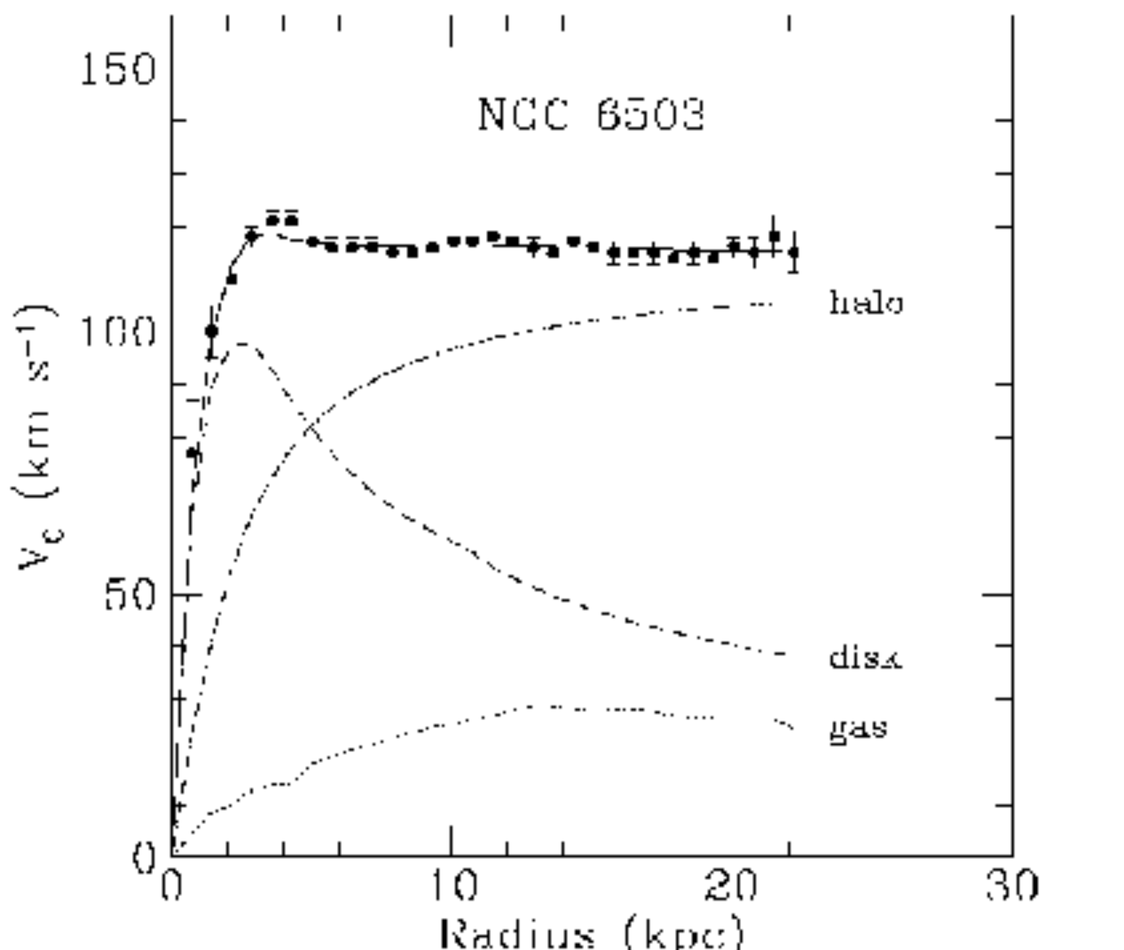
Unveiling Dark Matter: Headlines from Dark Matter Searches

Jodi Cooley
SMU / SuperCDMS

What is Dark Matter?

- **Abundance of evidence of missing mass**
  - Dynamics of stars, galaxies, and clusters
  - Rotation curves, gravitational lensing
  - Large Scale Structure formation



Rotation Curves

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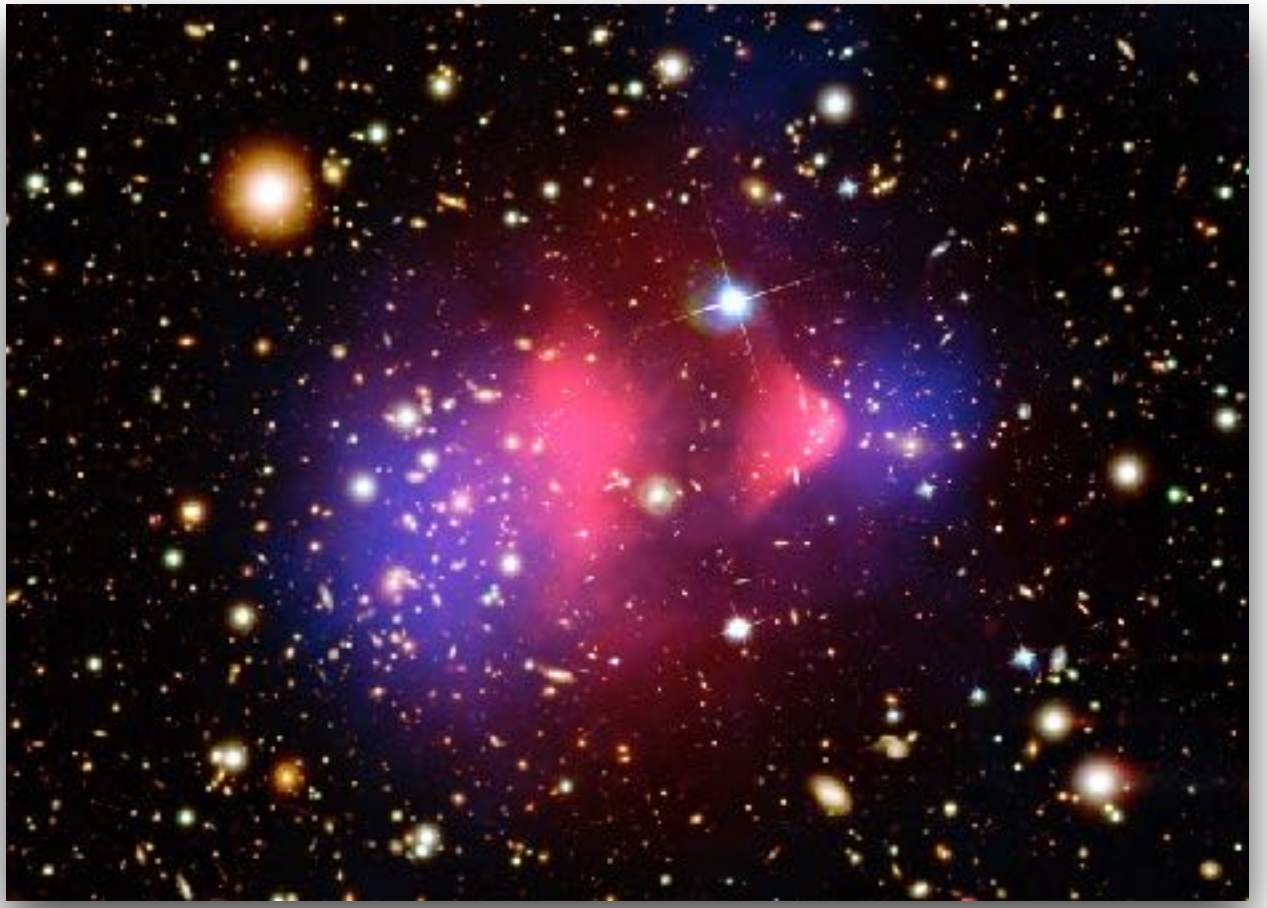
  - MOND has problems with Bullet Cluster



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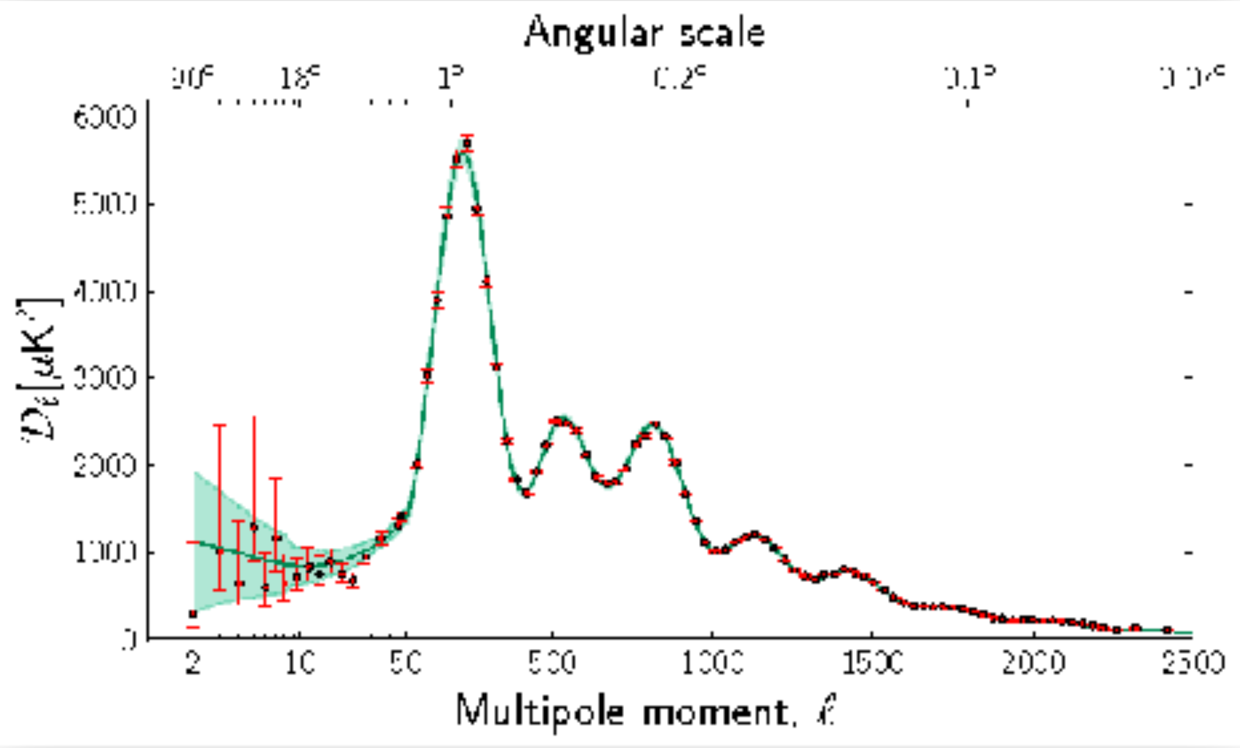

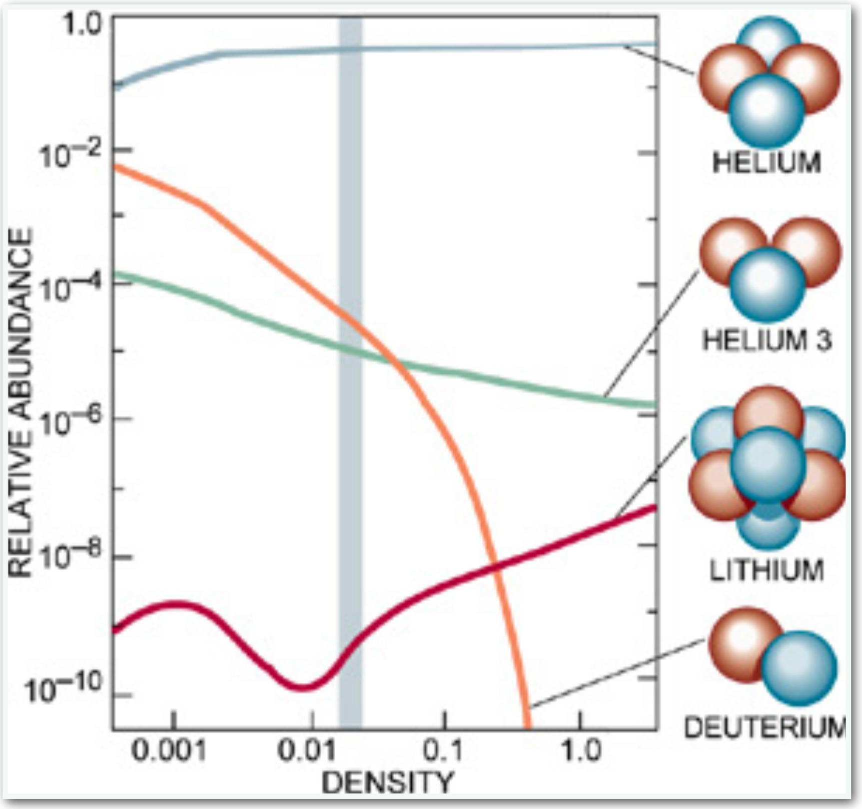

- **Non-baryonic**
    - Height of acoustic peaks in the CMB (Ω_b, Ω_m)
    - Power spectrum of density fluctuations (Ω_m)
    - Primordial Nucleosynthesis (Ω_b)

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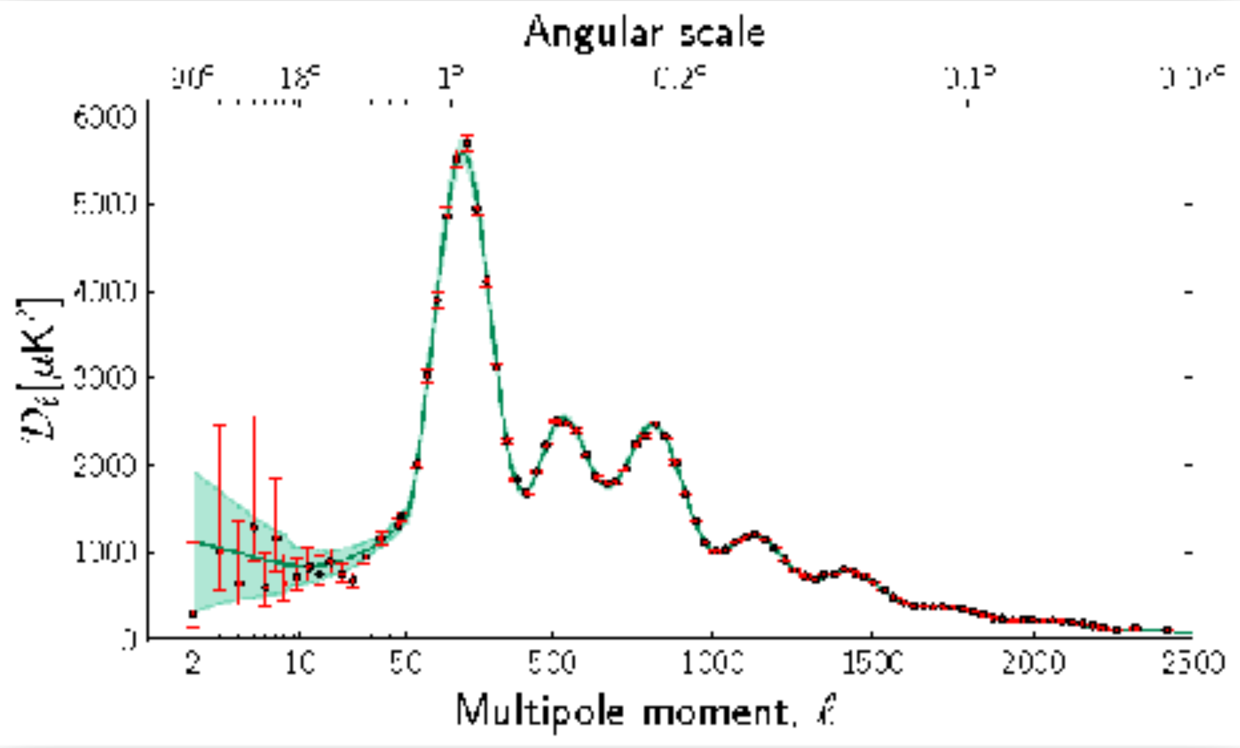
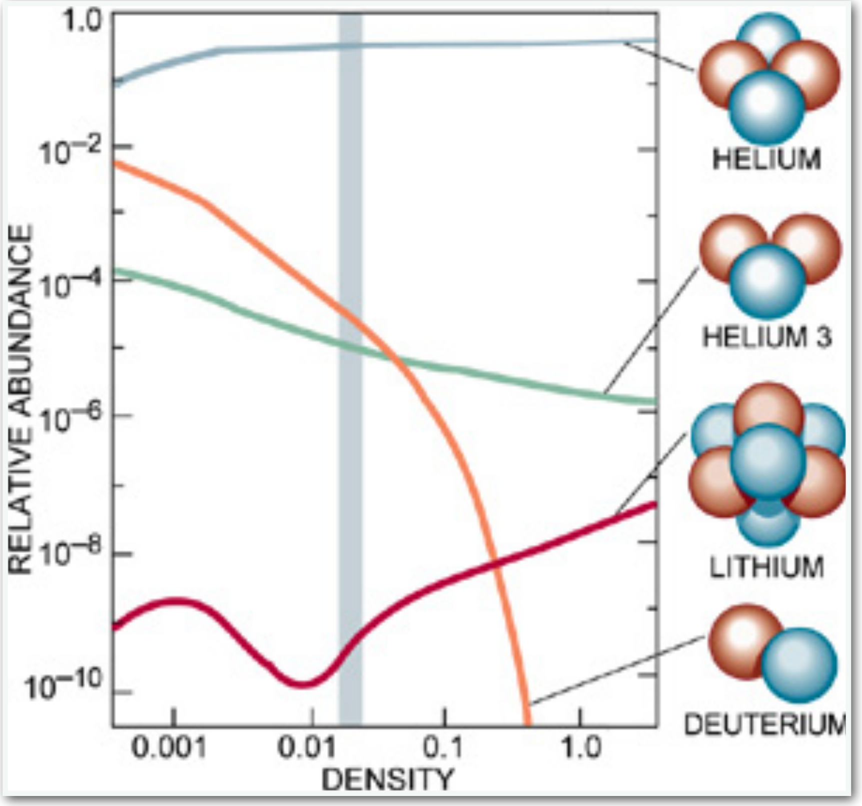
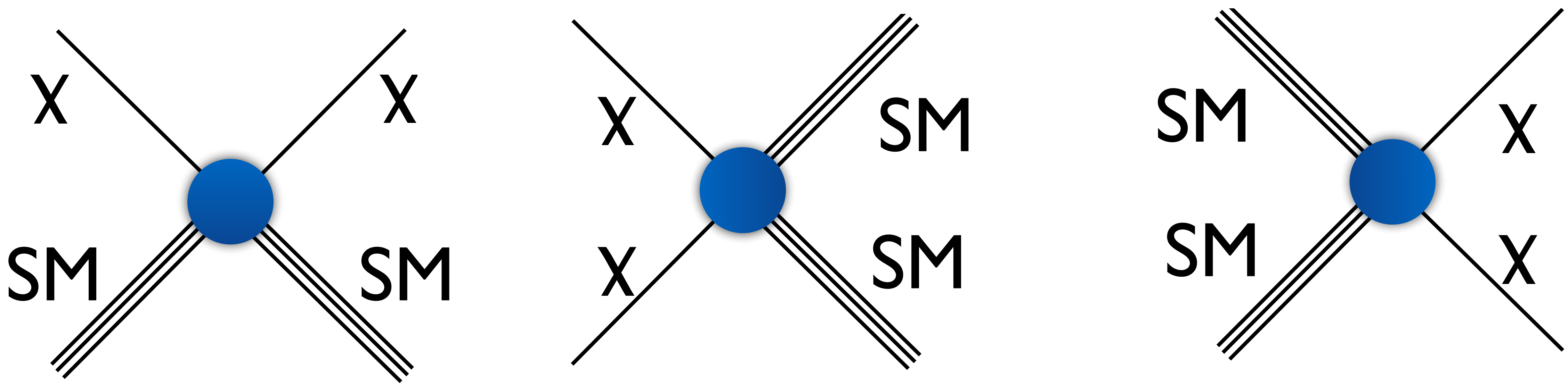




- **Non-baryonic**
  - Height of acoustic peaks in the CMB (Ω_b, Ω_m)
  - Power spectrum of density fluctuations (Ω_m)
  - Primordial Nucleosynthesis (Ω_b)
- **And STILL HERE!**
  - Stable, neutral, non-relativistic
  - Interacts via gravity and (maybe) a weak force

How to Detect It?

Shake It! Break It! Make It!



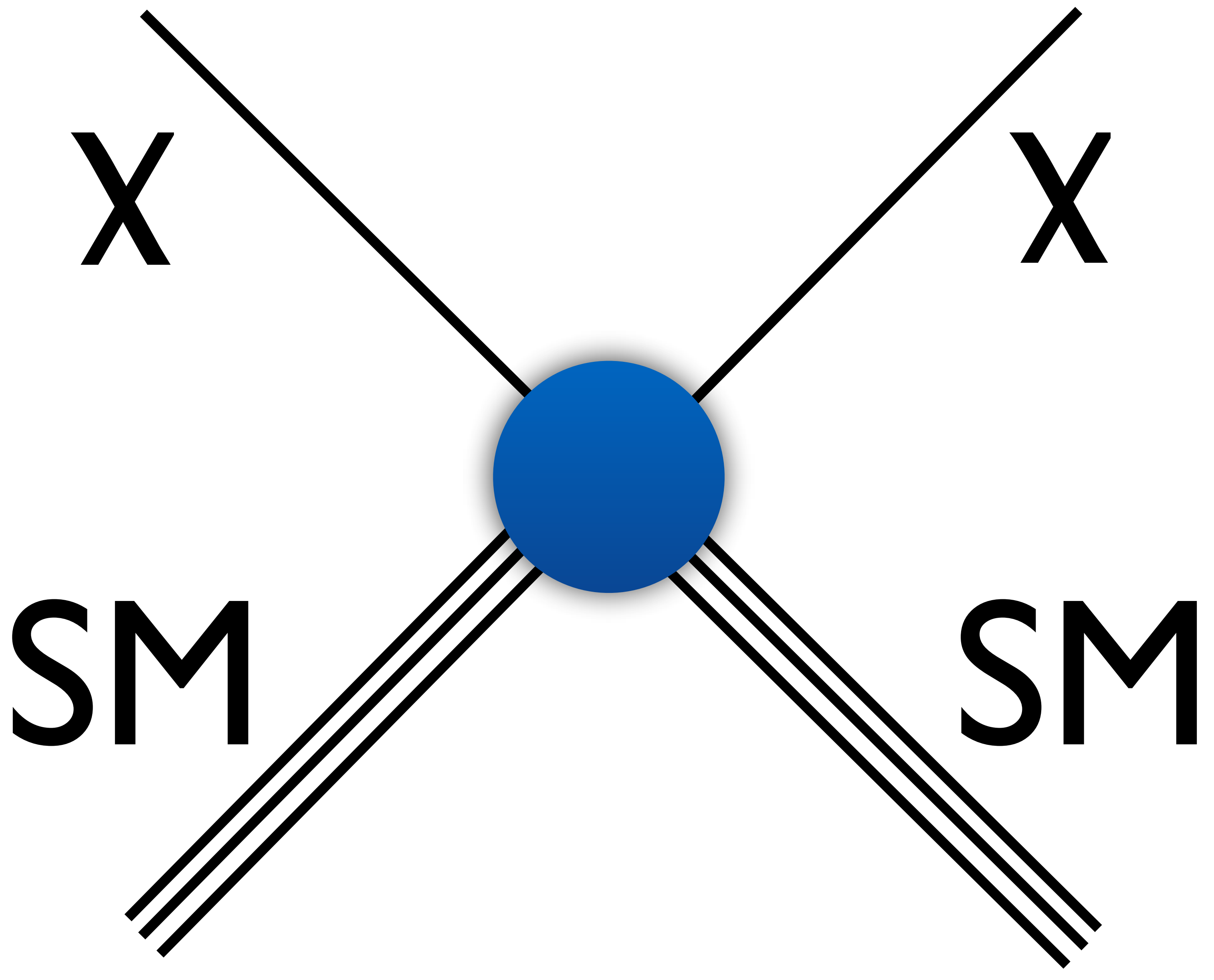
Time

Direct Detection (scattering)

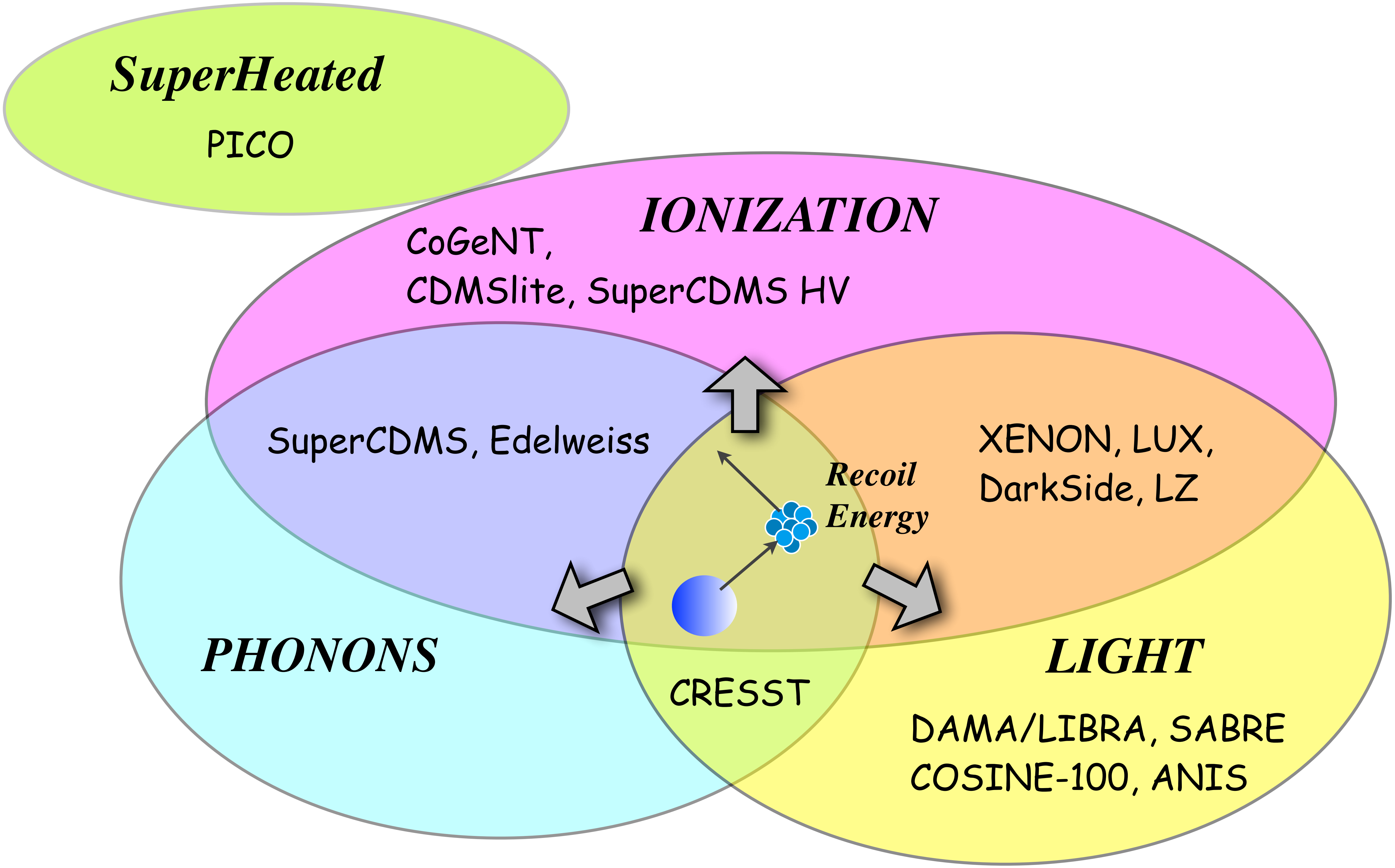
Indirect Detection (annihilation/decay)

Collider (production)

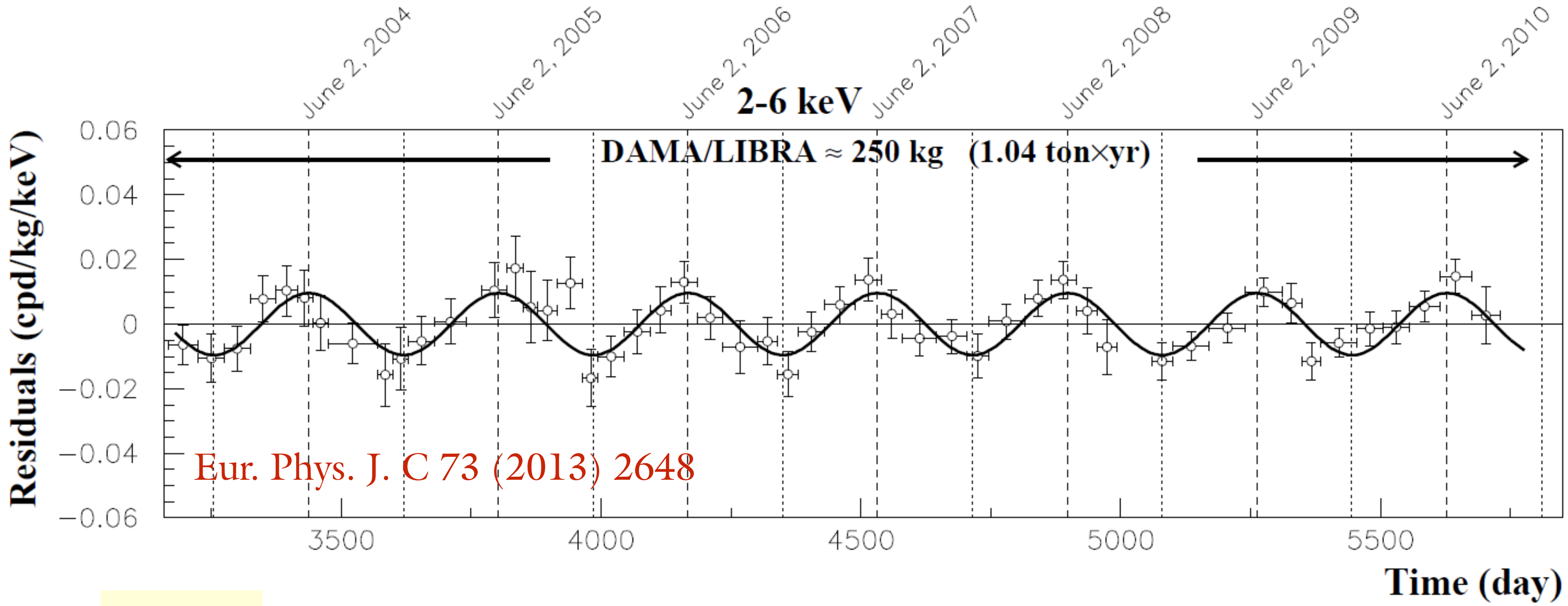
Shake It!

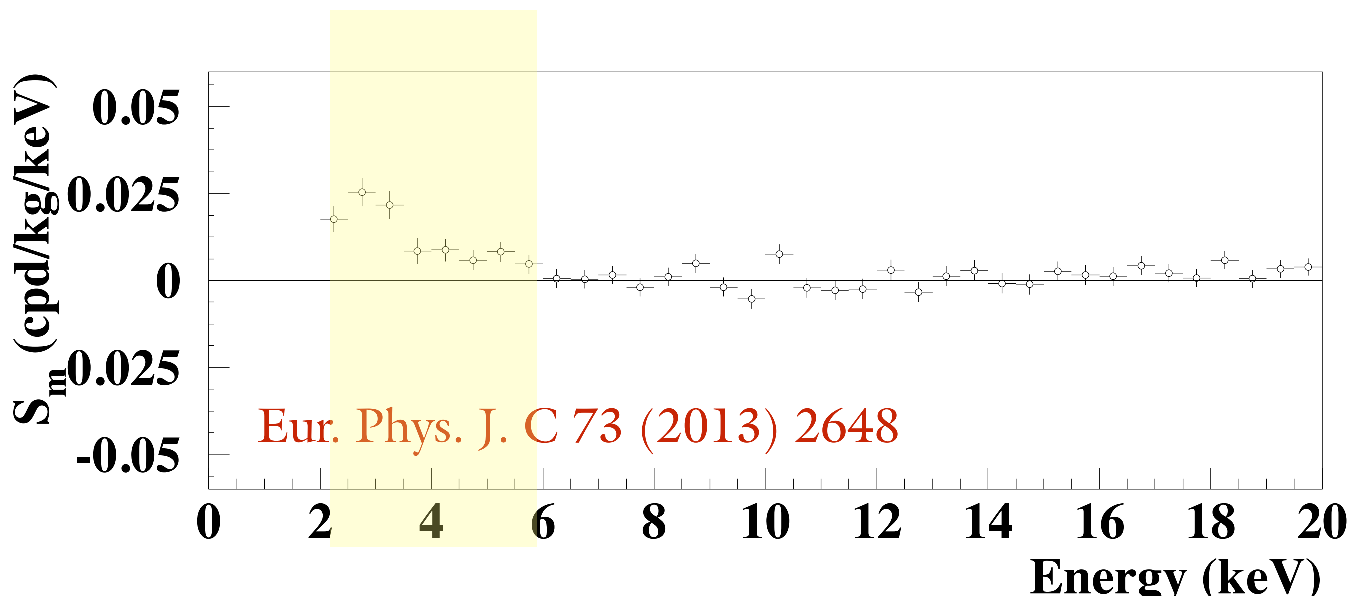


Direct Detection Principles



DAMA/LIBRA





$10 - 30\ keV_{nr}$ (Na)
$30 - 120\ keV_{nr}$ (I)

- Signal observed over 13 cycles at 9.3 σ for single scatter events (good) in lowest energy bin.
- No background/signal discrimination.
- Debate over background or dark matter interpretation

EFT - Possible Dark Matter?

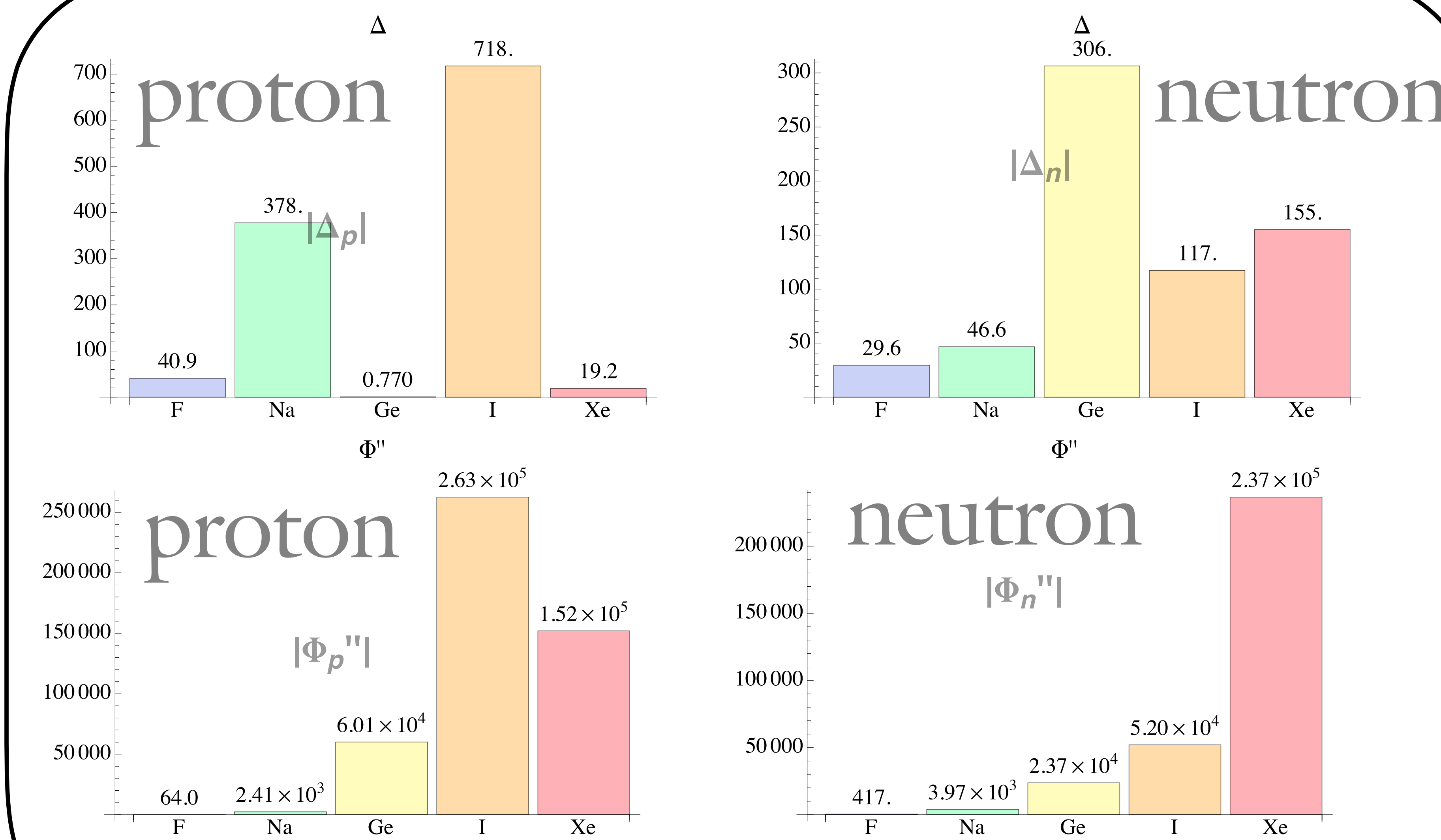
What if the couplings are not simple spin-independent or the standard spin-dependent case through neutron or proton spin?

nuclear angular momentum

$$\vec{L}$$

product of nuclear angular momentum & spin

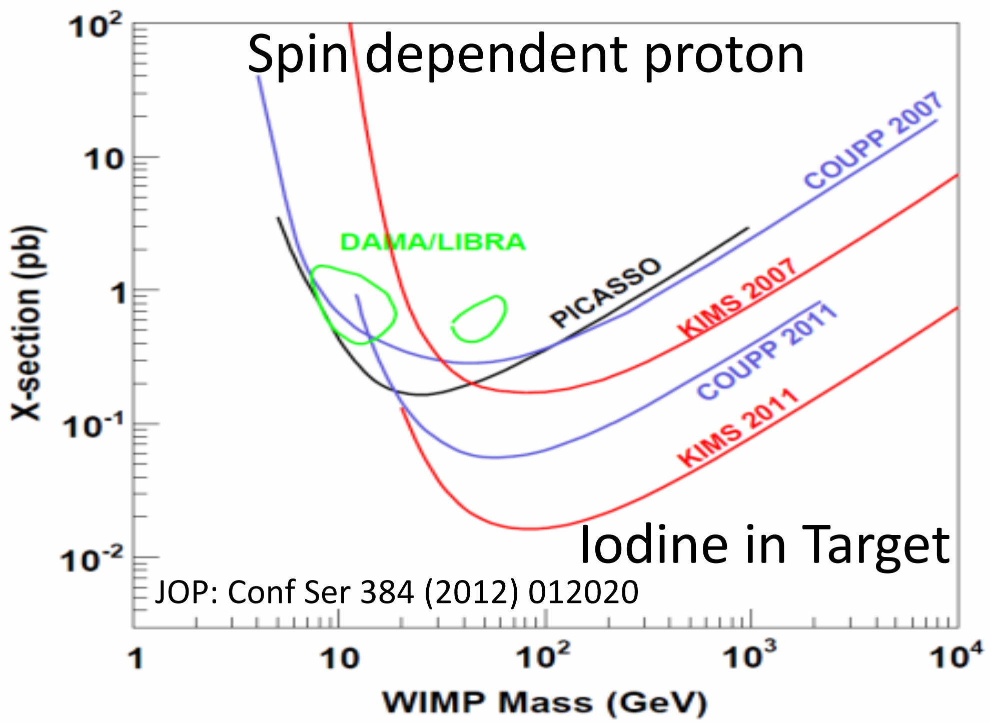
$$\vec{L} \cdot \vec{S}$$



Fitzpatrick et. al. arXiv:1203.3542

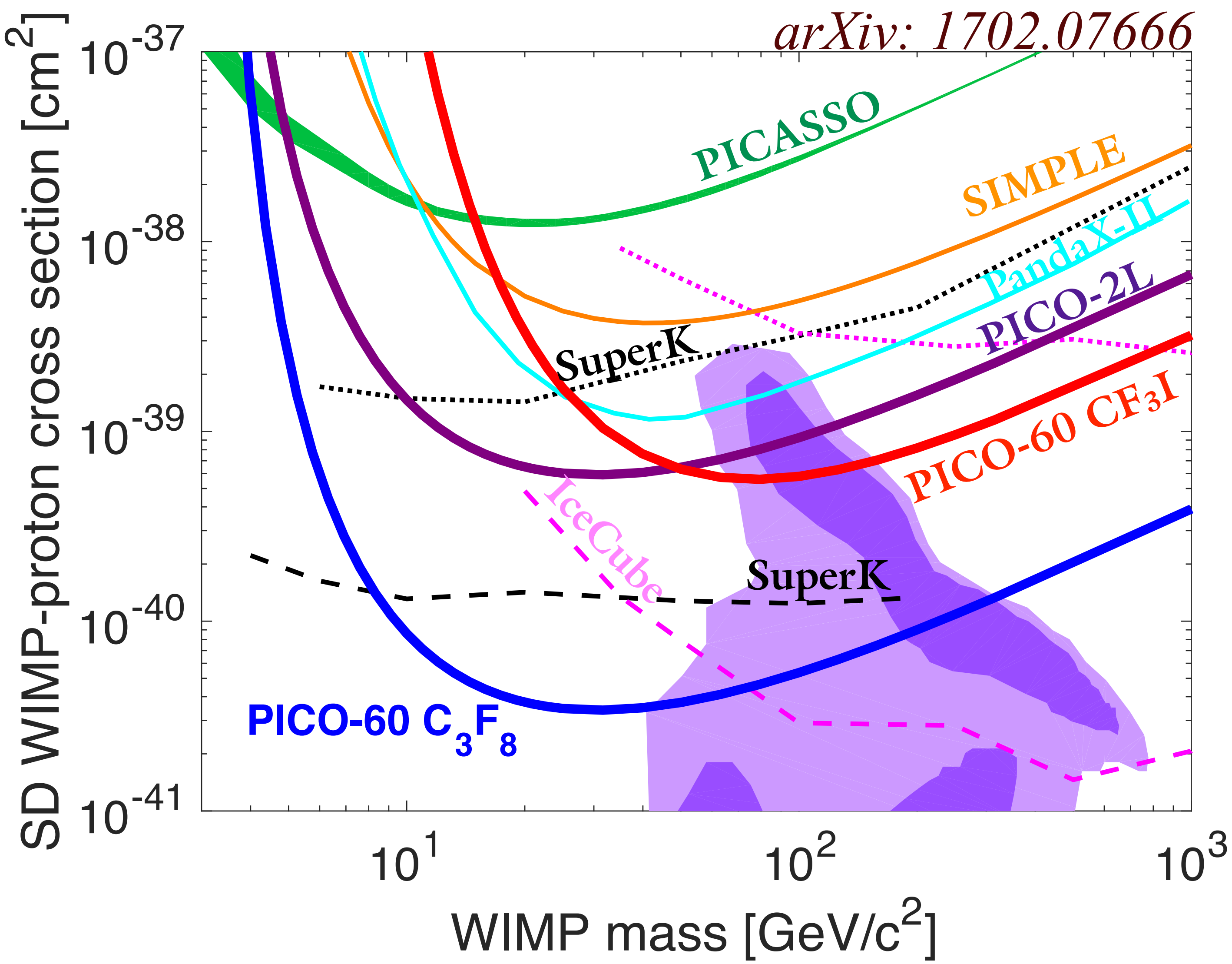
Spin Dependent

See Talk:
Carsten Krauss



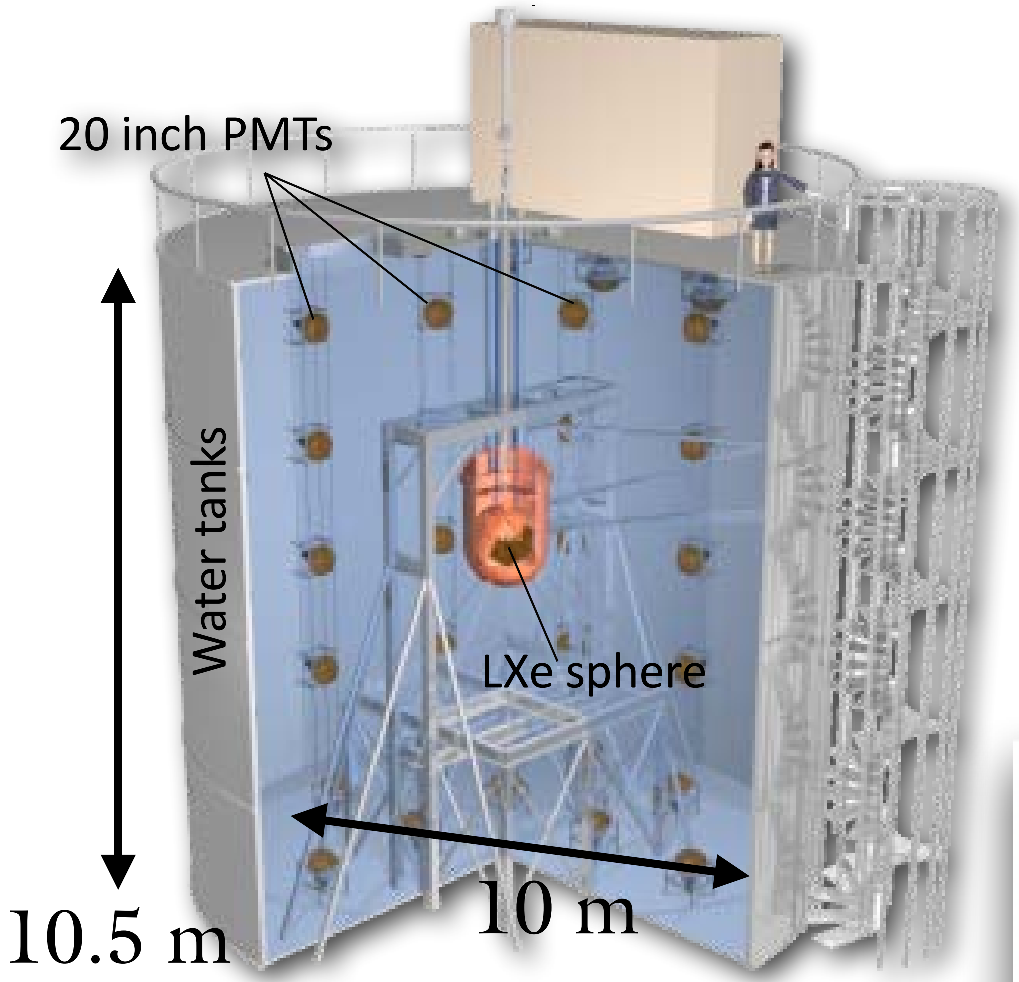
- Results by several experiments rule out standard spin-dependent assumptions.

- Most recent results from PICO-60 using a C_3F_8 target *(arXiv: 1702.07666)*



Single Phase: XMASS

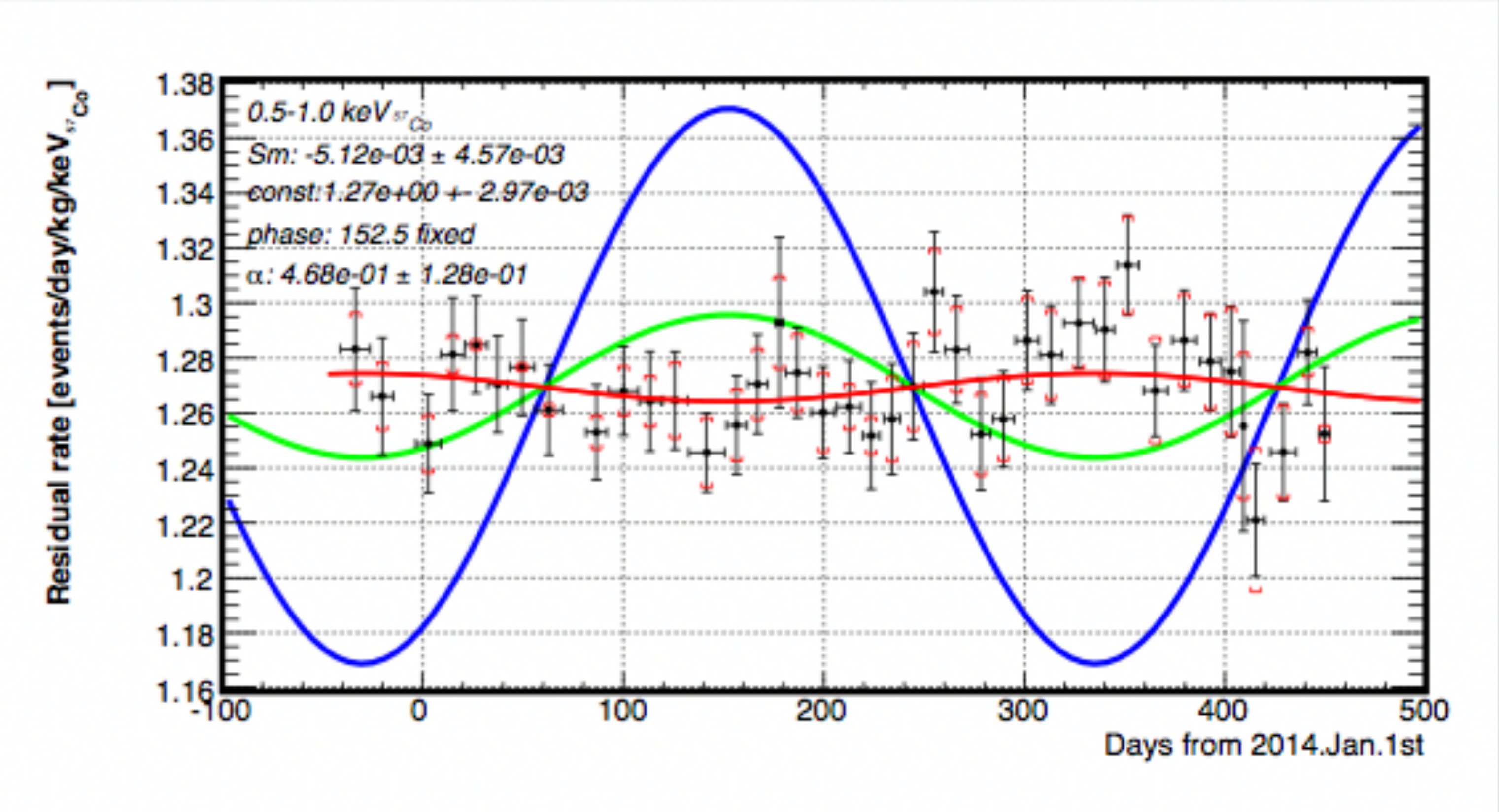
See Talk:
Katsuki Hiraide



- Located in the Kamioka Underground Observatory, Japan. Detector refurbished in 2013 to reduce radioactive background from PMTs.
- Total detector mass 800 kg xenon
- "self-shielding" from gammas. WIMPs and neutrons evenly distributed throughout volume.
- Water tank acts as an active muon veto.

arXiv:1511.04807

- Observed no modulation from Analysis preformed with data taken from 11/2013 - 3/2015.



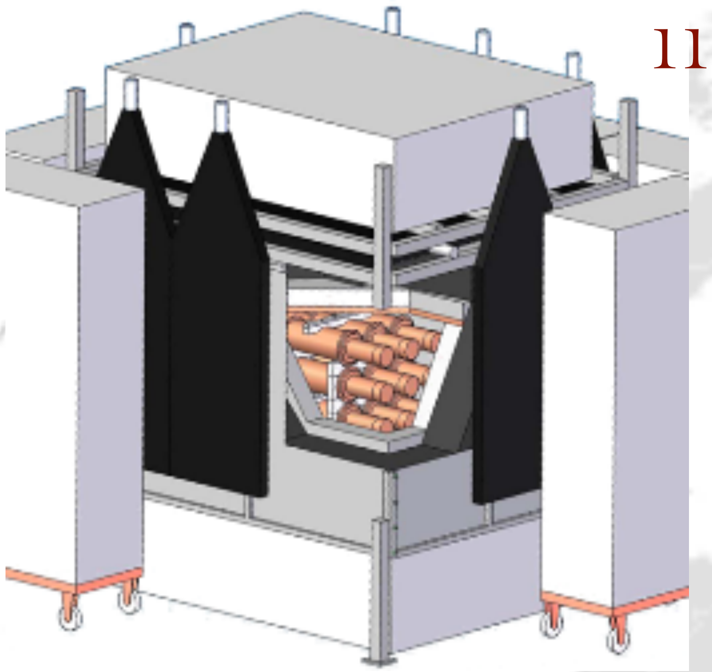
8 GeV/c², 2x10⁻⁴⁰cm² (blue)
7 GeV/c², 2x10⁻⁴⁰cm² (green)
Model Independent (red)

See Talk:
Jay Hyun Jo

Worldwide NaI Efforts

ANAIS

113 kg array, Canfranc



Canfranc Gran Sasso & Australia

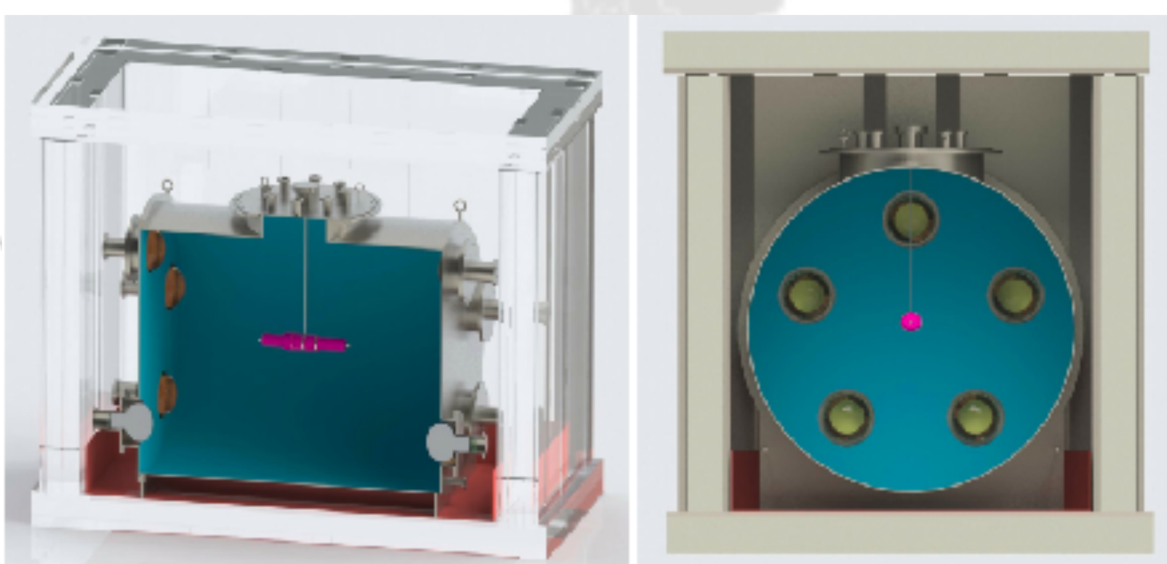
Yangyang

COSINE-100

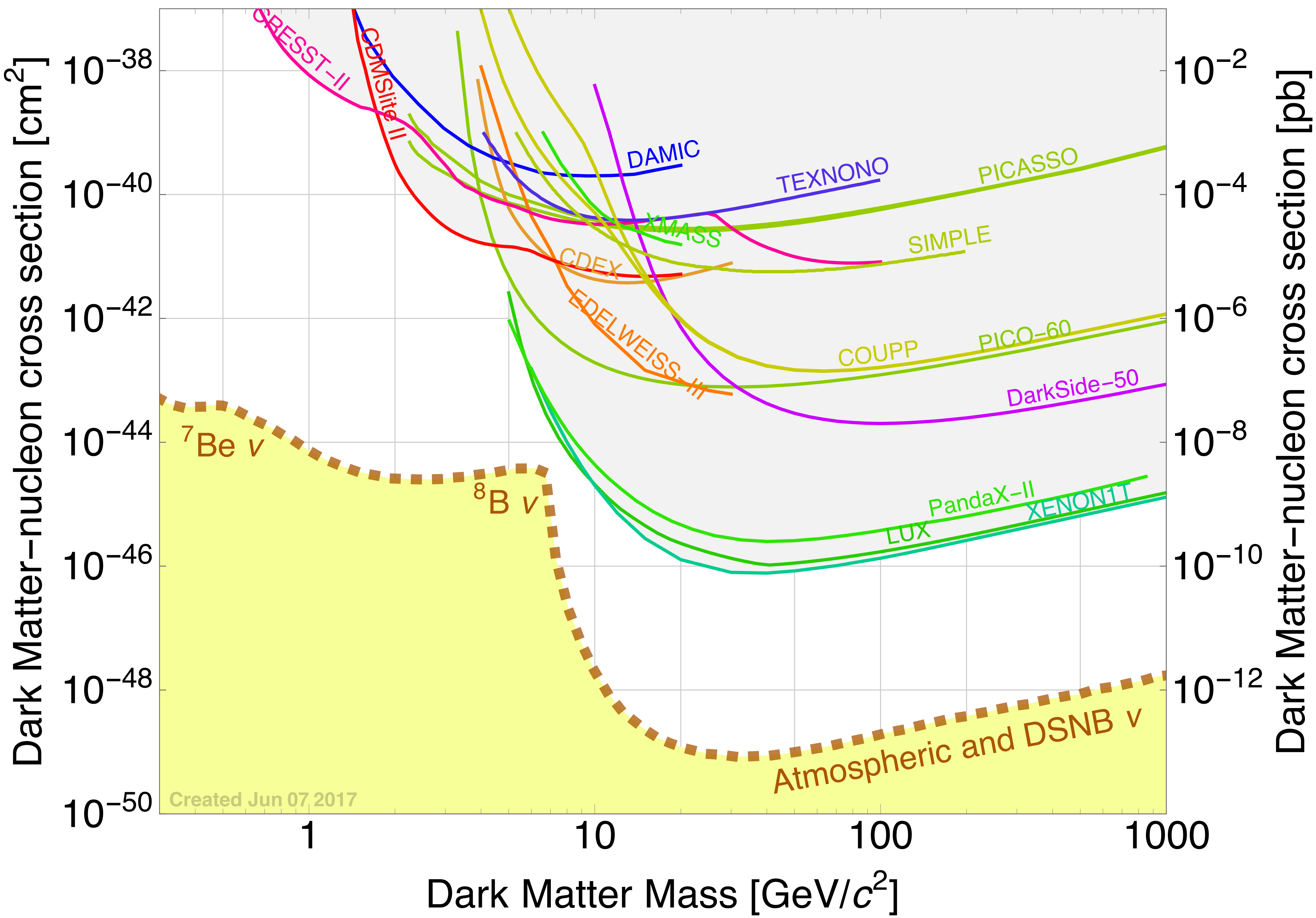
106 kg array, Yangyang

SABRE

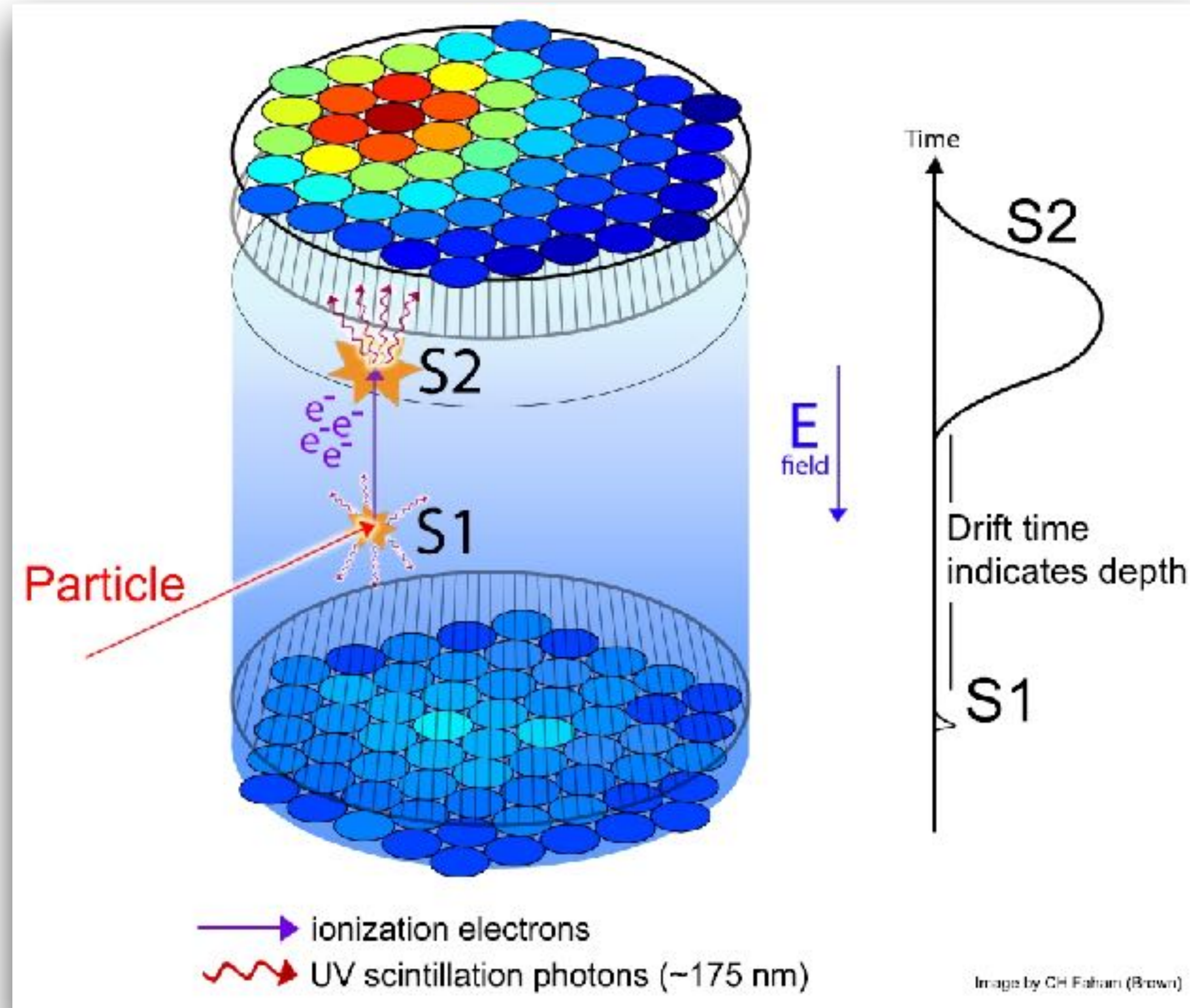
113 kg array,
Gran Sasso & Australia

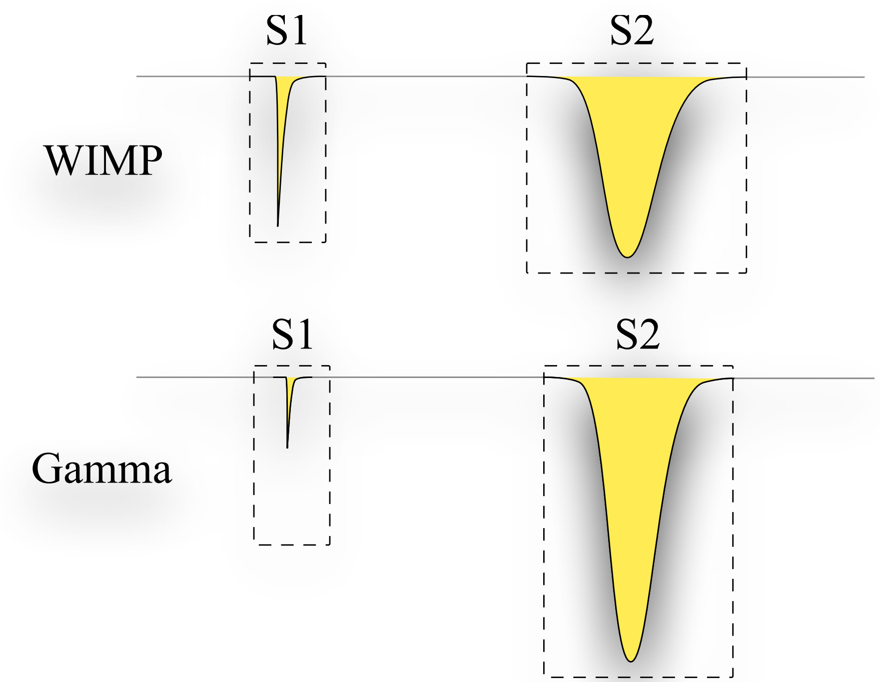


Spin Independent Landscape



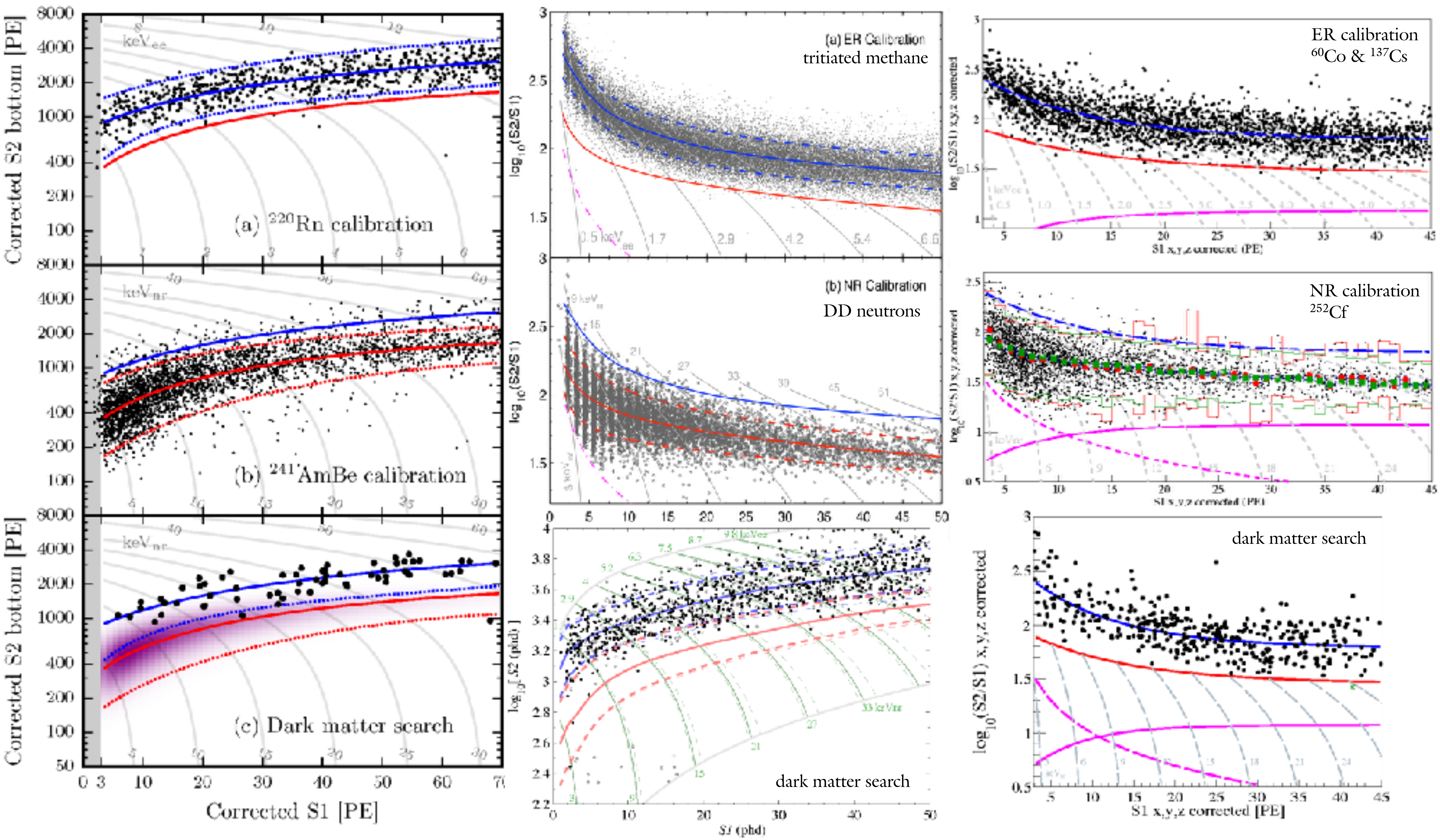
2-Phase Xenon Experiments





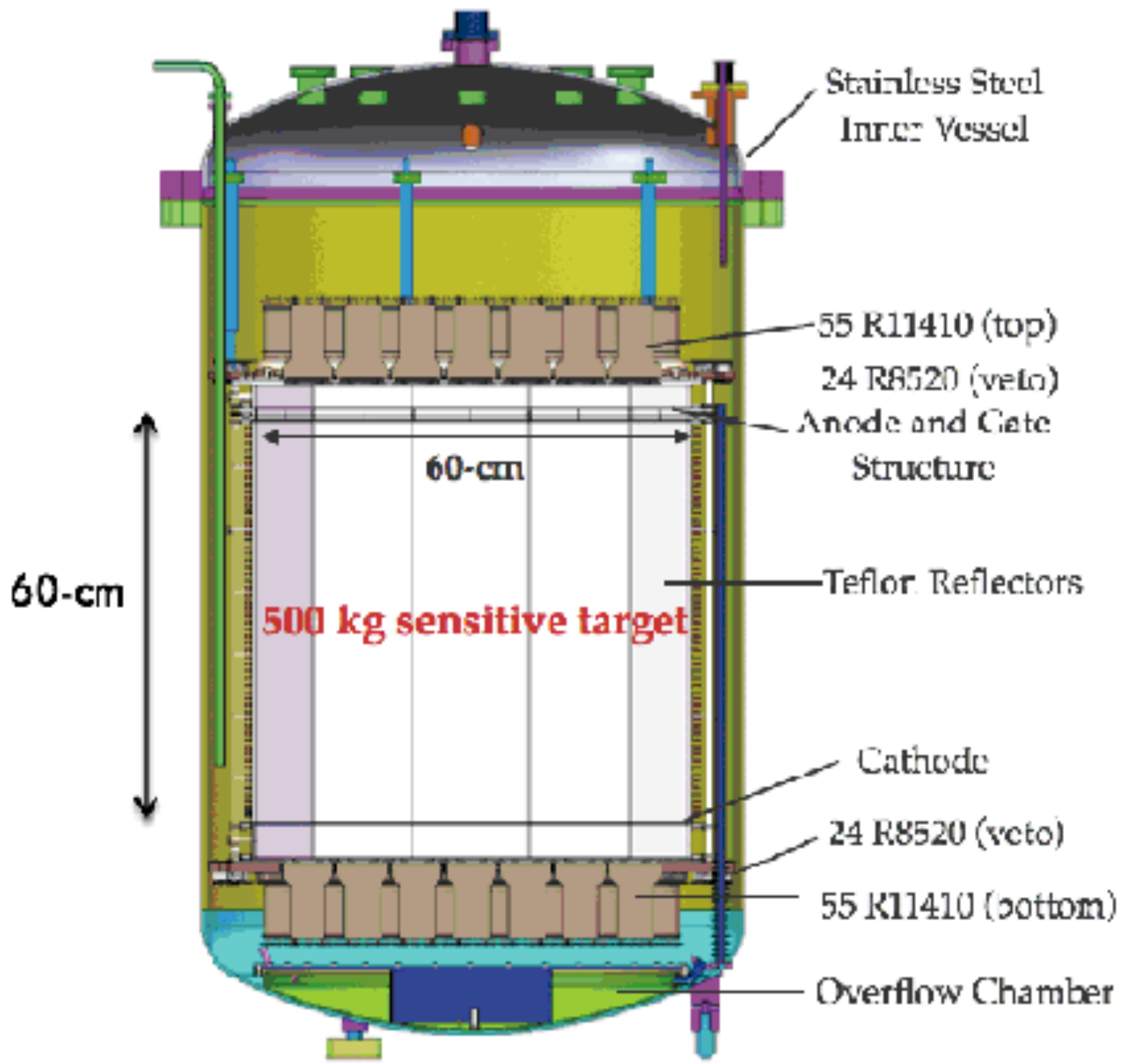
- Ratio of S2/S1 gives particle type.
- Time between S2 and S1 gives the depth.
- xy-position reconstructed from phototube hit pattern.

XENON1T - LUX - PandaX-II

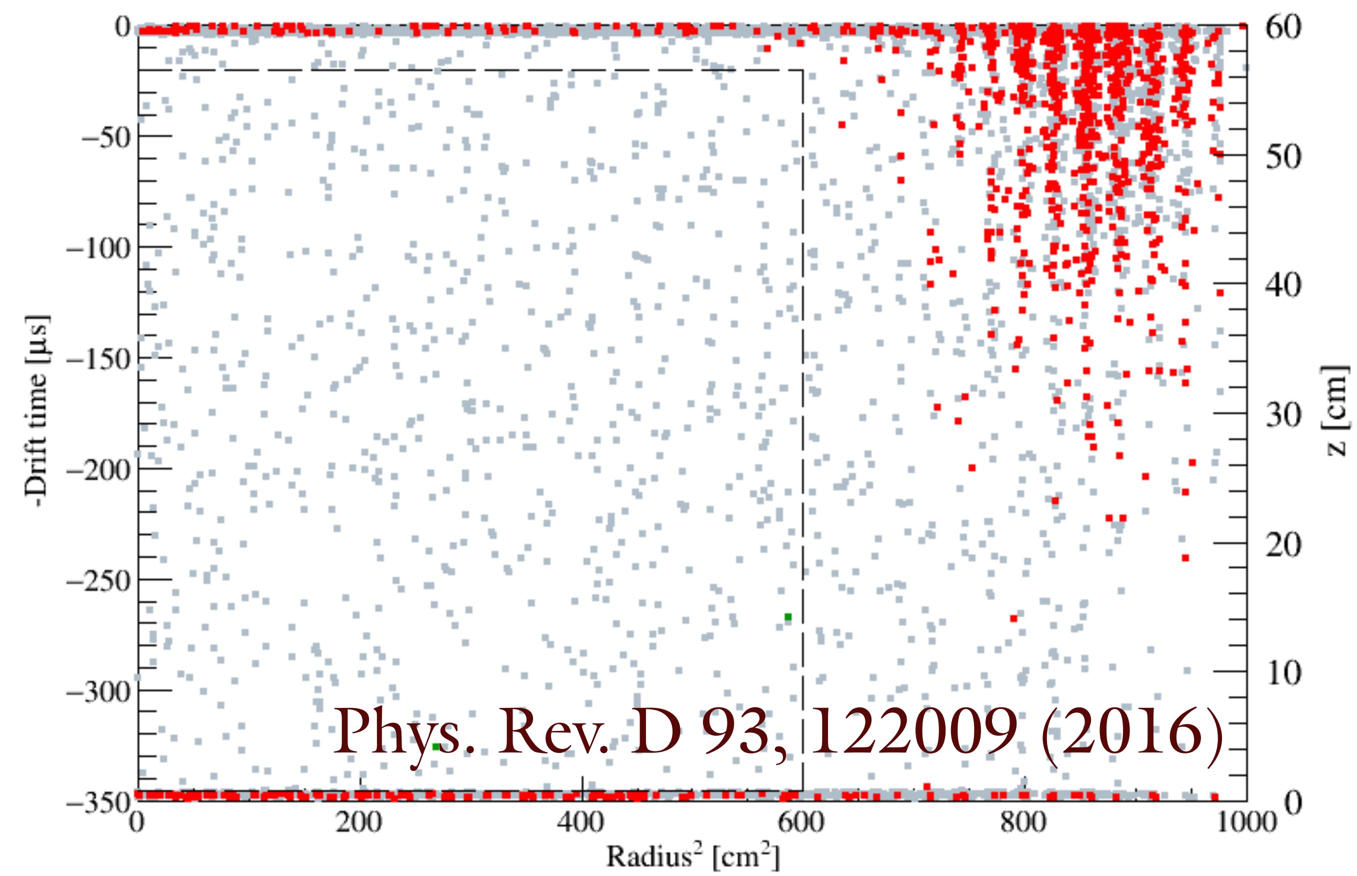


PANDAX-II

See Talk:
Mengjiao Xiao



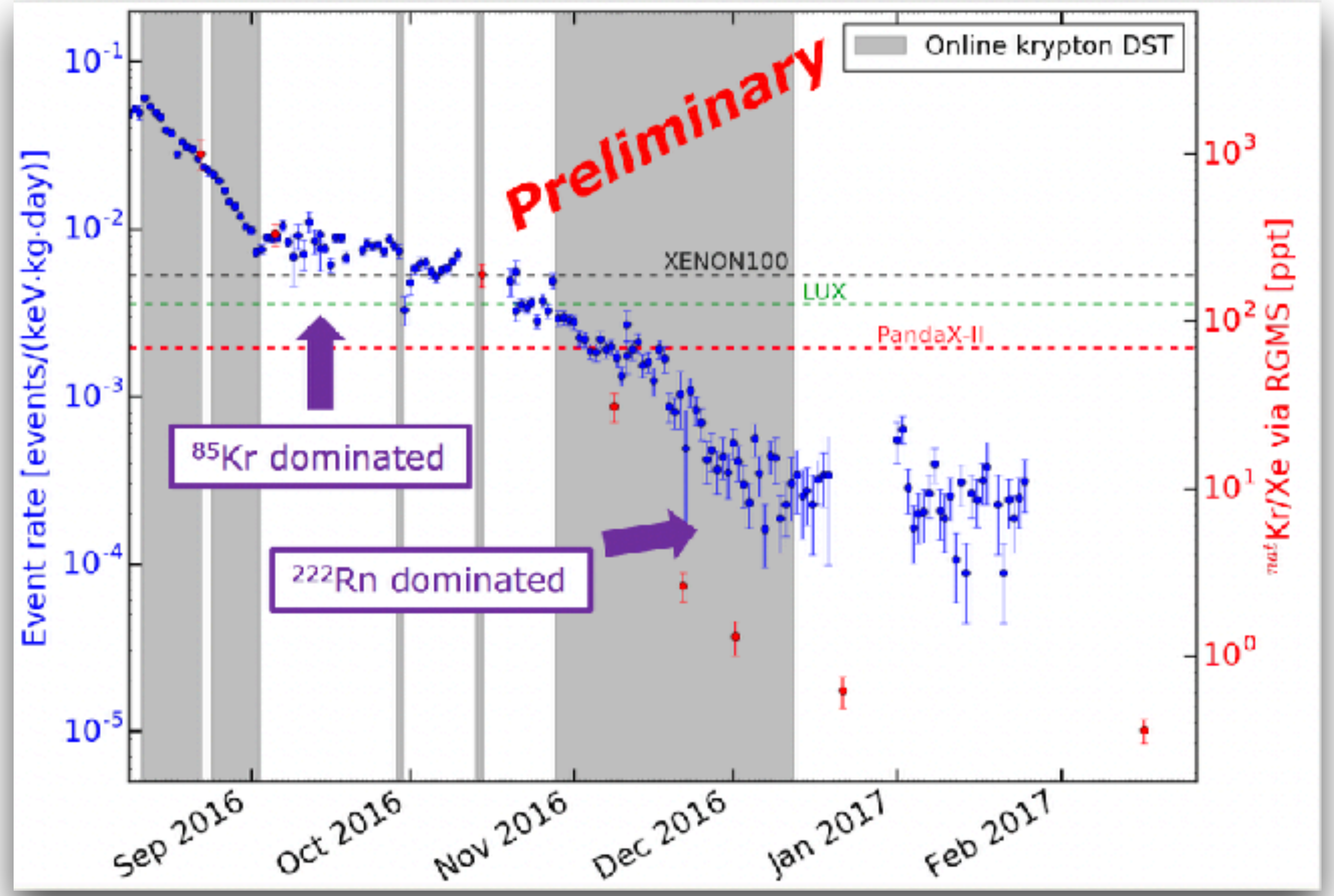
Gray: all
Red: below NR median
Green: below NR median & in FV



- ~306 kg-days total exposure
- 2.5×10^{-3}/keV$_{ee}$/kg/d, dominated by ^{85}Kr.
- 2 events observed on 3.2 background events expected.

XENON1T

See Talk:
Sara Diglio



- Achieved lowest background rates:
  - measured: $(1.93 \pm 0.25) \times 10{-}4$ events/kg/day/keVee
  - MC prediction: $(2.3 \pm 0.2) \times 10{-}4$ events/kg/day/keVee

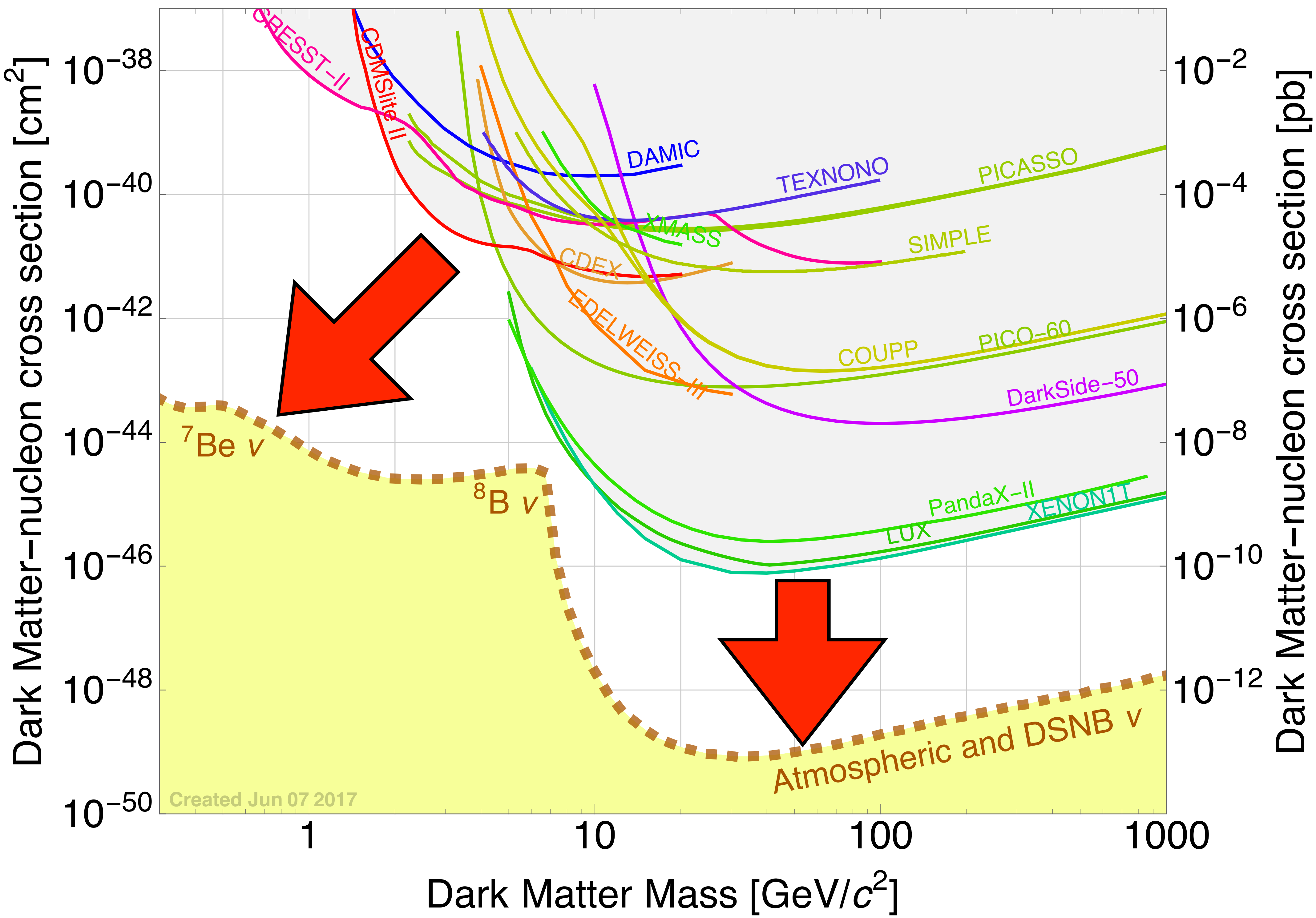
Low Mass Dark Matter

The Priorhedron

theory priors ↓ / cosmo priors →	← weaker	stronger →
↑ weaker	EFT couplings to new physics	thermal and quasi thermal relics, scalars from EUPT
↓ stronger	QCD axions w/o cosmology; scale-free DM	WIMPs; “classic” PQ axions

Neil Weiner, Rencontres de Blois 2017

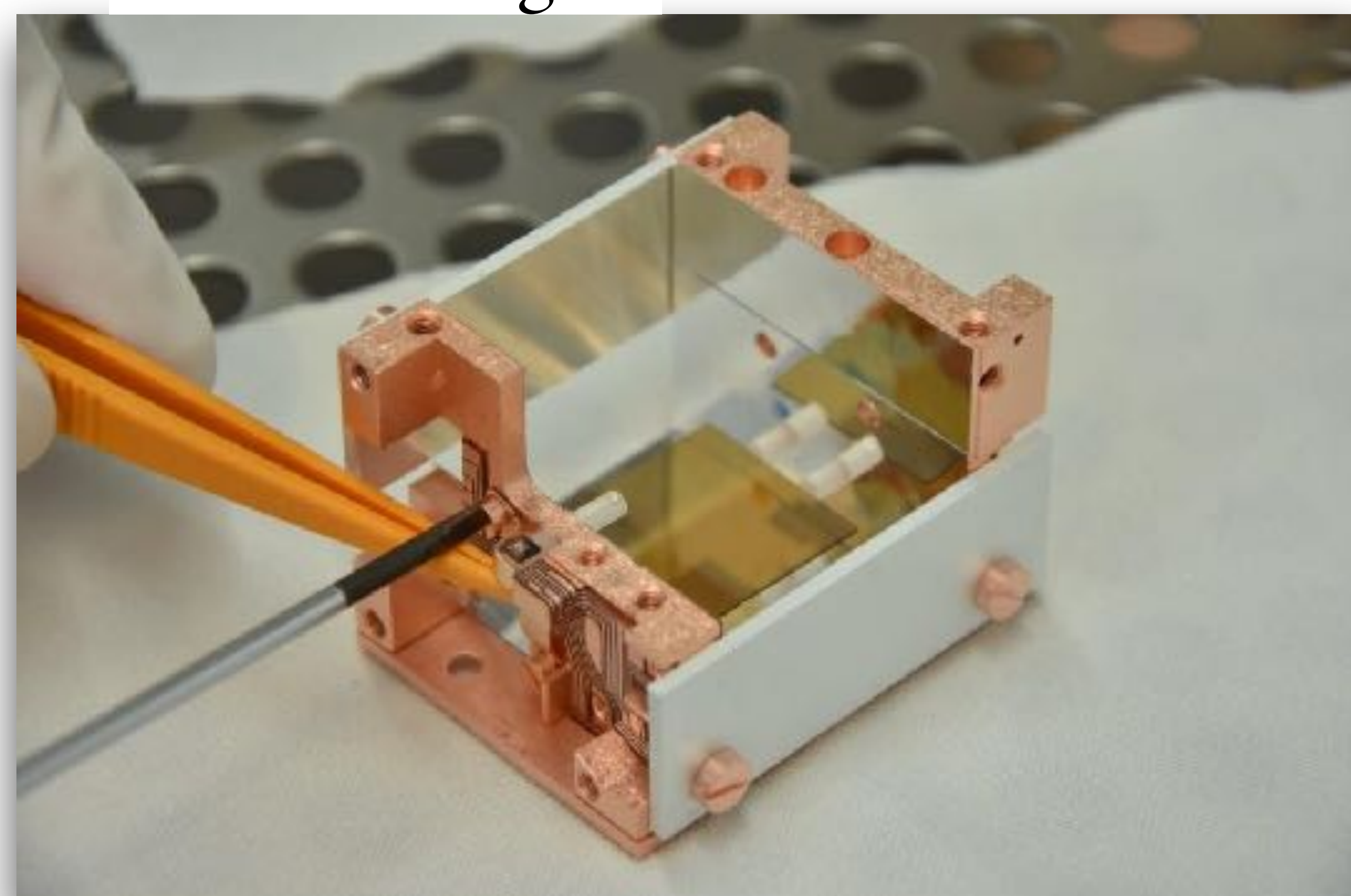
Low Mass Dark Matter

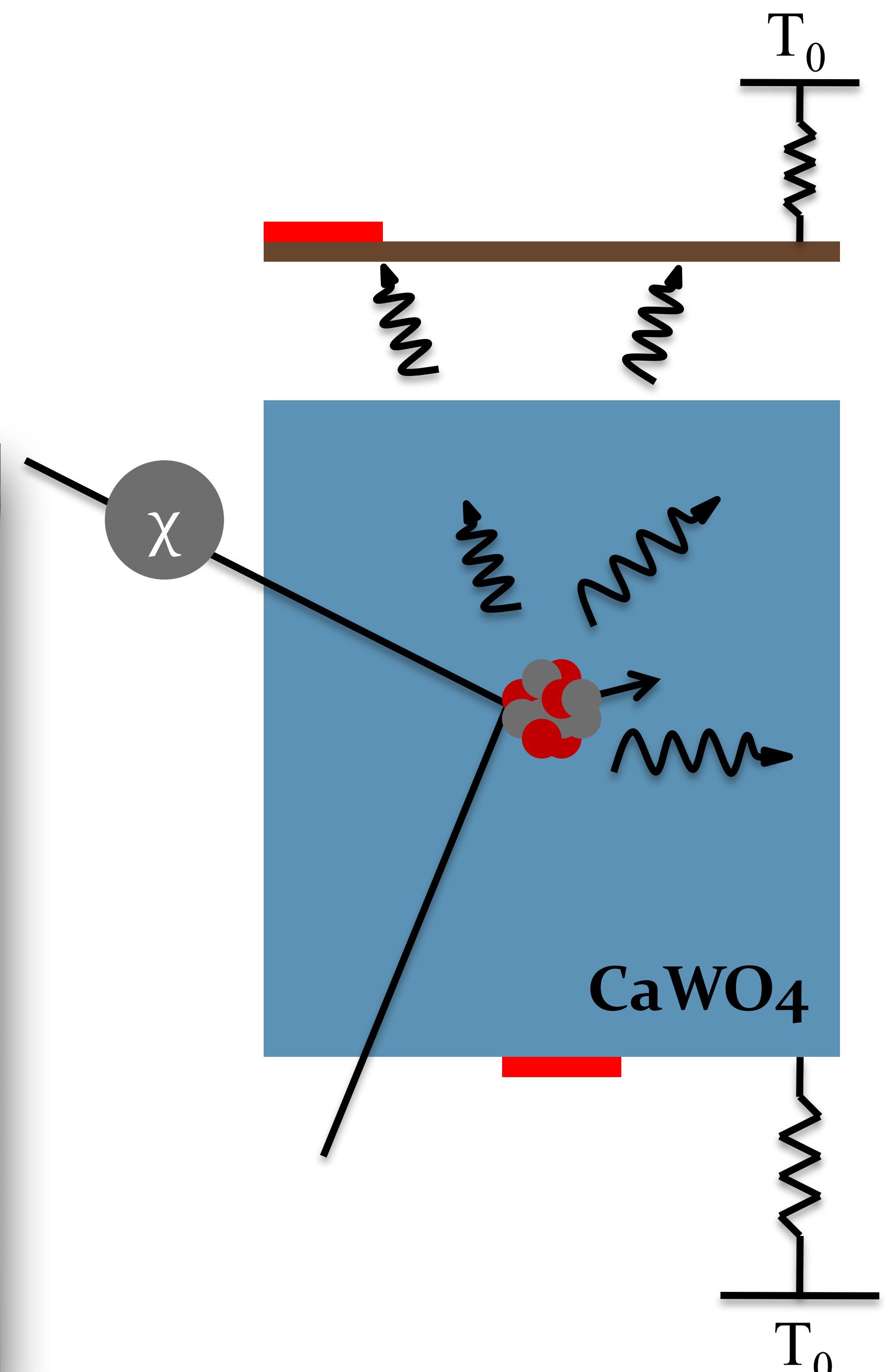


See Talk:
Michael Willers

CRESST III

- Scintillating 24 g $CaWO_4$ crystals as target collect both phonon and scintillating signals.
  - Tungsten TES reads out phonon signal
  - Light absorber (Si on sapphire) collects scintillation signal.





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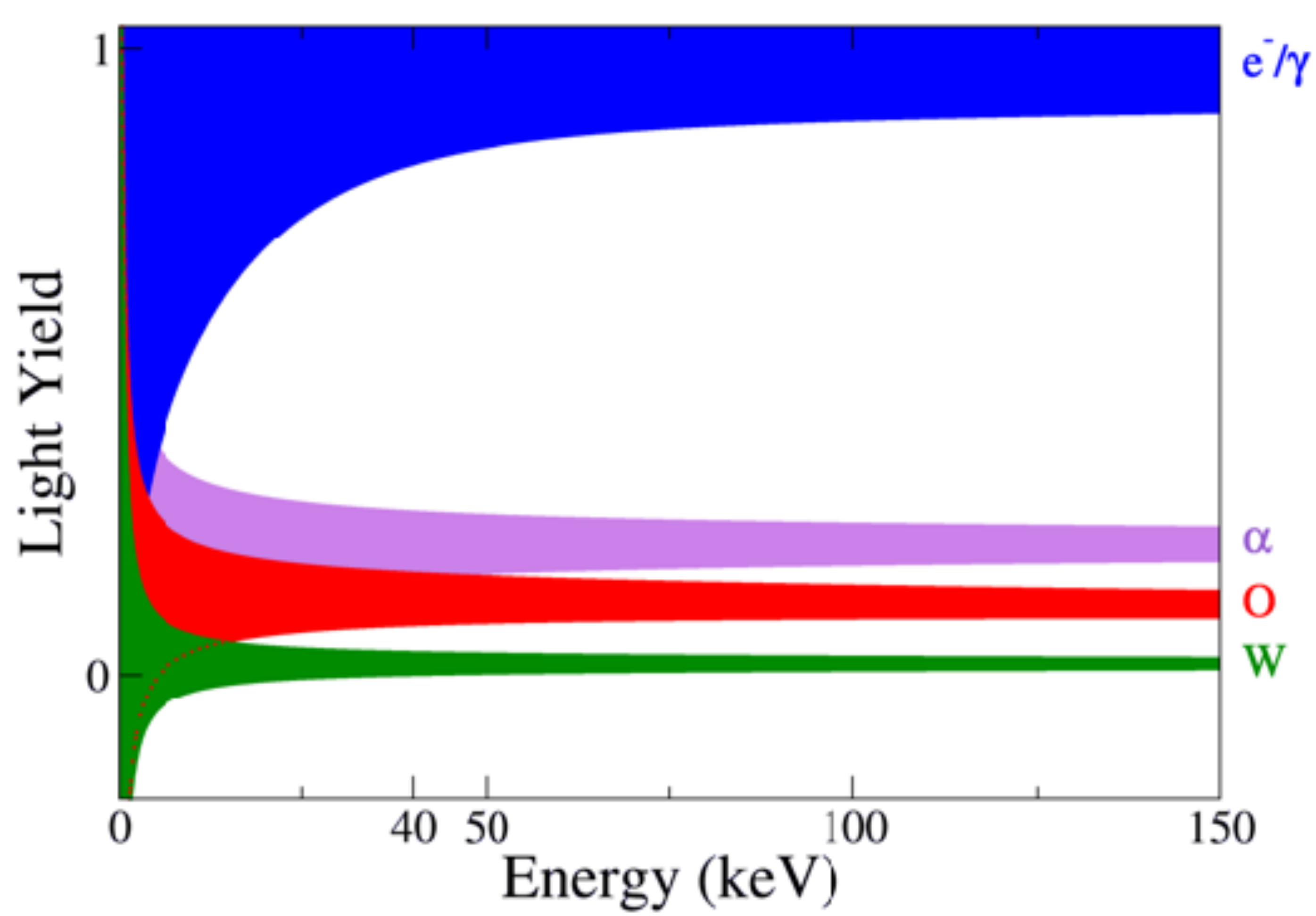
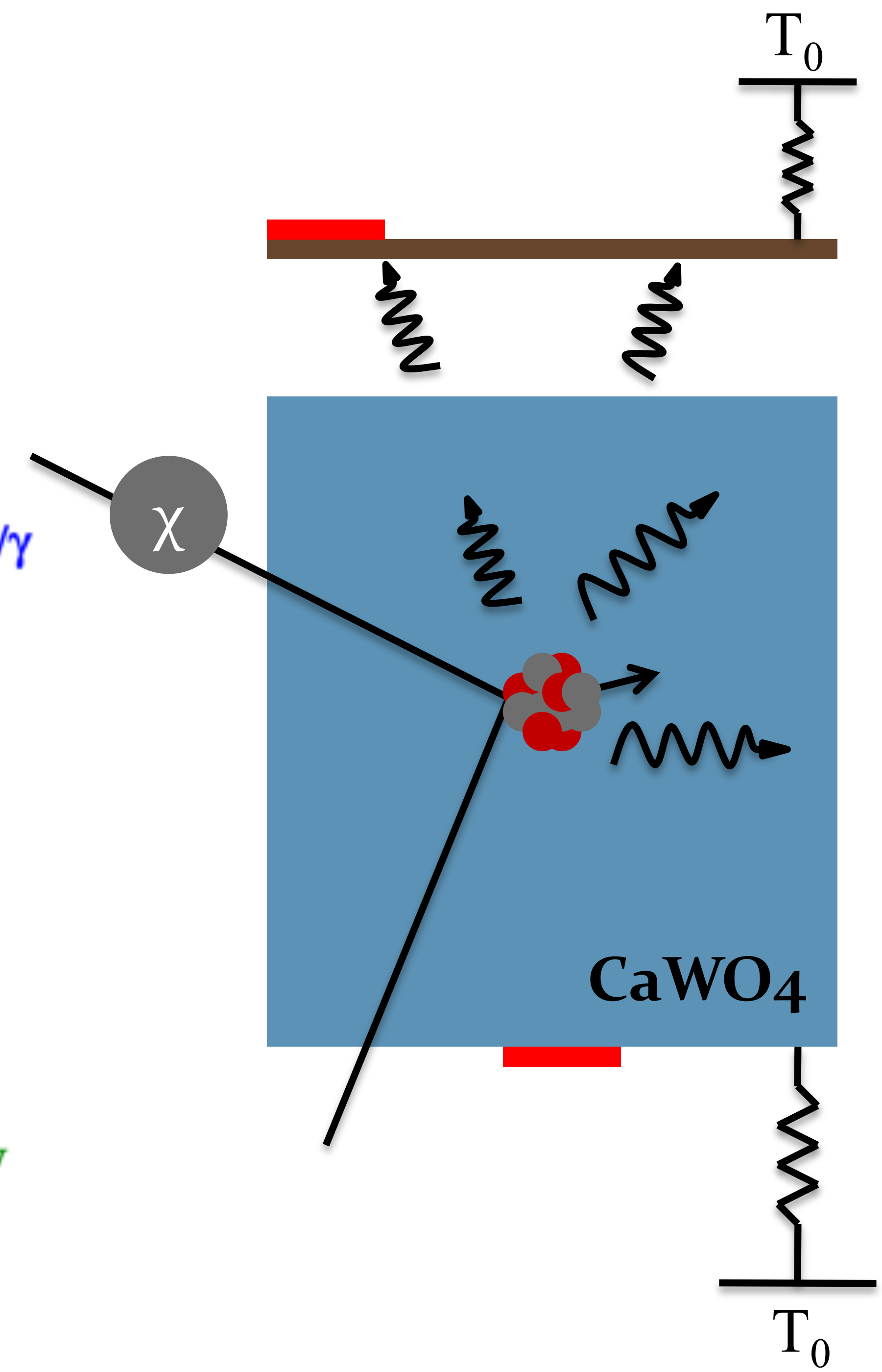


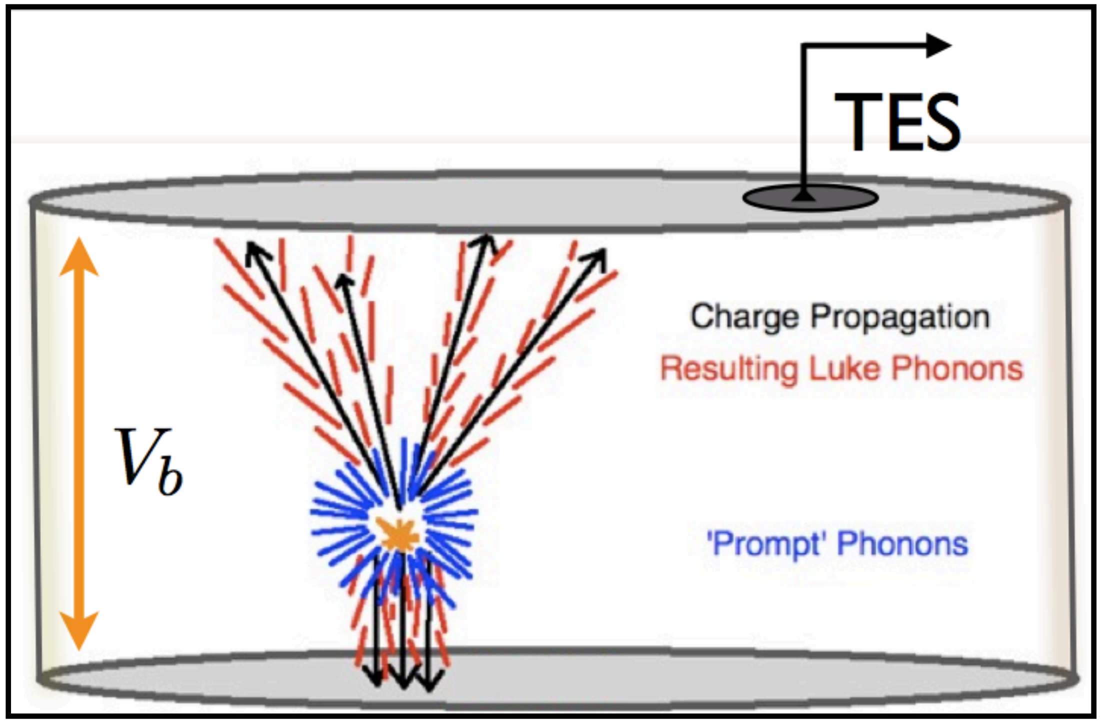


CDMSlite/SuperCDMS HV

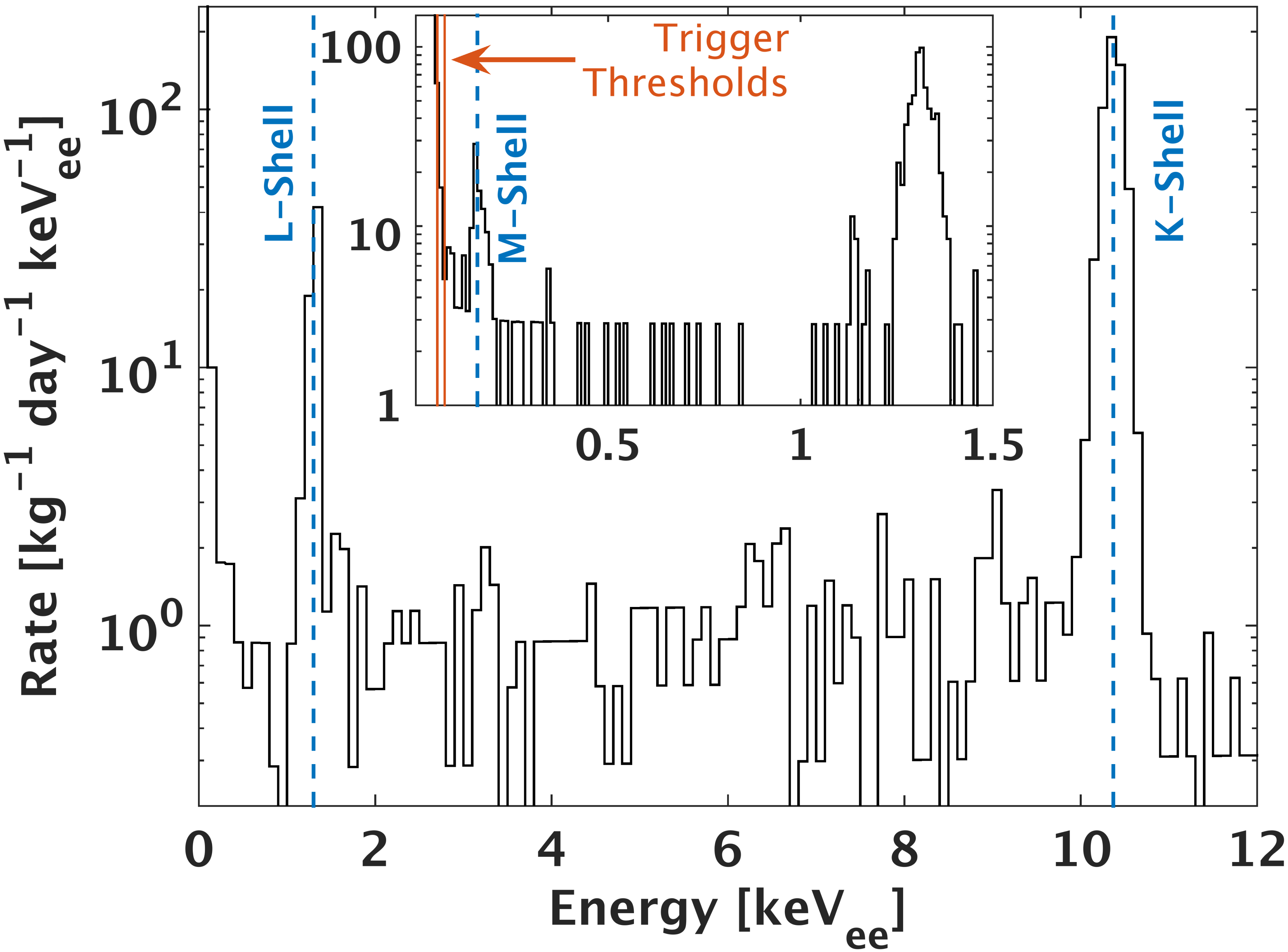
- Neganov-Luke amplification used to obtain low thresholds with high-resolution
  - Ionization only, uses phonon instrumentation to measure ionization
  - No event-by- event discrimination of nuclear recoils
- Drifting electrons across a potential (V) generates a large number of phonons (Luke phonons).

$$E_t = E_r + N_{eh} e V_b$$

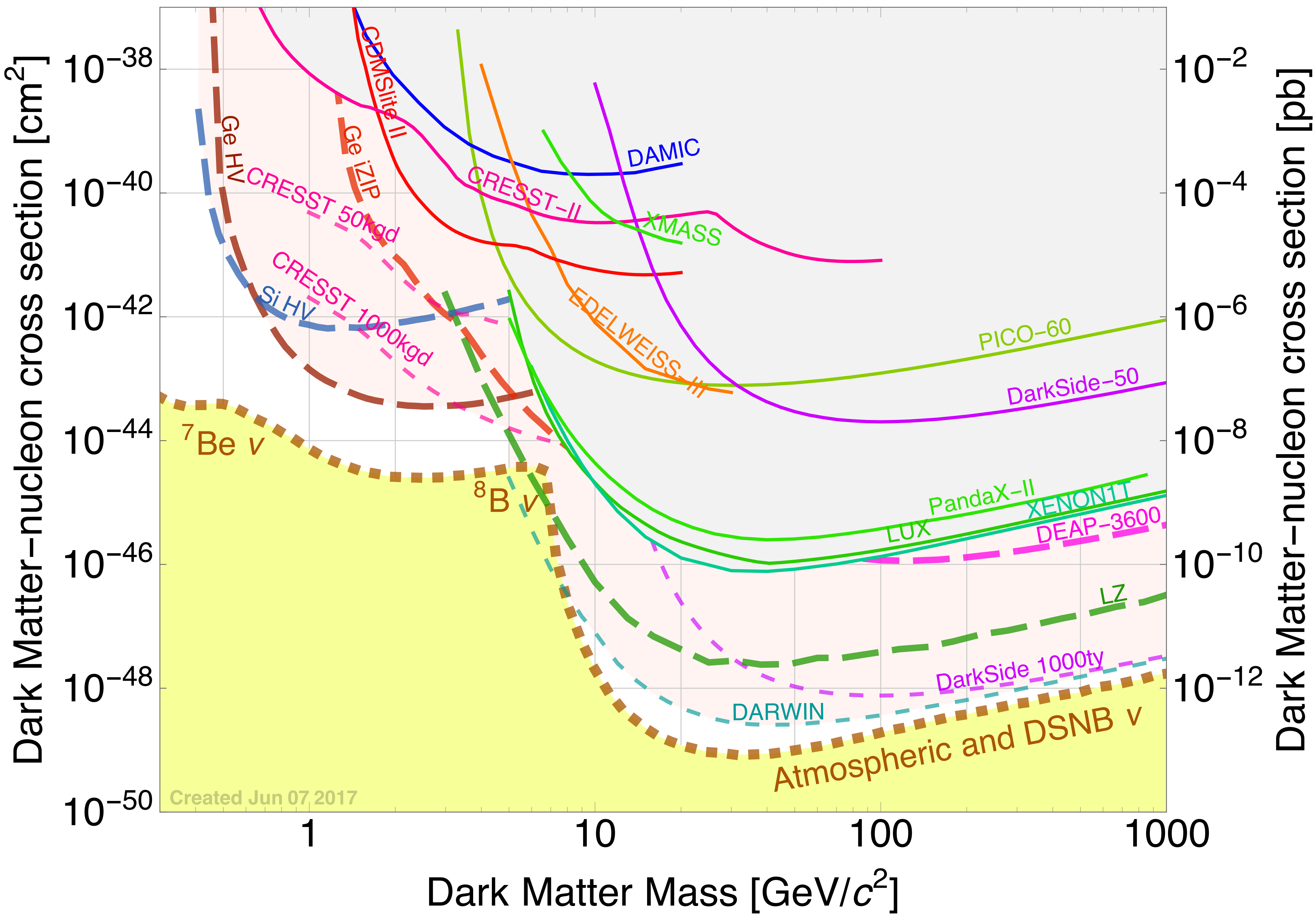
total phonon energy — *primary recoil energy* — *Luke phonon energy*



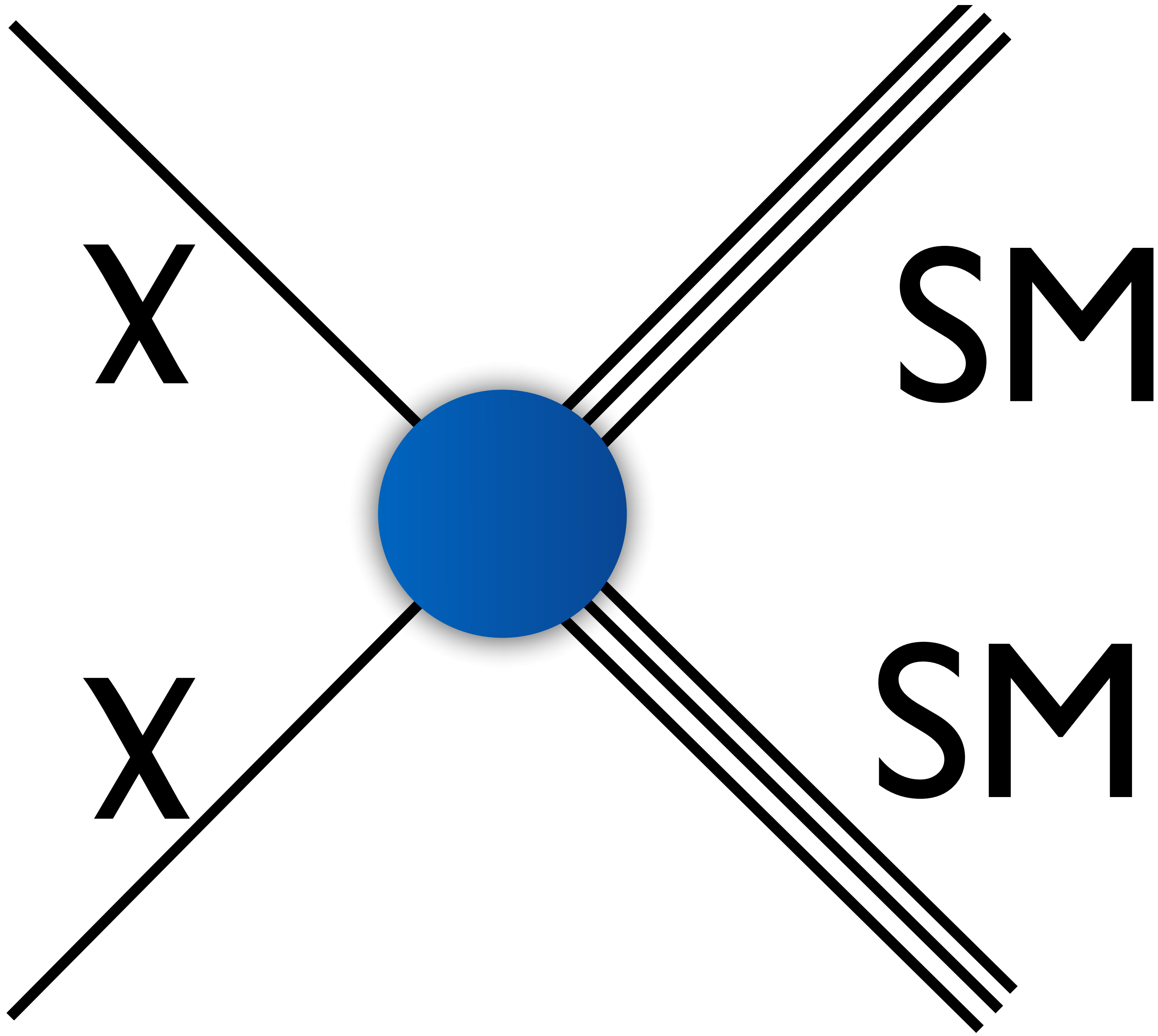
CDMSlite Run 2 Results

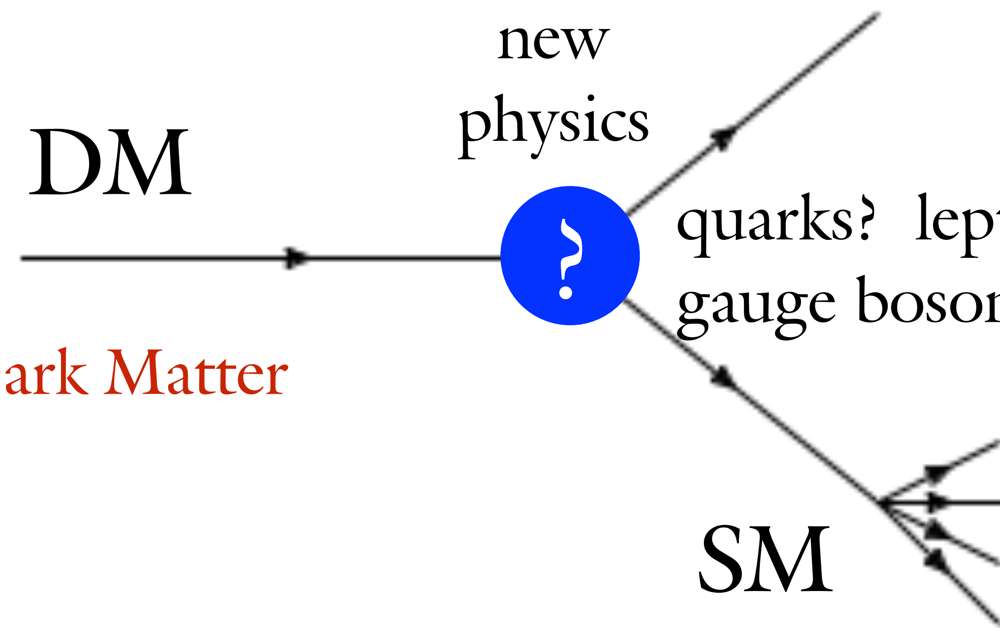


The Future is Bright!



Break It!

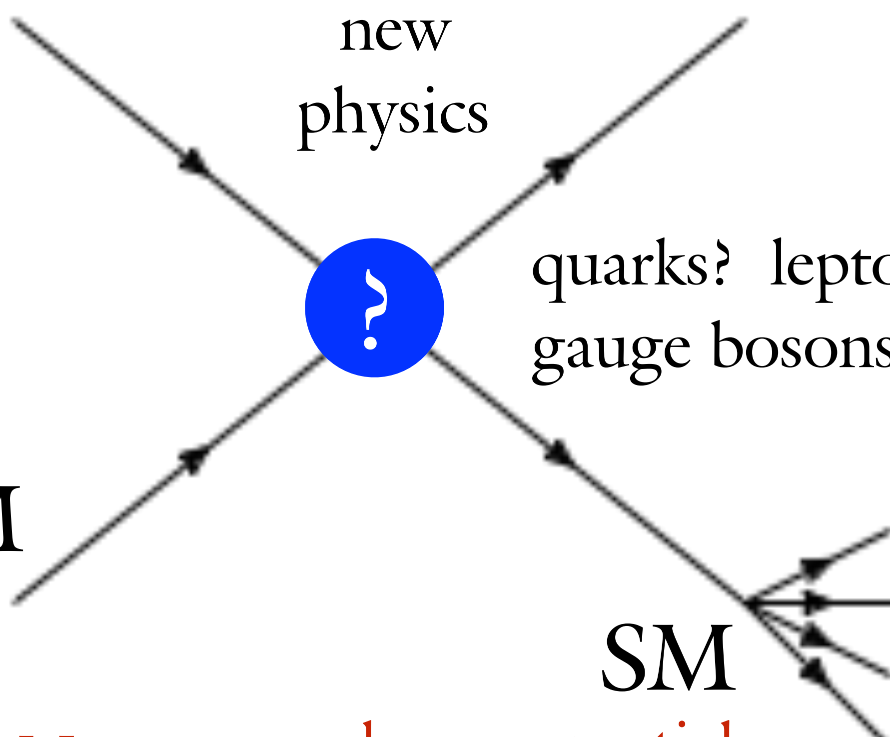




Decay

Cascading decays according to known SM processes

long lived known particles



Annihilation

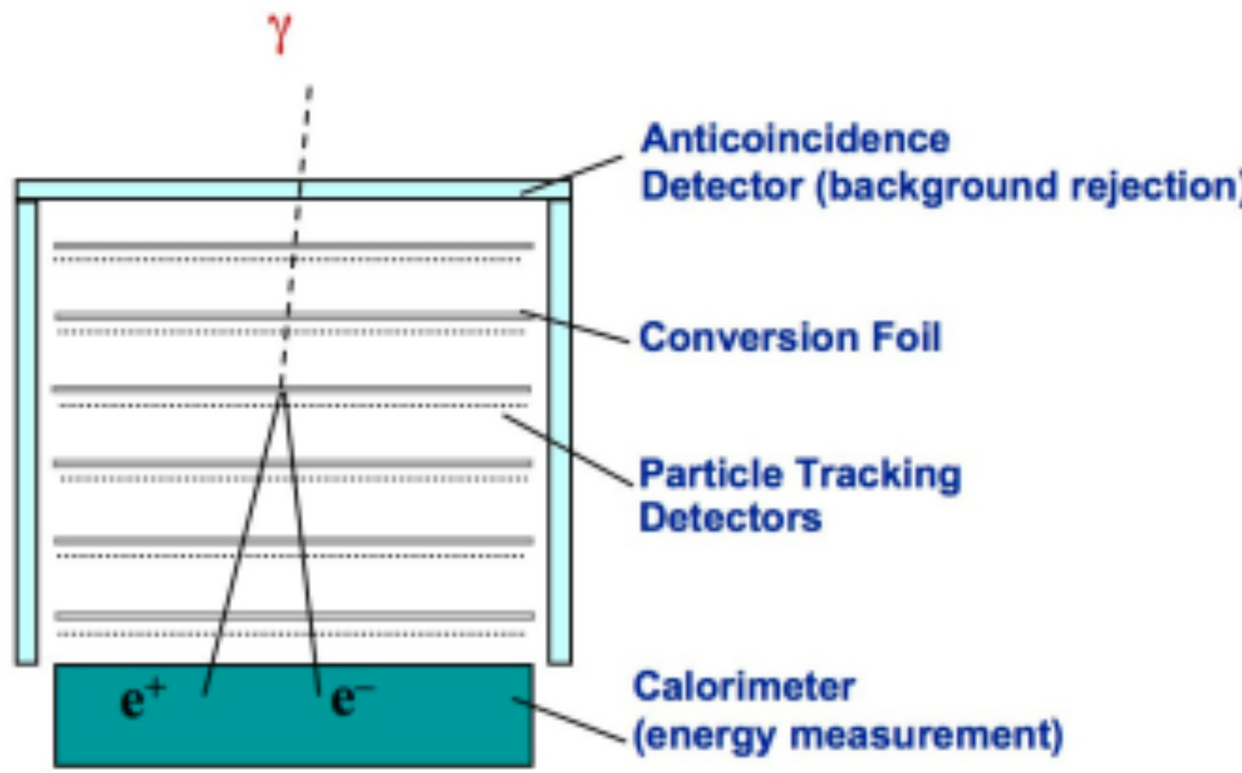
Cascading decays according to known SM processes

long lived known particles

See Talks:
Regina Caputo

Gamma Ray

http://mediaarchive.ksc.nasa.gov/detail.cfm?mediaid=36076



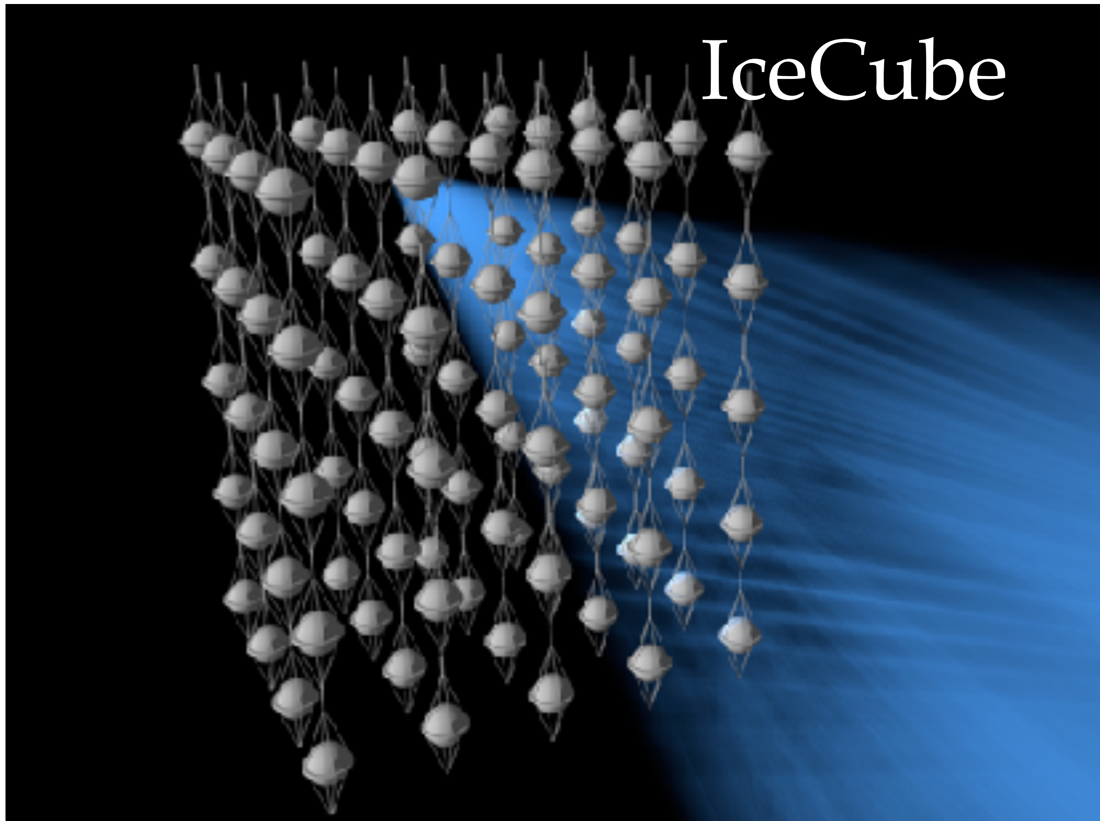
- Photons detected via pair production in high Z converter material.
- Cosmic rays are tagged by anti-coincident detector.
- Detects energies ~ 20 MeV to more than 300 GeV.

Gamma Rays

- Flux decreases quickly with energy for gamma rays.
- To reach the highest energy gamma rays large area Cherenkov detectors are necessary.

- Pros: point back to source and spectral information.
- Cons: backgrounds & attenuation

Neutrinos

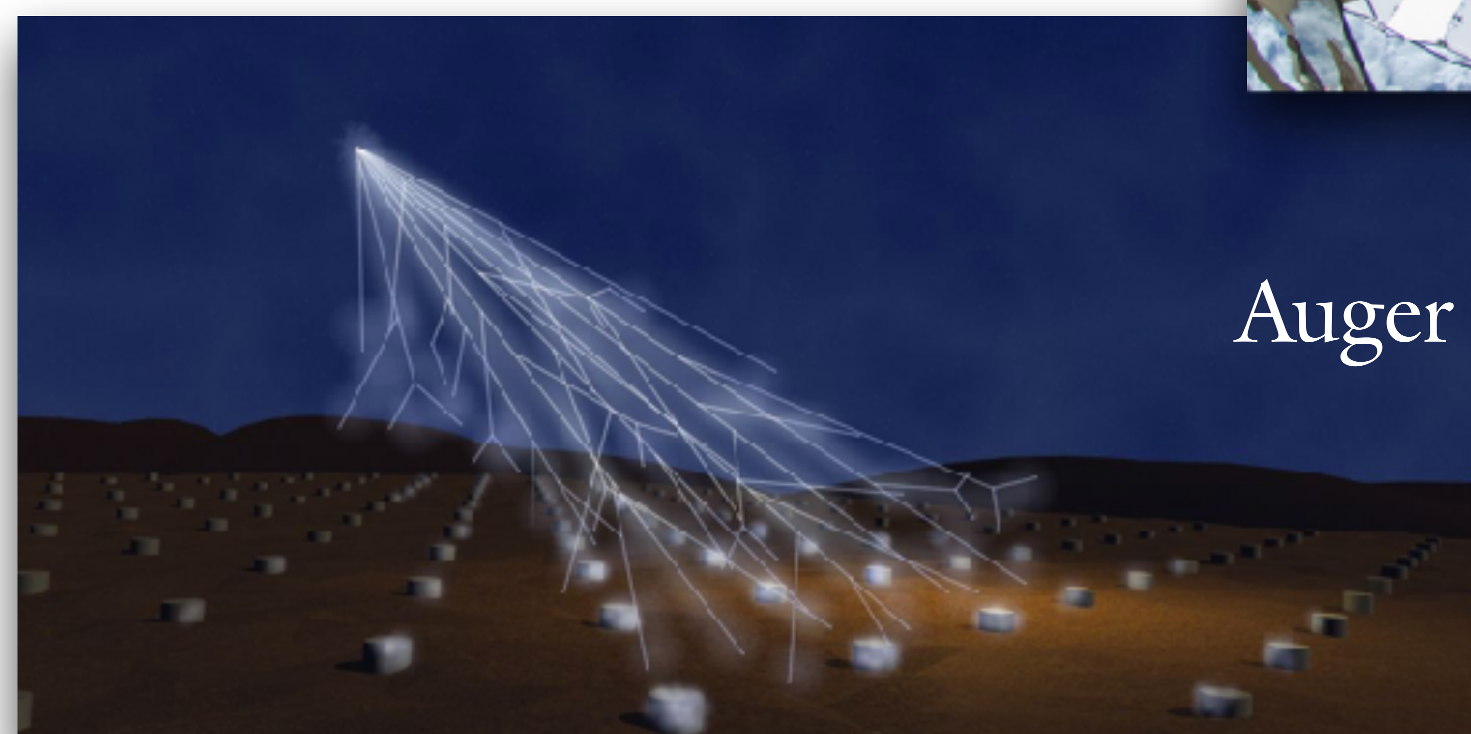


- Detect neutrinos produced in dark matter annihilations in the sun, center of Earth or galactic center.
- Pros: point back to source and spectral information, more directly comparable to direct detection σs.
- Cons: backgrounds & low stats

See Talks:
Ali Kheirandish
Ina Sarcevic
Katarzyna Frankiewicz
Morten Medici

Cosmic Rays

- Detect charged particles produced in dark matter annihilations and decays in the cosmos.



- Pros: spectral information and low background for antimatter searches.
- Cons: diffusion and do not point back to sources.

Current Limits in a Nutshell

- Thermal annihilation cross-section benchmarks either rule out or are in tension with dark matter with masses below 10 - 100 GeV (depends on final state).
- Decay lifetimes below ~ $10^{27\text{-}28}$s ruled out for most final states and keV - EeV dark matter masses; for MeV-GeV dark matter decaying to e^+e^- lifetimes can be as short as $10^{24\text{-}25}$s.

Tracey Slatyer, Rencontres de Blois 2017

Anomalies in a Nutshell

- The 3.5 keV Line:
  - First seen in XMM-Newton data at ~4σ level *(PRL 113, 251301)*
  - Simplest DM solution is 7 keV sterile neutrino, in tension with some observations.
  - Possible astrophysics backgrounds: atomic lines (K,Cl, Ar, ?), charge exchange with heavy nuclei and neutral gas. Future instruments (MacroX) may help resolve situation.

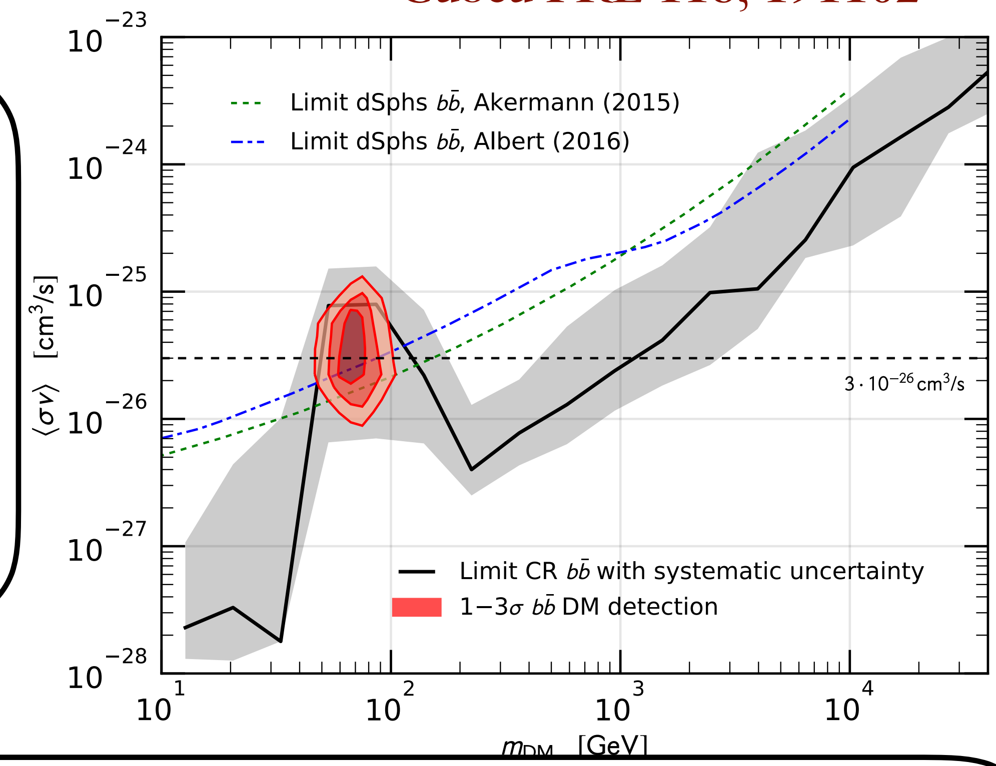
- The GeV excess @ Galactic Center:
  - First claimed in 2009 with Fermi data *(arXiv:0910.2998)*
  - Many studies suggesting *O* 10-100 GeV DM
  - Tension with non-detection in dwarf galaxies
  - Mounting evidence of large contribution from pulsars *(arXiv:1706.01199, PRL 116, 051102, arXiv:1412.6099)*

More Anomalies in a Nutshell

- AMS Antiprotons

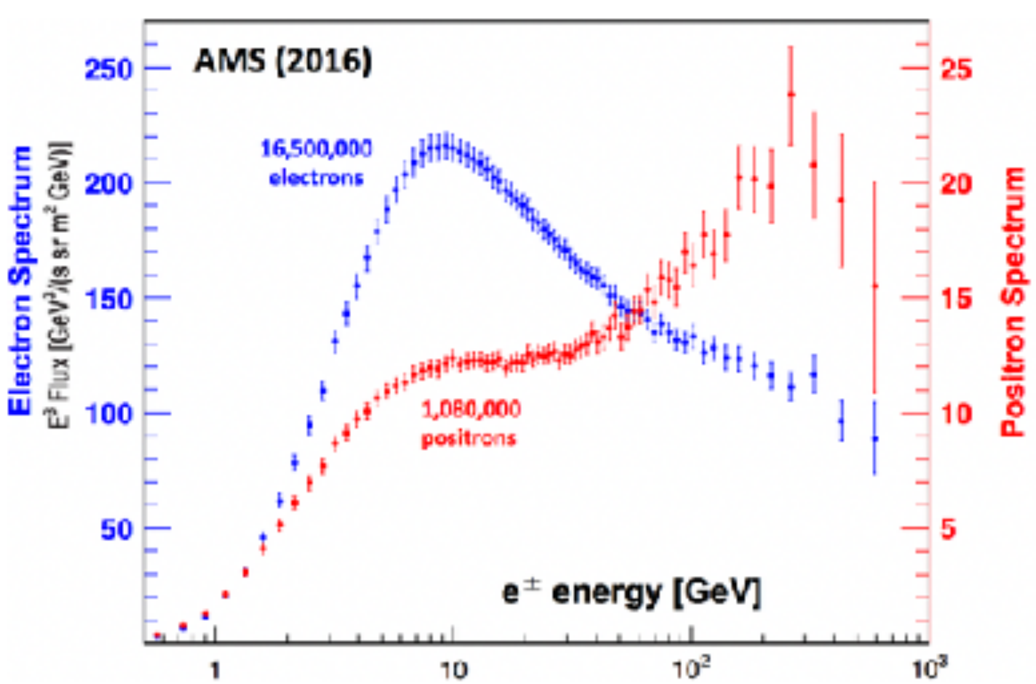
- Excess ~4.5σ possibly attributed to DM (*PRL 118, 191102; PRL 118, 191101)*
- Significant uncertainties: modeling of antiproton production cross section, cosmic-ray propagation, solar modulation.

Cuocu PRL 118, 191102



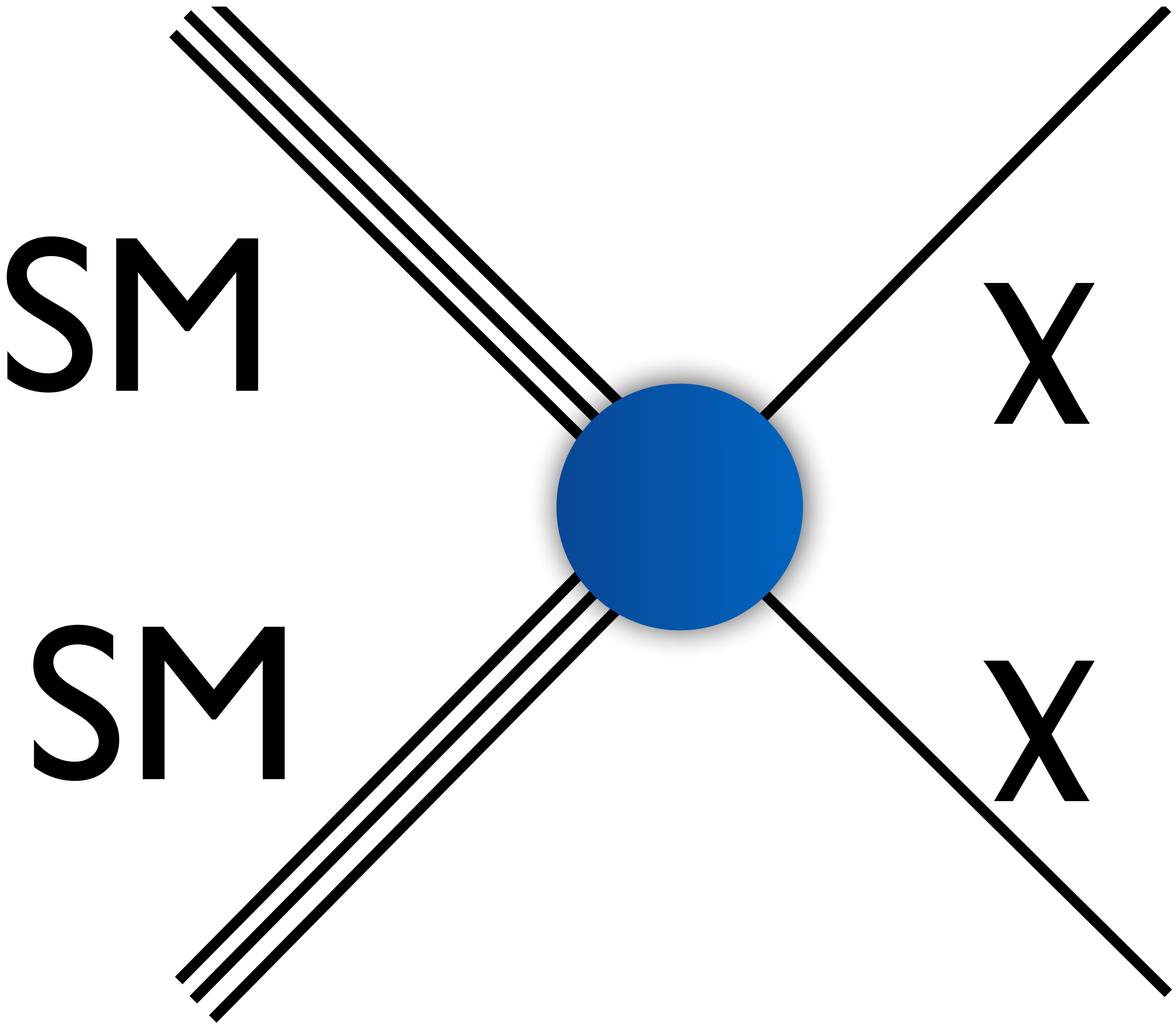
- AMS Positrons

Ting, 8/12/16 CERN Colloquium



- Large excess of e^+ > 10 GeV inconsistent with exceptions for secondary e^+ from proton collisions with interstellar medium.
- DM interpretation of signature for annihilation or decay in tension with other measurements.
- Potential for large pulsar contribution to signal. (arXiv:1702.08436)

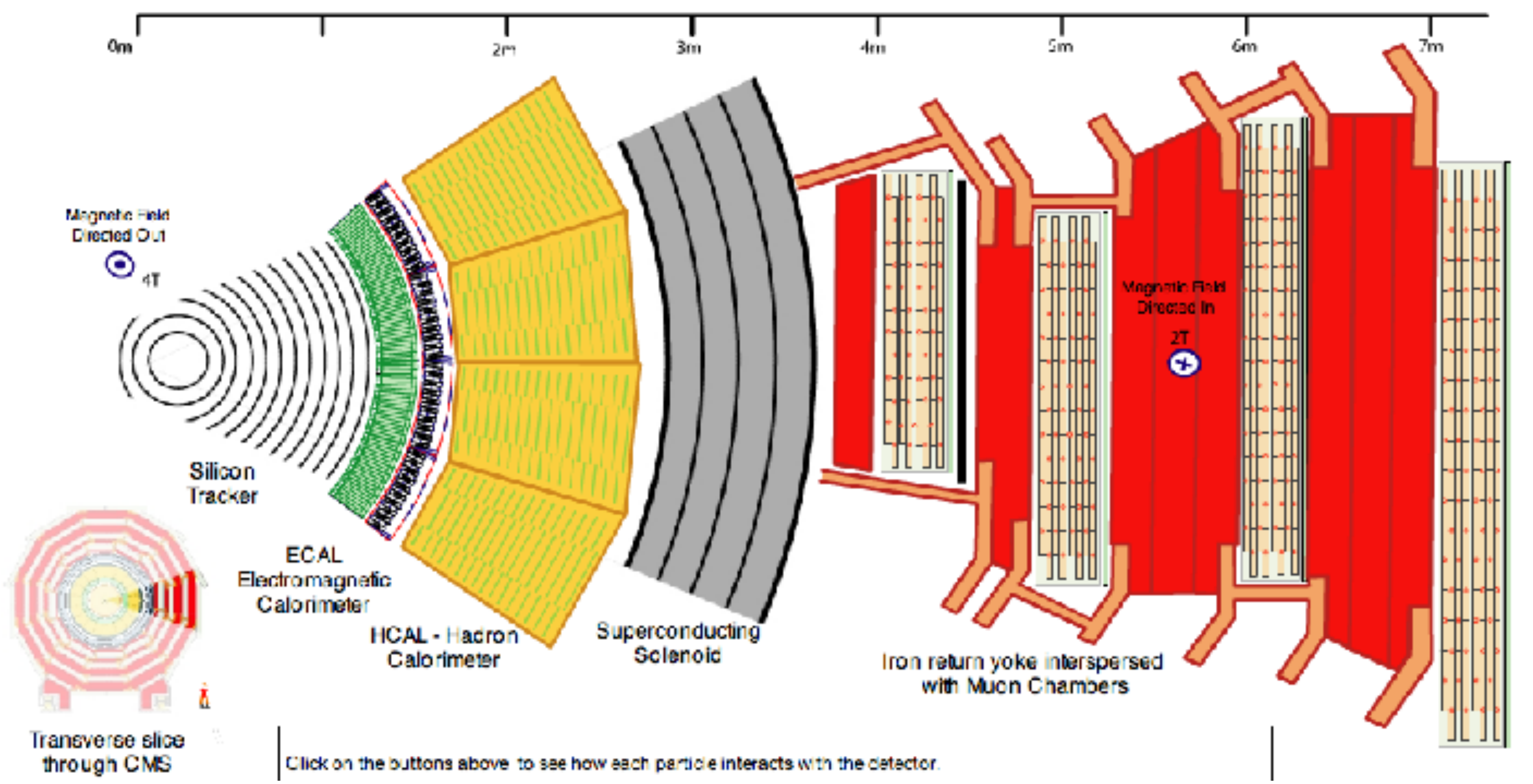
Make It!



See Talk:
Bhaskar Dutta

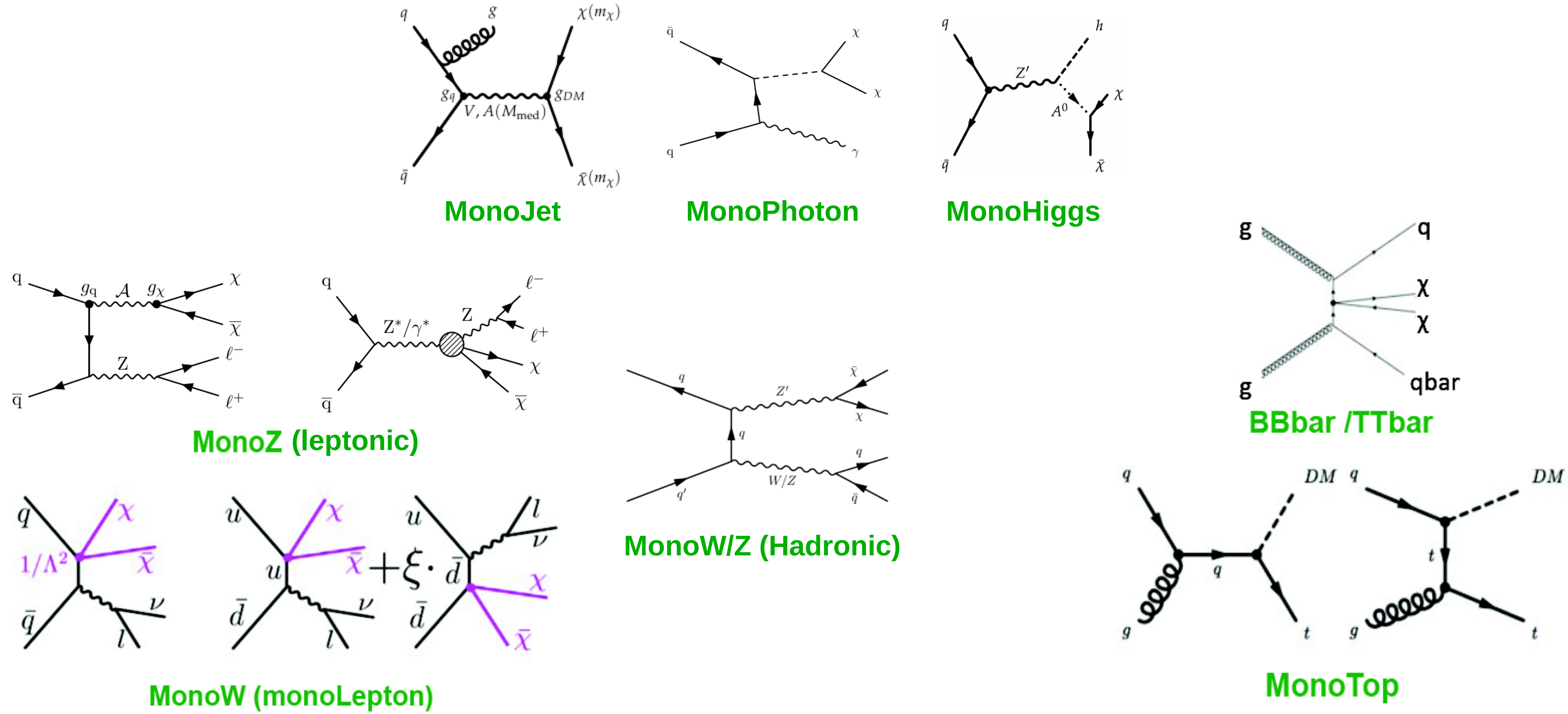
Colliders as DM Hunters

- Focus on WIMP-like particles: No interactions in the detector
- Signature is missing transverse momentum in the detector.
- DM can be produced directly or from cascade decays.



Steven Lowette, Rencontres de Blois 2017

Searches for Direct DM Production



https://twiki.cern.ch/twiki/bin/view/AtlasPublic
http://cms-results.web.cern.ch/cms-results/public-results/publications/

Steven Lowette, Rencontres de Blois 2017

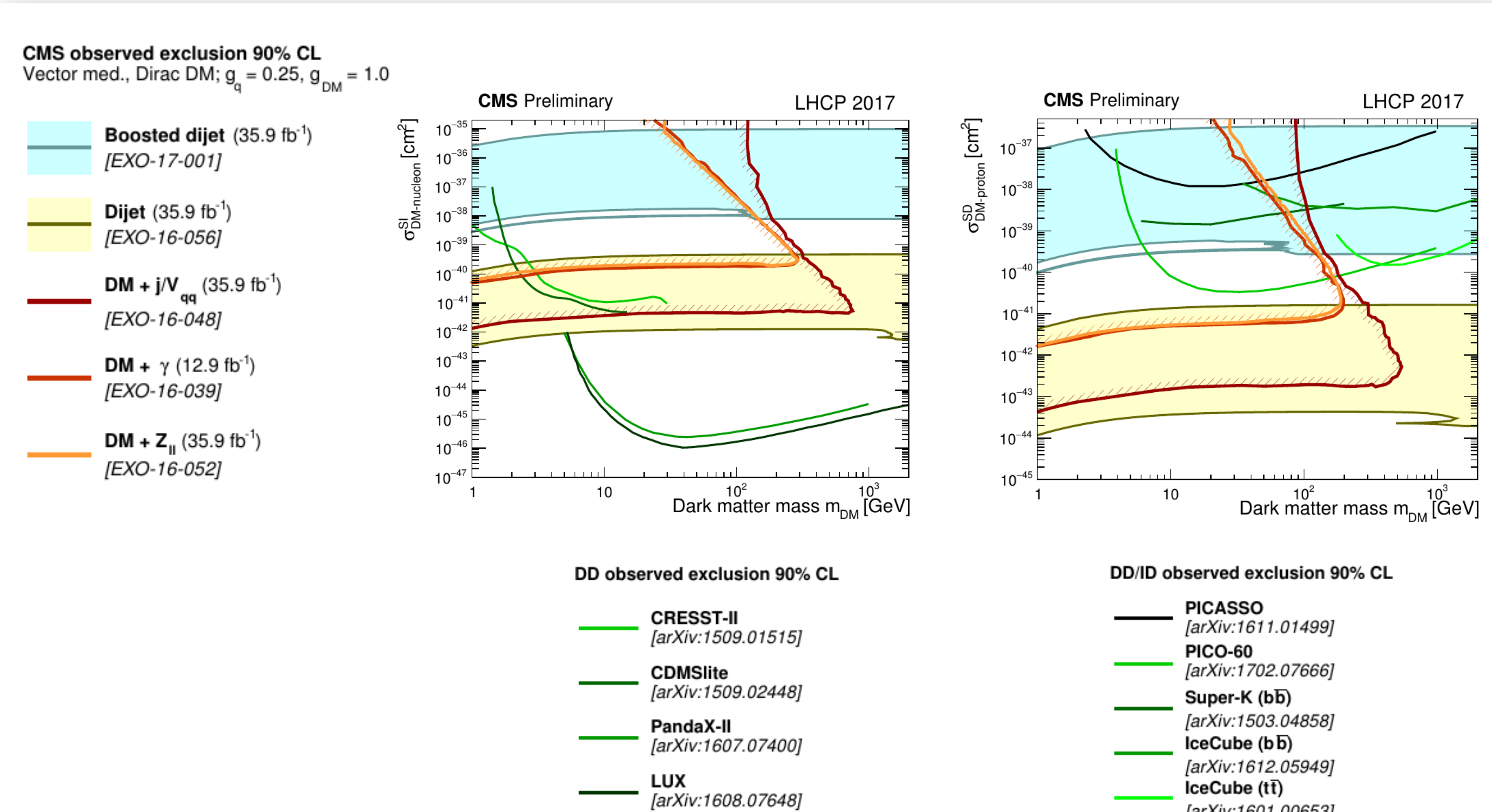
Is it possible to compare different techniques?

Yes, but …

WARNING:

Interpretations of LHC limits assume the coupling of DM and SM through a specific portal. Direct detection limits do not make a specific portal assumption!

Comparison?



Steven Lowette, Rencontres de Blois 2017

Conclusions

- There is a very large world-wide, multi-pronged approach for experimentally trying to detect the constituents of dark matter that includes direct detection of DM-nucleon scattering, indirectly detecting products of annihilation or decay of DM and producing DM in a collider.
- No compelling evidence for the detection of DM currently exists. However, there are perhaps tantalizing "hints" from indirect detection searches and the DAMA/LIBRA anomaly is not yet fully explained.
- All three approaches are complementary and are making fast headway in exploring new parameter space.
- Stay tuned! Current experiments are producing results at a fast pace and larger, more sensitive experiments are soon to come online.