# Cosmic Frontier

Harry Nelson
DPF UC Santa Cruz
August 17, 2013

## O.E.D.

**Pronunciation:** /wɪmp/

**Etymology:** Acronym < the initial letters of *w*eakly *i*nteracting *m*assive *p*article.

*Particle Physics.*

Any of several hypothetical subatomic particles which have relatively large mass but which interact only weakly with ordinary matter, postulated as the main constituents of the dark matter of the universe. Chiefly in *pl.*

Thesaurus »
Categories »

1985 *Sci. Amer.* Aug. 55/1 In 1977 John Faulkner of the University of California at Santa Cruz and one of his students, Ronald Gilliland..considered the effects of a weakly interacting massive particle (WIMP) on the flux of neutrinos by the sun.

- Cosmic Frontier Parallel Sessions
  - 26 talks by 24 speakers
  - Results, Commissioning/Operations, Projections, Ideas
- Ernest Rutherford:
  - `If your experiment needs statistics, you ought to have done a better experiment'... Over a long time ago.
  - Big data analyzed by the very skilled
- Wonderful youthful spirit… Namaste

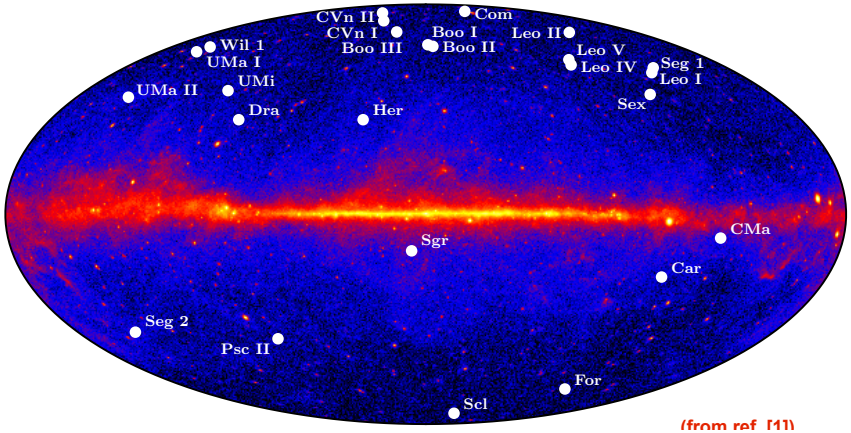
# Some themes

- WIMPs… well defined, models, lines to cross
  - Majorana or Dirac or neither?
  - Just one particle or a whole `dark sector'?
- Dark Energy… a great discovery where `lines to cross' is perhaps inappropriate

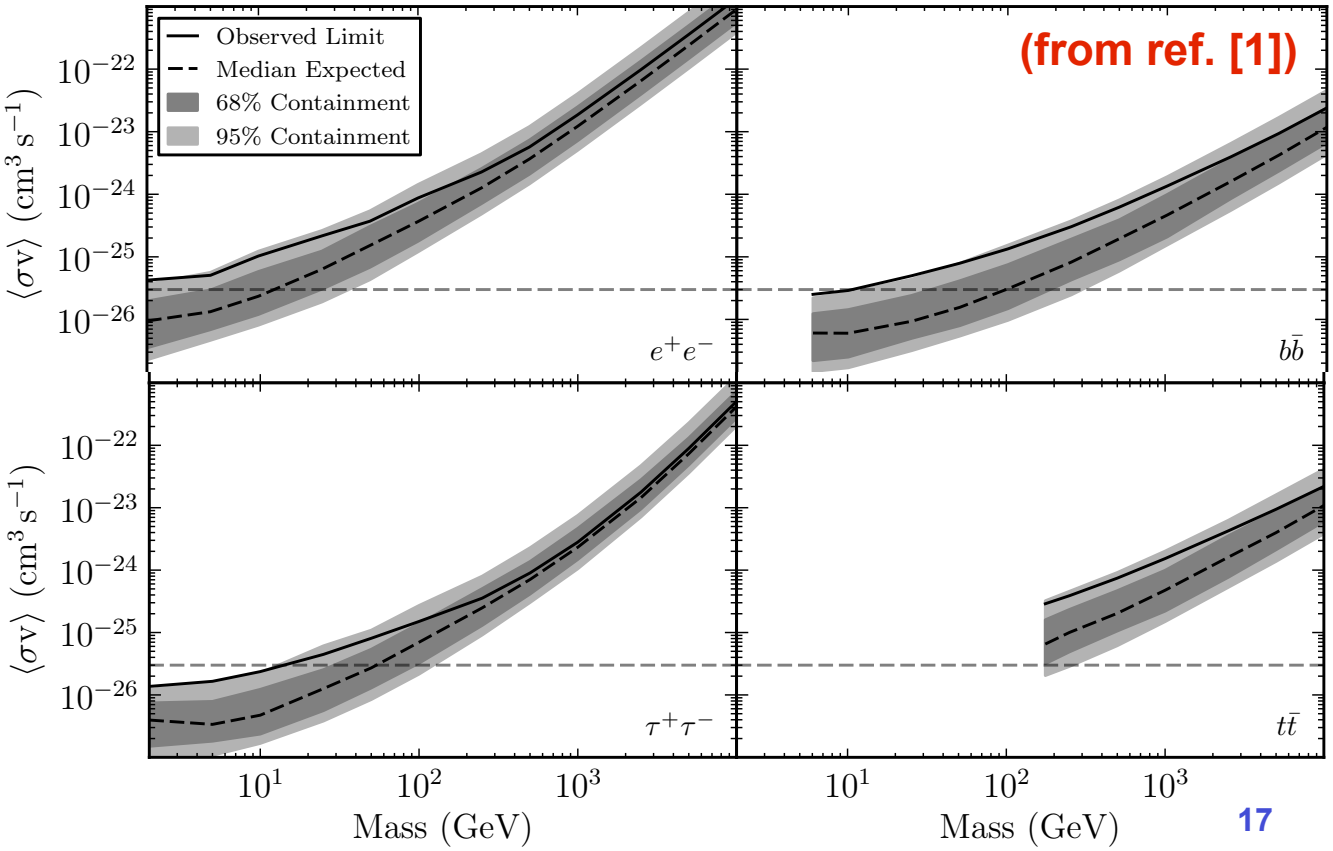
- New ideas that seek a repeat

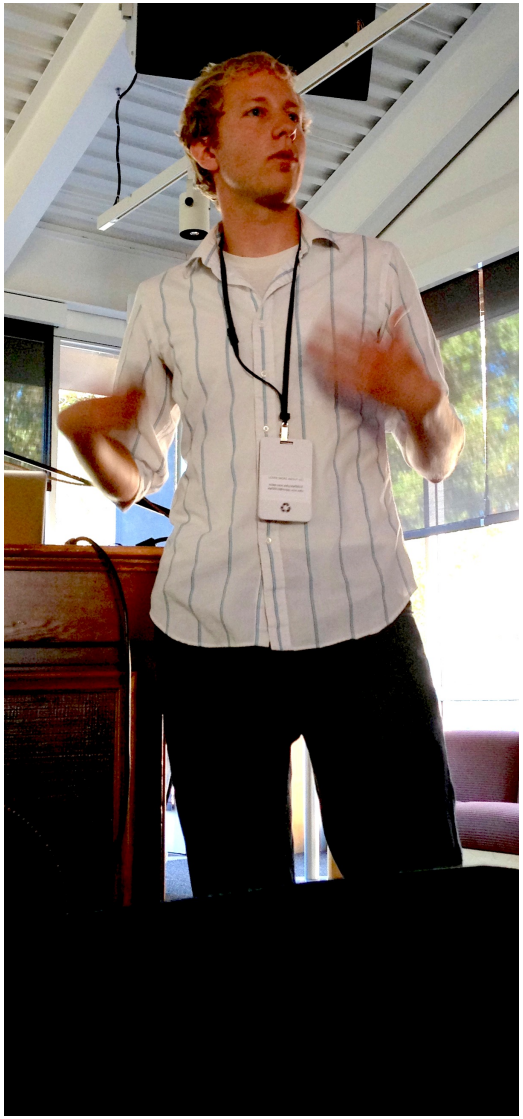
# Astrophysical Searches for Daughters from Dark Matter Annihilation & Related

# Alex Drlica-Wagner / Fermi-LAT

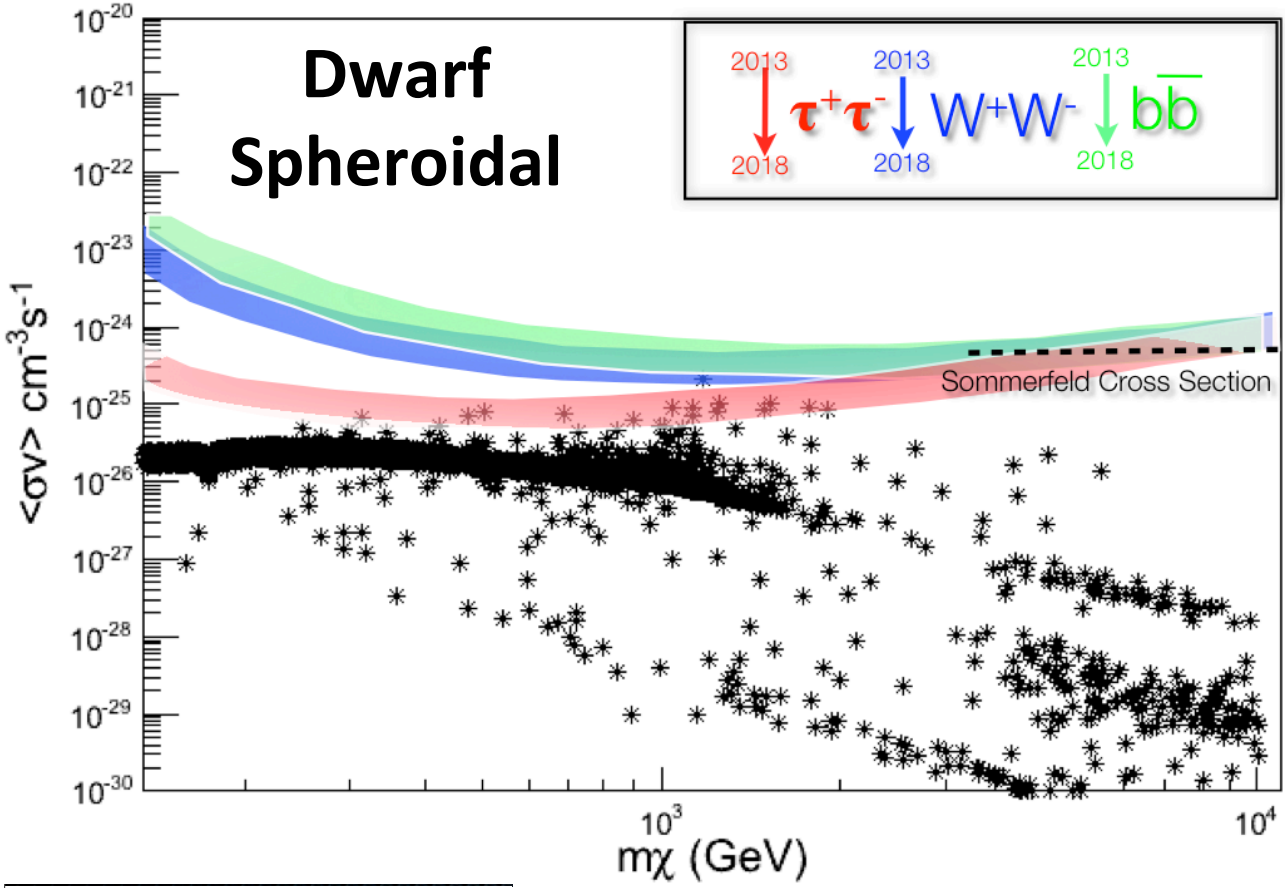


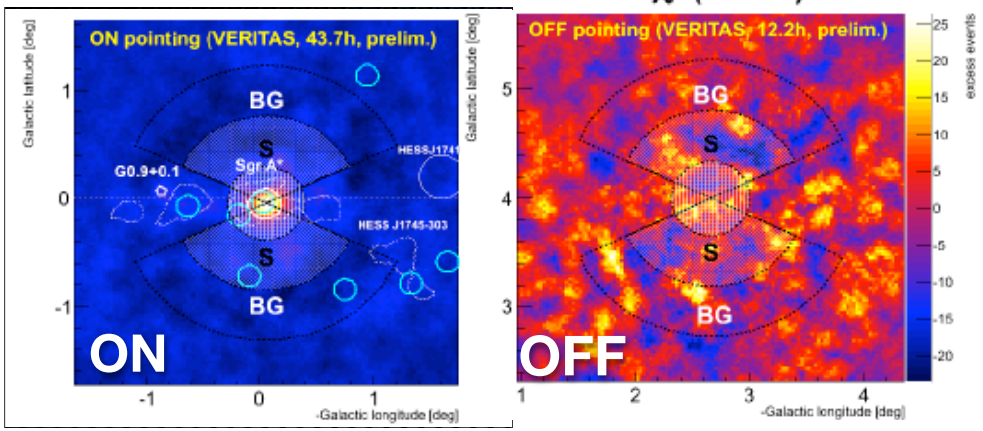

(from ref. [1])



# Andrew Smith / Veritas

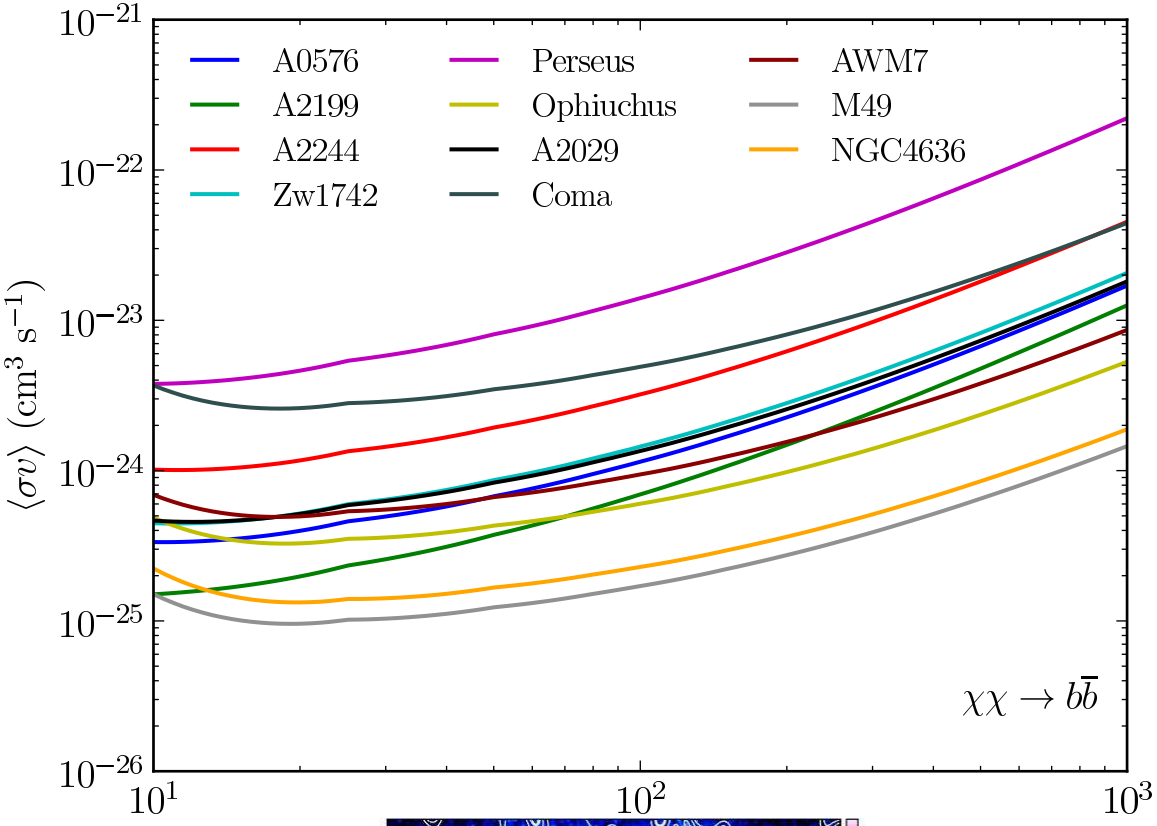


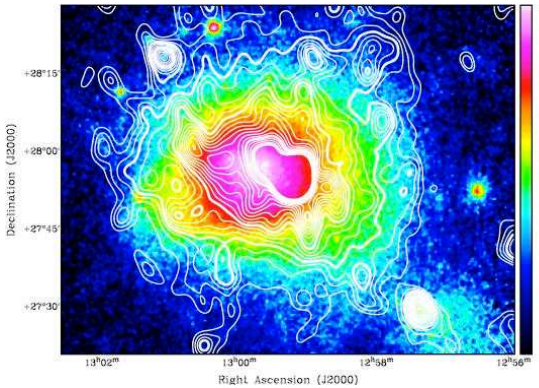




Galactic Center

# Emma Storm / Radio

## Galaxy Clusters


Coma Cluster. Radio contours overlaid on X-ray.
Brown & Rudnick, 2011, MNRAS, 412, 2.

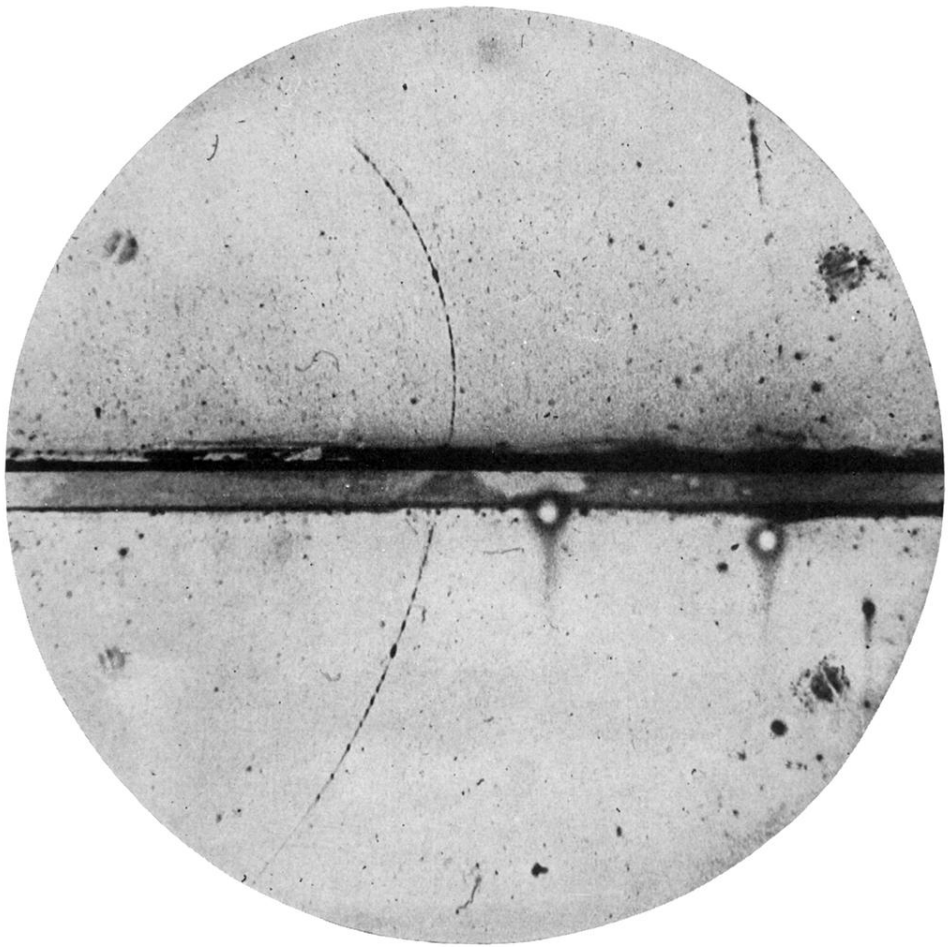


FIG. 1. A 63 million volt positron ($H\rho = 2.1 \times 10^5$ gauss-cm) passing through a 6 mm lead plate and emerging as a 23 million volt positron ($H\rho = 7.5 \times 10^4$ gauss-cm). The length of this latter path is at least ten times greater than the possible length of a proton path of this curvature.

# Positron Discovery (1932)

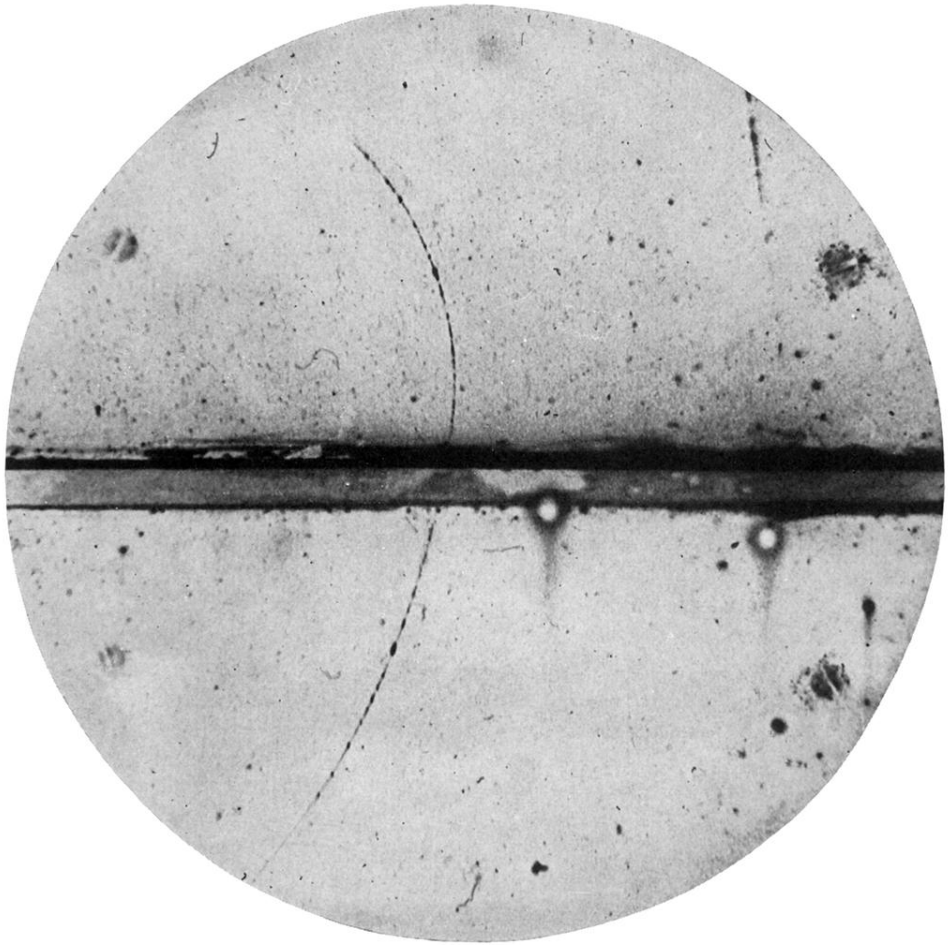
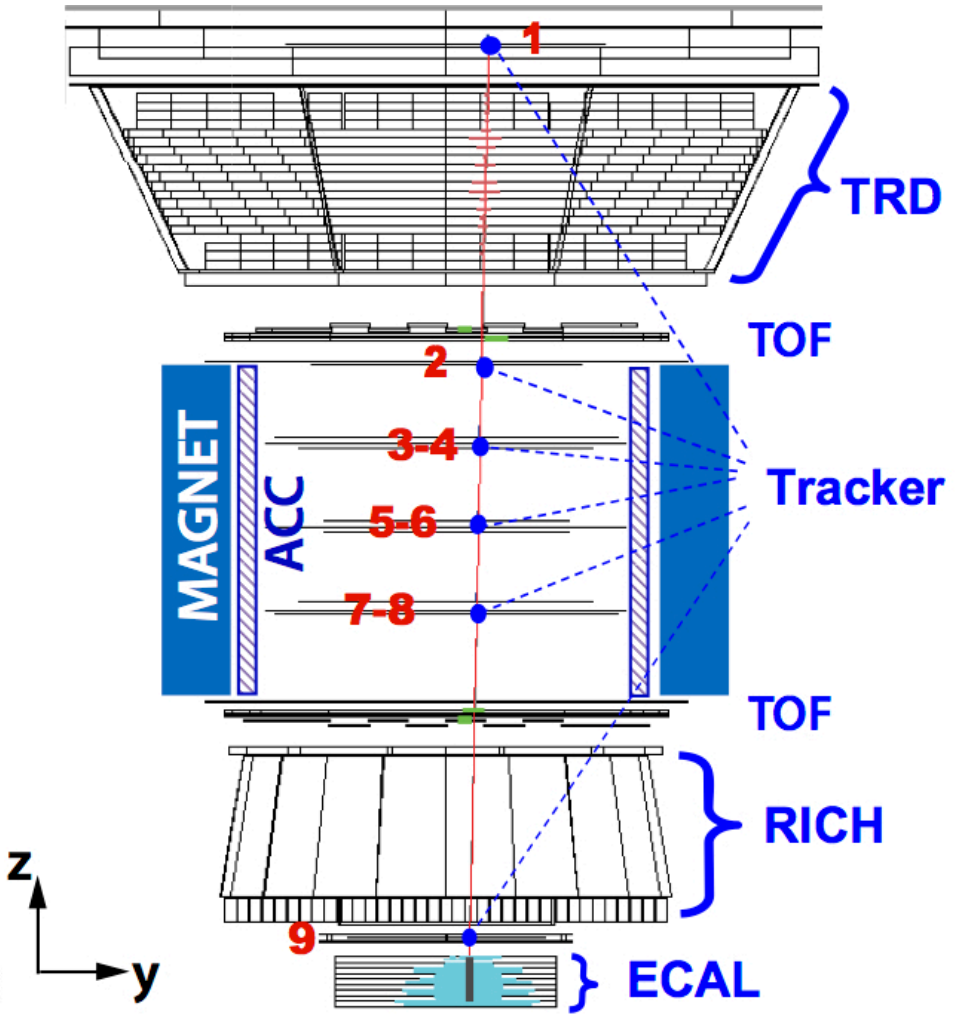
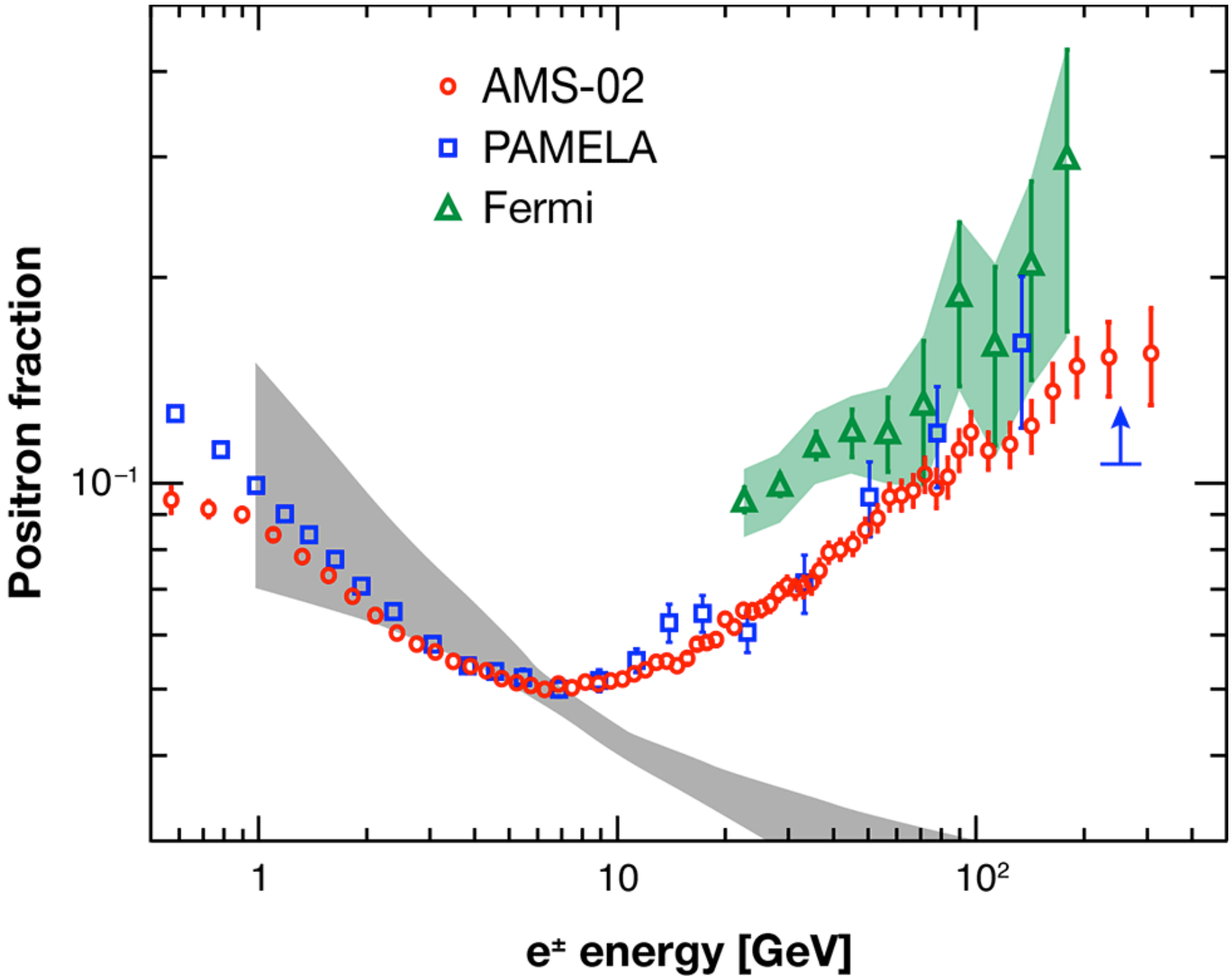


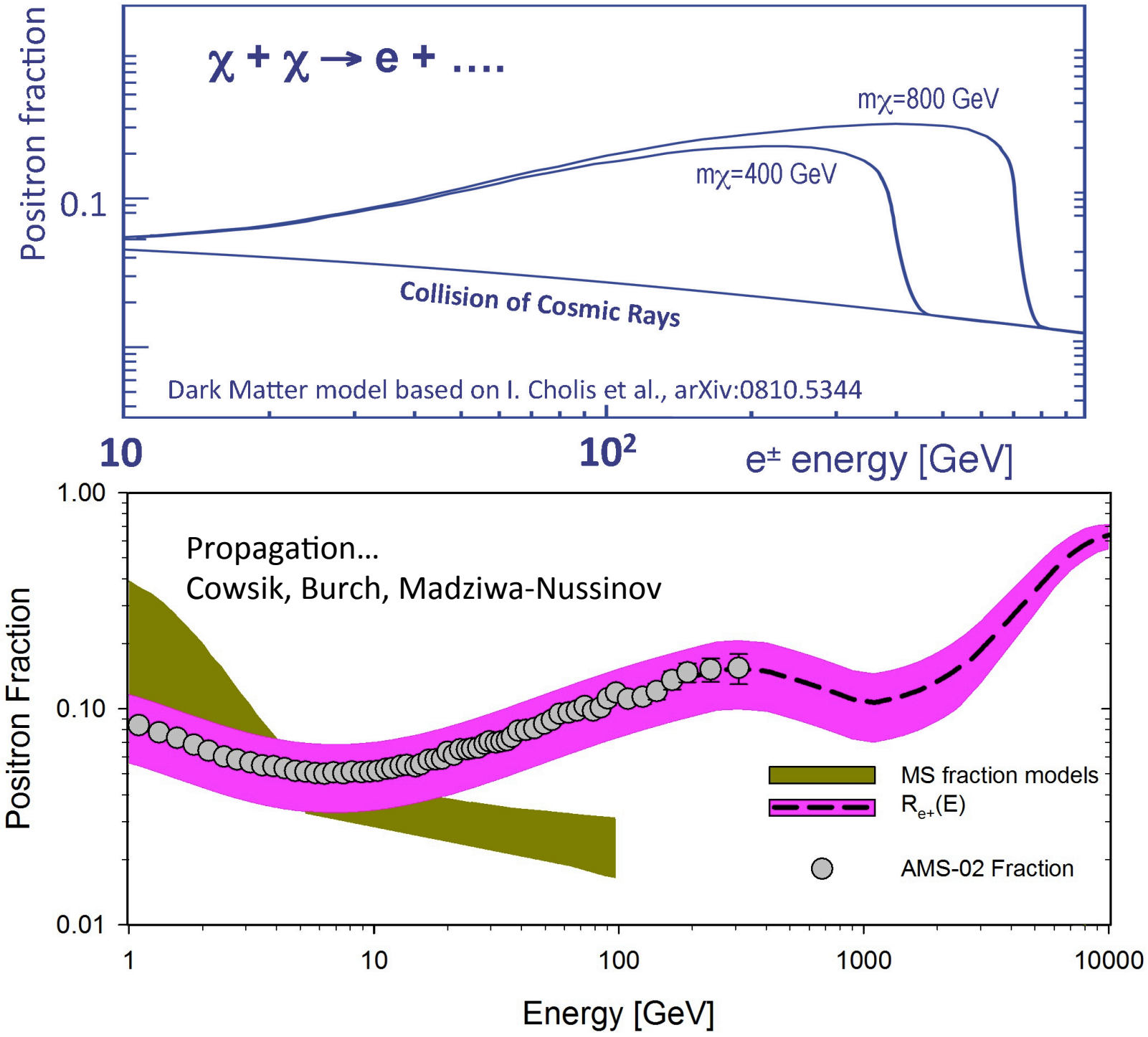
FIG. 1. A 63 million volt positron ($H\rho = 2.1 \times 10^5$ gauss-cm) passing through a 6 mm lead plate and emerging as a 23 million volt positron ($H\rho = 7.5 \times 10^4$ gauss-cm). The length of this latter path is at least ten times greater than the possible length of a proton path of this curvature.




# Positron Discovery (1932)

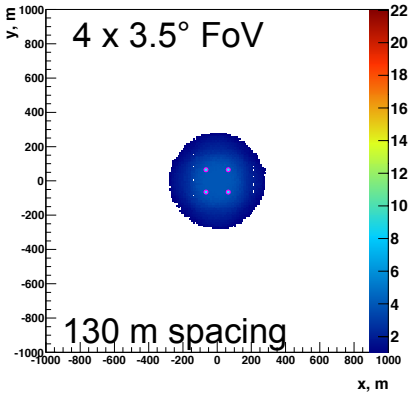
# AMS 369 GeV $e^+$ (2013)

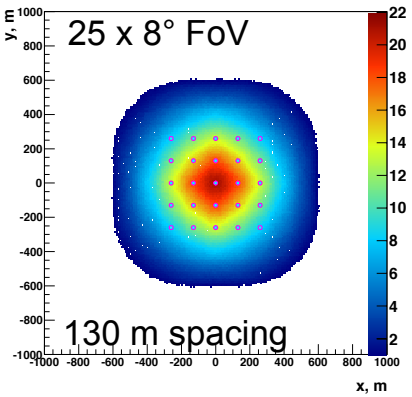

AMS-02
PAMELA
Fermi
Positron fraction
$10^{-1}$
1
10
$10^2$
e± energy [GeV]

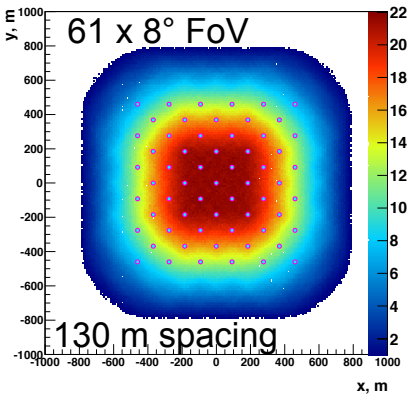

Positron fraction
0.1
χ + χ → e + ....
mχ=800 GeV
mχ=400 GeV
Collision of Cosmic Rays
Dark Matter model based on I. Cholis et al., arXiv:0810.5344
10
10²
e± energy [GeV]
1.00
0.10
0.01
Positron Fraction
Propagation…
Cowsik, Burch, Madziwa-Nussinov
MS fraction models
R_e+(E)
AMS-02 Fraction
1
10
100
1000
10000
Energy [GeV]

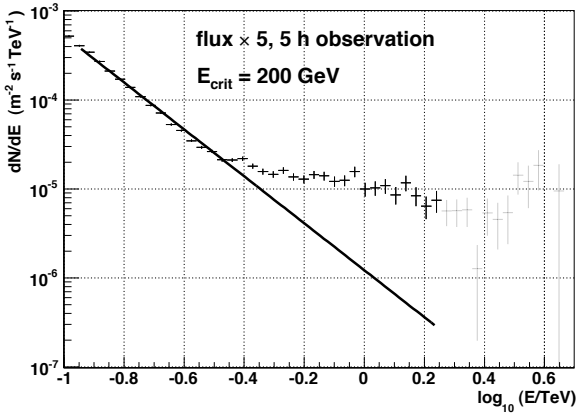
# David Williams / CTA

Figures from Slava Bugaev

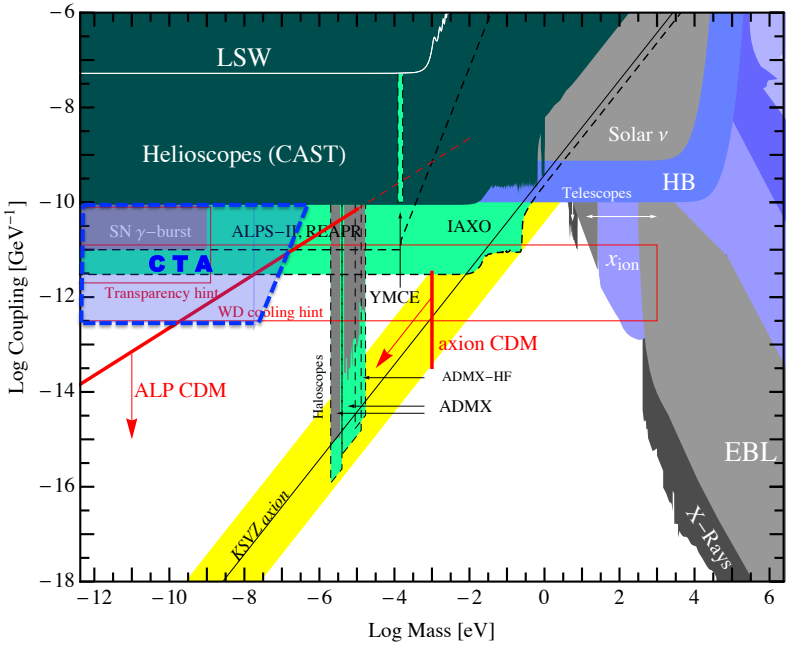


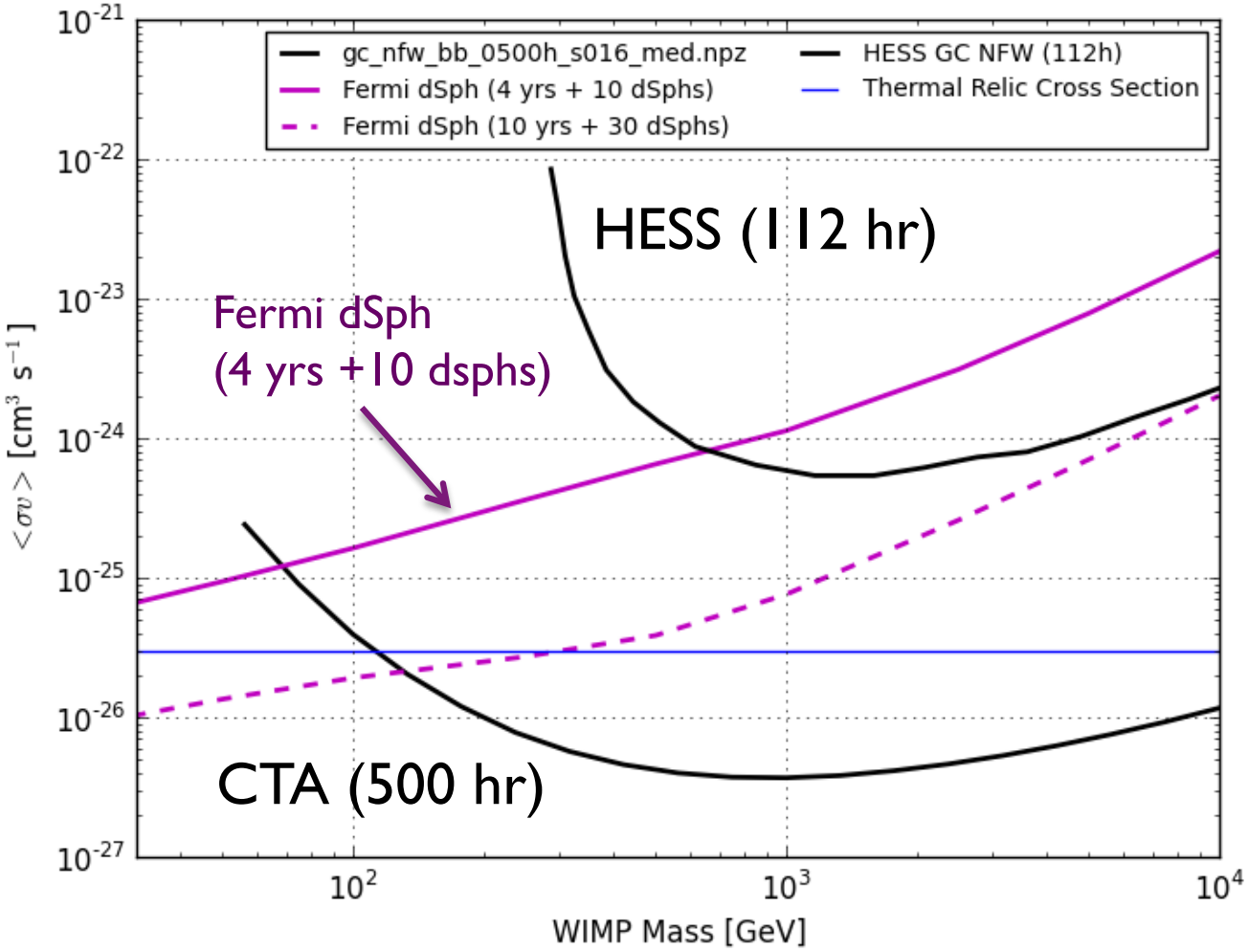




Simulated CTA observation
Bright flare from 4C 21.35
0.1 nG IGMF
EBL of Dominguez et al. 2011



# Matthew Wood/ CTA



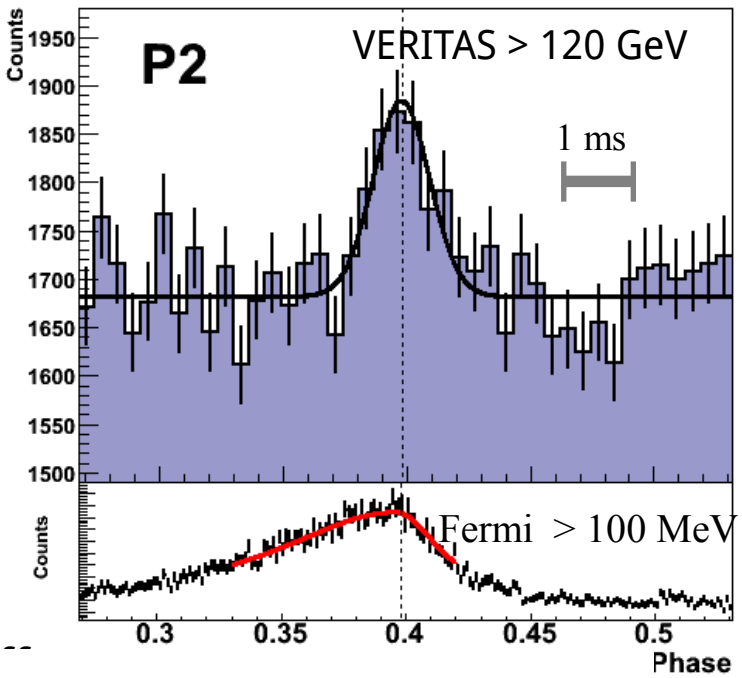

# Nepomuk Otte / Review

$$c'(E) = c + a \cdot \frac{E}{E_{\mathrm{LIV}}} + b \cdot \left(\frac{E}{E_{\mathrm{LIV}}}\right)^2$$

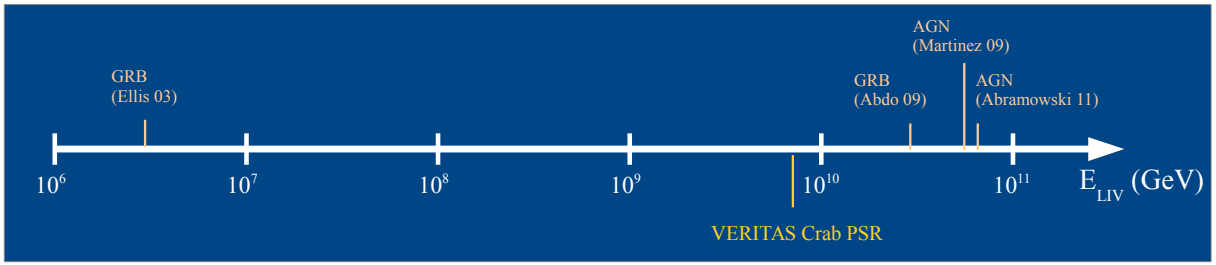
$$\Delta t_1 = \frac{d}{c} \cdot \frac{E_{\mathrm{h}} - E_{\mathrm{l}}}{E_{\mathrm{LIV}}} \quad \text{Linear term}$$

$$\Delta t_2 = \frac{d}{c} \cdot \frac{3}{2} \cdot \frac{E_{\mathrm{h}}^2 - E_{\mathrm{l}}^2}{E_{\mathrm{LIV}}^2} \quad \text{Quadratic term}$$

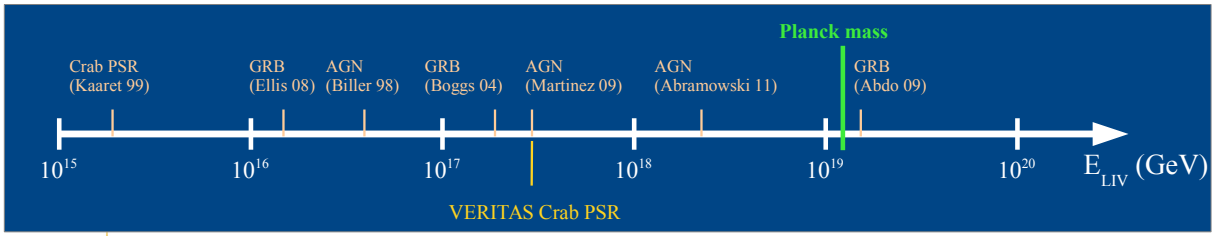
## Tests of Lorentz Invariance




**Quadratic term:**

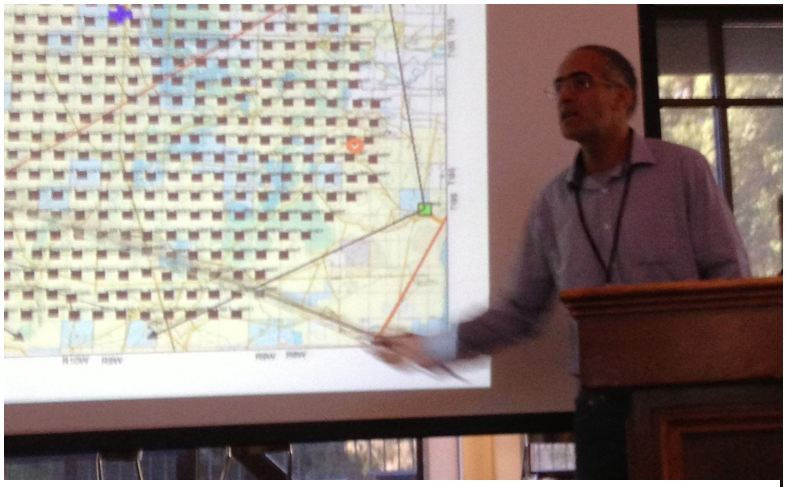


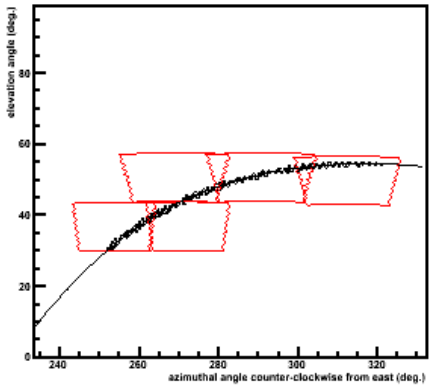

**Linear term:**

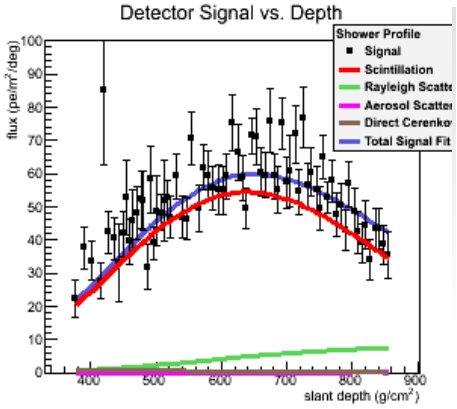


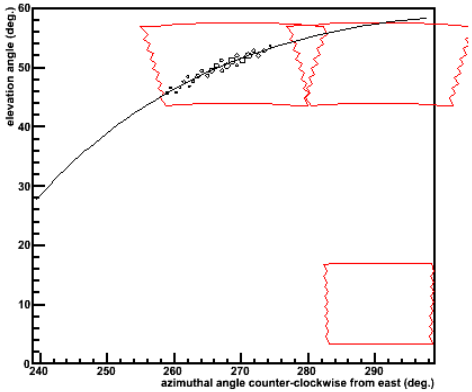
# Tareq AbuZayyad / TALE

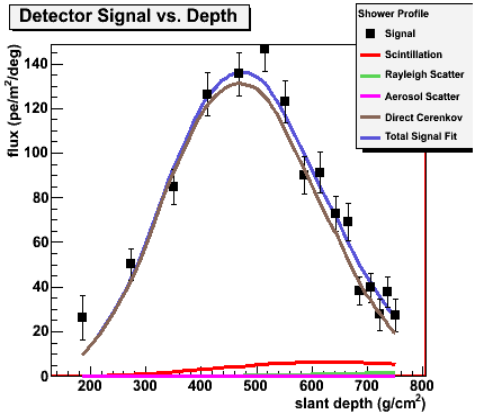
## Cherenkov Response

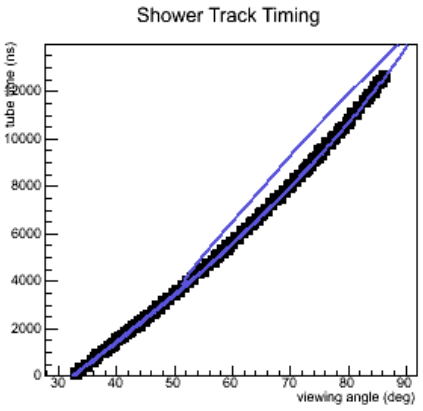




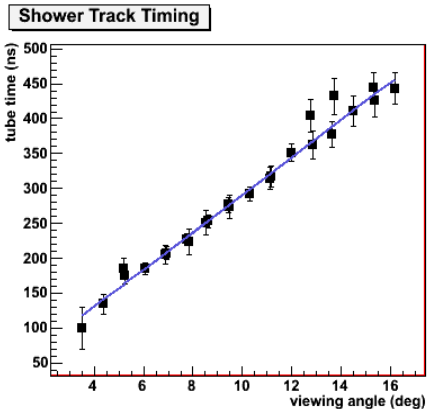

TALE event data

Event Starting: 7: 0:0.695370

Energy: 0.530 EeV
Shower max size: 3.565e+08 particles
Shower max depth: 631.247 g/cm$^2$
Profile Fit $\chi^2$/ndf: 1.2395

Rp Magnitude: 5.839 km
$\psi$ angle: 55.1 degrees

Shower azimuthal angle: 8.2 degrees
Shower zenith angle: 48.0 degrees
Angle to Magnetic field: 60.5 degrees




TALE event data

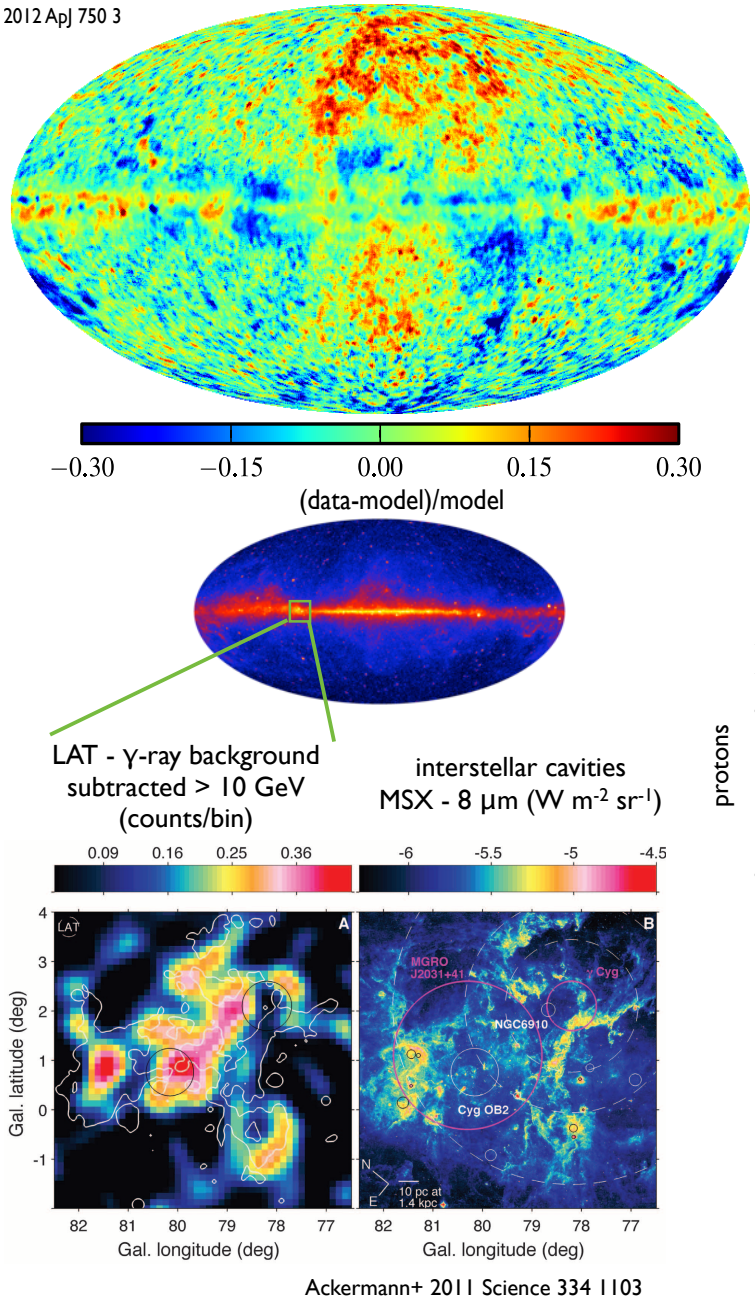
Event Starting: 0: 0:0.139663747441801

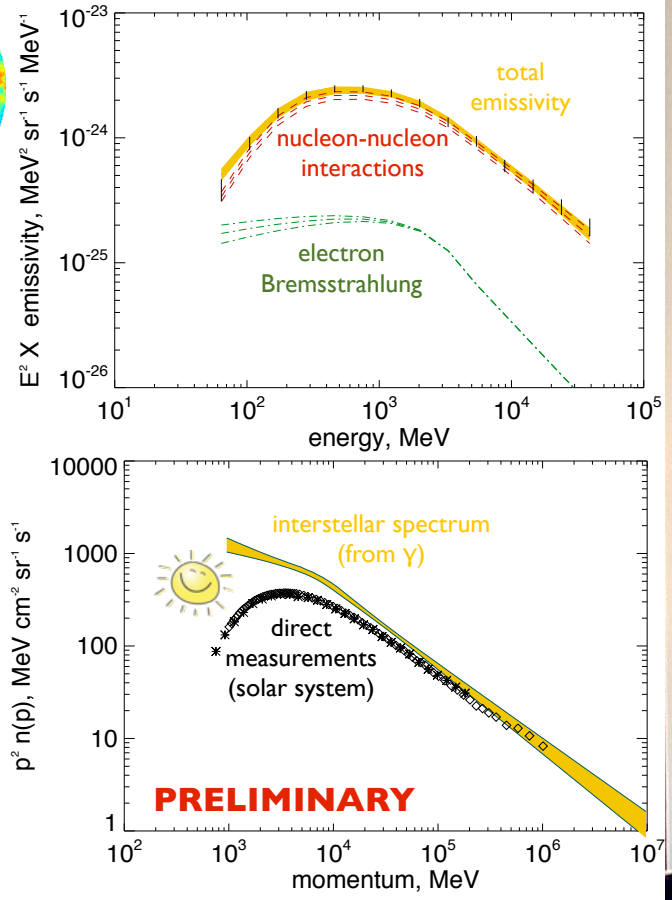
Energy: 9.241 PeV
Shower max size: 6.143e+06 particles
Shower max depth: 605.810 g/cm$^2$
Profile Fit $\chi^2$/ndf: 0.7362

Rp Magnitude: 0.912 km
$\psi$ angle: 106.9 degrees

Shower azimuthal angle: -80.1 degrees
Shower zenith angle: 35.0 degrees

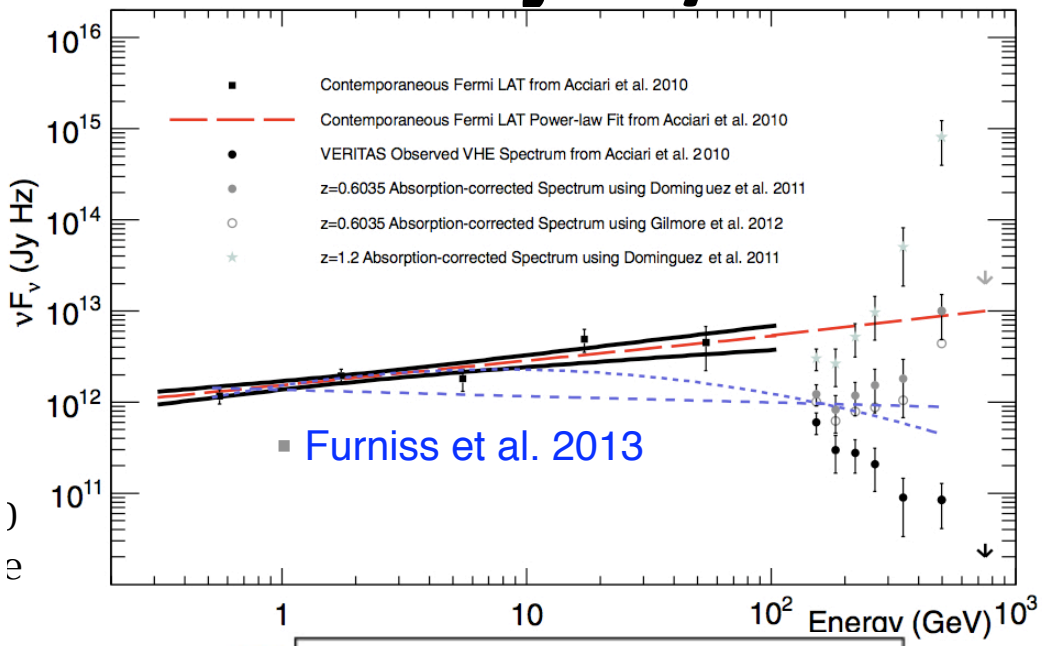
# Luigi Tibaldo / Fermi-LAT



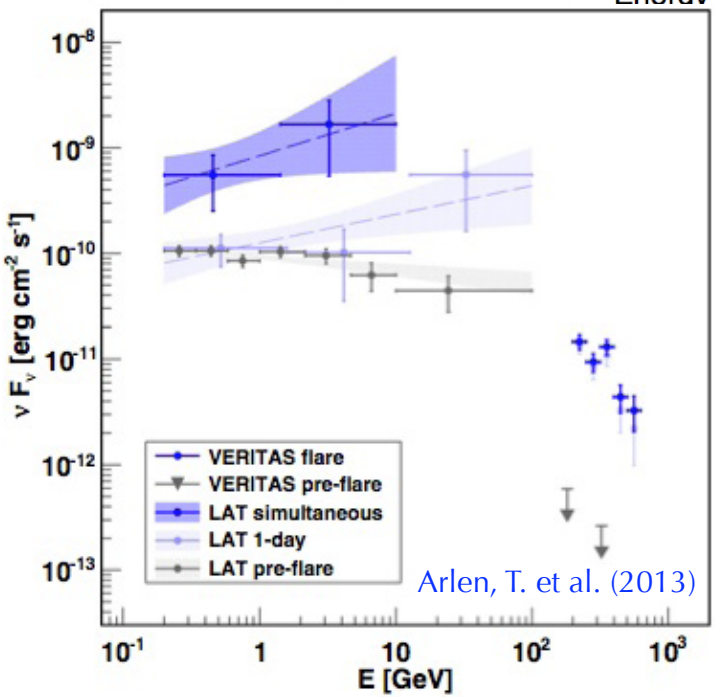



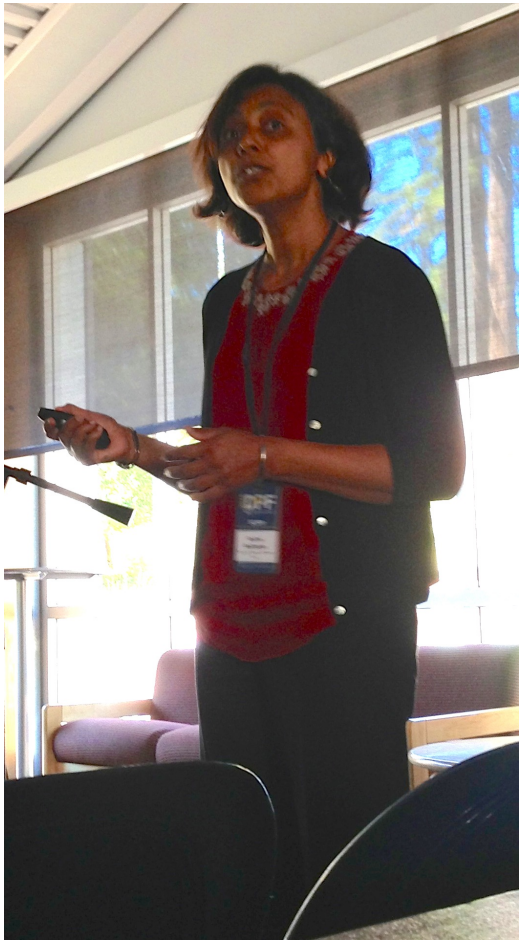

# Reshmi Mukherjee / Veritas

**PKS 1424+240**

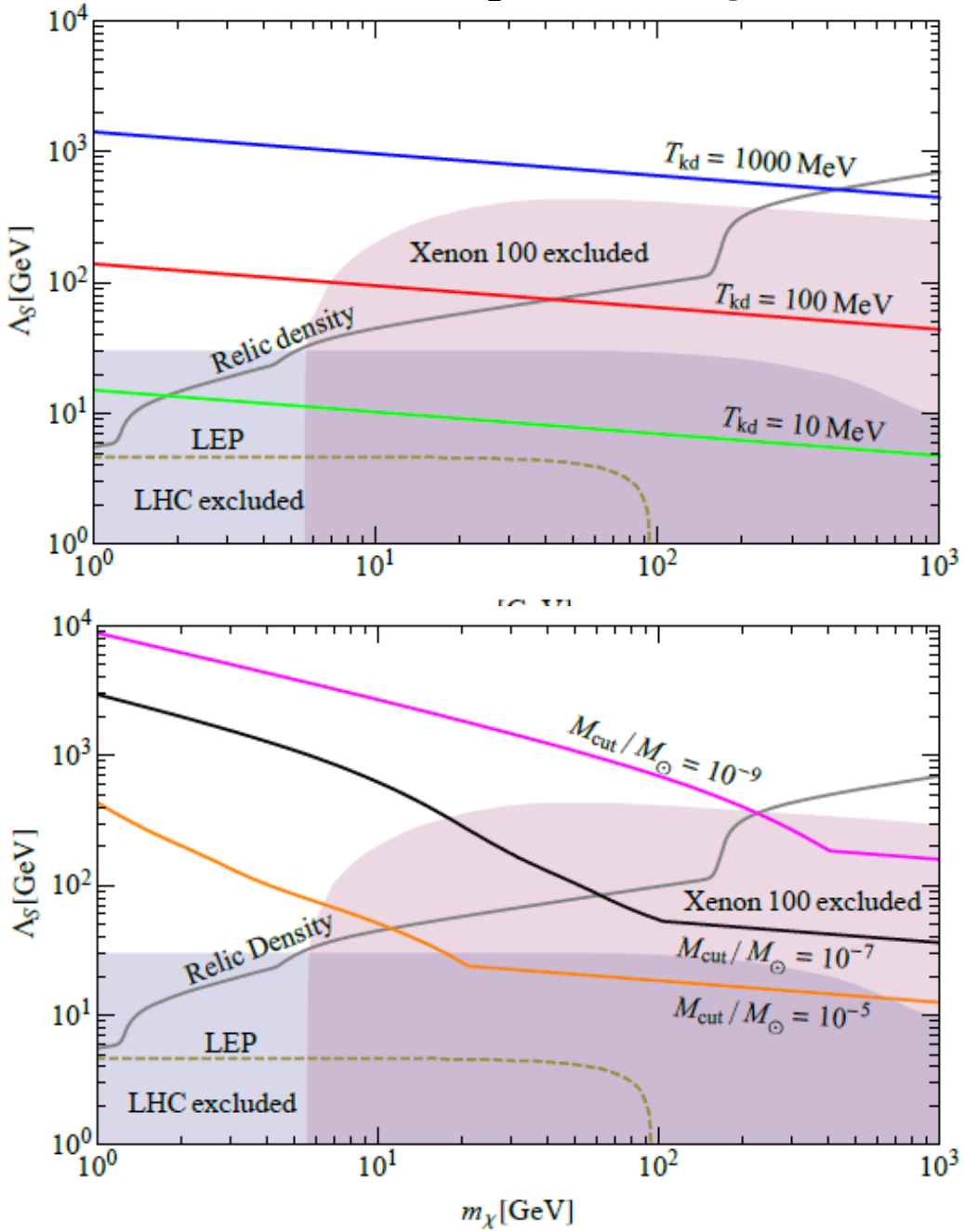



**BL Lacertae**

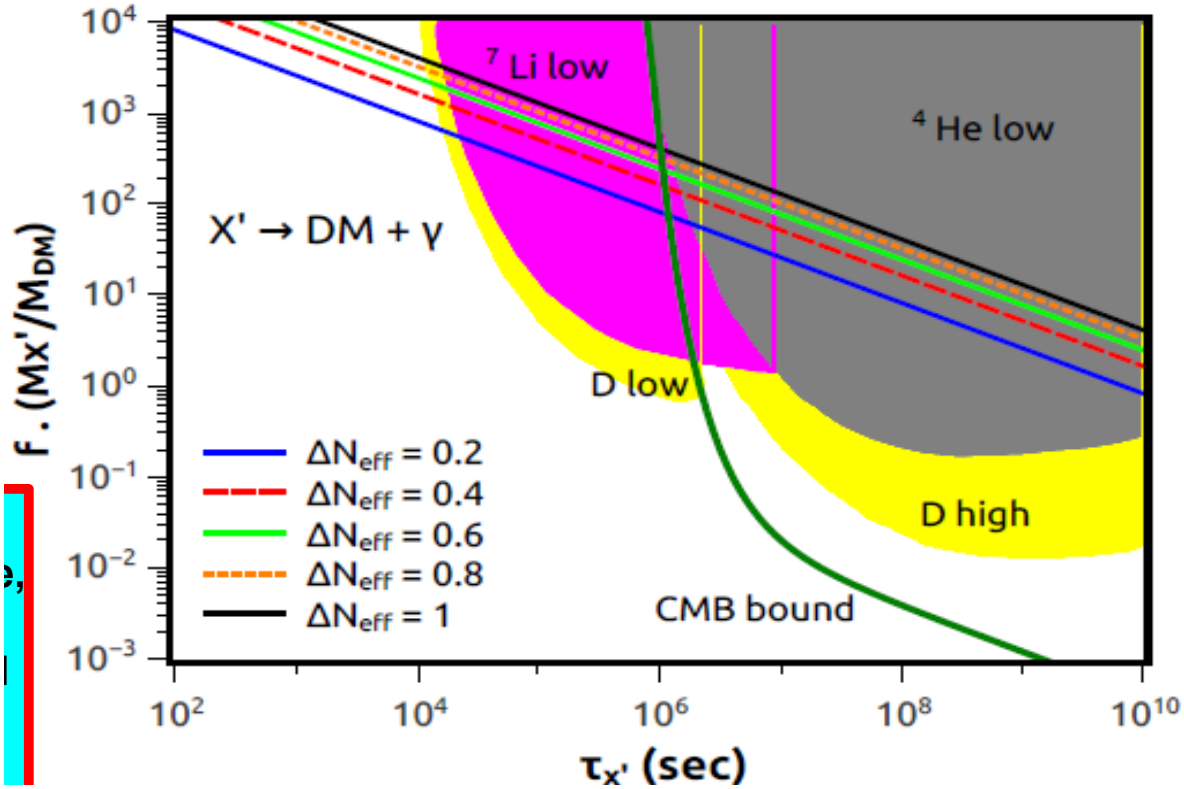


# William Shepherd/ Theory




# Farinaldo Queiroz / Theory



# Neutrinos : Earth > Cosmos
# (Dark Matter : Cosmos > Earth)

*The Average Energy of Disintegration of Radium E.*

By C. D. Ellis, Ph.D., Lecturer in the University of Cambridge, and W. A. Wooster, B.A., Charles Abercrombie Smith Student of Peterhouse, Cambridge.

(Communicated by Sir Ernest Rutherford, O.M., P.R.S.—Received August 3, 1927.)

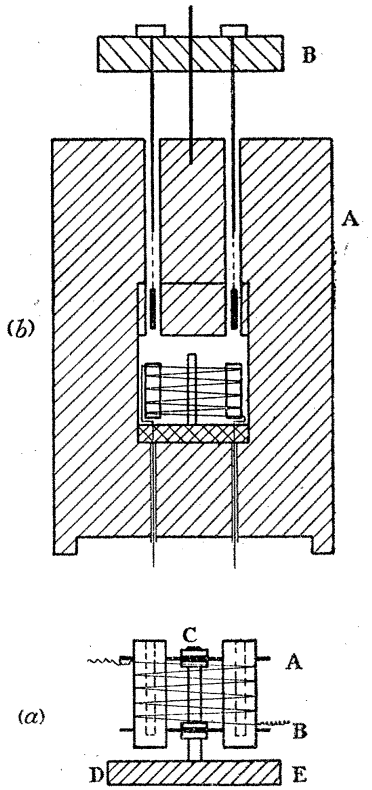



Fig. 2.

*Proc. R. Soc. Lond. A* 1927 **117**, doi: 10.1098/rspa.1927.0168,
published 1 December 1927

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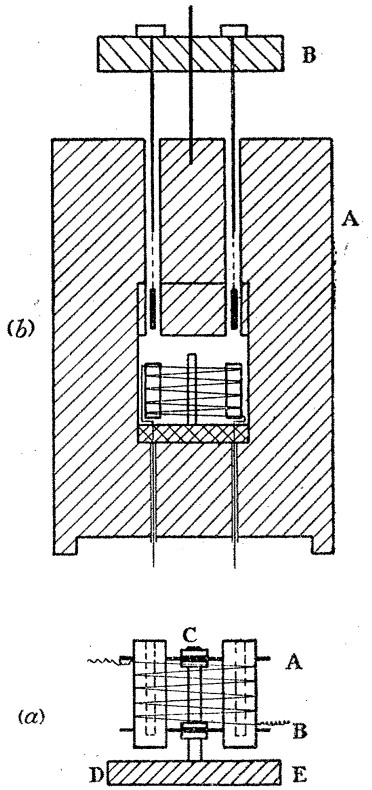


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*Proc. R. Soc. Lond. A* 1927 **117**, doi: 10.1098/rspa.1927.0168, published 1 December 1927

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## COSMOLOGICAL LIMITS TO THE NUMBER OF MASSIVE LEPTONS

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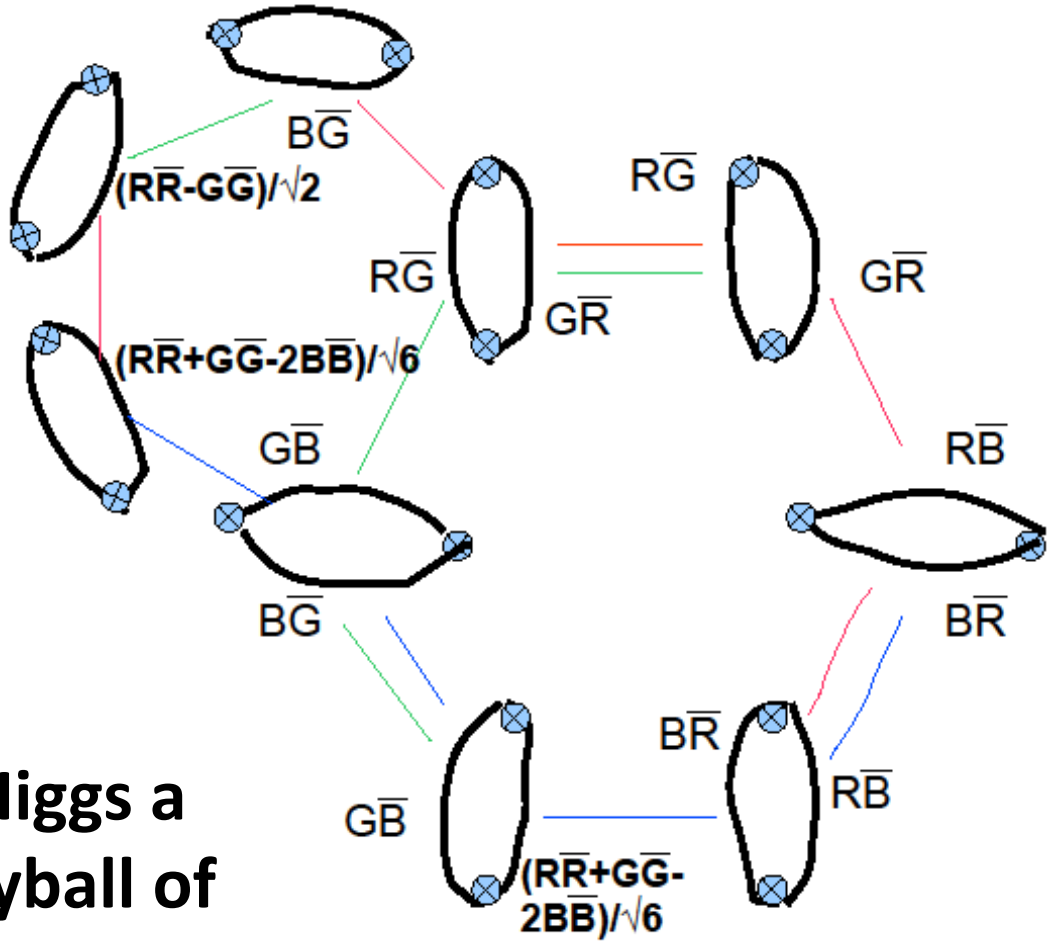
David N. SCHRAMM
*University of Chicago, Enrico Fermi Institute (LASR), 933 E 56th, Chicago, Ill. 60637, USA*

James E. GUNN
*University of Chicago and California Institute of Technology[2], USA*

Received 29 November 1976

If massive leptons exist, their associated neutrinos would have been copiously produced in the early stages of the hot, big bang cosmology. These neutrinos would have contributed to the total energy density and would have had the effect of speeding up the expansion of the universe. The effect of the speed-up on primordial nucleosynthesis is to produce a higher abundance of $^4$He. It is shown that observational limits to the primordial abundance of $^4$He lead to the constraint that the total number of types of heavy lepton must be less than or equal to 5.

# Kazuyoshi Kitazawa / Theory




**Ur-Higgs a buckyball of glueballs!!!**

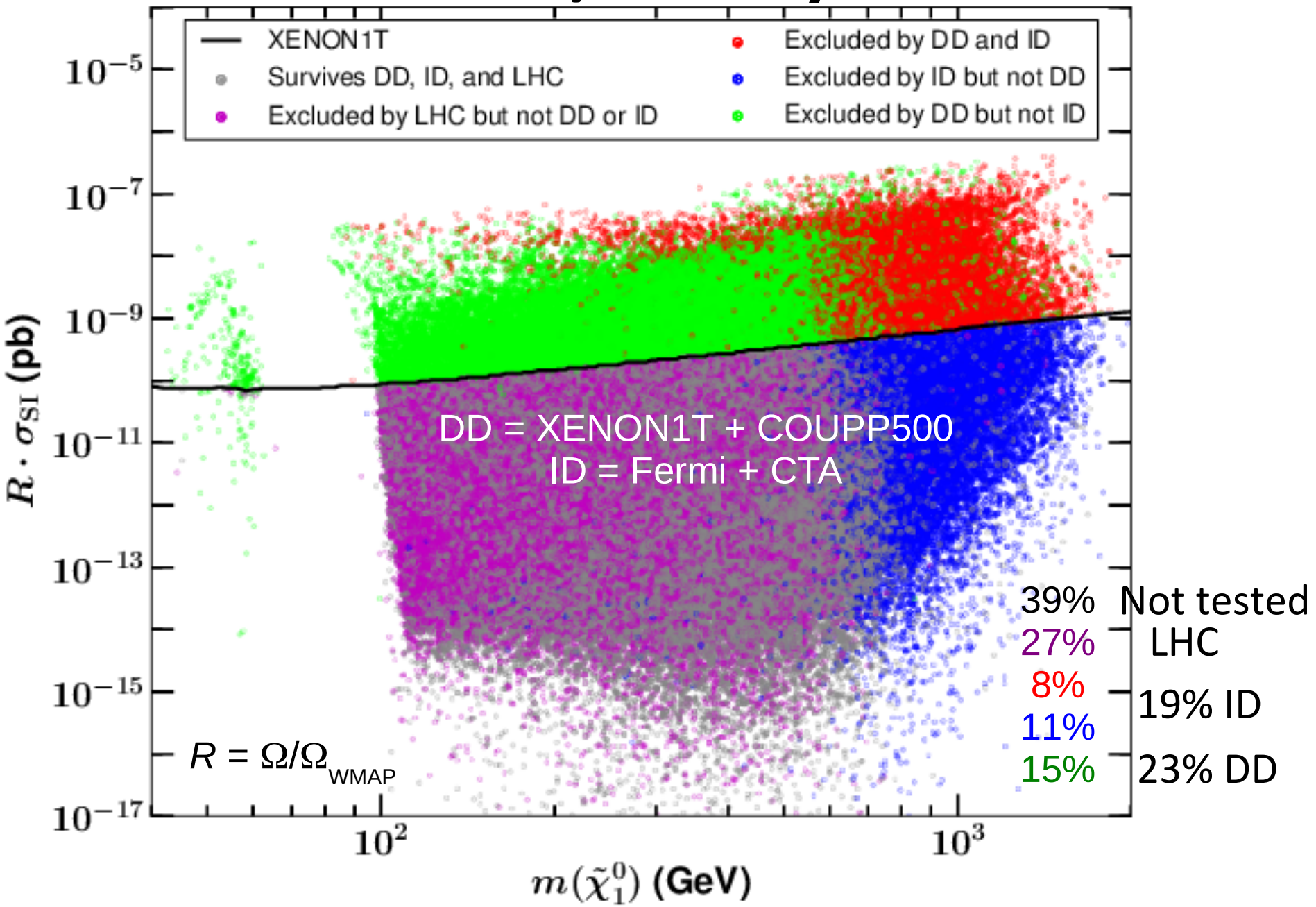


# Ahmed Ismail/ Theory

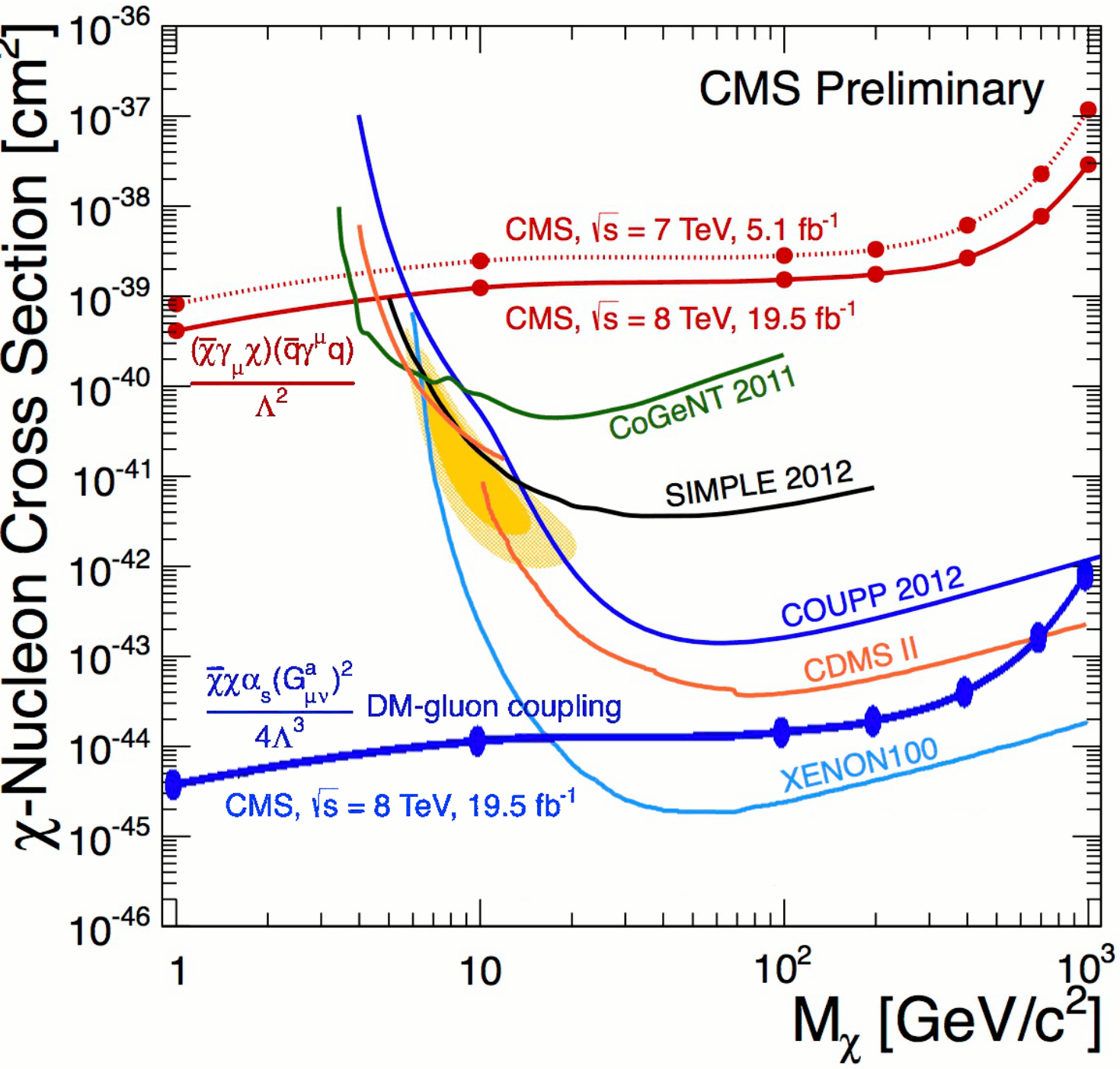
## The phenomenological MSSM

- The full MSSM has 105 new free parameters, many of which are strongly constrained
- Impose minimal flavor violation, diagonal sparticle mass matrices with degenerate first two generations, CP conservation
- Generated random points in resulting 19-dim. space passing precision EW, flavor, DM constraints
- Produced set of ~2.2 x $10^5$ consistent models in late 2011

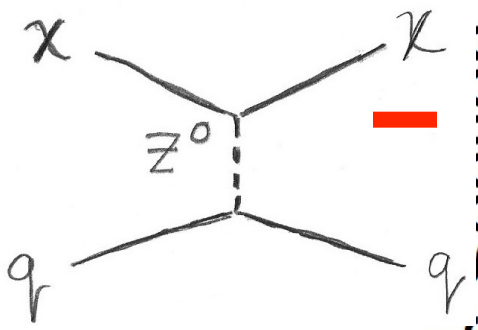
# Ahmed Ismail/ Theory

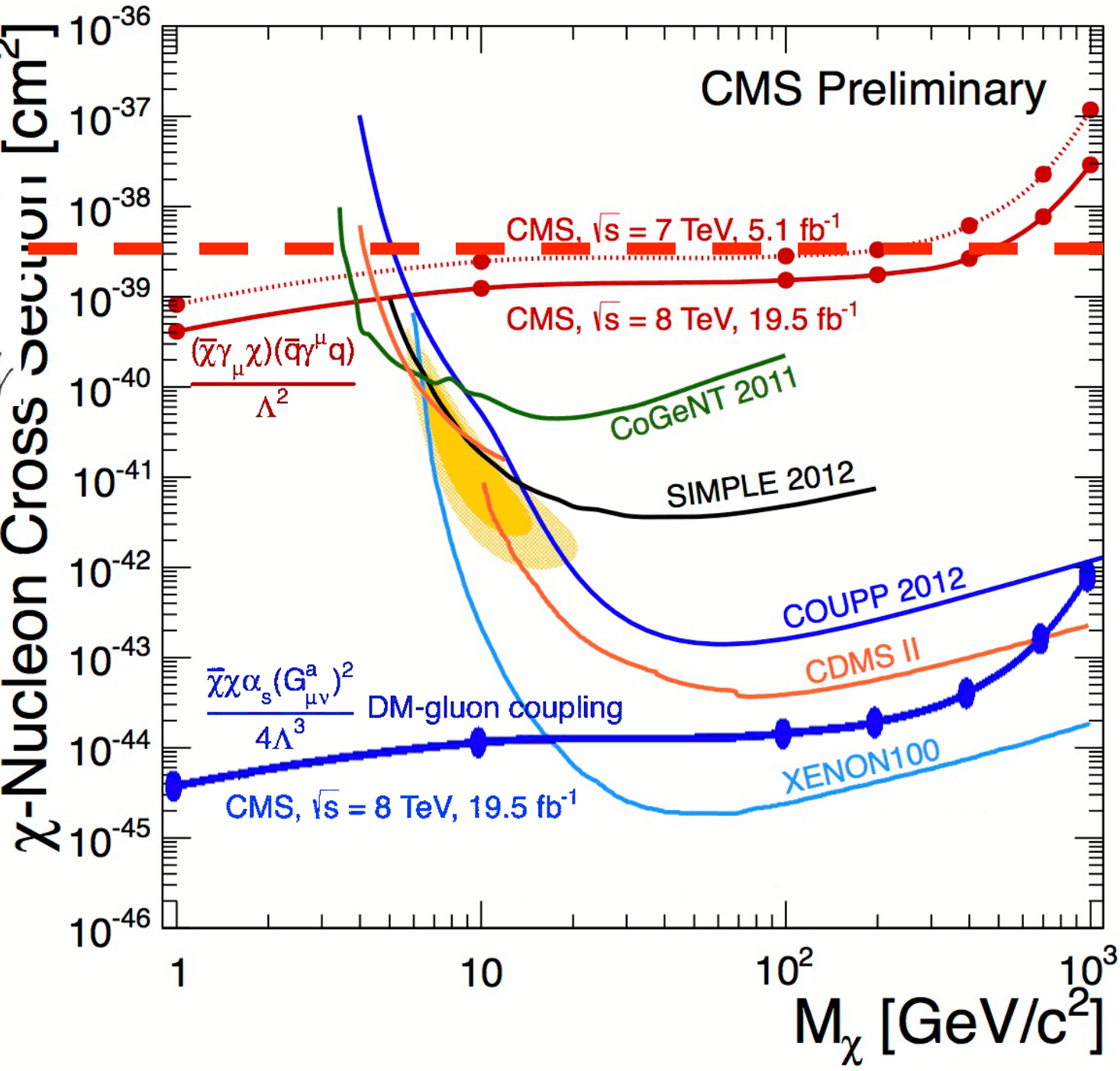


# Spin Independent

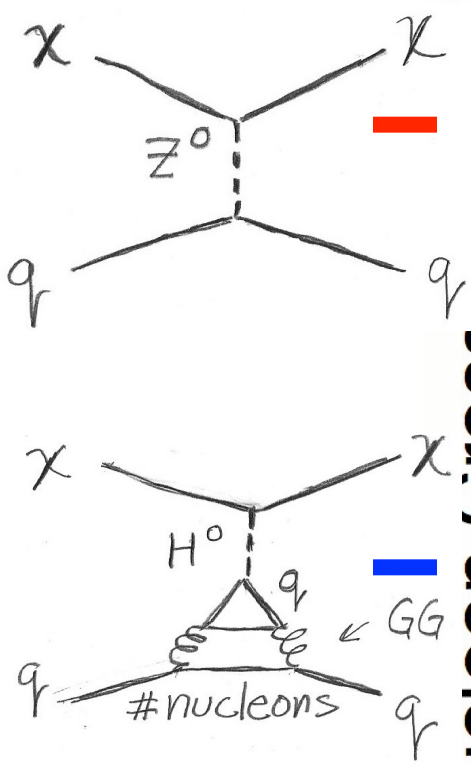


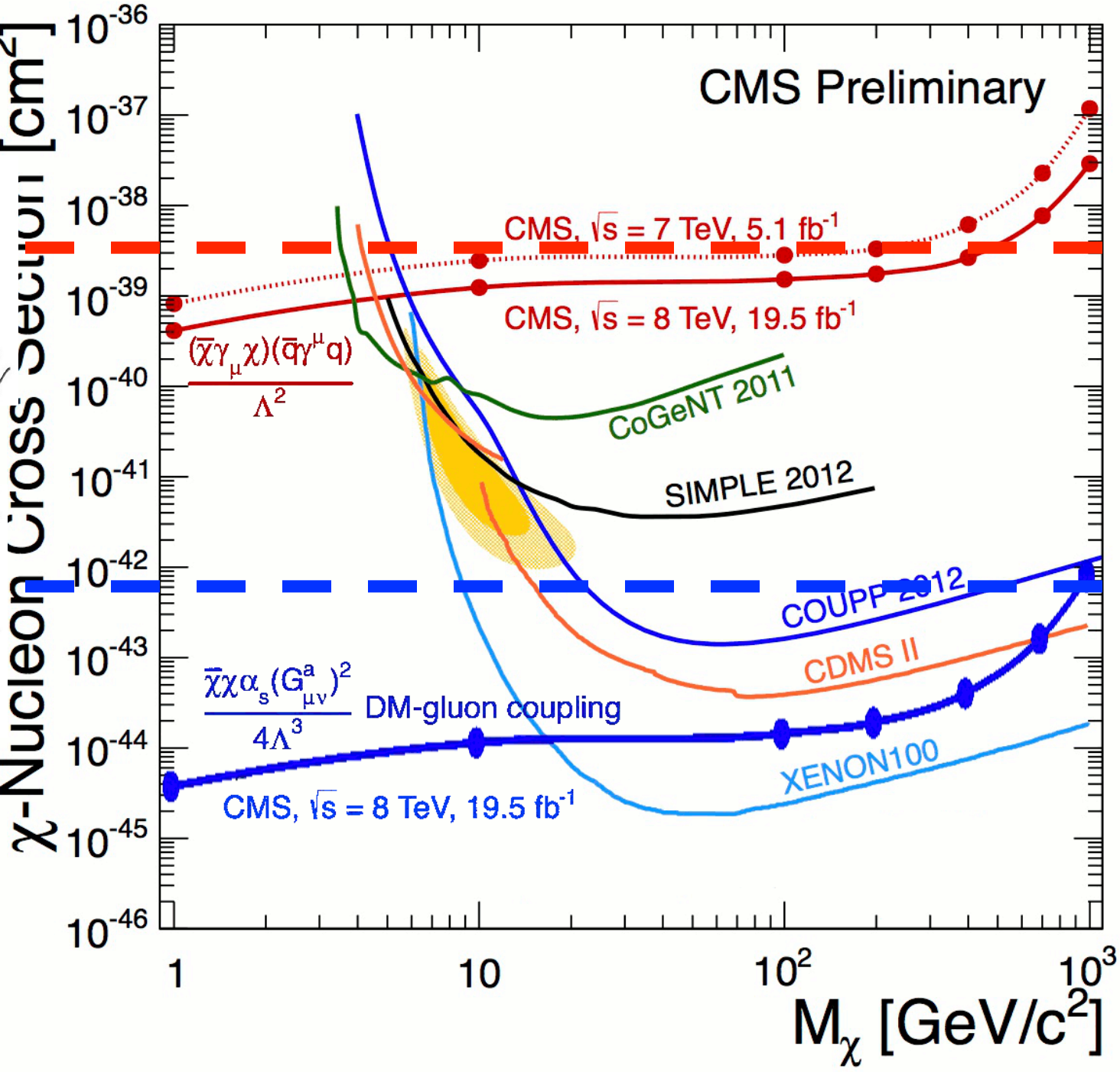
# Spin Independent

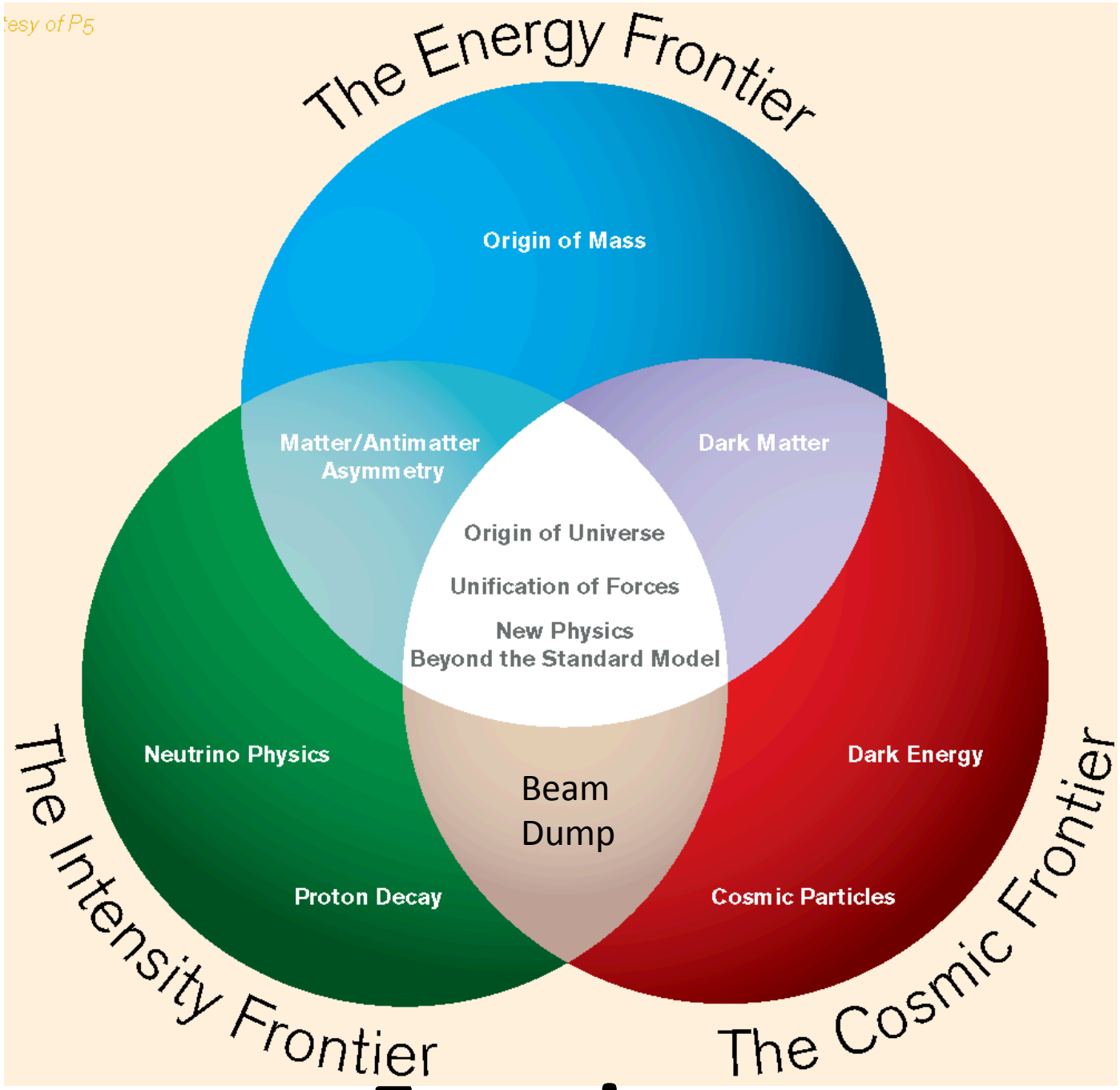


# Spin Independent

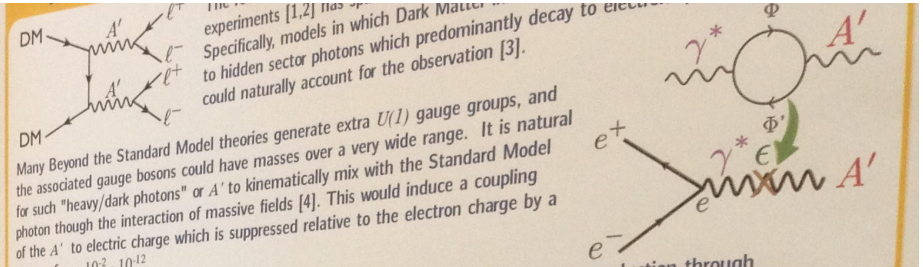



tesy of P5
The Energy Frontier
Origin of Mass
Matter/Antimatter Asymmetry
Dark Matter
Origin of Universe
Unification of Forces
New Physics Beyond the Standard Model
Neutrino Physics
Beam Dump
Dark Energy
Proton Decay
Cosmic Particles
The Intensity Frontier
The Cosmic Frontier

# Frontiers

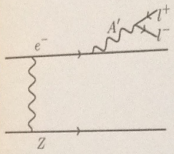
# Omar Moreno
# Heavy Photon Search




experiments [1,2] has s... Specifically, models in which Dark Matter ... to hidden sector photons which predominantly decay to elect... could naturally account for the observation [3].

Many Beyond the Standard Model theories generate extra $U(1)$ gauge groups, and the associated gauge bosons could have masses over a very wide range. It is natural for such "heavy/dark photons" or $A'$ to kinematically mix with the Standard Model photon though the interaction of massive fields [4]. This would induce a coupling of the $A'$ to electric charge which is suppressed relative to the electron charge by a factor of $\varepsilon \sim 10^{-2} - 10^{-12}$.




The coupling of the $A'$ to electric charge allows for its production through bremsstrahlung, subsequently decaying to $e^+e^-$ or $\mu^+\mu^-$ pairs. The HPS experiment will utilize a compact large acceptance forward spectrometer consisting of a silicon microstrip detector along with a lead tungstate electromagnetic calorimeter and a muon detector, to measure the invariant mass and vertex position of the $A'$.

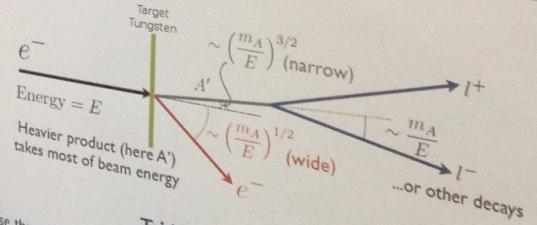

[1] O. Adriani et al. [PAMELA Collaboration], Nature 458, 607 (2009)
[2] M. Ackermann et al. [Fermi LAT Collaboration], Phys. Rev. D 82, 092004 (2010)
[3] N. Arkani-Hamed, D. P. Finkbeiner, T. R. Slatyer and N. Weiner, Phys. Rev. D 79, 015014 (2009)
[4] B. Holdom, Phys. Lett. B 166, 196 (1986), P. Galison et al, Phys. Lett. B 136 (1984) 279


## Signals and Backgrounds

### Heavy Photon Signal

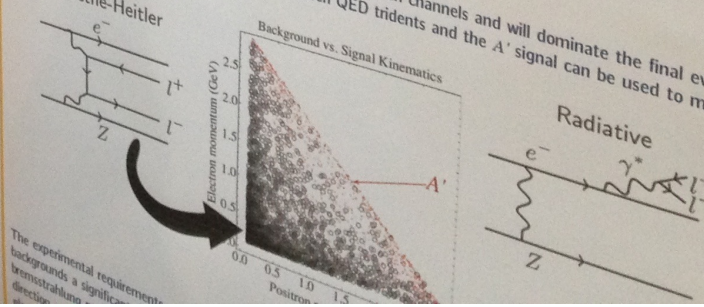
$A'$ particles are generated in electron collisions on a fixed target by a process analogous to ordinary photon bremsstrahlung. The rate and kinematics of $A'$ radiation differ from massless bremsstrahlung in several important ways:

- The total $A'$ production cross section when using a fix target setup is $\sigma \sim \alpha^3 Z^2 \varepsilon^2 / (m_{A'})^2$ and is suppressed relative to photon bremsstrahlung by a factor $\sim (m_e)^2 \varepsilon^2 / (m_{A'})^2$
- The $A'$ is produced at small angles while the opening angle of its decay products is $\sim m_{A'}/E_{\text{beam}}$
- The $A'$ bremsstrahlung spectrum is sharply peaked a $x = E_{A'}/E_{\text{beam}} = 1 \Rightarrow$ results in the produced $A'$ carrying nearly all of the beam energy




### Trident Backgrounds

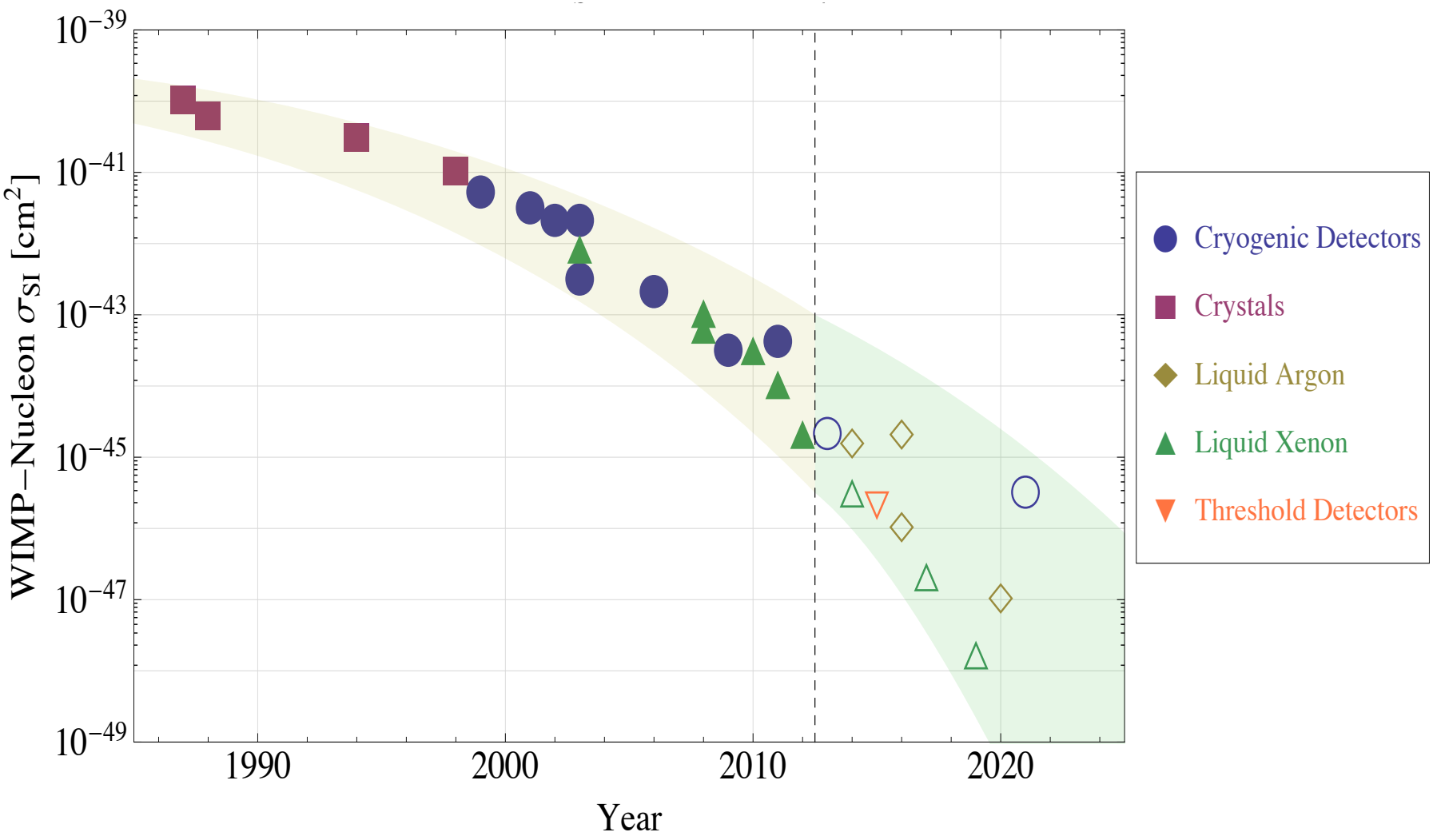
QED tridents comprise the primary background to the $A' \to l^+l^-$ search channels and will dominate the final event sample. However, the stark kinematic differences between QED tridents and the $A'$ signal can be used to maximize the signal to background ratio.



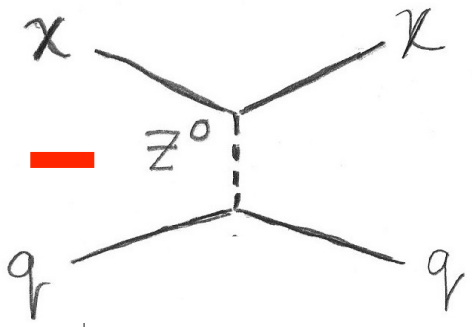

The experimental requirement... backgrounds a signific... bremsstrahlung... direction...

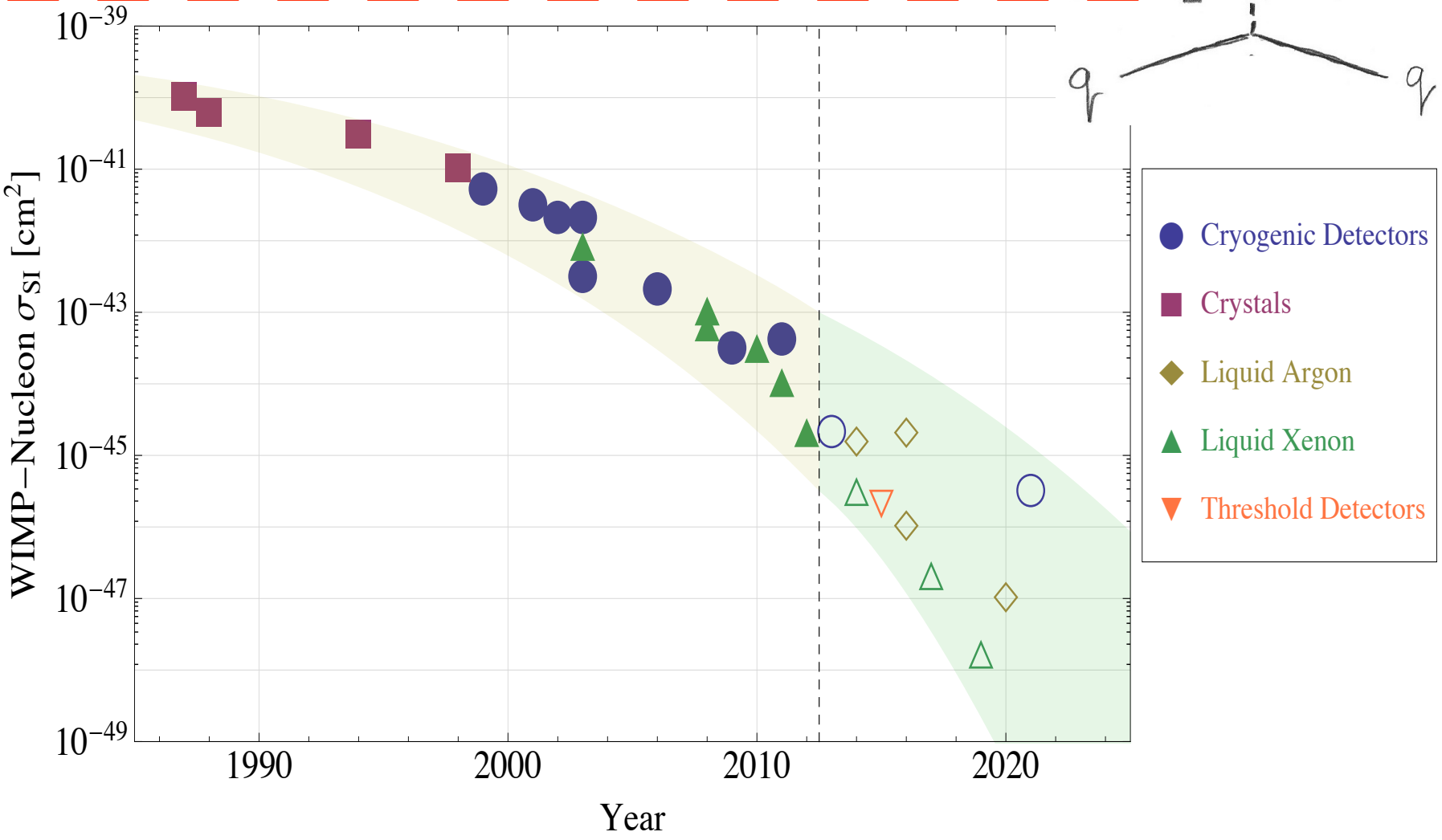
# Searches
# for
# Direct Interactions
# of
# Dark Matter

# Spin Independent, 50 GeV

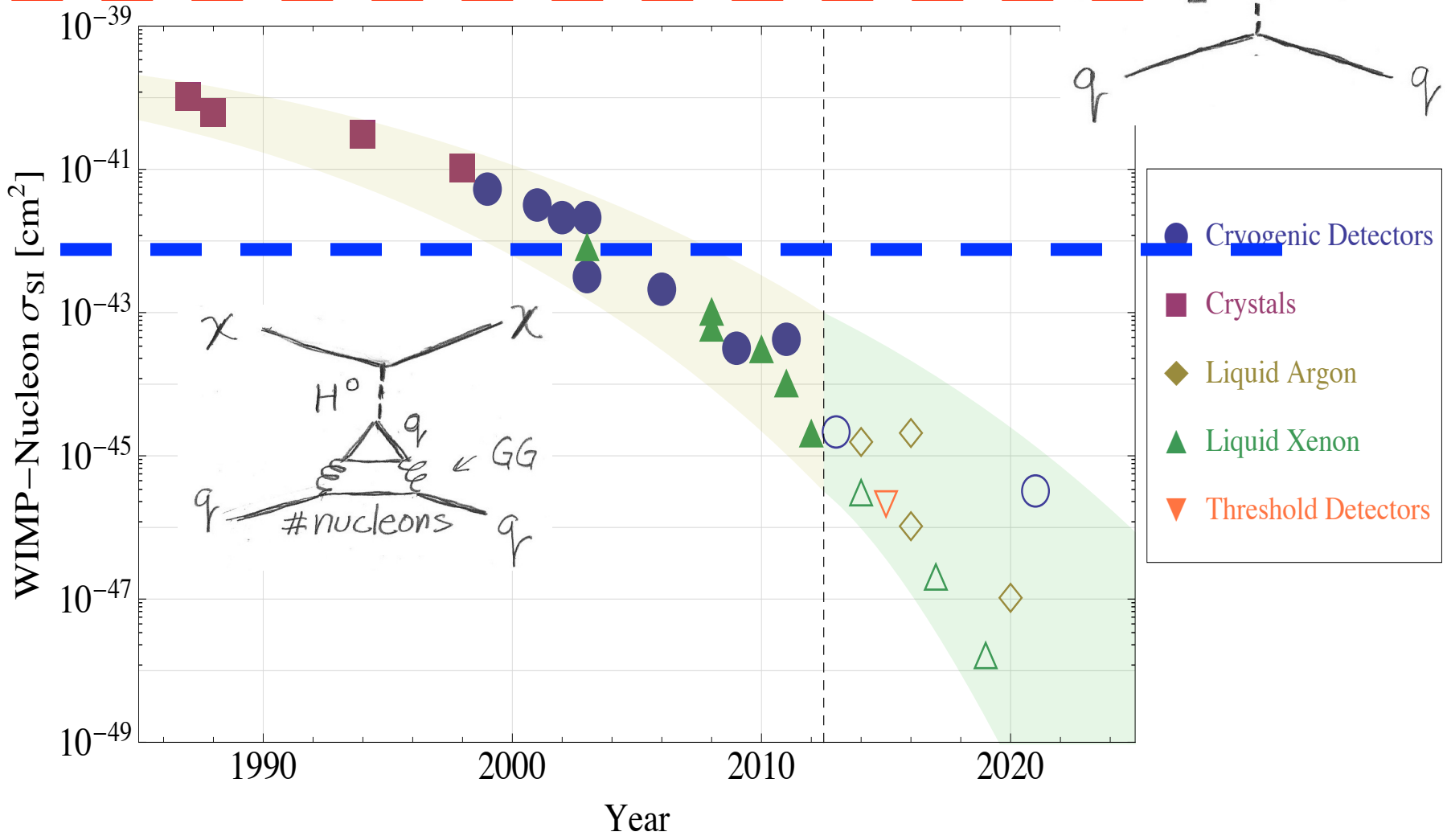


# Spin Independent, 50 GeV

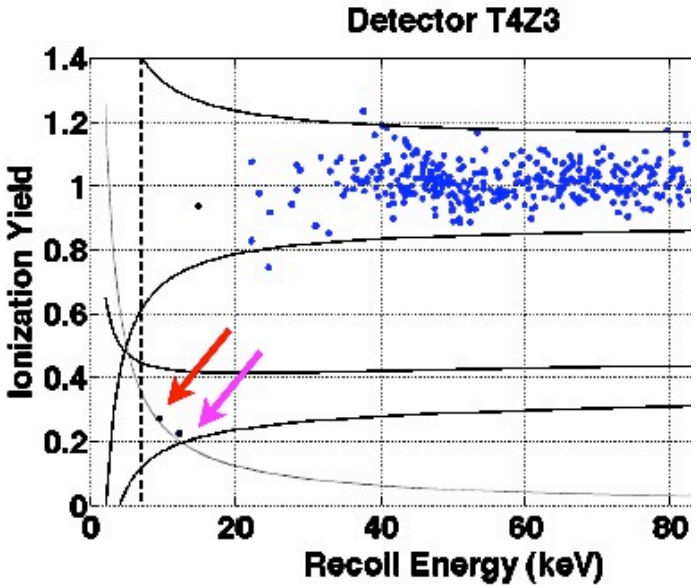


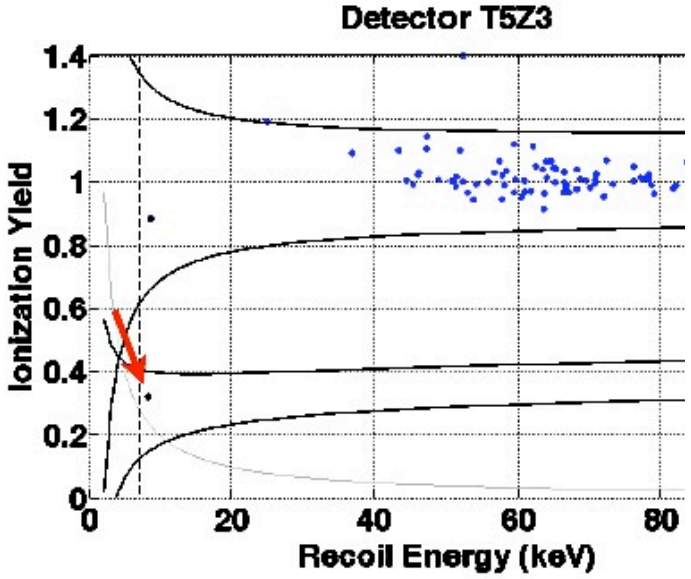



# Spin Independent, 50 GeV



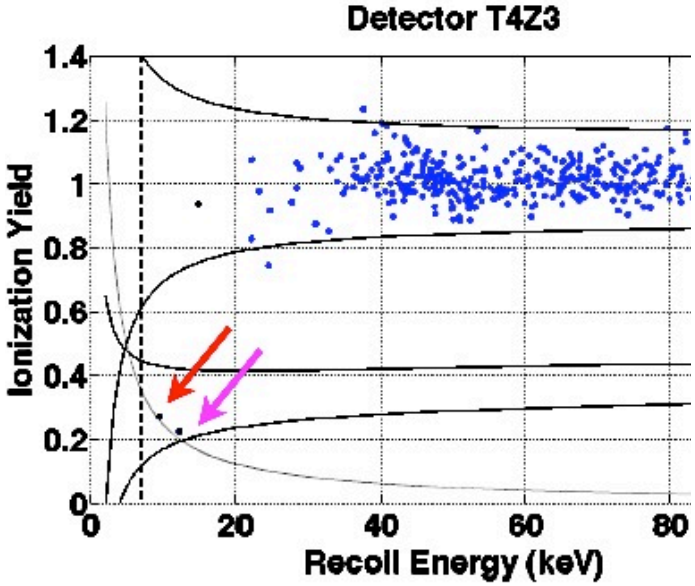
# Prisca Cushman / CDMS

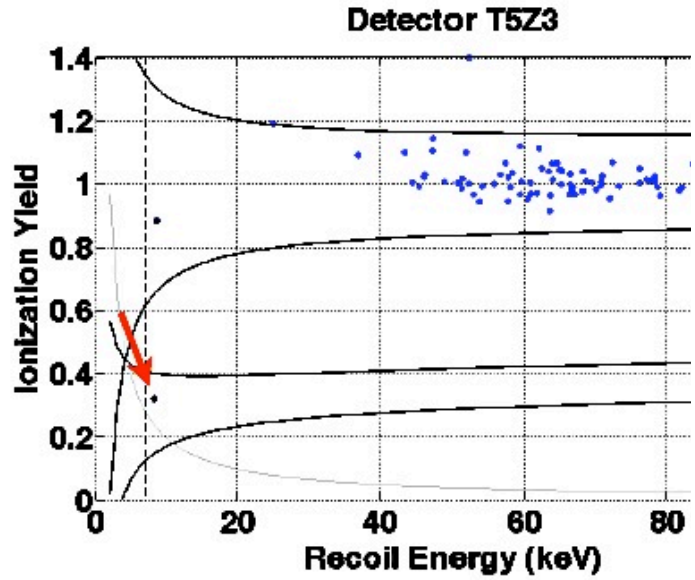


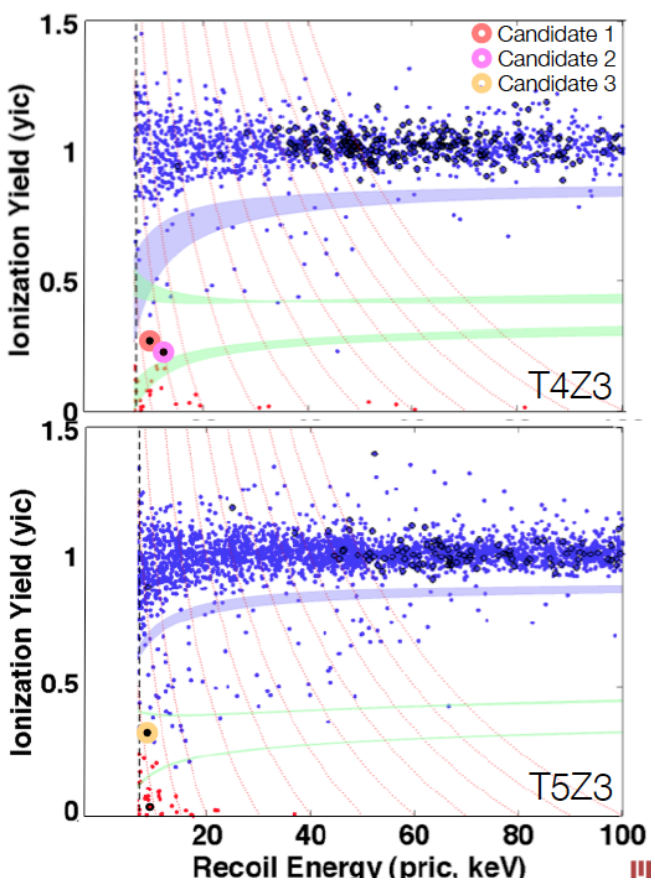




$$0.41^{+0.20}_{-0.08}(stat.)^{+0.28}_{-0.24}(syst.)$$

# Prisca Cushman / CDMS




$$0.41^{+0.20}_{-0.08}(stat.)^{+0.28}_{-0.24}(syst.)$$

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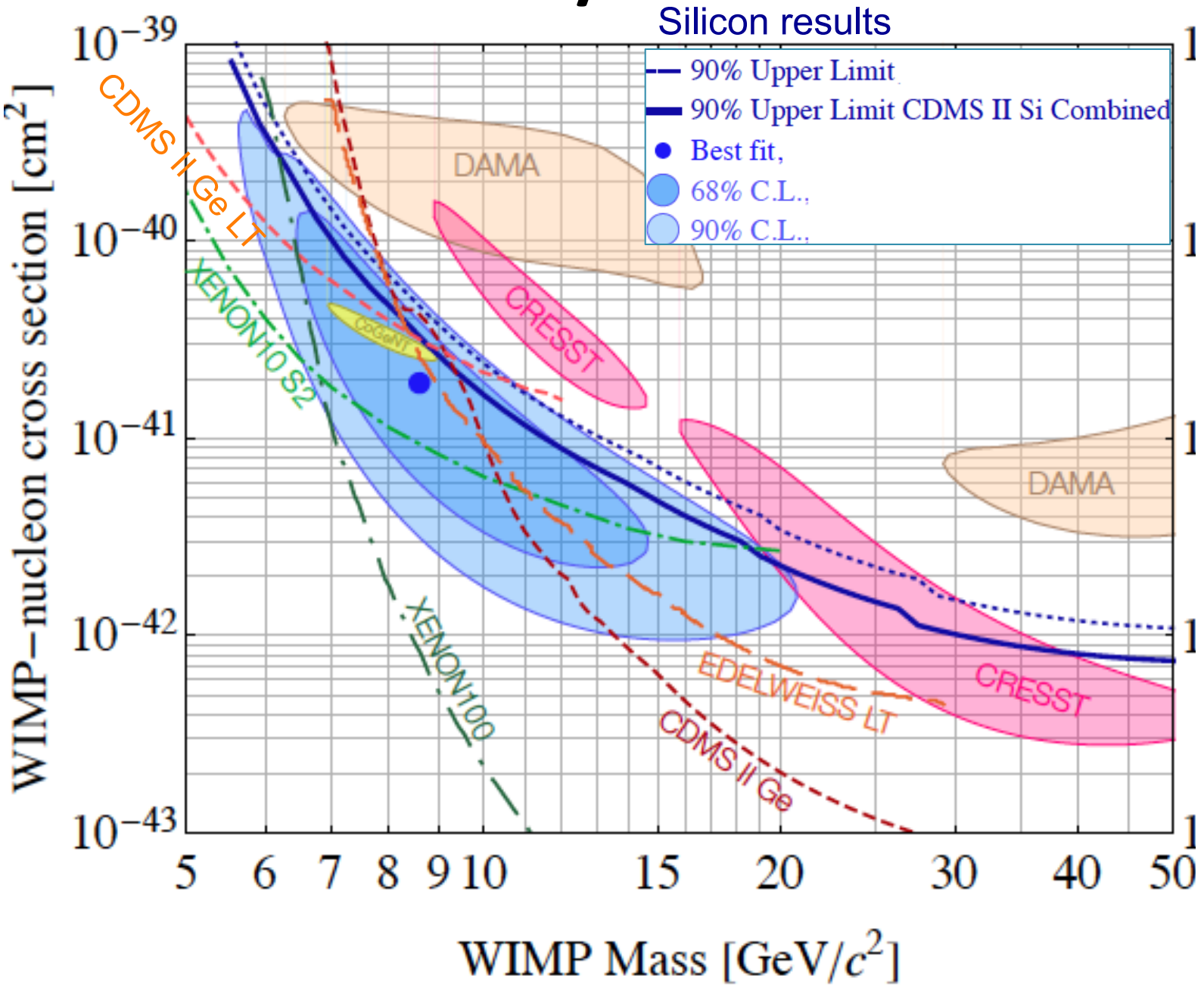
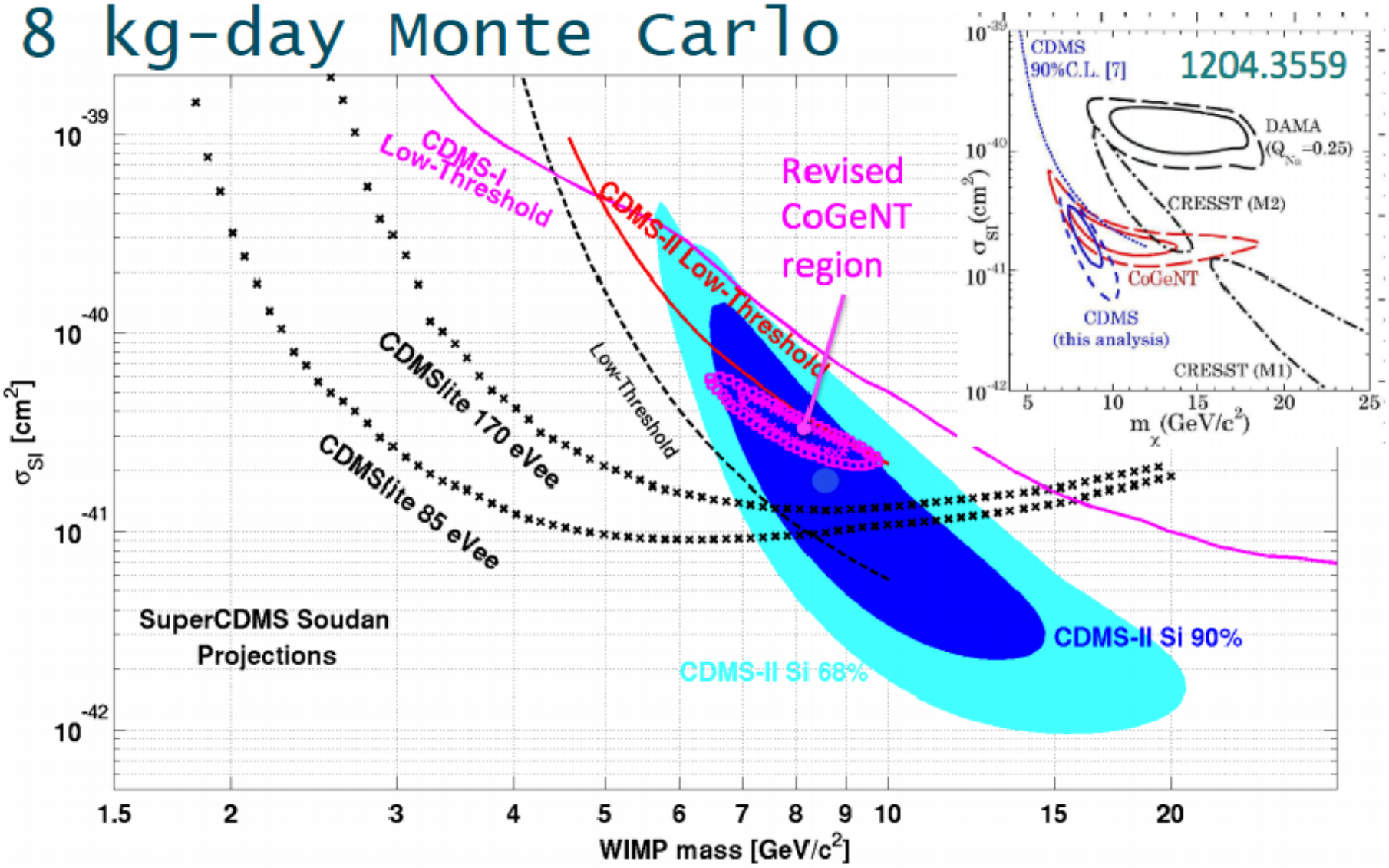
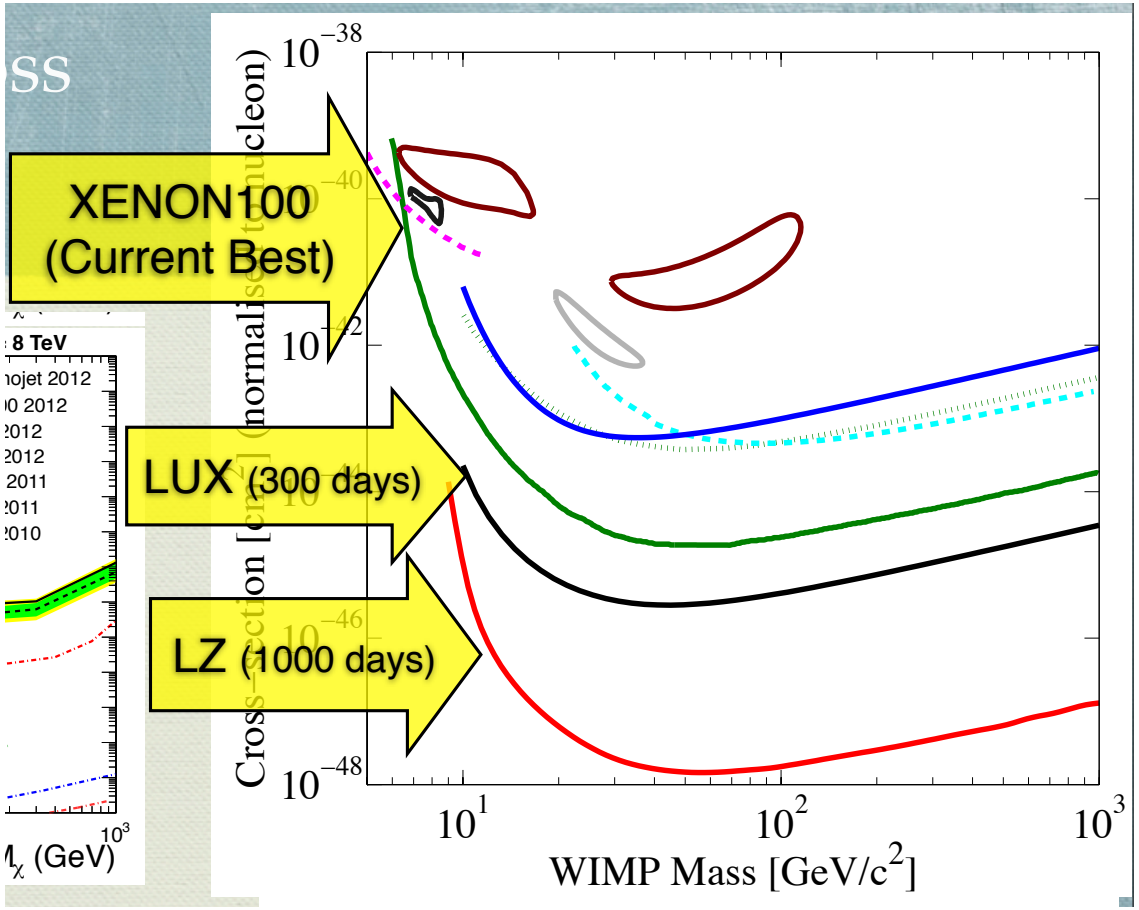


# Prisca Cushman / CDMS

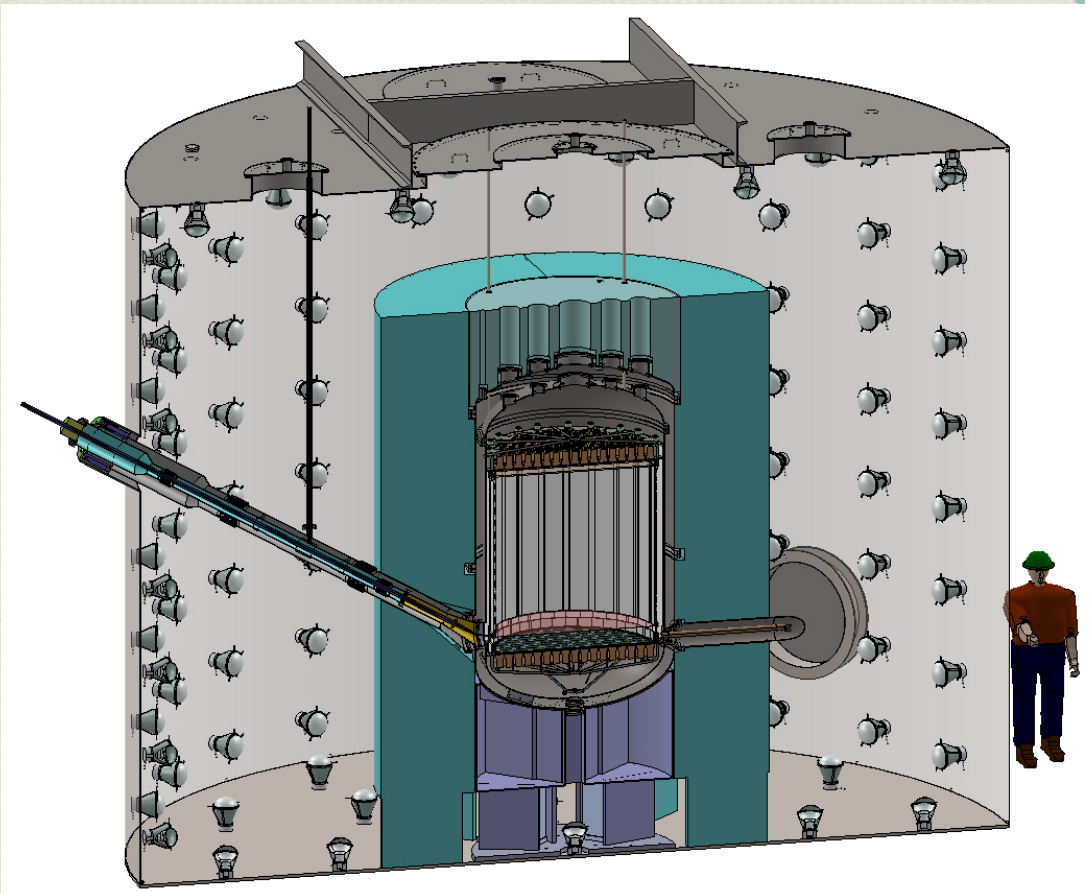


# Monica Pangilinan/ LUX-LZ




# Scaling up: The LZ Experiment

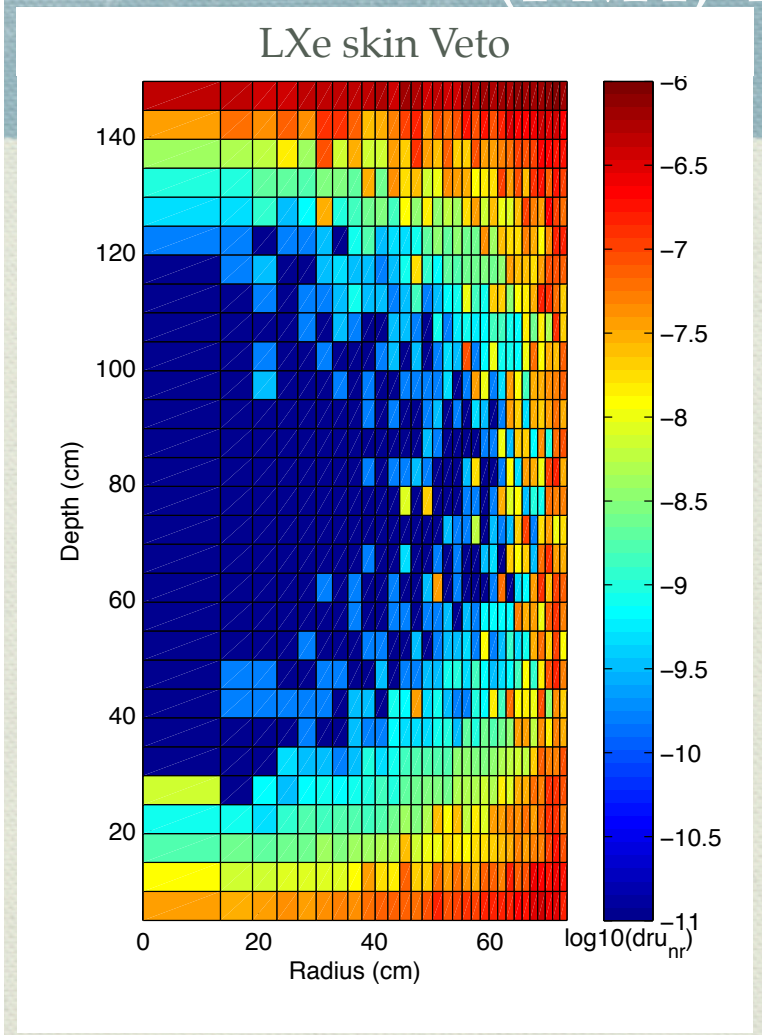
- LUX + ZEPLIN collaboration
- 7.2 tonnes ~~370 kg~~ liquid Xenon time projection chamber (TPC)
- detector in 8m x 6m water tank
- 4850 ft underground at Homestake mine in Lead, SD
- low radioactivity Ti
- ~500 R11410 ~~122 R8778~~ PMTs for detection
- PTFE reflector cage
- Thermosyphon for cooling Xe to ~170K

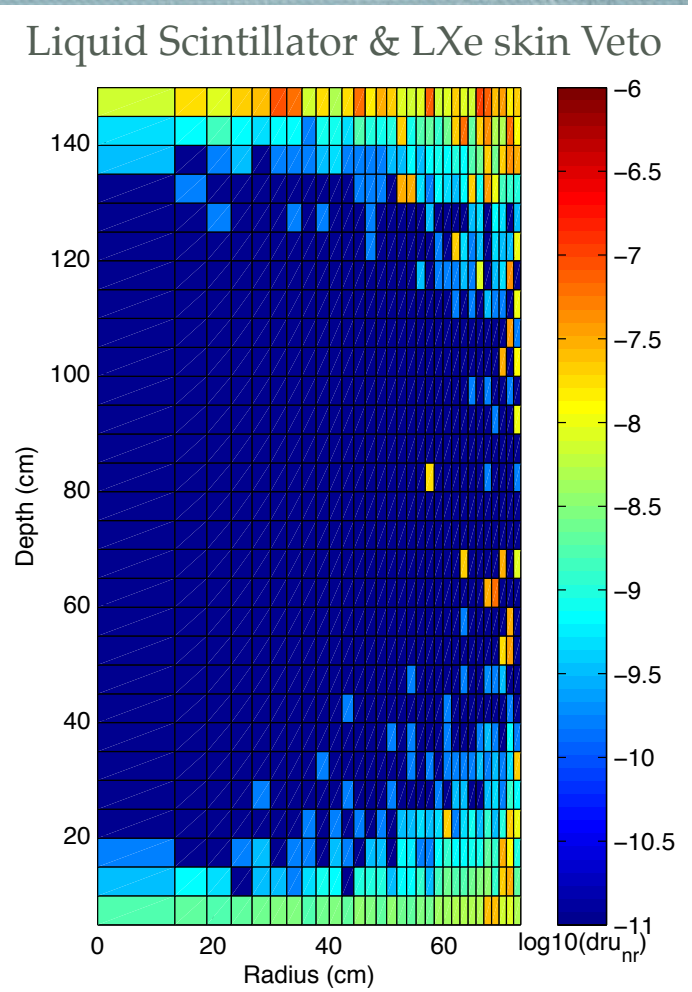


Addition of liquid scintillator veto outside Ti cryostats and instrument liquid Xe skin outside of field cage

# Monica Pangilinan/ LUX-LZ

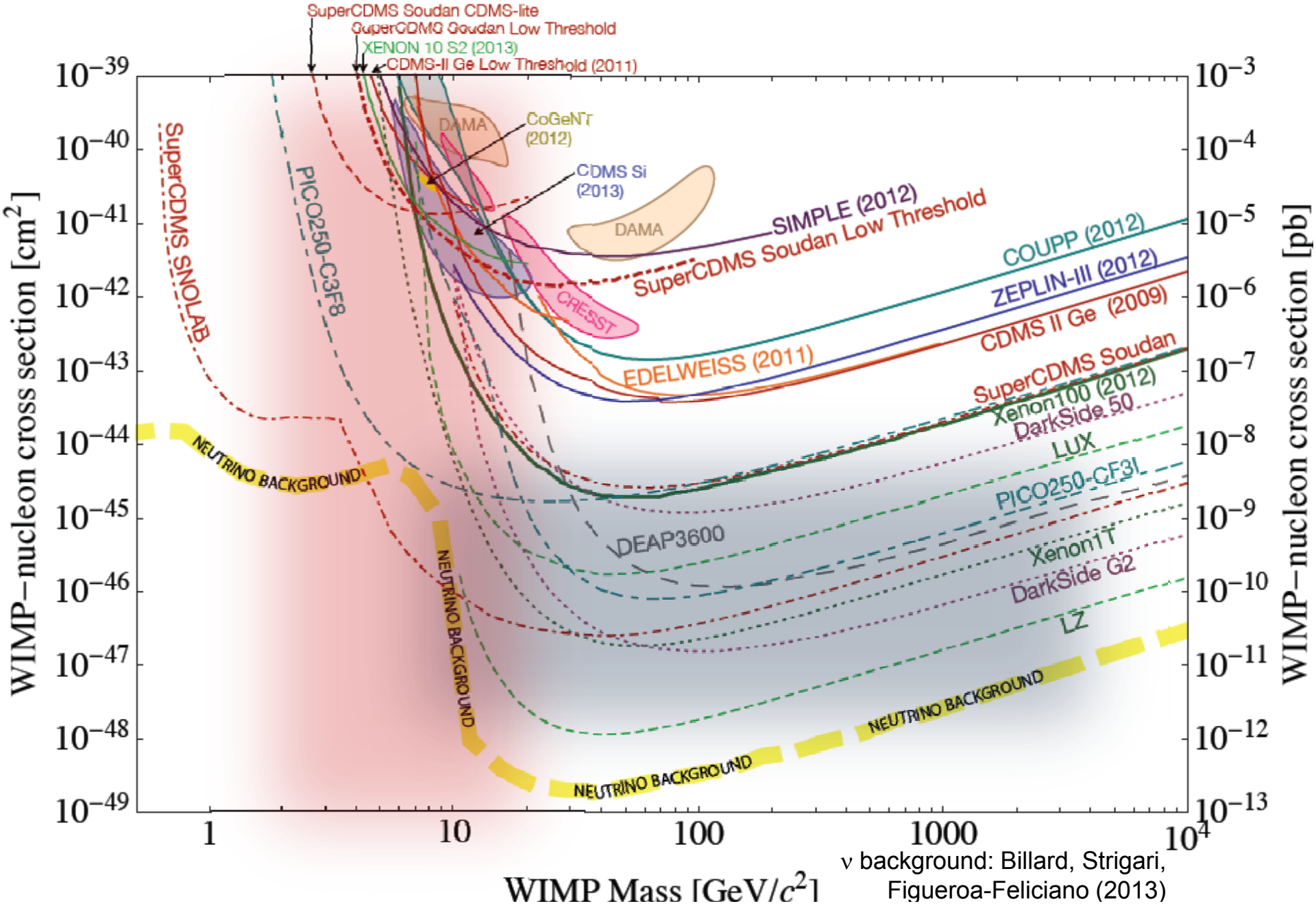
## Major Internal Neutron Backgrounds (PMT, Ti, PTFE)



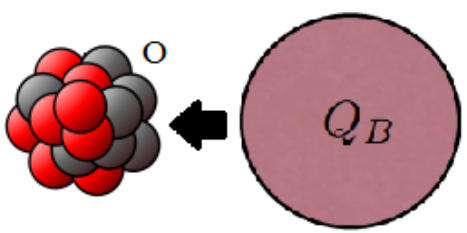

$dru_{nr} = cts/kg/keV_{nr}/day$

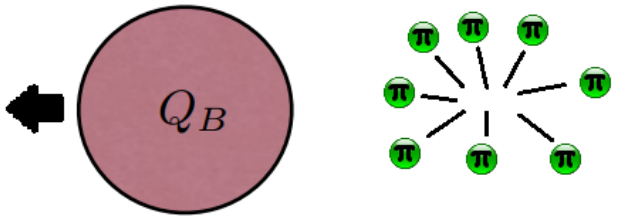
# Direct Detection Future

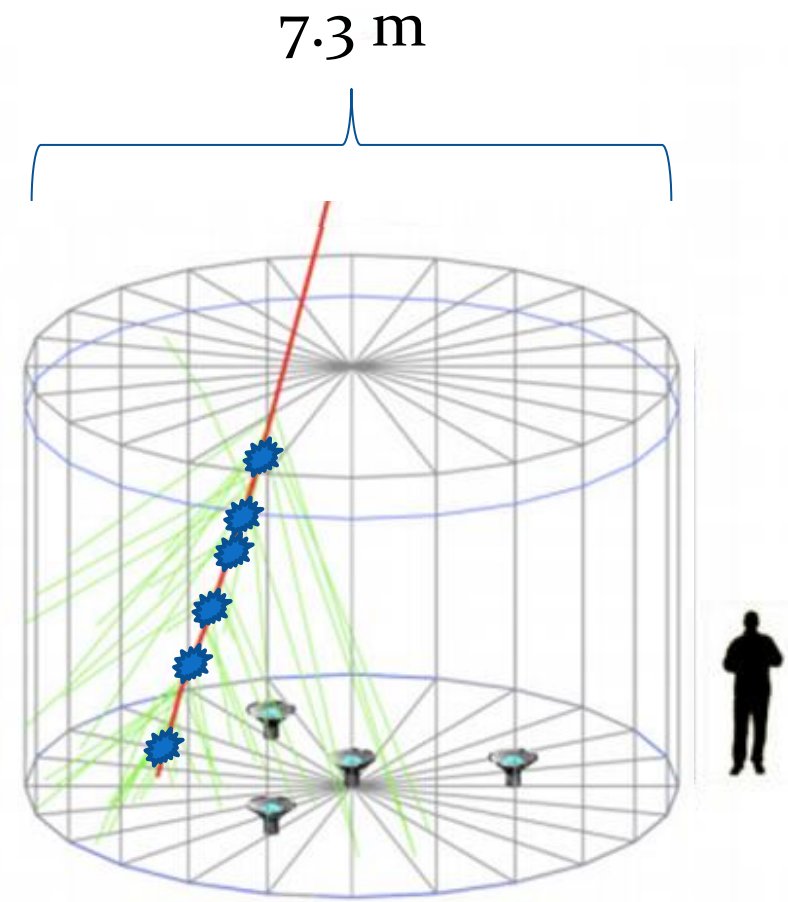


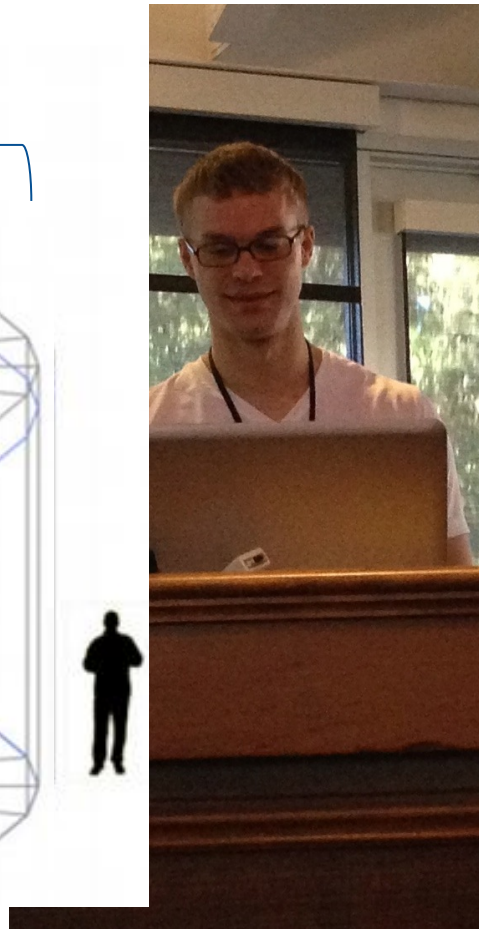

ν background: Billard, Strigari, Figueroa-Feliciano (2013)

# Peter Karn / HAWC

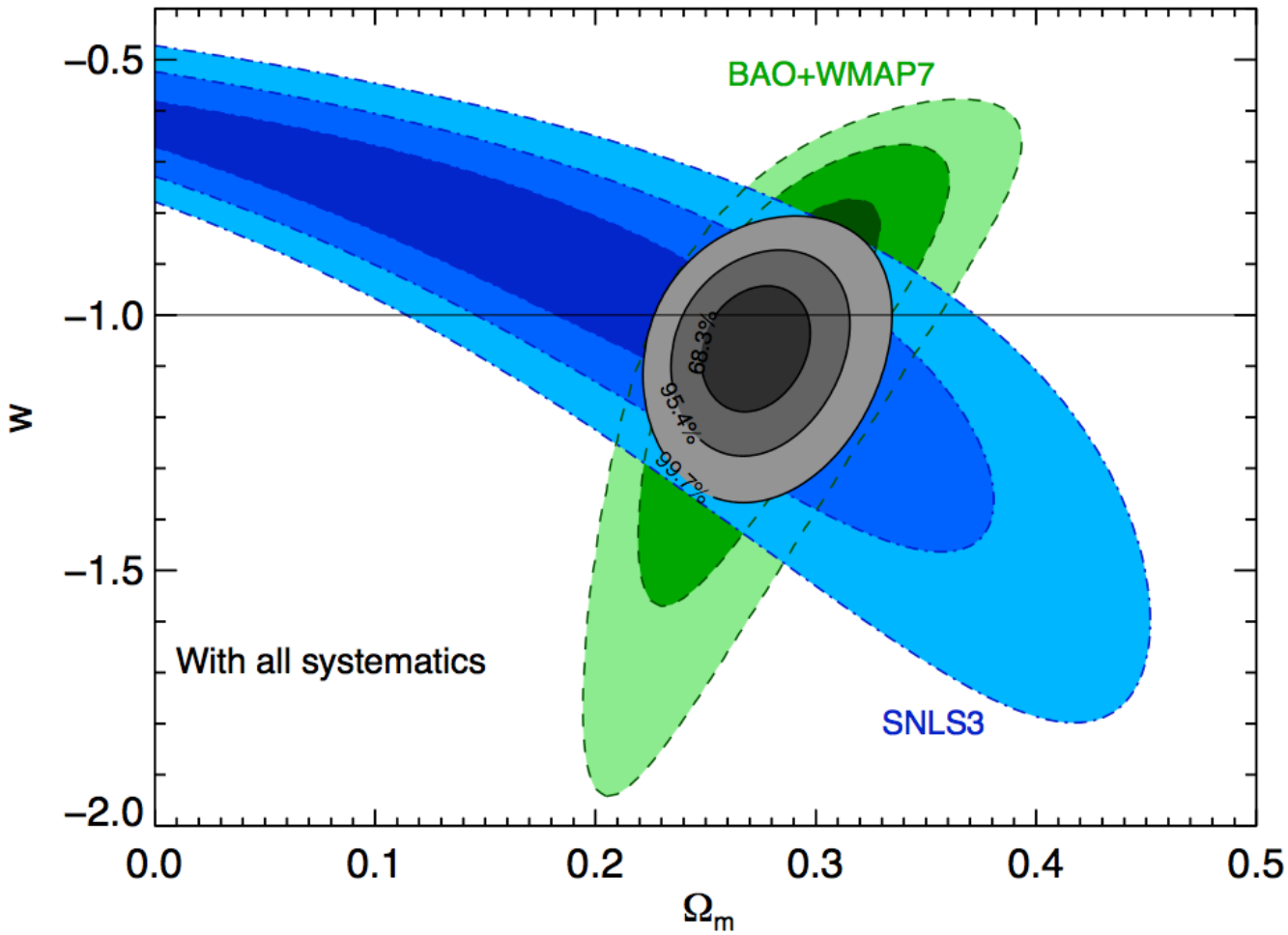


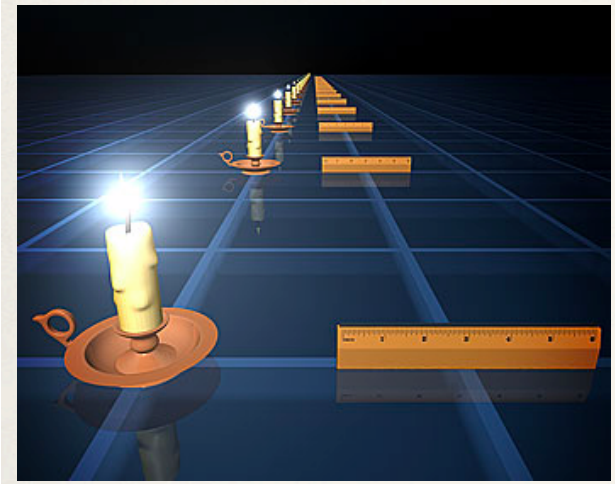



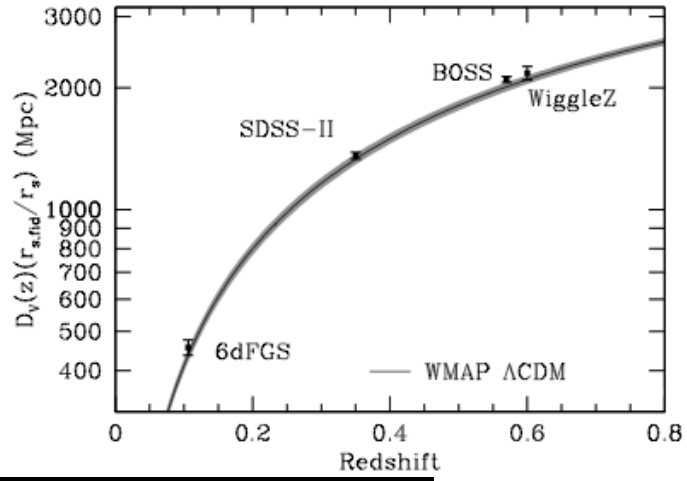



# Dark Energy


BAO+WMAP7
SNLS3
With all systematics
68.3%
95.4%
99.7%
w
−0.5
−1.0
−1.5
−2.0
0.0
0.1
0.2
0.3
0.4
0.5
Ωm

# Beth Reid / SDSS-III BOSS





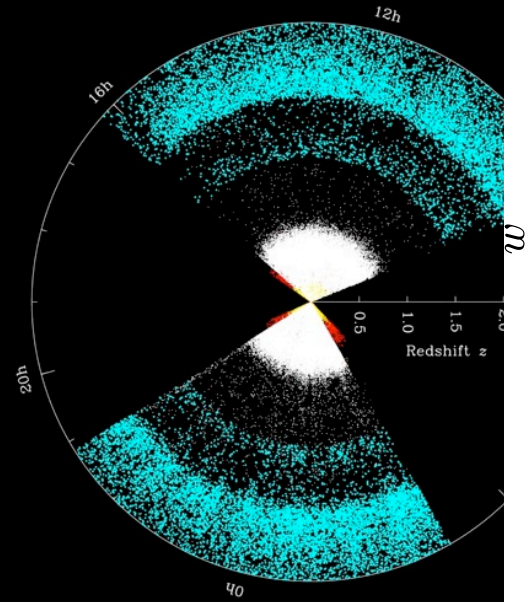

- 10,000 deg$^2$, 1.35M new redshifts
- %-level distances at z = 0.35, 0.6, 2.3

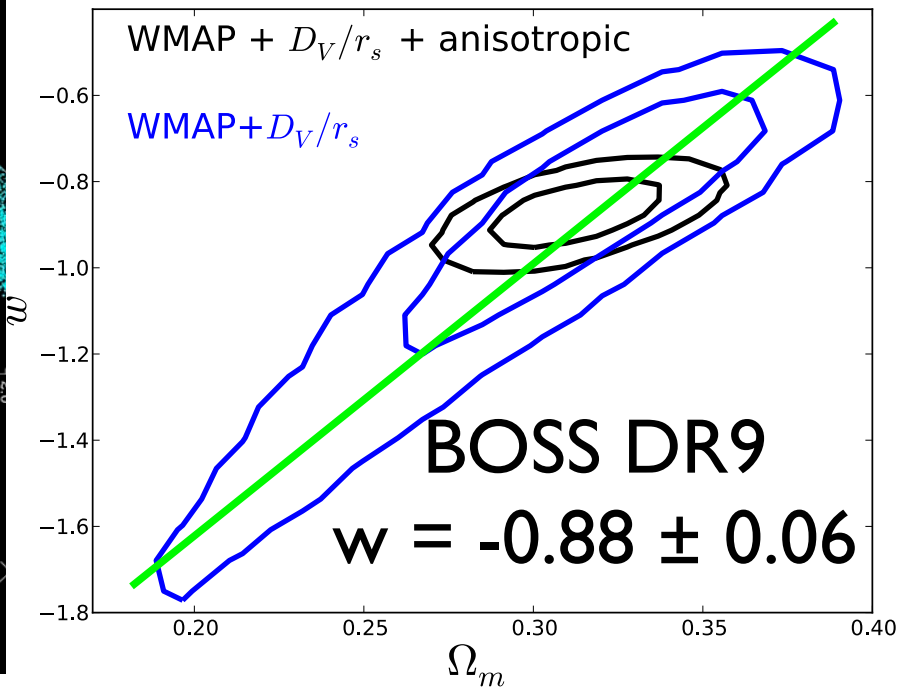
QUASARS

BOSS galaxies

SDSS Main

SDSS LRGs

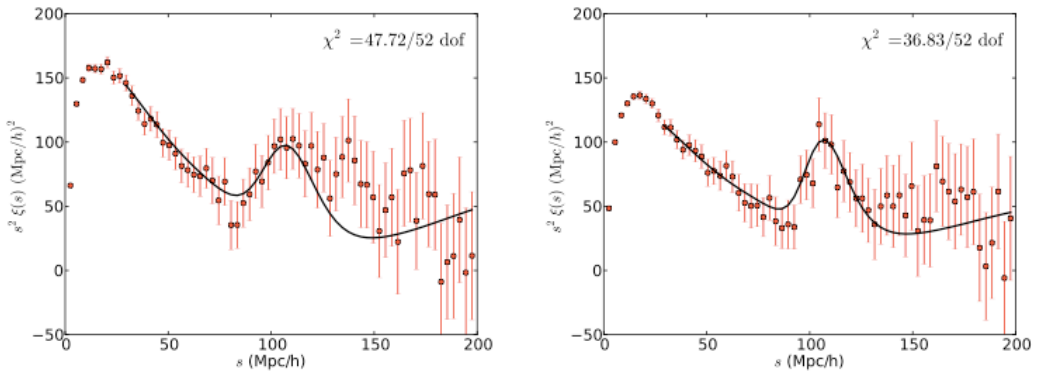


# Mariana Vargas-Magaña / SDSS-III BOSS

## First Reconstruction with SDSS I-II Galaxy samples DR7

Padmanabham et al 2012

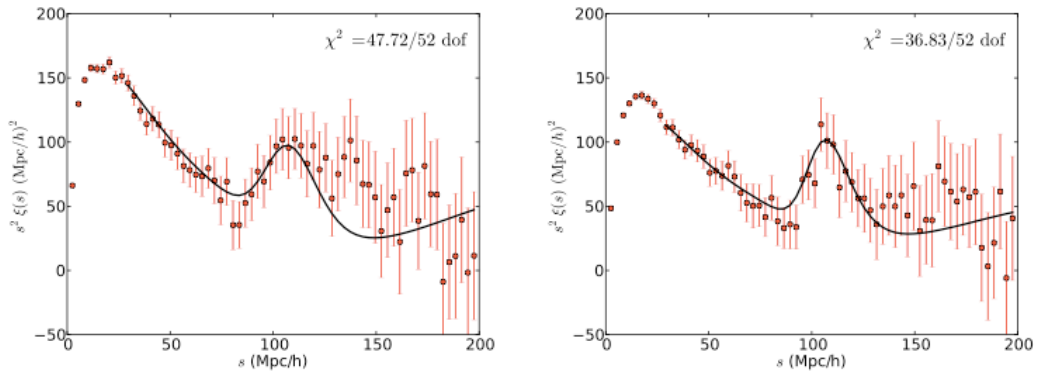



- Reduces error from **3.5% to 1.9%** in the measurement of the distance to z=0.35 **equivalent to a survey with three times the volume of SDSS.**
- **Improves significance** of the BAO feature from 3.3 sigma to 4.2 sigma.

# Mariana Vargas-Magaña / SDSS-III BOSS

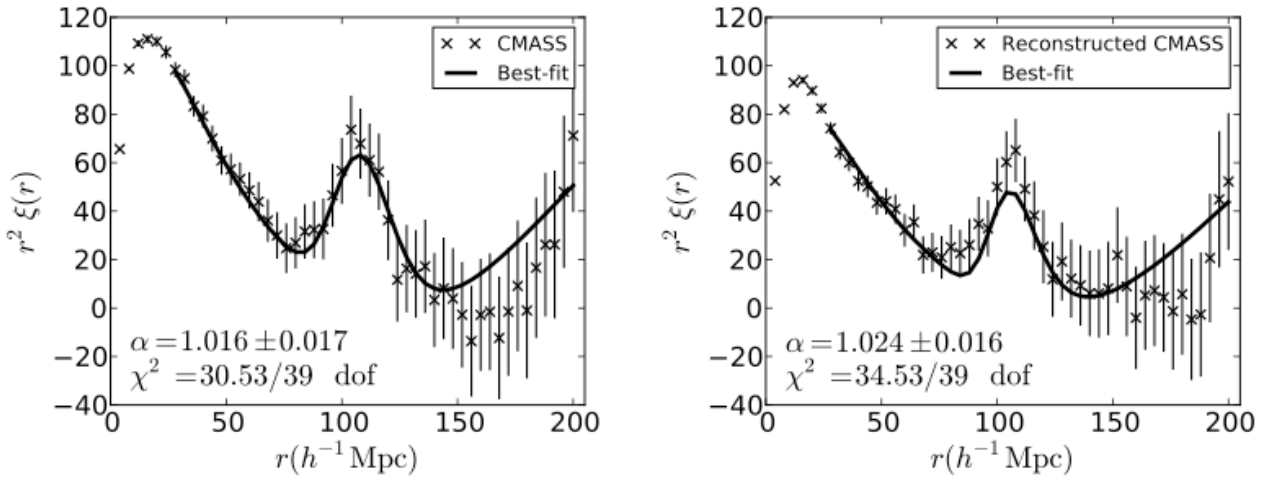
## First Reconstruction with SDSS I-II Galaxy samples DR7

Padmanabham et al 2012




## Reconstruction on BOSS DR9

Anderson et al 2012

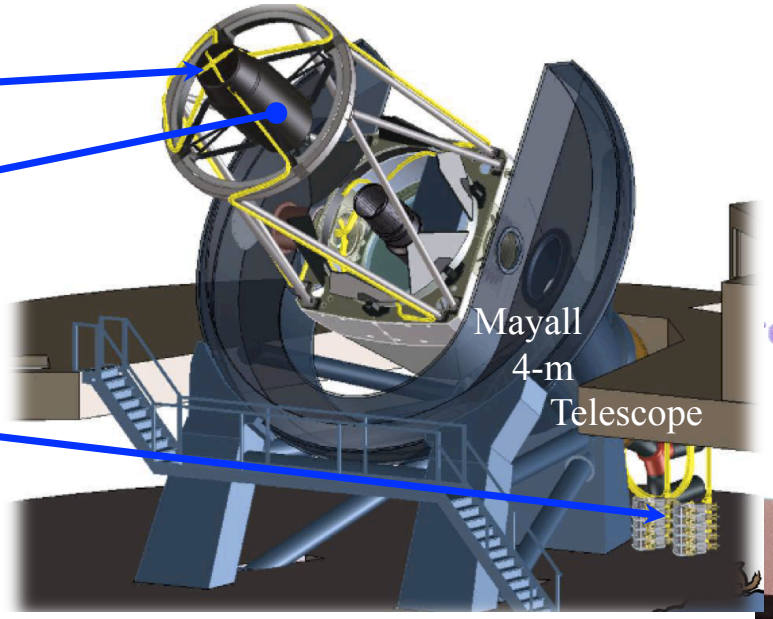



# Michael Levi / DESI

5000 fiber actuators

New 3° field-of-view corrector

New spectrographs

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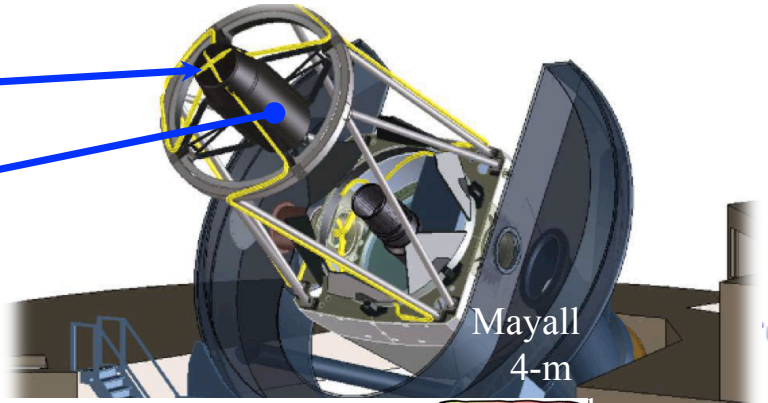
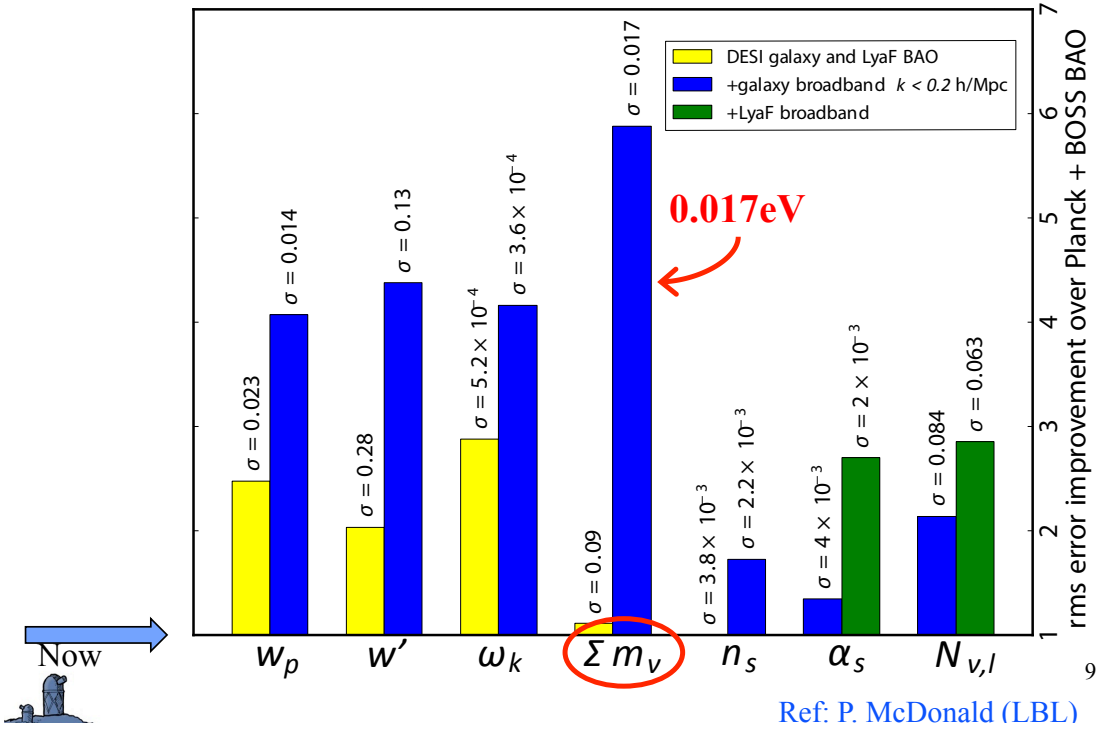




## Broad Scientific Goals

**Improvement over Planck + BOSS (normalized to 1.0):**

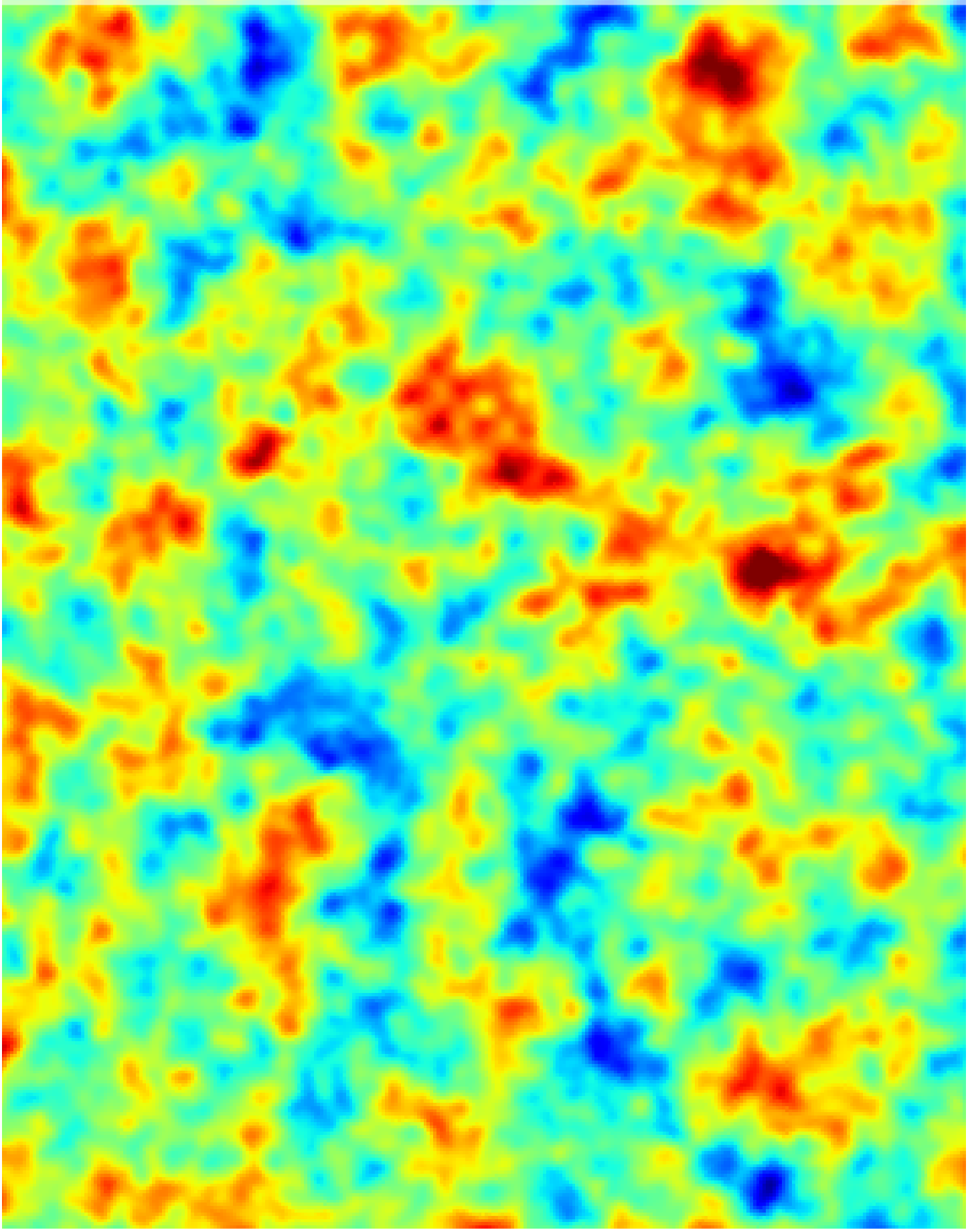



Ref: P. McDonald (LBL)

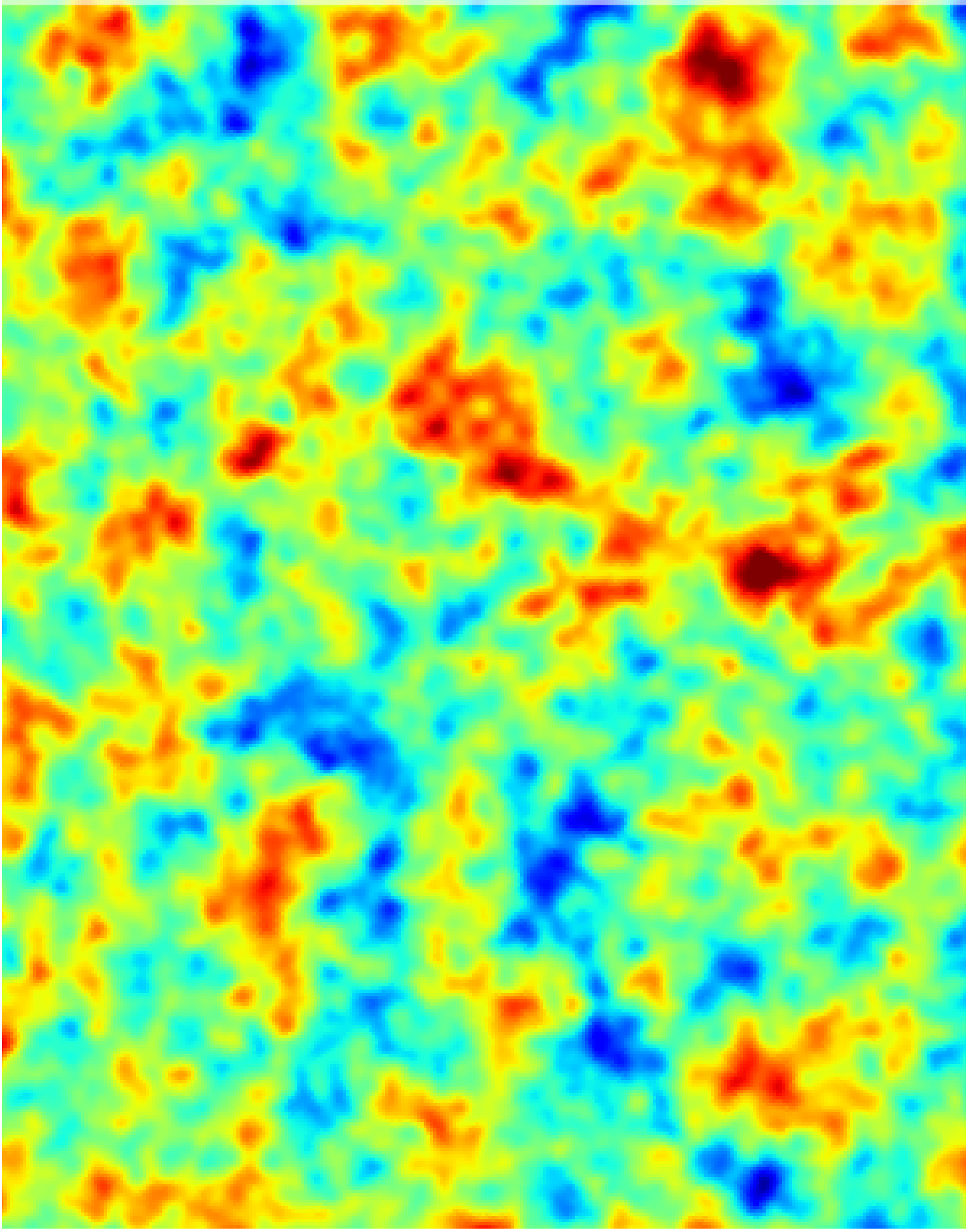
# Neutrino Mass from CMB

Duncan Hansen

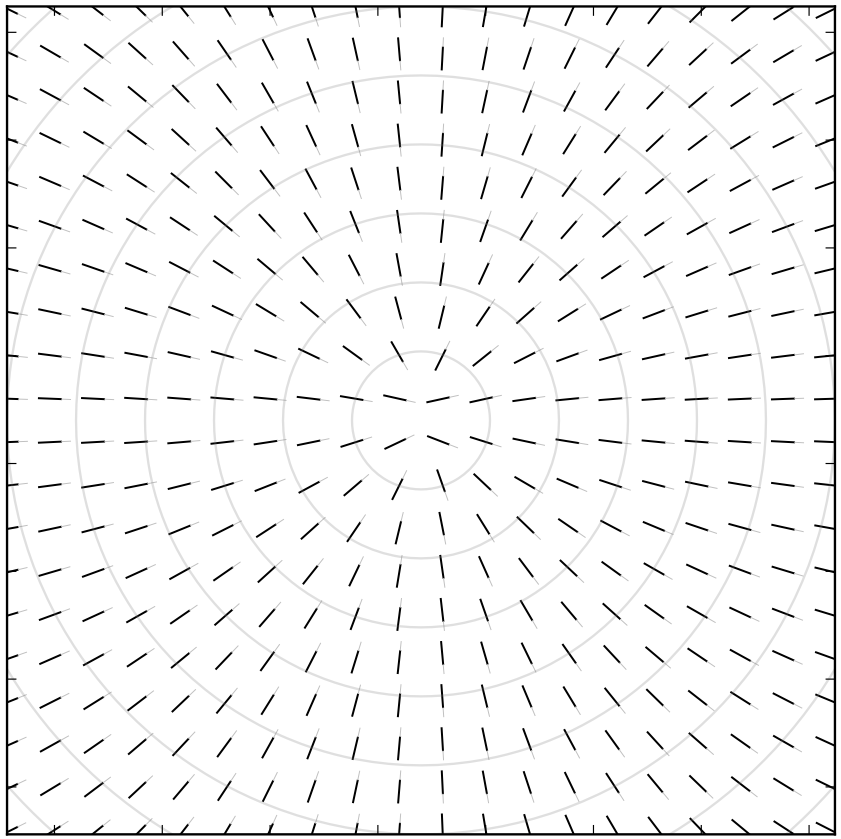
CMB Temperature Unlensed



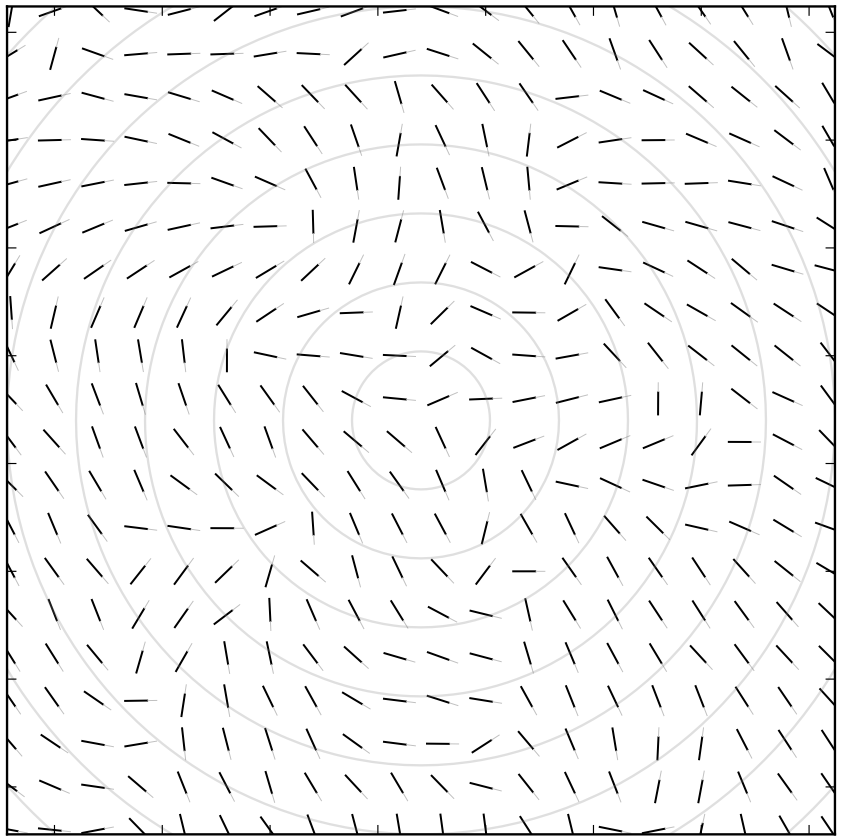
CMB Temperature Lensed



Breaking polarization into E- and B-modes, lensing has qualitatively different behaviour in polarization.

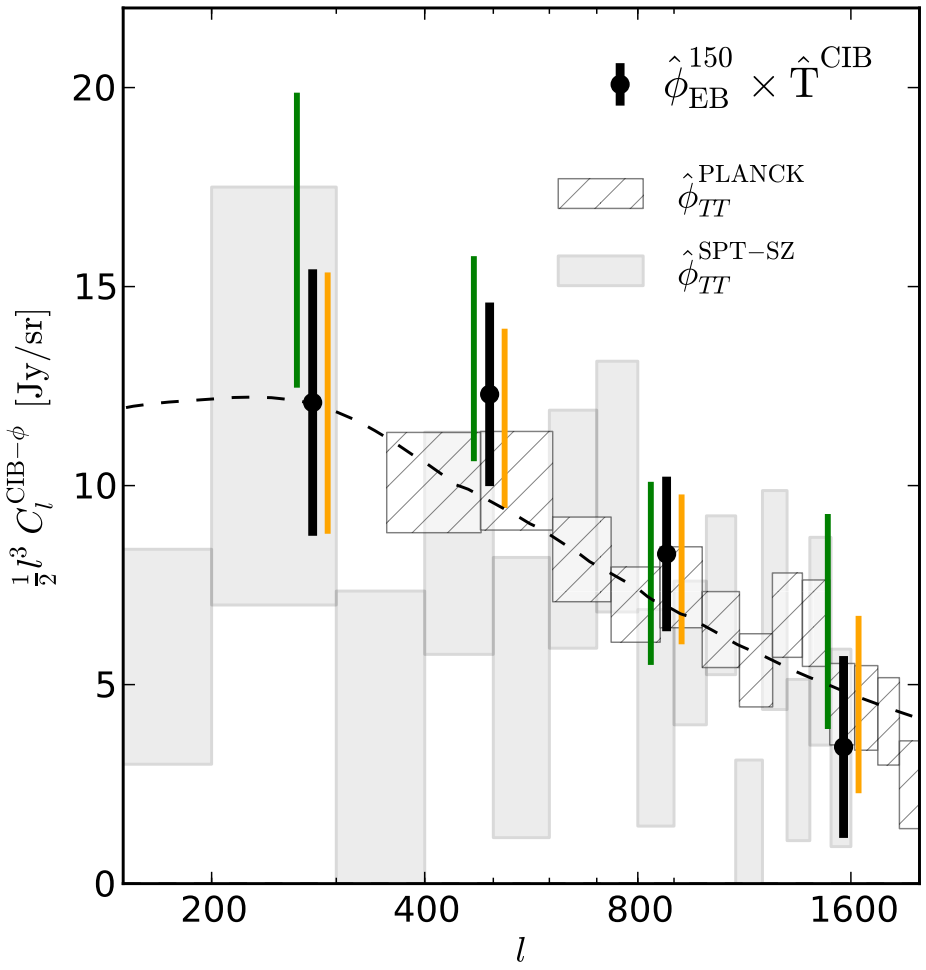


«E-mode»

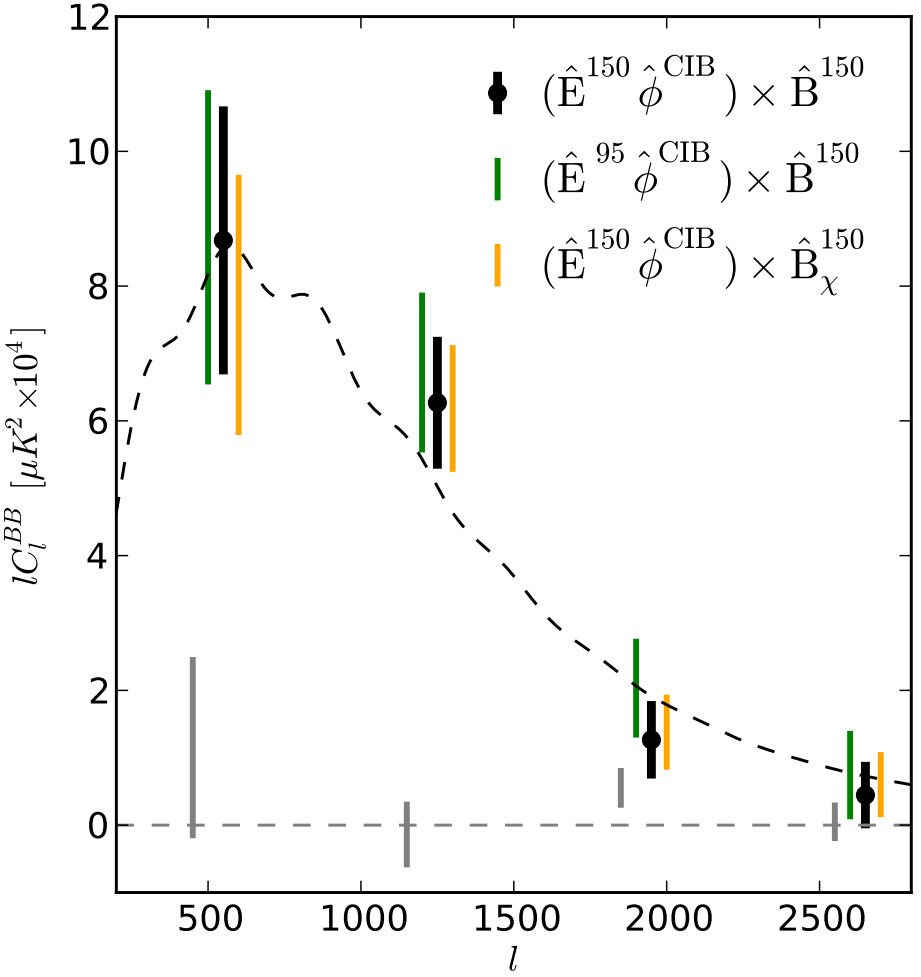


«B-mode»

# B modes detected!



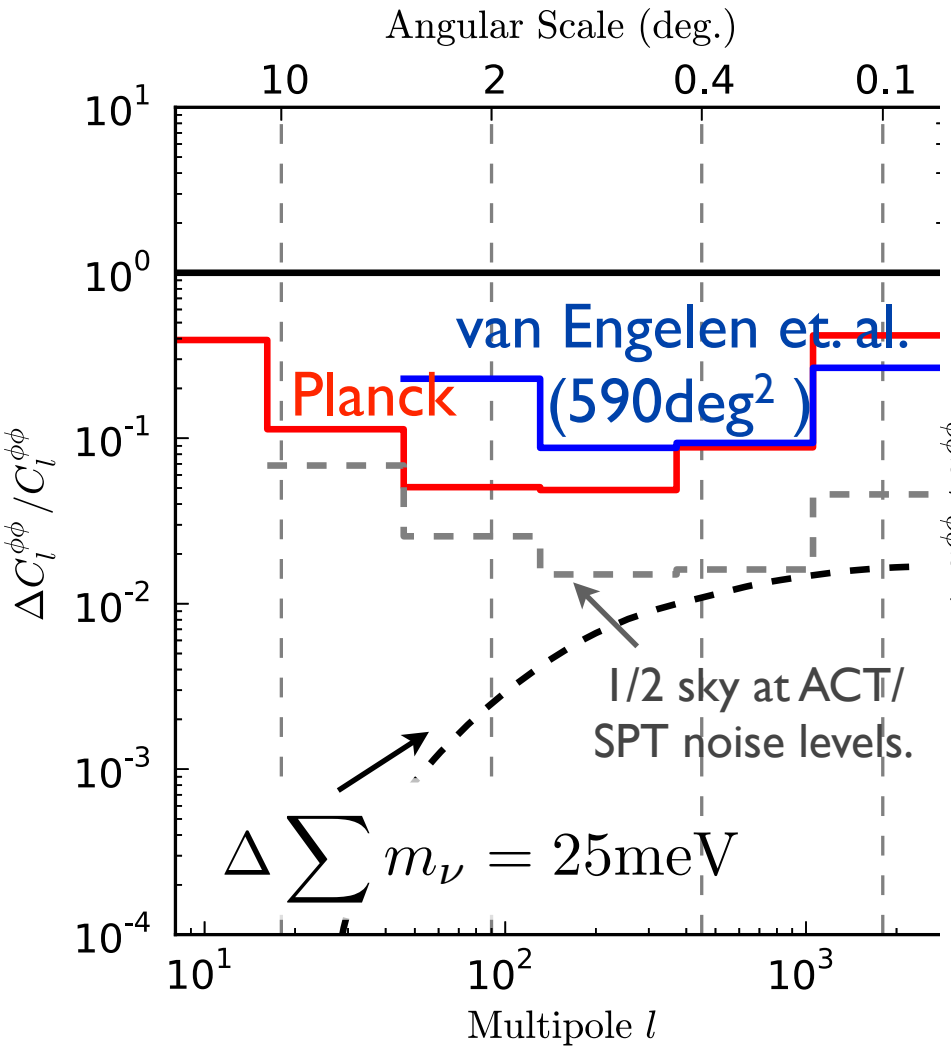

«Lensing view»



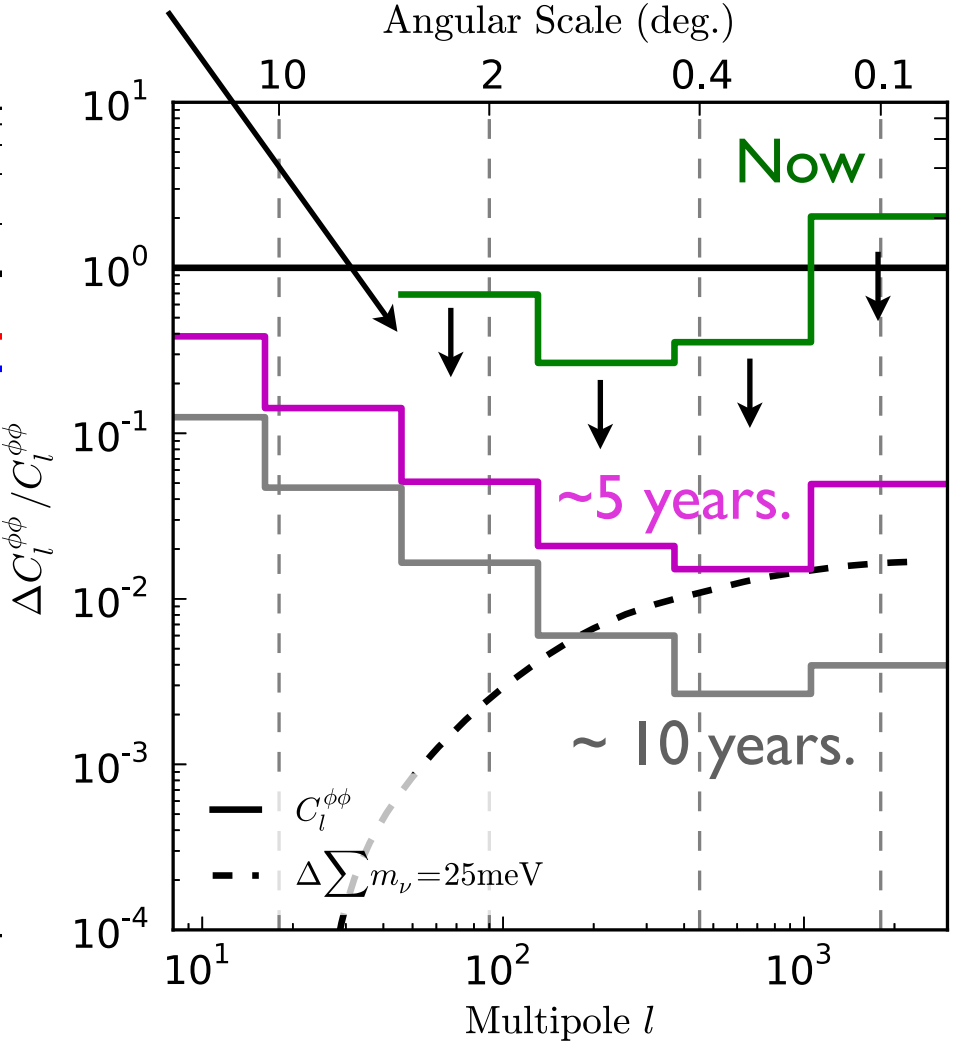

«B mode view»

**7.7σ**

# B modes… smaller systematics




Other (<230 meV)




B modes

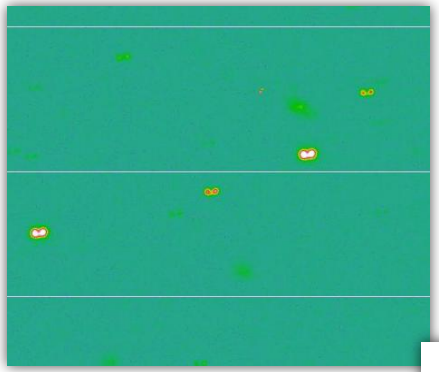
# Dark Energy Survey

Cerro Tololo Inter-American Observatory

# Marcelle Soares-Santos / DES

## SV Accomplishments

- Data flowing to NCSA
- First Cut Processing
- Verified proper signal and noise levels
- Astrometric solution with 20 mas RMS
- Fixed faulty primary mirror support
- OBSTAC runs properly
- SISPI (DAQ) works, improved
- AOS control of focus and collimation
- Look Up tables for pointing
- Cross talk measured, saturation detected
- Documentation
- Quick Reduce works, enhanced
- SN fields selected, templates
- SN pipeline works
- Photometric calibration regimen in place
- Repeatability to 0.02 mag verified
- Color terms as expected (except Y)
- Mirror cooling recommissioned
- RASICAM working
- Fringing measured, stable and small
- Detector non-linearities identified
- RA damper motor recommissioned
- Vastly improved tracking
- Ghost & scattering sources identified
- Photo-z calibration fields imaged
- BCAMS operating
- … and more …



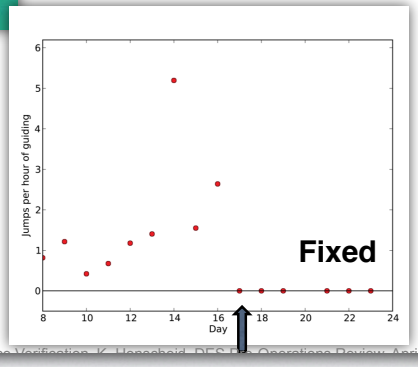
Observers, Eyeball Squad

Diagnosis:

**Unusual force on mirror hardpoint when guider corrections jump (TCS Database)**

Solution:

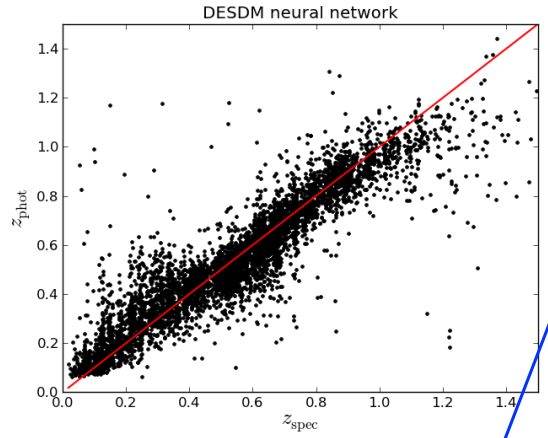
**Replace broken controller for mirror support (Mamac)**





# DES Commisioning

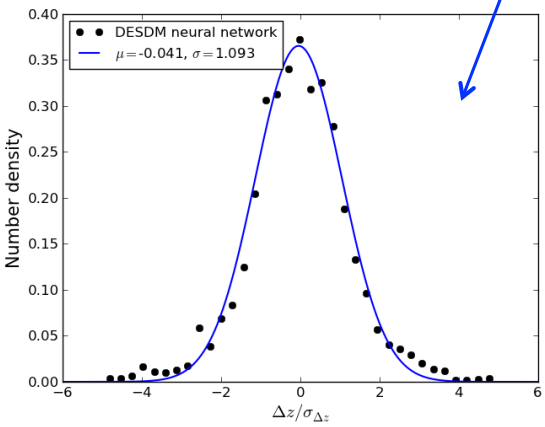
# Huan Lin / DES

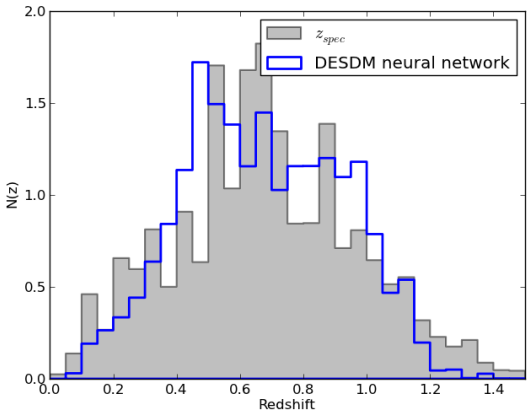



*Top left: Photo-z vs. spectro-z*

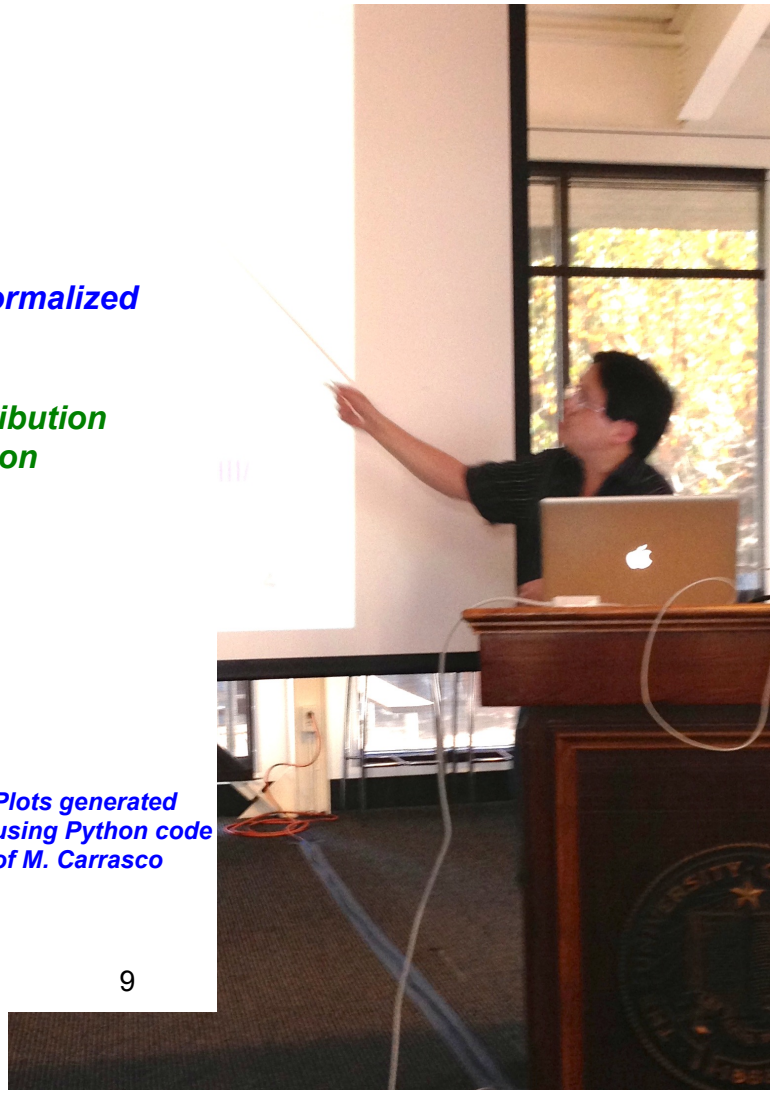
*Bottom left: Photo-z – spectro-z, normalized by photo-z errors, and Gaussian fit*

*Bottom right: Photo-z redshift distribution compared to true redshift distribution*



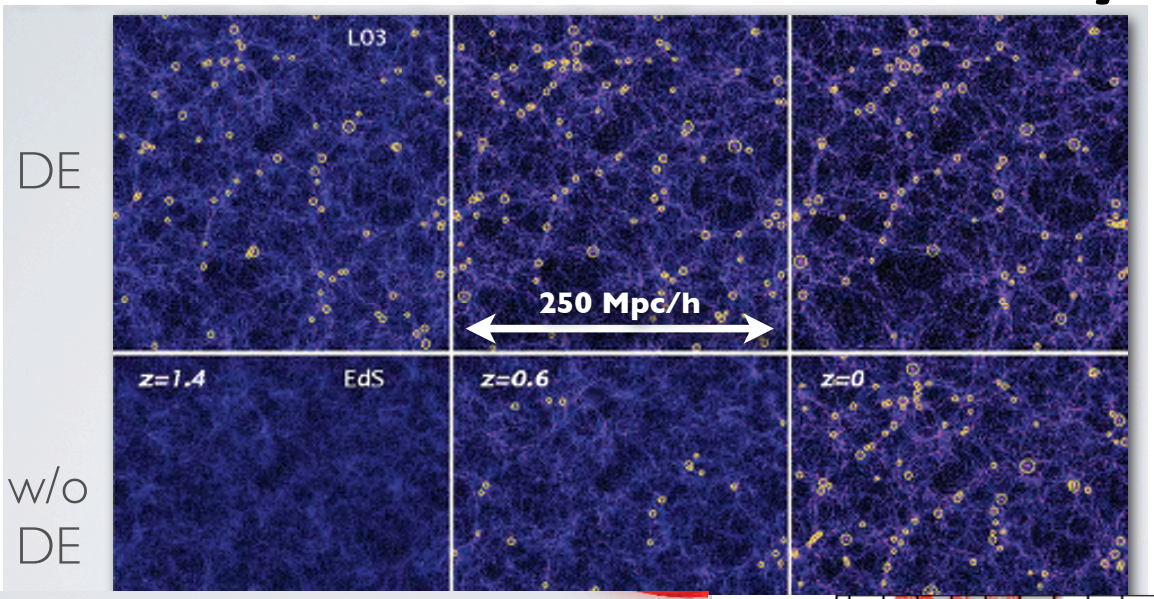

*Plots generated using Python code of M. Carrasco*

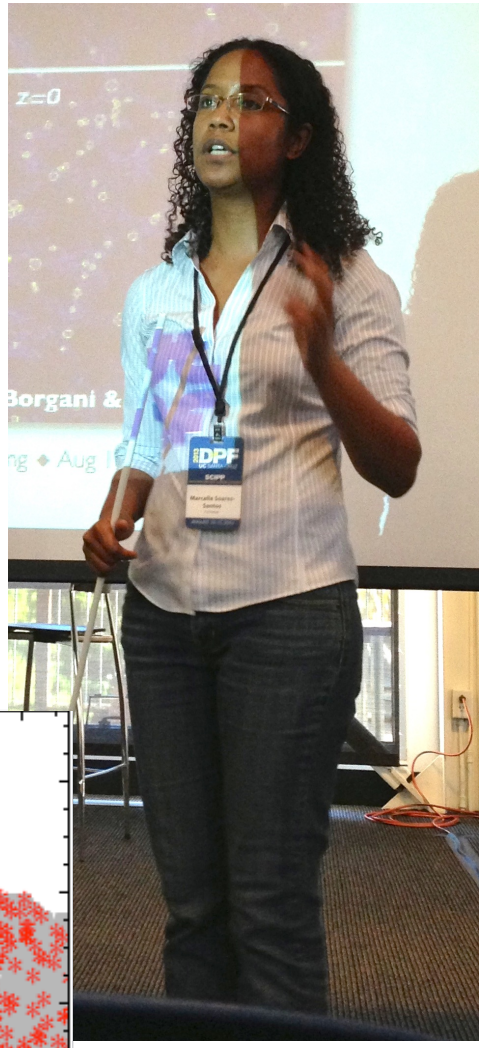


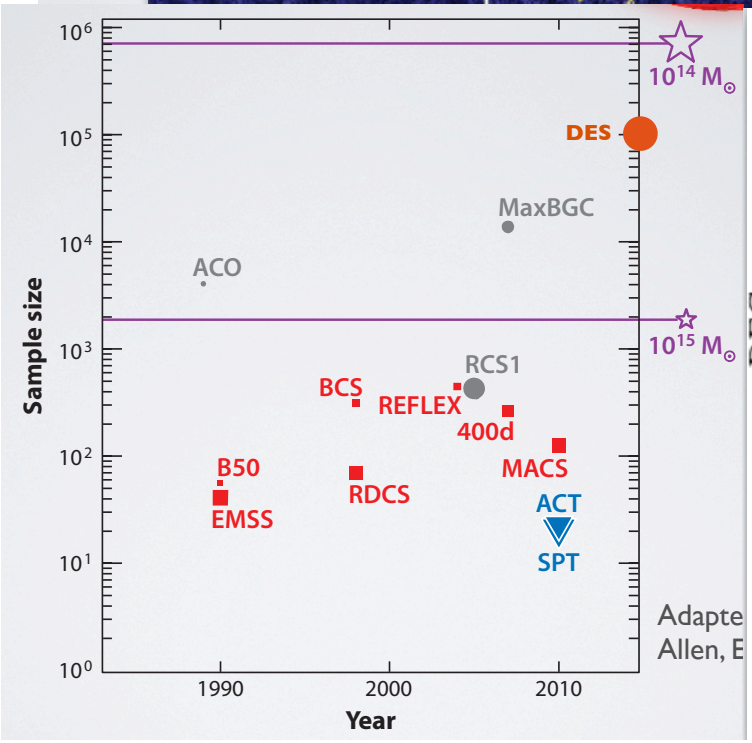


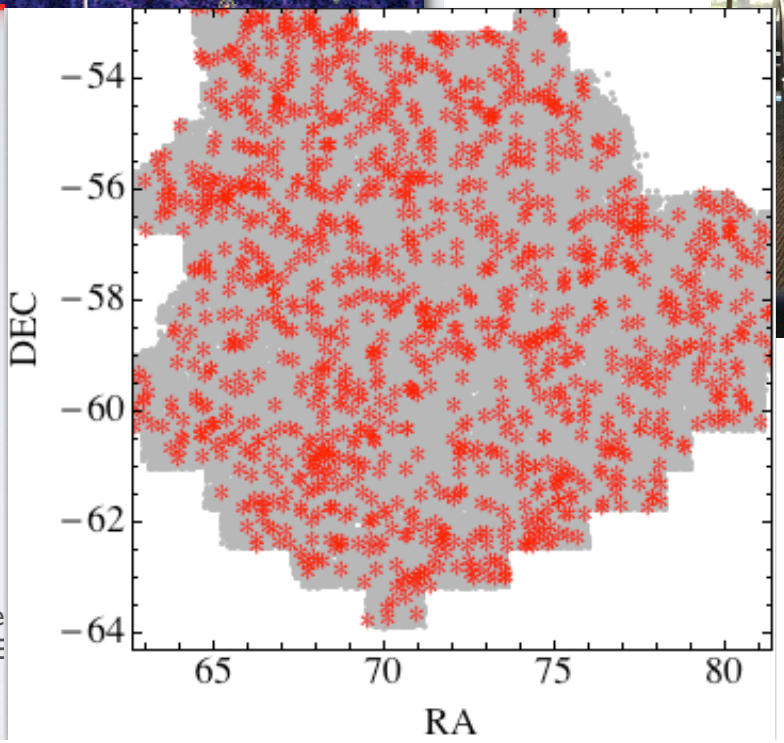
# Photometric Red Shift Calibration

# Marcelle Soares-Santos / DES



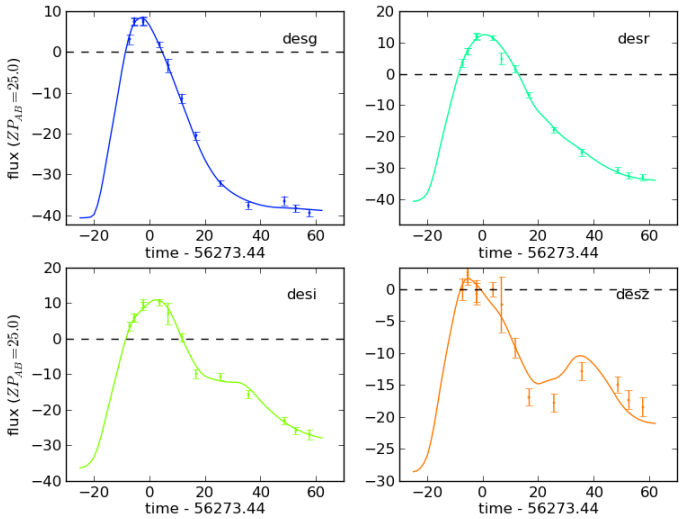




**Cluster Finding**

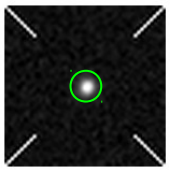
# Kyle Barbary / DES

| | Dark Energy Survey | Current Major Survey (SNLS: Megacam @ CFHT) |
|---|---|---|
| Number of Type Ia SNe | ~3500 (Photometric typing) | ~500 (spectroscopic typing) |
| Redshift range | up to z ~ 1.2 (deep z band) | up to z ~ 1.0 |
| Fields | 10 pointings @ 3 deg$^2$ (8 “shallow”, 2 “deep”) | 4 pointings @ 1 deg$^2$ (all “deep”) |
| Cadence | ~5 day cadence over 5 months | (similar) |
| Spectroscopic Follow-up | **Subset** of candidates observed by 4-10m class telescopes | **All** SN Ia candidates confirmed at 4-10m class telescopes |


## Science Verification: Supernovae

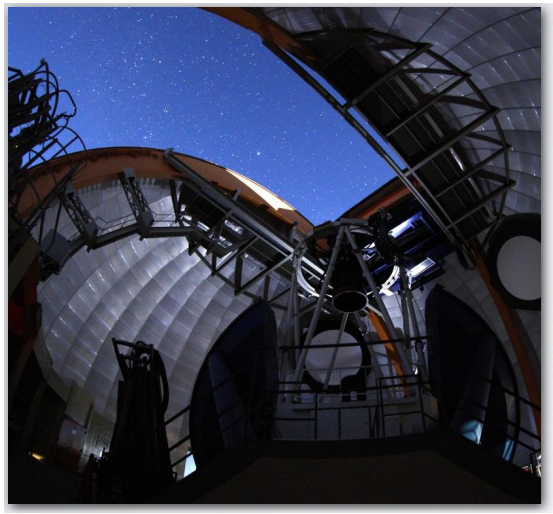



$z = 0.243$
DES12C1b
(636359)



# Supernova Finding

# Carlos Cunha / Dark Energy Survey



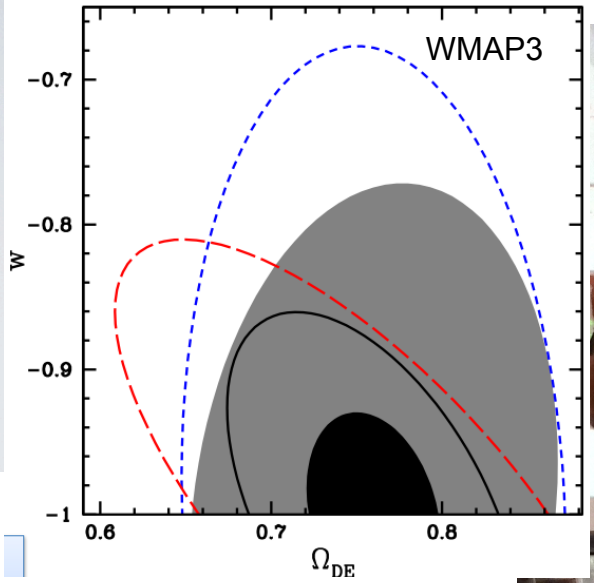
Construction: 2008–2011

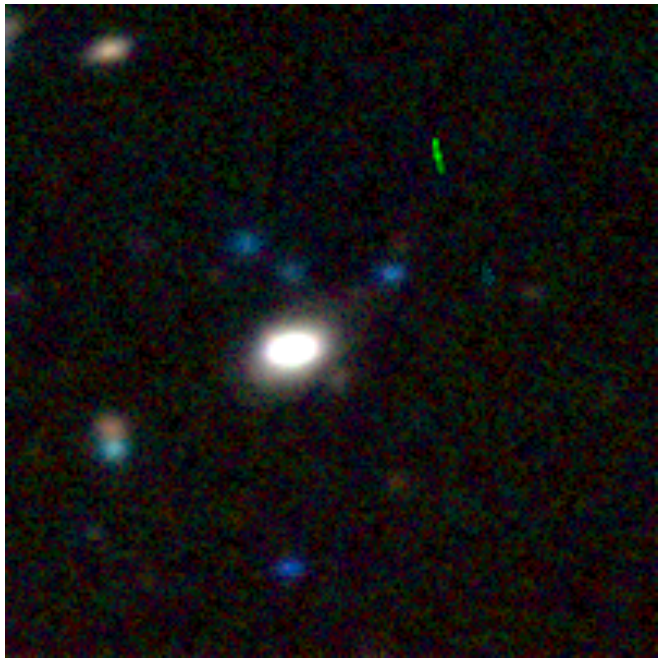
Installation: Feb–Aug 2012

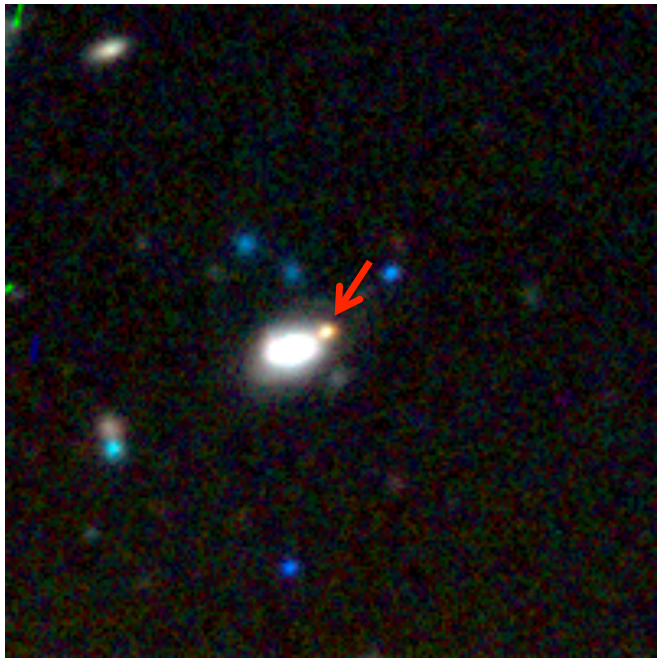
Commissioning:
Sep–Oct 2012

Science Verification:
Nov–Feb 2013

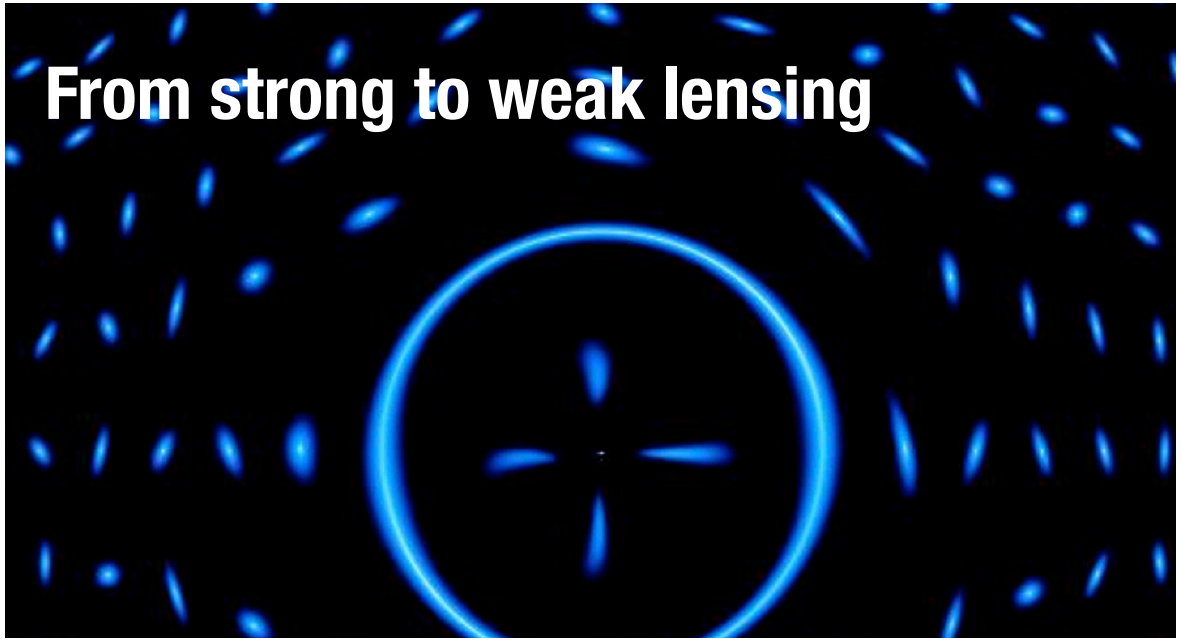
DES: next 5 years

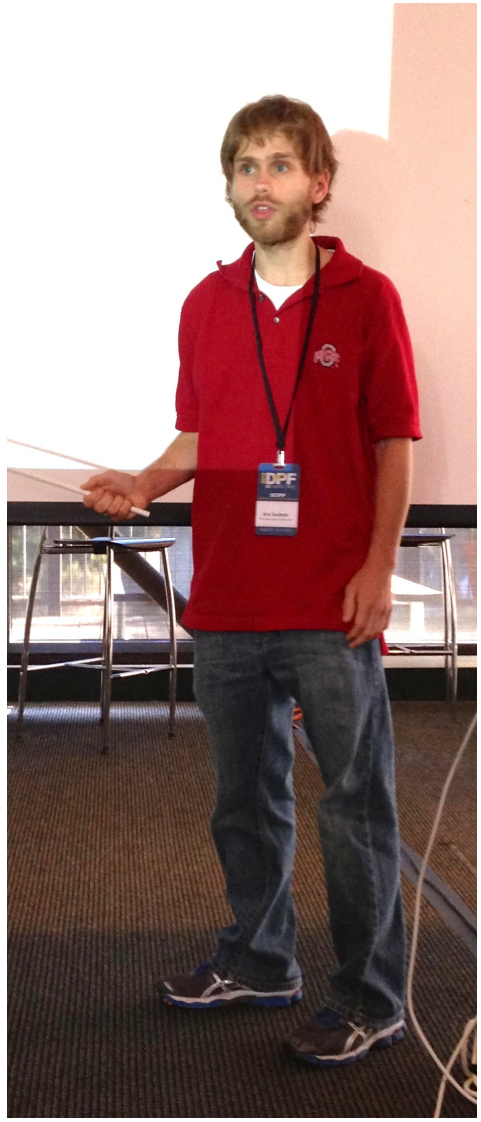


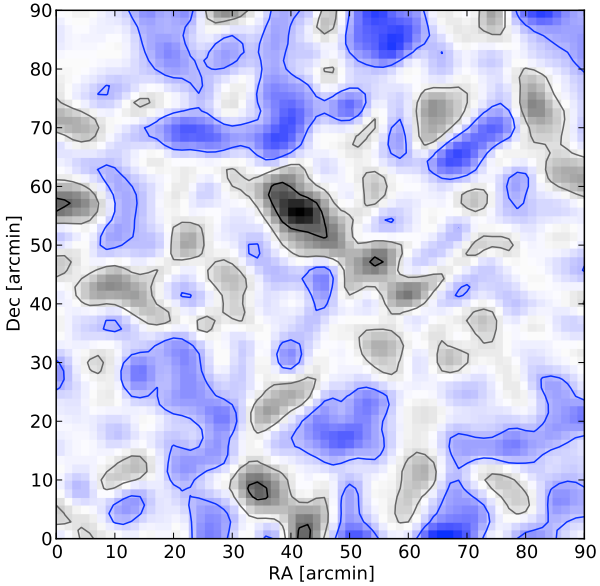





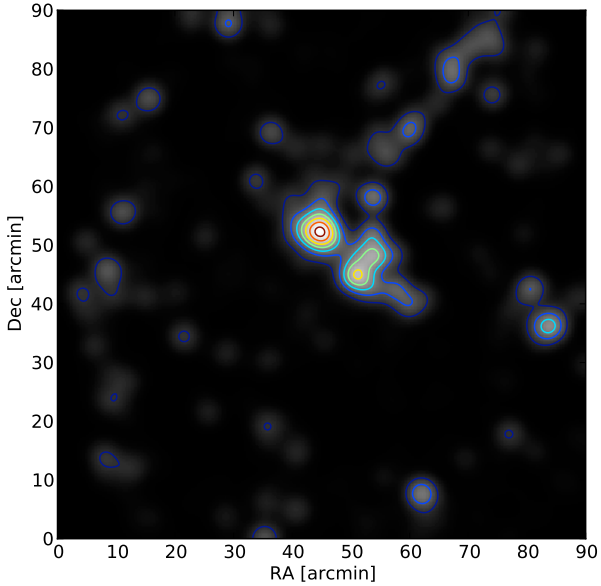
# Eric Suchtya / DES





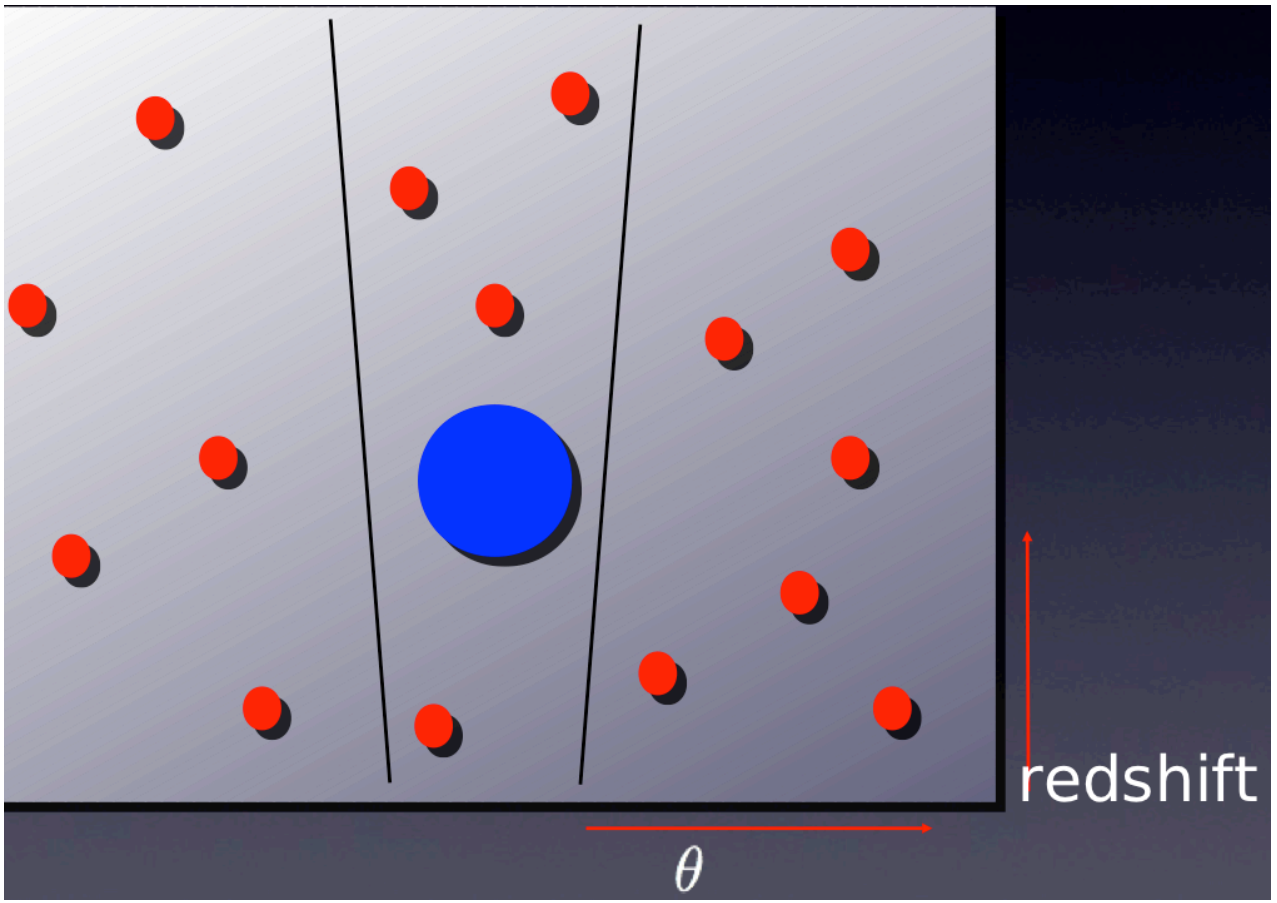

SaWLens WL mass reconstruction




redMaPPer galaxy distribution at z=0.35

Preliminary

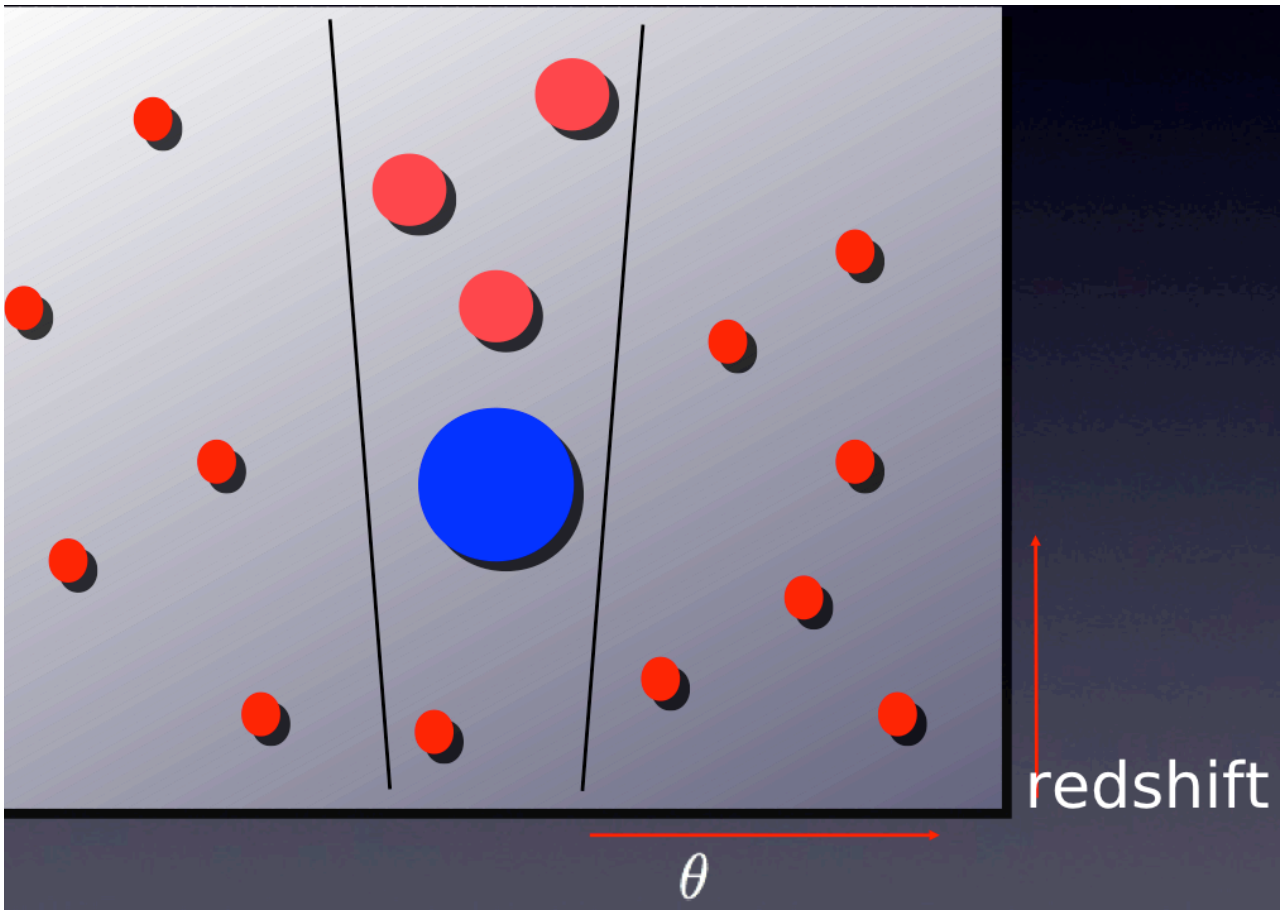
# Eric Suchyta/ DES





# Lensing from Magnification

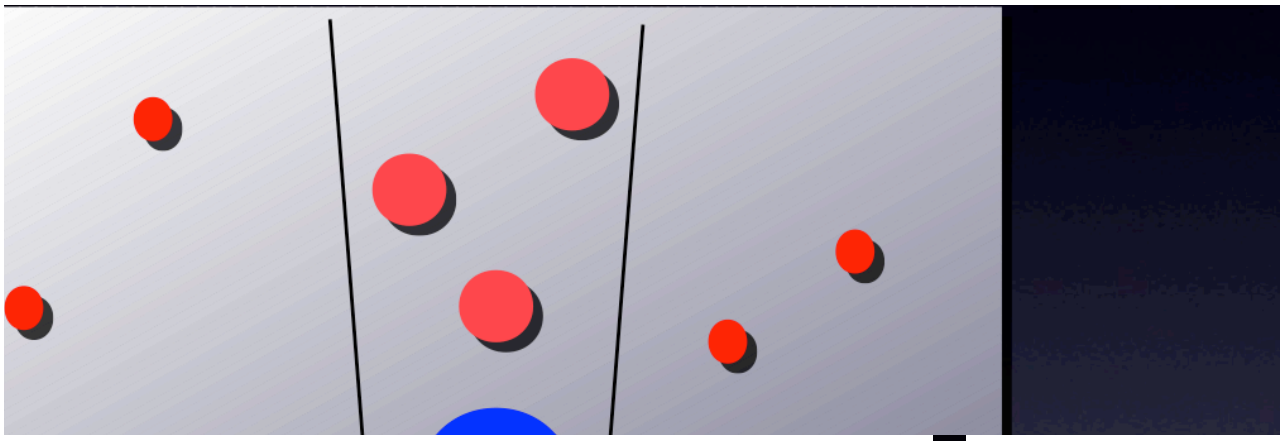
# Eric Suchyta/ DES

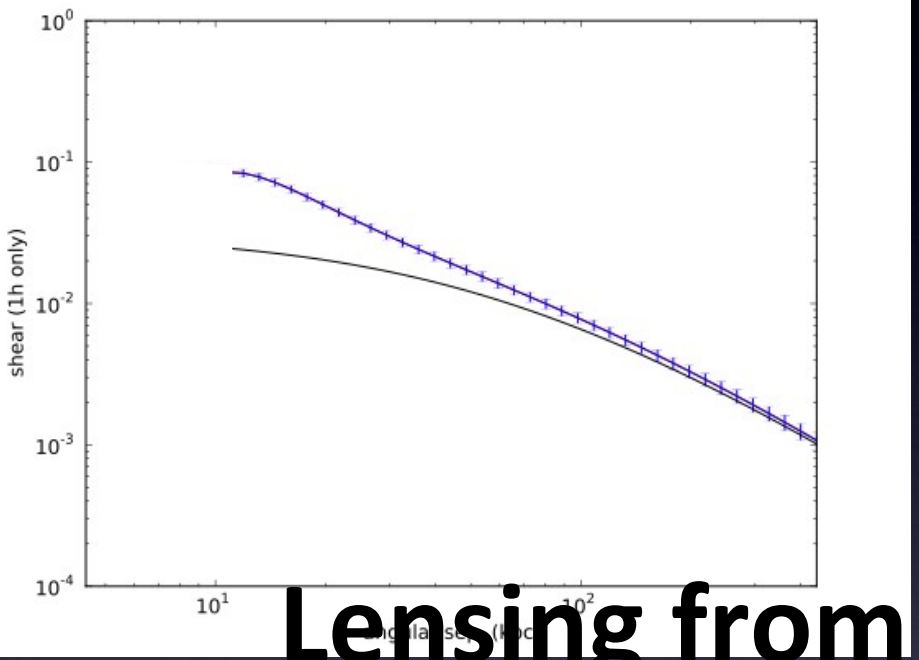


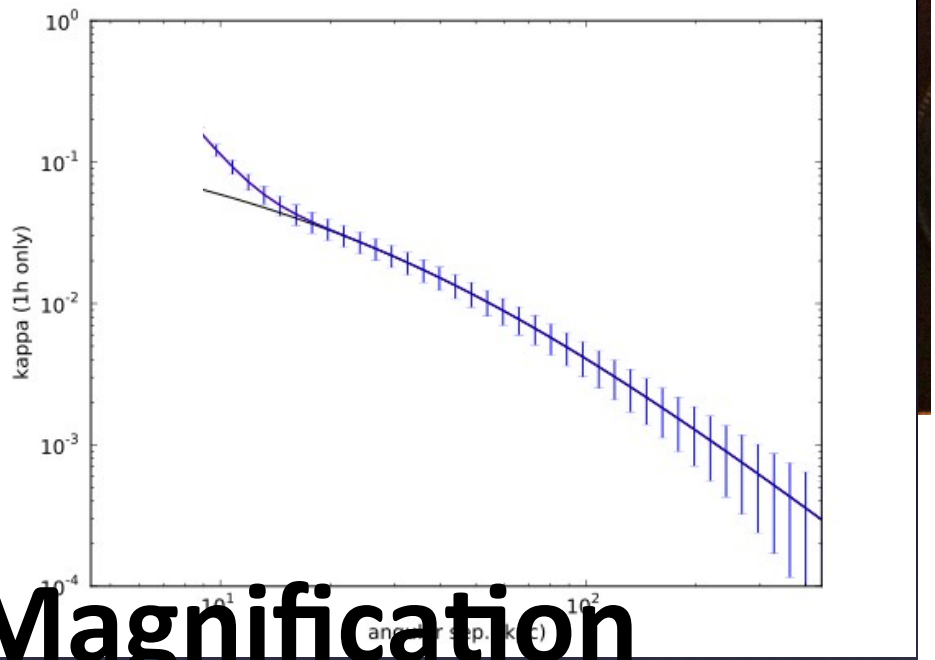


# Lensing from Magnification

# Eric Suchyta/ DES

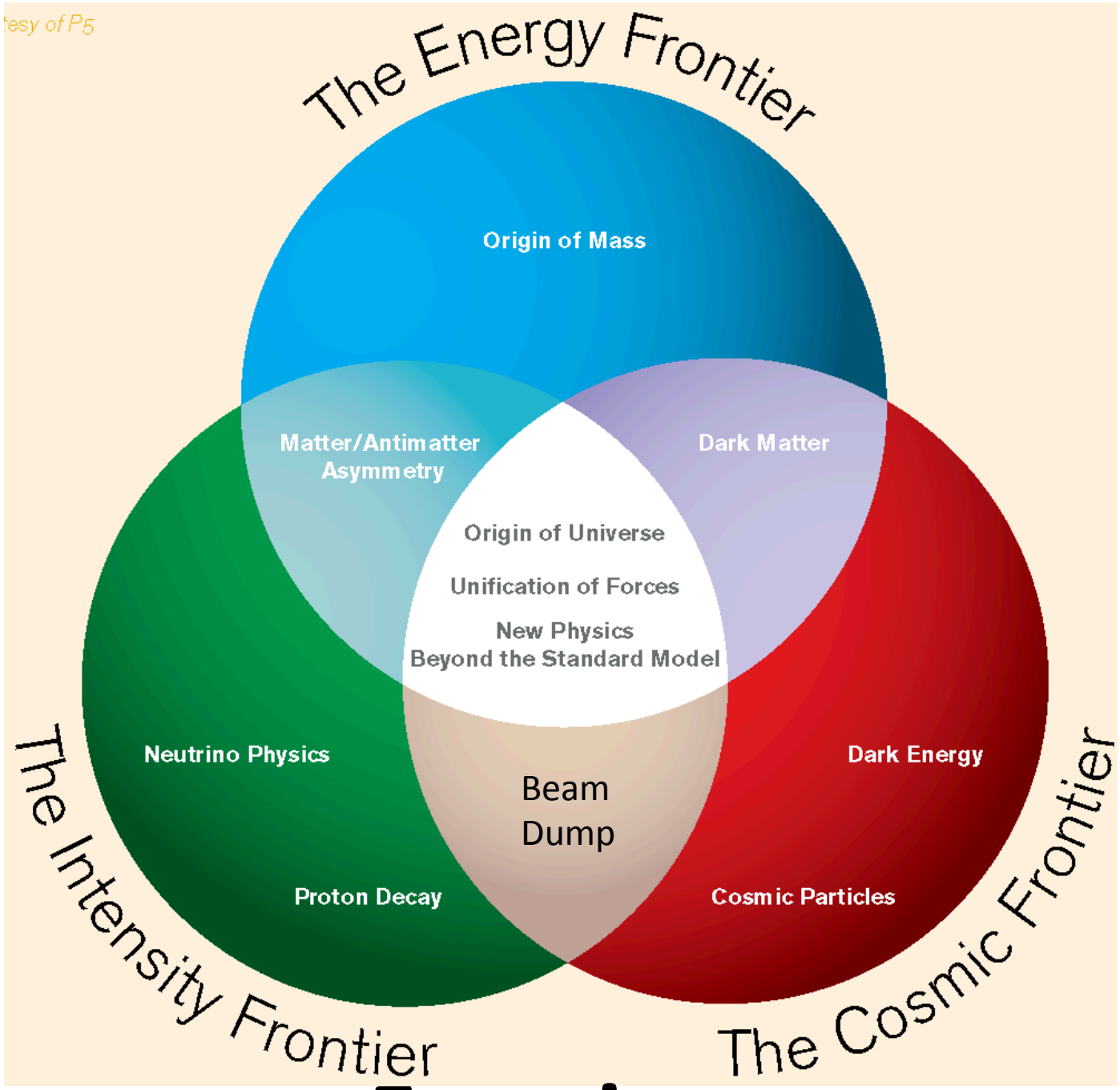


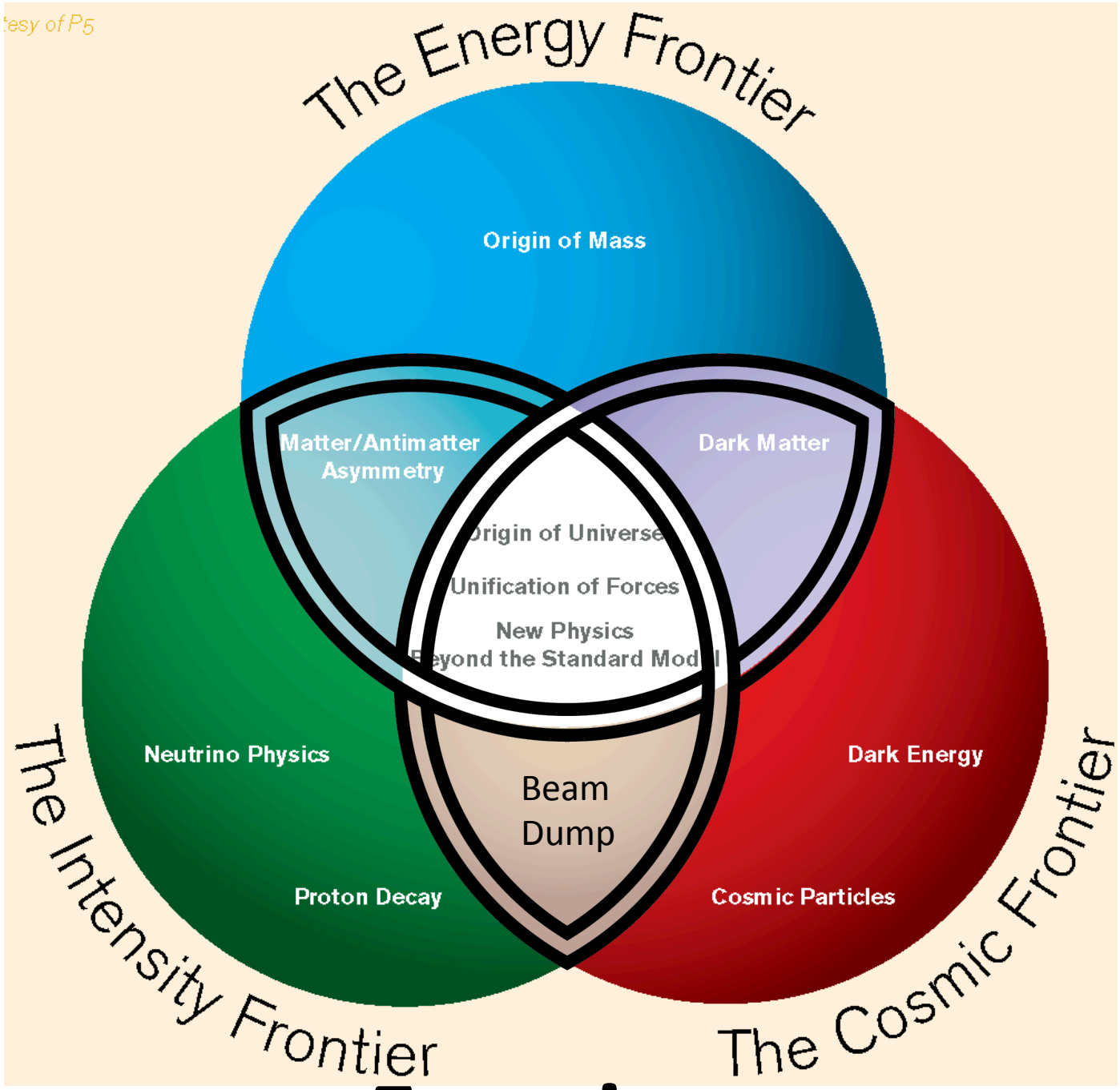




# Lensing from Magnification

shear magnification


tesy of P5
The Energy Frontier
Origin of Mass
Matter/Antimatter Asymmetry
Dark Matter
Origin of Universe
Unification of Forces
New Physics Beyond the Standard Model
Neutrino Physics
Beam Dump
Dark Energy
Proton Decay
Cosmic Particles
The Intensity Frontier
The Cosmic Frontier

# Frontiers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The Energy Frontier
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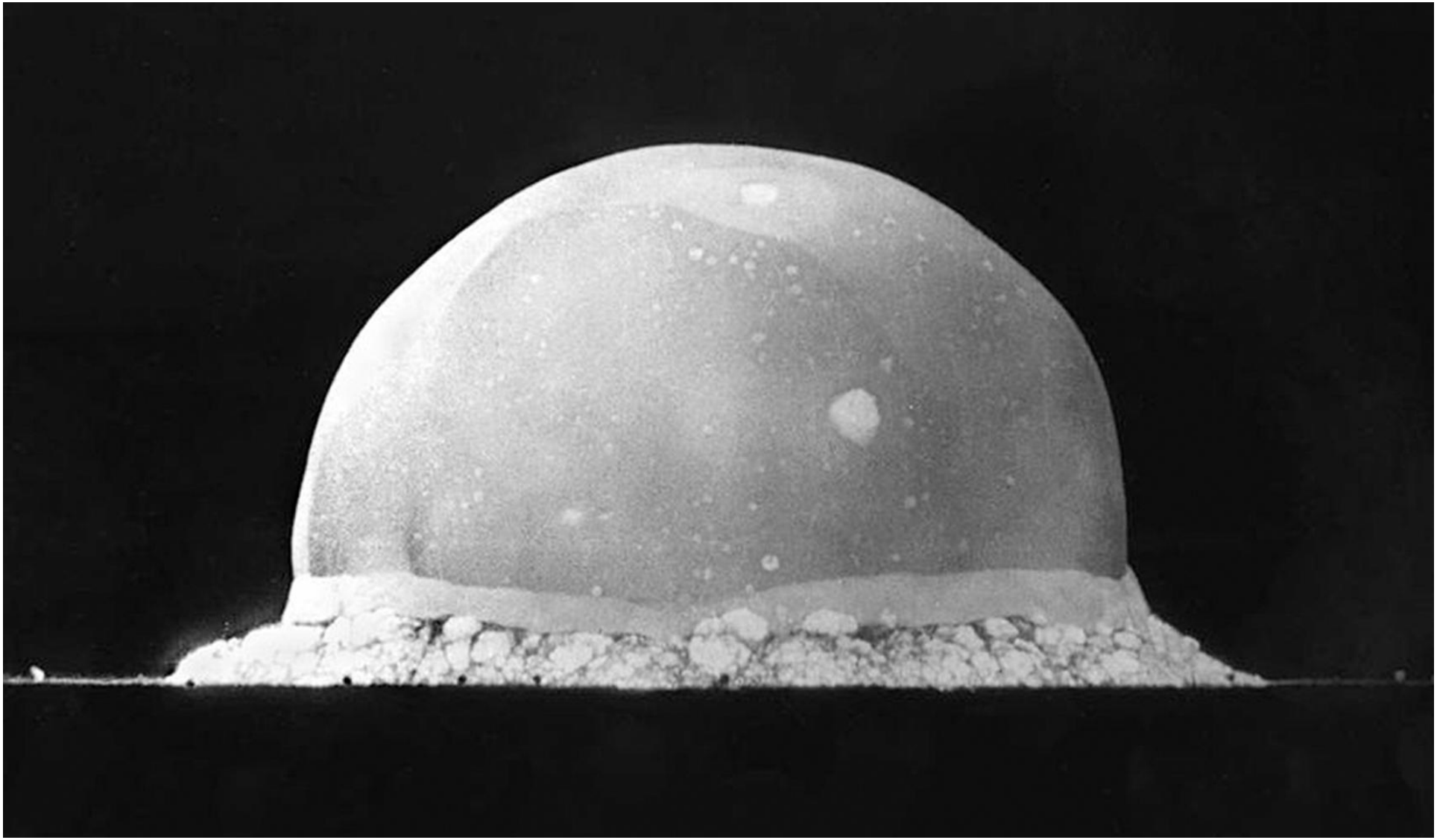

# Trinity

**Calamity Jane**

**Wild Bill Hickok**

**Martha Jane Canary**

**Wild Bill Hickok**

**Al Swearengen**

# Voyageurs