

# Searching for the $A'$ Boson

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Searching for a New Gauge Boson at JLab

Jefferson Laboratory, Sept. 20th, 2010

# Outline

- Theory
- Indirect Searches
- Direct Searches

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- Theory
- Indirect Searches
  - Fermi, WMAP, ...
- Direct Searches
  - $e^+e^-$  colliders
  - Tevatron & LHC
  - fixed target

# Theory

## Standard Model

strong    weak    electromagnetic

$g$

$W^{\pm}, Z$

$\gamma$

# Theory

Standard Model

Hidden Sector?

strong

weak

electromagnetic

new force?

$g$

$W^\pm, Z$

$\gamma$

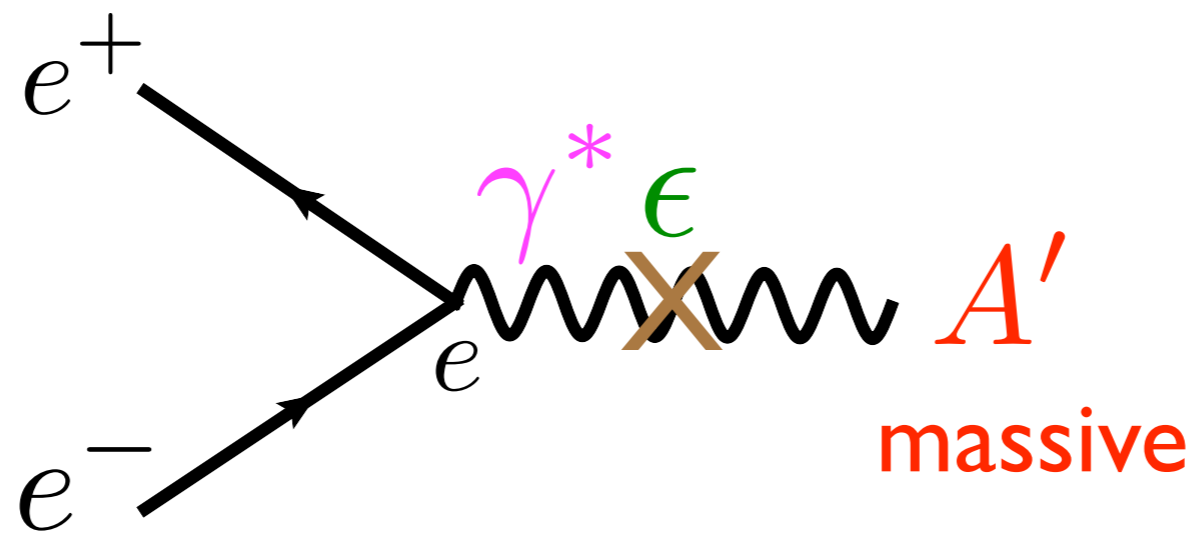
$A'$

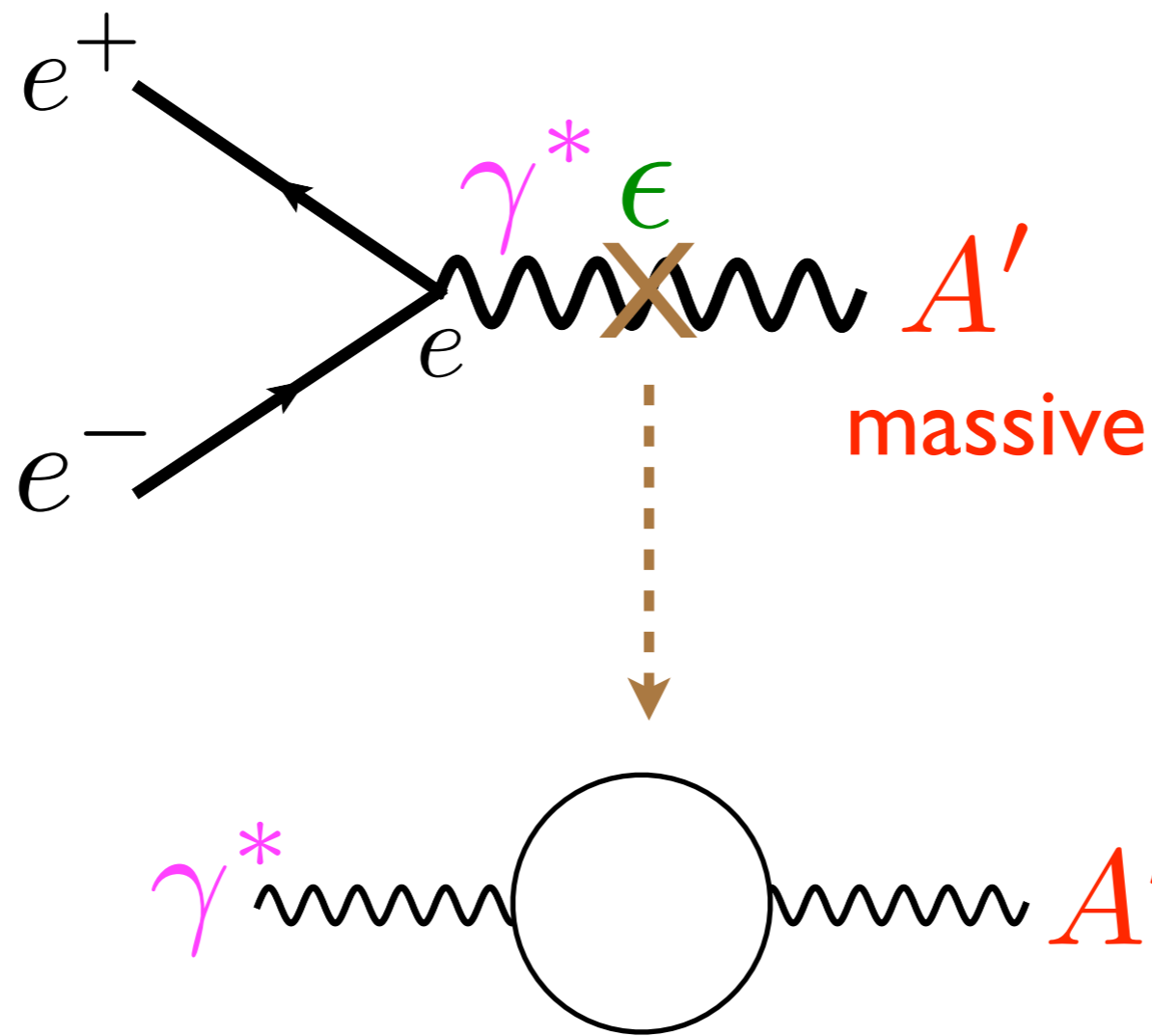
An **exciting** possibility!

# Generic Coupling of Standard Model to a Hidden Sector

Photon can mix with a new Vector Boson  $A'$







$$\Delta\mathcal{L} = \frac{\epsilon}{2} F^{Y,\mu\nu} F'_{\mu\nu}$$

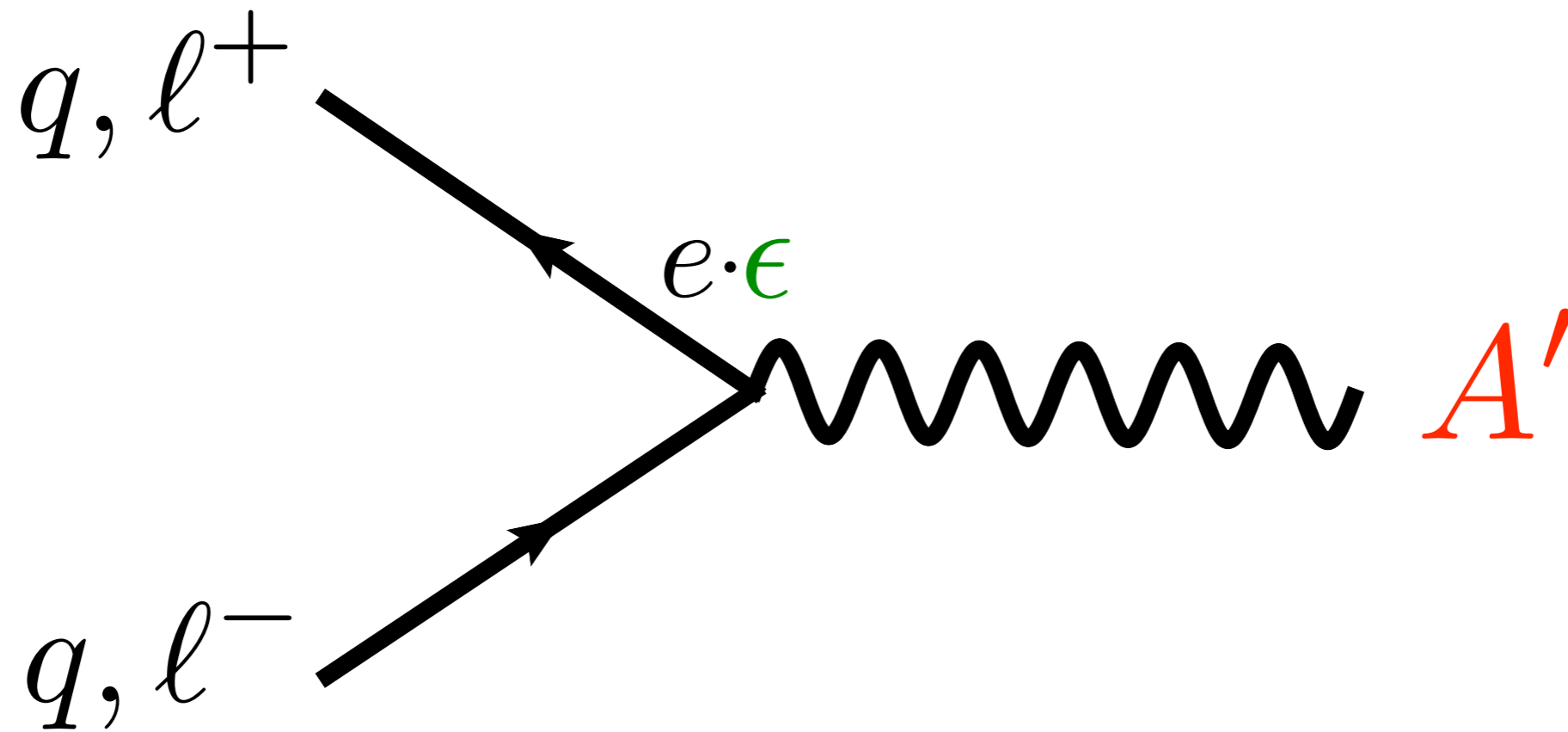
Generated by heavy particles  
interacting with  $\gamma$  and  $A'$

“Kinetic Mixing”

[Holdom]



# Quarks & charged Leptons couple to $A'$

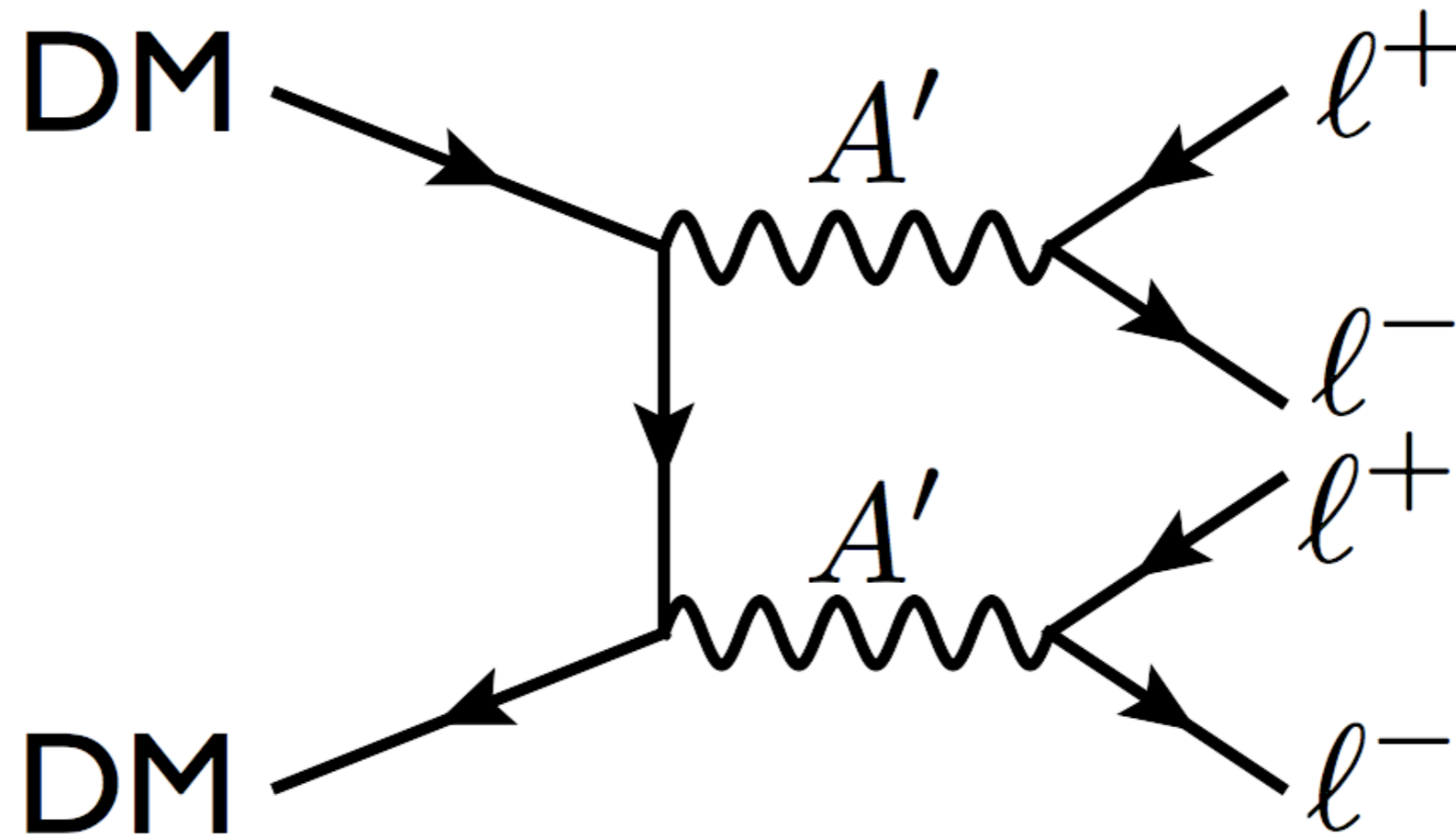


# Outline

- Theory
- Indirect Searches
  - Fermi, WMAP, ... (if  $A'$  couples to DM)
- Direct Searches
  - $e^+e^-$  colliders
  - Tevatron & LHC
  - fixed target

# What if dark matter annihilates to $A'$ 's?

Arkani-Hamed, Finkbeiner, Slatyer, Weiner  
Pospelov & Ritz



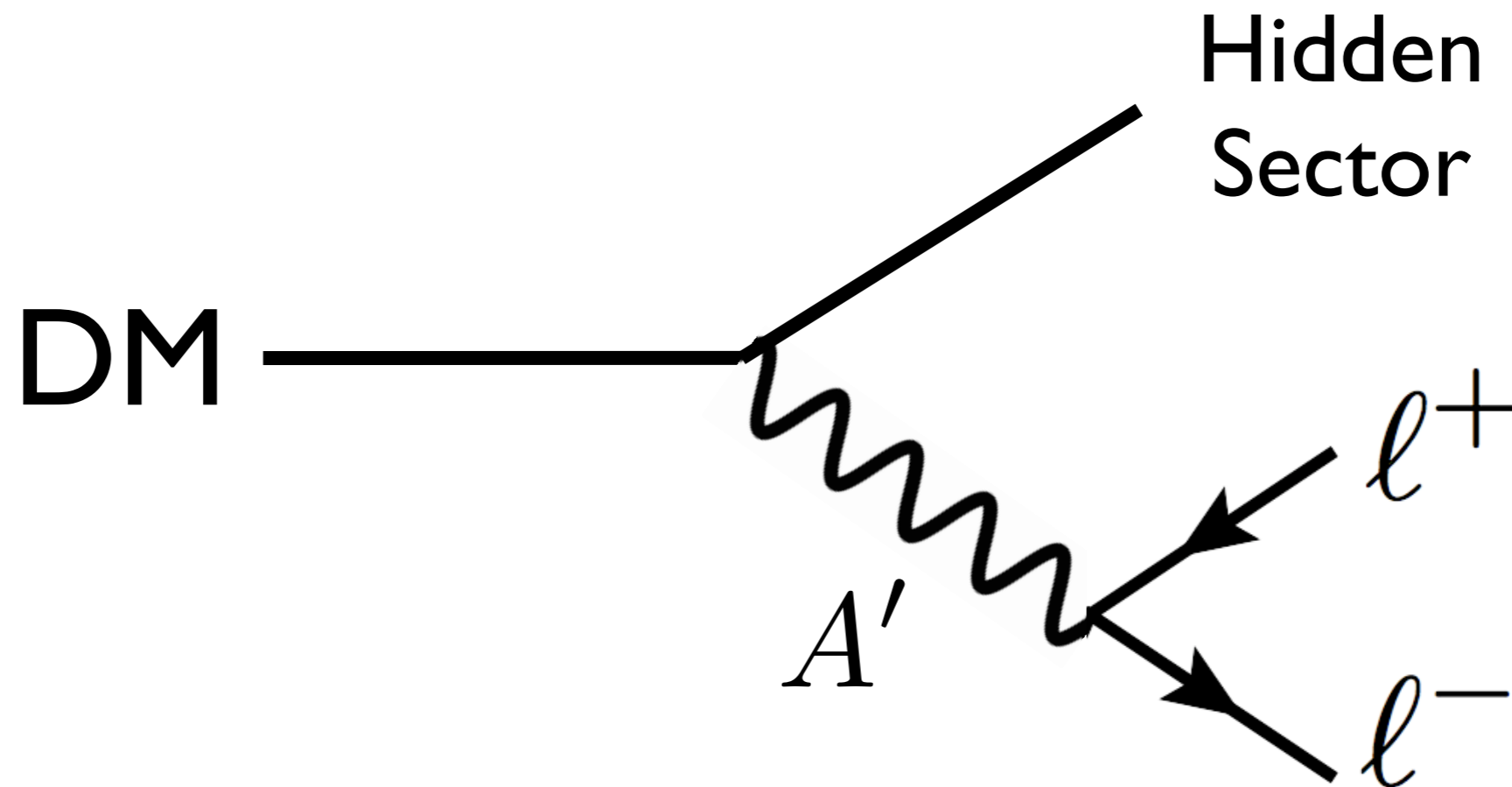
$m_{\text{DM}} \sim \text{TeV}$

$m_{A'} \sim \text{GeV}$

# Or what if dark matter decays to $A'$ 's?

[Ruderman, Volansky]

[RE, Kaplan, Schuster, Toro]

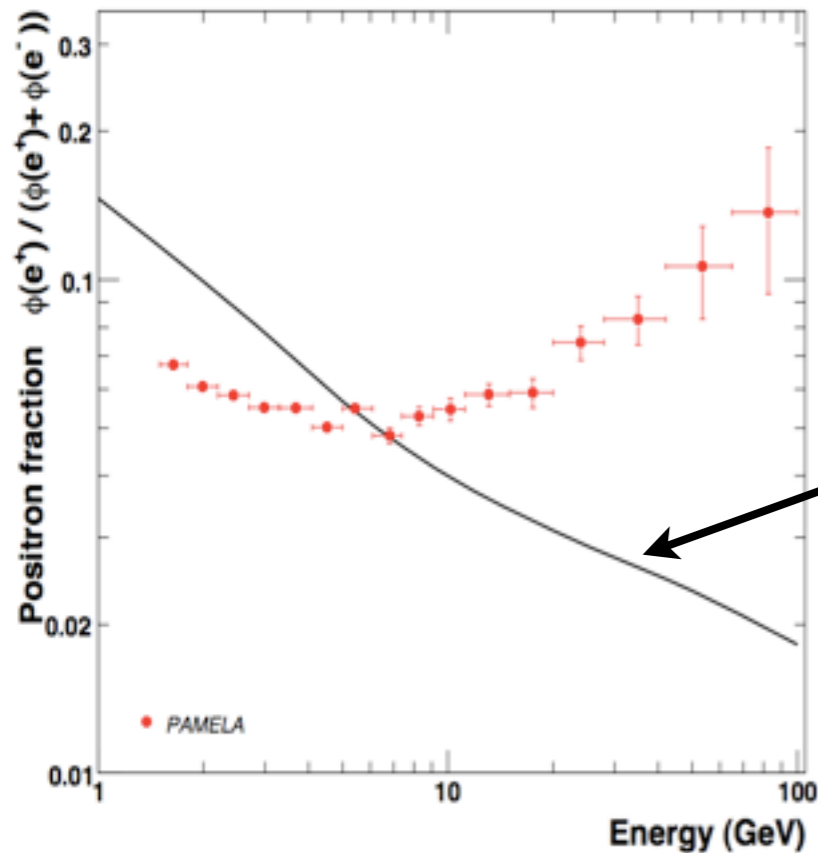


$$m_{DM} \sim \text{TeV}$$

$$m_{A'} \sim \text{GeV}$$

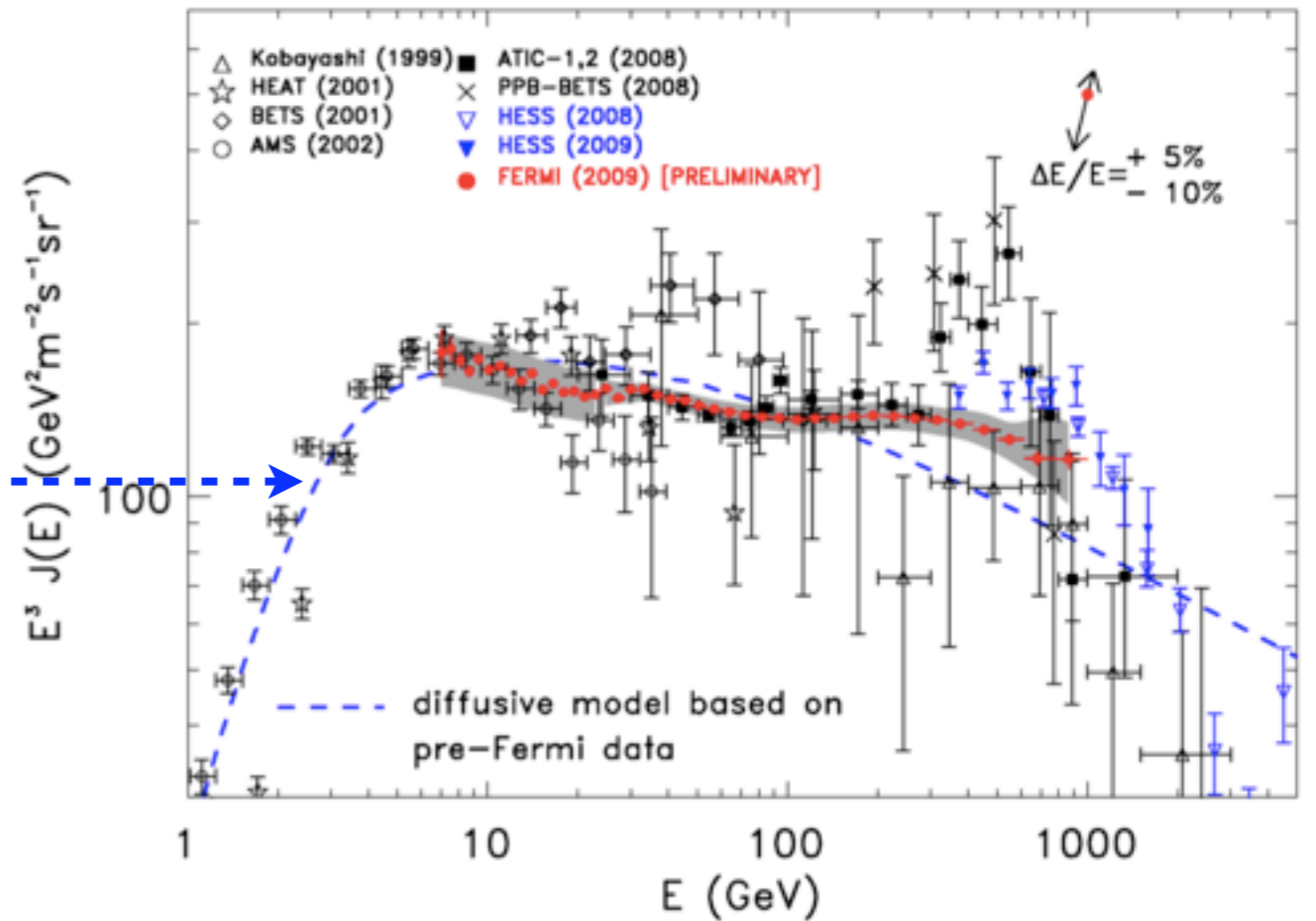
# Get observed cosmic-ray excesses

PAMELA:  $e^+$  fraction



theory  
expectation

Fermi:  $e^+ + e^-$  flux

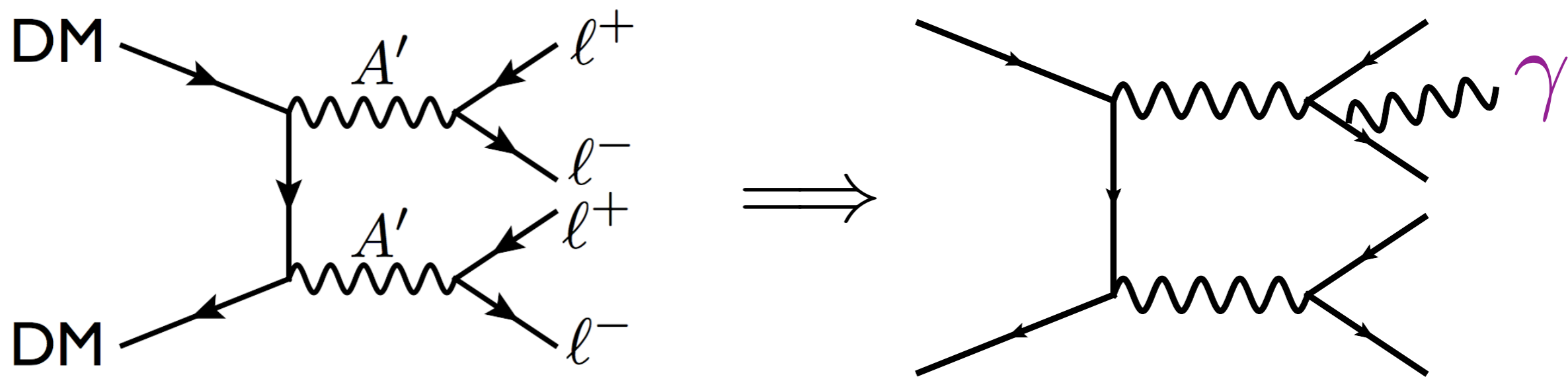


(Improved measurements from AMS-02 ~1-2 year)

Several other interesting consequences...

# Gamma-rays guaranteed

## 1. Final state radiation

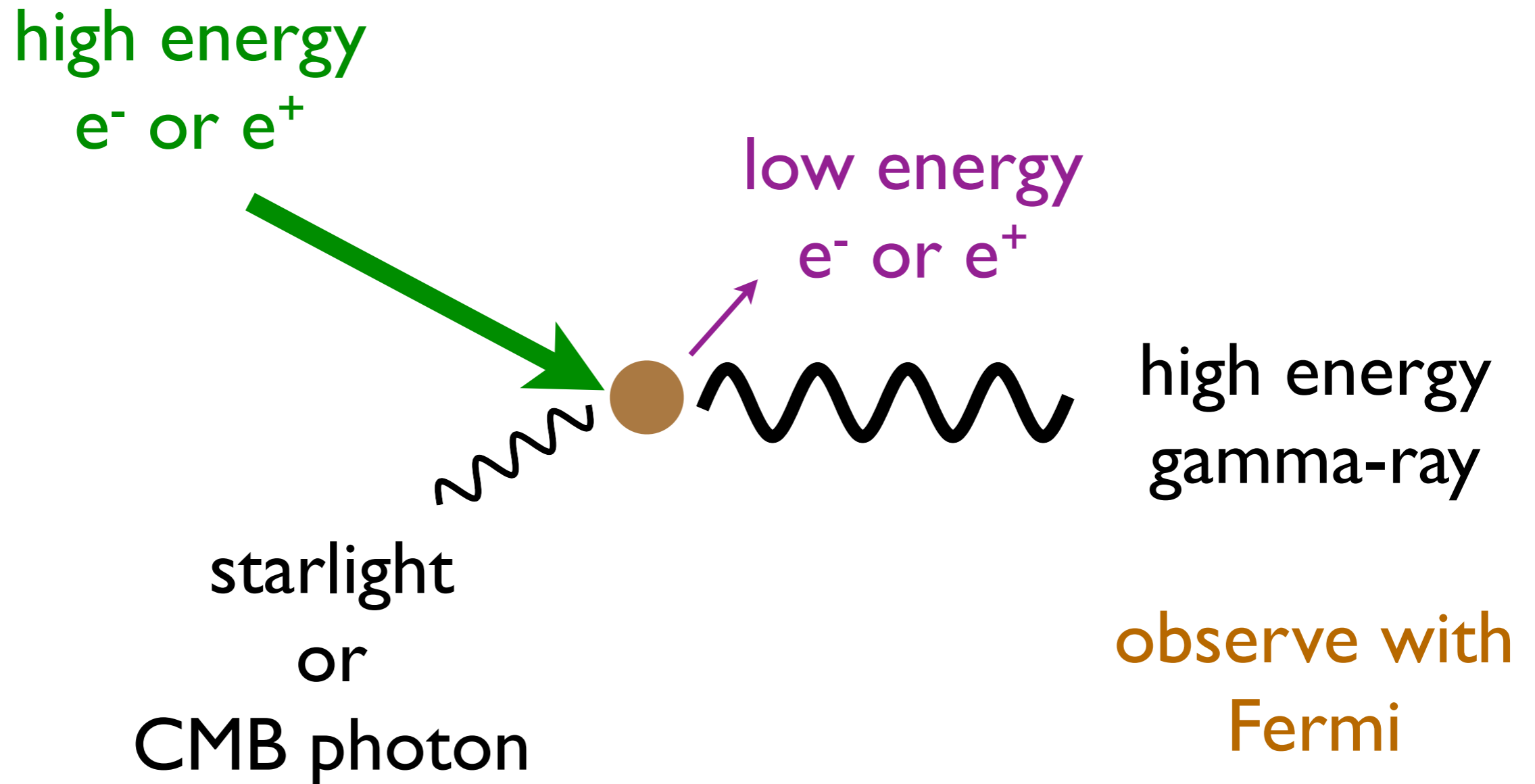


Observe with:

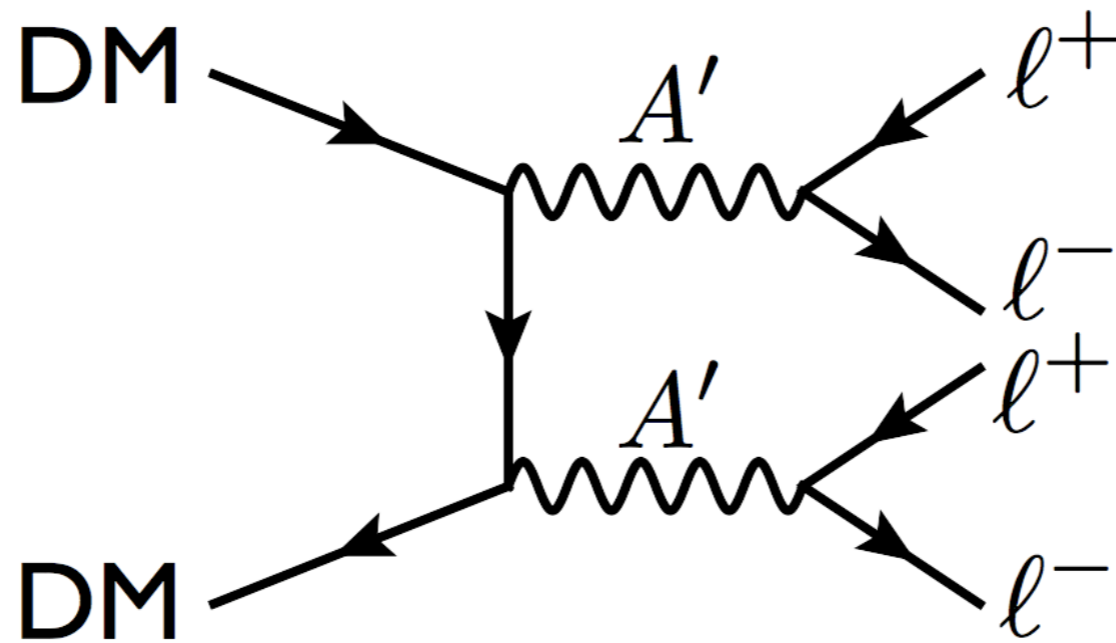
- **Fermi**
- **Atmospheric Cherenkov Telescopes (VERITAS, HESS, MAGIC...)**

# Gamma-rays guaranteed

## 2. Inverse Compton Scattering



# Neutrinos possible



Neutrinos guaranteed if  $l = \mu, \tau$

$$\tau \rightarrow \mu \nu_\mu \nu_\tau, \quad \mu \rightarrow e \nu_e \nu_\mu$$

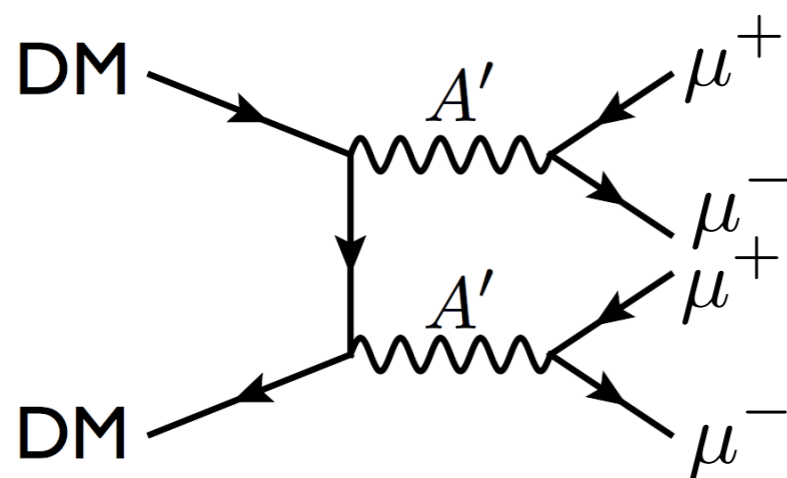
observe with IceCube, Super-K



# No $\gamma$ -ray signal seen with existing data

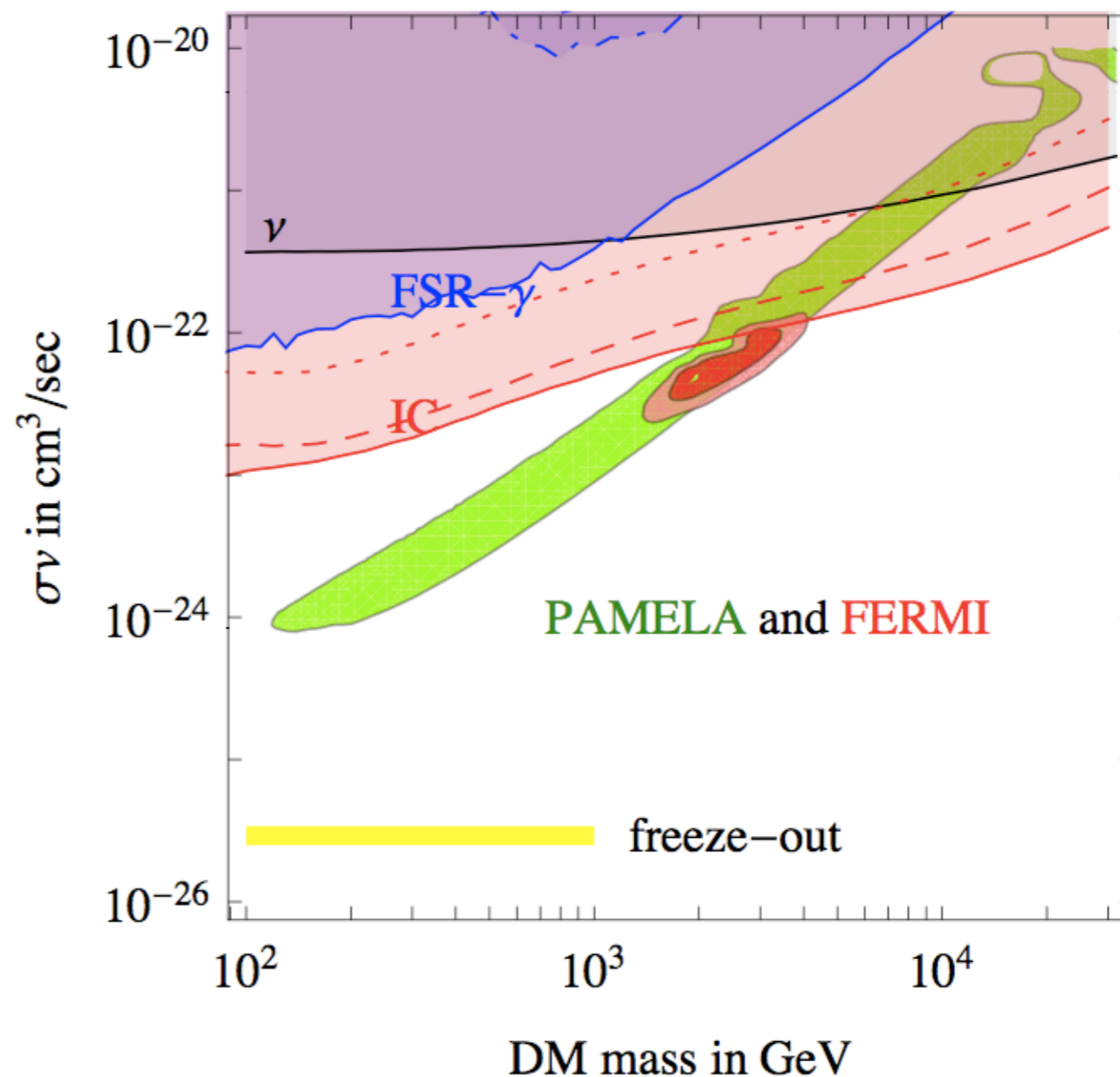
Can set constraints

e.g. for:



constraints from  
Milky-Way halo

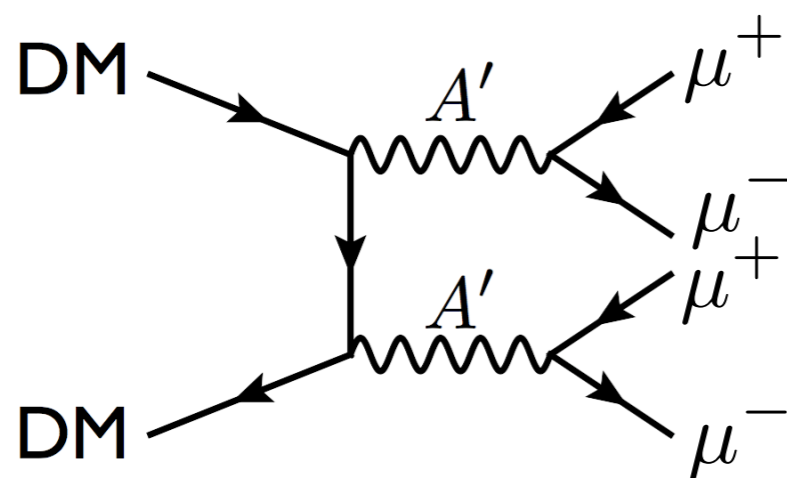
DM DM  $\rightarrow 4\mu$ , isothermal profile



# No $\gamma$ -ray signal seen with existing data

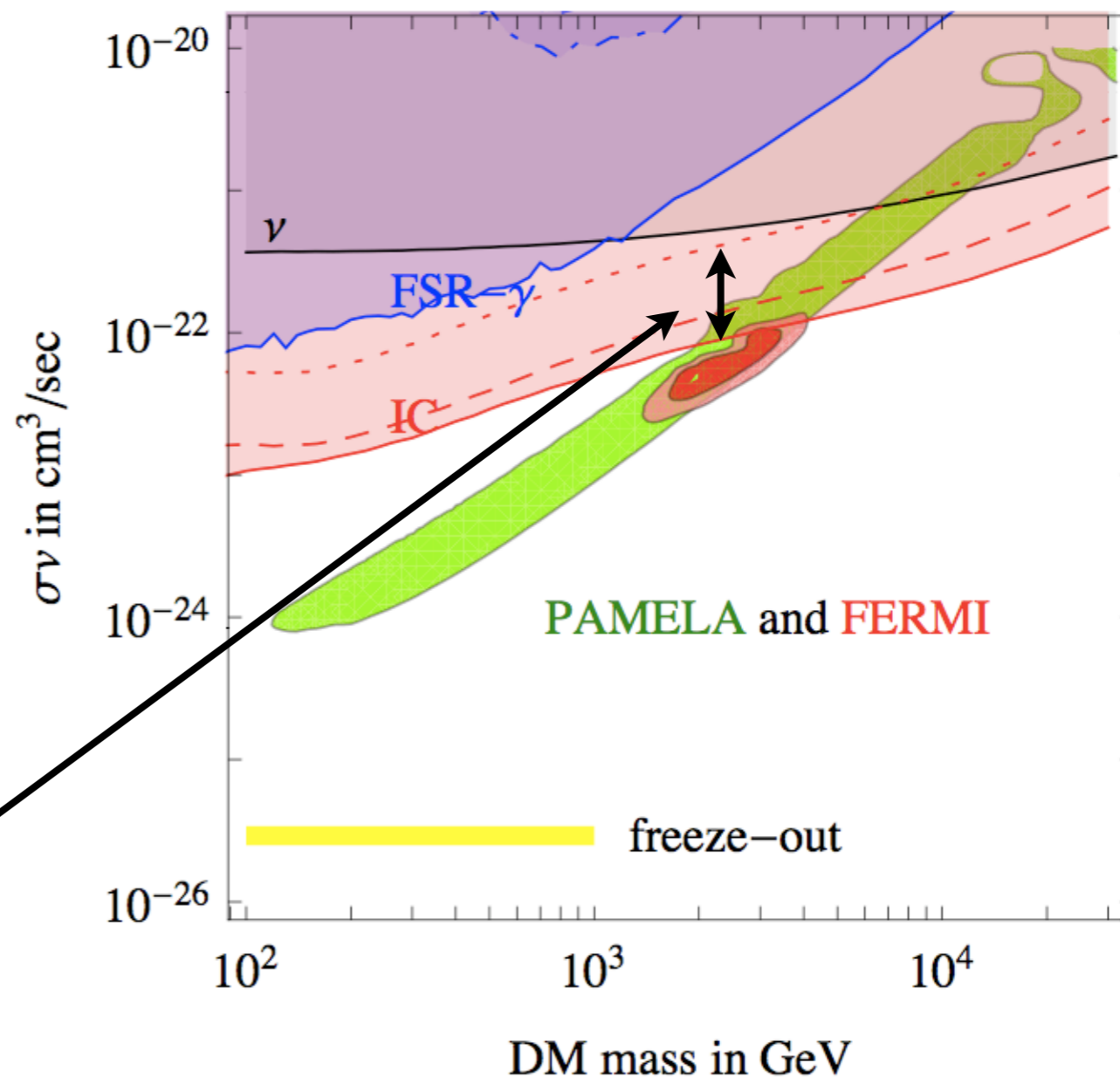
Can set constraints

e.g. for:



constraints depend on diffusion of  $e^+$ ,  $e^-$  in halo

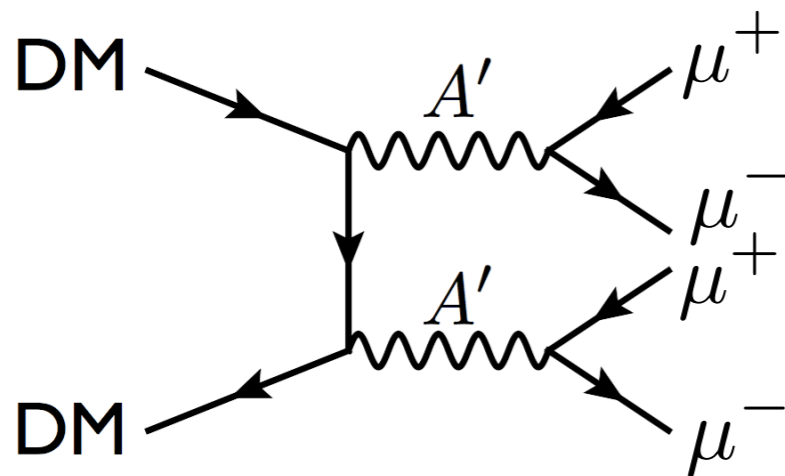
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# No $\gamma$ -ray signal seen with existing data

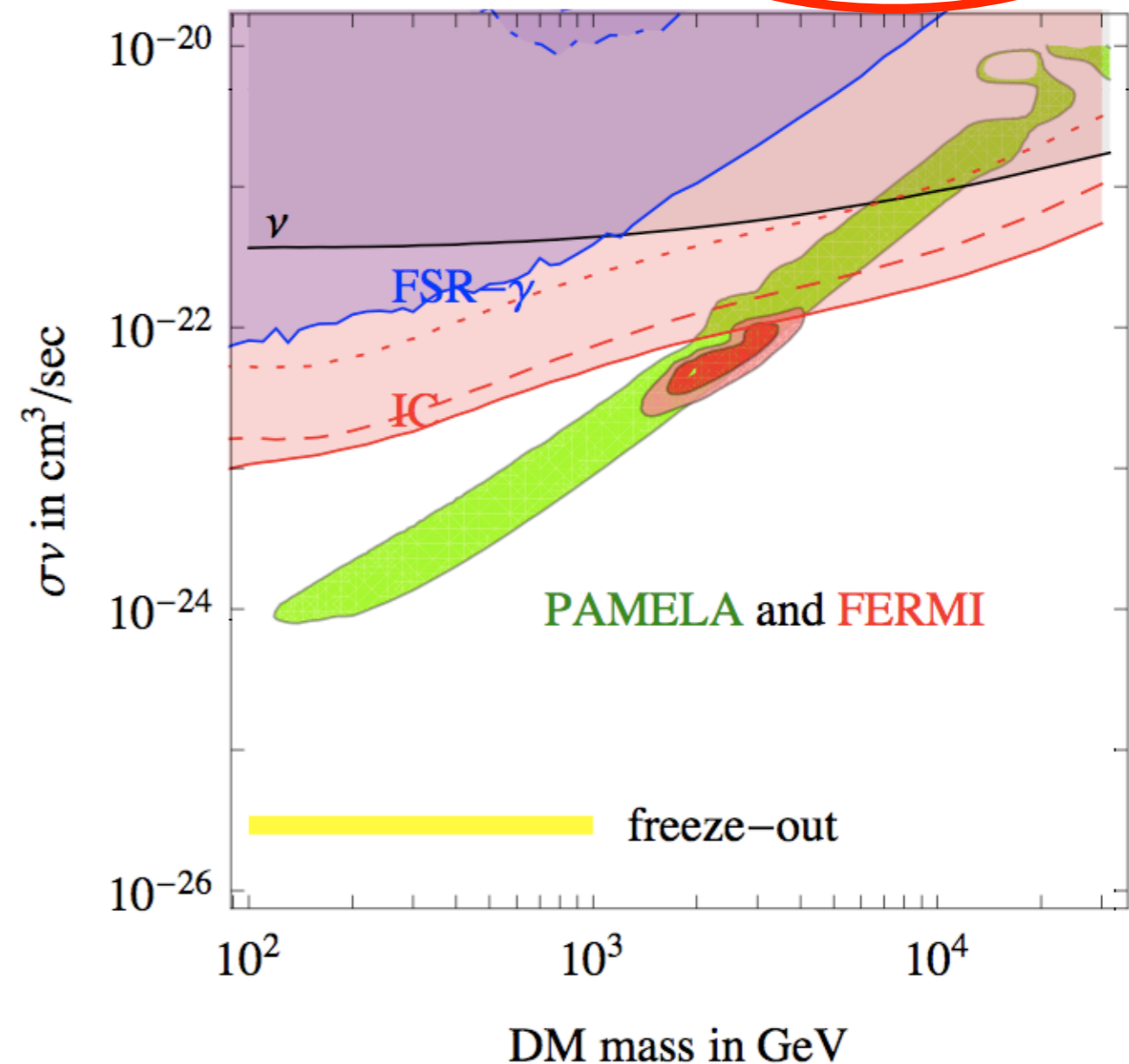
Can set constraints

e.g. for:



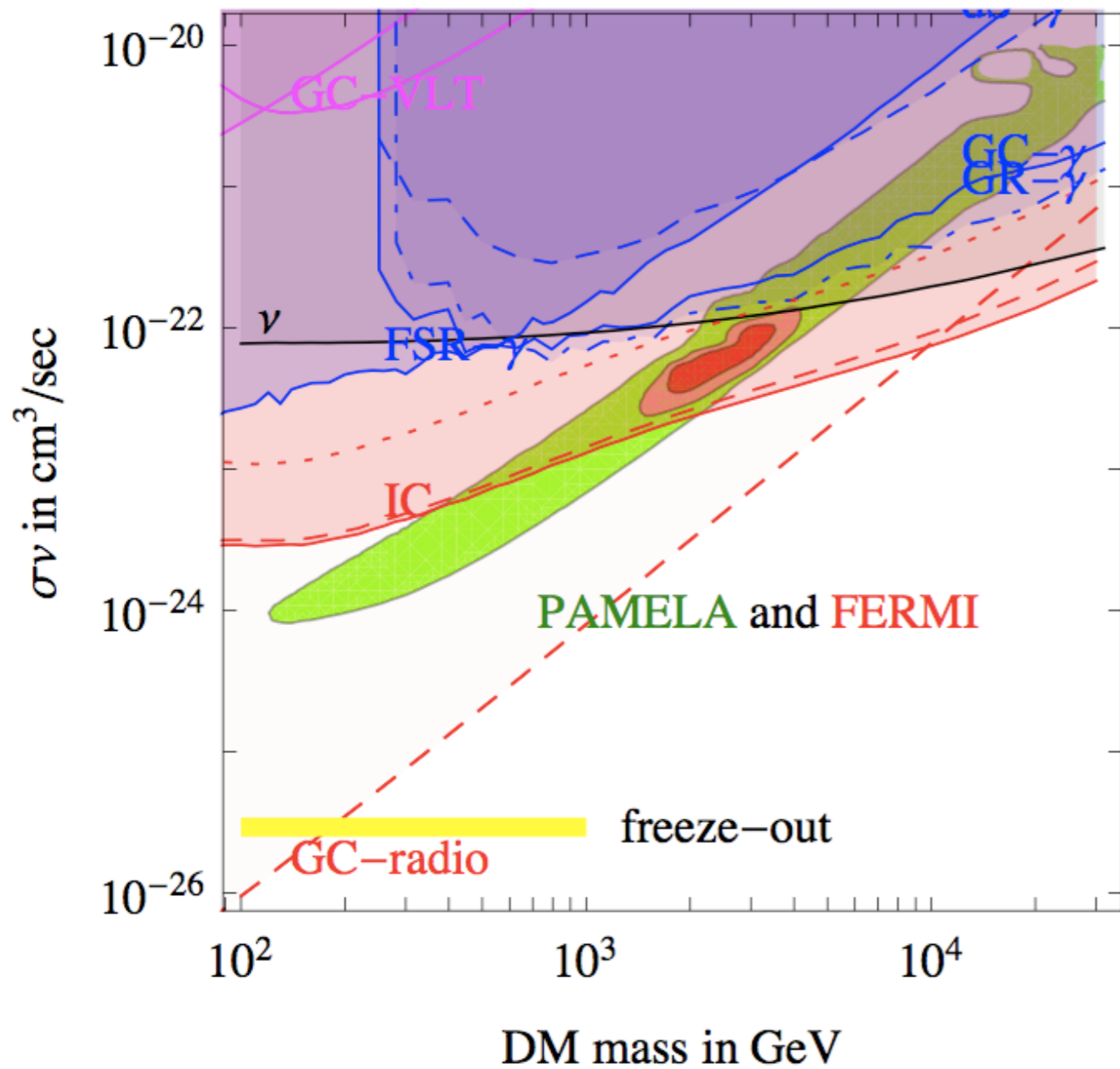
constraints  
depend on  
DM profile

DM DM  $\rightarrow 4\mu$ , isothermal profile



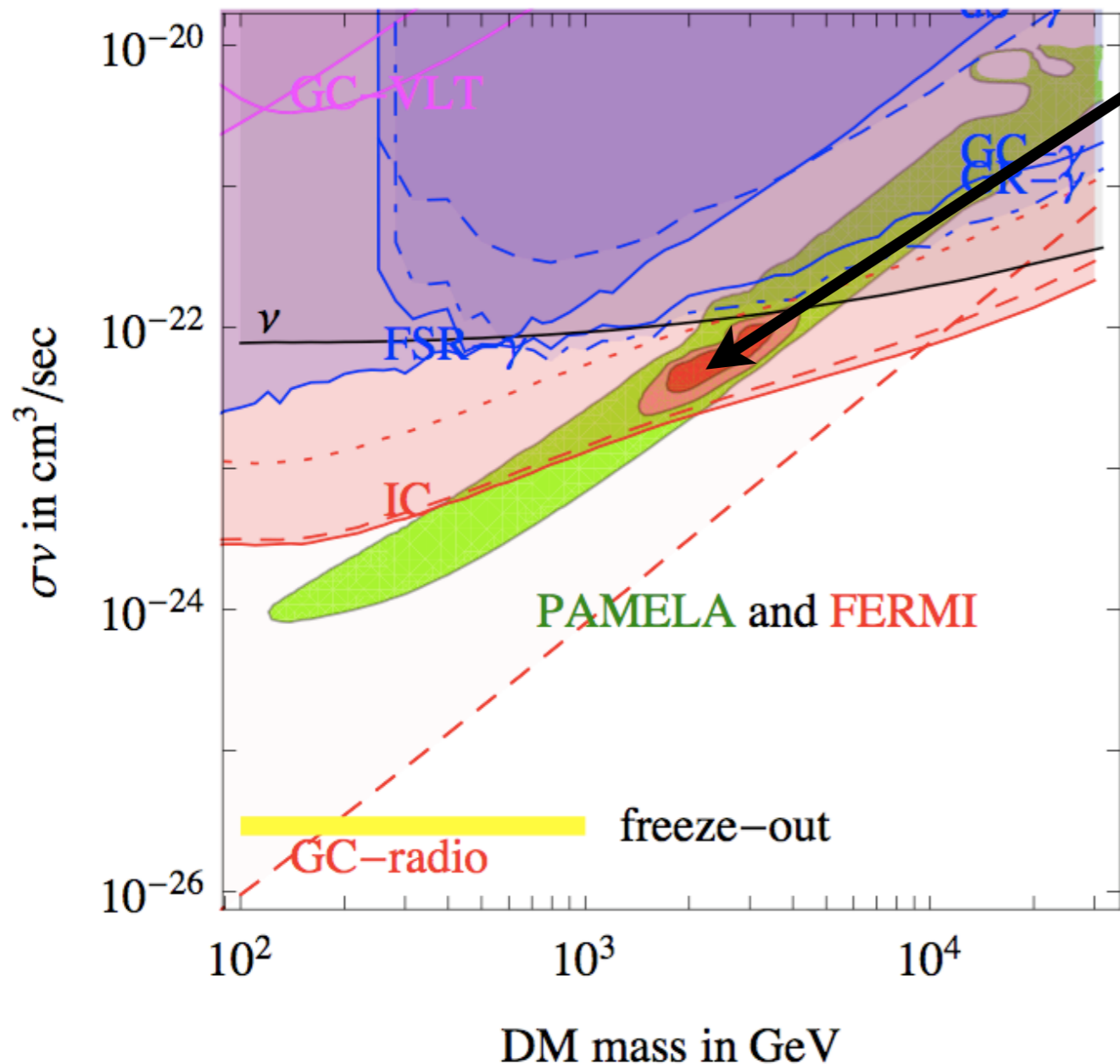
# Stronger constraints for sharper profile

DM DM  $\rightarrow 4\mu$ , NFW profile



# Stronger constraints for sharper profile

DM DM  $\rightarrow 4\mu$ , NFW profile



Preferred region also uncertain:

- Local DM density?
- astro backgrounds?
- $e^+$ ,  $e^-$  propagation?
- Contribution from substructure?

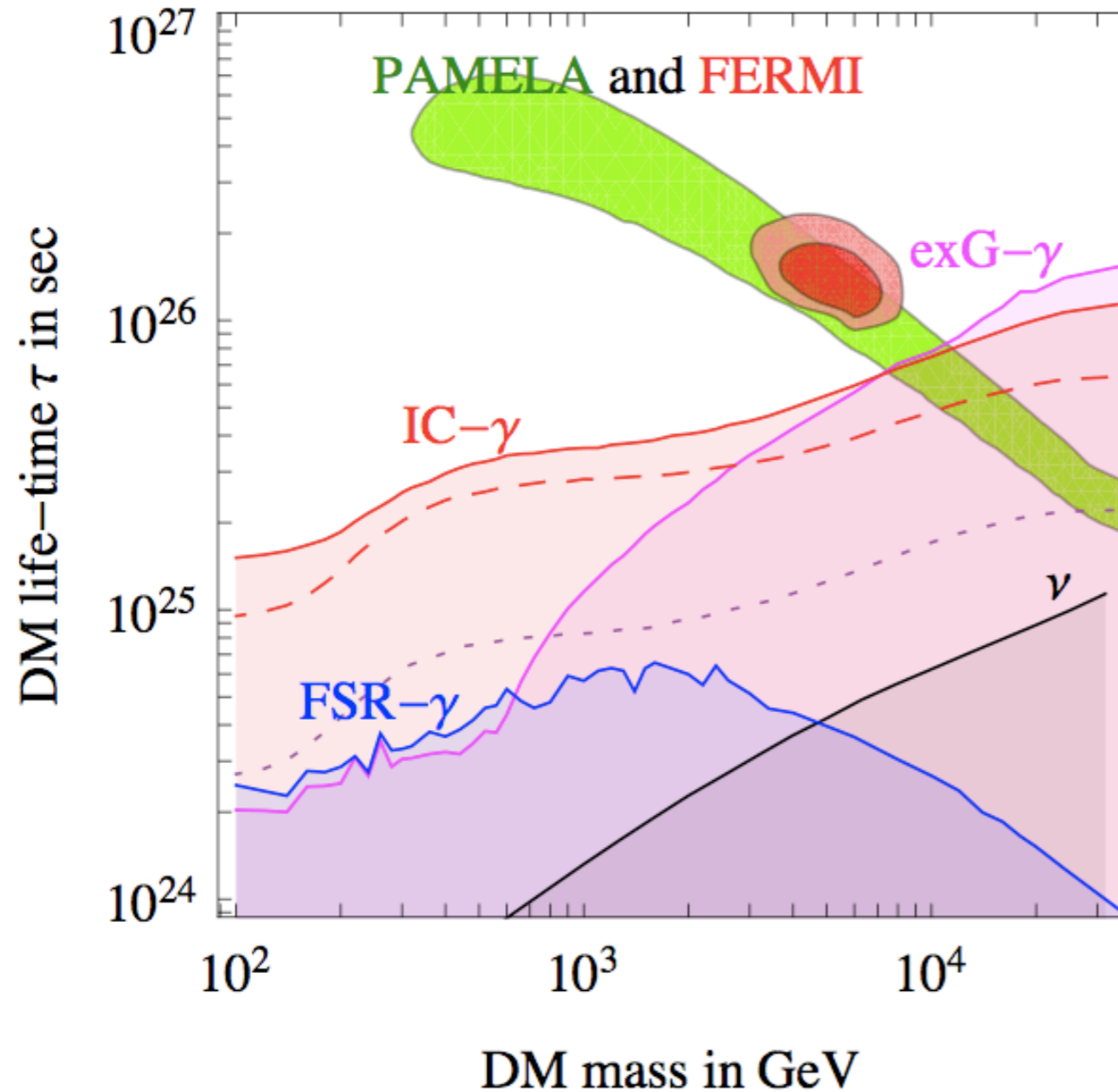
$\Rightarrow$  can shift down  $\sigma v$  of preferred regions

More recent (preliminary!) results from Fermi seem stronger

can expect more results soon...

# Weaker constraints for dark matter decays

DM  $\rightarrow 4\mu$ , NFW profile

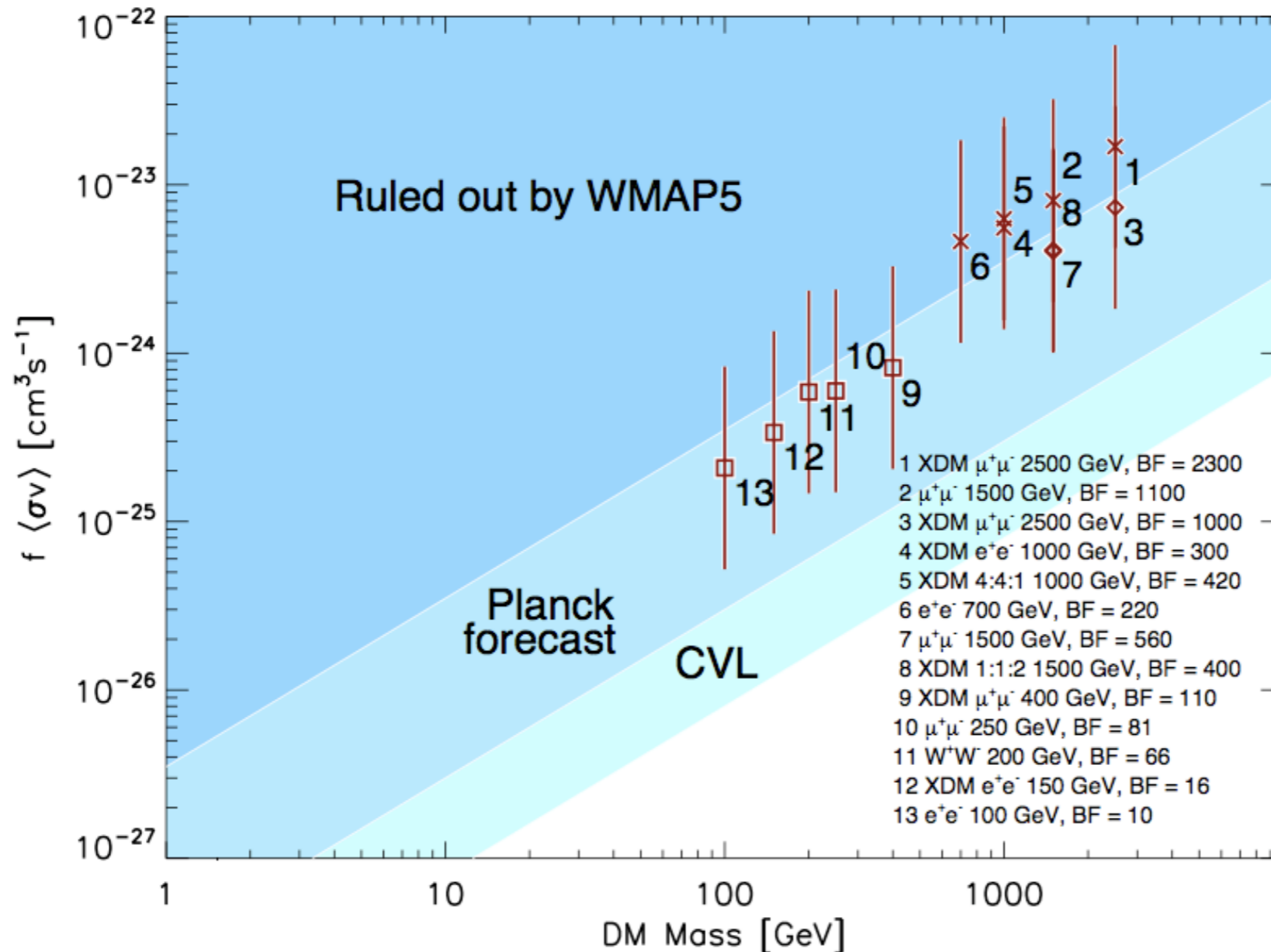


weaker constraints  
even for sharper profile

Future observations  
should see a signal

# Cosmic Microwave Background (CMB)

Dark matter annihilation into high-energy  $e^+$  and  $e^-$  in early Universe affects CMB



interesting  
constraints from  
WMAP

Planck expected  
to be decisive

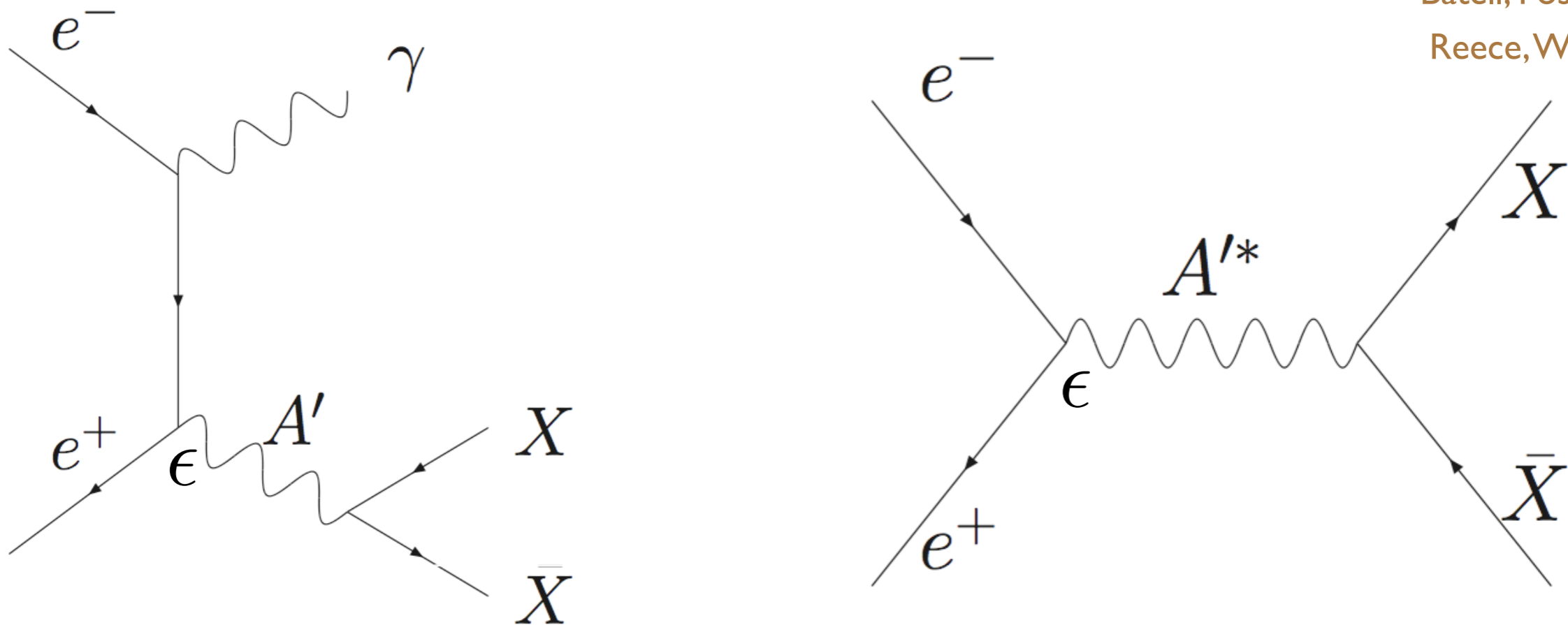
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- Theory
- Indirect Searches
  - Fermi, WMAP, ...
- Direct Searches
  - $e^+e^-$  colliders
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# Probe GeV-scale directly with $e^+e^-$ Colliders

RE, Schuster, Toro  
Batell, Pospelov, Ritz  
Reece, Wang

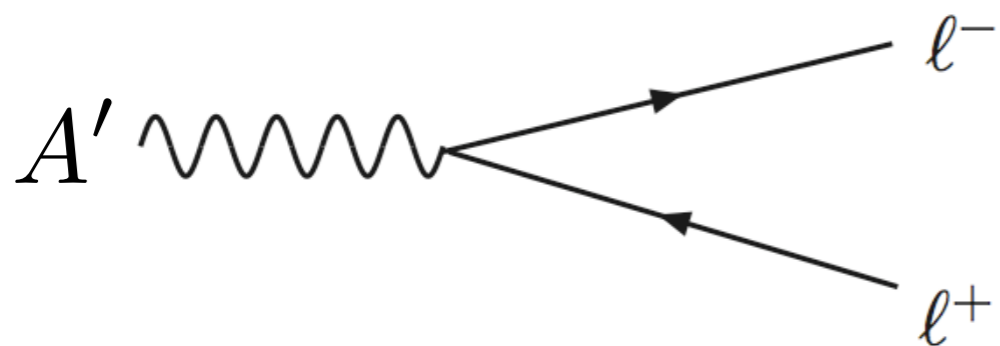


$X$  = Standard Model or hidden-sector particle

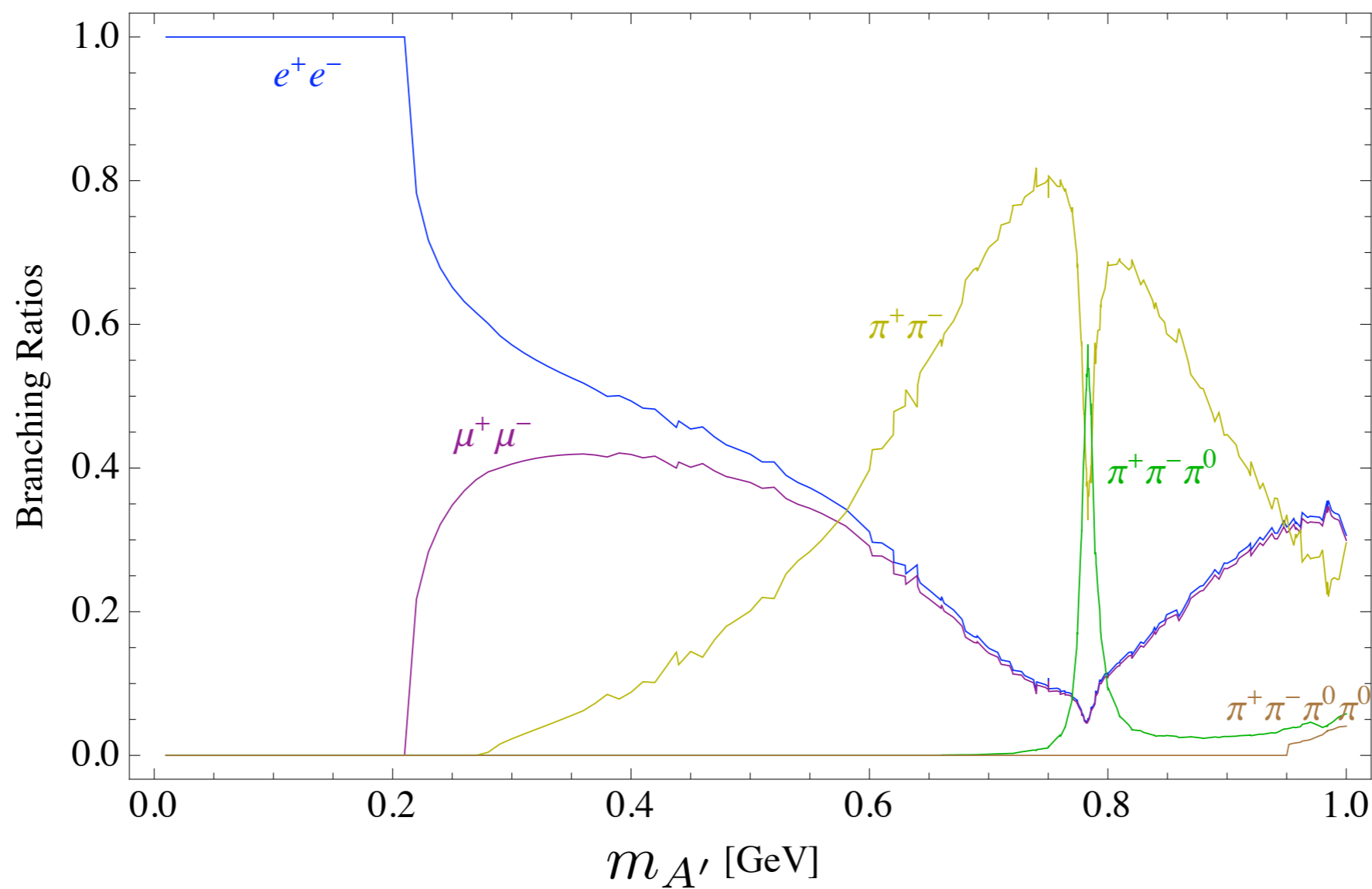
$$\sigma \propto \frac{\epsilon^2}{E_{cm}^2} \implies \text{want low-energy, high-luminosity collider}$$

(BaBar, BELLE, KLOE, CLEO-c, BESIII, ...)

# $A'$ decays

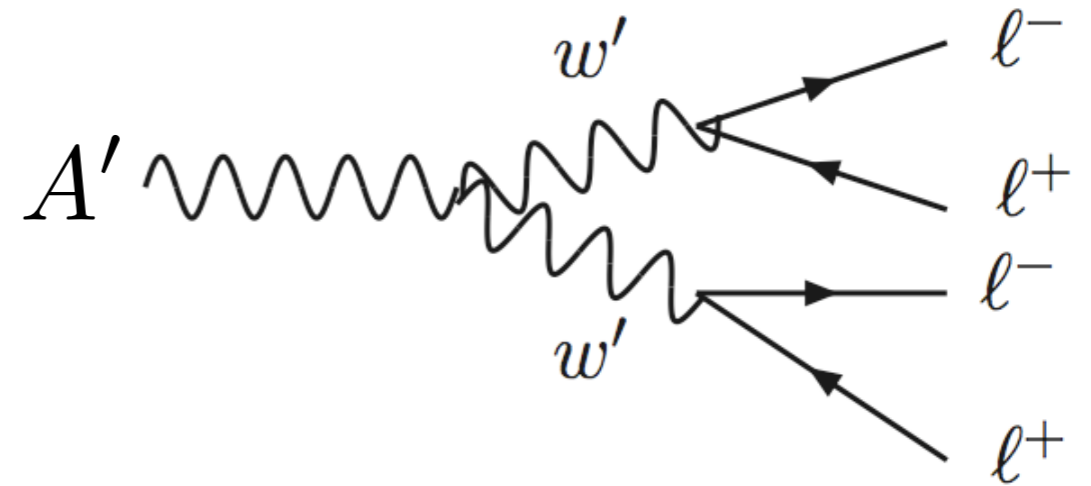
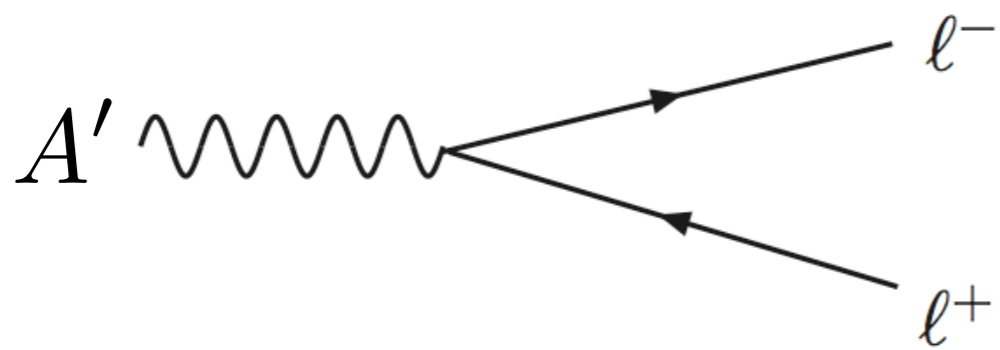


Can decay directly  
to Standard Model

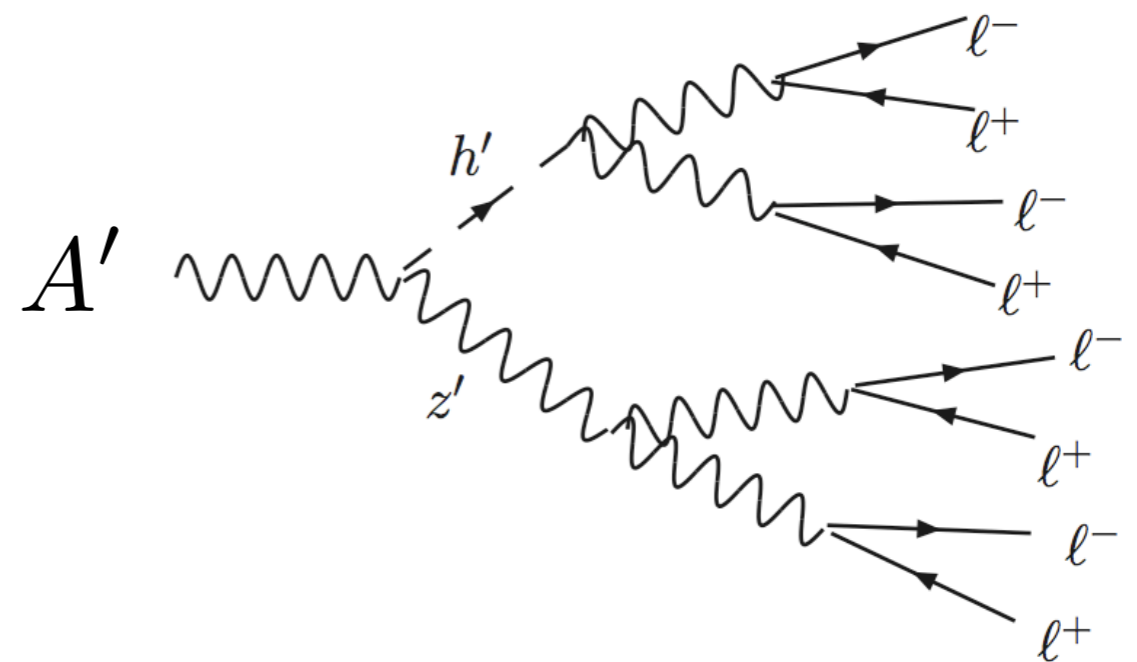
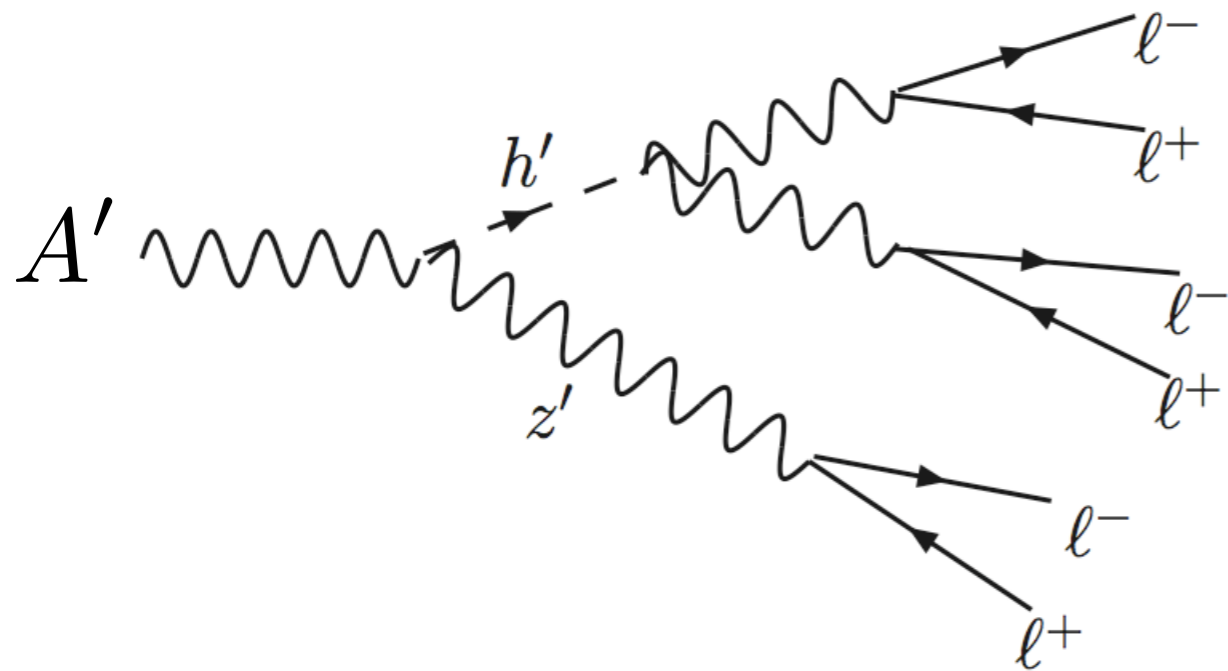
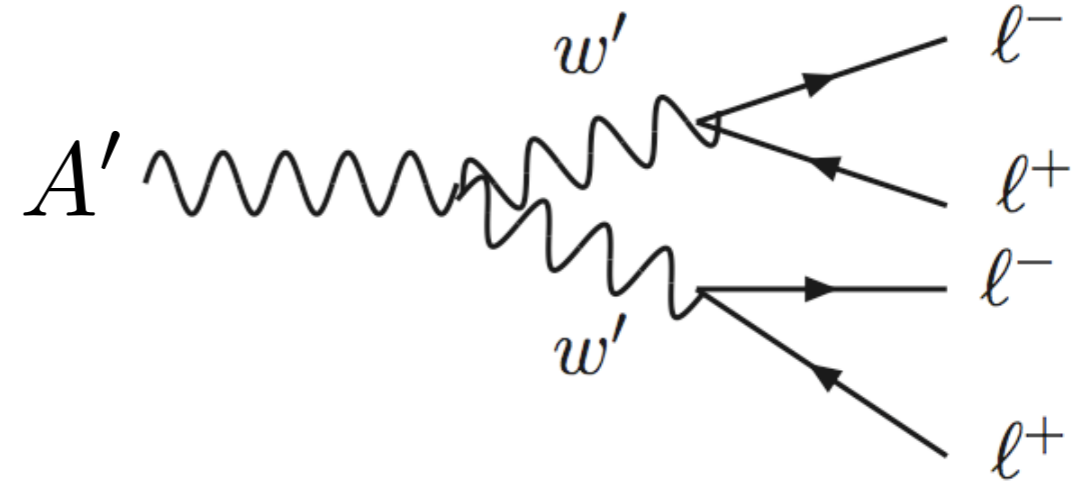
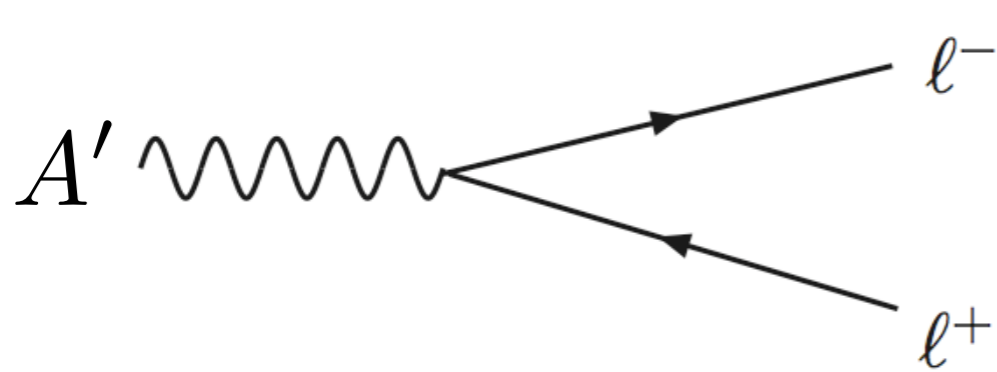


[used without permission from Meade]

# Many other model dependent possibilities



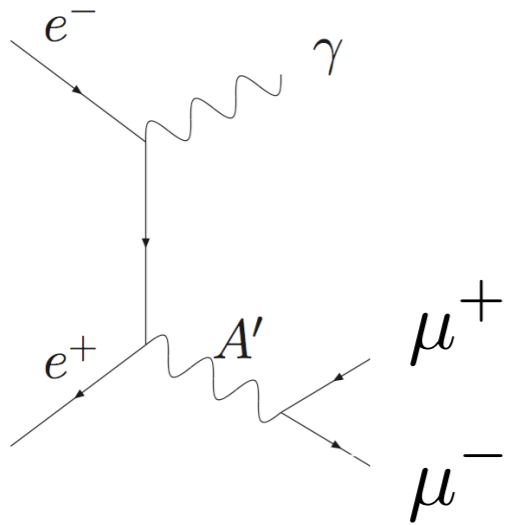
# Many other model dependent possibilities



**Broad array of searches needed!**

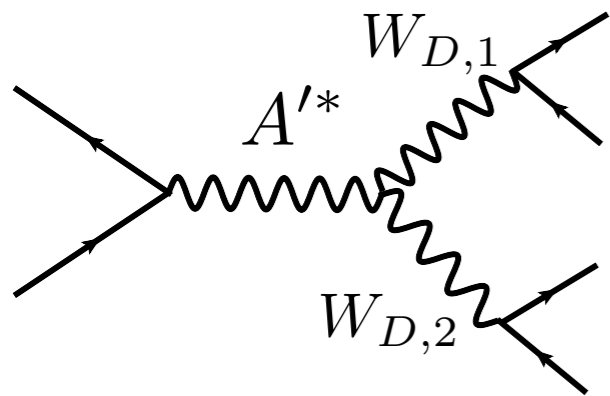
What searches have been done?

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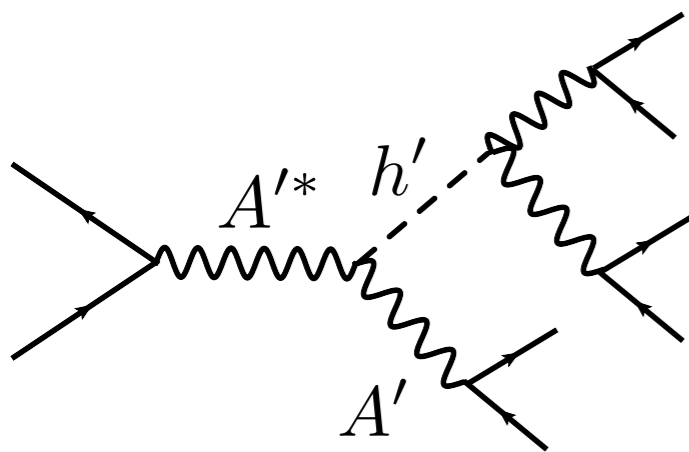
Done  
 $\gamma\mu^+\mu^-$

BaBar (partial data set)



Done  
 $4e, 4\mu, 2e + 2\mu$

BaBar  
 [Graham & Roodman]  
 not yet:  $\gamma + 4l$

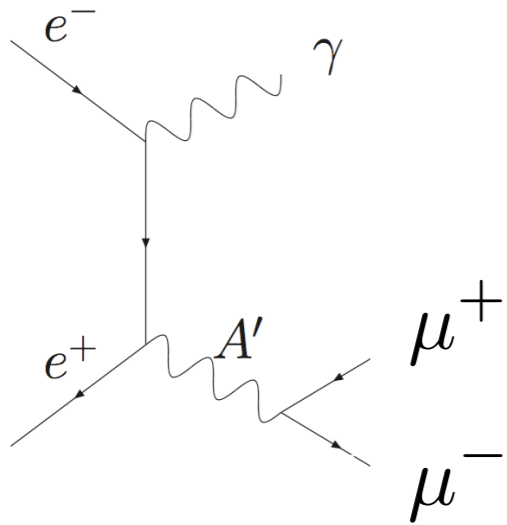


Not yet  
 $2l, 6l$

Higgs'-strahlung  
 [Batell, Pospelov, Ritz]

multi-lepton + pion searches in progress

# What searches have been done?

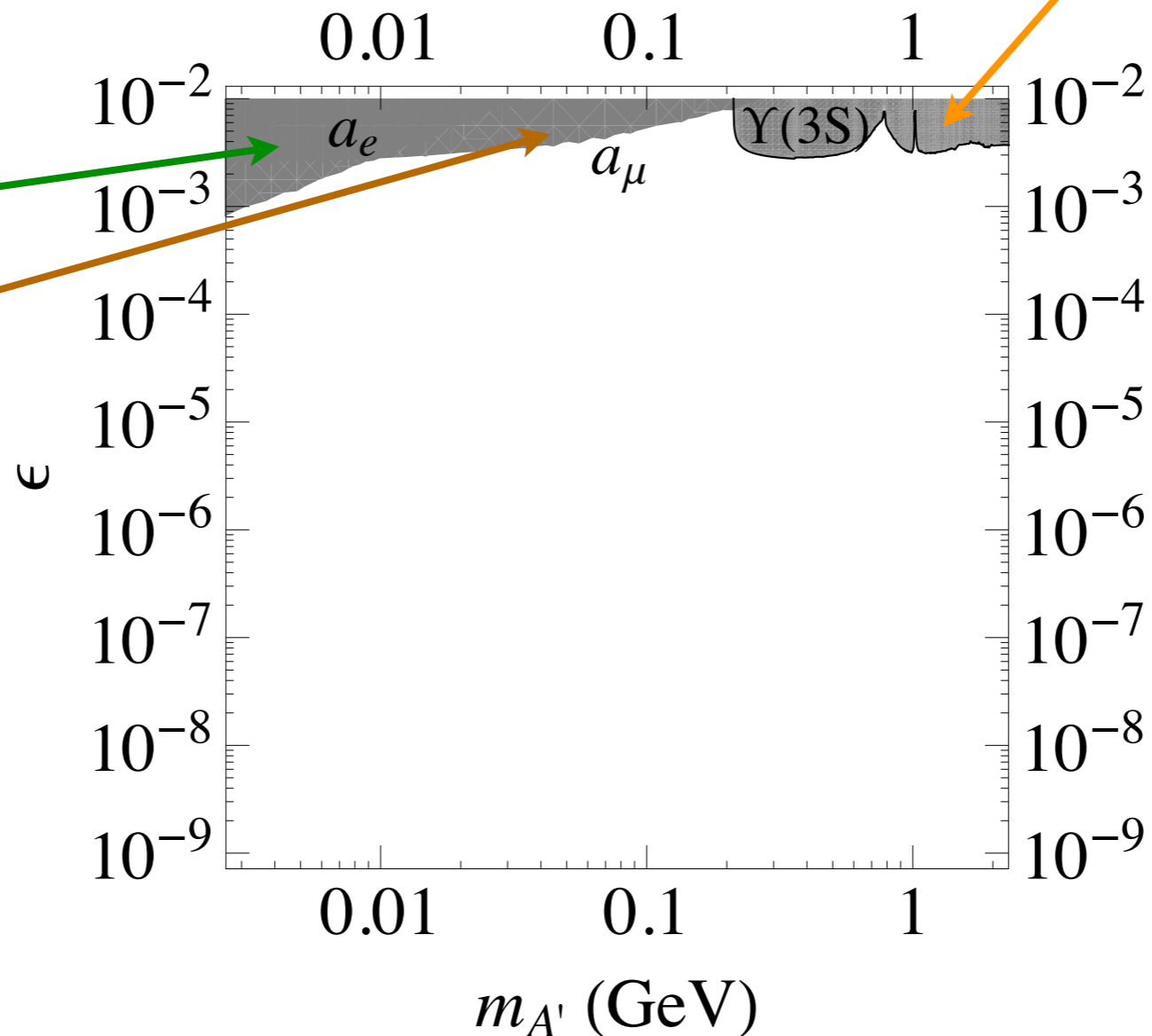


Done

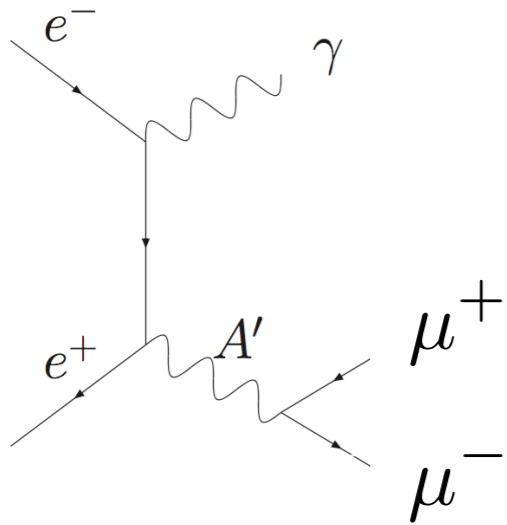
$\gamma\mu^+\mu^-$

BaBar (partial data set)

g-2 for  
electron  
and muon



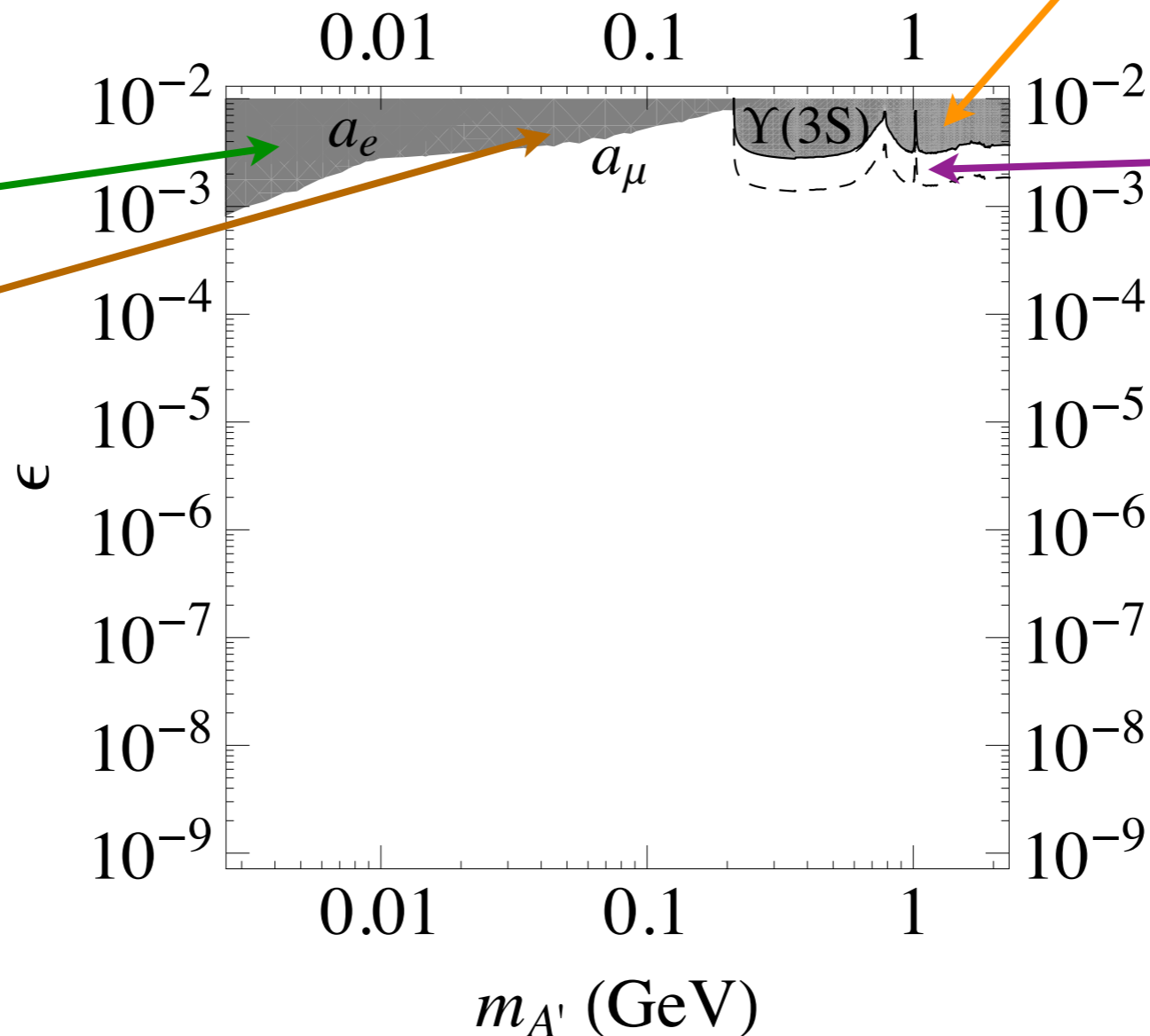
# What searches have been done?



**Done**  
 $\gamma\mu^+\mu^-$

BaBar (partial data set)

g-2 for  
electron  
and muon



Belle  
(full dataset)  
not yet



# Rare meson decays

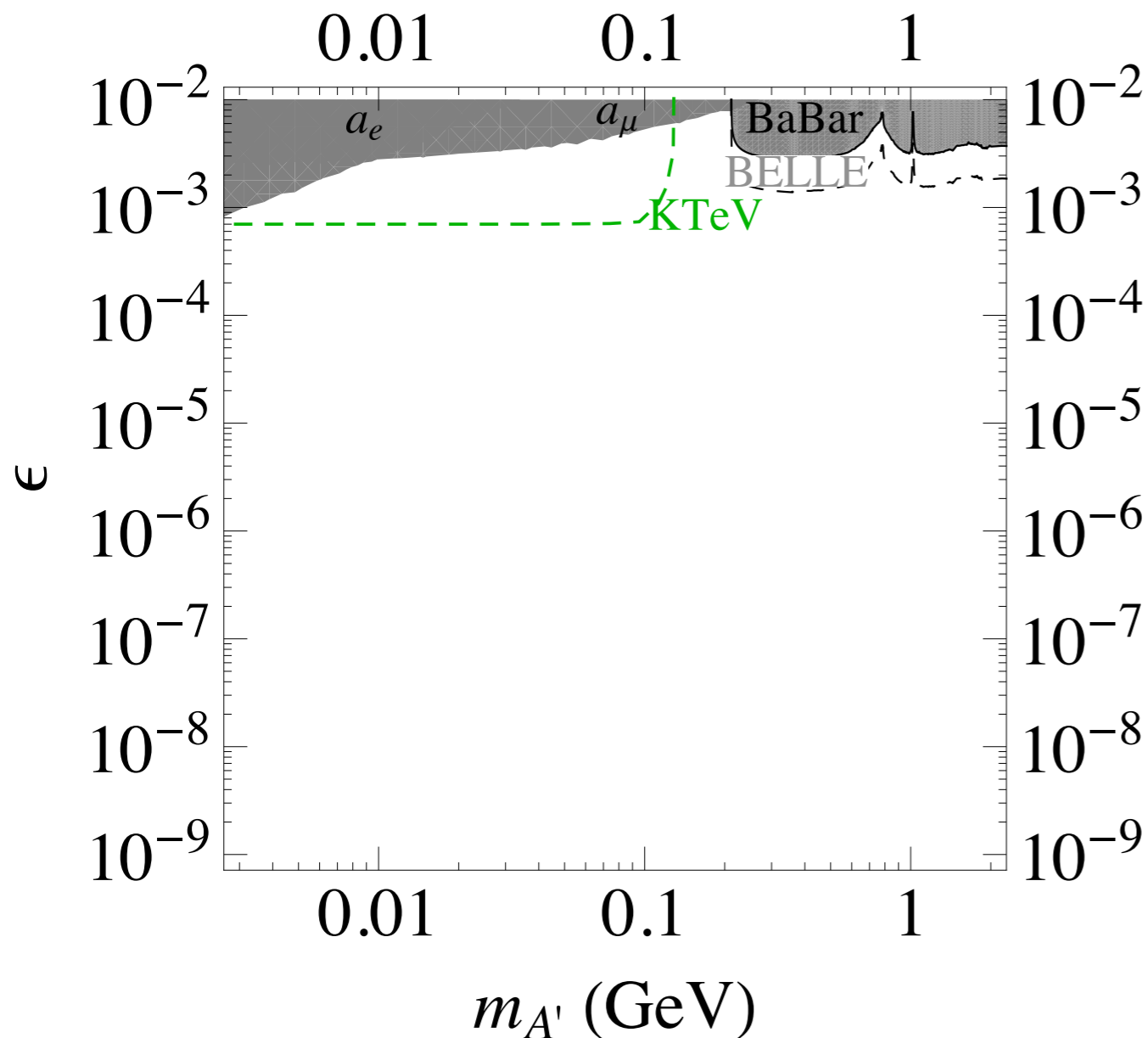
Many possibilities; focus on best channels:

1.  $\pi^0 \rightarrow \gamma A' \rightarrow \gamma e^+ e^-$     **KTeV**  $\sim 10^{10} \pi^0$  (analysis not done)

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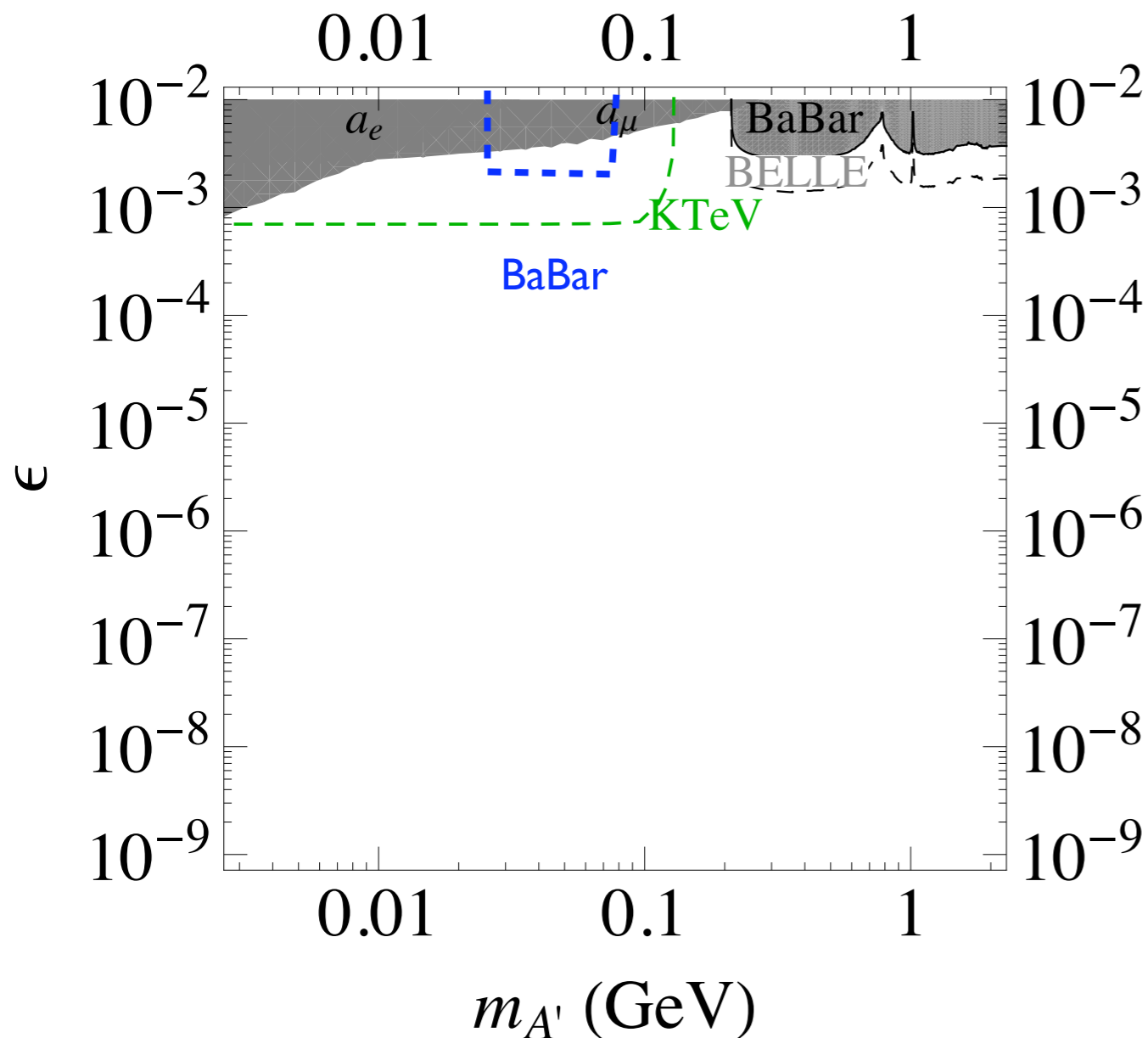
mass resolution  $\sim 2$  MeV ?

sensitivity is probably overestimated

# Rare meson decays

Many possibilities; focus on best channels:

1.  $\pi^0 \rightarrow \gamma A' \rightarrow \gamma e^+ e^-$  **KTeV**  $\sim 10^{10} \pi^0$  (analysis not done)



mass resolution  $\sim 2$  MeV ?

sensitivity is probably  
overestimated

**BaBar**  $\sim \text{few} \times 10^9 \pi^0$   
(analysis ongoing)

estimate from Art Snyder

# Rare meson decays

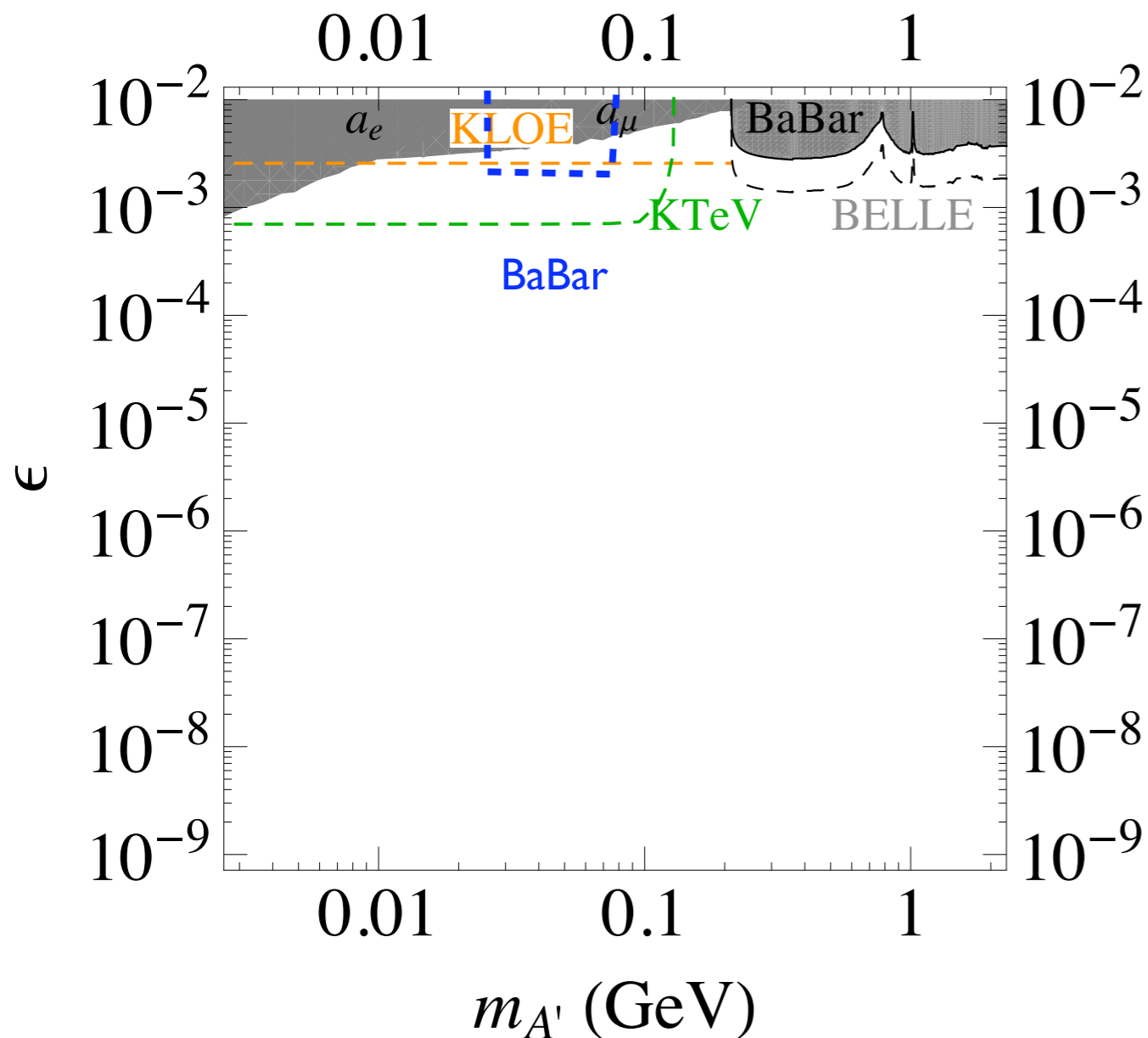
Many possibilities; focus on best channels:

2.  $\phi \rightarrow \eta A' \rightarrow \eta e^+ e^-$  KLOE  $\sim 10^{10} \eta^0$  (analysis underway)

# Rare meson decays

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# Outline

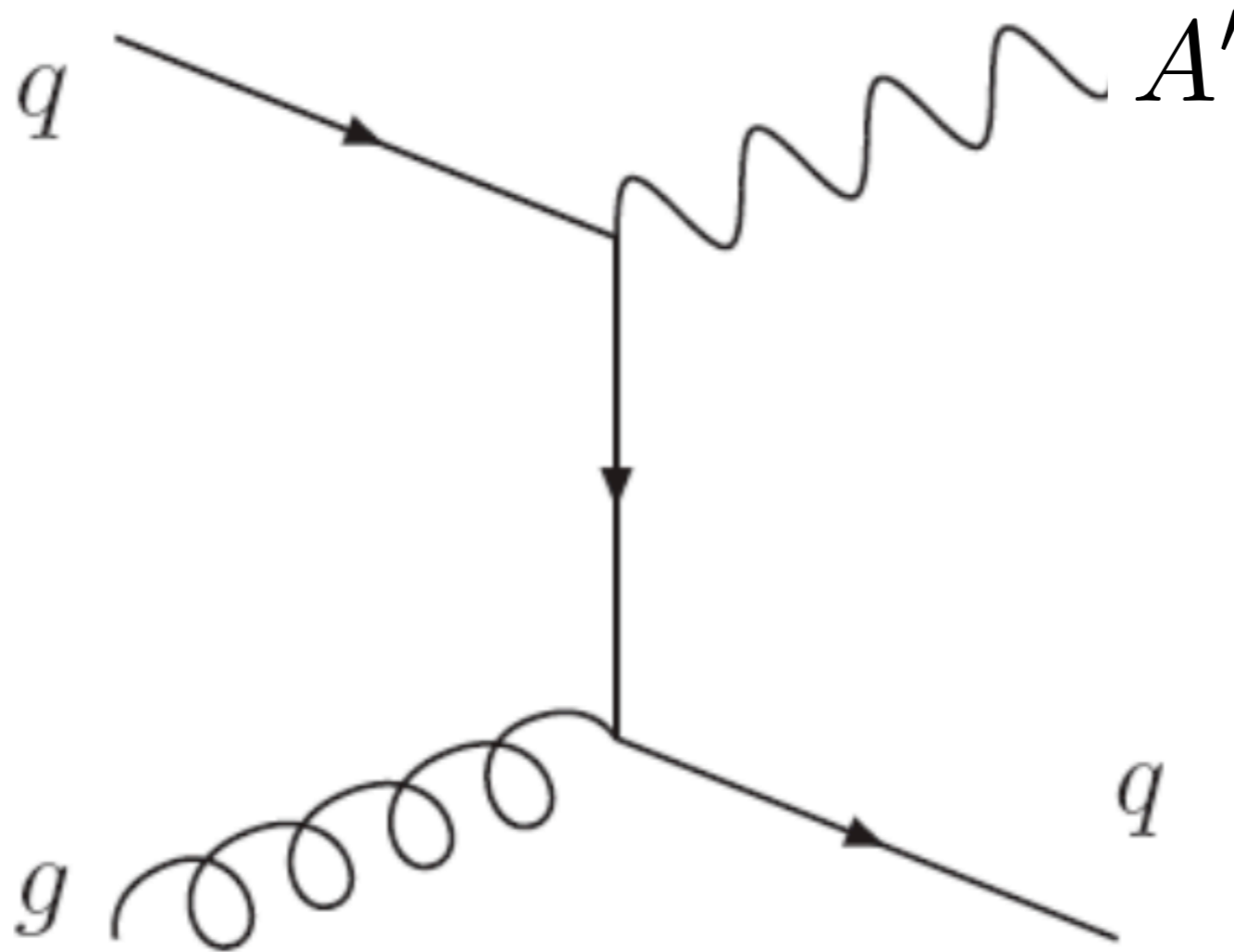
- Theory
- Indirect Searches
  - Fermi, WMAP, ...
- Direct Searches
  - $e^+e^-$  colliders
  - Tevatron & LHC (proton colliders)
  - fixed target

# Direct production

Arkani-Hamed, Weiner

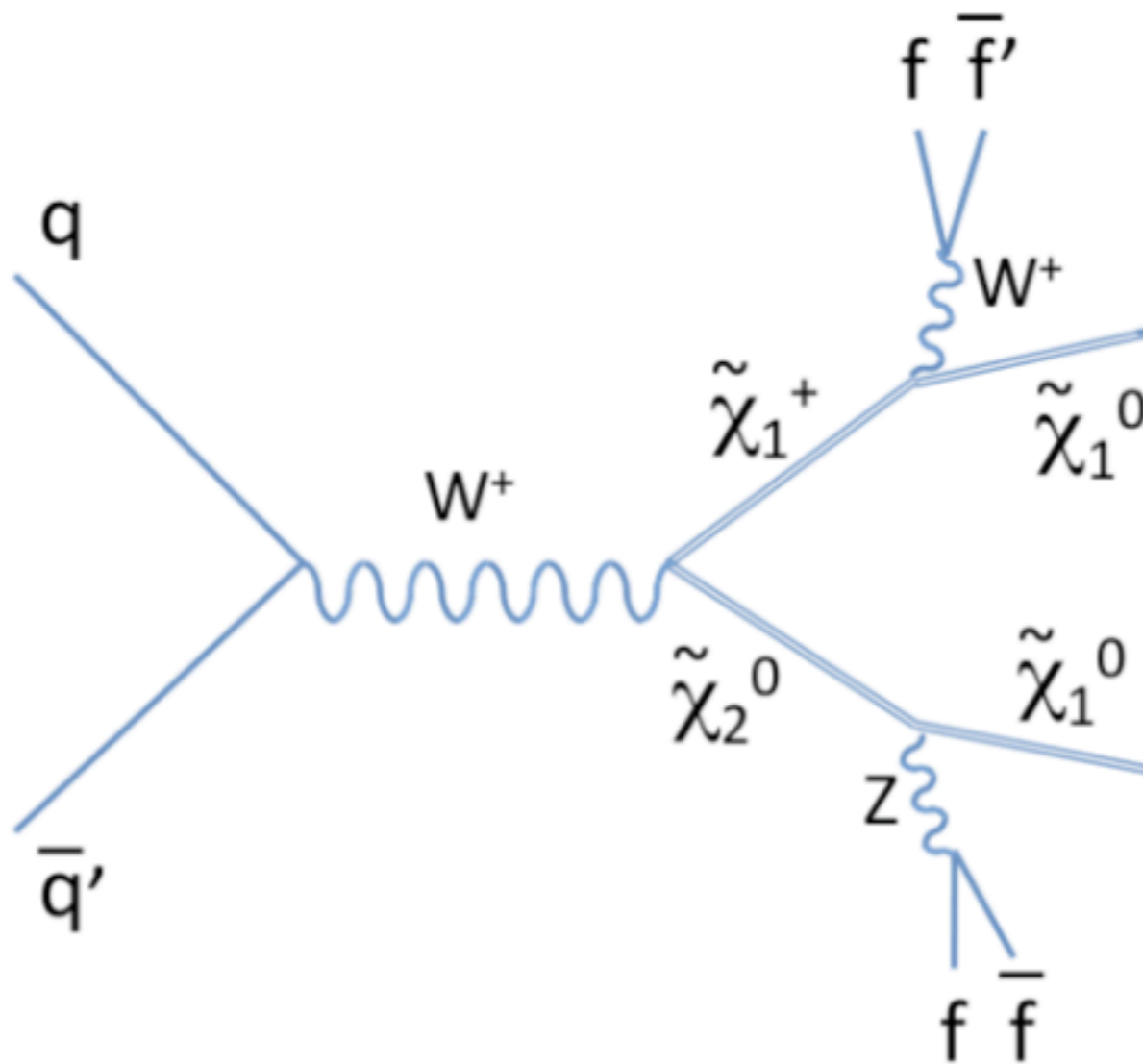
Bumgart, Cheung, Ruderman, Wang, Yavin

Cheung, Ruderman, Wang, Yavin



visibility above backgrounds depends on  $A'$  decay

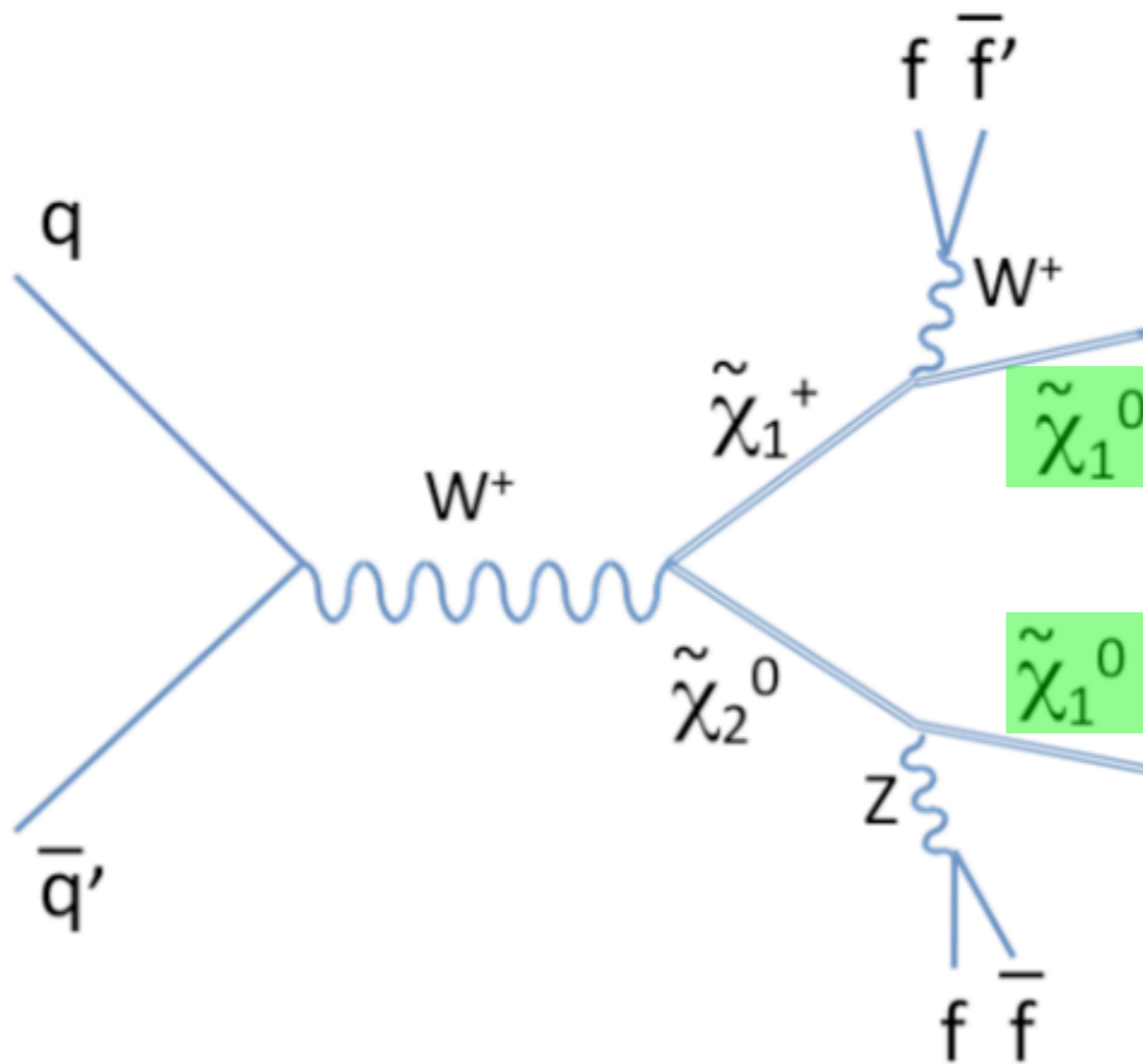
# Dramatic but speculative: production through SUSY





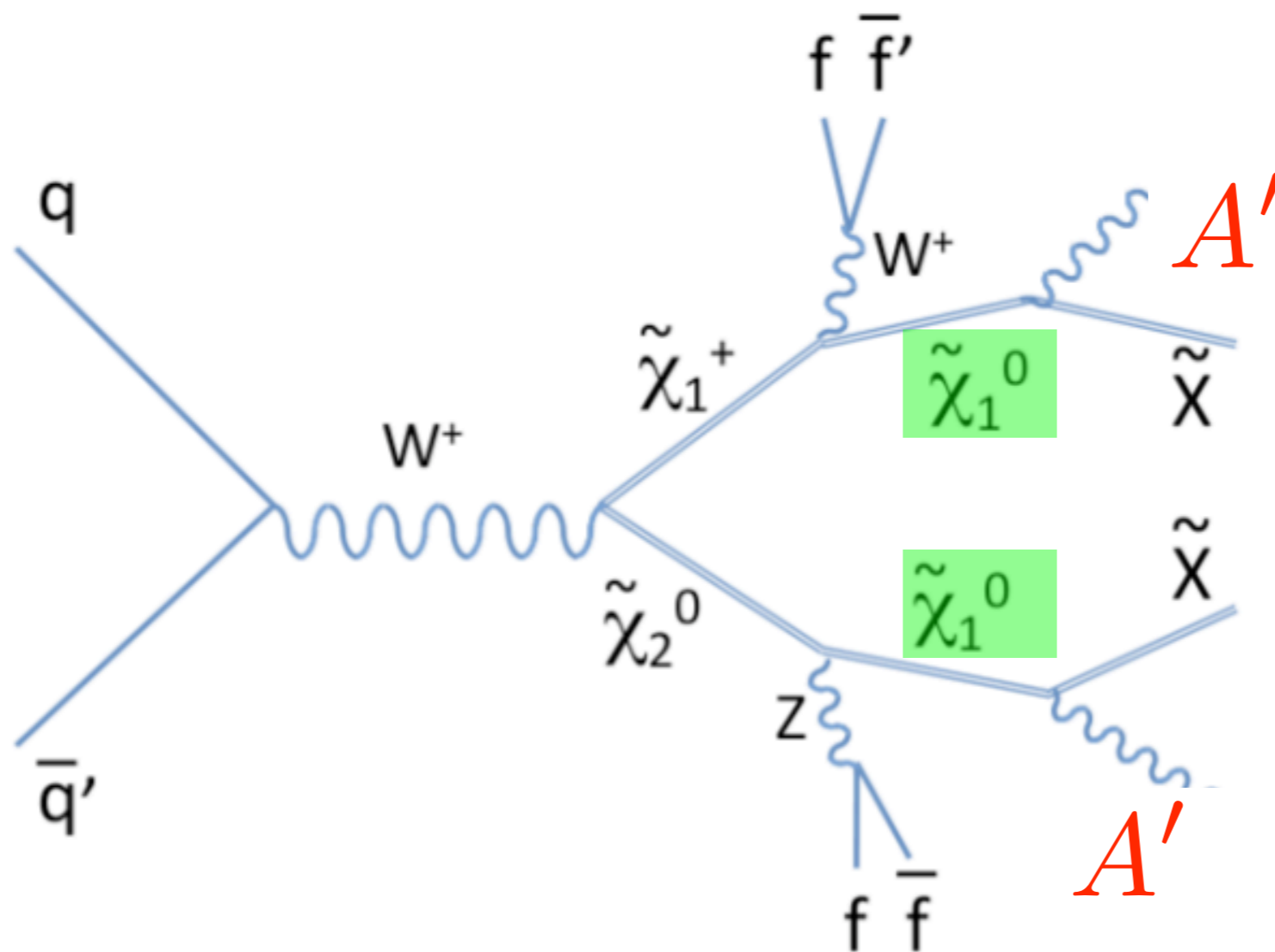
# Dramatic but speculative: production through SUSY

Lightest SUSY particle (“LSP”) not stable,  
and can decay to  $A'$  + hidden sector



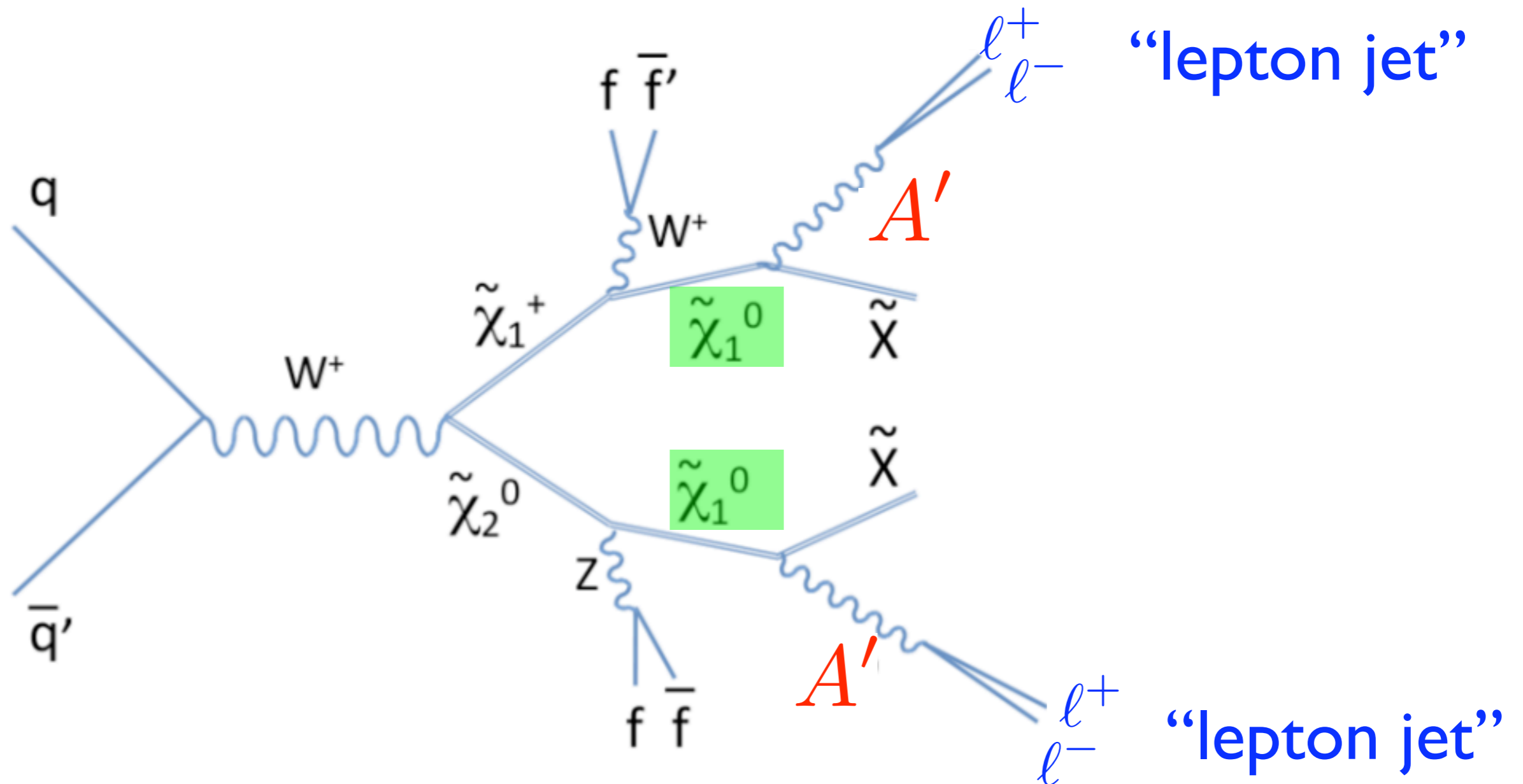
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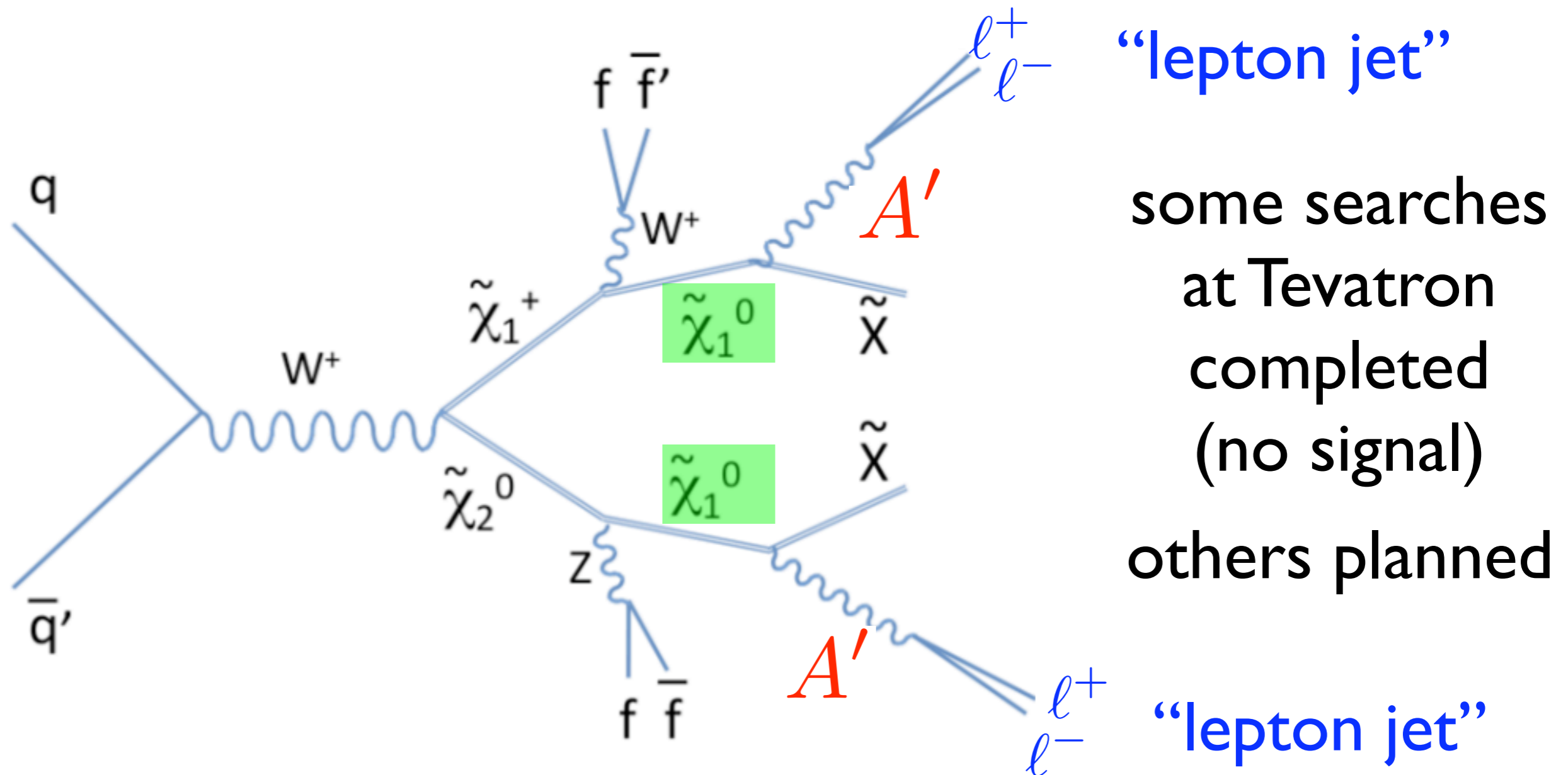
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# Dramatic but speculative: production through SUSY

Lightest SUSY particle (“LSP”) not stable,  
and can decay to  $A'$  + hidden sector



“lepton jet”

some searches  
at Tevatron  
completed  
(no signal)

others planned

“lepton jet”

# Outline

- Theory
- Indirect Searches
  - Fermi, WMAP, ...
- Direct Searches
  - $e^+e^-$  colliders
  - Tevatron & LHC
  - fixed target (electron and proton)

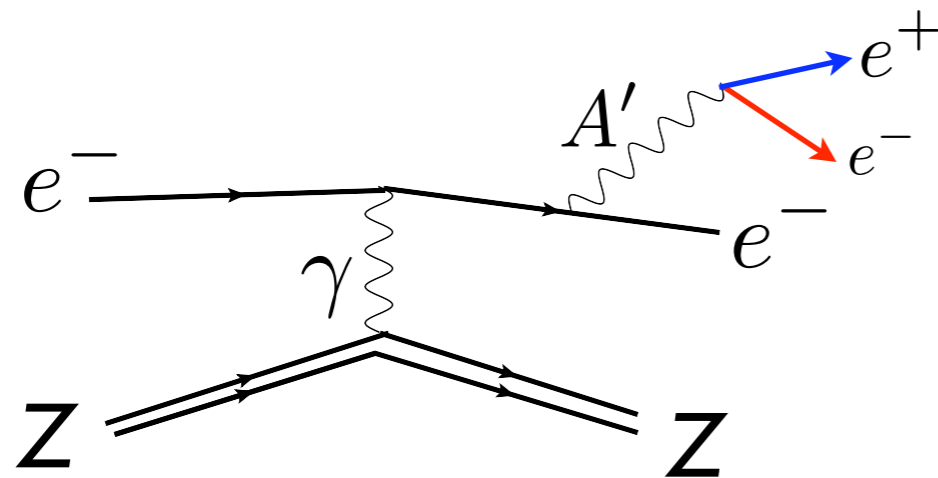
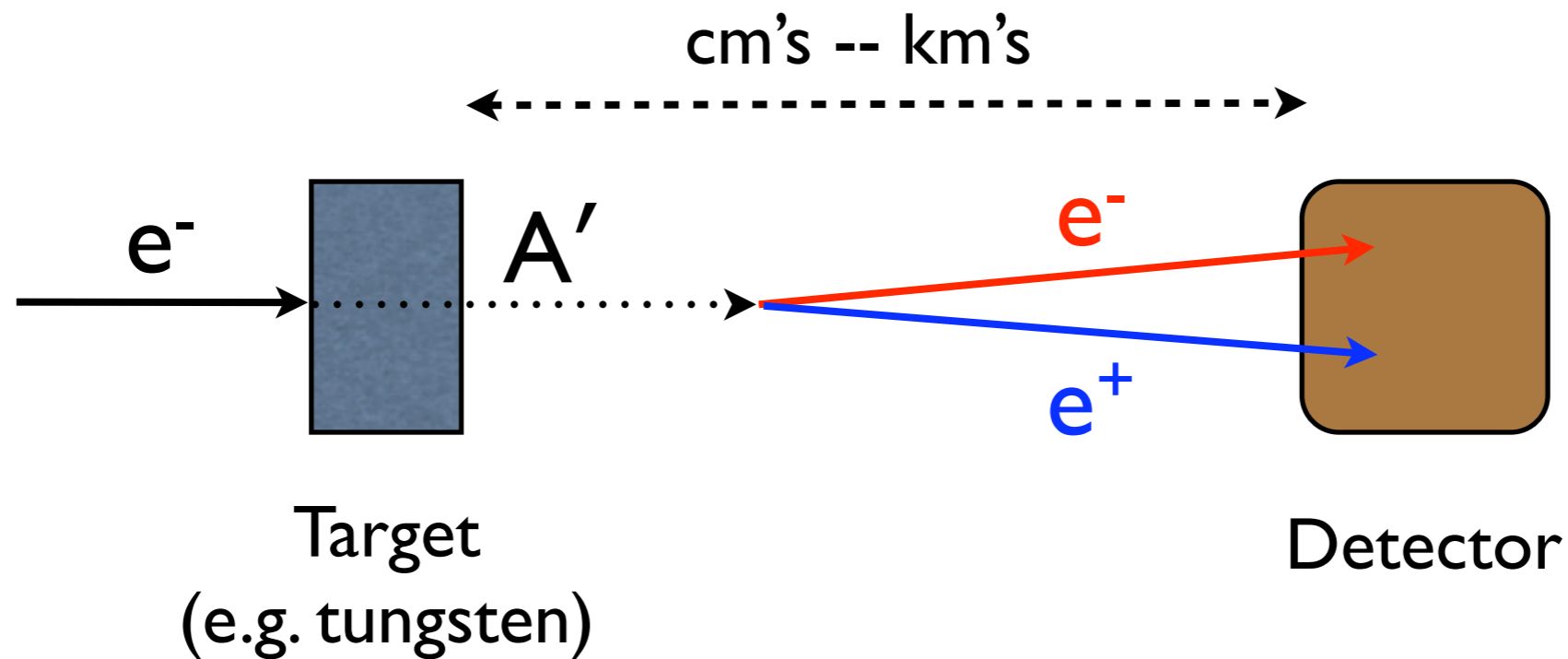
# Fixed-Target Experiments

[Bjorken RE, Schuster, Toro]

[Batell, Pospelov, Ritz]

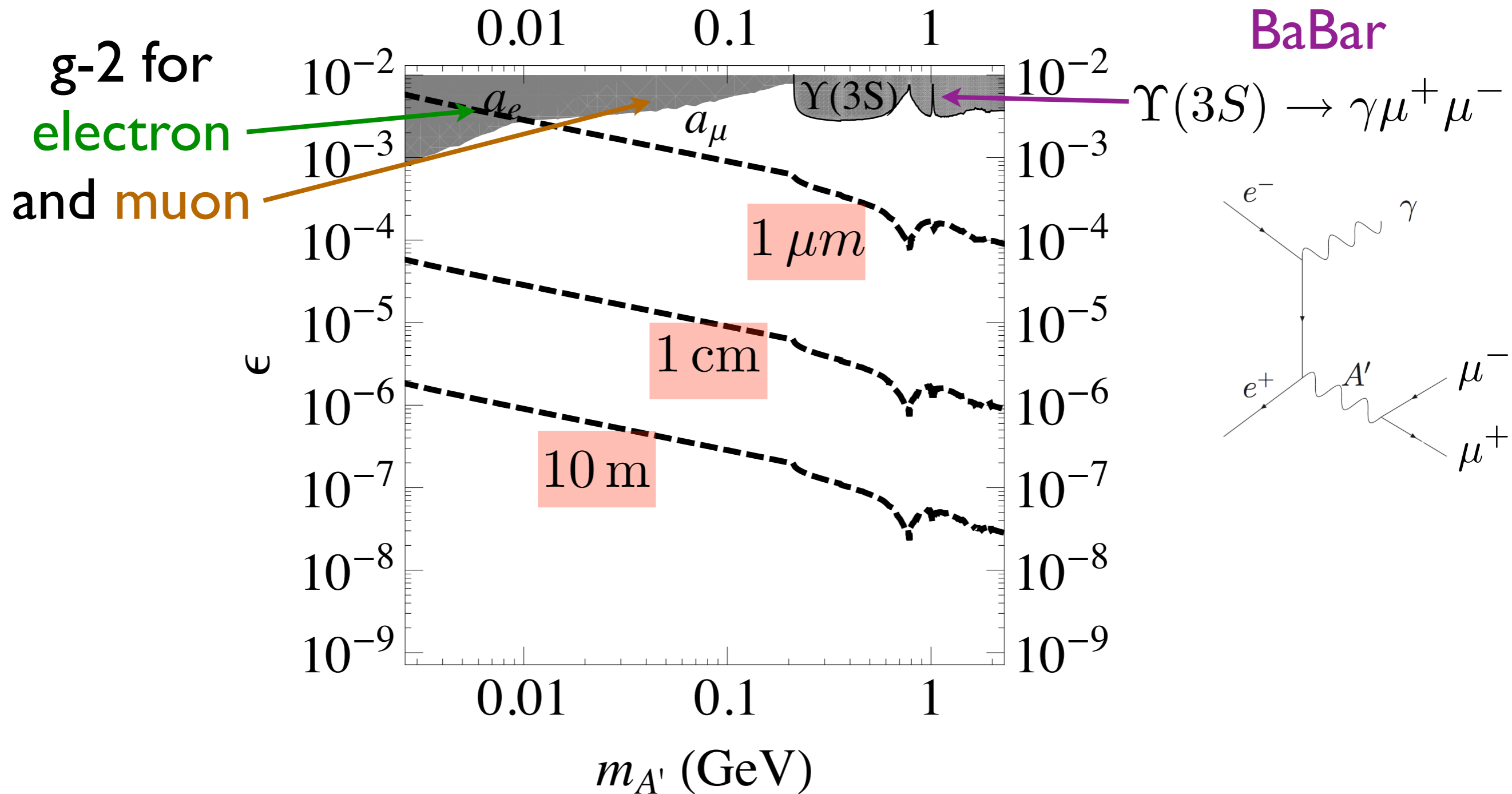
[Reece & Wang]

Produce  $A'$  via bremsstrahlung off  $e^-$  beam on fixed target



assume  $A'$  decays  
to  $e^+e^-$  pair

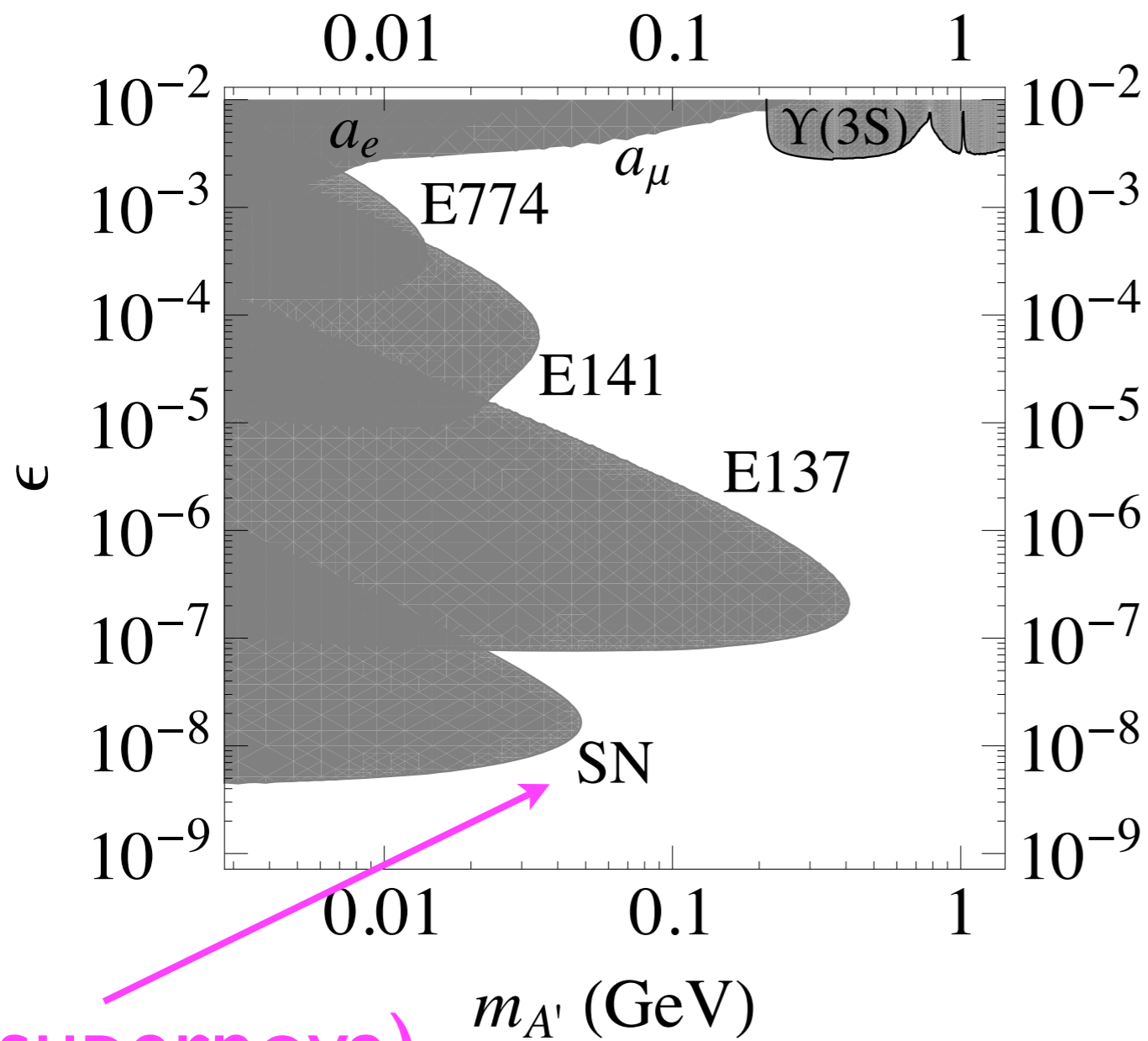
# $A'$ Lifetime varies by orders of magnitude



Need various strategies to cover whole range

# Good Beam Dump Constraints exist

[Bjorken RE, Schuster, Toro]



(supernova)

	Shield (m)	$E_{\text{beam}}$ (GeV)	Lumi ( $e^-$ )
<b>E137</b>	200	20	$10^{20}$
<b>E141</b>	0.12	9	$2 \times 10^{15}$
<b>E774</b>	0.3	275	$5 \times 10^9$

Bjorken et.al.

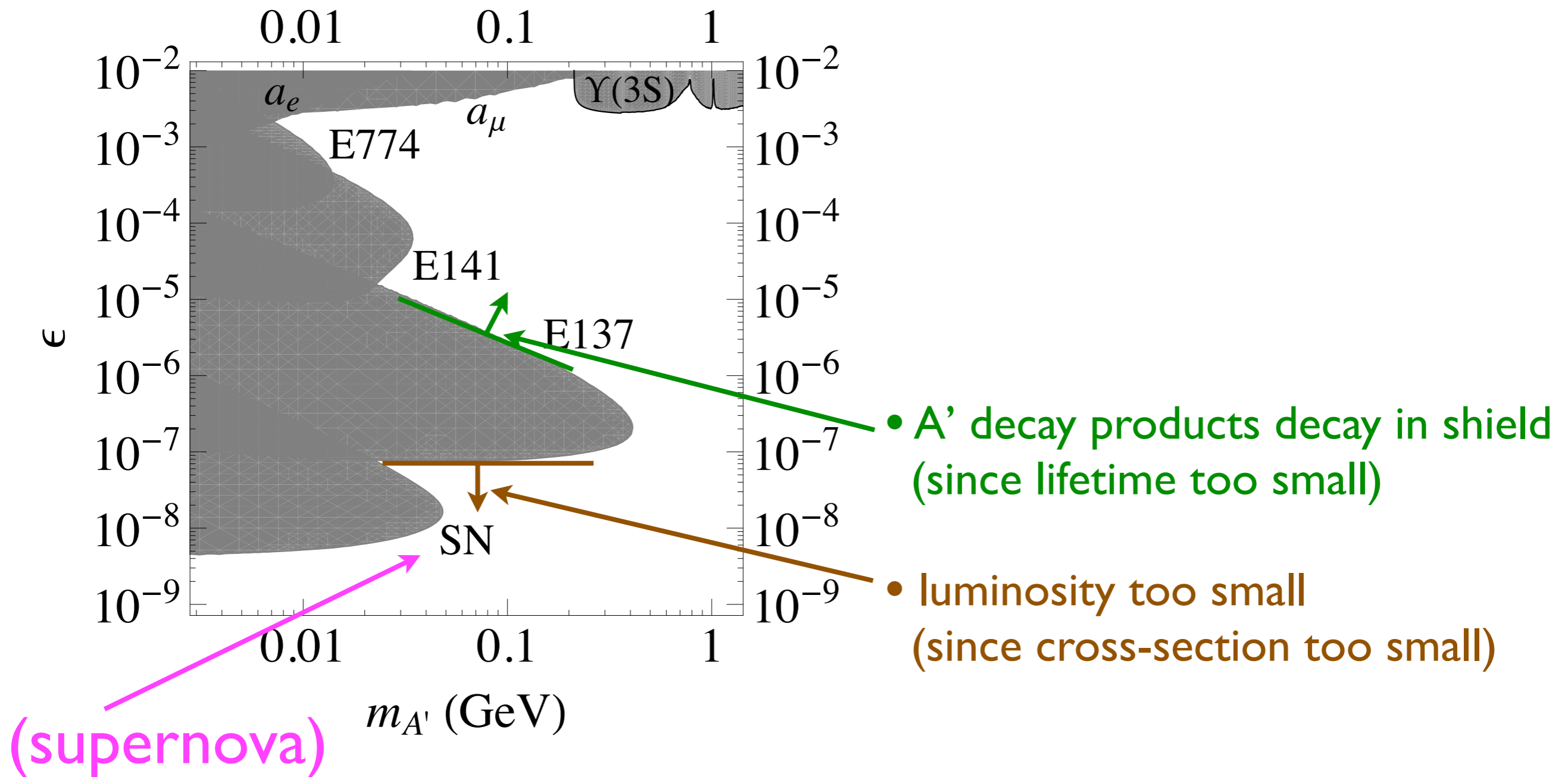
Riordan et.al.

Bross et.al.



# Good Beam Dump Constraints exist

[Bjorken RE, Schuster, Toro]

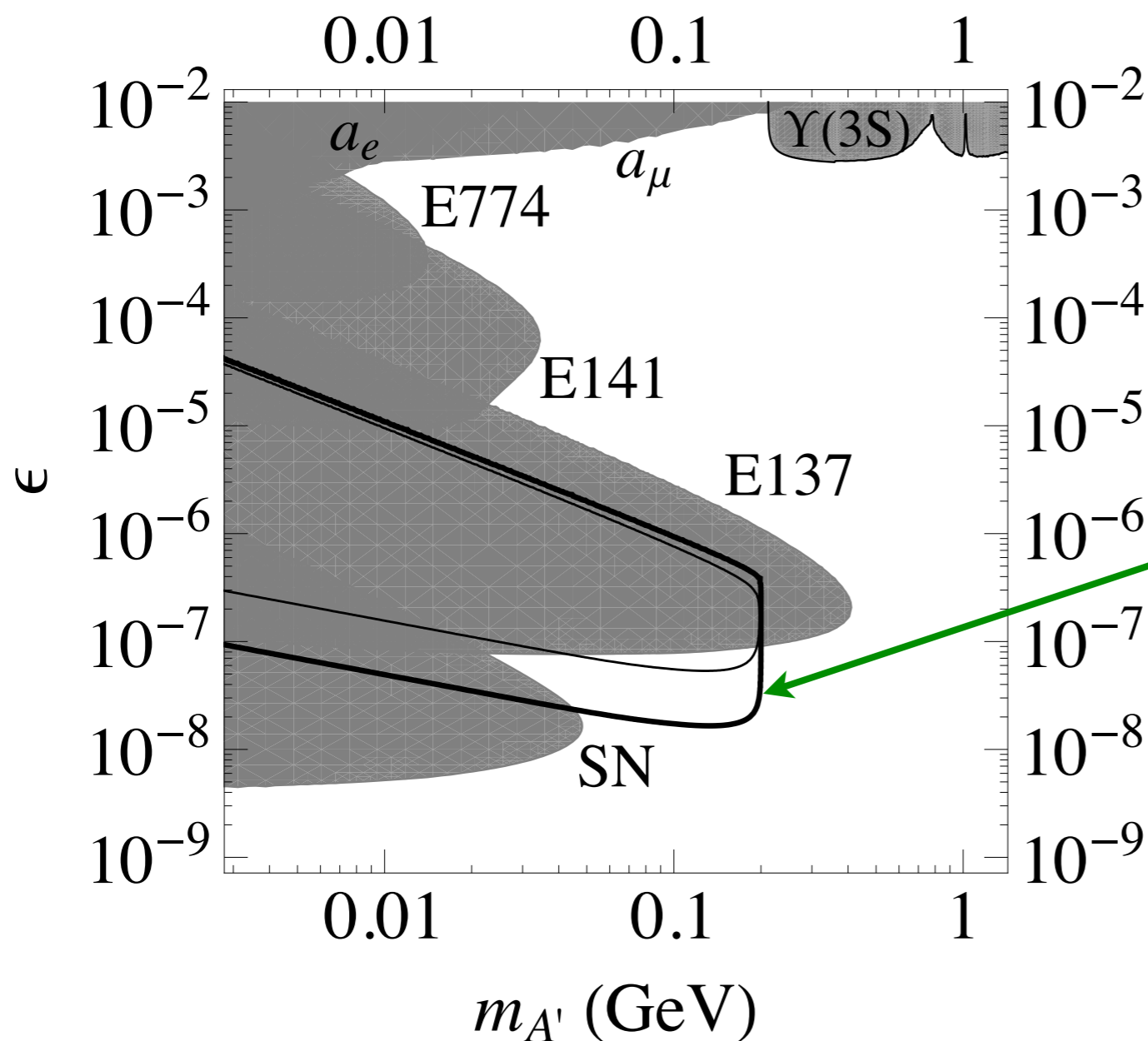


# Proton beam dumps

[Batell, Pospelov, Ritz]

produce large number of mesons

e.g. LSND dumped  $\sim 10^{23}$  protons, producing  $\sim 10^{22}$  pions



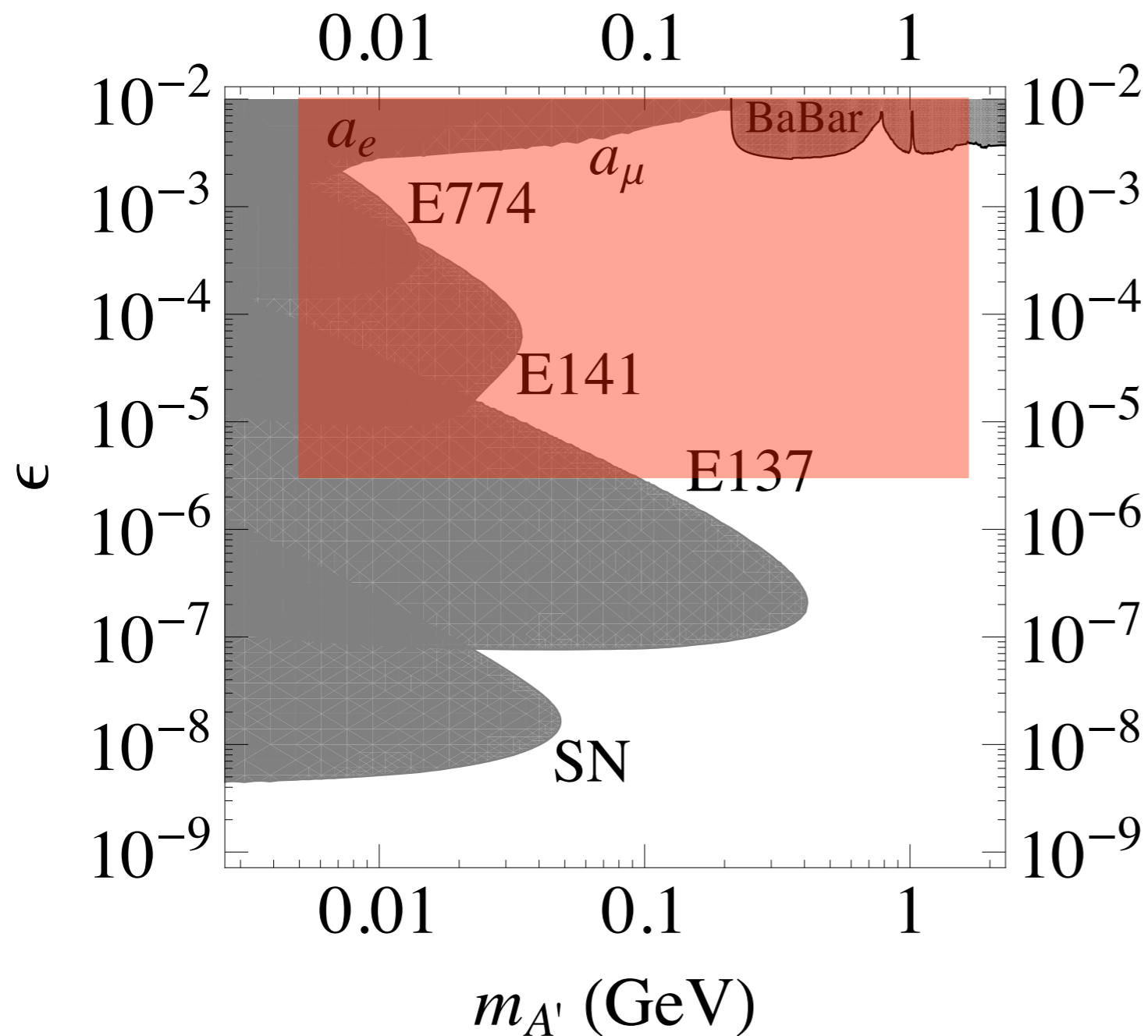
$$\pi^0 \rightarrow \gamma A' \rightarrow \gamma e^+ e^-$$

rough sensitivity

[Batell, Pospelov, Ritz]

[RE, Harnik, Kaplan, Toro]

# Summary



Very interesting  
unexplored region

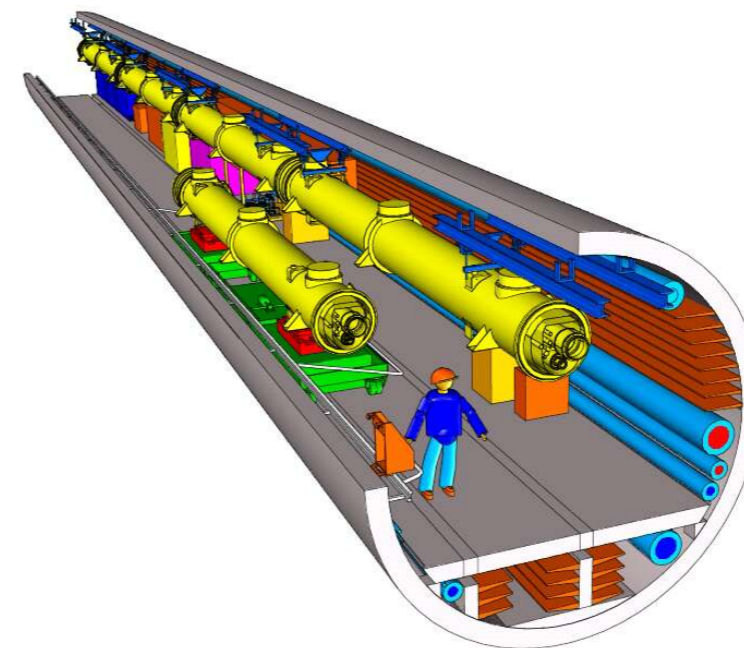
Need new experiments

Bjorken RE, Schuster, Toro

# Beam dump/fixed target opportunities at DESY

## Beams at DESY

- > suited: electrons and positrons at DESY II
  - DESY II: 10 nA, 450 MeV – 6 GeV
- > suited in principle: electrons at FLASH and XFEL
  - FLASH: 30  $\mu$ A, 1.2 GeV
  - XFEL: 30  $\mu$ A, 14 GeV



x  
z  
y



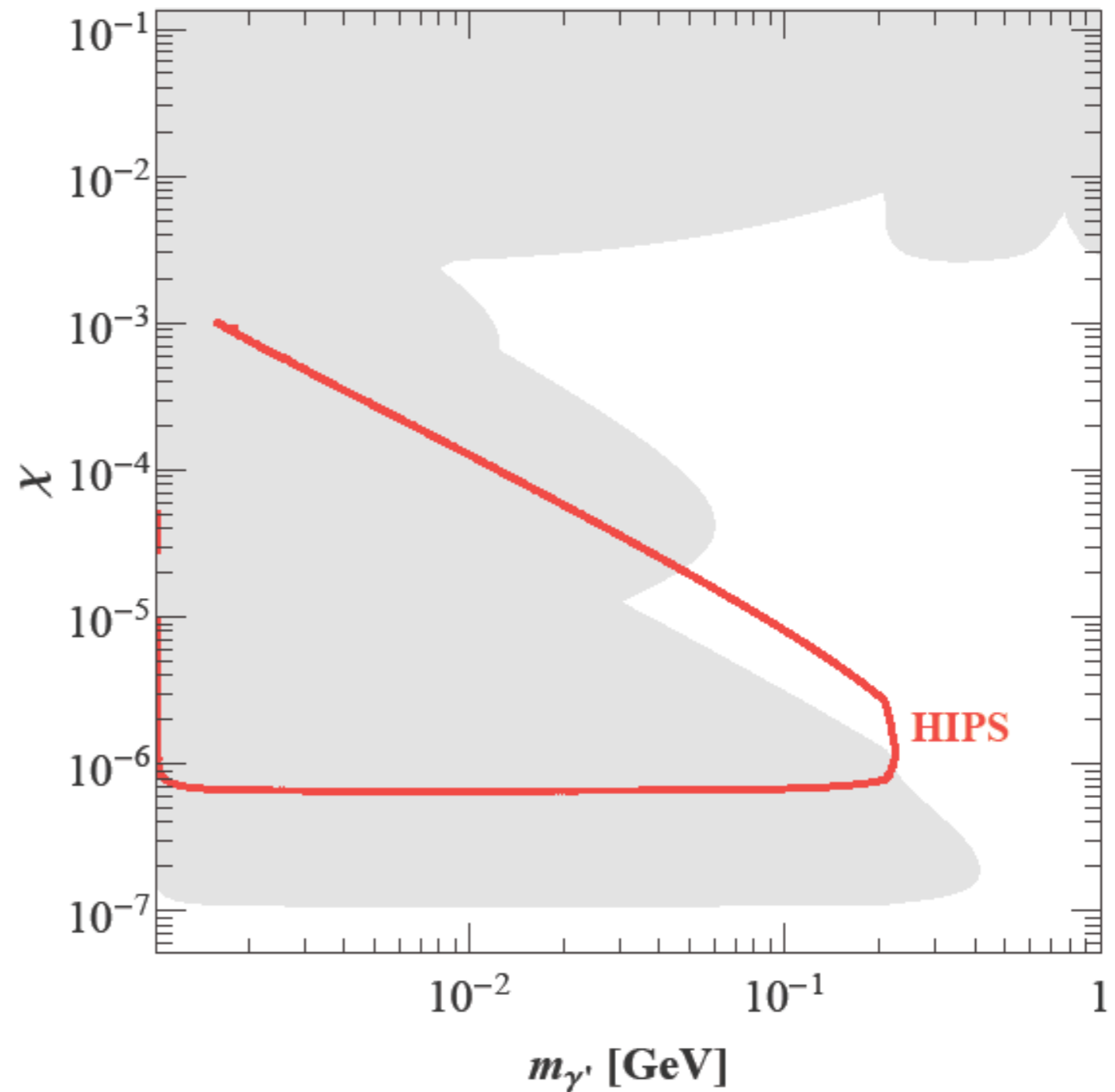
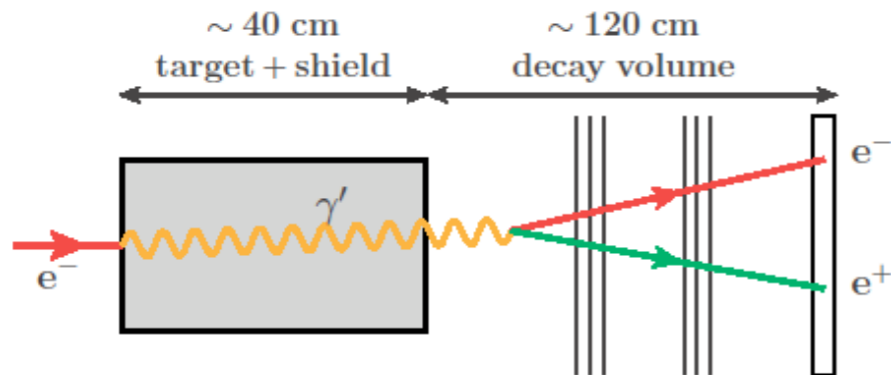
[slides from A. Ringwald, S. Andreas, E. Garutti, P. Bechtel, A. Lindner, C. Niebuhr, S. Ghazaryan, H. Ehrlichmann]

# Hidden Particle Search HIPS at DESY II

## > First setup at DESY II

- beam dump of 10 nA at 450 MeV
- complementary to JLab experiments

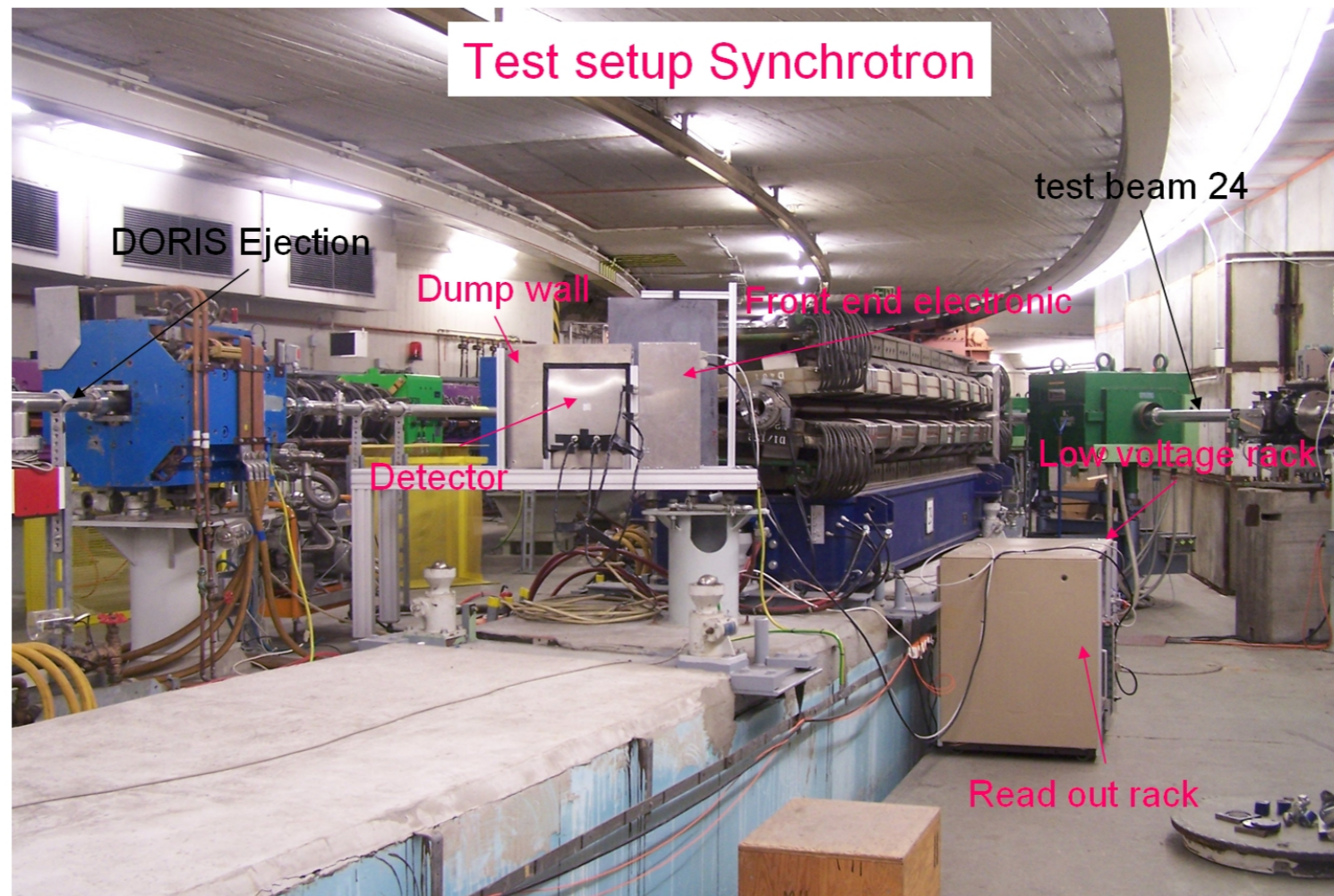
one event in  $10^7$  seconds running time



# Hidden Particle Search HIPS at DESY II

## > Current situation

- detector parts installed in DESY II tunnel for background studies
- simulations for background, signal and sensitivity ongoing
- more hardware (ZEUS MVX detector; CALICE ECAL) considered to be installed soon



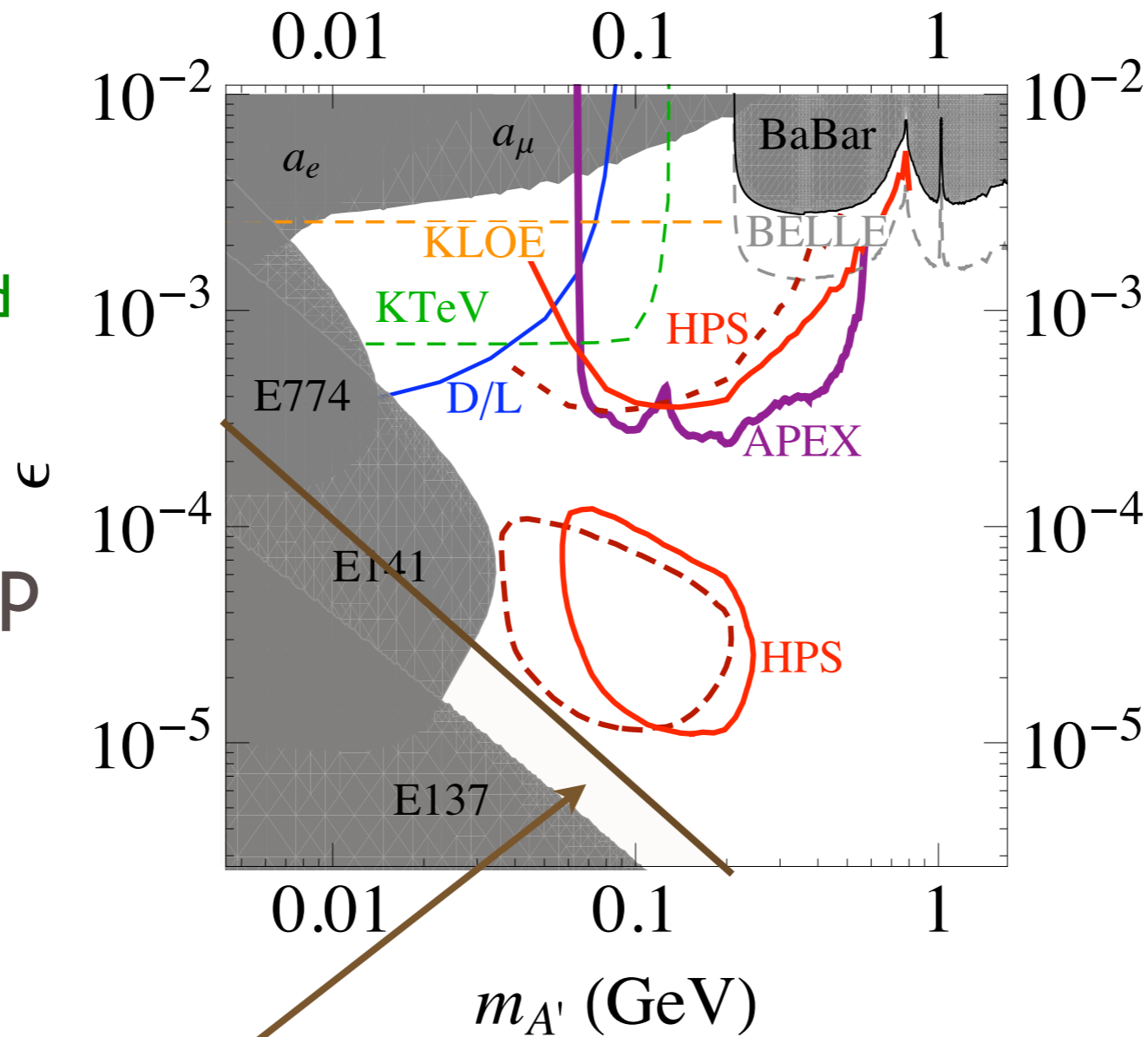
[slides from A. Ringwald, S. Andreas, E. Garutti, P. Bechtler, A. Lindner, C. Niebuhr, S. Ghazaryan, H. Ehrlichmann]



# Summary of proposed experiments

+ Mainz  
(similar proposed reach to APEX)

+ beam dump  
at JLab  
+ PrimEx



HIPS @ DESY

# Summary of proposed experiments

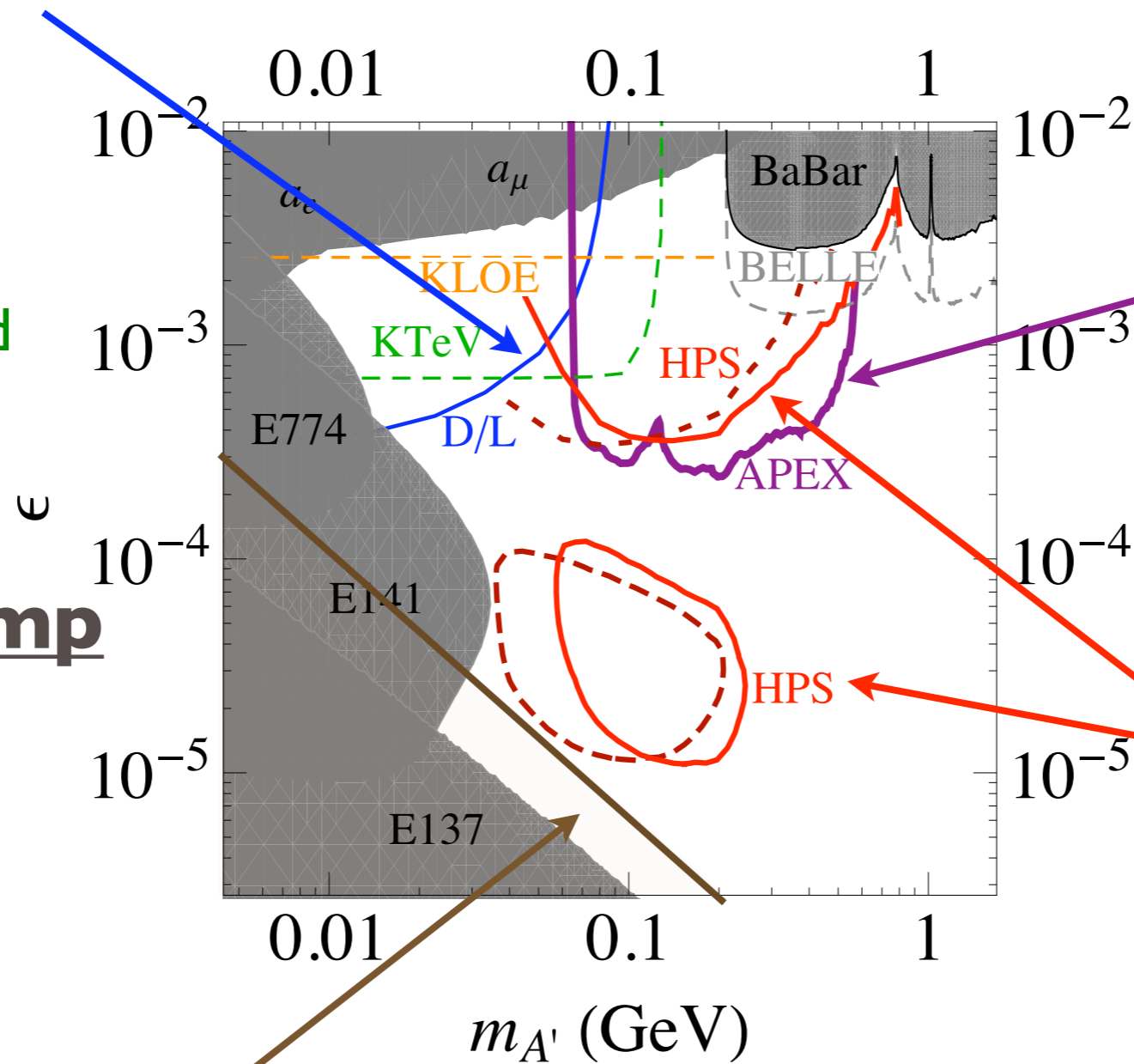
## DarkLight

[reach from Freytsis, Ovanesyanyan, Thaler, arXiv:0909.2862]

**See talks at this workshop**

+ **Mainz**  
(similar proposed reach to APEX)

+ **beam dump at JLab**  
+ **PrimEx**



**APEX**

**Heavy Photon Search**

**HIPS @ DESY**

Andreas Ringwald is at workshop



# Conclusions

- **New dark forces:**  
an exciting and well-motivated possibility
- Searches for **indirect signals from dark matter annihilation or decay** ongoing

expect more data from AMS-02, Fermi, IceCube, Planck, ACTs etc.

- **Direct searches** ongoing and planned at  $e^+e^-$  colliders, Tevatron/LHC, and fixed target experiments

**Fixed target experiments have unparalleled sensitivity**

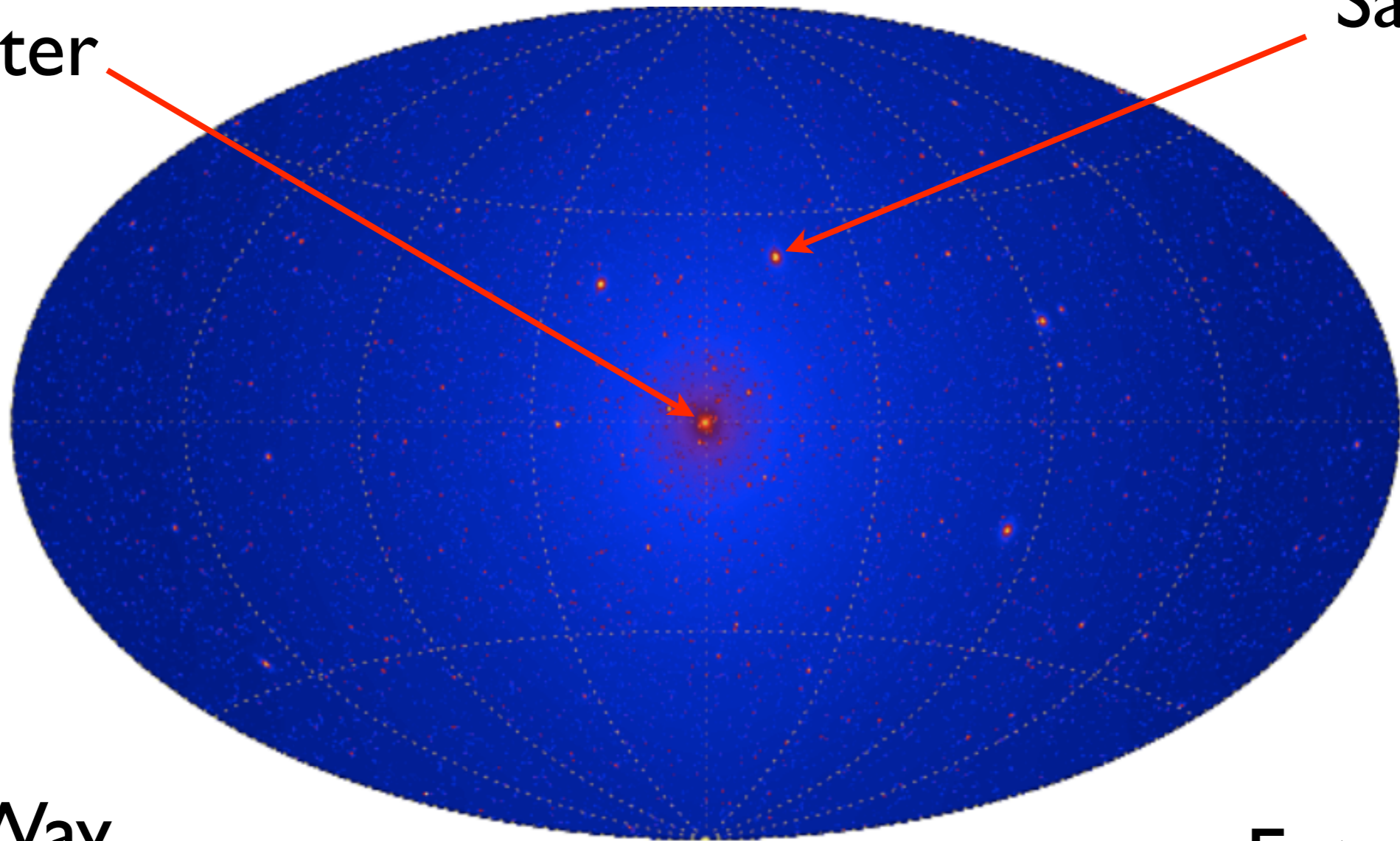
**JLab has very important role to play**

**Backup**

# Search Strategies

Galactic  
Center

Satellites

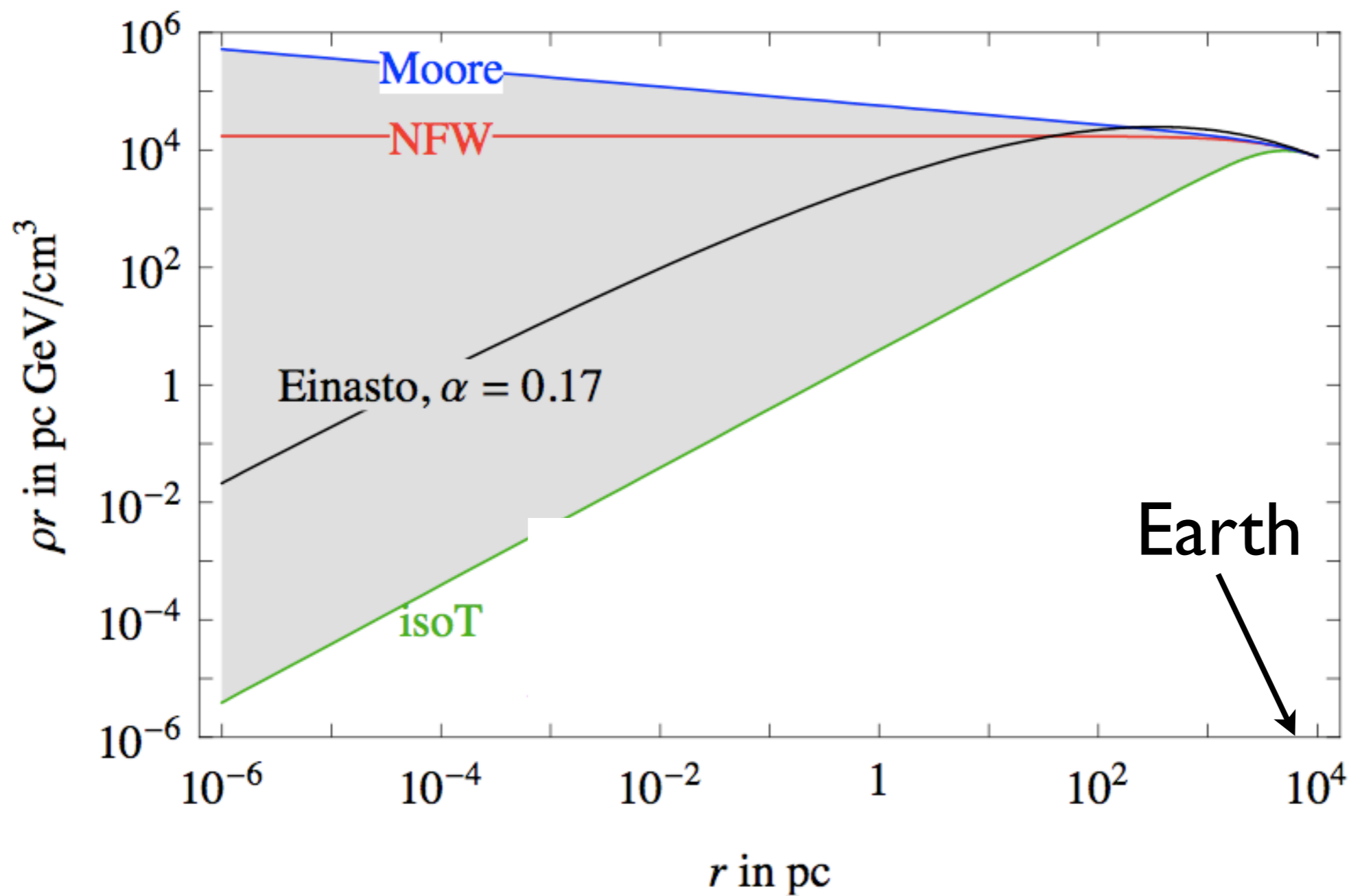


Milky-Way  
Halo

Extragalactic

All-sky map of gamma rays from  
DM annihilation, 0908.0195,  
based on Via Lactea II simulation

# DM density profile?

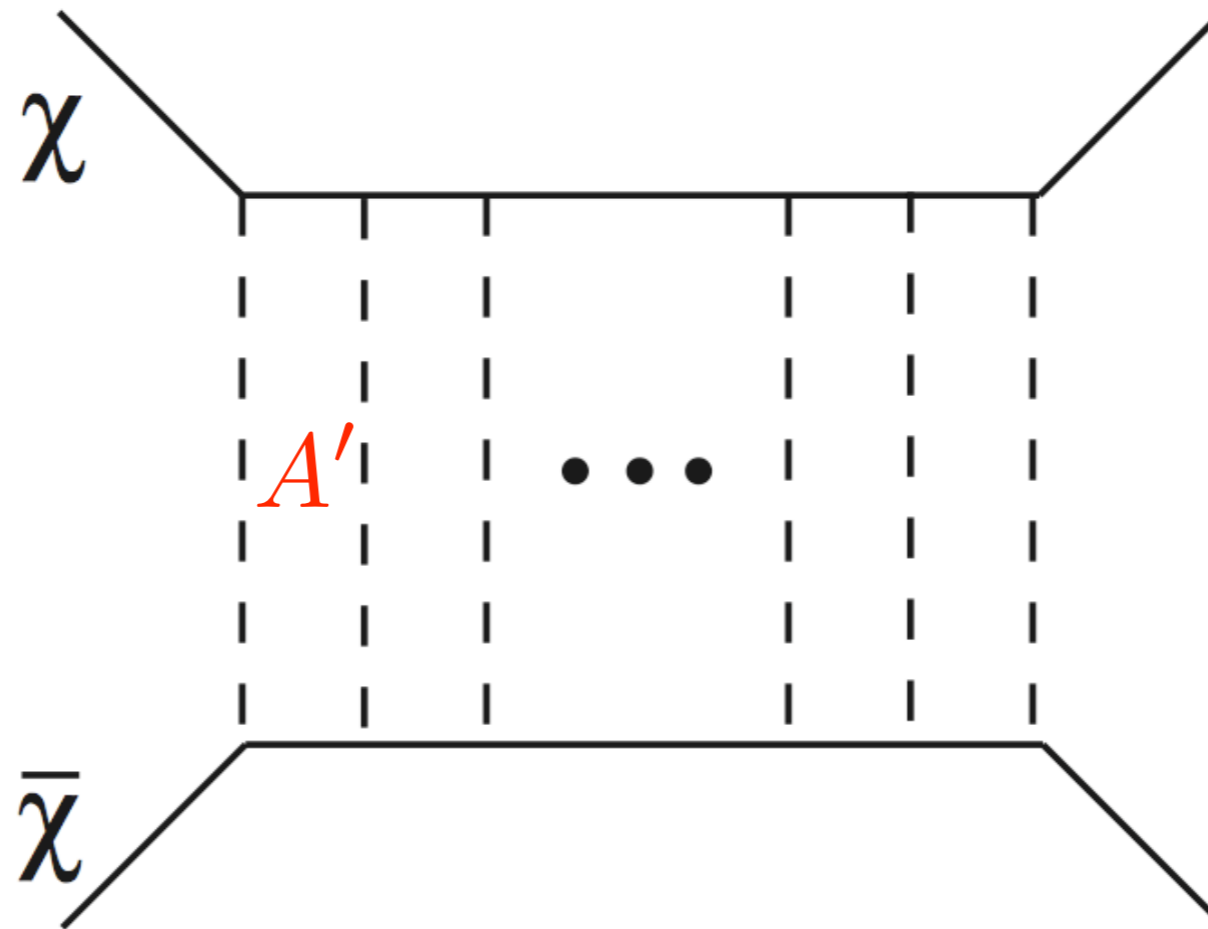


⇒ signal size difficult to predict

# Increased DM self-interactions due to $A'$

affects structure formation

e.g. DM self-interactions destroy satellite galaxies



Buckley, Fox  
Feng, Kaplinghat, Yu

larger effect for small  $m_{A'}$   $\implies m_{A'} \gtrsim 30$  MeV  
(with assumptions!)