The Status of A' Searches

(with slight emphasis on APEX)

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Yang Institute for Theoretical Physics, Stony Brook

Hall A Collaboration Meeting

Jefferson Laboratory, Dec. 16th, 2011

Outline

- Theory Review
- Motivation (“hints”)
- Searches
  - e^+e^- colliders
  - Tevatron & LHC
  - fixed target (APEX etc.)

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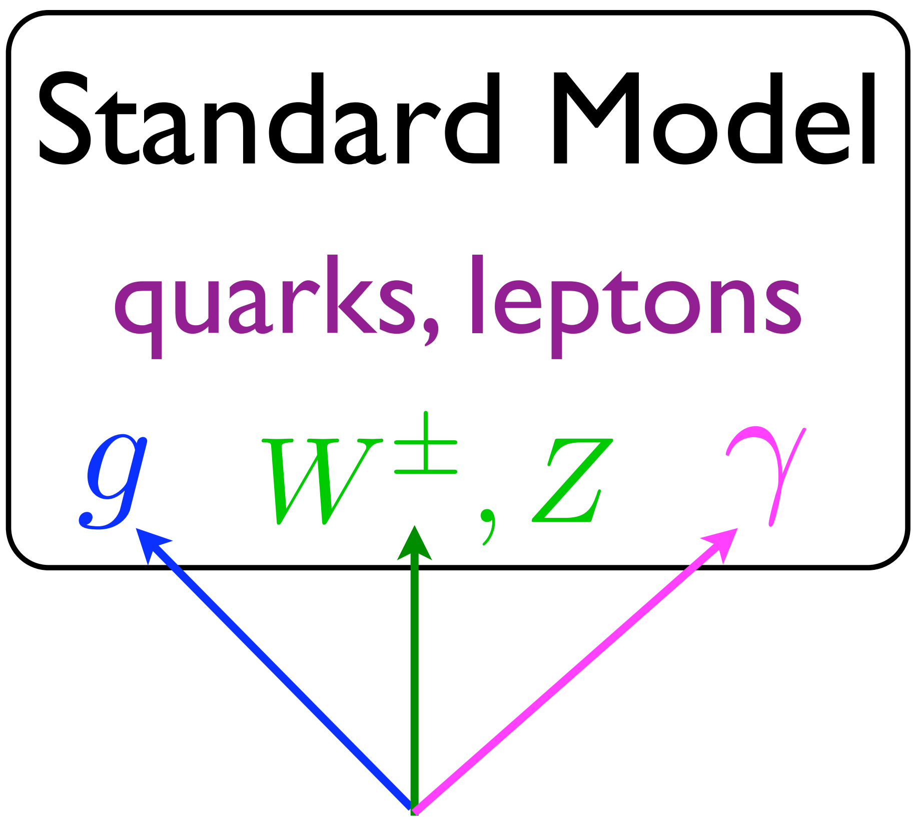
A new force

Standard Model

quarks, leptons

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

A new force

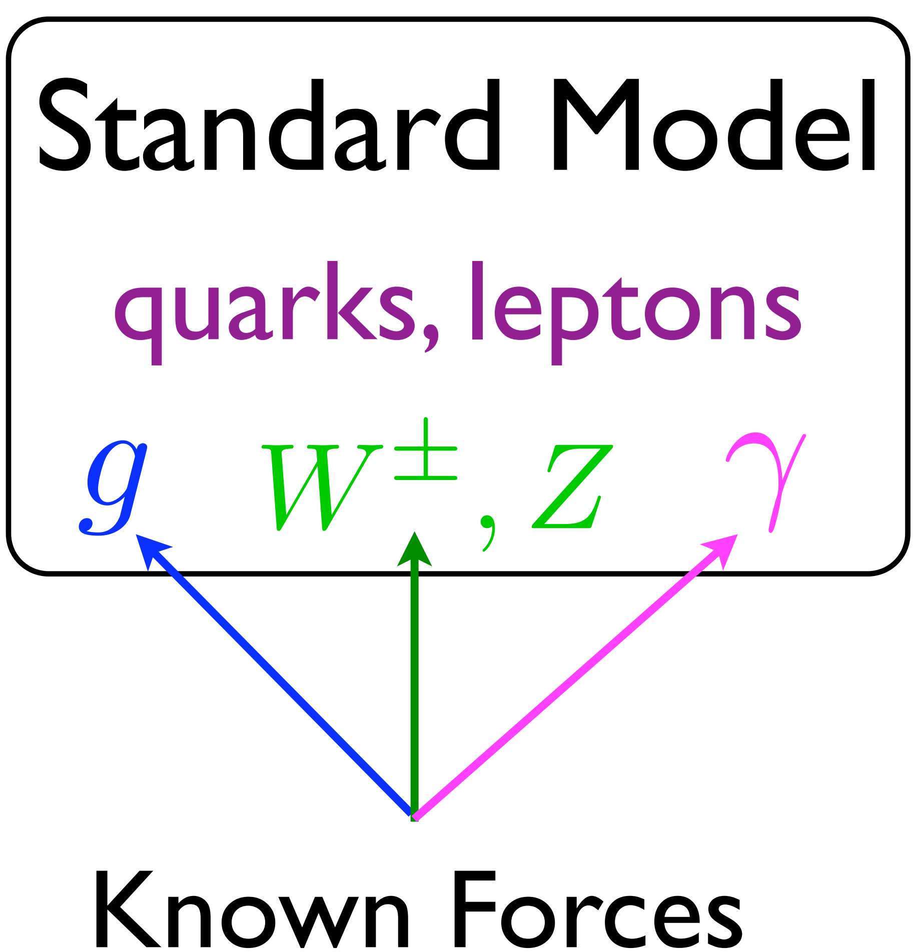


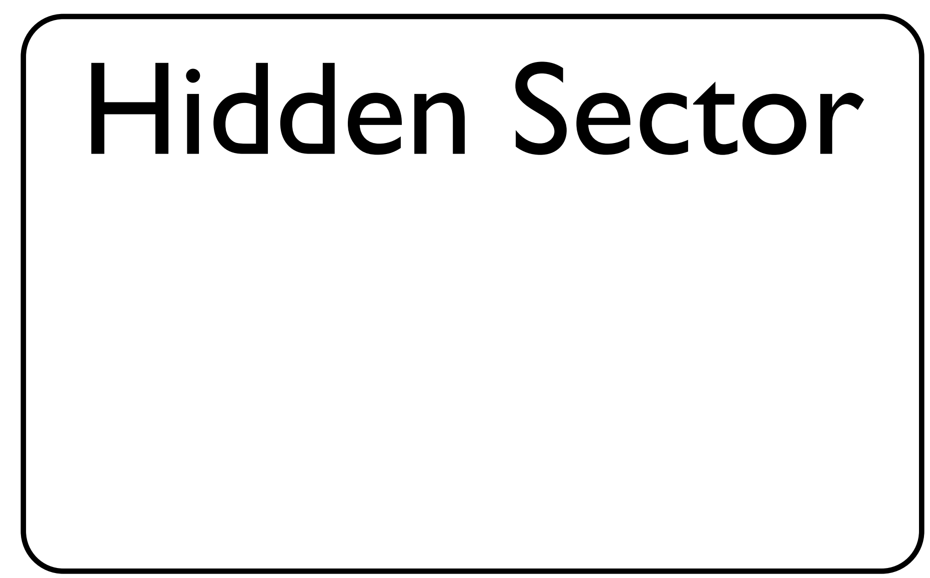
Known Forces

$$SU(3)_C \times SU(2)_L \times U(1)_Y$$

A new force

A hidden sector, with particles that do not couple to known forces





cf. "Hidden Valley" models
Strassler et.al. [2006]

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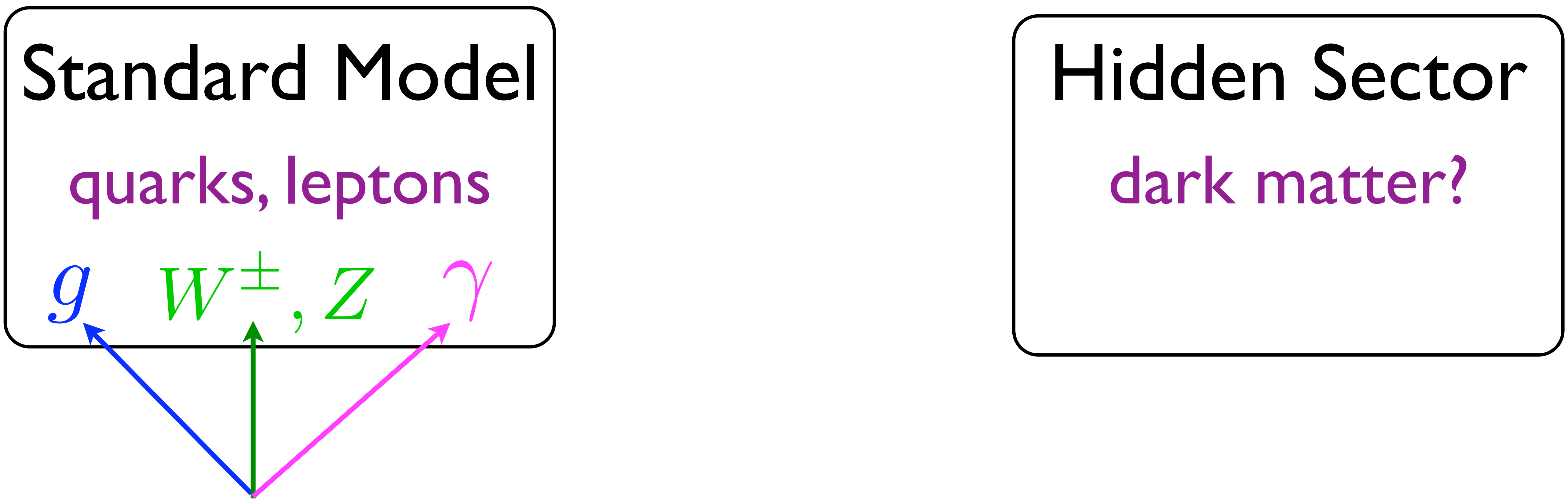

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Known Forces

$SU(3)_C \times SU(2)_L \times U(1)_Y$

Hidden Sector

dark matter?

A' (massive)

New force

$U(1)'$

Coupling?

Standard Model

quarks, leptons

g $W^{\pm}, Z$ γ

?

Hidden Sector

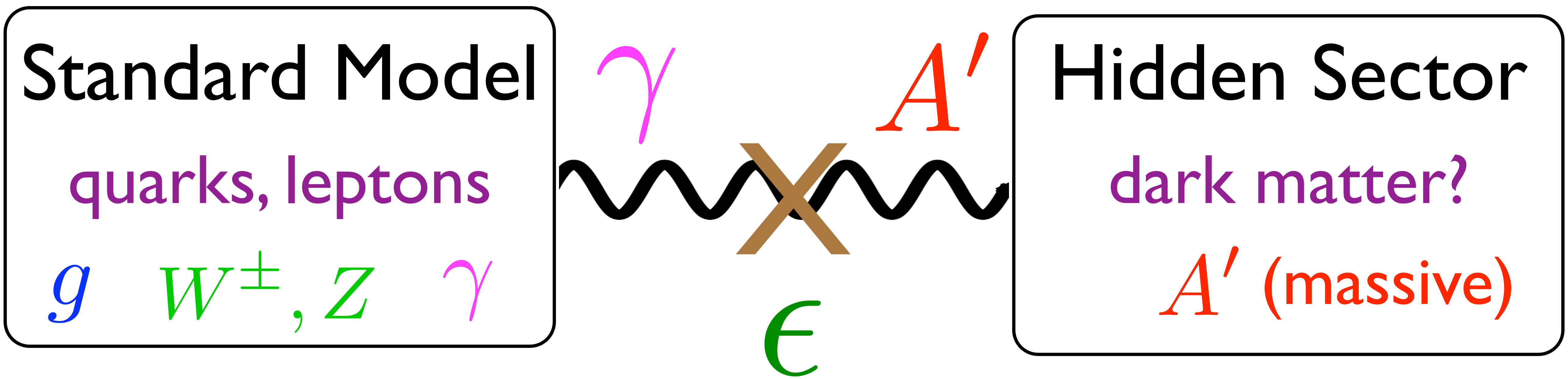
dark matter?

A' (massive)

The photon and A′ can mix !

Holdom

Galison, Manohar



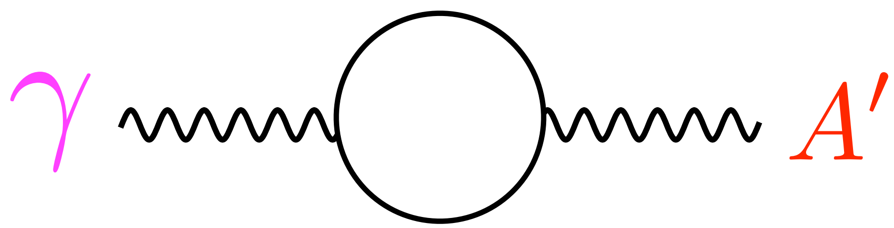
$$\Delta\mathcal{L} = \frac{\epsilon}{2} F^{Y,\mu\nu} F'_{\mu\nu}$$

“Kinetic Mixing”

Generating Kinetic Mixing

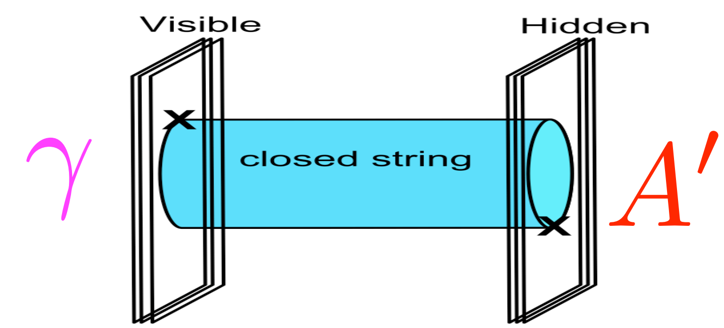
Examples:

loops of heavy particles



$$\epsilon \sim 10^{-8} - 10^{-2}$$

string theory



$\epsilon \ll 1$ is possible

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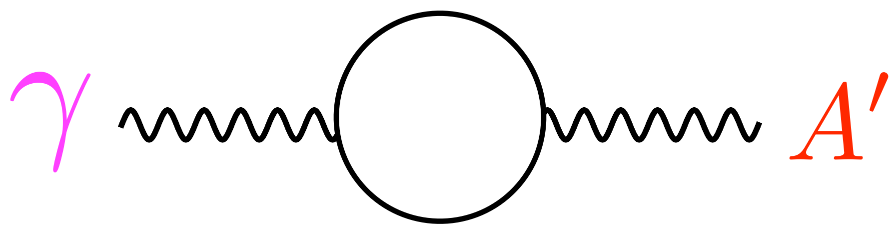

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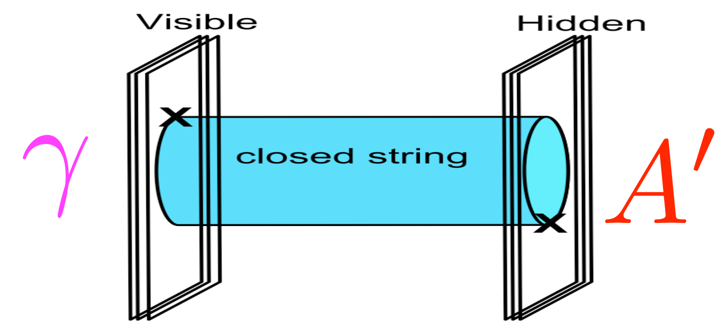


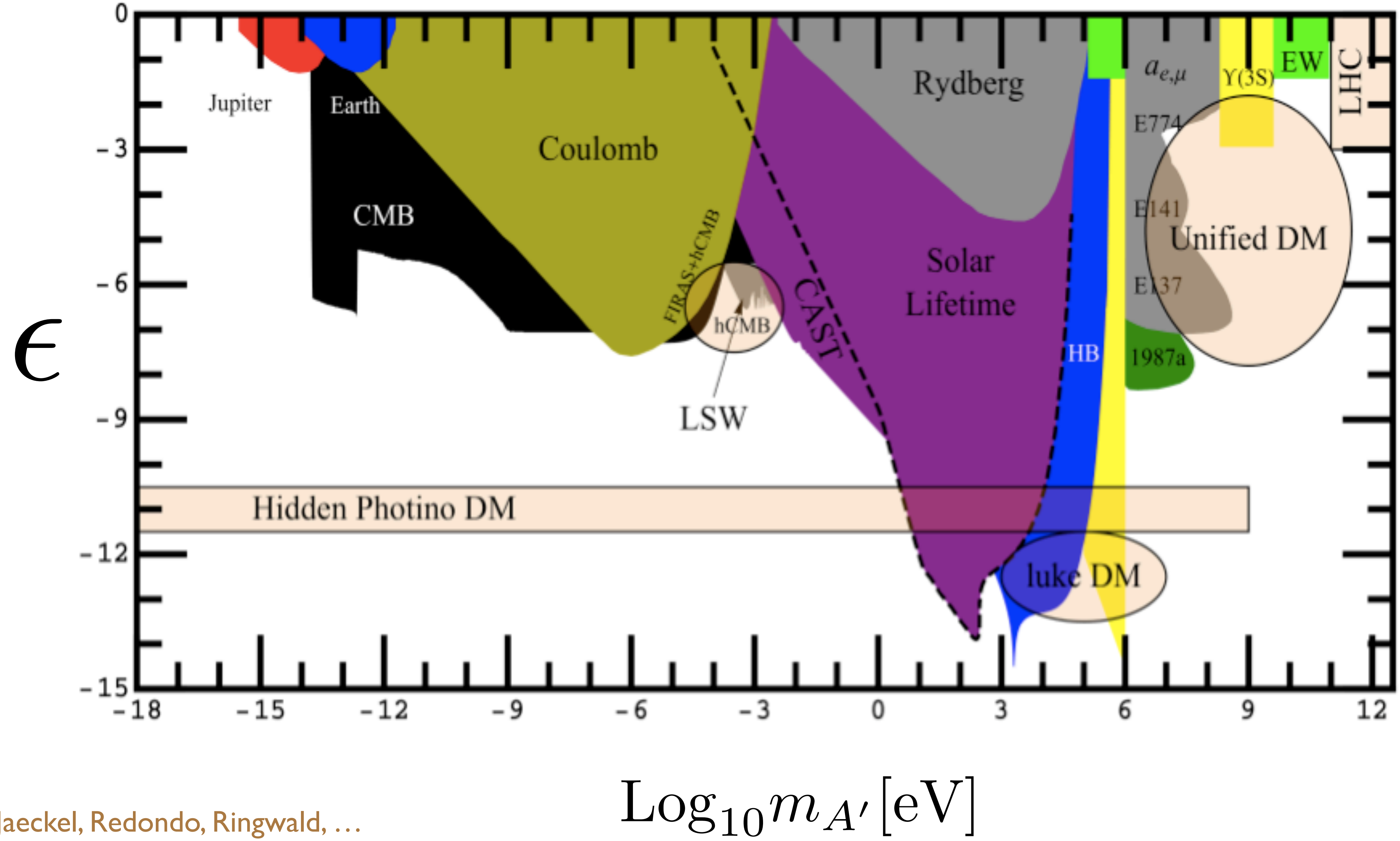
$\epsilon \ll 1$ is possible

A′ Mass: two natural possibilities

if inherited from Weak-scale, can get: $\sim 1\ \mathrm{MeV} - 1\ \mathrm{GeV}$

in string theory, can also get $\ll \mathrm{eV}$

Need to cover large A′ parameter space



Jaeckel, Redondo, Ringwald, …

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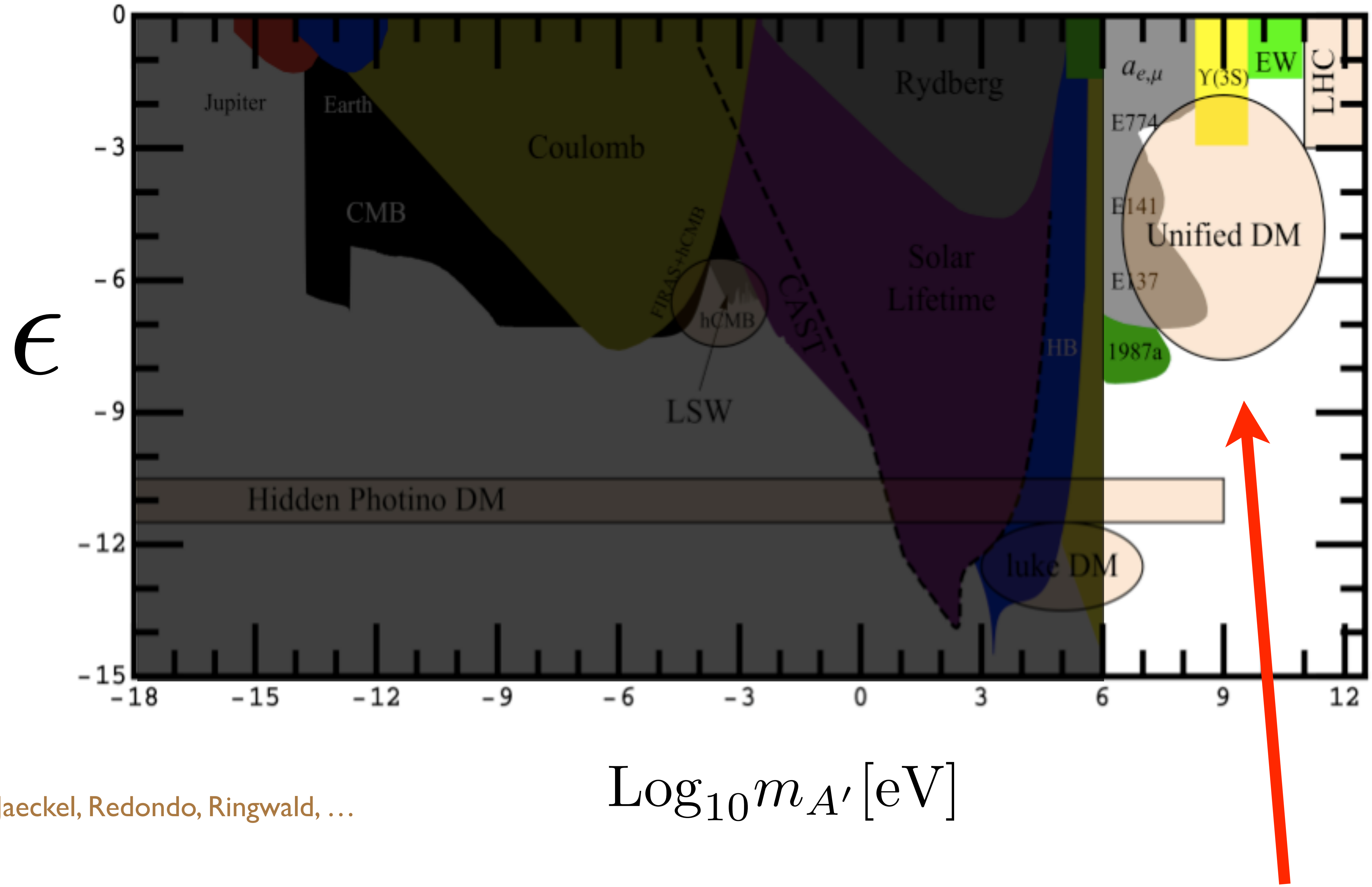
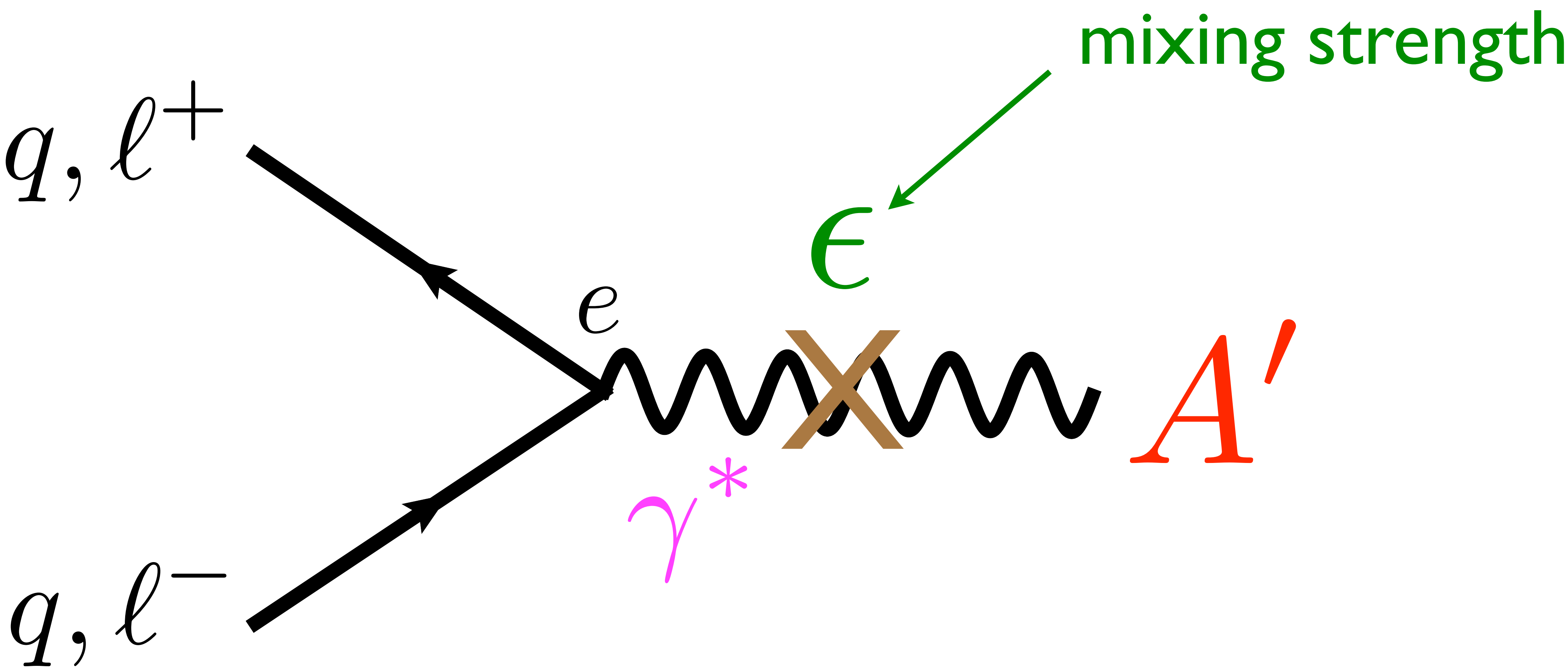


Jaeckel, Redondo, Ringwald, …

Fixed target experiments (like APEX) focus on $m_{A'} > \mathrm{MeV}$

Why can an A′ be detected?



A′ couples to Quarks and charged Leptons

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Hint from muon's anomalous magnetic moment?

magnetic dipole moment

$$\vec{\mu} = g_s \left(\frac{q}{2m} \right) \vec{s}$$

spin

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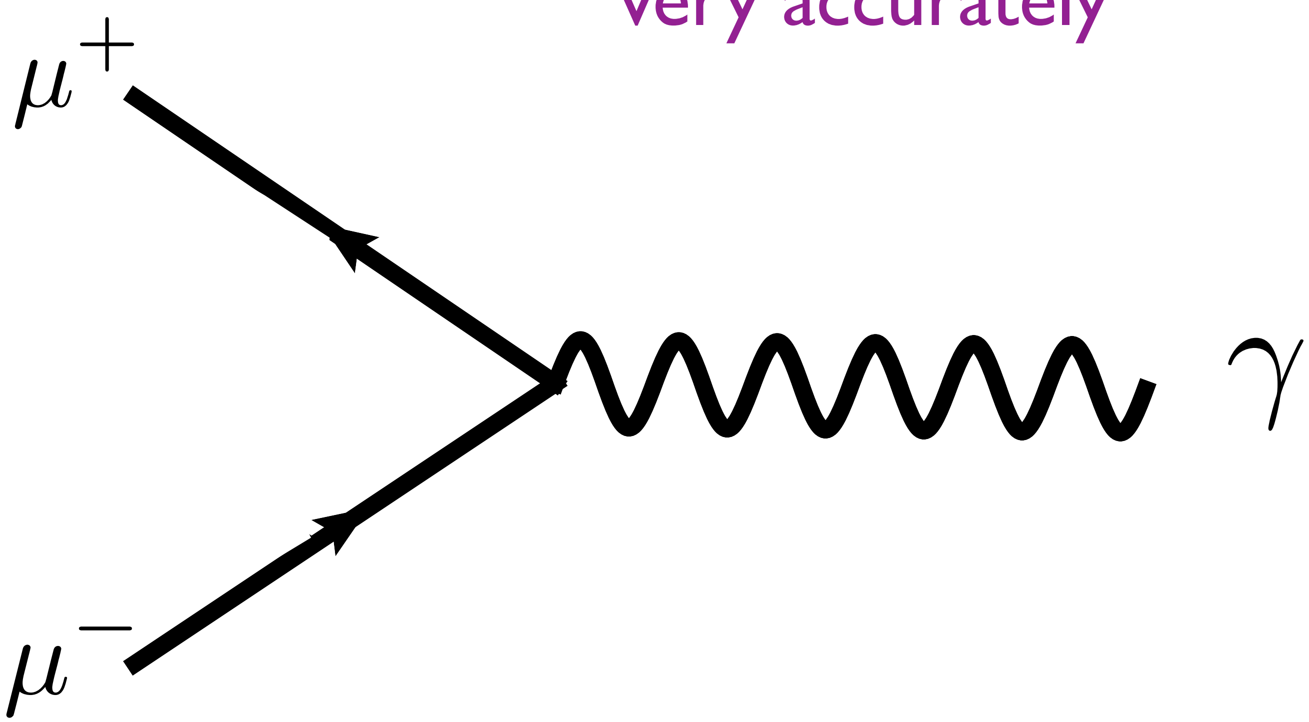

$$g_s = 2$$

(Dirac)

Hint from muon's anomalous magnetic moment?

magnetic dipole moment

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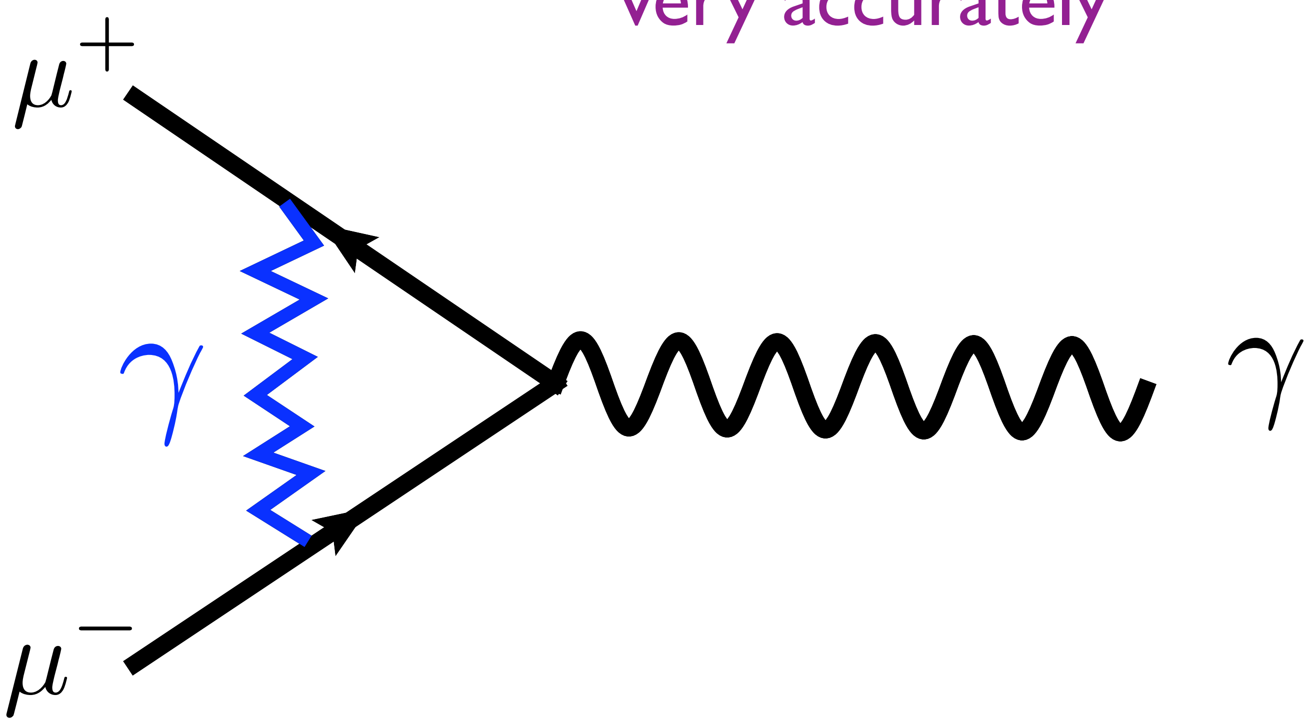
spin

can be measured very accurately



$g_s \neq 2$

(Standard Model)

Standard Model

$(g_s - 2)_\mu$ versus Data

$\sim 3.4\ \sigma$ deviation

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magnetic dipole moment

$$\vec{\mu} = g_s \left(\frac{q}{2m} \right) \vec{s}$$

spin

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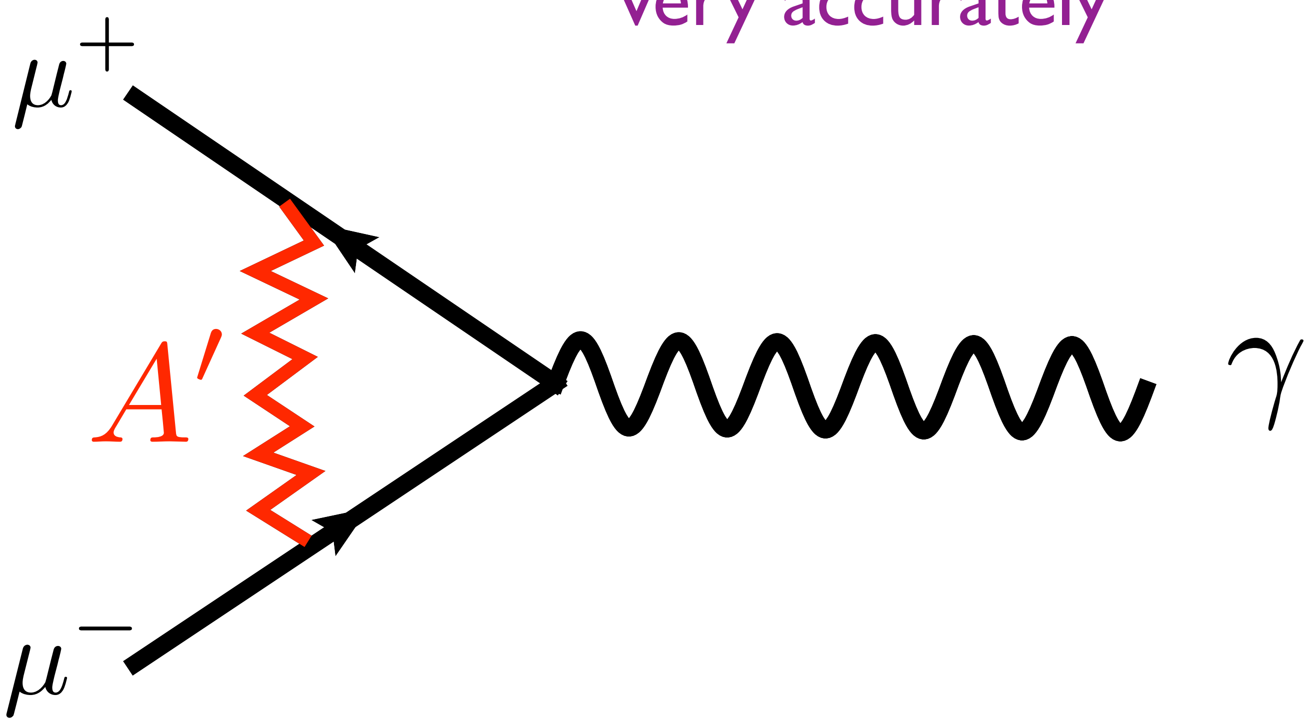

$g_s \neq 2$

Pospelov
Boehm, Fayet

A′ may explain observed $(g_s - 2)_\mu$!

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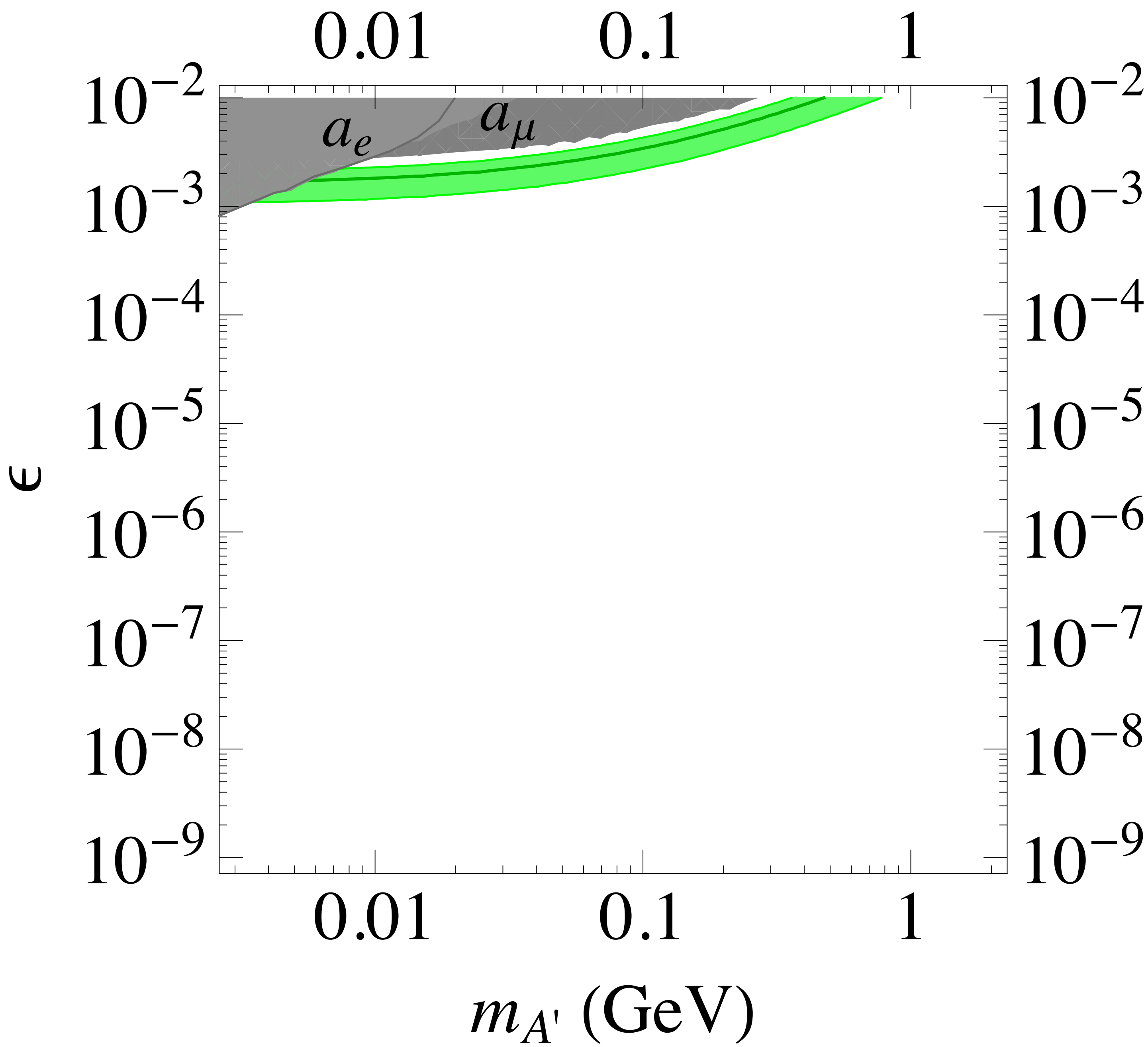

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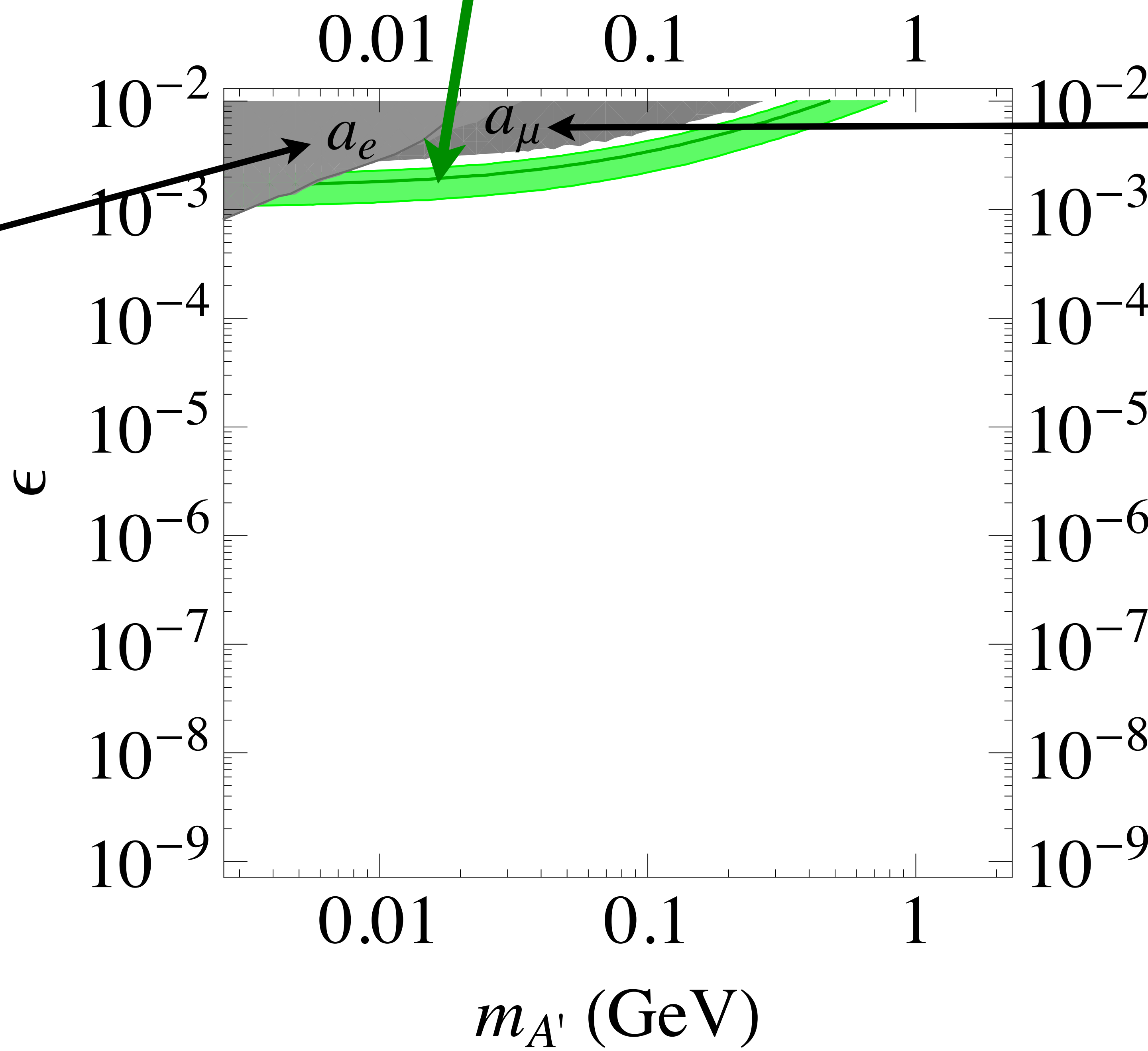
A′ may explain observed $(g_s - 2)_\mu$

constraint from g_s-2 for electron



constraint from g_s-2 for muon

Pospelov
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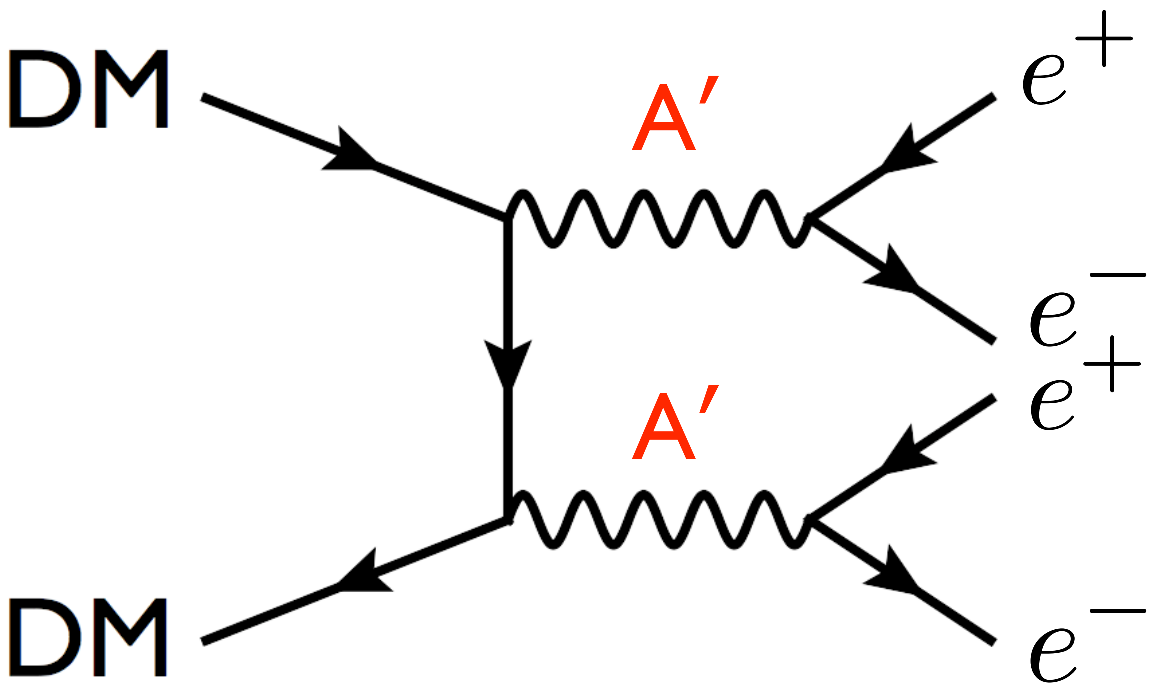
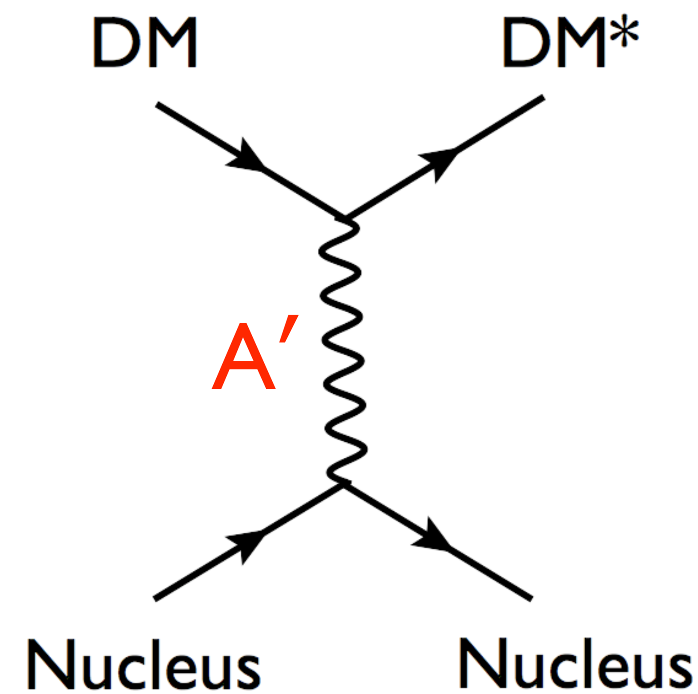
A′ Hints from Dark Matter searches?

Arkani-Hamed et.al.; Cholis et.al.; Pospelov & Ritz





cosmic-ray e^+, e^- excesses?

PAMELA, Fermi, …

direct detection hints?

DAMA, CoGeNT, CRESST

Speculative, but amazing if true

hints inconclusive… laboratory expt's could help

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Many possibilities, will only highlight a few !

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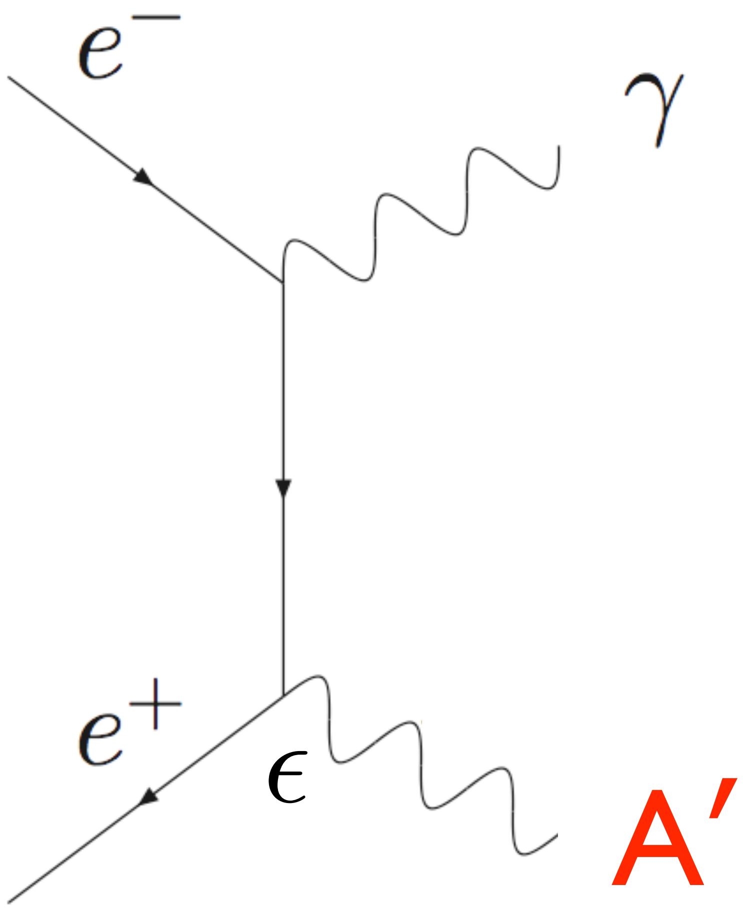
Produce A′ in e⁺e⁻ collisions

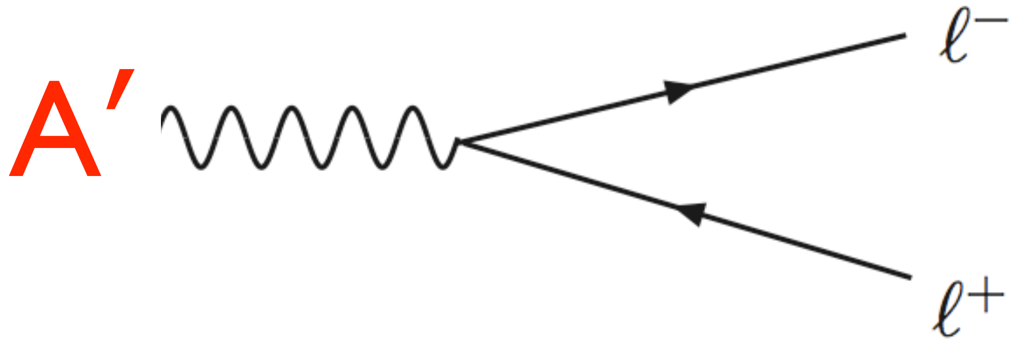
RE, Schuster, Toro
Batell, Pospelov, Ritz
Reece, Wang
Borodatchenkova et.al.
Fayet



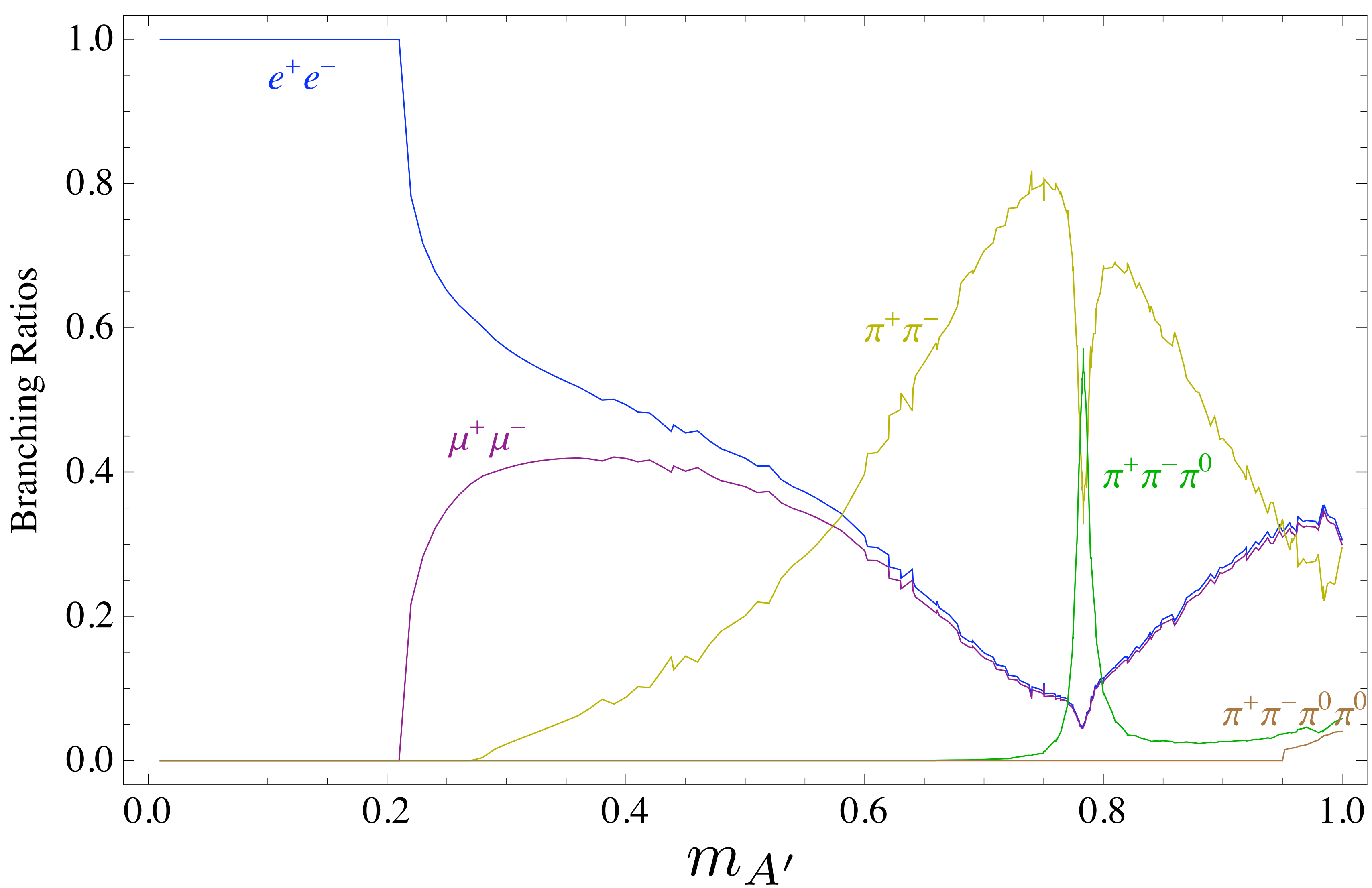
$$\sigma \propto \frac{\epsilon^2}{E_{cm}^2}$$

$\Longrightarrow$ want low-energy (1-10 GeV), high intensity colliders (BaBar, BELLE, KLOE, ...)

A′ can decay directly to Standard Model



($A' \longrightarrow$ hidden sector also possible)

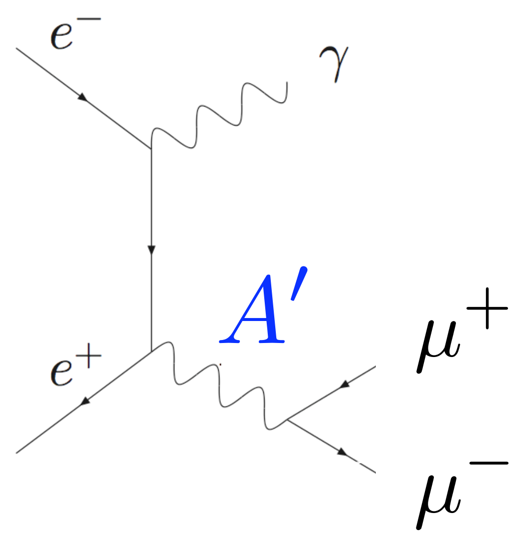


[Meade]

Broad array of searches needed and underway

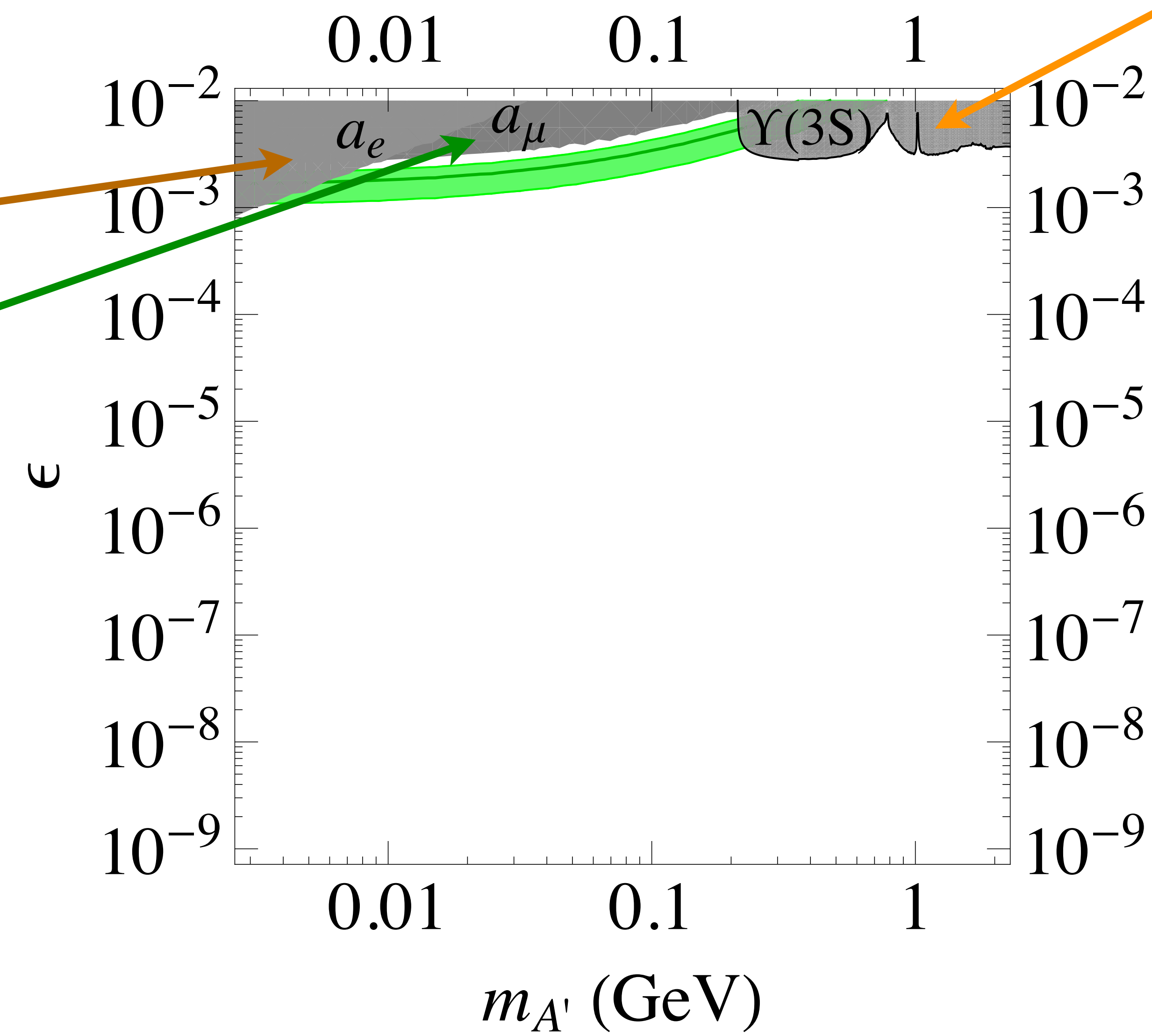
Constraint

RE, Schuster, Toro, Wojtsekhowski
Reece, Wang



g-2 for
electron
and muon

BaBar
(partial data set)



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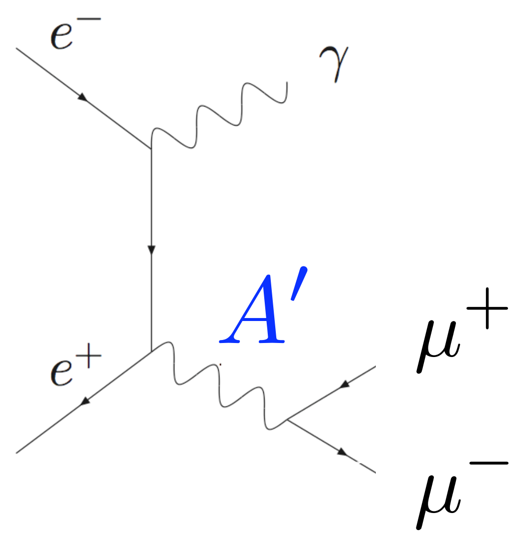

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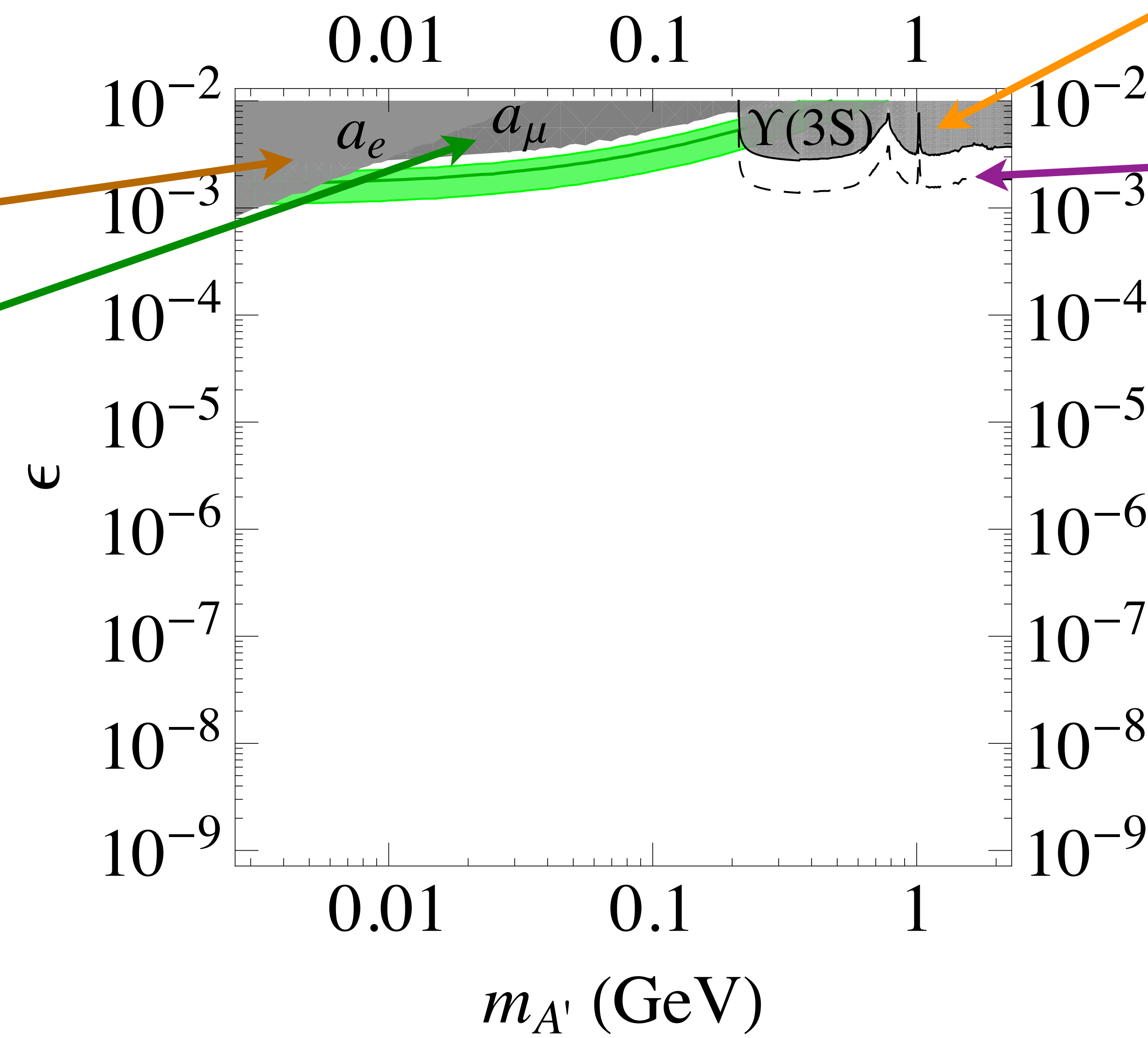

BaBar (partial data set)

BaBar/Belle (full dataset)

analysis in progress (some results before end of year?)

Rare meson decays

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

Many possibilities… e.g.

$\phi \to \eta A'$ $\quad$ $A' \to e^+ e^-$ $\quad$ $\eta \to \pi^+ \pi^- \pi^0$

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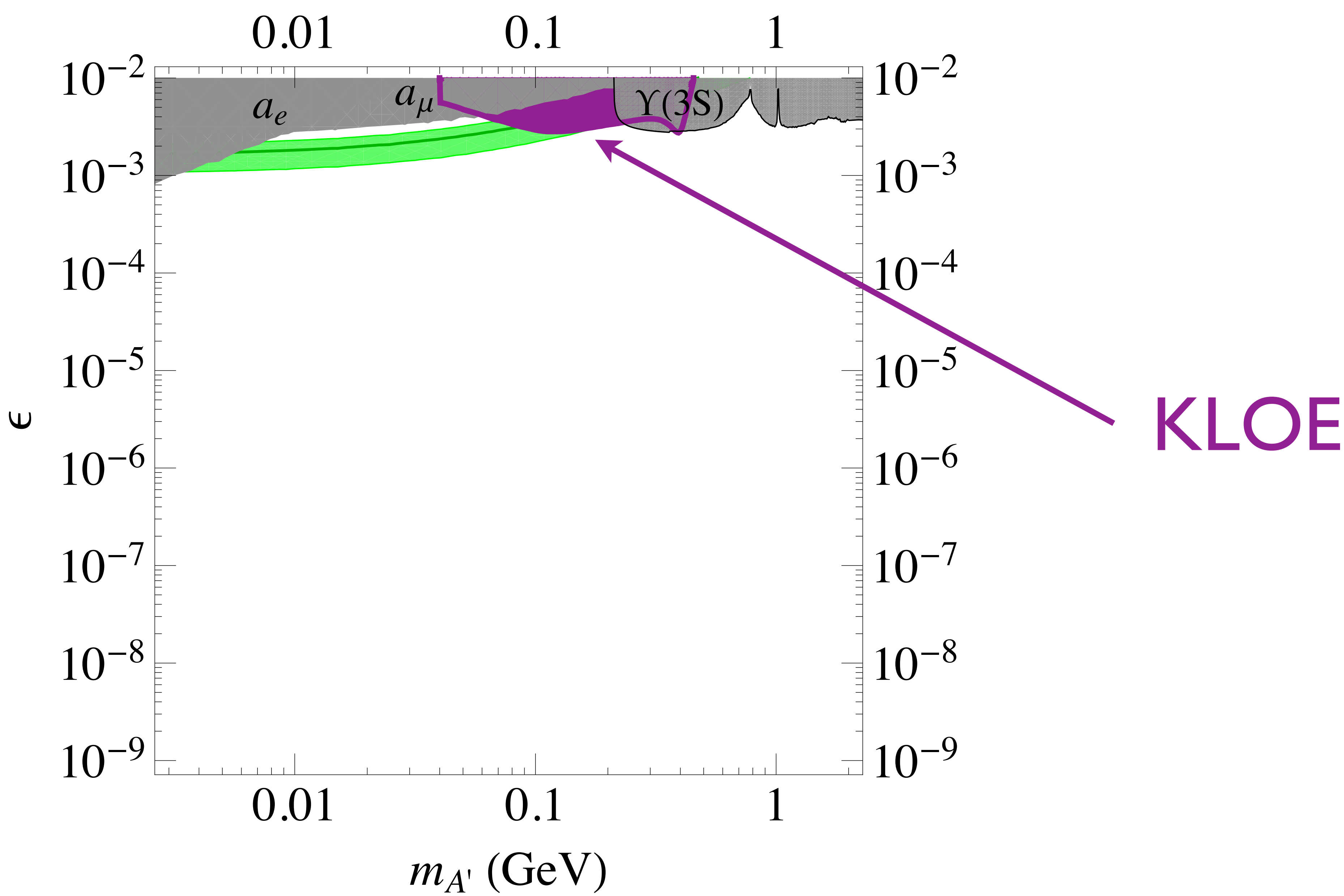

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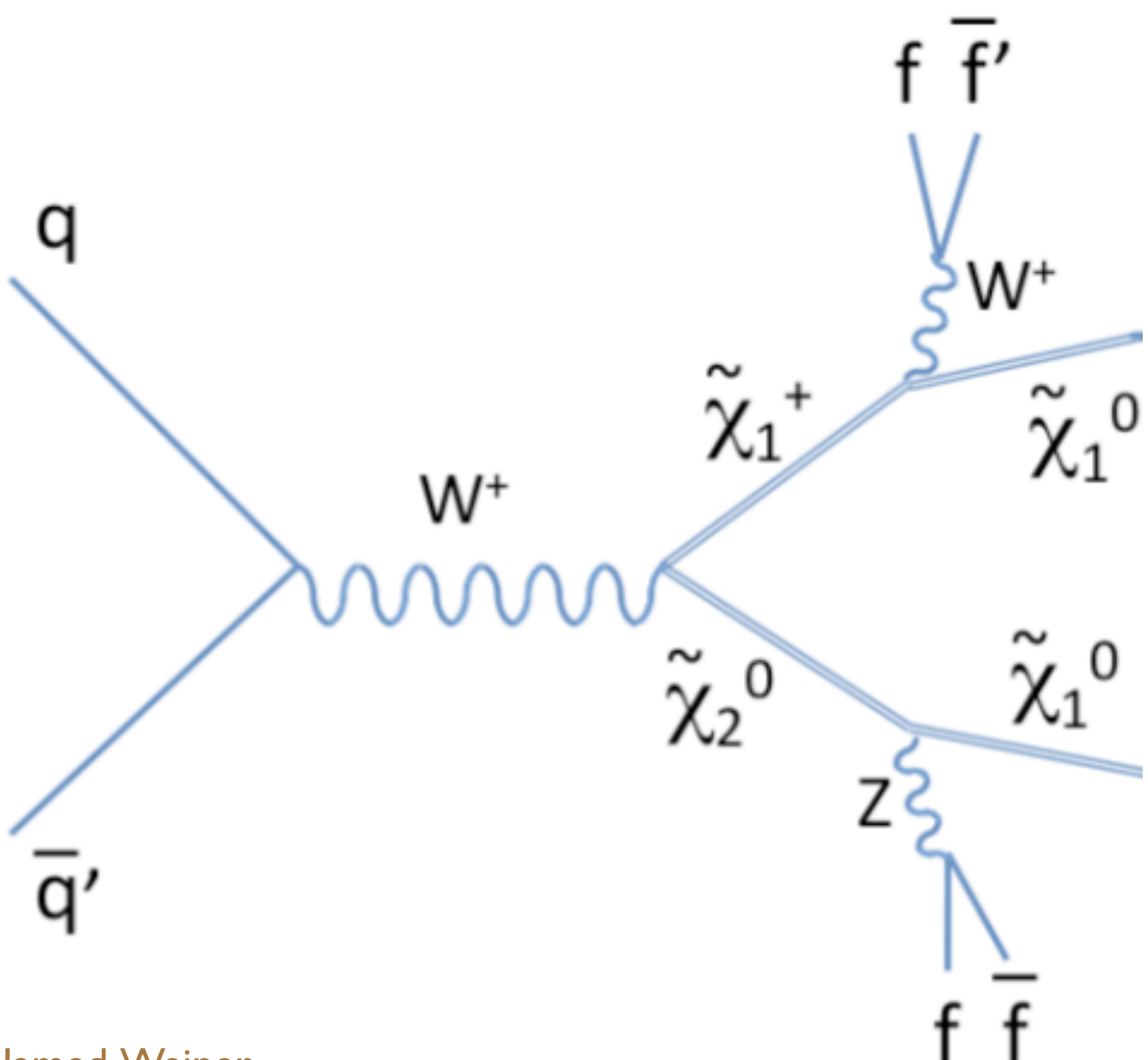
Collider Signals, assuming SUSY exists

cf. "Hidden Valley" models
Strassler et.al. [2006]

Produce A′ through supersymmetry



a typical collider event in supersymmetry...

Arkani-Hamed, Weiner

Baumgart, Cheung, Ruderman, Wang, Yavin

Shih, Thomas

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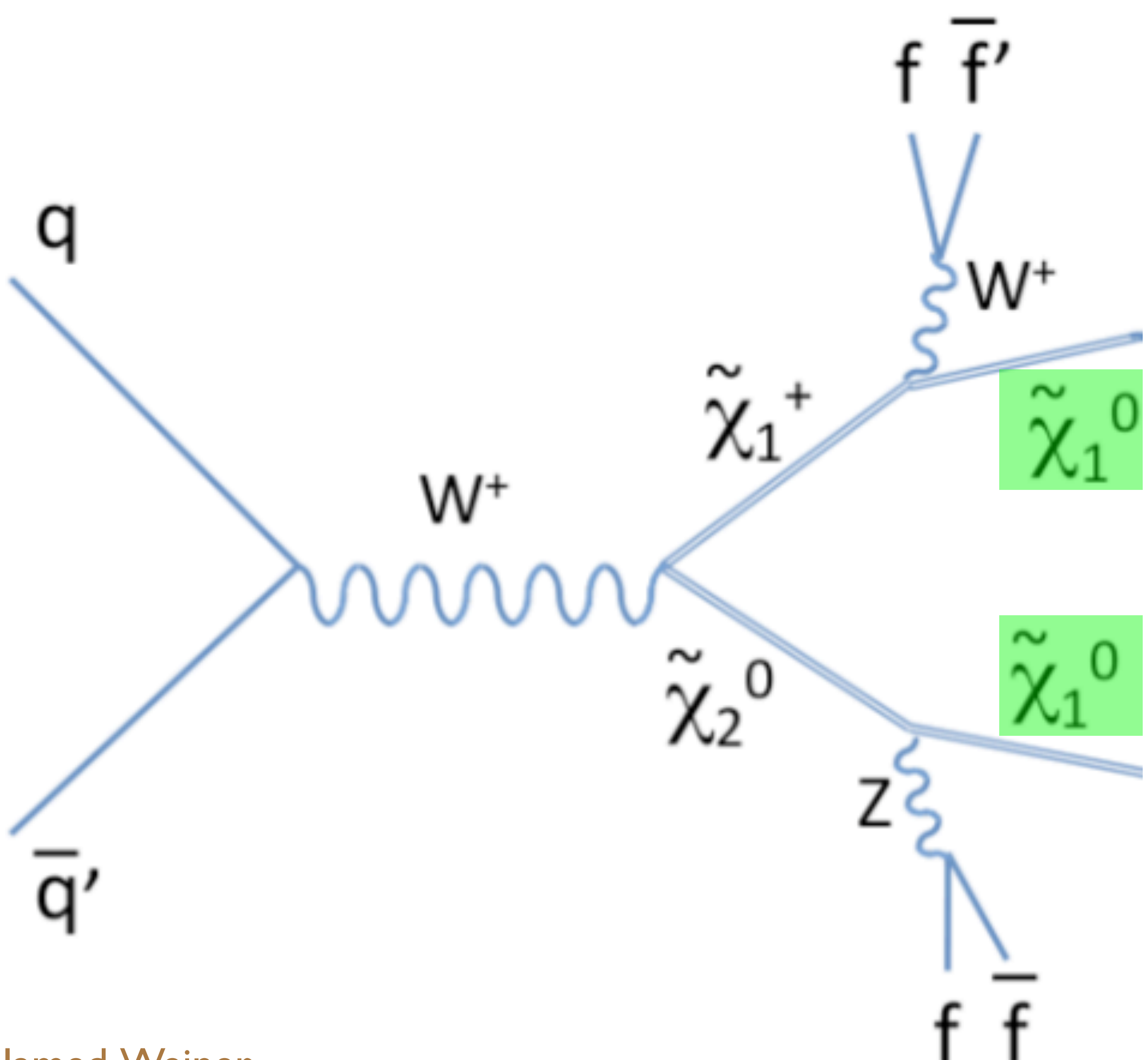

a typical collider event in supersymmetry...

Lightest SUSY particle ("LSP") is often stable…

Arkani-Hamed, Weiner
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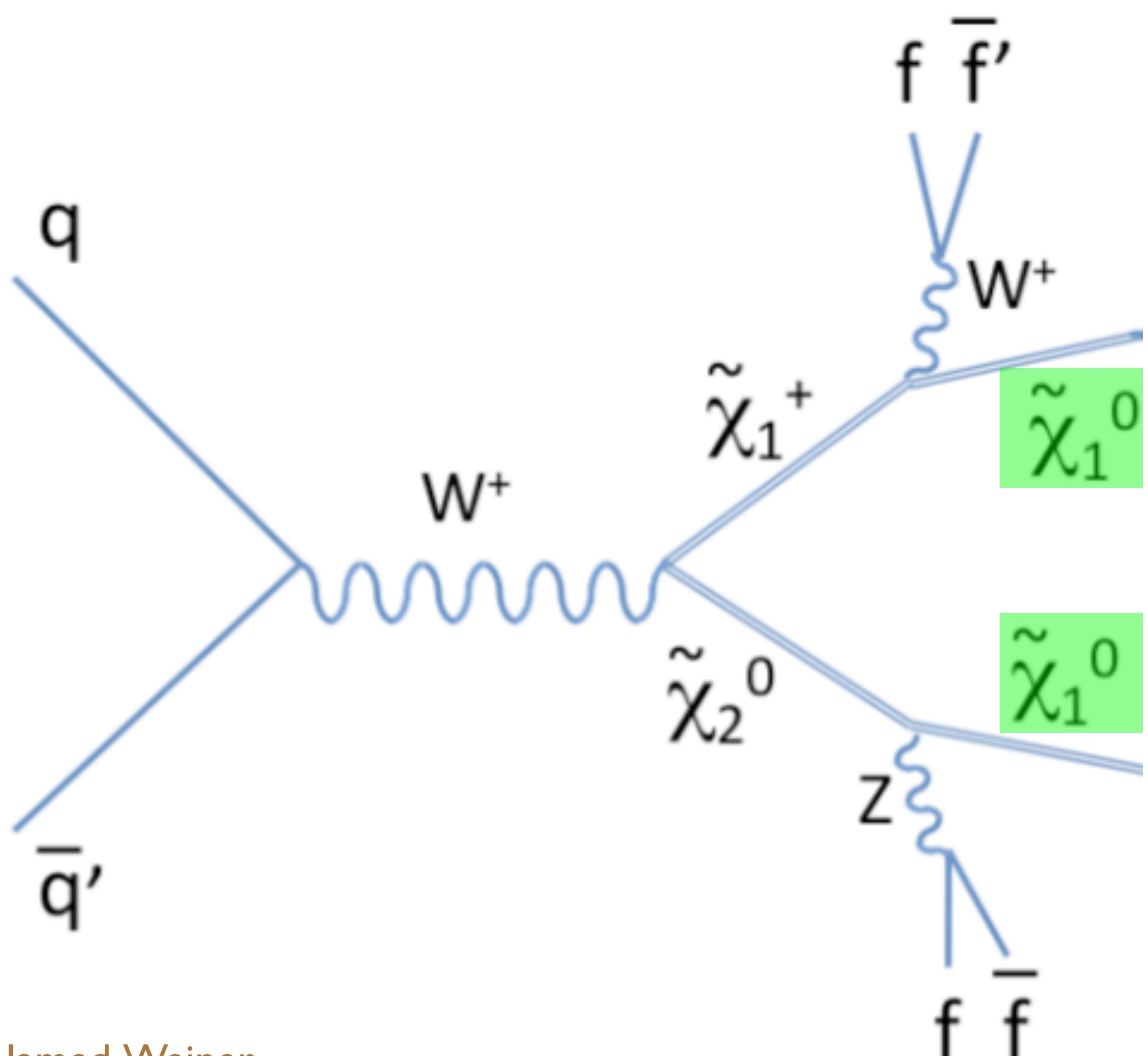

But with an A':

Lightest SUSY particle ("LSP") is *unstable*…

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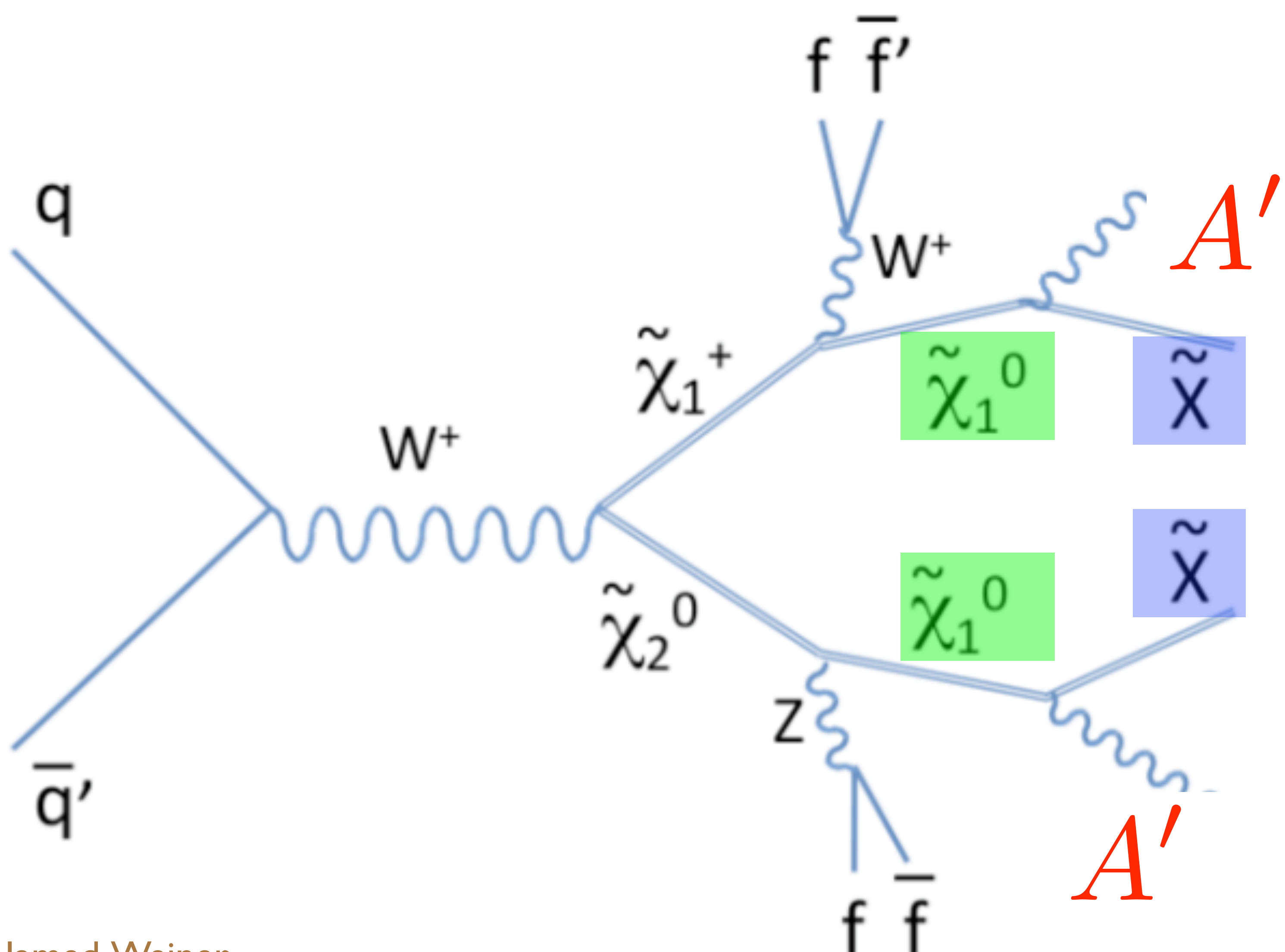

But with an A′:

Lightest SUSY particle ("LSP") is *unstable*…

decays to

A′ + hidden sector

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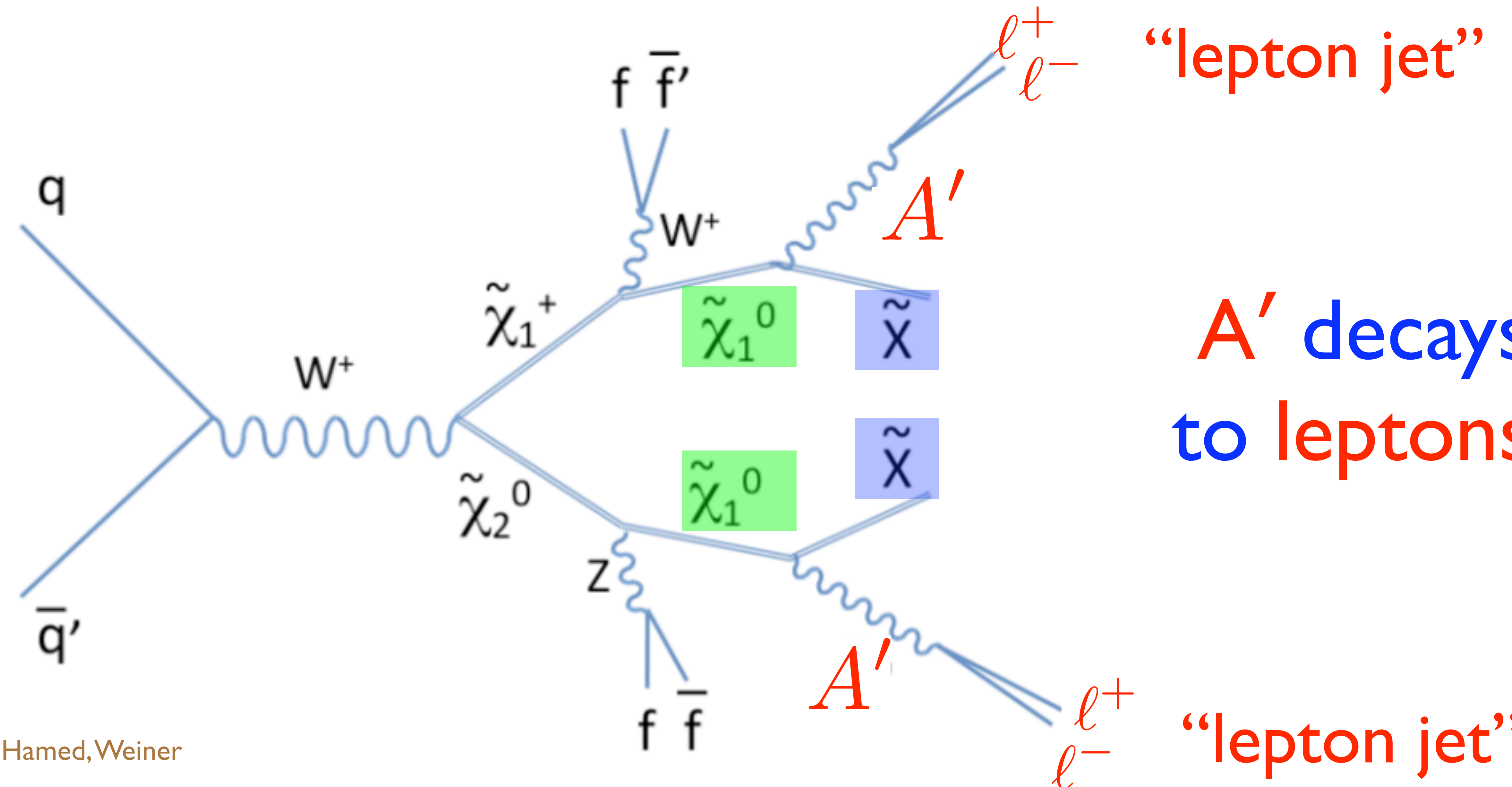

A′ decays to leptons!

Arkani-Hamed, Weiner
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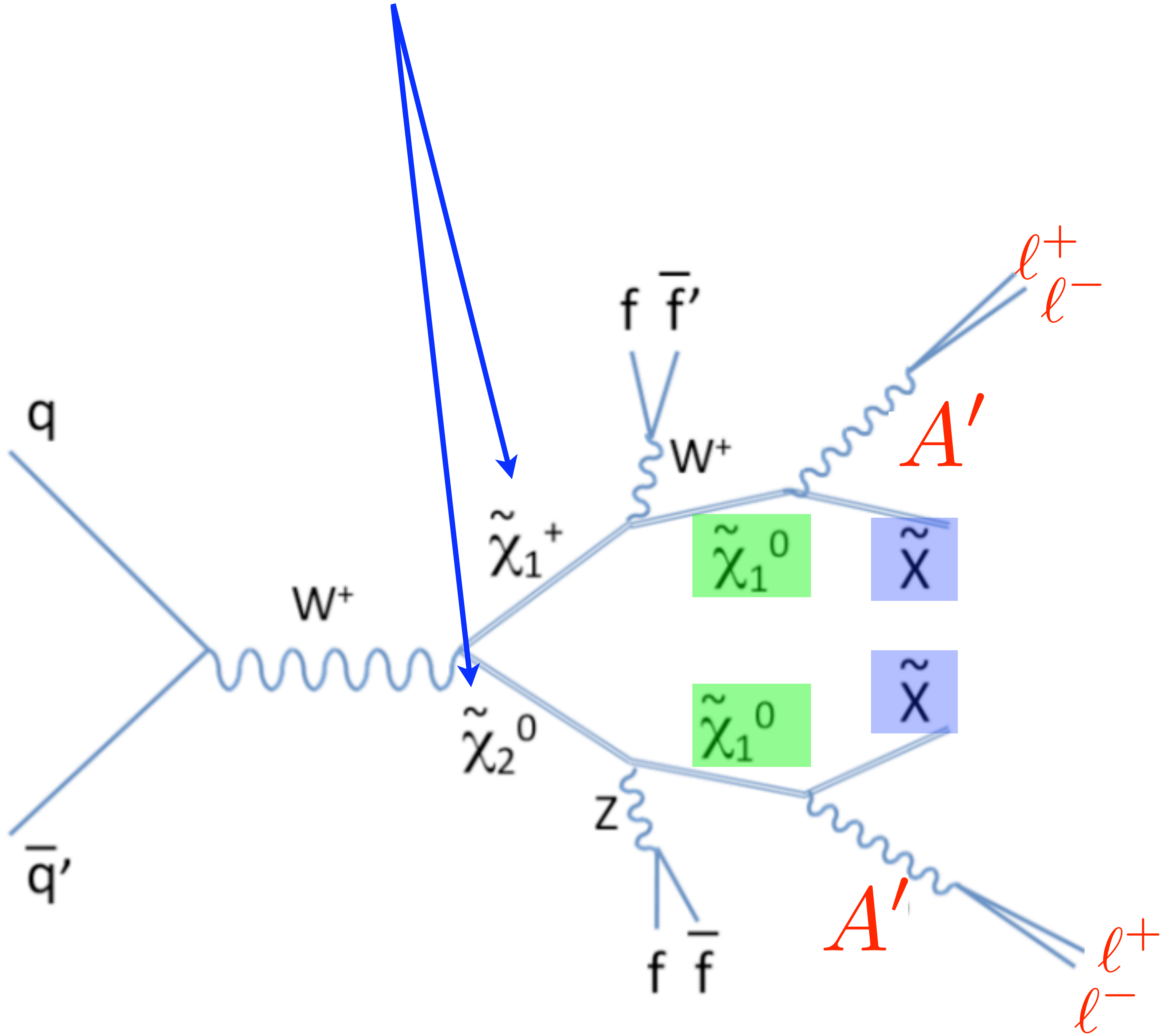
Shih, Thomas

If SUSY particles too heavy, then can't produce these events



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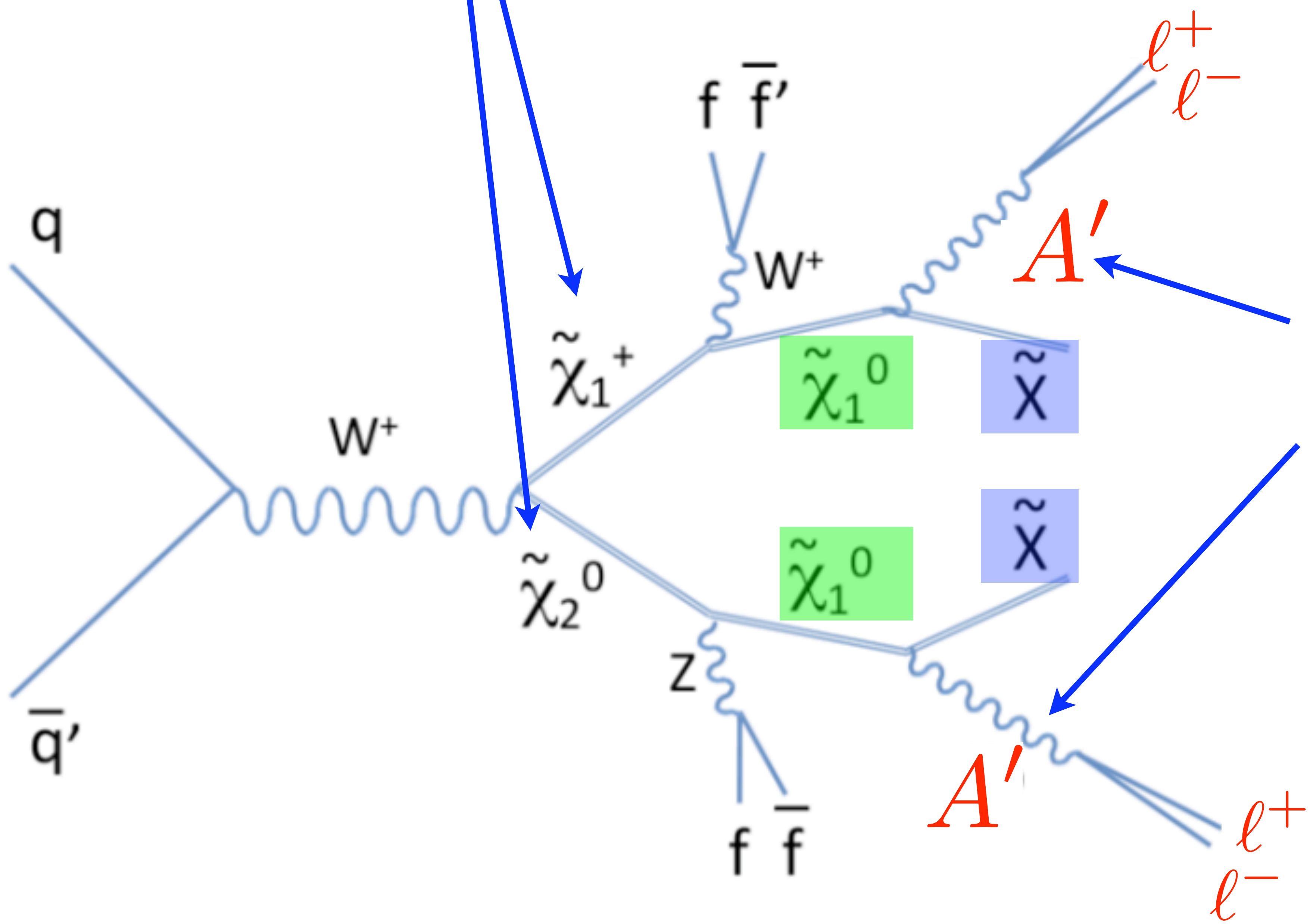
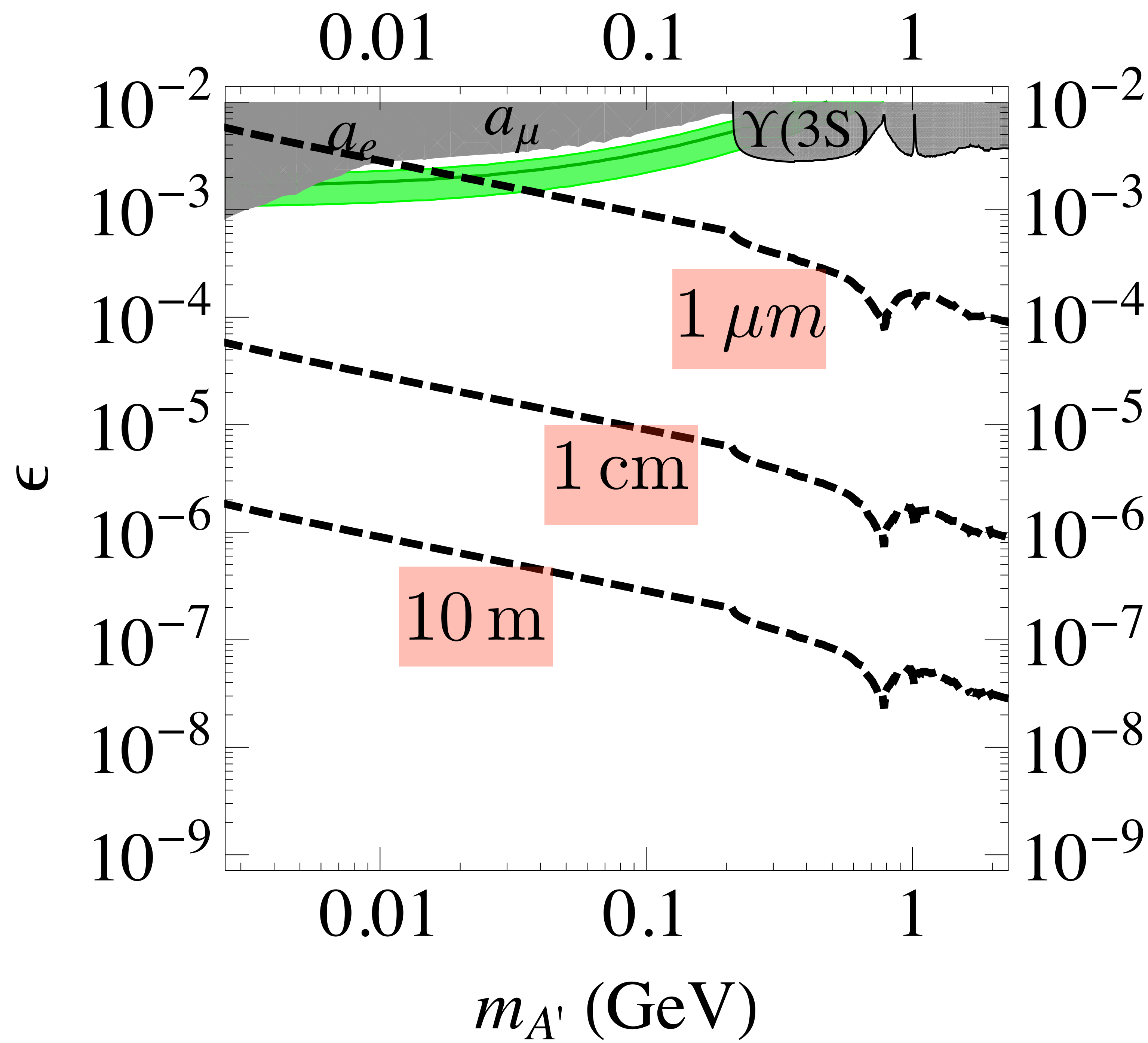


and need to assume A′ decays inside detector (i.e. lifetime is not too long)

A′ lifetime varies by orders of magnitude



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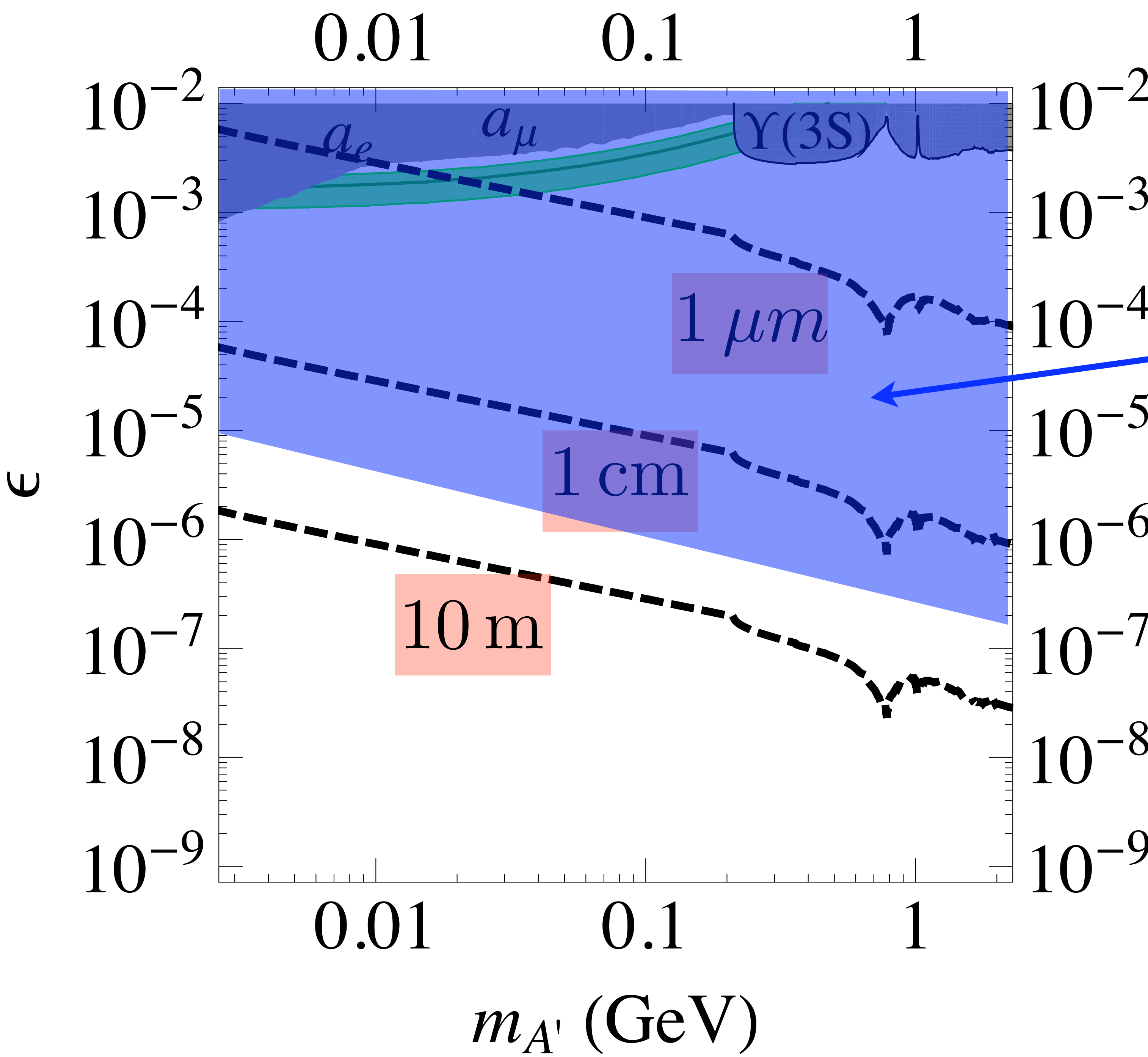
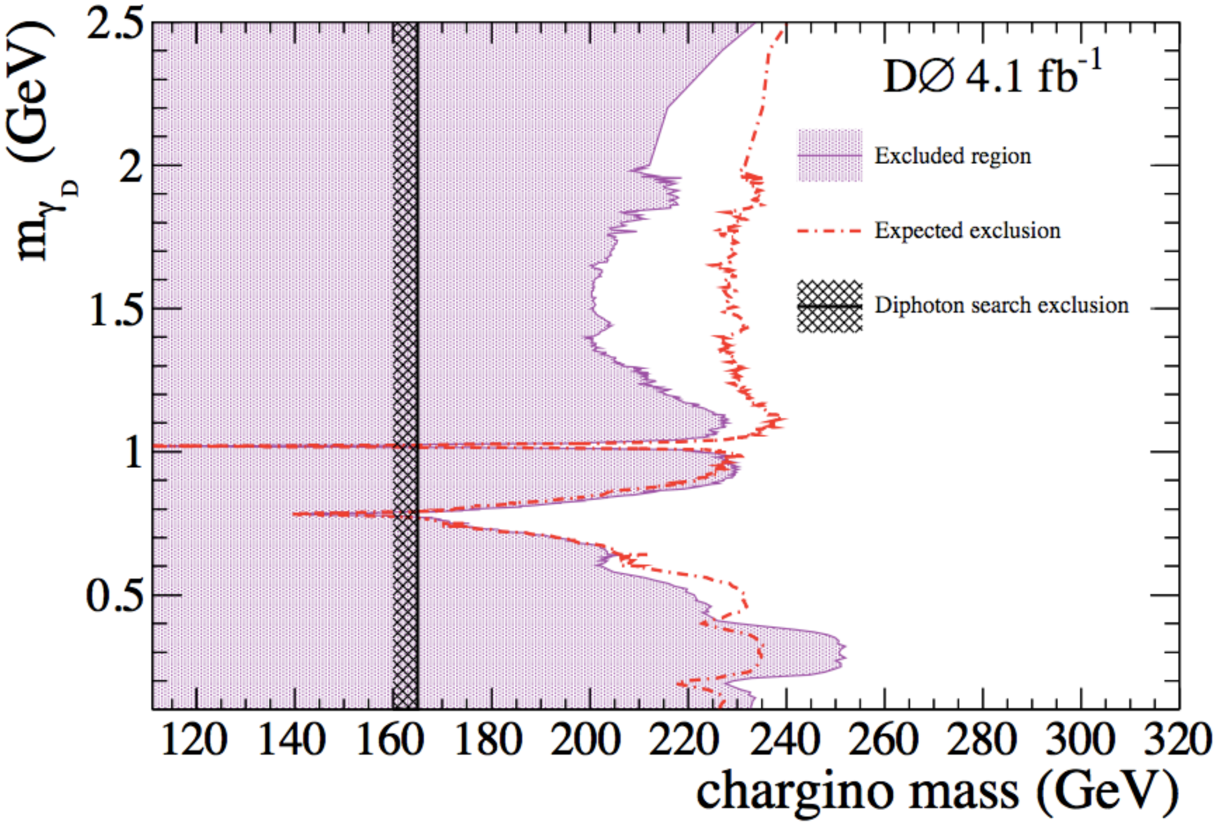
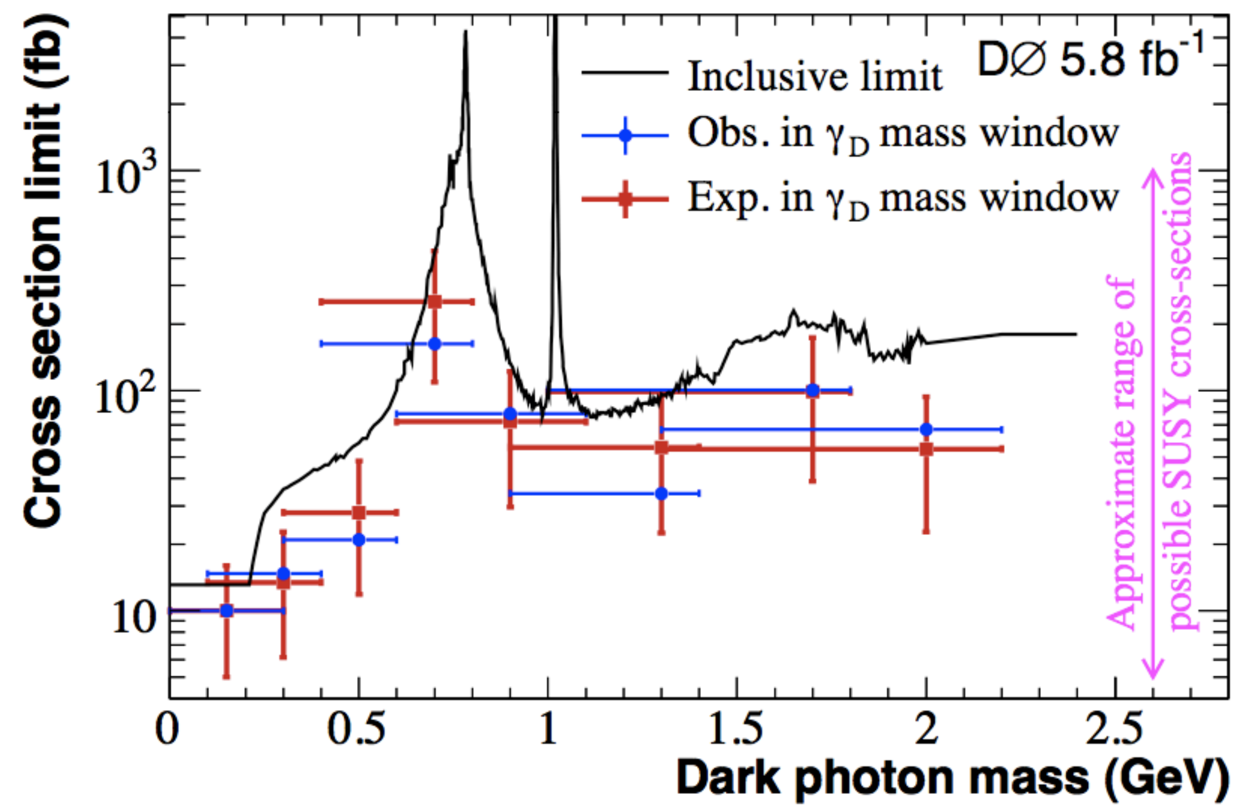


LHC/Tevatron *could* probe this region, *if SUSY particles are light enough*

Some Tevatron Results

no signal yet...





arXiv:0905.1478,1008.3356

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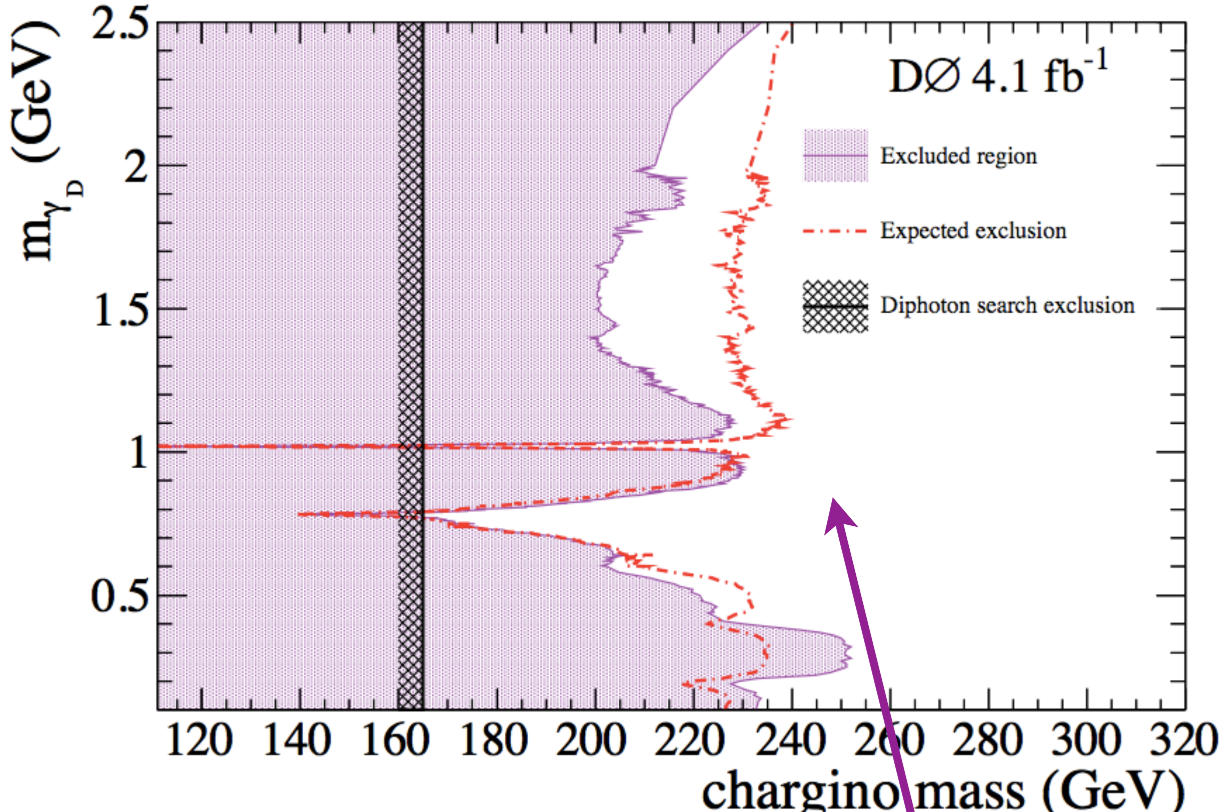

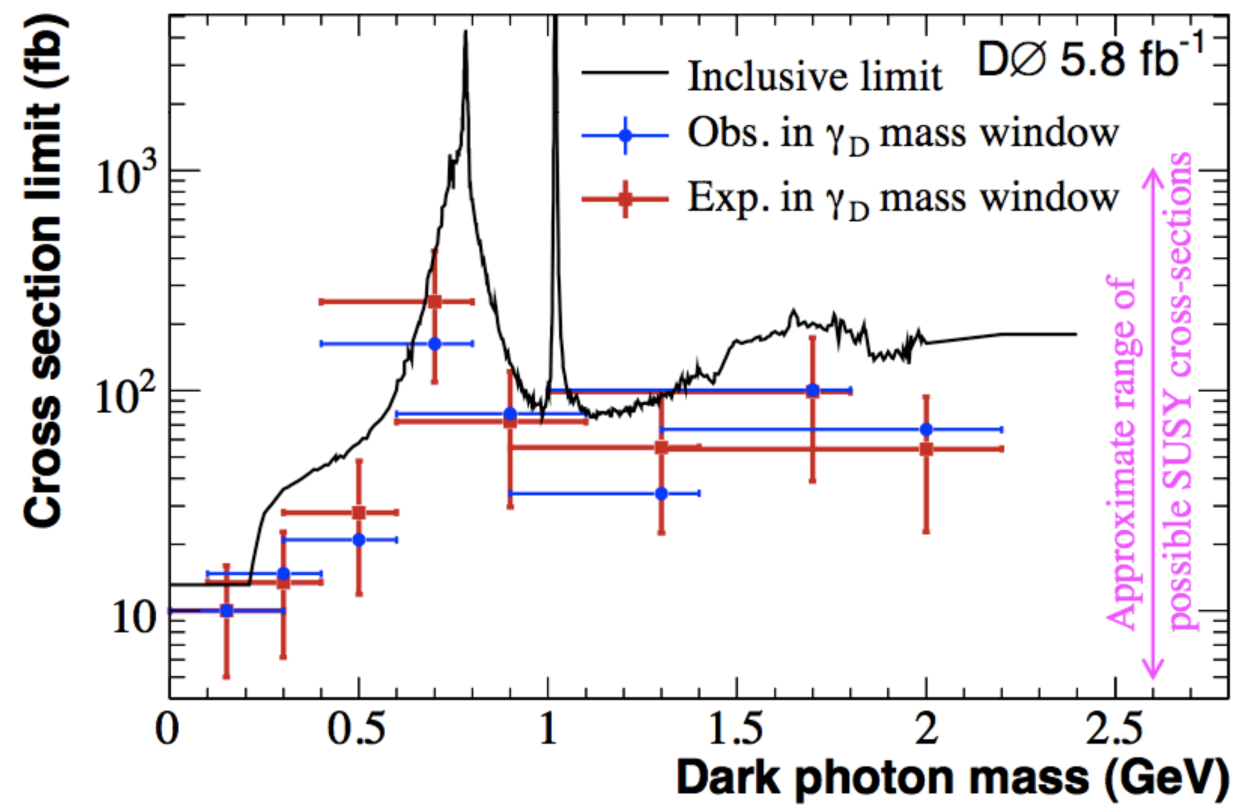

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no limit if SUSY particles are too heavy !

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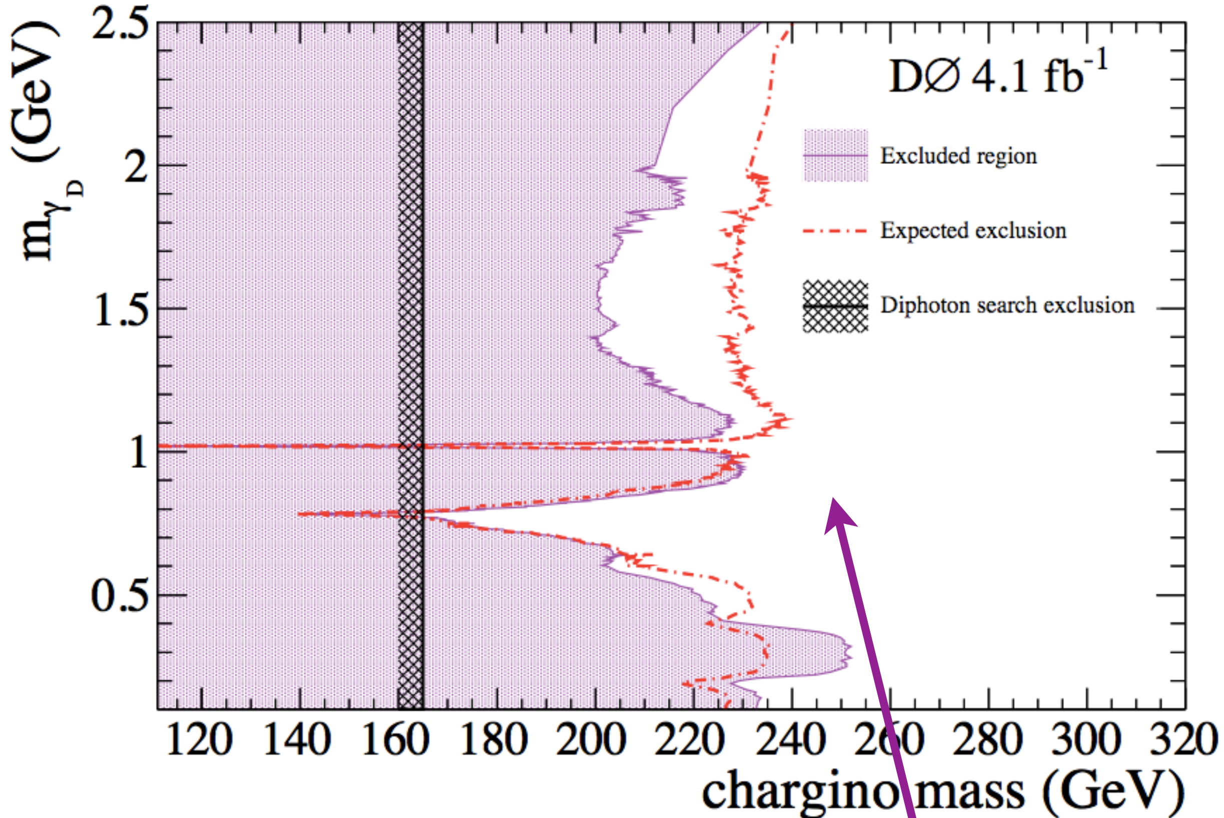

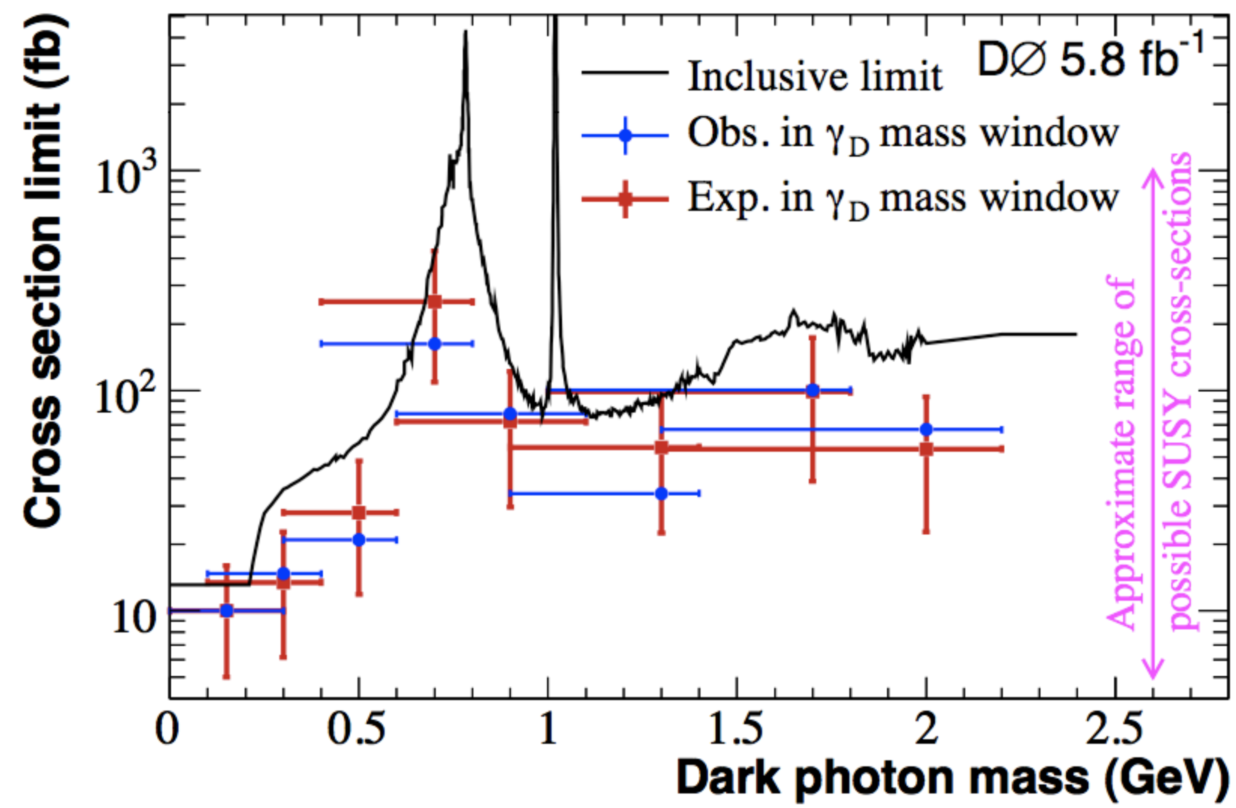

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many LHC searches underway…

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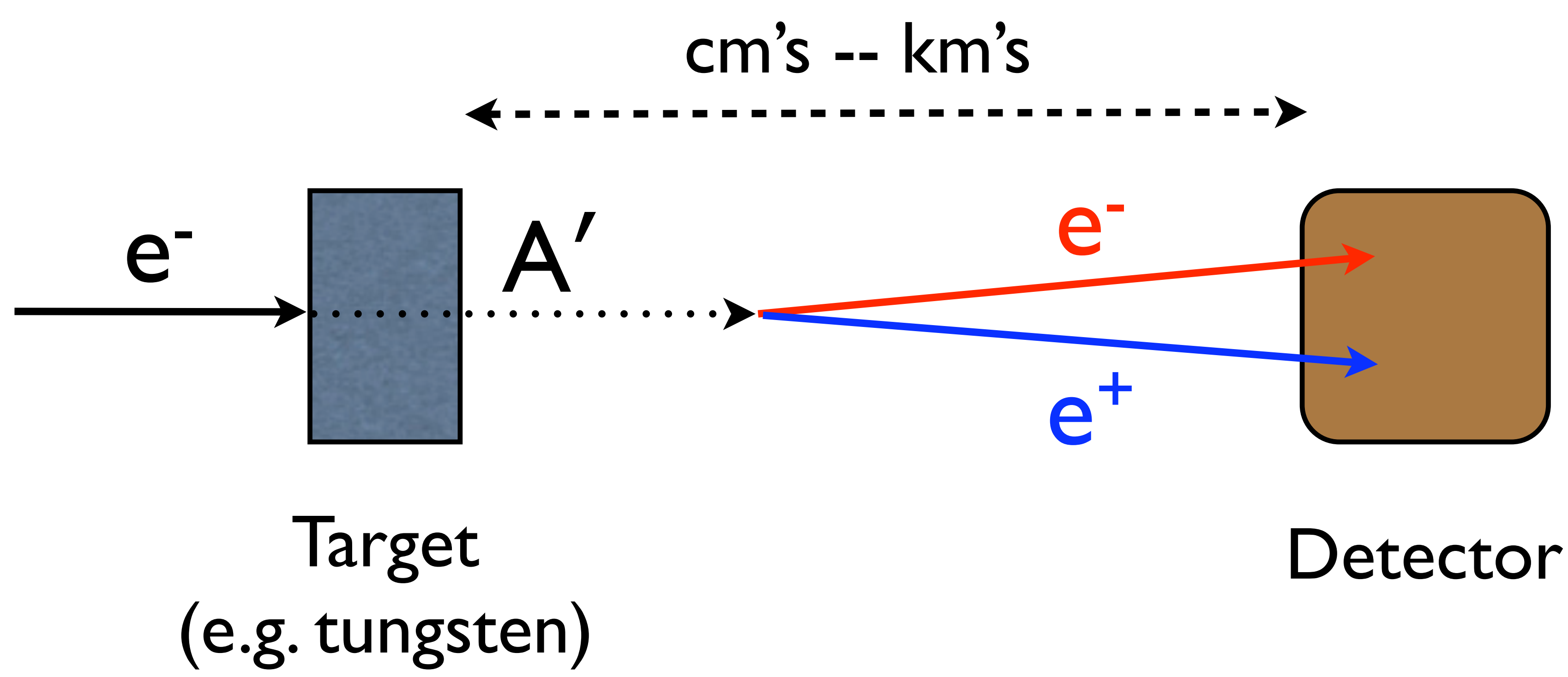
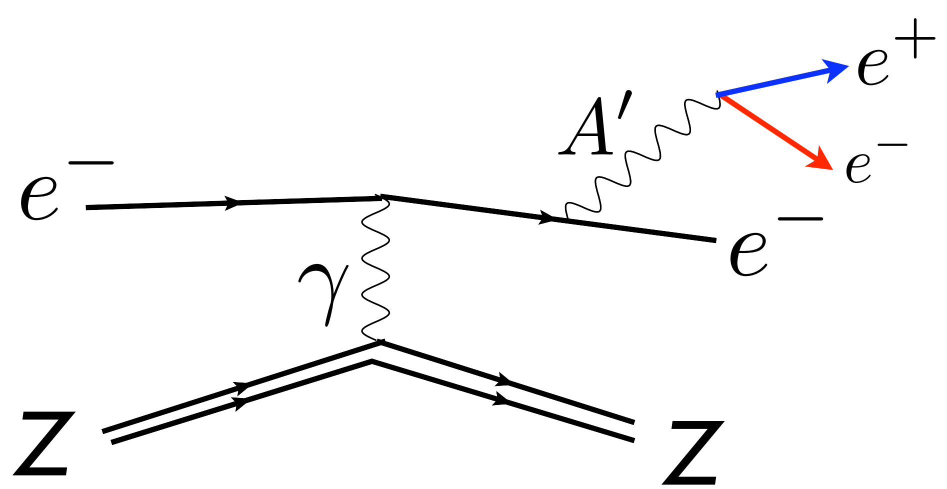
Fixed-Target Experiments

[Bjorken RE, Schuster, Toro]
[Batell, Pospelov, Ritz]
[Reece & Wang]

Produce A′ via bremsstrahlung off e⁻ beam on fixed target

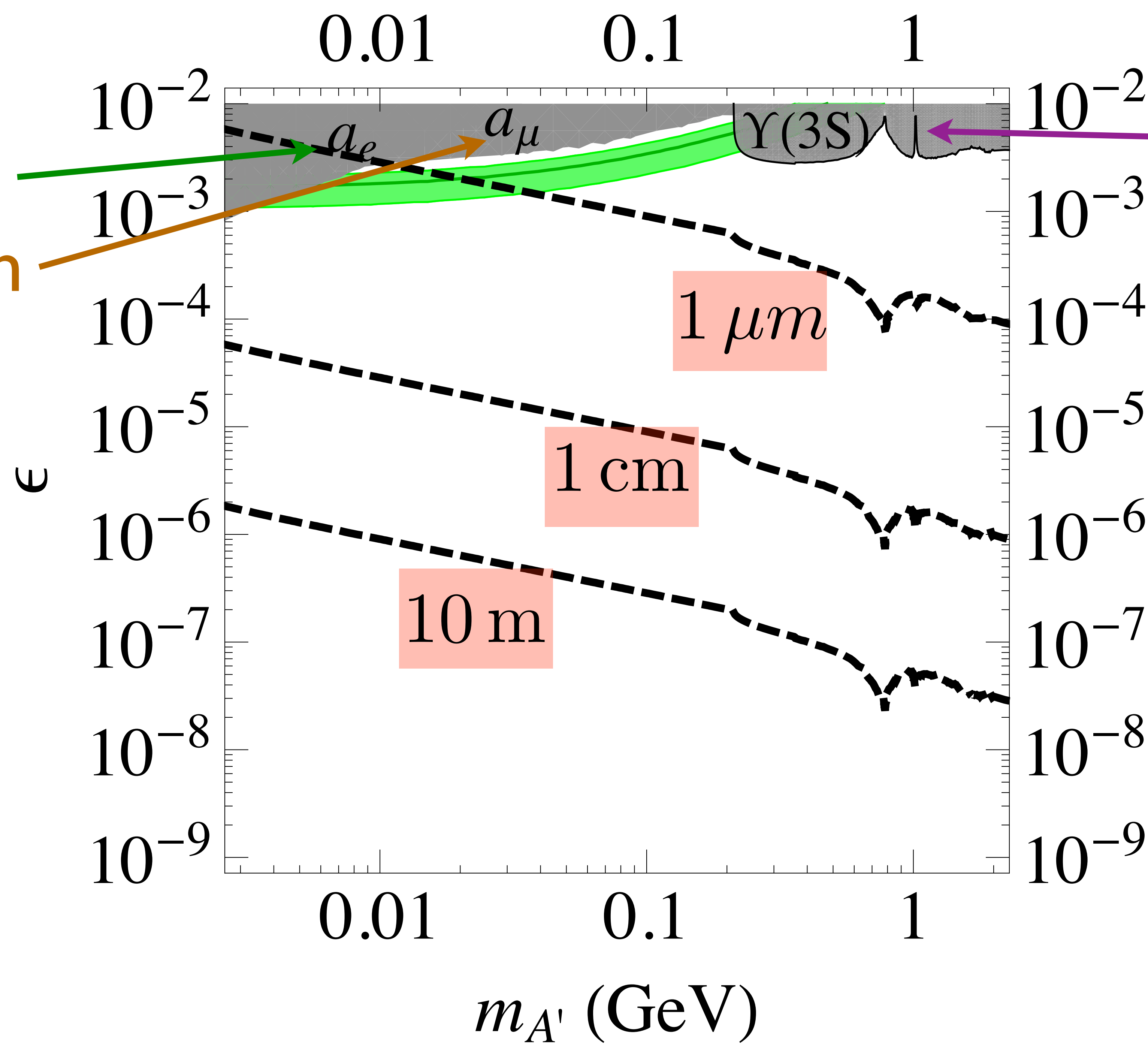




assume A′ decays to e^+e^- pair

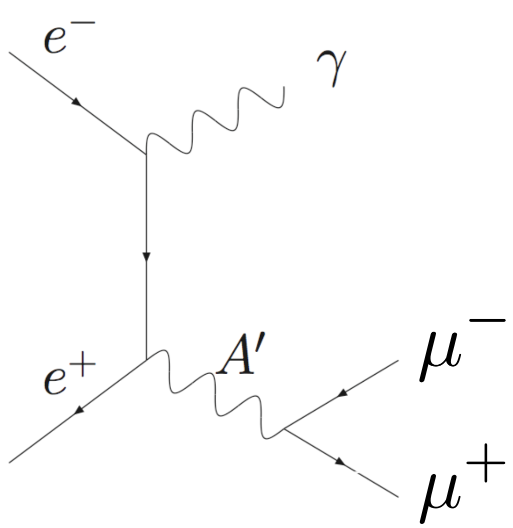
A′ lifetime varies by orders of magnitude

g_s-2 for electron and muon



BaBar

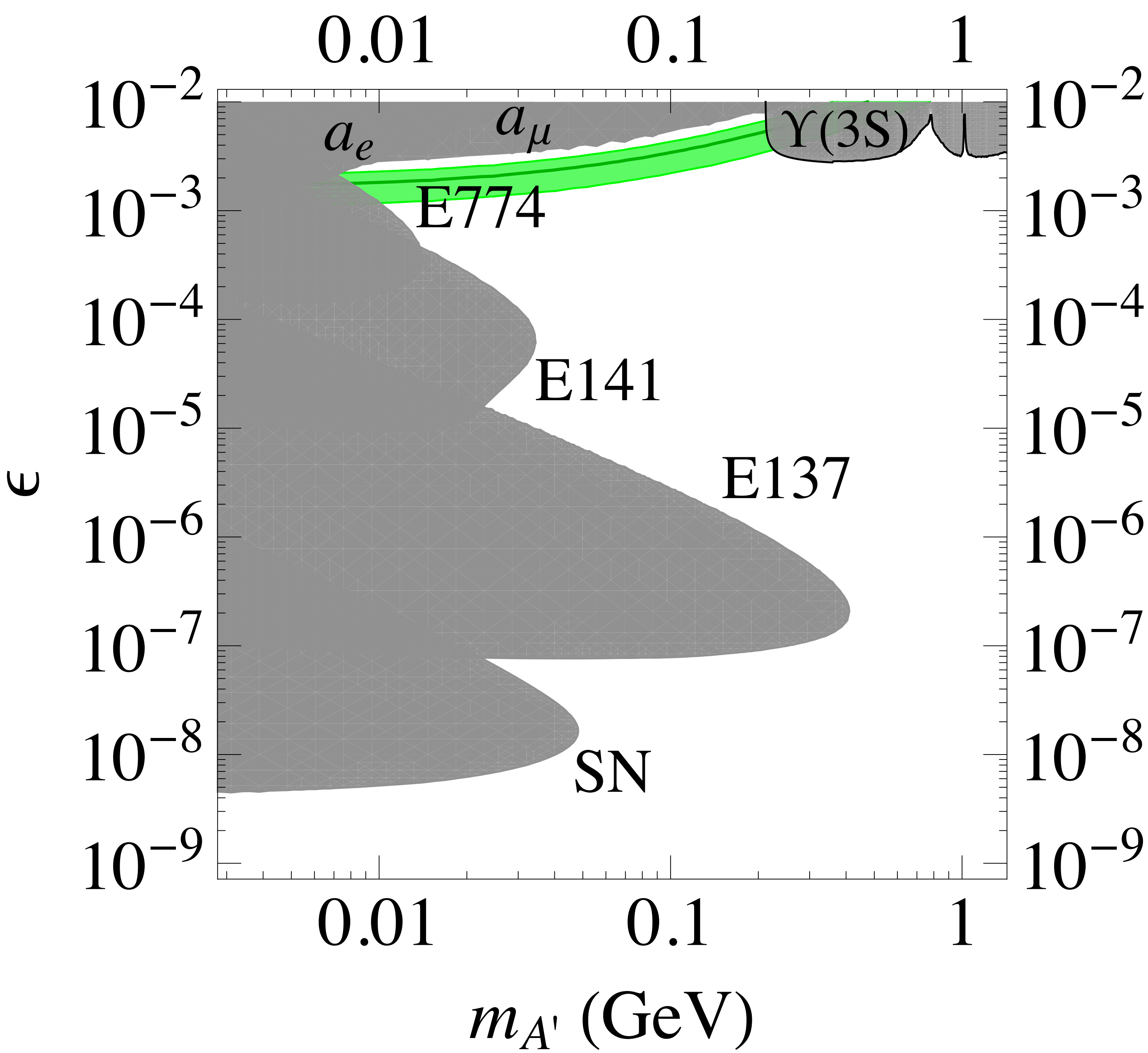
$\Upsilon(3S) \to \gamma\mu^+\mu^-$



Need various strategies to cover whole range

Good beam dump constraints exist

Bjorken, RE, Schuster, Toro



fixed target experiments w/ large shields

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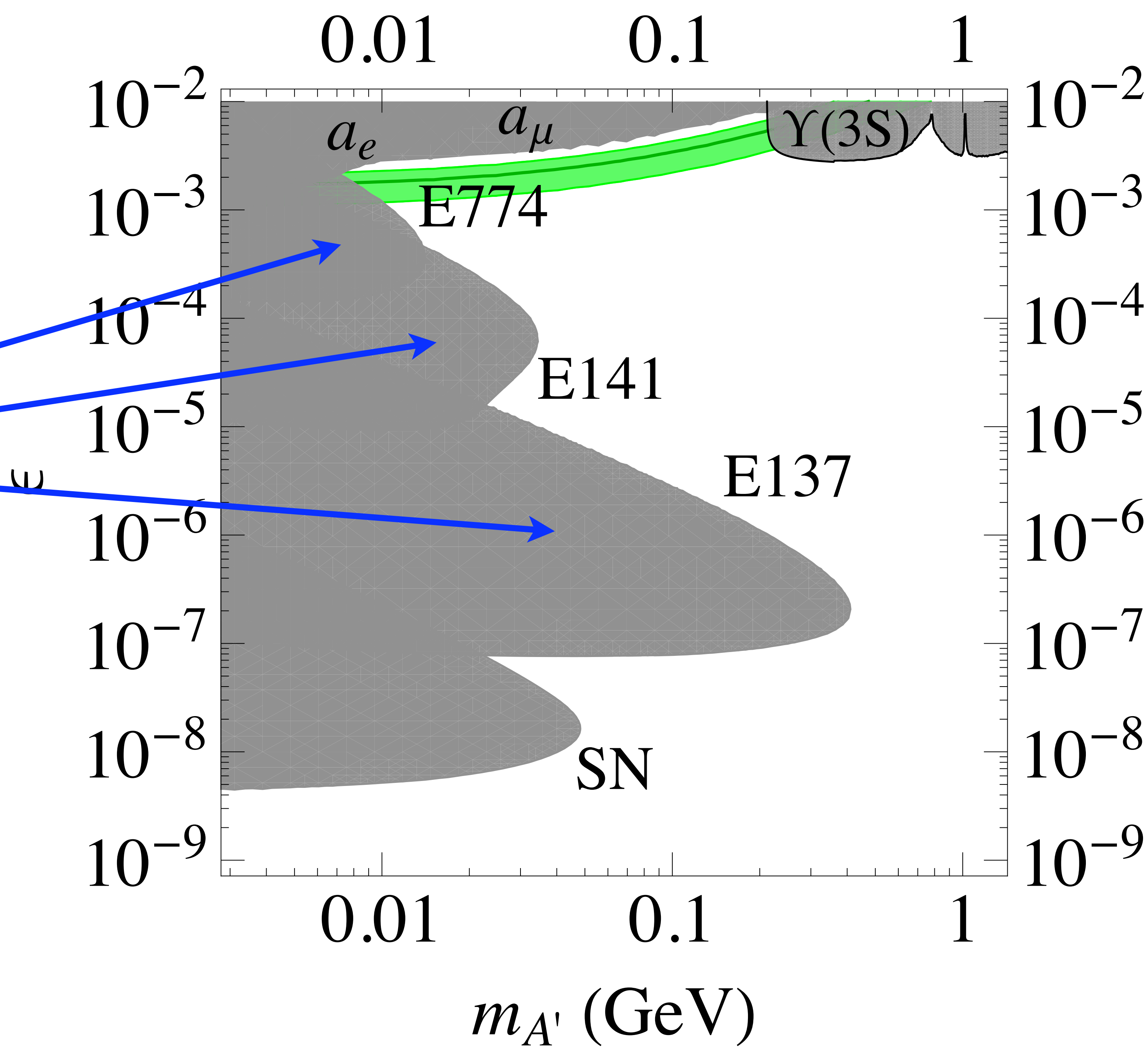
beam
dumps



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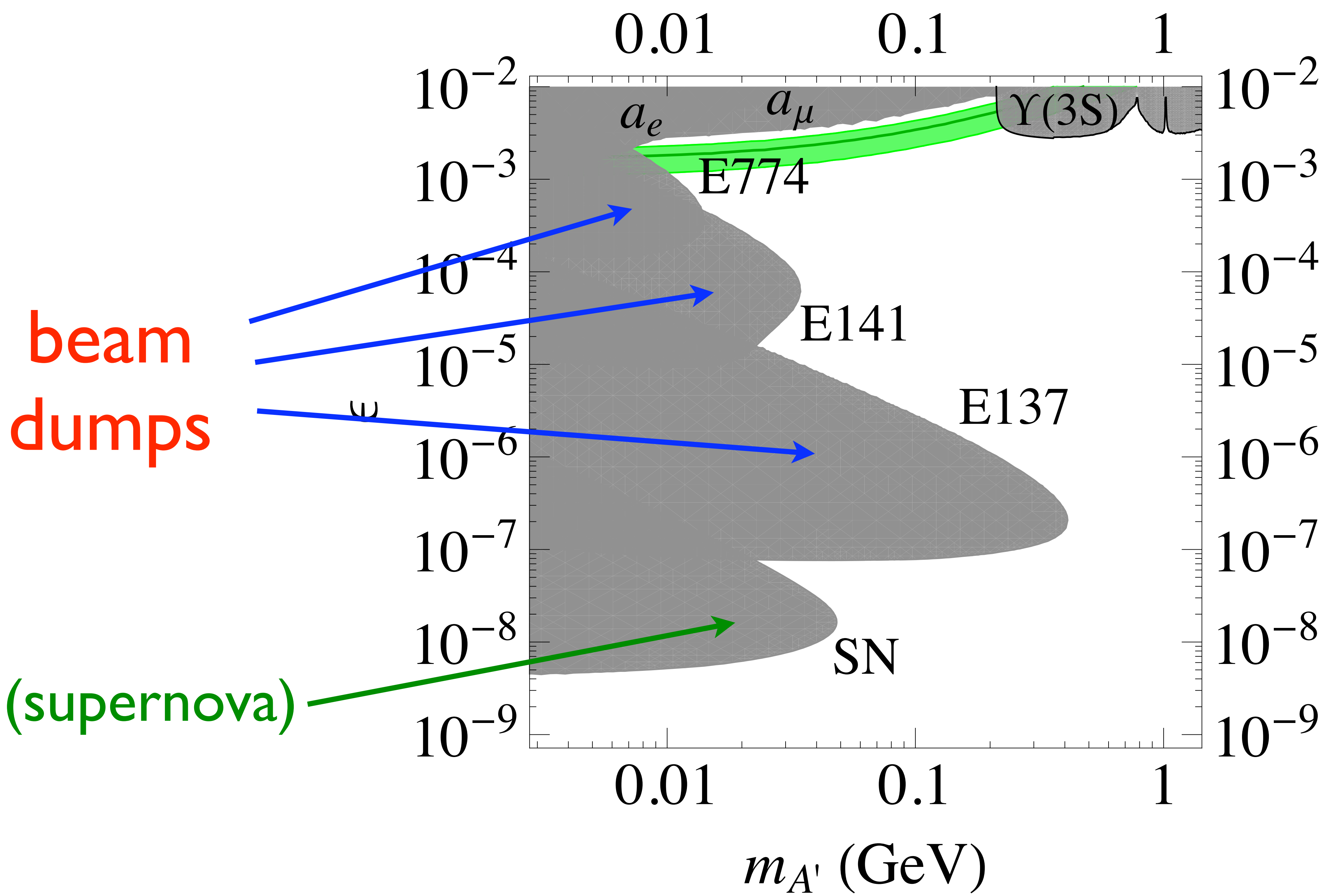


fixed target experiments w/ large shields

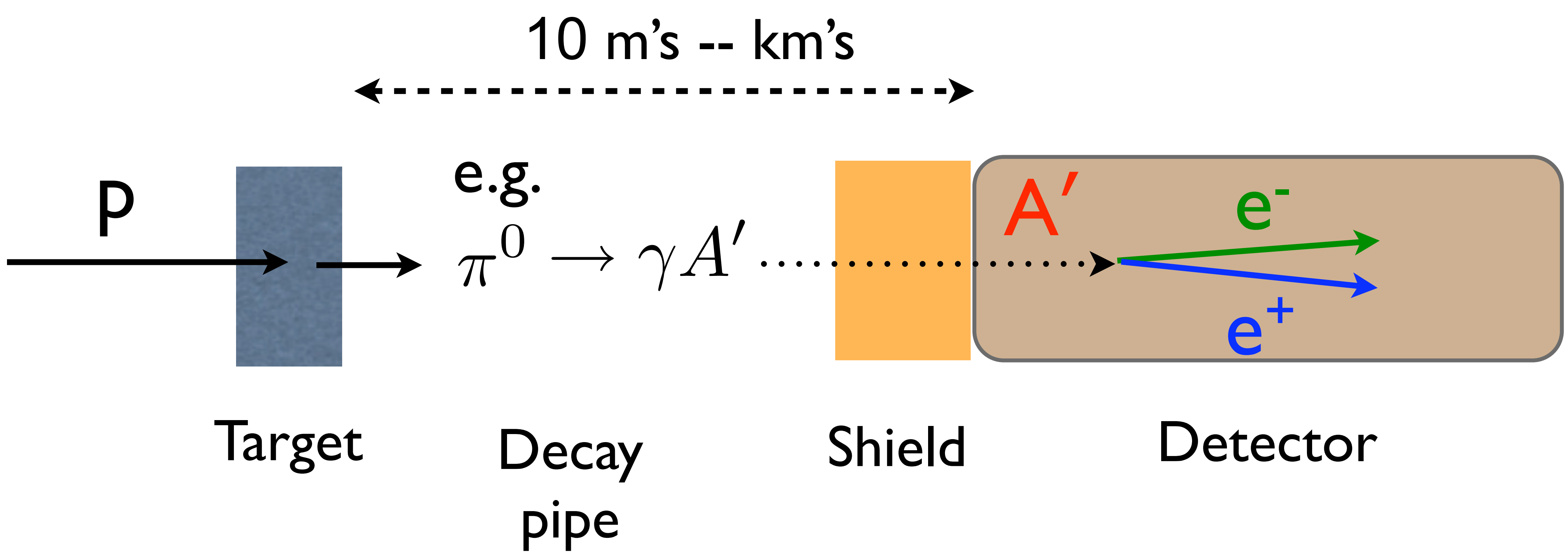
An aside: proton-beam fixed target experiments

[Batell, Pospelov, Ritz]

[RE, Harnik, Kaplan, Toro]

e.g. LSND, MINOS, MiniBooNE, Project X

produce A′ from meson decays

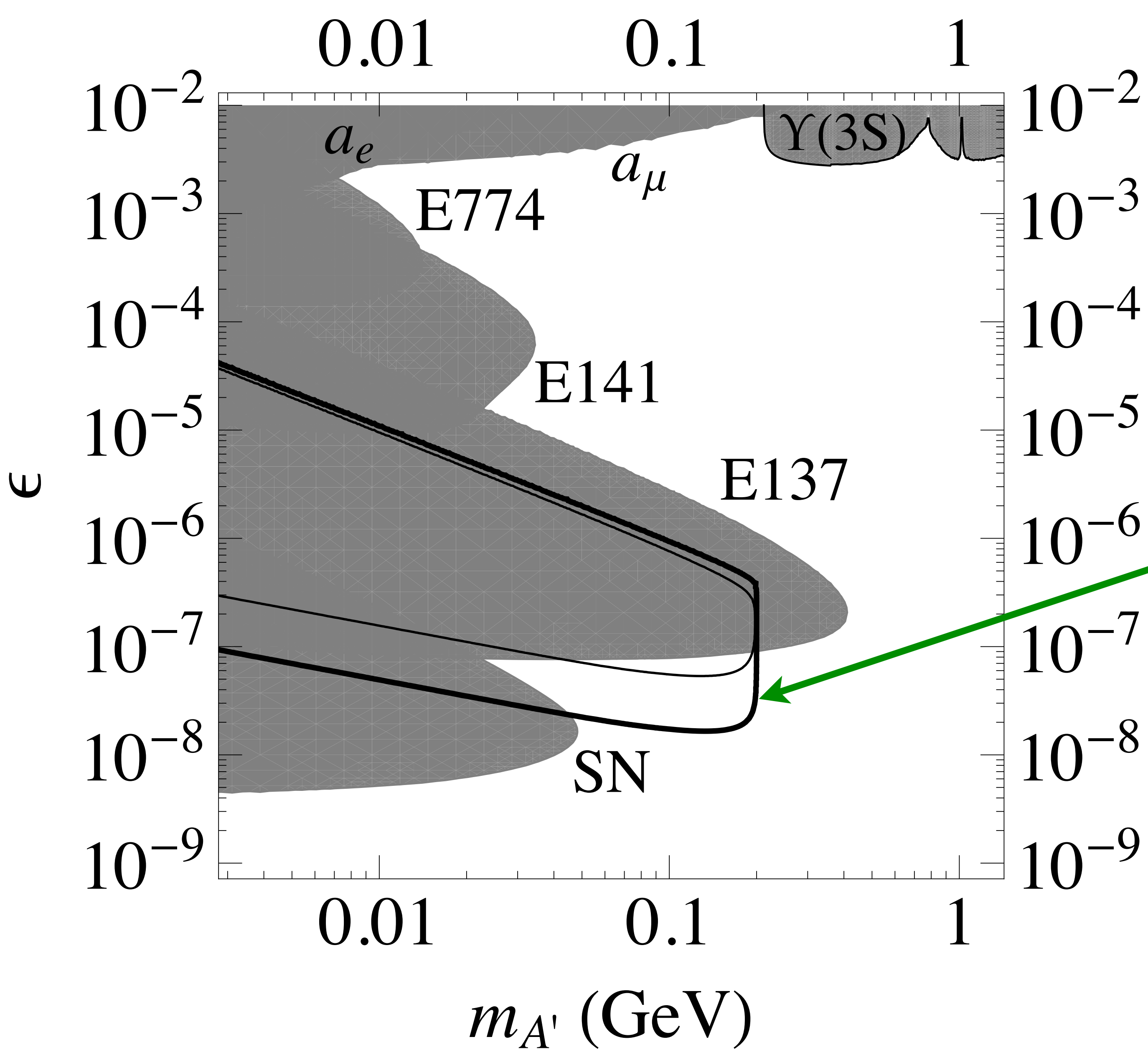


An aside: proton-beam fixed target experiments

[Batell, Pospelov, Ritz]
[RE, Harnik, Kaplan, Toro]

e.g. LSND dumped ~10^{23} protons, producing ~ 10^{22} pions

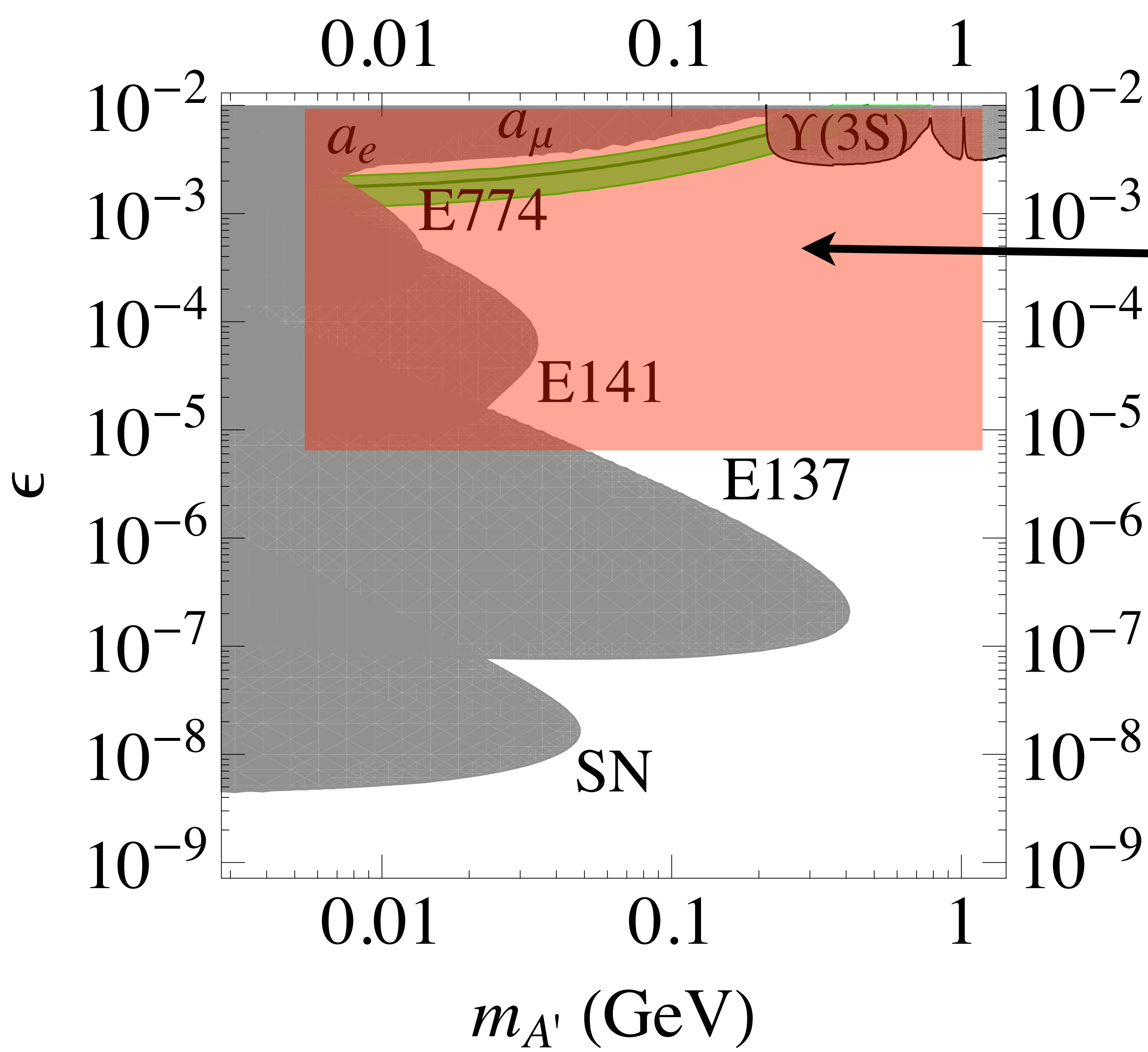
$$\pi^0 \to \gamma A' \to \gamma e^+ e^-$$



rough sensitivity

Need new experiments

Bjorken, RE, Schuster, Toro

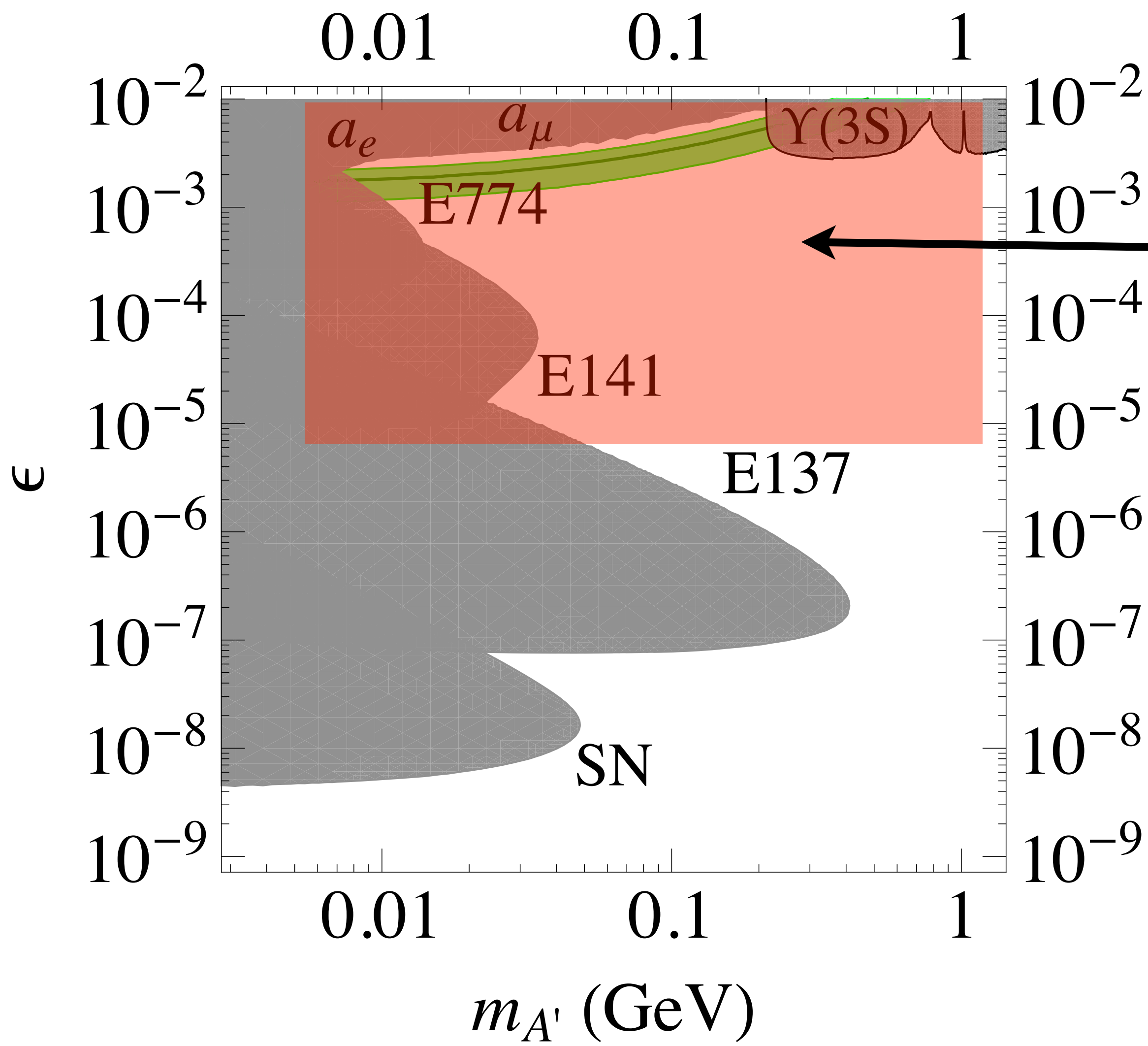


Interesting unexplored region

A′ lifetime short, so need *thin* target

Need new experiments

Bjorken, RE, Schuster, Toro

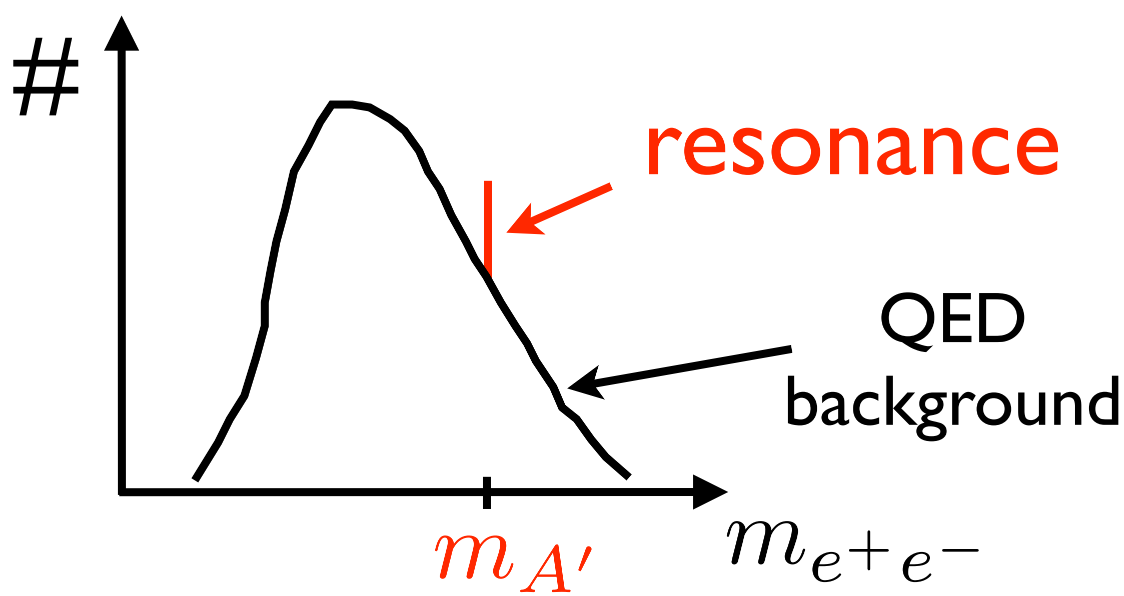


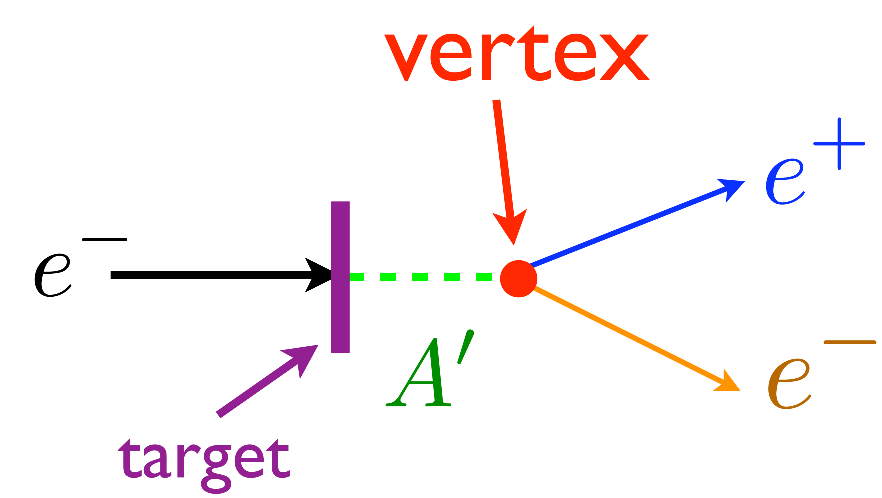
Interesting unexplored region

A′ lifetime short, so need *thin* target

Large background, but:

look for resonance or vertex





Current & Planned Experiments

JLab
- A′ Experiment (APEX)
- Heavy Photon Search (HPS)
- DarkLight

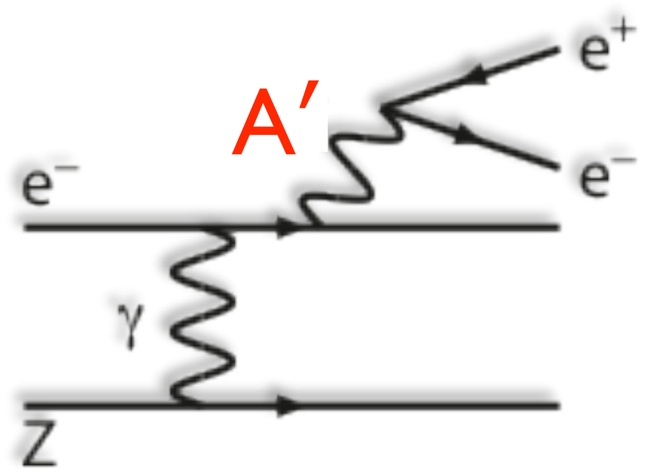
Germany
- MAMI in Mainz

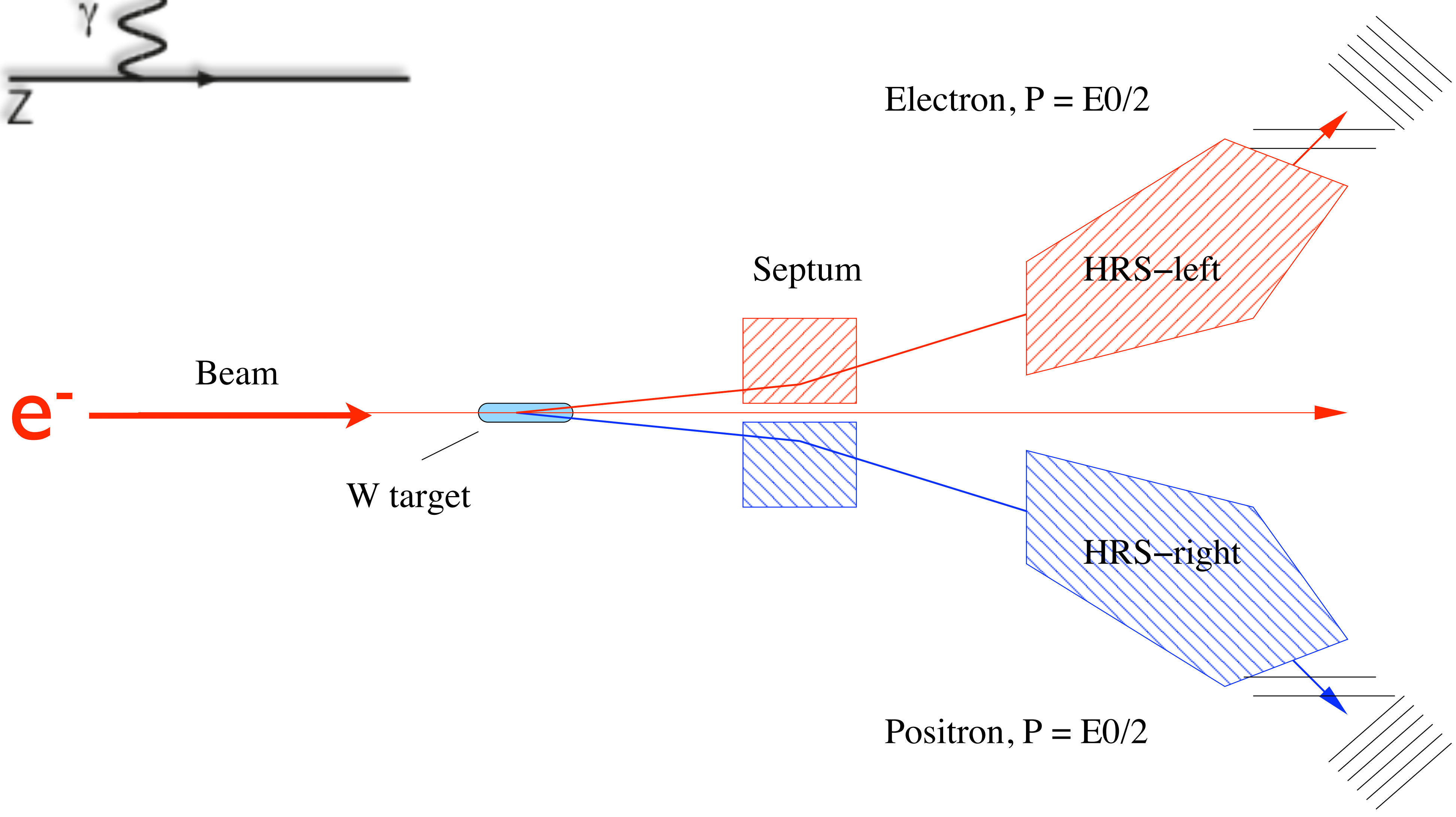
Russia
- VEPP-3

The A′ Experiment (APEX)

S. Abrahamyan, A. Afanasev, Z. Ahmed, E. Aliotta, K. Allada, D. Anez, D. Armstrong, T. Averett, A. Barbieri, K. Bartlett, J. Beacham, S. Beck, J. D. Bjorken, J. Bono, P. Bosted, J. Boyce, P. Brindza, N. Bubis, A. Camsonne, O. Chen, K. Cranmer, C. Curtis, E. Chudakov, M. Dalton, C.W. de Jager, A. Deur, J. Donaghy, R. Essig (co-spokesperson), C. Field, E. Folts, A. Gasparian, A. Gavalya, S. Gilad, R. Gilman, A. Glamazdin, N. Goeckner-Wald, J. Gomez, M. Graham, O. Hansen, D.W. Higinbotham, T. Holmstrom, J. Huang, S. Iqbal, J. Jaros, E. Jensen, A. Kelleher, M. Khandaker, I. Korover, G. Kumbartzki, J. J. LeRose, R. Lindgren, N. Liyanage, E. Long, J. Mammei, P. Markowitz, T. Maruyama, V. Maxwell, J. McDonald, D. Meekins, R. Michaels, M. Mihovilovič, K. Moffeit, S. Nanda, V. Nelyubin, B. E. Norum, A. Odian, M. Oriunno, R. Partridge, M. Paolone, E. Piasetzky, I. Pomerantz, A. Puckett, V. Punjabi, Y. Qiang, R. Ransome, S. Riordan, Y. Roblin, G. Ron, K. Saenboonruang, A. Saha, B. Sawatzky, P. Schuster (co-spokesperson), J. Segal, L. Selvy, A. Shahinyan, R. Shneor, S. Širca, R. Subedi, V. Sulkosky, S. Stepanyan, N. Toro (co-spokesperson), D. Waltz, L. Weinstein, B. Wojtsekhowski (co-spokesperson), J. Zhang, Y. Zhang, B. Zhao, and **The Hall A Collaboration**

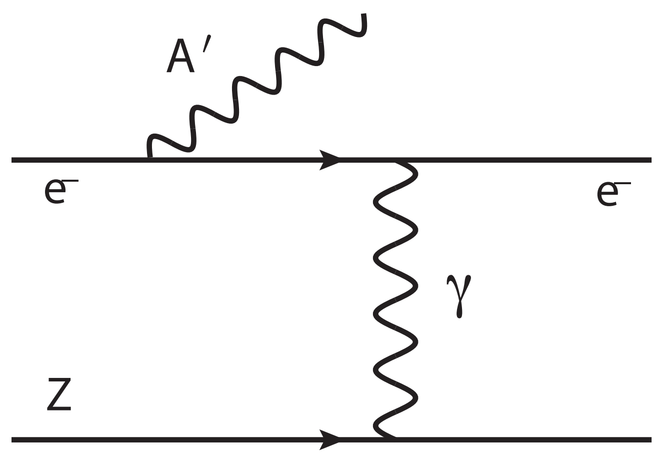
Experimental Setup



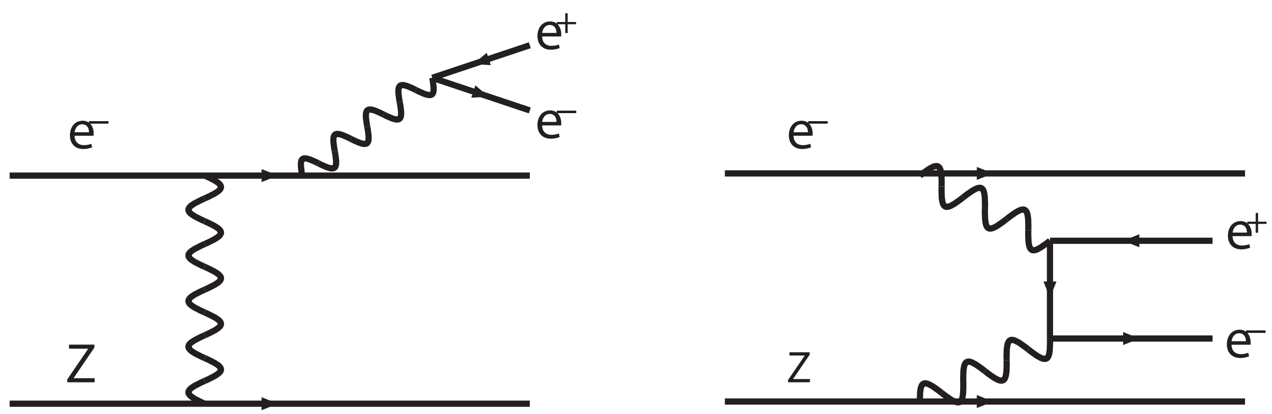


choose symmetric configuration (angles and energy)

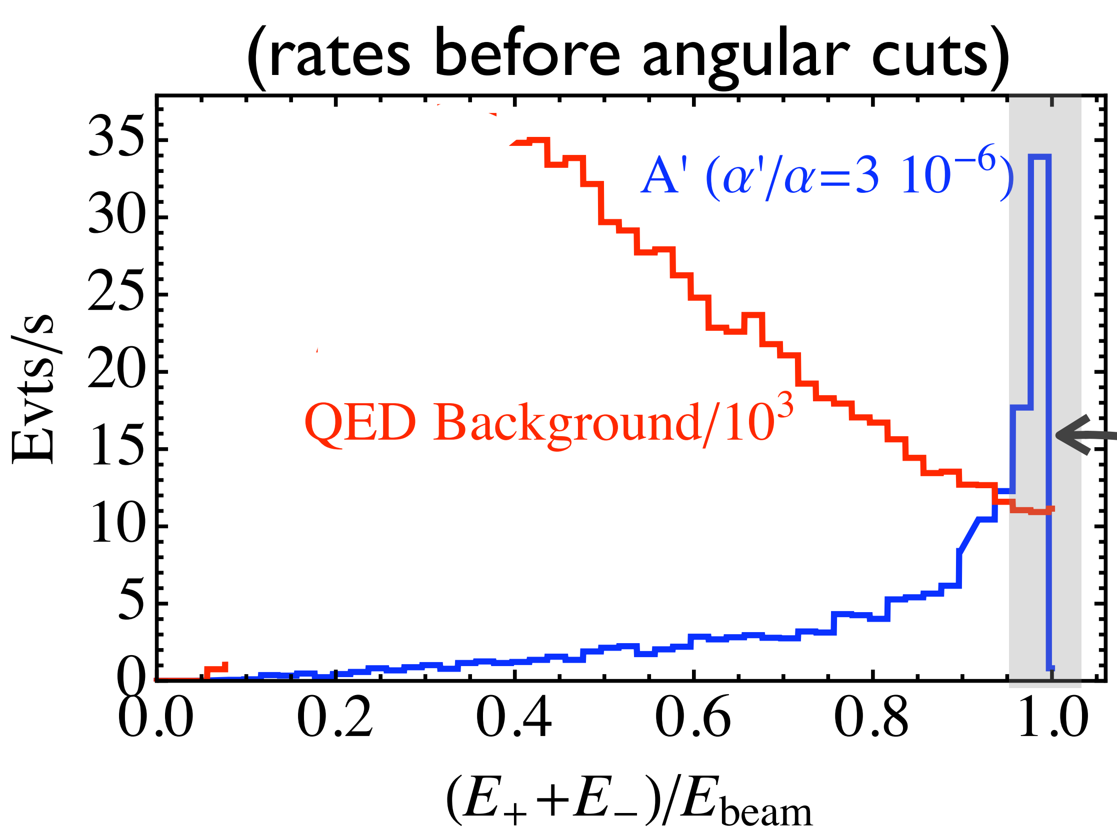
Symmetric configuration maximizes signal over background



A′ signal



Backgrounds



A′ products carry (almost) full beam energy

Symmetric energy, angles in two arms optimize A′ acceptance

$E^+ \approx E^- \approx E_{beam}/2$

APEX Test Run

- Test run in July 2010

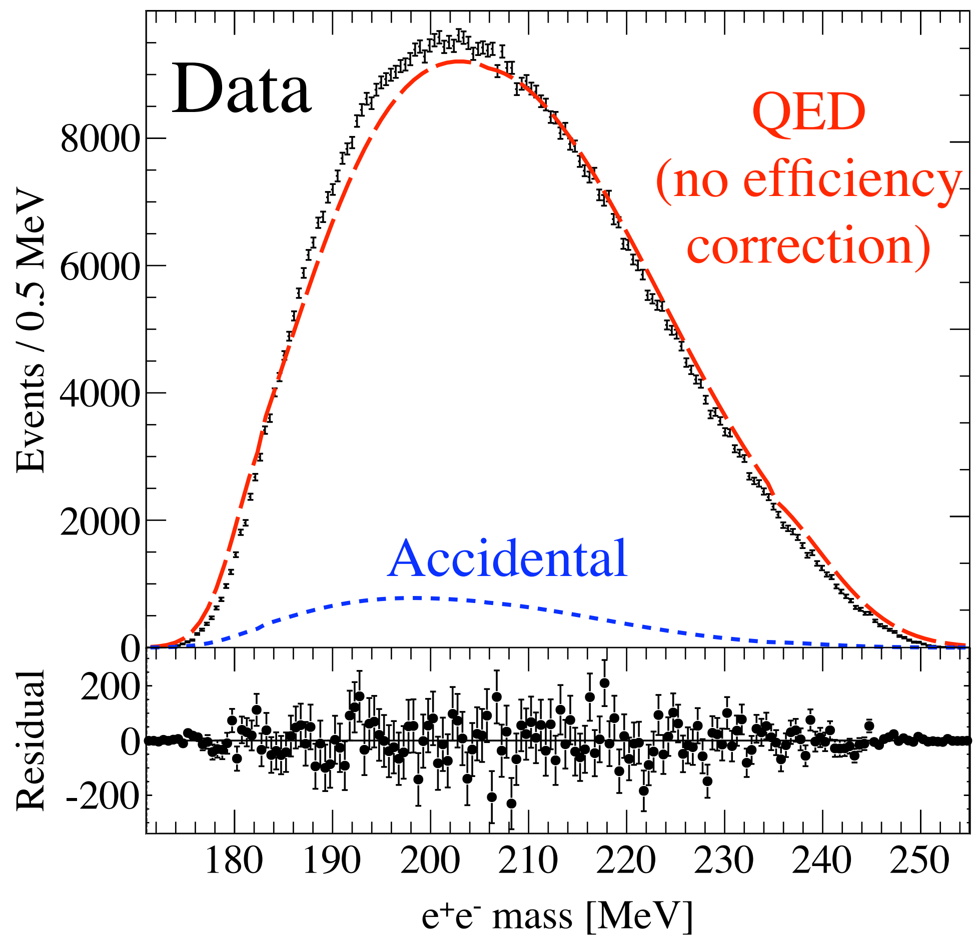
  Many thanks to JLab & Hall A staff for tremendous support!

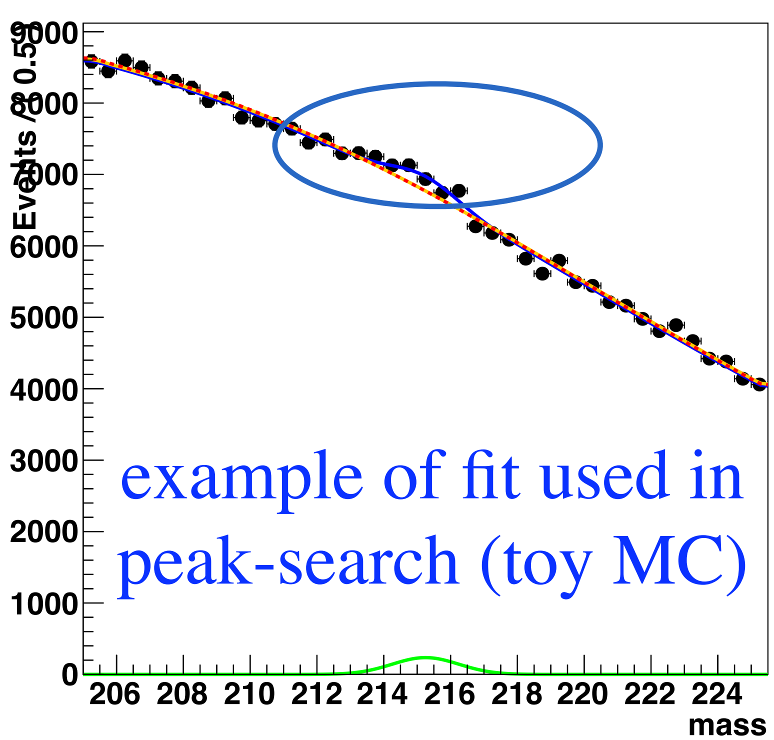
- Results published in PRL 107 (2011) 191804, arXiv:1108.2750

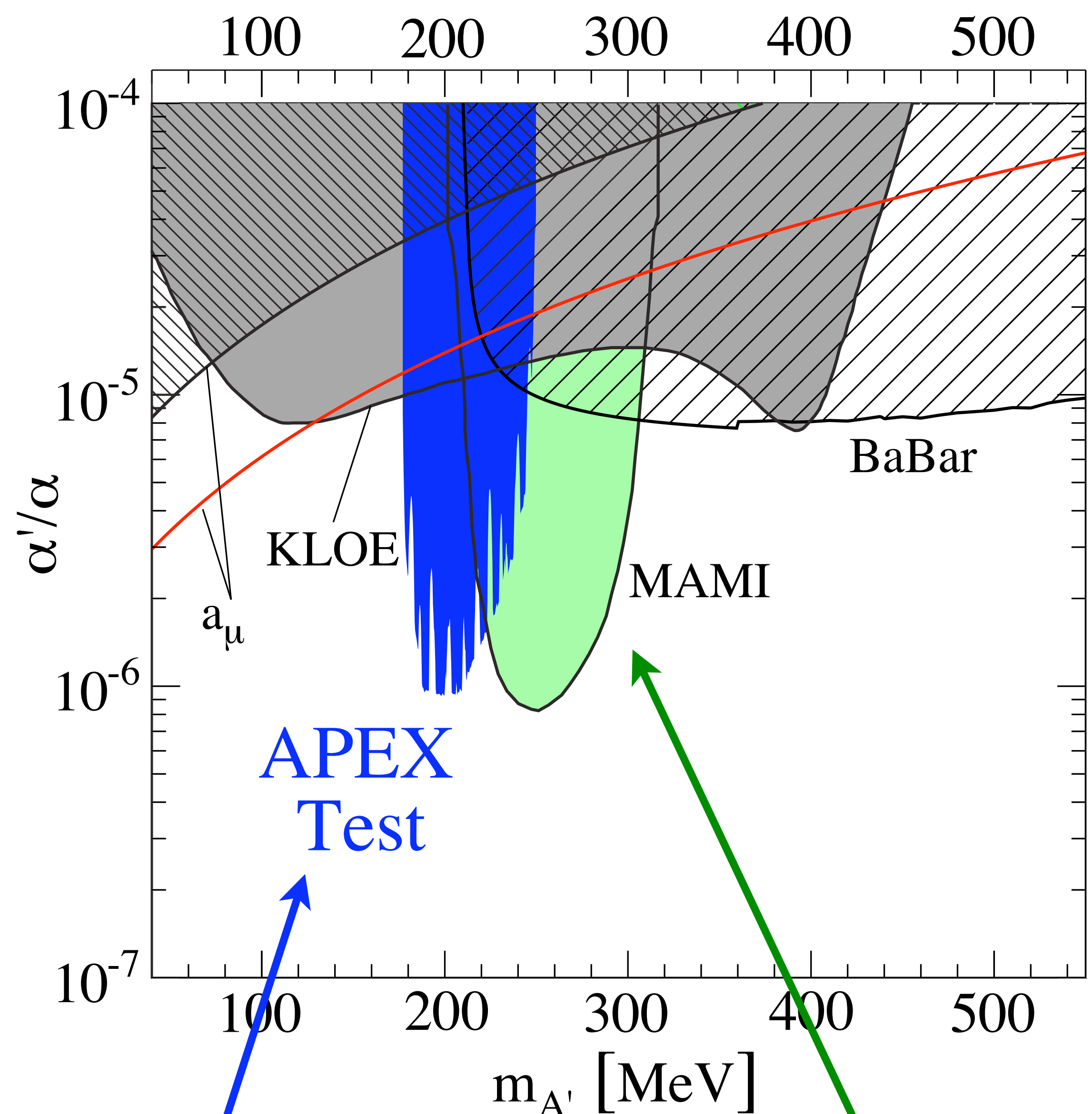
- Demonstrated many key elements for full experiment

  – accurate & efficient VDC reconstruction at high e^- track rate
  – coincidence trigger on S2 scintillators and Gas Cherenkov (e^+ arm)
  – tested understanding of background processes
  – spectrometer optics & mass resolution
  – resonance search on 700K good trident events

APEX Test Run Results



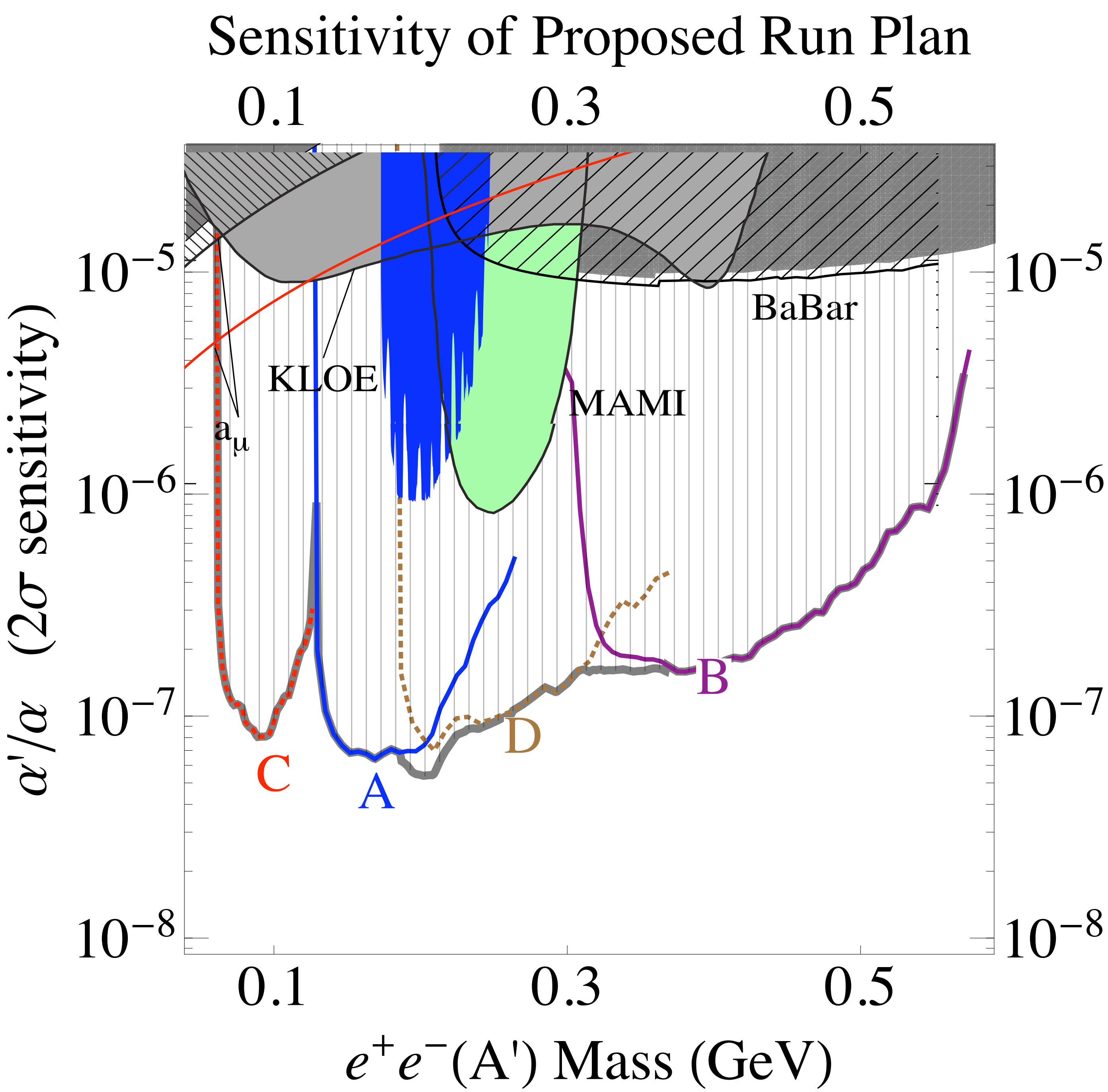




APEX Test Run

Mainz Test Run based on APEX setup

APEX Plans



~1 Month Beam Time
- 6 days at 1,2,3 GeV
- 12 days at 4.5 GeV

approved by JLab PAC 37 (pending radiation studies)
planning underway for full run

Heavy Photon Search (HPS) @ JLab Hall B

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University of California, Santa Cruz, CA 95064

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University of Connecticut, Department of Physics, Storrs, CT 06269

W. Cooper
Fermi National Accelerator Laboratory, Batavia, IL 60510-5011

A. Micherdzinska
The George Washington University, Department of Physics,Washington, DC 20052

G. Ron
Hebrew University of Jerusalem, Jerusalem, Israel

M. Battaglieri, R. De Vita
INFN, Sezione di Genova, 16146 Genova, Italy

M. Holtrop (Co-Spokesperson), K. Slifer, S. K. Phillips, E. Ebrahim
University of New Hampshire, Department of Physics, Durham, NH 03824

M. Khandaker, C. Salgado
Norfolk State University, Department of Physics, Norfolk, VA 23504

S. Bueltmann, L. Weinstein
Old Dominion University, Department of Physics, Norfolk, VA 23529

A. Fradi, B. Guegan, M. Guidal, S. Niccolai, S. Pisano, E. Rauly, P. Rosier and D. Sokhan
Institut de Physique Nucleaire d'Orsay, 91405 Orsay, France

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Perimeter Institute, Ontario, Canada N2L 2Y5

P. Stoler, A. Kubarovsky
Rensselaer Polytechnic Institute, Department of Physics, Troy, NY 12181

R. Essig, C. Field, M. Graham, G. Haller, R. Herbst, J. Jaros (Co-Spokesperson), C. Kenney, T. Maruyama, K. Moffeit, T. Nelson, H. Neal, A. Odian, M. Oriunno, R. Partridge, S. Uemura, D. Walz
SLAC National Accelerator Laboratory, Menlo Park, CA 94025

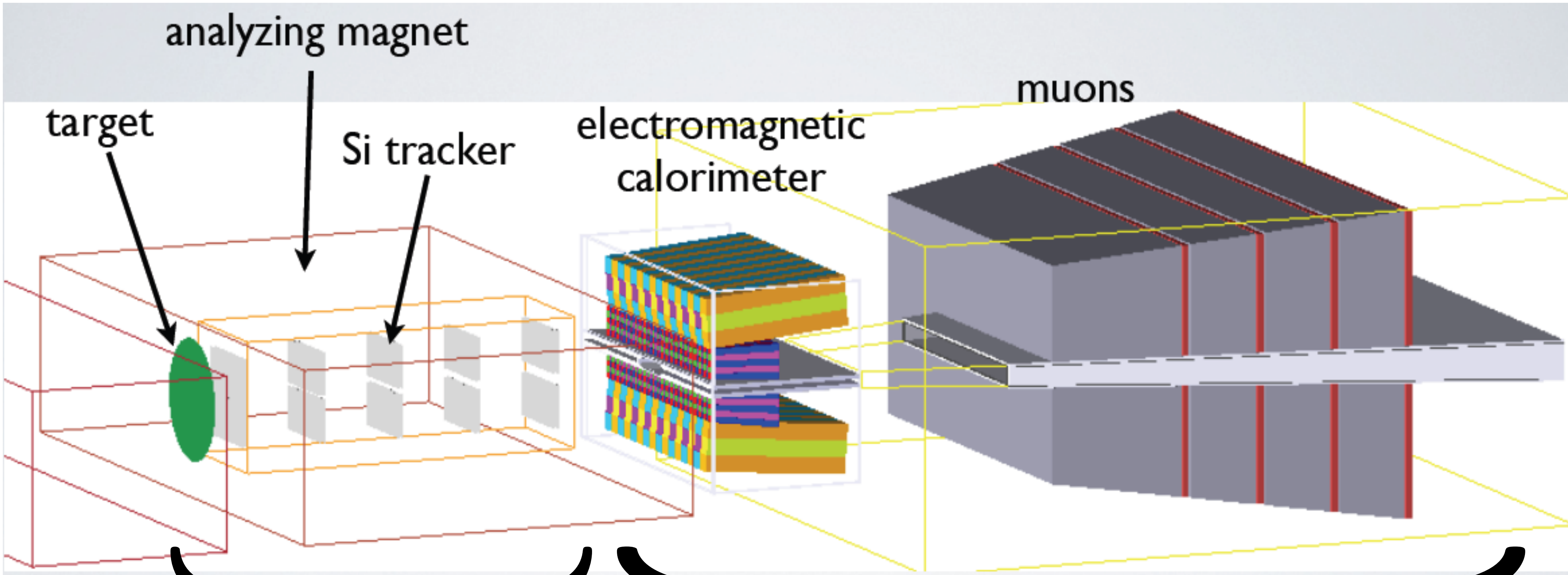
S. Boyarinov, V. Burkert, A. Deur, H. Egiyan, L. Elouadrhiri, A. Freyberger, F.-X. Girod, V. Kubarovsky, Y. Sharabian, S. Stepanyan (Co-Spokesperson), B. Wojtsekhowski
Thomas Jefferson National Accelerator Facility, Newport News, VA 23606

K. Griffioen
The College of William and Mary, Department of Physics, Williamsburg, VA 23185

N. Dashyan, N. Gevorgyan, R. Paremuzyan, H. Voskanyan
Yerevan Physics Institute, 375036 Yerevan, Armenia

Spokespeople:
Maurik Holtrop
John Jaros
Stepan Stepanyan

HPS Experimental Setup and Status



momentum & vertex measurement

trigger & particle ID

with vertexing can probe smaller couplings

- Proposal submitted Dec 2010
- Approved by JLAB PAC conditional on successful test run
- Requested test run in 6 GeV era & 6-month run in 12 GeV era

DarkLight

Detecting A Resonance Kinematically with eLectrons Incident on Gaseous Hydrogen Target

P. Balakrishnan, J. Balewski, J. Bernauer, W. Bertozzi, R. Cowan, K. Dow, C. Epstein, P. Fisher, S. Gilad, E. Ihloff, Y. Kahn, A. Kelleher, J. Kelsey, R. Milner, R. Russell, J. Thaler, C. Tschalaer, A. Winnebeck

Laboratory for Nuclear Science, M.I.T.

S. Benson, J. Boyce, D. Douglas, R. Ent, P. Evtushenko, H. C. Fenker, J. Gubeli, F. Hannon, J. Huang, K. Jordan, G. Neil, T. Powers, D. Sexton, M. Shinn, C. Tennant, S. Zhang

Jefferson Lab

M. Freytsis

Physics Dept. U.C. Berkeley

R. Fiorito, P. O'Shea

Institute for Research in Electronics and Applied Physics, University of Maryland

R. Alarcon, R. Dipert

Physics Department, Arizona State University

B. Surrow

Temple University

G. Ovanesyan

Los Alamos National Laboratory

M. Kohl

Physics Dept., Hampton University

T. Horn

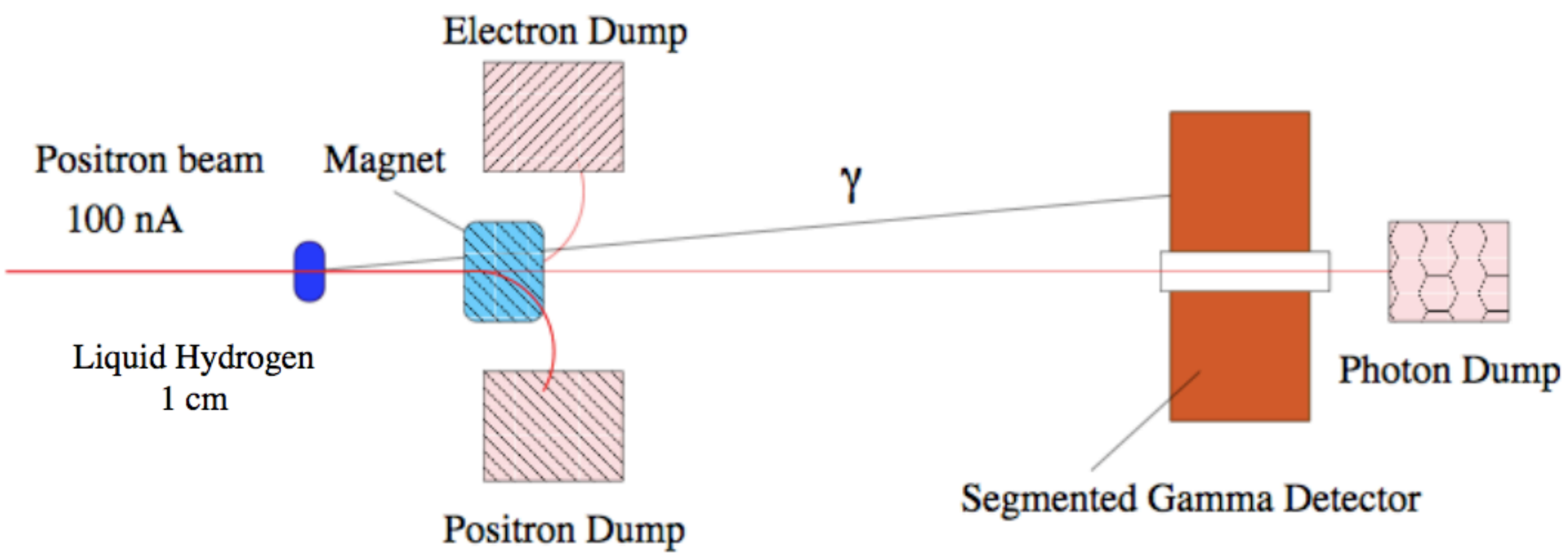
Physics Dept., Catholic University of America

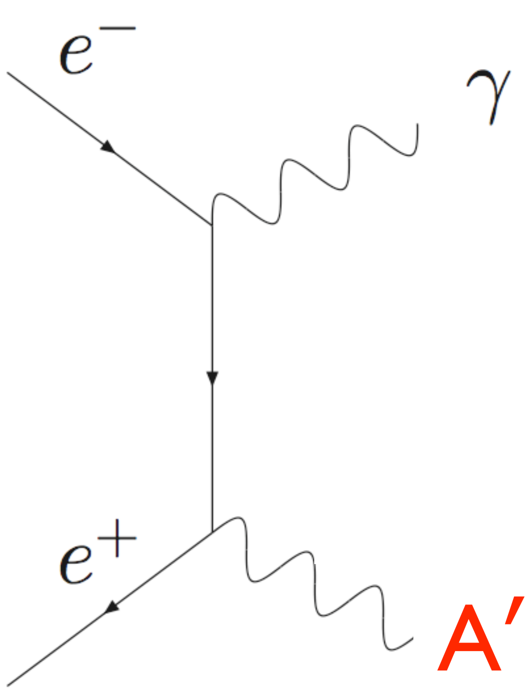
uses JLab FEL, e^- beam on hydrogen gas target

also sensitive to invisible A' decays

VEPP-3

Wojtsekhowski et.al.

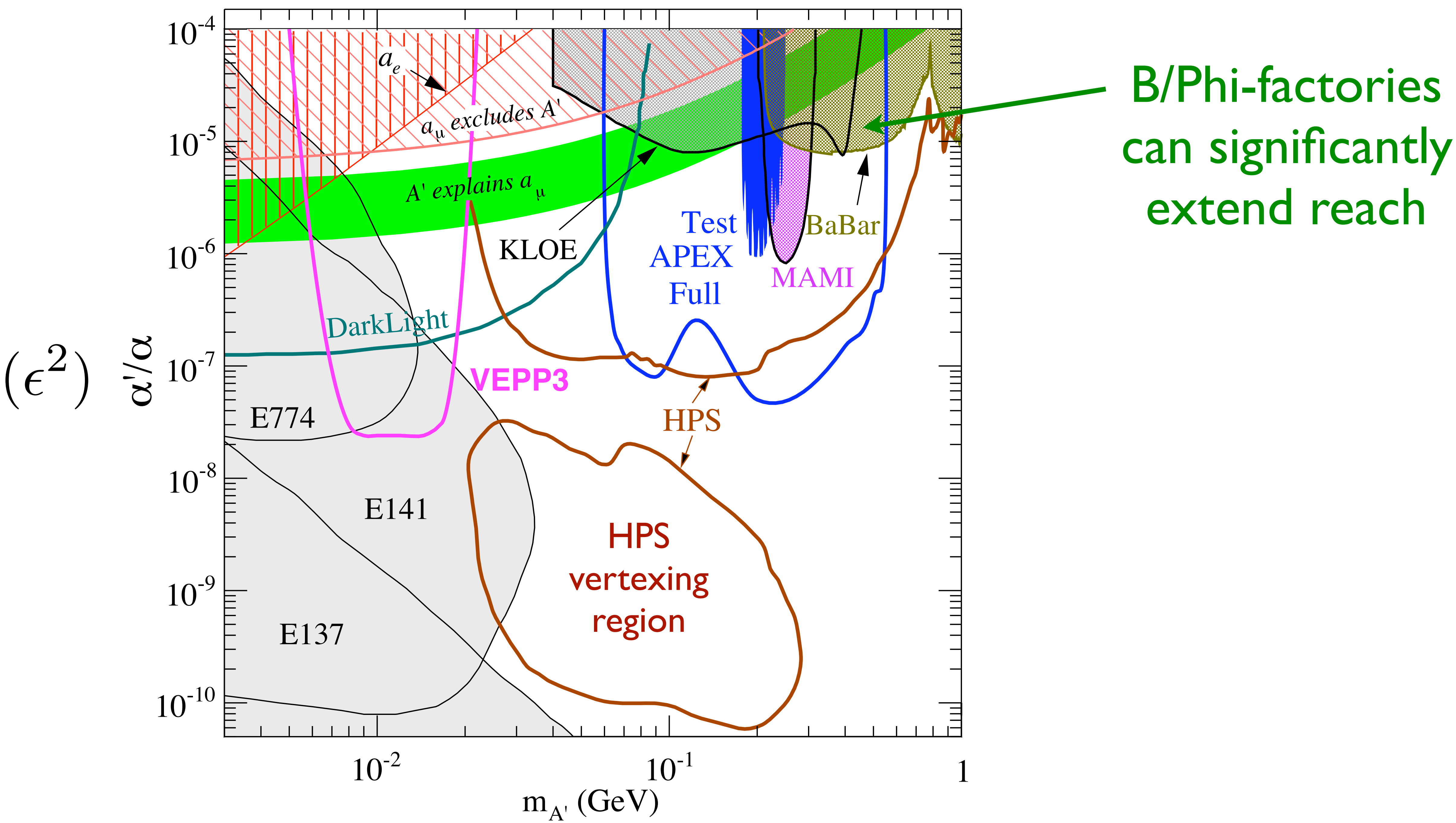




~500 MeV positron beam
on liquid hydrogen target

look for A′ resonance or detect only photon (sensitive to invisible A′ decays)

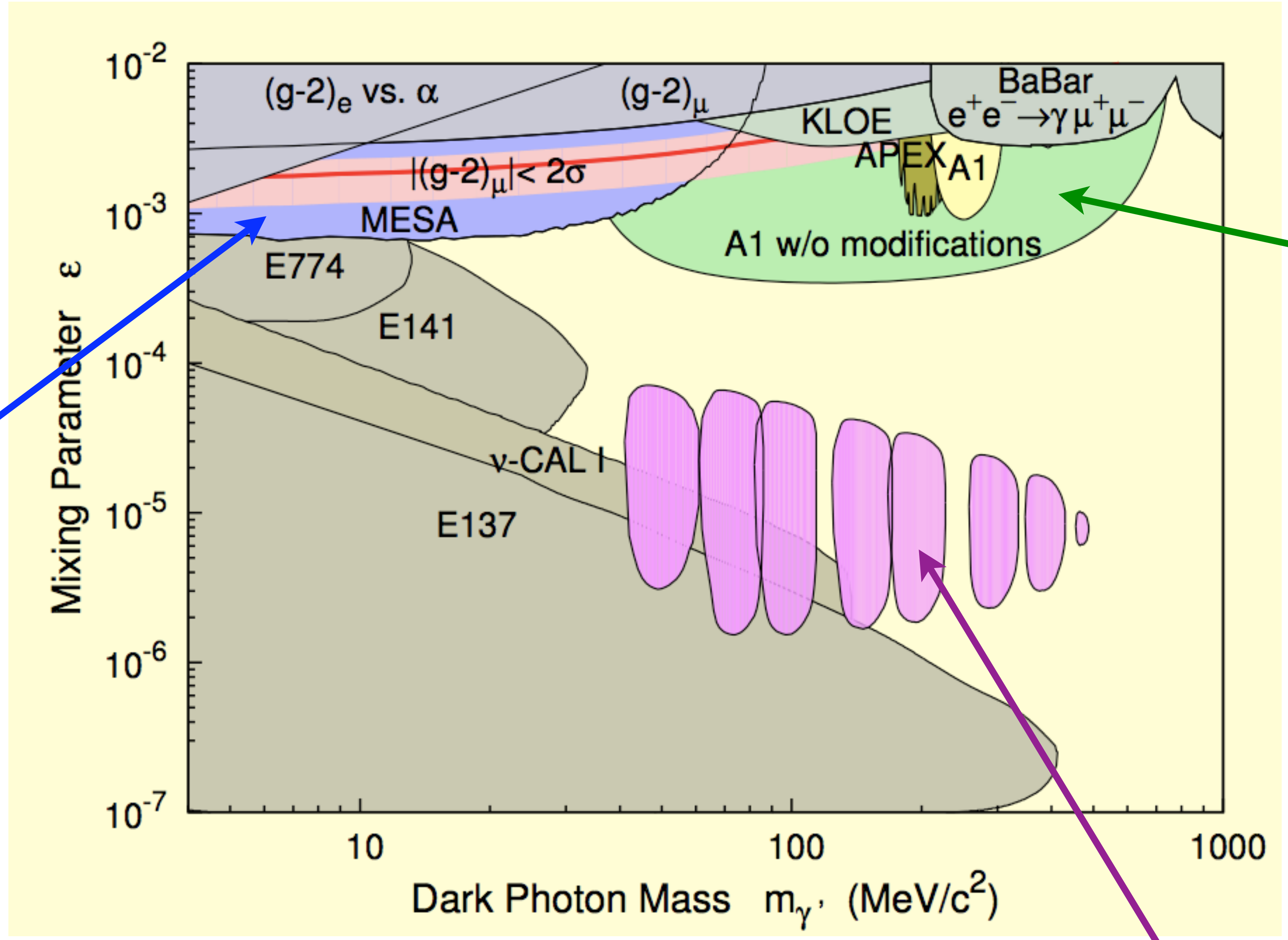
Summary: A′ constraints & prospects



region motivated by theory, dark matter, muon g-2

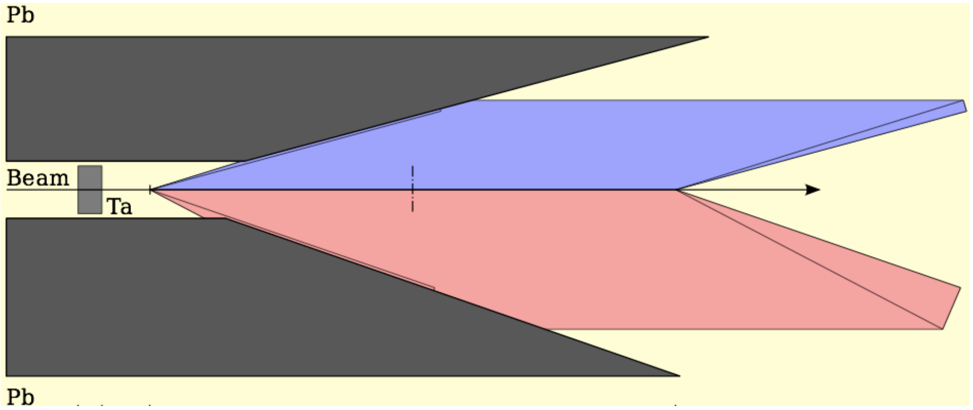
Plans at Mainz

see talk by Merkel at
Intensity Frontier Workshop

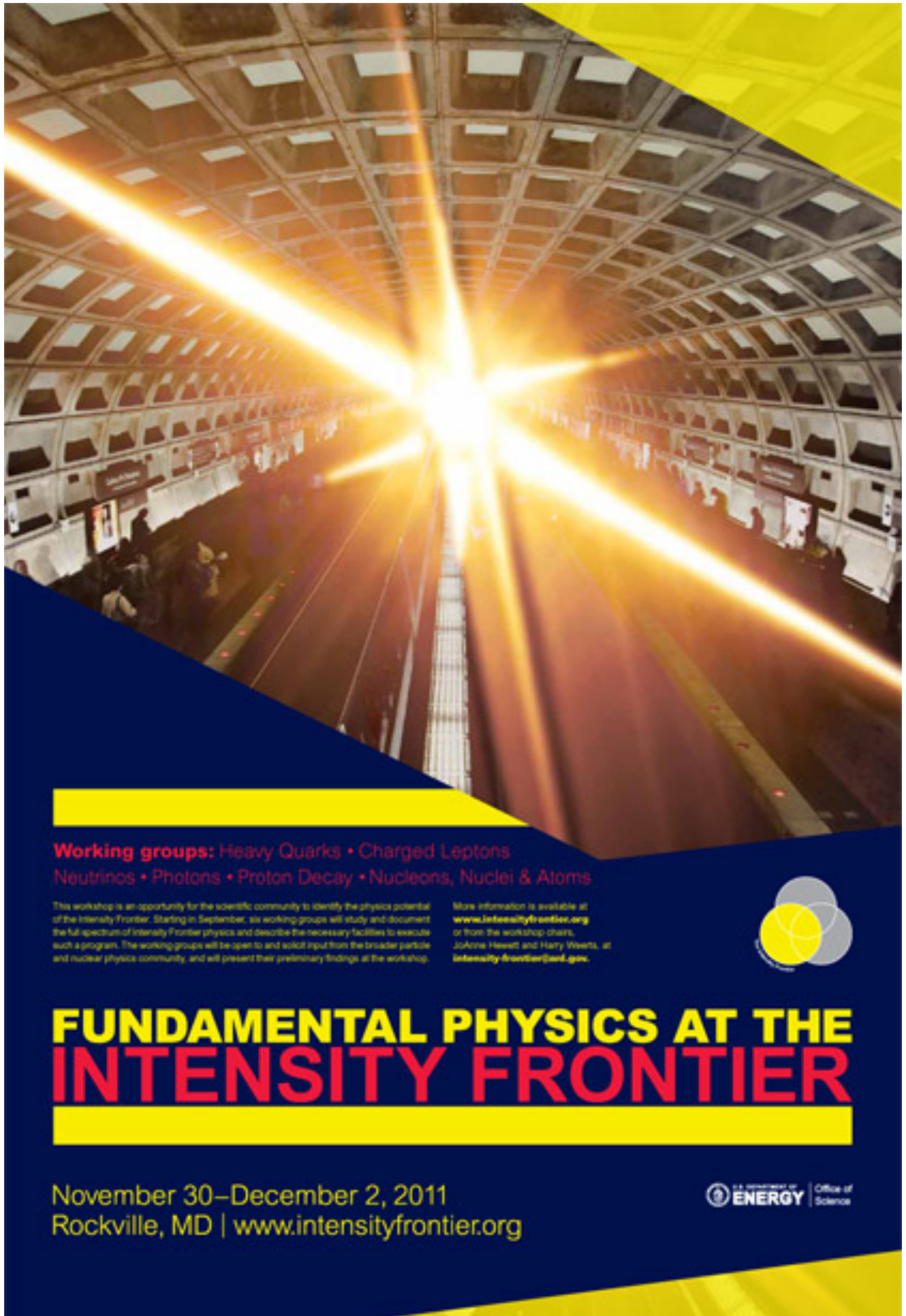


APEX-like
setup

DarkLight-like
setup using
MAMI's FEL



Vertexing:
shield target
region



Intensity Frontier Workshop requested by DoE

reviewed physics opportunities

A′ searches (and searches for light, weakly coupled particles in general) must be part of any sensible future U.S. Intensity Frontier Program

Conclusions

- Worldwide effort to search for A'
- JLab ideally suited for this physics
- JLab can play significant role: need to pursue aggressively

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- JLab ideally suited for this physics
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APEX

- Test Run demonstrated feasibility of experiment
- with relatively modest effort, APEX has enormous increase in sensitivity over existing searches: not common occurrence in physics!
- Ideal experiment to run as soon as possible…