U.S. Cosmic Visions: New Ideas in Dark Matter Workshop

WG4: New Candidates, Targets, and Complementarity

Conveners: Jonathan Feng and Patrick Fox
(UC Irvine) (FNAL)

INTRODUCTION

- Working Group 4 was charged with exploring
  - New Candidates: new dark matter models and frameworks
  - Targets: motivated regions of parameter space
  - Complementarity: of proposed (small-scale) experiments with existing (large-scale) DM experiments, of proposed experiments with each other, of different classes of DM probes, in potential for discovery, in potential for studying DM after discovery, etc.

- This led to an extraordinarily diverse and exciting workshop program, full of innovative ideas in both theory and experiment, and *very* lively discussions: thanks to all participants!

- Hard to summarize in a pithy way, but the talks and topics may be divided into 4 broad and overlapping areas
  - Anomalies as Targets
  - Astrophysics and Cosmology Constraints and Targets
  - New Candidates and Relic Abundance as Targets
  - Complementarity

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The talks

Anomalies as Targets

- Non-accelerator probes of light bosons: the 8Be anomaly and a photophobic 5th force, Iftah Galon
- 8Be and axial vectors, Jonathan Kozaczuk
- 8Be nuclear theory predictions, Xilin Zhang
- Proton radius, Richard Hill
- Future 8Be Experiments, Rafael Lang
- Future 8Be Experiments, Kyle Leach
- Isotope Shift Spectroscopy, Claudia Frugiuele

Astrophysics as Targets /Constraints

- Small scale structure, Annika Peter
- Self-interacting DM, Manoj Kaplinghat
- Supernovae constraints on dark mediators, Sam McDermott
- CMB, Tracy Slatyer

The talks

Relic abundance/Theory as Targets

- Non-abelian dark sectors, Nikita Blinov
- SIMPle DM and Non-abelian Hidden sectors, Kim Boddy
- SIMPs and ELDERs, Maxim Perelstein
- Dynamical DM, Keith Dienes
- Inelastic thermal relics, Gordan Krnjaic
- Axions and WIMPs in natural SUSY, Howie Baer

Complementarity

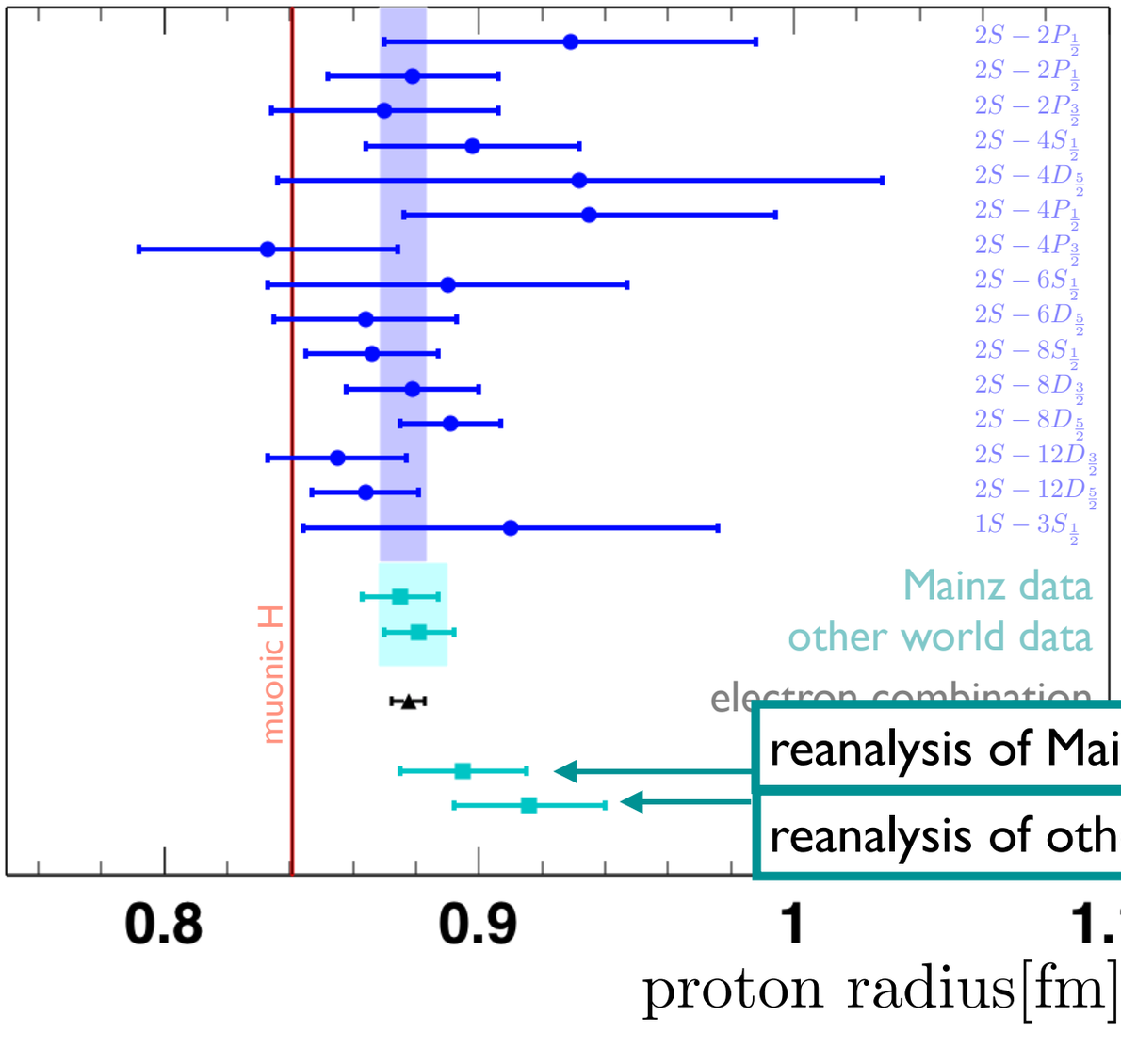
- Accelerator Complementarity, Philip Schuster
- HPS First results, Omar Moreno
- Sensitivity of neutrino facilities to Z' and DM, Claudia Frugiuele
- LAr DM searches: Darkside-20k and beyond, Mark Boulay
- ATLAS/CMS and light DM, Marco Trovato
- LHCb and light DM, Philip Ilten
- CTA, Brian Humensky
- Laser-trapped atom search for sterile neutrino DM, Jeff Martoff
- N-mirrorN oscillations, Leah Broussard/Ben Rybolt
- Search for 10-100 Msolar mass MACHOs, Will Dawson

Anomalies and how to test them

Anomalies that may require new light weakly interacting bosons

$(g-2)_\mu$ No explicit talk, but ubiquitous

R. Hill



Light particles ~10 MeV
that distinguish mu from e

1505.01489

Anomalies and how to test them

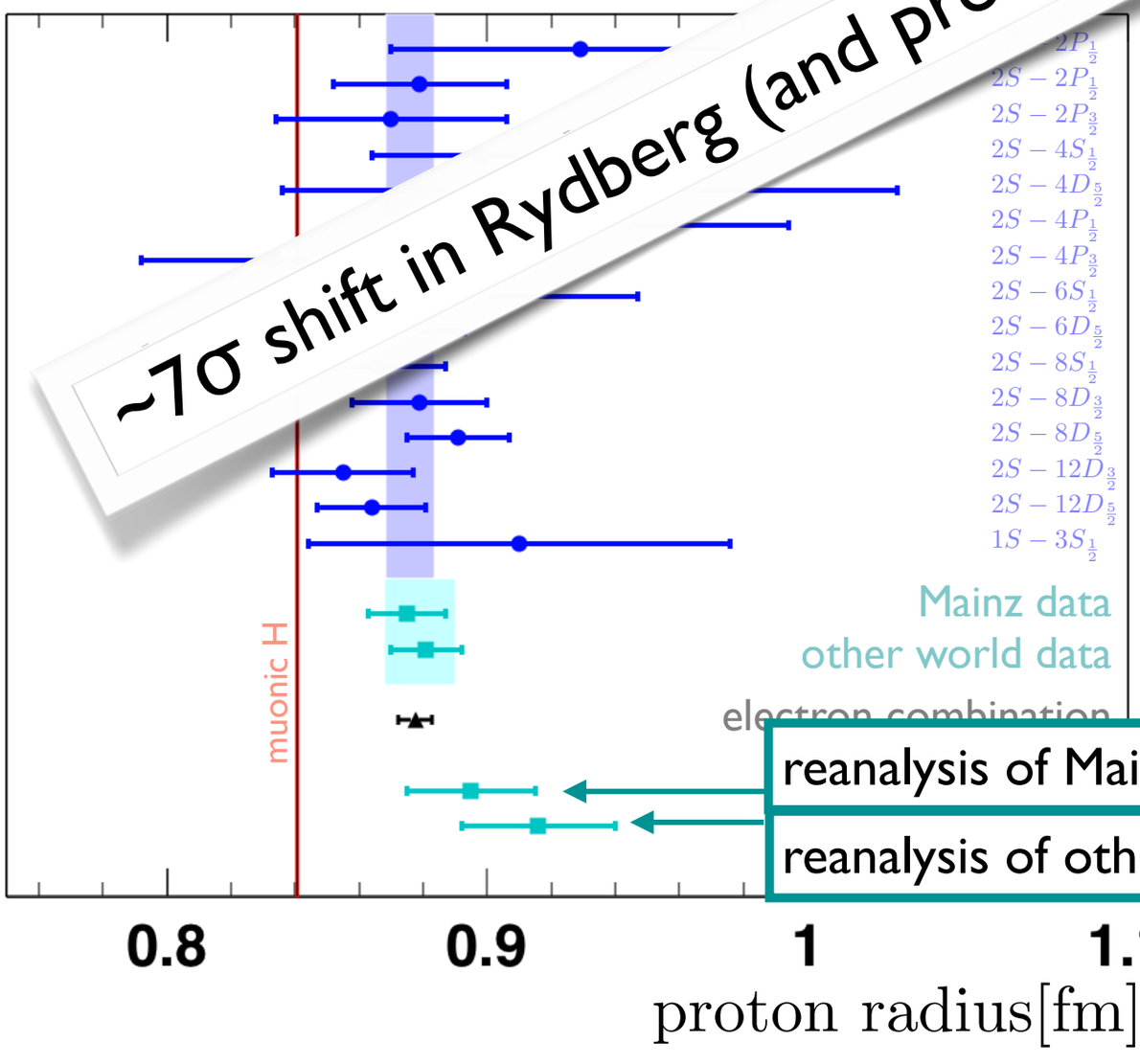
Anomalies that may require new light weakly interacting bosons

$(g-2)$ 3.5σ excess

...plicit talk, but ubiquitous

R. Hill

~7σ shift in Rydberg (and proton radius)



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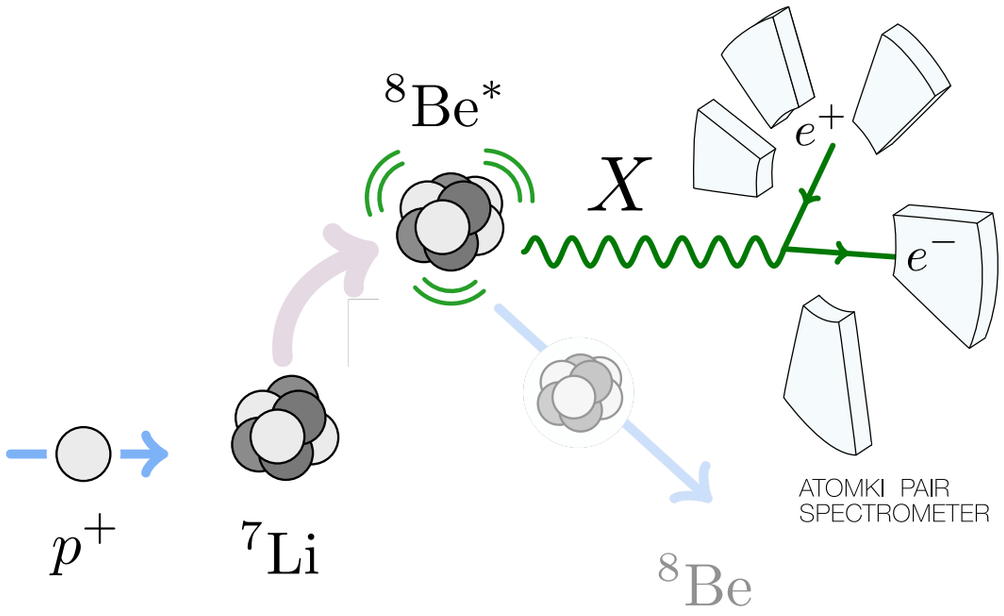
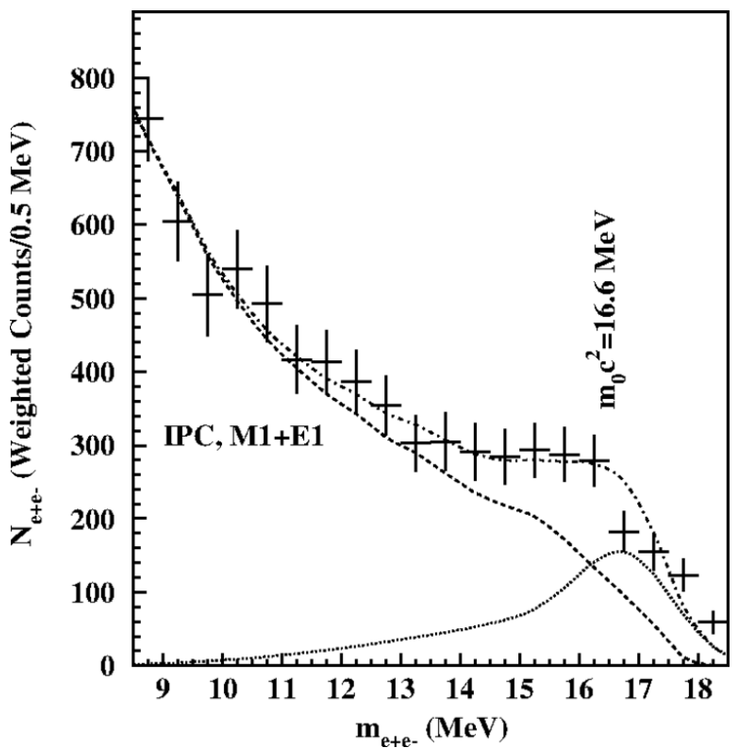
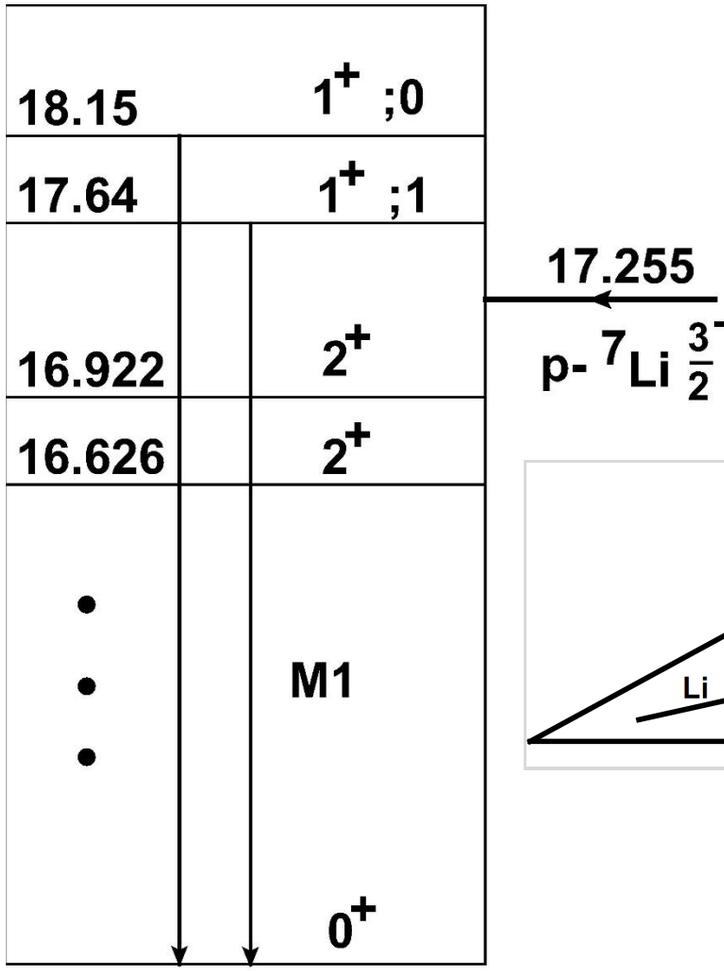
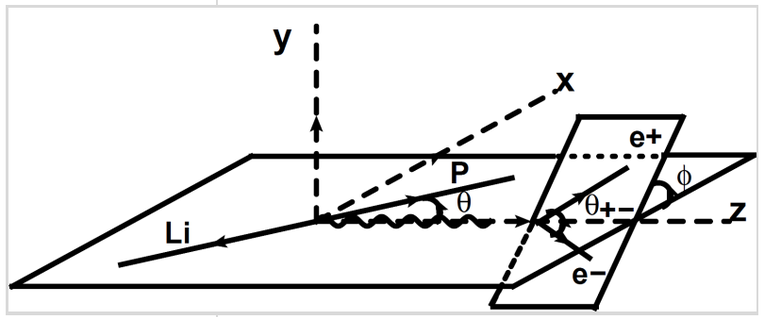
I.Galon





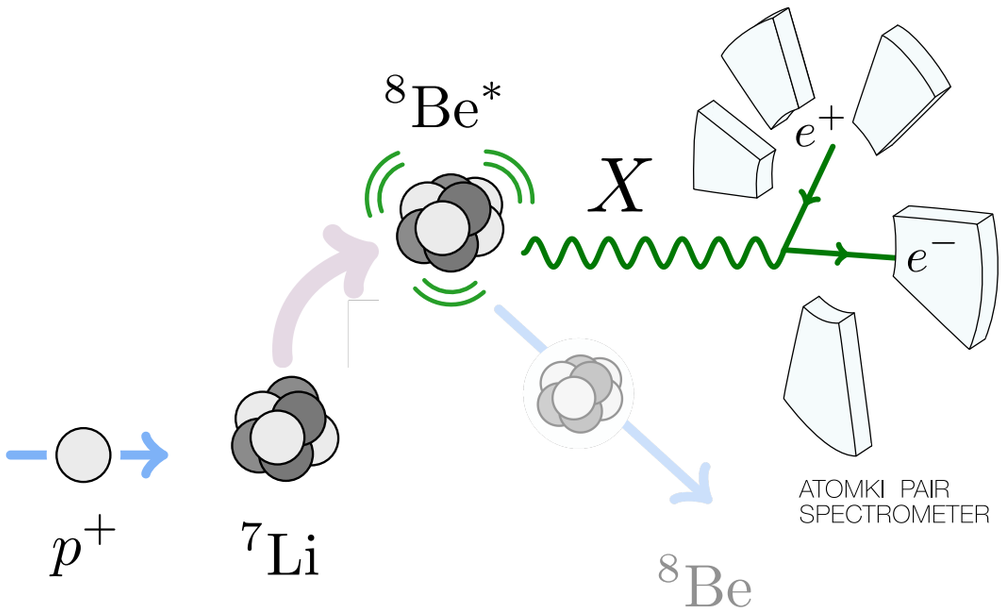
X. Zhang



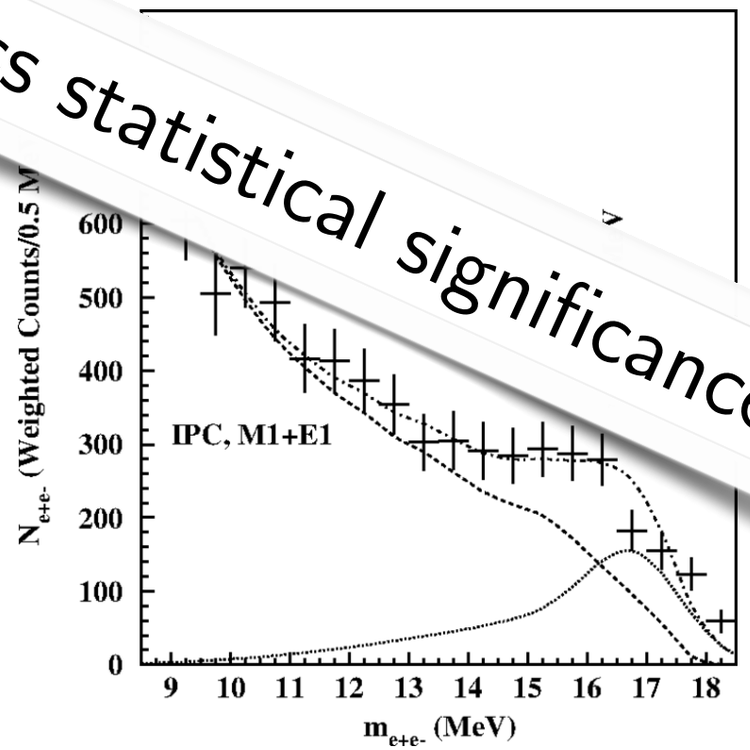


- Model including interference effects now available
- Non-trivial angular dependence
- Can’t explain it with nuclear theory

I.Galon



Excess statistical significance 6.8σ



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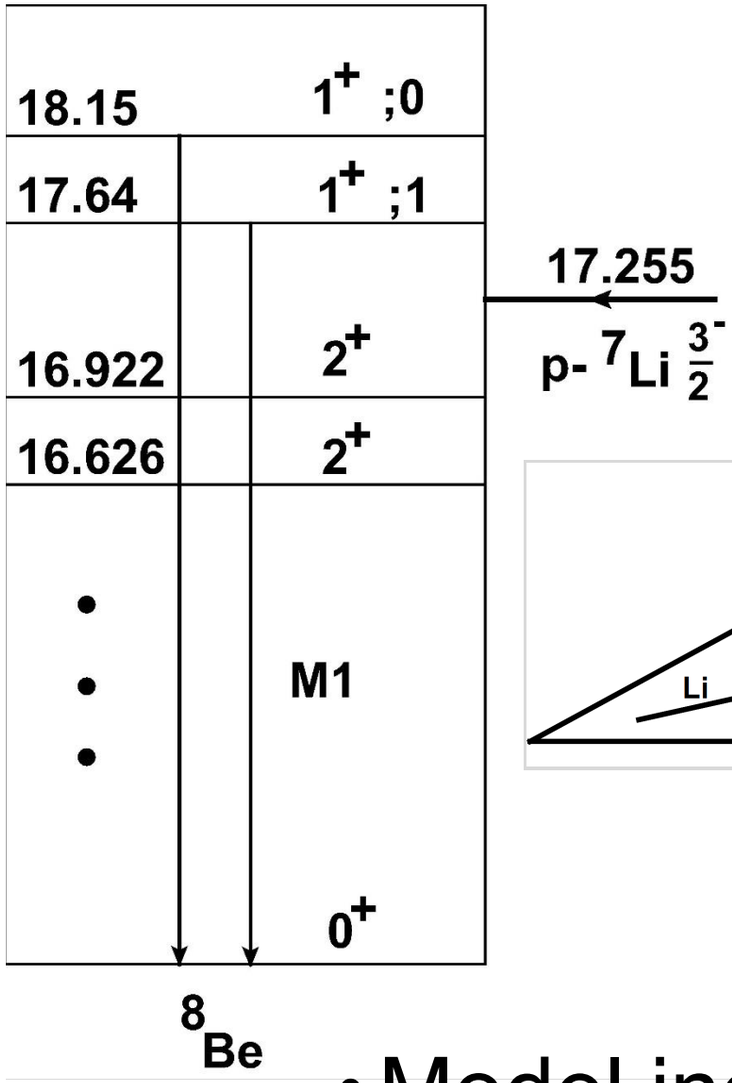

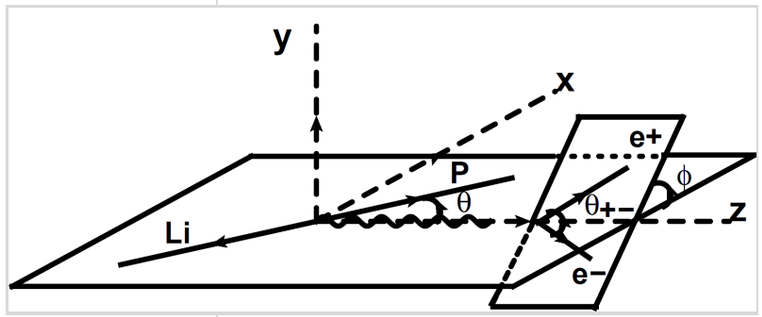

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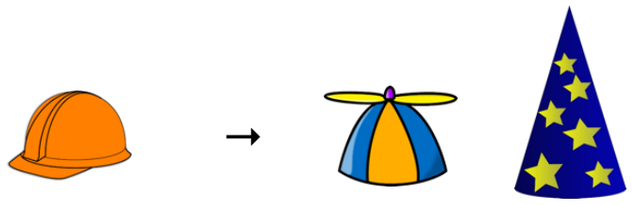
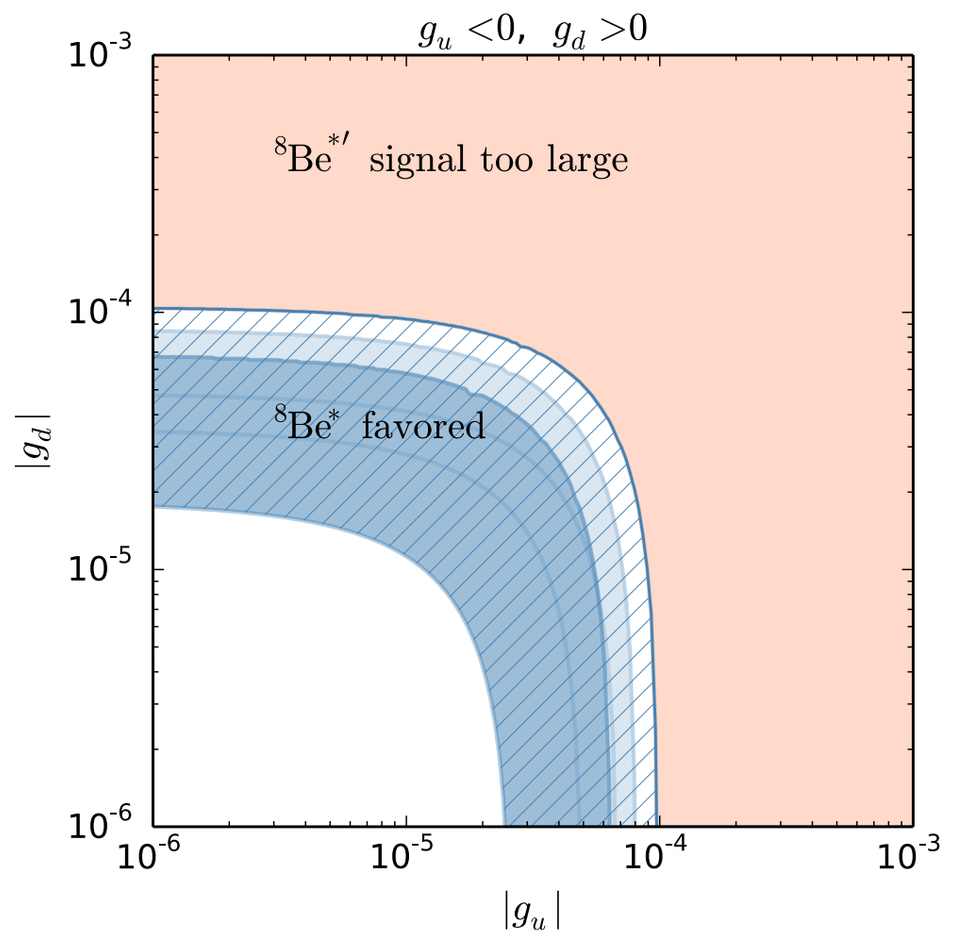
Anomalies and models to explain them



"Never trust an experimental result until it has been confirmed by theory"—Eddington

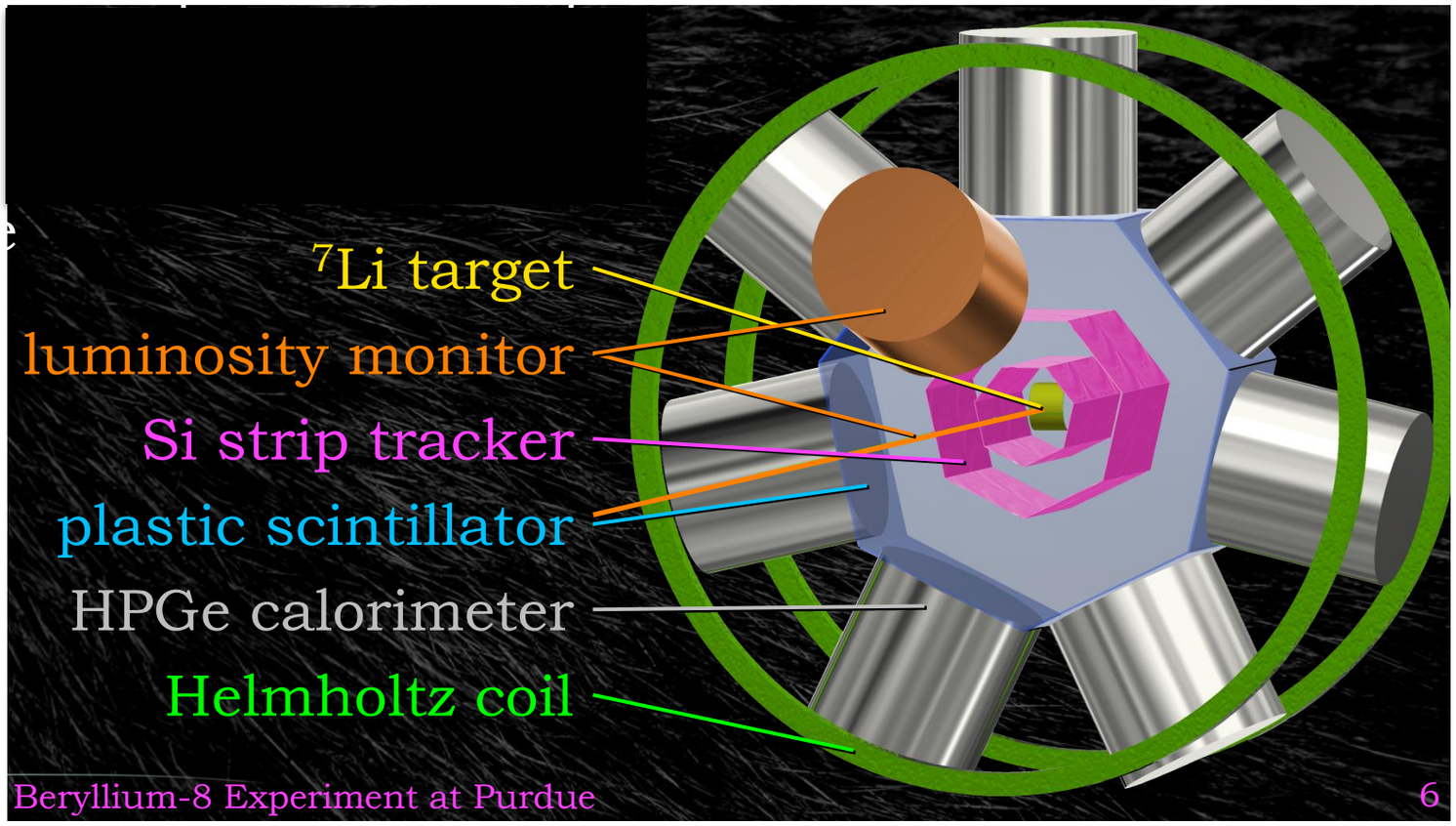
- rp can be explained by light vector or scalar in 1-10 MeV range
  - small quark couplings, distinguish e from mu
- 8Be can be explained by ~17 MeV boson coupling to e
  - proto-phobic vector I.Galon
  - Axial-vector J. Kozaczuk

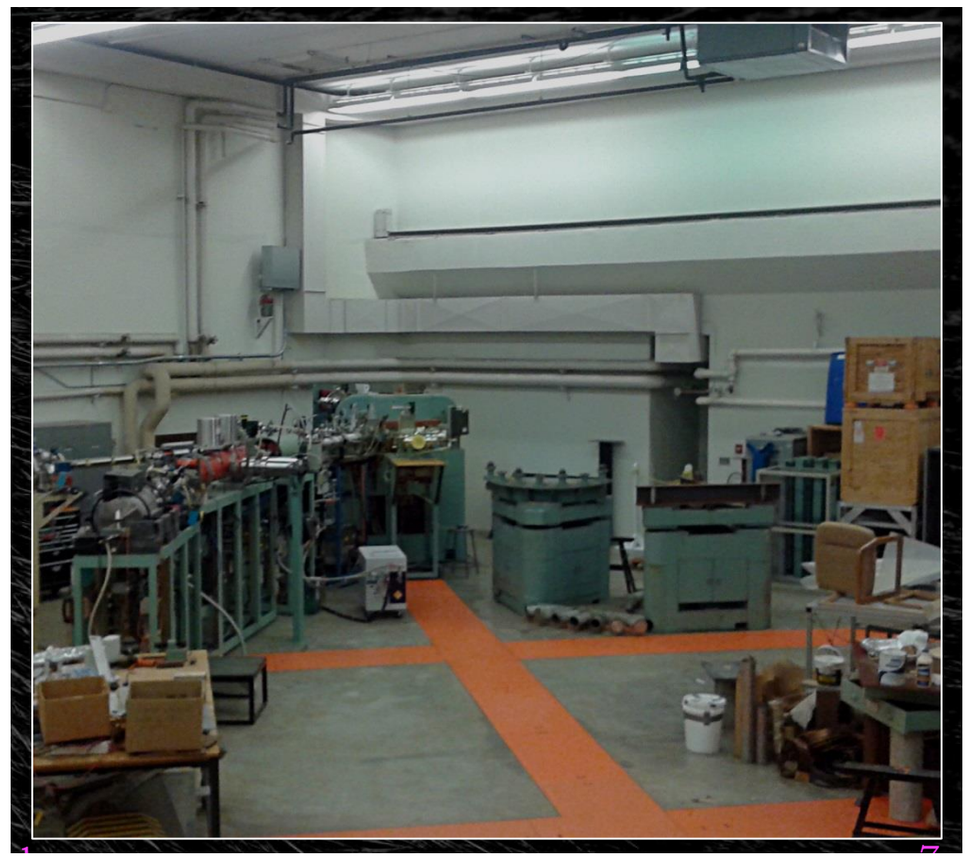
$$\frac{\Gamma(^8\mathrm{Be}^* \to ^8\mathrm{Be}X)}{\Gamma(^8\mathrm{Be}^* \to ^8\mathrm{Be}\gamma)} \propto \frac{\langle ^8\mathrm{Be}\,|J^\mu_X|\,^8\mathrm{Be}^*\rangle}{\langle ^8\mathrm{Be}\,|J^\mu_{\mathrm{EM}}|\,^8\mathrm{Be}^*\rangle} = \frac{a_0\langle ^8\mathrm{Be}\,|\bar{N}\gamma^\mu\gamma^5 N|\,^8\mathrm{Be}^*\rangle}{\langle ^8\mathrm{Be}\,|\bar{N}\gamma^\mu N|\,^8\mathrm{Be}^*\rangle}$$



Anomalies and experiments to test them

R.Lang





- 8Be followup: parts “just lying around”
- Quick, cheap cross-check
- Hunting bumps requires good energy resolution, <70keV
- Improve bounds on <~20 MeV bosons

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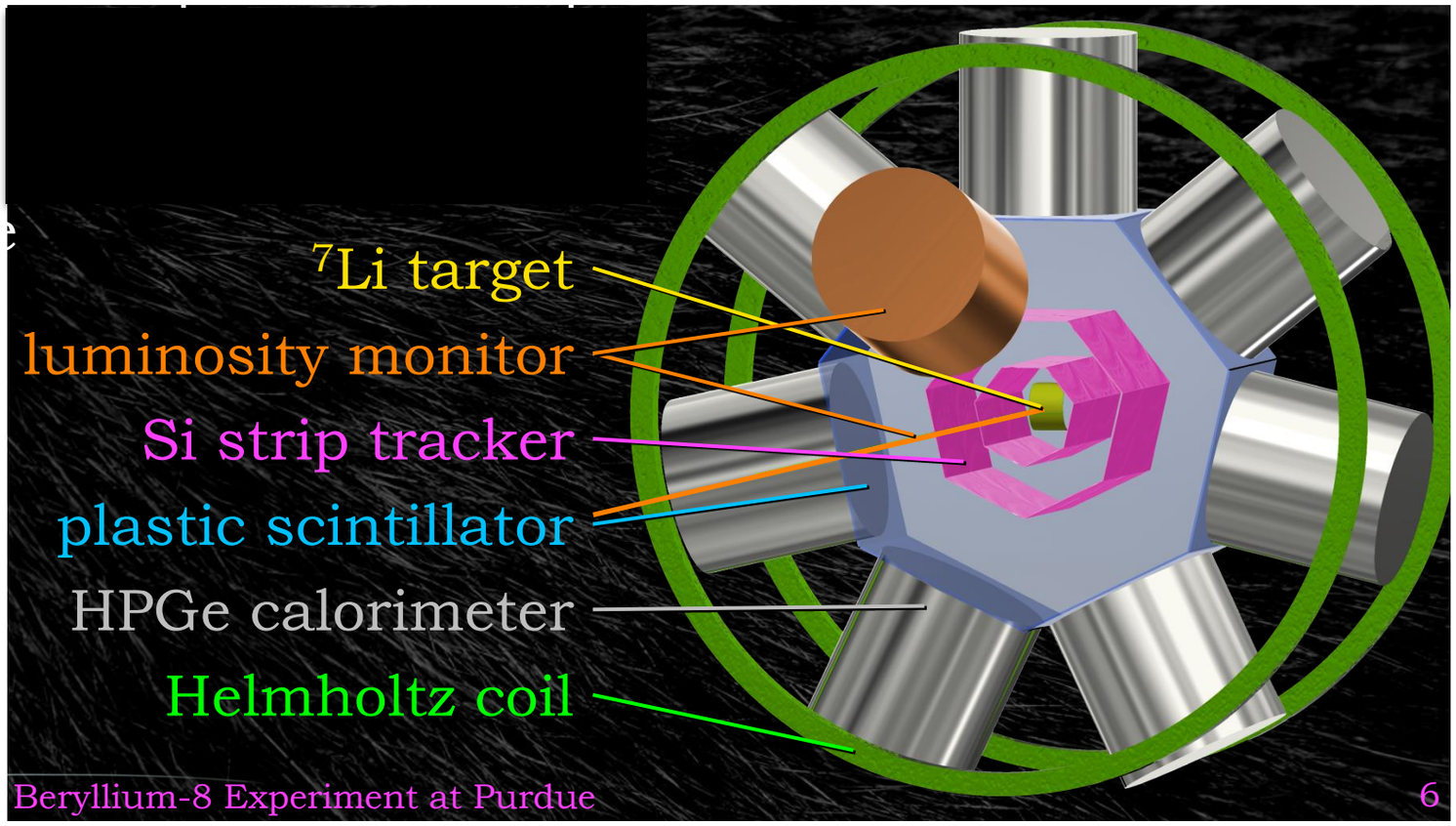

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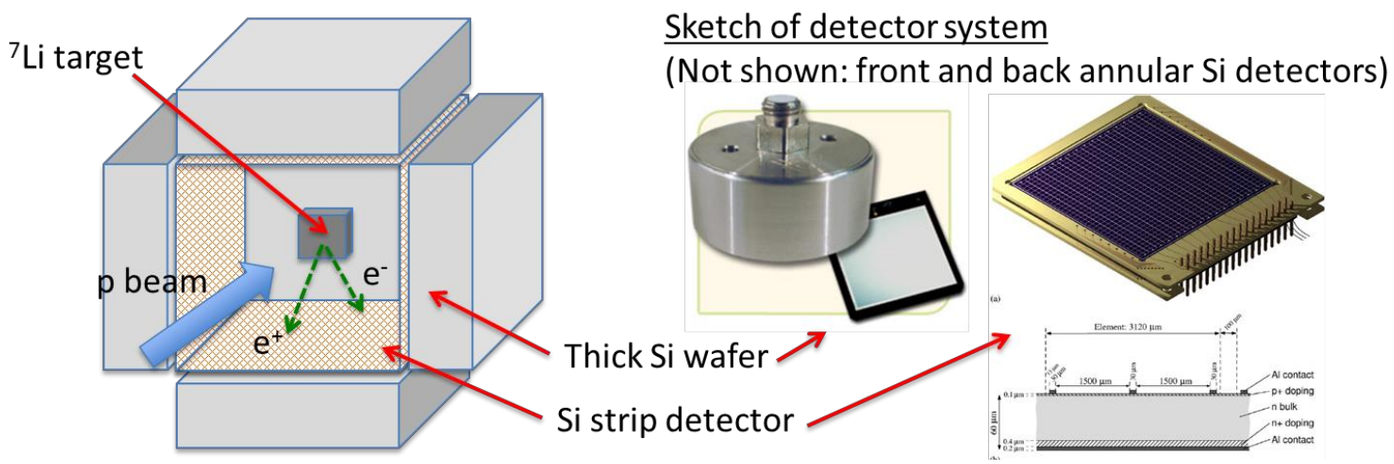
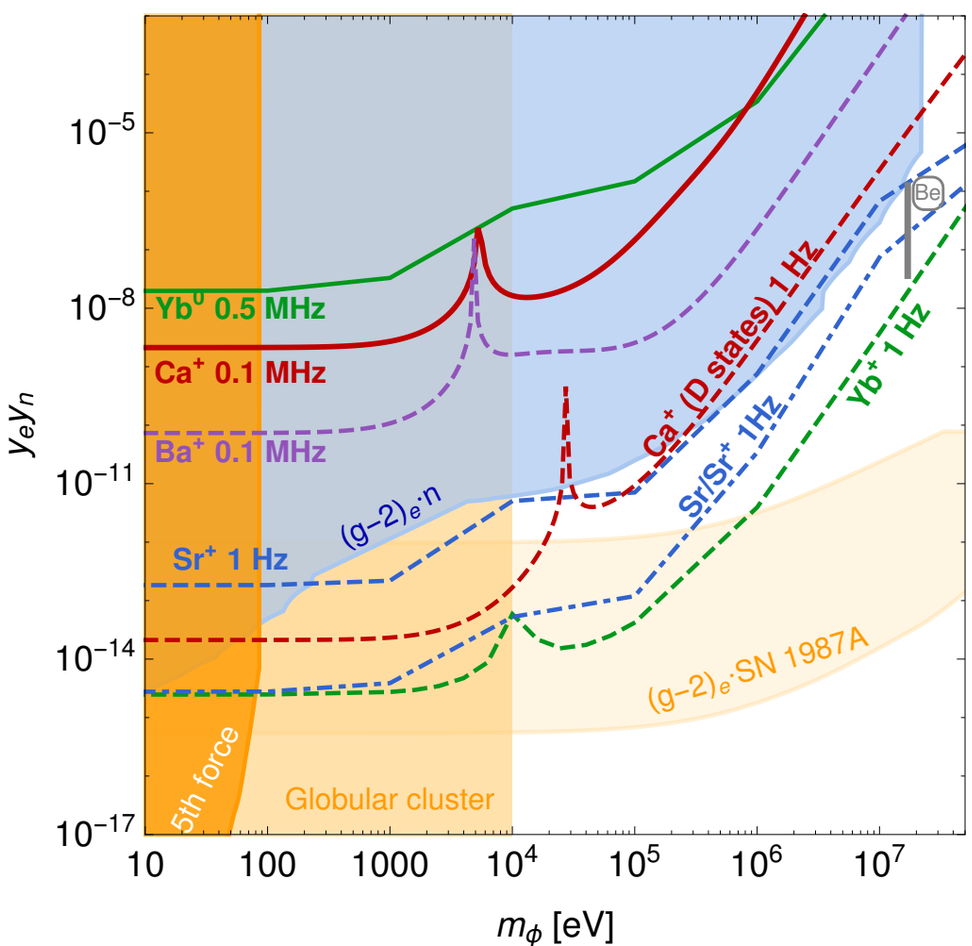
Anomalies and experiments to test them

M. Brodeur and K. Leach

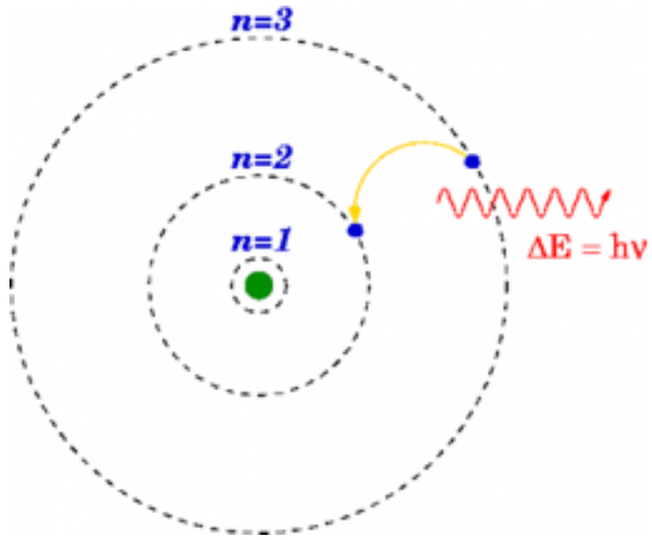


- Test Atomki result
- ~4pi detector
- 200 microA
- Cheap, fast
- Move on to other targets
- Smaller couplings

C. Frugiuele



- Atomic spectroscopy probes new long-range n-e force
- “King linearity”



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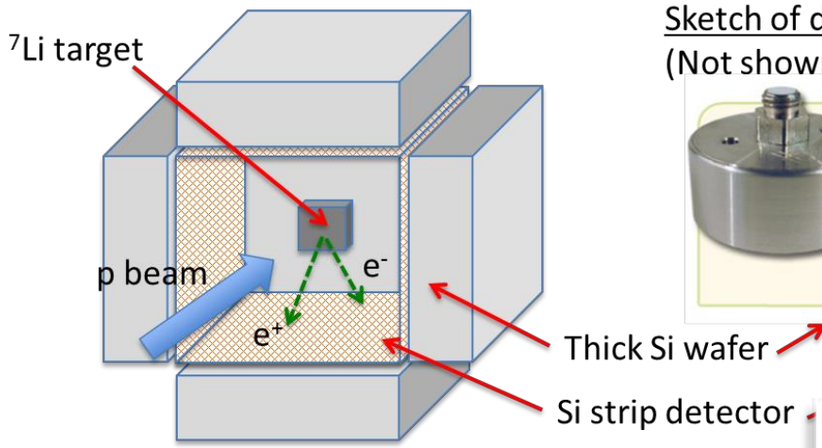
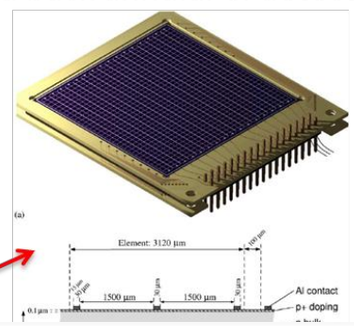


Sketch of detector system
(Not shown: front and back annular Si detectors)



Thick Si wafer

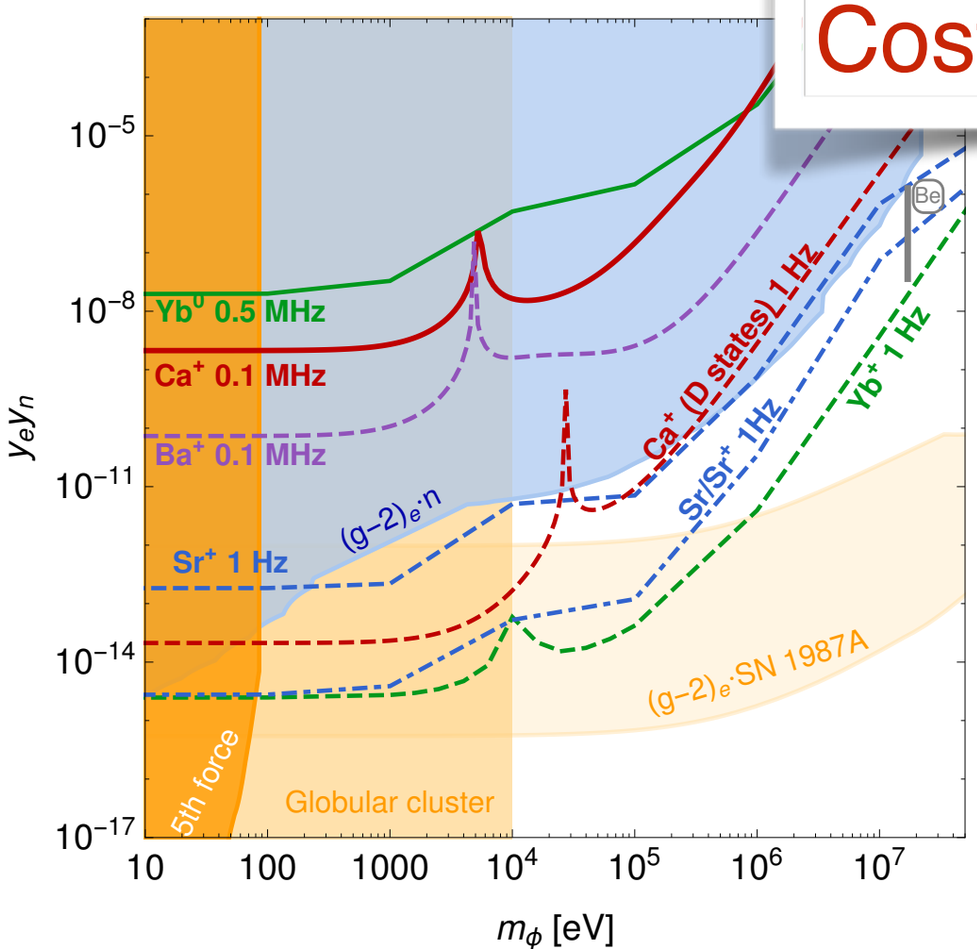
Si strip detector

Timescale: 1-2 years

Cost: <$1M

- Test Atomki result
- ~4pi detector
- 200 microA
- Cheap, fast
- Move on to other targets

ller couplings



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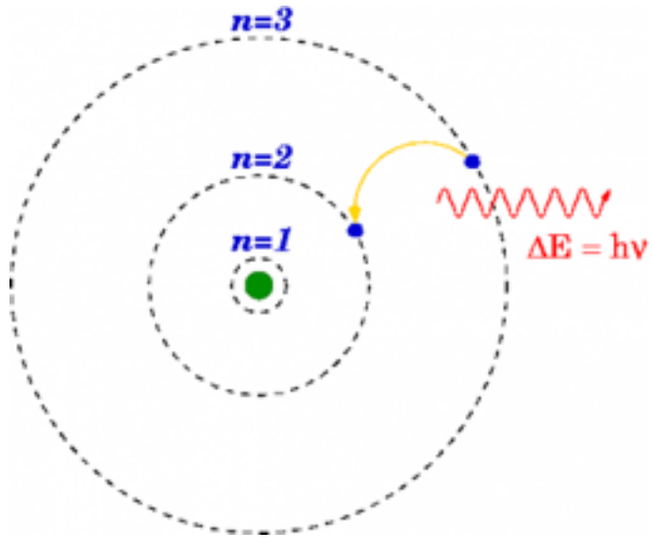

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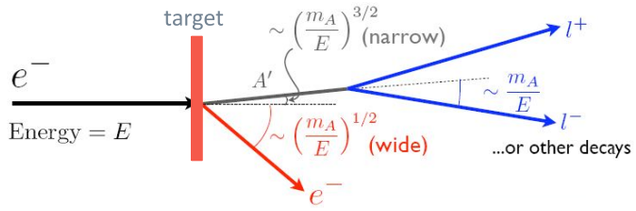
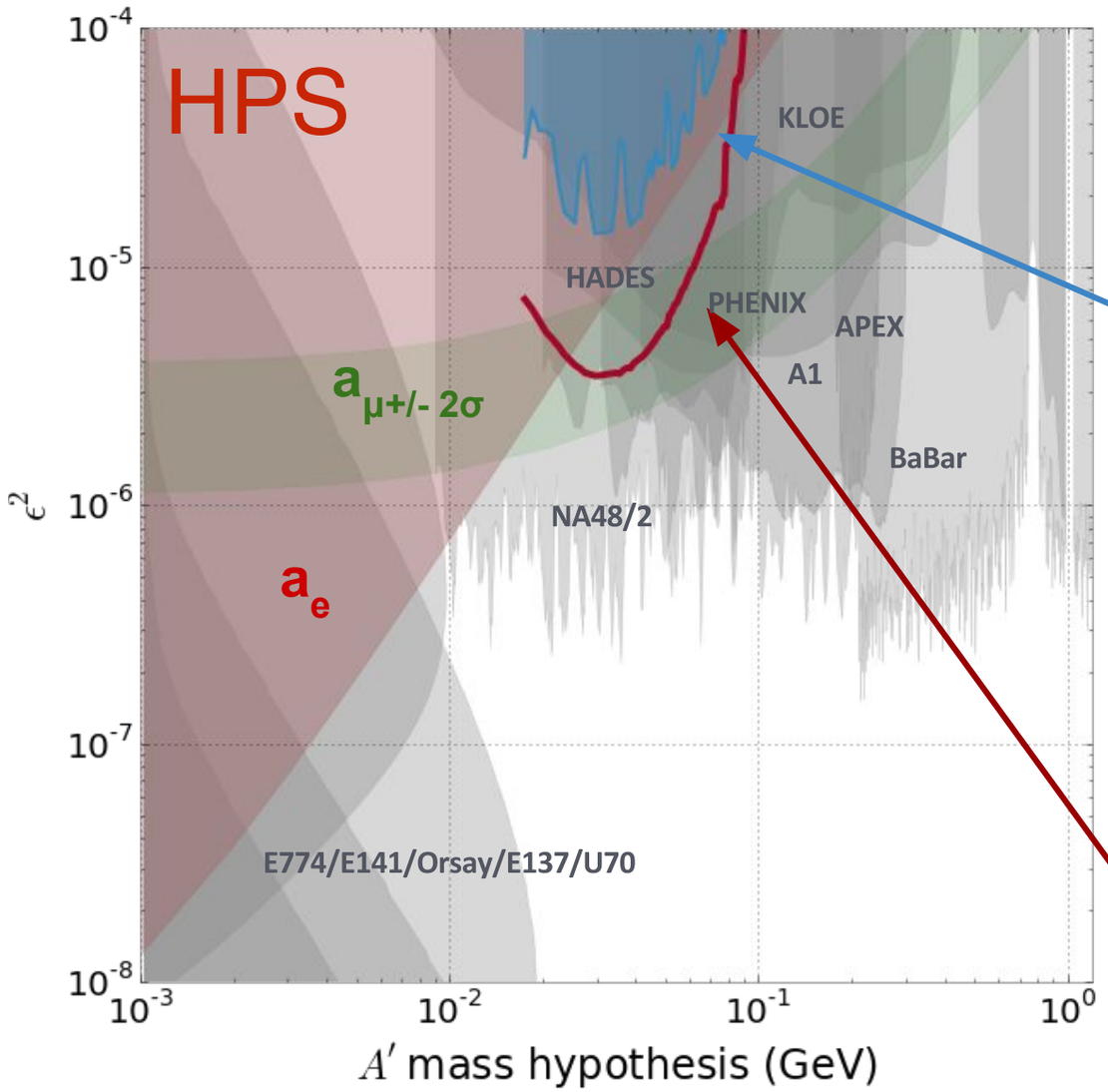


Omar Moreno

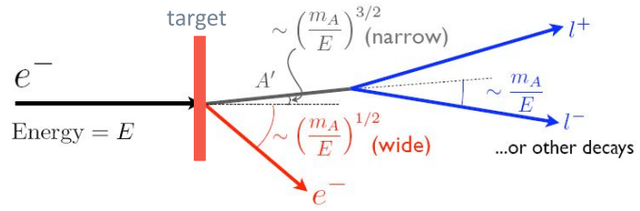


10% 2015 run

projected 2015 run

- Accelerator probes (HPS and many others) and low-energy nuclear and atomic expts. (8Be, isotope spectroscopy) probe complementary mass ranges

Anomalies and experiments to test them



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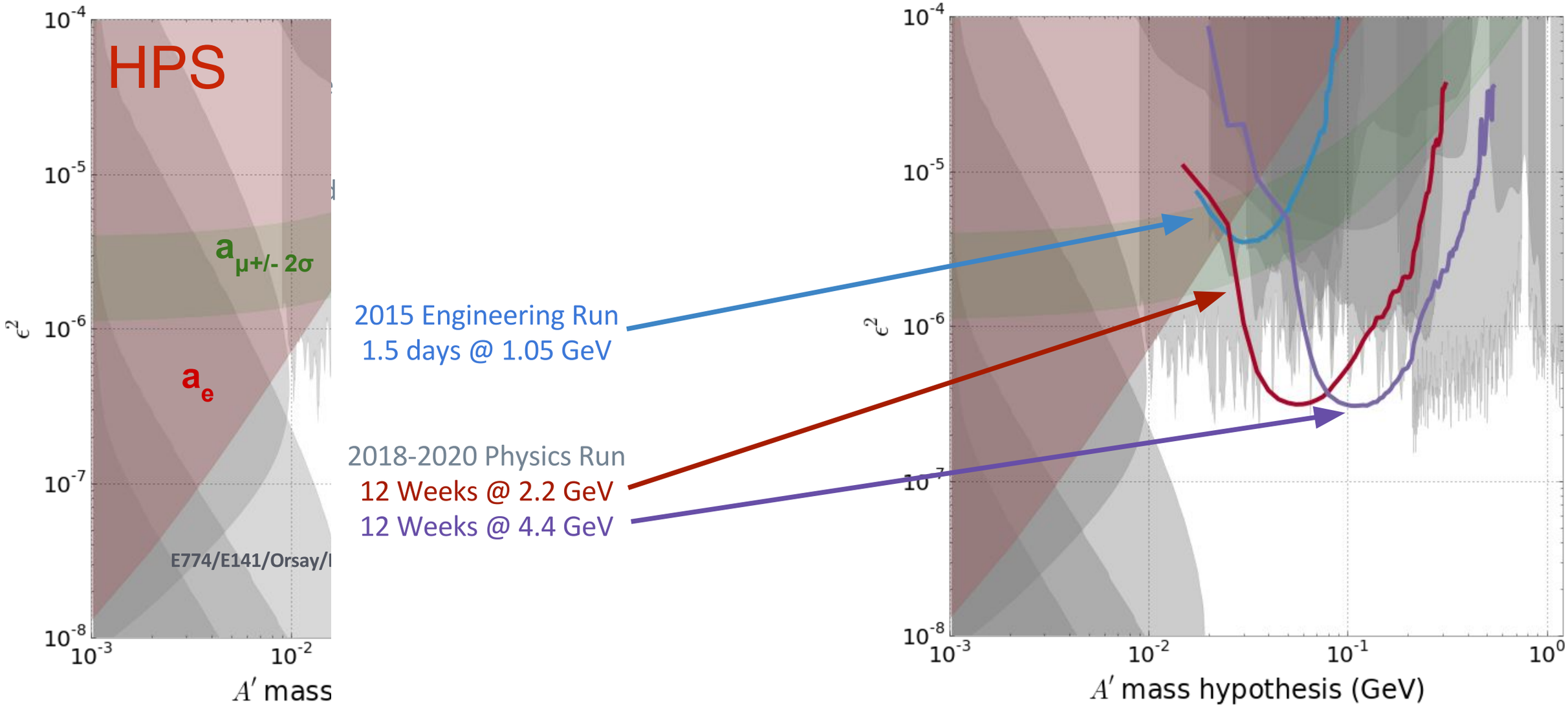

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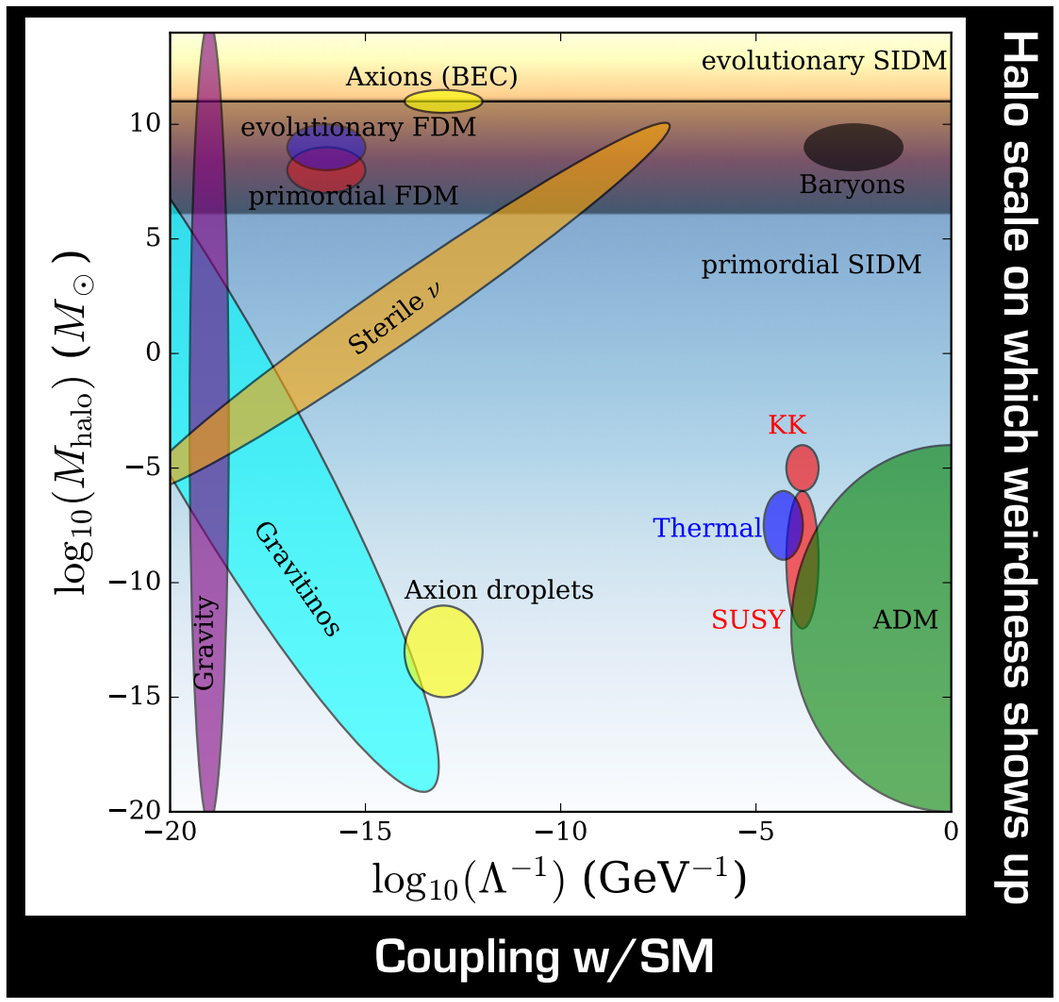
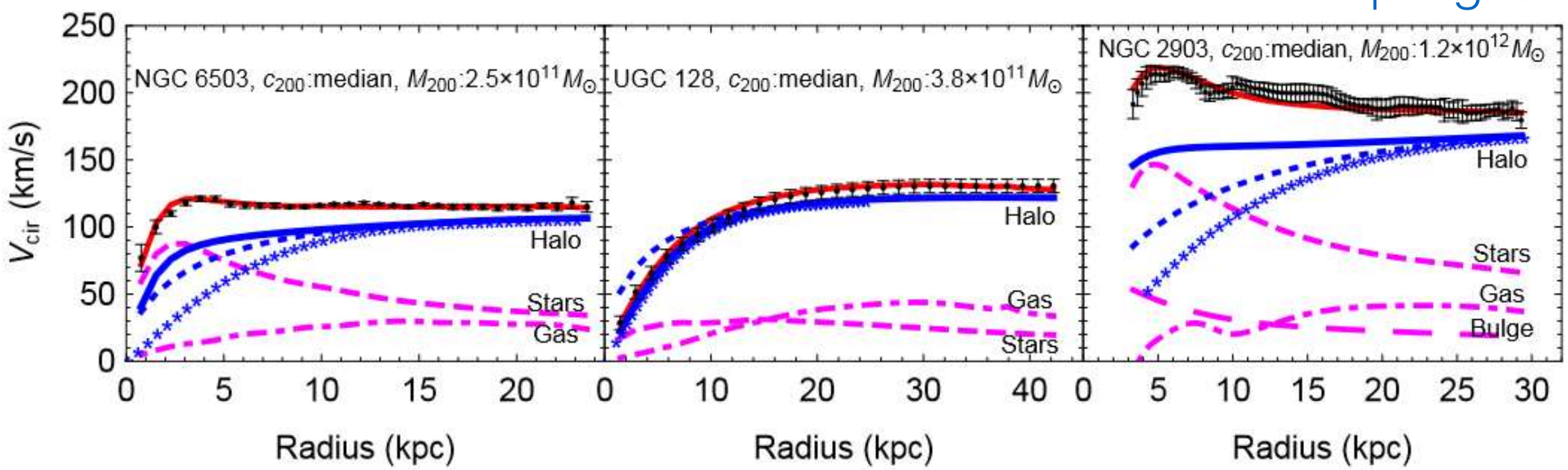
Astrophysics as a target

A. Peter



- Microphysics <—> Macrophysics
- Lots of data, limited by people and $’s, need better simulations
- Puzzling diversity in galaxy rotation curves
  - Fixed by SIDM $\sigma/m \sim 1{\rm cm}^2/{\rm g}$
  - Velocity dependent
  - Motivates DM interacting through 1-00 MeV mediator

M. Kaplinghat



Astrophysics as a complementary probe

DM-DM self interactions can *only* be probed through astrophysics

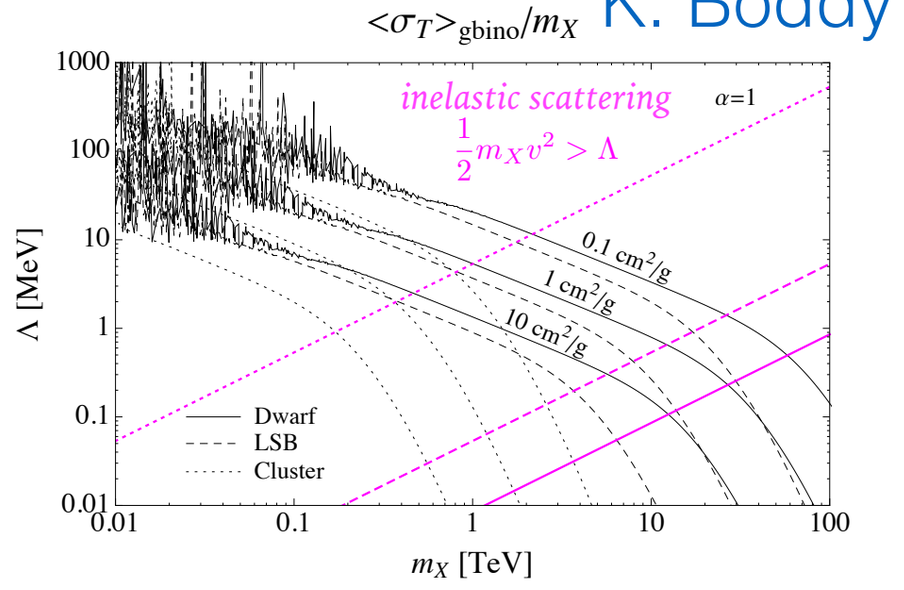
New light force carriers in the dark sector would give SIDM, possibly with velocity dependent couplings

Learn something entirely new about the dark sector:

observe

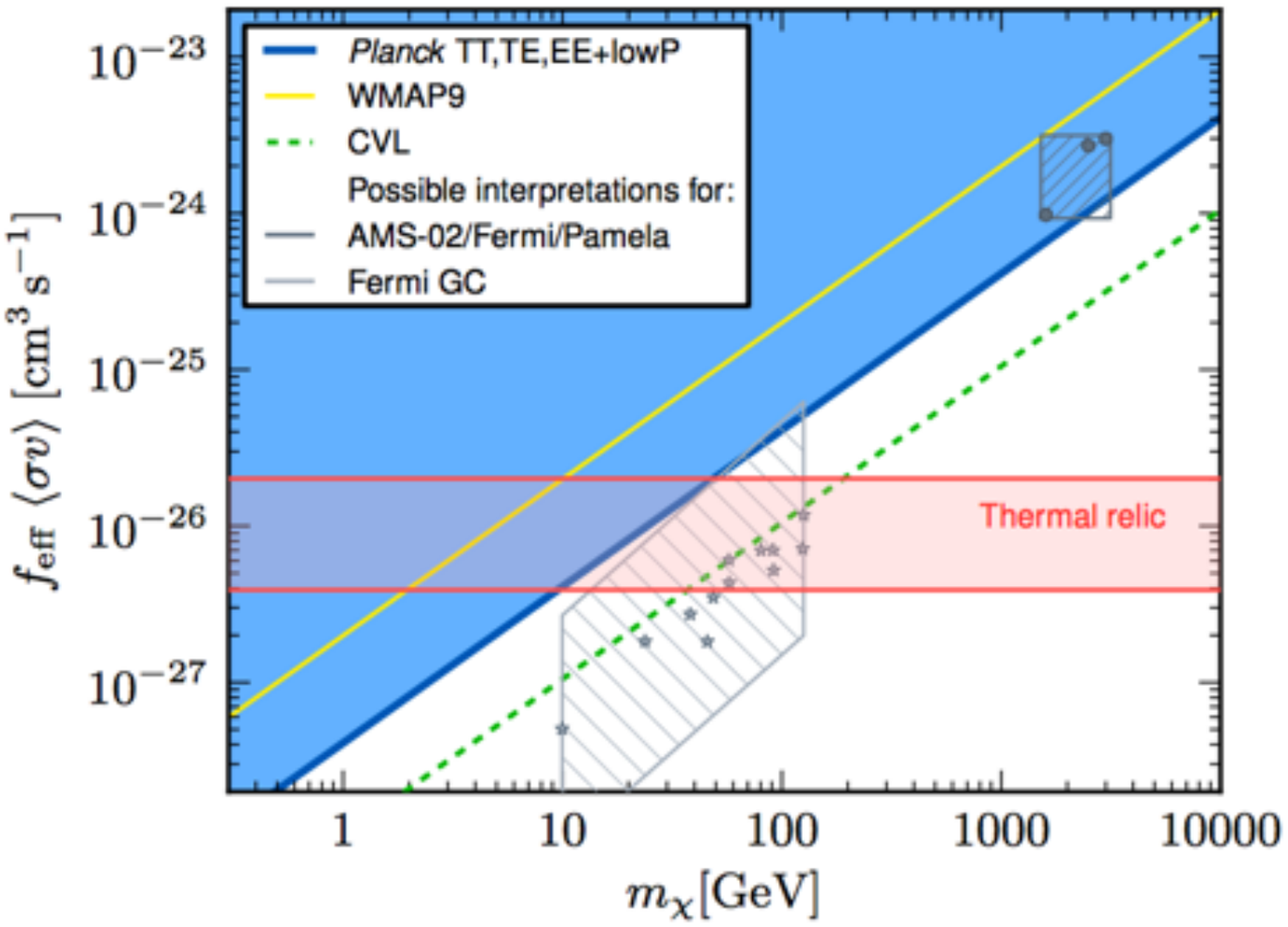
or bound

the size of its self interactions



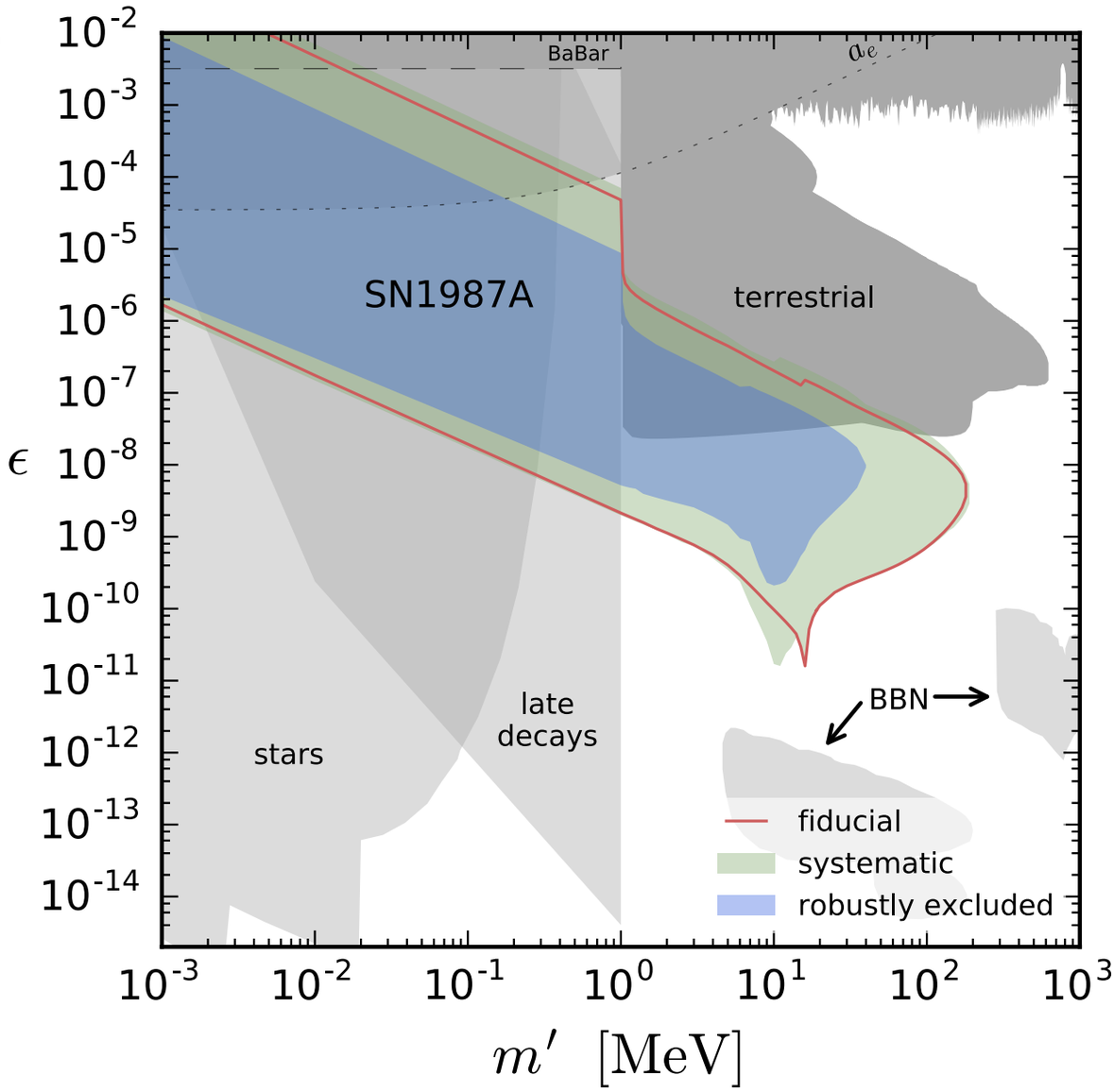
Dark and explosive times

T. Slatyer



- CMB constrains addition of e, γ
- Excludes many DM possibilities, motivates models with e.g. p-wave annihilation

S. McDermott



- SN constraints on dark photon
- Include resonance & F.T. effects
- Probes low coupling param. space, completely inaccessible to particle expts.

WIMPs

"Keep on keeping on"
Large scale experiments to search for weak scale DM

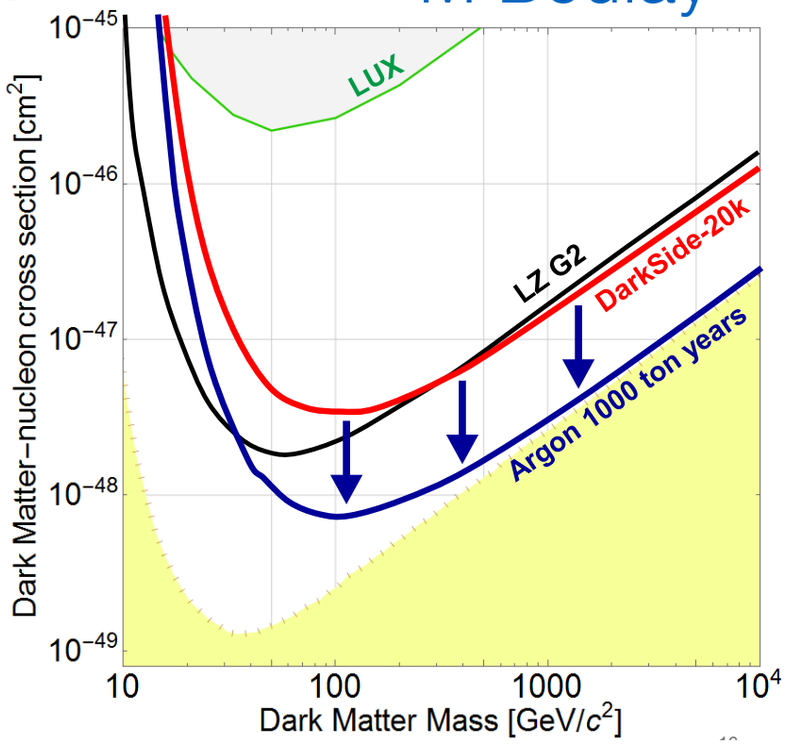
Worldwide Ar community now unified into single collaboration

Expect DEAP3600 results this year

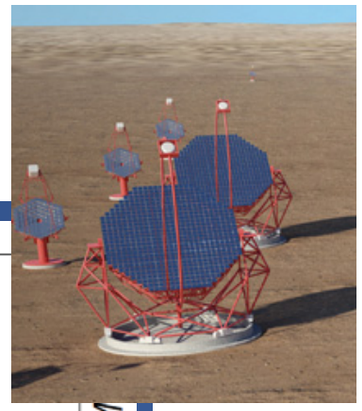
- DarkSide
- DEAP
- ArDM
- MiniCLEAN

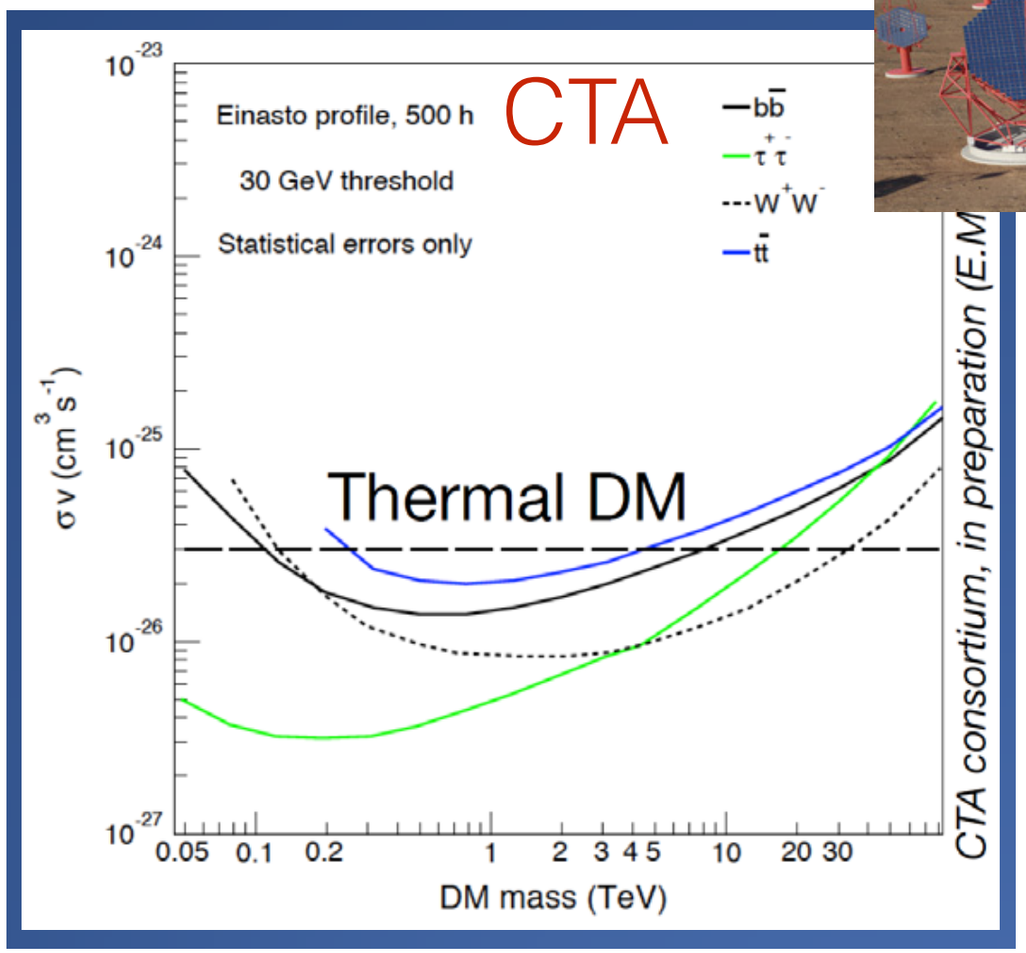
→ DS-20K → multi-100-T

M Boulay



B. Humensky





Complementarity: Natural SUSY models with axions and WIMPs

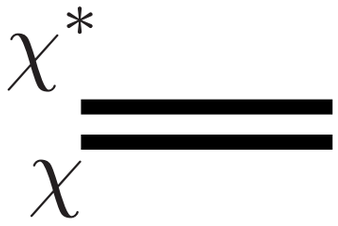
H. Baer

Models of dark sectors

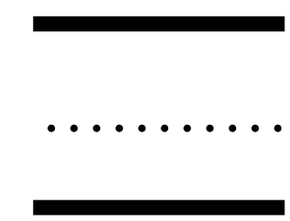
Models of DM have come a long way in 10-20 years
Often a result of dynamic experiment-theory interface

WIMPs
(Coannihilation)

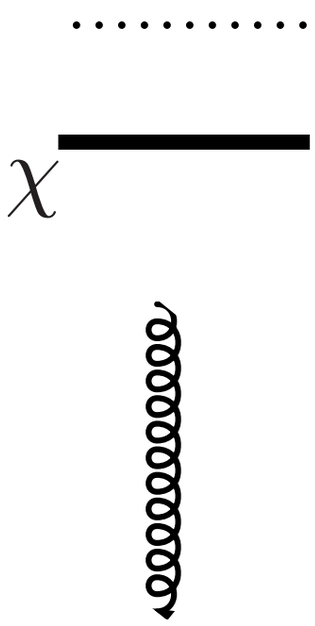
iDM
exDM
....



G. Krnjaic



non-abelian
dark sectors



K. Boddy
N. Blinov

dynamical DM

K. Dienes

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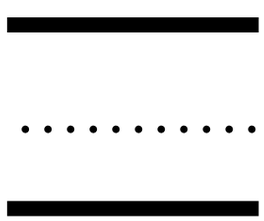

non-abelian
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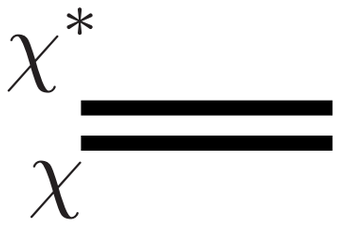
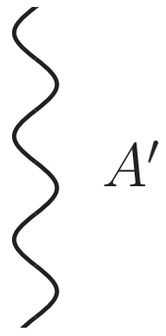
dynamical DM





G. Krnjaic

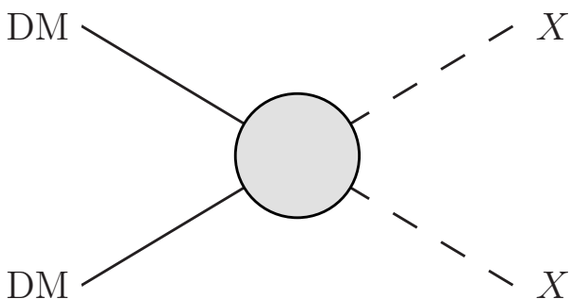
K. Boddy
N. Blinov

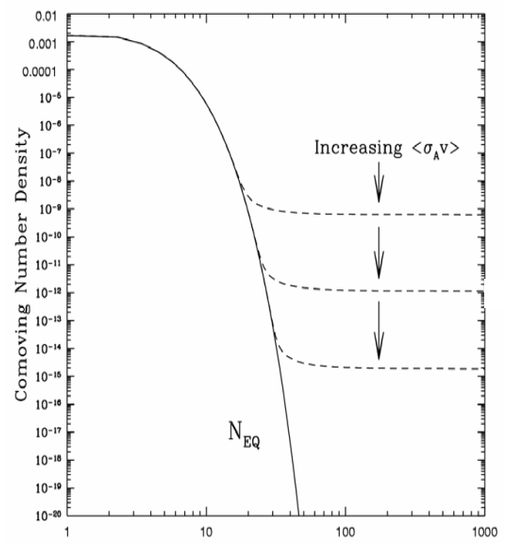
K. Dienes

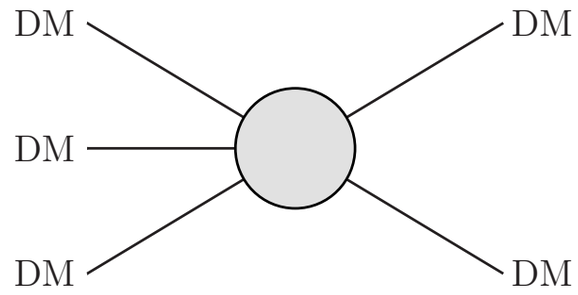
Relics as a target

M. Perelstein
K. Boddy
N. Blinov

Leads to interesting changes in cosmology

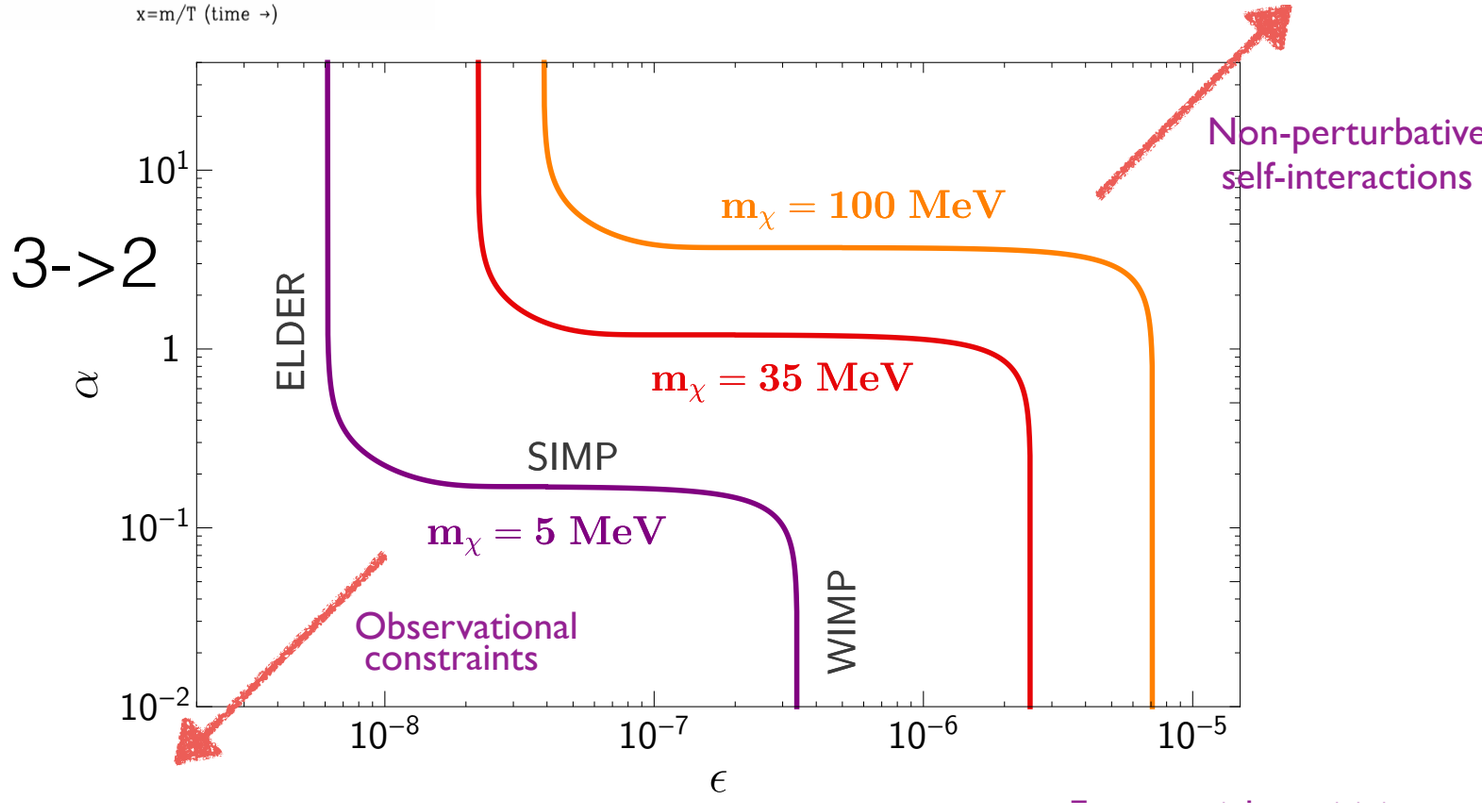






cannibalization

WIMPless-miracle
(1-100 MeV scale)
SIMP-miracle
ELDER…
all smoothly connected
in parameter space

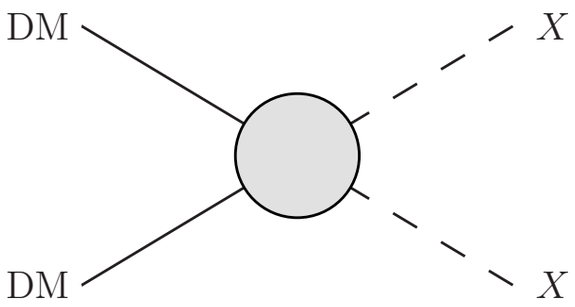


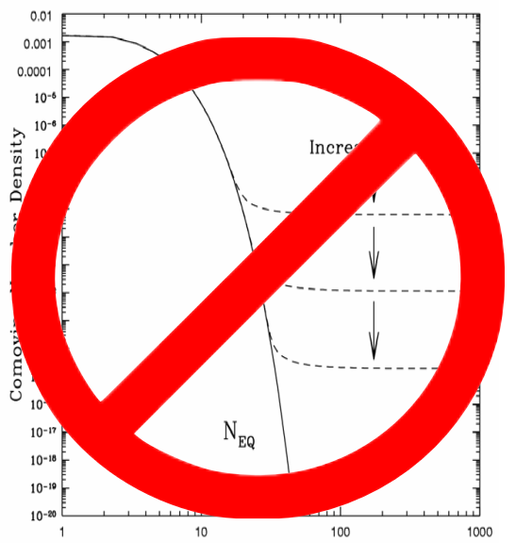
DM-SM elastic scatter

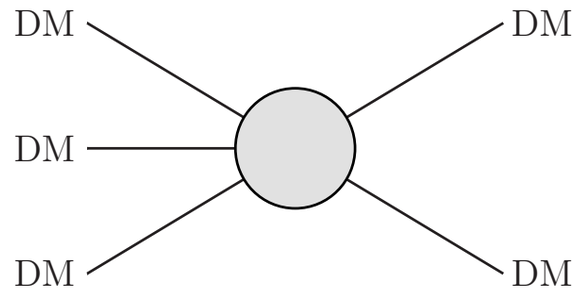
Relics as a target

M. Perelstein
K. Boddy
N. Blinov

Leads to interesting changes in cosmology

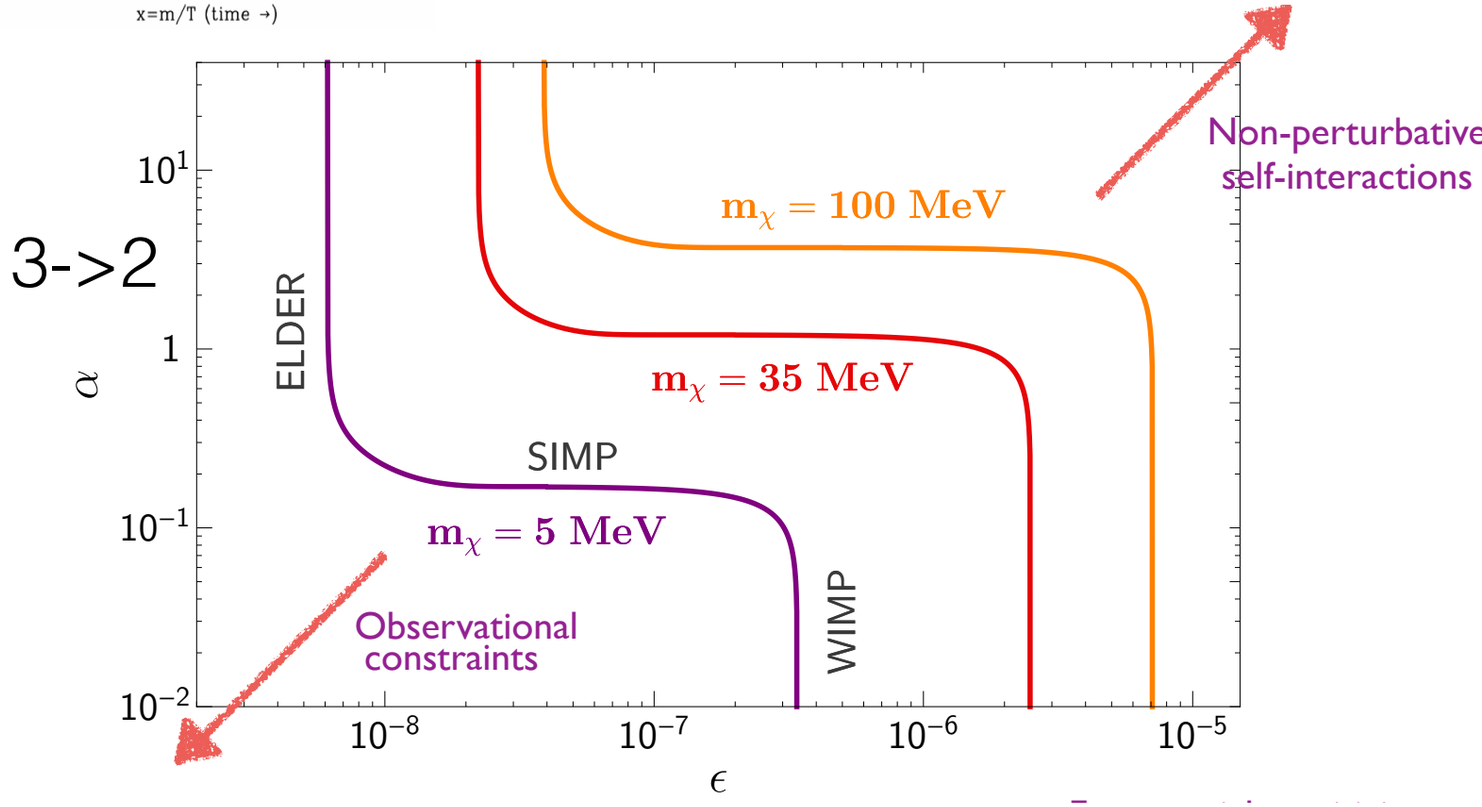






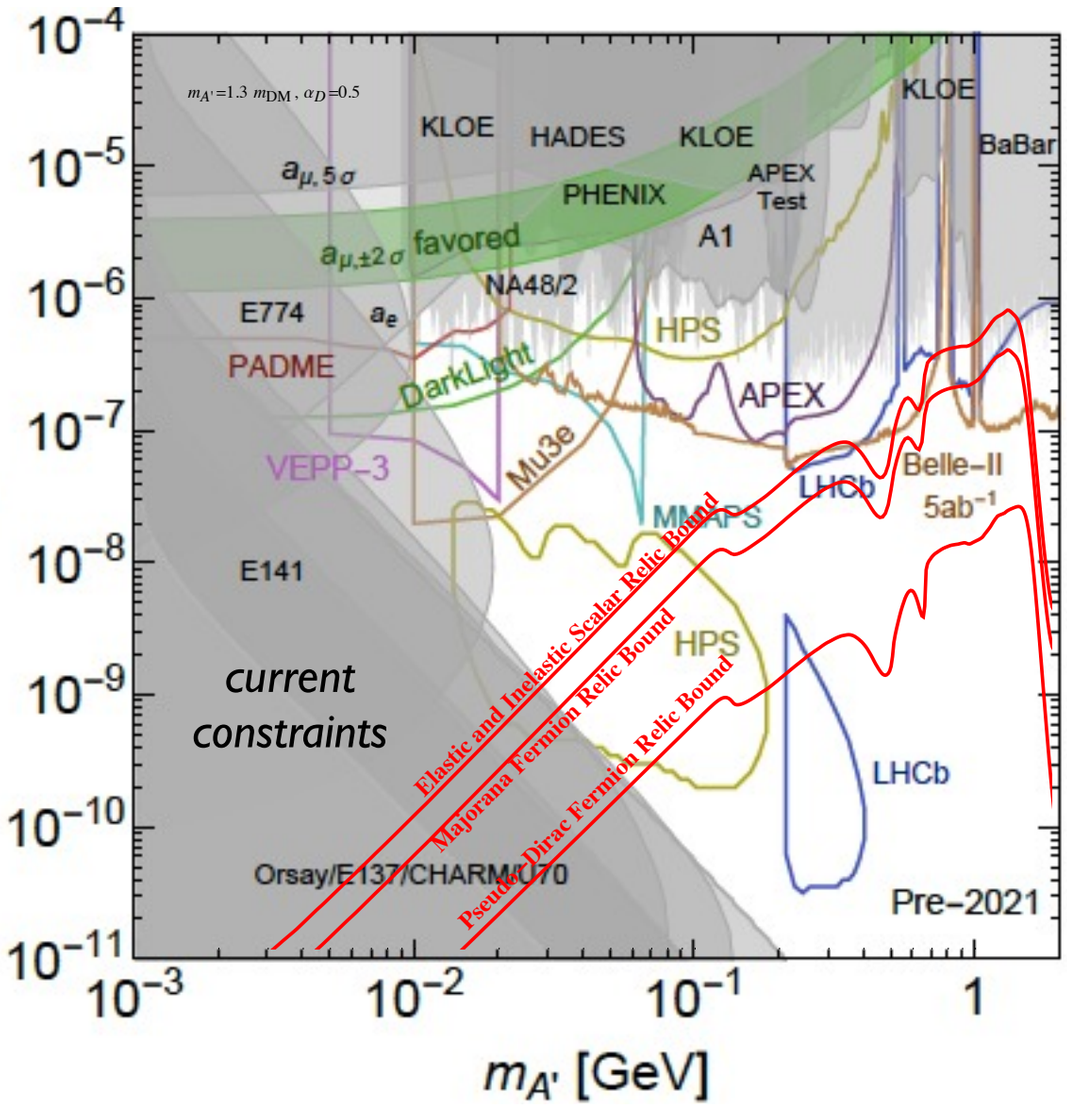
cannibalization

WIMPless-miracle
(1-100 MeV scale)
SIMP-miracle
ELDER…
all smoothly connected
in parameter space



DM-SM elastic scatter

P. Schuster

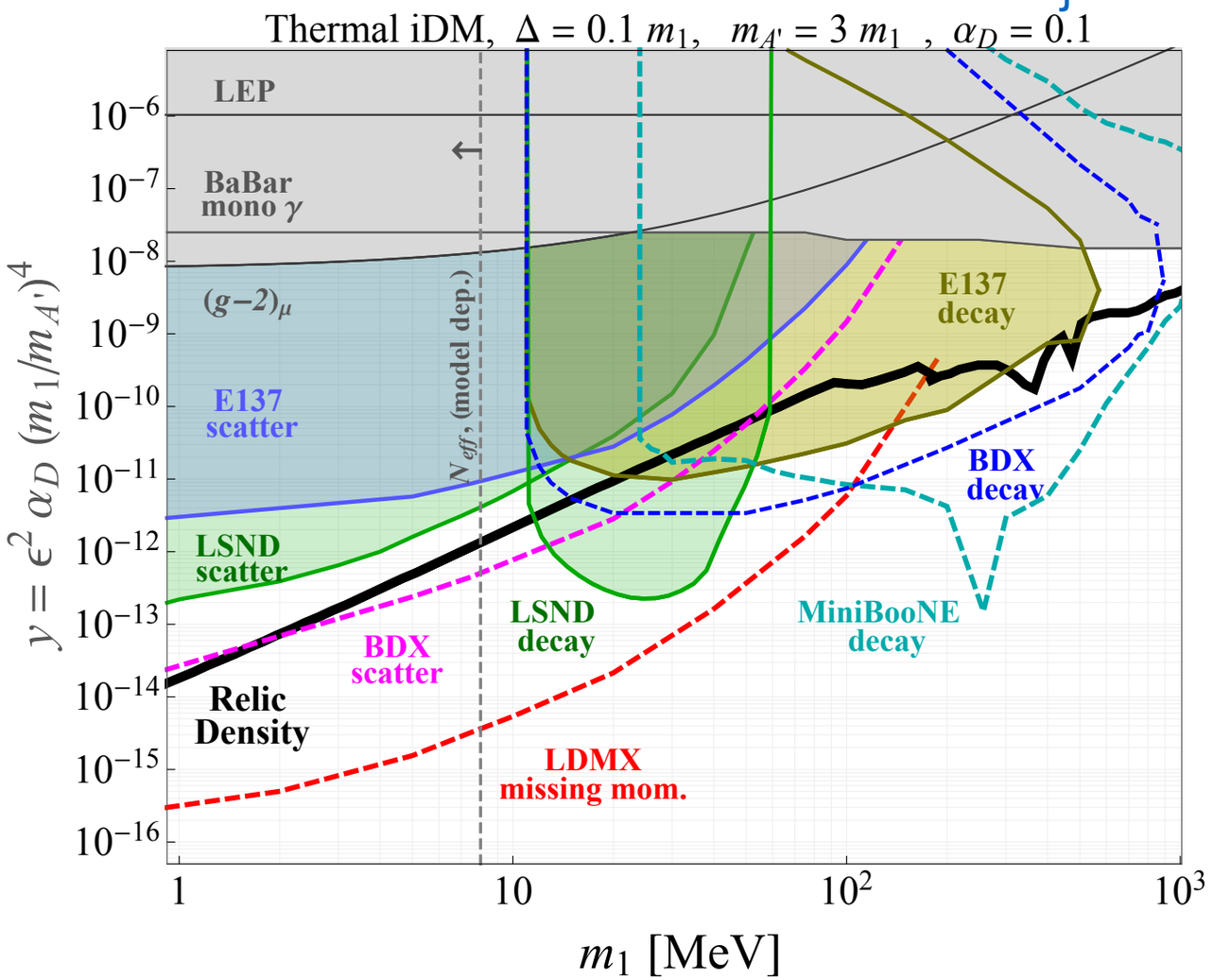


Correct relic abundance requires non-zero couplings of mediator to SM

Complementary probe at accelerators, beam dumps

LHCb has sensitivity through electron scattering, electron-positron annihilation and hadron decays

G. Krnjaic



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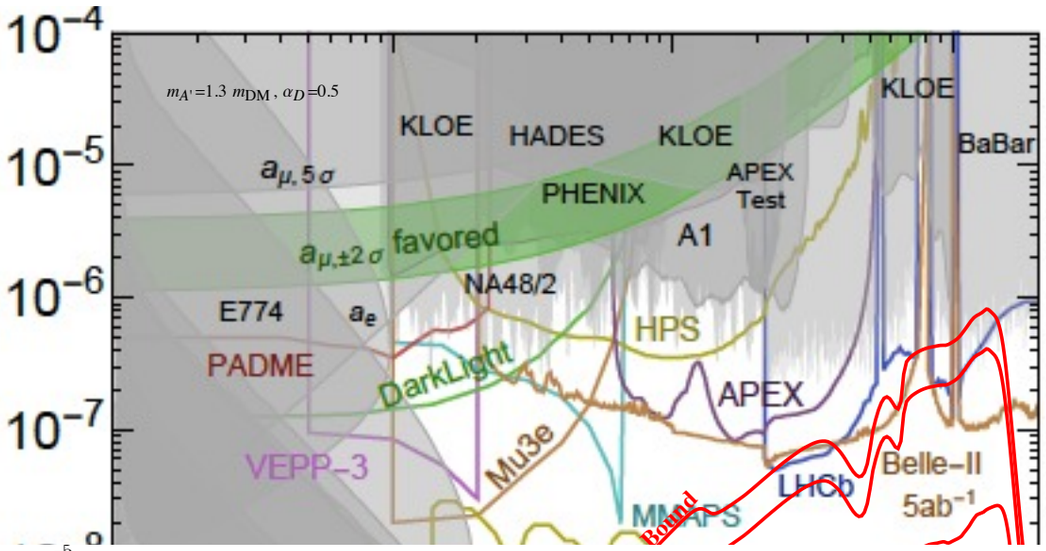
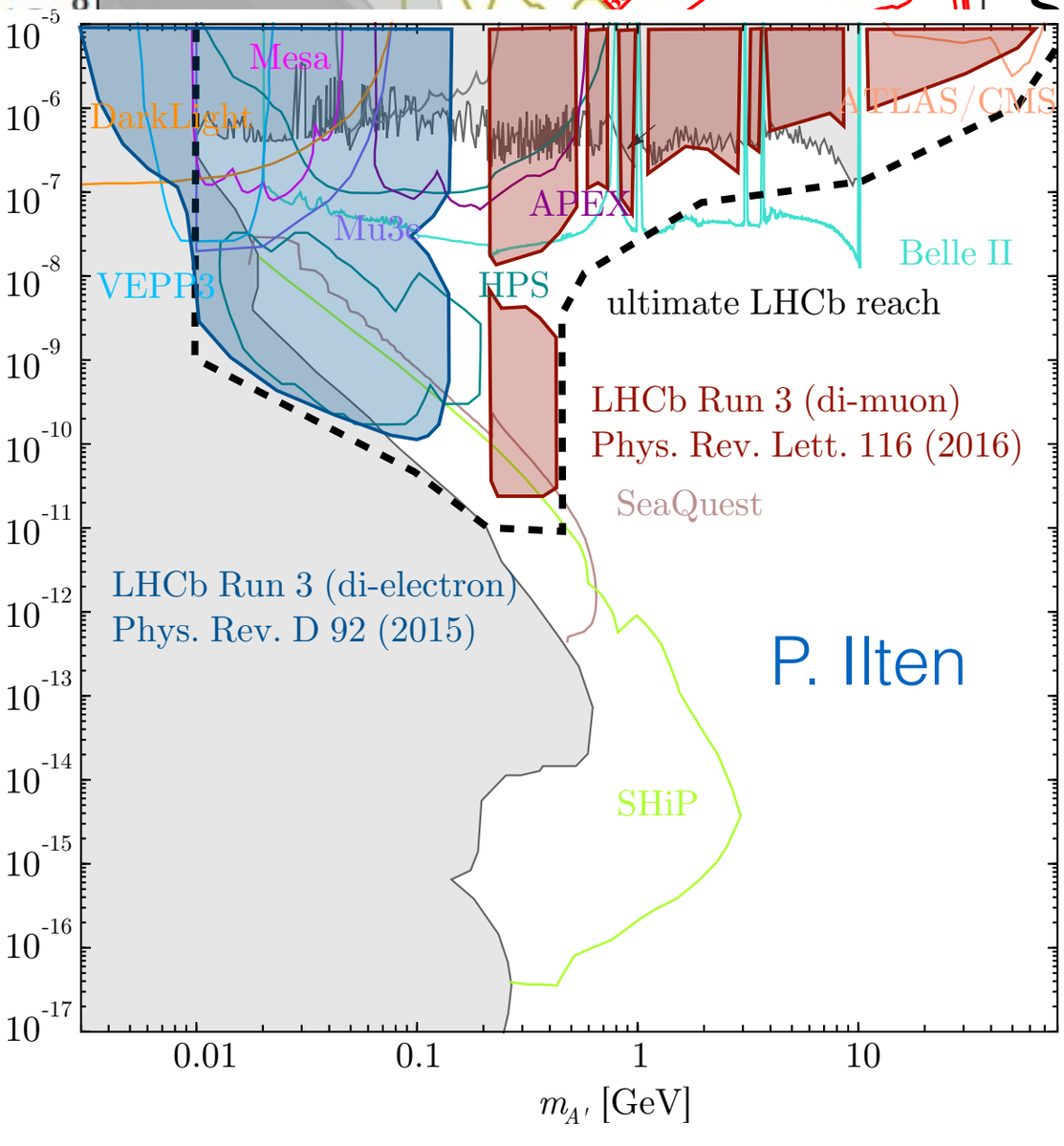
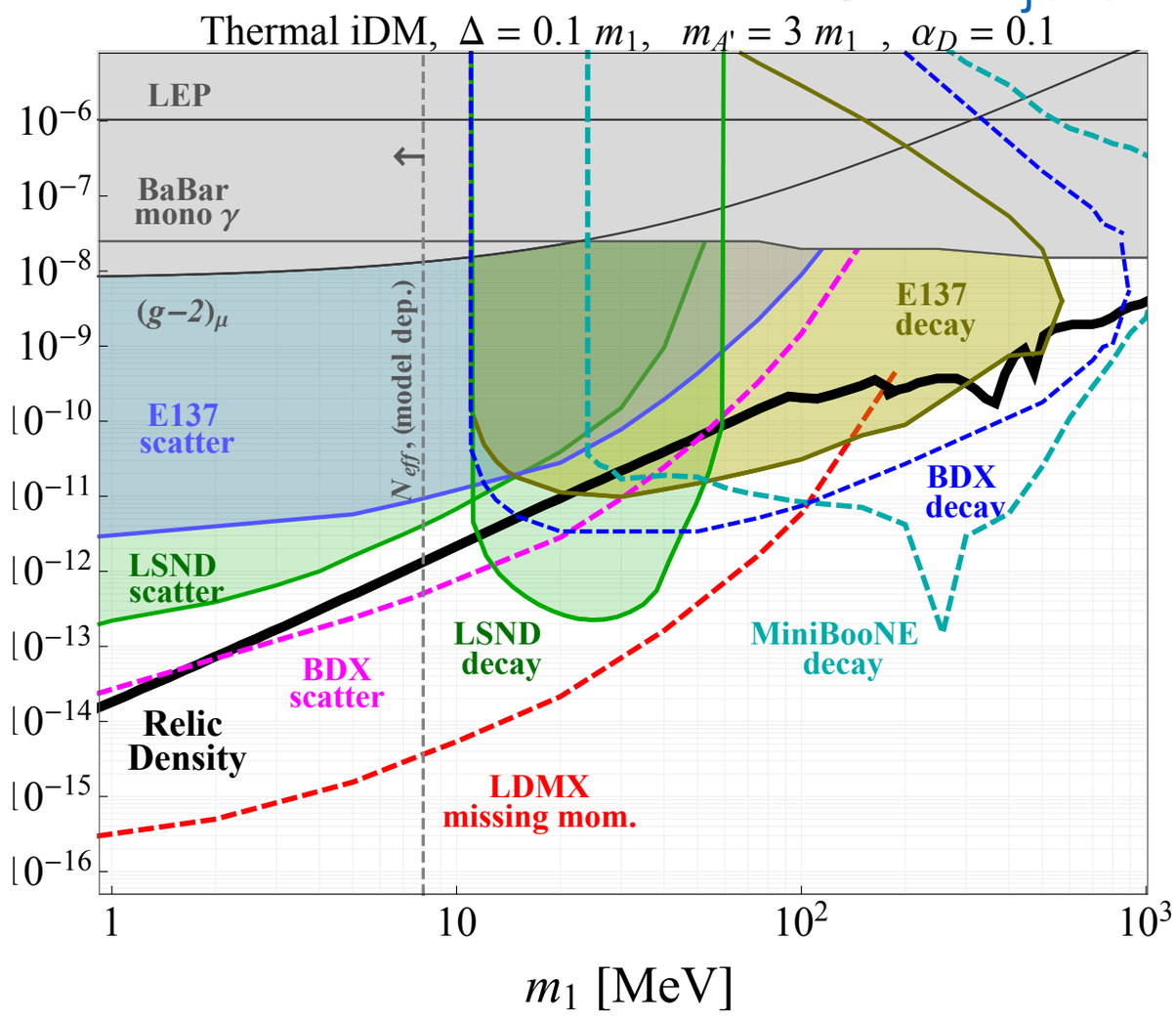




P. Ilten

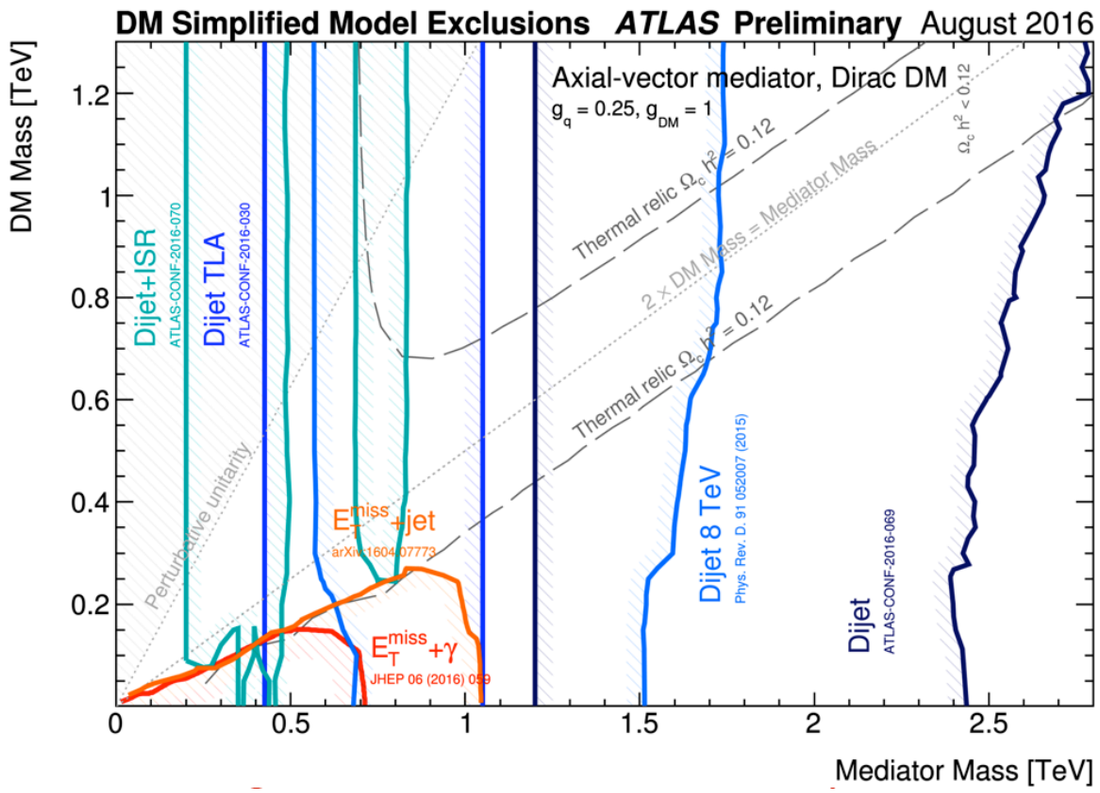
G. Krnjaic

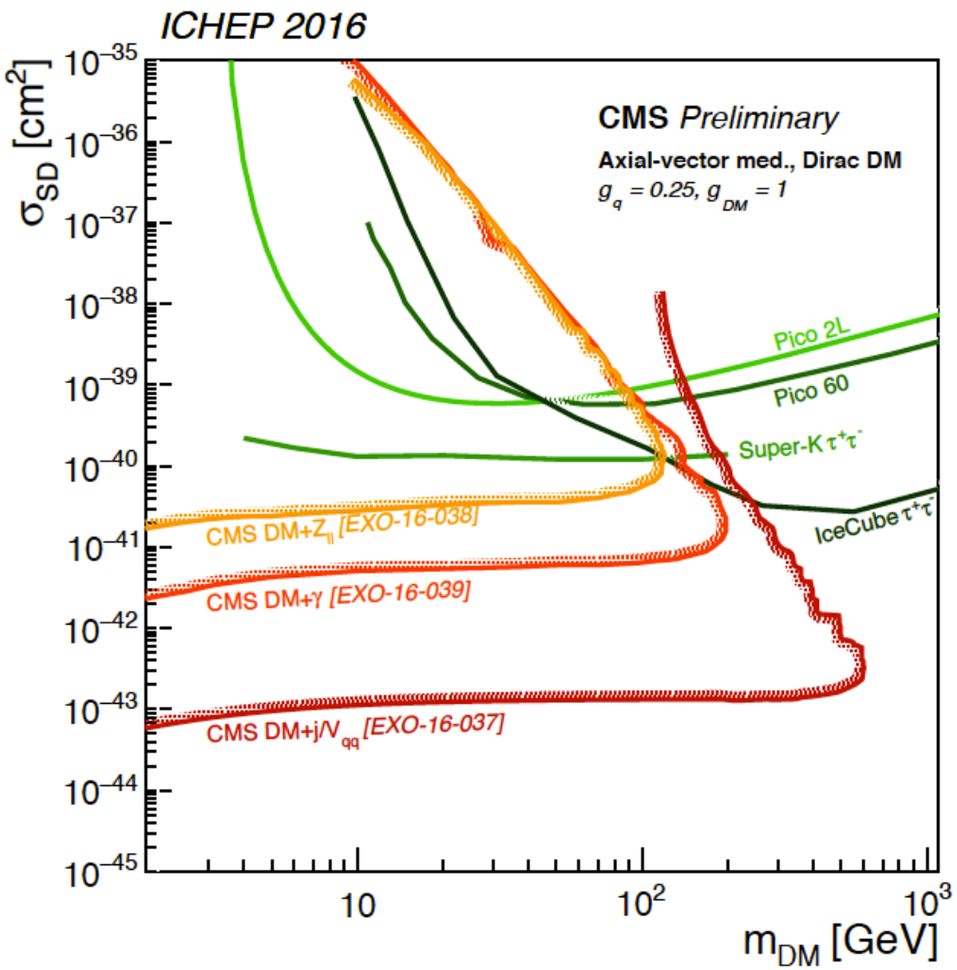


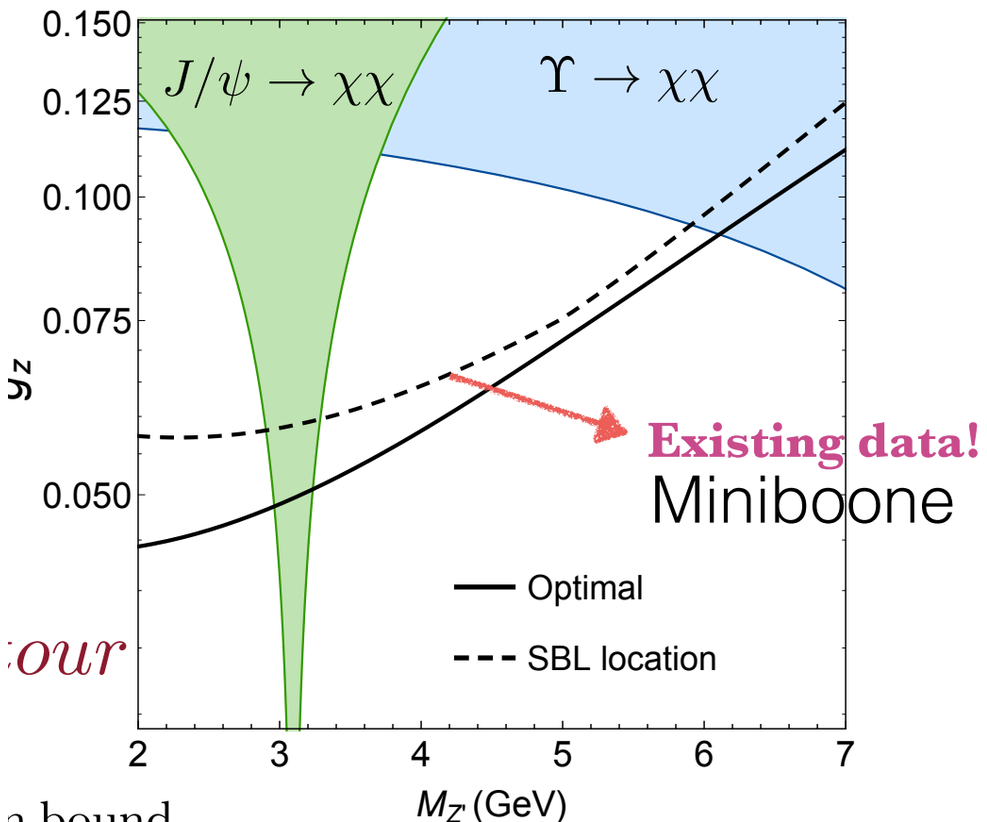
DM-nucleon couplings

M Trovato

ATLAS and CMS have full suite of mono-X searches, and dijet



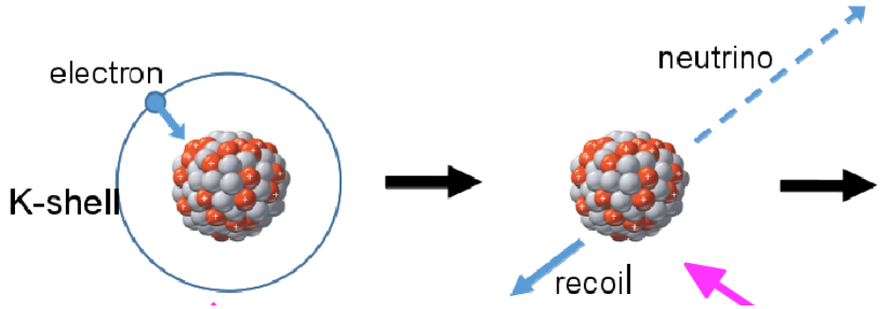




Use FNAL main injector to make a beam of DM, see recoil in near detector
Optimal placement?

C. Frugiuele

keV sterile neutrinos

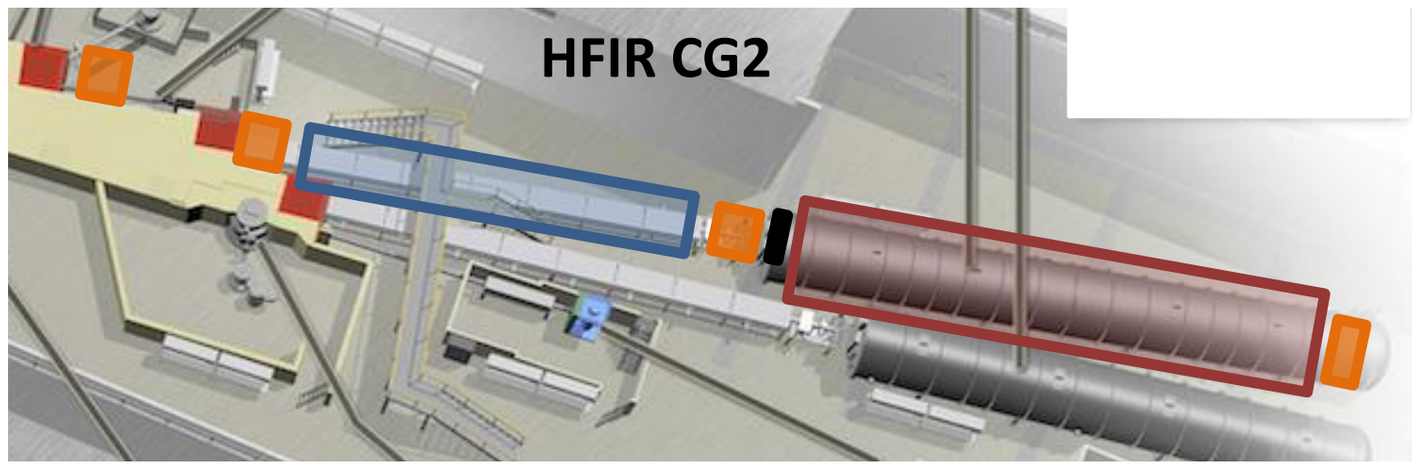


HUNTER expt

J. Martoff

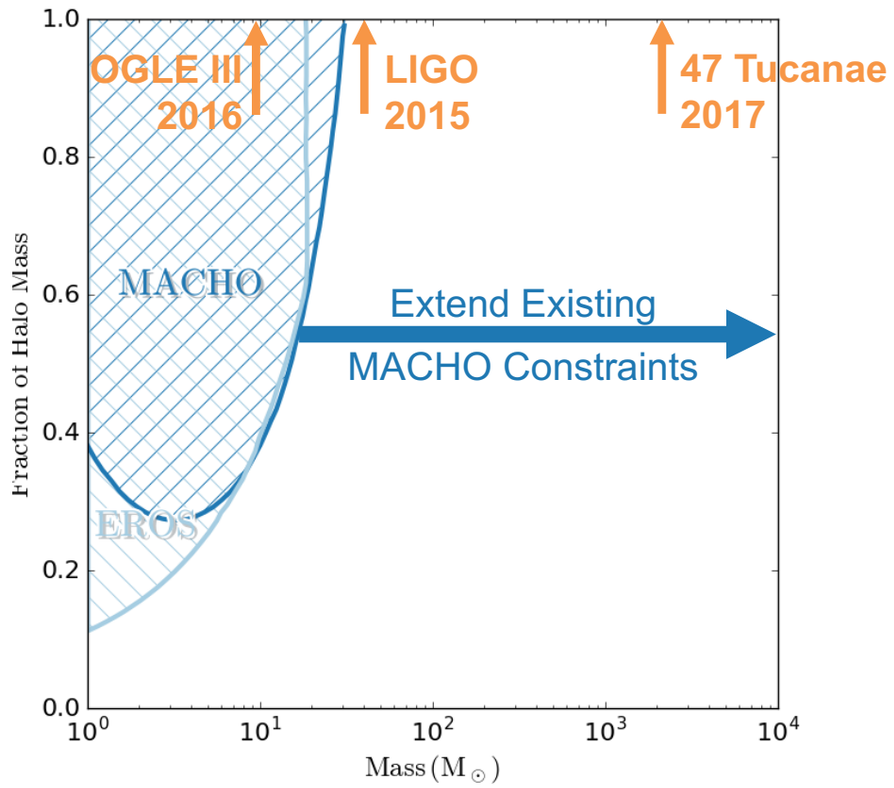
N-mirrorN oscillations

B.Rybolt and L. Broussard

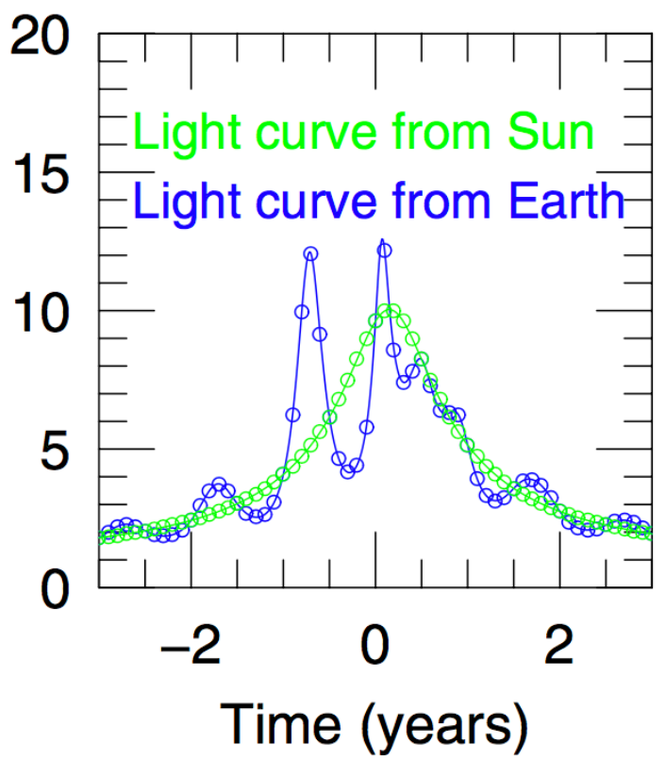


W. Dawson

DECam and LSST microlensing search for BH DM

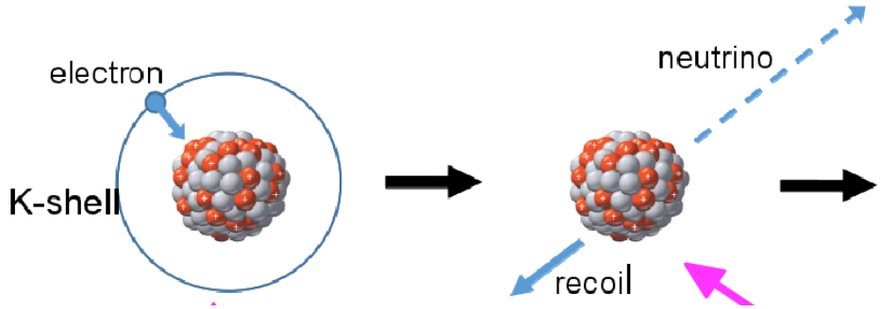


Parallax to the rescue!



Expect ~100 events in 5 years if all of DM
Cheap-leverage existing infrastructure

keV sterile neutrinos



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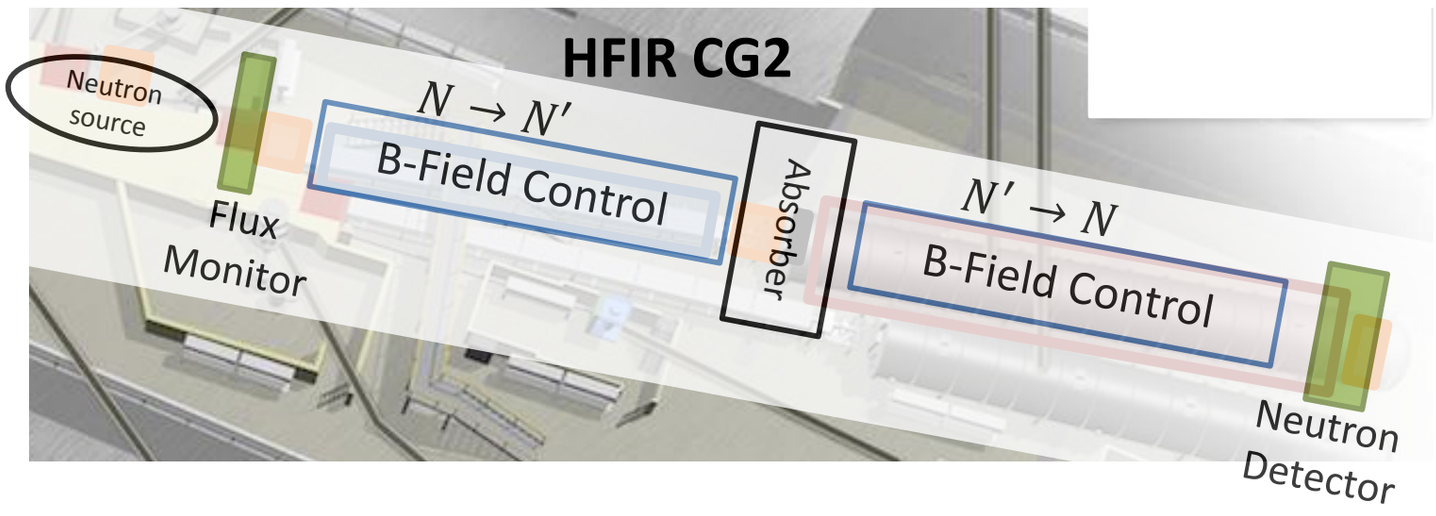

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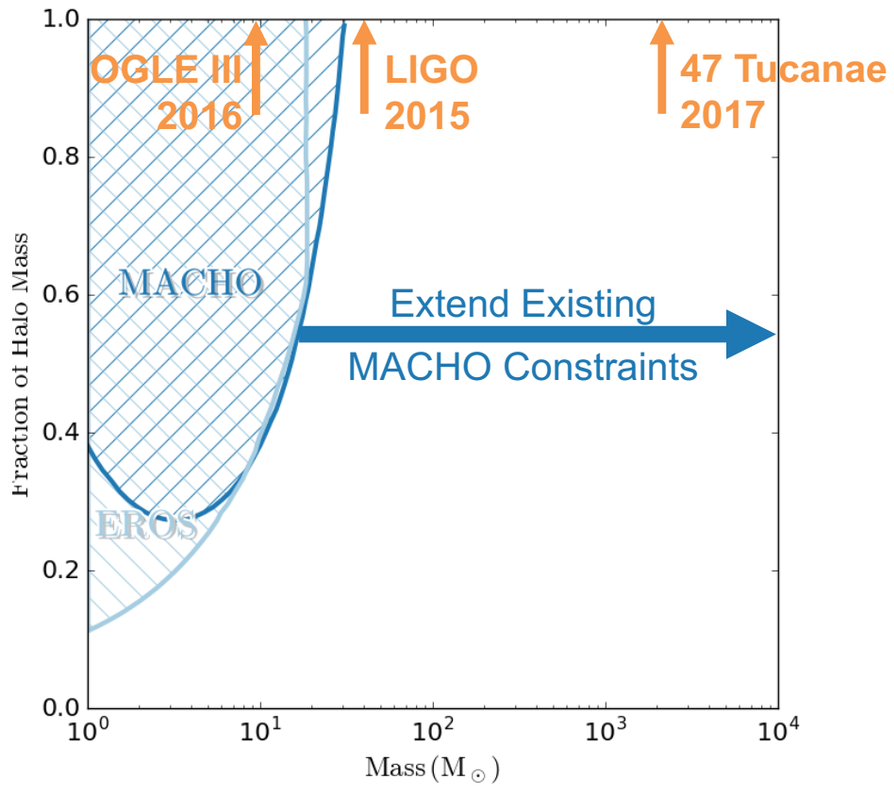

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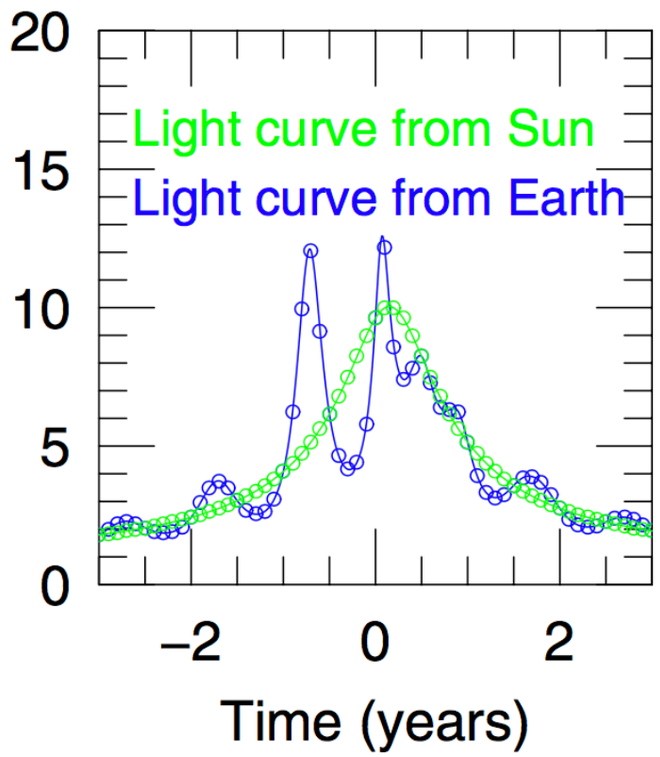

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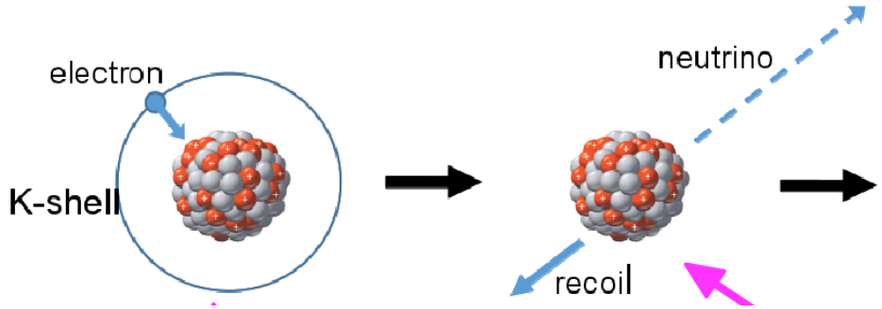

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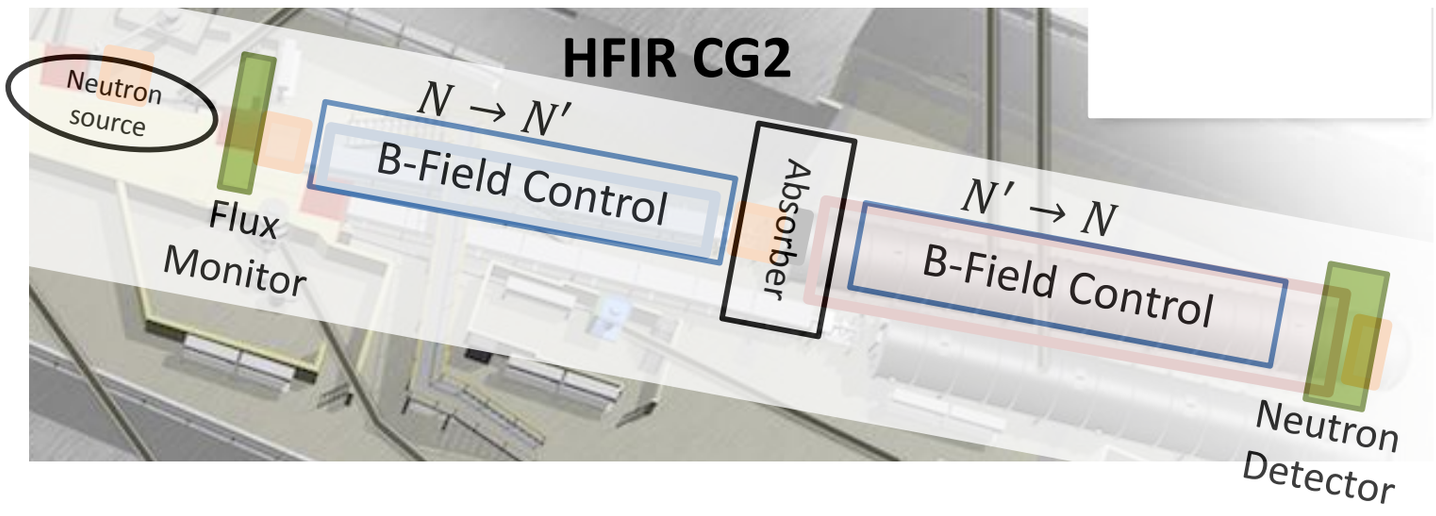

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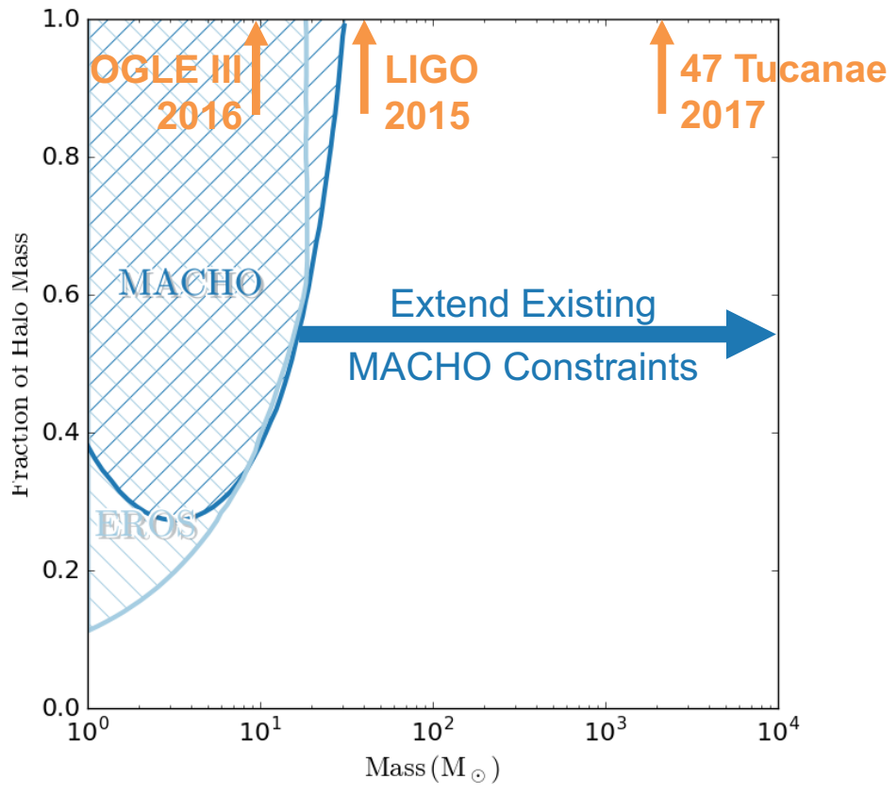

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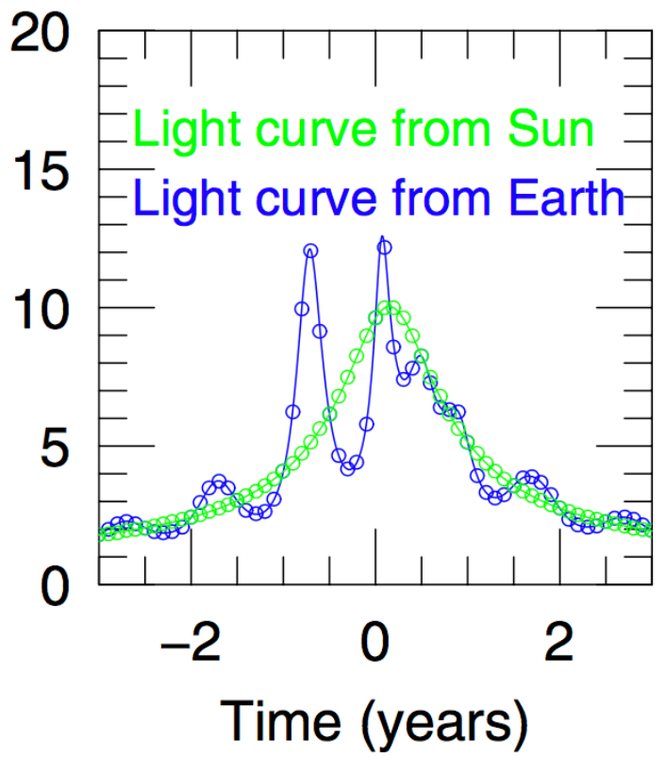


Expec ts in
5 ye)M
Ch e
existi ture

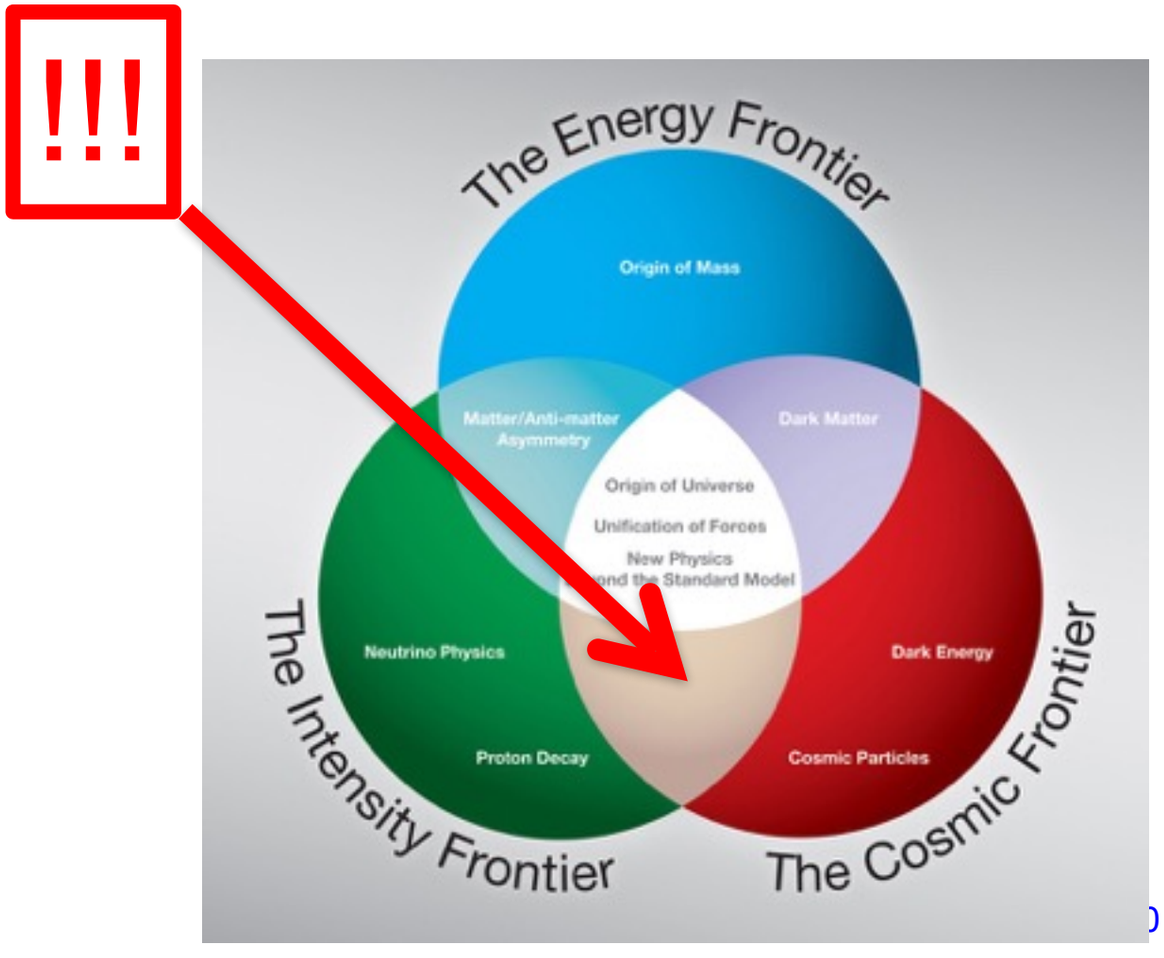
W. Dawson

TAKE HOME #1: A NEW ERA IN DARK MATTER

- Dark matter has long been one of the leading scientific problems of our time, but it has been transformed in recent years by innovative cross talk across many fields of physics

- Previously: an astrophysical problem that leaked into particle physics: the cosmic frontier

- Now: an incredibly fertile field for creative ideas about new particles and forces, spanning the cosmic, energy, and intensity frontiers, and also drawing on nuclear physics, condensed matter physics, and atomic physics



TAKE HOME #2: SYNERGY WITH COSMOLOGY

- Precision cosmology now both constrains and motivates new ideas for the *microscopic (particle)* properties of dark matter

- For example: CMB and supernovae constrain regions of parameter space inaccessible to particle experiments; small scale structure motivates new ideas about self-interactions with implications for particle experiments

- Investments in simulations and astroparticle theory leverage the enormous amount of cosmological data already being collected and are *guaranteed* to tell us something interesting about dark matter properties

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Limits for Self-interaction Cross Section of Dark Matter Particle (X^0) on X^0

PDG 2020

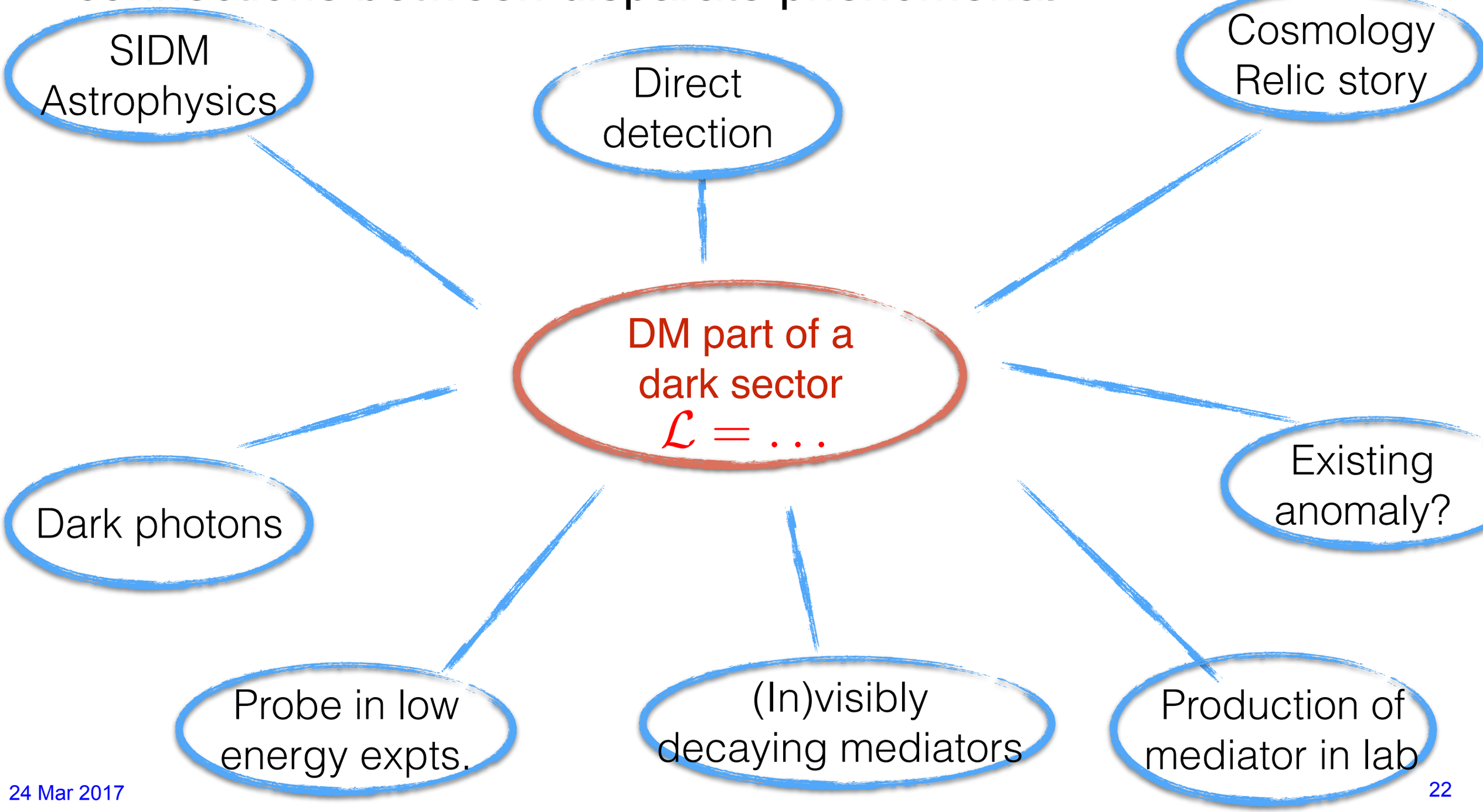
$$\frac{\sigma_{\chi\chi\to\chi\chi}}{m}\ (\mathrm{cm}^2/\mathrm{g})$$

For limits from X^0 annihilation in the Sun, the assumed annihilation final state is shown in parenthesis in the comment.

VALUE cm^2/g	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.22 ± 0.08	90	**MKAP**	16	**SSS**	**inc. cluster data**
0.29 ± 0.1	90	**HY**	15		**dwarf halo**

TAKE HOME #3: IMPORTANCE OF THEORY

- Theory motivates new models and regions of parameter space, suggests new search methods, and draws connections between disparate phenomena.



TAKE HOME #4: FAST AND CHEAP EXPERIMENTS

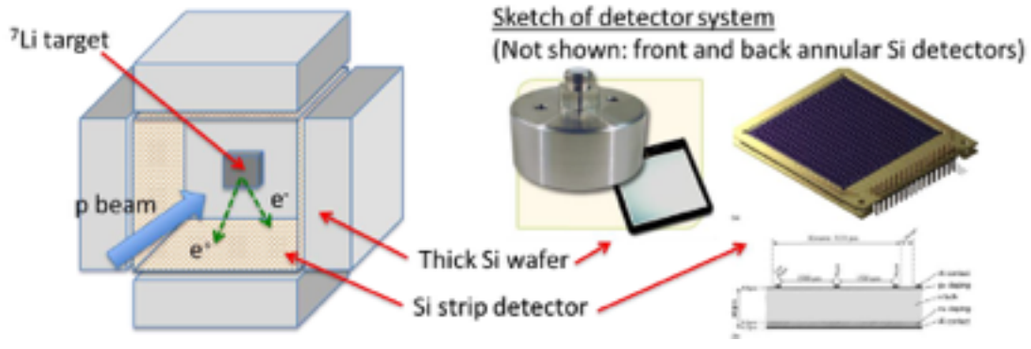
- New ideas and anomalies motivate ongoing and planned experiments, but also fast (<2 years) and cheap (~$1M) experiments: there is a rich menu to choose from!

COLORADOSCHOOLOFMINES
Electroweak Interactions Group

INSTITUTE FOR STRUCTURE AND NUCLEAR ASTROPHYSICS

A ^{8}Be IPC Decay Measurement at the Notre Dame-NSL

M. Brodeur (U. Notre Dame) and K.G. Leach (Colorado School of Mines)



Claudia Frugiuele

מכון ויצמן למדע
WEIZMANN INSTITUTE OF SCIENCE

Probing new long range interactions via isotope spectroscopy

A DECam and LSST microlensing survey of intermediate mass black hole dark matter

U.S. Cosmic Visions: New Ideas in Dark Matter

2017 March 24

Will Dawson[1], Mark Ammons[1], Tim Axelrod[2], George Chapline[1], Alex Drlica-Wagner[3], Nathan Golovich[4], and Michael Schneider[1]
1 Lawrence Livermore National Laboratory, 2 University of Arizona, 3 Fermi National Accelerator Laboratory, 4 University of California: Davis

Thank you to all WG4 participants!