

# SOMMERFELD ENHANCEMENT OF DARK MATTER

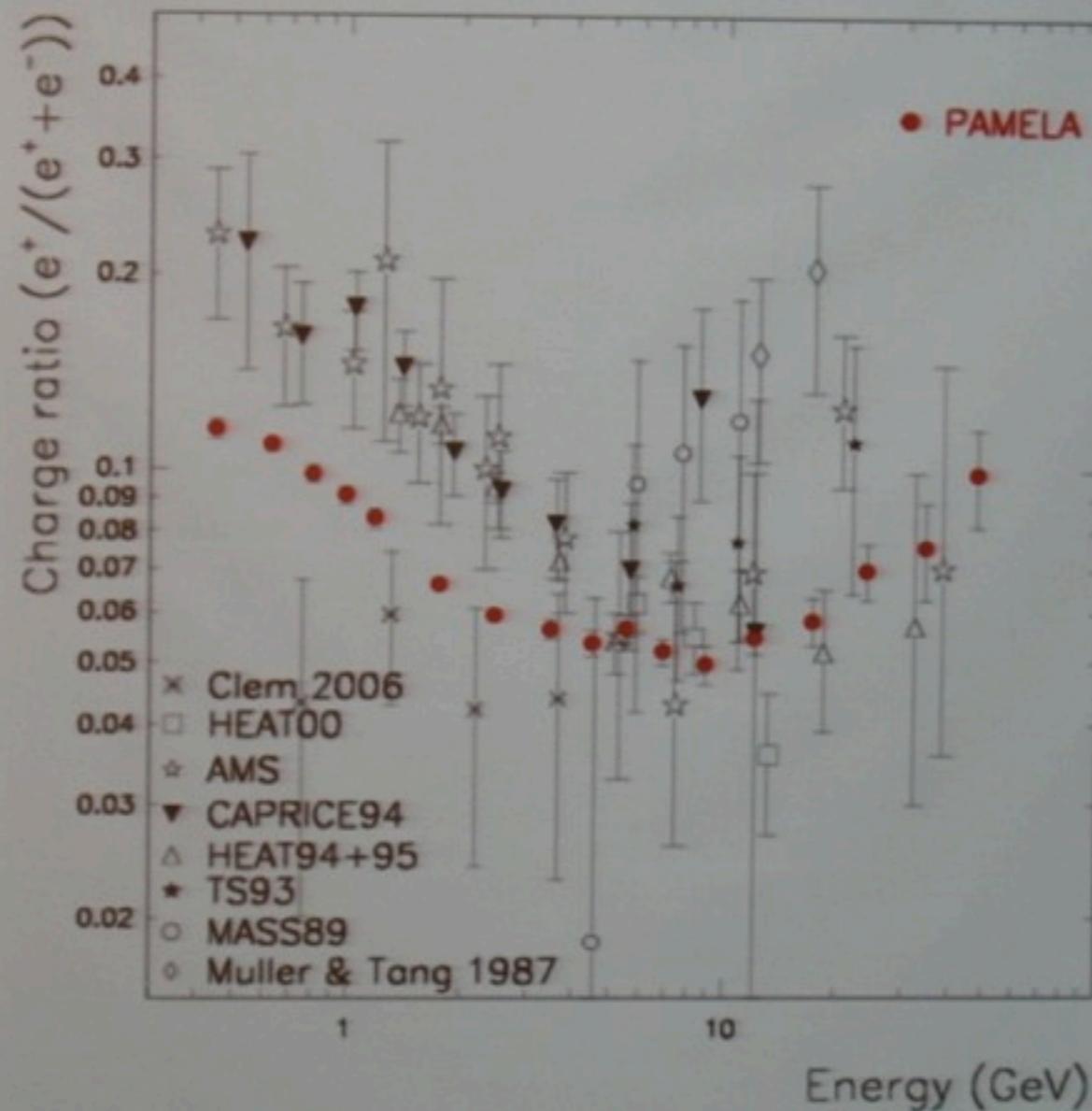
Neal Weiner  
CCPP NYU  
Feb 9, 2011

work with Doug Finkbeiner, Lisa Goodenough, Tracy Slatyer, Natalia Toro, Mark Vogelsberger

# 2008

## Positron to Electron Fraction

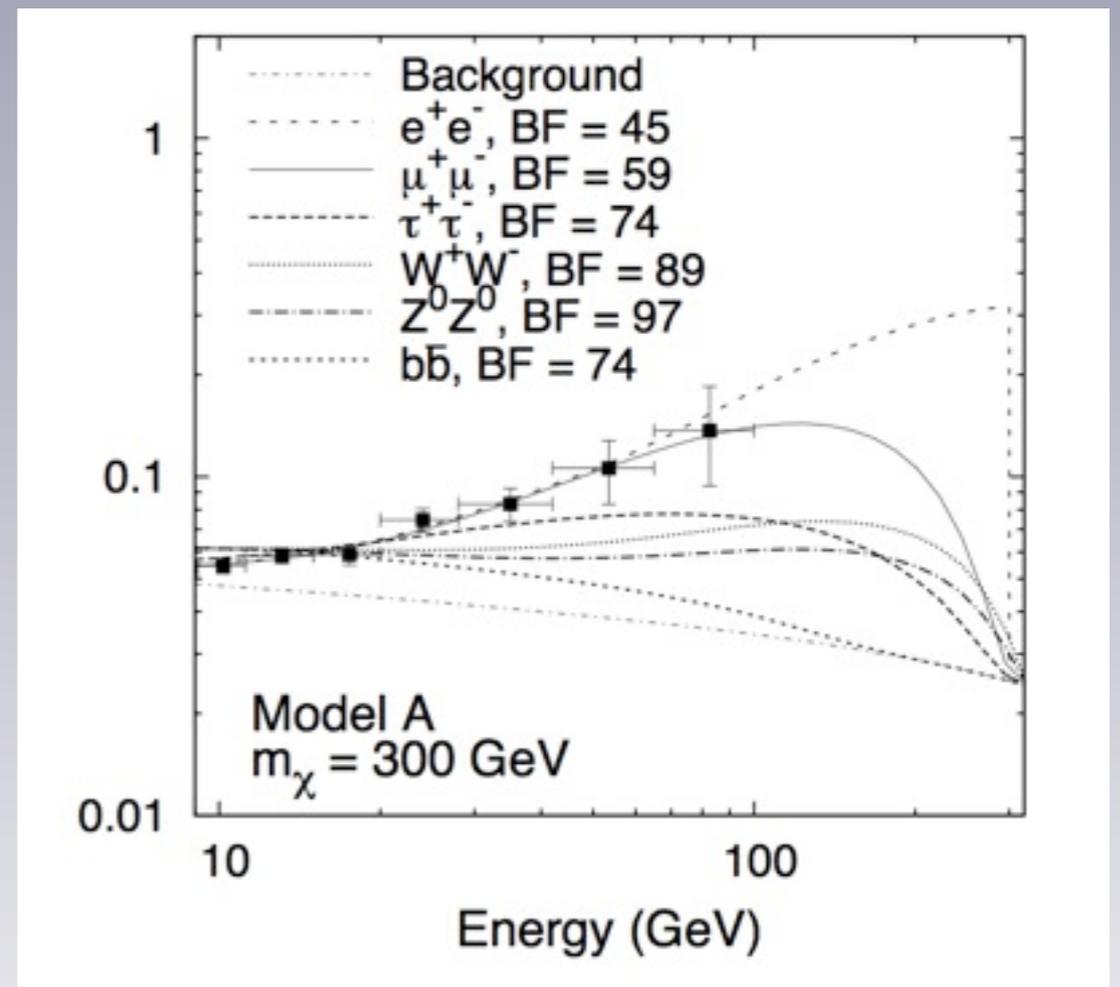
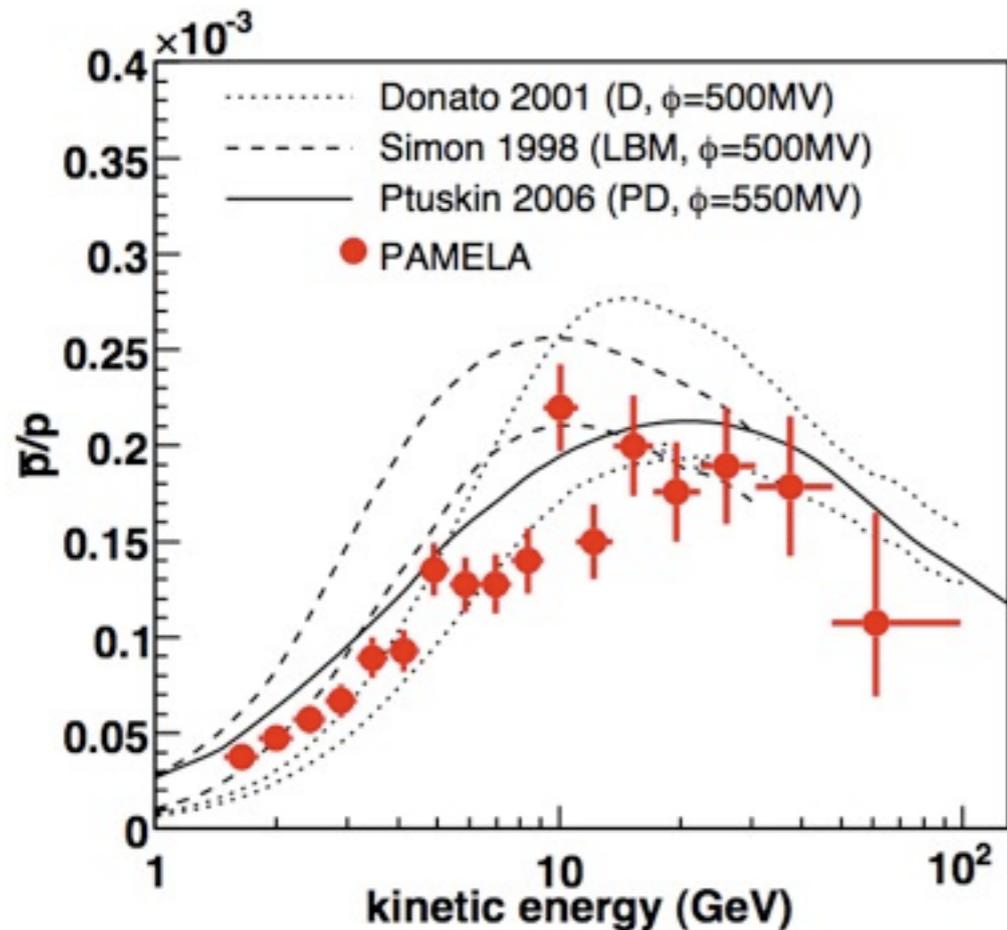
Preliminary!!!



End 2007:  
~20 000  
positrons total  
~2000 > 5 GeV

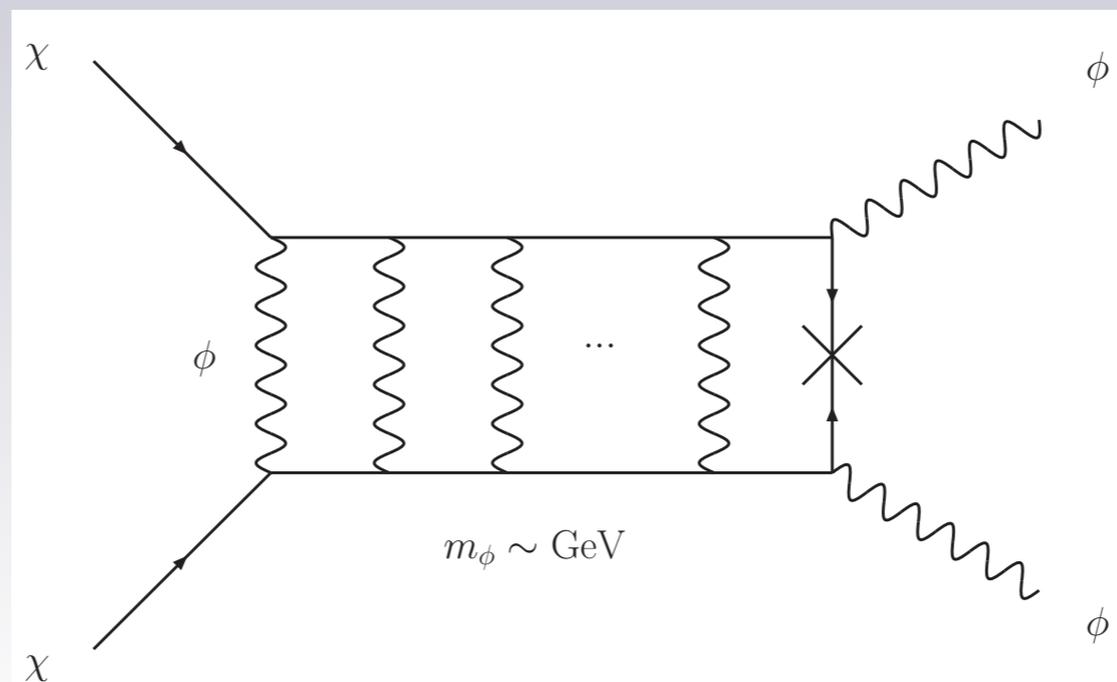
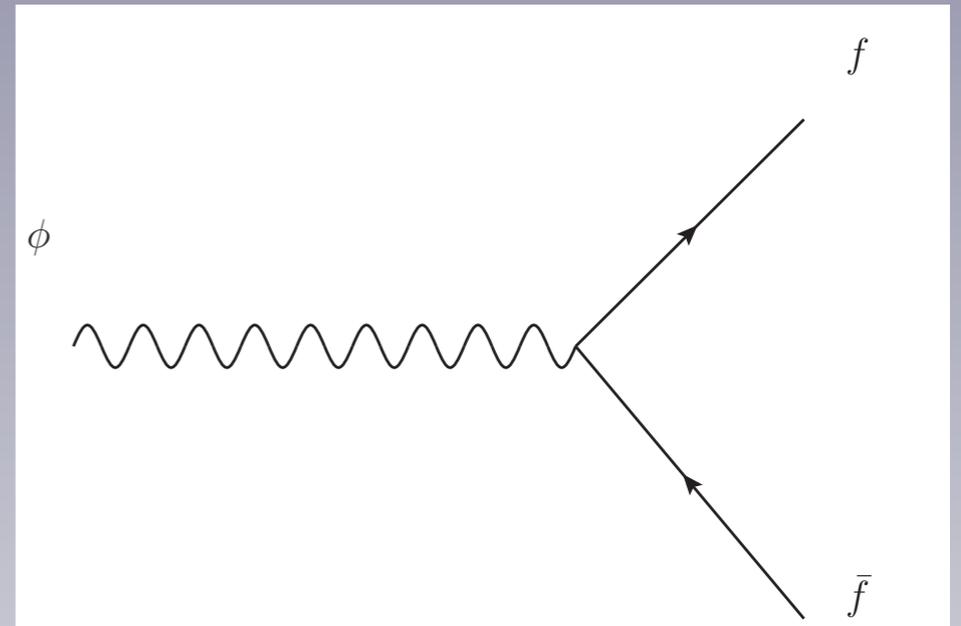
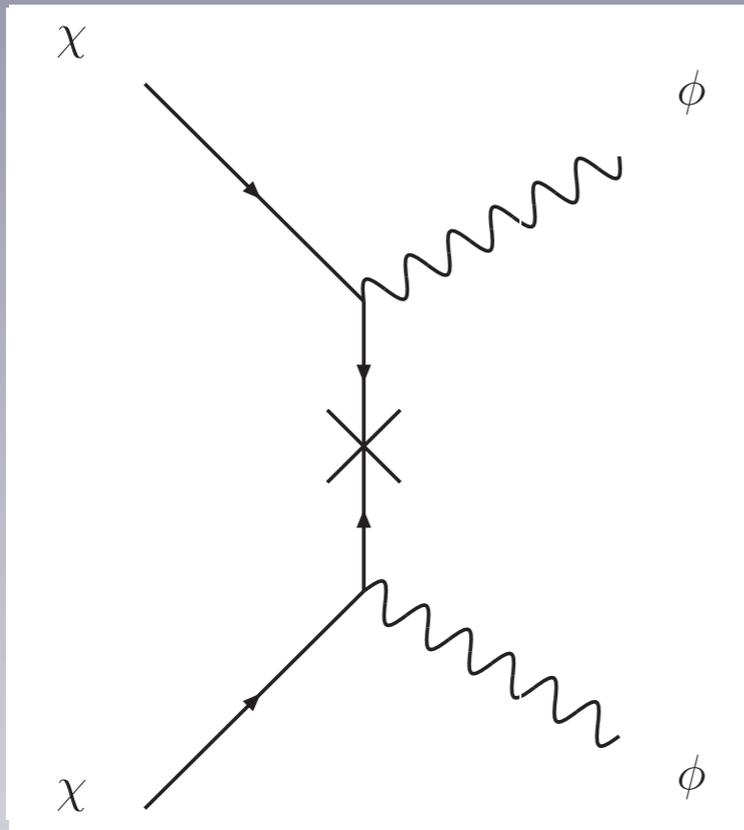


# A WIMP?



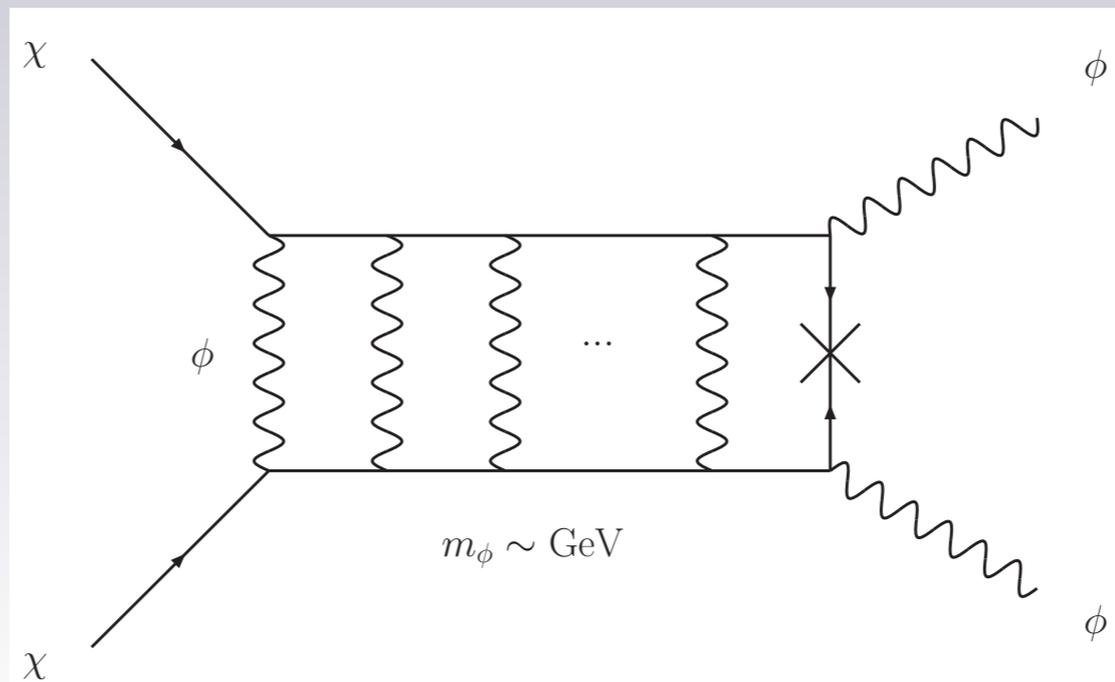
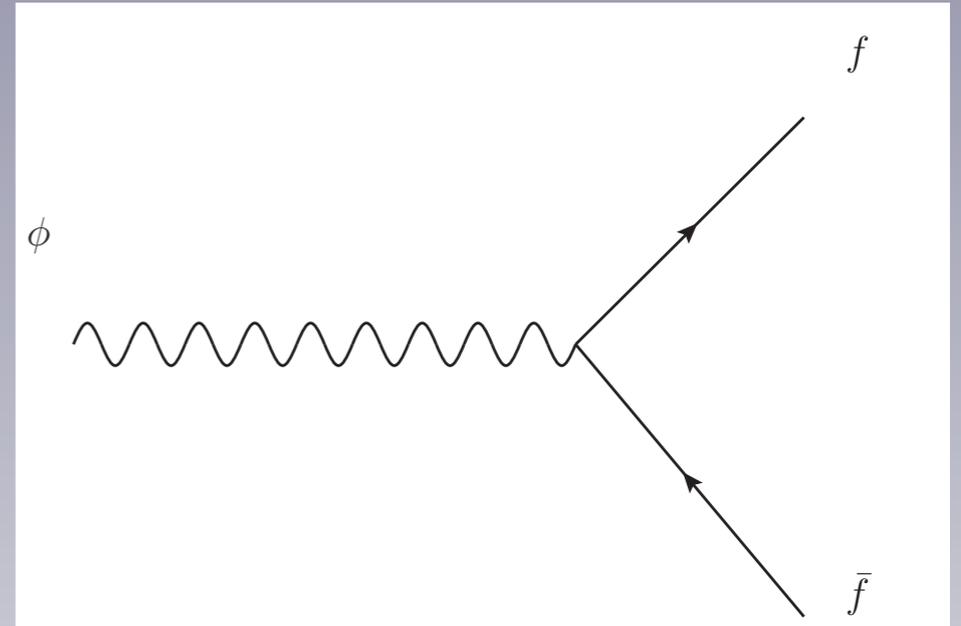
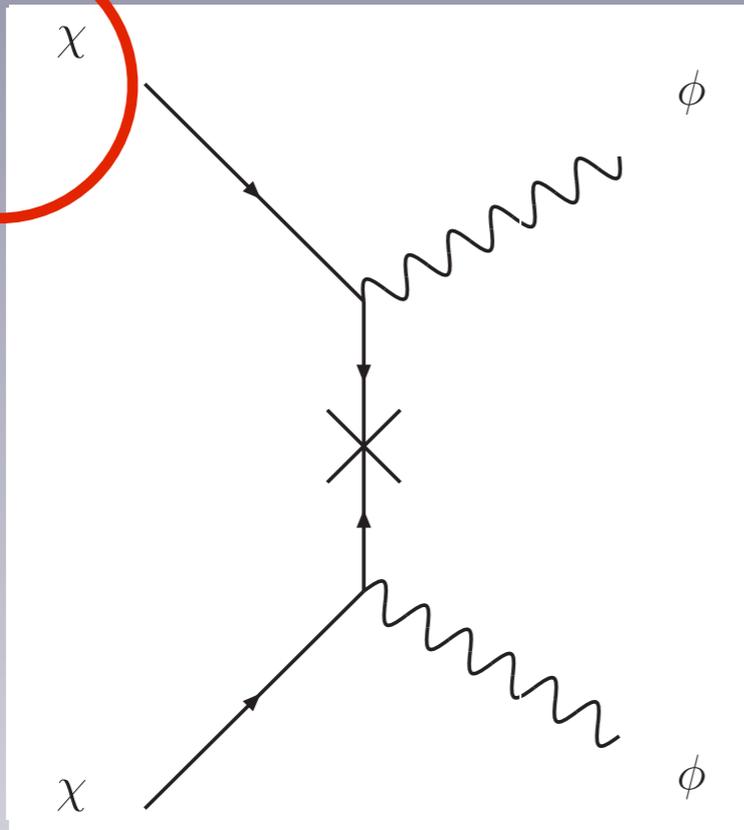
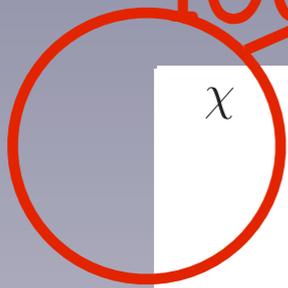
No antiprotons, hard leptons, large boosts

# SOMMERFELD MODELS



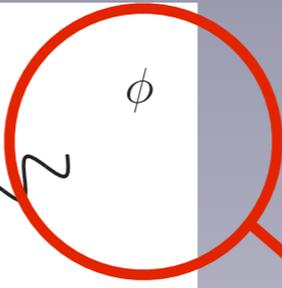
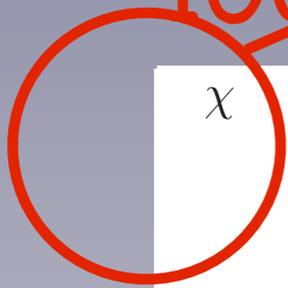
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1000 GeV

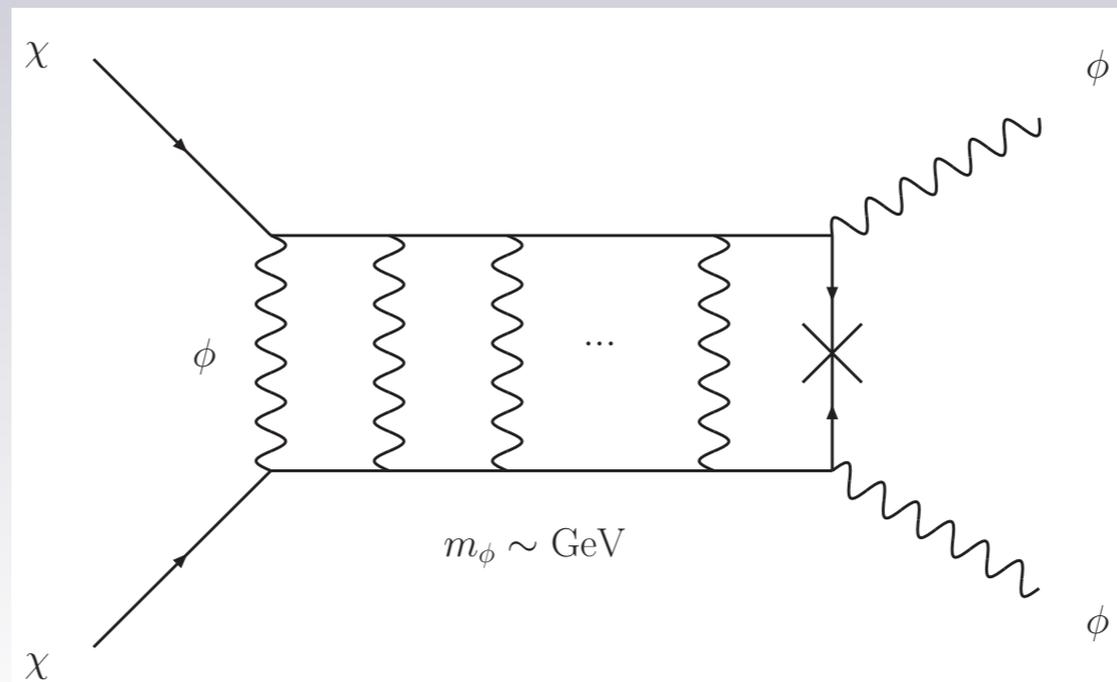
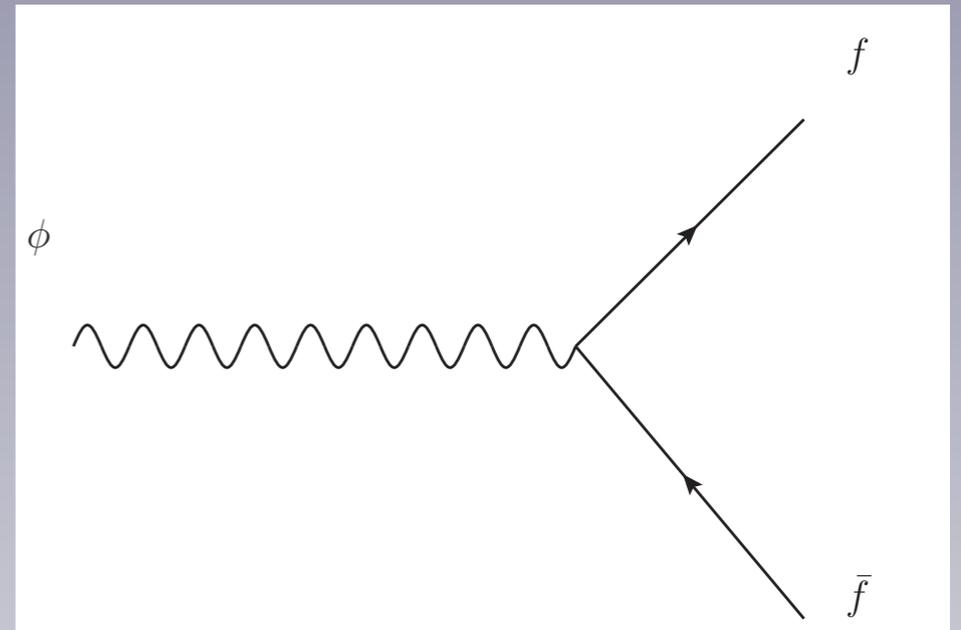
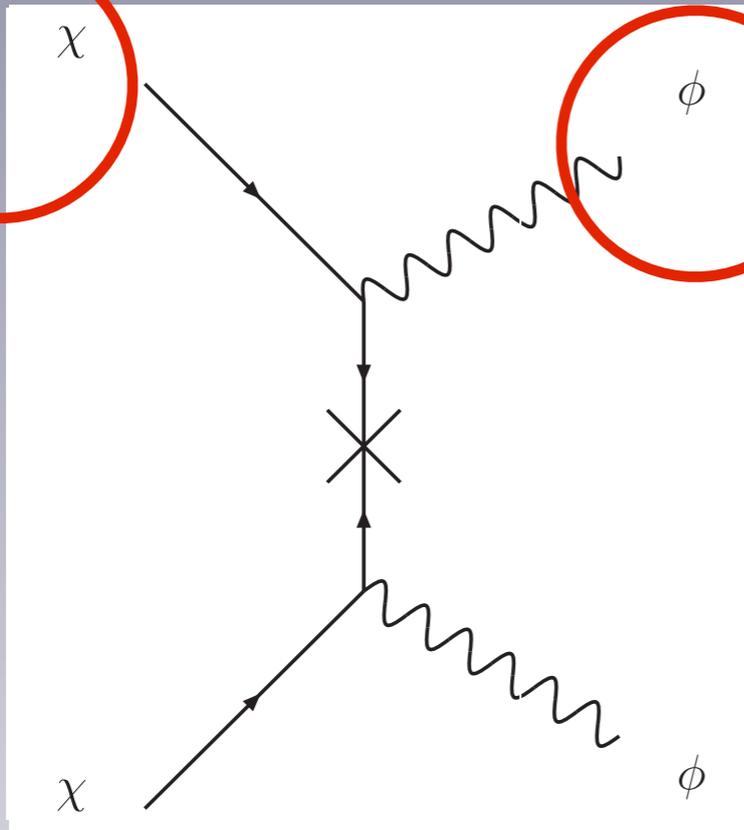


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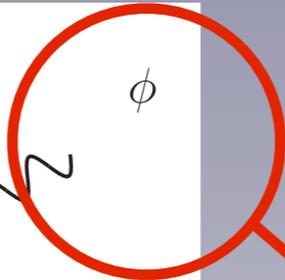
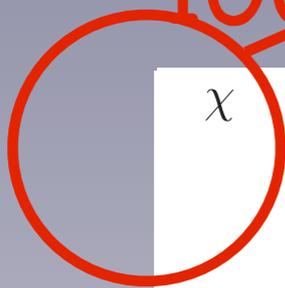


GeV

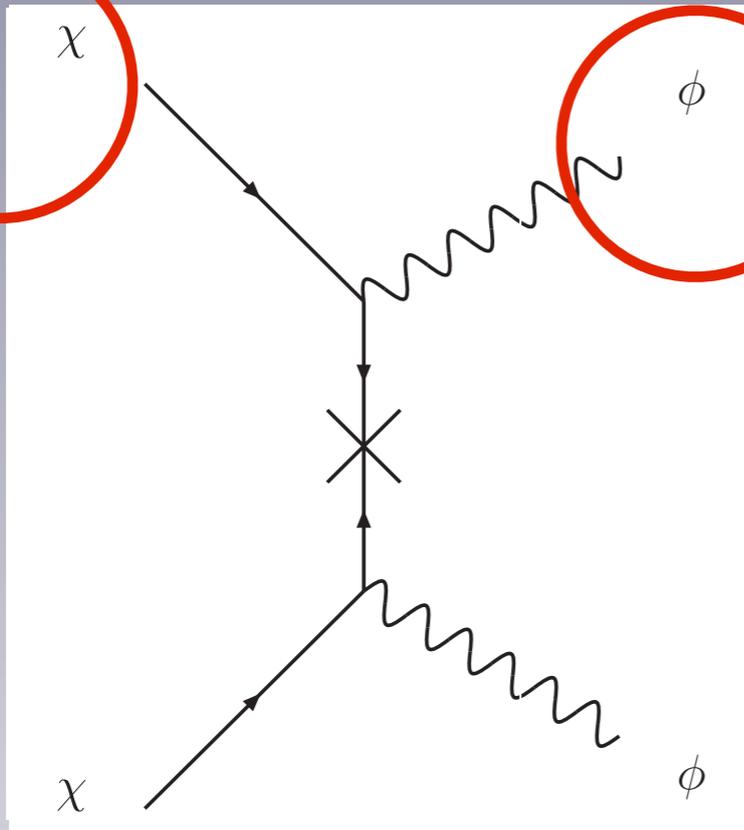


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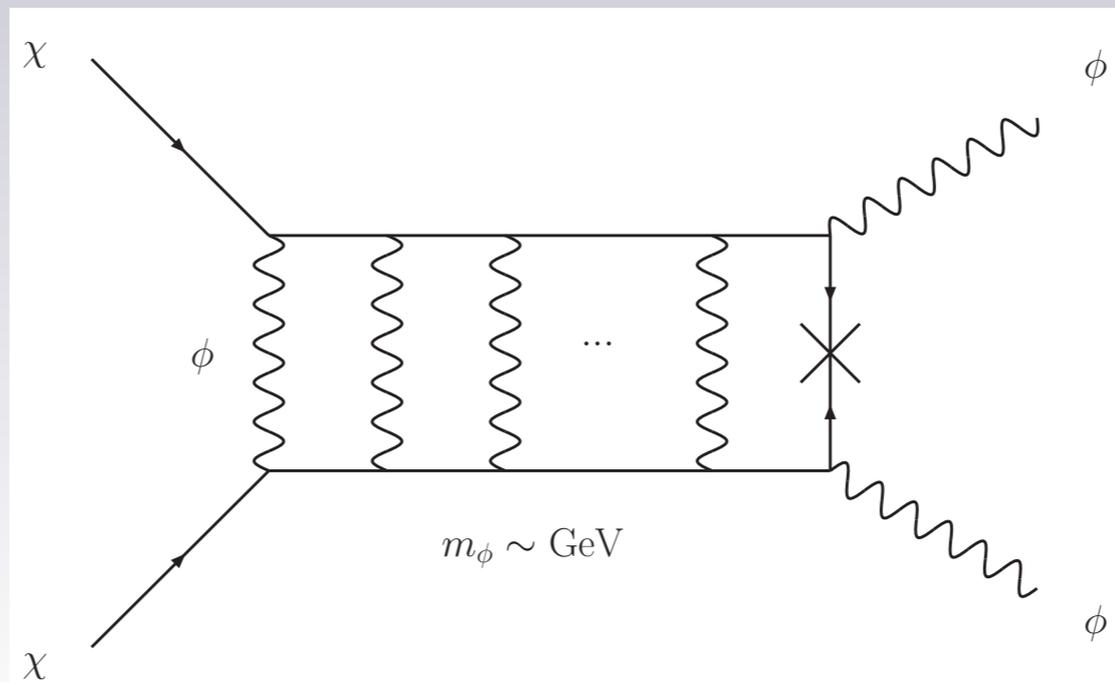
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GeV

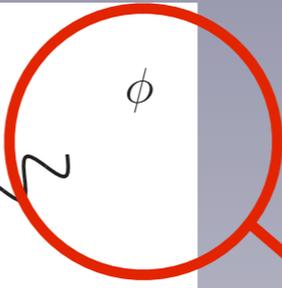
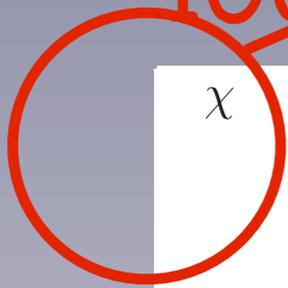


hard leptons / no  
antiprotons from  
kinematics

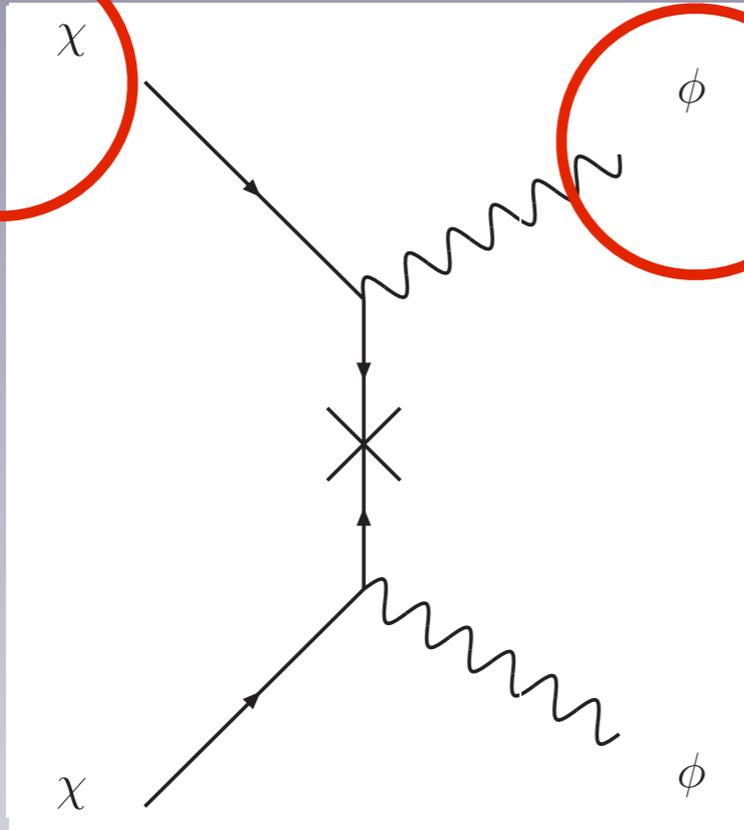


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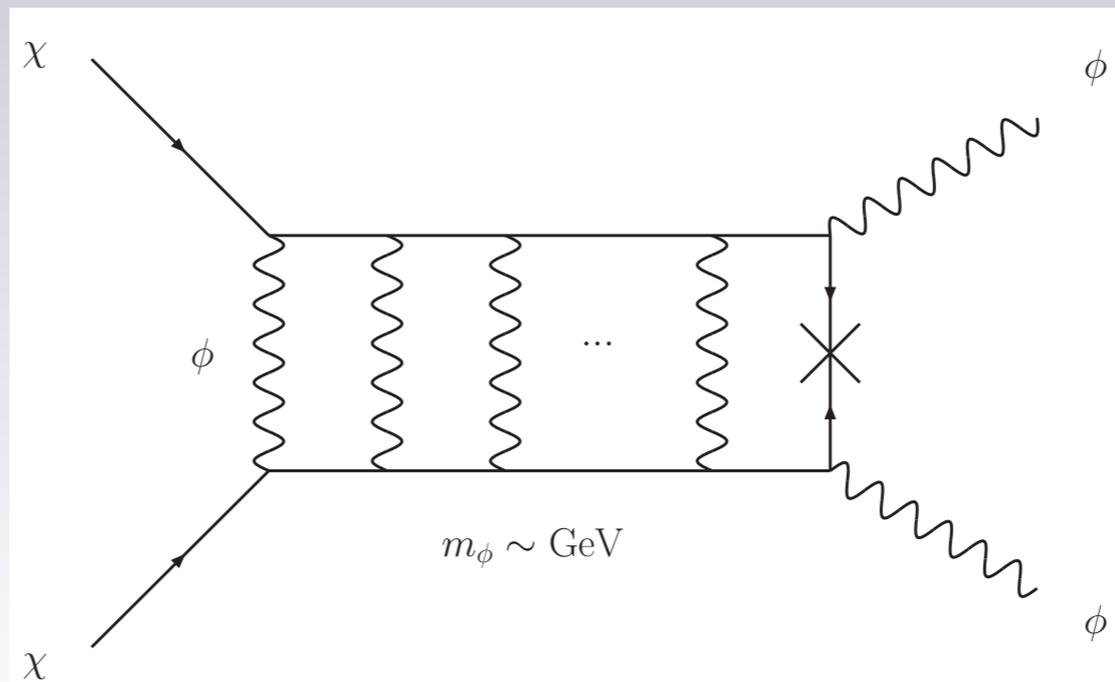


GeV



hard leptons / no  
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large boosts from  
Sommerfeld  
enhancement



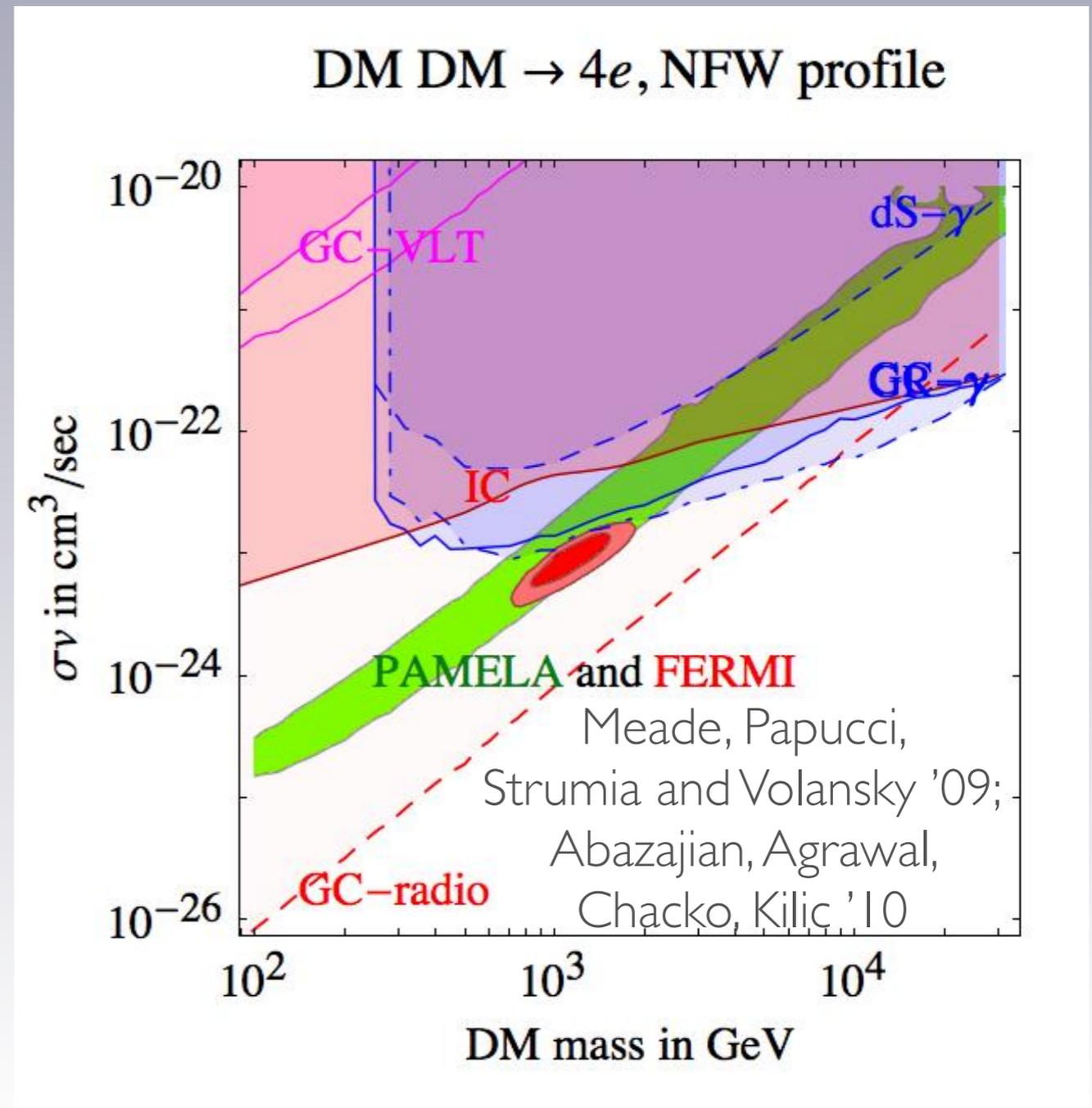
# TENSIONS

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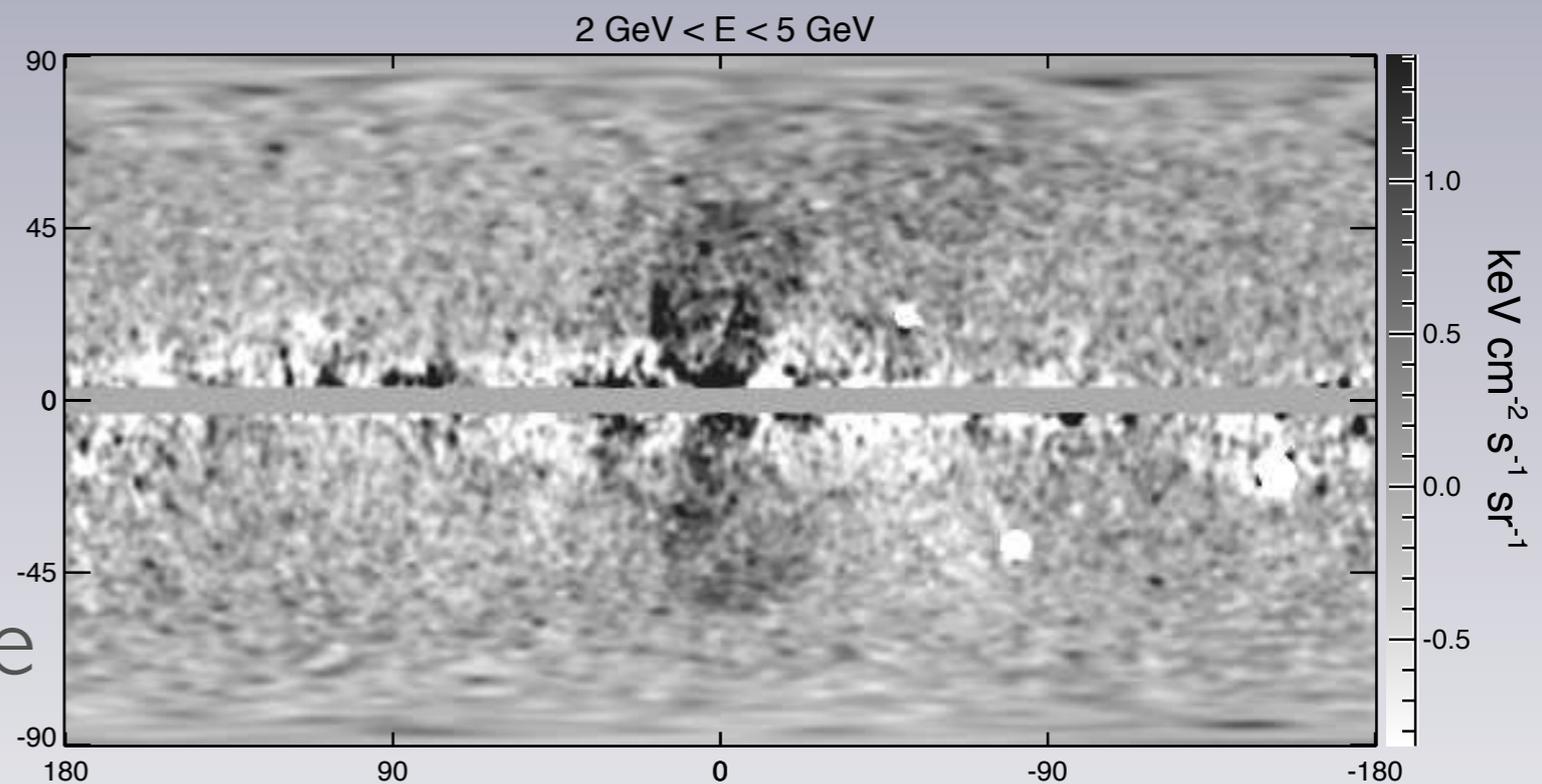
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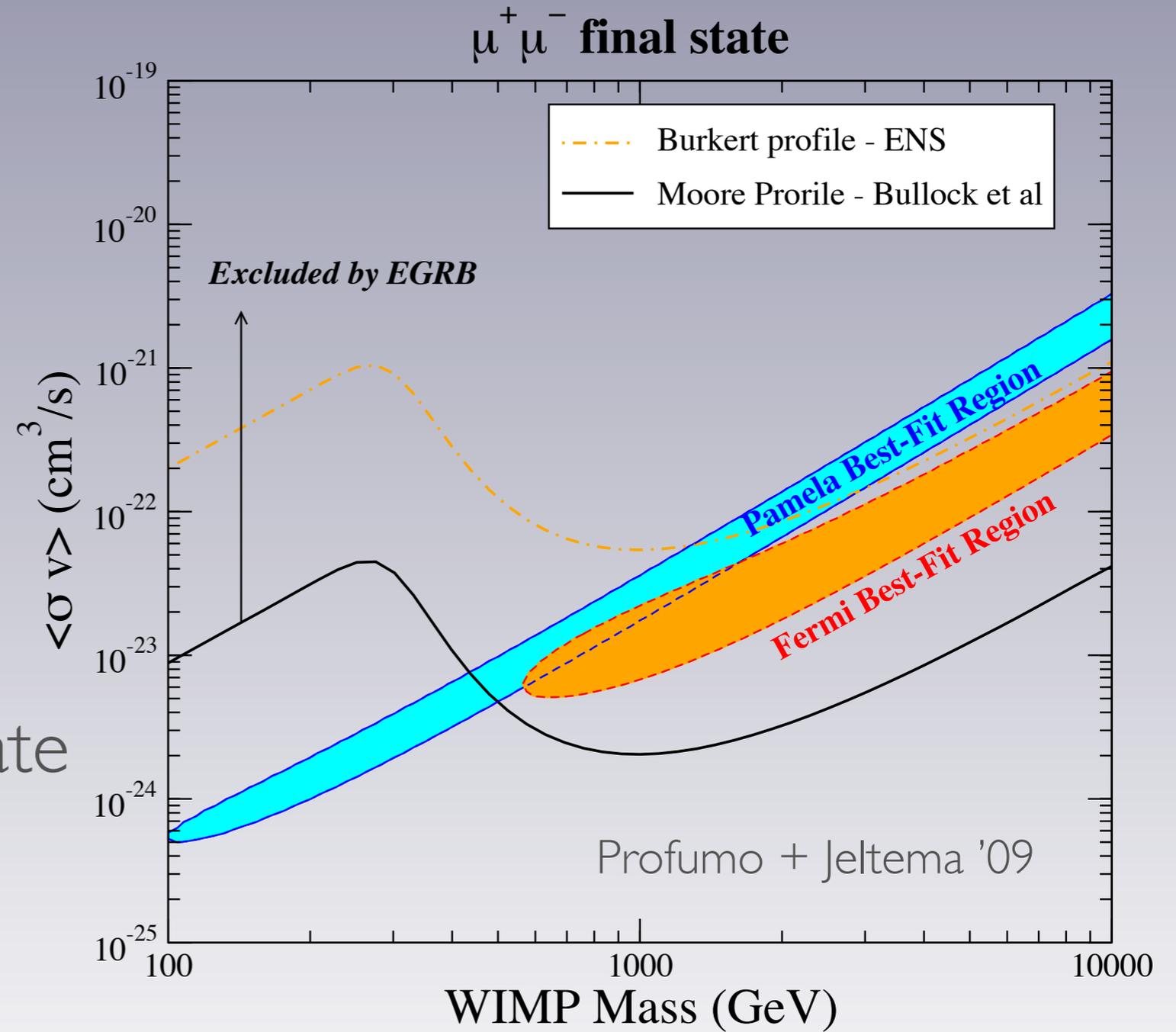
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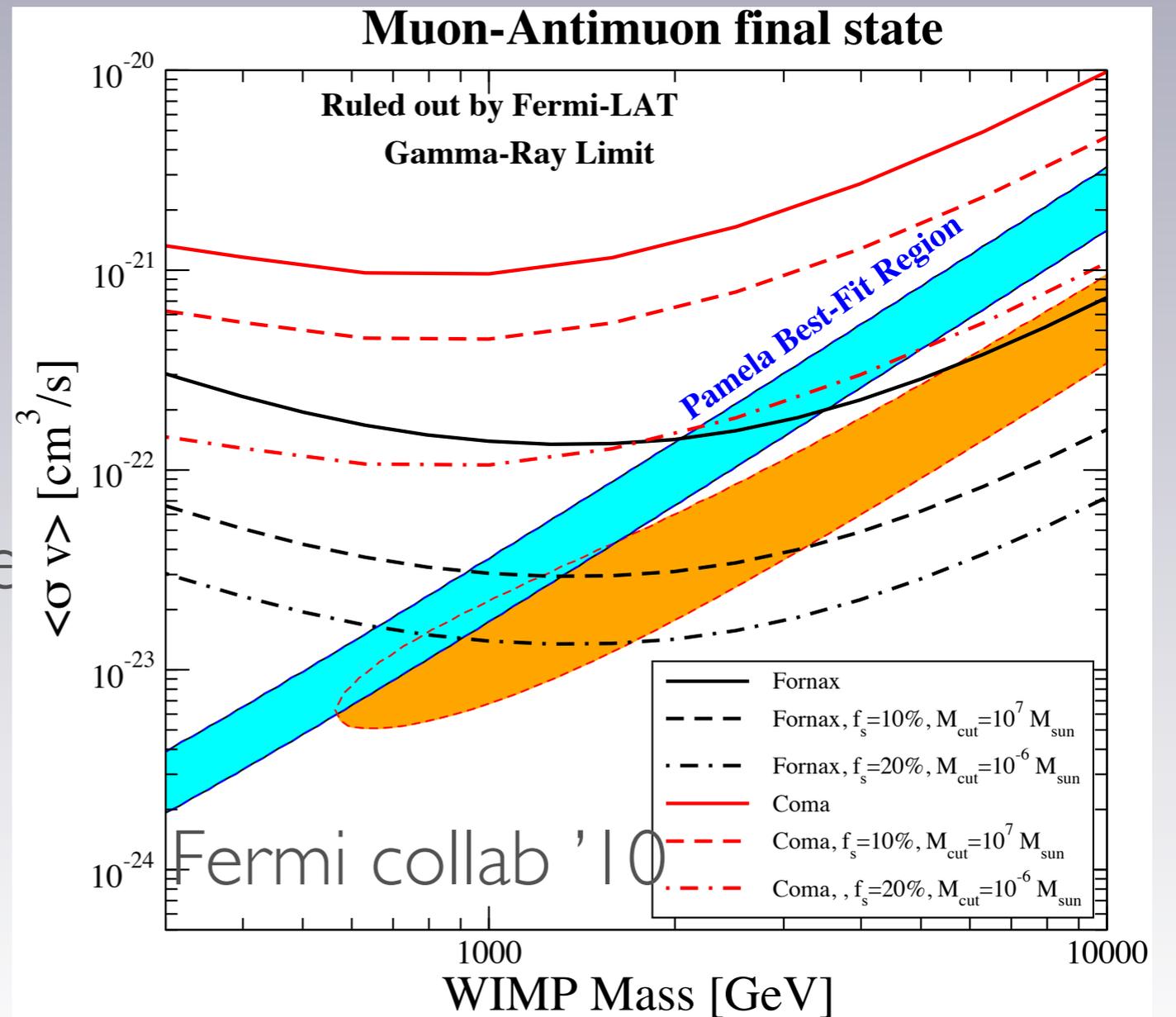


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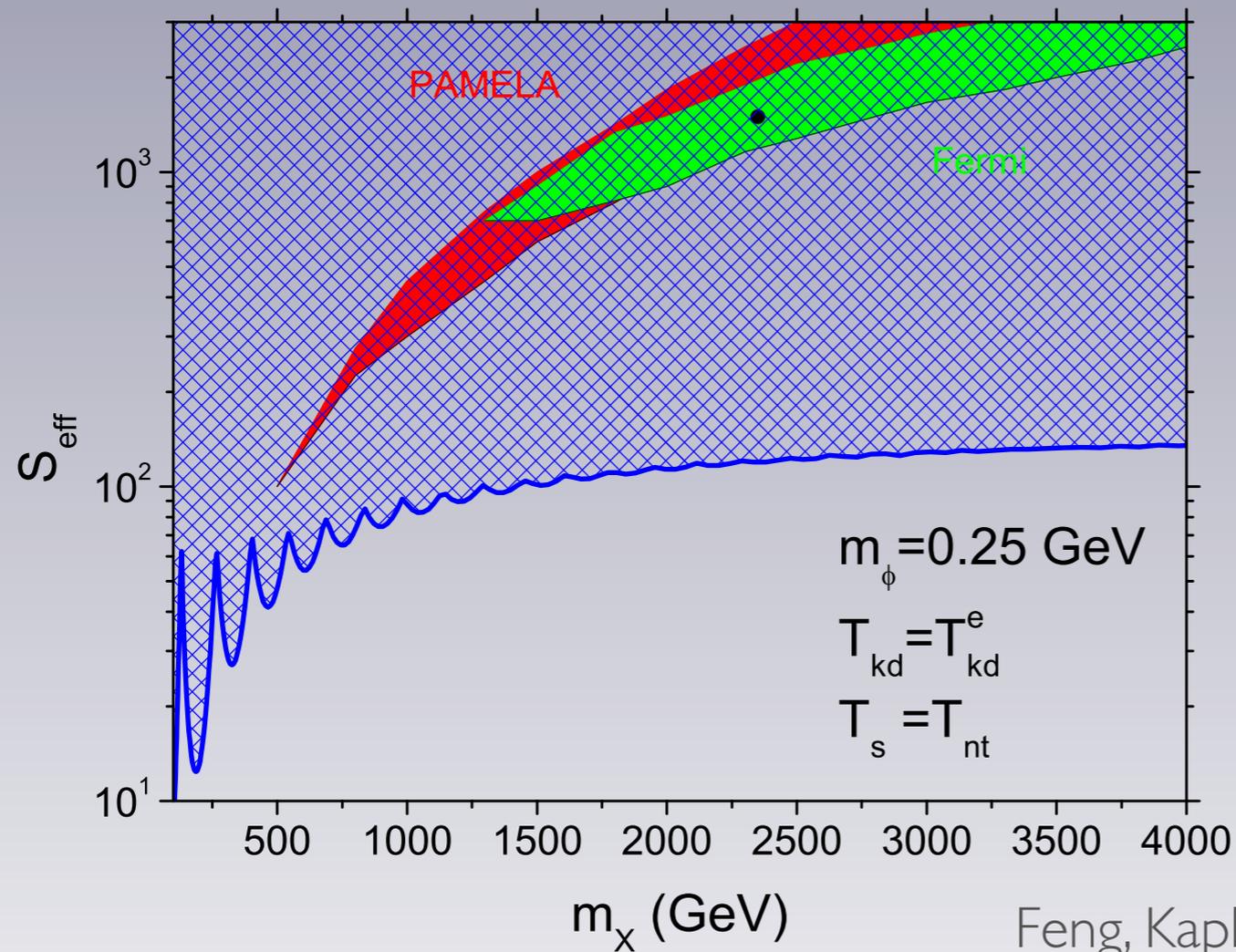
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# TENSION WITH ABUNDANCE?



Can you get the whole scenario at once?

Feng, Kaplinghat, Yu '10

# BENCHMARKS

- Can you find complete models that
  - produce the correct relic abundance
  - avoid constraints from the CMB
  - produce adequately large boosts (i.e., fit PAMELA/Fermi)

# BENCHMARKS

Finkbeiner, et al 2010

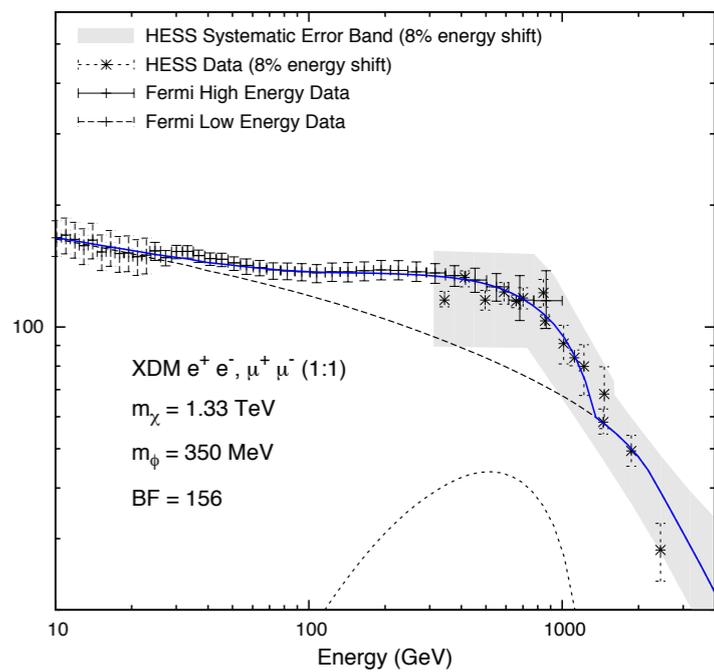
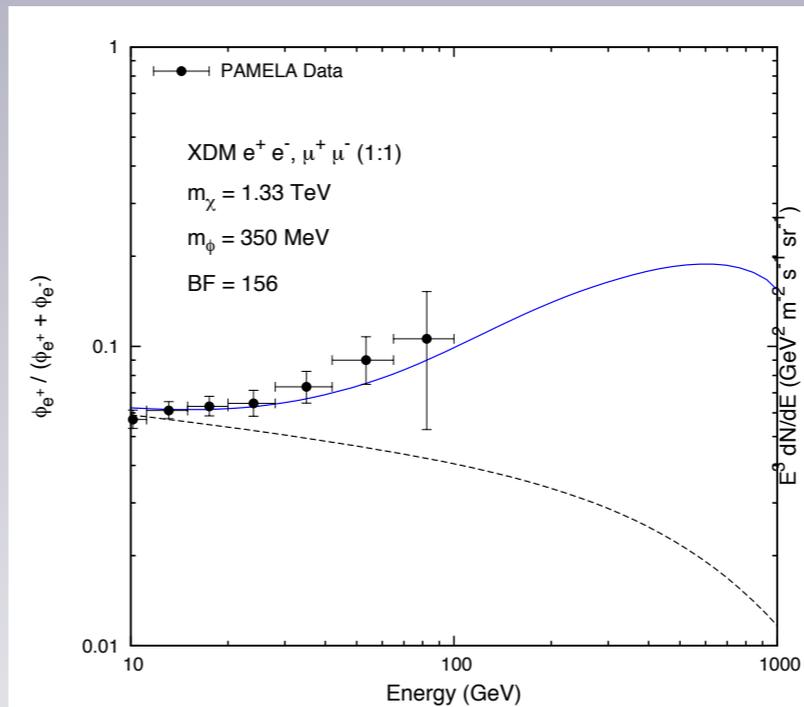
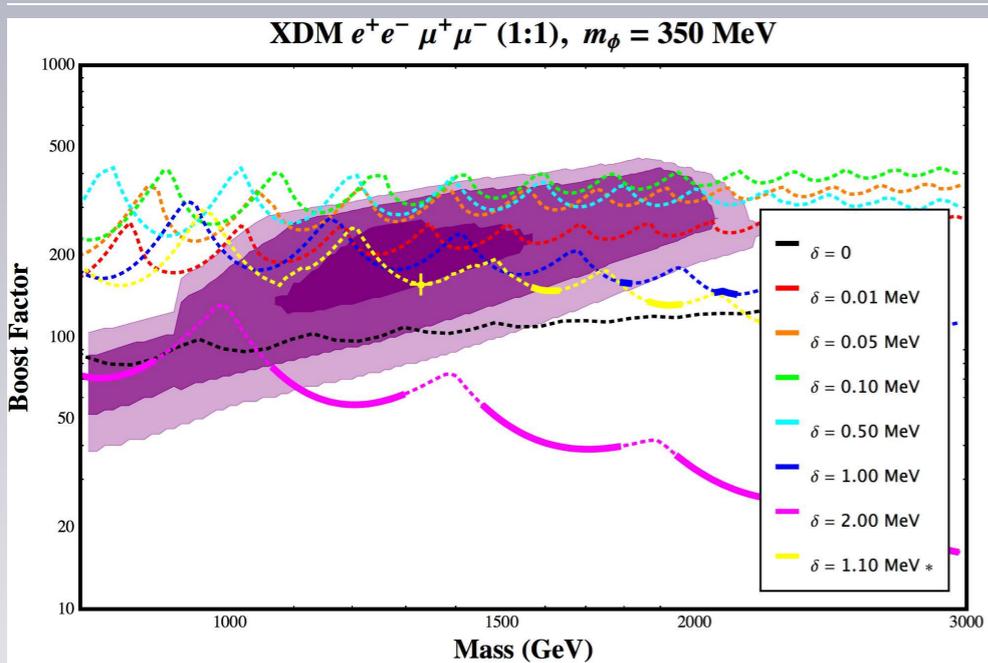
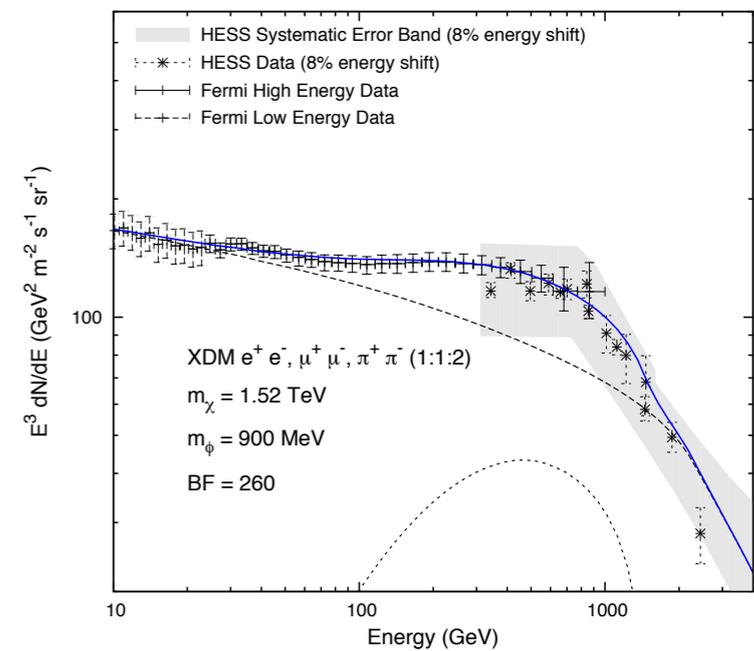
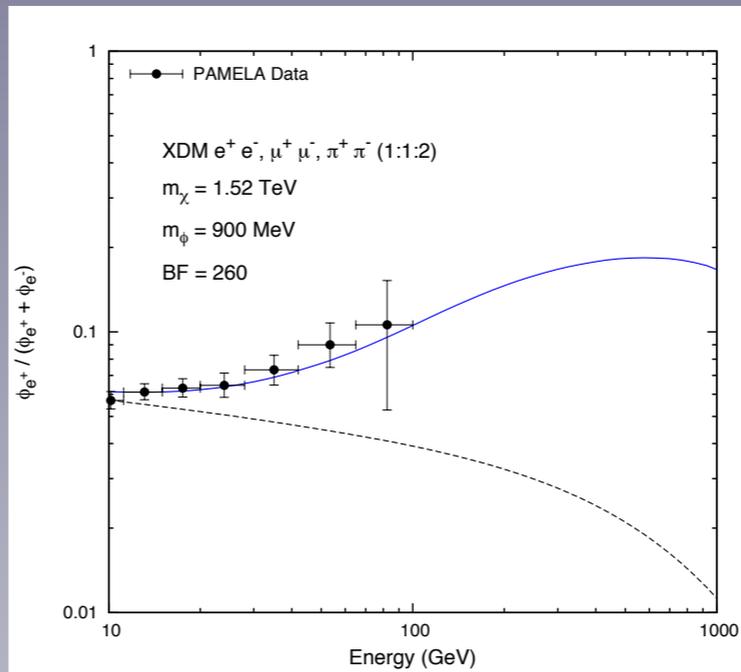
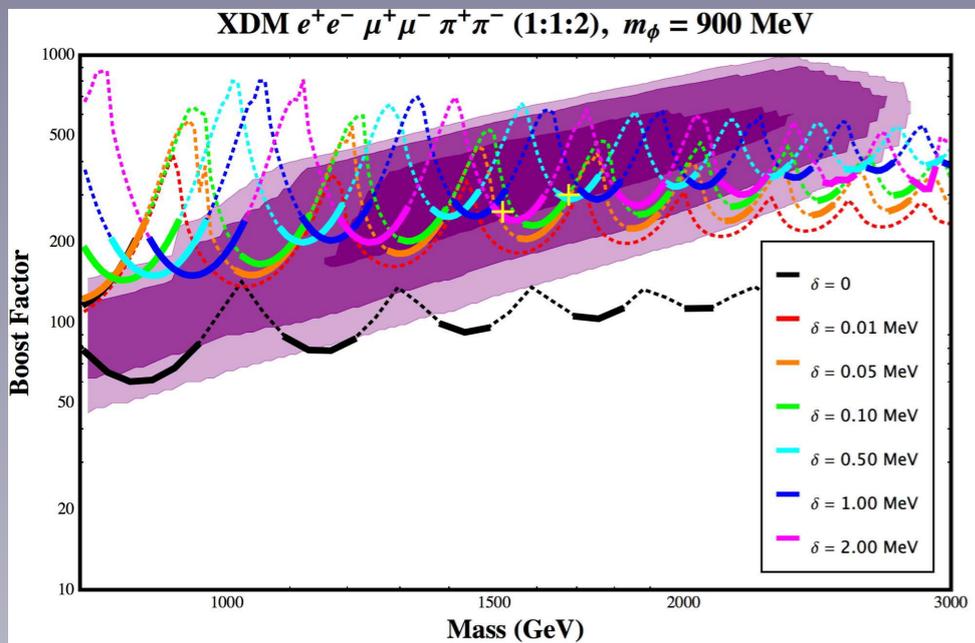
Annihilation Channel	$m_\phi$ (MeV)	$m_\chi$ (TeV)	$\alpha_D$	$\delta$ (MeV)	Local BF	Saturated BF	CMB limit
1:1:2 $e^\pm : \mu^\pm : \pi^\pm$	900	1.68	0.04067	0.15	300	530	600
1:1:2 $e^\pm : \mu^\pm : \pi^\pm$	900	1.52	0.03725	1.34	260	360	545
1:1:1 $e^\pm : \mu^\pm : \pi^\pm$	580	1.55	0.03523	1.49	250	437	490
1:1:1 $e^\pm : \mu^\pm : \pi^\pm$	580	1.20	0.03054	1.00	244	374	379
1:1 $e^\pm : \mu^\pm$	350	1.33	0.02643	1.10	156	339	340
$e^\pm$ only	200	1.00	0.01622	0.70	67	171	171

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Annihilation Channel	$m_\chi$ (TeV)	$n_e \times 10^{-10}$ @ 34.5 GeV	$\gamma_{e1}$	$E_{e1}$ (GeV)	$\gamma_{e2}$	$E_{e1}$ (GeV)	$\gamma_{e3}$	$n_p \times 10^{-9}$ @ 100 GeV	$\gamma_{p1}$	$E_{p1}$ (GeV)	$\gamma_{p2}$
1:1:2 $e^\pm : \mu^\pm : \pi^\pm$	1.68	3.12763	n/a	4.0	2.45	2200	3.3	5.66361	1.98	9.0	2.11
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1:1:1 $e^\pm : \mu^\pm : \pi^\pm$	1.20	3.06444	n/a	4.0	2.50	2200	3.3	5.20440	1.98	9.0	2.11
1:1 $e^\pm : \mu^\pm$	1.33	3.09604	n/a	4.0	2.45	2200	3.3	5.74014	1.98	9.0	2.11
$e^\pm$ only	1.00	3.10299	n/a	4.0	2.45	2200	3.3	5.74014	1.98	9.0	2.11



Relic abundance not a problem  
 (no substructure assumed)

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- $0.3 \text{ GeV/cm}^3$  vs  $0.4 \text{ GeV/cm}^3$

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- 4 muon final states vs states with electrons
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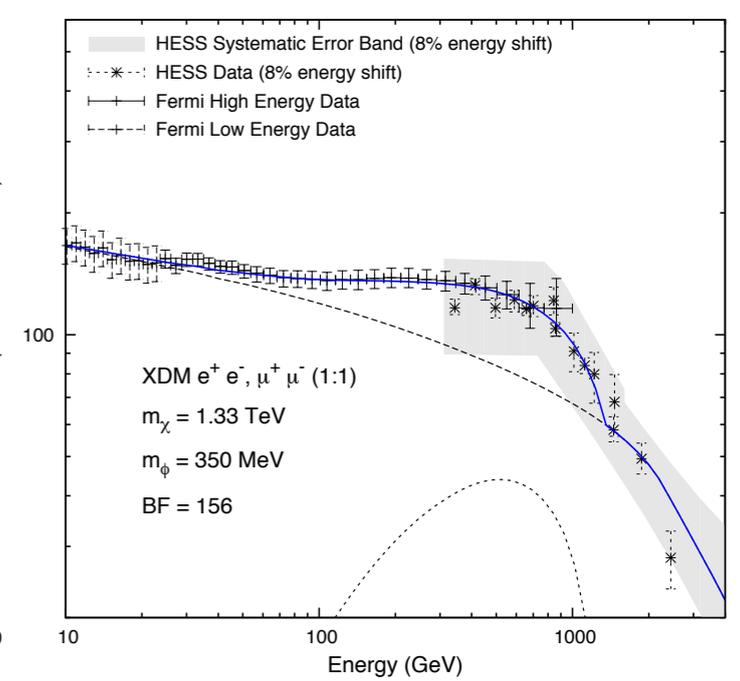
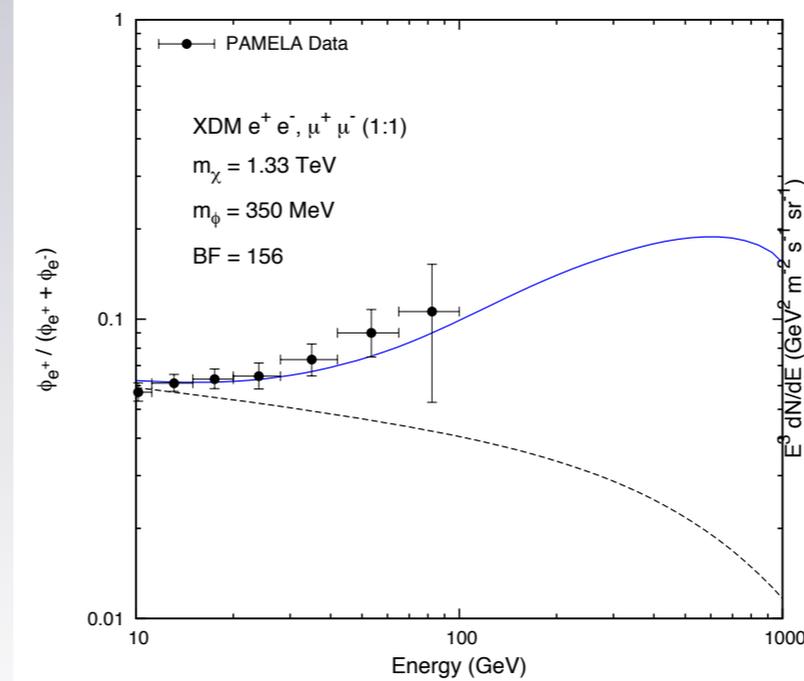
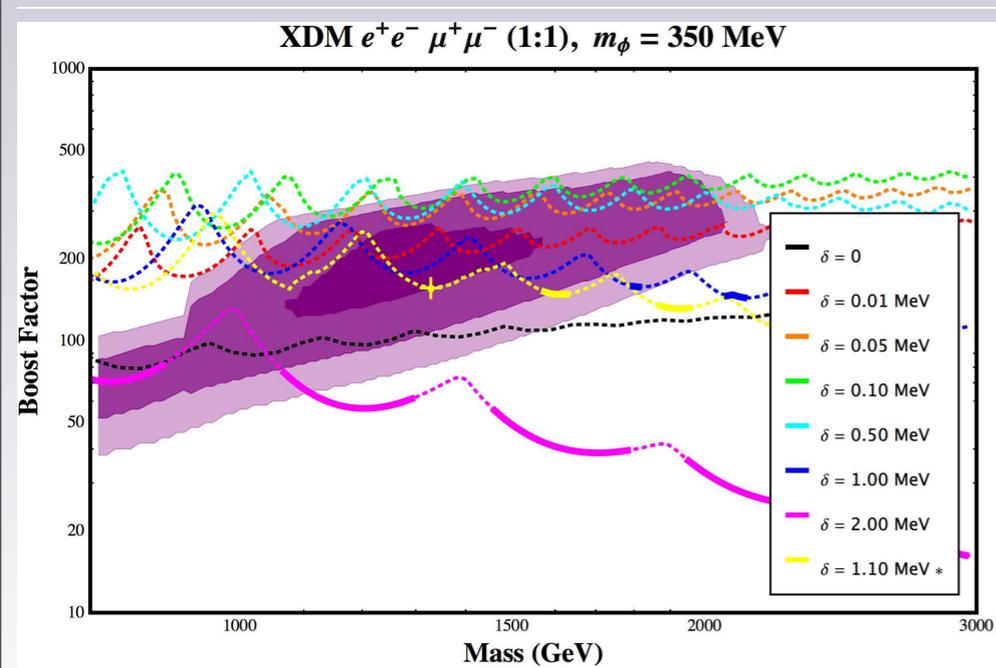
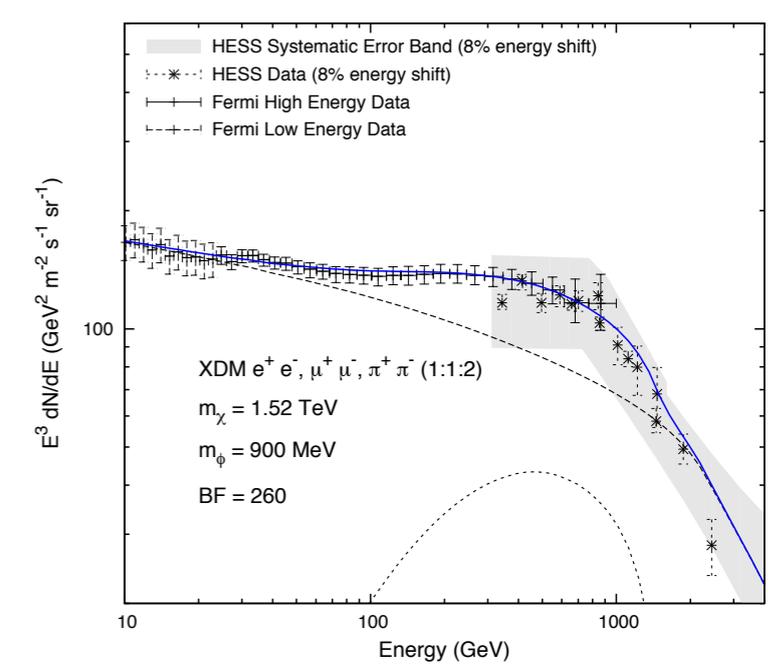
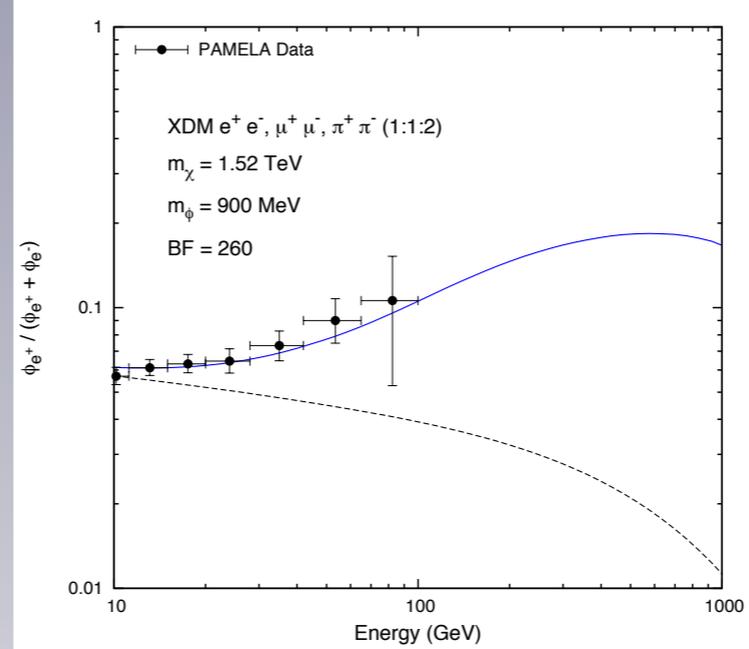
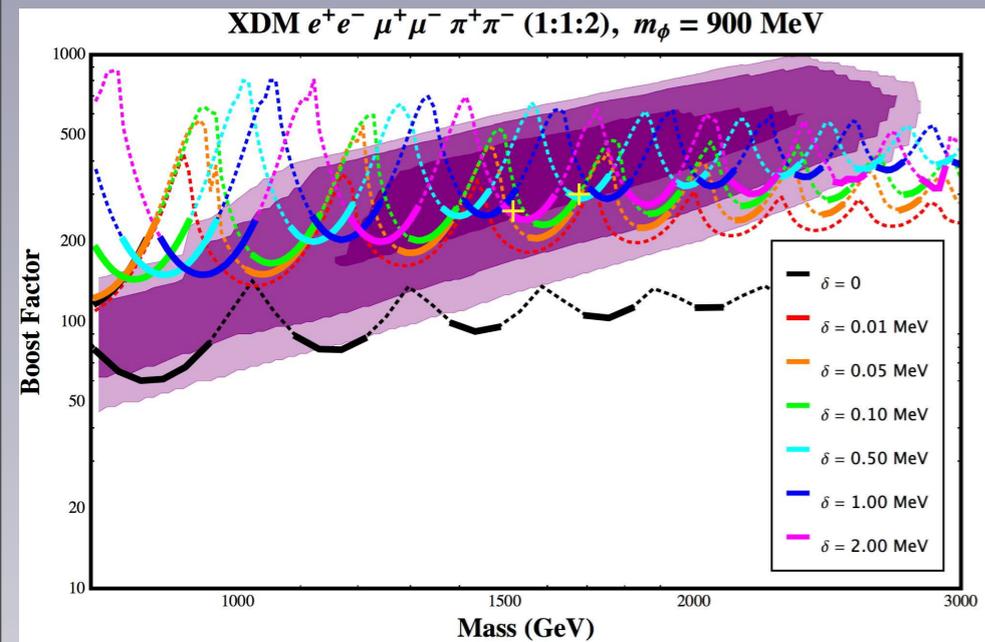
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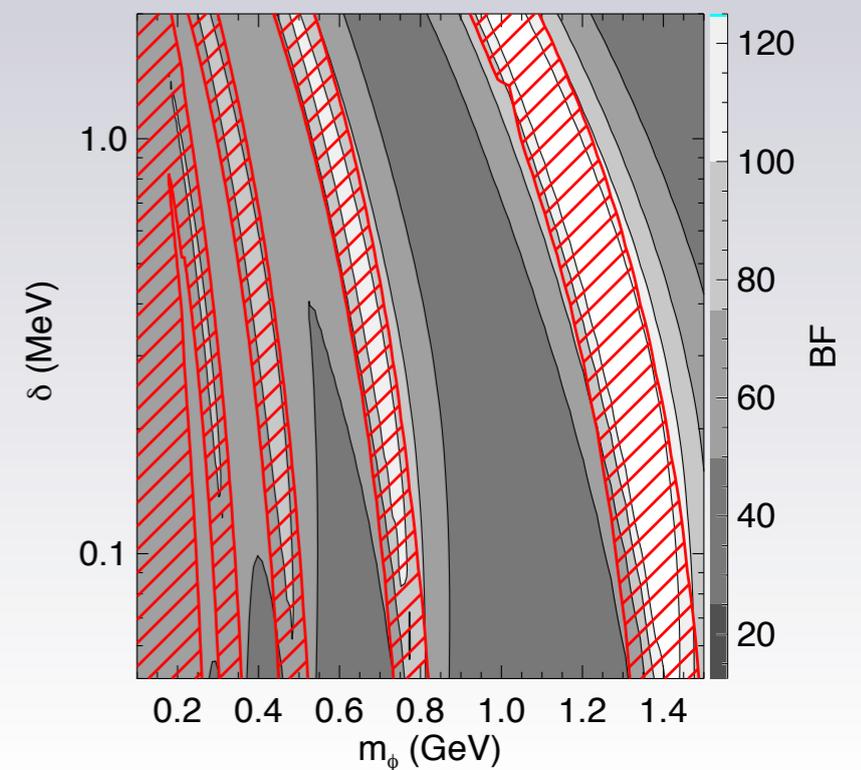
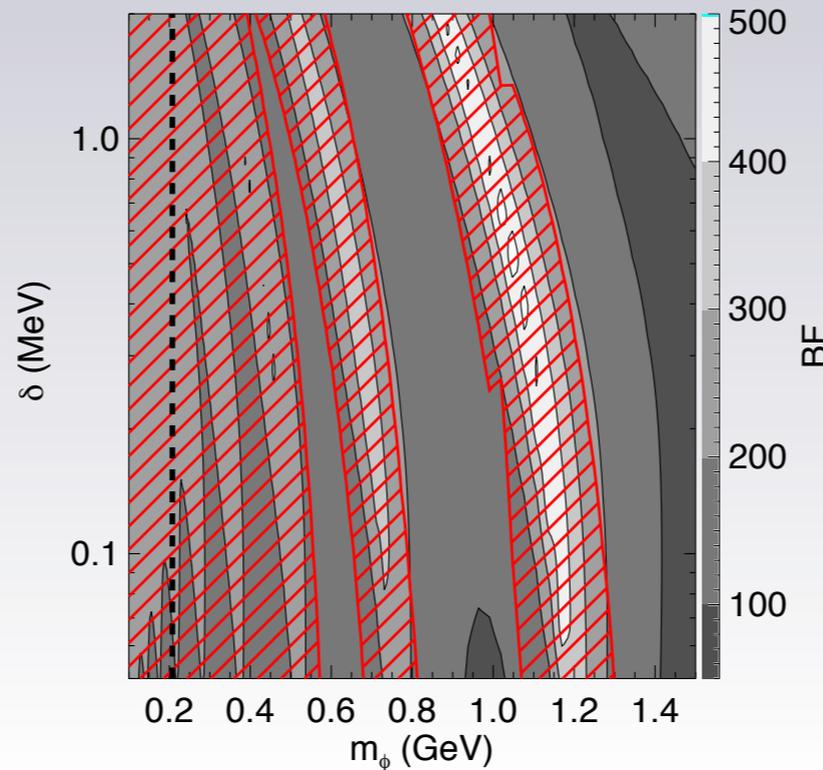
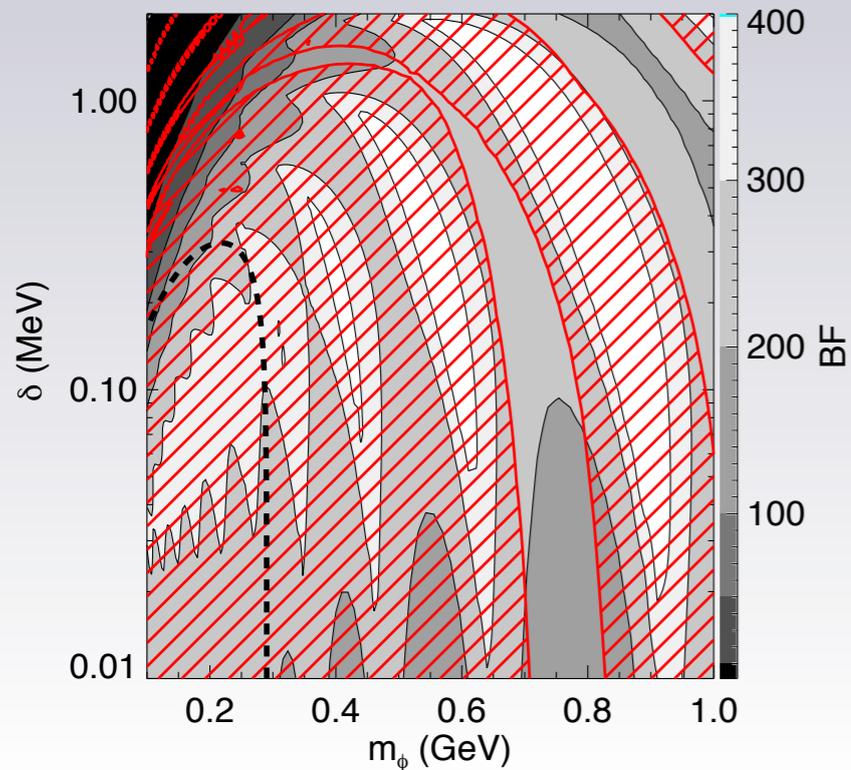
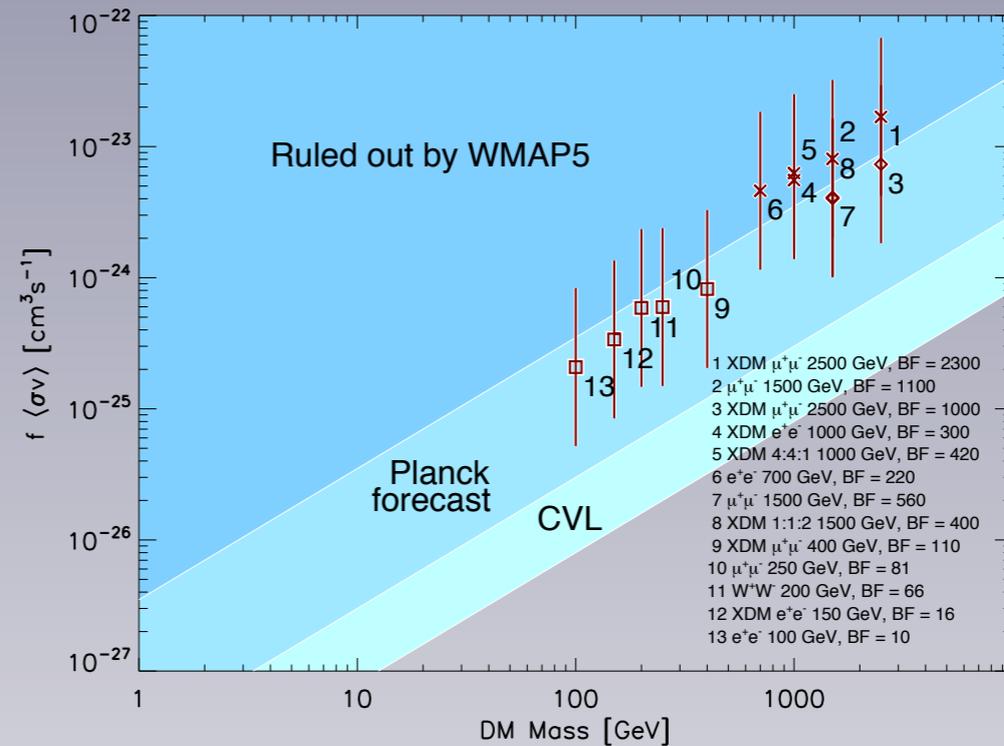
*Results agree over same parameter space*

# WHAT ARE THE LIMITS?

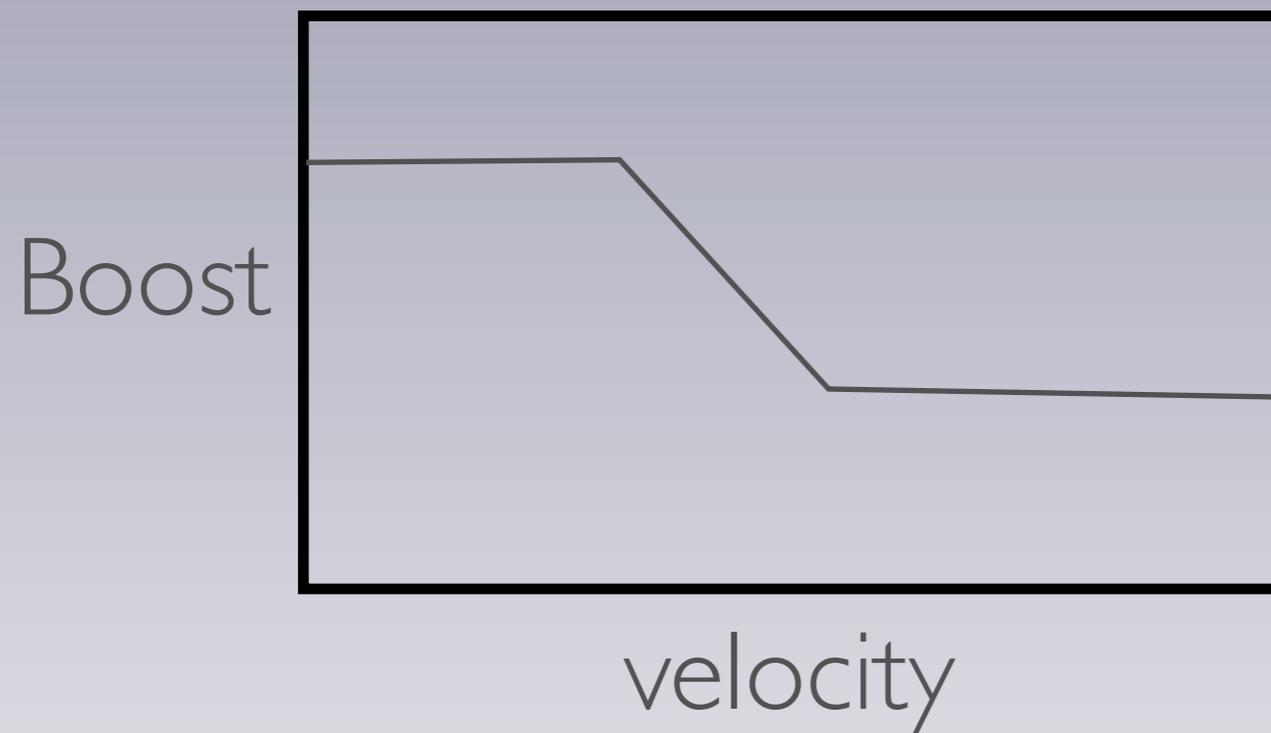


# CMB CONSTRAINTS

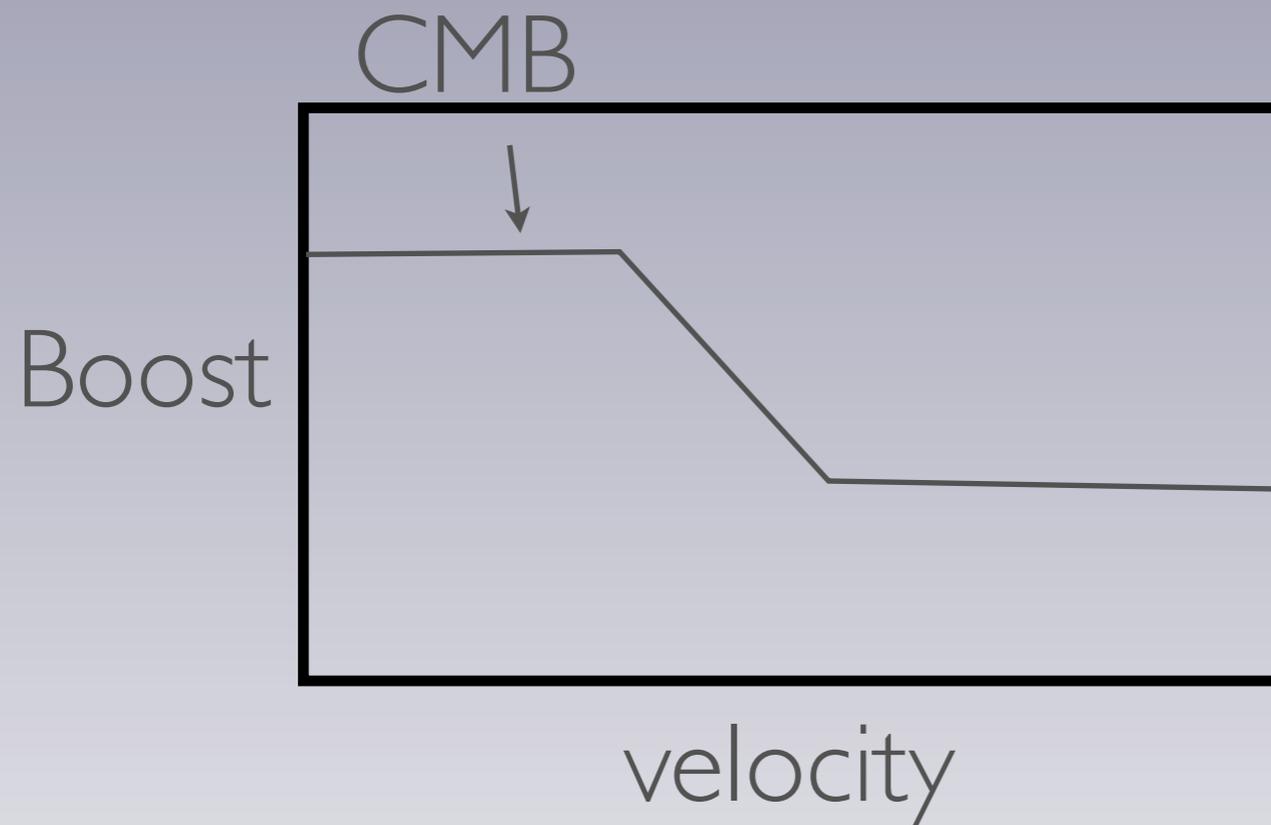
Finkbeiner, Padmanabhan '05; Galli,  
Iocco, Bertone, Melchiorri '09; Slatyer,  
Padmanabhan, Finkbeiner, '09



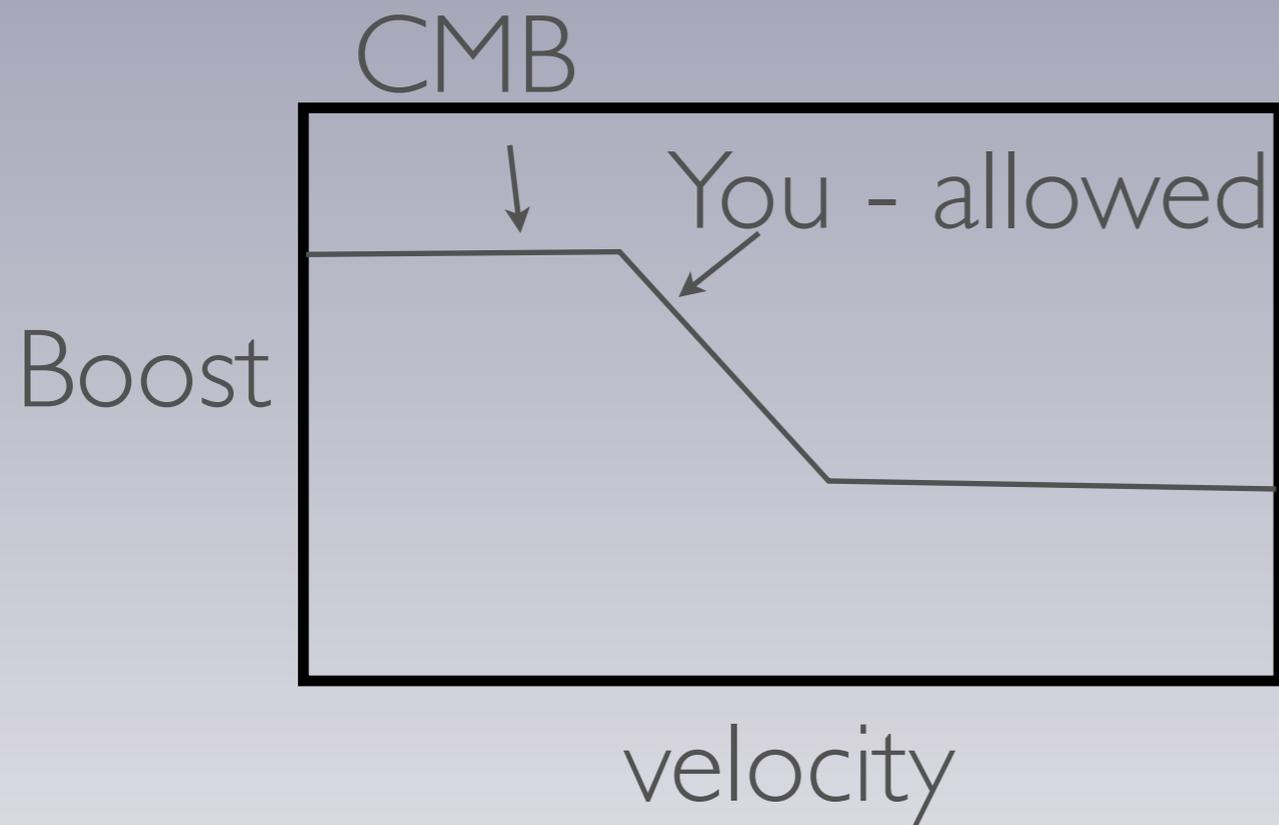
# LOW MASSES = BIG BOOSTS AT LOW VELOCITIES



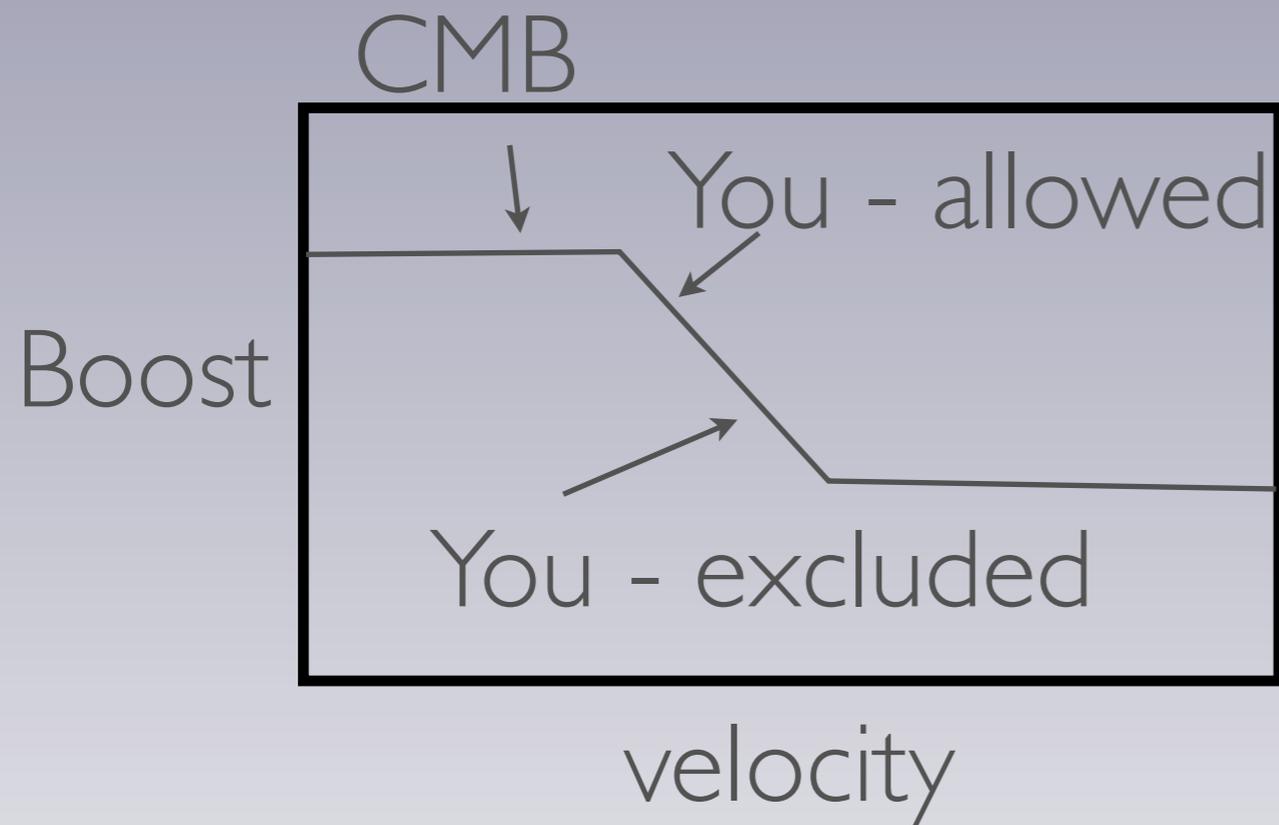
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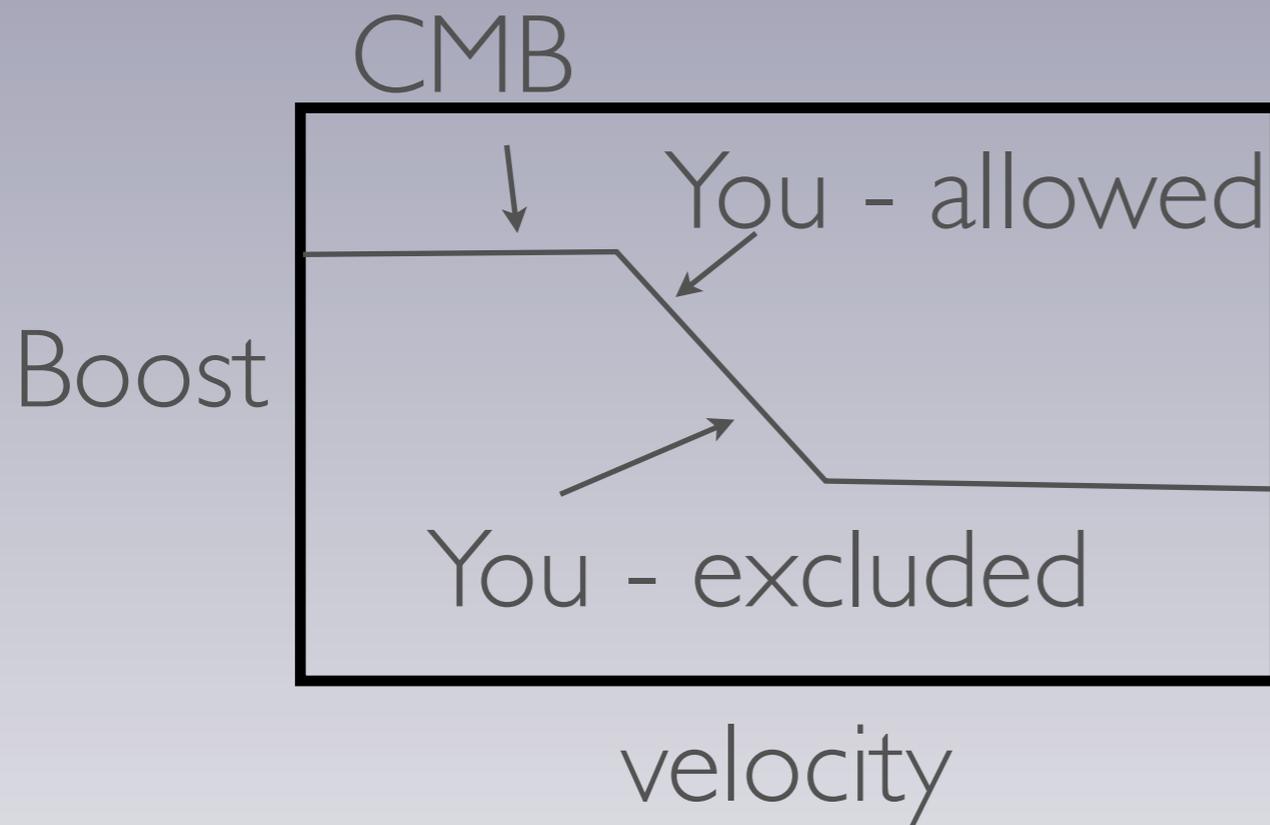
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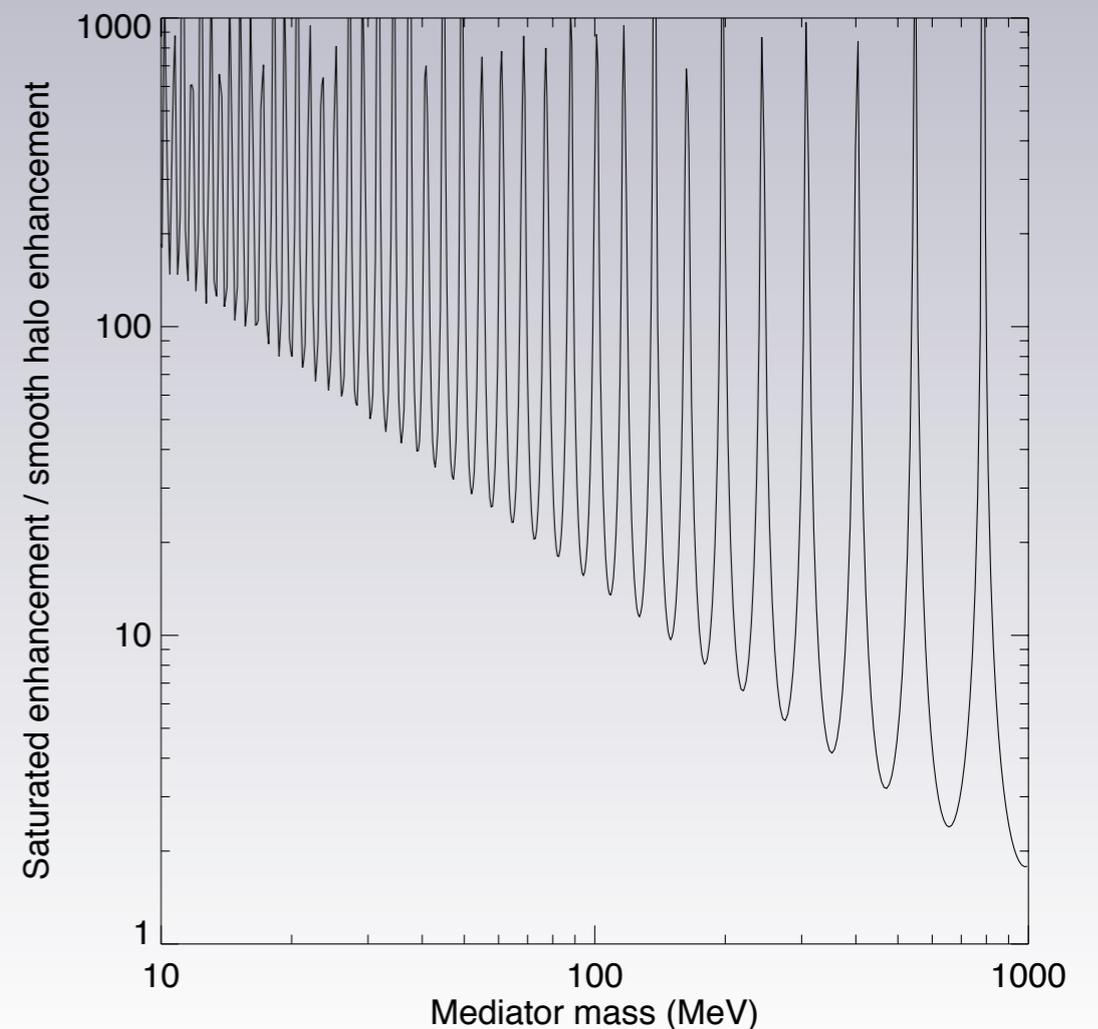
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Light mediators  
seem in trouble!



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What is the effect of substructure on the *local* signal?

$$\langle \rho^2 \rangle = \rho_{smooth}^2 + \rho_{sub}^2$$

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That simulation missed important effects  
- A. Zenter response to comment

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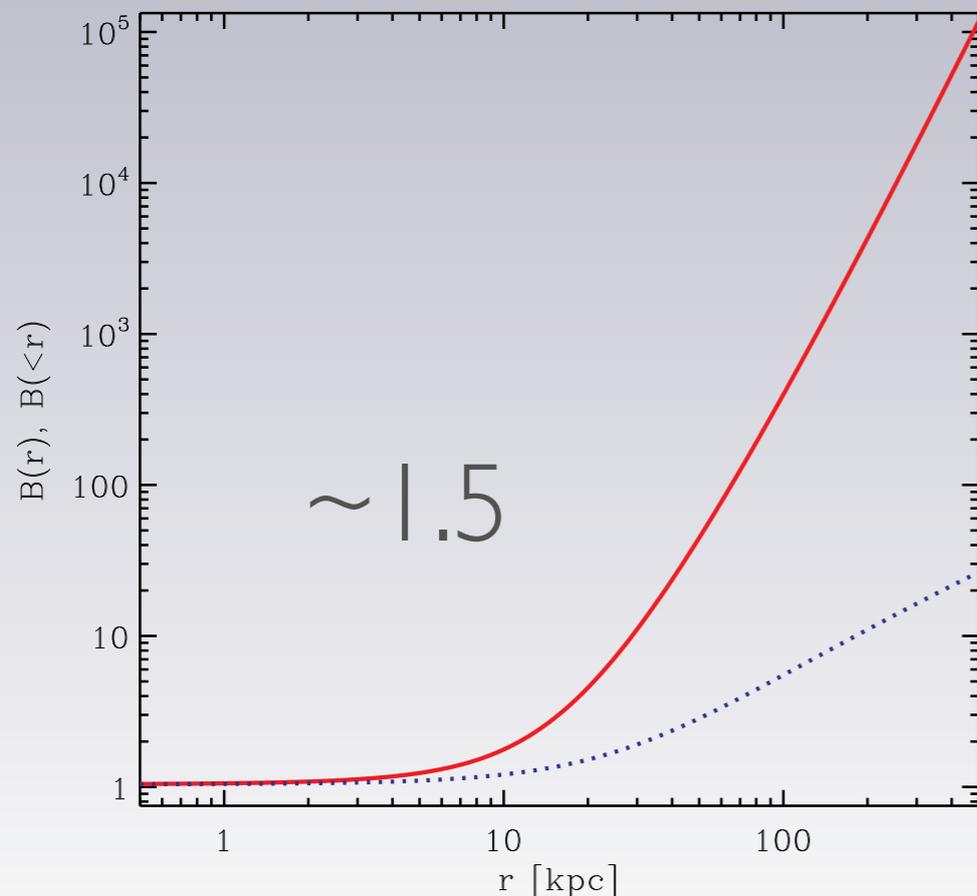
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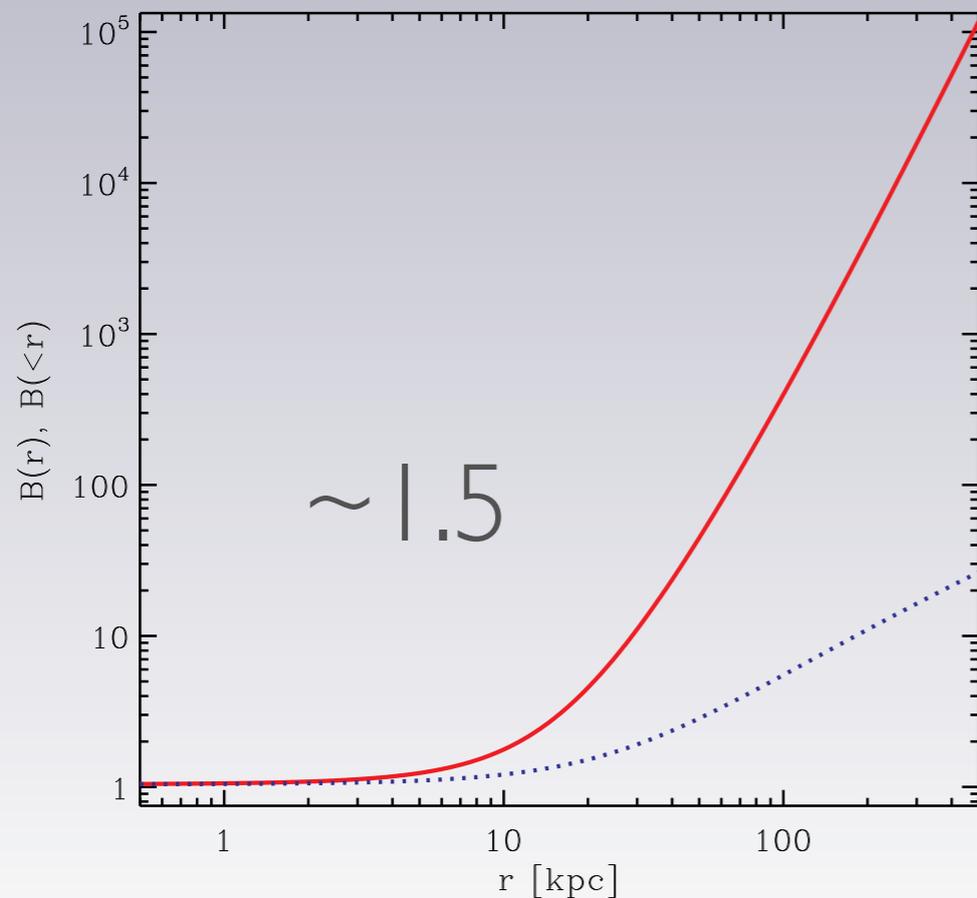


Kamionkowski, Koushiappas, Kuhlen '10

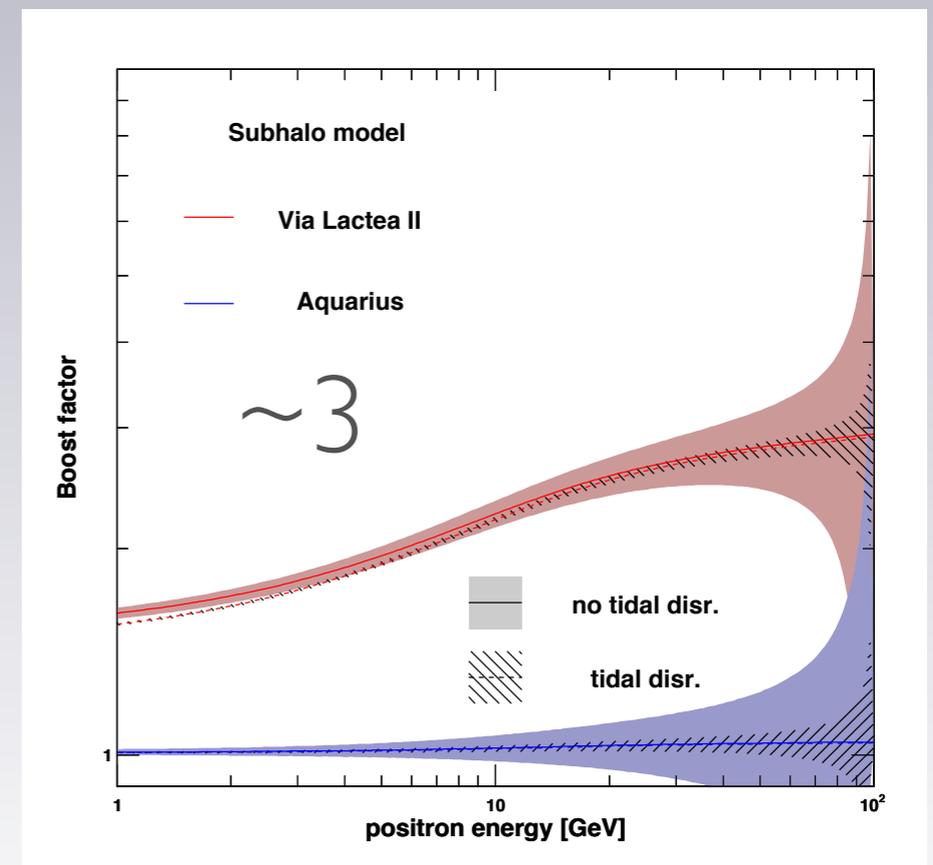
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Kamionkowski, Koushiappas, Kuhlen '10



Pieri, Lavalle, Bertone, Branchini, '10

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~200 km/s

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$\sim 200$  km/s

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Substructure is dominated by *saturated* Sommerfeld  
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Lattanzi + Silk '09, Kamionkowski, Koushiappas, Kuhlen, '09, others...

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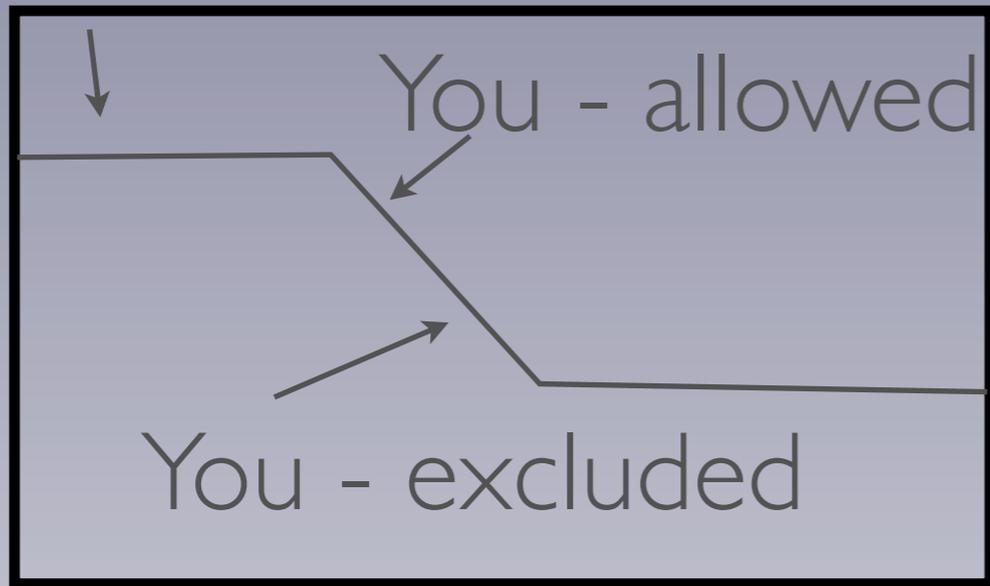
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Lattanzi + Silk '09, Kamionkowski, Koushiappas, Kuhlen, '09, others...

$$\langle \sigma v \rho^2 \rangle = \langle \sigma v \rangle S_{200} \rho_{smooth}^2 + \langle \sigma v \rangle S_{saturated} \rho_{sub}^2$$

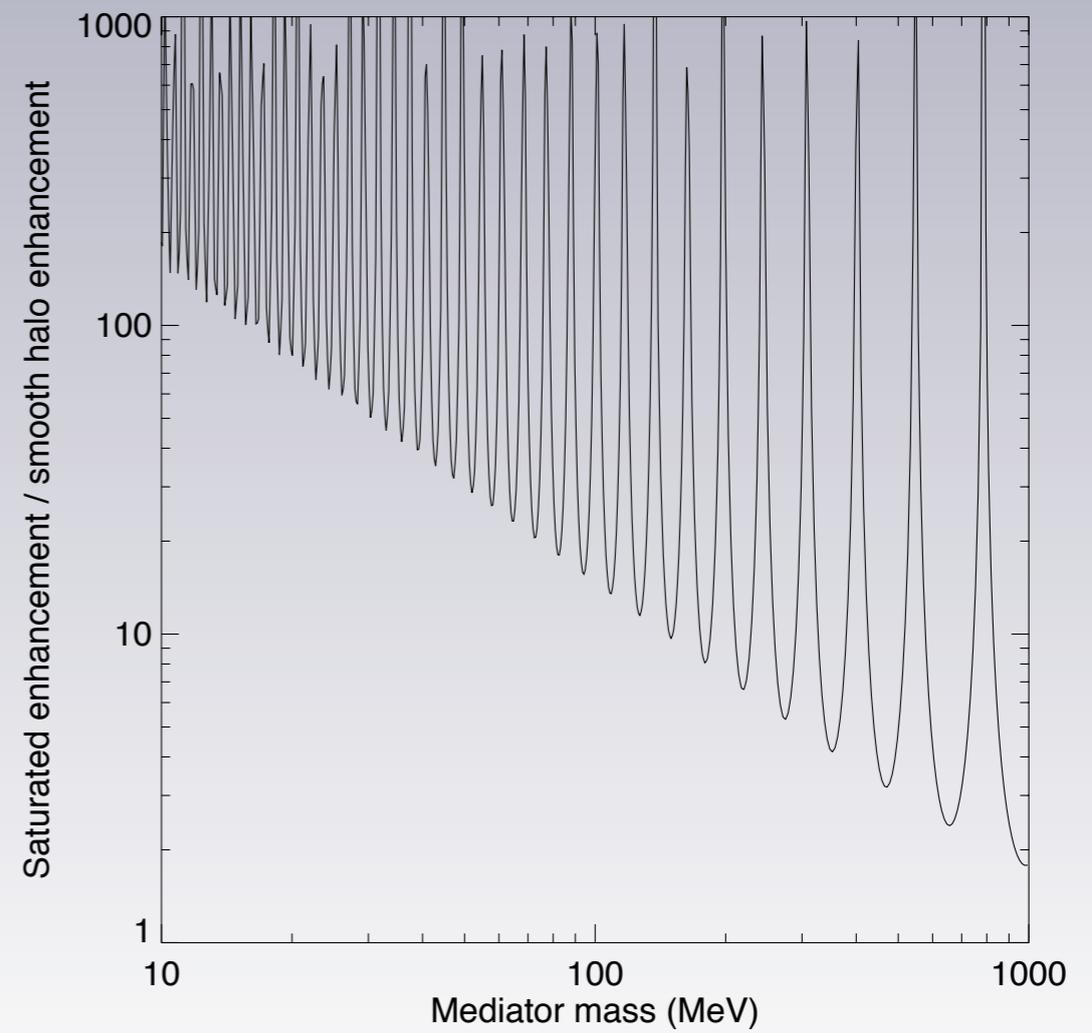
$\uparrow$   
can dominate

CMB



Boost

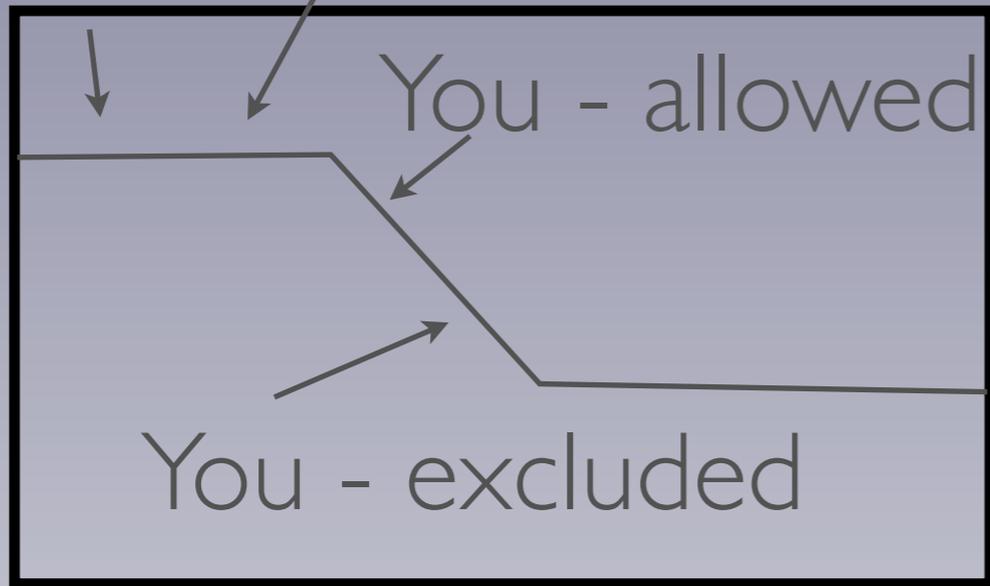
velocity



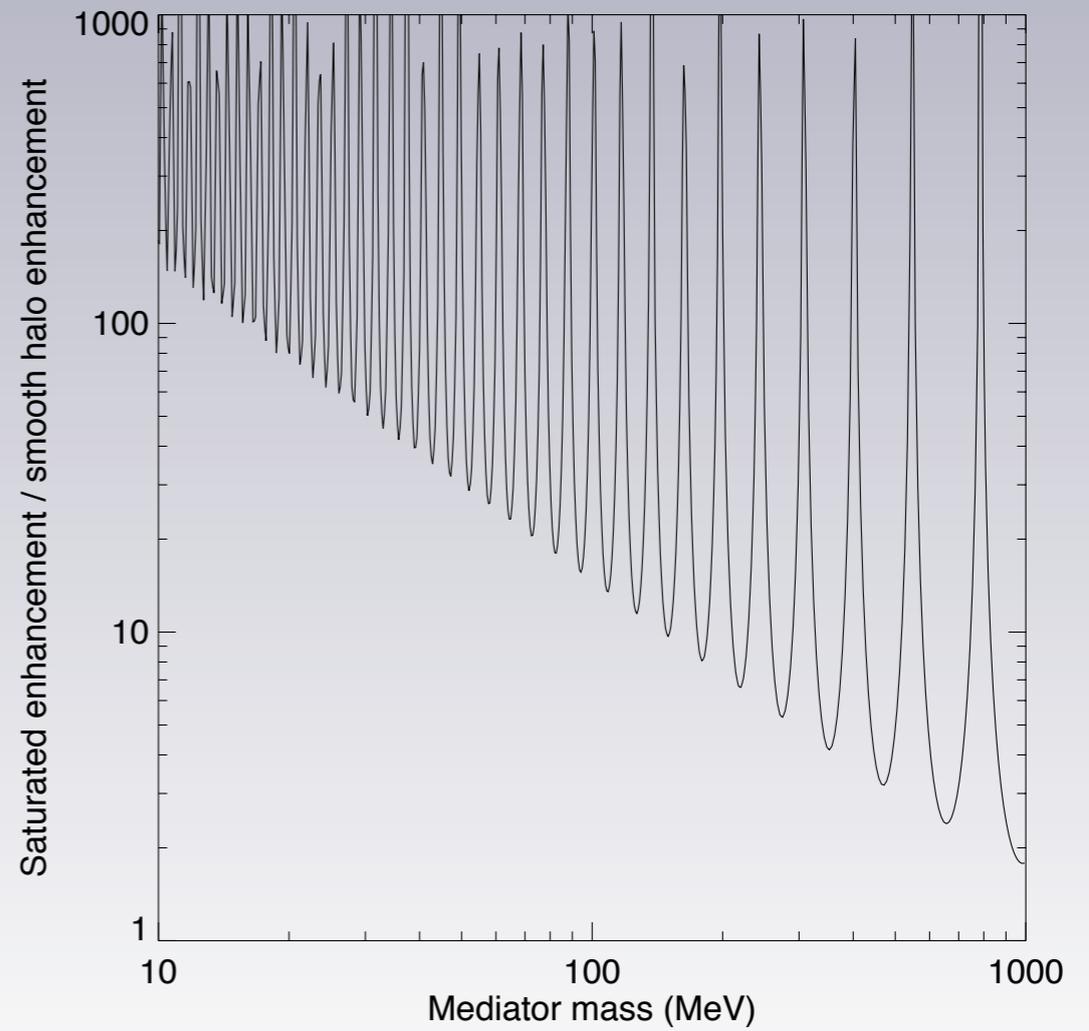
CMB

You - saturated, allowed

Boost

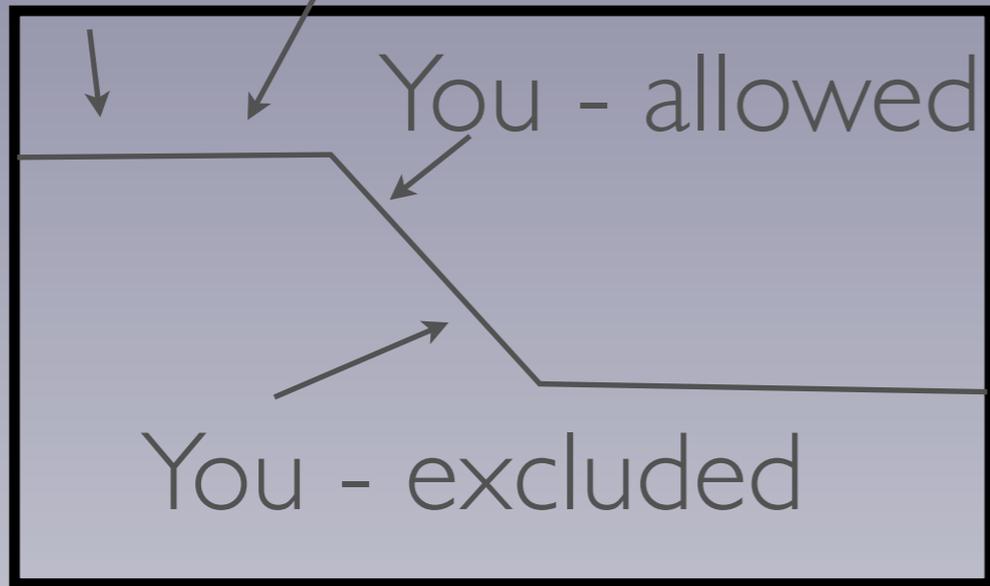


velocity

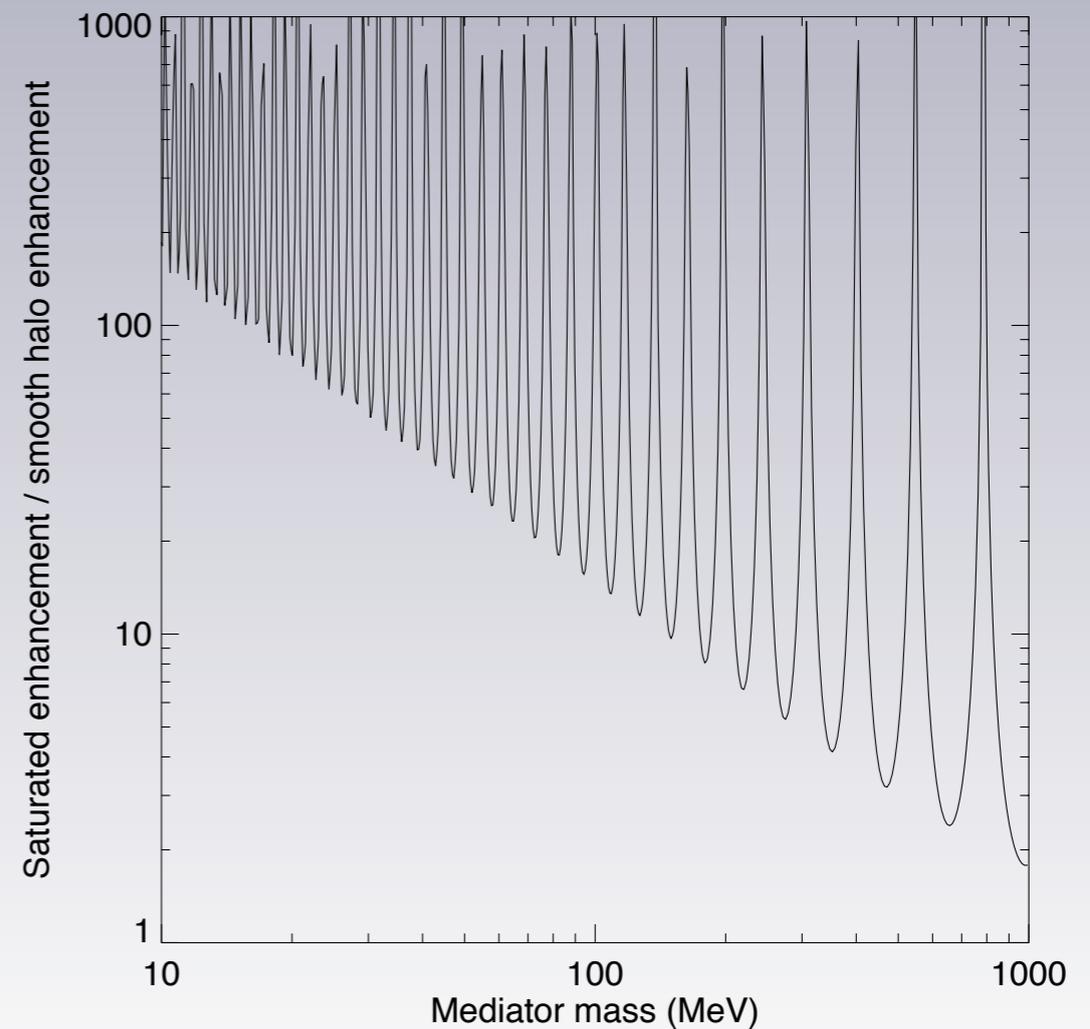


CMB

You - saturated, allowed

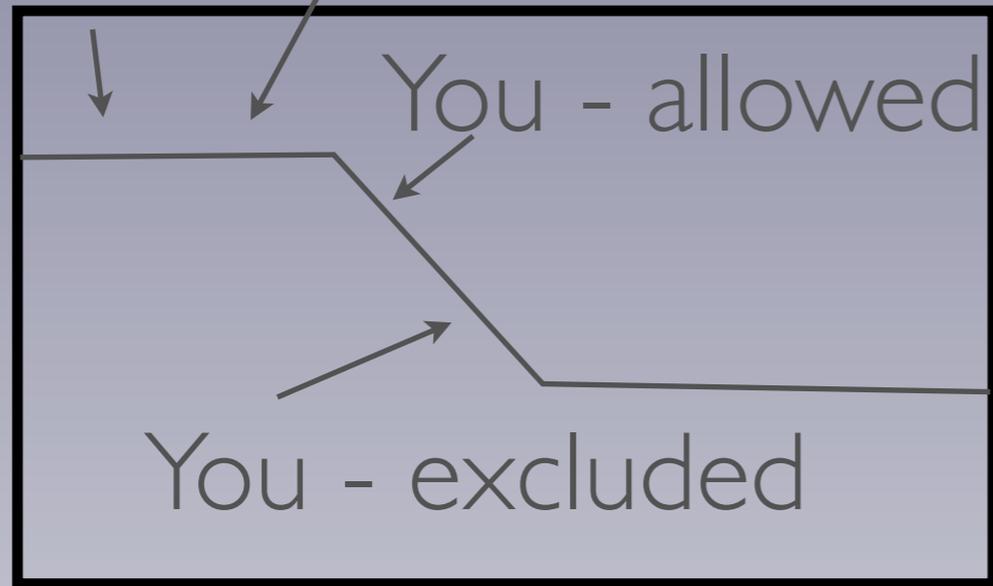


CMB constraints weaken



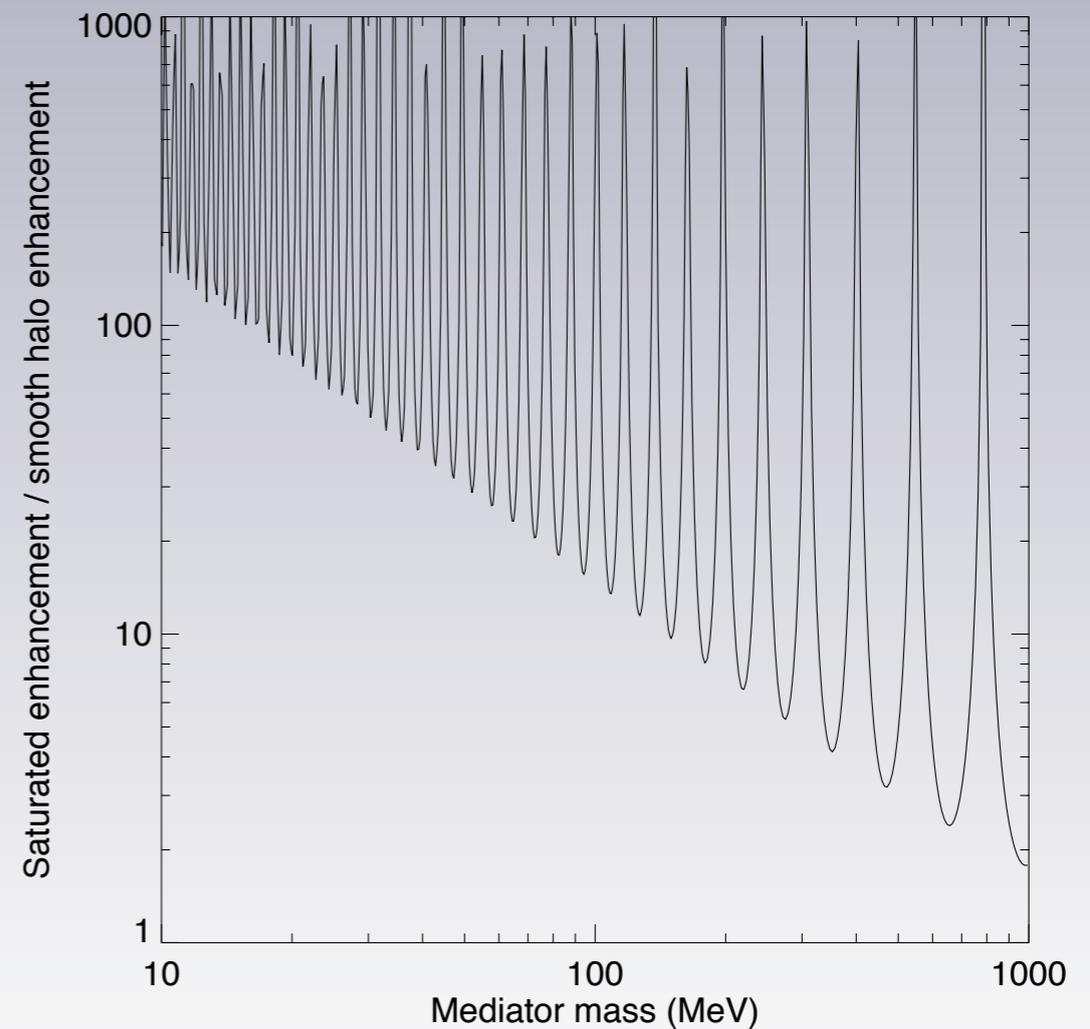
CMB

You - saturated, allowed



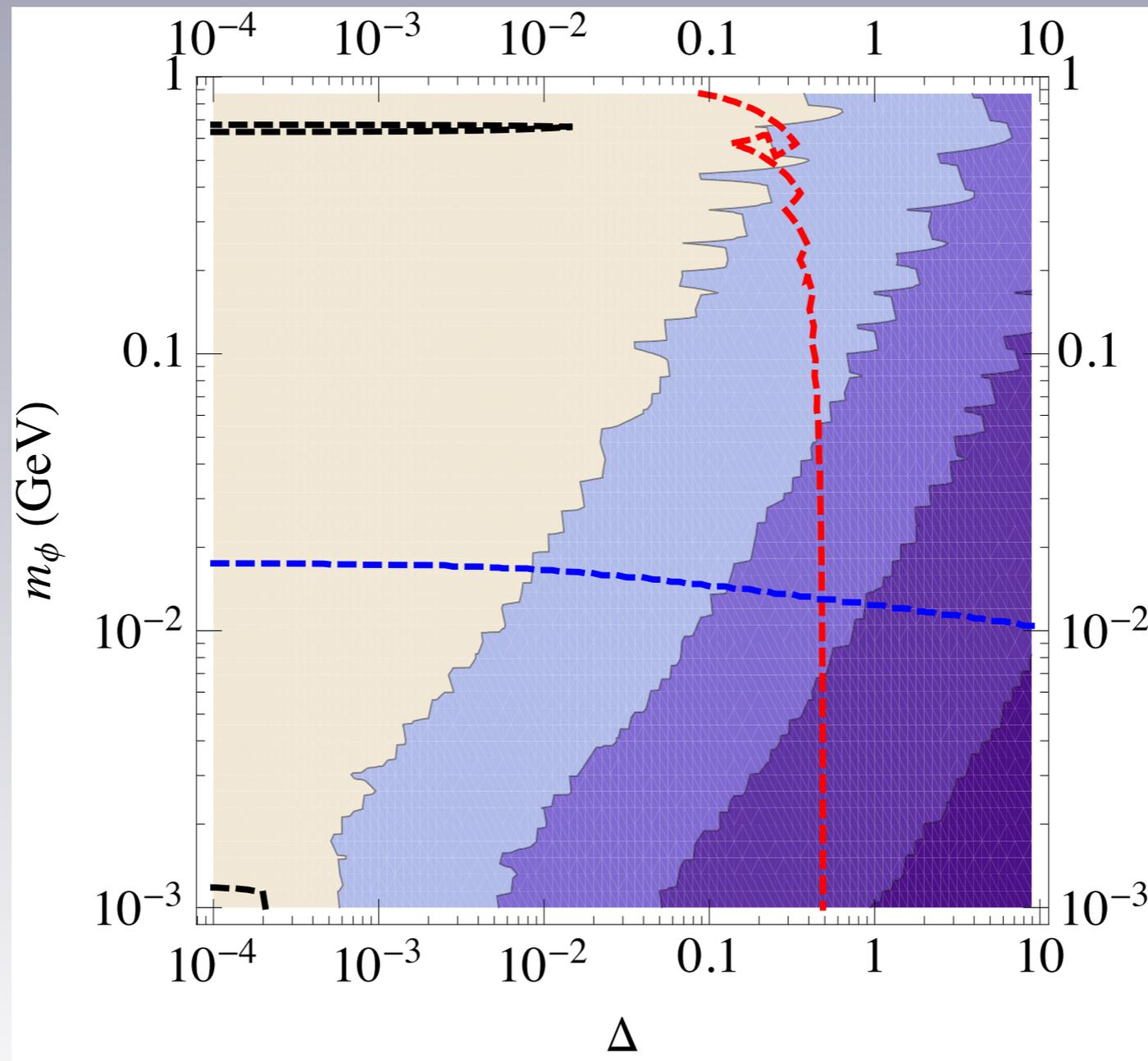
CMB constraints weaken

Big boosts allowed w/  
consistent relic abundance



# CONSTRAINTS WITH SUBSTRUCTURE

(in progress)

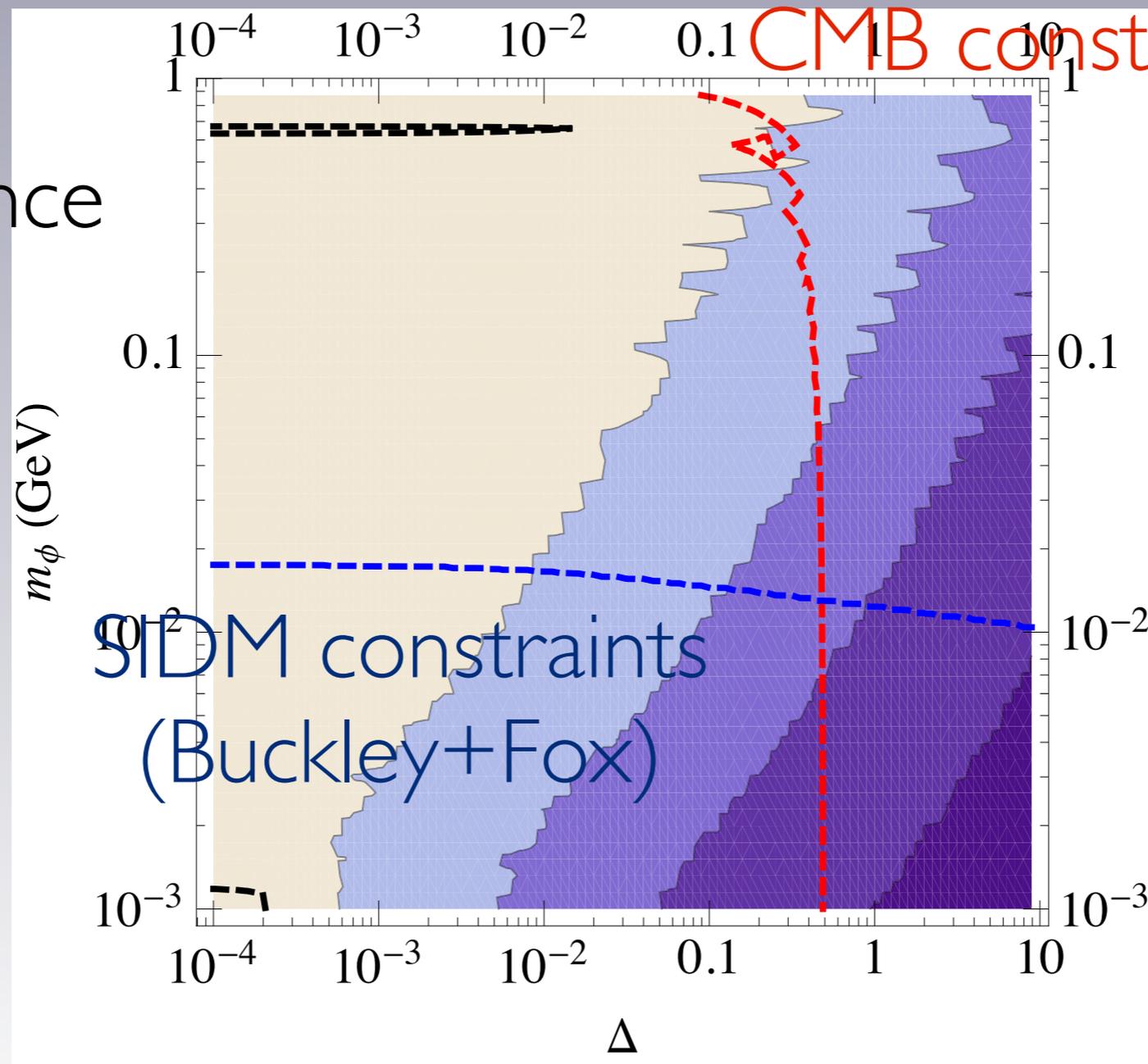


$$\langle \rho^2 \rangle = \rho_{smooth}^2 + \rho_{sub}^2 = \rho_{smooth}^2 (1 + \Delta)$$

# CONSTRAINTS WITH SUBSTRUCTURE

Relic Abundance

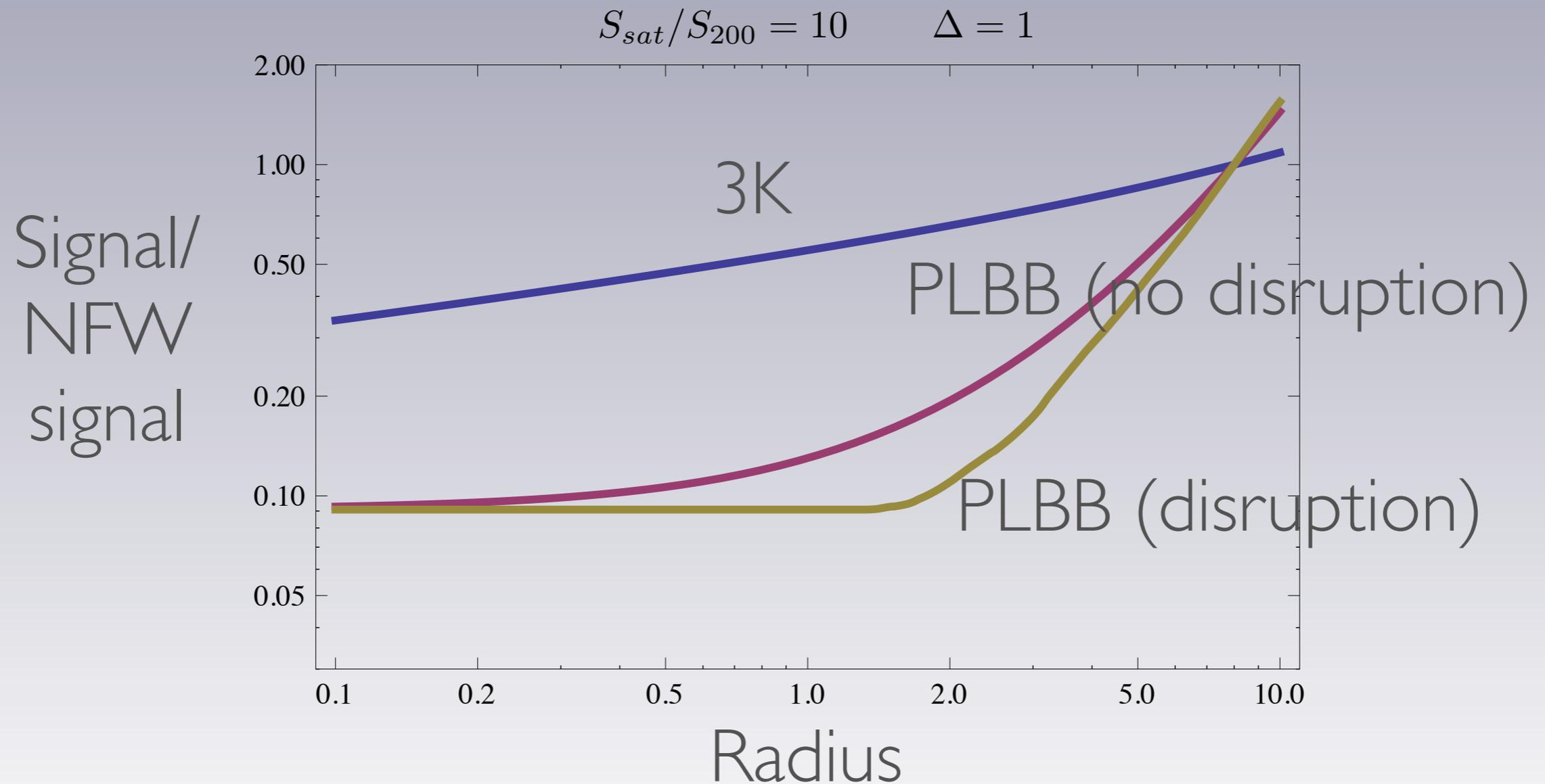
(in progress)



$$\langle \rho^2 \rangle = \rho_{smooth}^2 + \rho_{sub}^2 = \rho_{smooth}^2 (1 + \Delta)$$

# GALACTIC CENTER

Tidal disruption depletes structure in inner galaxy



Suppresses naive GC signal by 3 - lots





Makes e+e-



Makes e+e-



Makes e+e-

Right OOM



Makes e+e-

Right OOM



Makes e+e-

Right OOM

exists?



Makes e+e-

Right OOM

exists



Makes e+e-

Right OOM

exists?



Makes e+e-

Right OOM

exists

Really want to test, irrespective of what *can* explain it

# STATUS OF SOMMERFELD MODELS

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- More data can only help