A New Proposal to Jefferson Lab PAC35

Search for a New Vector Boson A' Decaying to e^+e^-

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Spokespersons

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(SLAC, Stanford, JLab)

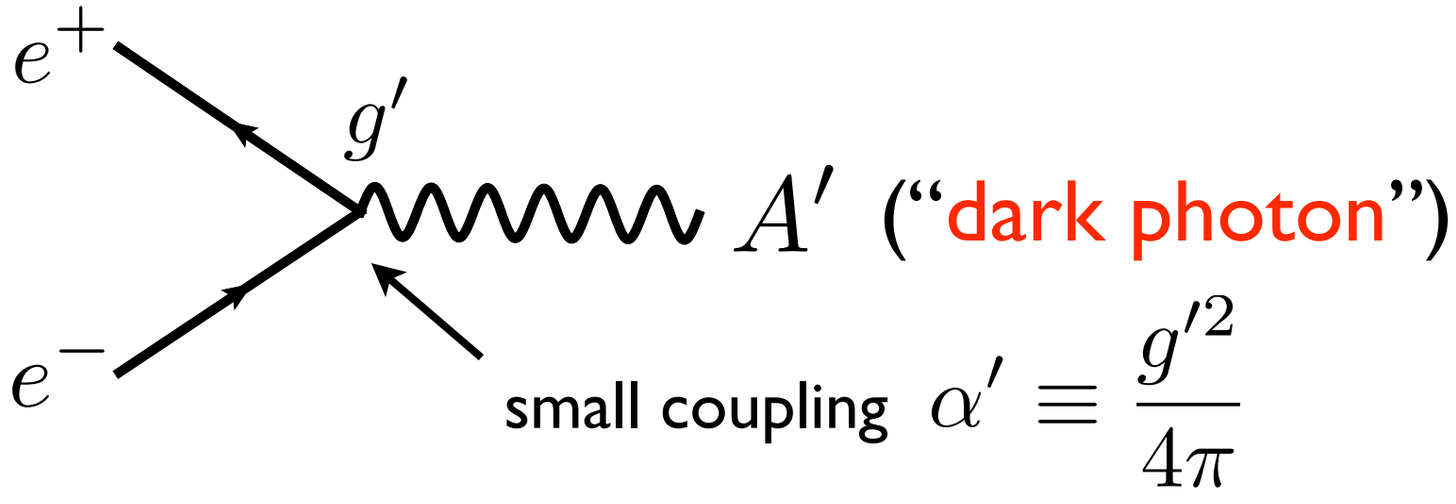
Hall A Collaboration Approval

Total: 40 collaborators

http://www.jlab.org/~bogdanw/AP-boson.pdf

Aim of Proposed Experiment

Search for a new ~100 MeV vector boson (A')
with weak coupling to electrons



Significant new reach in α' (~2-3 orders of magnitude)

A' search interesting to large fraction
of particle physics community

Proposed Experiment

Similar in spirit to other JLab experiments

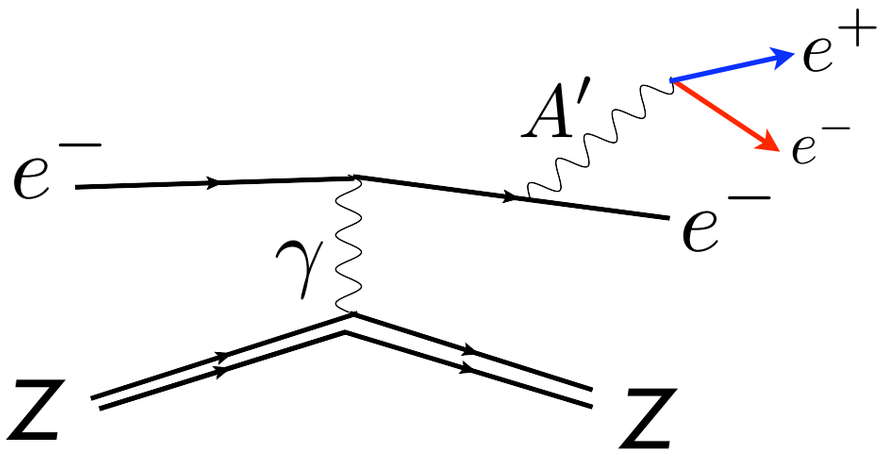
e.g. precise θ_W measurement &
parity-violation search using Møller scattering

We also want to search for new interactions

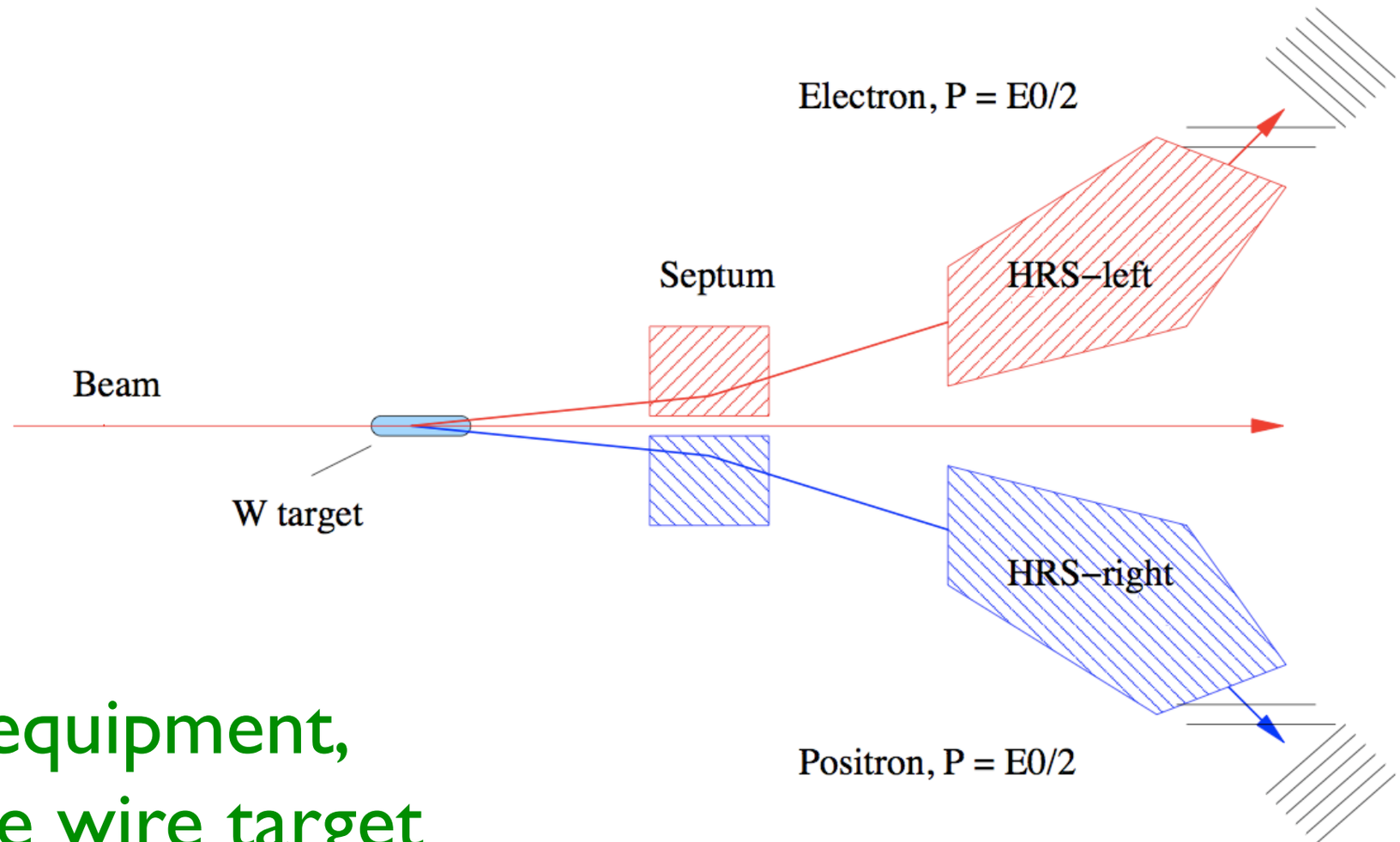
Here want to directly
produce new force carrier

The Proposed Experiment

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



A' produced forward carrying most of energy & promptly decays to e^+e^- pair

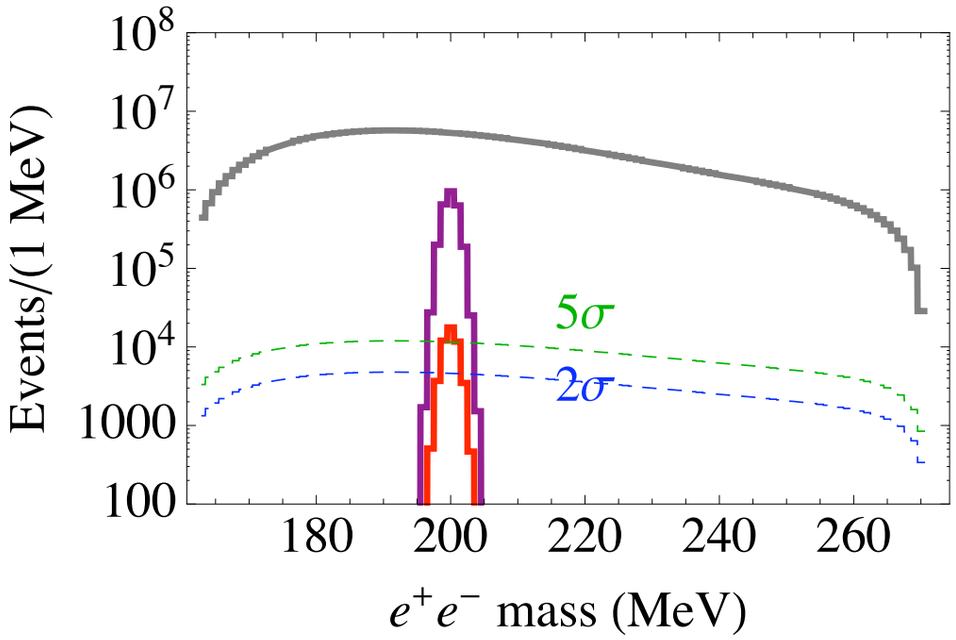


Use existing Hall A equipment, PREX septum, simple wire target

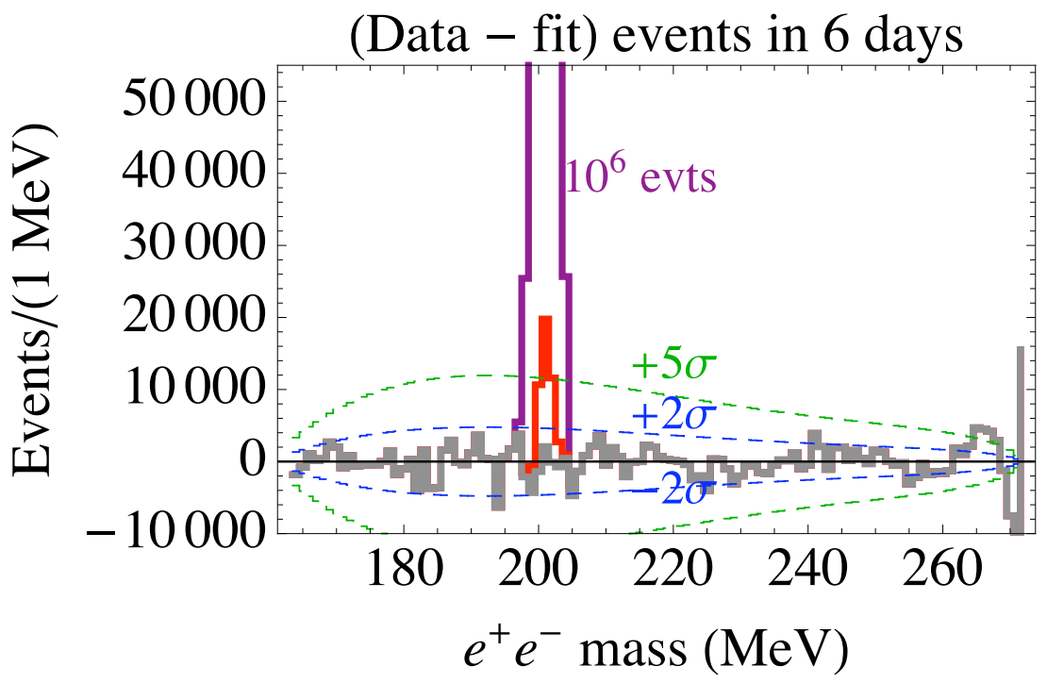
A′ appears as small resonance on QED background

Unprecedented statistics achievable

before background subtraction



after background subtration



Run Plan (6–12 days at each setting, 80 μA)

Beam energy (GeV)	**1.1**	**2.3**	**3.3**	**4.5**
Beam current (μA)	80	80	80	80
Central angle (μA)	5.0°	5.0°	5.0°	5.5°
Target thickness (X_0)	0.58%	4.25%	10%	10%
Time Requested (hrs)	158	154	158	318

→ 788 (~33 days total)

This Talk:

Motivation for New Physics at the GeV scale and a JLab A' search

- New GeV scale interactions are weakly constrained
- Evidence for Dark Matter interactions with ordinary matter
- JLab A' search will probe nature of these interactions

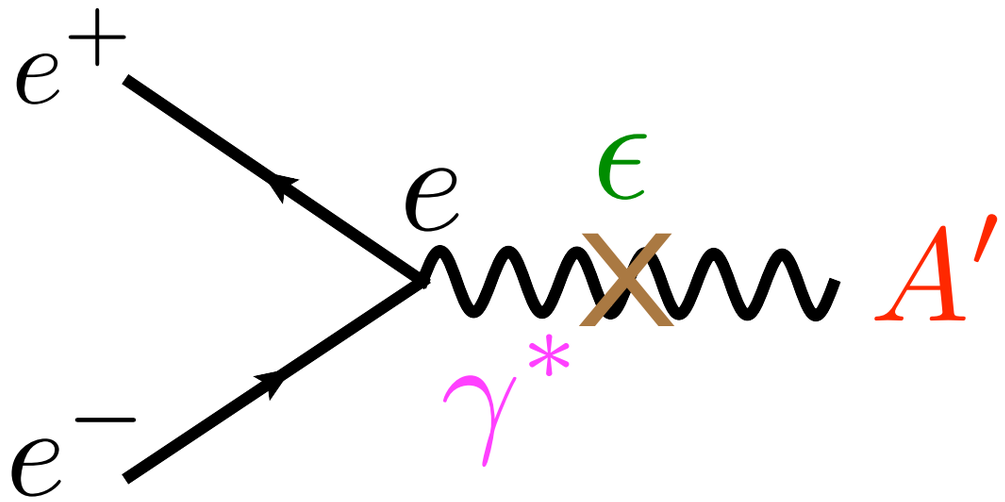
New Dark Forces

Standard Model			Dark Sector?
strong	weak	electromagnetic	???
g	$W^{\pm}, Z$	γ	A'

Strong constraints on light new matter with Standard Model interactions

New very weak interactions of ordinary matter are allowed and an exciting possibility!

Photon can mix with New Vector Boson A'



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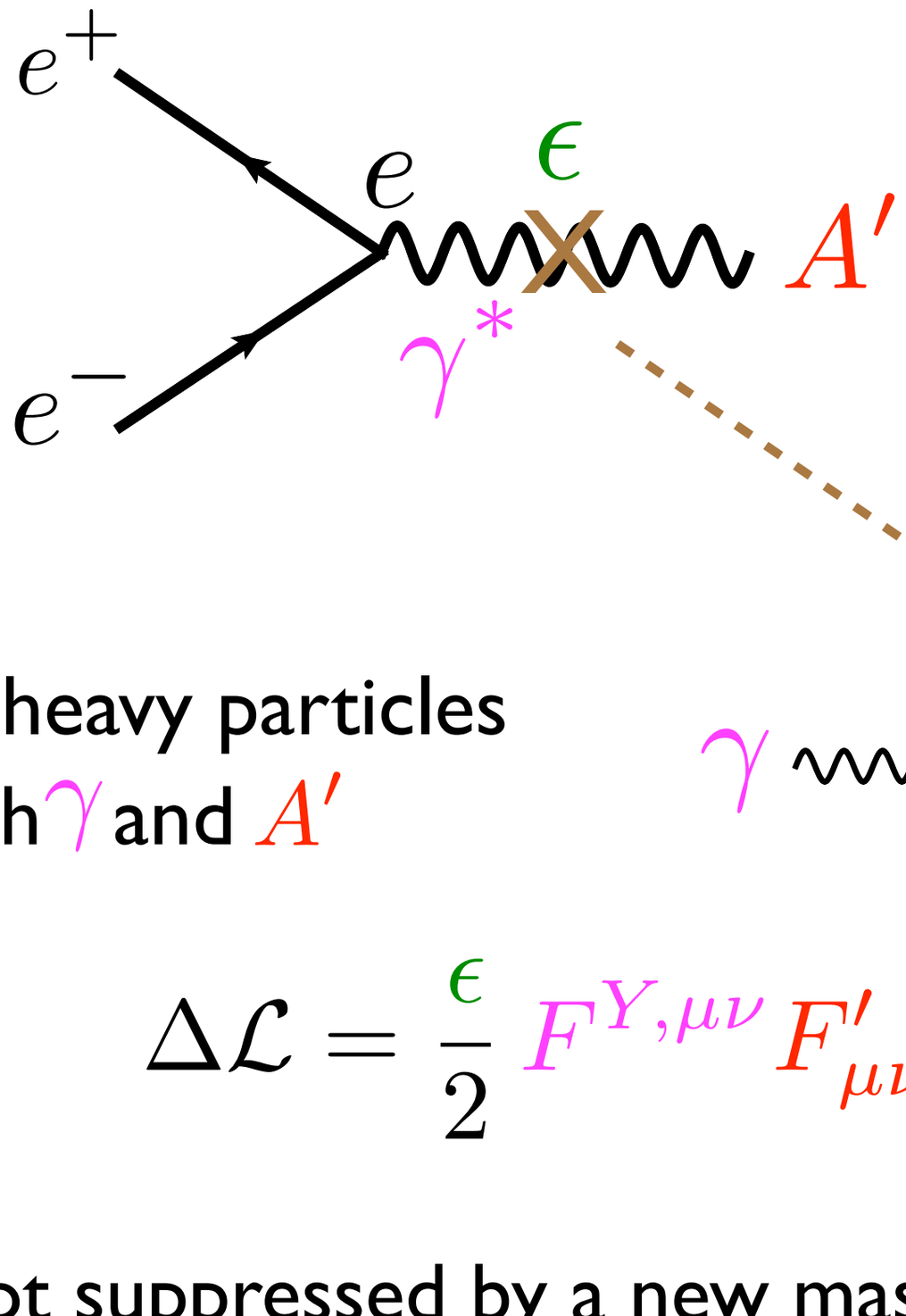
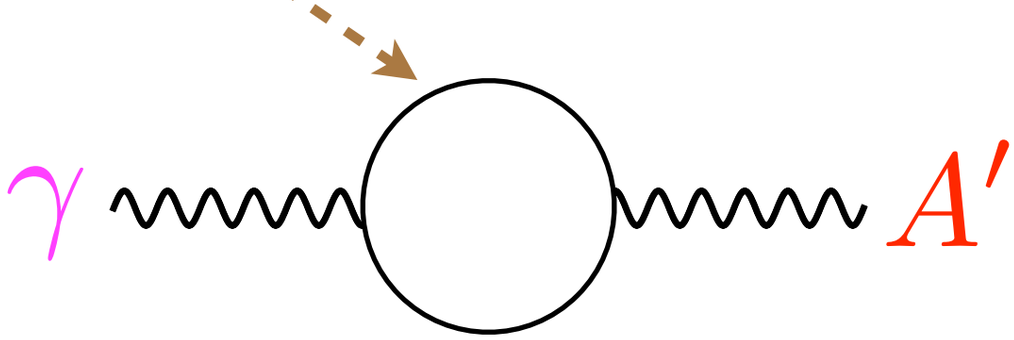


Generated by heavy particles interacting with γ and A'

(generic)



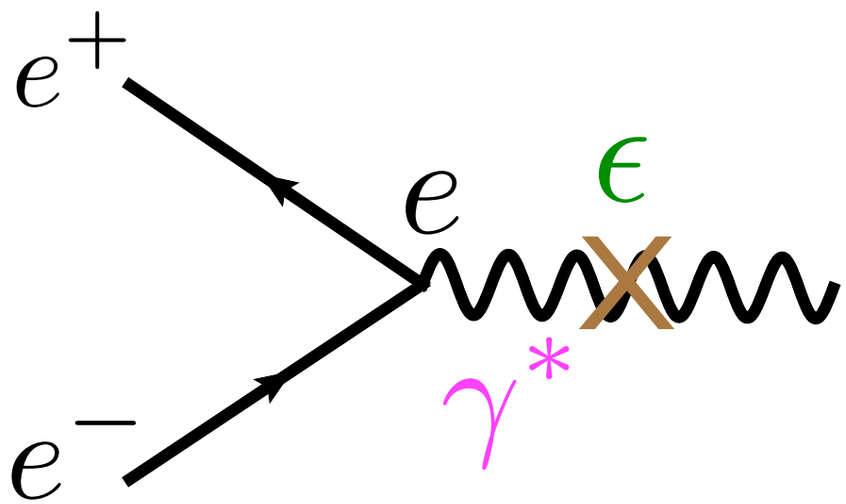
$$\Delta\mathcal{L} = \frac{\epsilon}{2} F^{Y,\mu\nu} F'_{\mu\nu}$$

"kinetic mixing"

[Holdom]

(not suppressed by a new mass scale)

Photon can mix with New Vector Boson A'



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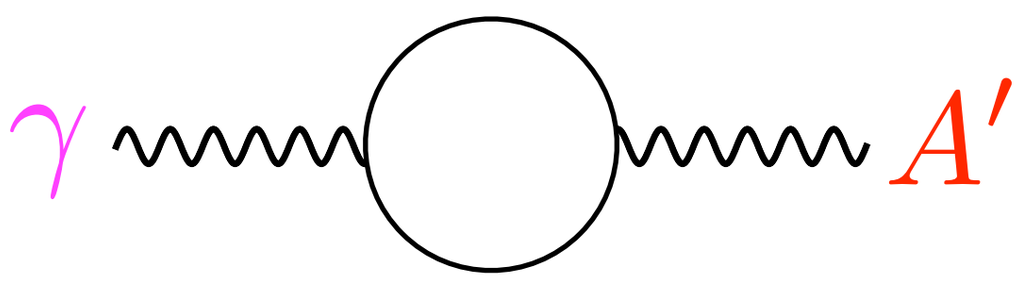
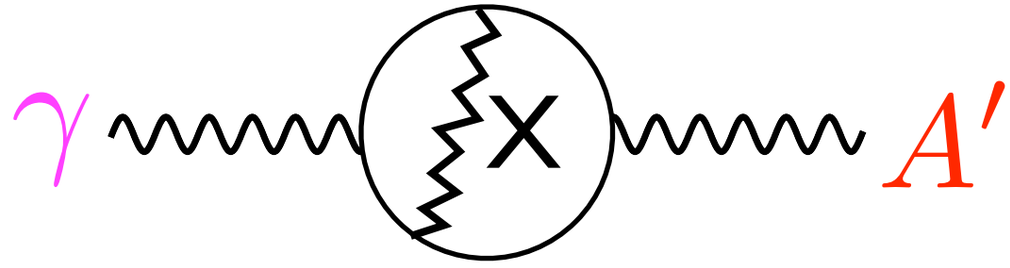


$$\epsilon \sim 10^{-4} - 10^{-2}$$

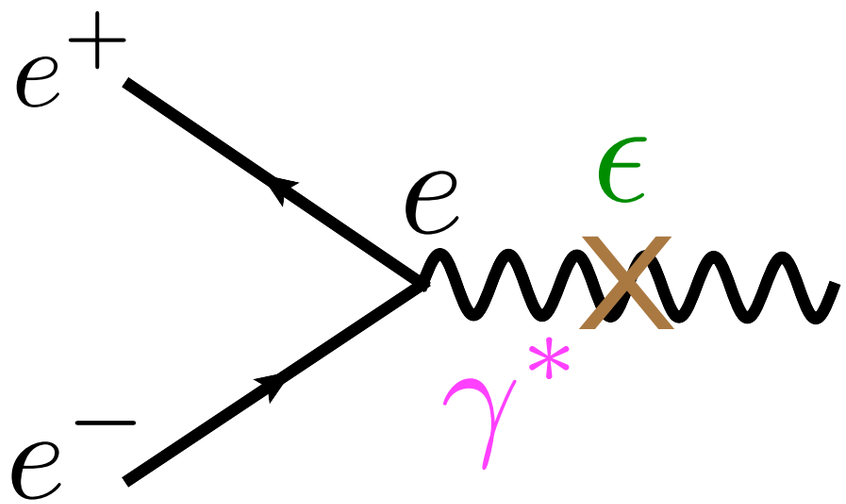


$$\epsilon \sim 10^{-5} - 10^{-3}$$

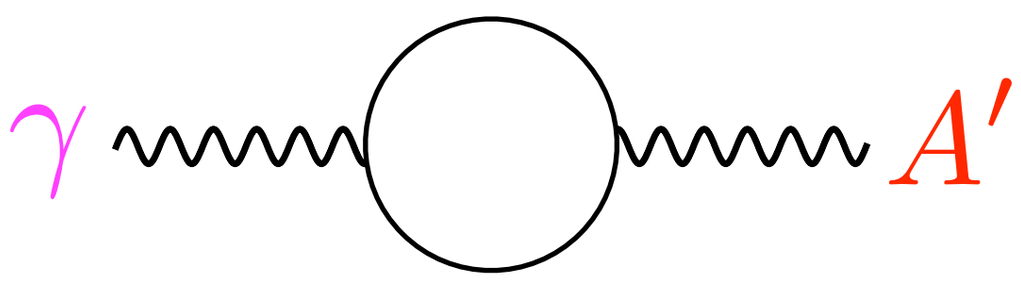
(if SM unifies in a GUT)

current constraint: $\epsilon \lesssim (0.3 - 1) \times 10^{-2}$

Photon can mix with New Vector Boson A'



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



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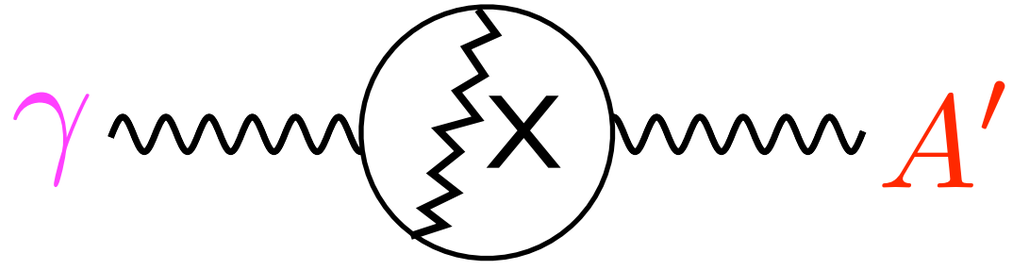

$$\epsilon \sim 10^{-5} - 10^{-3}$$

(if SM unifies in a GUT)

$$m^2_{A'} \sim \epsilon M^2_W \sim \mathrm{MeV}^2 - \mathrm{GeV}^2$$

in simple models

[e.g. Cheung, Ruderman, Wang, Yavin; Katz, Sundrum; Morrissey, Poland, Zurek]

GeV-scale A' is weakly constrained and theoretically natural

Next:

Evidence from Dark Matter for New GeV-scale Force

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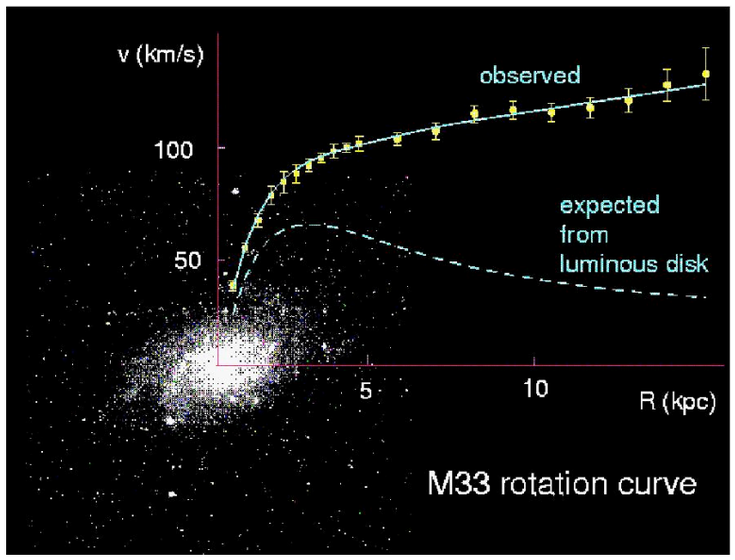
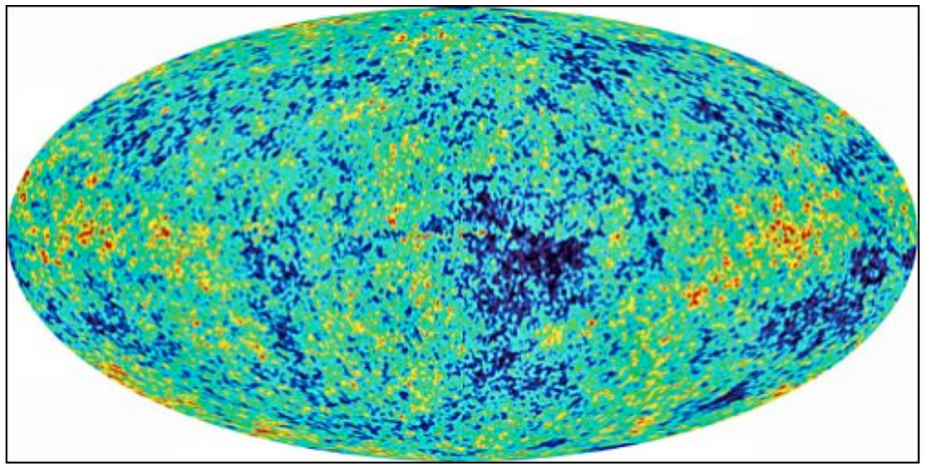
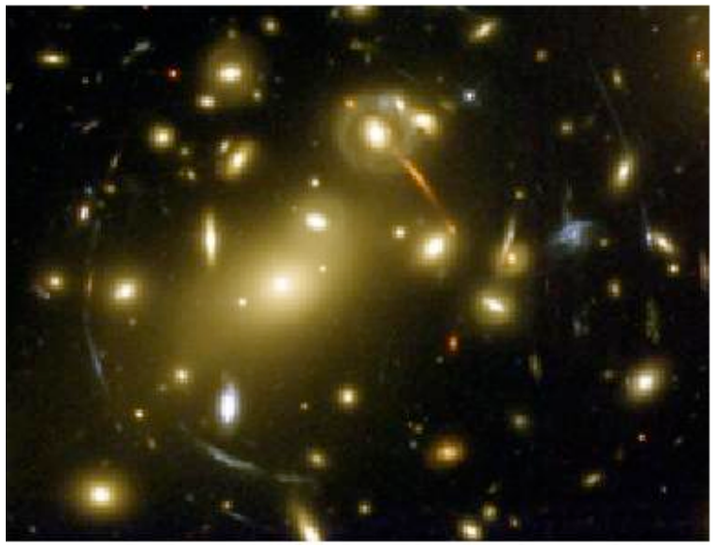
Evidence from Dark Matter for New GeV-scale Force

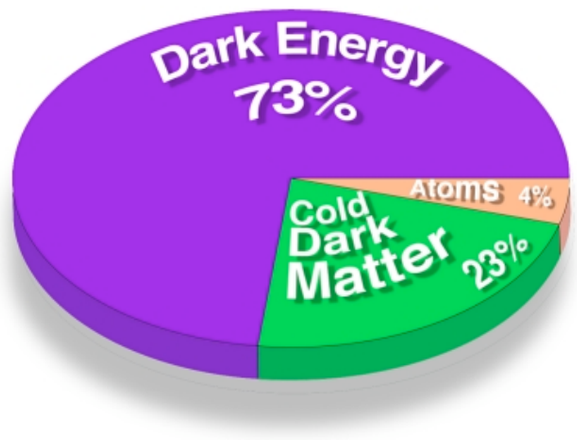
but first...

What do we know about Dark Matter?









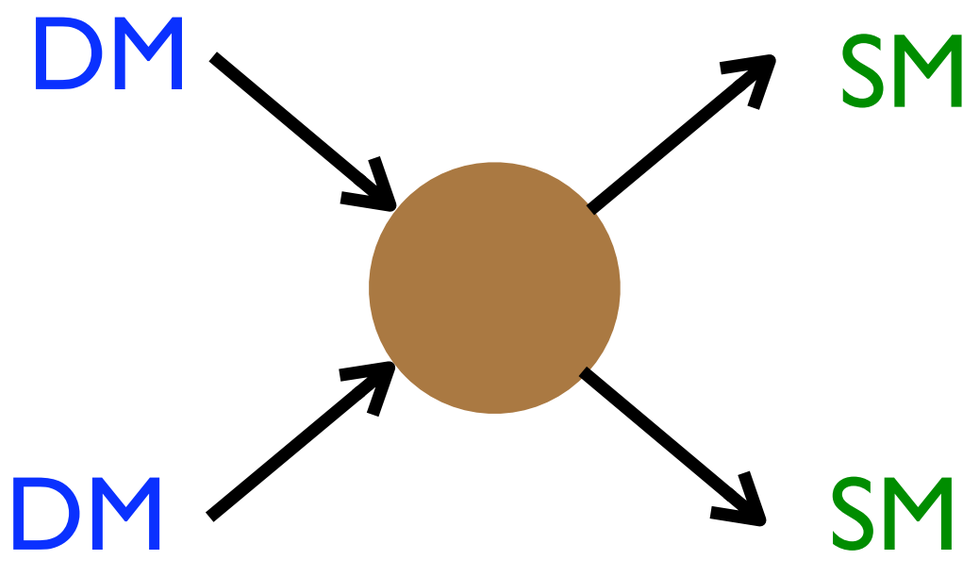
Source: Robert Kirshner
Source: NASA/WMAP Science Team

Existence
well-established !

Dark Matter interacts with us through *gravity*

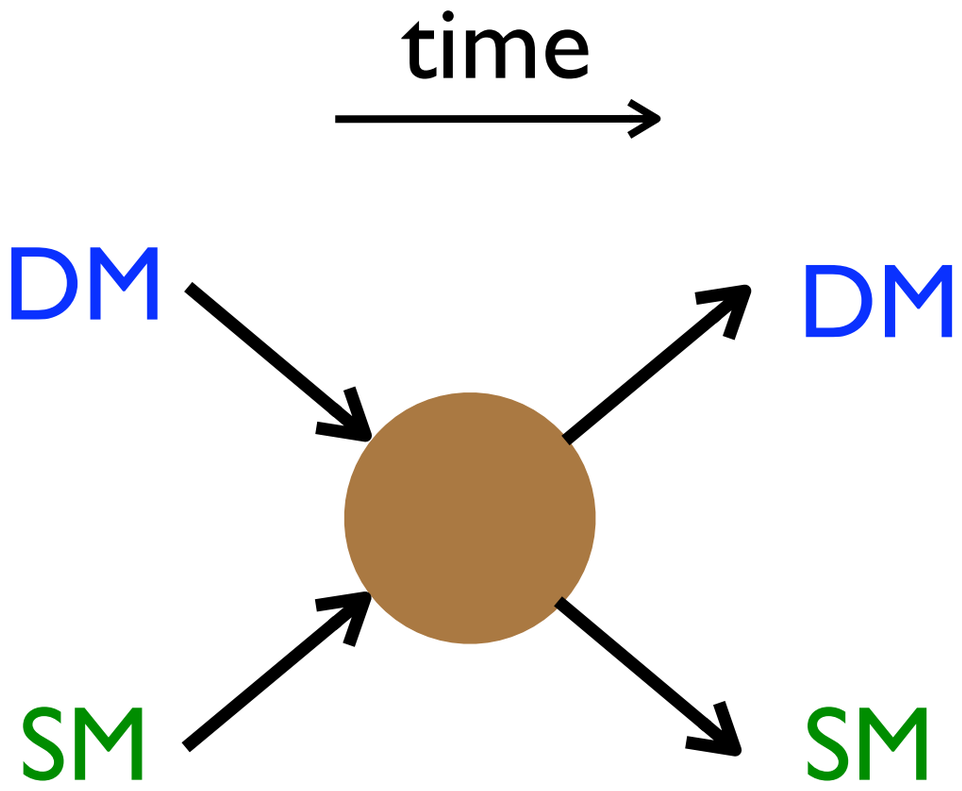
But does it have *other interactions* with us ?

Dark Matter interactions with ordinary matter?



Indirect detection:
Cosmic-rays, photons, ...

PAMELA, Fermi, HESS,
ATIC, ACTs, WMAP



Direct detection

CDMS, DAMA/LIBRA, XENON,
CRESST, LUX, COUPP, KIMS, ...

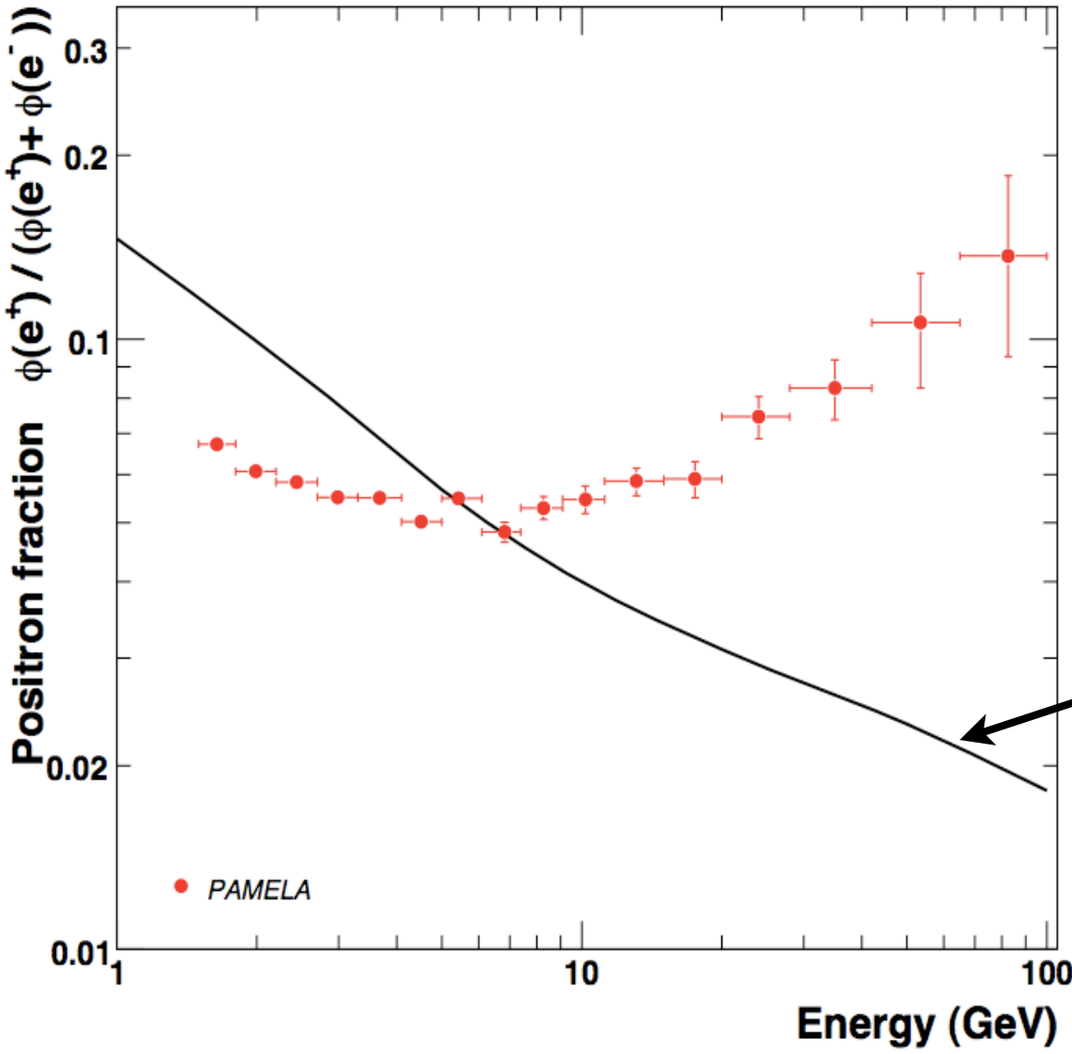
Abundance of Data

Many Anomalies

All suggestive that dark matter interacts with us *not just through gravity*

Cosmic-ray positron excess

PAMELA satellite



An excess at high energies

Nature, 2009

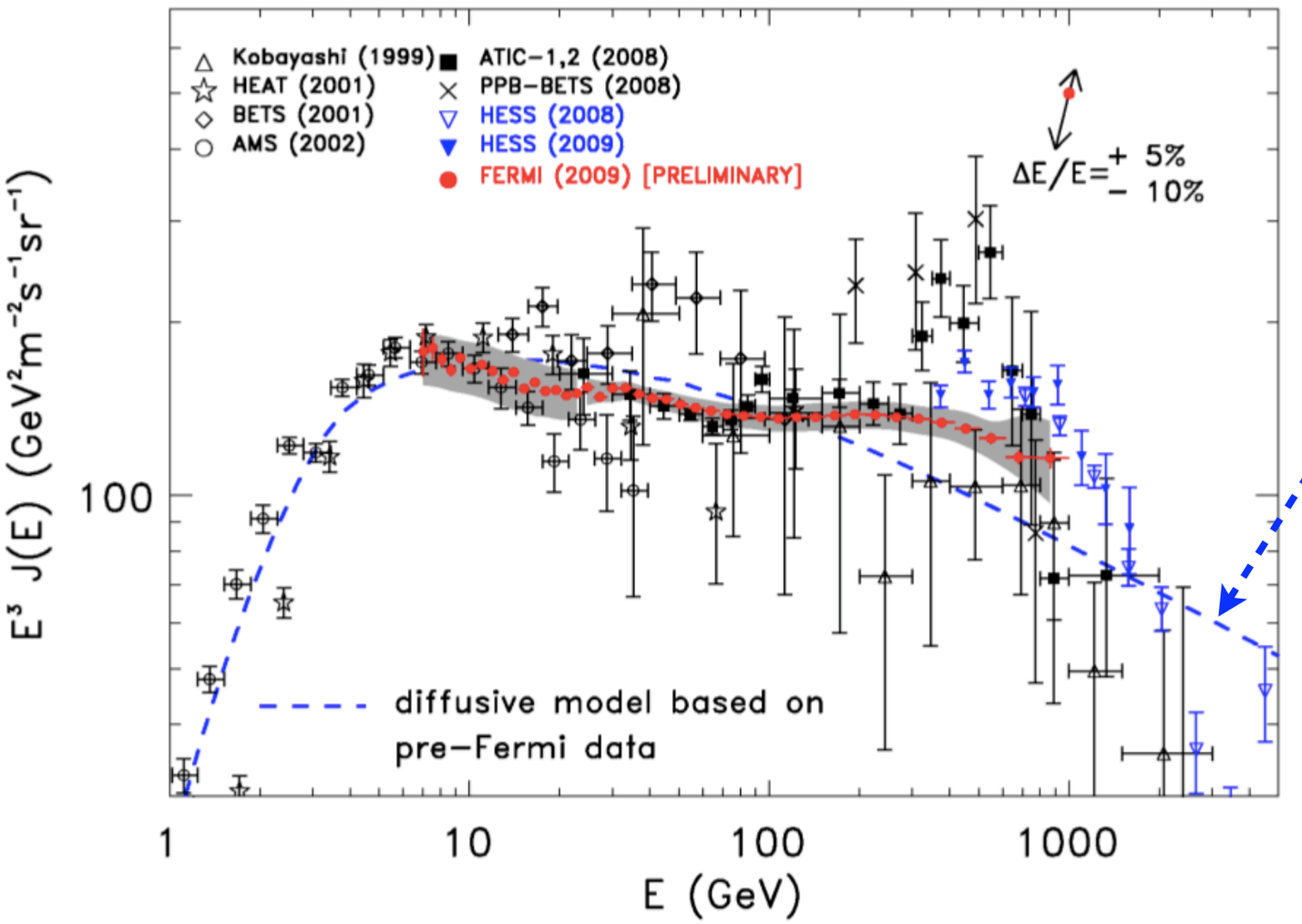
(415 citations, ~1/day)

Cosmic-ray positron+electron excess

Fermi satellite

HESS

$e^+ + e^-$ flux



theory expectation

An excess at high energies

Something is producing an excess of high energy electrons and positrons in our Galaxy...

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Very suggestive of Dark Matter annihilation (with $m_{DM} \sim 1$ TeV)

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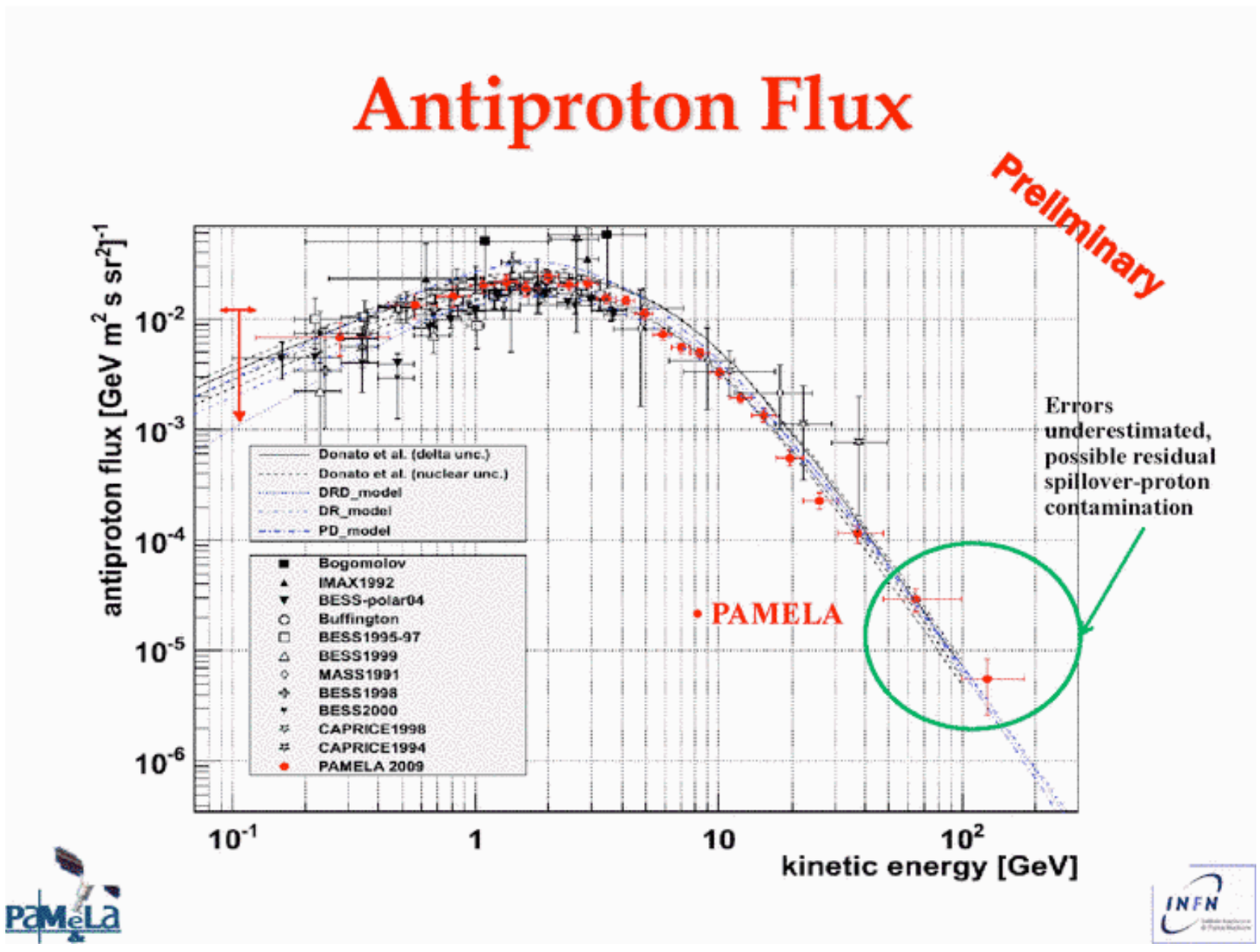
Very suggestive of Dark Matter annihilation (with $m_{DM} \sim 1$ TeV)

It must couple to ordinary matter...
But how?

No antiproton excess !

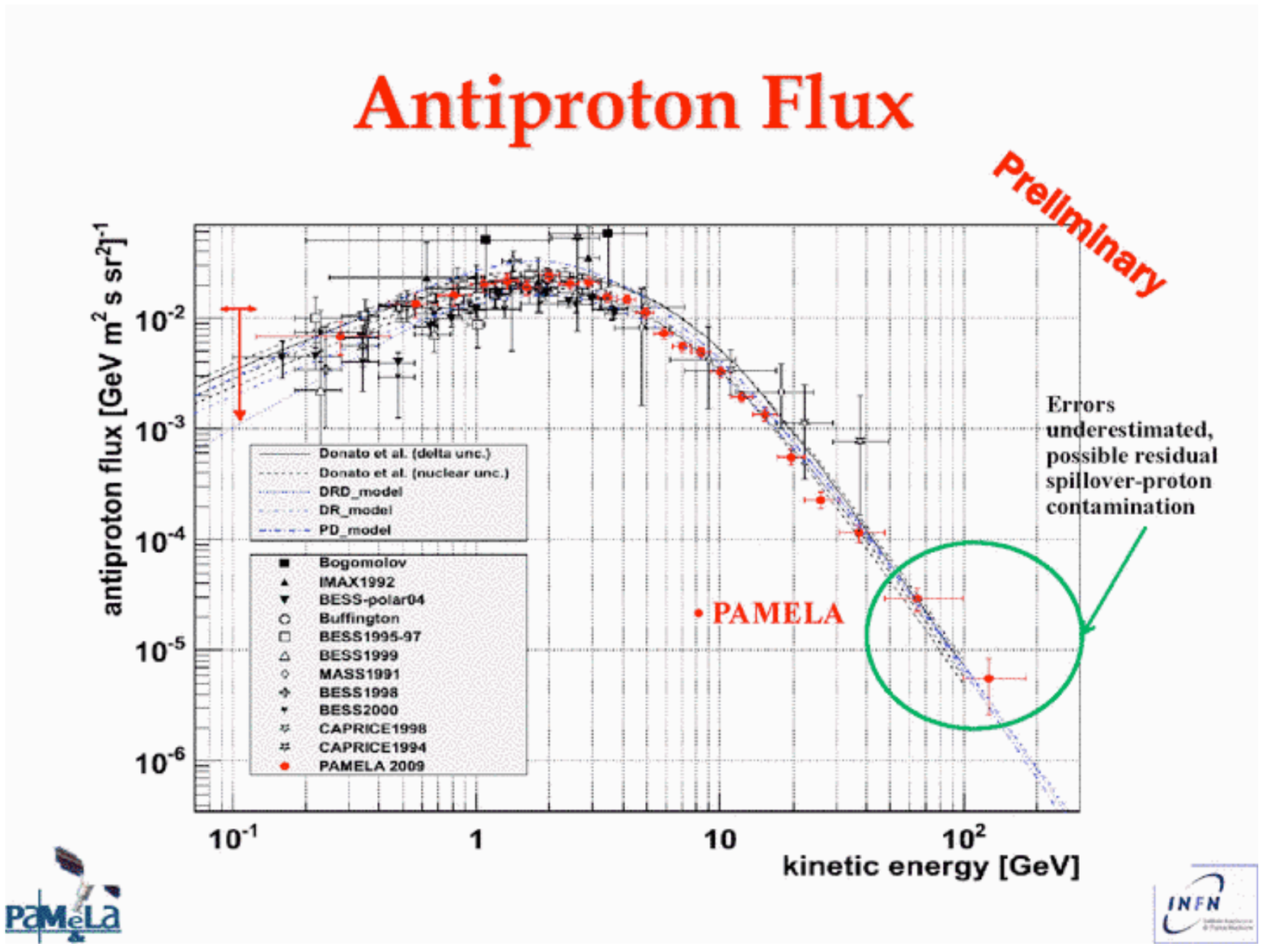
PAMELA satellite



Slide (with updated results) from M. Boezio
KITP DM workshop (now)

No antiproton excess !

PAMELA satellite



Forbids DM annihilation to

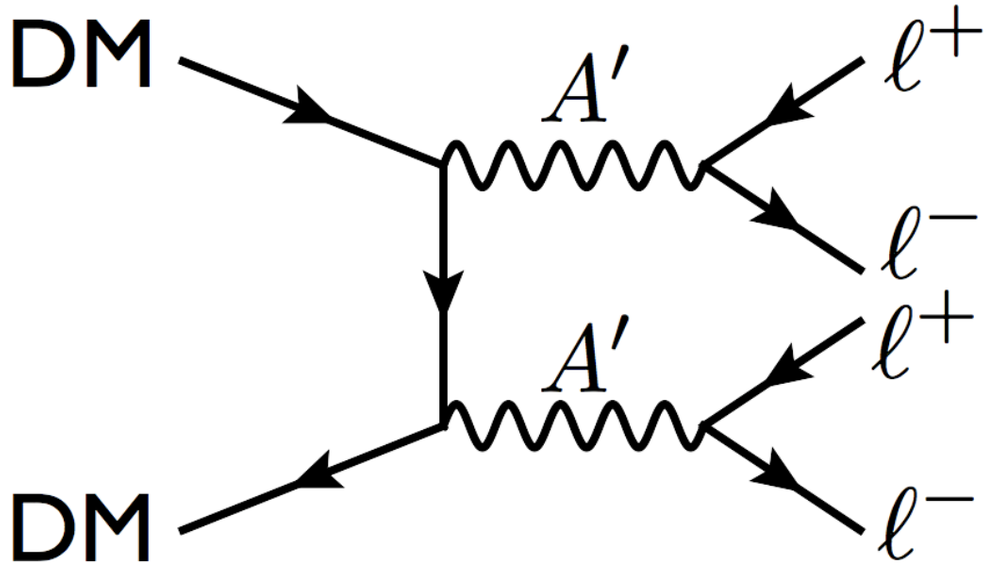
$g \quad W^{\pm} \quad Z$

Slide (with updated results) from M. Boezio KITP DM workshop (now)

New force implies new annihilation channels

Arkani-Hamed, Finkbeiner, Slatyer, Weiner;
Pospelov & Ritz
(10/09, total ~351 citations)

New force implies new annihilation channels



For $m_{A'} \lesssim 1\,\mathrm{GeV}$: $A' \to \ell^+\ell^-, \pi^+\pi^-$

Simple kinematics forces

dark matter annihilation to produce e^+ & e^-

excess, but no anti-proton excess !

A second challenge to fit e^+e^- data

DM relic abundance is determined in early Universe:

$$\Omega_{\rm DM} \propto \frac{1}{\langle \sigma v \rangle}$$

If $\langle \sigma v \rangle$ is too large, then $\Omega_{\rm DM}$ is too small

The challenge:

To fit cosmic-ray e^+ & e^- excess requires:

$\langle \sigma v \rangle$ ~1000 times too large

to obtain correct $\Omega_{\rm DM}$

Dark matter interacting with a sub-GeV A' solves this challenge

A sub-GeV A' provides a "long-range force" between dark matter particles

Light A' mediates long-range force

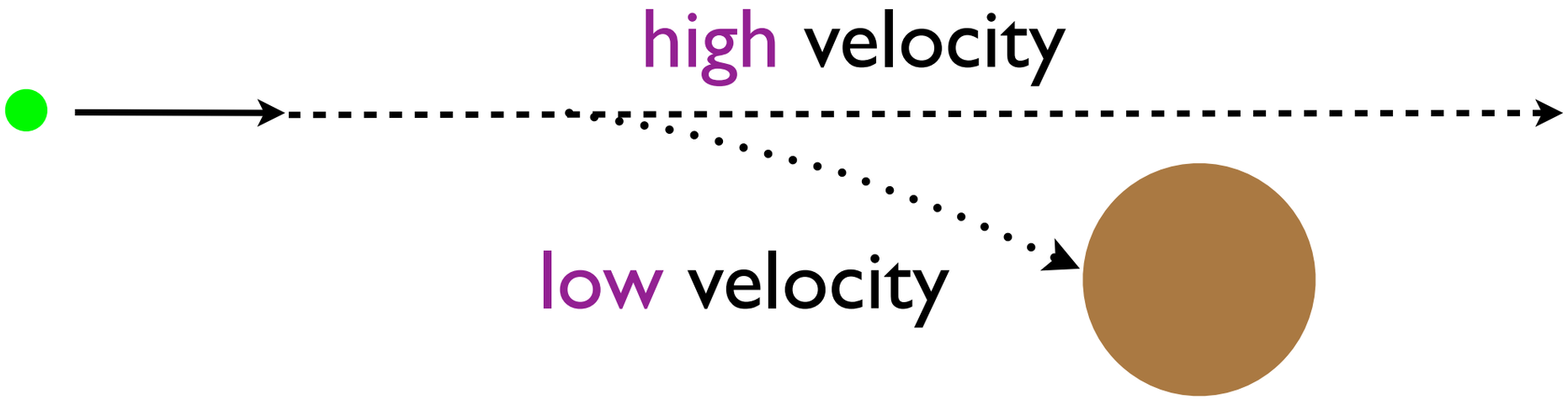
Sommerfeld enhancement

Light A' mediates long-range force

Sommerfeld enhancement

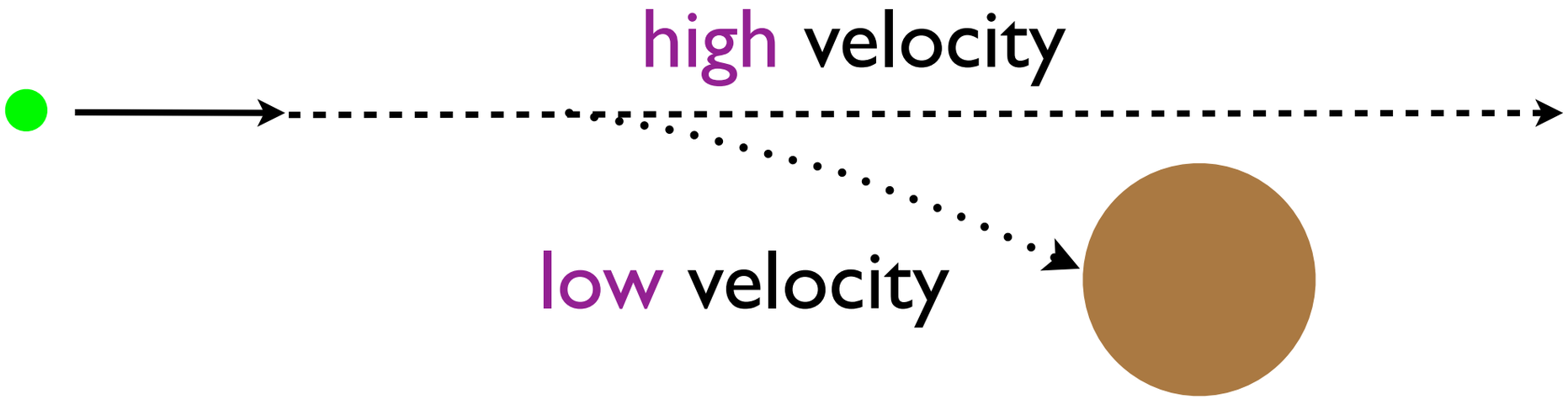
Light A' mediates long-range force

Sommerfeld enhancement



Light A' mediates long-range force

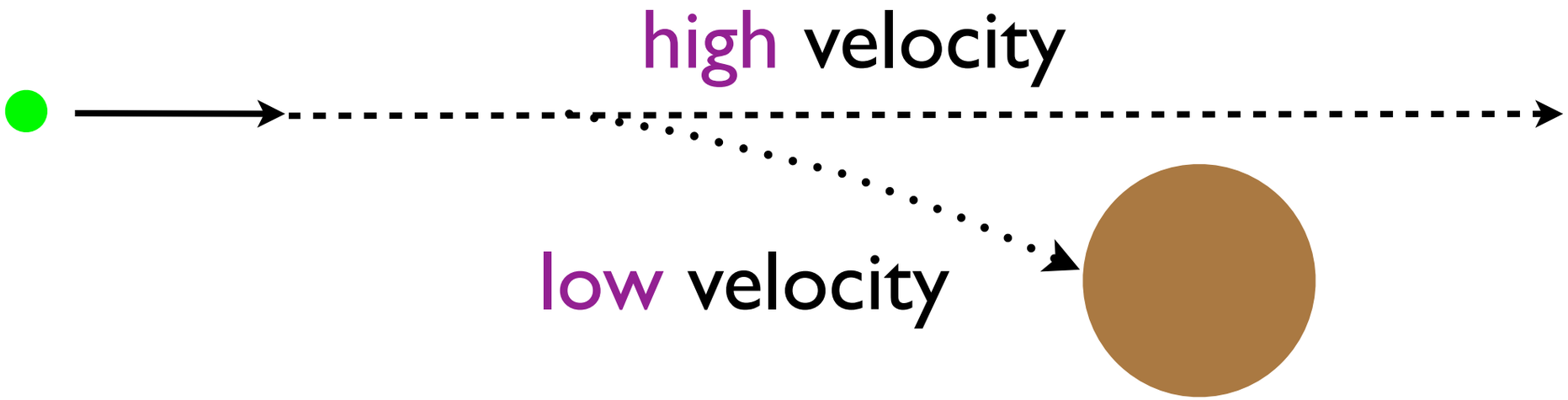
Sommerfeld enhancement



$$\langle \sigma v \rangle \propto \frac{1}{v}$$

Light A' mediates long-range force

Sommerfeld enhancement



$$\langle \sigma v \rangle \propto \frac{1}{v}$$

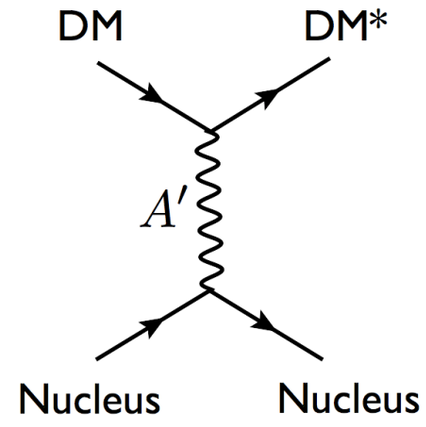
Today: v small, so $\langle \sigma v \rangle$ is large

In Early Universe: v large, so $\langle \sigma v \rangle$ is small

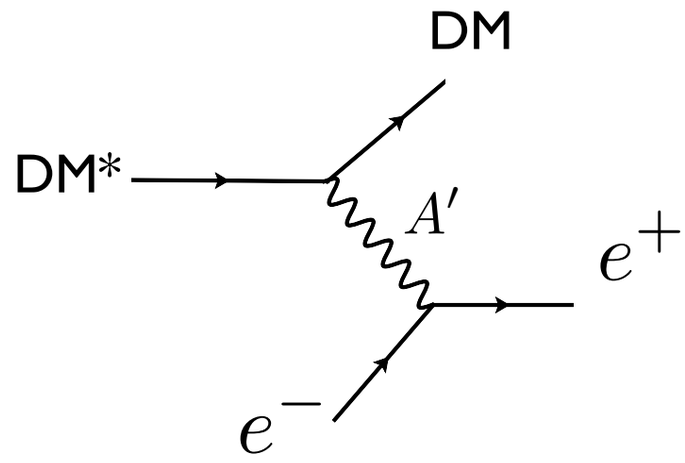
can obtain correct relic abundance + explain e^+e^- data

Further hints for new forces

Many other Dark Matter anomalies:



- WMAP+Fermi "Haze"
  [Finkbeiner, Dobler et.al.]
- DAMA/LIBRA annual modulation
  [Bernabei et.al., Tucker-Smith & Weiner]
- INTEGRAL 511 keV line
  [Finkbeiner & Weiner]



Other hints:

- anomalous muon g-2 [Pospelov]

need much more time to discuss all exciting details

We have many hints that dark matter interacts with ordinary matter (through an A'?)

Large interest in searching for an A'

To stimulate progress we organized the SLAC Dark Forces Workshop

~100 participants

Searches for New Forces at the GeV-scale

http://www-conf.slac.stanford.edu/darkforces2009/

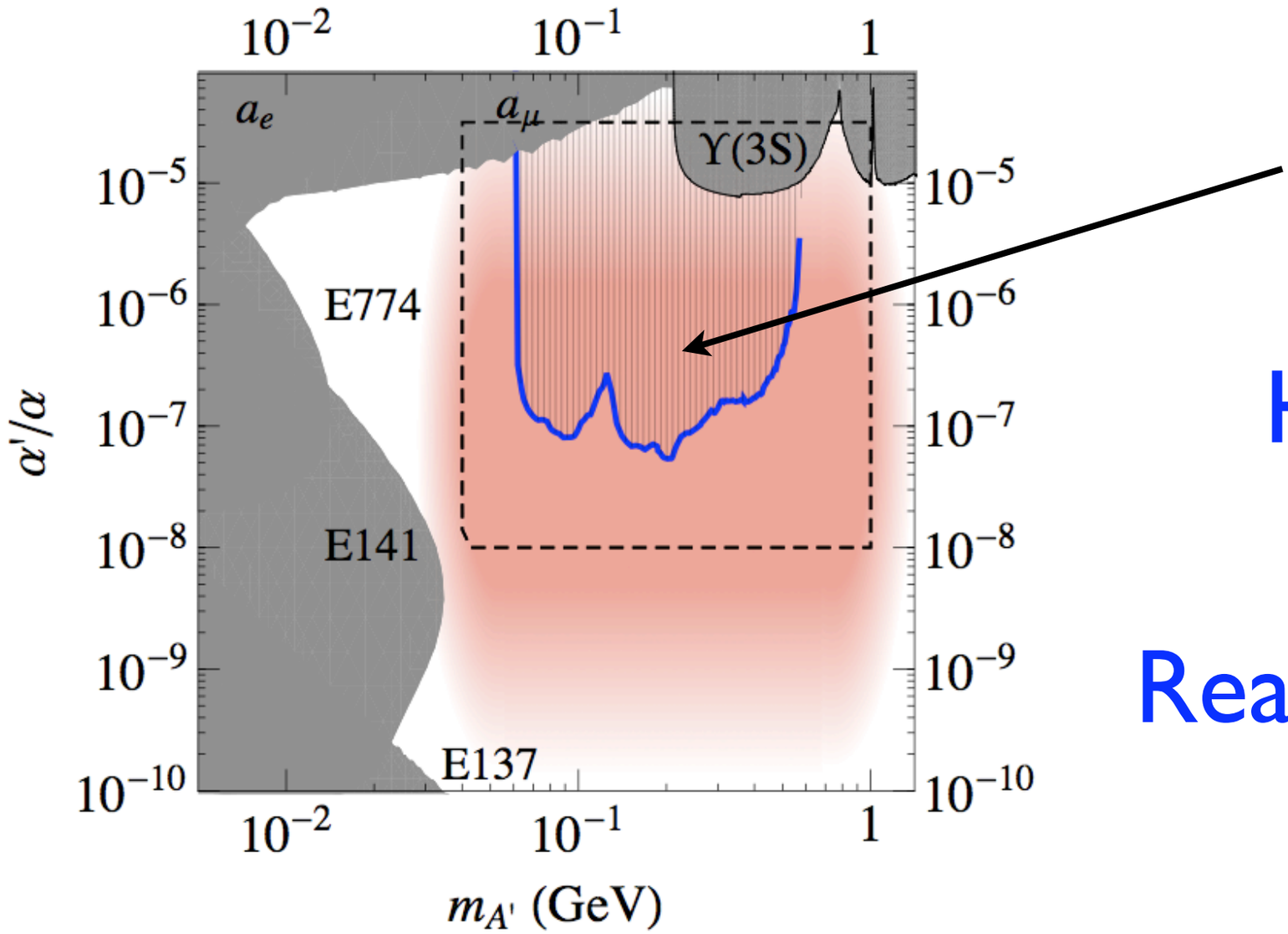
see also Perimeter Conference "New Lights on Dark Matter"

http://www.perimeterinstitute.ca/en/Events/New_Lights_on_Dark_Matter/New_Lights_on_Dark_Matter/

Fixed-Target Experiments have cross-sections + luminosity advantage

Proposed Experiment at JLab Hall A

- High resolution, large forward acceptance
- Unprecedented statistics achievable (~10^9 QED e+e- events)
- Use existing equipment, PREX septum, simple wire target



A' preferred region

Huge discovery potential

Ready to run anytime

for existing constraints see Bjorken, RE, Schuster, Toro

Many more details in proposal

- Comprehensive summary of physics motivation
- Details on A' production in fixed target exp.'s
- MC simulation of signal + backgrounds
- Target design
- Trigger + DAQ
- etc.

http://www.jlab.org/~bogdanw/AP-boson.pdf

Summary

- New vector bosons A' are theoretically well-motivated
- Data very suggestive of dark matter interacting with ordinary matter
- Hall A experiment can probe nature of these interactions
- Large interest in A' search
- A discovery would have enormous impact
- Experiment is simple, ready to run anytime

Backup

Large interest

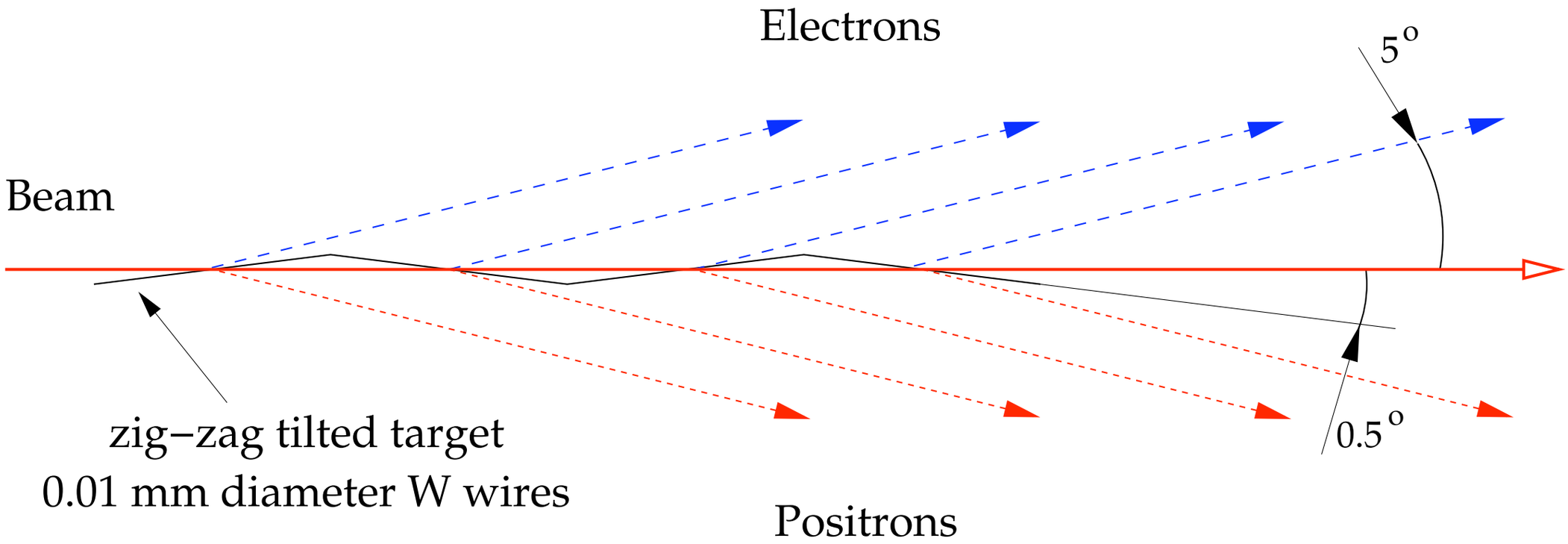
- PAMELA positron excess (415 citations, ~1/day)
- Fermi e+e- excess (203 citations, ~1/day)
- HESS e+e- excess (125+92 citations, about ~1 every 2-3 days)
- PAMELA no anti-proton excess (201 citations, ~1 every 2 days)
- DAMA/LIBRA 175 citations (~175 citations)
- INTEGRAL anomaly + Exciting DM (48 citations)
- WMAP Haze (120 citations)

Many Theory papers

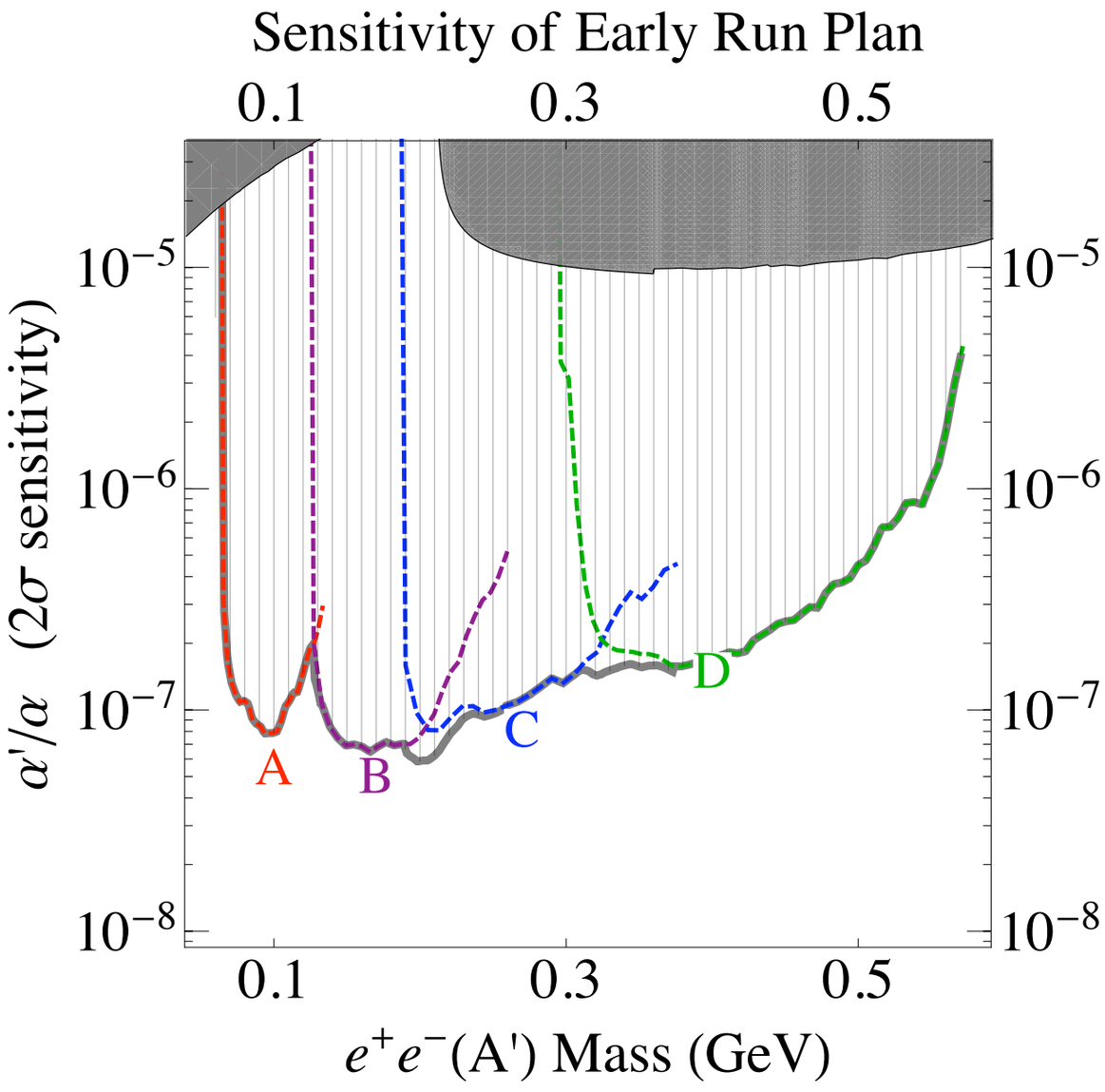
Several Papers on Searches for Dark Forces

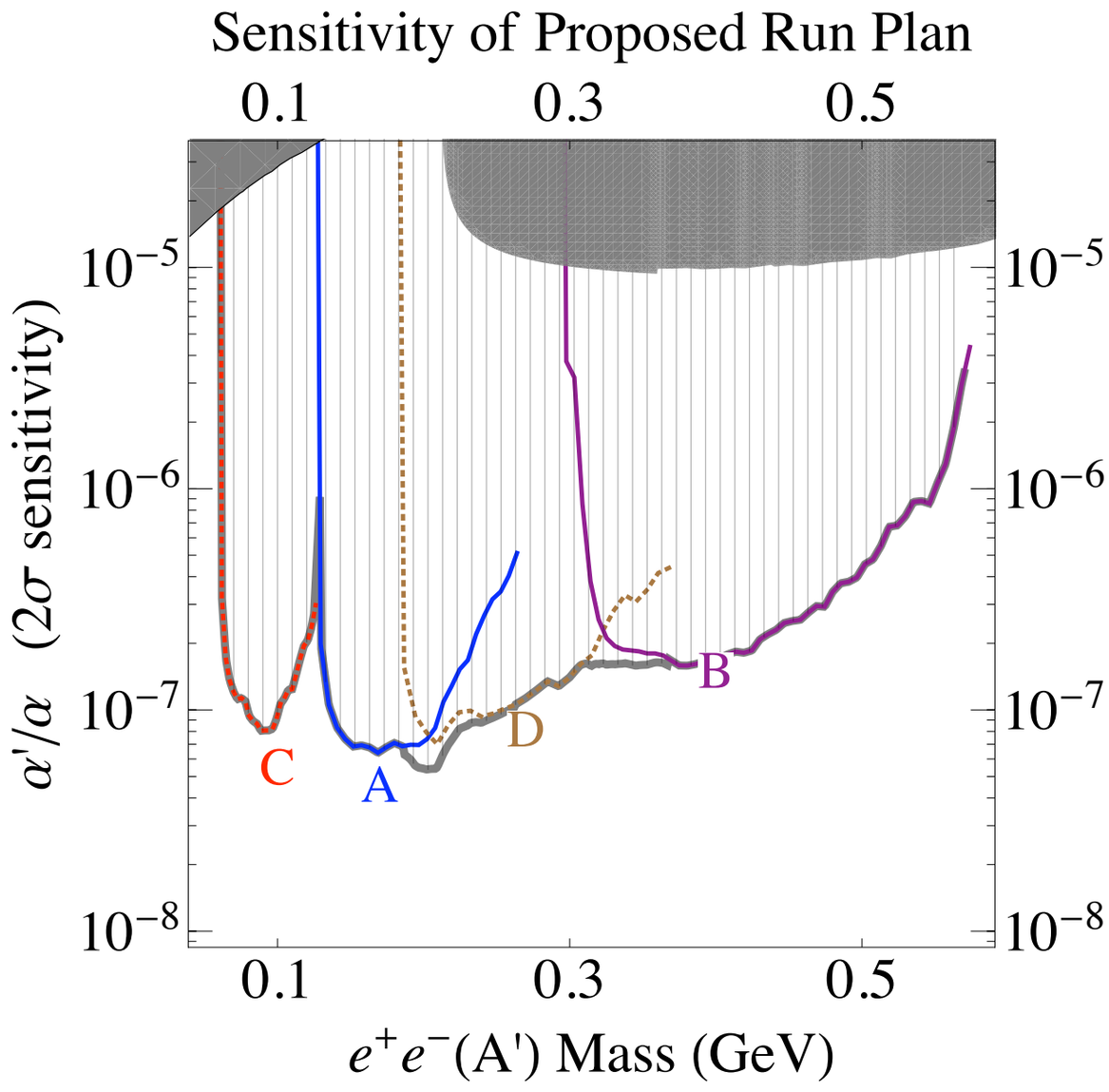
(including from low-energy e+e- colliders & Tevatron)

The Target


Electrons
5°
Beam
zig−zag tilted target
0.01 mm diameter W wires
0.5°
Positrons

Sensitivity of Early Running vs Proposed Run Plan





Proposed Running

Settings	**A**	**B**	**C**	**D**
Beam energy (GeV)	2.302	4.482	1.1	3.3
Beam current (μA)	80	80	80	80
Target thickness (X_0)	4.25%	10%	0.58%	10%
Beam on target (hrs)	146	290	146	146
Time Requested (hrs)	154	318	158	158
	$\rightarrow$ 788 ($\sim$33 days total)			

Proposed Running

Settings	**A**	**B**	**C**	**D**
Beam energy (GeV)	2.302	4.482	1.1	3.3
Beam current (μA)	80	80	80	80
Nominal central angle	5.0°	5.5°	5.0°	5.0°
Time Requested (hrs)				
Energy change	–	4	4	4
Angle change	–	16	–	–
Magnet setup	4	4	4	4
Optics calibration	4	4	4	4
10% $\mathcal{L}$	2	2	2	2
Normal $\mathcal{L}$	144	288	144	144
Total	154	318	158	158

Proposed Running

Settings	**A**	**B**	**C**	**D**
Beam energy (GeV)	2.302	4.482	1.1	3.3
Central angle	5.0°	5.5°	5.0°	5.0°
Effective angles	(4.5,5.5)	(5.25,6.0)	(4.5,5.5)	(4.5,5.5)
Target T/X_0 (ratio[a])	4.25% (1:1)	10% (1:1)	0.58% (1:3)	10% (1:1)
Beam current (μA)	80	80	80	80
Central momentum (GeV)	1.145	2.230	0.545	1.634
Singles (negative polarity)				
e^- (MHz)	4.5	0.7	6.	2.9
π^- (kHz)	640.	2200	36.	2500.
Singles (positive polarity)				
$\pi+$ [p] (kHz)	640.	2200	36.	2500.
e^+ (kHz)	31.	3.6	24.	23.
Trigger/DAQ:				
Trigger[b] (kHz)	4.	0.4	3.2	3.4
Signal to background:				
Trident (Hz)	610	70	350	530
Two-step (Hz)	35	15	5	75
Background[c] (Hz)	70	1.3	70	35

[a] The listed total target thickness is split between two sets of wire mesh planes, located at different z to produce the two indicated effective angles. The numbers in parentheses denote the ratio of target thickness at the larger effective angle to that at the smaller effective angle.

[b] Trigger: Coincidence with 20 ns time window between S0-N (assuming pions are rejected by a factor of 100) and S0-P signals.

[c] Dominated by e^+e^- accidental rate. We assume pion rejection by a factor of 10^4 in offline cuts, a 2 ns time window and additional factor of 4 rejection of accidentals from the target vertex. Further rejection using kinematics is expected, but not included in the table.

Early Running

Settings	**A**	**B**	**C**	**D**
Beam energy (GeV)	1.162	2.262	3.362	4.462
Beam current (μA)	80	80	80	80
Nominal central angle	5.0°	5.0°	5.0°	5.5°
Time Requested (hrs)				
Energy change	–	4	4	4
Angle change	–	–	–	16
Magnet setup	4	4	4	4
Optics calibration	4	4	4	4
10% $\mathcal{L}$	2	2	2	2
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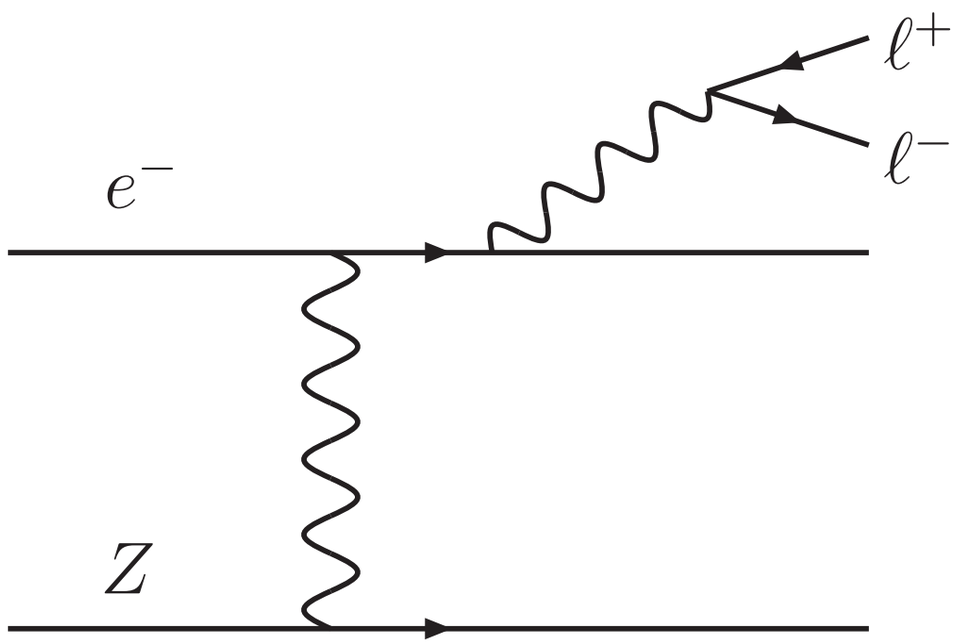
Settings	**A**	**B**	**C**	**D**
Beam energy (GeV)	1.162	2.262	3.362	4.462
Central angle	5.0°	5.0°	5.0°	5.5°
Effective angles	(4.5,5.5)	(4.5,5.5)	(4.5,5.5)	(5.25,6.0)
Target T/X_0^a	0.0069 (1:3)	0.04 (1:1)	0.1 (1:1)	0.1 (1:1)
Beam current (μA)	80	80	80	80
Central momentum (GeV)	0.575	1.125	1.664	2.220
Singles (negative polarity)				
e^- (MHz)	6.	4.5	2.7	0.7
$\pi-$ (kHz)	46.	580.	2500.	2200.
Singles (positive polarity)				
π^+ [p] (kHz)	46.	580.	2500	2200.
e^+ (kHz)	25.	31.	22.	3.7
Trigger/DAQ:				
Trigger^b (kHz)	3.4	3.9	3.1	0.5
Signal to background:				
Trident (Hz)	365	595	500	70
Two-step (Hz)	5	35	70	15
Background^c (Hz)	70	70	30	1.4

[a] The listed total target thickness is split between two sets of wire mesh planes, located at different z to produce the two indicated effective angles. The numbers in parentheses denote the ratio of target thickness at the larger effective angle to that at the smaller effective angle.

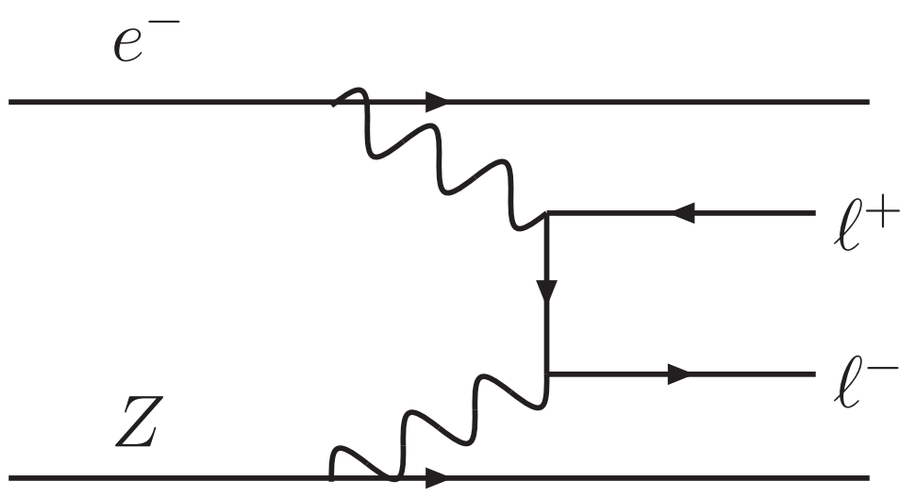
[b] Trigger: Coincidence with 20 ns time window between S0-N and S0-P signals (assuming pions are rejected online by a factor of 100).

[c] Dominated by e^+e^- accidental rate. We assume pion rejection by a factor of 10^4 in offline cuts, a 2 ns time window and additional factor of 4 rejection of accidentals from the target vertex. Further rejection using kinematics is expected, but not included in the table.

Dominant Backgrounds

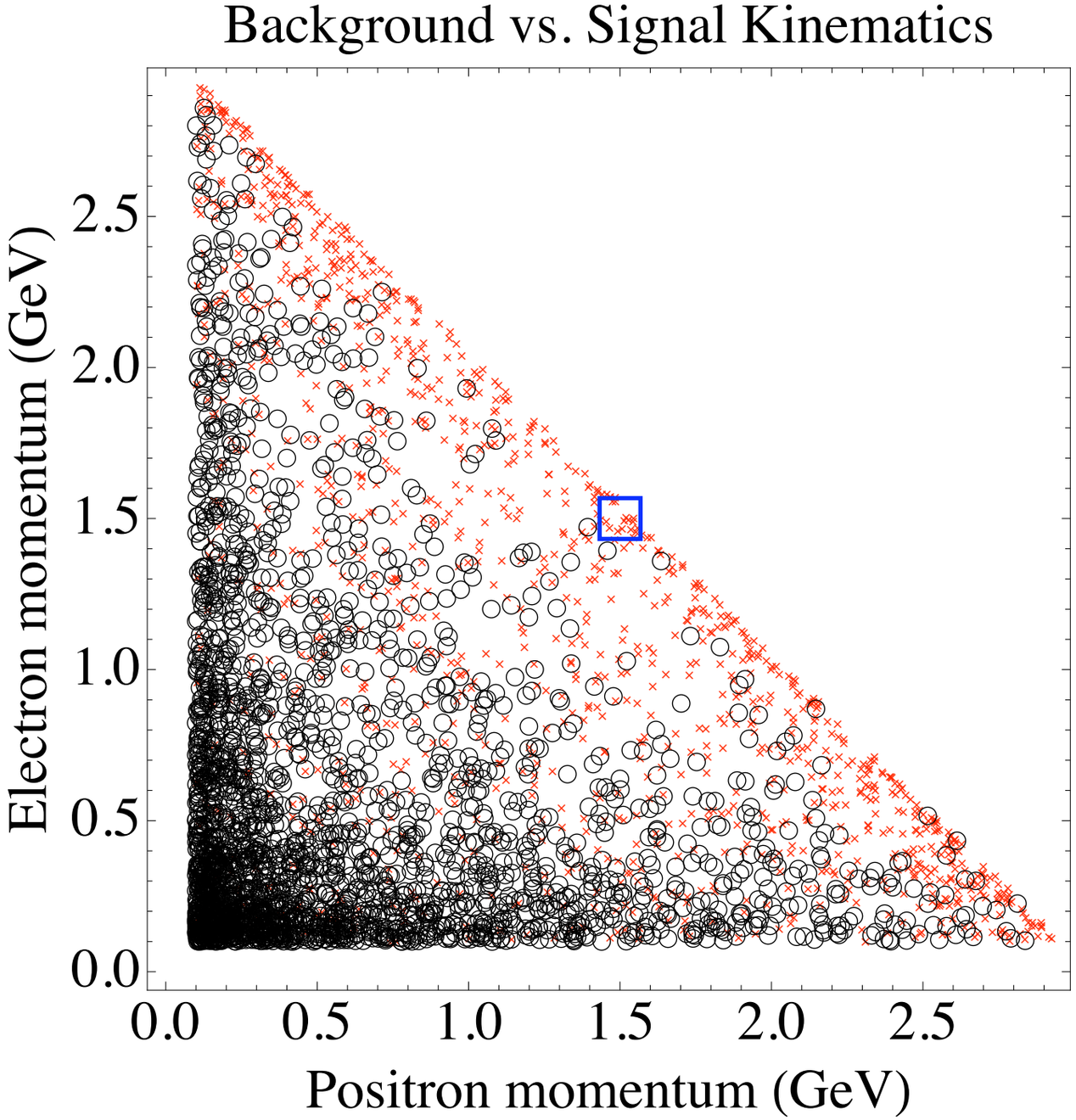


(a)



(b)

Background vs. Signal Kinematics



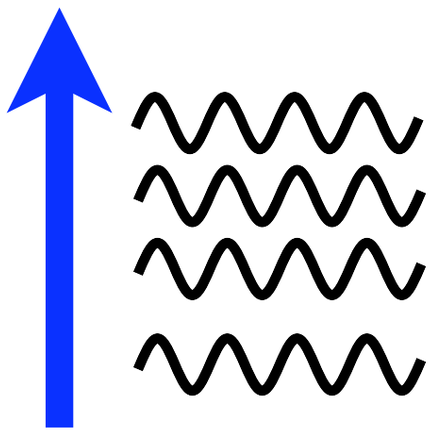
Further evidence for an excess of high energy electrons and positrons in our Galaxy

“WMAP Haze”
&
“Fermi Haze”

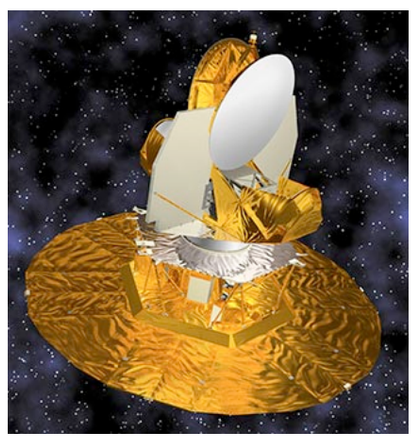
Microwave excess near Galactic center

high energy
e^- or e^+

moving in
Galactic magnetic field

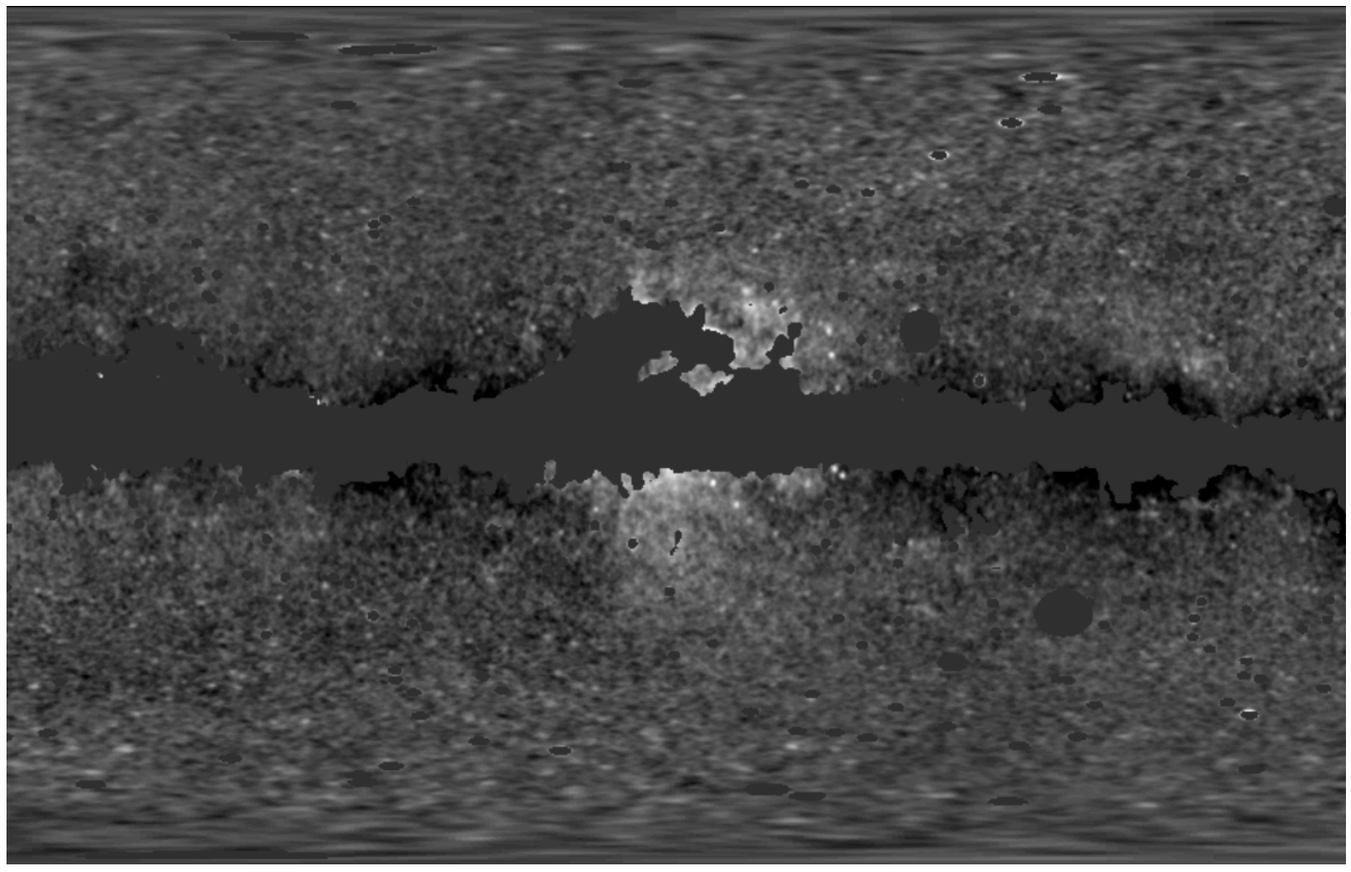


synchrotron
radiation



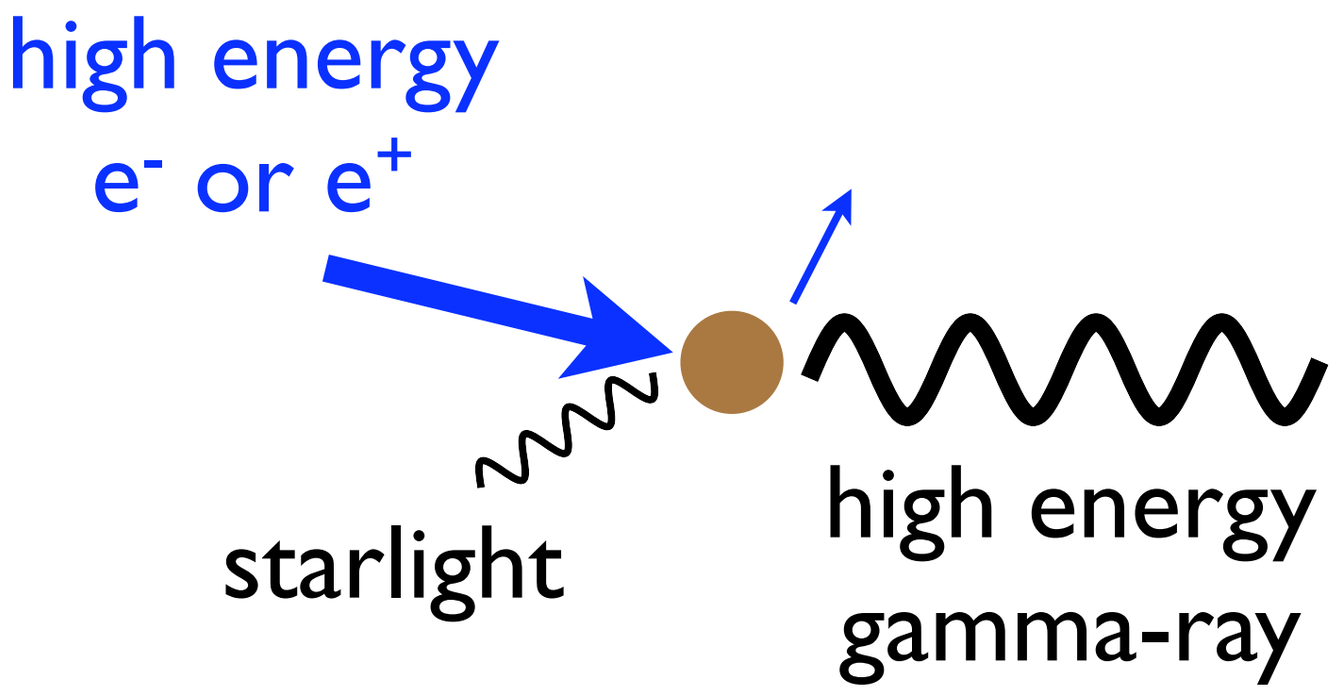
WMAP
satellite

Finkbeiner



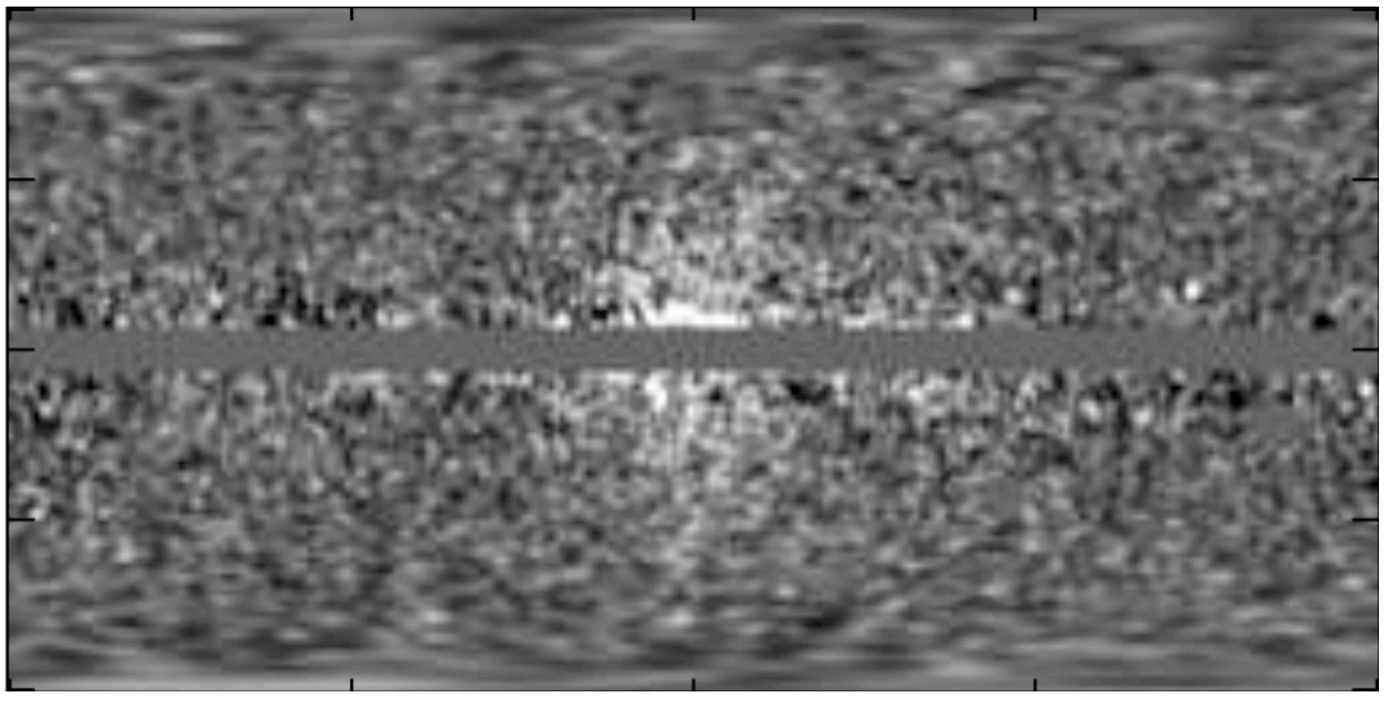
Consistent with
synchrotron radiation
from an excess of
high-energy electrons
and positrons

Gamma-ray excess near Galactic center



Fermi satellite

Dobler et. al.



Consistent with Inverse Compton Scattering of starlight off high energy electrons and positrons