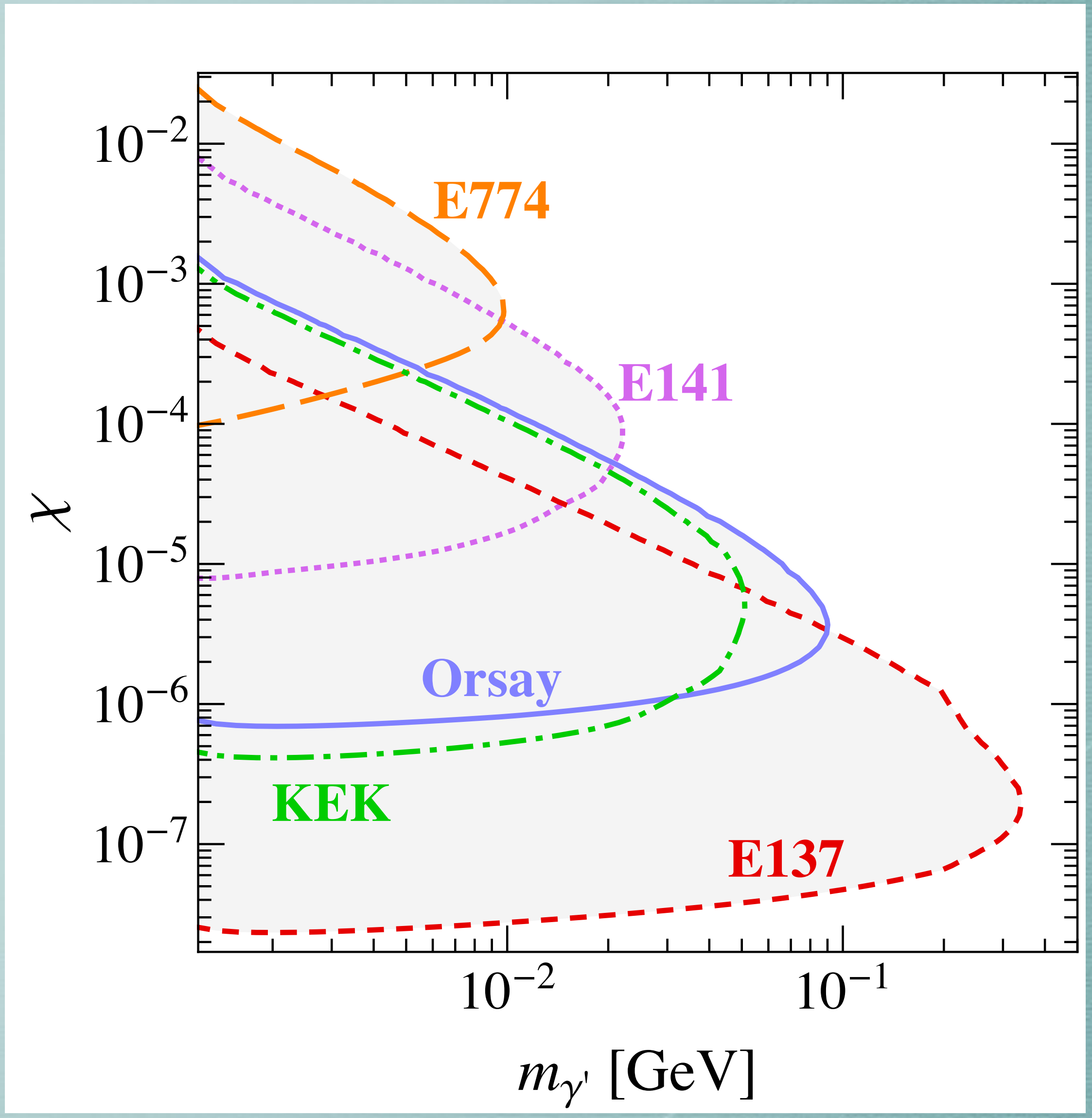
$1/l_{\gamma'} \propto (\varepsilon\, m_{A'})^2$

$\sigma \propto (\varepsilon / m_{A'})^2$



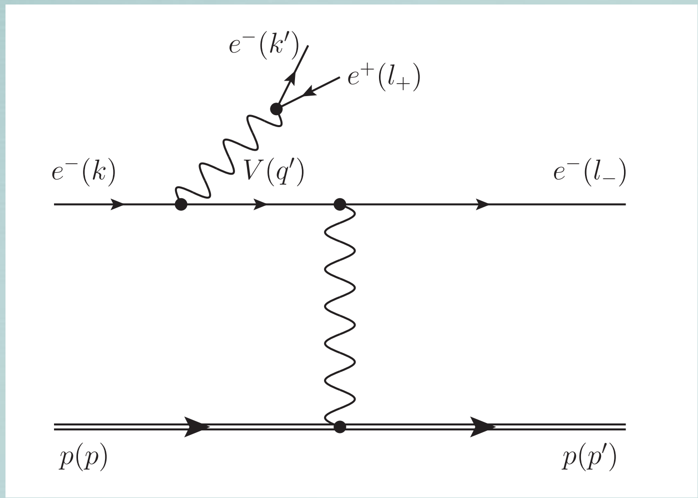
Beam Dump Exps

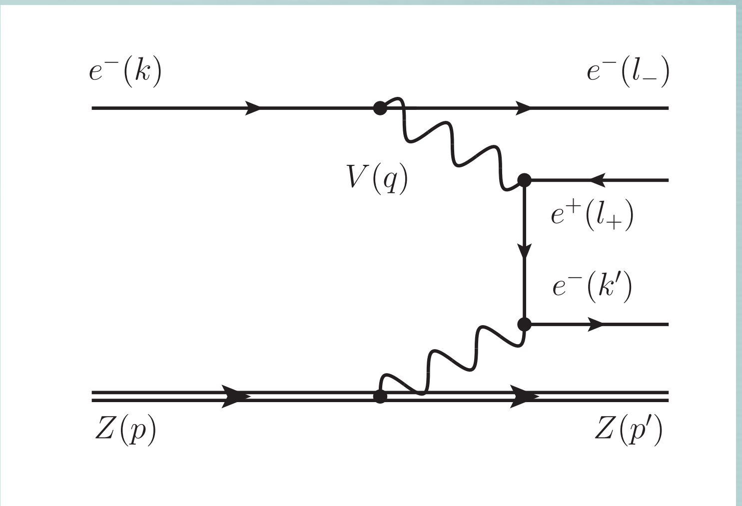
	target	E_0 [GeV]	N_{el} #electrons	Coulomb	L_{sh} [m]	L_{dec} [m]	N_{obs}	$N_{95\%up}$
KEK	$^{183.84}_{74}$W	2.5	1.69×10^{17}	27 mC	2.4	2.2	0	3
E141	$^{183.84}_{74}$W	9	2×10^{15}	0.32 mC	0.12	35	1126^{+1312}_{-1126}	3419
E137	$^{26.98}_{13}$Al	20	1.87×10^{20}	30 C	179	204	0	3
Orsay	$^{183.84}_{74}$W	1.6	2×10^{16}	3.2 mC	1	2	0	3
E774	$^{183.84}_{74}$W	275	5.2×10^{9}	0.83 nC	0.3	2	0^{+9}_{-0}	18



Collider or Fixed target

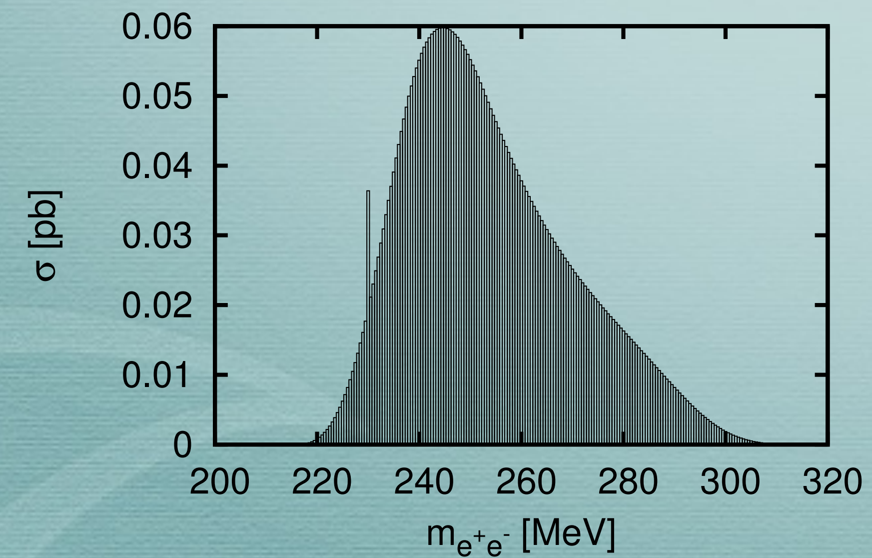
1. signal vs background





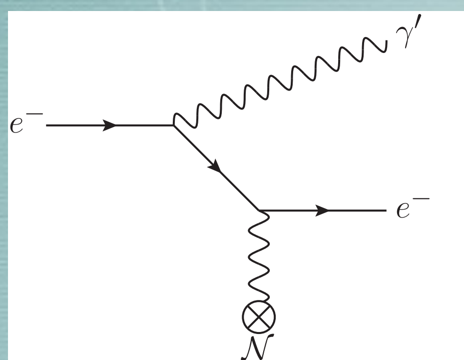
2. Estimate S/√B

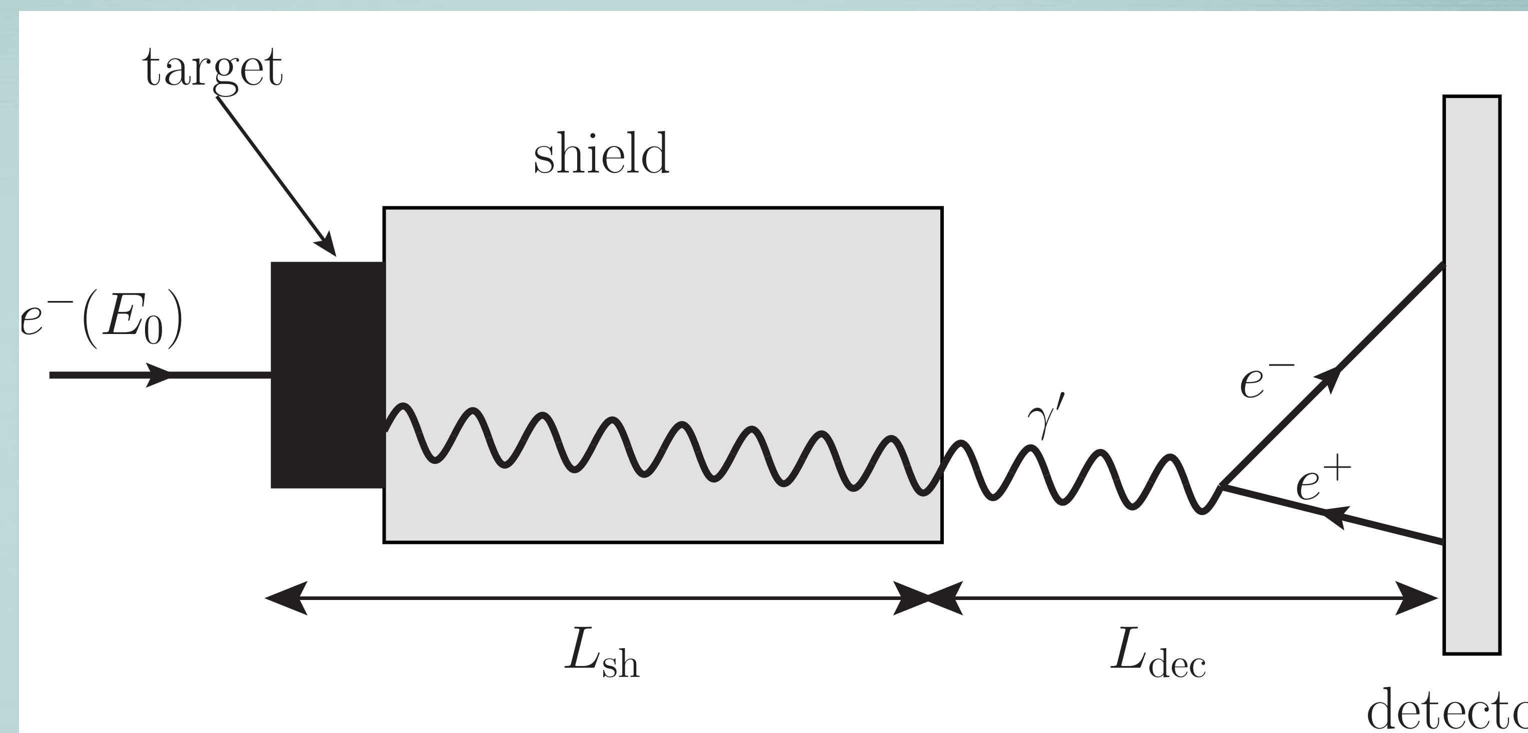
$$\frac{\mathrm{S}}{\sqrt{\mathrm{B}}} \sim \sqrt{\sigma_0 \mathcal{L}} \frac{\epsilon^2}{\sqrt{\alpha/\pi}} \sqrt{\frac{m_U}{\delta m}} \times \ \mathrm{BR}(U \to \ell^+\ell^-)$$



Beam Dump Exp

1. beam dump experiments





2. Decay length of dark photon, (displaced vertex vs. prompt decay)

decay length ≃ 0.8 cm × (E_0/ 10 GeV) $(10^{-4}/ \varepsilon)^2$ (100 MeV/ $m_{A'})^2$

decay length ~ $1/ (\varepsilon \times m_{A'})^2$

Beam Dump Reach Plot

$$N_{\gamma'} \simeq N_e \frac{N_0 X_0}{A} \int_{m_{\gamma'}}^{E_0 - m_e} dE_{\gamma'} \int_{E_{\gamma'}+m_e}^{E_0} dE_e \int_0^{T_{\rm sh}} dt_{\rm sh}$$
$$\left[I_e(E_0, E_e, t_{\rm sh}) \, \frac{1}{E_e} \, \frac{d\sigma}{dx_e}\bigg|_{x_e = \frac{E_{\gamma'}}{E_e}} e^{-L_{\rm sh}/l_{\gamma'}} \left(1 - e^{-L_{\rm dec}/l_{\gamma'}}\right) \right] {\rm BR}_{\rm detect}$$

$1/l_{\gamma'} \propto (\varepsilon\, m_{A'})^2$

$\sigma \propto (\varepsilon/m_{A'})^2$

	target	E_0 [GeV]	$N_{\rm el}$ #electrons	$N_{\rm el}$ Coulomb	$L_{\rm sh}$ [m]	$L_{\rm dec}$ [m]	$N_{\rm obs}$	$N_{95\%{\rm up}}$
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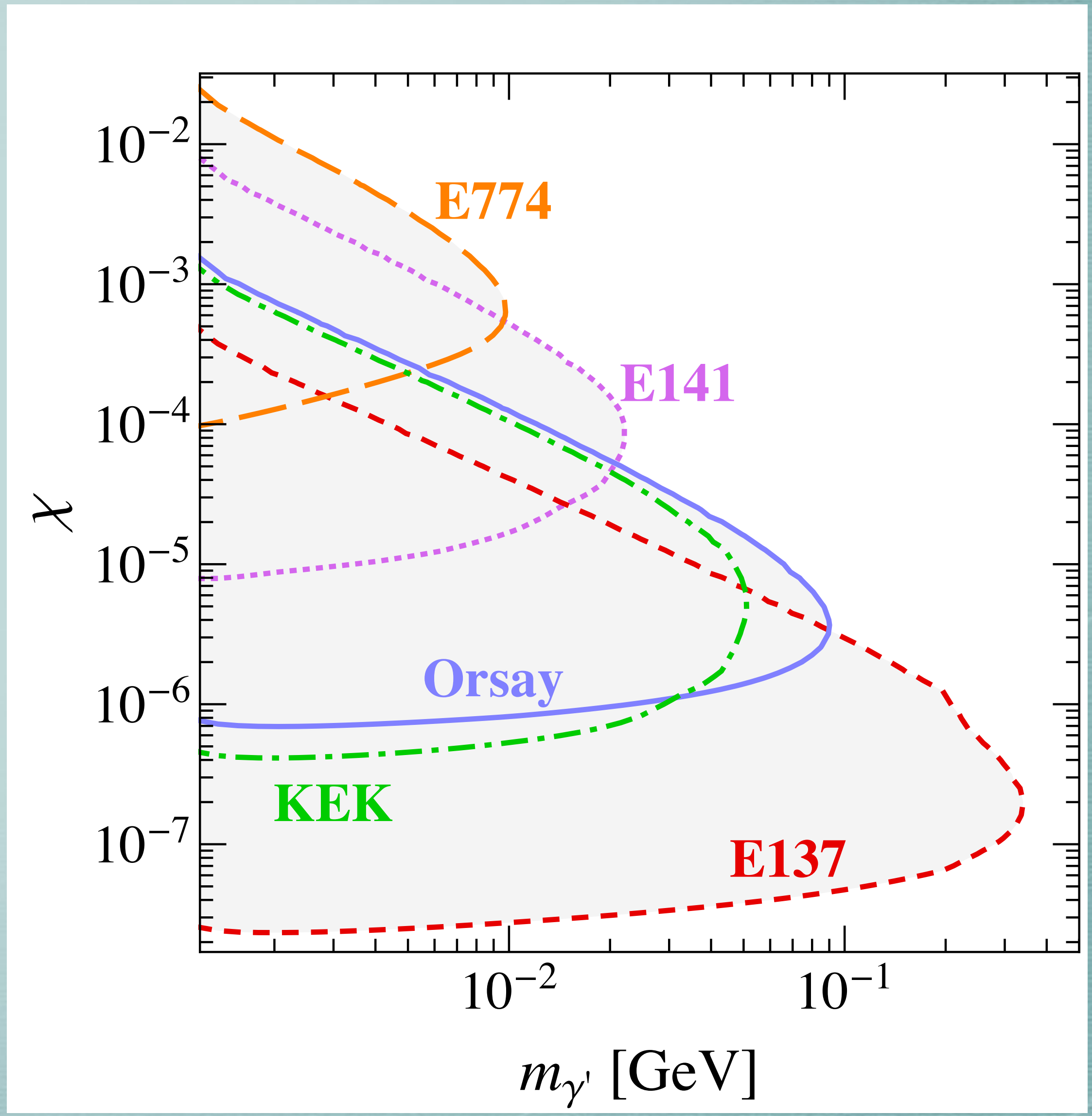


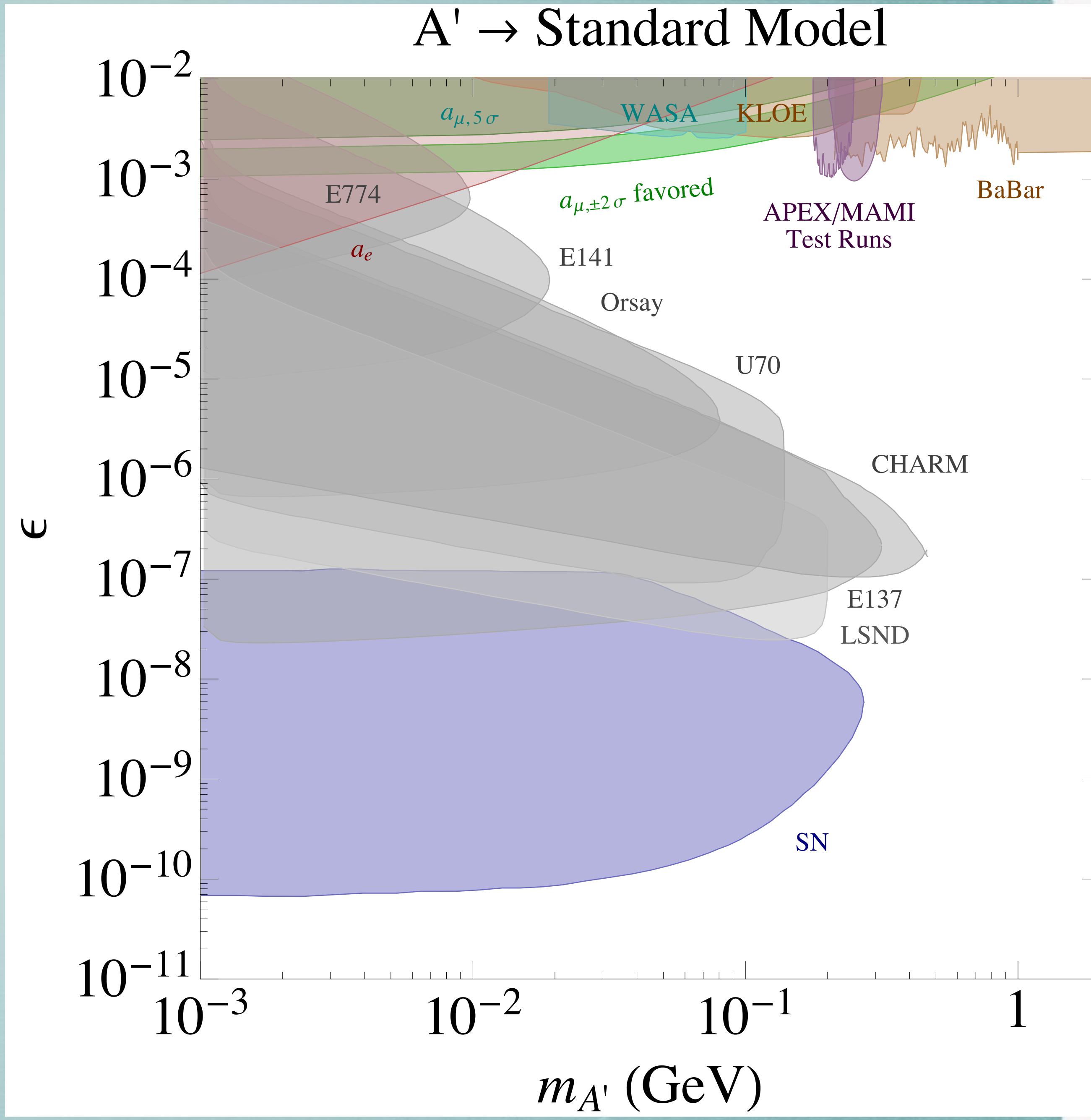
Summary

1. Beam dump :
   upper and lower limit

2. fixed target and collider
   trident process is the background

   $S/\sqrt{B} \propto (N\, \varepsilon^4)^{1/2}$

   $\varepsilon \lesssim 10^{-4}$



Collider or Fixed target

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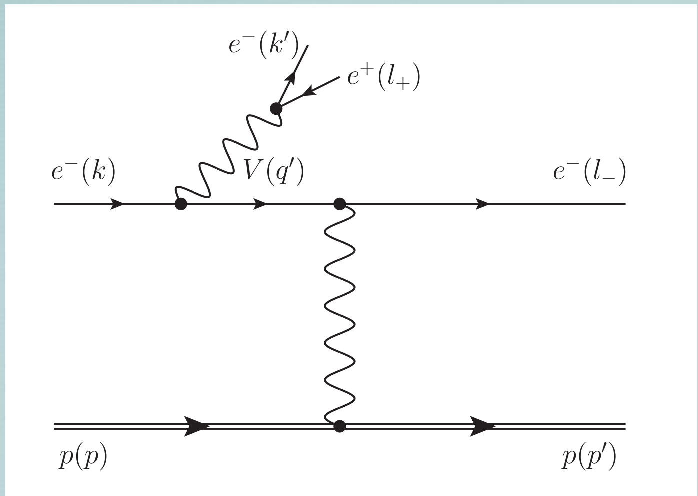
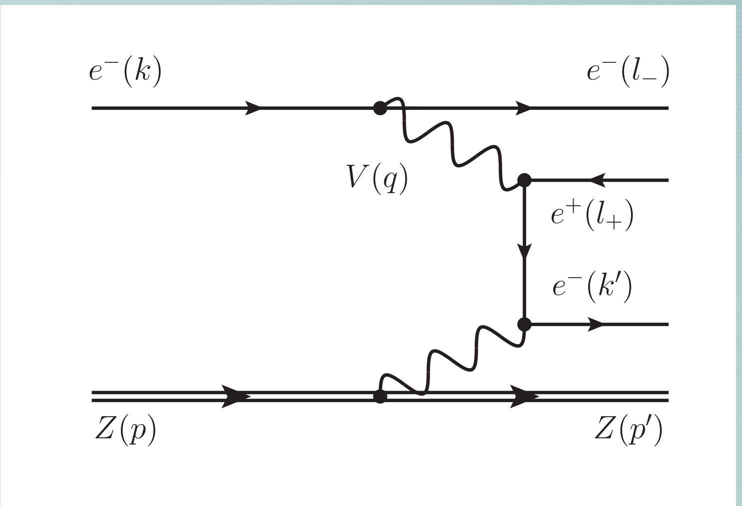
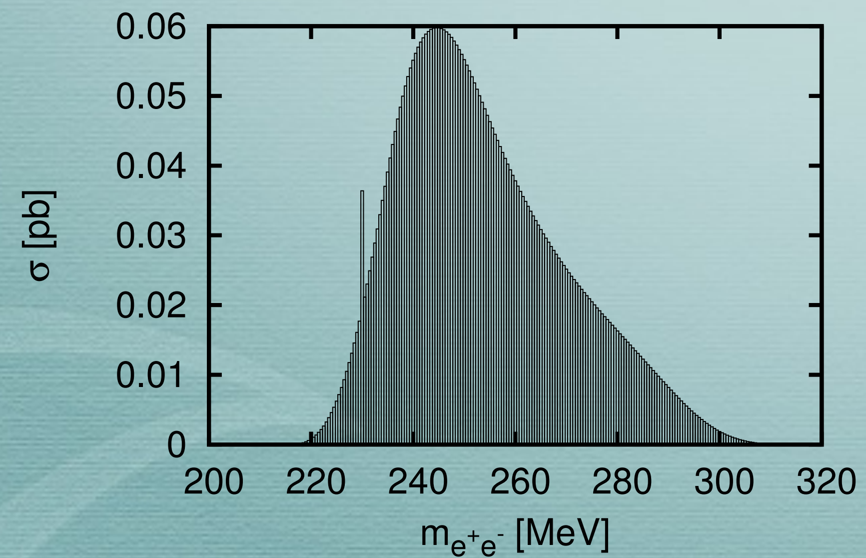




2. Estimate S/√B

$$\frac{\mathrm{S}}{\sqrt{\mathrm{B}}} \sim \sqrt{\sigma_0 \mathcal{L}} \frac{\epsilon^2}{\sqrt{\alpha/\pi}} \sqrt{\frac{m_U}{\delta m}} \times \mathrm{BR}(U \to \ell^+ \ell^-)$$



PLAN

1. Dark Photon Search

2. GeV Gamma Ray Excess in the Galatic Center
   statistical and systematical uncertainties

3. Dark Photon Portal
   Gamam Ray and Electrons

4. Constraints
   AMS02 constraints on 2e , 4e final states

5. Dark Matter Bremsstrahlung + Dark Matter ICS

6. Dark Scalar

7. Conclusion