Dark Matter Searches

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Fermilab

DPF2011
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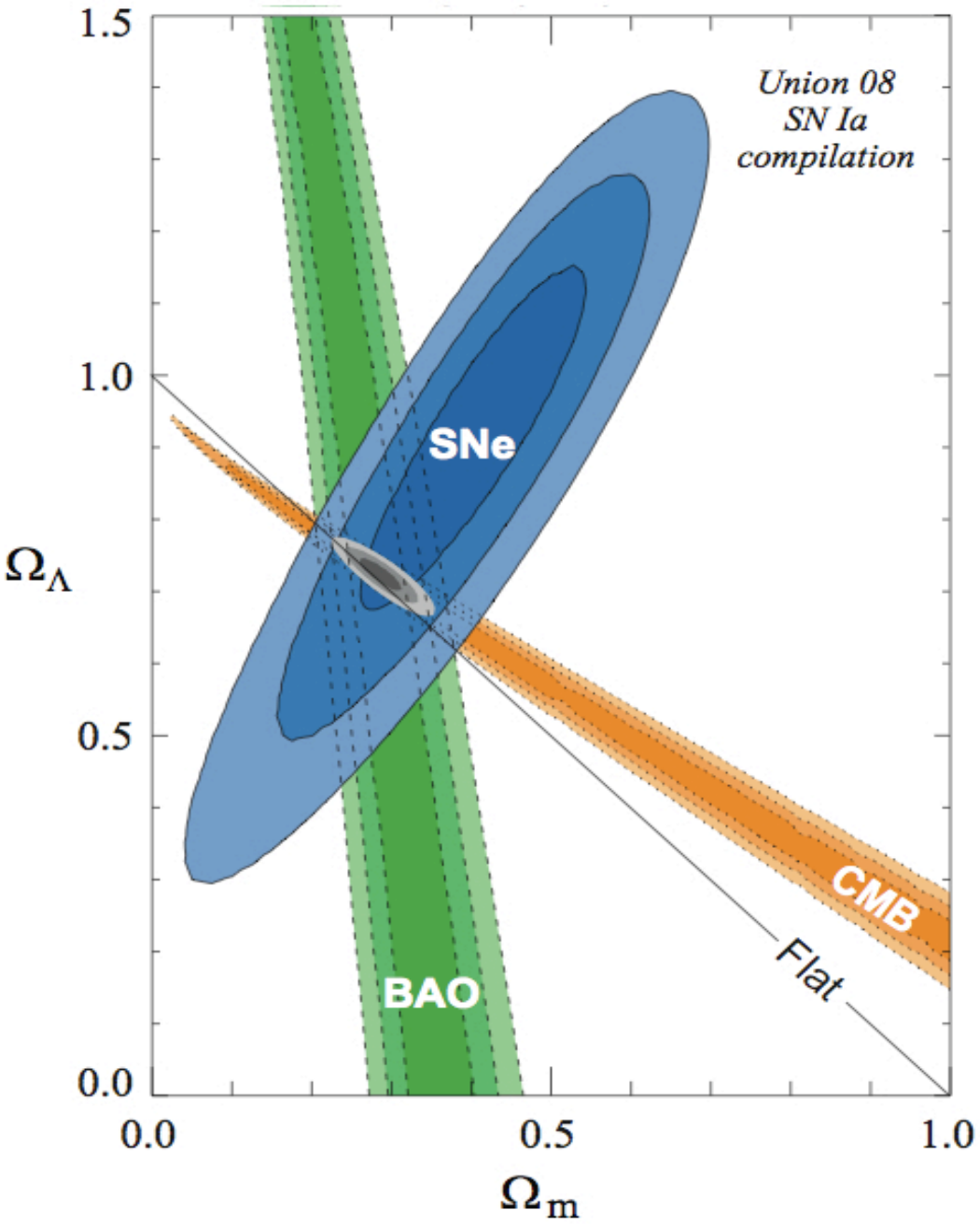
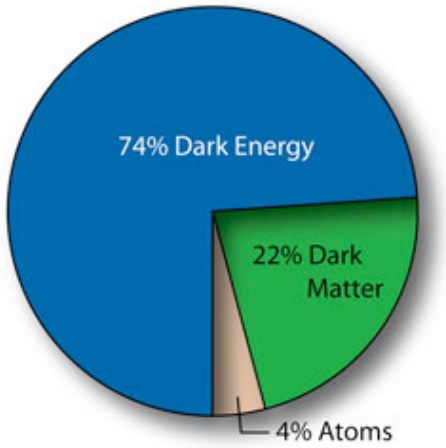
Universe is Dark





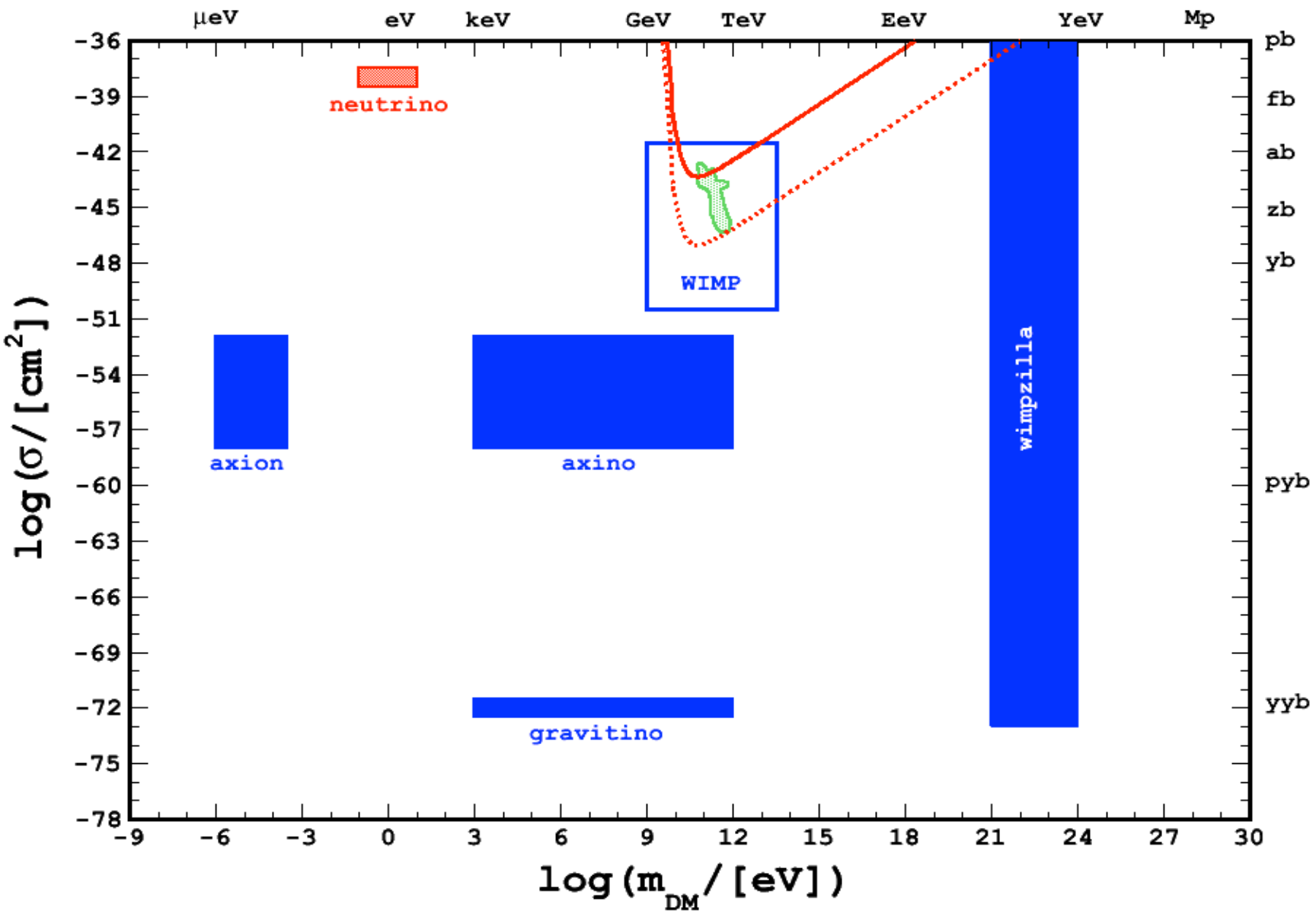
- We know that the Dark Matter is stable / non-baryonic / nonrelativistic / interacts gravitationally
- We don't know what it actually is: mass / coupling / spin / composition / distribution in the Universe …
- Cosmology suggests to probe EW scale

$$\Omega_{DM} \sim \langle \sigma_A v \rangle^{-1}$$

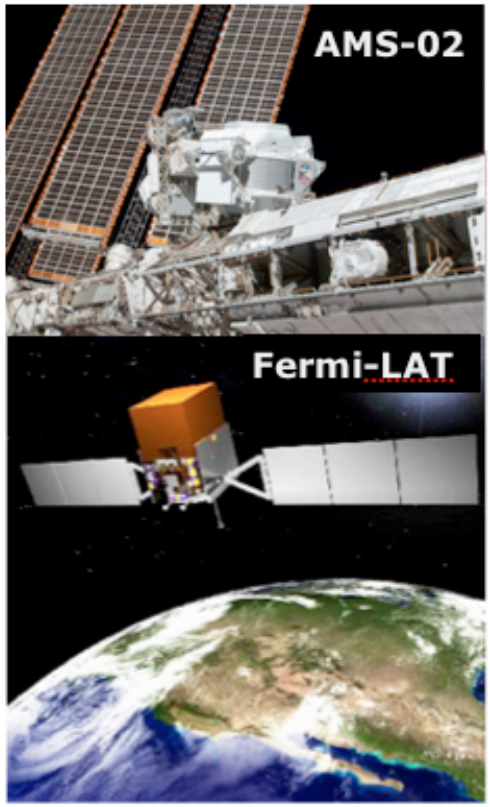
$$\sigma_A = \alpha^2 / M^2_{EW}$$

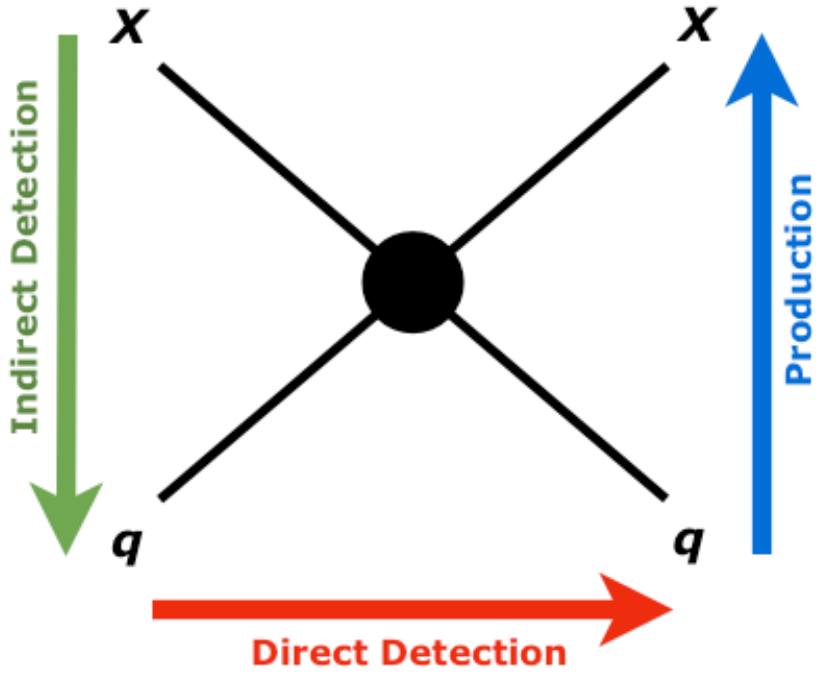
- SUSY model provides electroweak scale stable neutral particle

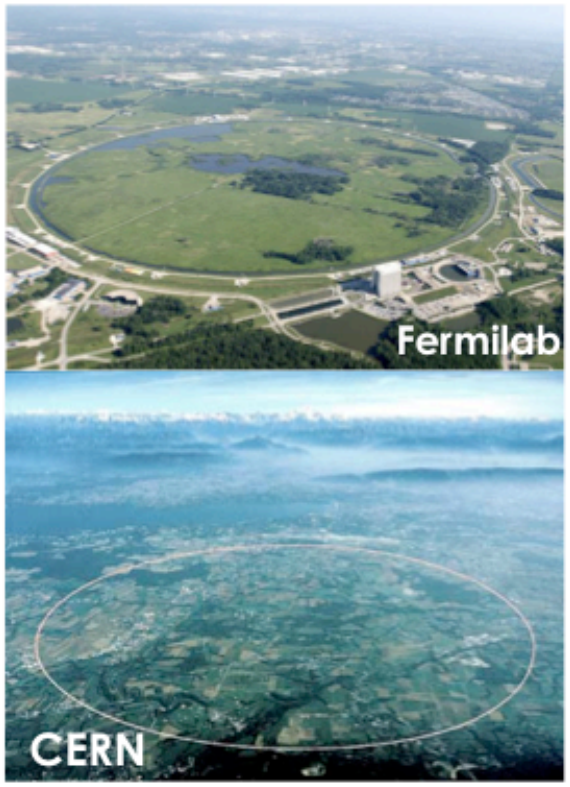
Dark Matter Candidates

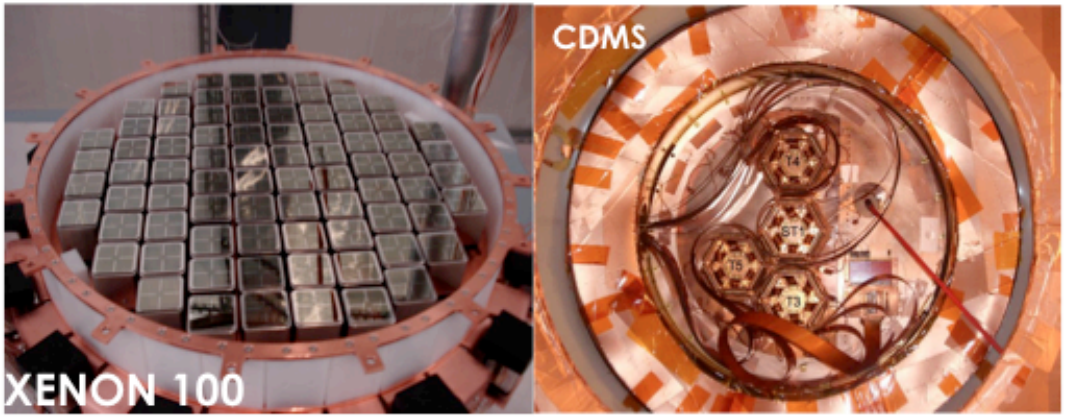


Search for Dark Matter





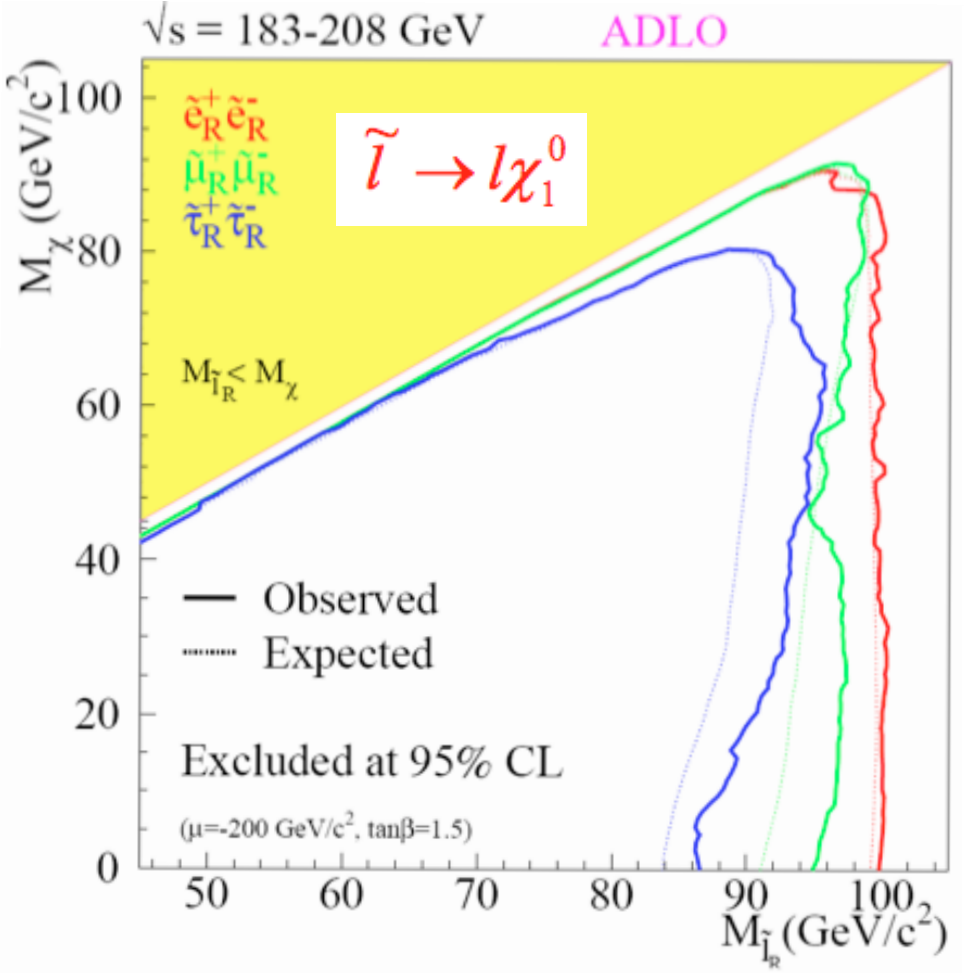


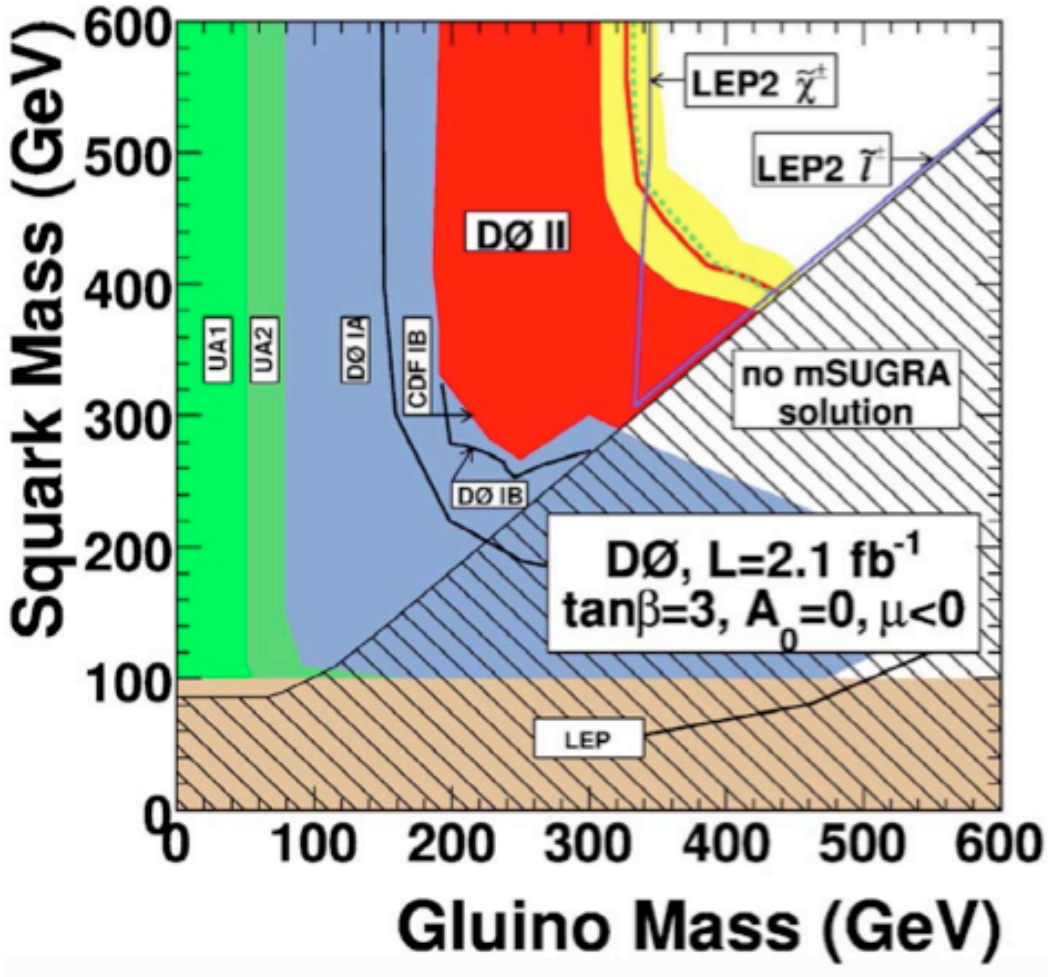


Collider Search: LEP and Tevatron

- LEP bound : M_{LSP}>~40GeV (CMSSM/mSUGRA)
- Tevatron bound: w/o M_{LSP} bound
  M_{Squark} > ~400GeV
  M_{Gluino} > ~450GeV

No deviation from SM





Collider Search: LHC

1.04 fb^{-1} ($\sqrt{s}$ = 7 TeV) results from ATLAS

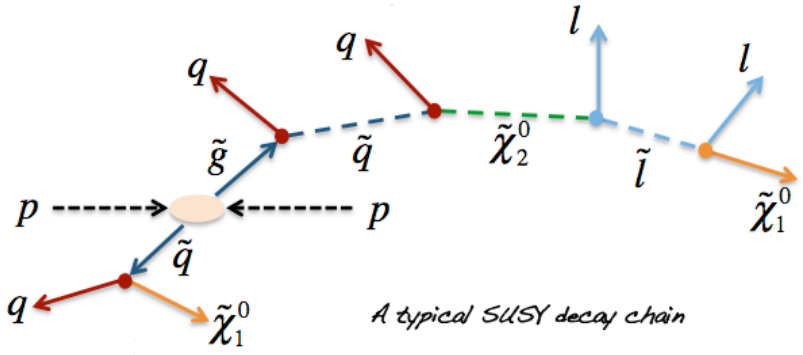
EPS-HEP 2011 July (Taffard)

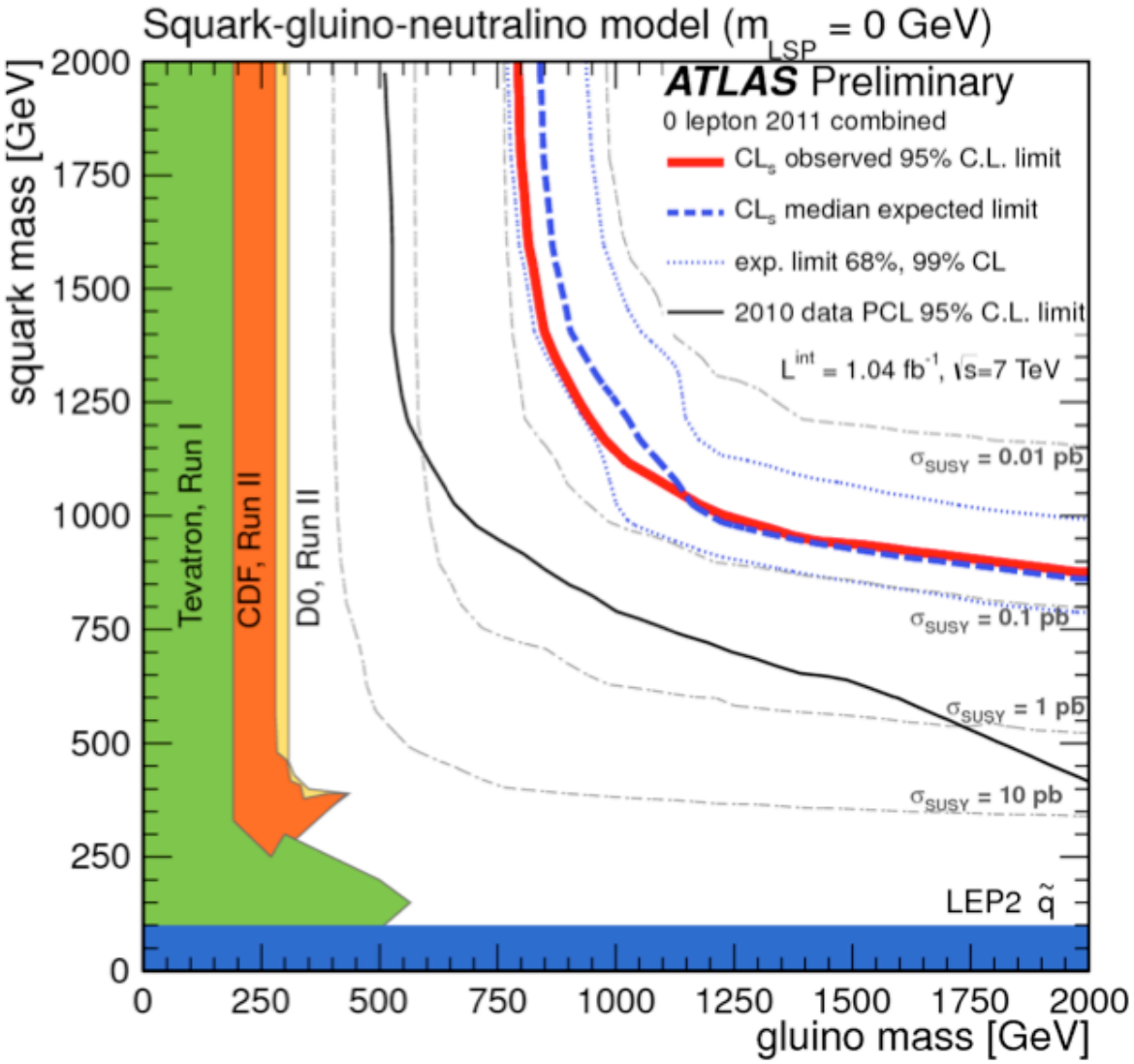
MSSM model search (M_{LSP}=0)

Jets+E_T^{miss} bound (95%C.L.)

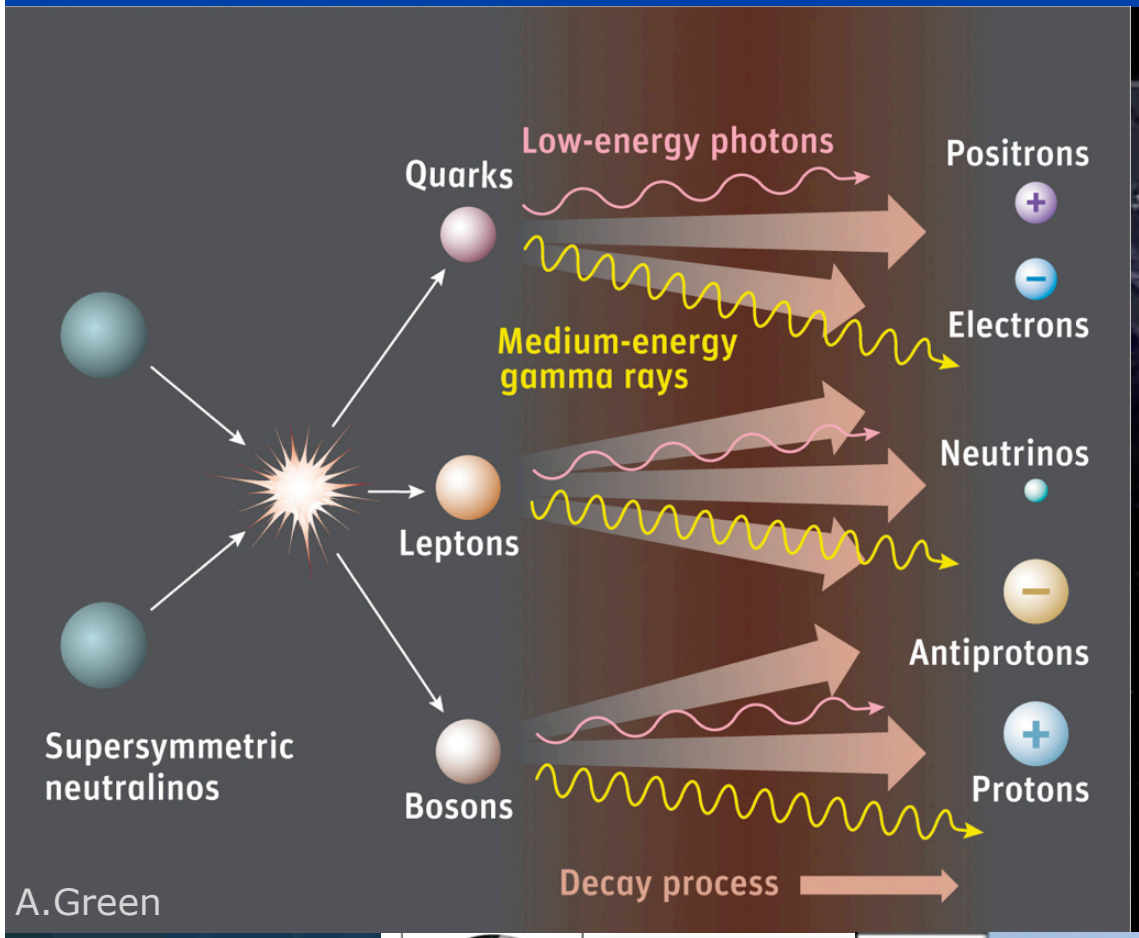
M_{squark} > 850 GeV

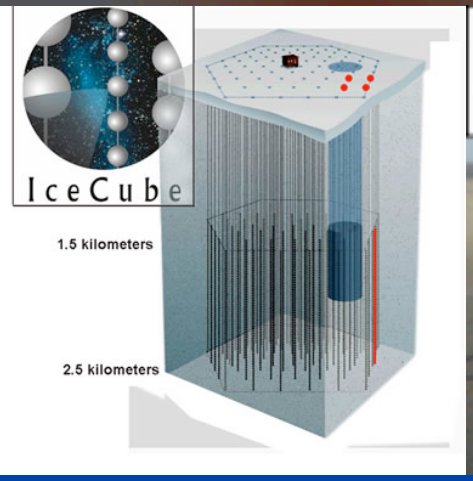
M_{gluino} > 800 GeV





Indirect Search





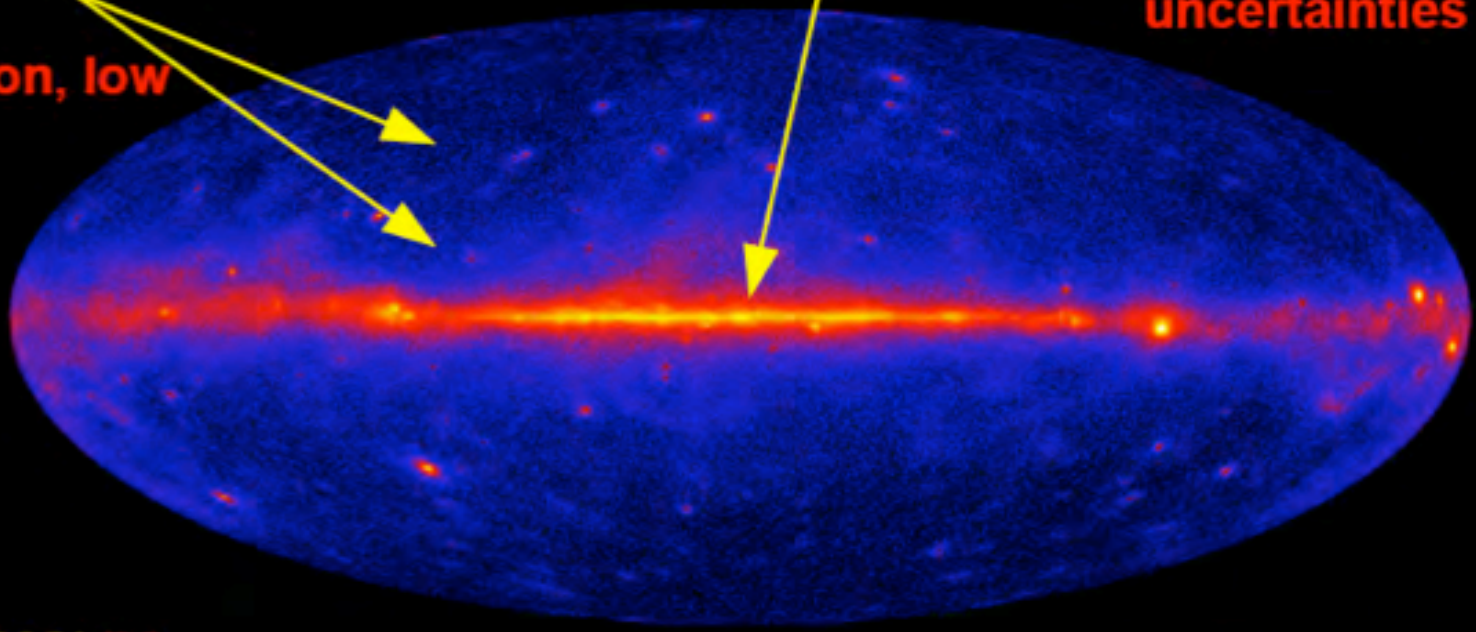
Indirect Search

Where to look for gamma-ray signatures of dark matter?

Galactic Centre: good statistics, strong background/foreground + source confusion

Satellites: low background + good source identification, low statistics,

Halo: large statistics, diffuse Galactic emission uncertainties



Spectral lines: no astrophysical uncertainties, low statistics

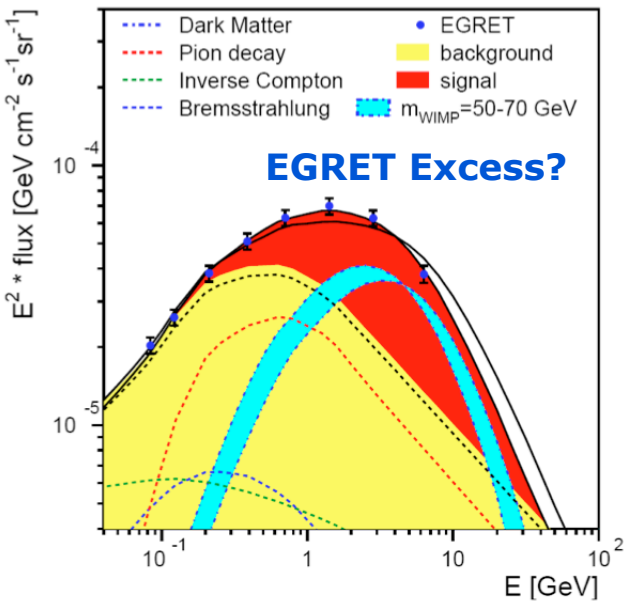
Extragalactic diffuse: large statistics foreground subtraction + astrophysical source populations

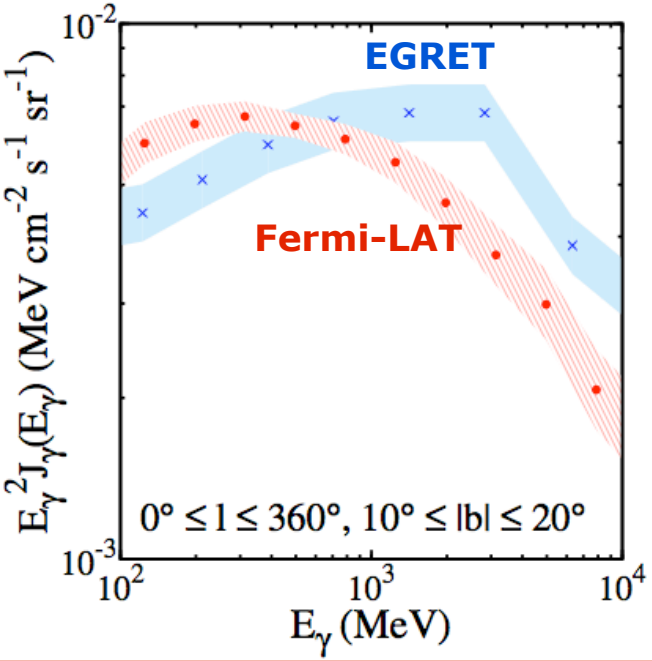
Galaxy clusters: low background, low statistics

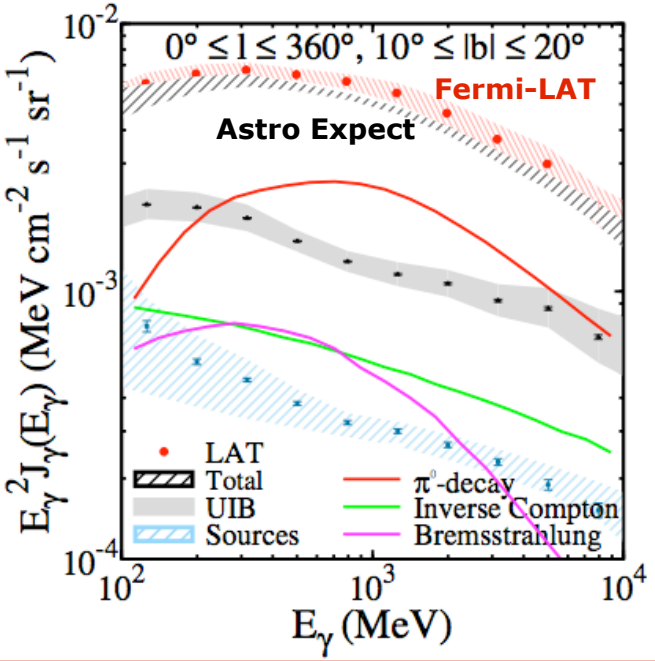
T.Porter

Indirect Search

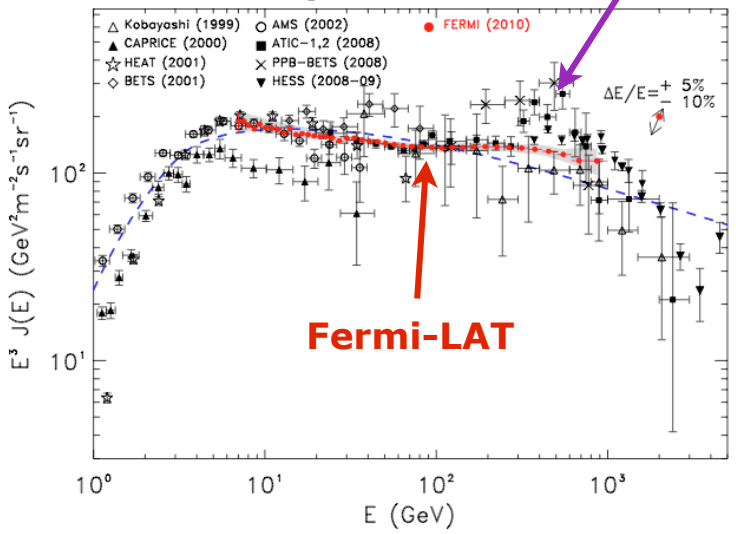
Diffusive gamma-ray



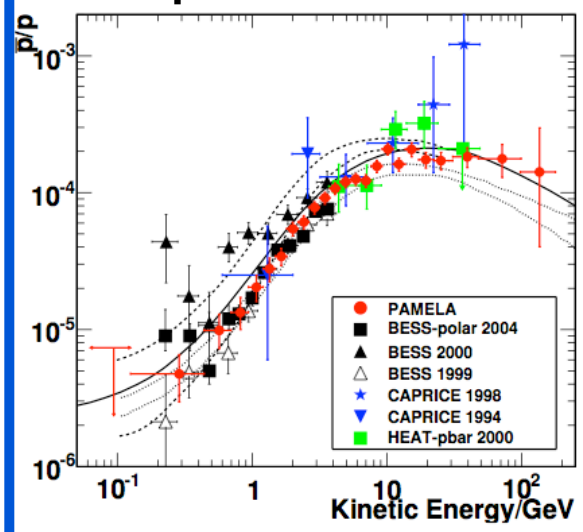




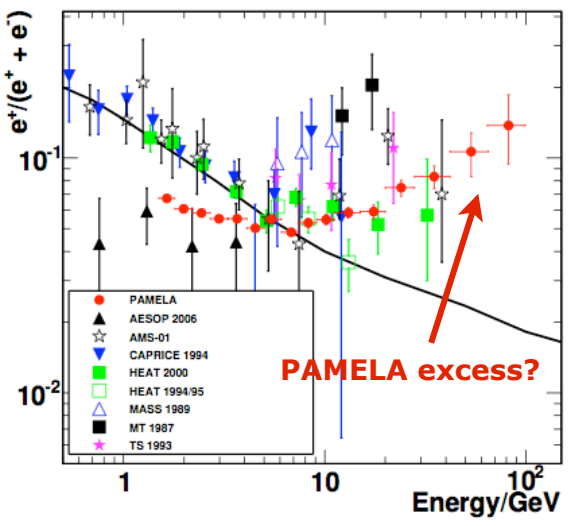
Cosmic $e^+ + e^-$ spectrum



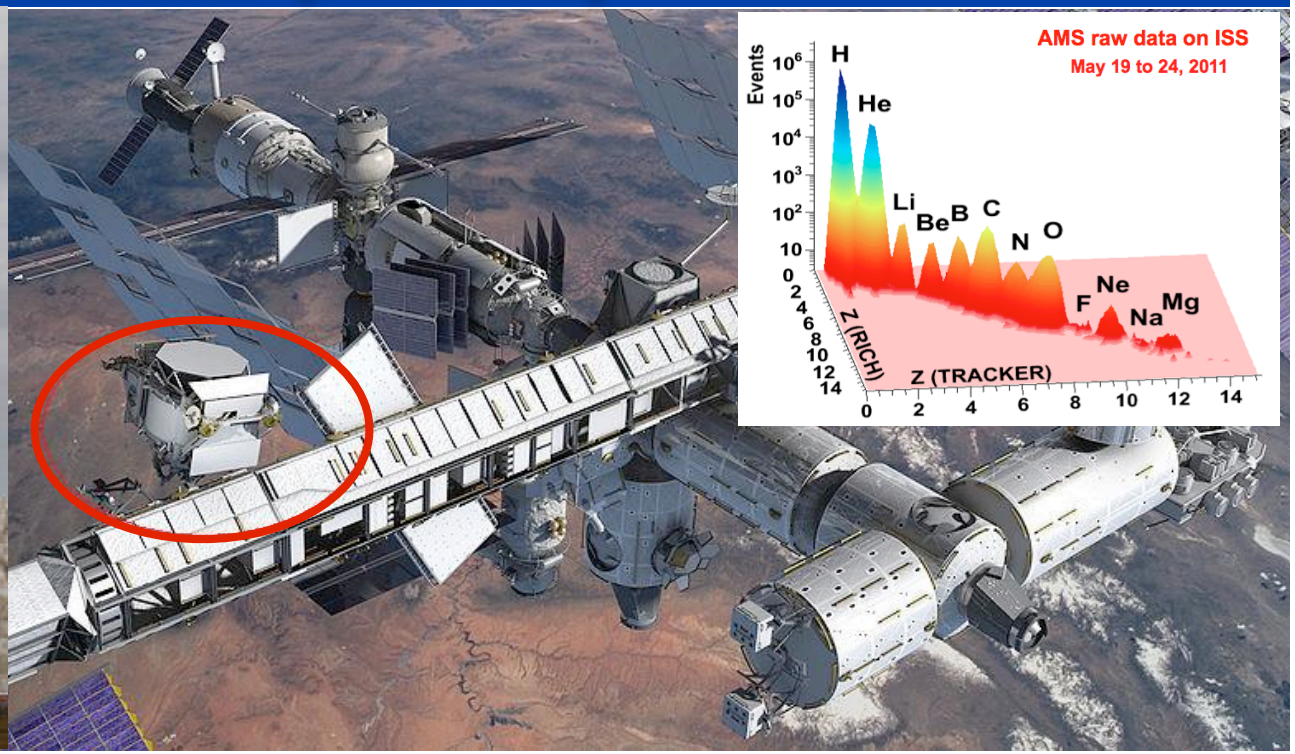
Antiproton fraction

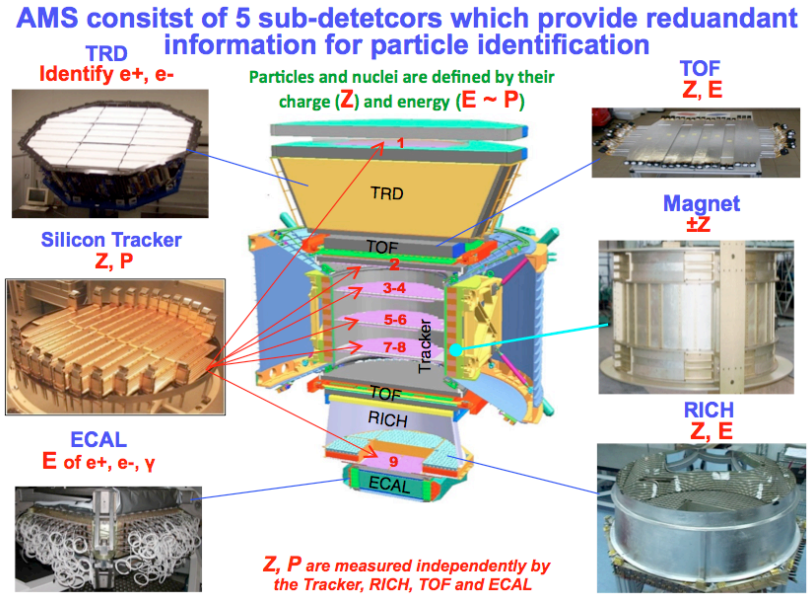


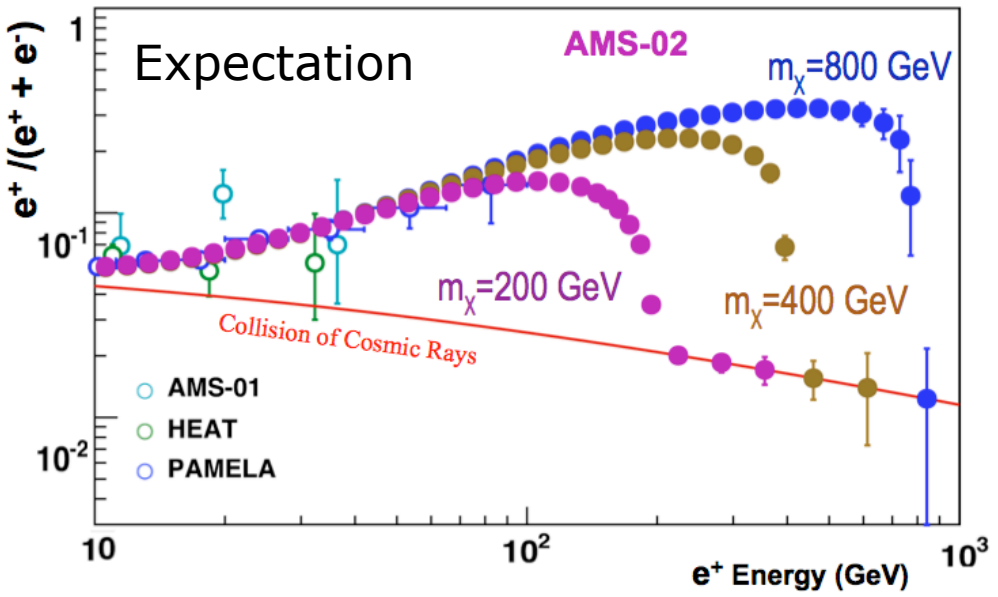
Positron fraction



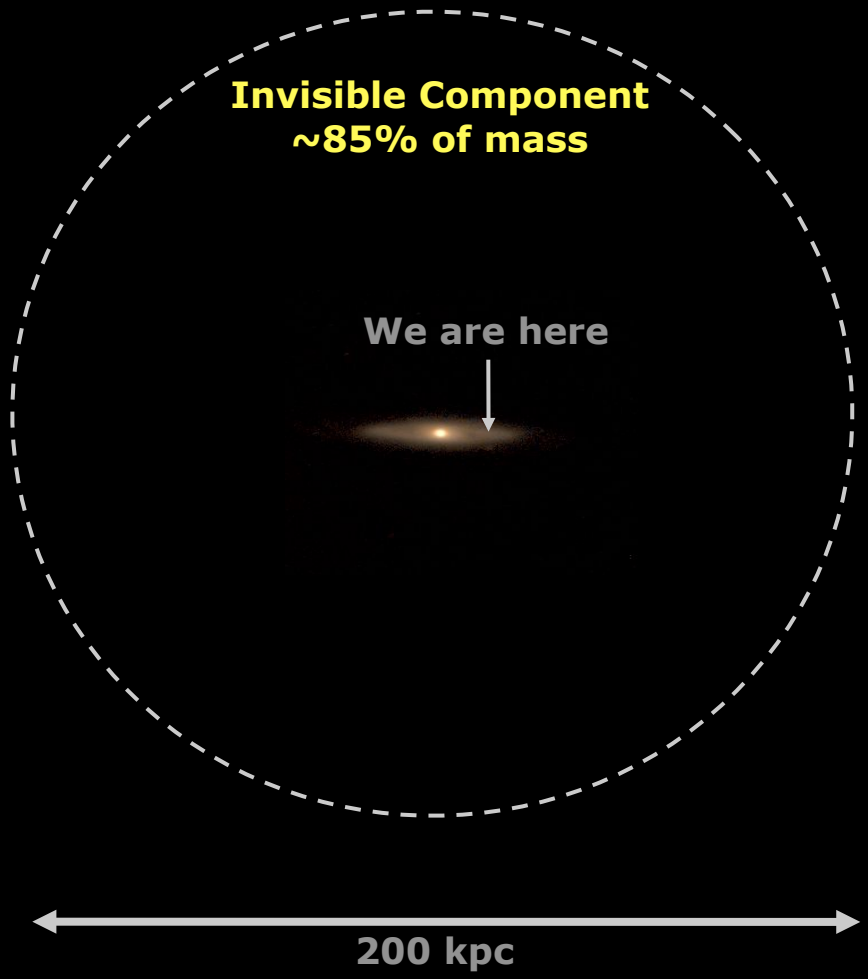
Alpha Magnetic Spectrometer (AMS-02)





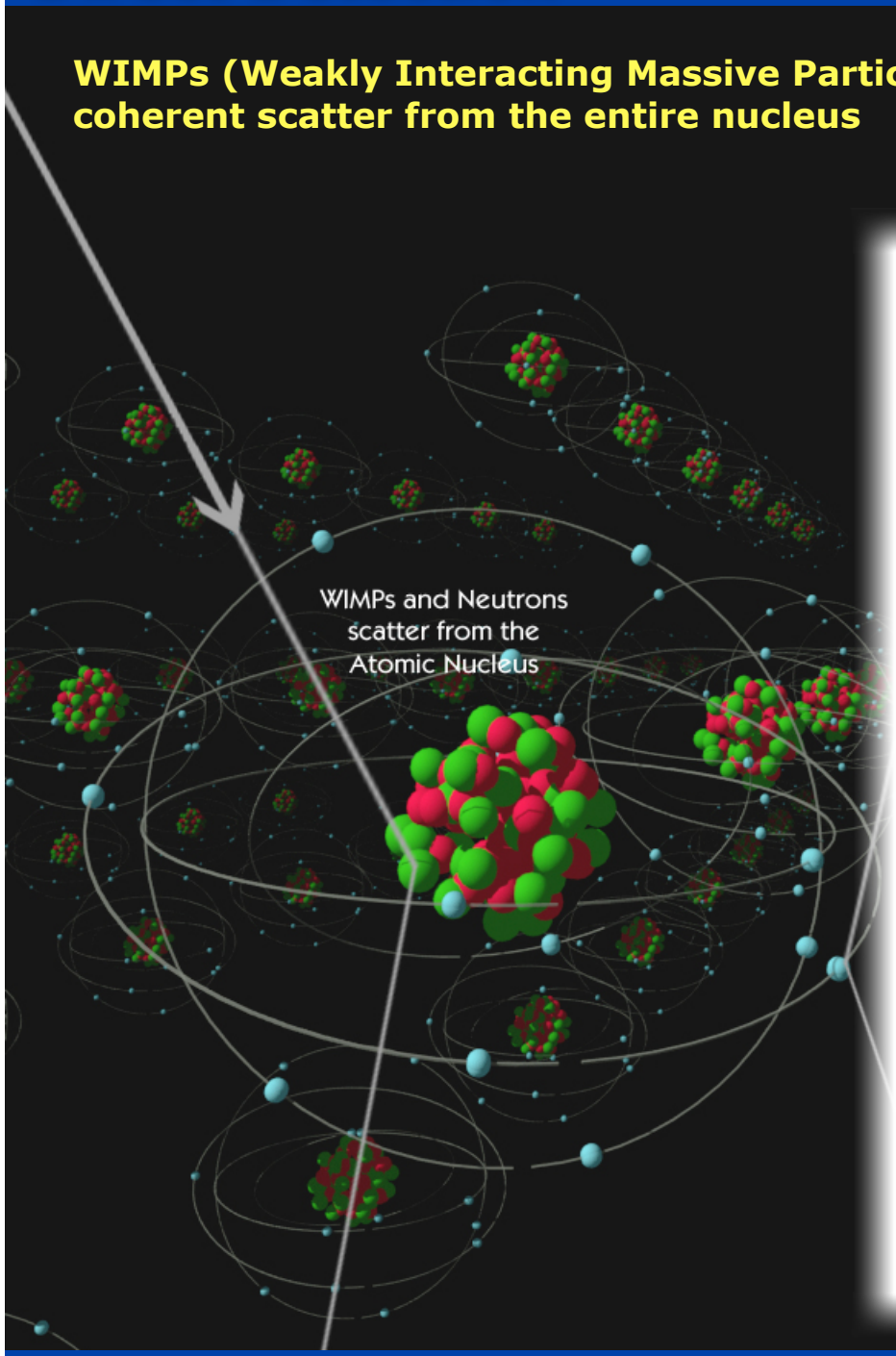


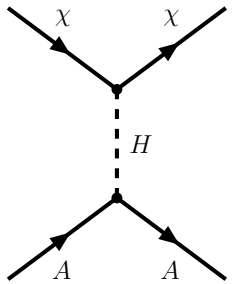
Direct Search: Dark Matter Halo



Direct Detection

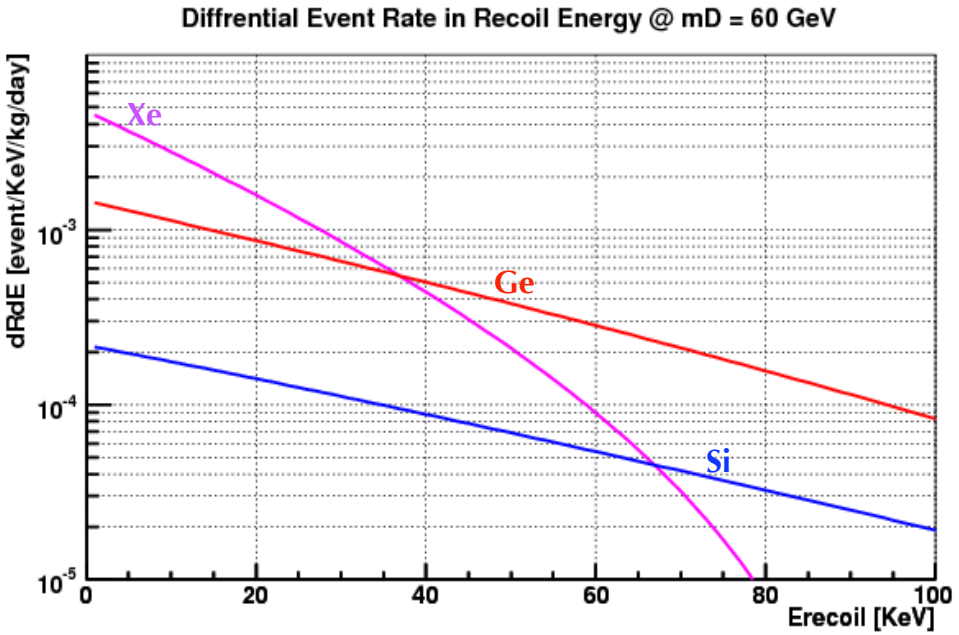
WIMPs (Weakly Interacting Massive Particles)
coherent scatter from the entire nucleus





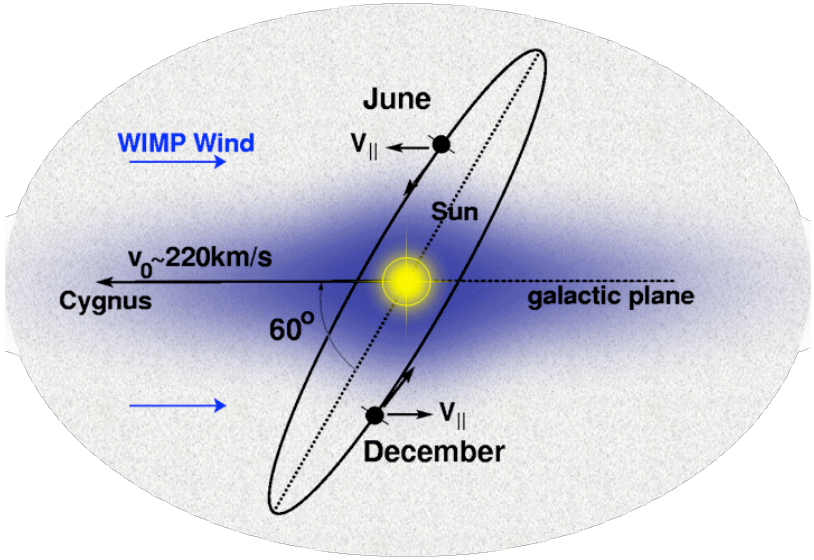
$$\sigma_{\chi N} \simeq \frac{4}{\pi}\mu^2[Zf_p + (A-Z)f_n]^2$$

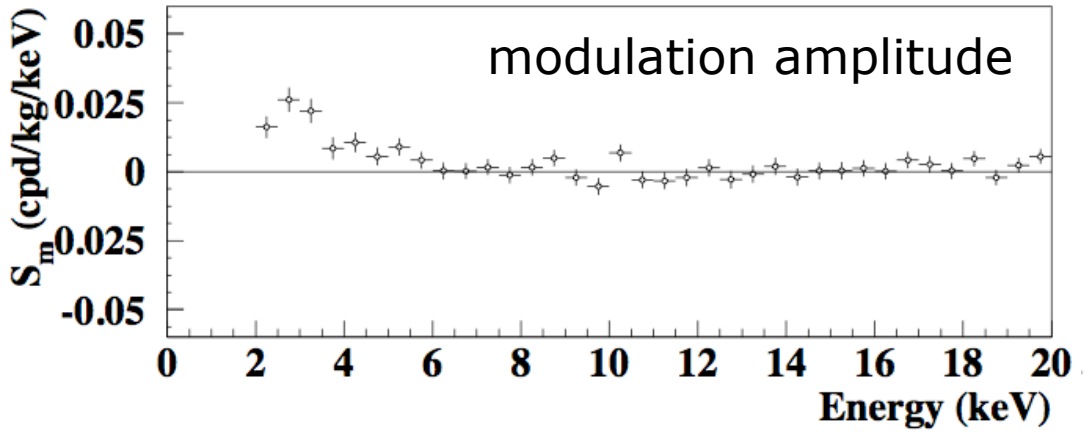
$$\frac{dR}{dE} = \frac{\sigma_0}{m_\chi}\frac{A^2}{2\mu_n^2}F_A^2(E) \times \rho_0 \int_{v_m} \frac{f(v)}{v}dv$$



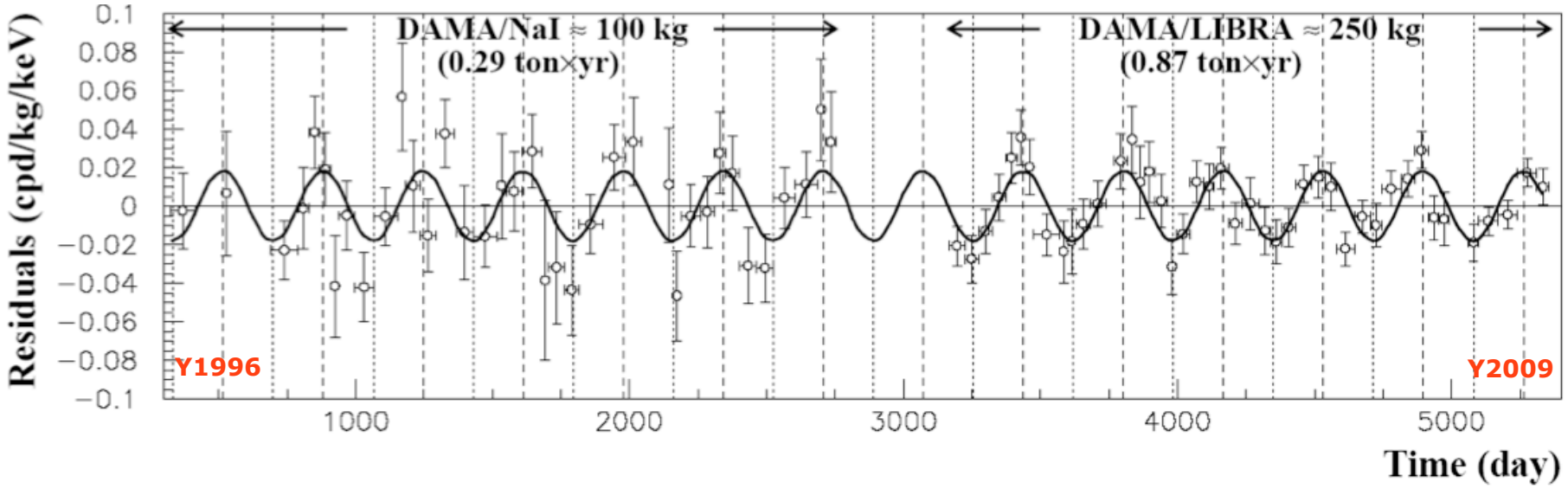
DAMA/LIBRA

- 242 kg High purity NaI(Tl) scintillator (LNGS)
- 1.17 ton-year exposure (13 year cycle)
- Observed clear signature of modulation
  - Null modulation ruled out by >8σ
  - expected DM phase: 152.5d (peak at June 2)
  - observed phase 146±7d

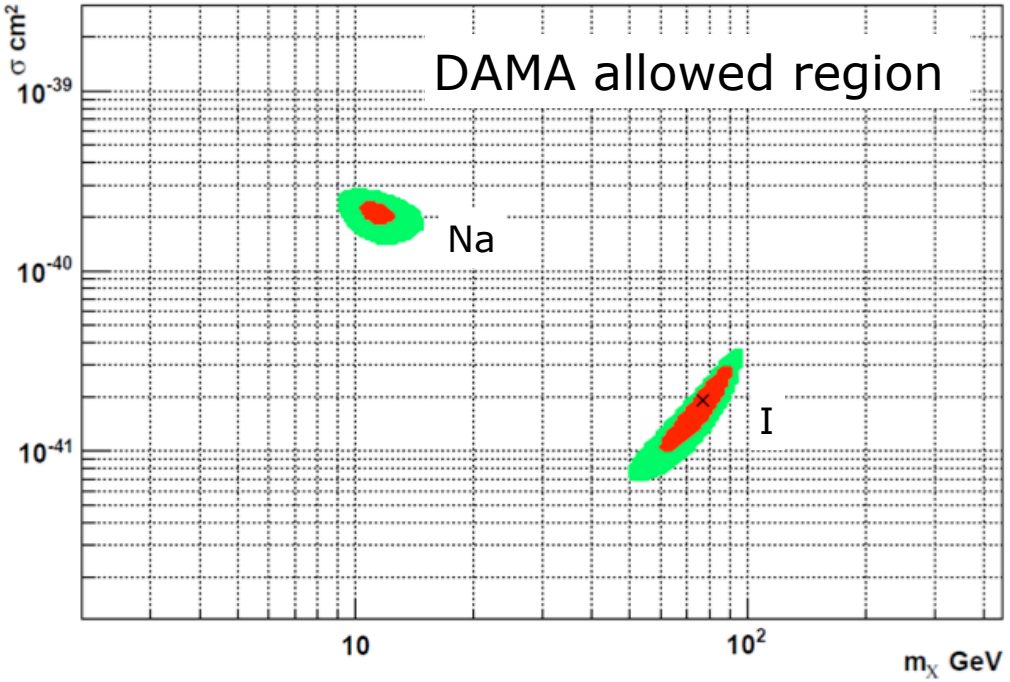




2~4keV

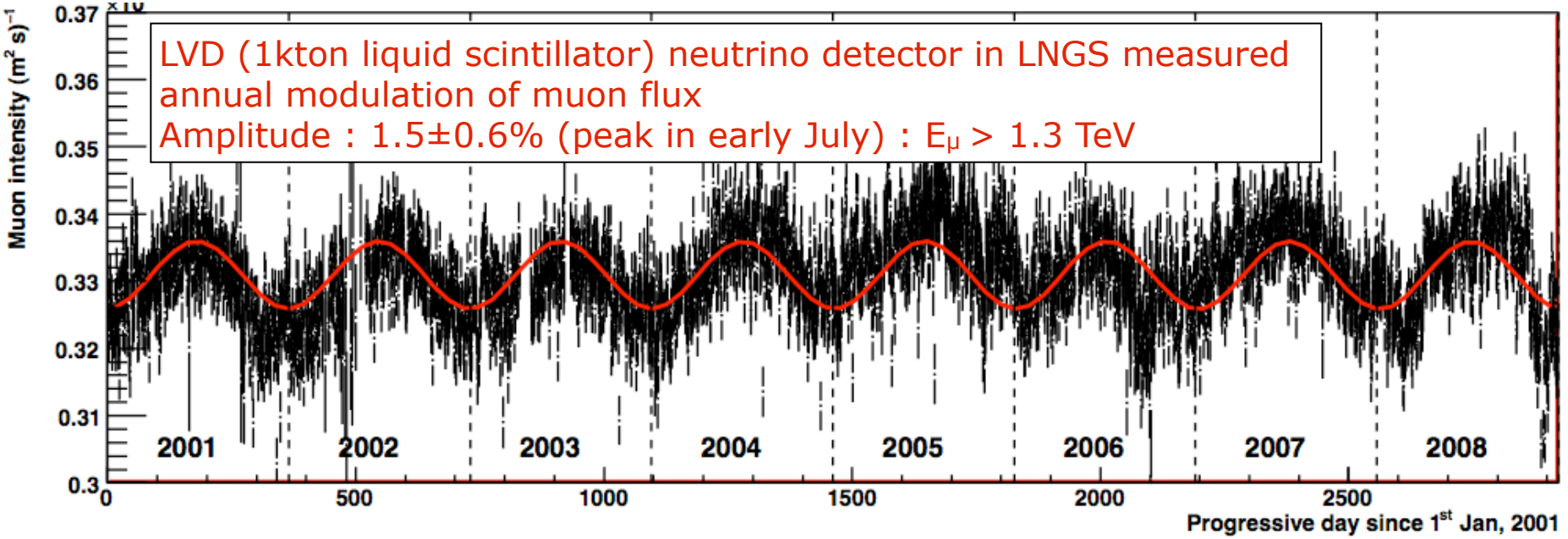


DAMA/LIBRA



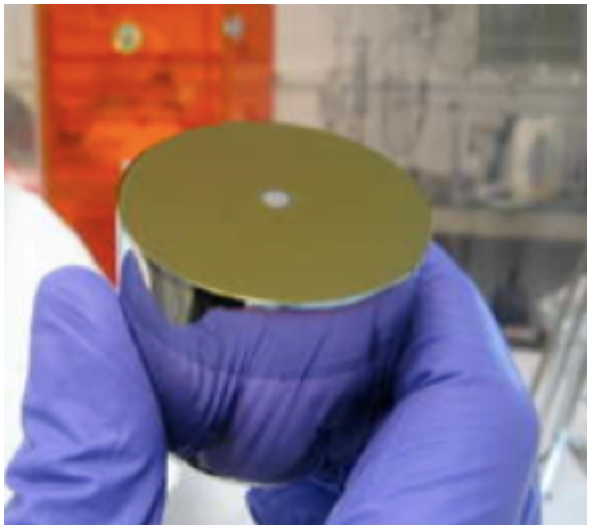
Systematics in dru (=cpd/kg/keV)
- radon $<2.5\times10^{-6}$ dru
- other backgrounds $<10^{-4}$ dru
- temperature variation $<10^{-4}$ dru
- electric noise $<10^{-4}$ dru
- energy scale $<10^{-4}$ dru
- cut efficiency $<10^{-4}$ dru
- muon flux at LNGS $<3\times10^{-3}$ dru

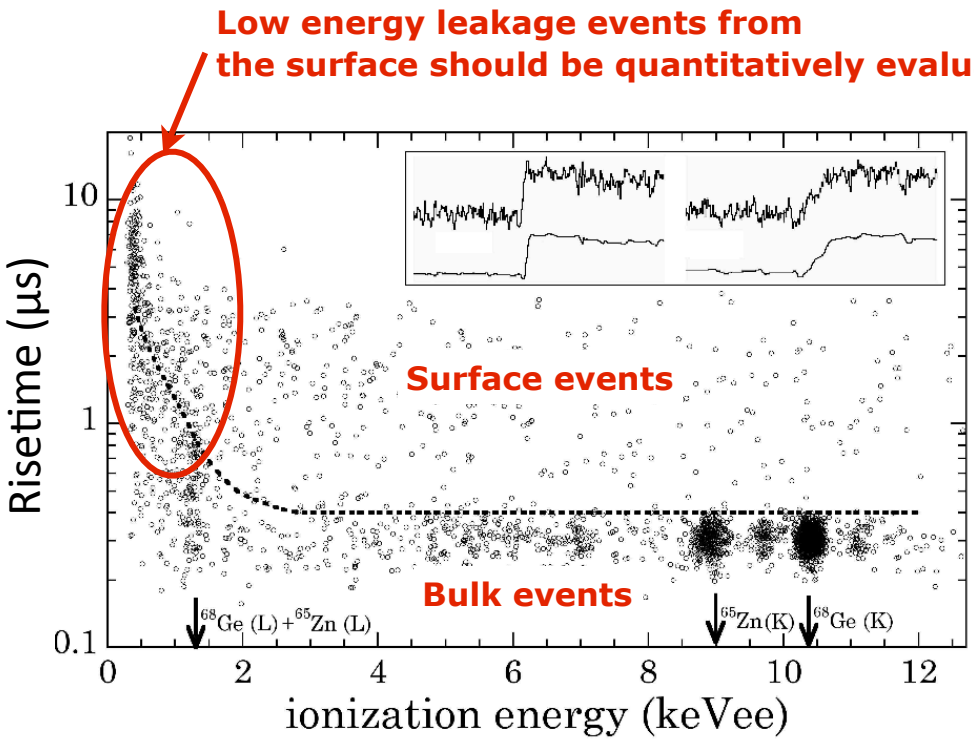
→ DM-ICE (NaI in IceCube) experiment proposed to check DAMA modulation

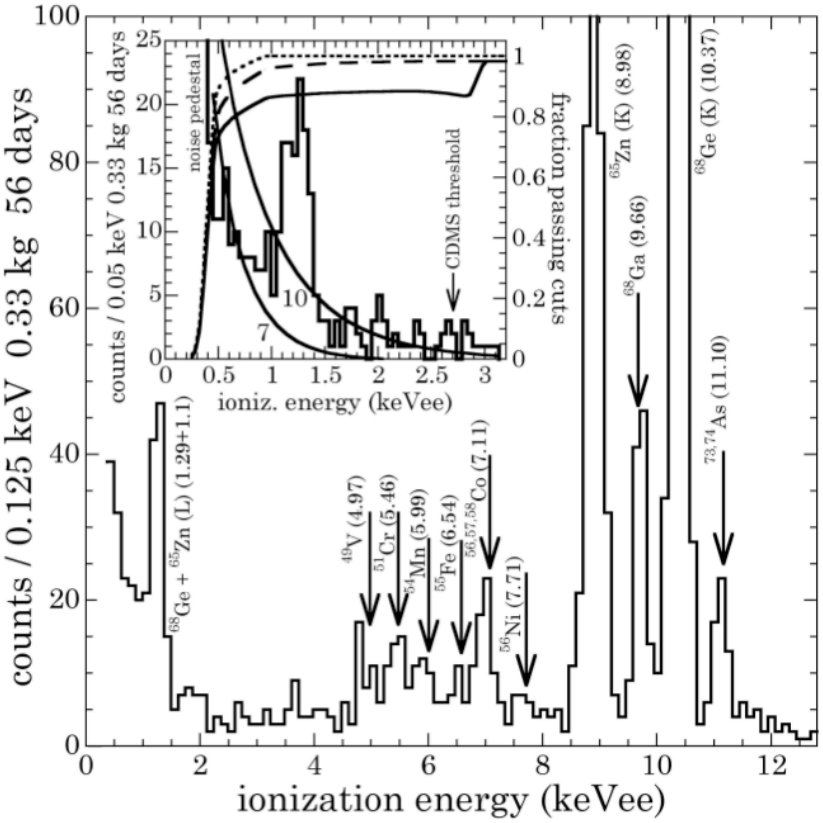


P-type Point Contact (PPC) Germanium Detector

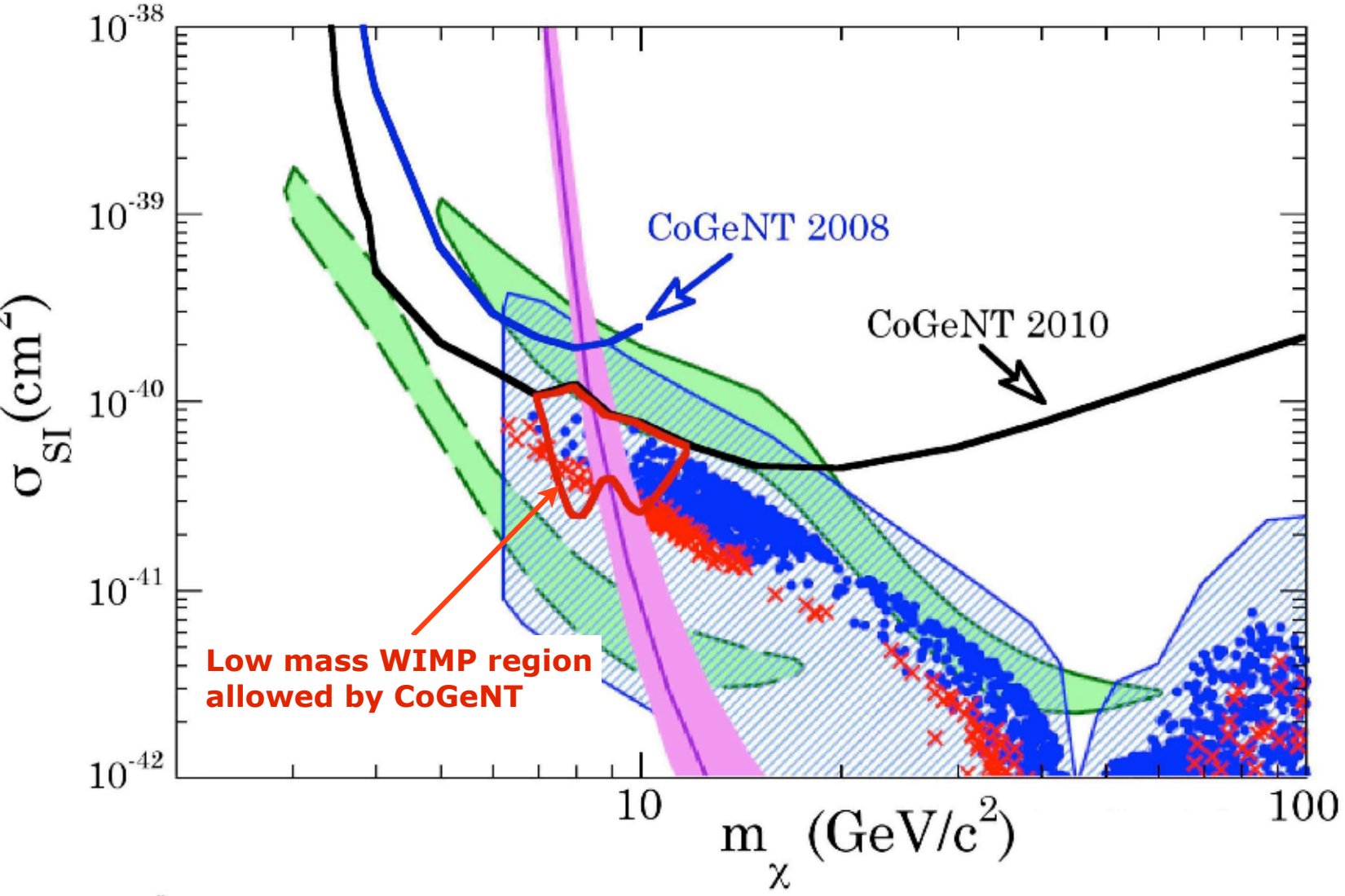
- 440g/detector operated in Soudan Underground Lab
- Low electric noise (small capacitance)
- Low energy threshold (~0.4 keV)
- Surface events rejection: pulse risetime
- Multiple scattering event rejection: pulse shape
- No discrimination between ER and NR





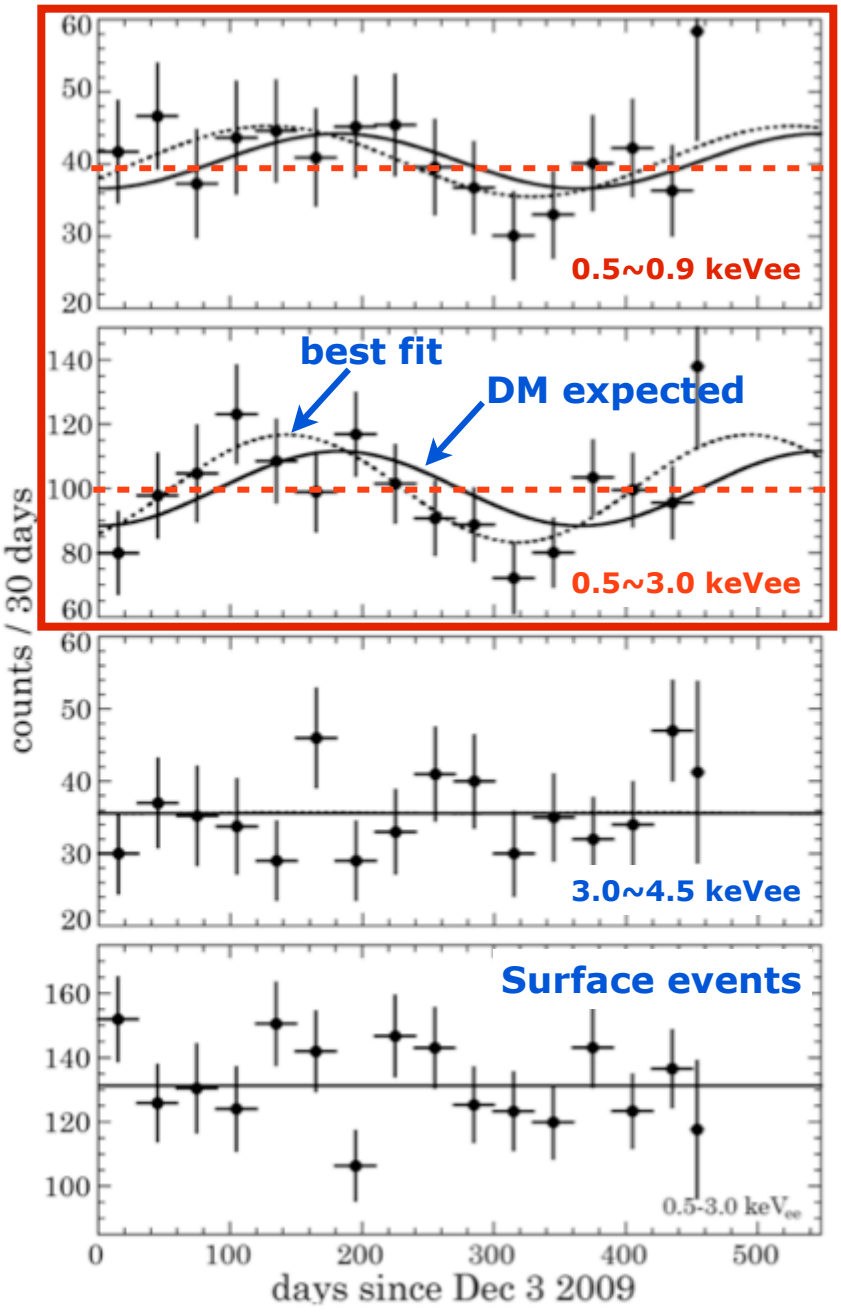


CoGeNT: Low Mass Dark Matter?

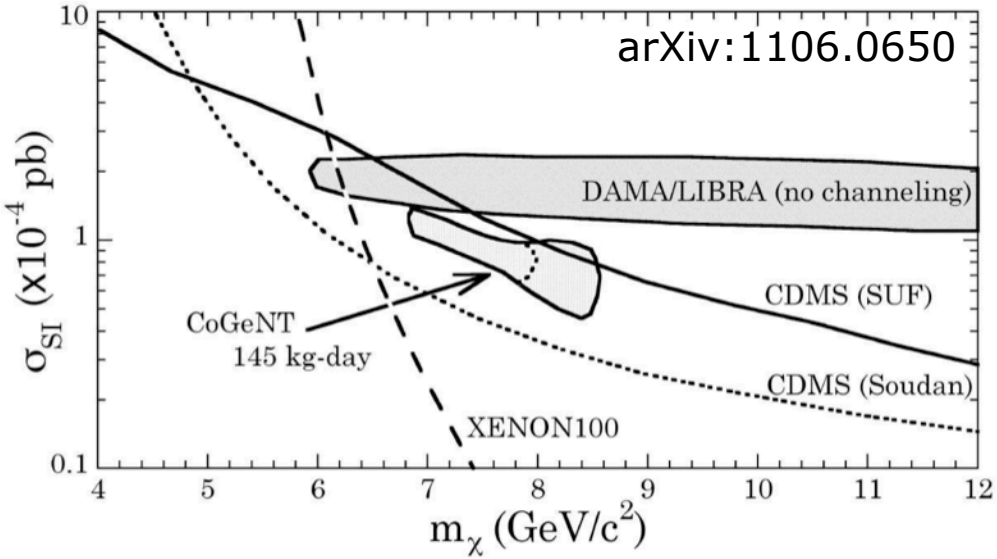


- In MSSM, M_X<~40GeV disfavored by accelerator constraints (LEP)
- Alternate models : NMSSM, mirror DM, extended Higgs, asymmetric DM, etc.

CoGeNT: Annual Modulation?



- Additional Data 2009/12/03~2011/03/06
- Data taking stopped due to Soudan accident (fire at Soudan mine shaft 2011/03/17)
- Noise, trigger thresholds stability demonstrated
- Modulation preferred ~2.8σ over the null hypothesis: seen only in the low energy ranges (0.5~3.0 keVee), and modulation in the higher energies and surface events → need more data



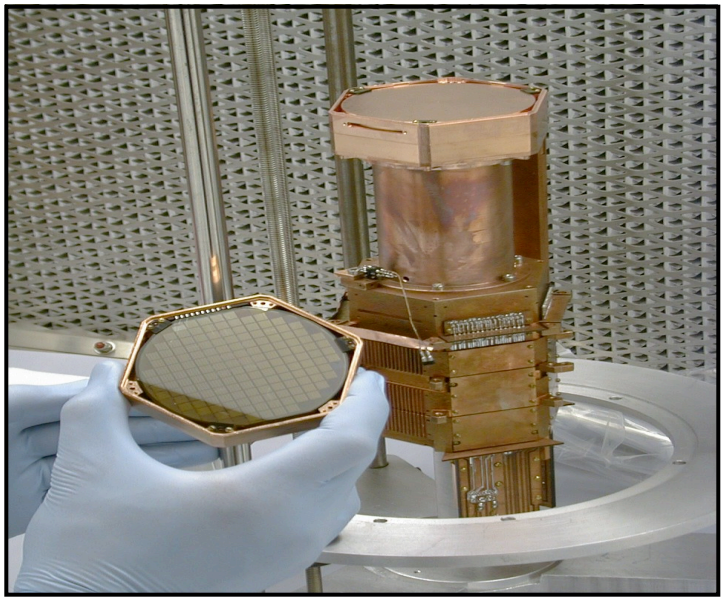
→ see Collar's talk on CoGeNT

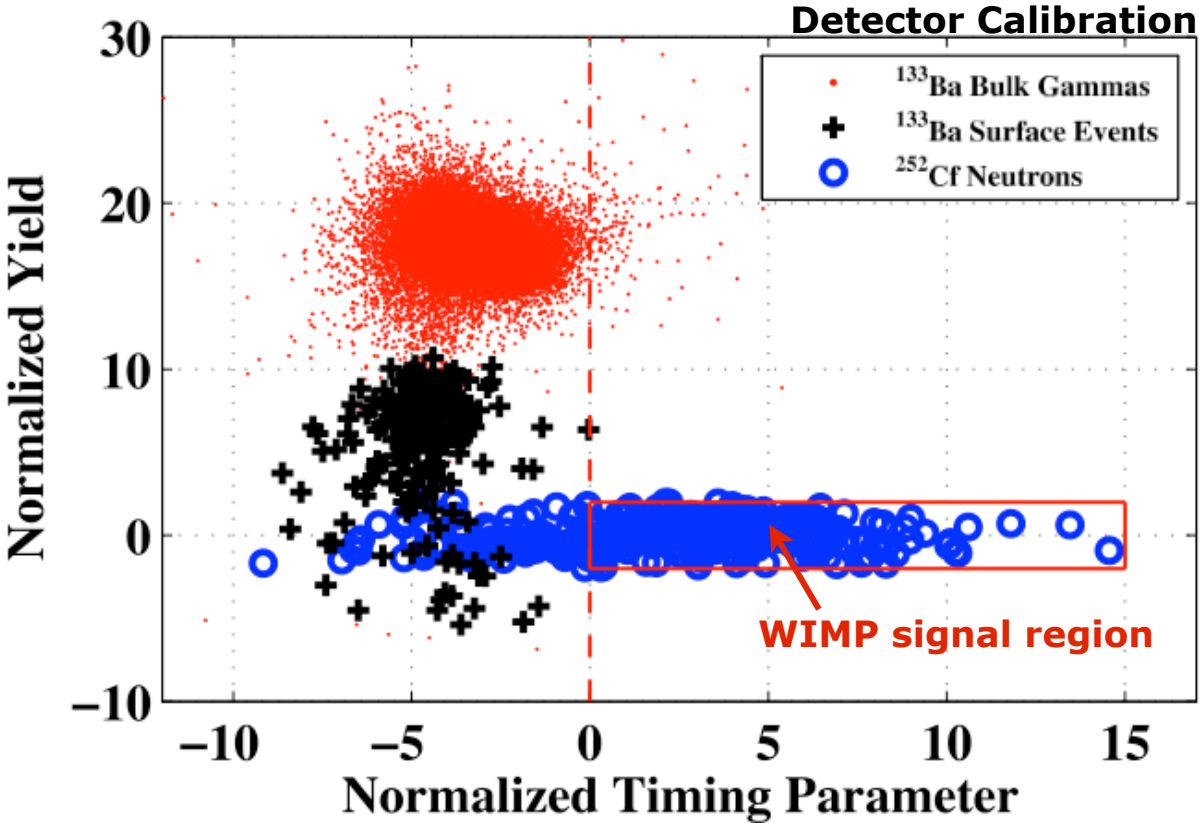
CDMS

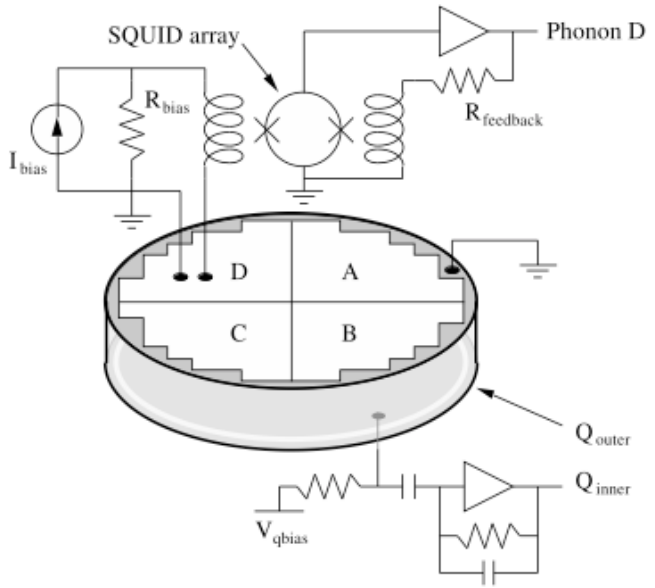
- Cryogenic Dark Matter Search
  - Soudan Underground Laboratory

- Z-sensitive Ionization & Phonon detector (ZIP)
  - 19x230g Ge and 11x100g Si detectors
  - Standard WIMP search energy range: 10~100keV

- Ionization yield and phonon risetime
  → discriminate ER, NR and surface electrons



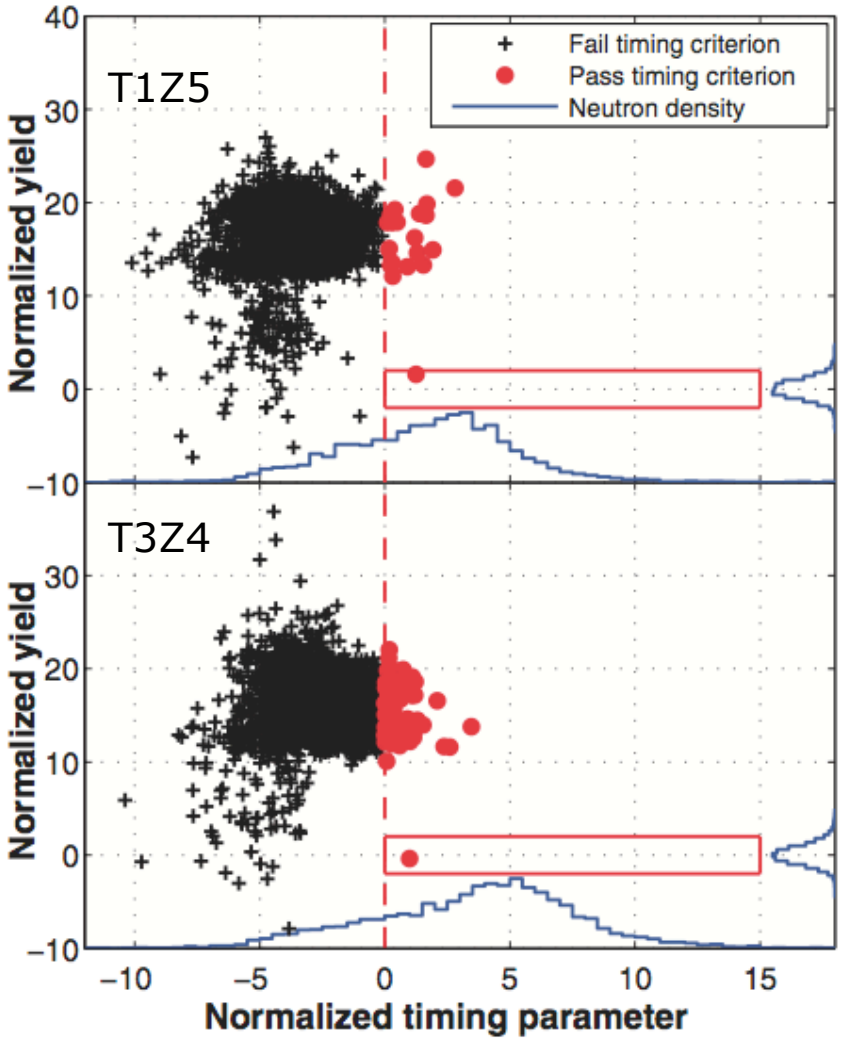


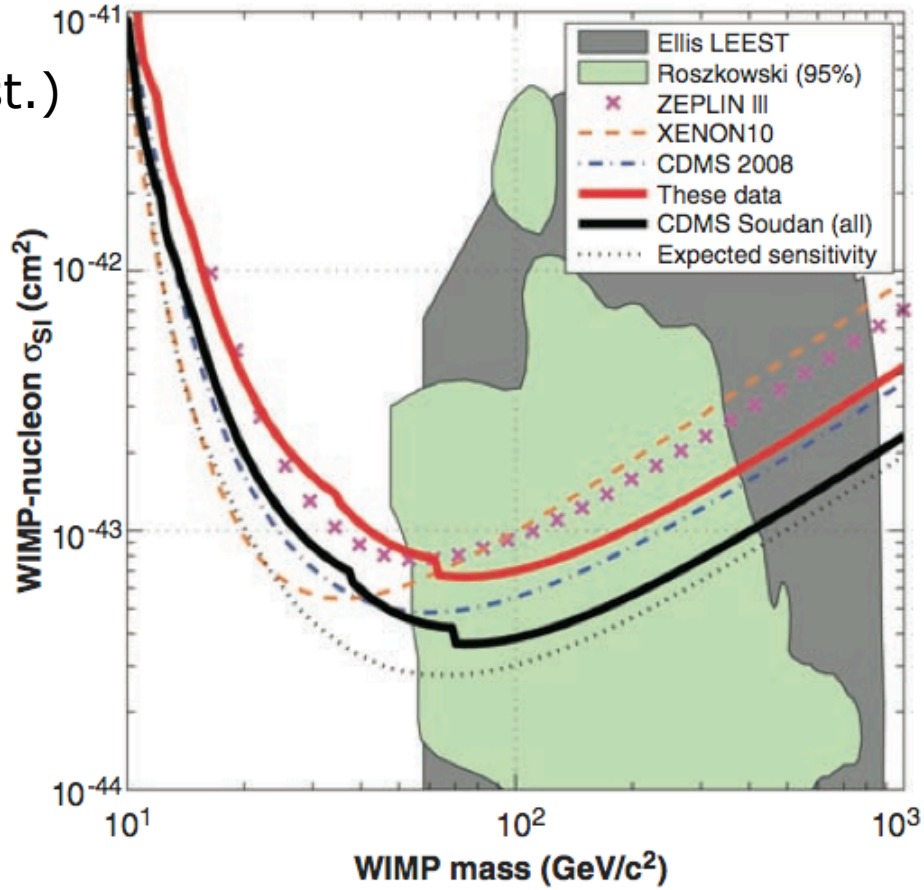


CDMS Standard WIMP Search Analysis

- **CDMS-II results (2009)**
  612 kg-days raw exposure
  estimated BG: 0.8±0.1(stat.)±0.2(syst.)
  2 events observed in the signal region

*Science **327** 1619 (2010), arXiv:0912.3592*





- SuperCDMS@Soudan(15kg Ge, 2011)
- SuperCDMS@SNOLab(100kg Ge, 2013)
- GEODM@SNOLab/DUSEL(1.5ton Ge)

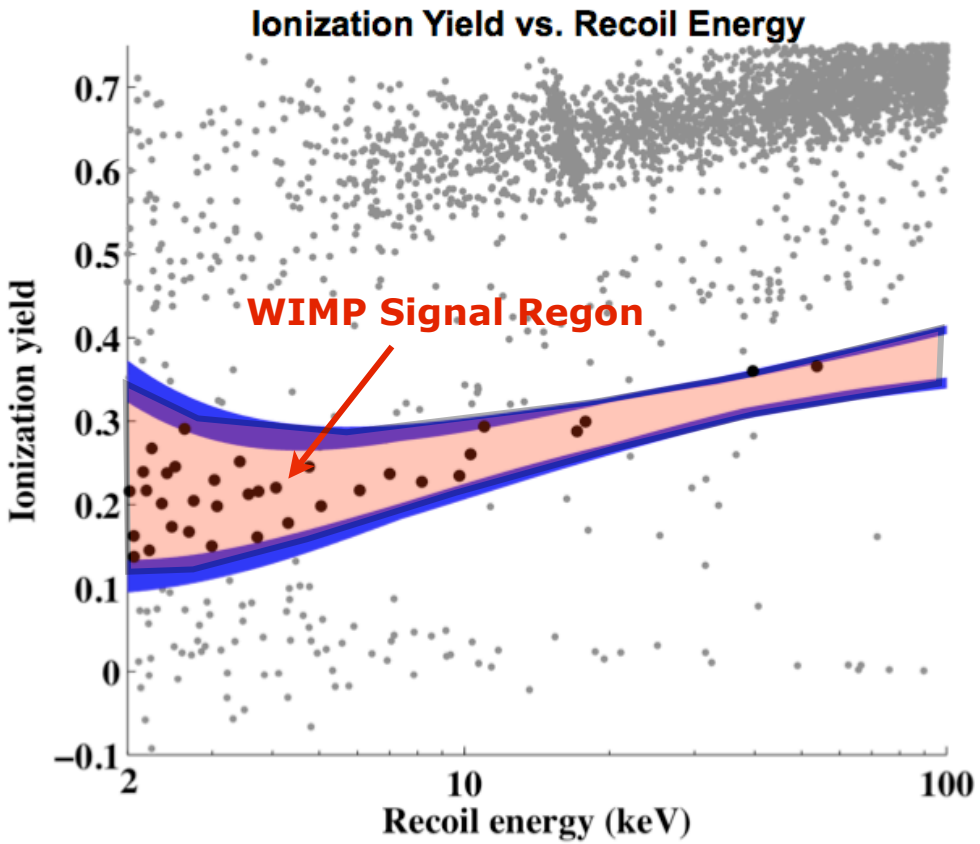
→ see Kamaev's talk on CDMS/SuperCDMS

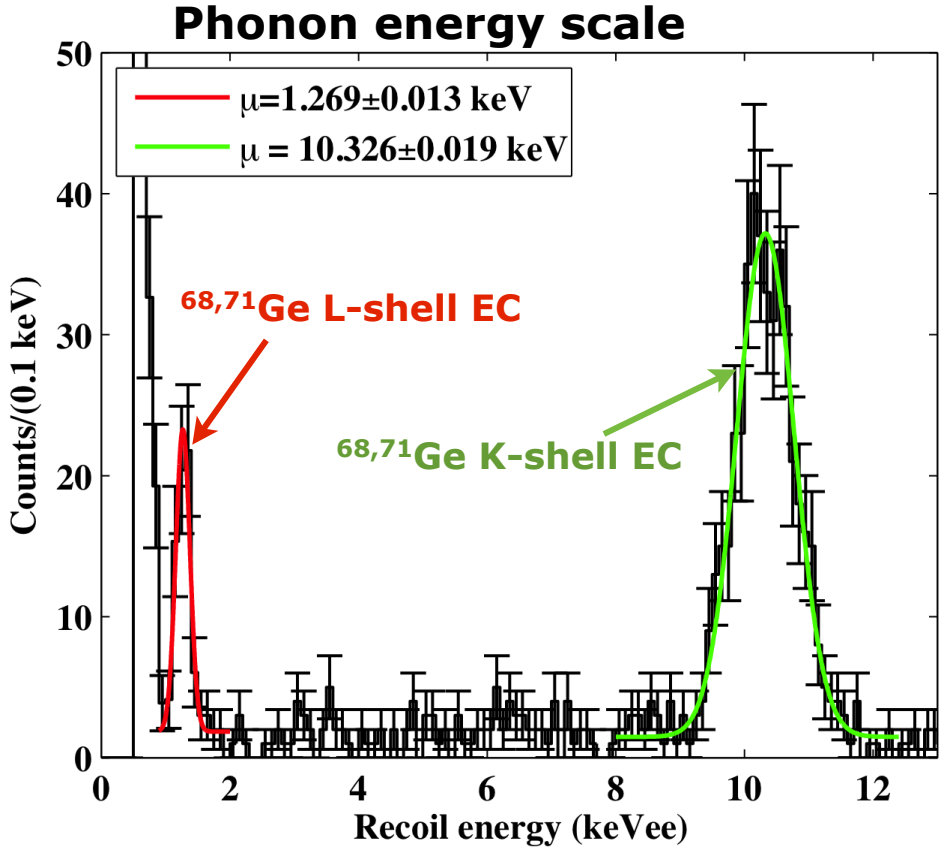
CDMS Low Energy Threshold Analysis

- Reanalyzed with 2keVnr energy threshold
  - Used 8 Ge detectors which lowest trigger thresholds (1.5~2.5keV)

- Small subset(~25%) data used to study backgrounds at low energy
  - Remaining data (241 kg-day) used for low mass WIMP search

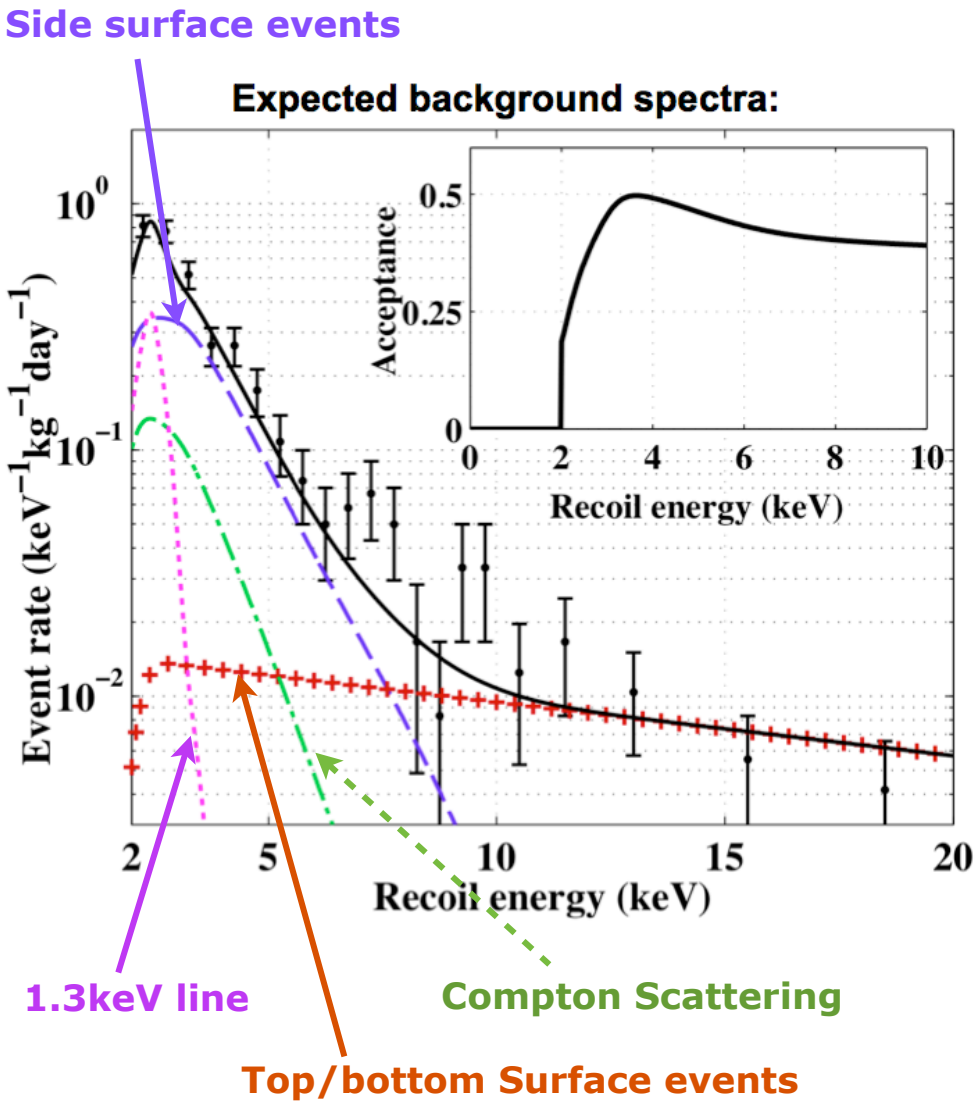
- Nuclear recoil acceptance region defined as (+1.25,-0.5)σ band in ionization energy
  → maximize sensitivity to nuclear recoils while minimizing expected backgrounds

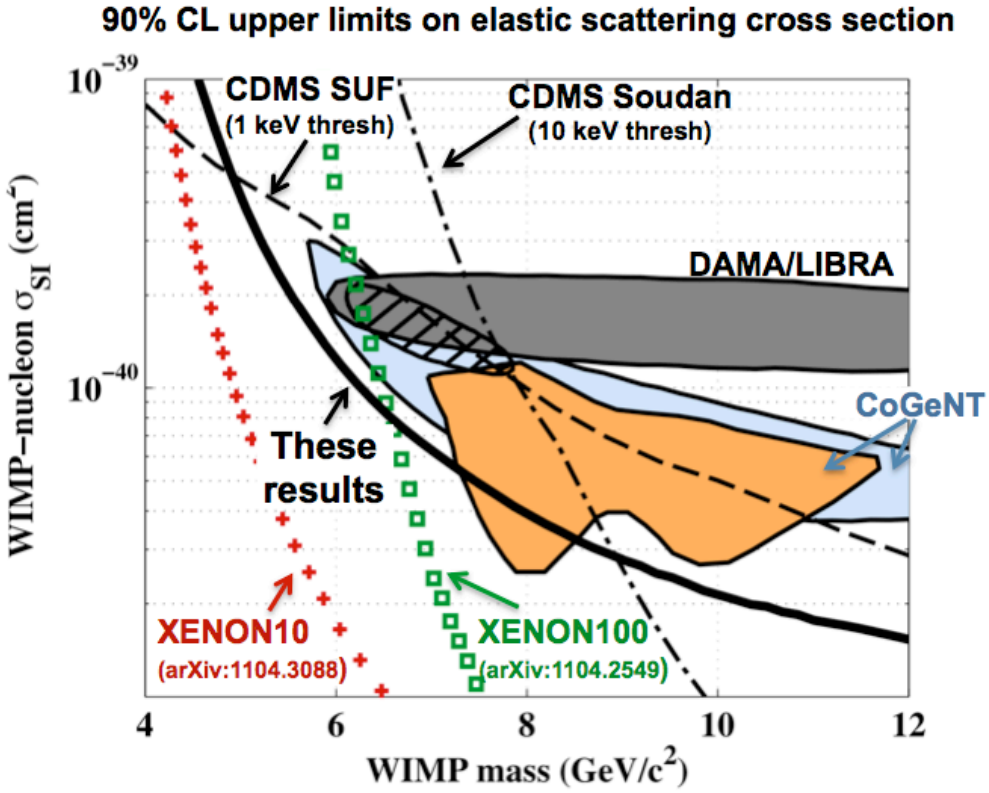




CDMS Low Energy Threshold Analysis

- Observed low energy events can be explained by extrapolations of background events from sidebands



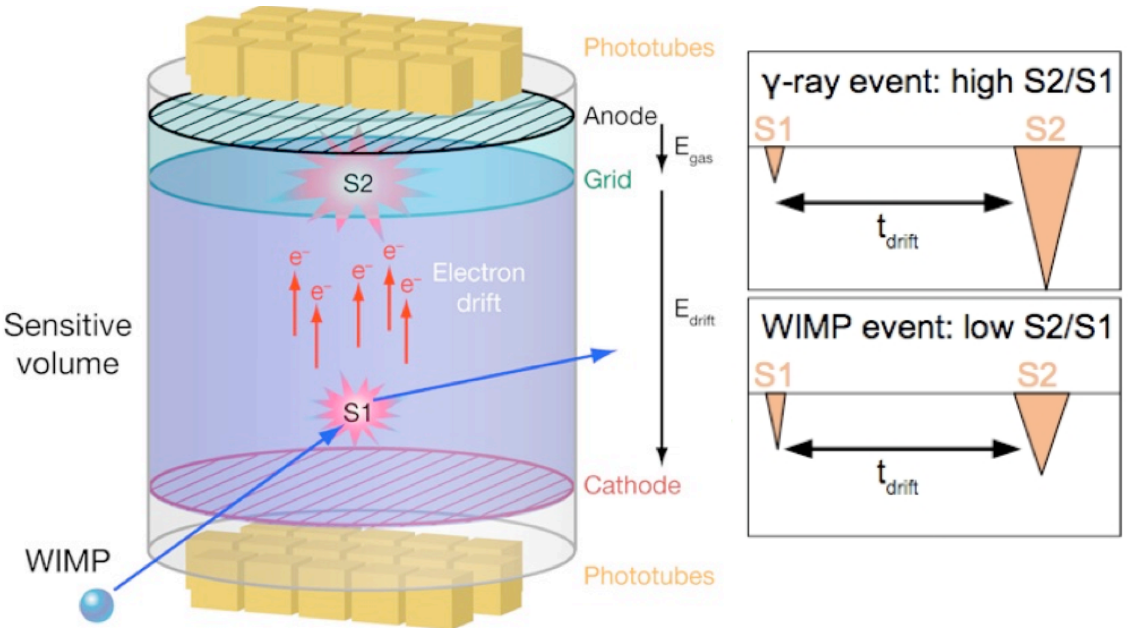


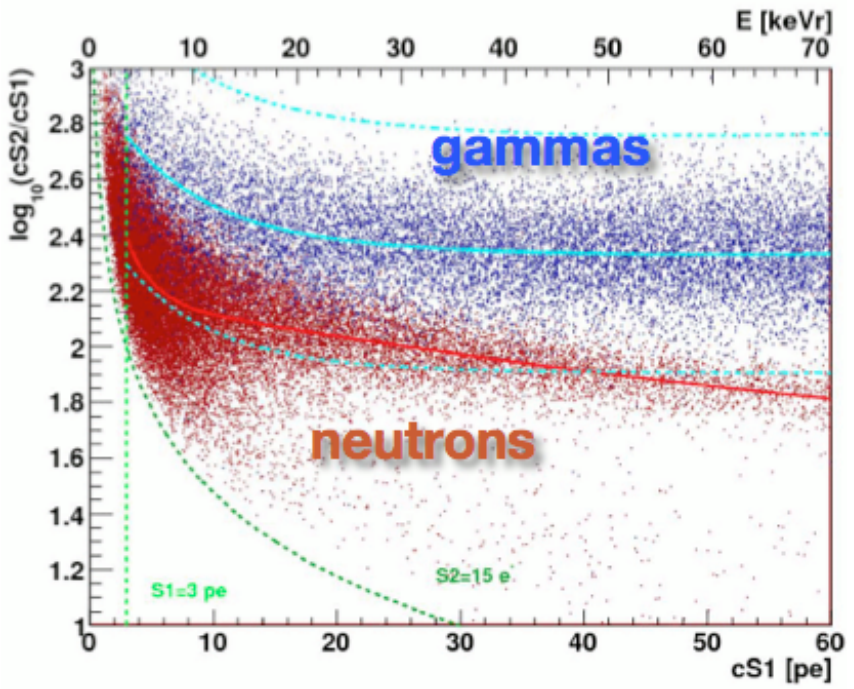
- This limit is set by without background subtraction hence very conservative limit

- Low mass WIMP interpretation of GoGeNT low energy excess is practically ruled out

→ see Hertel's talk on CDMS

XENON100



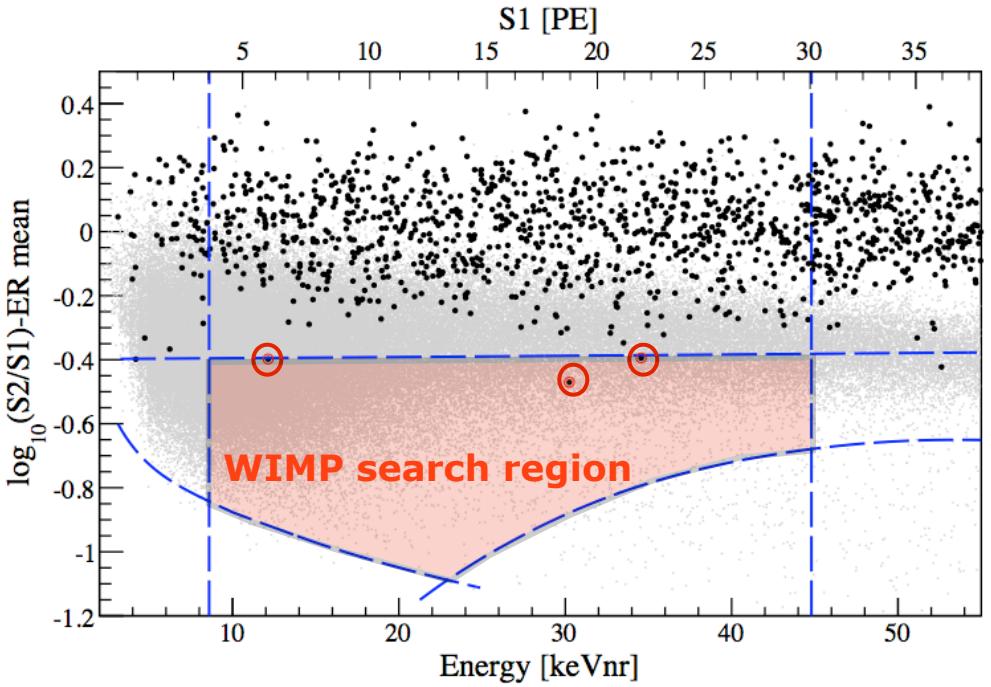


- Dual phase Liquid Xenon TPC
  - Total 160kg (48kg fiducial) and 100.9 detector live days
- Prompt Scintillation(S1) and charge readout in gas phase(S2) provides discrimination between NR and ER
- 3D event localization: ~mm resolution
- ^{nat}Kr ~700ppt and overall ER background rates < 0.02cpd/kg/keV
- Improved measurement of scintillation light efficiency (arXiv:1104.2587)

XENON100

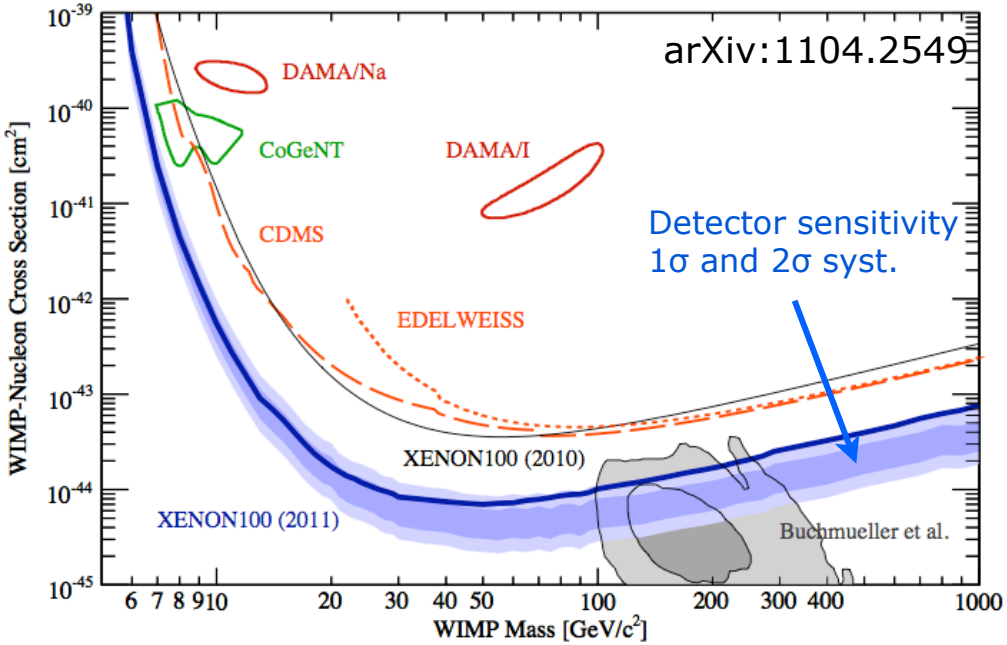
- Expected backgrounds:1.8±0.6
  - ^{85}Kr BG: 1.14±0.48
  - Other Leakage: 0.56+0.21-0.27
  - neutron BG: 0.1±0.08±0.04

- 3 events observed in signal region

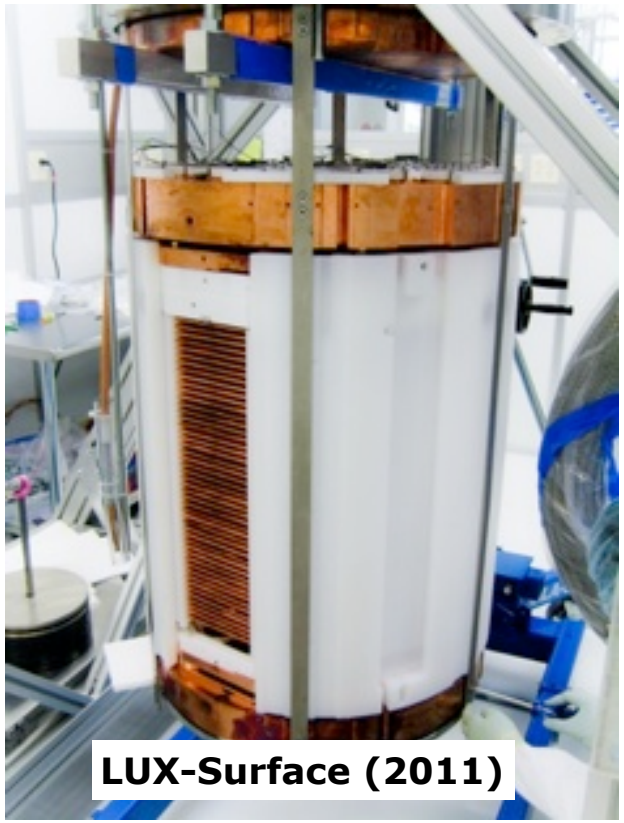


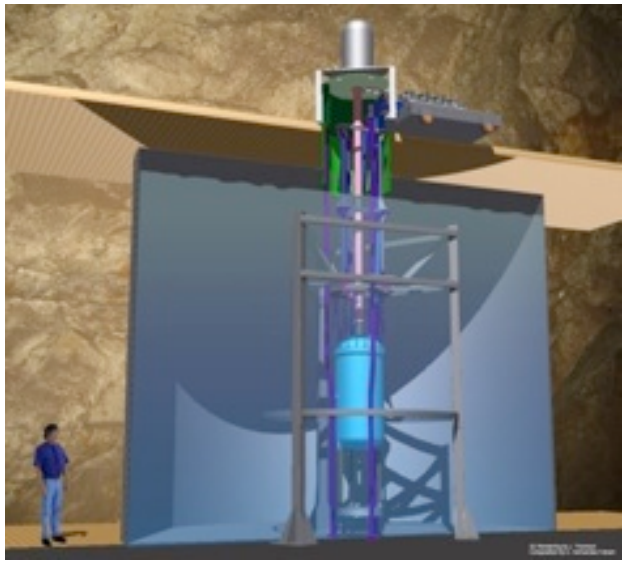
- Best WIMP search limit to date
  - σ(SI)>7x10^{-45}cm^2(@50GeV,90%CL)

- LNGS approved XENON-1ton program
  - construction starts late 2011
  - full physics reach 2015
  - WIMP search : σ(SI)>5x10^{-47}cm^2

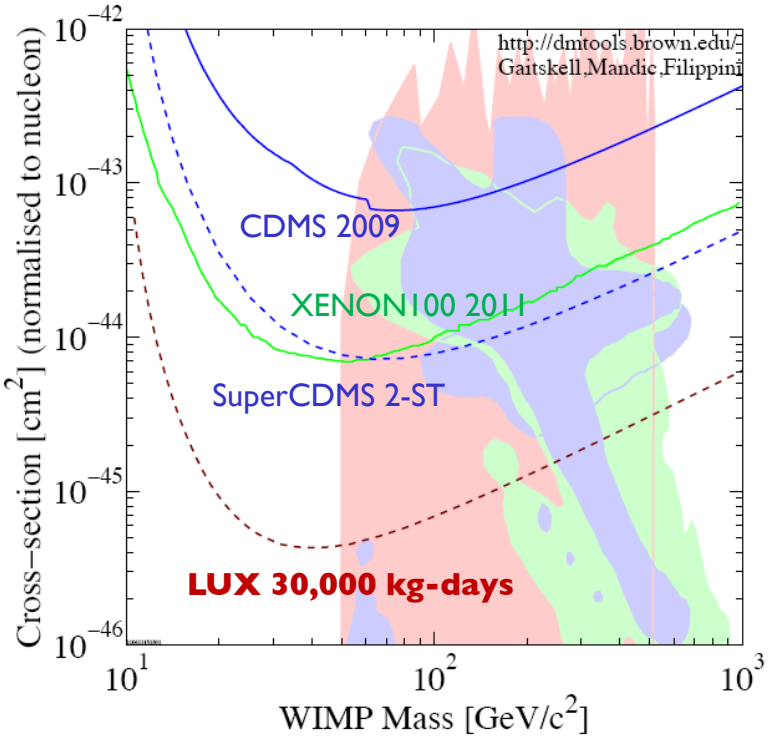


LUX: Large Underground Xenon Experiment


LUX-Surface (2011)



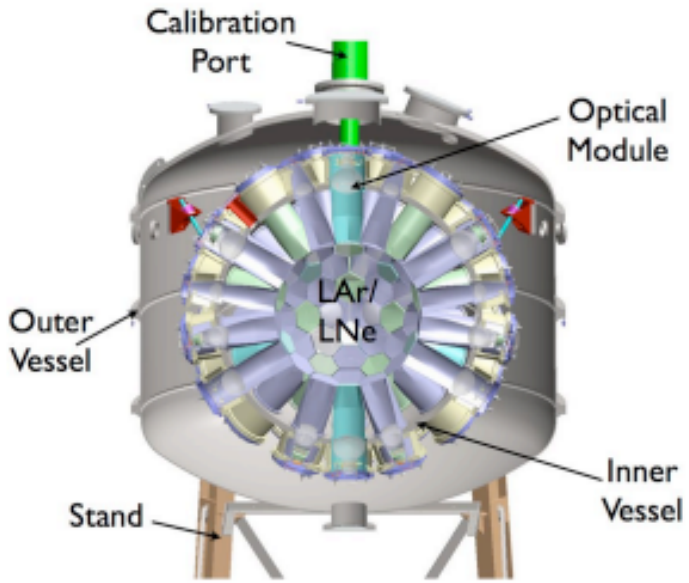

LUX-Underground (2012~)



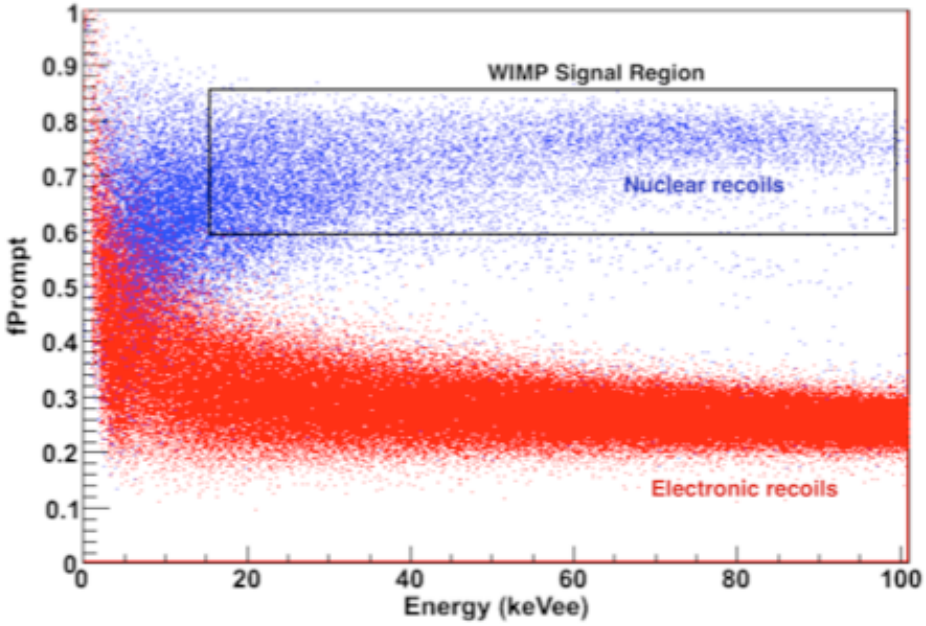
- Dual phase Liquid Xenon TPC, total 350kg (100kg fiducial)
- Low-background Titanium cryostat and low background PMTs
- Currently Running at Homestake surface building (2011)
- LUX-Underground (Homestake Davis cavern 2012)
  - WIMP search sensitivity after 1-year run : $\sigma(SI) > \sim 5 \times 10^{-46}$ cm^2

→ see Chapman's talk on LUX and Malling's talk on LZ

DEAP/CLEAN



miniCLEAN



Single phase LAr/LNe detector

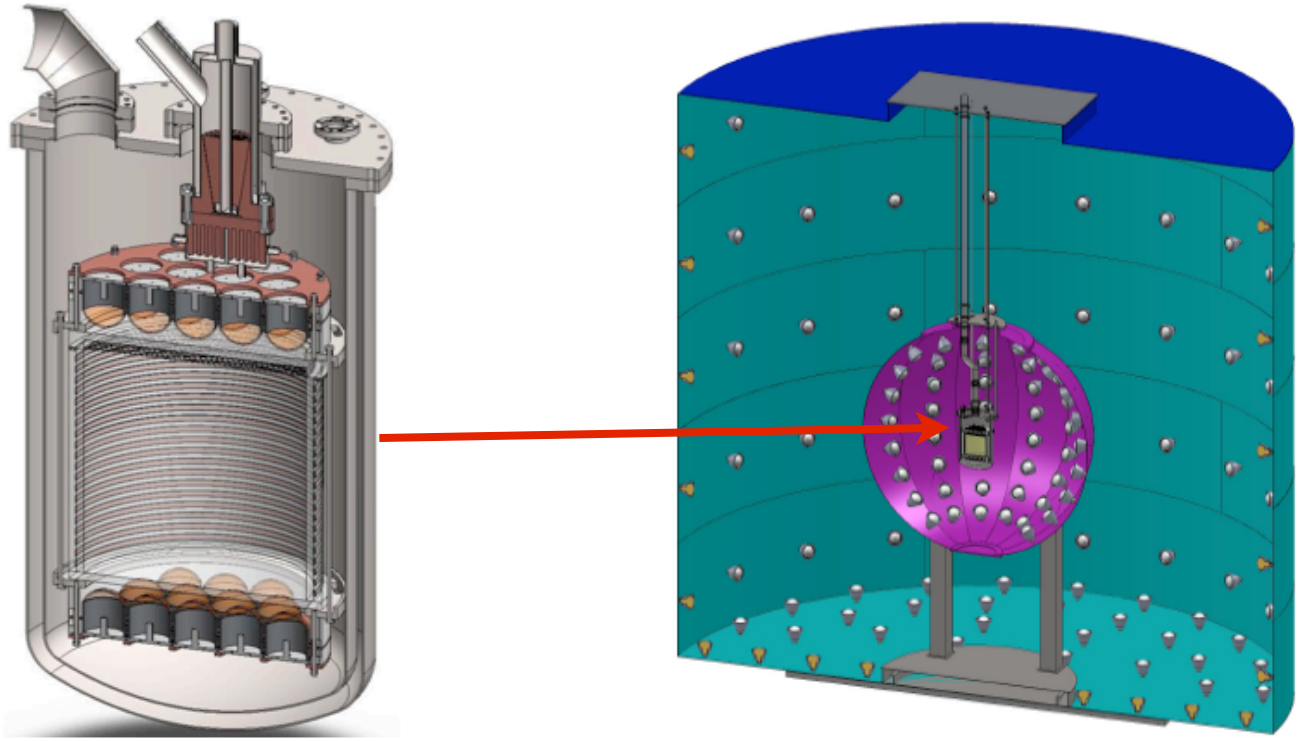
Pulse Shape Discrimination ($<10^{-8}$)

6pe/keV demonstrated

- **miniCLEAN (G1):**
  SNOLab 2011
  500kg LAr or LNe (150kg fiducial)
- **DEAP-3600 (G2):**
  SNOLab 2012
  3600kg LAr (1000kg fiducial)
- **DEAP/CLEAN (G3)**
  DUSEL
  50ton LNe/LAr (10ton fiducial)

→ see Hime's talk on miniCLEAN

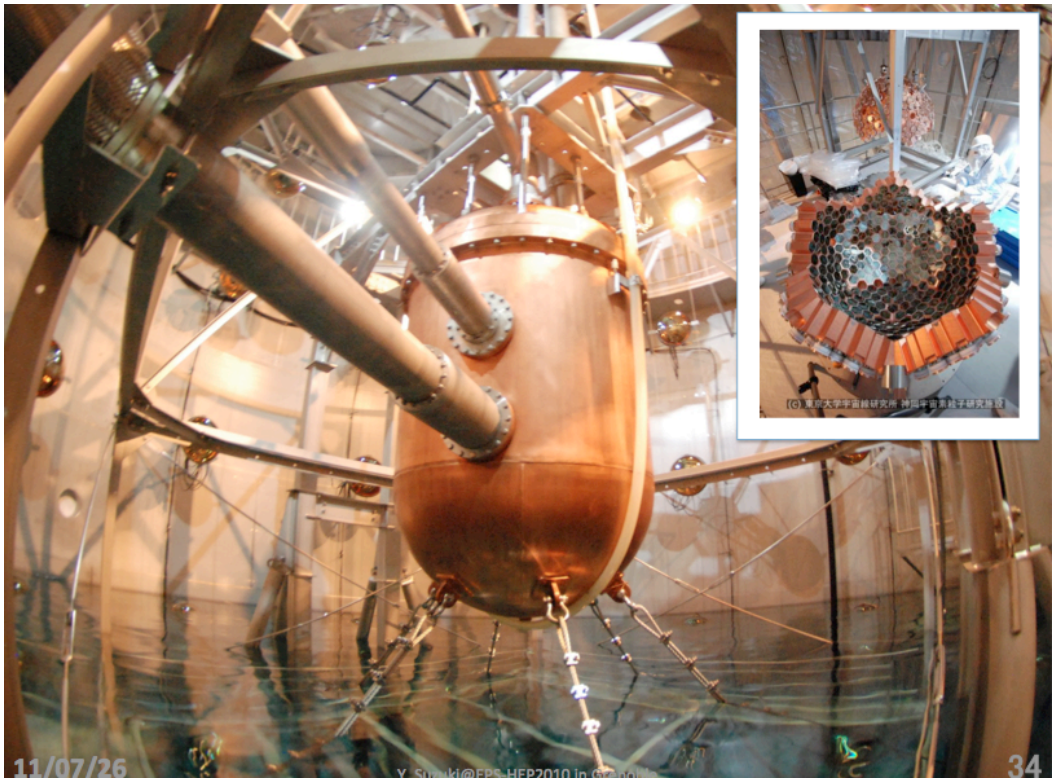
DarkSide

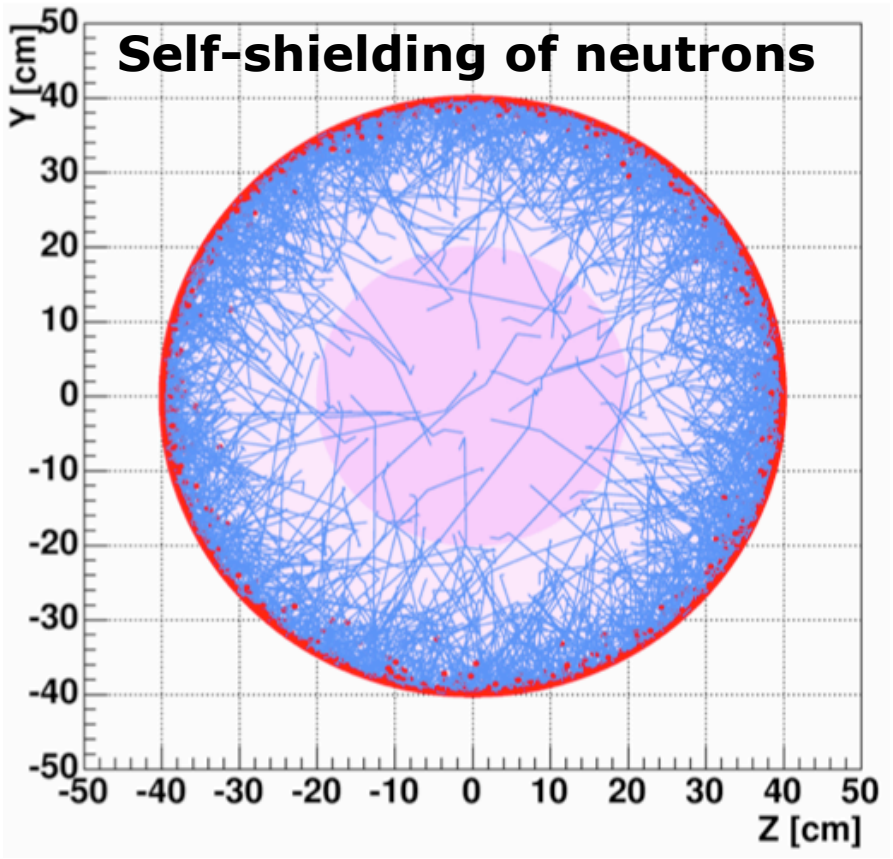


- Dual phase depleted (^{39}Ar) LArTPC + pulse shape discrimination
  (cf. ^{39}Ar decay rate in ^{nat}Ar ~1Bq/kg)
- DarkSide 10kg prototype (@Princeton): detector concept demonstrated
  → Low BG test @LNGS (Summer 2011)
- DarkSide-50 planned (2012)
  - Water Cherenkov + boron-loaded liquid scintillator : active neutron veto
  - New low BG photosensor : Quartz Photon Intensifying Device (QUPID)
- DarkSide-5ton project (G2) planned

→ see WRIGHT's talk on DarkSide

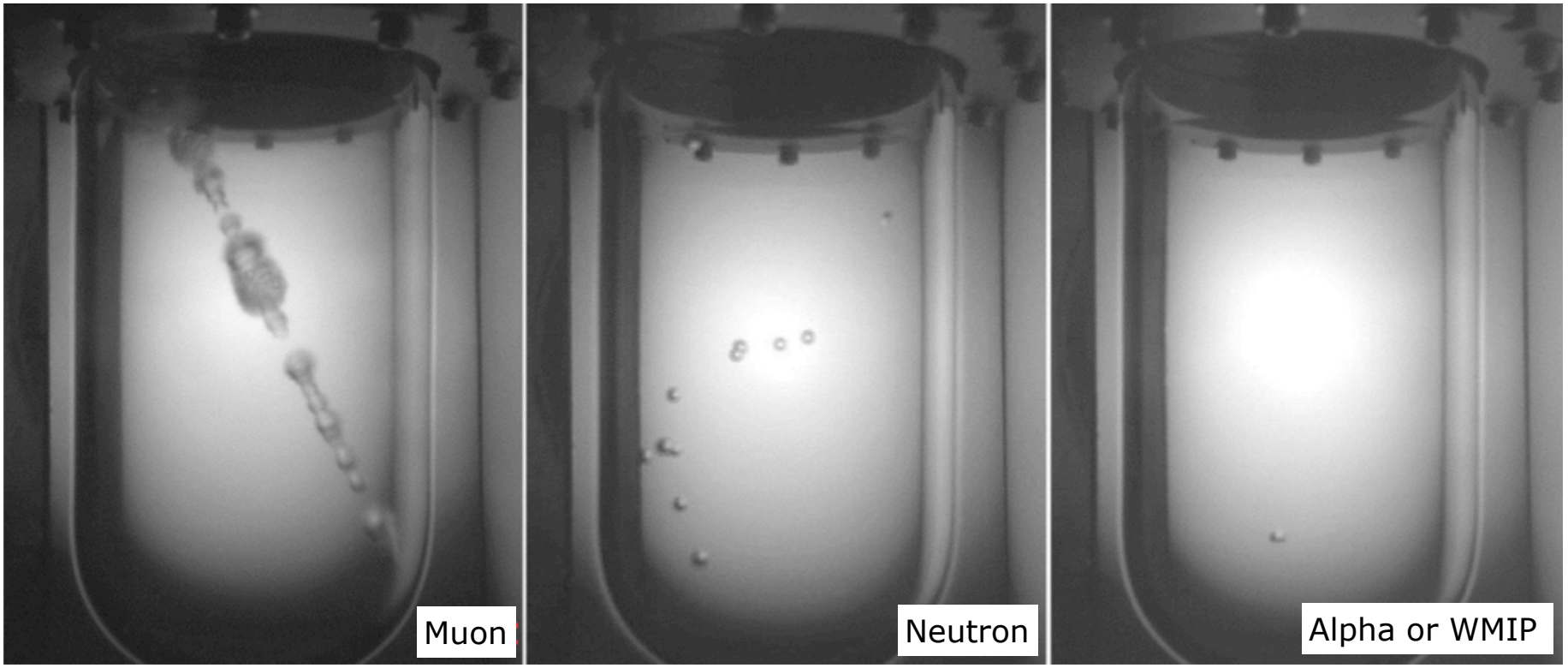
XMASS: Kamioka Underground Laboratory





- Single phase LXe detector: 850kg active volume (100kg fiducial)
- 642 ultra low background PMTs (<10mBq/PMT): 62% photo coverage
- Energy resolution: ~4%(rms)@122keV; ~15 p.e/keV measured
- Self-shielding of EM and NR backgrounds: 10^{-4} cpd/kg/keV
- ^{85}Kr background controlled ~3ppt level
- WIMP search sensitivity σ(SI) > 10^{-45}cm (@2keVee threshold, 100days)
- Now commissioning → Start data taking in a few months

COUPP: Bubble Chamber Dark Matter Detector



- Revival of old bubble chamber technology
  + acoustic discrimination between neutrons and alphas(or WIMPs)
- Insensitive to electromagnetic backgrounds
- Super-heated CF_3I → sensitive both SI and SD interactions

- COUPP-4kg(@Fermilab MINOS cavern 300mwe) results: $\sigma(SI) > 5x10^{-42}cm^2$
- COUPP-4kg@SNOLAB and COUPP-60kg@Fermilab are currently commissioning
- COUPP-500kg design phase funded by NSF and DOE/FNAL

Current and Future Dark Matter Search Effort

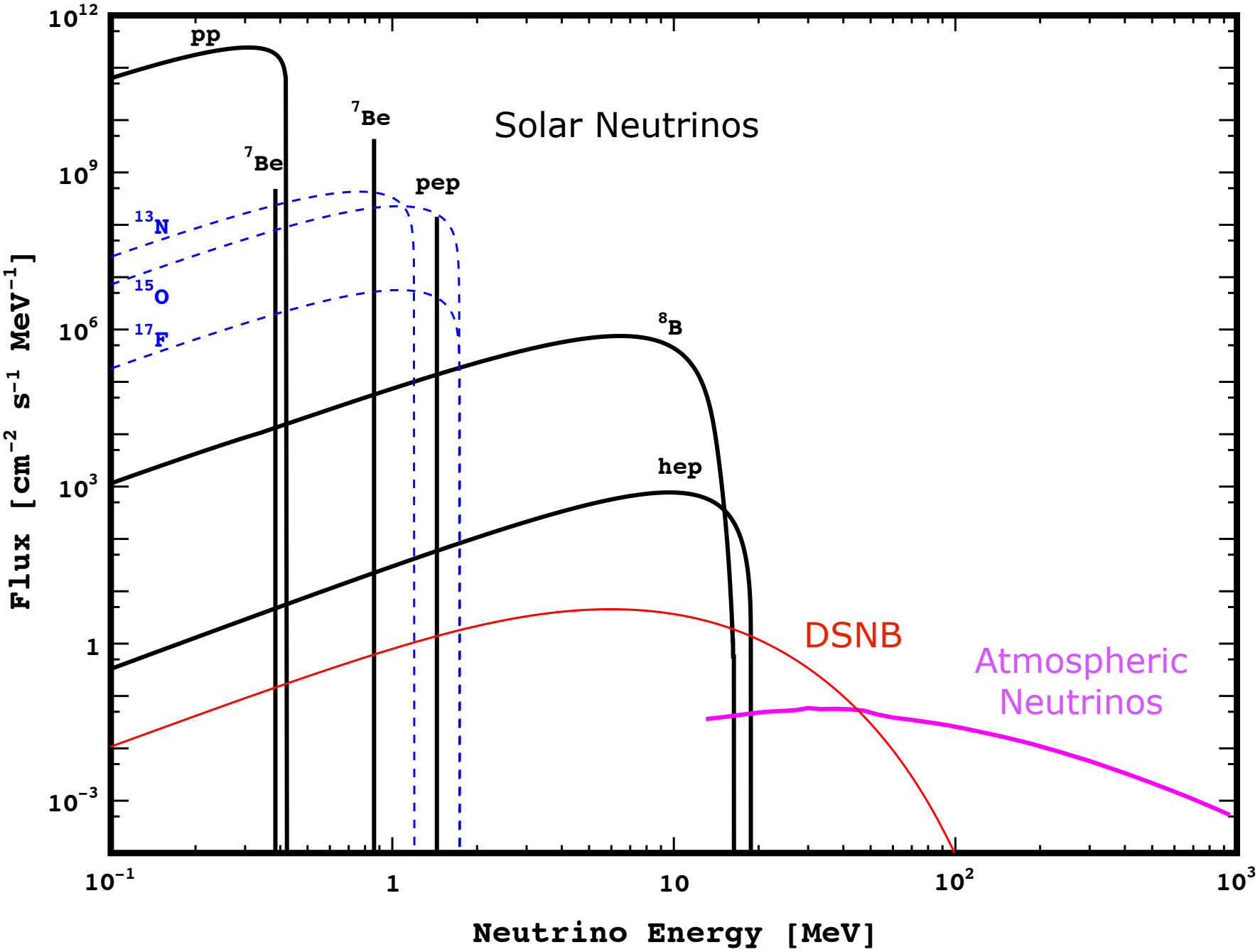
- **Direct Search**
  CDMS,SuperCDMS, GEODM, EDELWEISS, XENON100, XENON-1ton, ZEPLIN-III, XMASS, PANDA-X, LUX, LZ, WARP, ArDM, DarkSide, DEAP, miniCLEAN, CLEAN, DARWIN, MAX, PICASSO, SIMPLE, COUPP, KIMS, CINDMS, CRESST, ROSEBUD, DAMA/LIBRA, CoGeNT, DAMIC, DM-ICE, EURECA, DRIFT-III, DM-TPC, NEWAGE, MiMac, Cygnus, ADMX … (not a full list)

- **Indirect Search**
  AMS, Fermi-LAT, AGILE, EGRET, INTEGRAL, PAMELA, ATIC, CREAM, VERITAS, H.E.S.S., CANGAROO, MAGIC, CTA, AMANDA, IceCube, Super-Kamiokande, Baikal, ANTARES, NESTOR, Km3net… (not a full list)

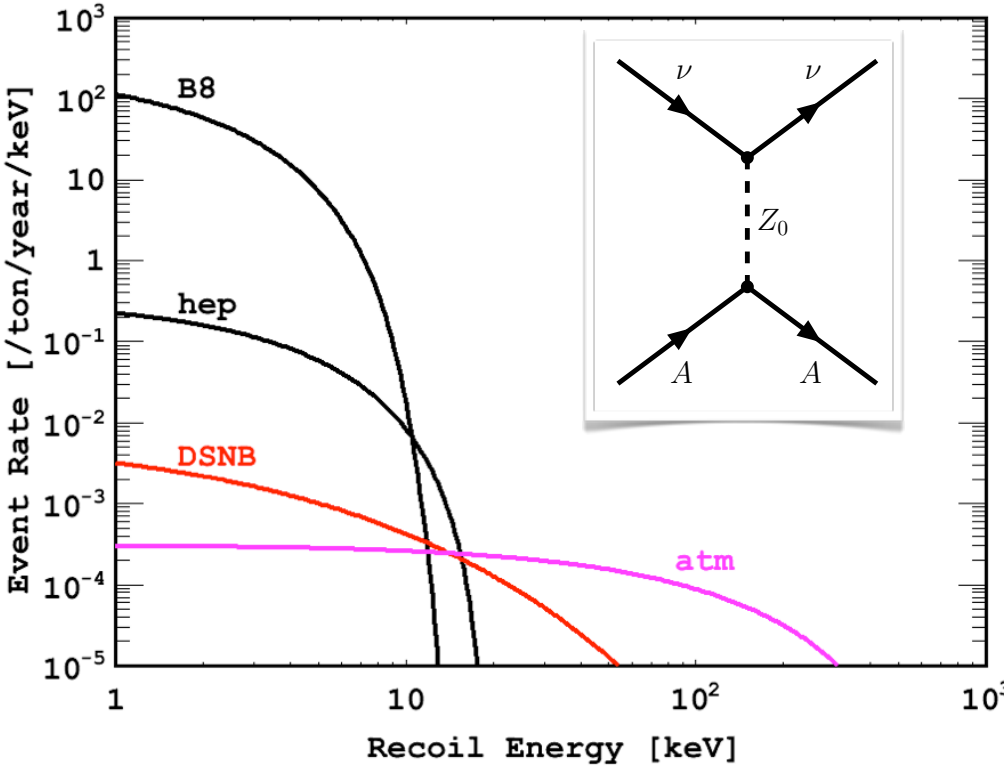
- **Collider**
  Tevatron(CDF/D0), LHC(CMS/ATLAS)

- **Theory**
  Neutralinos, Kaluza-Klein DM, Gravitino, Sterile Neutrino, Axion, Axino, Sneutrino, Little Higgs DM, Wimpzillas, Q-balls, Mirror DM, charged DM, Cryptons, Primordial Black Holes, Braneworld DM, Messenger states in GMSB, Branons, Asymmetric DM, Leptophilic DM, Inelastic DM, Isospin violating DM, Complex Scalar DM, Resonant DM … (not a full list)

Irreducible Backgrounds in WIMP Search



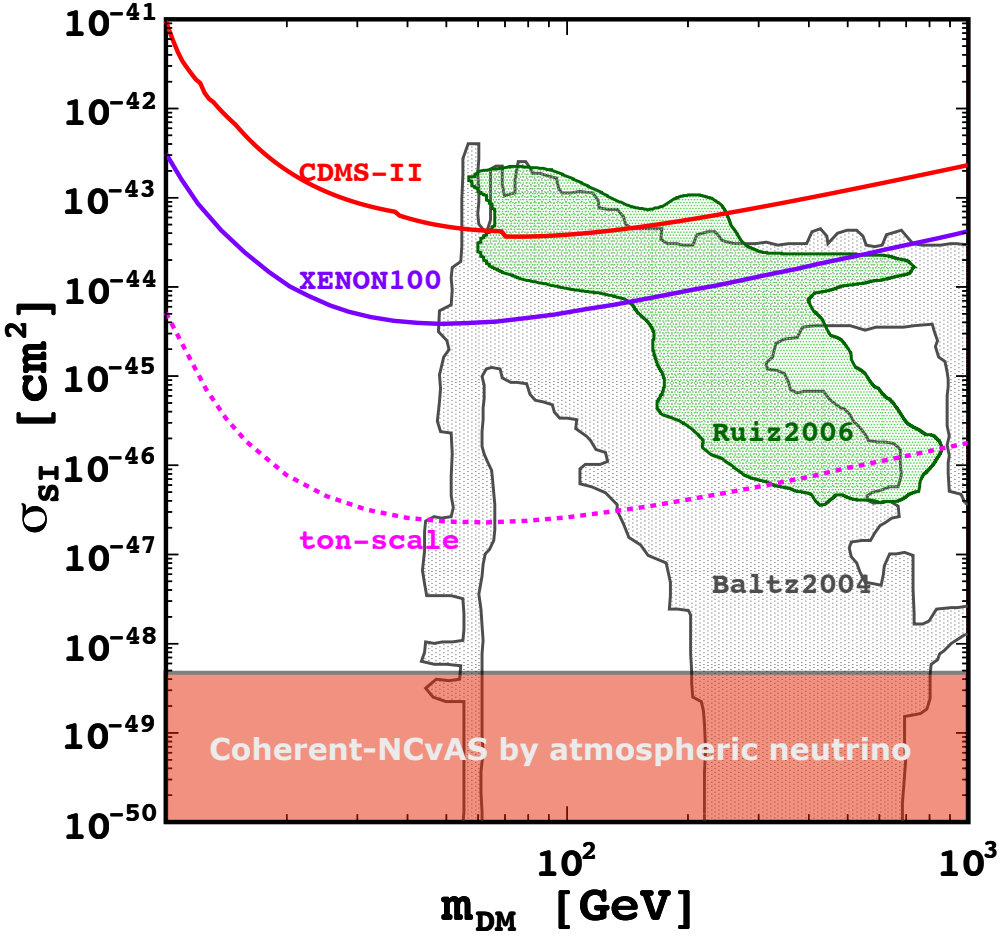
Irreducible Backgrounds in WIMP Search



$$\sigma_{\nu N} \simeq \frac{4}{\pi} E_\nu^2 \left[Z\omega_p + (A-Z)\omega_n \right]^2$$

$$\omega_p = \frac{G_F}{4}(4\sin^2\theta_W - 1), \qquad \omega_n = \frac{G_F}{4}$$

$$\sigma_{\nu N} \simeq 10^{-39} cm^2$$



Atmospheric neutrinos are irreducible background for beyond-G3 detectors (Strigari, arXiv:0903.3630)

- Coherent-NCvAS has never been measured since it's first prediction in 1974

Summary

- Cold Dark Matter search is very Hot Field
- No convincing smoking gun yet
- New tools are ready
  - Lots of direct detection experiments
  - Fermi-LAT and AMS are up and running
  - LHC is operational
  - New theories
- Discovery may happen anytime soon